Search for New Physics in the All-Hadronic Final States at CMS

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on behalf of the CMS Collaboration

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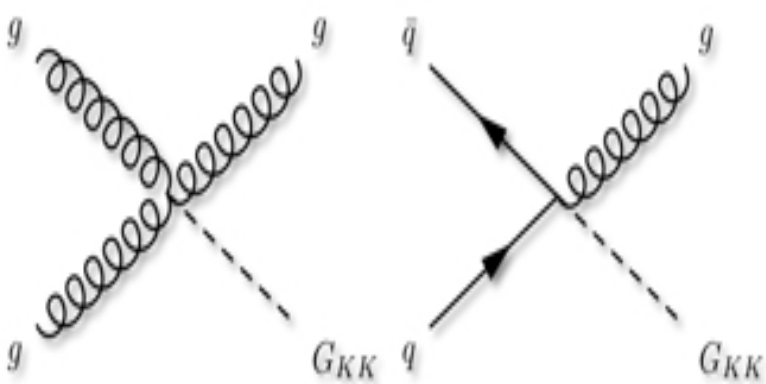
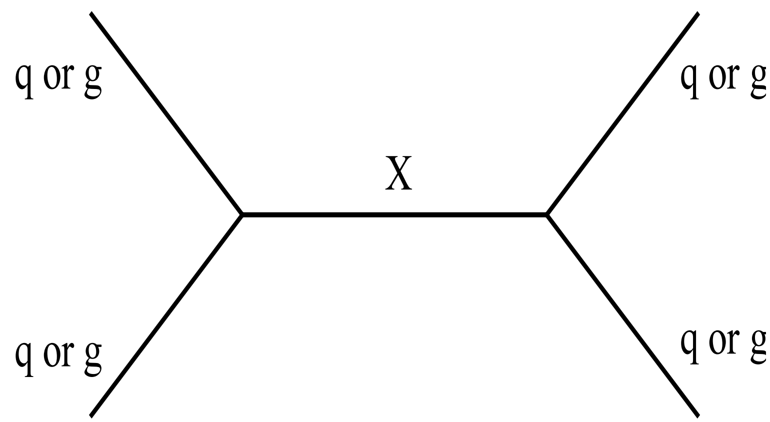
- The CMS detector and Jet Reconstruction
- Monojet + MET
- Dijet Resonances
- Multijet Resonances
- Multijet Transverse Momentum Sum Shape (Black Hole)
- Conclusion

Motivation

- All hadronic final state is sensitive to new physics from various models
  - Strong Dynamics: Jet Resonances
  - Extra Dimension: Jet Resonance, Monojet, Black hole
  - SUSY: Multijet Resonances (RPV)
- A channel with many potential discoveries

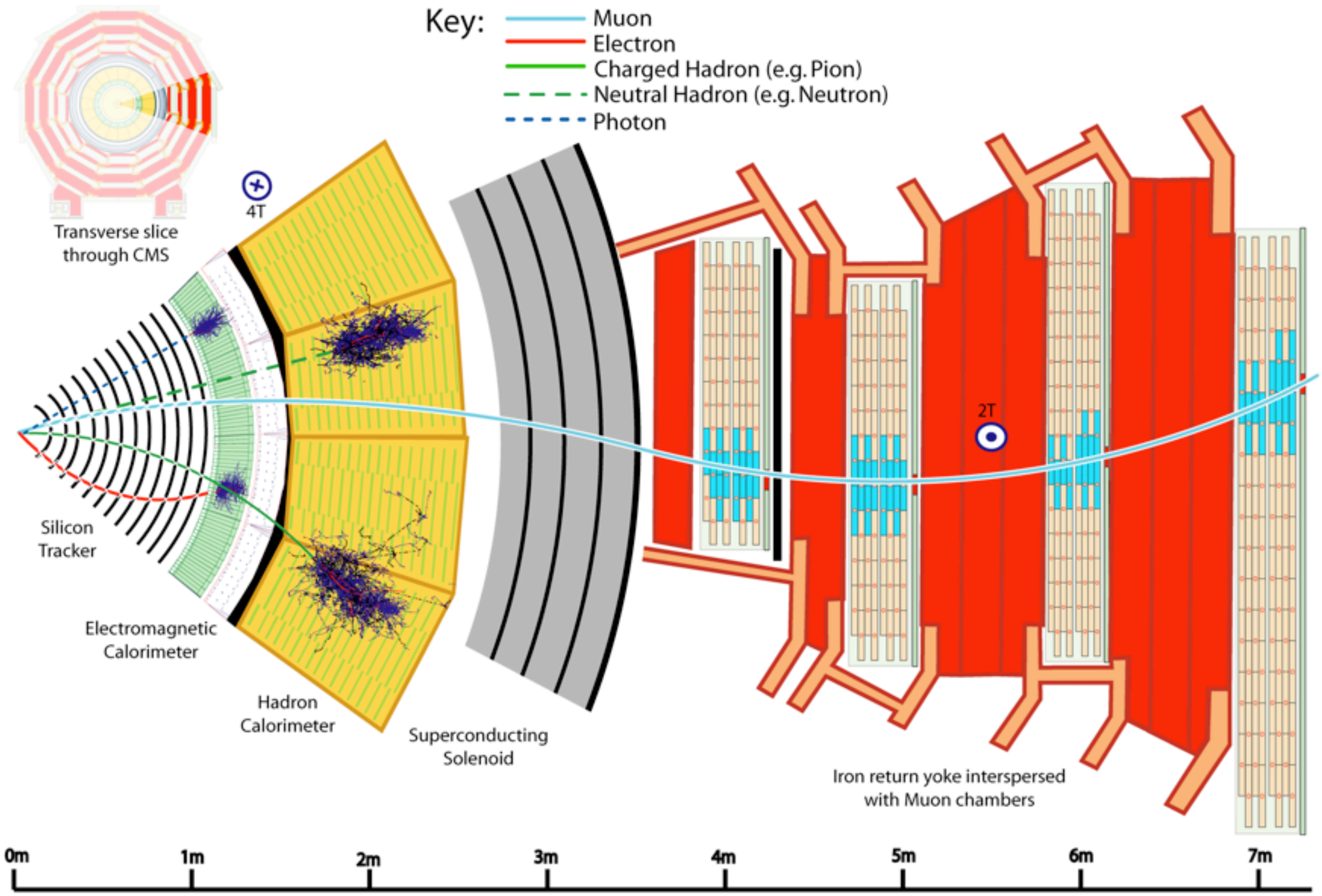


Graviton



Dijet resonance

The CMS Detector



Jet and MET Reconstruction

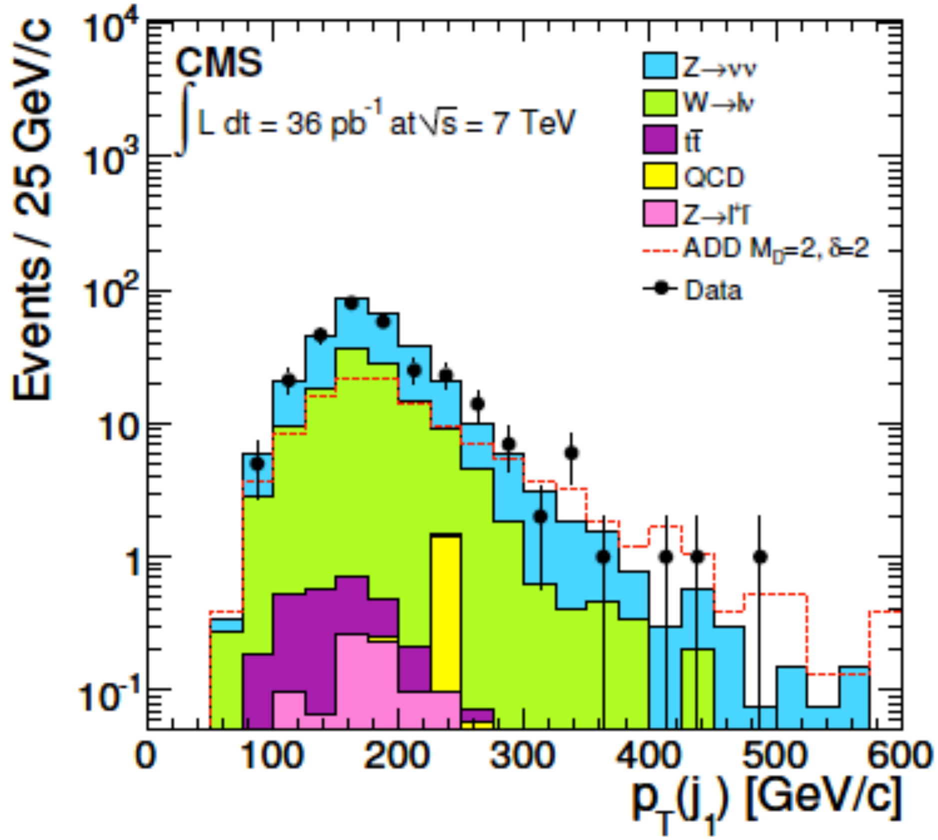
- Anti-kt (AK) clustering algorithm with cone size of 0.5 (AK5) and 0.7 (AK7)
  - Infrared and collinear safe
- Jet types:
  - Calorimeter Jets:

    Reconstructed from energy deposits in the EM and HAD calorimeter, grouped in projective calo towers
  - Particle Flow (PF) Jets:

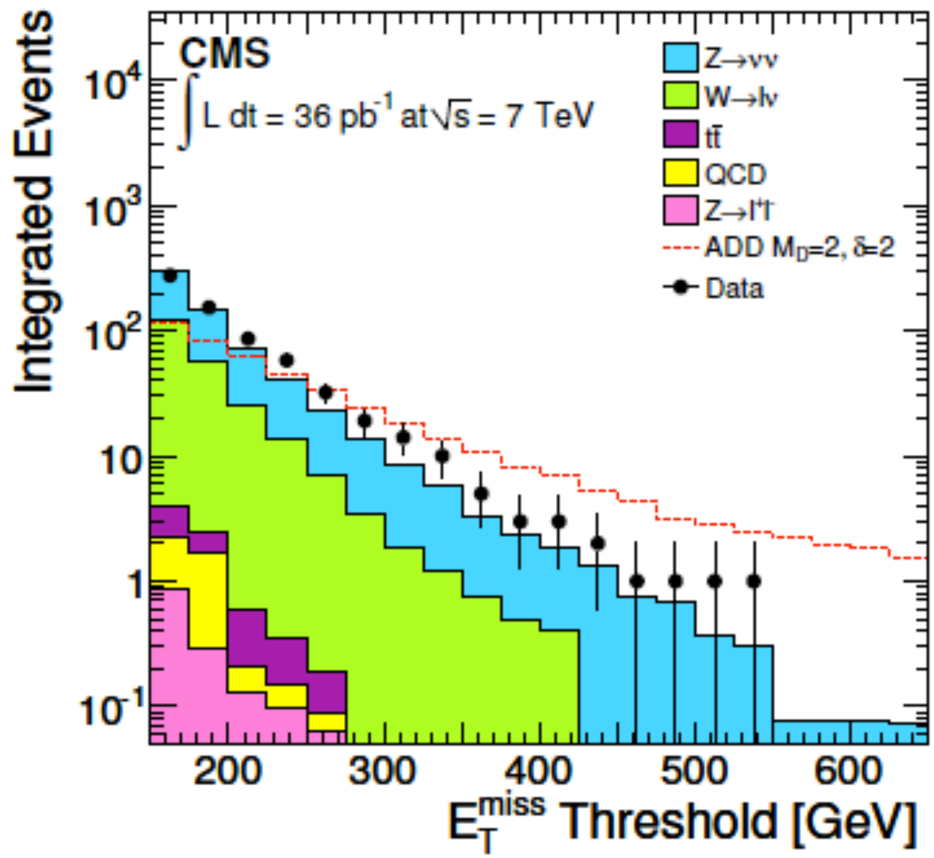
    Use all detector elements to reconstruct particles and cluster to jets.
  - Fat Jets:

    Clusters of AK5 PF Jets within radius of 1.1, optimize dijet resonance resolution by recombining FSR into the two leading jets
- Jet energy corrections: using MC truth information and real data
  - Uncertainty on jet energy scale < 3%
  - Uncertainty on Jet energy resolution ~10%
- MET: negative vector sum of transverse momenta of all particle

Monojet + MET (Direct Graviton)



- Signature: Monojet + MET (graviton)
  - MET >150 GeV
  - At most 2 jets (pT>30 GeV)
    - ✓ p_{T1}>110 GeV, $|\eta_1|$<2.4
    - ✓ p_{T2}>30 GeV, $\Delta\phi_{12}$<2.0



- Data-driven background estimation using μ+jets sample, consistent with QCD MC
  - W/Z + jets
  - Z(νν) + jets
- No significant excess is observed

arXiv:1106.4775 [hep-ex]

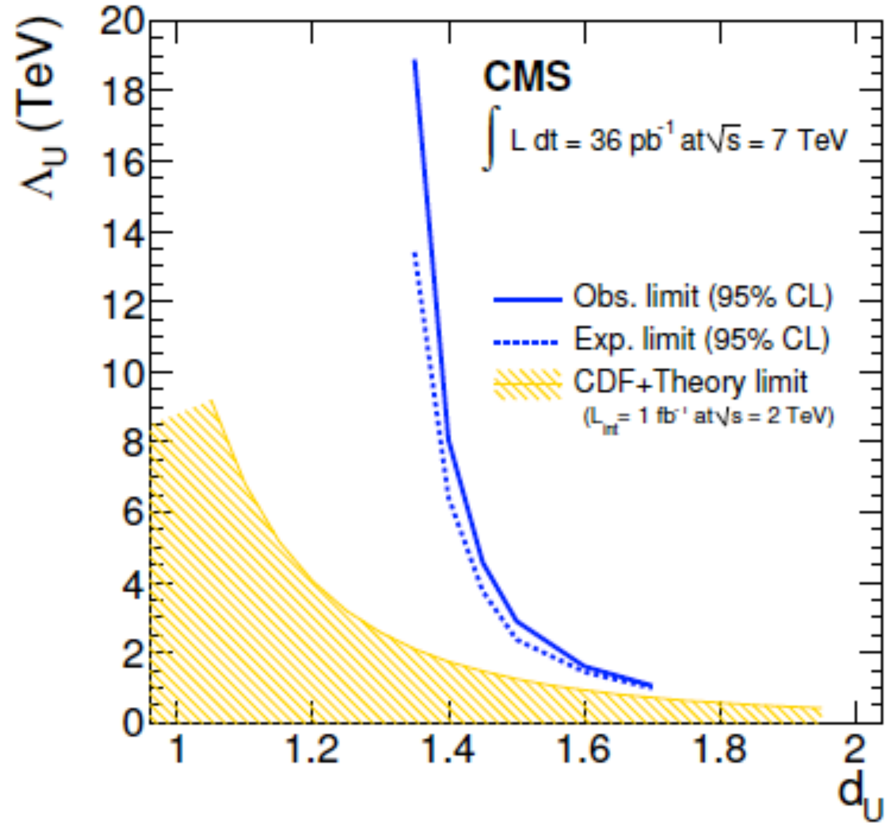
Limit with 36 pb^{-1}

- Observed and expected limit @95% CL on the ADD parameter M_D (TeV/c2) as functions of δ (# of extra-dim)

δ	NLO Exp	NLO Obs
2	2.41	2.56
3	1.99	2.07
4	1.78	1.86
5	1.68	1.74
6	1.62	1.68

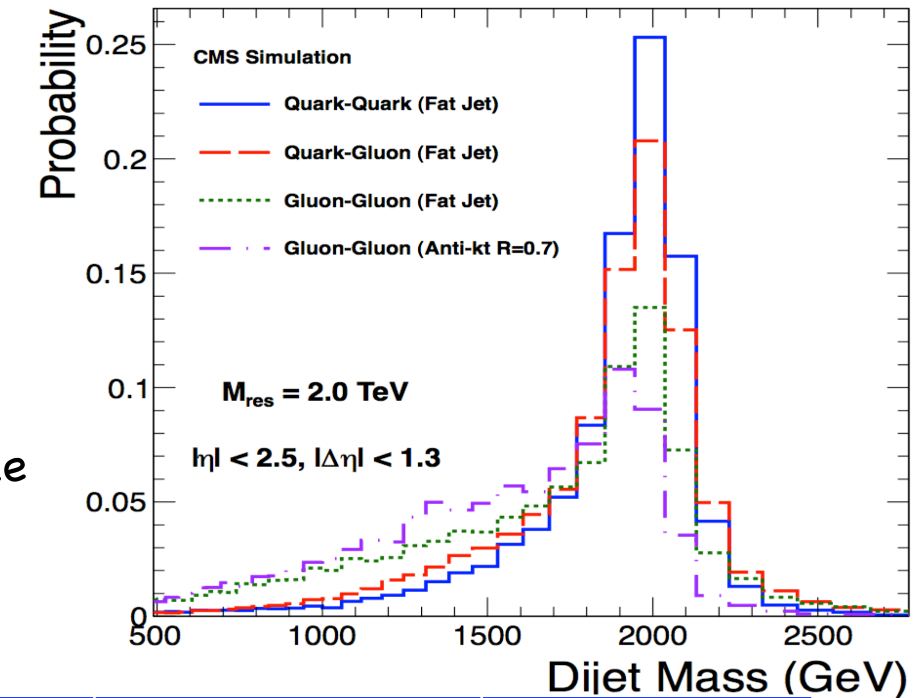
- Significant improvement:
  - δ =4:
    LEP: 0.94 TeV, D0: 0.85 TeV
    CDF 1.04 TeV, CMS: 1.86 TeV
  - δ =2:
    LEP: 1.60 TeV, D0: 0.92 TeV
    CDF 1.40 TeV, CMS: 2.56 TeV

- Observed and expected limit @95% CL on the allowed region of unparticle model parameters d_U and Λ_U
  - PRD 81 (2010) 056003
  - arXiv:1012.3737



Dijet Resonances Search

- Parton resonances decaying into dijets from various models
- Search for 3 generic types of narrow dijet resonances
  - qq,qg,gg resonances
  - Using fat jet in this result
  - Fat jets shows better resolution due to more recovery of FSR



Models	X	Color	J^P	Γ/(2M)	Chan
Excited quark	q*	Triplet	½⁺	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	qq, 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	qg, $q\bar{q}$,gg

Dijet Resonances with 1 fb^{-1}

- Fat PF Jet, $|\eta|<2.5$ & $|\Delta\eta|<1.3$
- Data are in good agreement with QCD
- Fit to a parameterization, good χ^2/d.o.f=27.5/28
- No evidence of new physics

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

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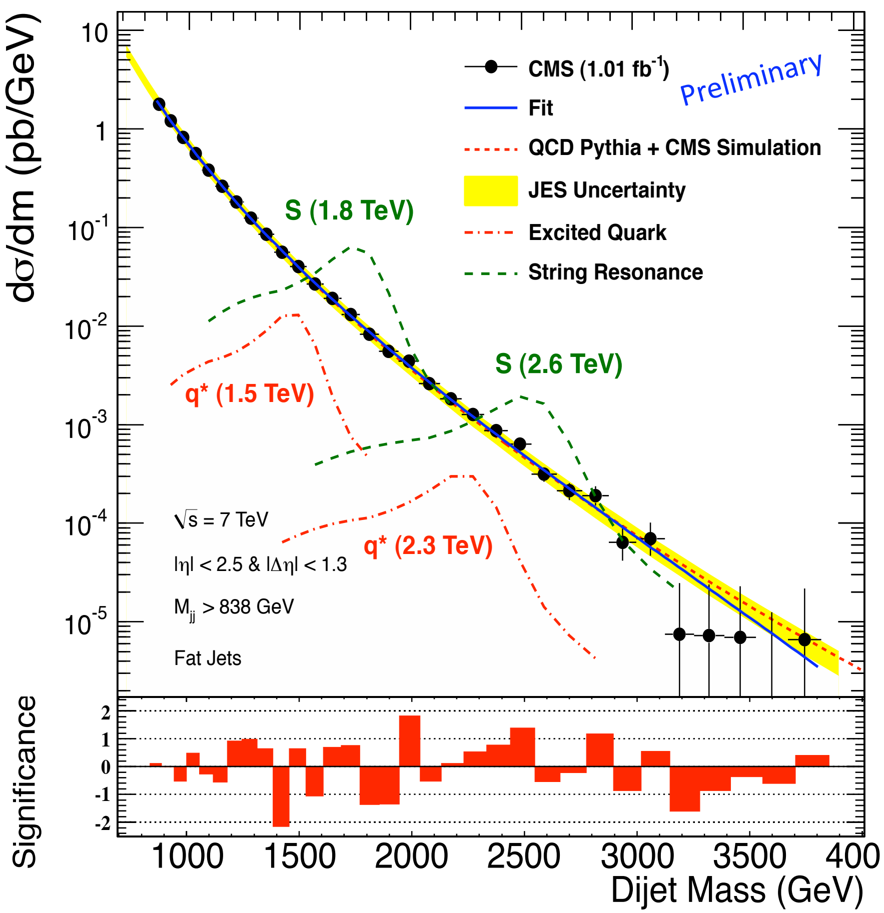
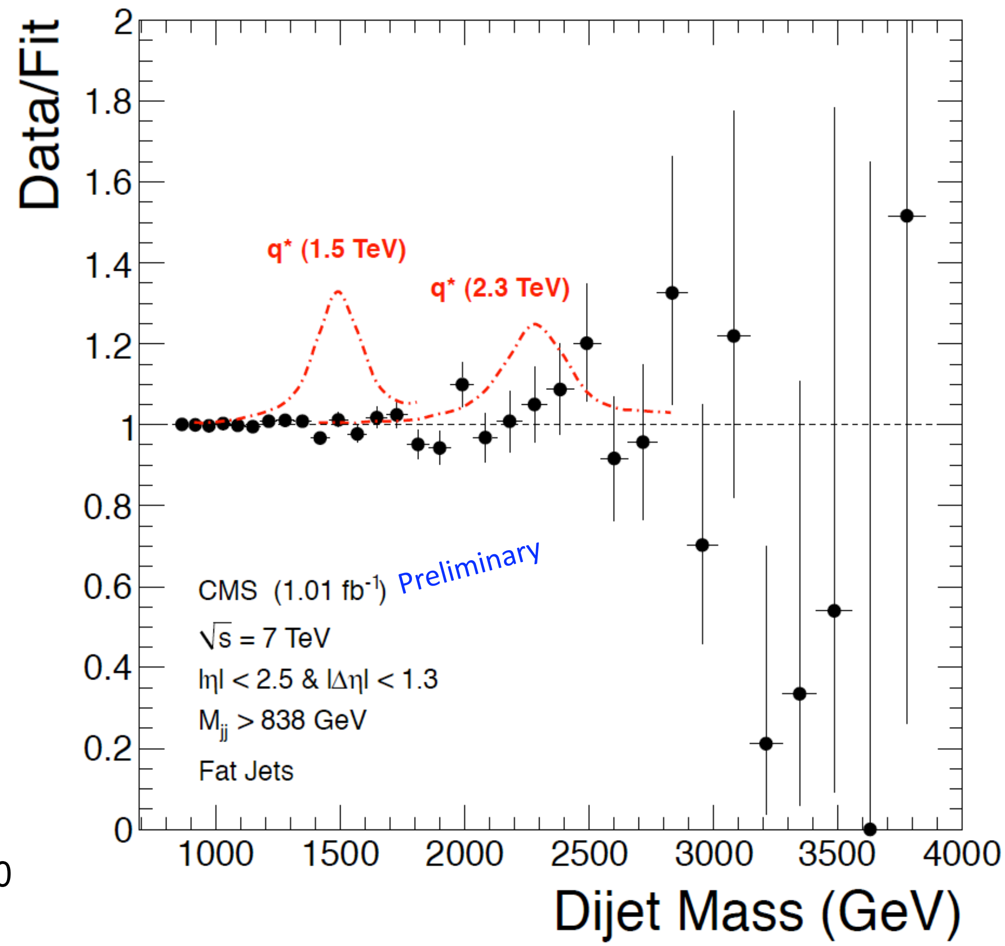
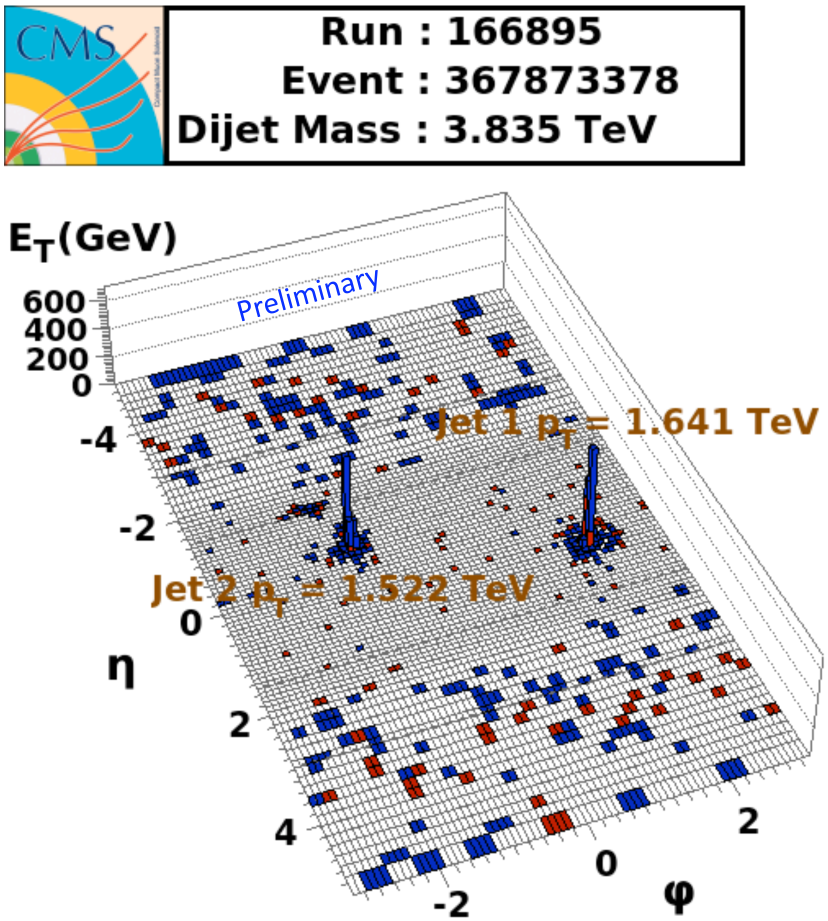
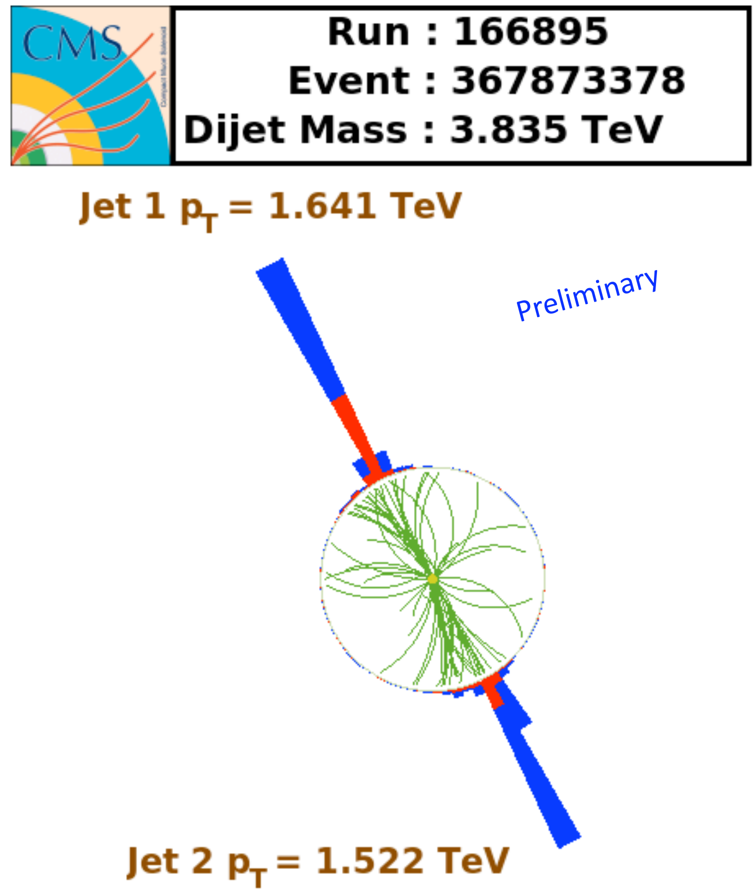




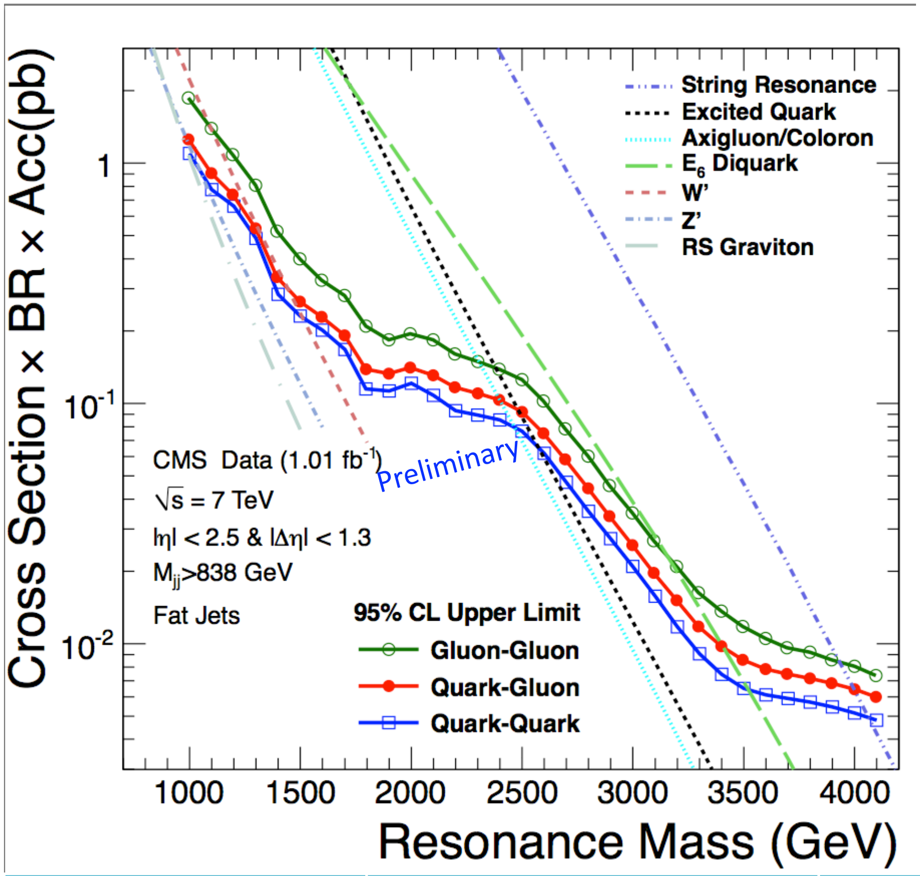
Highest Dijet Mass Event

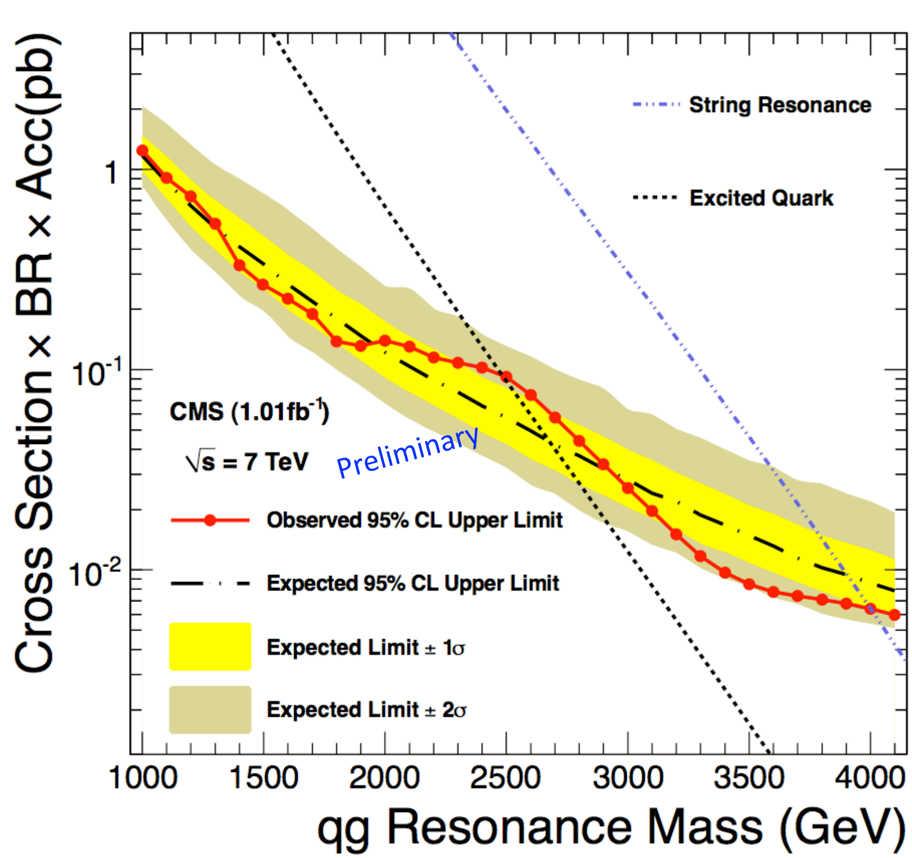




❖ Well balanced dijet event

Dijet Resonance Limit with 1 fb^{-1}

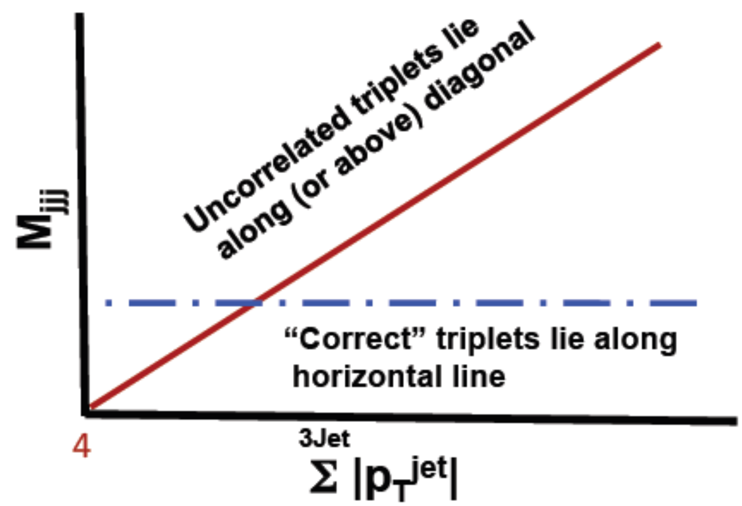




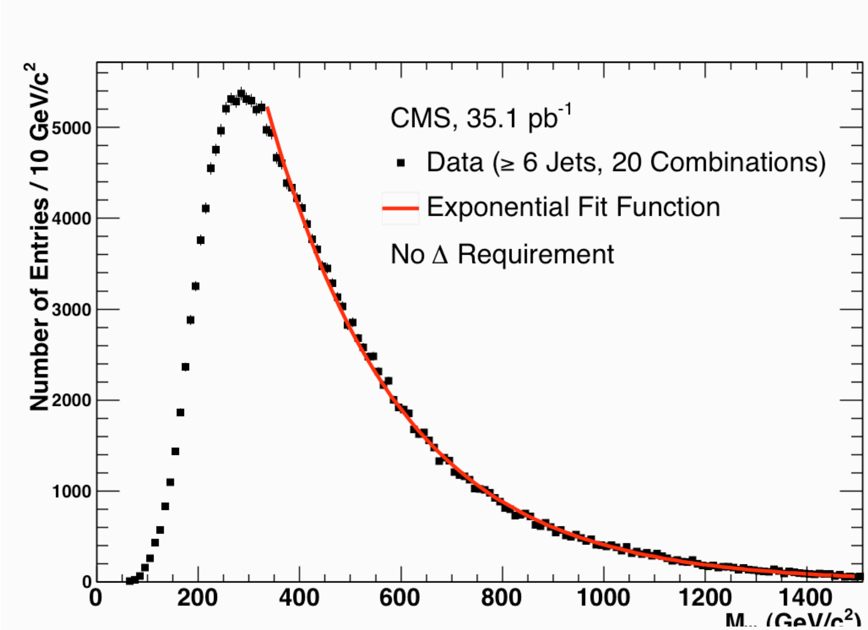
Model	Previous CMS Excluded @95% w/ 3 pb^{-1} (TeV)	Excluded @95% CL w/ 1fb-1 (TeV)	Expected limit (TeV)
String Resonance	0.5-2.5	1.0 – 4.00	3.90
Excited Quark	0.5-1.58	1.0 – 2.49	2.67
Axigluon/Coloron	0.5-1.52	1.0 – 2.47	2.66
E_6 Diquark	0.5-0.58,0.97-1.08,1.45-1.6	1.0 – 3.52	3.28
W'	N/A	1.0 – 1.51	1.42

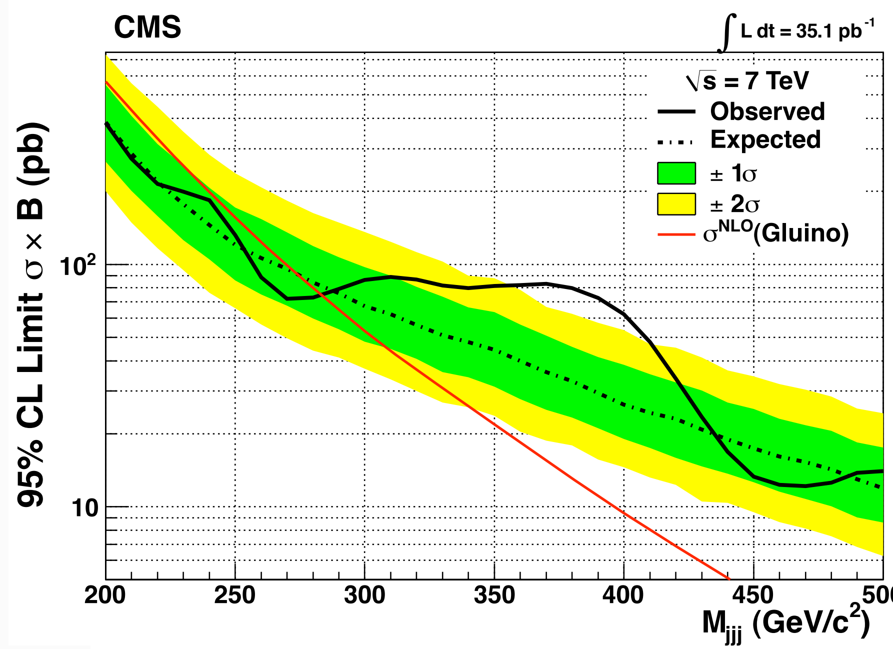
Multijet Resonances

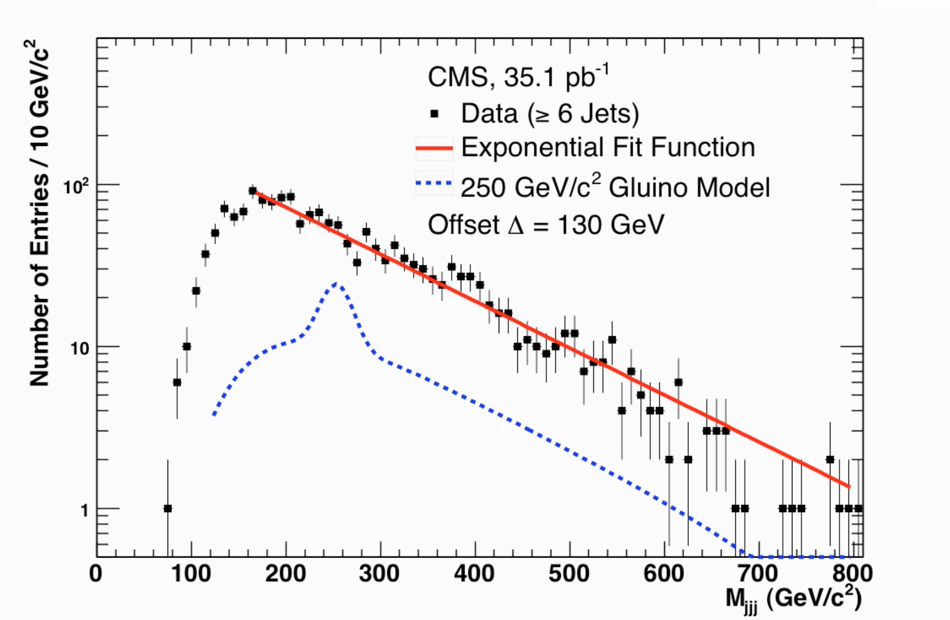
- Search for pair produced R-Parity violating Supersymmetry gluino (no MET) from 6 jet final state
- Huge combinatorial background besides QCD background
  - 20 triplet combinations from 6 jets
- Use a diagonal cut to remove combinatorial background as well as QCD background:
  - $m_{jjj} < \Sigma\ |p_T(\text{triplet})| - \alpha$ (Offset)
- Critical cut in multijet resonances search



Multijet Resonances with 36 pb^{-1}







No significant excess is observed

Excluded mass limit of RPV gluino at Bayesian 95% CL is between 200 GeV and 280 GeV

- The highest limit to date and the first limit from pp collisions.

arXiv:1107.3084 [hep-ex]

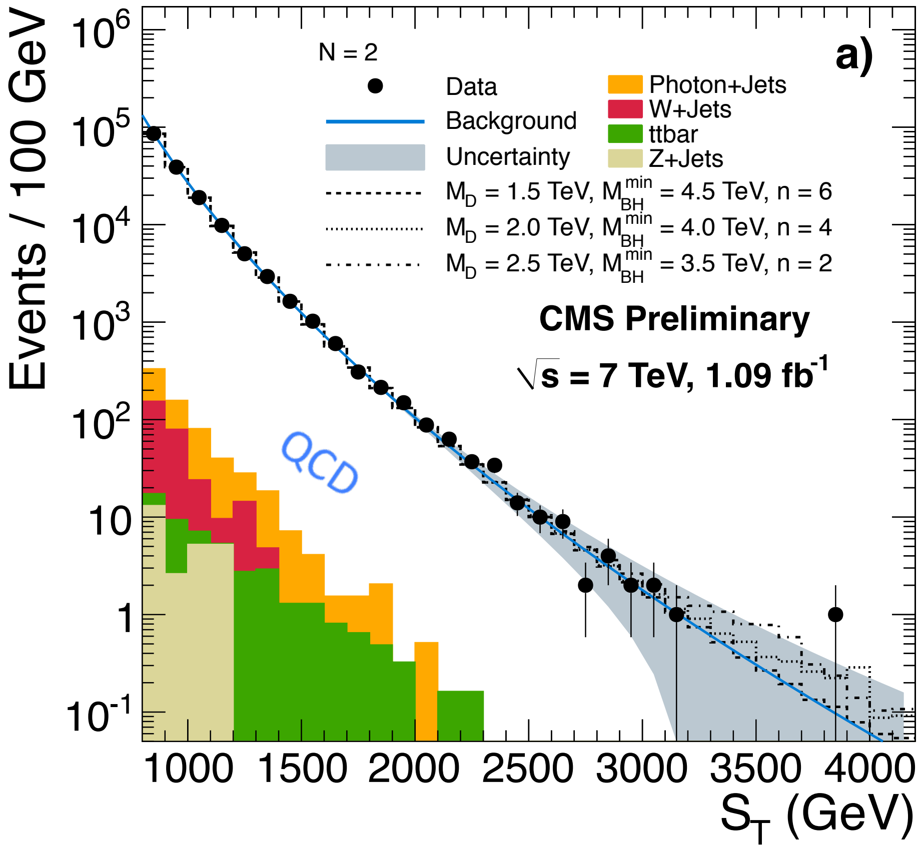
Microscopic Black Hole Search

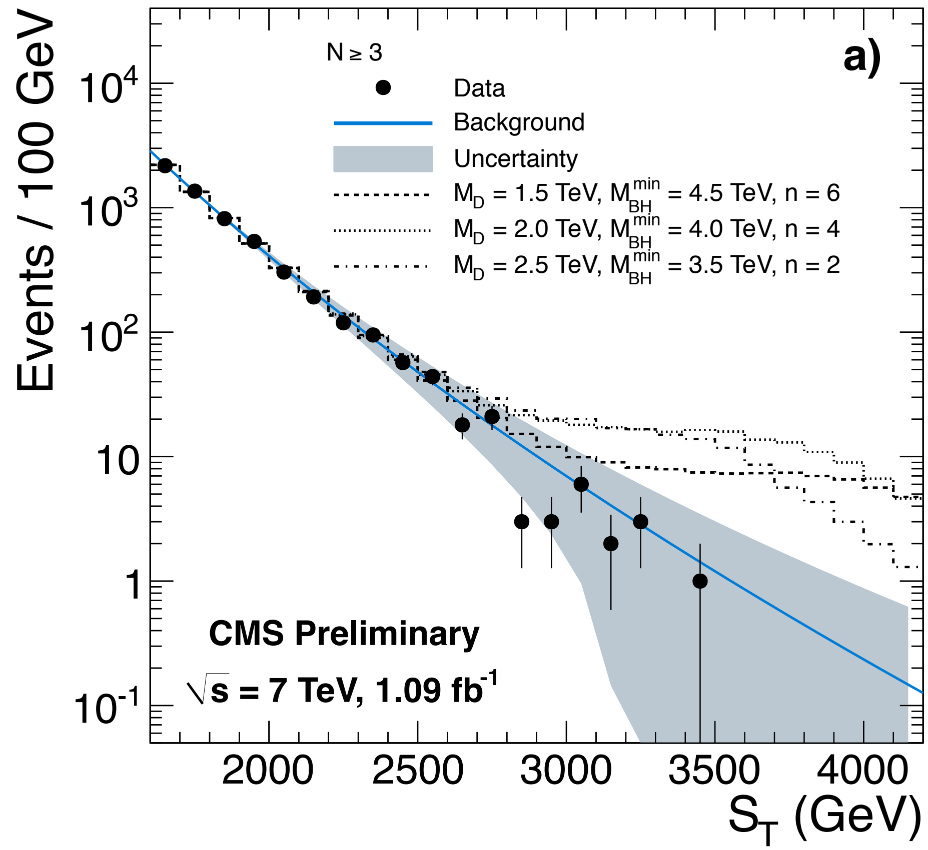
- ADD (Arkani-Hamed, Dimopoulos and Dvali) model's solution to the hierarchy problem:
  - $M_{PI}^2 = 8\pi M_D^{n+2} r^n$,where M_{PI} is the Planck scale (~10^{16} TeV), M_D is the "true" Planck Scale in 4+n dimension at the electroweak scale
  - The parton-level cross section $\sigma = \pi r_s^2$, where r_s (Schwarzschild radius) is defined as:

$$r_S = \frac{1}{\sqrt{\pi} M_D} \left[\frac{M_{BH}}{M_D} \frac{8\Gamma(\frac{n+3}{2})}{n+2} \right]^{\frac{1}{n+1}}$$

- Signature: high multiplicity, democratic, and highly isotropic decays with the final-state particles carrying hundreds of GeV of energy.
- CMS search through $S_T = \sum E_T(\text{jet}, e, \mu, \gamma)$ w/ $E_T > 50$ GeV, MET is included.
  - Extract S_T shape from N=2,3 samples.
  - Normalize to events with multiplicity N ≥ 3,4,5,6,7,8.

Microscopic Black Holes with 1 fb^{-1}





- Non-QCD standard model backgrounds are negligible
- Fit to parameterization

- No significant excess is observed

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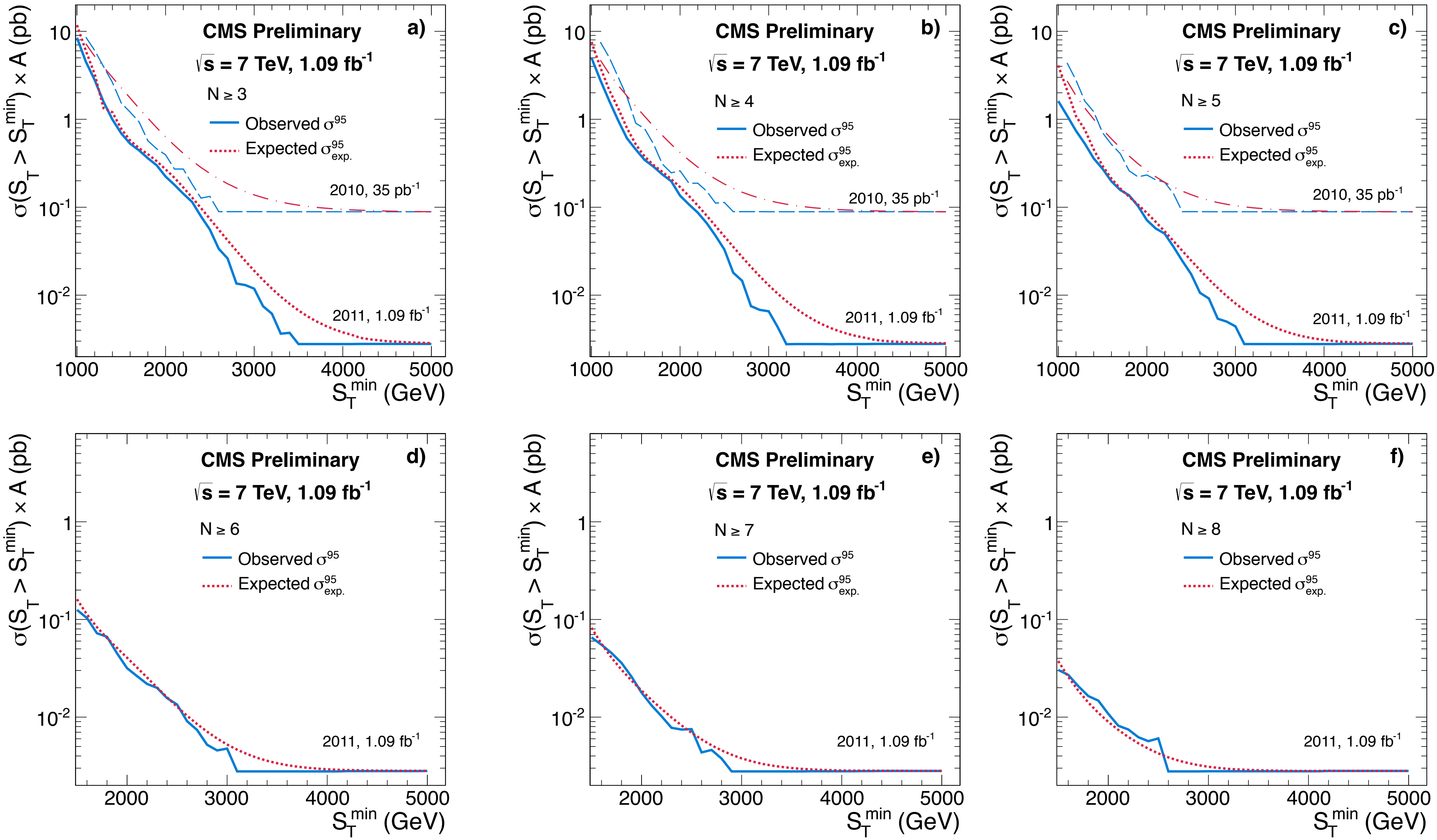
Model Independent Limit with 1 fb^{-1}



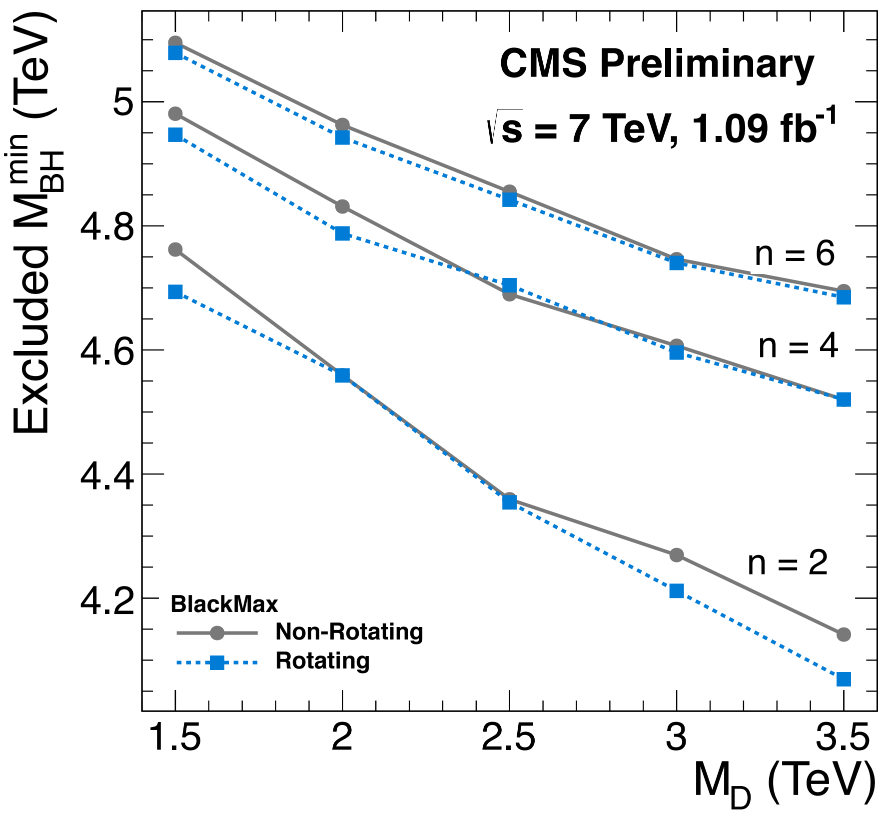
- Significant improvement comparing with 2010 data
- See backup for model dependent limit

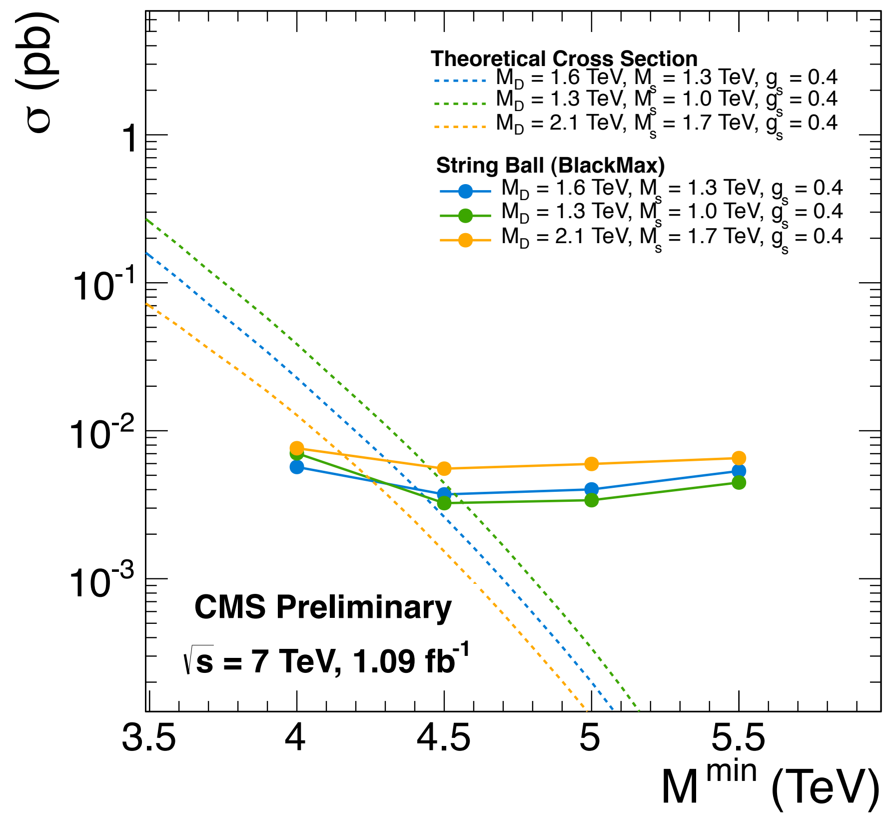
Conclusion

- CMS hadronic resonance searches have been presented based on 2010 and 2011 data.
- No evidence for new physics yet.
- Data significantly constrain many models of new physics.
- 2011 data is quickly supersede 2010 results
  - 1 fb^{-1} on tape
  - A few more fb^{-1} expected this year
- Ample space for discoveries.

Stay tuned!

Limit on Microscopic Black Hole



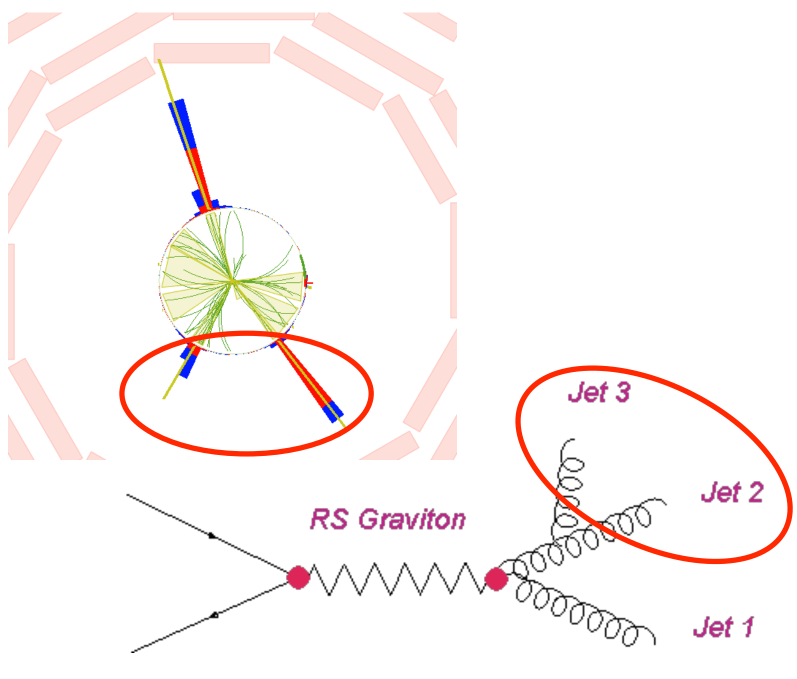


- The corresponding black hole mass limit with different black hole parameters: from ~4.1 to ~5.1 TeV
- New limit for the first time on string Ball (BLackMax): from 4.1 to 4.5 TeV
  - string balls are hypothesized precursors of the semiclassical black holes when the mass of the object is close to the Planck scale.

Fat jets definition

Fat jets optimize dijet resonance resolution by recombining FSR into the two leading jets

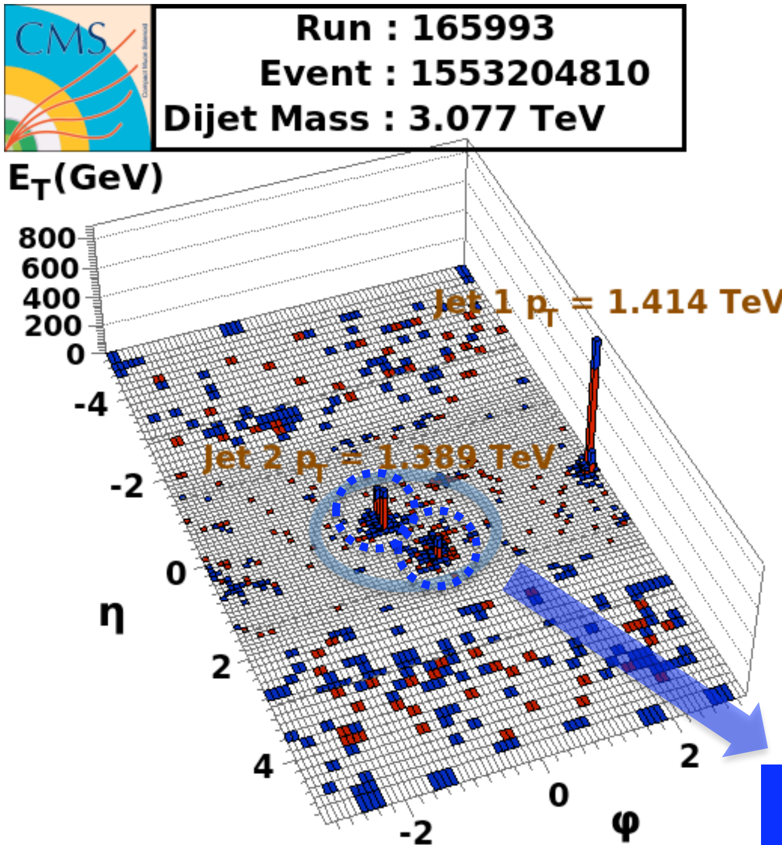
Fat Jets : clusters of AK5 PF Jets
Cluster radius : R=1.1

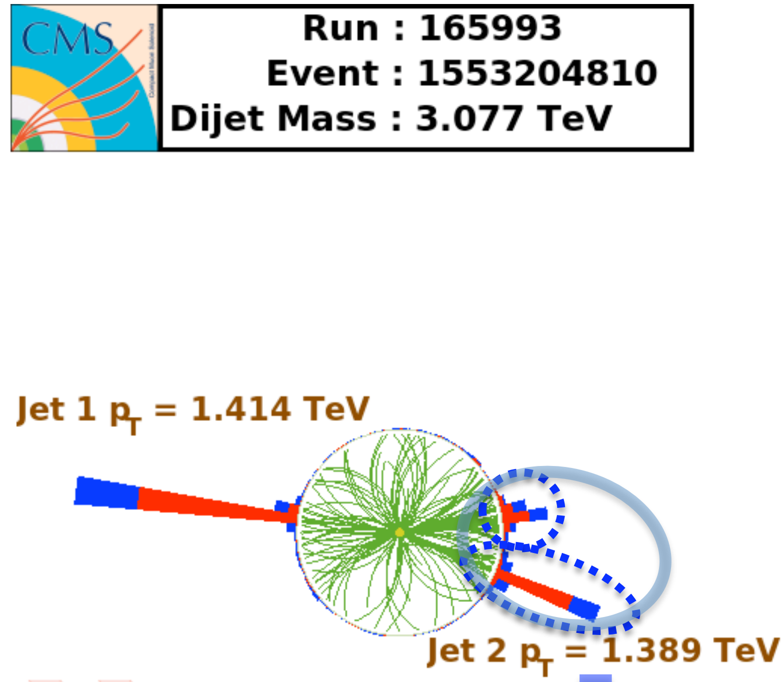


Fat Jets algorithm

- Select 2 leading AK5 PF jets.
- For AK5 PF jets j from 3 to n:
  - Require:
    - ✓ $p_{T,j} > 10$ GeV
    - ✓ $|\eta| < 2.5$
  - If $\Delta R_{1j} < R_{Fat}$ and ΔR_{2j}.
    - ✓ Add j to Fat Jet 1.
  - If $\Delta R_{j2} < R_{Fat}$ and ΔR_{1j}.
    - ✓ Add j to Fat Jet 2.
- R = 1.1 is best choice for a single search for qq, qg and gg resonances.

Recombination of Radiation



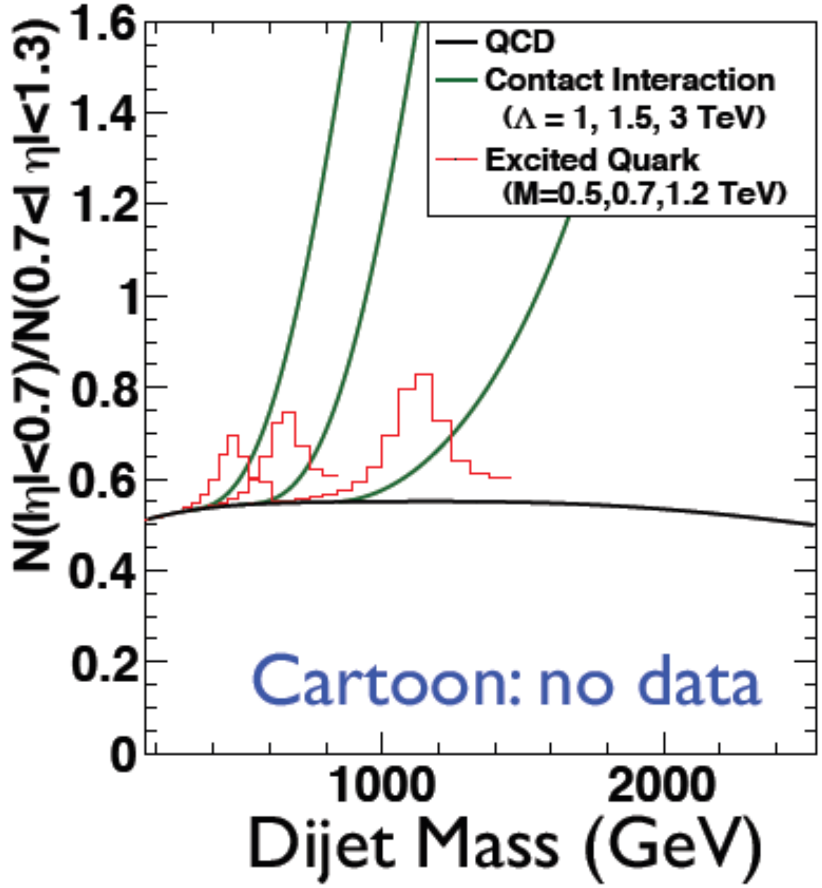


Combined into 1 Fat jet

Dijet Centrality Ratio

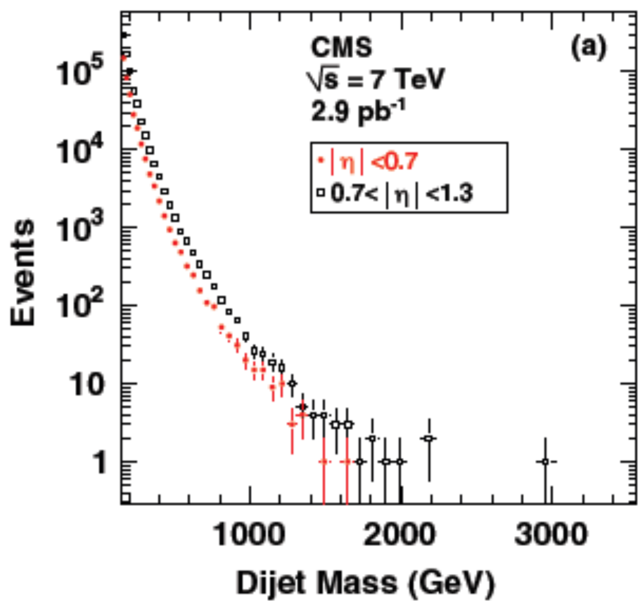
$$R = \frac{N(|\eta| < 0.7)}{N(0.7 < |\eta| < 1.3)} = \frac{N(\text{inner})}{N(\text{outer})}^{*}$$

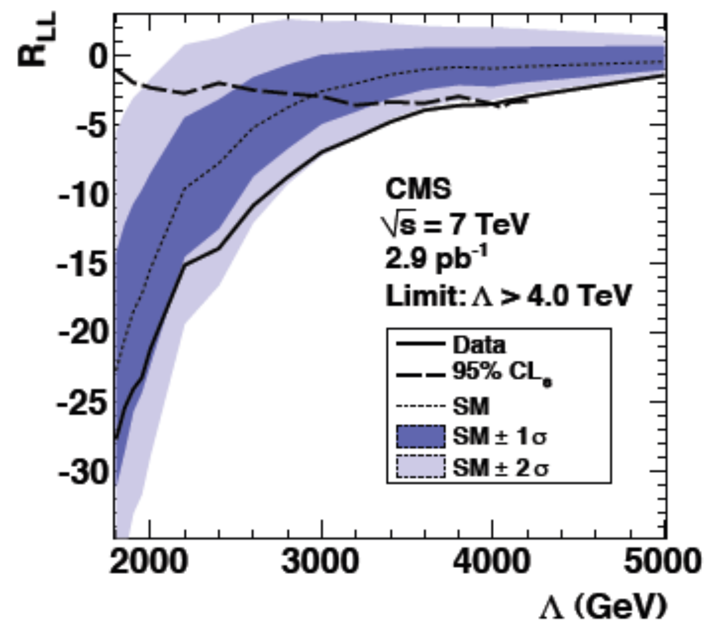
*Both jets inner or outer.

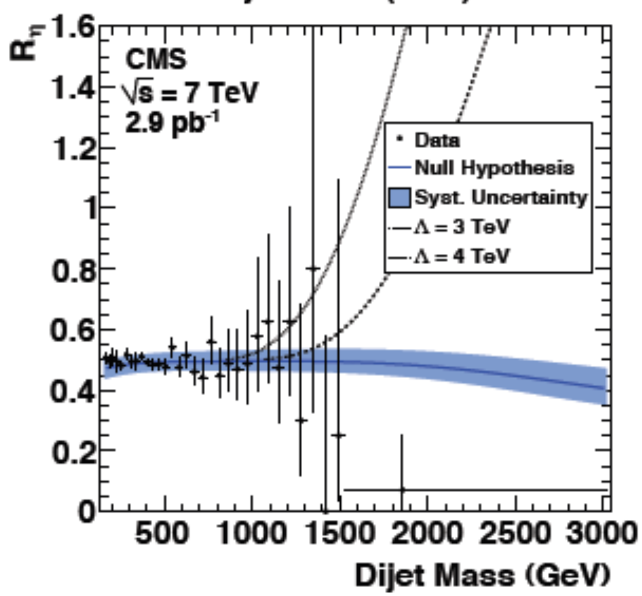


- Quantifies the centrality of the dijet angular distribution at a given dijet mass.
  - both leading jets are required to lie in the same η range.
- Important experimental uncertainties cancel because of the ratio (absolute jet energy scale, luminosity).
- "t-channel" scattering for QCD vs "schannel" for most new Physics models
  - roughly flat vs dijet mass for QCD.
  - rises vs dijet mass for contact interactions.
  - "bumps" in dijet mass for dijet resonances.

Dijet Centrality Ratio







- Anti-kt CaloJets with R=0.7
- Data is agree with the predictions of the standard model.
- No sign of new physics.
- Set limit on contact interaction scale Λ with modified frequentist approach (CLs) method.
- Contact interaction scale excluded for Λ<4.0 TeV at 95% CL.

PRL 105, 262001 (2010)

Background shape for black hole

- Assume the shape (tail) of QCD ST spectrum is invariant for difference multiplicity bins, we can model background from lower multiplicity, and rescale to higher multiplicity.
- Fit exclusive multiplicity = 2/3 with the following functions, in ST [800, 2500] GeV.
- **Parameterizations**
  - 0) P0 (1+x)^P1 / x^(P2 + P3 * log(x))
  - 1) P0 / (P1 + P2 * x + x^2)^P3
  - 2) P0 / (P1 + x)^P2
  - 3) P0 * exp((P3+(P1*log(x)))+(P2*(log(x)^2)))*((P3+P4*log(x)))/x)
  - 4) P0 *exp(P1*log(x) + P2*x)
- **Normalization**
- Rescale the fit to inclusive multiplicity ≥3,4,5,6,7,8 in ST [1800, 2000] GeV.