Search for Narrow Resonances Decaying to Dijets in Proton-Proton Collisions at 13 TeV

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HEP 2016 - Conference on Recent Developments in High Energy Physics and Cosmology, 12-15 May 2015, Thessaloniki, Greece

Outline

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Signal shapes

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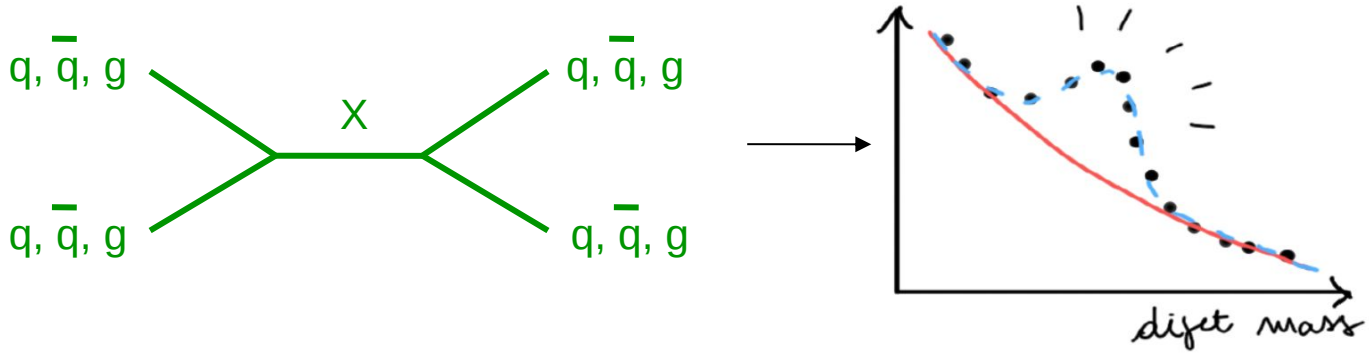
Motivation

Search:

Dijet Resonances



Powerful: LHC in run 2 is a dijet resonance factory at a new energy scale

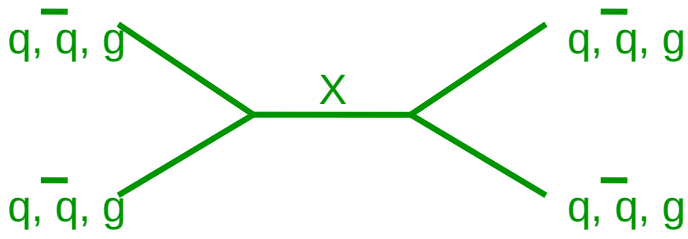
Broad: search for many sources of new physics in a single simple search

- **String resonances** from string theory
- **Excited quarks** from theories of quark compositeness
- **W'**, **Z'** and **scalar diquarks** from grand unified theory
- **Gravitons** from the Randall-Sundrum model of extra dimensions
- **Axigluons**, **Colorons** and **Color Octet Scalars** from other new models

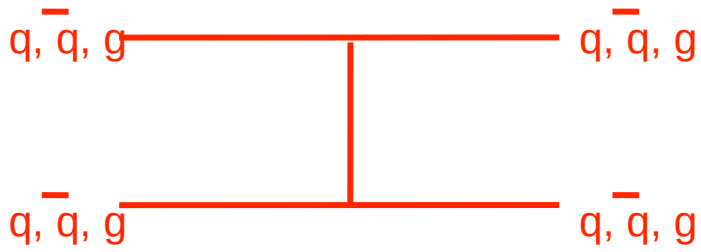
Model Independent: Search results are applicable to any model of narrow qq, qg, or gg resonances.

Analysis overview

Resonance Signal



QCD Background



Reconstructed objects

- Particle Flow jets
- No b-jet or H-jet tagging needed for inclusive search

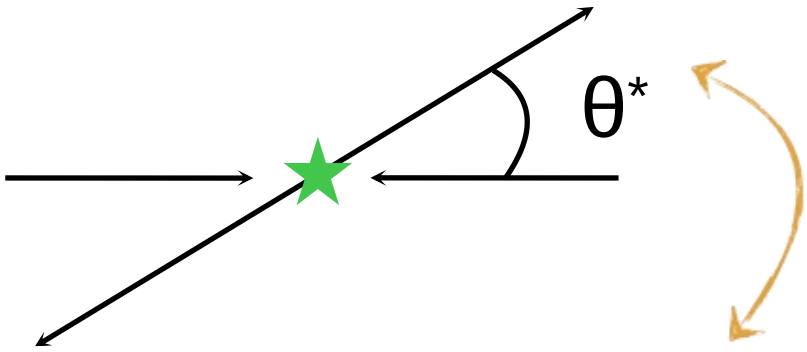
Physics observables

Use two leading jets:

M(jj) → Resonance Mass

Δη(jj) → Resonance Spin

(X rest frame)



$$\Delta\eta_{12} = |\eta_{jet1} - \eta_{jet2}| = \ln\frac{1 + |\cos\theta^*|}{1 - |\cos\theta^*|}$$

Reconstruction and Selection

Selecting events with:

Number of jets >=2

pT_1 > 60 GeV, pT_2 > 30 GeV,

|η|<2.5 (tracker acceptance),

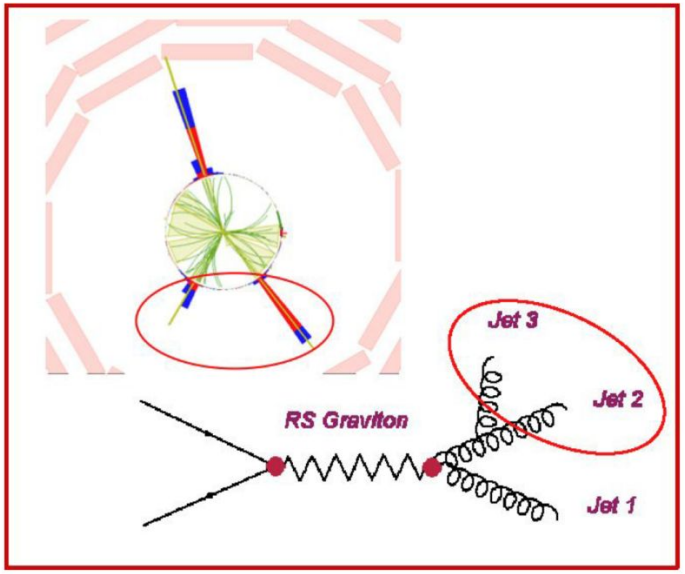
JetID criteria for all jets -> remove noise

(see M. Diamantopoulou's talk afterwards)

For recovering the Final State Radiation use "Wide Jets" (gives better sensitivity) on AK4:

The clustering starts with the two leading jets which have to satisfy jet criteria. All other jets are added to the closest leading jet if they are within **ΔR=1.1** and have **pT > 30 GeV**.

Wide Jet Reconstruction



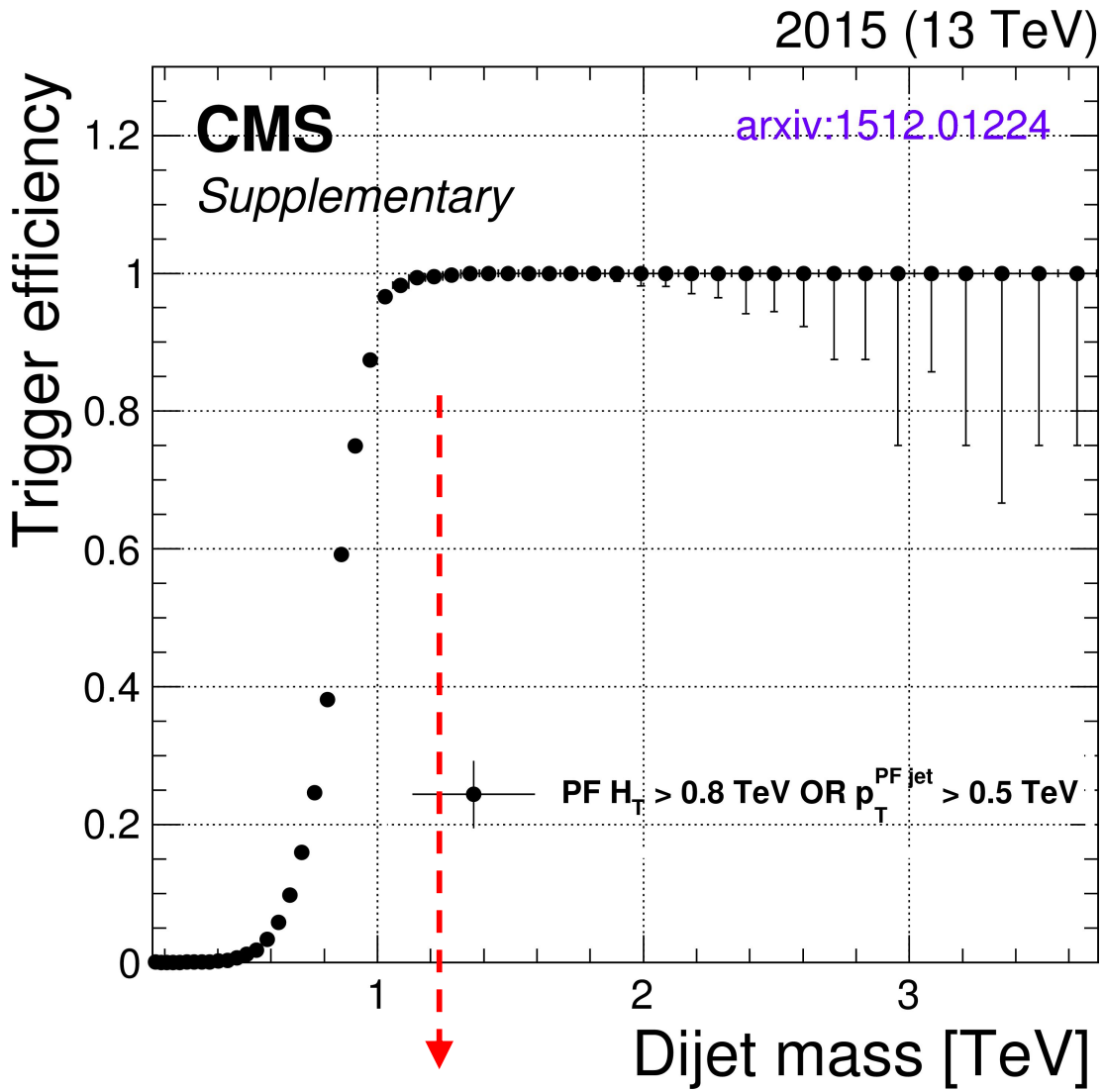
Dijet Event Selection:

|Δη| < 1.3 suppresses QCD (t-channel) and enhances signal (s-channel)

Dijet Mass > Trigger Cut for full efficiency

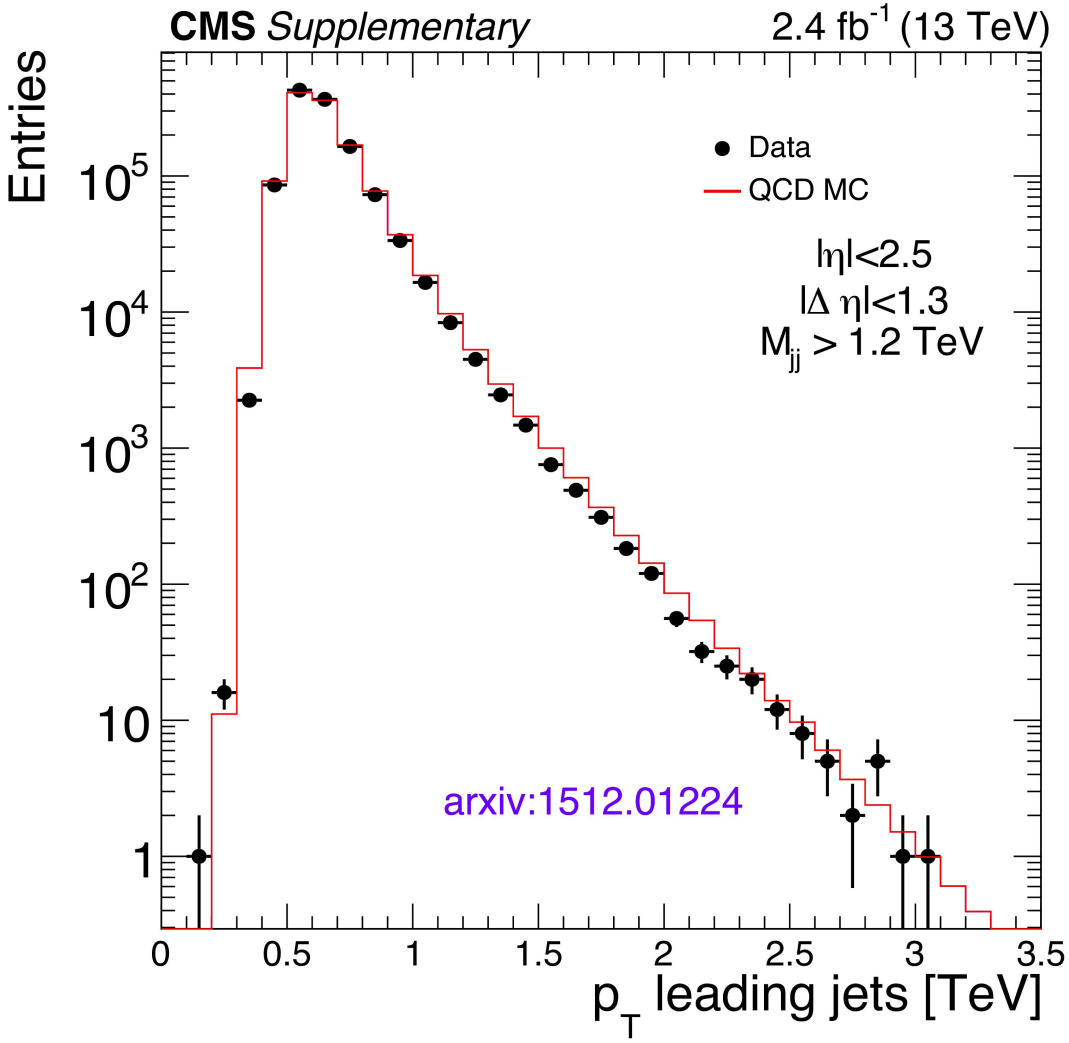
Reconstruction and selection is optimal at both √s = 8 and 13 TeV.

Trigger and Dijet Mass Cut



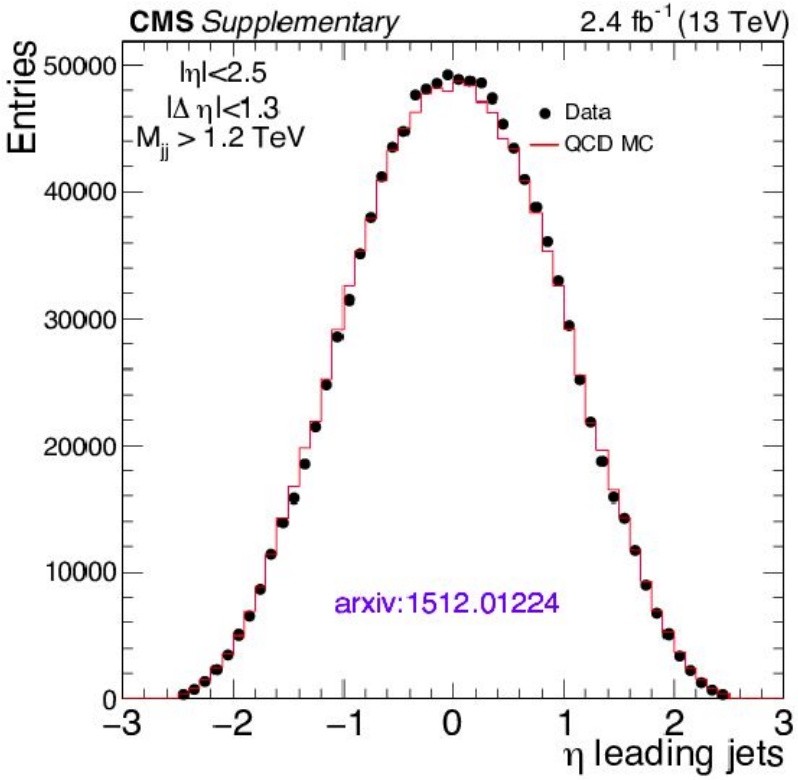
We require dijet mass > 1.2 TeV for full trigger efficiency.

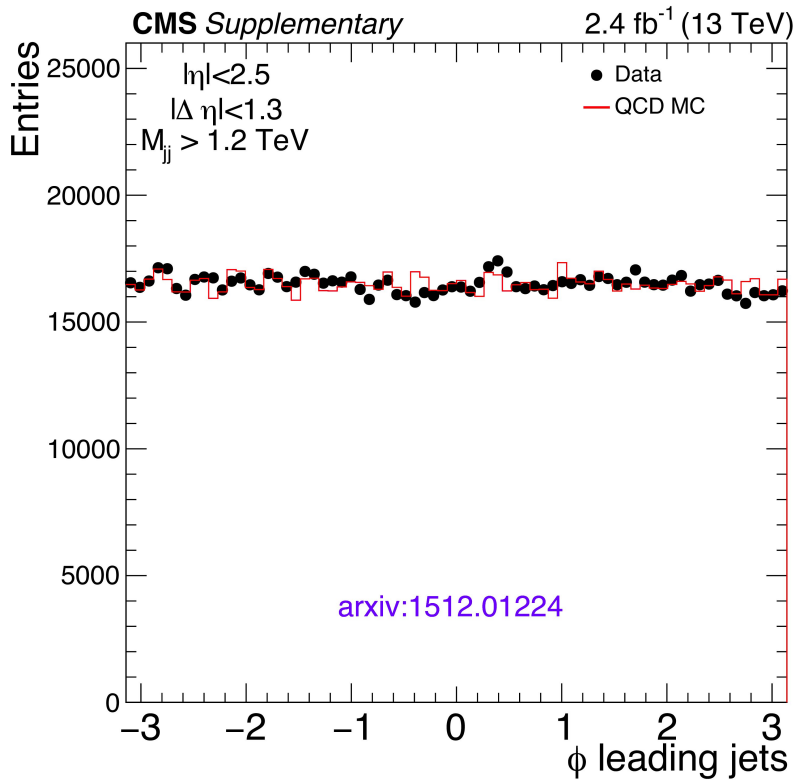
Data Quality: Jet p_T



p_T of two leading jets fall steeply and smoothly as expected from QCD.

Data Quality: Jet η and φ





Leading jets vs η plateaus and smoothly falls off as predicted

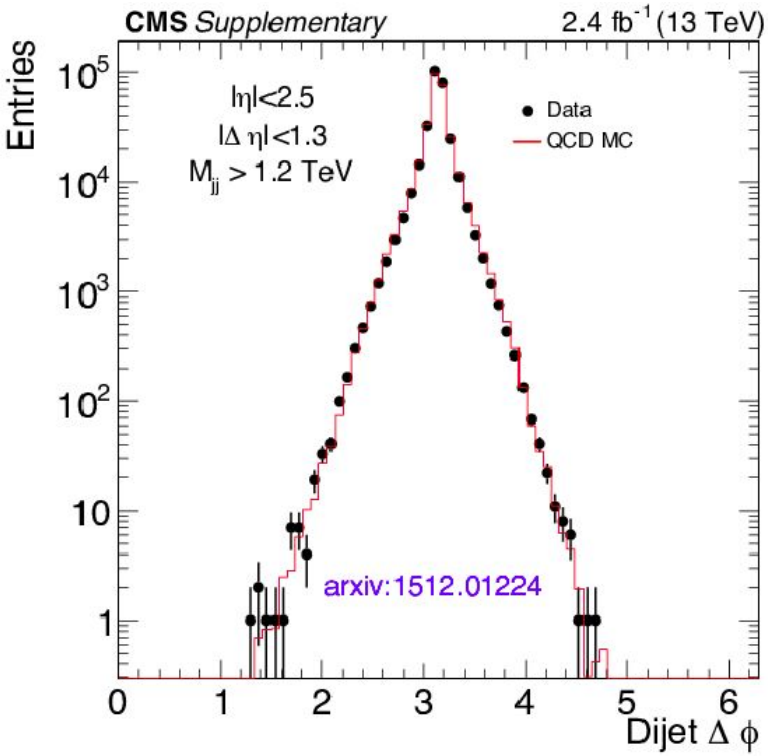
Jet response vs η well understood after applying data-driven JEC

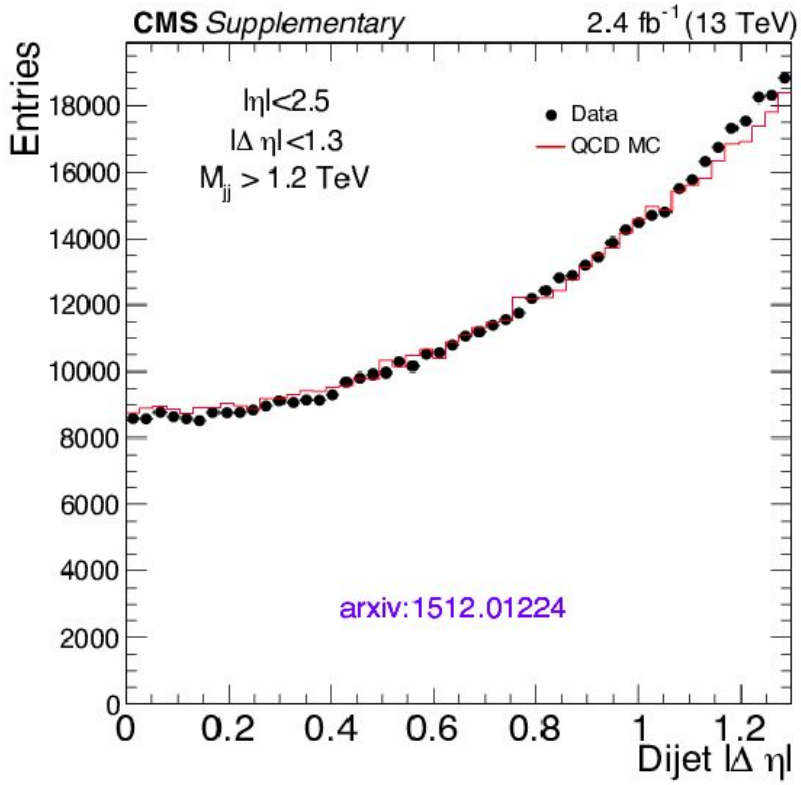
Leading jets vs φ is flat as expected

Jet response uniform vs φ:

no hot or dead areas in calorimeter

Data Quality: Δφ and Δη

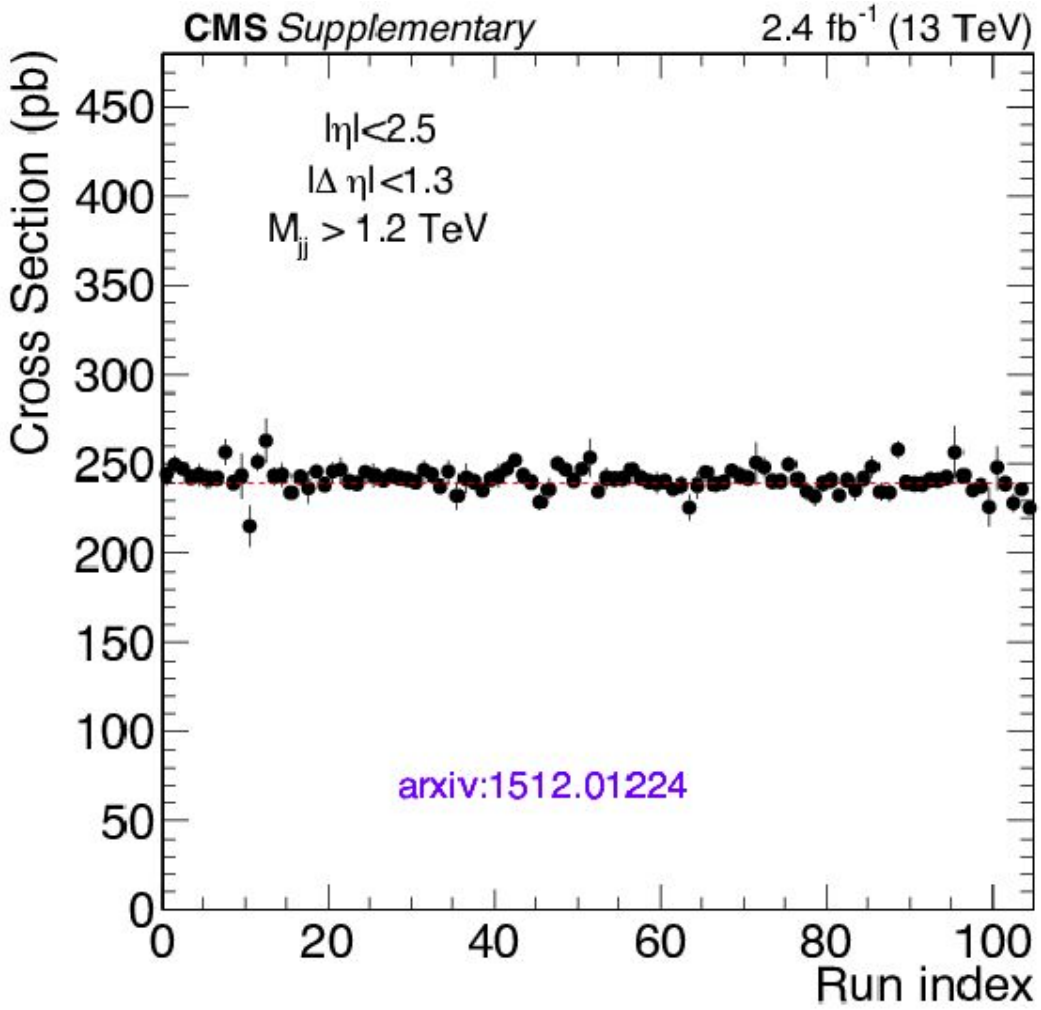




Δφ shows back-to-back dijet events, clear physics, without signs of noise

Δη demonstrates the QCD t-channel angular distribution of dijets

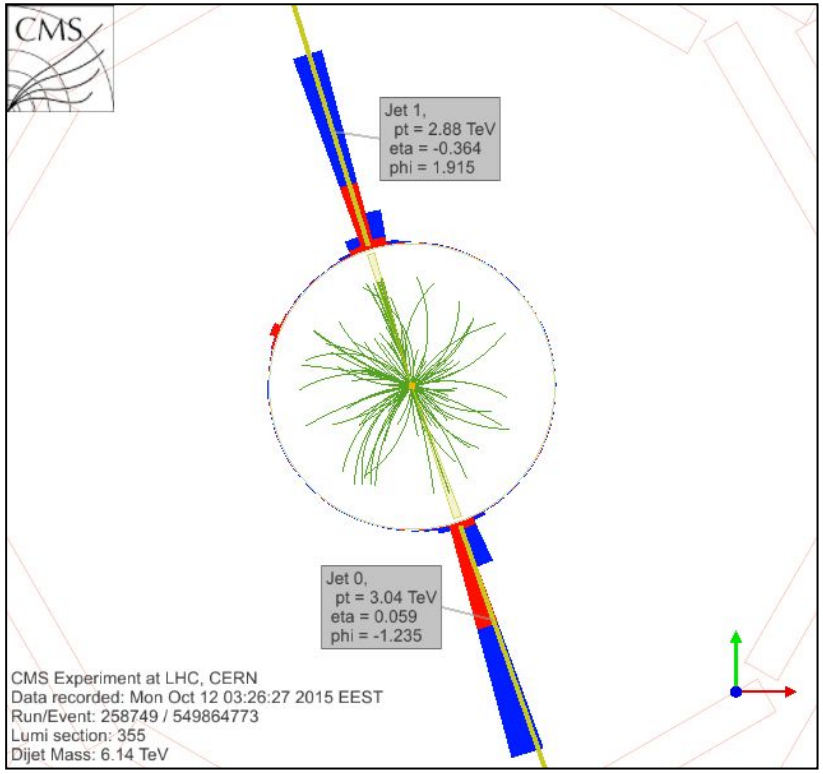
Cross Section Stability



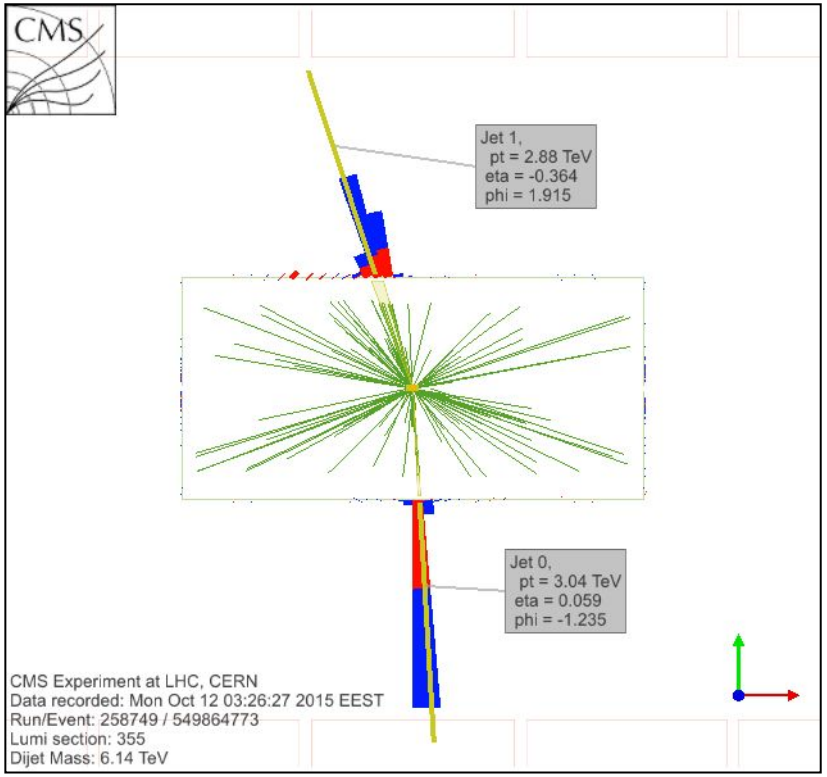
Cross Section vs. Run demonstrates data stability with time.

Highest Dijet Mass Event: m_{jj} = 6.14 TeV

The transverse view
with respect to the beam



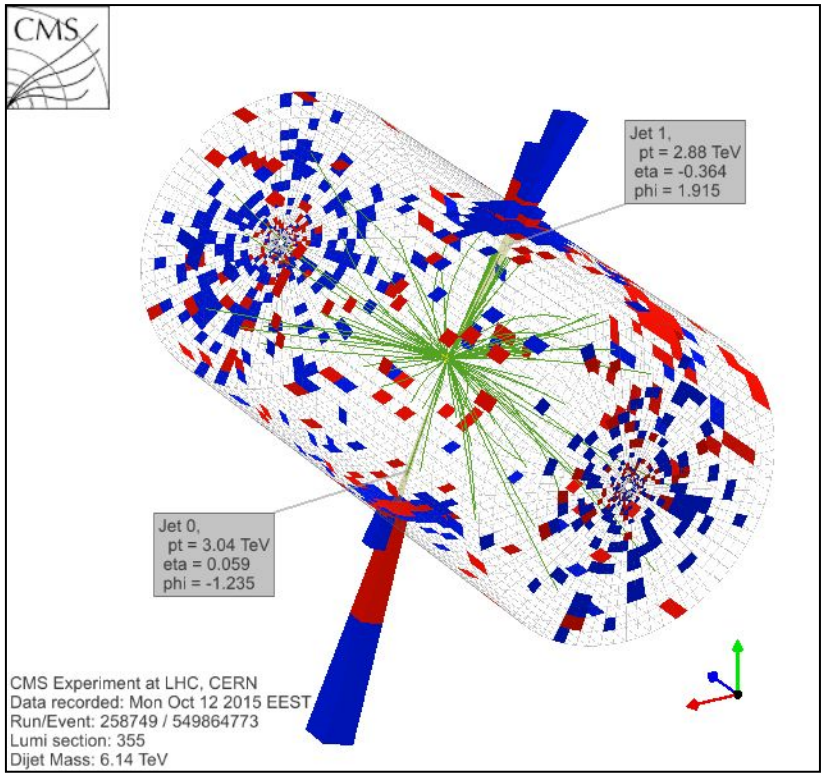
The longitudinal view
with respect to the beam axis



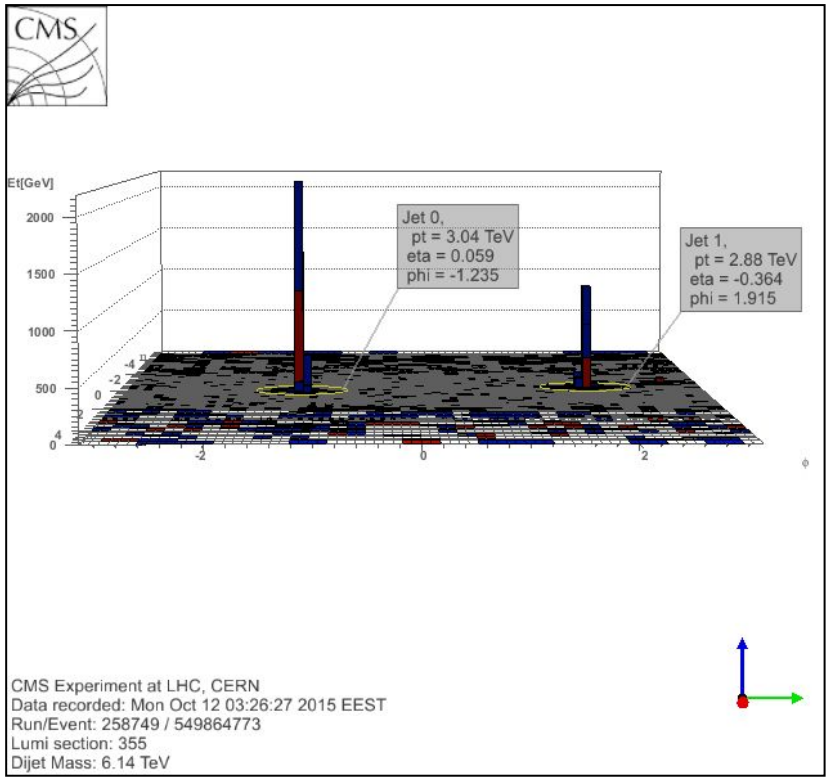
Highest dijet mass event is a clean back-to-back dijet in the barrel.

Highest Dijet Mass Event: m_{jj} = 6.14 TeV

3D view



lego view



Highest dijet mass event is a clean back-to-back dijet in the barrel.

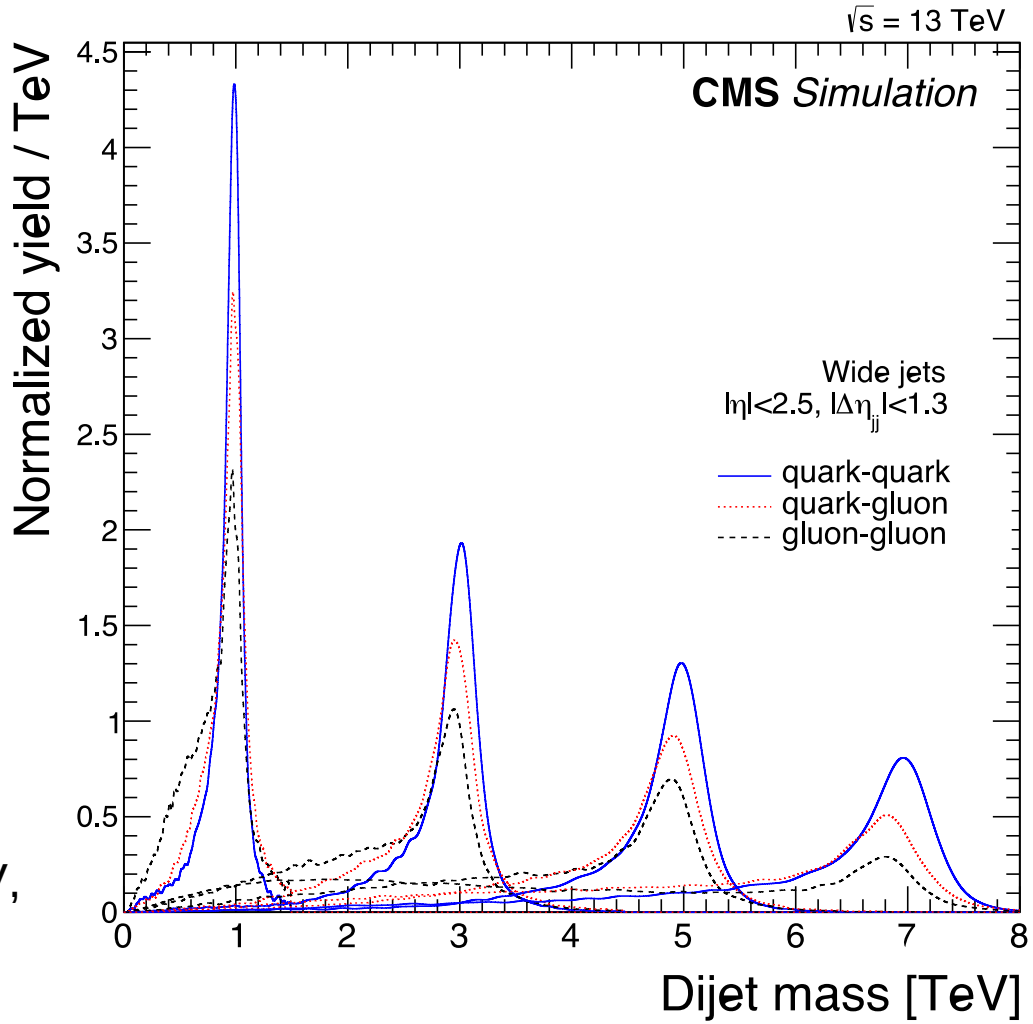
Signal Shape

Narrow dijet resonances modeled using PYTHIA8:

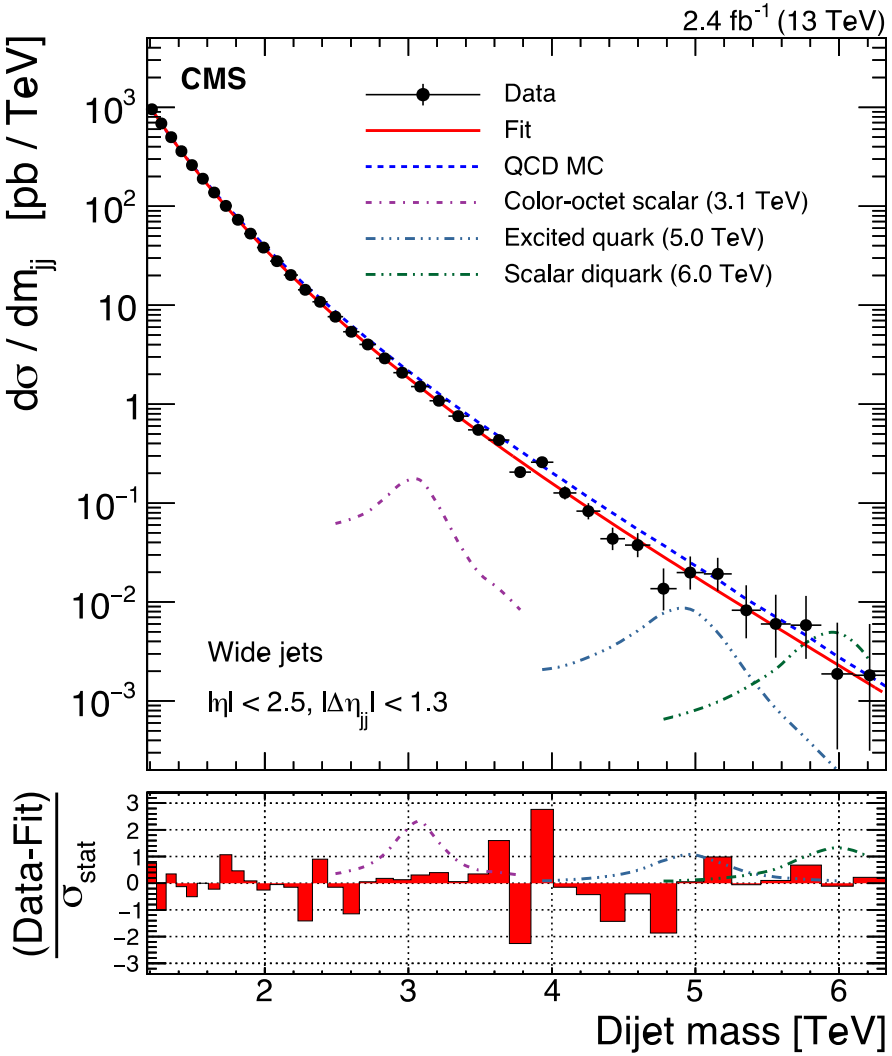
- quark-quark ($qq \rightarrow G \rightarrow qq$)
- quark-gluon ($qg \rightarrow q^* \rightarrow qg$)
- gluon-gluon ($gg \rightarrow G \rightarrow gg$)

Resonance shape peaks close to the pole mass.
Long tail to low mass mainly from QCD radiation.
Tail gets longer with more gluons in the final state

At the highest masses, near 7 TeV, parton distributions contribute to the low mass tail.



Dijet Mass Spectrum and Fit



Variable mass binning corresponding to the estimated dijet mass resolution.

Data is fitted with 4 parameter function*:

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

Data well described by fit

$\chi^2/\text{ndf} = 31/35$

There is no evidence for a narrow resonance in the data.

Most significant excess at 3.9 TeV.

Local statistical significance of 1.7σ when fit with qq resonance.

* A fully non-parametric data-driven background prediction is also studied (see D. Karasavvas' talk afterwards).

Statistical Analysis

Likelihood function

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

Events in data — Signal events — Expected background events

Amount of signal in each bin determined by the signal resonance shape.

Background comes from the background component of a S+B fit to the data.

We calculate the likelihood separately for each resonance mass hypothesis.

Bayesian formalism with flat prior for the positive signal cross section and zero otherwise.

Systematic uncertainties introduced as nuisance parameters.

For local significance estimate with statistical uncertainties only using a likelihood ratio significance estimator:

$$\mathrm{Sig} = \mathrm{sgn}(S)\sqrt{-2\ln\left(\frac{L_B}{L_{S+B}}\right)}$$

Generic Search Limits

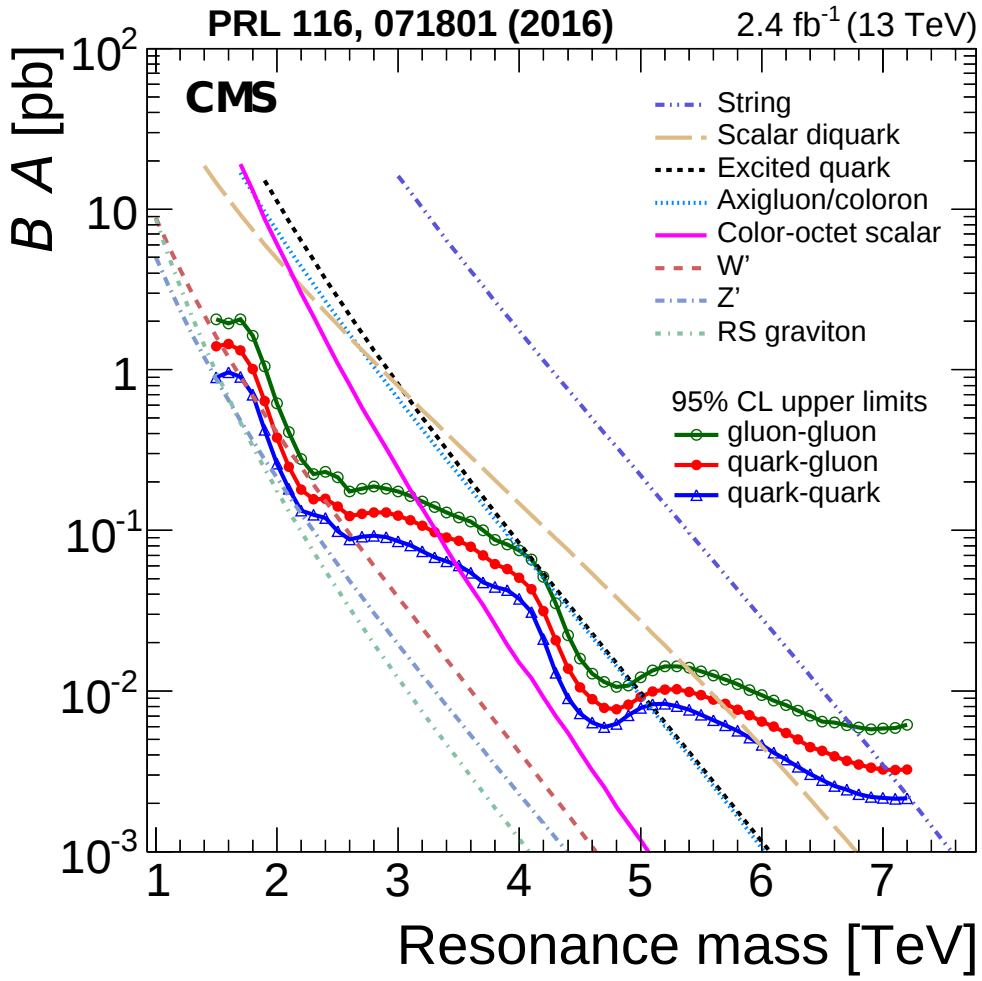
We set upper limits at 95% CL on cross section of qq, qg and gg resonances.

- Limits get worse when there are gluons in the final state because radiation increases and resolution degrades.

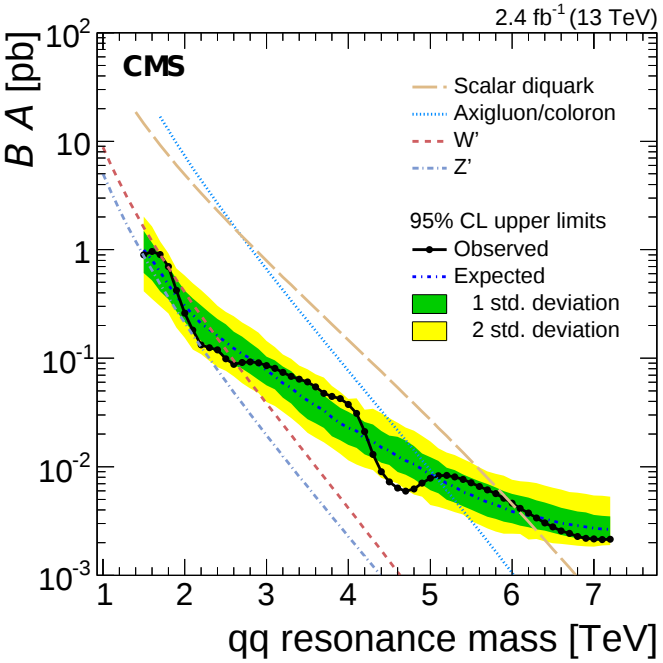
Our limits extend to 7 TeV in dijet mass for the first time.

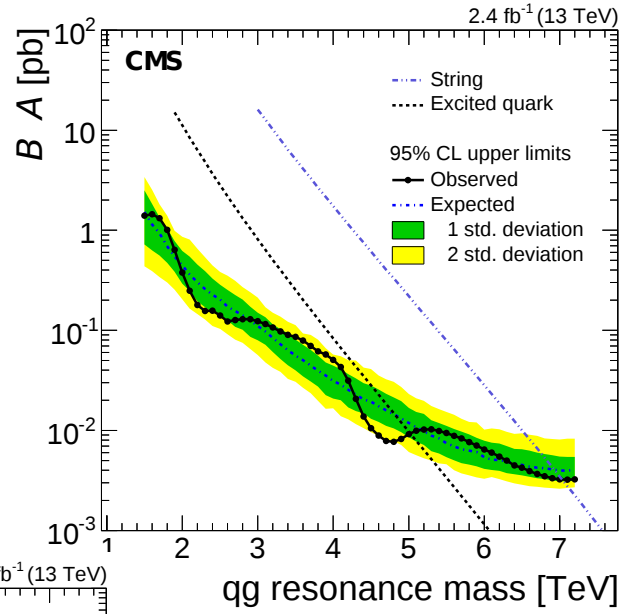
- Limit plateaus at high mass due to absence of events.

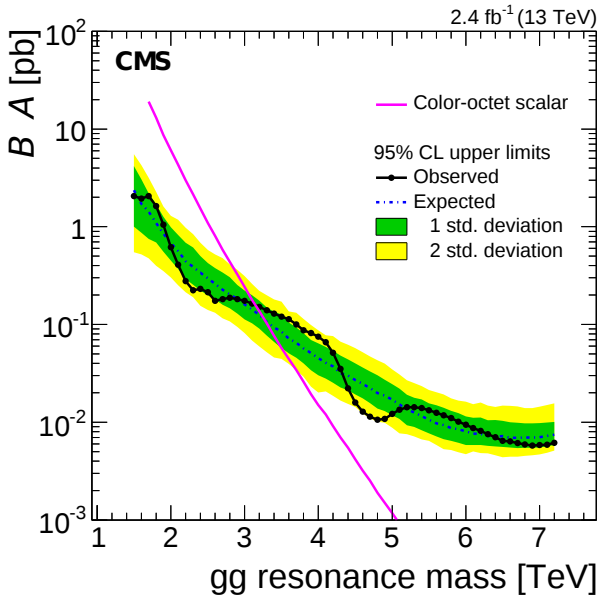
We compare with model cross sections to set mass limits.



Resonance Limits for specific models







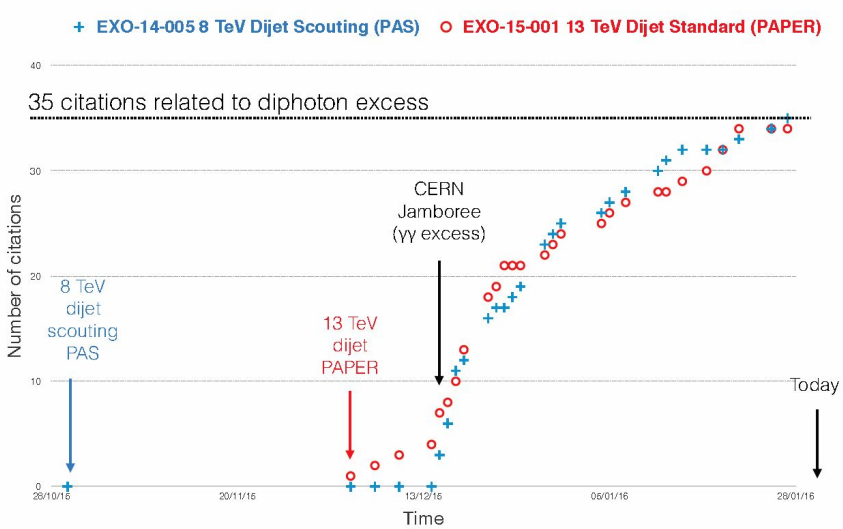
PRL 116, 071801 (2016)

Limit Summary Table

Narrow Resonance Model	Mass Limits (TeV)			
	CMS Run 1 (20 fb^{-1})		CMS Run 2 (2.4 fb^{-1})	
	Observed	Expected	Observed	Expected
String Resonance (S)	5.0	4.9	7.0	6.9
Scalar Diquark (D)	4.7	4.4	6.0	6.1
Axigluon (A) / Coloron (C)	3.7	3.9	5.1	5.1
Excited Quark (q*)	3.5	3.7	5.0	4.8
Color Octet Scalar (S8)	2.7	2.6	3.1	3.3
Heavy W (W')	1.9, 2.0-2.2	2.2	2.6	2.3
Heavy Z (Z')	1.7	1.8	--	--
RS Graviton (G)	1.6	1.3	--	--

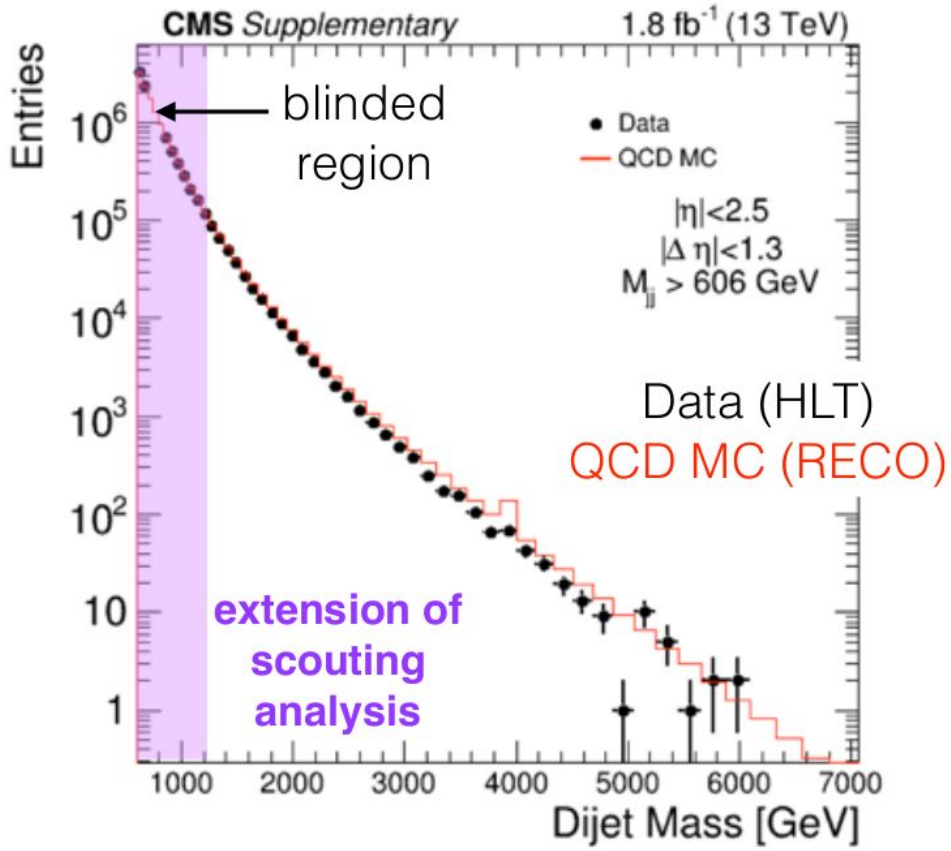
Probing the 750 GeV region with Dijets

High Mass Dijet Analysis starts at 1200 GeV due to trigger efficiency.
Our goal: Discover or constrain dijet resonance around 750 GeV with data scouting samples.
Scouting is a loose online data selection with a reduced data format.
Objects are reconstructed at the HLT, allowing a lower trigger (HT > 450 GeV) .



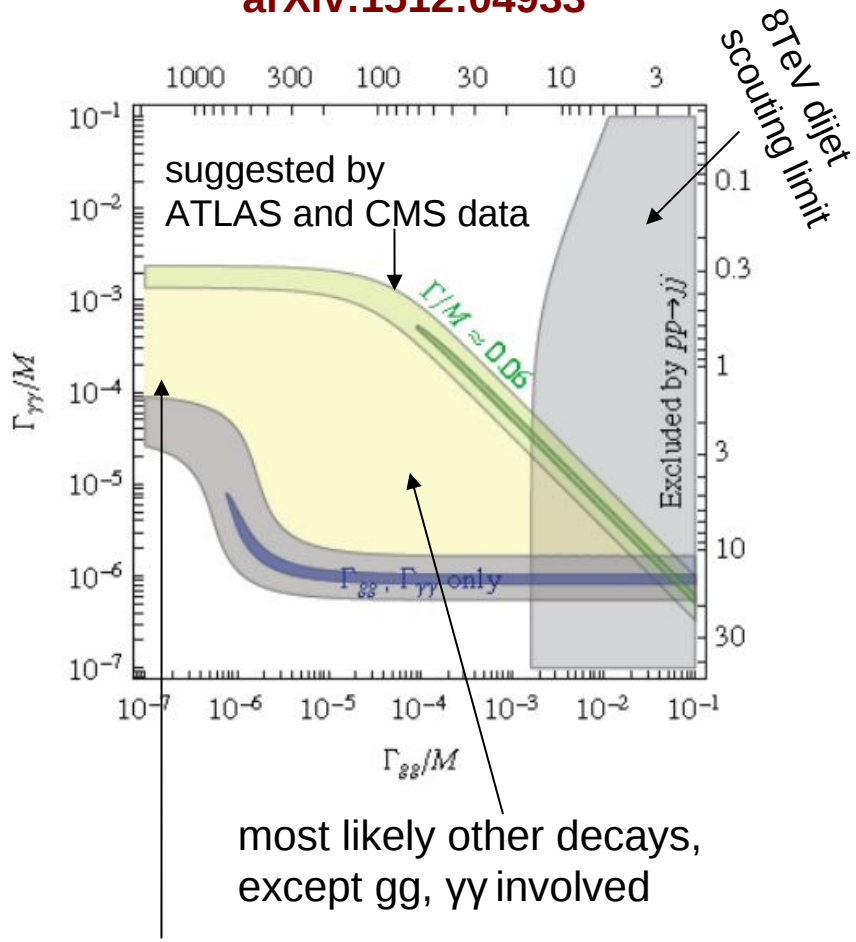
Great interest for scouting in theory community.

Probing the 750 GeV region with Dijets



Fit data with the 4 parameter function and simultaneously fit the trigger efficiency.

arXiv:1512:04933



If $\Gamma_{\gamma\gamma} >> \Gamma_{gg}$ (γ production dominates) then Run 2 and Run 1 data become incompatible.

Conclusions

We have presented the first search for dijet resonances at √s = 13 TeV.

The data are clean, stable vs. time and behave as expected for dijets.

The dijet mass distribution is smoothly falling and well modeled by our background parameterization.

We set upper limits at 95% CL on the cross section of narrow resonances, out to a mass of 7.2 TeV.

Compare them with predictions from models of new physics and set mass limits on String Resonances, Excited Quarks, Axigluons/Colorons, Scalar Diquarks, Color Octet Scalars, W' bosons, Z' bosons and Randall-Sundrum Gravitons.

We set mass limits on 6 out of the 8 models.

Significantly beyond Run 1 limits for mjj > 2 TeV.

We are analyzing scouting data in order to probe the 750 GeV region with aim to discover or constrain a dijet resonance.

Back Up

Sources of systematic uncertainties

- Jet energy scale: 2% => shift signal shape ± 2%
- Jet energy resolution: 10% => change width of signal shape by ± 10 %
- Integrated Luminosity: 12 % => propagate to the normalization of the signal
- Background estimation: changes in the values of the parameters describing the background introduce a change in the signal strength that is accounted.

- The dependence of the signal mass distributions on the number of PU interactions is negligible.