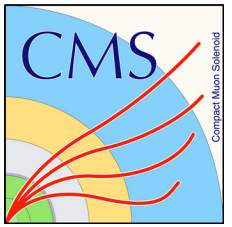

Model-independent searches and anomaly detection at the CMS experiment

Louis Moureaux on behalf of the CMS Collaboration

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EPS-HEP conference in Marseille, 11.07.2025

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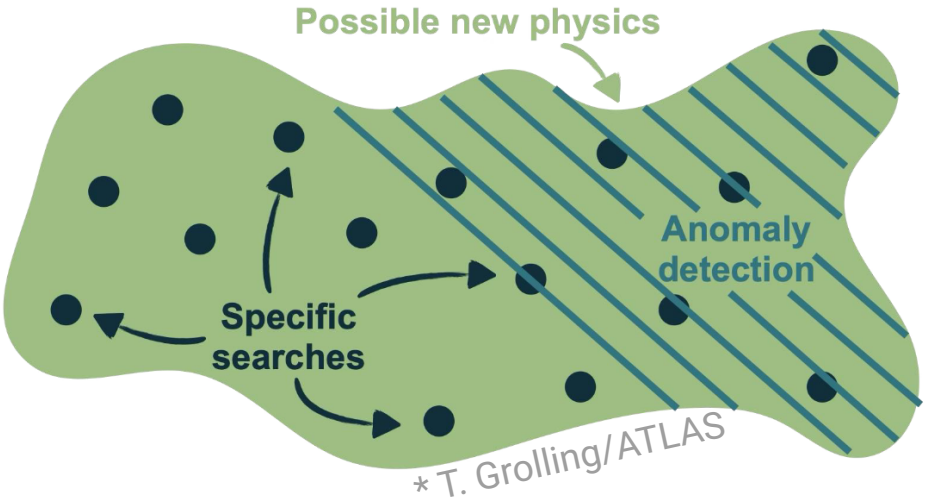
Motivation

Found no BSM physics at the LHC so far

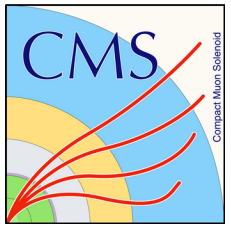
- Despite strong arguments!
- Have we looked for the right model?
- Have we even *imagined* the right model?



Model-independent searches cover these cases

When enhanced with machine learning, we call them **anomaly detection**

Anomaly detection in CMS



First anomaly detection results from CMS:

- Resonant particles in a dijet final state

  Rep. Prog. Phys. 88 (2025) 067802 [2412.03747]

New results first shown today!

New for EPS

- Further exploring the methods from the dijet search
- Data-driven selection of boosted top quarks

  Watch out this space on CDS ➔

Also doing trigger-level anomaly detection, see e.g. 2411.19506

Targeted signature

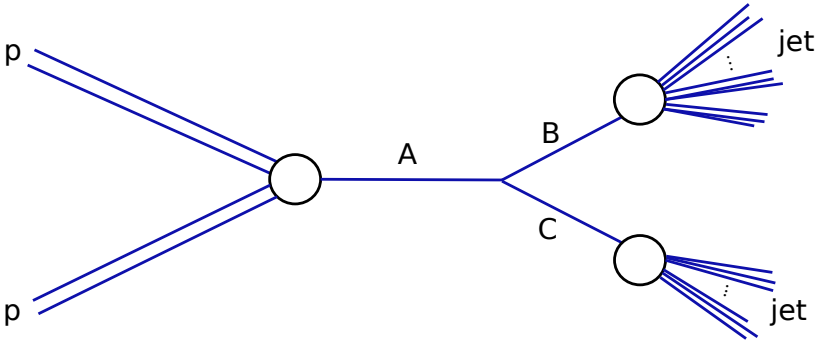
We look for *any* A ➔ BC ➔ 2 jets (anti-k_T, R = 0.8)

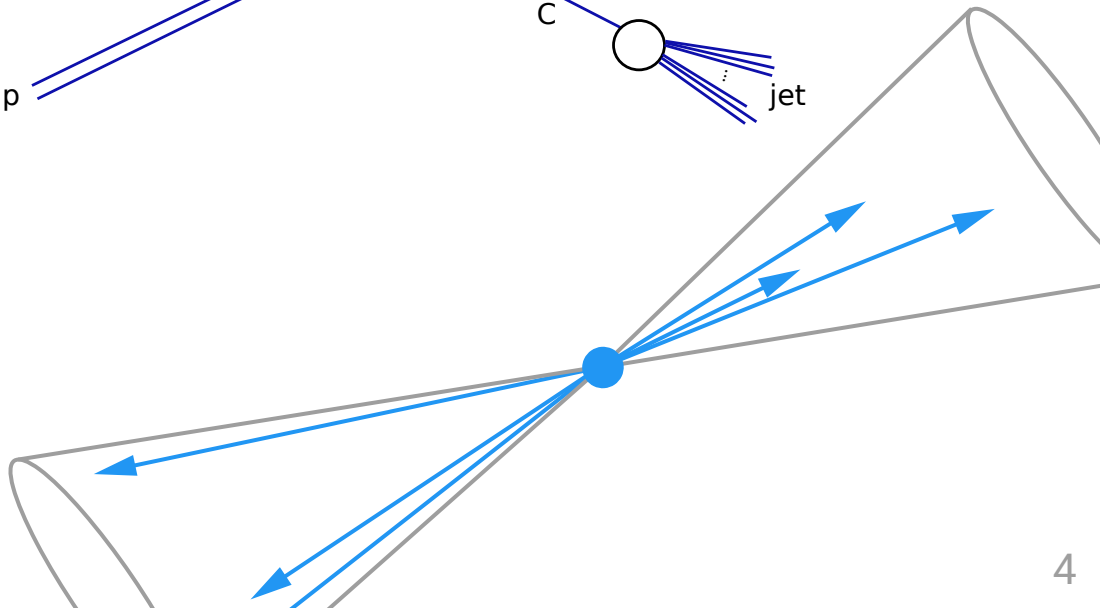
- Heavy (m_A ~ TeV) and narrow
- Encompasses many final states that have **never been searched for**

Examples

Z' → T'T' → tZtZ $m_{Z'}$ = [2,3,5] TeV $m_{T'}$ = [400] GeV	
	Y → HH → tttt m_Y = [2,3,5] TeV m_H = [400] GeV

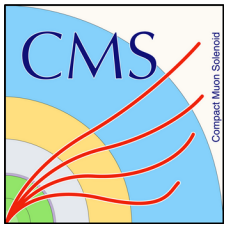
- Need machine learning to achieve sensitivity





[2412.03747]

Analysis strategy

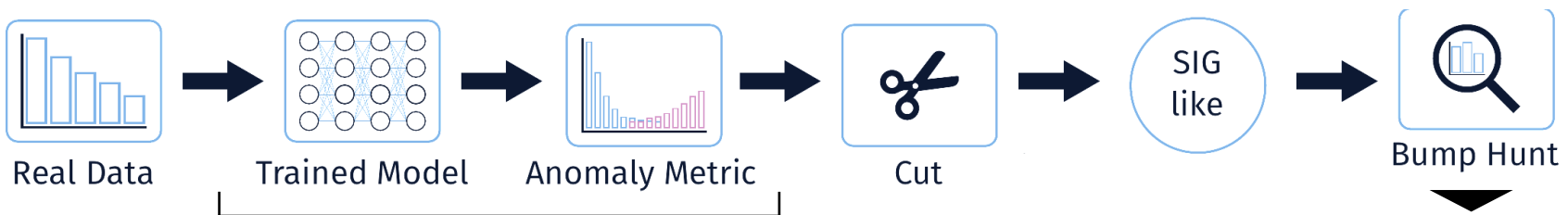


[2412.03747]

Start from **data**

Anti-k_T jets with $R = 0.8$
Basic selection criteria

Keep ~**1%** most anomalous events



5 anomaly detection methods

CWoLa Hunting / TNT / CATHODE(-b) / VAE-QR / QUAK

Resonance?

Fit m_{jj} spectrum and obtain significance

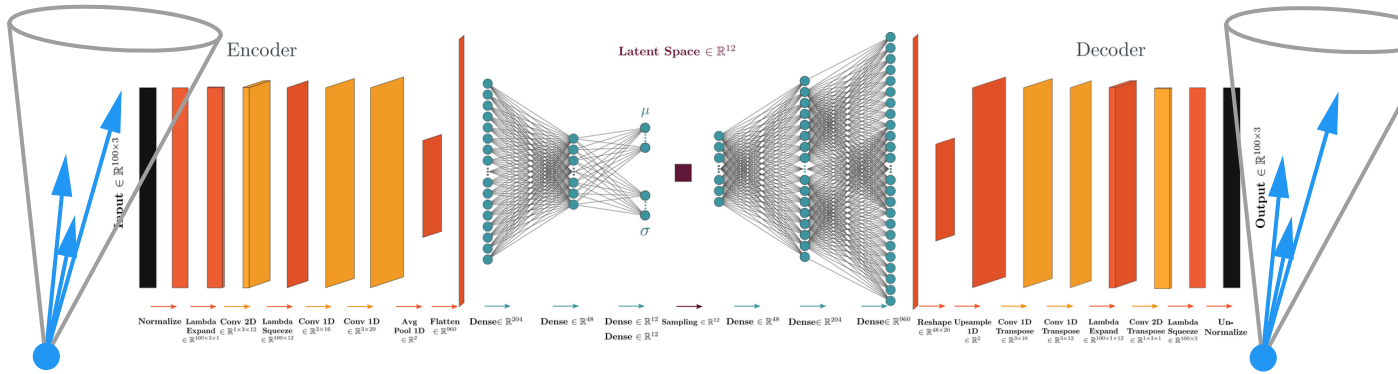
* T. Quadfasel

Methods: VAE-QR, QUAK

[2412.03747]

VAE-QR

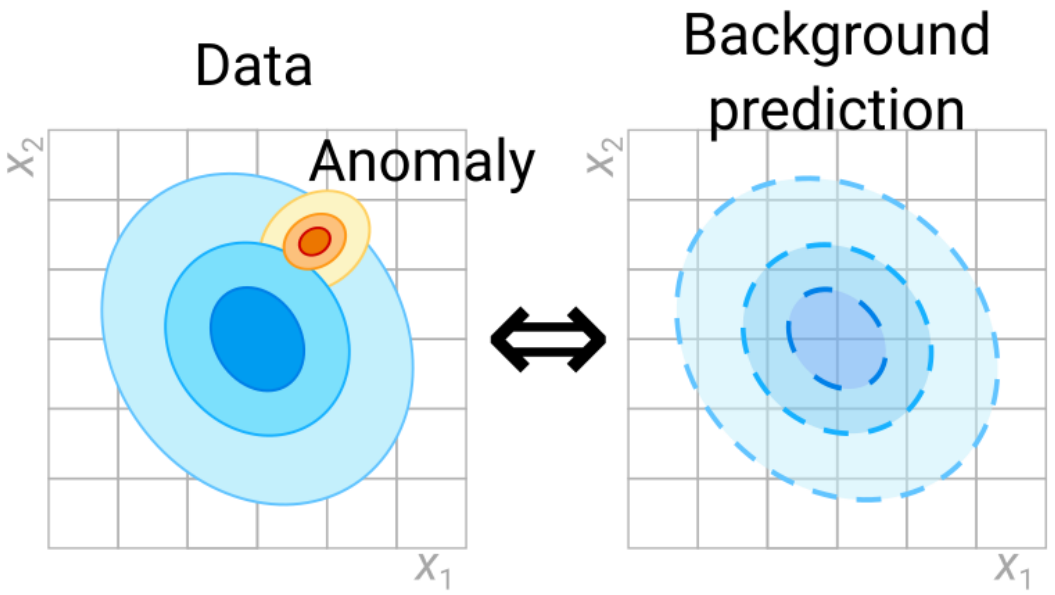
- Encode **100** particles per jet **to 12 dimensions**, then **decode**
- Train in a background-dominated sideband
- Anomalies are badly reconstructed
- Score = how badly



QUAK

- Similar concept, adds a **prior from simulated signal events**
- Select events in the (signal, background) “badness” plane

Methods: Weak supervision



[2412.03747]

Variables: jet mass, N-subjettiness, b tagging score, …

Find anomalies by classifying between data and background

3 methods for background estimation:

- **CWoLa Hunting:** 1902.02634
- **Tag N' Train:** 2002.12376
- **CATHODE:** 2109.00546

A challenge: finding the top

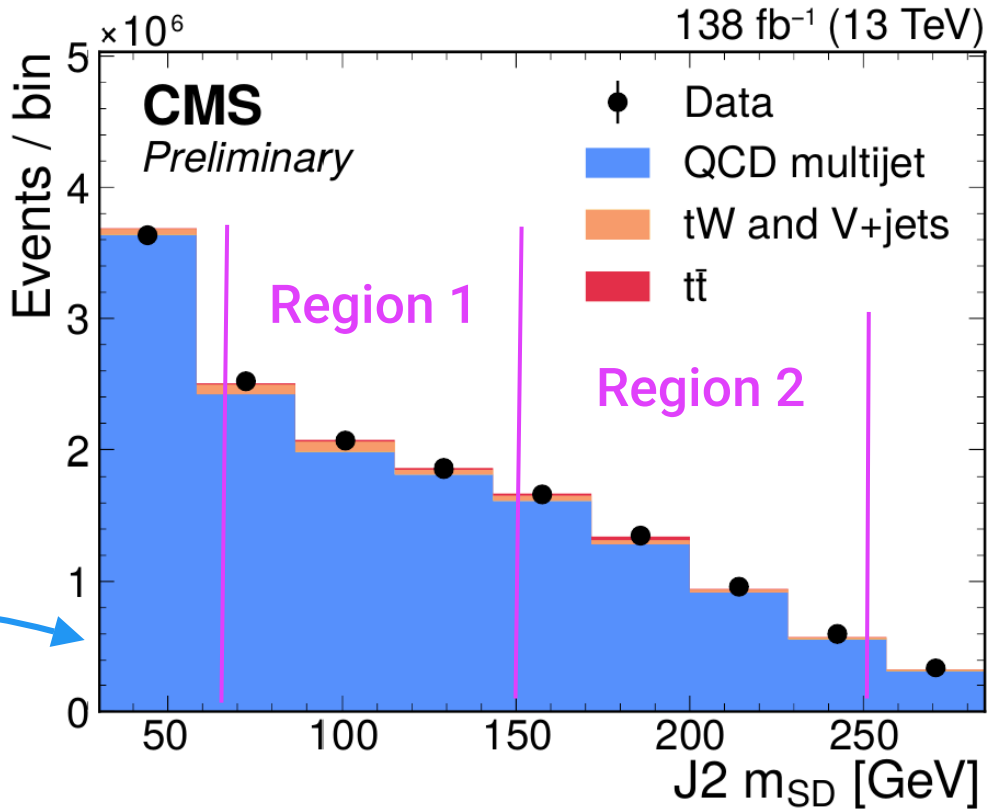
New for EPS

Link to CDS

Does it work?

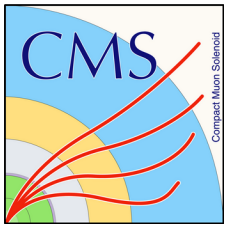
Slightly modified strategy:

- Run weak supervision in data
- Jet mass as the resonant variable
- Setup adapted for pair-produced boosted resonances
- Initially, QCD dominates



After anomaly detection

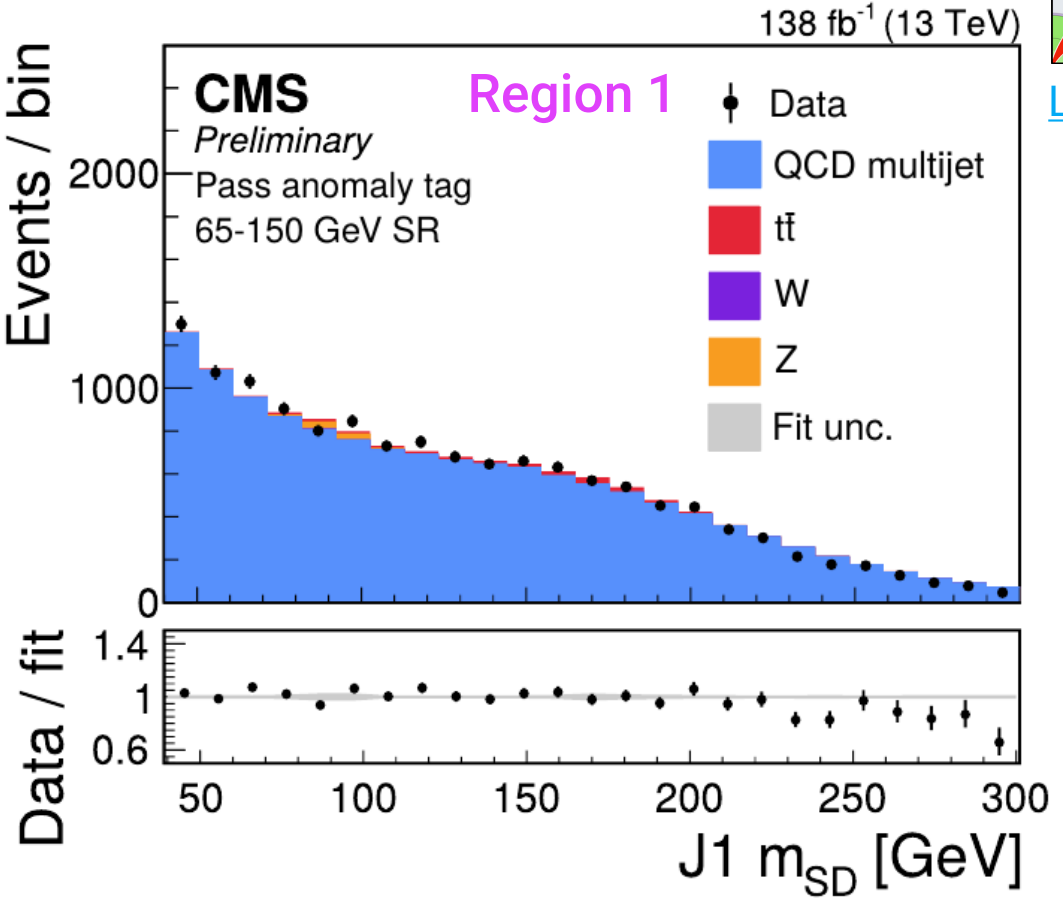
New for EPS



Link to CDS

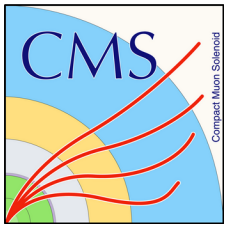
First signal region

Top quark not visible



After anomaly detection

New for EPS



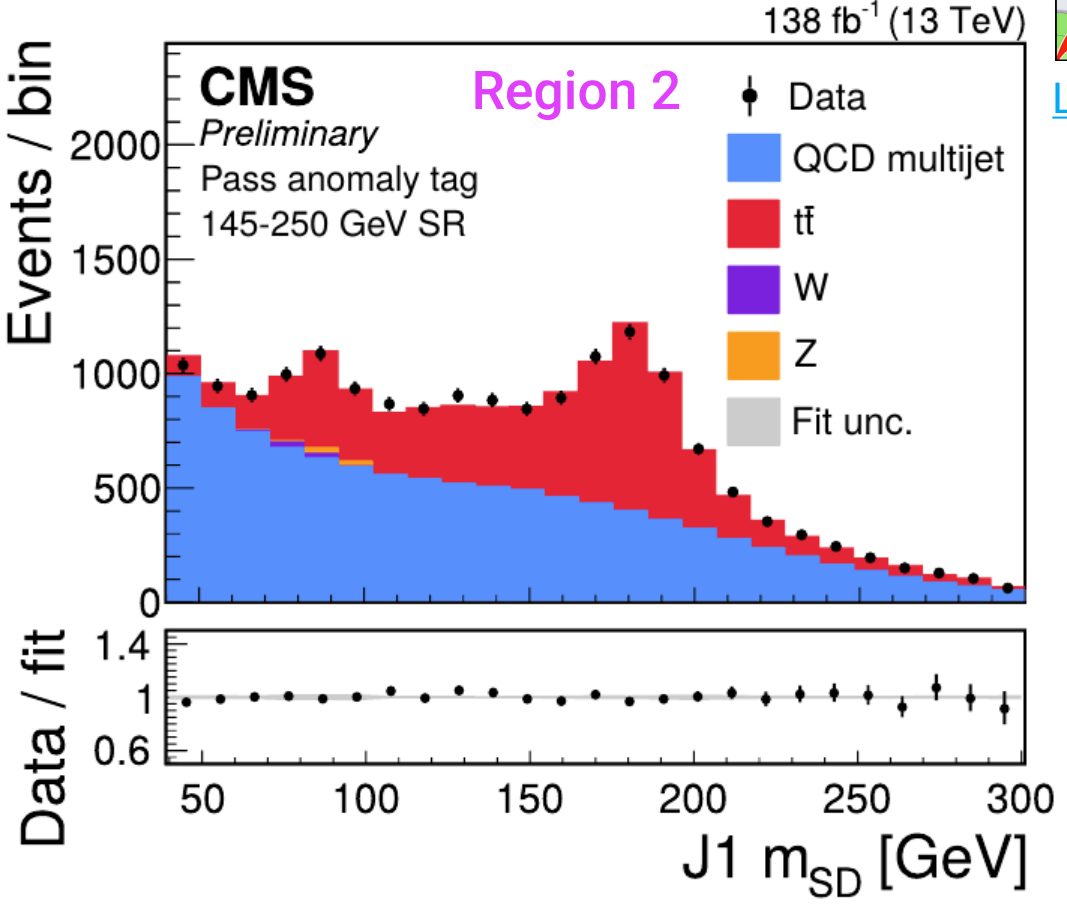
Link to CDS

Second signal region

Here is the top quark!

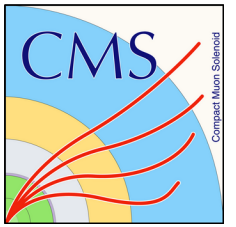
Reminder:

- Trained on data
- Evaluated on data
- No MC involved!
  (except for plotting)



Excess interpretation

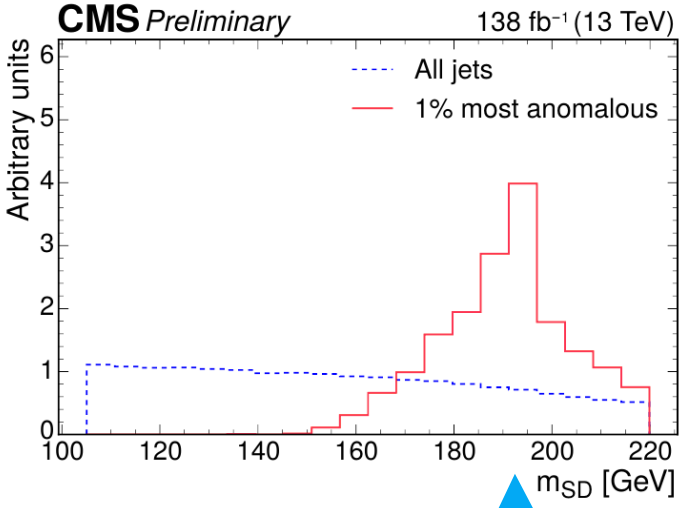
New for EPS



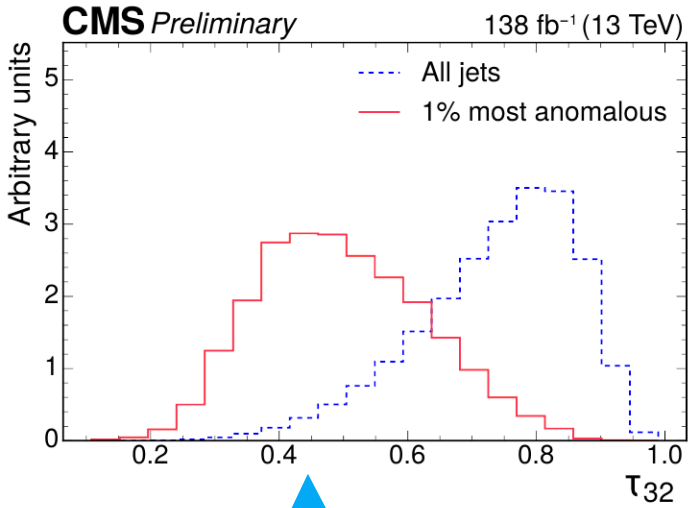
Link to CDS

Can we figure out some top quark properties?

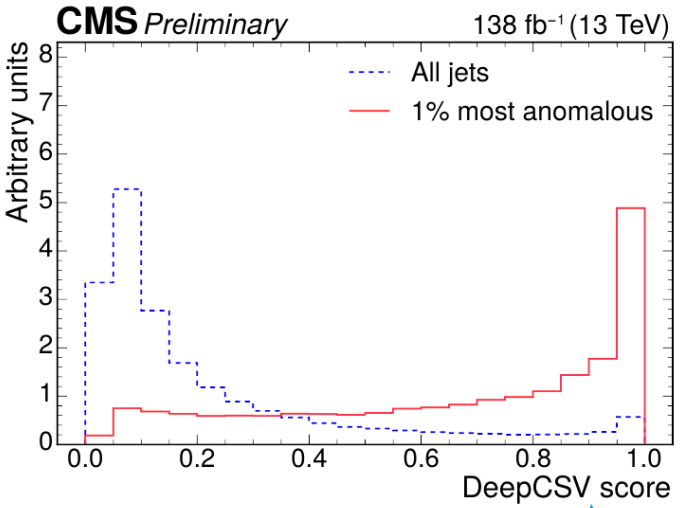
Compare **selected events** and **the rest**:



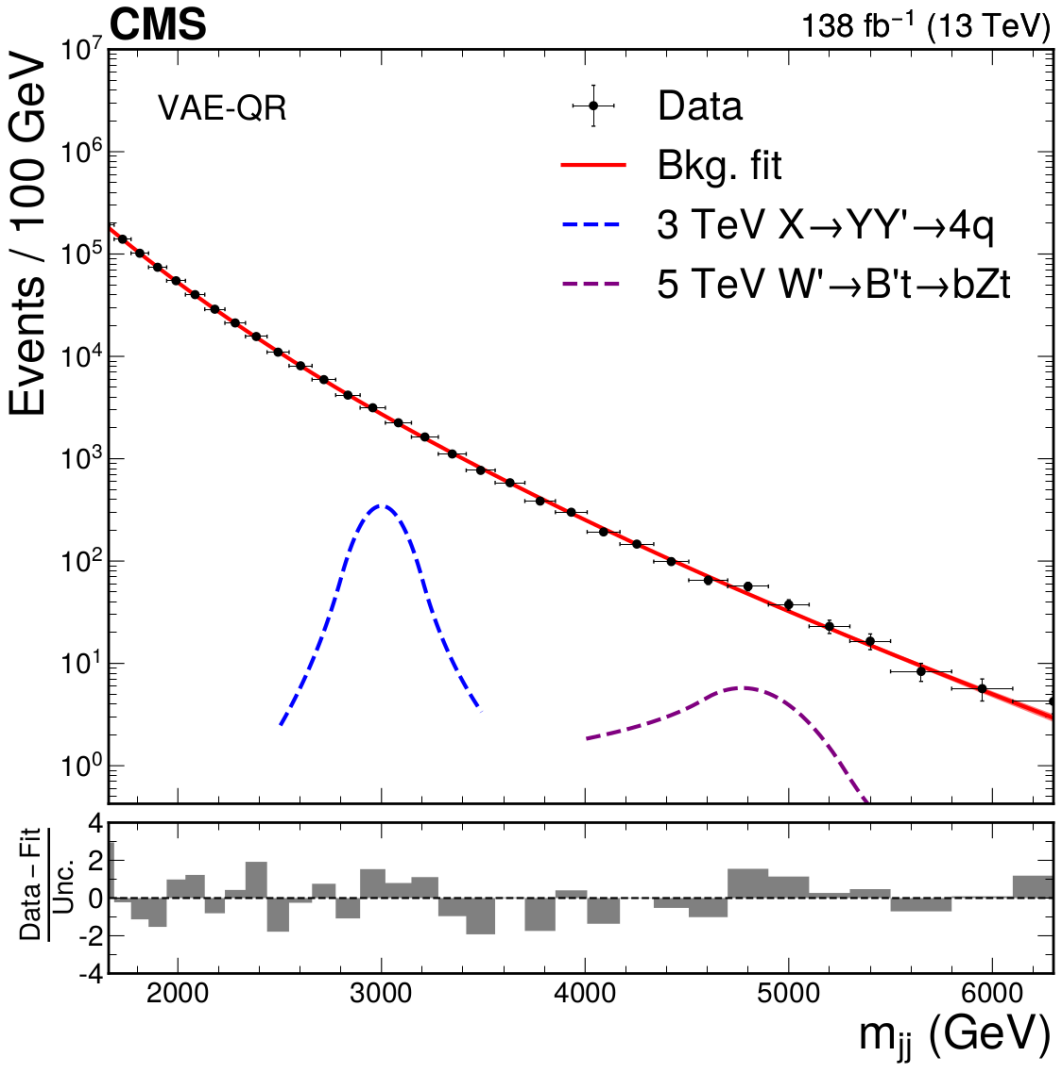
Jet mass = 190 GeV



3-body decay



Has b quarks



Results of the dijet search

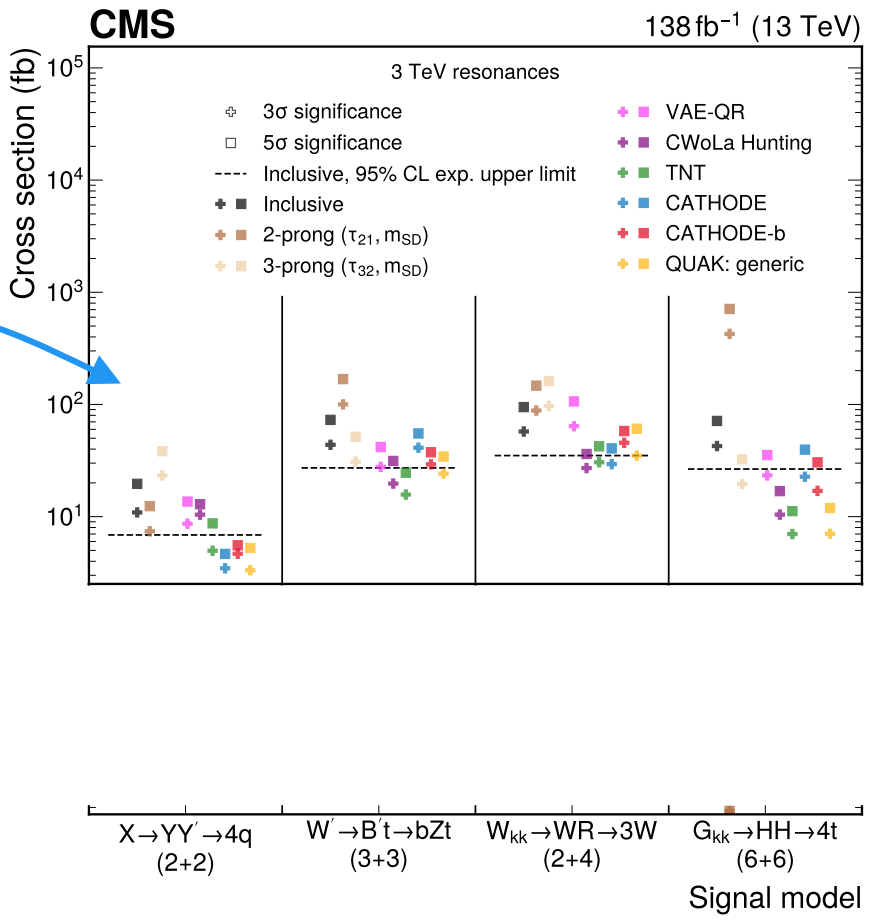
[2412.03747]

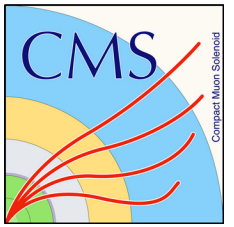
No BSM particle found

- Showing anomalous events selected by **VAE-QR**
- Negative results from other methods as well

Benchmark models

- Use 4 benchmark models to study sensitivity
- Report the cross section for a 3/5σ excess





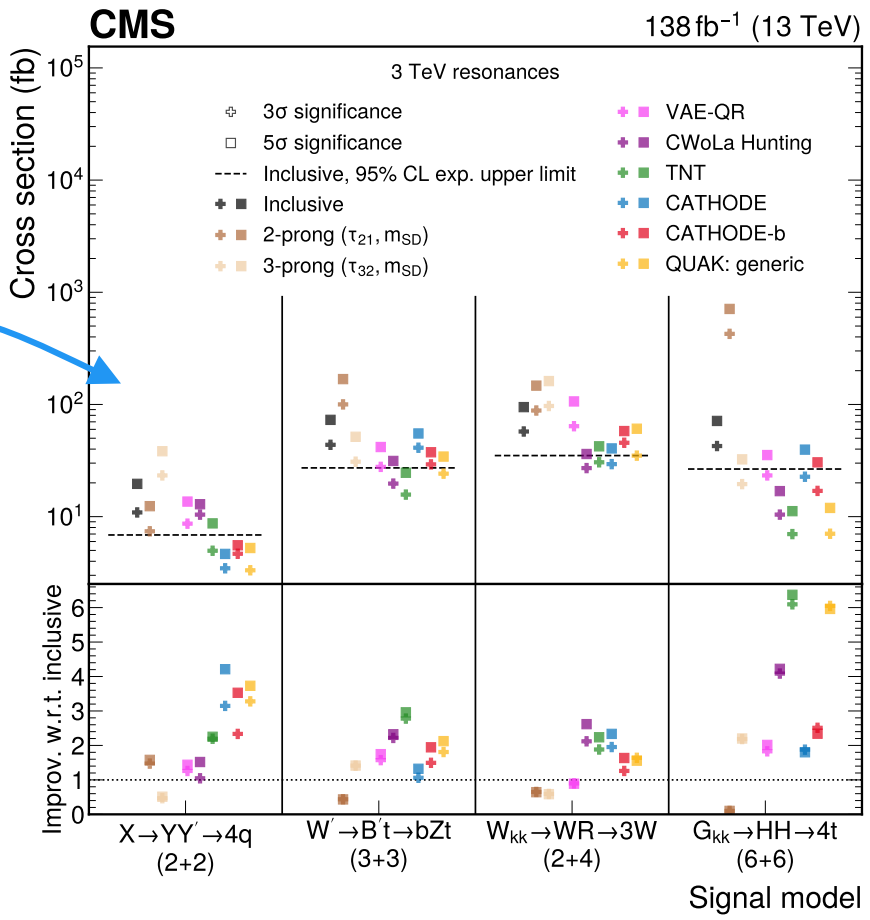
[2412.03747]

*Also in paper: more models, limits

Benchmark models

- Study sensitivity with 4 benchmark models
- Report the cross section for a 3/5σ excess
- 3–7 × better than naive bump hunt
- More general than simple substructure cuts

*Also in paper: more models, limits



[2412.03747]

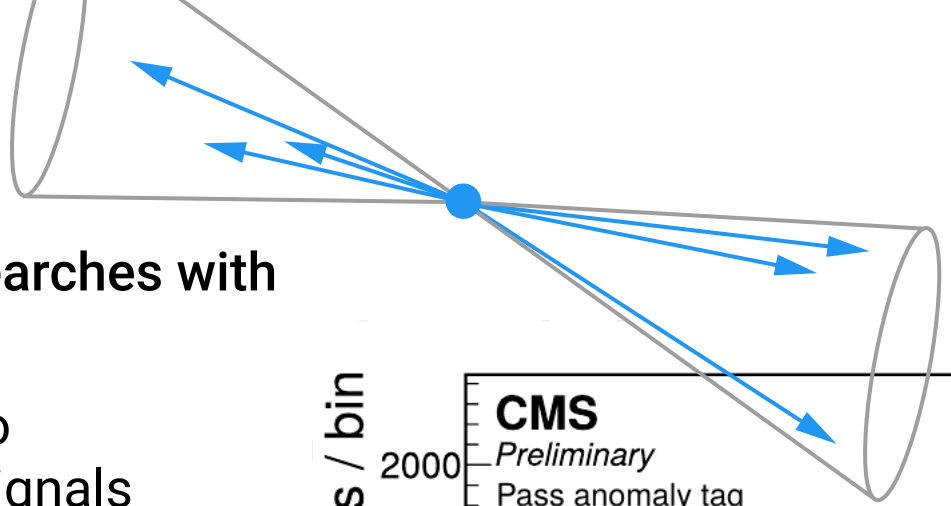
Summary

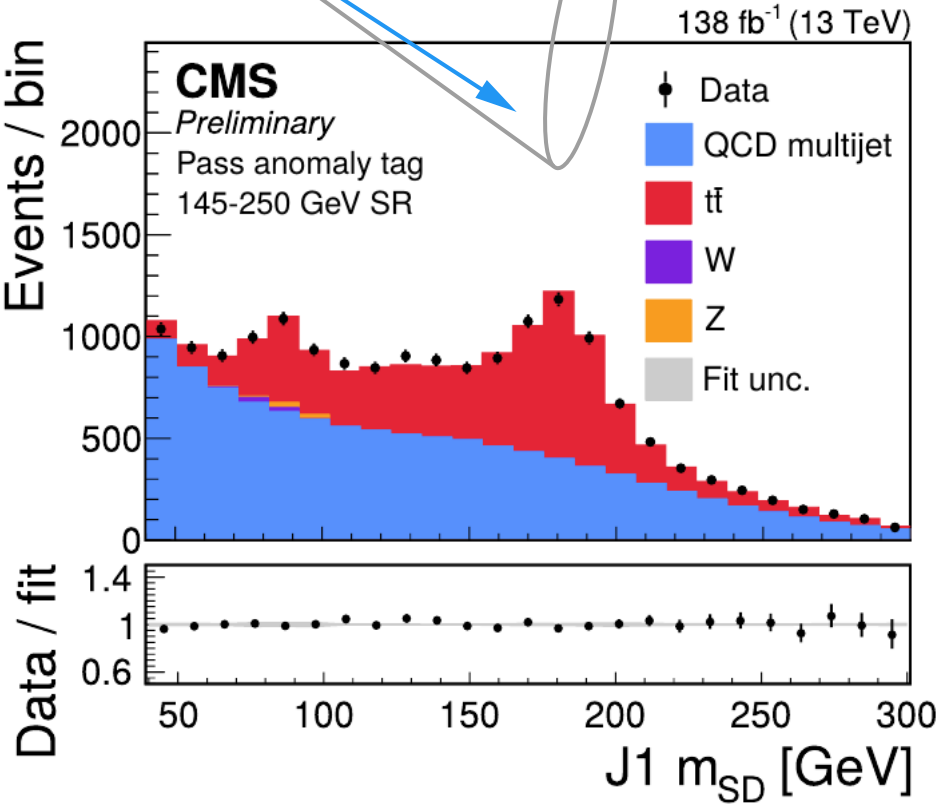
CMS enhances traditional searches with anomaly detection

- 3–7 × better sensitivity to a broad range of (dijet) signals
- Various substructure hypotheses tested
- Read more in 2412.03747

New! Study of the methods

- Data-driven top selection *and more*
- Watch out this space on CDS



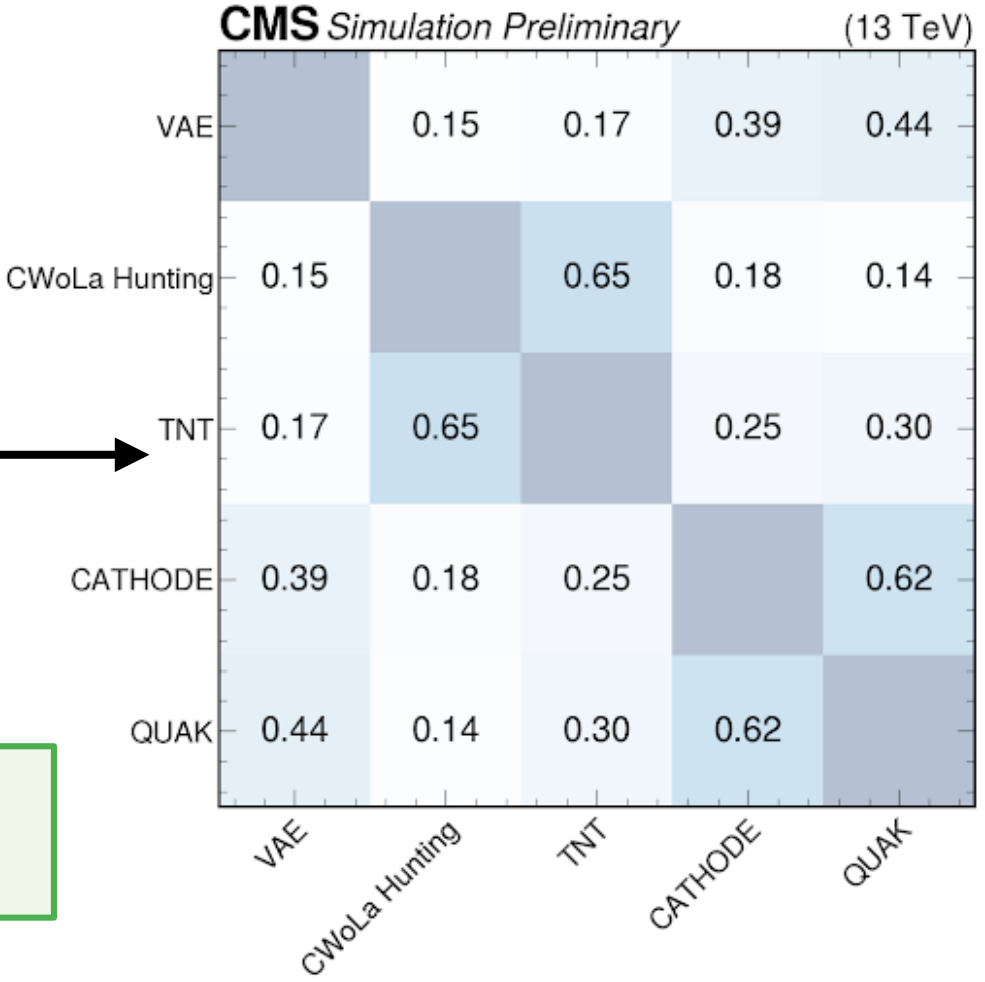


Complementarity

Do all methods flag the same events?

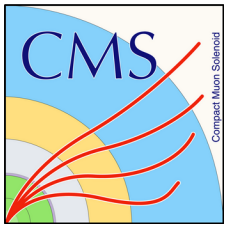
Check correlation between scores in simulation →

Signal:
X(3000) ➔ YY' ➔ qq qq



X(3000) ➔ YY' ➔ qq qq

Small correlations
➡ Complementary



Link to CDS