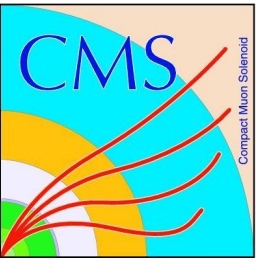
CMS Searches for New Physics in Hadronic Final States



Francesco Carnevali
INFN & Università degli Studi di Napoli Federico II

On behalf of the CMS Collaborations

EPS-HEP 2023

20th- 25th Aug 2023

Outline

• Recent results on the searches for new physics in hadronic final states at the CMS detector at LHC with Run II collision data (13 TeV):

- Search for pair-produced multijet resonances using data scouting. EXO-21-004
- Search for narrow trijet resonances in proton-proton collisions at $\sqrt{s} = 13$ TeV. EXO-22-008
- Search for leptoquarks produced in lepton-quark collisions and coupling to τ leptons. EXO-22-018
- Search for leptoquarks decaying to muons and bottom quarks. EXO-21-019
- Search for a high-mass dimuon resonance produced in association with b quark jets. EXO-22-016

•https://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO/index.html
•https://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html

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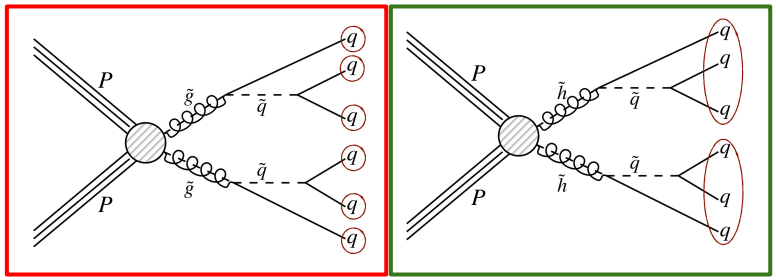
Search for pair-production multijet resonance

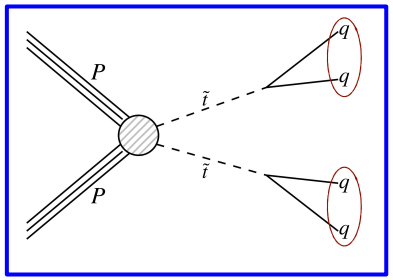
Run2 result 128 fb^{-1} , search for pair-produced multijet signatures, measuring the average mass distribution of pairs of trijets, and pairs of merged dijets.

The pair production of higgsinos, gluinos, and top squarks, in the R-parity violating (RPV) supersymmetric framework is considered.

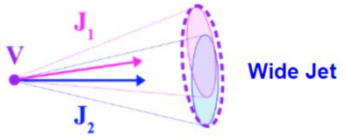
Three different signatures are taken into account according to the number of jets (AK4 or AK8) in final state and the AK8 jets substructure:

- pair of 3 AK4 jets
- pair of 2 AK8 jets, with a 2-prong sub-structure
- pair of 2 AK8 jets, with a 3-prong sub-structure

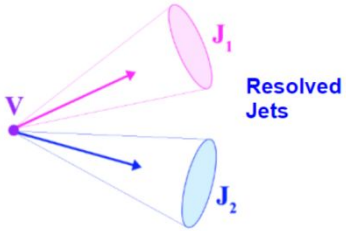




Fat Jet
Anti-Kt R=0.8
(AK8)



Narrow Jet
Anti-Kt R=0.4
(AK4)



EXO-21-004

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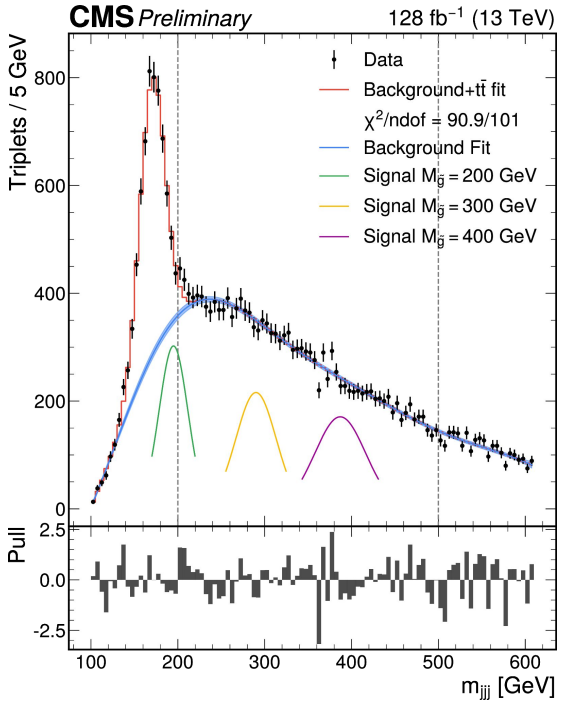
Search for pair-production multijet resonance

The three signatures are analyzed independently, but for all of them CMS scouting dataset is used: **partially reconstructed events** with H_T>450 GeV are saved.

The $t\bar{t}$ and the hadronically decaying Z/W bosons are backgrounds respectively to the **resolved trijets** and **boosted trijets** searches, and to the **boosted dijets** search. Monte Carlo samples are used to estimate these backgrounds.

The QCD multijet background is dominant, several requirements are applied to the events in order to reduce it, such as Quark-Gluon discriminator and Dalitz variables, $N^1_{2,DDT}$ and $\tau_{32,DDT}$. The latter make use of a Designed Decorrelator Tagger (DDT).

The remaining QCD background in the analyses is estimated using Gaussian Processes (GP) regression



Region	Gluino mass range (GeV)	Jet p_T (GeV)	H_T (GeV)	Sixth jet p_T (GeV)	$D^2_{[(6,3)+(3,2)]}$	A_m	Δ (GeV)	$D^2_{[3,2]}$
1	200–500	>30	>600	>40	<1.25	<0.25	>250	<0.05
2	500–900	>30	>600	>50	<1.00	<0.175	>180	<0.175
3	900–2000	>50	>900	>125	<0.9	<0.15	>175	<0.2

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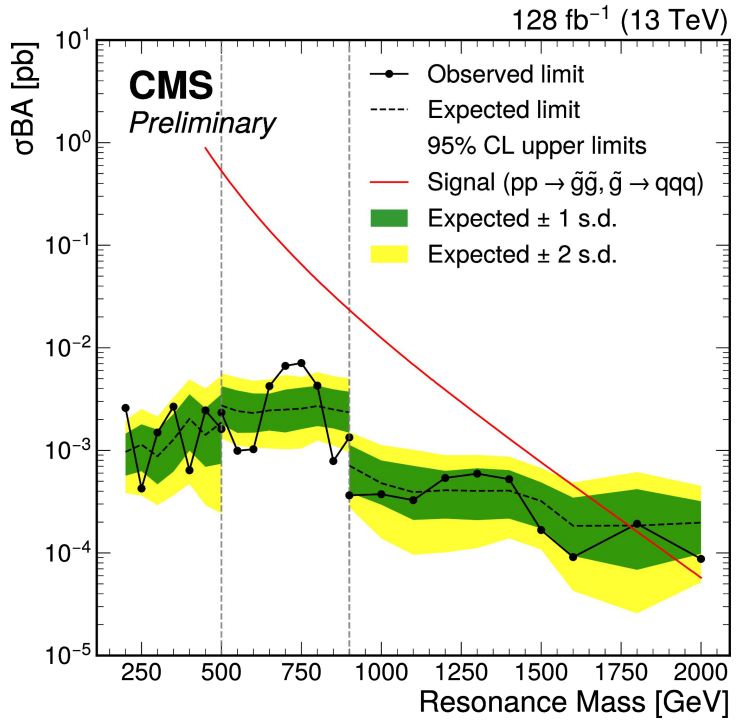

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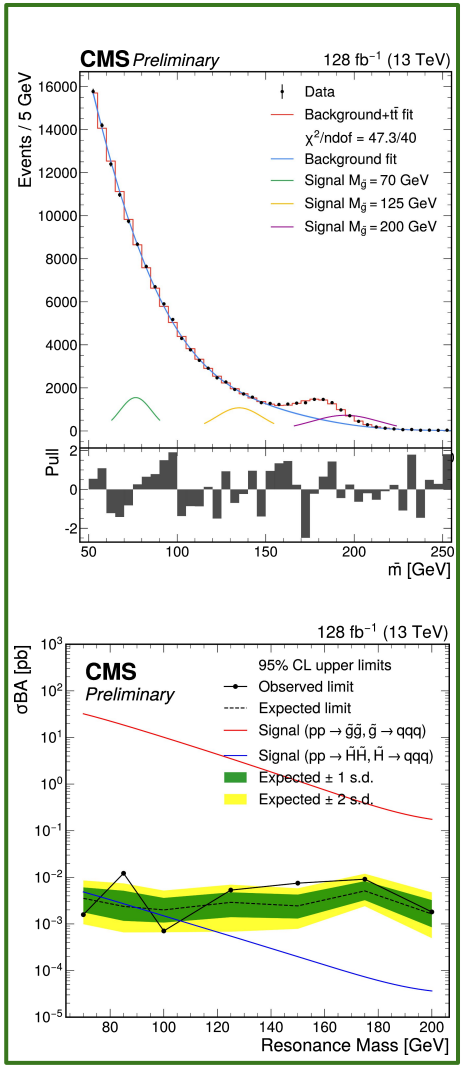
Search for pair-production multijet resonance

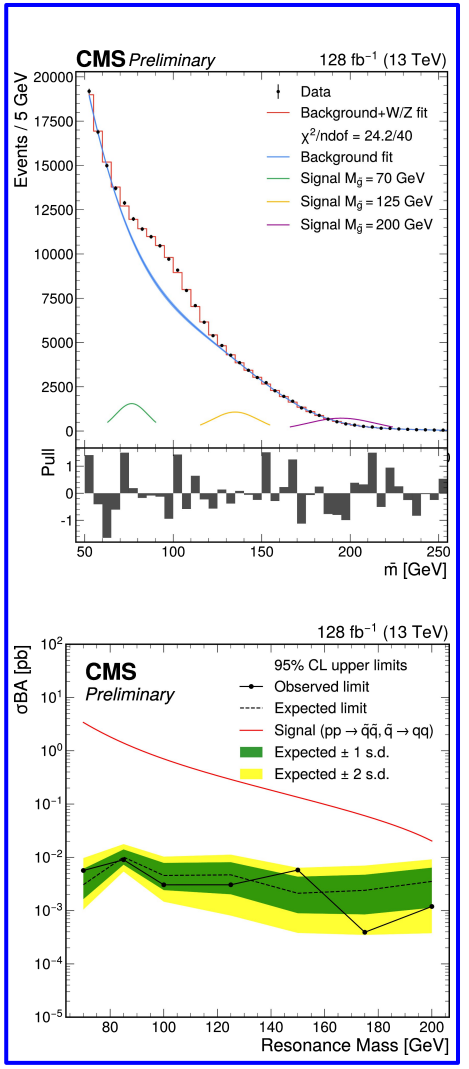
The trijet searches exclude RPV gluinos with mass between 70 GeV and 1.7 TeV.

The boosted dijet resonance search excludes RPV top squarks with masses between 70 and 200 GeV.

The boosted trijet resonance excludes RPV higgsinos masses between 70 and 75 GeV and between 95 and 105 GeV.

Most significant SM deviation at resonance mass of 768 GeV for the resolved search





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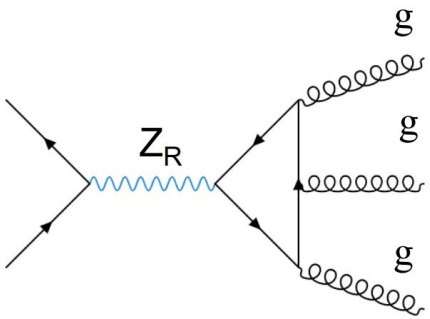
Search for narrow trijet resonances

Full Run2 result 138 fb^{-1} , search for three narrow jets resonances.

Different signal model are considered:

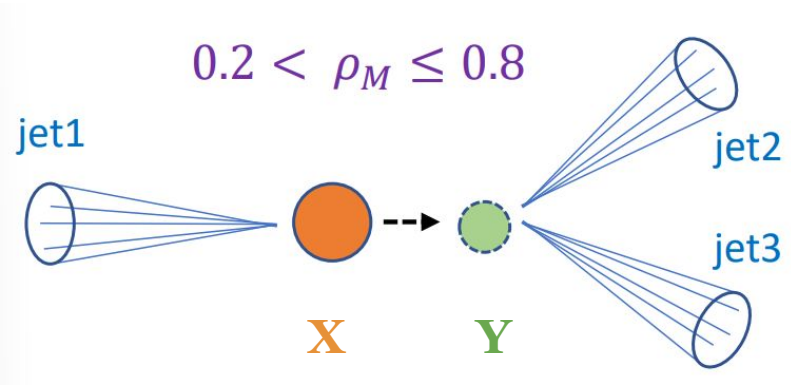
•direct 3-body decay of a right-handed Z_R boson, both with narrow and SM-like width



•cascade decay of a initiale resonance X, a Kaluza-Klein gluon or an excite quark q*, with intermediate resonance Y.

The new resonance X mass considered in the range 1.75-9.00 TeV.

In the mass range of Y, given by ratio ϱ_M requirements, its decay would form 2 resolved narrow jets.



$\varrho_M = M_Y/M_X$

EXO-22-008

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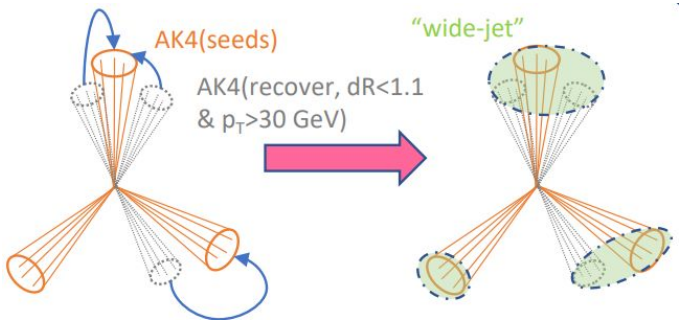
Search for narrow trijet resonances

Energy radiated by final state gluon is recovered reclustering the three leading AK4 jets into “wide-jets”



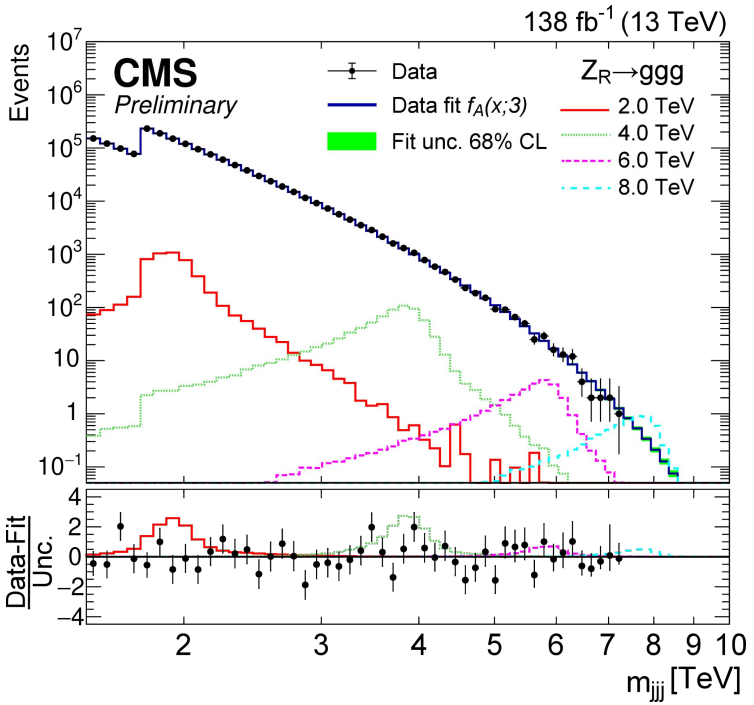
The trijet mass m_{jjj} is to be greater than 1.50 TeV ans 1.76 TeV, respectively for 2016 and for 2017/2018.

The QCD multijet is the dominant SM background. The background is estimated with data-driven method, fitting the trijet mass distribution with 3 parametric functions:

$$f_A(x;N) = p_0 \times \frac{(1-x)^{p_1}}{(x)^{\sum_{i=2}^{N} p_i \log^{i-2}(x)}}$$

$$f_B(x;N) = p_0 \times \frac{e^{-p_1(x)}}{(x)^{\sum_{i=2} p_i \log^{i-2}(x)}}$$

$$f_C(x;N) = p_0 \times (x)^{\sum_{i=1}^{N} p_i \log^{i-1}(x)}$$



x= $m_{jjj}/\sqrt{s}$ and N is the order of the fit function, which is determined using a Fisher F-test.

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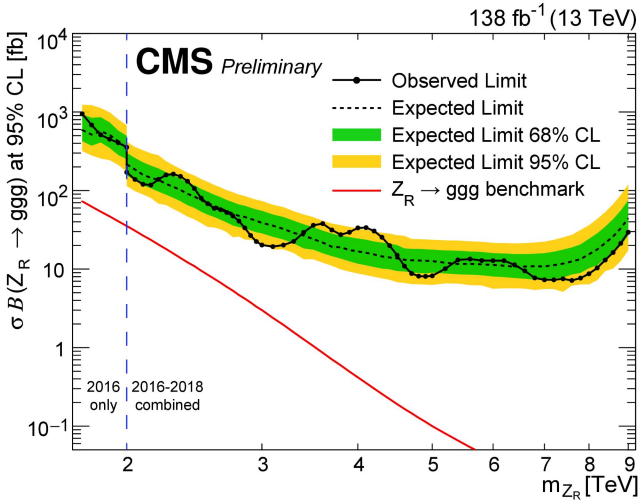
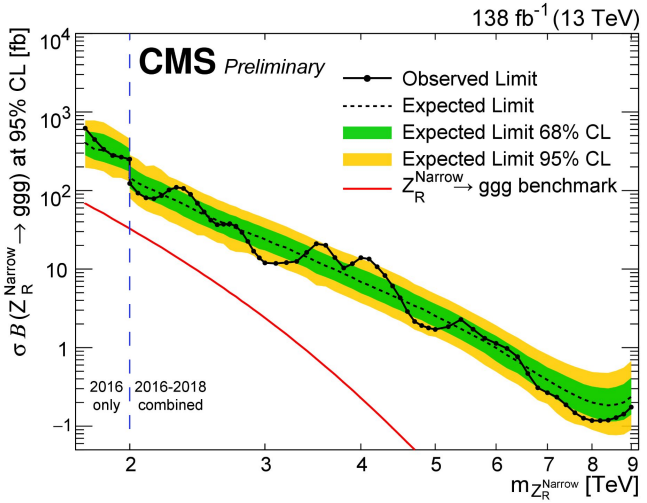
Search for narrow trijet resonances

The signal is extracted using a binned maximum-likelihood fit with variable bin size approximating the m_{jjj} resolution.

No significant excesses compatible with the signal hypotheses are observed.

For the $Z_R \rightarrow 3g$ signal scenario, the current data set does not provide sufficient sensitivity to constrain the Z_R model.





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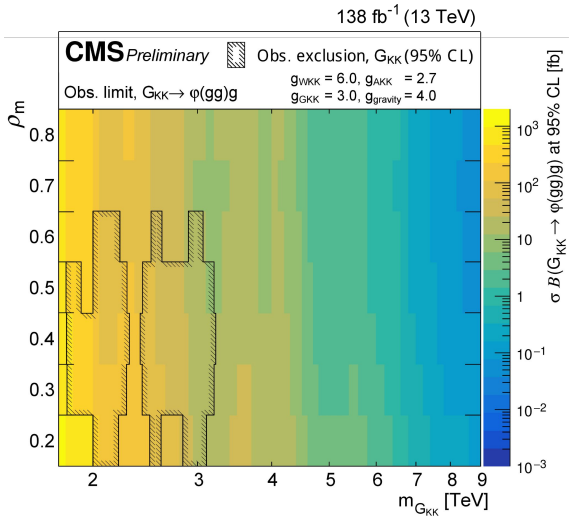
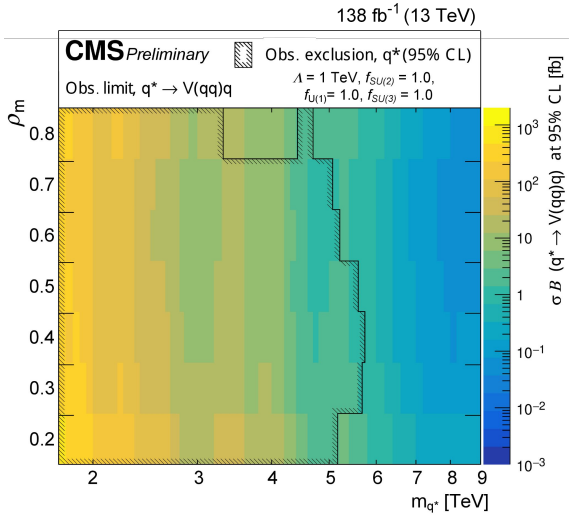
For the $X \rightarrow Y(gg)g$ and $X \rightarrow Y(qq)q$ cascade decay scenarios, upper limits are estimated as function of m_X and ρ_m.

At $\rho_m = 0.2$ this search shows similar sensitivity of previous search for the 3g decay mode.





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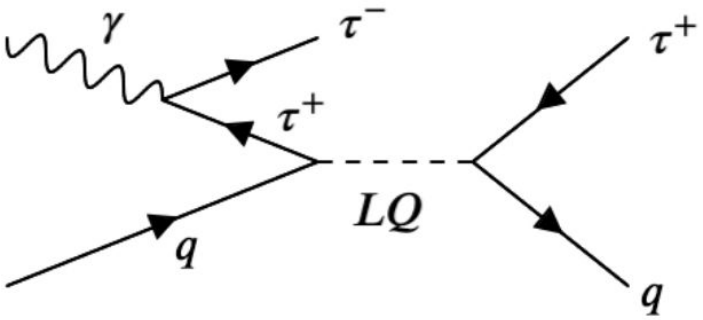
Search for leptoquarks coupling to τ leptons

Full Run2 result 138 fb^{-1} , search for leptoquarks produced in lepton-quark collisions and coupling to the τ lepton.

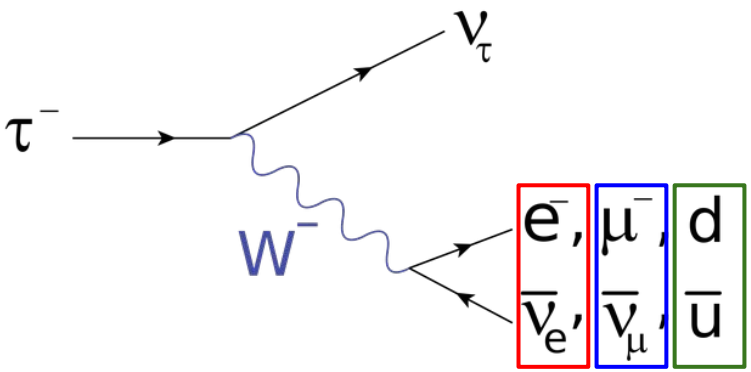
The leptoquarks (LQs) are color-triplet bosons carrying both baryon and lepton number that could explain the observed deviation from the SM measured in B meson decays.



The final state consists of a jet, missing transverse energy, and the τ lepton reconstructed through its leptonic or hadronic degays.

Three different final states are considered:

- e + jet
- μ + jet
- τ_h + jet



EXO-22-018

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Search for leptoquarks coupling to τ leptons

The requirements for the three channels are slightly different to take into account different background composition. The additional lepton veto ensure the orthogonality between the searches.

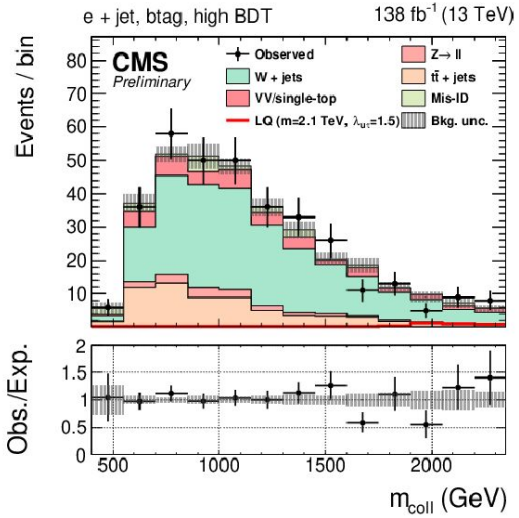
	τ_h + jet	μ + jet	e + jet
p_T^ℓ (GeV)	> 200	> 100	> 100
$\lvert\eta^\ell\rvert$	< 2.1	< 2.1	< 2.1
p_T^{jet}	> 300	> 200	> 200
$\lvert\eta^{jet}\rvert$	< 2.4	< 2.4	< 2.4
p_T^{miss} (GeV)	> 100	> 150	> 150
$p_T(\vec{\ell} + \vec{p}_T^{miss})$ (GeV)	> 100	> 100	> 100
$\lvert\Delta\phi(\ell, \vec{p}_T^{miss})\rvert$	< 0.3	< 0.2	< 0.2
$\Delta R(\ell, jet)$	> 0.5	> 0.5	> 0.5

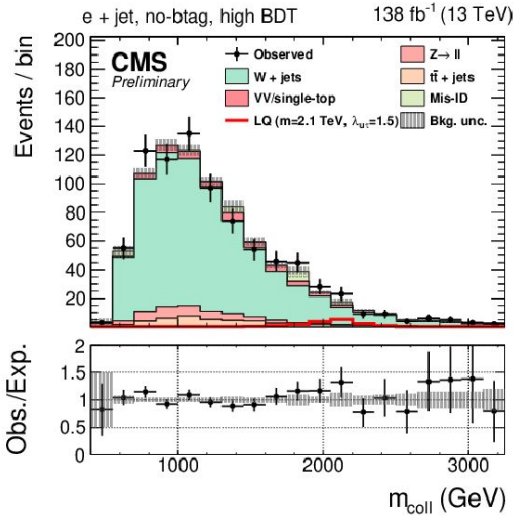
Events are classified in “btag” or “no-btag” category.

The main SM backgrounds with a prompt lepton in the final state are estimated from simulation. Normalization of W+jets in the “btag”category is extracted from data.

The dominant background in the τ_h channel is the QCD multijet. The jet misid of the total background is estimated from data with fake factor method.

BDTs are trained for each final state to separate signal from background





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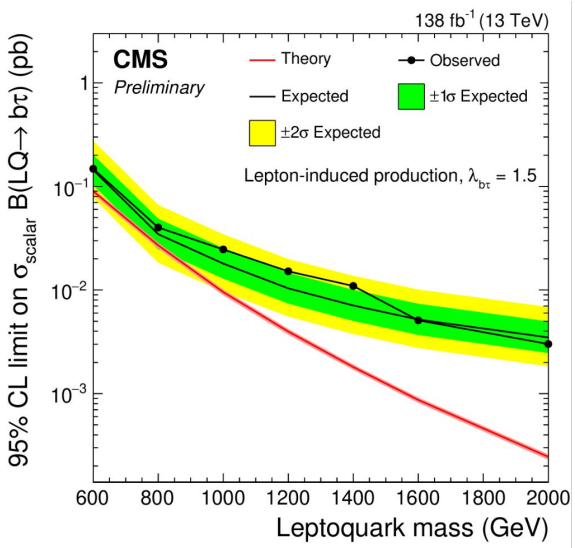
Search for leptoquarks coupling to τ leptons

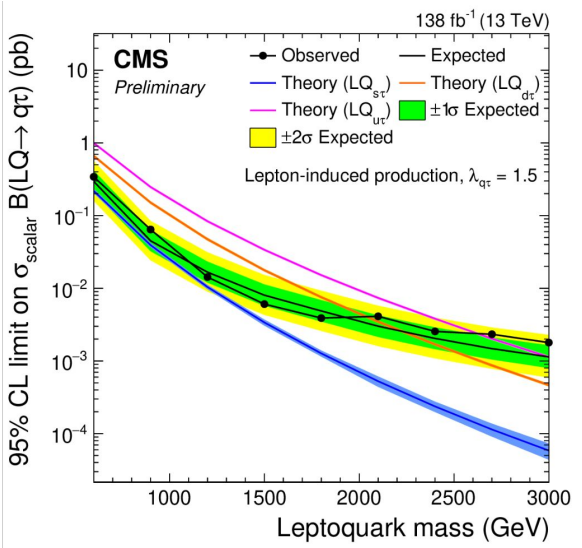
LQs coupling with light quarks (u, d, s) and b quarks are considered

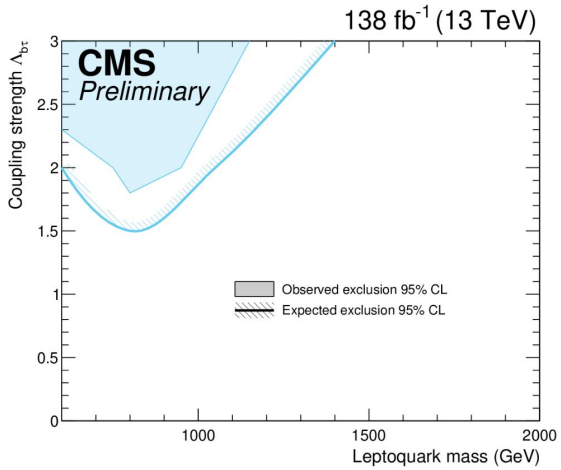
A maximum likelihood fit is performed with the signal normalization as a free parameter.

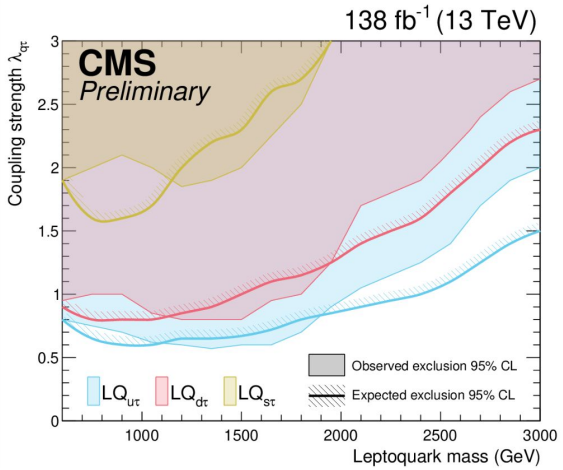
No statistically significant excess above the SM backgrounds is observed.

Upper limits at 95% confidence level are set on the LQ production cross section times branching fraction for different coupling hypotheses.









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Search for Leptoquarks decaying to muons and bottom quarks

Full Run2 result 138 fb^{-1} , search for LQs pair production, considering cross-generational coupling, i.e. lepton and quark from LQ decay of different generations.

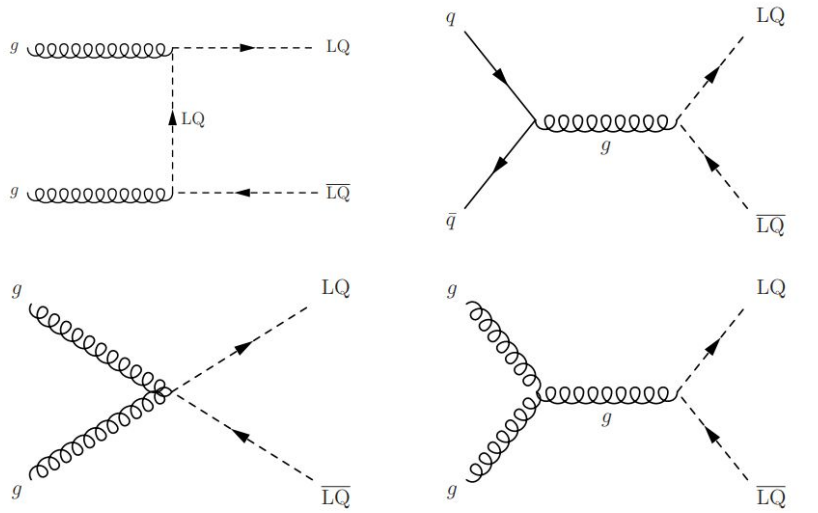
Masses above 300 GeV are investigated up to 3 TeV.

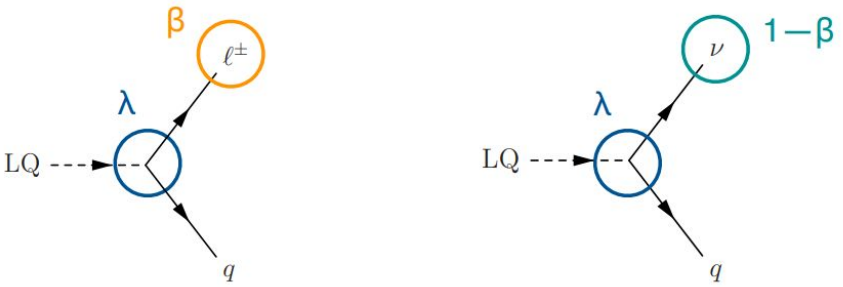
Events are selected applying kinematic cuts on muons and AK4 jets.

DeepJet b-tag requirement is required for at least one of the two jets.

$M_{\mu\mu} > 50$ GeV.

Veto on a third lepton.





EXO-21-019

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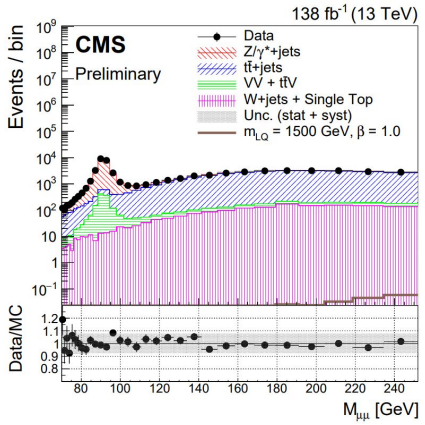
Search for Leptoquarks decaying to muons and bottom quarks

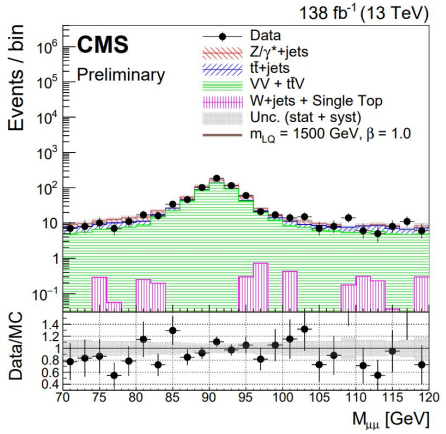
The main SM backgrounds shapes are taken from simulations, normalized to data at preselection in orthogonal CRs:

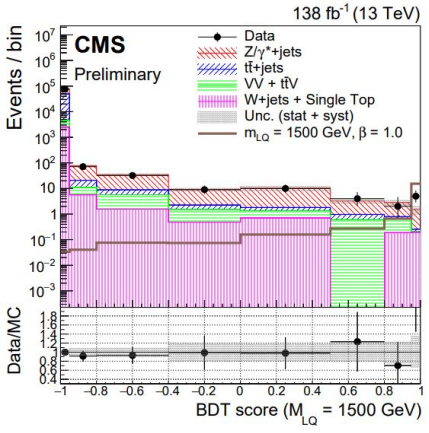
- Z+jets, $80<M_{\mu\mu}<100$ GeV in bin of N_{jets}
- $t\bar{t}$, $100<M_{\mu\mu}<250$ GeV
- Diboson and ttV, $80<M_{\mu\mu}<100$ GeV lepton ≥ 3 and bjet ≥ 0

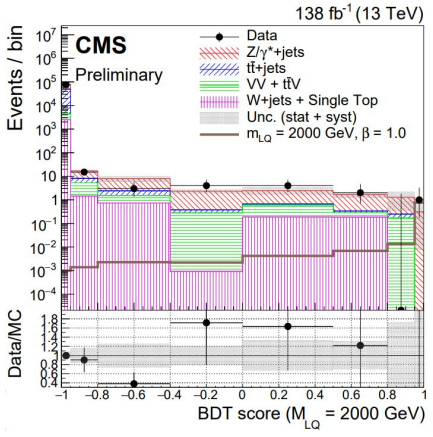
A boosted decision tree (BDT) is trained for each m_{LQ} hypothesis.

Key variables: $M_{\mu j1}$, $M_{\mu j2}$, $M_{\mu\mu jj}$, and ST









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Search for Leptoquarks decaying to muons and bottom quarks

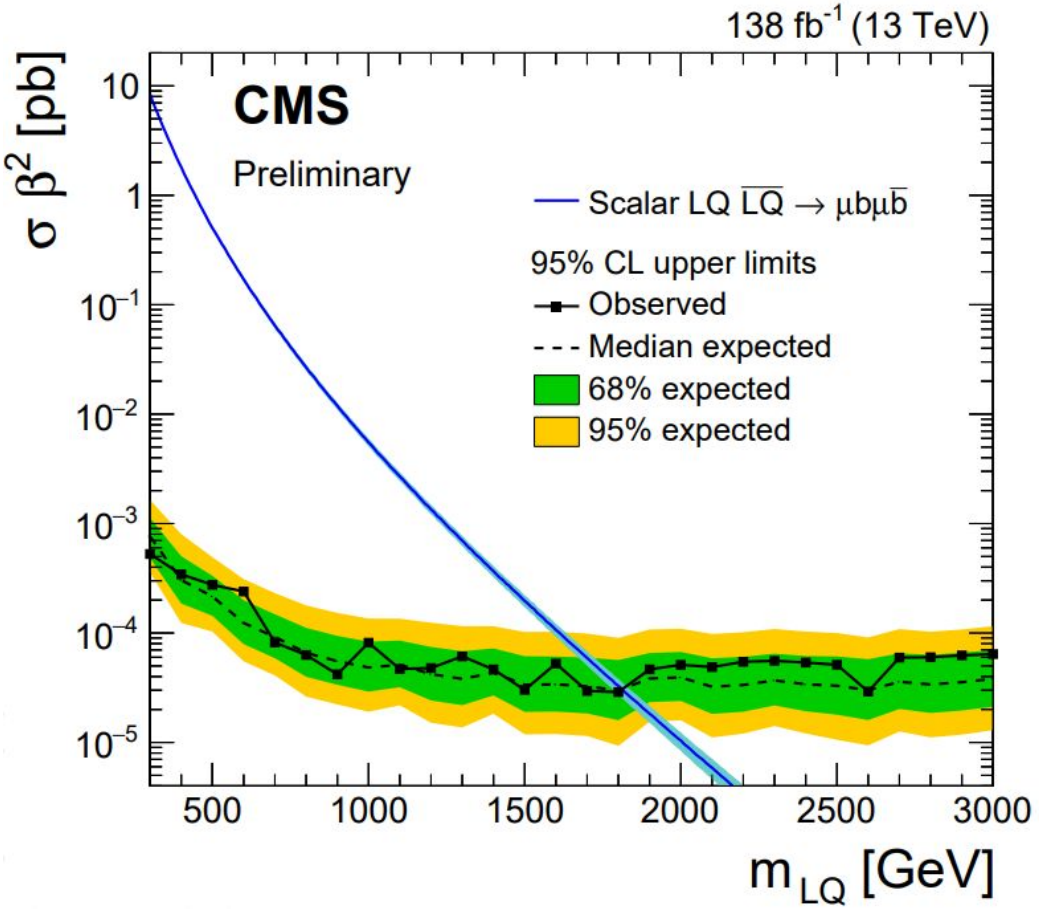
Final selection with a cut-and-count approach, optimized with final selection cut on BDT output.

Optimization with Punzi significance as figure of merit:

$$\frac{\epsilon(t)}{\frac{a}{2} - \sqrt{B(t)}}$$

No excess has been observed.

Leptoquarks with masses less than 1810 GeV are excluded for $\beta = 1$.



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Search for high-mass dimuon resonance with b quark jets

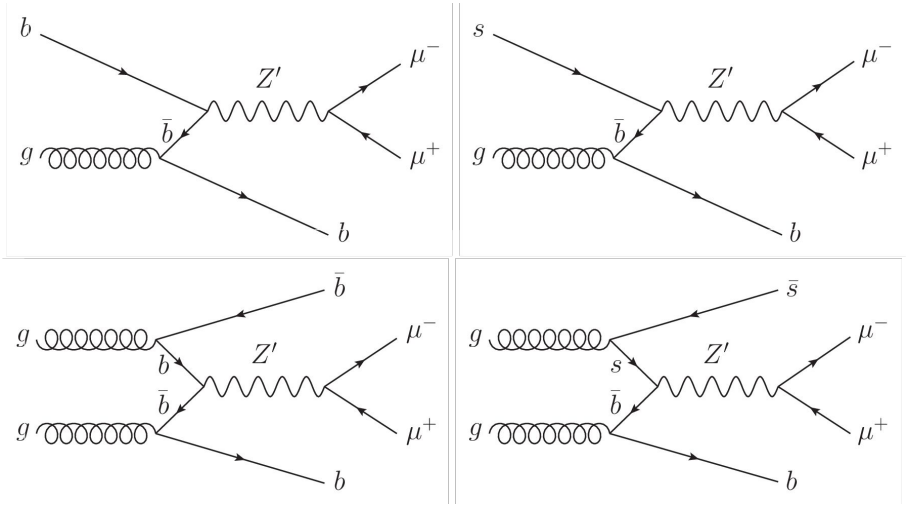
Full Run2 result 138 fb^{-1} , considering 4 different production of Z' boson, decaying to a dimuon couple.

Masses above 350 GeV are investigated and the Z' boson would couple to b and s quark.

Events are categorized according to the multiplicity of b quark jet:

- $N_b = 1$
- $N_b \geq 2$

DeepJet Tight and Relaxed requirements are used to identify these jets.



The width of the resonance is assumed to be narrow -> assumption validity ensured by restricting the search to the regions of parameter space where the Z′ width does not exceed half of the dimuon mass resolution

EXO-22-016

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Search for high-mass dimuon resonance with b quark jets

The dominant backgrounds are:

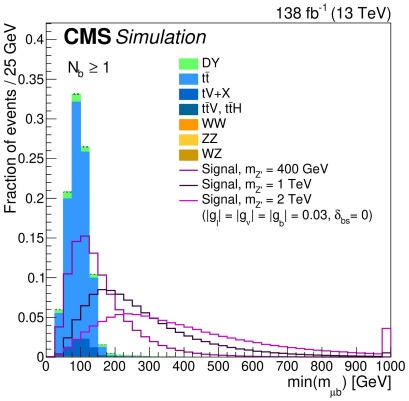
•Drell-Yan, reduced requiring at least one b-tagged jet

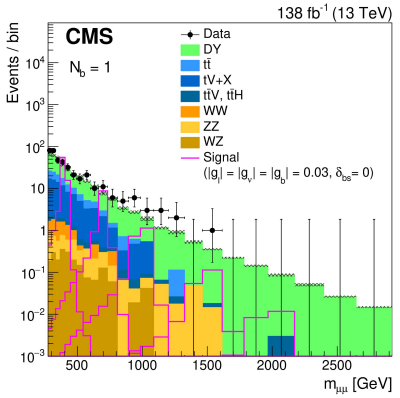
•$t\bar{t}$, suppressed by requiring $\min(m_{\mu b}) > 175$ GeV

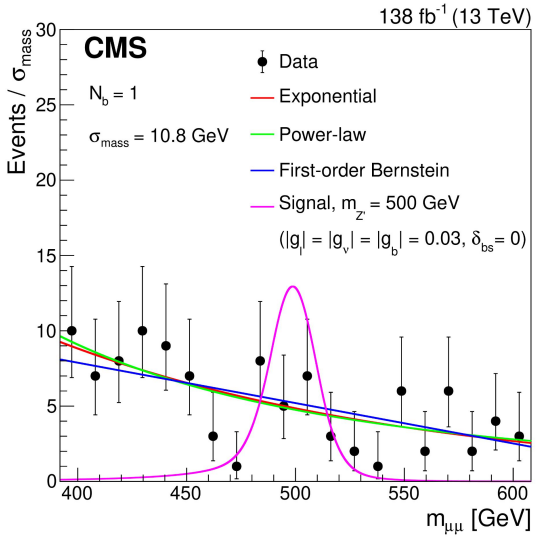
The search is performed by simultaneously fitting the unbinned $m_{\mu\mu}$ distributions in the two categories (depending on N_b)

•the signal distribution is parametrized as the sum of a Gaussian with a double sided Crystal Ball and a common resolution width σ_{mass}

•the background distribution can be modeled with Bernstein polynomials, or exponential, or power-law functions







Fit performed in a ± 10 σ_{mass} (which depends on the Z' mass) window

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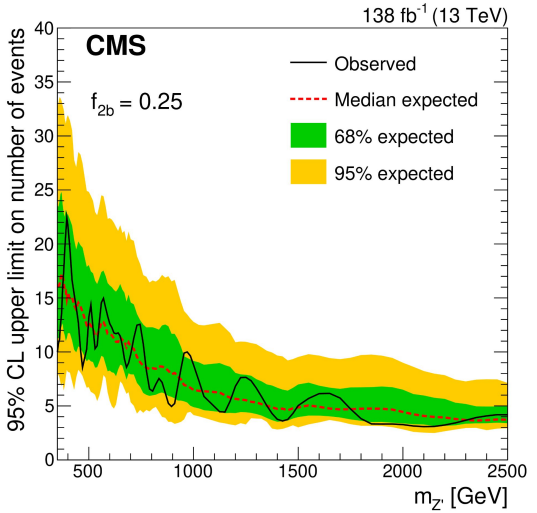
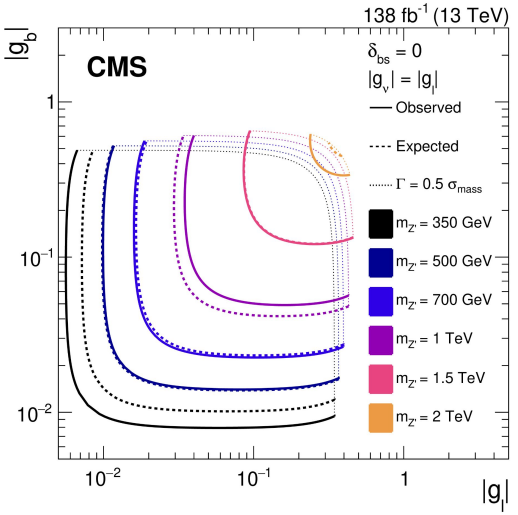
Search for high-mass dimuon resonance with b quark jets

No significant excess is observed over the background-only expectation in any of the mass windows.

The results are used to set model-independent limits at 95% confidence level (CL) on the number of signal events, taking into account different hypotheses of f_{2b} (fraction of signal events with $N_b>1$)

Results are also interpreted in terms of a lepton flavor-universal model, the exclusions are set on coupling strengths.





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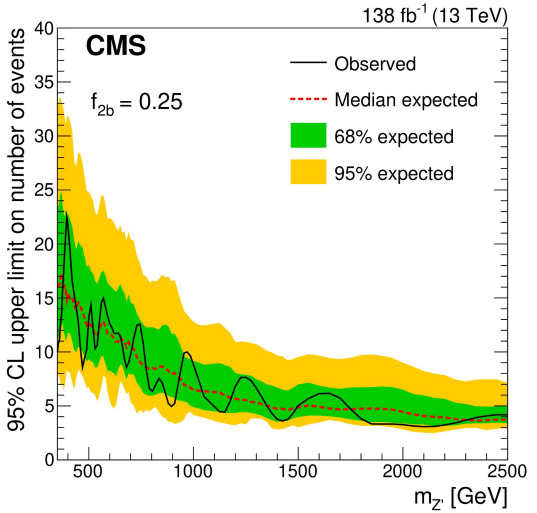
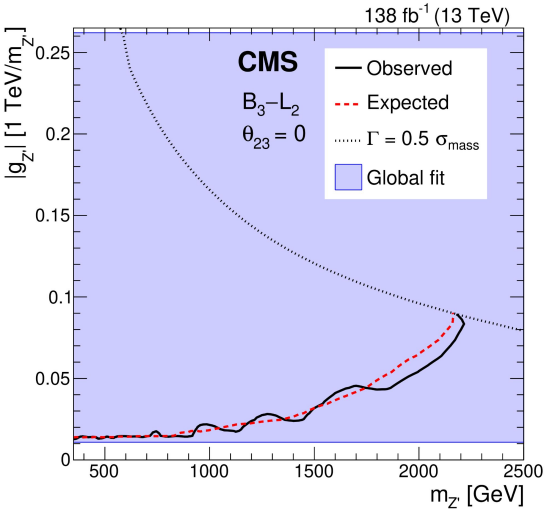
Constraints are also set on a specific Z′ model (B3−L2), taking into account $b \rightarrow s\, l^- l^+$ transitions beyond the standard model. Most of the allowed parameter space is excluded for a Z′ boson with $350 < m_{Z'} < 500$ GeV, but large regions of the parameter space are also excluded at higher masses.





Conclusions

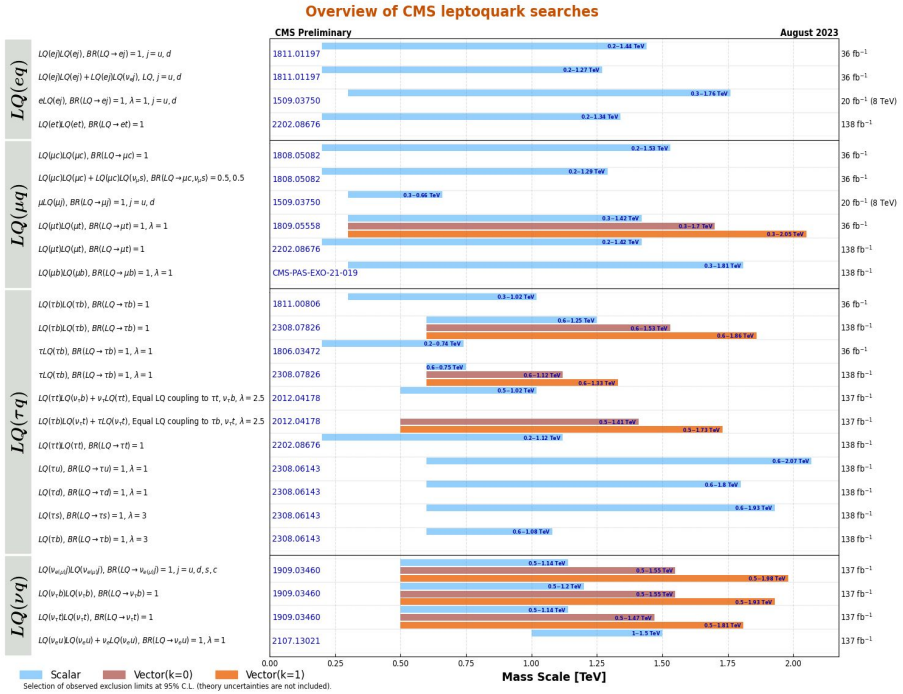
- Presented recent results on the searches for new physics in hadronic final states at the CMS detector at LHC.
- New selection and background modeling techniques has been used to improve the results.
- Most significant SM deviation at mass of 768 GeV for the resolved search of pair-produced multijet resonances using data scouting. This search set new limits on RPV gluinos, higgsinos, and top squarks masses.
- The search for a high-mass dimuon resonance produced in association with b quark jets provides model-independent constraints, together with exclusion limits on lepton flavor-universal model.
- This also excludes $m_{Z'}$ in the range 350-500 GeV, but large regions of the parameter space are also excluded at higher masses. Limits are set on a specific Z′ model (B3−L2).

Francesco Carnevali

Conclusions

- Limits on the coupling of LQs to light-flavour quarks and tau lepton are set for the first time, while b-tau coupling are competitive with those set using other production modes than the lepton-induce one. Pair-production LQs limits exclude masses below 1810 GeV.

- First time limits are set on the search for the three-body decay of high-mass resonances into three resolved jets at the LHC, with and without an intermediate resonance.

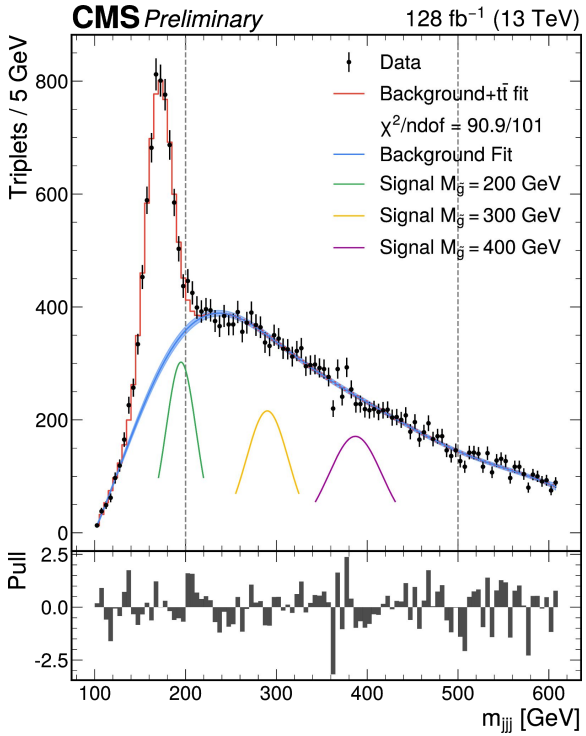


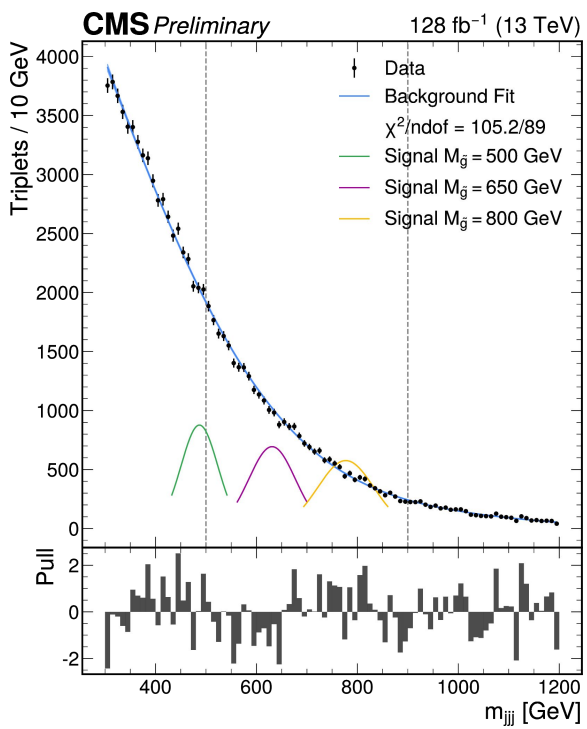
THANK YOU!

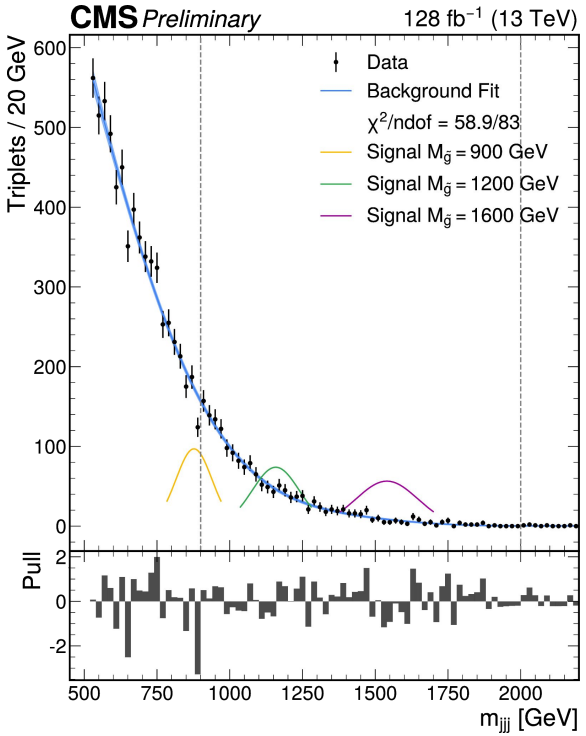
Francesco Carnevali

Search for pair-production multijet resonance

The remaining QCD background in the analyses is estimated using Gaussian Processes (GP) regression







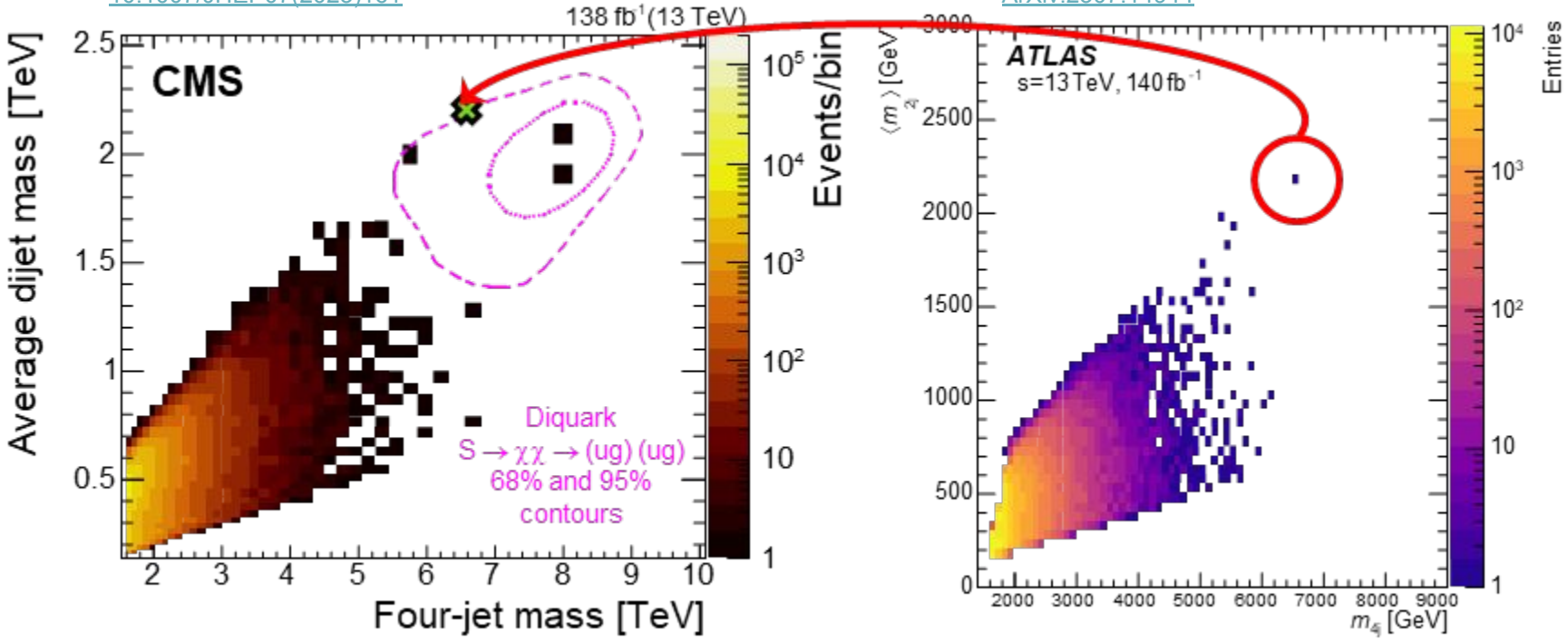
Region	Gluino mass range (GeV)	Jet p_T (GeV)	H_T (GeV)	Sixth jet p_T (GeV)	$D^2_{[(6,3)+(3,2)]}$	A_m	Δ (GeV)	$D^2_{[3,2]}$
1	200–500	>30	>600	>40	<1.25	<0.25	>250	<0.05
2	500–900	>30	>600	>50	<1.00	<0.175	>180	<0.175
3	900–2000	>50	>900	>125	<0.9	<0.15	>175	<0.2

Francesco Carnevali

Search for paired dijet resonances

10.1007/JHEP07(2023)161

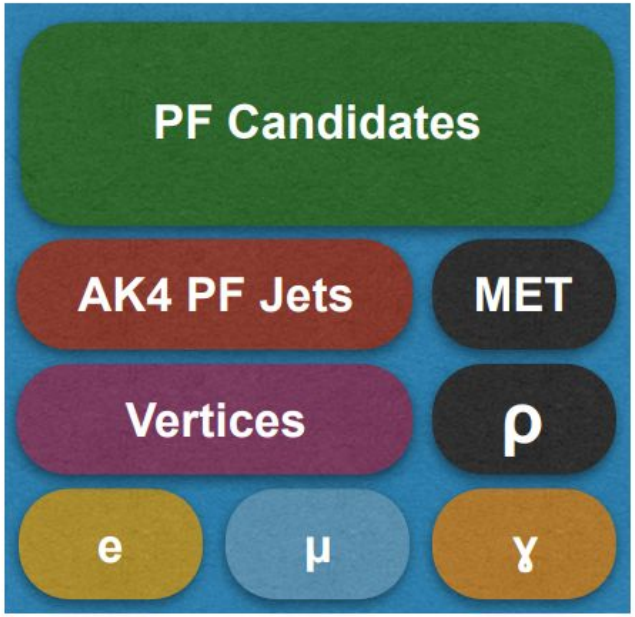
ArXiv:2307.14944



- The highest mass event recorded by the ATLAS experiment with the Run2 data has a four-jet mass of 6.6 TeV and a dijet mass of 2.2 TeV.
- ATLAS performed a paired dijet search with the same selection criteria as the CMS search, such that they are directly comparable, and reported no statistically significant excesses.
- This event lies on the boundary of our 95% CL contour for an 8.4 TeV diquark resonance.

CMS Data Scouting

- The aim of data scouting is to record physics events at the highest possible rate while providing physics objects whose performance is suitable for offline analysis.
- The data scouting strategy is implemented via dedicated streams at the HLT. Each data scouting stream contains a number of trigger paths (scouting triggers), which perform event reconstruction and selection in the same way as standard HLT paths. However, the selection criteria are much looser than for standard paths .
- Partially reconstructed event are saved and analysed.



https://arxiv.org/pdf/1808.00902.pdf