Searches for new physics in dijet & multijet final states @ CMS

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Introduction

This talk will focus on

- some of the most recent "resonant" searches in dijet & multijet final states using CMS Run 2 data (~36 fb^{-1}) @ 13 TeV
- some of the interesting BSM theories we've tested so far
  - leptophobic Z', Extra dimensions, Compositeness and Quantum Black Hole (QBH), Sphalerons, RPV SUSY etc..

Most results have been published or submitted/accepted for publication.

Only recent 13 TeV results will be shown here today - More on the way.

All CMS dijet & multijet searches are detailed in:

CMS EXO

http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

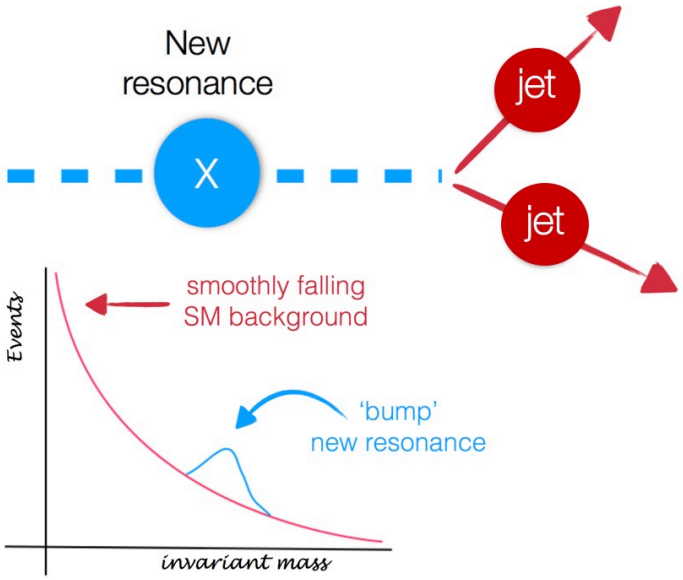
Dijet & Multijet Resonance

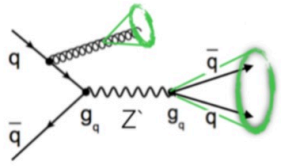
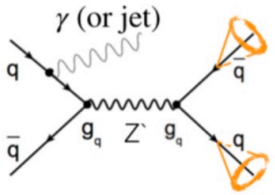
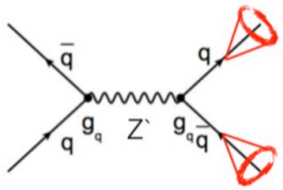
Motivation

- many models of BSM require new particles that couple to quarks and/or gluons and decay to jets
- clear experimental signature: peak in the mass spectrum [bump hunt]
- one of the most direct ways to find new physics

Search strategy

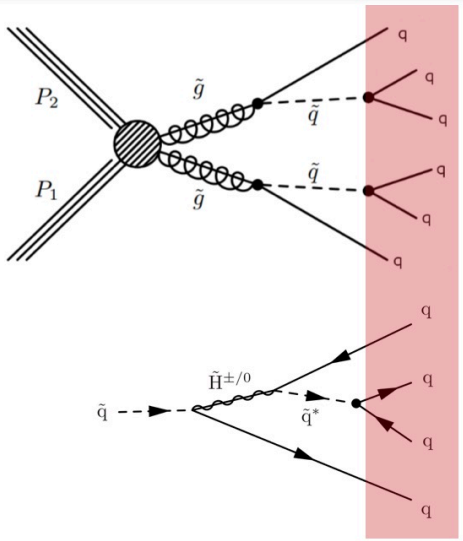
- CMS performed a series of searches for dijet & multijet resonances
- This cover a wide range of resonance masses depending on final state signatures and models



Associated Production (ISR)		Inclusive Analysis	
Boosted dijet	Resolved jets	Trigger Level Analysis	Standard Triggers
1 ISR jet + 1 widejet	1 ISR jet or γ + 2 jets	2 jets	2 jets
			
Very Low-Mass	Low-Mass	Intermediate-Mass	High-Mass

50 GeV 200 GeV 500 GeV 1.5 TeV 8.0 TeV

RPV SUSY with Multijet



Experimental challenges

- In order to reach to lower masses we need different trigger strategy
- Very low-mass resonance decay products merge into one or more single fat jet → require jet-substructure & jet-ensemble techniques

EXO-16-056
arXiv:1806.00843 (2018)

Dijet Resonances

Look for bump in dijet mass spectrum

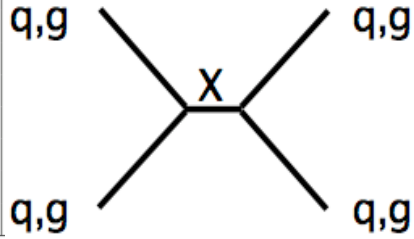
- sensitive to the coupling of any new massive object to quarks and gluons
- separates searches by final state (qq, qg, gg)

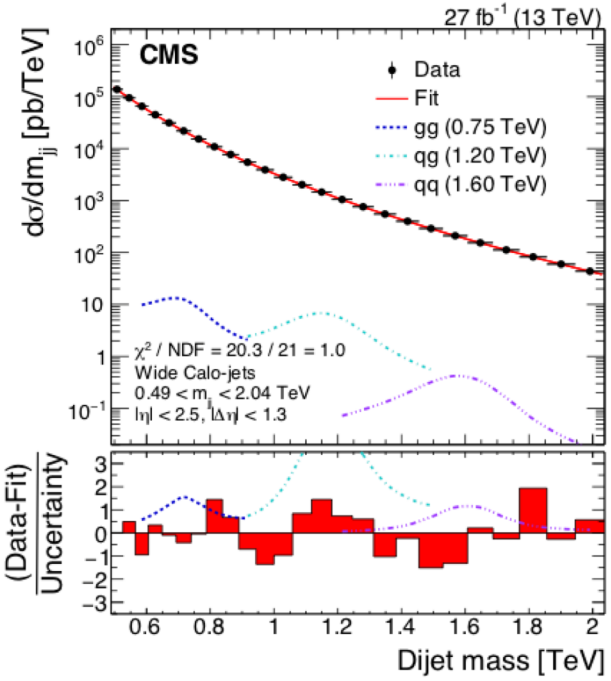
Select dijet in event with $|\eta_1,\eta_2| < 2.5$ & $|\Delta\eta| < 1.3$

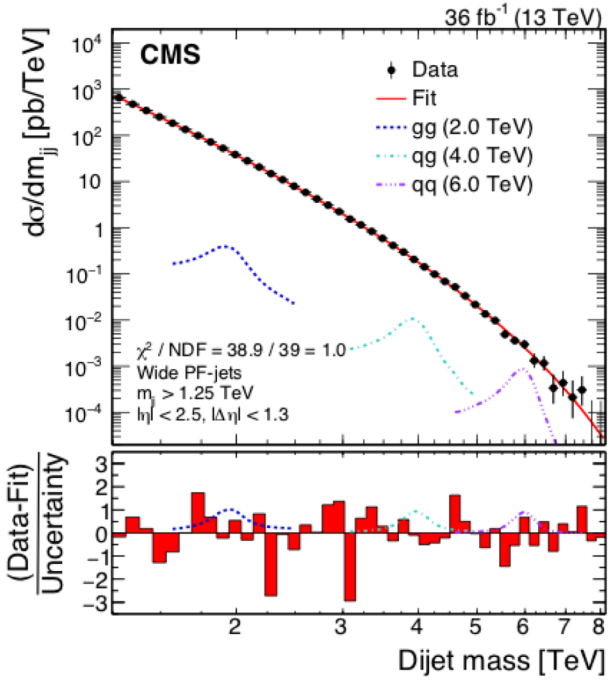
- CMS uses an FSR-recovery technique by combining anti-k_T 0.4 jets within $\Delta R < 1.1$

Model Name	Final-state Partons
String	$q\bar{q}$, qq, gg and qg
Axigluon	$q\bar{q}$
Coloron	$q\bar{q}$
Excited Quark	qg
E_6 Diquark	qq
RS Graviton	$q\bar{q}$, gg
Heavy W	$q\bar{q}$
Heavy Z	$q\bar{q}$

Dijet Resonance







Analysis strategy

① High-mass search
- fully efficient after 1246 GeV
- use particle flow AK4 jets

② Low-mass search
- fully efficient after 489 GeV
- use calorimeter AK4 jets

Data well fit to a smooth, steeply falling function

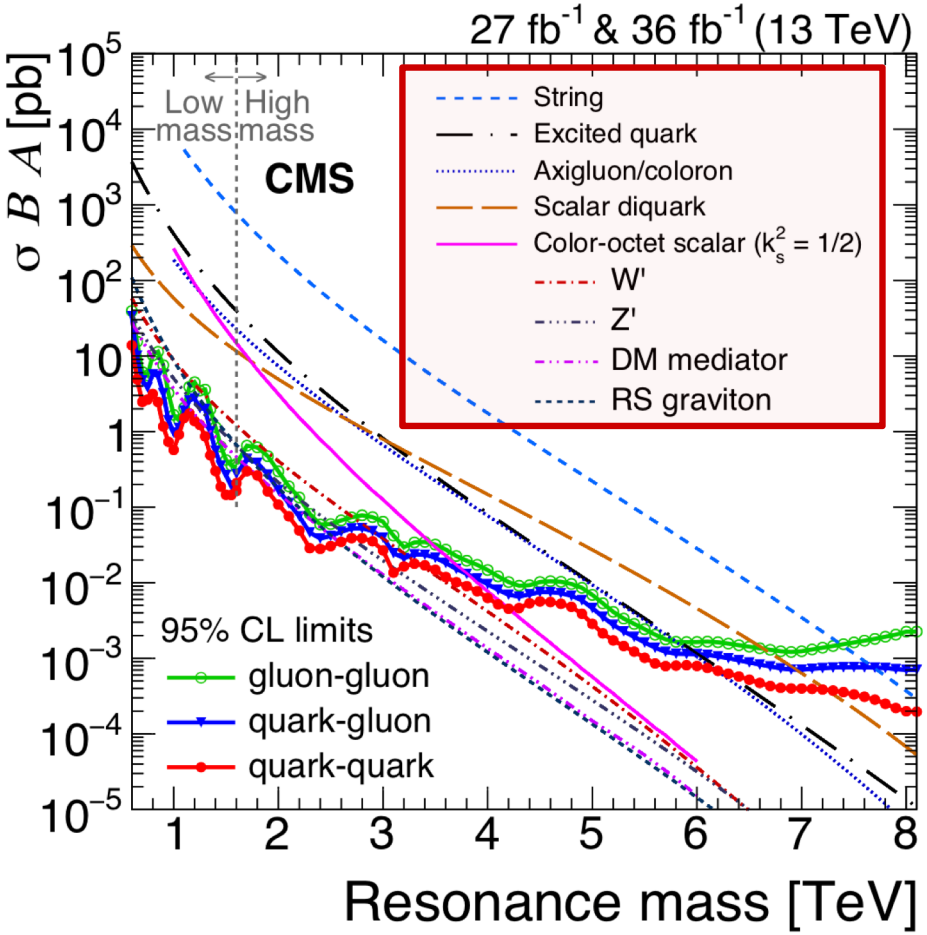
➡ no resonance signal observed

➡ set model-independent limits on several models

EXO-16-056
arXiv:1806.00843 (2018)

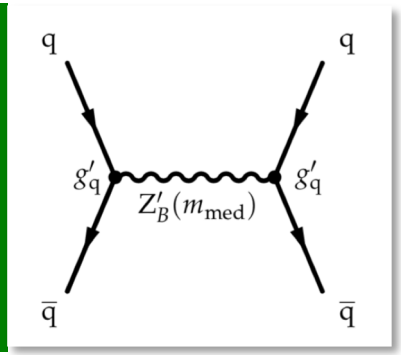
Dijet Resonances

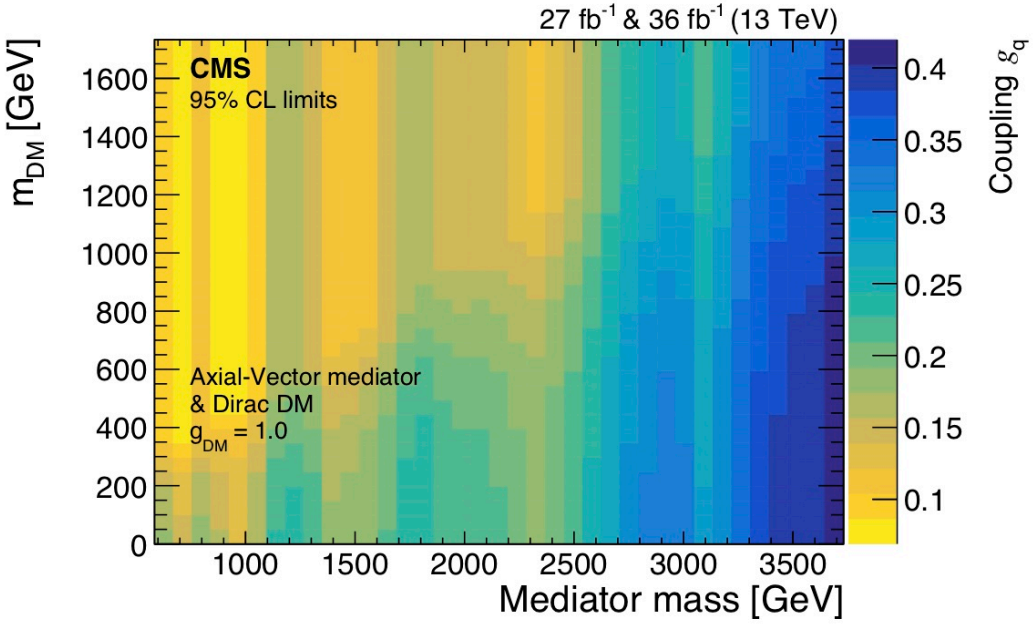
We obtain generic cross section limits on qq, qg, gg resonances and set the most stringent limits on 9 benchmark models.



constraints on dark matter mediators

- DM mediator may directly produced a dijet resonance
- set limits on a quark coupling g_q in the plane of the DM particle mass vs mediator mass for an (axial-) vector mediator



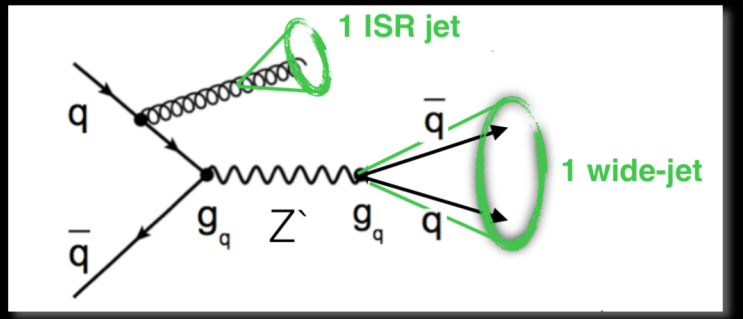


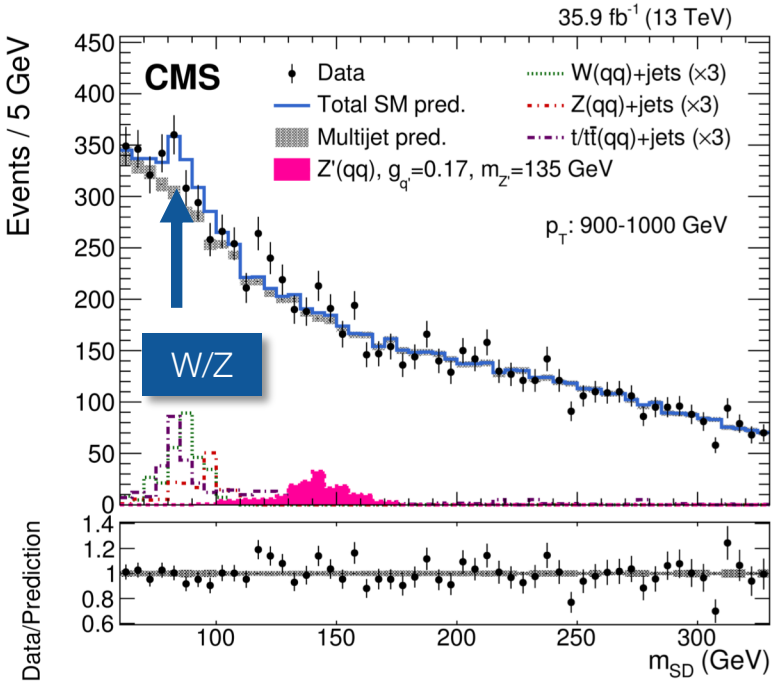
EXO-17-001
JHEP 01 (2018) 097

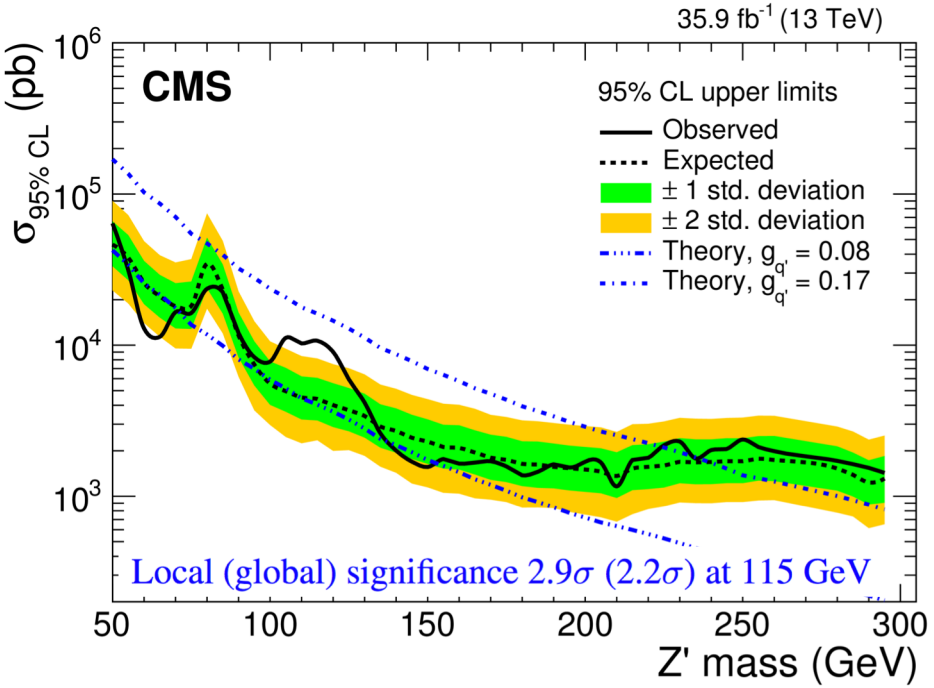
Boosted Dijet Resonances

Merged (di)jet light resonance

- going even lower in mass: dijet starts to merge into 1wide- jet
  - signature: a merged jet(+ ISR jet for triggering)
  - exploring masses between 50 and 300 GeV
- experimental challenge
  - a standard bump-hunt strategy doesn't work due to SM bkg.
  - use substructure tagging techniques to estimate bkg. shape & yield
- no significant deviation from SM expectation; set limit on Z' prod. x-section







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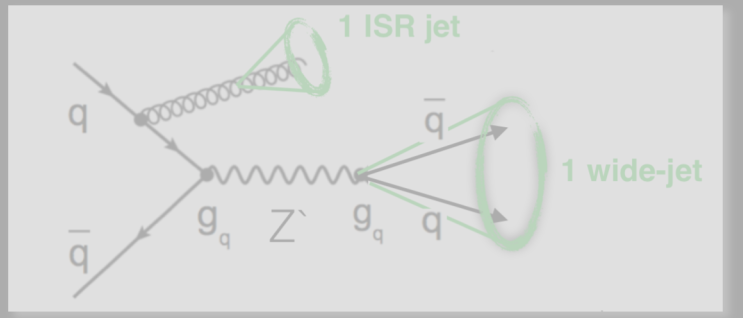
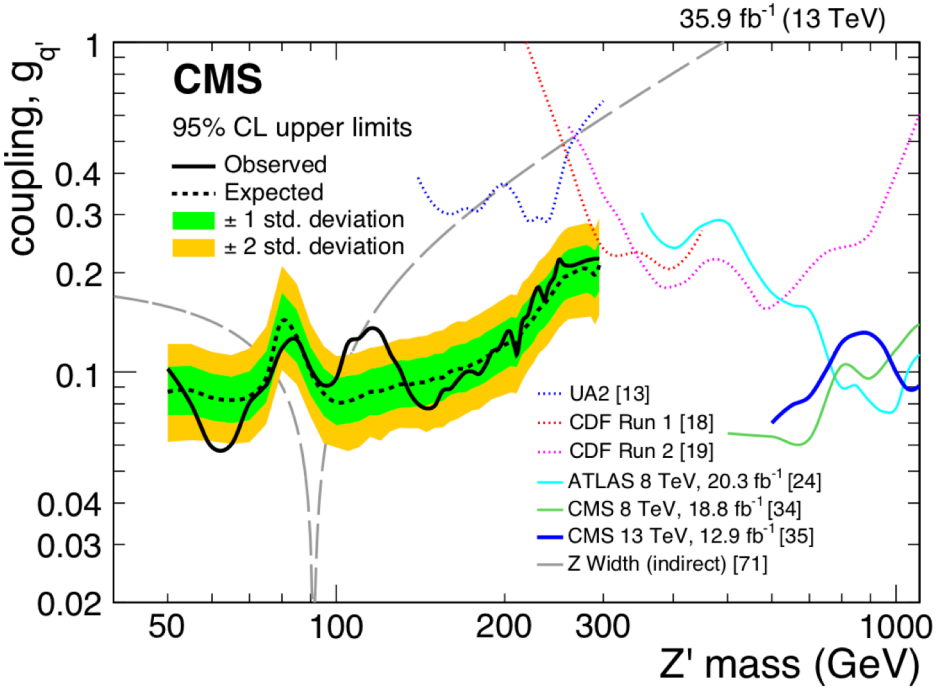


- Also, set upper limit on quarks coupling **vs** resonance mass for a leptophobic Z′



probe new mass & coupling regions

- Limits from other relevant searches and an indirect constraint on a potential Z′ signal from the SM Z boson width are also shown.
- The results are the most sensitive to date, extending for the first time the search region to masses below 100 GeV.

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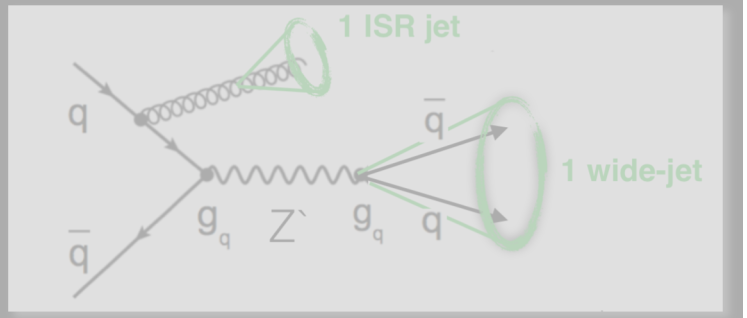
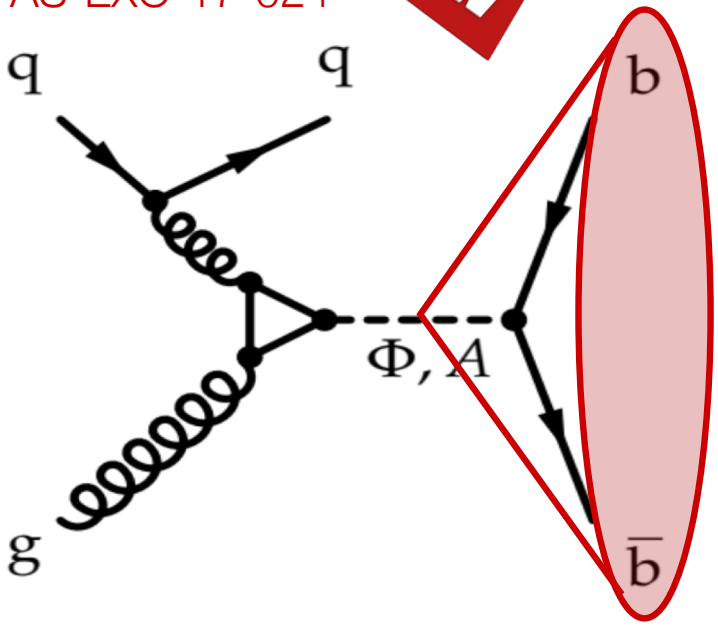


CMS-PAS-EXO-17-024

New



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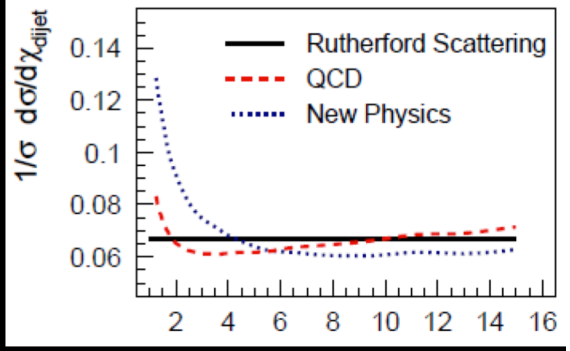
CMS has also performed search for boosted b-tagged dijet resonance: see Andreas Albert's talk at Dark Matter Detection session this morning.

EXO-16-046
arXiv:1803.08030 (2018)

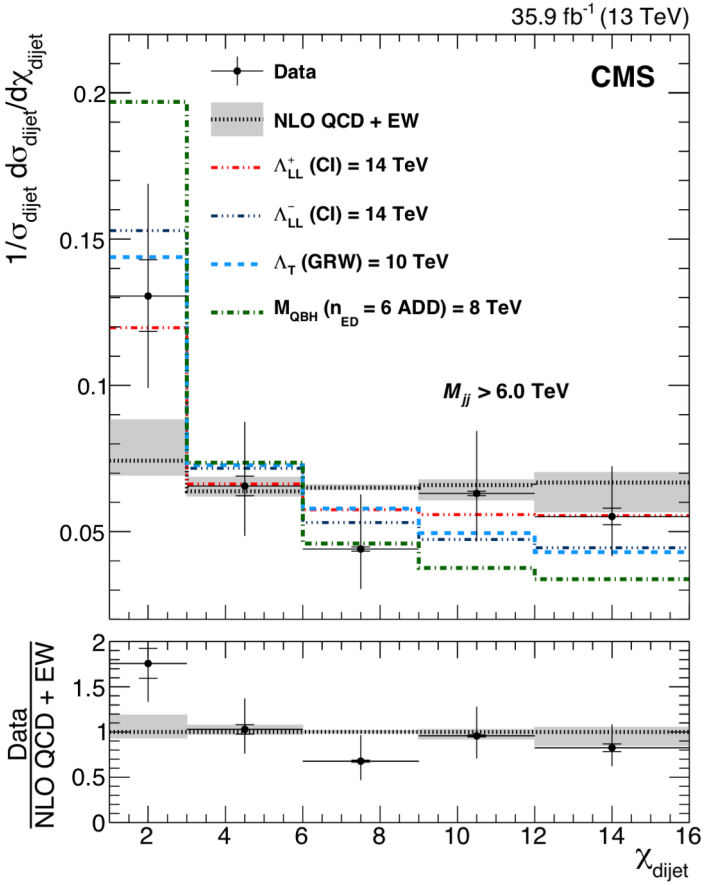
Dijet Angular Search

Look for dijet scattering angle q* via χ variable

$$\chi_{\mathrm{dijet}} = \frac{1 + |\cos\theta^*|}{1 - |\cos\theta^*|}$$



- χ flat QCD but sensitive to non-resonant (or wide width) phenomena at low χ & high mass
- unfolded data in good agreement w/ NLO QCD+EW; set limits on various benchmark models



Model		Observed lower limit (TeV)
CI	$\Lambda^{+}_{\mathrm{LL/RR}}$	12.8
	$\Lambda^{-}_{\mathrm{LL/RR}}$	17.5
	$\Lambda^{+}_{\mathrm{VV}}$	14.6
	$\Lambda^{-}_{\mathrm{VV}}$	22.4
	$\Lambda^{+}_{\mathrm{AA}}$	14.7
	$\Lambda^{-}_{\mathrm{AA}}$	22.3
	$\Lambda^{+}_{(\mathrm{V-A})}$	9.2
	$\Lambda^{-}_{(\mathrm{V-A})}$	9.3
ADD	Λ_{T} (GRW)	10.1
	M_{S} (HLZ) $n_{\mathrm{ED}} = 2$	10.7
	M_{S} (HLZ) $n_{\mathrm{ED}} = 3$	12.0
	M_{S} (HLZ) $n_{\mathrm{ED}} = 4$	10.1
	M_{S} (HLZ) $n_{\mathrm{ED}} = 5$	9.1
	M_{S} (HLZ) $n_{\mathrm{ED}} = 6$	8.5
QBH	M_{QBH} (ADD $n_{\mathrm{ED}} = 6$)	8.2
	M_{QBH} (RS $n_{\mathrm{ED}} = 1$)	5.9
DM	Vector/Axial-vector M_{Med}	2.0–4.6

CI scale Λ
> 9.2 – 22.4 TeV

ADD
> 8.5 – 12 TeV

QBH
> 5.9 – 8.2 TeV

Z'
> 2.0 – 4.6 TeV

EXO-16-046
arXiv:1803.08030 (2018)

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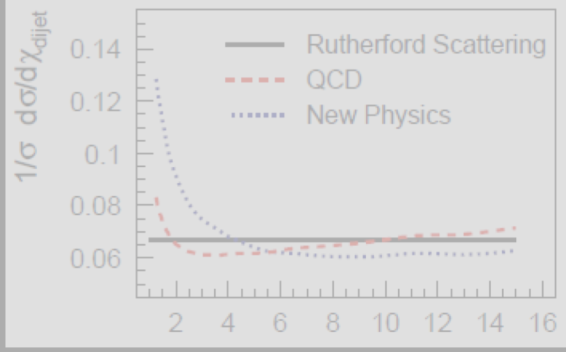

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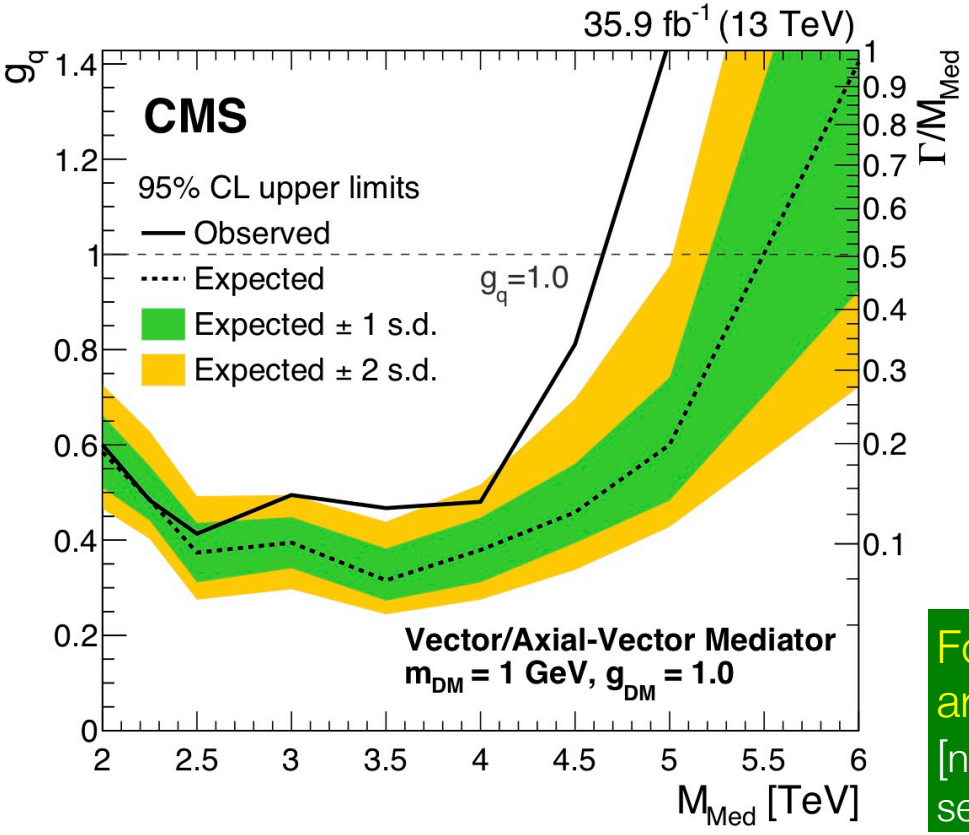
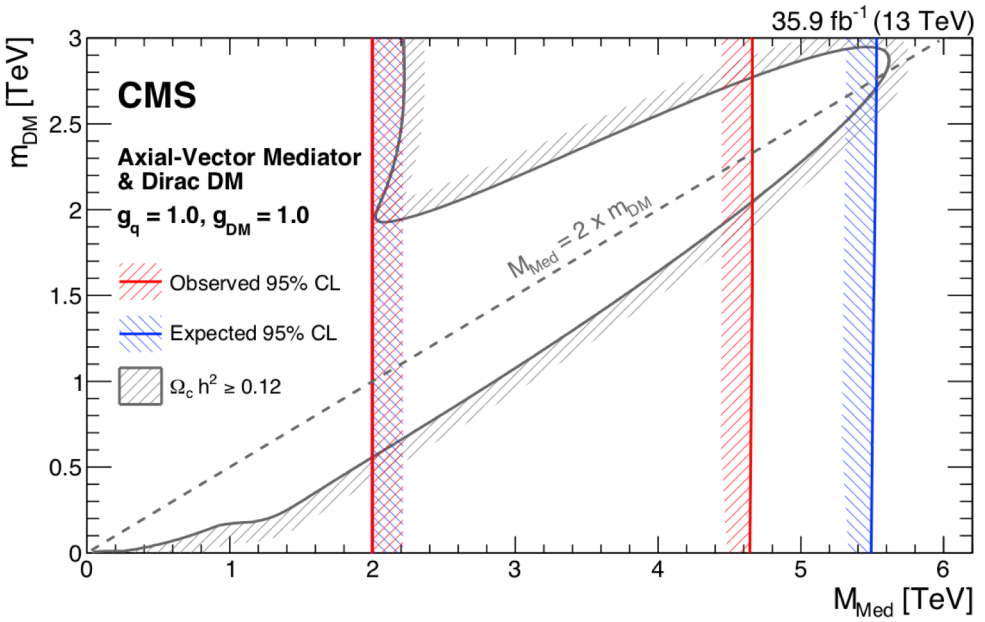




For the first time, lower limits between 2.0 & 4.6 TeV are set on the mass of a DM mediator, for $g_q \geq 1$.

[note] This region is not accessible through dijet resonance searches.

EXO-16-057
PRL 120 (2018) 201801

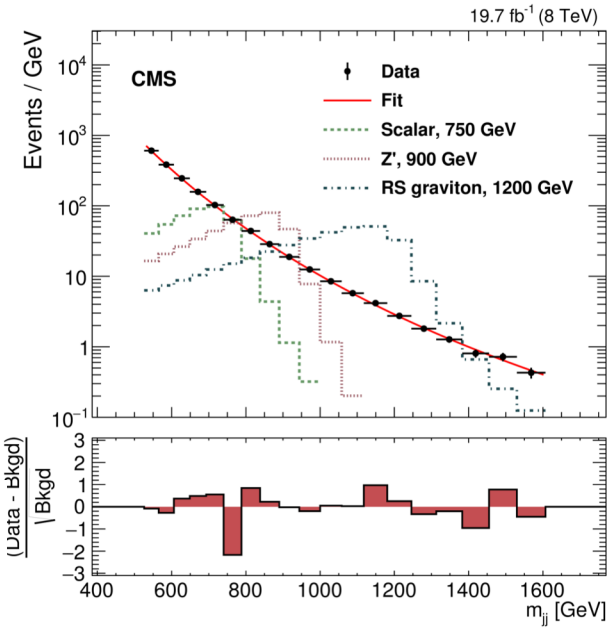
b-tagged Dijet Resonances

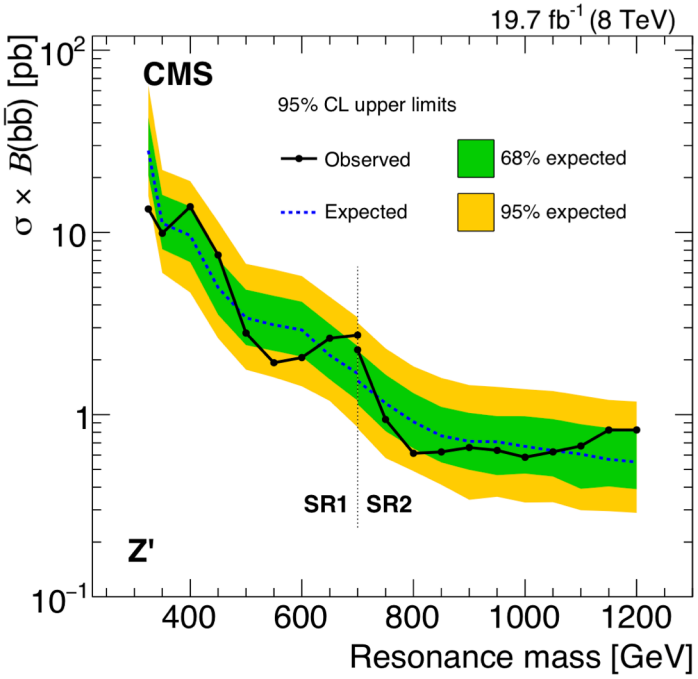
Look for bump in b-tagged dijet mass spectrum

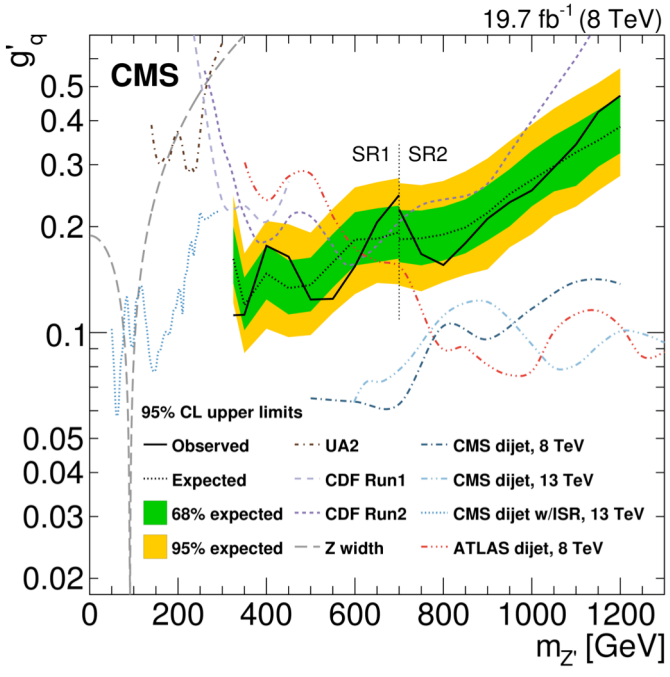
- using online b-tagging in Run 1 dataset, analysis extends the dijet invariant mass range down to ~ 325 GeV
- 2 triggers define 2 signal regions, SR1 (low mass) & SR2 (high mass)

No significant excesses observed.

- Limits set on spin-0 (Higgs), 1 (Z'), and 2 (RS G) models decaying to bottom quarks, for 325 GeV < m_X < 1200 GeV.







Interpretations

① limits on leptophobic Z′ DM mediator; best limits on gq in the range [325–500] GeV

② Also, for the 1st time provide interpretation in the 'zeta' simplified model framework

EXO-17-023
arXiv:1805.06013 (2018)

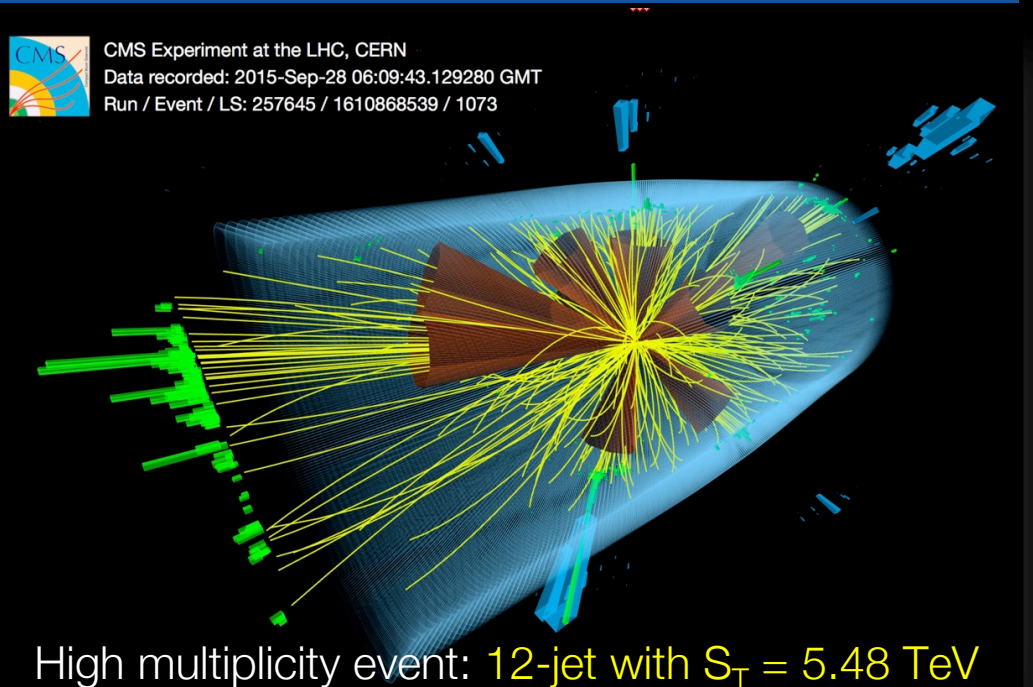
Search for Black Holes

Smoking gun signature of TeV scale quantum gravity

- BH produce large number of energetic objects

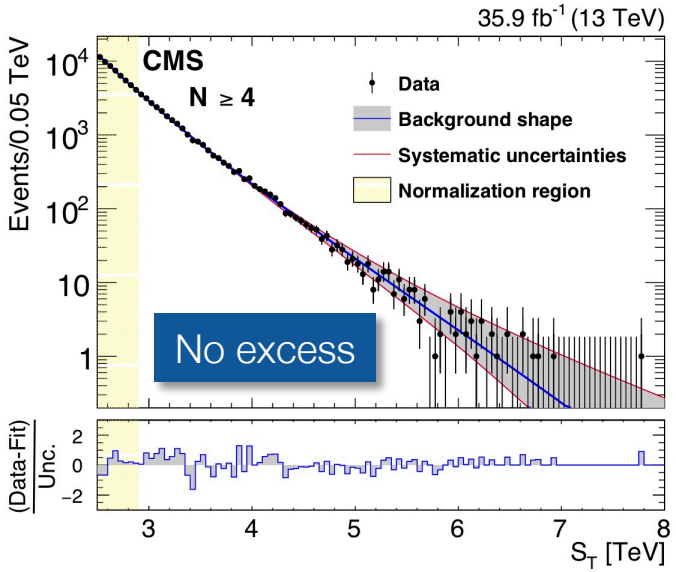
Search for deviation in S_T distribution in bins of object multiplicity (n > 3; go up to N > 11)

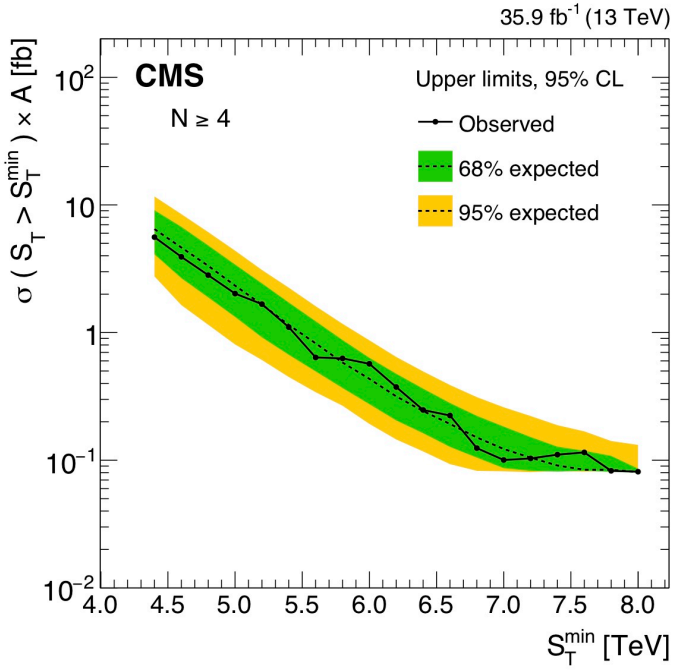
- S_T = scalar sum of all objects with p_T > 50 GeV



High multiplicity event: 12-jet with S_T = 5.48 TeV

BH mass excluded in range below ~10 TeV depending on assumptions: semi-classical BH & quantum BH





EXO-17-023
arXiv:1805.06013 (2018)

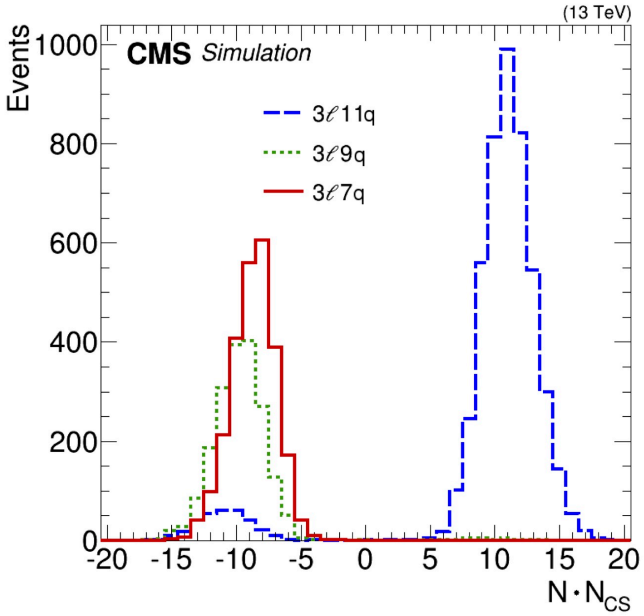
Search for Sphalerons

Sphalerons

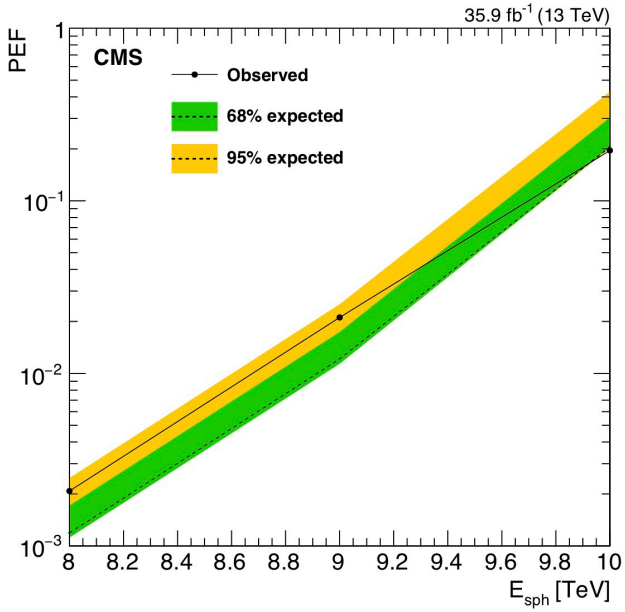
- a solution to SM that was first proposed by 't Hooft in 1976
- Higgs discovery allowed to calculate the sphaleron transition, which, at LO, is at E_{sph} ~ 9 TeV

Sphalerons phenomenology

- Sphaleron transition results in 12 fermions in the final state (3 quarks + 1 lepton, from each generation);
  e.g. e udd ν_μ ccs τ ttb
- particles sharing 9 TeV so each has on average about 760 GeV



- we can reinterpret previous result as a limit on EW sphalerons
- this is the first dedicated experimental search
- used BaryoGen generator [arXiv:1805.02786]



The limits are set on the pre-exponential factor* (PEF), which is the fraction of collisions with the c.o.m. energy above E_{sph},

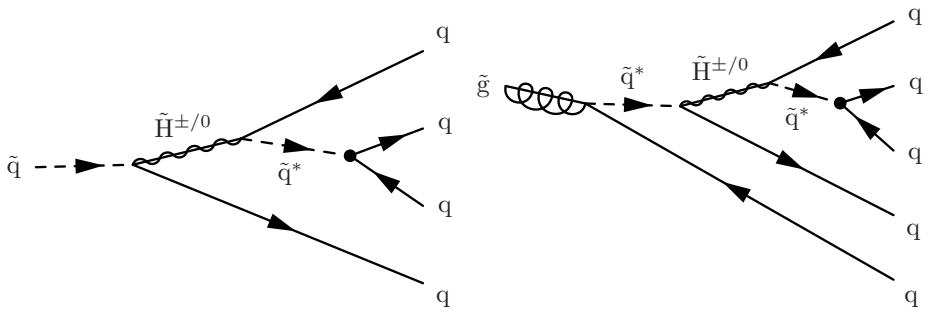
- The limit of PEF < 0.021 @ 95% CL for E_{sph} = 9 TeV

* [Ellis and Sakurai, arXiv:1601.03654]

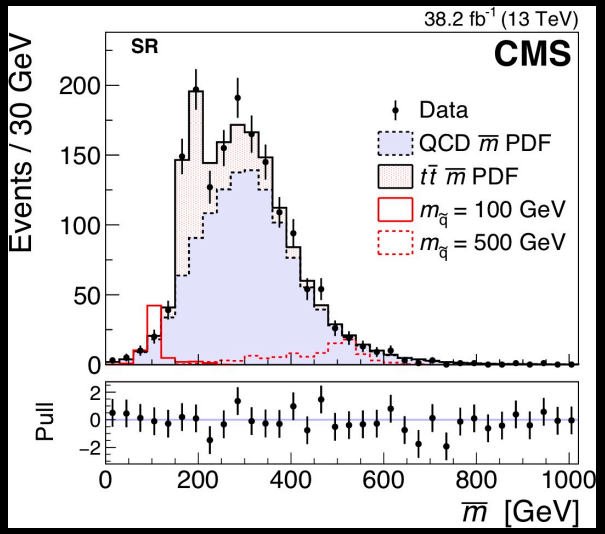
CMS-EXO-17-022; arXiv:1806.01058 [2018]

RPV SUSY w/ boosted wide-jets

Search for pair-produced squarks decaying to 4 quarks or gluinos decaying to 5 quarks via RPV

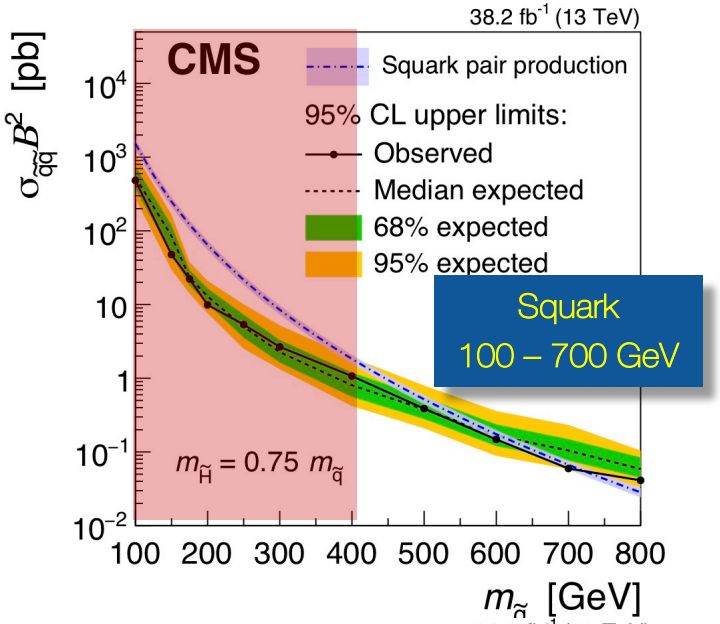


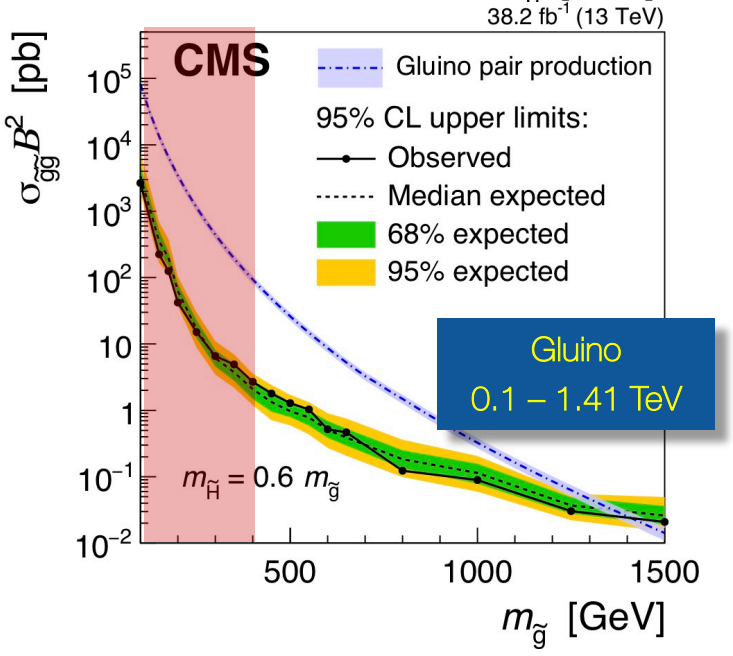
- require two wide jets with p_T > 400 GeV
- suppress QCD background by N-subjettiness variables
- estimate QCD background via event mixing technique



average pruned mass of the two p_T-leading wide jets in an event

the first constraints on light pair-produced particles (w/ mass below 400 GeV) dacaying to ≥ 4 quarks

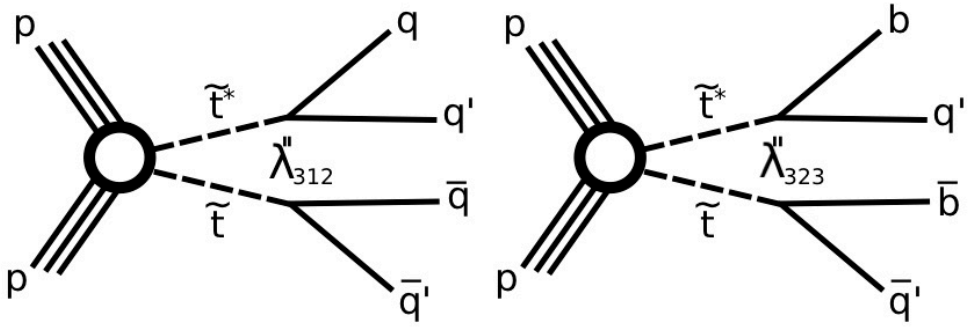




Search for Pair-Produced Dijet Resonance

Model on stop pair production via a hadronic RPV coupling

- each stop decays qq′ via λ''_{312} , and bq′ via λ''_{323}

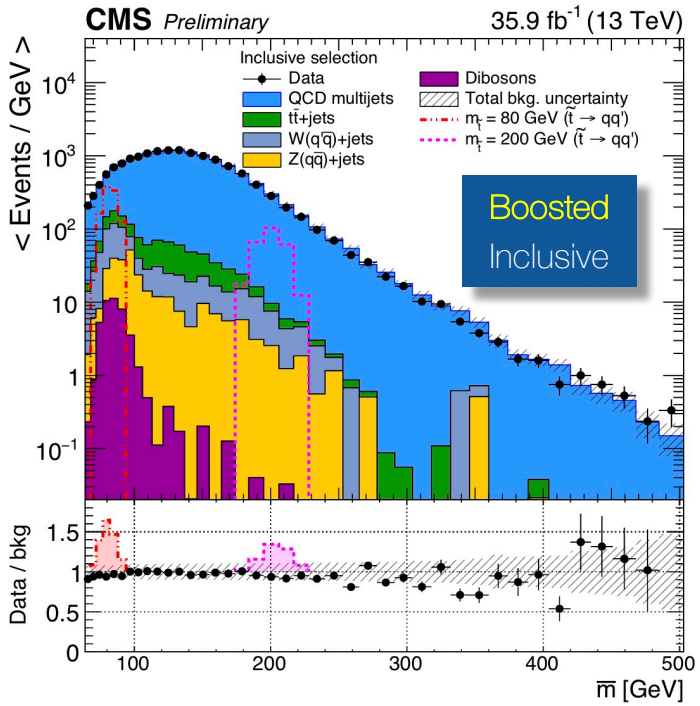


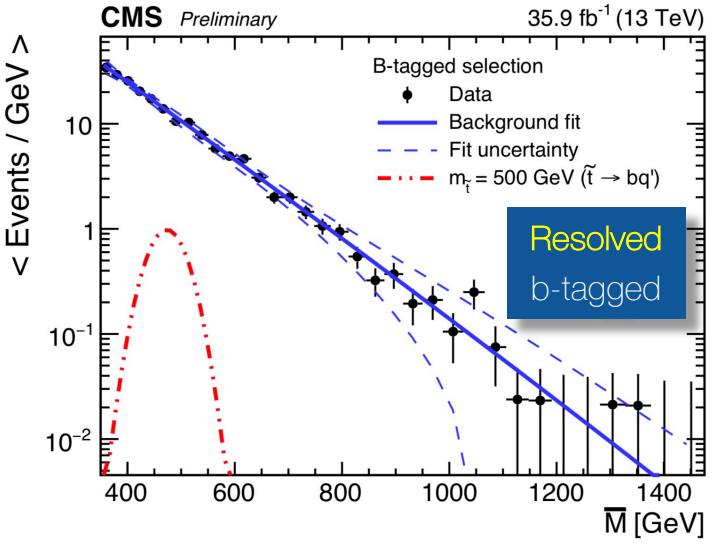
The search is conducted separately for two mass regions:

1. lighter resonances [80-400 GeV]
   - two jet events in a boosted jet topology
2. higher resonance [> 400 GeV]
   - four-jet events in a resolved jet topology

Look for bump in average dijet mass spectrums

- no significant excess is seen for boosted & resolved searches





CMS-EXO-17-021

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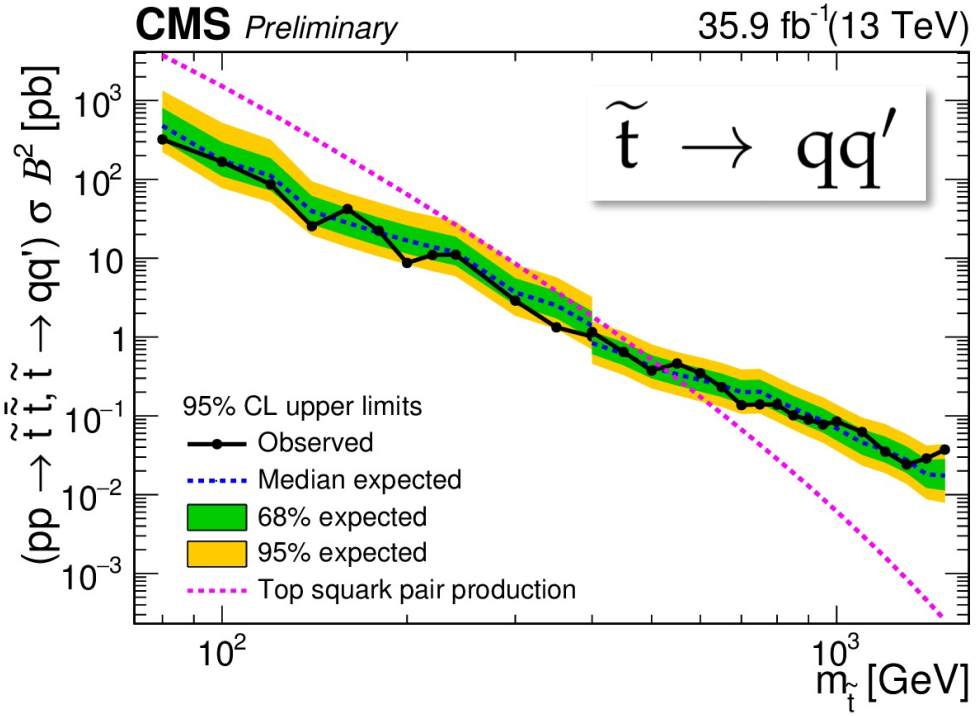
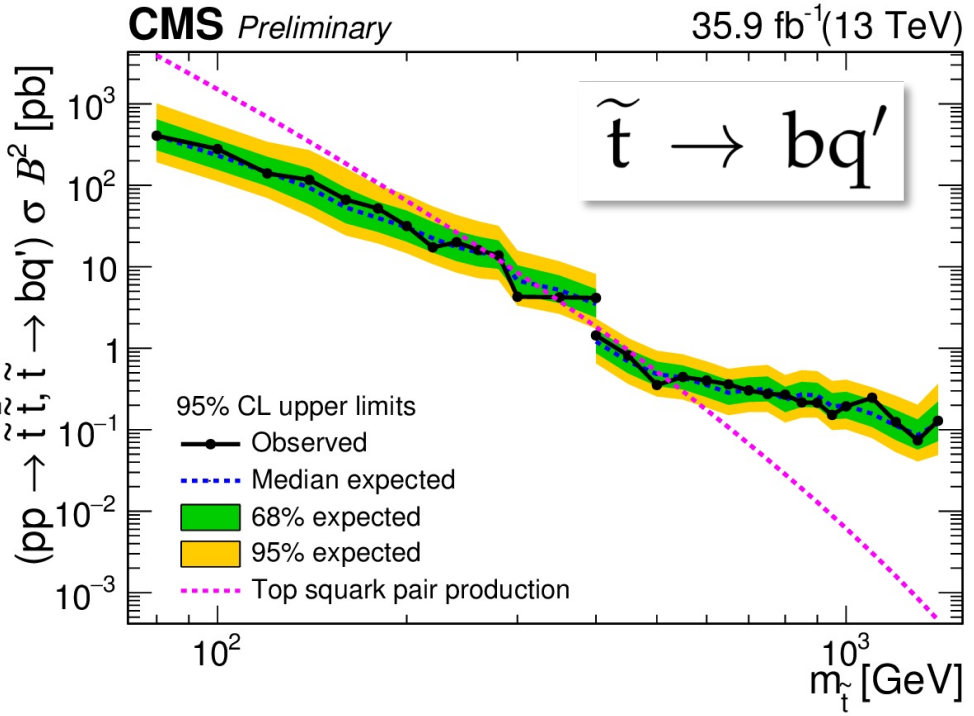
Model on stop pair production via a hadronic RPV coupling

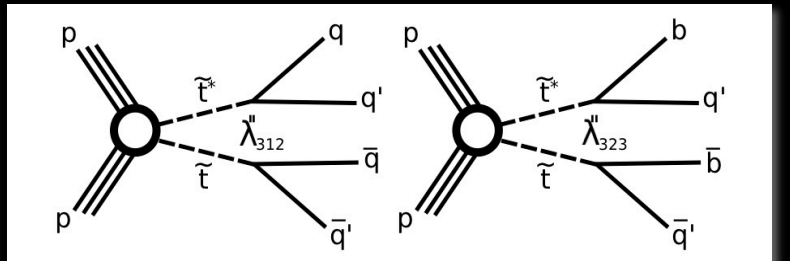
- each stop decays qq′ via λ''_{312} , and bq′ via λ''_{323}





- no significant excess is seen for boosted & resolved searches

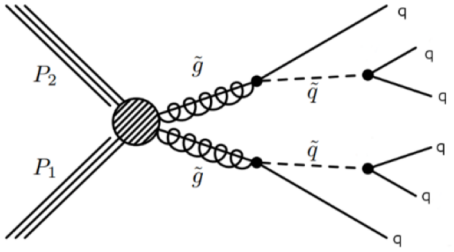
✧ Limits are set for stop → qq′ between 80 and 520 GeV,
& for stop → bq′ between 80 to 270 GeV,
285 to 340 GeV, &
400 to 525 GeV

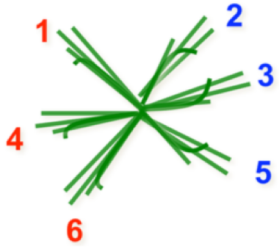


CMS-PAS-EXO-17-030

Search for Pair-Produced 3-Jet Resonance

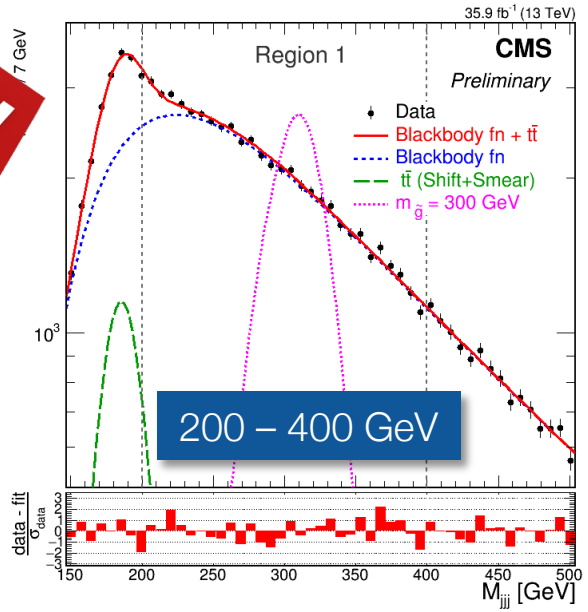
Model on RPV gluino decay, predict 3-jet resonance



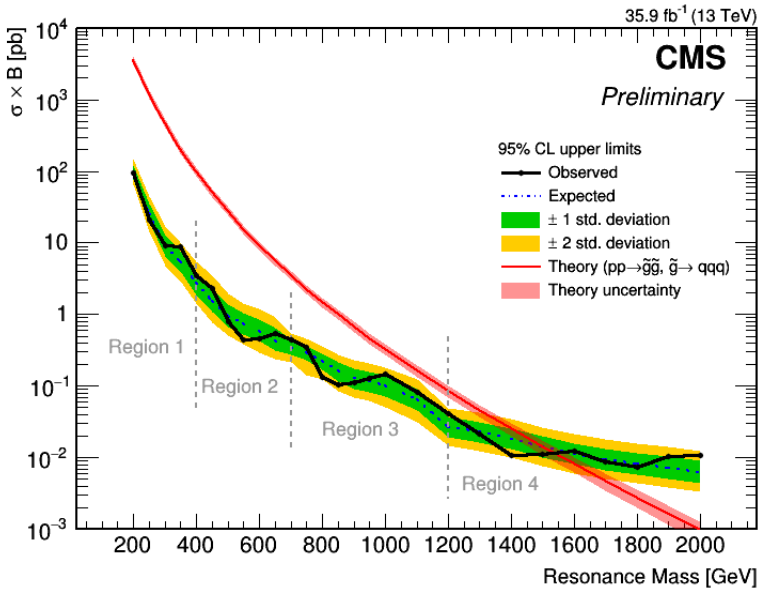


New

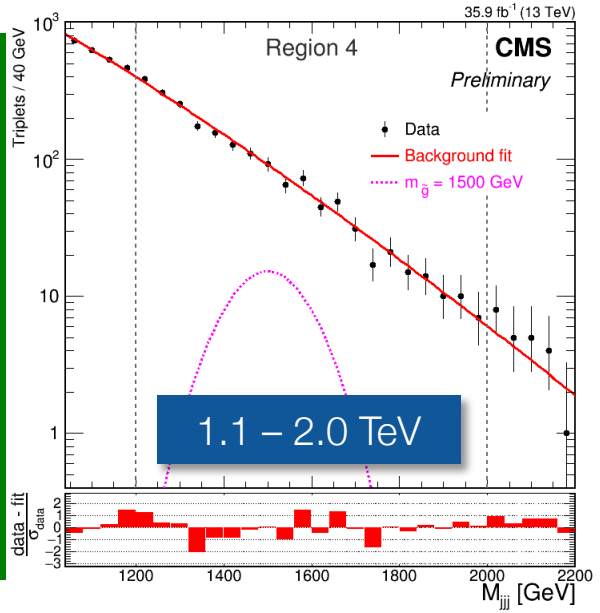
The search is optimized separately for 4 mass ranges from 200 GeV to 2000 GeV



- using PF scouting, run 2 search extends the invariant mass range down to ~ 200 GeV
- jet-ensemble technique, events with >= 6 jets
- make 10 triplet pairs & look at bump in triplet mass spectrum



- significant improvements in sensitivity compared to previous analyses, especially at low masses
- exclude gluino masses below 1.5 TeV
- This is the most stringent mass limit to date on this model of RPV gluino decay



Conclusions

- Searching for heavy resonances is one of the most direct ways to find new physics at TeV scale
- CMS has performed many dijet & multijet searches at 8 & 13 TeV.
- No significant excess observed in data (yet!)
- Only recent 13 TeV results are shown here today - many new results to arrive in the coming months.
- CMS has begun exploring the full Run 2 13 TeV dataset. Stay tuned!