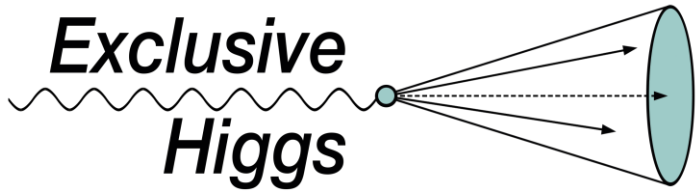
Searches for resonances decaying to boson pairs in ATLAS

Panagiotis Bellos



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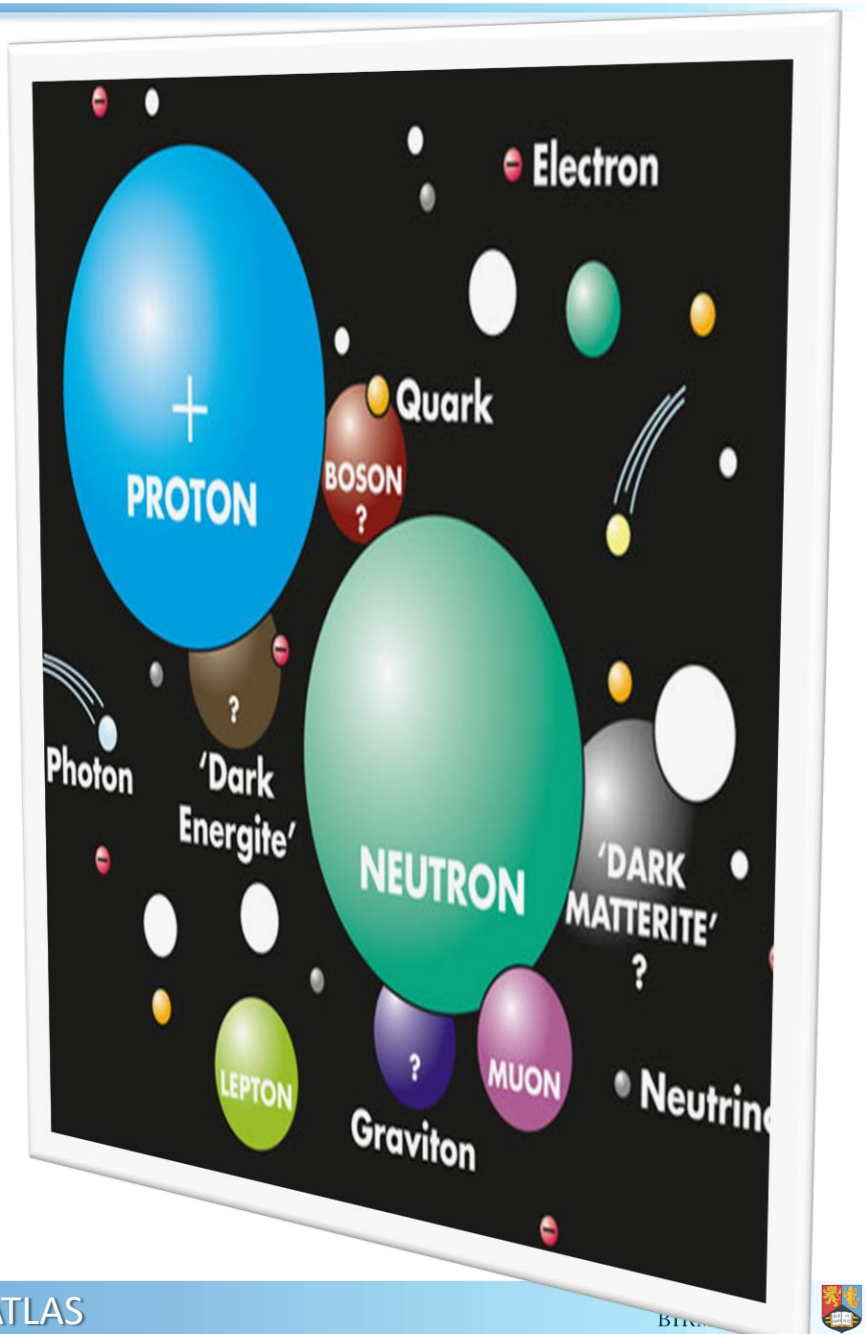
23/2/2023

Beyond Standard Model resonances

- **2 Higgs Doublet Model (2HDM)**
  - 2 neutral (H, h), 1 pseudoscalar (A), 2 charged ($H^{\pm}$)
- **Seesaw model (type II)**
  - 4 charged ($H^{\pm\pm}$, $H^{\pm}$) , 1 pseudoscalar (A^0) , 2 neutral (H^0 , h^0)
- **Georgi–Machacek (GM) model**
  - A fiveplet $H_5{}^{++}$, $H_5{}^{+}$, $H_5{}^{0}$, $H_5{}^{-}$, $H_5{}^{--}$
- **Heavy Vector Triplet (HVT)**
  - 3 heavy vector bosons (W'$^{\pm}$, Z')
- **Warped Extra Dimensions**
  - Spin 2 Graviton, spin 0 Radion
- **Axion Like Particles**
- **Model independent resonances**



ATLAS X → Diboson searches

Diboson state	Final states
HH	4b, 2b2W, 2b2τ, 4W, 2b2γ, 2W2γ, 2blνlν
HZ	qqbb, ννbb, llbb
HW	qqbb, lνbb
ZZ	qqqq, ννqq, llqq, llνν, llll
ZW	qqqq, ννqq, lνqq, llqq, lνll
WW	qqqq, lνqq, lνlν
Hγ	bbγ
Zγ	llγ, qqγ
Wγ	lνγ, qqγ
γγ	γγ

- **Many BSM searches by ATLAS**
  - Currently searches focus on high masses
  - High mass resonances → diboson decays

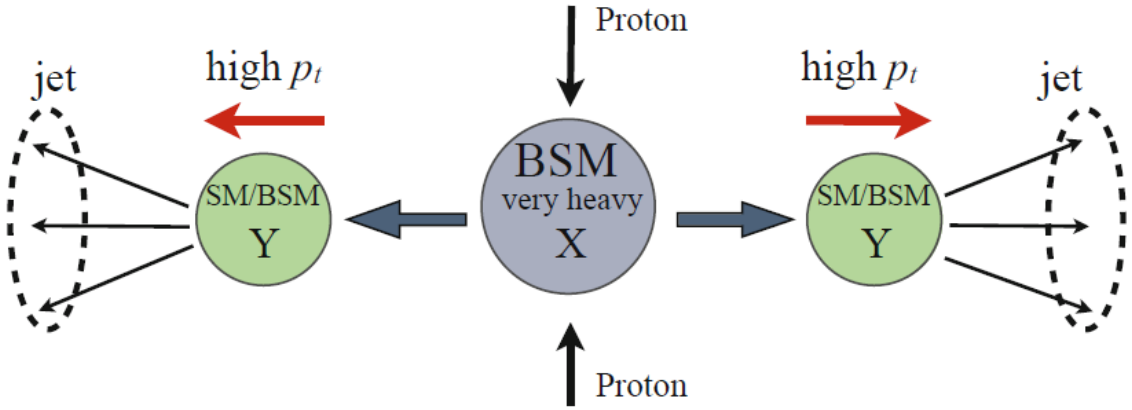
Hadronic decays

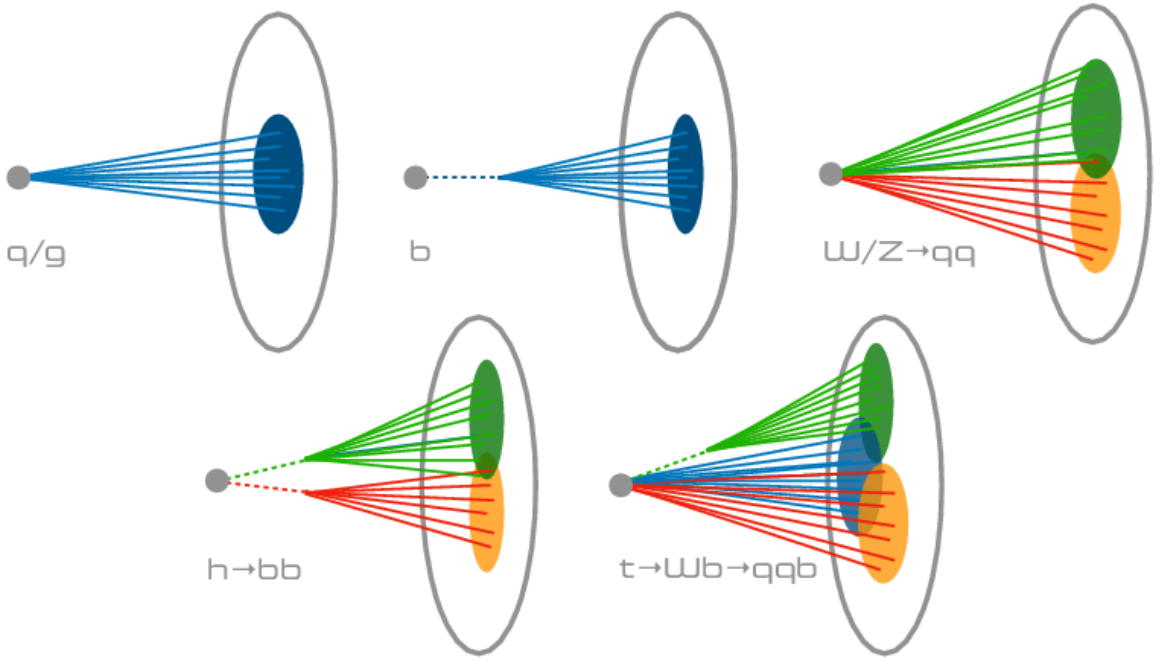
- **Typical heavy BSM resonance decay**
  - X → 2Y high p_T particles

- **Large hadronic Branching Ratios**
  - Z → hadrons ≈ 70%
  - W → hadrons ≈ 67%
  - H → hadrons ≈ 80%

- **Hadronic decays of high p_T particles**
  - Highly boosted collimated jets
  - Reconstructed as single large jet

- **Large R-Jets**
  - Anti-k_t aggregates Topo clusters until certain R
  - Increase R from 0.4 to 1 for large jets
  - Particle identification from jet substructure



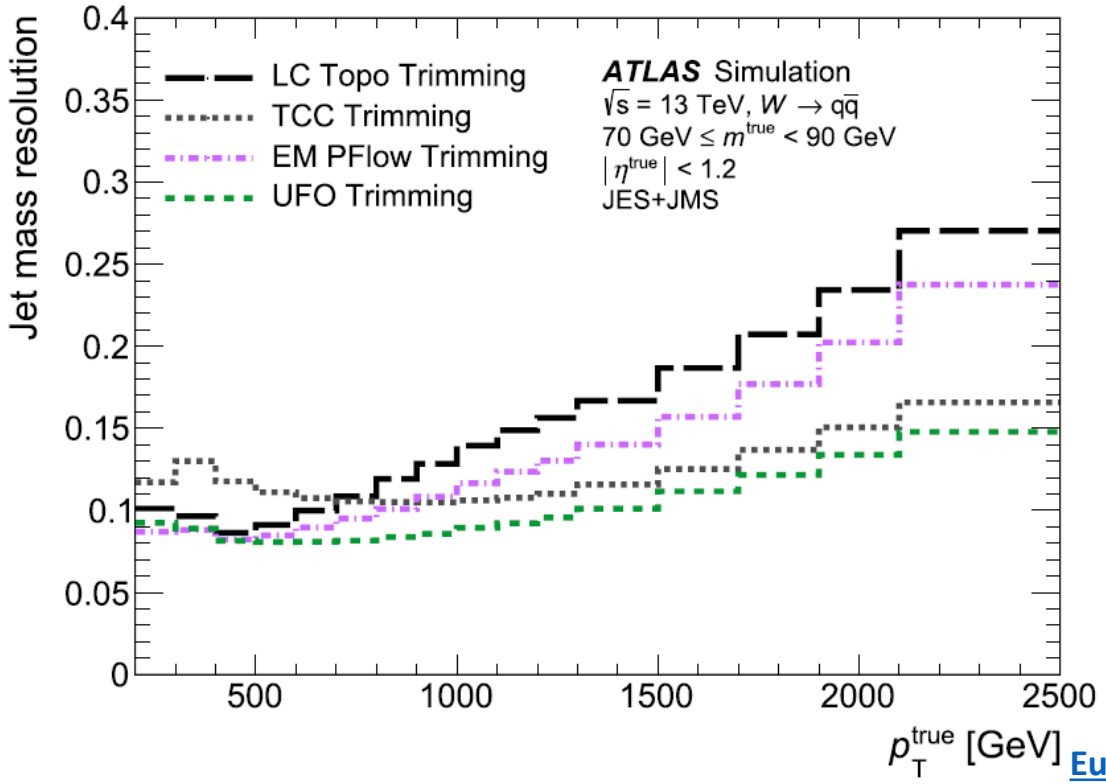


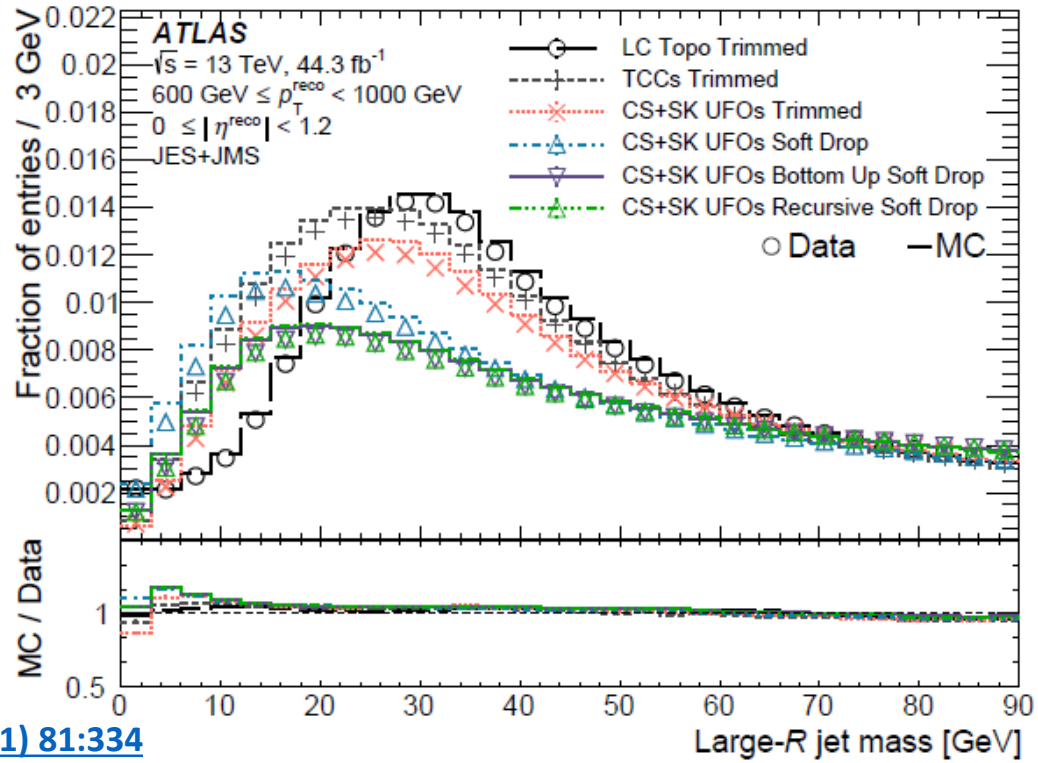
Jet reconstruction

- **Track-CaloClusters (TCCs)**
  - Developed for massive boosted objects
  - Combine the strengths of calorimeter (p_T, m) and ID (ϕ,η)
  - Optimized for jet substructure reconstruction performance
  - Better performance on high p_T jets

- **Unified Flow Objects (UFO)**
  - TCCs and Particle Flow Objects merged into UFO
  - UFO has overall best performance

- **Pile – up subtraction and calibration**
  - Pile-up mitigation and/or grooming algorithms
  - Detector response and simulation mismodelling





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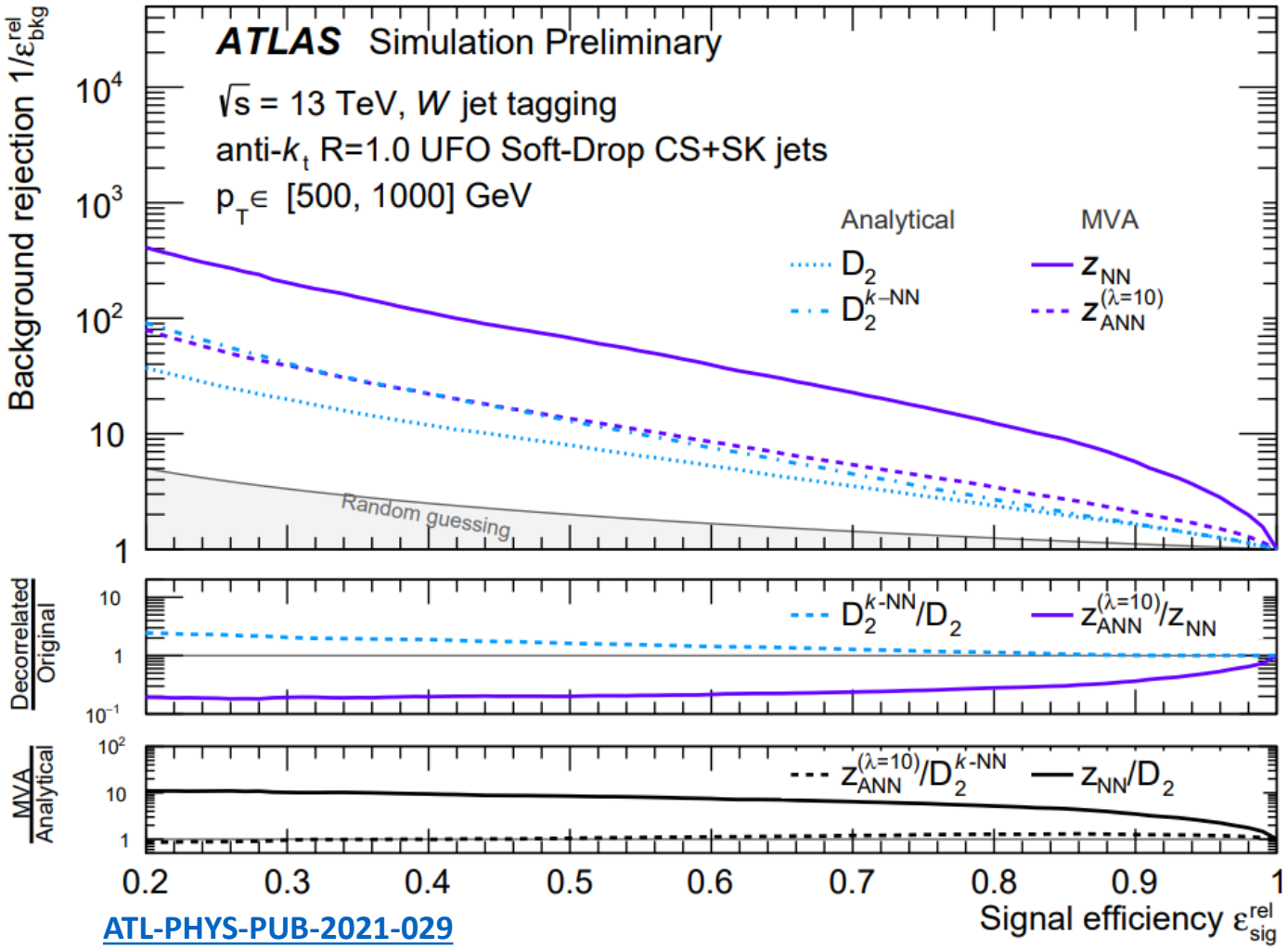
Z/W Tagging

- **W/Z tagging**
  - 2-prong decays with relatively equal momentum sharing

- **Machine learning techniques**
  - Sophisticated substructure variables
  - Adversarial NN to ensure no mass correlation
  - x10 improvement in bkg rejection wrt the cut based tagger
  - x2-4 improvement due to using UFO jets



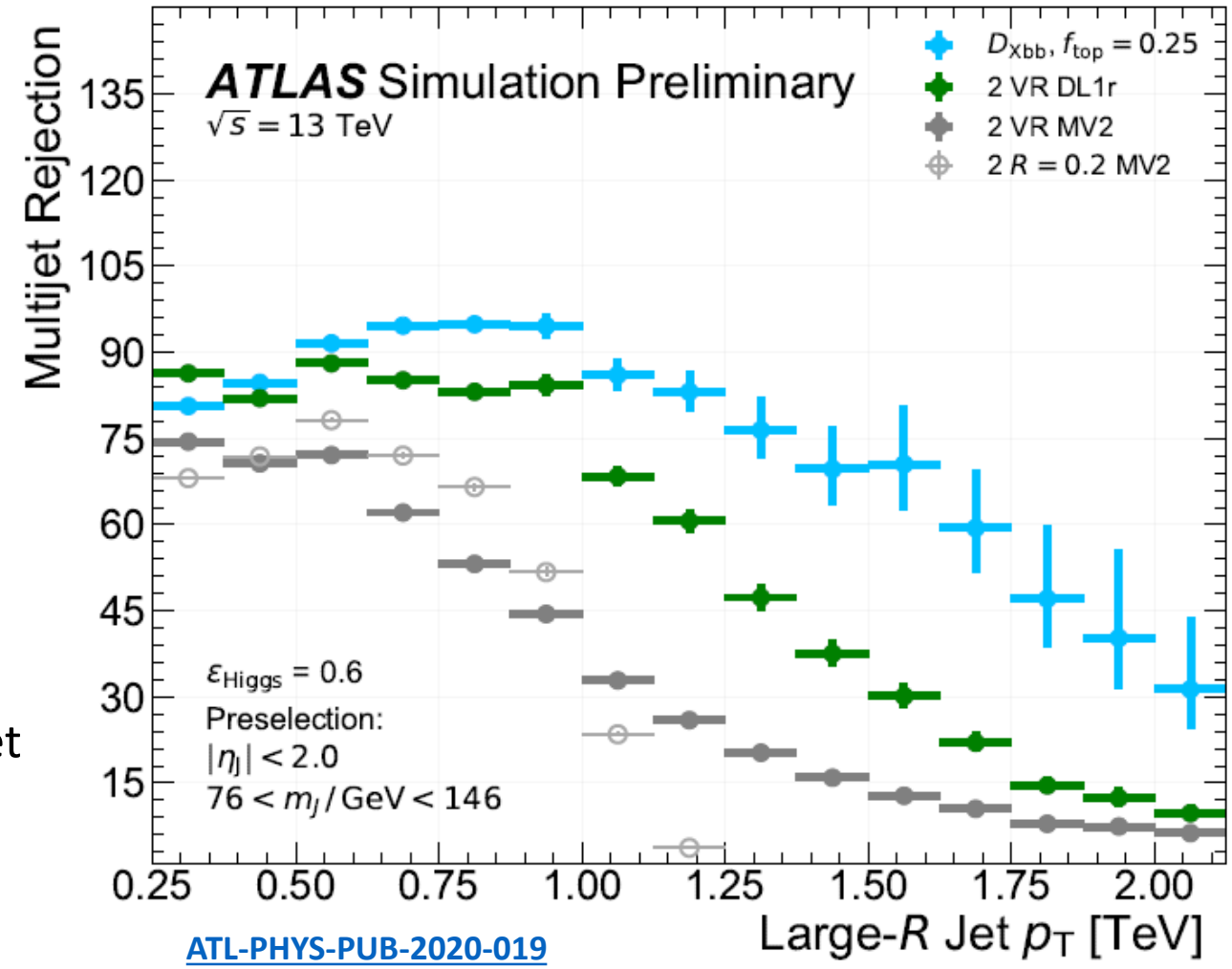
ATL-PHYS-PUB-2021-029

Higgs Tagging

- **Higgs tagging**
  - Usually identified from the b-jets
  - Several exclusive Higgs-tagging algorithms

- **b-jet tagging**
  - Displaced vertex / Large mass / High decay multiplicity
  - Highly sophisticated ML algorithms (DL1r)
  - Jet topology, secondary vertices, tracks
  - DL1r discriminates b, c, light flavor jets

- **Boosted H->bb tagger**
  - Extends the application of b-tagging at the large-R jet
  - Neural network
  - Combines large-R jet kinematics with flavor tagging info

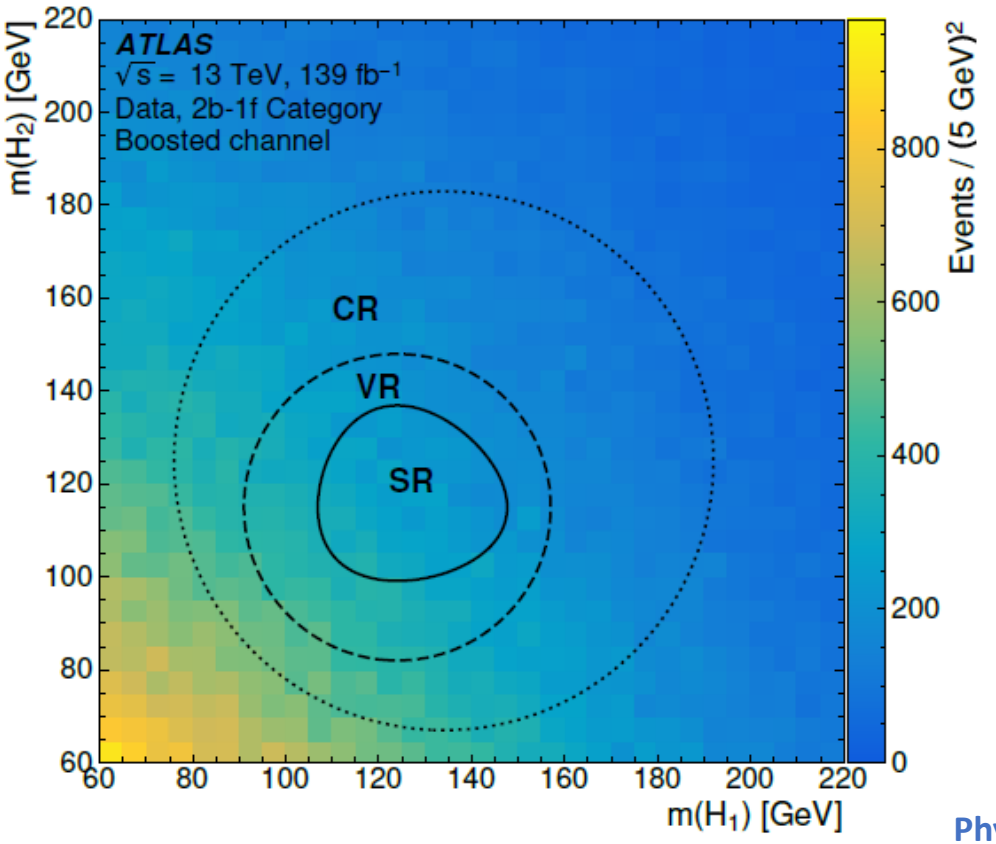


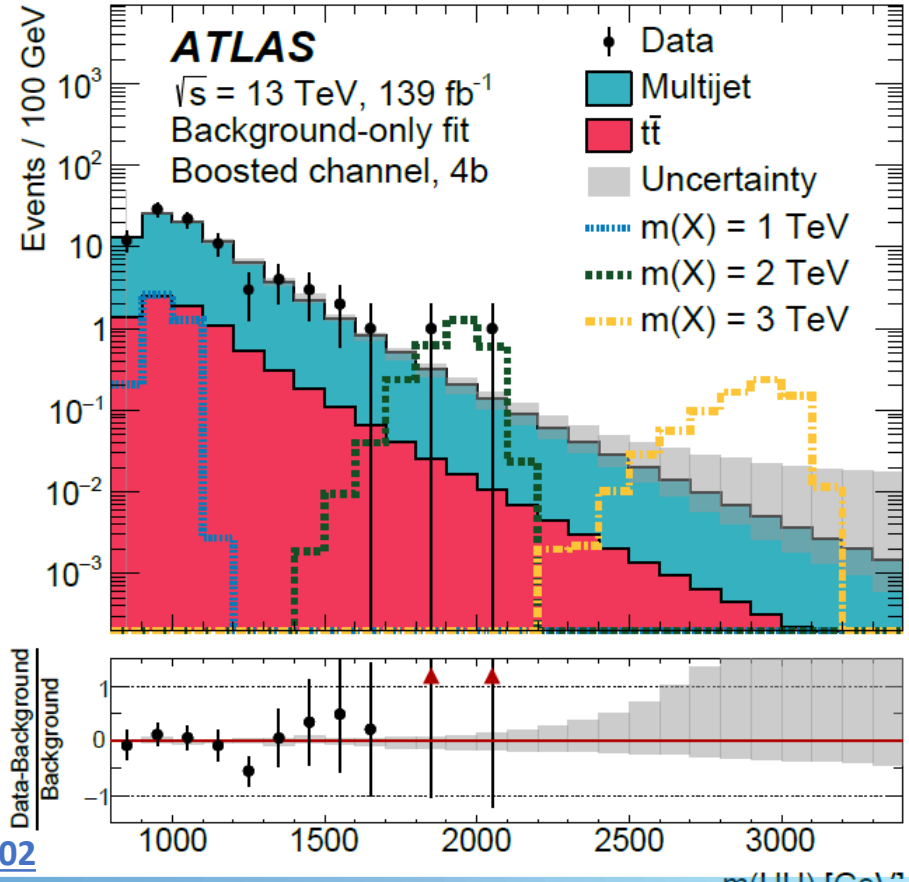
ATL-PHYS-PUB-2020-019

Search for X → HH → 4b

- **Analysis strategy**
  - Multijet background
  - Boosted / resolved topologies
  - 2 large-R jets Topo / 4 small-R PFlow

- 3 signal-enriched categories “4b”, “3b”, “2b”
  - Signal region is defined by bb pairs masses
  - General spin 0 and Graviton interpretations

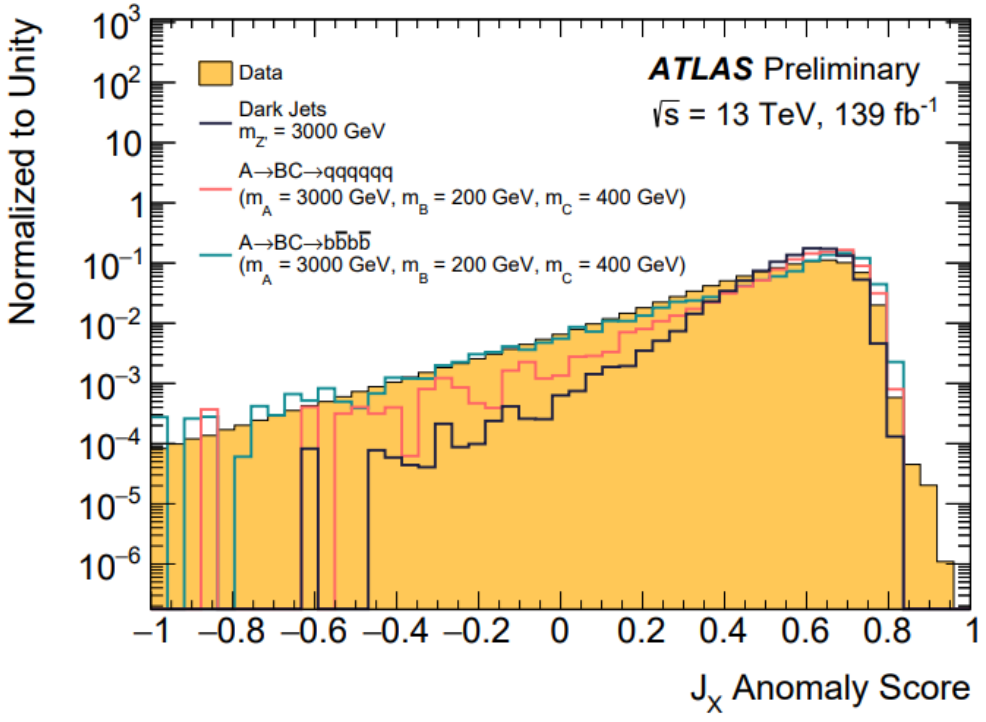




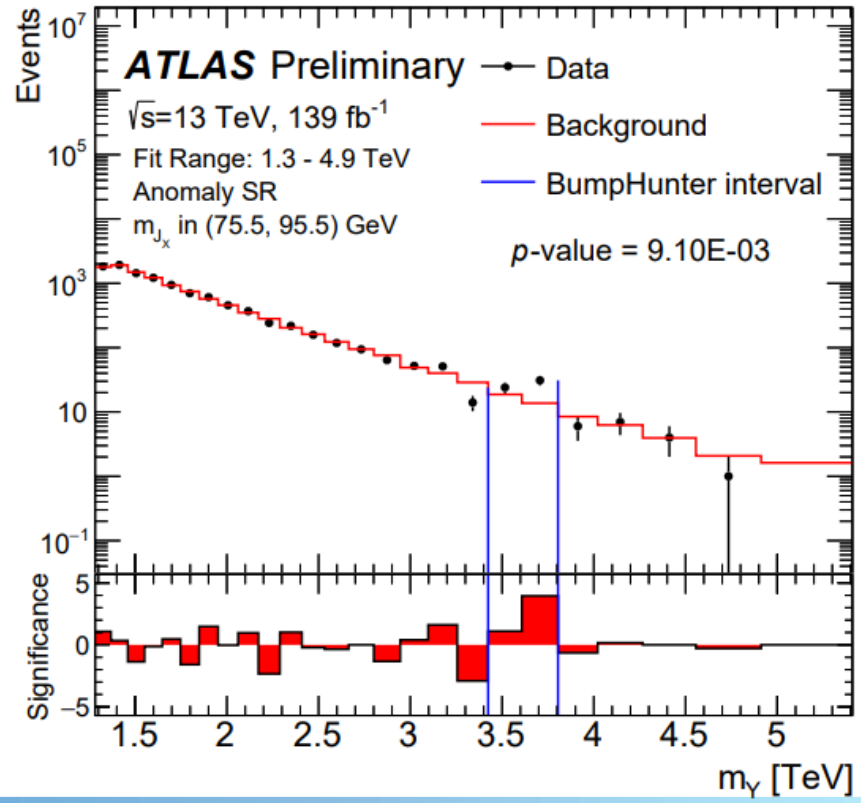
Phys. Rev. D 105 (2022) 092002

Anomaly detection search for Y → XH

- **Analysis strategy**
  - Multijet background
  - 2 highest p_T large-R TCC jets & boosted H->bb tagger
  - Jet-level Anomaly Score for the Signal Region
  - 2 supplementary SRs for 2-prong X decay, boosted/ resolved topology
  - Small excess found (global significance 1.47σ)



- **Variational recurrent neural network (VRNN)**
  - Unsupervised learning for Anomaly Detection
  - Trained over large jets modeled as sequence of constituent 4-vectors
  - Designed to reveal correlations between constituents and substructure to reveal any anomaly

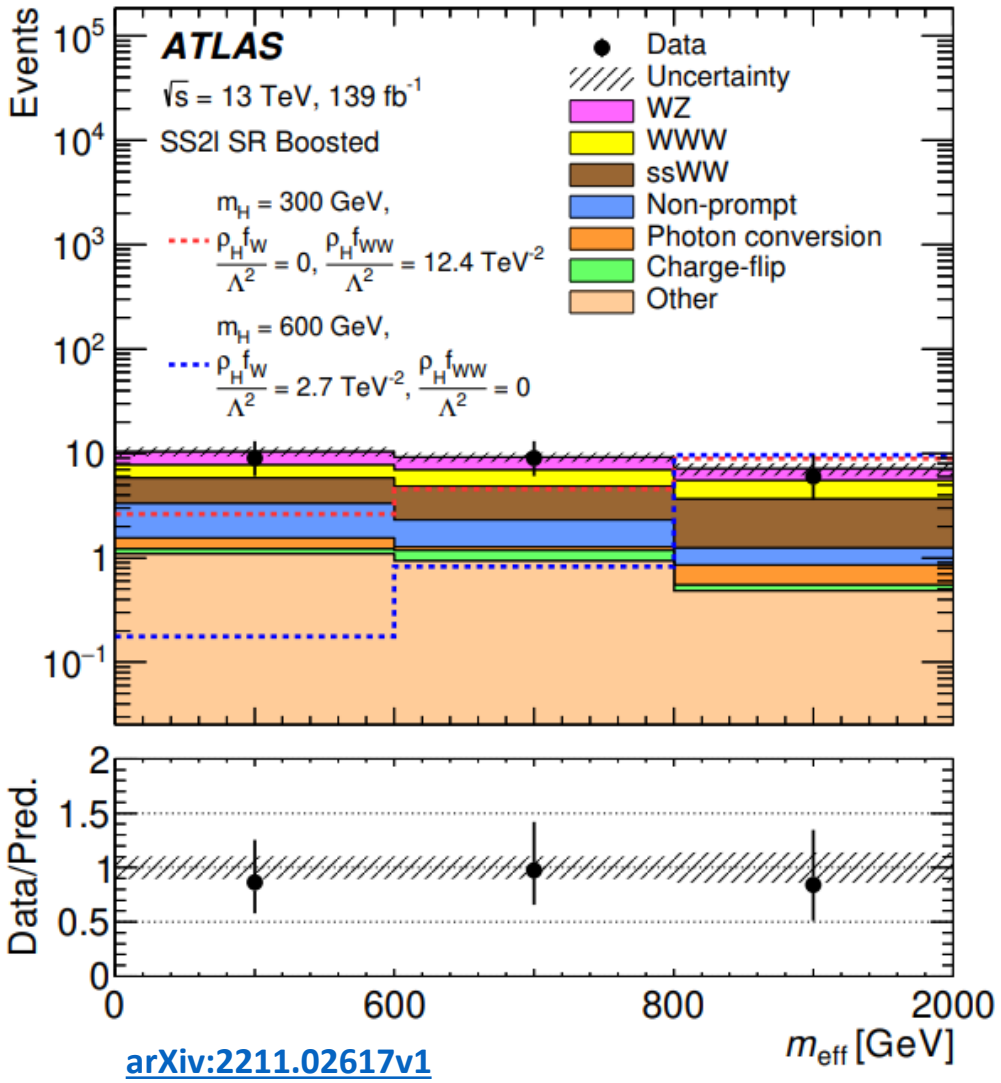


ATLAS-CONF-2022-045

Search for HW → WWW → lvlvjj

- **Analysis strategy**
  - Background from VVV, VV, etc.
  - Boosted / Resolved topologies
  - 2 leptons, E_{Tmiss} , 1 large Topo /2 small PFlow jets
  - Boson tagger to distinguish W jets
  - Effective mass discriminant (sum of P_T^{lep} ,p_T^j, E_{Tmiss})

- **W/Z tagger**
  - 3D (jet mass, D_2, n_{trk}) tagger
  - Parametrized as function of p_T
  - Optimized for maximum significance

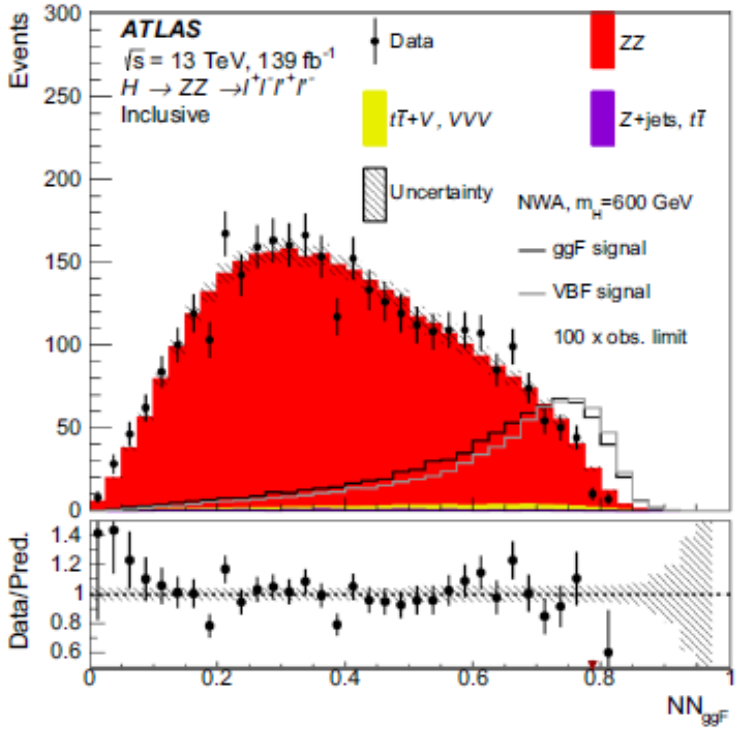


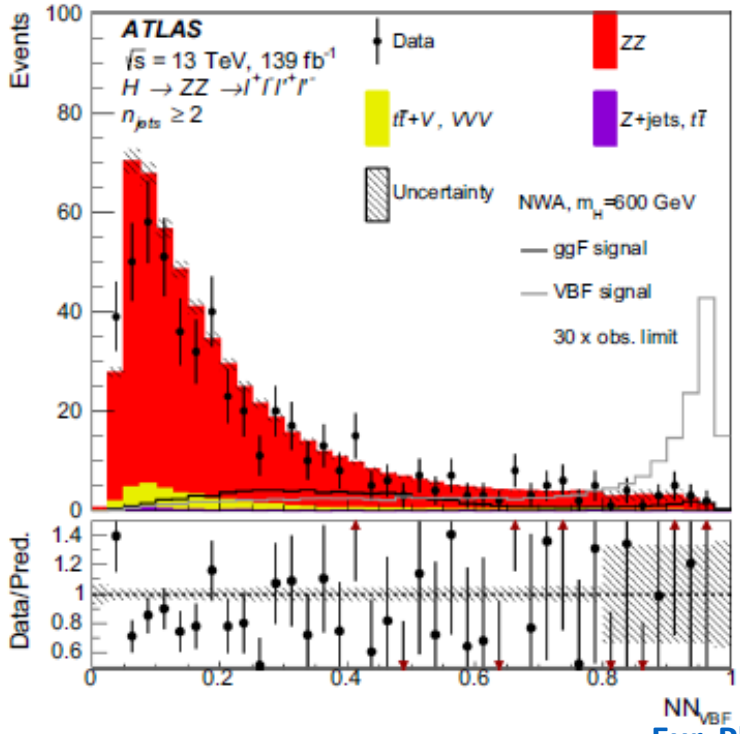
arXiv:2211.02617v1

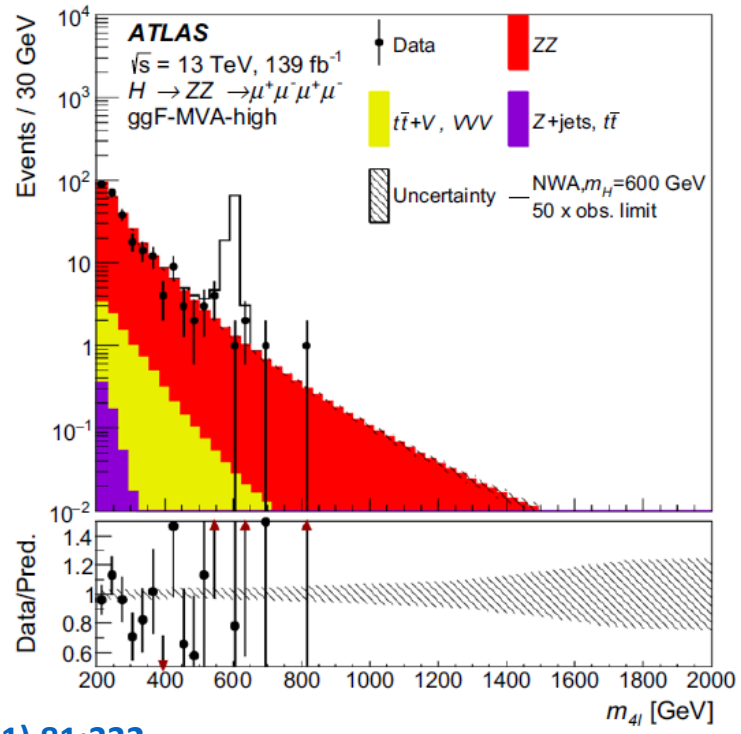
Search for X → ZZ → 4l

- **Analysis strategy**
  - Background from qq/gg → ZZ
  - 4 leptons compatible with ZZ
  - ggF and VBF category
  - 2HDM and Graviton interpretations

- **2 Deep Neural Networks**
  - Probe the ggF/VBF signal
  - Trained on event kinematic variables
  - Advanced design combining RNN and MLP
  - 11 mass points (PNN)
  - Separate events in ggF/VBF/rest







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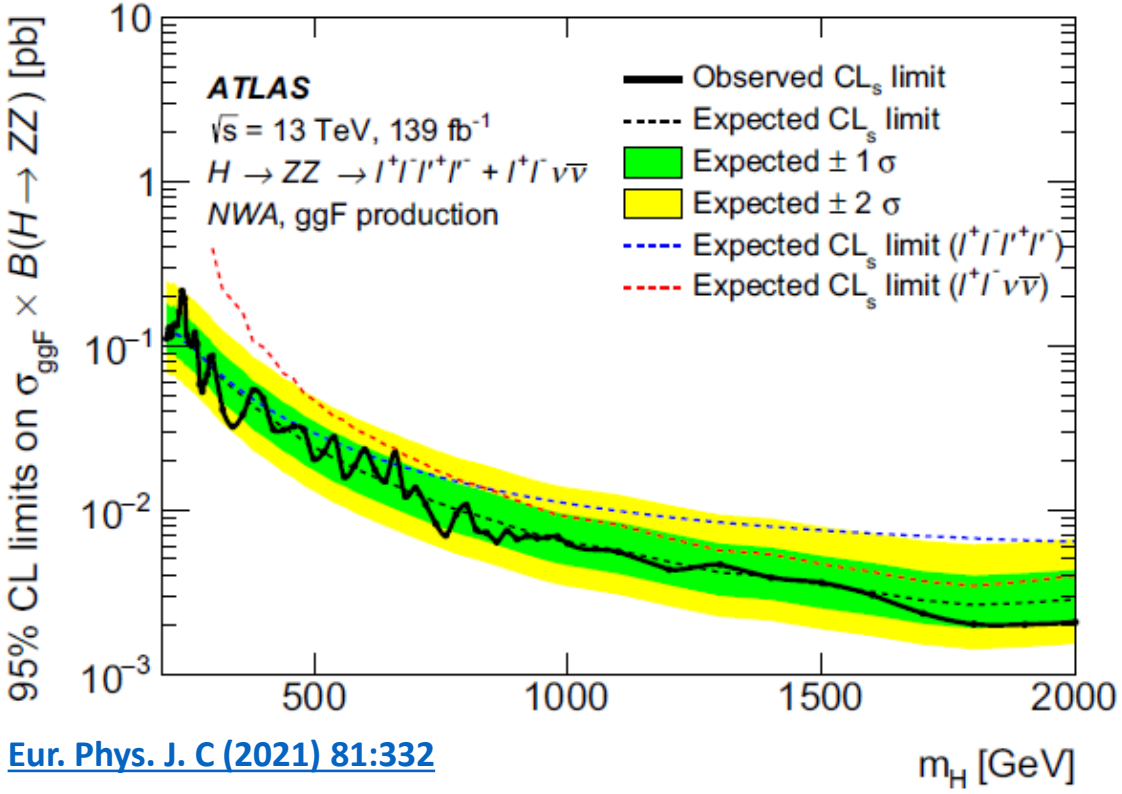
Results – Full Run II



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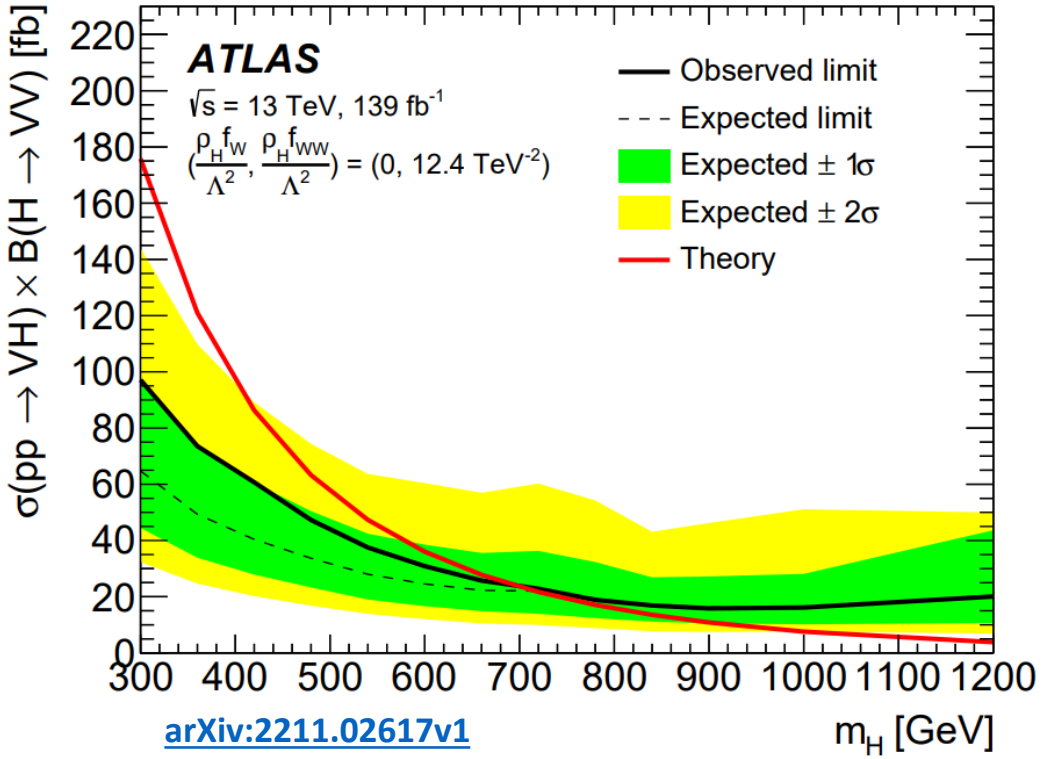
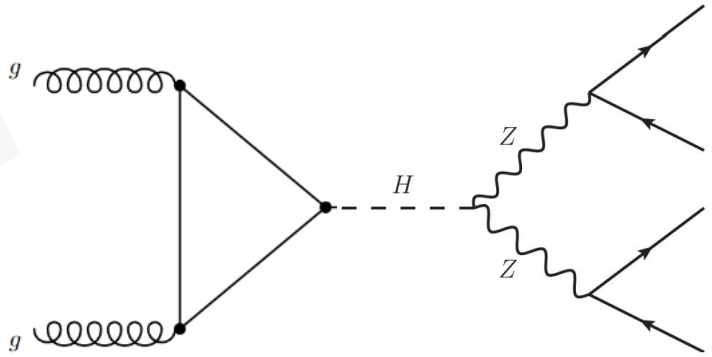
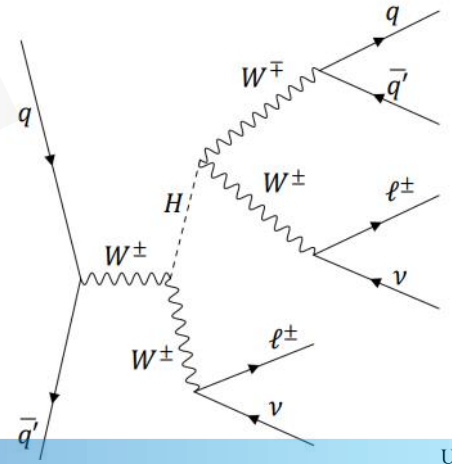


arXiv:2211.02617v1

Heavy Higgs
H → ZZ → 4l/2l2ν



Heavy Higgs
HW → WWW → lνlνjj



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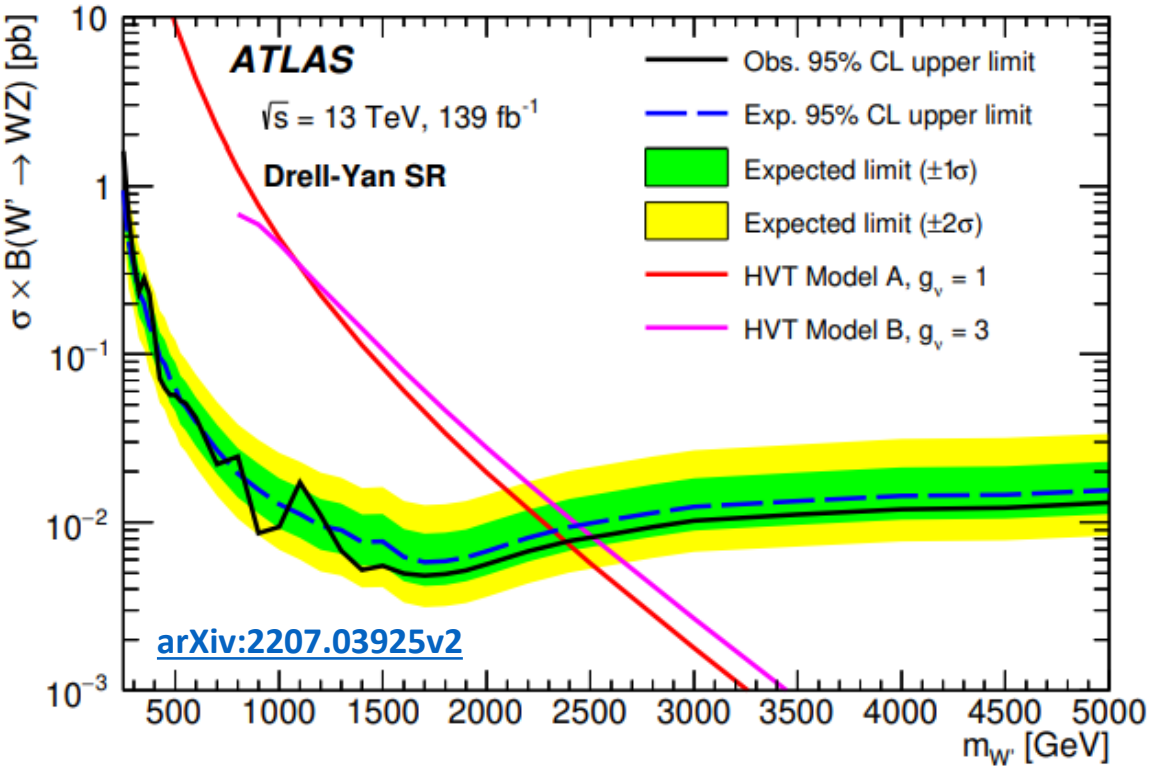
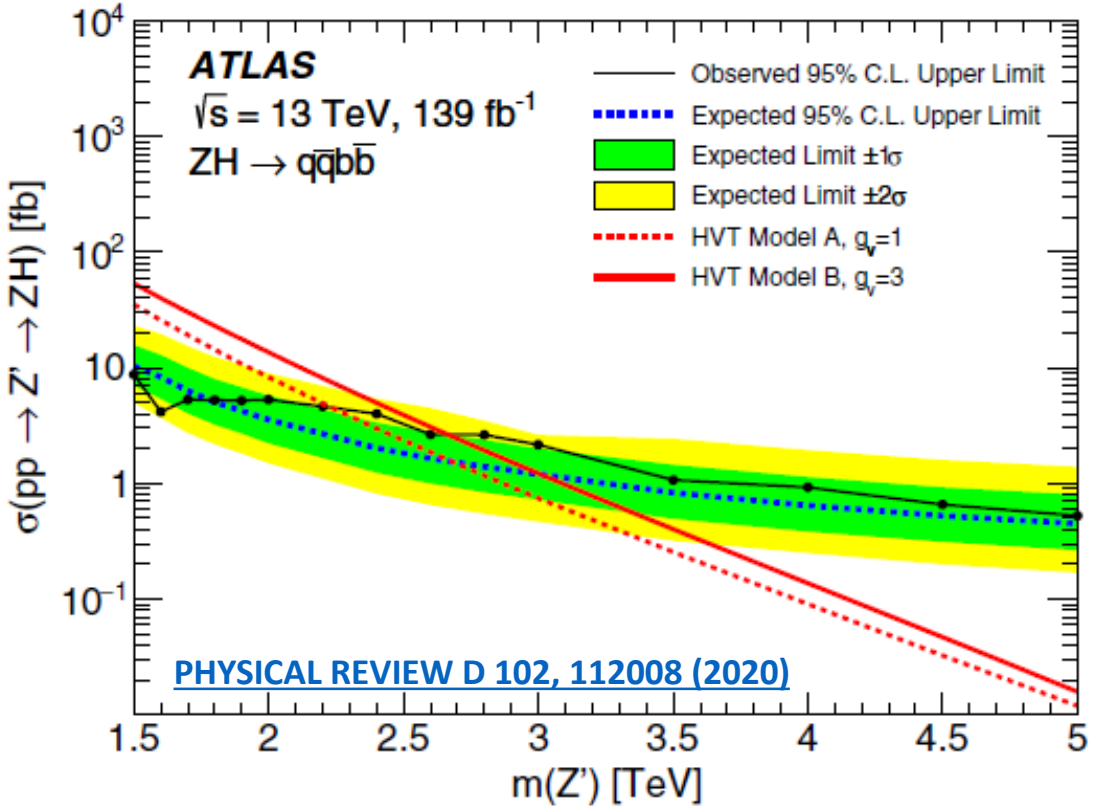
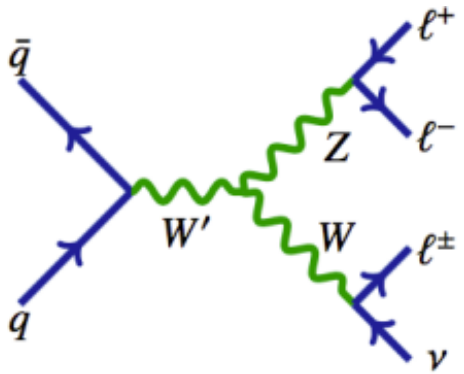
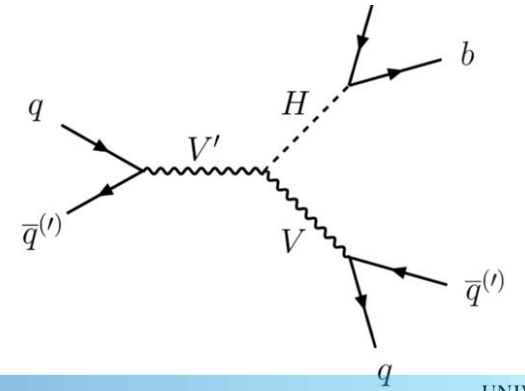




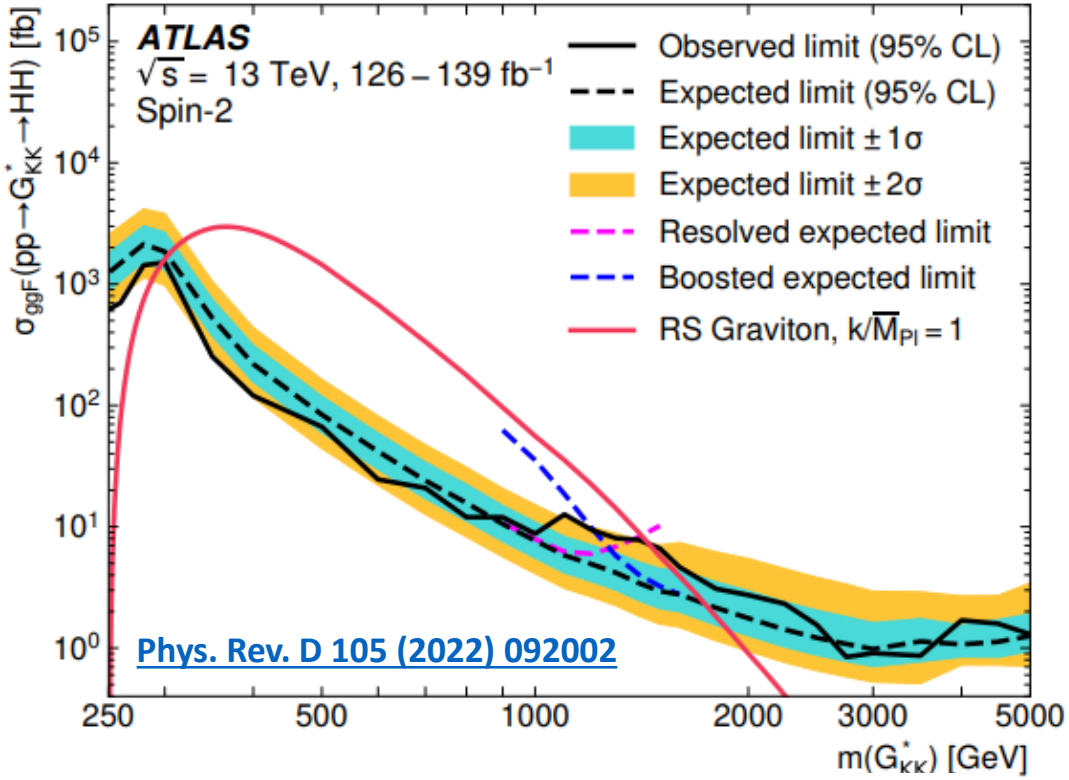
Heavy W
W' → WZ → lllν



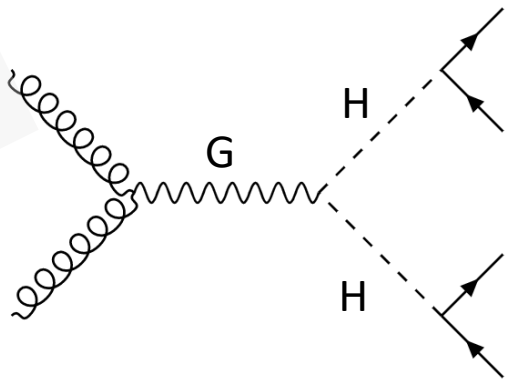
Heavy Z
Z' → ZH → qqbb

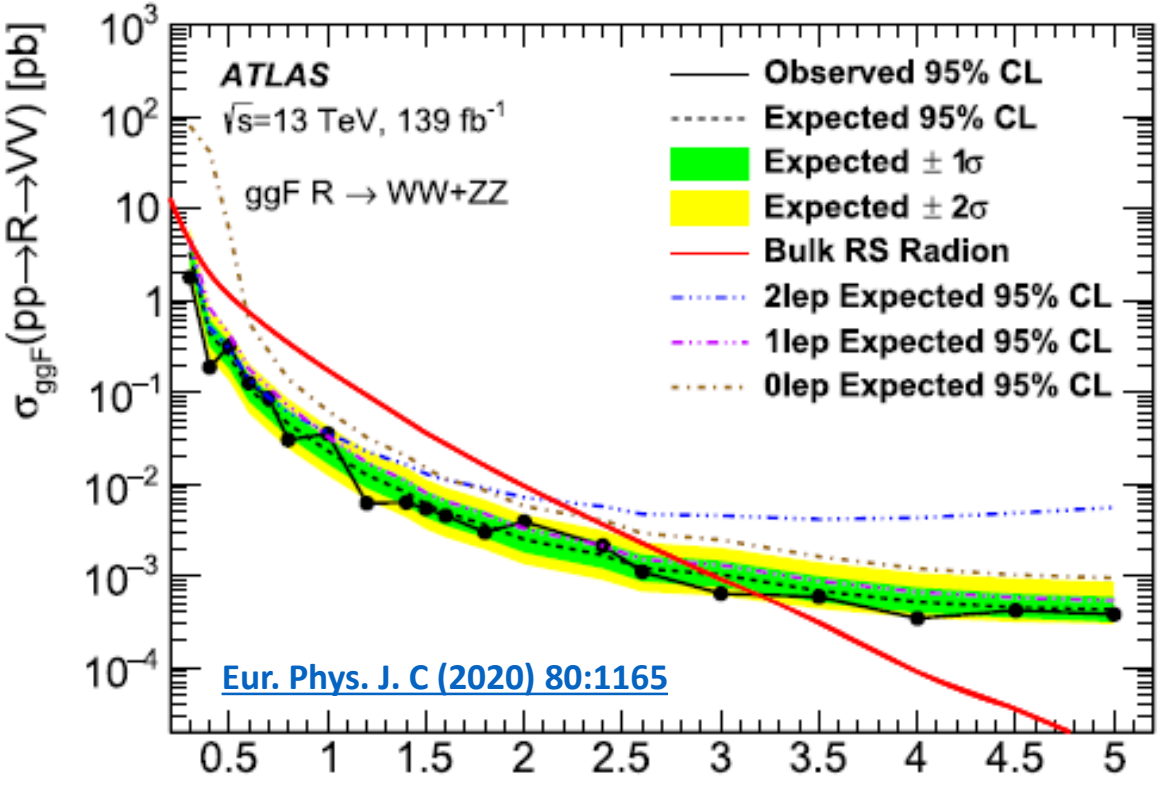


Results – Full Run II

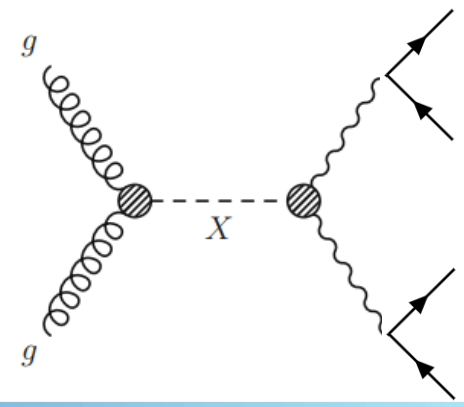


Graviton
G → HH->bb̄bb̄





Radion
R →VV →qqll/lv/vv



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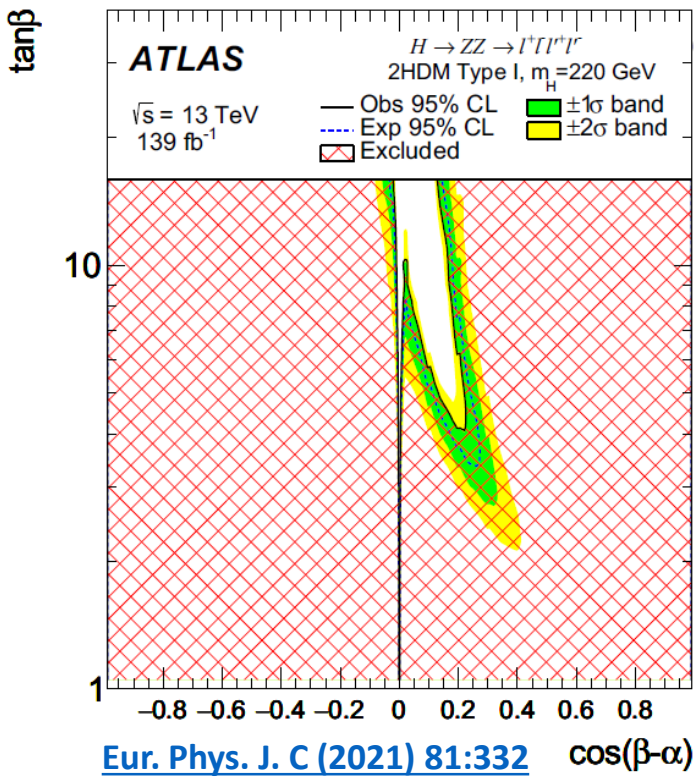

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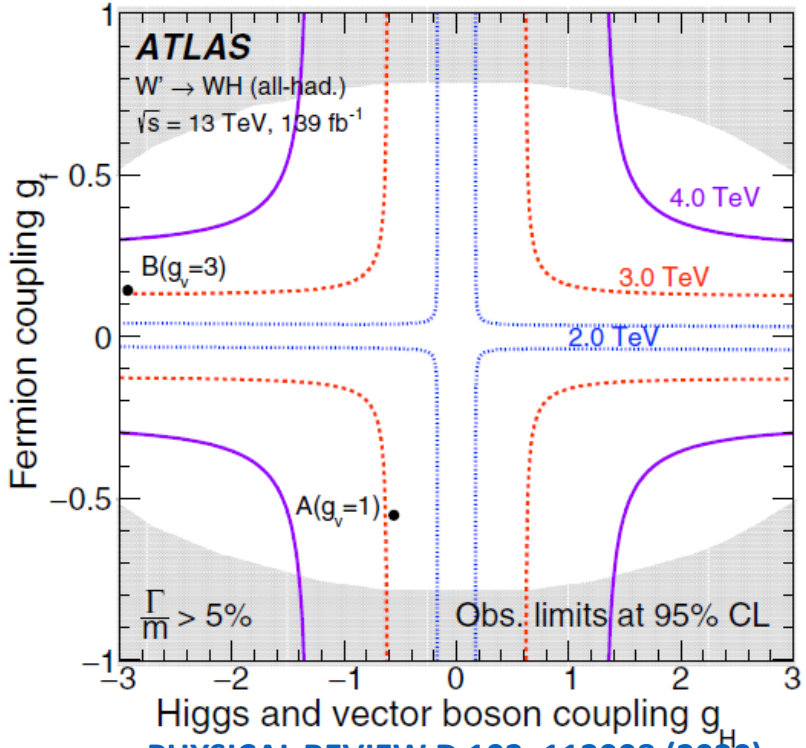

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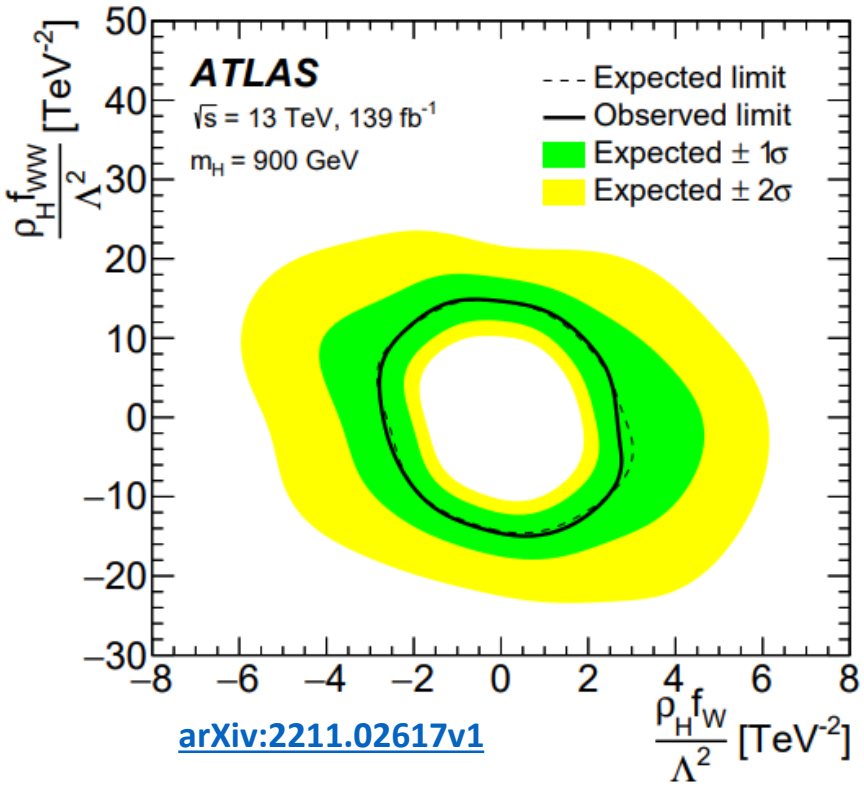
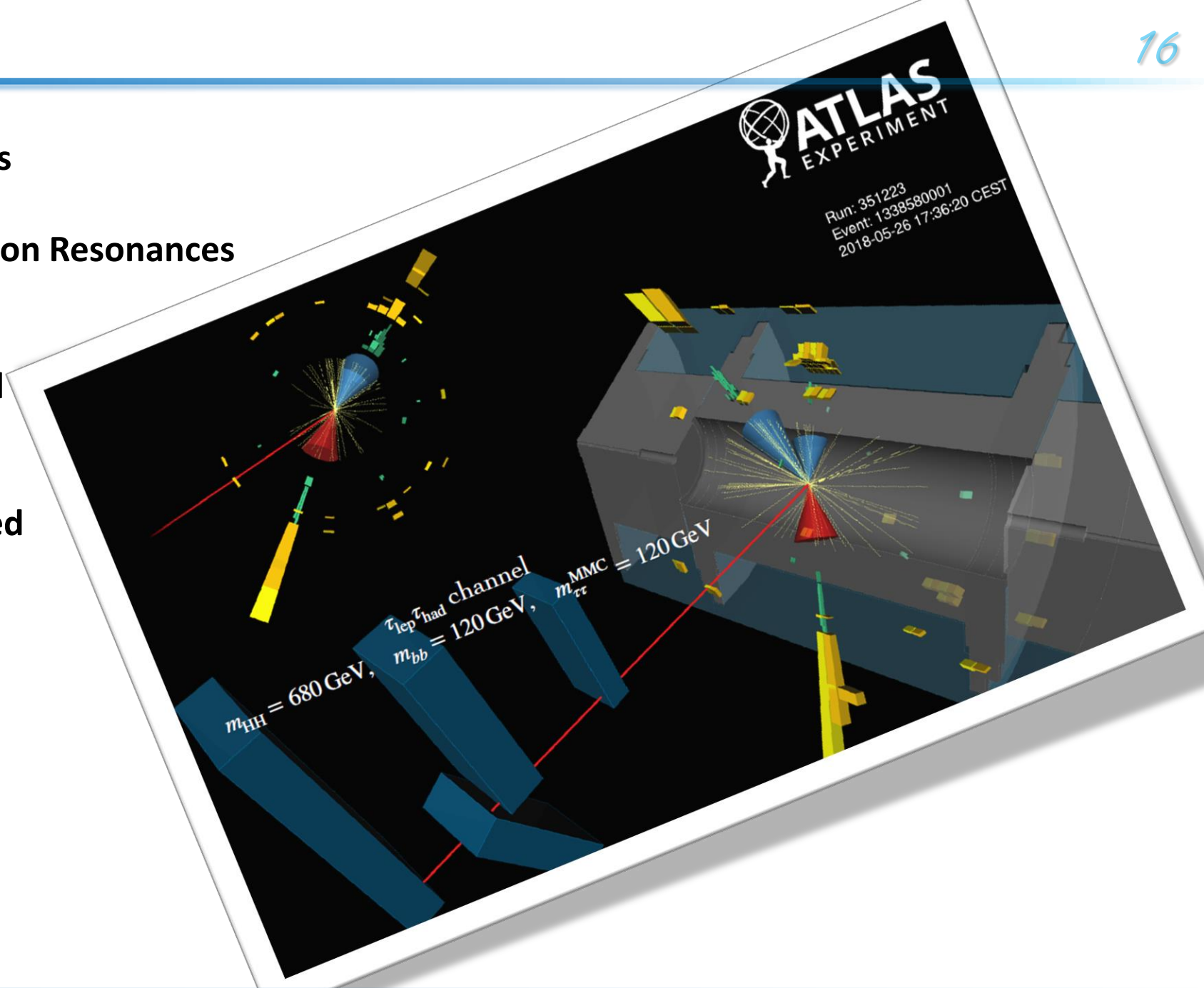


arXiv:2211.02617v1

- **H → ZZ → 4l (2HDM)**
  - Ratio of the vacuum expectation values of the 2 Higgs doublets (tanβ)
  - Mixing angle between the CP-even Higgs bosons (α)
- **W' → WH → qqbb (HVT)**
  - W' – fermions coupling
  - W' – Higgs coupling
- **HW → WWW → lvlvjj (EFT)**
  - H anomalous couplings to W

Summary

- Many BSM predict new resonances
- Large variety of searches for Diboson Resonances by ATLAS
- Boosted jets final states are crucial
- Jet substructure and several new experimental techniques developed during Run II
- No significant excess so far
- Run III has already began
  More exciting results !