What has been achieved since Les Houches 2005 ?

What could be started at this workshop ?

NLO multi-leg group
(Feynman diagrammatic approaches)

Gudrun Heinrich

Les Houches 05: NLO wishlist for LHC

process ($V \in \{Z, W, \gamma\}$)	background to
1. $pp \to V\,V$ jet	$t\bar{t}H$, new physics
2. $pp \to H + 2$ jets	H production by VBF
3. $pp \to t\bar{t}\,b\bar{b}$	$t\bar{t}H$
4. $pp \to t\bar{t} + 2$ jets	$t\bar{t}H$
5. $pp \to V\,V\,b\bar{b}$	VBF$\to H \to VV$, $t\bar{t}H$, new physics
6. $pp \to V\,V + 2$ jets	VBF$\to H \to VV$
7. $pp \to V + 3$ jets	various new physics signatures
8. $pp \to V\,V\,V$	SUSY trilepton

achieved (from wishlist):

- $pp \to H + 2\,\text{jets}$ Campbell, Ellis, Giele, Zanderighi '05/06

- $pp \to Z\,Z\,Z$ Lazopoulos, Melnikov, Petriello '07

- $pp \to Z\,Z + 2\,\text{jets}$,
  $pp \to W\,W + 2\,\text{jets via VBF}$ Jäger, Oleari, Zeppenfeld '06

- $pp \to W\,Z + 2\,\text{jets via VBF}$ Bozzi, Jäger, Oleari, Zeppenfeld '07

The 2006/07 Checklist

have a look into the
2006/07 gift box and discover

$$pp \rightarrow W^+W^- jj \; ✔ \qquad pp \rightarrow ZZjj \; ✔$$

$$pp \rightarrow W^+Zjj \; ✔ \quad pp \rightarrow W^-Zjj \; ✔$$

at order $\alpha^6 \alpha_s$

still on the wishlist: $pp \rightarrow VVjj$ at order $\alpha^4 \alpha_s^3$

VV production via VBF

Barbara Jäger @ Loopfest VI

That's all ???
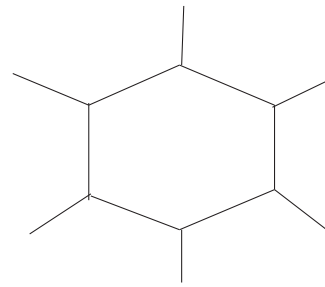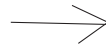
NO !

- processes which were not on the wishlist
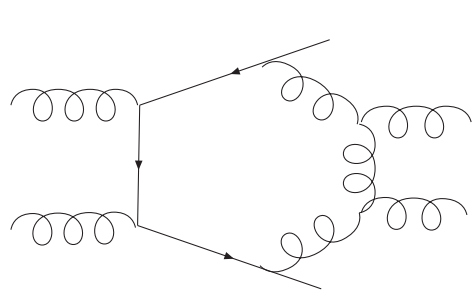
  examples: (SM, LHC kinematics only, $N > 4$ only)

  - $pp \to t\bar{t} +$ jet   Dittmaier, Uwer, Weinzierl '07

  - $pp \to Z +$ 2 jets, $W +$ 2 jets with one b-quark tag
    Campbell, Ellis, Maltoni, Willenbrock '06, '07

  - $pp \to H\, b\bar{b}$ Febres Cordero, Reina, Wackeroth '06

  - $pp \to HHH$ Plehn, Rauch '05; Binoth, Karg, Kauer, Rückl '06

  - . . .

- **important new technical developments**

  - **analytic methods** (twistor/string inspired)
    → Lance's talk
  - **semi-numerical methods**
    - generation of amplitude in terms of Feynman diagrams
    - tensor reduction $\Rightarrow$ set of "basis integrals":
      (boxes, triangles, bubbles, tadpoles) known analytically

$$\mathcal{A} = C_4 \,\square\, + C_3 \,\triangleleft\, + C_2 \,\bigcirc\, + \mathcal{R}$$

tensor reduction

non-trivial tensor structure   scalar 6-point function

$+$ integrals with less legs
from reduction of tensor rank and
number of legs at the same time
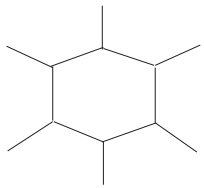
$$\text{(hexagon)} = \sum_{i=1}^{6} b_i \,\, \text{(pentagon)}_i \quad \ldots$$
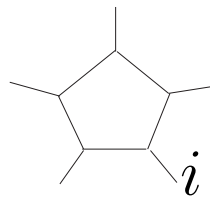
factorial growth in complexity!

(semi-)numerical methods cont'd.

possible solutions:

- do tensor reduction (partly) numerically
  Campbell, Ellis, Giele, Zanderighi; Denner, Dittmaier, Uwer, Weinzierl;
  Del Aguila, Pittau...

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  non-scalar basis integrals (partly) numerically

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- don't do tensor reduction at all

technical developments cont'd.

- **fully numerical methods:**
  do integration over loop momenta and/or Feynman
  parameters numerically
  problem: isolation of singularites

  Anastasiou, Beerli, Daleo, Kunszt; Ferroglia, Passera, Passarino, Uccirati;

  Lazopoulos, Melnikov, Petriello; Krämer, Nagy, Soper; Kurihara, Kaneko, . . .

- **improved methods for real radiation at NLO**

  (partly inspired by NNLO efforts)

  Daleo, Gehrmann, Maître; Nagy, Somogyi, Trocsanyi;

  Weinzierl, Schwinn, . . .

superficial comparison of methods

- ### analytic methods

  - \+ compact expressions

  - \+ evaluation of analytic expressions fast

  - \- processes with massive particles in the loop and/or many different mass scales difficult

  - \- automatisation in its infancy, numerical behaviour not yet studied sufficiently

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  - + trade-off between speed (analytic expressions) and generation of intractably large expressions optimised
  - + automated processing can make use of already existing "industry"
  - - expressions not compact, numerical stability can be delicate

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- ## numerical methods
  - + do not generate large analytic expressions
  - - numerical integration in multi-dimensional parameter space with intricate pole structure non-trivial

towards NLO 2 → 4 scattering

6-point results achieved:

- 🔴 complete one-loop amplitudes for
  - 🟢 **6 gluons**
    Britto, Feng, Mastrolia; Ellis, Giele, Zanderighi;
    Berger, Bern, Dixon, Dunbar, Forde, Kosower; Xiao, Yang, Zhou;
    Bedford, Brandhuber, Spence, Travaglini;
    Britto, Buchbinder, Cachazo, Feng, ...'94-'06
  - 🟢 **6 photons**
    Nagy, Soper; Binoth, Gehrmann, GH, Mastrolia;
    Papadopoulos, Ossola, Pittau; Forde '06/07

- 🔴 full electroweak corrections to $e^+e^- \rightarrow 4\,f$
  Denner, Dittmaier, Roth, Wieders Feb. 05, but should be mentioned

- 🔴 $e^+e^- \rightarrow HH\nu\bar{\nu}$
  GRACE group (Boudjema et al.) 10/05

- important developments towards matching NLO with parton showers

  Frixione, Nason, Webber, . . . , Nagy, Soper, . . . , Giele, Kosower, Skands, Krämer, Mrenna, . . . , Gieseke, Latunde-Dada, Ridolfi, . . .

- resummation:

  - diphoton Balazs, Berger, Nadolsky, Yuan '07

  - H production, doubly differential in q_T and y

    Bozzi, Catani, DeFlorian, Grazzini '07

  - single-inclusive jet production near threshold

    DeFlorian, Vogelsang '07

- . . .

Issues to be addressed during this workshop

- update the 2005 wishlist
  maybe coordinate/distribute tasks

- automatisation:
  - can we achieve high level of modularity to compare/exchange pieces of code which are common to many approaches?
    (e.g. colour algebra, one-loop master integrals, graph generation, dipole subtraction terms, ...)

  - some kind of "Les Houches Accord" on input/output ?

to be addressed during this workshop

- How can "string inspired/standard approaches" maximally profit from each other?

  - make use of complementarity of different approaches

  - assess limitations and future prospects of "traditional/new" approaches

  - discuss in particular rational parts, massive loops

  - . . .

to be addressed during this workshop

- Matching of NLO with parton showers
  - review most recent developments
  - discuss different approaches, modularity
- Concrete comparison of different methods:
  - speed/stability for (semi-)numerical methods
    (agree on simple benchmark examples)
  - compare (partial) results of different groups where possible
- NNLO:
  - asses where it is needed
  - compare different methods → Session II only ?
- resummation, log-enhanced EW corrections, power corrections, BFKL, ...