Tools and Monte-Carlos

for the

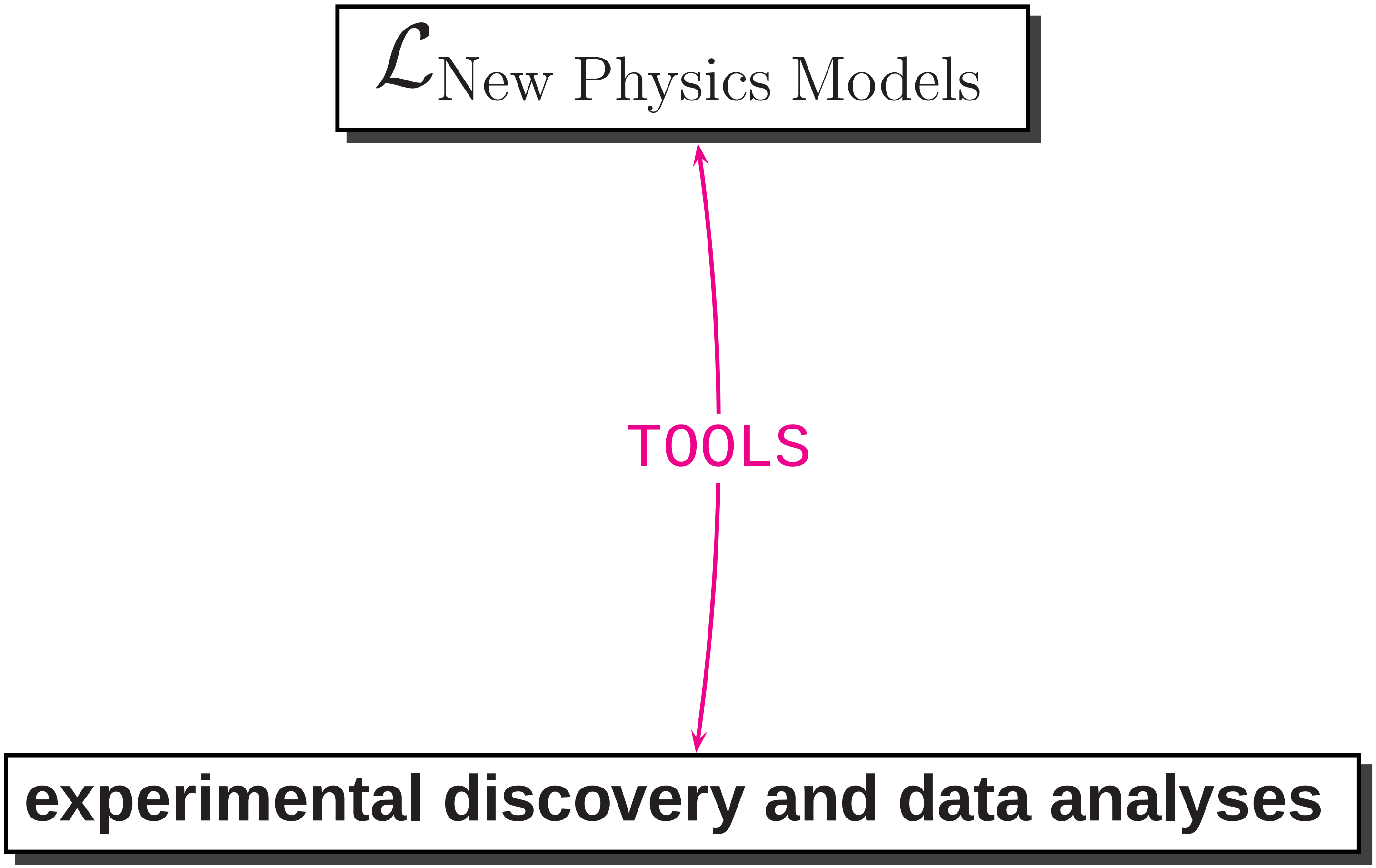
New Physics

Fawzi BOUDJEMA

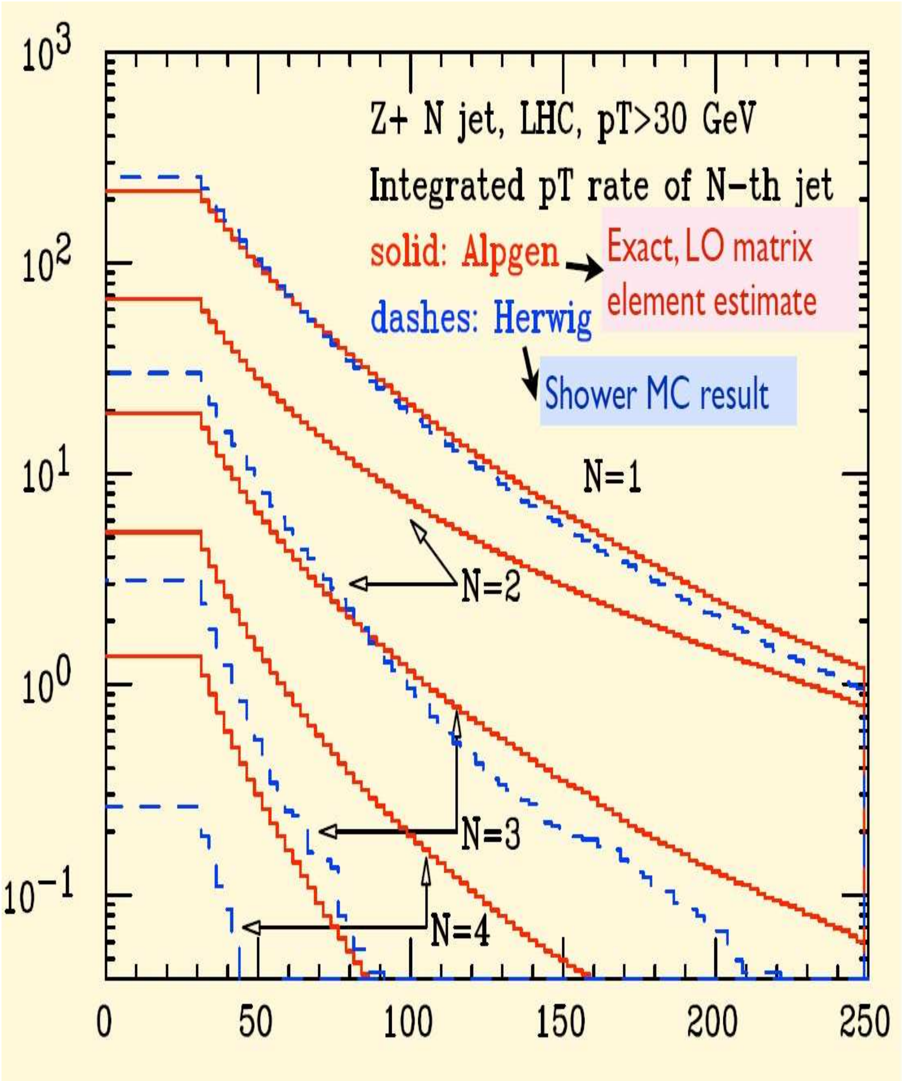
LAPTH-Annecy, France

Part B

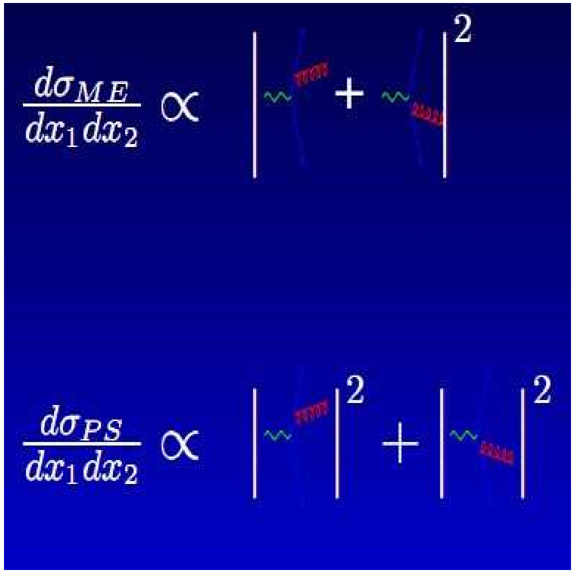
MEG, Codes, Accords


$\mathcal{L}_{\text{New Physics Models}}$
TOOLS
experimental discovery and data analyses

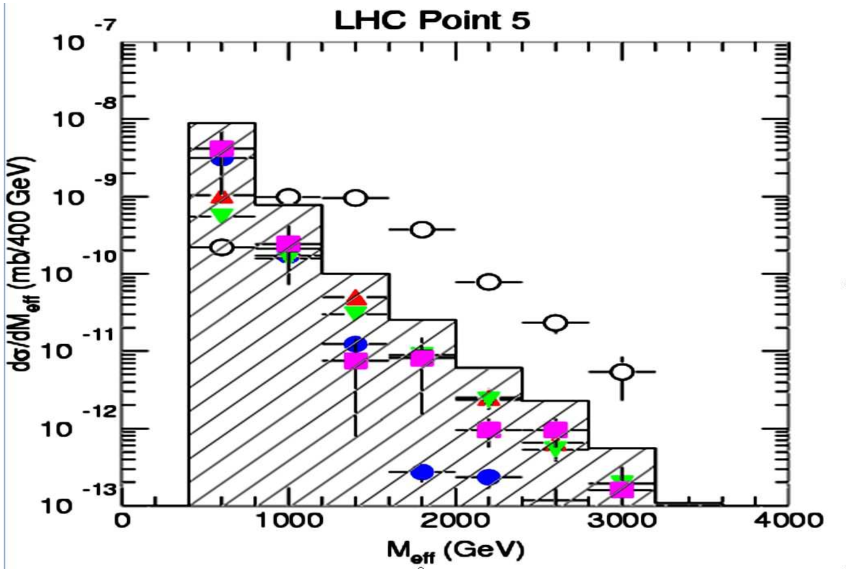
ME vs PS: Limitations of PS



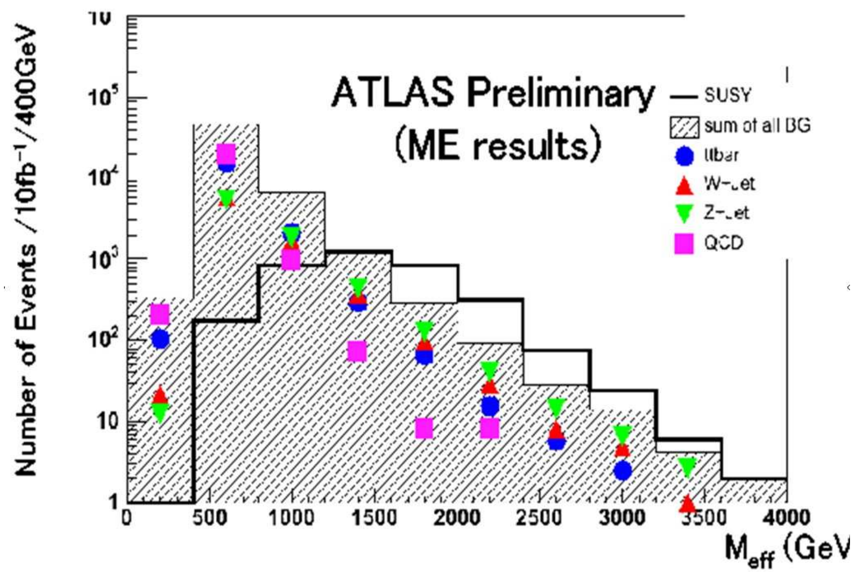
- PS do not describe hard jets
- ME do but in practice can not produce as many jets as PS
- ME evaluates the complete set of all diagrams/configurations: costly
- some real progress has been made in interfacing ME with PS



ATLAS TDR (same with CMS)



ATLAS TDR 98
(mSUGRA point, PreWMAP)



ATLAS 2006

QCD and SM processes can also produce hard jets! and these are/were lacking in PS/MC

ME vs PS: Limitations of PS

- The majority of the processes in the general purpose event generators were implemented one by one, most of them are $2 \rightarrow 2$ processes.
- However for the LHC we are often interested in higher multiplicity final states.
- These require specialized matrix element generators
- These are usually dedicated specialised stand-alone codes or recently some of the EG have built in MEG or at least part of the components of these MEG

ME vs PS: Limitations of PS, Pythia classes of processes

Currently implemented processes, complete with respect to groups, but with some individual processes missing for lack of space (represented by "..."). In the names, a "2" separates initial and final state, an "(s:X)", "(t:X)" or "(l:X)" occasionally appends info on an s- or t-channel- or loop-exchanged particle X.

ProcessGroup	ProcessName
SoftQCD	minBias,elastic, singleDiffractive, doubleDiffractive
HardQCD	gg2gg, gg2qqbar, qg2qg, qq2qq, qqbar2gg, qqbar2qqbarNew, gg2ccbar, qqbar2ccbar, gg2bbbar, qqbar2bbbar
PromptPhoton	qg2qgamma, qqbar2ggamma, gg2ggamma, ffbar2gammagamma, gg2gammagamma
WeakBosonExchange	ff2ff(t:gmZ), ff2ff(t:W)
WeakSingleBoson	ffbar2gmZ, ffbar2W, ffbar2ffbar(s:gm)
WeakDoubleBoson	ffbar2gmZgmZ, ffbar2ZW, ffbar2WW
WeakBosonAndParton	qqbar2gmZg, qg2gmZq, ffbar2gmZgm, fgm2gmZf qqbar2Wg, qg2Wq, ffbar2Wgm, fgm2Wf
Charmonium	gg2QQbar[3S1(1)]g, qg2QQbar[3PJ(8)]q, ...
Bottomonium	gg2QQbar[3S1(1)]g, gg2QQbar[3P2(1)]g, ...
Top	gg2ttbar, qqbar2ttbar, qq2tq(t:W), ffbar2ttbar(s:gmZ), ffbar2tqbar(s:W)
FourthBottom, FourthTop, FourthPair (fourth generation)	
HiggsSM	ffbar2H, gg2H, ffbar2HZ, ff2Hff(t:WW), ...
HiggsBSM	h, H and A as above, charged Higgs, pairs
SUSY	qqbar2chi0chi0 (not yet completed)
NewGaugeBoson	ffbar2gmZZprime, ffbar2Wprime, ffbar2R0
LeftRightSymmmetry	ffbar2ZR, ffbar2WR, ffbar2HLHL, ...
LeptoQuark	ql2LQ, qg2LQl, gg2LQLQbar, qqbar2LQLQbar
ExcitedFermion	dg2dStar, qq2uStarq, qqbar2muStarmu, ...
ExtraDimensionsG*	gg2G*, qqbar2G*, ...

ffff 1

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WeakBosonExchange	ff2ff(t:gmZ), ff2ff(t:W)
WeakSingleBoson	ffbar2gmZ, ffbar2W, ffbar2ffbar(s:gm)
WeakDoubleBoson	ffbar2gmZgmZ, ffbar2ZW, ffbar2WW
WeakBosonAndParton	qqb … ffbar2gmZgm, fgm2gmZf qqb … r2Wgm, fgm2Wf
Charmonium	gg2 … qg2QQbar[3PJ(8)]q, ...
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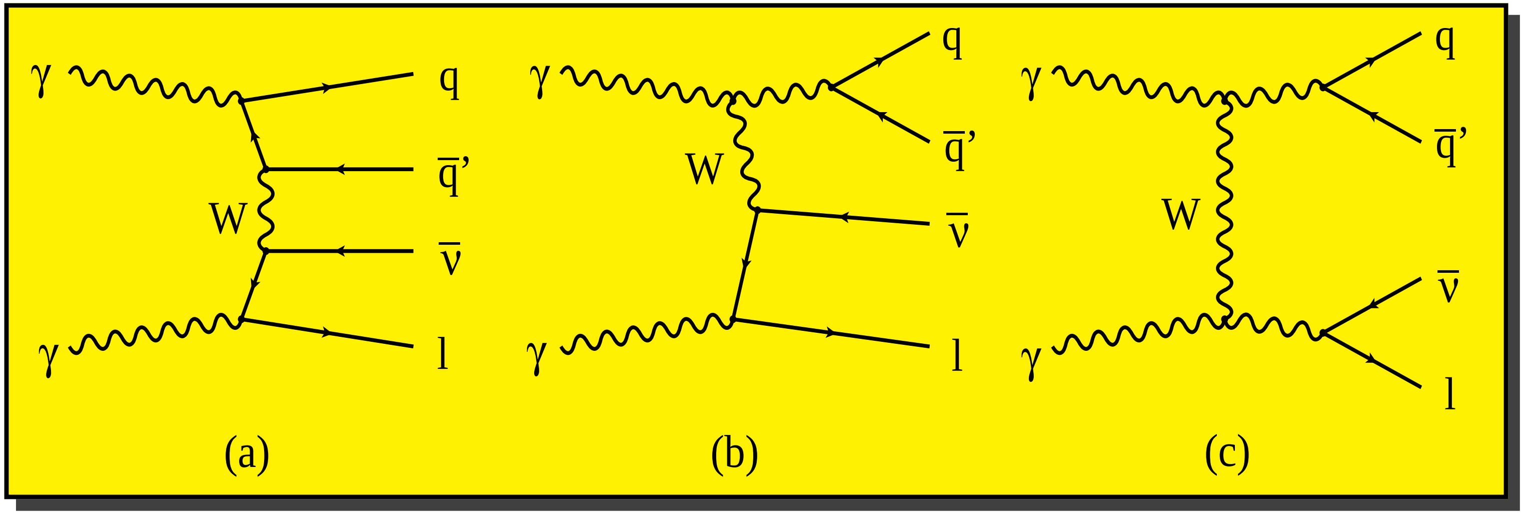
mostly $2 \to 2$

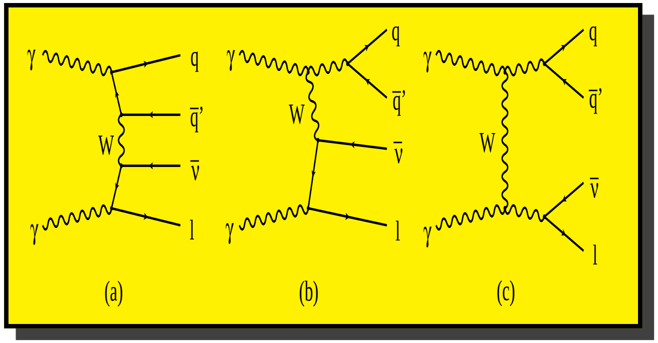
ME vs PS: Resonant vs non resonant



(a) Peripheral (b) single W production (c) Resonant diagram

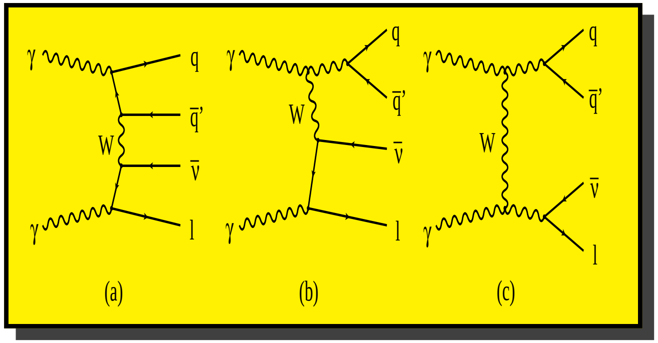
$\gamma\gamma \to W^- W^+ \; W^{\pm} \to l\nu_l, W^{\mp} \to jj'$ with $l = e, \mu$.

ME vs PS: Resonant vs non resonant



- Full calculation needs to evaluate $|\mathcal{M}|^2$
- draw all Feynman diagrams,
- associate Feynman rules to each vertex,
- sum over all diagrams $\mathcal{M} = \sum_i \mathcal{M}_i$

ME vs PS: Resonant vs non resonant



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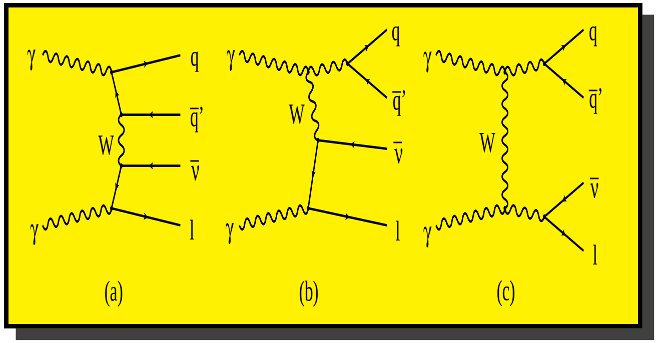
Squaring technique

- Most textbook will tell you to **square** summing over all polarisations, with tricks like spinors leading to traces, pola. vectors to completeness relations $\sum_\lambda (\epsilon_\mu \epsilon_\nu) \to -g_{\mu\nu}$,....
- with more than $2 \to 2$ this is intractable wit huge number of terms (due to *interference*) $\mathcal{M}_i \mathcal{M}_j^*$ with long expressions from squaring
- Any info on polarisation (initial or final, that can be crucial) is lost
- This technique can be automatised and is used in `CompHEP, CalcHEP`

ME vs PS: Resonant vs non resonant



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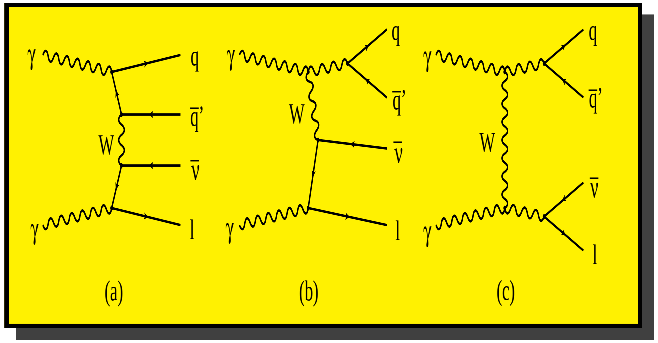
Helicity amplitude

- Calculate each $\mathcal{M}_i$ for a helicity configuration h_α, $\mathcal{M}_i(h_\alpha)$
- each $\mathcal{M}_i(h_\alpha)$ is a c-number
- Sum over i to get the full amplitude (sum before squaring) $\sum_i \mathcal{M}_i(h_\alpha) = \mathcal{M}(h_\alpha)$
- Store $\mathcal{M}(h_\alpha)$ to get polarised/unpolarised/spin-correlation
- Used in GRACE, MadGraph,...

ME vs PS: Resonant vs non resonant



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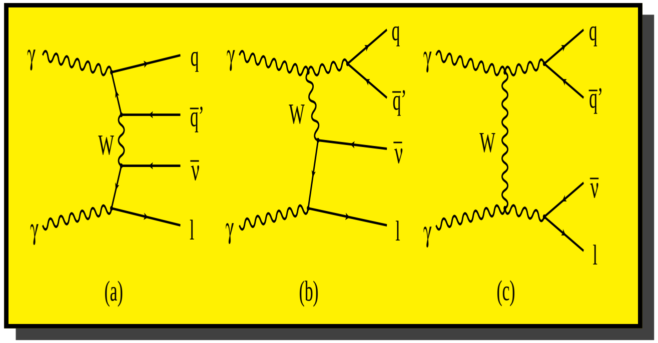
Recursion relations (mostly for massless states within QCD)

- not based on Feynman diagrams
- idea is to build amplitude for $N+1$ leg from N leg recursively
- Methods based on off-shell currents (Berends-Giele)
- New techniques MHV (Maximum Helicity Violating) based on *formal, twistor inspired* work by Cachazo-Svreck-Witten(CVS)
- Many developments (BCFW, Britto-Cachazo-Feng-Witten) including some applications to massive states

ME vs PS: Resonant vs non resonant



- Full calculation needs to evaluate $|\mathcal{M}|^2$
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Approximation: Resonant diagrams only?

- Production $\times$ decay
- $\sigma = \sigma_{WW} \times Br_{W+} Br_{W-}$ is OK only for total cross section without cuts
- distribution sensitive to the spin of decaying particles
- improve with full spin correlation

ME vs PS: Resonant vs non resonant, Density Matrix, Full Spin Correlation

$$\frac{\mathrm{d}\sigma(\gamma(\lambda_1)\gamma(\lambda_2)\to W^+W^-\to f_1\bar{f}_2 f_3\bar{f}_4)}{\mathrm{d}\cos\theta\;\;\mathrm{d}\cos\theta^*_-\;\;\mathrm{d}\phi^*_-\;\;\mathrm{d}\cos\theta^*_+\;\;\mathrm{d}\phi^*_+} = Br_W^{f_1\bar{f}_2}\, Br_W^{f_3\bar{f}_4}\,\frac{\beta}{32\pi s}\left(\frac{3}{8\pi}\right)^2 \quad\times$$

$$\sum_{\lambda_-\lambda_+\lambda'_-\lambda'_+} \mathcal{M}_{\lambda_1,\lambda_2;\lambda_-\lambda_+}(s,\cos\theta)\,\mathcal{M}^*_{\lambda_1,\lambda_2;\lambda'_-\lambda'_+}(s,\cos\theta)\times$$

$$D_{\lambda_-\lambda'_-}(\theta^*_-,\phi^*_-)D_{\lambda_+\lambda'_+}(\pi-\theta^*_+,\phi^*_++\pi)$$

$$\equiv \frac{\mathrm{d}\sigma(\gamma(\lambda_1)\gamma(\lambda_2)\to W^+W^-)}{\mathrm{d}\cos\theta}\left(\frac{3}{8\pi}\right)^2 Br_W^{f_1\bar{f}_2}\, Br_W^{f_3\bar{f}_4}$$

$$\sum_{\lambda_-\lambda_+\lambda'_-\lambda'_+} \rho^{\lambda_1,\lambda_2}_{\lambda_-\lambda_+\lambda'_-\lambda'_+}\; D_{\lambda_-\lambda'_-}(\theta^*_-,\phi^*_-)\; D_{\lambda_+\lambda'_+}(\pi-\theta^*_+,\phi^*_++\pi)$$

with

$$\rho^{\lambda_1,\lambda_2}_{\lambda_-\lambda_+\lambda'_-\lambda'_+}(s,\cos\theta) = \frac{\mathcal{M}_{\lambda_1,\lambda_2;\lambda_-\lambda_+}(s,\cos\theta)\,\mathcal{M}^*_{\lambda_1,\lambda_2;\lambda'_-\lambda'_+}(s,\cos\theta)}{\sum_{\lambda_-\lambda_+}|\mathcal{M}_{\lambda_1,\lambda_2;\lambda_-\lambda_+}(s,\cos\theta)|^2},$$

ME vs PS: Resonant vs non resonant, Density Matrix, Full Spin Correlation

$$\frac{d\sigma(\gamma(\lambda_1)\gamma(\lambda_2) \rightarrow W^+W^- \rightarrow f_1\bar{f}_2 f_3\bar{f}_4)}{d\cos\theta \;\; d\cos\theta^*_- \;\; d\phi^*_- \;\; d\cos\theta^*_+ \;\; d\phi^*_+} = Br_W^{f_1\bar{f}_2} Br_W^{f_3\bar{f}_4} \frac{\beta}{32\pi s} \left(\frac{3}{8\pi}\right)^2 \times$$

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W decay functions

$$D^{W^-}_{\lambda,\lambda'}(\theta^*,\phi^*) \equiv D_{\lambda,\lambda'}, \qquad D_{\lambda,\lambda'} = D^*_{\lambda',\lambda}$$

$$D_{+,-} = \frac{1}{2}(1-\cos^2\theta^*)e^{2i\phi^*}, \qquad D_{\pm,0} = -\frac{1}{\sqrt{2}}(1\mp\cos\theta^*)\sin\theta^* e^{\pm i\phi^*},$$

$$D_{\pm,\pm} = \frac{1}{2}(1\mp\cos\theta^*)^2, \qquad D_{0,0} = \sin^2\theta^*.$$

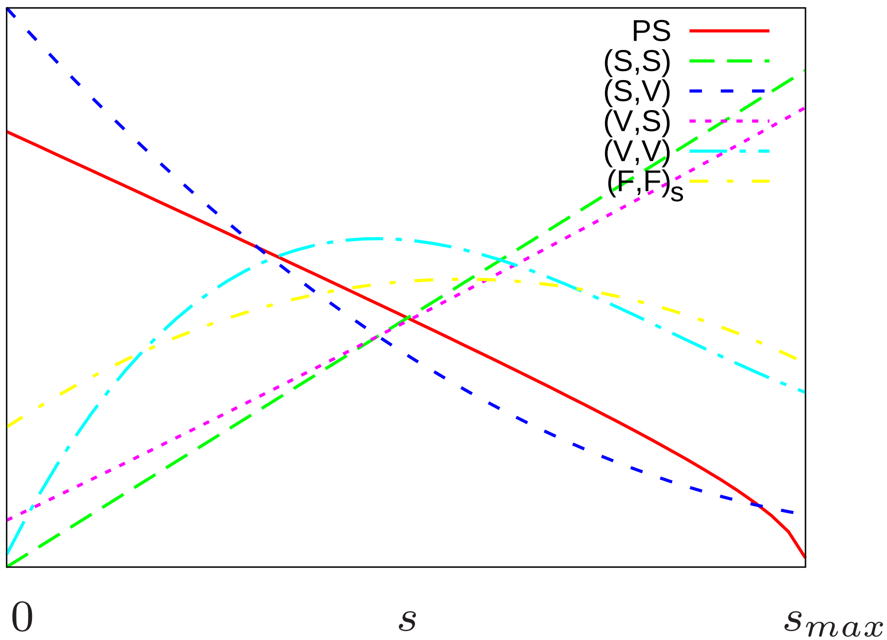
ME vs PS: Resonant vs non resonant

$\lambda_1\ \lambda_2$	Inv. Mass. Cuts	Narrow Width Improved	All diag. $\Gamma_W(M_W^2)$	All diag. $\Gamma_W(s)$	All diag. Fudge	"Resonant" Subset
$\sqrt{s} = 400$ GeV						
$+\ +$	None	2288	2310	2312	2309	2354
$+\ -$	None	1893	1926	1927	1923	1975
$-\ +$	None	1890	1927	1927	1926	1975
$-\ -$	None	2186	2184	2183	2183	2252
$+\ +$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	1759	1762	1764	1761	1761
$+\ -$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	1455	1458	1458	1456	1456
$-\ +$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	1454	1457	1458	1457	1456
$-\ -$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	1681	1683	1681	1682	1682
$\sqrt{s} = 1600$ GeV						
$+\ +$	None	377	389	389	389	456
$+\ -$	None	320	335	335	335	388
$-\ +$	None	320	336	336	336	391
$-\ -$	None	427	447	447	447	490
$+\ +$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	290	291	291	291	291
$+\ -$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	246	246	246	246	246
$-\ +$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	246	246	247	246	247
$-\ -$	$\Delta_{jj}, \Delta_{l\nu} < 5$ GeV	328	329	329	330	329

Spin and distributions

Edelhauser, Porod, Ritesh (2010)

$\frac{d\Gamma}{ds} : PS$



Differential width divided by a phase space factor PS for the different decays $X \to f\bar{f}Y$, $X, Y \in S, V$ taking $m_f = 0$, $m_X/m_Y = 0.1$ and all couplings equal. In addition the phase space factor is drawn.

Spin Correlation and Radiation

Usual techniques require production and decay to be generated at the same time

In a generator the difficulty is that

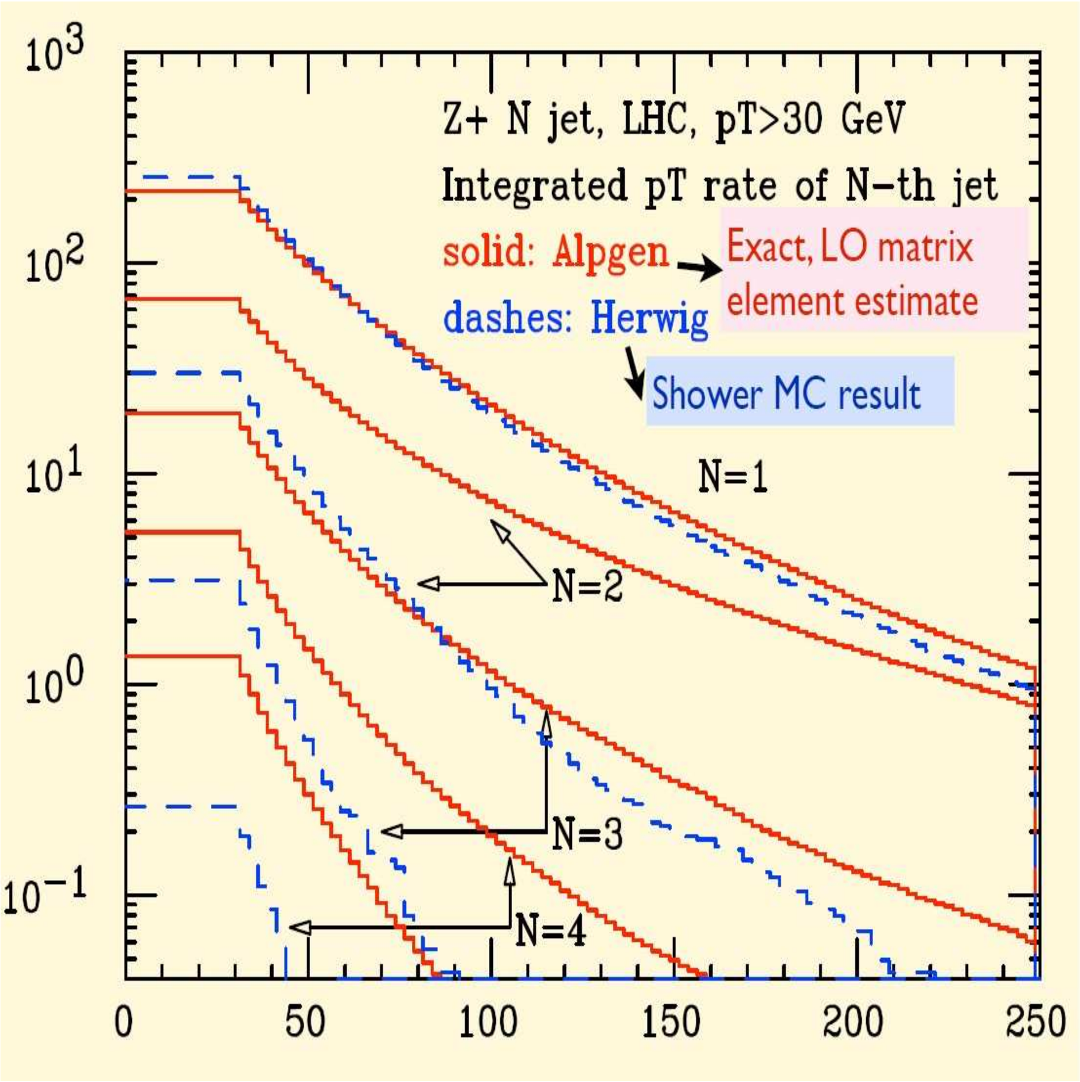
- We need to generate QCD radiation before particle decays
- There may be a long chain of sequential decays
- The particle may have different decay channels
- There may be a few final state particles

Need an algorithm for the production and decay to be done separately

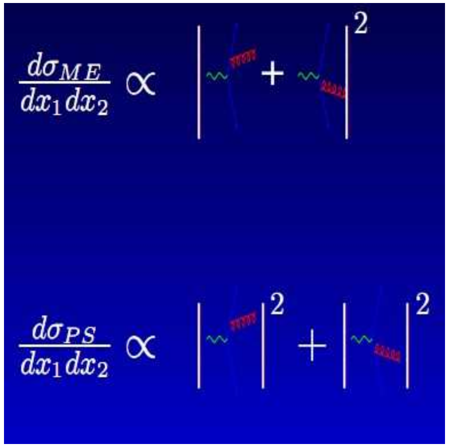
Complexity should not grow more than the number of external particles

in HERWIG spin correlation is implemented not always the case for Pythia (even without radiation)

ME vs PS: Limitations of PS



- PS do not describe hard jets
- some real progress has been made in interfacing ME with PS
- CKKW, MLM (say more if time permits)



Automation of LO calculations of (partonic) processes $2 \longrightarrow N$ are now automatised including integration, for (say) $N < 8$ based on different methods

- ALPGEN
- CompHEP/CalcHEP
- Grace
- HELAS/PHEGAS
- MADGRAPH/MADEVENT
- O'Mega/WHIZARD
- SHERPA/Amegic

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the more particles one deals with a (Feynman) diagrammatic calculations is costly as the number of diagrams grows N!

#gluons	2	3	4	5	6	7	8
#diagrams	4	25	220	2485	34300	0.5M	80M

Basics and ingredients of automated MEG

How would I go about calculating a Matrix element or/and a cross section without a dedicated tool?

tool: does not include pen/chalk, computer, (Symbolic manipulation software)

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Figure out what my particles are

spin assignment, colour, charges,...quantum numbers

Label them

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Get the set of Feynman rules

get them from a trustworthy source (text book?)

better to have the complete set!

getting the full from different sources is asking for trouble

derive the rules myself

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Keep a table for numerics, parameters

masses, couplings, combinations of such

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Would need a tool or efficient way for algebraic manipulations

Mathematica, Maple, Form,..

compilers for numerics also

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Define the Process

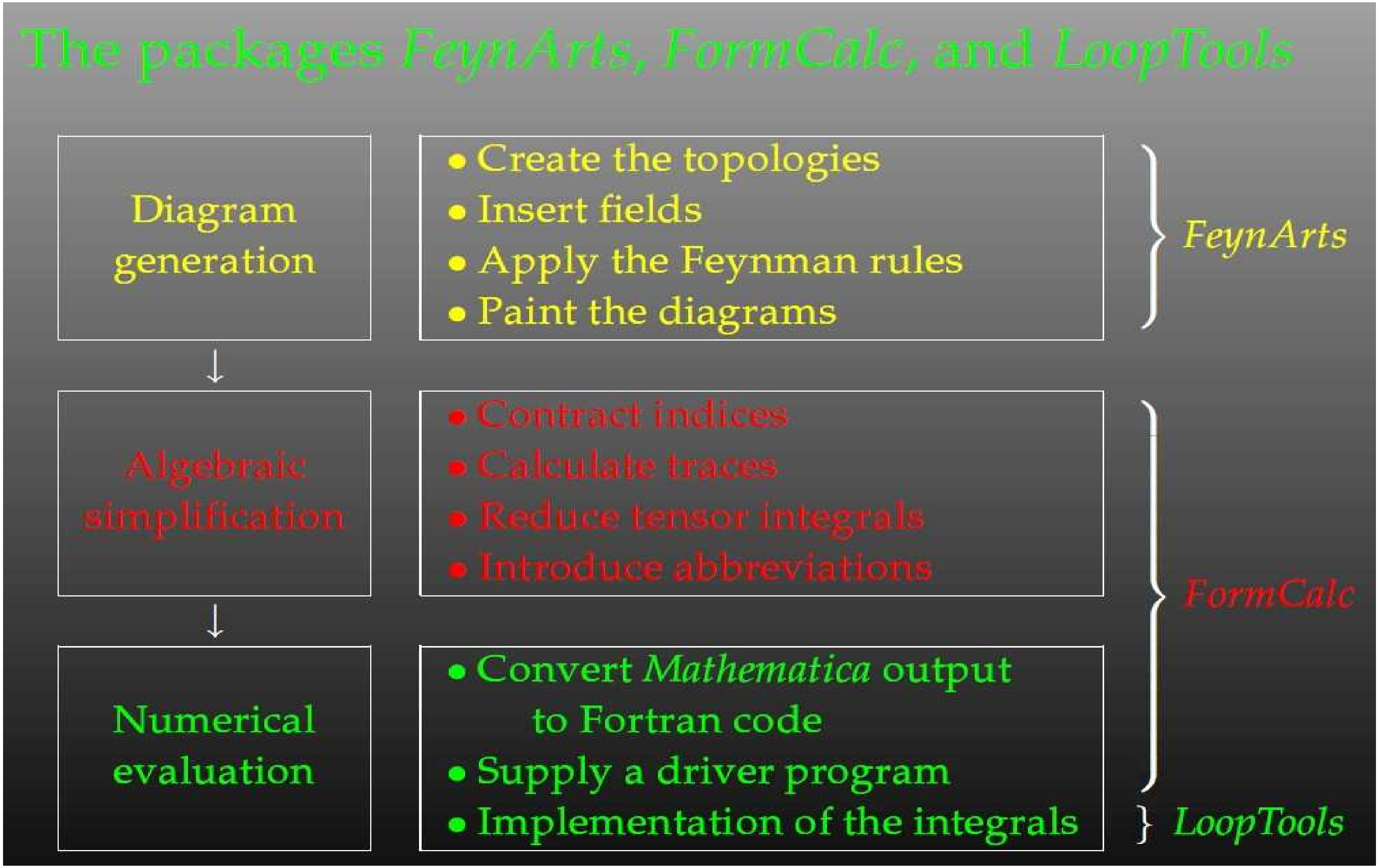
Squaring technique or helicity amplitude?

Integration over phase space. Analytical?, numerical, MC?

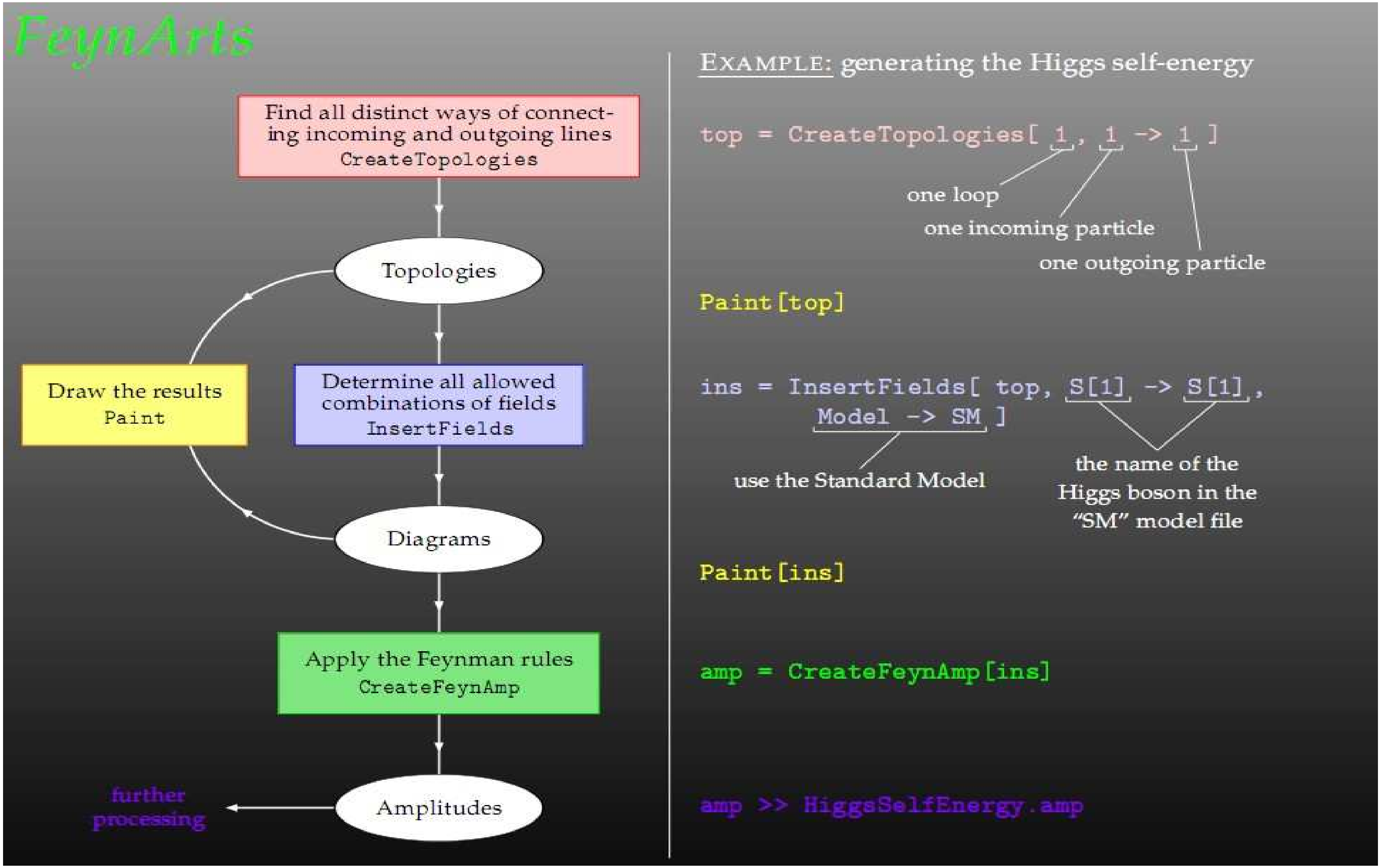
Feynman Recipe, knitting with vertices and propagators

Draw all possible types of diagrams	topology
Figure out which particles can run on each type of diagram	combinatorics
Translate diagrams into expressions applying the Feynman rules	data-base look up
contract indices, take traces, (multiply add blocks)	algebra
Collect and write up the results as a computer code integrate over phase space	programming coding/computing
run the program to get numerical values	waiting!

Your desiderata and wishes come true!



Feyn Package



Very simple and compact tools for spin-1 manipulations, 20lines

```
ok /: ok[x_] := FreeQ[{sca, Times, List, Dot, Plus, Power, Cos, Sin}, x]

tens /: tens := % /. (f_) ?ok[y__] → SequenceForm[f, Superscript[SequenceForm[y]]]

Format[sca[k_, k_]] := k^2

Format[sca[k_, f_]] := SequenceForm[k, ".", f]


Attributes[g] = {Orderless}

Attributes[sca] = {Orderless}

sca /: sca[x_, y_ + z_] := sca[x, y] + sca[x, z]

sca /: sca[-x_, y_] := -sca[x, y]

g /: g[u_, u_] := 4

g /: g[u_, v_] k_[x___, u_, y___] := k[x, v, y]

g /: g[u_, v_]^2 := 4

Unprotect[Times, Power]

Times /: k_[u_] f_[u_] := sca[k, f]

Power /: k_[u_]^2 := sca[k, k]

Protect[Times, Power]
```

Mathematica 5.0 - [TENSEUR.m *]

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TENSEUR.m *

```
g/:g[u_,v_]^2:=4

Unprotect[Times,Power]

Times/:k_[u_] f_[u_]:=sca[k,f]

Power/:k_[u_]^2:=sca[k,k]

Protect[Times,Power]

Out[20]= {Orderless}

Out[21]= {Orderless}

Out[27]= {Times, Power}

Out[30]= {Times, Power}

In[31]:= k[mu] k[mu]

Out[31]= k^2

In[32]:= g[mu, mu]

Out[32]= 4

In[33]:= g[mu, nu] k[nu]

Out[33]= k[mu]
```

FeynCalc.m, 8000 lines (dirac, PV reduction,..)

```
Dot @@ (Reverse[{Spinor[-pe1, ma1], yz, Spinor[-pe2, ma2]}]/.
                    DiracGamma[5]->(-DiracGamma[5])/.
                   {DiracGamma[6] :> DiracGamma[7],
                    DiracGamma[7]:>DiracGamma[6]}
       );

 ComplexConjugate /: ComplexConjugate[ComplexConjugate[x_]]:=x;
 cLIndex[x_, dime___] := LorentzIndex[ComplexConjugate[x], dime];
 cSIndex[x_] := SUNIndex[ComplexConjugate[x]];
 Unprotect[Conjugate];
 Conjugate[x_] := x /. {Polarization[k_,1,in___] :> Polarization[k,-1,in],
                        Polarization[k_,-1,in___] :>Polarization[k,1,in]
                       }/.  Complex[a_, b_] -> Complex[a, -b] /.
                       Dot -> rev /. rev -> Dot /.
                       LorentzIndex -> cLIndex /.
                       SUNIndex   -> cSIndex;
 Protect[Conjugate];
 Polarization/:Momentum[Polarization[k_,i___],di_Symbol
                                   ]:=Momentum[Polarization[k,i]];
 Polarization/:Momentum[Polarization[k__], di_Symbol - 4 ]:= 0;
(* ##################################################################### *)
(*                                 Main14                                *)
(* ##################################################################### *)
(* MetricTensordef *)
 Options[MetricTensor]={Dimension->4};
MetricTensor[x__]:=MetricTensor[x]=metricTensor[x];
 loin1[x_,___]:=x;
 metricTensor[a_ b_,opt___]:=metricTensor[a,b,opt];
 metricTensor[a_^2 ,opt___]:=metricTensor[a,a,opt];
 metricTensor[ x__ ]:=(metricTensor@@({x}/.LorentzIndex->loin1));
 metricTensor[x_,x_,op_:{}]:=(Dimension/.op/.Options[MetricTensor]);
 metricTensor[ x_, y_,op_:{} ] :=
    Pair[ LorentzIndex[x,Dimension/.op/.Options[MetricTensor] ],
          LorentzIndex[y,Dimension/.op/.Options[MetricTensor] ]
        ];
(* PolarizationVectordef *)
Polarization[k_]:=Polarization[k]=Polarization[k,1];
PolarizationVector[x__]:=PolarizationVector[x]=polarizationVector[x];

(* By default a second argument "1" is put into Polarization *)
(* This is changed to "-1" for conjugate polarization vectors *)
 polarizationVector[k_,mu_]:=
       FourVector[Polarization[k,1], mu, Dimension->4 ];
 polarizationVector[k_,mu_,glu_]:=
```

```
(*trilinear vertex W-(m,mu) W+(p,nu) Z/gamma(z,rho) all momenta entering*)
(*-i e*)WWZ[m_, p_, z_, mu_, nu_, rho_] := g[mu, nu] (m[rho] - p[rho]) +
   (z[nu] g[mu, rho] - z[mu] g[nu, rho]) + (p[mu] g[nu, rho] - m[nu] g[mu, rho]);
(*quadratic*)
(*-i e^2*)
WWZZ[mu_, nu_, rho_, sig_] :=
  -2 g[mu, nu] g[rho, sig] + g[mu, rho] g[nu, sig] + g[mu, sig] g[nu, rho];
(*Propagator of massive spin-1*)
(*-i*)
PropagV[M_, p_, mu_, nu_] := (g[mu, nu] - p[mu] p[nu] / M^2) / (sca[p, p] - M^2);
(*Sum on polarisations*)
PolVVsq[M_, p_, mu_, nu_] := g[mu, nu] - p[mu] p[nu] / M^2;
```

```
(*Z (k,rho,ez) to W-(p1,mu,em) W+(p2,nu,ep)*)
(*kinematics*)
sca[k, k] = Mz^2;
sca[p1, p1] = Mw^2;
sca[p2, p2] = Mw^2;
sca[p1, p2] = Mz^2/2 - Mw^2;
sca[p1, k] = Mz^2/2;
sca[p2, k] = Mz^2/2;
sca[ez, k] = 0;
sca[ez, p1] = -Mz*beta*st/2;
sca[ez, p2] = +Mz*beta*st/2;
sca[em, p1] = 0;
sca[em, k] = Mz^2*beta/2/Mw;
sca[em, ep] = (1+beta^2)*Mz^2/4/Mw^2;
sca[em, ez] = -(Mz/2/Mw)*st;
sca[ep, ez] = (Mz/2/Mw)*st;
sca[ep, p2] = 0;
sca[em, p2] = Mz*beta*Mz/2/Mw;
sca[ep, p1] = Mz*beta*Mz/2/Mw;
sca[ep, k] = Mz^2*beta/2/Mw;
```

Z'decay matrix element squared technique

```
(*Matrix Elements Squared over ALL polarisations*)
Expand[WWZ[-p1, -p2, k, mu, nu, rho] * WWZ[-p1, -p2, k, mup, nup, rhop] *
  PolVVsq[Mw, p1, mu, mup] * PolVVsq[Mw, p2, nu, nup] * PolVVsq[Mz, k, rho, rhop]]
```

```
sca[p1, k] = Mz^2 / 2;
sca[p2, k] = Mz^2 / 2;
sca[ez, k] = 0;
sca[ez, p1] = -Mz * beta * st / 2;
sca[ez, p2] = +Mz * beta * st / 2;
sca[em, p1] = 0;
sca[em, k] = Mz^2 * beta / 2 / Mw;
sca[em, ep] = (1 + beta^2) * Mz^2 / 4 / Mw^2;
sca[em, ez] = -(Mz / 2 / Mw) * st;
sca[ep, ez] = (Mz / 2 / Mw) * st;
sca[ep, p2] = 0;
sca[em, p2] = Mz * beta * Mz / 2 / Mw;
sca[ep, p1] = Mz * beta * Mz / 2 / Mw;
sca[ep, k] = Mz^2 * beta / 2 / Mw;

General::spell1 : Possible spelling error: new symbol name "beta" is similar to existing symbol "Beta". More…

In[72]:= (*Matrix Elements Squared over ALL polarisations*)
Expand[WWZ[-p1, -p2, k, mu, nu, rho] * WWZ[-p1, -p2, k, mup, nup, rhop] * PolVVsq[Mw, p1, mu, mup] * PolVVsq[Mw, p2, nu, nup] * P
```

Out[72]= $12\,Mw^2 + 17\,Mz^2 - \frac{4\,Mz^4}{Mw^2} - \frac{Mz^6}{4\,Mw^4}$

```
Simplify[Expand[WWZ[-p1, -p2, k, mu, nu, rho] ez[rho] em[mu] ep[nu]]]
```

```
sca[ep, p1] = Mz * beta * Mz / 2 / Mw;
sca[ep, k] = Mz^2 * beta / 2 / Mw;
```

General::spell1 : Possible spelling error: new symbol name "beta" is similar to existing symbol "Beta". More…

```
In[72]:= (*Matrix Elements Squared over ALL polarisations*)
Expand[WWZ[-p1, -p2, k, mu, nu, rho] * WWZ[-p1, -p2, k, mup, nup, rhop] * PolVVsq[Mw, p1, mu, mup] * PolVVsq[Mw, p2, nu, nup] * PolVVsq[Mz,
```

Out[72]= $12\,Mw^2 + 17\,Mz^2 - \frac{4\,Mz^4}{Mw^2} - \frac{Mz^6}{4\,Mw^4}$

```
(*transversality*)

In[77]:= Expand[WWZ[-p1, -p2, k, mu, nu, rho] k[rho] p1[mu] p2[nu]]
```

Out[77]= 0

```
In[84]:= Simplify[Expand[WWZ[-p1, -p2, k, mu, nu, rho] ez[rho] em[mu] ep[nu]]]
```

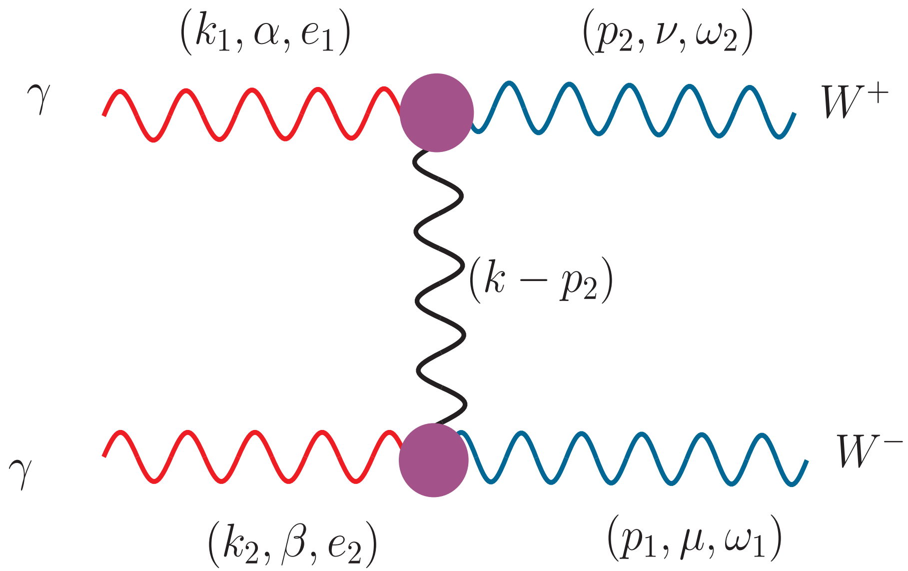
Out[84]= $-\sqrt{1 - \frac{4\,Mw^2}{Mz^2}}\,Mz\,st - \frac{\sqrt{1 - \frac{4\,Mw^2}{Mz^2}}\,Mz^3\,st}{2\,Mw^2}$

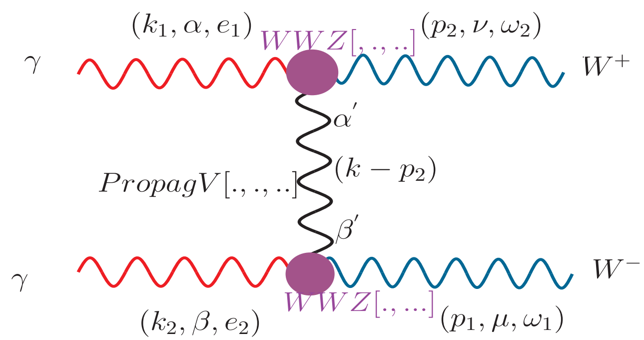
```
In[85]:= Expand[WWZ[-p1, -p2, k, mu, nu, rho] ez[rho] p1[mu] p2[nu]]
```

Out[85]= $-\frac{1}{2}\sqrt{1 - \frac{4\,Mw^2}{Mz^2}}\,Mz^3\,st$

```
In[81]:= beta = Sqrt[1 - 4 * Mw^2 / Mz^2]
```

$\gamma\gamma \to W^+W^-$






```
(*First diagram*)
S1abmn = WWZ[p2 - k1, -p2, k1, alp, nu, al]
    PropagV[Mw, k1 - p2, alp, bep] WWZ[k1 - p2, -p1, k2, bep, mu, be];
(*second diagram*)
S2abmn = WWZ[p2 - k2, -p2, k2, bep, nu, be]
    PropagV[Mw, k2 - p2, bep, alp] WWZ[k2 - p2, -p1, k1, alp, mu, al];
(*third diagram*)
Qabmn = -WWZZ[al, be, mu, nu];
```

Kinematics for $\gamma\gamma \to W^+W^-$

```
(*kinematics for gamma(k1,al,e1) gamma(k2,be,e2) to W-
  (p1,mu,w1) W+(p2,nu,w2)*)sca[k1, k1] = 0;
(*kinematics*)
sca[k2, k2] = 0;
sca[k1, e1] = 0;
sca[k2, e2] = 0;
sca[k1, k2] = s / 2;
sca[p1, p1] = Mw^2;
sca[p2, p2] = Mw^2;
sca[p1, p2] = s / 2 - Mw^2;
sca[p1, w1] = 0;
sca[p2, w2] = 0;
sca[k1, p1] = (Mw^2 - t) / 2;
sca[k2, p2] = (Mw^2 - t) / 2;
sca[k1, p2] = (Mw^2 - u) / 2;
sca[k2, p1] = (Mw^2 - u) / 2;
```

Helicity amplitude for $\gamma\gamma \to W^+W^-$

The photons with helicity λ_1 (λ_2) are in the $+z$ ($-z$) direction and the outgoing W^- (W^+) with helicity λ_- (λ_+) and 4-momentum p_- (p_+):

$$p^\mu_\mp = \frac{\sqrt{s}}{2}(1, \pm\beta\sin\theta, 0, \pm\beta\cos\theta) \quad ; \quad \beta = \sqrt{1-4/\gamma}\;;\; \gamma = s/M_W^2.$$

The polarisations for the helicity basis are defined as

$$\epsilon^\mu_1(\lambda_1) = \frac{1}{\sqrt{2}}(0, -\lambda_1, -i, 0) \qquad \epsilon^\mu_2(\lambda_2) = \frac{1}{\sqrt{2}}(0, \lambda_2, -i, 0) \quad \lambda_{1,2} = \pm$$

$$\epsilon^\mu_-(\lambda_-)^* = \frac{1}{\sqrt{2}}(0, -\lambda_-\cos\theta, i, \lambda_-\sin\theta) \qquad \epsilon^\mu_+(\lambda_+)^* = \frac{1}{\sqrt{2}}(0, \lambda_+\cos\theta, i, -\lambda_+\sin\theta) \quad \lambda_\pm =$$

$$\epsilon^\mu_-(0)^* = \frac{\sqrt{s}}{2M_W}(\beta, \sin\theta, 0, \cos\theta) \qquad \epsilon^\mu_+(0)^* = \frac{\sqrt{s}}{2M_W}(\beta, -\sin\theta, 0, -\cos\theta) \quad \lambda_\pm = 0.$$

Helicity amplitude for $\gamma\gamma \to W^+W^-$, pretty compact

$$\mathcal{M}_{\lambda_1\lambda_2;\lambda_-\lambda_+} = \frac{4\pi\alpha}{1-\beta^2\cos^2\theta}\ \mathcal{N}_{\lambda_1\lambda_2;\lambda_-\lambda_+},$$

where

$$\begin{aligned}
\mathcal{N}_{\lambda_1\lambda_2;00} &= -\frac{1}{\gamma}\left\{-4(1+\lambda_1\lambda_2)+(1-\lambda_1\lambda_2)(4+\gamma)\sin^2\theta\right\}, \\
\mathcal{N}_{\lambda_1\lambda_2;\lambda_-0} &= \sqrt{\frac{8}{\gamma}}\ (\lambda_1-\lambda_2)(1+\lambda_1\lambda_-\cos\theta)\sin\theta, \qquad \lambda_- = \pm \\
\mathcal{N}_{\lambda_1\lambda_2;0,\lambda_+} &= -\sqrt{\frac{8}{\gamma}}\ (\lambda_1-\lambda_2)(1-\lambda_1\lambda_+\cos\theta)\sin\theta, \qquad \lambda_+ = \pm \\
\mathcal{N}_{\lambda_1\lambda_2;\lambda_-\lambda_+} &= \beta(\lambda_1+\lambda_2)(\lambda_-+\lambda_+)+\frac{1}{2\gamma}\{-8\lambda_1\lambda_2(1+\lambda_-\lambda_+) \\
&\qquad +\gamma(1+\lambda_1\lambda_2\lambda_-\lambda_+)(3+\lambda_1\lambda_2) \\
&+ \quad 2\gamma(\lambda_1-\lambda_2)(\lambda_--\lambda_+)\cos\theta-4(1-\lambda_1\lambda_2)(1+\lambda_-\lambda_+)\cos^2\theta \\
&+ \quad \gamma(1-\lambda_1\lambda_2)(1-\lambda_-\lambda_+)\cos^2\theta\} \qquad \lambda_\pm = \pm.
\end{aligned}$$

Take as an example GRACE and $e^+e^- \rightarrow W^+W^-\gamma$

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Model="sm.mdl";
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Process;
  ELWK=3;
  Initial={electron, positron};
  Final  ={photon, W-plus, W-minus};
  Kinem="2302";
Pend;
```

Take as an example GRACE and $e^+e^- \to W^+W^-\gamma$

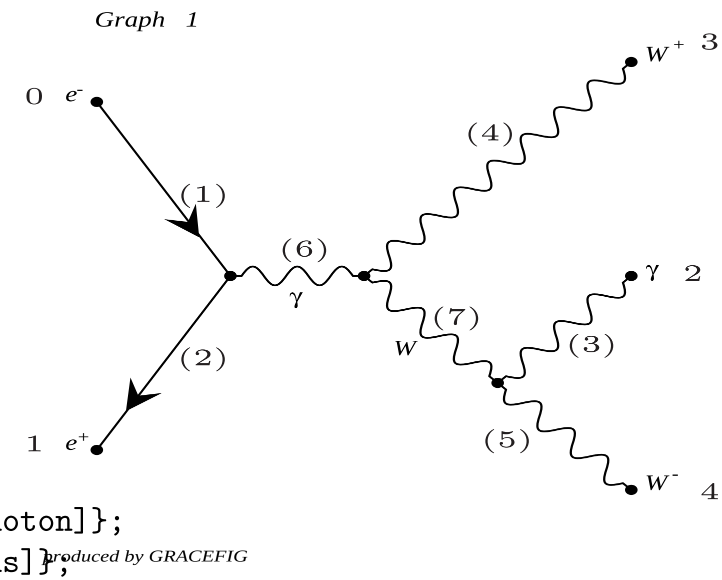
1. Generate the number of vertices.
   The number of vertices is restricted by the order of the coupling constants for the physical process. Each vertex has a fixed number of propagators and external particles to be connected.
2. Connect vertices with propagators or external particles.
   There are multiple ways to connect vertices. All possible configuration are to be generated.
3. Particle assignment.
   Particles are assigned to propagators confirming that the connected vertex is defined in the model. As there will be many ways to assign particles to propagators, all possible configurations are to be generated.
4. Conservation laws such as electric charge and fermion numbers conservation will be employed in order to avoid fruitless trials.
5. Avoid duplication, use graph theory (edges and nodes)
6. QGRAPH: Powerful generator of graphs

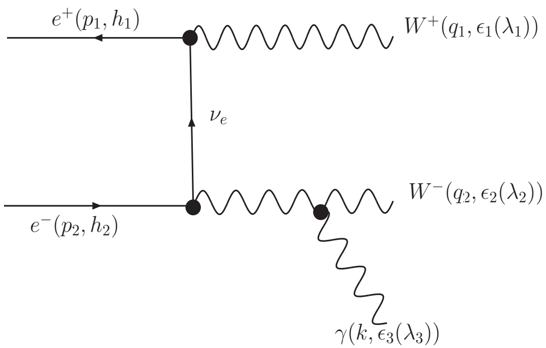
Take as an example GRACE and $e^+e^- \rightarrow W^+W^-\gamma$

```
Process=1; External=5;
      0= initial electron;
      1= initial positron;
      2= final photon;
      3= final w-plus;
      4= final w-minus;
   Eend; elwk=3;Loop=0;

   Graph=1; Gtype=1; Sfactor=-1; Vertex=3;
      0={    1[positron]};
      1={    2[electron]};
      2={    3[photon]};
      3={    4[w-plus]};
      4={    5[w-minus]};
      5[order={1,0}]={    1[electron],    2[positron],    6[photon]};
      6[order={1,0}]={    4[w-minus],    6[photon],    7[w-plus]};
      7[order={1,0}]={    3[photon],    5[w-plus],    7[w-minus]};
   Vend; Gend;

   Graph=2;
       ...
```





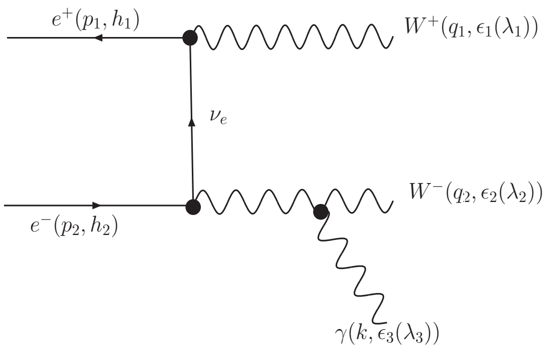
$$T_{fi}\big((p_1,h_1),(p_2,h_2),(q_1,\lambda_1),(q_2,l_2),(k,\lambda_3)\big) =$$

$$\overline{v}(p_1,h_1)\,c^{\eta}_{eW}\,\epsilon_{1\eta}(q_1)\,S_F(-p_1+q_1,0)\,c^{\mu}_{eW}\,u(p_2,h_2)$$

$$\times D_{V\,\mu\nu}(q_2+k,M_W)\,c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\,\epsilon_{2\rho}(q_2)\,\epsilon_{3\sigma}(k)$$

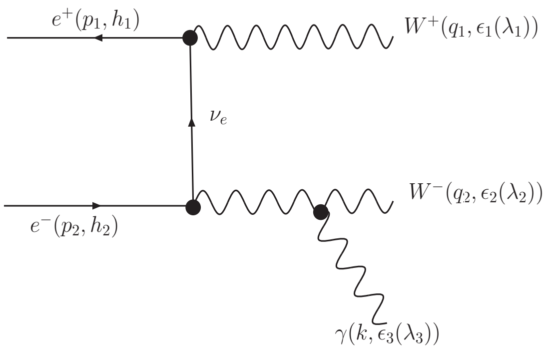
$$c^{\mu}_{eW} = \frac{eM_Z}{\sqrt{2(M_Z^2-M_W^2)}}\,\gamma^{\mu}\,\frac{1-\gamma_5}{2}$$

$$c^{\nu\rho\sigma}_{WW\gamma}(p,q,r) = e[(p-q)^{\sigma}g^{\nu\rho}+(q-r)^{\nu}g^{\rho\sigma}+(r-p)^{\rho}g^{\sigma\nu}]$$



$$T_{fi}\big((p_1,h_1),(p_2,h_2),(q_1,\lambda_1),(q_2,l_2),(k,\lambda_3)\big) =$$
$$\overline{v}(p_1,h_1)\, c^{\eta}_{eW}\, \epsilon_{1\eta}(q_1)\, S_F(-p_1+q_1,0)\, c^{\mu}_{eW}\, u(p_2,h_2)$$
$$\times D_{V\,\mu\nu}(q_2+k,M_W)\, c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\, \epsilon_{2\rho}(q_2)\, \epsilon_{3\sigma}(k)$$
$$c^{\mu}_{eW} = \frac{eM_Z}{\sqrt{2(M_Z^2-M_W^2)}}\gamma^{\mu}\frac{1-\gamma_5}{2}$$
$$c^{\nu\rho\sigma}_{WW\gamma}(p,q,r) = e[(p-q)^{\sigma}g^{\nu\rho} + (q-r)^{\nu}g^{\rho\sigma} + (r-p)^{\rho}g^{\sigma\nu}]$$

$$S_F(p,m) = (\not{p}+m)D(p,m) \qquad D_{V\,\mu\nu}(p) = \Big(-g_{\mu\nu}+\frac{p_\mu p_\nu}{M^2}\Big)D(p,m) \qquad D(p,m)=\frac{1}{p^2-m^2}$$



$$T_{fi}\Big((p_1,h_1),(p_2,h_2),(q_1,\lambda_1),(q_2,l_2),(k,\lambda_3)\Big) =$$

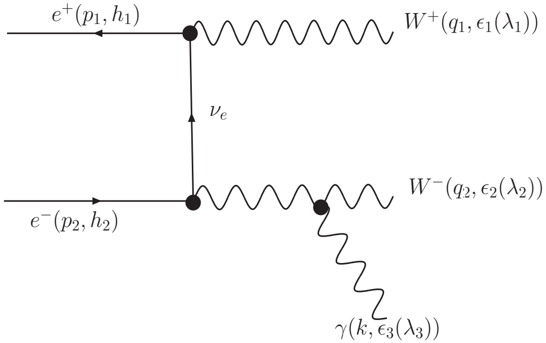
$$\overline{v}(p_1,h_1)\, c^{\eta}_{eW}\, \epsilon_{1\eta}(q_1)\, S_F(-p_1+q_1,0)\, c^{\mu}_{eW}\, u(p_2,h_2)$$

$$\times D_{V\,\mu\nu}(q_2+k,M_W)\, c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\, \epsilon_{2\rho}(q_2)\, \epsilon_{3\sigma}(k)$$

$$c^{\mu}_{eW} = \frac{eM_Z}{\sqrt{2(M_Z^2-M_W^2)}}\,\gamma^{\mu}\,\frac{1-\gamma_5}{2}$$

$$c^{\nu\rho\sigma}_{WW\gamma}(p,q,r) = e[(p-q)^{\sigma}g^{\nu\rho} + (q-r)^{\nu}g^{\rho\sigma} + (r-p)^{\rho}g^{\sigma\nu}]$$

$$S_F(p) = \frac{\sum_{\alpha i} w_{\alpha,i}\, U^{\alpha}(h^{(i)},p^{(i)})\, \overline{U}^{\alpha}(h^{(i)},p^{(i)})}{p^2-m^2}, \qquad D_{V\,\mu\nu}(p) = \frac{\sum_i\, w_i\, \epsilon^{(i)}_{\mu}(p)\, \epsilon^{(i)}_{\nu}(p)}{p^2-m^2}$$



$$T_{fi}\big((p_1,h_1),(p_2,h_2),(q_1,\lambda_1),(q_2,l_2),(k,\lambda_3)\big) =$$

$$\overline{v}(p_1,h_1)\, c^{\eta}_{eW}\, \epsilon_{1\eta}(q_1)\, S_F(-p_1+q_1,0)\, c^{\mu}_{eW}\, u(p_2,h_2)$$

$$\times D_{V\,\mu\nu}(q_2+k,M_W)\, c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\, \epsilon_{2\rho}(q_2)\, \epsilon_{3\sigma}(k)$$

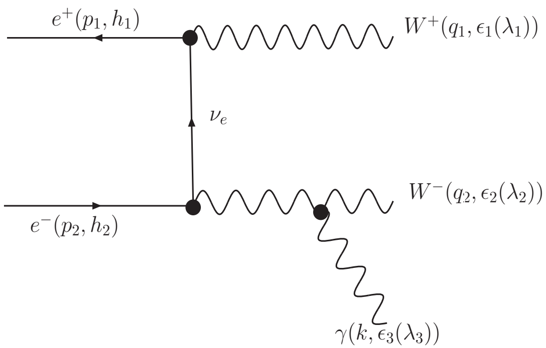
$$c^{\mu}_{eW} = \frac{eM_Z}{\sqrt{2(M_Z^2-M_W^2)}}\,\gamma^{\mu}\,\frac{1-\gamma_5}{2}$$

$$c^{\nu\rho\sigma}_{WW\gamma}(p,q,r) = e[(p-q)^{\sigma}g^{\nu\rho}+(q-r)^{\nu}g^{\rho\sigma}+(r-p)^{\rho}g^{\sigma\nu}]$$

$$S_F(p) = \frac{\sum_{\alpha i} w_{\alpha,i}\, U^{\alpha}(h^{(i)},p^{(i)})\, \overline{U}^{\alpha}(h^{(i)},p^{(i)})}{p^2-m^2}, \qquad D_{V\,\mu\nu}(p) = \frac{\sum_i\, w_i\, \epsilon^{(i)}_{\mu}(p)\, \epsilon^{(i)}_{\nu}(p)}{p^2-m^2}$$

$$T_{fi} = D(-p_1+q_1,0)\; D(q_2+k,m_W)\; \sum_{\alpha,i} w_{\alpha,i} \sum_l w_l \times V^{(\alpha,i)}_{eW+}\, V^{(\alpha,i,l)}_{eW-}\, V^{(l)}_{WW\gamma},$$

Matrix Elements Generation and Automation: Helicity amplitude, How it works



$$T_{fi}\big((p_1,h_1),(p_2,h_2),(q_1,\lambda_1),(q_2,l_2),(k,\lambda_3)\big) =$$
$$\overline{v}(p_1,h_1)\, c^{\eta}_{eW}\, \epsilon_{1\eta}(q_1)\, S_F(-p_1+q_1,0)\, c^{\mu}_{eW}\, u(p_2,h_2)$$
$$\times D_{V\,\mu\nu}(q_2+k,M_W)\, c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\, \epsilon_{2\rho}(q_2)\,\epsilon_{3\sigma}(k)$$

$$c^{\mu}_{eW} = \frac{eM_Z}{\sqrt{2(M_Z^2-M_W^2)}}\gamma^{\mu}\frac{1-\gamma_5}{2}$$

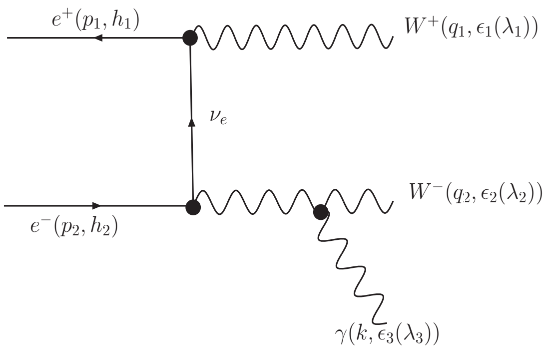
$$c^{\nu\rho\sigma}_{WW\gamma}(p,q,r) = e[(p-q)^{\sigma}g^{\nu\rho} + (q-r)^{\nu}g^{\rho\sigma} + (r-p)^{\rho}g^{\sigma\nu}]$$

$$S_F(p) = \frac{\sum_{\alpha i} w_{\alpha,i}\, U^{\alpha}(h^{(i)},p^{(i)})\,\overline{U}^{\alpha}(h^{(i)},p^{(i)})}{p^2-m^2}, \qquad D_{V\,\mu\nu}(p) = \frac{\sum_i w_i\, \epsilon^{(i)}_{\mu}(p)\,\epsilon^{(i)}_{\nu}(p)}{p^2-m^2}$$

$$T_{fi} = D(-p_1+q_1,0)\; D(q_2+k,m_W)\; \sum_{\alpha,i} w_{\alpha,i} \sum_{l} w_l \times V^{(\alpha,i)}_{eW+}\, V^{(\alpha,i,l)}_{eW-}\, V^{(l)}_{WW\gamma},$$

The building blocks: c-numbers Library subroutines

$$\begin{aligned}
V^{(\alpha,i)}_{eW+} &= \overline{v}(p_1,h_1)\, c^{\eta}_{eW}\, \epsilon_{1\eta}(q_1)\, U^{\alpha}((-p_1+q_1)^{(i)},h^{(i)}), \quad \text{FFV}\\
V^{(\alpha,i,l)}_{eW-} &= \overline{U}^{\alpha}(p^{(i)},h^{(i)})\, c^{\mu}_{eW}\, \epsilon^{(l)}_{\mu}(q_2+k)\, u(p_2,h_2),\\
V^{(l)}_{WW\gamma} &= c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\, \epsilon^{(l)}_{\nu}(q_2+k)\, \epsilon_{2\rho}(q_2)\, \epsilon_{3\sigma}(k) \quad \text{VVV}.
\end{aligned}$$



$$T_{fi}((p_1,h_1),(p_2,h_2),(q_1,\lambda_1),(q_2,l_2),(k,\lambda_3)) =$$
$$\overline{v}(p_1,h_1)\, c^{\eta}_{eW}\, \epsilon_{1\eta}(q_1)\, S_F(-p_1+q_1,0)\, c^{\mu}_{eW}\, u(p_2,h_2)$$
$$\times D_{V\,\mu\nu}(q_2+k,M_W)\, c^{\nu\rho\sigma}_{WW\gamma}(q_2+k,-q_2,-k)\, \epsilon_{2\rho}(q_2)\, \epsilon_{3\sigma}(k)$$
$$c^{\mu}_{eW} = \frac{eM_Z}{\sqrt{2(M_Z^2-M_W^2)}}\,\gamma^{\mu}\,\frac{1-\gamma_5}{2}$$
$$c^{\nu\rho\sigma}_{WW\gamma}(p,q,r) = e[(p-q)^{\sigma} g^{\nu\rho} + (q-r)^{\nu} g^{\rho\sigma} + (r-p)^{\rho} g^{\sigma\nu}]$$

$$S_F(p) = \frac{\sum_{\alpha i} w_{\alpha,i}\, U^{\alpha}(h^{(i)},p^{(i)})\, \overline{U}^{\alpha}(h^{(i)},p^{(i)})}{p^2-m^2}, \qquad D_{V\,\mu\nu}(p) = \frac{\sum_i w_i\, \epsilon^{(i)}_{\mu}(p)\, \epsilon^{(i)}_{\nu}(p)}{p^2-m^2}$$

$$T_{fi} = D(-p_1+q_1,0)\; D(q_2+k,m_W)\, \sum_{\alpha,i} w_{\alpha,i} \sum_{l} w_l \times V^{(\alpha,i)}_{eW+}\, V^{(\alpha,i,l)}_{eW-}\, V^{(l)}_{WW\gamma},$$

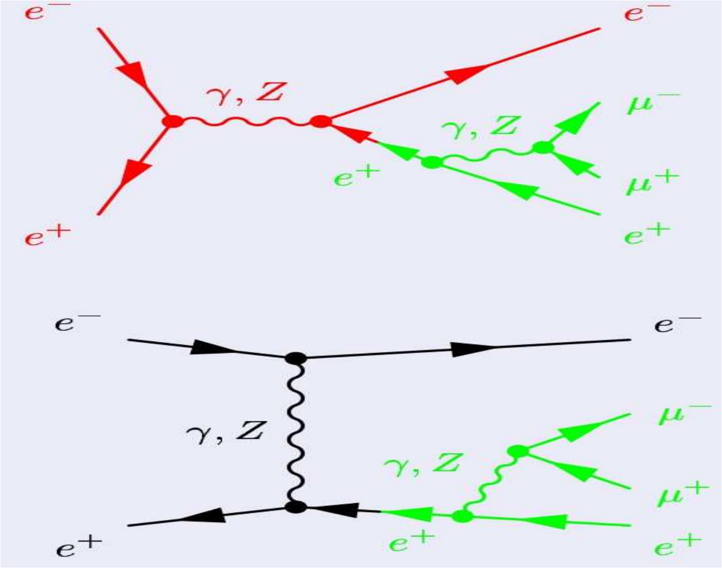
The building blocks: c-numbers Library. If New Physics? extend library?

read in new Feynman rules, calculate new entries for subroutines

$$V^{(\alpha,i)}_{eW+} = \overline{v}(p_1,h_1)\, c^{\eta}_{eW,NP}\, \epsilon_{1\eta}(q_1)\, U^{\alpha}((-p_1+q_1)^{(i)},h^{(i)}),$$
$$V^{(\alpha,i,l)}_{eW-} = \overline{U}^{\alpha}(p^{(i)},h^{(i)})\, c^{\mu}_{eW,NP}\, \epsilon^{(l)}_{\mu}(q_2+k)\, u(p_2,h_2),$$
$$V^{(l)}_{WW\gamma} = c^{\nu\rho\sigma}_{WW\gamma,NP}(q_2+k,-q_2,-k)\, \epsilon^{(l)}_{\nu}(q_2+k)\, \epsilon_{2\rho}(q_2)\, \epsilon_{3\sigma}(k).$$

- This is now used in SHERPA and HERWIG
- The method is purely numerical.
- The amplitude for each Feynman graph is first decomposed into vertex sub-amplitudes
- Each of these sub-amplitudes is read from a pre-defined model file library
- **drawback:** Library exists for Standard Couplings, higher order operators, spin > 2, need to be generated from scratch

can speed up by reusing common pieces GRACE, AMEGIC



but we need to feed in the Feynman rules

what if the new physics is like the MSSM? huge number of vertices?

need to input new models quickly and efficiently

ME based MC Codes

Int/Amp.	Squaring	Helicity	Off-Shell	On-Shell
Adaptive	CompHEP/CalcHEP	GRACE	ALPGEN	?
Multi-Channel	-	MadGraph/Sherpa		?
	-	HELAC/Whizard		

LanHEP (A. Semenov) as prototype for automatic Feynman rules generation

http://theory.sinp.msu.ru/~semenov/lanhep.html

- LanHEP was developed since 1994 as a part of CompHEP project to help to create new models (complete set of Feynamn rules) starting from the Lagrangian, the first goal was MSSM.
- can now output to FeynArts/FeynCalc
- Lagrangian writes in a texbook format, outputs also to LateX
- extremely powerful, extended to one-loop: generates counterterms and new vertices
- A model in a MEG (CompHEP/CalcHEP/FeynArts,..) is defined by the tables of parameters, particles and interaction vertices with implicit Lorentz structure.
- Flexible model format allows to introduce into these MEG new gauge theories as well as various anomalous terms.
- Not restricted to dim-4 (renormalisable) operators.
- Gauge theories highly automated (gauge-fixing, ghost, BRST)
- Powerful use of compact objects (multiplets, supermultiplets,..)

and thus SUSY-friendly: 2-component fermions and superpotential notation

LanHEP as prototype for automatic Feynman rules generation

- The LanHEP program is written in C, external mathematical software is NOT required.
- LanHEP reads an input file which describes the physical model by a set of statements.
- Large projects can be split into several files.
- Conditional processing of the model file allows the user to use the same input file(s) for several species of the physical model. This feature allows, for example, to chose gauge fixing and MSSM extensions by setting some switches instead of creating several slightly different input files.
- Command-line tool: no graphical interface means easy compilation on any platform where 32-bit C compiler exists.

An example: Lanhep in CompHEP/CalcHEP

A physical model in CompHEP/CalcHEP is defined by the (3/4) tables of

- parameters
- particles
- interaction vertices with implicit Lorentz structure (any Lorentz structure is allowed)
- a file for book-keeping (constraints, dependent parameters)

A physical model in CompHEP is defined by the tables of parameters, particles and interaction vertices

Parameters

```
EE    |0.31345      |Electromagnetic coupling constant (<->1/127.9)
MW    |MZ*CW
```

Particles

```
photon       |A  |A  |2      |0      |0      |1     |G  |A
Z boson      |Z  |Z  |2      |MZ     |wZ     |1     |G  |Z
W boson      |W+ |W- |2      |MW     |wW     |1     |G  |W^+
electron     |e  |E  |1      |Me     |0      |1     |   |e
```

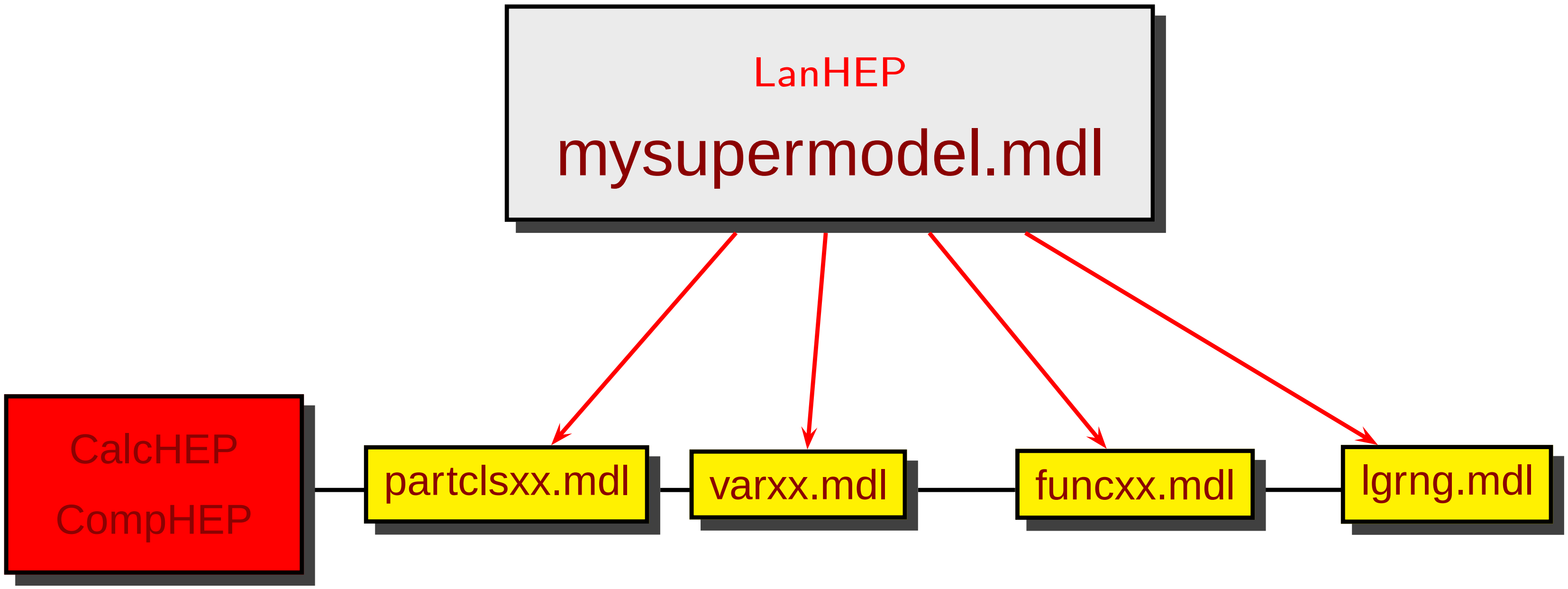
Vertices

```
E    |e    |A    |     |EE                         |G(m3)
E    |e    |H    |     |-EE*Me*ca/(2*MW*SW*cb)     |1
E    |e    |H3   |     |i*EE*Me*tb/(2*MW*SW)       |G5
E    |e    |Z    |     |EE/(2*S2W)                 |C2W*G(m3)*(1-G5)-2*SW^2*
E    |e    |Z.f  |     |-i*EE*Me/(2*MW*SW)         |G5
E    |e    |h    |     |EE*Me*sa/(2*MW*SW*cb)      |1
E    |ne   |H-   |     |EE*Me*Sqrt2*tb/(4*MW*SW)|(1-G5)
E    |ne   |W-   |     |-EE*Sqrt2/(4*SW)           |G(m3)*(1-G5)
E    |ne   |W-.f |     |-EE*Me*Sqrt2/(4*MW*SW)     |(1-G5)
```

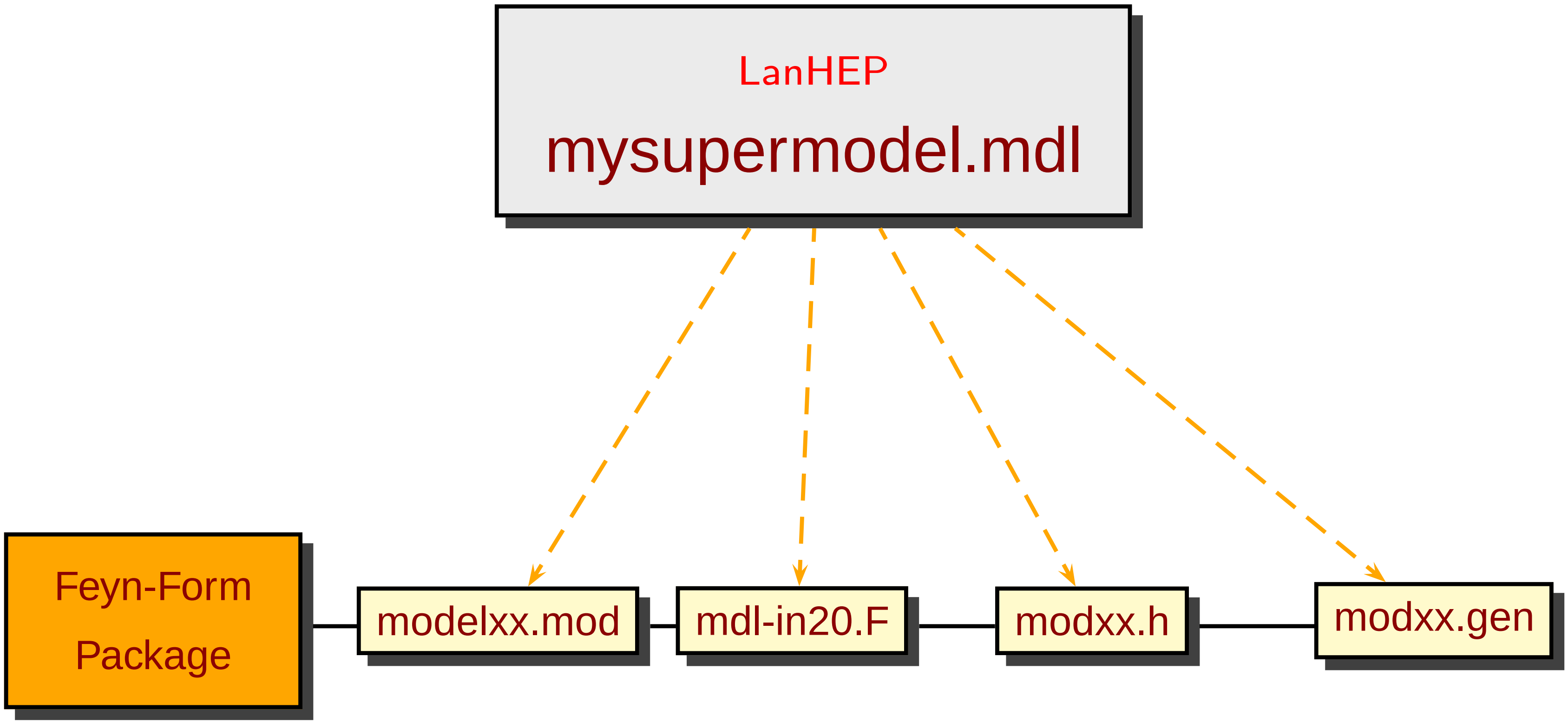
LanHEP

mysupermodel.mdl

LanHEP to MEG



LanHEP to MEG



- The user declares the physical parameters to be included in the Lagrangian. The value of a parameter can be a number or an expression:

```
parameter ee=0.31333:'elementary electric charge'.
parameter sw=0.478:'sinus of weak angle'.
parameter cw=Sqrt(1-sw**2):'cosine of weak angle'.
```

- The user declares scalar, spinor, vector, (also spin 3/2 and 2) particles . It is possible to prescribe the colour structure for a particle:

```
spinor e1/E1:(electron, mass Me=0.000511).
spinor q/Q:(quark, color c3, mass Mq=10).
vector A/A:(photon, gauge).
```

- New symmetry groups are also possible. They can be defined in a way like color $SU(3)$ symmetry is defined, as well as corresponding matrices and structure constants:

```
group color:SU(3).
repres color:(c3/c3b,c8).
special lambda:(color c3, color c3b, color c8).
```

- The user can define the substitution rules, for example for covariant derivative $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$:

```
let F^mu^nu = deriv^mu*A^nu - deriv^nu*A^mu.
```

- It is possible to define multiplets, and their components:

```
let l1 = {n1,e1}, L1 = {N1,E1}.
```

- The user can write Lagrangian terms with Lorenz and multiplet indices explicitly or omit indices (all or part of them):*(QED vertex $\bar{e}(x)\gamma^\mu A_\mu(x)e(x)$)*

```
lterm E1^a*gamma^a^b^mu*A^mu*e1^b.
lterm E1*gamma^mu*A^mu*e1.
lterm E1*gamma*A*e1.
```

- LanHEP performs explicit summation over the indices of Lagrangian terms, if the corresponding components for multiplets and matrices are introduced.

- 2-component fermion notation makes possible the introduction of supersymmetric Lagrangian in a more natural way, closer to the form used in most textbooks on the supersymmetry.
- Superpotential can be used for supersymmetric theories; this option allows to introduce easily various extensions of MSSM (R-parity violation, NMSSM, etc). Yukawa and F^*F terms are now automatically derived by the program.
- Generating Hermitian conjugate terms allow to simplify model description.
- Constructing the ghost Lagrangian from BRST transformation.
- Conterterms can be generated if the necassy shifts for parameters and fields are prescribed.

LanHEP features

- Checking the correctness of the model
  - Electric charge conservation
  - Hermiticity
  - Probing kinetic and mass terms, the mass matrix is extracted
  - BRST invariance
  - Extracting classes of vertices
- Simplifying the expression for vertices
  - Orthogonal (and hermitian) matrices
  - Trigonometric expressions $(\sin\alpha \pm \beta)$
  - Lengthly expressions in the vertices can be transferred to the table of parameters.

Some new Lagrangians implemented by LanHEP

- Complete MSSM in unitary and t'Hooft-Feynman gauges with the Higgs sector by linking with the FeynHiggs, effective potential is used to take into account radiative corrections to Higgs masses and interaction; mSUGRA and GMSB by means of SLHA interface
- MSSM extensions include:
  - MSSM with R-parity violation
  - Model with gravitino and sgoldstinos
  - NMSSM (an extension of the MSSM by a gauge singlet N with hypercharge 0)
  - MSSM with CP violation
- Complete Leptoquark model which includes Yukawa couplings for all types of LQ, gauge couplings and anomalous gauge couplings for vector LQ
- Complete two-Higgs-doublet model with conserved or broken CP invariance
- Anomalous quartic vector bosons self-couplings

- A new signature for color octet pseudoscalars at the LHC, in theories of extra-dim. Alfonso R. Zerwekh, Claudio O. Dib, Rogerio Rosenfeld;
- Minimal Higgsless model, Chivukula et al;
- Inert Doublet Model, Pierce and Thaler;
- Excited fermions, Boos et al;
- Technihadrons, technicolour, Zerwekh;
- Little Higgs Models, Phenomenology of littlest Higgs model with T-parity: including effects of T-odd fermions. Alexander Belyaev, Chuan-Ren Chen, Kazuhiro Tobe, C.-P. Yuan (Michigan State U.);
- Universal extra-dim, Matchev et al.

New option allows to modify the format of the output particle table and to add new proprties (new columns in the table). One can add, say, PDG particle number to the table:

```
prtcformat fullname:' Full   Name ',
           name:' p ',
           aname:' ap',
           spin2,color,mass,width, aux,
           pdg:'PDG ID',
           texname:'  latex P name ',
           atexname:' latex aP name ' .
```

Then the new property value can be written in the particle declaration statement:

```
scalar h:(higgs, mass Mh, pdg 123, width wh).
```

- Electric charge can be extracted automatically from the photon interaction and then added to the table.

Vertices table format: explicit colour structure

Color matrices and dot products can be optionally written in the Lorentz Part, e.g. QCD plus quark-photon interactions produces the following vertices file:

```
P1    |P2    |P3    |P4    |>    Factor    <|> dLagrangian/ dA(p1) dA(p2) dA(p3
G     |G     |G     |      |gg              |m2.p3*m1.m3*F(c1,c2,c3)
      |      |      |      |                 -m1.p3*m2.m3*F(c1,c2,c3)
      |      |      |      |                 +m3.p1*m1.m2*F(c1,c2,c3)
      |      |      |      |                 -m2.p1*m1.m3*F(c1,c2,c3)
      |      |      |      |                 -m3.p2*m1.m2*F(c1,c2,c3)
      |      |      |      |                 +m1.p2*m2.m3*F(c1,c2,c3)
G.C   |G.c   |G     |      |-gg             |m3.p2*F(c1,c2,c3)
Q     |q     |G     |      |gg              |L(c1,c2,c3)*G(m3)
Q     |q     |A     |      |ee/3            |c1.c2*G(m3)
G     |G     |G     |G     |gg^2            |m1.m3*m2.m4*F(c1,c2,c0)*F(c3,c4,c0
      |      |      |      |                 -m1.m4*m2.m3*F(c1,c2,c0)*F(c3,c4,c
      |      |      |      |                 +m1.m2*m3.m4*F(c1,c3,c0)*F(c2,c4,c
      |      |      |      |                 -m1.m4*m2.m3*F(c1,c3,c0)*F(c2,c4,c
      |      |      |      |                 +m1.m2*m3.m4*F(c1,c4,c0)*F(c2,c3,c
      |      |      |      |                 -m1.m3*m2.m4*F(c1,c4,c0)*F(c2,c3,c
```

Claude Duhr (in collaboration with N. D. Christensen and B. Fuks)

http://feynrules.phys.ucl.ac.be

- FeynRules has been developed since 2008 originally as a part of the MadGraph
- FeynRules is a Mathematica package that allows to derive Feynman rules from a Lagrangian.
- The syntax of FeynRules is an extension of the syntax used in FeynArts
- The only requirements on the Lagrangian are:
  - All indices need to be contracted (Lorentz and gauge invariance)
  - Locality
  - Supported field types: spin 0, 1/2, 1, 2 and ghosts (ghost Lagrangian not automatically derived though)
- In progress
  - Support for Weyl fermions and superfields
  - Diagonalisation of mass matrices
- can export the Feynman rules into a TeX file.

Implemented Models in FeynRules

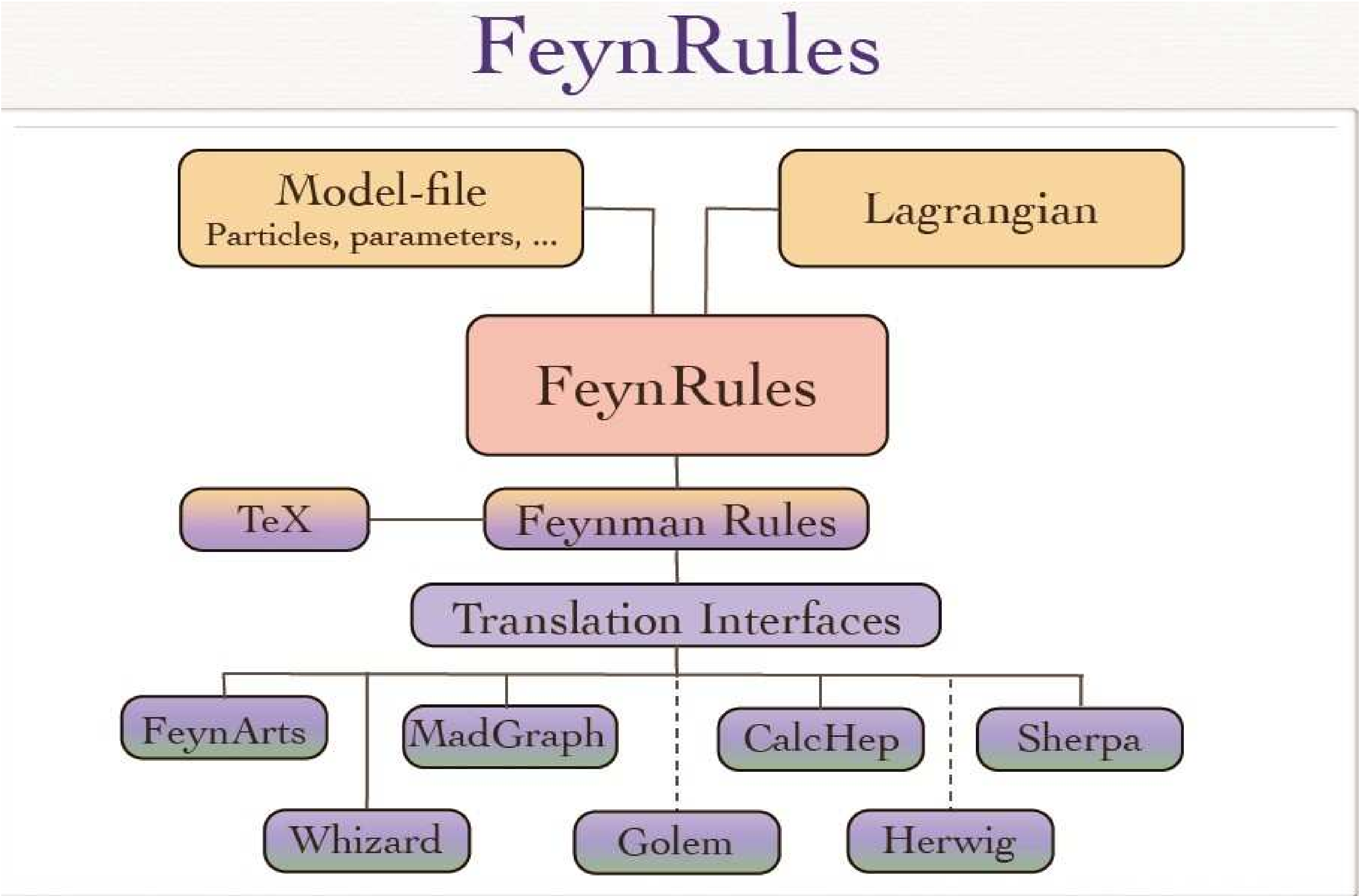
- Standard Model (CD, N. Christensen)
- Most general two Higgs doublet model (CD, M. Herquet)
- Minimal Higgsless Model (N. Christensen)
- Validation of the models:
- Full MSSM (B. Fuks)
- NMSSM (B. Fuks)
- R-symmetric MSSM (B. Fuks)
- RPV MSSM (B. Fuks)
- Universal Extra Dimensions (P. de Aquino)
- Large extra dimensions (P. de Aquino)
- Randall-Sundrum I (P. de Aquino)
- Strongly interacting Little Higgs (C. Degrande)
- Composite Top model (C. Degrande)
- Chiral perturbation theory (C. Degrande)

Validation

- 3-site model: 222 key-processes tested in CalcHep/CompHep

	Lanhep CalcHEP Feynman	Lanhep CalcHEP Unitary	FeynRules CalcHEP Feynman	FeynRules CalcHEP Unitary	FeynRules CompHEP Feynman
$u\bar{u}\to gg$	170.5	170.5	170.5	170.5	170.49
$u'\overline{u'}\to gg$	0.098763	0.098763	0.098763	0.098763	0.098761
$t\bar{t}\to\gamma Z$	1.1233	1.1233	1.1233	1.1233	1.1233
$t'\bar{t}\to\gamma Z$	0.033204	0.033204	0.033204	0.033204	0.033204
$t'\overline{t'}\to Z'Z'$	1.887	1.887	1.887	1.887	1.887
$t\bar{b}\to ZW^{+\prime}$	1.5603	1.5603	1.5603	1.5603	1.5604
$e\bar{e}\to e'\bar{e}$	0.093127	0.093127	0.093127	0.093127	0.093127
$e'\bar{e}\to u'\bar{u}$	2.3603	2.3603	2.3603	2.3603	2.3603
$e\overline{\nu_e}\to\mu'\overline{\nu_\mu'}$	0.0005618	0.0005618	0.0005618	0.0005618	0.00056181
$e'\overline{\nu_e'}\to d'\overline{u'}$	2.5761	2.5761	2.5761	2.5761	2.5762
$gg\to gg$	114310.	114310.	114310.	114310.	114310.
$ZZ\to Z'Z'$	0	0	0	0	0
$W^+W^{-\prime}\to\gamma Z$	8.329	8.329	8.329	8.329	8.3288

Feynrules flow, note the need for 2 input files



Strong feature: could output to many MEG,.... in principle (higher order operators? specific Lorentz structures?,...)

How to use FeynRules

- The input requested form the user is twofold.

- The Model File:
  Definitions of particles and parameters (e.g., a quark)

```
F[1] ==
  {ClassName     ->  q,
   SelfConjugate -> False,
   Indices       -> {Index[Colour]},
   Mass          -> {MQ,  200},
   Width         -> {WQ, 5}   }
```

- The Lagrangian:

$$\mathcal{L} = -\frac{1}{4} G^a_{\mu\nu}\, G^{\mu\nu}_a + i\bar{q}\,\gamma^\mu\, D_\mu q - M_q\,\bar{q}\,q$$

```
L =
-1/4 FS[G,mu,nu,a] FS[G,mu,nu,a]
+ I qbar.Ga[mu].del[q,mu]
- MQ qbar.q
```

- Once this information has been provided, FeynRules can be used to compute the Feynman rules for the model:

  FeynmanRules[L]

- Equivalently, we can export the Feynman rules to a matrix element generator, e.g., for MadGraph 4,

  WriteMGOutput[L]

Feynrules and ALOHA project, in planning

- MEG based on squaring techniques (CalcHEP/CompHEP and FeynArts/FomCalc with some(!) tweaking) are not restricted to particular Lorentz structures: dim-4, gauge structures,...

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- MEG based on helicity amplitudes are based on HELAS/Grace subroutines so a vertex must be recognised first so a general output of LanHEP or FeynArts will be of no use

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- Madgraph/FeynArts development: ALOHA (Automatic Languageindependent Output of Helicity Amplitudes) a code that allows to create HELAS routines from...
- UFO Universal FeynRules Output

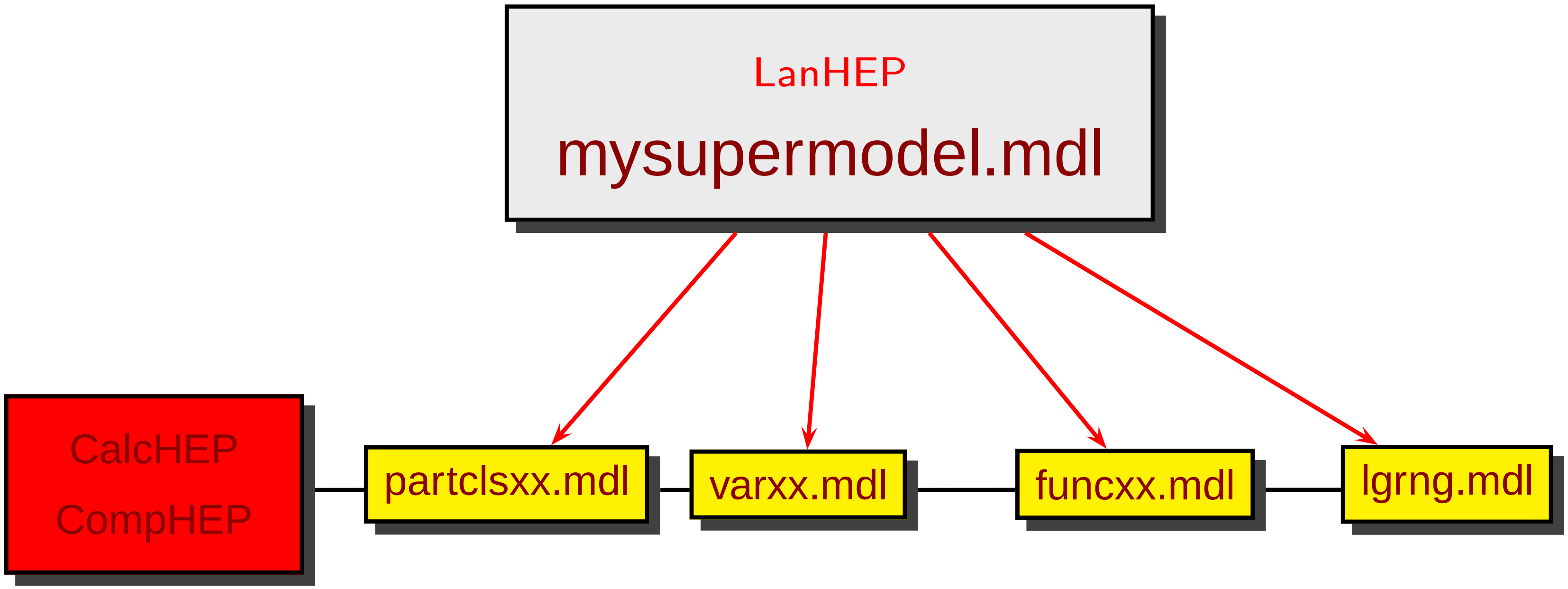
  Idea: Create Python modules that can be linked to other codes and contain all the information on a given model.

  The UFO is a self-contained Python code, and not tied to a specific matrix element generator.

LanHEP

mysupermodel.mdl

LanHEP to MEG



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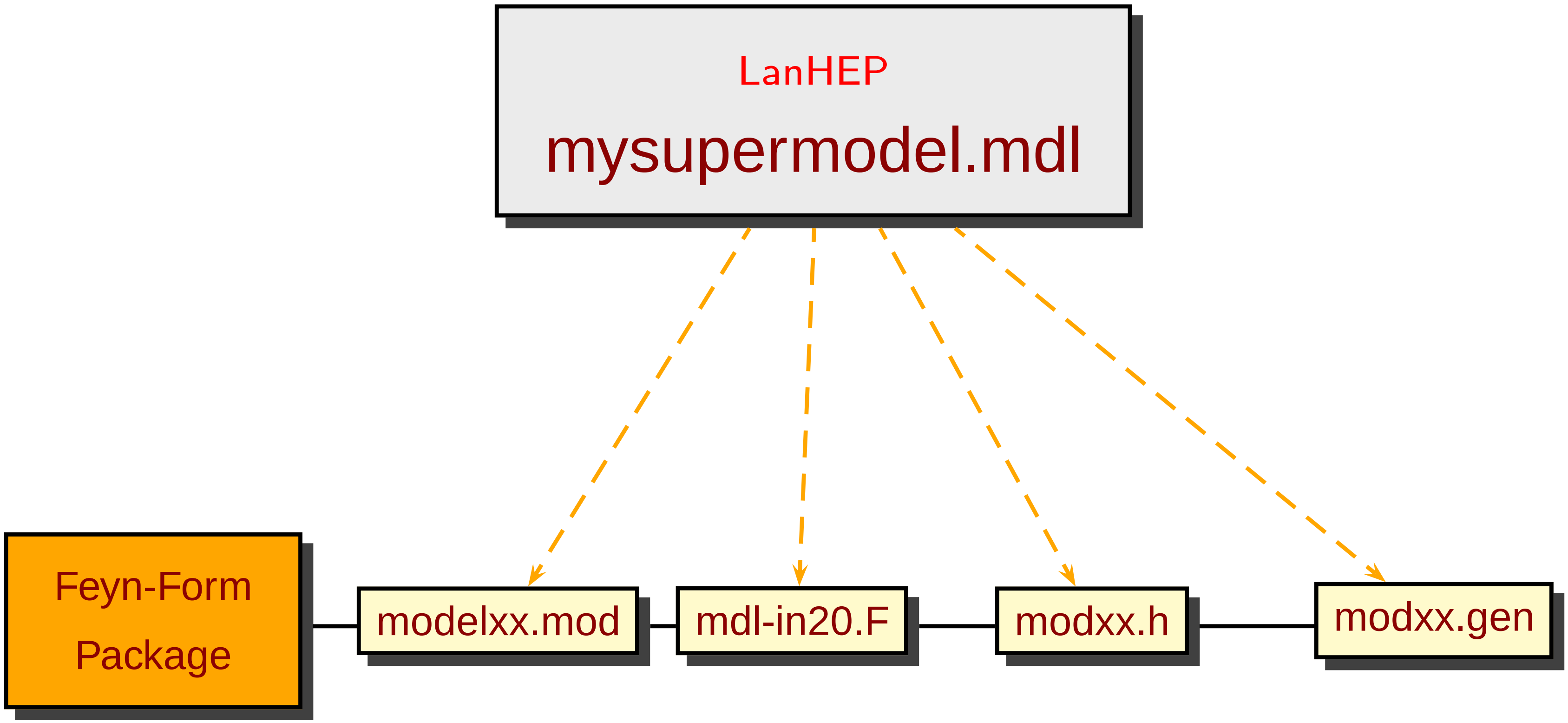

QED simple

$$\mathcal{L}_{QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{e}\gamma^{\mu}(i\partial_{\mu} + g_e A_{\mu})e - m\bar{e}e, \quad \mathcal{L}_{GF} = -\frac{1}{2}(\partial_{\mu}A^{\mu})^2.$$

QED simple

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```
model QED/1.
parameter ee=0.31333:'elementary electric charge'.
spinor e1/E1:(electron, mass me=0.000511).
vector A/A:(photon).
let F^mu^nu=deriv^mu*A^nu-deriv^nu*A^mu.
lterm -1/4*(F^mu^nu)**2 - 1/2*(deriv^mu*A^mu)**2.
lterm E1*(i*gamma*deriv+me)*e1.
lterm ee*E1*gamma*A*e1.
```

QED simple

$$\mathcal{L}_{QED} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \bar{e}\gamma^\mu(i\partial_\mu + g_e A_\mu)e - m\bar{e}e, \quad \mathcal{L}_{GF} = -\frac{1}{2}(\partial_\mu A^\mu)^2.$$

```
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lterm -1/4*(F^mu^nu)**2 - 1/2*(deriv^mu*A^mu)**2.
lterm E1*(i*gamma*deriv+me)*e1.
lterm ee*E1*gamma*A*e1.
```

```
lterm ee*E1^a*gamma^a^b^mu*A^mu*e1^b.
```

QCD on paper

$$L_{YM} = -\frac{1}{4} F^{a\mu\nu} F^a_{\mu\nu},$$

where

$$F^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu - g_s f^{abc} G^b_\mu G^c_\nu,$$

$$L_F = \bar{q}_i \gamma^\mu \partial_\mu q_i + g_s \lambda^a_{ij} \bar{q}_i \gamma^\mu q_j G^c_\mu,$$

where λ^a_{ij} are Gell-Mann matrices.

$$L_{GF+Gh} = -\frac{1}{2} (\partial_\mu G^\mu_a)^2 + i g_s f^{abc} \bar{c}^a G^b_\mu \partial^\mu c^c,$$

$(c, \bar{c})$ ghost fields.

```
model QCD/2.
parameter gg=1.117:'Strong coupling'.
spinor q/Q:(quark, mass mq=0.01, color c3).
vector G/G:(gluon, color c8, gauge).
let F^mu^nu^a = deriv^nu*G^mu^a - deriv^mu*G^nu^a -
    gg*f_SU3^a^b^c*G^mu^b*G^nu^c.
lterm -F**2/4-(deriv*G)**2/2.
lterm Q*(i*gamma*deriv+mq)*q.
lterm i*gg*f_SU3*ccghost(G)*G*deriv*ghost(G).
lterm gg*Q*gamma*lambda*G*q.
```

```
model QCD/2.

parameter       gg= 1.13 : 'Strong coupling'.

vector  G/G: (gluon, color c8, gauge). spinor  q:(quark, color c3,
mass Mq=0.02). lterm  i*gg*f_SU3*ccghost(G)*G*deriv*ghost(G).
lterm Q*gamma*(i*deriv + gg*lambda*G)*q. lterm -F**2/4  where
        F=deriv^mu*G^nu^a-deriv^nu*G^mu^a+i*gg*f_SU3^a^b^c*G^mu^b*G^nu^c
```

Fields in the vertex				Variational derivative of Lagrangian by fields
$G_{\mu p}$	$\bar{\eta}^G_q$	$\eta^G{}_r$		$-g_s p_3^\mu f_{pqr}$
$\bar{q}_{ap}$	q_{bq}	$G_{\mu r}$		$g_s \gamma^\mu_{ab} \lambda^r_{pq}$
$G_{\mu p}$	$G_{\nu q}$	$G_{\rho r}$		$g_s f_{pqr}(p_3^\nu g^{\mu\rho} - p_2^\rho g^{\mu\nu} - p_3^\mu g^{\nu\rho} + p_1^\rho g^{\mu\nu} + p_2^\mu g^{\nu\rho} - p_1^\nu g^{\mu\rho})$
$G_{\mu p}$	$G_{\nu q}$	$G_{\rho r}$	$G_{\sigma s}$	$g_s^2(g^{\mu\rho} g^{\nu\sigma} f_{pqt} f_{rst} - g^{\mu\sigma} g^{\nu\rho} f_{pqt} f_{rst} + g^{\mu\nu} g^{\rho\sigma} f_{prt} f_{qst}$
				$+g^{\mu\nu} g^{\rho\sigma} f_{pst} f_{qrt} - g^{\mu\sigma} g^{\nu\rho} f_{prt} f_{qst} - g^{\mu\rho} g^{\nu\sigma} f_{pst} f_{qrt})$

We introduce a complex/charged scalar field ϕ

```
model qedscal/20.
parameter ee = 0.3133: 'Electric charge'.
vector A/A:photon.
let F^mu^nu=deriv^mu*A^nu-deriv^nu*A^mu.
spinor e1:(electron, mass me=0.000511).
scalar phi/PHI:(scalar, mass mphi=100).
lterm ee*E1*gamma*A*e1.
let Dphi^mu = (deriv^mu+i*ee*A^mu)*phi.
let DPHI^mu = (deriv^mu-i*ee*A^mu)*PHI.
lterm DPHI*Dphi.
```

```
qedscal
 Particles
 Full  name   | P | aP| number |2*spin| mass |width |color|aux|>  LaTeX(A
photon        |A  |A  |      22|2     |0     |0     |1    |   |A
electron      |e1 |E1 |      11|1     |me    |0     |1    |   |e1
scalar        |phi|PHI|       0|0     |mphi  |0     |1    |   |phi
```

LanHEP output CalcHEP/CompHEP, variables: varxx.mdl

```
qedscal
 Variables
 Name | Value        |>  Comment                                         <|
ee    |0.3133        |Electric charge
me    |0.000511      |mass of electron
mphi  |100           |mass of scalar
```

```
qedscal
 Constraints
  Name |> Expression     <&> Comment           <|
```

```
qedscal
 Lagrangian
P1   |P2   |P3   |P4   |>   Factor  <|> dLagrangian/ dA(p1) dA(p2) dA(p3
A    |PHI  |phi  |     |ee            |m1.p2-m1.p3
E1   |e1   |A    |     |ee            |G(m3)
A    |A    |PHI  |phi  |2*ee^2        |m1.m2
```

LanHEP output Feyn package: mdl ini20.F

```fortran
*      LanHEP output produced at Mon Jul 19 17:57:52
*      Model named 'qedscal'

       subroutine ModelDefaults
       implicit none

#include "model.h"

       ee = 0.3133D0
       me = 0.000511D0
       mphi = 100D0

       end


       subroutine ModelConstIni(fail)
       implicit none
       integer fail

#include "model.h"

       fail=0
       call mtrini
       end

       subroutine mtrini
       implicit none
#include "model.h"

       integer m1,m2,m3,m4


       end

************************************************
```

```fortran
************************************************

       subroutine ModelVarIni(fail, sqrtS)
       implicit none
       double precision sqrtS
       integer fail
       double precision Alfas

#include "model.h"

c       double precision ALPHAS2
c       external ALPHAS2

c       Alfas = ALPHAS2(sqrtS)
c       GG = sqrt(4*pi*Alfas)
       fail=0
       end

************************************************

       subroutine ModelDigest
       implicit none

#include "model.h"


       end
```

LanHEP output Feyn package: mdl ini20.F

```
*       LanHEP output produced at Mon Jul 19 17:57:52 2010
*       Model named 'qedscal'

        subroutine ModelDefaults
        implicit none

#include "model.h"

        ee = 0.3133D0
        me = 0.000511D0
        mphi = 100D0

        end


        subroutine ModelConstIni(fail)
        implicit none
        integer fail

#include "model.h"
```

LanHEP output Feyn package: Generic file: modelxx.gen

```
   (* general vector boson propagator: *)

 AnalyticalPropagator[External][ s1 V[j1, mom, {li2}] ] ==
   PolarizationVector[V[j1], mom, li2],

 AnalyticalPropagator[Internal][ s1 V[j1, mom, {li1} -> {li2}] ] ==
   -I PropagatorDenominator[mom, Mass[V[j1]]] *
     (MetricTensor[li1, li2] - (1 - GaugeXi[V[j1]]) *
        FourVector[mom, li1] FourVector[mom, li2] *
        PropagatorDenominator[mom, Sqrt[GaugeXi[V[j1]]] Mass[V[j1]]]),

   (* general mixing scalar-vector propagator: *)

 AnalyticalPropagator[Internal][ s1 SV[j1, mom, {li1} -> {li2}] ] ==
   I Mass[SV[j1]] PropagatorDenominator[mom, Mass[SV[j1]]] *
     FourVector[mom, If[s1 == 1 || s1 == -2, li1, li2]],

   (* general scalar propagator: *)

 AnalyticalPropagator[External][ s1 S[j1, mom] ] == 1,

 AnalyticalPropagator[Internal][ s1 S[j1, mom] ] ==
   I PropagatorDenominator[mom, Sqrt[GaugeXi[S[j1]]] Mass[S[j1]]],

   (* general Fadeev-Popov ghost propagator: *)

 AnalyticalPropagator[External][ s1 U[j1, mom] ] == 1,

 AnalyticalPropagator[Internal][ s1 U[j1, mom] ] ==
   I Sqrt[GaugeXi[U[j1]]] *
      PropagatorDenominator[mom, Sqrt[GaugeXi[U[j1]]] Mass[U[j1]]]
}


   (* Generic analytical couplings for the model *)

M$GenericCouplings = {

   (* V-V *)
   AnalyticalCoupling[ s1 V[j1, mom1, {li1}], s2 V[j2, mom2, {li2}]] ==
  G[1][ s1 V[j1], s2 V[j2]] .
   { MetricTensor[li1, li2] ScalarProduct[mom1, mom2],
     MetricTensor[li1, li2],
     FourVector[mom1, li2] FourVector[mom2, li1] },

   (* S-V *)
   AnalyticalCoupling[ s1 S[j1, mom1], s2 V[j2, mom2, {li2}]] ==
```

LanHEP output Feyn Generic file: modelxx.gen

```
M$GenericPropagators = {

    (* general fermion propagator: *)

  AnalyticalPropagator[External][ s1 F[j1, mom] ] ==
    NonCommutative[ SpinorType[j1][-mom, Mass[F[j1]]] ],

    (* Remarks:
       Fermionic propagators have (like all others, too) their
       momentum flowing from left to right. The fermion flow (for
       Dirac fermions: fermion number flow) is from right to left.
       If the fermion inside the propagator has no sign (i.e. fermion
       number flow is opposite to fermion flow or fermion is self
       conjugate) we just use the internal propagator S(-p).
       If the fermion has a sign, we have to use the Feynman rule S(p)
       according to the Majorana paper. However, this rule is given
       for a momentum flowing against the fermion flow so, again, we
       end up with S(-p). *)

  AnalyticalPropagator[Internal][ s1 F[j1, mom] ] ==
```

LanHEP output Feyn package: modelxx.mod

```
(*
    LanHEP output produced at Mon Jul 19 17:57:52 2010
    from the file '/home1/Work_In_Progress/SloopS-FC6/lanhep304/mdl/qedscal.mdl
    Model named 'qedscal'
*)


IndexRange[ Index[Colour] ] = NoUnfold[Range[3]]
IndexRange[ Index[Gluon] ] = NoUnfold[Range[8]]

VSESign := -1

        (* Model particles  *)

M$ClassesDescription = {

  V[1] ==  { (* photon *)
    SelfConjugate -> True,
    Indices -> {},
    Mass -> 0,
    PropagatorLabel -> "A",
    PropagatorType -> Sine,
    PropagatorArrow -> None },

  F[1] ==  { (* electron *)
    SelfConjugate -> False,
    Indices -> {},
    Mass -> me,
    PropagatorLabel -> "e1",
    PropagatorType -> Straight,
    PropagatorArrow -> Forward },

  S[1] ==  { (* scalar *)
    SelfConjugate -> False,
    Indices -> {},
    Mass -> mphi,
    PropagatorLabel -> "phi",
    PropagatorType -> ScalarDash,
    PropagatorArrow -> Forward }}
```


```
    PropagatorLabel -> "phi",
    PropagatorType -> ScalarDash,
    PropagatorArrow -> Forward }}
```


```
prt["A"]  = V[1]
prt["E1"]  = -F[1]
prt["e1"]  = F[1]
prt["PHI"]  = -S[1]
prt["phi"]  = S[1]



GaugeXi[_]  = 1


M$CouplingMatrices = {

  (*------    PHI  phi  A  ------*)
   C[ -S[1], S[1], V[1] ] == I ee *
{
 { 1 },
 { -1 }
},
  (*------    E1  e1  A  ------*)
   C[ -F[1], F[1], V[1] ] == I ee *
{
 { 1 },
 { 1 }
},
  (*------    PHI  phi  A  A  ------*)
   C[ -S[1], S[1], V[1], V[1] ] == 2 I ee^2 *
{
 { 1 }
}
}

M$LastModelRules = {}

Scan[ (RealQ[#] = True)&,
  { ee, me, mphi  } ]
```

```
(*
    LanHEP output produced at Mon Jul 19 17:57:52 2010
    from the file '/home1/Work_In_Progress/SloopS-FC6/lanhep304/mdl/qedsc
    Model named 'qedscal'
*)


IndexRange[ Index[Colour] ] = NoUnfold[Range[3]] IndexRange[
Index[Gluon] ] = NoUnfold[Range[8]]

VSESign := -1

        (* Model particles  *)

M$ClassesDescription = {

  V[1] ==  { (* photon *)
    SelfConjugate -> True,
    Indices -> {},
    Mass -> 0,
```

LanHEP output: modelxx.mod part 2

```
GaugeXi[_] = 1


M$CouplingMatrices = {

  (*------    PHI  phi  A  ------*)
   C[ -S[1], S[1], V[1] ] == I ee *
{
 { 1 },
 { -1 }
},
  (*------    E1  e1  A  ------*)
   C[ -F[1], F[1], V[1] ] == I ee *
{
 { 1 },
 { 1 }
},
  (*------    PHI  phi  A  A  ------*)
   C[ -S[1], S[1], V[1], V[1] ] == 2 I ee^2 *
{
```

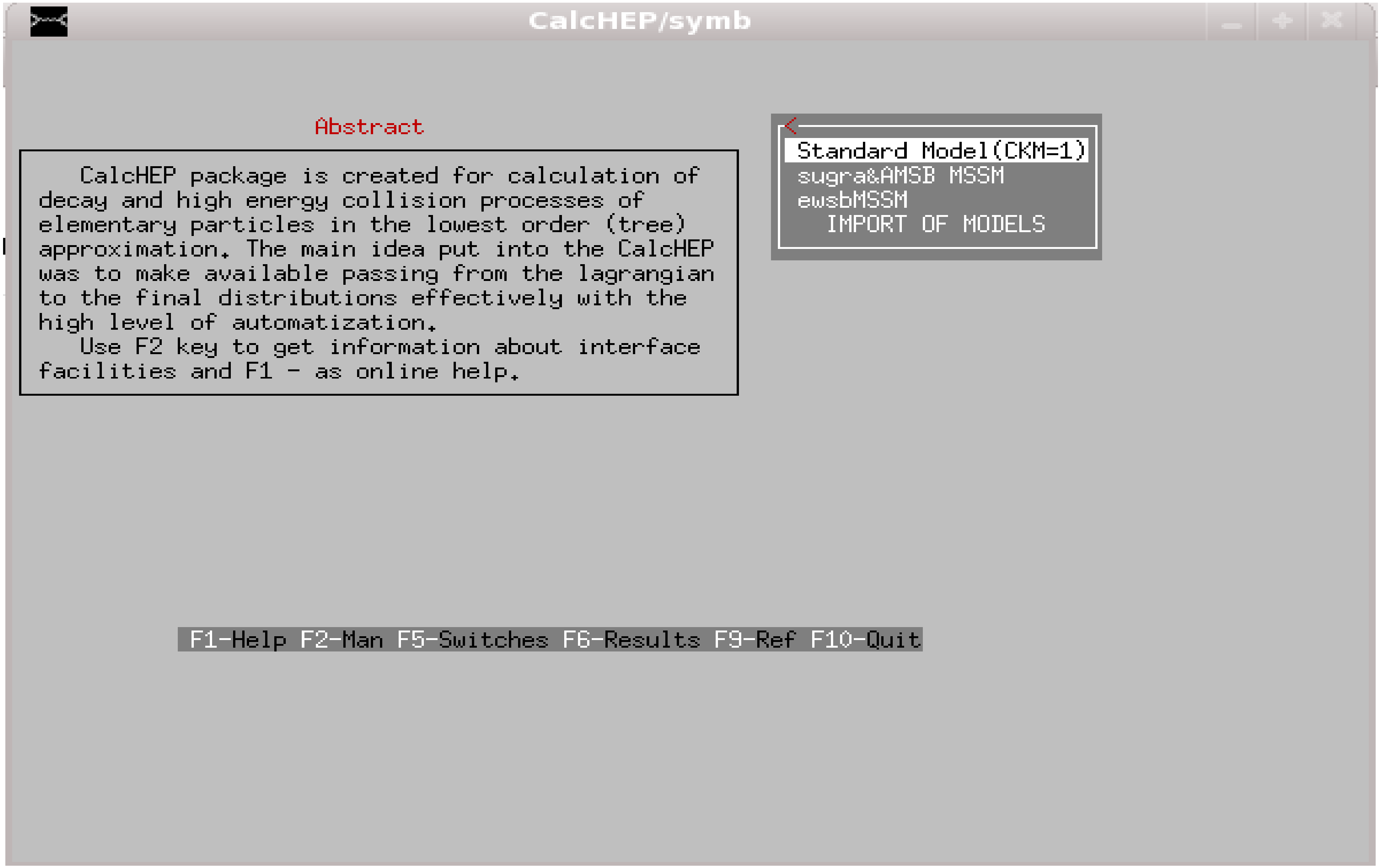
LanHEP output Feyn package: modelxx.mod

feynrules-selfcouplingsWW.m | kinemggtoWW.m | Zpdecay-kinema.m | TENSEUR.M | FeynCalc.m | func20.r

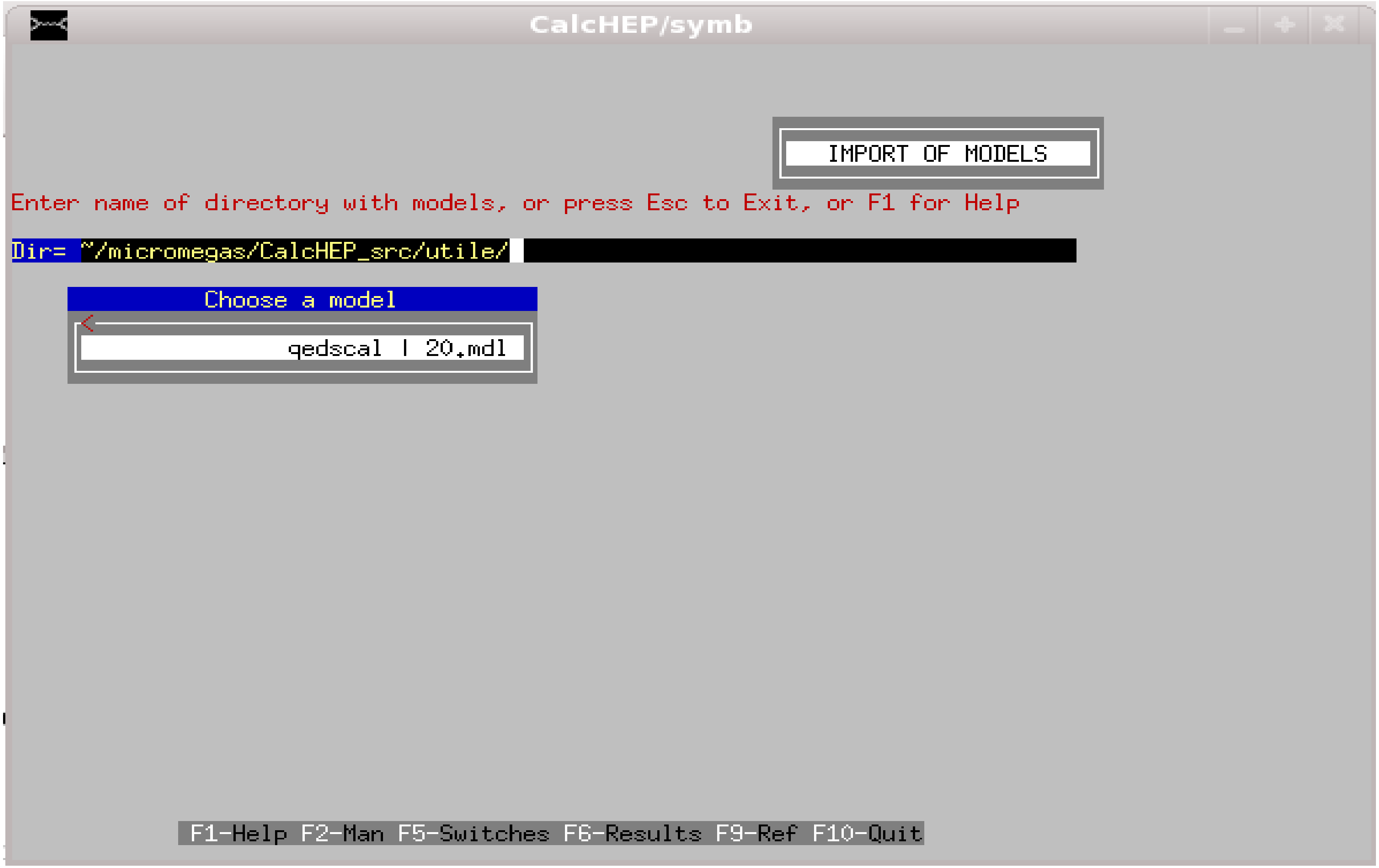
```
*     LanHEP output produced at Mon Jul 19 17:57:52 2010
*     Model named 'qedscal'

      double precision Sqrt2, pi, degree, hbar_c2,bogus
      parameter (Sqrt2=1.41421356237309504880168872421D0)
      parameter (pi = 3.1415926535897932384626433832795029D0)
      parameter (degree = pi/180D0)
      parameter (hbar_c2 = 3.8937966D8)
      parameter (bogus = -1D123)
      double complex cI
      parameter (cI = (0D0, 1D0))

      double precision Divergence
      common /renorm/ Divergence

      double precision ee, me, mphi, GG


      common /mdl_para/
     &    ee, me, mphi, GG
```

```
*       LanHEP output produced at Mon Jul 19 17:57:52 2010
*       Model named 'qedscal'

        double precision Sqrt2, pi, degree, hbar_c2,bogus
        parameter (Sqrt2=1.41421356237309504880168872421D0)
        parameter (pi = 3.1415926535897932384626433832795029D0)
        parameter (degree = pi/180D0)
        parameter (hbar_c2 = 3.8937966D8)
        parameter (bogus = -1D123)
        double complex cI
        parameter (cI = (0D0, 1D0))

        double precision Divergence
        common /renorm/ Divergence

        double precision ee, me, mphi, GG


        common /mdl_para/
       &    ee, me, mphi, GG
```

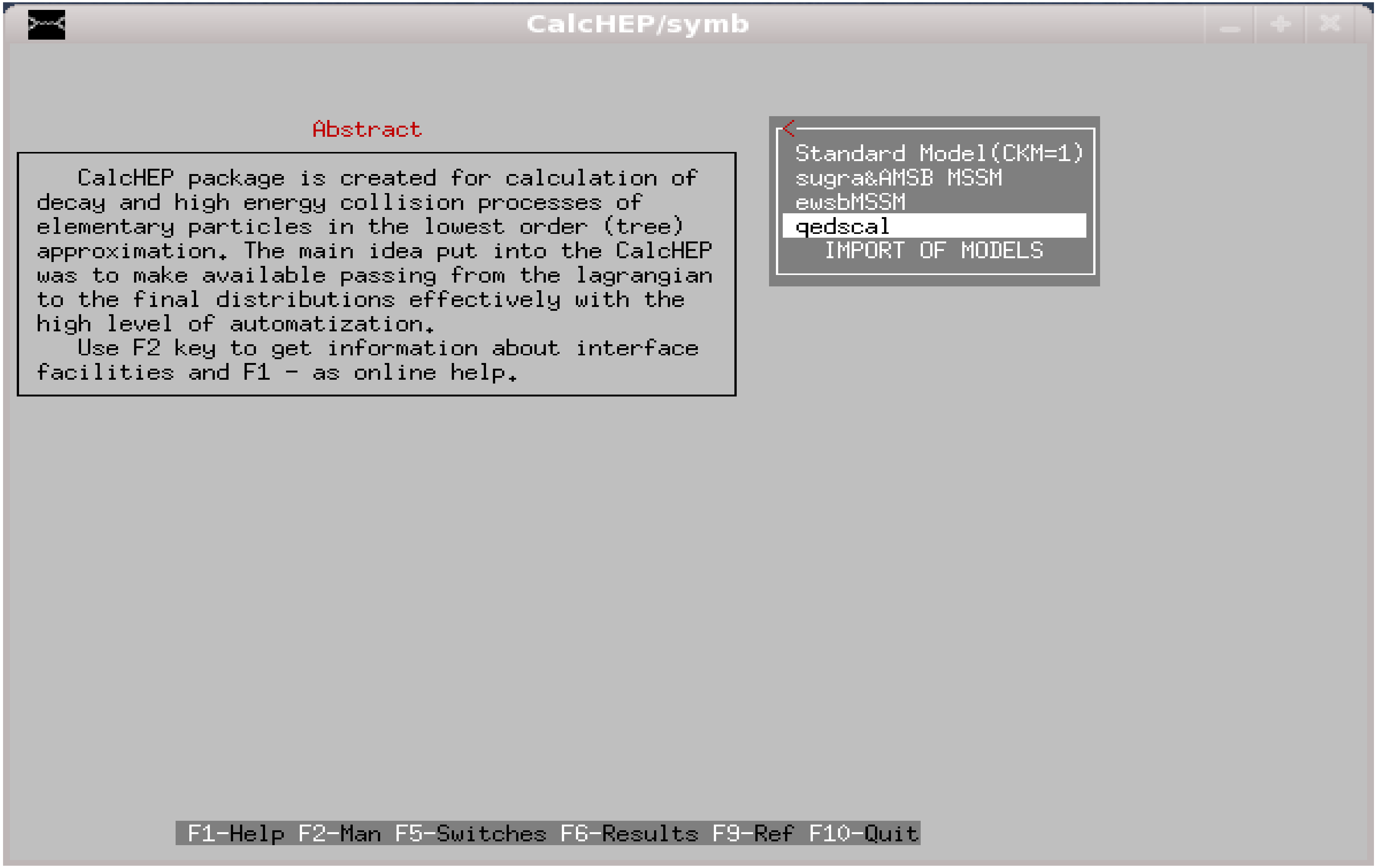
Using our newly implemented model in CalcHEP 1.



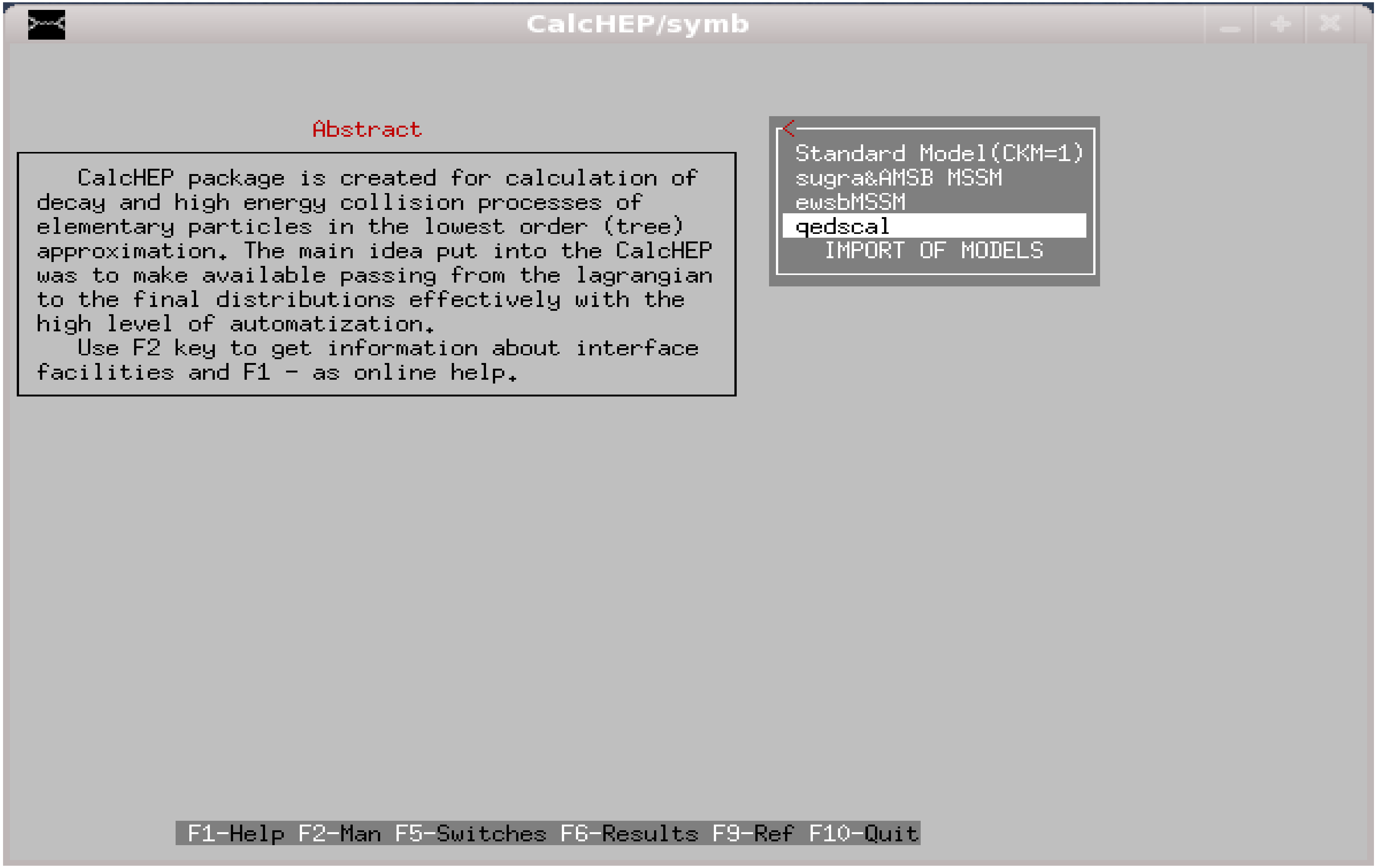
Using our newly implemented model in CalcHEP 2.



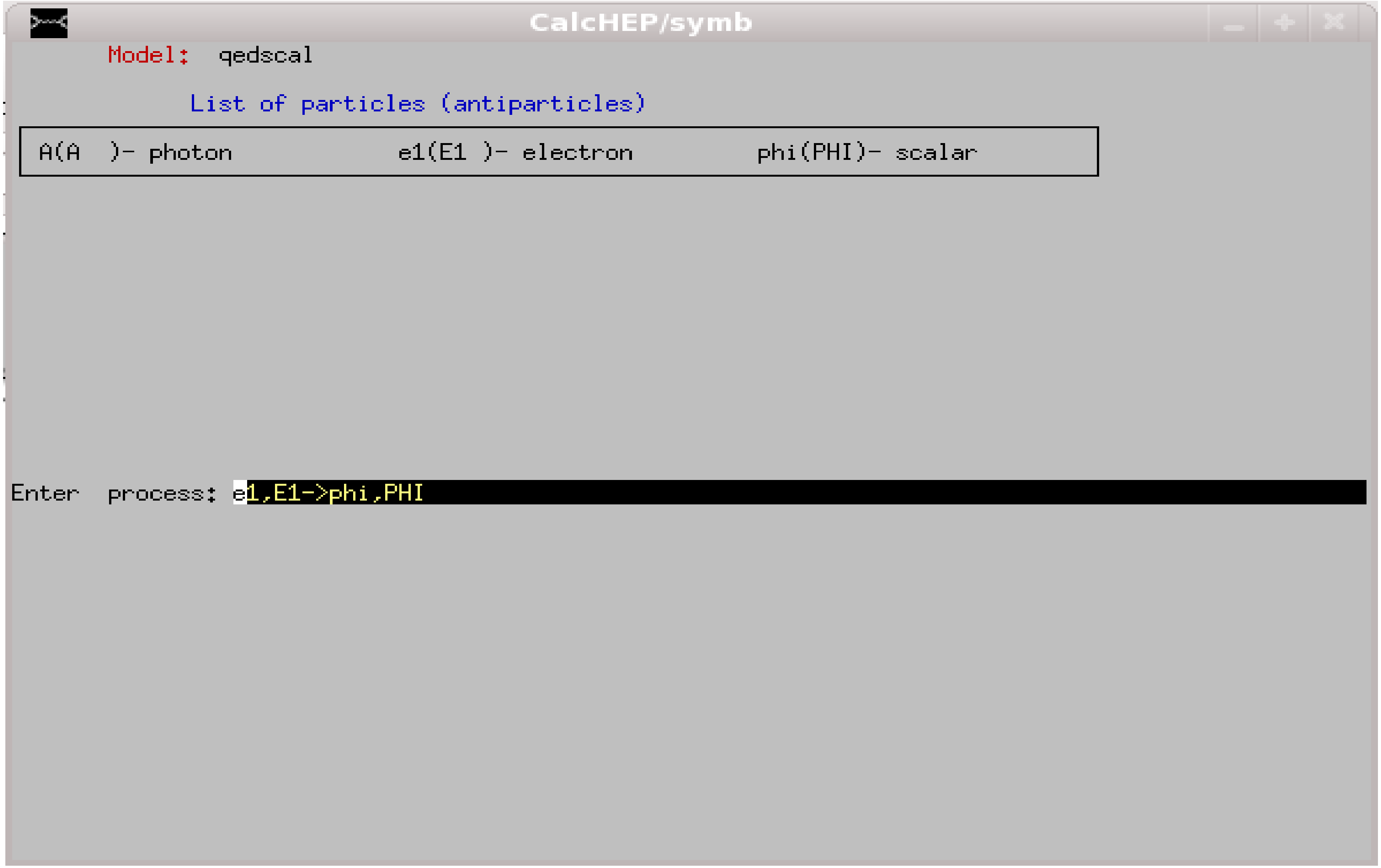
Using our newly implemented model in CalcHEP 3.



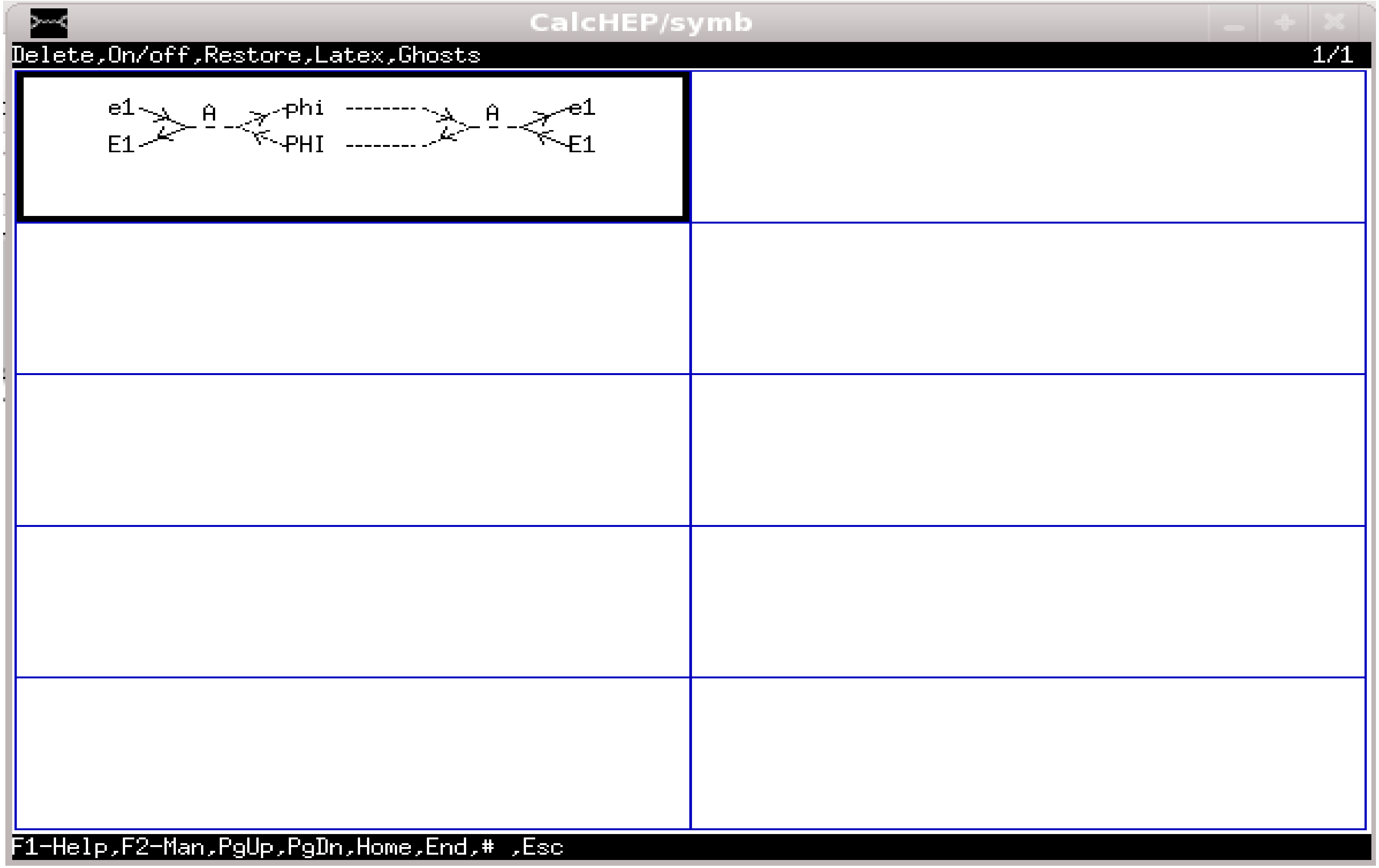
Using our newly implemented model in CalcHEP 3.



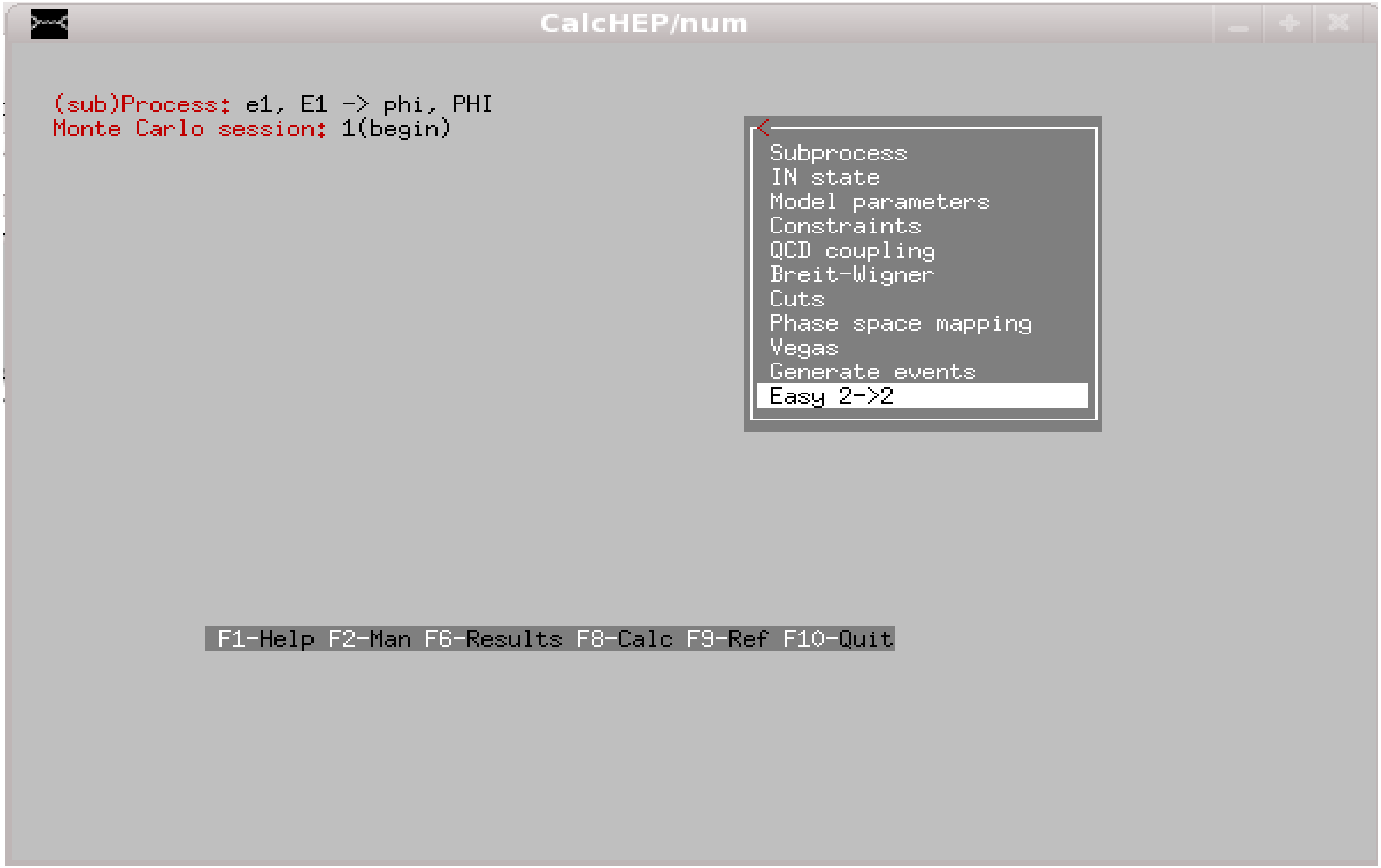
Using our newly implemented model in CalcHEP 4.



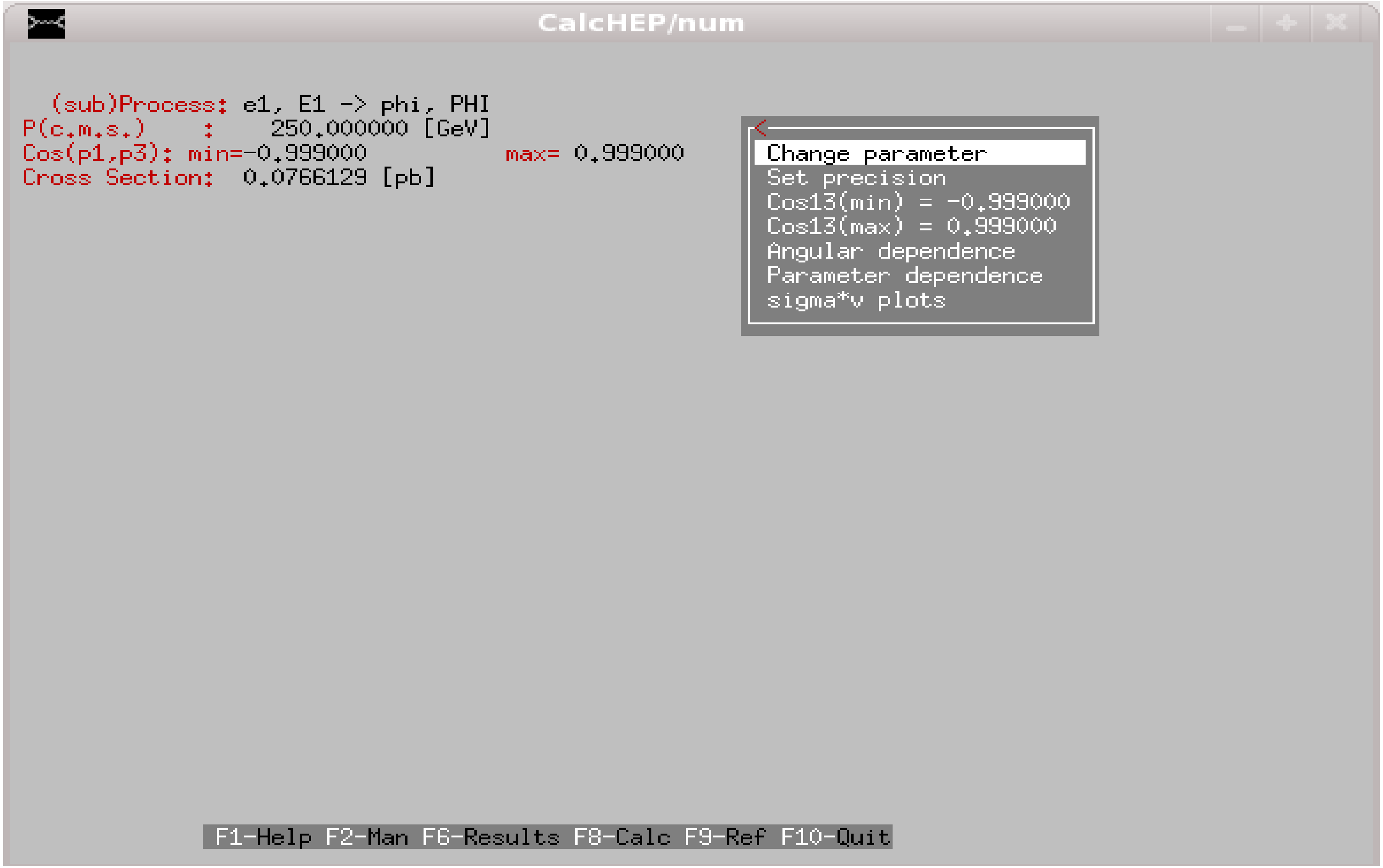
Using our newly implemented model in CalcHEP 5.



Using our newly implemented model in CalcHEP 6.



Using our newly implemented model in CalcHEP 7.



Using our newly implemented model in Feyn-Form Package 1.

lgrng20.mdl | lgrng13.mdl | prtcls20.mdl | genscatree.m | model20.mod

```

<< ../FeynArts-3.4/FeynArts.m '
<< FormCalcGUI60.m '

time1 = SessionTime[]

CKM = IndexDelta

(*Neglect[ME] = Neglect[ME2] = 0*)


(*process = {-F[2, {1}], F[2, {1}]} -> {-F[3, {3}], F[3, {3}]}*)

process = {prt["e1"],prt["E1"]} -> {prt["phi"],prt["PHI"]}

name = "e1E1phiPHI_QEDSCAL"

SetOptions[InsertFields, Model -> "model20", GenericModel->"model20"]


SetOptions[Paint, PaintLevel -> {Classes}, ColumnsXRows -> {4, 5}]

 (*take the comments out if you want the diagrams painted
$PaintSE = MkDir[name <> ".diagrams"];*)
DoPaint[diags_, file_, opt___] := Paint[diags, opt,
  DisplayFunction -> (Export[ToFileName[$PaintSE, file <> ".ps"], #]&)]


Print["Born"]

tops = CreateTopologies[0, 2 -> 2];
ins = InsertFields[tops, process];
DoPaint[ins, "born"];
born = CalcFeynAmp[CreateFeynAmp[ins]];




amps = {born};


(*
{born, self, vert, box} = Abbreviate[amps, 6,
  Preprocess -> OnSize[100, Simplify, 500, DenCollect]];
*)
```

Using our newly implemented model in Feyn-Form Package 2.

process.h (~/Work_In_Progress/SloopS-FC6/FormCalc-6.0/fortran_e1E1phiPHI_QEDSCAL) - gedit (sur lappc-f169.in2p3.fr)

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lgrng20.mdl | lgrng13.mdl | prtcls20.mdl | genscatree.m | model20.mod | process.h

```
* process.h
* defines all process-dependent parameters
* this file is part of FormCalc
* last modified 26 May 08 th


* Definition of the external particles.
* Each TYPEn is one of SCALAR, FERMION, PHOTON (= GLUON), or VECTOR.
* (PHOTON/GLUON is equivalent to VECTOR, except that longitudinal
* modes are not allowed)

* Note: The initial definitions for particles 2...5 are of course
* sample entries for demonstration purposes.

#define TYPE1 FERMION
#define MASS1 me
#define CHARGE1 -1

#define TYPE2 FERMION
#define MASS2 me
#define CHARGE2 1

#define TYPE3 SCALAR
#define MASS3 mphi
#define CHARGE3 -1

#define TYPE4 SCALAR
#define MASS4 mphi
#define CHARGE4 1

#define TYPE5 typepart5
#define MASS5 masspart5
#define CHARGE5 chargpart5


* When using Dirac fermions (FermionChains -> Chiral|VA) and
* the trace technique (HelicityME), the following flag should be
* defined to compute unpolarized cross-sections efficiently,
* i.e. without actually summing up the different helicities.
* This has no effect on the result, only on the speed of the
* calculation.
* Note: DIRACFERMIONS must NOT be defined when using Weyl fermions,
* i.e. FermionChains -> Weyl in CalcFeynAmp.

```

Using our newly implemented model in Feyn-Form Package 3.

```
chalons@lappc-f169:~/Work_In_Progress/SloopS-FC6/FormCalc/fortran_e1E1phiPHI_QEDSCAL$ ./run uuuu 500,500
 ====================================================
   FF 2.0, a package to evaluate one-loop integrals
 written by G. J. van Oldenborgh, NIKHEF-H, Amsterdam
 ====================================================
 for the algorithms used see preprint NIKHEF-H 89/17,
 'New Algorithms for One-loop Integrals', by G.J. van
 Oldenborgh and J.A.M. Vermaseren, published in
 Zeitschrift fuer Physik C46(1990)425.
 ====================================================
./run.UUSS.00500,00500,00010/0000001

total number of errors and warnings
===================================
fferr: no errors

chalons@lappc-f169:~/Work_In_Progress/SloopS-FC6/FormCalc/fortran_e1E1phiPHI_QEDSCAL$ more run.UUSS.00500,00500,00010/0000001
 Patterson integration results:
 nregions = 1
 neval    = 21
 fail     = 0
 1   0.766130322358816E-01 +-     0.000000000000000       p = -1.000
 2    0.000000000000000     +-     0.000000000000000       p = -1.000
|     500.0000000
|+      0.766130322358816E-01    0.000000000000000
|+       0.000000000000000       0.000000000000000
|
|
```

Using our newly implemented model in Feyn-Form Package 3.

result agrees with CalcHEP

```
chalons@lappc-f169:~/Work_In_Progress/SloopS-FC6/FormCalc/fortran_e1E1phiPHI_QEDSCAL$ ./run uuuu 500,500
 ====================================================
   FF 2.0, a package to evaluate one-loop integrals
 written by G. J. van Oldenborgh, NIKHEF-H, Amsterdam
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 Oldenborgh and J.A.M. Vermaseren, published in
 Zeitschrift fuer Physik C46(1990)425.
 ====================================================
./run.UUSS.00500,00500,00010/0000001

total number of errors and warnings
===================================
fferr: no errors

chalons@lappc-f169:~/Work_In_Progress/SloopS-FC6/FormCalc/fortran_e1E1phiPHI_QEDSCAL$ more run.UUSS.00500,00500,00010/0000001
 Patterson integration results:
 nregions = 1
 neval    = 21
 fail     = 0
 1   0.766130322358816E-01 +-     0.000000000000000       p = -1.000
 2    0.000000000000000     +-     0.000000000000000       p = -1.000
|      500.0000000
|+      0.766130322358816E-01    0.000000000000000
|+       0.000000000000000       0.000000000000000
|
|
```

- A particle that could qualify as a DM candidate need to be neutral and stable.

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- One way for it to be stable is that it has to have a new quantum number that is odd as compared to the SM which would have this quantum number even.

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- simple model: add both a charged scalar $s, S \longrightarrow phi, Phi$ and a heavy neutrino n, N to our QED model

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- simple model: add both a charged scalar $s, S \longrightarrow phi, Phi$ and a heavy neutrino n, N to our QED model
- n will couple through a magnetic moment coupling to the photon (example of a higher dim operator)

- A particle that could qualify as a DM candidate need to be neutral and stable.
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- simple model: add both a charged scalar $s, S \longrightarrow phi, Phi$ and a heavy neutrino n, N to our QED model
- n will couple through a magnetic moment coupling to the photon (example of a higher dim operator)
- both n, s are odd, we will label them as $\tilde{n}, \tilde{s}$

```
model qedscalneutrino/31.
parameter ee = 0.3133: 'Electric charge'.
parameter  mag = 0.01: 'magnetic momentum'.
vector A/A:photon.
let F^mu^nu=deriv^mu*A^nu-deriv^nu*A^mu.
spinor e1:(electron, mass me=0.000511).

spinor ~nu/ ~Nu :(neutrino, mass mnu=90, width wnu=0).
scalar ~s/ ~S:(scalar, mass mS=100, width wS=0).

lterm ee*E1*gamma*A*e1.

let Dphi^mu = (deriv^mu+i*ee*A^mu)*'~s'.
let DPHI^mu = (deriv^mu-i*ee*A^mu)*'~S'.

lterm DPHI*Dphi.

lterm  i*mag/2*'~Nu'*(gamma^mu*gamma^nu-gamma^nu*gamma^mu)*'~nu'*F^mu^nu

CheckHerm.
```

Lanhep pdg code for calchep.

PDG CODE not generated....

```
~/micromegas/CalcHEP_src/utile$ ./lan2calchep /home1/
Work_In_Progress/SloopS-FC6/lanhep304/mdl/ 30 30
Warning! Monte Caro code for ~nu (neutrino     ) is unknown.
 Replaced by zero. Improve it!
Warning! Monte Caro code for ~phi (scalar      ) is unknown.
 Replaced by zero. Improve it!
```

```
qedscalneutrino
 Lagrangian
P1    |P2    |P3    |P4    |>   Factor  <|> dLagrangian/ dA(p1) dA(p2) dA(p3
A     |~S    |~s    |      |ee             |m1.p2-m1.p3
E1    |e1    |A     |      |ee             |G(m3)
~Nu   |~nu   |A     |      |mag            |G(p3)*G(m3)-G(m3)*G(p3)
A     |A     |~S    |~s    |2*ee^2         |m1.m2
```

LanHEP output, variables

```
qedscalneutrino
 Variables
  Name | Value       |>  Comment                       <|
 ee    |0.3133       |Electric charge
 mag   |0.01         |magnetic momentum
 me    |0.000511     |mass of electron
 mnu   |90           |mass of neutrino
 wnu   |0            |width of neutrino
 mS    |100          |mass of scalar
 wS    |0            |width of scalar
```

Results of micrOMEGAs, large magnetic moment

```
=== MASSES OF ODD SECTOR: ===

Masses of odd sector Particles: ~nu  : mnu   =    90.0 || ~s   :
mS    =   100.0 ||

==== Physical Constraints: =====

==== Calculation of relic density =====
Dark Matter candidate is ~nu Xf=3.40e+01 Omega=5.83e-06

Channels which contribute to 1/(omega) more than 1%.
Relative contributions in % are displayed
 97% ~nu ~Nu -> A A
  3% ~nu ~Nu -> e1 E1

==== Indirect detection =======
1.38E-02 gamma with E > 1.00E-01 are generated at one collision
gamma flux for fi=0.00E+00[rad] is 3.00E-06[ph/cm^2/s/sr]

==== Calculation of WIMP-nucleons amplitudes =====
```

```
mS  100. mnu 99.9. mag 0.0001.
=== MASSES OF ODD SECTOR: ===

Masses of odd sector Particles:
~nu  : mnu   =    99.9  ||
~s   : mS    =   100.0  ||

==== Physical Constraints: =====

==== Calculation of relic density =====
Dark Matter candidate is ~nu Xf=2.46e+01 Omega=1.22e-01

Channels which contribute to 1/(omega) more than 1%.
Relative contributions in % are displayed
 95% ~s ~S -> A A
  4% ~nu ~Nu -> e1 E1
  1% ~s ~S -> e1 E1

==== Indirect detection =======
4.78E-01 gamma with E > 1.00E-01 are generated at one collision
gamma flux for fi=0.00E+00[rad] is 2.49E-10[ph/cm^2/s/sr]
```

Use of multiplets (doublets)

$$\Phi = \begin{pmatrix} -iW_f^+ \\ (\frac{2M_W}{es_W} + H + iZ_f)/\sqrt{2} \end{pmatrix},$$

Use of multiplets (doublets)

$$\Phi = \begin{pmatrix} -iW_f^+ \\ (\frac{2M_W}{e s_W} + H + iZ_f)/\sqrt{2} \end{pmatrix},$$

Option `gauge` in the declaration of gauge fields allows to use `gsb(Z)` and `gsb('W+')` for the goldstone bosons.

```
model Higgs/1.
parameter EE = 0.31333 :  'Electromagnetic coupling constant',
      SW = 0.4740 :  'sin of the Weinberg angle (PDG-94)',
      CW = Sqrt(1-SW**2) :  'cos of the Weinberg angle'.
let g=EE/SW, g1=EE/CW.

vector A/A: (photon, gauge),
      Z/Z:('Z boson', mass MZ = 91.187, gauge),
      'W+'/'W-':  ('W boson', mass MW = MZ*CW, gauge).
scalar H/H:(Higgs, mass MH = 200, width wH = 1.461).

let B = -SW*Z+CW*A.
let W = {'W+', CW*Z+SW*A, 'W-'}.
let phi = { -i*gsb('W+'), (vev(2*MW/EE*SW)+H+i*gsb(Z))/Sqrt2 },
      Phi = anti(phi).

lterm -2*lambda*(phi*anti(phi)-v**2/2)**2 where
          lambda=(g*MH/MW)**2/16, v=2*MW*SW/EE.
let D^a^b^mu =(deriv^mu+i*g1/2*B^mu)*delta(2)^a^b
          +i*g/2*taupm^a^b^c*W^mu^c,
      Dc^a^b^mu=(deriv^mu-i*g1/2*B^mu)*delta(2)^a^b
          -i*g/2*taupm^a^b^c*anti(W)^mu^c.
lterm D^a^b^mu*phi^b*Dc^a^c^mu*Phi^c.
```

Bosonic sector of the SM, Feynman rules

Fields in the vertex	Variational derivative of Lagrangian by fields
$A_\mu \quad {W^+}_\nu \quad W_F^-$	$ieM_W g^{\mu\nu}$
$A_\mu \quad W_F^+ \quad {W^-}_\nu$	$-ieM_W g^{\mu\nu}$
$A_\mu \quad W_F^+ \quad W_F^-$	$-e(p_2^\mu - p_3^\mu)$
$H \quad {W^+}_\mu \quad {W^-}_\nu$	$\frac{eM_W}{s_w} g^{\mu\nu}$
$H \quad {W^+}_\mu \quad W_F^-$	$-\frac{1}{2}\frac{ie}{s_w}(p_1^\mu - p_3^\mu)$
$H \quad W_F^+ \quad {W^-}_\mu$	$\frac{1}{2}\frac{ie}{s_w}(p_2^\mu - p_1^\mu)$
$H \quad Z_\mu \quad Z_\nu$	$\frac{eM_W}{{c_w}^2 s_w} g^{\mu\nu}$
$H \quad Z_\mu \quad Z_F$	$-\frac{1}{2}\frac{ie}{c_w s_w}(p_1^\mu - p_3^\mu)$
${W^+}_\mu \quad W_F^- \quad Z_\nu$	$-\frac{ieM_W s_w}{c_w} g^{\mu\nu}$
${W^+}_\mu \quad W_F^- \quad Z_F$	$\frac{1}{2}\frac{e}{s_w}(p_3^\mu - p_2^\mu)$
$W_F^+ \quad {W^-}_\mu \quad Z_\nu$	$\frac{ieM_W s_w}{c_w} g^{\mu\nu}$
$W_F^+ \quad {W^-}_\mu \quad Z_F$	$\frac{1}{2}\frac{e}{s_w}(p_1^\mu - p_3^\mu)$
$W_F^+ \quad W_F^- \quad Z_\mu$	$-\frac{1}{2}\frac{(1-2{s_w}^2)e}{c_w s_w}(p_1^\mu - p_2^\mu)$
$A_\mu \quad A_\nu \quad W_F^+ \quad W_F^-$	$2e^2 g^{\mu\nu}$
$A_\mu \quad H \quad {W^+}_\nu \quad W_F^-$	$\frac{1}{2}\frac{ie^2}{s_w} g^{\mu\nu}$
$A_\mu \quad H \quad W_F^+ \quad {W^-}_\nu$	$-\frac{1}{2}\frac{ie^2}{s_w} g^{\mu\nu}$
$A_\mu \quad {W^+}_\nu \quad W_F^- \quad Z_F$	$-\frac{1}{2}\frac{e^2}{s_w} g^{\mu\nu}$
$A_\mu \quad W_F^+ \quad {W^-}_\nu \quad Z_F$	$-\frac{1}{2}\frac{e^2}{s_w} g^{\mu\nu}$
$A_\mu \quad W_F^+ \quad W_F^- \quad Z_\nu$	$\frac{(1-2{s_w}^2)e^2}{c_w s_w} g^{\mu\nu}$
$H \quad H \quad {W^+}_\mu \quad {W^-}_\nu$	$\frac{1}{2}\frac{e^2}{{s_w}^2} g^{\mu\nu}$
$H \quad H \quad Z_\mu \quad Z_\nu$	$\frac{1}{2}\frac{e^2}{{c_w}^2 {s_w}^2} g^{\mu\nu}$
$H \quad {W^+}_\mu \quad W_F^- \quad Z_\nu$	$-\frac{1}{2}\frac{ie^2}{c_w} g^{\mu\nu}$
$H \quad W_F^+ \quad {W^-}_\mu \quad Z_\nu$	$\frac{1}{2}\frac{ie^2}{c_w} g^{\mu\nu}$
${W^+}_\mu \quad W_F^+ \quad {W^-}_\nu \quad W_F^-$	$\frac{1}{2}\frac{e^2}{{s_w}^2} g^{\mu\nu}$
${W^+}_\mu \quad {W^-}_\nu \quad Z_F \quad Z_F$	$\frac{1}{2}\frac{e^2}{{s_w}^2} g^{\mu\nu}$
${W^+}_\mu \quad W_F^- \quad Z_\nu \quad Z_F$	$\frac{1}{2}\frac{e^2}{c_w} g^{\mu\nu}$
$W_F^+ \quad {W^-}_\mu \quad Z_\nu \quad Z_F$	$\frac{1}{2}\frac{e^2}{c_w} g^{\mu\nu}$
$W_F^+ \quad W_F^- \quad Z_\mu \quad Z_\nu$	$\frac{1}{2}\frac{(1-2{s_w}^2)^2 e^2}{{c_w}^2 {s_w}^2} g^{\mu\nu}$
$Z_\mu \quad Z_\nu \quad Z_F \quad Z_F$	$\frac{1}{2}\frac{e^2}{{c_w}^2 {s_w}^2} g^{\mu\nu}$

$$\psi = \begin{pmatrix} \xi \\ \bar{\eta} \end{pmatrix}, \quad \psi^c = \begin{pmatrix} \eta \\ \bar{\xi} \end{pmatrix}, \quad \bar{\psi} = \begin{pmatrix} \eta \\ \bar{\xi} \end{pmatrix}^T, \quad \bar{\psi}^c = \begin{pmatrix} \xi \\ \bar{\eta} \end{pmatrix}^T.$$

If the user has declared a spinor particle p (with antiparticle P), the LanHEP notation for its components is:

$$\begin{aligned} \xi &\longrightarrow \texttt{up(p)} \\ \bar{\eta} &\longrightarrow \texttt{down(p)} \\ \eta &\longrightarrow \texttt{up(cc(p))} \textit{ or } \texttt{up(P)} \\ \bar{\xi} &\longrightarrow \texttt{down(cc(p))} \textit{ or } \texttt{down(P)} \end{aligned}$$

Weyl and two component fermion vs Dirac

$$\psi = \begin{pmatrix} \xi \\ \bar{\eta} \end{pmatrix}, \quad \psi^c = \begin{pmatrix} \eta \\ \bar{\xi} \end{pmatrix}, \quad \bar{\psi} = \begin{pmatrix} \eta \\ \bar{\xi} \end{pmatrix}^T, \quad \bar{\psi}^c = \begin{pmatrix} \xi \\ \bar{\eta} \end{pmatrix}^T.$$

$\eta_1\xi_2 = \bar{\psi}_1 P_L \psi_2$	`up(P1)*up(p2)`	$\longrightarrow$	`P1*(1-gamma5)/2*p2`
$\bar{\eta}_1\bar{\xi}_2 = \bar{\psi}_1 P_R \psi_2$	`down(P1)*down(p2)`	$\longrightarrow$	`P1*(1+gamma5)/2*p2`
$\xi_1\xi_2 = \bar{\psi}^c_1 P_L \psi_2$	`up(p1)*up(p2)`	$\longrightarrow$	`cc(p1)*(1-gamma5)/2*p2`
$\bar{\xi}_1\bar{\xi}_2 = \bar{\psi}_1 P_R \psi^c_2$	`down(P1)*down(P2)`	$\longrightarrow$	`P1*(1+gamma5)/2*cc(P2)`
$\xi_1\eta_2 = \bar{\psi}^c_1 P_L \psi^c_2$	`up(p1)*up(P2)`	$\longrightarrow$	`cc(p1)*(1-gamma5)/2*cc(F`
$\bar{\xi}_1\bar{\eta}_2 = \bar{\psi}^c_1 P_R \psi^c_2$	`down(p1)*down(P2)`	$\longrightarrow$	`cc(p1)*(1+gamma5)/2*cc(F`
$\eta_1\eta_2 = \bar{\psi}_1 P_L \psi^c_2$	`up(P1)*up(P2)`	$\longrightarrow$	`P1*(1-gamma5)/2*cc(P2)`
$\bar{\eta}_1\bar{\eta}_2 = \bar{\psi}^c_1 P_R \psi_2$	`down(p1)*down(p2)`	$\longrightarrow$	`cc(p1)*(1+gamma5)/2*p2`
$\bar{\xi}_1\sigma^\mu\xi_2 = \bar{\psi}_1\gamma^\mu P_L \psi_2$	`down(P1)*sigma*up(p2)`	$\longrightarrow$	`P1*gamma*(1-gamma5)/2*p2`
$\bar{\eta}_1\sigma^\mu\eta_2 = \bar{\psi}^c_1\gamma^\mu P_L \psi^c_2$	`down(p1)*sigma*up(P2)`	$\longrightarrow$	`cc(p1)*gamma*(1-gamma5)/`

$$\mathbf{W} = eps_{ij}(\mu H_i^1 H_j^2 + M_l^{IJ} H_i^1 L_j^I R^J + M_d^{IJ} H_i^1 Q_j^I D^J + M_u^{IJ} H_i^2 Q_j^I U^J)$$

(H_i, L, Q, R, U, D defined as doublets and singlets, here in terms of scalar part.)

```
keep_lets W.
let W=eps*(mu*H1*H2+ml*H1*L*R+md*H1*Q*D+mu*H2*Q*U).
```

Yukawa interactions

$$-\frac{1}{2}\left(\frac{\partial^2 W}{\partial A_i \partial A_j}\Psi_i\Psi_j + h.c.\right)$$

Ψ_i fermionic partners of A_i

```
lterm - df(W,H1,H2)*fH1*fH2 - ...  + AddHermConj.
```

$F_i^* F_i$ terms, $F_i = \partial W / \partial A_i$

```
lterm - df(W,H1)*df(Wc,H1c) - ....
```

or even shorter

```
lterm - dfdfc(W,H1) - ....
```

run lanHEP to generate the output files (compHEP)

```
cd ~/lanhep304/mdl/
./lhep qedscalneutrino.mdl
```

run convert output from compHEP to calcHEP

```
cd ~/micromegas/CalcHEP_src/utile/
./lan2calchep ~/lanhep304/mdl/ 30 1
```

running micrOMEGAs

```
cd ~/micromegas
```

create new project with new model

```
./newProject DMheavyneut
cd DMheavyneut
```

import the model (into CalcHEP)

```
mv ~/micromegas/CalcHEP_src/utile/*1.mdl work/models/.
```

compile and execute

```
gmake main=main.c
./main data.par
```

Lanhep at one-loop

New gauge structures, novel gauge fixing

Interface with FeynArts/FormCacl/LoopTools

MSSM example

N. Baro, FB, G. Chalons, G. Drieu La Rochelle, S. Hao, Ninh Le Duc, A. Semenov, (D. Temes)

SLOOPS

- Need for an automatic tool for susy calculations, for Colliders and Dark Matter, On-Shell scheme
- handles large numbers of diagrams both for tree-level
- and loop level
- able to compute loop diagrams at $v = 0$: dark matter, LSP, move at galactic velocities, $v = 10^{-3}$
- ability to check results: UV and IR finiteness but also gauge parameter independence for example
- ability to include different models easily and switch between different renormalisation schemes
- Used for SM one-loop multi-leg: new powerful loop libraries (with Ninh Le Duc)

- *FeynArts* and *FormCalc* are used for matrix element calculation: *FeynArts* model format output implemented in LanHEP.
- Shifts in fields and parameters to produce counterterms by LanHEP:

```
infinitesimal dMHsq, dMZsq, dMWsq,dZAA, dZAZ, dZZA, dZZZ, dZW,
dZH. infinitesimal   dEE= -(dZAA - SW/CW*dZZA)/2. transform
A->A*(1+dZAA/2)+dZAZ*Z/2, Z->Z*(1+dZZZ/2)+dZZA*A/2,
      'W+'->'W+'*(1+dZW/2),'W-'->'W-'*(1+dZW/2), H->H*(1+dZH/2).
```

  Different normalization schemes can be used, easy to switch between different RS
- Non-linear gauge fixing (see later)

SloopS

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SloopS

is a code for the calculation of cross sections and other observables at one-loop in the MSSM. Renormalisation is performed in the On-Shell Scheme with the possibility of easily switching to other schemes. SloopS has been designed so that it has applications not only for physics at colliders but also for astrophysics and cosmology.

The principle behind the code is **modularity**. Considering the complex structure of the MSSM (large number of parameters) and that no simple complete renormalisation scheme of the MSSM has emerged one should have a code that is flexible enough so that it simple to define the model file. Moreover since different codes exist already that deal with important ingredients in the calculation of loops it is best to exploit these, combine them together and whenever improve on them.

The model file is implemented in automatic way both at tree-level and at the one-loop level with the help of **LANHEP** adapted such that it can be interfaced with the **FeynCalc/FormCalc** package. LANHEP has been extended so that it can generate counterterms in a most efficient manner.

- Model file:
    - **example** of particle definition, gauge fixing and ghost Lagrangian via BRS in LANHEP.
    - Feynman rules including counterterms (see **here**).
    - renormalisation conditions (see **here**).
- A poweful feature of the code is the use of a non-linear gauge fixing condition (see **here**).
- The aim of the code is also to be used for annihilation of dark matter that is highly non relativistic, this calls for an added routine in the loop tensor reduction that avoids Gram determinants. Our trick is to do **this** and **this.**
    - Overview of strategy (**here**)
    - **Example** of combining SloopS with **micrOMEGAs** to predict the photon flux from neutralino annihilation.

Home

There are no Items to display

LATEST POSTINGS

- Tools of the Project
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CALENDAR

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Strategy: Exploiting and interfacing modules from different codes

Lagrangian of the model defined in LanHEP

- particle content
- interaction terms
- shifts in fields and parameters
- ghost terms constructed by BRST

$\downarrow$ $\downarrow$

Generic Model
-kinematical structures

Classes Model
-Feynman rules, including CT

$\Downarrow$

Evaluation via FeynArts-FormCalc

LoopTools modified!!
tensor reduction inappropriate for small relative velocities
(Zero Gram determinants)

$\Uparrow$

Renormalisation scheme

- definition of renorm. const. in the classes model

Non-Linear gauge-fixing constraints, gauge parameter dependence checks

From the Lagrangian to the Feynman Rules

```
vector
    A/A: (photon, gauge),
    Z/Z:('Z boson', mass MZ = 91.1875, gauge),
    'W+'/'W-': ('W boson', mass MW = MZ*CW, gauge).
scalar  H/H:(Higgs, mass MH = 115).



transform A->A*(1+dZAA/2)+dZAZ*Z/2, Z->Z*(1+dZZZ/2)+dZZA*A/2,
    'W+'->'W+'*(1+dZW/2),'W-'->'W-'*(1+dZW/2).
transform H->H*(1+dZH/2), 'Z.f'->'Z.f'*(1+dZZf/2),
    'W+.f'->'W+.f'*(1+dZWf/2),'W-.f'->'W-.f'*(1+dZWf/2).

let pp = { -i*'W+.f',  (vev(2*MW/EE*SW)+H+i*'Z.f')/Sqrt2 },
PP=anti(pp).



lterm -2*lambda*(pp*anti(pp)-v**2/2)**2
     where
    lambda=(EE*MH/MW/SW)**2/16, v=2*MW*SW/EE .

let Dpp^mu^a = (deriv^mu+i*g1/2*B0^mu)*pp^a +
     i*g/2*taupm^a^b^c*WW^mu^c*pp^b.
let DPP^mu^a = (deriv^mu-i*g1/2*B0^mu)*PP^a
    -i*g/2*taupm^a^b^c*{'W-'^mu,W3^mu,'W+'^mu}^c*PP^b.
lterm DPP*Dpp.
```

Gauge fixing and BRS transformation

```
let G_Z = deriv*Z+(MW/CW+EE/SW/CW/2*nle*H)*'Z.f'.

lterm -G_A**2/2 - G_Wp*G_Wm - G_Z**2/2.

lterm -'Z.C'*brst(G_Z).
```

From the Lagrangian to the Feynman Rules

```
vector
    A/A: (photon, gauge),
    Z/Z:('Z boson', mass MZ = 91.1875, gauge),
    'W+'/'W-': ('W boson', mass MW = MZ*CW, gauge).
scalar  H/H:(Higgs, mass MH = 115).



transform A->A*(1+dZAA/2)+dZAZ*Z/2, Z->Z*(1+dZZZ/2)+dZZA*A/2,
    'W+'->'W+'*(1+dZW/2),'W-'->'W-'*(1+dZW/2).
transform H->H*(1+dZH/2), 'Z.f'->'Z.f'*(1+dZZf/2),
    'W+.f'->'W+.f'*(1+dZWf/2),'W-.f'->'W-.f'*(1+dZWf/2).

let pp = { -i*'W+.f',  (vev(2*MW/EE*SW)+H+i*'Z.f')/Sqrt2 },
PP=anti(pp).



lterm -2*lambda*(pp*anti(pp)-v**2/2)**2
     where
    lambda=(EE*MH/MW/SW)**2/16, v=2*MW*SW/EE .

let Dpp^mu^a = (deriv^mu+i*g1/2*B0^mu)*pp^a +
     i*g/2*taupm^a^b^c*WW^mu^c*pp^b.
let DPP^mu^a = (deriv^mu-i*g1/2*B0^mu)*PP^a
    -i*g/2*taupm^a^b^c*{'W-'^mu,W3^mu,'W+'^mu}^c*PP^b.
lterm DPP*Dpp.
```

Gauge fixing and BRS transformation

```
let G_Z = deriv*Z+(MW/CW+EE/SW/CW/2*nle*H)*'Z.f'.

lterm -G_A**2/2 - G_Wp*G_Wm - G_Z**2/2.

lterm -'Z.C'*brst(G_Z).
```

Output of Feynman Rules with Counterterms !!

```
M$CouplingMatrices = {

  (*------    H   H   ------*)
   C[ S[3], S[3] ] == - I *
{
 { 0 , dZH },
 { 0 , MH^2 dZH + dMHsq }
},
  (*------    W+.f   W-.f   ------*)
   C[ S[2], -S[2] ] == - I *
{
 { 0 , dZWf },
 { 0, 0 }
}, (*------    A   Z   ------*)
   C[ V[1], V[2] ] == 1/2 I / CW^2 MW^2 *
{
 { 0, 0 },
 { 0 , dZZA },
 { 0, 0 }
},

(*------    H   H   H   ------*)
   C[ S[3], S[3], S[3] ] == -3/4 I EE / MW / SW *
{
 { 2 MH^2 , 3 MH^2 dZH -2 MH^2 / SW dSW - MH^2 / MW^2 dMWsq
},
  (*------    H  W+.f   W-.f   ------*)
   C[ S[3], S[2], -S[2] ] == -1/4 I EE / MW / SW *
{
 { 2 MH^2 , MH^2 dZH + 2 MH^2 dZWf -2 MH^2 / SW dSW - MH^2 /
},

  (*------    W-.C   A.c   W+   ------*)
   C[ -U[3], U[1], V[3] ] == - I EE *
{
 { 1 },
 { - nla }
},
```

From the Lagrangian to the Feynman Rules

```
vector
    A/A: (photon, gauge),
    Z/Z:('Z boson', mass MZ = 91.1875, gauge),
    'W+'/'W-': ('W boson', mass MW = MZ*CW, gauge).
scalar  H/H:(Higgs, mass MH = 115).



transform A->A*(1+dZAA/2)+dZAZ*Z/2, Z->Z*(1+dZZZ/2)+dZZA*A/2,
    'W+'->'W+'*(1+dZW/2),'W-'->'W-'*(1+dZW/2).
transform H->H*(1+dZH/2), 'Z.f'->'Z.f'*(1+dZZf/2),
    'W+.f'->'W+.f'*(1+dZWf/2),'W-.f'->'W-.f'*(1+dZWf/2).

let pp = { -i*'W+.f',  (vev(2*MW/EE*SW)+H+i*'Z.f')/Sqrt2 },
PP=anti(pp).



lterm -2*lambda*(pp*anti(pp)-v**2/2)**2
     where
    lambda=(EE*MH/MW/SW)**2/16, v=2*MW*SW/EE .

let Dpp^mu^a = (deriv^mu+i*g1/2*B0^mu)*pp^a +
     i*g/2*taupm^a^b^c*WW^mu^c*pp^b.
let DPP^mu^a = (deriv^mu-i*g1/2*B0^mu)*PP^a
    -i*g/2*taupm^a^b^c*{'W-'^mu,W3^mu,'W+'^mu}^c*PP^b.
lterm DPP*Dpp.
```

Gauge fixing and BRS transformation

```
let G_Z = deriv*Z+(MW/CW+EE/SW/CW/2*nle*H)*'Z.f'.

lterm -G_A**2/2 - G_Wp*G_Wm - G_Z**2/2.

lterm -'Z.C'*brst(G_Z).
```

```
RenConst[ dMHsq ] := ReTilde[SelfEnergy[prt["H"] -> prt["H"], MH]]
RenConst[ dZH ] := -ReTilde[DSelfEnergy[prt["H"] -> prt["H"], MH]]
RenConst[ dZZf ] := -ReTilde[DSelfEnergy[prt["Z.f"] -> prt["Z.f"],
MZ]] RenConst[ dZWf ] := -ReTilde[DSelfEnergy[prt["W+.f"] ->
prt["W+.f"], MW]]
```

Output of Feynman Rules with Counterterms !!

```
M$CouplingMatrices = {

  (*------    H   H   ------*)
   C[ S[3], S[3] ] == - I *
{
 { 0 , dZH },
 { 0 , MH^2 dZH + dMHsq }
},
  (*------    W+.f  W-.f   ------*)
   C[ S[2], -S[2] ] == - I *
{
 { 0 , dZWf },
 { 0, 0 }
}, (*------    A   Z   ------*)
   C[ V[1], V[2] ] == 1/2 I / CW^2 MW^2 *
{
 { 0, 0 },
 { 0 , dZZA },
 { 0, 0 }
},

(*------    H   H   H   ------*)
   C[ S[3], S[3], S[3] ] == -3/4 I EE / MW / SW *
{
 { 2 MH^2 , 3 MH^2 dZH -2 MH^2 / SW dSW - MH^2 / MW^2 dMWsq
},
  (*------    H  W+.f  W-.f   ------*)
   C[ S[3], S[2], -S[2] ] == -1/4 I EE / MW / SW *
{
 { 2 MH^2 , MH^2 dZH + 2 MH^2 dZWf -2 MH^2 / SW dSW - MH^2 /
},

  (*------    W-.C  A.c  W+   ------*)
   C[ -U[3], U[1], V[3] ] == - I EE *
{
 { 1 },
 { - nla }
},
```

TREE LEVEL CALCULATIONS

Comparison with public codes: Grace and CompHEP

Cross-section [pb]	SloopS	CompHEP	Grace
$h^0 h^0 \to h^0 h^0$	3.932×10^{-2}	3.932×10^{-2}	3.929×10^{-2}
$W^+ W^- \to \tilde{t}_1 \bar{\tilde{t}}_1$	7.082×10^{-1}	7.082×10^{-1}	7.083×10^{-1}
$e^+ e^- \to \tilde{\tau}_1 \bar{\tilde{\tau}}_2$	2.854×10^{-3}	2.854×10^{-3}	2.854×10^{-3}
$H^+ H^- \to W^+ W^-$	6.643×10^{-1}	6.643×10^{-1}	6.644×10^{-1}
Decay [GeV]			
$A^0 \to \tilde{\chi}_1^+ \tilde{\chi}_1^-$	1.137×10^{0}	1.137×10^{0}	1.137×10^{0}
$\tilde{\chi}_1^+ \to t \bar{\tilde{b}}_1$	5.428×10^{0}	5.428×10^{0}	5.428×10^{0}
$H^0 \to \tilde{\tau}_1 \bar{\tilde{\tau}}_1$	7.579×10^{-3}	7.579×10^{-3}	7.579×10^{-3}
$H^+ \to \tilde{\chi}_1^+ \tilde{\chi}_1^0$	1.113×10^{-1}	1.113×10^{-1}	1.113×10^{-1}

... ... # 200 processes checked

Non-linear gauge implementation

$$\mathcal{L}_{GF} = -\frac{1}{\xi_W}|\partial.W^+ + \xi_W \frac{g}{2} v G^+|^2$$
$$-\frac{1}{2\xi_Z}(\partial.Z + \xi_Z \frac{g}{2c_W} v + G^0)^2 - \frac{1}{2\xi_\gamma}(\partial.A)^2$$

This only affects the propagators. Usually calculations done with $\xi = 1$, otherwise large expressions, higher rank tensors, unphysical thresholds,..

$$\frac{1}{k^2 - M_W^2}\left(g_{\mu\nu} - (1 - \xi_W)\frac{k_\mu k_\nu}{k^2 - \xi_W M_W^2}\right)$$

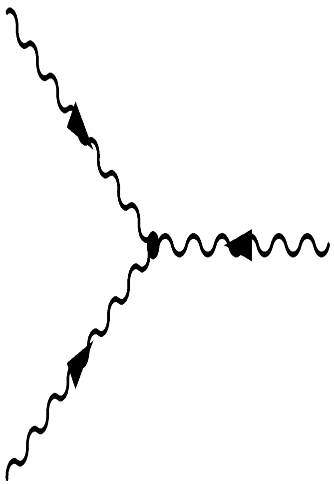
how to have $\xi = 1$ and still check for gauge parameter independence?

Non-linear gauge implementation

$$\mathcal{L}_{GF} = -\frac{1}{\xi_W}|(\partial_\mu - ie\tilde{\alpha}A_\mu - igc_W\tilde{\beta}Z_\mu)W^{\mu\,+} + \xi_W\frac{g}{2}(v+\tilde{\delta}h+\tilde{\omega}H+i\tilde{\rho}A^0+i\tilde{\kappa}G^0)G^+|^2$$
$$-\frac{1}{2\xi_Z}(\partial.Z+\xi_Z\frac{g}{2c_W}(v+\tilde{\epsilon}h+\tilde{\gamma}H)G^0)^2 - \frac{1}{2\xi_\gamma}(\partial.A)^2$$

- quite a handful of gauge parameters, but with $\xi_i = 1$, no "unphysical threshold", no higher rank tensors, gauge parameter dependence in gauge/Goldstone/ghosts vertices.
- more important: no need for higher (than the minimal set)for higher rank tensors and tedious algebraic manipulations

$$\mathcal{L}_{GF} = -\frac{1}{\xi_W}|(\partial_\mu - ie\tilde{\alpha}A_\mu - igc_W\tilde{\beta}Z_\mu)W^{\mu\,+} + \xi_W\frac{g}{2}(v + \tilde{\delta}h + \tilde{\omega}H + i\tilde{\rho}A^0 + i\tilde{\kappa}G^0)G^+|^2$$
$$-\frac{1}{2\xi_Z}(\partial.Z + \xi_Z\frac{g}{2c_W}(v + \tilde{\epsilon}h + \tilde{\gamma}H)G^0)^2 - \frac{1}{2\xi_\gamma}(\partial.A)^2$$



$p_1\ (\mu)$	$p_2\ (\nu)$	$p_3\ (\rho)$	
W^-	W^+	A	$e\Big[g^{\mu\nu}(p_1-p_2)^\rho + (1+\tilde{\alpha}/\xi_W)(p_3^\nu g^{\mu\rho} - p_3^\mu g^{\nu\rho}) + (1-\tilde{\alpha}/\xi_W)(p_2^\mu g^{\nu\rho} - p_1^\nu g^{\mu\rho})\Big]$
W^-	W^+	Z	$e\frac{c_W}{s_W}\Big[g^{\mu\nu}(p_1-p_2)^\rho + (1+\tilde{\beta}/\xi_W)(p_3^\nu g^{\mu\rho} - p_3^\mu g^{\nu\rho}) + (1-\tilde{\beta}/\xi_W)(p_2^\mu g^{\nu\rho} - p_1^\nu g^{\mu\rho})\Big]$

not your usual VVV gauge vertex!

- Default: on-shell, GI, renormalisation in **ALL** sectors

SloopS: SUSY renormalisation at one-loop

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- possibility to switch to other schemes easily (DRbar,..)

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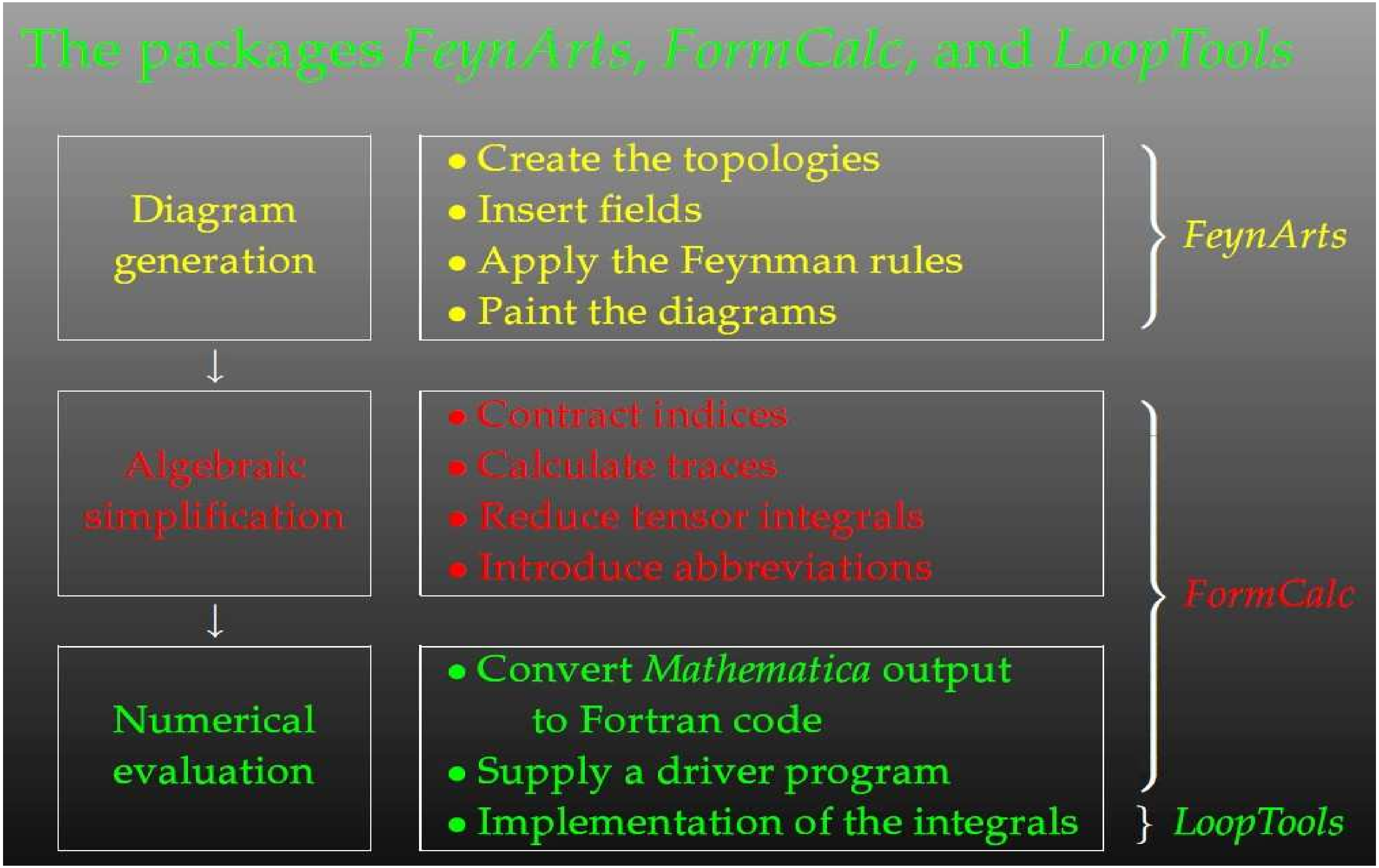
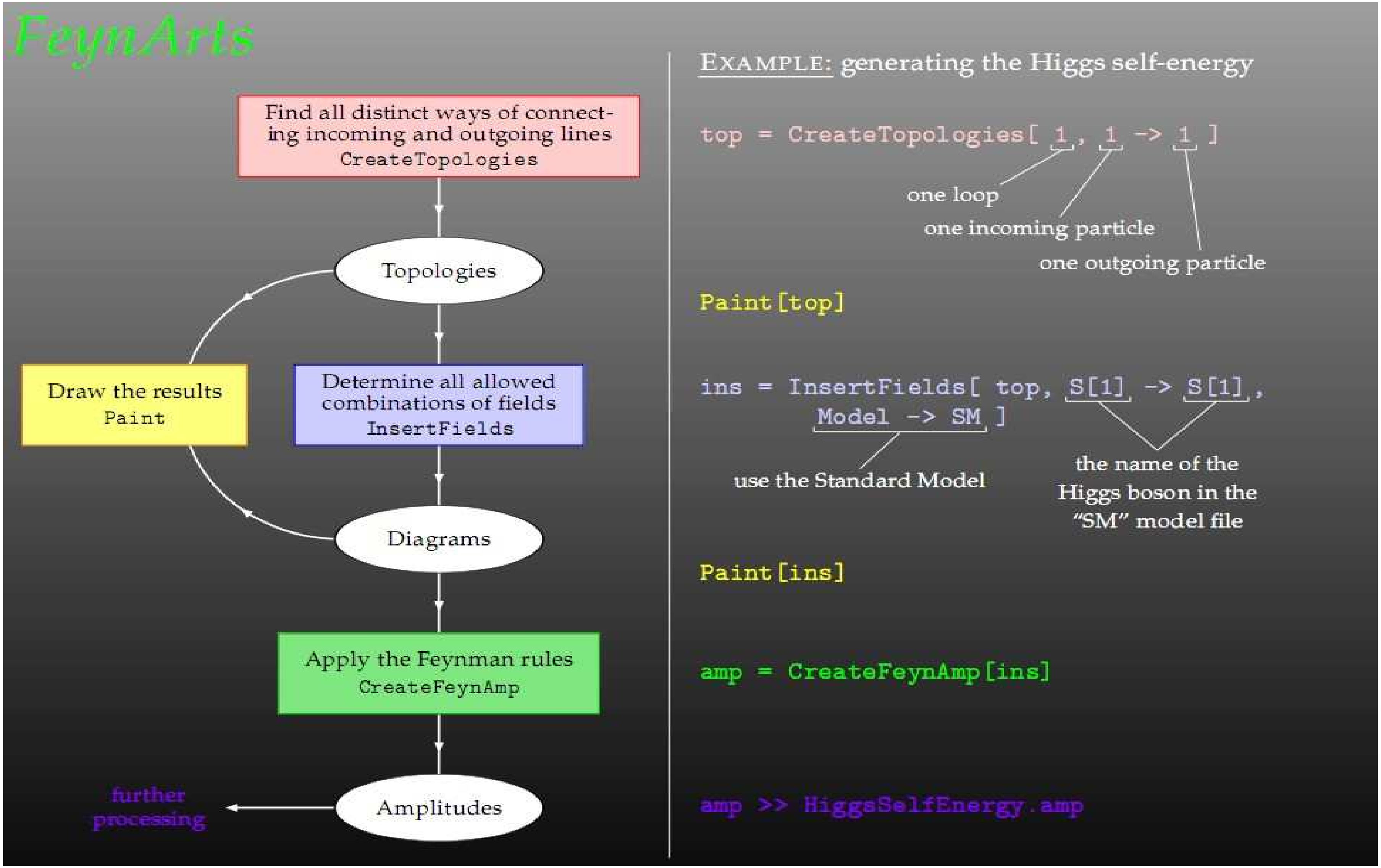
- Same for mixing angle in the sfermion sector.
- Good scale dependence of ren. csts.

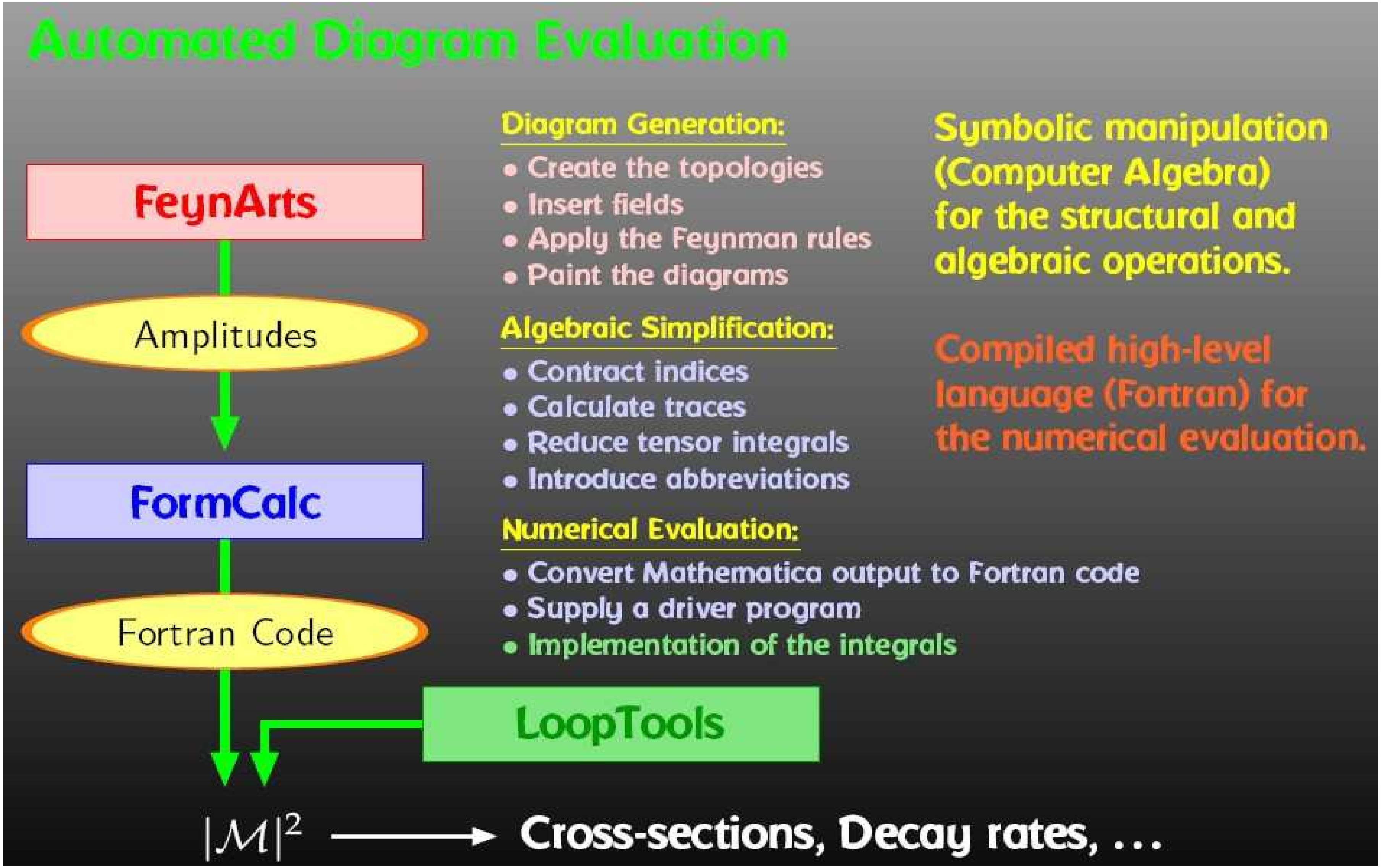
1. Draw all possible types of diagrams	topology
Figure out which particles can run on each type of diagram	combinatorics
Translate diagrams into expressions applying the Feynman rules	data-base look up
contract indices, take traces, (multiply add blocks)	algebra
Collect and write up the results as a computer code integrate over phase space	programming coding/computing
run the program to get numerical values	waiting!

Feyn Package




FeynArts
Find all distinct ways of connecting incoming and outgoing lines
CreateTopologies
Topologies
Determine all allowed combinations of fields
InsertFields
Draw the results
Paint
Diagrams
Apply the Feynman rules
CreateFeynAmp
Amplitudes
further processing
EXAMPLE: generating the Higgs self-energy
top = CreateTopologies[1, 1 -> 1]
one loop
one incoming particle
one outgoing particle
Paint[top]
ins = InsertFields[top, S[1] -> S[1],
Model -> SM]
use the Standard Model
the name of the Higgs boson in the "SM" model file
Paint[ins]
amp = CreateFeynAmp[ins]
amp >> HiggsSelfEnergy.amp

Feyn Package

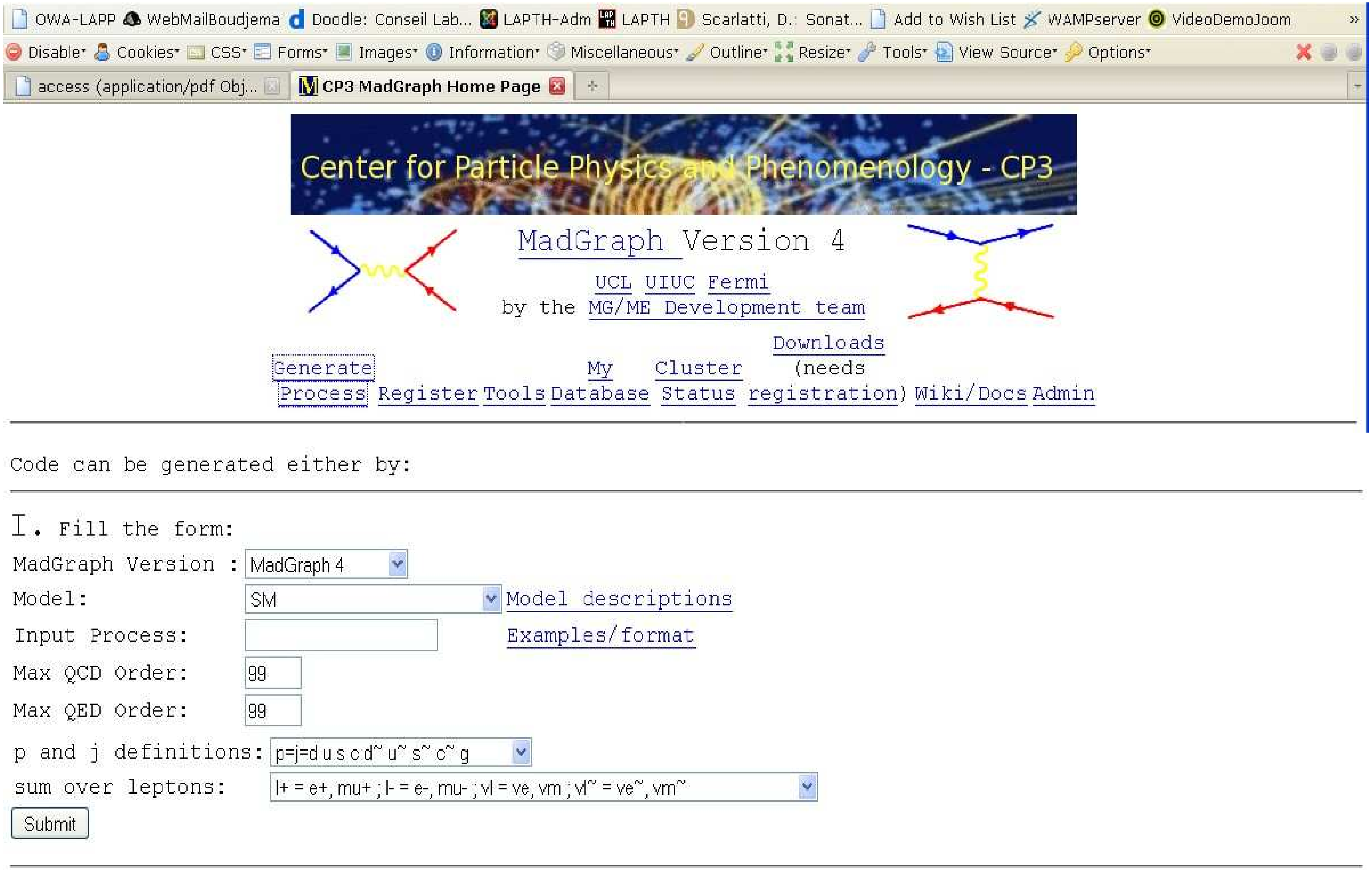


Finally

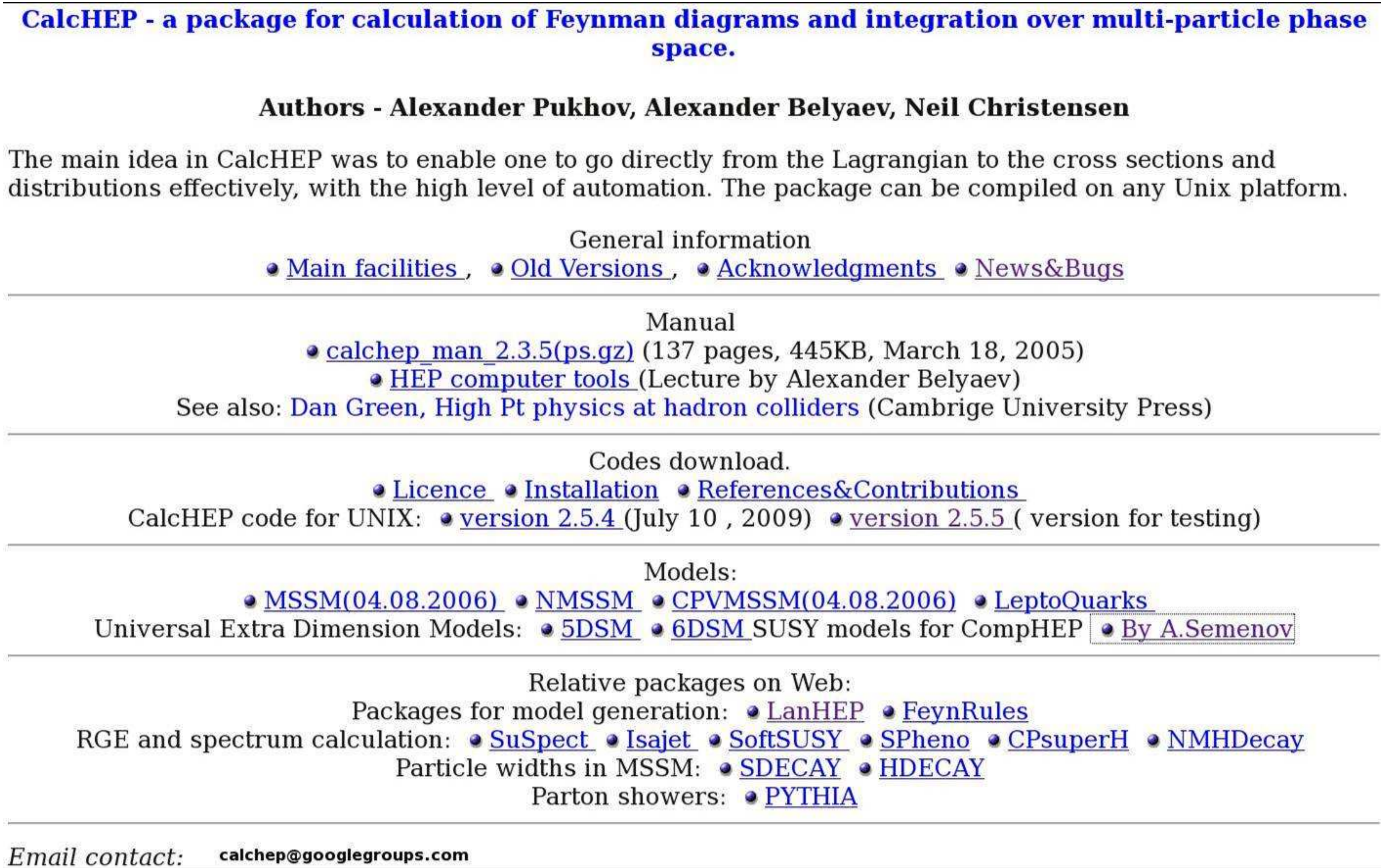
Using FeynArts and FormCalc is a lot like driving a car:

- You have to decide where to go (this is often the hardest decision).
- You have to turn the ignition key, work gas and brakes, and steer.
- But you don't have to know, say, which valve has to open at which time to keep the motor running.
- On the other hand, you can only go where there are roads. You can't climb a mountain with your car.

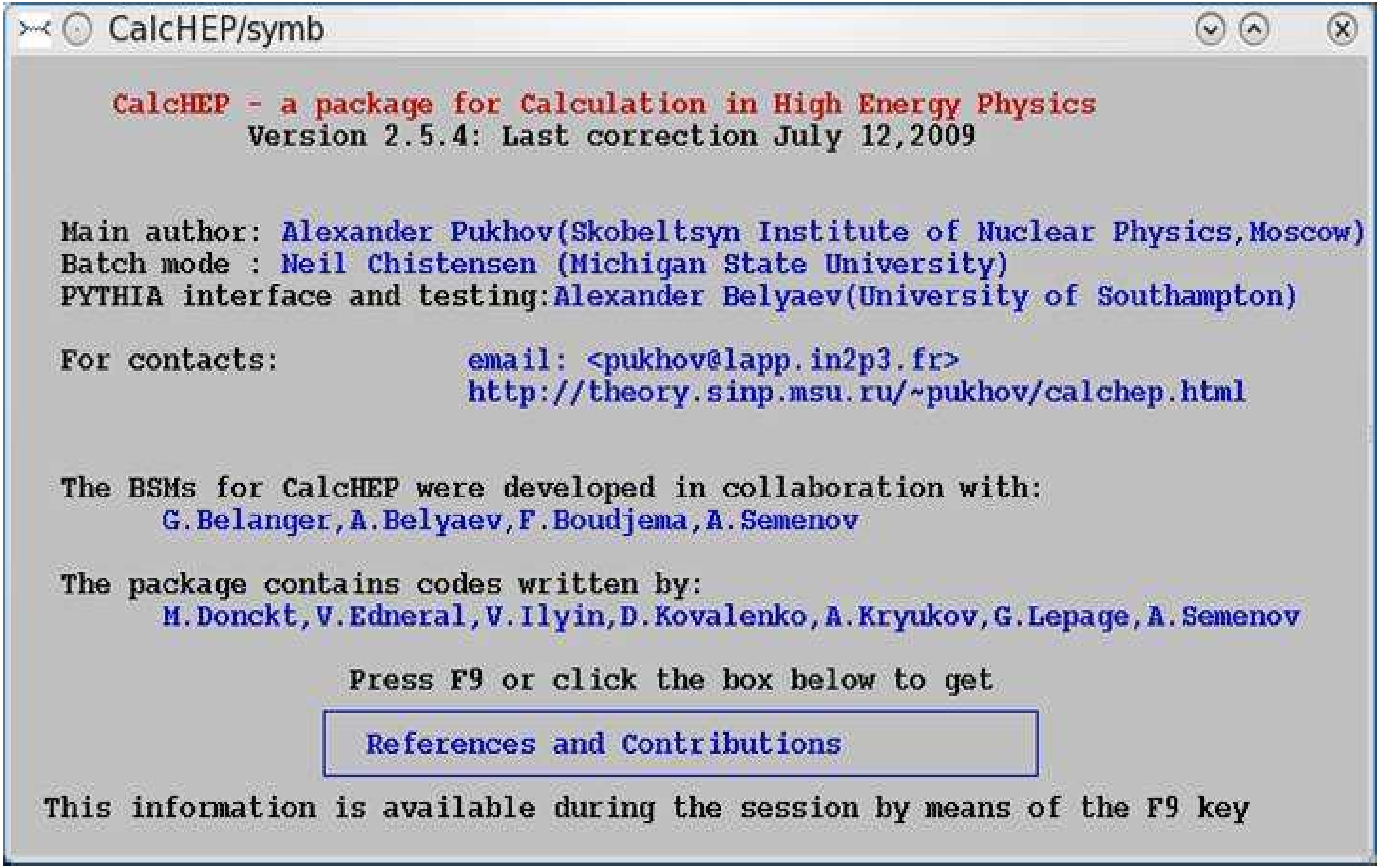
Madgraph Web Interface, you've had a tutorial already



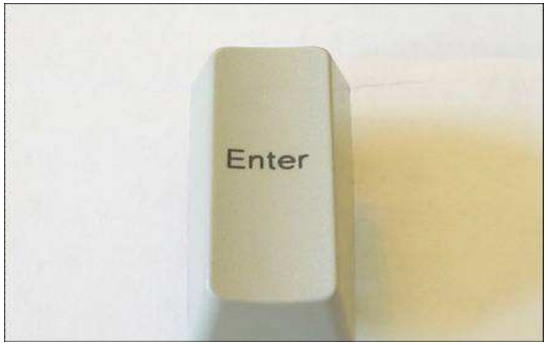
CalcHEP webpage



CalcHEP start page



In interactive mode you only need to know/press 3 keys

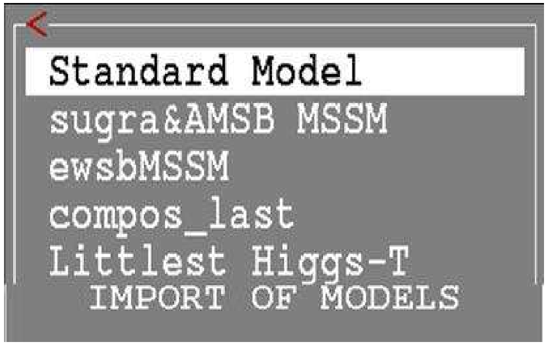


Enter menu selection
(forward)

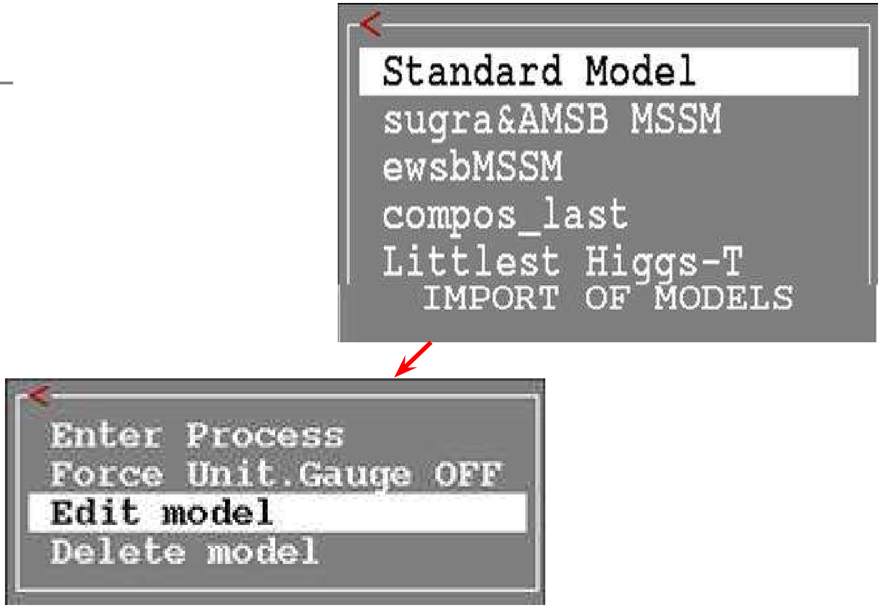
Exit menu selection
(back)

Help !
(or details of menu choice)

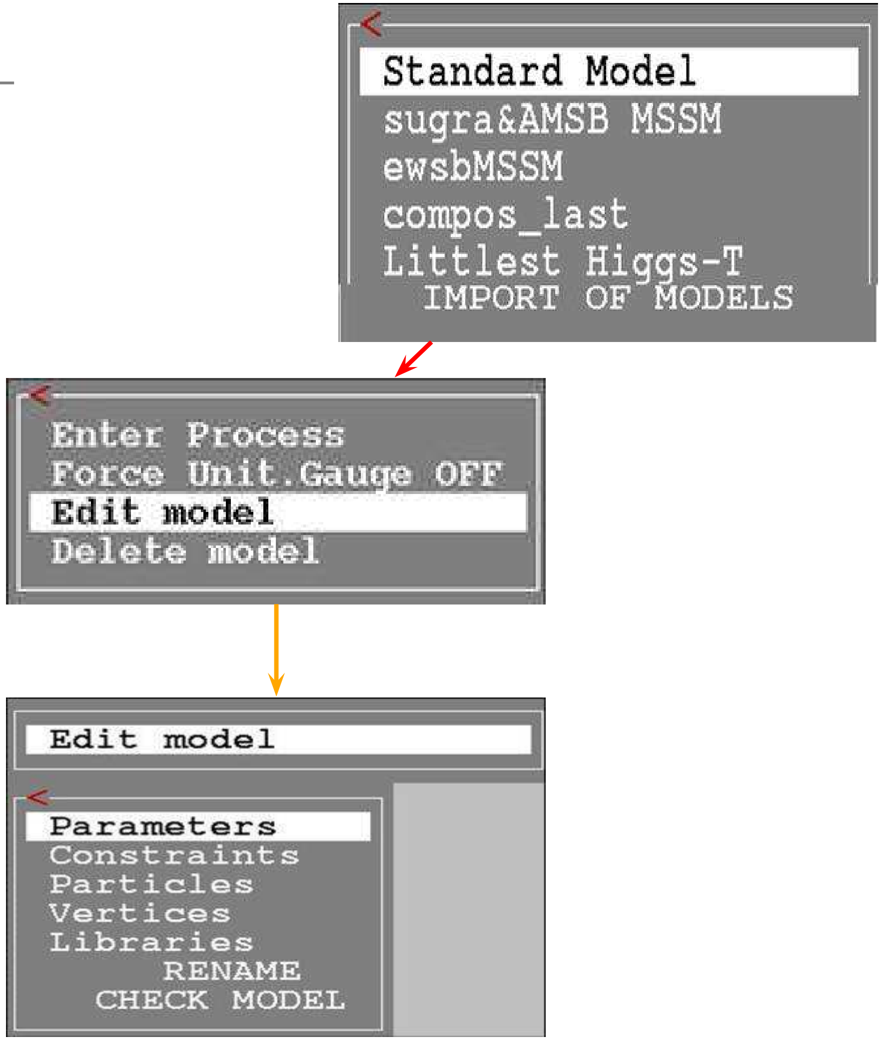
Work flow


Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS

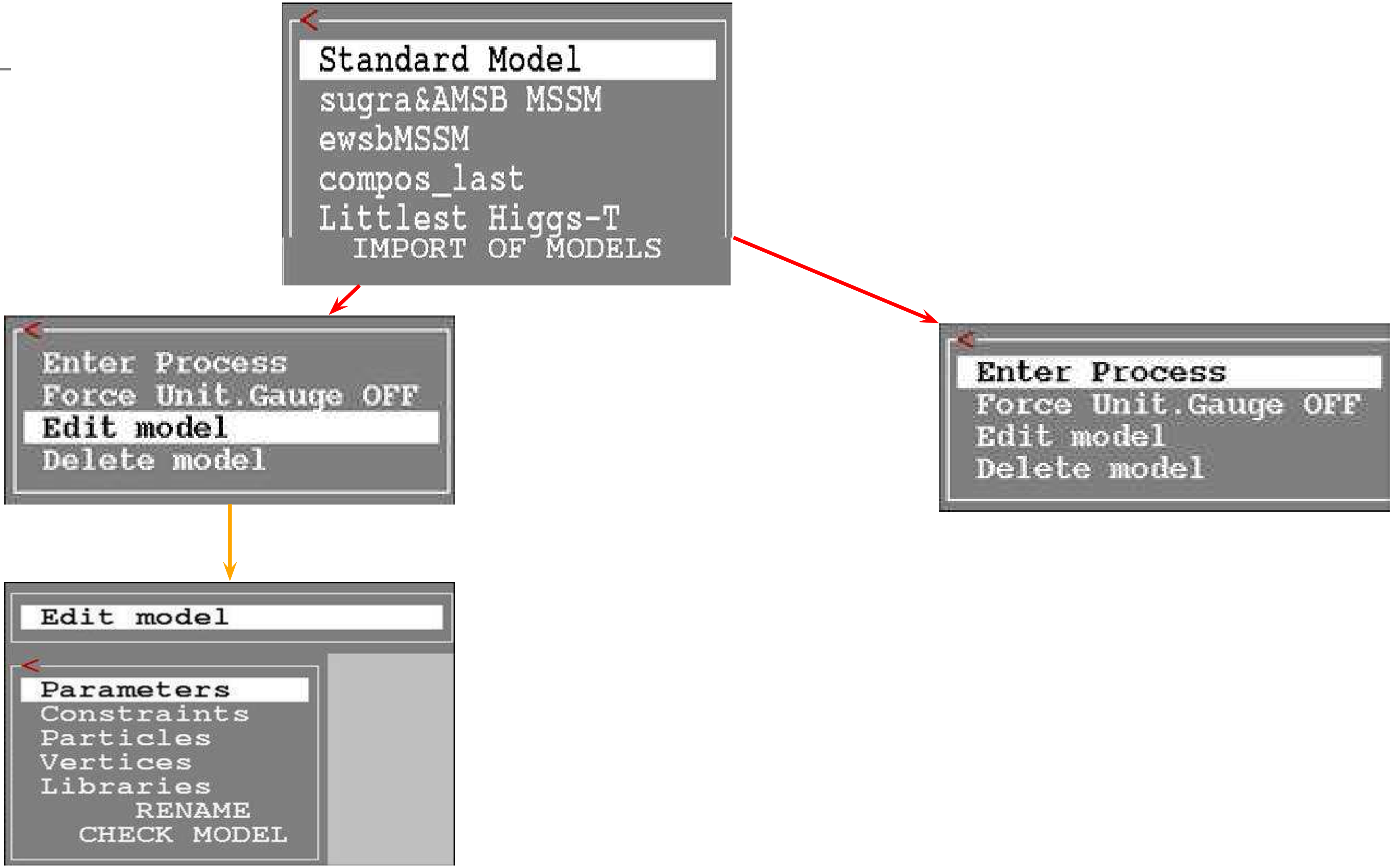
Work flow


Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model

Work flow


Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
Edit model
Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

Work flow


Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
Enter Process
Force Unit.Gauge OFF
Edit model
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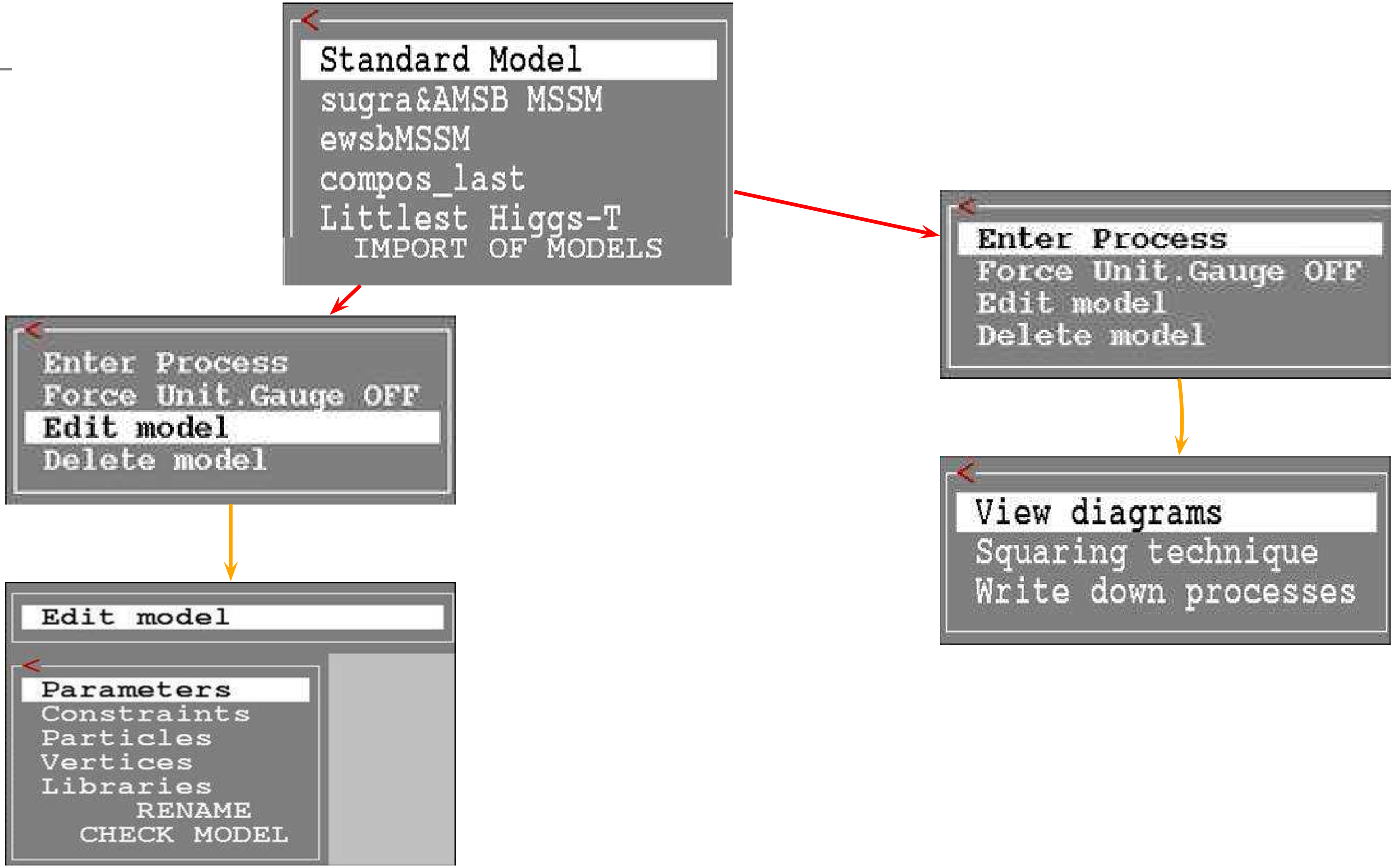
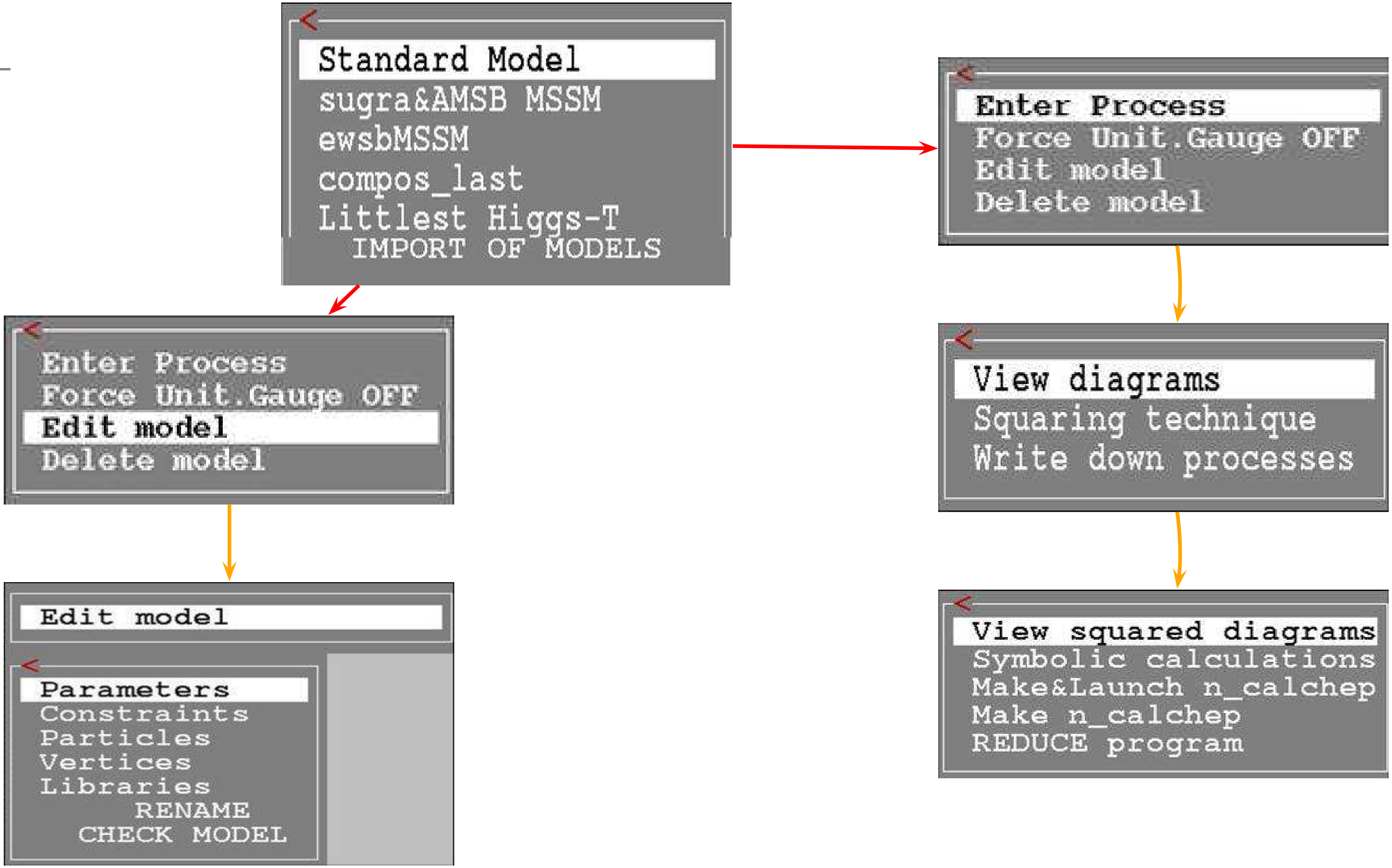
Edit model
Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

Work flow

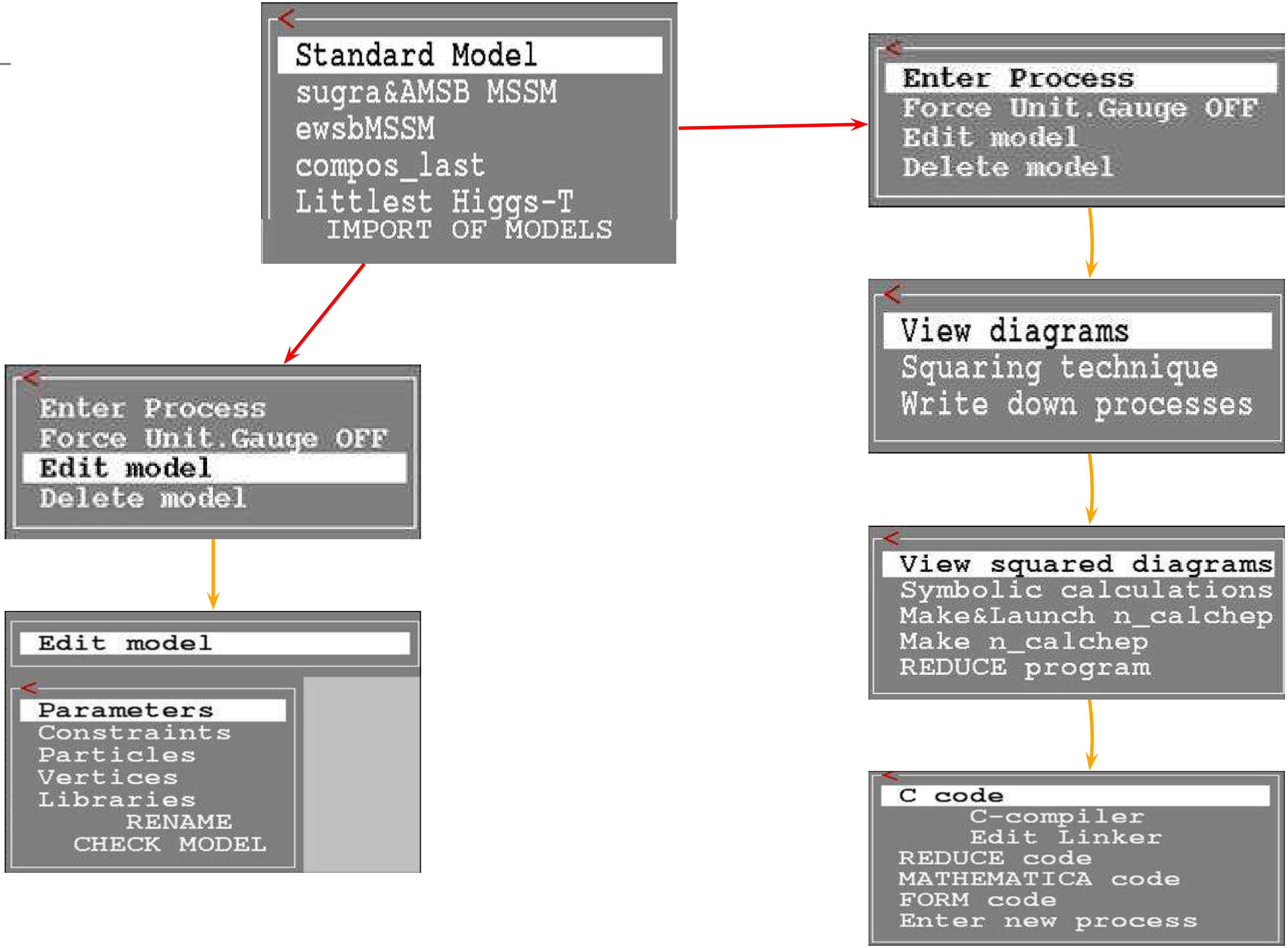

Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
View diagrams
Squaring technique
Write down processes
Edit model
Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

Work flow



Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
Edit model
Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL
View diagrams
Squaring technique
Write down processes
View squared diagrams
Symbolic calculations
Make&Launch n_calchep
Make n_calchep
REDUCE program

Work flow



Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS
Enter Process
Force Unit.Gauge OFF
Edit model
Delete model
Edit model
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Particles
Vertices
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CHECK MODEL
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Force Unit.Gauge OFF
Edit model
Delete model
View diagrams
Squaring technique
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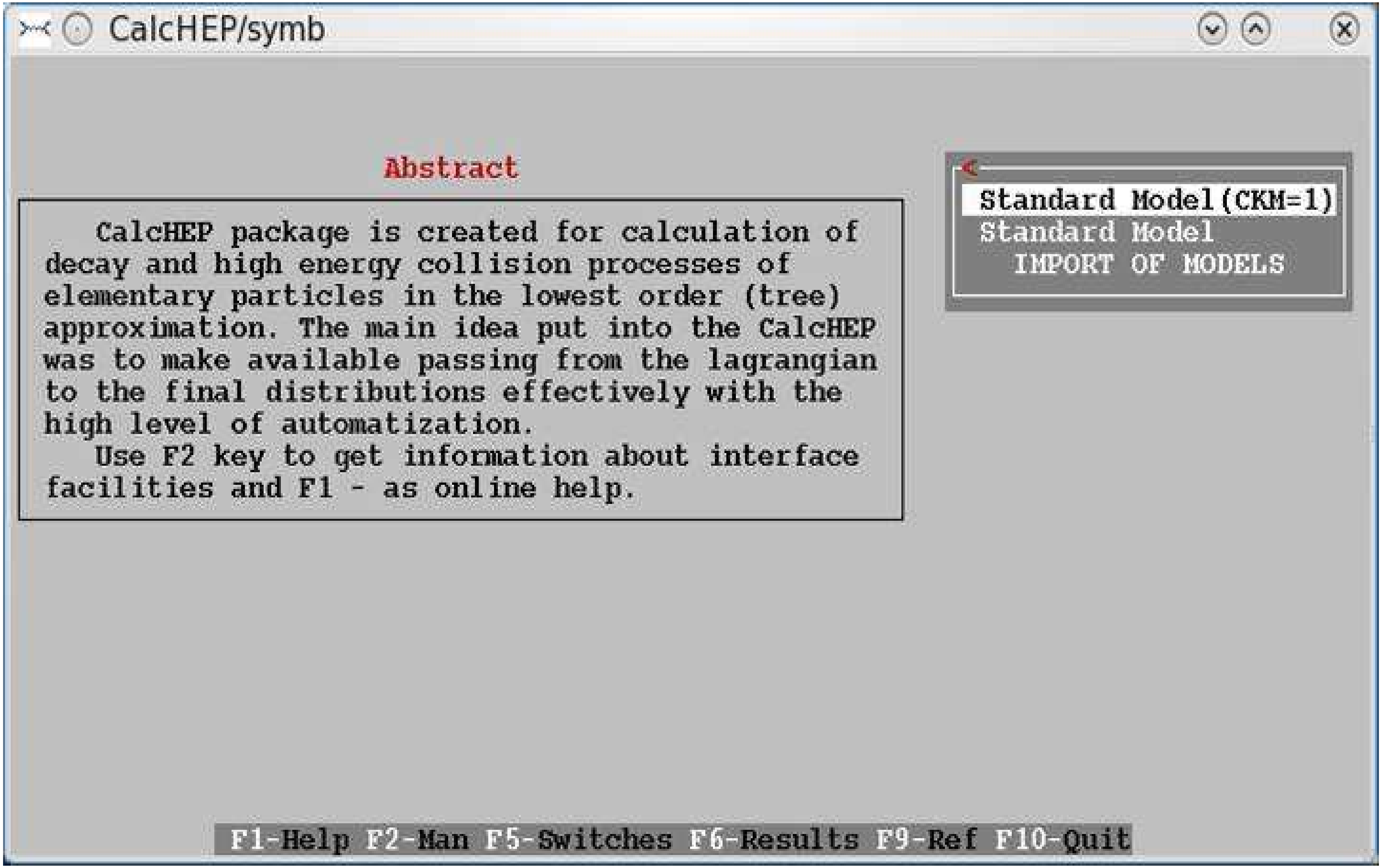
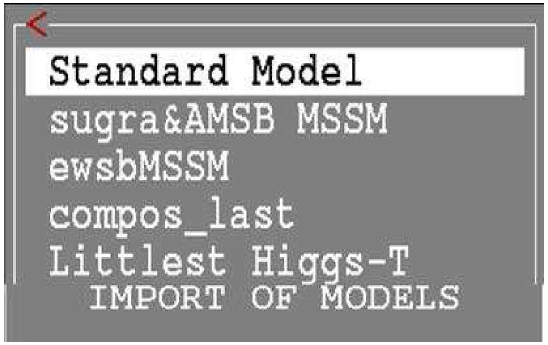
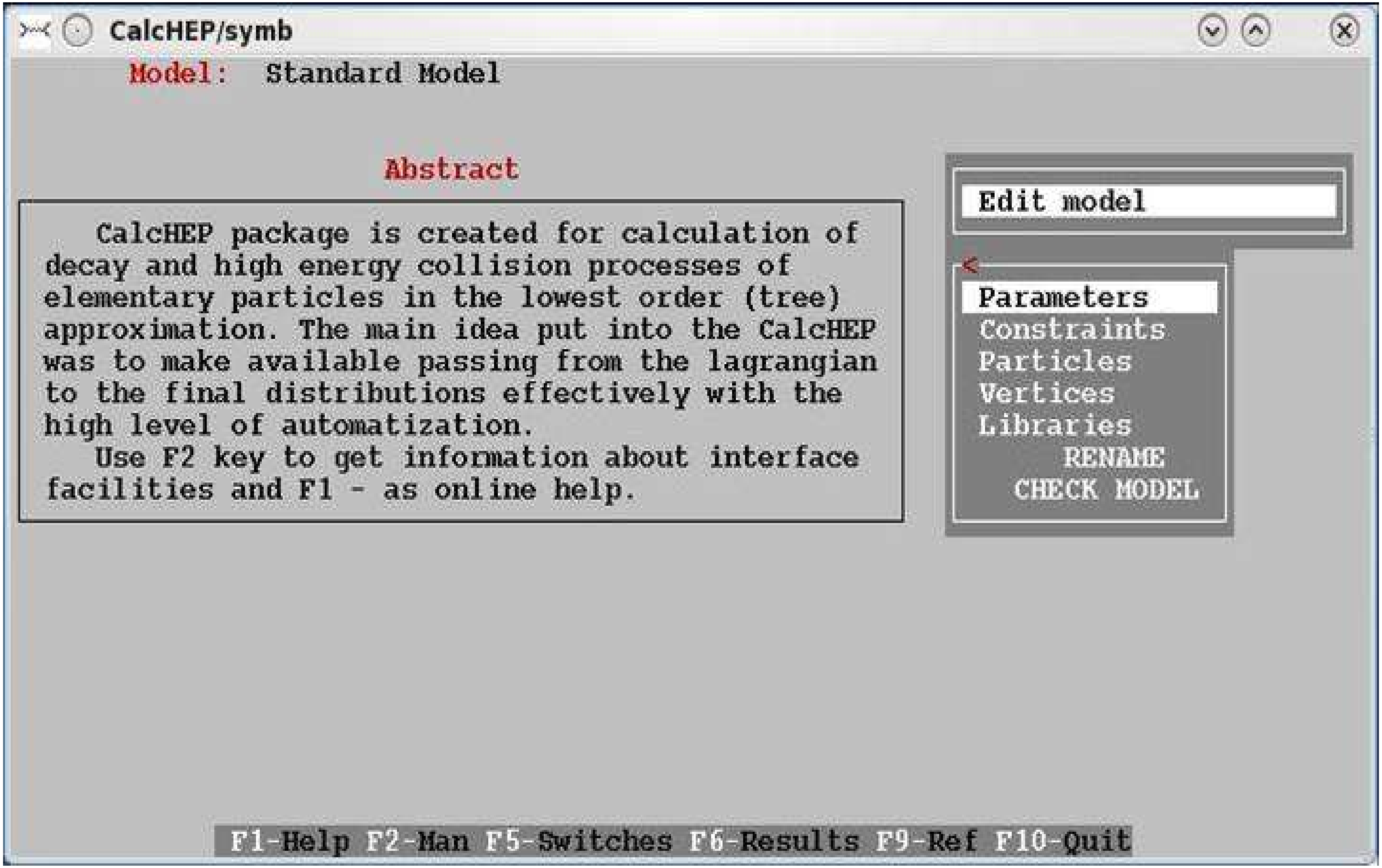
Symbolic calculations
Make&Launch n_calchep
Make n_calchep
REDUCE program
C code
C-compiler
Edit Linker
REDUCE code
MATHEMATICA code
FORM code
Enter new process


CalcHEP/symb
Abstract
CalcHEP package is created for calculation of decay and high energy collision processes of elementary particles in the lowest order (tree) approximation. The main idea put into the CalcHEP was to make available passing from the lagrangian to the final distributions effectively with the high level of automatization.
Use F2 key to get information about interface facilities and F1 - as online help.
Standard Model(CKM=1)
Standard Model
IMPORT OF MODELS
F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit


Standard Model
sugra&AMSB MSSM
ewsbMSSM
compos_last
Littlest Higgs-T
IMPORT OF MODELS


CalcHEP/symb
Model: Standard Model
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Edit model
Parameters
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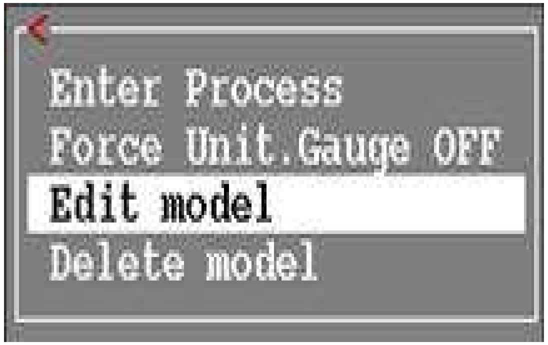
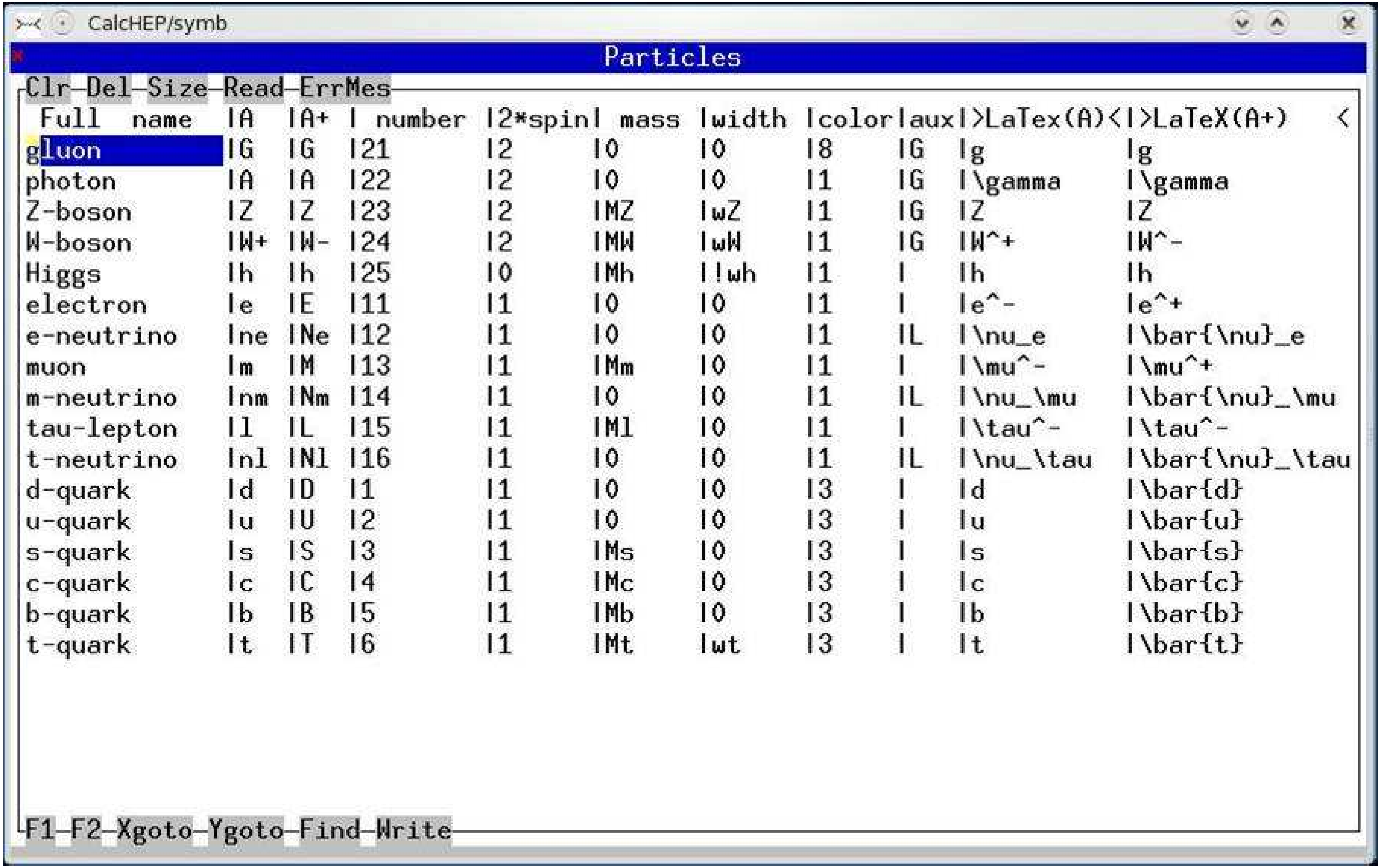
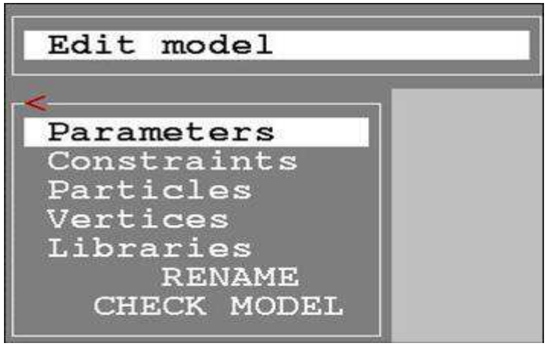
Particles
Vertices
Libraries
RENAME
CHECK MODEL
F1-Help F2-Man F5-Switches F6-Results F9-Ref F10-Quit


Enter Process
Force Unit.Gauge OFF
Edit model
Delete model



Full name	A	A+	number	2*spin	mass	width	color	aux	>LaTex(A)<	>LaTeX(A+) <
gluon	G	G	21	2	0	0	8	G	g	g
photon	A	A	22	2	0	0	1	G	\gamma	\gamma
Z-boson	Z	Z	23	2	MZ	wZ	1	G	Z	Z
W-boson	W+	W-	24	2	MW	wW	1	G	W^+	W^-
Higgs	h	h	25	0	Mh	!wh	1		h	h
electron	e	E	11	1	0	0	1		e^-	e^+
e-neutrino	ne	Ne	12	1	0	0	1	L	\nu_e	\bar{\nu}_e
muon	m	M	13	1	Mm	0	1		\mu^-	\mu^+
m-neutrino	nm	Nm	14	1	0	0	1	L	\nu_\mu	\bar{\nu}_\mu
tau-lepton	l	L	15	1	Ml	0	1		\tau^-	\tau^-
t-neutrino	nl	Nl	16	1	0	0	1	L	\nu_\tau	\bar{\nu}_\tau
d-quark	d	D	1	1	0	0	3		d	\bar{d}
u-quark	u	U	2	1	0	0	3		u	\bar{u}
s-quark	s	S	3	1	Ms	0	3		s	\bar{s}
c-quark	c	C	4	1	Mc	0	3		c	\bar{c}
b-quark	b	B	5	1	Mb	0	3		b	\bar{b}
t-quark	t	T	6	1	Mt	wt	3		t	\bar{t}


Edit model
Parameters
Constraints
Particles
Vertices
Libraries
RENAME
CHECK MODEL

CalcHEP/symb

Parameters

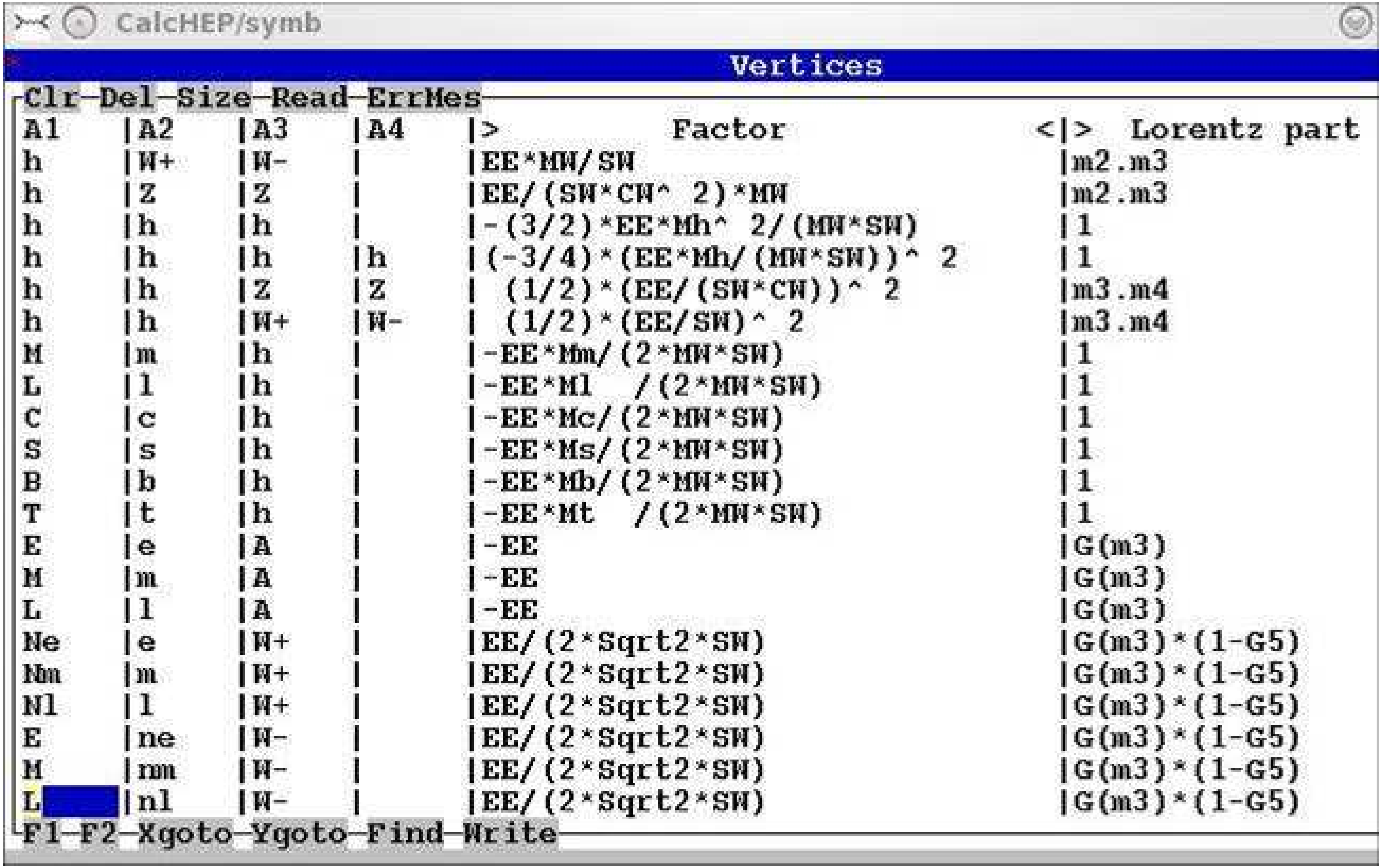
Clr Del Size Read ErrMes

Name	Value	> Comment
alfEMZ	0.0078180608	MS-BAR electromagnetic alpha(MZ)
alfSMZ	0.1172	Srtong alpha(MZ) for running mass calculation
Q	100	scale for running mass calculation
GG	1.238	Running Strong coupling. The given value doesn't matter.
SW	0.481	MS-BAR sine of the electroweak mixing angle
s12	0.221	Parameter of C-K-M matrix (PDG96)
s23	0.041	Parameter of C-K-M matrix (PDG96)
s13	0.0035	Parameter of C-K-M matrix (PDG96)
Mm	0.1057	muon mass
Ml	1.777	tau-lepton mass
McMc	1.2	Mc(Mc)
Ms	0	s-quark mass (pole mass, PDG96)
MbMb	4.25	Mb(Mb)
Mtp	175	t-quark pole mass
MZ	91.187	Z-boson mass
Mh	120	higgs mass
wt	1.59	t-quark width (tree level 1->2x)
wZ	2.49444	Z-boson width (tree level 1->2x)
wW	2.08895	W-boson width (tree level 1->2x)

F1 F2 Xgoto Ygoto Find Write

```
CalcHEP/symb
                              Constraints
Clr Del Size Read ErrMes
 Name   |> Expression
EE      |sqrt(16*atan(1.)*alfEMZ)           % electromagnetic constant
CW      |sqrt(1-SW^ 2)                      % cos of the Weinberg angle
MW      |MZ*CW                              % W-boson  mass
c12     |sqrt(1-s12^ 2)                     % parameter  of C-K-M matrix
c23     |sqrt(1-s23^ 2)                     % parameter  of C-K-M matrix
c13     |sqrt(1-s13^ 2)                     % parameter  of C-K-M matrix
Vud     |c12*c13                            % C-K-M matrix element
Vus     |s12*c13                            % C-K-M matrix element
Vub     |s13                                % C-K-M matrix element
Vcd     |-s12*c23-c12*s23*s13               % C-K-M matrix element
Vcs     |c12*c23-s12*s23*s13                % C-K-M matrix element
Vcb     |s23*c13                            % C-K-M matrix element
Vtd     |s12*s23-c12*c23*s13                % C-K-M matrix element
Vts     |-c12*s23-s12*c23*s13               % C-K-M matrix element
Vtb     |c23*c13                            % C-K-M matrix element
qcdOk   |initQCD(alfSMZ,McMc,MbMb,Mtp)
 Mb     |MbEff(Q)*one(qcdOk)
 Mt     |MtEff(Q)*one(qcdOk)
 Mc     |McEff(Q)*one(qcdOk)

F1 F2 Xgoto Ygoto Find Write
```

```
CalcHEP/symb
Constraints
Clr Del Size Read ErrMes
  Name  |> Expression
 smOk   |saveSM(MbMb,Mtp,SW,alfSMZ,alfEMZ,MZ,Ml)*saveSLHA(1)
mssmOk  |suspectEwsbMSSMc(smOk,tb,MG1,MG2,MG3,Am,Al,At,Ab,MH3,mu,Ml2,Ml3,Mr2,Mr3,Mq2,Mq
%mssmOk |isajetEwsbMSSMc(smOk,tb,MG1,MG2,MG3,Am,Al,At,Ab,MH3,mu,Ml2,Ml3,Mr2,Mr3,Mq2,Mq3
%mssmOk |softSusyEwsbMSSMc(smOk,tb,MG1,MG2,MG3,Am,Al,At,Ab,MH3,mu,Ml2,Ml3,Mr2,Mr3,Mq2,M
%mssmOk |sphenoEwsbMSSMc(smOk,tb,MG1,MG2,MG3,Am,Al,At,Ab,MH3,mu,Ml2,Ml3,Mr2,Mr3,Mq2,Mq3
*drho   |deltarho(mssmOk)
*gmuon  |gmuon(mssmOk)
*bsgnlo |bsgnlo(mssmOk)
*bsmumu |bsmumu(mssmOk)
*LEPlim |masslimits(mssmOk)
 Mb     |MbEff(Q)*one(smOk)
 Mt     |MtEff(Q)*one(smOk)
*SC     |sqrt(alphaQCD(Q)/12.566371)*one(smOk)
 Mh     |Mh(mssmOk)
 MHH    |MHH(mssmOk)
 MHc    |MHc(mssmOk)
 alpha  |alpha(mssmOk)
 MNE1   |MNE1(mssmOk)
 MNE2   |MNE2(mssmOk)
 MNE3   |MNE3(mssmOk)
 MNE4   |MNE4(mssmOk)
 MC1    |MC1(mssmOk)
 MC2    |MC2(mssmOk)
 MSG    |MSG(mssmOk)
 MSne   |MSne(mssmOk)
```



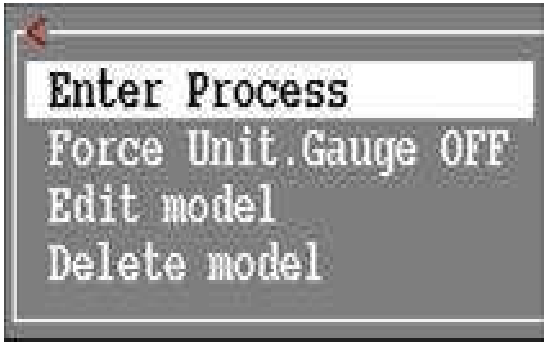
CalcHEP/symb

Vertices

Clr-Del-Size-Read-ErrMes

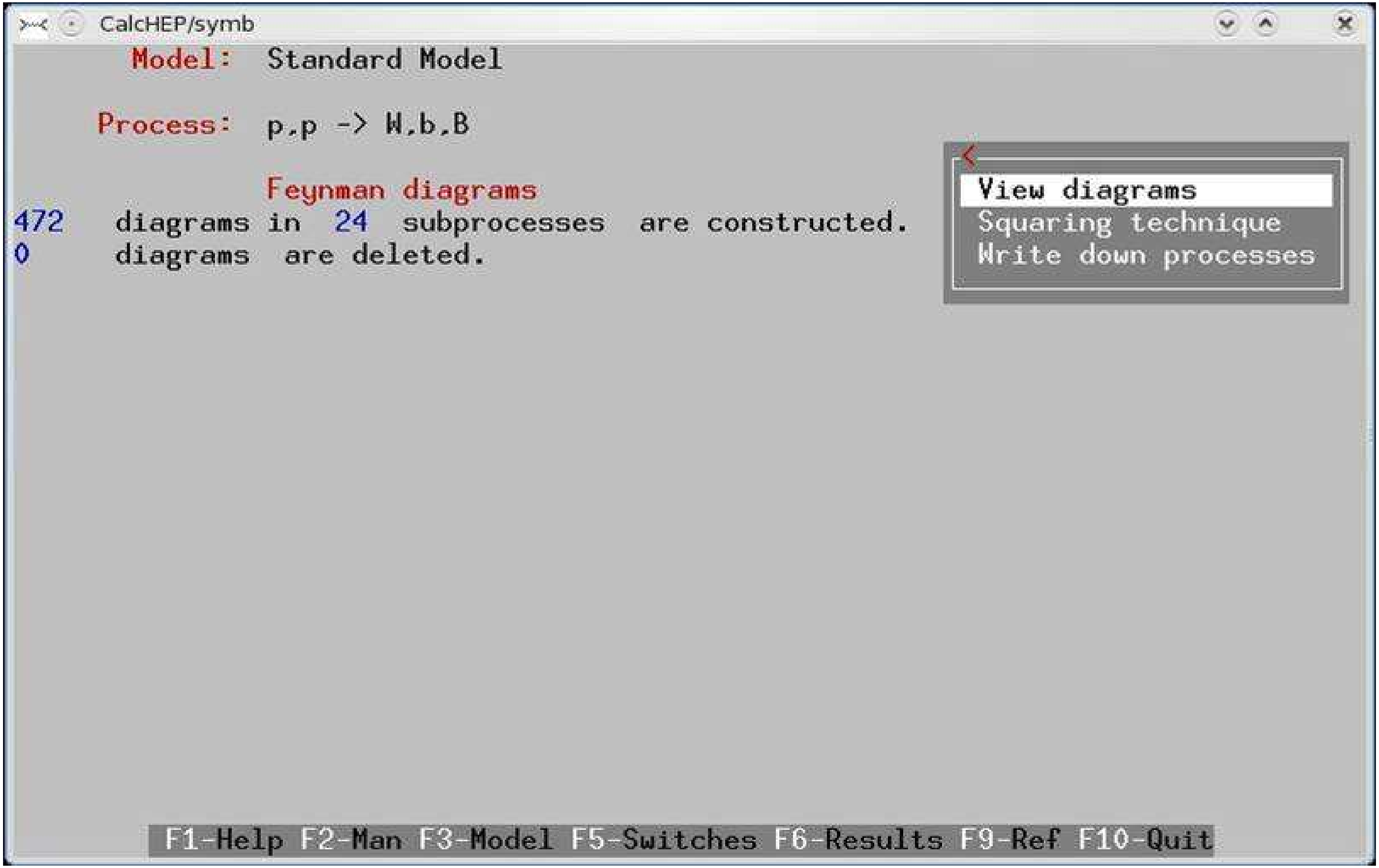
A1	A2	A3	A4	> Factor	<|> Lorentz part
h	W+	W-		EE*MW/SW	m2.m3
h	Z	Z		EE/(SW*CW^ 2)*MW	m2.m3
h	h	h		-(3/2)*EE*Mh^ 2/(MW*SW)	1
h	h	h	h	(-3/4)*(EE*Mh/(MW*SW))^ 2	1
h	h	Z	Z	(1/2)*(EE/(SW*CW))^ 2	m3.m4
h	h	W+	W-	(1/2)*(EE/SW)^ 2	m3.m4
M	m	h		-EE*Mm/(2*MW*SW)	1
L	l	h		-EE*Ml /(2*MW*SW)	1
C	c	h		-EE*Mc/(2*MW*SW)	1
S	s	h		-EE*Ms/(2*MW*SW)	1
B	b	h		-EE*Mb/(2*MW*SW)	1
T	t	h		-EE*Mt /(2*MW*SW)	1
E	e	A		-EE	G(m3)
M	m	A		-EE	G(m3)
L	l	A		-EE	G(m3)
Ne	e	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
Nm	m	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
Nl	l	W+		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
E	ne	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
M	nm	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)
L	nl	W-		EE/(2*Sqrt2*SW)	G(m3)*(1-G5)

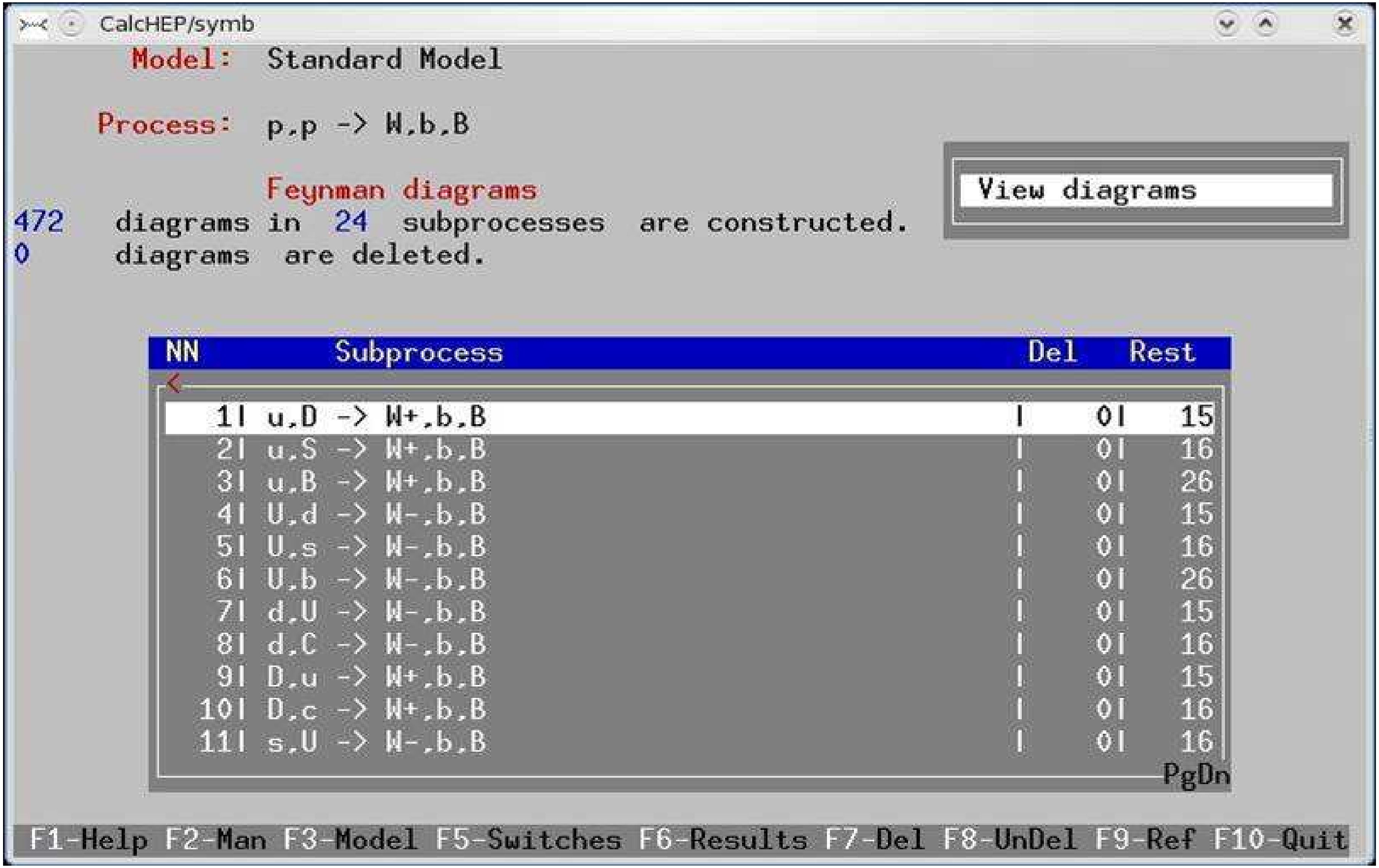
F1-F2-Xgoto-Ygoto-Find-Write

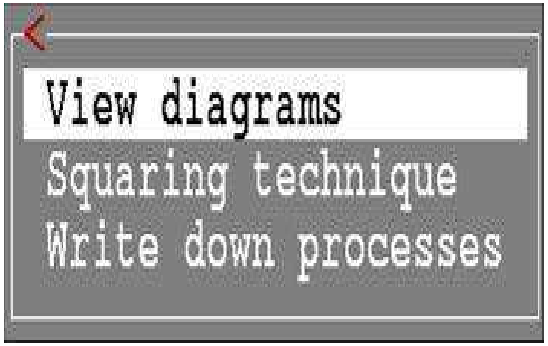

Enter Process
Force Unit.Gauge OFF
Edit model
Delete model

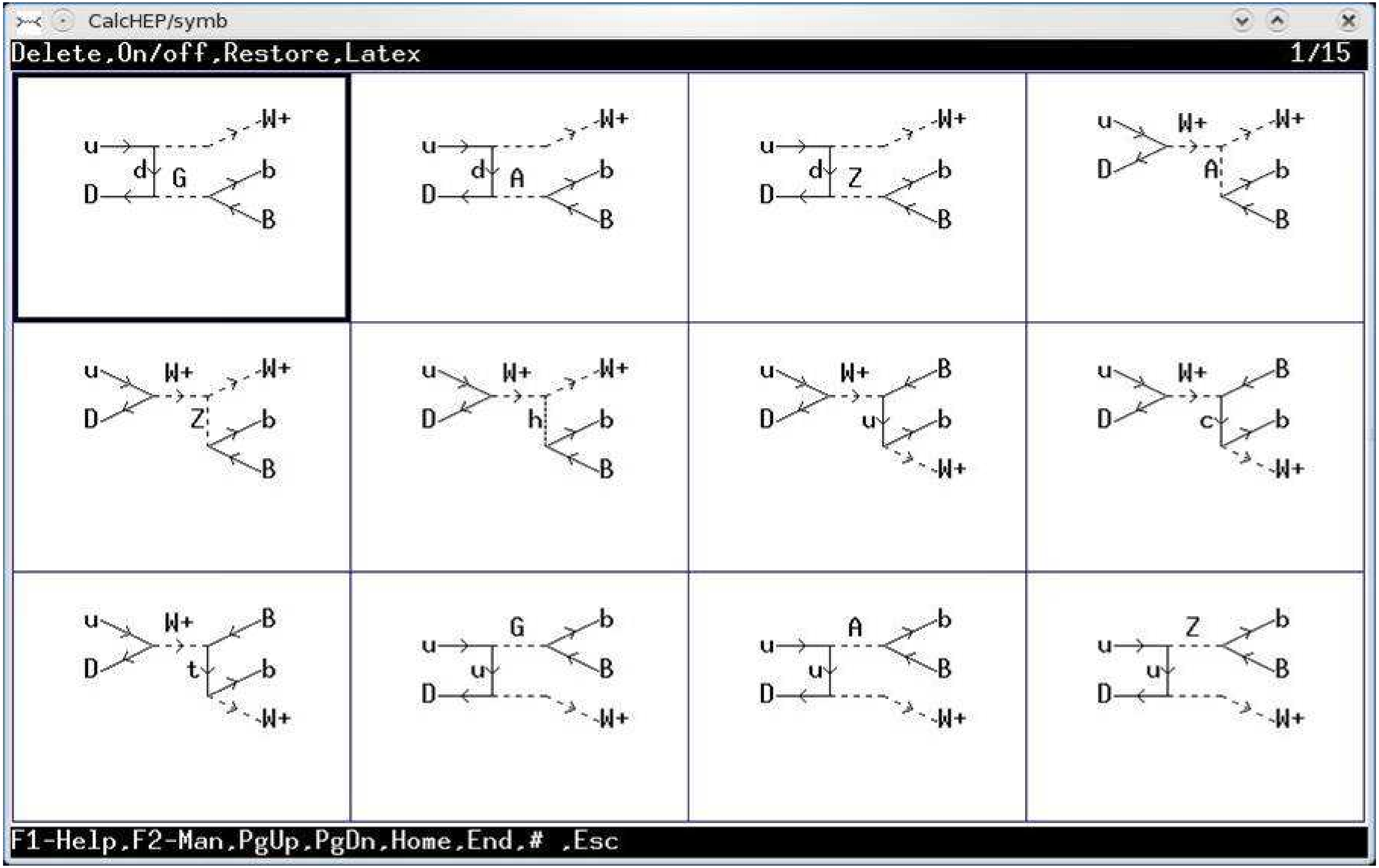
CalcHEP/symb

```
     Model:  Standard Model

          List of particles (antiparticles)

 G(G  )- gluon            A(A  )- photon          Z(Z  )- Z-boson
 W+(W- )- W-boson         h(h  )- Higgs           e(E  )- electron
 ne(Ne )- e-neutrino      m(M  )- muon            nm(Nm )- m-neutrino
 l(L  )- tau-lepton       nl(Nl )- t-neutrino     d(D  )- d-quark
 u(U  )- u-quark          s(S  )- s-quark         c(C  )- c-quark
 b(B  )- b-quark          t(T  )- t-quark

Enter  process: p,p -> W,b,B
composit 'p'  consists of: u,U,d,D,s,S,c,C,b,B,G
composit 'W'  consists of: W+,W-
Exclude diagrams with
```


CalcHEP/symb
Model: Standard Model
Process: p,p -> W,b,B
Feynman diagrams
472 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
View diagrams
Squaring technique
Write down processes
F1-Help F2-Man F3-Model F5-Switches F6-Results F9-Ref F10-Quit


CalcHEP/symb
Model: Standard Model
Process: p,p -> W,b,B
Feynman diagrams
472 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
View diagrams
NN Subprocess Del Rest
1| u,D -> W+,b,B | 0| 15
2| u,S -> W+,b,B | 0| 16
3| u,B -> W+,b,B | 0| 26
4| U,d -> W-,b,B | 0| 15
5| U,s -> W-,b,B | 0| 16
6| U,b -> W-,b,B | 0| 26
7| d,U -> W-,b,B | 0| 15
8| d,C -> W-,b,B | 0| 16
9| D,u -> W+,b,B | 0| 15
10| D,c -> W+,b,B | 0| 16
11| s,U -> W-,b,B | 0| 16
PgDn
F1-Help F2-Man F3-Model F5-Switches F6-Results F7-Del F8-UnDel F9-Ref F10-Quit


View diagrams
Squaring technique
Write down processes


CalcHEP/symb
Delete,On/off,Restore,Latex
1/15
u D W+ b B d G
u D W+ b B d A
u D W+ b B d Z
u D W+ W+ A b B
u D W+ W+ Z b B
u D W+ W+ h b B
u D W+ B u b W+
u D W+ B c b W+
u D W+ B t b W+
u D G b B u W+
u D A b B u W+
u D Z b B u W+
F1-Help,F2-Man,PgUp,PgDn,Home,End,# ,Esc

CalcHEP/symb

Model: Standard Model

Process: p,p -> W,b,B

View squared diagrams

Feynman diagrams

472 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.

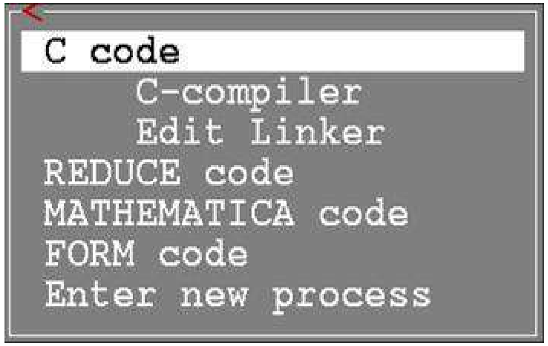
Squared diagrams

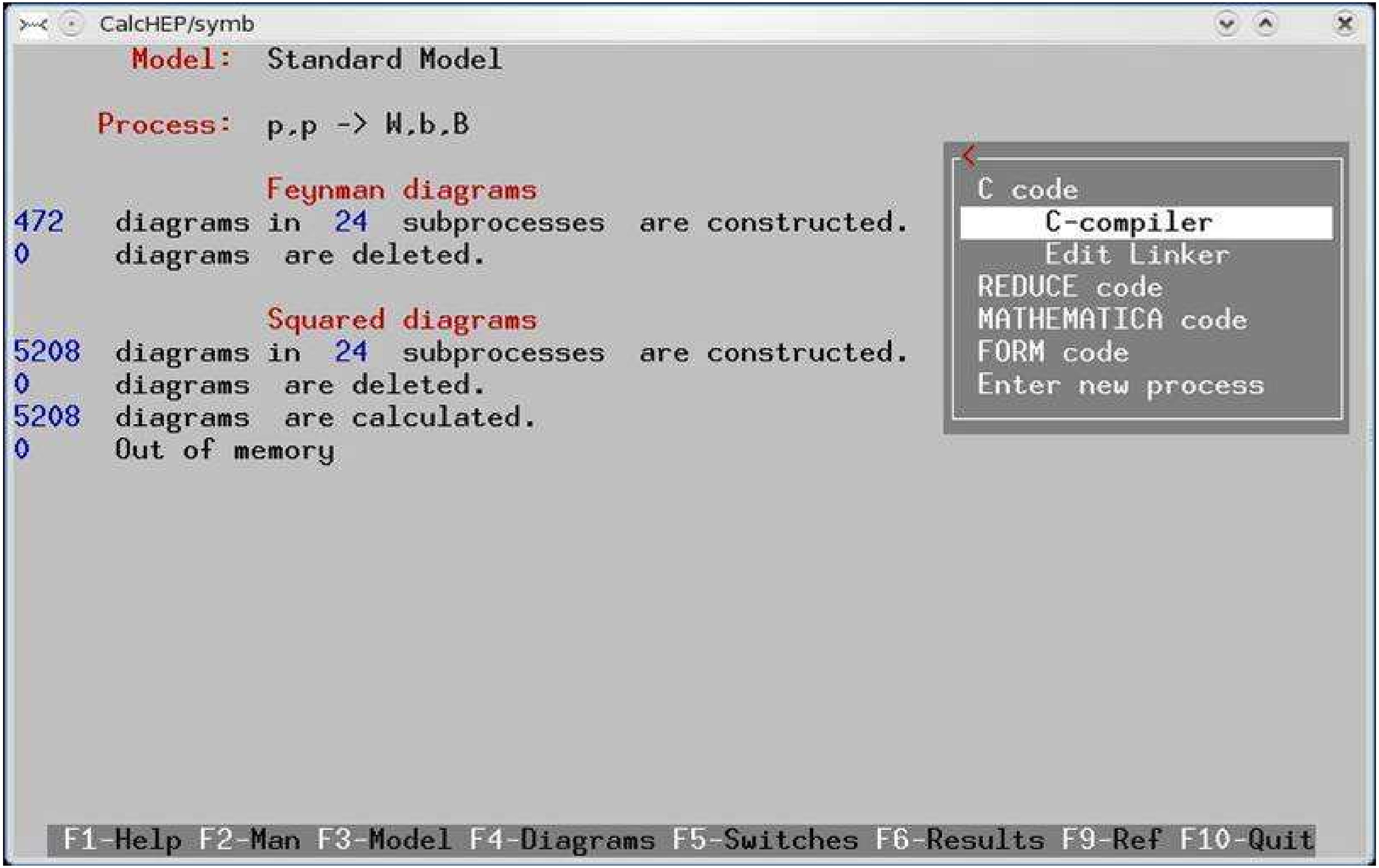
5208 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
0 diagrams are calculated.

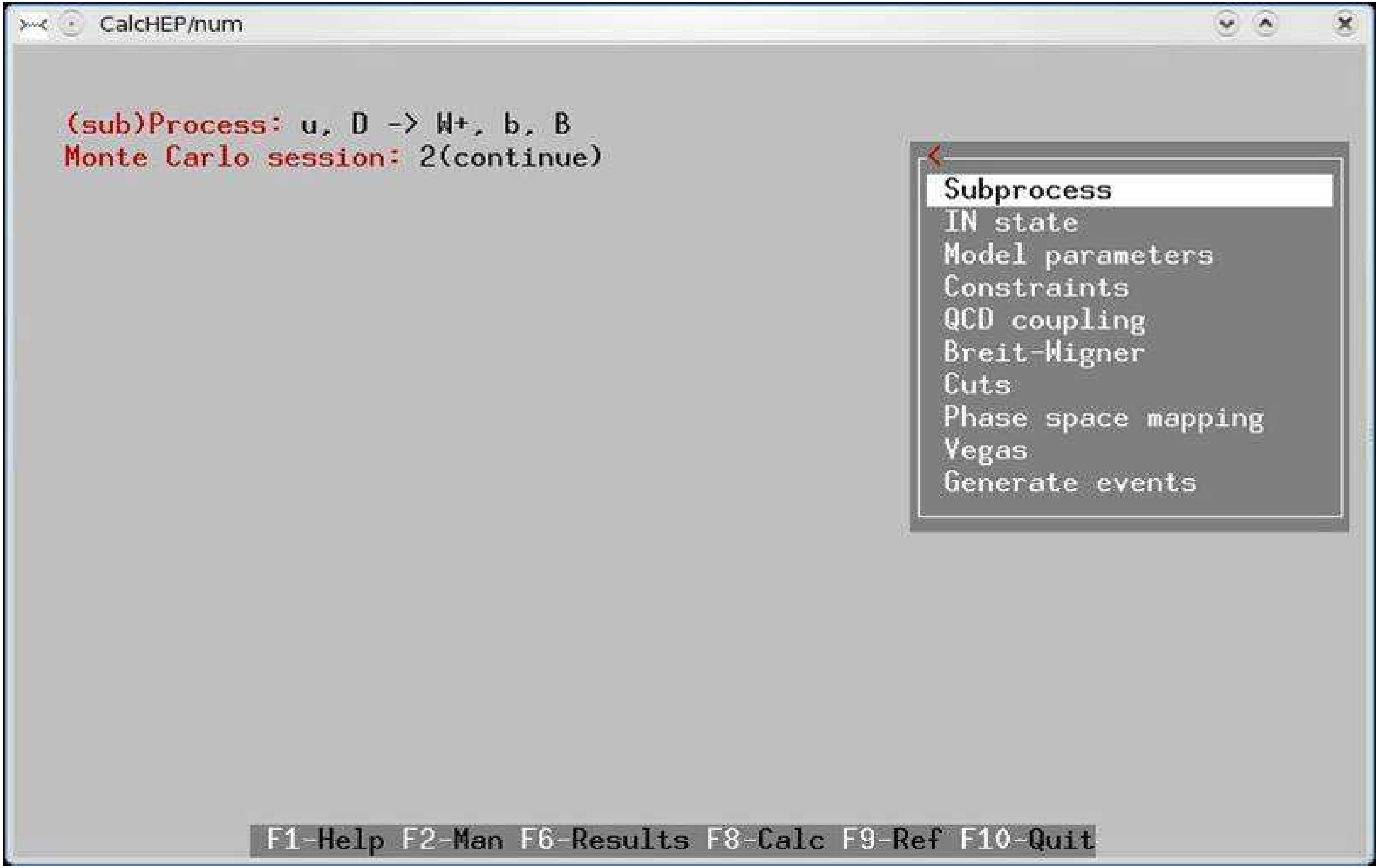
NN	Subprocess	Del	Calc	Rest
1	u,D->W+,b,B	0	0	120
2	u,S->W+,b,B	0	0	136
3	u,B->W+,b,B	0	0	351
4	U,d->W-,b,B	0	0	120
5	U,s->W-,b,B	0	0	136
6	U,b->W-,b,B	0	0	351
7	d,U->W-,b,B	0	0	120
8	d,C->W-,b,B	0	0	136
9	D,u->W+,b,B	0	0	120

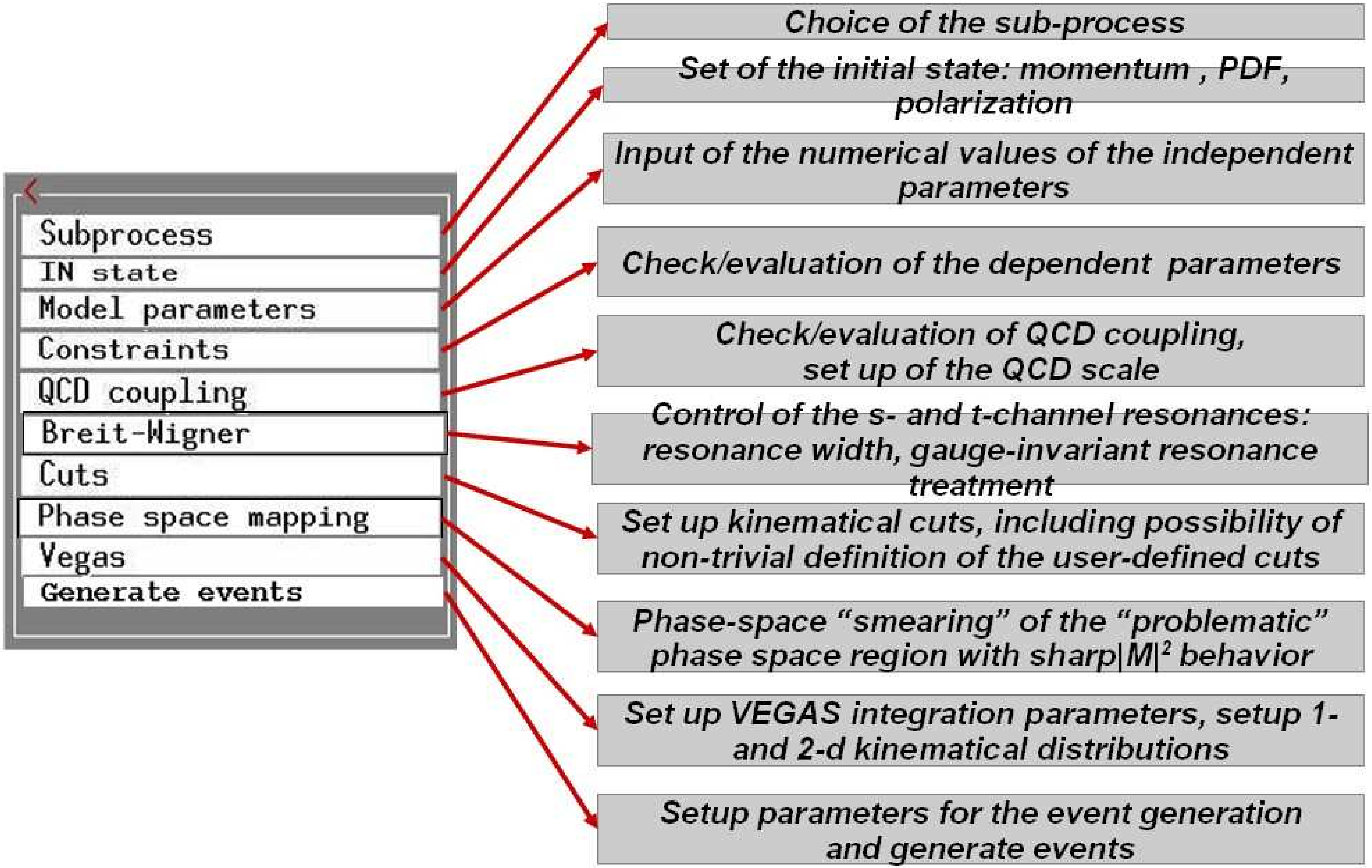
PgDn

F1-Help F2-Man F3-Model F4-Diagrams F5-Switches F6-Results F9-Ref F10-Quit

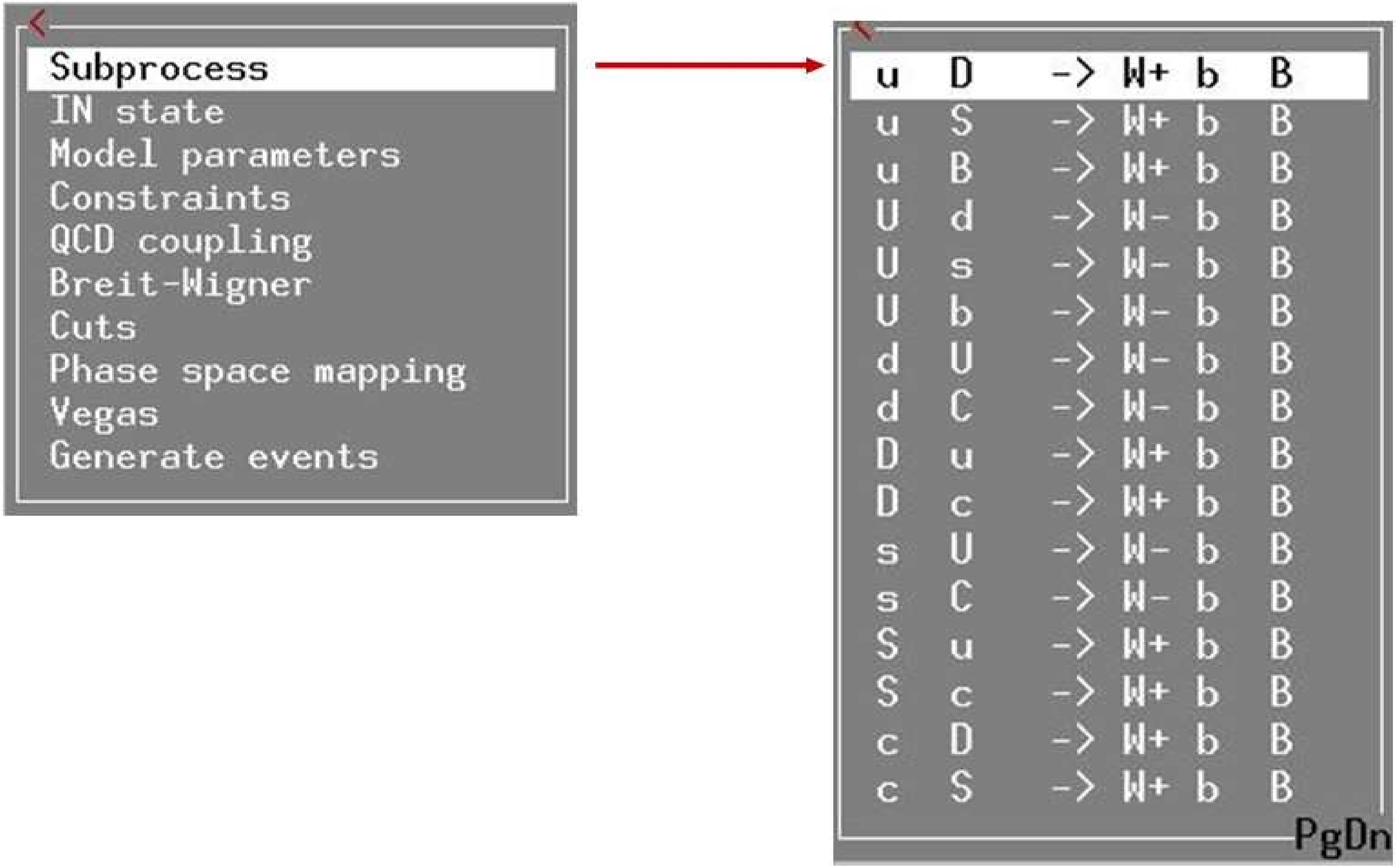

C code
C-compiler
Edit Linker
REDUCE code
MATHEMATICA code
FORM code
Enter new process


CalcHEP/symb
Model: Standard Model
Process: p,p -> W,b,B
Feynman diagrams
472 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
Squared diagrams
5208 diagrams in 24 subprocesses are constructed.
0 diagrams are deleted.
5208 diagrams are calculated.
0 Out of memory
C code
C-compiler
Edit Linker
REDUCE code
MATHEMATICA code
FORM code
Enter new process
F1-Help F2-Man F3-Model F4-Diagrams F5-Switches F6-Results F9-Ref F10-Quit

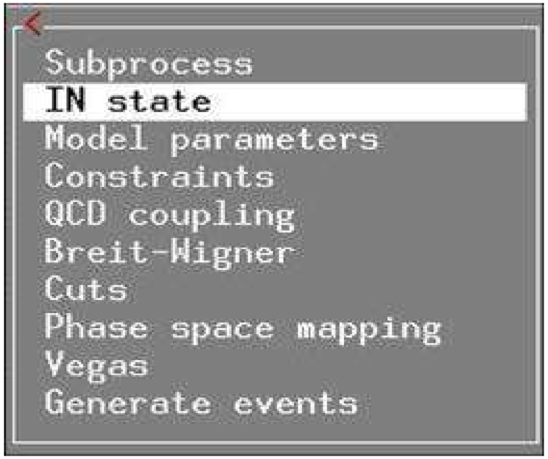

CalcHEP/num
(sub)Process: u, D -> W+, b, B
Monte Carlo session: 2(continue)
Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
F1-Help F2-Man F6-Results F8-Calc F9-Ref F10-Quit


Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
Choice of the sub-process
Set of the initial state: momentum , PDF, polarization
Input of the numerical values of the independent parameters
Check/evaluation of the dependent parameters
Check/evaluation of QCD coupling, set up of the QCD scale
Control of the s- and t-channel resonances: resonance width, gauge-invariant resonance treatment
Set up kinematical cuts, including possibility of non-trivial definition of the user-defined cuts
Phase-space “smearing” of the “problematic” phase space region with sharp|M|2 behavior
Set up VEGAS integration parameters, setup 1- and 2-d kinematical distributions
Setup parameters for the event generation and generate events

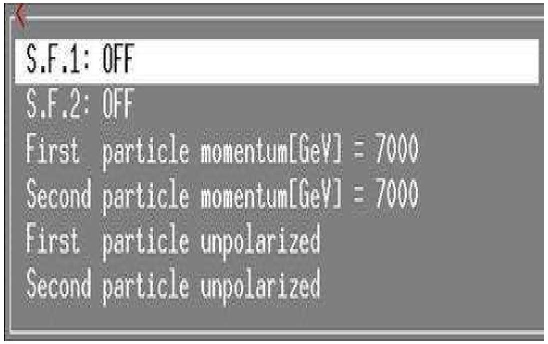
List of sub-processes



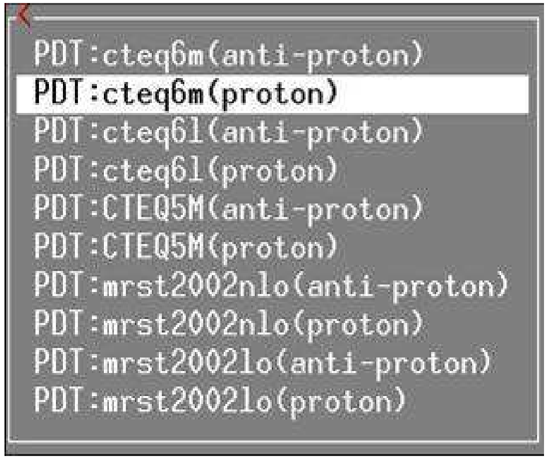
IN-STATE, Structure functions



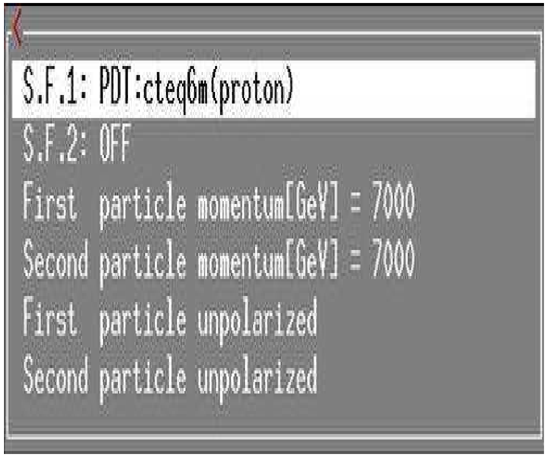
IN-STATE, Structure functions



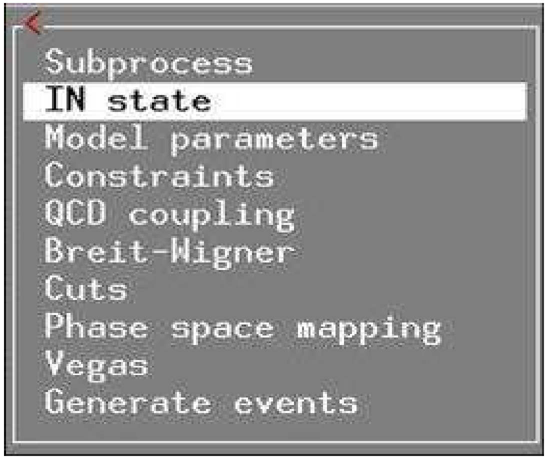
IN-STATE, Structure functions



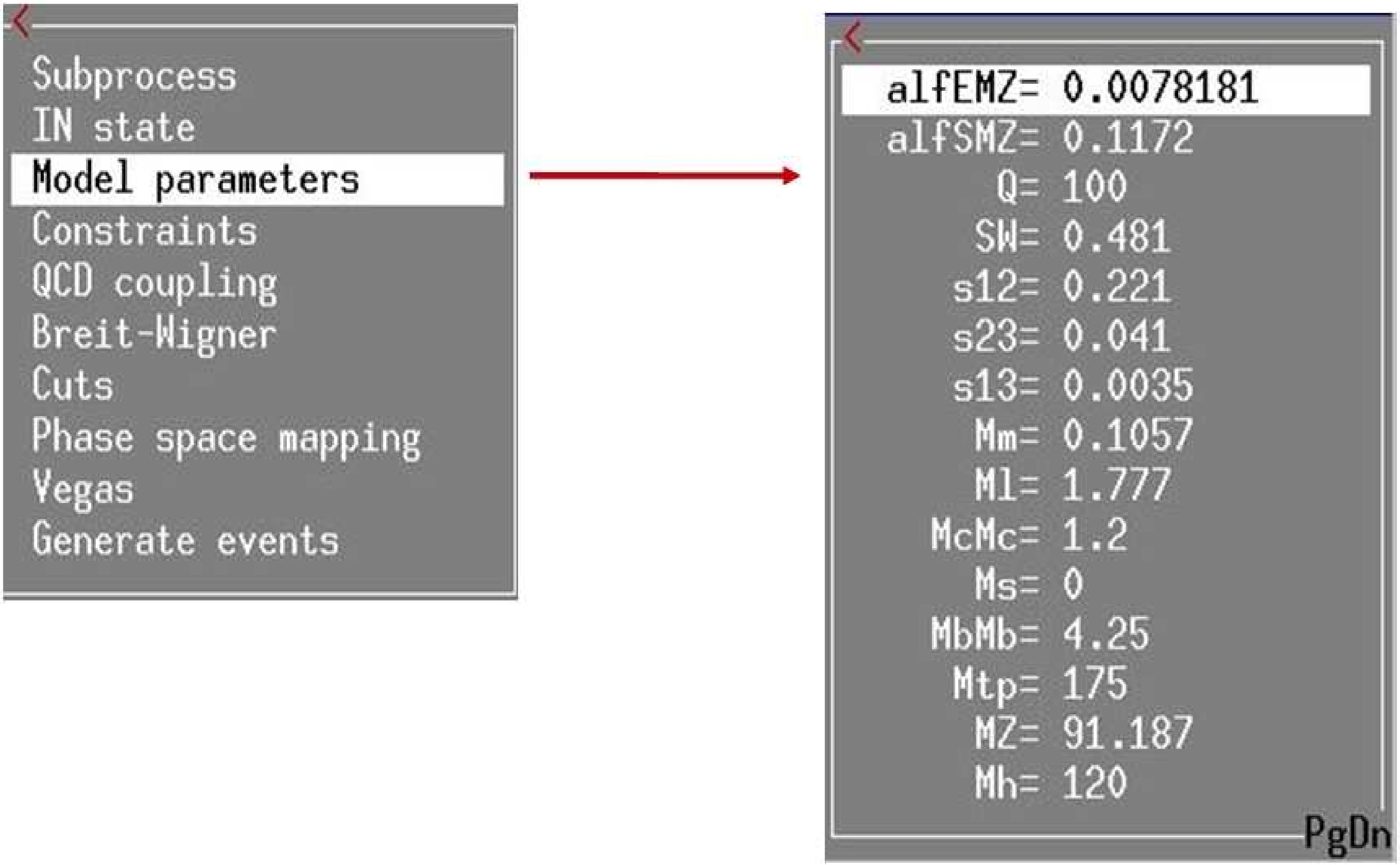
IN-STATE, Structure functions



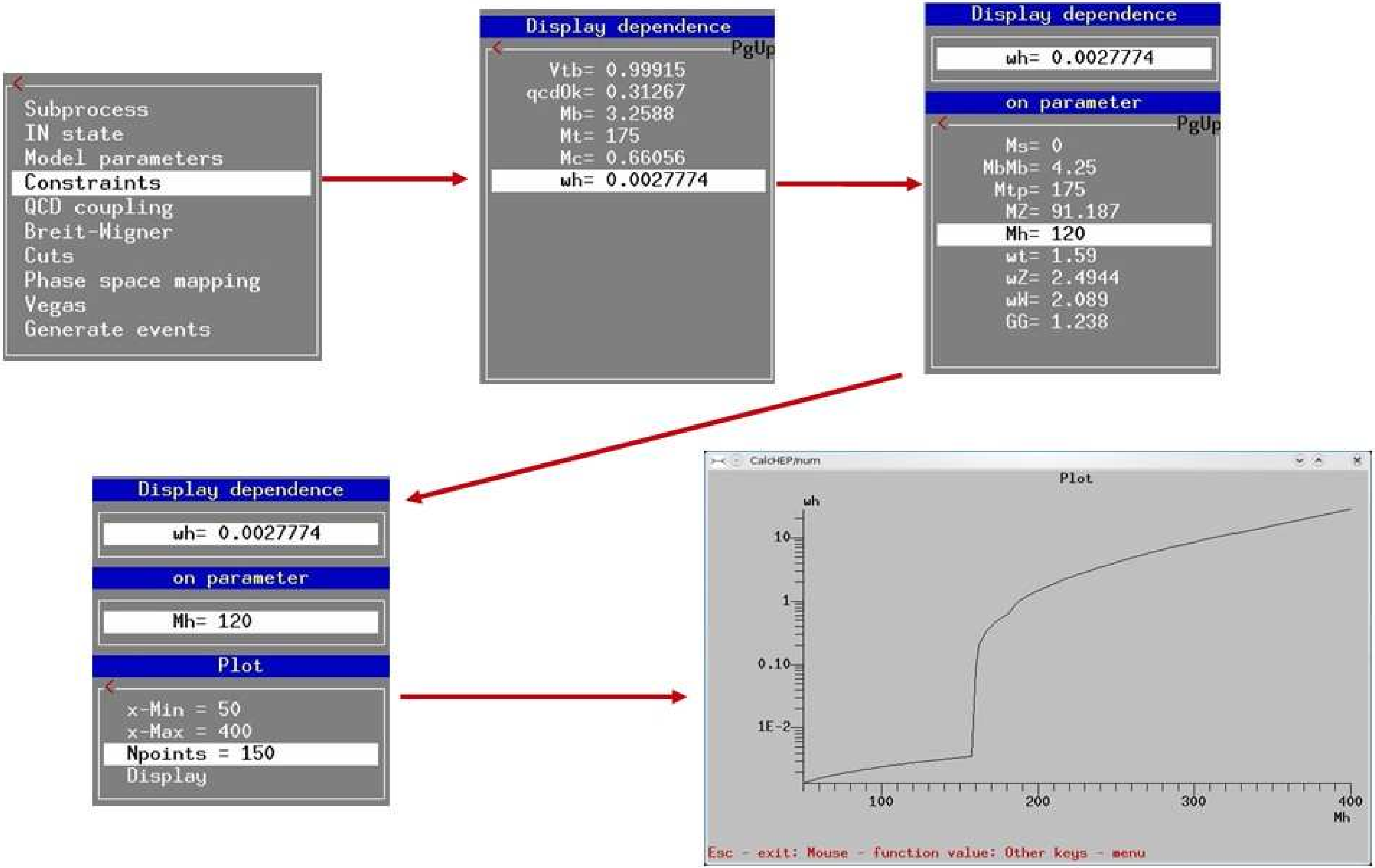
back to menu


Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events

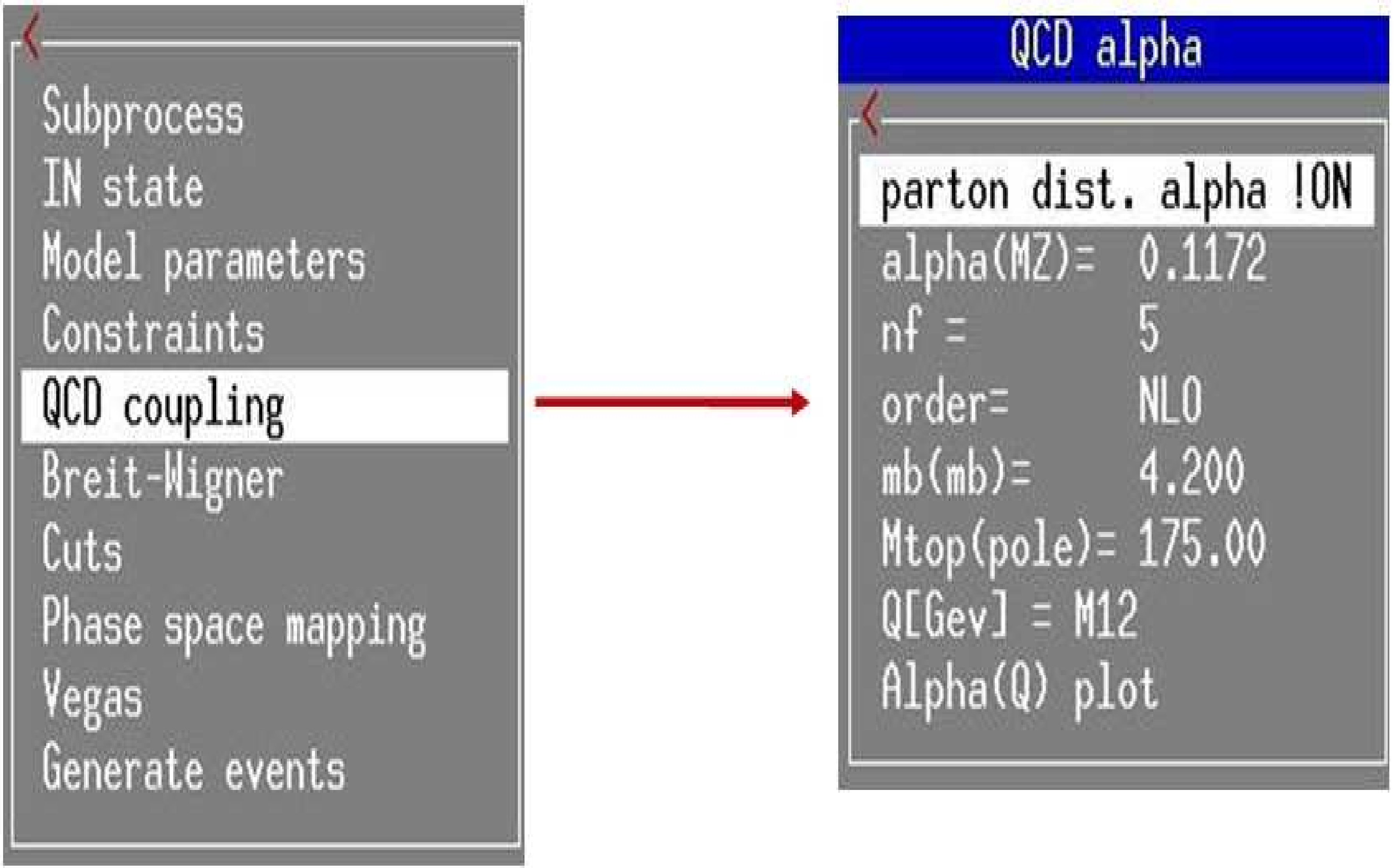
Model Parameters



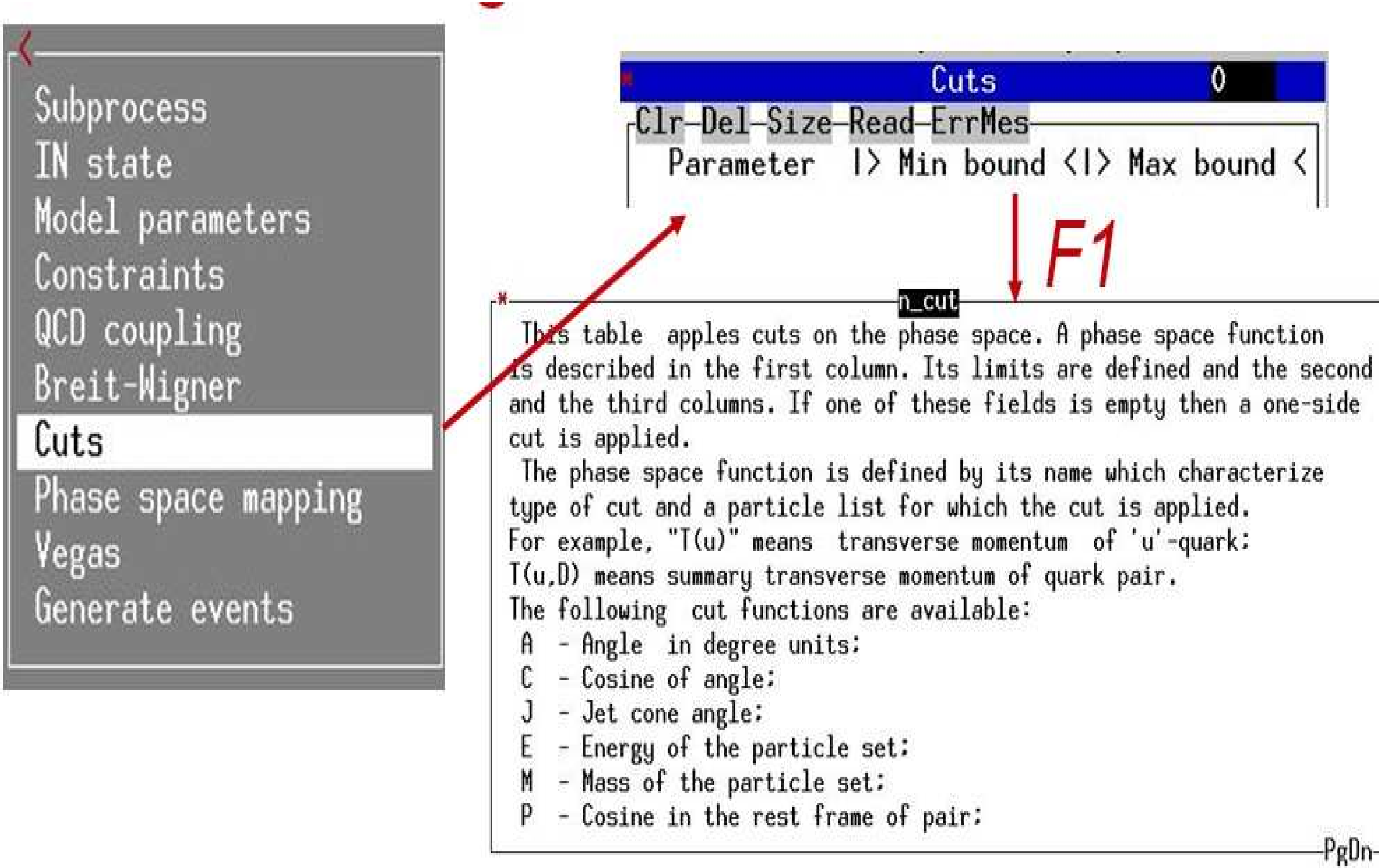
Constraints, (Higgs width on the fly)



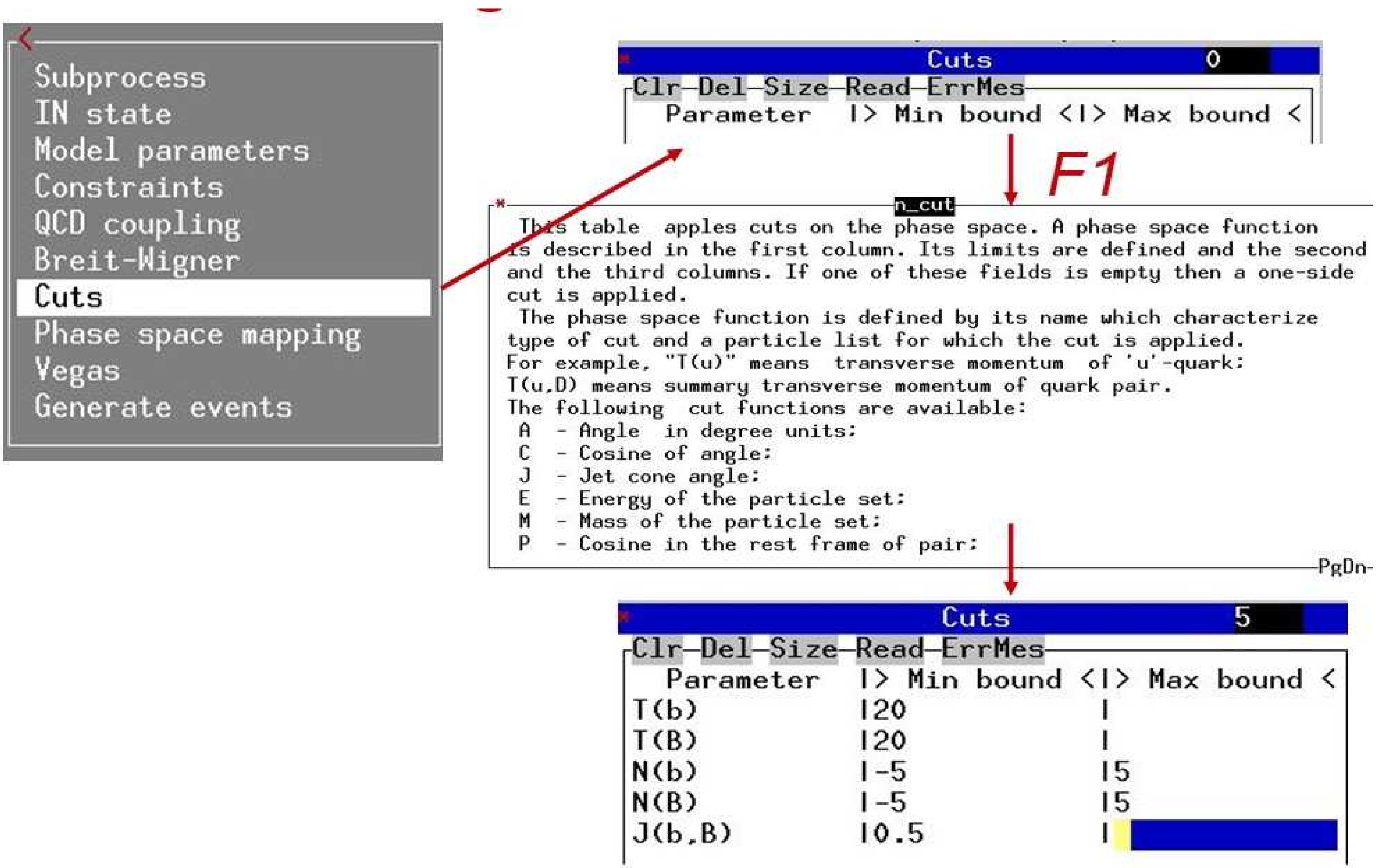
$\alpha_s(Q^2)$

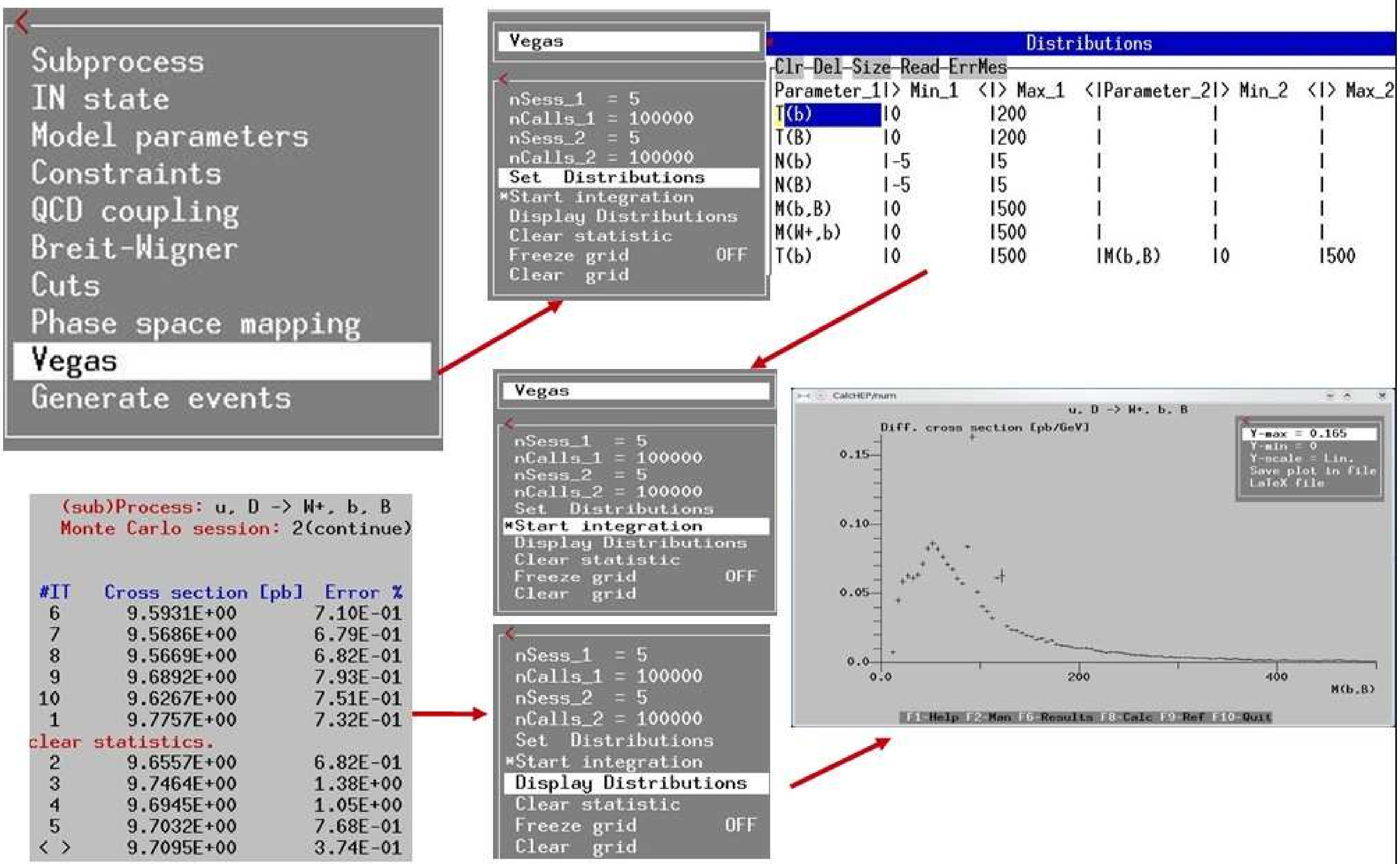

Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
QCD alpha
parton dist. alpha !ON
alpha(MZ)= 0.1172
nf = 5
order= NLO
mb(mb)= 4.200
Mtop(pole)= 175.00
Q[Gev] = M12
Alpha(Q) plot

Setting cuts before integration

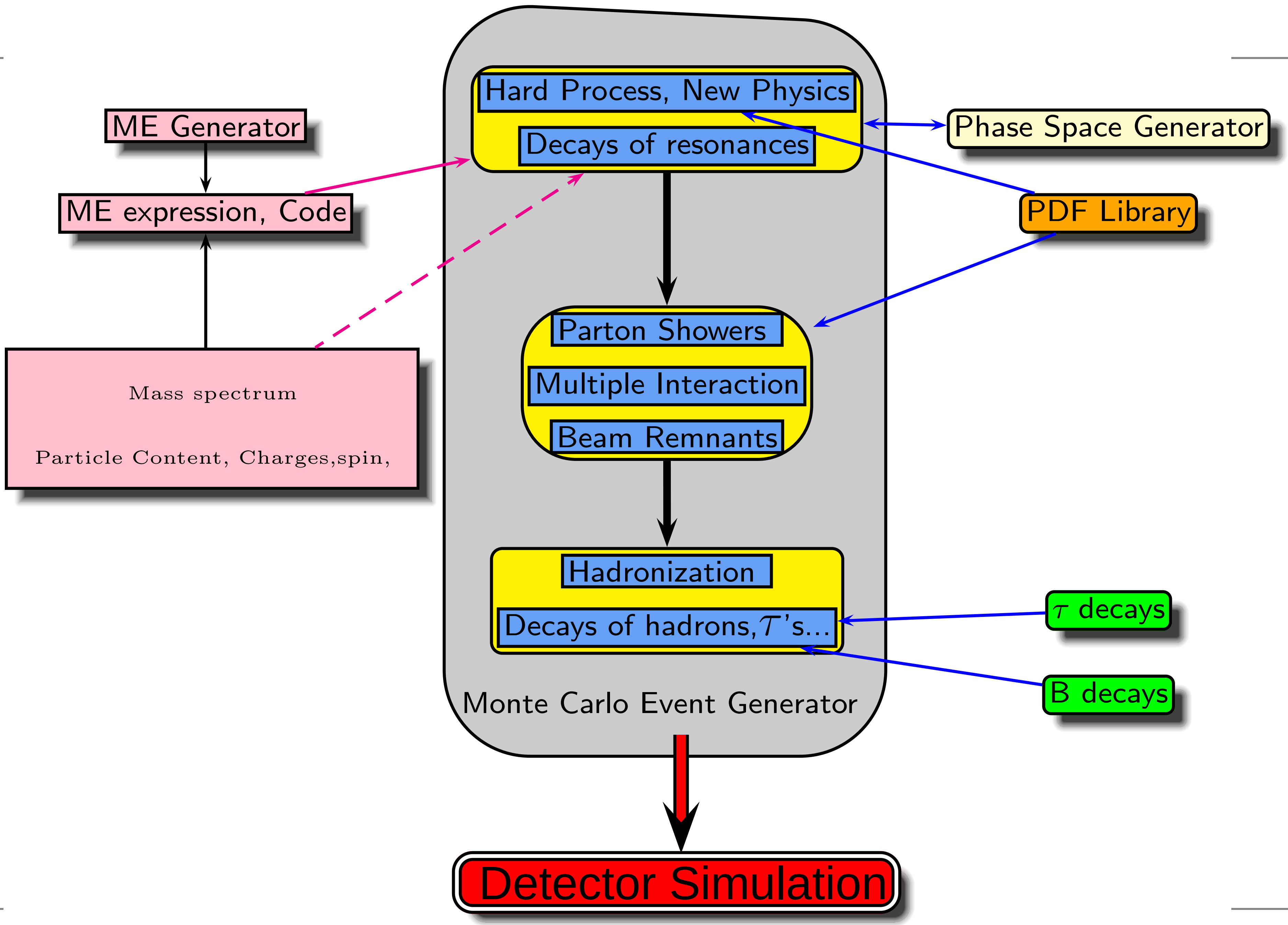


Setting cuts before integration

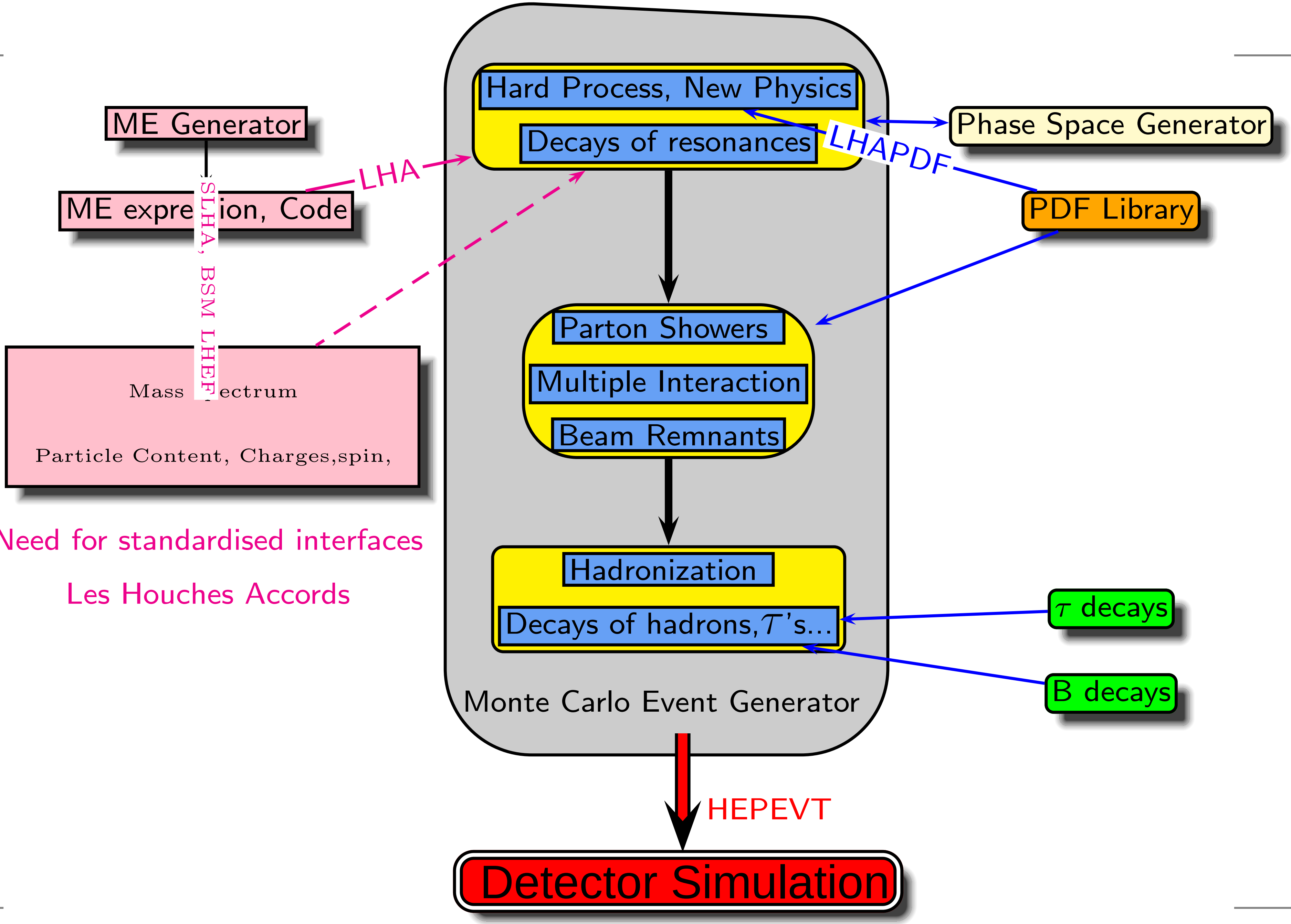



Subprocess
IN state
Model parameters
Constraints
QCD coupling
Breit-Wigner
Cuts
Phase space mapping
Vegas
Generate events
Vegas
nSess_1 = 5
nCalls_1 = 100000
nSess_2 = 5
nCalls_2 = 100000
Set Distributions
*Start integration
Display Distributions
Clear statistic
Freeze grid OFF
Clear grid
Distributions
Clr-Del-Size-Read-ErrMes
Parameter_1|> Min_1 <|> Max_1 <|Parameter_2|> Min_2 <|> Max_2
T(b) |0 |200
T(B) |0 |200
N(b) |-5 |5
N(B) |-5 |5
M(b,B) |0 |500
M(W+,b) |0 |500
T(b) |0 |500 |M(b,B) |0 |500
(sub)Process: u, D -> W+, b, B
Monte Carlo session: 2(continue)
#IT Cross section [pb] Error %
6 9.5931E+00 7.10E-01
7 9.5686E+00 6.79E-01
8 9.5669E+00 6.82E-01
9 9.6892E+00 7.93E-01
10 9.6267E+00 7.51E-01
1 9.7757E+00 7.32E-01
clear statistics.
2 9.6557E+00 6.82E-01
3 9.7464E+00 1.38E+00
4 9.6945E+00 1.05E+00
5 9.7032E+00 7.68E-01
< > 9.7095E+00 3.74E-01
u, D -> W+, b, B
Diff. cross section [pb/GeV]
Y-max = 0.165
Y-min = 0
Y-scale = Lin.
Save plot in file
LaTeX file
0.15
0.10
0.05
0.0
0.0
200
400
M(b,B)
F1-Help F2-Man F6-Results F8-Calc F9-Ref F10-Quit

Putting all together



Putting all together, Les Houches Accords



Need for standardised interfaces

Les Houches Accords

Pass on the names in a standard manner: PDG code.

Code	Name	Code	Name	Code	Name	Code	Name
1	d	11	e^-	21	g		
2	u	12	ν_e	22	γ	35	H^0
3	s	13	μ^-	23	Z^0	36	A^0
4	c	14	ν_μ	24	W^+	37	H^+
5	b	15	τ^-	25	h^0		
6	t	16	ν_τ			39	G (graviton)

SM fundamental particle codes (+ extended Higgs sector)

Pass on the names in a standard manner: PDG code.

Code	Name	Code	Name	Code	Name	Code	Name
1	d	11	e^-	21	g		
2	u	12	ν_e	22	γ	35	H^0
3	s	13	μ^-	23	Z^0	36	A^0
4	c	14	ν_μ	24	W^+	37	H^+
5	b	15	τ^-	25	h^0		
6	t	16	ν_τ			39	G (graviton)

SM fundamental particle codes (+ extended Higgs sector)

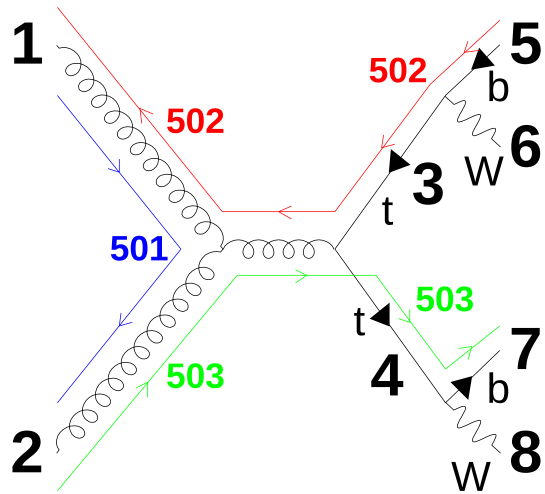
For New Physics particles, create new code names (1000000+), SLHA2

Scalar Quarks

FLV / RPV / CPV	No / No / No	Yes / No / No	No / Yes / No	No / No / Yes	Yes / Yes / No	Yes / No / Yes	NMSSM
1000001	$\tilde{d}_L$	$\tilde{d}_1$	$\tilde{d}_1$	$\tilde{d}_L$	$\tilde{d}_1$	$\tilde{d}_1$	$\tilde{d}_L$
1000002	$\tilde{u}_L$	$\tilde{u}_1$	$\tilde{u}_1$	$\tilde{u}_L$	$\tilde{u}_1$	$\tilde{u}_1$	$\tilde{u}_L$
1000003	$\tilde{s}_L$	$\tilde{d}_2$	$\tilde{d}_2$	$\tilde{s}_L$	$\tilde{d}_2$	$\tilde{d}_2$	$\tilde{s}_L$
1000004	$\tilde{c}_L$	$\tilde{u}_2$	$\tilde{u}_2$	$\tilde{c}_L$	$\tilde{u}_2$	$\tilde{u}_2$	$\tilde{c}_L$
1000005	$\tilde{b}_1$	$\tilde{d}_3$	$\tilde{d}_3$	$\tilde{b}_1$	$\tilde{d}_3$	$\tilde{d}_3$	$\tilde{b}_1$
1000006	$\tilde{t}_1$	$\tilde{u}_3$	$\tilde{u}_3$	$\tilde{t}_1$	$\tilde{u}_3$	$\tilde{u}_3$	$\tilde{t}_1$
2000001	$\tilde{d}_R$	$\tilde{d}_4$	$\tilde{d}_4$	$\tilde{d}_R$	$\tilde{d}_4$	$\tilde{d}_4$	$\tilde{d}_R$
2000002	$\tilde{u}_R$	$\tilde{u}_4$	$\tilde{u}_4$	$\tilde{u}_R$	$\tilde{u}_4$	$\tilde{u}_4$	$\tilde{u}_R$
2000003	$\tilde{s}_R$	$\tilde{d}_5$	$\tilde{d}_5$	$\tilde{s}_R$	$\tilde{d}_5$	$\tilde{d}_5$	$\tilde{s}_R$
2000004	$\tilde{c}_R$	$\tilde{u}_5$	$\tilde{u}_5$	$\tilde{c}_R$	$\tilde{u}_5$	$\tilde{u}_5$	$\tilde{c}_R$
2000005	$\tilde{b}_2$	$\tilde{d}_6$	$\tilde{d}_6$	$\tilde{b}_2$	$\tilde{d}_6$	$\tilde{d}_6$	$\tilde{b}_2$
2000006	$\tilde{t}_2$	$\tilde{u}_6$	$\tilde{u}_6$	$\tilde{t}_2$	$\tilde{u}_6$	$\tilde{u}_6$	$\tilde{t}_2$

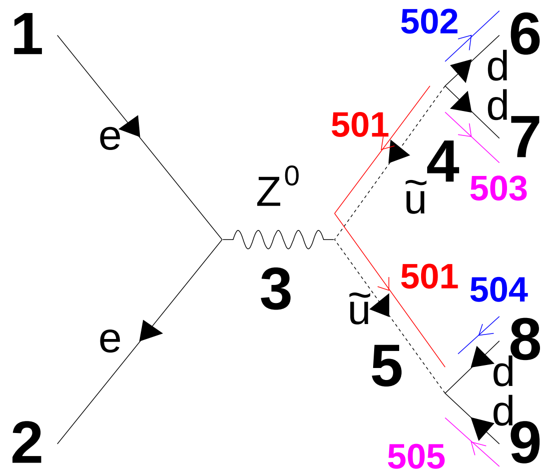
Particle codes and corresponding labels for squarks.
The labels in the first column correspond to the current PDG nomenclature.

Les Houches Accord: Examples



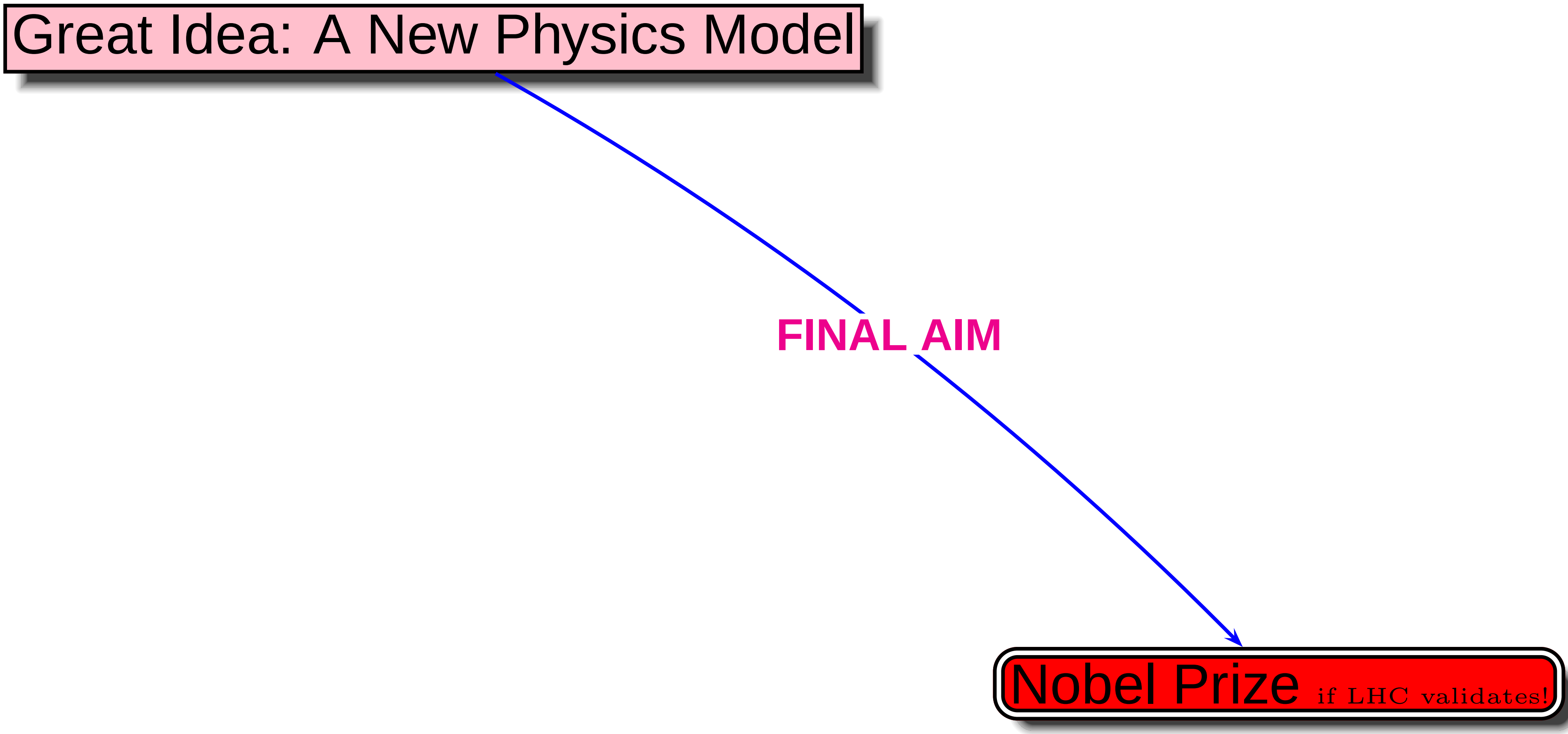
I	ISTUP(I)	IDUP(I)	MOTHUP(1,I)	MOTHUP(2,I)	ICOLUP(1,I)	ICOLUP(2,I)
1	–1	21 (g)	0	0	501	502
2	–1	21 (g)	0	0	503	501
3	+2	–6 ($\bar{t}$)	1	2	0	502
4	+2	6 (t)	1	2	503	0
5	+1	–5 ($\bar{b}$)	3	3	0	502
6	+1	–24 (W^-)	3	3	0	0
7	+1	5 (b)	4	4	503	0
8	+1	24 (W^+)	4	4	0	0

Pass the colour information, essential for parton shower and hadronisation, apart of course from the kinematics

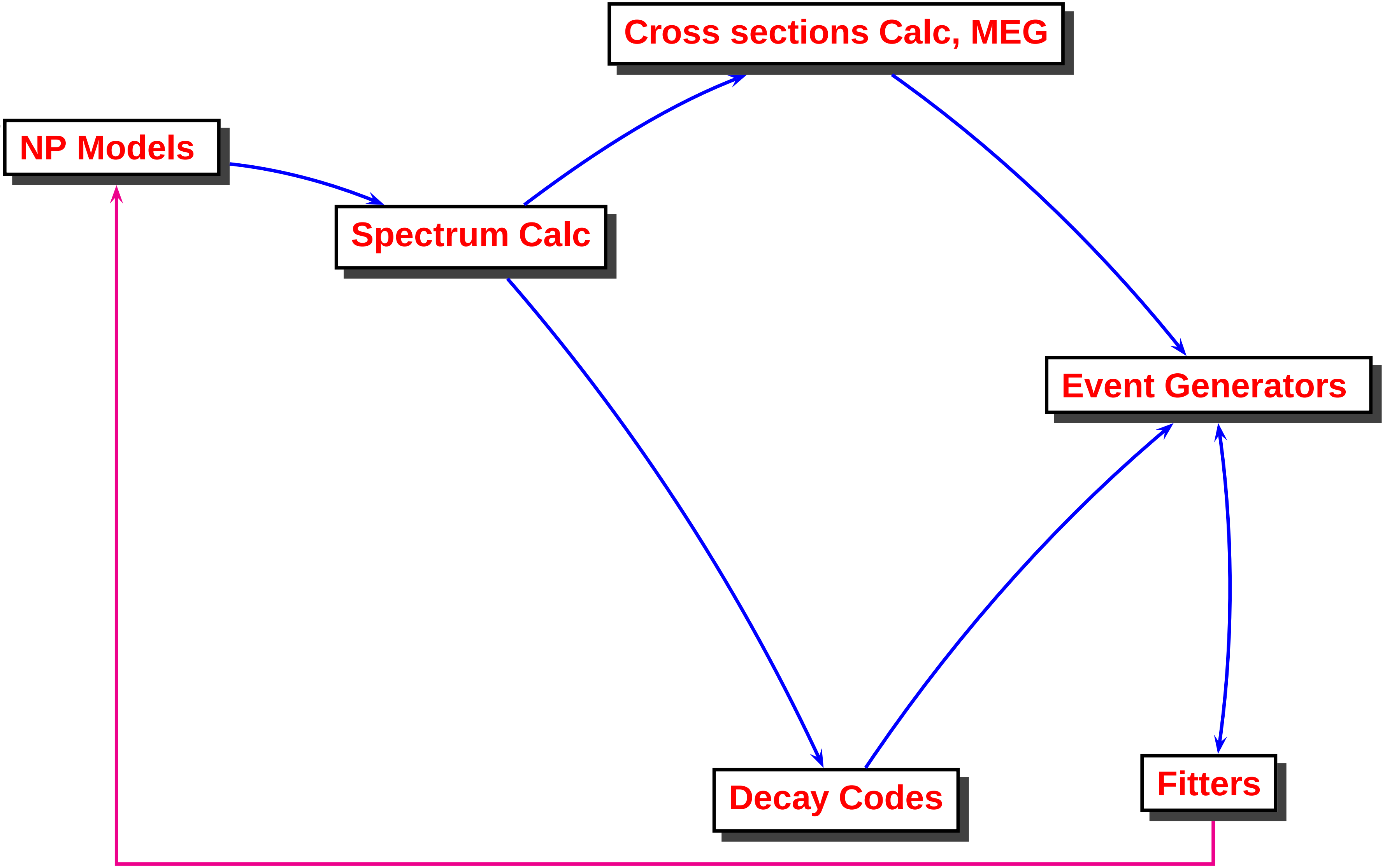


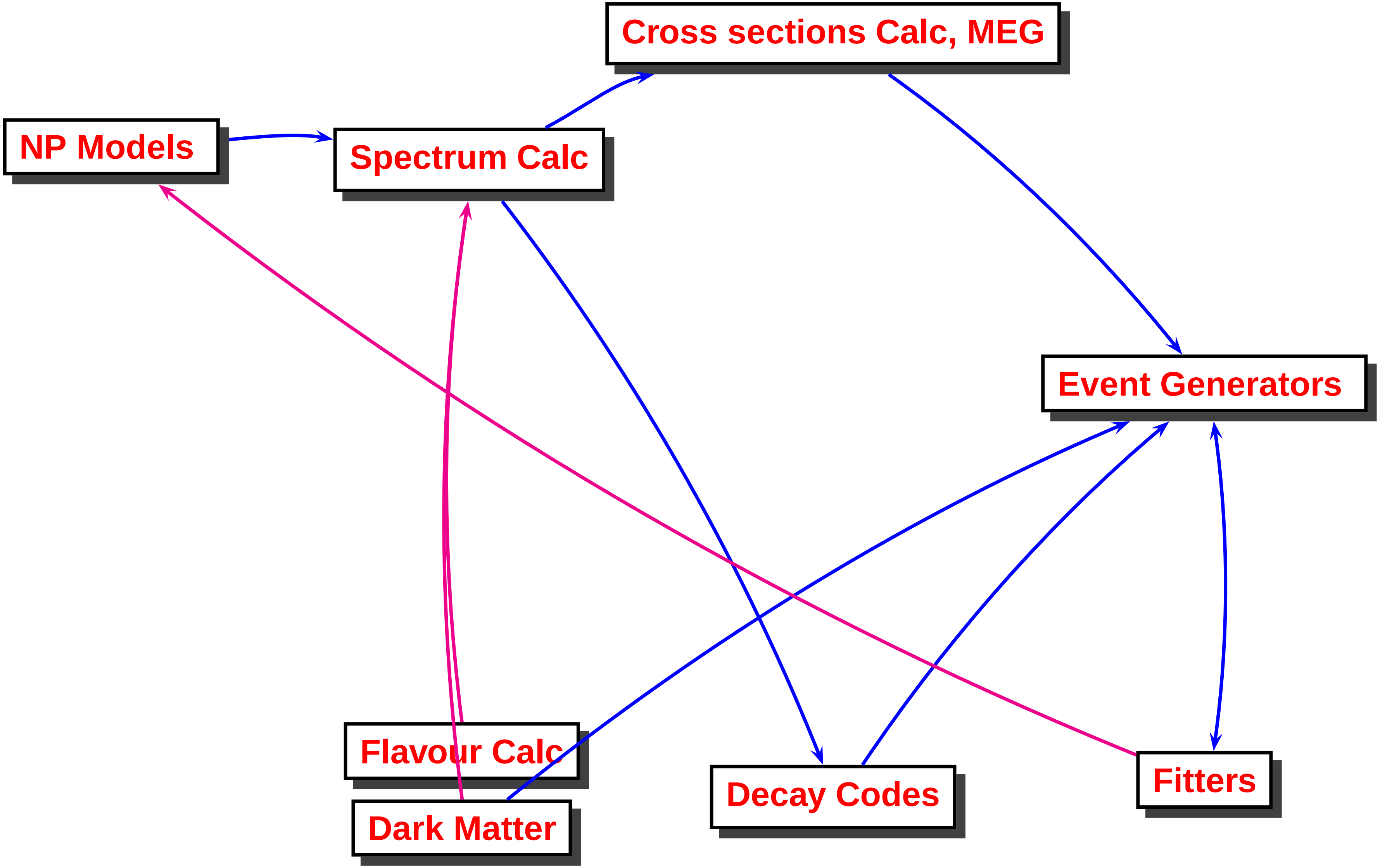
I	ISTUP(I)	IDUP(I)	MOTHUP(1,I)	MOTHUP(2,I)	ICOLUP(1,I)	ICOLUP(2
1	–1	11 (e^-)	0	0	0	0
2	–1	–11 (e^+)	0	0	0	0
3	+2	23 (Z^0)	1	2	0	0
4	+2	–1000002 ($\tilde{\bar{u}}$)	3	3	0	501
5	+2	1000002 ($\tilde{u}$)	3	3	501	0
6	+1	1 (d)	4	4	502	0
7	+1	1 (d)	4	4	503	0
8	+1	–1 ($\bar{d}$)	5	5	0	504
9	+1	–1 ($\bar{d}$)	5	5	0	505

Baryon number violation, SUSY RPV


Great Idea: A New Physics Model
FINAL AIM
Nobel Prize if LHC validates!


NP Models
FINAL AIM
Event Generators


Cross sections Calc, MEG
NP Models
Spectrum Calc
Event Generators
Decay Codes
Fitters


Cross sections Calc, MEG
NP Models
Spectrum Calc
Event Generators
Flavour Calc
Dark Matter
Decay Codes
Fitters

Cross sections Calc, MEG

NP Models

Spectrum Calc

- SUSY
  - MSSM
  - mSUGRA
  - GMSB, AMSB
  - NMSSM
  - RPV, CPV,...
- TeXColour
- Extra-dim
- Little Higgs
- $f^\star, V'$
- Black Holes (!)

Event Generators

Flavour Calc

Dark Matter

Decay Codes

Fitters

Cross sections Calc, MEG

NP Models

- SUSY
  - MSSM
  - mSUGRA
  - GMSB, AMSB
  - NMSSM
  - RPV, CPV,...
- TeXColour
- Extra-dim
- Little Higgs
- $f^{\star}, V'$
- Black Holes (!)

Spectrum Calc

- `FeynHiggs`
- `NMHDECAY`$\star$
- `CPSuperH`
- RGE Codes
  - `Isasusy`
  - `SoftSusy`
  - `Spheno`
  - `Suspect`

Event Generators

Flavour Calc

Dark Matter

Decay Codes

Fitters

Spectrum Calc

- FeynHiggs
- NMHDECAY$\star$
- CPSuperH
- RGE Codes
  Isasusy
  SoftSusy
  Spheno
  Suspect

Cross sections Calc, MEG

NP Models

- SUSY
  MSSM
  mSUGRA
  GMSB, AMSB
  NMSSM
  RPV, CPV,...
- TeXColour
- Extra-dim
- Little Higgs
- $f^\star, V'$
- Black Holes (!)

Event Generators

Flavour Calc

- $(g-2)_\mu$
- $b \to s\gamma$
- $B_s \to \mu^+\mu^-$
- Asym, $\Delta M, \cdots$

Decay Codes

Fitters

Dark Matter

NP Models

- SUSY
  MSSM
  mSUGRA
  GMSB, AMSB
  NMSSM
  RPV, CPV,...
- TeXColour
- Extra-dim
- Little Higgs
- $f^\star, V'$
- Black Holes (!)

Spectrum Calc

- FeynHiggs
- NMHDECAY⋆
- CPSuperH
- RGE Codes
  Isasusy
  SoftSusy
  Spheno
  Suspect

Flavour Calc

Dedicated Codes

- SusyBSG
- SuperIso

Dark Matter

Cross sections Calc, MEG

- Tree-level,any
  CalcHEP, CompHEP
  GRACE, FORMCalc
  Madgraph
  SHERPA/Amegic++
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Event Generators

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CatFish, Charybdis, TrueNoir

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Feynman rules

(Eff. Pot.)

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manual

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(Eff. Pot.)

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manual

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LanHEP/FeynRules

Feynman rules

(Eff. Pot.)

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automated

automated

Flavour Calc

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Cross talks

SLHA,BSM-LHEF

Cross sections Calc, MEG

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Feynman rules

SLHA 1 and 2

SLHA (1): MSSM, SLHA2 (CPV,RPV,NMSSM) Most of the authors have adopted it

- Signs (μ,..), factors of $\sqrt{2}$
- Mixing angles conventions
- Eigenstates decomposition
- Renormalisation schemes/scales !!!
- Effective field content (sparticles integrated out or not)
- SLHA2 more of a headache, but we got there eventually

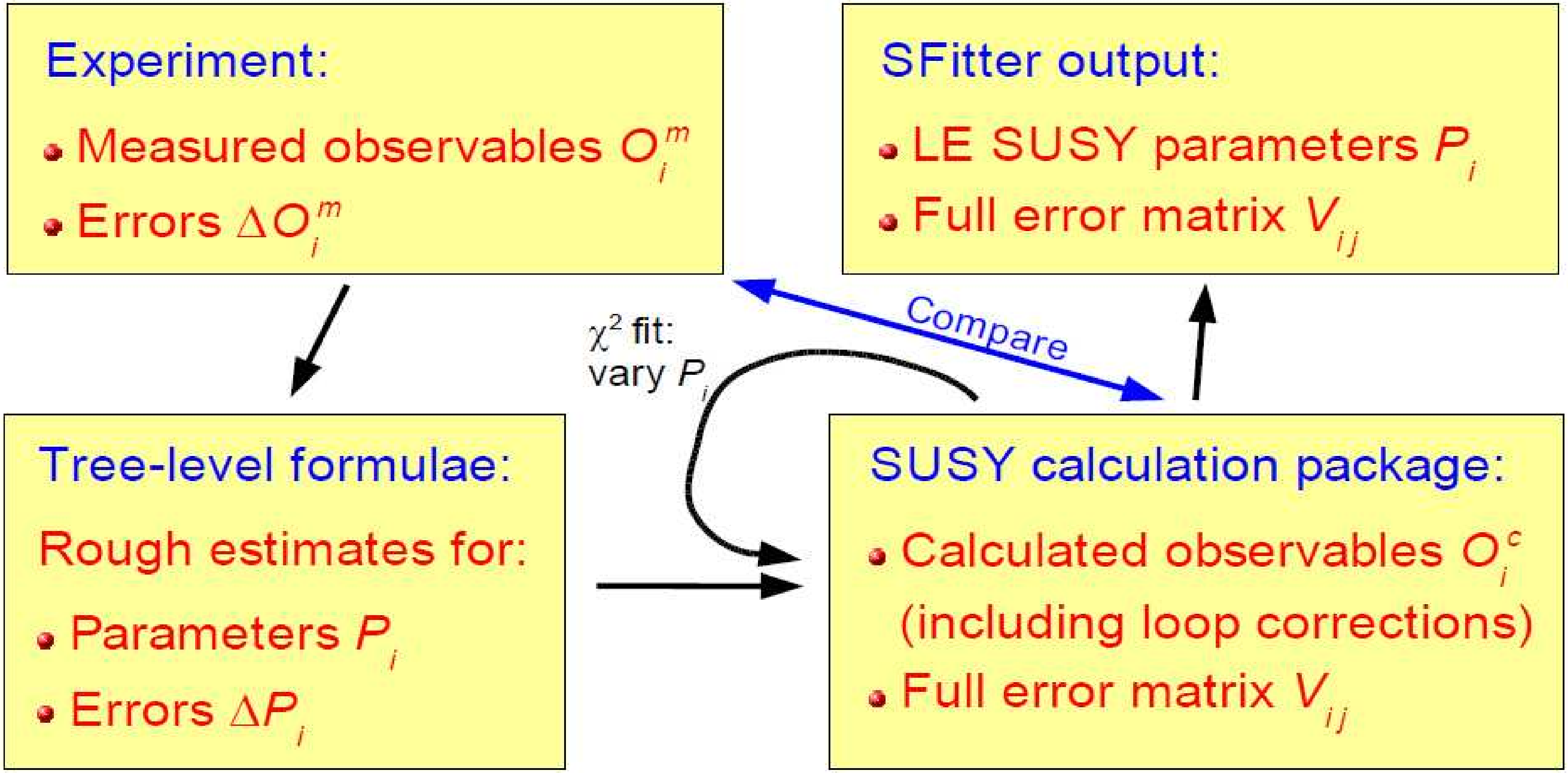
BSM LHEF

This is a mix of

- SLHA2 and (model parameters)

  introduce new SLHA like blocks QNUMBERS for each BSM particle containing PDG code, spin, elec. charge, colour rep., particle/antiparticle

- and LHEF2 (xml format) for event files



tree-level vs "1-loop level"

- I have not said much about MC at NLO
- Essential for normalisation
- Intense activity these last few years in NLO multi-leg
- many new techniques
- plans for $2 \to 3, 4$ and benchmark cross sections

Yuri Dokhsitzer: "virtual SUSY is helping QCD (*twistor techniques!*), QCD will pay back discovering *"real"* SUSY

BSM Tools Repository

- http://www.ippp.dur.ac.uk/montecarlo/BSM

  Please submit your code or get a code from there

  otherwise google the codes I have described

  for SUSY, see recent review by Ben Allanach (arxiV:0805.2088[hep-ph]

  If you contribute a code make it SLHA/LHEF compliant, if SLHA exists for the model please give a description of the code: what physics there is inside not just how to run it!!

  at the moment 37 BSM tools listed so far...

- other repositories, e.g. http://mcelrath.org/Notes/Software (see also open directory project)

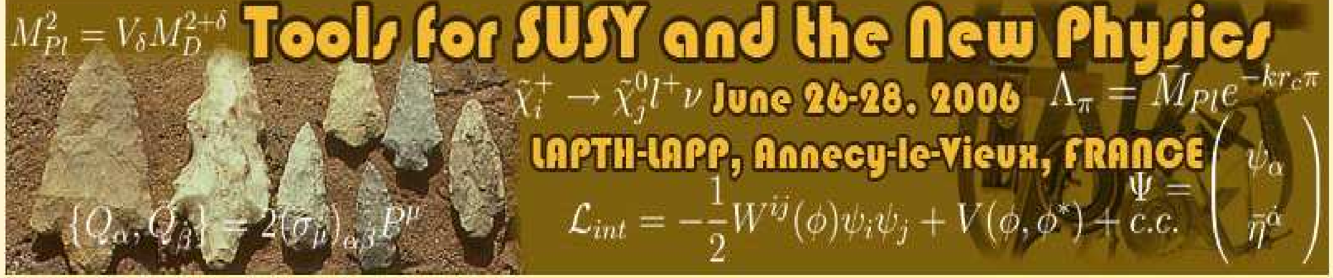
- old tools for susy, GDR Outils

  http://wwwlapp.in2p3.fr/gdr-outils/GDRoutils/outilsp1.html

- For codes that do the same things (or supposed to do the same thing)
  Comparison page like what is done with RGE (see Sabine Kraml's page)

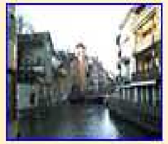
Organise round-tables involving model builders, calculation theorists, experimentalists

- More work on New Physics which is not SUSY
- for some SUSY models, probably need "background tools": contact with SM/QCD tools
- experimentalists need to speak up and ask what is needed most urgently : priority list (similar to what has been done for SM in Les Houches)
- how should codes be interfaced and written: modules, C++, SLHA,LHEF
- go to the Monte Carlo Schools and or the SUSY-BSM tools



Welcome | Registration | Program | Participants | Accomodation | Committee

TOOLS 2006

Tools for Susy and the New Physics
June 26-28, 2006 LAPTH-LAPP, Annecy-le-Vieux, France

The aim of the Workshop is to review the main calculational tools, including generators and Monte-Carlos, for the beyond standard model particle searches at present and future colliders as well as in non collider physics experiments such as dark matter searches. Apart from the talks, discussion sessions are planned. In these round tables we expect to discuss how the existing programs could be improved, how to incorporate different existing constraints, how to best present future data and how modules from different codes could sewn together and interchanged.

Tools for SUSY : 1998 - 1999 - 2000

Secretariat

TOOLS 2006 (Organisation Email) : tools2006@lapp.in2p3.fr
Secretary : Turc-Poencier Dominique Tel : +33 4 50 09 16 84

Progress/Conclusions

- A lot of progress and a lot of tools
- more and more on modularity and exchange of modules
- much easier now to contribute a new model
- Flexibility is the key

  [-] Need to be ready to implement a model quickly

  [-] Check output with different ME Calc./MC/MG
- This is now possible, while earlier even parameters of simple models hard wired, model implementation needed experts
- Now many tools automatize the different steps and as long as

  [-] particles has spin ≤ 2

  [-] Standard couplings through known Lorentz structures, this precludes higher order operators in some MEG but ALOHA is on the way and CalcHEP/CompHEP are ready...

  [-] decay chain does not end up in higher order or unusual colour representations

End

That's all folks

do go through the notes

and send typos to

boudjema@lapp.in2p3.fr