Searches For New Physics in Multijet Final States at CMS

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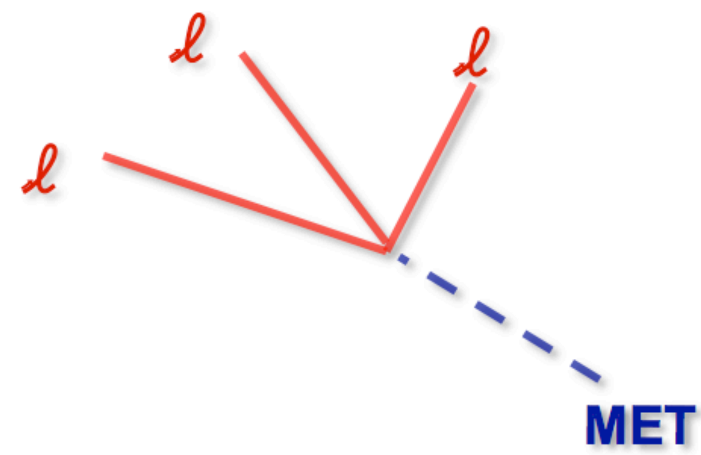
Has there been a blind spot in searches for new physics?

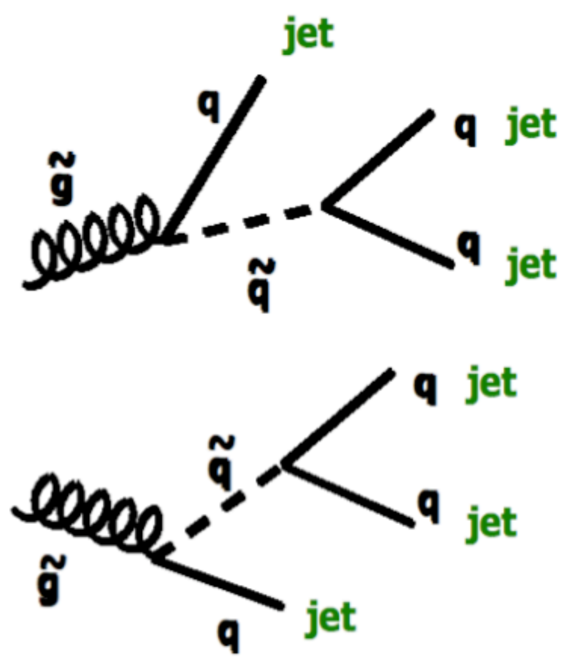
- Most new physics searches require either
  - Leptons, especially (e, μ)
  - Missing momentum (ie. MET) from ν, lightest neutralino, extra dimensions…
  - Photons (γ)



- What if new physics has color (*q*- or *g*- like)?
  - Not produced at e^+e^- colliders
  - Could be pair-produced at hadron colliders
  - Of course, massive QCD backgrounds

What If New Physics Has Color?

- **New Physics Search in a Multi-Jet final state**
- **Studying pp → QQ → 3j + 3j = 6 jets**
  - **Q = g = $SU(3)_C$ Adjoint Majorana Fermion**
  - **R-Parity violating (No Missing E_T)**
  - **Modeled as RPV (uds Yukawa) gluino (negligible intrinsic width)**



- **Large Backgrounds**
  - **6 jet selection essentially all QCD**
- **We use a *new* technique of an ensemble of jet combinations:**

Make use of kinematic features in an ensemble of jets with minimal model-dependent assumptions

This technique could also be useful for future searches with leptons, MET, photons

Usual Tricks No Longer Work

- Picking the correct 3 jets in a multiple-jet event is difficult:
  - In a six-jet event, 6 choose 3 = $\binom{6}{3} = 20$ different triplet combinations
  - Some of these hard jets are from initial- and final-state radiation (not part of signal)
- Neural Networks and other multi-variate techniques are only valid if you're very sure of the model's kinematics, and are prone to a tailored model-dependence
- QCD 6-jet cross-section, kinematics not well known (besides being really big)
- Our solution? Look at all 20 combinations!

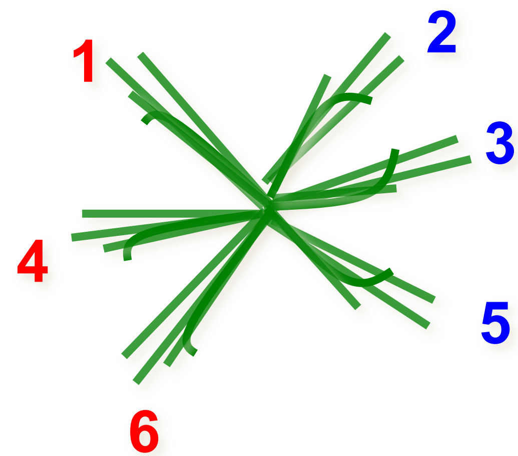
Jet Ensemble Construction

pp → QQ

Q→ j j j

Q→ j j j

$Q = \tilde{g}$



Constructing ensembles:

In the 6 jet scenario, there are 20(!) unique combinations of jet triplets:

123, 124, 125, 126, 134, 135, 136, 145, 146, 156,
234, 235, 236, 245, 246, 256, 345, 346, 356, 456

The challenge:

Separating the good ensembles (resonances) from everything else!

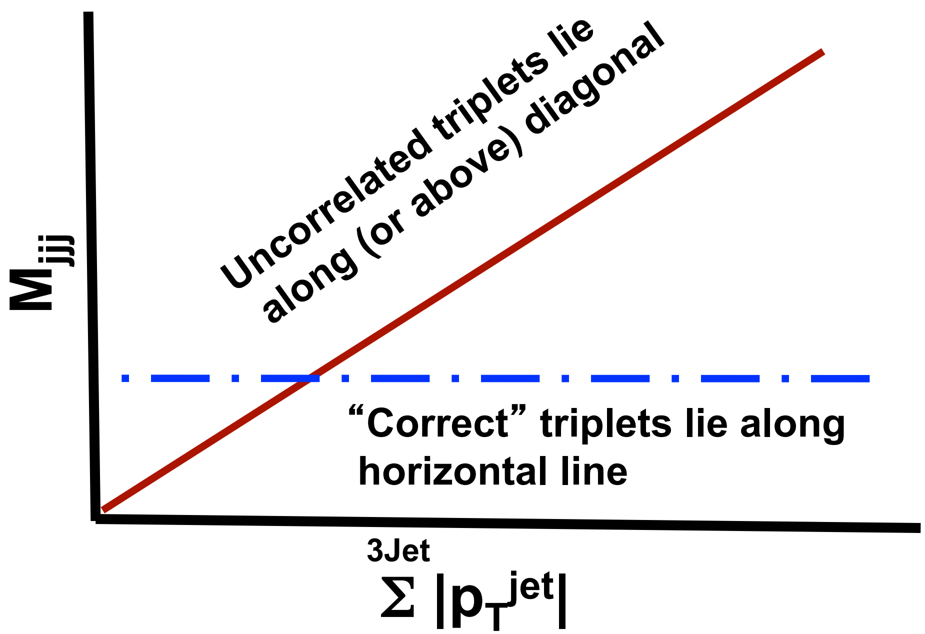
Signal Selection

- **Construct an ensemble of jet triplets (20 Combinations)**
- **For all jet triplets, plot the triplet mass versus the triplet scalar sum p_T:**

M_{jjj} vs. $\sum^{3Jet} |p_T^{jet}|$

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

$M_{jjj} < \sum^{3Jet} |p_T^{jet}|$ - Δ (Offset)



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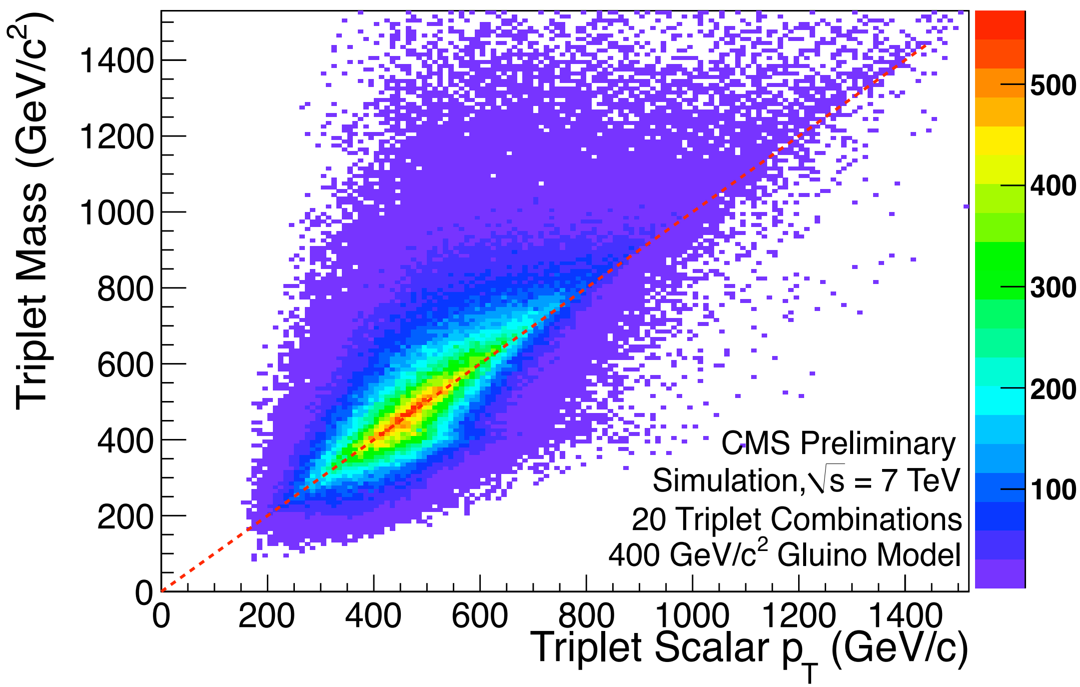

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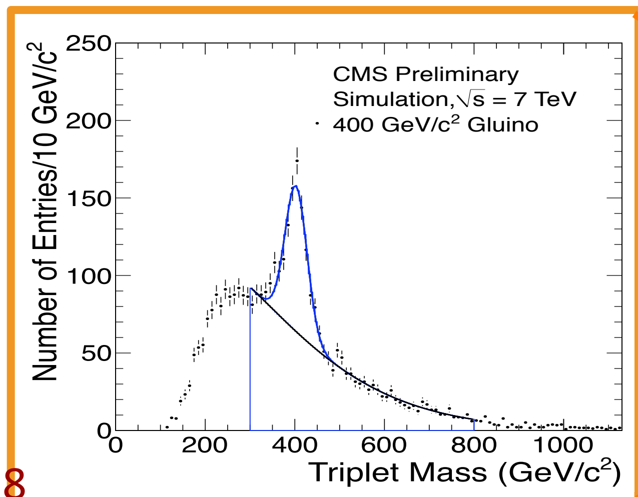
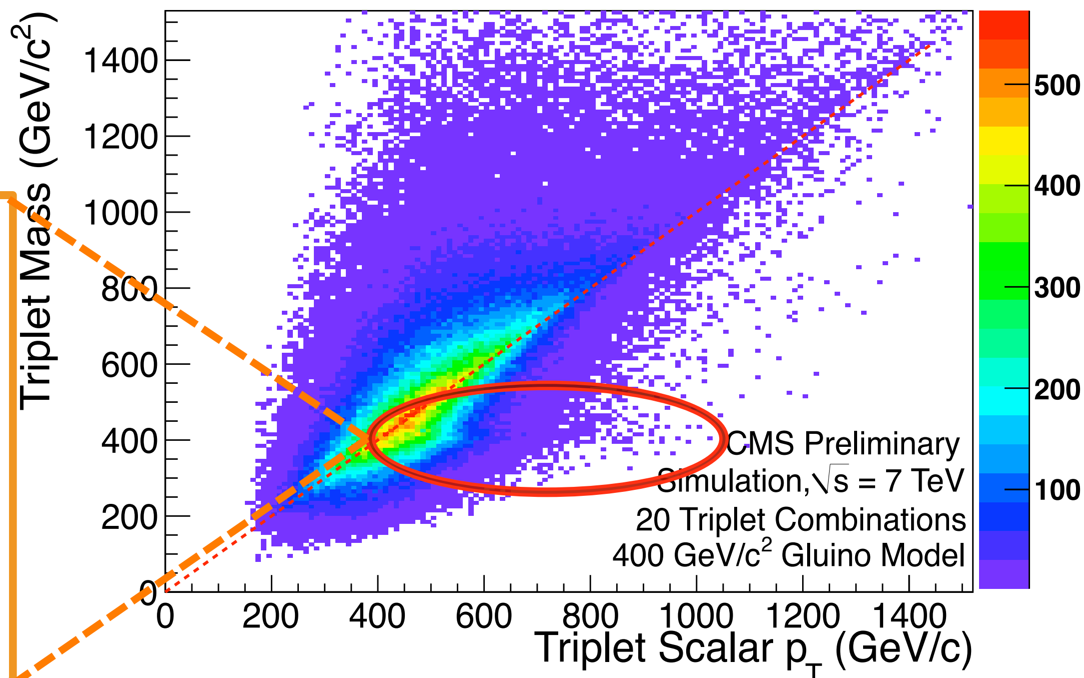
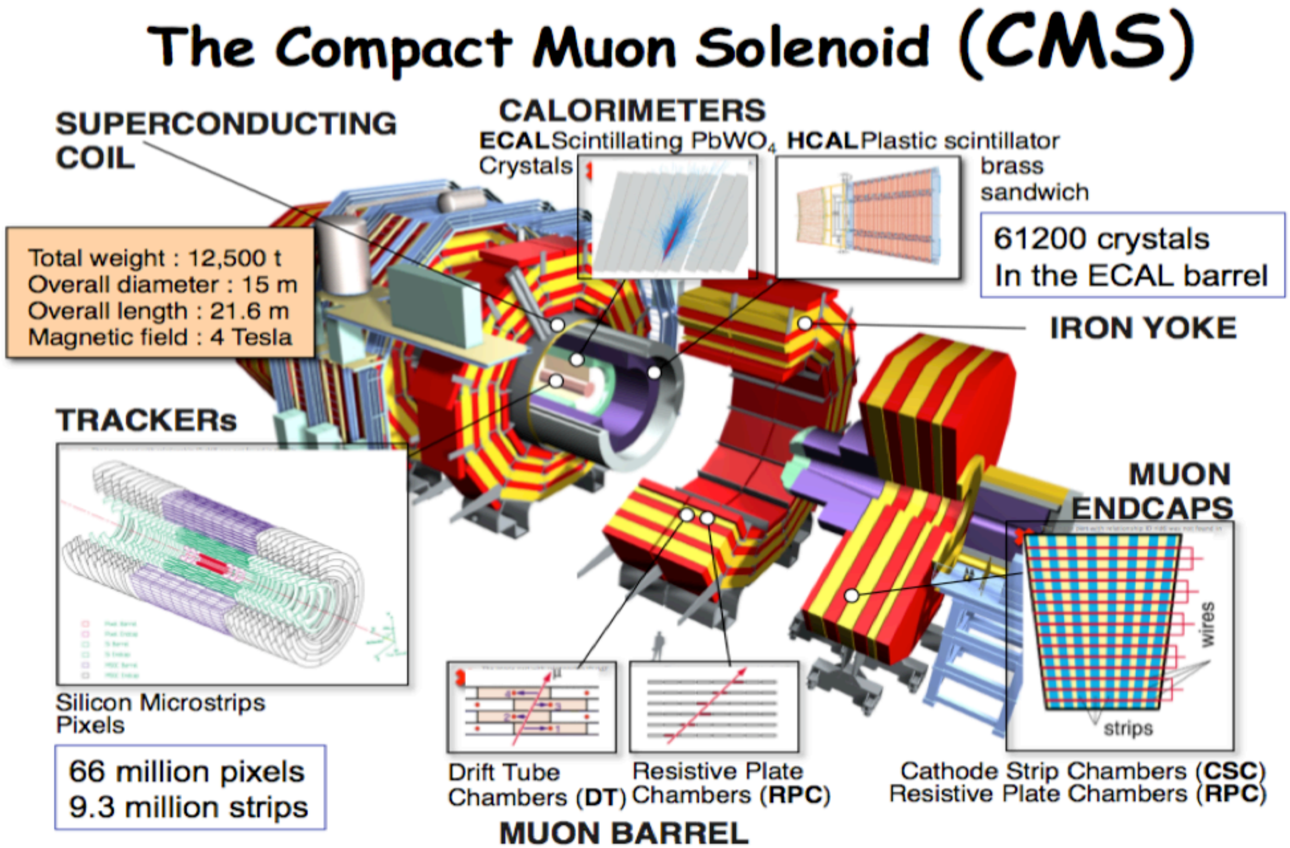




CMS Detector and Datasets

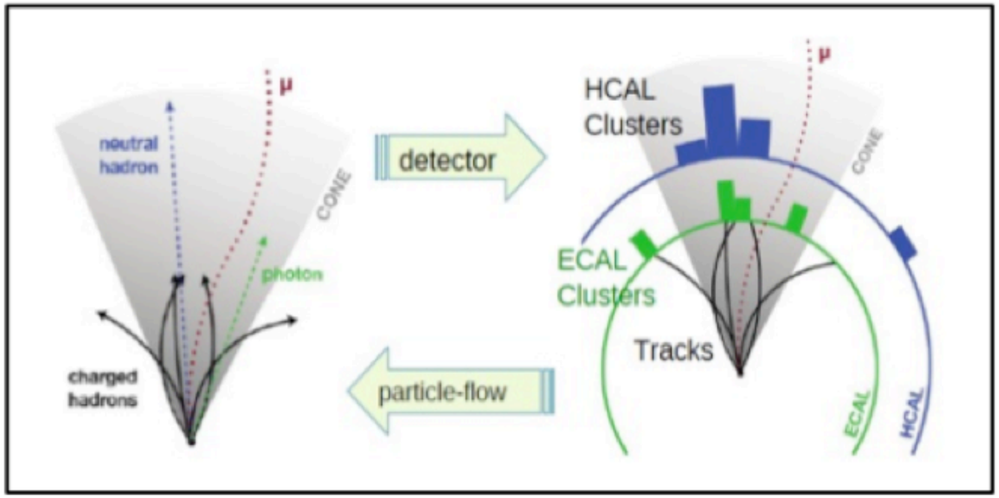


Two datasets (and two analyses):

- 2010 Data: 35.1 pb^{-1}
- 2011 Data: 5.0 fb^{-1}

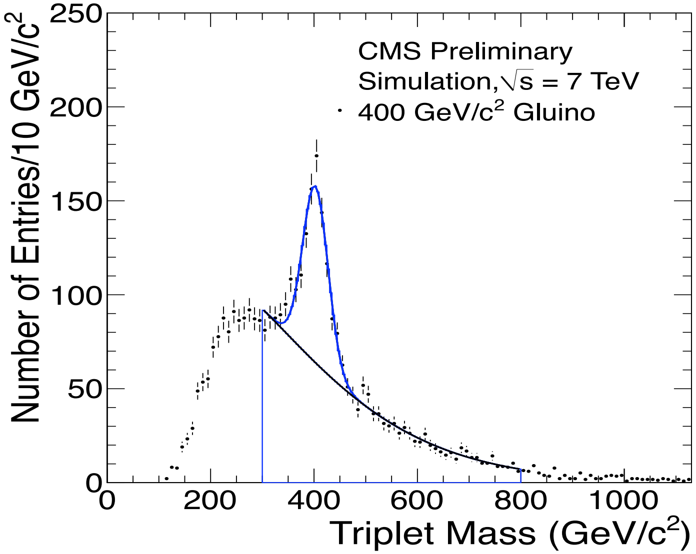
Event Selection and PFlow Jets

- Sophisticated "particle flow" reconstruction algorithm:
  - Exploits the excellent tracker performance and the fine granularity of the ECAL
- Reconstructed individual particles according to their detection signature:
  - Charged hadrons: (tracks + linked ECAL/HCAL deposits)
  - Neutral hadrons (unlinked HCAL deposits)
  - Photons (unlinked ECAL deposits)
  - Electrons (tracks + linked ECAL deposits with E/p ~ 1)
  - Muons (tracks + muon chamber hits)



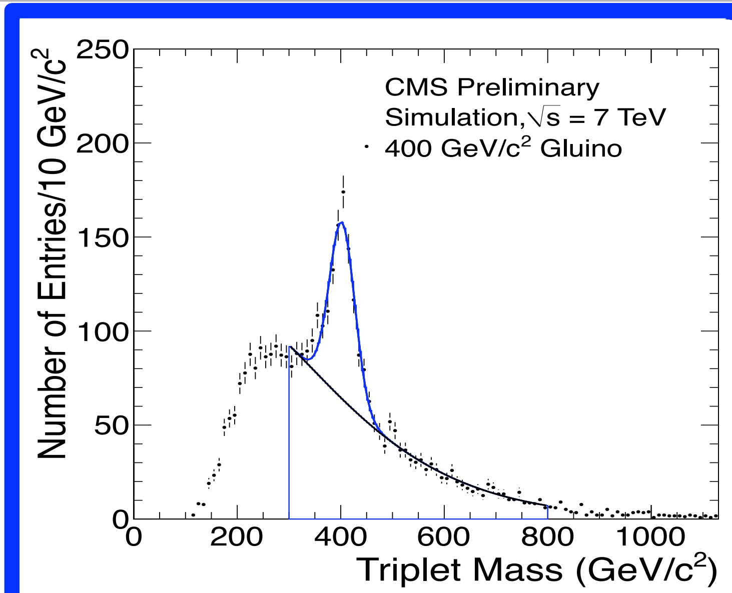
2011 (2010) Event Selection:

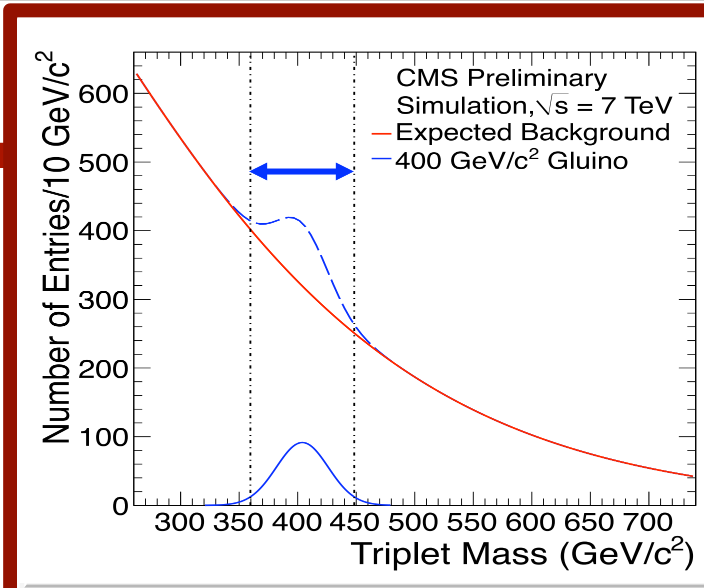
- ✓ At least 6 jets with p_T > 45 (20) GeV
- ✓ Σ p_T of selected jets > 900 (425) GeV
  - ➢ Ensures 100% trigger efficiency
- ✧ No selection on missing energy, leptons, or angular distributions



Method:

- The optimization is a basic scan over multiple 6th jet p_T and diagonal offset Δ requirements
  - For each operating point:
    - Obtain the data-driven background shape with form: $\frac{P_0(1 - x/\sqrt{s})^{P1}}{(x/\sqrt{s})^{P2+ P3 \log(x/\sqrt{s})}}$
    - Fit RPV Monte Carlo Signal + Background parameterization
    - Find number of signal and background events within a 2.0 sigma window about the signal Gaussian
    - Calculate Signal (S) over Signal + Background (B): S/(S + B)





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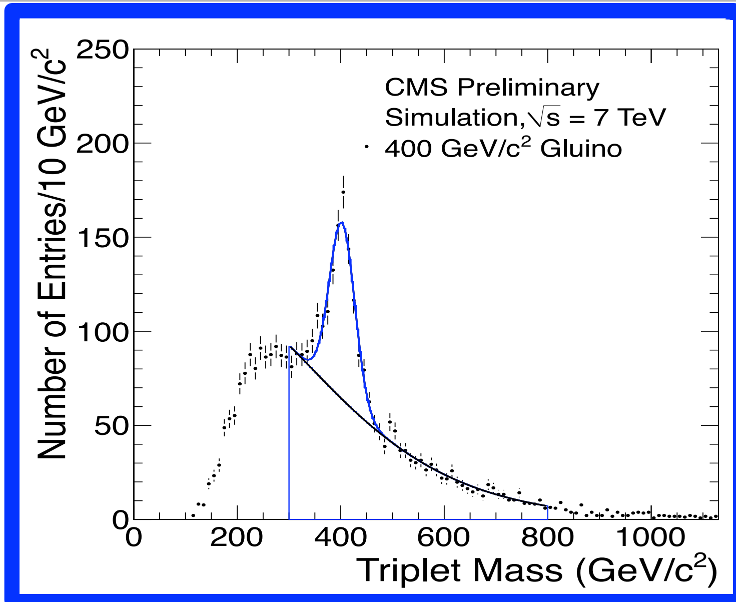

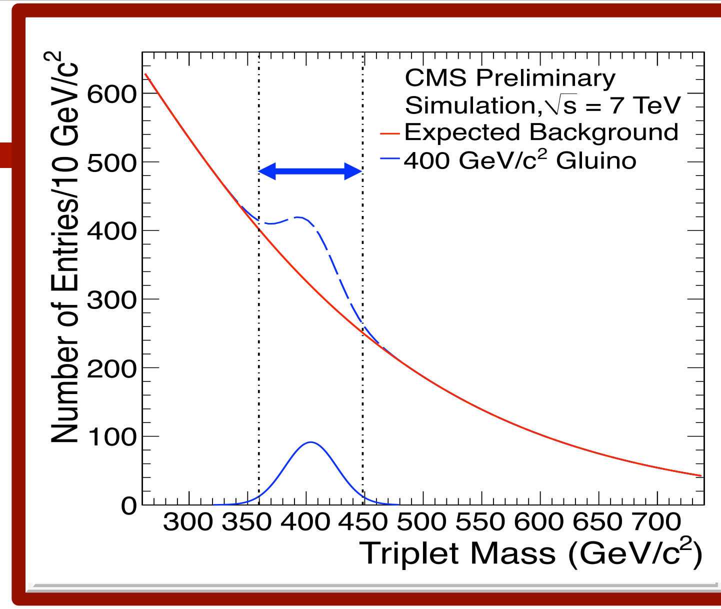

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- 6th jet p_T > 70 (45) GeV, Δ value of 160 (130) GeV

Background Modeling

- We consider 2 main background parameterizations:
  - Use the same technique employed by other searches
    (Dijet mass, dijet pair searches)
    - Background triplets have a steeply falling shape
    - A resonance results in a localized disagreement
    - Functional form of background for 2011 analysis consistent with other multijet searches:

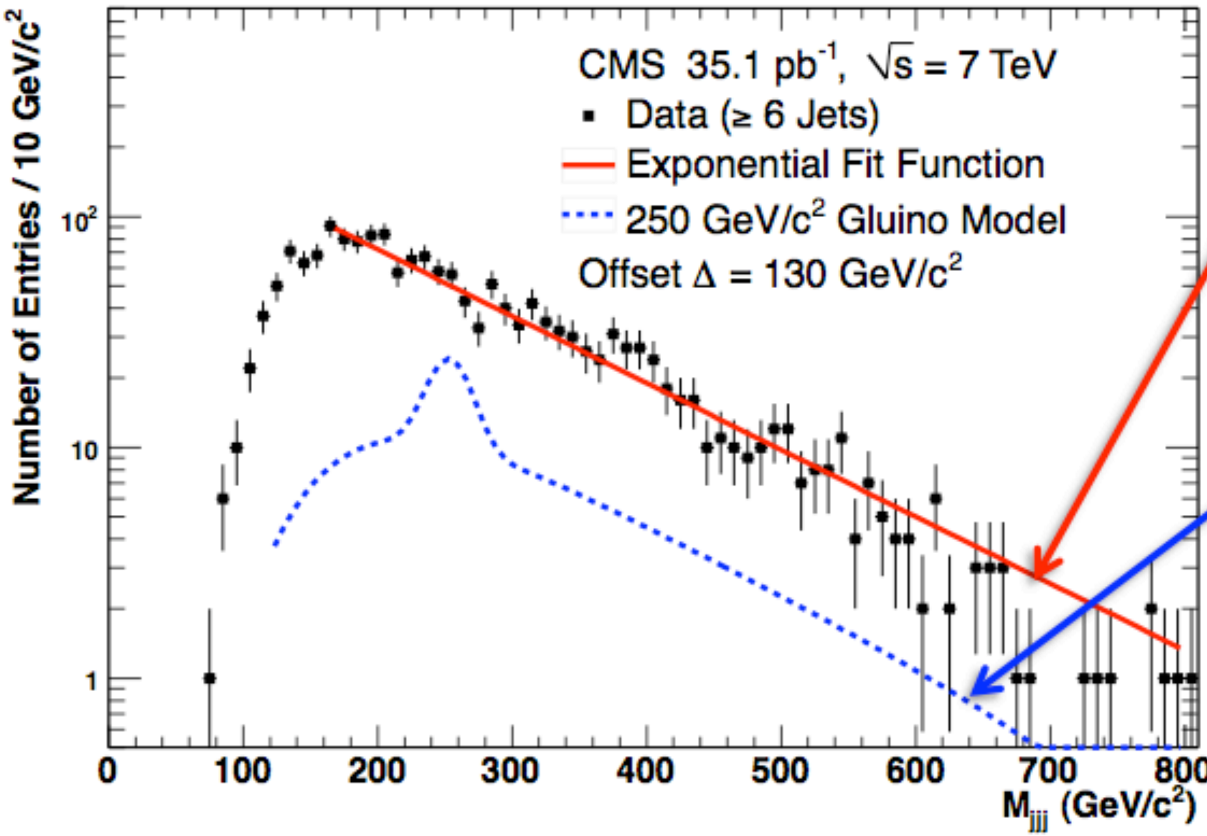
Main fit function 2011:

$$\boxed{P_0 \frac{(1-x/\sqrt{s})^{P_1}}{(x/\sqrt{s})^{P_2+P_3 \log x/\sqrt{s}}}}$$

Main fit function of 2010:

$$\boxed{e^{P_0+P_1 x}}$$

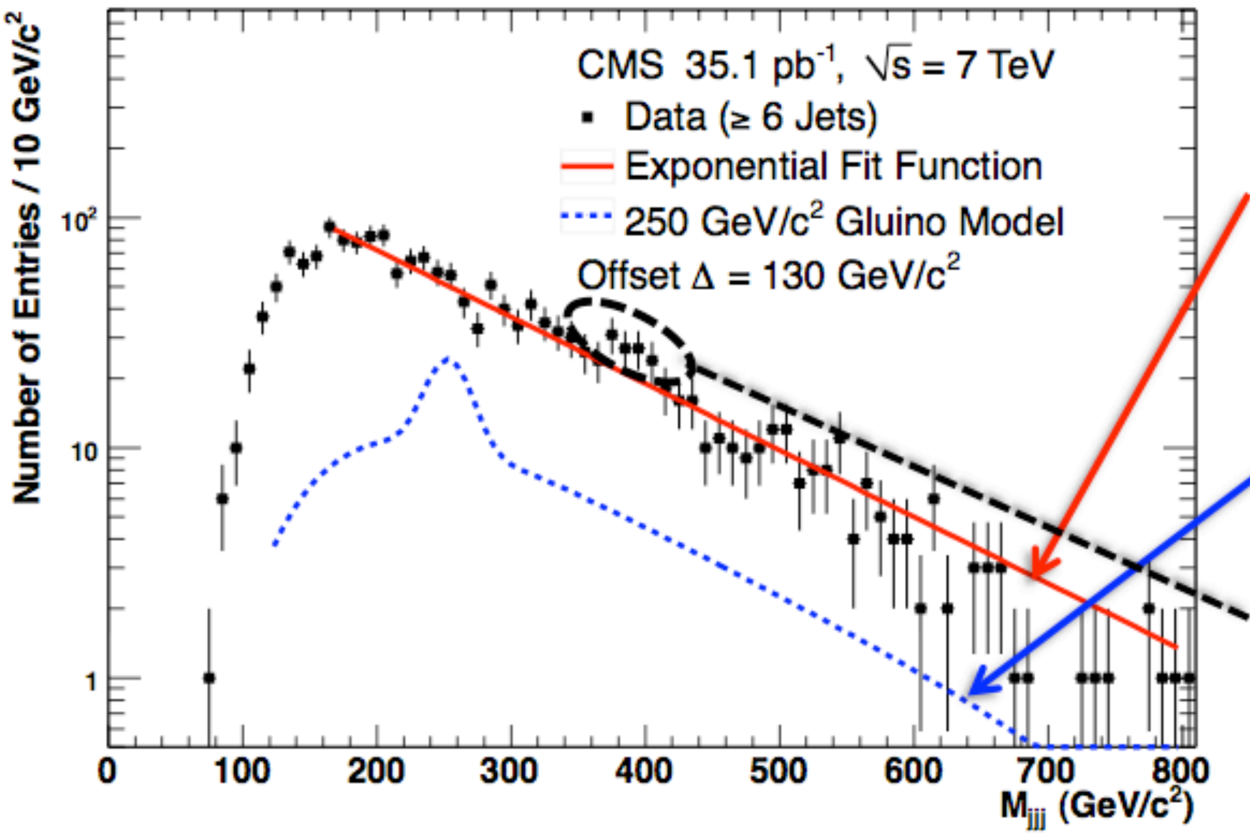
Results from 2010 Data



Best-fit background Parameterization is exponential

Expectation for 250 GeV signal gluino

Results from 2010 Data



Best-fit background Parameterization is exponential

Expectation for 250 GeV signal gluino

Small excess seen in data shape

Three Jet Resonances in Multi-Jet Events

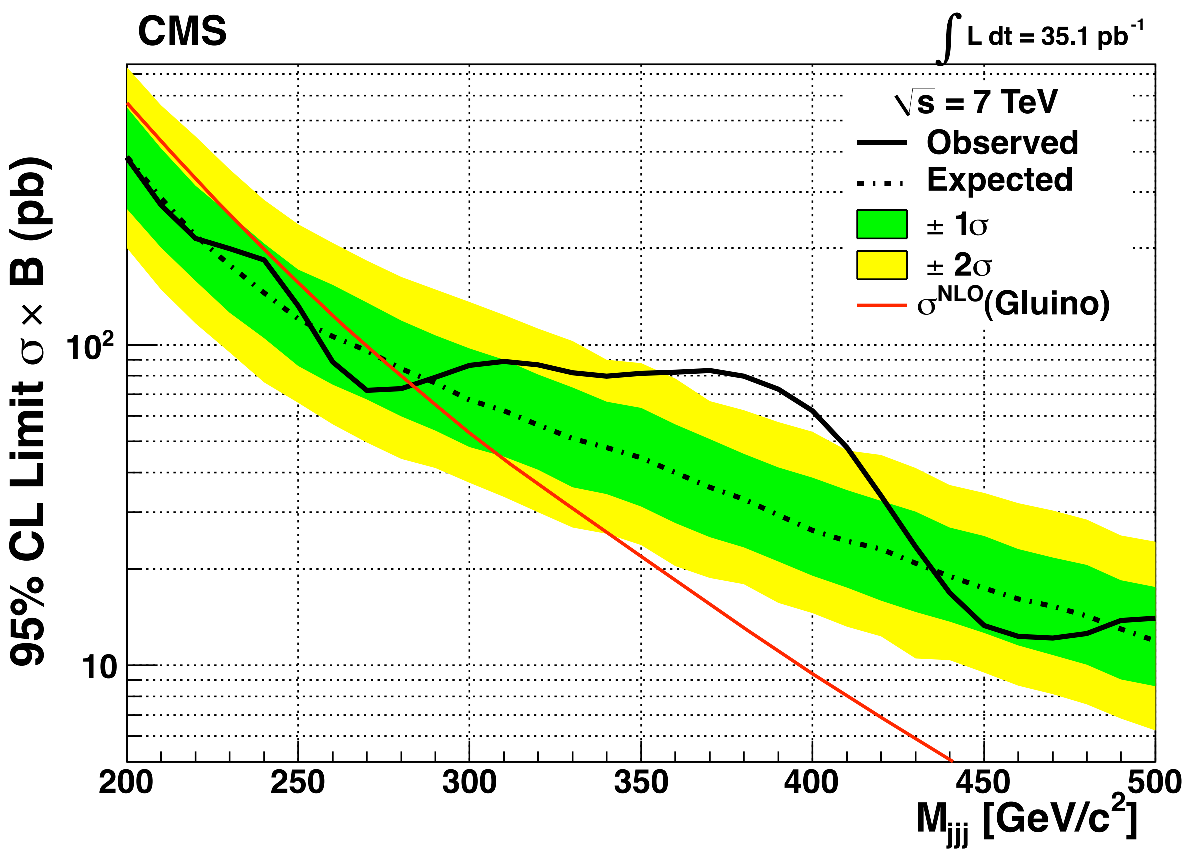
95% CL limits from Bayesian likelihood approach

Uncertainties treated as Gaussian nuisance parameters:

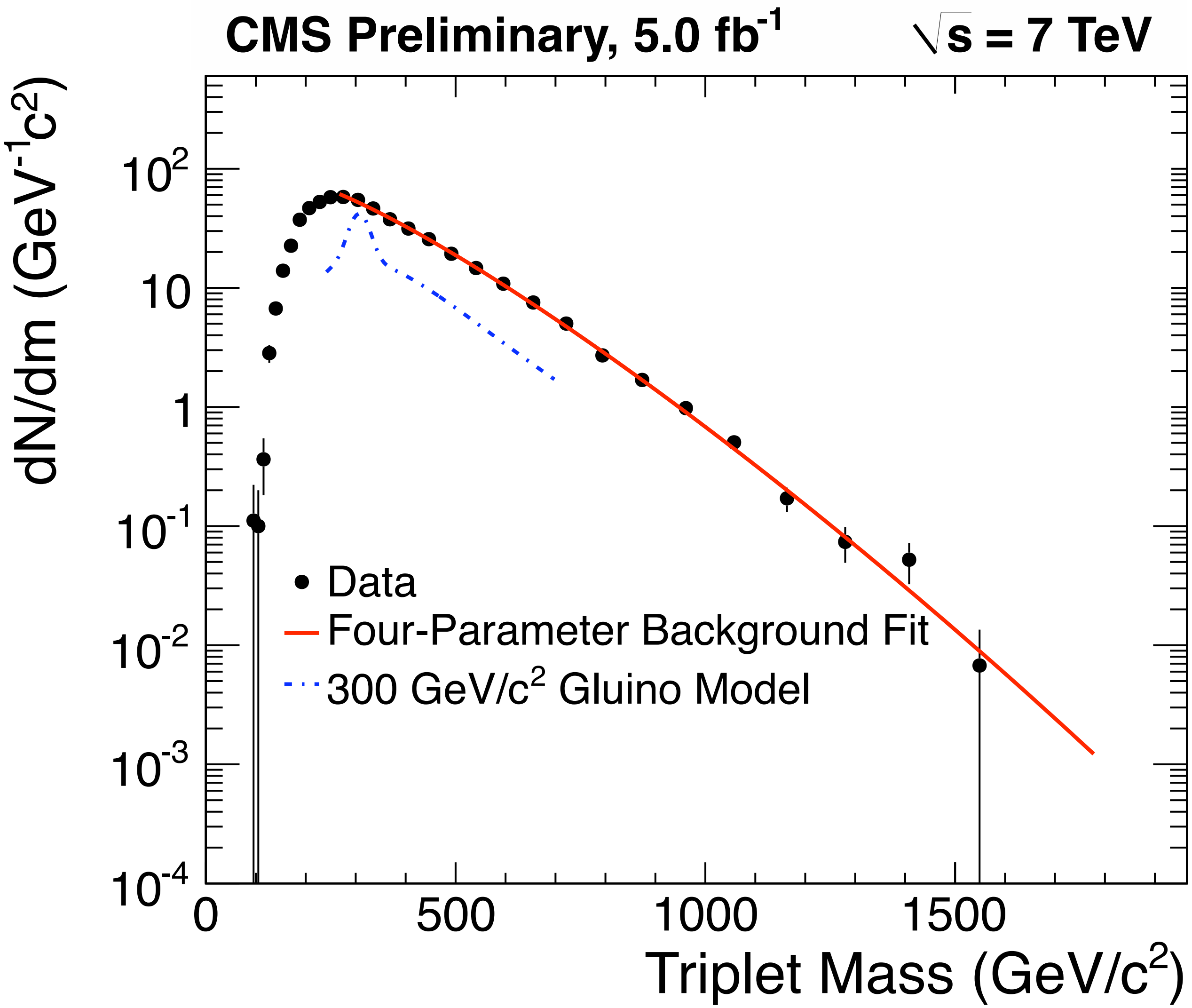
Largest uncertainties from JES (8 – 17%)

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

1st direct limits on RPV gluino decays at the LHC



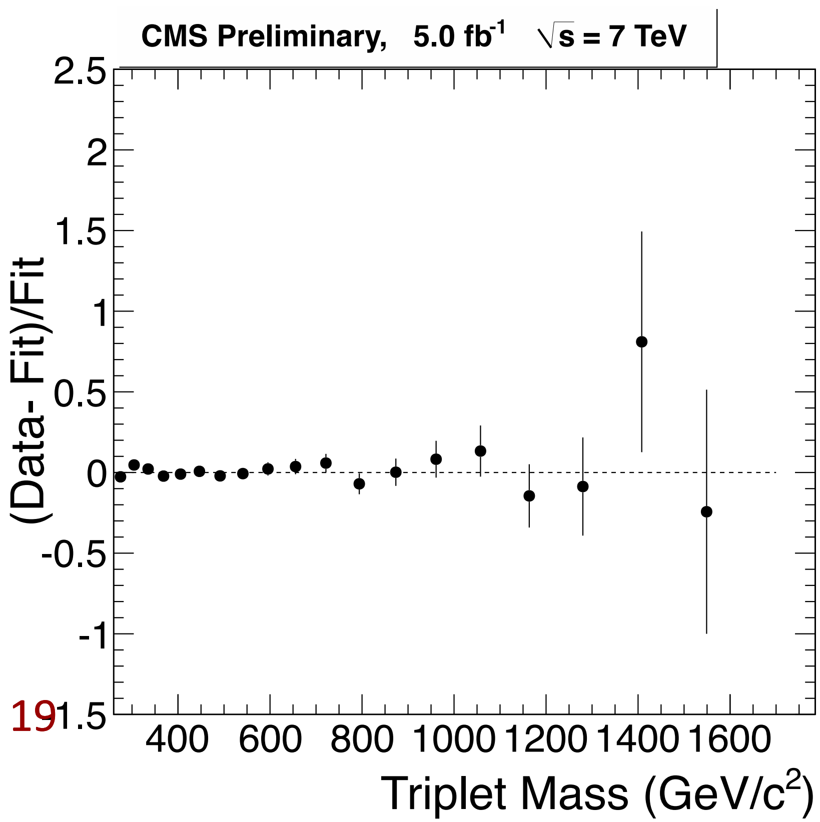
Run2011 Selected Data

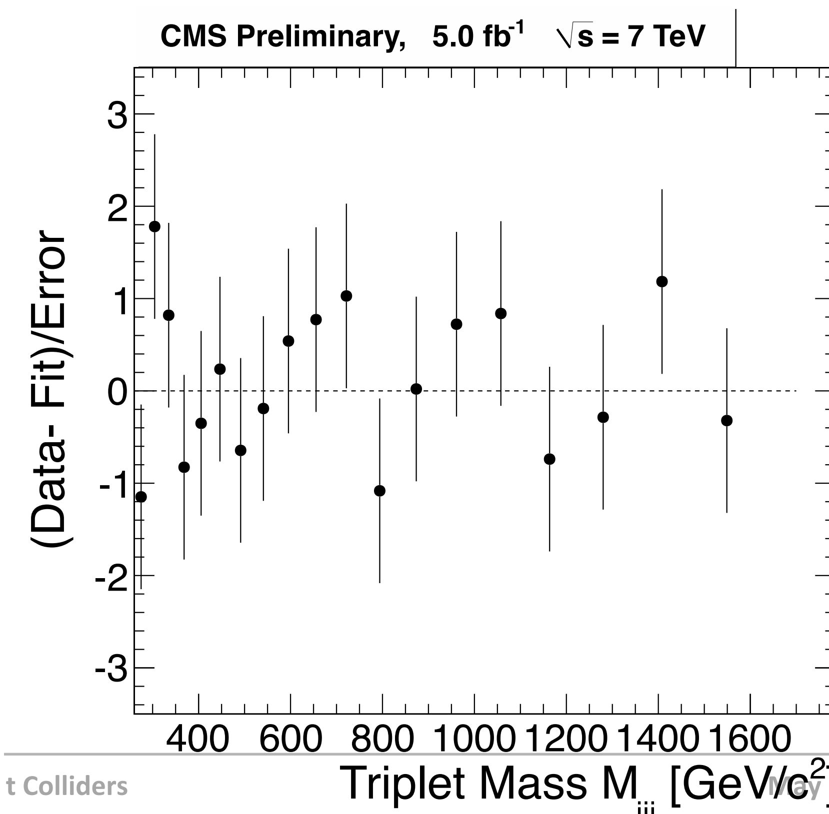


2011 Data to Fit Comparisons

- **Direct comparisons of data to background fit give a quantitative indication of agreement**
  - **We perform two types of comparison:**

1st: (Data – Fit)/Fit **2nd: (Data – Fit)/Error**



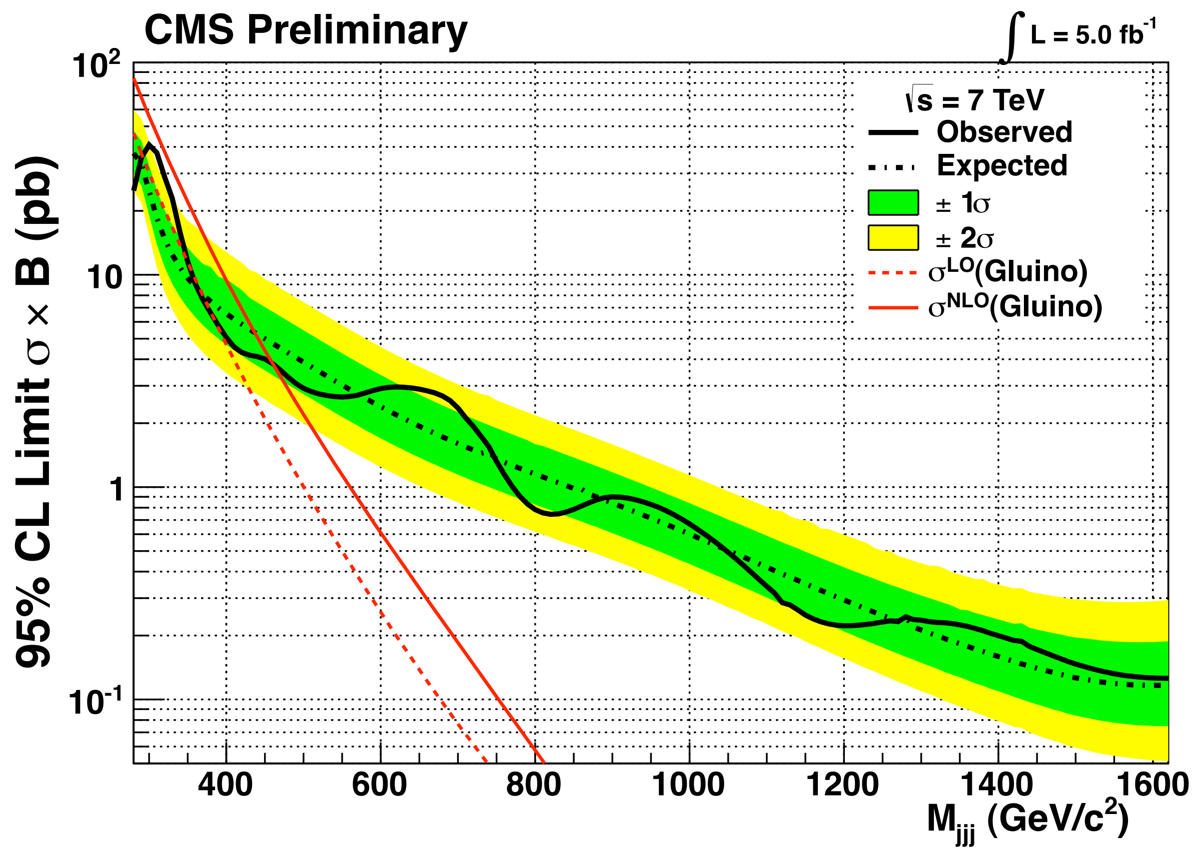


95% CL limits from CLs frequentist aymptoptotic calculator

Uncertainties treated as log-normal constraints:
Largest uncertainties from JES (9 – 19%)

Exclusion for gluinos (RPV decay) for masses 280 < M < 460 GeV/c^2

Highest (preliminary) limits to date



Conclusions

- We have done a *model-independent* search for 3 jet resonances.
  - *BSM bumps cannot hide!*
  - *We have tools to go after strongly coupled physics!*

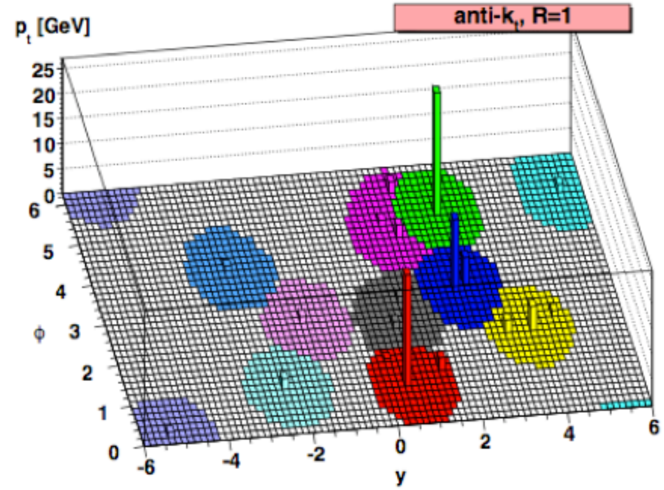
- Highest limits to date on RPV gluino production and the first limits at the LHC:
  - 200 – 280 GeV/c^2 excluded in 2010
  - 280 – 460 GeV/c^2 now preliminarily excluded in 2011

- CMS's multijet program is large and growing
  - New analyses already public or in progress: dijet pairs 8 jets, multi- b-jets
  - *Triggers tailored for multijet searches already taking 8 TeV!*

Backup Slides

Anti-k_T Jet Algorithm

- **This search uses the anti-k_T clustering algorithm (R = 0.5):**
  - **Sequential recombination (belongs to the k_T family)**
  - **Theoretically sound (infrared and collinear safe)**
  - **Geometrically well-defined (circular shape in the $\eta - \phi$ plane)**
  - **Tends to cluster around the hard energy depositions**
  - **Distance parameter R**
- **The inputs to the jet clustering algorithm are calorimeter towers or particle-flow candidates**

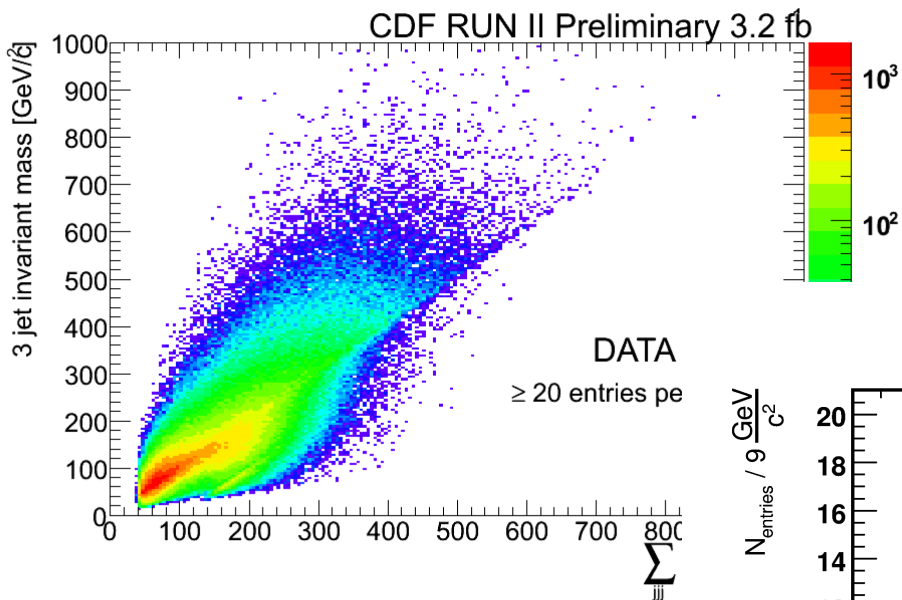


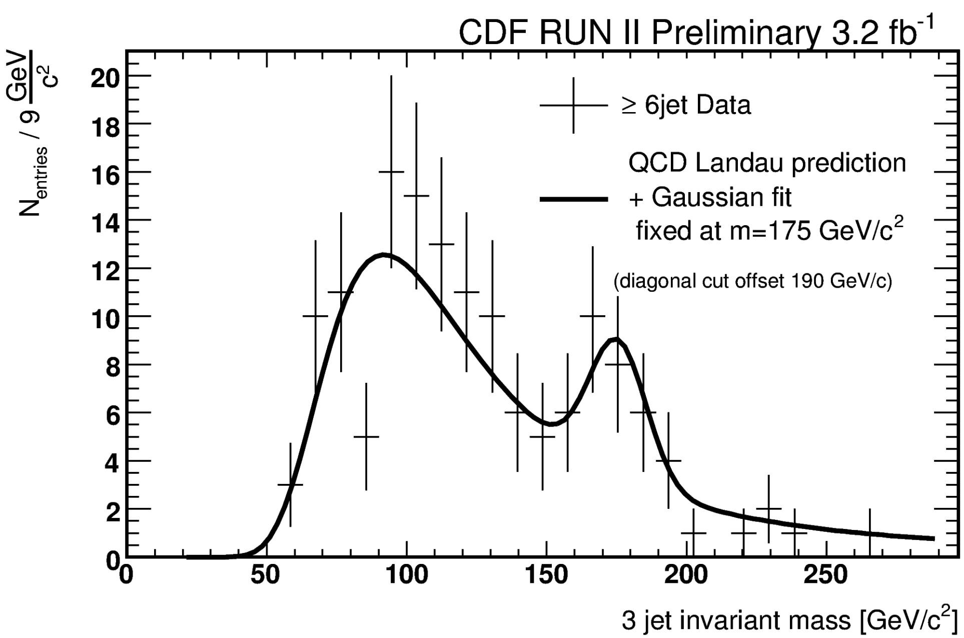
$$d_{ij} = \min\left(p_{Ti}^{-2}, p_{Tj}^{-2}\right) \frac{\Delta R_{ij}^2}{R^2}$$
$$d_{iB} = p_{Ti}^{-2}$$
$$\Delta R_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$$

Limit-Setting for 2011 Data

- In general:
  - Define a likelihood such that $L = \prod_i \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!}$
    - where $\mu_i = \mu_S + \mu_B$ and $\mu_S = \sigma_S \cdot \mathcal{L} \cdot A$
    - Signal is modeled by Gaussian, background by 4 parameter fit
    - Consider the following as constraints (nuisance parameters):
      - Normalization of background, lumi, acceptance, signal width
      - Constraints taken as log-normal in shape
  - Roostats used to calculate CLs frequentist aymptoptotic limits

Did you do this at CDF?





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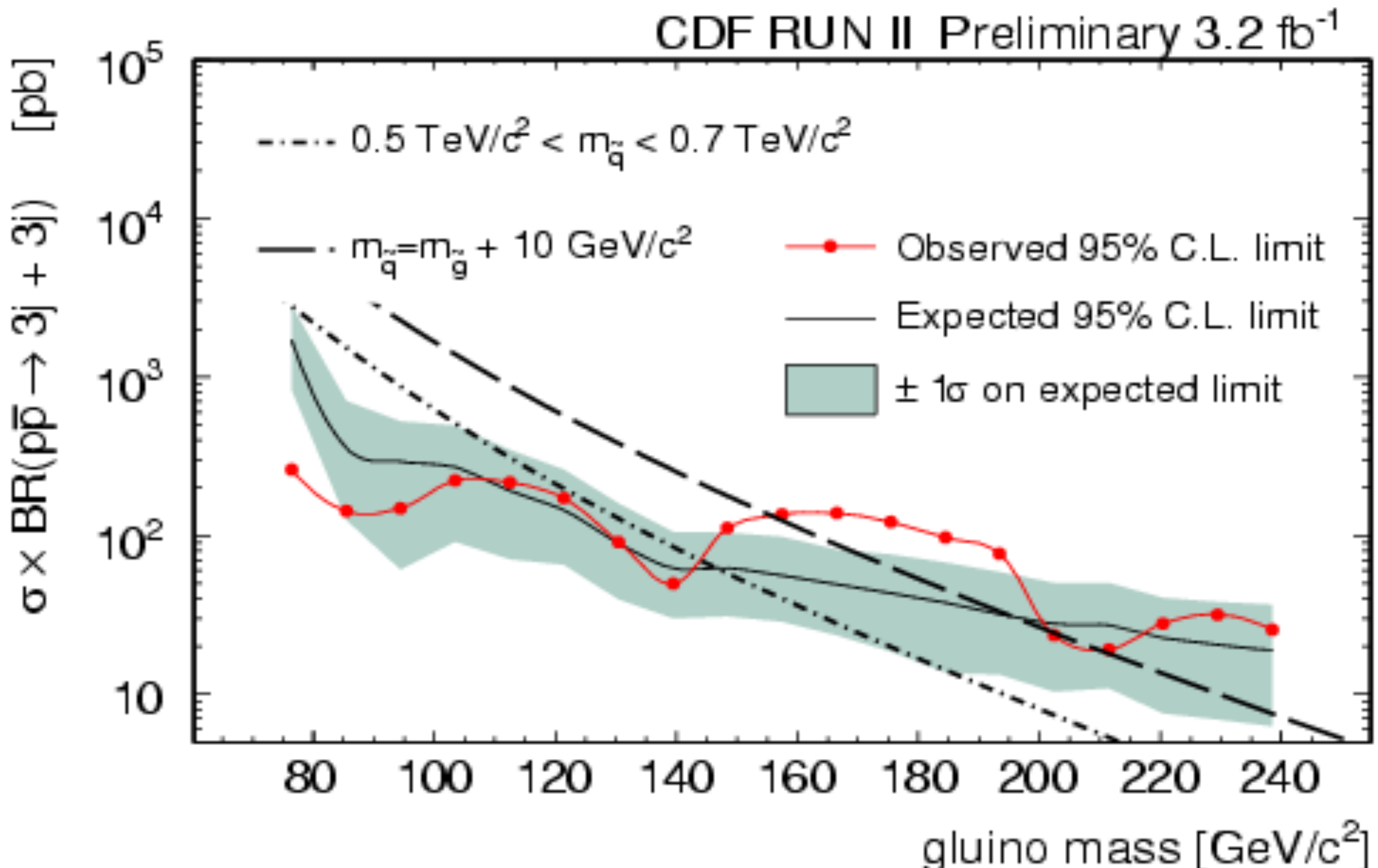

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