Forward Physics at CMS

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(on behalf of the CMS collaboration)

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Outline

- **Forward Energy Flow Measurement**
  - Physics Motivation
  - CMS Detector
  - Analysis Strategy and Event Selection
  - Forward Energy Flow Measurement and MC Comparison

- **Forward Jets Reconstruction**
  - Physics Motivation
  - Event and Jet Selection
  - Jet Size and Shape
  - $p_T$ and $\eta$ Spectrum

- **Conclusion**
Measurement of the Forward Energy Flow at different $\sqrt{s}$
(900 GeV, 2.36 TeV and 7 TeV)
[CMS PAS FWD-10-002]
Physics Motivation (I)

• Forward region probes small $x$ content of the proton
  • parton densities might become very large
  • probability for more than one partonic interaction per event should increase

→ Measurement of the forward energy flow sensitive to
  • the modelling of parton radiation at large $\eta$
  • the description of the multiparton interaction

increasing $\sqrt{s}$
decreasing $x$
Physics Motivation (II)

• Energy flow as a function of $\eta$ at $\sqrt{s} = 7$ TeV for MB events and for events with a central dijet with $E_{T,jet} > 20$ GeV and $|\eta| < 2.5$

• Predictions from PYTHIA using 2 sets of parameters tuned to describe TEVATRON data in central region (D6T and Perugia), together with predictions without multiparton interaction → Significant difference in the forward region $|\eta| > 3$

Input from forward measurement complementary to central studies to constrain MPI
CMS Detector
Hadronic Forward calorimeters (HF)

- Located at 11.2 m from IP on both sides of CMS
- Rapidity coverage $2.9 < |\eta| < 5.2$
- Cerenkov calorimeter made of steel absorbers and embedded radiation-hard quartz fibers, light from the fibers detected by PMT
- 2 types of fibers: long (run over the full depth) and short (start at 22 cm from the front of HF) → possible to distinguish showers generated by $e/\gamma$ from showers generated by hadrons
- 13 rings in $\eta$ with a segmentation $\Delta \eta = 0.175$ (except for the 2 most inner rings and the most outer one)
• Beam Scintillator Counters BSC1
• located at ± 10.86 m from IP
• each BSC is a set of 16 tiles
• designed to provide hits and coincidence rates

• Beam Pick-up Timing for the eXperiments BPTX
• designed to provide precise info on the bunch structure and timing of the incoming beam
Analysis Strategy and Event Selection

• Forward energy flow measured at 3 different $\sqrt{s}$ in 2 event classes
  • Minimum Bias events
  • Events with a hard scale provided by a central dijet system

• Minimum Bias events selection
  • Trigger signal in each of the BSC in coincidence with a signal from both BPTX (reject large fraction of diffractive events)
  • Good primary vertex
  • Rejection of beam halo candidates & beam background events
  • Rejection of events with large and isolated signal in HF
  • Sum all energy deposits in HF above noise threshold of 4 GeV

• Dijet events selection
  • Jets reconstructed by anti-$k_T$ jet algorithm ($R = 0.5$)
  • At least two leading jets with $|\eta| < 2.5$ & $|\Delta\phi (j1,j2) - \pi| < 1$
  • $p_T > 8$ GeV ($\sqrt{s} = 900$ GeV or 2.36 TeV), $p_T > 20$ GeV (7 TeV)
Energy flow - MB - 900 GeV & 2.36 TeV

- Main systematic uncertainty: global HF energy scale: 15 %
- At $\sqrt{s} = 900$ GeV & 2.36 TeV: data best described by D6T PHOJET below the data
- At $\sqrt{s} = 900$ GeV: PROQ20, P0 below the data
Energy flow - Dijet - 900 GeV & 2.36 TeV

- At $\sqrt{s} = 900$ GeV & 2.36 TeV: D6T too high compared to data, PHOJET too low
- At $\sqrt{s} = 900$ GeV: P0 below the data, data best described by PROQ20
• **MB at $\sqrt{s} = 7$ TeV:** prediction below the data for all PYTHIA6 tunes
  - PYTHIA8 also below the data, close to PROQ20

• **Dijet at $\sqrt{s} = 7$ TeV:** data again best described by PROQ20
  - PYTHIA8 reasonable description
  - D6T too high, P0 and PHOJET too low
Forward Jets in proton – proton Collisions at $\sqrt{s} = 7$ TeV

[CMS DPS-2010/026]
Physics Motivation

• Jet production has never been investigated in such a forward region as the one covered by the CMS HF calorimeter

→ first measurement of forward jets in the range $3.2 < |\eta| < 4.7$

• Forward jets probe the low $x$ region

• First step: validate jet reconstruction in the forward region
Event and Jet Selection

• Event selection similar to the Minimum Bias event selection

• Integrated luminosity $L \approx 10 \text{ nb}^{-1}$

• Jet reconstructed by anti-$k_T$ jet algorithm ($R = 0.5$)

• Jet energy corrected

• $35 < E_T < 120 \text{ GeV}$

• $3.2 < |\eta| < 4.7$
Jet Size and Shape

- Look at size and shape of calorimeter jets through the distribution of the transverse energy flow $E_T$ around jet axis
- sensitive test of the description of data by MC (PYTHIA6 D6T)

$\sqrt{s}=7$ TeV, $3.2 < |\eta_{\text{CaloJets}}| < 4.7$

CMS Preliminary

$\Delta\eta = |\eta_{\text{CaloTower}}| - |\eta_{\text{CaloJets}}|$

$\Delta\phi = \phi_{\text{CaloTower}} - \phi_{\text{CaloJet}}$

→ transverse energy flow $E_T$ inside the jets well described by MC
\( p_T \) and \( \eta \) Spectrum

- 7 TeV data, detector level distributions
- no unfolding, no systematic uncertainties
  → reasonable agreement between data and MC (PYTHIA6 D6T)
- expected resolutions:
  - \( \sigma(p_T)/p_T \sim 15 \% \) at 20 GeV, \( \sim 12 \% \) at 100 GeV
  - \( \sigma(\Delta\eta), \sigma(\Delta\phi) \sim 0.035 \) at 20 GeV, \( \sim 0.025 \) at 100 GeV
Conclusion

• First measurement in hadron-hadron collisions of the forward energy flow in the region $3.15 < |\eta| < 4.9$, for MB events and for events with a hard scale defined by a central dijet system.

• Increase with $\sqrt{s}$ reproduced by MC for dijet events, not for MB events → strongest increase in data than in the MC (for all tunes).

• None of the MC can describe all the measurements in all aspects, MB data energy flow at 7 TeV larger than any MC predictions.

• MC tunes giving best description in forward region ≠ those giving best description of charged particle spectra in central region (DW) → forward region provides further input for MC tuning constrains parton radiation modelling at large $\eta$.

• Measurement of forward jets in the HF acceptance and validation of the forward jet reconstruction with 7 TeV data.
Back Up
Minimum Bias Events Selection

• Trigger signal in each of the BSC scintillators in coincidence with a signal from both BPTX detectors

• Primary vertex with $|z| < 15$ cm
  transverse distance from z axis < 2 cm
  at least 3 tracks used in the vertex fitting

• Rejection of beam halo candidates

• Rejection of beam background events (fraction of high-quality tracks > 25 % for events with more than 10 tracks)

• Noise threshold of 4 GeV for the uncorrected energy in HF (value determined through measurement of energy deposits in HF in non-interaction events)

• Rejection of events with large and isolated signal in HF consistent with noise (charge particle traversing a PMT window)
## Statistics – PMT hits – Diffraction

<table>
<thead>
<tr>
<th>√s</th>
<th>900 GeV</th>
<th>2.36 TeV</th>
<th>7 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB sample</td>
<td>177475</td>
<td>10245</td>
<td>3713294</td>
</tr>
<tr>
<td>Dijet sample</td>
<td>433</td>
<td>86</td>
<td>4292</td>
</tr>
<tr>
<td>PMT hits</td>
<td>1117</td>
<td>84</td>
<td>56425</td>
</tr>
<tr>
<td>fraction SD-DD in MB sample</td>
<td>5%</td>
<td>4%</td>
<td>2%</td>
</tr>
</tbody>
</table>
Systematic Uncertainties

• Main systematic uncertainty: global HF energy scale: 15 % (MB energy flow measured separately in HF+ and HF-: Δ < 10 %)

• Channel-by-channel miscalibration: channel response randomly varied between ±15% → effect on energy flow < 1 %

• Influence of remaining calorimetric noise: noise threshold in HF increased to 4.5 GeV → effect on energy flow ~ 2 %

• Influence of remaining noise from PMT hits: alternative rejection algorithm is used → effect on energy flow < 3 %

• η measured wrt origin of CMS reference system: for events with a vertex far from that point, energy flow is shifted → estimate this effect by dividing the sample in 3: |z| < 4 cm, 4 < |z| < 9 cm, 9 < |z| < 15 cm → effect on energy flow < 1 %
PYTHIA MPI tunes

• Perturbative 2-to-2 partonic cross-section is regularized in PYTHIA by the introduction of a cutoff $p_{T0}$:

$$\sigma \propto \frac{1}{(p_T^2 + p_{T0}^2)^2}$$

• $p_{T0}$ governs the description of the amount of MPI: larger MPI activity for smaller values of $p_{T0}$

• $p_{T0}(\sqrt{s}) = p_{T0}(\sqrt{s_0}) (\sqrt{s}/\sqrt{s_0})^\epsilon$

<table>
<thead>
<tr>
<th></th>
<th>$p_{T0}(\sqrt{s_0})$</th>
<th>$\sqrt{s_0}$</th>
<th>$\epsilon$</th>
</tr>
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<tbody>
<tr>
<td>D6T</td>
<td>1.84</td>
<td>1.96</td>
<td>0.16</td>
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<tr>
<td>PROQ20</td>
<td>1.9</td>
<td>1.8</td>
<td>0.22</td>
</tr>
<tr>
<td>P0</td>
<td>2.0</td>
<td>1.8</td>
<td>0.26</td>
</tr>
<tr>
<td>DW</td>
<td>1.9</td>
<td>1.8</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Integrated Luminosity 2010

92% data taking efficiency