Jet performance in CMS

EPS HEP 2013 Stockholm, 18 July 2013
QCD: Jet Physics

Henning Kirschenmann on behalf of the CMS Collaboration
Universität Hamburg
CMS detector (for jets)

$\eta = 0.0$

**Tracker:** Silicon Pixel and Strip detector
- 1.5% at 100 GeV
- 10% at 1000 GeV

**ECAL:** $PbWO_4$ Crystal calorimeter
- Photons (~60 GeV): 1.1-2.5% in the barrel

**HCAL:** Brass/scintillator ($|\eta| < 3$)

Central jets (with ECAL):
$$\frac{\sigma_{\text{Calo}}(E)}{E} \sim \frac{100\%}{\sqrt{E}} \oplus 5\%$$

**CMS specifics**
- Very precise tracker and ECAL
- Highly granular ECAL
- Strong magnetic field (3.8 T)
- Tracking and calorimeters contained within superconducting magnet
Particle Flow (PF) approach

- Tries to reconstruct individual particles to form jets using all subdetector information
- Commissioned successfully on data
- Used in most CMS analyses
Particle Flow improves jet energy resolution

- Large fraction of PF jet components well measured by ECAL/tracker
- Jet energy resolution improved, especially at low $p_T$, same resolution at very high $p_T$ for different jet types
Challenging pileup conditions in 2012

Methods for pileup mitigation:

**Particle Flow Charged Hadron Subtraction (CHS)**
- Majority of pileup is from charged particles
- CHS removes charged hadrons from pileup vertices

Additional pileup corrections for remaining pileup components
Jet energy corrections

JEC corrects reconstructed jets – on average – back to particle level.

Factorized approach:

- Pileup corrections to correct for offset energy
- Correction to particle level jet vs. $p_T$ and $\eta$ from simulation

- Only for data: Small residual corrections (relative and absolute) to correct for differences between data and simulation
Pileup corrections

- Average per-event UE/pileup density $\rho$ and jet-area $A$ used to subtract offset energy from additional minimum bias events (pileup).
- Parameterized for data and simulation as a function of $\rho, A, p_T$ and $\eta$
Corrections from simulation

- Correction for $p_T$ and $\eta$ dependence
- Reference scale is that of the particle/generator jet
- Final correction step for simulated data
Jet energy scale determination in data

Average absolute scale in $|\eta|<1.3$

Scale relative to $|\eta|<1.3$ (as function of $\eta$)
Absolute residuals ($\gamma/Z$+jet)

R\text{balance} = \frac{p_{T,\text{jet}}}{p_{T,\gamma/Z}} \quad \text{and} \quad R_{\text{MPF}} = 1 + \frac{E_{T,\text{miss}}}{p_{T,\gamma/Z}} \left( \frac{p_{T,\gamma/Z}}{p_{T}} \right)^2

MPF (Missing $E_T$ Projection Fraction)
- Idea: No intrinsic $E_{T,\text{miss}}$ in such events (only induced by mismeasurement): projection of $E_{T,\text{miss}}$ along reference object axis gives response

Complementary analyses/topologies used for calibration of central detector ($|\eta|<1.3$)
- $Z \rightarrow \mu^+\mu^-$ as central method, $Z \rightarrow e^+e^-$, $\gamma$ as cross checks
- Extrapolation to perfect topology

Residual difference of response from MPF method used as residual correction
Relative residuals (dijet)

Relative response from dijet balance

\[ B = \frac{p_T^{\text{probe}} - p_T^{\text{tag}}}{p_T^{\text{ave}}} \]

\[ \langle R_{\text{balance}} \rangle = \frac{2 + \langle B \rangle}{2 - \langle B \rangle} = \frac{\langle p_T^{\text{probe}} \rangle}{\langle p_T^{\text{tag}} \rangle} \]

\[ R_{MPF} = 1 + \frac{E_{\text{miss}} \cdot p_T^{\text{tag}}}{(p_T^{\text{tag}})^2} \]

Dijet events used to relate response in central barrel region to any \( \eta \)

- Suppression of additional event activity (third jet)
- MPF method, traditional dijet balance as cross-check
- Below 5% within tracker coverage
JEC uncertainties

- Pileup, extrapolation, and jet flavor dominating uncertainties in $|\eta|<1.3$, relative scale at high $|\eta|$.
- Uncertainties below 1% for jets with $p_T>100$ GeV.
Conclusion

- Particled Flow algorithm used for most analyses in CMS (energy resolution better than 12% at $p_T > 30$ GeV)
  - Challenging pileup conditions tackled by advanced techniques like charged hadron subtraction
- CMS factorizes Jet Energy corrections:
  - Make best use of simulation that accurately describes data
  - Correct for small remaining differences using data-driven residual corrections
- Small additional correction on data: ~2% absolute scale ($Z$+jet), relative inter-$\eta$ (dijets)
- JES uncertainty <1% for $p_T > 100$ GeV in central region
Backup
References

- **Determination of jet energy calibration and transverse momentum resolution in CMS**
  - *JINST* 6 P11002
  - Most recent paper on Jet Energy Correction and Uncertainties

- **Detector performance summaries**
  - Status of the 8 TeV Jet Energy Corrections and Uncertainties based on 11 fb$^{-1}$ of data in CMS (CMS DP-2013/011)
  - Jet Energy Corrections and Uncertainties. Detector Performance Plots for 2012 (CMS DP 2012/012)
  - Jet Energy Scale performance in 2011 (CMS DP-2012/006)

- **CMS Physics Analysis Summaries**
  - Jet Performance in pp Collisions at $\sqrt{s} = 7 TeV$ (JME-10-003)
  - Jet Energy Corrections determination at $\sqrt{s} = 7 TeV$ (JME-10-010)
  - Commissioning of the Particle-flow Event Reconstruction with the first LHC collisions recorded in the CMS detector (CMS-PAS-PFT-10-001)
• Flavor uncertainties now relative to reference Z+jet flavor composition, default assumed composition for uncertainties is QCD mixture.
• Part of uncertainty source framework: Provide ~20 individual sources that are mutually uncorrelated. Propagating individual sources to potentially reduce total uncertainty on measured quantities.
Uncertainty sources

**Absolute scale**
- Scale uncertainty (combined ECAL (photon) and tracking (Z) reference scale)
- FSR +ISR correction
- Statistical uncertainty

**Relative scale**
- Jet energy resolution
- Residual $p_T$-dependence (difference between log-linear and constant fit)
- Statistical uncertainty
- Modelling/FSR correction

**Extrapolation**
- Underlying event and fragmentation differences from PYTHIA/Herwig++
- Single particle response variation ($\pm 3\%$) propagated to jets

**Pileup**
- 20% of Data/MC differences in data-based random cone method (separate corrections provided)
- $p_T$- dependence of measured offset, e.g. due to zero suppression effects
- Random cone method bias in MC

**Jet flavor**
- Based on PYTHIA/Herwig++ differences in uds/c/b-quark and gluon responses, default covers extrapolating from Z+jet to dijet QCD flavor mixture, but gives access to individual sources

**Time**
- Observed instability in the endcap region, presumably linked to aging
Particle Flow Composition

- Additional handle to quality of MC modelling
- agreement for track (charged hadrons), ECAL (photons), and HCAL (neutral hadrons) energies to within 1% in barrel

H. Kirschenmann - Universität Hamburg 18 July 2013
Particle Flow Composition

- Additional handle to quality of MC modelling
- agreement for track (charged hadrons), ECAL (photons), and HCAL (neutral hadrons) energies to **within 1%** in barrel
Relative Residuals, dijets

**Need for very high statistics**
- QCD dijet events have very high statistics (and high pt-reach)

**Caveat**
- Not as well defined reference object

**Strategy**
- Calibrate jets relative to central region
- Data/MC ratios as residual correction
- Extrapolate to perfect topology

**Event selection**
- Two highest $p_T$ jets
- $\Delta\phi(j_1, j_2) > 2.7$
- $|\eta_{\text{tag}}| < 1.3$

**Relative response from dijet balance**

$$B = \frac{p_T^{\text{probe}} - p_T^{\text{tag}}}{p_T^{\text{ave}}} \to \langle R_{\text{balance}} \rangle = \frac{2+\langle B \rangle}{2-\langle B \rangle} = \frac{p_T^{\text{probe}}}{p_T^{\text{tag}}}$$

For narrow $p_T^{\text{ave}}$ bin

**MPF (Missing $E_T$ Projection Fraction)**

$$R_{\text{MPF}} = 1 + \frac{E_T^{\text{miss}} \cdot p_T^{\text{tag}}}{(p_T^{\text{tag}})^2}$$

18 July 2013
Absolute residuals, Z+jet and γ+jet

2 complementary response estimators:
$p_T$ balance

\[
R_{\text{balance}} = \frac{p_T^{\text{jet}}}{p_T^{\gamma}}
\]

MPF (Missing $E_T$ Projection Fraction)

\[
R_{\text{MPF}} = 1 + \frac{E_T^{\text{miss}} p_T^{\gamma}}{(p_T^{\gamma})^2}
\]

• Idea: No intrinsic $E_T^{\text{miss}}$ in such events (only induced by mismeasurement)
  • projection of $E_T^{\text{miss}}$ along reference object axis gives response

Data/MC ratio determined for different cuts on $p_T^{\text{Jet2}}$

• Extrapolation to zero additional event activity
• MPF largely reduces dependence (default method)
Absolute residuals, $Z+$jet and $\gamma+$jet

$Z+$jet gives central value
- Data/MC ratios of both methods agree
- $Z+$jet and $\gamma+$jet as cross checks