NLM “exp.” Summary, or
“Some enlightenment happened...”

G. Dissertori
ETH Zurich
Les Houches 2009
How I as an LHC experimentalist feel ...
Outline

Lots of interesting discussions, in general all very constructive

This summary: obviously a biased view of the panorama

Content:

- Vector bosons in the final state
  - photons, W, Z, (+jets)
- Normalization
- Higgs
- AOB

In this summary: mostly “head-lines”, “buzz-words”, no details …
Photons

New CDF measurement shown by Joey raised interesting discussion on photon isolation.

High Purity - how much worry about details of isolation def?

Contribution of UE and PU

CDF Data, L=2.5 fb⁻¹
systematic uncertainty
NLO pQCD JETPHOX
CTEQ6.1M / BFG II
μ_f=μ_v=μ_R=E_T^γ
CTEQ6.1M PDF uncertainties
scale dependence μ=0.5E_T^γ and μ=2E_T^γ
**Photons**

**Isolation criterion**

courtesy J.P. Guillet

\[
\begin{align*}
E_T^{\text{had}} & \leq E_{T \text{ max}} \text{ inside} \\
(g - y)^2 + (\phi - \phi_y)^2 & \leq R_{\text{exp}}^2
\end{align*}
\]

Large Log. when \( R_{\text{exp}} \to 0 \) and \( E_{T \text{ max}} \to 0 \)

Other isolation criterion (S. Frixione) where \( E_{T \text{ max}} = F(r) \)

**Action Items:**

- Susan, Joey, Kajari, Jean-Philippe

**Exp:**

Look again in detail at the Frixione criterion, what is the impact at LHC of UE/PU, of fragmentation; see if some “hybrid” (simple cone vs Frixione) can be found, suitable for exp. application.

**Theory:**

Use existing (and possibly upgraded) codes to study difference in x-sections obtained with Frixione-criterion and some “pedestal” allowed in the central cone.

Look also at “democratic” approach.

**Higgs to gamma-gamma (Susan Gascon)**

- ongoing: detailed study of HO effects (signal and bkg, for LHC)
- included in studies: new Gamma2MC code (Dixon et al), gg->photon-photon box diag.

**Side remark**: With ever increasing precision of QCD predictions: Increasing importance of EWK corrections...
**W+γ at LHC**

Activity started in LH: Comparison of photon spectrum from various calculations/generators.

NLO effects very important ➔ K factor is large AND dependent on $P_T\gamma$

study spectra from Sherpa, ALPGEN, MCFM, ...

One of the main issues:
definition of *isolated photon* in the final state in theoretical predictions.

Preliminary look at jet-fragmentation into a hard photon in Pythia, using 1M di-jet evts.

Rate of direct $\gamma$ production is $\sim 10^{-5}$

Compare different tunings for quark fragmnt.:  
**a measure of its uncertainty**

<table>
<thead>
<tr>
<th>Selection Criteria</th>
<th>CMS-default</th>
<th>TuneA+Prof.</th>
<th>TuneDW+Prof.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_T\gamma &gt; 30\text{GeV},</td>
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<td></td>
<td></td>
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<tr>
<td>\midline</td>
<td></td>
<td></td>
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<tr>
<td>$P_T\gamma &gt; 40\text{GeV},</td>
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Mazumdar, Guillet, Skands, Mrenna
W+3 jets

- Very recently: new NLO results by two groups
  - Full Colour (FC) by Blackhat
  - Leading Colour (LC) by Rocket

- Some results shown by Giulia Zanderighi
  - Attention with multi-jet final states: usage of an IR safe or un-safe jet algo becomes an issue
  - Rescaling of NLO LC-prediction with ratio of FC/LC at LO

**Cross-section at the Tevatron**

\[ \sigma_{W+3j}(p_{\perp,j} > 25 \text{ GeV}) = (0.84 \pm 0.24) \text{ pb} \]

<table>
<thead>
<tr>
<th>SiS Cone</th>
<th>anti-ktT</th>
<th>LO_{LC}</th>
<th>LO_{FC}</th>
<th>( r = \frac{LO_{FC}}{LO_{LC}} )</th>
<th>NLO_{LC}</th>
<th>r \cdot NLO_{LC}</th>
<th>Berger et al. (LC, v3)</th>
<th>Berger et al. (FC, prelim)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.89^{+0.55}_{-0.31}</td>
<td>0.81^{+0.50}_{-0.28}</td>
<td>0.91</td>
<td>1.01^{+0.05}_{-0.17}</td>
<td>0.91^{+0.05}_{-0.12}</td>
<td>0.908^{+0.044}_{-0.142}</td>
<td>0.882^{+0.057}_{-0.138}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.12^{+0.68}_{-0.39}</td>
<td>1.01^{+0.62}_{-0.35}</td>
<td>0.91</td>
<td>1.10^{+0.01}_{-0.13}</td>
<td>1.00^{+0.01}_{-0.12}</td>
<td>---</td>
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<td></td>
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</tr>
</tbody>
</table>

NB: errors are standard scale variation errors, statistical errors smaller
W+3 jets (contd)

- the issue of K-factors (incl. vs. differential) ..... 

- in particular, seen in many cases: jet vetos reduce the K-factors drastically....

- issue of the “choice of the right renorm. scale”:
  - Blackhat shows that $H_T$ appears to be a good one
  - in general : for such final states:
    - $m_W$ not good, rather $m_W + \text{sum}(p_T^J)$, or $m_W + \langle p_T^J \rangle$, ....

- Importance for users of LO+PS models: NEVER forget to plot the uncertainty band, even if you “believe” to have chosen a good central scale...
W+jets

NLO EWK+QCD corrections

S. Dittmaier, A. Denner, T. Kasprzik, A. Mück

Theoretical status:

- NLO QCD  
  DYRAD [Giele et al. '93]; MCFM [Campbell/R.K.Ellis '02]; 
  Melnikov/Petriello '06; Catani et al. '09

- NLO EW for stable W bosons  
  Kühn, Kulesza, Pozzorini, Schulze '07; Hollik, Kasprzik, Kniehl '07

Motivation for this work:
Inclusion of full off-shell effects in NLO QCD+EW predictions
  e.g. essential for W-mass determination

Size of corrections:

- EW corrections particularly large at high $p_T$ of leptons and jets
- photon-induced processes and EW–QCD interferences phenomenologically unimportant

EWK subleading corr:
Relevant if people want to attack $O(20 \text{ MeV})$ regime of precision on $m_W$
Interesting example of newly proposed “ratio observable”:

\[ \frac{\sigma(W+ \geq 3j)}{\sigma(W+ \geq 2j)} \]

>= 3rd jet production as function of rap.diff. of 2 leading jets.

Reduced sensitivity to exp. uncert?

Useful to test MC models!

Shower MC need “help” of extra hard partons!

\[ k_{\perp}\text{-jet}, \ R = .4, \ p_{\perp} > 40\text{GeV}; \text{ incl: } W+ \geq 3 \text{ jets, excl: } W+” = ”3\text{jets} \]
Z+jets

Properties of the recoiling hadronic part of the event

V. Ciulli, P. Lenzi, A. Tricoli, J. Andersen

\( \Delta y \) either of leading jets or largest |y| jets identified as a variable sensitive to details of jets production

- ME+PS vs BFKL factorization vs (N)NLO
- Maybe also rather insensitive to JES

Plans to study \( \Delta y \) dependence of:

- \( \langle n \text{ jet} \rangle \)
- \( \sigma(W+n+1)/\sigma(W+n) \)
- \( \langle \cos \Delta \phi \rangle \)

Other interesting observables:

- \( \sigma(W+n)/\sigma(Z+n) \): is it really insensitive to all jet production details?
- \( \sigma(W^+)/\sigma(W^-) \) vs \( \langle n \text{ jet} \rangle \) \( \Rightarrow \) pdf’s

Event shape variables (like thrust or differential jet rate \( n+1 \rightarrow n \)): can be rather sensitive to UE
Normalization

Expected uncertainty from luminosity monitors ≈ 10%? Better?

Alternative: use W/Z counting as luminosity monitor

\[ N_{pp \rightarrow Z} = L_{pp} \cdot PDF(x_1, x_2, Q^2) \cdot \sigma_{q,\bar{q} \rightarrow Z} (+\text{HO}) \]

count extract as inputs

or: normalize processes to number of Zs (parton-parton luminosity)

\[ N_{pp \rightarrow WW} = N_{pp \rightarrow Z} \cdot \frac{\sigma_{q,\bar{q} \rightarrow WW}}{\sigma_{q,\bar{q} \rightarrow Z}} \cdot \frac{PDF(x_1', x_2', Q'^2)}{PDF(x_1, x_2, Q^2)} \]

\[ \Delta L_{pp} = 0! \]

Calculate ratios (at best available approx)
Reduced uncertainties(?)
Extend to gluon-induced processes...at N^nLO
Di-Boson prod, normalized...

Detailed study presented by Bruce Mellado et al.

**Ratio $ZZ(WW)/Z^{(*)}$**

- The production of $ZZ$ and $WW$ is enhanced by large contributions from $gg\rightarrow VV$ with gluons in the initial state
- Formally a part of the NNLO contribution, but enhanced due to the large gluon flux

$$R = \frac{\sigma_{NLO}^{qq\rightarrow ZZ,WW} + \sigma_{LO}^{gg\rightarrow ZZ,WW}}{\sigma_{NLO}^{q\bar{q}\rightarrow Z^{(*)}}$$

**PDF Uncertainties (ratios)**

- Use CTEQ6.1 and evaluate the 40 pdf checks
- Results depends weakly on cms energy

**Uncertainties in %**

<table>
<thead>
<tr>
<th>$\sqrt{s}$</th>
<th>$\delta \sigma(ZZ)/\sigma(Z)$</th>
<th>$\delta \sigma(ZZ)/\sigma(Z^*)$</th>
<th>$\delta \sigma(WW)/\sigma(Z)$</th>
<th>$\delta \sigma(WW)/\sigma(Z^*)$</th>
<th>$\delta \sigma(ZW)/\sigma(Z)$</th>
<th>$\delta \sigma(ZW)/\sigma(Z^*)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>1.4</td>
<td>0.5</td>
<td>1.3</td>
<td>0.3</td>
<td>1.4</td>
<td>0.4</td>
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<tr>
<td>10</td>
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<td>0.5</td>
<td>1.4</td>
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<tr>
<td>8</td>
<td>1.5</td>
<td>0.6</td>
<td>1.4</td>
<td>0.3</td>
<td>1.5</td>
<td>0.6</td>
</tr>
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</table>

**Note:** Presented by Grigorious Chachamis:
He and his collaborators are attacking $qq\rightarrow WW$ at NNLO
$gg\rightarrow WW$ at NLO !

Runner-up for the quote of the week:
“Goal is to have a NNLO MC for Gauge boson pain production”

**Pdf-related errors of VV**
are more correlated with $Z^*$ and with $Z$

Campell, Castaneda-Miranda, Fang, Kauer, Mellado, Wu; arXiv:0906.2500
Normalization idea transported to tT...

Bruce Mellado, Rohini Godbole, Joey Huston

**tt/(Z/\gamma^*+jet) Studies**

- We are investigating the possibility of normalizing tt (WW->l\nu\nu) with high P_T Drell-Yan events.
- Use MCFM process 41 (Z/\gamma^*+jet) and 157 (tt).
- Apply basic acceptance cuts and evaluate the correlations of cross-sections due to pdf uncertainties.
- We know that these are anti-correlated for inclusive Z and tt. Try to investigate the correlation when channels with g in the initial state open up.
- Evaluate correlations as a function of Z P_T.

### Z+jet Cross-Sections

<table>
<thead>
<tr>
<th>P_T (GeV)</th>
<th>\sigma (fb)</th>
<th>N (200 pb^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>271797</td>
<td>54359.4</td>
</tr>
<tr>
<td>50</td>
<td>92077.3</td>
<td>18415.5</td>
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<tr>
<td>75</td>
<td>38581.6</td>
<td>7716.31</td>
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<tr>
<td>100</td>
<td>18344.1</td>
<td>3668.82</td>
</tr>
<tr>
<td>125</td>
<td>9581.94</td>
<td>1916.39</td>
</tr>
<tr>
<td>150</td>
<td>5429.62</td>
<td>1085.92</td>
</tr>
<tr>
<td>175</td>
<td>3242.12</td>
<td>648.423</td>
</tr>
<tr>
<td>200</td>
<td>1987.19</td>
<td>397.439</td>
</tr>
</tbody>
</table>

No experimental lepton efficiency applied

**Good stat. even at large p_T!**

### Errors (%) on tt/Z+(j) ratios using CTEQ6ME

<table>
<thead>
<tr>
<th></th>
<th>\delta \sigma(tt)</th>
<th>\delta \sigma(ti)</th>
<th>\delta \sigma(tt)</th>
<th>\delta \sigma(ti)</th>
<th>\delta \sigma(ti)</th>
<th>\delta \sigma(ti)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>6.3</td>
<td>5.7</td>
<td>5.2</td>
<td>4.3</td>
<td>3.5</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Idea appears to work!
Intermezzo for the laptop-during-session addicts....
Summary of the Higgs Systematics Discussion

Discussion Points about Systematic errors in Higgs Searches:

1) Signal + Bkg x-sec uncert

2) Exp. Issue:
   a) how ‘smooth’ will we know the syst.
   b) when does it matter
   c) Data-driven Bkg at.
   d) eff. uncert

3) How to combine channels?
Summary of the Higgs Systematics Discussion

- Dedicated session: exp. and theo. systematic uncertainties for Higgs search, in particular H->WW
- Gluon-induced: apply same normalization idea as for tT !?
- Dominant backgrounds: tT and WW (exp. uncert. of O(15-20%))

Action Items / Needed:

- best possible prediction of tT, in particular ratio of cross section in (signal enhanced/bkg enhanced) phase space region, such as phi_ll.
- and if possible: in different jet-mult. bins (0,1,>=2 jets)
- evaluate possibility of signal normal. to high \( p_T \) Z prod. Can it be done to accuracy between 5 and 10 %? How well do we know the exp. efficiencies?
- For Higgs search below 150 GeV: need even better syst. control than for ~165 GeV (worse S/B)
- current theo. uncertainties on signal prod.
  (B. Anastasiou, R. Boughezal, F. Petriello / D. DeFlorian, M. Grazzini)
  - scale: -11%,+7%; PDF: +- 8-9% (taking MSTW)
  - note: pdf err. is 90% CL! MSTW error eigenvectors include alpha_s variation!
- Study how much lumi is needed to feed LHC info back into pdf determinations, in particular from Z rap, Z \( p_T \), W+/W-
H→WW at the Tevatron, NNLO

B. Anastasiou, GD, M. Grazzini, F. Stoeckli, B. Webber

arXiv:0905.3529

NNLO analysis of the H→WW→lνlν channel at the TEVATRON, with exp. cuts

theo. uncertainties of inclusive cross section and after dividing the sample into different jet-samples:
estimate up to a factor 2 larger theo. uncertainty compared to CDF and D0

Looked at kinematic distributions of leptons, and at selection efficiencies
(including isolation, MET, jet veto cuts)

MC@NLO and HERWIG not too far away from NNLO, PYTHIA lower by up to ~20%.

NNLO prediction of Neural Network output, with leptonic (no hadronic) variables as input

see good description of shapes by MCs compared to NNLO

During one of the discussion sessions: question of inclusion of theo. uncert. in uncert. band of Tevatron exclusion plot? Should band be completely below the SM line?
H$\to$ 4f

M. Weber, A. Bredenstein, A. Denner, S. Dittmaier

**PROPHECY4F**: Monte Carlo generator for $H \to WW/ZZ \to 4f$
- complete $\mathcal{O}(\alpha)$ electroweak and $\mathcal{O}(\alpha_s)$ QCD corrections
- weighted and unweighted event generation
- code available

**Comparison HDECAY: $H \to W^*(*)W^*(*) \to \nu e^+\mu^-\bar{\nu}_\mu$**

Partial decay width

results relative to $H \to 4f$ leading order

Differences w.r.t. HDECAY also at the level of the Branching Ratio, to be checked

HDECAY
- includes leading 1 and 2-loop corrections for large $m_H$
- off-shell effects taken into account below threshold
New Ideas on tTH

“Totgesagte leben länger”

- Experimental challenges (after Analysis):
  - Poor signal to background ratio (~10%):
  - Very sensitive to background systematic uncertainties
- Fake b-pairing: the main problem is the b-jets exchange between top quarks and the Higgs:
  - Higgs purity (correct pairing) is ~30%
  - Higgs boson reconstructed with only one correct b-jet: ~55%
    (The other wrong jet is mainly coming from the top quarks)
- Reconstructed signal looks like the background:
  - Large tails and width in the bb invariant mass
  - No visible peak on top of physical background, side band extraction difficult
- **3 parallel efforts @ les Houches:** (to be included in Likelihood analysis)
  - New observables to improve s/b
  - Improve the correct b-quark pairing for signal and background
  - Boosted Higgs and Jet substructure
- “NLO/LO” issues with ttbb (presentation by S. Pozzorini, new NLO calc, large K-fac):
  - Repeat the work done with $R_j = 0.4$ instead of 0.8 and test jet veto
- ttH: 2 separate issues and only one has been focused on of late.
  - Discovery
  - Measurement of H couplings
New Ideas on tTH

Investigated observables:
- In $t\bar{t}$ spin correlation:
  - $\Delta \phi_{\text{lep-anti-b(anti-t)}}$
- Invariant mass of $t\bar{t}H$ system
- Minimum invariant mass of $b$-pair. (smaller in $t\bar{t}bb$ than in $t\bar{t}H$)
- many other variables (see wiki)…

Delta-Phi has separating power ($S/B$), it also reduces the combinatorics, and should be rather insensitive to HO corr (and also exp. syst ?)

Rohini Godbole, Samir Ferrag, Simon Dean, Matthew Schwartz, Fabio Maltoni, Fulvio Piccinini
Any other business (AOB)

Upcoming: alpha_s at LEP, from NNLO+NLLA
- Observe for some variables, such as Thrust
  - apparently still missing HO corrections (beyond NNLO)
  - in tuning of LO+PS MCs to LEP data: missing HO are (over-)compensated by adjusting some parameters --> leads in the end to underestimation of hadronization corrections --> “larger” alpha_s

New ideas on WH (Giacinto Piacquadio)
- look at H->bb, at high pT --> one fat (bb) jet, apply well adapted jet algos for sub-jet study

Project: Define and implement a common ROOT ntuple output format for NLO programs (starting with MCFM/tt)
- Joey Huston, Frank-Peter Schilling, Joanna Weng
- Twiki: http://www.lpthe.jussieu.fr/LesHouches09Wiki/index.php/ROOT_ntuples

Clear wish/need expressed for NLO+PS code for QCD di-jet production! (presentation on incl. jet prod. by Paolo Francavilla)
Some further comments

- My personal opinion: with whatever data we get, we should try to measure as many (ratios) of (combinations of) cross sections and observables as possible, in order to make sure that we have a consistent picture...

- News from the LHC...

- Big thanks to all contributors, those who helped to prepare the talk; apologies to those I haven’t mentioned, for things I forgot, things I didn’t get right, ....
Hopefully ...

A long story, but with a happy end.