BSM - Summary - Part II

Meenakshi Narain
(Brown University)

Topics Covered:

1. Multi-leptons
2. Di-leptons
3. Lepton+jets+Missing Et

Multileptons
and W+gamma

Technicolor

- Black, Bose, Gershtein, Hubisz, Lane, Martin, Narain, Rosenfeld, Sanz

- Focus on *lowest-lying* ρ_T, ω_T and a_T, with $M_{\rho_T} \simeq M_{\omega_T} \lesssim M_{a_T} < 2M_{\pi_T} \simeq 200-600\,\text{GeV}$

- All decay rates are electroweak or suppressed by powers of $1/N_D$.
$\Longrightarrow$ ρ_T, ω_T, a_T are **VERY NARROW**, $\Gamma \lesssim$ few GeV !!

2. What we've done:

- **Processes put into** Pythia

Process	$V_{V_T G\pi_T}$	$A_{V_T G\pi_T}$
$\omega_T \to \gamma\pi_T^0$	$\cos\chi$	0
$\to \gamma\pi_T^{0\prime}$	$(Q_U+Q_D)\cos\chi'$	0
$\to Z_\perp^0\pi_T^0$	$\cos\chi\cot 2\theta_W$	0
$\to Z_\perp^0\pi_T^{0\prime}$	$-(Q_U+Q_D)\cos\chi'\tan\theta_W$	0
$\to W_\perp^\pm\pi_T^\mp$	$\cos\chi/(2\sin\theta_W)$	0
$\to \gamma Z_L^0$	$\sin\chi$	0
$\to W_\perp^\pm W_L^\mp$	$\sin\chi/(2\sin\theta_W)$	0
$\to Z_\perp^0 Z_L^0$	$\sin\chi\cot 2\theta_W$	0
$\rho_T^0 \to \gamma\pi_T^0$	$(Q_U+Q_D)\cos\chi$	0
$\to \gamma\pi_T^{0\prime}$	$\cos\chi'$	0
$\to Z_\perp^0\pi_T^0$	$-(Q_U+Q_D)\cos\chi\tan\theta_W$	0
$\to Z_\perp^0\pi_T^{0\prime}$	$\cos\chi'\cot 2\theta_W$	0
$\to W_\perp^\pm\pi_T^\mp$	0	$\pm\cos\chi/(2\sin\theta_W)$
$\to \gamma Z_L^0$	$(Q_U+Q_D)\sin\chi$	0
$\to W_\perp^\pm W_L^\mp$	0	$\pm\sin\chi/(2\sin\theta_W)$
$\to Z_\perp^0 Z_L^0$	$-(Q_U+Q_D)\sin\chi\tan\theta_W$	0
$\rho_T^\pm \to \gamma\pi_T^\pm$	$(Q_U+Q_D)\cos\chi$	0
$\to Z_\perp^0\pi_T^\pm$	$-(Q_U+Q_D)\cos\chi\tan\theta_W$	$\pm\cos\chi/\sin 2\theta_W$
$\to W_\perp^\pm\pi_T^0$	0	$\mp\cos\chi/(2\sin\theta_W)$
$\to W_\perp^\pm\pi_T^{0\prime}$	$\cos\chi'/(2\sin\theta_W)$	0
$\to \gamma W_L^\pm$	$(Q_U+Q_D)\sin\chi$	0
$\to W_\perp^\pm Z_L^0$	0	$\mp\sin\chi/(2\sin\theta_W)$
$\to W_L^\pm Z_\perp^0$	$-(Q_U+Q_D)\sin\chi\tan\theta_W$	$\pm\sin\chi/(\sin 2\theta_W)$

Amplitude factors for $V_T \to G\pi_T$.

Process	$V_{a_T G\,\pi_T/V_T}$	$A_{a_T G\,\pi_T/V_T}$
$a_T^0 \to W_\perp^\pm \pi_T^\mp$	0	$\mp \cos\chi/(2\sin\theta_W)$
$\to Z_\perp^0 \pi_T^{0\prime}$	$-\cos\chi'/\sin 2\theta_W$	0
$\to \gamma\rho_T^0$	$Q_U + Q_D$	0
$\to \gamma\omega_T$	1	0
$\to W_\perp^\pm \rho_T^\mp$	0	$\pm 1/(2\sin\theta_W)$
$\to Z_\perp^0 \rho_T^0$	$-(Q_U + Q_D)\,\tan\theta_W$	0
$\to Z_\perp^0 \omega_T$	$\cot 2\theta_W$	0
$\to W_\perp^\pm W_L^\mp$	0	$\mp \sin\chi/(2\sin\theta_W)$
$\to W_\perp^\pm \pi_T^\mp$	0	$\mp \cos\chi/(2\sin\theta_W)$
$\to Z_\perp^0 \pi_T^{0\prime}$	$-\cos\chi'/\sin 2\theta_W$	0
$\to \gamma\rho_T^0$	$Q_U + Q_D$	0
$\to \gamma\omega_T$	1	0
$\to W_\perp^\pm \rho_T^\mp$	0	$\pm 1/(2\sin\theta_W)$
$\to Z_\perp^0 \rho_T^0$	$-(Q_U + Q_D)\,\tan\theta_W$	0
$\to Z_\perp^0 \omega_T$	$\cot 2\theta_W$	0
$a_T^\pm \to \gamma\pi_T^\pm$	0	$\mp \cos\chi$
$\to W_\perp^\pm \pi_T^0$	0	$\pm \cos\chi/(2\sin\theta_W)$
$\to W_\perp^\pm \pi_T^{0\prime}$	$-\cos\chi'/(2\sin\theta_W)$	0
$\to Z_\perp^0 \pi_T^\pm$	0	$\mp \cos\chi \cot 2\theta_W$
$\to \gamma\rho_T^\pm$	$Q_U + Q_D$	0
$\to W_\perp^\pm \rho_T^0$	0	$\mp 1/2\sin\theta_W$
$\to W_\perp^\pm \omega_T$	$1/2\sin\theta_W$	0
$\to Z_\perp^0 \rho_T^\pm$	$-(Q_U + Q_D)\tan\theta_W$	$\pm 1/\sin 2\theta_W$
$\to \gamma W_L^\pm$	0	$\mp \sin\chi$
$\to \gamma\pi_T^\pm$	0	$\mp \cos\chi$
$\to W_\perp^\pm Z_L^0$	0	$\pm \sin\chi/(2\sin\theta_W)$
$\to W_L^\pm Z_\perp^0$	0	$\mp \sin\chi \cot 2\theta_W$
$\to W_\perp^\pm \pi_T^0$	0	$\pm \cos\chi/(2\sin\theta_W)$
$\to W_\perp^\pm \pi_T^{0\prime}$	$-\cos\chi'/(2\sin\theta_W)$	0
$\to Z_\perp^0 \pi_T^\pm$	0	$\mp \cos\chi \cot 2\theta_W$
$\to \gamma\rho_T^\pm$	$Q_U + Q_D$	0
$\to W_\perp^\pm \rho_T^0$	0	$\mp 1/2\sin\theta_W$
$\to W_\perp^\pm \omega_T$	$1/2\sin\theta_W$	0
$\to Z_\perp^0 \rho_T^\pm$	$-(Q_U + Q_D)\tan\theta_W$	$\pm 1/\sin 2\theta_W$

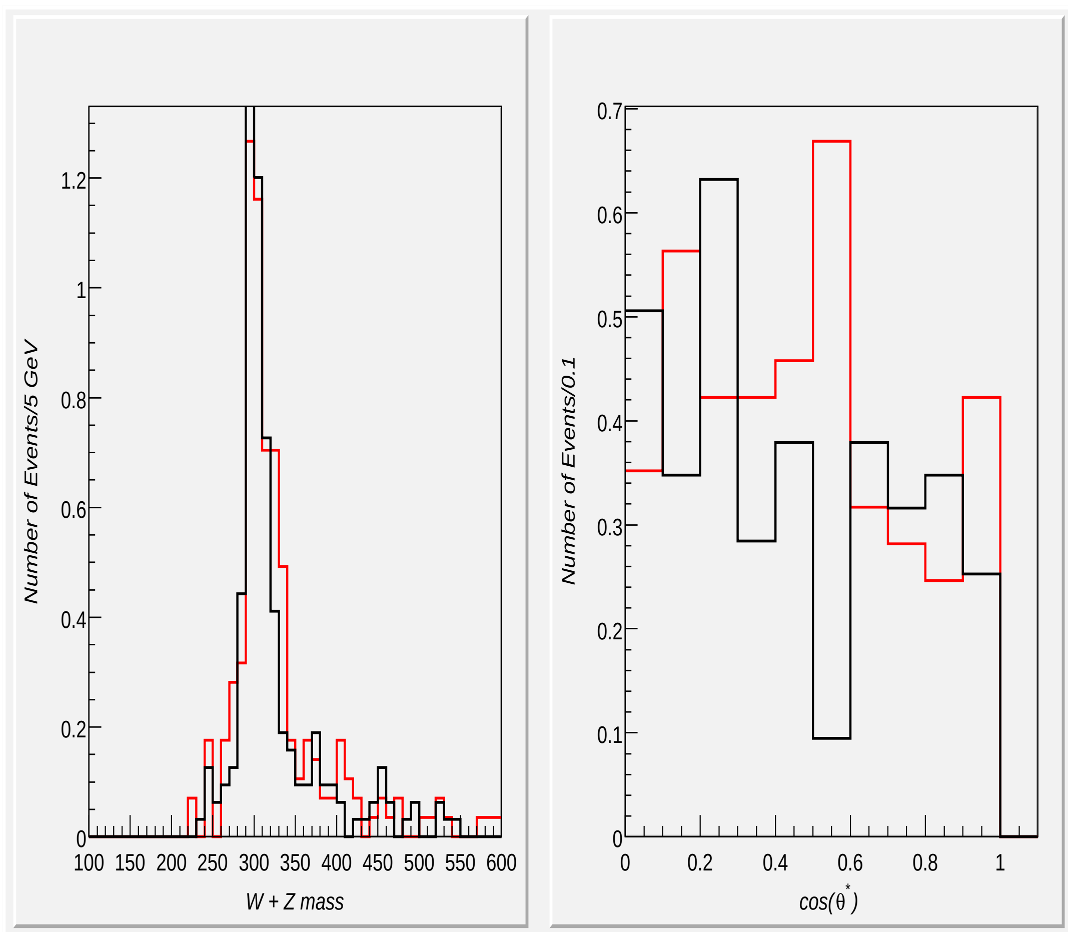
Parameter	Default Value	Parameter	Default Value
N_{TC}	4	α_{ρ_T}	$2.16(3/N_{TC})$
$Q_U = Q_D + 1$	$\frac{4}{3}$	α_{a_T}	$2.16(3/N_{TC})$
$\alpha_{a_T \rho_T \pi_T}$	$2.61(3/N_{TC})$		
$\sin\chi$	$\frac{1}{3}$	$\sin\chi'$	$1/\sqrt{6}$
$C_{1\tau,c,b}$	1	C_{1t}	m_b/m_t
C_{1g}^2	$\frac{4}{3}$	$\lvert\epsilon_{\rho\omega}\rvert$	0.05
$F_T = F_\pi \sin\chi$	82 GeV	$M_{\pi_T^\pm,\pi_T^0,\pi_T^{0\prime}}$	115 GeV
$M_{\rho_T^\pm,\omega_T,\rho_T^0}$	220 GeV	M_{a_T}	230 GeV
M_{V_1,A_1}	200 GeV	M_{V_2,A_2}	200 GeV
M_{V_3,A_3}	200 GeV		

Default values for parameters in the Technicolor Straw Man Model.

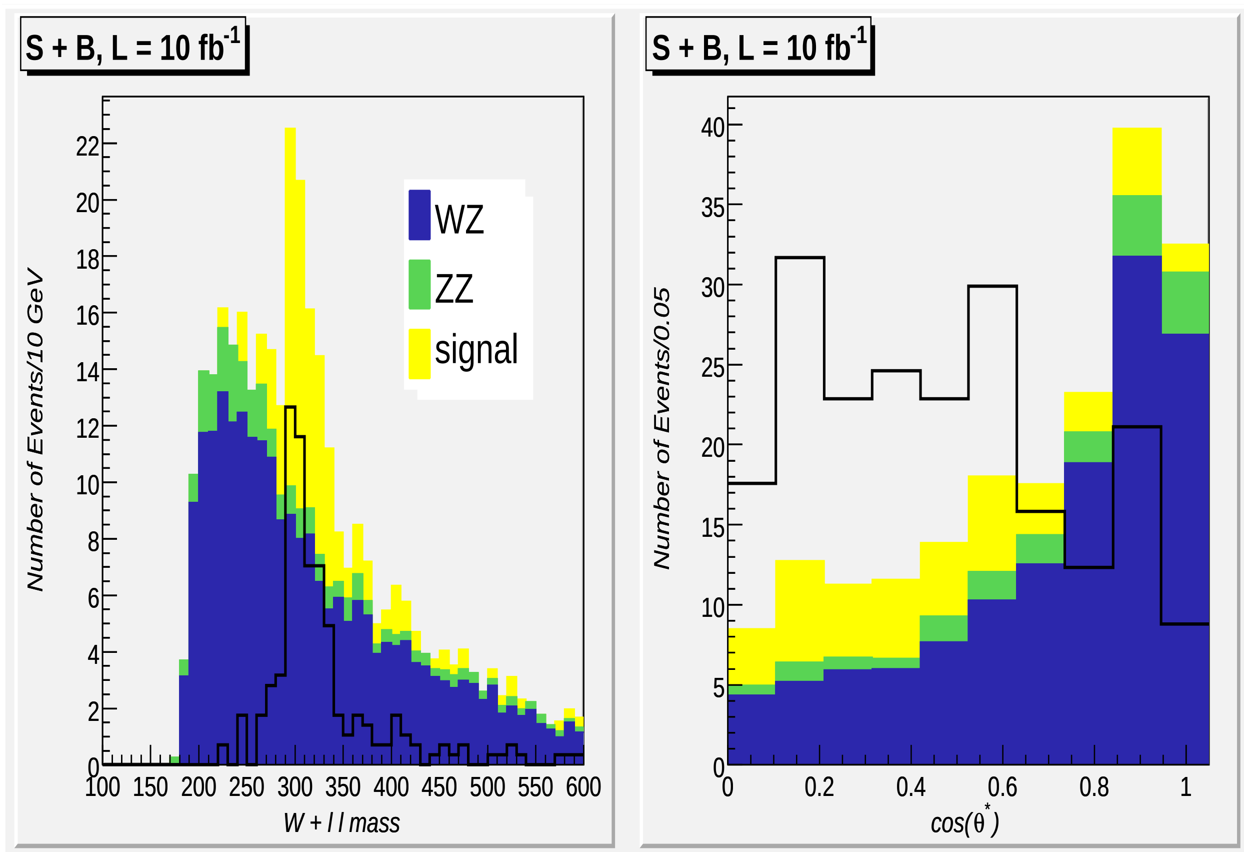
- We're test-driving the new Pythia – not sure it's going in the right direction yet.

- At the LHC, $\rho_T \to W^\pm \pi_T$ is swamped by $\bar{t}t$ and $W +$ HF. Go to $\rho_T^\pm \to W^\pm Z$. ($a_T^\pm \to W^\pm Z$ *seems* too small to see at LHC!)

- Results (so far) for $pp \to \rho_T^\pm + a_T^\pm \to W^\pm Z^0$ via Drell-Yan:

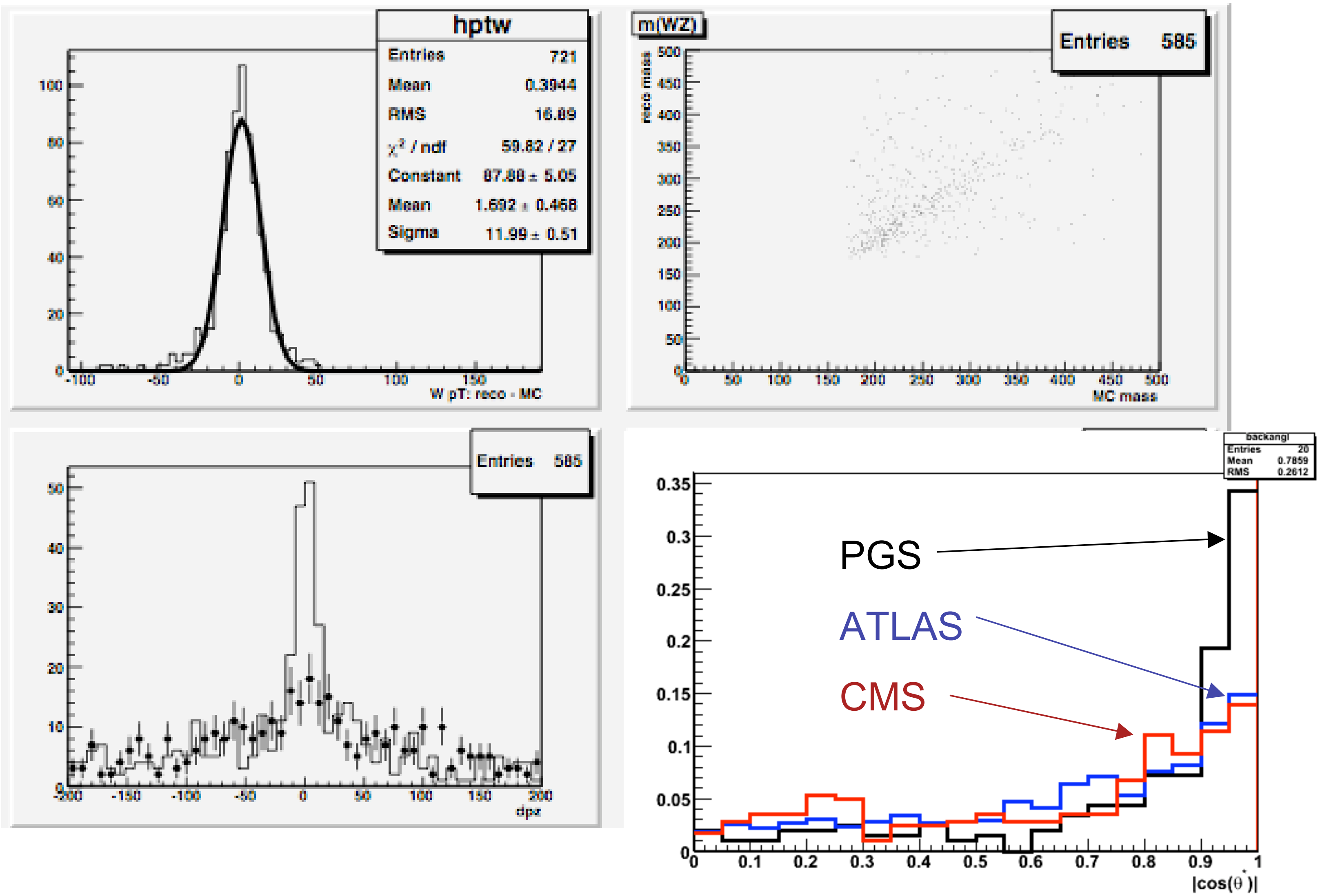


Comparison of $\rho_T^\pm$ (black) and $\rho_T^\pm + a_T^\pm \to W^\pm Z$ mass (left) and $\cos\theta^*$ (right) distributions.



Signal and backgrounds for $\rho_T^\pm$, $a_T^\pm \to W^\pm Z$ mass and angular distributions. $M_{\rho_T} = 300\,\mathrm{GeV}$, $M_{a_T} = 333\,\mathrm{GeV}$, $M_{\pi_T} = 200\,\mathrm{GeV}$.

WZ background using detector simulation



3. <u>What we'll do:</u>

- $\rho_T^{\pm} \to W^{\pm}Z$ analysis so far based on CMS study by P. Kreuzer. Critically examine Kreuzer's cuts. Re-optimize for $\cos\theta^*$ study — enhance signal purity.

- Study $\not{E}_T$ resolution.

- Study $p_{\nu,z}$ solution; e.g., maximize $\widehat{\boldsymbol{p}}_\nu \cdot \widehat{\boldsymbol{p}}_\ell$?

- Repeat for other mass points up to $M_{\rho_T} \simeq 600\,\mathrm{GeV}$; etc., etc.

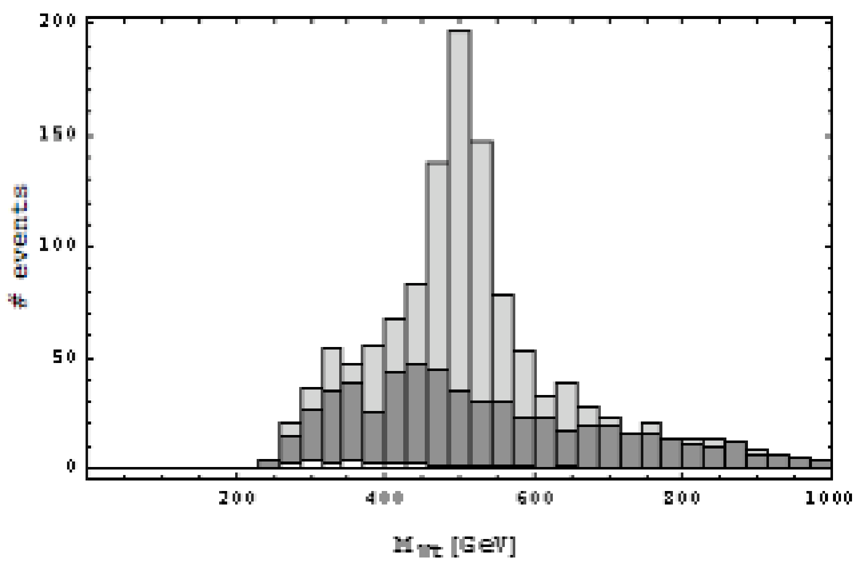
- P.S. WZ fusion of ρ_T, a_T is hopelessly small.

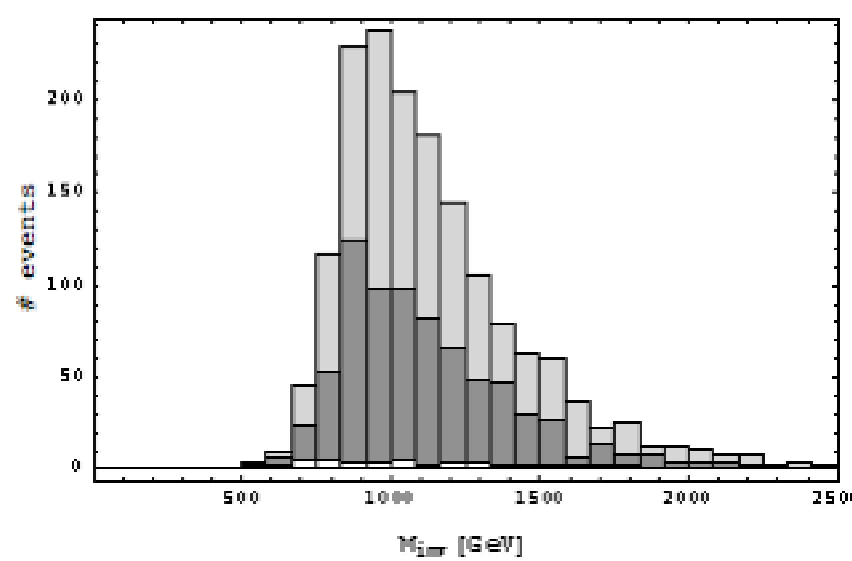
- Study discovery and angular distribution of $a_T^{\pm} \to \gamma W^{\pm}$, $\omega_T \to \gamma Z$ and $\omega_T, \rho_T^0 \to \gamma \pi_T^0 \to \gamma b\bar{b}$.
Very exciting possibilities here!

Dileptons

Composite Higgs

- Dileptons+jets
- New heavy quarks $T^{5/3}$ or $B^{-1/3} \rightarrow ttWW$
  - Contino, Servant, Delgado, Piccinini
  - Interested exp: Narain, Gershtein
- Require two same sign dileptons+6 jets





Dileptons

Drell-Yan/Resonances

Introduction

- ***2 sides: Understand the Standard Model before looking for BSM***

– **Standard Model side**: *Controlling the "Drell-Yan"*
  - **Uncertainties:**
    - PDF:
      - theory
      - experimentation
    - Factorisation and renormalisation scale
  - **Higher order corrections:**
    - QCD NLO (NNLO)
    - EW NLO
    - EW logs

    . Doreen W, Fulvio P, Stefano P, Stefano M, Claire S-T, Samir F, Johann K, Nadia A, Valerie H.

→ ***Draw the uncertainty band of SM prediction and any deviation of this band signs new physics***

– **Exotic side**
  - **Many models**
    - S-channel resonances: Z' $Z_{H,}Z_{KK}$ G
    - Virtual exchange of gravitons
    - Leptoquarks, Leptogluons, Heavy scalars...
  - **Disentangle the models:**
    - Invariant mass spectrum, angular distributions, parameter measurements...
    - **Greg L, Samir F, Edward B, Rohini G, Gregory M, Marcel V, Saurabh R, Claire S-T, Valerie H, Tim T, Kevin B, Meena M, Michel H.**
  - **Dileptons in KK: Edward B.**
  - **EW fits:**
    - **Maarten B, Marie L, Henri B,**

Projects at les houches

- Controlling the Drell-Yan
  - Defining the strategy (ll+X, ll+vetoes...?): Samir +Claire
  - Combining QCD & EW MCs for the Drell Yan: code from Fulvio, Doreen (Samir, Claire...)
  - Including beyond EW NLO corrections in MC: Doreen, Fulvio, Stefano
- Exotic
  - Disentangling models: Greg et al
  - EW Fits: Saclay

Using the EW and QCD Tools

QCD

- NLO/NNLO corrections to W/Z total production rate

  G. Altarelli, R.K. Ellis, M. Greco and G. Martinelli, Nucl. Phys. **B246** (1984) 12

  R. Hamberg, W.L. van Neerven, T. Matsuura, Nucl. Phys. **B359** (1991) 343

  W.L. van Neerven and E.B. Zijlstra, Nucl. Phys. **B382** (1992) 11

- Fully differential NNLO corrections to $l\bar{l}'$ (FEWZ)

  C. Anastasiou et al., Phys. Rev. **D69** (2004) 094008

  K. Melnikov and F. Petriello, hep-ph/0603182

- resummation of LL/NLL p_T^W/M_W logs (RESBOS)

  C. Balazs and C.P. Yuan, Phys. Rev. **D56** (1997) 5558

- NLO ME merged with HERWIG PS (MC@NLO)

  S. Frixione and B.R. Webber, JHEP **0206** (2002) 029

- Matrix elements Monte Carlos (ALPGEN, SHERPA,...) matched with PS

  M.L. Mangano et al., JHEP **0307**, 001 (2003)

  F. Krauss et al., JHEP **0507**, 018 (2005)

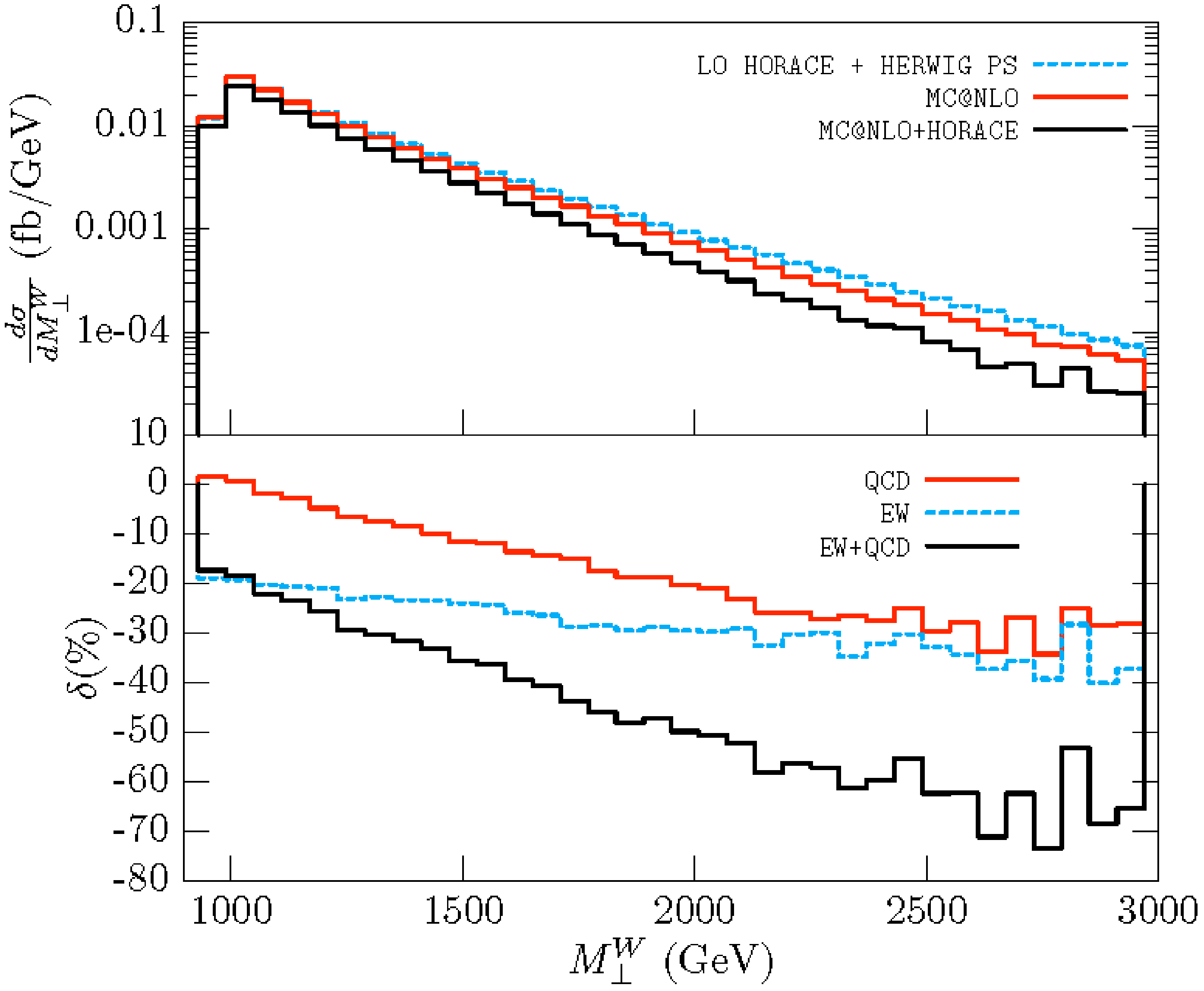
EW

- $\mathcal{O}(\alpha_S^2) \approx \mathcal{O}(\alpha_{\rm em}) \rightarrow$ need to worry about electroweak corrections!
- Electroweak corrections to W production
  - ⋆ Pole approximation ($\sqrt{\hat{s}} = M_W$)
    - → D. Wackeroth and W. Hollik, PRD **55** (1997) 6788
    - → U. Baur et al., PRD **59** (1999) 013002
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - → V.A. Zykunov et al., EPJC **3** 9 (2001)
    - → S. Dittmaier and M. Krämer, PRD **65** (2002) 073007 — DK
    - → U. Baur and D. Wackeroth, PRD **70** (2004) 073015 — WGRAD2
    - → A. Arbuzov, et al., EPJC **46**,407 (2006) — SANC
    - → C.M. Carloni Calame. et al., JHEP12 016 (2006) — HORACE
- Multi-photon radiation
  - → C.M. Carloni Calame et al., PRD **69**, 037301 (2004), JHEP 0505:019 (2005), JHEP12 016 (2006) — HORACE
  - → S. Jadach, W. Płaczek, EPJC **29** 325 (2003) — WINHAC

- Lot of MC tools including QCD and EW corrections exist
- Resembled in the W production study (Piccinini et al)
- Get the tuned software and redo the exercise for neutral D-Y

Results on the charged Drell-Yan

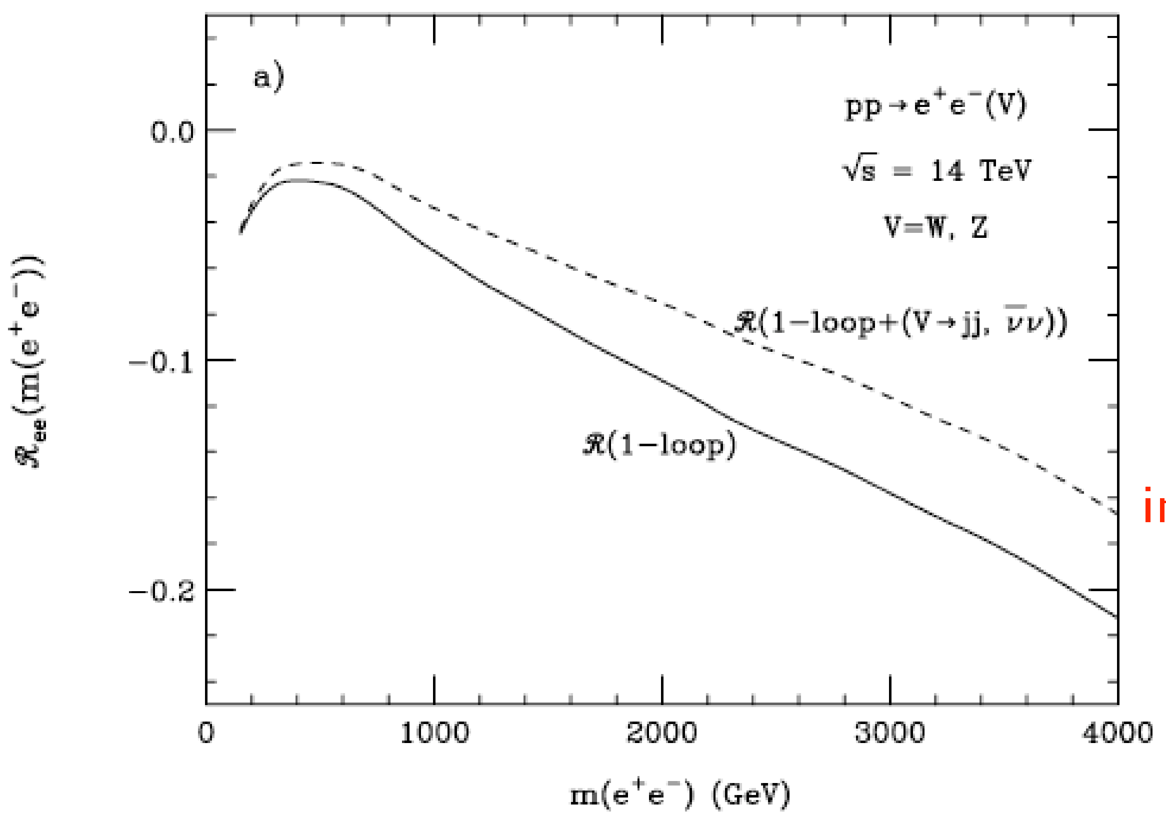
- Study done for both Tevatron and LHC
- PDF and energy scale uncertainties estimated
- QCD, EW, QCD+EW effects copared and estimated
- Fulvio and Doreen will provide us tuned software and we will be redo the exercise



EW corrections beyond NLO

Do we need to include them ?

Effect on $M(ee)$ distribution including complete $\mathcal{O}(\alpha)$ corrections (solid) and real $V = W, Z$ radiation (dashed):



impact of EW Sudakov-like logarithms

$\alpha^L log^N(s/M_V^2), 1 \leq N \leq 2L$

here: $L = 1$ (1-loop)

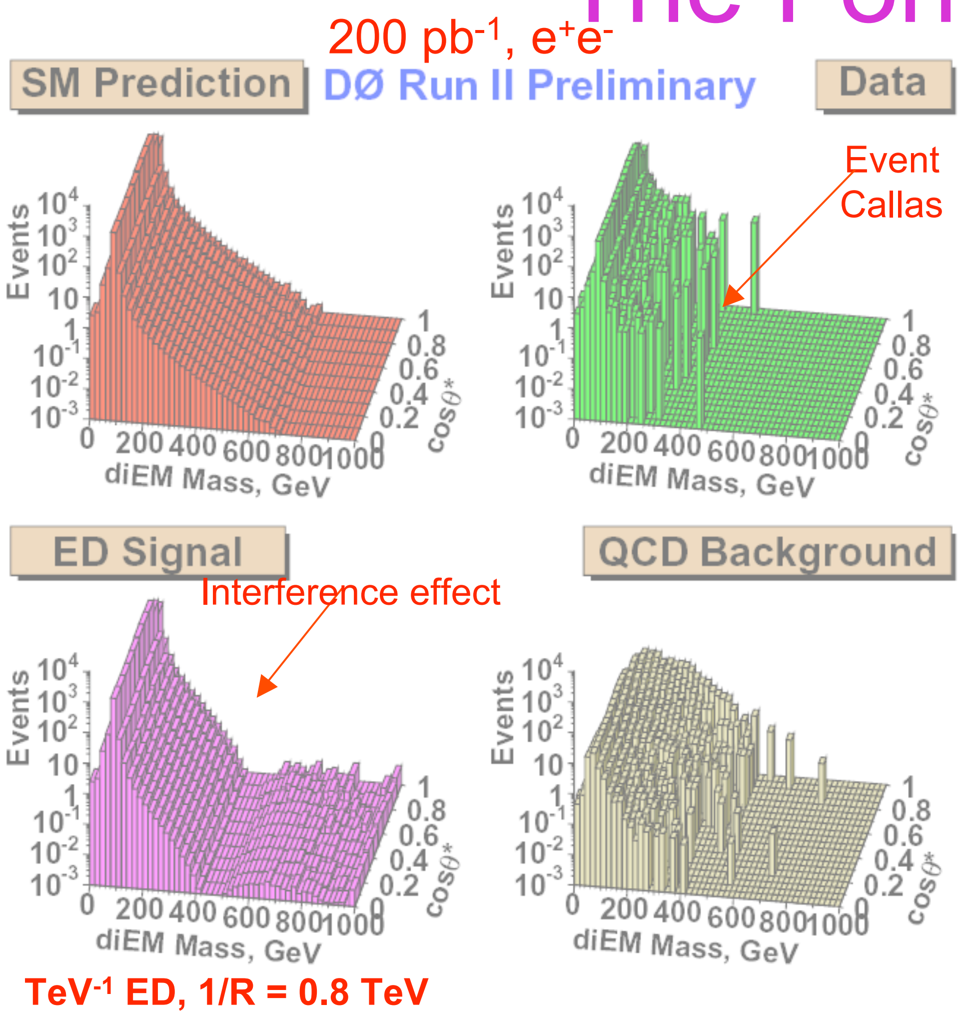
from U.Baur, PRD75 (2007)

NLO EW corrections decrease the LO $M(ee)$ distribution by -7%(-3%)at $M(ee) = 1\,TeV$ and by -20%(-16%)at $M(ee) = 4\,TeV$.

Dileptons in Early LHC Data

- Many models predict observable effects in the dilepton spectrum:
  - Mass peak(s)
  - Broad enhancement or depression of the DY background
- Two issues:
  - How to claim an observation?
  - How to interpret an excess?
- Proposal:
  - Differential cross section or amplitude fit to a template

The Formalism



- Clean signature, low backgrounds

- Two variables: the dilepton invariant mass and the scattering angle in the c.o.m. frame define the LO $2 \rightarrow 2$ process completely
  - NLO effects smear $\cos\theta^*$ distribution leaving the M_{ll} intact
- Formalism: 2D fit:

$$\frac{d^2\sigma}{d\cos\theta^* dM} = \frac{d^2\sigma_{SM}}{d\cos\theta^* dM} + \frac{\lambda}{\Lambda} f_1\left(\cos\theta^*, M\right) + \frac{1}{\Lambda^2} f_2\left(\cos\theta^*, M\right) + \frac{N\left(\cos\theta^*\right)}{\sqrt{2\pi\sigma}} e^{-\frac{(M-M_0)}{2\sigma^2}}$$

Disentangling the Exotic Models

Model	Effect	Next step
G_{RS}	$\Lambda = 0, N \neq 0$	Look in diphotons; look for BH, second resonance
Z_{KK}/γ_{KK}	$\Lambda \neq 0, N \neq 0$	Correlate the interference dip with the peak cross section
Z', Z_H	$\Lambda = ?, N \neq 0$	C_u/C_d fit – get Tim Tait to work!
ADD	$\Lambda \neq 0, N = 0$	Look in diphotons; look for BH
ρ_T/ω_T	$\Lambda = 0, N \neq 0$	Look in W+jj channel; send Ken flowers; send Gordy a card
LQ's, RPV	$\Lambda \neq 0, N = 0$	Look for pair LQ production in lljj; generic search for RPV SUSY
Compositeness	$\Lambda \neq 0, N = 0$	Look in diphotons; correlate dielectrons and dimuons; look in dijets

Comments

- Amplitude vs. cross section fit:
  - Fitting amplitudes is theoretically cleaner
  - Extracting amplitudes may be experimentally challenging, especially due to NLO effects; need to study
- C_u/C_d approach:
  - Promising
  - Need to understand limitations
  - Attempt to put TC models on the C_u/C_d plane

Dileptons

- Drell-Yan spectrum analysis spectrum fit: functional form (+root code?)
  - Landsberg, Boos, Ferrag, Godbole, Moreau, Rindani, Shepherd-Themistocleous, Halyo, Tait, Black, Herquet)
- Z' + jets for model determination (Tait)
- DY spectrum analysis Electroweak corrections: comparisons with QCD, ...
  - Wackeroth, Piccinini, Pozzorini, Moretti, Shepherd-Themistocleous, Ferrag, Adam, Halyo
-

Lepton + Jets (Missing ET)

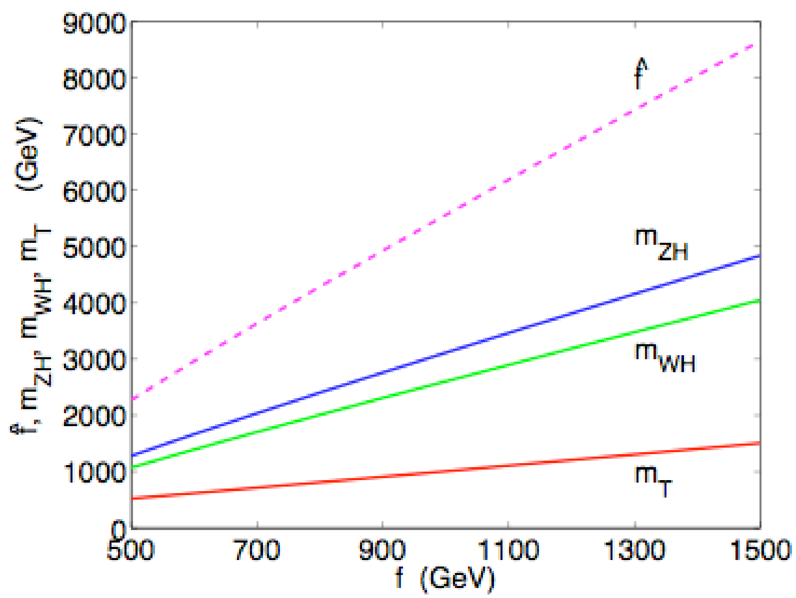
Twin Higgs Models

Shufang Su, Xinyu Miao, Marcel Vos, L. March, E. Ros

Little Higgs	Twin Higgs
Higgs is a pseudo-Goldstone boson of spontaneous breaking global symmetry	
collective symmetry breaking	discrete symmetry

- Heavy gauge bosons: W_H, Z_H
- Heavy top: t_H
- Other $SU(2)_R$ Higgses: $\phi^{\pm}$

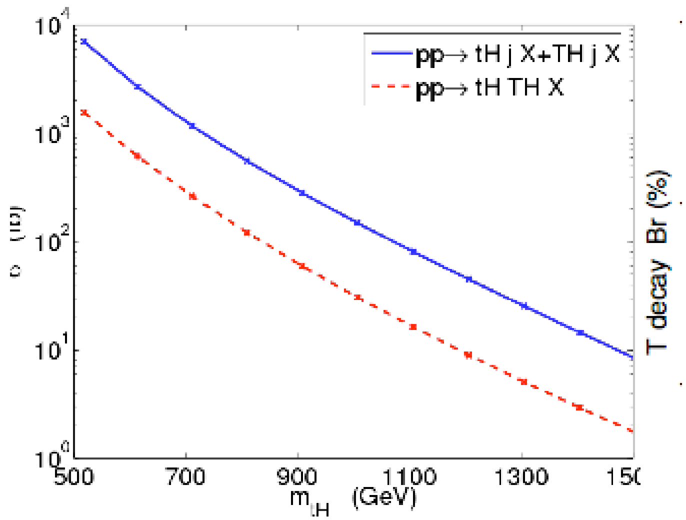
  ϕ^0



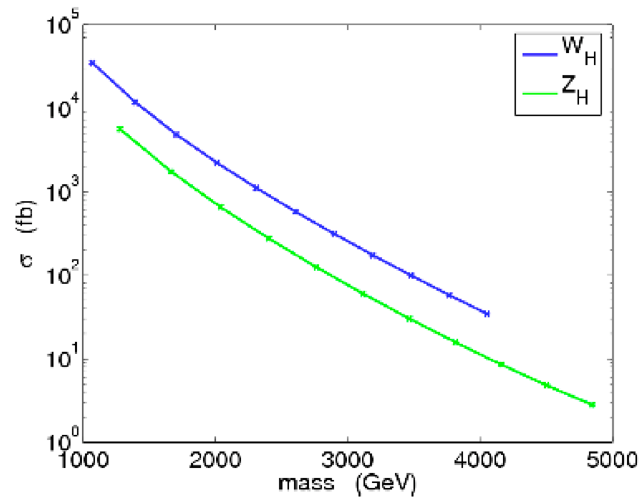
- Model parameters: f, M, (Λ, μ_R)

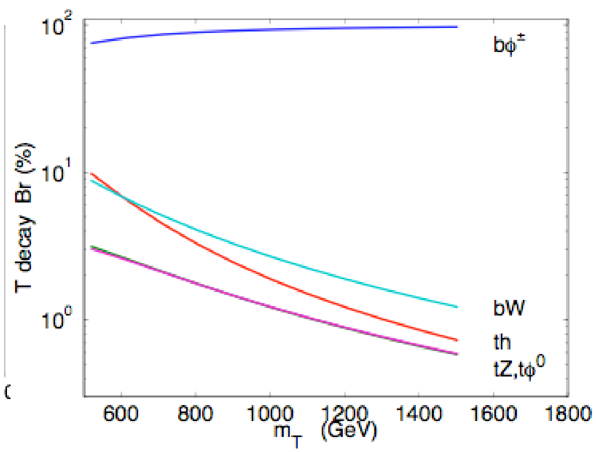
Production and Decay Signatures

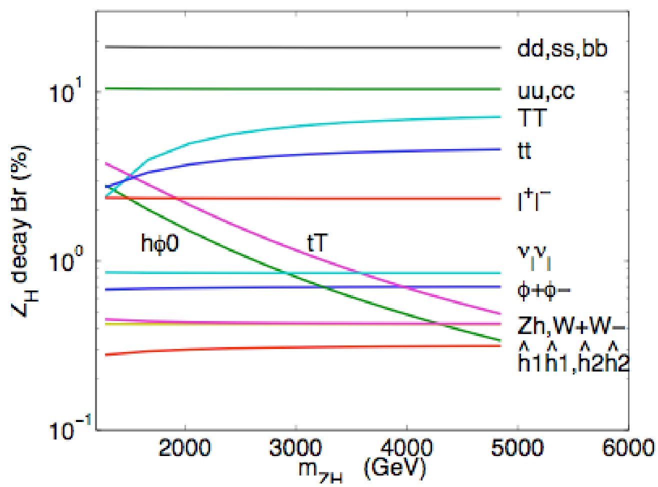
- single heavy top production dominate

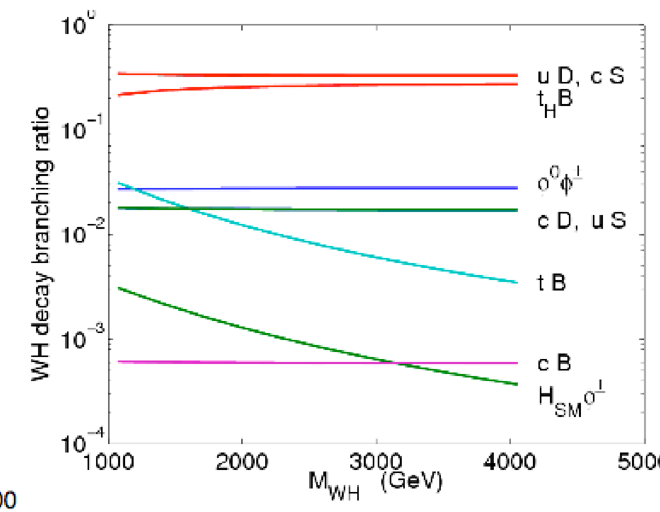


- Drell-Yan process $q\bar{q}' \to W_H, Z_H$

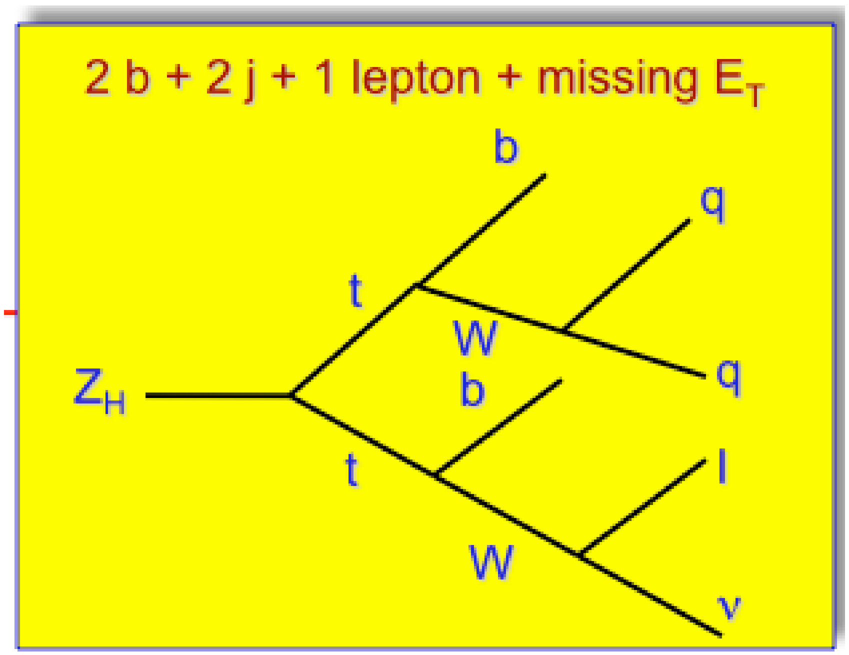


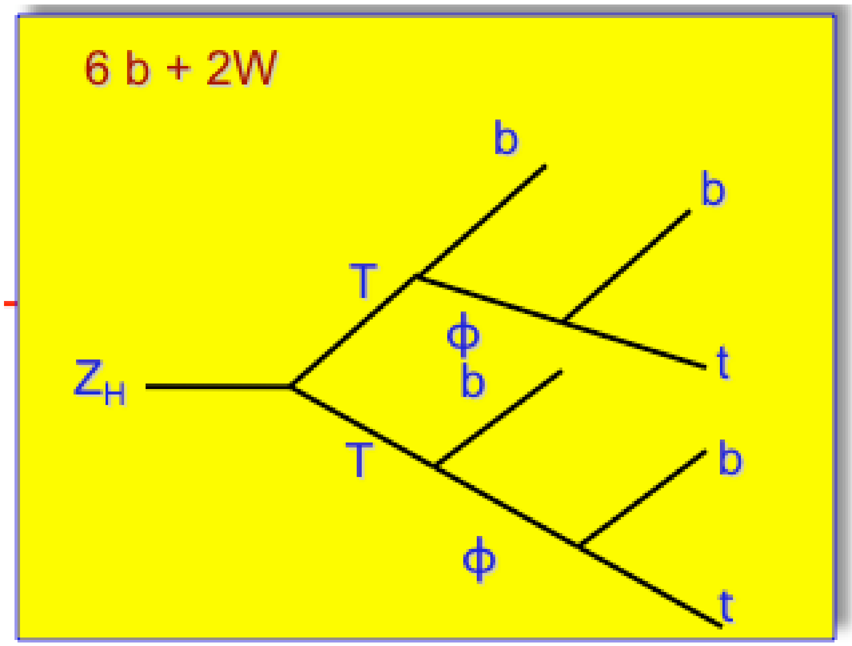






Some Signatures:





$W_H \to t_H\ B$

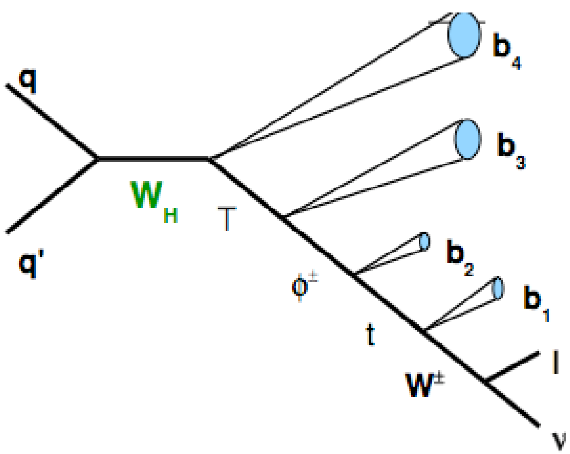
$t_H \to b\phi^{\pm}$: 4b + 1 lepton + missing E_T

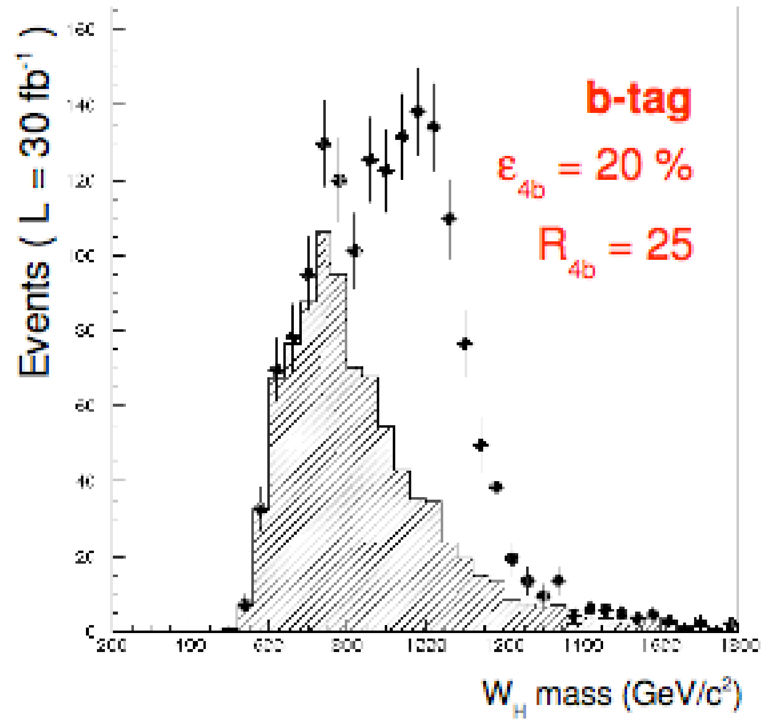
$t_H \to bW$: 2b + 1 lepton + missing E_T

$t_H \to tZ$: 2b + 3 lepton + missing E_T

Sensitivity Studies

- Lepton+High pT jets
- b-jets





N_{sig} = 651

N_{tt} = 377

N_{wj} ~ 0

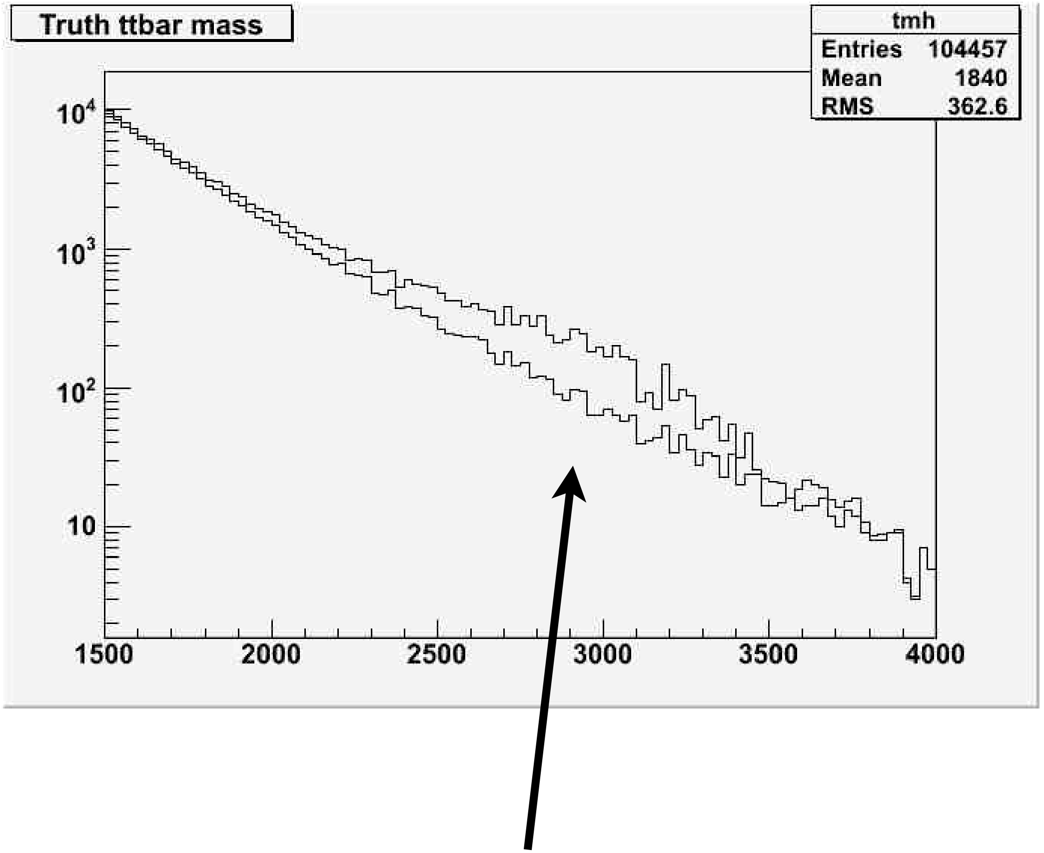
$N/\sqrt{B}$ = 33

Highly-Boosted Top Quarks

- A number of models predict high-mass resonances, decaying predominantly into top pairs
  - UED, RS models
  - Z′ with enhanced couplings to third generation
  - …
- Challenges:
  - Highly-boosted top is likely to be reconstructed as a single fat jet;
  - B-tagging is challenging as the opening angle between tracks with high IP is very small

High pT Top

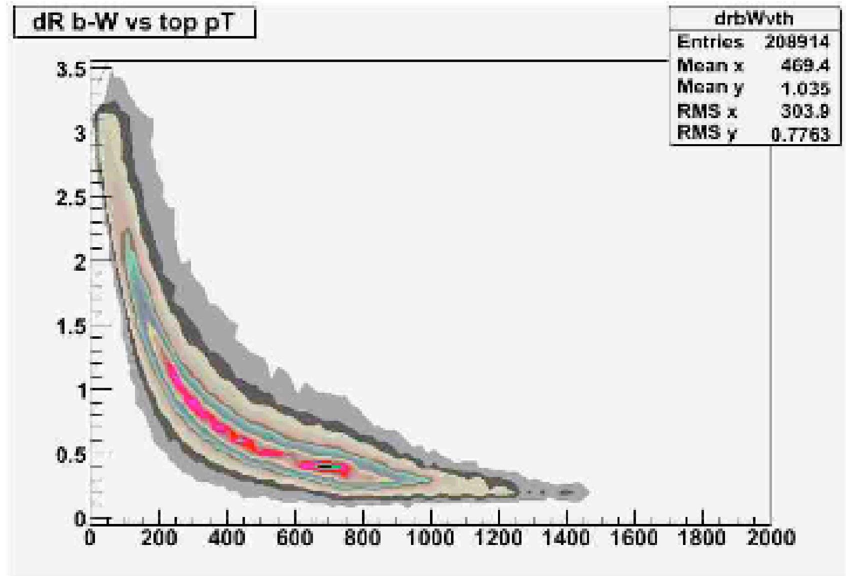
- Initial study with PGS
  - Produced 120k tt events with pythia (semileptonic)
    - m > 1.5 TeV, ~35 fb^{-1}
  - Reweighted qq->tt events with ratio of signal/qq background calculated by Gregory
  - Signal is a 3 TeV RS gluon excitation (a few points in parameter space)



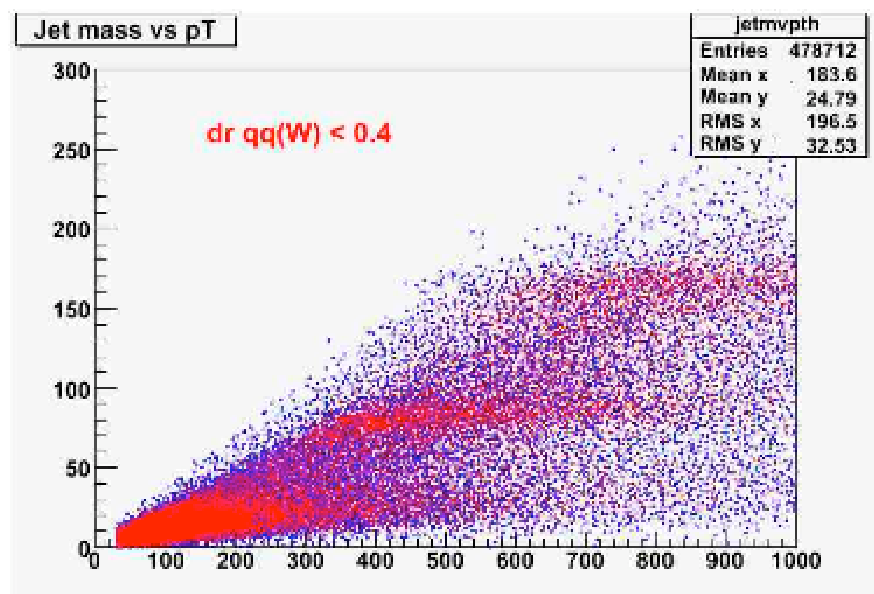
Worst case:
~800 GeV wide

Proximity of Decay Products

- All MC truth
  - Rarely less than 0.2 -> resolvable in LHC calorimeters
  - CMS HCAL 0.075x0.075
  - ATLAS HCAL 0.1x0.1



- Subjets resolvable in principle
  - kT-like algorithms ("ysplitter"), tools: siscone, Cambridge-Aach
  - jet mass
  - tracking info



Full Simulation Studies

- PGS is limited, many possibilities using tracks, kT, etc.
- Full simulation needed
  - CMS: 2 TeV & 5 TeV events available
    - Landsberg & Ribeiro
  - ATLAS: 0.7, 1, 1.5, 2 TeV events available
    - Brooijmans & Vos (?)
- Timescales should be ok for inclusion in report

Top Polarization

- Useful to distinguish SUSY vs UED vs ....
- Studies underway
  - CMS (Landsberg, Singh)
  - ATLAS (Ros, Vos)

Axigluon, Colorons

- Constraints on nonstandard, strongly interacting spin one particles from measurement of top production at the Tevatron/LHC
  - Godbole et al
- Propose to use top polarization to discriminate between axigluons, colorons, and SM backgrounds

Black Hole MC Generators

- TRUENOIR – a simple PYTHIA plug-in has been available since 2001
- Plans: continue adding feature in the code, maintaining the Web page:

  http://hep.brown.edu/users/Greg/TrueNoir/index.htm

Thank You

For all the contributions and

Looking forward to the near future work

for the proceedings

And

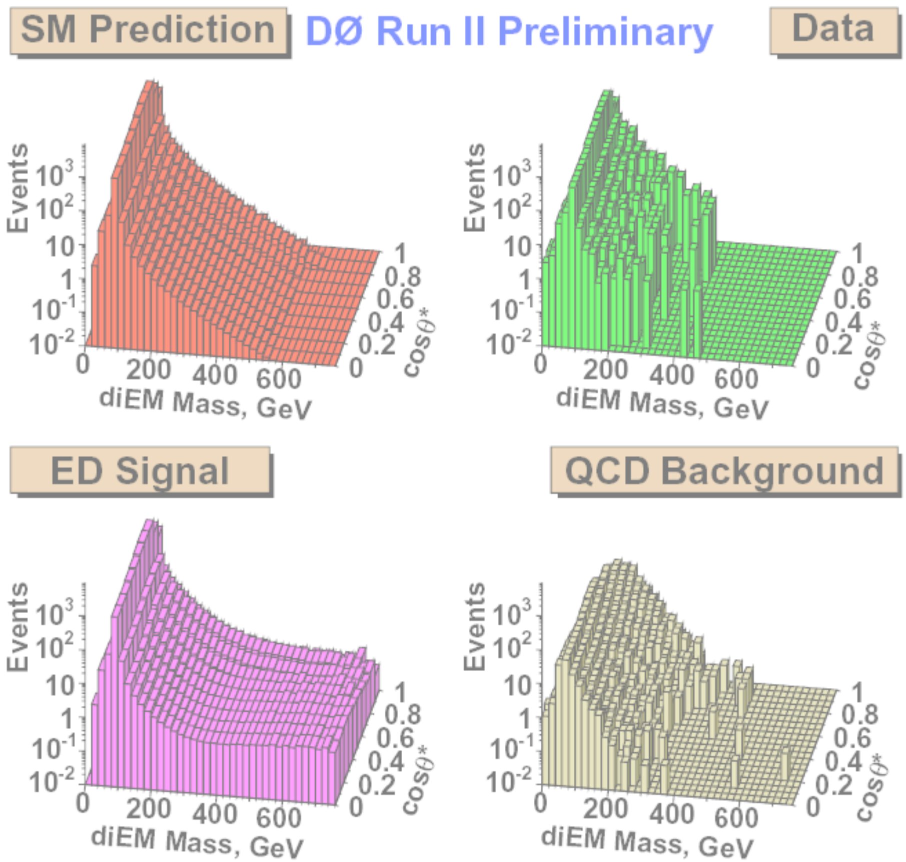
Many Thanks

to the Organizers for a stimulating workshop

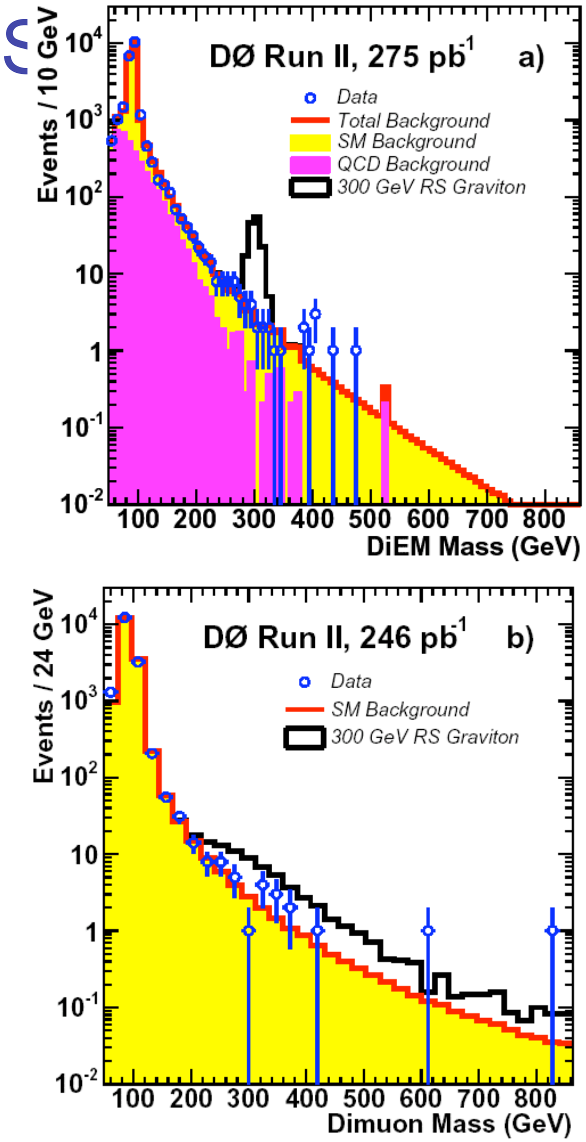
Other Possibilities

Compositeness/ADD

Run II, 200 pb^{-1}



RS



Plans

- Provide a code to do the cross section or amplitude fit in the mass/scattering angle plane
- Look at the interference effects between the s-channel and t-channel processes, e.g. LQ's and DY