Towards Precision Measurements in the Standard Model Sector in ATLAS

Interplay of detector learning phase and measurements of SM processes as the luminosity is cumulated.

Atlas TDR 1999: under major revision in preparation for 2008

Corinne Goy (CNRS/IN2P3)
Standard Model Measurements @14TeV

- A fruitful adventure in:
  - Insuring the grounds of the Standard Model:
    - $\sin^2(\theta_W)$, rad cor, EW cor
  - PDFs
  - Detailed knowledge of key ingredients:
    - Z, W, b, Top
    - Production mechanism
    - Branching Ratio
- SM @ 14 TeV:
  - New energy domain
  - Precision Top physics
  - SU(2) non-abelian nature: gauge couplings
  - Ultimate(?) precision on $M_W$

→ Controlled Predictions
A tool to understand:

- Detector response to muons, electrons, gamma, jets
- Improve/monitor the detector response
  - calibration: $Z \rightarrow e^+e^-$
  - alignment: $Z \rightarrow \mu^+\mu^-$
- Develop sophisticated method
  - b-tagging, missing Et, tau-id, multivariable analysis (NN, pdfs, boosted decision trees etc)
A tool to understand a new Energy Domain

- down to small $x$
- up to higher $Q^2$
- PDfs extrapolated
First & Ultimate Background for New Physics

- High-\(p_T\) QCD jets
- \(W, Z\) production
- Gluon-to-Higgs fusion (light)
- Squarks, Gluinos (\(m \sim 1\) TeV)

Physics Signature
LHC: some numbers

- **Startup Conditions /Commissioning (2008 ....)**
  - beam crossing: 75ns or less
  - luminosity from $10^{31}$ to $10^{32}$
  - pile-up negligible

- **~2009 conditions**
  - evolving to nominal conditions
  - crossing angle
  - designed beam crossing: 25ns
  - luminosity: $\sim 10^{33}$
  - pile-up

- **Onwards**
  - nominal conditions

**Detailed Parameters**

<table>
<thead>
<tr>
<th>ATLAS</th>
<th>ALICE</th>
<th>CMS</th>
<th>LHC-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>L(t)</td>
<td>7.32</td>
<td>6.23</td>
<td>7.13</td>
</tr>
<tr>
<td>L(t)1e28 cm-2s-1</td>
<td>0.78</td>
<td>0.68</td>
<td>0.78</td>
</tr>
<tr>
<td>/L(t) cm-2s-1</td>
<td>0.70</td>
<td>0.52</td>
<td>0.90</td>
</tr>
<tr>
<td>BKG 1</td>
<td>0.45</td>
<td>0.82</td>
<td>0.50</td>
</tr>
<tr>
<td>BKG 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$\rightarrow O(100 \text{ pb}^{-1})$

$\rightarrow O(10 \text{ fb}^{-1})$
• 2T Solenoid for inner tracker
• Tracker: silicon (pixel + strips) and TRT ($|\eta|<2.5$)
• Sampling calorimetry ($|\eta|<4.9$)
• Toroid system for muons
Z and W production

- Expected large production:
  - systematics are rapidly a potential limitation

- Production Mode
  - small x
  - gluon PDF: the least known

- NNLO / DGLAP extrapolation at small X

<table>
<thead>
<tr>
<th></th>
<th>(\sigma(\text{LO}))</th>
<th>(\varepsilon)</th>
<th>Evts/pb(^{-1})</th>
<th>Statistical Uncertainty pb(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>nb</td>
<td>%</td>
<td></td>
<td>1 week</td>
</tr>
<tr>
<td>• (Z \rightarrow e^+e^-)</td>
<td>1.65</td>
<td>~20</td>
<td>~350</td>
<td>5%</td>
</tr>
<tr>
<td>• (Z \rightarrow \mu^+\mu^-)</td>
<td>16.8</td>
<td>~20</td>
<td>~3500</td>
<td>2%</td>
</tr>
</tbody>
</table>

\(|\eta| < 2.5\)
Some Plots

- Typical W Selection:
  - e-ID
  - $P_t^{e,\mu} > 25$ GeV
  - $|\eta| < 2.5$
  - $P_t^{\nu} > 25$ GeV
  - no jet with $P_t > 20$ GeV
  - hadronic recoil < 30 GeV

- Typical Z Selection
  - opposite charge Muon Track
  - $P_t ^ {\mu} > 15$ GeV, 25 GeV
  - Isolation
  - $|\eta_{\mu}| < 2.5$

Clean Signal:
- efficiency → PDF
- calibration → Uniformity
- isolation → SUSY events
Tag&Probe efficiency

- Efficiency from Data:
  - $Z \rightarrow e^+e^-$, $Z \rightarrow \mu^+\mu^-$
  - reduced reliance on MC
  - 2 sources of uncertainties
    - statistical
    - background subtraction
    - comparison with MC Truth

- Application:
  - trigger
  - reconstruction
  - selection

- Dominant experimental error:
  - $\sim 1\%$ @ 50 pb$^{-1}$ (stat)
  - overlap region
PDFs

- Sensitivity to PDF not degraded after detector response
  - up to 8% on diff cross-section

- Improvement if experimental systematic error less than 4%
  - achievable

- Proof of principle:
  - 100 pb$^{-1}$ simulated W data
  - gluons parameter uncertainty reduced by 35% [ $xg(x)=x^{-\lambda}$ ]

hep-ex/0509002
Example: Ecal Calibration/Uniformity

- About a 12-18 months to reach nominal performance

Uniformity necessary for $H \rightarrow \gamma\gamma$
Example: Isolation a powerful tool

But in real condition control of:
- Electronic Noise
- Physics dependance : Bremstrahlung
- Eta/Phi dependance
- Underlying Events modelling
- Machine Noise / Pile-up

At the end a tool to clean new (other) physics signature:
- Z+jets
- SUSY events
pp -> W/Z + Jets / γ + Jets

- QCD Studies
- An application of Isolation criteria (trigger/offline) & sophisticated method

100 pb⁻¹

Relevant background for many new particles searches, top physics studies

First step in reducing jet energy scale uncertainties:
- recoil to Z/γ mass

JES : 2-3%

ATLAS preliminary in preparation

+ Multivariable analysis
A needless motivation for TOP Physics @LHC

Top in the Standard Model:
- The heaviest known particle
- The least known – limited by statistics of Tevatron

A top factory: $10^6$ events per fb$^{-1}$

- 4 jets $p_T > 40$ GeV
- Isolated lepton $p_T > 20$ GeV $\equiv$ trigger
- $p_T^{\text{miss}} > 20$ GeV

early data, no b tagging
**TOP Physics (cont’)**

- **Precision Top Physics:**
  - mass +/- 1 GeV (ultimately) seems feasible.
  - b jet scale.

- **B tagging:**
  - Event fully reconstructed

- **(Final) Jet Energy Scale:**
  - W mass constraint

- **LHC New Physics Signature**
T (and more) GC

Effective couplings independent of underlying theory

Fake gamma rate
Tails’ description

Neutral TGC : 0 in SM
With 100 fb$^{-1}$: sensitivity to $10^{-3}$ to $10^{-4}$
Tevatron $\sim 10^{-1}$ to $10^{-3}$ / Weak LEP limit

See Detailed Talk by Alan Wilson

<table>
<thead>
<tr>
<th>Vertex</th>
<th>Coupling</th>
<th>Present Value (LEP &amp; Tevatron)</th>
<th>Atlas Sensitivity (95% CL, 30 fb$^{-1}$ one experiment)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WWZ</td>
<td>$\Delta g_1^Z$</td>
<td>$-0.016 \pm 0.022 / 0.019$</td>
<td>$-0.003 - 0.016$</td>
</tr>
<tr>
<td></td>
<td>$\lambda_Z$</td>
<td>$-0.088 \pm 0.063/0.061$</td>
<td>$-0.008 - 0.005$</td>
</tr>
<tr>
<td></td>
<td>$\Delta\kappa_Z$</td>
<td>$-0.076 \pm 0.061/0.64$</td>
<td>$-0.069 - 0.131$</td>
</tr>
<tr>
<td>WW$\gamma$</td>
<td>$\lambda_\gamma$</td>
<td>$-0.028 \pm 0.020/0.021$</td>
<td>Stat limited $300$ fb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td>$\Delta\kappa_\gamma$</td>
<td>$-0.027 \pm 0.044/0.045$</td>
<td></td>
</tr>
</tbody>
</table>

LEPEWWG/TGC/2005-01

ATLAS preliminary in preparation
Determination of $\sin^2 \theta_W(M_Z^2)$

- $Z$ decay asymmetric:
  \[ \frac{1}{\sigma} \frac{d\sigma}{d \cos \theta} = \frac{3}{8} N_c [1 + \frac{4}{3} A_{FB} \cos \theta + \cos^2 \theta] \]

- $A_{FB} = b \{ a - \sin^2 \theta_W(M_Z^2) \}$
  
  $a$, $b$ calculated to NLO QED and QCD

- Selection:
  - at least 1 electron in central region > charge
  - $P_T > 20$ GeV
  - Mass window $M_Z \pm 6$ GeV
  - Missing Et cut < 20 GeV
\( \sin^2(\vartheta_W) \) (cont’)

| y cuts – \( e^+e^- \) (|y(Z)| > 1) | \( A_{FB\%} \) | \( \Delta A_{fb \text{ stat}} \) |
|--------------------------------|----------------|-----------------|
| | 100 fb\(^{-1} \) |
| | 3.0 x 10\(^{-4} \) | 4.0 x 10\(^{-4} \) |
| | 2.3 x 10\(^{-4} \) | 1.4 x 10\(^{-4} \) |

- Systematic due to PDF
  - under more complete study
  - effect of Higher Order

World average error: 1.6x10\(^{-4} \)

Electron in Forward region:
- \( \text{etmiss} \)
- new phys signature
THE precision measurement: $M_W$

$$m_W^2 = \frac{\pi \alpha_{em}}{\sqrt{2} G_F \sin^2 \theta_W (1 - \Delta r)}$$

- Current error:
  - CDF Run II: 48 MeV
  - WA: 25 MeV
- Aim: $M_W < 15$ MeV
- Observables sensitive to $M_W$
  - Lepton Transverse Momentum
  - Transverse Mass

Sensitivity from the Edge:
- Energy Scale
- Resolution
- QED rad

Background:
- Pileup
- Underlying events

Acceptance:
- PDFs $|\eta_l| < 2.5$
Exemple : Energy Scale

- Systematics controls from the (huge) Z sample:
  - precise Mass (LEP): $2 \times 10^{-5}$
  - similar production mechanism
  - similar phase space

<table>
<thead>
<tr>
<th>Channel</th>
<th>$W \rightarrow l\nu$</th>
<th>$Z \rightarrow l\bar{l}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross-section (pb)</td>
<td>19800</td>
<td>1870</td>
</tr>
<tr>
<td>Lepton $\eta$ acceptance</td>
<td>0.63</td>
<td>0.51</td>
</tr>
<tr>
<td>Trigger &amp; Selection eff.</td>
<td>$\sim 0.2$</td>
<td>$\sim 0.2$</td>
</tr>
<tr>
<td>Expected statistics (10 fb$^{-1}$)</td>
<td>$4 \times 10^7$</td>
<td>$3.5 \times 10^6$</td>
</tr>
</tbody>
</table>

**LEP : $\sim 4 \times 10^6$ Z / exp**

- Additional data sets: E/p

5-11/01/2008 LHC New Physics Signature 21
### Conclusions: The Ground to New Physics

<table>
<thead>
<tr>
<th>O(10pb-1)</th>
<th>W/Z</th>
<th>Calibration /Alignment Lepton ID Missing Et Isolation</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>O(100pb-1)</td>
<td>W/Z + jets Top physics</td>
<td>PDfs B tagging, missing Et “Multi Variables” analysis</td>
<td></td>
</tr>
<tr>
<td>O(1fb-1)</td>
<td>Precision Top Physics TGC</td>
<td>In Situ Final Jets Calibration Full detector understanding</td>
<td>2009</td>
</tr>
<tr>
<td>O(100fb-1) and more</td>
<td>sin²(θ) $M_W$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Solid Grounds for New Physics Should be Established**
Di lepton (electron) spectrum

<table>
<thead>
<tr>
<th>Mass (TeV)</th>
<th>Nevt (1fb-1)</th>
<th>10 evts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>~160</td>
<td>~70 pb-1</td>
</tr>
<tr>
<td>1.5</td>
<td>~30</td>
<td>~300 pb-1</td>
</tr>
<tr>
<td>2</td>
<td>~7</td>
<td>1.5 fb-1</td>
</tr>
</tbody>
</table>

\[ Z' \rightarrow e^+ e^- \text{ with SM-like couplings} \]
Anyway a lot to learn from SM at the end