

# Searches for New Physics in Multijet Final States with CMS

**EPS-HEP CONFERENCE, STOCKHOLM  
JULY 18, 2013**

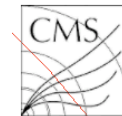
**CLAUDIA SEITZ, RUTGERS UNIVERSITY,  
FOR THE CMS COLLABORATION**



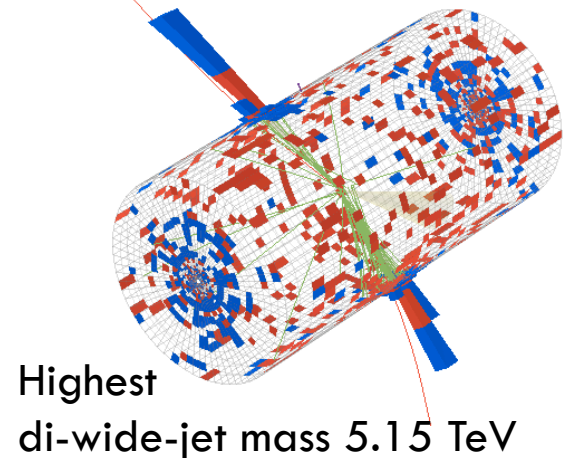
# Searches for New Physics with Multijets

2

- ❑ What if new physics signals couple strongly and decay into quarks and gluons?
- ❑ Difficulty is the large QCD background
- ❑ Broad range of searches in different jet multiplicities including light and heavy-flavors
- ❑ Latest results from CMS at 8 TeV:
  - ❑ QCD Jet Extinction
  - ❑ Search for Dijet Resonances including heavy-flavor final states
  - ❑ Search for Light- and Heavy-flavor Three-Jet Resonances



CMS Experiment at LHC, CERN  
Data recorded: Fri Oct 5 12:29:33 2012 CEST  
Run/Event: 204541 / 52508234  
Lumi section: 32



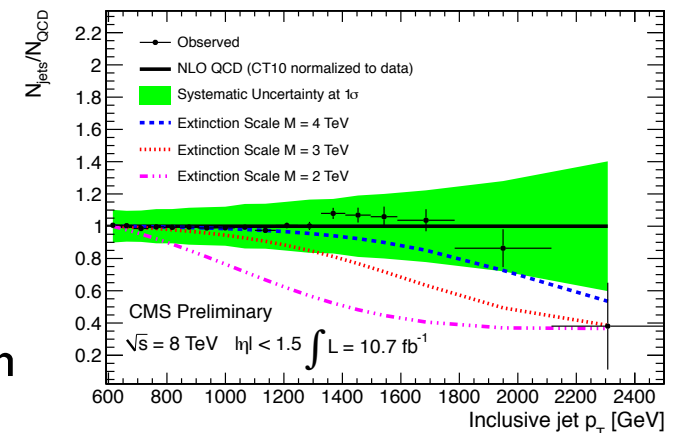
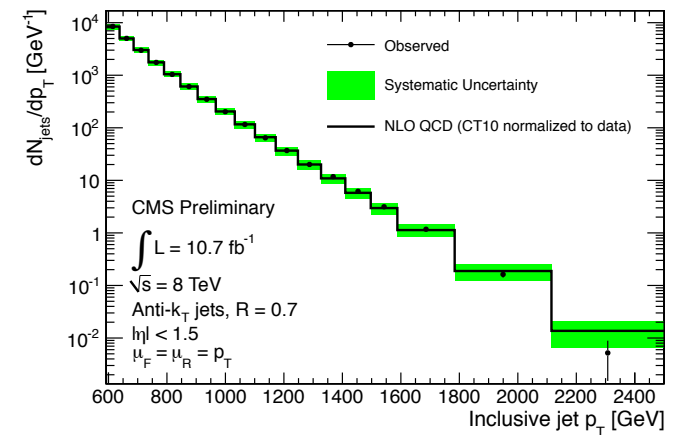
# QCD Jet Extinction

EXO-12-051

3

- ❑ Search for terrascale gravity in the inclusive jet  $p_T$  spectrum in  $10.7 \text{ fb}^{-1}$  of data
- ❑ Introduction of a extinction scale  $M$  (2TeV, 3TeV, 4TeV) which predicts suppression of high- $p_T$  jets beyond  $M$
- ❑ Comparison of data with NLO simulation based on CT10 PDF set
  - ❑ NLOJet++ calculator
  - ❑ including perturbative corrections
  - ❑ convolved with the detector response
  - ❑ normalized to the total observed cross section

Selection: anti- $k_T$   $R=0.7$  jets,  
 $p_T > 592 \text{ GeV}$ ,  $|\eta| < 1.5$

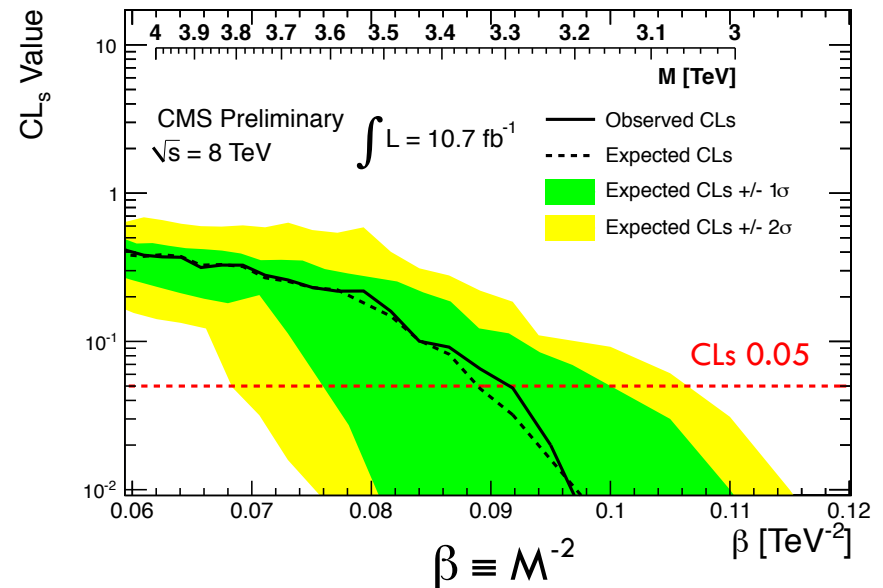


# QCD Jet Extinction: Results

EXO-12-051

4

- ❑ Good agreement is found between inclusive  $p_T$  spectrum and prediction from theory
- ❑ Systematic uncertainties take into account correlations between different  $p_T$  bins
  - ❑ PDF uncertainties will affect different parts of the spectrum
  - ❑ Evaluation of jet energy scale and resolution uncertainties takes into account bin-migration
- ❑ New extinction scale excluded at  $M = 3.3$  TeV



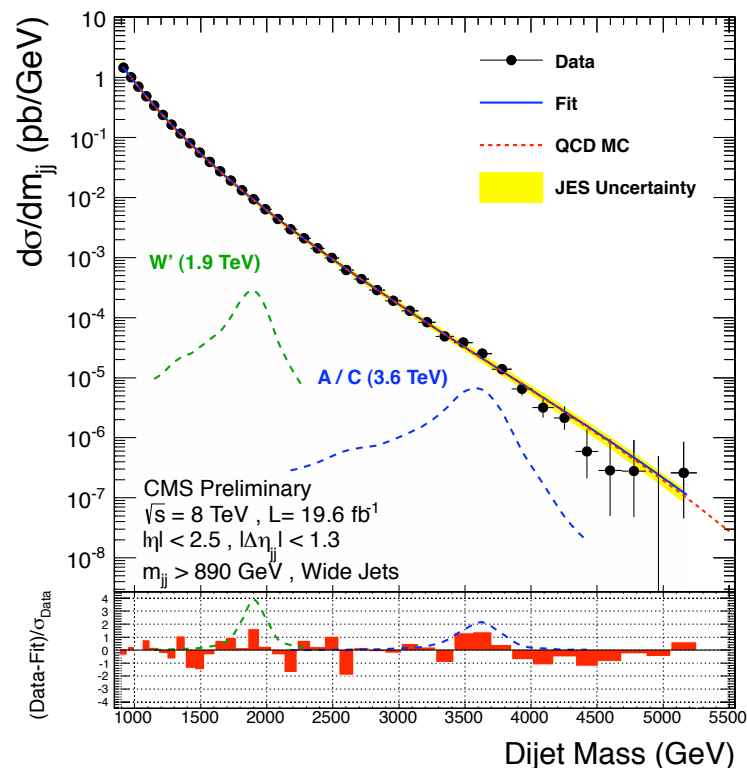
# Dijet Resonance Search

EXO-12-059

5

- ❑ Search for narrow resonances in the dijet mass spectrum in  $19.6 \text{ fb}^{-1}$  of data
- ❑ Several new physics models predict heavy resonances that decay into dijets (qq, qg or gg)
- ❑ Wide jet technique
  - ❑ Start with two leading anti- $k_T$ ,  $R=0.5$  jets  $> 30 \text{ GeV}$
  - ❑ Add Lorentz vectors from adjacent jets within cone of  $\Delta R=1.1$
  - ❑ Reduces sensitivity to gluon radiation

Selection: 2 wide jets in the event with  $|\eta| < 2.5$  and  $|\Delta\eta| < 1.3$  and  $m_{jj} > 890 \text{ GeV}$

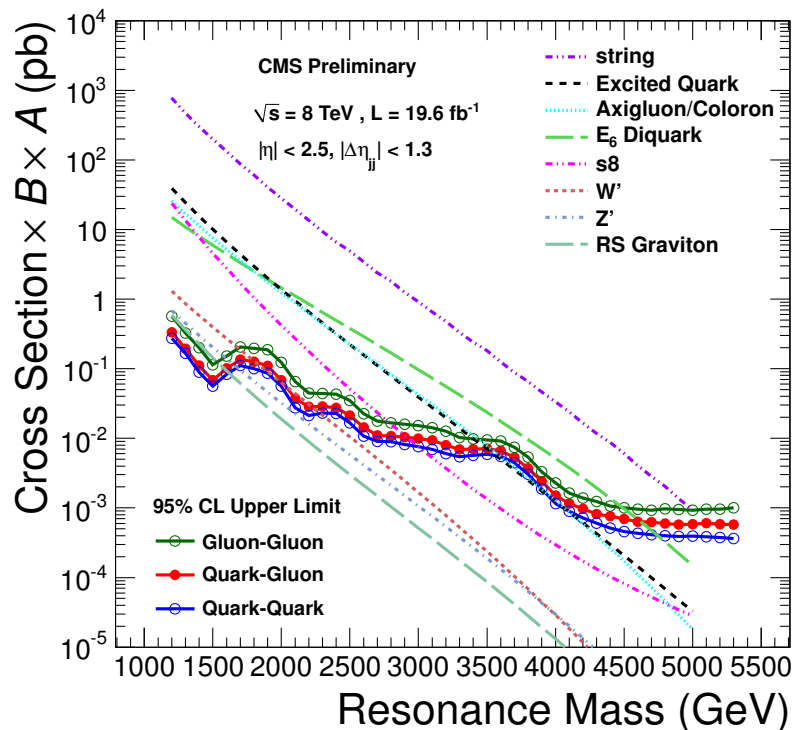


# Dijet Resonance Search: Results

EXO-12-059

6

- Result presented as model independent limits on  $\sigma \times \text{Br} \times A$
- Limit differs depending on the final state  $qq$ ,  $qg$  or  $gg$  because of dependence of resonance shape on parton content



Limit up to 5.1 TeV for string resonances

Model	Final State	Obs. Mass Excl. [TeV]	Exp. Mass Excl. [TeV]
<b>String Resonance (S)</b>	qg	[1.20, 5.08]	[1.20, 5.00]
<b>Excited Quark (q*)</b>	qg	[1.20, 3.50]	[1.20, 3.75]
<b>E6 Diquark (D)</b>	qq	[1.20, 4.75]	[1.20, 4.50]
<b>Axigluon (A), Coloron (C)</b>	q $\bar{q}$	[1.20, 3.60] + [3.90, 4.08]	[1.20, 3.87]
<b>W' Boson</b>	q $\bar{q}$	[1.20, 2.29]	[1.20, 2.28]
<b>Z' Boson</b>	q $\bar{q}$	[1.20, 1.68]	[1.20, 1.87]
<b>RS Graviton (G)</b>	q $\bar{q}$ +gg	[1.20, 1.58]	[1.20, 1.43]
<b>Color Octet Scalar (s8)</b>	gg	[1.20, 2.79]	[1.20, 2.74]

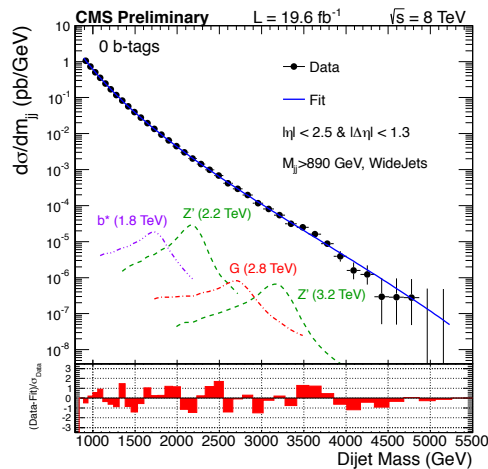
# Dijet Resonance Search with b jets

EXO-12-023

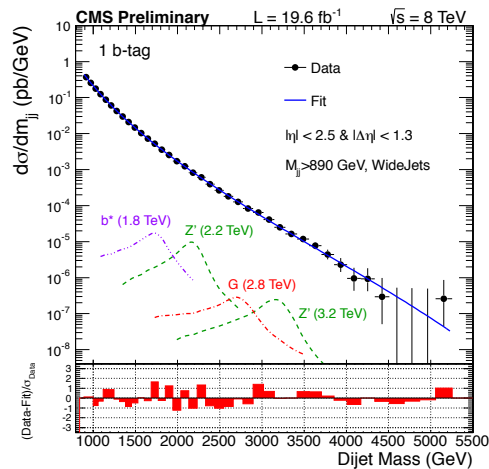
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- ❑ New physics models of  $Z'$ ,  $b^*$  and Randall Sundrum Gravitons ( $G$ ) predict final states with b quarks
- ❑ Adding b tagging to the analysis reduces SM background
- ❑ Similar wide jet technique as in nominal dijet search
- ❑ Data is split up into three categories 0, 1, and 2 b tags

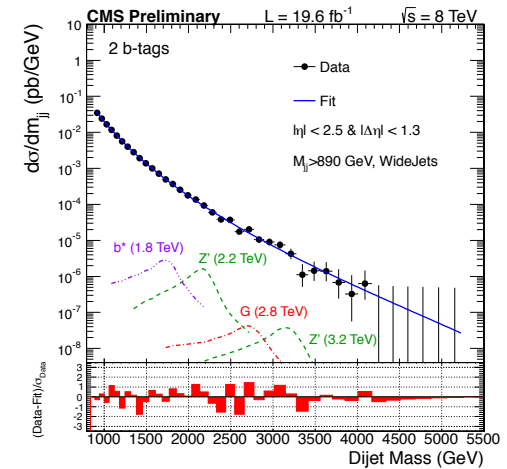
0 b tags



1 b tags



2 b tags

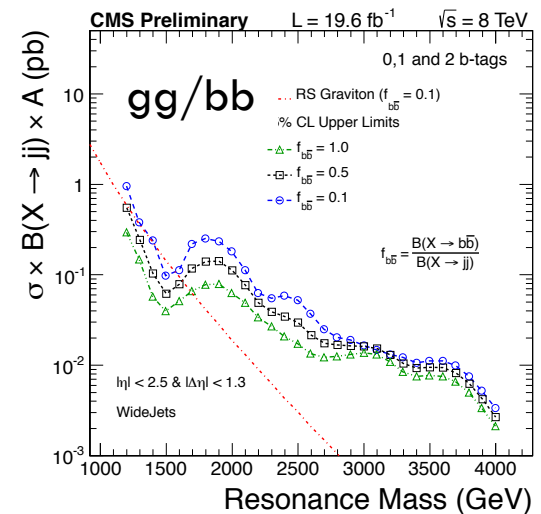
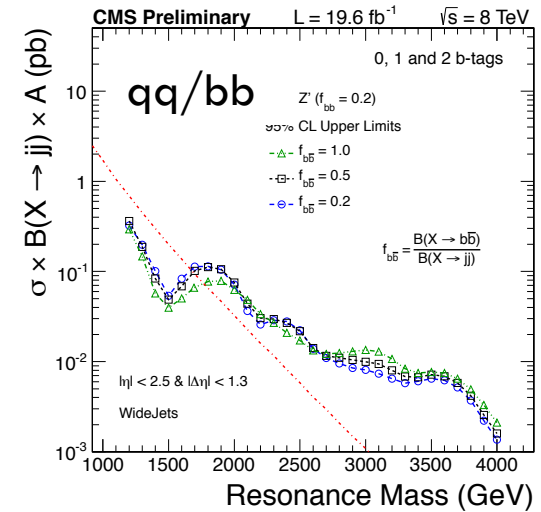


# Dijet Resonance Search with b jets: Results

EXO-12-023

8

- Result presented as model independent limits on  $\sigma \times \text{Br} \times A$
- Different limits for
  - Parton (qq or gg) content of the resonance due to different line shapes
  - $f_{b\bar{b}} = \frac{B(X \rightarrow b\bar{b})}{B(X \rightarrow jj)}$  due to change in contribution to 0, 1, and 2 b category
- Exclusion
  - $Z'$  [1.20, 1.68] TeV ( $f_{b\bar{b}} = 0.2$ )
  - RS Graviton [1.42, 1.57] TeV
  - $b^*$  [1.34, 1.54] TeV





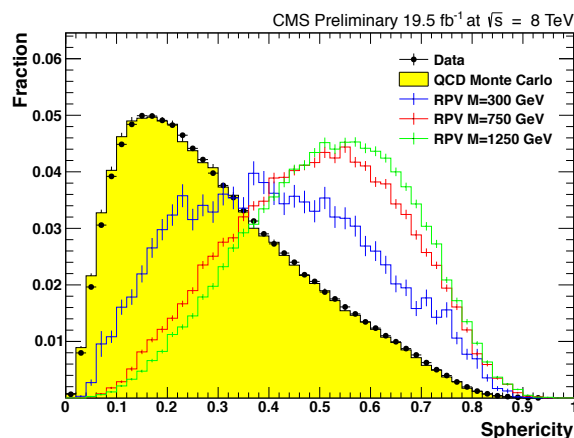
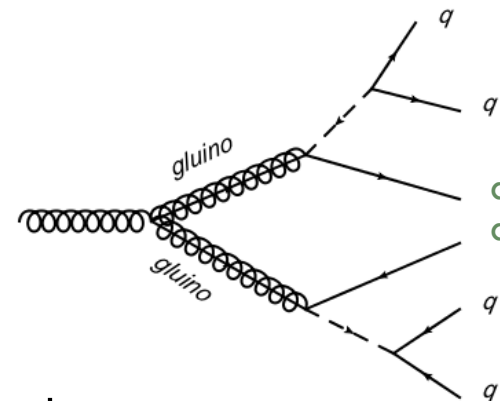
NEW

# Search for Three-jet Resonances

EXO-12-049

9

- ❑ Search for strongly coupled resonances decaying into three jets
- ❑ Benchmark model pair produced gluinos with R-parity violating decay
  - ❑ Scenario 1: light-flavor decay  $\tilde{g} \rightarrow uds$
  - ❑ Scenario 2: heavy-flavor decay  $\tilde{g} \rightarrow udb$  or  $\tilde{g} \rightarrow csb$



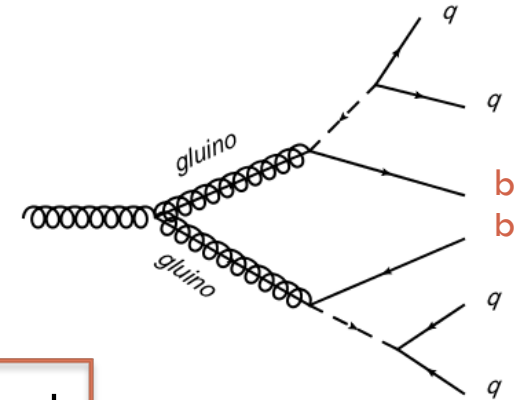
- ❑ Event Selection:
  - ❑  $\geq 6$  jets (4<sup>th</sup>-jet  $> 80$  GeV, 6<sup>th</sup>-jet  $> 60$  GeV) increases to 110 GeV for higher masses
  - ❑ Use of event shape variable sphericity to reduce background for higher masses
  - ❑ b-tagging for scenario 2

# Search for Three-jet Resonances

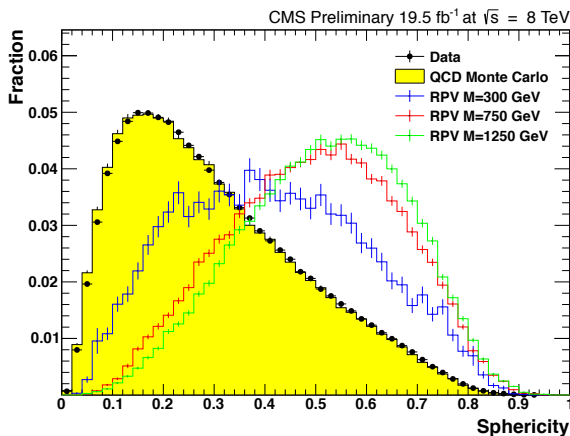
EXO-12-049

10

- ❑ Search for strongly coupled resonances decaying into three jets
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**First search for heavy-flavor**



## Event Selection:

- ❑  $\geq 6$  jets (4<sup>th</sup>-jet  $> 80$  GeV, 6<sup>th</sup>-jet  $> 60$  GeV) increases to 110 GeV for higher masses
- ❑ Use of event shape variable sphericity to reduce background for higher masses
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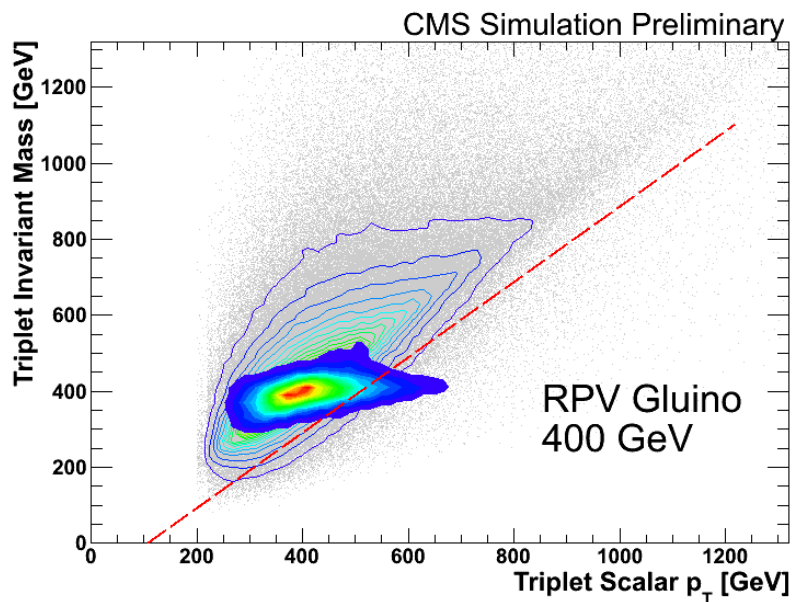
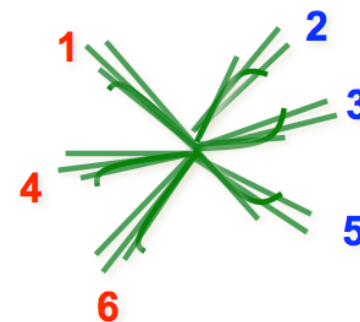
NEW

# Search for Three-jet Resonances: Jet Ensemble

EXO-12-049

11

- Combine the six highest jets into 20 unique triplet combinations  
123, 124, 125, 126, 134, 135, 136, 145,  
**146**, 156, 234, **235**, 236, 245, 246, 256,  
345, 346, 356, 456
- For each triplet plot  $M_{jjj}$  versus  $\sum^{jjj} |p_T^{\text{Jet}}|$



NEW

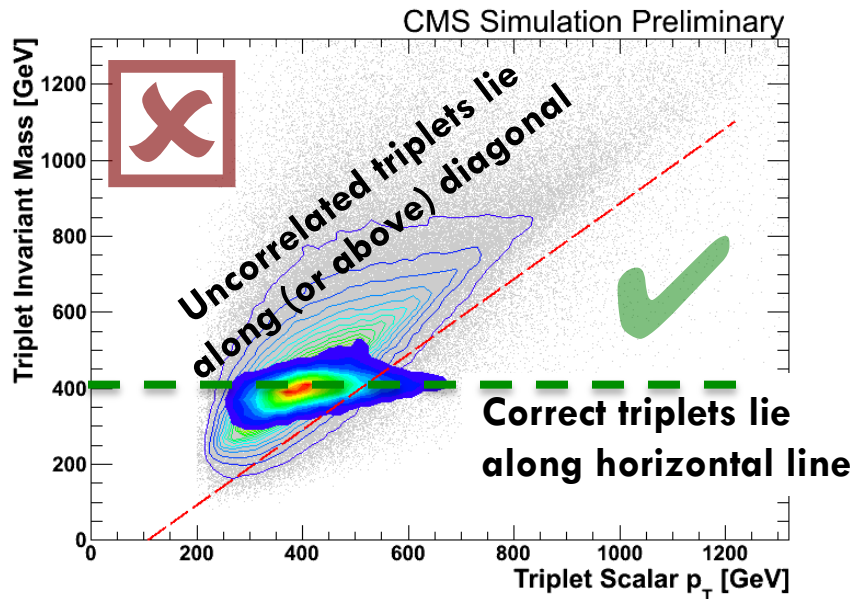
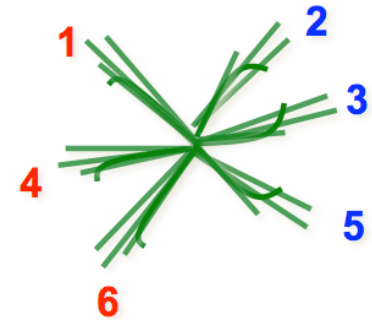
# Search for Three-jet Resonances: Jet Ensemble

EXO-12-049

12

- ❑ Combine the six highest jets into 20 unique triplet combinations
- ❑ For each triplet plot  $M_{\text{iii}}$  versus  $\sum^{jjj} |p_{\text{T}}^{\text{Jet}}|$
- ❑ Require each triplet to pass

$$M_{\text{iii}} < \sum^{jjj} |p_{\text{T}}^{\text{Jet}}| - \Delta \text{ (offset)}$$



NEW

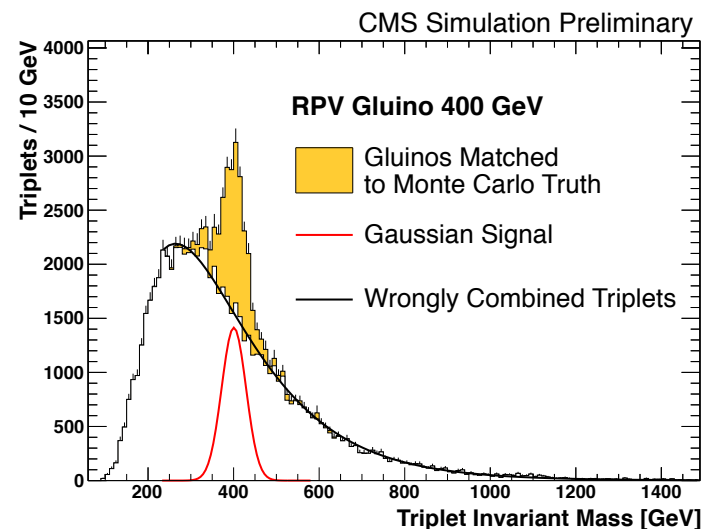
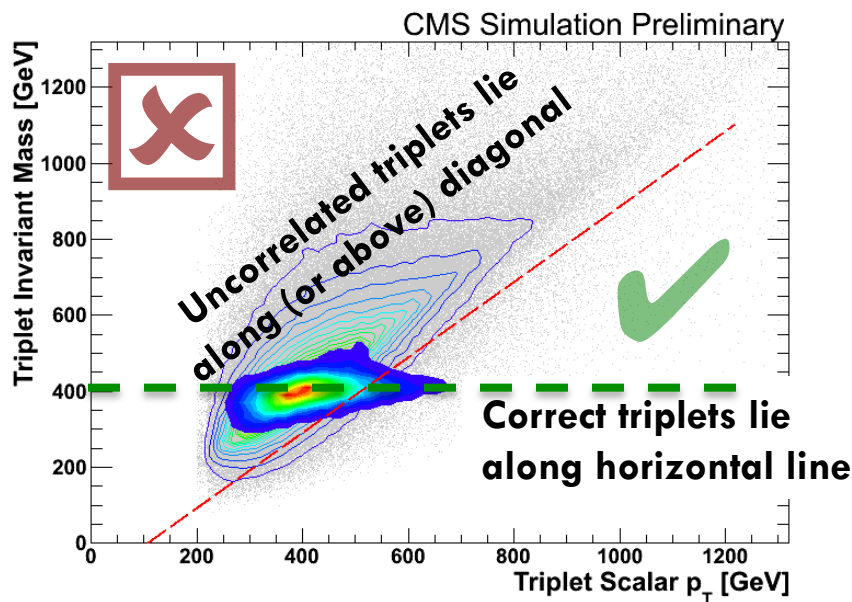
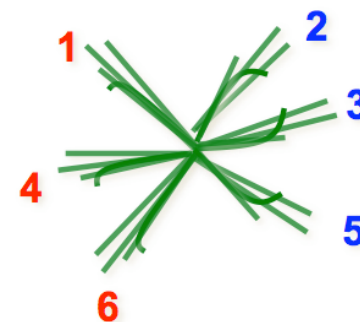
# Search for Three-jet Resonances: Jet Ensemble

EXO-12-049

13

- Combine the six highest jets into 20 unique triplet combinations
- For each triplet plot  $M_{\text{iii}}$  versus  $\sum^{jjj} |p_{\text{T}}^{\text{Jet}}|$
- Require each triplet to pass

$$M_{\text{iii}} < \sum^{jjj} |p_{\text{T}}^{\text{Jet}}| - \Delta \text{ (offset)}$$



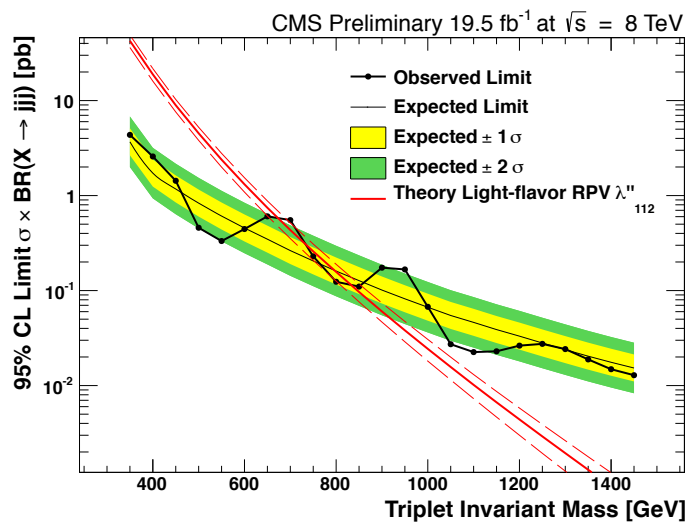
NEW

# Search for Three-jet Resonances: Results

EXO-12-049

14

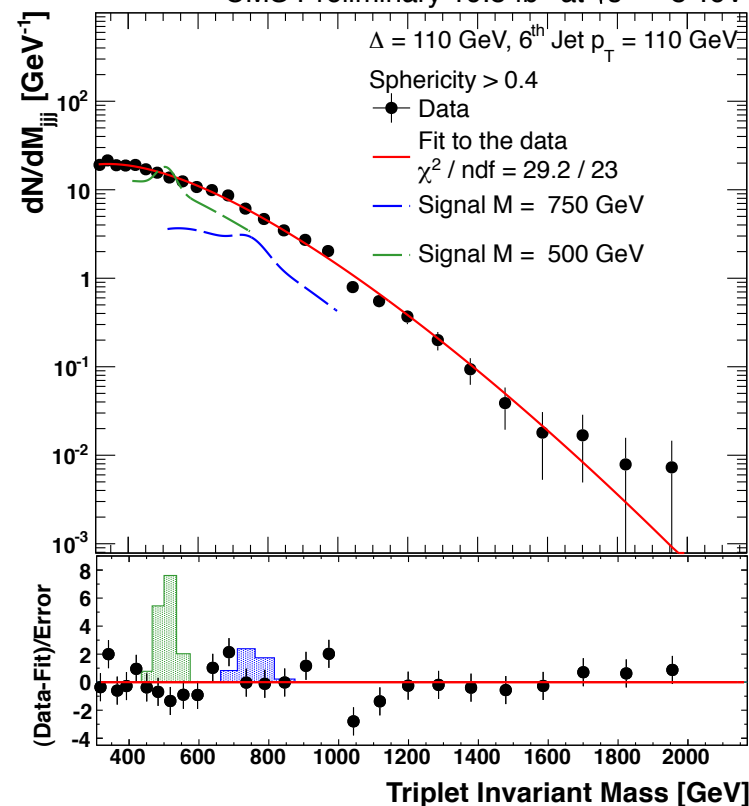
- ❑ Background for light-flavor search comes from parameterized fit
- ❑ Good agreement between data and fit
- ❑ Similar function as in dijet search
- ❑ Limits are placed at 650 GeV



## Scenario 1

Data after  $\Delta = 110$  GeV

CMS Preliminary 19.5 fb<sup>-1</sup> at  $\sqrt{s} = 8$  TeV



NEW

# Search for Three-jet Resonances: Results

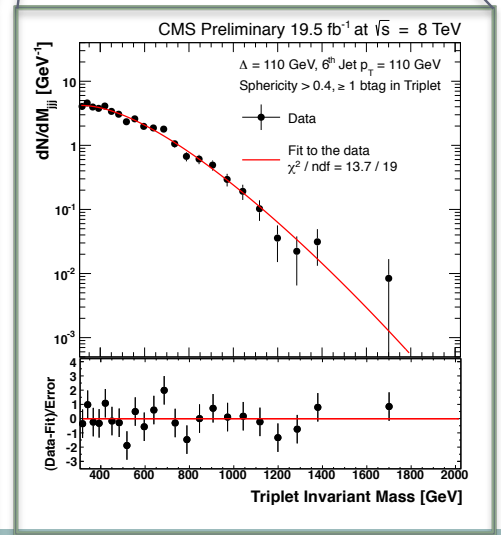
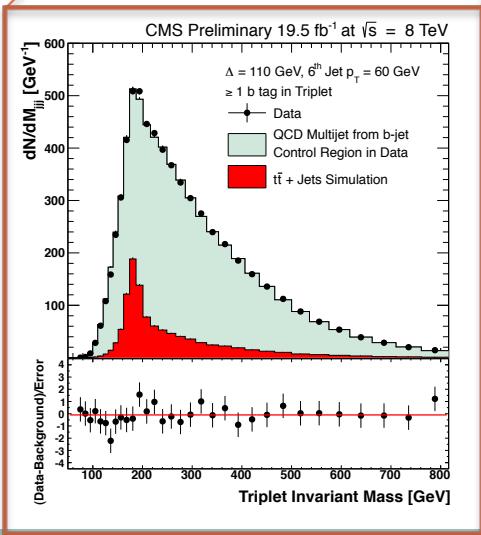
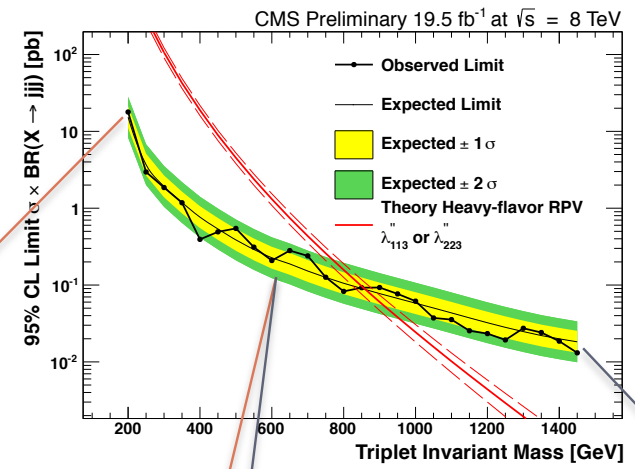
EXO-12-049

15

- Require  $\geq 1$  b tag in the triplet
- Low mass (200 – 600 GeV)
  - All-hadronic  $t\bar{t}$  becomes visible
  - Background estimated from b jet control region in data and  $t\bar{t}$  MC

- High mass ( $> 600$  GeV)
  - Background from parameterized fit
- Heavy-Flavor RPV excluded below 835 GeV

## Scenario 2



# Summary

16

- ❑ CMS has an extensive search program for new physics in multijet final states → still more to come
  - ❑ W/Z tagged dijet search – Andreas Hinzmann, Today 15:45h
  - ❑ Dark Matter search with Monojets – Kerstin Hoepfner, Saturday 11:15h
  
- ❑ Four searches presented today with 2012 data at 8 TeV
  - ❑ Limits up to 3.3 TeV on QCD extinction scale
  - ❑ Limits up to 5.1 TeV on string resonances in dijet search
  - ❑ Dedicated search for couplings to b quarks in dijet final state
  - ❑ New results for pair produced three-jet resonances:
    - ❑ Light-flavor RPV gluinos excluded below 650 GeV
    - ❑ Heavy-flavor RPV gluinos excluded below 835 GeV
  - ❑ <https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO>



# Backup



# References

18

- ❑ Exo-12-051: Search for Jet Extinction in the Inclusive Jet pT Spectrum at  $\sqrt{s} = 8$  TeV  
CMS-PAS-12-051: <http://cds.cern.ch/record/1545286>
  
- ❑ Exo-12-059: Search for Narrow Resonances using the Dijet Mass Spectrum with 19.6fb<sup>-1</sup> of pp Collisions at  $\sqrt{s} = 8$  TeV  
CMS-PAS-12-059: <http://cds.cern.ch/record/1519066>
  
- ❑ Exo-12-023: Search for Heavy Resonances Decaying into bb and bg Final States in pp Collisions at  $\sqrt{s} = 8$  TeV  
CMS-PAS-12-023: <http://cds.cern.ch/record/1542405>
  
- ❑ Exo-12-049: Search for Light- and Heavy-flavor Three-jet Resonances in Multijet Final States at  $\sqrt{s} = 8$  TeV  
CMS-PAS-12-049: soon to come

# Resonance Shape Dijet Search

19

- ❑ Dijet resonances shape depends on parton content of the resonances
- ❑ Gaussian core from JER
- ❑ Low mass tail from QCD radiation
  - ❑ Resonances containing gluons are more susceptible to radiation leading to a longer low mass tail

