Search for low-mass pair-produced dijet resonances at 13 TeV

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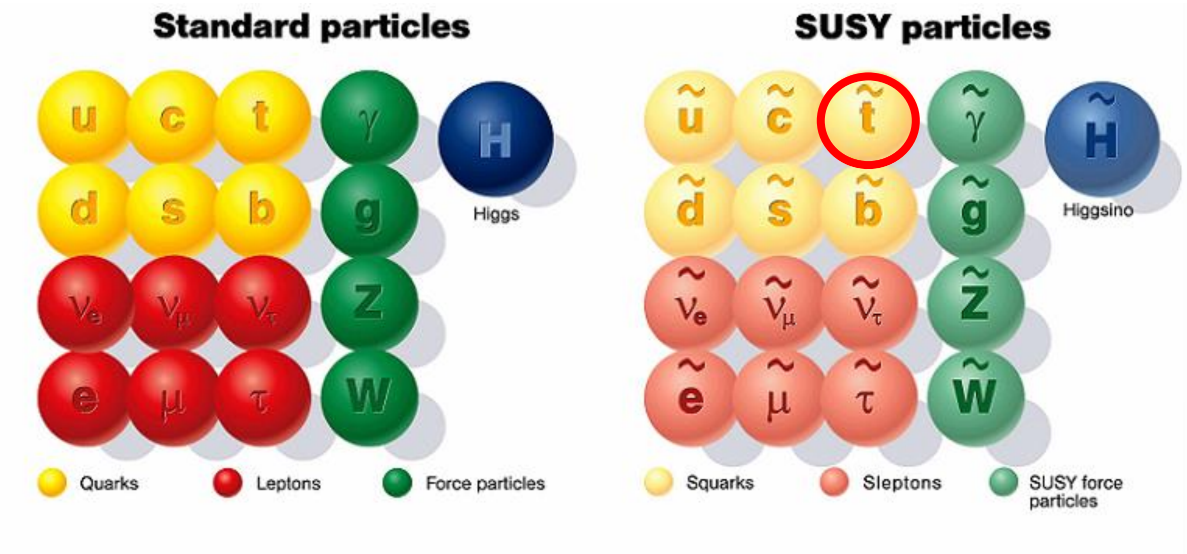
Outline

- Theory Model
- Physics Motivation
- Substructure Techniques
- Analysis Strategy
  - Trigger
  - Event Selection
  - Background Estimation
- Results
- Summary

Theory Model

Supersymmetry:

spin based symmetry relating fermions and bosons
Each particle has a “superpartner” – fermions have bosonic superpartners and vice versa

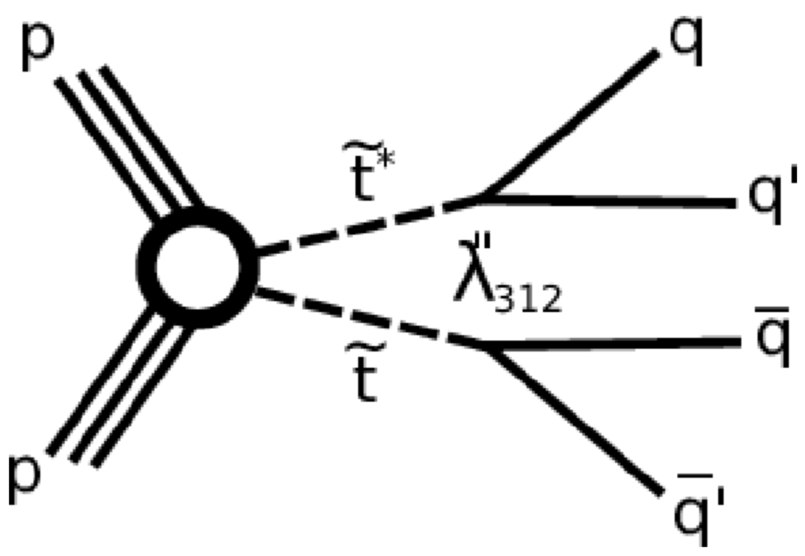


R-Parity Violation

R-parity $= (-1)^{3(B+L)+2s}$

R = 1(-1) for SM (SUSY) particles

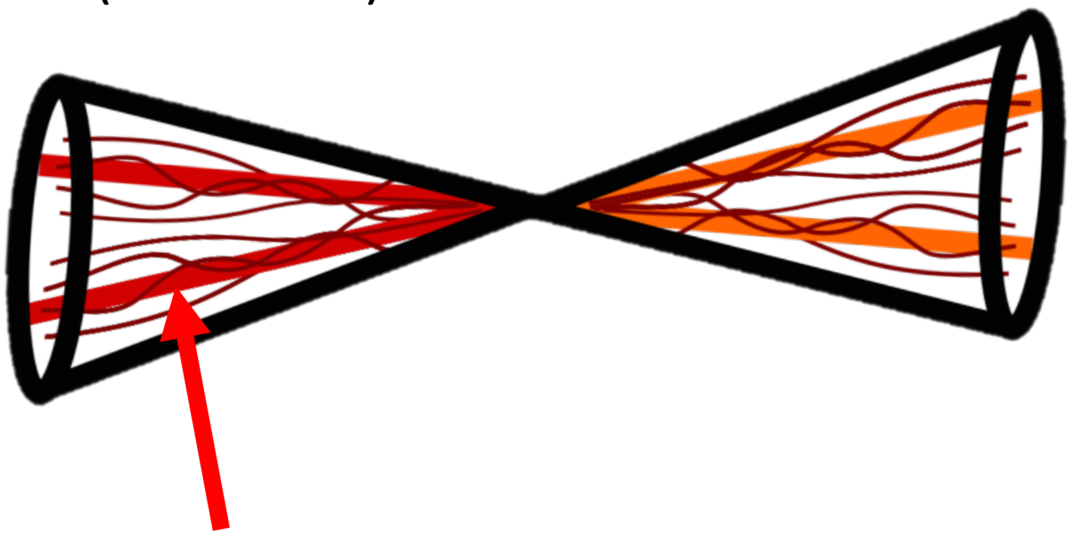
Physics Motivation



We perform a search for pair produced R-Parity violating (RPV) supersymmetric stop quarks decaying into two light quarks

Boosted topologies

The current LHC energy allows us to study this boosted signature and probe lower BSM particle masses (~100 GeV)



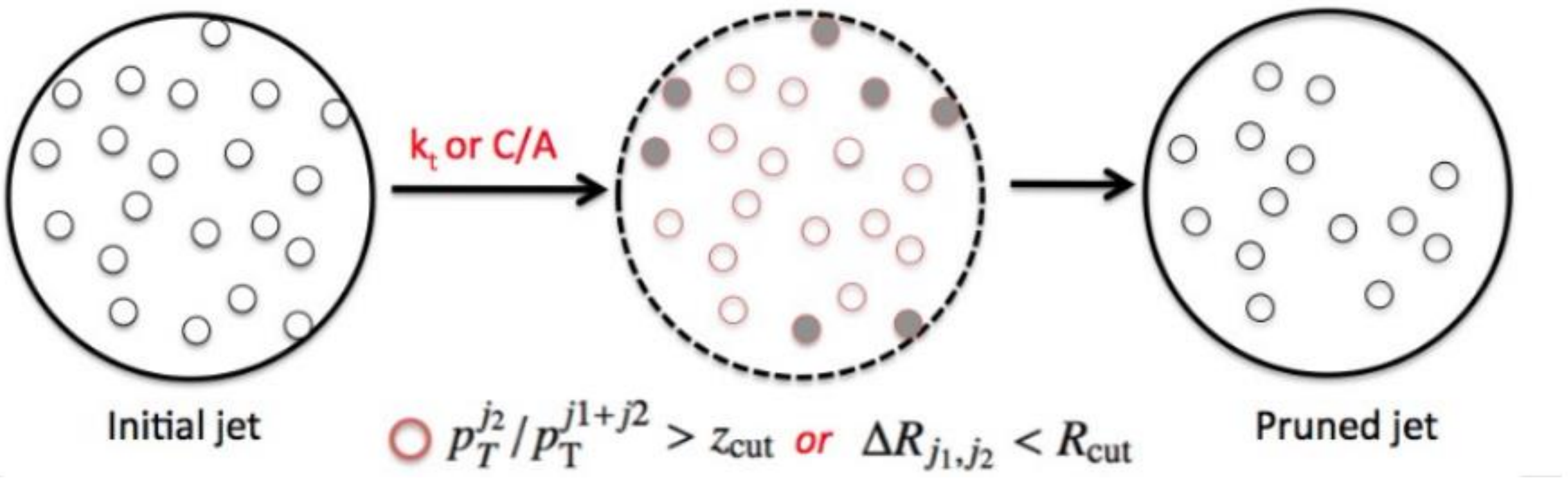
Use internal structure to reduce QCD (our main background) and other SM backgrounds (ttbar, wjets…) – 2 main techniques

Substructure Techniques

"Pruning" http://arxiv.org/abs/0912.0033
(S. Ellis, C. Vermilion, J. Walsh)

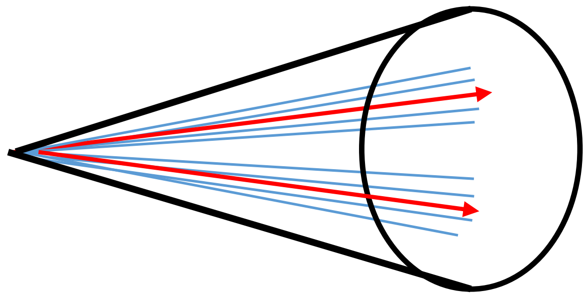
1. Recombine jet constituents
2. Remove wide angle and soft constituents

Note: Does not recreate subjets but prunes at each point in jet reconstruction



Substructure Techniques

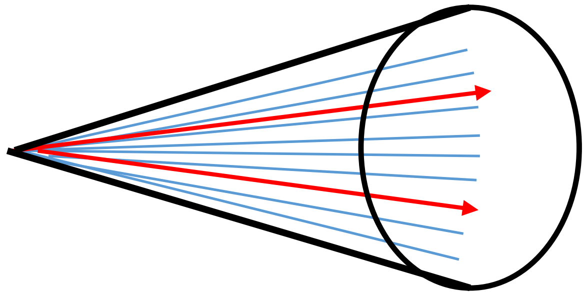
"N-subjetiness" http://arxiv.org/abs/1108.2701
(J. Thaler, K. Van Tilburg)



Low τ_2 (desired)
(constituents close to axes)

1. Creates N subjet axes within a jet
2. Measures how close each jet constituent is to the subjet axis

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \times \min(\Delta R_{1,k}, \ldots \Delta R_{N,k})$$



High τ_2
(constituents far from axes)

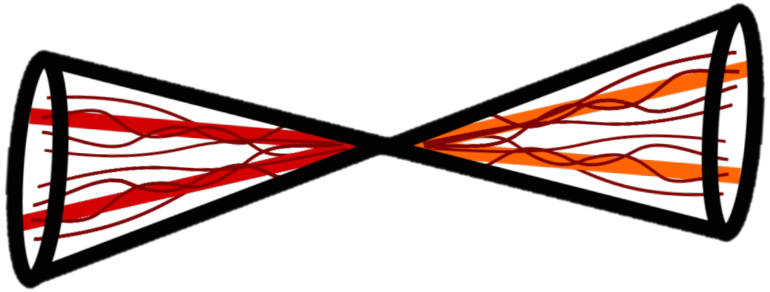
Designed to identify boosted hadronic objects.
(Low $\tau_{21} = \tau_2 / \tau_1$ means 2 subjets)

Analysis Strategy

- Search for 2 AK8 Jets with high pT and substructure
- Trigger: we developed a trigger for this search using the pT sum of AK8 jets (HT) and the pruned jet mass
- Estimate background contributions using a data driven method
  - > Use sidebands in the data to predict the background in the signal region
- Investigate the average mass spectrum and look for an excess/set limits

Variables

Variables Used



Mass Asymmetry: defined as $M_{asym} = \frac{|m_1 - m_2|}{m_1 + m_2}$

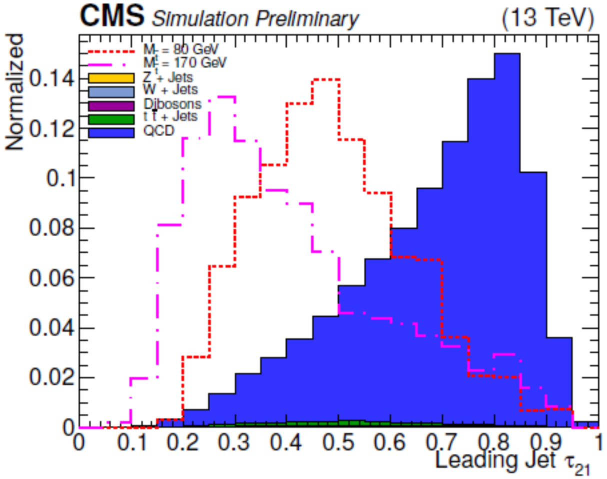
$| \eta_1 - \eta_2 |$: the absolute value of the difference in η between the two candidate jets

N-subjetiness: Because the ratio between N-subjetiness variables gives us better discrimination power, we considered $\tau_{21} = \tau_2 / \tau_1$

Event Selection

Variable	Selection
Number of AK8 Jets	2 Leading p_T Jets
Jet p_T	> 150 GeV
Jet $\|\eta\|$	< 2.4
H_T	> 900 GeV
M_{asym}	< 0.1
$\|\eta_1 - \eta_2\|$	< 1.5
1st and 2nd Jet τ_{21}	< 0.45

Each variable is plotted with all selection criteria apart from that on the variable being shown, normalized to unit area

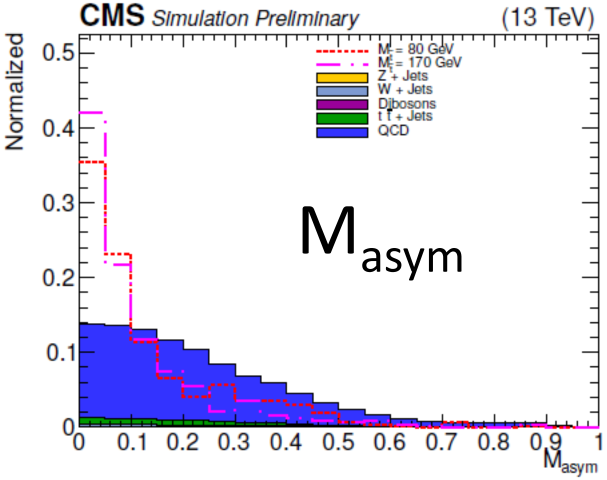


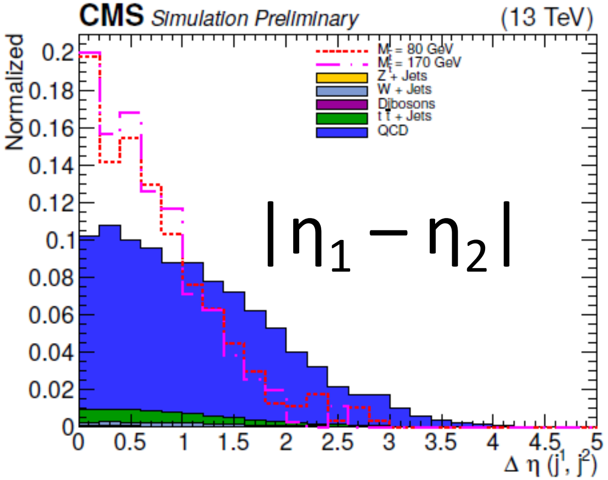
τ_{21}

Blue – QCD

Dashed Red – 80 GeV Signal

Dashed Pink – 170 GeV Signal



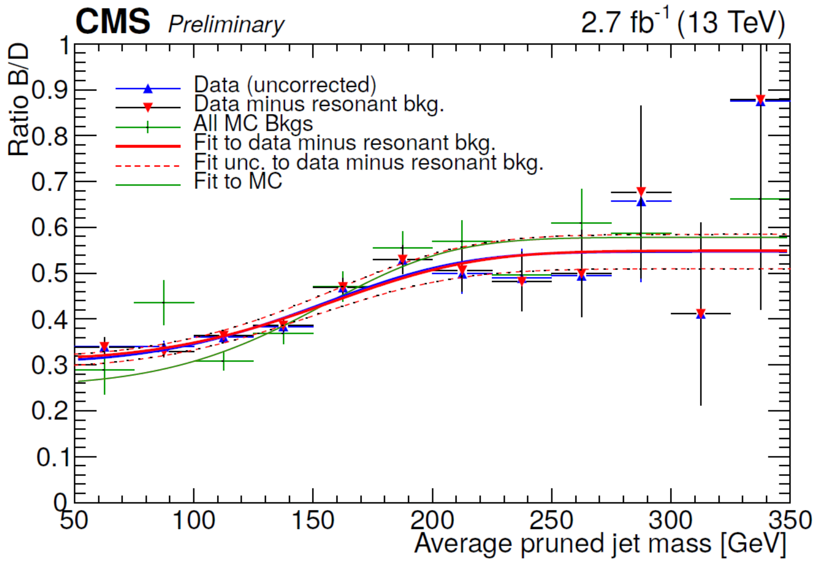


Background Estimation

Non-resonant backgrounds (QCD):

ABCD method (in $|\eta_1 - \eta_2|$ and mass asymmetry M_{asym}): use background enriched sidebands binned in mass to estimate the background in the signal region

Region B/Region D binned in average mass



Basic Idea:

$$B/D = A/C$$

$$\rightarrow A = C^*(B/D)$$

	$M_{asym} < 0.1$	$M_{asym} > 0.1$
$\lvert\eta_1 - \eta_2\rvert > 1.5$	Region B	Region D
$\lvert\eta_1 - \eta_2\rvert < 1.5$	**Region A**	Region C

We define the sidebands using mass asymmetry and $|\eta_1 - \eta_2|$ because of low correlation

Results (CMS PAS EXO-16-029)

Resonant backgrounds:

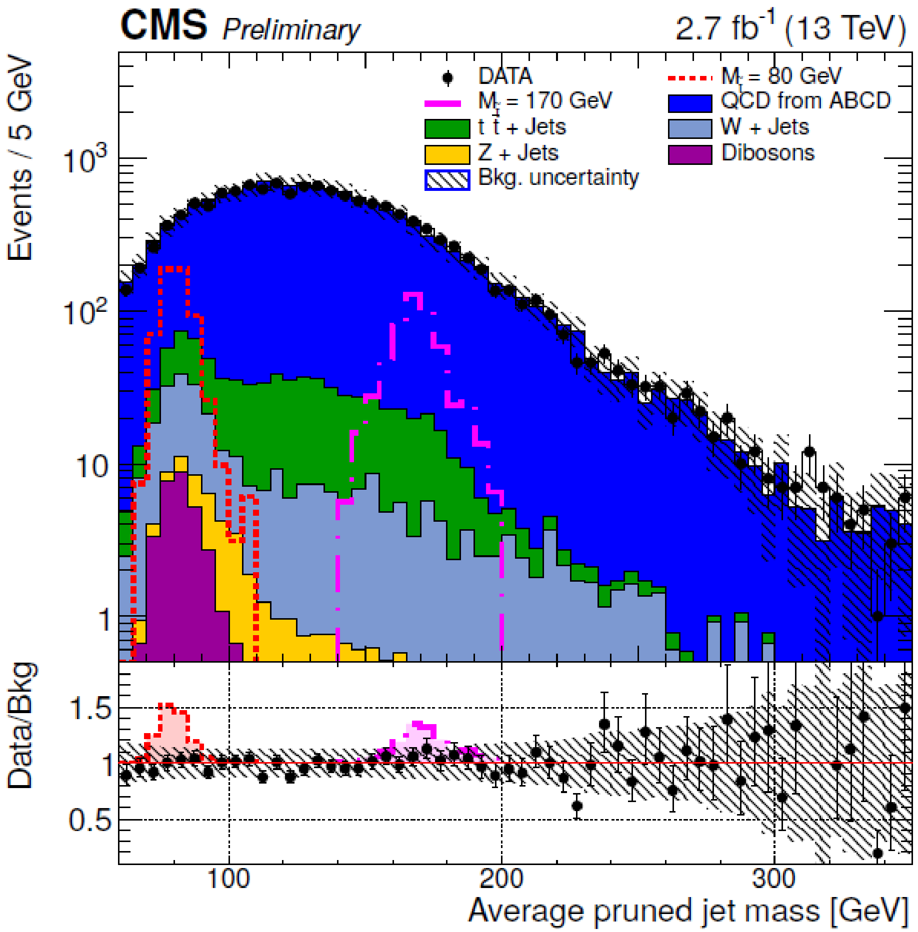
5% of total background: ttbar, Wjets, Zjets, dibosons.

Use MC samples, properly validated

The final background estimate is the sum of:

1. QCD multijets background measured in data via the ABCD method (previous slide)
2. The sub-dominant resonant backgrounds from MC

We take into account all the standard systematics on our background estimation and signal acceptance, more details are in the backup

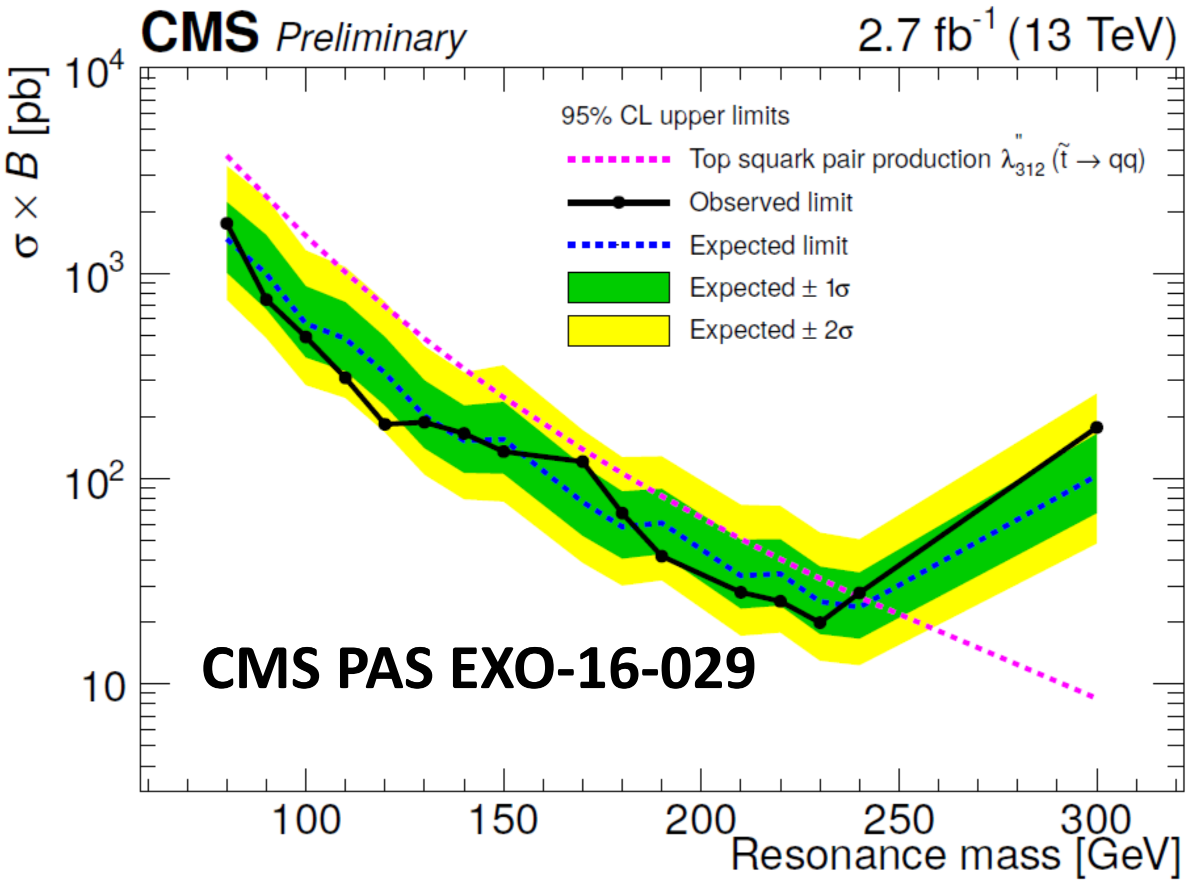


Note the 80 GeV and 170 GeV signals plotted on top of the background estimate. They are shown as the shaded regions in the ratio plot.

Summary

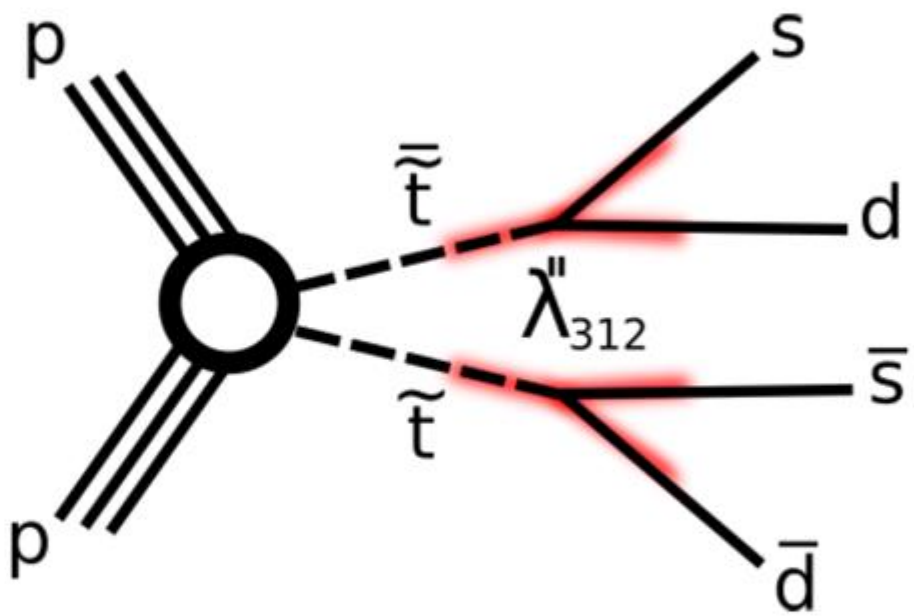
- We present a search for paired dijet resonances in the boosted regime at 13 TeV with 2015 data
- Look for a resonance in average pruned mass
- We use a data-driven method to estimate the non-resonant backgrounds and MC samples for the sub-dominant resonant backgrounds.
- No excess → exclude production of the RPV stops decaying via the coupling λ''_{312} below 240 GeV, filling the 100-200 GeV gap from prior results

We exclude masses below 240 GeV



Backup

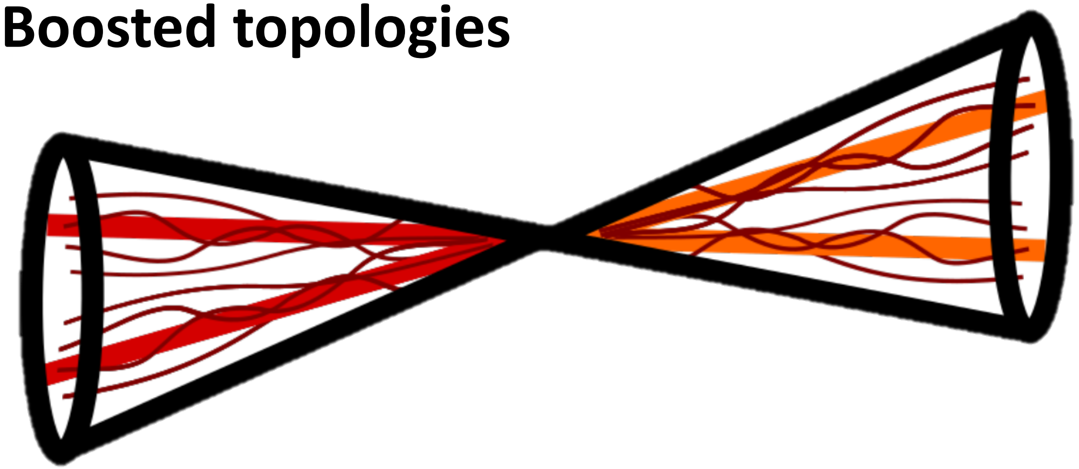
Theory Model/Physics Motivation



Pair production of stops decaying via the UDD312 RPV coupling into two light quarks

Exploit current LHC energy to study this boosted signature and probe lower BSM particle masses

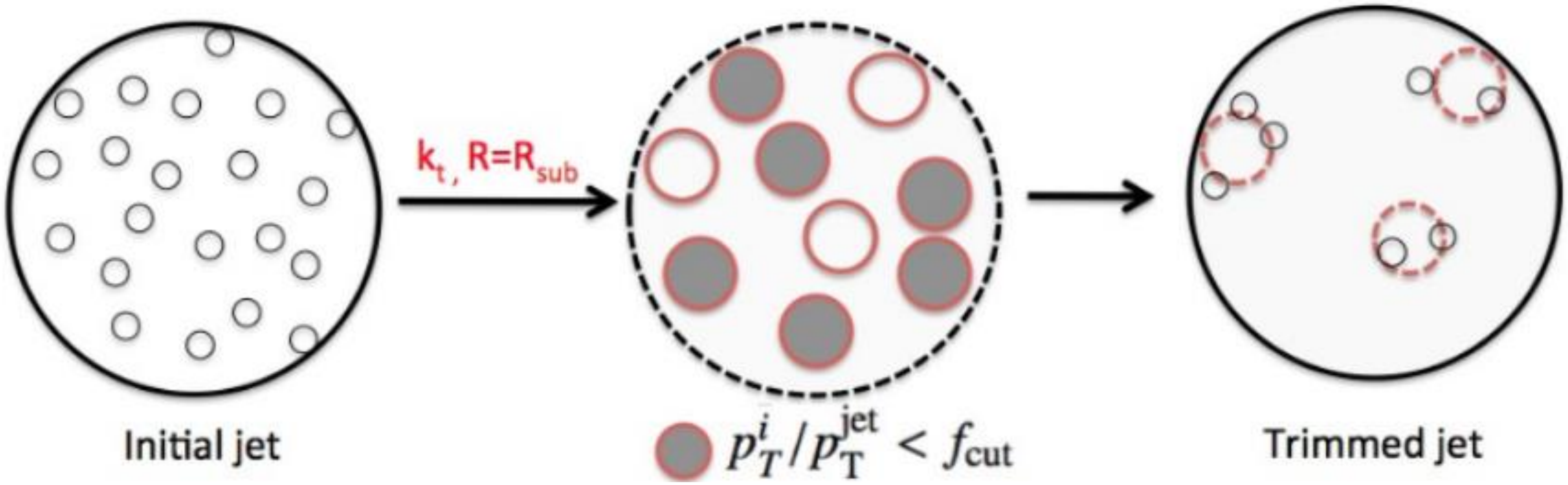
Boosted topologies



Substructure Techniques

"Trimming" http://arxiv.org/abs/0912.1342 (D. Krohn, J. Thaler, L. Wang)

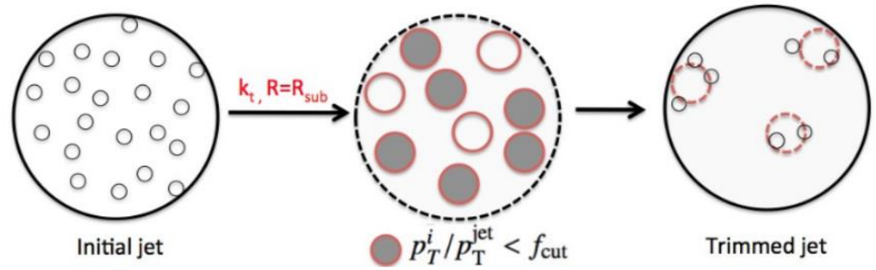
1. Creates subjets from the constituents of the initial jet
2. If the p_T of the jet is too small, removes them



Substructure Techniques

"Trimming" http://arxiv.org/abs/0912.1342 (D. Krohn, J. Thaler, L. Wang)

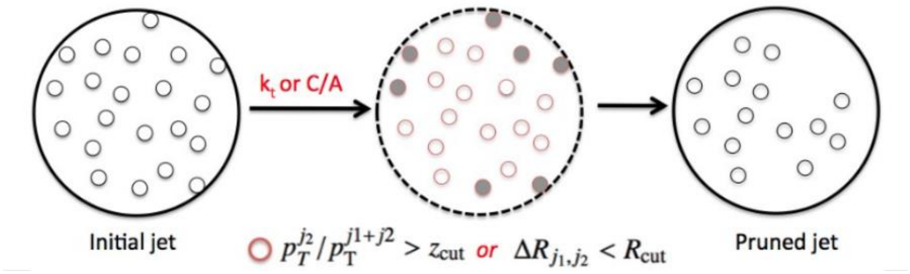
- Uses k_t algorithm to create subjets of size R_{sub} from the constituents of the large-R jet: Any subjets failing $p_T i/p_T < f_{cut}$ are removed



Tuned parameters:
f_{cut} and R_{sub}

"Pruning" http://arxiv.org/abs/0912.0033 (S. Ellis, C. Vermiliion, J. Walsh)

- Recombine jet constituents with C/A or k_t while vetoing wide angle (R_{cut}) and softer (z_{cut}) constituents. Does not recreate subjets but prunes at each point in jet reconstruction



Tuned parameters:
R_{cut} and z_{cut}

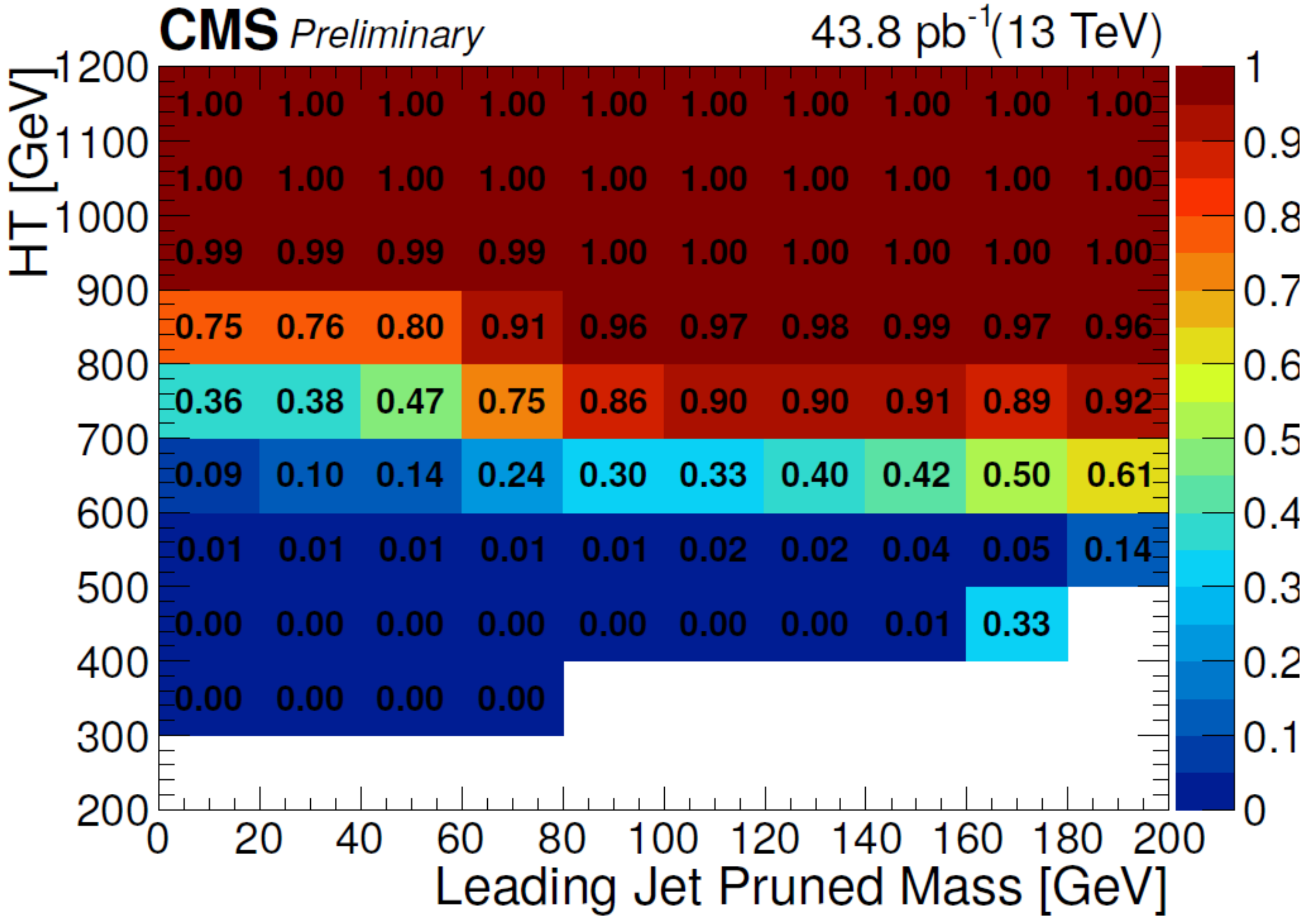
"N-subjetiness" http://arxiv.org/abs/1108.2701 (J. Thaler, K. Van Tilburg)

- Creates N subjet axes within a jet and sums angular distances of jet constituents to their nearest subjet axis. This variable is a jet shape designed to identify boosted hadronic objects.

High Level Trigger (HLT)

We developed an HLT trigger for this search using the pT sum of AK8 jets (HT) and grooming techniques.

Here we show the trigger efficiency in HT vs Leading Jet pruned mass for a logical OR between that trigger and the nominal HT hadronic trigger.

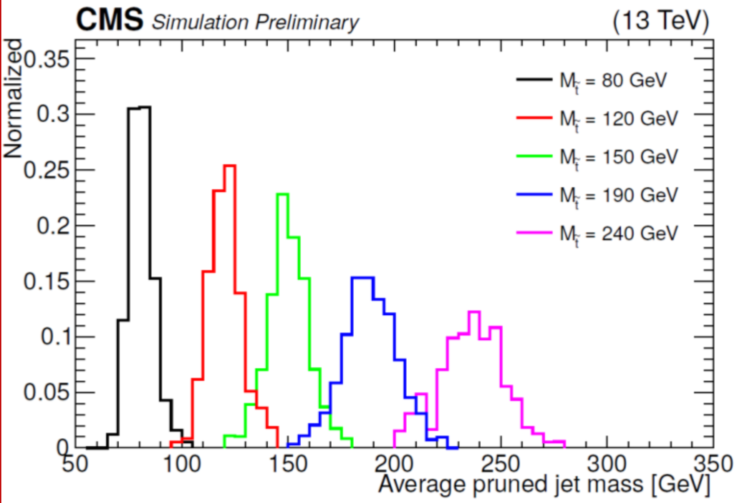


Systematics

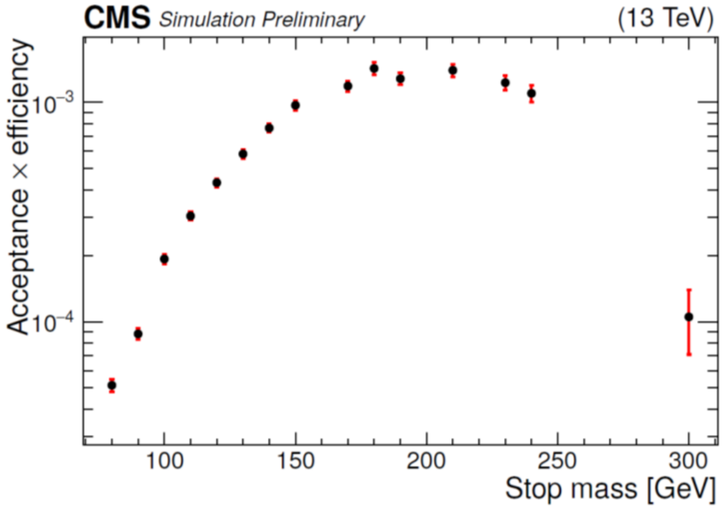
Source of Systematic	Effect	Value
Luminosity	Yield	2.7%
Trigger	Yield	2%
Pileup	Yield	1.5%
PDF	Yield	12%
Two-prong Tagger Scale Factor	Yield	17%
Jet Energy Scale	Yield	0.8%-5%
Jet Energy Resolution	Yield	0.6%-3%
MC Statistics	-	bin-by-bin
Jet Mass Scale	Resonance Shape	2%
Jet Mass Resolution	Resonance Shape	11%

Background	Source of Systematic	Effect	Value
QCD ABCD method:	Closure	Yield	10%
	Transfer Factor Fit Uncertainty	Shape	0.8%-8%
	Statistics in Sideband Region (C)	Shape	bin-by-bin
Resonant backgrounds:	Systematic in MC Backgrounds	Yield	50%
	MC Statistics	Shape	bin-by-bin

Signal MC Simulations



signal shapes after the final selection



acceptance x efficiency

Systematics

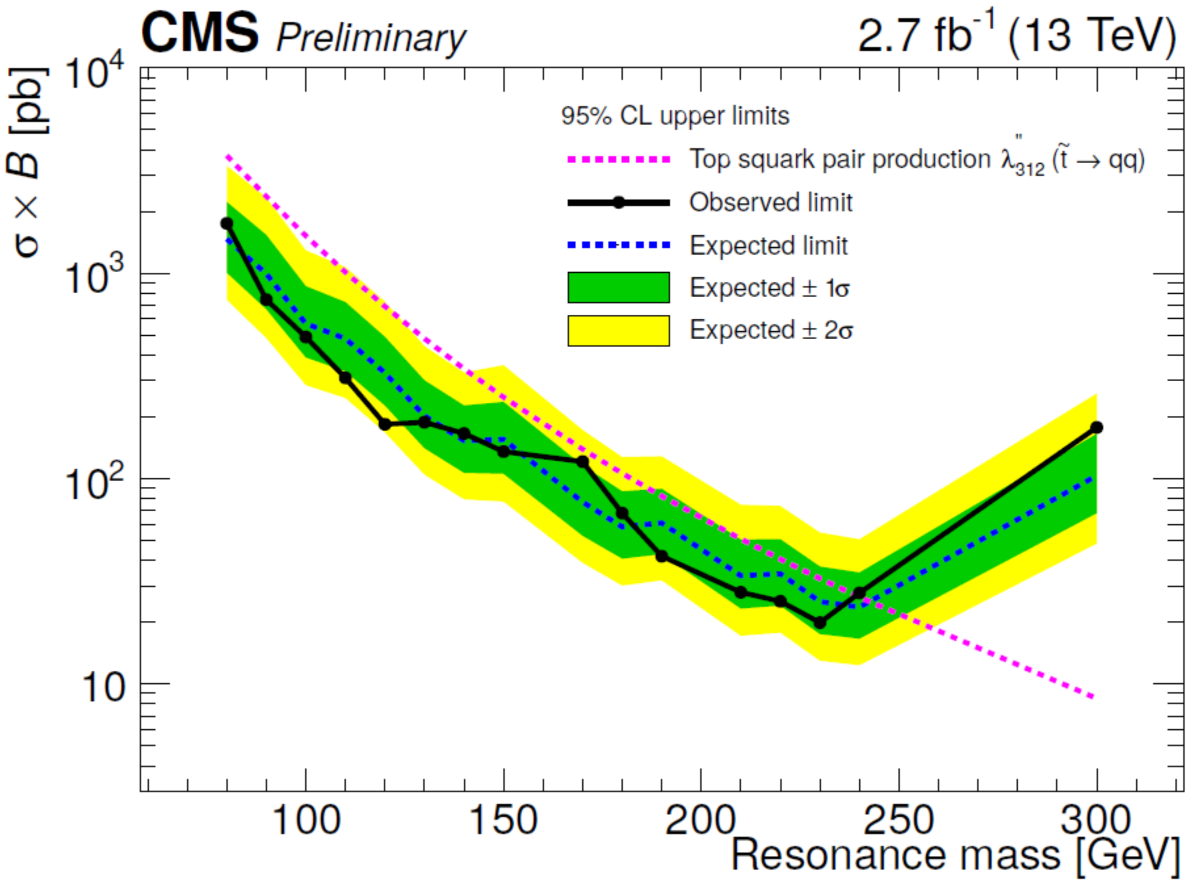
Previous analyses have measured a Data/MC scale factor for the tau21 two-prong tagger working point which we use

- $SF^2 = 0.88 \pm 0.15$ (The scale factor is squared because we apply tag both jets)
- This is applied to the signal acceptance and the error is taken as a systematic uncertainty.

In addition, we take into account all other standard systematics on the signal acceptance such as: lumi, JES/JER (taken from JME-16-003), pileup, and PDF (table in backup)

Limits

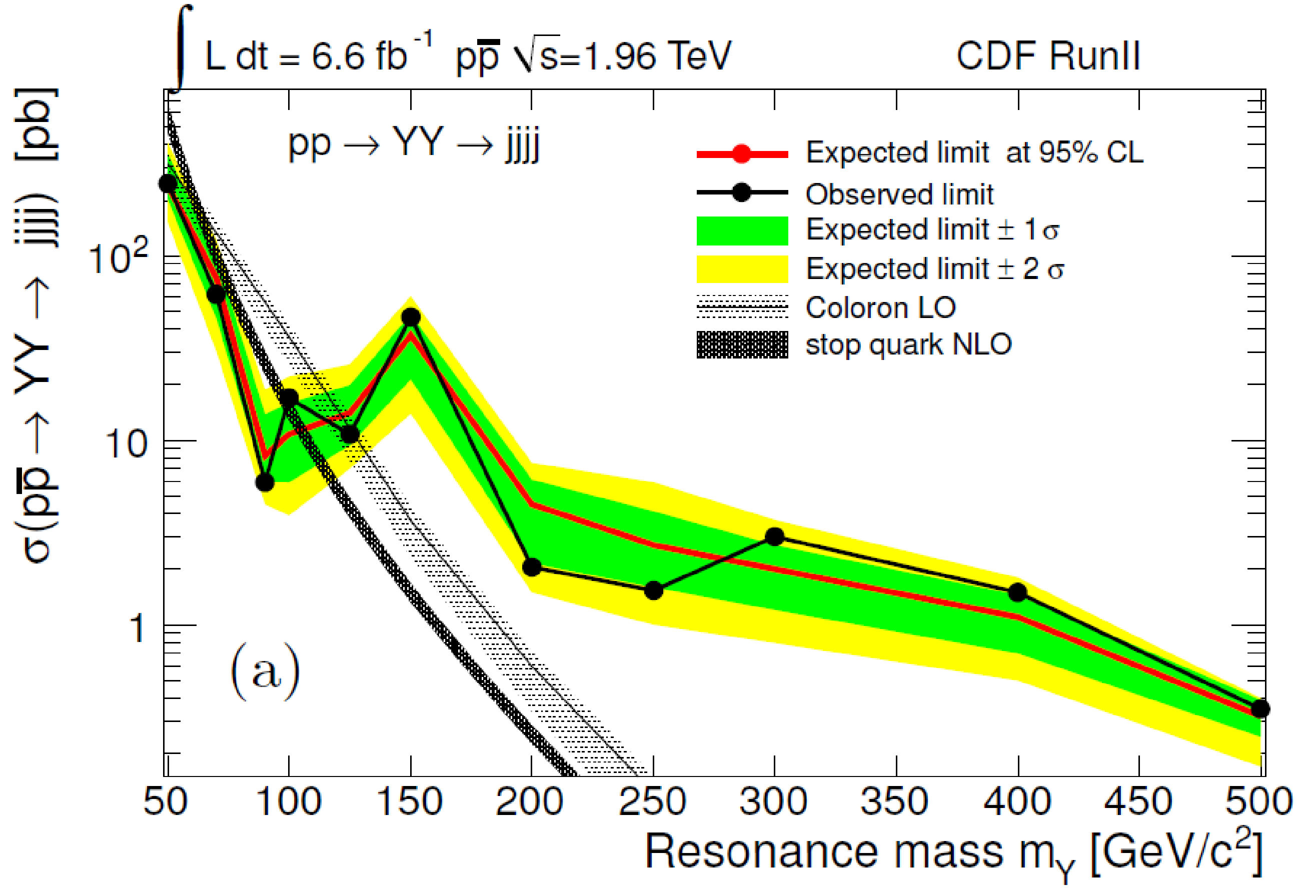
- The distribution in the average pruned jet mass of selected events has been used to search for an excess compatible with a resonance signal above the SM background estimate.
- No significant deviation is found
- Exclusion limits are set on the top squark pair production cross section with decays through the RPV SUSY coupling UDD312 to light flavor jets at 95% confidence level



We exclude masses below 240 GeV

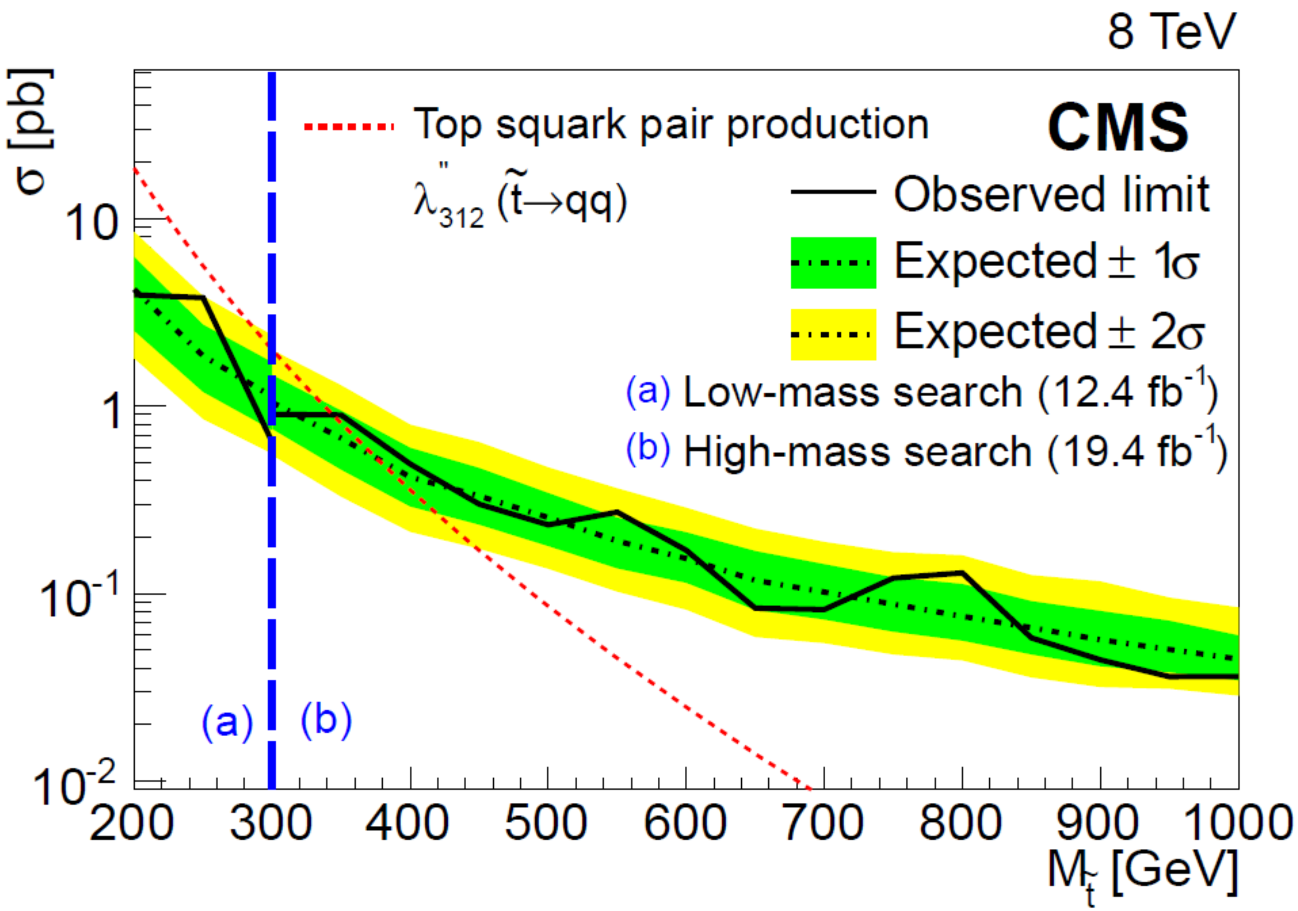
Current limits in RPV Stops production

- [1303.2699]
  - CDF set limits on the production of RPV Stops using a 4-jet final state (resolved analysis) and excluded mass 50-100 GeV



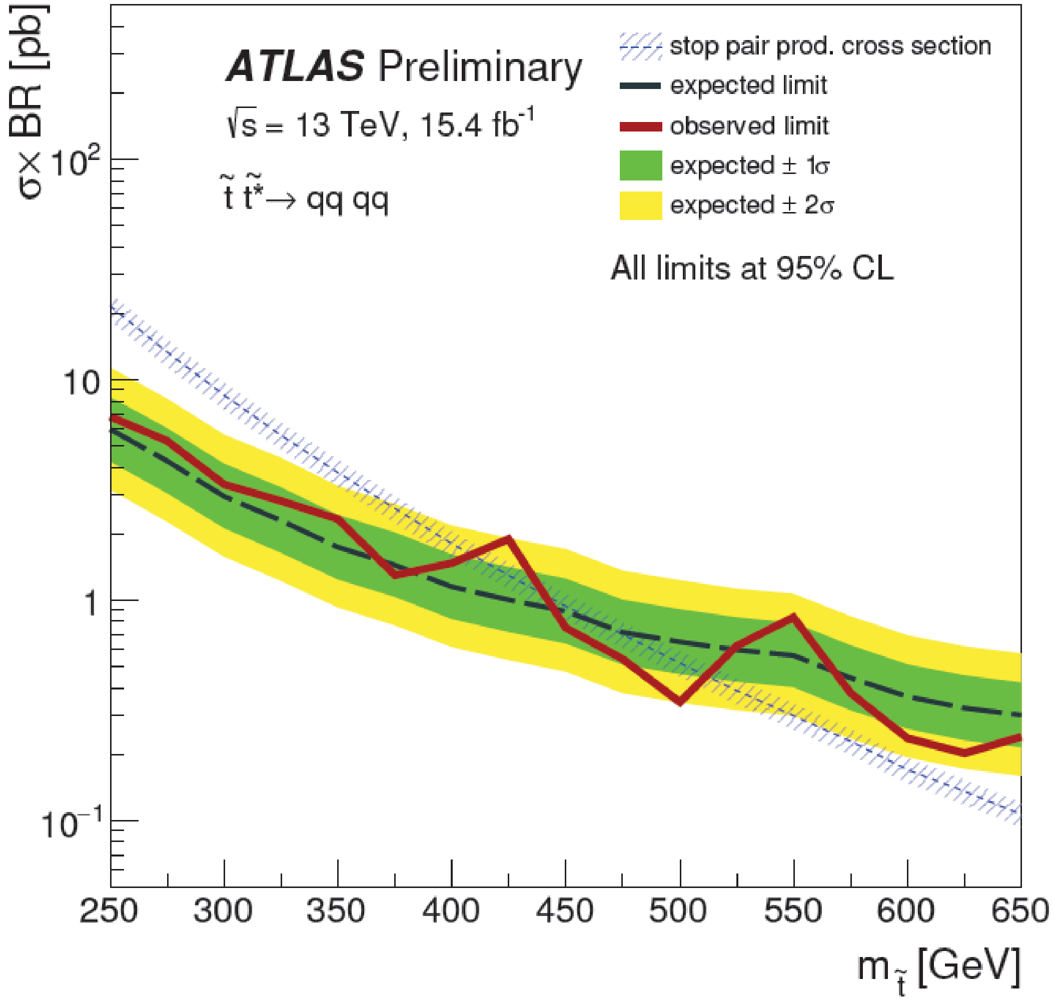
Current limits in RPV Stops production

- [1412.7706v1]
  - The CMS Run I analysis also used the 4 jet signature and excluded stop masses 200-350 GeV



Current limits in RPV Stops production

- [CONF-2016-084]
  - The Atlas Run II analysis also used the 4 jet signature and excluded stop masses from 250 to 405 GeV and 445 to 510 GeV, leaving the open window between 100-200 GeV for RPV Stops



Current limits in RPV Stops production

- 1406.1122
  - For the boosted case, ATLAS published a Run I result with **b-tags**, limiting the production in the region of stop mass 100 to 310 GeV