Search for Light- and Heavy-flavor Three-Jet Resonances with CMS

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FOR THE CMS COLLABORATION

New Physics: Supersymmetry

- Supersymmetry as possible extension of the Standard Model
  - R-parity to distinguish between SM and SUSY

    (B=Baryon number, L=Lepton number, s=Spin)

$$R = (-1)^{(2s+3B+L)} = \begin{cases} +1 & \text{For SM particles} \\ -1 & \text{For SUSY particles} \end{cases}$$

R-parity conservation (RPC)

- Always pairs of sparticles
- Lightest supersymmetric particle (LSP) is stable
- Final state decay has at least one LSP

R-parity violation (RPV)

- Either lepton or baryon number violation
- Sparticles can decay exclusively to SM particles
- Low missing energy in the final state

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Focus of this talk

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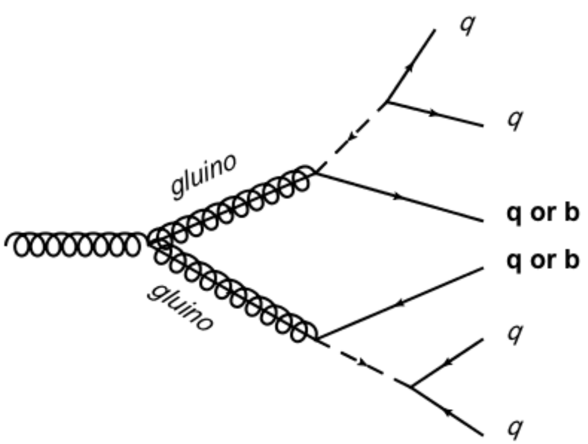
Multijet Resonances

- What if new physics signals couple strongly and decay into quarks and gluons?
- Difficulty is the large QCD background
- Search for strongly coupled resonances decaying into three jets



- Benchmark model pair produced gluinos with R-parity violating decay
  - Inclusive search: light-flavor decay $\tilde{g} \rightarrow uds$
  - Heavy-flavor search: heavy-flavor decay $\tilde{g} \rightarrow udb$ or $\tilde{g} \rightarrow csb$

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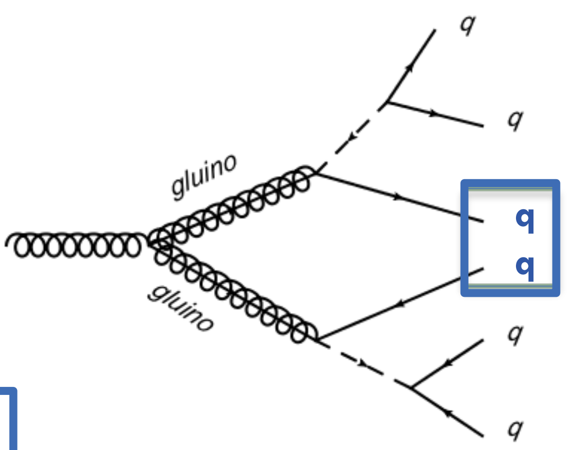

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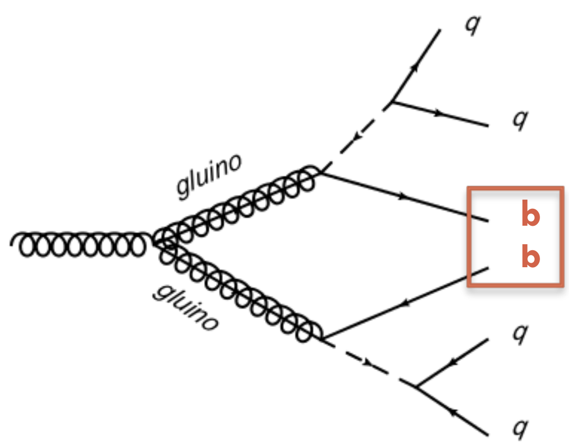

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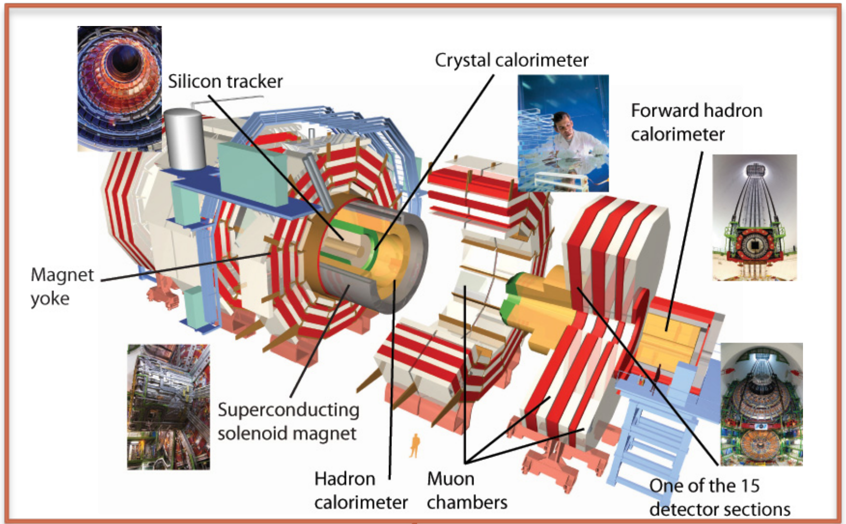
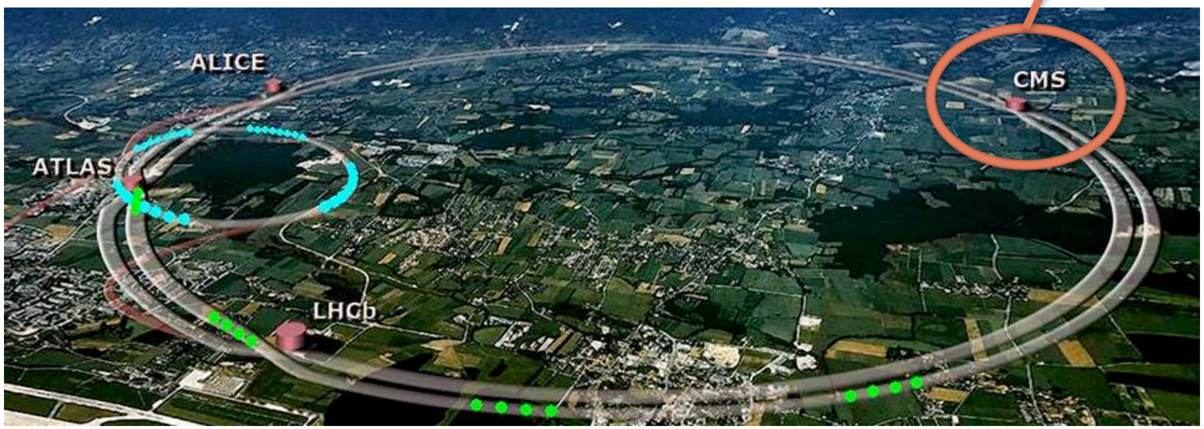
First search in this final state

Large Hadron Collider and the CMS experiment

- **NEW RESULT: EXO-12-049**
  Analysis uses 19.5/fb of data collected with CMS during 2012 at 8 TeV

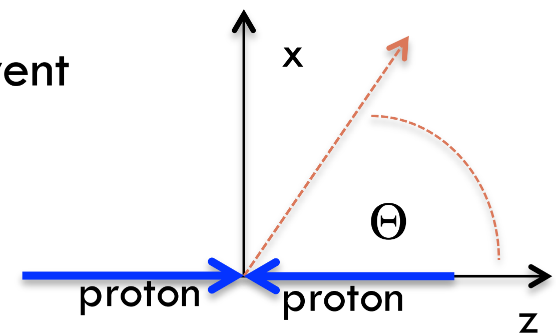




Event Selection

- Trigger: 4 calorimeter jets > 60 GeV, 2 calorimeter jets > 20 GeV
- Good Primary Vertex

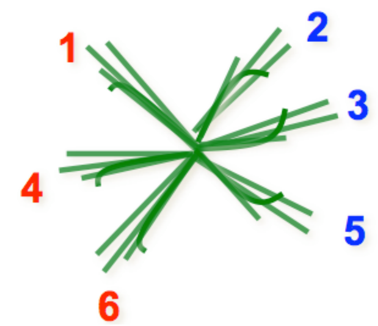
- Jet selection
  - Particle Flow Algorithm (PF)
    - Attempt to reconstruct every particle in the event
  - Anti-k_T jet clustering algorithm with R=0.5
    - Quality selection applied on the jets
  - At least 6 PF jets > 35 GeV and η < 2.5
    - 4^{th}-jet p_T > 80 GeV
    - 6^{th}-jet p_T > 60 GeV (optimized for higher masses)
  - b tagging
    - Combined Secondary Vertex (CSV) algorithm



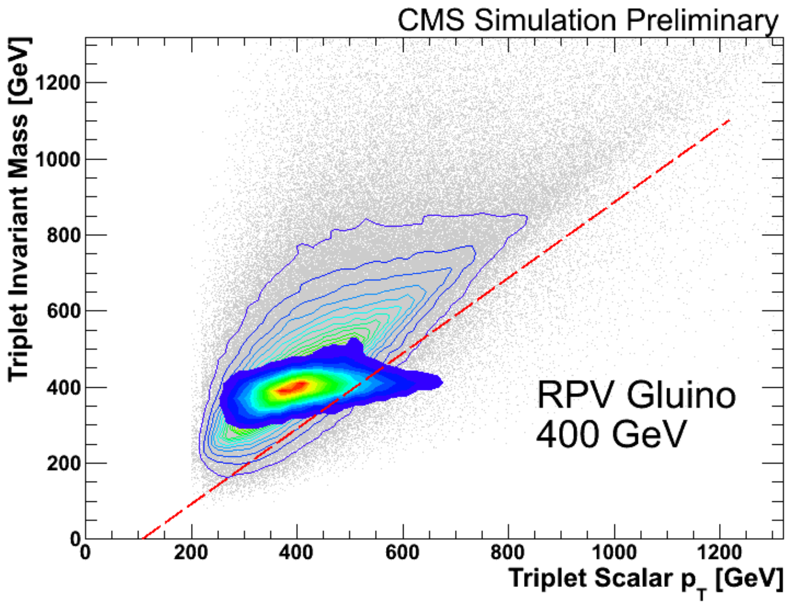
pseudo rapidity $\eta = -\ln[\tan\Theta / 2]$

Jet Ensemble Technique

- 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



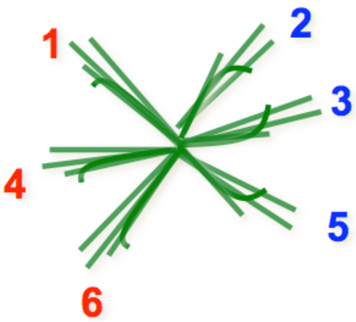
- For each triplet plot M_{jjj} versus $\sum^{jjj} |p_T^{Jet}|$

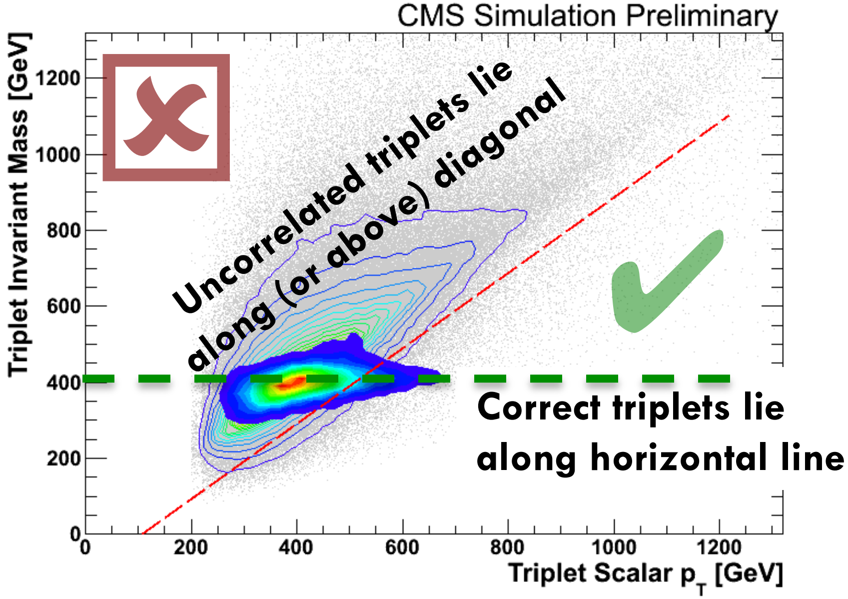


Jet Ensemble Technique

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

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





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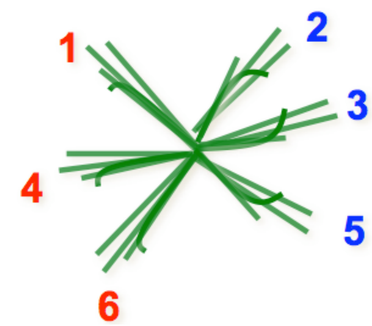
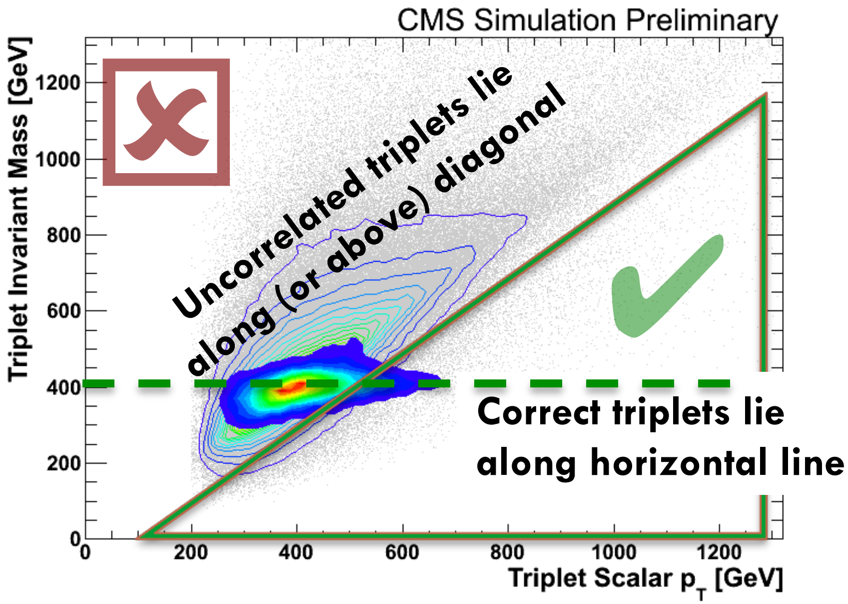
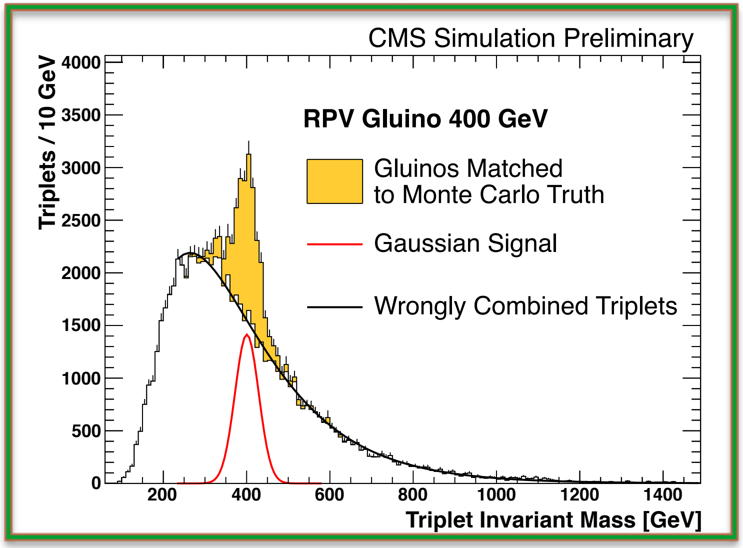






Search for Gaussian peak

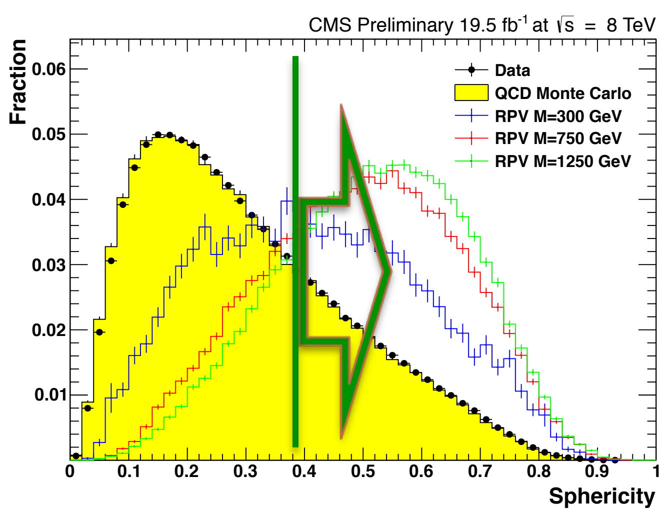
Selection Optimization

- Diagonal cut $\Delta = 110$ GeV
  - Separates successfully Gaussian signal from intrinsic background of wrong combinations
  - Chosen based on largest accessible mass range in data
- Three additional handles
  - **Event shape variables:** distinguish heavy resonance decays from QCD background
  - **6^{th} Jet p_T selection:** improves sensitivity for high mass gluinos
  - **b tags:** reduce background for heavy flavor search

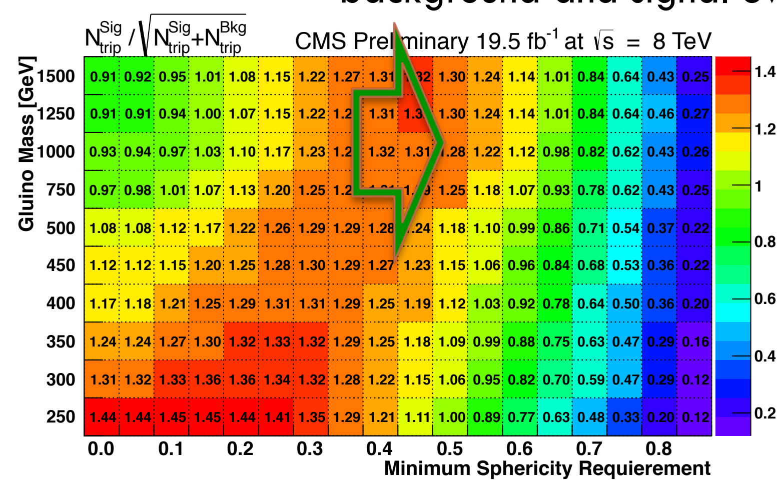
Selection Optimization: Event Shape Variables

- Heavy gluinos are produced with little boost and decay almost isotropically in the detector
- QCD events have a more dijet like structure
- Sphericity variable $S = \frac{3}{2}(\lambda_2 + \lambda_3)$ from eigenvalues of sphericity tensor is a good measure of the event shape

$$S^{\alpha\beta} = \frac{\sum_i p_i^\alpha p_i^\beta}{\sum_i |p_i|^2}$$

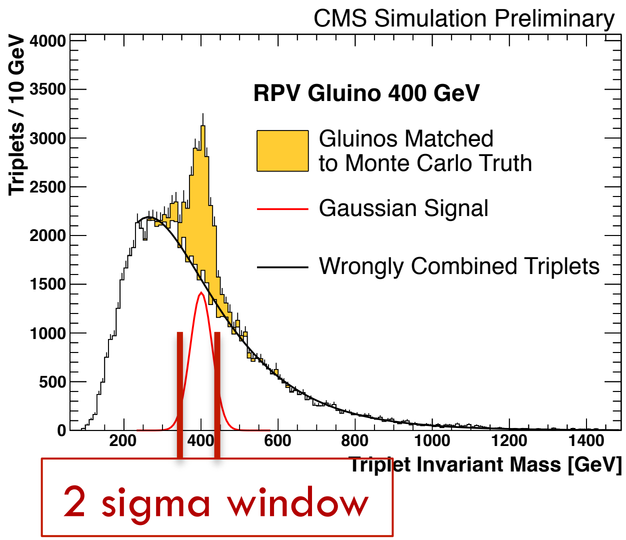


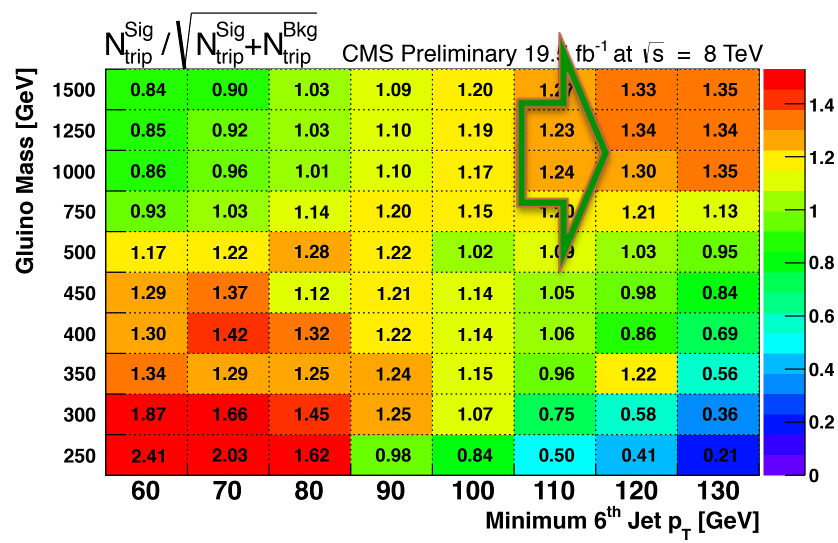
Optimization based on expected background and signal events



Selection Optimization: 6^{th} Jet p_T

- Changes in 6^{th} jet p_T and adding b tags can changes peak position of the M_{jjj} background distribution ➔ optimization at triplet level
  - Metric $N_{sig}/\sqrt{(N_{sig}+N_{bkg})}$ N = number of triplets
  - N_{sig}: Gaussian integral ± 2 sigma
  - N_{bkg}: fit to the data, integral in the same mass range





Selection Optimization: Conclusion

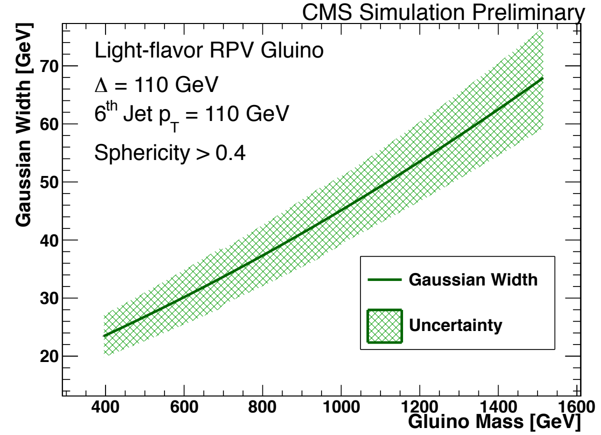
- Diagonal cut Δ = 110 GeV
- **Inclusive search**
  - 6^{th}-jet p_T > 110 GeV
    - previous exclusion in 2011 up to 460 GeV http://arxiv.org/pdf/1208.2931.pdf
  - Sphericity > 0.4
- **Heavy-flavor search**
  - >= 1 b tags in the triplet
  - Low mass (200 – 600 GeV):
    - 6^{th}-jet p_T > 60 GeV, 4^{th}-jet p_T > 80 GeV
  - High mass (600 – 1500 GeV):
    - 6^{th}-jet p_T > 110 GeV
    - Sphericity > 0.4

Signal Modeling

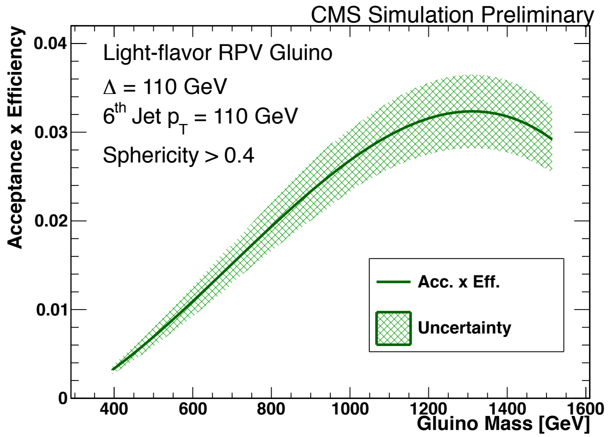
- Signal is modeled as a Gaussian peak
- Determined from the M_{jjj} distribution of simulated events
- Two parameters to model signal
  - Gaussian width
  - Acceptance x Efficiency
    - **f1**: fraction of **events** passing all cuts
    - **f2: average** number of triplets per event passing the diagonal cut
    - **f3**: ratio of **triplets in the Gaussian** signal peak with respect to all triplets

$$\text{Acceptance x Eff.} = f1 \times f2 \times f3 = \frac{N_{Evt}^{Pass}}{N_{Evt}^{Generated}} \times \langle N_{Triplet} \rangle \times \frac{N_{Triplet}^{Gauss}}{N_{Triplet}}$$

Gaussian width



Acceptance x Efficiency

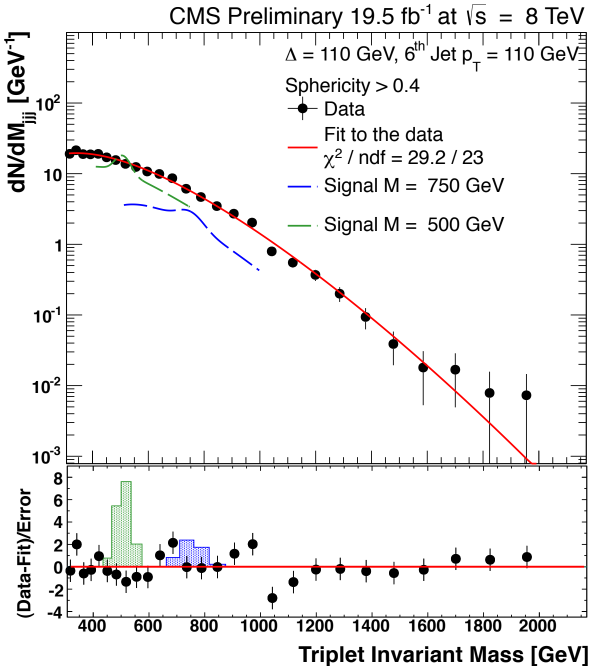


Background Modeling

Inclusive search

$$P4 = n_{bkg} \frac{(1 - \frac{x}{\sqrt{s}})^b}{(\frac{x}{\sqrt{s}})^{c + d \log \frac{x}{\sqrt{s}}}}$$

- Fit directly to the data



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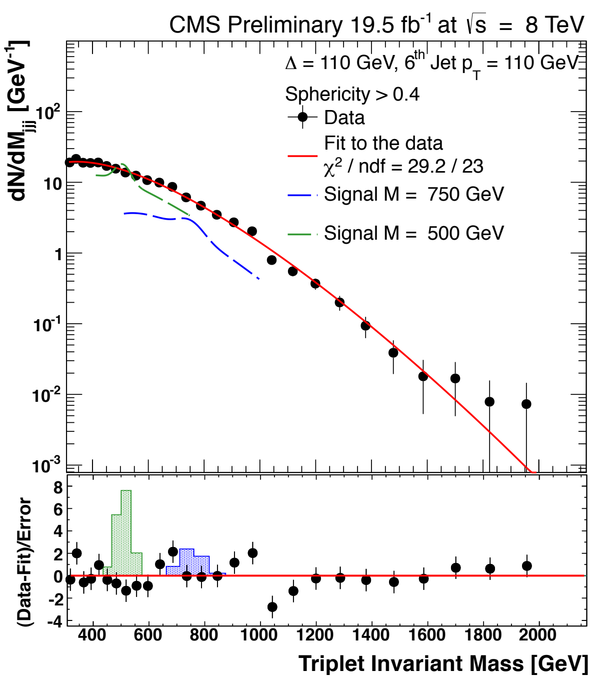
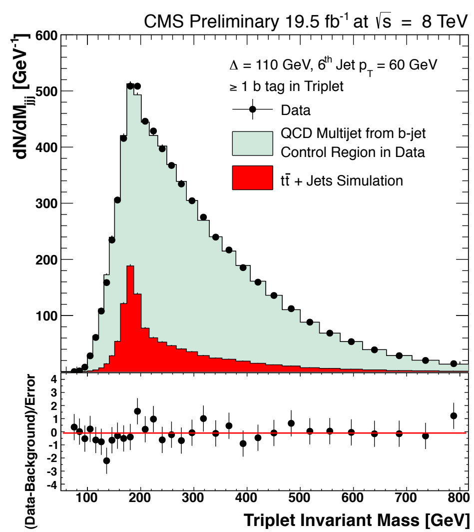
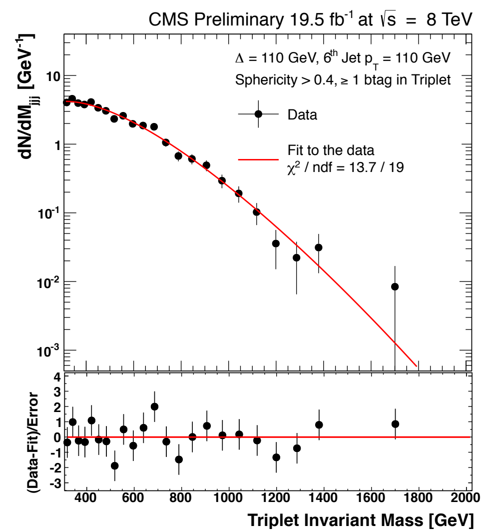


Heavy-flavor search





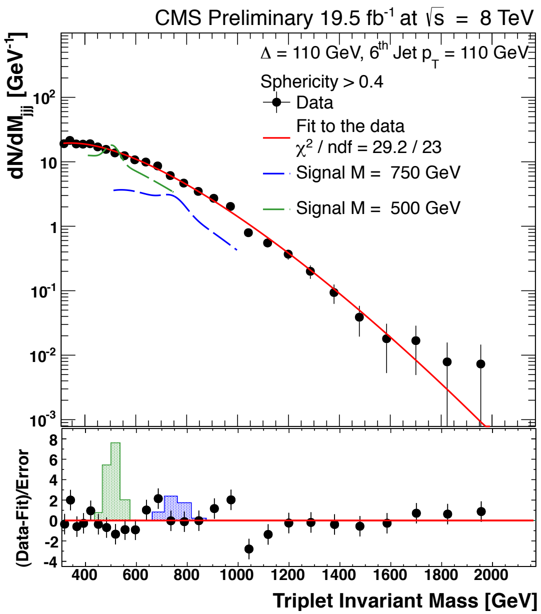
- Low mass (200 – 600 GeV)
- Background from simulated $t\bar{t}$ events and b jet control region in data

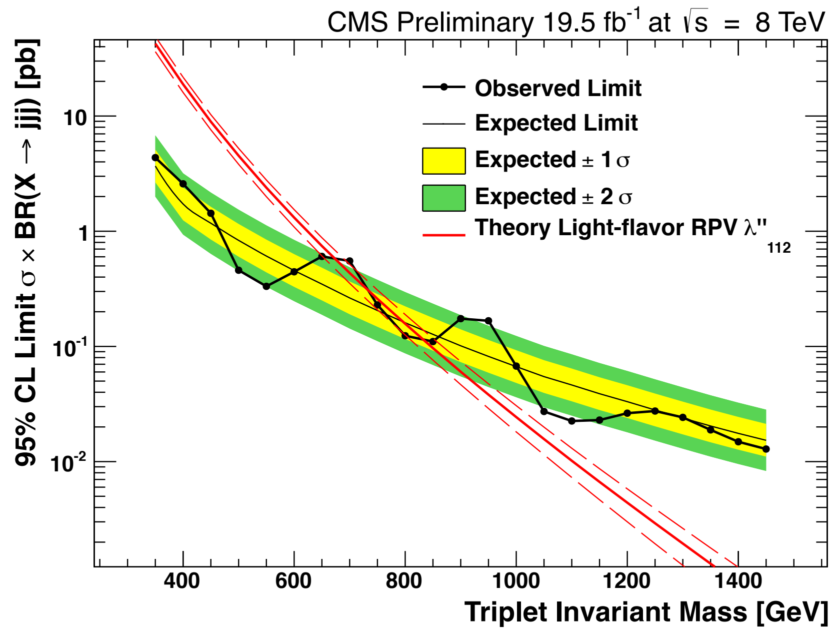
- High mass (600 – 1450 GeV)
- Fit directly to the data

Results: Inclusive Analysis

- Background for light-flavor search from parameterized fit
- Good agreement between data and fit
- Limits are placed at 95% C.L. at 650 GeV

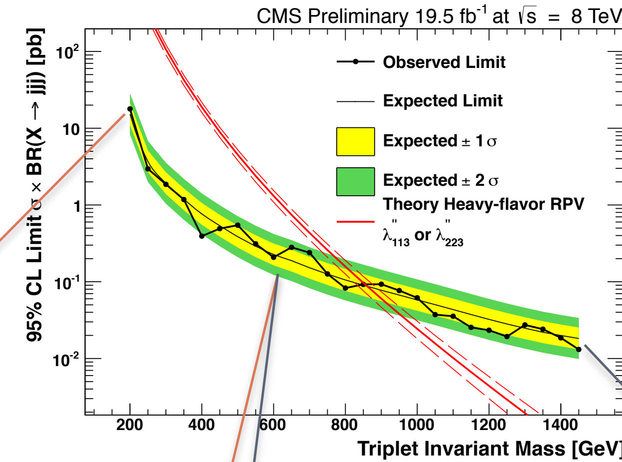
Data after $\Delta = 110$ GeV

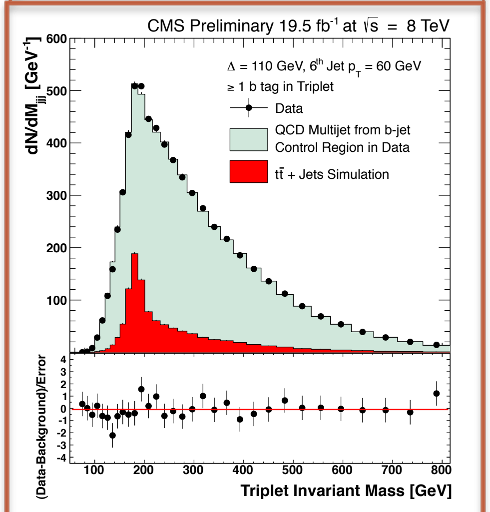


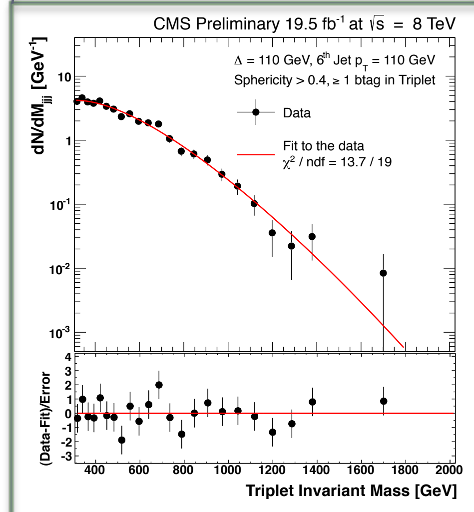


Results: Heavy-Flavor Search

- Require ≥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 at 95% C.L. below 835 GeV







Summary

- Presented search for three-jet resonances in an all-hadronic final stated using jet-ensemble technique in 19.5/fb of data
- First time search for heavy-flavor jets in this final states

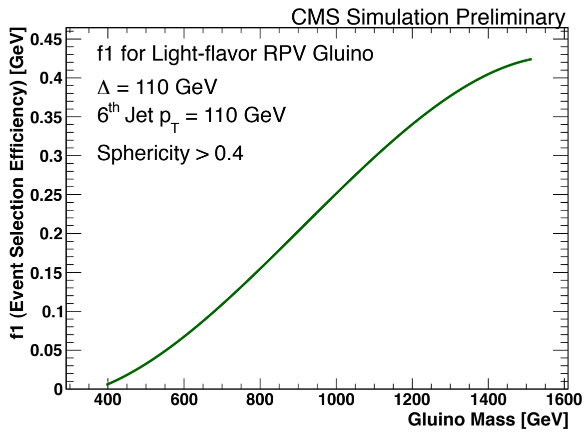
- Substantial improvement of previous limits
  - Gluinos decaying to light-flavor jets: 650 GeV
  - Gluinos decaying to light-and heavy-flavor jets: 835 GeV

- More information:
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO12049
  - CMS-PAS-EXO-12-049 http://cds.cern.ch/record/1563139

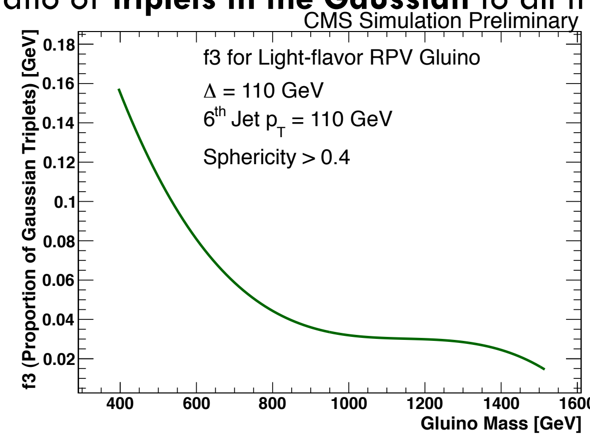
Backup

Signal Model: Acceptance x Efficiency

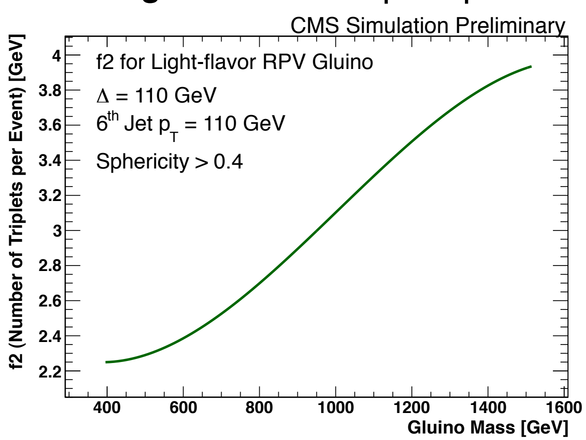
f1: fraction of **events** passing all cuts



f3: ratio of **triplets in the Gaussian** to all triplets



f2: average number of triplets per event



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