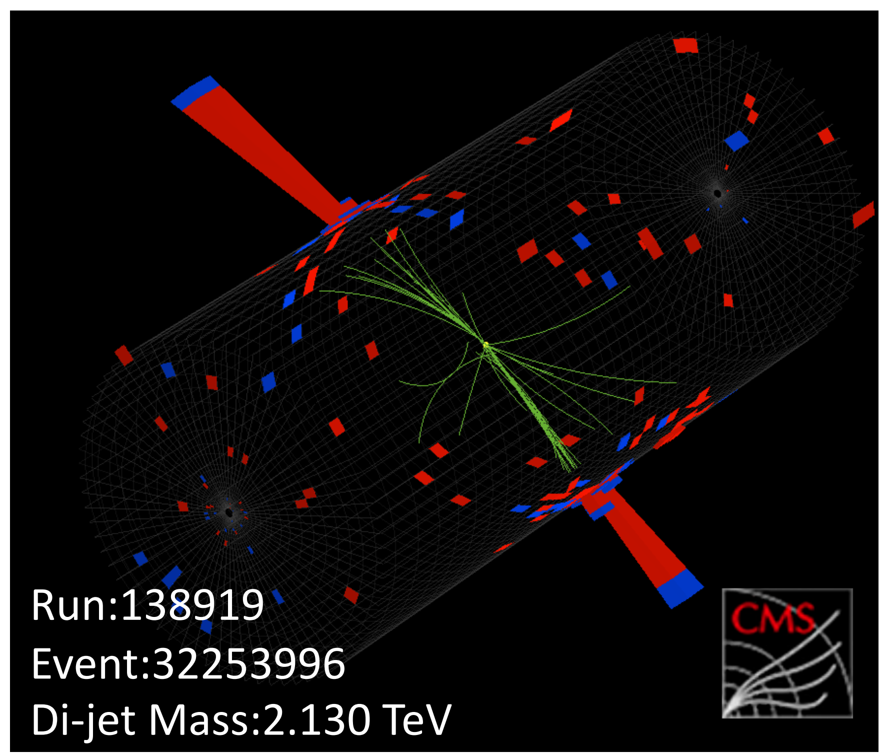
Measurement of Inclusive Jet Cross Section & Transverse Structure and Momentum Distributions in pp Collisions at $\sqrt{s}$=7 TeV at CMS



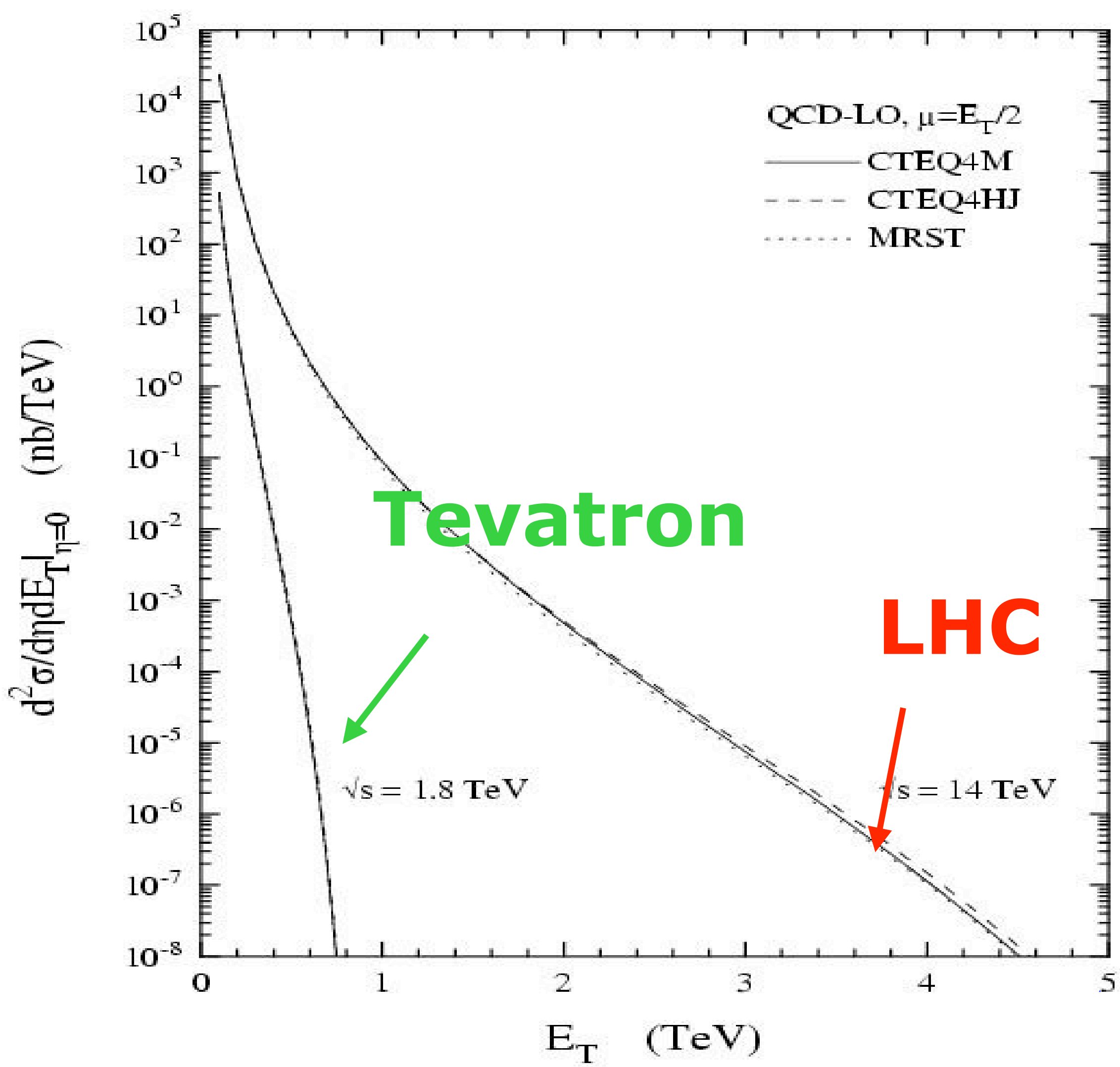
Pelin KURT, Vanderbilt University
for the CMS Collaboration

Implications of First LHC Data, 11 August 2010, MIT-Berkeley, USA

QCD Studies at the LHC

Huge jet cross section at the LHC will allow us to study many QCD physics analyses. Jets are experimental signatures of quarks and gluons from hard collisions. They are crucial for many measurements (QCD analyses and others).

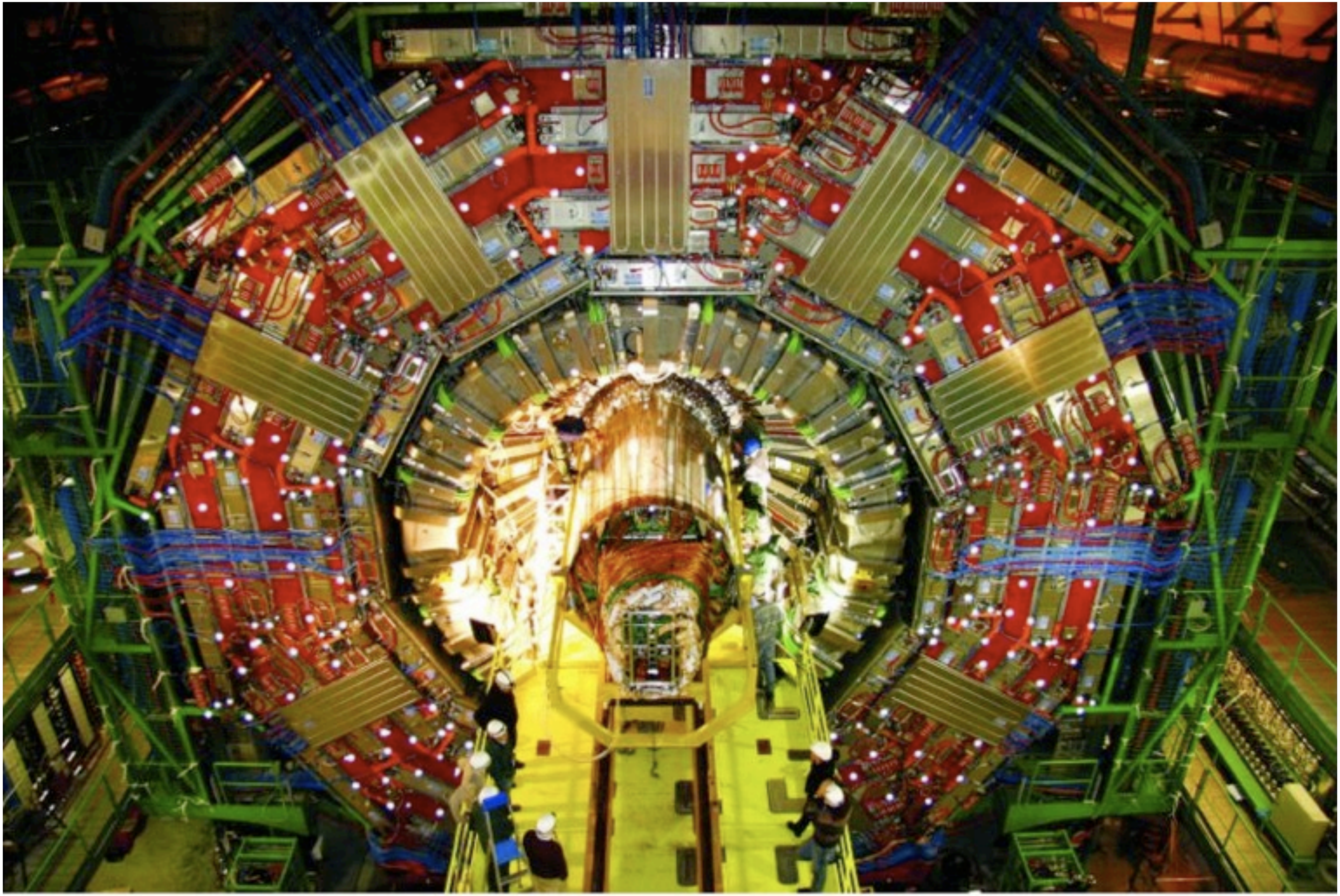
Huge cross sections:
Eg for 1 fb^{-1} ~ 10000 events with E_T> 1 TeV
100 events with E_T> 2 TeV



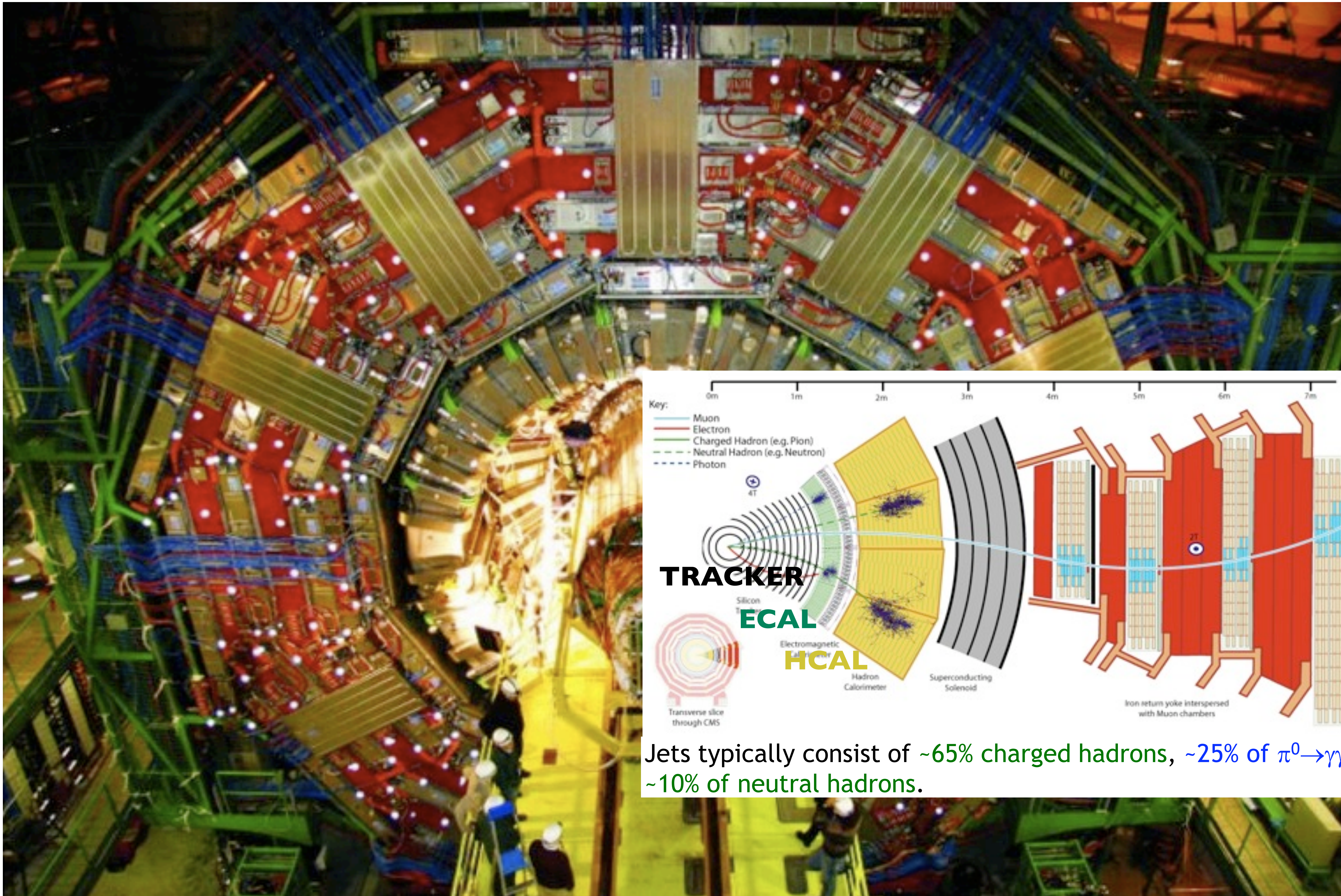
- MinBias, Underlying Event
- Inclusive Jets (there is also dijet mass...)
- Jet Shapes
- Event Shapes
- PDFs, α_s
- New Physics etc...

I will be discussing "Inclusive Jets" and "Jet Shapes" in this talk !!

The CMS Detector



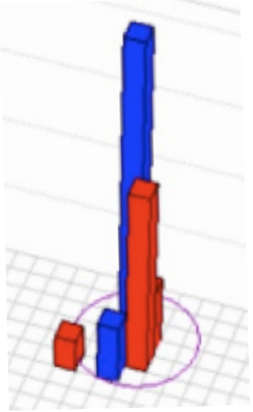
The CMS Detector



Jets typically consist of ~65% charged hadrons, ~25% of $\pi^0 \rightarrow \gamma\gamma$, ~10% of neutral hadrons.

Jet Reconstruction in CMS

The default jet clustering algorithm is anti k_T (R=0.5 and R=0.7).

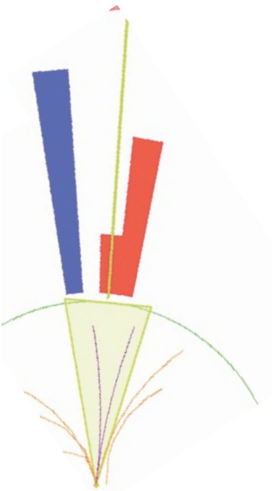


- **Calorimeter Jets**

  Jets are clustered from ECAL and HCAL deposits (CaloTowers). Tower E_T > 0.5 GeV

- **Track Jets**

  Reconstructed from tracks of charged particles : completely independent from calorimetric jet measurements.

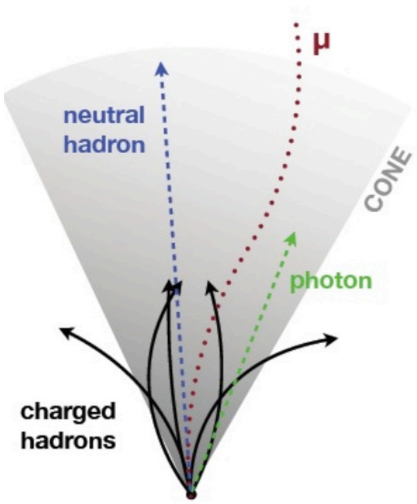


- **Jet Plus Track Jets (JPT)**

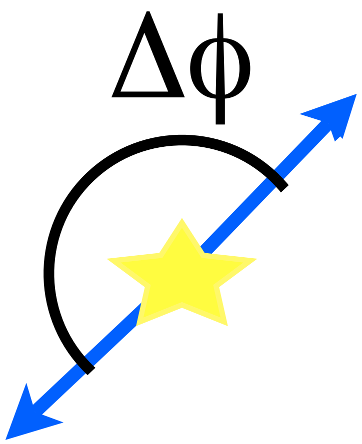
  Subtract average calorimeter response from CaloJet and replace it with the track measurement.

- **Particle Flow Jets (PF)**

  Cluster Particle Flow Objects: Unique list of calibrated particles.

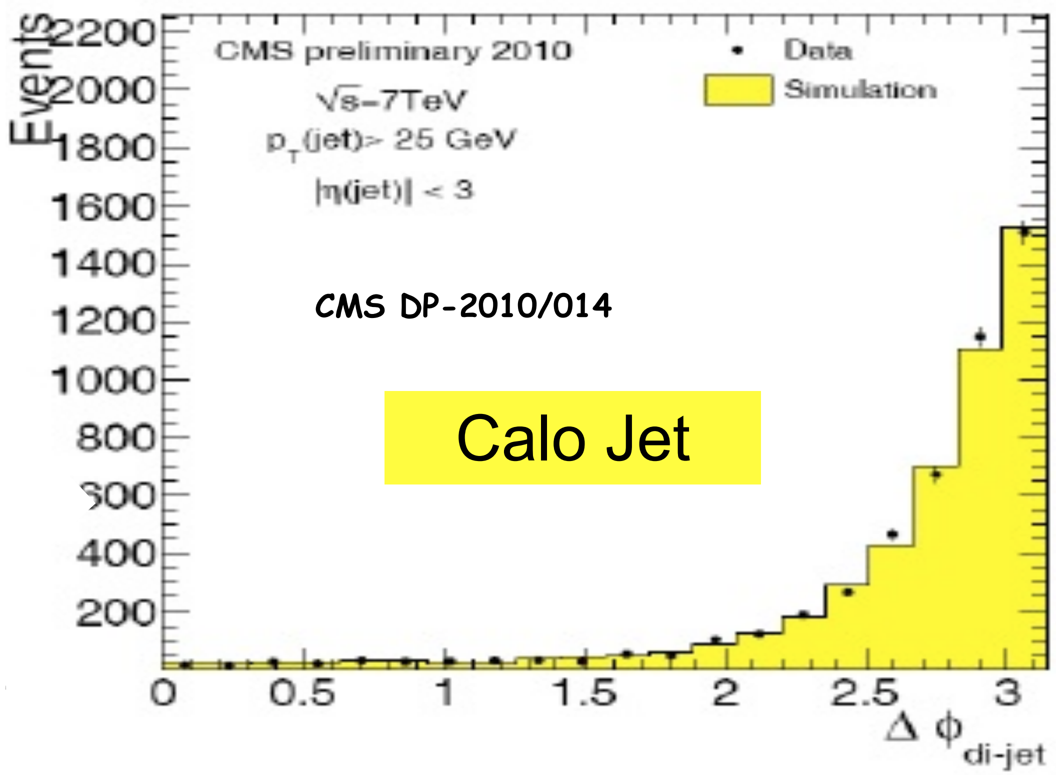


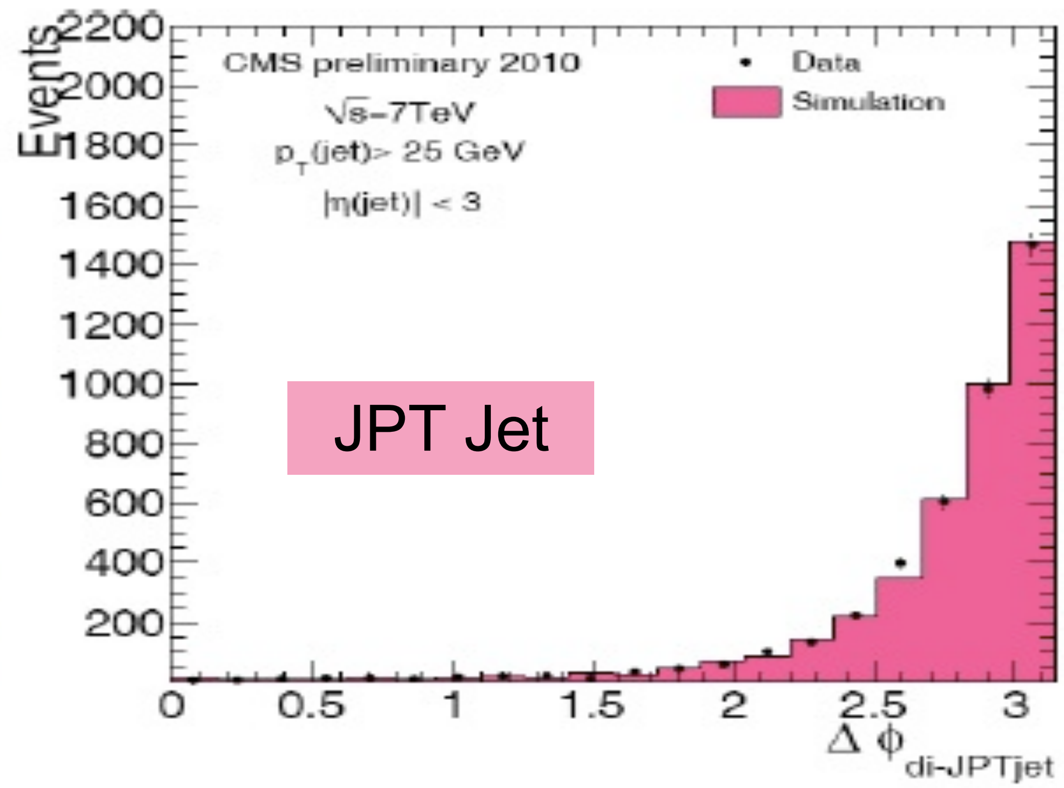
Example : Dijets ΔΦ in Data and MC

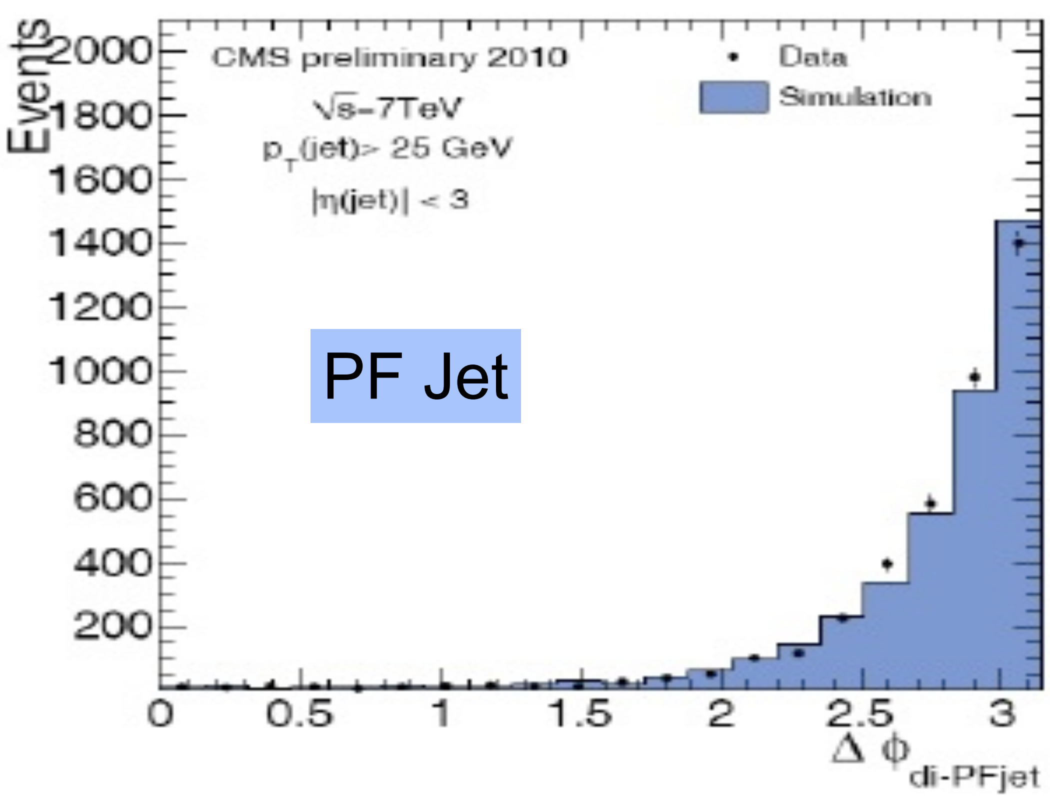


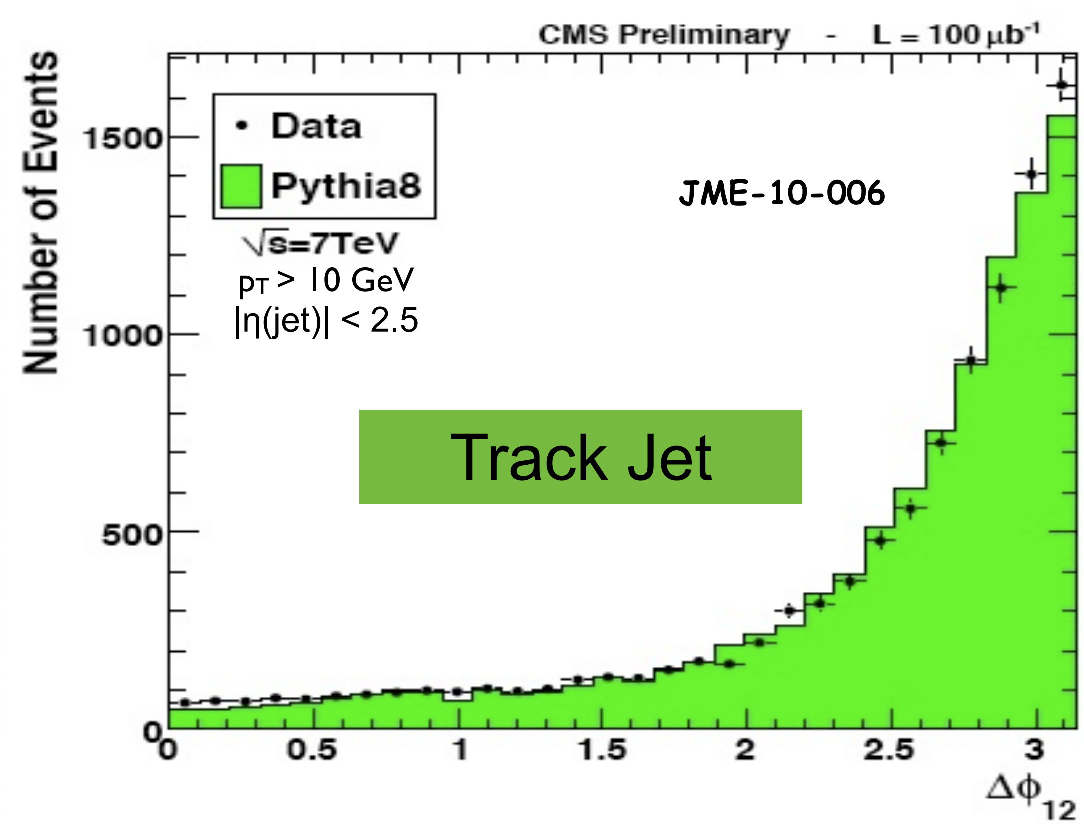
dijet events are back-to-back in delta phi

Good agreement for all jet types between data and MC





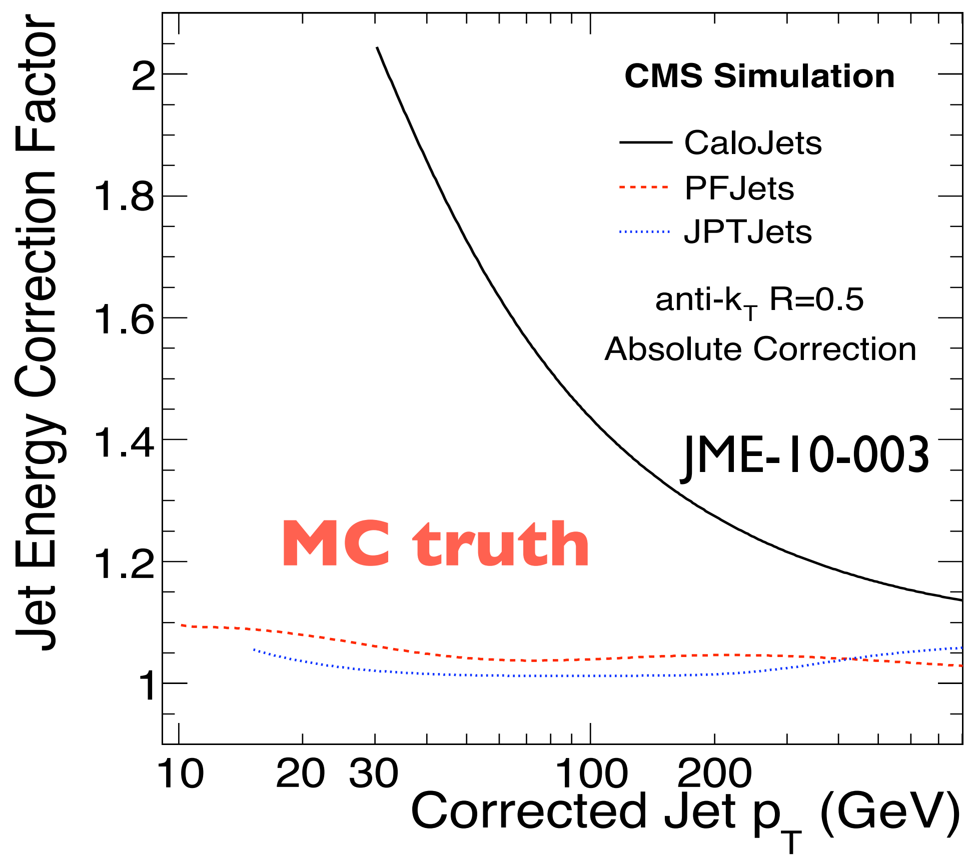




Jet Energy Corrections (JEC)

The calorimeter of the CMS detector has non linear response in p_T and is non uniform as a function of $|\eta|$. Majority of CMS physics analyses currently use MC-truth JEC.

- Factorized approach
  - Offset Correction : remove pile up and noise contribution
  - Relative Correction : flattens the jet response in $|\eta|$
  - Absolute Correction : flattens the jet response in p_T
- Data driven approach
  - Di-jet balancing (relative correction)
  - γ+jet balancing (absolute correction)
- Optional corrections
  - EMF, Flavor, UE, Parton



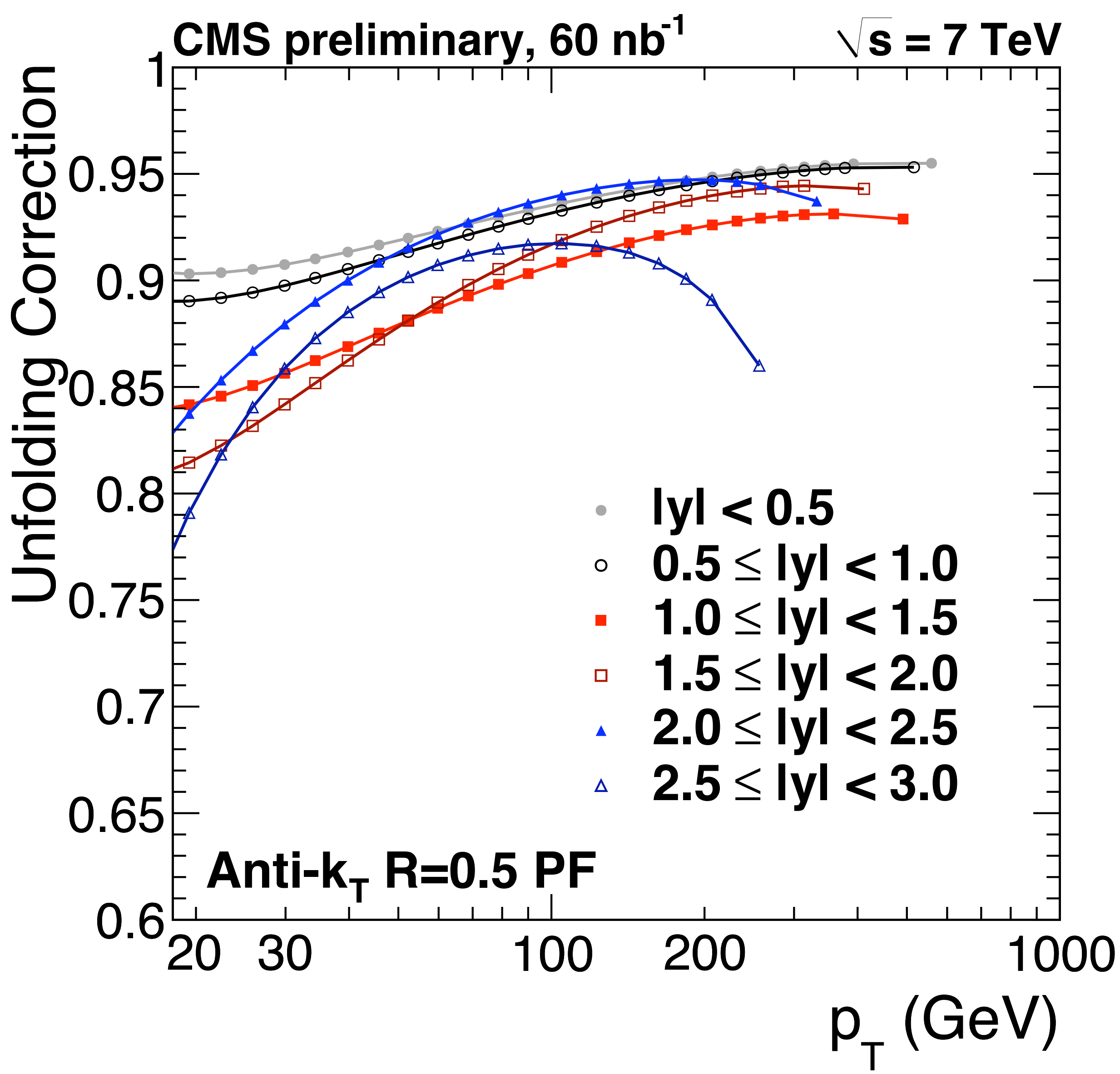
Current estimate of the uncertainties (JME-10-003):

- ±10% constant in p_T for the absolute calibration of CaloJets
- ±5% constant in p_T for the absolute calibration of the track based jets (PFJets, JPTJets, TrackJets)
- ±2% per unit of pseudorapidity, constant in p_T, for the relative calibration for all types of jets.

Inclusive Jet Cross Section

Inclusive Jets : Experimental Uncertainties

Correction for energy resolution



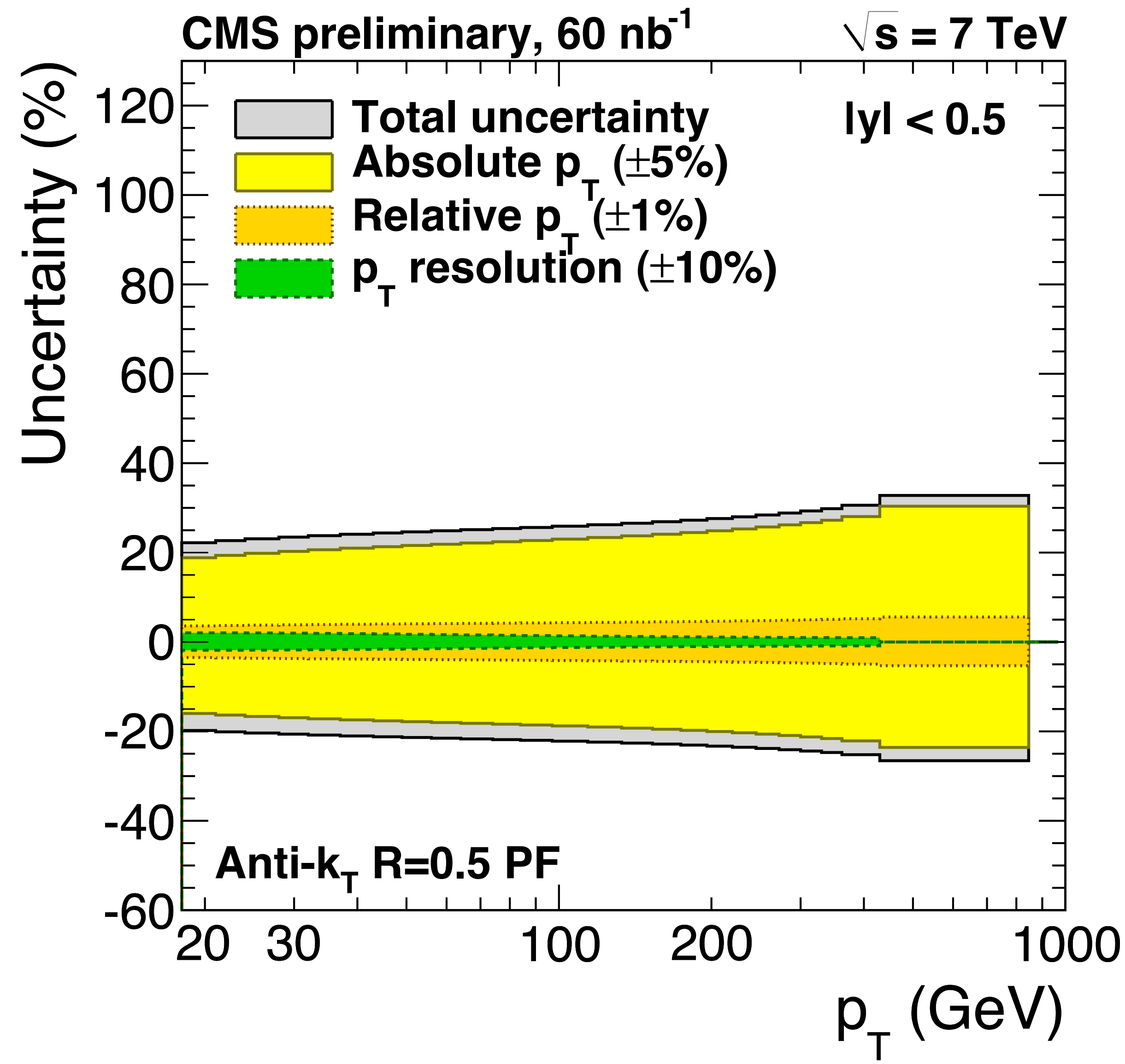
The measured jet p_T spectra is corrected for resolution effects using ***ansatz*** unfolding.

$$f(p_T) = N_0 p_T^{-\alpha} \underbrace{\left(1 - \frac{2p_T \cosh(y_{\min})}{\sqrt{s}}\right)^{\beta}}_{\text{high } p_T} \underbrace{\exp(-\gamma/p_T)}_{\text{low } p_T \text{ and b-jets}}$$

new

$$C_{\text{smear}}(p_T) = \frac{f(p_T)}{F(p_T)}, \qquad F(p_T) = \int_{x=0}^{x=\infty} f(x) g(p_T - x) dx$$

Absolute jet energy scale is dominant

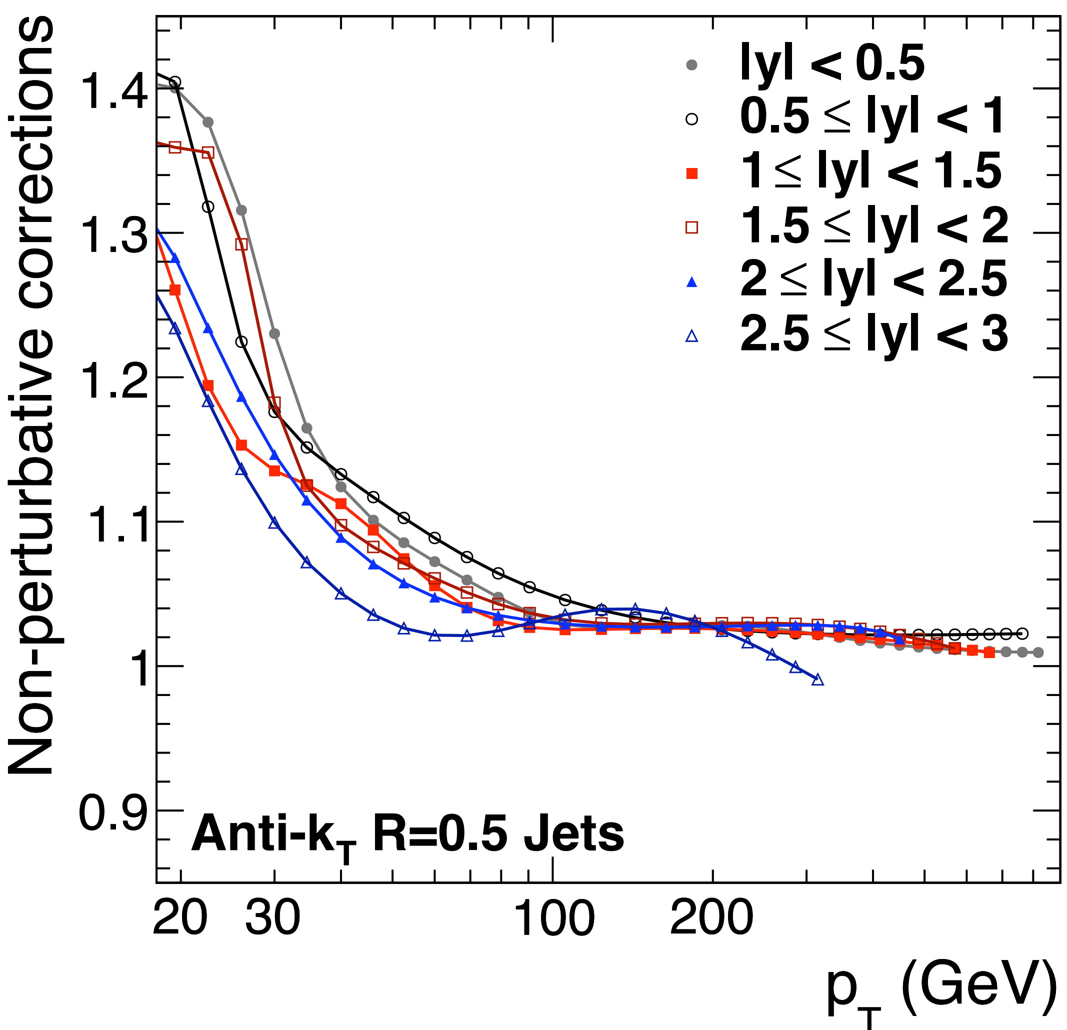


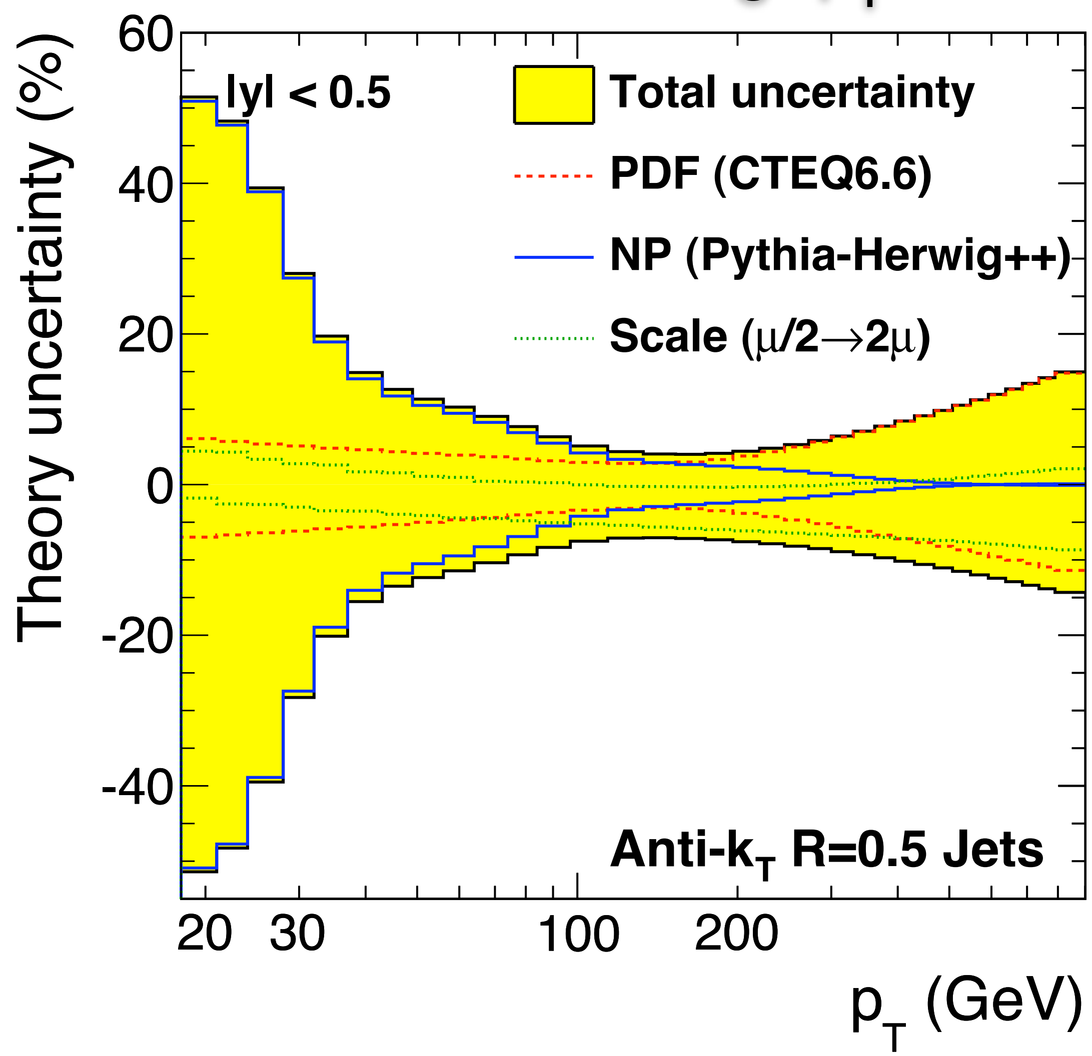
This is the JEC uncertainty band for the 5% in contrast to 10% for CaloJets

Inclusive Jets : Theory Uncertainties

- To compare with Data, NLO has to be corrected due to the effects:
  - Multiple Parton Interaction (MPI)
  - Hadronization and Decays (Lund & Cluster)

- From theory side, dominant systematics :
  - Non Perturbative (NP) corrections at low p_T
  - PDFs at high p_T

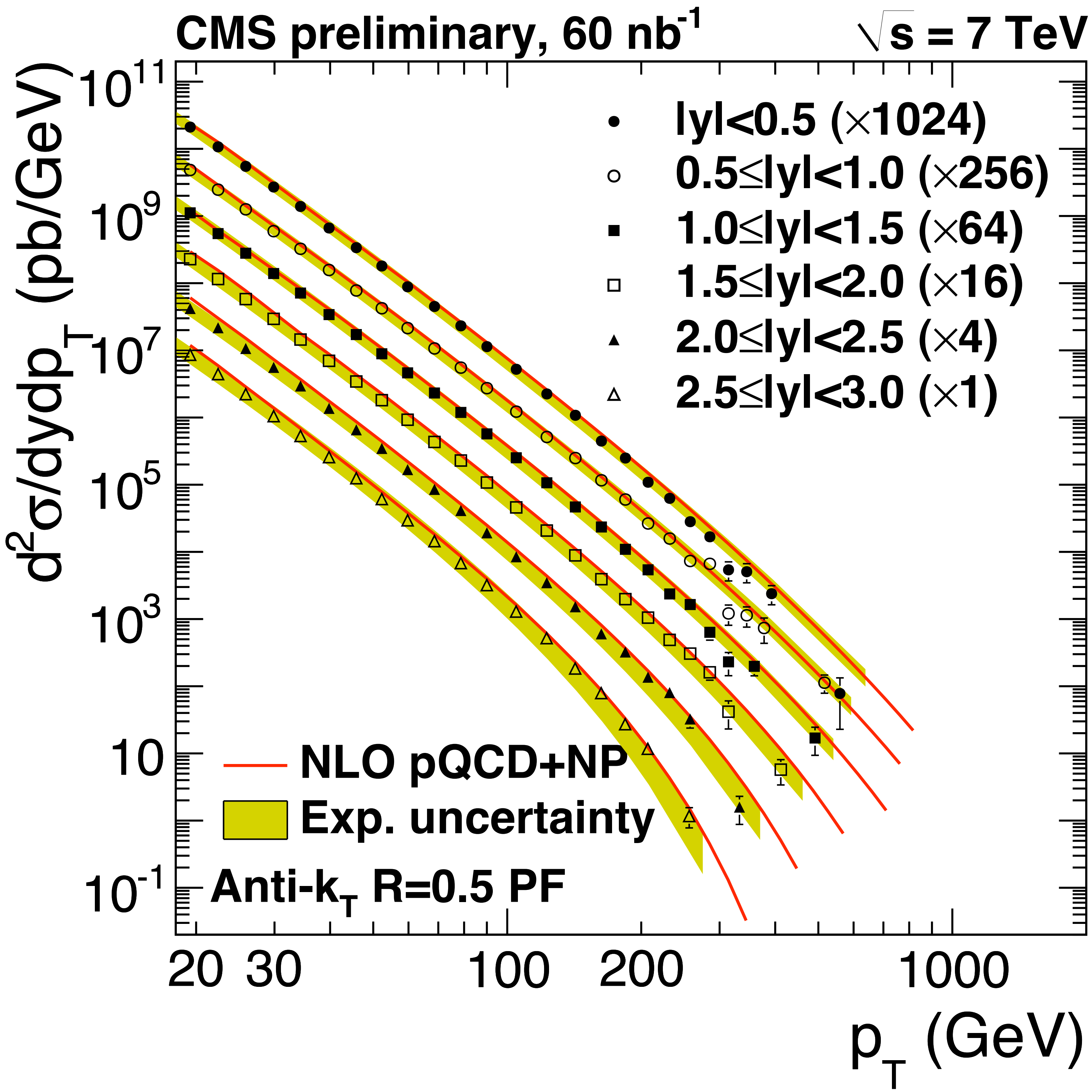




Pythia 6.4 and Herwig++ are used to predict NP corrections. The mean of the two predictions is taken as the correction.

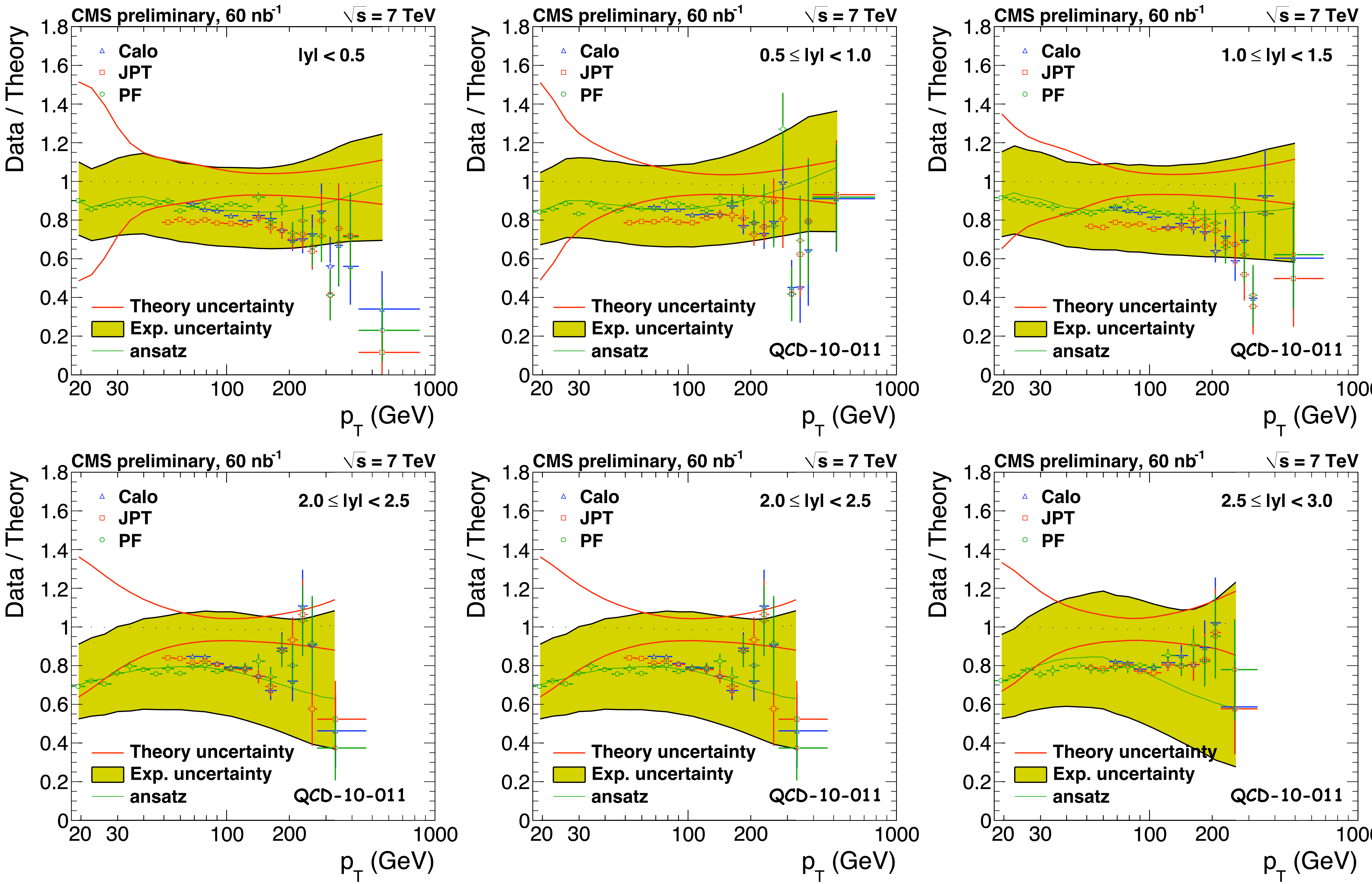
The leading sources of theoretical uncertainty are shown.

Inclusive Jet P_T Cross section



- Inclusive jet p_T spectra are in good agreement with NLO for all reconstruction types.
- Tevatron published record high p_T jet is 624 GeV (0.7 fb^{-1}), and has measured inclusive jet cross section down to 50 GeV jets at Run II.
- CMS PF jets have very good resolution and we can probe down to 18 GeV jets.
- Extending up to |y|=3.

Inclusive Jet P_T Cross section (Data/Theory)



All three methods show good agreement with each other and with theory within uncertainties.

Jet Shapes

Two different method have been used to study the internal structure of jets :

☑ ***Jet Charged Component structure at 7 TeV***

It is based on strategy proposed in CMS PAS QCD-08-002

☑ ***Classical Jet Shapes Analysis at 7 TeV***

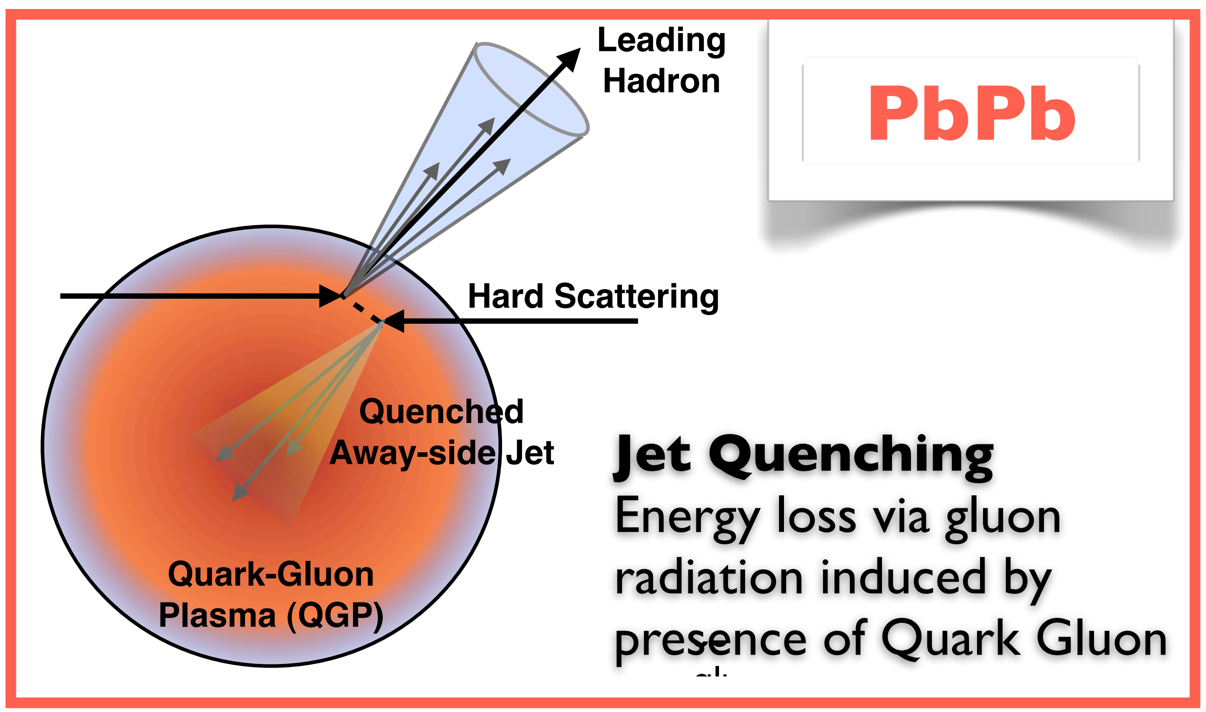
Based on CMS PAS QCD-08-005

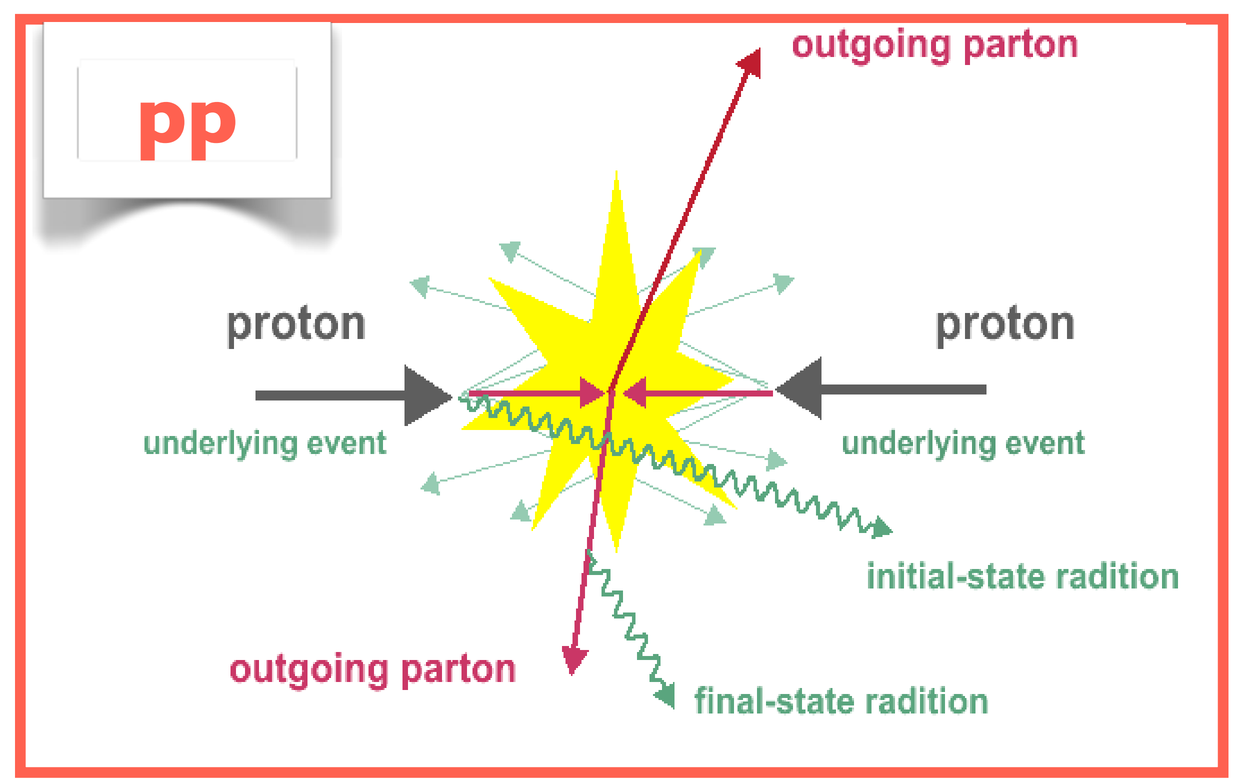
Motivation (Jet Shapes)

Jet Shapes measure the average distribution of energy flow as a function of the distance away from the jet axis:

- ☑ Test showering models in Monte Carlo generators.
- ☑ Discriminate between different underlying event models.
- ☑ Sensitive to the quark/gluon jet mixture.
- ☑ Provide insight into performance of jet clustering algorithms.
- ☑ Jet shapes can discriminate between competing models of jet quenching which have all successfully described leading particle suppression in Relativistic Heavy Ion Collider (RHIC) data.

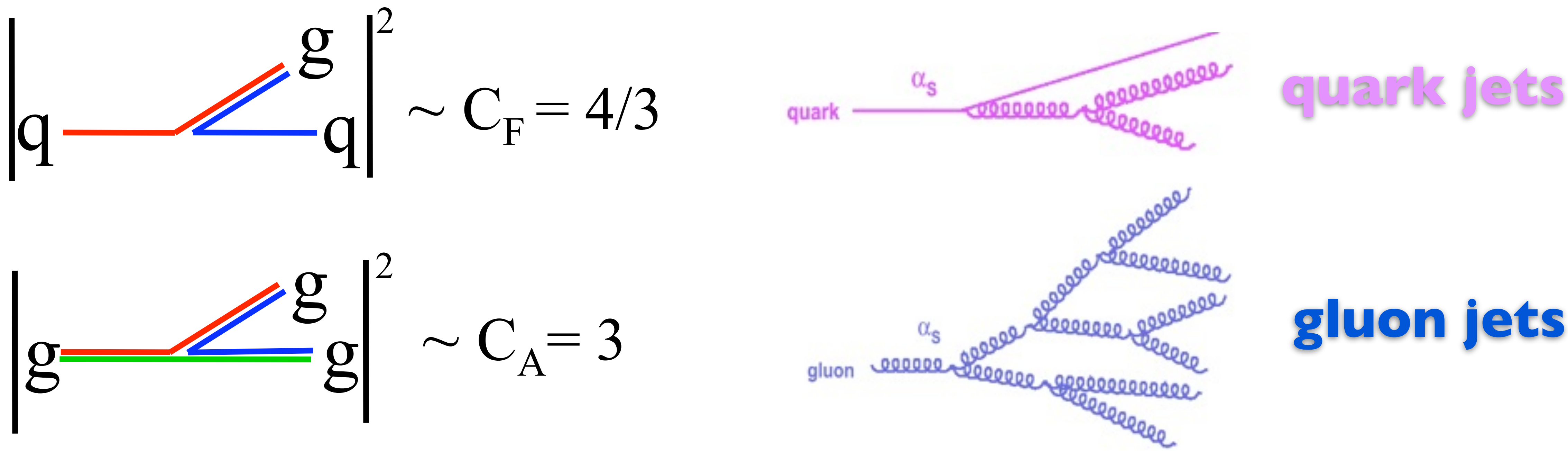
arXiv:0810.2807 (Ivan Vitev (LANL) and et. al)





Quark and Gluon Jets

- Jet Shapes are sensitive to quark/gluon jet mixture
  - Can separate quark and gluon jets in a statistical way
- Quark and Gluon jets radiate proportionally to their color factors
  - CF : strength of gluon coupling to quarks
  - CA : strength of gluon self coupling



- In QCD, quark jets are expected to be narrower than gluon jets.
- Jets initiated by quarks and gluons are also expected to have different average multiplicities and p_T spectra of constituents.

Jet Charged Component

Jet Charged Component

The following observables are used to characterize the structure of jets:

- Charged particle multiplicity in jet (**N_{ch}**)
- Charged particle transverse shape variable (**δR^2**)

A measure of the width of a jet in the $\eta - \varphi$ plane.

$$< \delta R^2 > (p_T) = < \delta\varphi^2 > (p_T) + < \delta\eta^2 > (p_T)$$

$$< \delta\eta^2_{jet} > (p_T) = \frac{\sum_{i \in jet} (\eta_i - < \eta >)^2 \cdot p_T^{\,i}}{\sum_{i \in jet} p_T^i}$$

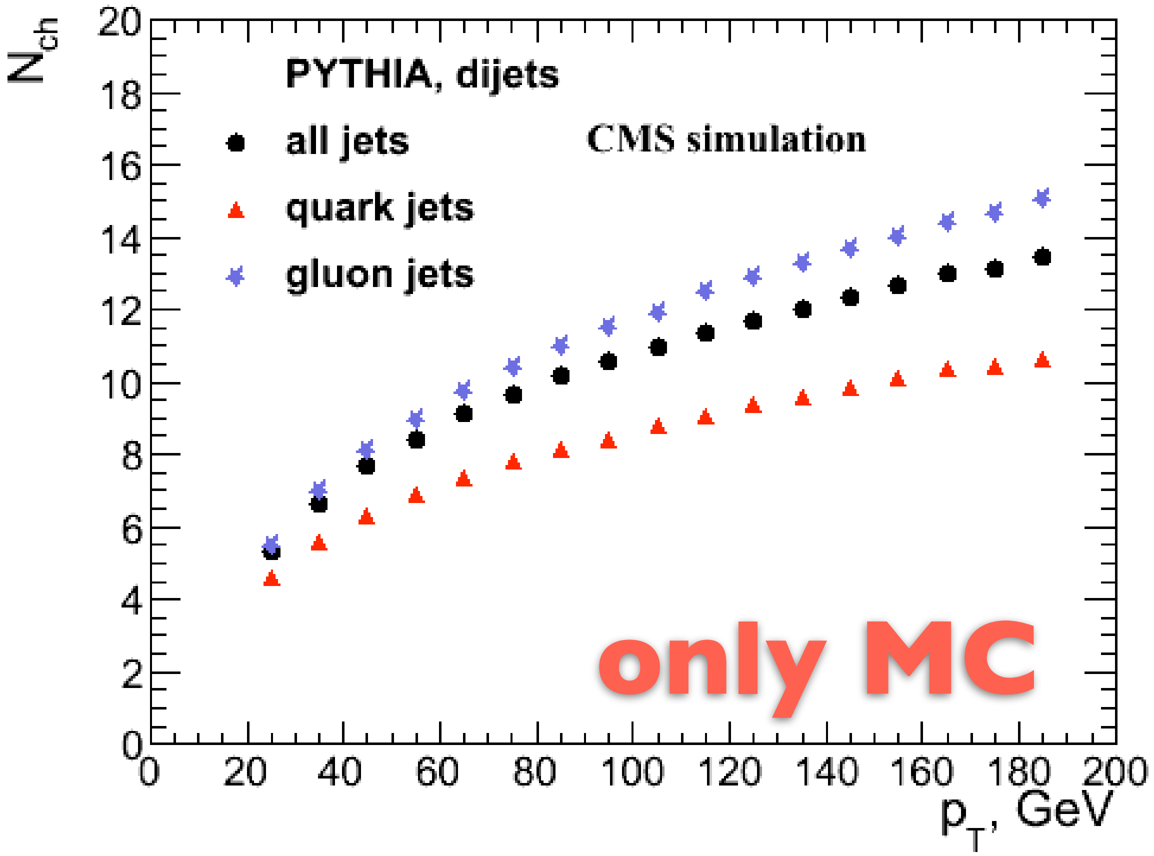
$$< \delta\phi^2_{jet} > (p_T) = \frac{\sum_{i \in jet} (\phi_i - < \phi >)^2 \cdot p_T^{\,i}}{\sum_{i \in jet} p_T^i}$$

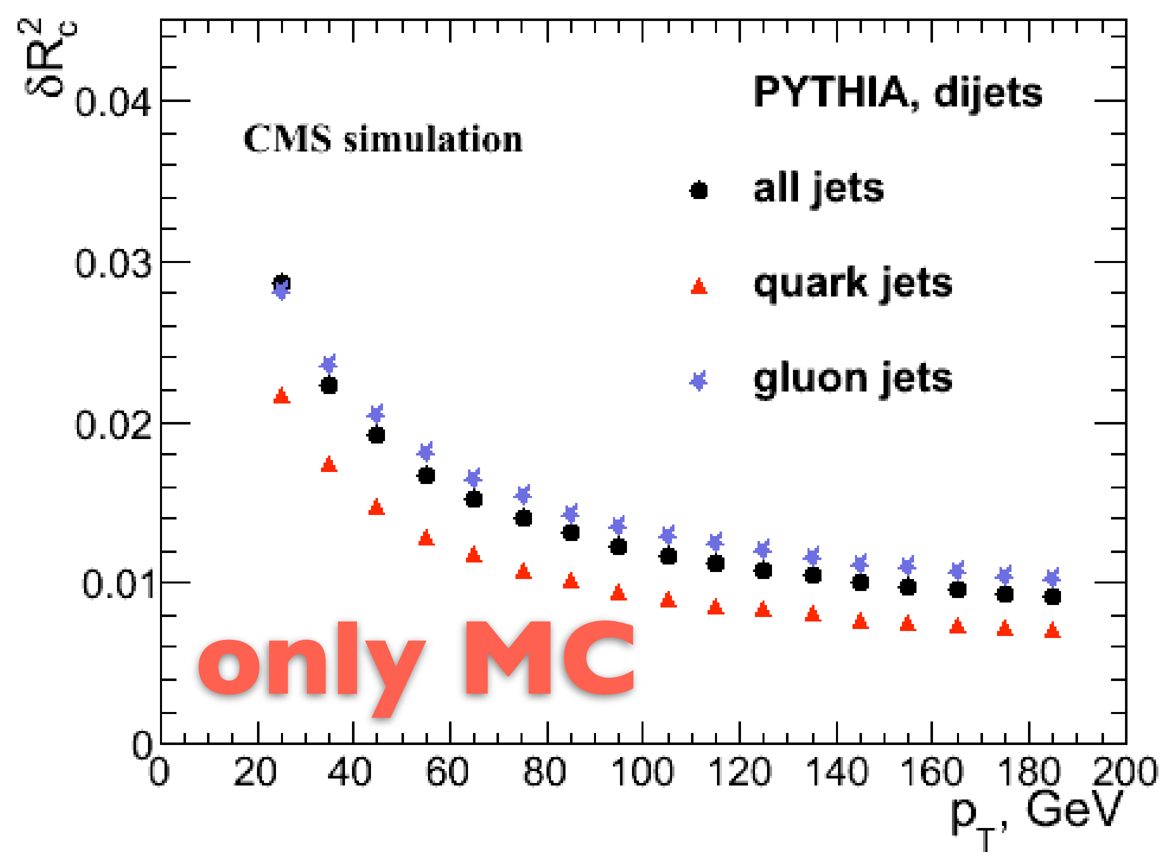
δR² and N_{ch} for jet flavors (dijets)

The combination with minimum

$\sum \Delta r^2$ (parton;jet) = Δr^2(i1;j1)+ Δr^2(i2;j2)

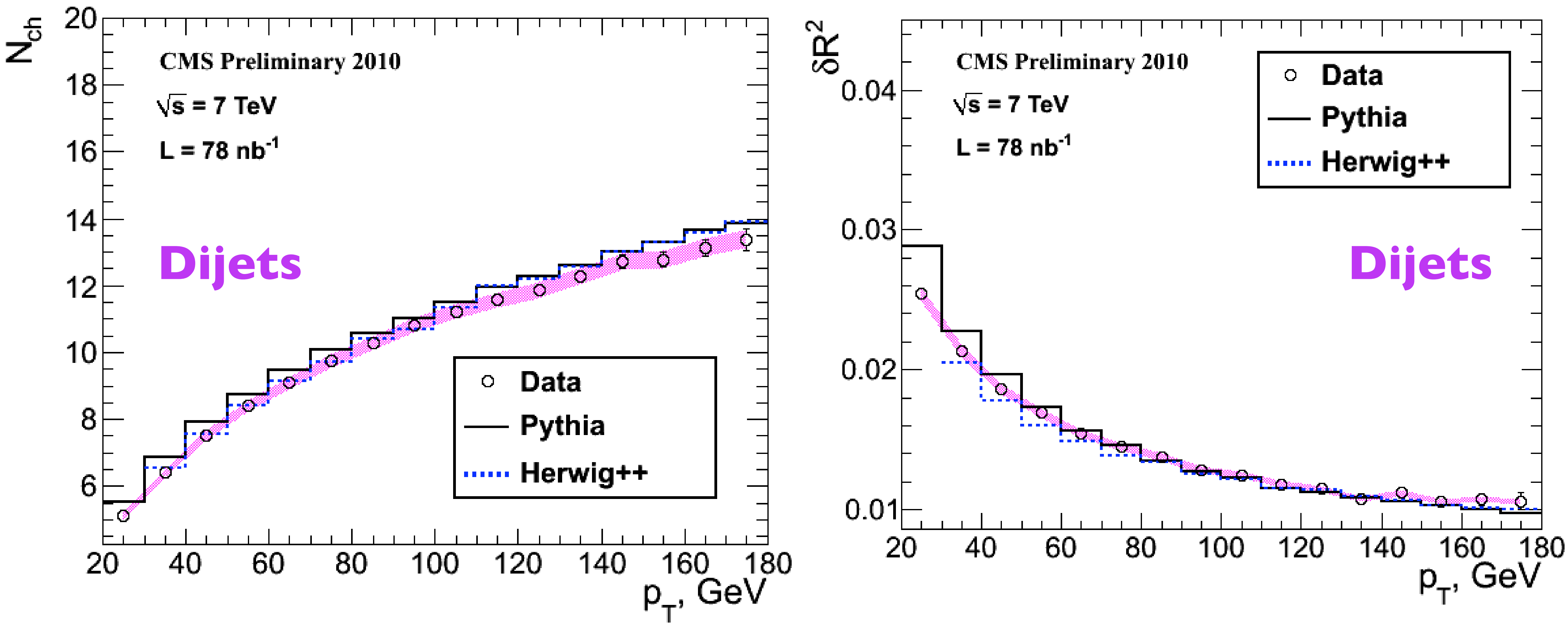
PYTHIA, |η| < 1
Detector level





The mean of N_{ch} increases whereas the transverse jet shape δR² drops as a function of the jet transverse momentum.

Charged multiplicity (N_{ch}) and δR^2 vs P_T^{jet}

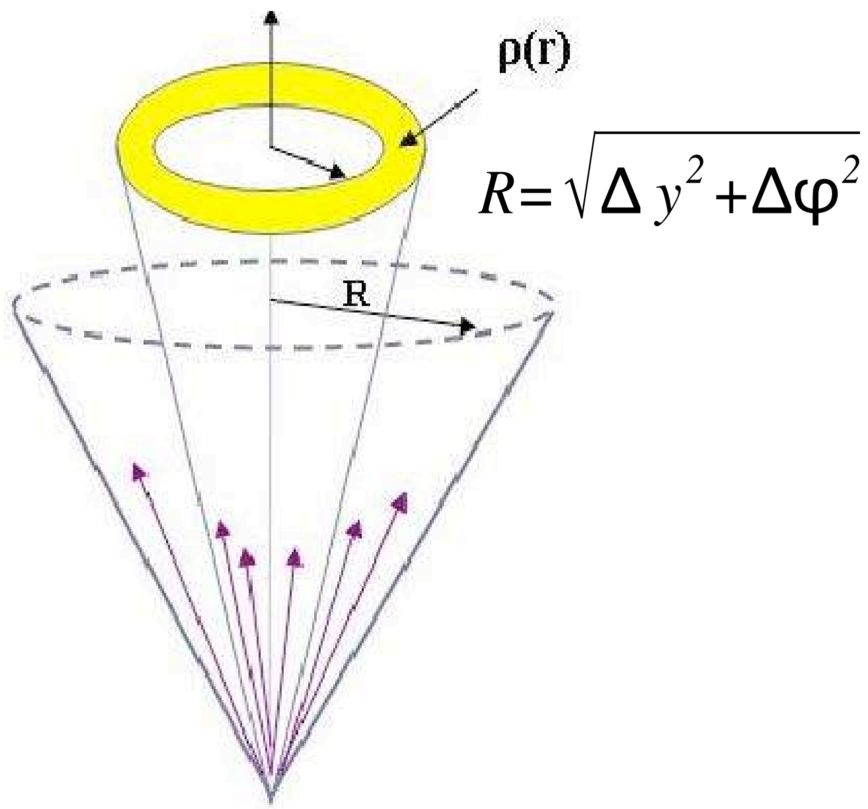


Statistical uncertainty is assigned to data points.
Systematical uncertainty due to jet energy scale is shown with pink band.

- At low jet transverse momentum ($20 < p_T < 50$GeV) the measured jets are a few percent broader than predicted by Herwig++ and narrower than predicted by Pythia D6T.

Jet Shapes

Jet Shapes



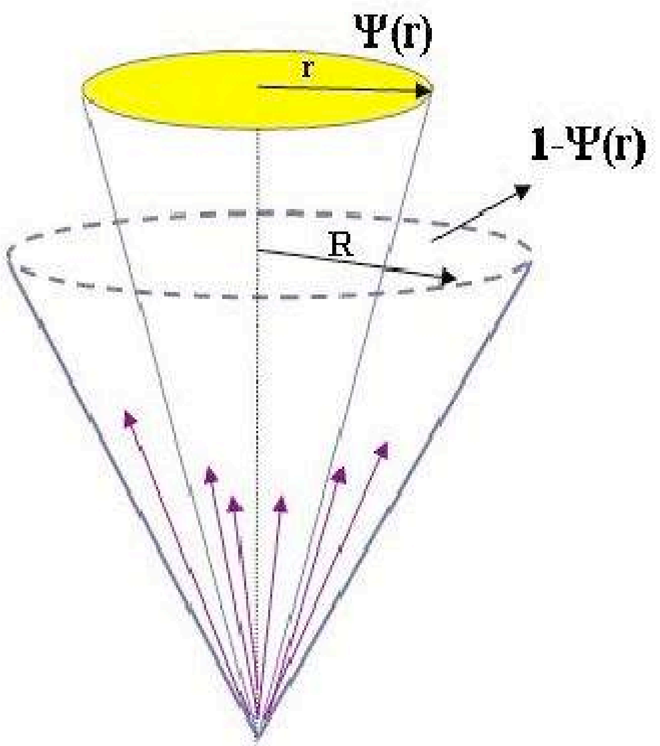
Differential Jet Shape

Definition: The average fraction of the jet transverse momentum inside an <u>annulus</u> in the y-ϕ plane of inner (outer) radius r-Δr/2 (r+Δr/2) concentric to the jet axis.

$$\rho(r) = \frac{1}{\delta r}\frac{1}{N_{jet}}\sum_{jets}\frac{P_T(r-\delta r/2, r+\delta r/2)}{P_T(0,R)}$$

Definition: Integrated jet shape is defined as the average fraction of jet transverse momentum inside a cone of radius *r* concentric to the jet axis.

$$\Psi(r) = \frac{1}{N_{jets}}\sum_{jets}\frac{P_T(0,r)}{P_T^{jet}(0,R)}$$



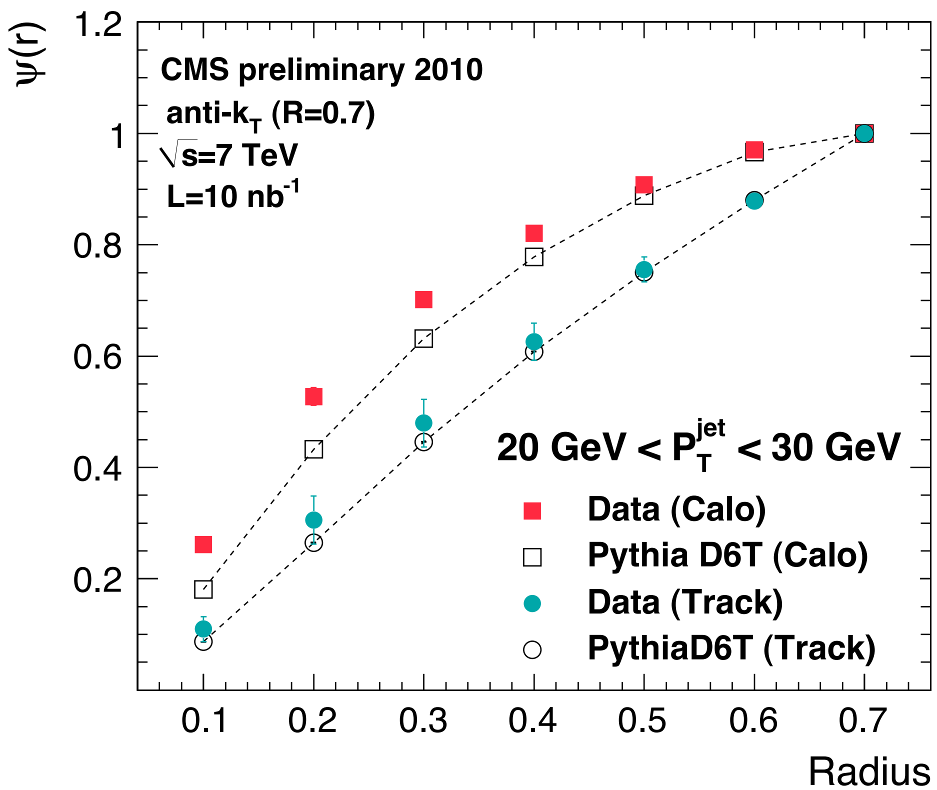
Integrated Jet Shape

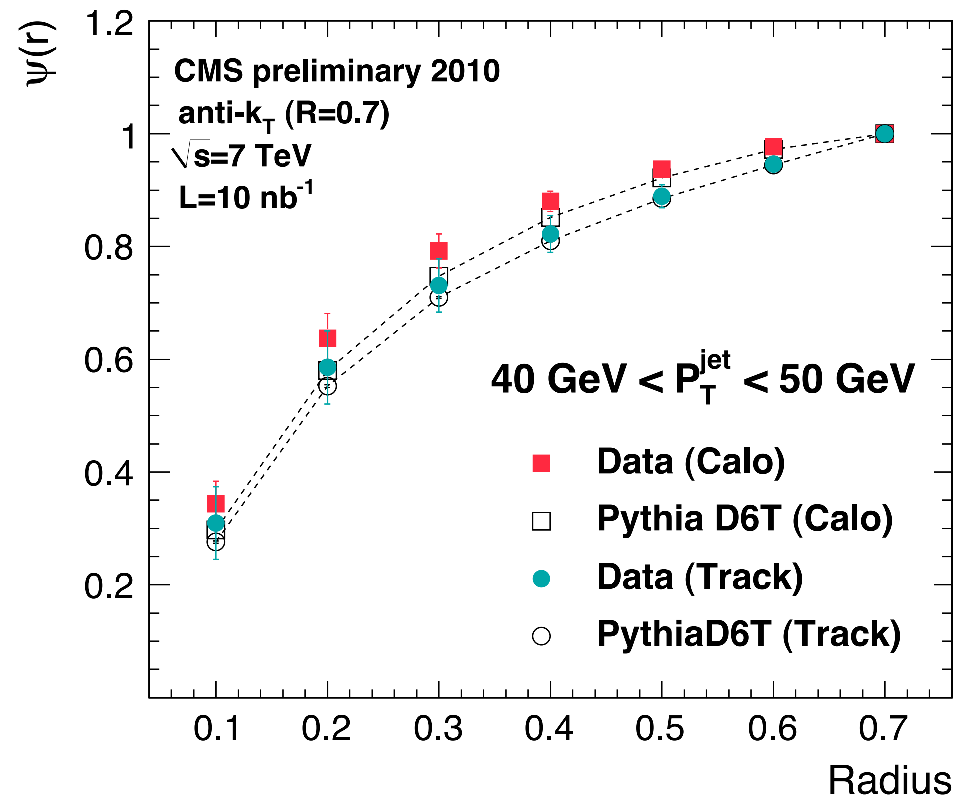
Systematic Uncertainties

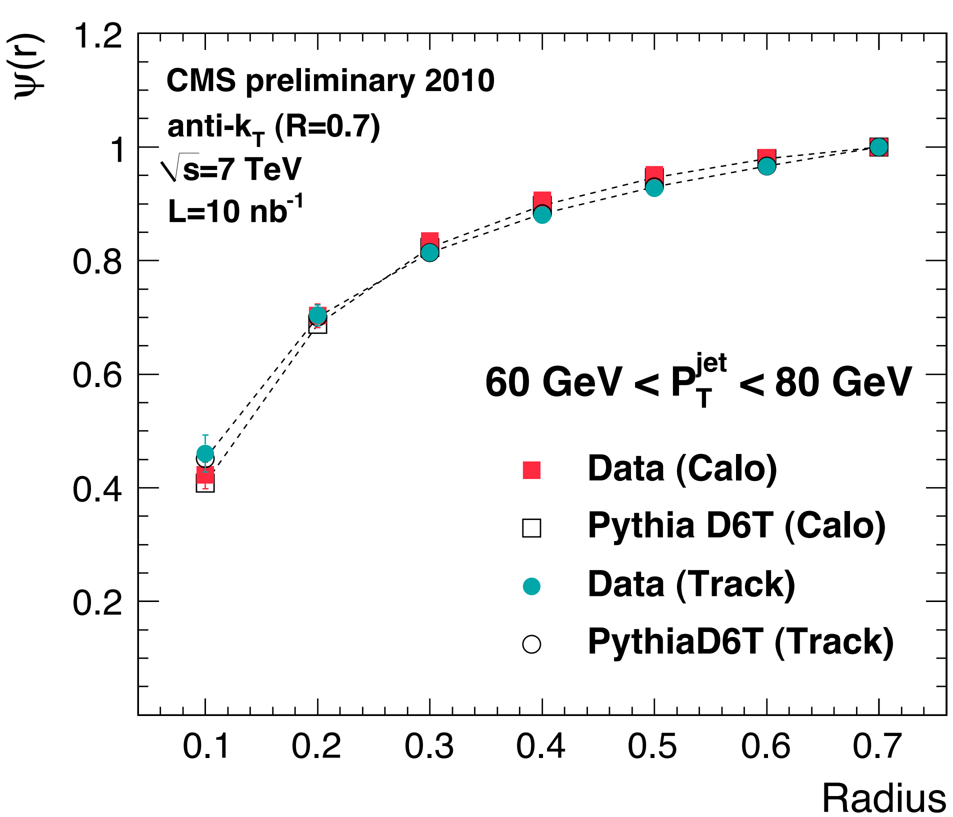
- Jet Energy Scale
- Calorimeter Response and Transverse Shower Shape
  - The measured jet shapes depend on the calorimeter response to hadrons and on the transverse showering. There is uncertainty due to simulation of these effects.
    - Data driven approach is used to estimate the sensitivity of the jet shapes to the calorimeter resolution by looking track jet shapes and calorimeter level jet shapes.
    - Hadrons deposit energy in several neighboring towers. This transverse showering affects the measured jet shapes but may not be simulated exactly.
- Jet Fragmentation
  - The calorimeter response simulation, and hence jet shape corrections, depends on the fragmentation model.
  - To determine systematic uncertainty due to the fragmentation model we compared the jet shape correction factors for Pythia D6T and Herwig++.

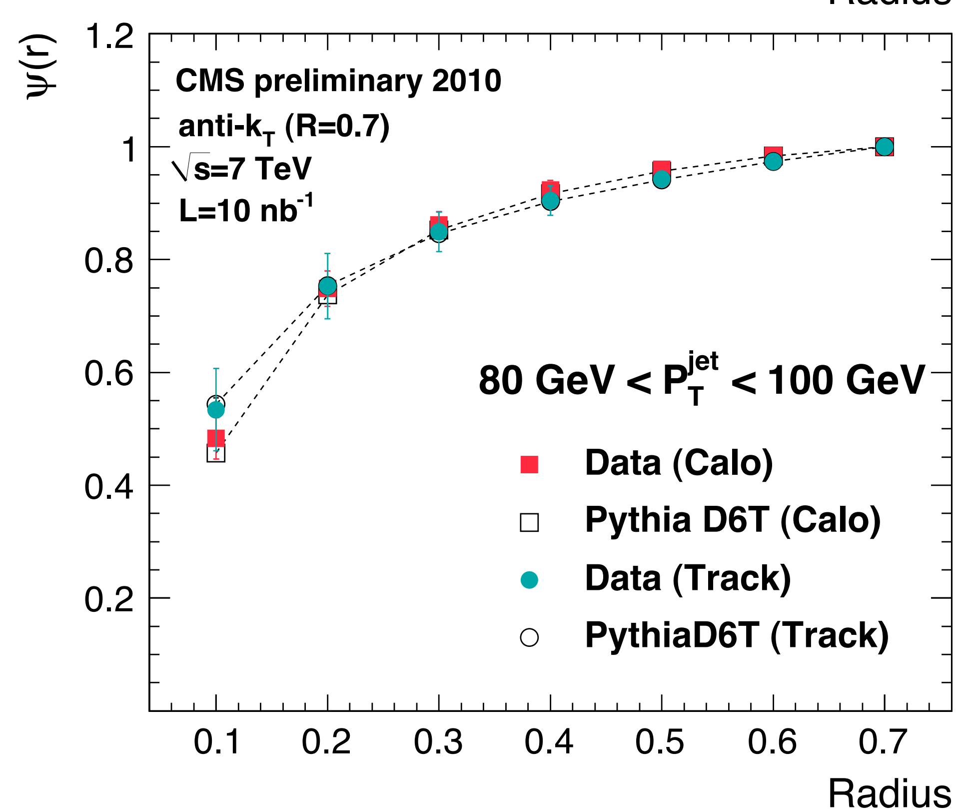
All results/distributions are "uncorrected" for detector effects !!!
We are working on correcting the distributions to particle level !!!

Integrated Jet Shapes





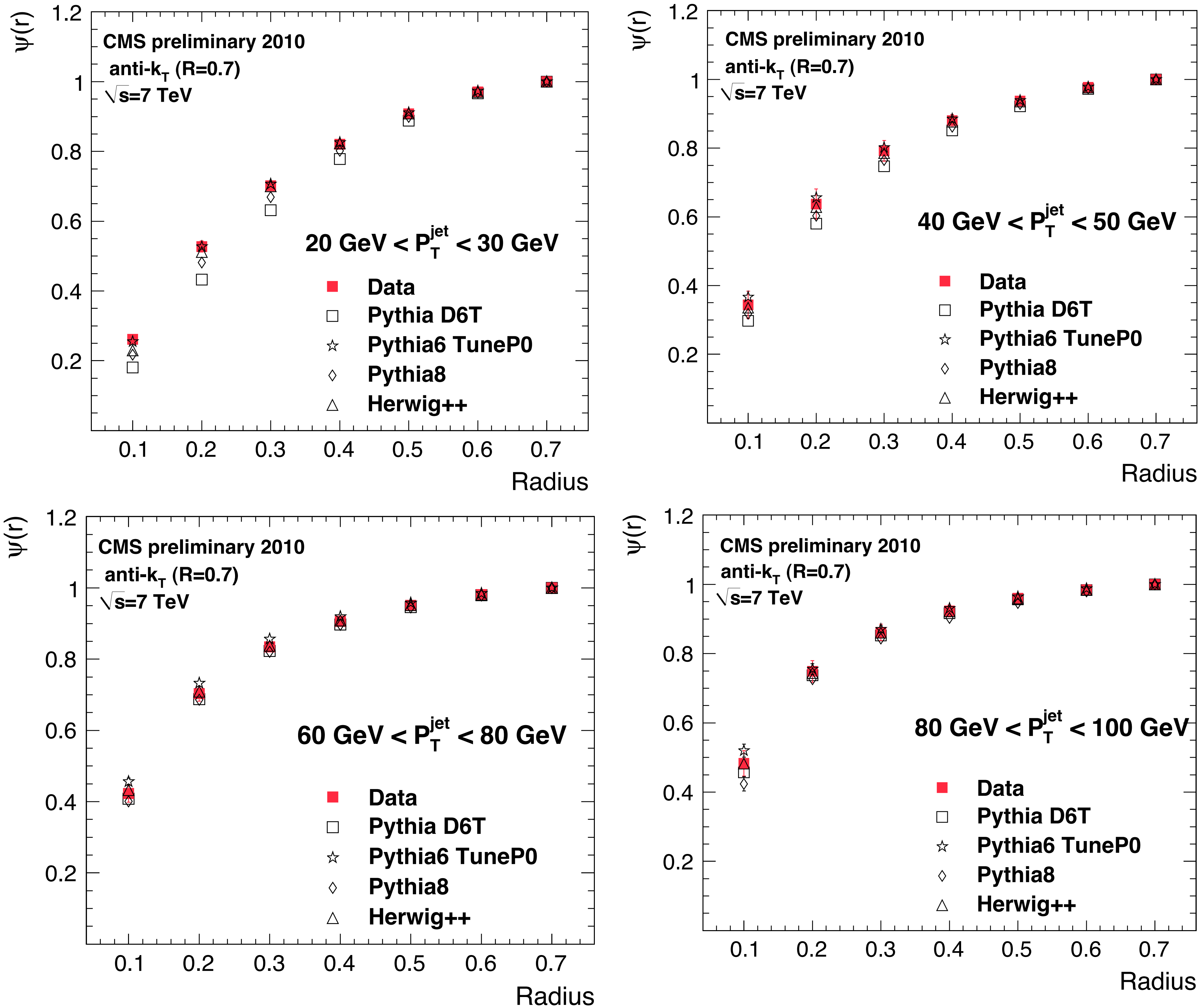




The jet shapes variables increase with p_T indicating that jets are more collimated.

Sensitivities to different PYTHIA Tunes and Jet Fragmentation

Well tuned MC's are essential for the new physics searches.



- The difference in UE contribution has visible effect especially at very low P_T. Pythia TuneP0 has narrower jet shapes.
- Herwig++ predicts narrower jet shapes than Pythia D6T and is in good agreement with data.

Summary

Inclusive Jets

- Using about 60 nb^{-1} of data collected from pp collisions delivered by the Large Hadron Collider at $\sqrt{s}$=7 TeV, the jet transverse momentum spectrum is measured in the p_T range of 18-700 GeV in different rapidity bins.
- The theoretical calculation predicts the inclusive jet cross section observed in the data well, both in transverse momentum and in rapidity.

Jet Shapes

- First jet shapes results have been shown for data set corresponding to an integrated luminosity of 10 nb^{-1} and 78 nb^{-1} recorded by the CMS detector at $\sqrt{s}$=7 TeV.
- In general, the data follow trends expected from QCD as a function of jet p_T.
- Jet shapes are sensitive to underlying event (at R~0 due to ψ(Rcone)=1), but not yet precise enough to differentiate between theoretical predictions.
- More data to be added, and distributions will be corrected to particle level.

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