DIS 2009

High p_T Jet Studies with CMS

On behalf of the CMS Collaboration
Andreas Oehler
University of Karlsruhe (KIT)

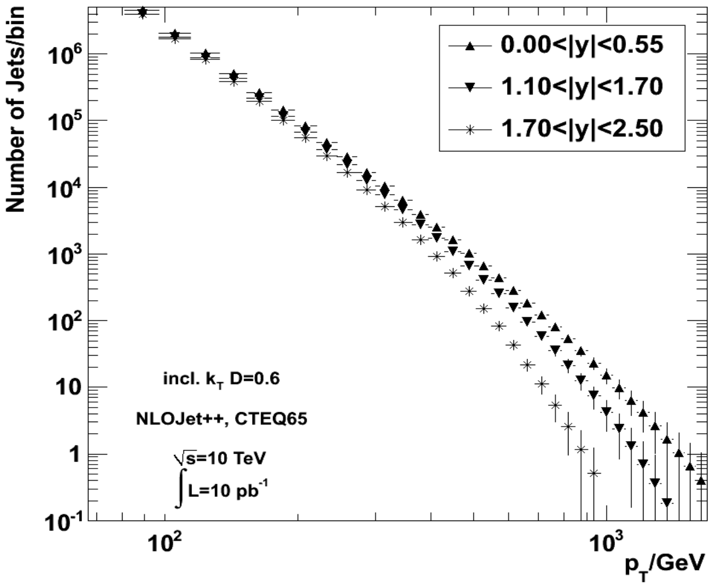
XVII International Workshop on Deep-Inelastic Scattering and Related Subjects
DIS 2009, 26-30 April 2009, Madrid

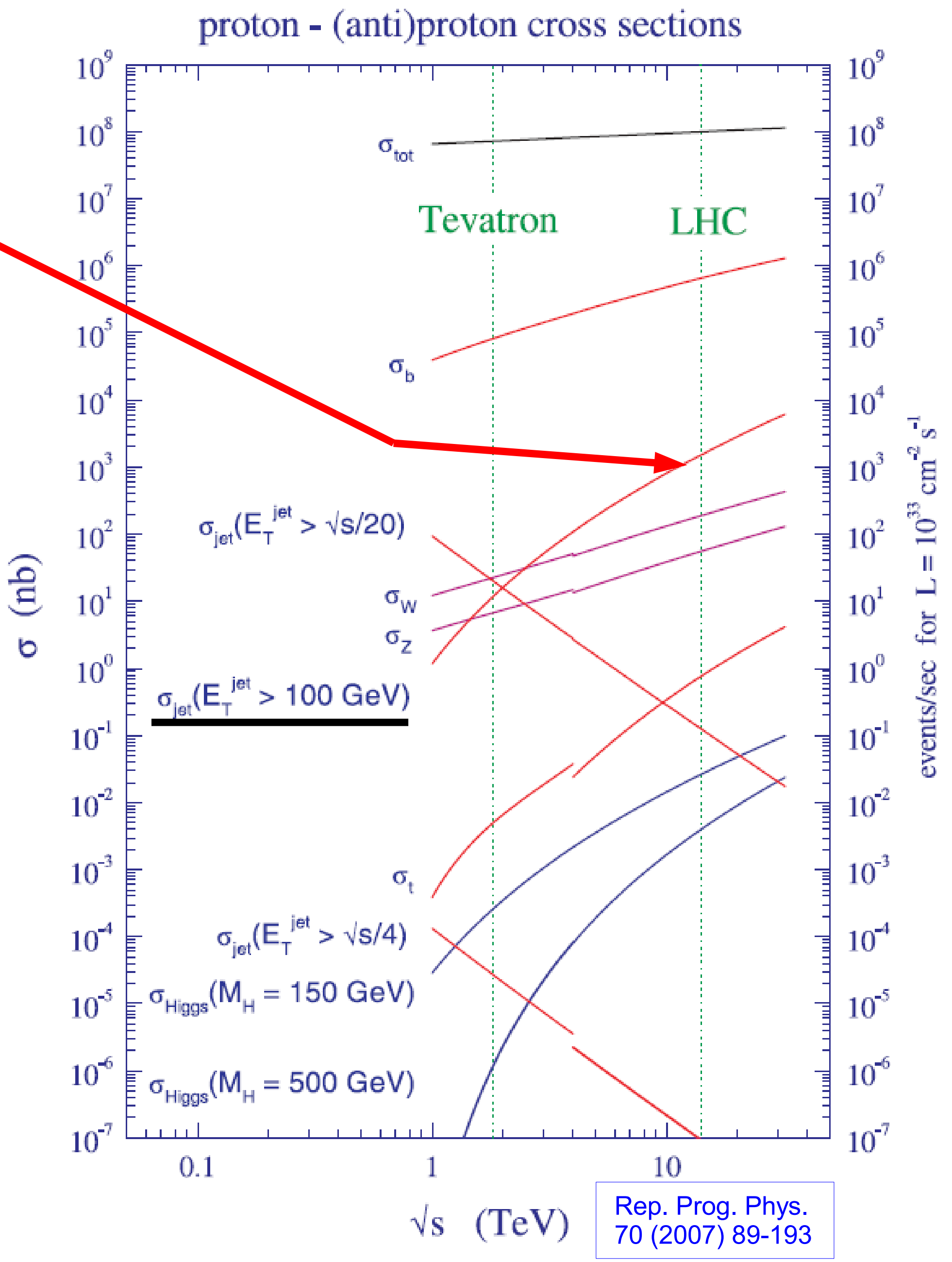
Outline

- **QCD Cross Section at the LHC**
- **Jet Measurement at CMS**
    - Jet Energy Calibration
    - Jet p_T Response
- **QCD & New Physics with High p_T Jets**
    - Inclusive Jets
    - Dijet Mass Cross Section
    - Dijet Angular Distributions
    - Jet Shapes
- **Outlook**

Introduction

- QCD processes dominate LHC cross sections
- High p_T jet measurements will allow:
  - Detector comissioning
  - Sensitivity to new physics
  - Confrontation of pQCD at the TeV scale
  - Tests of current PDF extrapolations
  - Probe α_S
  - Understand multijet production (background to other searches)





Rep. Prog. Phys. 70 (2007) 89-193

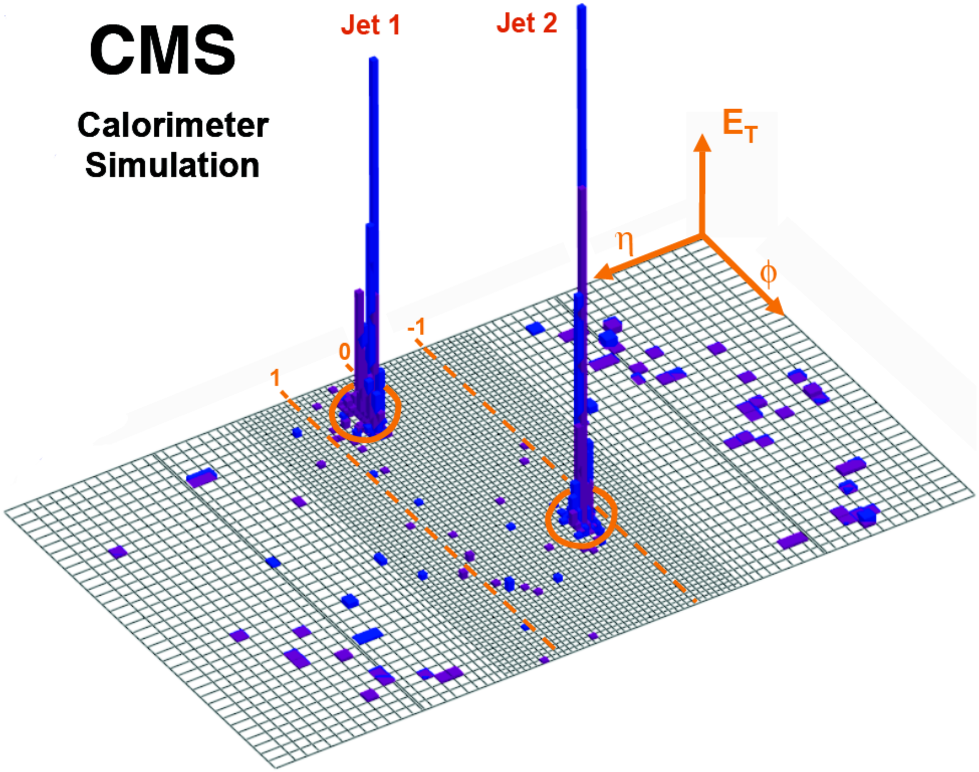
Jet Measurement

- **Jets are sprays of particles**, collimated due to QCD interaction.
- **Jet algorithms** define an unambigous way to **combine particles** to one fourvector:
  - Cone algorithms
  - Successive recombination algorithms
- **Input** to the algorithms are fourvectors from:
  - Calorimetric energy depositions
  - Tracks
  - Particle or energy flow reconstructed objects
  - Simulated or generated particles

FastJet: http://www.lpthe.jussieu.fr/~salam/fastjet/

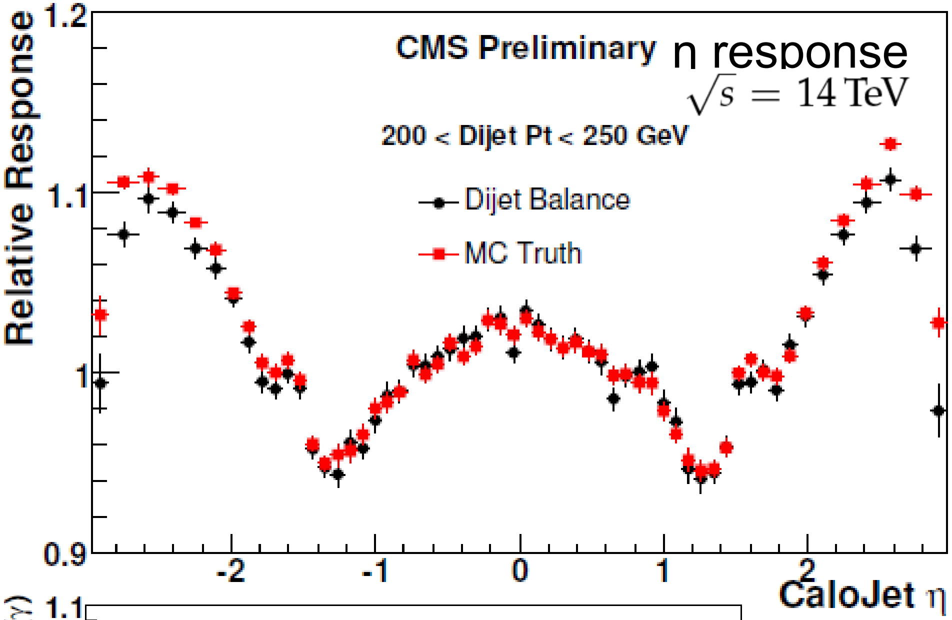
Jet algorithms used in CMS

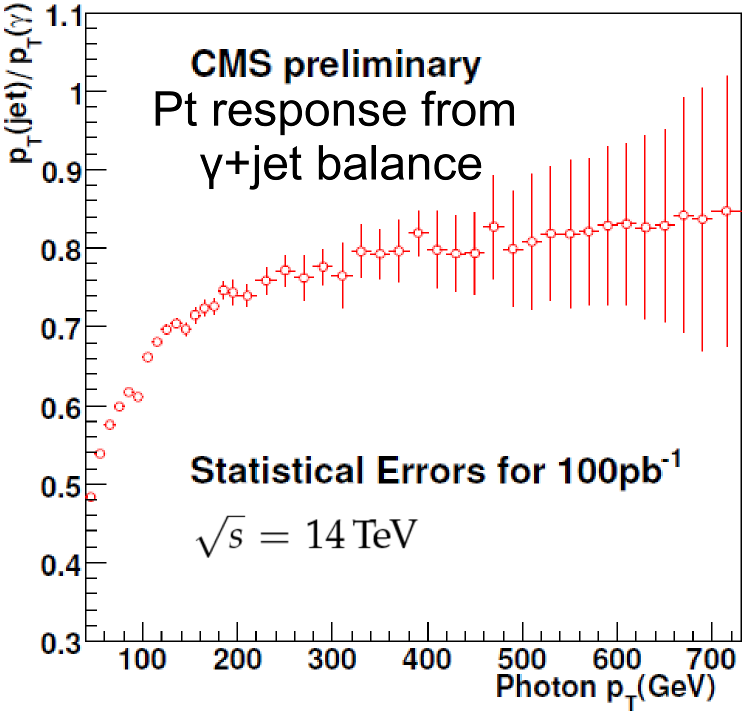
Iterative Cone, R=0.5 (in trigger)
fast, predictible reconstruction time
SISCone, R=0.5, 0.7
infrared and collinear save,
FastJet implementation
incl. k_T, D=0.4, 0.6
infrared and collinear save,
use *FastJet* implementation



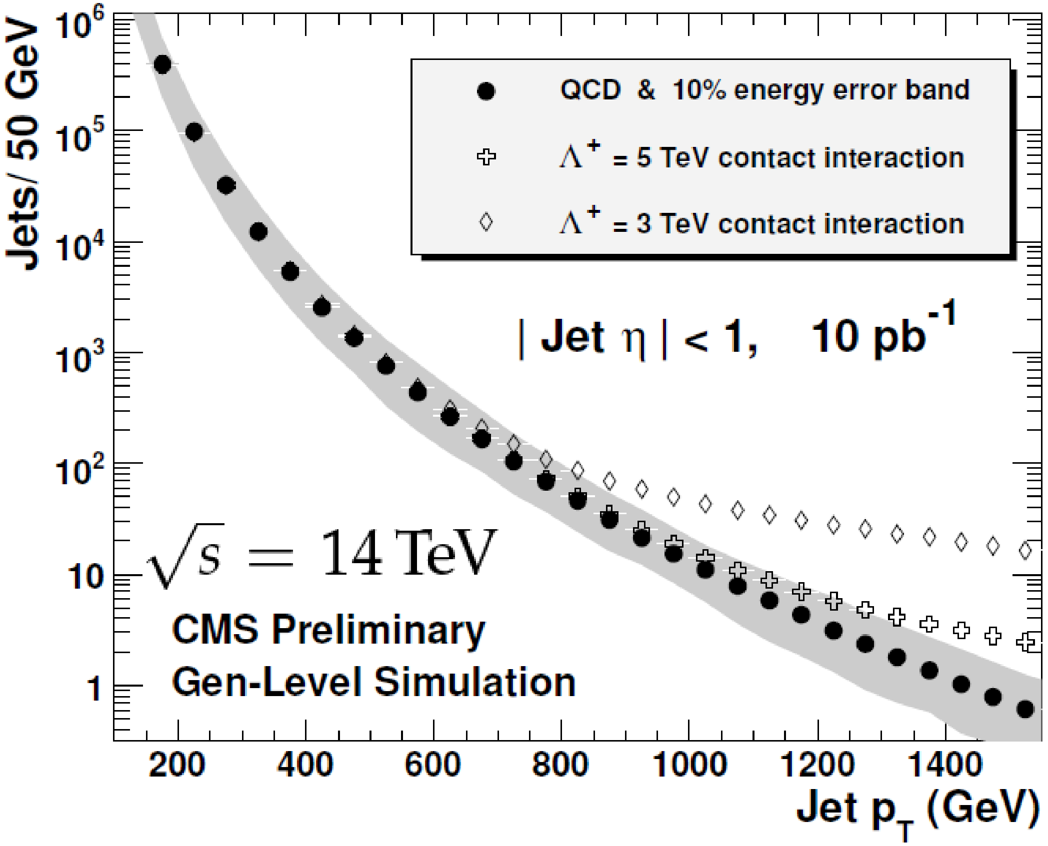
Jet Energy Calibration

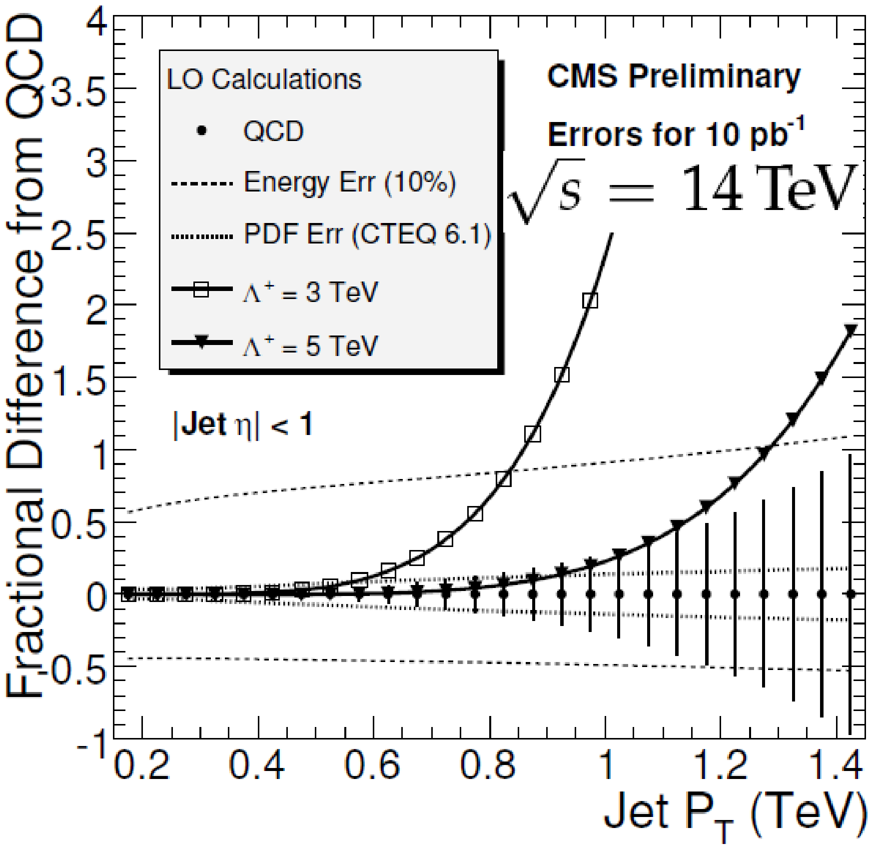
- **Default: correction to particle level**
- **Factorized approach** (like e.g. CDF)
  - **Offset correction** (remove pile-up and noise contribution)
  - **Relative correction** (flattens the jet response in η)
  - **Absolute correction** (flattens the jet resonse in p_T)
- **Data driven approach**:
  - Di-jet balancing (relative correction)
  - γ+jet, Z+jet balancing (absolute correction)
- **Optional corrections**:
  - Electromagnetic fraction dependence
  - Flavour dependence
  - Parton level
  - Underlying event
- **Systematic uncertainty ~10% at startup, improving to ~5% with first data.**





Inclusive Jet Cross Section





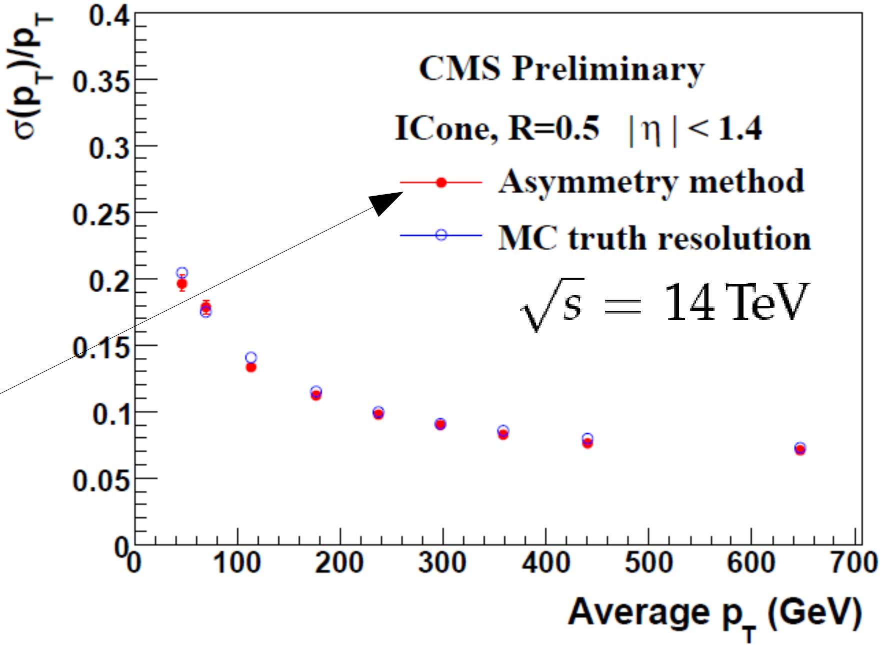
- Important jet comissioning measurement.
- Even a small amount of data is enough to exceed the Tevatron p_T reach (~700GeV).
- Sensitive to **contact interactions**: with 10pb^{-1} @ 14TeV a discovery beyond the Tevatron limit (2.7 TeV) is possible.
- The jet energy scale is the dominating experimental systematic uncertainty.
- Could be used to constrain PDFs, which requires profound knowledge of systematic uncertainties.

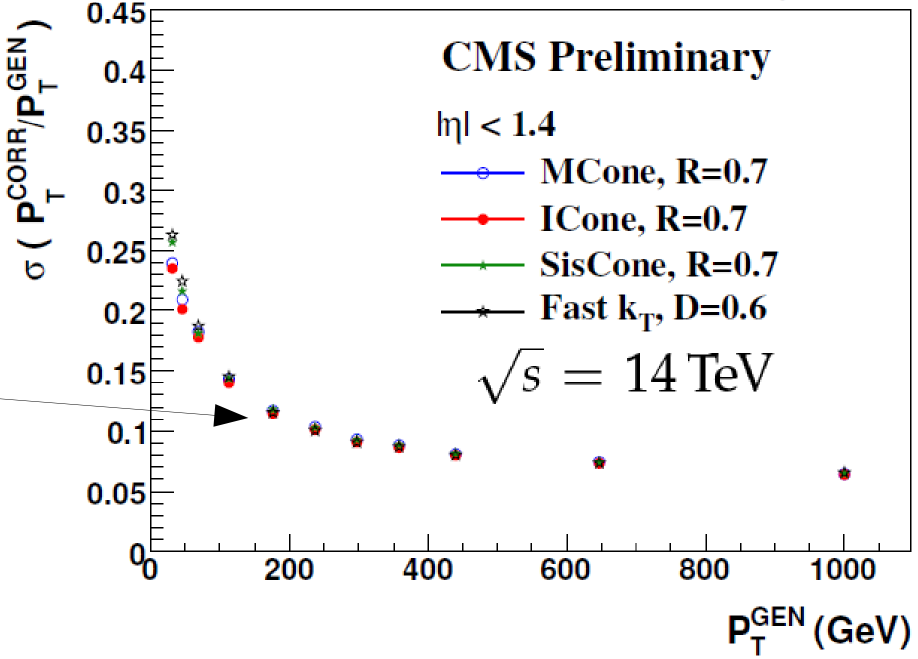
Jet Pt Resolution

- Finite detector resolution affects measurements. The jet p_T resolution is a leading systematic effect for e.g. inclusive jets after jet energy scale and luminosity.
- Can be determined from MC truth matching (MC tuned to data), or by direct measurement from dijet events (Asymmetry Method).
- Jet p_T resolution usually parametrized by

$$\sigma(p_T) = p_T \cdot \sqrt{C^2 + \frac{S^2}{p_T} + \frac{N^2}{p_T^2}}$$

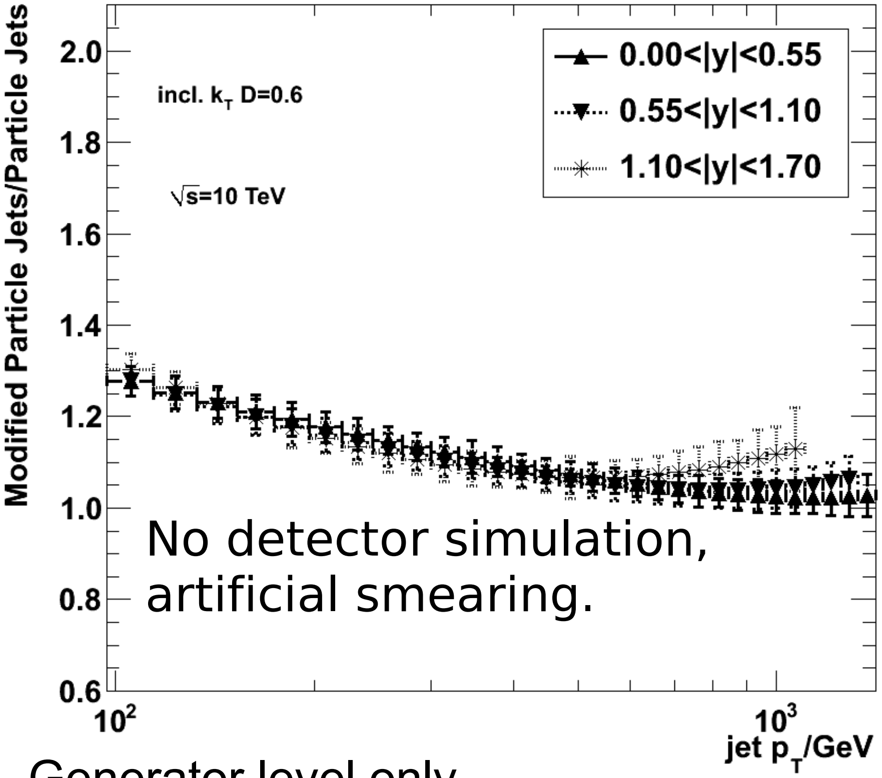
- Fairly independent of the specific jet algorithm.
- Can use combined calorimetric+track information (compensation correction) to improve the jet energy resolution





Unsmearing Procedure 1/2

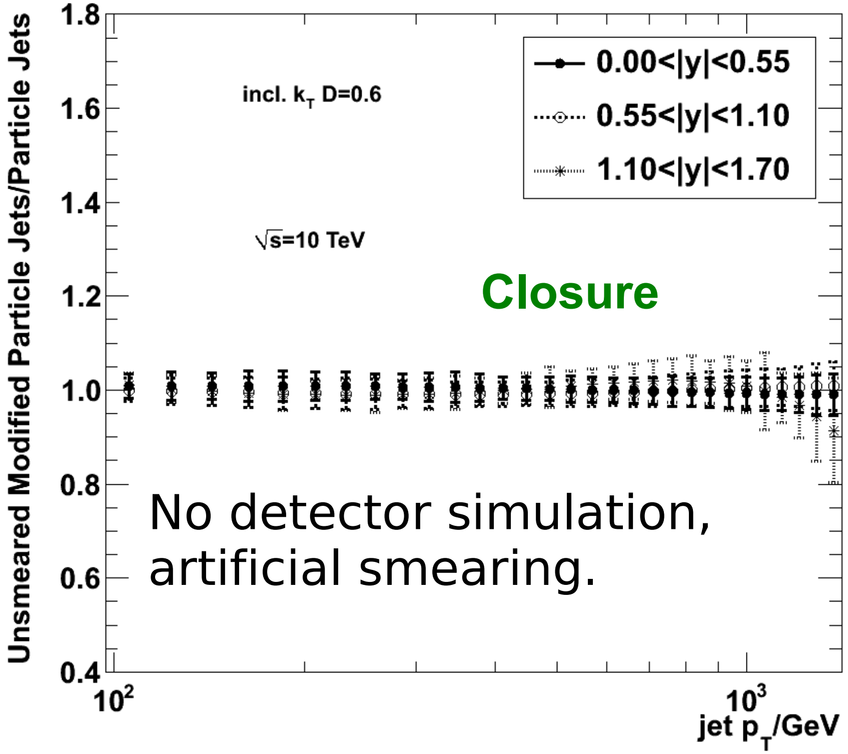
Inclusive jet spectrum needs a correction for the finite jet p_T resolution



No detector simulation, artificial smearing.

unsmearing by
“Ansatz Method”

- Generator level only.
- Artificially smear jets by Gaussian with an arbitrary (but reasonable) width.
- Apply Ansatz Method for unsmearing.
- Method corrects p_T smearing effects on steeply falling spectrum.



Closure

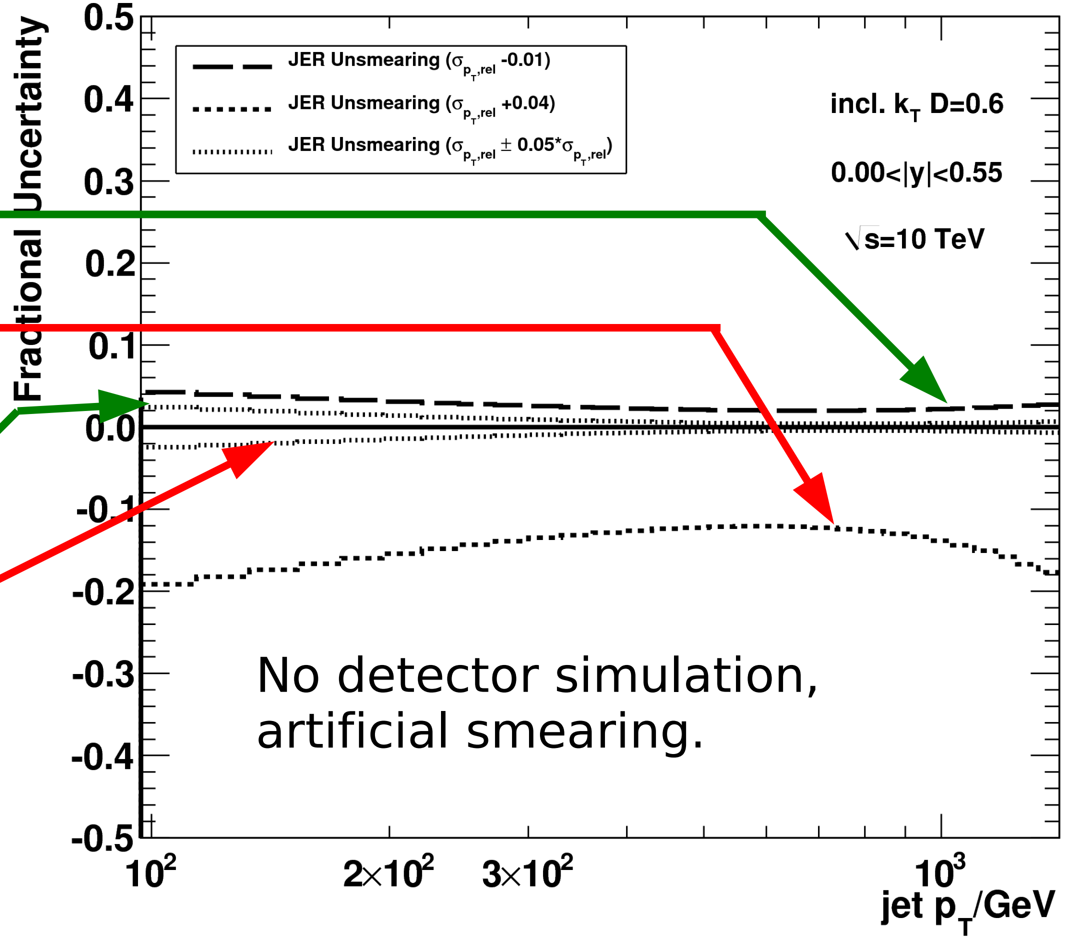
No detector simulation, artificial smearing.

Unsmearing Procedure 2/2

- Ansatz Method can correct finite resolution effects on the steeply falling spectrum
- However a good knowledge of the resolution is required
- A wrong assumption of the resolution can shift the final spectrum easily by some percent

Two unsmearing scenarios studied:

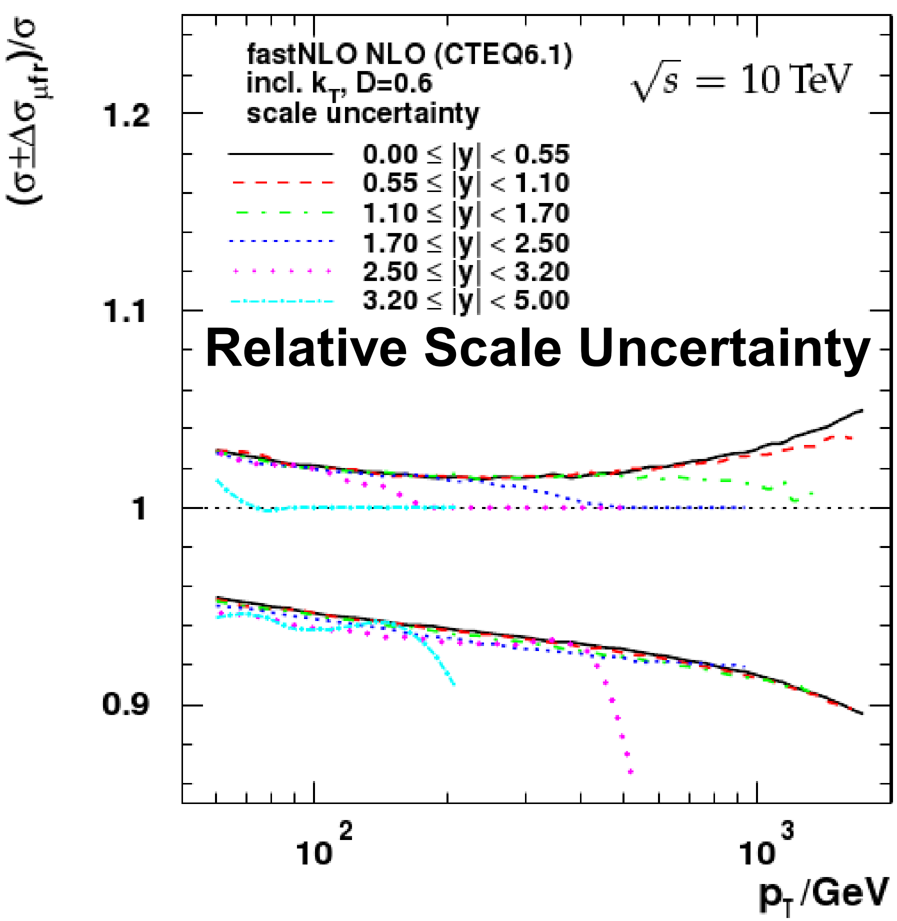
- Shift response used by *fraction of jet p_T*
  - assume 1% better resolution in unsmearing than used for smearing
  - assume 4% worse resolution in unsmearing than used in smearing
- Shift response used by *fraction of itself*
  - assume 5% better resolution in unsmearing than used for smearing
  - assume 5% worse resolution in unsmearing than used for smearing



No detector simulation, artificial smearing.

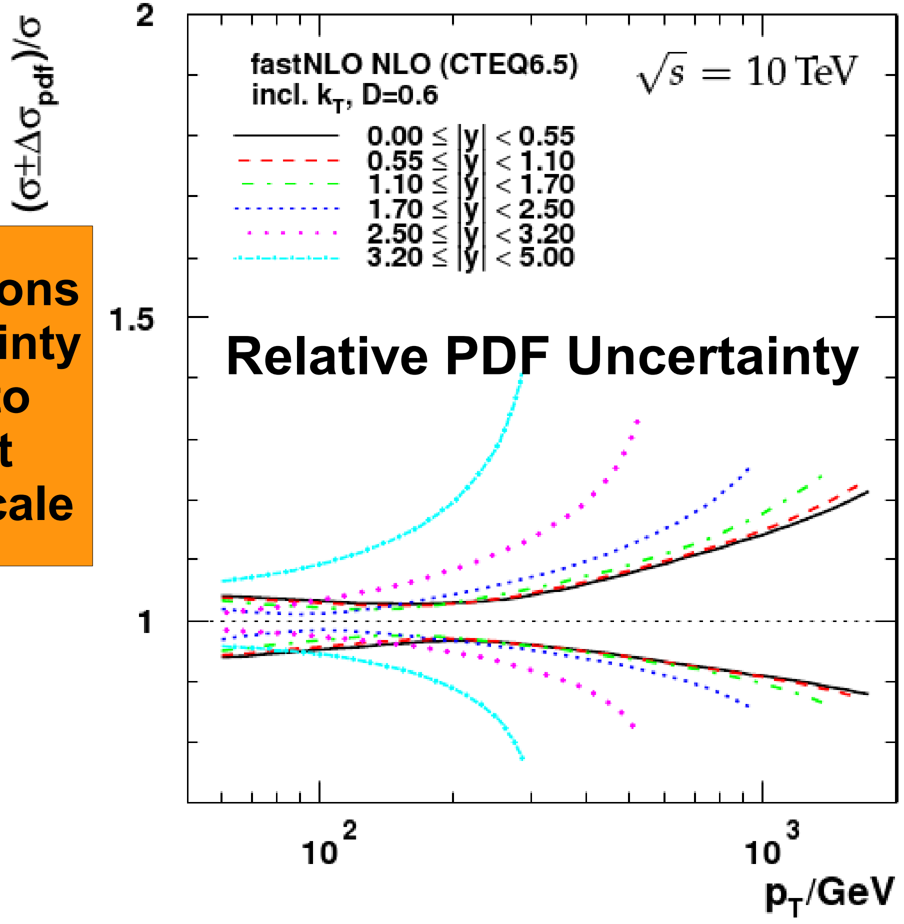
Theoretical Uncertainties

- Dominant theoretical uncertainties come from the uncertainties of the parton distribution functions and scale uncertainties in the calculations



Relative Scale Uncertainty

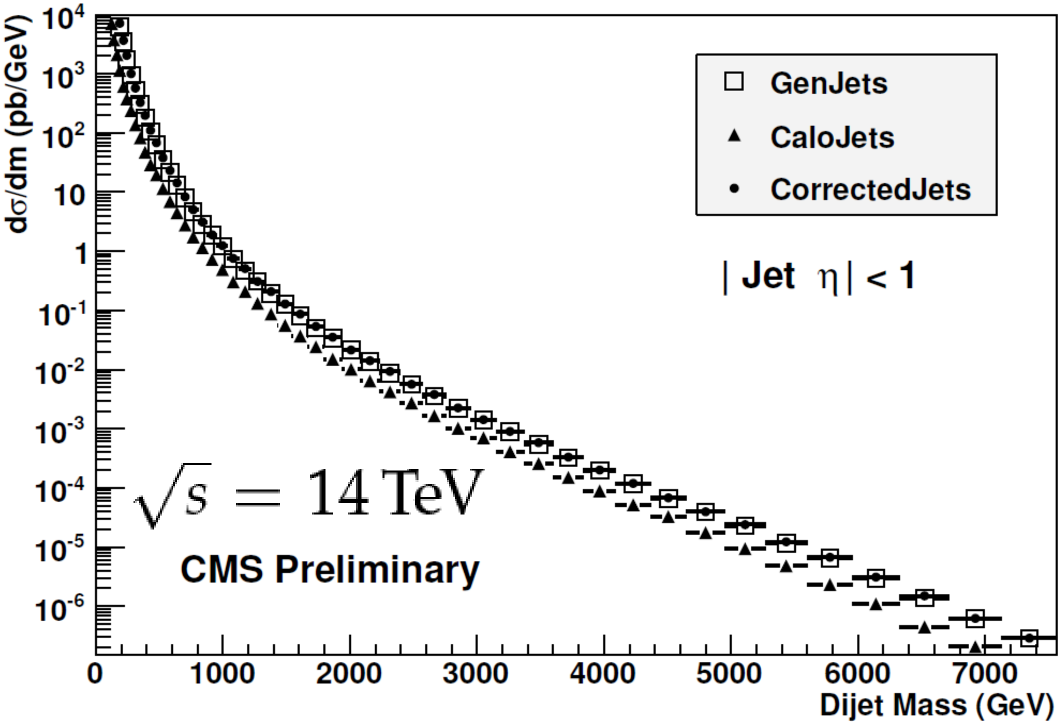
Contributions to uncertainty rise up to 5-20% at the TeV scale

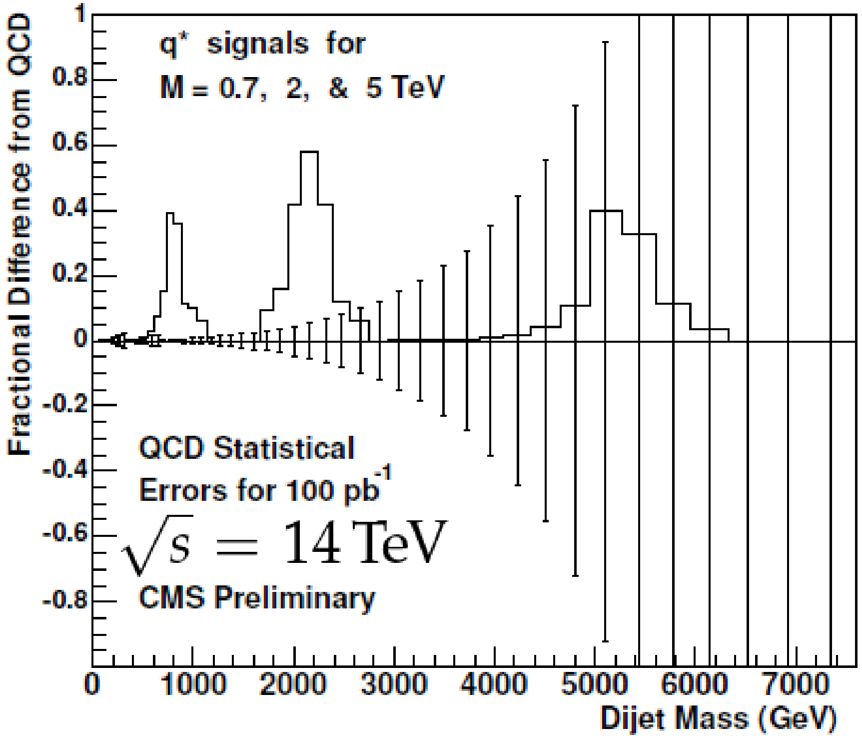


Relative PDF Uncertainty

- Probing pQCD with high p_T jets means mainly comparing measurements to calculations in NLO. This procedure currently involves uncertainties from the non-perturbative corrections needed (uncertainty about 15% at low pt, reduced to almost zero at 1 TeV).

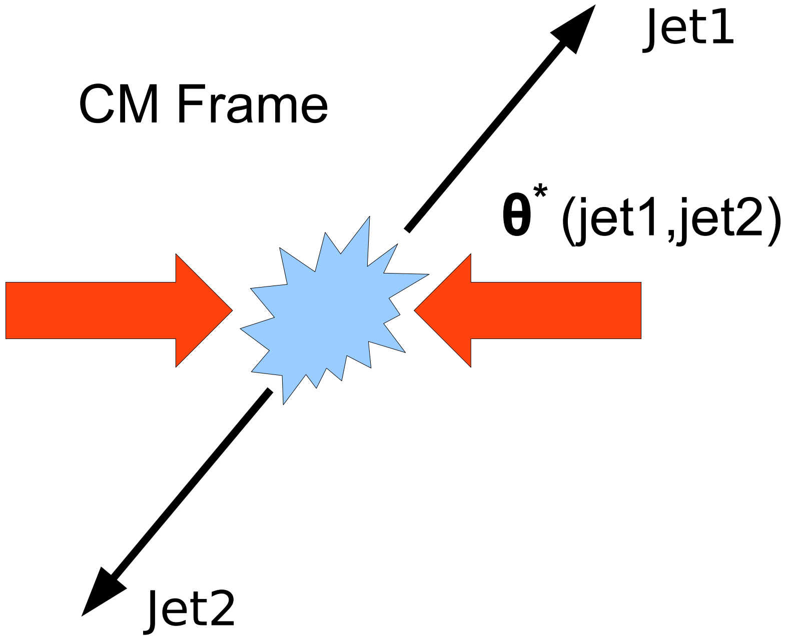
Dijet Mass Cross Section

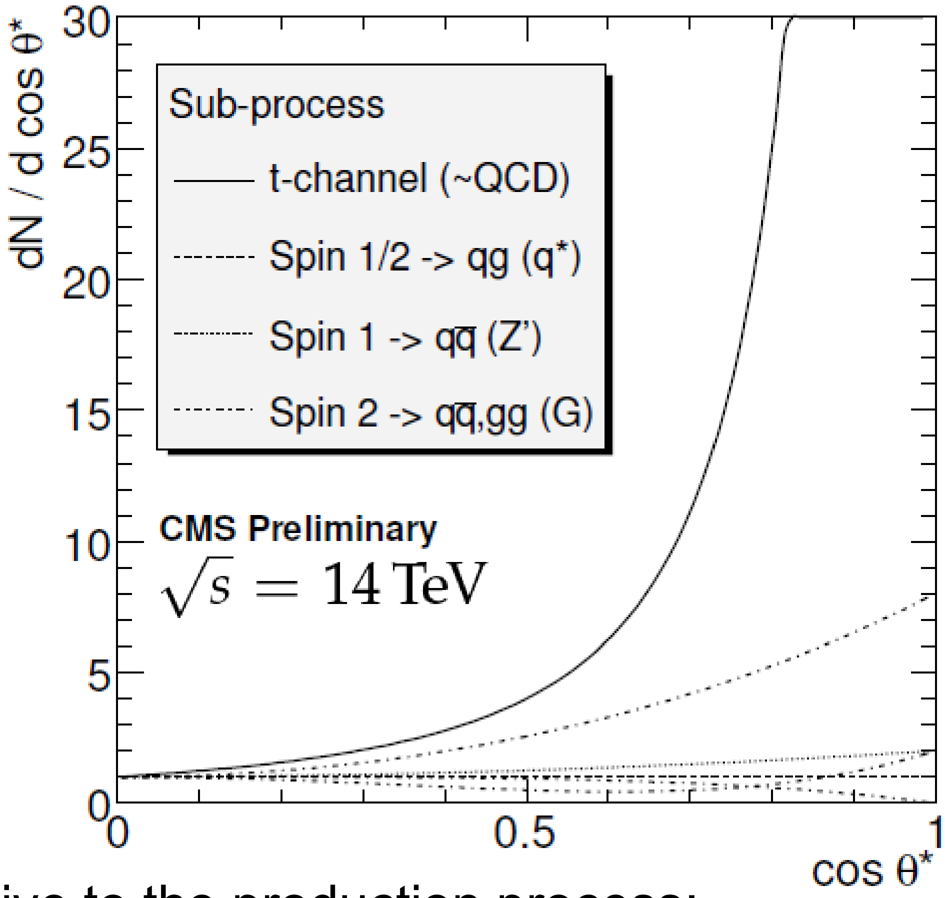




- Invariant mass of 2 leading jets.
- The jet energy scale is the dominant experimental systematic uncertainty
- Sensitive to objects decaying into 2 jets (**dijet resonances:** q*, Z', etc.)
- **With 100 pb^{-1} a 2 TeV excited quark can be clearly seen (Tevatron excludes: M<0.87 TeV)**

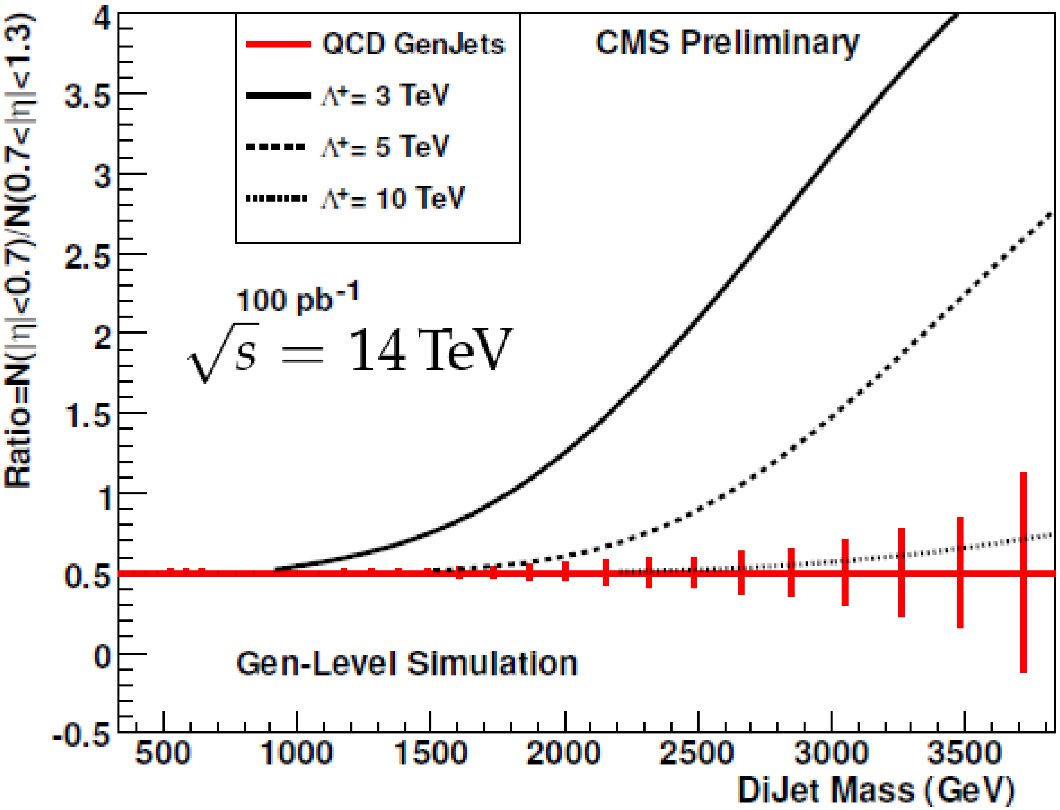
Dijet Angular Distributions

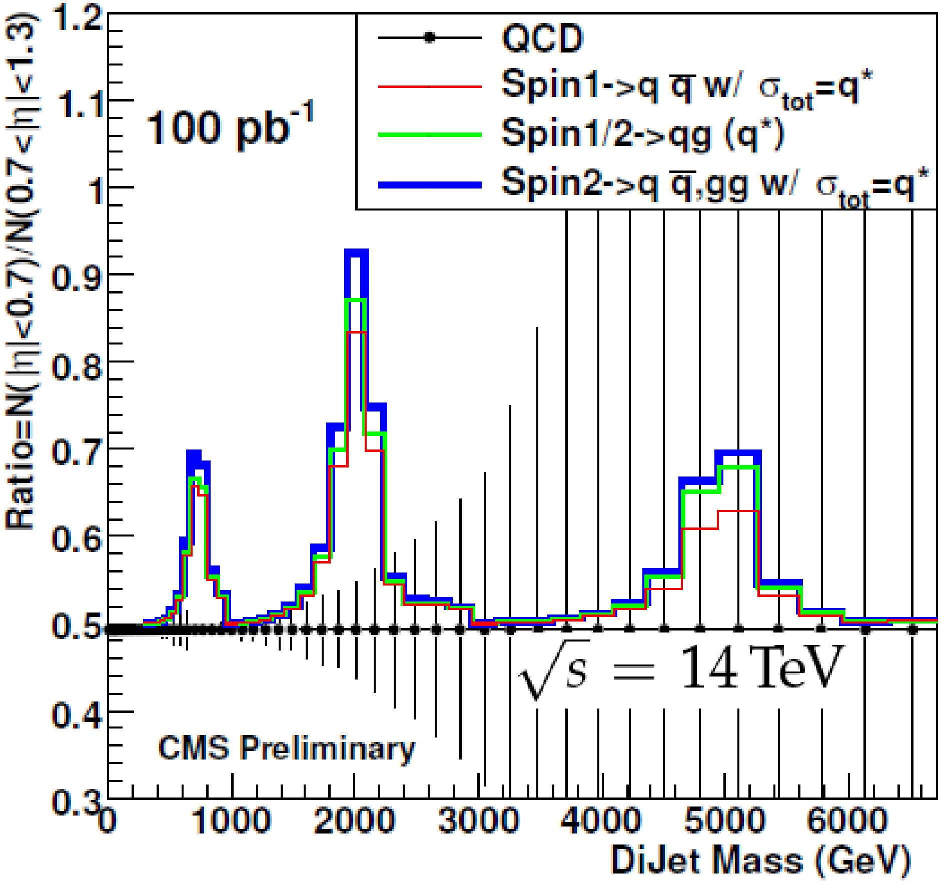




- The dijet angular distributions are sensitive to the production process:
  - QCD dominated by t-channel scattering
  - Resonance decays and contact interations tend to be more isotropic
- The dijet angular distributions will confirm any deviation from QCD observed in the dijet mass spectrum

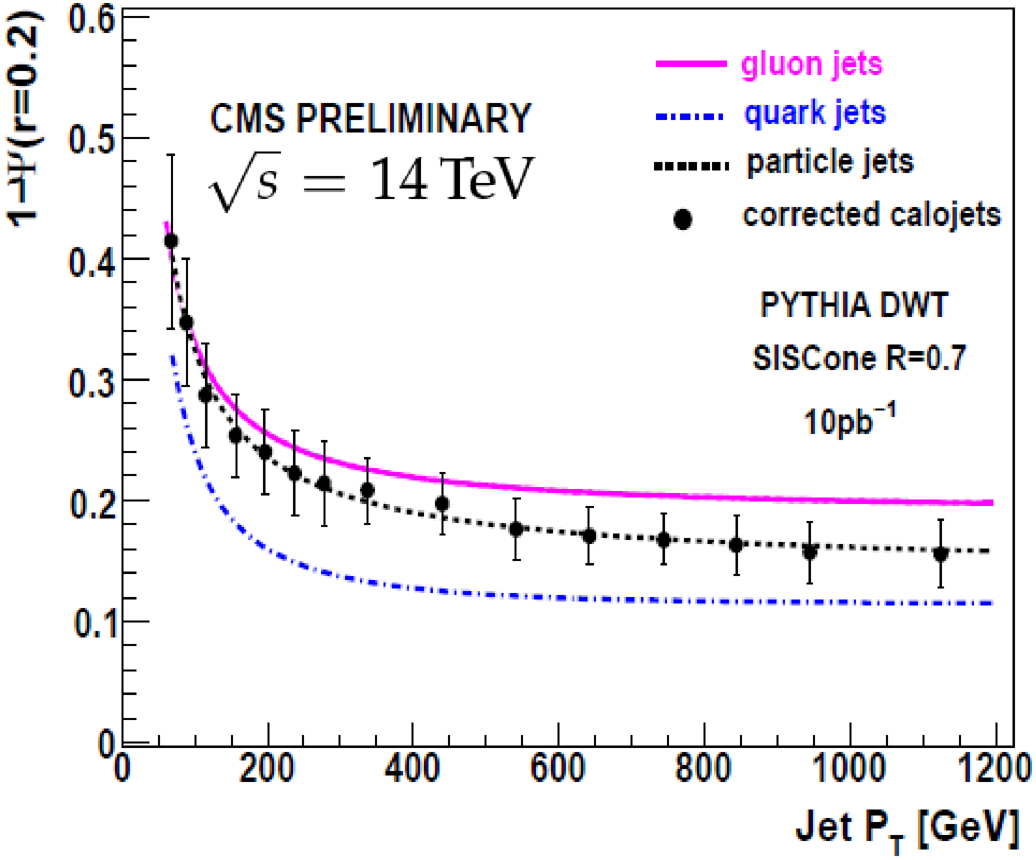
Dijet Ratio





- The dijet ratio N(|η|<0.7)/N(0.7<|η|<1.3) vs mass is a robust way to identify deviations from QCD.
- Sensitivity to **contact interactions** (discovery up to Λ=6.8 TeV with 100pb^{-1} @ 14 TeV)
- Sensitivity to **dijet resonances**. At higher luminosity spin measurement is also feasible.
- Ideal measurement for startup. JES and luminosity uncertainties are largely cancelled.

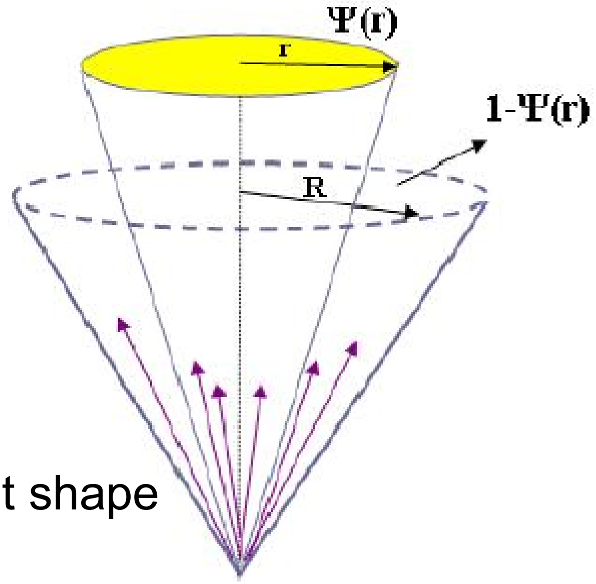
Jet Shapes



For Hadronic Event Shape studies see talk of M. Weber.

- Jet shape measurements can be used to discriminate between different underlying event models.
- Can be used to distinguish gluon initiated jets from quark jets.

- Measurement of the average integrated (differential) energy flow inside jets.
- Jet shape measurements can be used to test the showering models in the MC generators.



Integrated jet shape Ψ(r)

Outlook

- Jet final states are critical both for studying the detector performance and for the “re-discovery” of the Standard Model at the LHC.
- LHC p-p collisions will probe a previously unexplored kinematic region and a small amount of early data will be enough for QCD measurements exceeding the p_T reach of the Tevatron.
- Jet measurements are sensitive to new physics. Contact interactions and resonances decaying into dijets can be discovered early on, even with 10% JES uncertainty at startup.
- Precision QCD measurements will require much more data and effort to constrain the systematic uncertainties.
- Establishing the JES with a small systematic uncertainty (~1%) is a challenging task which will require a huge effort and a large integrated luminosity.

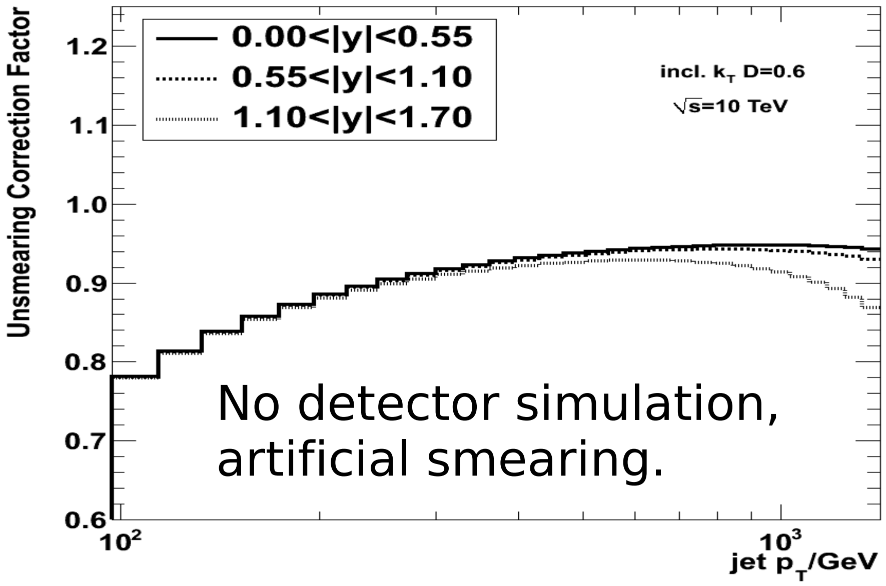
BACKUP

BACKUP SLIDES

Unsmearing Procedure

Motivation

The **observed** cross section is **higher than** the true one due to the falling shape of the spectrum and the finit p_T resolution. More events migrate into a bin of measured p_T than out of it.



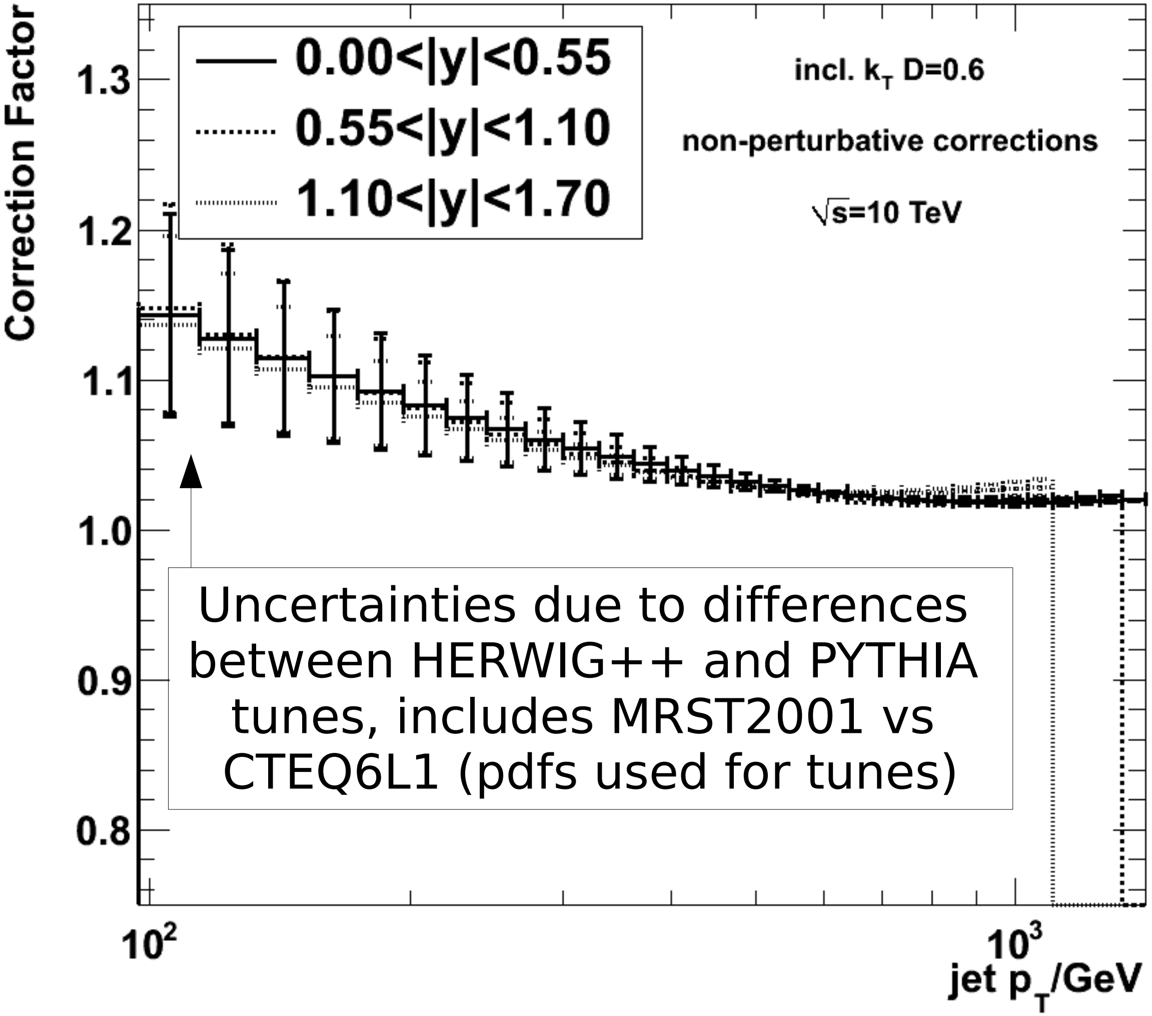
No detector simulation, artificial smearing.

Unsmearing steps:

- Analytical expression of the p_T resolution ➡ $$R(p'_T, p_T) = \frac{1}{\sqrt{2\pi}\sigma(p'_T)} \exp\left[-\frac{(p'_T - p_T)^2}{2\sigma^2(p'_T)}\right]$$
- Ansatz function with free parameters to be determined by the data ➡ $$f(p_T) = N \cdot p_T^{-a} \cdot \left(1 - \frac{2\cosh(y_{min})p_T}{\sqrt{s}}\right)^b \exp(-\gamma p_T)$$
- Fitting the data with the Ansatz function smeared with p_T resolution. ➡ $$F(p_T) = \int_0^\infty f(p'_T) R(p'_T, p_T) dp'_T$$
- Unsmearing correction calculated bin by bin. ➡ $$C_{bin} = \frac{\int_{bin} f(p_T) dp_T}{\int_{bin} F(p_T) dp_T}$$

Non Perturbative Corrections

- Correction factor for non perturbative effects, for which NLO calclations do not account for
- PYTHIA: V6.4, D6T, CTEQ6L1
- HERWIG++: default tune, MRST2001



Uncertainties due to differences between HERWIG++ and PYTHIA tunes, includes MRST2001 vs CTEQ6L1 (pdfs used for tunes)