Search for Dijet Resonance in 7 TeV pp Collisions at CMS

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Search for Dijet Resonance

- A MC based analysis was done for 10 TeV collisions and a CMS reviewed paper (*PAS QCD 2009-006)* and an analysis note (*CMS AN-2009/070*) were written.
- The results based on **120 nb^{-1}** (*PAS EXO 2010-001*) were approved for ICHEP 2010
- The results based on **836 nb^{-1}** data (*PAS EXO 2010-010*) were approved for HCP 2010
- The results based on **2.88 pb^{-1}** data have been accepted by PRL and it will cover my Ph.D. thesis.

✓ http://arxiv.org/abs/1010.0203

✓ It is the first search and jet paper of CMS.

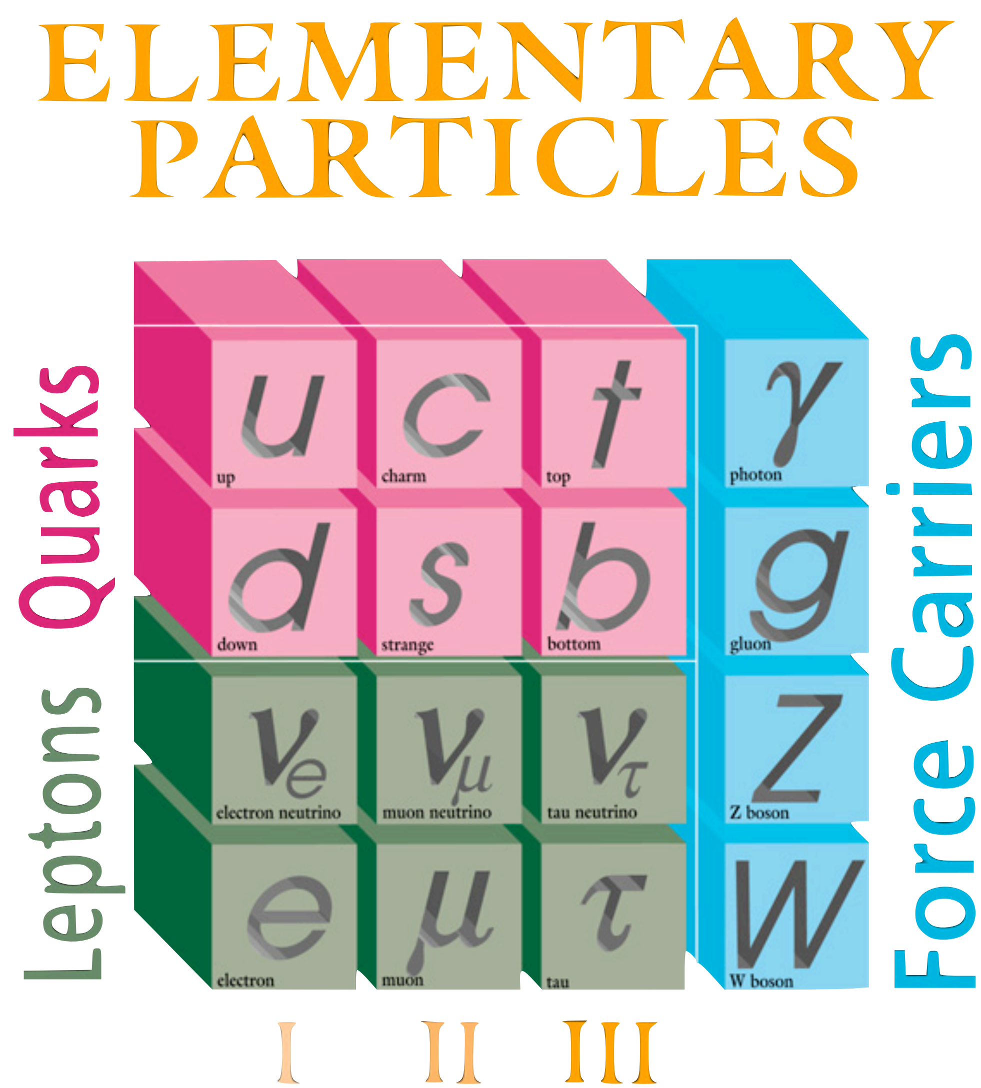
Outline

- Motivation
- Measurement of Dijet Mass Spectrum
  - ✓ Data Sample and Event Selection
  - ✓ Trigger Efficiency and Basic Distributions
  - ✓ Dijet Mass Distribution and QCD
  - ✓ Fits for Background
- Search for Dijet Resonance
  - ✓ Signal Modeling
  - ✓ Largest Fluctuation in Data
  - ✓ Limits on Dijet Resonances
    - Statistical Error Only
    - Including Systematic Uncertainties
- Results
- Conclusion

Part I.
Motivation

Standard Model and Beyond

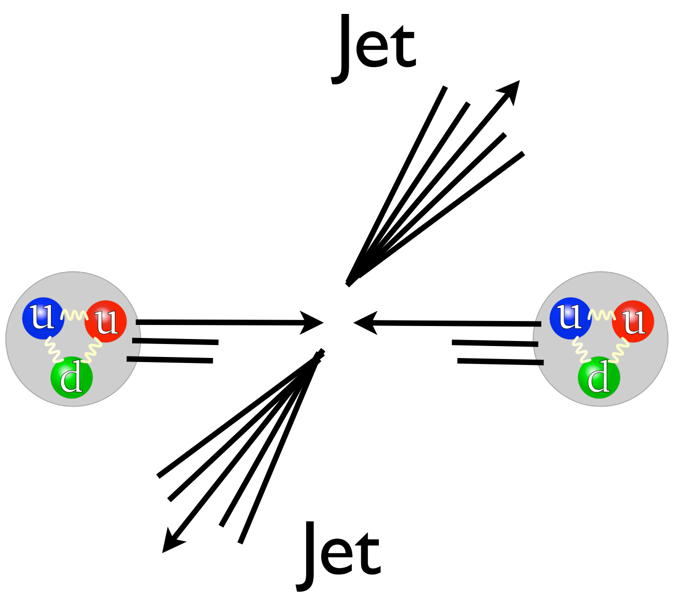
- In terms of Standard Model,
  - ✓ 6 quarks & 6 leptons
    - u and d quarks and electron make matter
  - ✓ 4 force carrying particles (ϒ, W, Z and g)
- The Standard Model raises questions.
  - ✓ Why three nearly identical generations of quarks and leptons?
  - ✓ What causes the flavor differences within a generation?
  - ✓ How do we unify the forces?
- These questions suggest there will be new physics beyond the Standard Model.
- We will search for new physics with Dijets.

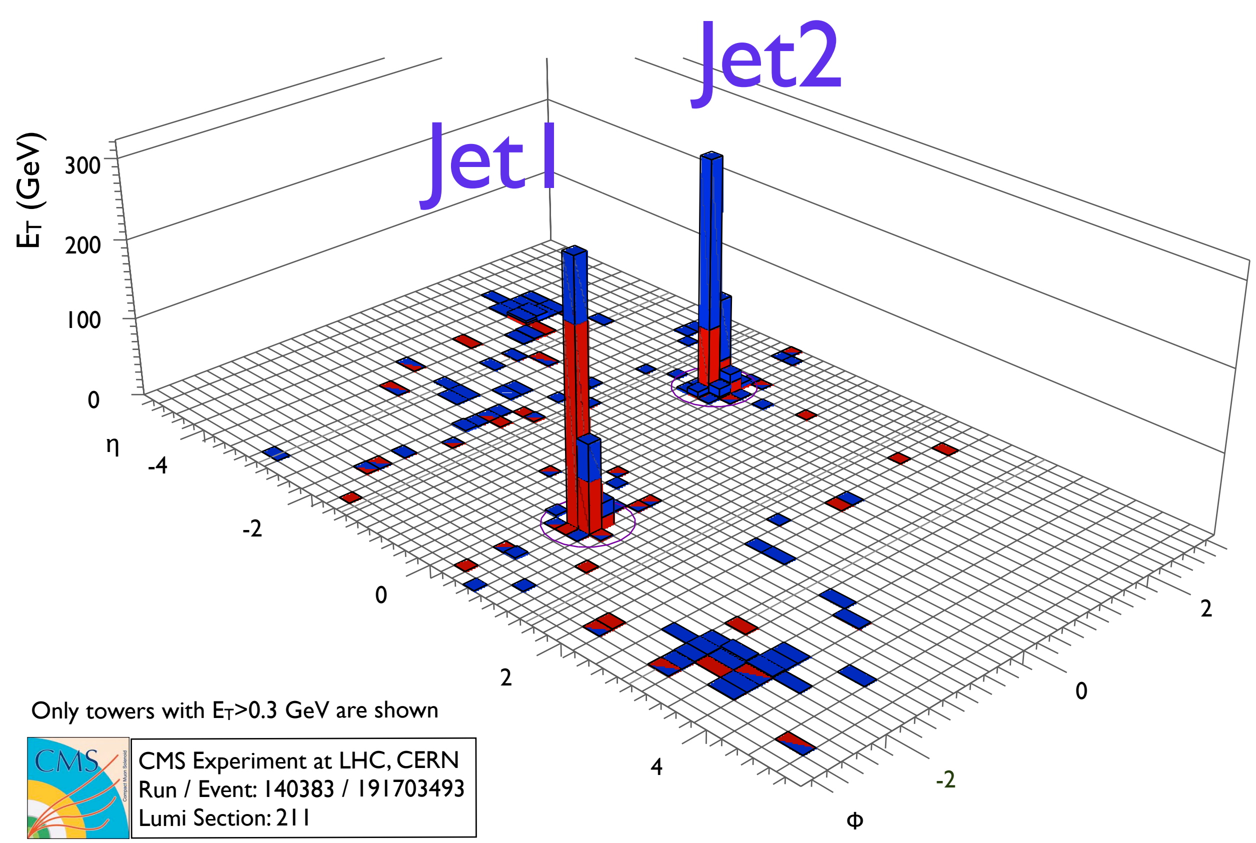


Dijet in Standard Model

- What is a Dijet?
  - ✓ Dijet results from simple 2→2 scattering of "partons", dominant process
  - ✓ The final state partons become jets of observable particles
    - Jet is the experimental signature of a parton, materialized as a spray of highly collimated hadrons.
  - ✓ Dijet is the two leading jets in an event.
- Dijet Mass from final state

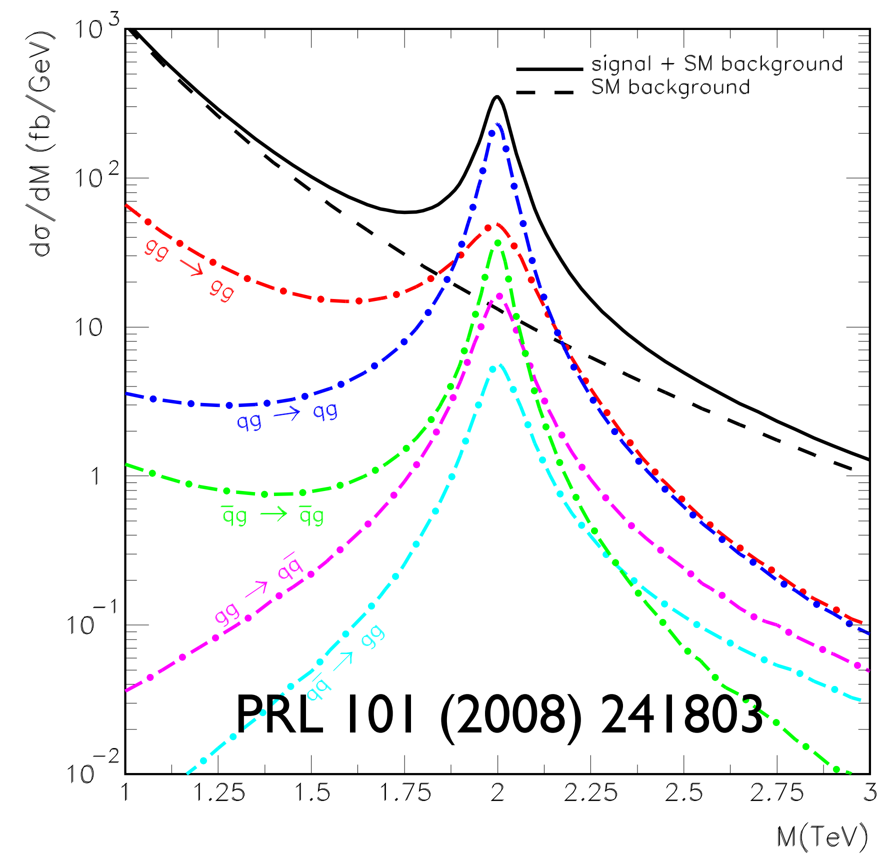
$$m = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$



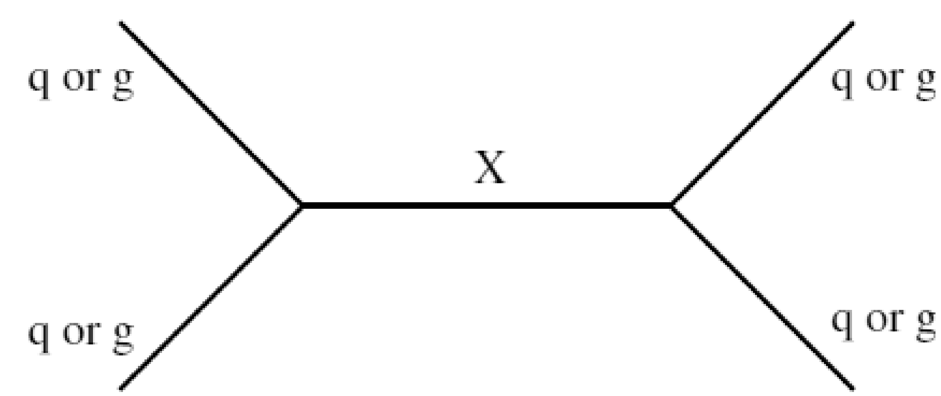


Dijet Resonance Models

Model Name	X	Color	J^P	$\Gamma/(2M)$	Chan
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
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	$q\bar{q}$
String	S	mixed	mixed	0.003 – 0.037	$q\bar{q}$, gg and qg



- We search for the new particles in "Dijet Mass" spectrum
  - ✓ If a resonance exists, it can show up as a bump in Dijet Mass spectrum
- The models which are considered in this analysis are listed.
  - ✓ Produced in "s-channel"
  - ✓ Parton-Parton Resonaces
    - Observed as dijet resonances.
- Search for model with narrow width Γ.



Experimental Technique

- Measurement of dijet mass spectrum
- Comparison to PYTHIA QCD Monte Carlo prediction
- Fit of the measured dijet mass spectrum with a smooth function and search for resonance signal (bump)
- If no evidence, calculate model independent cross section upper limit and compare with any model cross section.

Part II.
Measurement of Dijet Mass Spectrum

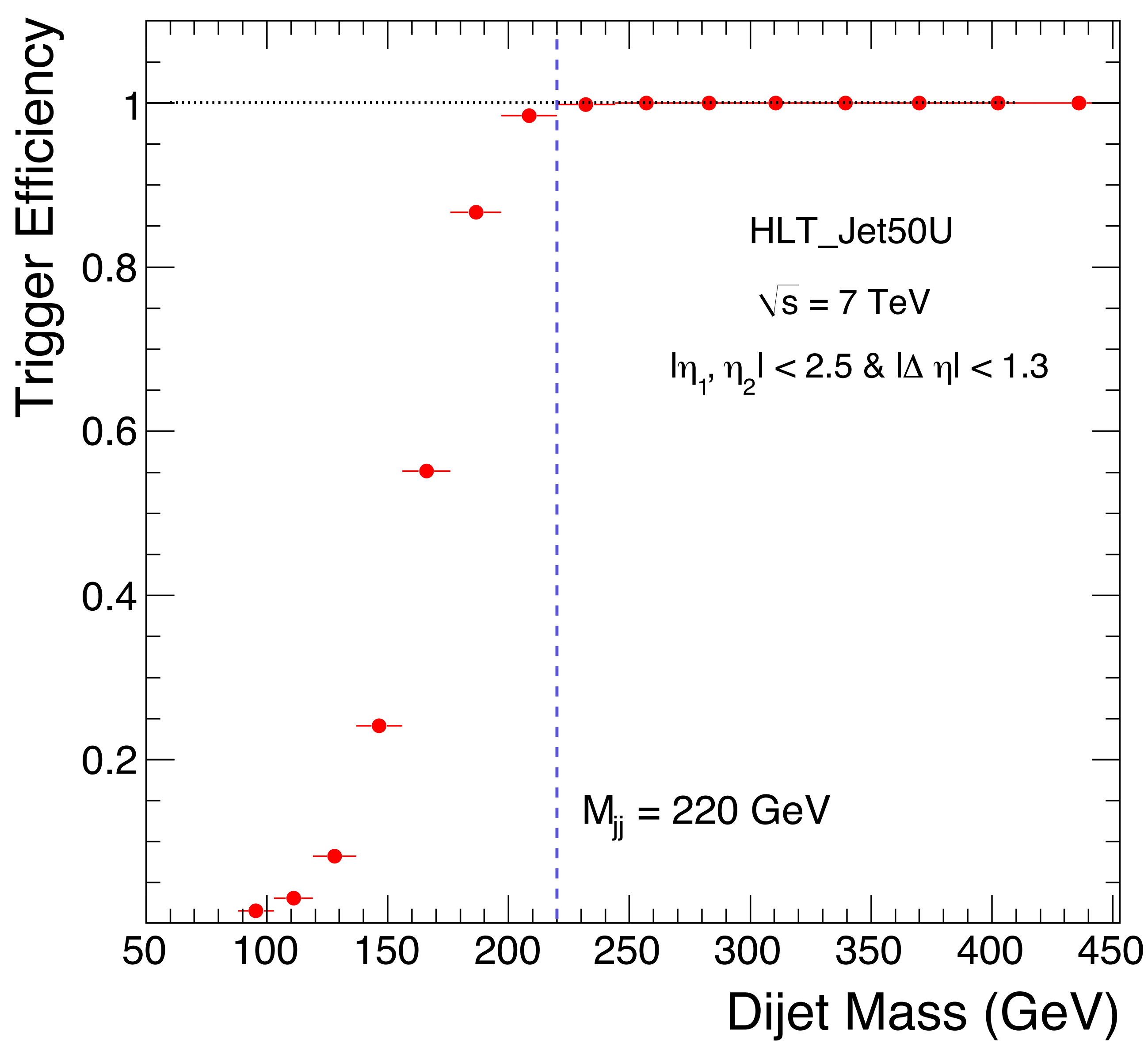
Data and Event Selection

- Dataset
  - ✓ `JetMETTau/*/RECO` and `JetMET/*/RECO`
  - ✓ Official JSON Files
  - ✓ Estimated Integrated Luminosity: 2.875 pb^{-1} (with 11% uncertanity)
- Trigger
  - ✓ Technical Bit TT0 (for bunch crossing)
  - ✓ HLT_Jet50U (un-prescaled)
- Event Selection
  - ✓ Good primary vertex
  - ✓ At least two reconstructed jets
    - AK7caloJets
    - JEC: L2+L3, "Summer10" + Residual data-driven relative
  - ✓ Require both the leading jets to satisfy $|\eta|< 2.5$ and $|\Delta\eta|<1.3$
    - Suppress QCD process significantly.
  - ✓ Require both leading jets passing the "loose" jet id & Mjj > 220 GeV

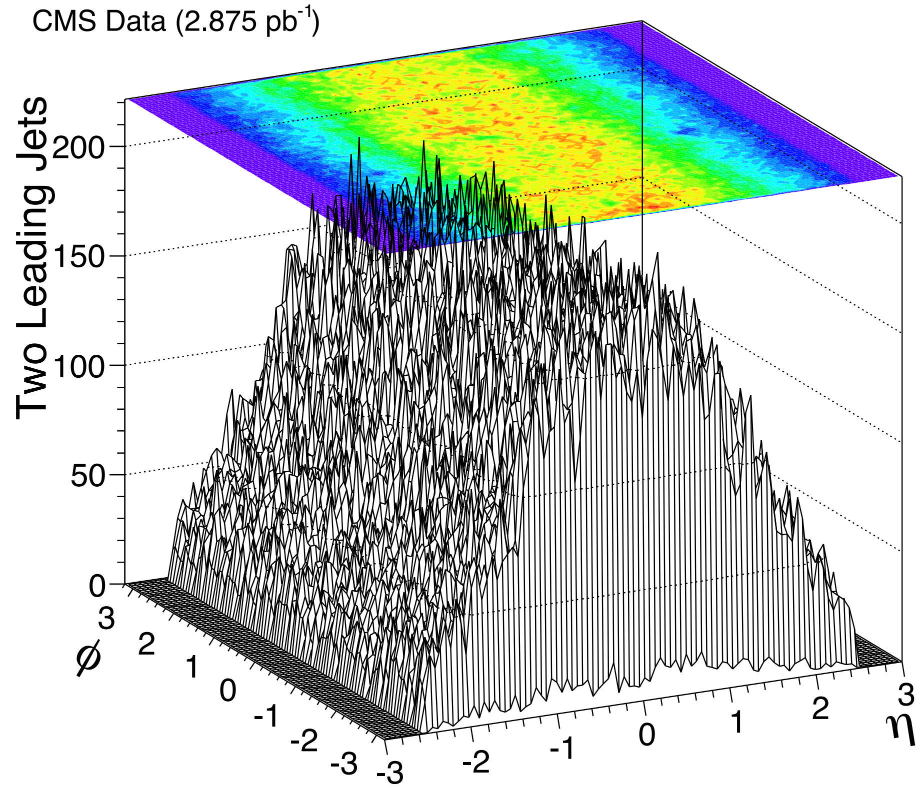
	Events
Events after pre-selection cut	6126910
Events after vertex cut	6125930
Events after dijet eta cuts	2088922
Events after dijet mass cut	414645
Events after jet id cut	414131

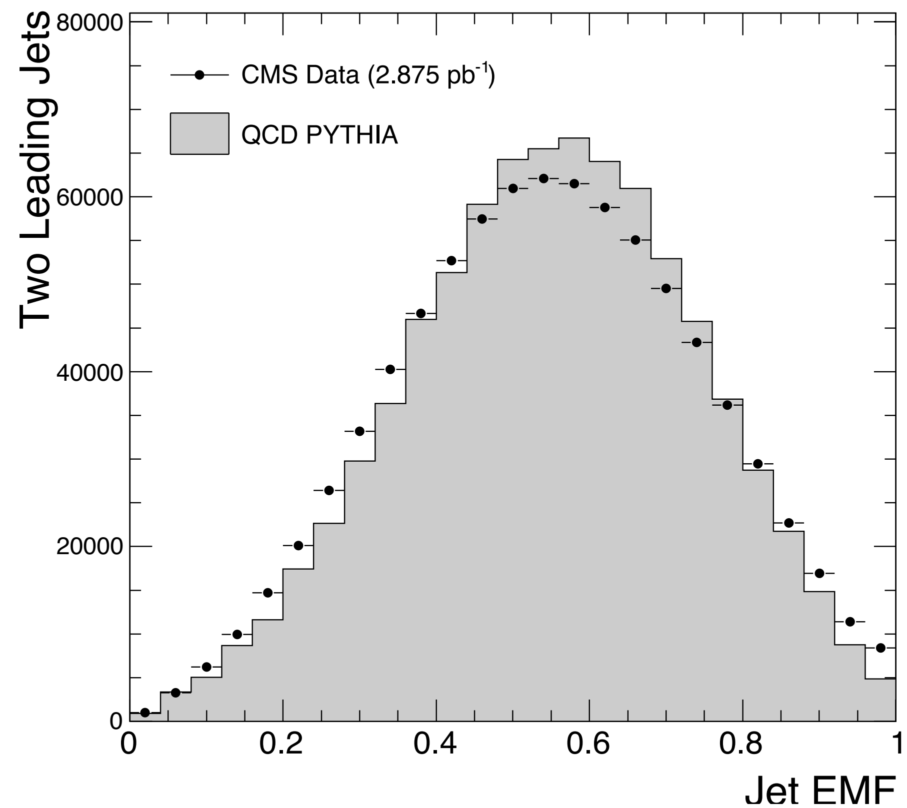
Trigger Efficiency

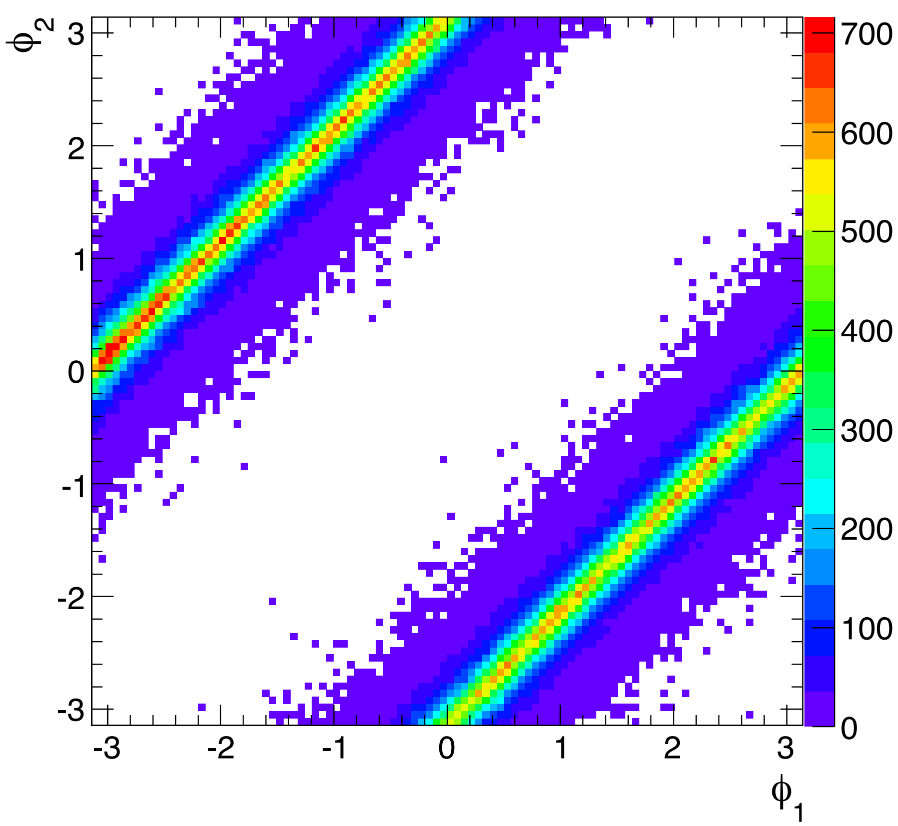
- Start analysis of Dijet Mass distribution at 220 GeV.
  - ✓ 220 GeV chosen for full trigger efficiency.

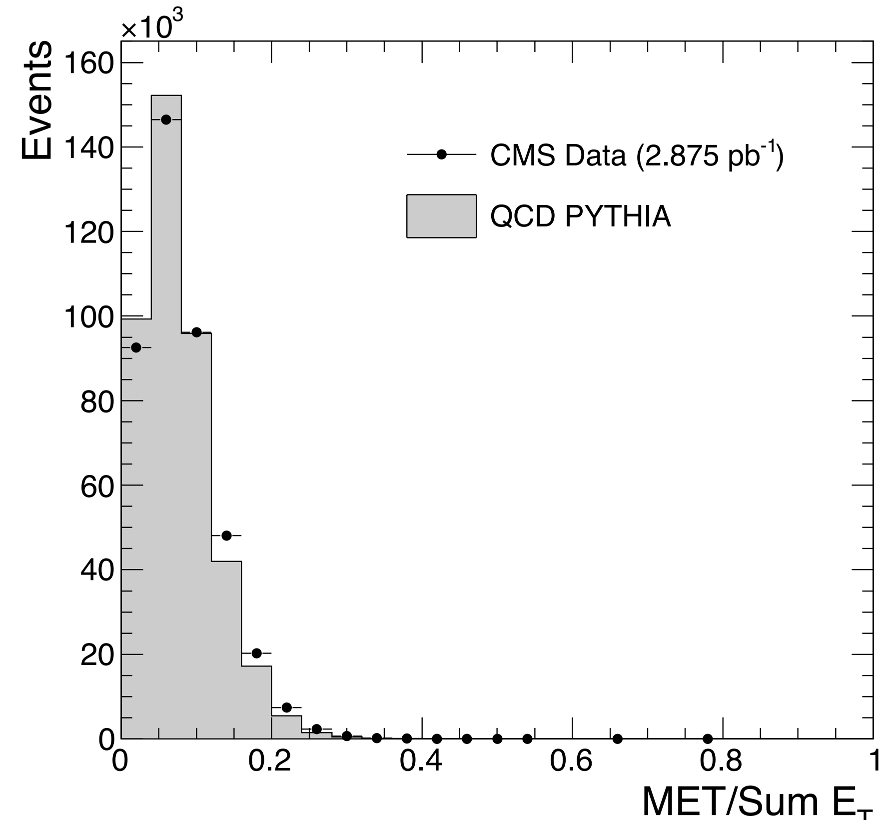


Dijet Data Quality

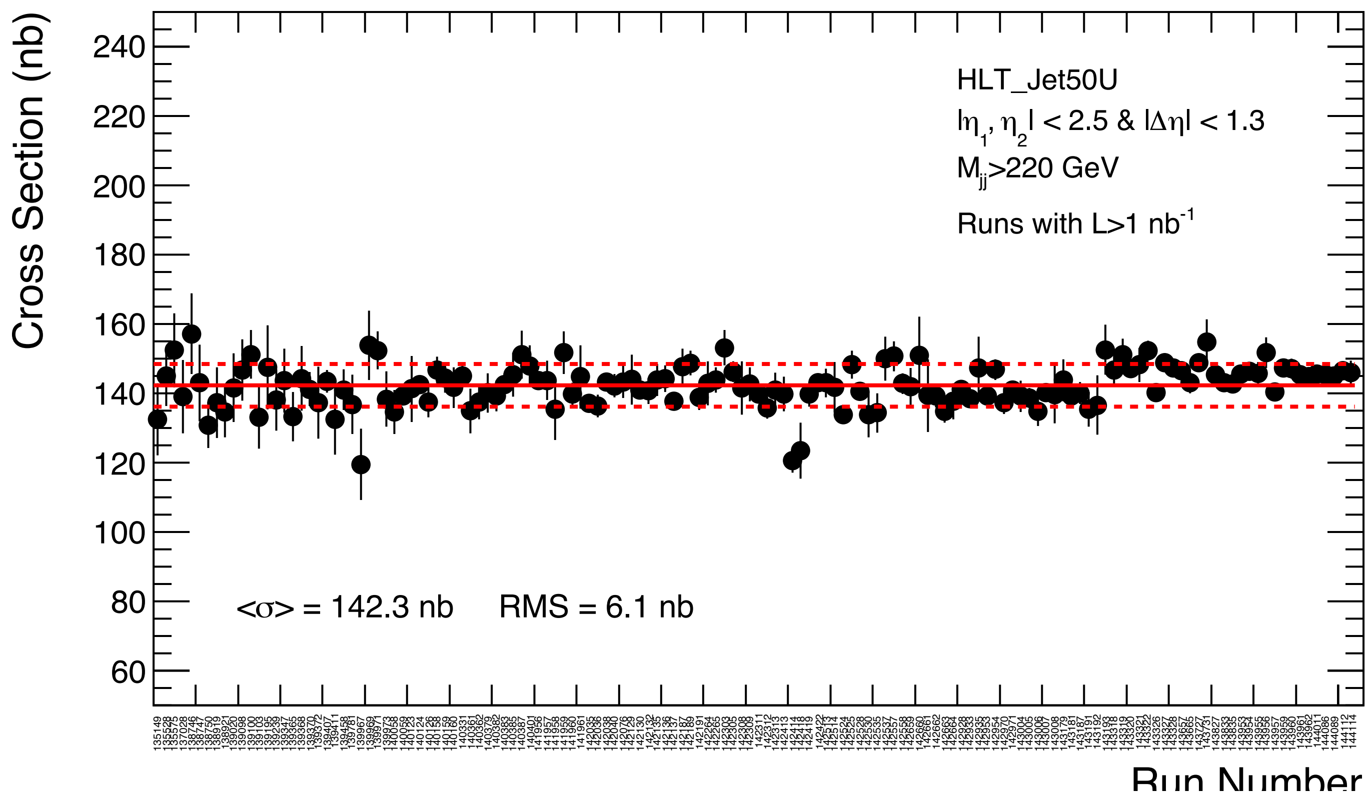


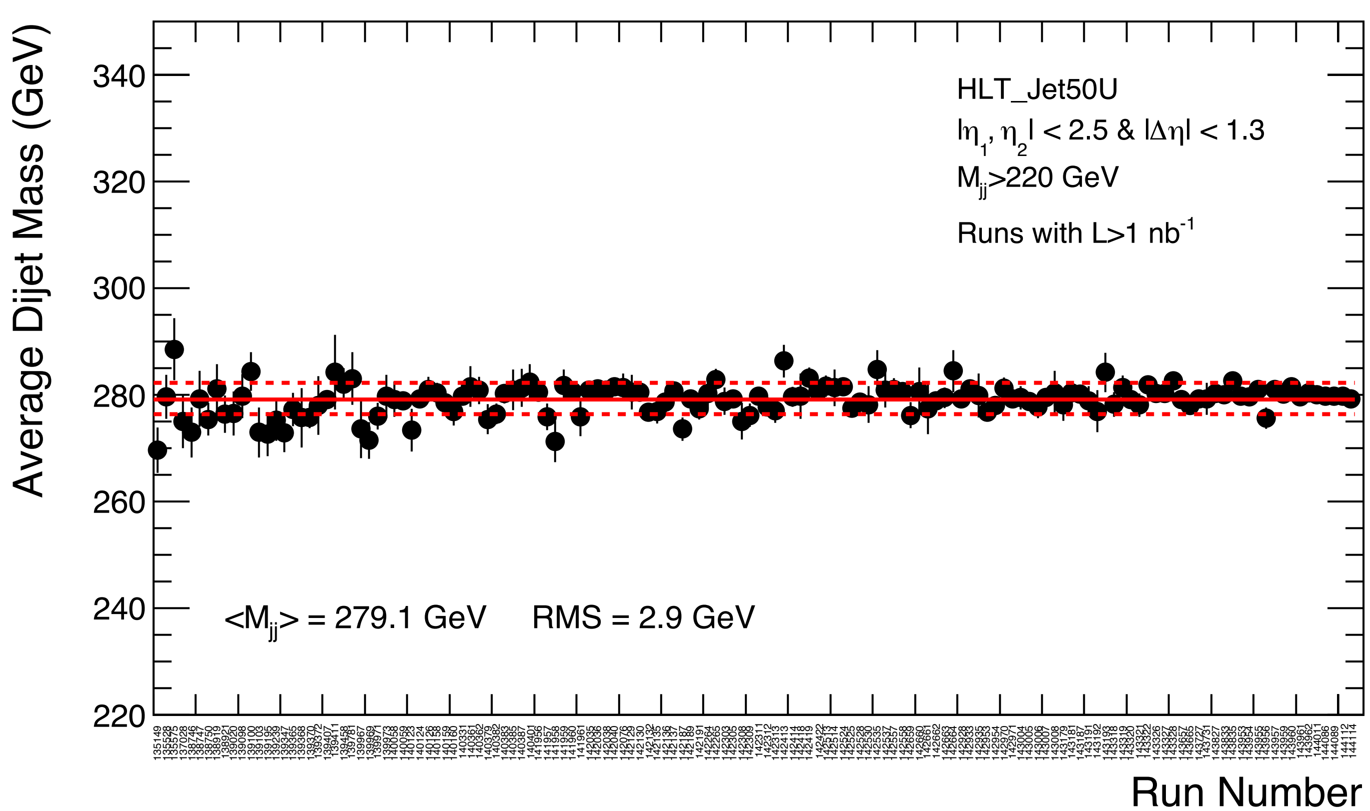






Dijet Data Stability

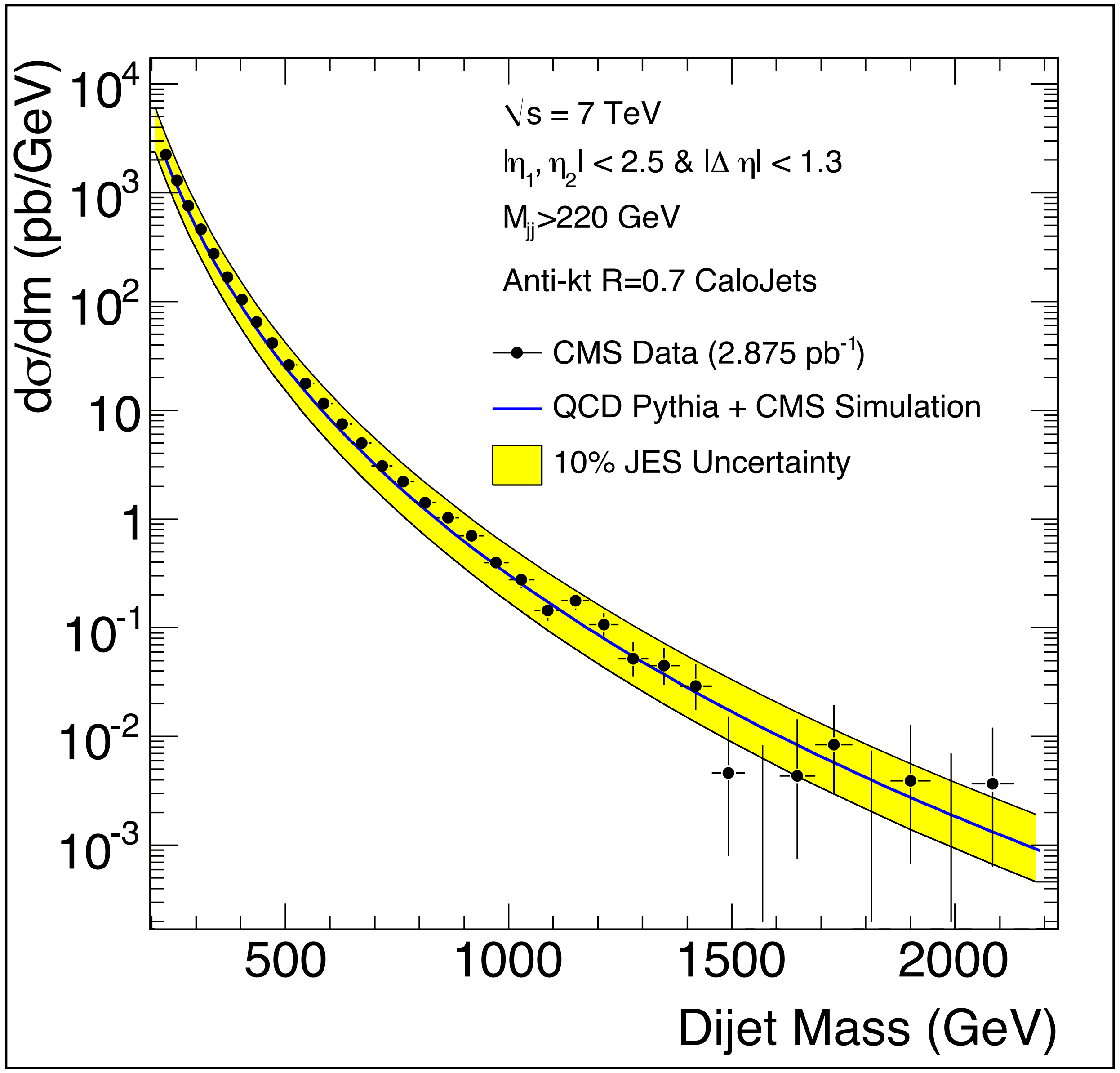


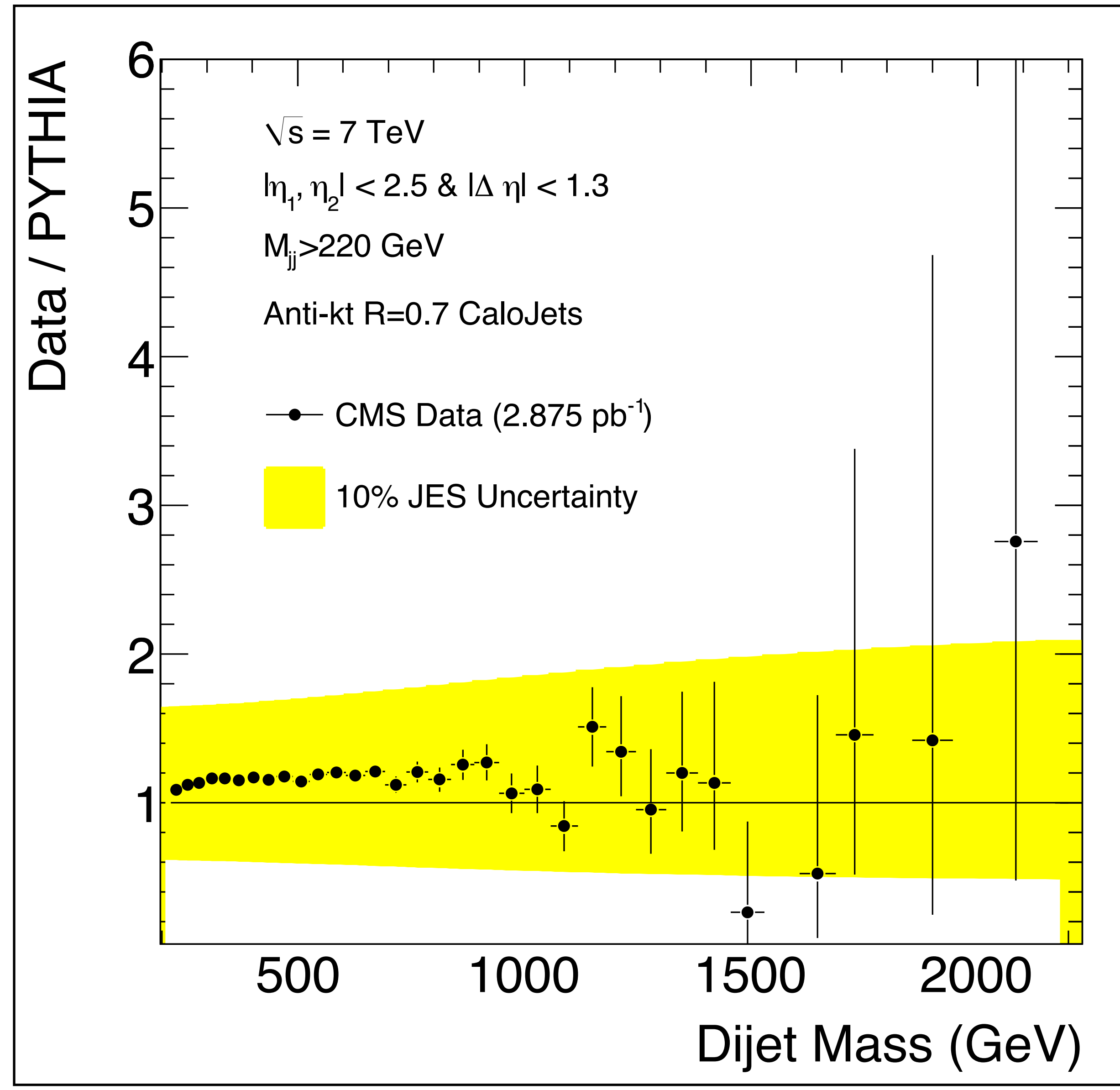


- Average dijet mass and observed cross section for each runs are shown.
- There is a good stability.
- The observed cross section stability is an indication of a stable calorimeter energy scale and luminosity evaluation.

Dijet Mass and QCD

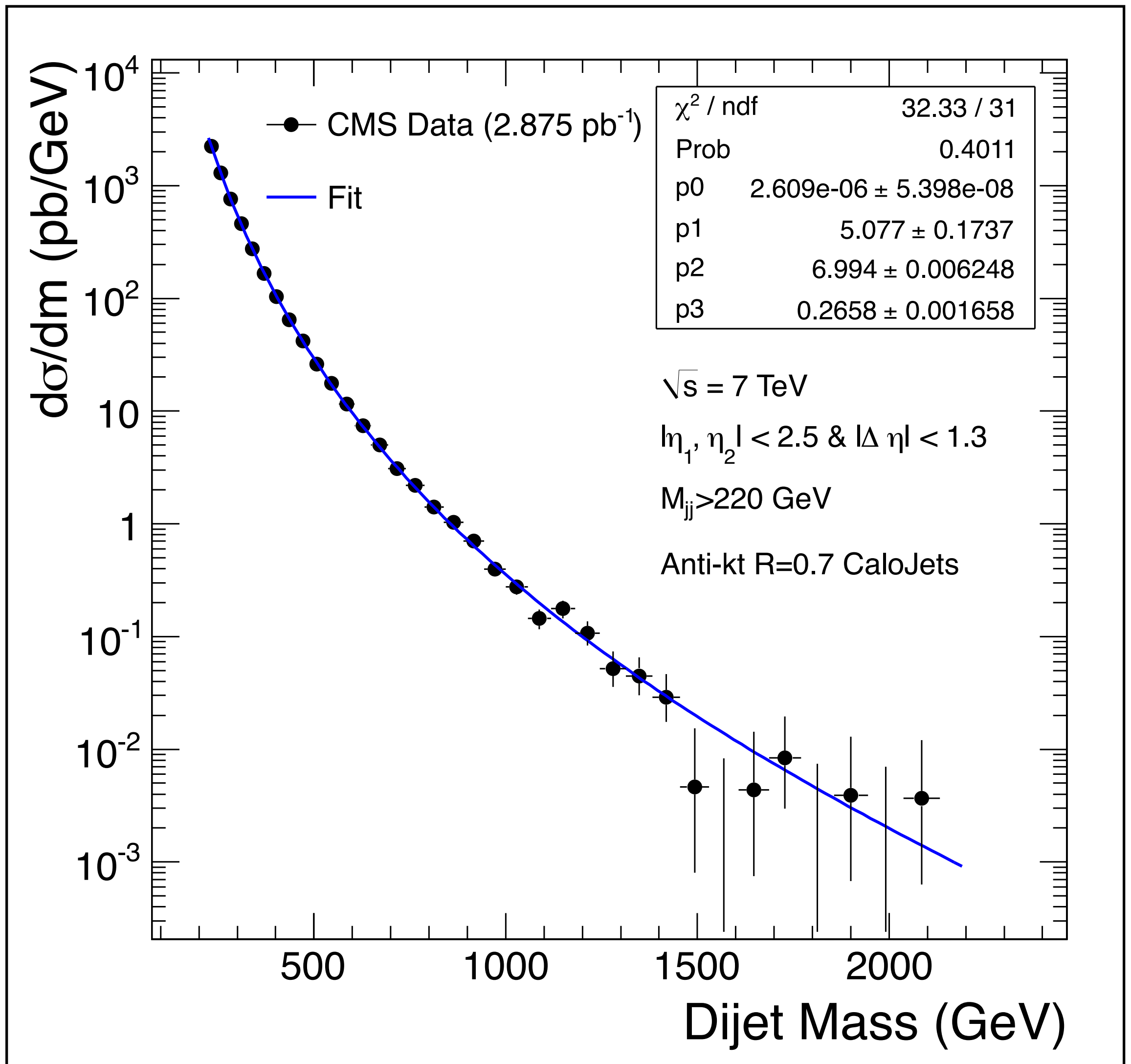
- The data is in good agreement with the full CMS simulation of QCD from PYTHIA.

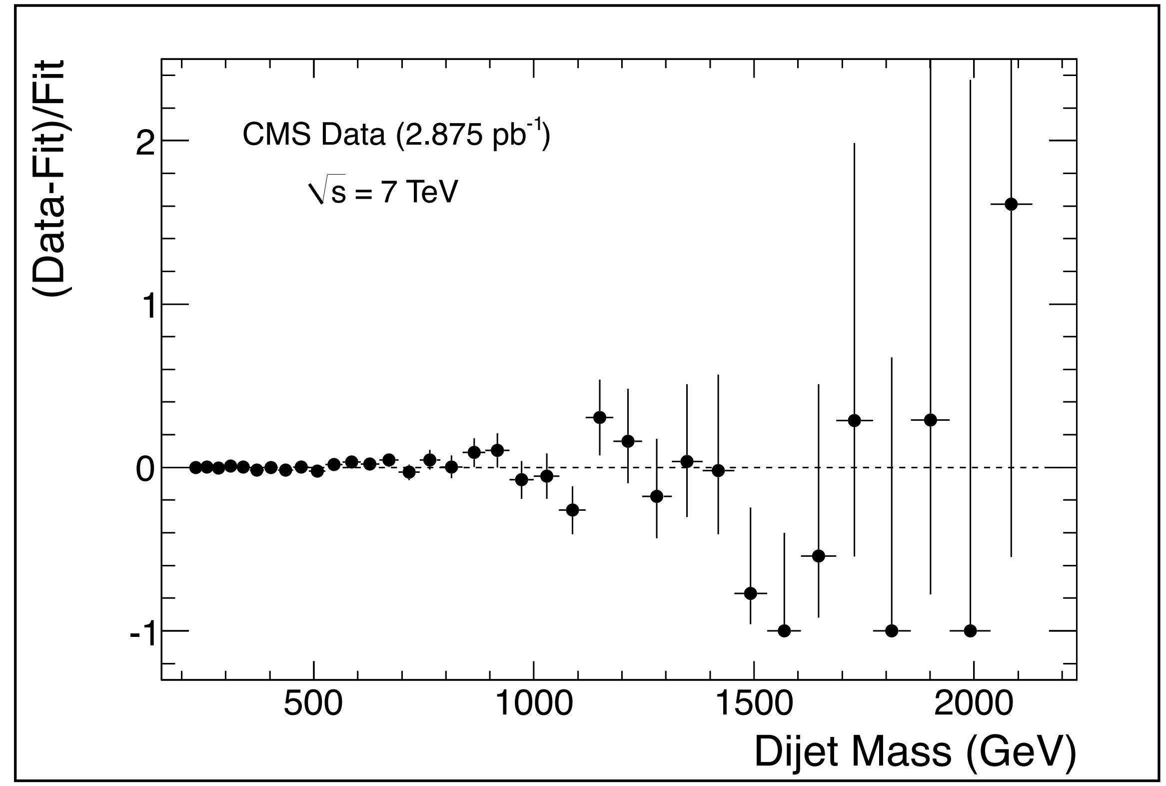


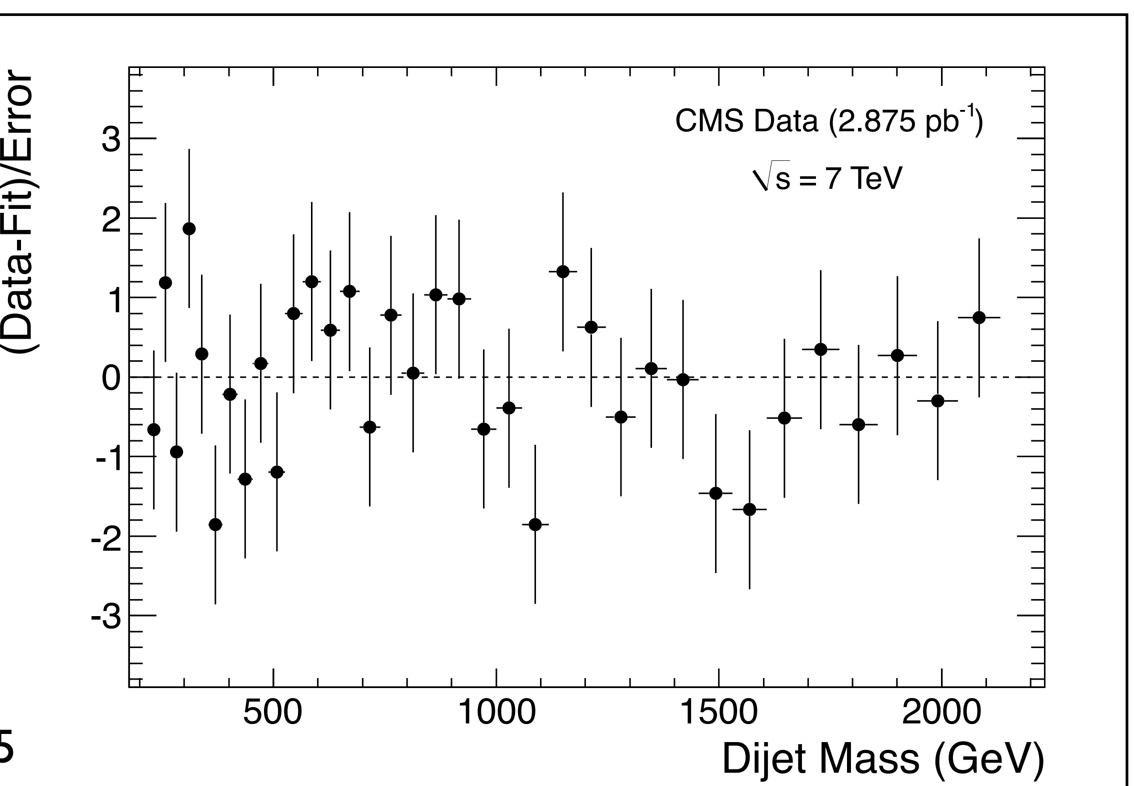


Dijet Mass and Fit

- We fit the data to a function containing 4 parameters used by CDF Run II and ATLAS.
- We get a good fit.
- No evidence for new physics

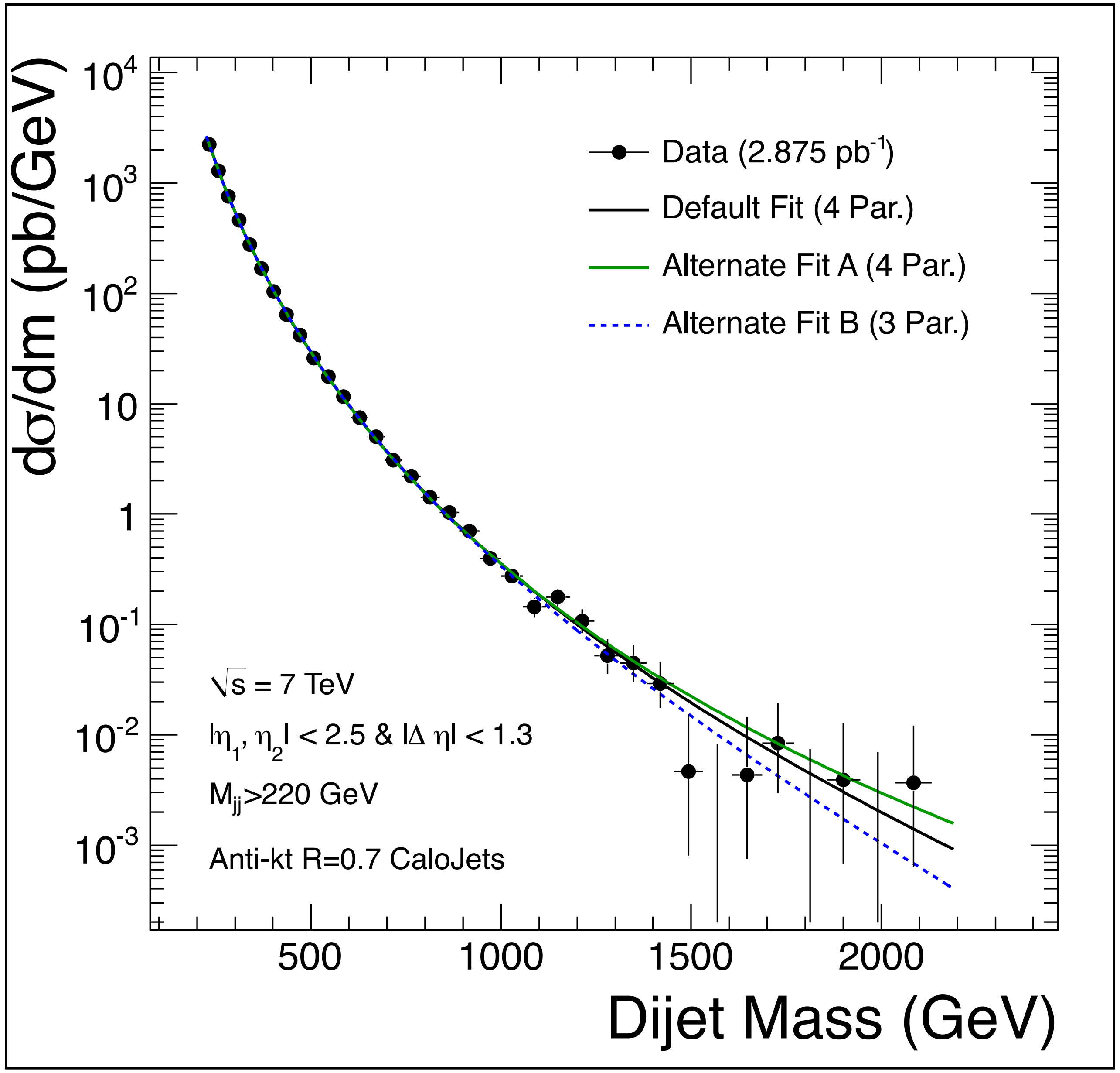






$$\frac{d\sigma}{dm} = p_0 \frac{(1-X)^{p_1}}{X^{p_2+p_3\ln(X)}} \qquad x = m_{jj}/\sqrt{s}$$

Another Fit Parametrization



- In addition to the default fit, two alternate functional forms are considered.
- Default 4 parameters fit gives the best results.

χ^2/NDF for Default Fit: 32.3 / 31
χ^2/NDF for Fit A: 36.8 / 31
χ^2/NDF for Fit B: 39.3 / 32

Default
$$\frac{P_0 \cdot (1 - m/\sqrt{s})^{p_1}}{(m/\sqrt{s})^{p_2 + p_3 ln(m\sqrt{s})}}$$

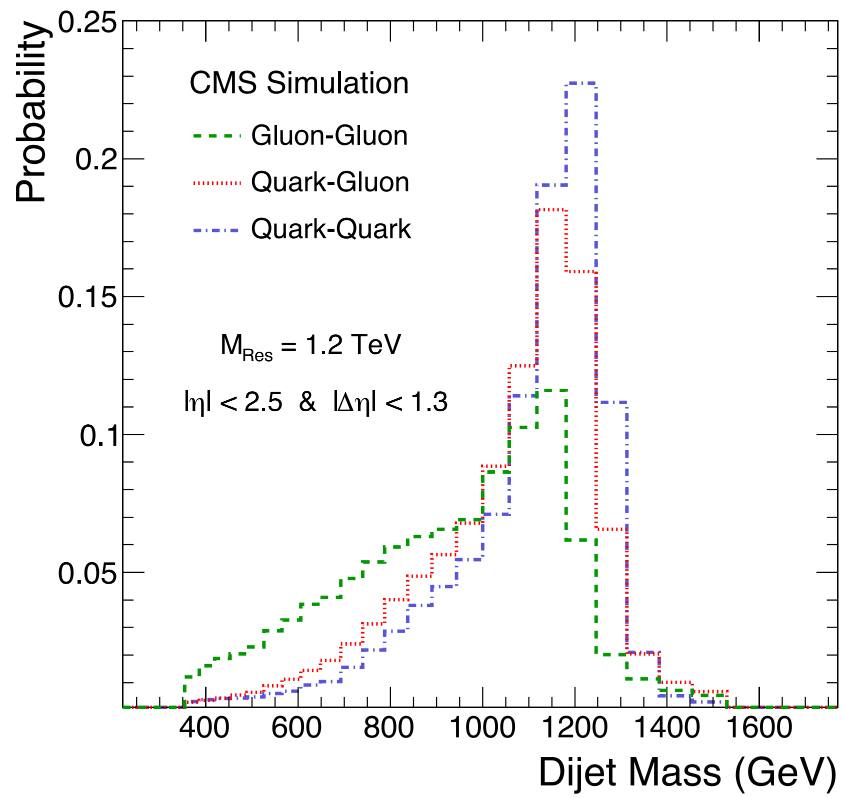
Fit A
$$\frac{P_0 \cdot \left(1 - m/\sqrt{s} + P_3 \cdot (m/\sqrt{s})^2\right)^{P_1}}{m^{P_2}}$$

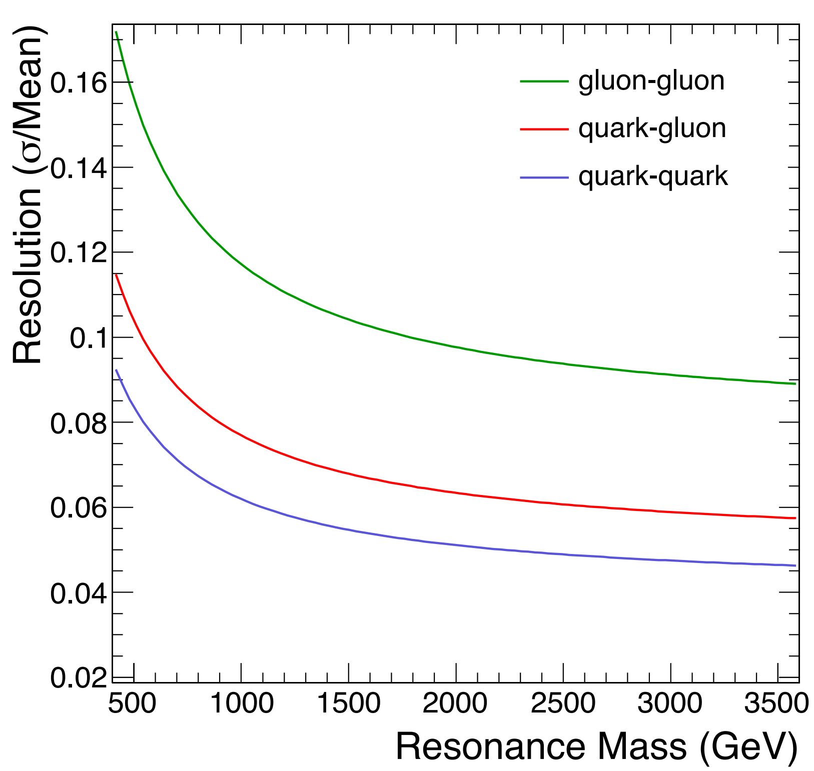
Fit B
$$\frac{P_0 \cdot (1 - m/\sqrt{s})^{P_1}}{m^{P_2}},$$

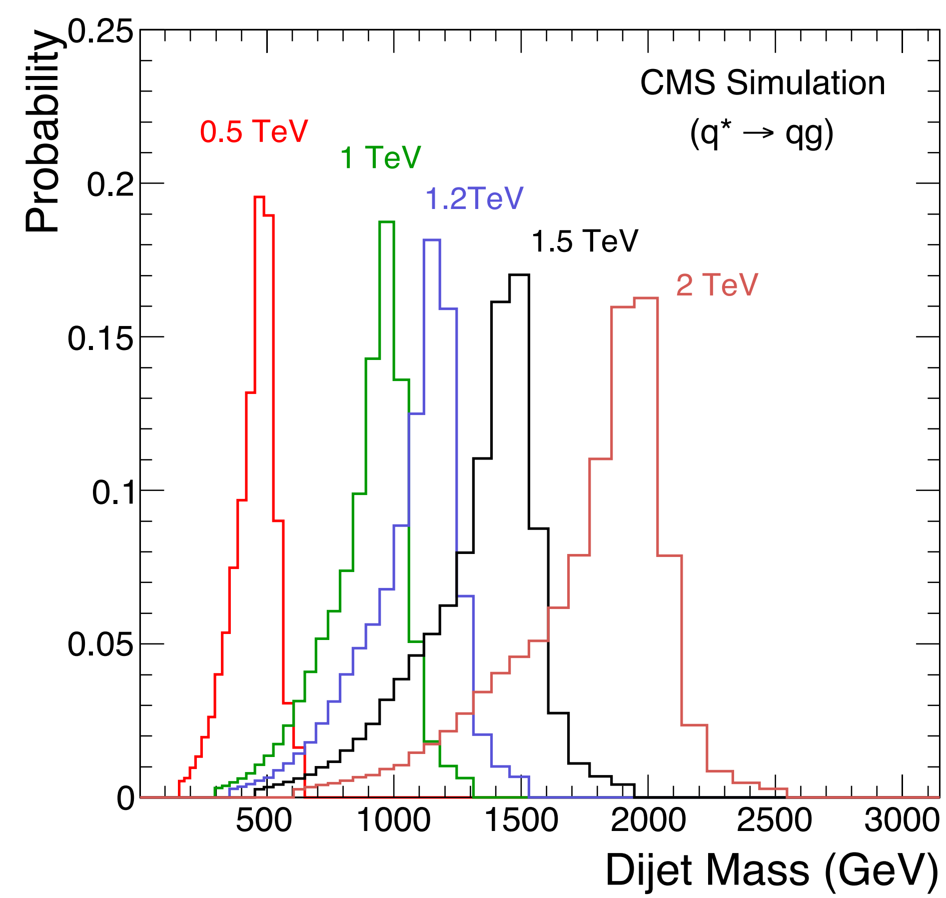
Part III.
Search For Dijet Resonance

Resonance Shapes

- We have simulated dijet resonances using CMS simulation + PYTHIA.
  - ✓ Three types of parton pairs
    - **gg→G→gg**, **qg→q*→qg** and **qq→G→qq**
- qq, qg and gg resonances have different shape mainly due to FSR.
  - ✓ The width of dijet resonance increases with number of gluons because gluons emit more radiation than quarks.
- We search for these three basic types of narrow dijet resonance in our data.

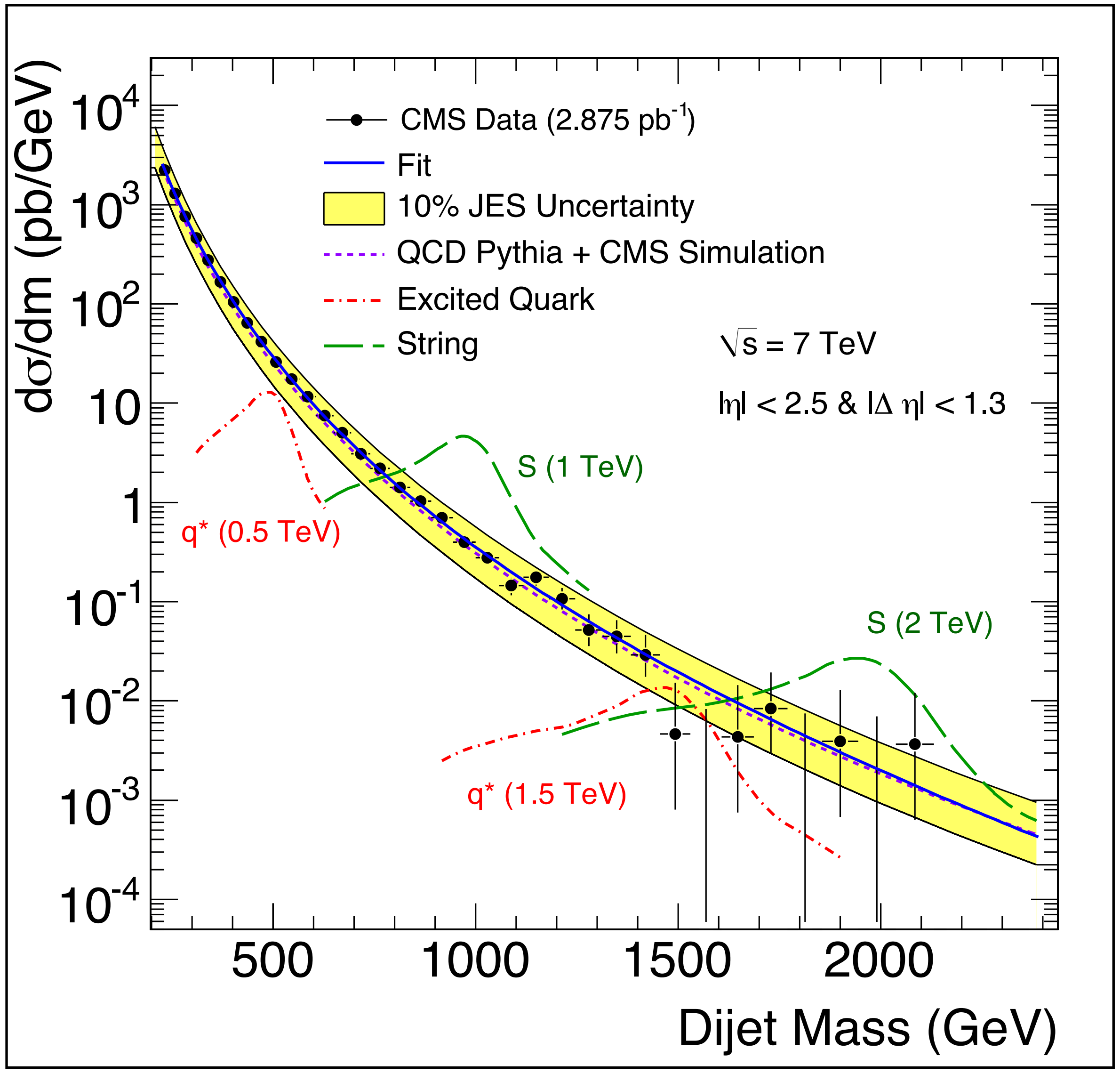


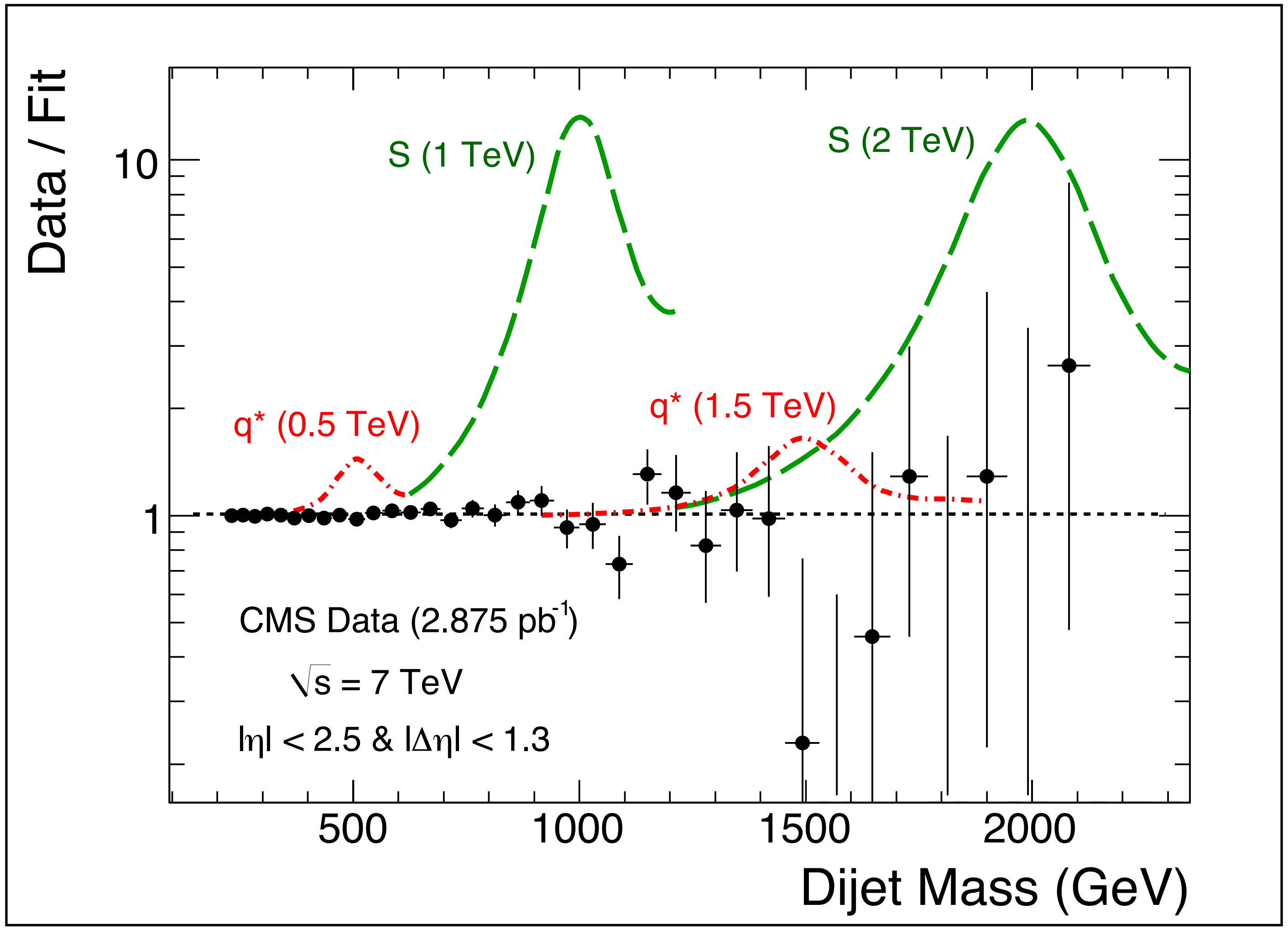




Fit and Signal

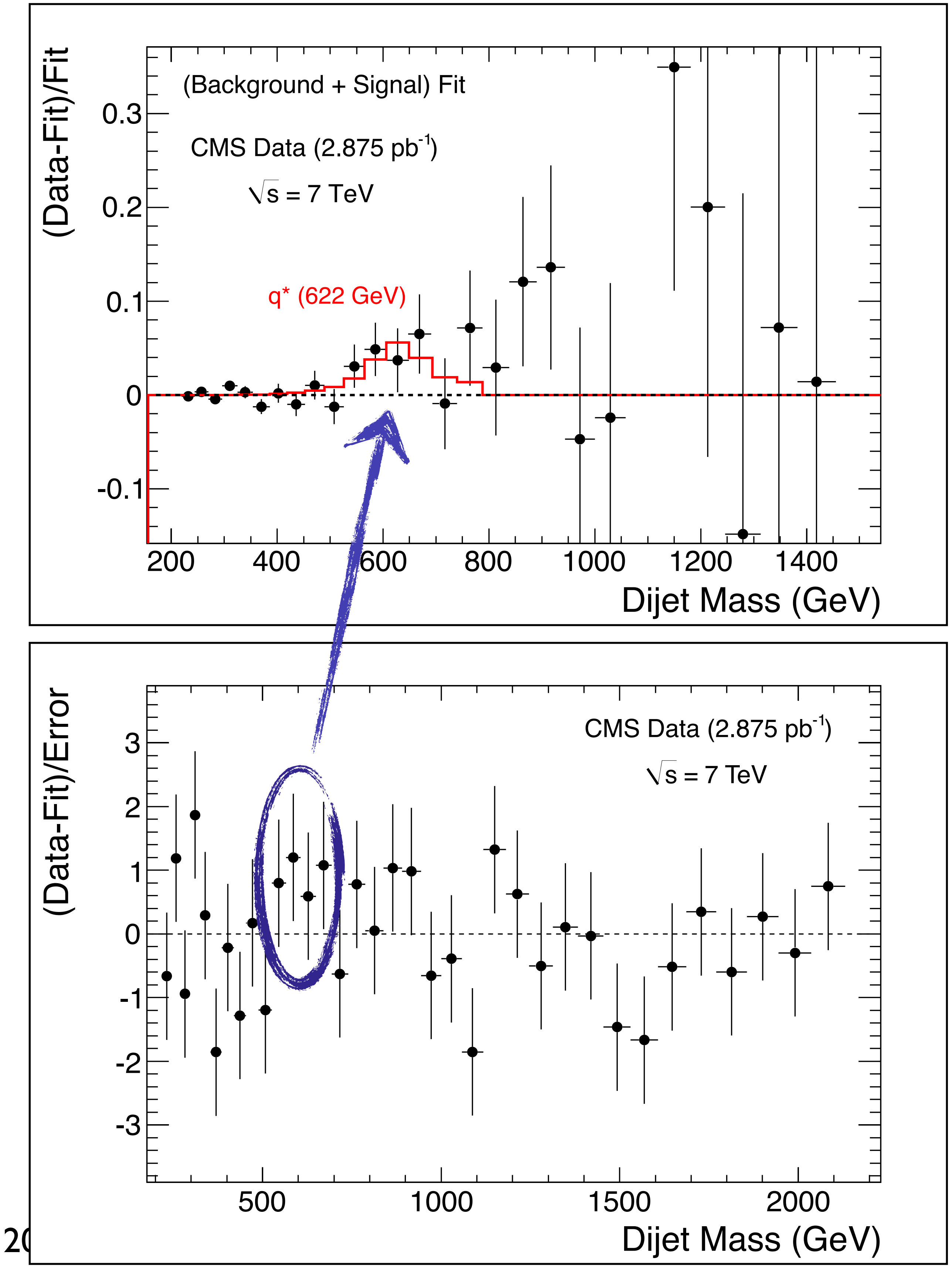
- We search for dijet resonance signal in our data.
- Excited quark signals are shown at 0.5 TeV and 1.5 TeV.
- String resonances are shown at 1 TeV and 2 TeV.





The Largest Fluctuation in Data

- Upward fluctuations around 600 GeV and 900 GeV
- Best fit resonance is at 622 GeV with local significance of 1.86 sigma from log likelihood ratio.
- There is no evidence for dijet resonances.



Setting Limits

- For setting upper limit on the resonance production cross section, a Bayesian formalism with a uniform prior is used.

$$L(n|\mu) = \prod_i \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!} \qquad \mu_i = \alpha N_i(S) + N_i(B).$$

Measured # of events in data

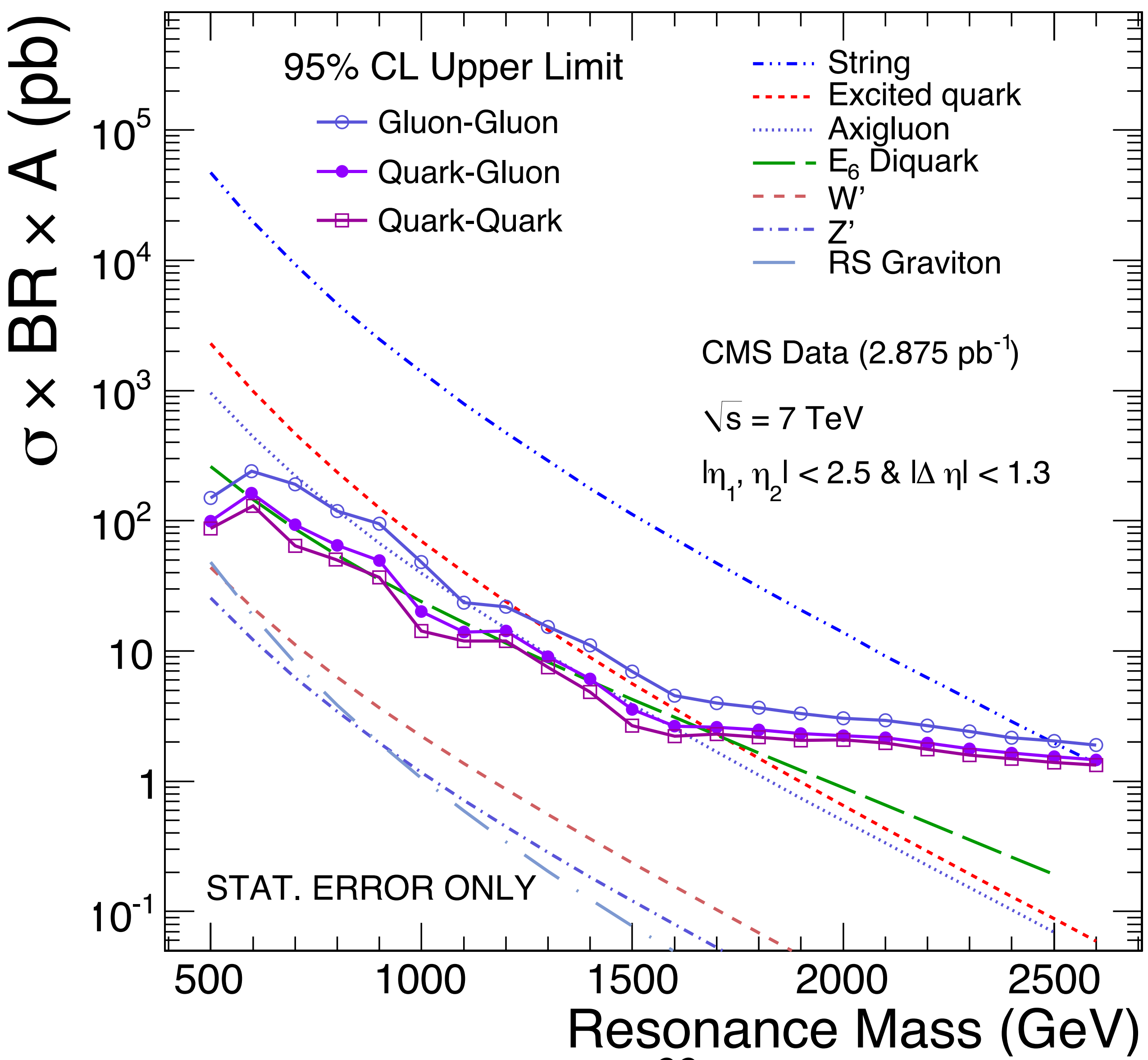
# of event from signal

Expected # of event from background

- The signal comes from our dijet resonance shapes.
- The background comes from fixed to the best Background+Signal fit.
- The 95% CL upper limits are calculated for resonances with mass from 0.5 TeV to 2.6 TeV in 0.1 TeV steps.

Limits with Stat. Error Only

- 95% CL Upper limit with Stat. Error. Only compared to cross section for various model.
  - ✓ Show quark-quark and quark-gluon and gluon-gluon resonances separately.
  - ✓ gluon-gluon resonance has the lowest response and is the widest and gives worst limit.

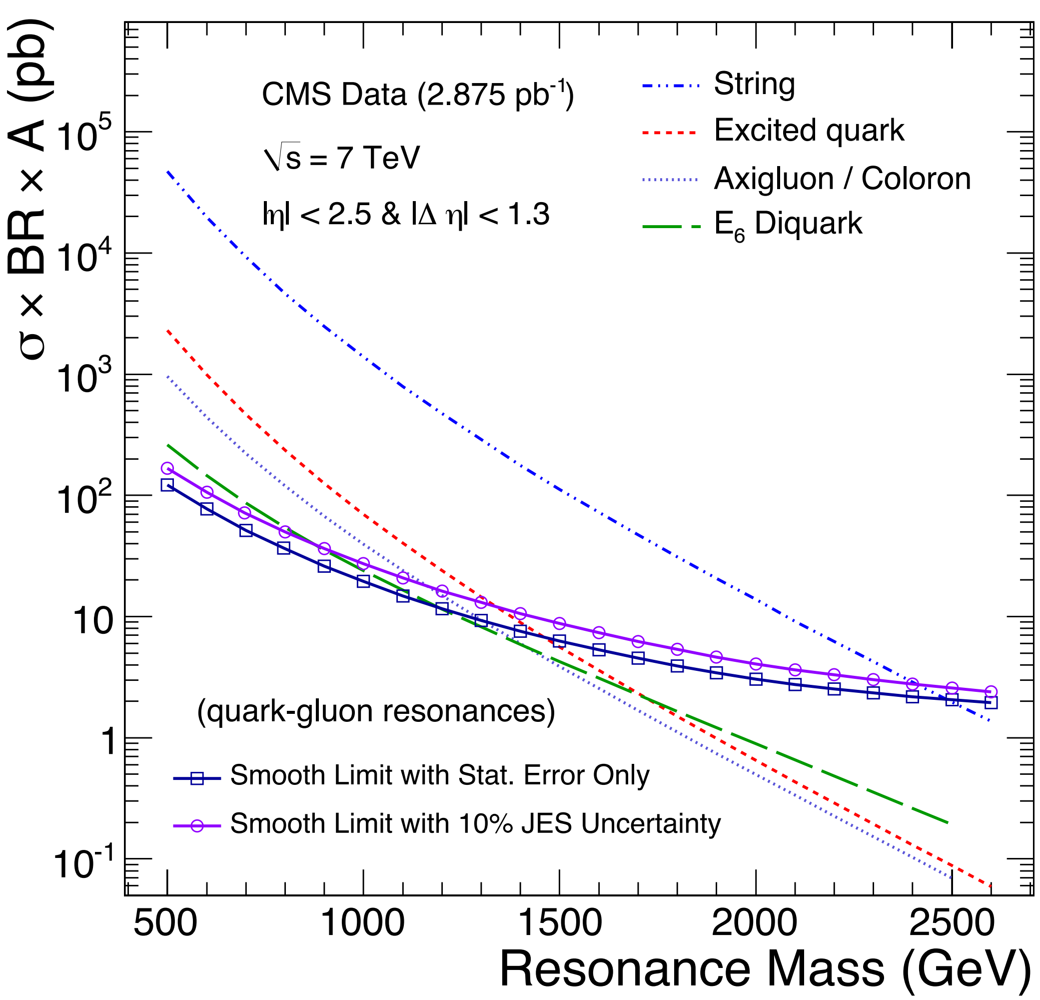


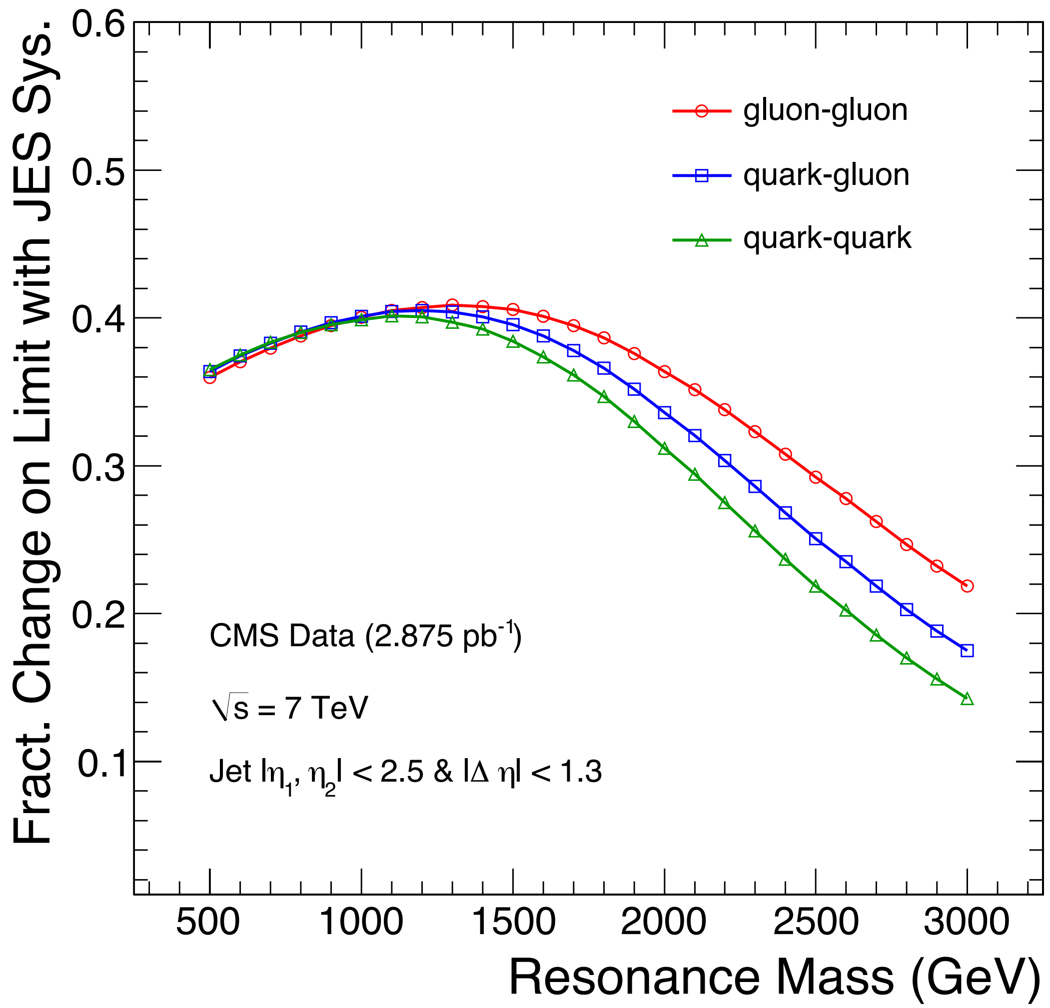
Systematics

- We found the uncertainty in dijet resonance cross section from following sources.
  - ✓ Jet Energy Scale (JES)
  - ✓ Jet Energy Resolution (JER)
  - ✓ Choice of Background Parametrization
  - ✓ Luminosity

Jet Energy Scale (JES)

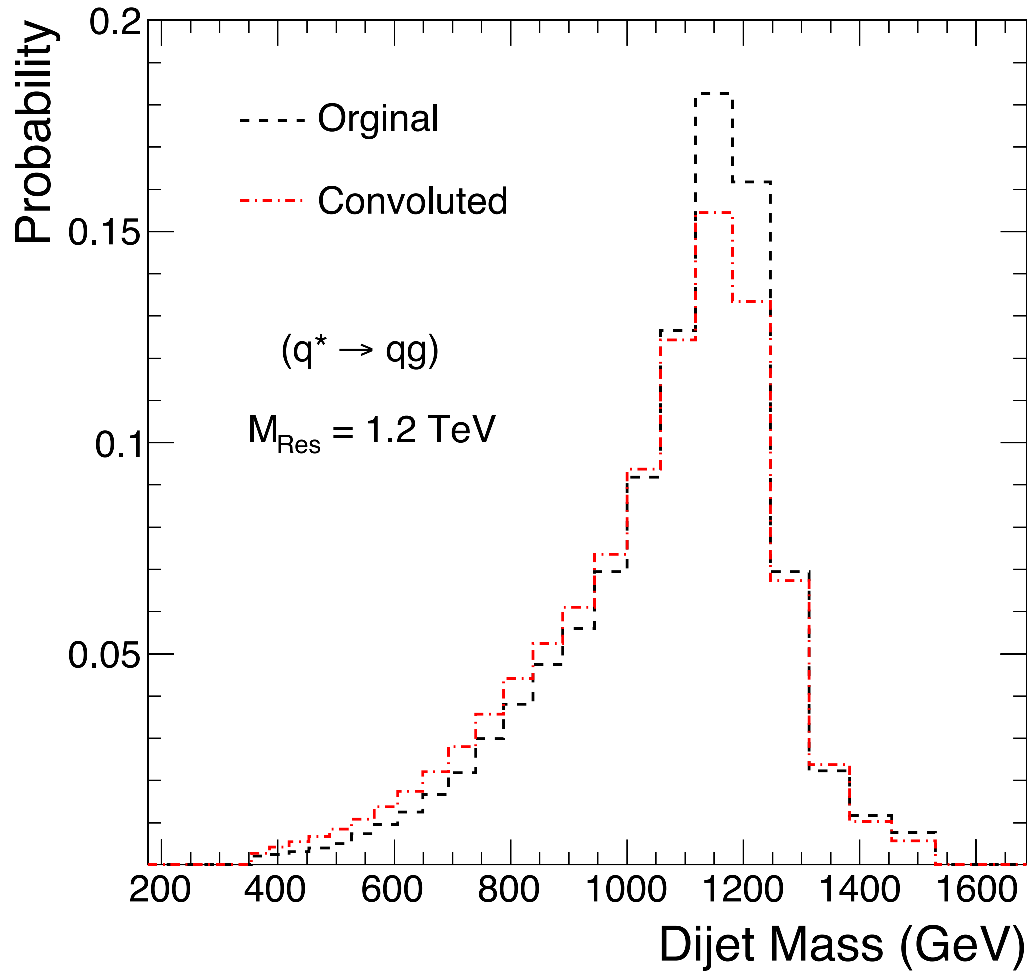
- JetMET guidance is 10% uncertainty in jet energy scale.
  - ✓ Shifting the resonance 10% lower in dijet mass gives more QCD background.
  - ✓ Using a smooth fit to the QCD background instead of actual data is to eliminate the wiggles in the upper limit curves.
  - ✓ Increases the limit between 14% and 42% depending on resonance mass and type.

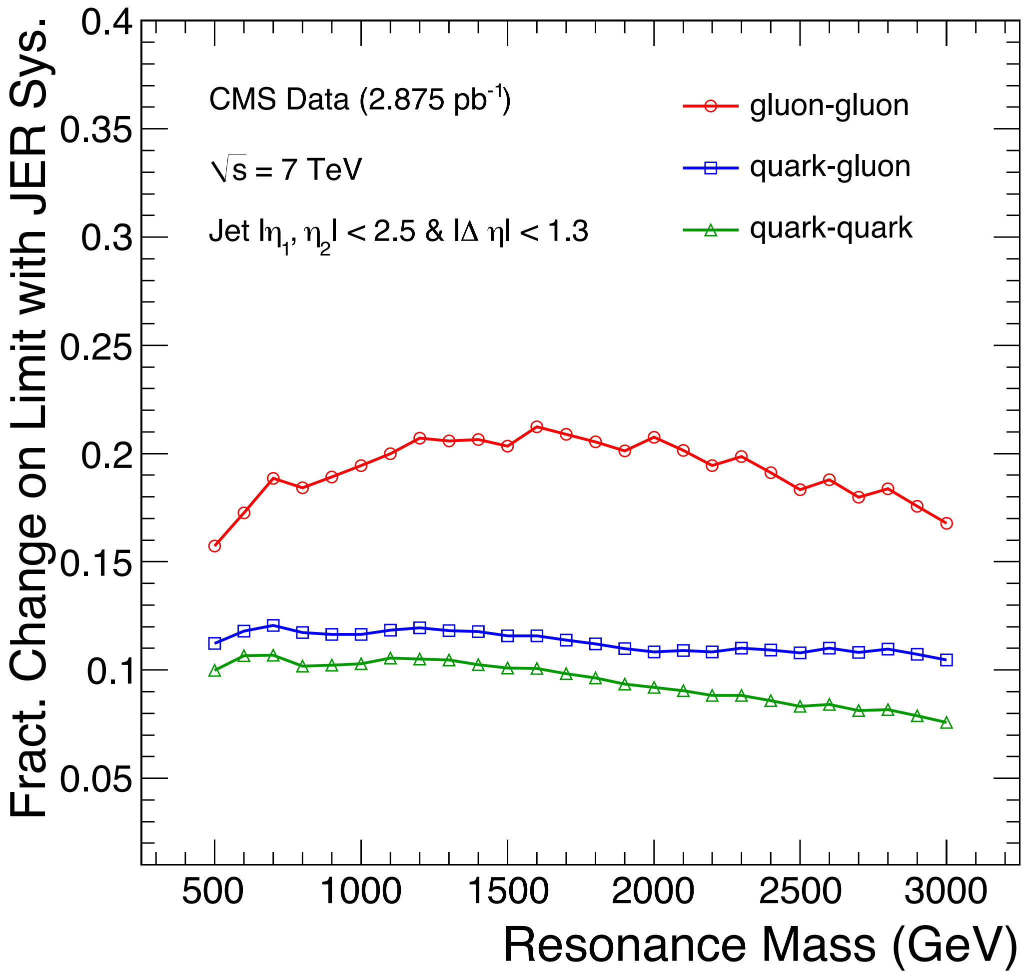




Jet Energy Resolution (JER)

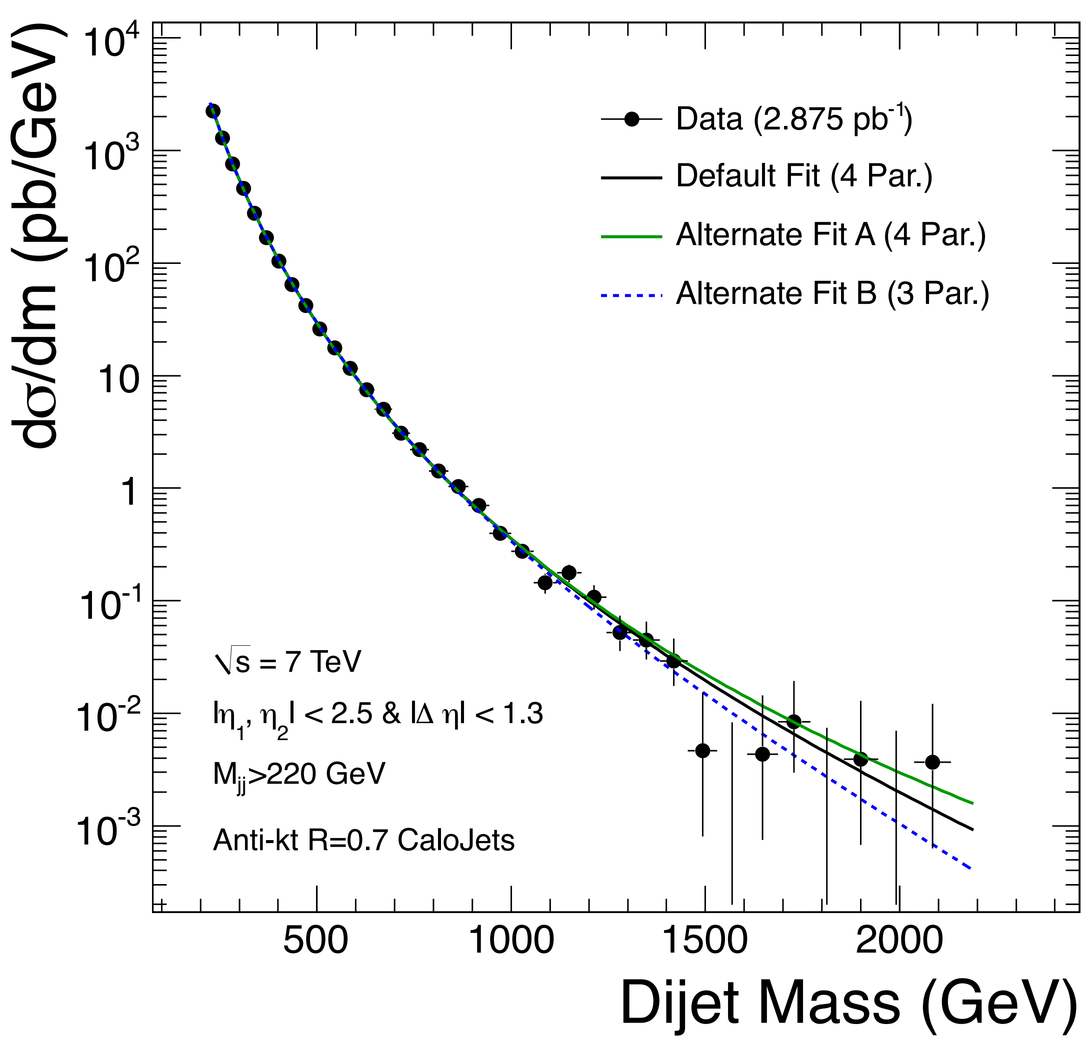
- JetMET guidance is 10% uncertainty in jet energy resolution.
- We smear our resonance shapes with a gaussian designed to increase the core width by 10%.
  - ✓ $\sigma_{Gaus} = \sqrt{(1.1)^2 - 1}\ \sigma_{Res}$
- This increases our limit between 7% and 22% depending on resonance mass and type.

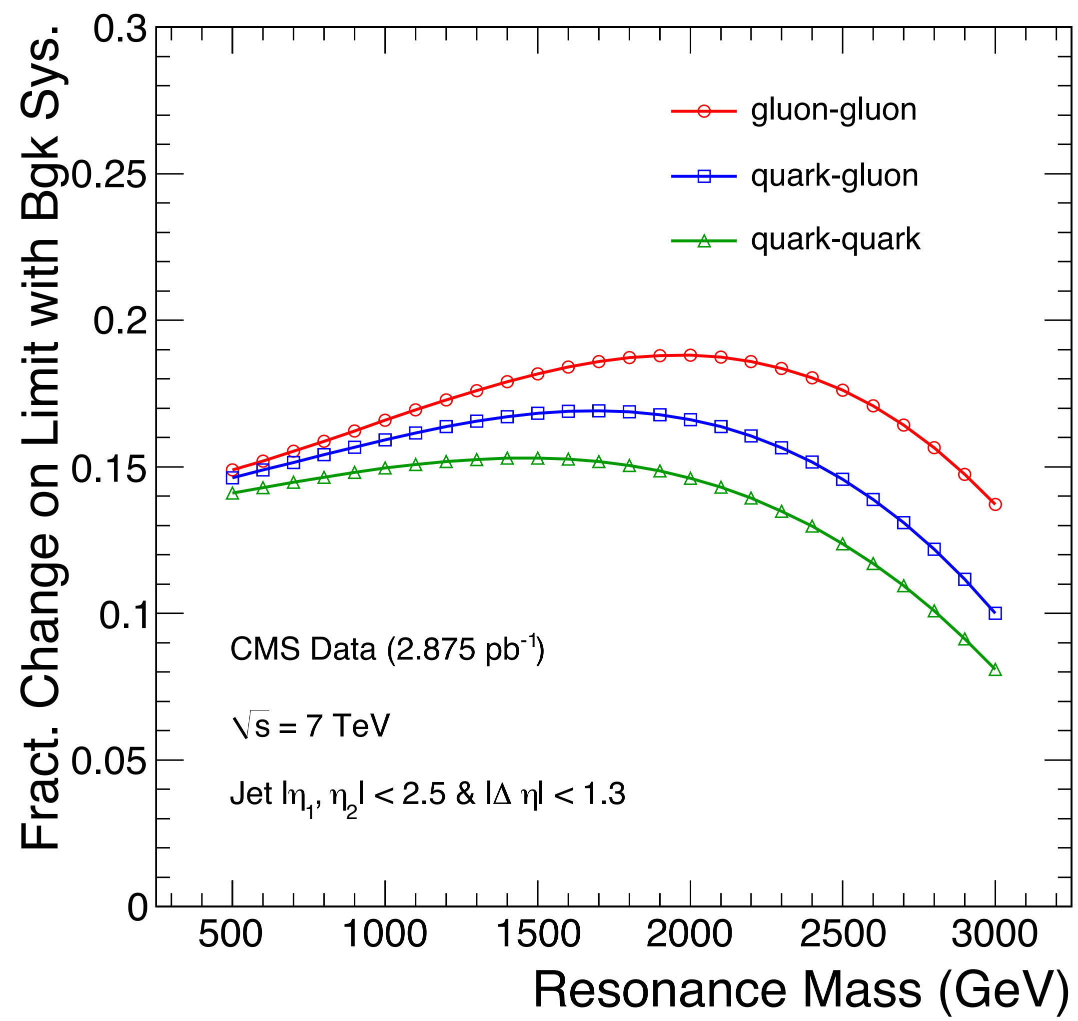




Background Parametrization Systematics

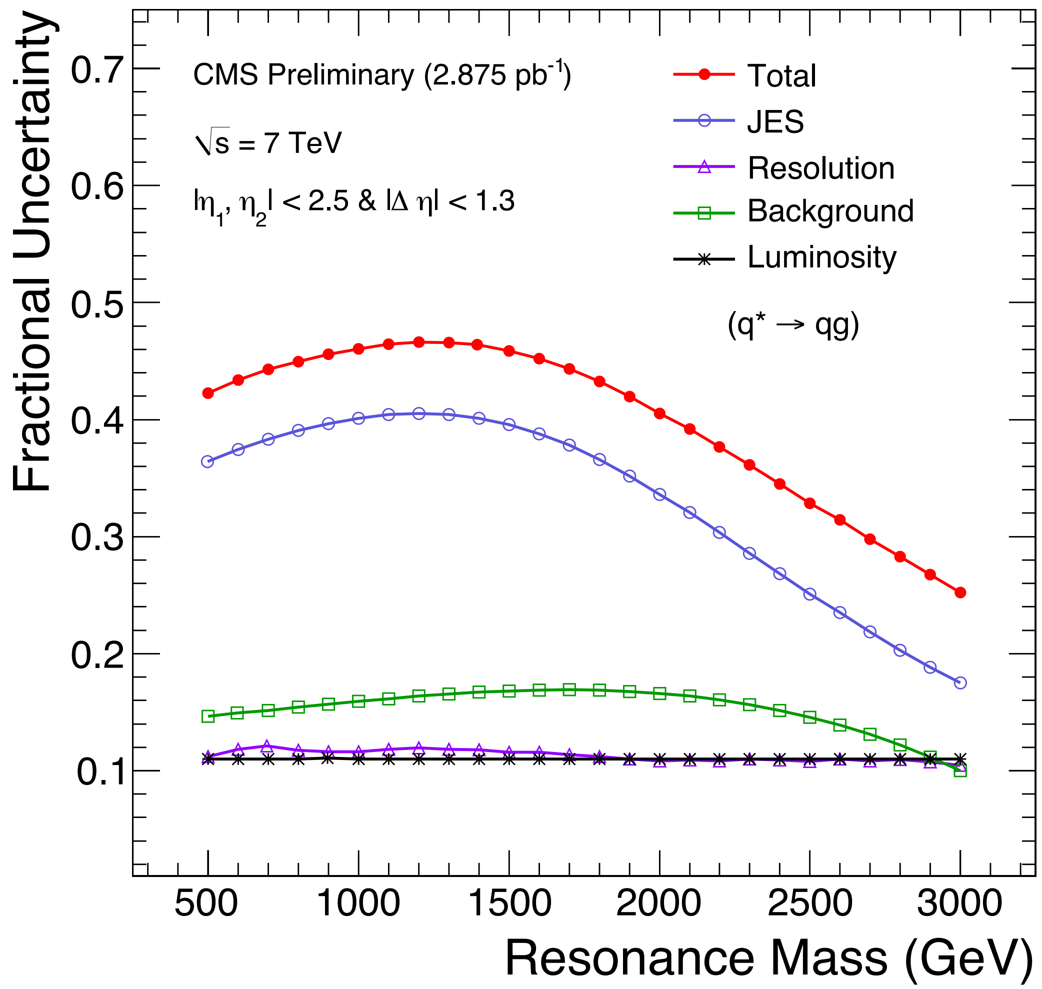
- We consider other functional forms to parametrize the QCD background.
- We use the 4 parameter fit as a systematic on our background shape.
- This increases our limit between 8% and 19% depending on resonance mass and type.

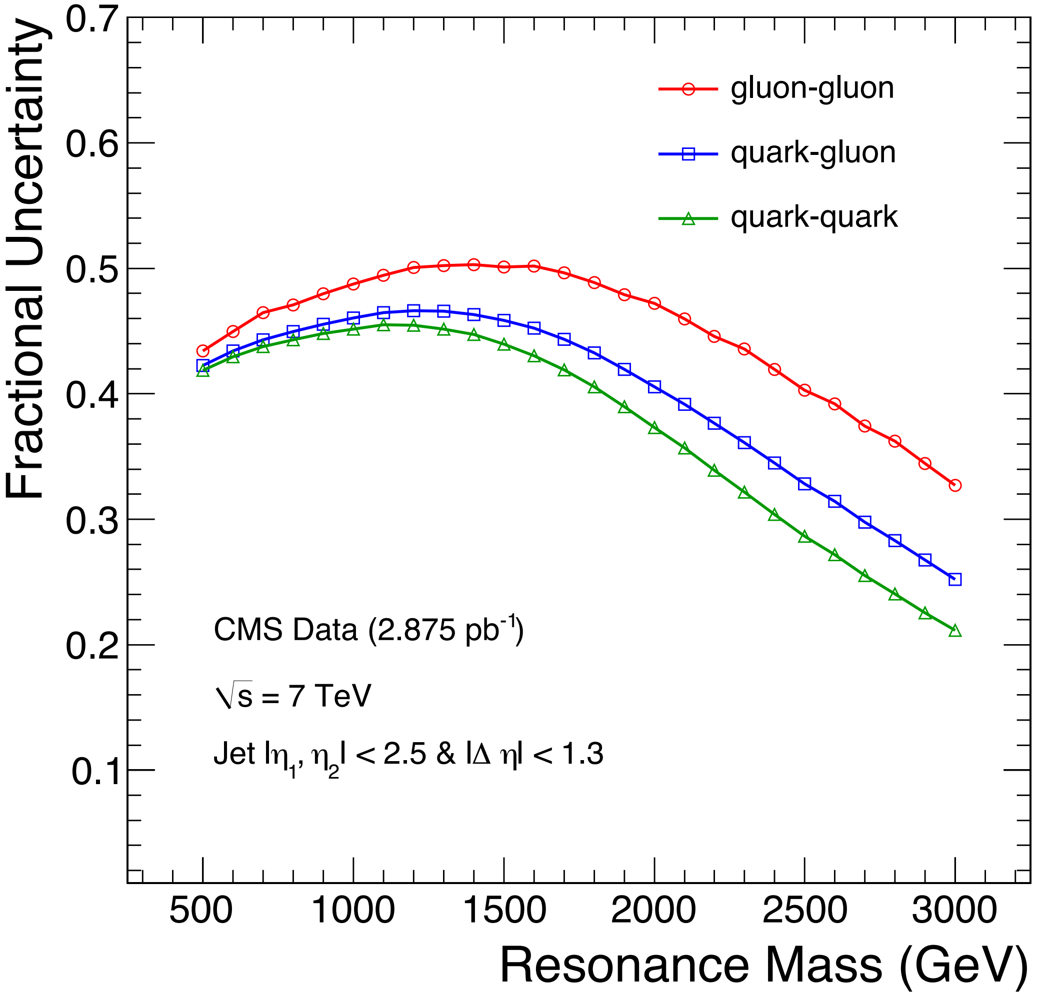




Total Systematic Uncertainties

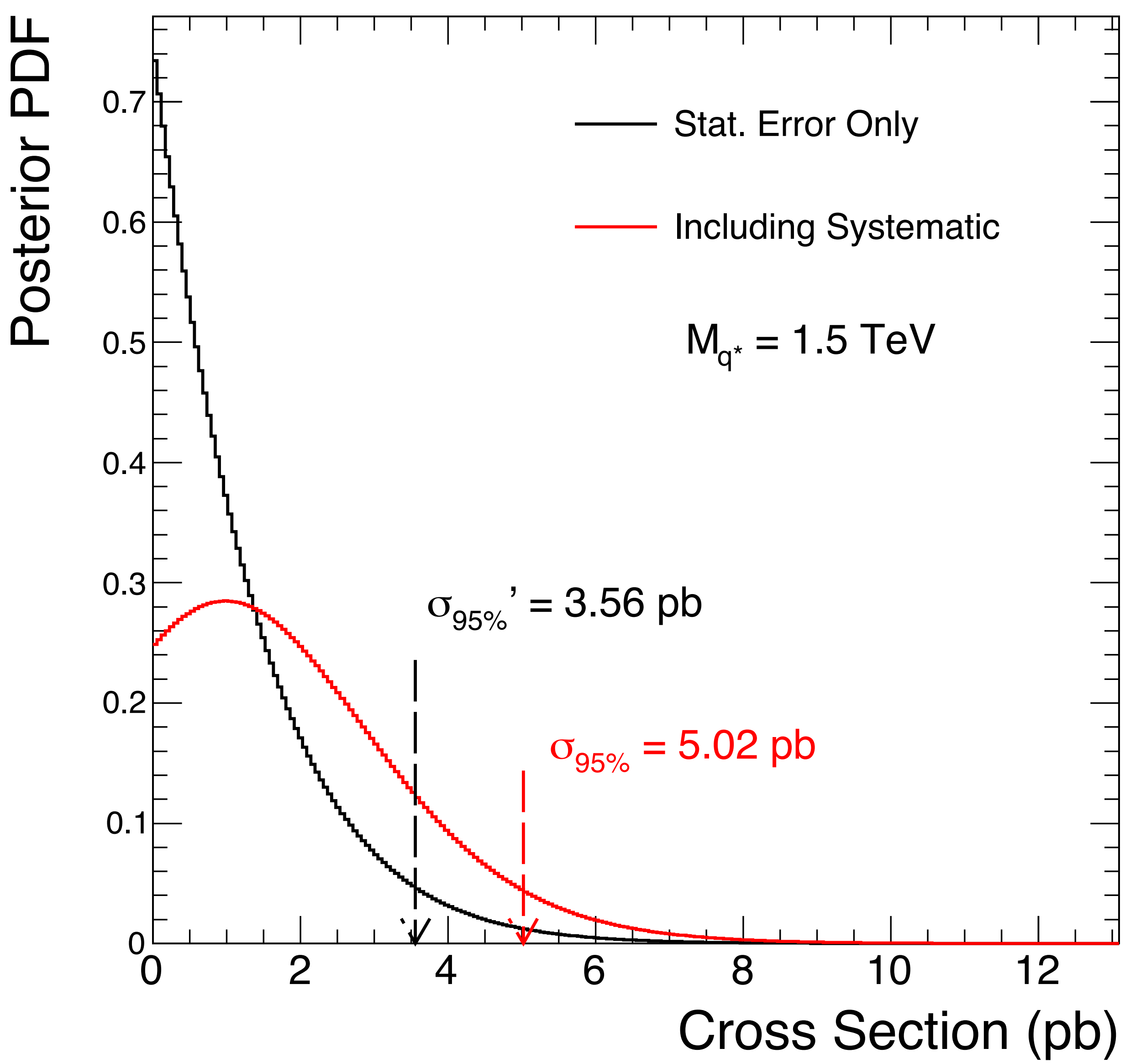
- We add all mentioned systematic uncertainties in quadrature, also 11% for luminosity.
- JES is dominant systematic uncertainty.
- Total systematic uncertainty varies from 24% to 48% depending on resonance mass and type.





Incorporating Systematic

- We convolute posterior PDF with Gaussian systematics uncertainties.
  - ✓ Posterior PDF including systematics is broader and gives higher upper limit.

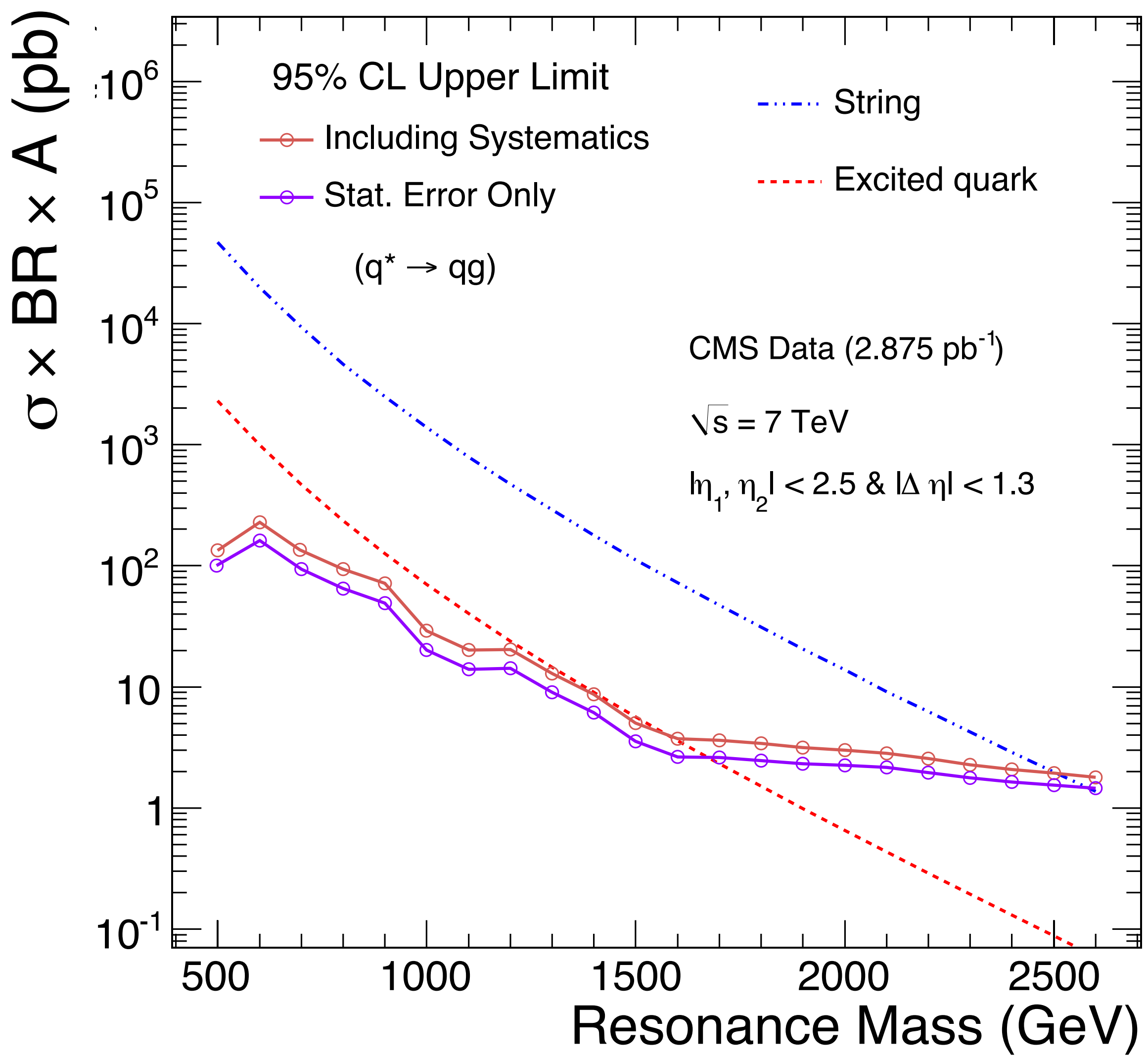


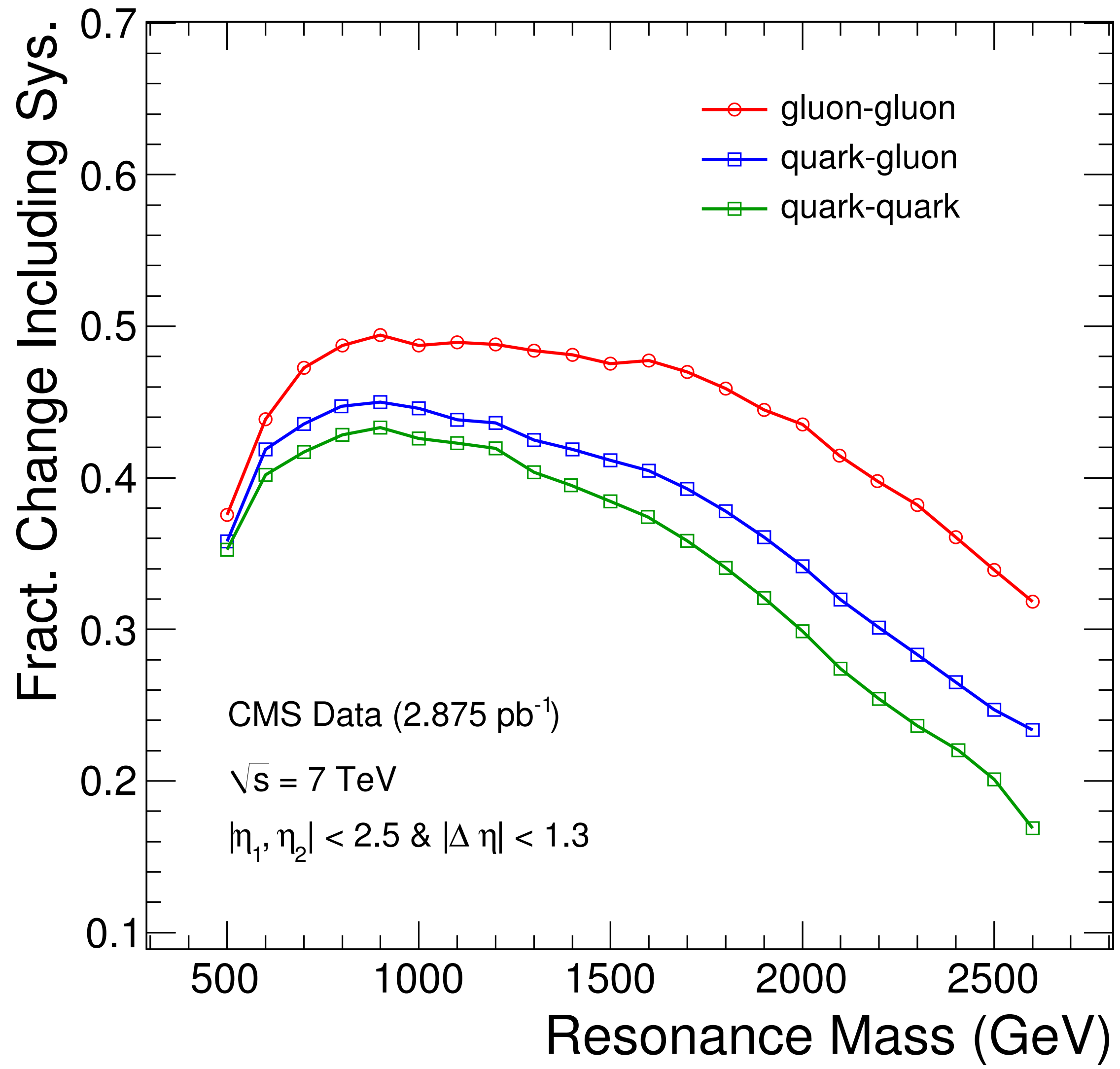
$$L(\sigma) = \int_0^{\infty} L(\sigma')G(\sigma,\sigma')d\sigma'$$

G: Gaussian distribution with RMS width equal to systematic uncertainty in cross section

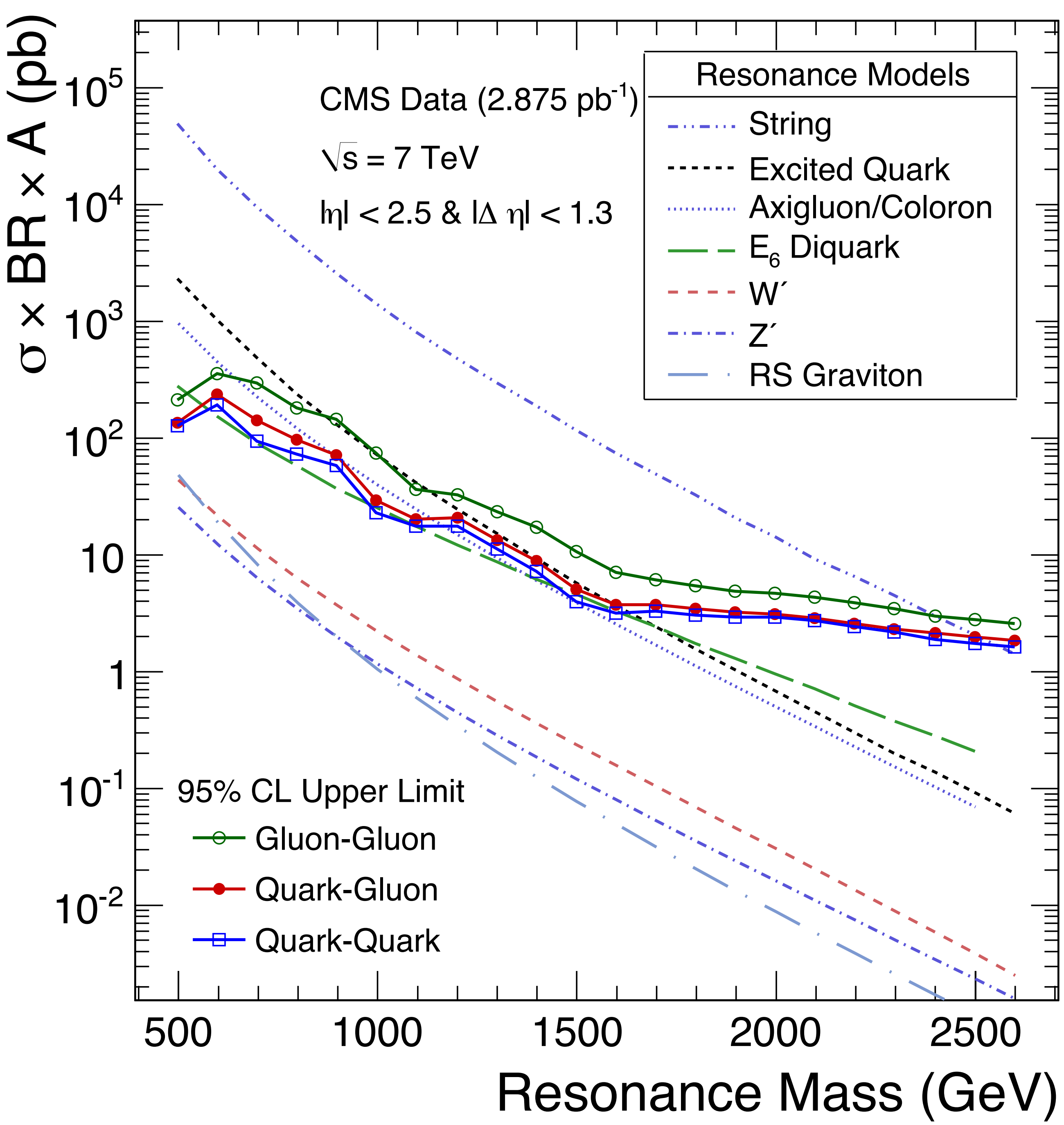
Effect of Systematics on Limit

- 95% CL Upper limit with Stat. Error. Only and Including Sys. Uncertainties are shown separately
- Systematic uncertainties reduce the mass limit by 0.1 TeV for both string resonance and excited quark.



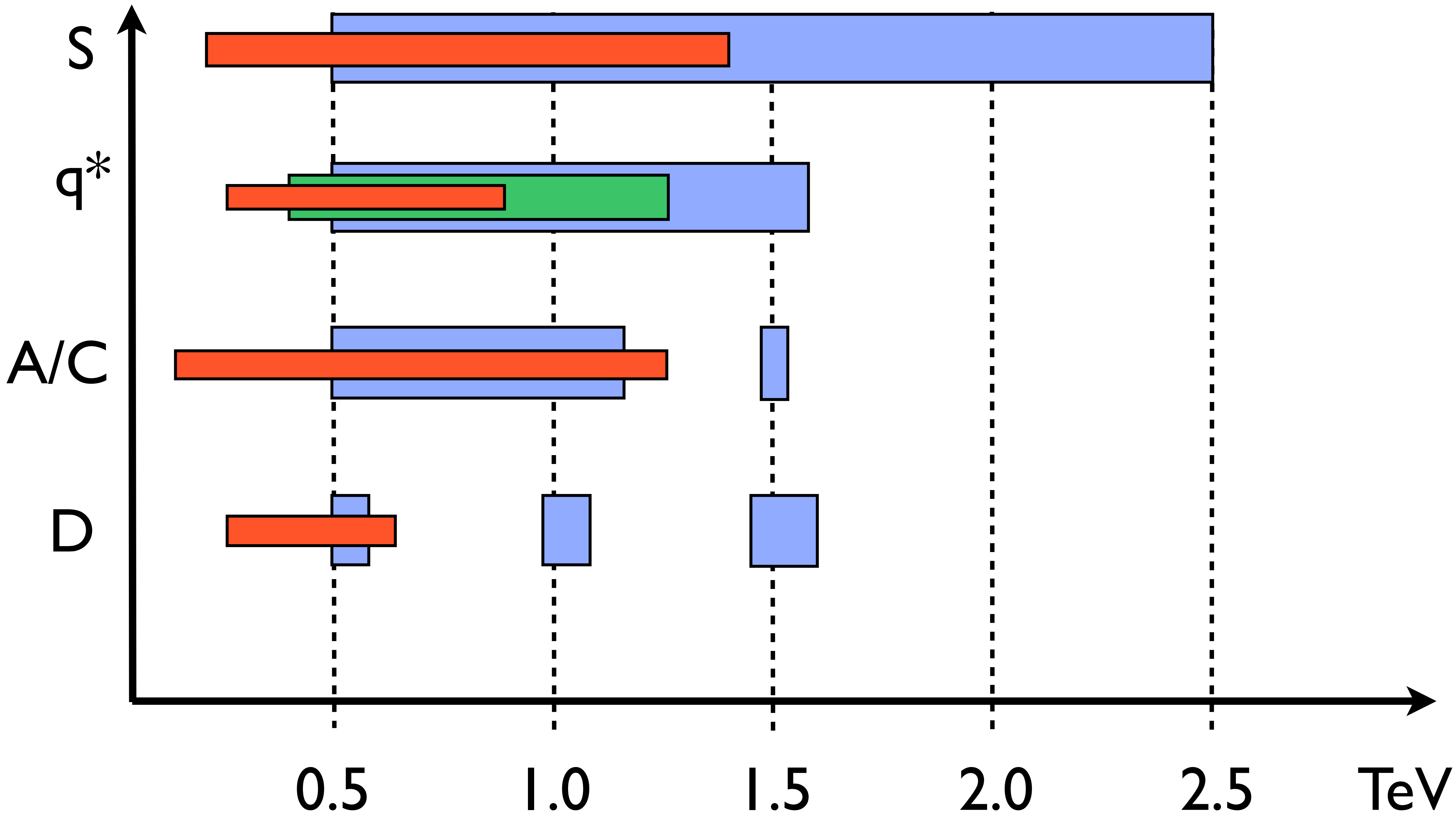


Results



- We exclude the following mass ranges with 2.9 pb^{-1} data:
- String
  - ✓ **0.50<M(S)<2.50 TeV**
    - M(S)<1.40 from CDF (1 fb^{-1})
- Excited Quark
  - ✓ **0.50<M(q*)<1.58 TeV**
    - 0.40<M(q*)<1.26 from ATLAS (0.32 pb^{-1})
- Axigluon/Coloron
  - ✓ **0.50<M(A)<1.17 TeV & 1.47<M(A)<1.52 TeV**
    - 0.12<M(A)<1.25 TeV from CDF (1 fb^{-1})
- E6 Diquark
  - ✓ **0.50<M(D)<0.58 TeV & 0.97<M(D)<1.08 TeV & 1.45<M(D)<1.60 TeV**
    - 0.29<M(D)<0.63 TeV from CDF (1 fb^{-1})

Published Excluded Mass at 95% CL



CMS (2.9 pb^{-1})
ATLAS (0.32 pb^{-1})
CDF (1 fb^{-1})

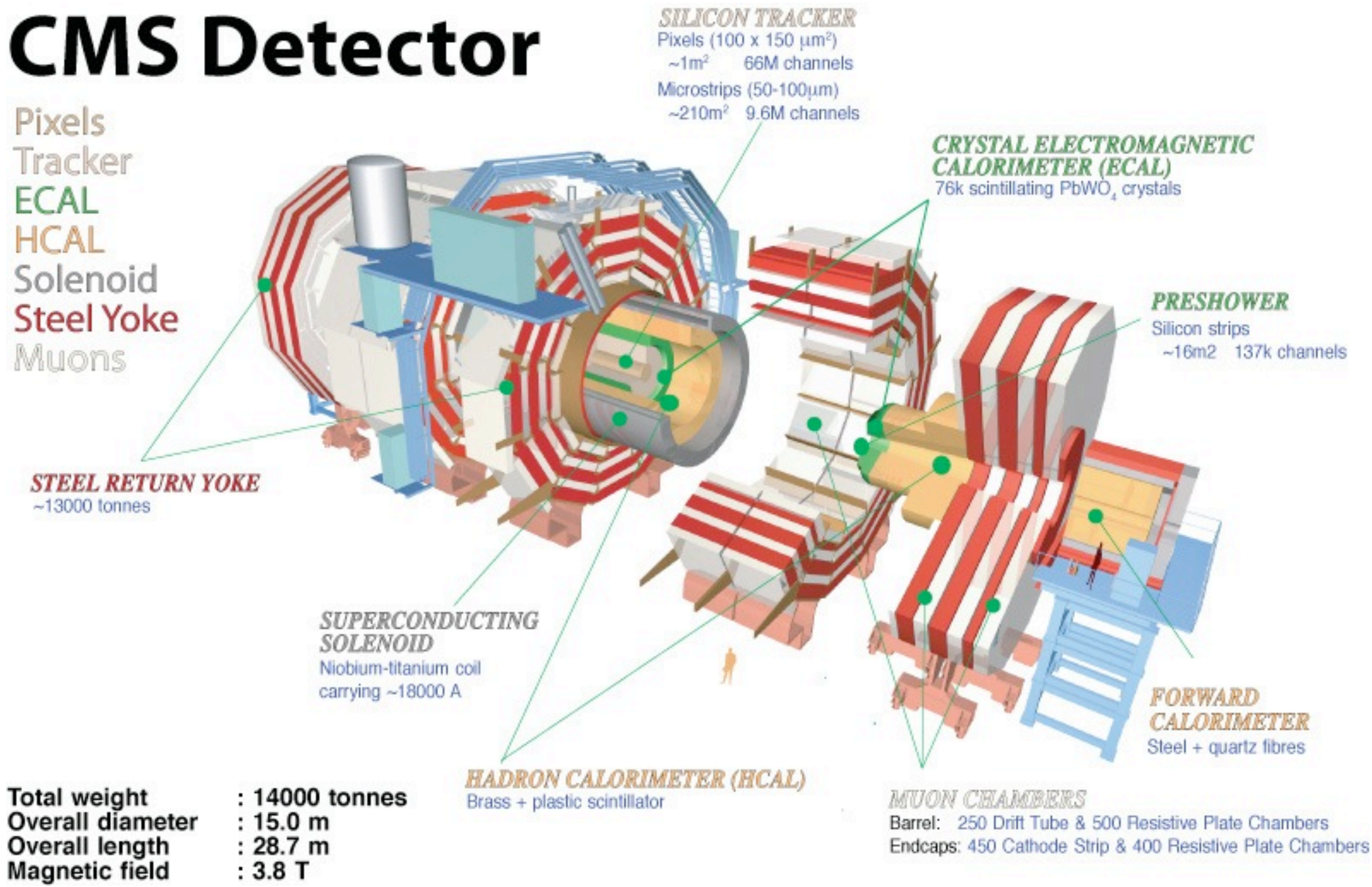
CMS Collaboration, Accepted by Phys. Rev. Lett., arXiv: 1010.0203
ATLAS Collaboration, Phys. Rev. Lett. 105, 161801 (2010)
CDF Collaboration, Phys. Rev., D79, 112002 (2009)

Conclusion

- The CMS dijet mass spectrum extends to 2.1 TeV with 2.9 pb^{-1} data.
- The dijet mass data is in good agreement with a full CMS simulation of QCD from PYTHIA.
- There is no evidence for dijet resonances.
- We have generic cross section upper limits on qq, qg, gg resonances that can be applied to any model.
- We have the best mass limits on dijet resonance models, beyond those published by Tevatron and ATLAS.
- This analysis is the first CMS search paper and the first CMS jet paper and it has been accepted by PRL.
- We plan to submit another paper based on full 2010 data (30-40 pb^{-1}) at the end of this year.

Back-Up Slides

CMS Detector



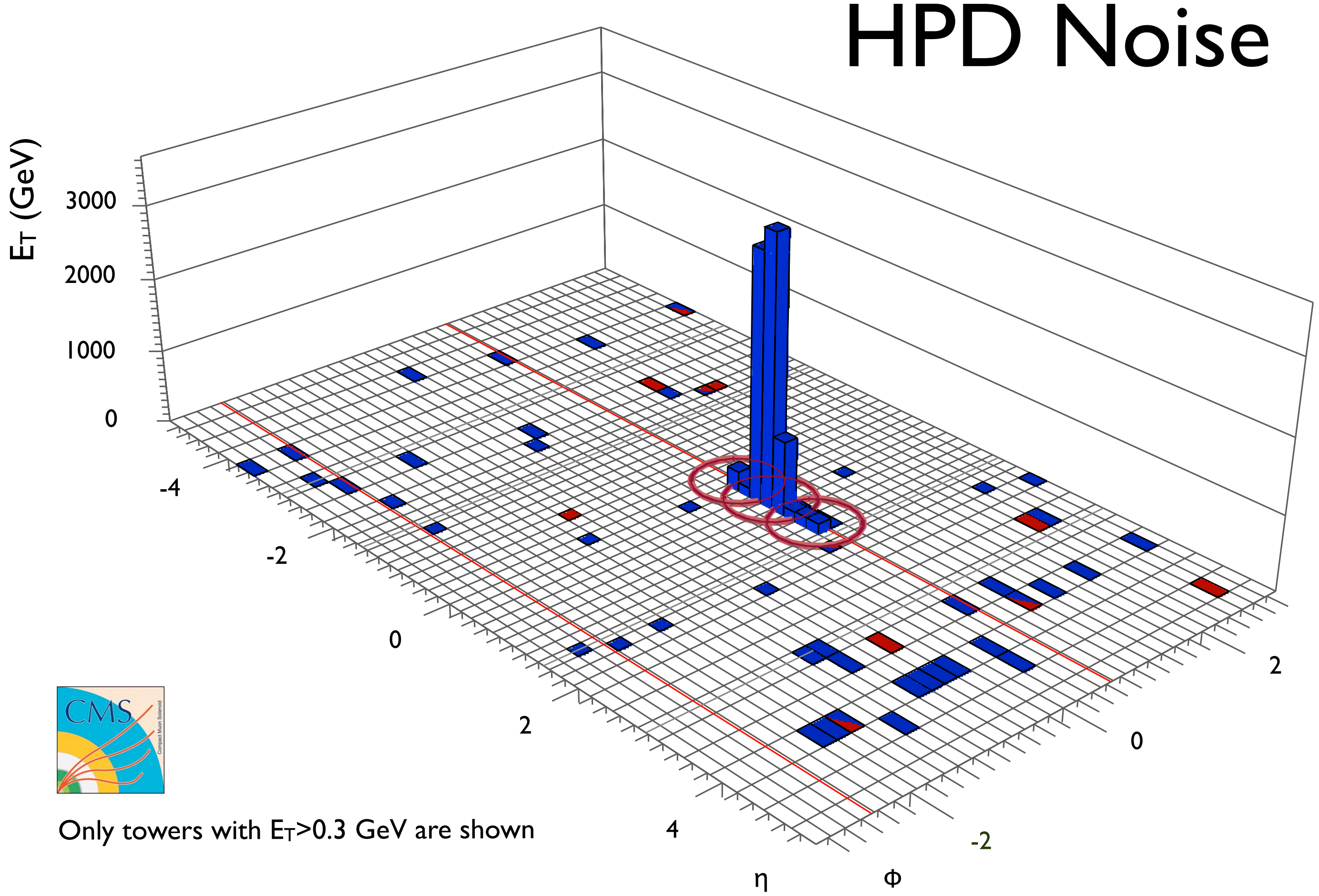
Data Set

- Dataset
  - ✓ (135059-135735) - /MinimumBias/Commissioning10-SD_JetMETTau-Jun14thSkim_v1/RECO
  - ✓ (136066-137028) - /JetMETTau/Run2010A-Jun14thReReco_v2/RECO
  - ✓ (137437-139558) - /JetMETTau/Run2010A-PromptReco-v4/RECO
  - ✓ (139779-140159) - /JetMETTau/Run2010A-Jul16thReReco-v1/RECO
  - ✓ (140160-141899) - /JetMETTau/Run2010A-PromptReco-v4/RECO
  - ✓ (141900-142664) - /JetMET/Run2010A-PromptReco-v4/RECO
- /QCDDijet_PtXXtoYY/Spring10-START3X_V26_S09-v1/GEN-SIM-RECO
- Official JSON Files
- Estimated Integrated Luminosity: 2.875 pb^{-1} (with 11% uncertainty)

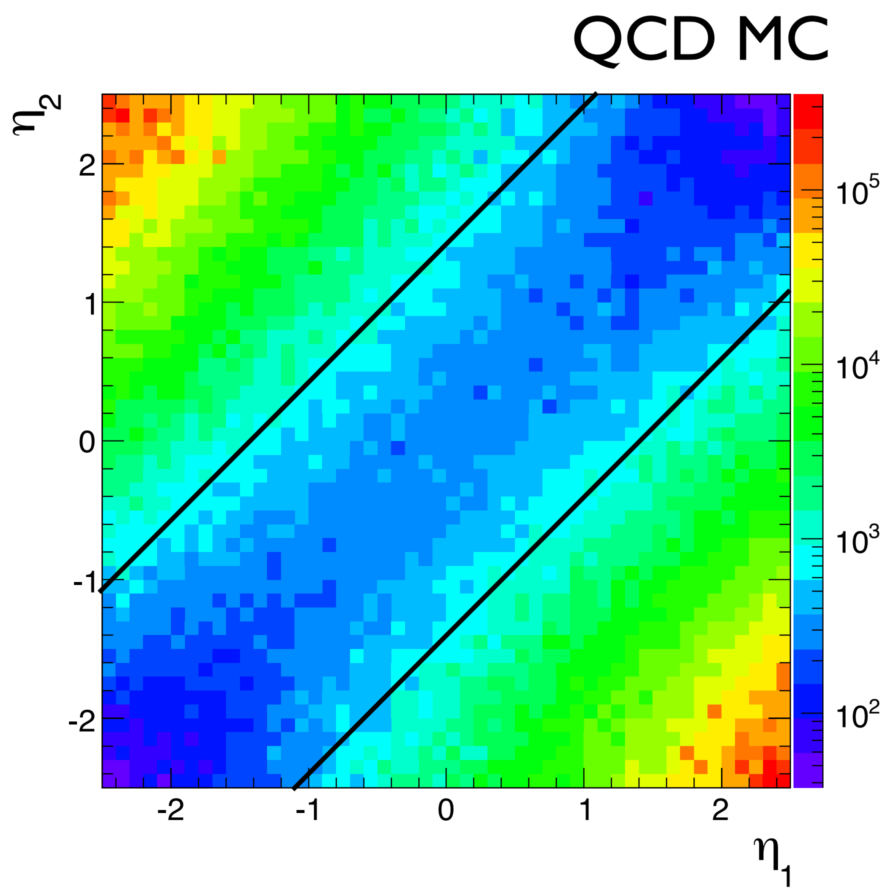
JetID for CaloJets in CMS

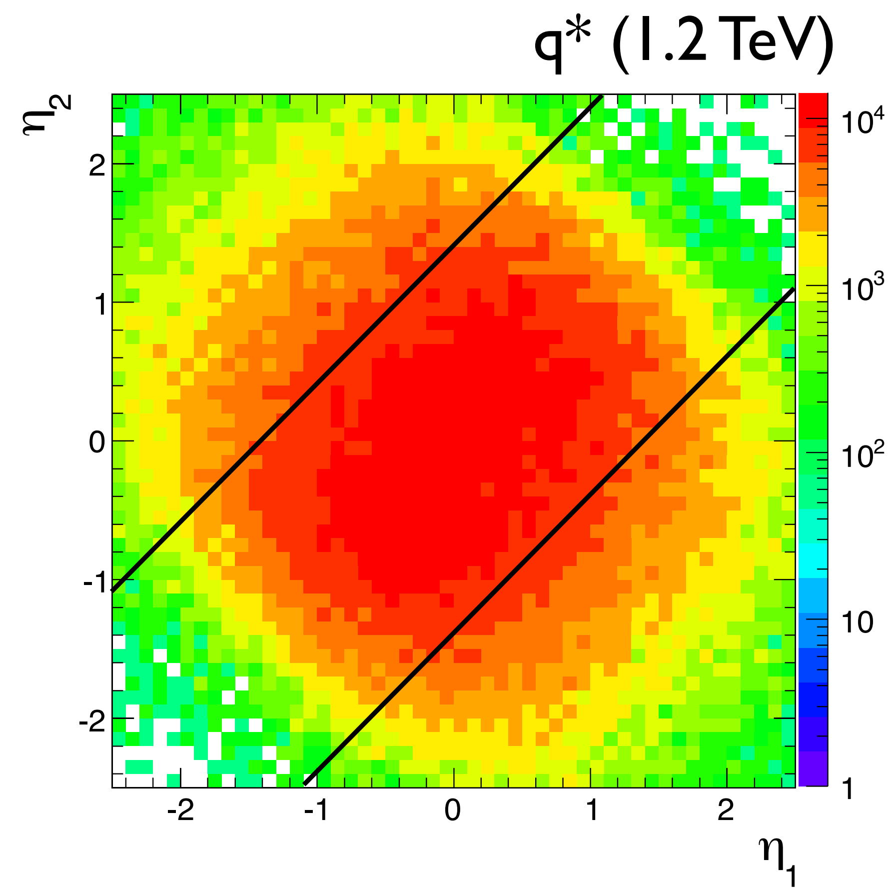
- **Electromagnetic energy fraction (EMF).** A low cut defends against HCAL noise.
  - ✓ EMF>0.01
- **n90hits.** Minimum number of energy ordered rechits in the calotowers which carry 90% of the jet energy.
  - ✓ n90hits>1
- **fHPD.** Fraction of the energy contributed by the hottest HPD.
  - ✓ fHPD<0.98

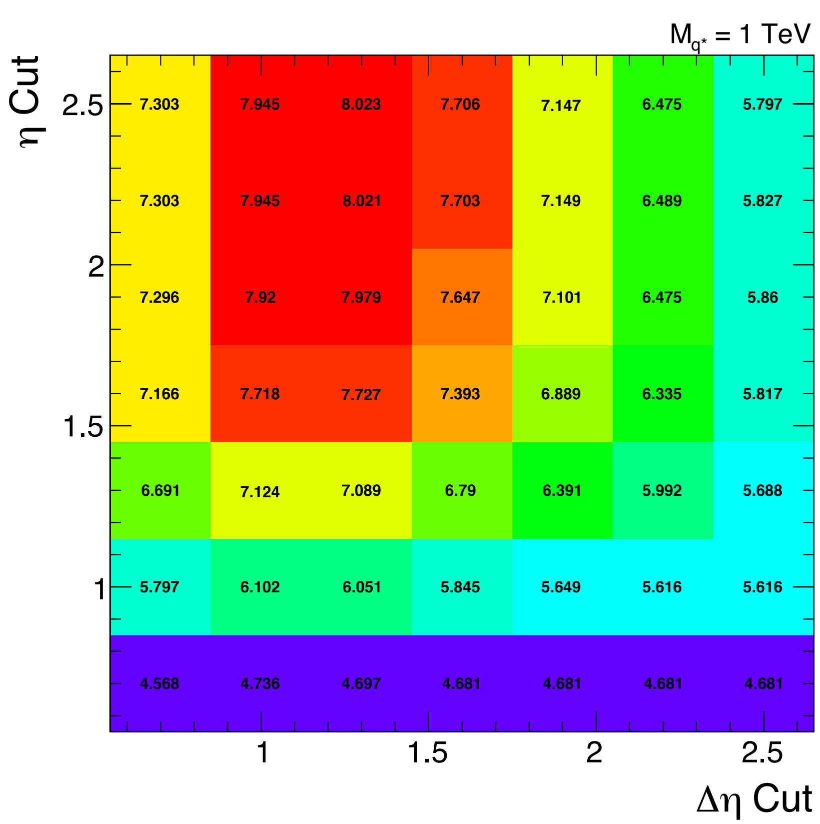
HPD Noise



Eta Cut Optimization

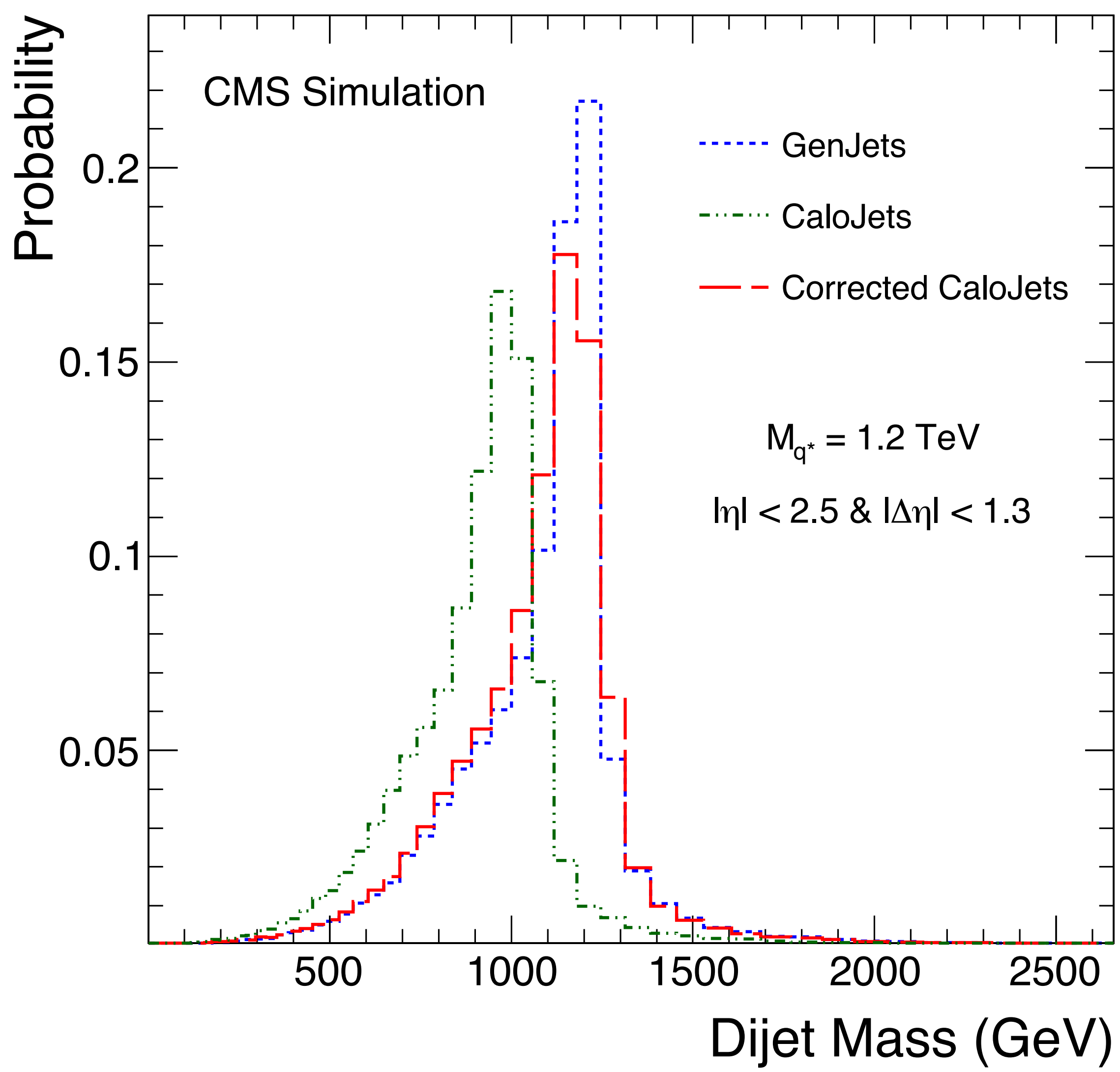


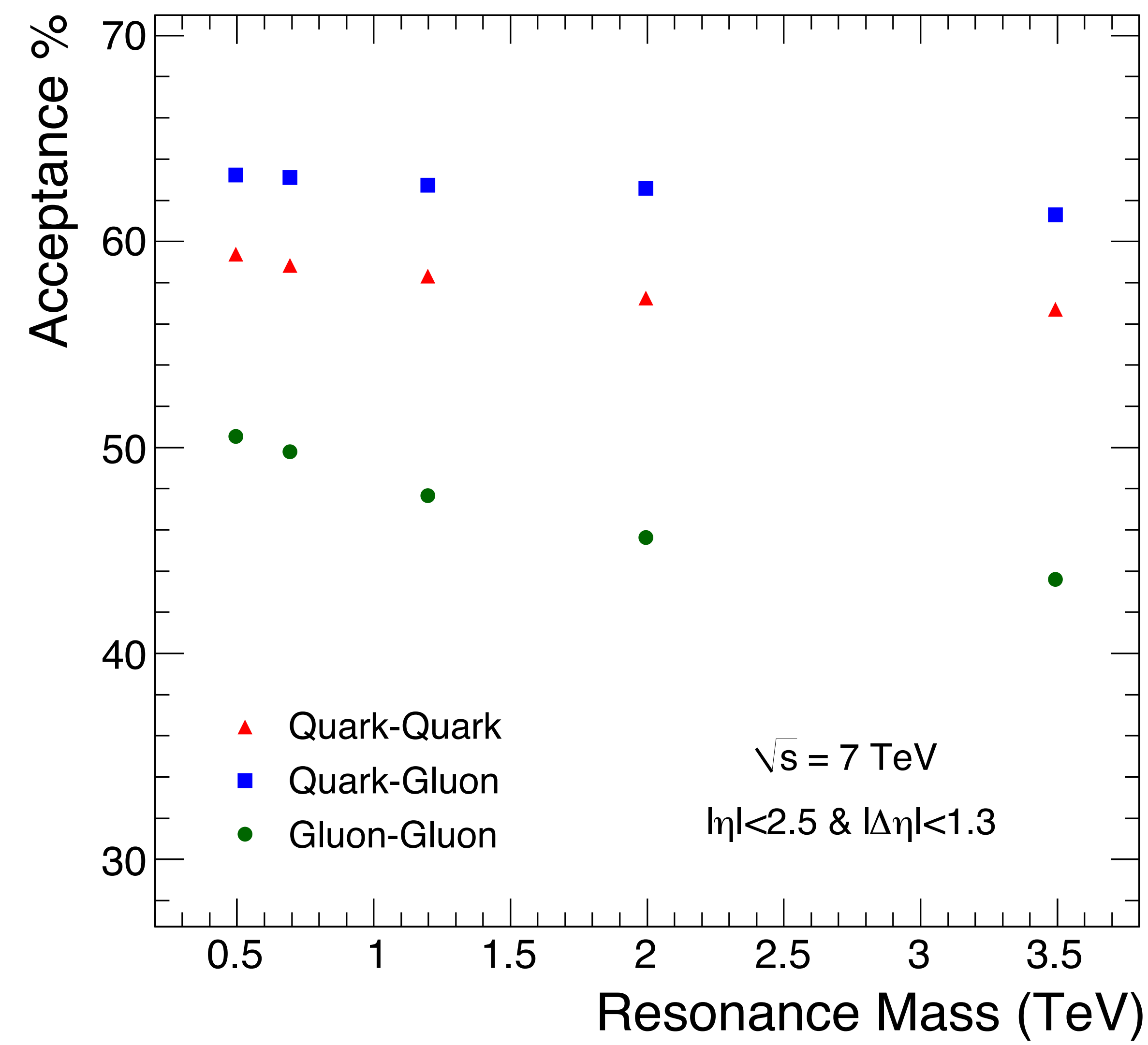




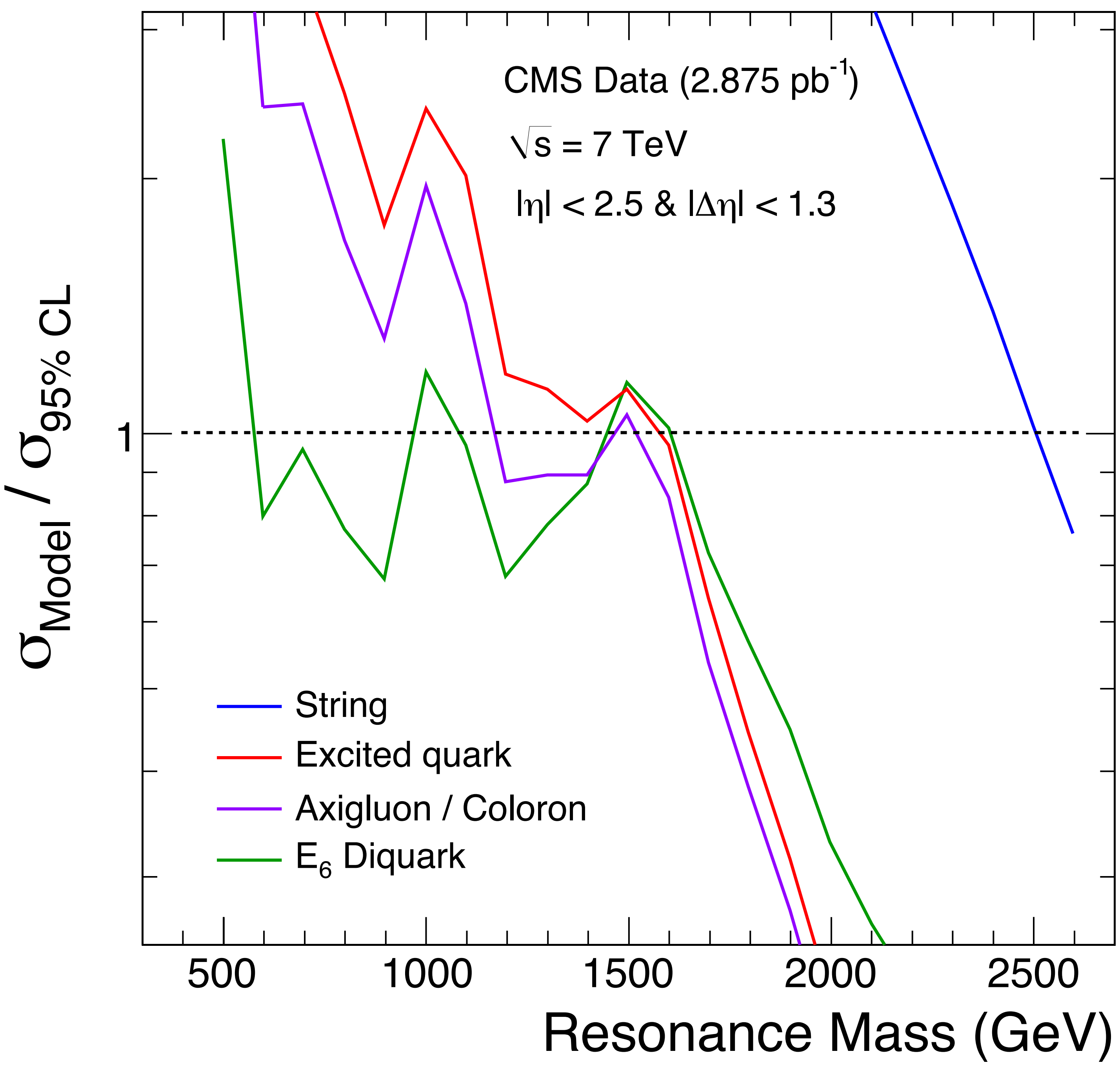
- $|\Delta\eta|$ cut directly removes QCD t-channel pole in center of mass.
- $|\Delta\eta| < 1.3$ optimal for isotropic decays (q*).

Signal Acceptance



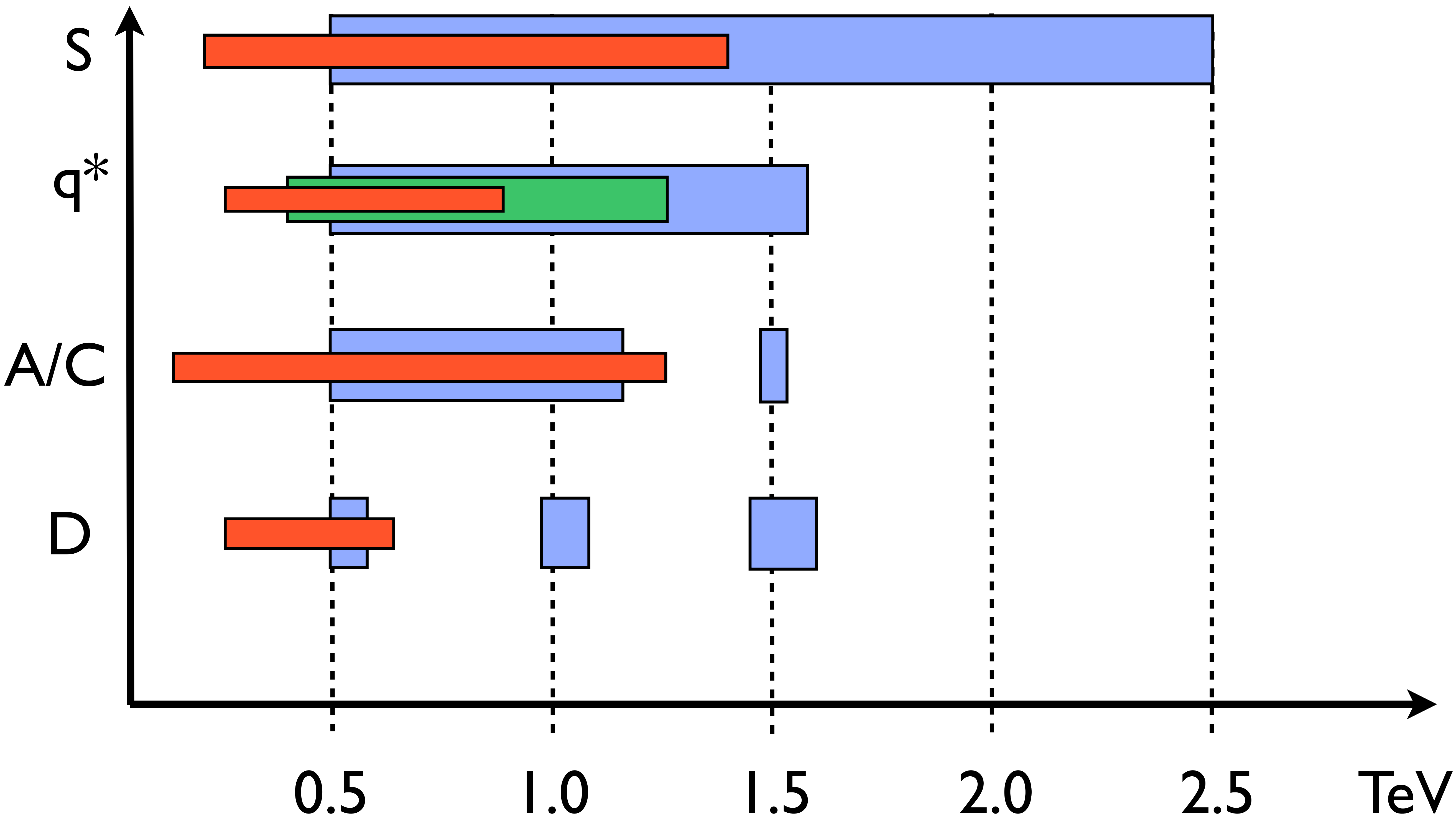


- The peak of resonance shapes of GenJets and Corrected CaloJets are roughly at the expected resonance mass.
- The resonance shape of corrected calojet is wider than genjets due to detector smearing effect.
- The signal acceptances of qq and qg resonances are around 60%,which is reasonable.

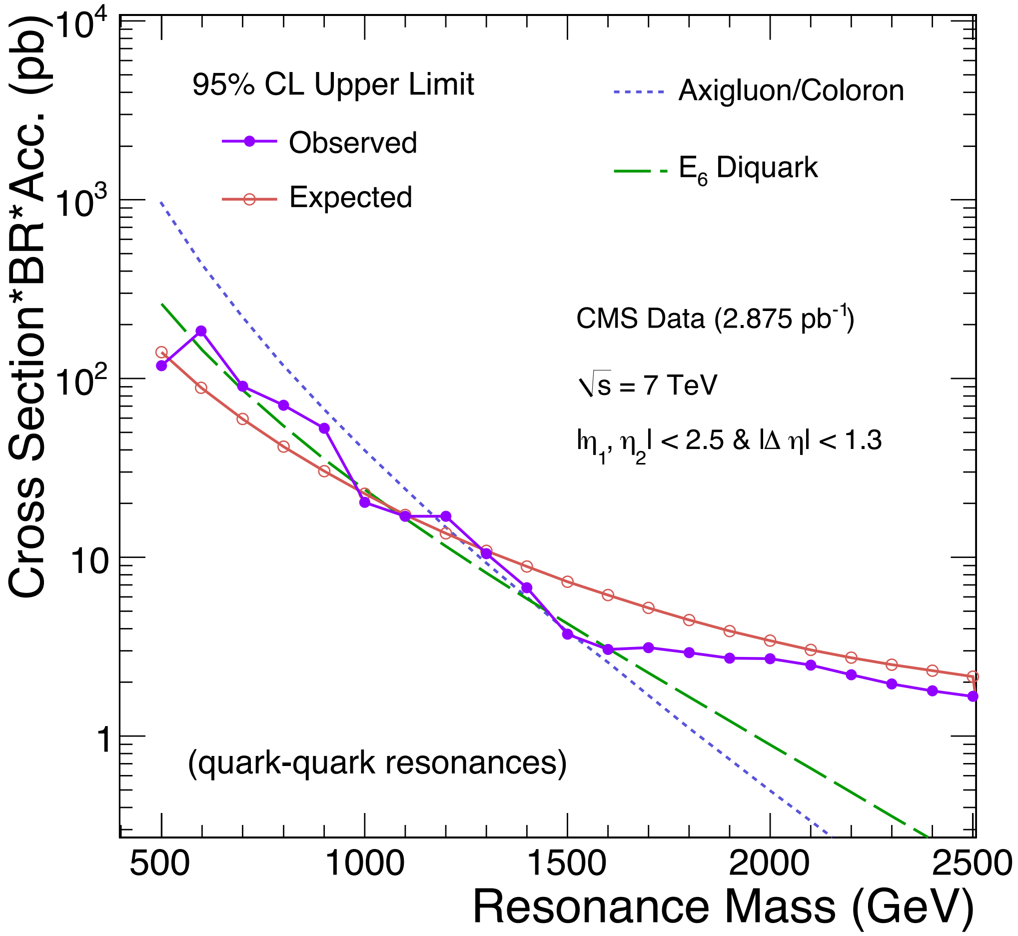


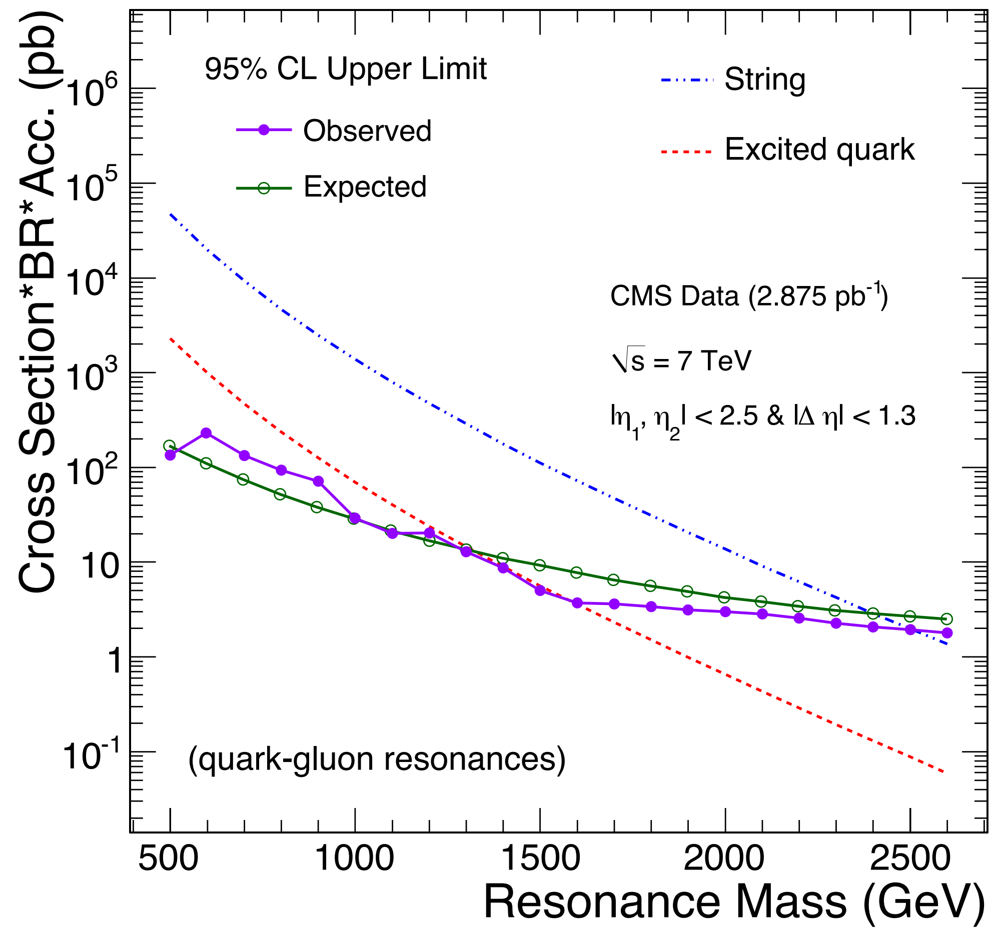
- The model cross section divided by the 95% CL upper limits on the cross section.

Published Limits



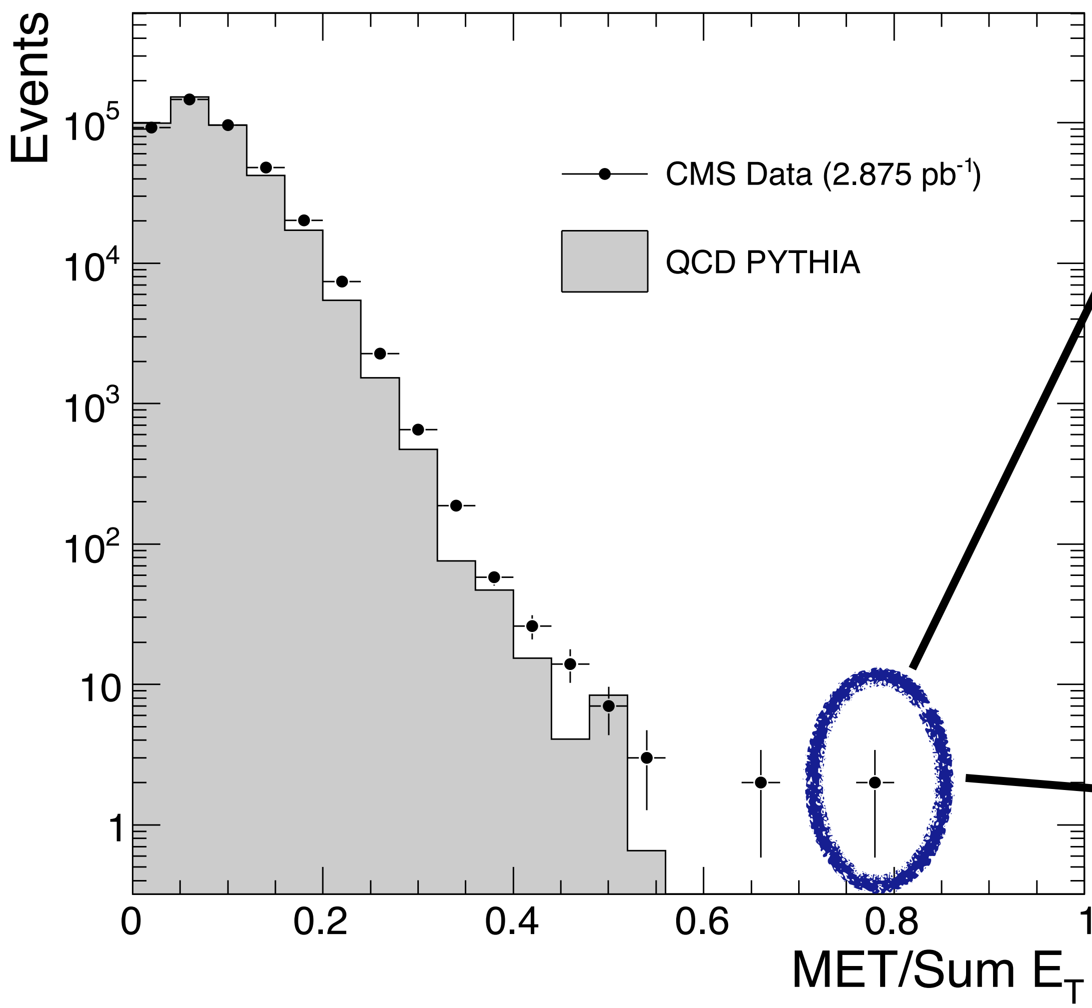
Expected Limits

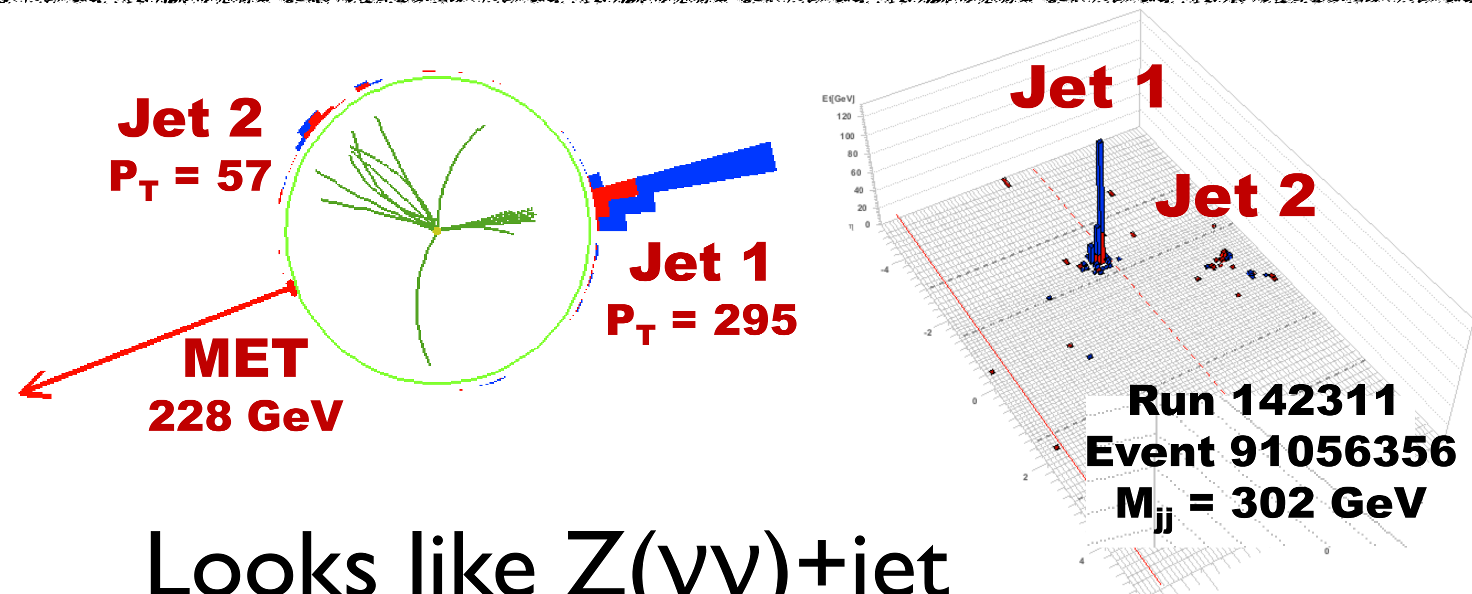




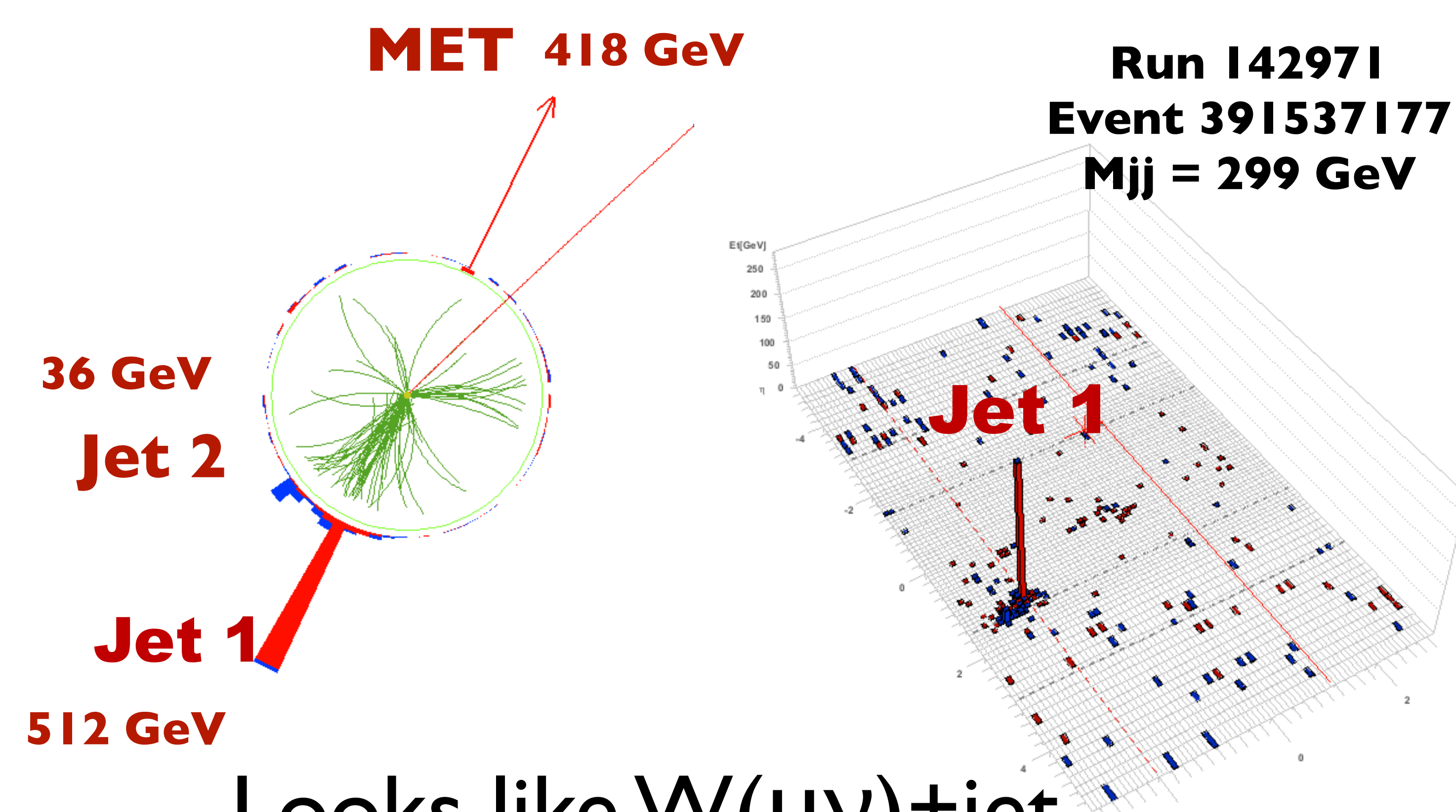
Model	Observed Mass Limit (Tev)		Expected Mass Limit (TeV)
	Including Systematics	Stat. Error Only	Including Systematics
String Resonance	$0.50 < M(S) < 2.50$	$0.50 < M(S) < 2.58$	$0.50 < M(S) < 2.40$
Excited Quark	$0.50 < M(q*) < 1.58$	$0.50 < M(q*) < 1.68$	$0.50 < M(q*) < 1.32$
Axigluon/Coloron	$0.50 < M(A) < 1.17$ & $1.47 < M(A) < 1.52$	$0.50 < M(A) < 1.63$	$0.50 < M(A) < 1.23$
E_6 Diquark	$0.50 < M(D) < 0.58$ & $0.97 < M(D) < 1.08$ & $1.45 < M(D) < 1.60$	$0.50 < M(A) < 0.87$ & $0.90 < M(D) < 1.19$ & $1.23 < M(D) < 1.70$	$0.50 < M(A) < 1.05$

Some Monojet Events





Looks like Z(νν)+jet



Looks like W(μν)+jet