Resonances in Hadronic Channels and Quark Substructure

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For the CMS Collaboration

Introduction

- **Many predicted New Physics outside the SM live in the hadronic sector:**
  - **Axigluons, excited quarks, gluinos, Z', contact interactions and many more**
- **Dedicated analyses with jets probe all of these final states using 2010 LHC data**

New Physics in the Dijet Mass Spectrum (2.9 pb^{-1})

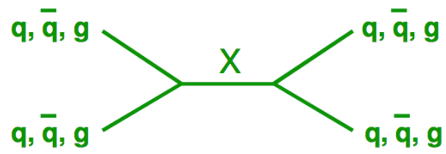
Quark Compositeness in Dijet Angular Distributions (36 pb^{-1})

Three Jet Resonances in Multi-Jet Events (35 pb^{-1})

Resonances in Semi-leptonic Top-pair Decays (36 pb^{-1})

New Physics in the Dijet Mass Spectrum

- **Narrow resonances decaying to dijets**
  - **Quark-quark, quark-gluon, gluon-gluon**

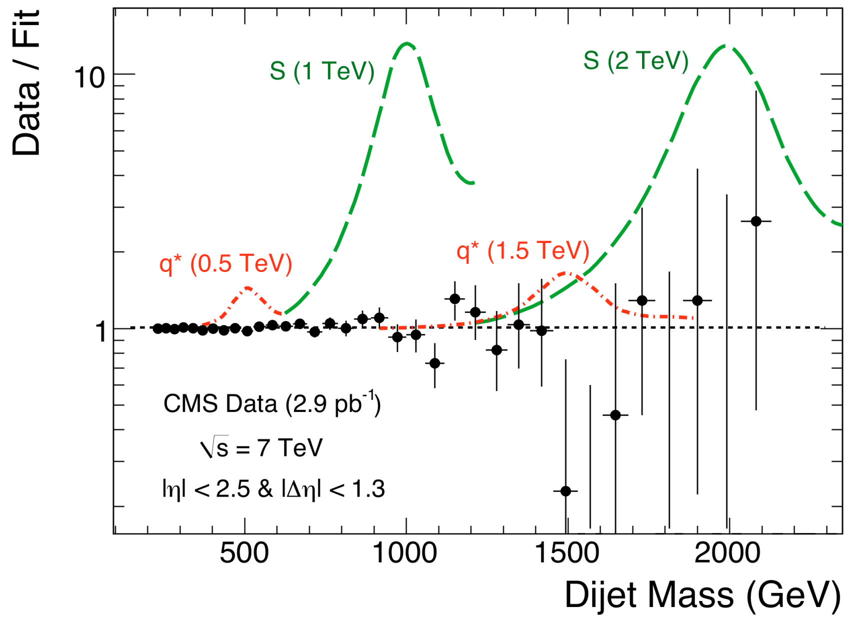


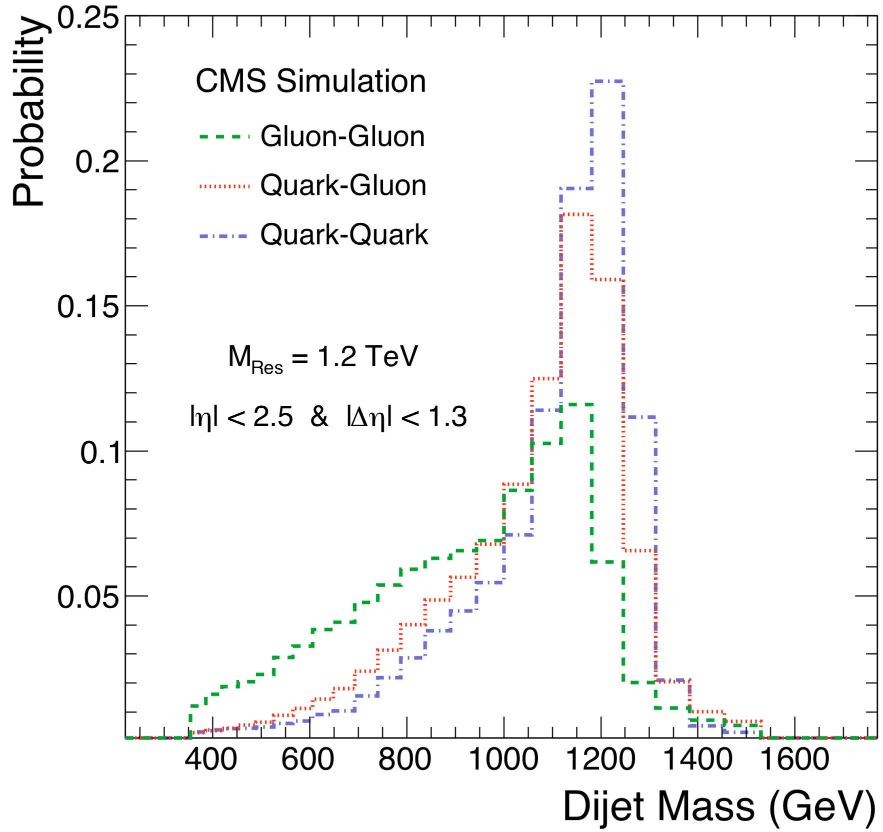
Signature Selection

Leading 2 jets in event :

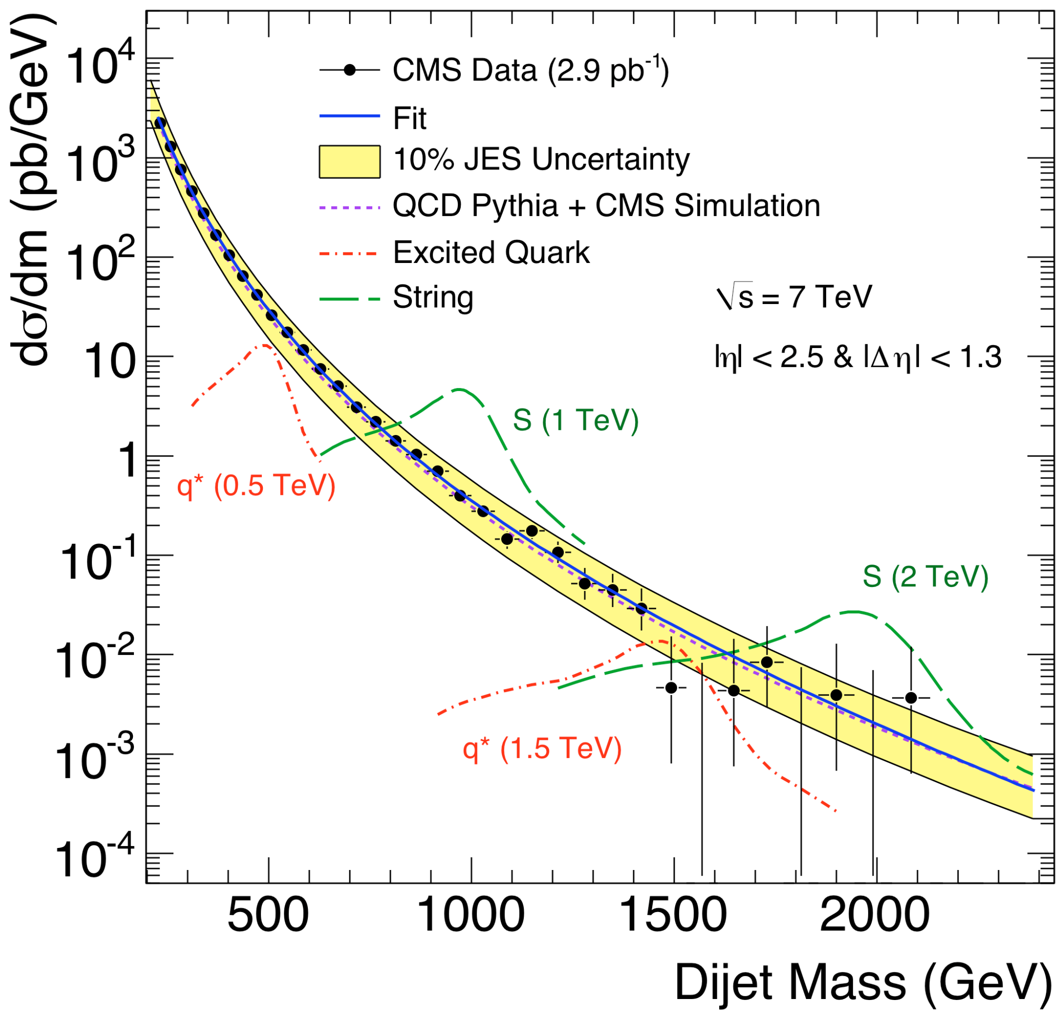
M_{jj} > 220 GeV

$|\eta_{1,2}| < 2.5$, $|\Delta\eta_{1,2}| < 1.3$





New Physics in the Dijet Mass Spectrum



Backgrounds:

- All QCD multi-jet event

  SM predicts smoothly falling distribution

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

Systematics (23–49%)

- Jet Energy Scale (15 – 38%)

  Due to JES per jet from 10%
- Background shape parameterization

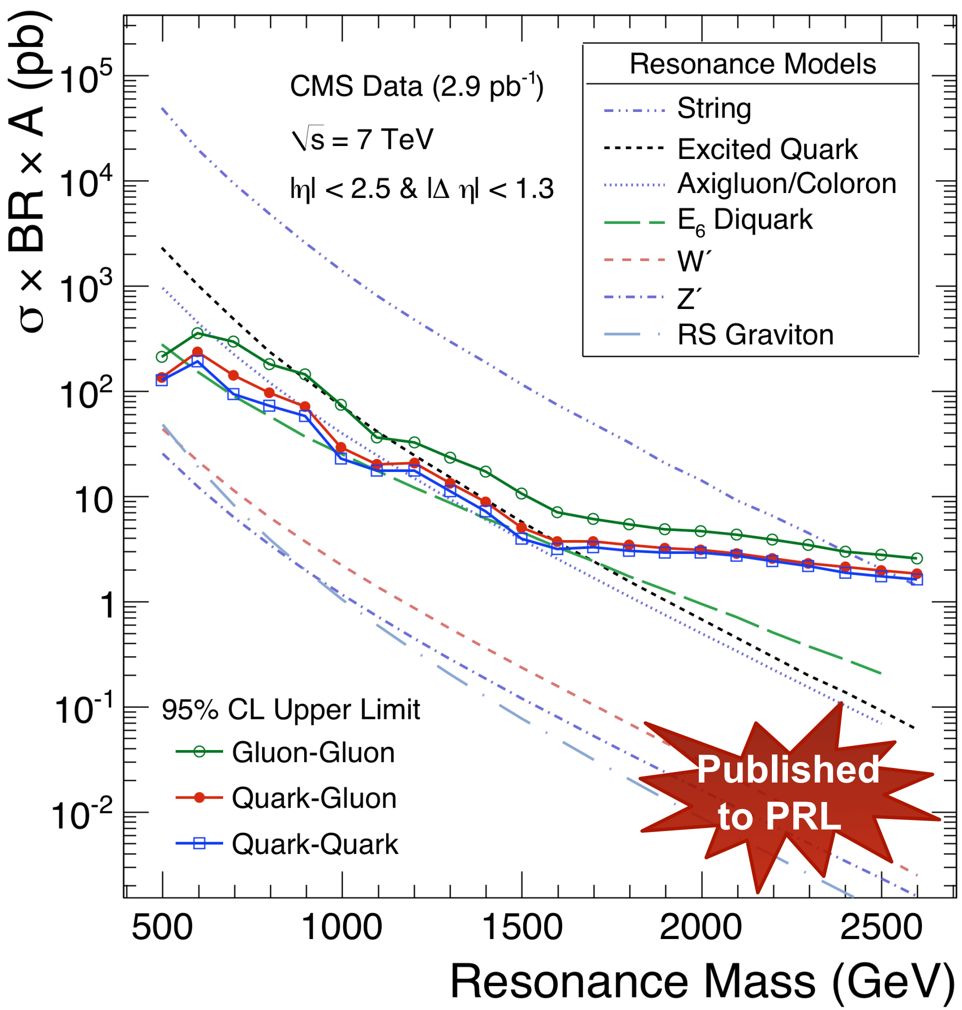
  Alternate 4 parameter fit function
- Jet Energy Resolution
- Luminosity (11%)

  Reduction from 11% to 4%

New Physics in the Dijet Mass Spectrum

- **Limits are set using Bayesian approach with constant prior**
- **Model-independent limits tested for 7 benchmark resonances**

Model	Exclusion regions [TeV]
String resonance	0.50 – 2.50
Excited quark	0.50 – 1.58
Axigluon / Coloron	0.50 – 1.17 & 1.47 – 1.52
E_6 diquark	0.50-0.58, 0.97-1.08, & 1.45-1.60



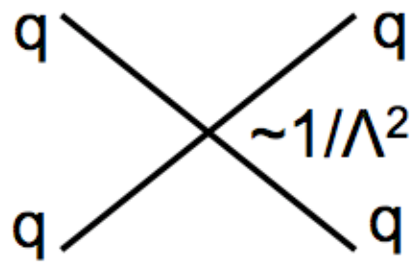
Quark Compositeness in Dijet Angular Distributions

- **New Physics in dijet angular distributions:**
  - χ **is related to scattering angle θ* as**

    $$\chi = e^{2y^*} = \exp(|y_1 - y_2|)$$

  - **Background from QCD is flat in** χ
  - **Isotropic new physics peaks at low** χ

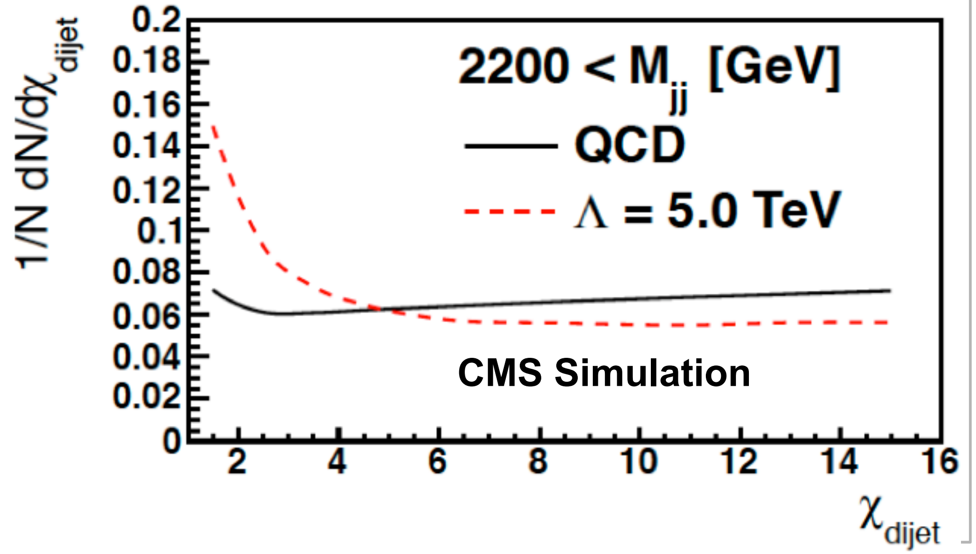
    Benchmark Model: quark compositeness



Signature Selection

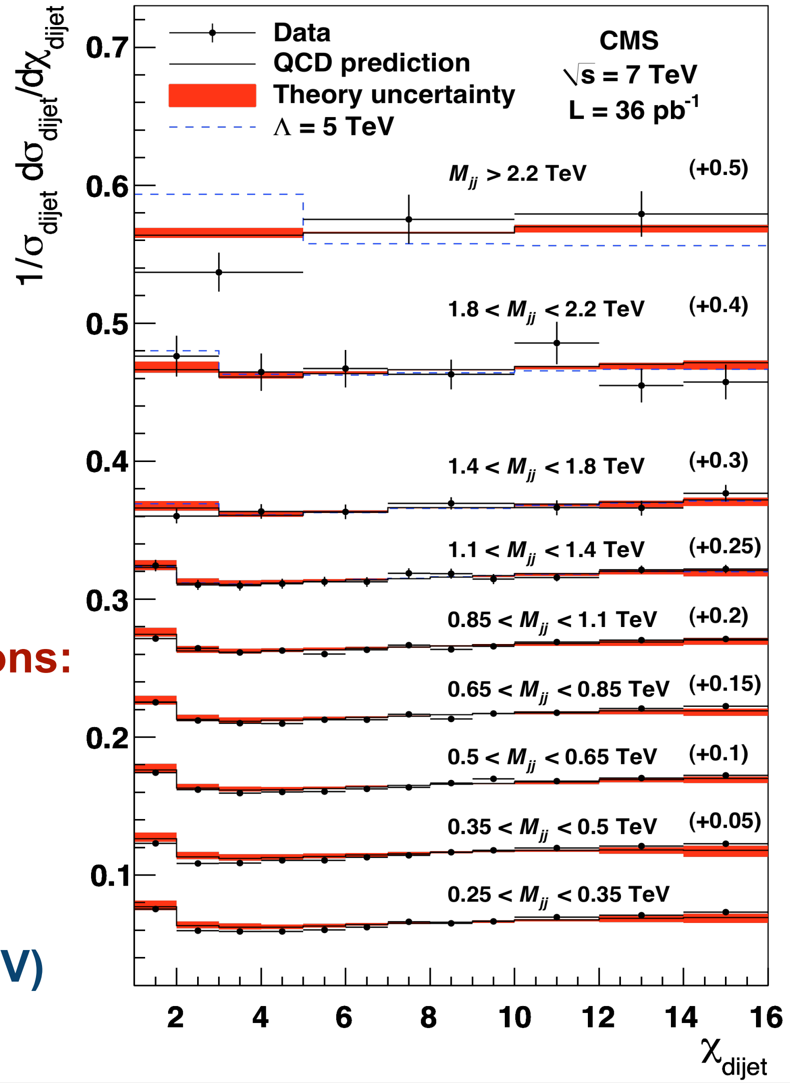
Leading 2 jets in event :

- $M_{jj} > 250 - 850$ GeV
- $|\eta_{1,2}| < 2.5$
- $y_{BOOST} = \frac{1}{2}(y_1 + y_2) < 1.11$
- $y^* = \frac{1}{2}|y_1 - y_2| < 1.39$



Quark Compositeness in Dijet Angular Distributions

- **QCD Background:**
  - NLO QCD MC with non-perturb. Corrections
  - Data corrected back to particle level
- **Data and uncertainties (stat. ⊕ syst.):**
  - Jet Energy Scale (1.5 – 3%)
  - Jet Energy Resolution (0.5 – 1.5%)
  - Additionally, going to particle level:
    - Total unsmearing uncertainty < 2%
- **NLO prediction + Non-perturbative corrections:**
  - NLO scale uncertainty (6 – 9%)
  - NLO PDF uncertainties (0.5%)
  - Non-perturbative correction uncert (0.1 – 4%)
- **Good agreement with NLO QCD(M_{jj} < 2.2 TeV)**
  - Slight low fluctuation seen for M_{jj} > 2.2 TeV

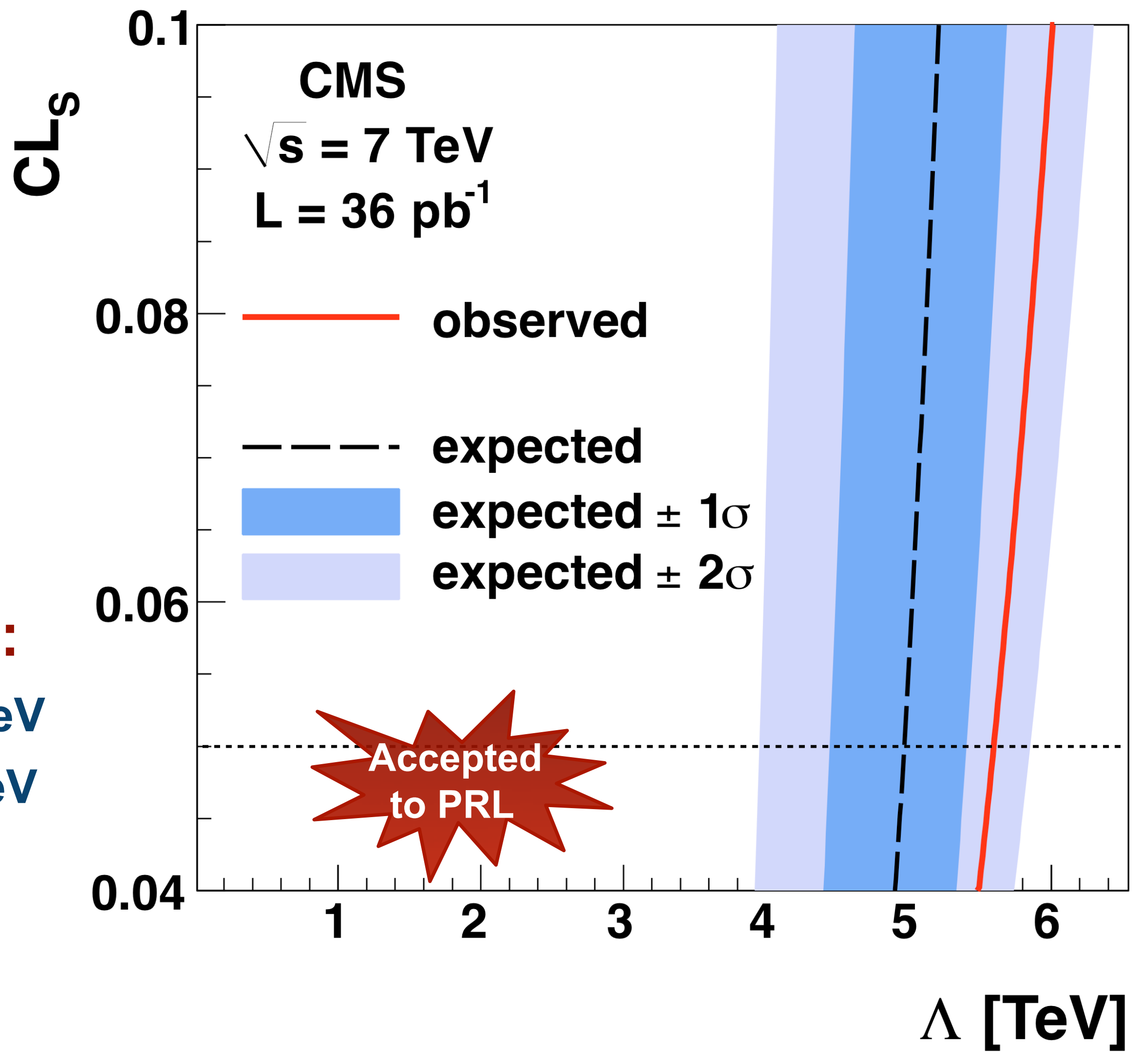


Quark Compositeness in Dijet Angular Distributions

- **Modified Frequentist approach for limits:**

$$CL_s = \frac{P_{QCD+CI}(Q \geq Q_{obs})}{1 - P_{QCD}(Q \leq Q_{obs})}$$

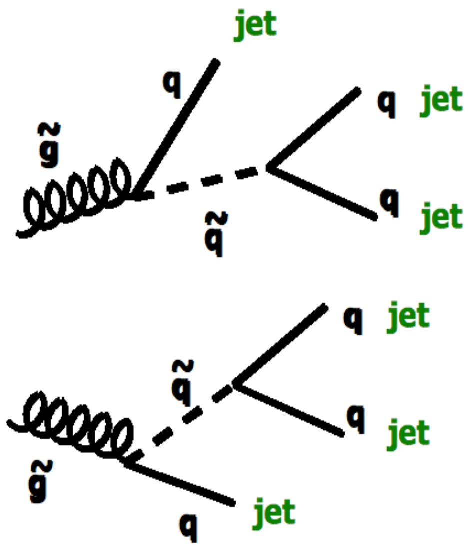
- **Exclusion at 95% CLs:**
  - **Observed limit: Λ > 5.6 TeV**
  - **Expected limit: Λ > 5.0 TeV**



Three Jet Resonances in Multi-Jet Events

- **Searching for strongly coupled resonances decaying to three-jets**

  Benchmark model: R-parity violating gluino decays (pair-produced + strongly coupled to *uds* quarks)



<u>Signature Selection</u>

High Jet Multiplicity (≥ 6 Jets)

Large event scalar sum p_T (> 425 GeV)

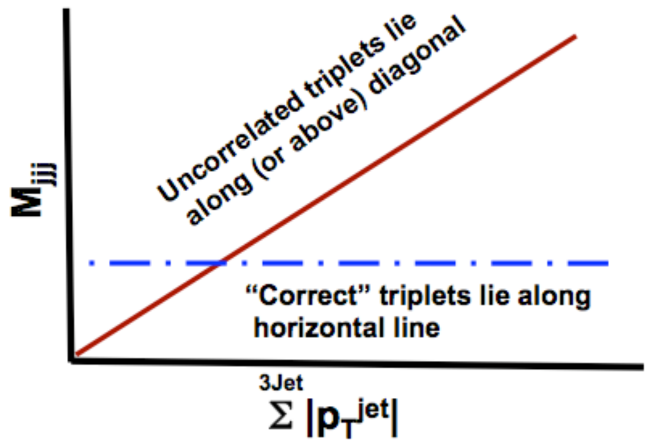
Construct Jet M_{jjj} Triplets (20 Combinations

For all jet triplets, plot :

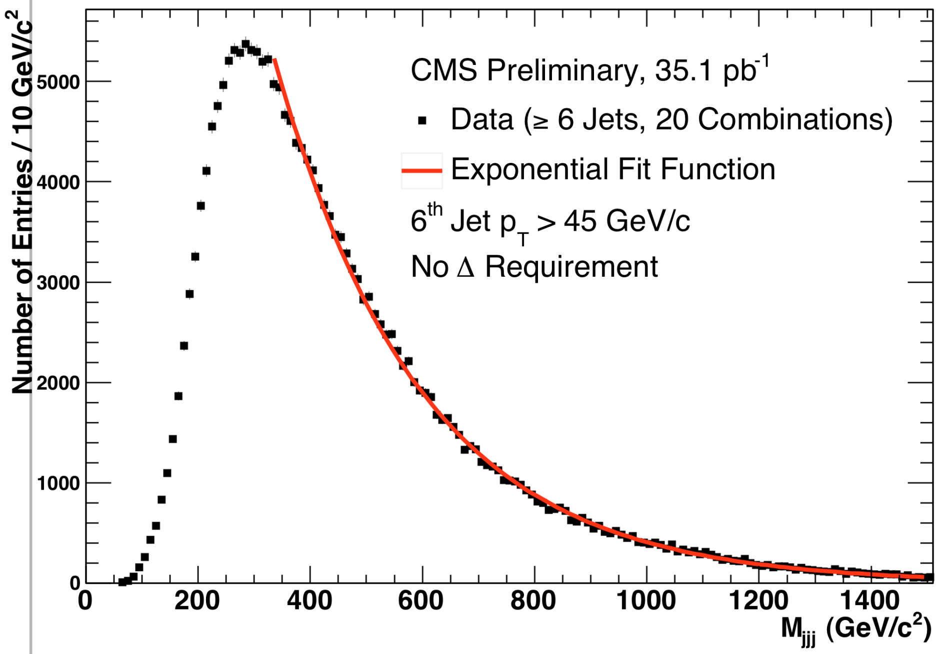
M_{jjj} vs. $\Sigma\,|p_T^{jet}|$

Require <u>each</u> to pass:

$M_{jjj} < \Sigma\,|p_T^{jet}| - \Delta$ (Offset)

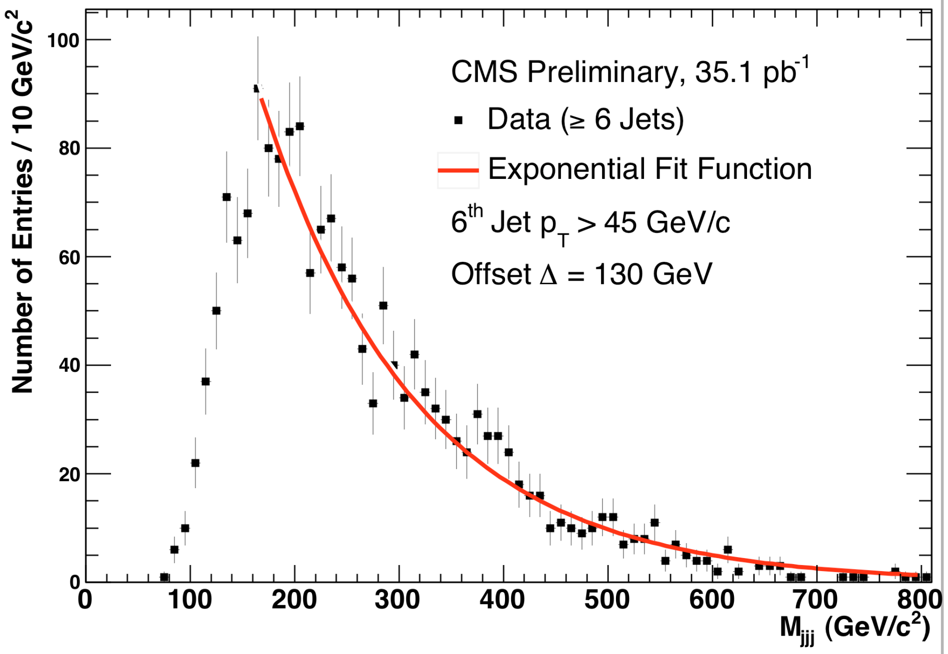


Three Jet Resonances in Multi-Jet Events



Three-jet mass for control region

Control region with all 20 jet triplets: used to test quality of 2 parameter fit



Three-jet mass for final selection:

130 GeV offset Δ

6^{th} jet p_T > 45 GeV

Parameters of fit function taken from exclusive N_{JET} bins in data

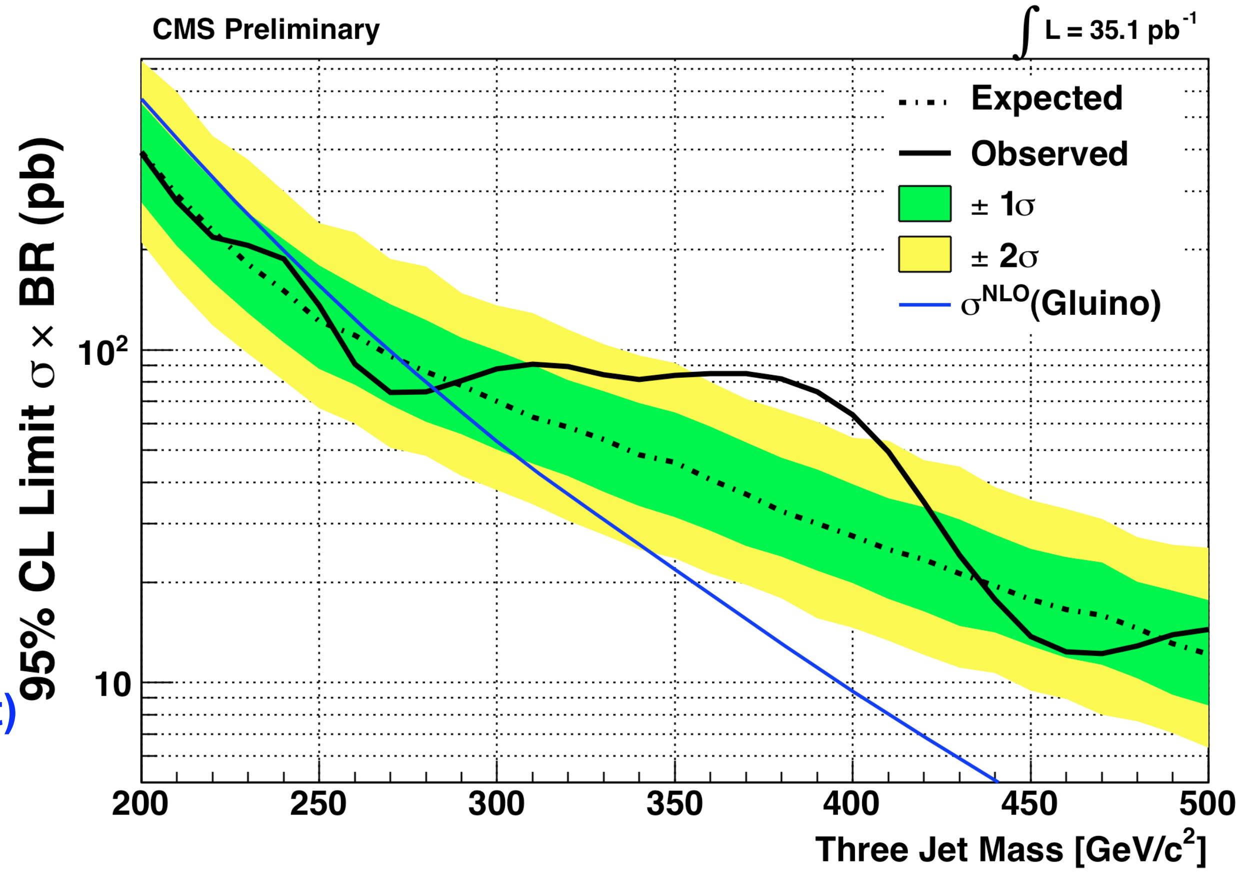
Three Jet Resonances in Multi-Jet Events

95% CL limits from Bayesian likelihood approach

Uncertainties treated as Gaussian nuisance parameters:
Largest uncertainties from JES (8 – 17%)

Exclusion for gluinos (RPV decay) for masses 200 < M < 280 GeV/c^2

Largest excess seen at 390 GeV/c^2 corresponding to 1.9σ (with look-elsewhere effect)

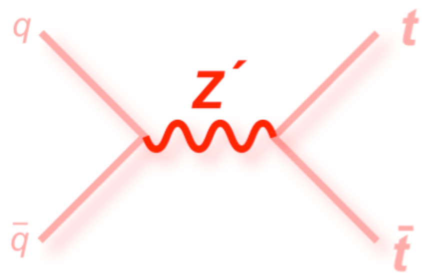


1st limits from the LHC
Highest limits to date

Resonances in Semi-leptonic Top-pair Decays

- **Search for narrow resonances to top-quark pairs**

  Benchmark: Leptophobic Z'

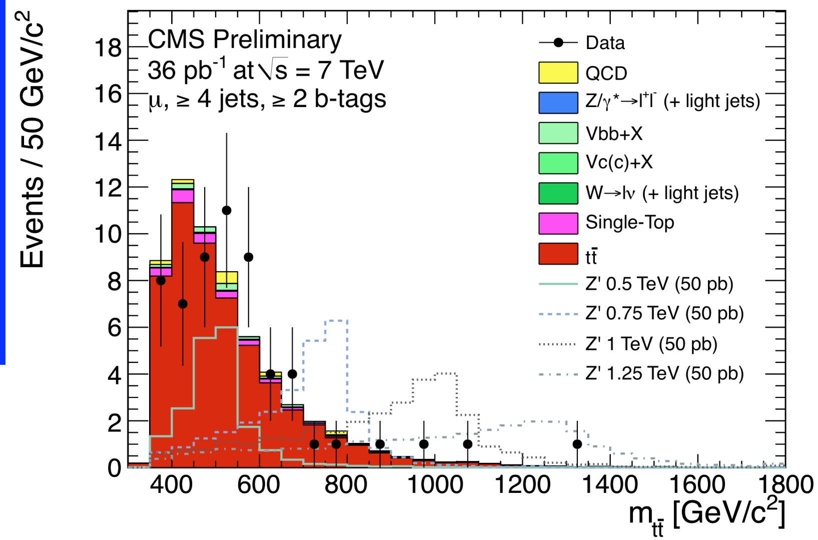


Signature Selection

Baseline selection:

Lepton + jets channel

- **1 muon with p_T > 20 GeV *or***
- **1 electron with p_T > 30 GeV**
  - **(Veto any additional leptons)**
- **At least 3 (4) jets with**
  - **p_T > 70 / 50 / 30 / (30) GeV**
  - **Split into 0,1,2 b-tagged jet samples**
- **Missing E_T > 20 GeV**

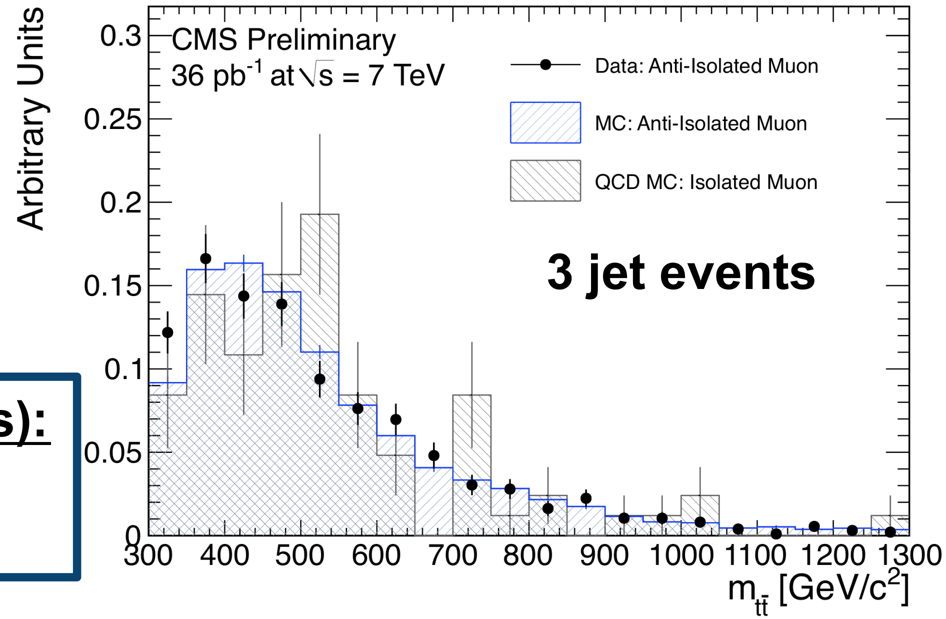


Resonances in Semi-leptonic Top-pair Decays

Background Sources

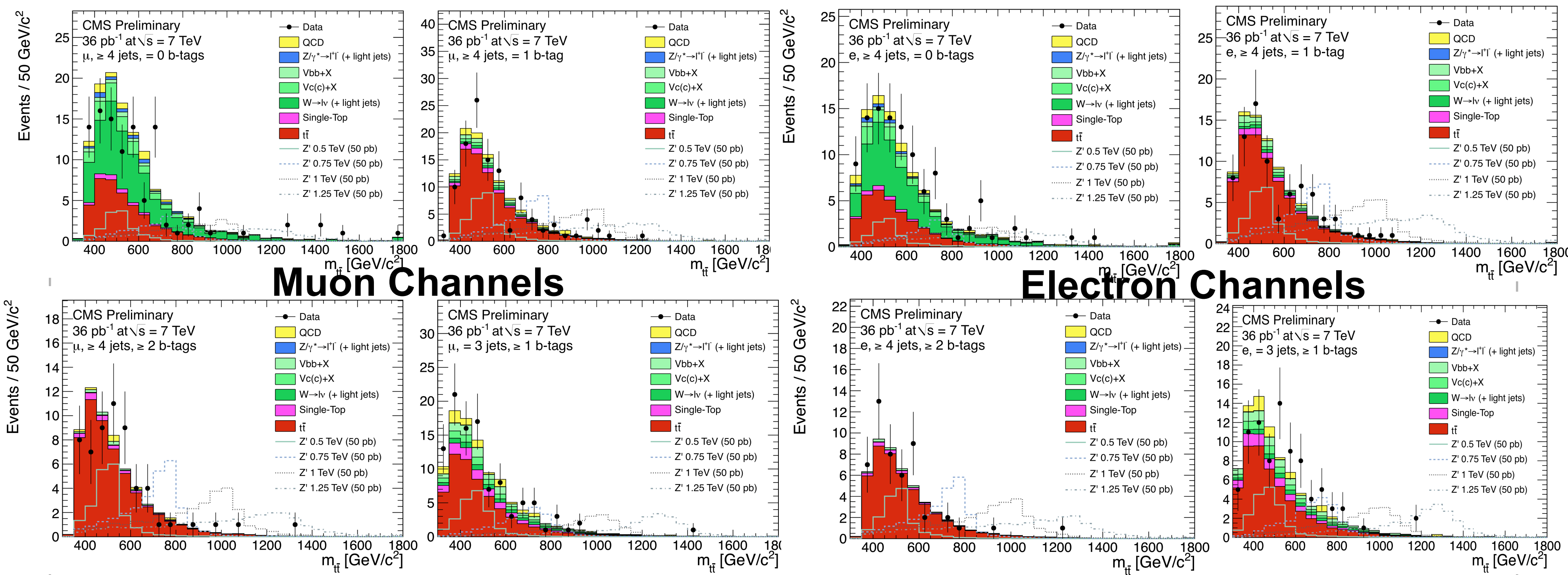
Top pair production
W/Z + jets
Electron QCD
Muon QCD
Single-top

QCD background from Data (muons):
Invert isolation requirement
Reweight according to muon p_T



Yields	$t\bar{t}$	W/Z+LF	W/Z+HF	Single-top	QCD	Data	Sum BG
μ 3j1t	96.9 ± 0.6	7.9 ± 0.2	28.6 ± 1.1	11.6 ± 0.1	8.2 ± 8.2	142 ± 11.9	153.2 ± 8.3
μ 4j0t	40.4 ± 0.5	62.8 ± 2.2	25.0 ± 1.0	2.5 ± 0.1	4.5 ± 4.5	107 ± 10.3	135.1 ± 5.1
μ 4j1t	84.8 ± 0.6	3.8 ± 0.1	12.5 ± 0.7	4.2 ± 0.1	5.1 ± 5.1	112 ± 10.6	110.5 ± 5.2
μ 4j2t	51.6 ± 0.4	0.1 ± 0.0	2.4 ± 0.2	2.0 ± 0.0	1.0 ± 1.0	58 ± 7.6	57.1 ± 1.1
e 3j1t	80.3 ± 0.6	5.4 ± 0.1	22.8 ± 1.0	8.5 ± 0.1	9.4 ± 9.4	114 ± 10.7	126.4 ± 9.5
e 4j0t	31.8 ± 0.4	47.0 ± 1.9	19.1 ± 0.9	1.9 ± 0.0	10.8 ± 10.8	106 ± 10.3	110.4 ± 11.0
e 4j1t	66.7 ± 0.5	2.8 ± 0.1	9.0 ± 0.6	3.2 ± 0.1	3.0 ± 3.0	80 ± 8.9	84.7 ± 3.1
e 4j2t	40.9 ± 0.4	0.1 ± 0.0	2.1 ± 0.2	1.5 ± 0.0	0.1 ± 0.1	50 ± 7.1	44.6 ± 0.5

Resonances in Semi-leptonic Top-pair Decays

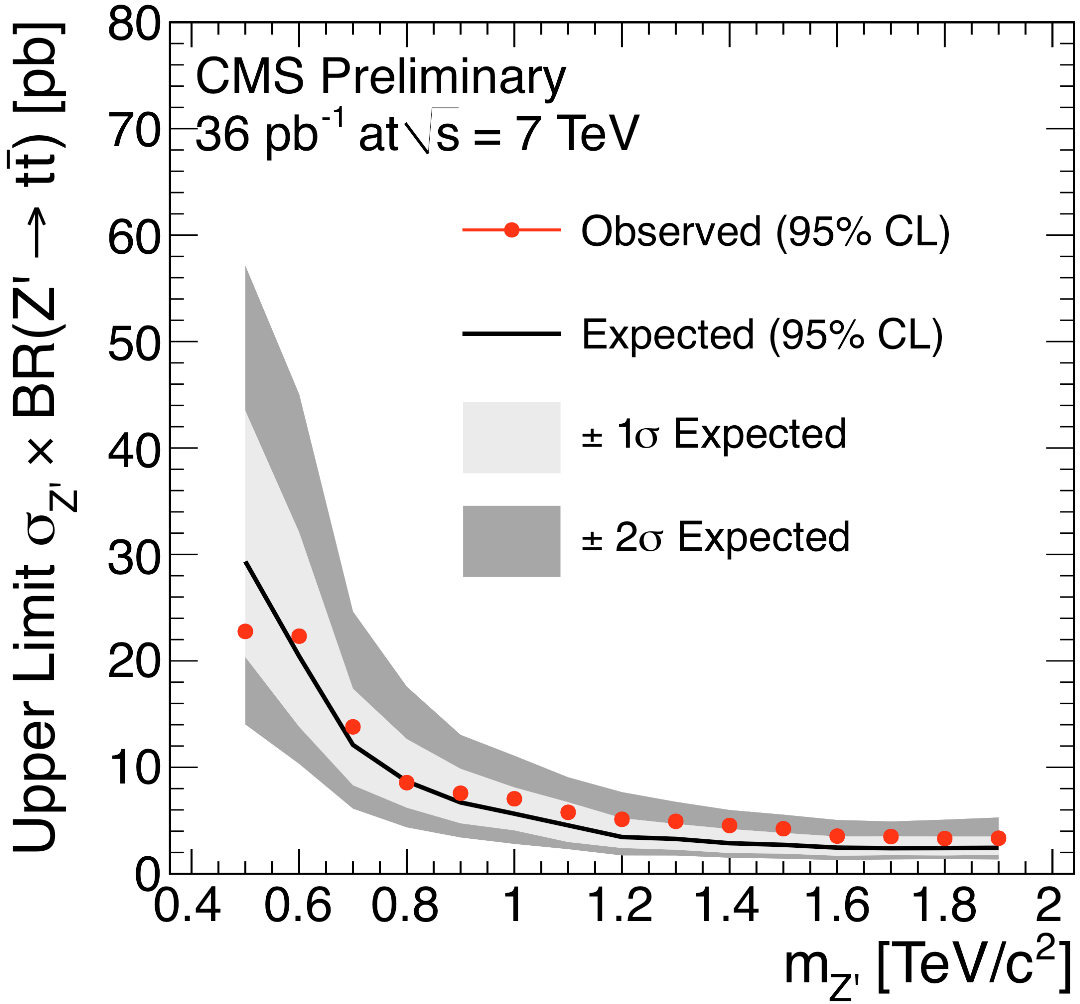


- **Good agreement found, but no excess seen in any M(tt) channels**

  Limits are set using a simutaneous fit of all channels

Resonances in Semi-leptonic Top-pair Decays

- **Bayesian integration to derive 95% CL upper limits**
  - **Implemented with *theta* using Markov Chain MC**
  - **Perform full integration at each mass point**
  - **Derive upper limits from 95% quantiles of posterior probability densities**



Leading Systematics

Shape based: Lumi, top pair cross section, ratio of W/Z + HF jets to σ(W)

Rate based: jet energy scale, b-tagging efficiency, top pair modeling, Q^2 of top pairs

Conclusions

- No discoveries yet for hadronic resonances using 2010 data, but..
  - Well understood backgrounds and data-driven techniques
  - Competitive limits are set in all analyses, and in most cases world's best limits are set
- Already plans for updating results with 2011 data and extending analyses into new channels

  Potential for New Physics is right on the horizon!