Searches in CMS for new physics in final states with jets

Lepton-Photon 2025

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RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

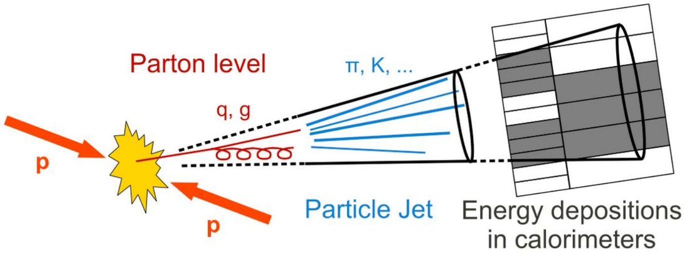
CMS
Compact Muon Solenoid

Introduction

- Despite being our most successful theory of particle physics, **the Standard Model is incomplete**.
    - What is 95% of the universe made of? Nature of dark matter?

- Many theoretical models involve Beyond the Standard Model **(BSM) processes that result in jets in final states.**
    - New fermions (T', B'...)
    - New gauge groups (Z', W'...)

    . . .



- The **CMS Experiment** has a rich program of searching for such processes. **In this talk I will be covering a selection of recent results performed using CMS data from Run II (2016-2018) :**

    - **EXO-24-038 :** Broad resonance reinterpretation of high-mass $Y \rightarrow XX \rightarrow (jj)(jj)$
    - **EXO-23-004 :** Search for dijet resonances ($X \rightarrow jj$) with data scouting
    - **B2G-22-001 :** Search for $X \rightarrow t(bqq)\phi(bb)$ in boosted final state **(NEWEST!)**

TeV scale resonances

Scouting data

ML-based taggers

Resolved/Boosted final states

General Analysis Methodology

Analysis Strategy

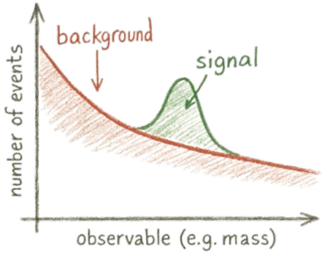
Reconstruct the mass of final state observed particles mass spectrum of BSM candidates and search for bumps/resonances in top of the invariant mass spectrum

Signal Modeling

Simulate signals (narrow, with width smaller than the detector resolution, or broad resonances).

Background estimation

Model the background from Standard Model processes (Data-driven bkgd. function or sidebands, Simulation)



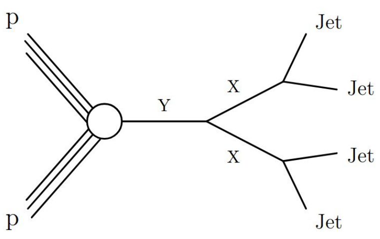
Limit extraction and Significance estimation

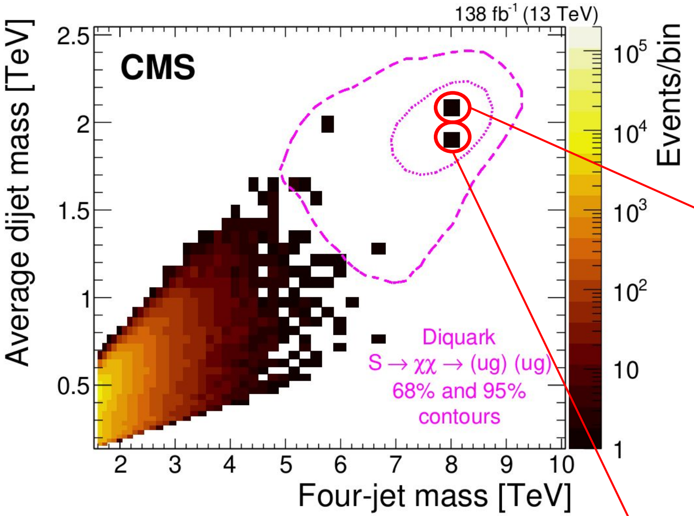
Fit the jet invariant mass spectrum using background and signal templates with systematics as nuisance parameters.

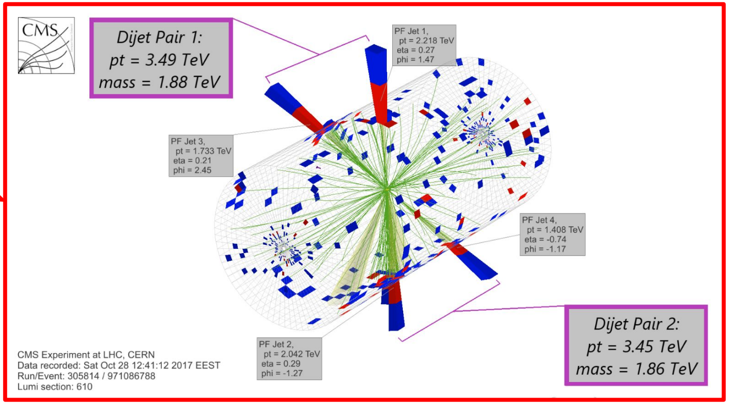
EXO-24-038 :
Broad resonance reinterpretation of high-mass $\mathbf{Y} \rightarrow \mathbf{XX} \rightarrow (\mathbf{jj})(\mathbf{jj})$

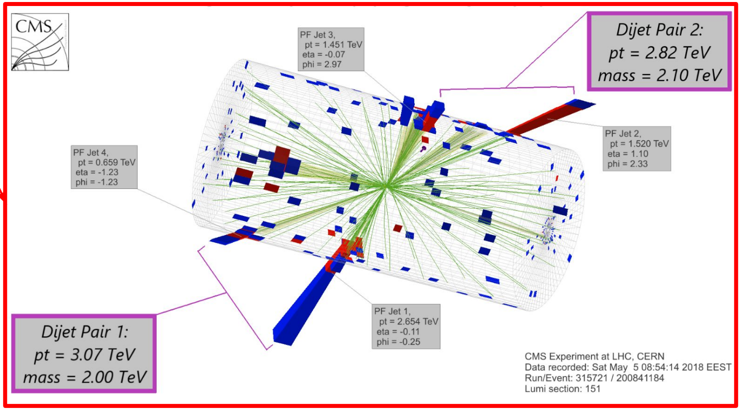
Narrow resonance search for high-mass $Y \rightarrow XX \rightarrow (jj)(jj)$

JHEP07(2023)161





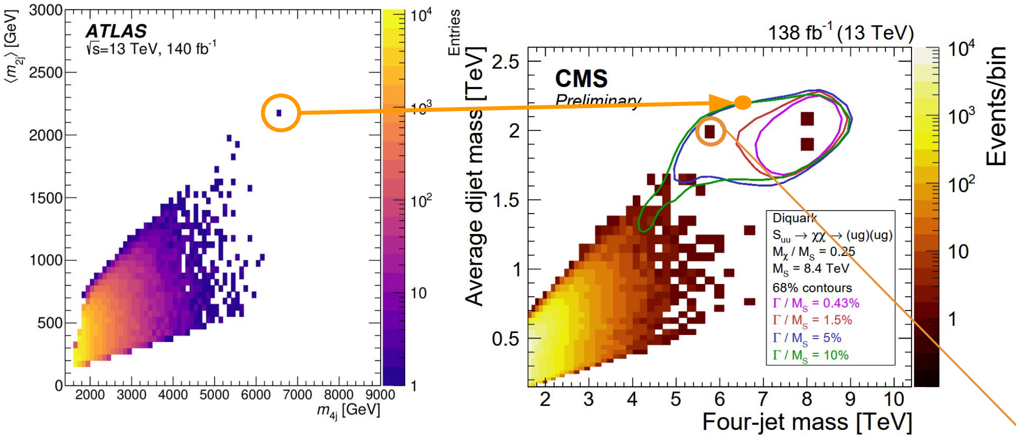


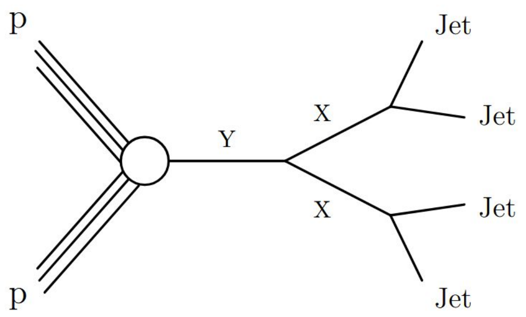


- We published **a narrow resonance search that found two high mass events causing an effect at M_Y=8.6 TeV with a local significance of 3.9 sigma, global significance 1.6 sigma.** [JHEP07(2023)161]

Broad resonance reinterpretation of high-mass $Y \to XX \to (jj)(jj)$

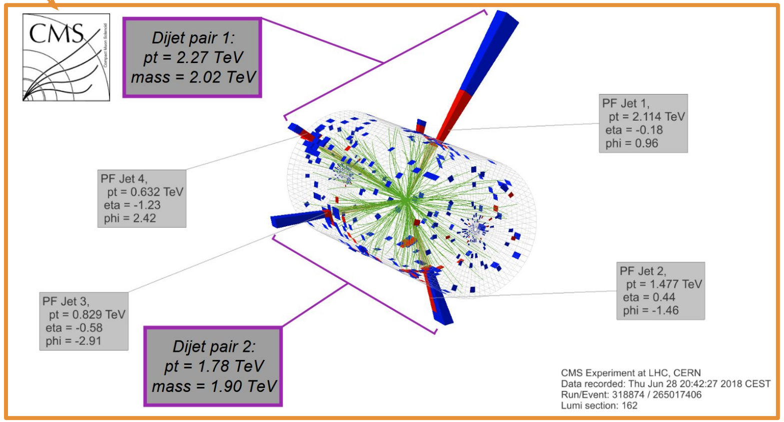
[CMS-PAS-EXO-24-038](#)
[arXiv:2507.17884](#)





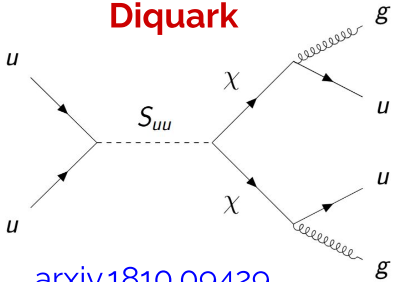
- **Reinterpretation of [JHEP07(2023)161](#), motivated by CMS and ATLAS Run-2 data [[PhysRevD.108.112005](#)] with $\langle m_{2j} \rangle \sim$ 2 TeV and a wide spread in m_{4j}.**

- Searching here for a **broad mediator, Y,** decaying into a pair of **narrow dijet resonances, X.** Resolved jet final state.

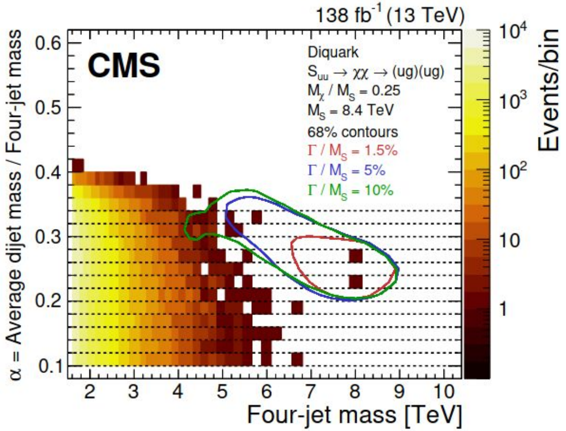


Broad resonance reinterpretation of high-mass $\mathrm{Y} \rightarrow \mathrm{XX} \rightarrow (\mathrm{jj})(\mathrm{jj})$

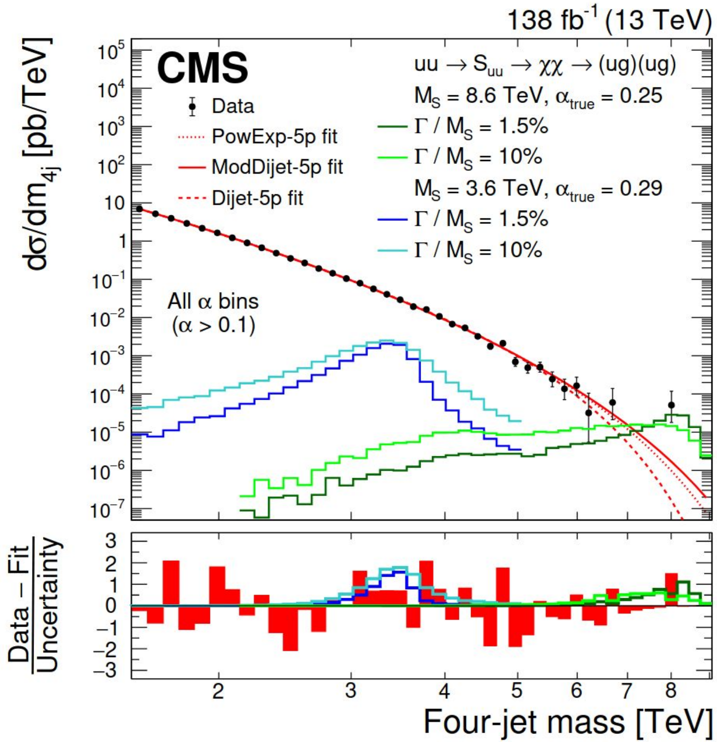
Diquark



[arxiv.1810.09429](https://arxiv.org/abs/1810.09429)
(Dobrescu et al)



[CMS-PAS-EXO-24-038](https://cds.cern.ch/)



- Same data as in the **narrow resonance (Γ(Suu)/MS < 0.5%) search [JHEP07(2023)161]**, **fitted now with broad resonances, with a width of Γ(Suu)/MS = 1.5%, 5%, 10%.**

Dominant Background

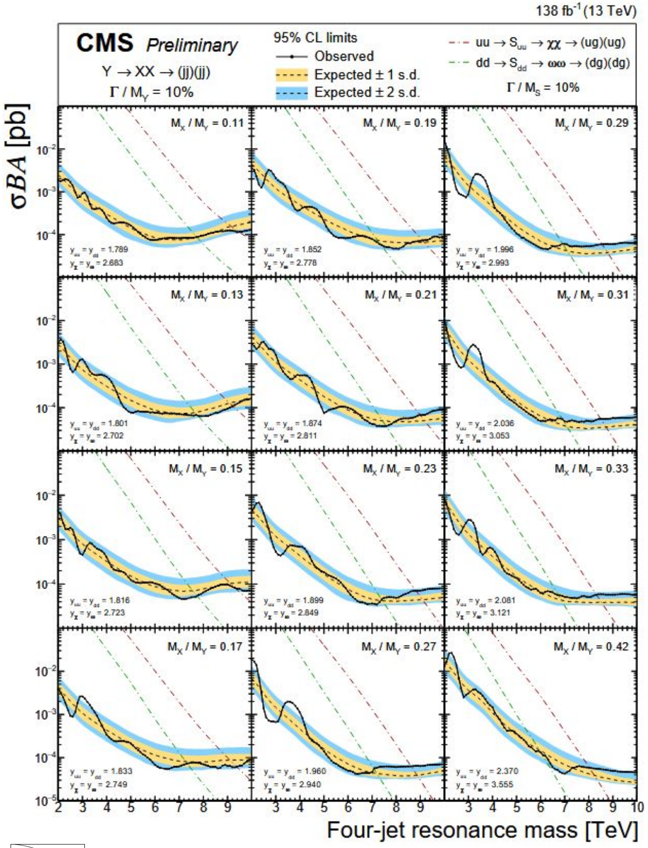
QCD multijet production

Data-driven background prediction

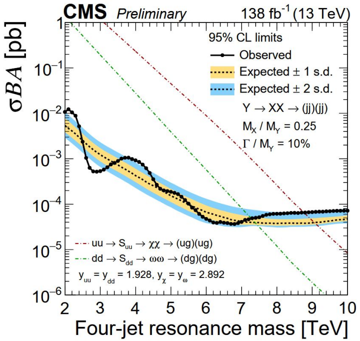
Four-jet mass is fitted simultaneously in bins of $\alpha = \langle m2j \rangle / m4j$ with 3 parametric functions using the discrete profiling method

Broad resonance reinterpretation of high-mass $\mathbf{Y \to XX \to (jj)(jj)}$

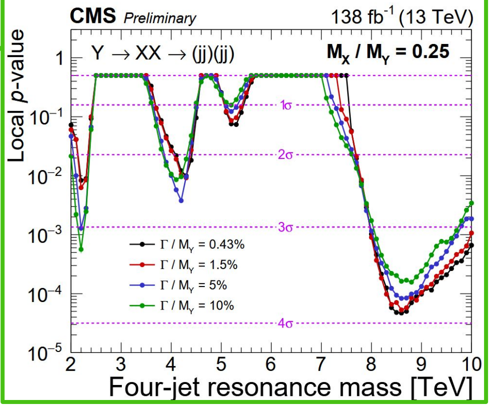
[CMS-PAS-EXO-24-038](#)



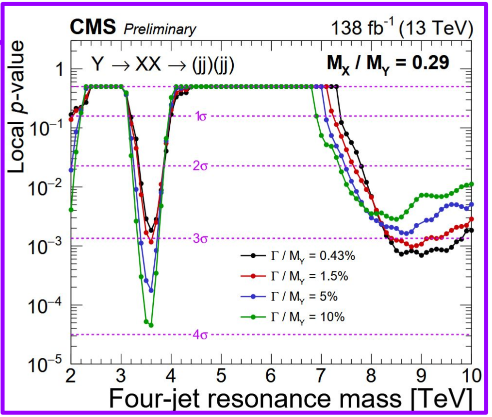
- Set **model-independent** cross section limits for **various $\mathbf{Y}$ and $\mathbf{X}$ masses, and $\mathbf{Y}$ widths up to 10%.**
- **Mass limits on diquarks $\mathbf{Suu}$ and $\mathbf{Sdd}$ decaying into vector-like quarks.** [arXiv:1810.09429](#)



At M_Y= 8.6 TeV a broad resonance is an equally valid interpretation of the excess: 3.6σ wide vs. 3.9σ narrow.



A second effect is reported at M_Y = 3.6 TeV, M_X = 1.0 TeV and Γ/M_Y = 10%: 3.9σ (2.2 σ) local (global) significance.



EXO-23-004 :
Search for dijet resonances ($\mathbf{X}\rightarrow jj$) with data scouting

Search for dijet resonances (X→jj) with data scouting

Data scouting
(Jacopo Pazzini's talk)

Dijets reconstructed online at the High Level Trigger (HLT) from calorimeter information (CALO jets)

⇩

Enables us to probe dijet resonance masses between 600 and 1800 GeV, previously inaccessible with common datasets.

CMS-PAS-EXO-23-004

Search for dijet resonances ($X \to jj$) with data scouting

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Dijets reconstructed online at the High Level Trigger (HLT) from calorimeter information (CALO jets)

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Enables us to probe dijet resonance masses between 600 and 1800 GeV, previously inaccessible with common datasets.

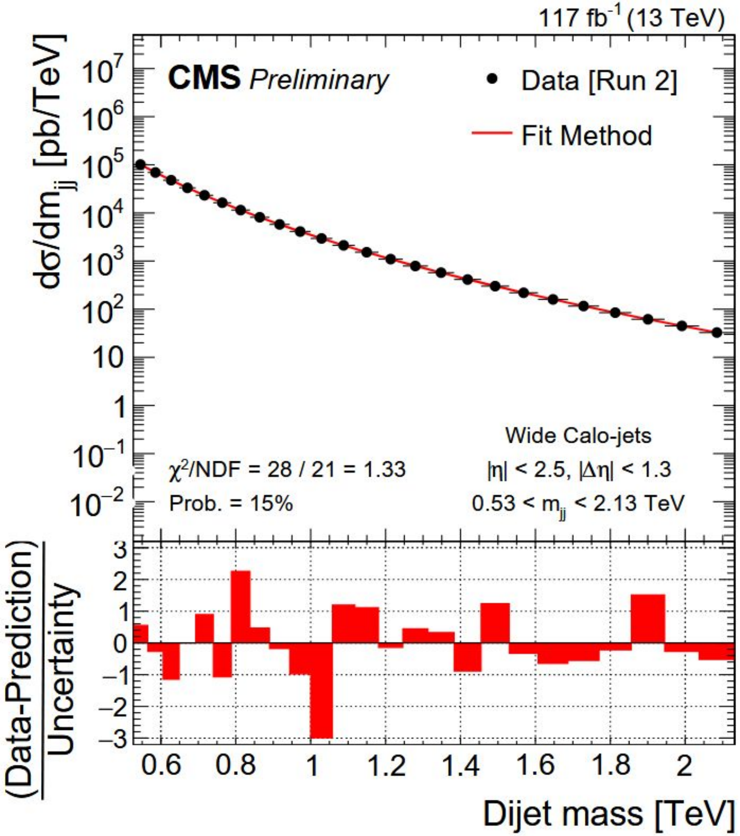
- **This analysis : Search for generic narrow dijet resonances in qq, qg and gg final states.**

- **Experimental Signature : A dijet, formed by two wide-jets.**
  Wide-jet reconstruction : *The two leading (in p_T) AK4 jets are used as seeds. Spatially close jets (ΔR < 1.1) are combined into a wide jet.*

Dominant Background : QCD multijet production

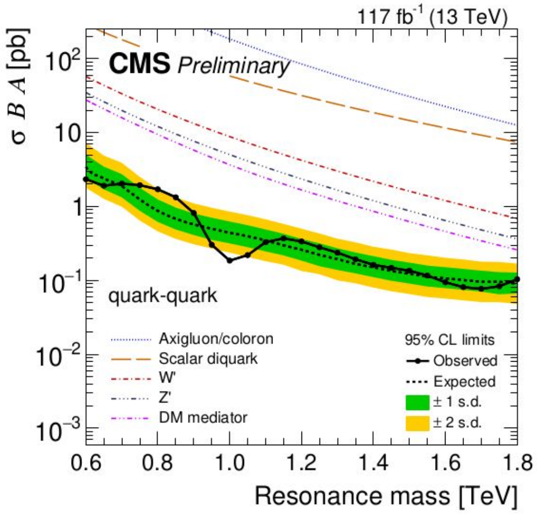
Data-driven background prediction : Model QCD by fitting data directly with a background function.

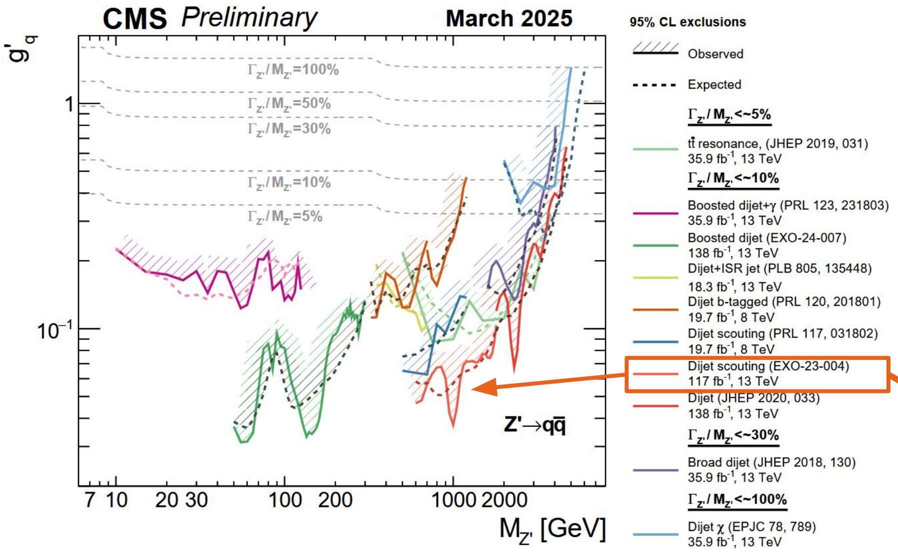
CMS-PAS-EXO-23-004

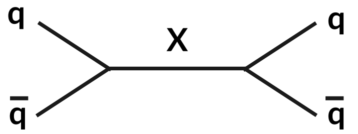


Search for dijet resonances (X→jj) with data scouting

[CMS-PAS-EXO-23-004]







Best limits on dark matter mediator coupling to quark, gq' in the probed mass range

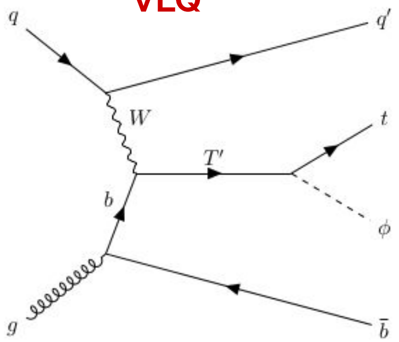
- **Signal extraction**: Due to **large dataset** and to **avoid correlations between signal strength and background nuisance parameters → fit Run-2 sub-datasets simultaneously → Robust results.**
- Use of **4-parameter function** instead of 5-parameter used in 2016 publication → **improved sensitivity (more than lumi scaling)**

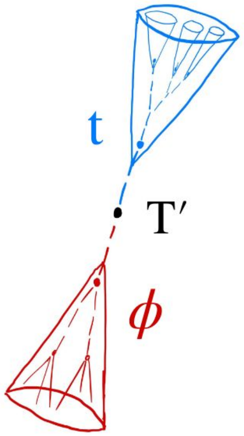
NEWEST!

EXO-22-001 :
Search for $X \rightarrow t(bqq)\phi(bb)$ in boosted final state

Search for $X \to t(bqq)\phi(bb)$ in boosted final state

VLQ





Newest! [CMS-PAS-B2G-22-001]

B2G-18-003 : T'->tH, H->bb
This analysis : Extending search to consider decay of VLQ to new scalars

Boosted regime :
Top quark and ϕ highly boosted →Dijet topology, with two high pT large-radius jets

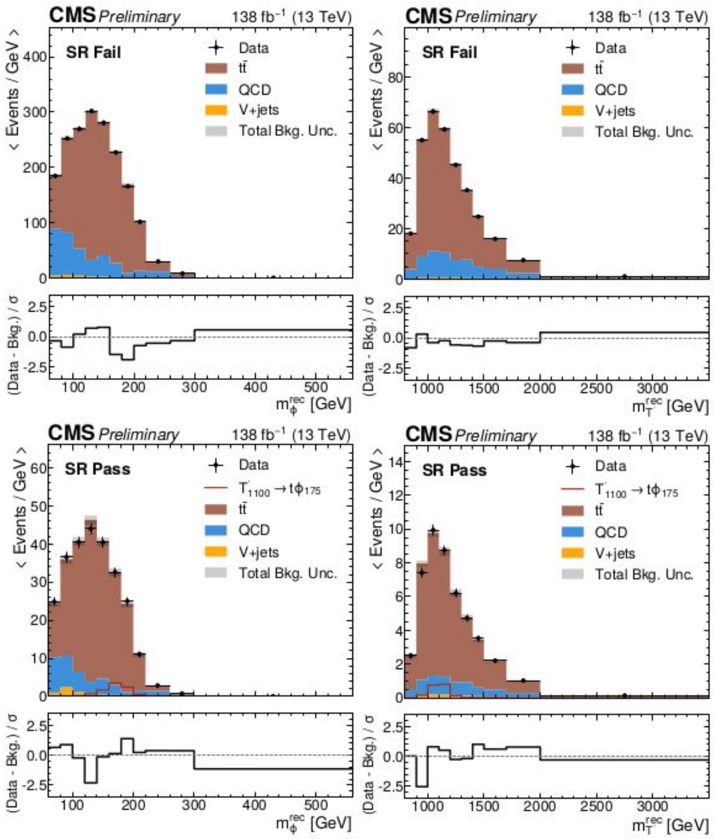
Benchmark model
T': Vector-Like Quarks
ϕ: SM Higgs or BSM scalar
$m_{T'} \in$ [900, 4000] GeV
$m_{\phi} \in$ [75, 500] GeV

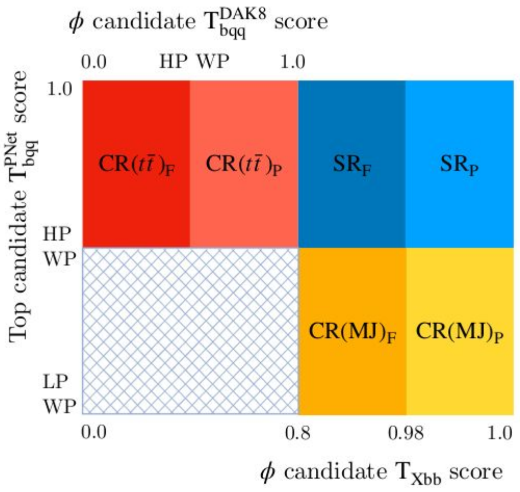
The analysis exploits **state-of-the-art substructure techniques and taggers to identify boosted final states**:

- **ParticleNET jet tagger** to identify jets from **top** and **$H \to b\bar{b}$** : **the leading graph-based tagger in CMS** [PhysRevD.101.056019]
- **DeepAK8 jet tagger** to identify jets from the second **$\bar{t}$op** only in **tt control-region**: **CNN based tagger** [arXiv:2004.08262]

Search for X→t(bqq)ϕ(bb) in boosted final state

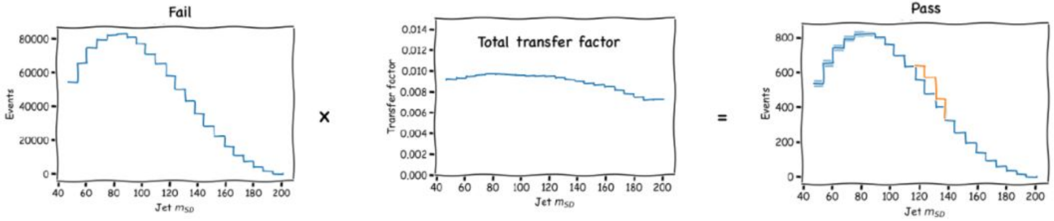
Newest! CMS-PAS-B2G-22-001





Final results derived from **simultaneous fit of CR(tt) and SR**

Validation Region



Dominant backgrounds

QCD multijet → data-driven prediction

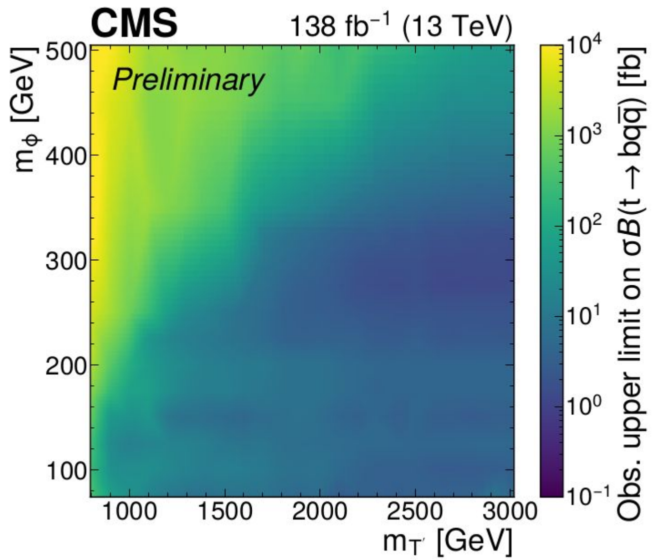
Resonant $t\bar{t}$ production → MC simulation

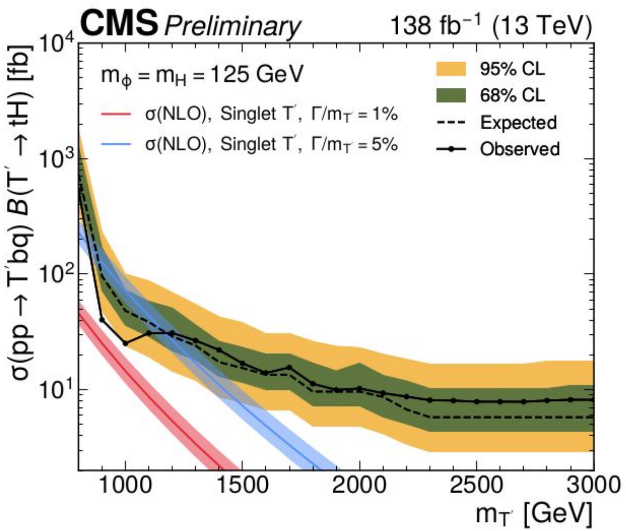
(Much) smaller backgrounds:

V + jets → prediction from MC

Search for $X \to t(bqq)\phi(bb)$ in boosted final state

Newest! [CMS-PAS-B2G-22-001]





- A 2D maximum likelihood fit is performed in $m_{T'}^{rec}$ and m_{ϕ}^{rec} , simultaneously in SR and CR(tt).
- No significant deviation from Standard Model observed. Upper limits set on the cross-section of T' production, as a function of ($m_{T'}$, m_{ϕ}).
- For T' -> tH, T' mass exclude below at 1.2 TeV at 95% CL for T' singlet with 5% width.

Summary

- **CMS has reinterpreted its search for resonant production of pairs of dijet resonances in Run 2:**
  - **The effect at M=8.6 TeV is compatible with a broad resonance**, and **there are candidate events from both CMS and ATLAS**
  - **There is also an effect at M=3.6 TeV with a local significance of up to 3.9 sigma.**

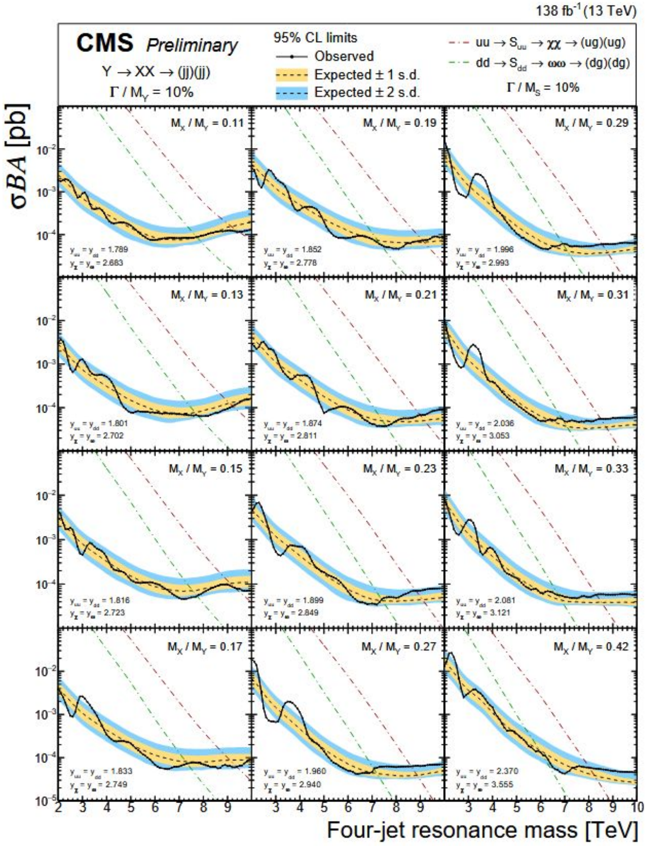
- **A rich program of searches exploring variety of benchmark signal models**, **different topologies in different mass regimes**.

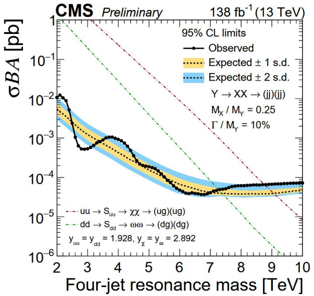
- **Presented only three results out of many more. Available at** CMS EXO public results and CMS B2G public results.

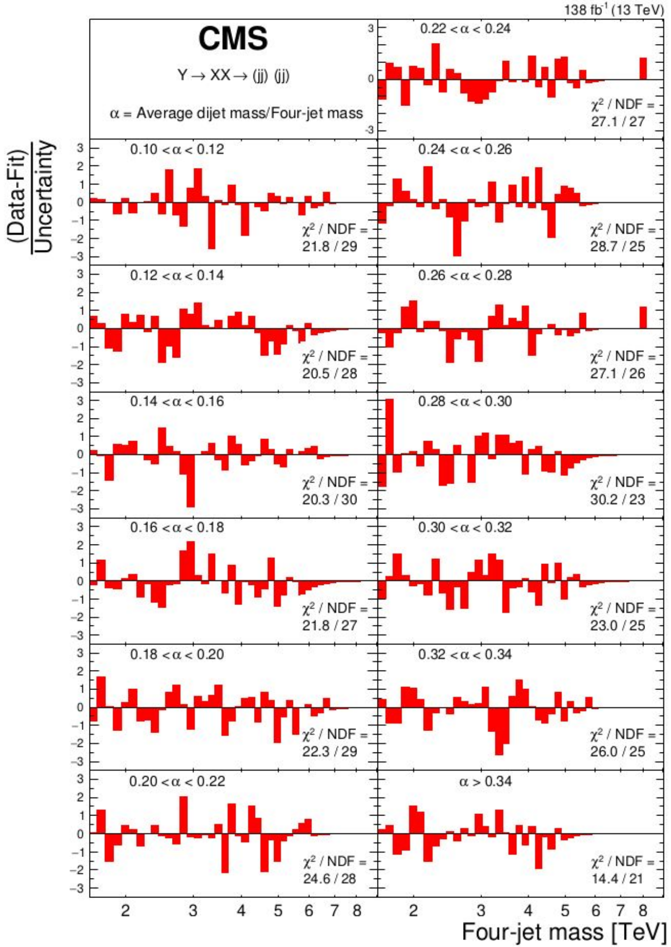
- **Stay tuned for new results using Run 2 and Run 3 data!**
  - Resonant and non-resonant paired dijet search with b-jets in final state using Run 2 data.
  - Resonant and non-resonant paired dijet search using Run 3 data.

BACKUP

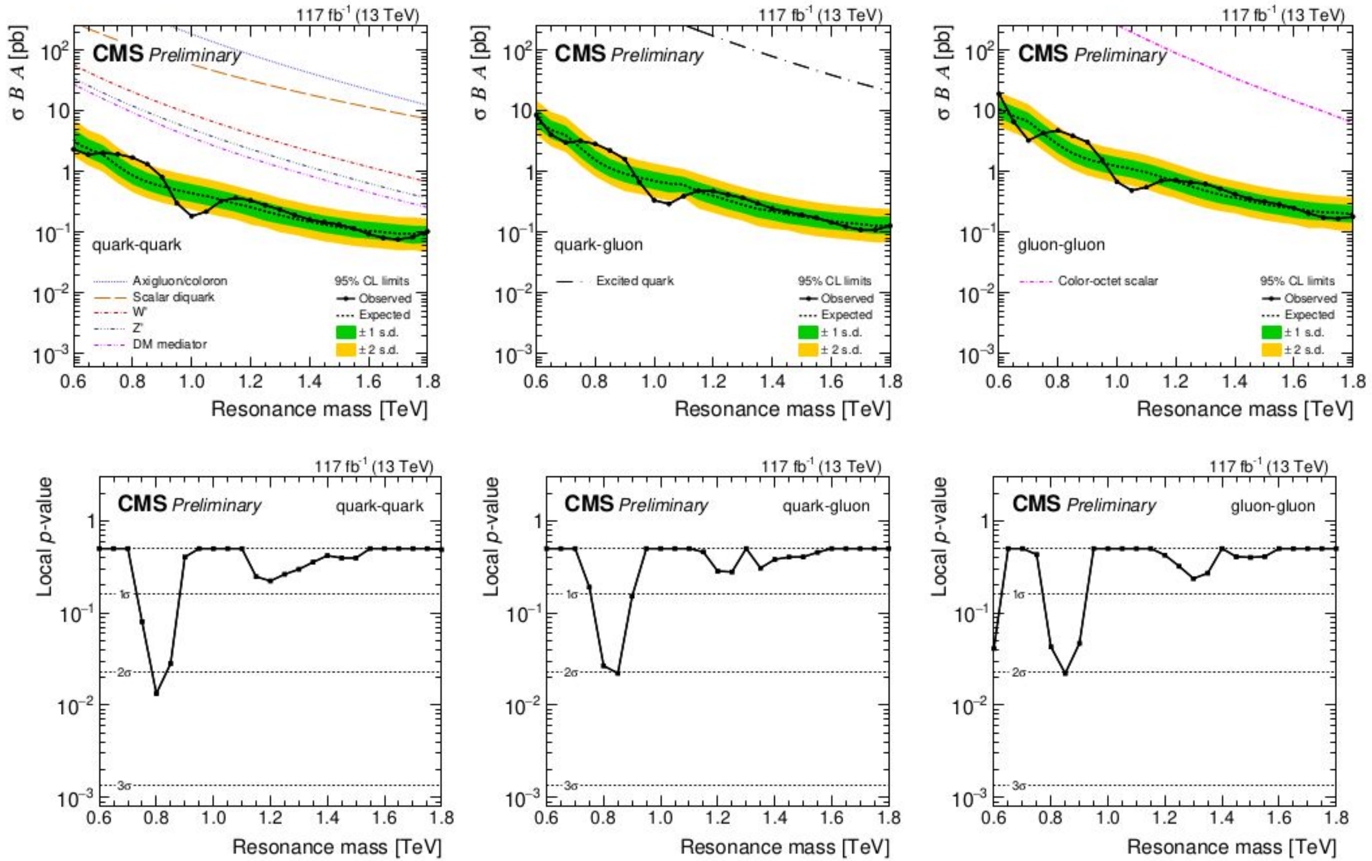
Broad resonance reinterpretation of high-mass $Y \rightarrow XX \rightarrow (jj)(jj)$

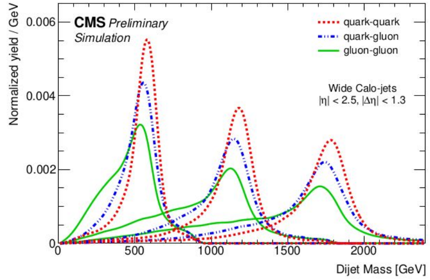






Search for dijet resonances (X→jj) with data scouting





Search for X→t(bqq)ϕ(bb) in boosted final state