Dijet Physics with the CMS Detector at LHC

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on behalf of the CMS collaboration

Inclusive Jet Cross Section

The inclusive jet cross section is one of the basic measurements at hadron colliders used to test perturbative QCD.
The **differential inclusive jet cross section** is defined as:

$$\frac{d^2\sigma}{dp_T dy} = \frac{\overset{\text{unsmearing correction}}{C_{res}}}{\underset{\text{luminosity}}{\mathcal{L}} \cdot \underset{\text{selection efficiency}}{\epsilon}} \cdot \frac{\overset{\text{number of jets}}{N_{jets}}}{\underbrace{\Delta p_T \cdot \Delta y}_{\text{bin widths}}}$$

Trigger selection: min-bias and single jet triggers (6, 15, 30, 50 GeV)
Unsmearing correction (using the *ansatz* method):

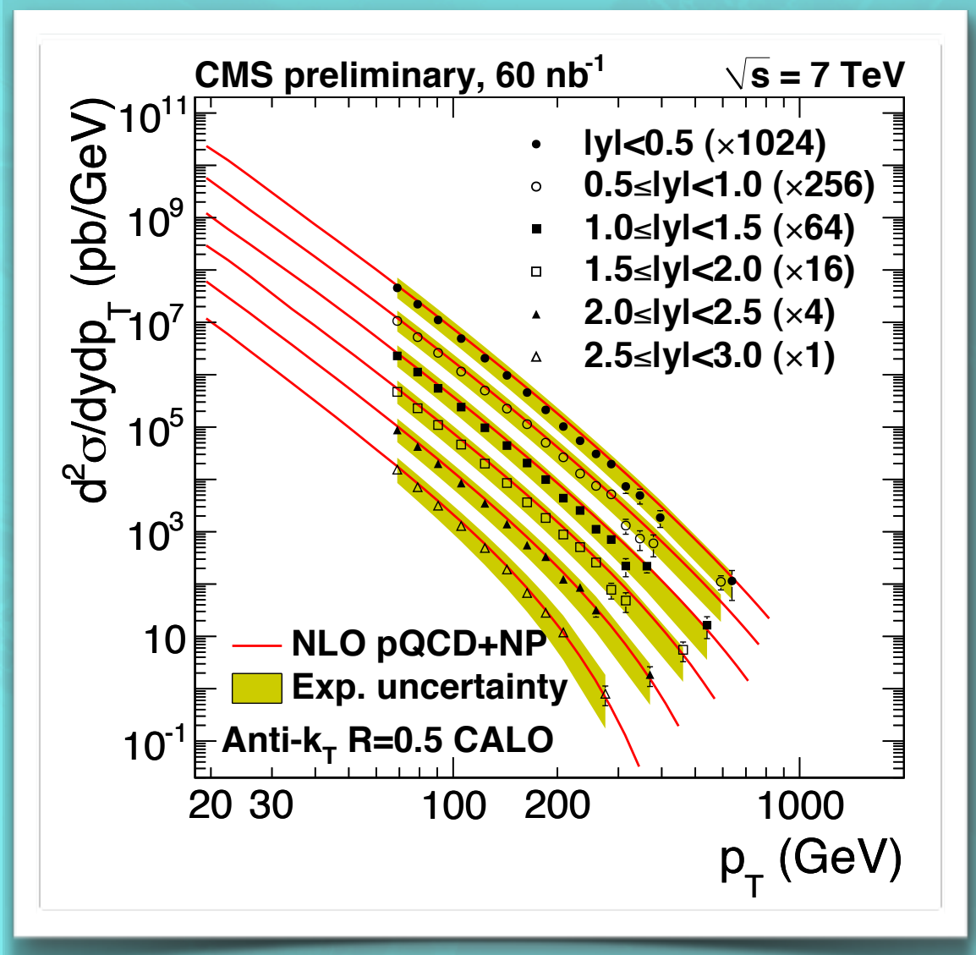
- a parametrization is assumed for the true p_T spectrum
- the parameters of the model are determined by fitting the smeared p_T spectrum to data

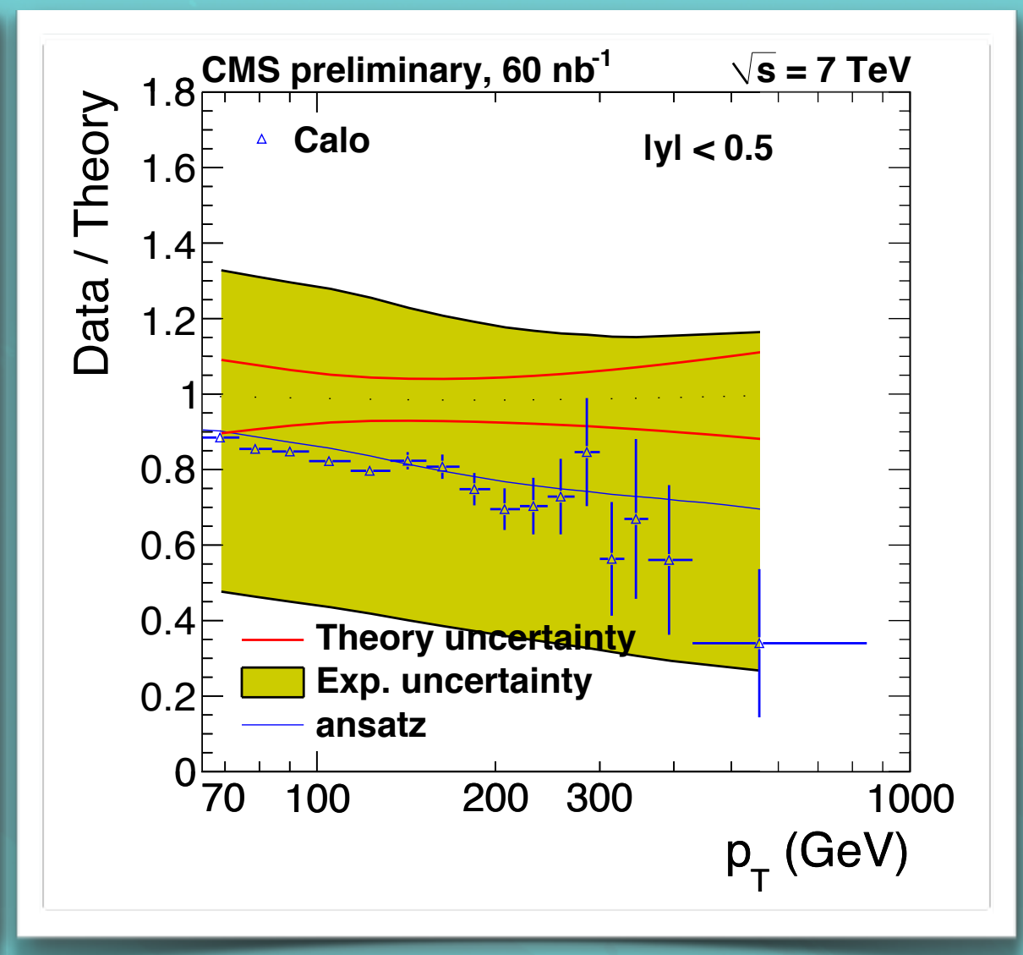
Systematic uncertainties:

- jet energy scale (10% absolute and 2% linear increase in η)
- jet energy resolution (10%)
- luminosity (11%)

NLO predictions (fastNLO and CTEQ6.6 PDFs):

- corrected for non-perturbative effects





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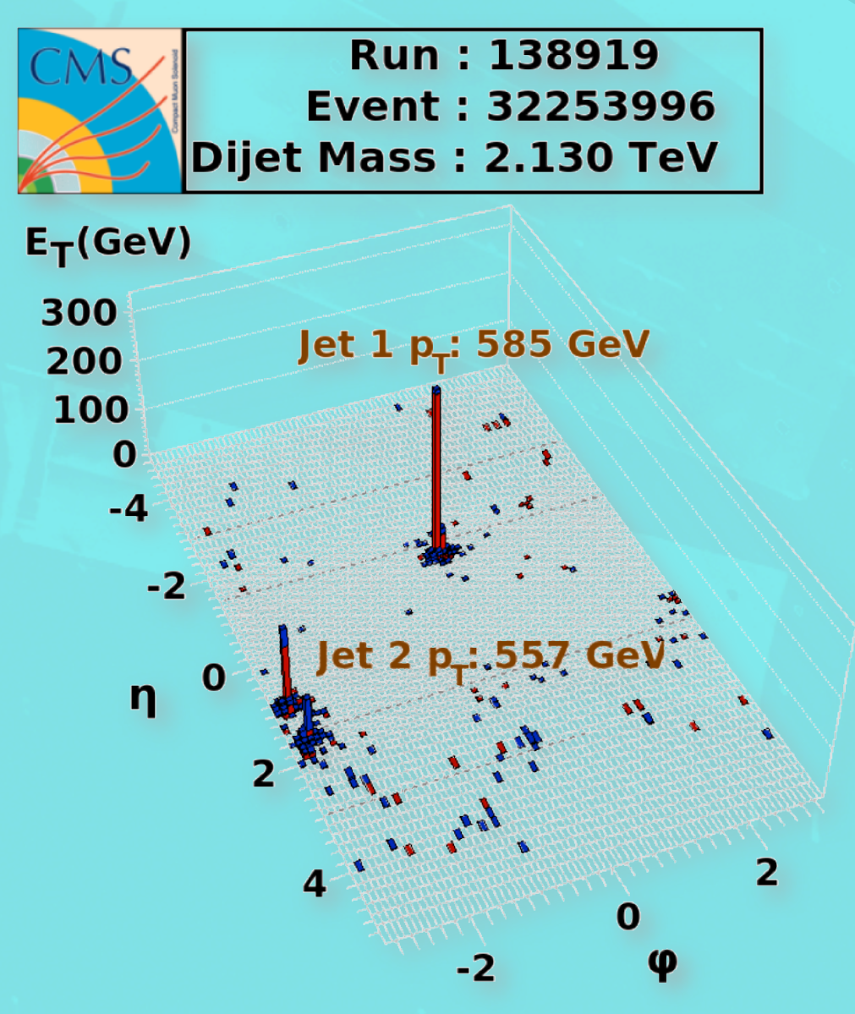
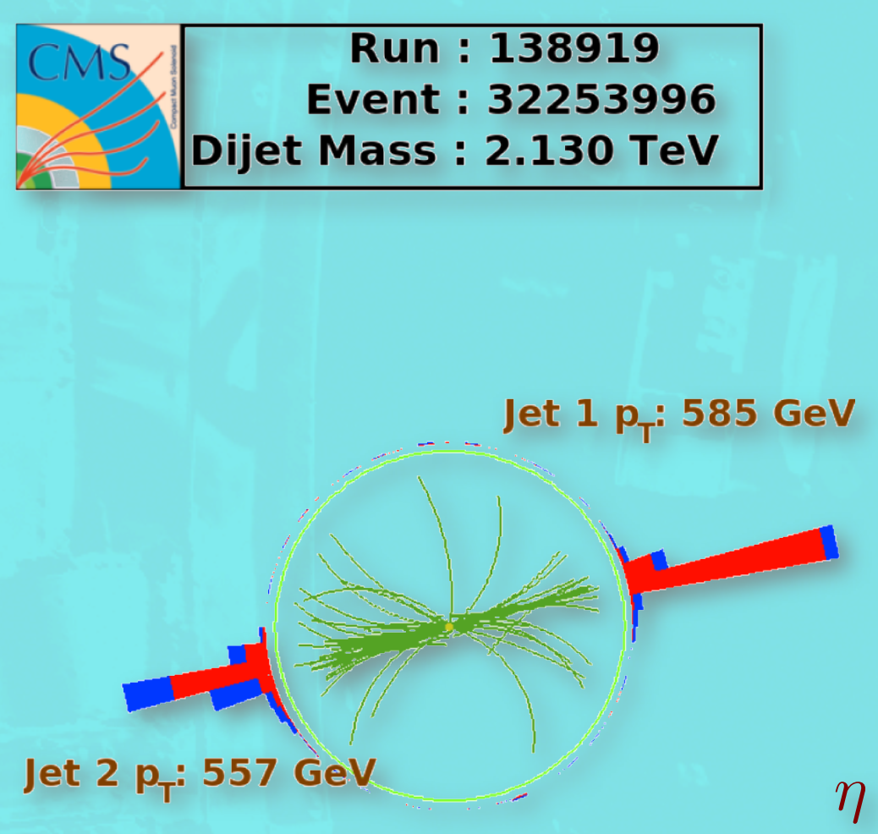
$$y = ln\left[\frac{E+p_z}{E-p_z}\right]$$



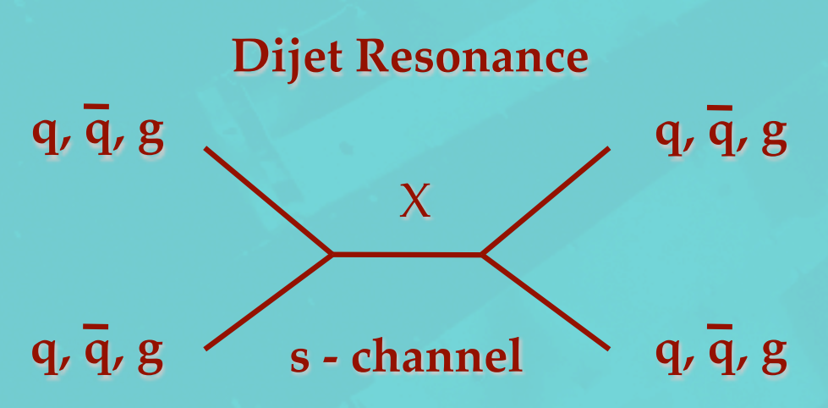


$$\eta = -ln\left[tan\left(\frac{\theta}{2}\right)\right]$$

Dijet Mass Distribution

The dijet mass spectrum predicted by QCD falls smoothly and steeply with increasing dijet mass. Many extensions of the SM predict the existence of new massive objects that couple to quarks and gluons giving rise to resonances in the dijet mass spectrum.
The **dijet mass spectrum** is defined as:

$$\frac{d\sigma}{dm} = \frac{1}{\underset{\text{luminosity}}{\mathcal{L}}} \cdot \frac{\overset{\text{number of events}}{N_i}}{\underbrace{\Delta m_i}_{\text{bin width}}}$$



The **parametrization function** is:

$$\frac{d\sigma}{dm} = \frac{P_0 \cdot (1 - m/\sqrt{s})^{P_1}}{m^{P_2}}$$

$$m = \sqrt{(E_1+E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

$$\sqrt{s} = 7\ TeV$$

Trigger selection:

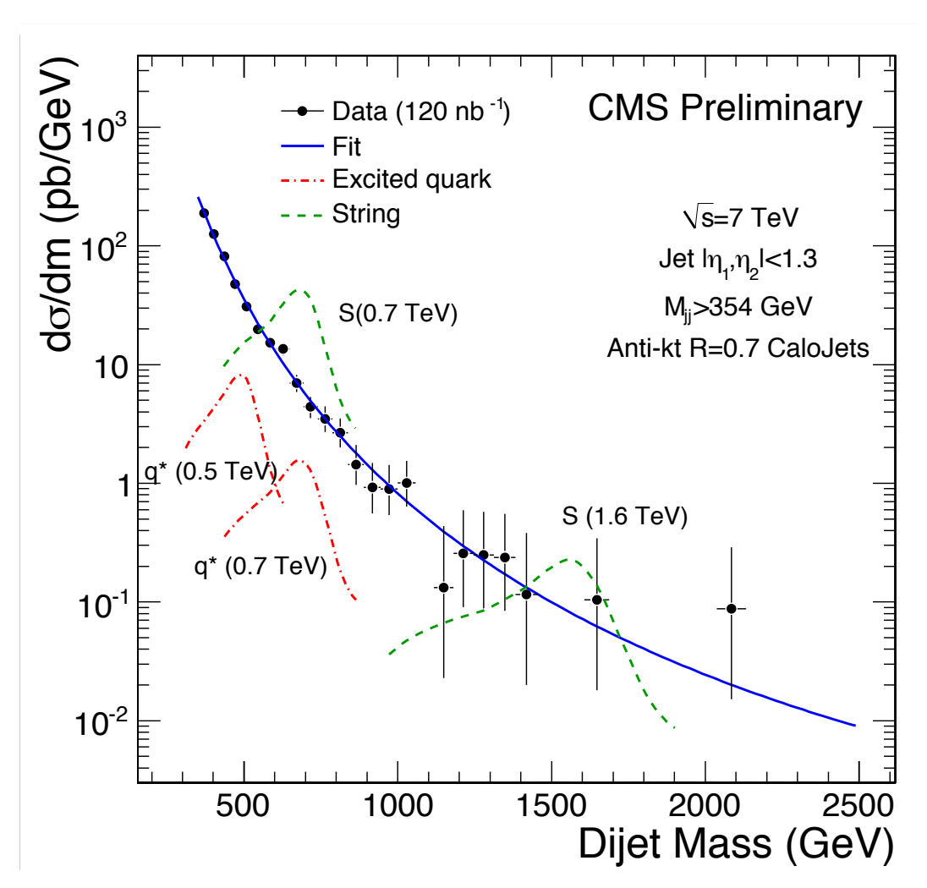
- single jet trigger with $p_T > 50$ GeV

Event selection:

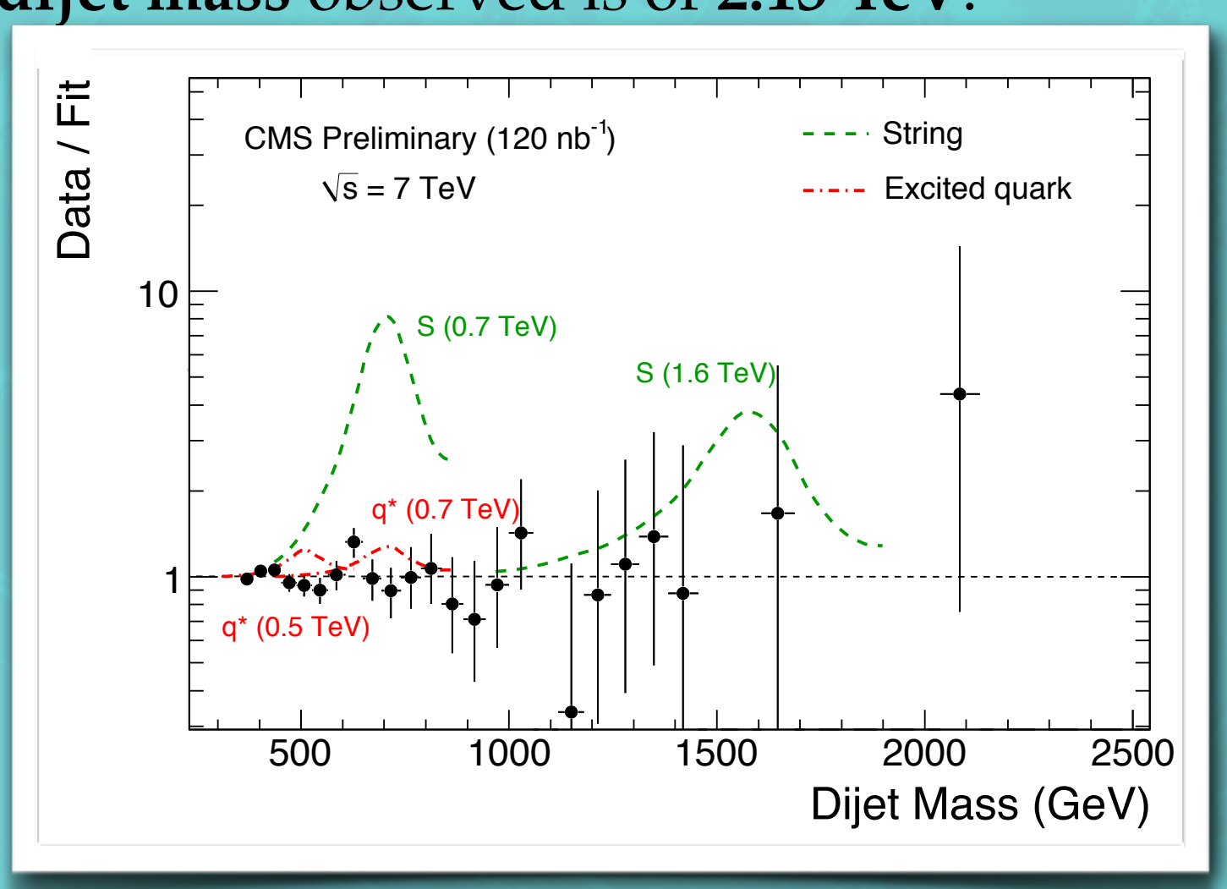
- both jets with |η| < 1.3
- dijet mass above 354 GeV

Systematic uncertainties:

- jet energy scale (10%)
- jet energy resolution (10%)
- luminosity (11%)
- background parametrization



The **highest dijet mass** observed is of **2.13 TeV**.



Exclusion limits (95% C.L.) with 120 nb^{-1}:

- *string resonances* with **M < 1.67 TeV** (1.4 at Tevatron)
- *excited quarks* with M < 0.59 TeV (0.87 TeV at Tevatron)
- *axigluons/colorons* with M < 0.52 TeV (1.25 TeV at Tevatron)

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3-Jet to 2-Jet Cross Section Ratio

Production of events with three or more jets in the final state originate from higher order QCD processes (e.g., gluon radiation).
The **inclusive 2-jet and 3-jet differential cross sections** are:

$$H_T = \sum p_T^{jet}$$

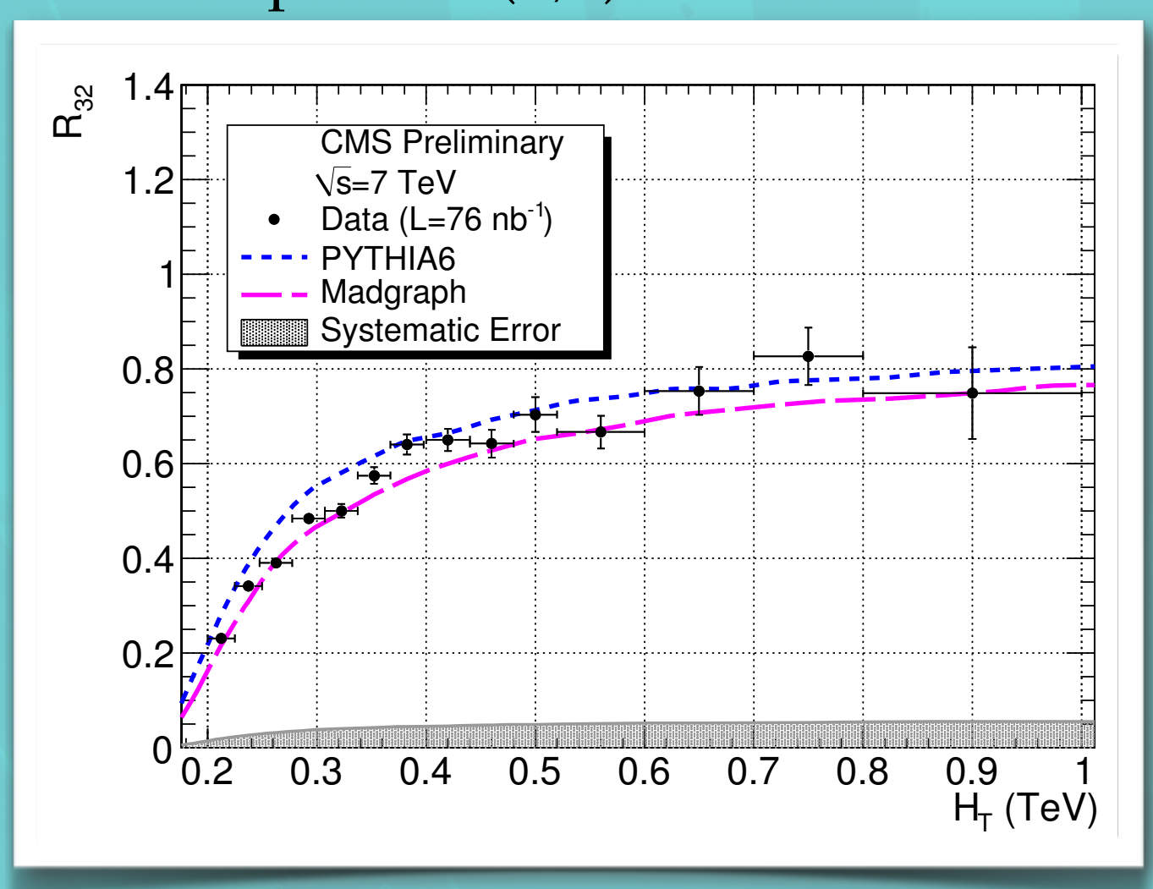
$$\frac{d\sigma_i}{dH_T} = \frac{\overset{\text{unsmearing correction}}{C_i}}{\underset{\text{luminosity}}{\mathcal{L}} \cdot \underset{\text{selection efficiency}}{\epsilon_i}} \cdot \frac{\overset{\text{number of events}}{N_i}}{\underbrace{\Delta H_T}_{\text{bin width}}}$$

The **three-jet to two-jet ratio** (**R_{32}**) is sensitive to higher order radiation and to the QCD coupling constant (α_s). R_{32} is defined as:

$$R_{32} = \frac{d\sigma_3/dH_T}{d\sigma_2/dH_T}$$

Trigger selection: single jet trigger with $p_T > 30$ GeV
Event selection: two (three) jets with $p_T > 50$ GeV and |y| < 2.5
Systematic uncertainties:

- jet energy scale (10% absolute and 2% linear increase in η)
- MC to data discrepancies (5%)



The R_{32} rises with H_T as the phase space opens up for a third jet to be emitted, up to a saturation plateau.

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Jets in CMS

Jets are the experimental signature of quarks and gluons. They are reconstructed using an **anti-k_T** jet clustering algorithm with R = 0.5 or 0.7, depending on the analysis.
Calorimeter jets: formed by clustering the 4-vectors of calorimeter towers (e.g., 1 HCAL cell & 5x5 ECAL crystals in the barrel)
Particle jets: localized streams of MC particles as results of soft quark and gluon radiation and hadronization processes
The observed jet energy is corrected for detector effects:

- **relative correction** (removes the η dependence)
- **absolute correction** (restores the response to unity)

The jet energy and position resolutions, derived from simulation, are within 10% when compared to data.

Common event selection:

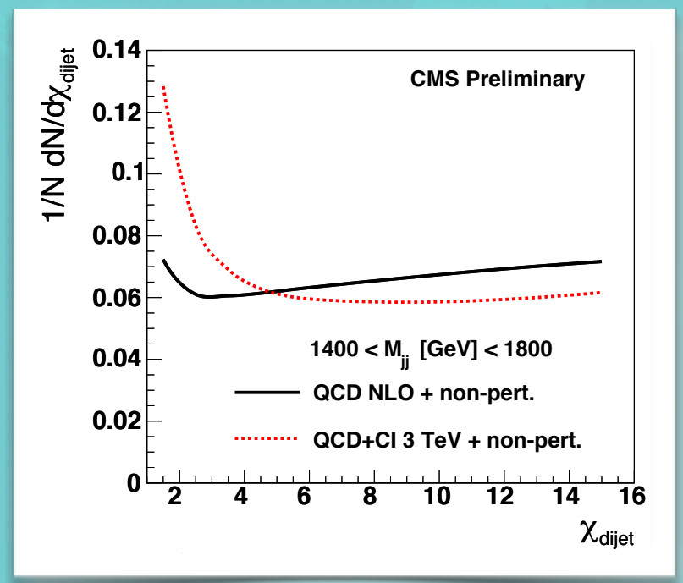
- **good primary vertex** with $|z_{PV}| < 15$cm and at least five associated tracks (~100% efficiency)
- **loose jet identification** (~100% for $p_T > 50$ GeV):
  - ➡ electromagnetic energy fraction > 1% for |η| < 2.6
  - ➡ less than 90% of jet energy in one calorimeter tower
  - ➡ less than 98% of jet energy in the hottest HCAL readout channel

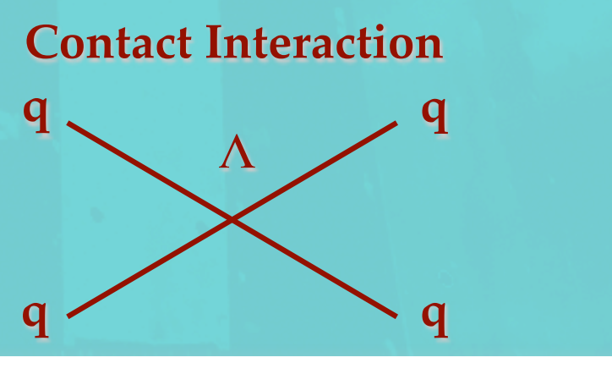
Dijet Angular Distributions

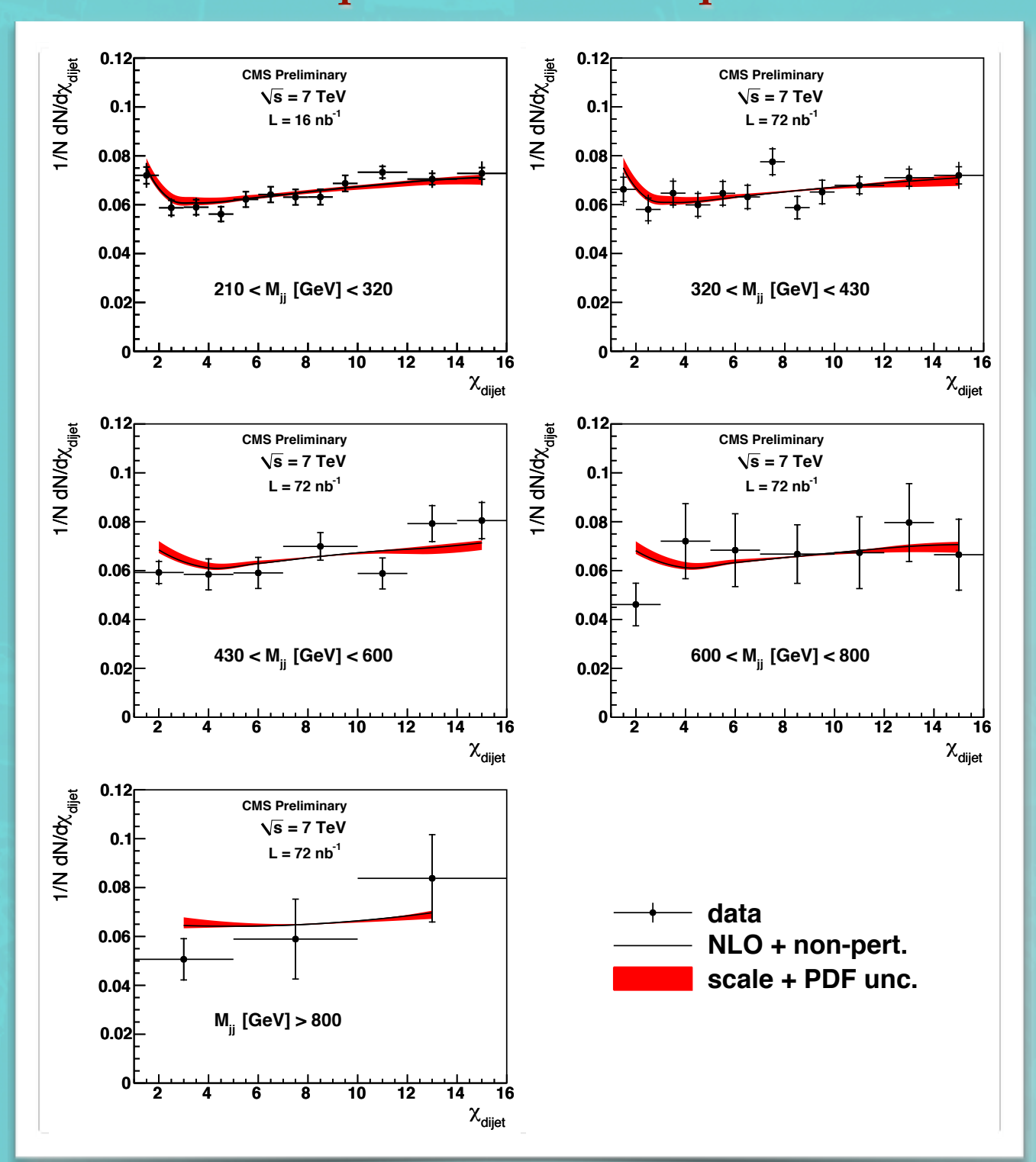
The dijet angular distribution probes the properties of parton-parton scattering without strong dependence on the details of PDFs.
The **dijet angular distribution** is expressed as:

$$\chi_{dijet} = e^{|y_1 - y_2|}$$

In this variable QCD has a flat distribution. Signatures of new physics are expected to produce an excess at low values of χ_{dijet}.







Trigger selection:

- single jet triggers with $p_T > 15$ (30) GeV

Event selection:

- two jets with |y| < 2.5

Systematic uncertainties:

- jet energy scale (10% absolute and 2% linear increase in η)
- jet energy resolution (10% overall)
- unsmearing correction

NLO predictions (fastNLO and CTEQ6.6 PDFs):

- corrected for non-perturbative effects

Overall, there is a good agreement between the theoretical predictions and data.

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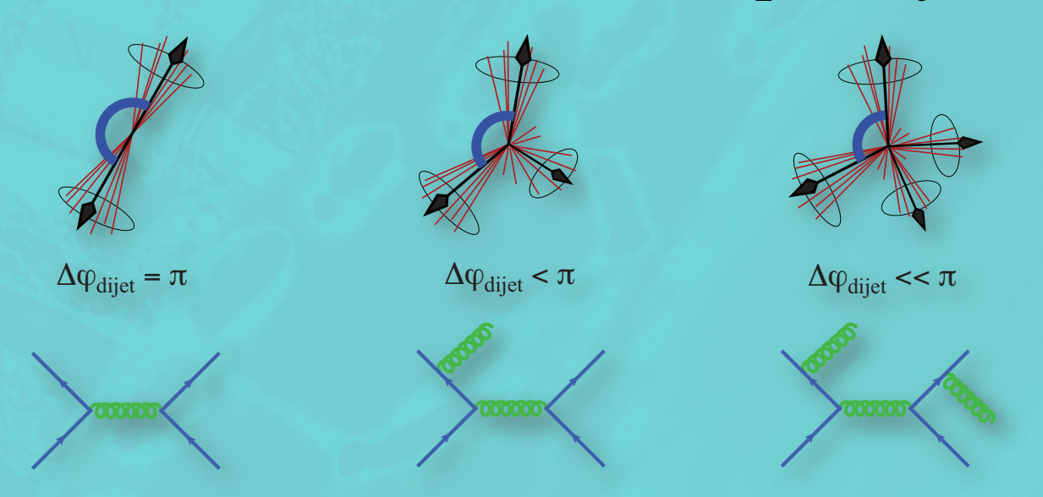
Dijet Azimuthal Decorrelations

The production of events with two jets with large p_T is one of the fundamental processes occurring at hadron colliders.

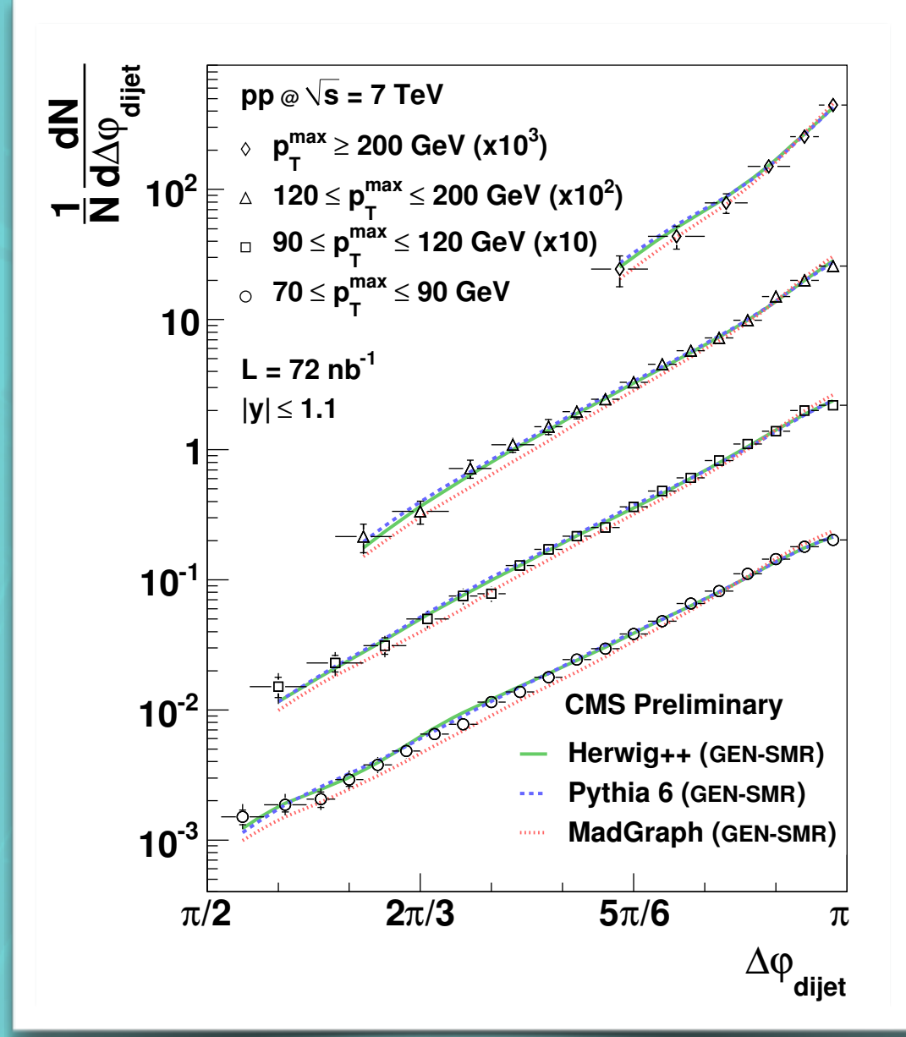
The **azimuthal angle** ($\Delta\varphi_{dijet} = |\varphi_{jet1} - \varphi_{jet2}|$) can be used to study higher order QCD radiation effects without the need to explicitly reconstruct additional jets.

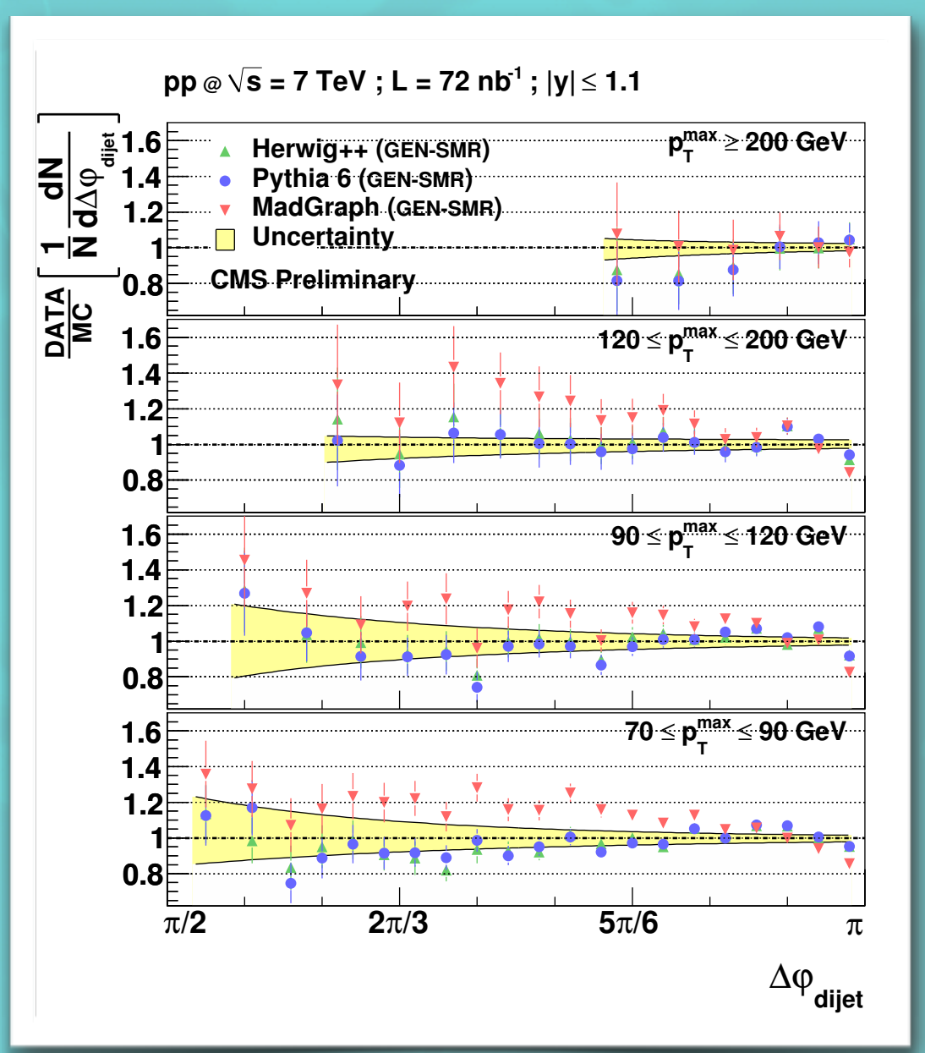
- leading order: **Δφ = π**
- soft radiation: **Δφ < π**
- hard radiation: **Δφ << π**



Trigger selection: single jet trigger with $p_T > 30$ GeV
Event selection: two jets with |y| < 1.1 and p_T (jet_2) > 30 GeV
Systematic uncertainties:

- jet energy scale (10% absolute and 2% linear increase in η)
- jet energy resolution (10%)





The **Δφ distributions**:

- strongly peaked at π; become narrower with increasing p_T
- 3-jet topologies for $\Delta\varphi_{dijet} > 2\pi/3$; 4-jet events below 2π/3

GEN-SMR ≡ detector effects added to MC predictions

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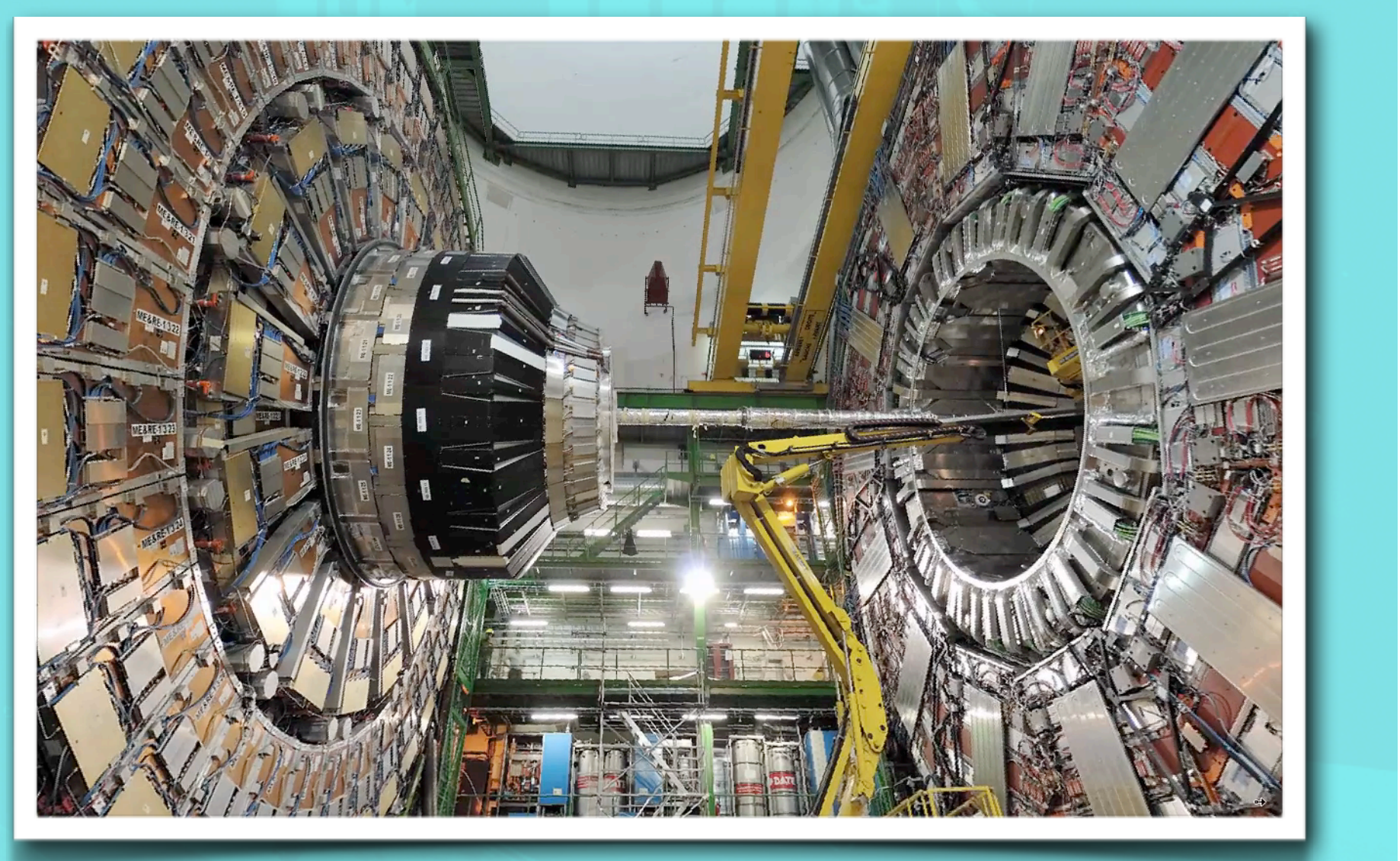
ABBREVIATIONS:

C.L.	- confidence level
CMS	- compact muon solenoid
ECAL	- electromagnetic calorimeter
HCAL	- hadronic calorimeter
MC	- Monte Carlo
NLO	- next-to-leading order
PDF	- parton distribution function
QCD	- quantum chromodynamics
SM	- standard model



Dijet Centrality Ratio

New physics beyond the SM typically produces more isotropic angular distributions than those predicted by QCD, resulting in more dijets at lower absolute values of η.
The **dijet centrality ratio** is defined as:

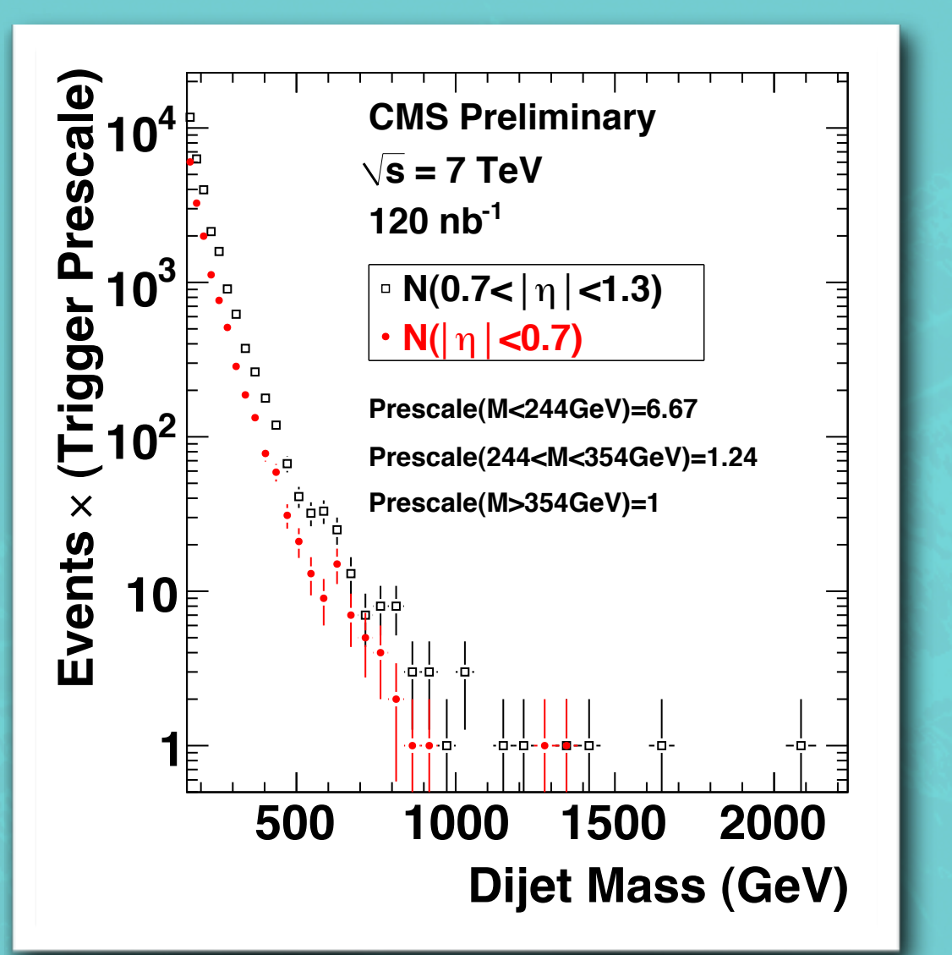
$$\frac{\overset{\text{number of events with both jets in the } inner\ \eta \text{ region}}{N(|\eta| < 0.7)}}{\underset{\text{number of events with both jets in the } outer\ \eta \text{ region}}{N(0.7 < |\eta| < 1.3)}}$$

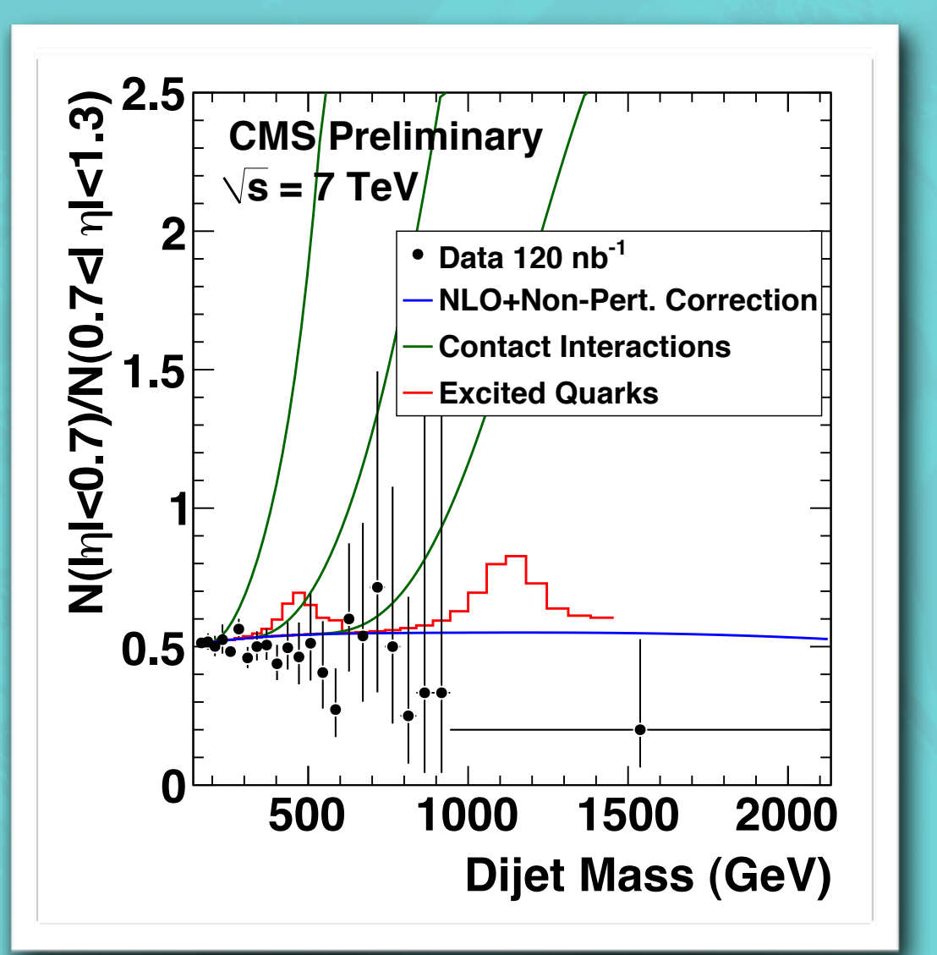
Trigger selection: single jet triggers with (15, 30, 50 GeV)
Event selection: two leading jets with |y| < 1.3
Systematic uncertainties:

- jet energy scale (10% absolute and 2% linear increase in η)
- jet energy resolution (10%)

NLO predictions (fastNLO and CTEQ6.6 PDFs):

- corrected for non-perturbative effects





The measured dijet centrality ratio is in good agreement with the prediction from NLO QCD.

Exclusion limits (95% C.L.) with 120 nb^{-1}:

- *contact interactions* with scale Λ < 1.86 TeV (2.8 at Tevatron)

CMS PAS EXO-10-002