Jet Results from CMS

Cosmin Dragoiu

University of Illinois at Chicago
(for the CMS Collaboration)

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The CMS detector
Jet reconstruction
  - Jet energy calibration
  - Jet energy resolution
Inclusive jet cross section
Dijet mass cross section
Dijet azimuthal decorrelations
Dijet angular distributions

More about jet performance and multijet measurements at CMS in Joanna’s talk!
**CMS Detector**

**Tracking System** ($|\eta| < 2.5$)
- 10 layers (barrel): TIB (4L) + TOB (6L)
- 11 disks (endcap): TID (3D) + TEC (9D)

**Pixel** ($|\eta| < 2.5$)
- 3 layers (barrel)
- 2 disks (endcap)

**Muon System** ($|\eta| < 2.4$)
- 4 muon stations
- DT + RPC (barrel)
- CSC + RPC (endcap)

**Electromagnetic Calorimeter**
- EB ($|\eta| < 1.48$) + EE ($1.48 < |\eta| < 3.0$)
- Preshower ($1.65 < |\eta| < 2.6$)

**Hadronic Calorimeter**
- HB + HO ($|\eta| < 1.3$)
- HE ($1.3 < |\eta| < 3.0$)
- HF ($3.0 < |\eta| < 5.2$)

**CASTOR** ($5.2 < |\eta| < 6.6$)

**ZDC** ($|\eta| > 8.3$)

**Return Yoke**

**4T Magnet**
CMS 2010 DATA

- Delivered by LHC: 47/pb
- Recorded by CMS: 43/pb
- Data taking efficiency > 90%
  - with all subdetectors running > 85%
- Luminosity uncertainty: 4%
Jet Reconstruction

- Jet reconstruction algorithms available at CMS:
  - $k_T$, Anti-$k_T$
  - CMS default: Anti-$k_T$ $R = 0.5$ & $0.7$

**Calorimeter Jets**
- from calorimeter towers

**Track Jets**
- from tracks

**Jet plus Track**
- from calorimeter towers corrected using tracker information

**Particle Flow Jets**
- from identified particles using all detector components
Jet Energy Calibration

- Reconstructed Jet
  - Offset Correction
    - Removes pile-up and noise contributions
  - MC Correction ($\eta$ & $p_T$)
    - Flattens the jet response in $\eta$ and corrects the jet $p_T$ to particle level
  - Residual Correction ($\eta$ & $p_T$)
    - Accounts for the differences between data and MC (dijet $p_T$ balance, MPF method)

Calibrated Jet

- CMS-PAS-JME-10-010

Graphs showing data/MC comparisons and jet energy response plots.

- MC scaled for FSR and QCD bkg
- $\chi^2 / NDF = 14.2 / 12$
- CMS preliminary, $2.9 \text{ pb}^{-1}$
- $\sqrt{s} = 7 \text{ TeV}$

Absolute scale uncertainty [%]
- Total uncert.
- Total MPF
- Photon scale
- Extrapolation
- Offset (+1PU)
- Residuals

Data/MC
- CMS preliminary, $2.9 \text{ pb}^{-1}$
- $\sqrt{s} = 7 \text{ TeV}$
- $\chi^2 / NDF = 14.2 / 12$

Graph showing absolute scale uncertainty and data/MC comparison.
Jet Energy Resolution

CMS-PAS-JME-10-014

- Determined using the dijet asymmetry method (dijet $p_T$ balancing)
- The asymmetry is: $A = \frac{p_T^{jet1} - p_T^{jet2}}{p_T^{jet1} + p_T^{jet2}}$  
  Where $jet1$, $jet2$ - leading jets in the event (3rd jet $p_T \rightarrow 0$)
- The jet $p_T$ resolution is related to the width of the asymmetry distribution
  $$\frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$$

**Calorimeter Jets**

<table>
<thead>
<tr>
<th>$p_T$ [GeV]</th>
<th>jet $p_T$ resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>0.3</td>
</tr>
<tr>
<td>100</td>
<td>0.2</td>
</tr>
<tr>
<td>200</td>
<td>0.1</td>
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**Particle Flow Jets**

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Better resolution!
Represents an important test of the Standard Model

Extends up to $p_T$ of $1.1$ TeV and as low as $p_T$ of $18$ GeV when using particle flow jets

- NLO pQCD using NLOJET++
- Non-perturbative corrections (< 30%) from PYTHIA6 and HERWIG++

The data is corrected to particle level using an ansatz method
Inclusive Jet Production II

- Main experimental uncertainties:
  - Jet energy scale (3% to 5%)
  - Jet energy resolution (10% to 30%)
- Main theoretical uncertainties:
  - Scale ($\mu_r, \mu_f$) (5% to 10%)
  - PDF using PDF4LHC recipe (10%)

The data is compatible with NLO predictions!
Another important test of the Standard Model

The dijet invariant mass probes the proton momentum fractions of the scattering partons:

$$M_{JJ}^2 = x_1 \cdot x_2 \cdot s$$

The data is corrected to particle level

- Unfolding factors (0.95 to 0.98)

- NLO pQCD using NLOJET++

- Non-perturbative corrections (5% to 30%) from PYTHIA6 and HERWIG++

Using particle flow jets!

$$8 \cdot 10^{-4} \leq x_1 \cdot x_2 \leq 0.25$$
Main experimental uncertainties:
- Jet energy scale (15% to 60%)
- Jet energy resolution (1%)

Main theoretical uncertainties:
- PDF using PDF4LHC recipe (5% to 30%)
- Non-perturbative correction (2% to 15%)
- Scale ($\mu_r, \mu_f$) (2% to 32%)

Good agreement between data and NLO predictions!
\[ \Delta \varphi_{dijet} = |\varphi_{jet1} - \varphi_{jet2}| \]

- Measurement sensitive to higher order radiation without the need to reconstruct the radiated jets

- Systematic uncertainty (3% to 11%):
  - Jet energy scale (1% to 5%)
  - Jet energy resolution (1% to 5%)
  - Unfolding (1.5% to 8%)
  - Smearing (2.5%)

- Reasonable agreement between PYTHIA6, HERWIG++ and data

- MADGRAPH (PYTHIA8) predicts less (more) decorrelations than data
\[ \Delta \phi_{\text{dijet}} = |\phi_{\text{jet}1} - \phi_{\text{jet}2}| \]

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- \textbf{MADGRAPH (PYTHIA8)} predicts less (more) decorrelations than data
**Δφ Decorrelations II**

- **NLO pQCD predictions** using **NLOJET++**

- **Non-perturbative corrections** derived from **PYTHIA6** and **HERWIG++** (4% to 13%)

- **Theoretical uncertainty:**
  - Scale ($\mu_r, \mu_f$) (< 50%)
  - PDF using **CTEQ6.6** (2% to 9%)
  - Non-perturbative corrections (2% to 6%)

- NLO pQCD predictions mostly agree with data but undershoot the data for $\Delta\phi < 2\pi/3$ (effectively 2 $\rightarrow$ 4 LO)
Variation of ISR parameter PARP(67) in PYTHIA6

- D6T value 2.5 (tuned to D0 data)
- Change by ± 0.5 and ± 1.5

Sensitive to initial state radiation and mostly insensitive to final state radiation

- Changing PARP(67) by ± 0.5 → ± 30% change in $\Delta\phi$
  - Could be used to further tune ISR
Probes the parton-parton scattering angle

QCD predicts a relatively flat $\chi$ distribution while new physics (quark compositeness) is expected to produce an excess at low values of $\chi$

$$\chi_{dijet} = e^{y_1 - y_2} \sim \frac{1 + |\cos \theta^*|}{1 - |\cos \theta^*|}$$

The data is corrected to particle level (< 3%)

NLO pQCD predictions using NLOJET++

Non-perturbative corrections from PYTHIA6 and HERWIG++

Good agreement with pQCD predictions!
Experimental uncertainties (<3%):
- Jet energy scale (<2.5%)
- Jet energy resolution (<1%)
- Unfolding (<1%)

Theoretical uncertainties (<9%):
- Scale ($\mu_r, \mu_f$) (<9%)
- PDF using CTEQ6.6 (<0.5%)
- Non-perturbative correction (<4%)

Limits obtained using a modified $CL_s$ approach:
- Exclude $\Lambda^+ < 5.6$ TeV at 95% CL (expected $\Lambda^+ < 5.0$ TeV)
- Exclude $\Lambda^- < 6.7$ TeV at 95% CL (expected $\Lambda^- < 5.8$ TeV)
Summary

- LHC and CMS performed extremely well in 2010
- CMS has a rich jet physics program including precise QCD measurements and searches of new phenomena
- Many results are already submitted for publication or published
  - Analyses are already beginning to exceed the Tevatron reach
- High probability of reaching 1/fb in the coming months (25/pb already collected)
- Many new and interesting physics results are on the way
- All CMS public results can be accessed at:

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