Search for new Physics in the dijet mass spectrum and dijet ratio in pp Collisions at $\sqrt{s}$ = 7 TeV

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Outline

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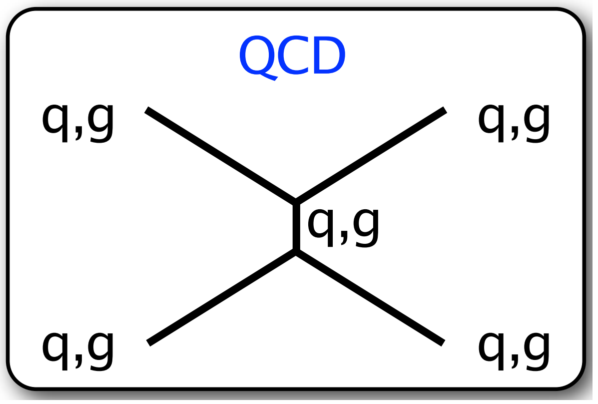
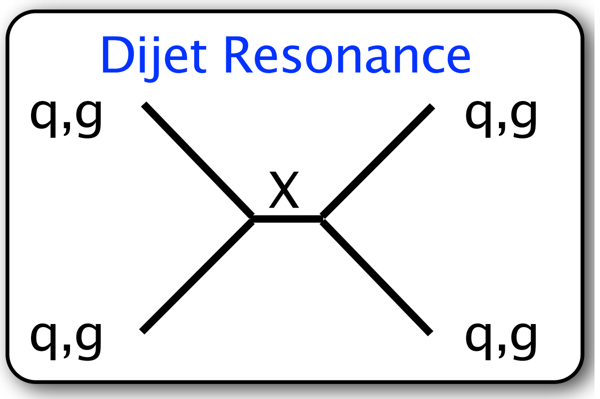
- Dijet Centrality Ratio
- Summary

Motivation

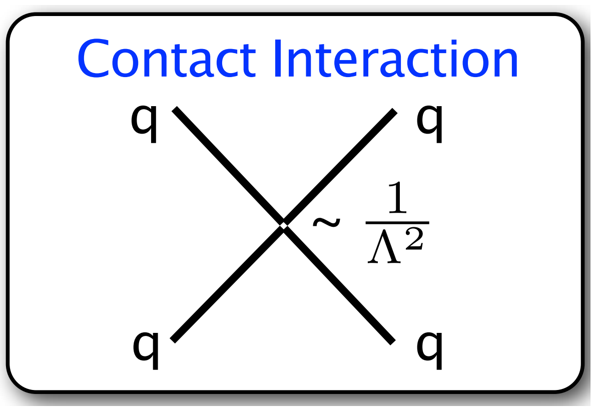
✦ We study the inclusive dijet final state using the **dijet mass spectrum** and the **dijet centrality ratio** observables.
✦ Together the Dijet Mass and Ratio provide a **test of QCD** and a **sensitive search** for new physics beyond the Standard Model.



- Dijet mass distribution is a simple check of rate vs dijet mass from QCD and PDFs.
- Dijet centrality ratio is a detailed measure of QCD dynamics from angular distribution.

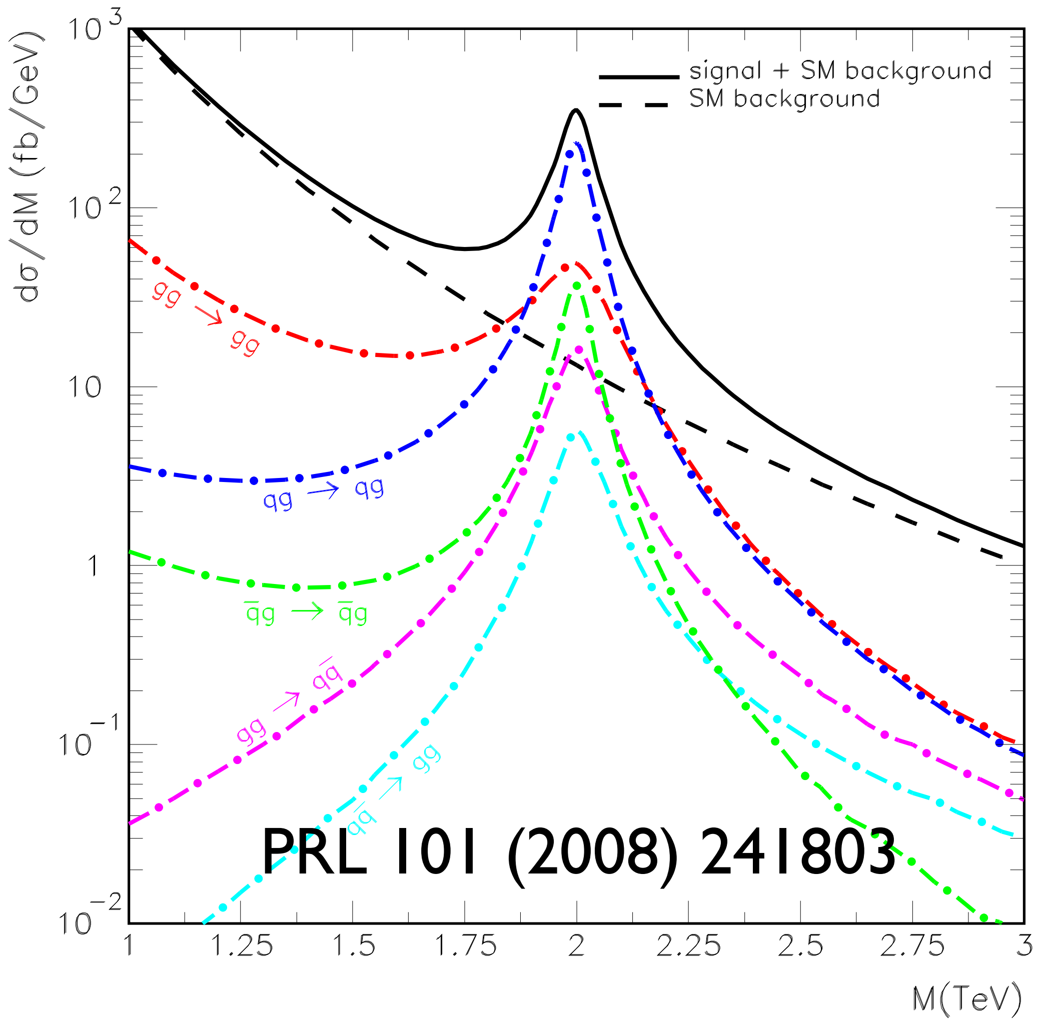


- Dijet mass provides most sensitive *"bump"* hunt for new particles decaying to dijets.
- Dijet centrality ratio can confirm that a *"bump"* is not QCD fluctuation.



- Dijet centrality ratio is more sensitive than the dijet mass to contact interactions from quark compositeness.
  - when all experimental uncertainties are considered.

Specific Dijet Resonance Models

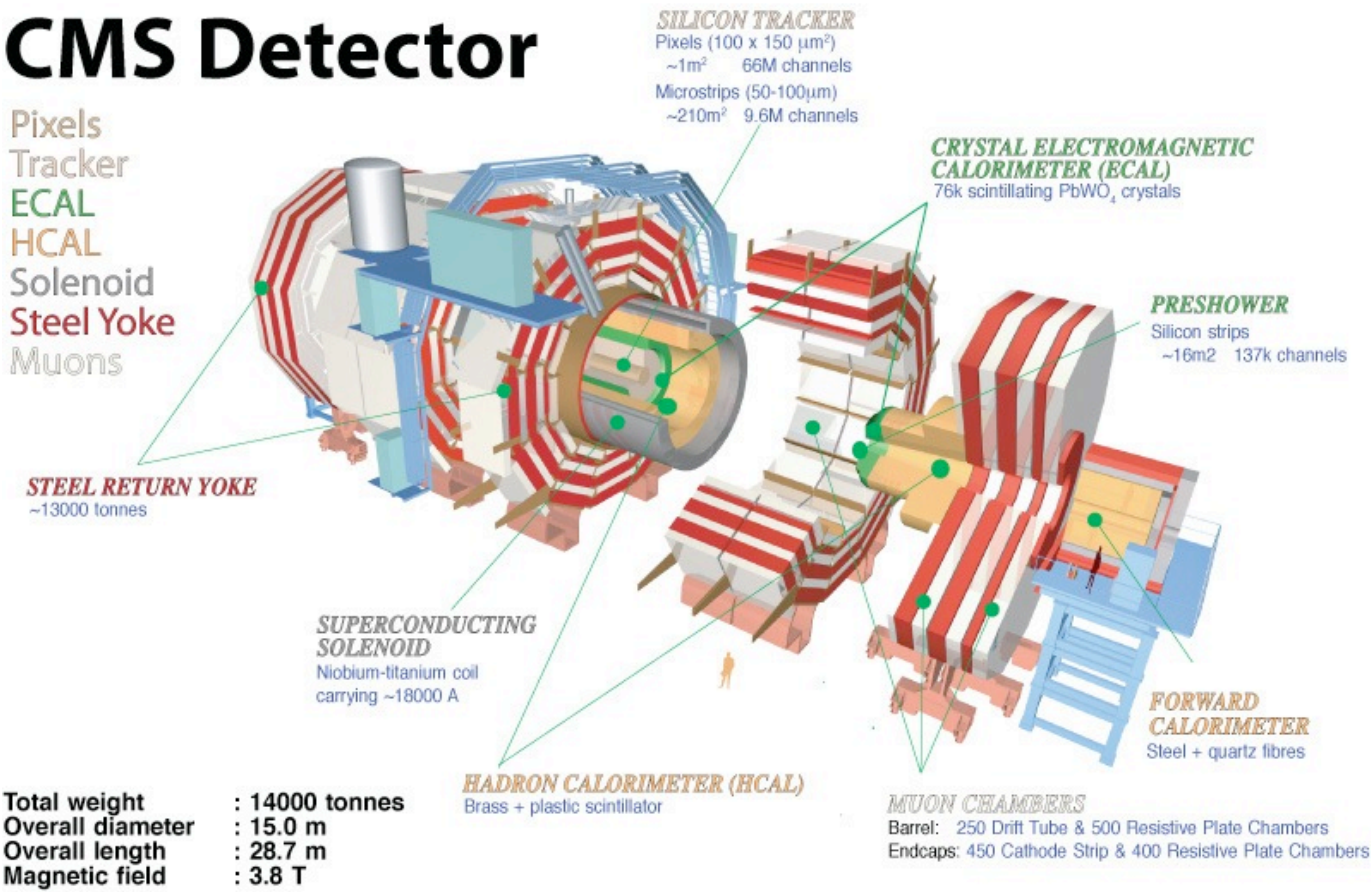


String resonances would produce a spectacular “bump” in the dijet invariant mass spectrum

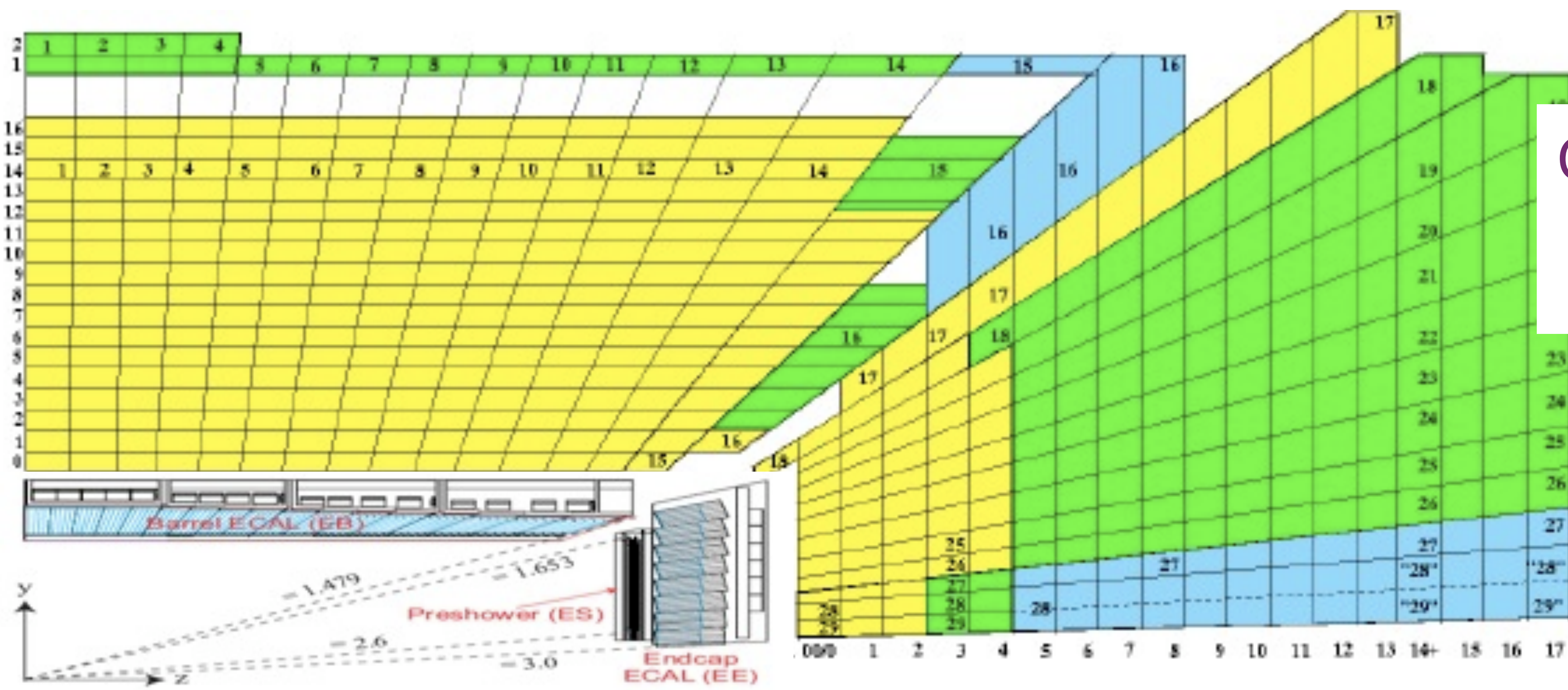
- Parton resonances decaying to dijets are predicted by various theory models:
  - Axigluons
  - Colorons
  - Excited Quarks
  - E_6 Diquarks
  - Randal-Sundrum Gravitons
  - New vector bosons (Z’,W’)
- Recent theoretical development: String Resonances
  - Regge excitations of quarks and gluons
  - Much higher cross-section than excited quark models by a factor ~25 (due to color, spin and chirality effects)

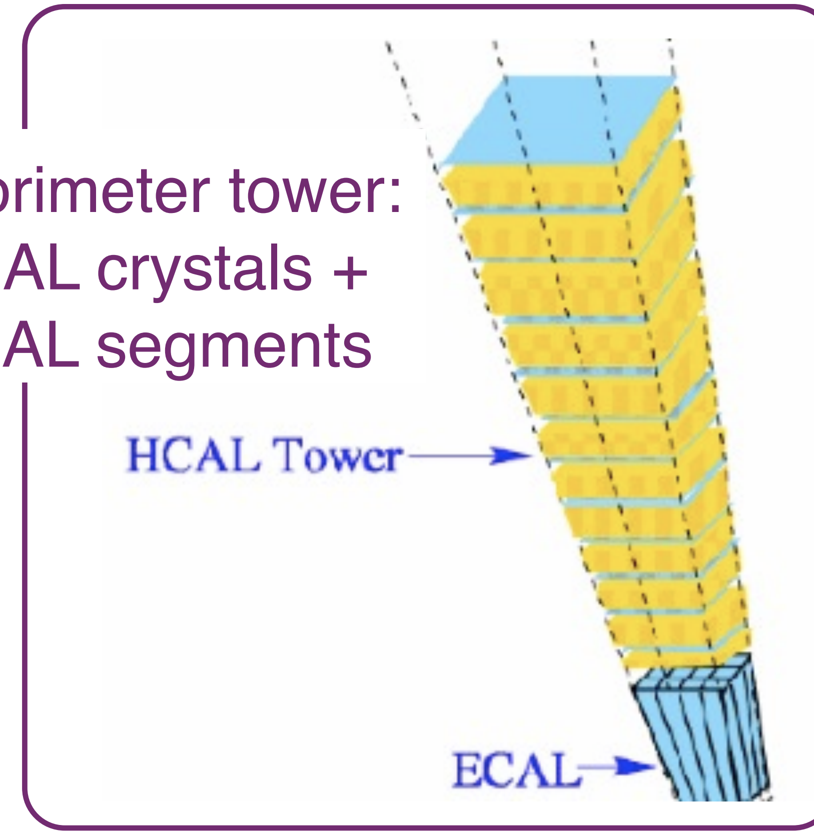
Model Name	X	Color	J^P	$\Gamma/(2M)$	Final-state Partons
String	S	mixed	mixed	0.003-0.037	$q\bar{q}$, qq, gg and qg
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W′	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z′	Singlet	1^-	0.01	$q\bar{q}$

The CMS Detector



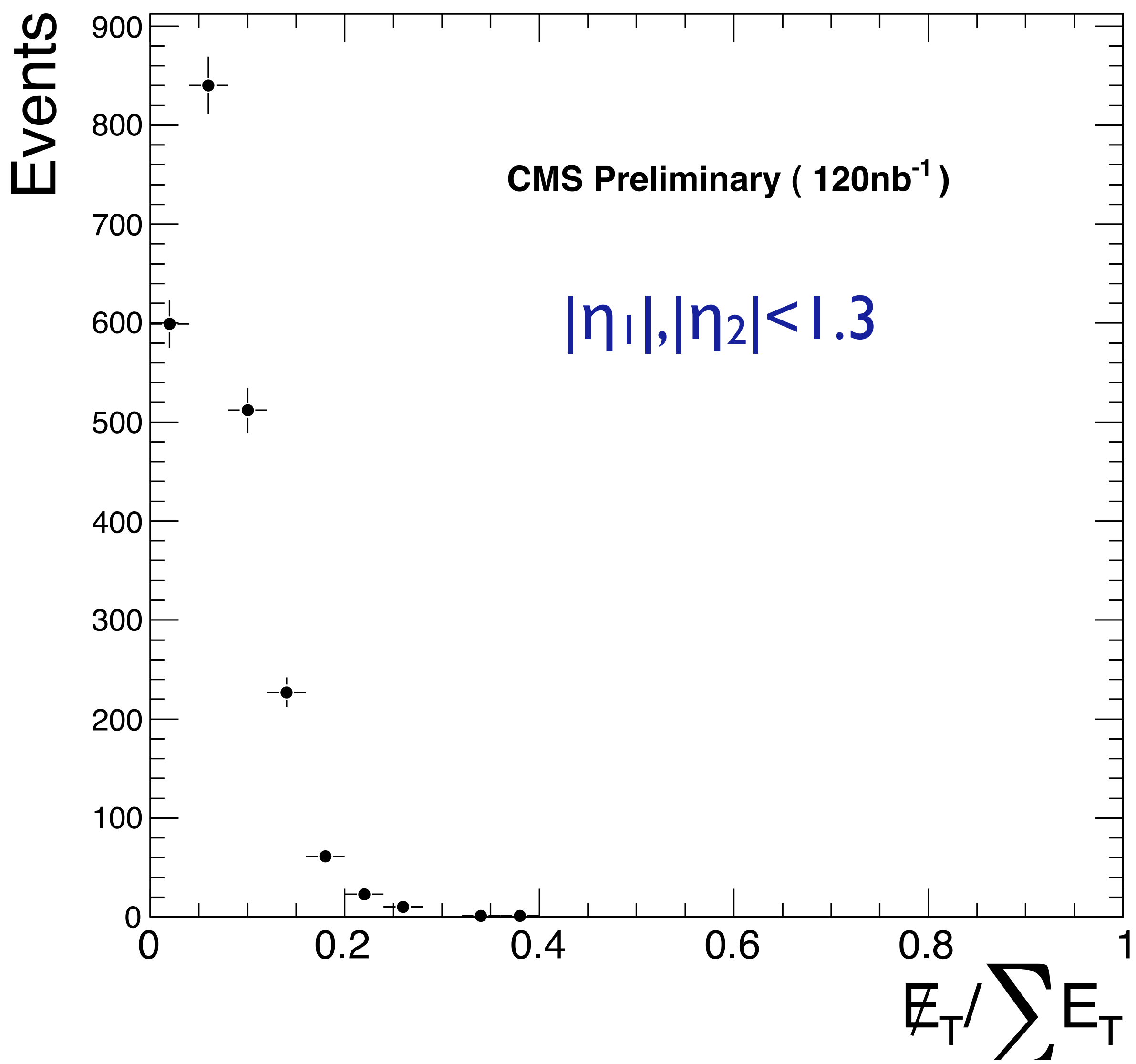
Jet Reconstruction

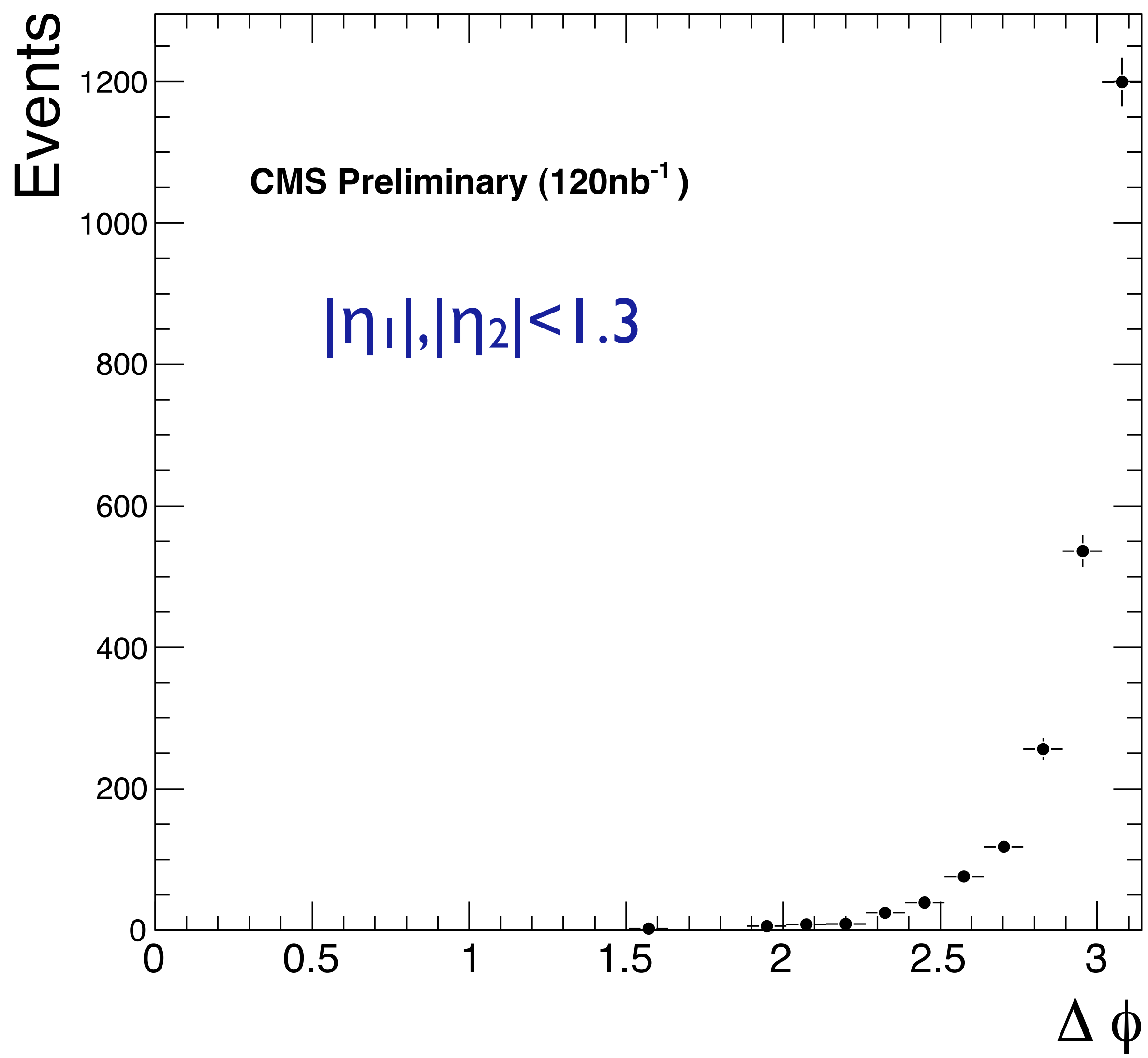




- Jets are reconstructed from energy depositions in the Electromagnetic and Hadron calorimeters, grouped in projective towers.
- **Anti-k_T** clustering algorithm with distance parameter **R=0.7**.
  - infrared and collinear safe, sequential recombination algorithm.
  - essentially behaves like a cone algorithm.
- Jet energy calibration from Monte Carlo truth.
  - preliminary in-situ measurements with γ+jet p_T balancing and of single particle response, indicate that the jet energy scale is known to better than 10%.
- Jet p_T resolution in the simulation agrees with in-situ measurement.

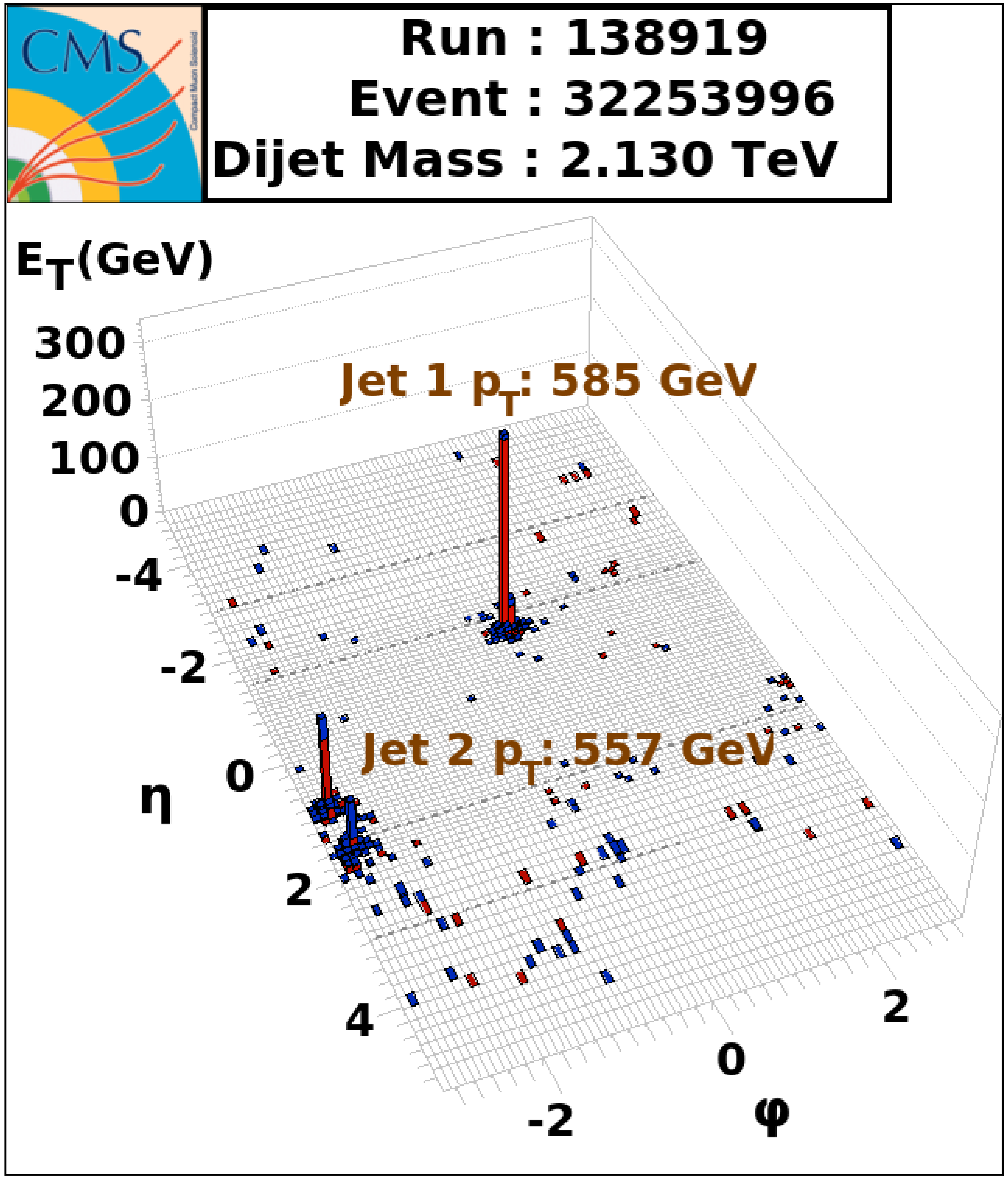
Dijet Topology

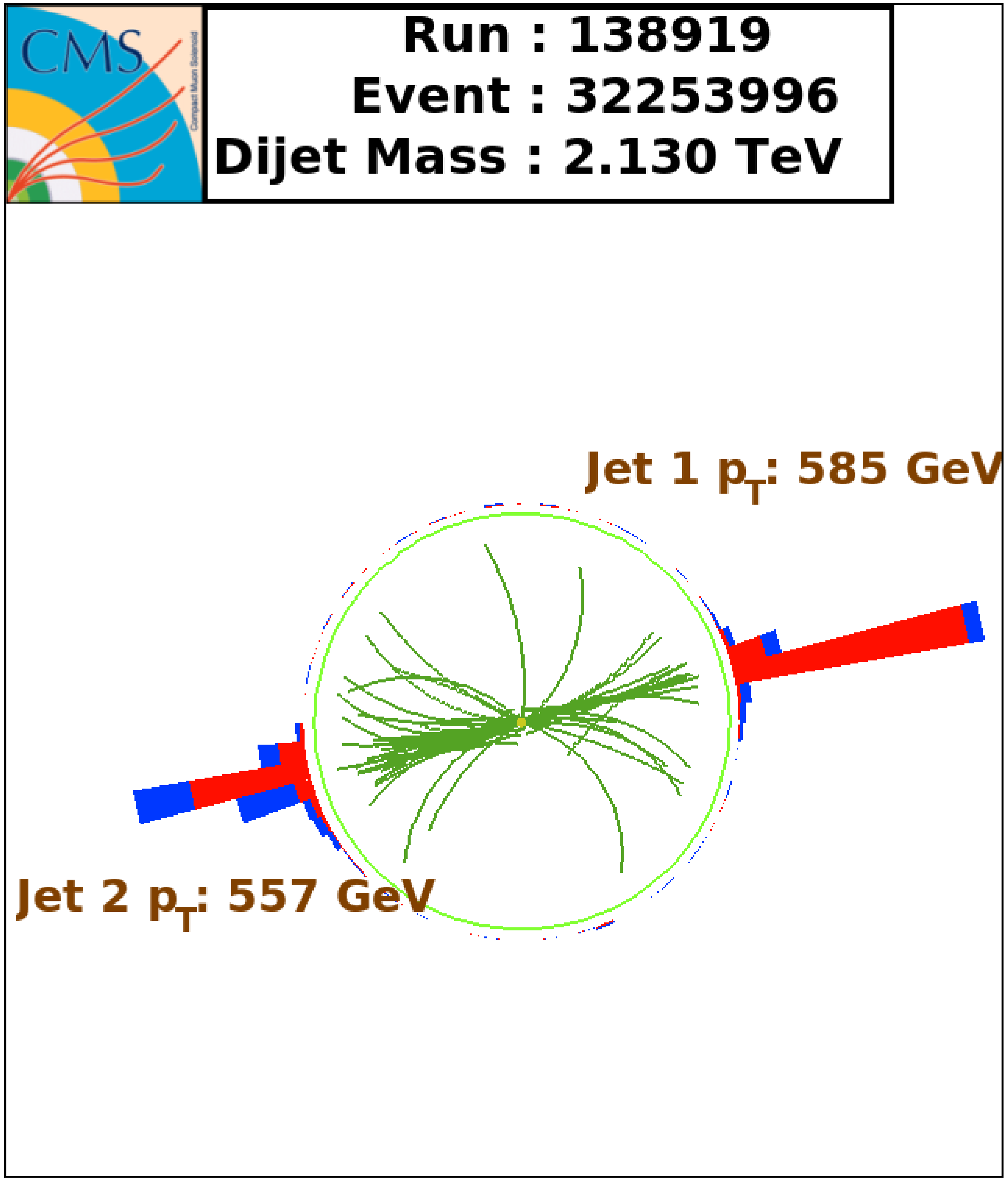




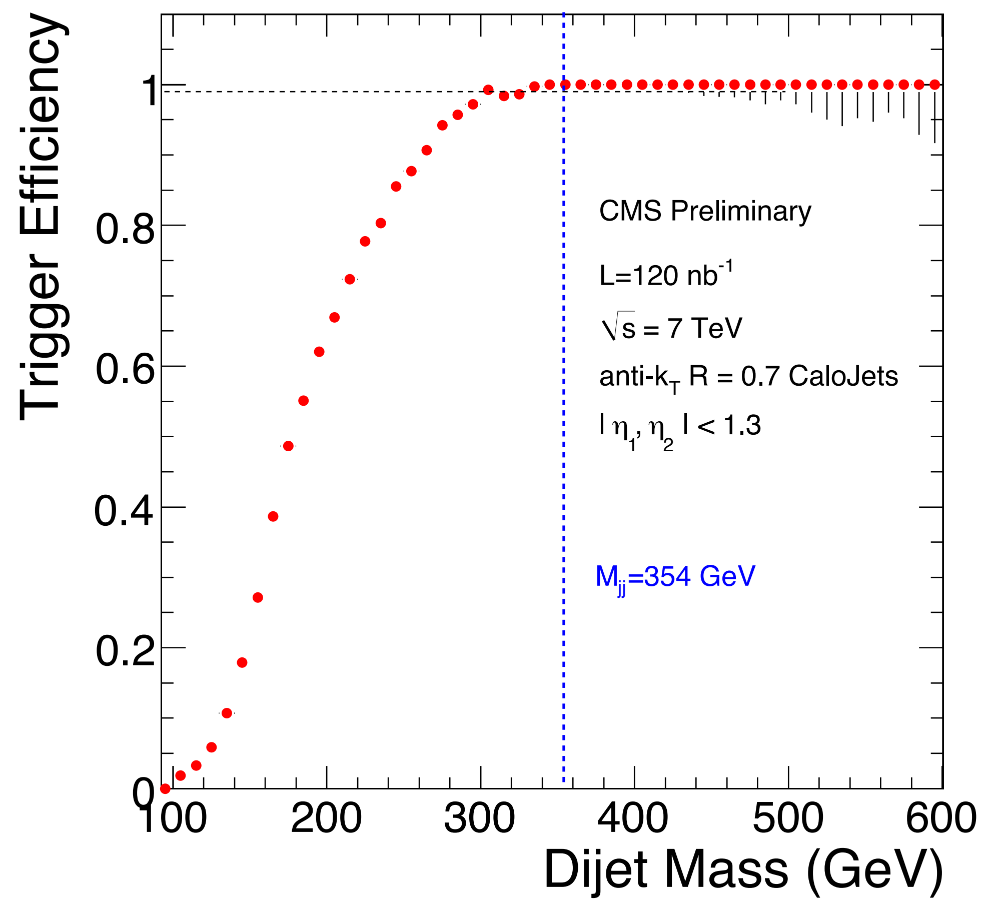
- Events are **well balanced**, as expected from the dijet topology.
- Events have low MET/SumET due to finite jet resolution, consistent with the QCD expectation.
  - unphysical backgrounds would show-up at MET/SumET ~1.
- Jets are "back-to-back" in azimuth φ.

Highest Dijet Mass Event

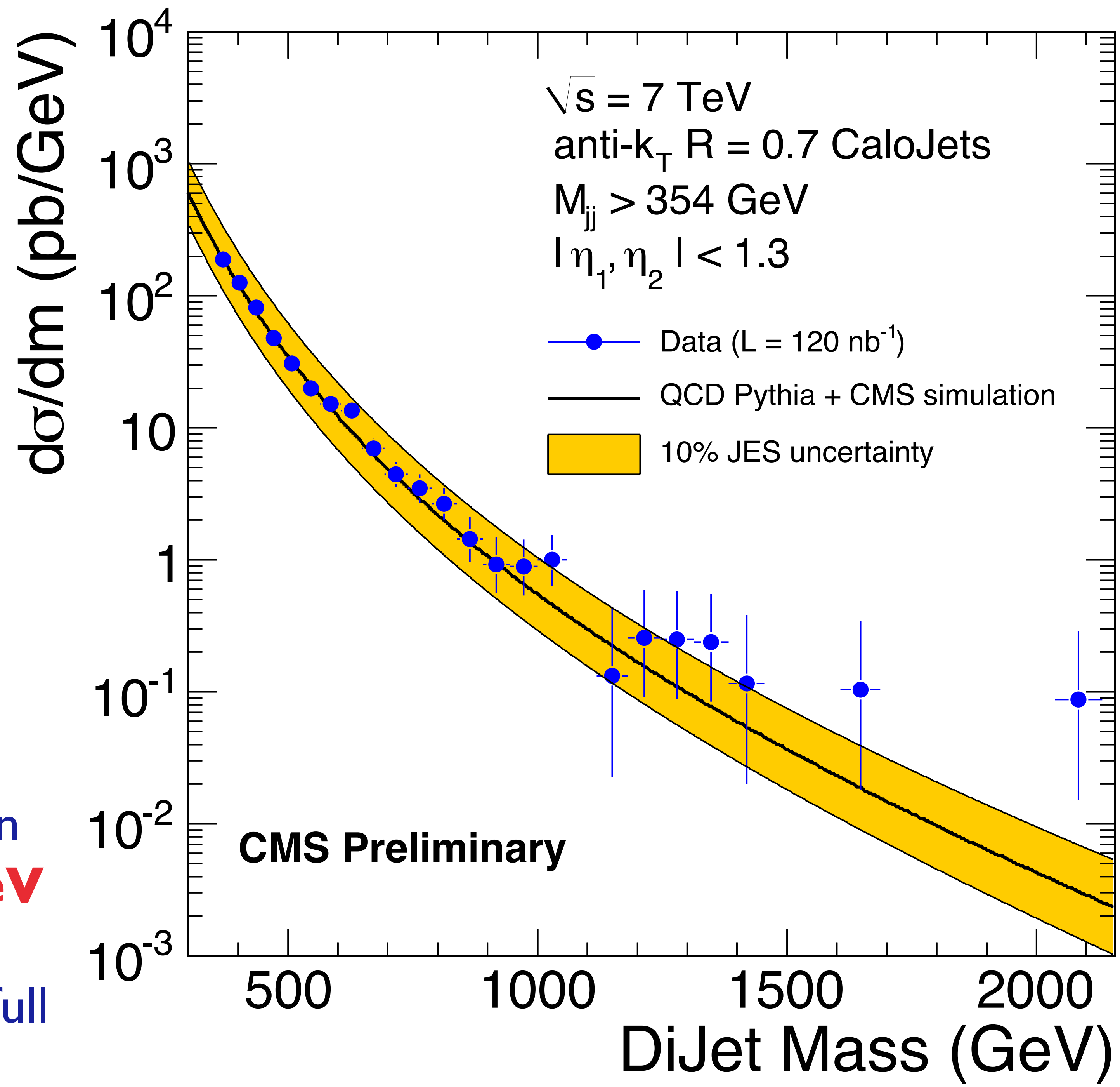




The Dijet Mass Spectrum

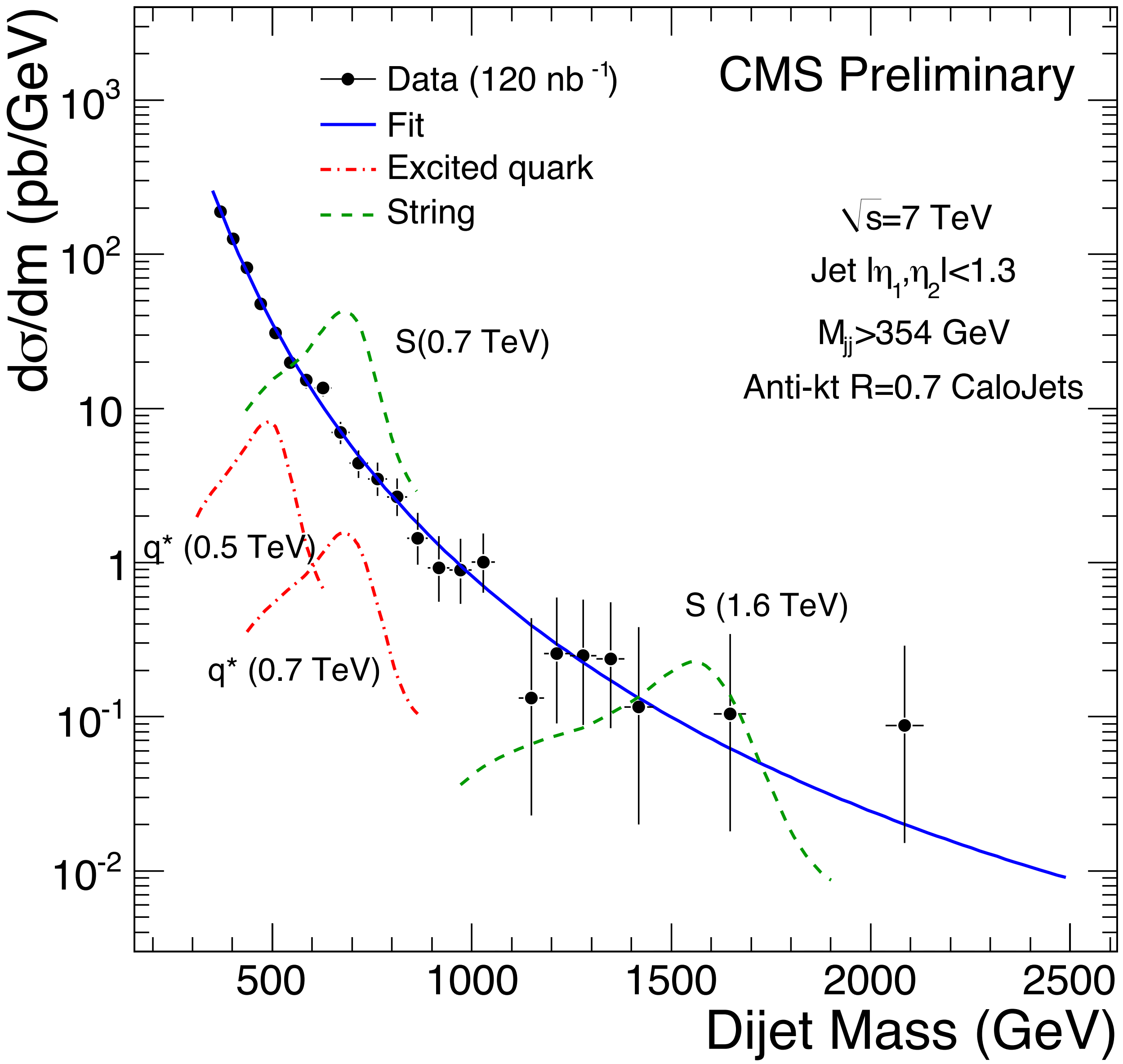


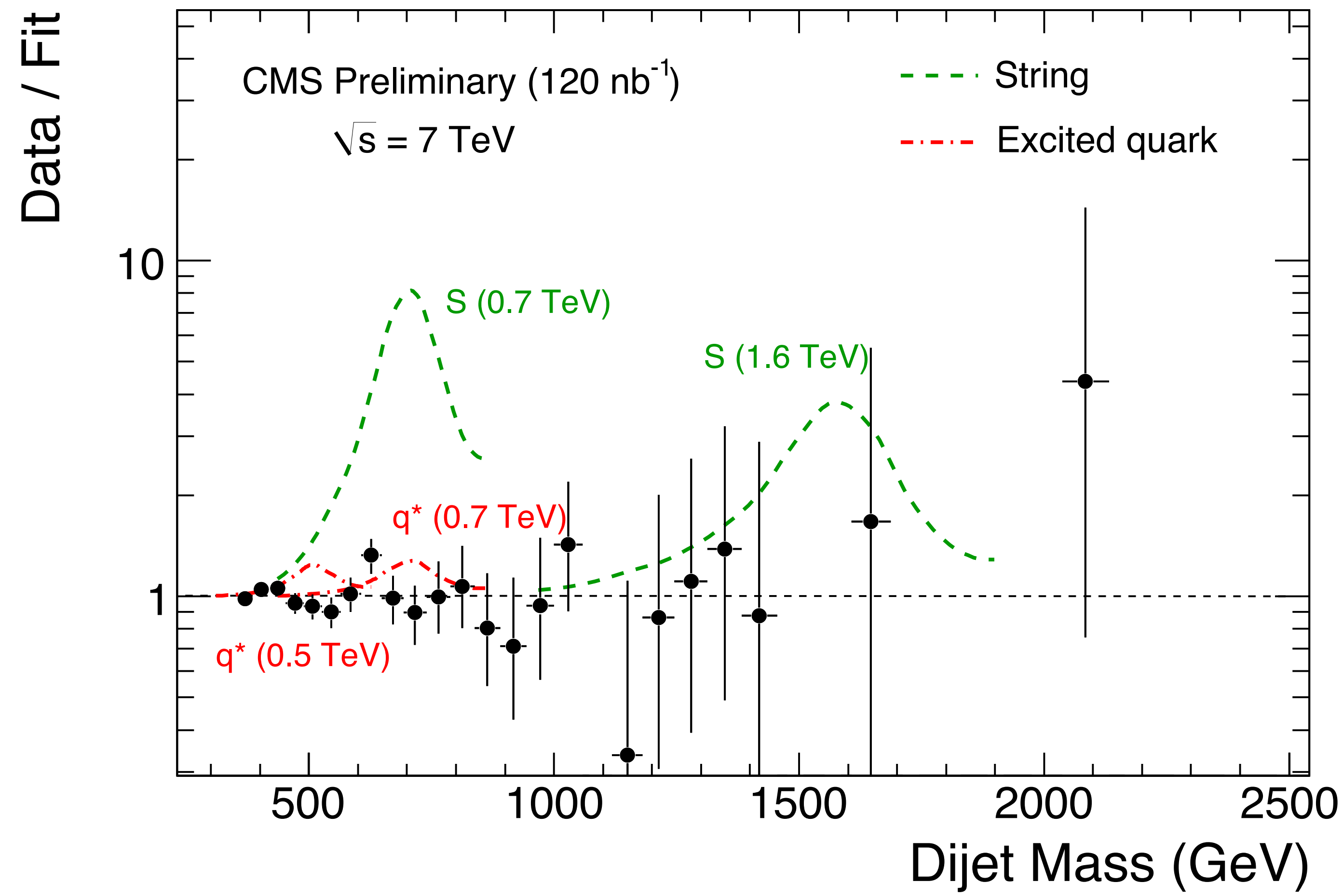
Measured cross-section



- We use a jet trigger requiring a single jet with E_T > 50 GeV uncorrected.
  - We measure the dijet mass spectrum where the trigger is fully efficient.
- The dijet mass spectrum with both jets in the range $|\eta_1|,|\eta_2|<1.3$, extends to **2.13 TeV** with **120 nb^{-1}**.
- The data is in good agreement with the full CMS simulation of QCD from PYTHIA.

Smooth Fit of the Data

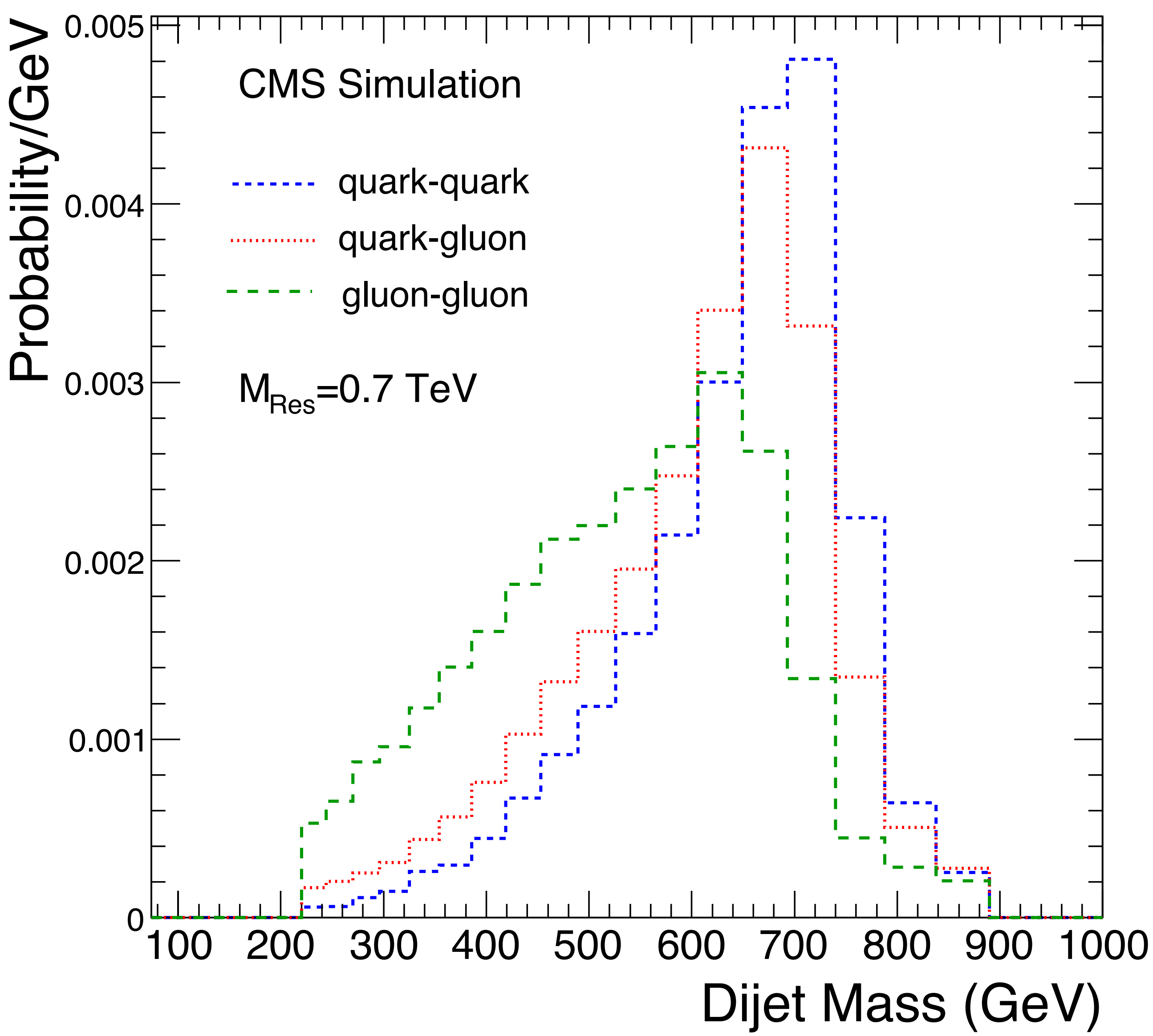




$$\frac{d\sigma}{dm} = P_0 \frac{\left(1 - m/\sqrt{s}\right)^{P_1}}{m^{P_2}}$$

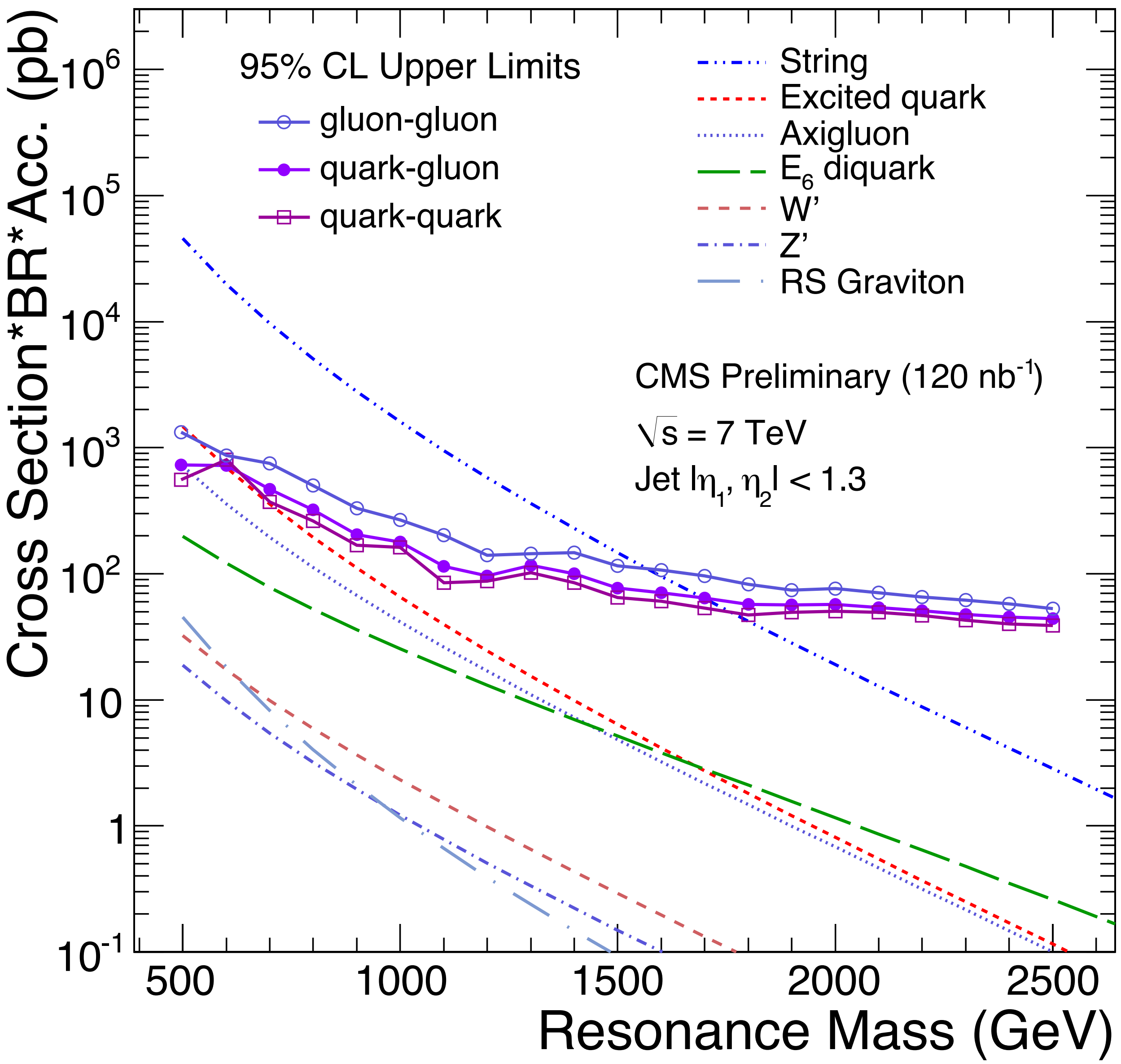
- Good fit of the data with only 3 parameters (χ^2/ndf = 13/20).
  - no indication of new Physics.
- String resonances have large cross-section and provide the highest search sensitivity.

Model-Independent Resonance Shapes



- ✦ Resonance shapes are produced with PYTHIA + CMS simulation.
- ✦ The 3 types of resonances (qq,qg,gg) have different shapes, mainly due to FSR.
  - The width of the dijet resonance increases with increasing number of gluons because they emit more radiation than the quarks.
- ✦ Gaussian core of dijet mass resolution for qg resonances varies from 11% at 0.5 TeV to 6% at 2.5 TeV
- ✦ **We search for these 3 generic types of narrow dijet resonances in the data.**

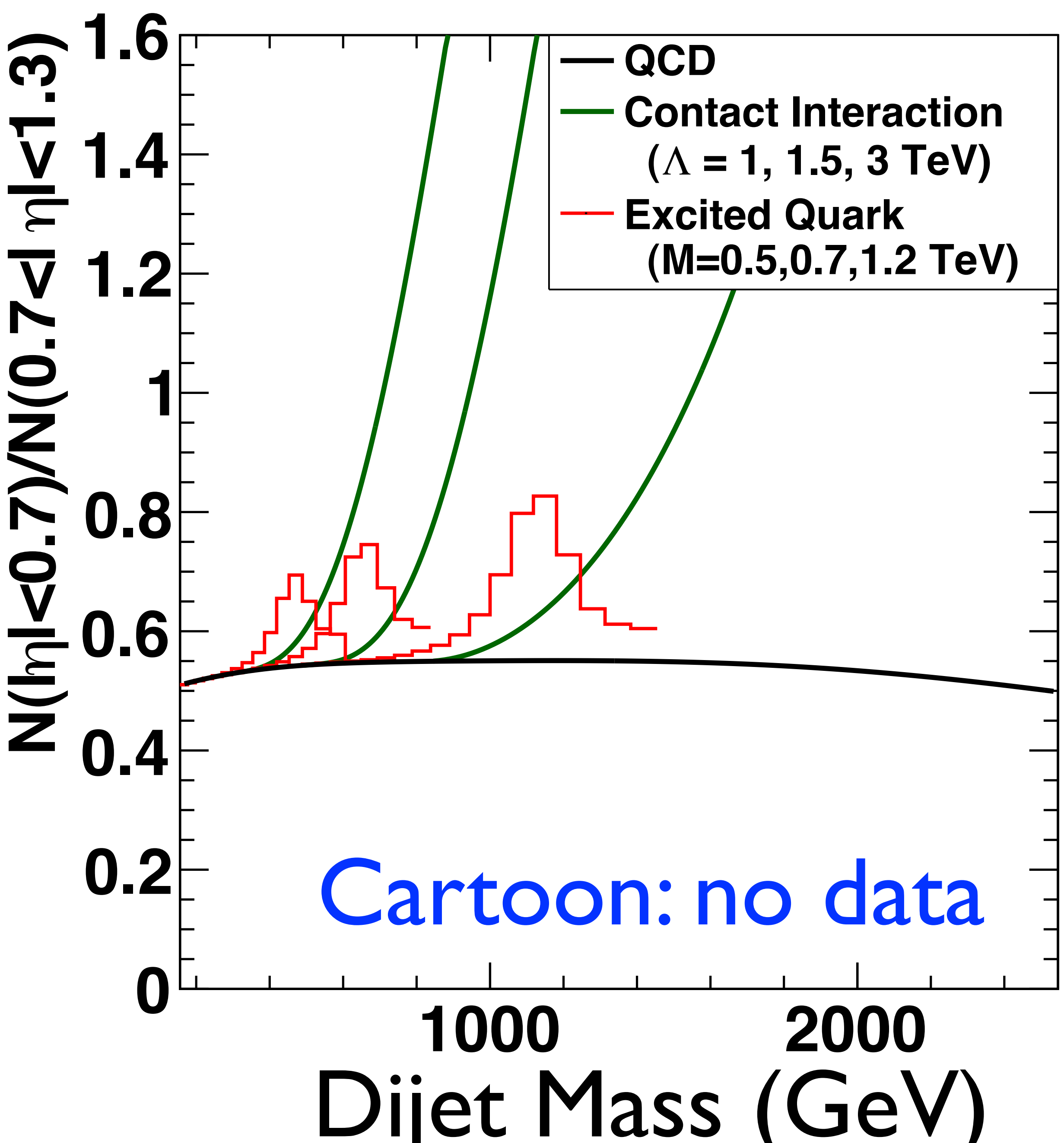
Model-Independent Cross-Section Limits



- ✦ We have **generic, cross-section upper limits** on quark-quark, quark-gluon and gluon-gluon resonances.
- ✦ The upper limits are compared to the expected cross-section for 7 resonance models.
- ✦ We exclude **excited quarks** (qg resonance) with mass **M < 0.59 TeV.** Tevatron limit is 0.87 TeV.
- ✦ We exclude **Axigluons/Colorons** (qq resonance) with **M < 0.52 TeV**. Tevatron limit is 1.25 TeV.
- ✦ **We exclude a string resonance with mass M<1.67 TeV**
  - string resonance decays predominantly to qg (75%).
  - we have taken into account its branching ratio to gg (12%) and qqbar (13%) as well.
  - more stringent than the Tevatron limit on string resonances of about 1.4 TeV (our evaluation of cross-section).

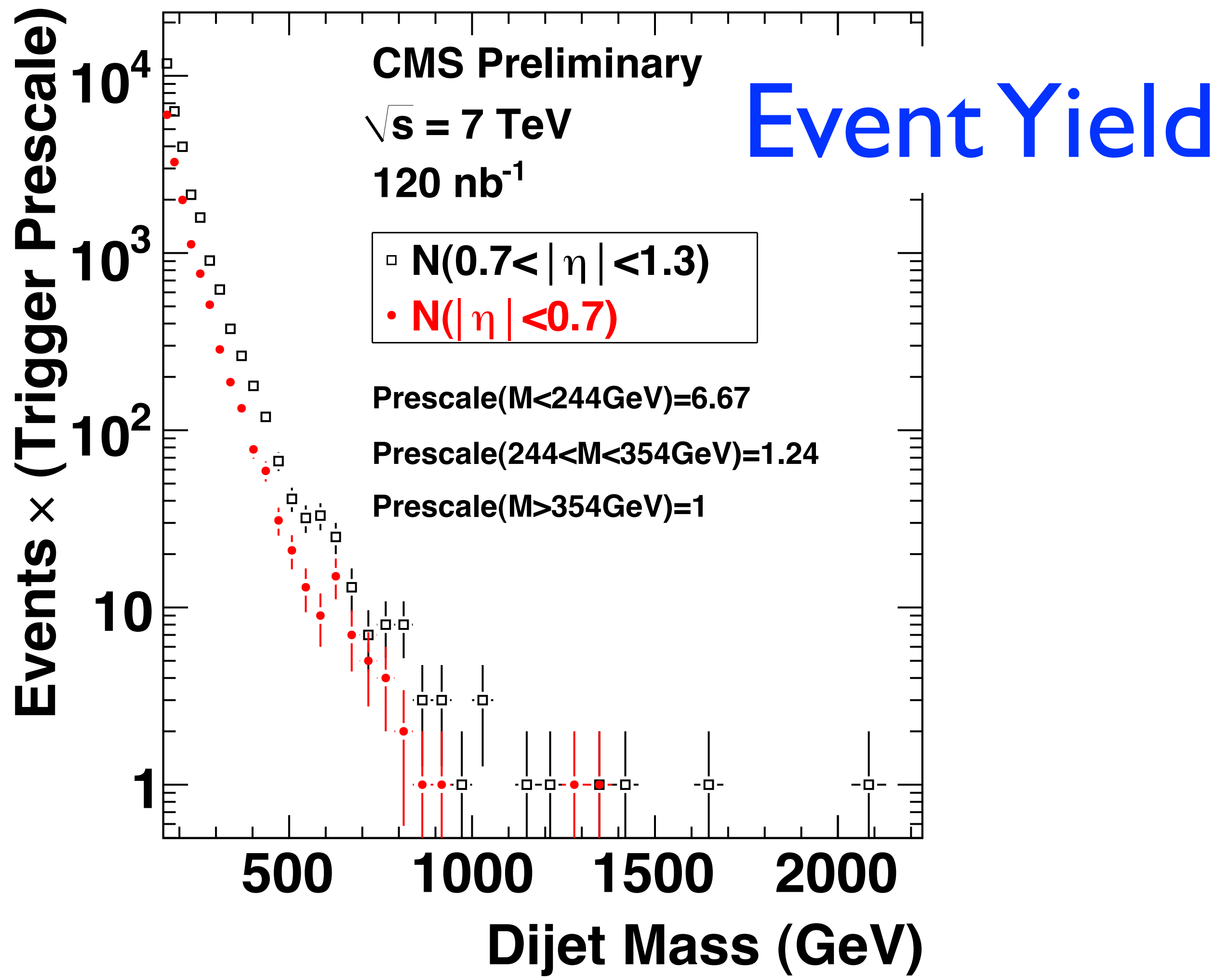
The Dijet Centrality Ratio

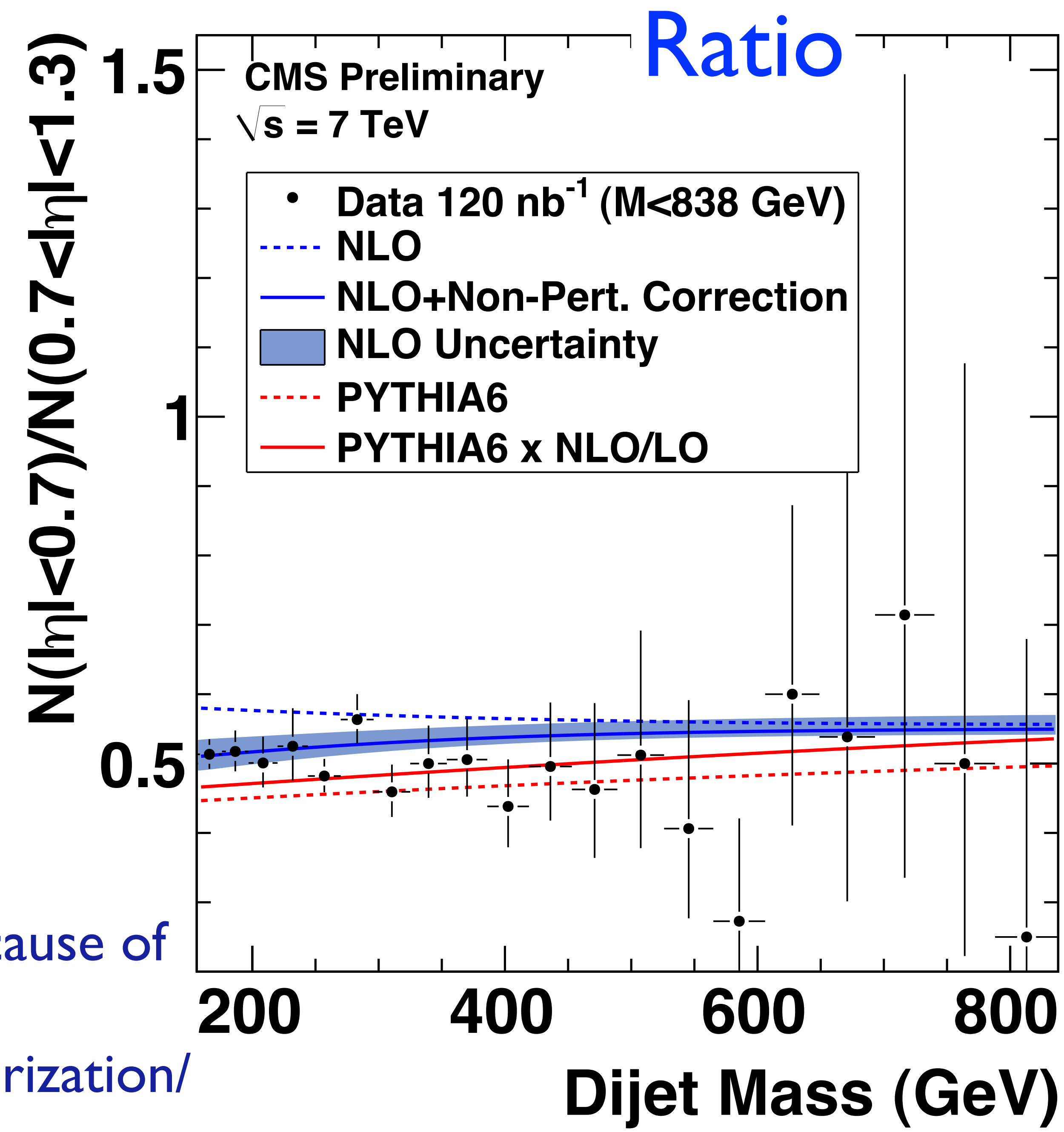
$$R = \frac{N(|\eta| < 0.7)}{N(0.7 < |\eta| < 1.3)}$$



- ✦ Quantifies the **centrality** of the dijet angular distribution at a given dijet mass.
  - both leading jets are required to lie in the same η range.
  - "t-channel" scattering for QCD vs "s-channel" for most new Physics models
  - approximately flat vs dijet mass for QCD.
  - rises vs dijet mass for contact interactions.
  - "bumps" in dijet mass for dijet resonances.
- ✦ The analysis of the dijet angular distribution is complimentary to the spectrum analysis.
- ✦ The dijet centrality ratio is used to confront the QCD prediction and search for new Physics.

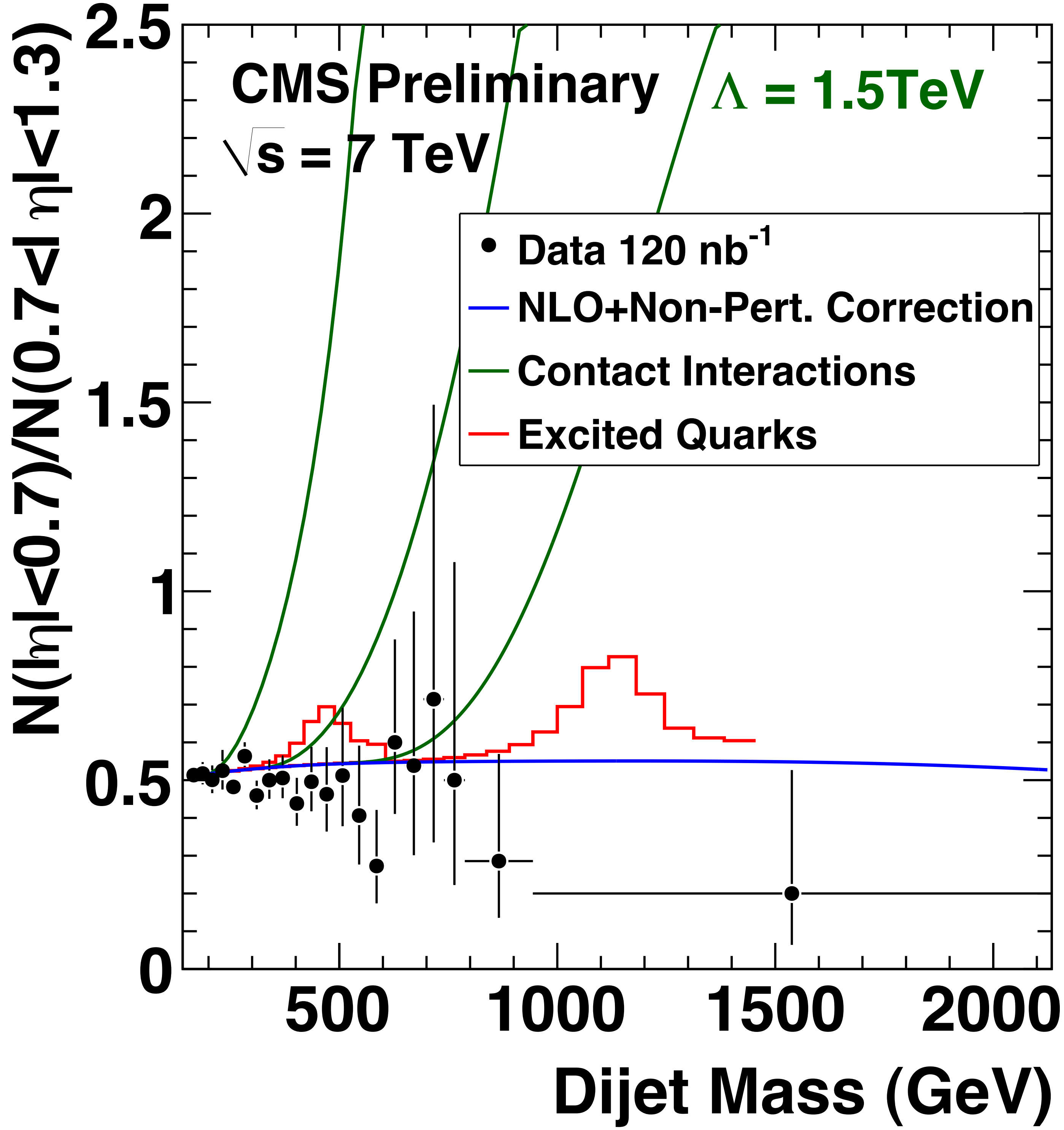
Comparison to QCD

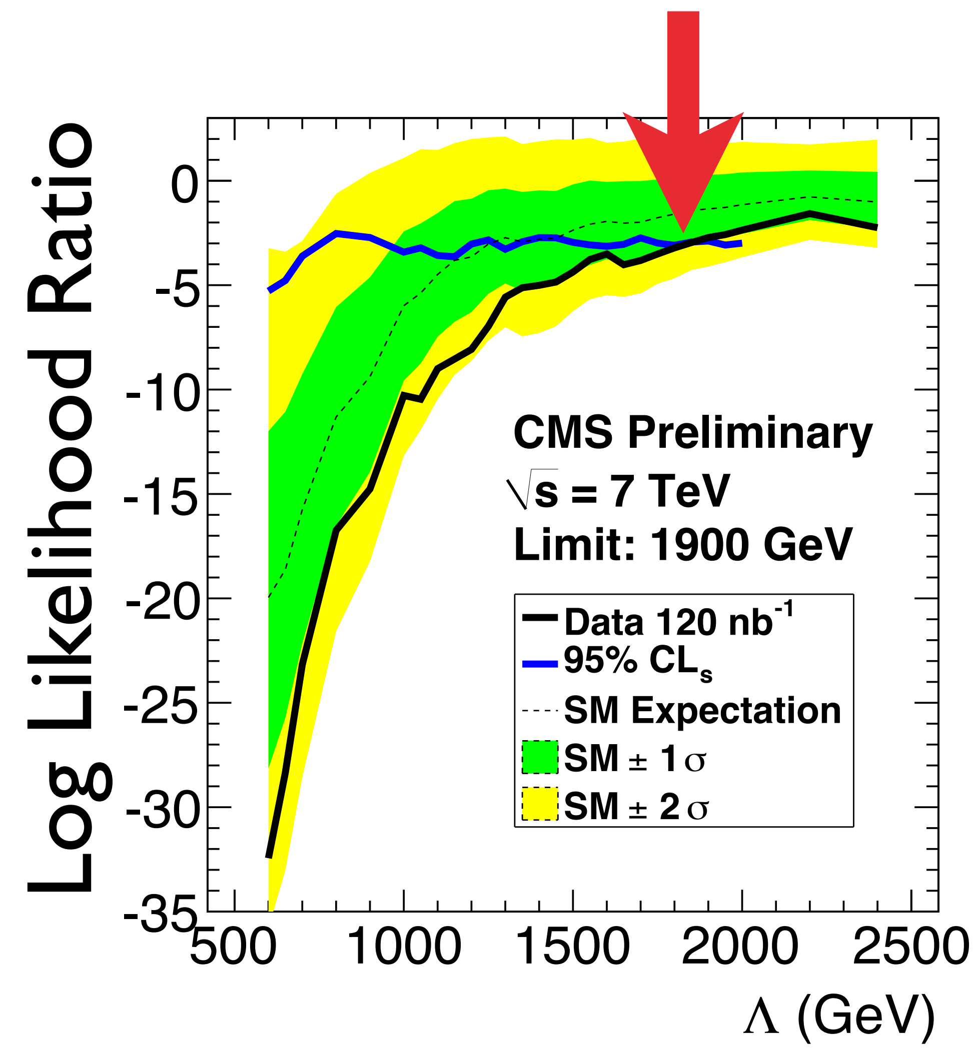




- ✦ Data compared to theory predictions.
- ✦ Important experimental uncertainties cancel because of the ratio (absolute jet energy scale, luminosity).
- ✦ NLO theory uncertainty dominated by the factorization/ renormalization scale and the non pert. correction.
- ✦ The data agree well with the NLO+non pert. correction prediction.

Limits with the Dijet Centrality Ratio

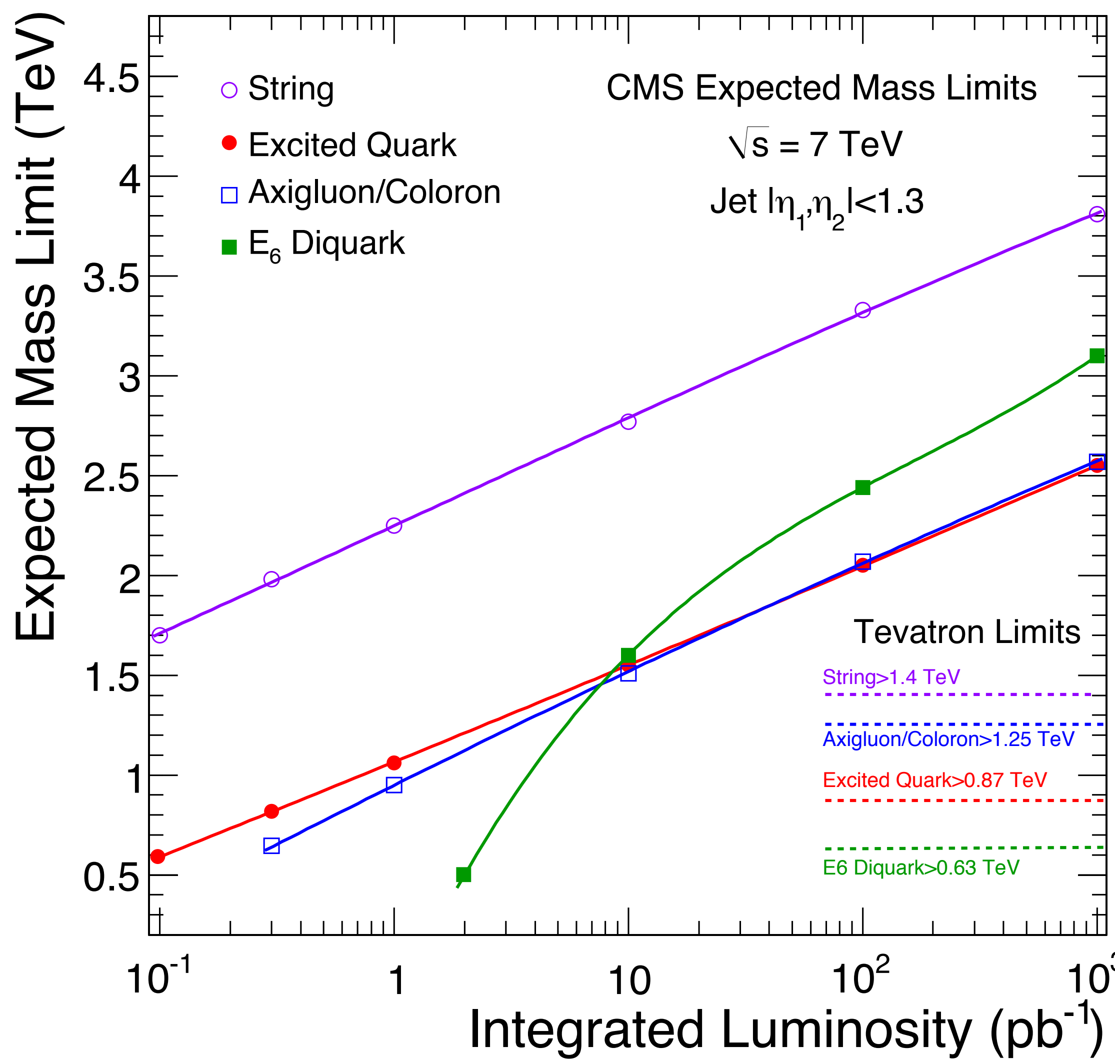




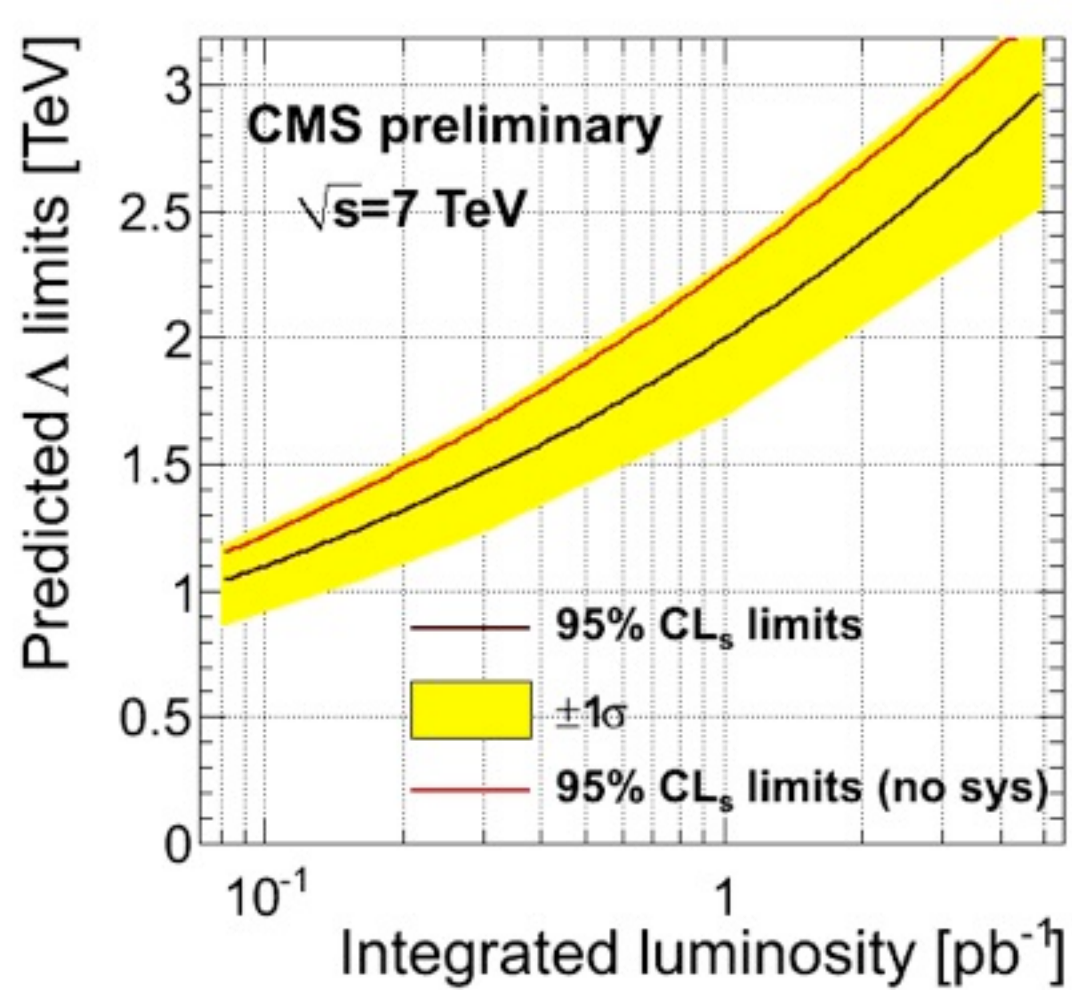
- Ratio is flat, no sign of new physics.
- Contact interaction scale excluded for **Λ<1.9 TeV** at 95% CL.
  - Tevatron excludes Λ<2.8 TeV

Future Prospects

Expected resonance mass limits from dijet spectrum



Expected contact interaction scale limits from dijet centrality ratio



- ✦ Expected limits indicate that we should reach the **Tevatron q* limit** of **870 GeV** with **400 nb^{-1}**.
- ✦ The Tevatron limit of **Λ > 2.8 TeV** (D0, 1fb^{-1}) is expected to be surpassed with **4 pb^{-1}**.
- ✦ CMS is now exploring **new territory**, beyond the Tevatron **String Resonance** limit.

Summary

✦ The dijet mass spectrum extends to **2.13 TeV** with **120 nb^{-1}** for **$|\eta_{1,2}|<1.3$**.

✦ The dijet mass spectrum is in good agreement with a full CMS simulation of QCD from PYTHIA.

✦ The dijet centrality ratio is in good agreement with the QCD perturbative prediction at NLO with non pert. corrections.

✦ We have limits on dijet resonance cross-sections, for qq, qg and gg resonances.

✦ We exclude **string resonances** with mass **M < 1.67 TeV** at 95% CL.
- Beyond the Tevatron limit of 1.4 TeV.

✦ We exclude **excited quarks** with mass **M < 0.59 TeV** and **axigluons** with mass **M < 0.52 TeV** at 95% CL.

✦ We exclude **contact interactions** for **Λ < 1.9 TeV** at 95% CL.

✦ Expected limits indicate that we should reach the **Tevatron q* limit** of **870 GeV** with **400 nb^{-1}** and surpass the **Λ > 2.8 TeV** limit with **4 pb^{-1}**.

References

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

(1) *"Search for Dijet Resonances in the Dijet Mass Distribution in pp Collisions at sqrt{s} = 7 TeV"*,
Physics Analysis Summary: EXO-10-001

(2) *"Search for New Physics with the Dijet Centrality Ratio"*,
Physics Analysis Summary: EXO-10-002

(3) *"Jet Performance in pp Collisions at sqrt{s} = 7 TeV"*,
Physics Analysis Summary: JME-10-003

(4) *"Single Particle Response in the CMS Calorimeters"*,
Physics Analysis Summary: JME-10-008

(5) *"The CMS physics reach for searches at 7 TeV"*,
CMS NOTE-2010/008

Experimental Technique

✦ Measurement of the dijet invariant mass spectrum and the dijet centrality ratio, in the fiducial region $|\eta|<1.3$, using the two highest p_T jets in an event.

✦ Comparison to the Monte Carlo (PYTHIA + CMS simulation) and perturbative QCD at NLO prediction, to check the overall agreement.

✦ Fit of the measured spectrum with a smooth function and search for resonances.

✦ Look at the dijet centrality ratio for resonance-like or compositeness-like deviations from the theory prediction.

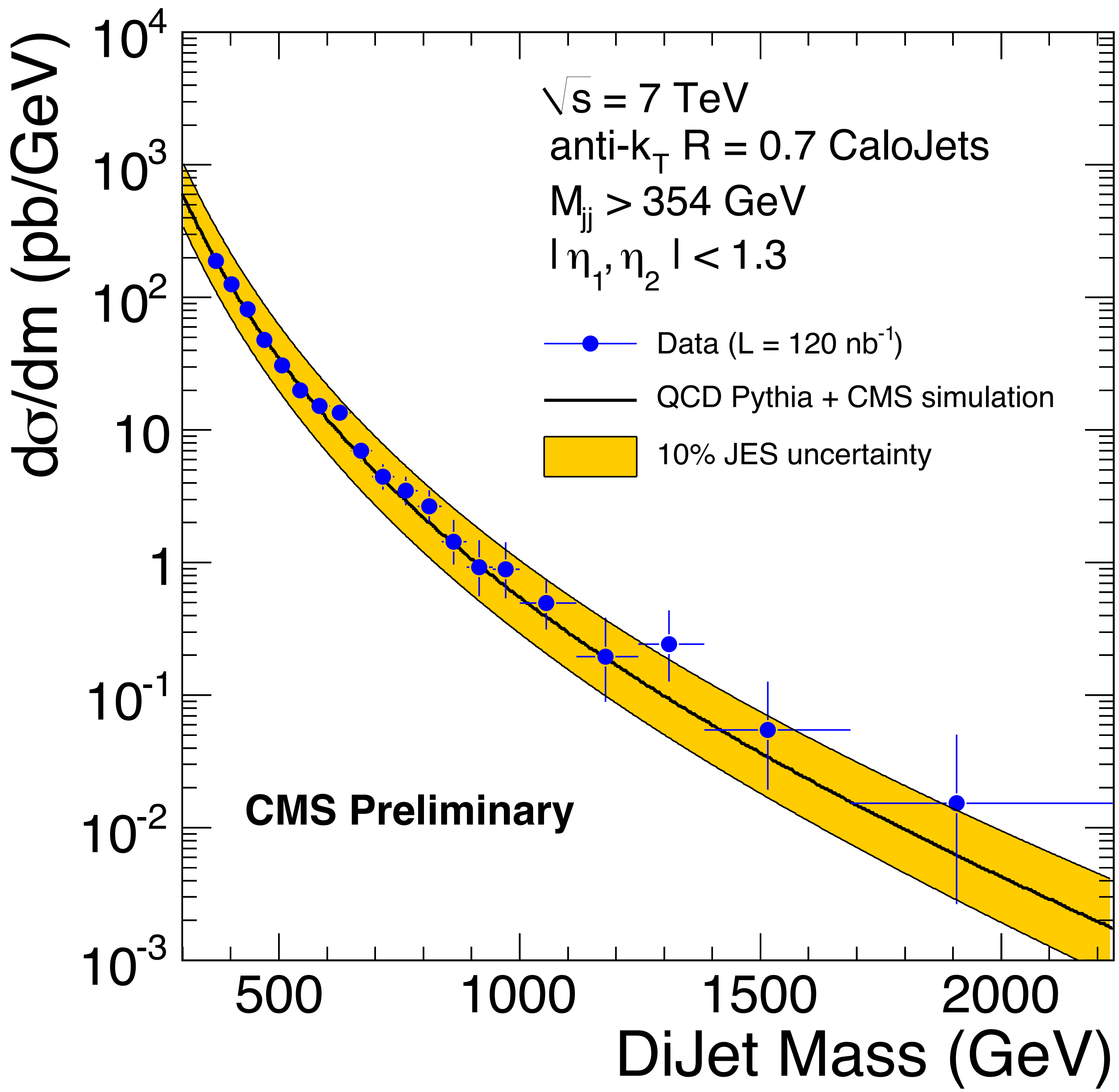
The Anti-k_T Clustering Algorithm

$$d_{ij} = min\left(k_{T,i}^{-2}, k_{T,j}^{-2}\right)\frac{\Delta R_{ij}^2}{R^2}$$

$$\Delta R_{i,j}^2 = \left(y_y - y_j\right)^2 + \left(\phi_i - \phi_j\right)^2$$

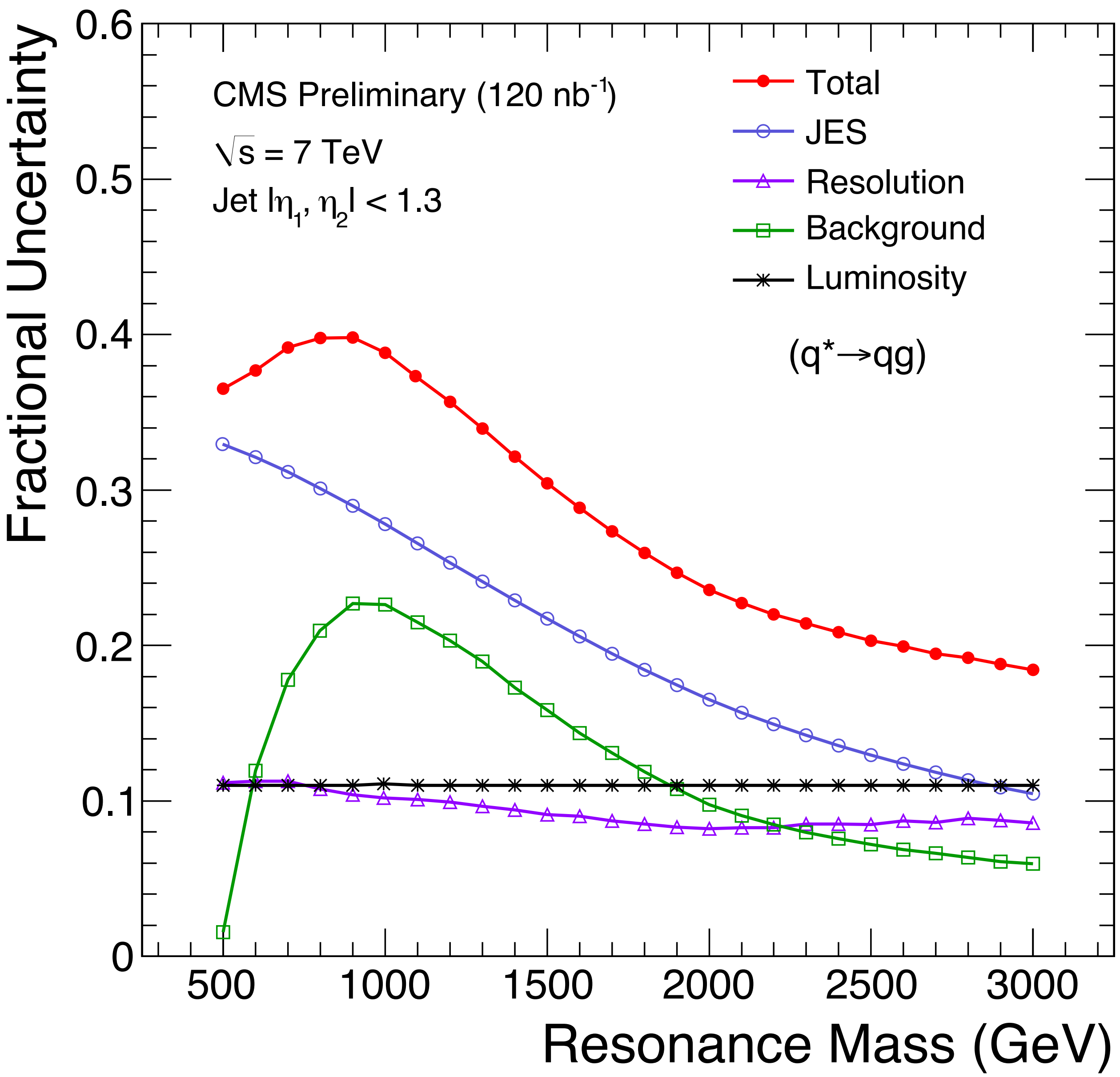
- New development in the jet clustering theory.
- Tends to cluster the energy around the hardest particles.
  - essentially behaves like a cone algorithm giving perfectly round jet areas
- Belongs to the "k_T" family.
  - merging of 4-vector pairs based on transverse momentum weighted distance in y-φ plane.
  - the clustering terminates when the weighted distance between particles is greater than a specific value **R** (resolution parameter).
  - the quantity **R** is of the order of unity.
- infrared and collinear safe (suitable for theory calculations).

Dijet Mass Spectrum in Coarse Bins



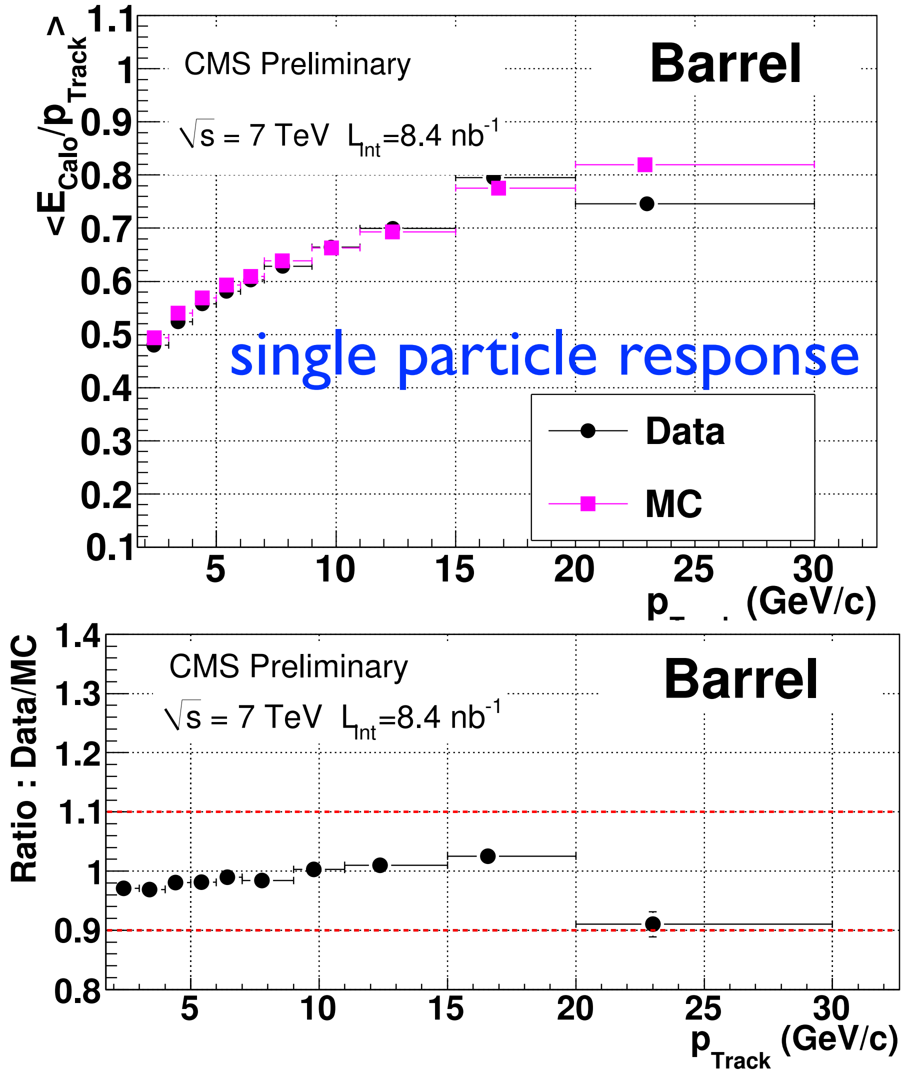
- We combine the fine mass bins at high mass to eliminate bins with 0 events.
  - the horizontal position of the points is found using the QCD spectrum.
  - this provides the fairest comparison between QCD and the data.
  - but these mass bins are too coarse to be used for resonance search.

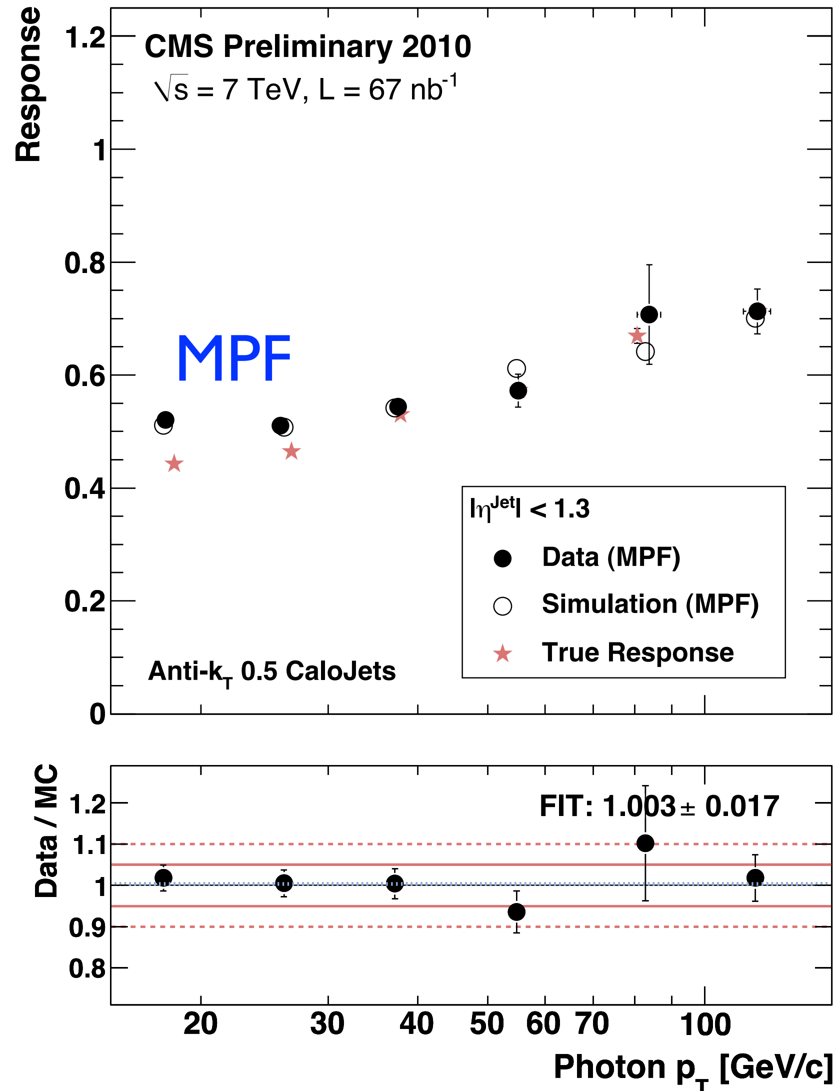
Uncertainties on the Cross-Section Limits

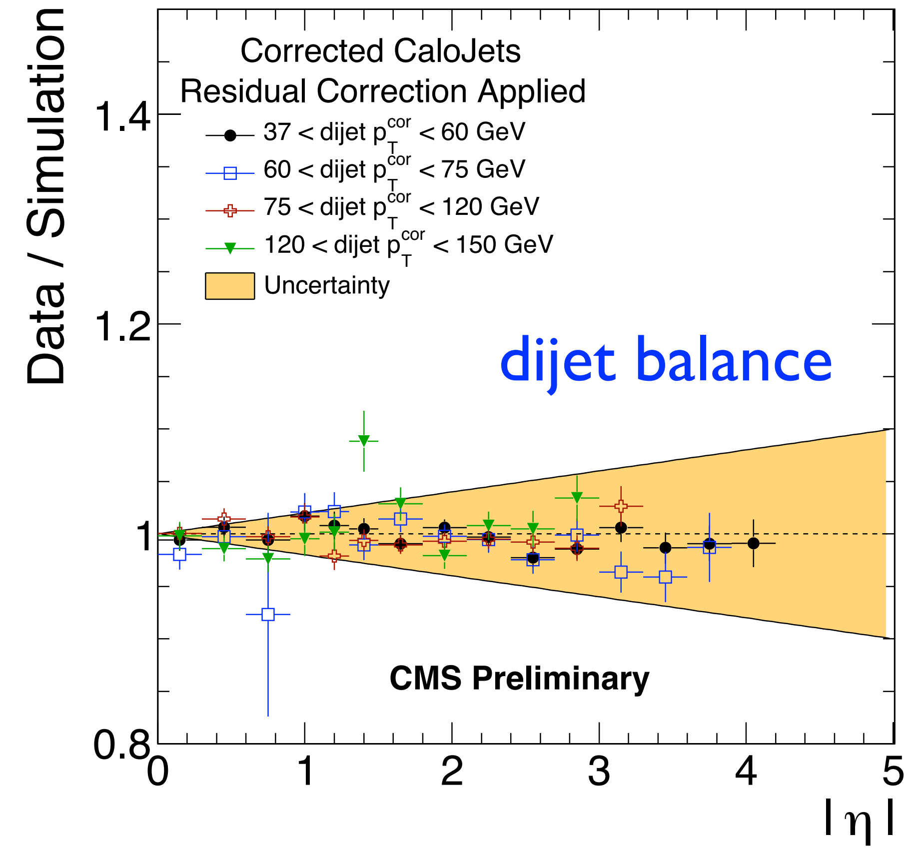


- ✦ Sources of systematic uncertainty
  - Jet Energy Scale
  - Jet Energy Resolution
  - Background Parametrization
  - Luminosity
- ✦ Total systematic uncertainty on the cross section limit varies between 16% and 43% depending on resonance mass and type.
- ✦ JEC is the dominant systematic uncertainty.
- ✦ We include the total systematic uncertainty in the limit using a conservative convolution technique.
  - This increases our cross section limits between 10% and 38% depending on resonance mass and type.

Jet Energy Scale







- ✦ Preliminary measurement of the single particle response indicates that the data vs MC agreement is better than 3% in the barrel.
  - ‣ the level of accuracy of the single particle response simulation, shows that the assigned 10% JES uncertainty is safe.
- ✦ Preliminary measurement of the jet energy response using the MPF method shows good agreement between data and MC.
- ✦ Direct measurement of the relative jet energy scale with dijet p_T balance shows that the uncertainty of the relative scale across η is less than 2%.