Looking for SUSY

35 pb\(^{-1}\) recorded in 2010

Colin Bernet (CERN, CNRS/LLR), for the CMS collaboration

Artist’s view
SUSY searches at hadron colliders

- Strong production of squarks and gluinos

- Here, direct decay to the lightest neutralino (LSP)
  - Off mass-shell squark

- Fully hadronic final state
  - High QCD background

Weakly interacting only
Cannot decay if:
- it is the lightest SUSY particle (LSP)
- R-parity conserved
  → Invisible (dark matter candidate)
SUSY searches at hadron colliders

- Strong production of squarks and gluinos

  Hadronic or leptonic cascade

  $\tilde{q}$ \rightarrow $\tilde{\chi}_1^0$ \rightarrow $\chi_1^0$ \rightarrow $W^-$ \rightarrow $l^-$

  $\tilde{g}$ \rightarrow $\tilde{\chi}_1^0$ \rightarrow $\chi_1^0$ \rightarrow $W^-$ \rightarrow $l^-$

- 1 lepton can appear
  - Less QCD background
  - Lower signal efficiency

- 2 leptons (opposite sign, same sign), and even more
  - Even less background
  - Even lower signal efficiency
The CMS Strategy

• Generic searches addressing most possible final states

• Robust physics objects
  – leptons, jets, missing momentum, \( \tau \)’s...

• Data-driven background prediction for all searches

• Well established statistical techniques

punch-line of this talk

15/03/2011 Moriond EWK, 2011
All Channels covered by CMS

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

c.f. Aspen

di-leptons

Opposite sign

e e μ μ e μ

Same sign

Lepton triggers

e e μ μ e μ

HT triggers

e e μ μ e μ
e τ μ τ τ τ

Multileptons

Lepton + photon

Z

Single lepton

ABCD

e μ

Lepton spectrum

e μ

R / MR (Razor)

e μ

Fully hadronic

Jets + MET

incl. b

R / MR (Razor)

e μ

c.f. Moriond QCD

2011 Moriond EWK, 2011
Outline

- Object reconstruction
- Multilepton searches
- 2-lepton searches
  - same sign + jets + “MET”
- 1-lepton search
  - e or mu + jets + “MET”
- 0-lepton search
  - jets + “MHT”
- Inclusive search
  - (e or mu) + jets, R & MR
- Limits / Interpretation
Physics objects definition

Highest MET multi-jet event recorded in 2010

$E_T^{miss} = MET = -\sum p_T$
All particles

$MHT = -\sum p_T$
Jets

$HT = \sum p_T$
Jets

$p_T = 214$ GeV
$p_T = 214$ GeV
$p_T = 393$ GeV
$p_T = 468$ GeV
$p_T = 57$ GeV

Reconstructed particles

MET = 647 GeV
MHT = 693 GeV

Factor 2 gained on MET resolution

55% \frac{\sqrt{\sum E_T}}{\sqrt{\sum E_T}}
Outline

- Object reconstruction

- Multilepton searches + jets, MET

- 2-lepton search
  - same sign + jets + “MET”

- 1-lepton search
  - e or mu + jets + “MET”

- 0-lepton search
  - jets + “MHT”

- Inclusive search
  - (e or mu) + jets, R & MR

- Limits / Interpretation
**Multi-Leptons: e, µ, τ**

- **Baseline selection:**
  - 3+ isolated leptons, \( p_T > 8 \text{ GeV/c} \)
  - 2 search regions:
    - MET > 50 GeV OR
    - HT > 200 GeV
  - 55 independent channels

GMSM: LSP = gravitino
If NLSP = sleptons:

\[
2 \times (\chi^0 \rightarrow \tilde{l}^+ \tilde{l}^- \rightarrow ggll)
\]

Copious source of 4 lepton events

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Background prediction and results table in back-up

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03/12/11 Moriond p1

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95% C.L. Limits:
- LO observed
- NLO observed
- NLO expected ± 1σ
- NLO expected ± 2σ

CMS
- \( L_{\text{int}} = 35 \text{ pb}^{-1}, \sqrt{s} = 7 \text{ TeV} \)

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Excluded

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300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
300 400 500 600 700 800 900
Gluino Mass (GeV/c^2)
Chargino Mass (GeV/c^2)
2 Leptons, same sign

- **Baseline selection:**
  - 2 same sign, isolated leptons (e or μ)
    - $p_T,1 > 20$, $p_T,2 > 10$ GeV
  - ≥ 2 jets:
    - $p_T > 30$ GeV, $|\eta| < 2.5$
  - MET:
    - > 30 GeV (ee and μμ)
    - > 20 GeV (eμ)

- **Main backgrounds:**
  - tt̄ (lepton from b)

<table>
<thead>
<tr>
<th></th>
<th>expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET&gt;80 GeV</td>
<td>1.2 ± 0.8</td>
<td>0</td>
</tr>
<tr>
<td>HT&gt;200 GeV</td>
<td>0.97 ± 0.74</td>
<td>1</td>
</tr>
</tbody>
</table>

Lepton efficiency parametrization agrees with CMS simulation

Data-driven method in back-up
Outline

• Object reconstruction

• Multilepton searches

• 2-lepton searches
  – same sign + jets + “MET”

• 1-lepton search
  – e or mu + jets + “MET”

• 0-lepton search
  – jets + “MHT”

• Inclusive search
  – (e or mu) + jets, R & MR

• Limits / Interpretation

• For each analysis:
  – Selection & main background
  – A nice idea in some details
  – Number of events expected and observed.
1 lepton

Analysis principles – the lepton spectrum method

- **Baseline selection:**
  - Isolated lepton:
    - \( p_T > 20 \) GeV
  - 4 jets:
    - \( p_T > 30 \) GeV, \( |\eta| < 2.4 \)

- **Main backgrounds**
  - \( \text{ttbar, } W\text{+jets} \).
  - Use the muon \( p_T \) spectrum to predict the \( \text{MET} \) spectrum
    - \( \text{MET} \) resolution and \( W \) polarization accounted for.

\*cMSSM: \( m_0 = 60 \) GeV, \( m_{1/2} = 250 \) GeV, \( A_0 = 0 \), \( \tan \beta = 10 \) and \( \text{sign}(\mu) > 0 \).
1 lepton

Results

<table>
<thead>
<tr>
<th></th>
<th>expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>$2.1 \pm 1.5$</td>
<td>2</td>
</tr>
<tr>
<td>$e$</td>
<td>$1.5 \pm 1.2$</td>
<td>0</td>
</tr>
</tbody>
</table>

Observation compatible with background prediction
Outline

- Object reconstruction
- Multilepton searches
- 2-lepton searches
  - same sign + jets + “MET”
- 1-lepton search
  - e or mu + jets + “MET”
- 0-lepton search
  - jets + “MHT”
- Inclusive search
  - (e or mu) + jets, R & MR
- Limits / Interpretation

For each analysis:
- Selection & main background
- A nice idea in some details
- Number of events expected and observed.
0 lepton: Jets + MHT

**Principle**

- **Baseline selection**
  - $\geq 3$ jets
    - $|\eta| < 2.5$
    - $p_T > 50$ GeV
  - $HT > 300$ GeV
    - $HT$ trigger fully efficient
  - Veto isolated $e$ or $\mu$
  - $\Delta \phi(j_{1,2}, \text{MHT}) > 0.3$
    - $\Delta \phi(j_3, \text{MHT}) > 0.5$
  - Event cleaning

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*Just an illustration. background prediction fully data-driven*

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15/03/2011

*\text{cMSSM: } m_0 = 60$ GeV, $m_{1/2} = 250$ GeV, $A_0 = 0$, $\tan \beta = 10$ and $\text{sign}(\mu) > 0.$*
0 lepton: Jets + MET

Background & Results

- **QCD**: next slide
- **Z → νν + jets**:  
  - Z → ll (W → lν + jets):  
    - Ignore leptons (correct for W/Z)  
    - Small stat, used as x-check  
  - γ + jets:  
    - Ignore photon, correct for γ/Z
- **W + jets (including top)**:  
  - μ + jets:  
    - Lost leptons:  
      - Ignore μ  
      - Use e-μ universality  
      - lepton ε corrected for, obtained from tag & probe  
    - W → τ hadronic decay  
      - Replace μ by simulated τ had.

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15/03/2011 Moriond EWK, 2011

<table>
<thead>
<tr>
<th>MHT&gt;250 GeV</th>
<th>expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHT&gt;250 GeV</td>
<td>18.8 ± 3.5</td>
<td>15</td>
</tr>
</tbody>
</table>

15/03/2011

* cMSSM: \( m_0 = 60 \text{ GeV}, m_{1/2} = 250 \text{ GeV}, A_0 = 0, \tan \beta = 10 \) and sign(μ) > 0.
Jet resolution distributions from simulation, and corrected using data:
- di-jet asymmetry,
- photon + jet

Closure in the simulation: 20% in the MHT tail
Outline

• Object reconstruction

• Multilepton searches

• 2-lepton searches
  – same sign + jets + “MET”

• 1-lepton search
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• 0-lepton search
  – jets + “MHT”

• Inclusive search
  – (e or mu) + jets, R & MR

• Limits / Interpretation

• For each analysis:
  – Selection & main background
  – A nice idea in some details
  – Number of events expected and observed.
0 or 1 lepton: $R & MR$

$MR$ definition: Signal

$\frac{p}{2} = \frac{M_{\Delta}}{2} = \frac{1}{2} \frac{M_{G}^{2} - M_{\chi}^{2}}{M_{G}}$

Centre of mass frame

- 2 massive particles:
  - produced at rest
  - decaying to a visible and an invisible part

Lab frame

Boost back to the frame where the momentum of the 2 jets is equal

$M_{R} \equiv 2p$

is peaking

http://arxiv.org/abs/1006.2727v1
0 or 1 lepton: $R & M_R$

$M_R$ definition: QCD di-jet

$P = \frac{\sqrt{s}}{2}$

Centre of mass frame

two jets, back to back

Boost

Lab frame

Boost back to the frame where the momentum of the 2 jets is equal

More than 2 objects?
Build 2 “hemispheres”

$M_R \equiv 2P = \sqrt{s}$

falls as a power law
0 or 1 lepton: \( R & M_R \)

New discriminating variables

\[ R = \frac{M_R^T}{M_R} \]
Max value: 1

Removes QCD

Background Shapes and normalization extracted from data

CMS Preliminary, Simulation

Peaking for signal

\[ M_R \sim M_\Delta = \frac{M_q^2 - M_{\chi}^2}{M_q} \]
0 or 1 lepton: $R&M_R$

**Results**

<table>
<thead>
<tr>
<th></th>
<th>$R$ cut</th>
<th>$M_R$ cut</th>
<th>Expected</th>
<th>Observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>MU</td>
<td>0.45</td>
<td>500</td>
<td>$0.51 \pm 0.20$</td>
<td>3</td>
</tr>
<tr>
<td>ELE</td>
<td>0.45</td>
<td>500</td>
<td>$0.63 \pm 0.23$</td>
<td>0</td>
</tr>
<tr>
<td>HAD</td>
<td>0.5</td>
<td>500</td>
<td>$5.5 \pm 1.4$</td>
<td>7</td>
</tr>
</tbody>
</table>

3 different searches.

Background in HAD box predicted using MU box.

No excess observed.
Outline

• Object reconstruction

• Multilepton searches

• 2-lepton searches
  – same sign + jets + “MET”

• 1-lepton search
  – e or mu + jets + “MET”

• 0-lepton search
  – jets + “MHT”

• Inclusive search
  – (e or mu) + jets, R & MR

• Limits / Interpretation

• For each analysis:
  – Selection & main background
  – A nice idea in some details
  – Number of events expected and observed.
Limits in the cMSSM

“jets+MHT” fully hadronic analysis

- ATLAS observed limit
- good agreement between expected and observed limit
- $\alpha_T$ analysis:
  - designed for fast discovery (QCD killer)
    - submitted beg. Jan
    - accepted last week
Limits in the cMSSM
“jets+MHT” fully hadronic analysis

Same plot as in prev. slide. Stretched for easy comparison with the next one.
Limits in the CMSSM

“R&MR” fully hadronic analysis

- Roughly the same limits as for the “jets + MHT” analysis
- Complementary
- Full scan up to $m_0 = 1$ TeV on the way
Limits in the CMSSM

1 lepton + jets
Simplified Models

Focus on the topology, put a limit on cross-section

Combining results for:
- $\alpha_T$
- jets + MHT
- $R$ & $MR$

Example: for this LSP and gluino mass, excluding all models giving $\sigma > 0.5 \text{ pb}^{-1}$
• Data-driven background predictions
  – stat error will decrease
  – relatively easy to adapt to different conditions
    • e.g. increased pile-up

• Many cross-checks

• Well established statistical methods

Looking forward to more of these events
All Channels covered by CMS

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

c.f. Moriond QCD

c.f. Aspen

Di-leptons
- Opposite sign
  - ee
  - μμ
  - eμ

- Same sign
  - Lepton triggers
    - ee
    - μμ
    - eμ

  - HT triggers
    - ee
    - μμ
    - eμ
    - eτ
    - μτ
    - ττ

Multileptons
- Single lepton
  - ABCD
    - e
    - μ

- Z
  - lepton + photon

- (di-)photons
  - Fully hadronic
    - αT incl.
    - b incl.

- Jets + MET
  - incl.
  - b incl.

R / MR (Razor)

R / MR (Razor)
Back-up
Multi-Leptons: e, μ, τ

More details

**Background prediction**

- **Z+jets:**
  - Channels without τ
    - fake lepton from a jet
    - dijet events $\rightarrow$ probability $f$ for an isolated track to fake a lepton
    - Background prediction: $N_{\text{di-lepton}} \cdot f \cdot N_{\text{tracks}}$
  - Channels with τ
    - Isolation sideband
- **ttbar and VV+jets**
  - Small contribution, well controlled in simulation
  - ttbar simulation controlled on OS-OF events in data

**Systematic errors**

- Shared by all channels
  - luminosity: 11%
  - renormalization scale: 10%
  - pdfs: <14%
  - trigger efficiency: 5%
- Lepton efficiency from tag & probe:
  - muons: 1.5 to 3%
  - electrons: up to 10%
  - tau: up to 30% (stat limited)
- Jet energy scale (HT): < 14%
# Multi-Leptons: $e$, $\mu$, $\tau$

Backgrounds, expected signals, observed events

<table>
<thead>
<tr>
<th>Channel</th>
<th>After Lepton ID Requirement</th>
<th>Inclusive</th>
<th>Hadronic</th>
<th>ML01 Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Z+\text{jets}$</td>
<td>$t\bar{t}$</td>
<td>$VV+\text{jets}$</td>
<td>$\Sigma$SM</td>
</tr>
<tr>
<td>$ll(OS)e$</td>
<td>1.7</td>
<td>0.1</td>
<td>1.2</td>
<td>4.4 $\pm$ 1.5</td>
</tr>
<tr>
<td>$ll(OS)\mu$</td>
<td>2.83</td>
<td>0.2</td>
<td>1.7</td>
<td>4.7 $\pm$ 0.5</td>
</tr>
<tr>
<td>$ll(OS)T$</td>
<td>121.5</td>
<td>0.5</td>
<td>0.7</td>
<td>123 $\pm$ 16</td>
</tr>
<tr>
<td>$ll(OS)\tau$</td>
<td>476</td>
<td>2.7</td>
<td>3.9</td>
<td>484 $\pm$ 77</td>
</tr>
<tr>
<td>$ll'T$</td>
<td>0.72</td>
<td>0.5</td>
<td>0.2</td>
<td>1.7 $\pm$ 0.7</td>
</tr>
<tr>
<td>$ll'T$</td>
<td>4.7</td>
<td>2.9</td>
<td>0.6</td>
<td>11.2 $\pm$ 2.5</td>
</tr>
<tr>
<td>$ll(SS)'l$</td>
<td>0.13</td>
<td>0.1</td>
<td>0.0</td>
<td>0.2 $\pm$ 0.1</td>
</tr>
<tr>
<td>$ll(SS)T$</td>
<td>0.25</td>
<td>0.0</td>
<td>0.1</td>
<td>0.7 $\pm$ 0.4</td>
</tr>
<tr>
<td>$ll(SS)\tau$</td>
<td>1.4</td>
<td>0.0</td>
<td>0.1</td>
<td>3.0 $\pm$ 1.1</td>
</tr>
<tr>
<td>$\Sigma llT(T)$</td>
<td>127.1</td>
<td>1.4</td>
<td>3.8</td>
<td>135 $\pm$ 16</td>
</tr>
<tr>
<td>$\Sigma llT(\tau)$</td>
<td>486.8</td>
<td>6.0</td>
<td>7.5</td>
<td>507 $\pm$ 77</td>
</tr>
<tr>
<td>$llTT$</td>
<td>47.1</td>
<td>0.33</td>
<td>0.1</td>
<td>48 $\pm$ 9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Channel</th>
<th>4-lepton channels</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$llll$</td>
<td>0</td>
<td>0</td>
<td>0.2</td>
<td>0.2 $\pm$ 0.1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>163.9</td>
<td>149.2</td>
</tr>
<tr>
<td>$llT$</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.1 $\pm$ 0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>62.3</td>
<td>–</td>
</tr>
<tr>
<td>$llT$</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.1 $\pm$ 0.1</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>33.2</td>
</tr>
<tr>
<td>$llTT$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.0 $\pm$ 0.1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>$llT$</td>
<td>8</td>
<td>1.1</td>
<td>0.1</td>
<td>3.2 $\pm$ 0.7</td>
<td>5</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>16.8</td>
</tr>
<tr>
<td>$\Sigma llT(T)$</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>0.3 $\pm$ 0.1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>246.8</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>$\Sigma llT(\tau)$</td>
<td>3</td>
<td>1.0</td>
<td>0.4</td>
<td>3.5 $\pm$ 0.7</td>
<td>5</td>
<td>–</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>199.2</td>
<td>–</td>
</tr>
</tbody>
</table>
2 Leptons, same sign

data-driven background estimation: single fake lepton

- all cuts applied
- but: one of the leptons not isolated $\Rightarrow$ N events
- prediction: $N \frac{\varepsilon_{\text{iso}}}{1 - \varepsilon_{\text{iso}}}$

- $\varepsilon_{\text{iso}}$ from “b tag & probe:
  - one b-tagged jet away from the lepton
    - dominated by QCD
  - reweight to the ttbar kinematics
2 Leptons, same sign

Figure 6: (Left) The probability to mismeasure the electron charge as a function of $\eta$ in the $P_T$ range 10–100 GeV, as obtained from Monte Carlo simulation. (Right) Same-sign $ee$ invariant mass distribution in data compared with $Z \rightarrow ee$ Monte Carlo expectations.
2 Leptons, same sign

Results, including tau channels

Table 2: Data and Monte Carlo yields summarized for all analyses.

<table>
<thead>
<tr>
<th>Search Region</th>
<th>ee</th>
<th>μμ</th>
<th>eμ</th>
<th>total</th>
<th>95% C.L. UL Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lepton Trigger</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E_T &gt; 80$ GeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td>0.05</td>
<td>0.07</td>
<td>0.23</td>
<td>0.35</td>
<td>(7.3 for LM0)</td>
</tr>
<tr>
<td>BG predicted</td>
<td>0.23 ± 0.35</td>
<td>0.23 ± 0.26</td>
<td>0.74 ± 0.55</td>
<td>1.2 ± 0.8</td>
<td></td>
</tr>
<tr>
<td>observed</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>$H_T &gt; 200$ GeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td>0.04</td>
<td>0.10</td>
<td>0.17</td>
<td>0.32</td>
<td>(9.6 for LM0)</td>
</tr>
<tr>
<td>BG predicted</td>
<td>0.71 ± 0.58</td>
<td>0.01 ± 0.24</td>
<td>0.25 ± 0.27</td>
<td>0.97 ± 0.74</td>
<td></td>
</tr>
<tr>
<td>observed</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

| **HT Trigger**      |      |      |      |       |                   |
| **Low-p_T**         |      |      |      |       |                   |
| MC                  | 0.05 | 0.16 | 0.21 | 0.41  | (9.1 for LM0)     |
| BG predicted        | 0.10 ± 0.07 | 0.30 ± 0.13 | 0.40 ± 0.18 | 0.80 ± 0.31 |                   |
| observed            | 1    | 0    | 0    | 1     |                   |
| **τ enriched**      |      |      |      |       |                   |
| MC                  | 0.36 | 0.47 | 0.08 | 0.91  | (2.0 for LM0)     |
| BG predicted        | 0.10 ± 0.10 | 0.17 ± 0.14 | 0.02 ± 0.01 | 0.29 ± 0.17 |                   |
| observed            | 0    | 0    | 0    | 0     | (3.4             |

Additional cuts for HT trigger:
- HT>300 GeV
- MET>30 GeV
- HT>350 GeV
- MET>50 GeV

The HT trigger allows to reach low pT leptons and taus
1 lepton search

More on the lepton spectrum method

- $W$ polarization very well known for ttbar [1]
- Not the case for $W$+jets
  - polarized pdf uncertainty
- No need to correct for $W$ polarization to get MC closure in this analysis

$$f_{\lambda=0} = 0.687 \pm 0.005,$$
$$f_{\lambda=-1} = 0.311 \pm 0.005,$$
$$f_{\lambda=+1} = 0.0017 \pm 0.0001$$

0 lepton: Jets + MET

Rebalance+smear QCD prediction: closure test

- lack of closure taken into account as a systematic error
Data-driven background estimation

Same slope for
- $Z \rightarrow ll +$ jets
- 1$^\text{st}$ W + jets component

The lepton enters the computation of R and MR

Slope directly measurable

Data/MC correction to $1^\text{st}$ W+jets slope
Z + jets slope

Data/MC correction to $2^\text{nd}$ W+jets slope
Top+X slope

Same slope for
- Top+X
- 2$^\text{nd}$ W + jets Component
- $Z \rightarrow \nu \nu$ in HAD Box

The lepton does not enter R and MR

Slope measured by ignoring the lepton

15/03/2011  Moriond EWK, 2011
R&MR

Data-driven background estimation

- W+jets dominated (>90%)
- Fit with 2 exponentials
- Extract the 1st component

- Plot as a function of (R cut)^2
- Correction factors:
  - p0 (data) / p0 (MC)
  - p1 (data) / p1 (MC)
Reconstructed Particle Jets

An event recorded in 2010

Showing jets with $p_T > 50$ GeV/c

$p_T = 393$ GeV
$p_T = 57$ GeV
$p_T = 468$ GeV
$p_T = 214$ GeV

$p_T = 393$ GeV
$p_T = 57$ GeV
$p_T = 468$ GeV
$p_T = 214$ GeV
Intervals and Limits for a Physically Bounded $\mu$

- Prototype: measurement $x$ is unbiased Gaussian estimate of $\mu$. (Let $\sigma=1$.) What is 95% C.L. Upper Limit (UL)?
- 1986: Six methods for UL surveyed by V. Highland (VH) include U.L. = max(0, $x + 1.64$) and U.L. = max(0,$x$) + 1.64.
- RPP 1986: Bayesian: uniform prior on the mean $\mu$ for $\mu \geq 0$, prior prob = 0 for $\mu < 0$. (VH’s other five not mentioned.)
- 1994,96: 3 ad-hoc frequentist recipes, one using max($x,0$).
- 1998: Feldman & Cousins (FC) “Unified Approach” in (Kendall and Stuart) replaces ad hoc frequentist
- 2002: CLS from LEP added to Bayesian and FC.
- CMS Statistics Committee recommends using (at least) one of the three (red) methods in 2002-present PDG RPP.
- ATLAS SC method implies U.L. = max(0, $x + 1.64$) before power constraint (PC), U.L. = max(-1,$x$) + 1.64 after PC.
Comparison of ATLAS PCL with the three methods in PDG

ATLAS PCL re-opens discussion on use of diagonal line along with ad hoc constraint, out of favor for many years, not recommended by CMS SC.

CMS and ATLAS SC’s are reviewing arguments and what has been learned in 25+ years. Academic statisticians have commented as well.

Just tip of iceberg: Poisson example brings in other issues. Nuisance parameters yet more. Choice of test statistic varies.

(Atlas unconstrained U.L. is zero, not null, for $x < -1.64$)
$\alpha_T$ fully hadronic analysis

$\alpha_T$ variable

- The $\alpha_T$ analysis was optimized for fast discovery
  - goal was: kill QCD
  - first LHC SUSY paper

\[
\alpha_T = \sqrt{\frac{E_{T,2}}{2 E_{T,1} (1 - \cos(\phi))}}
\]

QCD:
- $\alpha_T = 0.5$ if jets are back-to-back and well measured
- $\alpha_T < 0.5$ if energy mismeasurement
\( \alpha_T \) fully hadronic analysis

Data-driven background estimation

- **Inclusive**: \( \alpha_T \) ratio
- **Z\(\rightarrow\)\(\nu\nu + \)jets:**
  - \( \gamma + \)jets:
    - Ignore photon, correct for \( \gamma/Z \)
  - \( W\rightarrow l\nu + \)jets x-check
- **W + jets (incl. top):**
  - Select a \( \mu + \)jets sample in data and MC passing the final selections
  - Number of events in search region:

\[
N_{W; \text{had}}^{\text{data}} = \frac{N_{W; \text{had}}^{W; \mu}}{N_{W; \mu}^{\text{MC}}} N_{W; \mu}^{\text{MC}} \approx 0.86 \times N_{W; \mu}^{\text{data}}
\]