Exotic searches in multijet final states

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on behalf of CMS Collabotaion

Introduction

We will look at :

- Recent resonant Exotic searches in multi jet final states using the CMS Run 2 datasets @ 13 TeV

- These multi jet searches are modeled on R Parity Violating (RPV) SUSY, We will focus on the multi jet searches with hadronic RPV (*UDD)* coupling

- Among the CMS RPV SUSY Multijet searches, talk will be focused on the following:

  - $\tilde{t} \rightarrow qq(bq)$ (EXO-17-021[a])

  - $\tilde{q} \rightarrow qqq$ and $\tilde{g} \rightarrow qqqq$ (EXO-17-022[b])

  - $\tilde{g} \rightarrow qqq$ (EXO-17-030[c])

[a]:http://arxiv.org/abs/1808.03124 [b]:http://arxiv.org/abs/1806.01058 [c]:http://arxiv.org/abs/1810.10092

A little bit about RPV SUSY

- Natural (MSSM) SUSY is very desirable
  - Solves naturalness problem and provides a Dark Matter candidate
- But Searches in ATLAS and CMS have searched through the phase space and there is no hint in our current results
- We can reconsider our view of SUSY and take a look at RPV

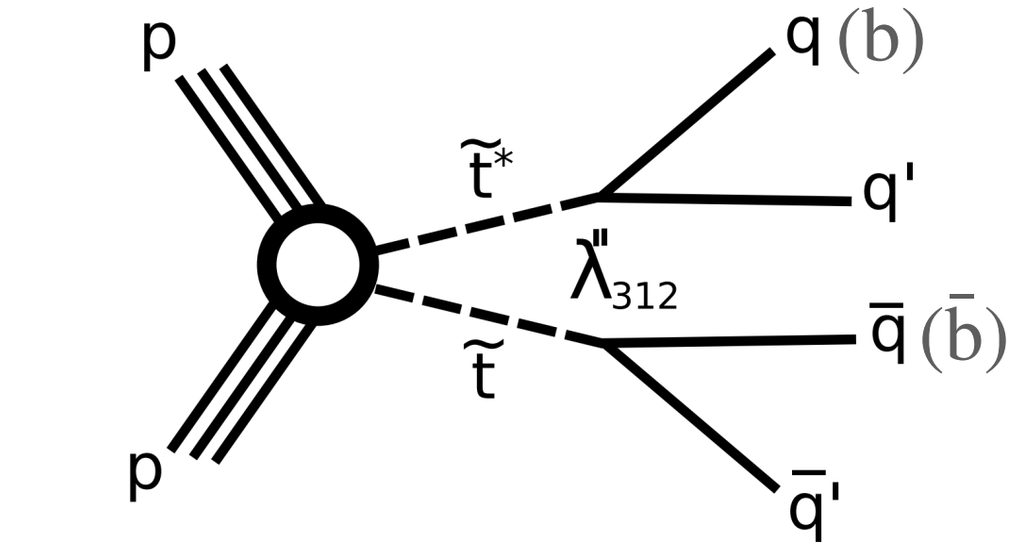
$$W_{\not R_p} = \boxed{\mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k} + \boxed{\frac{1}{2}\lambda''_{ijk} U^c_i D^c_j D^c_k}$$

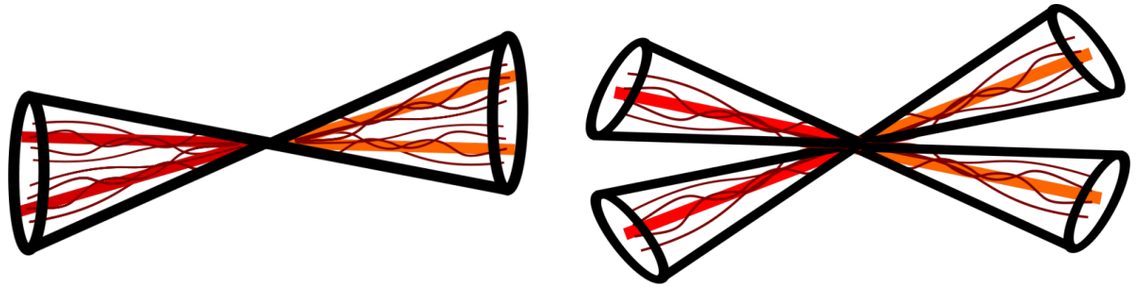
- We'll look at the searches considering baryon number violation that will lead multi quark final states

RPV stop

- Model on pair produced stop decaying via λ''_{312} and λ''_{323}

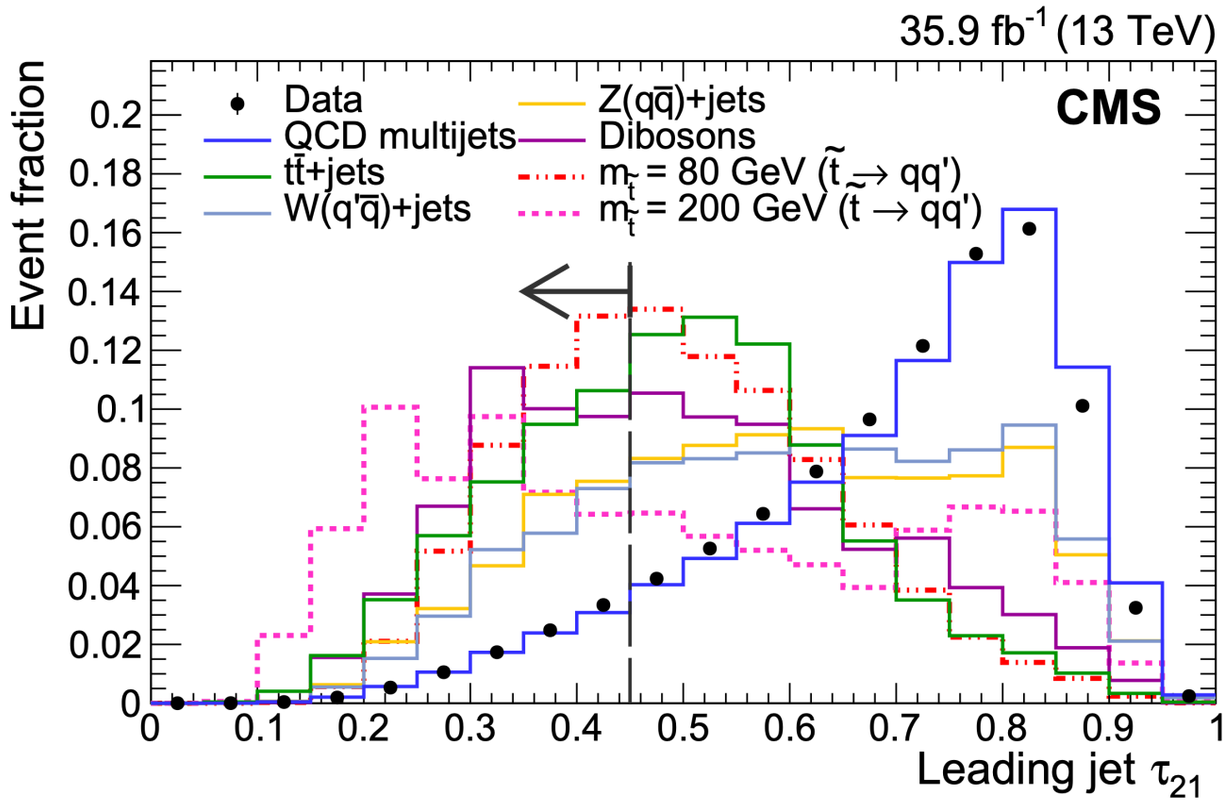
- Search was performed in two mass regions:
  - Boosted : Two merged AK8 jet events
  - Resolved : paired AK4 dijets in four jet events





- Looks for excess (bump) on average boosted AK8 dijet mass spectrum and paired AK4 dijet mass, in **qq** and **bq** final states

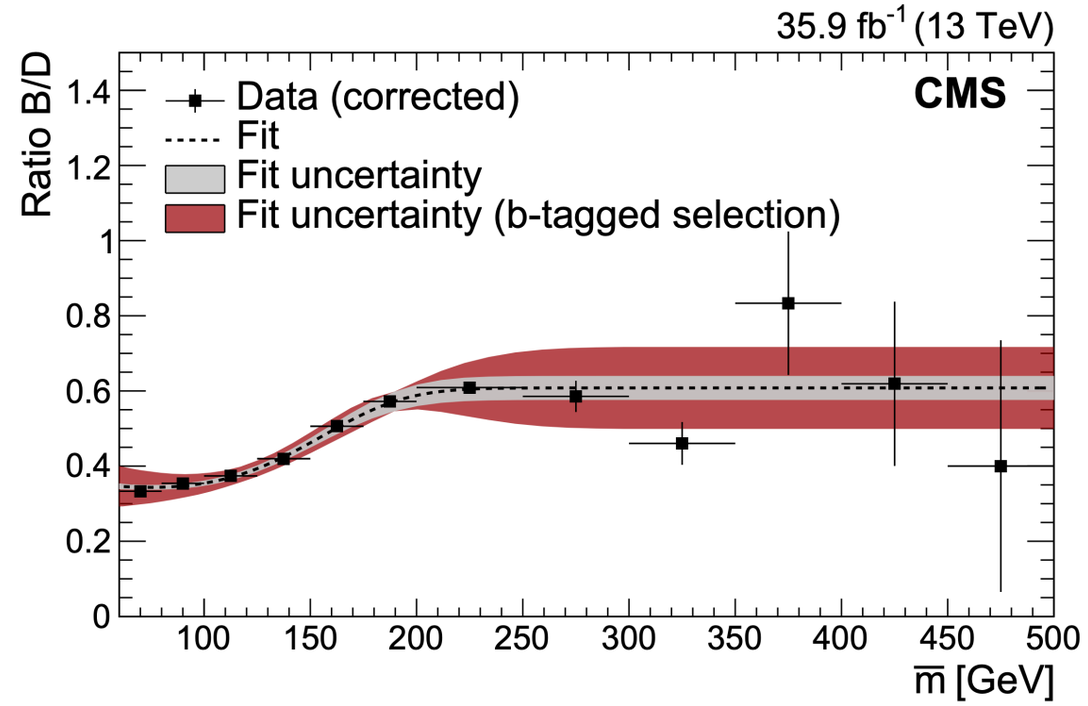
- Used substructure (tau variabels) and grooming (Pruning) to access low mass dijet spectrum

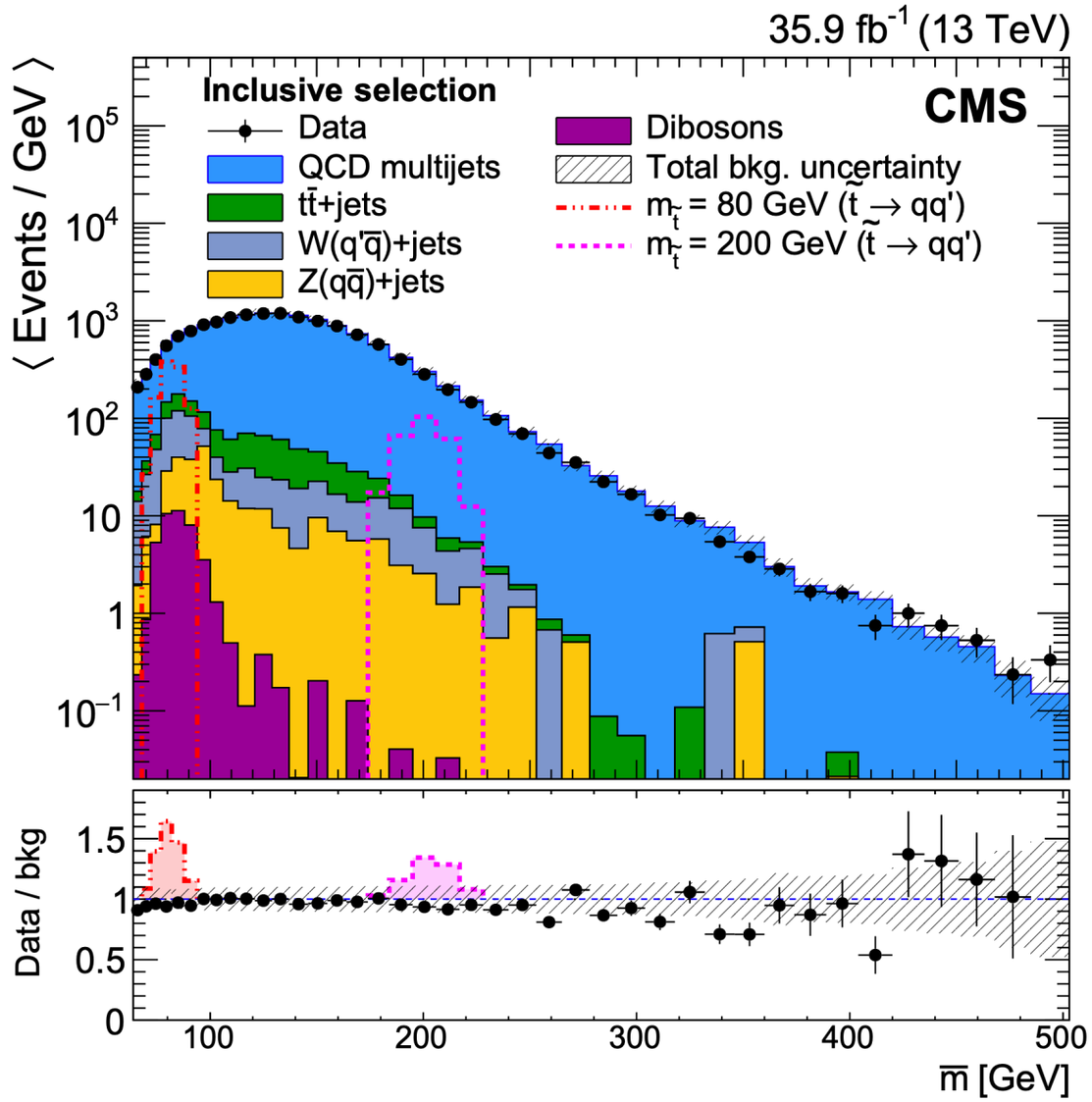


RPV stop :

- <u>Selection:</u>
  - Hadronic and substructure triggers: HT>900
  - Require two AK8 jets with
    - Pt > 150 GeV, $|\eta| < 2.5$, $M_{asym} < 0.1$, $|\Delta\eta| < 1.5$ $\tau_{21} < 0.45$, $\tau_{32} > 0.57$

- <u>Background estimation:</u>
  - Dominant background i.e, QCD is estimated with using data-driven ABCD method
  - ABCD regions are chosen in the space of M_{asym} and $\Delta\eta$
  - Subdominant backgrounds (ttbar, W/Z+jets) is estimated using MC
  - All the backgrounds are validated in CR



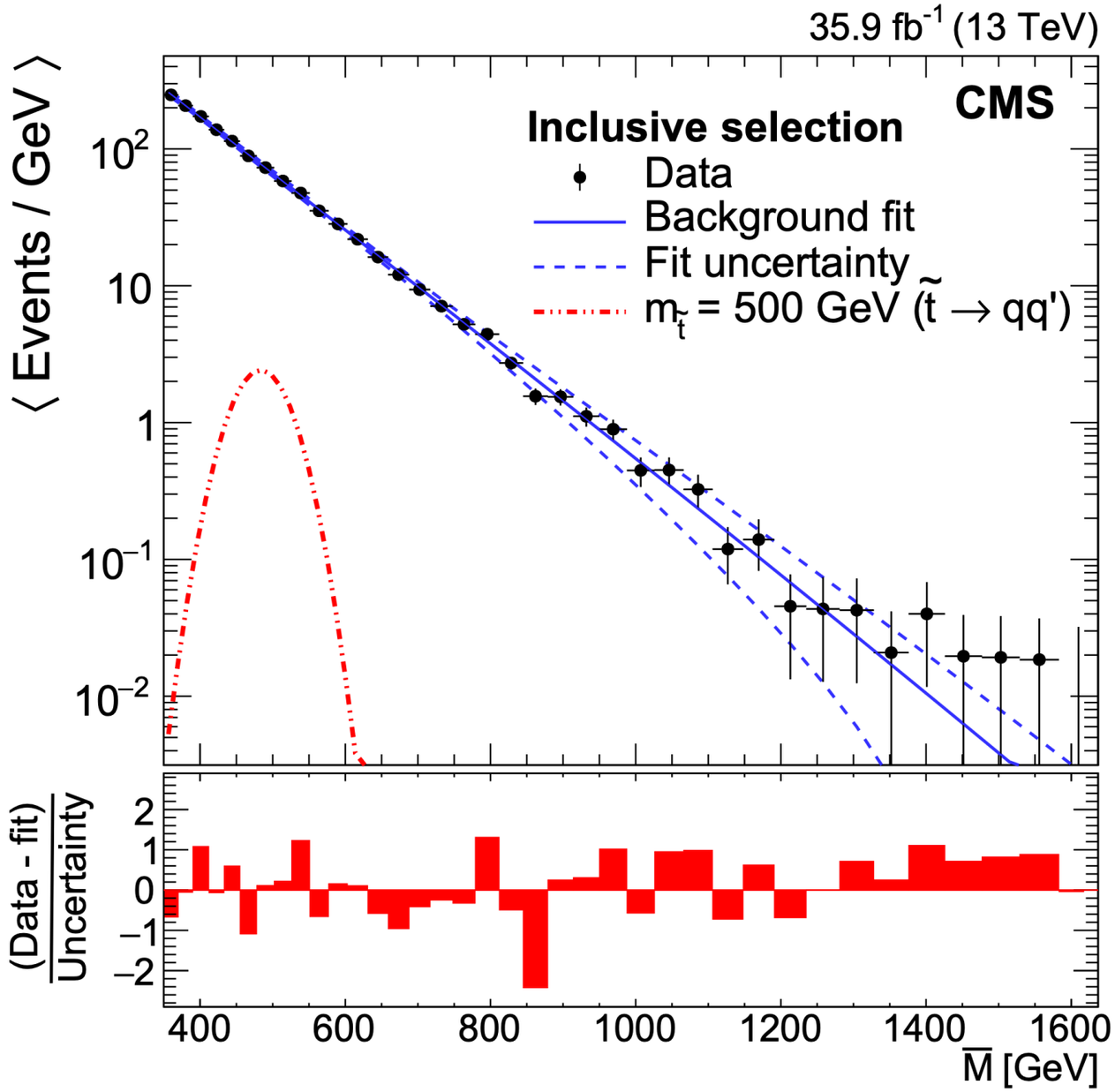


RPV stop :

- <u>Selection:</u>
  - Hadronic triggers: HT>900
  - Require four AK4 jets with
    - Pt > 80 GeV, $|\eta| < 2.5$, $M_{asym} < 0.1$, $\Delta\eta_{dijet} < 1.5$, $\Delta > 200$ GeV

- <u>Background estimation:</u>
  - Dominant background i.e, QCD is estimated by fitting smooth three parameter function to data

$$\frac{dN}{d\bar{M}} = \frac{p_0(1-x)^{p_1}}{x^{p2}}$$

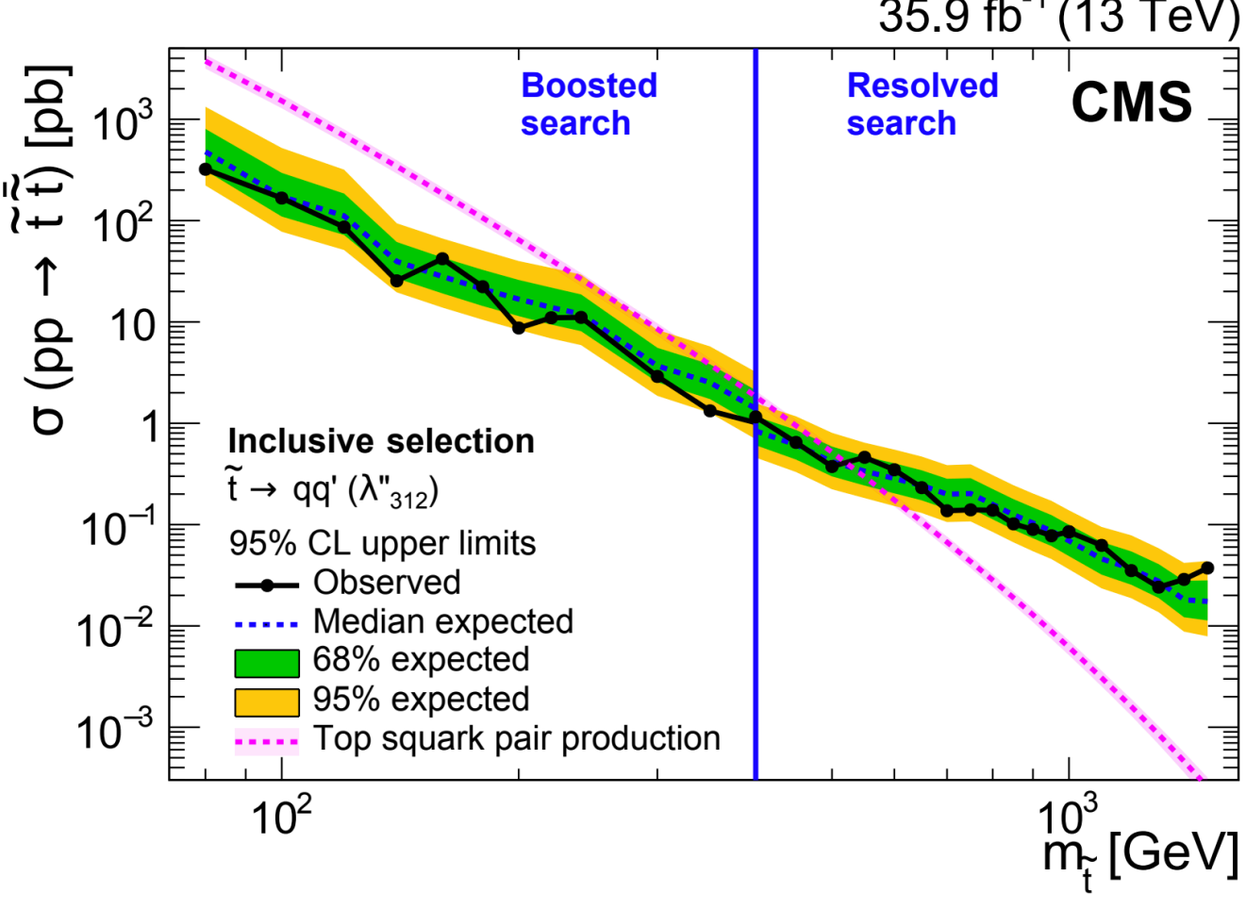


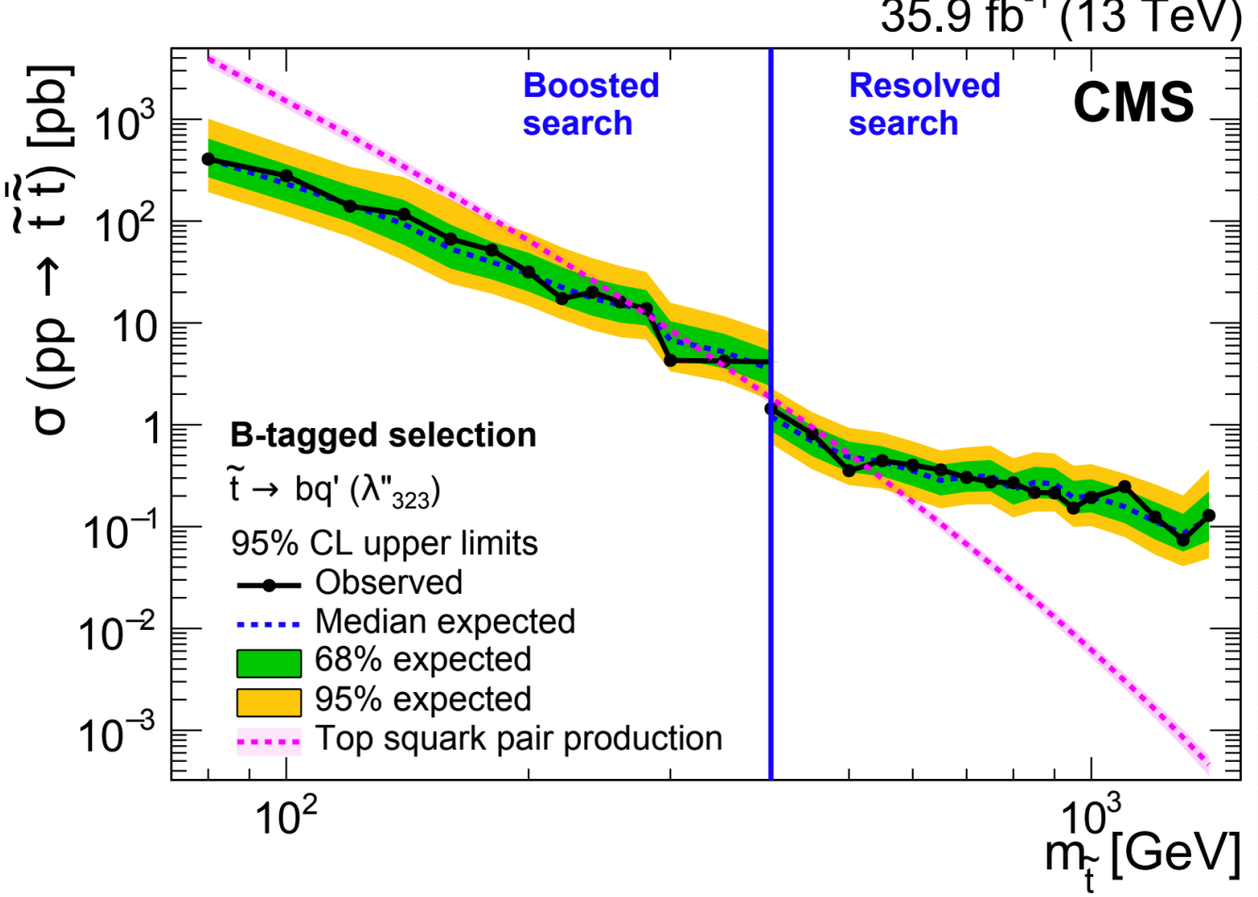
RPV Stop: results

- No excess found in average boosted AK8 dijet mass spectrum and paired AK4 dijet mass, in **qq** and **bq** final states

- Results interpreted in the context of pair production hadronic RPV stops.

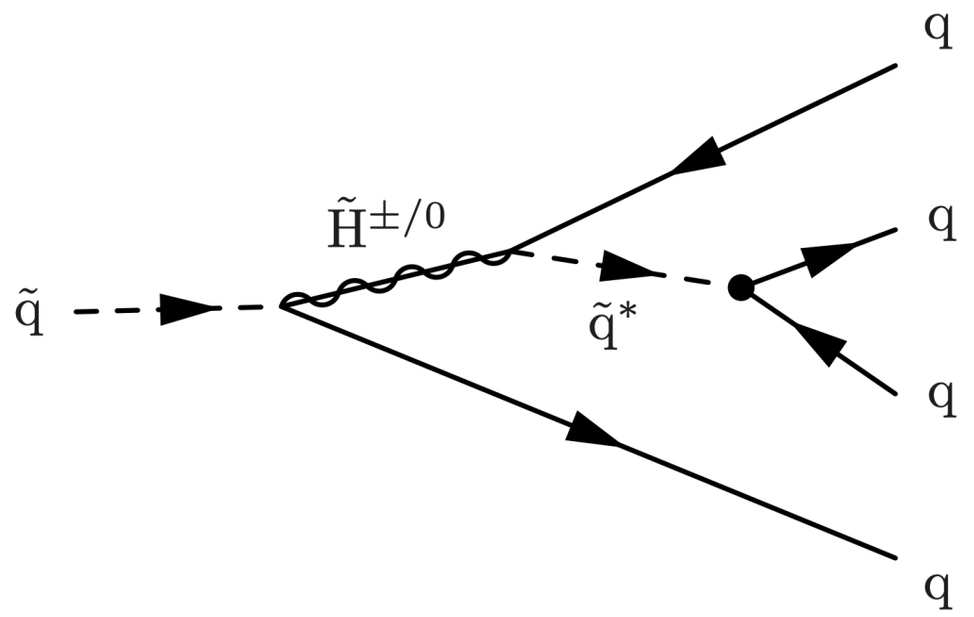
  - Limits set from 80 ≥ $m_{\tilde{t}}$ ≥ 520 GeV for inclusive search, and 80 ≥ $m_{\tilde{t}}$ ≥ 525 GeV(except for 270 ≥ $m_{\tilde{t}}$ ≥ 340 GeV and 340 ≥ $m_{\tilde{t}}$ ≥ 400 GeV) for b-tagged search.

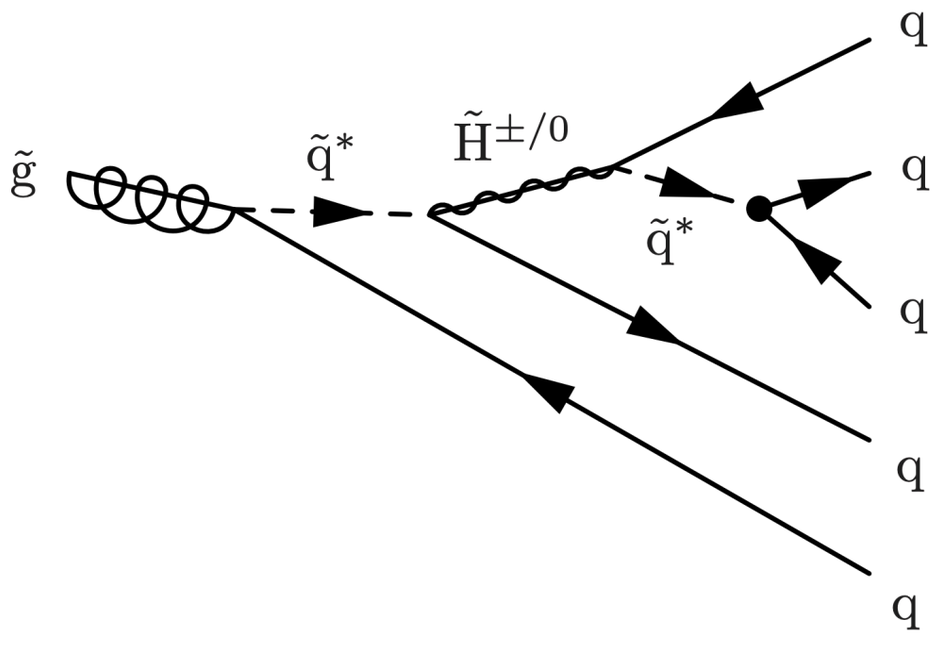




RPV squark

- Search for pair produced resonance decaying into at least four quarks
- Unexplored region of the SUSY model space until recently
- Uses fat jets to look for resonances decaying to multiple quarks
- Looks for resonance in CA12 dijet mass
- Uses N-subjetiness variables and pruning to suppress QCD and access low mass regions



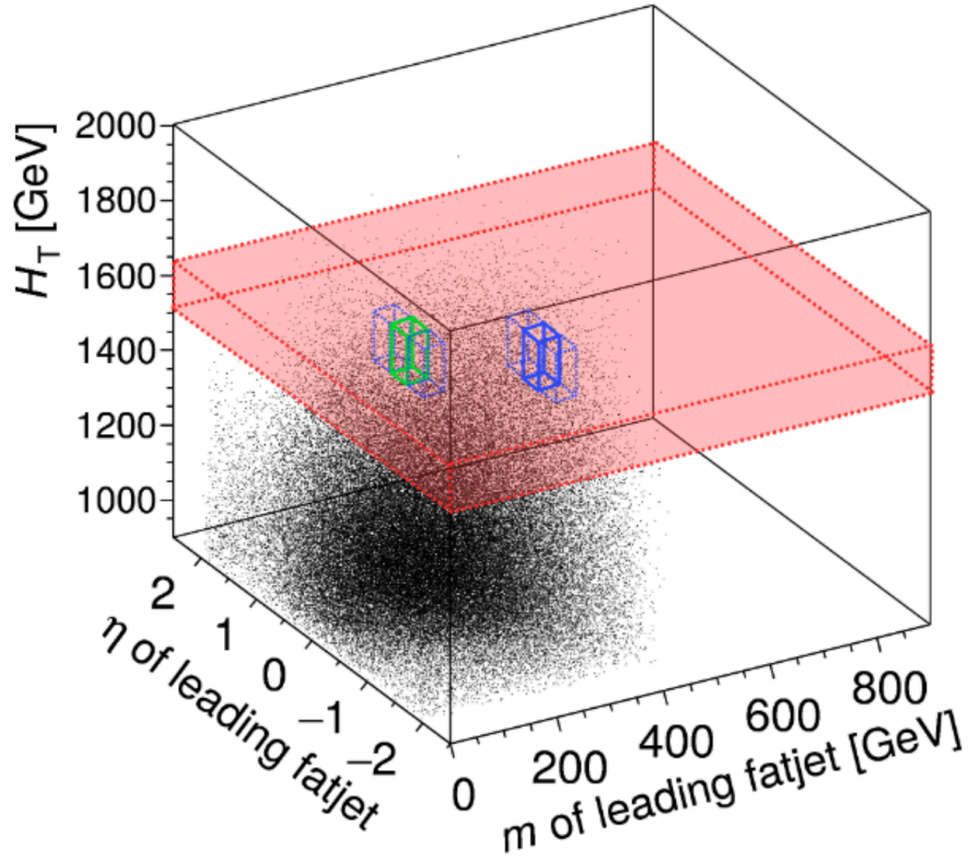


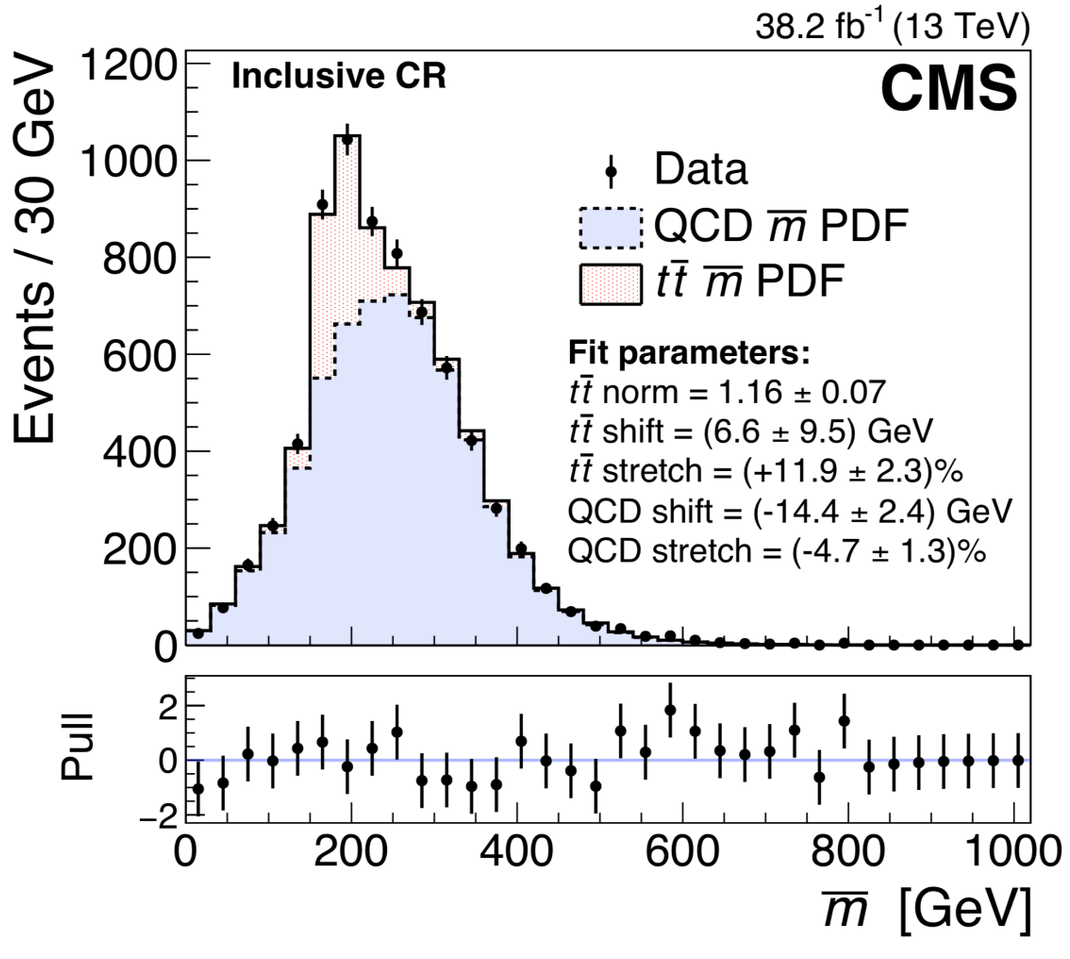
RPV squark

- <u>Selection:</u>
  - Hadronic and substructure triggers: HT>900
  - Require two CA12 jets with
    - Pt > 400 GeV, $|\eta| < 2$, $M_{asym} < 0.1$, $|\Delta\eta| < 1$

      $\tau_{21} < 0.75$, $\tau_{42} > 0.50$, $\tau_{43} < 0.80$

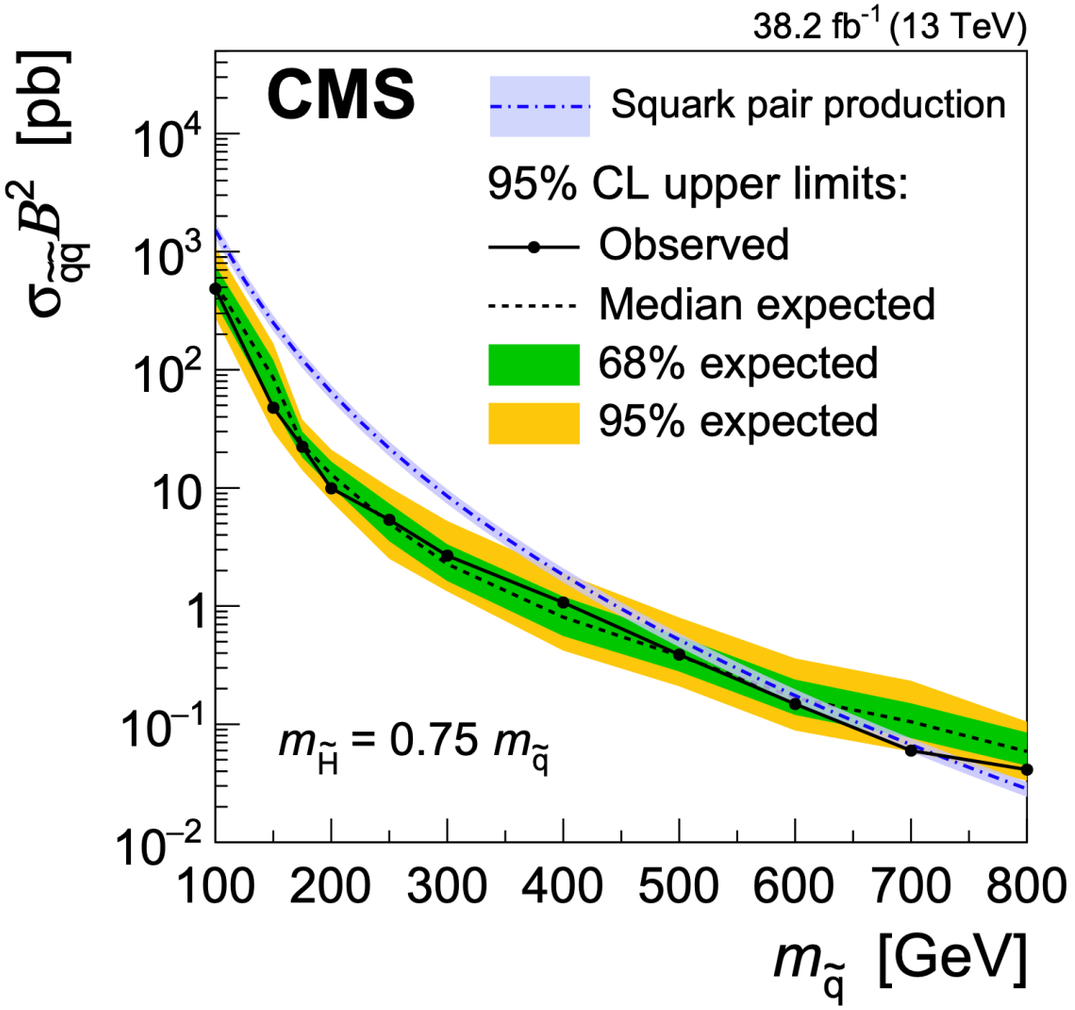
- <u>Background estimation:</u>
  - Dominant background i.e, QCD is estimated with using a new data-driven method:
  - Treat the leading fatjet mass distribution as a probability distribution P(m) from which two tagged fatjets are sampled.
  - Use this to calculate $p_{avg}(\bar{m})$. There by getting the QCD bkg template.
  - All the backgrounds are validated in CR

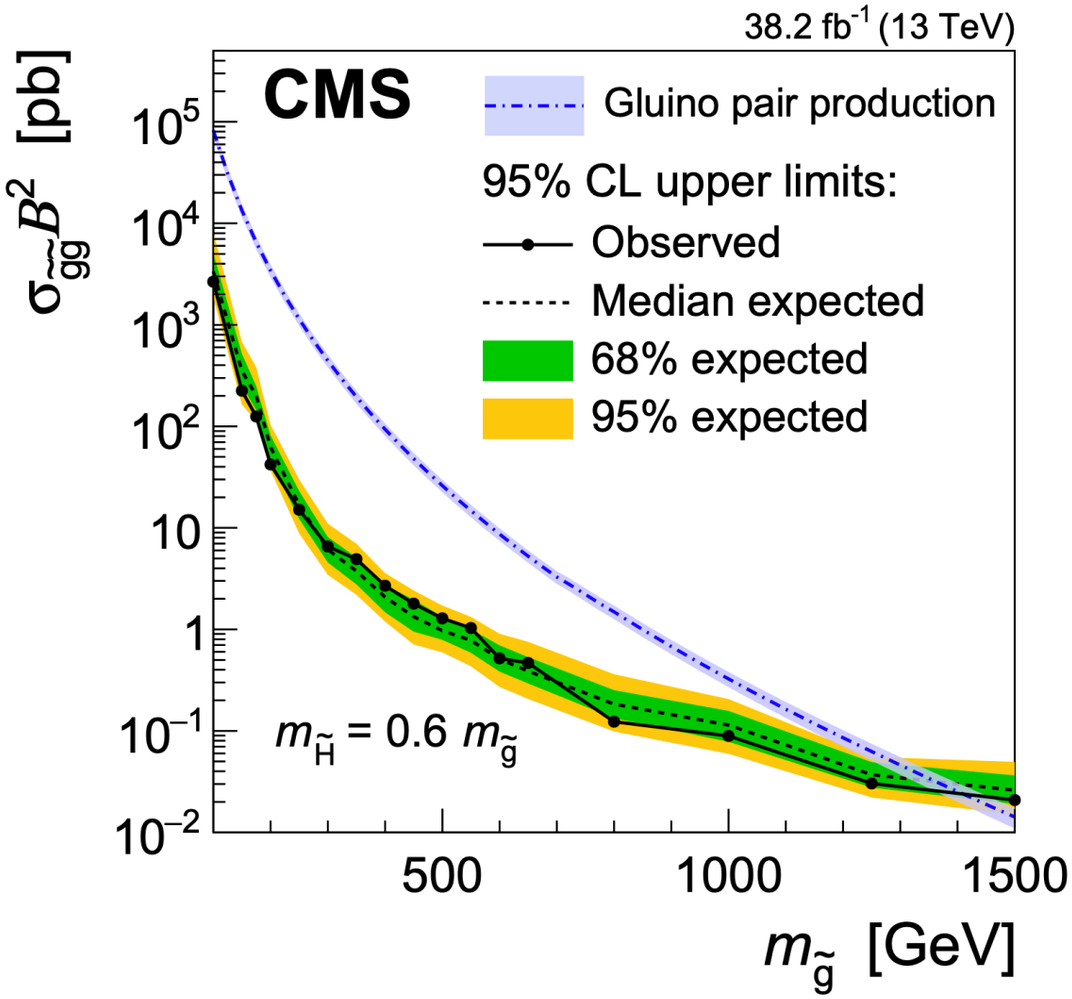




RPV squark

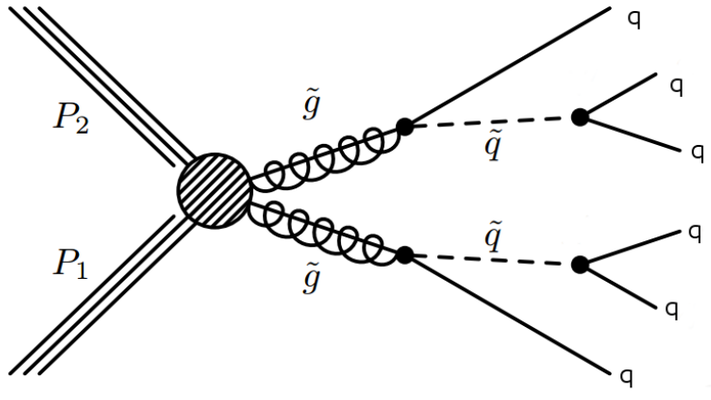
- No excess found in average CA12 dijet mass spectrum
- Results interpreted in the context of pair production hadronic RPV stops decaying to 4 quarks and RPV gluinos decaying to 5 quarks.
  - Limits set from 100 ≥ $m_{\tilde{t}}$ ≥ 700 GeV for RPV stops, and 100 ≥ $m_{\tilde{g}}$ ≥ 1410 GeV for RPV gluinos

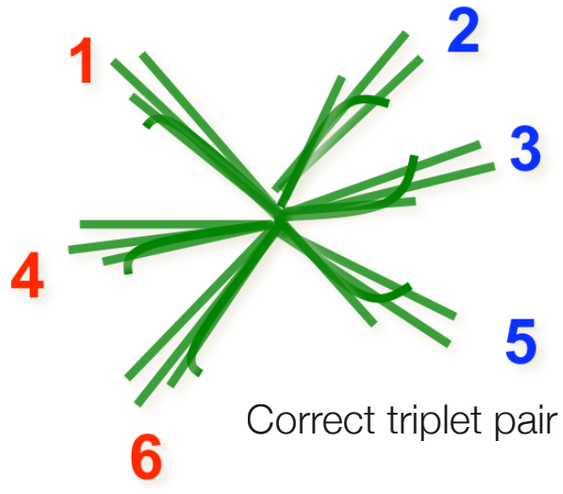




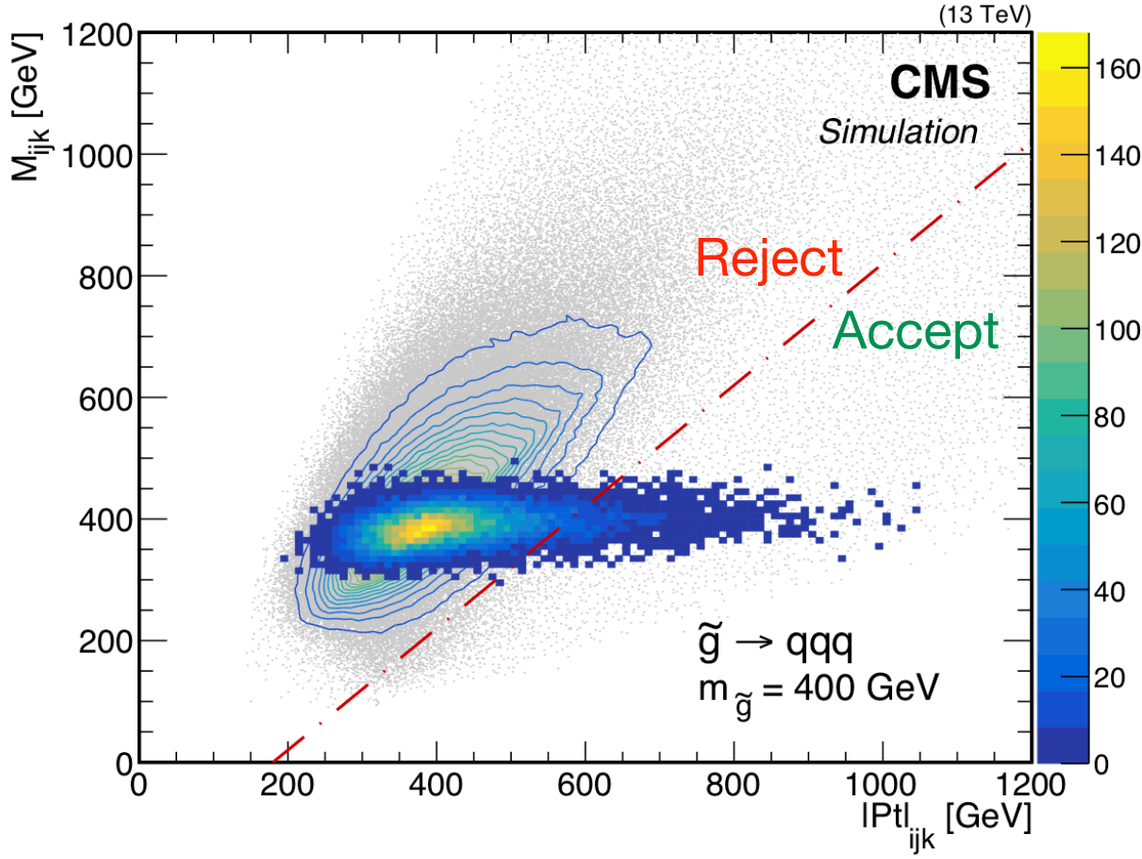
RPV Gluino

- Search for pair produced three-jet resonances.
- Modeled on RPV gluino decaying to 3 quarks with intermediate off-shell quarks.
- Employed jet-ensemble technique: Looks for all possible three jet combinations (triplet) and resulting triplet pair combinations.
- Looked for excess (bump) in triplet mass spectrum.
- Uses data scouting techniques and new background functions to cover wide mass rages
- First analysis to use Particle-Flow (PF) Scouting.
- Implemented novel techniques such as MDS and selection algorithm to gain higher sensitivity.





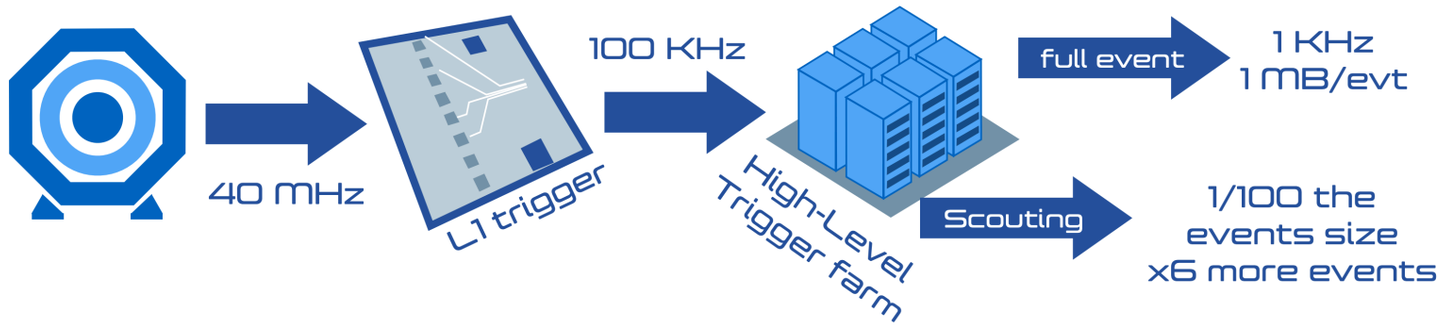
Correct triplet pair : 146 , 235

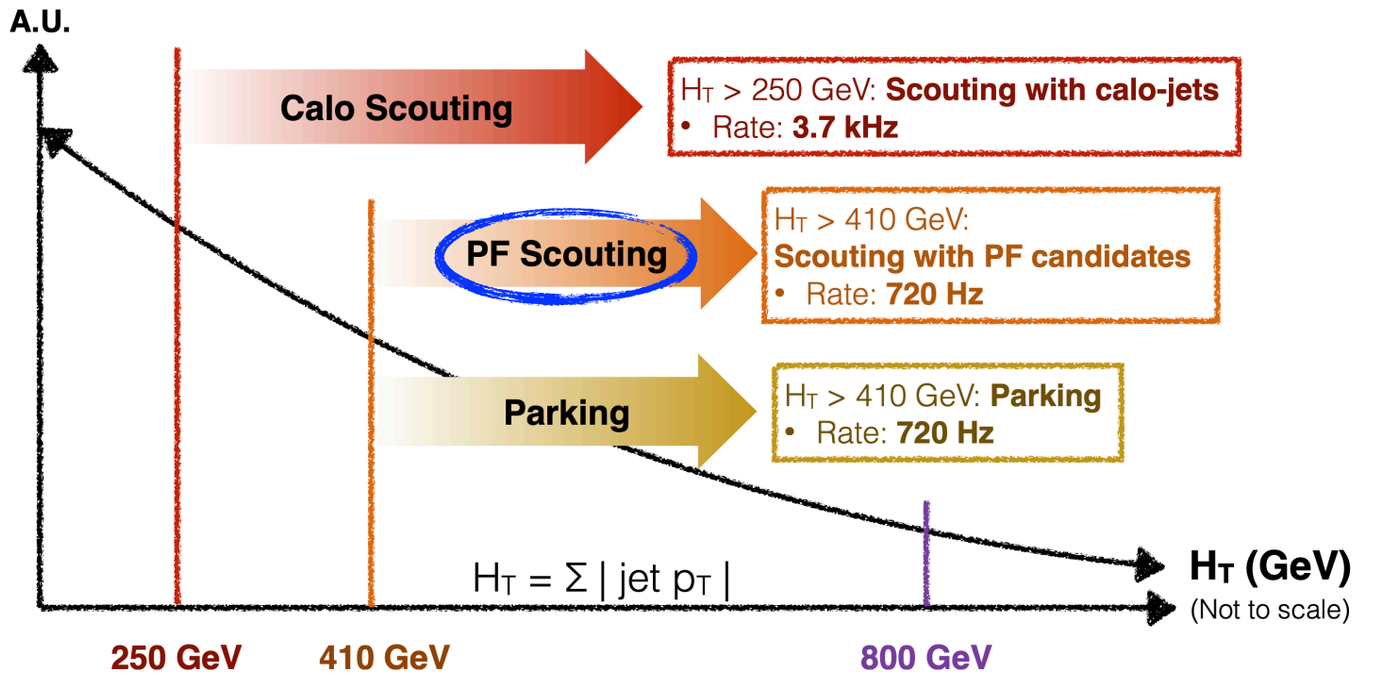


Δ Selection; Pt_{ijk}-$M_{ijk} > \Delta$

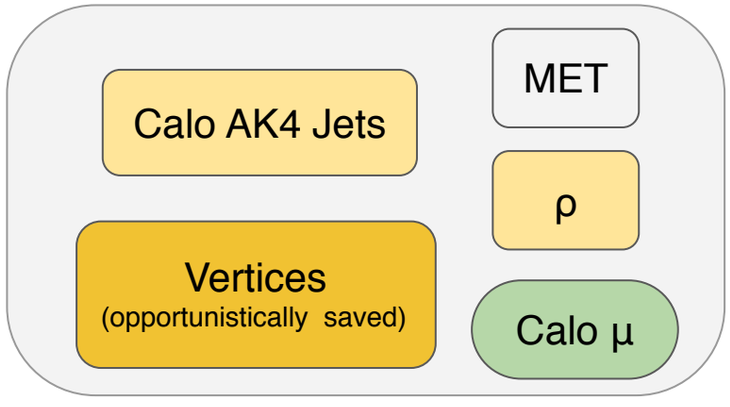
Data Scouting

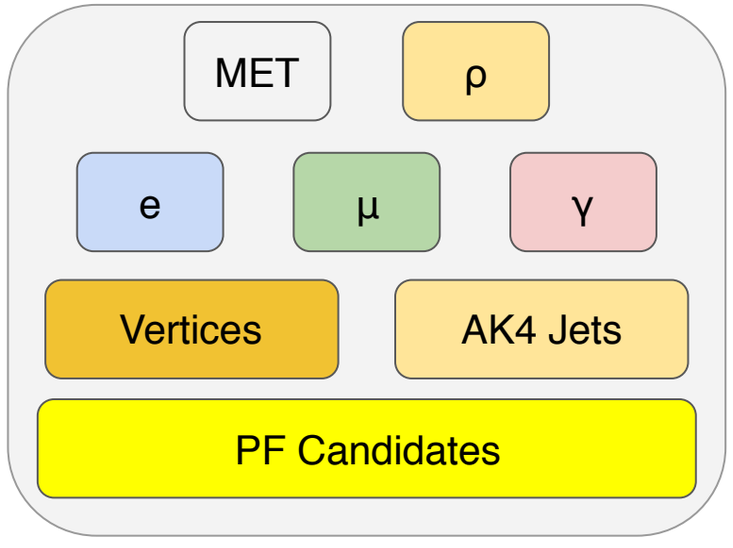
- Triggering is constrained by the CPU time and memory bandwidth available
- CMS records ~ 1kHz of events for physics analysis
- Forces triggers to have high thresholds, making CMS blind to physics at low masses
- Solution : Data Scouting
  - Make physics objets, online at HLT
  - Store only the required information:
    - Four vectors, etc . . .
  - Reduces event sizes (100x smaller)
  - Results in lower triggering thresholds





Lowest unprescaled HT trigger





Dalitz variables & Mass Distance squared

- Used to extract rich internal dynamics of a triplet and target certain decay topologies

- For a triplet, define dimensionless Dalitz variables as :

$$\hat{m}(3,2)^2_{ij} = \frac{m^2_{ij}}{m^2_{ijk} + m^2_i + m^2_j + m^2_k} \qquad (\text{i,j,k} \in \text{Jets } 1,2,3)$$

- Plotting the resulting three Dalitz variables gives information about internal dynamics of the triplet

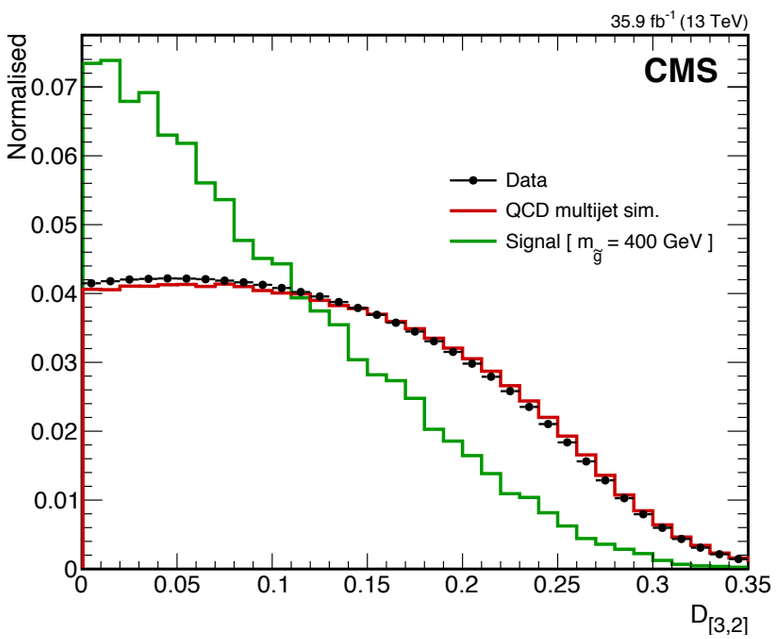
- Use this information to define a distance measure, Mass Distance Squared:

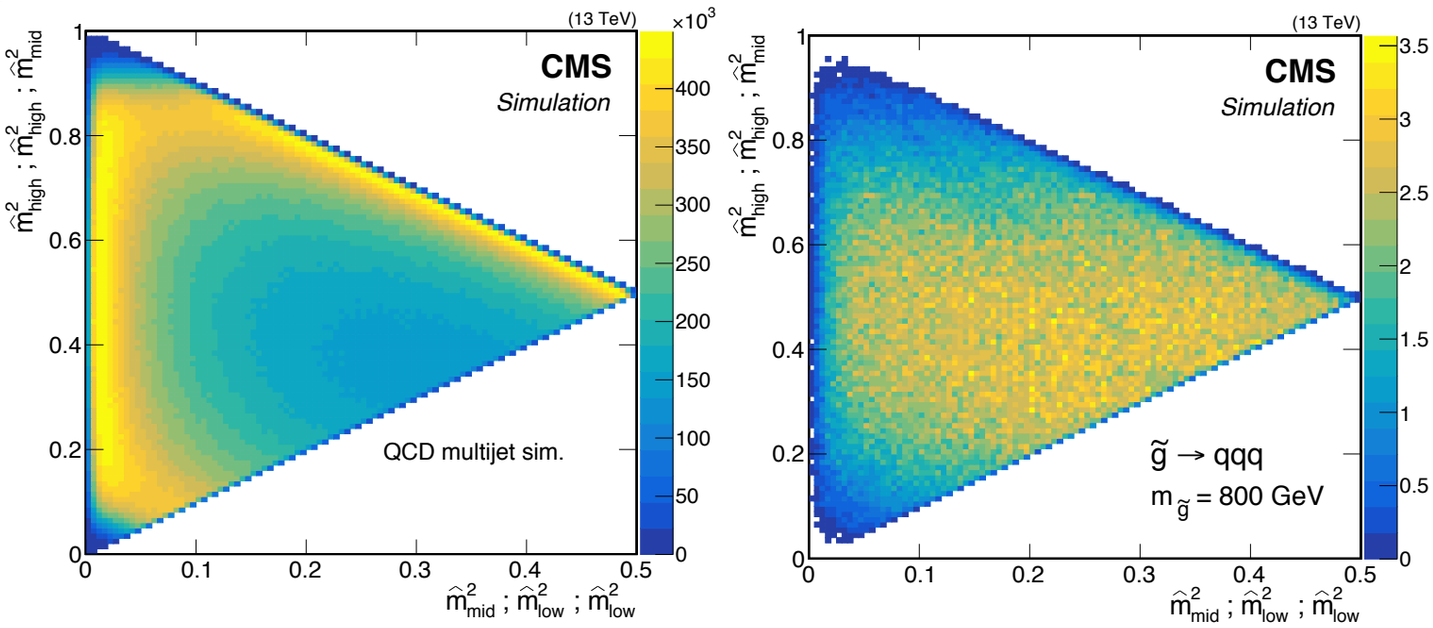
$$D^2_{[3,2]} = \sum_{i>j} \left(\hat{m}_{ij} - \frac{1}{\sqrt{3}} \right)^2$$

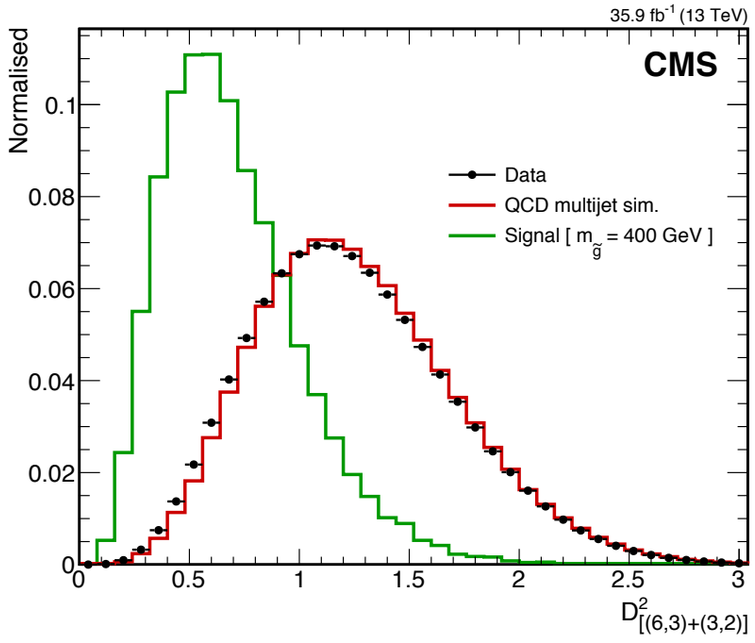
- Suppresses background, makes QCD turn at lower masses

- Extended this formalism to event-level, to target signal topologies

$$D^2_{[(6,3)+(3,2)]} = \sum_{i<j<k} \left(\sqrt{\hat{m}(6,3)^2_{ijk} + D^2_{[3,2],ijk}} - \frac{1}{\sqrt{20}} \right)^2$$

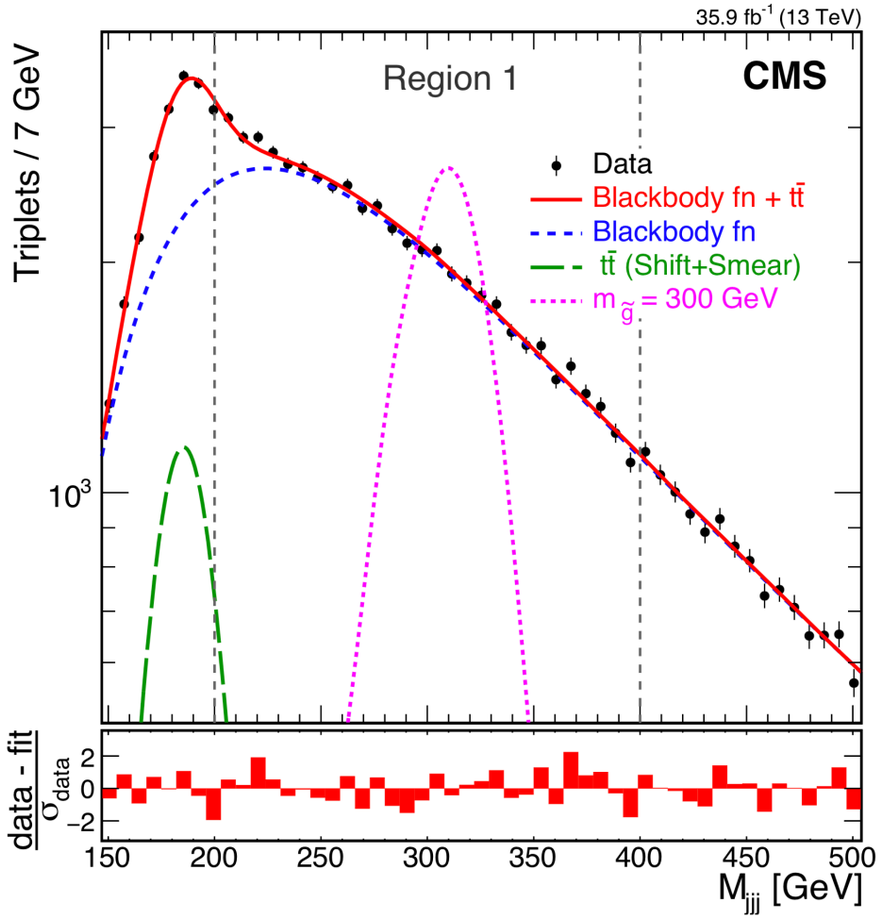






RPV Gluino

- Strategy:
  - Use a multi-level selection algorithm at event, pair and triplet level.
  - Split the search domain into four mass regions, optimized selection accordingly.
  - Triggers used : PF Scouting and Hadronic triggers
  - Use hadronic top peak to estimate corrections for PF scouting.

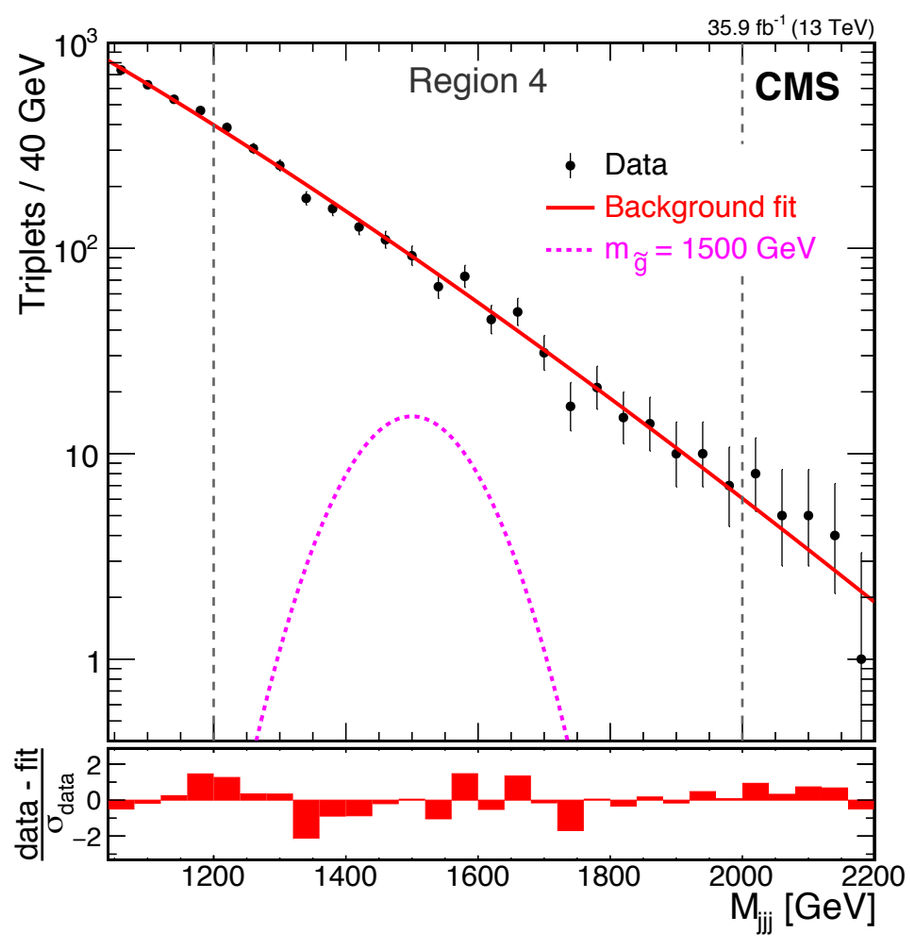


- Background estimation:
  - Dominant bkg: QCD
  - **New function inspired by Planck's law of blackbody radiation**, is used to model QCD turn on in Region 1

$$\frac{dN}{dx} = \frac{1}{(x+c)^{5+d\ln\frac{x}{\sqrt{s}}}} \frac{a}{e^{\frac{b}{x+c}} - 1}$$

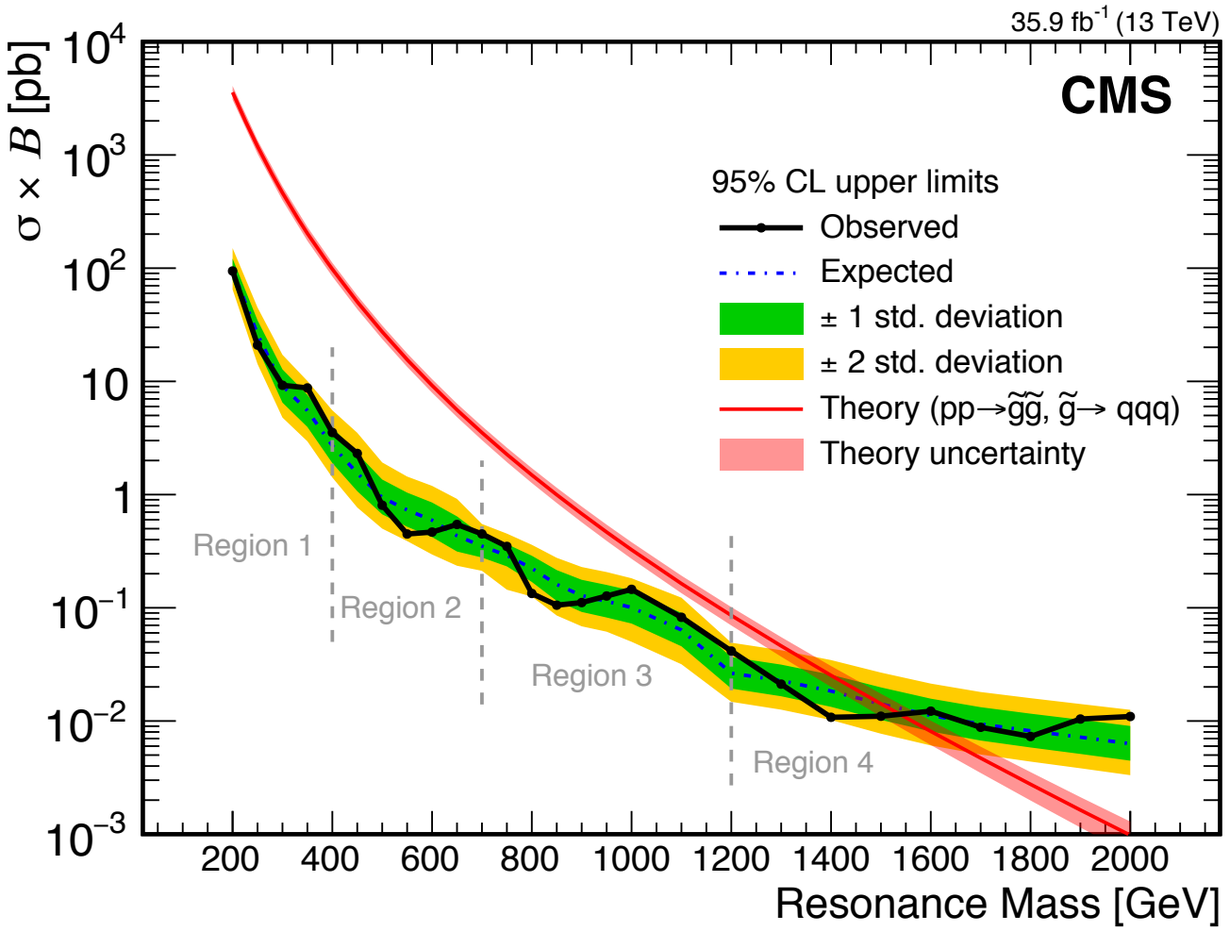
  - Four parameter function was used to model QCD in other three regions

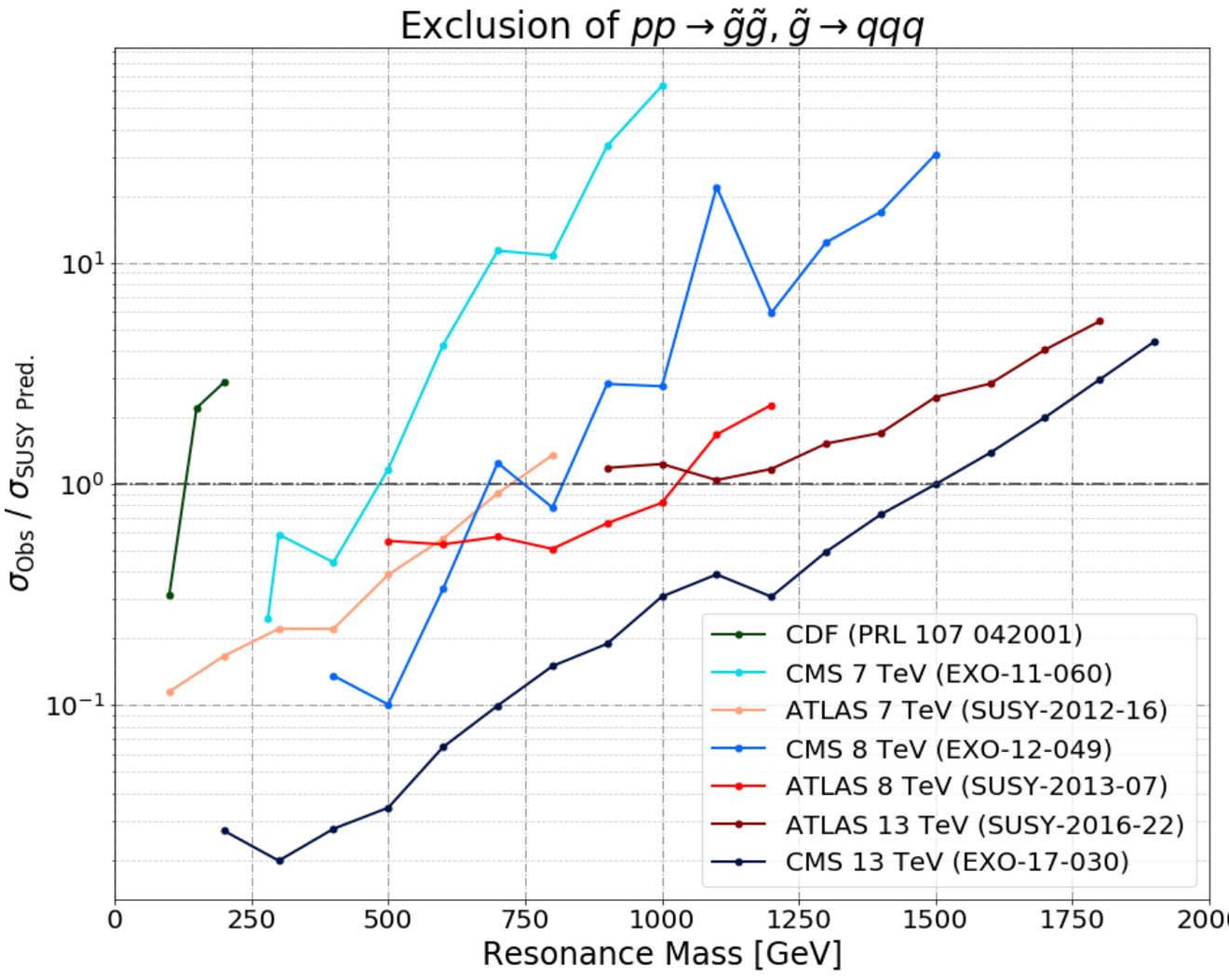
$$\frac{dN}{dx} = p_0 \frac{\left(1-\frac{x}{\sqrt{s}}\right)^{p_1}}{\left(\frac{x}{\sqrt{s}}\right)^{p_2+p_3\ln\frac{x}{\sqrt{s}}}}$$



RPV gluino

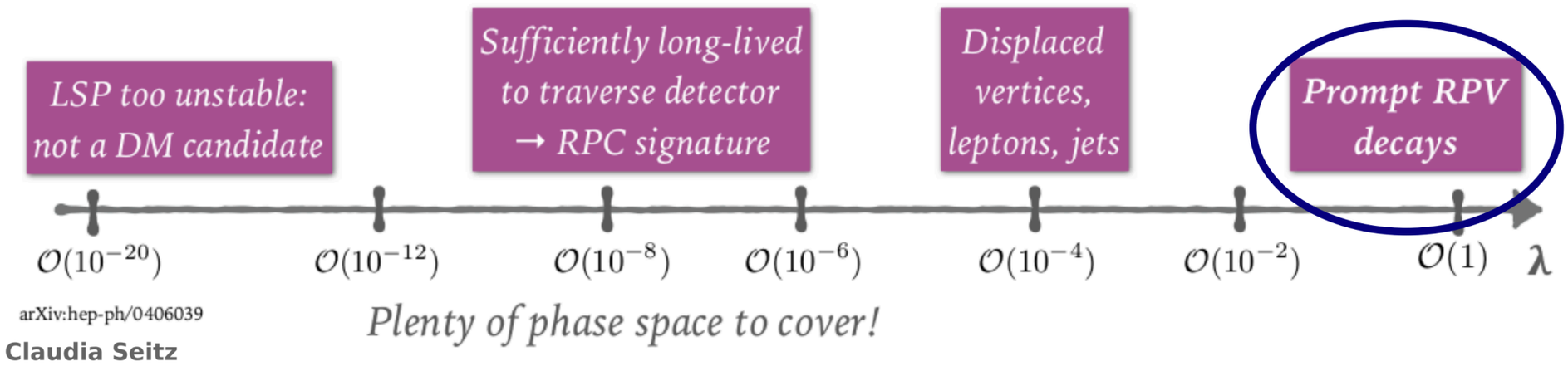
- No excess found in triplet mass spectrum
- Results interpreted in context of pair produced gluinos, excluding upto 1.5 TeV
- The limits set are the most stringent on this model, till date





Summay

- There no excess found in the data, in exotic searches to multi jet final states (Yet)
- Presented here cover some part of the multi-jet phase space, more are in works
- Work is in progress to obtain fat jets from PF Scouting and apply substructure techniques to search for even low masses
- New Exotic searches to multi-jet final States are in works !
  - Current on going work on singly produced three-jets resonances
- There still a lot of uncovered RPV phase space

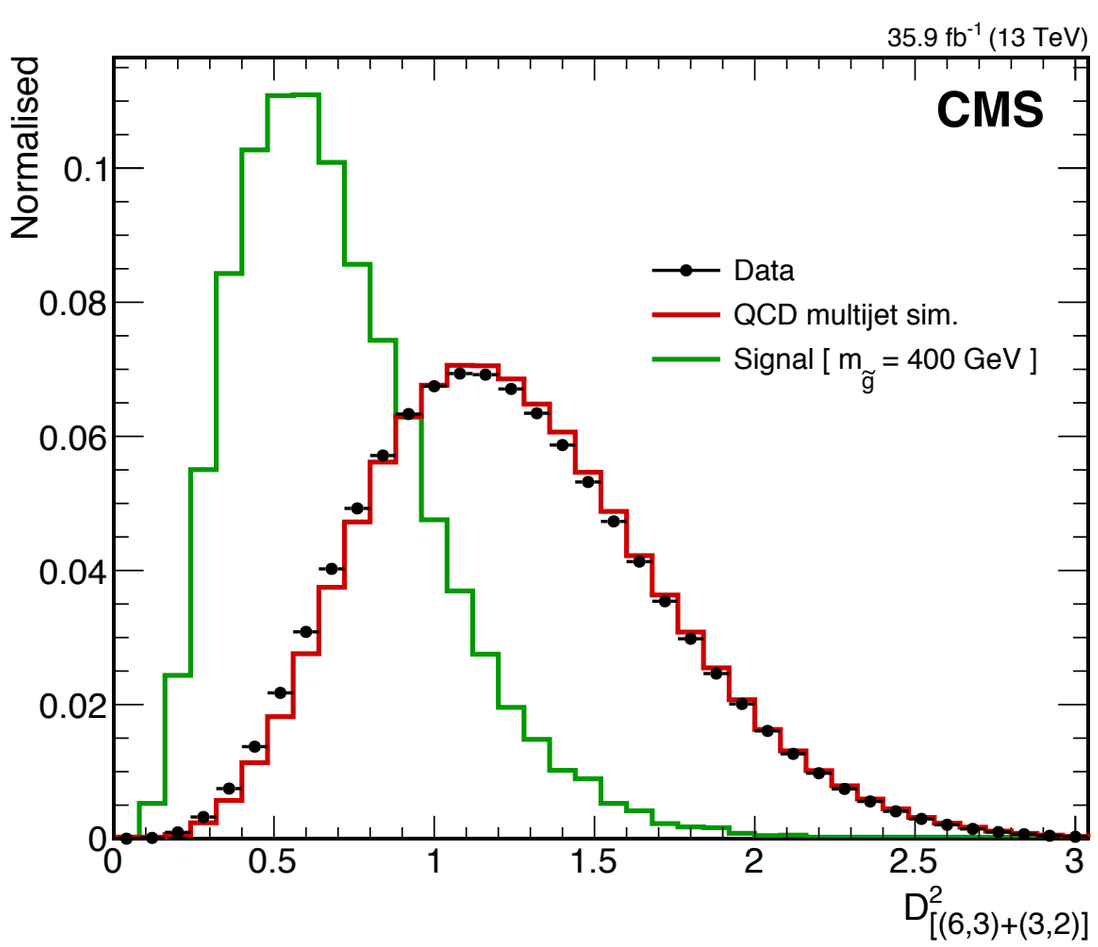


Back up

MDS: Event Level Variable.

- We take Idea of MDS in triplet and extend this to event level by taking 3-jet invariant Mass in 6-jet system.
- This variable measures the spread of jets (triplets) in a six jet ensemble
- Construct Normalized 3-jet Invariant mass $\hat{m}(6,3)^2_{ijk} = \frac{m^2_{ijk}}{4\ m^2_{ijklmn} + 6\ \sum_i m^2_i}$ where i…,n = {1,2,3,4,5,6} top 6 Pt Jets
- This information is combined with $D^2_{[3,2]}$ to create event level variable

$$D^2_{[(6,3)+(3,2)]} = \sum_{i<j<k} \left(\sqrt{\hat{m}(6,3)^2_{ijk} + D^2_{[3,2],ijk}} - \frac{1}{\sqrt{20}} \right)^2$$



RPV squark: Event-mixing background estimation

- Treat the leading fatjet mass distribution as a probability distribution P(m) from which two tagged fatjets are sampled.

- The probability to have a fatjet pair with a given average mass is the sum of the product of the probabilities for all mass combinations that result in that average mass (Satisfying $|\Delta\eta|$ and M_{asym} selection)

- The mass of a jet is correlated to its pT. In an event, the pT of one fatjet is correlated to the pT of the other, and both are correlated to the HT

- We correct for this effect by calculating $p_{avg}(\bar{m})$ from tagged fatjets in events with similar HT and then re-weighting each HT bin's contribution to the template

$$P_{\mathrm{avg}}(\overline{m}) = \int_0^{2\overline{m}} P(x) \cdot P(2\overline{m} - x) \cdot \theta\left(0.1 - \left|\frac{x - \overline{m}}{\overline{m}}\right|\right) dx$$

RPV gluino: Selection Algorithm

Pre-selection

P_T, H_T, >= 6 jets, $|\eta| < 2.4$

Event-level cuts

Top 6: 6th Jet PT, MDS Event level

Triplet-Pair cuts

Triplet-pair Mass Asymmetry (A_m)

$$\frac{|m_1 - m_2|}{m_1 + m_2}$$

1,2 = Triplets in pair

Triplet Cuts

MDS Triplet level and Delta

The final Mass plot may have multiple entries per event