# Dijet resonance searches at CMS

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Presenting work in progress.
On behalf of the CMS Dijet Resonance Search team

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# Outline

- CMS detector
- Motivation, Analysis Overview
- Event Selection
- Trigger Studies
- Signal Studies, Optimization studies for the cuts
- Background Studies
- Limits from the 8 TeV data
- First expected limits from the 13 TeV data
- Conclusions

# The CMS Detector

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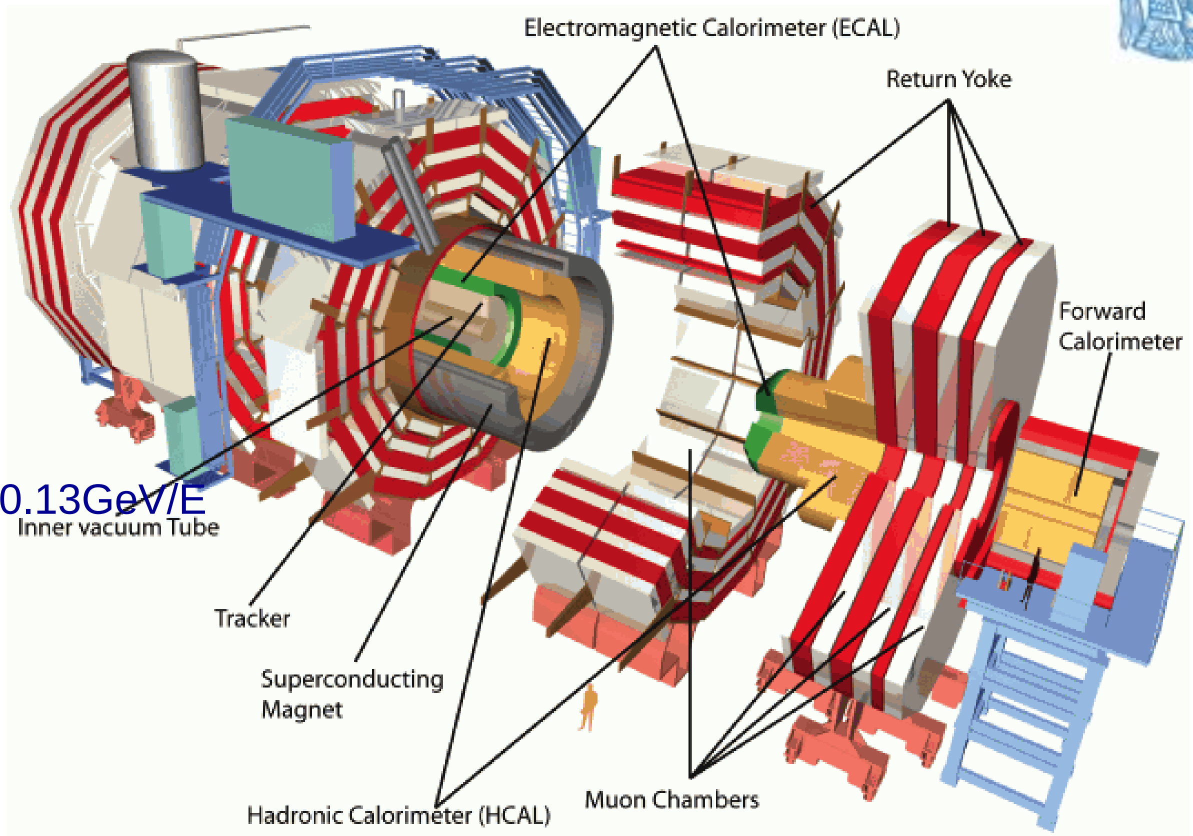



Pixels
$\sigma/p_T \sim 1.5\cdot10^{-4} p_T(\mathrm{GeV}) \oplus 0.005$

Electromagnetic Calorimeter
$\sigma E/E \approx 2.9\%/\sqrt{E(\mathrm{GeV})} \oplus 0.5\% \oplus 0.13\mathrm{GeV}/E$

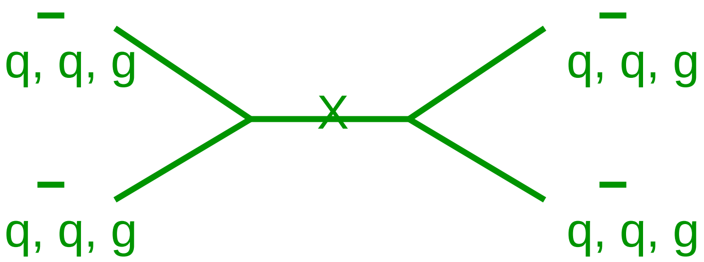
Hadronic Calorimeter
$\sigma E/E \approx 120\%/\sqrt{E(\mathrm{GeV})} \oplus 6.9\%$

Muon Spectrometer
$\sigma p_T/p_T \approx 1\%$ for low pT muons
$\sigma p_T/p_T \approx 5\%$ for 1 TeV muons

We collect the information of all detectors to reconstruct the particle flow (PF) jets.

# Motivation

## Dijet Resonance Search



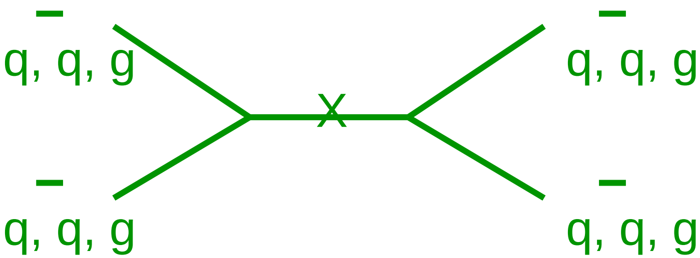

**Powerful:** **LHC at 13TeV is a dijet resonance factory** at a new energy scale.

**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 **(RSG)**
**Axigluons**, **Colorons**, and **Color Octect Scalars** from other models

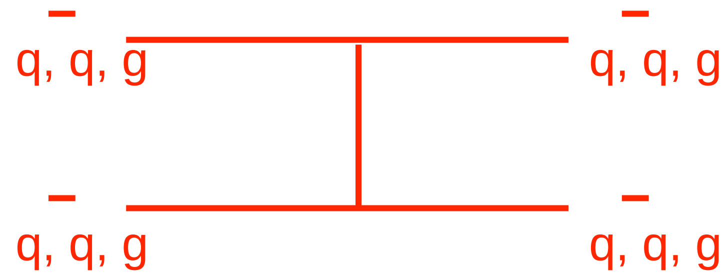
**Model independent:** Publish cross section upper limits that can constrain any present or future model of narrow qq, qg, or gg resonance.

# Analysis overview

**Resonance Signal**




**QCD Background**



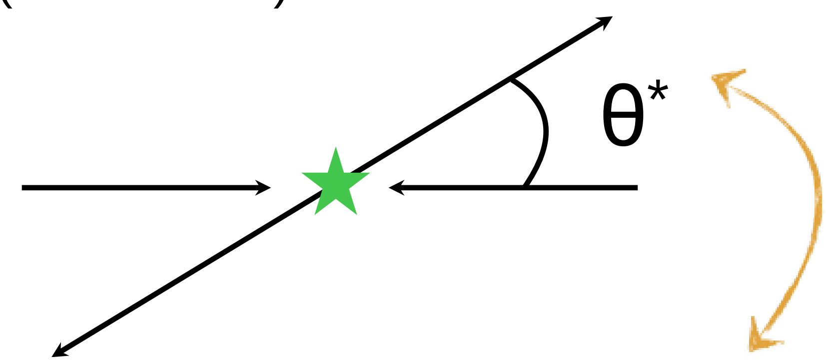

- **Reconstructed objects**

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

- **Physics observables**

Use two leading jets:
M(jj) → Resonance Mass
Δη(jj) → Resonance Spin

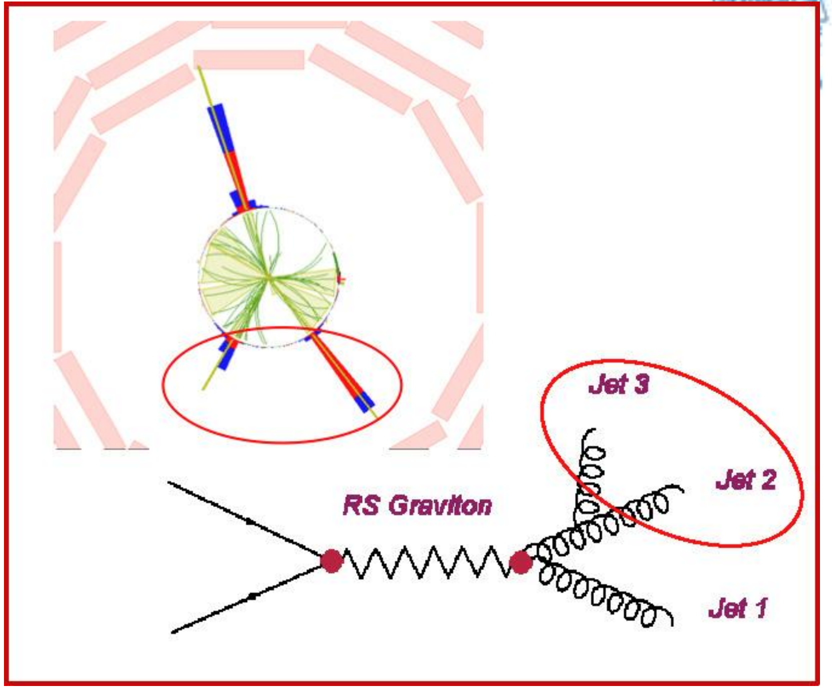
(X rest frame)




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

# Event Selection

- **Selecting events with:**
  - Number of jets >=2 (inclusive)
  - pT > 30 GeV,
  - pT leading jet > 60GeV,
  - |η|<2.5 (tracker acceptance),
  - Tight JetID for all jets -> removes noise
  - |Δη|<1.3 -> suppresses QCD (t-channel) and enhances signal (s-channel),
  - ΔR=1.1 for Wide Jets.

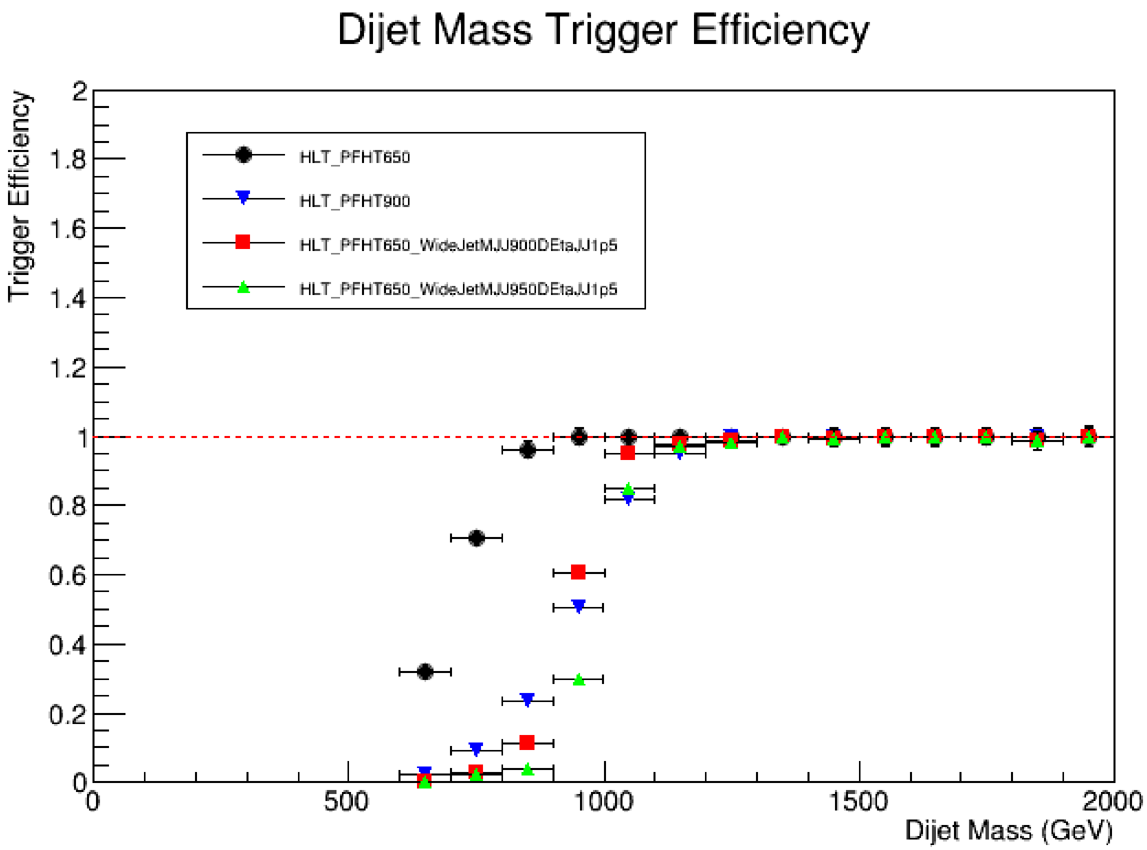



- **For recovering the Final State Radiation (FSR) use Wide Jets on AK4:**

  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**.

- These selection criteria have been found to be close to optimal with optimization studies at 13 TeV, as will be shown in the next slides.

# Trigger Studies




- PFHT650_wideJetMJJ900DEtaJJ1p5PF
HT > 650GeV &
M(jj) > 900 GeV &
|Δη(jj)| < 1.5
- PFHT650_wideJetMJJ950DetaJJ1p5
HT > 650GeV &
M(jj) > 950 GeV &
|Δη(jj)| < 1.5

Fully hadronic Dijet search can start **around 1.1 TeV.**

# MC signal samples

- We will only consider narrow resonances in this analysis, for which the natural resonance width is negligible compared to the CMS dijet mass resolution, so that the natural width does not affect the resonance shape.

- The type of parton pairs in the resonance decay (qq, qg, or gg) does affect the resonance shape.

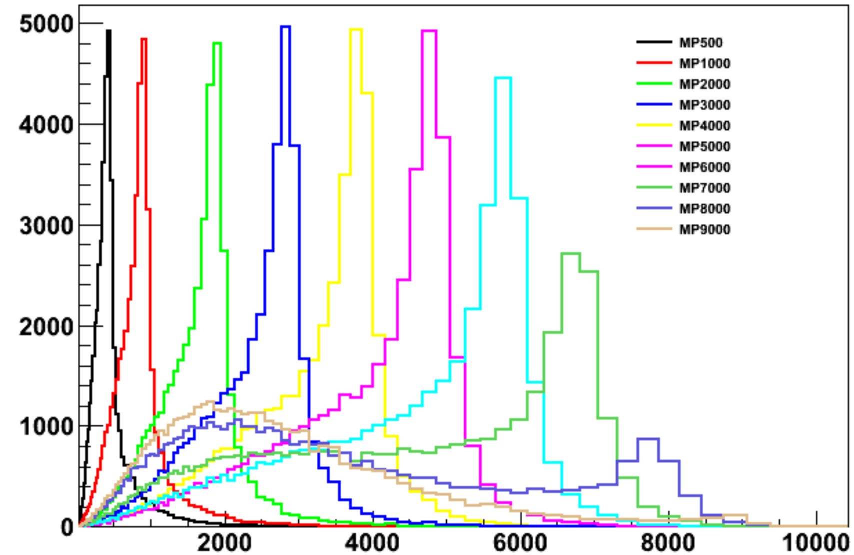
- To obtain generic shapes for these three types of parton pairings, the processes of

  $qg \rightarrow q^* \rightarrow qg$, $qq \rightarrow G \rightarrow qq$ and $gg \rightarrow G \rightarrow gg$

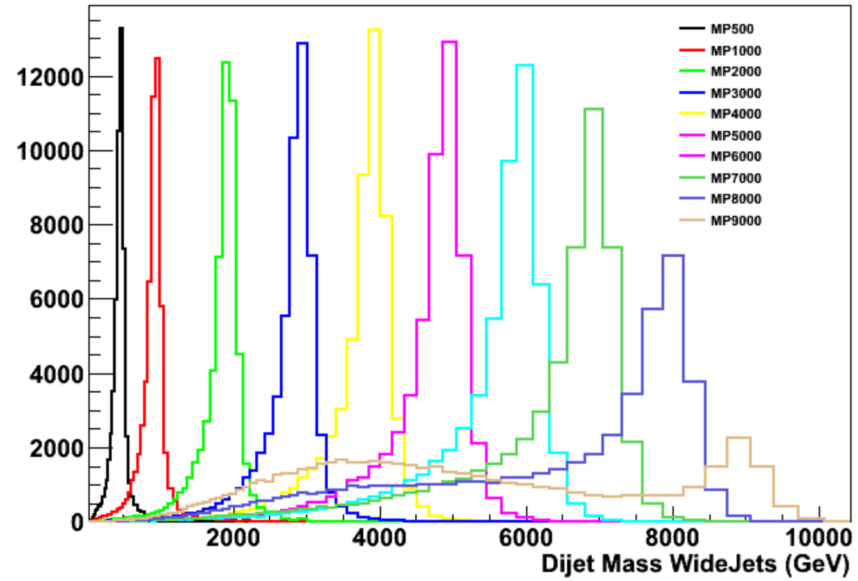
  were produced using PYTHIA simulation at ten different mass points from 500 GeV and 1 up to 9 TeV with a step of 1 TeV.

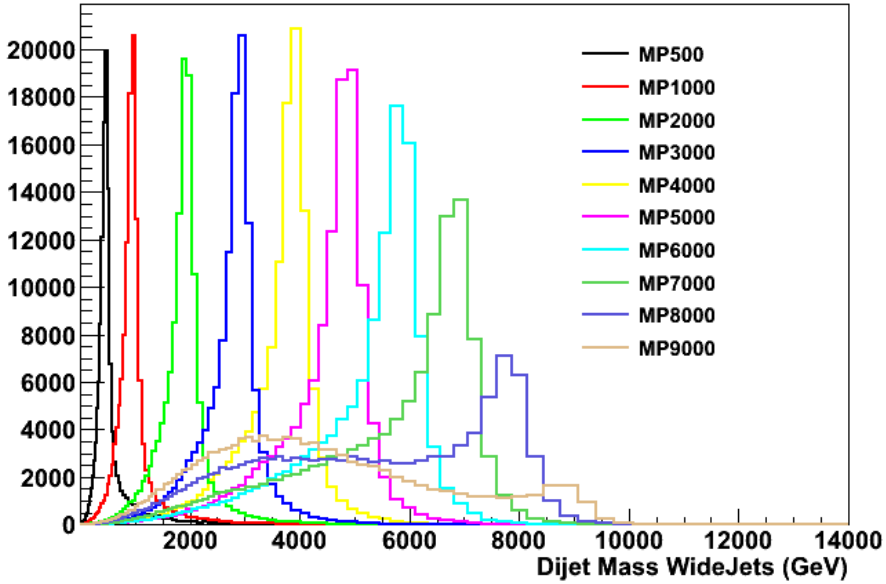
# Signal Shapes

RSG -> gg




RSG->qq



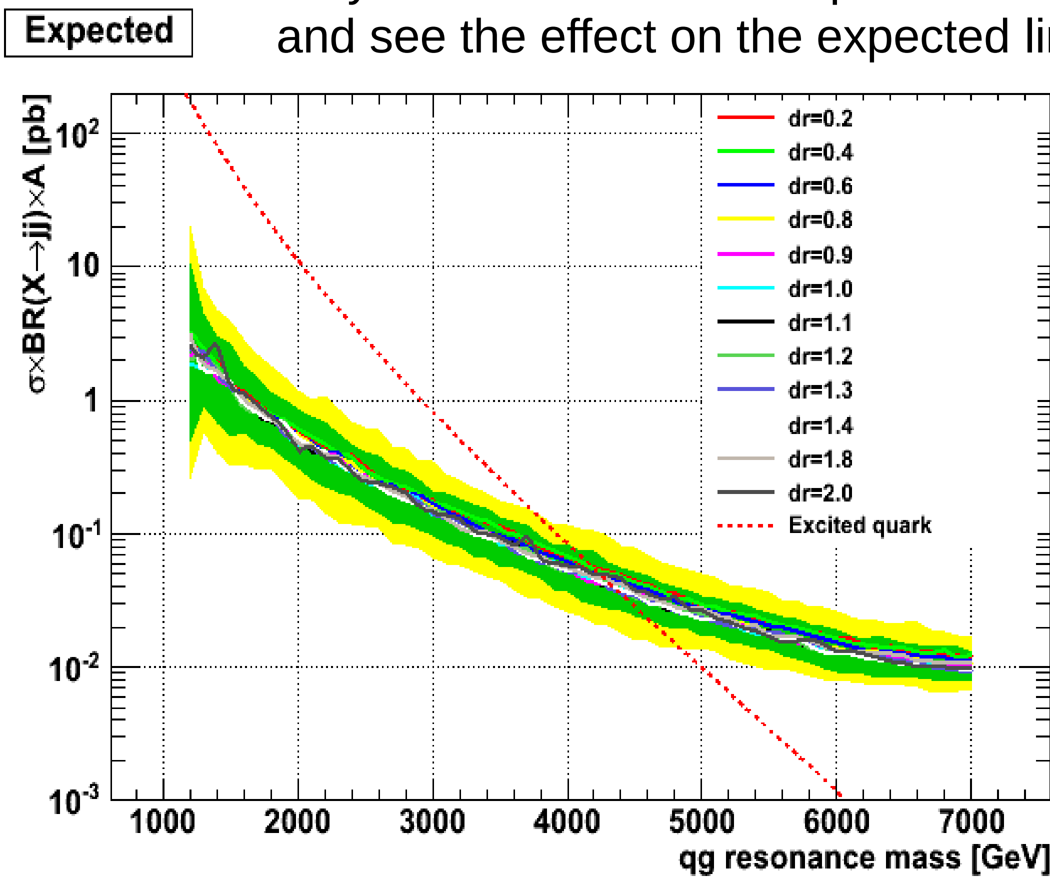




q*->qg

For **MP8000** and **MP9000**
the resonances are produced off shell.

# Optimization of ΔR: qg (Deta<1.3)

Vary ΔR values from 0.2 up to 2.0
and see the effect on the expected limits.

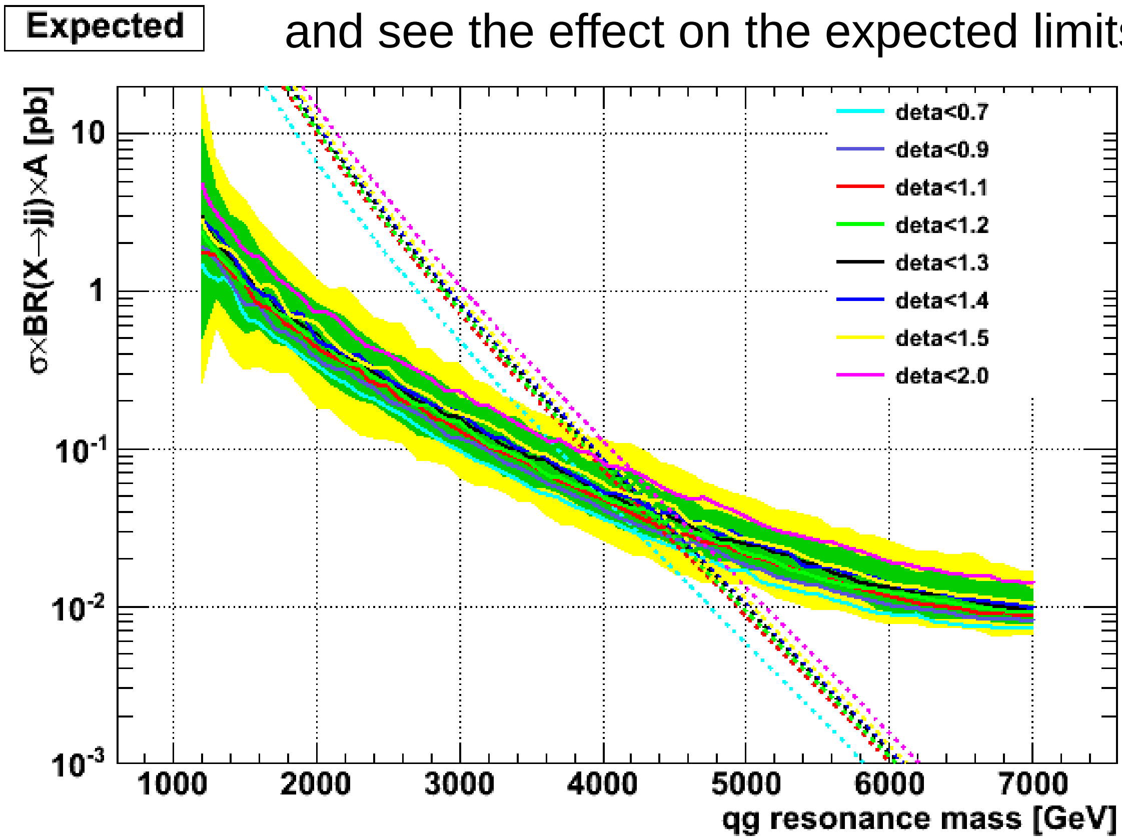



| ΔR | Excited quark (qg) | σ×BR×A |
|---|---|---|
| 0.2 | 4180 | 0.057 |
| 0.4 | 4200 | 0.054 |
| 0.6 | 4245 | 0.049 |
| 0.8 | 4315 | 0.042 |
| 0.9 | 4360 | 0.038 |
| 1.0 | 4290 | 0.044 |
| 1.1 | 4340 | 0.040 |
| 1.2 | 4310 | 0.042 |
| 1.3 | 4380 | 0.036 |
| 1.4 | 4353 | 0.040 |
| 1.8 | 4280 | 0.046 |
| 2.0 | 4245 | 0.049 |

**In the plateau,** the max difference from ΔR=1.1 is 1% on mass and 10% on σ×BR×A.

# Optimization of Δη: qg (DR = 1.1)

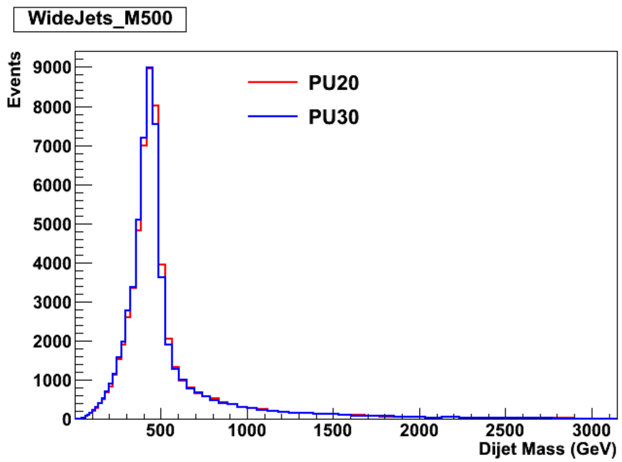
Vary Δη cut from 0.7 up to 2.0
and see the effect on the expected limits.

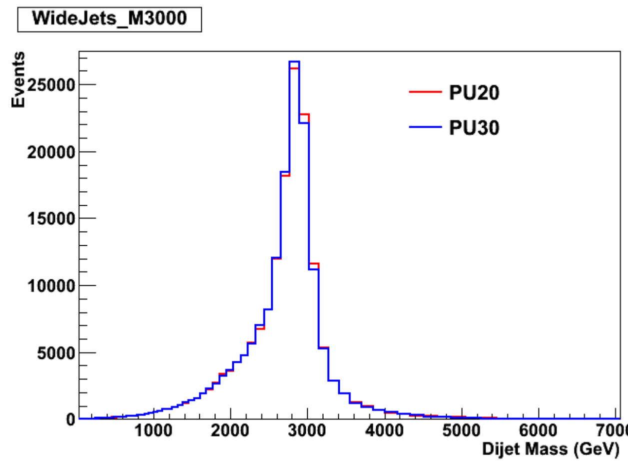


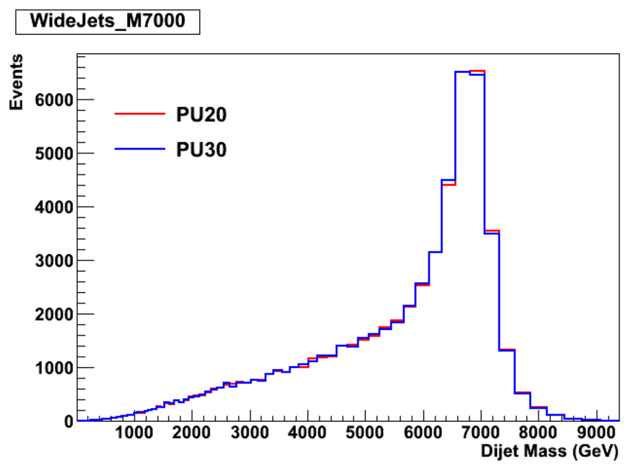

| Δη | Excited quark (qg) | σ×BR×A |
|---|---|---|
| 0.7 | 4255 | 0.029 |
| 1.1 | 4365 | 0.033 |
| 1.2 | 4300 | 0.041 |
| 1.3 | 4340 | 0.040 |
| 1.4 | 4360 | 0.041 |
| 1.5 | 4300 | 0.049 |
| 2.0 | 4200 | 0.07 |

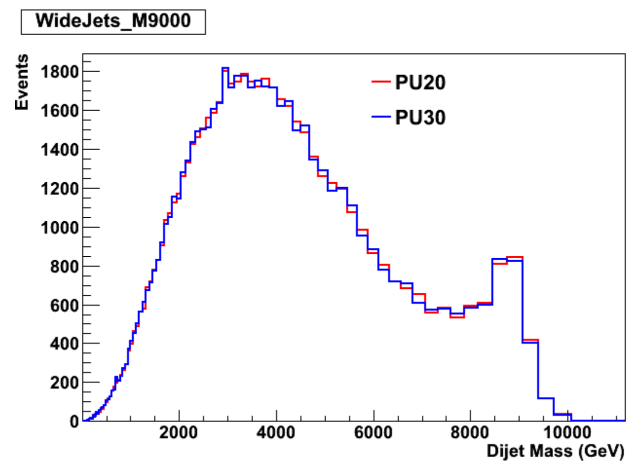
**In the plateau,** the max difference from Δη<1.3 is 1% on mass and 22% on σ×BR×A.

# **PU studies**: Comparison q*->qg Pileup 20 (25 ns) vs Pileup 30 (50ns)



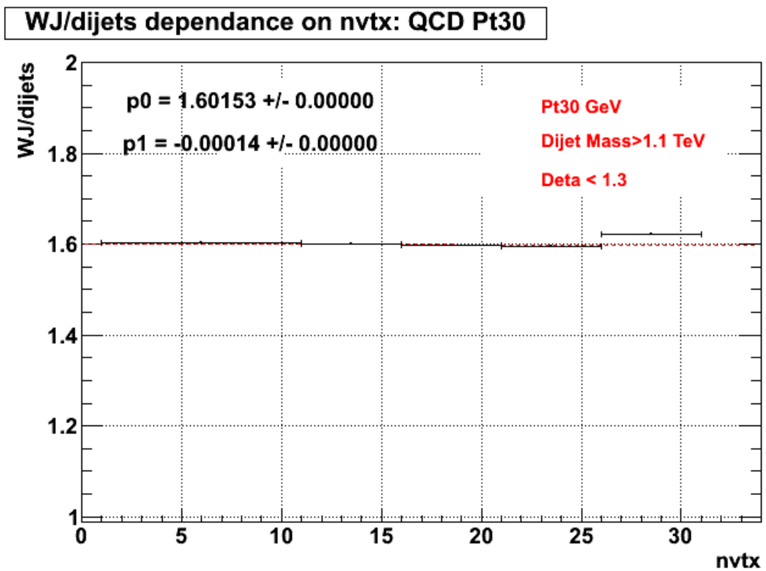



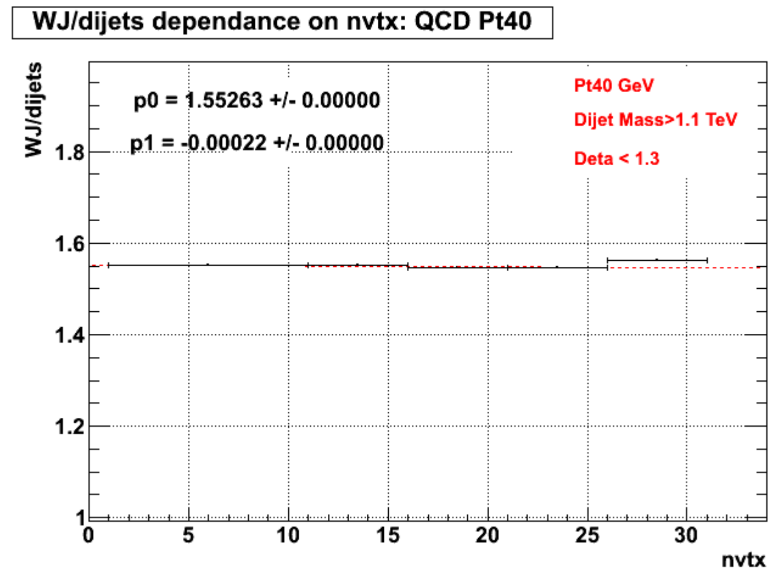



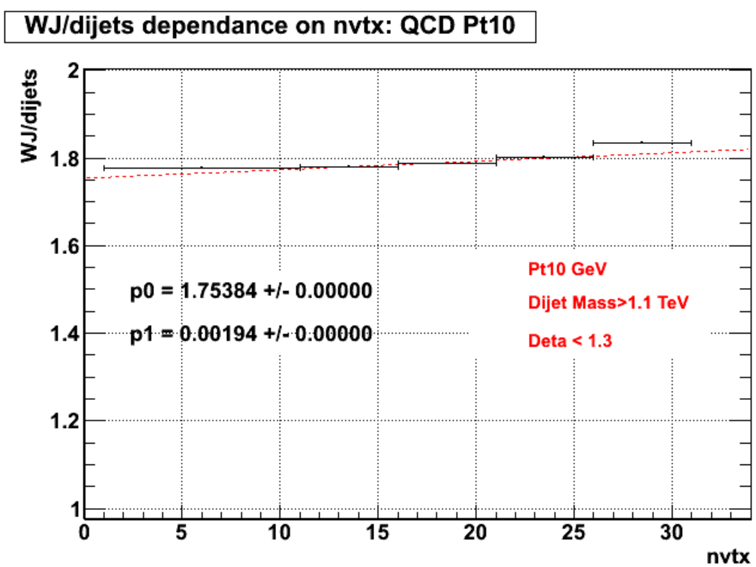

No differences observed. Same for all other mass points.

# PU studies: Optimization of pt in QCD

## The pile-up depedance of the ratio of Wijets and dijets for pt>30 GeV, pt>40 GeV and pt>10 GeV.




**As it was expected, for**
- **pt>30 or 40 GeV**

**we don't see any PU dependence**
- **pt>10 GeV**

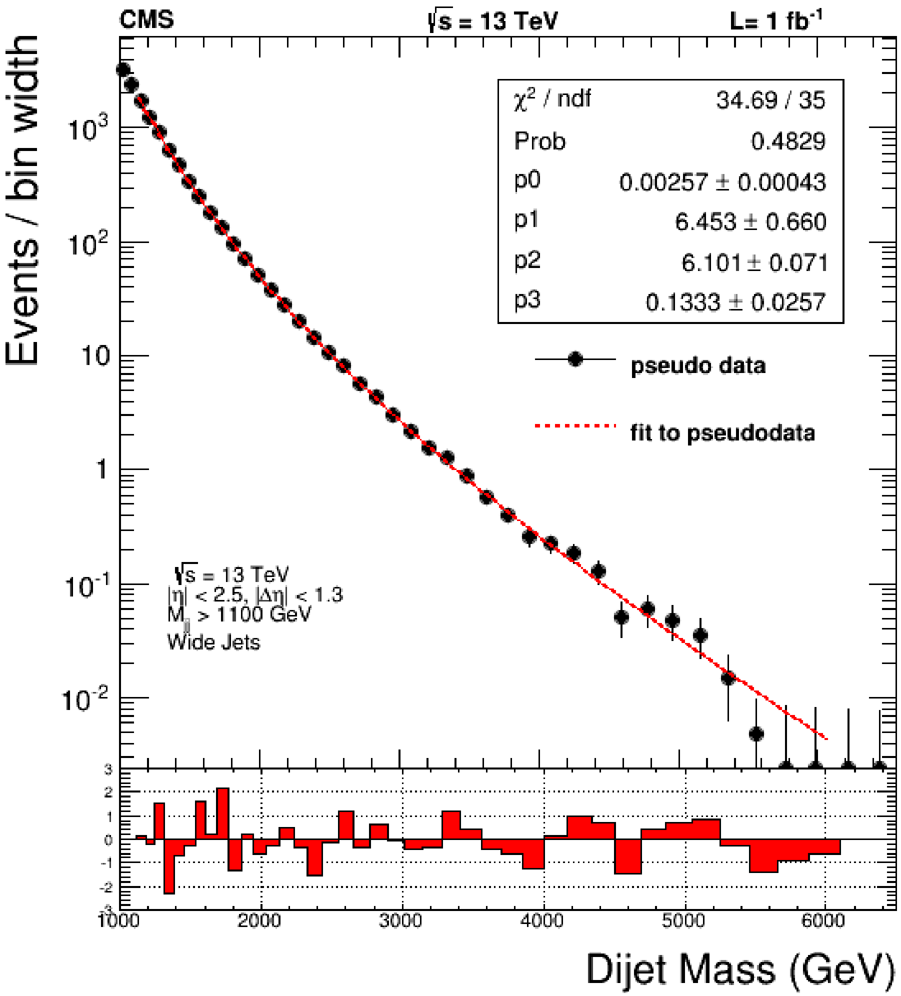
**we can observe a PU dependence.**

# Background pseudo-dataset and fit: 1 fb$^{-1}$

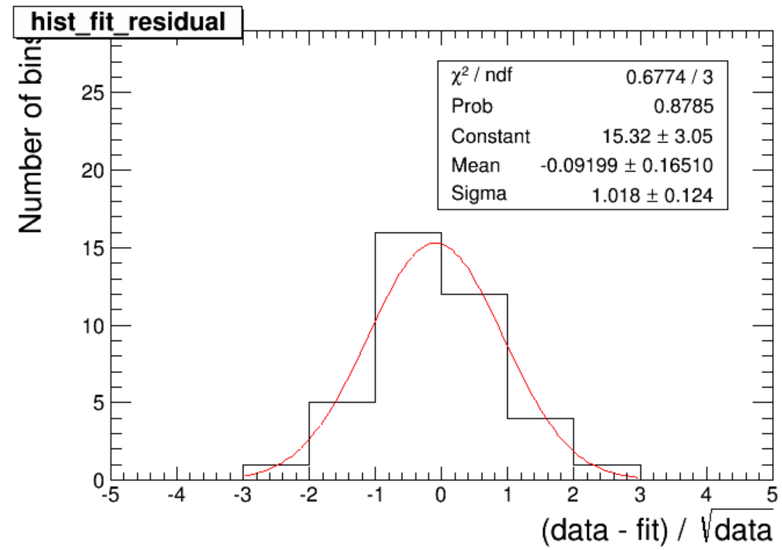
Variable mass binning corresponding to the estimated dijet mass resolution.

Pseudo dataset corresponding to **<u>1 fb</u>**$^{-1}$.

Fit with standard parametrization with 4 parameter, fit region 1.1 TeV → 6 TeV.



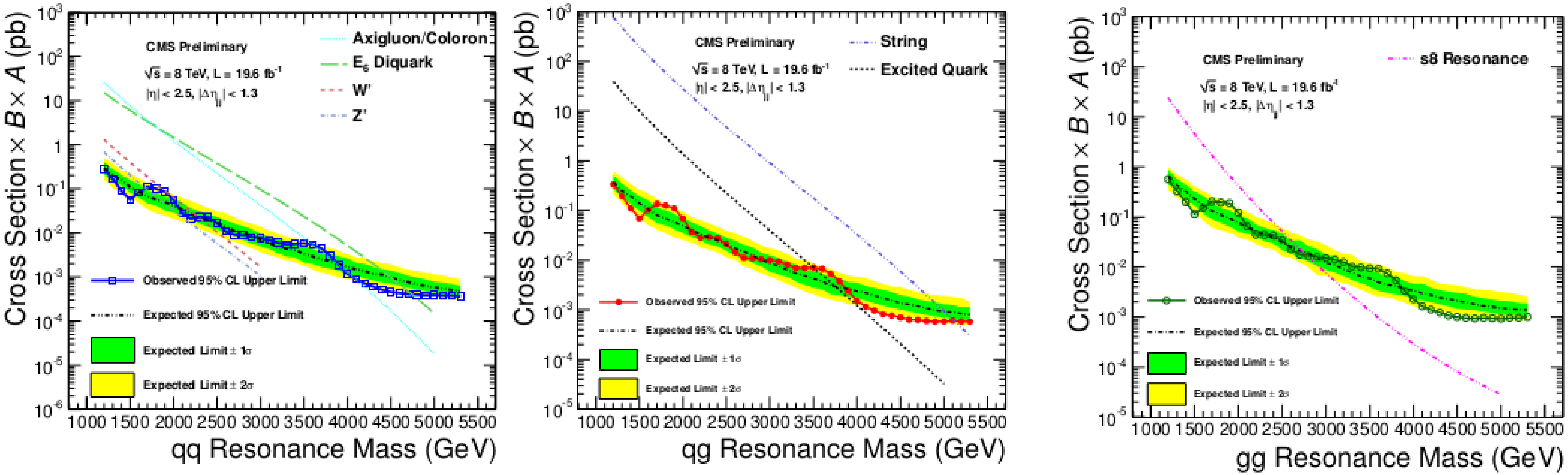

$$\frac{p_0\left(1-\frac{x}{13000}\right)^{p_1}}{\left(\frac{x}{13000}\right)^{p_2+p_3\log\left(\frac{x}{13000}\right)}}$$




The pseudo-data is well fitted with the standard parameterization.

# Limits from the 8 TeV data

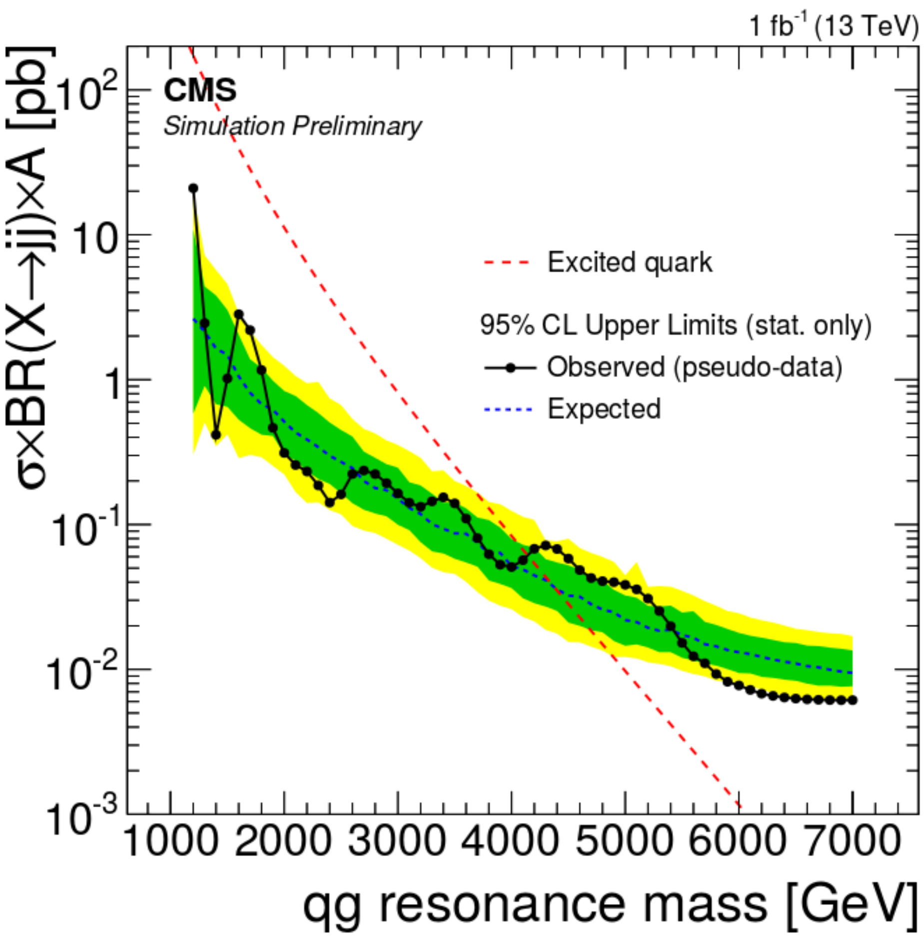
**Phys. Rev. D 87 (2013)**




| Model | Final State | Obs. Mass Excl. [TeV] | Exp. Mass Excl. [TeV] |
|---|---|---|---|
| String Resonance (S) | qg | [1.20,5.08] | [1.20,5.00] |
| Excited Quark ($q^*$) | qg | [1.20,3.50] | [1.20,3.75] |
| $E_6$ Diquark (D) | qq | [1.20,4.75] | [1.20,4.50] |
| Axigluon (A)/Coloron (C) | $q\bar{q}$ | [1.20,3.60] + [3.90,4.08] | [1.20,3.87] |
| Color Octet Scalar (s8) | gg | [1.20,2.79] | [1.20,2.74] |
| W′ Boson (W′) | $q\bar{q}$ | [1.20,2.29] | [1.20,2.28] |
| Z′ Boson (Z′) | $q\bar{q}$ | [1.20,1.68] | [1.20,1.87] |
| RS Graviton (G) | $q\bar{q}$+gg | [1.20,1.58] | [1.20,1.43] |

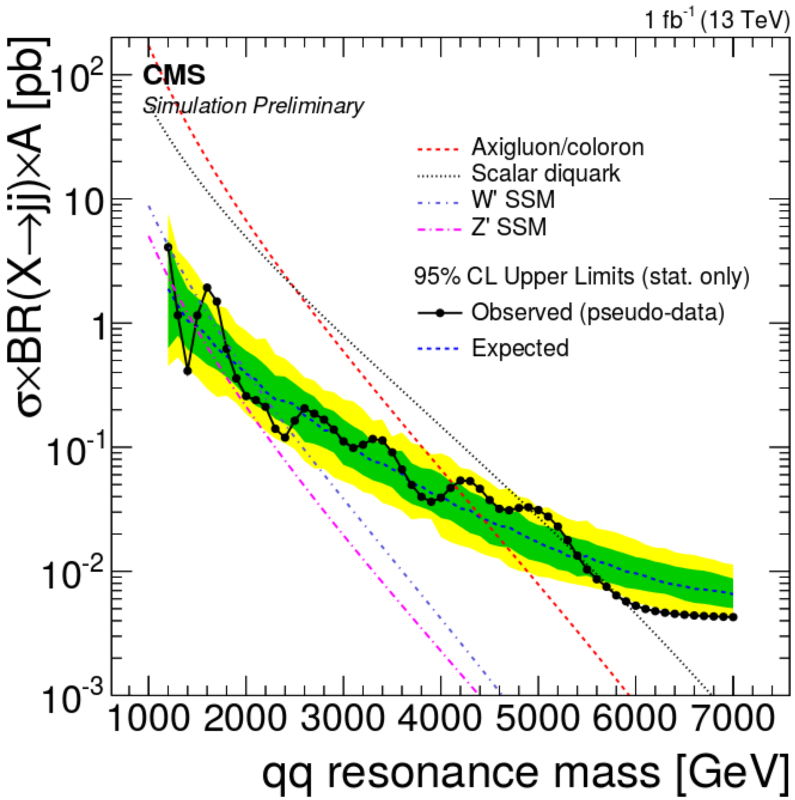
# Expected cross-section limits for 1 $fb^{-1}$

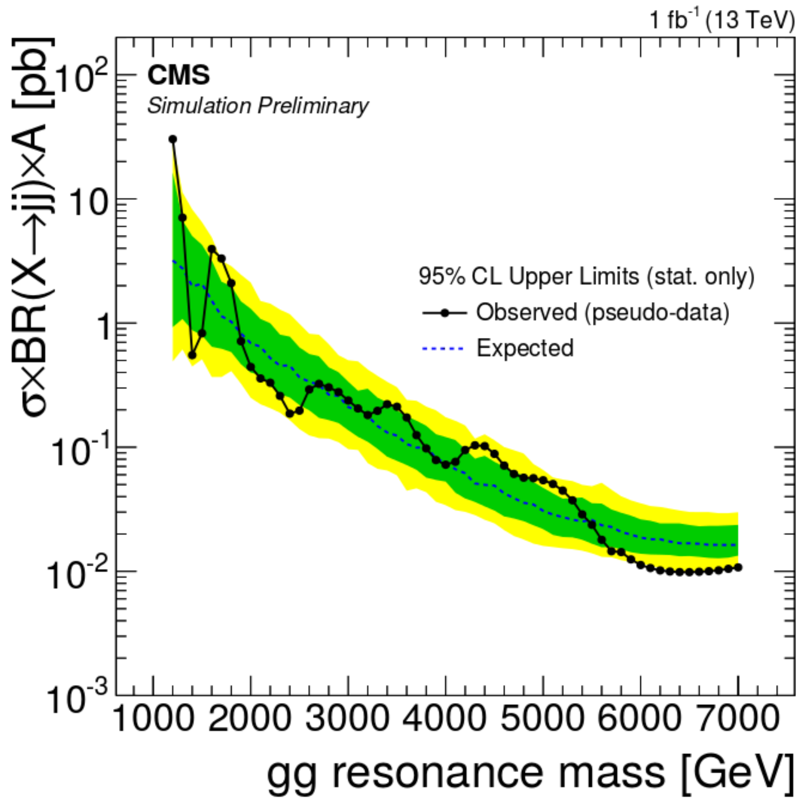
Mass points range from 1.2 to 7 TeV in steps of 100 GeV using interpolated signal shapes.




- Expected limits on dijet resonances with 1$fb^{-1}$ of pseudo data
- Expected q* mass limit 4.5 TeV exceeds Run I expected (3.7 TeV) & observed limit (3.5 TeV).

# Expected cross-section limits for 1 fb$^{-1}$




Our expected limits on Scalar Diquarks and Axigluons are greater than Run I.

# Conclusions

- The CMS Dijet resonance search has a great potential on discovering new physics with the first few $fb^{-1}$ of data at 13 TeV, and has produced exclusion limits so far.
- Analysis Framework is in place and ready to produce the limits for $1fb^{-1}$ (3 weeks of data taking).
- Optimization studies on several selection criteria show that the chosen values are close to the optimal.
- Several pileup studies indicate that the analysis is robust against it.
- The expected q*, Scalar Diquarks and Axigluons limits for 1 $fb^{-1}$ having only the statistical uncertainties already exceed the Run I results.
- We continue to improve and finalize our previous optimization, background fit and limit setting studies and we are waiting for the 13 TeV data!

# Interpolation Studies

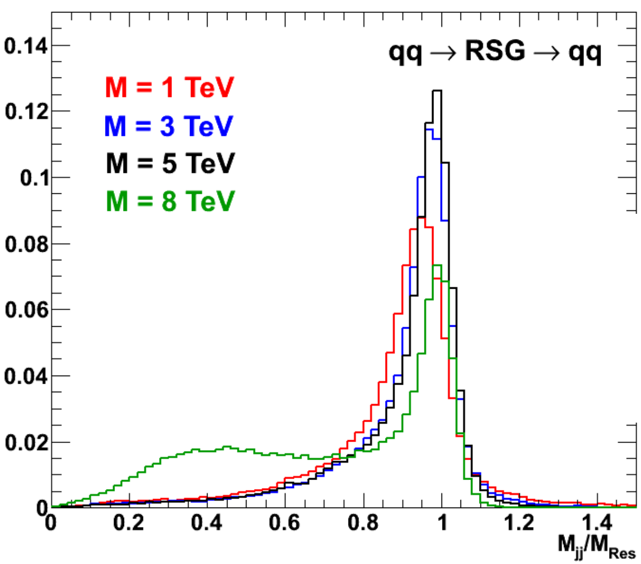
**Obtain resonance shapes at intermediate mass points using true MC signal shapes.**

• X = Mjj / $M_{res,}$ the X distribution for a resonance with mass of M is derived by the X distribution from MC samples with choosing neighbor resonance masses ($M_1$,$M_2$) using Eq.(1).

i.e. in order to generate resonance shape at 4 TeV, MC samples at 3 TeV and 5 TeV are used.

• The X distribution is converted to dijet mass using interpolation.

•At the end we have dijet mass shapes for every 100 GeV mass point.




$$Prob_M(x) = Prob_{M_1}(x) + \left[Prob_{M_2}(x) - Prob_{M_1}(x)\right] \cdot \frac{M - M_1}{M_2 - M_1} \quad \text{Eq.(1)}$$