# Dijet Resonance Search using Dijet Mass at 7 TeV

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# Outline

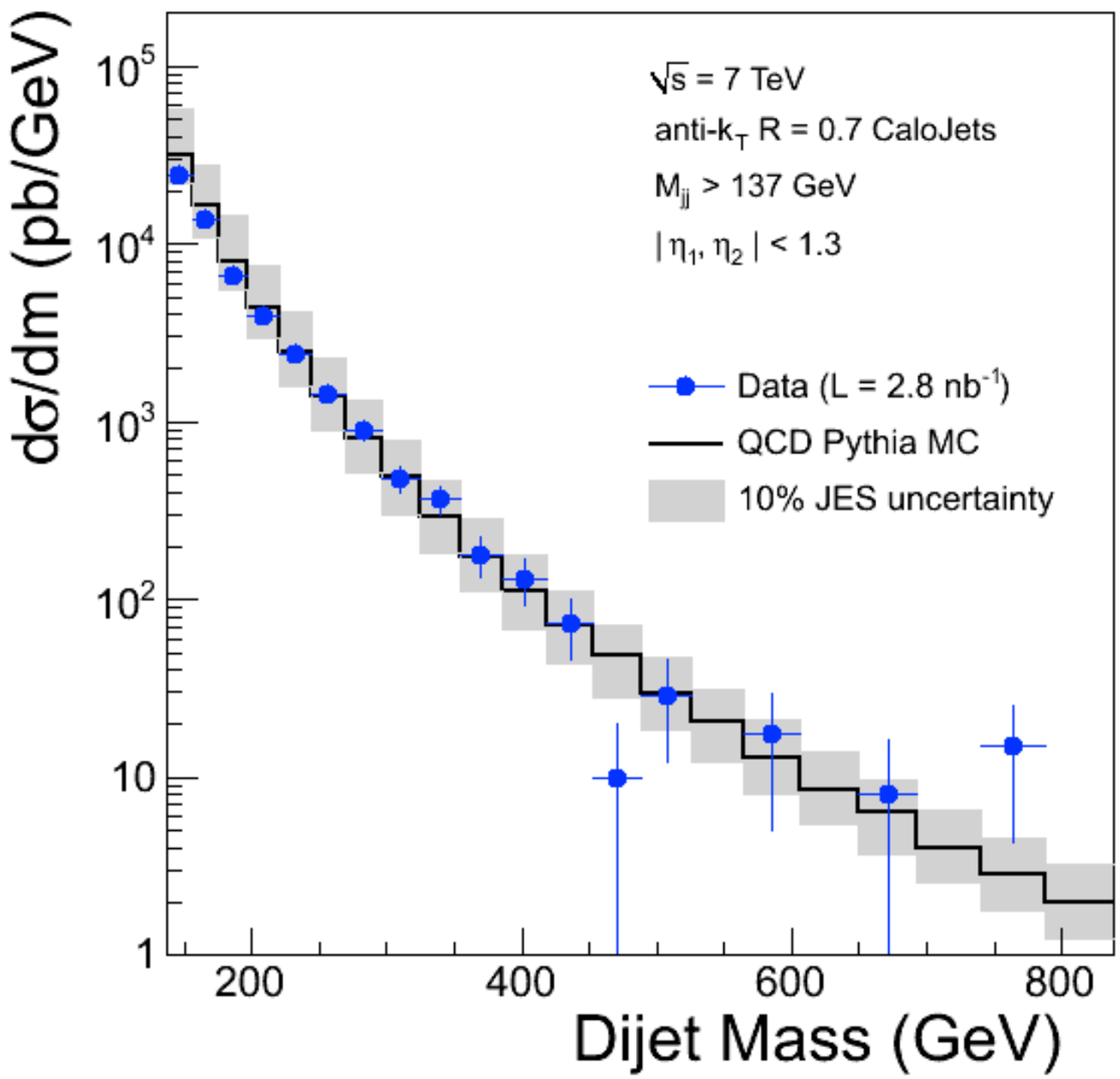
- Dijet Mass Data and QCD
- Dijet Mass Distribution and Fit
- Setting Early Limits on Dijet Resonances
- Expected Future Limits
- Conclusion

# Event Selection

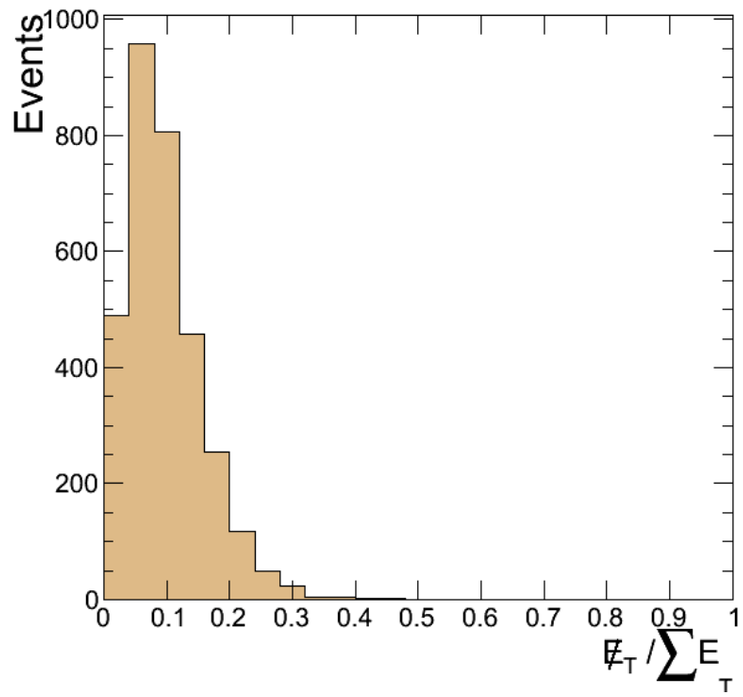
- Dataset
  - ✓ /MinimumBias/Commissioning10-PromptReco-v8/RECO (132599-133510)
  - ✓ /MinimumBias/Commissioning10-PromptReco-v9/RECO (133874-135175)
  - ✓ Run: 132599,132601,132602,132605,132606,132645-132648,132650-132654,132656,132658-132661,132958-132961,132965,133034,133035,133036,133038,133046,133158,133161,133320,133321,133324,133336,133446,133448,133450,133474,133483,133509,133510,133874,133875,133876,133877,133881,133885,133887,133881,133885,133887,133881,133885,133927,133928,135149,135175
  - ✓ Trigger bits: '0 AND (40 OR 41) AND NOT (36 OR 37 OR 38 OR 39)
  - ✓ HLT_MinBiasBSC (132599-133510),
  - ✓ HLT_L1Jet6U OR HLT_Jet15U OR HLT_Jet30U OR HLT_Jet50U (133874-135175)
  - ✓ Scrapping event removal
  - ✓ Estimated Luminosity: 2.84 $nb^{-1}$ (with 10-15% error)
- Event Selection
  - ✓ AK7caloJets
  - ✓ JEC: L2+L3, "Spring10"
  - ✓ Preselection: only jets with raw pt > 3 GeV & Mjj > 30 GeV (corrected)
  - ✓ |PVz| < 15 cm && PVndof >= 4
  - ✓ Both |Jet η|< 1.3
  - ✓ Both leading jets passing the "loose" jet id & Mjj > 137 GeV (corrected)
- Total: 3167 Dijet Events

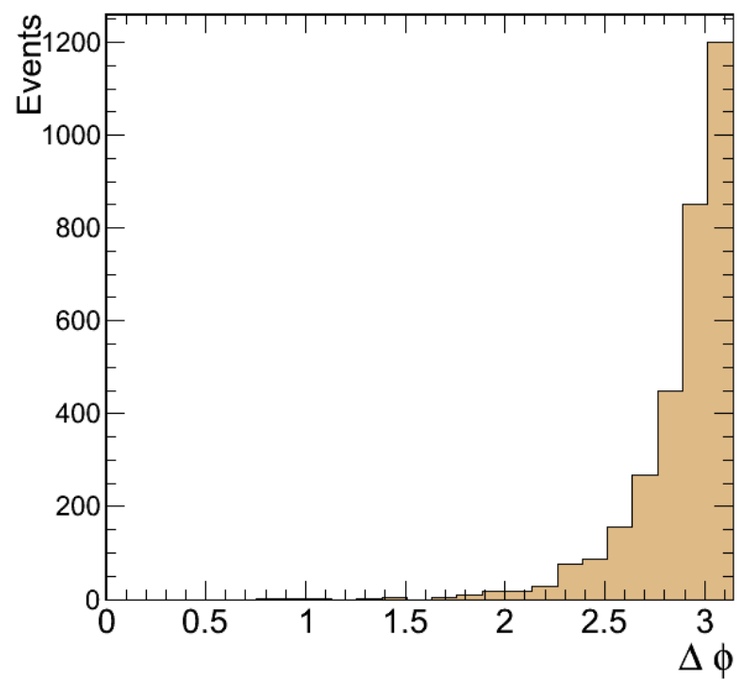
# Dijet Mass and QCD

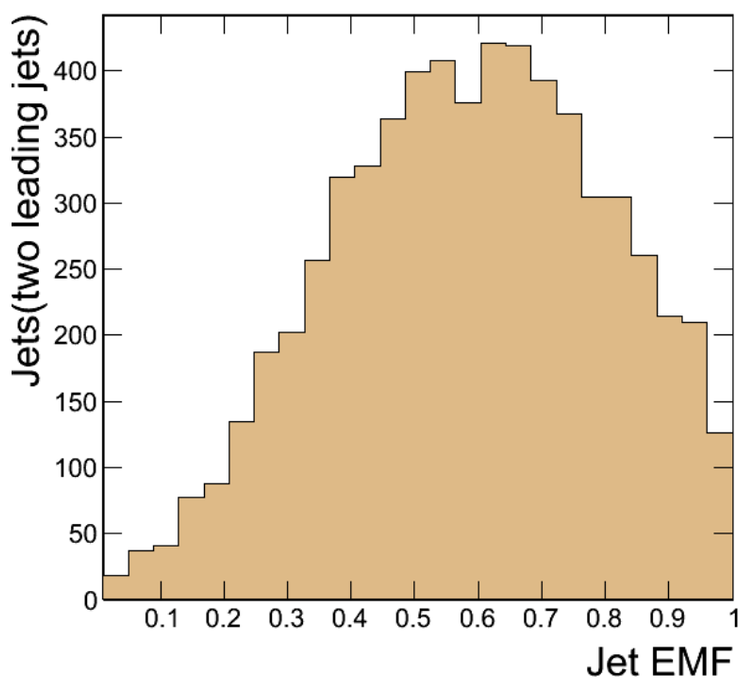
- The data is in good agreement with the full CMS simulation of QCD from PYTHIA.

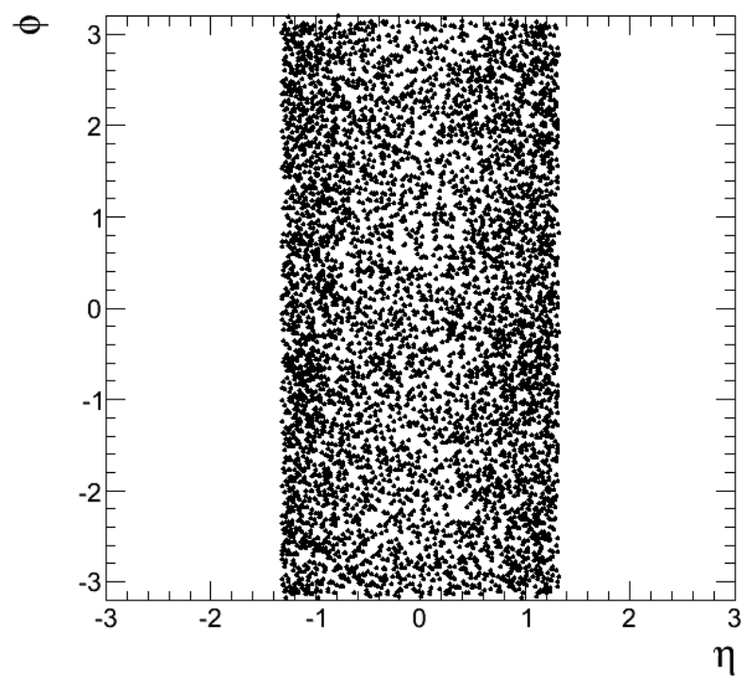


# Basic Jet Distributions



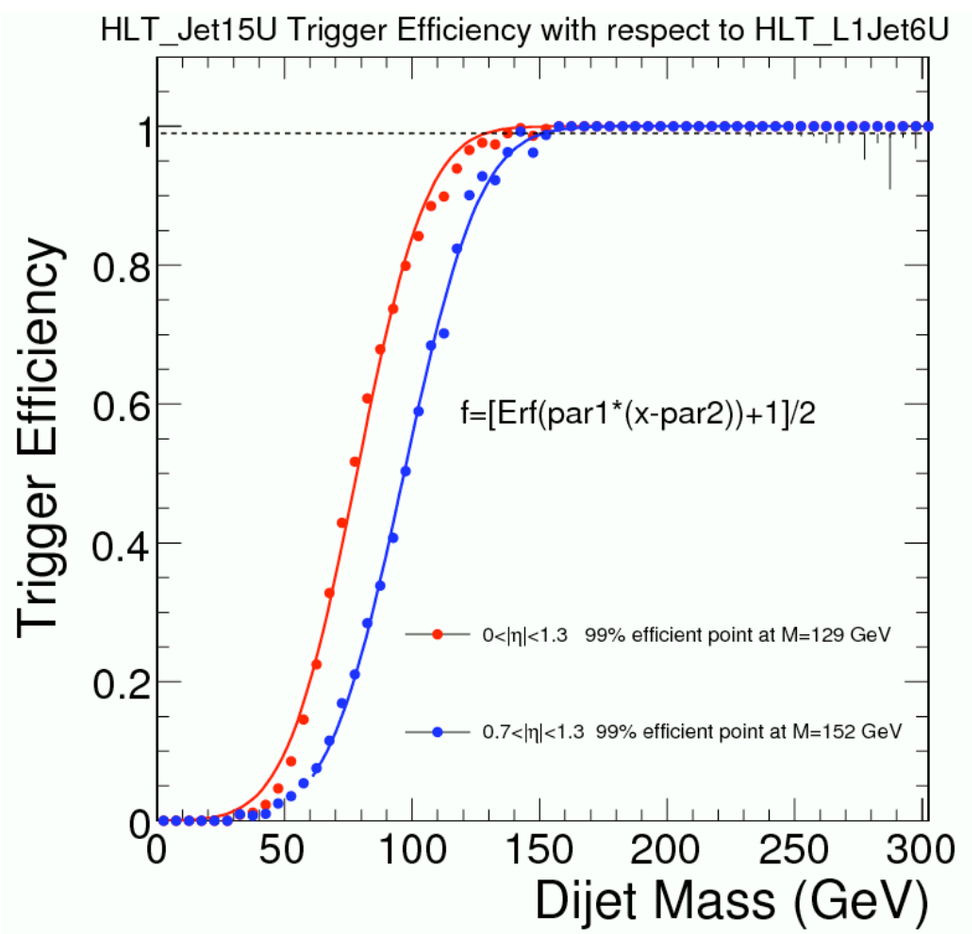



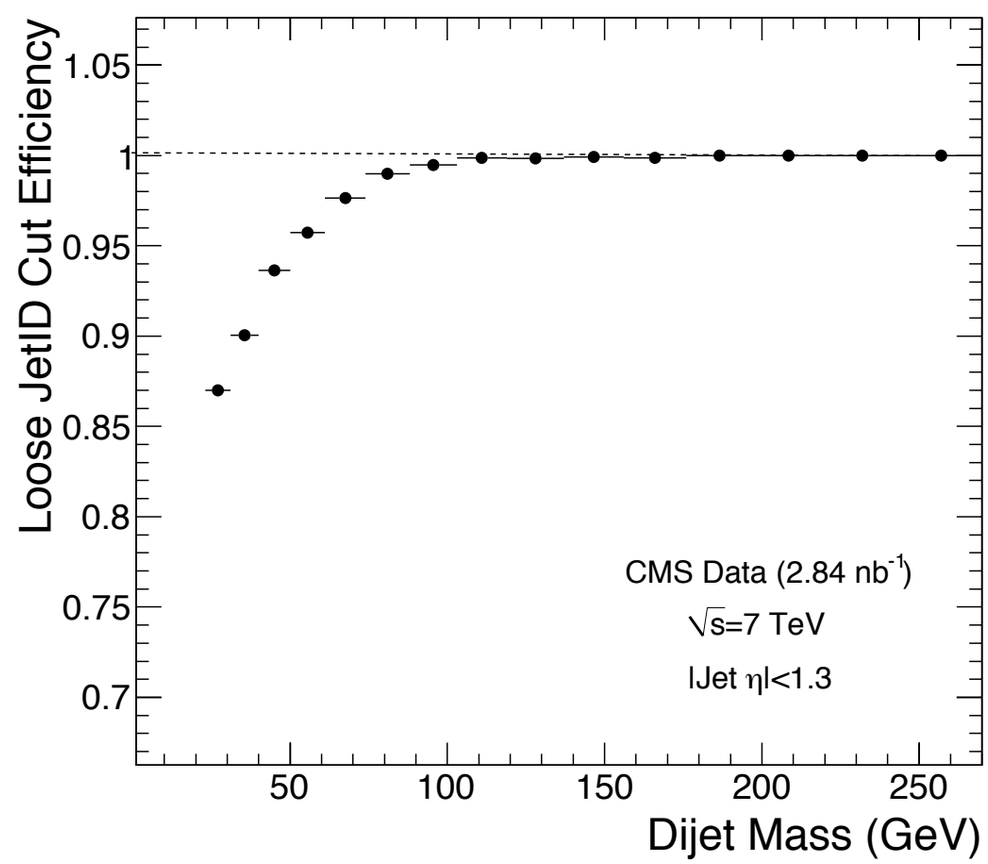




- Basic jet distributions look good.
  - ✓ Low MET
  - ✓ Back-to-Back in phi
  - ✓ No spike in EMF distribution
  - ✓ $\eta$-$\phi$ is uniform

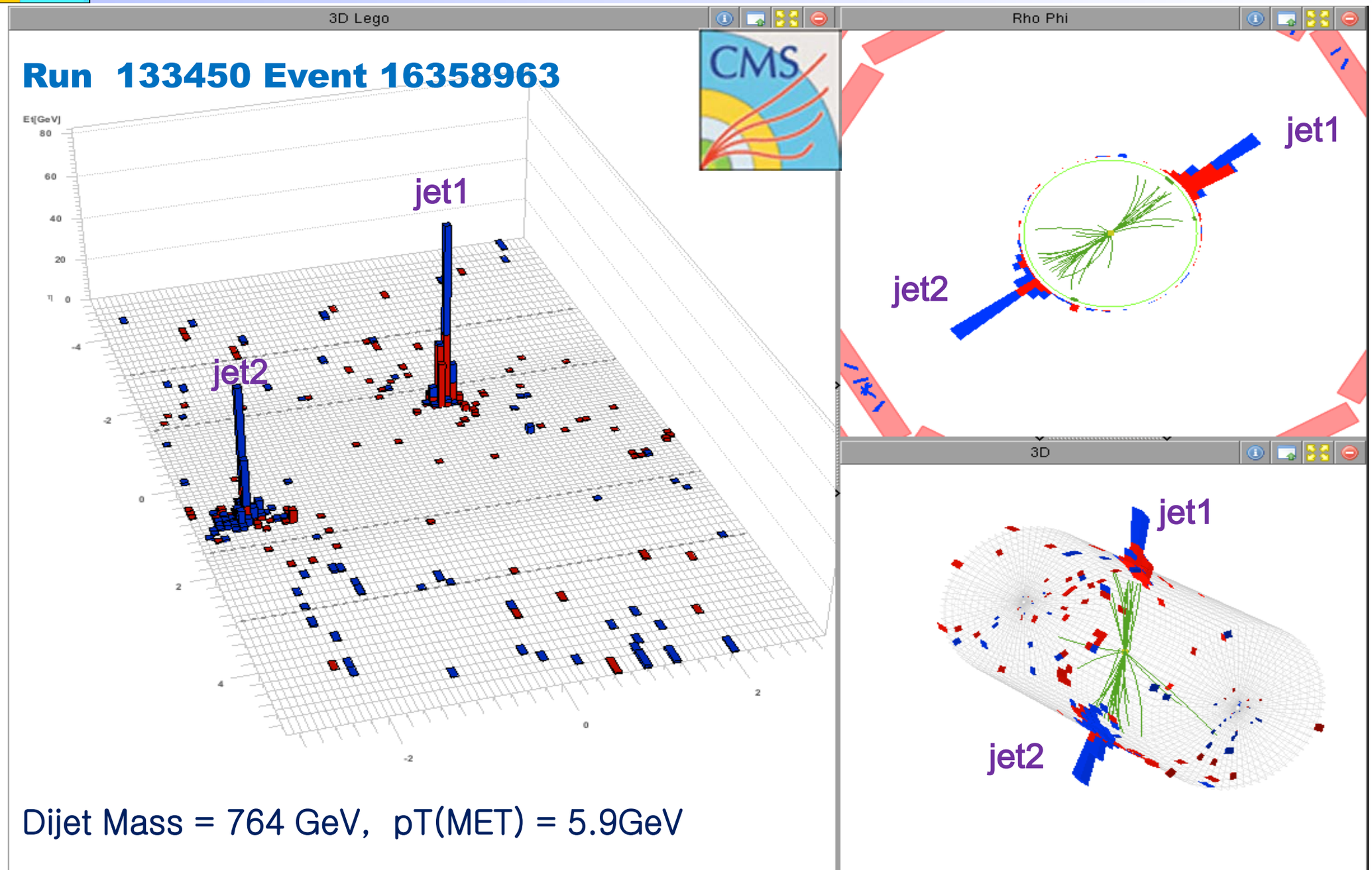
# Trigger and JetID Efficiencies

- The HLT_Jet15 trigger we are using is fully efficient
  - ✓ at $M_{jj}$=129 GeV for $|\eta|<1.3$ (for this analysis)
  - ✓ at $M_{jj}$=152 GeV for $0.7<|\eta|<1.3$ (for dijet ratio analysis)
- The loose JetID cut rejects only 2 events for $M_{jj}$>137 GeV leaving 3167 Dijet Events.



# High Mass Dijet Event




Dijet Mass = 764 GeV, pT(MET) = 5.9GeV

| Jets | $CorP_T$ (GeV) | η | Φ | n90hits | n90 | emf | nTrkCalo | fHPD | fRBX | met/sumet |
|---|---|---|---|---|---|---|---|---|---|---|
| Jet1 | 253 | -1.1 | 0.6 | 64 | 10 | 0.61 | 10 | 0.27 | 0.35 | 0.01 |
| Jet2 | 244 | 0.9 | -2.5 | 60 | 26 | 0.30 | 14 | 0.38 | 0.58 | |

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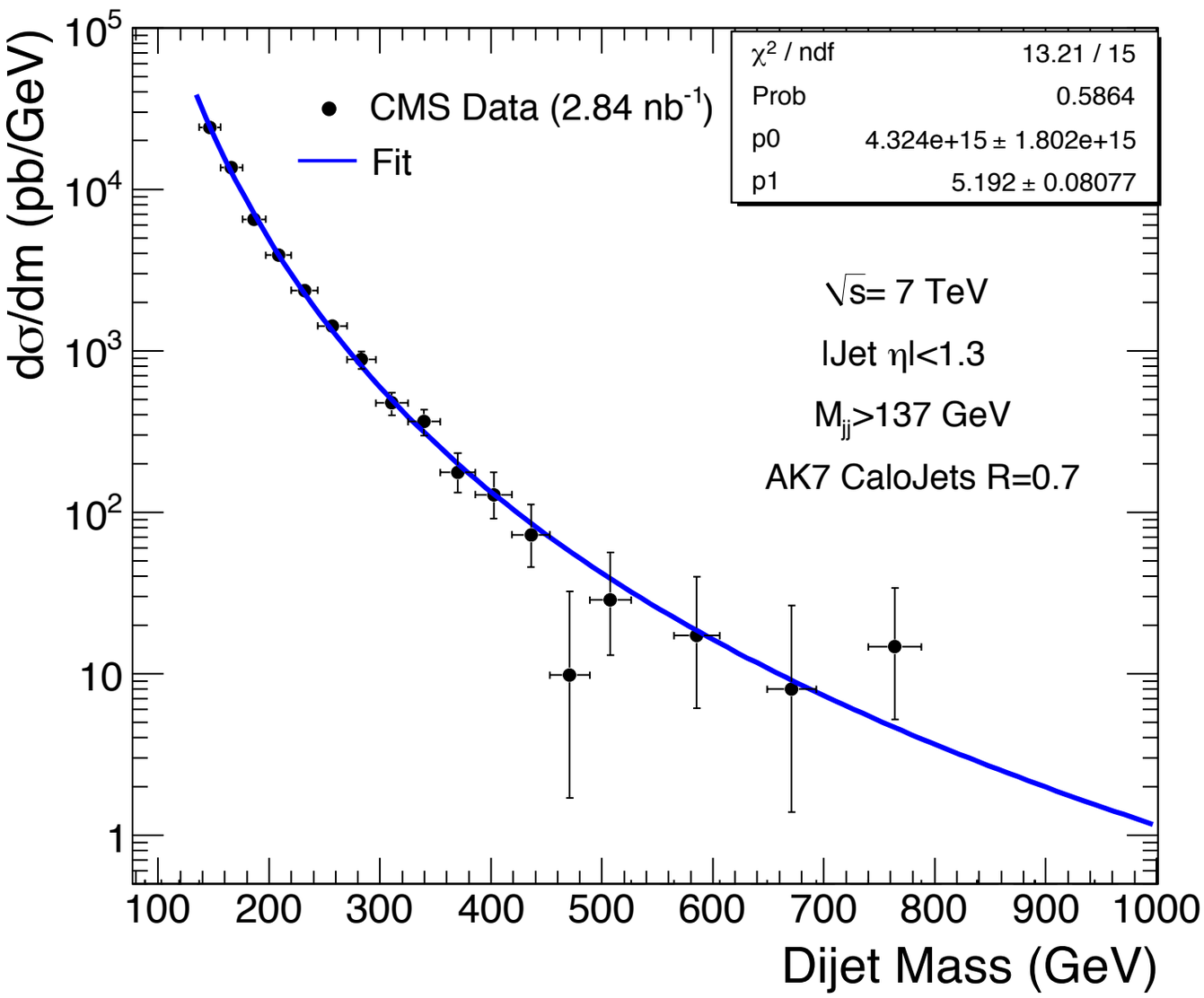
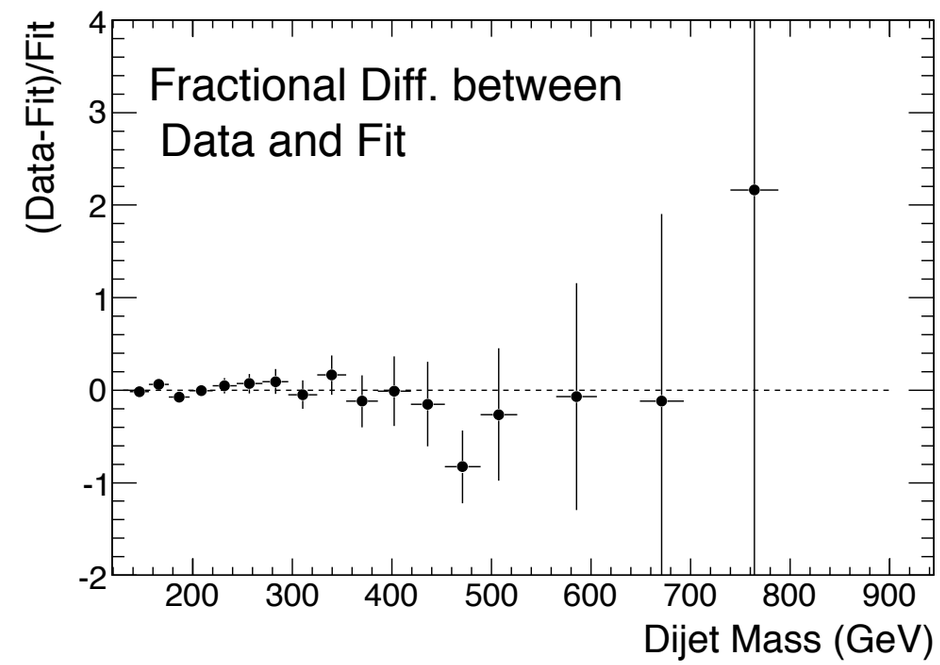
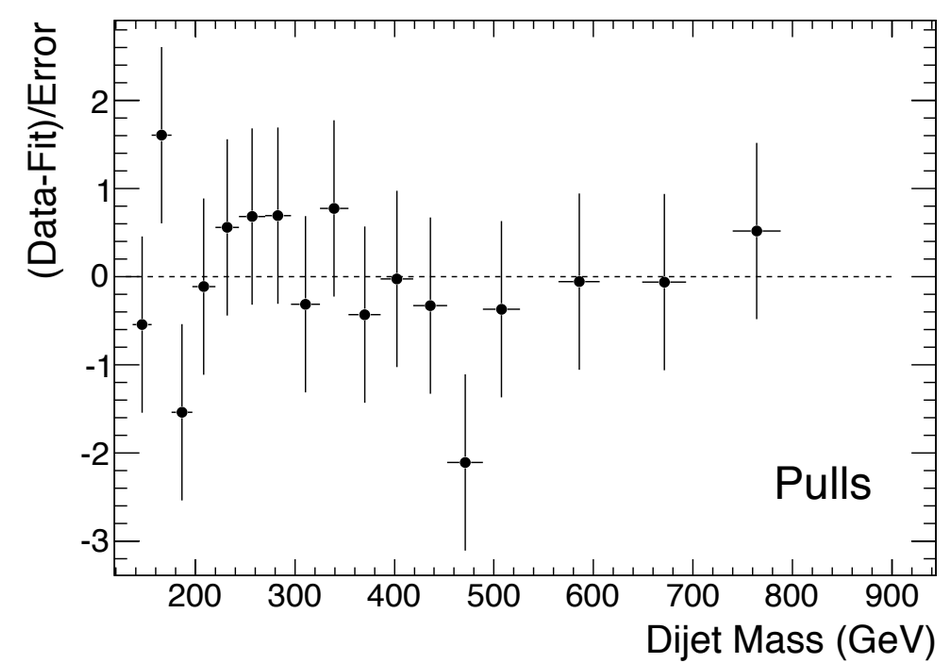
# Dijet Mass and Fit

- We fit the data with the function with $$\frac{d\sigma}{dm} = \frac{P_0}{m^{P_1}}$$
- We get a good fit.

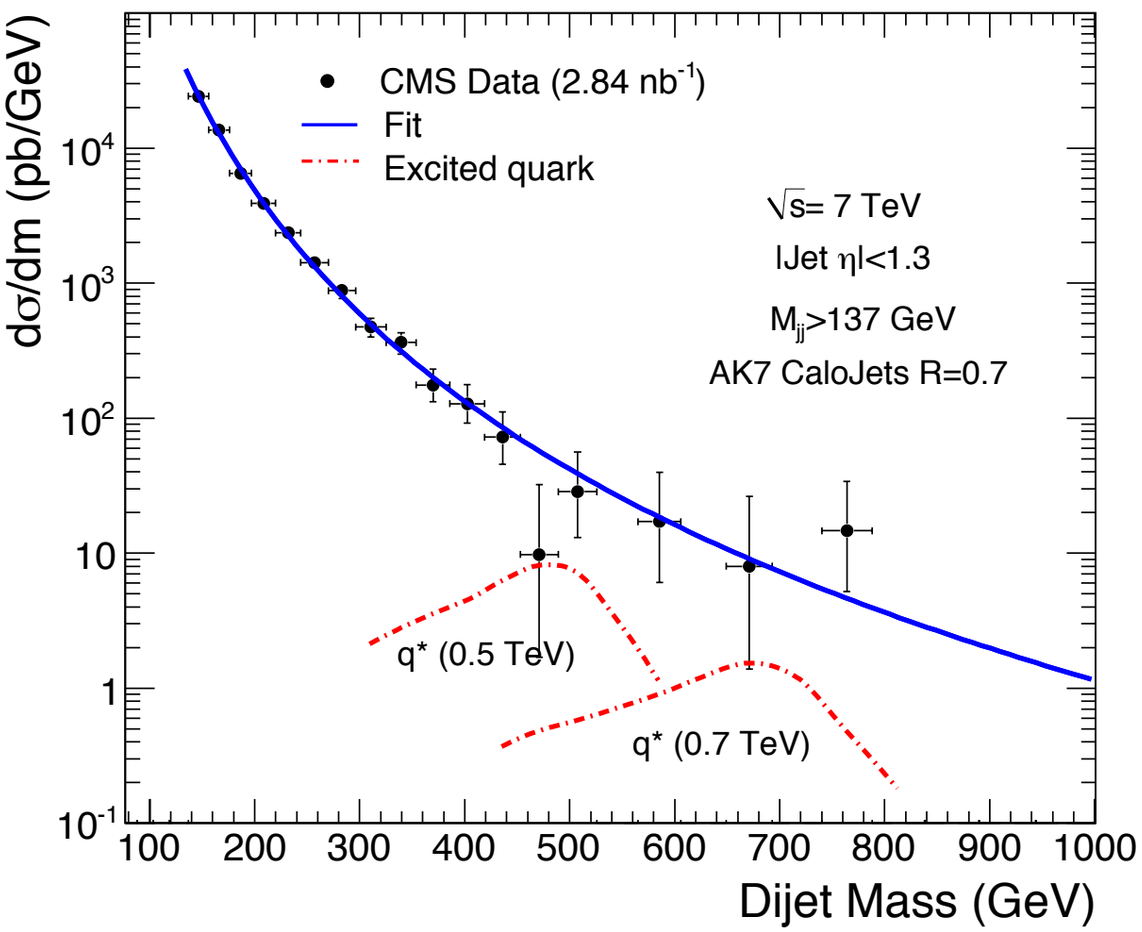


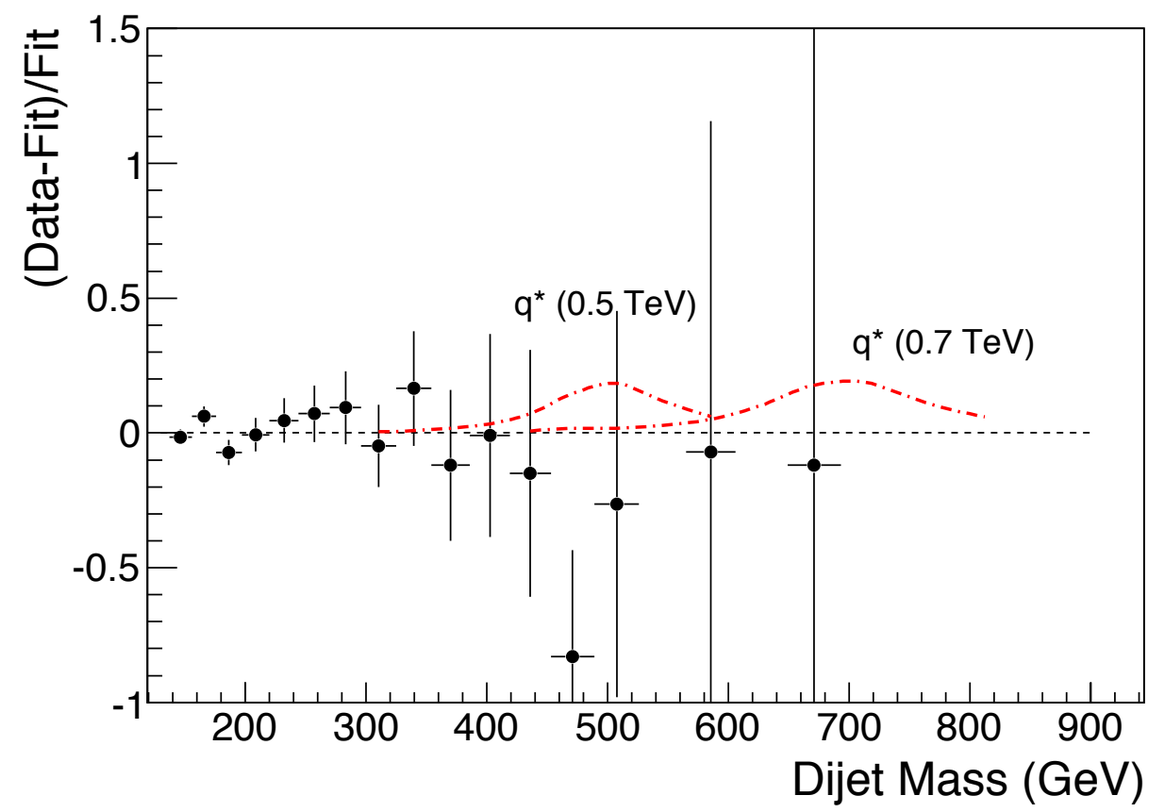



# Fit and Signal

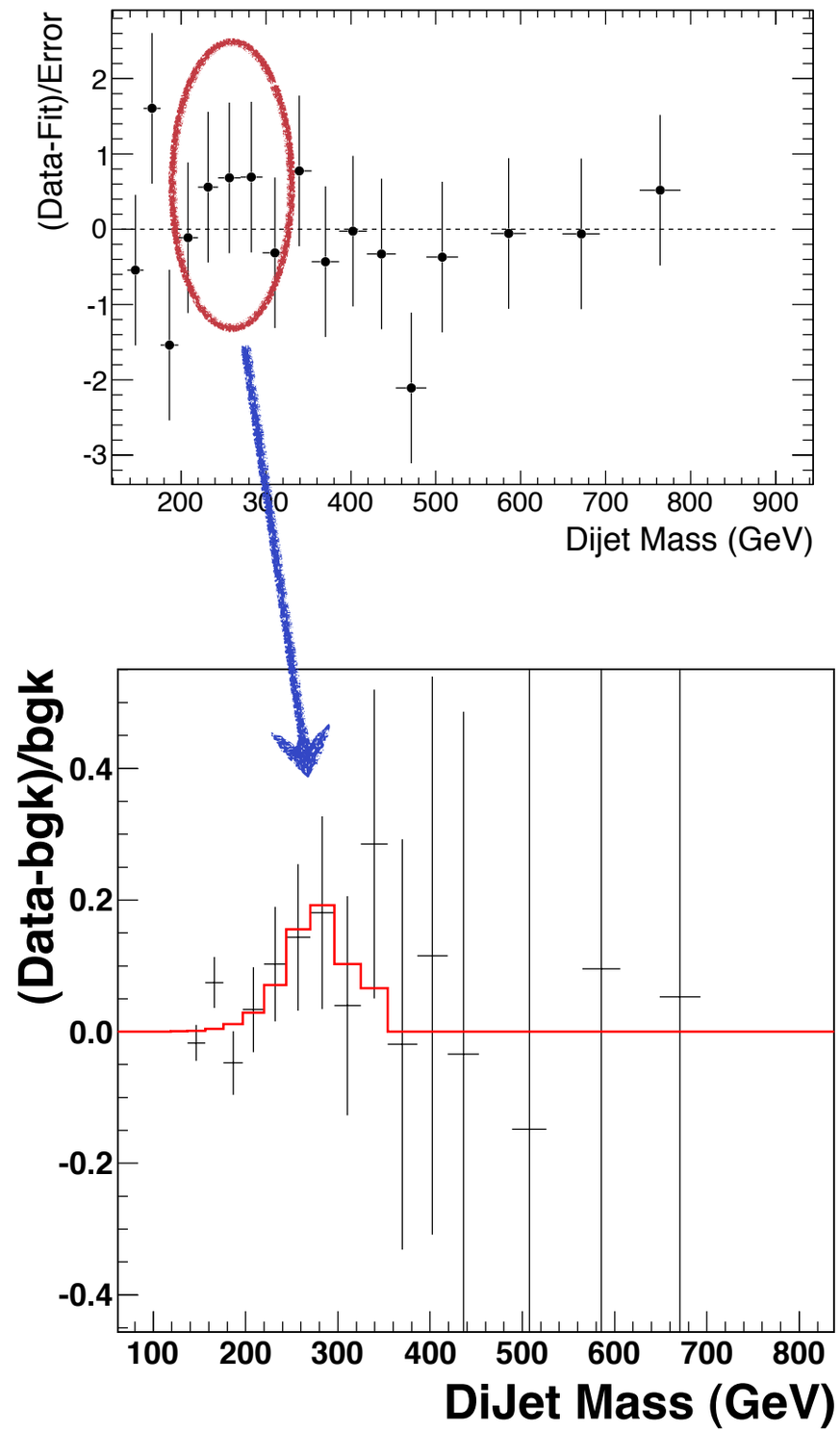
- We search for excited quark signal in our data.
- Simulation of Excited quark signals are shown at 0.5 TeV and 0.7 TeV.



# The Largest Fluctuation in Data

- Small fluctuation with shape of a resonance near 250 GeV
- Best fit resonance ($M_{jj}$=270 GeV) has significance only 1.4 sigma from log likelihood ratio.
- Significance reduced to just 0.4 sigma when including "look elsewhere" effect via a toy MC.



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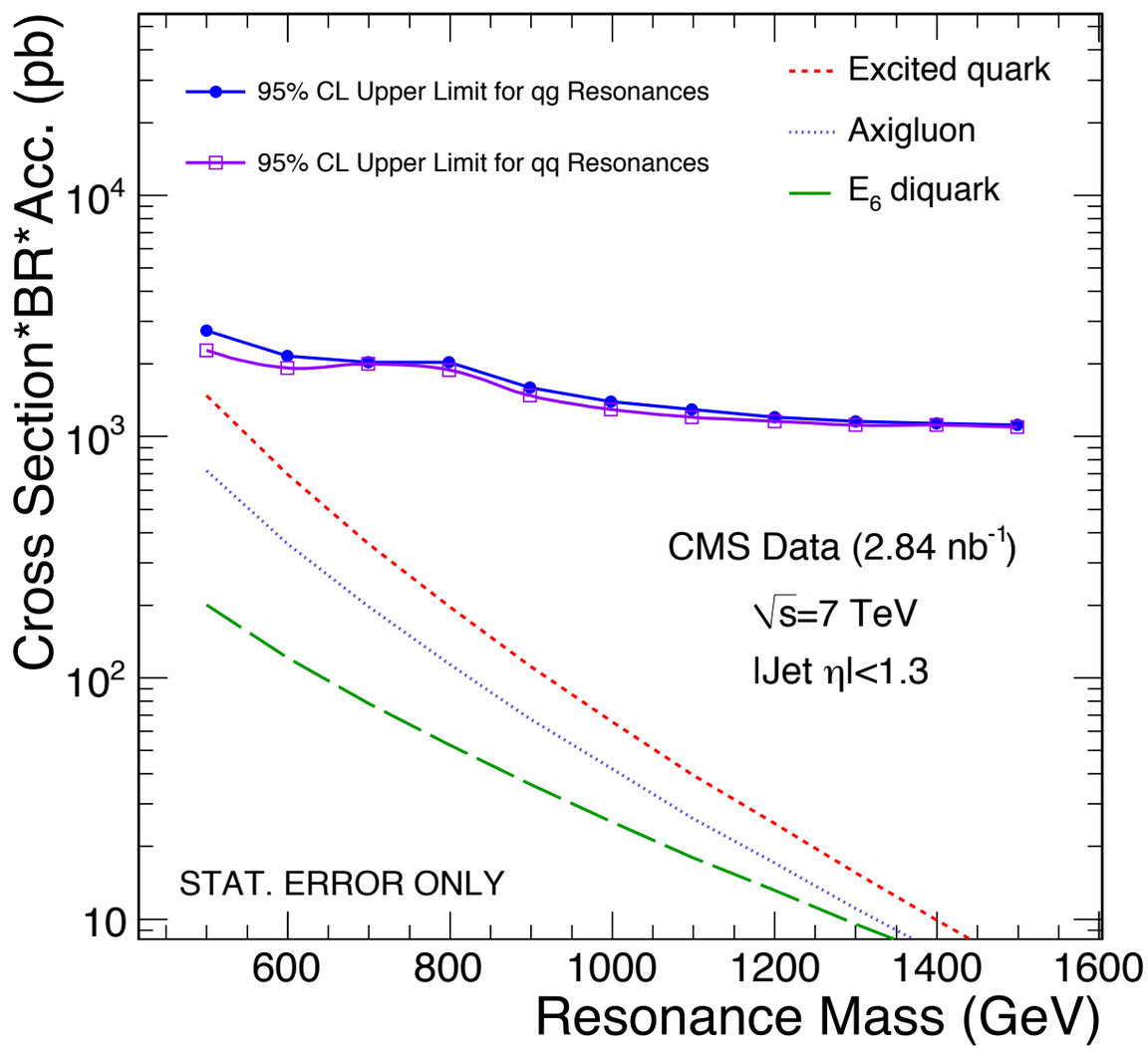
# Early Limits Stat. Error Only

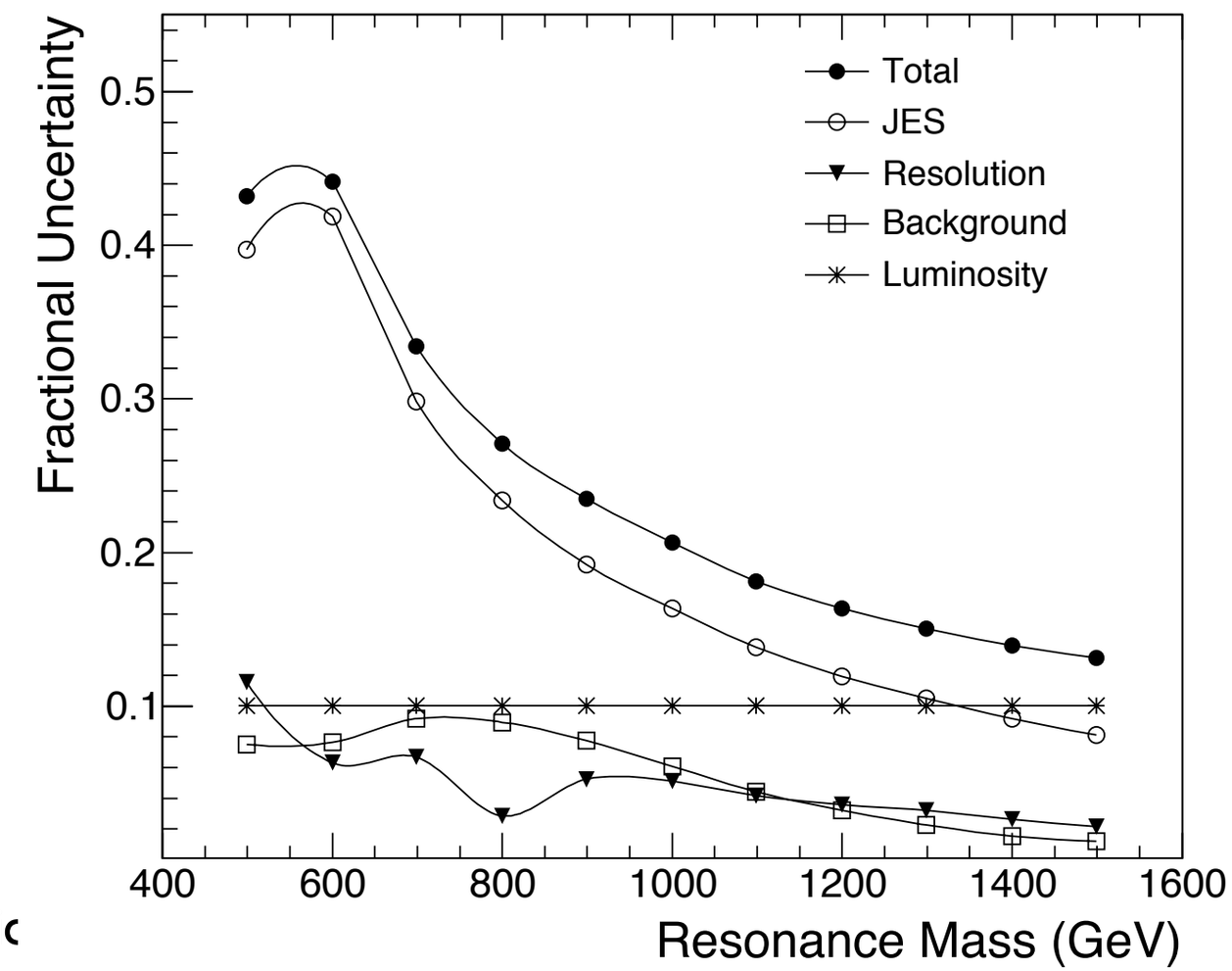
- To calculate limit on new particle cross section we use a binned likelihood by the Bayesian approach.
- 95% CL Upper limit with Stat. Error. Only compared to cross section for various model.
  - ✓ Show quark-gluon and quark-quark resonances separately. Difference is small.




| | 95% CL Upper Limit (pb) | |
|---|---|---|
| Mass (TeV) | quark-gluon | quark-quark |
| 0.5 | 2711 | 2270 |
| 0.6 | 2134 | 1893 |
| 0.7 | 2026 | 1995 |
| 0.8 | 2013 | 1866 |
| 0.9 | 1589 | 1461 |
| 1.0 | 1376 | 1288 |
| 1.1 | 1275 | 1201 |
| 1.2 | 1201 | 1150 |
| 1.3 | 1152 | 1115 |
| 1.4 | 1123 | 1096 |
| 1.5 | 1104 | 1084 |

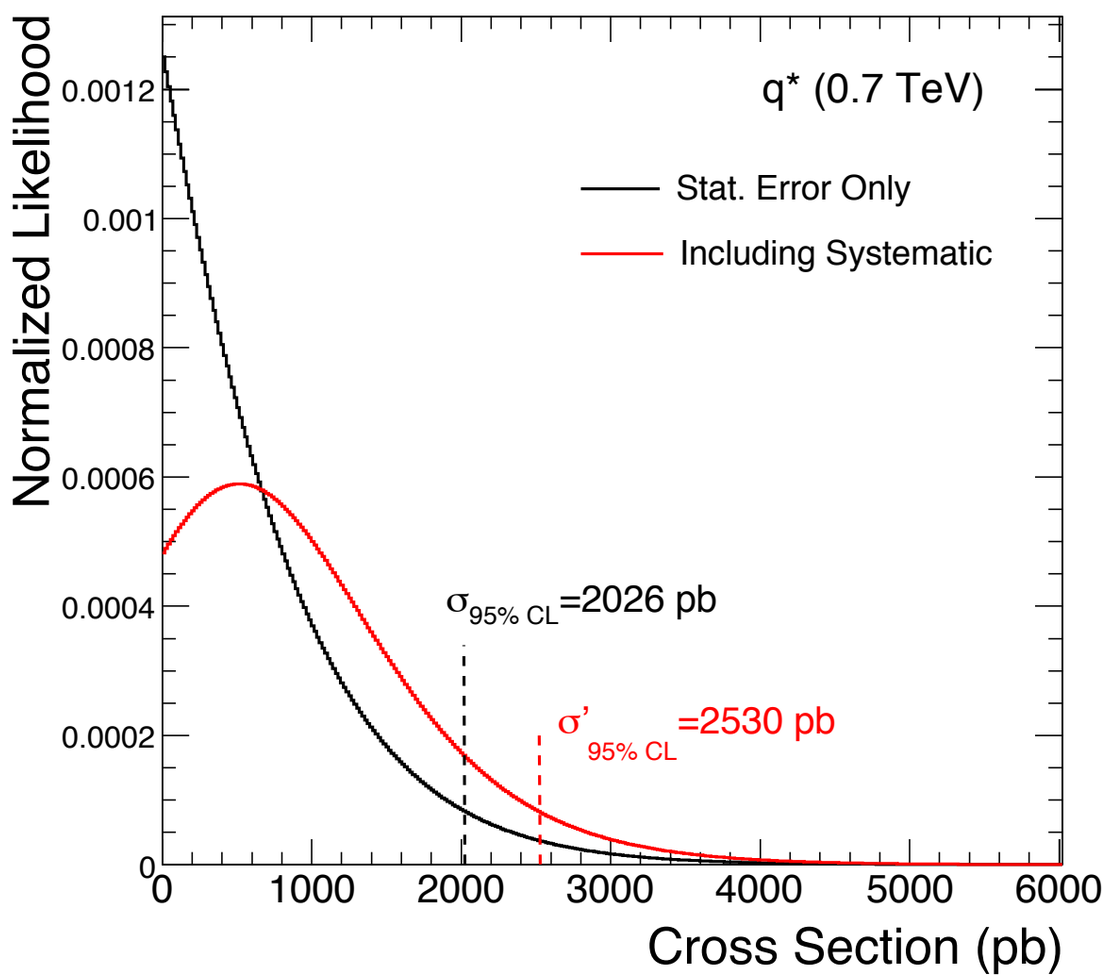
# Systematic Uncertainties

- We found the uncertainty in the dijet resonance cross section from following sources
  - ✓ Jet Energy Scale (JES)
    - Uncertainty assumed to be 10% at start-up
  - ✓ Jet Energy Resolution (JER)
    - Uncertainty assumed to be 10% at start-up
  - ✓ Choice of background parametrization
    - We consider more complex 4 functional form.
  - ✓ Luminosity
    - Uncertainty assumed to be 10% at start-up
- We add in quadrature the individual systematic uncertainties
  - ✓ Total systematic uncertainty varies from 45% at m=0.5 TeV to 15% at m=1.5 TeV



# Likelihood with Systematics

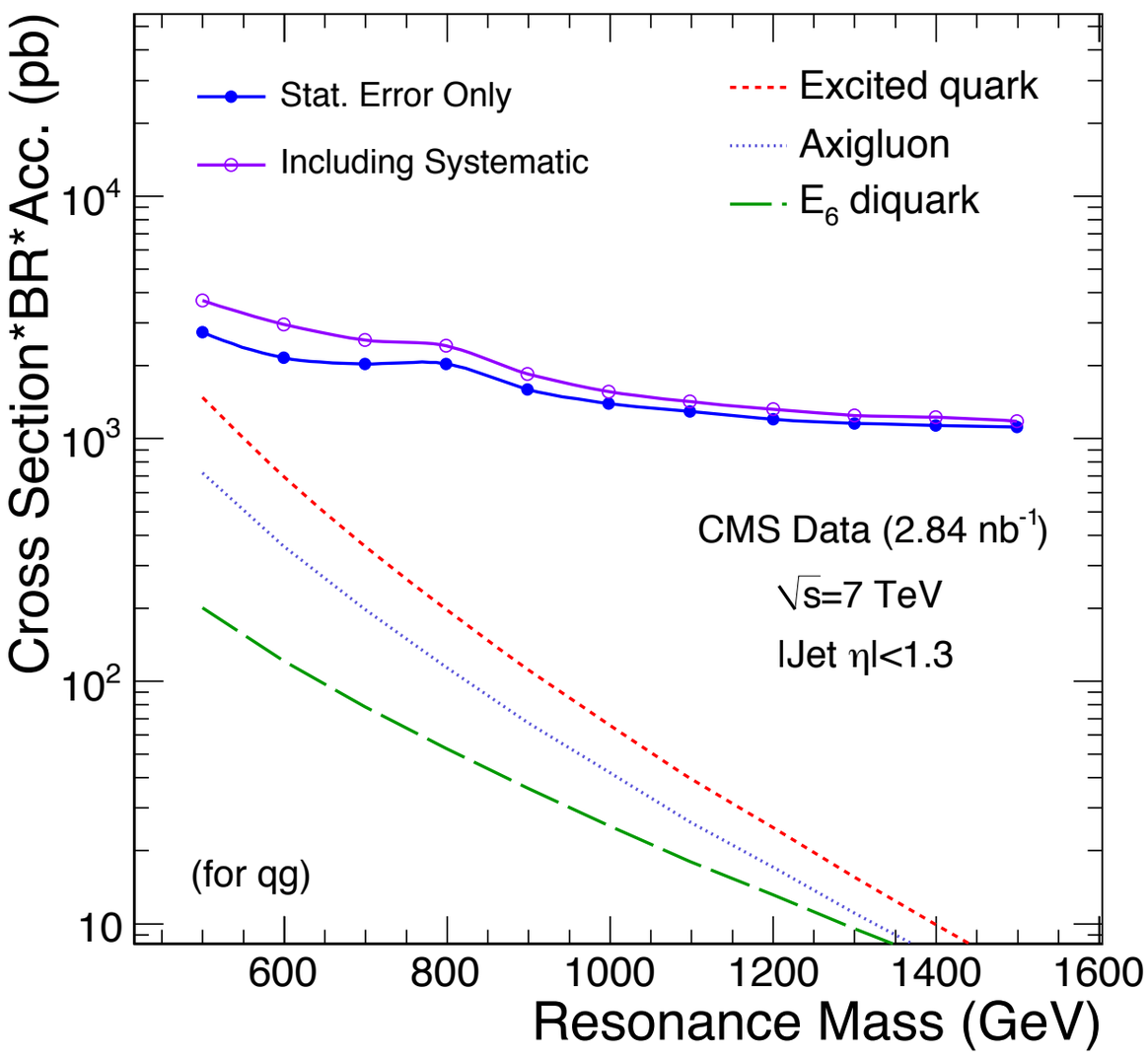
- We convolute Poisson likelihoods with Gaussian systematics uncertainties.
  - ✓ Total likelihood including systematics is broader and gives higher upper limit.




$$\frac{\int_0^{\sigma_{95}} L(\sigma)d\sigma}{\int_0^{\infty} L(\sigma)d\sigma} = 0.95$$

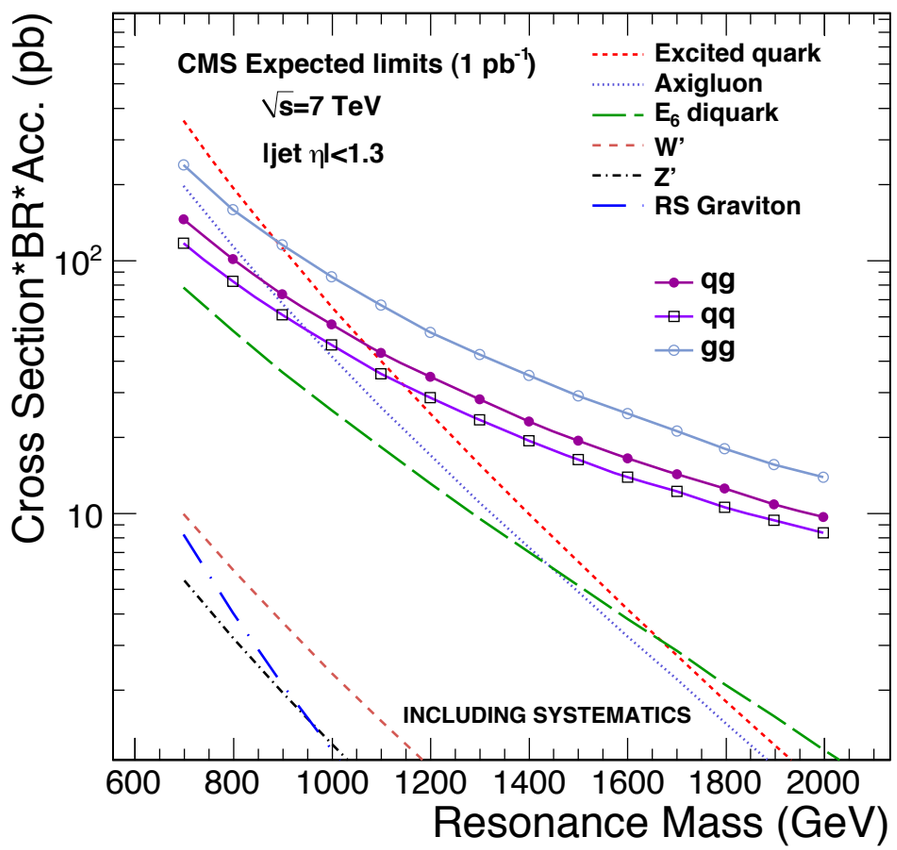
# Early Limits on Dijet Resonances

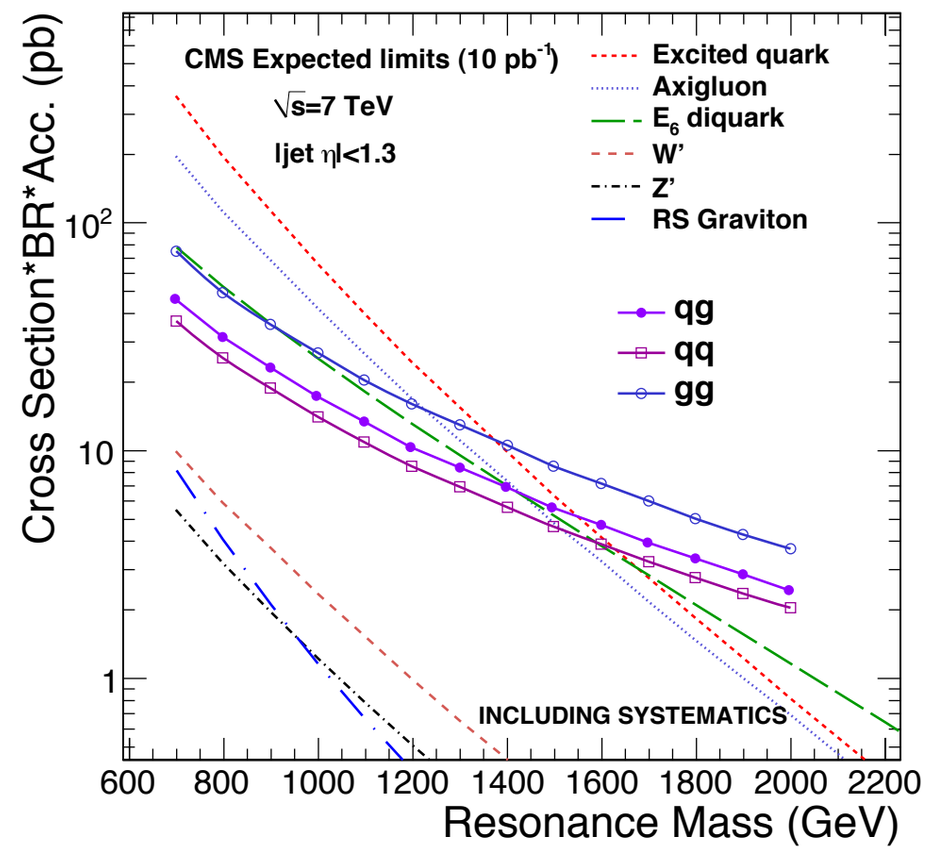
- We have a look at early limit for q* in the data with 2.84 $nb^{-1}$
  - ✓ 95% CL Upper limit with Stat. Error. Only and Including Sys. Uncertainties are shown separately.
  - ✓ qq resonance limits, in backup, are similar.




| | 95% CL Upper Limit (pb) (for qg) | |
|---|---|---|
| Mass (TeV) | Stat. Error Only | Inc. Systematics |
| 0.5 | 2711 | 3710 |
| 0.6 | 2134 | 2957 |
| 0.7 | 2026 | 2530 |
| 0.8 | 2013 | 2369 |
| 0.9 | 1589 | 1822 |
| 1.0 | 1376 | 1549 |
| 1.1 | 1275 | 1410 |
| 1.2 | 1201 | 1313 |
| 1.3 | 1152 | 1240 |
| 1.4 | 1123 | 1203 |
| 1.5 | 1104 | 1178 |

# Expected Future Limits



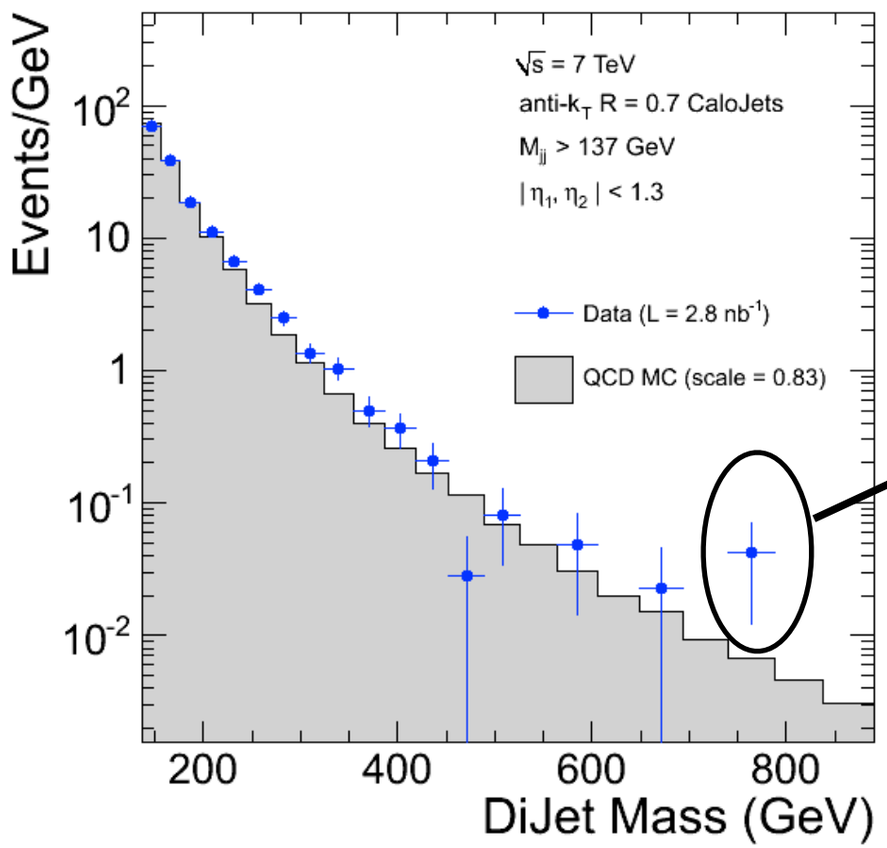

| 95% C.L. Excluded Mass (TeV) | | | | | |
|---|---|---|---|---|---|
| Model | CMS (Expected at 7TeV) | | | | CDF (Excluded at1.96 TeV) |
| | 1 pb$^{-1}$ | 10 pb$^{-1}$ | 100 pb$^{-1}$ | 1 fb$^{-1}$ | 1 fb$^{-1}$ |
| Excited quark | 1.06 | 1.55 | 2.05 | 2.55 | M<0.87 |
| Axigluon/Coloron | 0.95 | 1.51 | 2.07 | 2.57 | M<1.25 |
| E6 Diquark | N/A | 1.60 | 2.44 | 3.1 | M<0.63 |

# Conclusion

- We have a dijet mass spectrum that extends to 760 GeV with ~2.8 $nb^{-1}$ data.
- The dijet mass data is in reasonable agreement with the PYTHIA MC prediction
- The data is well fit by a simple power law.
- We have limits on dijet resonance cross section including systematics.
- We expect to start setting mass limit with ~10 $nb^{-1}$ and reach the Tevatron q* limit with ~100 $nb^{-1}$.
- Analysis note AN 2010/108 based on ~1 $nb^{-1}$ is available and will be updated periodically.

# Back-Up Slides

# Comparison Limits




| | $1-\alpha$ =90% | | $1-\alpha$ =95% | |
|---|---|---|---|---|
| $n$ | $\nu_{\rm lo}$ | $\nu_{\rm up}$ | $\nu_{\rm lo}$ | $\nu_{\rm up}$ |
| 0 | – | 2.30 | – | 3.00 |
| 1 | 0.105 | 3.89 | 0.051 | 4.74 |
| 2 | 0.532 | 5.32 | 0.355 | 6.30 |
| 3 | 1.10 | 6.68 | 0.818 | 7.75 |
| 4 | 1.74 | 7.99 | 1.37 | 9.15 |
| 5 | 2.43 | 9.27 | 1.97 | 10.51 |
| 6 | 3.15 | 10.53 | 2.61 | 11.84 |
| 7 | 3.89 | 11.77 | 3.29 | 13.15 |
| 8 | 4.66 | 12.99 | 3.98 | 14.43 |
| 9 | 5.43 | 14.21 | 4.70 | 15.71 |
| 10 | 6.22 | 15.41 | 5.43 | 16.96 |

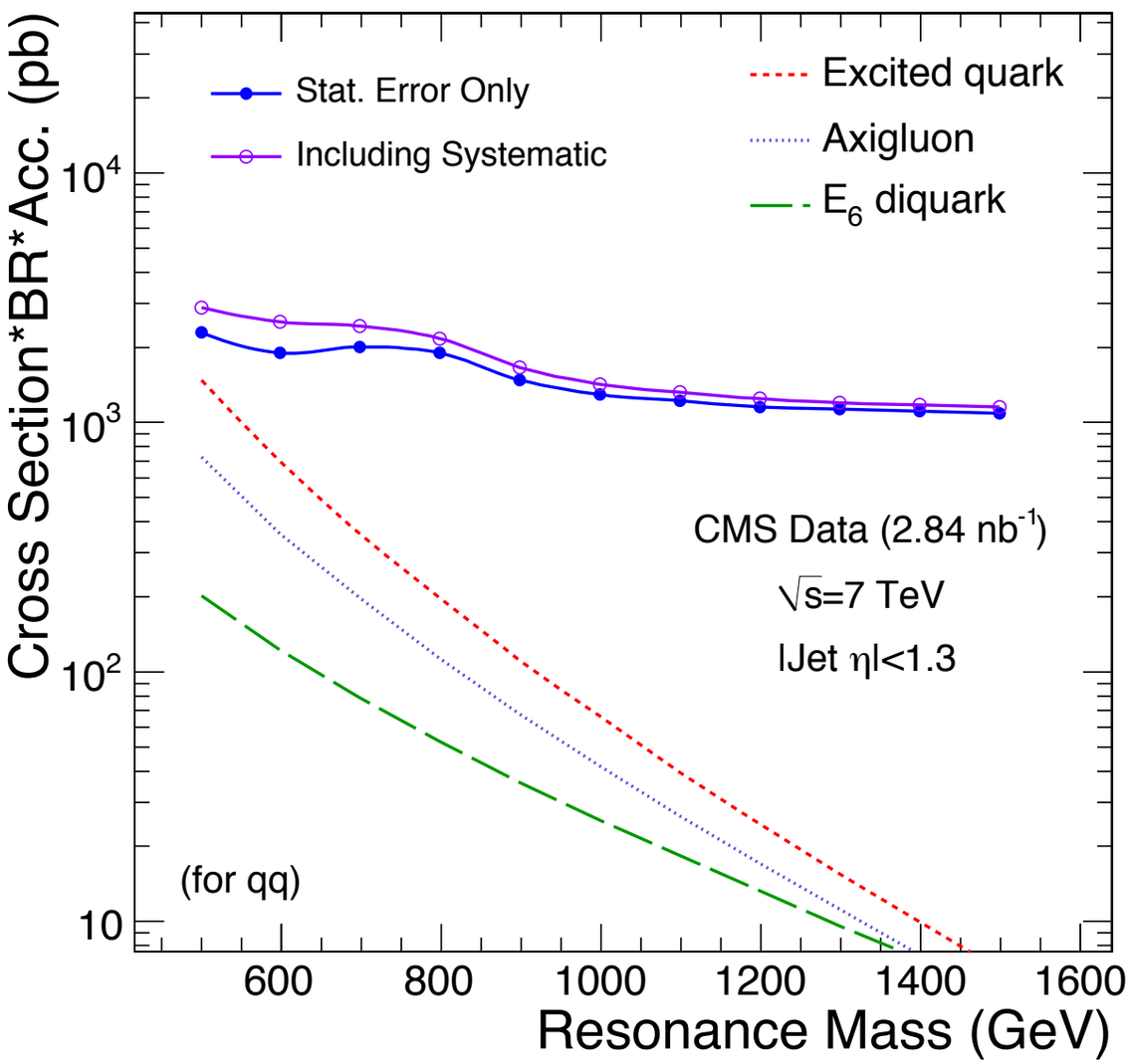
- 95% C.L. upper limit at high mass is roughly what we expect for two observed event at around 800 GeV

(6.30 events)/(2.84 $nb^{-1}$) = 2218 pb

| | 95% CL Upper Limit (pb) | |
|---|---|---|
| Mass (TeV) | Stat. Error. Only | Inc. Systematics |
| 0.8 | 2013 | 2369 |

# Early Limits on Dijet Resonances for qq

- We have a look at early limit for qq resonaces in the data with 2.84 $nb^{-1}$
  - ✓ 95% CL Upper limit with Stat. Error. Only and Including Sys. Uncertainties are shown separately




| | 95% CL Upper Limit (pb) (for qq) | |
|---|---|---|
| Mass (TeV) | Stat. Error Only | Inc. Systematic |
| 0.5 | 2270 | 2890 |
| 0.6 | 1893 | 2500 |
| 0.7 | 1995 | 2419 |
| 0.8 | 1866 | 2150 |
| 0.9 | 1461 | 1649 |
| 1.0 | 1288 | 1417 |
| 1.1 | 1201 | 1306 |
| 1.2 | 1150 | 1240 |
| 1.3 | 1115 | 1195 |
| 1.4 | 1096 | 1169 |
| 1.5 | 1084 | 1153 |

# Setting Limits

- To calculate limit on new particle cross section we use a binned likelihood by the Bayesian approach.

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

Measured # of events in data

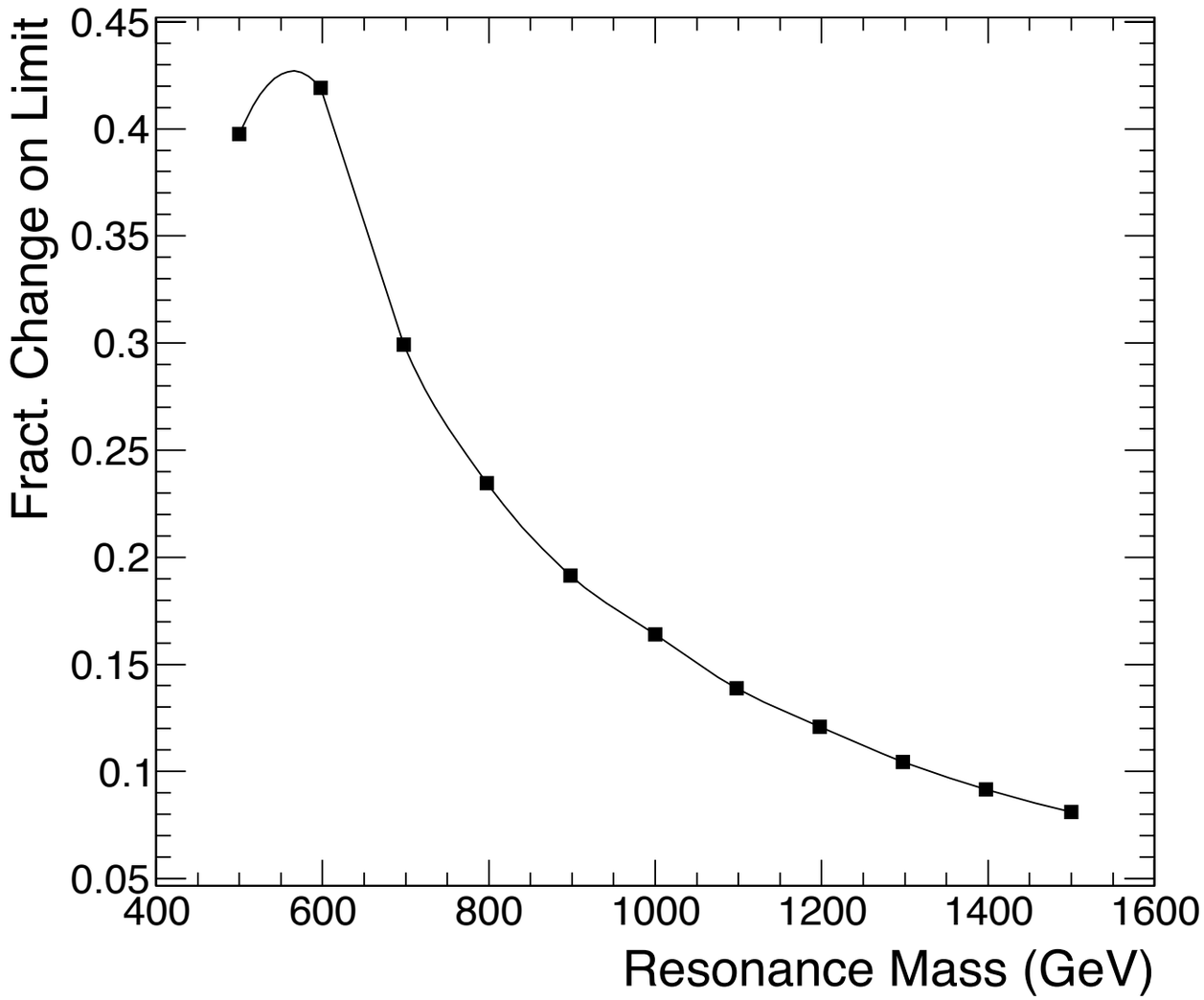
# of event from signal

Expected # of event from background

- The signal comes from our dijet resonance shapes for q*.
- The background comes from fit.

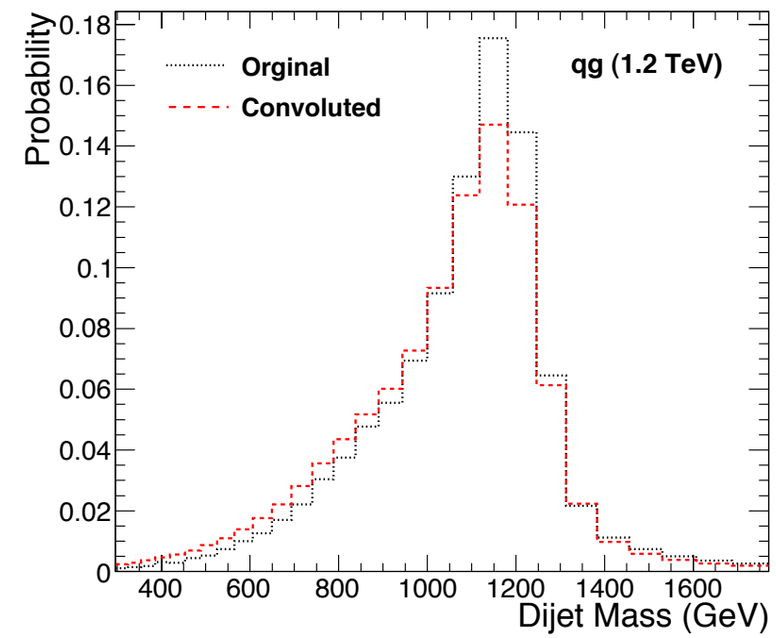
# Jet Energy Scale (JES)

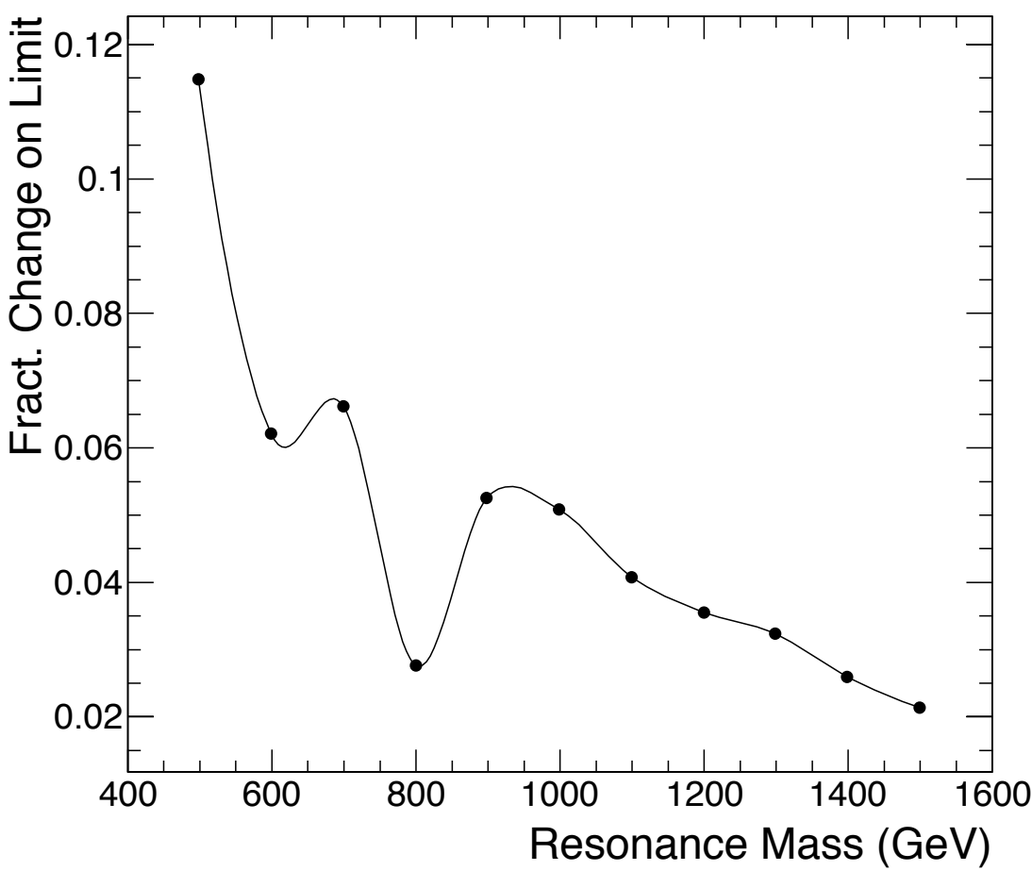
- Systematic uncertainty in jet energy is roughly 10% startup
  - ✓ We have decreased the mass of dijet resonance by 10%
  - ✓ This increases the background in the region of resonance, giving a worse limit.
  - ✓ Systematic uncertainty varies
    - from 45% at 0.5 TeV to 10% at 1.5 TeV.

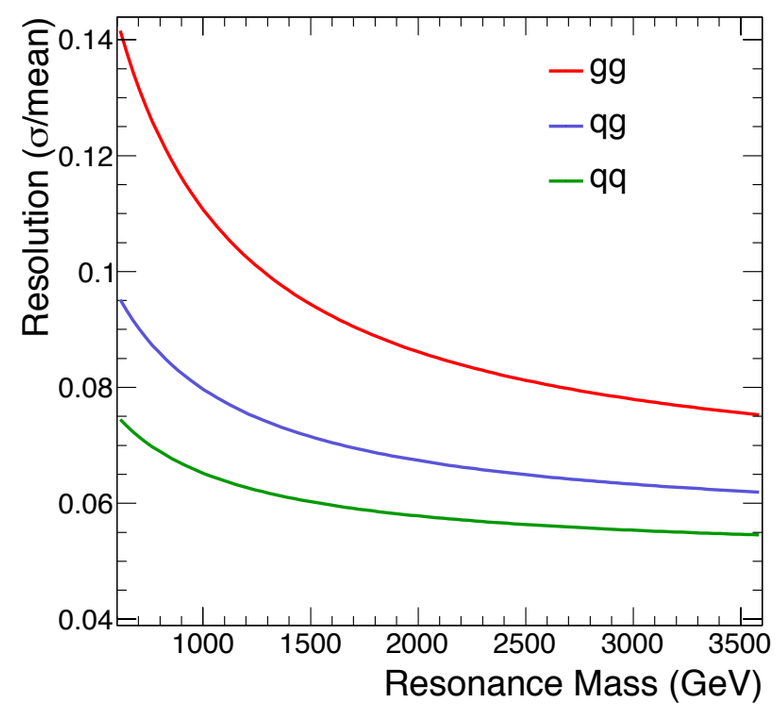


# Jet Energy Resolution (JER)

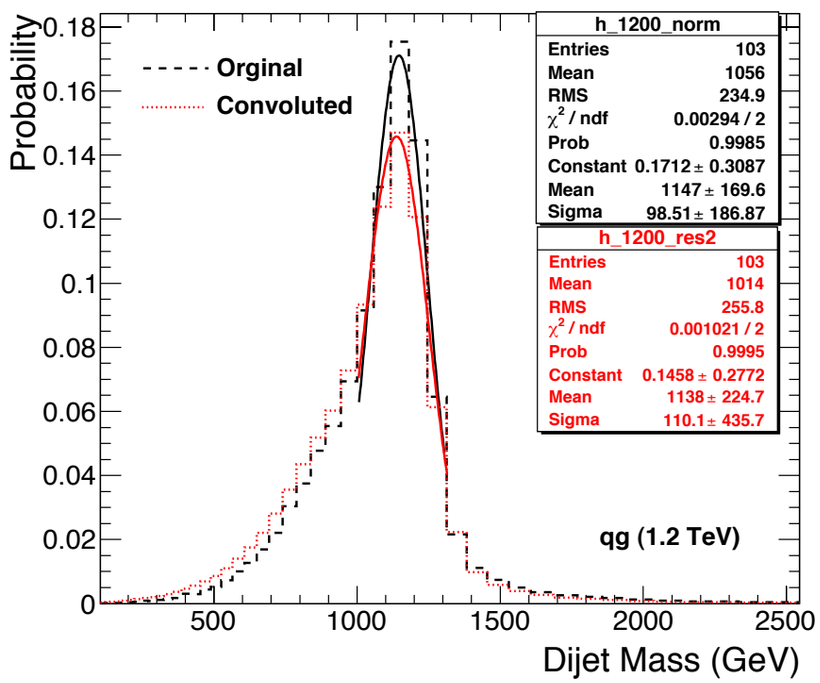
- We consider uncertainty on jet energy resolution by 10%.
- Resonance shapes are convoluted with a gaussian that increasing "core" resolution by 10%
  - ✓ $\sigma_{Gaus} = \sqrt{\{(1.1)^2-1\}}\,\sigma_{Res}$
- Effect of resolution uncertainty on limit is small



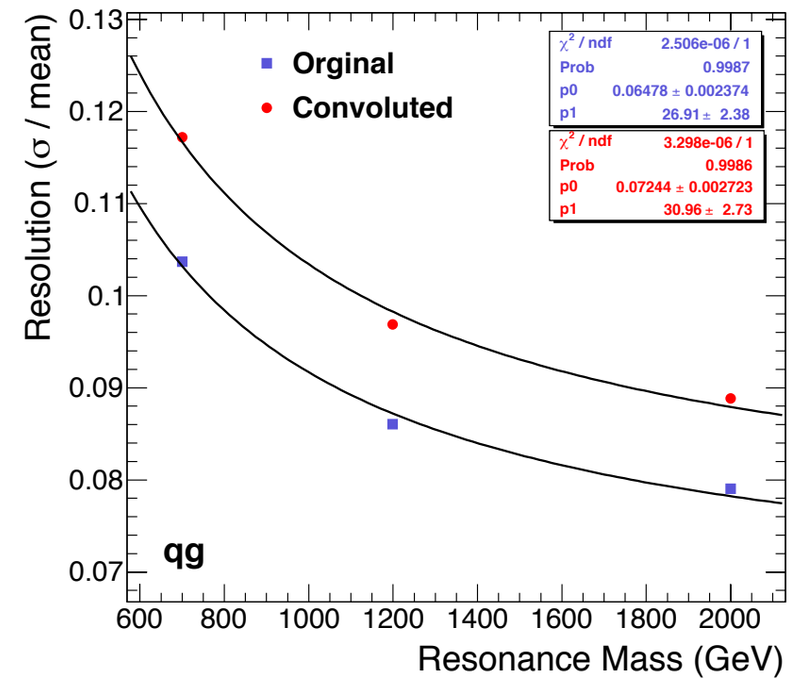



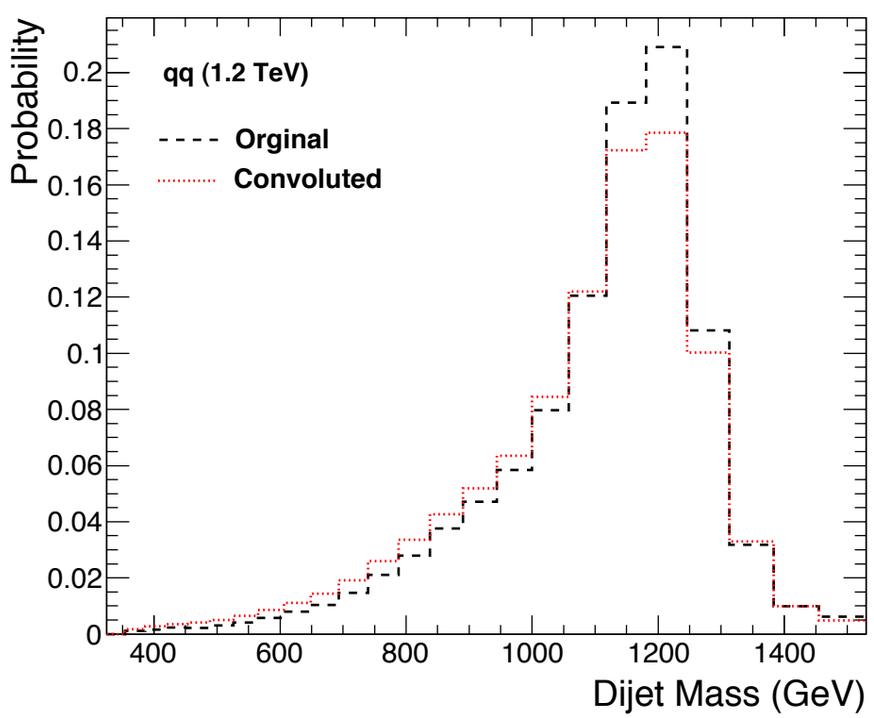
# Jet Energy Resolution

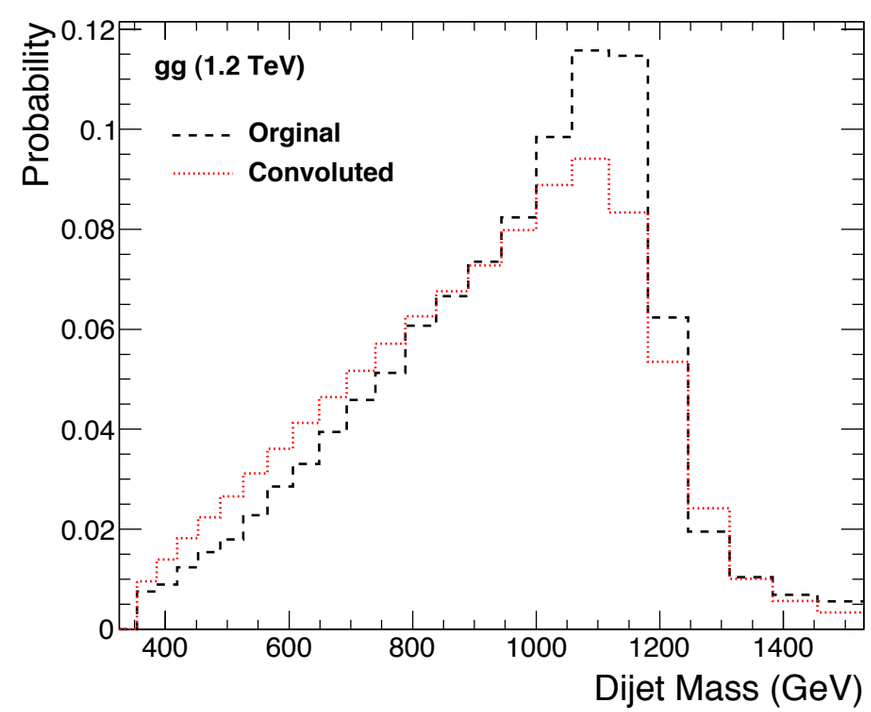



$$(\text{mean - } \sigma) \text{ to } (\text{mean} + 1.5\ \sigma)$$

Core Range

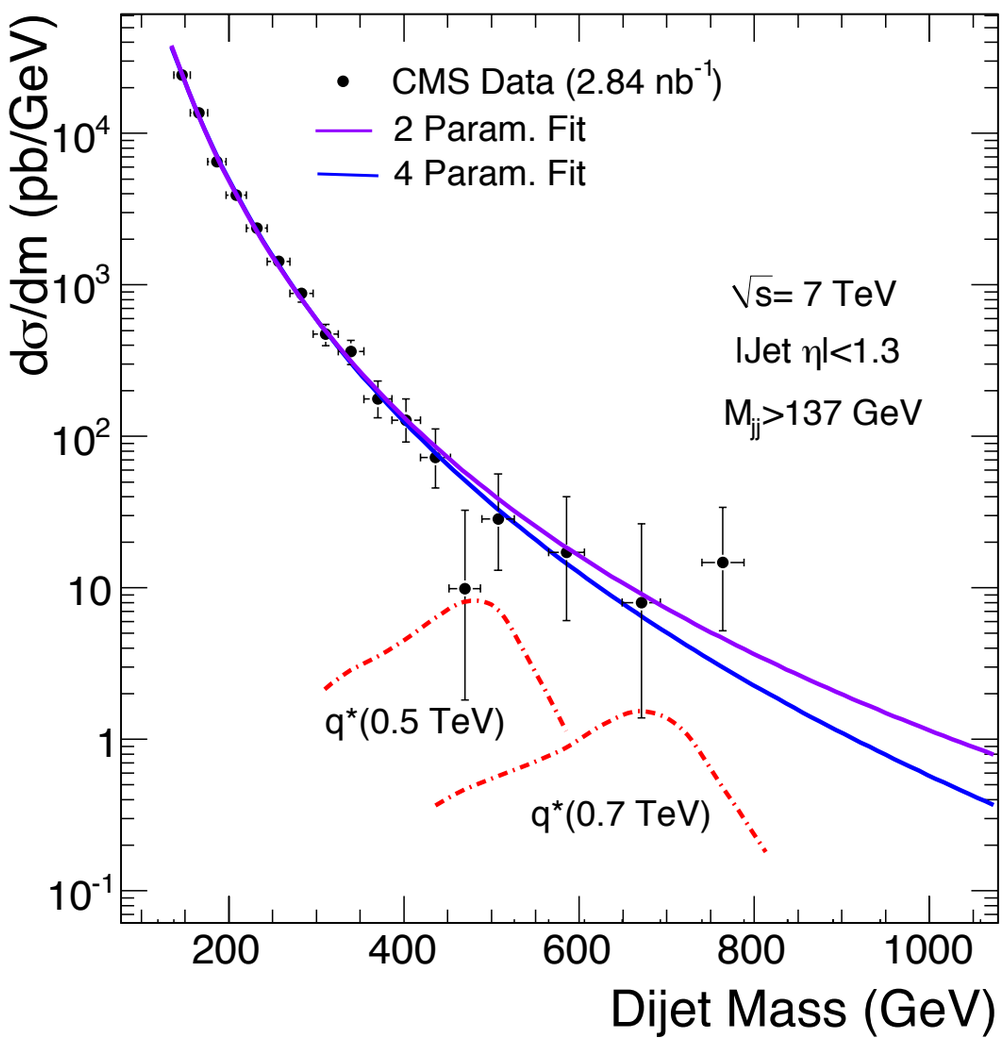


# Background Parametrization Systematics

- We have varied the choice of background parametrization
  - ✓ A more complex form with 4 parameter.
- Systematic uncertainty varies from 8% to 1%.
- We expect bigger change on Back. Param. Sys. when we have more data.




$$\frac{d\sigma}{dm} = p_0 \frac{(1 - \frac{m}{\sqrt{s}} + p_3(\frac{m}{\sqrt{s}})^2)^{p_1}}{(m)^{p_2}}$$

$$\frac{d\sigma}{dm} = \frac{P_0}{m^{P_1}}$$