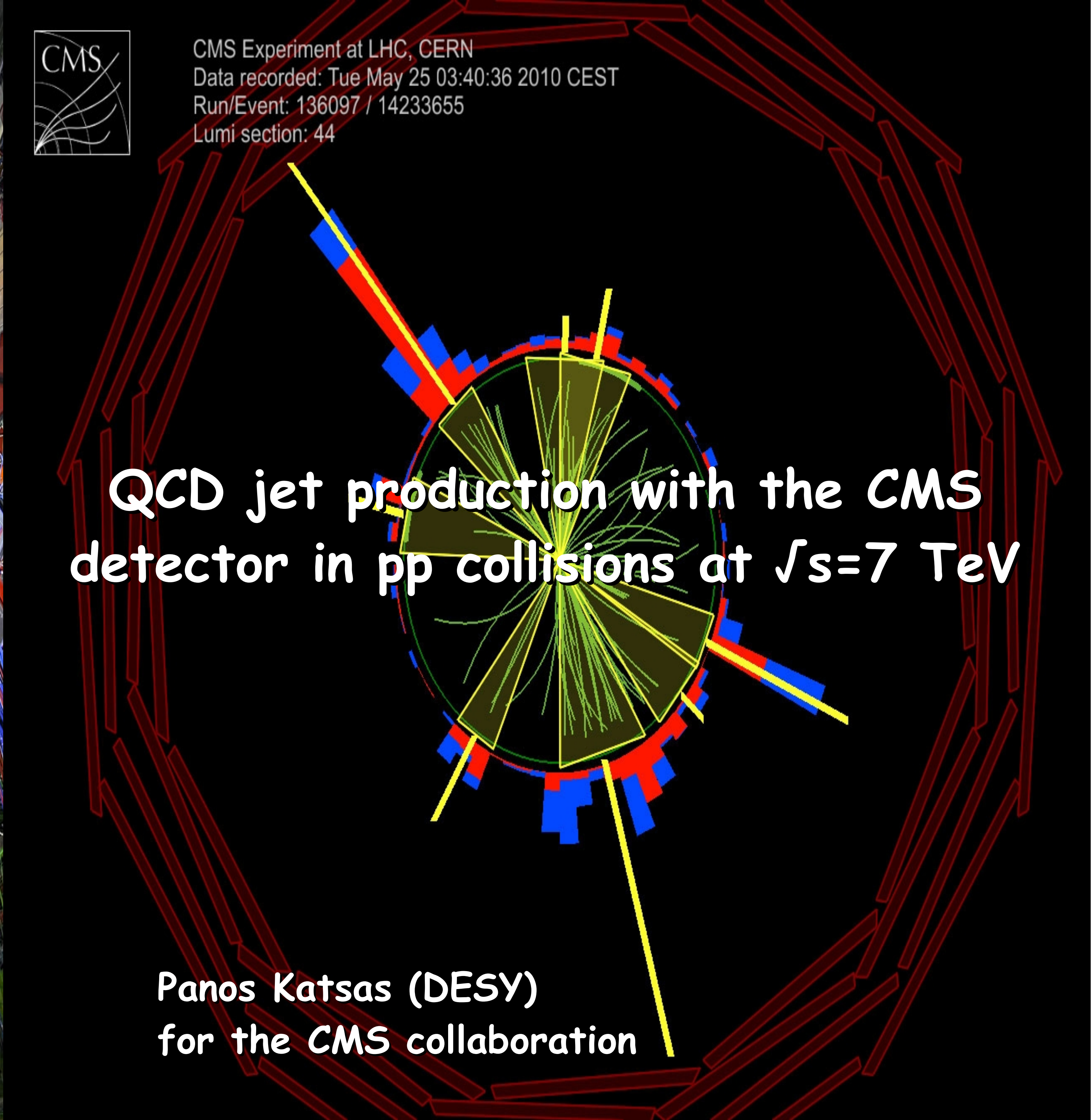
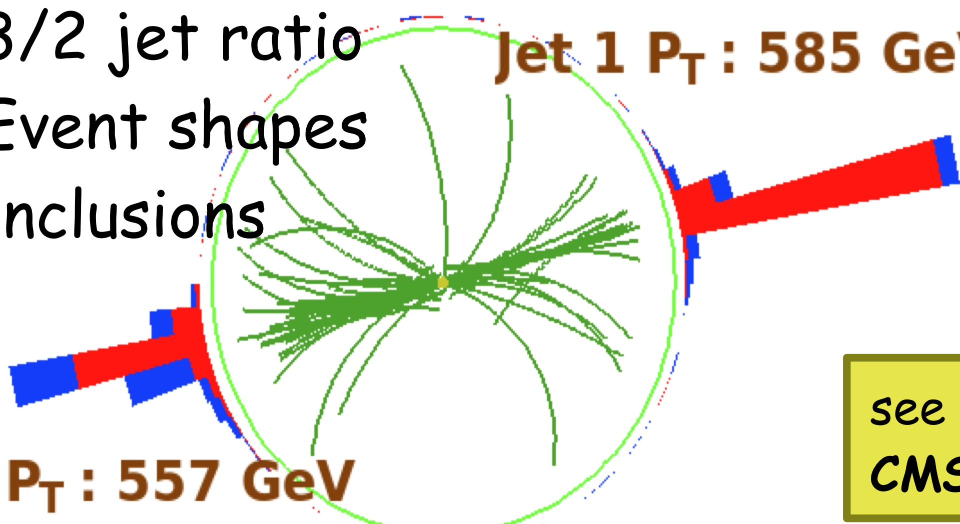


QCD jet production with the CMS detector in pp collisions at $\sqrt{s}=7$ TeV

Panos Katsas (DESY)
for the CMS collaboration

Outline

- Introduction
- CMS detector
- Jet reconstruction
- Trigger/event selection
- Results at $\sqrt{s}$=7 TeV
  - Inclusive jets
  - Jet shapes
  - Azimuthal decorrelations
  - Dijet angular distribution
  - 3/2 jet ratio
  - Event shapes
- Conclusions

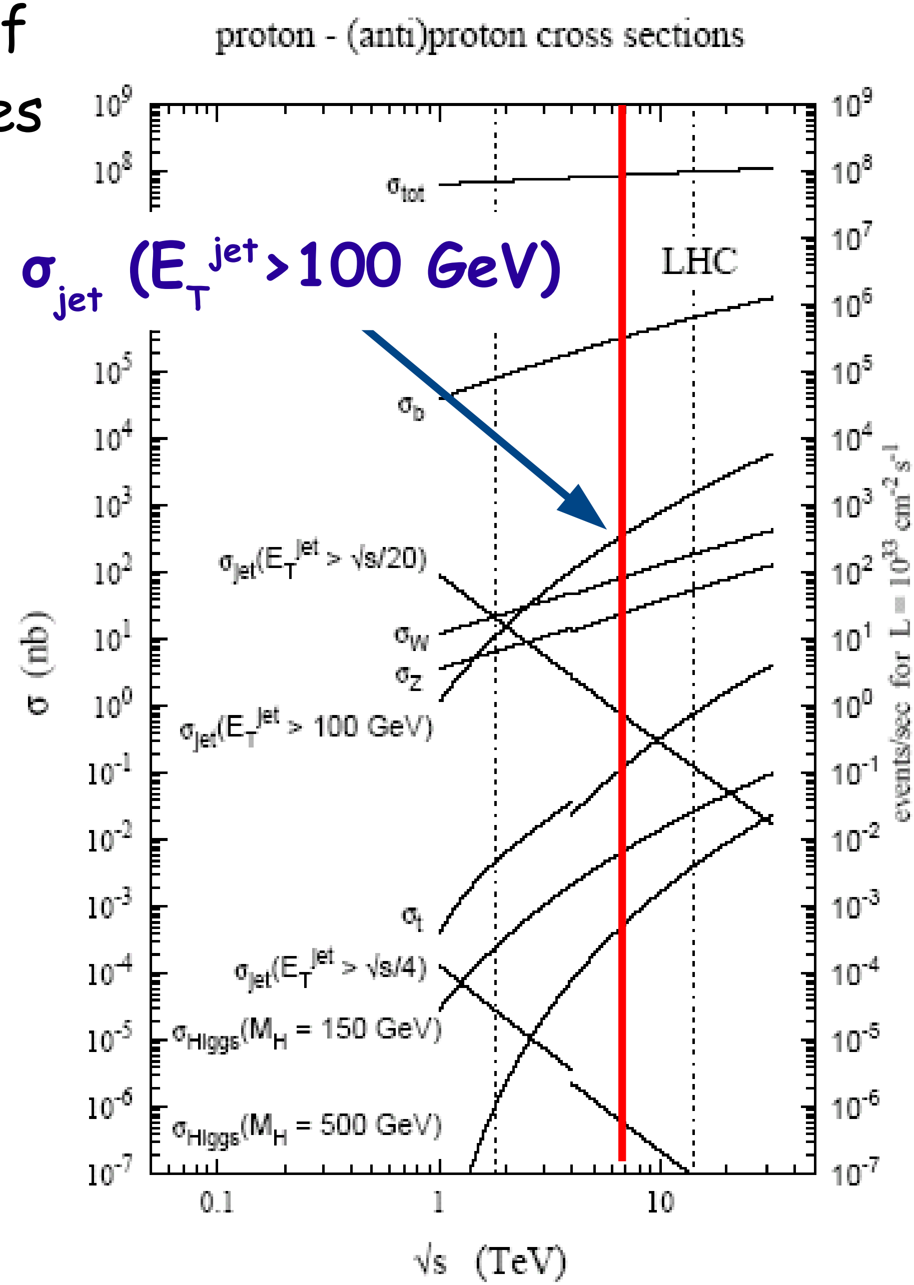


CMS Physics Analysis Summaries:
- QCD-10-011 (inclusive jets)
- QCD-10-012 (3/2 jets ratio)
- QCD-10-013 (event shapes)
- QCD-10-014 (jet transverse structure)
- QCD-10-015 (dijets)

Related analysis notes:
- JME-10-003 (jet performance)
- BPH-10-009 (b-jet production)
- JME-10-006 (track jets)
- PFT-10-002 (particle flow jets)
- JME-09-002 (jet+tracks jets)

see also **Forward energy & particle flow in CMS**, D. Sunar Cerci, ISMD, 23 Sept. 2010

- Jets are the experimental signatures of quarks and gluons, manifesting themselves as collimated stream of particles
- Sensitive to both the dynamics of the fundamental interaction and to the partonic structure of the initial-state hadrons
- Large cross section at the LHC; if not part of a signal, most likely background
- Why are jet measurements important?
  - commissioning of jets
  - confront pQCD at the TeV scale
  - sensitive to MC tunes
  - sensitive to new physics

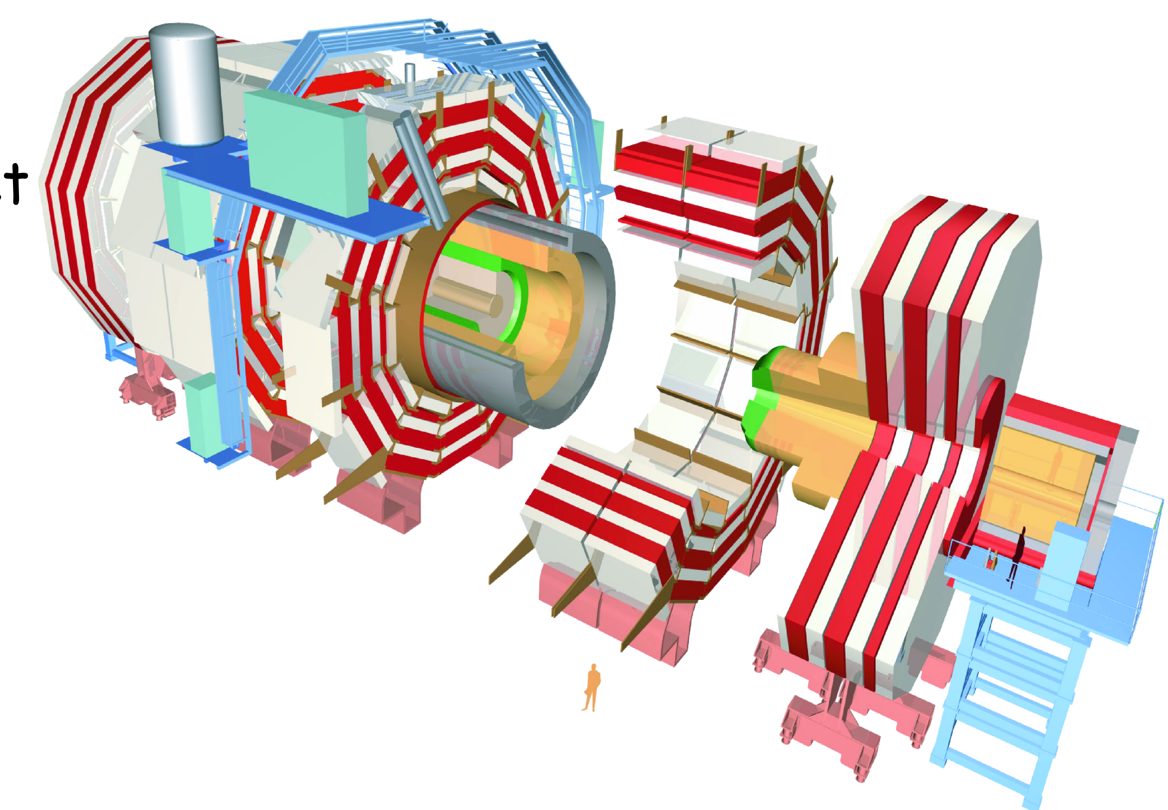


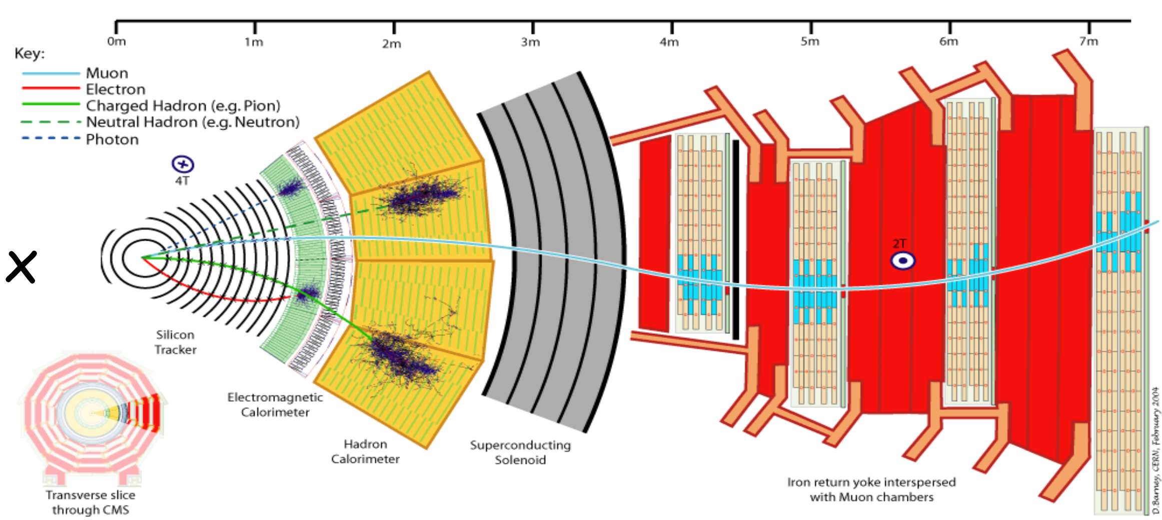
CMS detector

- Superconducting solenoid providing uniform B=3.8 T
- Muon chambers outside magnet
- Silicon pixel & silicon strip tracker at $|\eta| < 2.4$
- PbWO4 scintillating crystals ECAL at $|\eta| < 3.0$
- Brass-scintillator HCAL with barrel+endcaps at $|\eta| < 3.0$
- HF steel/quartz fiber calorimeter ($|\eta| < 5.2$)

Calorimeter cells grouped in projective towers of granularity $\Delta\eta \times \Delta\varphi = 0.087 \times 0.087$ (0.175 x 0.35 in the forward region)

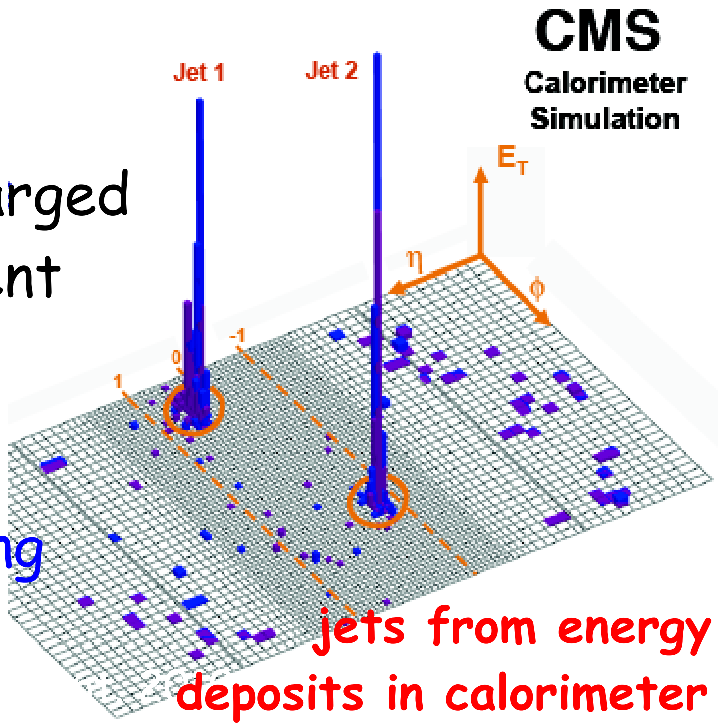
- Forward region enriched with CASTOR ($-5.2 < \eta < -6.6$) + ZDC





CMS jet reconstruction

- Four possible inputs (jet types) to the anti-kT algorithm with R=0.5
- Jet types in CMS
  - **Calorimeter jets**: formed from calorimeter towers, energy deposits in ECAL crystals & HCAL cells
  - **Jets Plus Tracks** (JPT): calorimeter towers clustered into jets -> jet energy corrected using the momentum of associated tracks
  - **Particle Flow Jets** (PF): formed by clustering 4-vectors of reconstructed particles, combining tracks, ECAL/HCAL clusters
  - **Track Jets**: reconstructed from tracks of charged particles measured in the tracker -> independent from the calorimetric measurements



jets from energy deposits in calorimeter

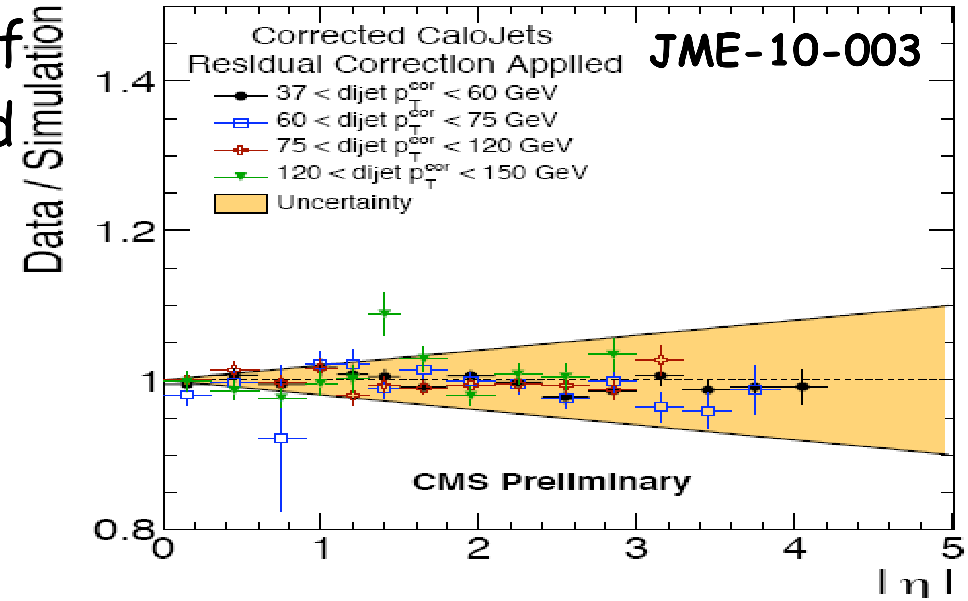
Different inputs allow to study and constrain experimental systematics for better understanding of jet identification, resolutions and energy scale

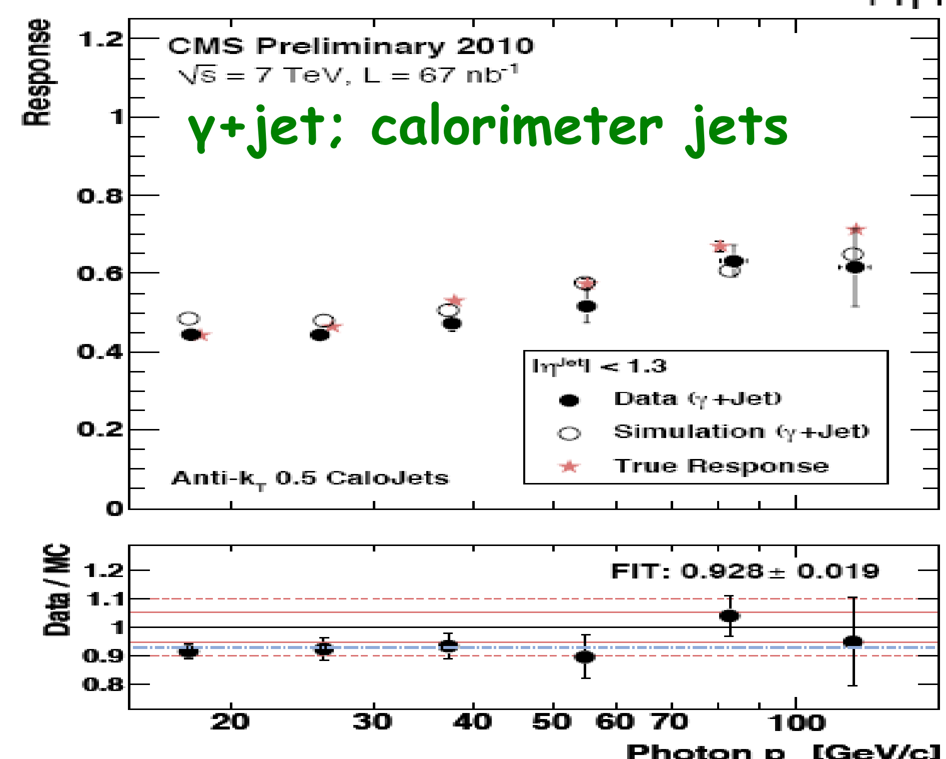
Jet energy calibration

- Factorized approach: different levels of correction applied sequentially with fixed order
  - offset correction (remove pile up and calorimeter noise contribution)
  - relative correction (flat jet response in pseudorapidity)
  - absolute correction (flat jet response in pT)
- Data-driven methods:
  - dijet pT balance (relative)
  - γ+jet events (absolute)

→ relative: systematic uncertainty of 2% times unit of rapidity

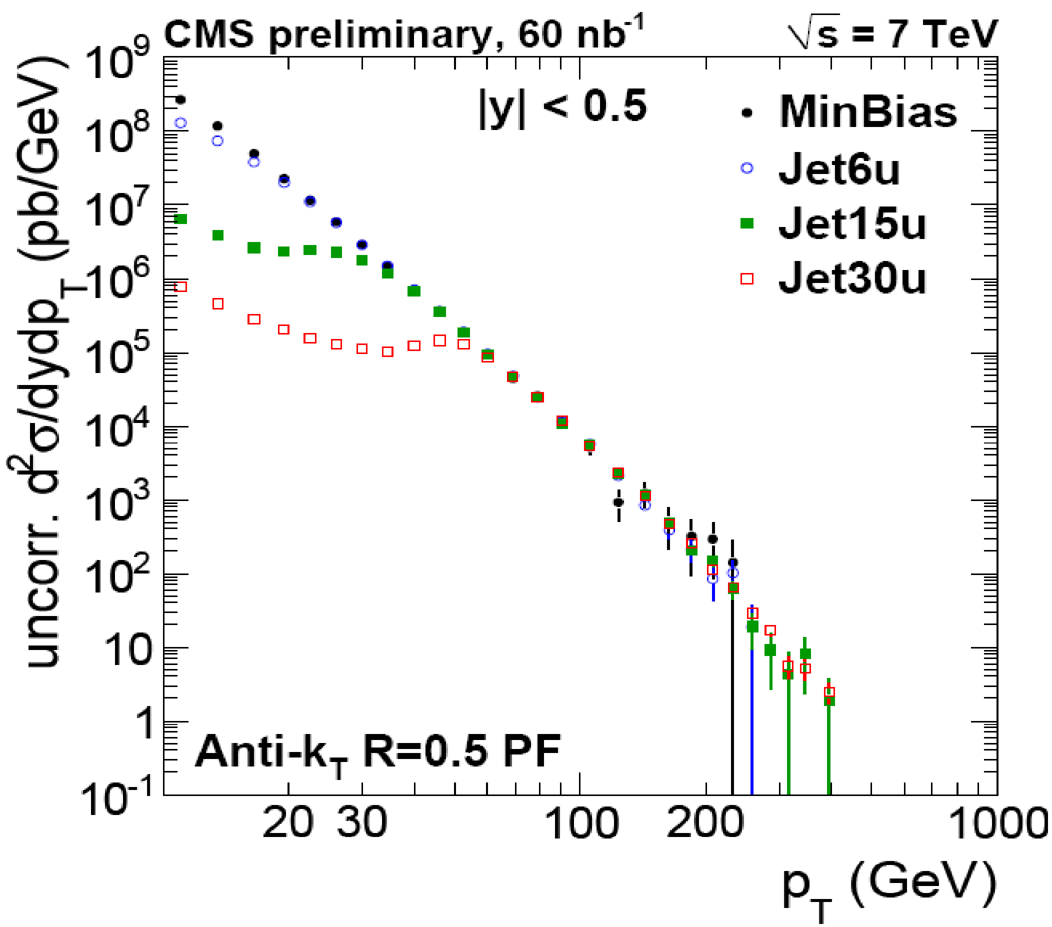
→ absolute: conservatively 5%/10% uncertainty for tracking-based/calo jets

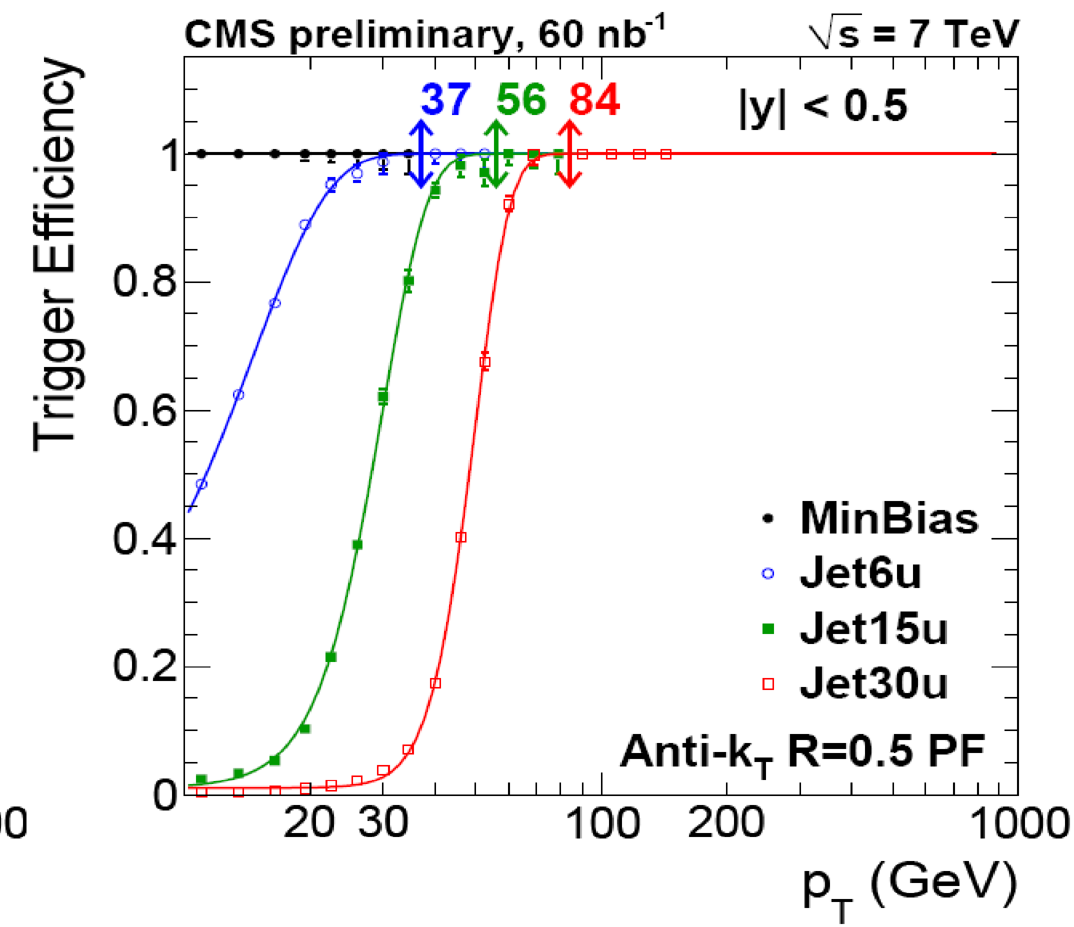




Triggers & event selection

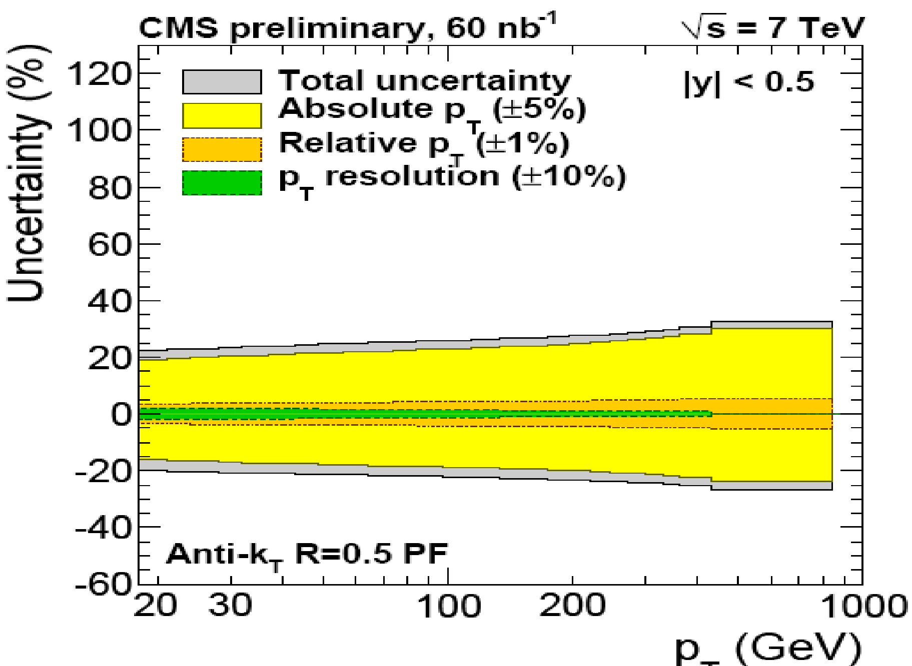
- Minimum Bias (lower pT) and single-jet triggers (higher pT)
- Good primary vertex ($|z_{PV}|$ < 15 cm, ndof >= 5, ρ_{PV} < 2cm), rejecting beam background
- Loose jet criteria (energy fraction & sharing among cells/particles)

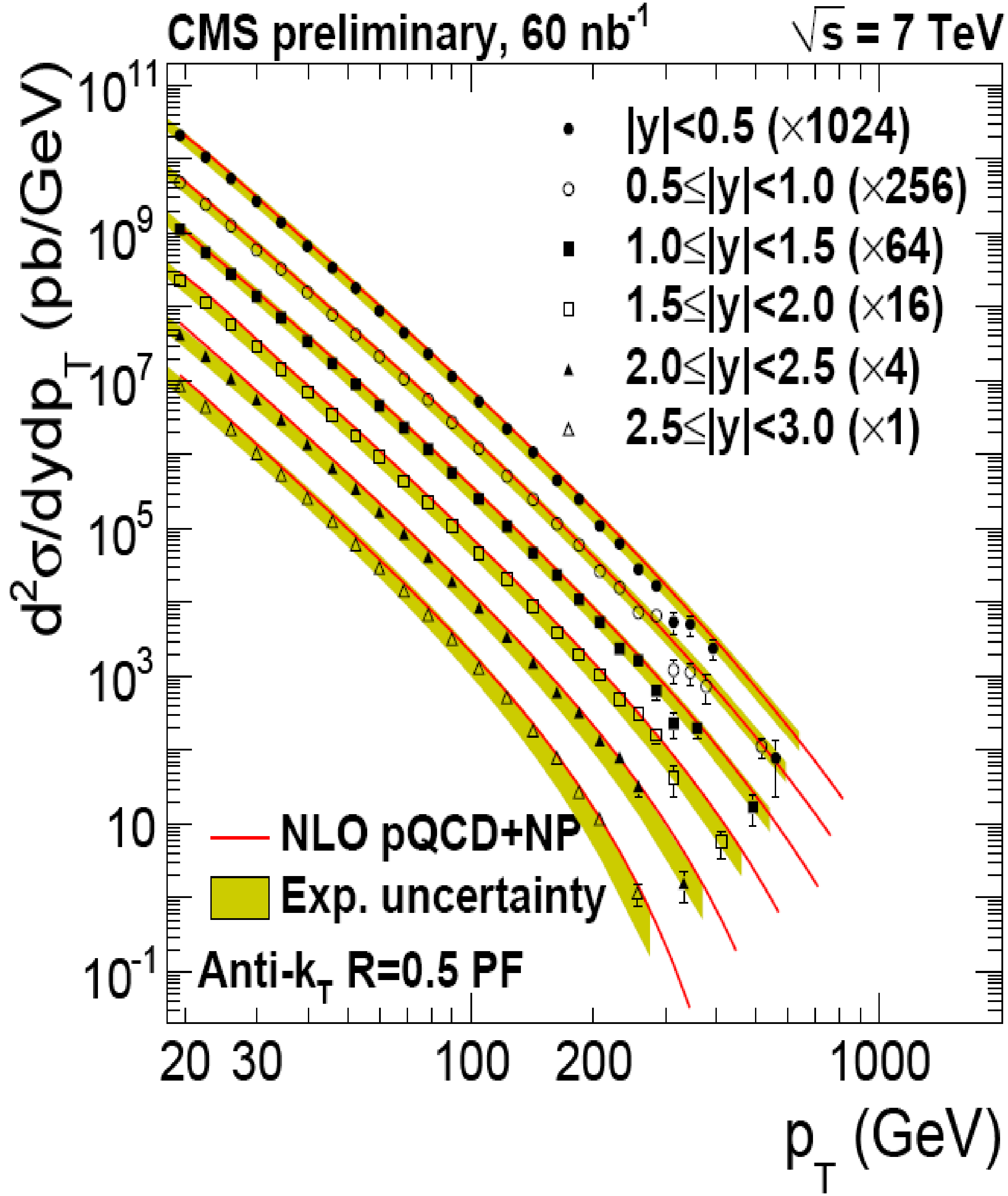




Inclusive jet cross-section

- Unfolded jet spectra |y| < 3.0, 18 < p_T < 700 GeV
- Different jet reconstruction methods agree within 20%
- Good agreement with NLO predictions for all jet types
- Systematics up to 25%





- Jet internal structure sensitive to the type of jet (quark/gluon induced) & pT
- At hadron colliders additional contributions from ISR (parton showering) & UE
- Extrapolation of models to LHC is uncertain

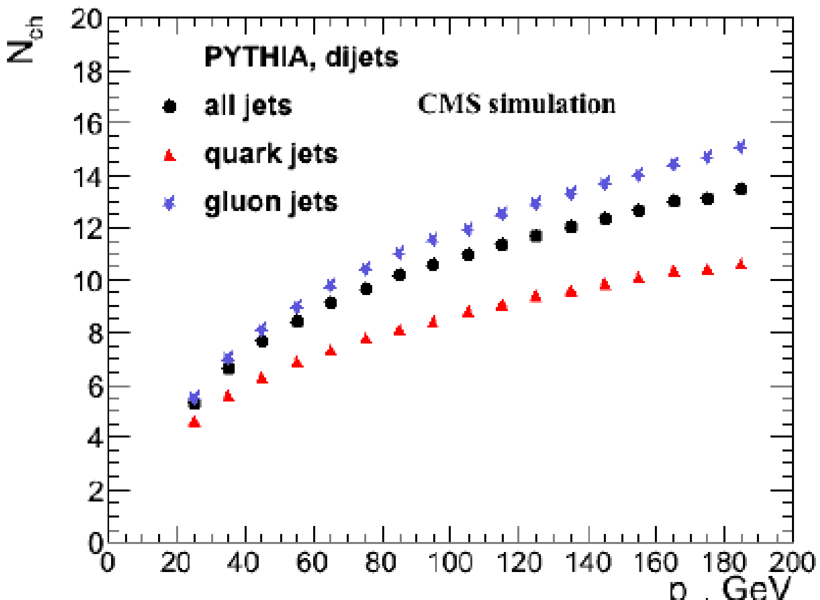
Observables

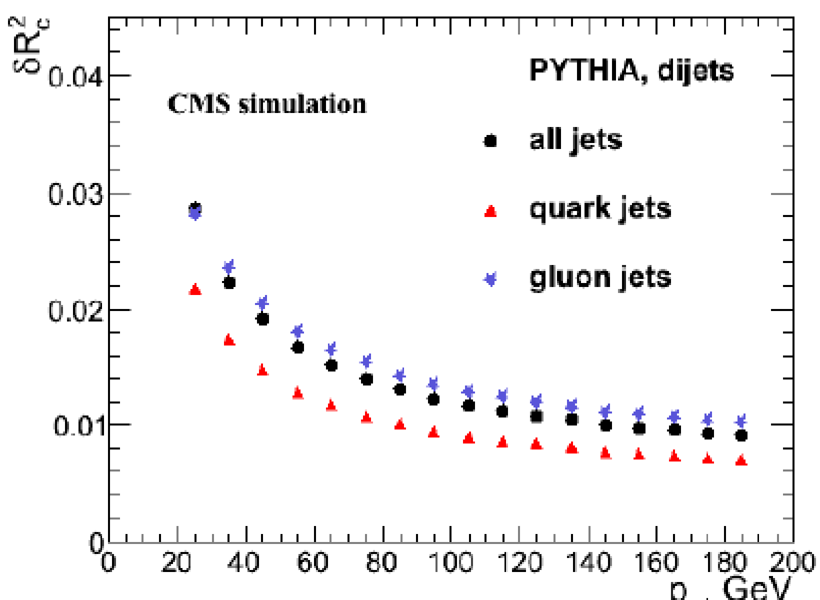
1. Charged particle multiplicity, Nch
2. Transverse jet shape:

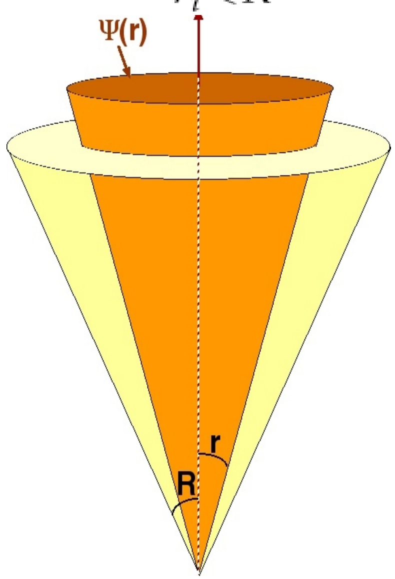
$$\delta R^2 = \langle \delta\phi^2 \rangle + \langle \delta\eta^2 \rangle$$

$$\langle \delta\phi^2 \rangle = \frac{\sum_{i\in \text{jet}} (\phi_i - \phi_C)^2 \cdot p_{T,i}}{\sum_{i\in \text{jet}} p_{T,i}} \quad \langle \delta\eta^2 \rangle = \frac{\sum_{i\in \text{jet}} (\eta_i - \eta_C)^2 \cdot p_{T,i}}{\sum_{i\in \text{jet}} p_{T,i}}$$

3. Integrated shapes: $\psi(r) = \frac{\sum_{r_i<r} p_{Ti}}{\sum_{r_i<R} p_{Ti}}$

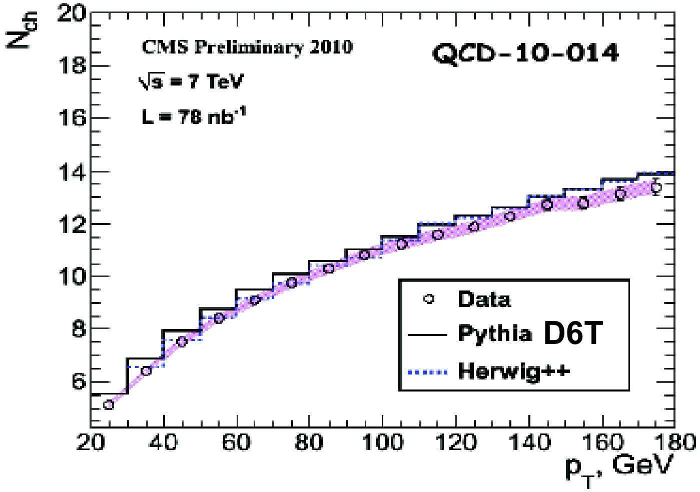


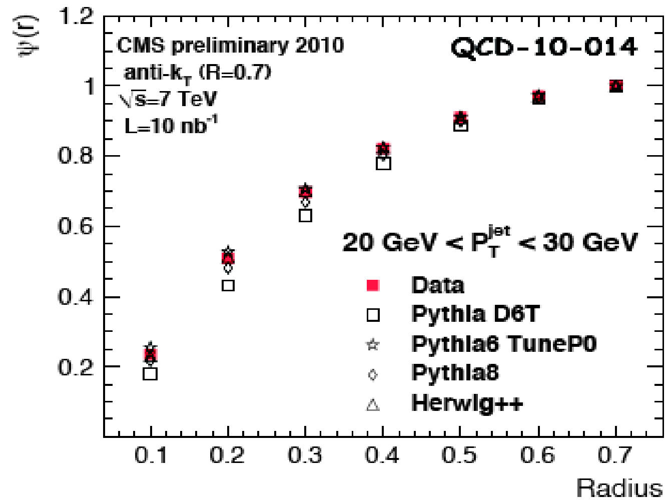


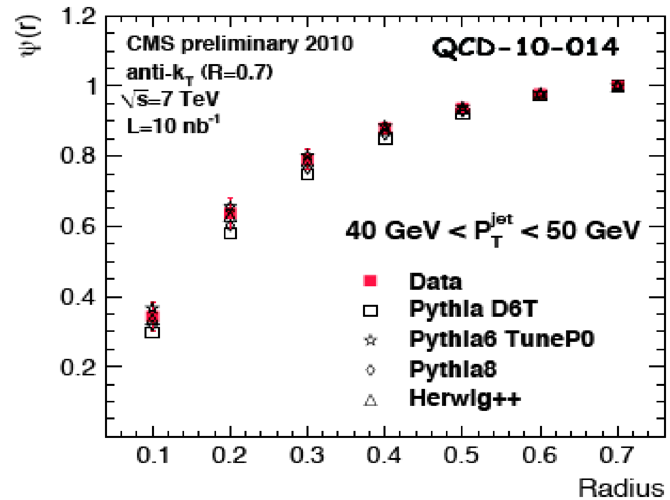


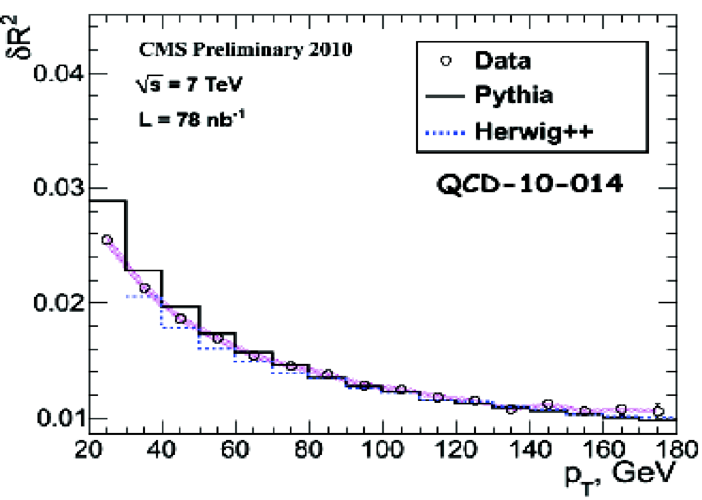
Jet structure (II)

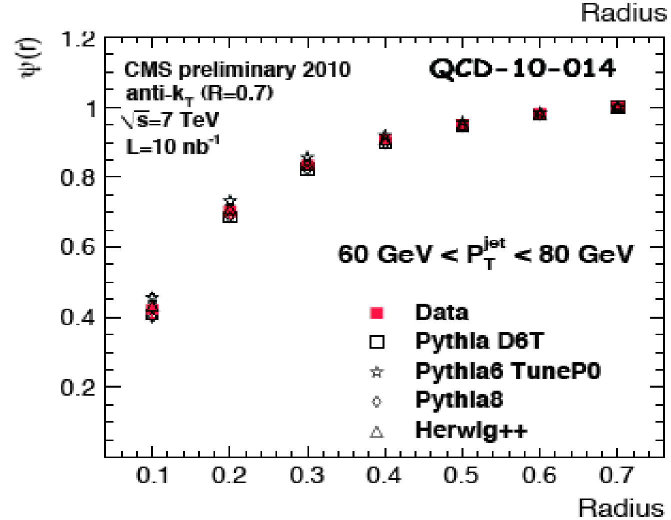
- At pT > 50 GeV good agreement between data & theory
- At pT < 50 GeV, PYTHIA/HERWIG predict broader/narrower jets than the data suggest
- Sensitivity to the UE expected at small radius, not yet conclusive

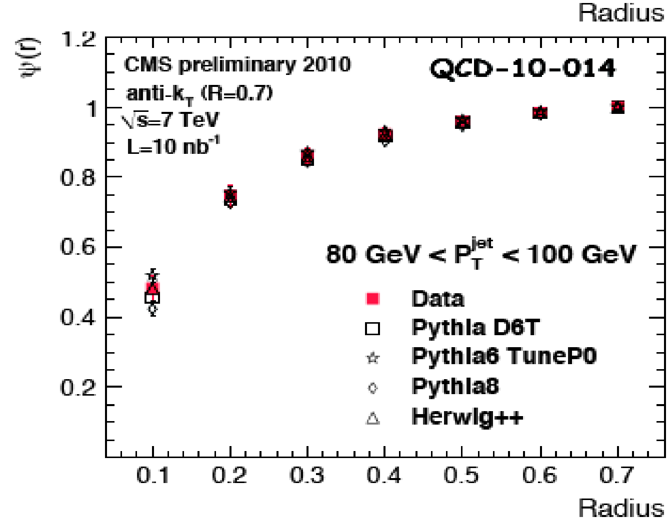






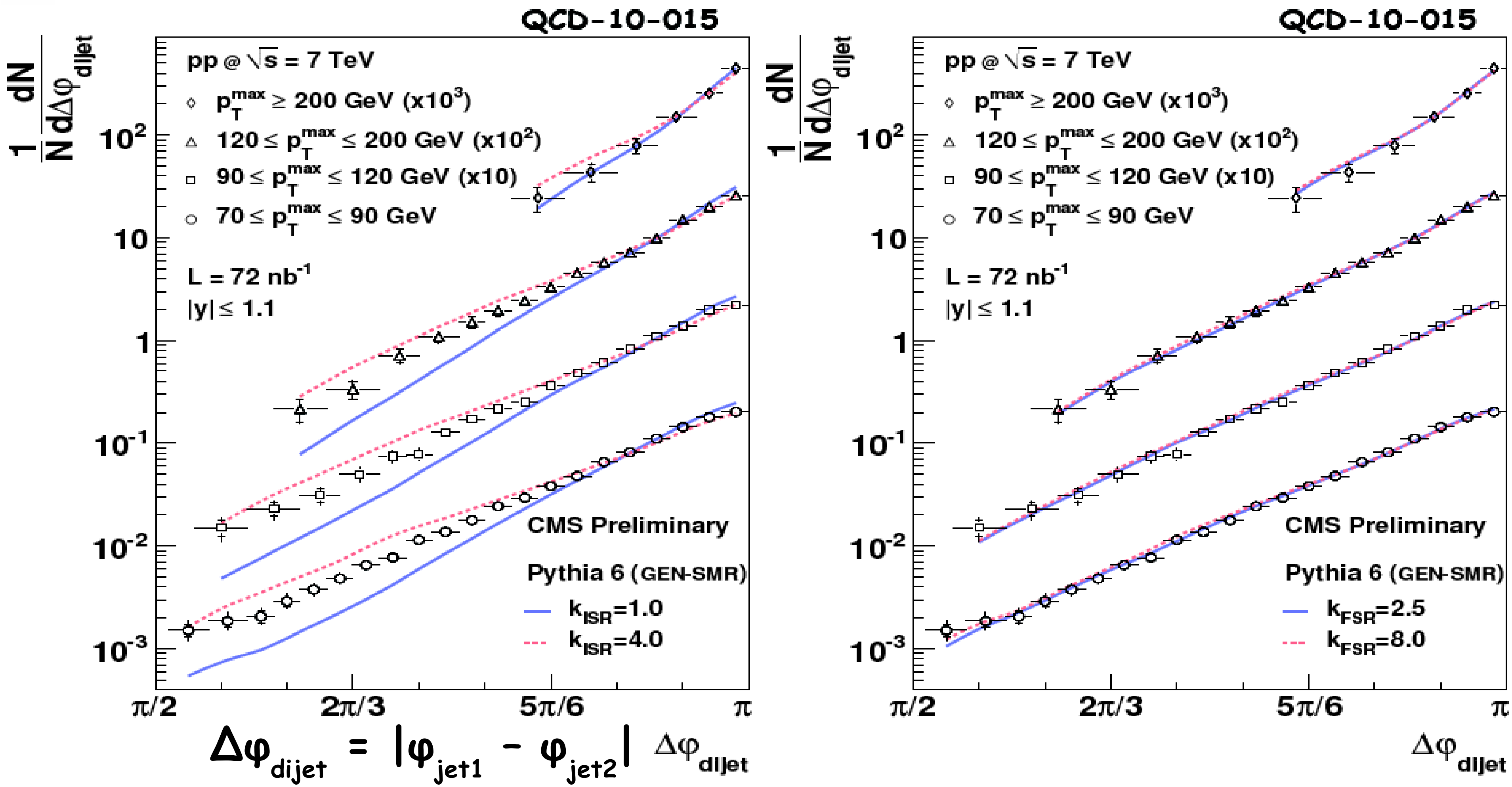






Azimuthal decorrelations (I)

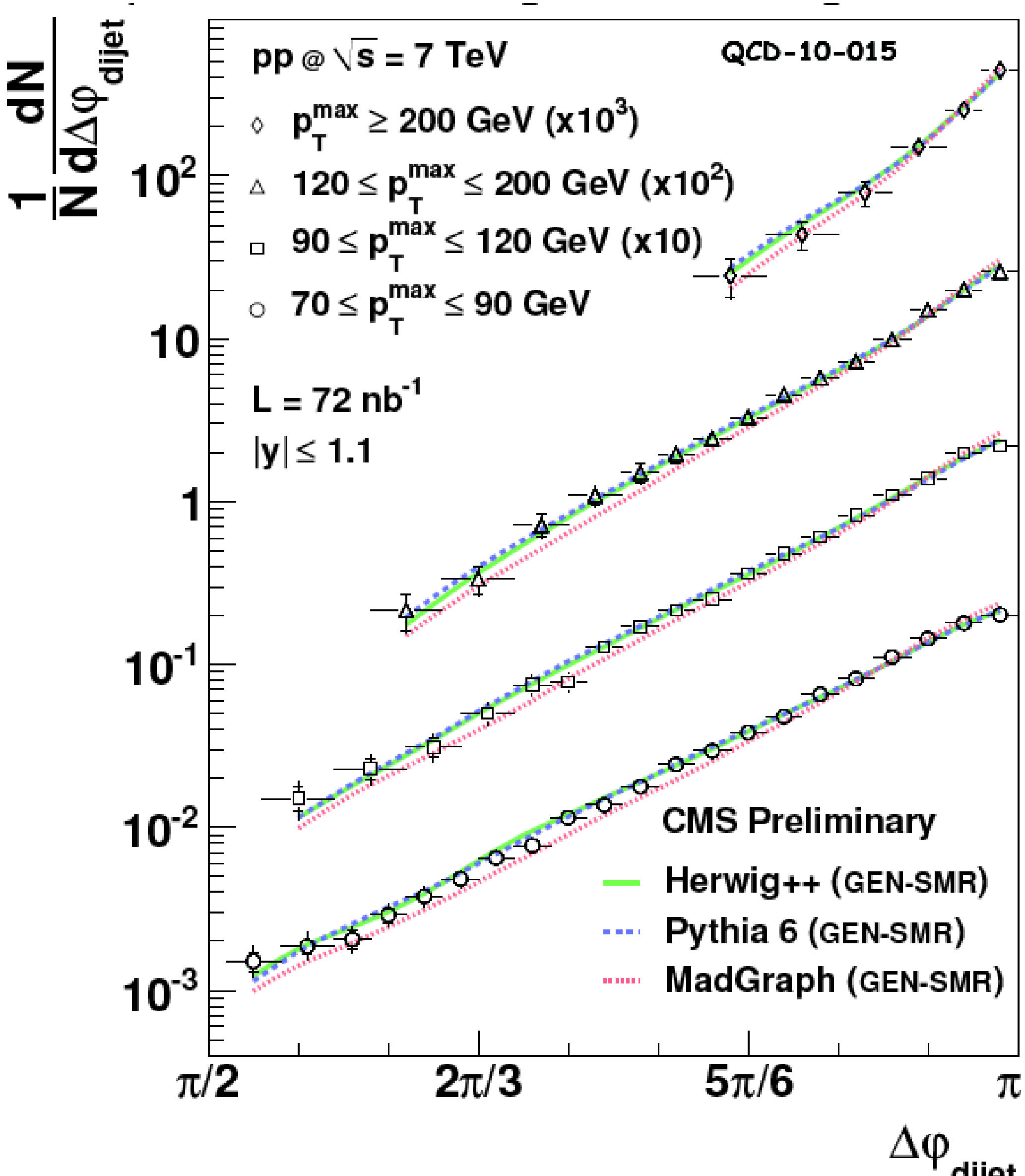
- Testing ground for pQCD & MC generators; decorrelations due to soft gluon emissions or multi-jet production
- More affected by initial state radiation
  - study of different parameter values k_{ISR}=PARP(67) and k_{FSR}=PARP(71)

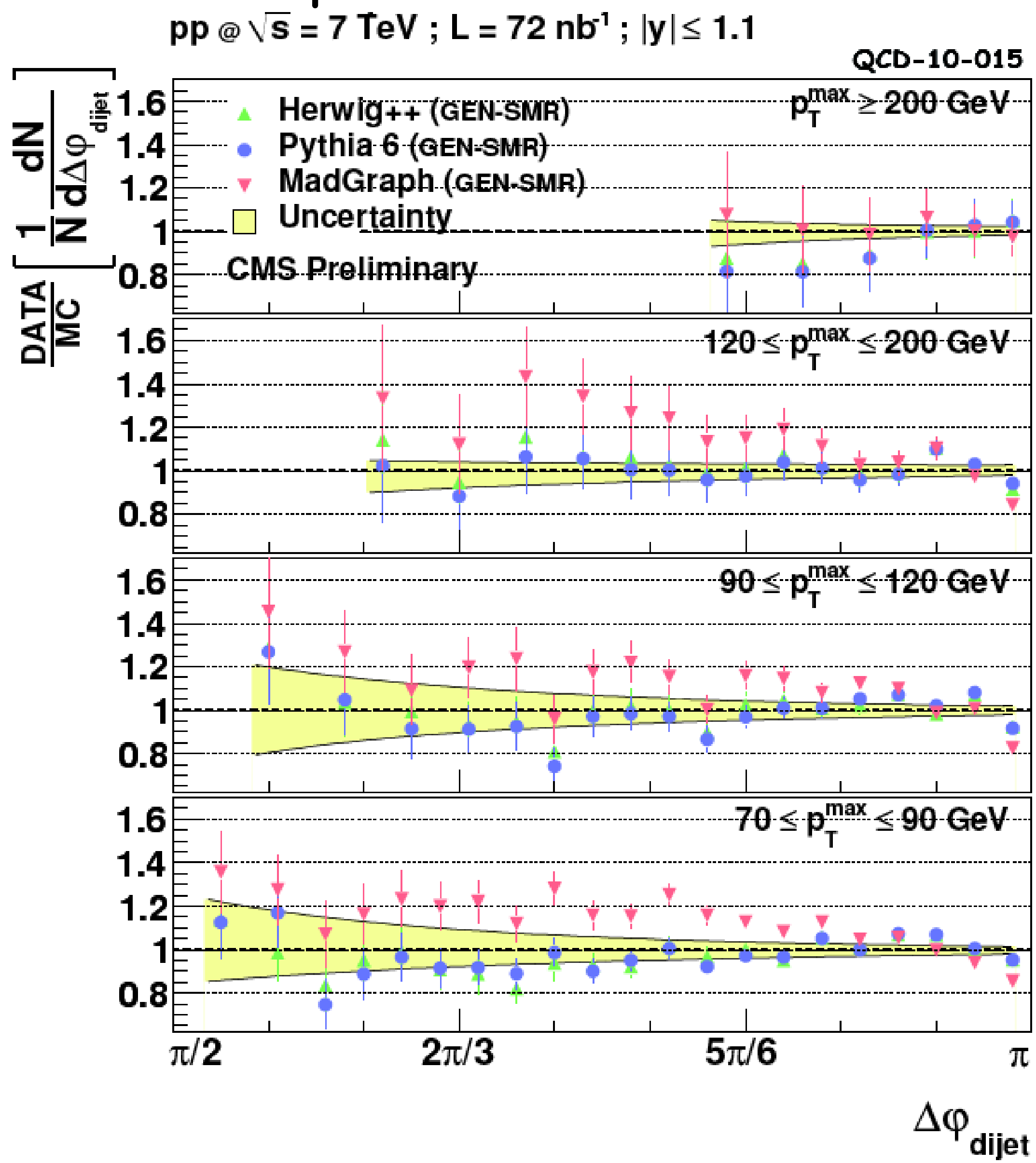


$\Delta\varphi_{dijet} = |\varphi_{jet1} - \varphi_{jet2}|$

Azimuthal decorrelations (II)

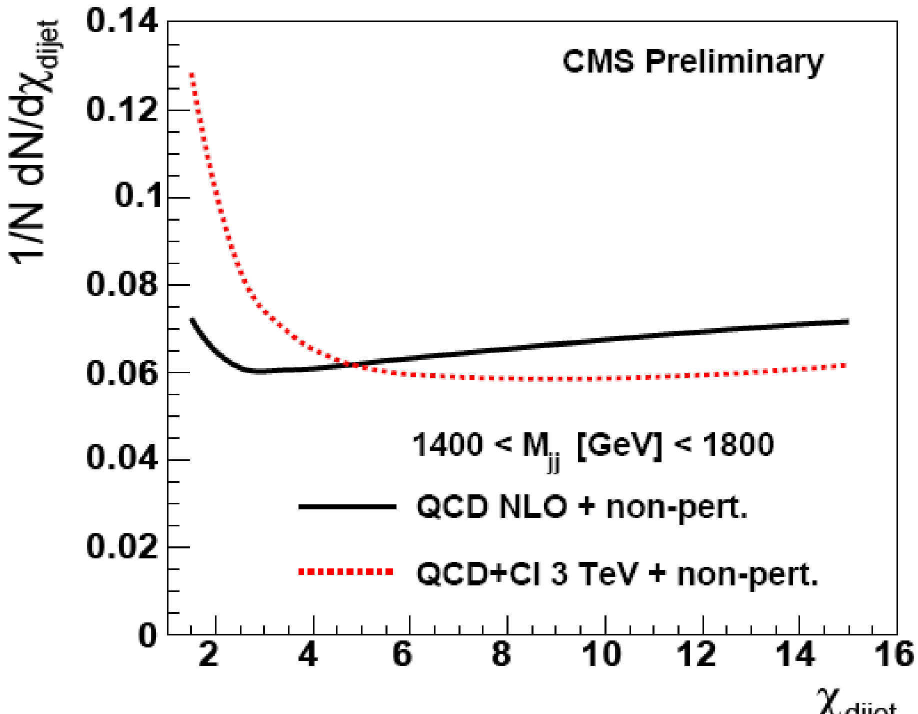
- Good agreement with PYTHIA & HERWIG
- Worse agreement with MadGraph at lower pT

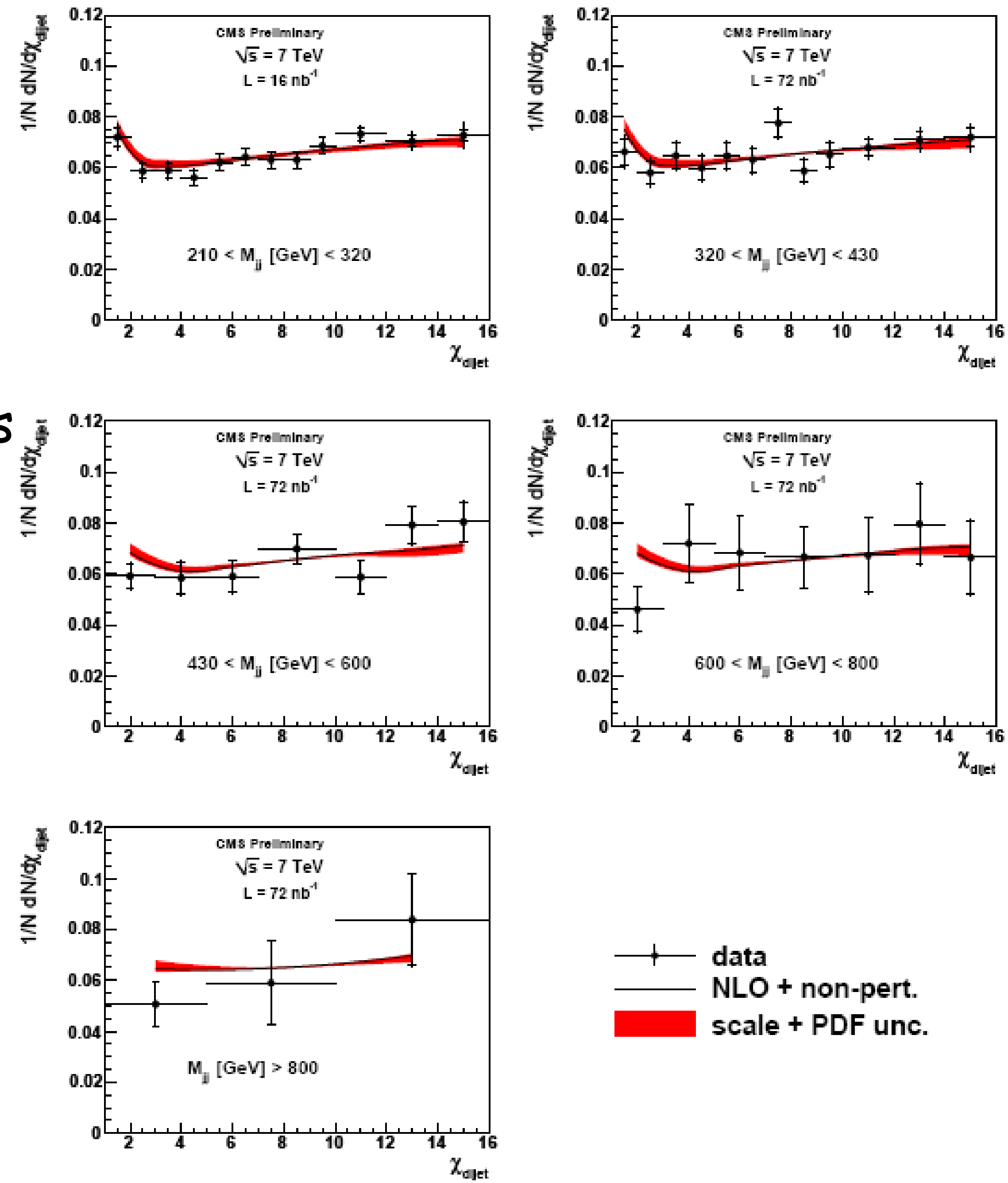




Dijet angular distribution

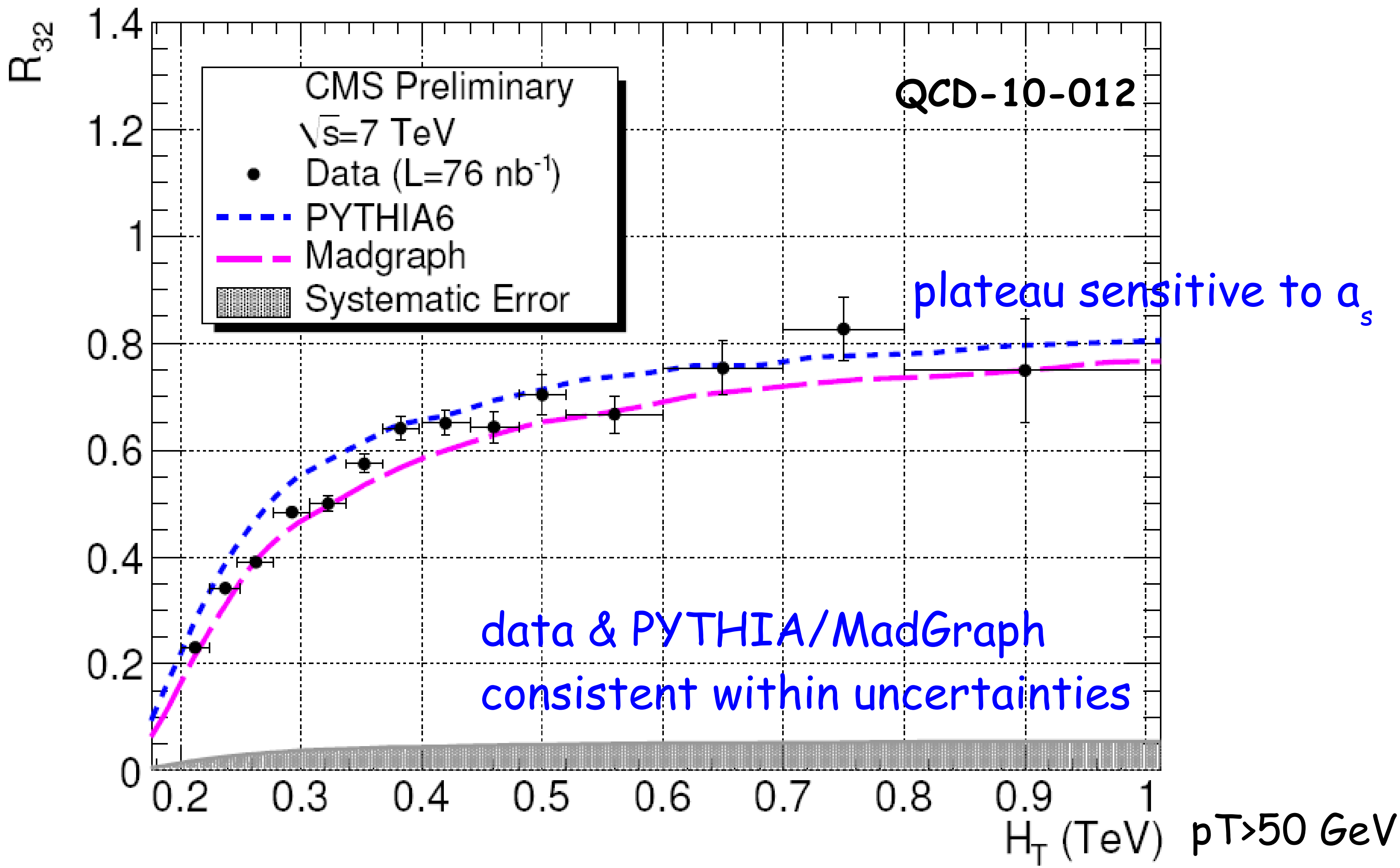
- Probes properties of parton-parton scattering without strong dependence on PDFs
- Observable : $(1/N)(dN/dX_{dijet})$, $X_{dijet} = \exp(|y_1-y_2|)$
- Study signatures for new physics (contact interactions)





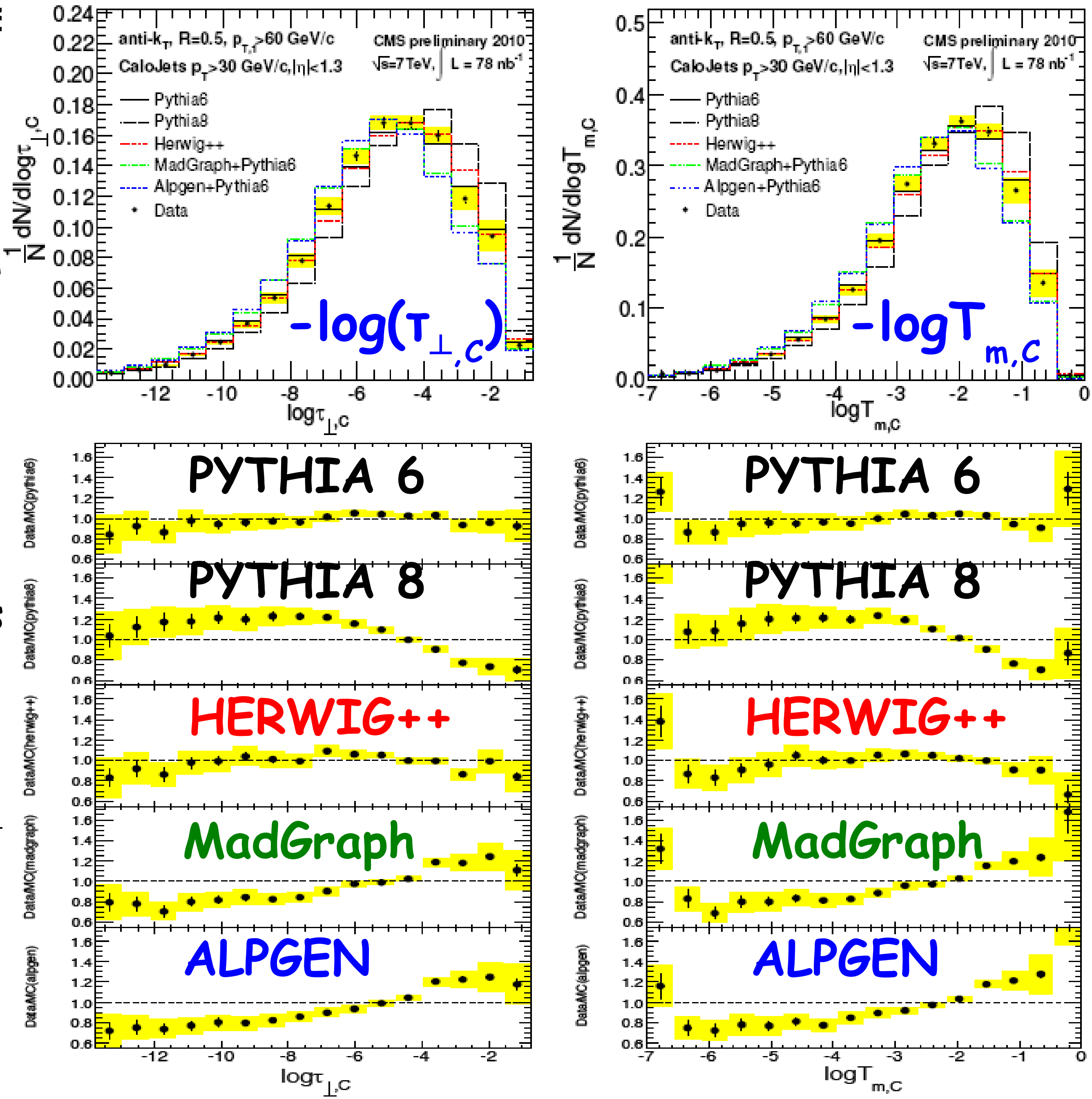
3/2 jet cross section ratio

- Ratio of the inclusive n/m jet cross section of order $O(a_s^{n-m})$
- Insensitive to PDFs, reduce luminosity, JEC uncertainty



Hadronic event shapes

- Probe geometrical properties of the energy flow in QCD events, final state geometry
- Collinear & infrared safe
- Tuning of MC models for non-perturbative effects
- Robust against experimental uncertainties
- PYTHIA 6/HERWIG in good agreement; MadGraph/Alpgen overestimate back-to-back dijets



Observables

1. Central transverse thrust:

$$T_{\perp,\mathcal{C}} \equiv \max_{\vec{n}_T} \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i}\cdot\vec{n}_T|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

2. Central thrust minor:

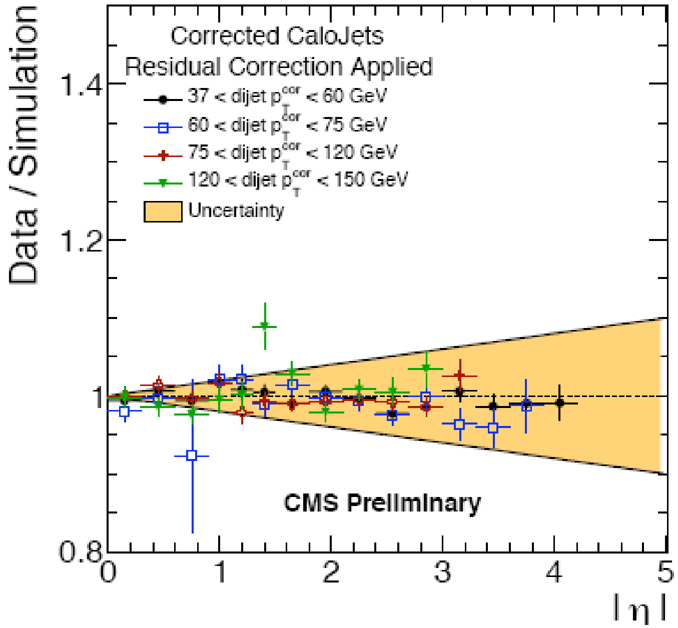
$$T_{m,\mathcal{C}} \equiv \frac{\sum_{i\in\mathcal{C}} |\vec{p}_{\perp,i}\times\vec{n}_{\mathrm{T},\mathcal{C}}|}{\sum_{i\in\mathcal{C}} p_{\perp,i}}$$

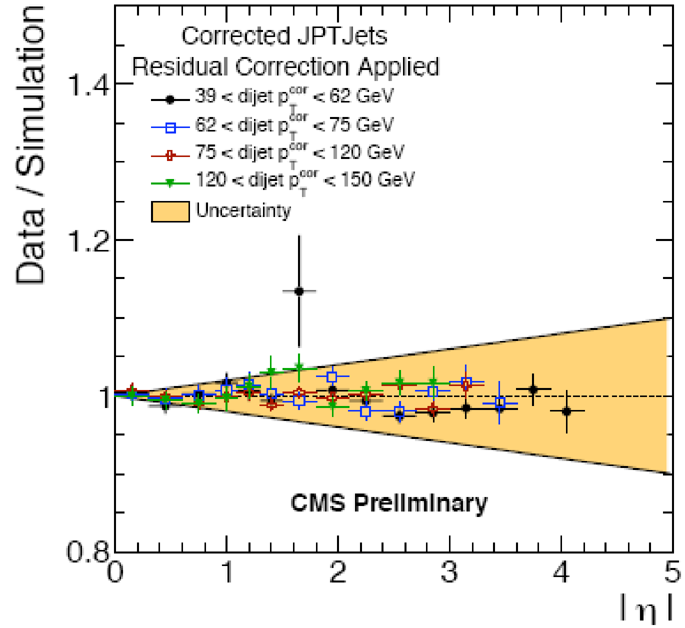
Conclusions

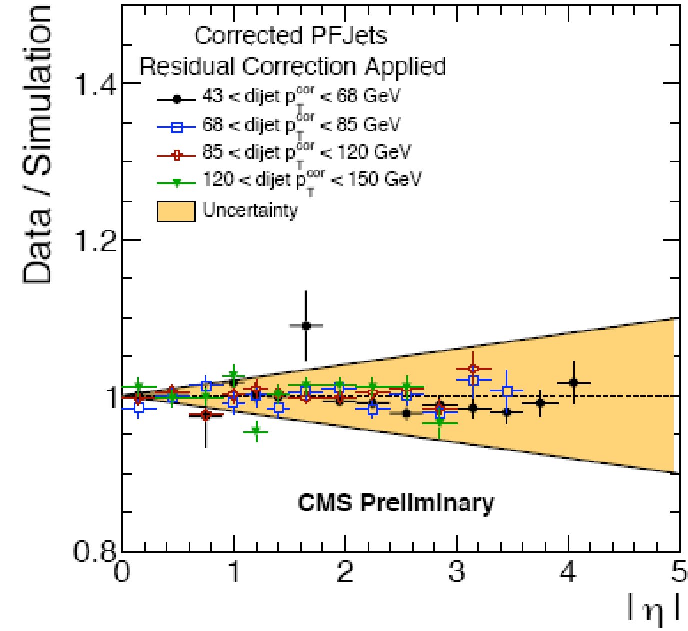
- Extensive list of QCD jet production studies already available at 7 TeV; data corresponding to L ~ 78 nb^{-1}
- First measurements concentrated on ratios reducing systematics from jet energy scale and jet resolution
- CMS detector simulation shows good agreement with data
- Benefit from multiple jet reconstruction algorithms & novel techniques
- MC models work reasonably well; studies for fine tuning underway

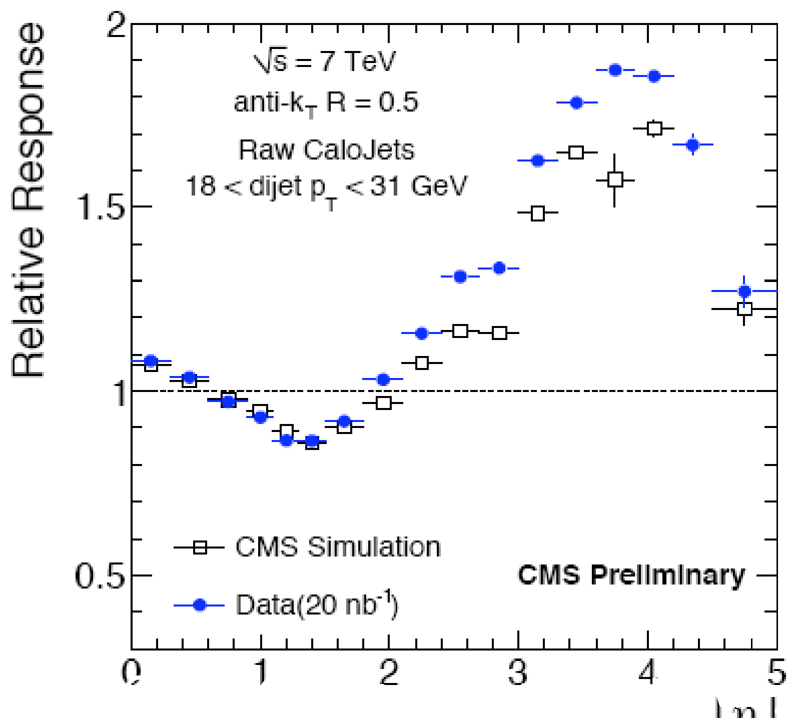
Supporting slides

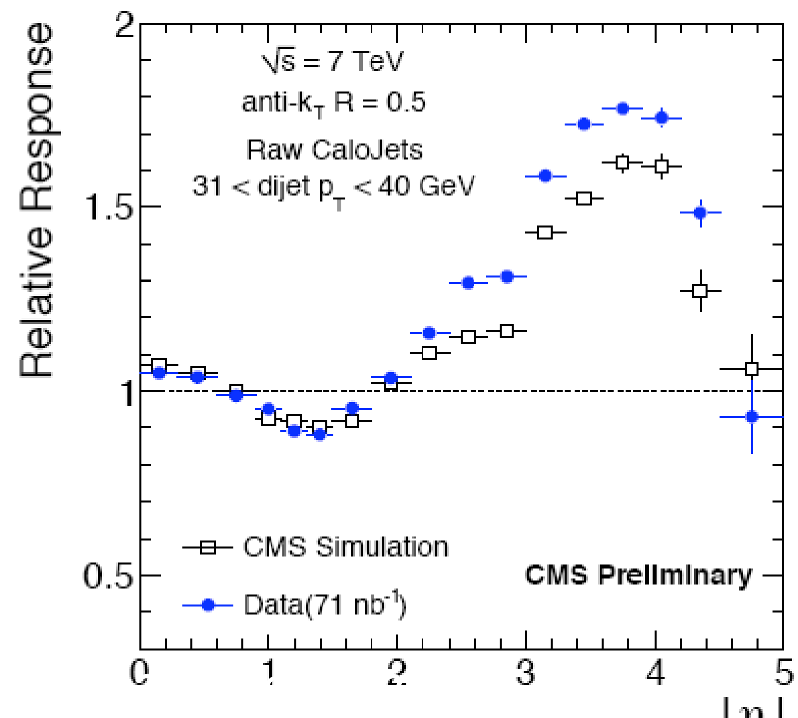
Relative corrections



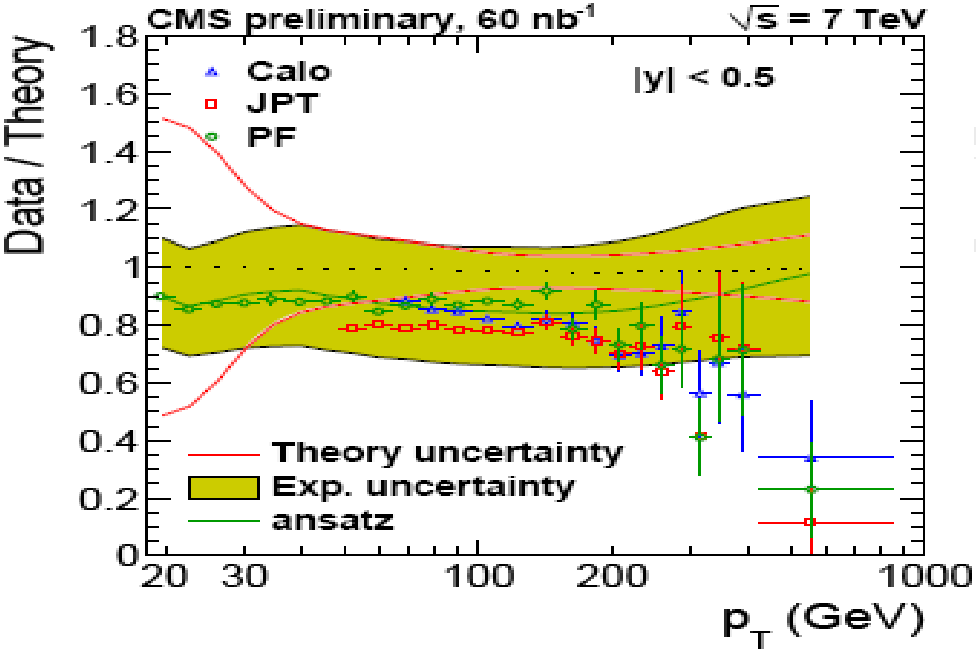


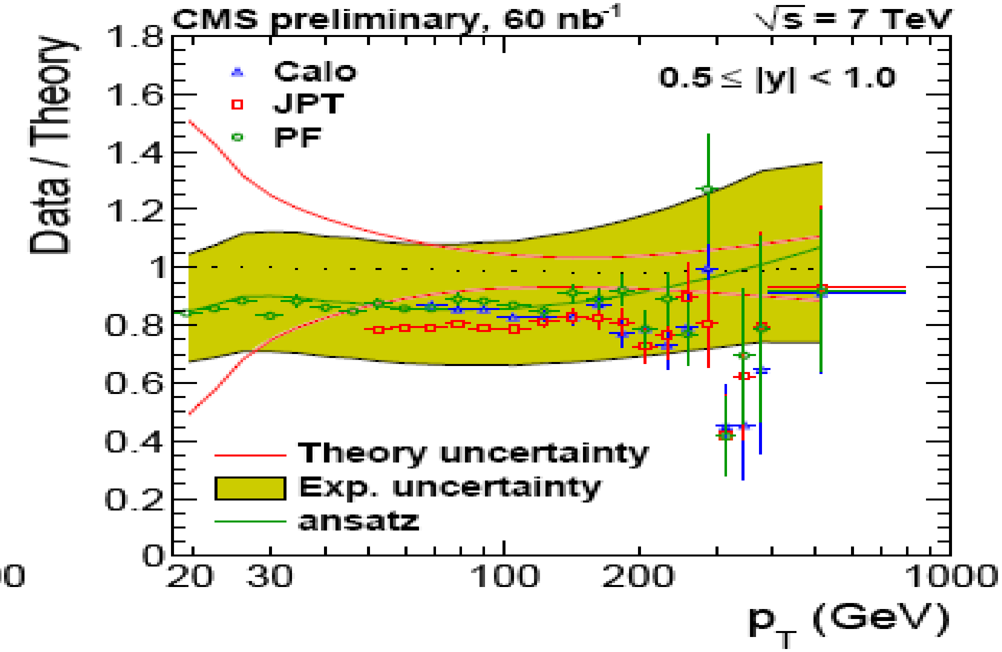


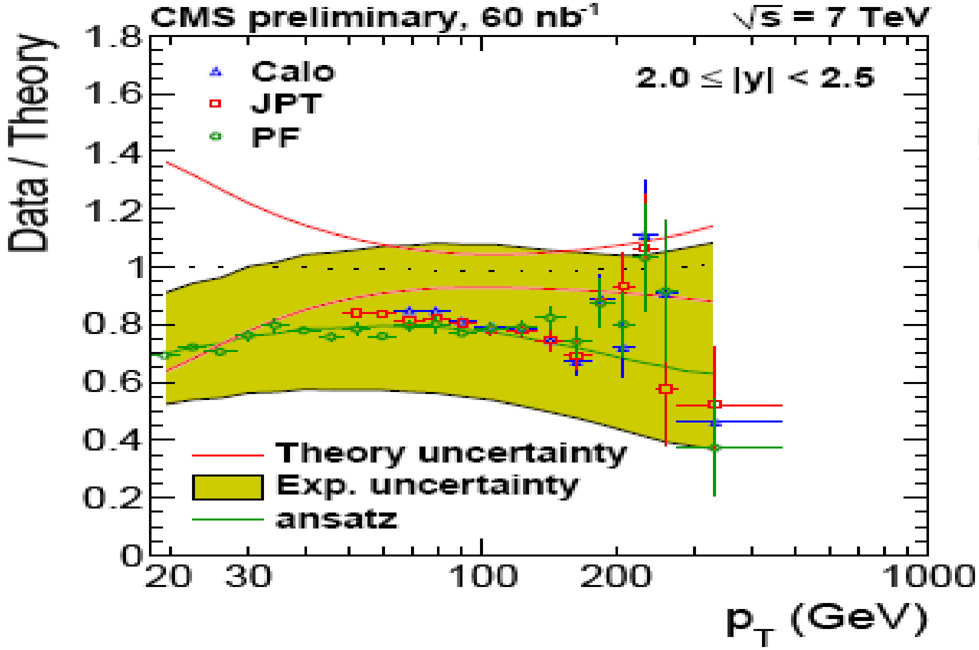


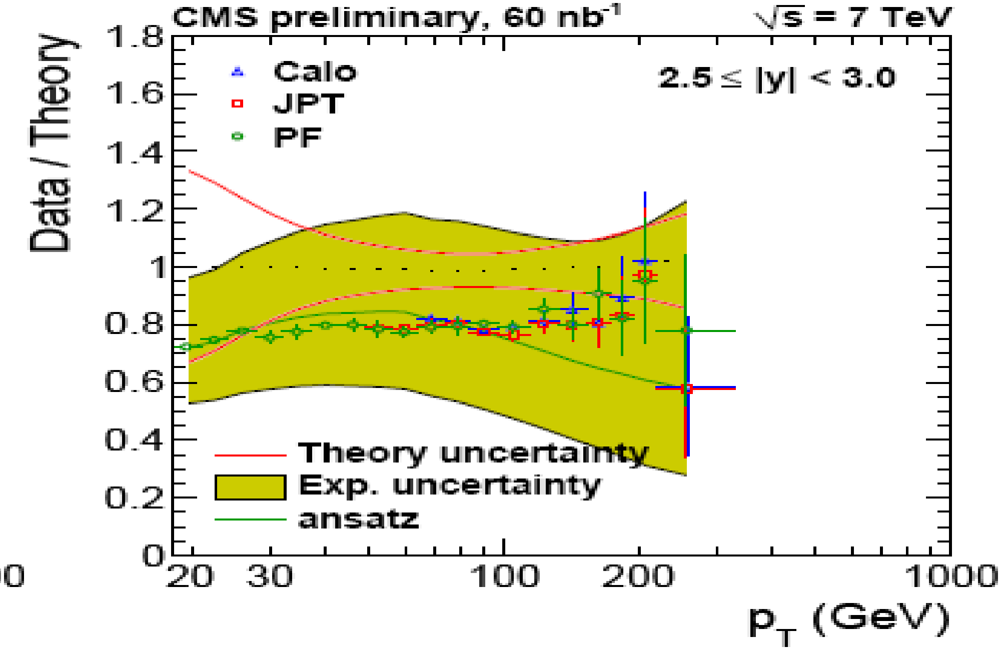


Inclusive jet cross-section

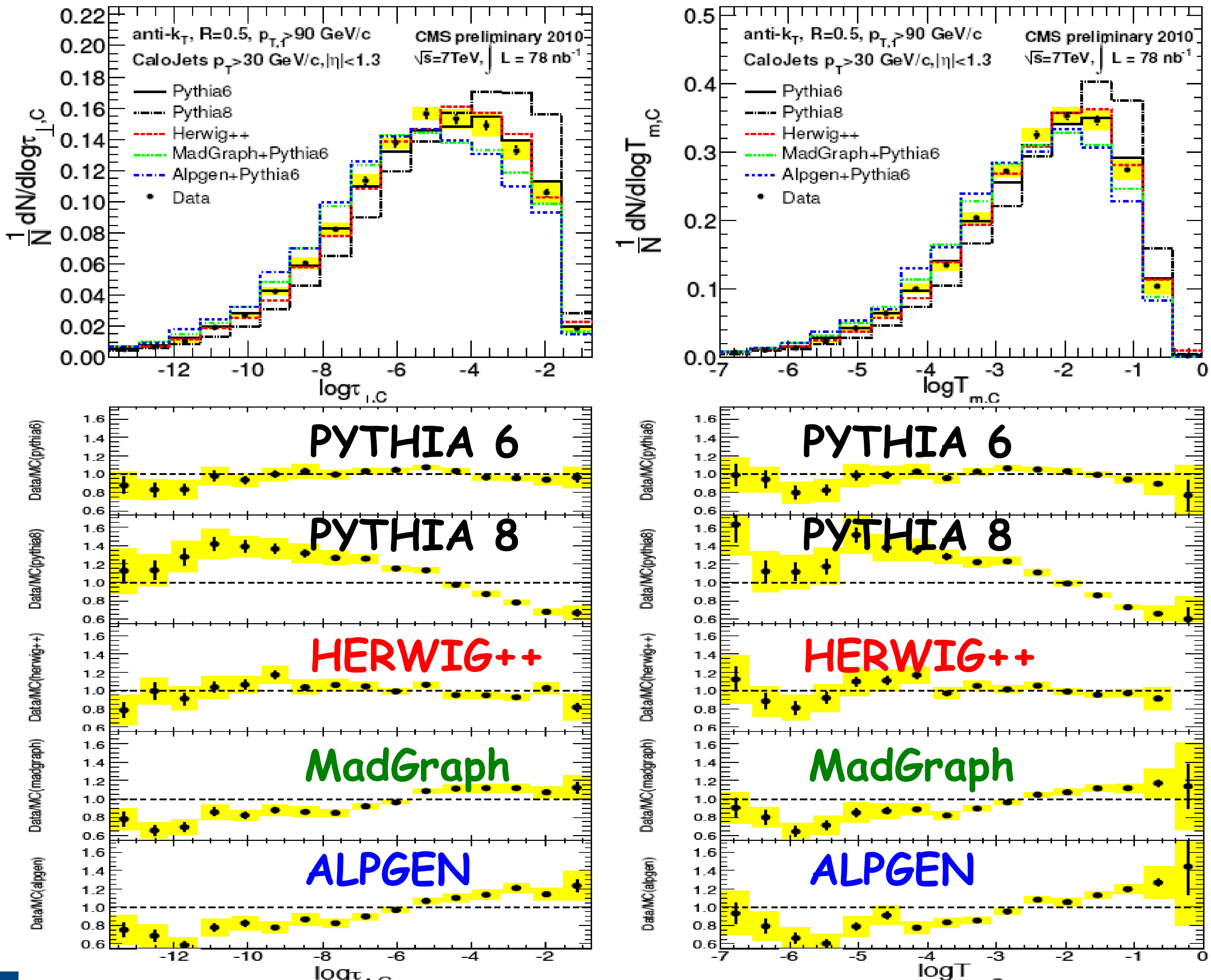








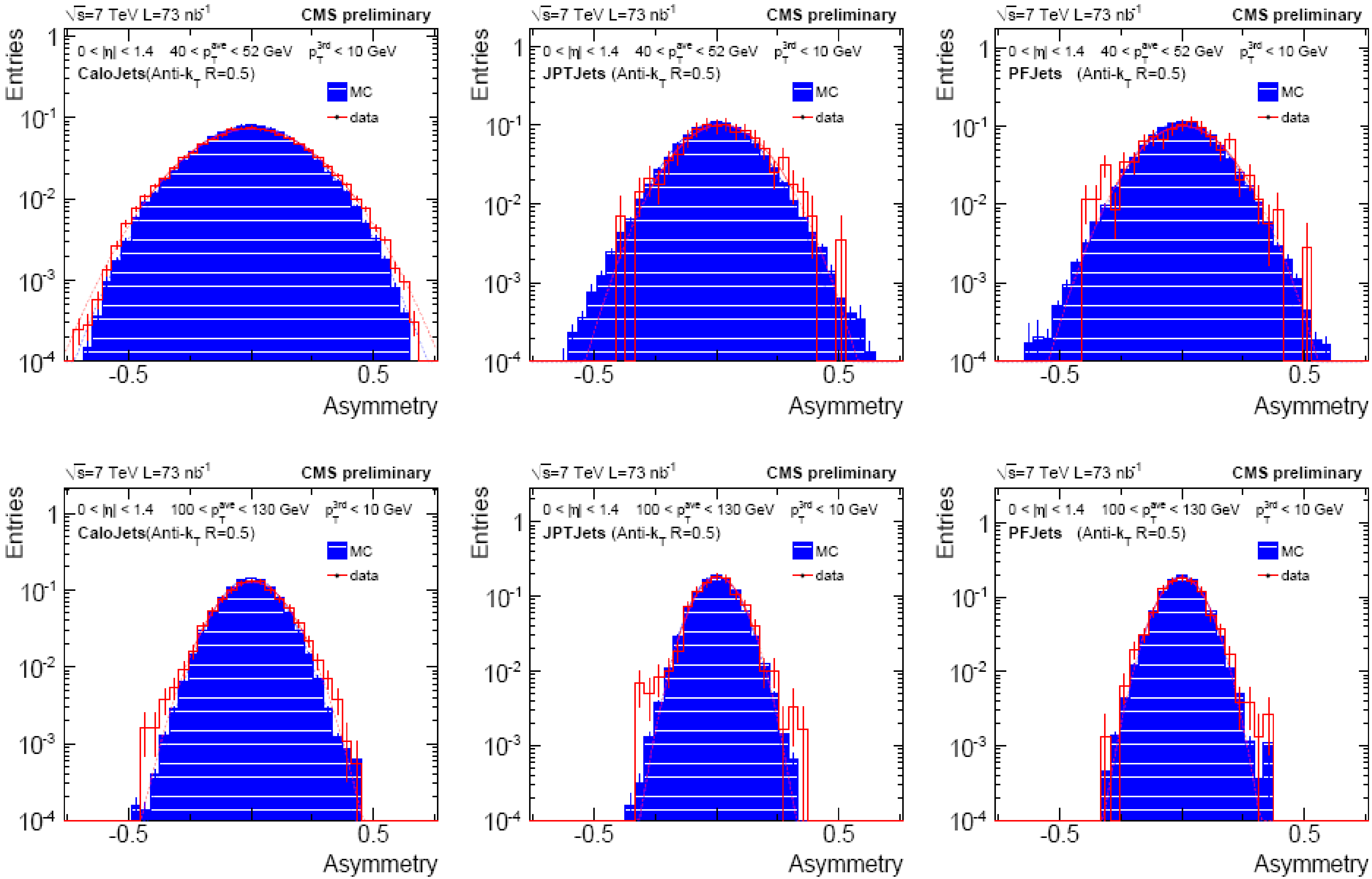
Hadronic event shapes



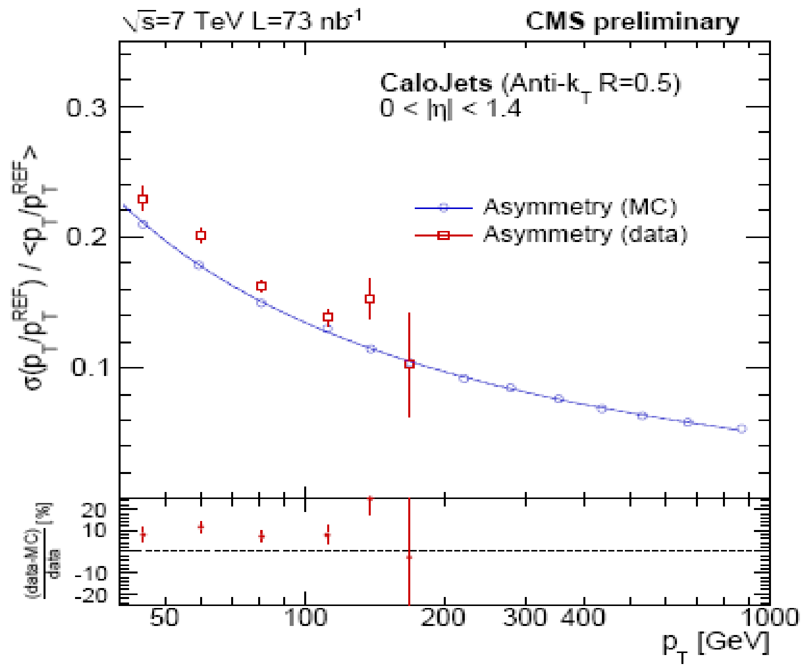
leading jet
pT>90 GeV

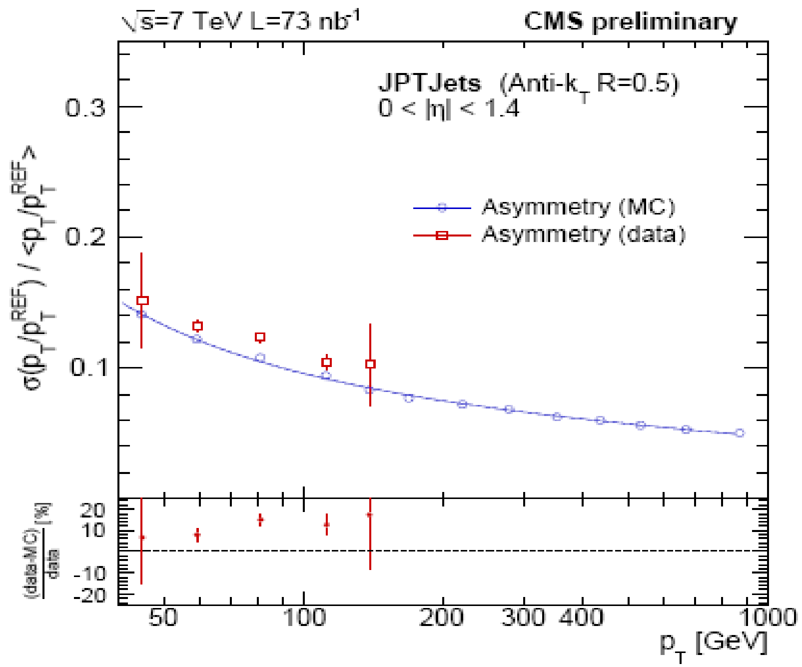
Jet resolution

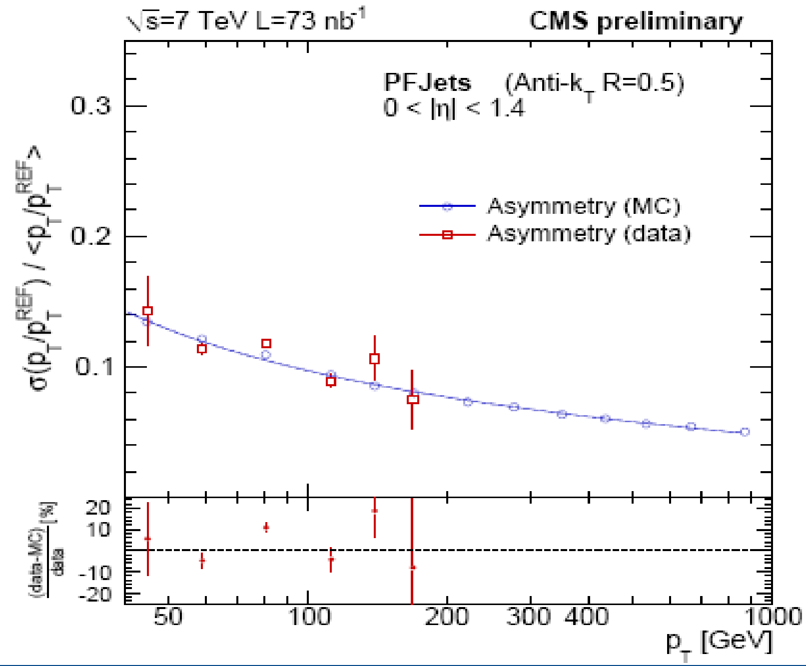
$$A = \frac{p_T^{\mathrm{jet1}} - p_T^{\mathrm{jet2}}}{p_T^{\mathrm{jet1}} + p_T^{\mathrm{jet2}}} \qquad \frac{\sigma(p_T)}{p_T} = \sqrt{2}\sigma_A$$



Jet resolution







Unfolding

- Correction for finite jet energy resolution
- Ansatz unfolding method:

$$f(p_T) = \mathcal{N} p_T^{-\alpha} \cdot \left(1 - \cosh(y_{\min}) \frac{2p_T}{\sqrt{s}}\right)^{\beta} \exp(-\gamma / p_T)$$

high pT — low pT + b-jets

$$F(p_T) = \int_0^{\infty} f(p'_T) R(p'_T - p_T; \sigma) dp'_T \qquad C_{\text{res}} = f(p_T)/F(p_T)$$