Overview of recent LHC results

Flera Rizatdinova,
Oklahoma State University

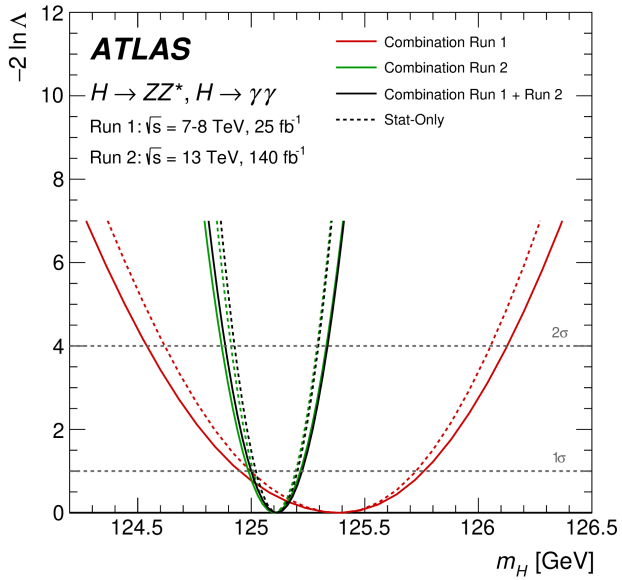
Introduction

- The Standard Model is a success, but there are solid reasons to believe it is incomplete
  - theoretical issues: mass hierarchy, strong CP problem
  - unexplained phenomena: gravity, dark matter, neutrino masses, matter-antimatter asymmetry
- ATLAS and CMS have comprehensive physics programs probing various aspects of the Standard Model
  - trying hard to find the cracks that would give us a hint of BSM physics
- In this talk:
  - latest LHC news: precise Higgs boson mass measurement, precise determination of the strong-coupling constant, search for magnetic monopoles
  - searches that resulted in ≥2 standard deviations from the SM: BSM Higgs, heavy resonances, lepton flavor violation

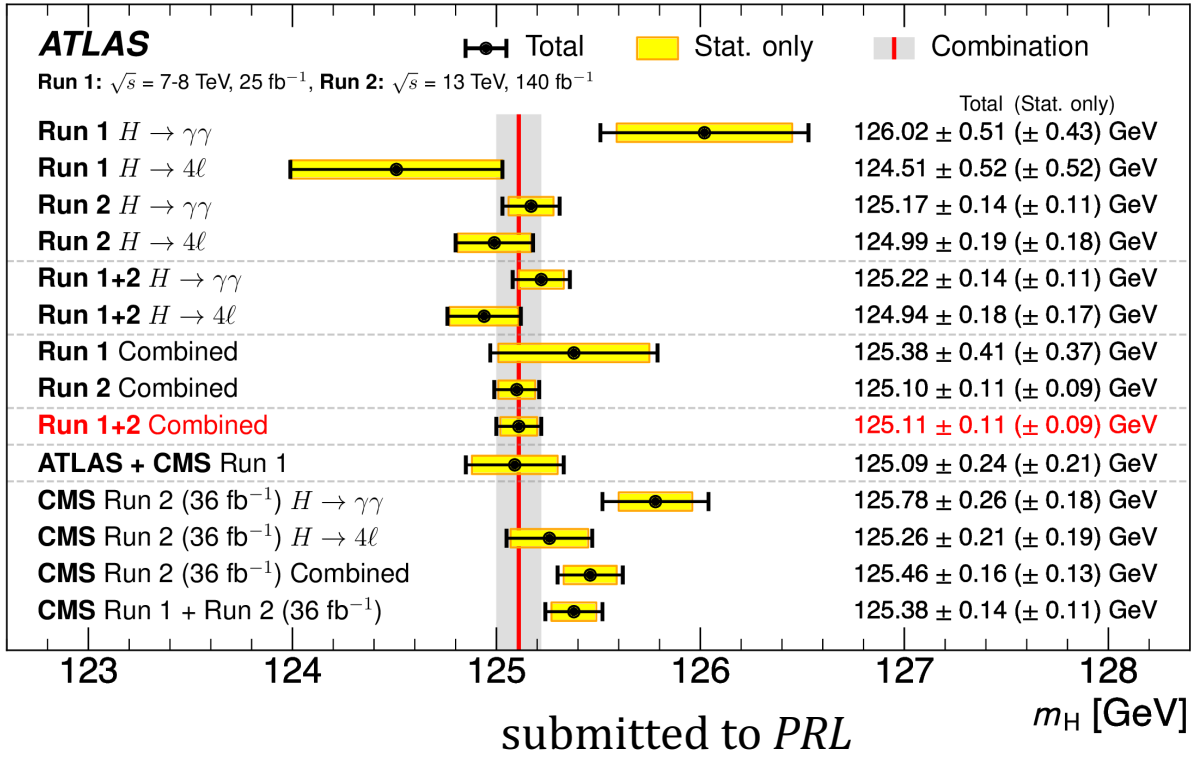
LHC news

Latest measurement of the Higgs boson mass

- A new measurement of the m_H combining the H→ZZ*→4l and H→ **γγ** decays
  - Helps to better understand H couplings to other elementary particles
- Precision achieved: 0.09%
  - Photon energy calibration, muon resolution calibration, statistics



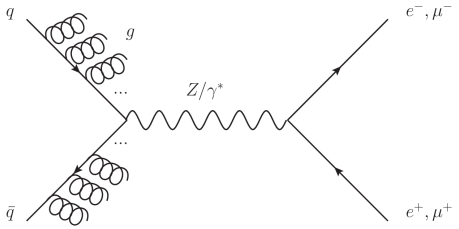
arXiv:2308.04775

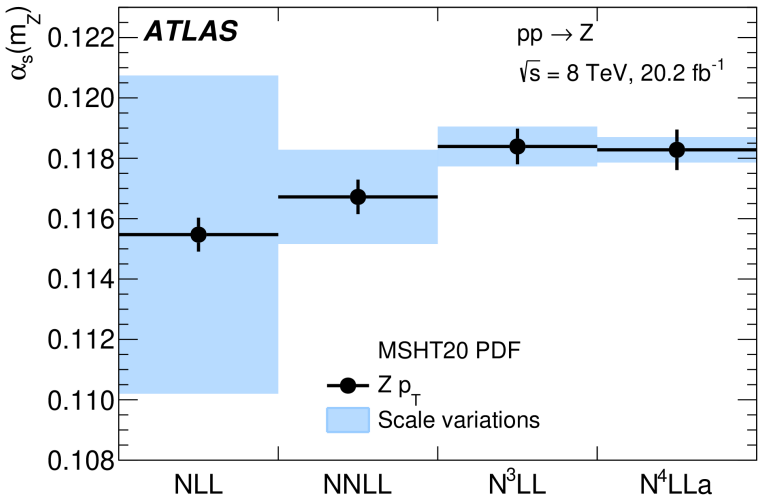


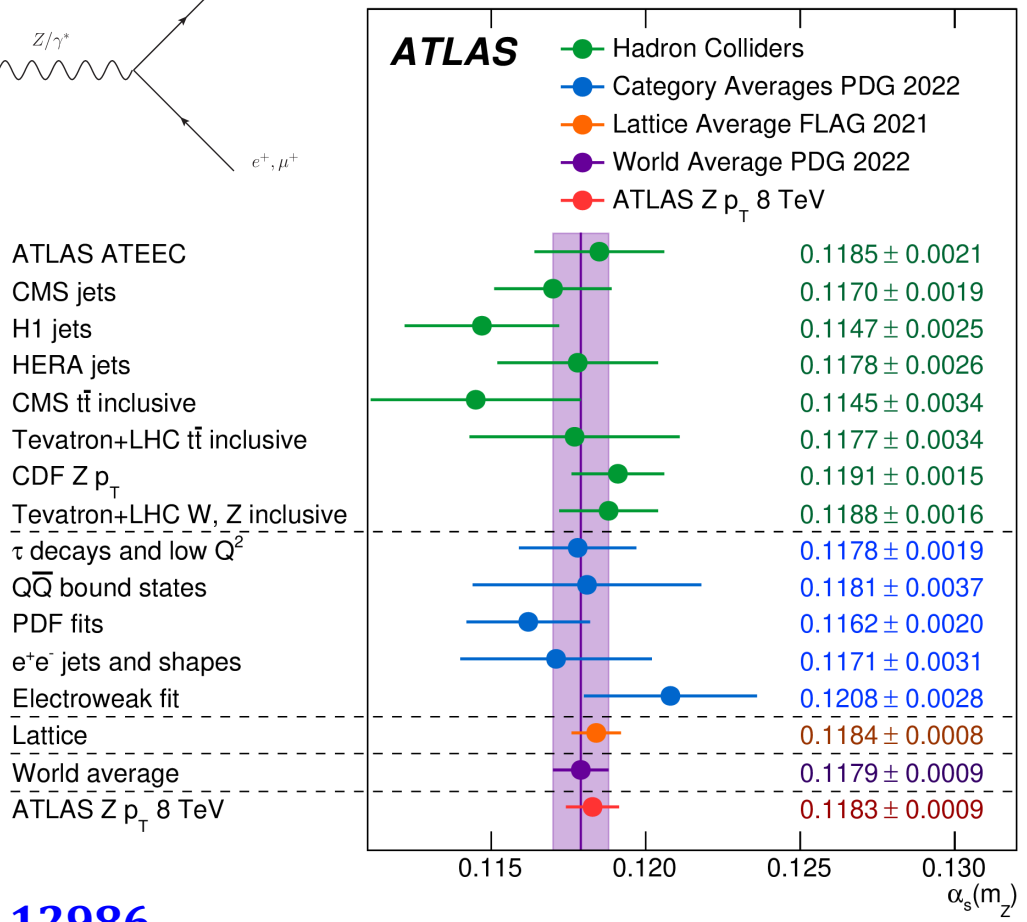
submitted to *PRL*

A precise determination of the strong-coupling constant from the recoil of Z bosons

- Measurement of the strong coupling at $Q=m_Z$, based on 20.2/fb of 8 TeV data
  - $\alpha_s(m_Z)=0.1183\pm0.0009$
- Method: double-differential (p_T:y) Z cross-section measurement





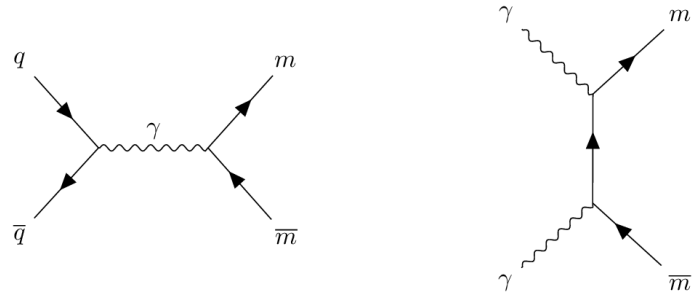


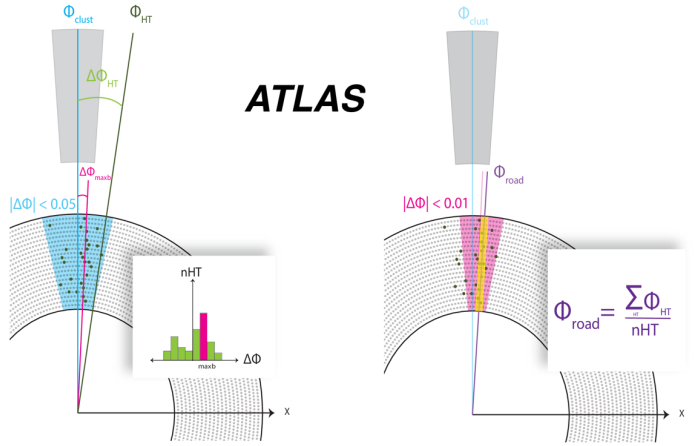
arXiv:2309.12986

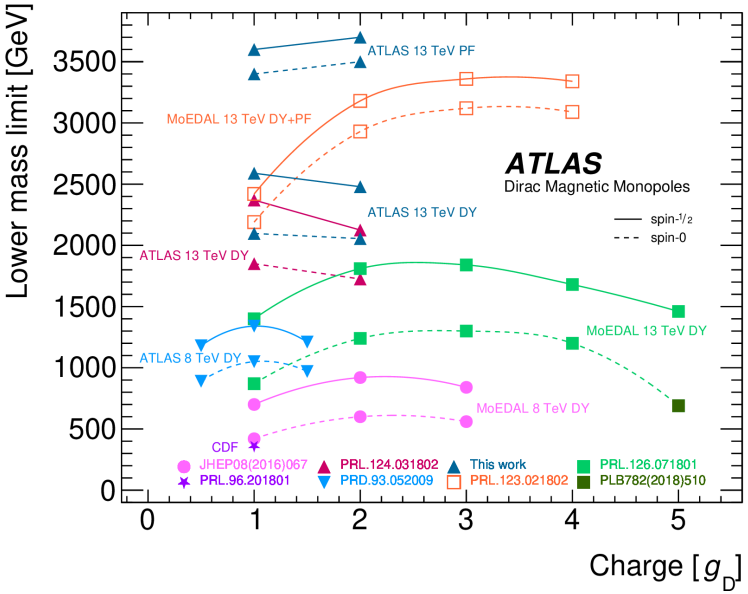
submitted to *Nature Phys.*

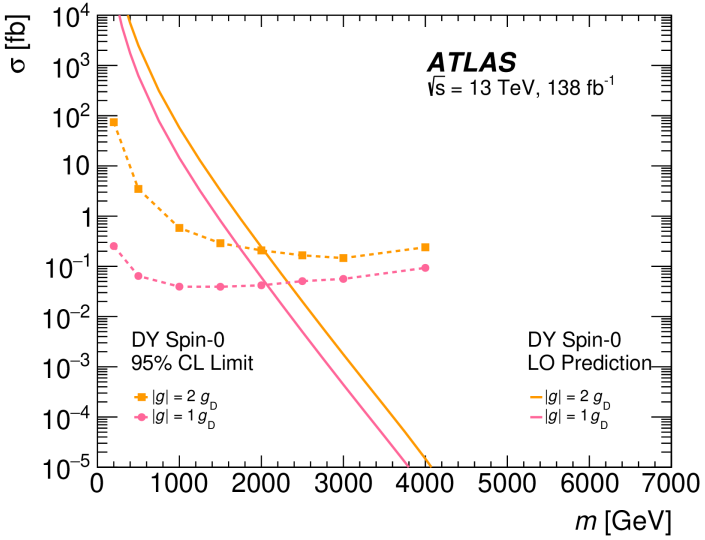
Search for magnetic monopoles and HECO

- High ionization particles (HIPs): strange and up-down quark matter, Q-balls
  - Dirac monopole: fundamental magnetic charge e/2α=68.5e
- ATLAS can detect a HIP as a blob of many TRT hits in a region aligned with a narrow energy deposit in ECAL
  - ×3 improvement on DY production in the 20<|z|<100 range





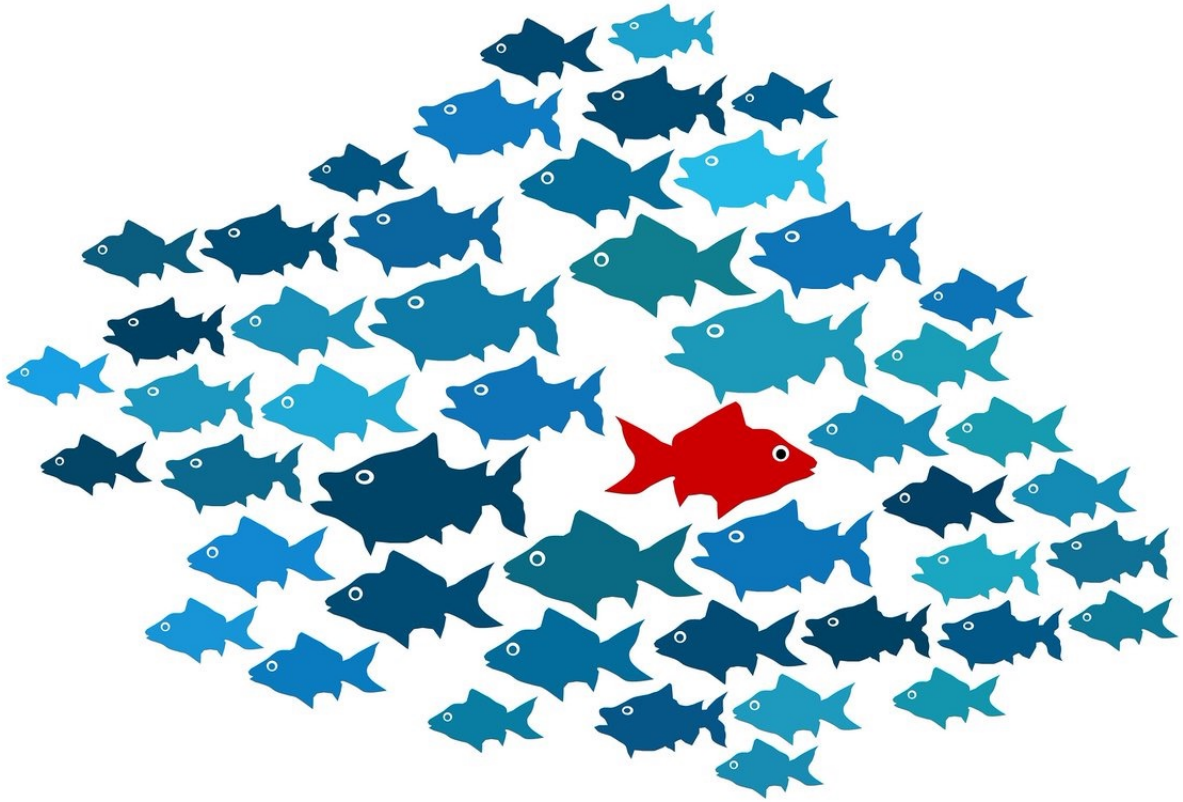




arXiv:2308.04835

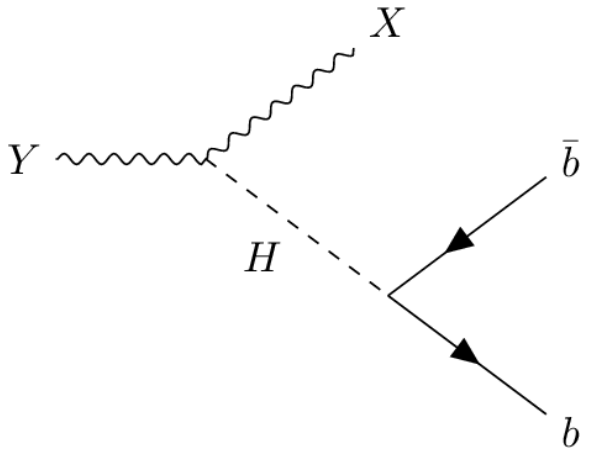
submitted to *JHEP*

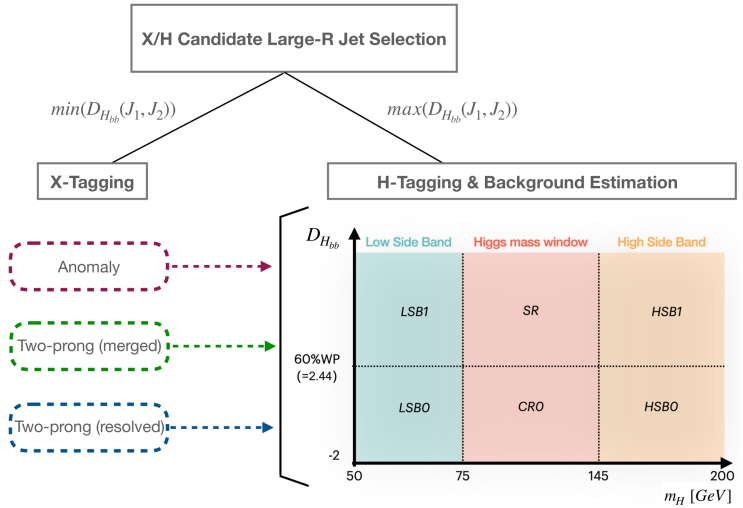
Anomalies



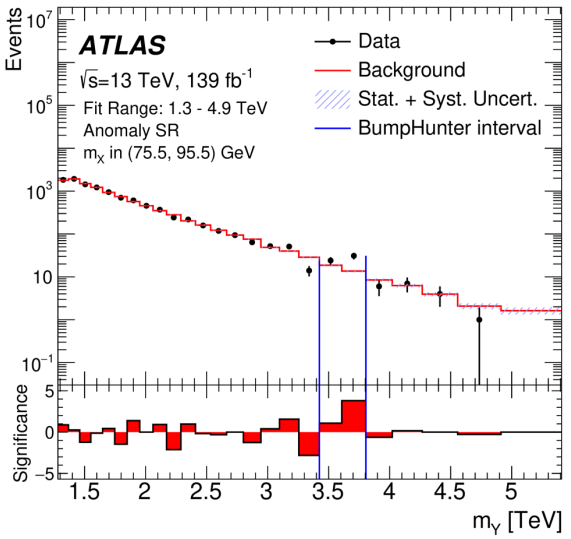
Search for new resonances with Higgs in the final state

- Generic search for $Y \rightarrow HX \rightarrow bbqq$ process
- Targets high-Y mass region (highly boosted H, X)
- Based on anomaly-detecting unsupervised learning (model trained on the BG-only data)
- NN-based bb tagger for boosted H, 1 large R or 2 small-R jets
- Main background: multi-jets.





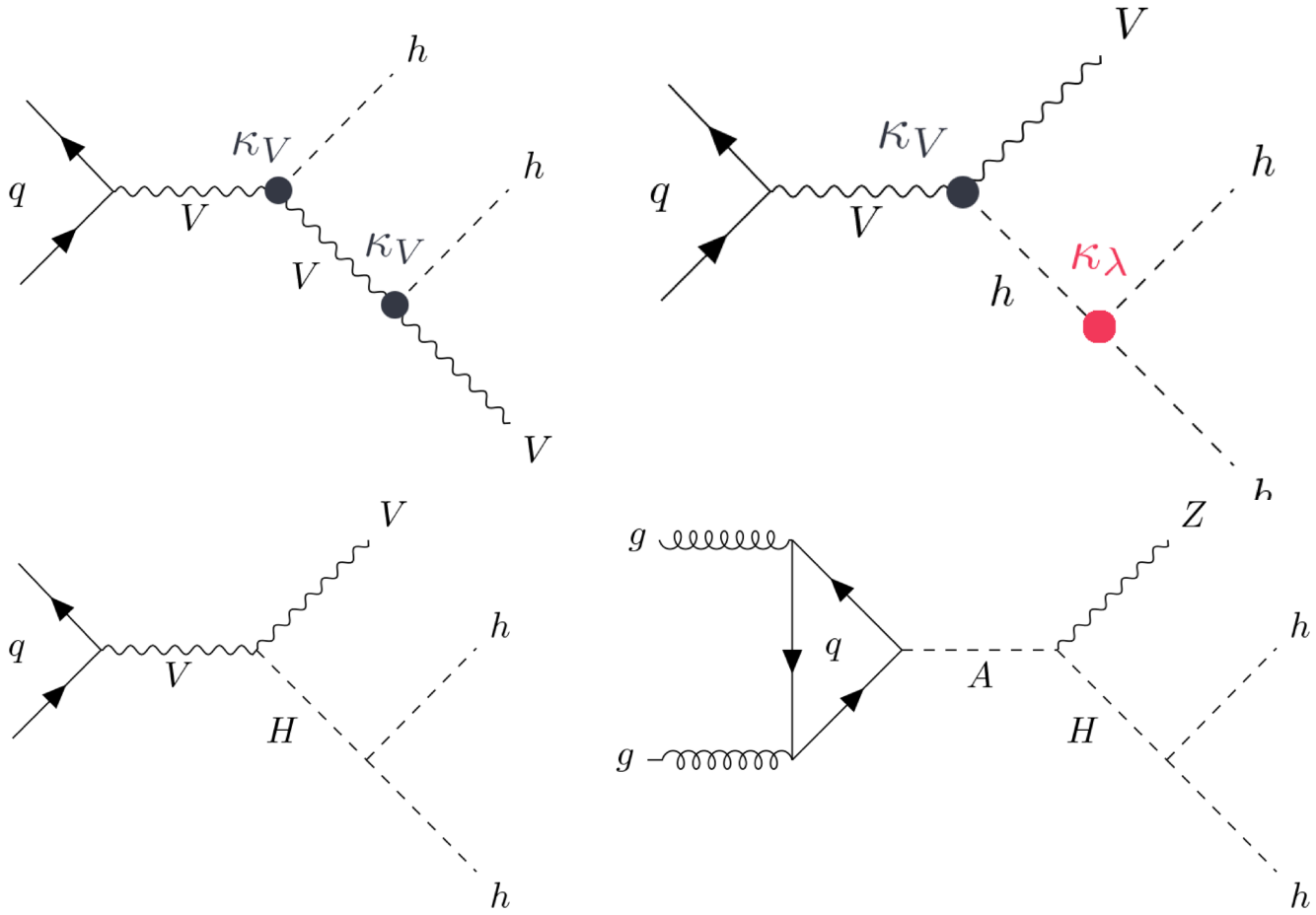
- Highest significance at m_Y= 3.7 TeV:
  - Local: **3.8σ**
  - Global: **1.5σ**



Phys. Rev. D 108 (2023) 052009

Search for non-resonant and resonant SM Higgs pair production in association with vector bosons

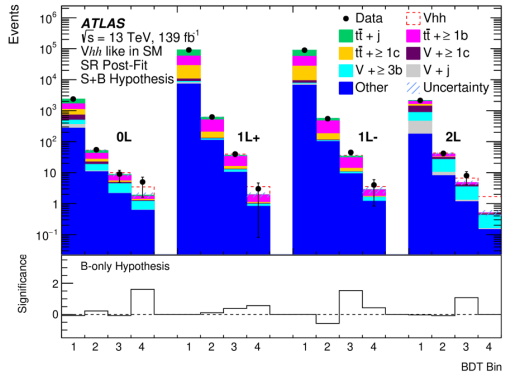
- Final state: $bbbb + 0\ell, 1\ell, 2\ell$
- Models for resonant production:
  - A neutral heavy scalar resonance H with $m \in [260,1000]$ GeV, $H \to hh$.
  - The production of a heavier neutral pseudoscalar resonance $A \to ZH$, with $m_A \in [360,800]$ GeV and $m_H \in [260\text{-}400]$ GeV.
- Main backgrounds: tt, V+jets
- BDTs for each channel to separate signal from background

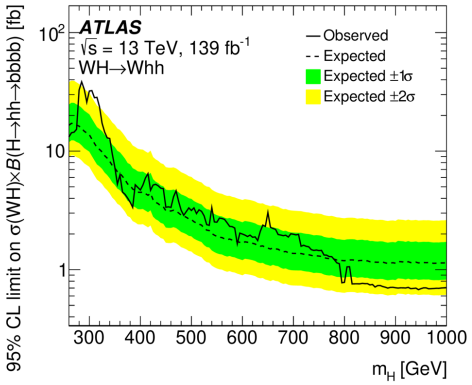


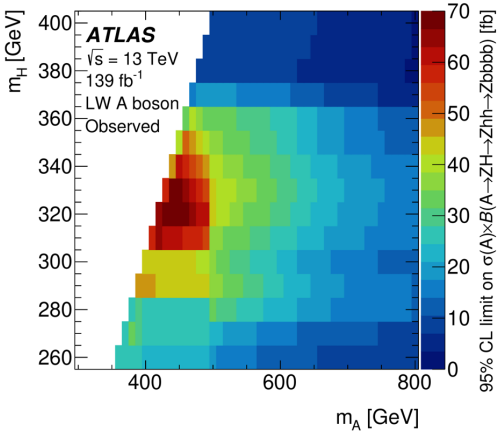
Eur. Phys. J. C 83 (2023) 519

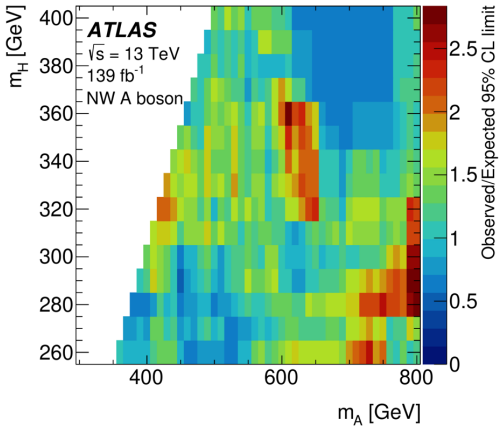
Search for SM Higgs pair production: results

- Non-resonant *Vhh* production:
  - Observed (expected) 95% CL intervals of $-34.4 < \kappa_\lambda < 33.3$ ($-24.1 < \kappa_\lambda < 22.9$) and $-8.6 < \kappa_{2V} < 10.0$ ($-5.7 < \kappa_{2V} < 7.1$) for the two coupling modifiers
- Resonant *Vhh*:
  - *WH* search: at m_H = 315 GeV with a local (global) significance of 2.5 σ(1.3 σ)
  - *ZH* search: at m_H =550GeV with a local(global) significance of 2.7σ (1.3σ)
- Search for $A \to ZH$ production:
  - Excesses are observed at (m_A,m_H) = (790,300) GeV with a local (global) significance of 3.9σ (2.1σ) in the NW scenario and at (m_A,m_H) = (420,320) GeV with a local (global) significance of 3.8σ (2.8σ) in the LW scenario.



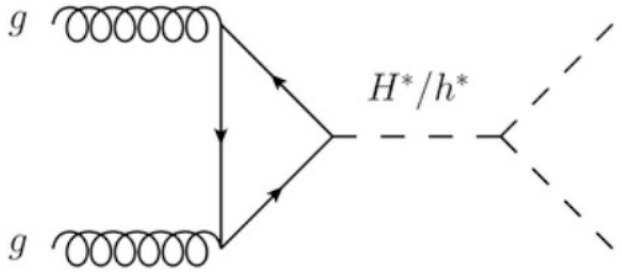


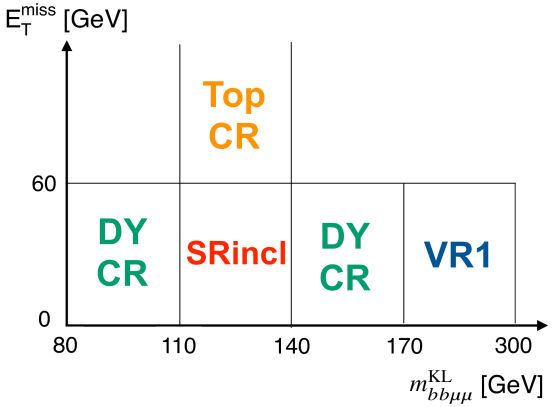


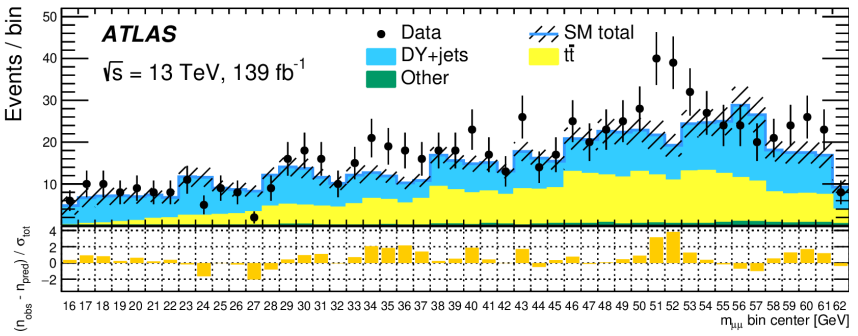


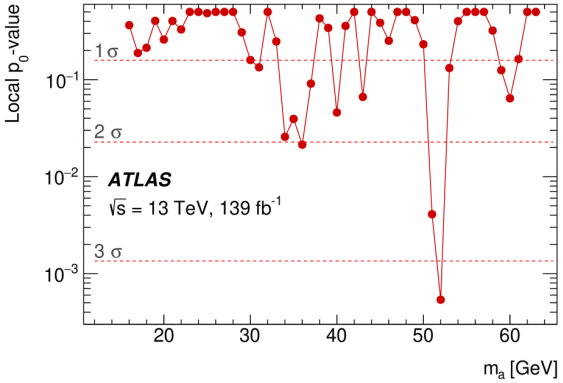
SM Higgs decaying to pseudoscalars

- Search for Higgs decay $H \to aa \to bb\mu\mu$
  - Narrow dimuon resonance $m_{\mu\mu} \in [16,62]\ GeV$.
- Major backgrounds: Z+jets, ttbar
- Used BDT to separate signal from the SM background
- Highest significance:
  - For $m_{\mu\mu} = 52$ GeV, local (global) significance is 3.3 (1.7) $\boldsymbol{\sigma}$





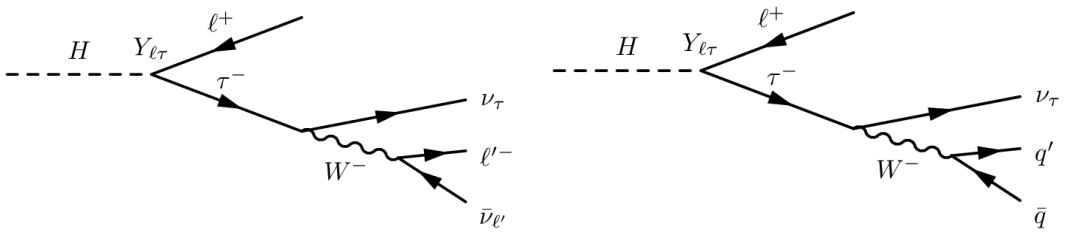


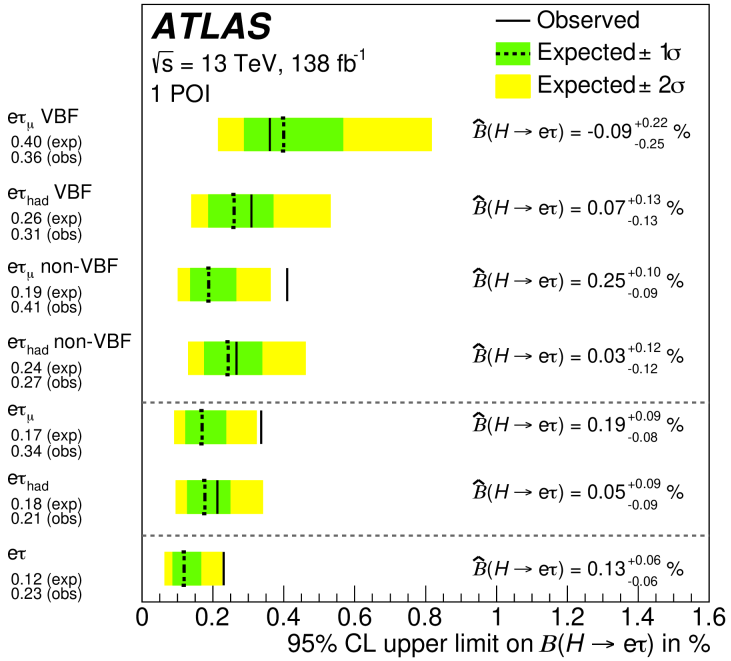


Phys. Rev. D 105 (2022) 012006

LFV Higgs decays

- Search for SM Higgs decays $H \to e(\mu)\tau$ performed by both ATLAS and CMS.
- ATLAS:
  - Main backgrounds: fake e, μ, τ – data-driven methods. Two independent searches, $e\tau, \mu\tau$ with leptonic and hadronic τ decays
  - Used multi-class NN classification to separate signal and background
- CMS:
  - The observed (expected) upper limits on the branching fractions are, respectively, $\mathrm{B}(H \to \mu\tau) < 0.15\ (0.15)\%$ and $\mathrm{B}(H \to e\tau) < 0.22\ (0.16)\%$ at 95% confidence level.



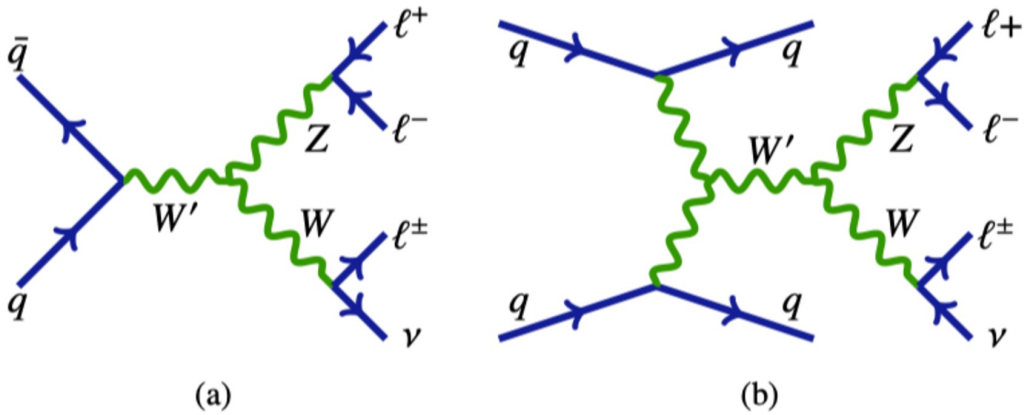


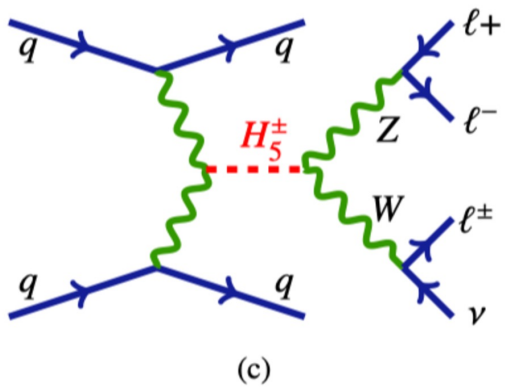
JHEP 07 (2023) 166

Phys. Rev. D 104 (2021) 032013

Search for resonant WZ production in three-lepton channel

- Models tested:
  - Heavy Vector Triplet, with the resonance produced by WZ fusion or the Drell-Yan process (a, b)
  - Charged Higgs of the Georgi-Machacek model, produced by WZ fusion (c)
- Evaluation of the BG:
  - WZ, ZZ – normalization from CR
  - Fake leptons – data-driven methods
  - Other – from MC
- Used ANN to separate signal from BG
  - 17 signal regions; several control regions to verify the performance



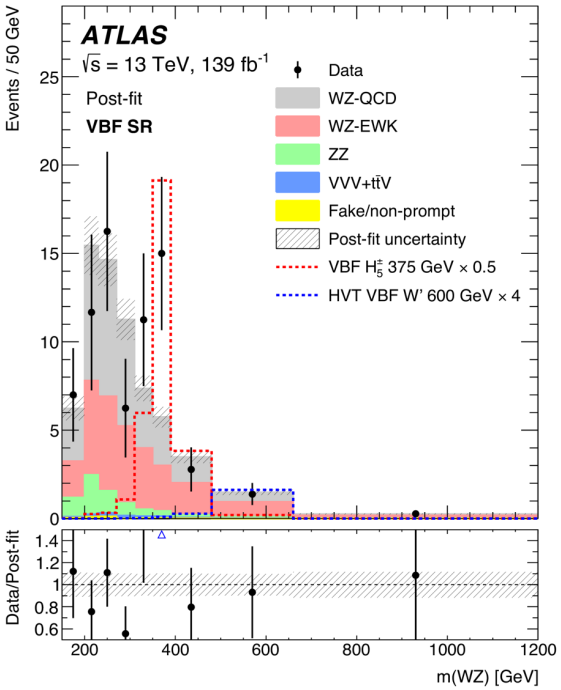


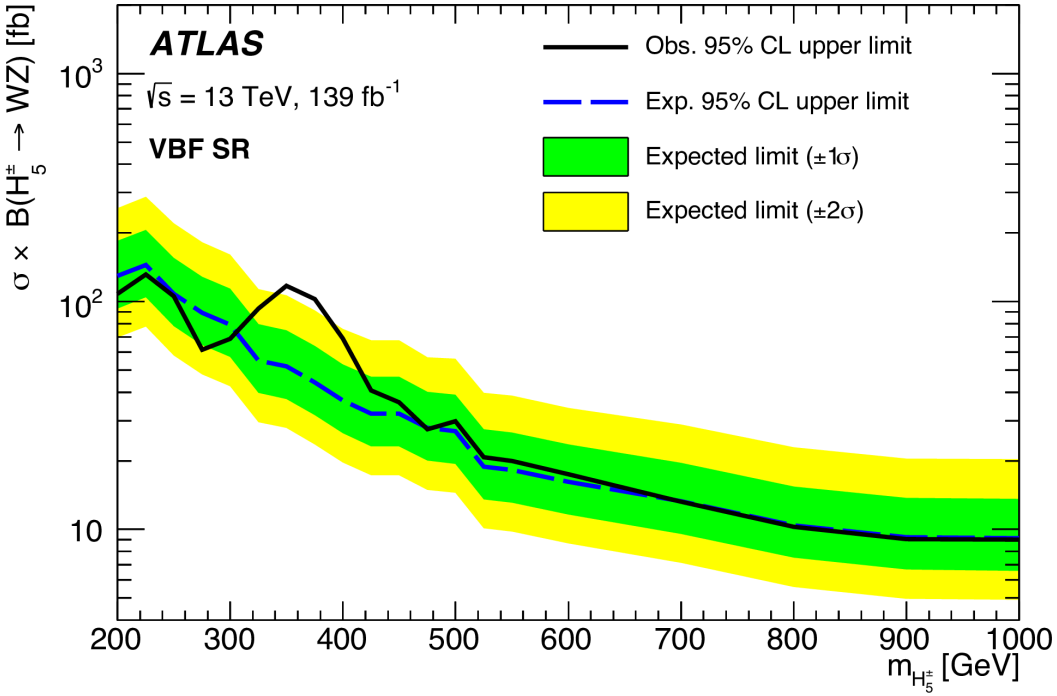
Eur. Phys. J. C 83 (2023) 633

Search for resonant WZ production in three-lepton channel: **results**

The maximum local significances for signals of a heavy vector W' boson or a $H^{\pm}$ (at 375 GeV) are 2.5σ and 2.8σ, respectively.

The respective global significances calculated considering the look-elsewhere effect are 1.7σ and 1.6σ

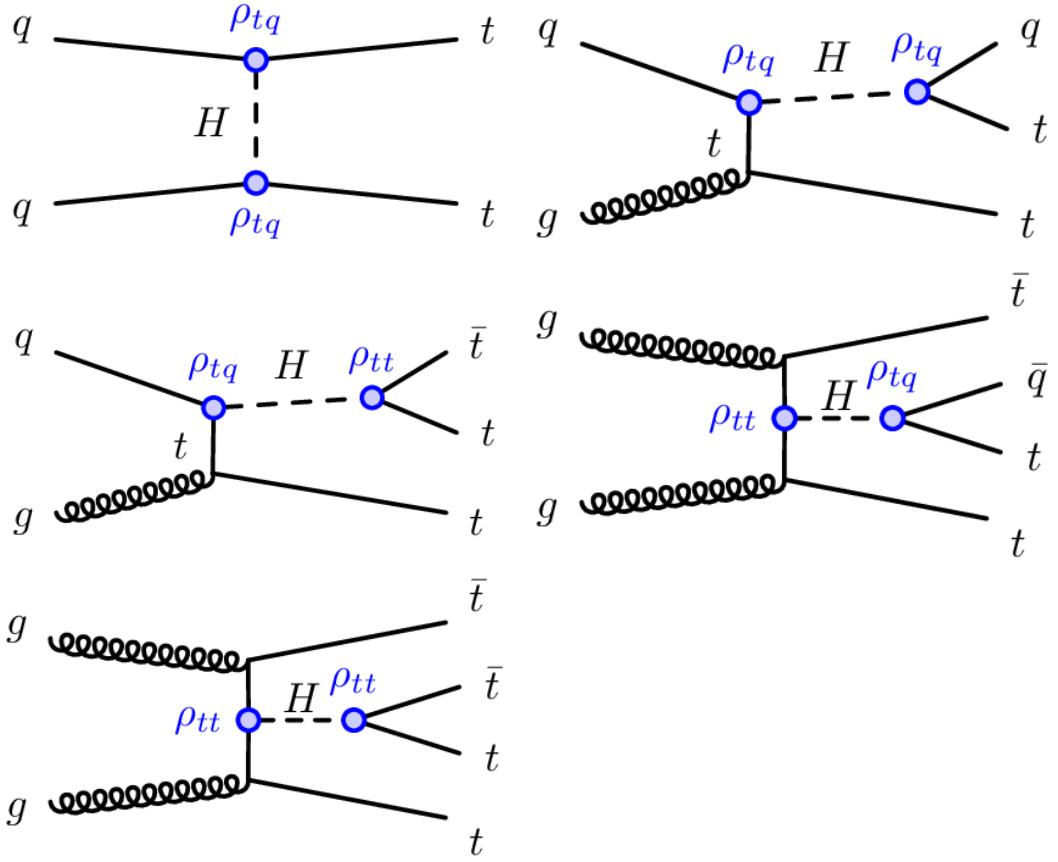




With no evidence of heavy W' vector-resonance production, limits on the production times branching ratio for the heavy vector triplet VBF production process have been obtained as a function of mass.

Search for heavy scalar with FCNH couplings in multilepton channel with b-tagged jets

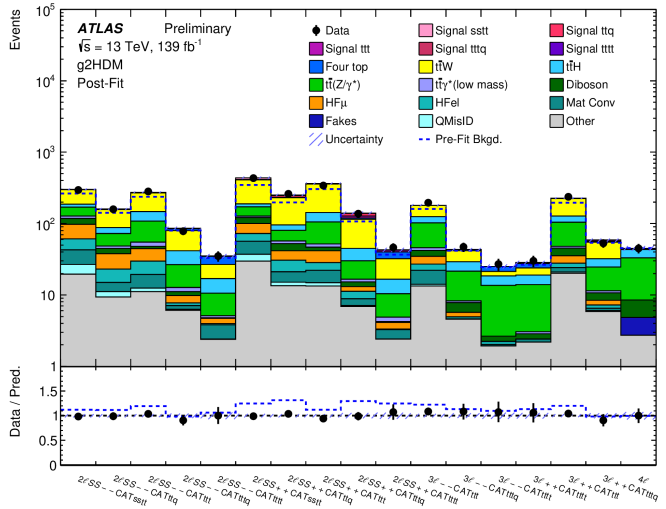
- Model tested:
  - General two-Higgs-doublet-model involving an additional scalar with couplings to the top-quark and the three up-type quarks (ρ_{tt}, ρ_{tc}, and ρ_{tu}). The targeted signals lead to final states with either a same-sign top-quark pair, three top-quarks, or four top-quarks.
- Main backgrounds:
  - ttW/Z, VV production
  - HF – evaluated using normalization to data in the CR; Charge flip – using data-driven methods
- Analysis strategy:
  - Used DNN to separate signal and backgrounds. (17 SR's)

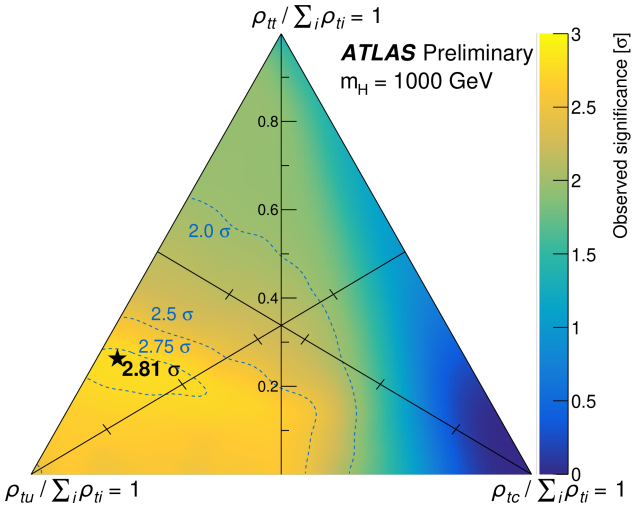


arXiv:2307.14759

Search for heavy scalar with FCNH couplings: **results**

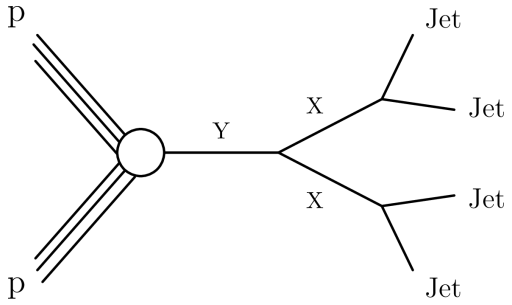
- A mild excess is observed over the Standard Model expectation corresponding to a local significance of 2.81 σ for a signal with m_H=1000 GeV and ρ_{tt}=0.32, ρ_{tc}=0.05, and ρ_{tu}=0.85.
- Exclusion limits at 95% confidence are set on the mass and couplings of the heavy Higgs boson.
- Masses of an additional scalar boson m_H between 200-630 (200-840) GeV with couplings ρ_{tt}=0.4, ρ_{tc}=0.2, and ρ_{tu}=0.2 are observed (expected) to be excluded at 95% CL.

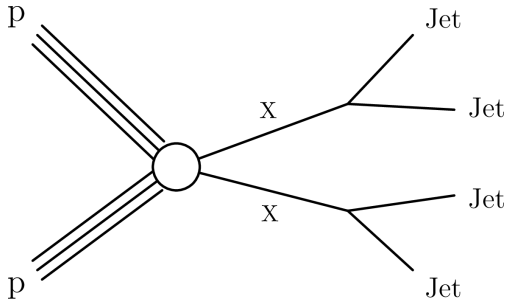


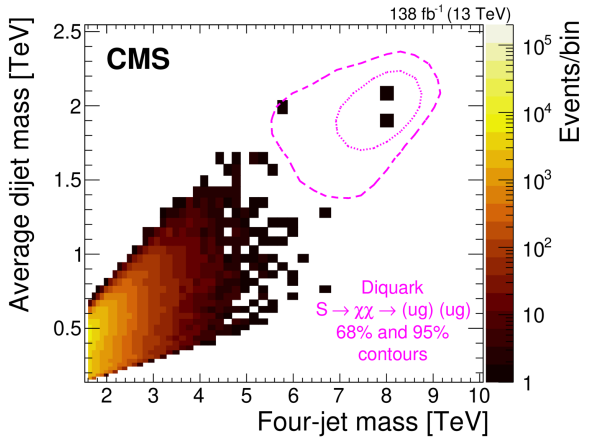


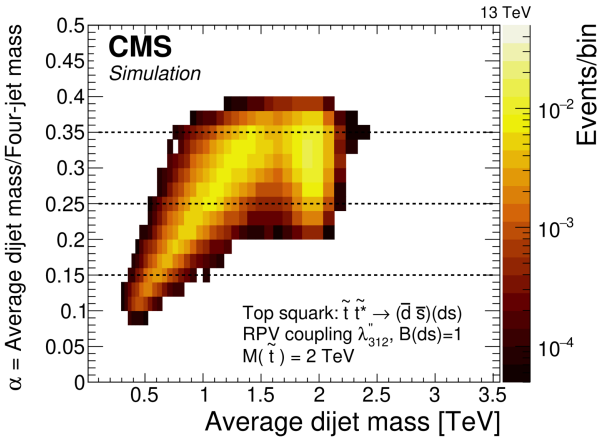
Search for resonant and non-resonant production of pairs of dijet resonances

- Generic search for pair production of a dijet resonance decaying to two jets
- Benchmark processes:
  - diquark decaying into a pair of VLQ $uu \rightarrow S \rightarrow \chi\chi \rightarrow (ug)(ug)$
  - RPV SUSY $\tilde{t}\tilde{t} \rightarrow (\bar{d}\bar{s})(ds)$
- Detection: correlations between four-jet mass and dijet masses
- Background: data driven





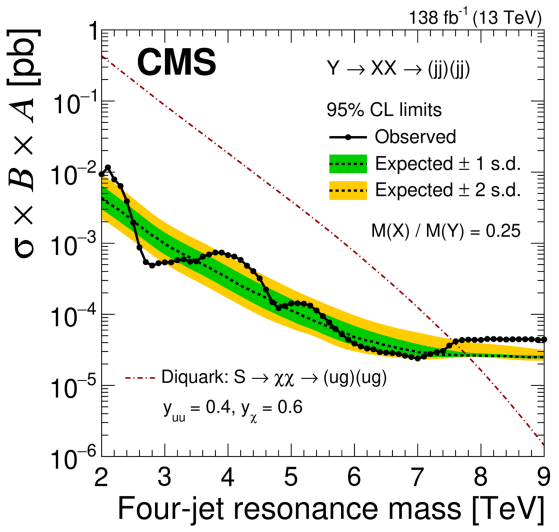


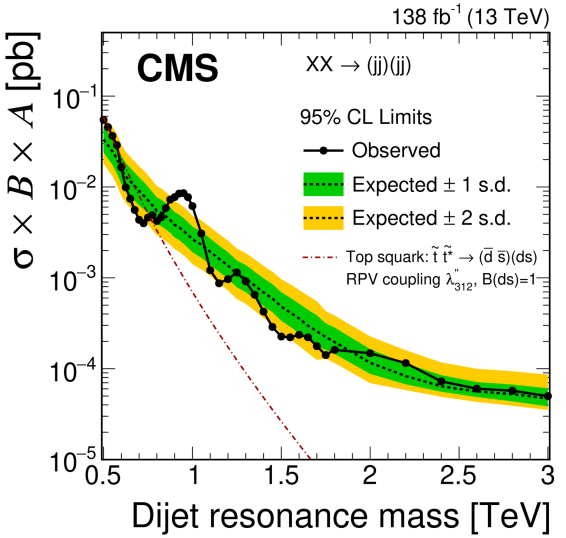


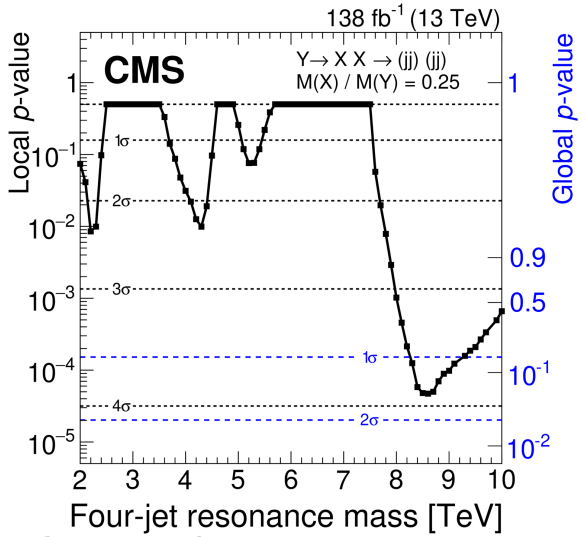
[JHEP 07 (2023) 161]

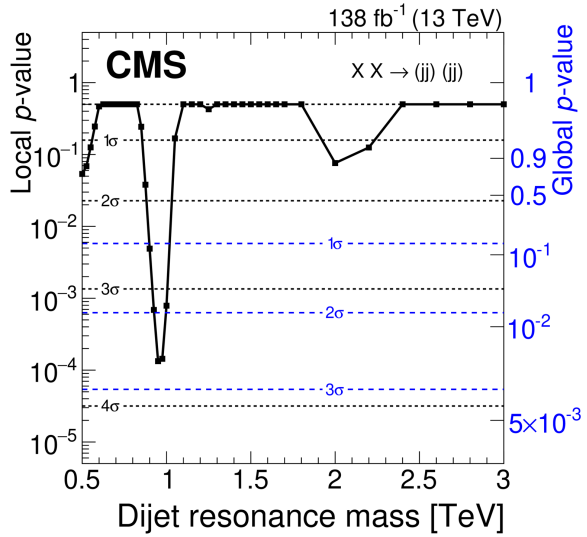
Search for pairs of dijet resonances: results

- Diquarks excluded up to 7.6 TeV
- Pair production of top squarks excluded for masses $0.50<m_{stop}<0.52$ TeV and $0.58<m_{stop}<0.77$ TeV
- Two events in the tails with m(4j)=8 TeV and average m(2j)=2 TeV
- Local (global) significance: 3.9(1.6) σ



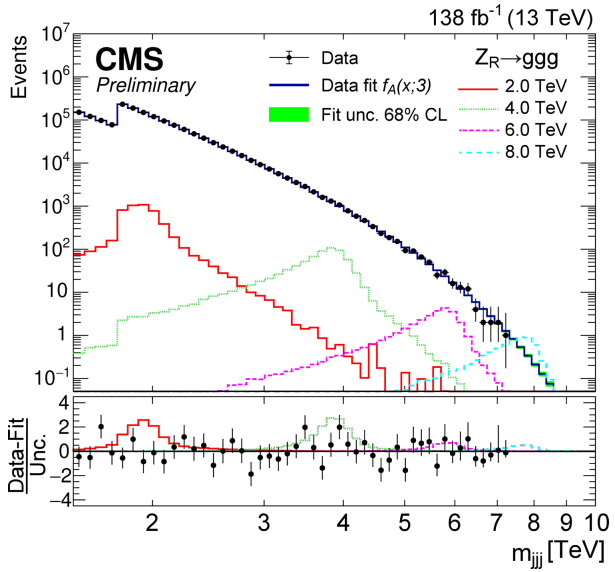


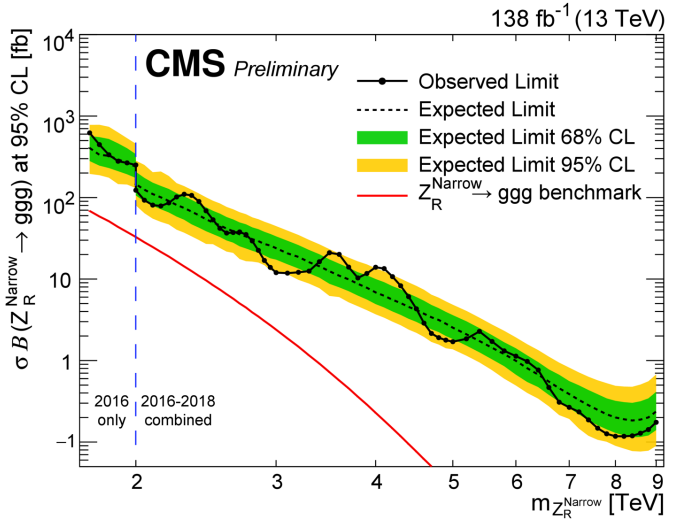




Search for narrow trijet resonances

- Generic search for resonances decaying to three jets
- Benchmark processes:
  - right-handed Z boson $Z_R \rightarrow ggg$
  - KK gluon $G_{KK} \rightarrow \varphi(gg)g$
  - excited quark $q^* \rightarrow V(qq)q$
- Background: QCD, evaluated as a smooth m(jjj) fit





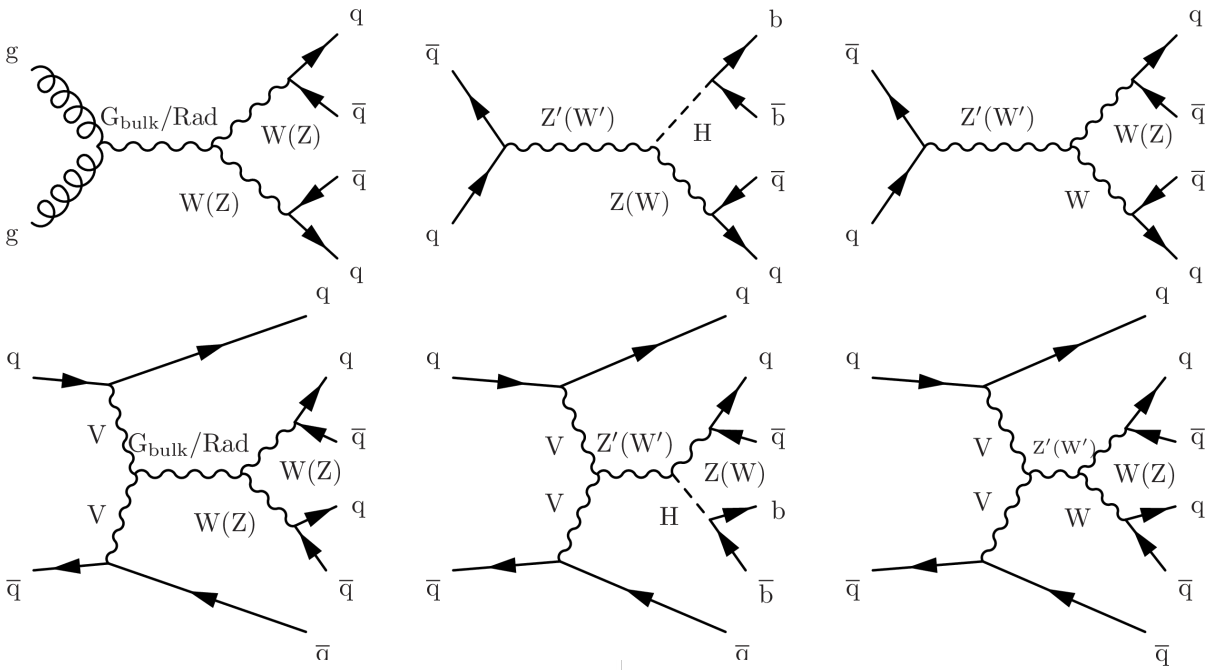
$Z_R \rightarrow ggg$ scenario: largest deviation observed at $m(Z_R)$=4.1 TeV, local (global) significance of 2.2(0.25)σ

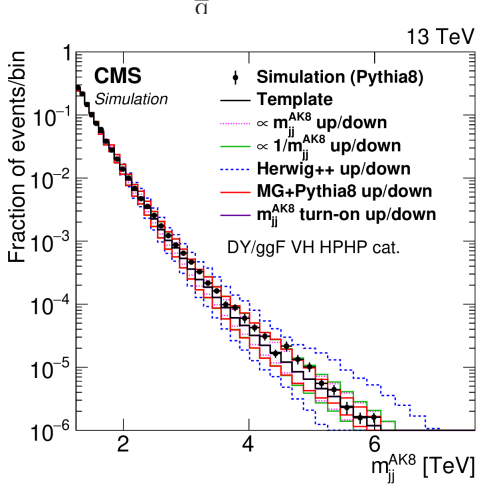
$X \rightarrow Y(gg)g$ scenario: largest deviation observed at m_X=4.1 TeV, local (global) significance of 2.2(0.36)σ

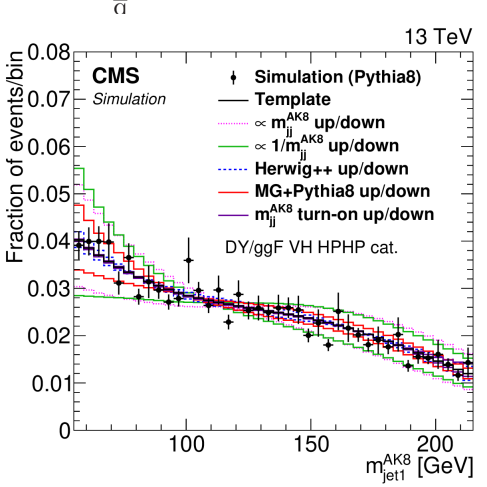
EXO-22-008

Search for new heavy resonances decaying to VV/VH in the all-jets final state

- Search for VV/VH resonances with masses 1.3<m<6 TeV produced via Drell-Yan / gluon fusion / vector boson fusion
- Benchmark processes:
  - graviton/radion → WW/ZZ
  - Z'→ZH / W'→WH
  - Z'→WW / W'→WZ
- Require at least two large-R jets with p_T>200 GeV, m(JJ)>1.25 TeV
- Background: QCD, V+jets (simulated)
- Signal extraction: 3D (m_{jj}, m_{j1}, m_{j2}) template fit



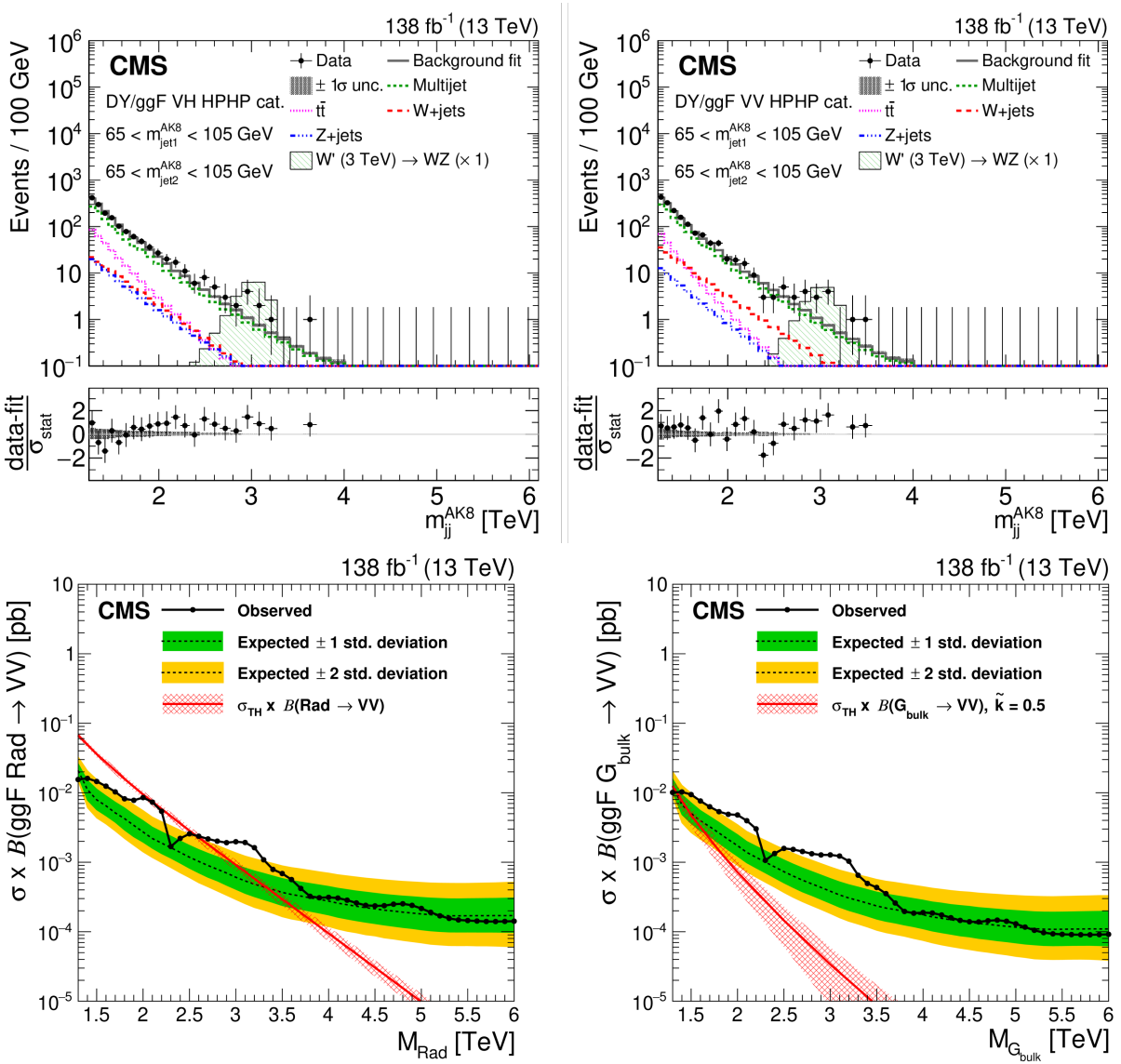




Phys. Lett. B 844 (2023) 137813

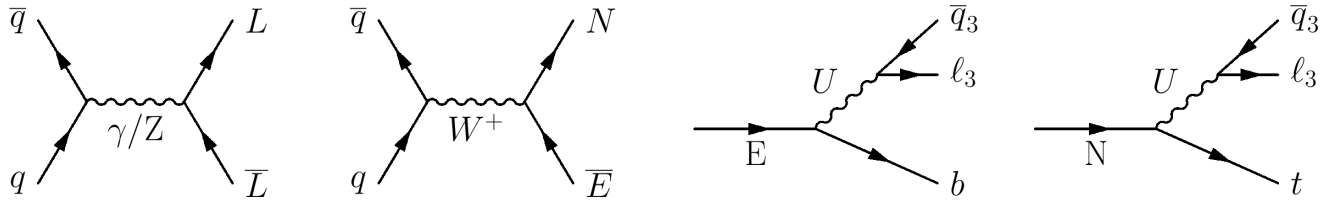
Search for VV/VH →all-jets resonances: **results**

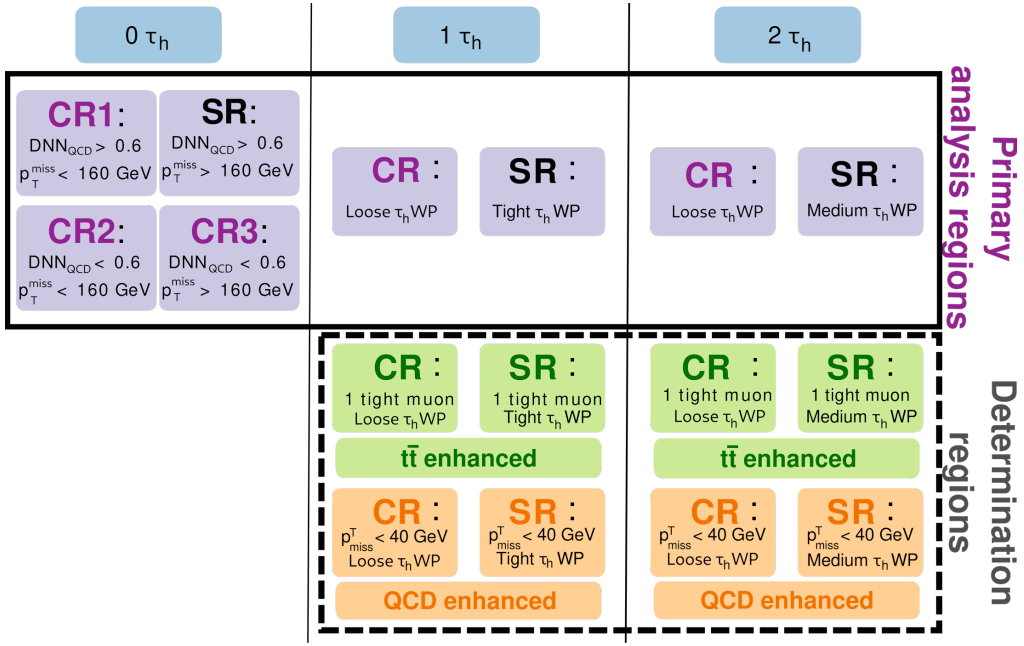
- Spin 1 Z' / W' excluded with masses below 4.8 TeV at 95% CL
- Spin 2 gravitons (spin 0 radions) excluded with masses below 1.4(2.7) TeV at 95% CL
- Excess of 3.6(2.3)σ local (global) significance observed at m_{jj} of 2.1 and 2.9 TeV



Search for pair-produced vector-like leptons in final states with third-generation leptons and ≥3 b-jets

- Search for vector-like leptons in the context of the "4321 model"
  - aimed at explaining B-physics measurements in tension with SM
- Final states: ≥3 b-jets + $\tau\tau/\tau\nu_\tau/\nu_\tau\nu_\tau$
- Background: ttbar (estimated with simulation), QCD (data driven)
- 12 VLL mass hypotheses (500 to 1050 GeV)
- Signal extracted using DNN_{QCD} and DNN_{ttbar} classifiers

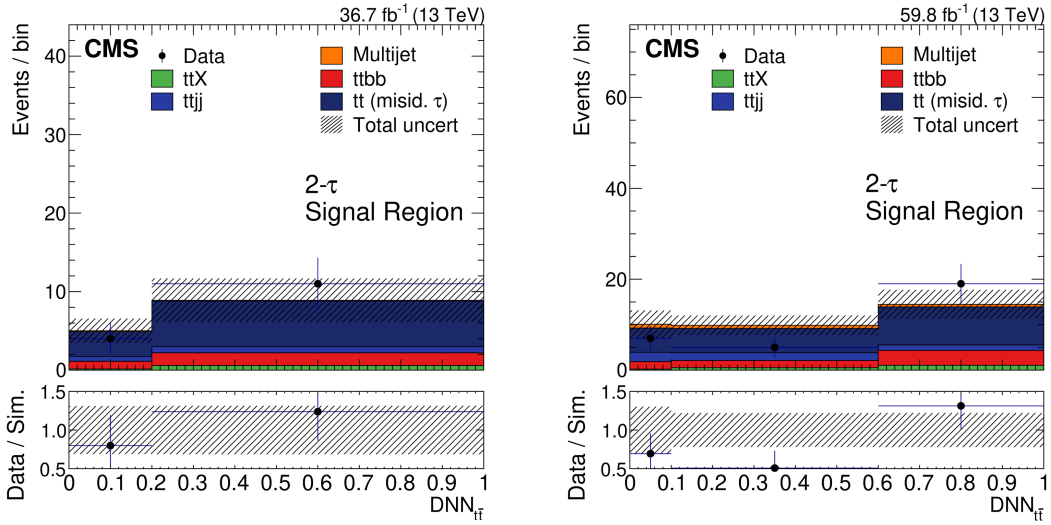


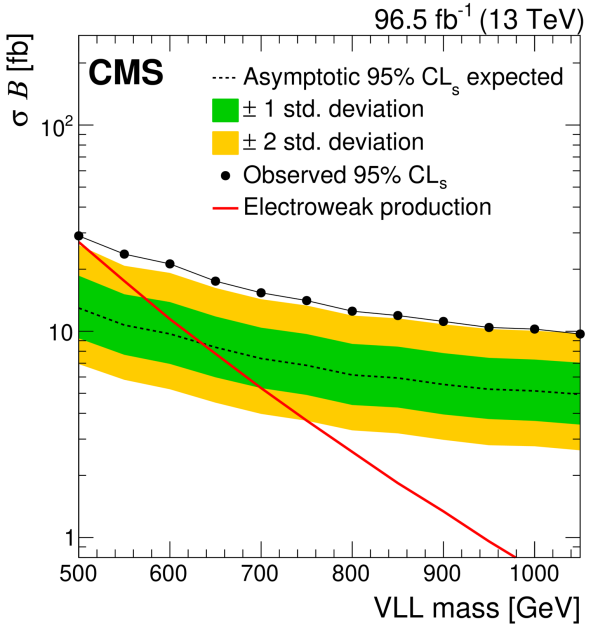


arXiv:2208.09700

Search for VLP pairs to $\tau\tau/\tau\nu_\tau/\nu_\tau\nu_\tau$ + ≥3 b-jets: results

- Observed data shows consistent excess in the highest DNN_{ttbar} bins
- As DNN_{ttbar} is not very sensitive to the signal mass, the excess is present for all mass points
- At representative VLL mass of 600 GeV, the excess is 2.8σ
- The excess holds when including Z' production of VLL pairs





Conclusion

- ATLAS and CMS Collaborations have an extensive physics search program
  - Various original analyses
  - Expanding coverage thanks to reinterpretation of existing results
- A lot of interesting results obtained with data collected during Runs 1 and 2
  - Some of them reveal hints of tension with SM
  - More is coming!
- Looking forward to taking more data with Run 3 that recently started!

Thank you!

And special thanks to:

DOE for supporting this research