ATLAS Exotic Heavy Resonance Searches

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ATLAS EXPERIMENT

What to expect today

ATLAS has an extensive program of resonant searches, with a large variety of target models and final states.

In this talk you will see :

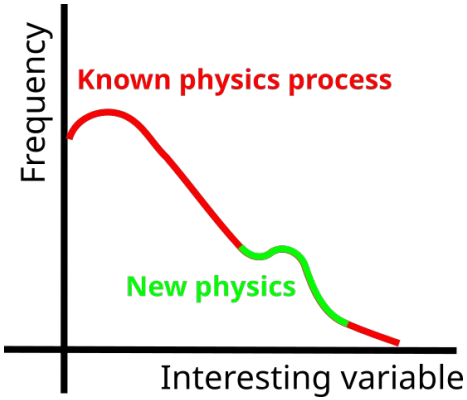
- A brief overview of 4 recent searches published by ATLAS
  - The 4 of them deal with final states with third generation fermions
- All of them correspond to the run 2 dataset
  - 140 fb^{-1} of data taken between 2015-2018

OTHER BSM talks from ATLAS @ICHEP

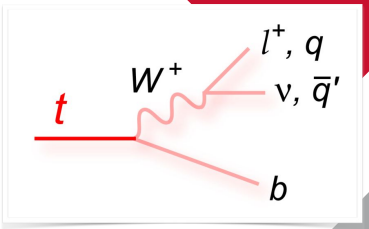
supersymmetry (non-minimal) | VLQ and LQ | Long-lived particles

supersymmetry (EW) | Hadronic final states | Dark matter searches

supersymmetry (strong) | Dijet searches



Searches with top quarks

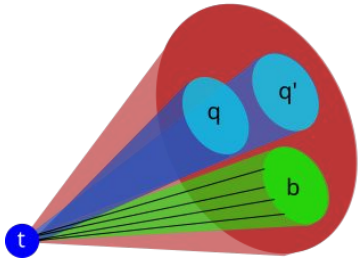


Large yukawa couplings → **Importance in electroweak symmetry breaking mechanism** → **Special role in many BSM theories**

Top reconstruction is the main experimental challenge

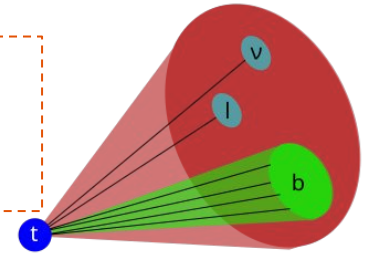
Top-tagging: technique used to identify large-R jets coming from top-quarks: **Deep Neural network (DNN) using substructure information**

B-tagging :technique used to identify jets originated from b-quarks: **DNN using tracking and vertexing information**



Hadronic
*1 b-tagged jet, 2 additional jets **or** 1 top-tagged large-R jet*

leptonic
1 b-tagged jet, 1 charged lepton and missing transverse energy

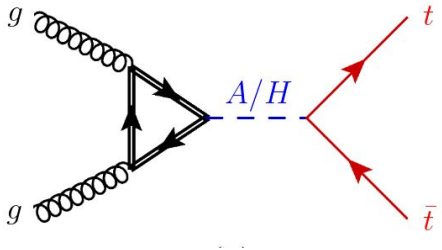


A/H->ttbar search

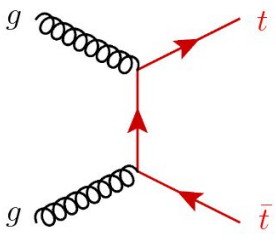
2404.18986

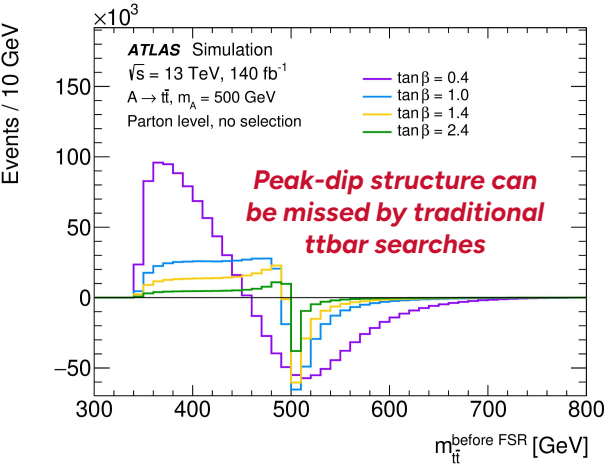
Look for the resonant decay of a pair of top quarks characteristic of 2HDM models.

Why is a dedicated search needed here?



Interference





1-lepton (electron or muon)

- 1 isolated lepton **and** additional jets
- MET related cuts to reject Multijet
- **Merged selection** top reconstruction
  - Based on a large-R jet top-tagged jet
- **Resolved selection** top reconstruction
  - Based on 4 jets chosen using a χ^2 method

2-leptons (electron or muon)

- 2 opposite sign leptons and additional jets
- Additional cuts on MET and the dilepton system

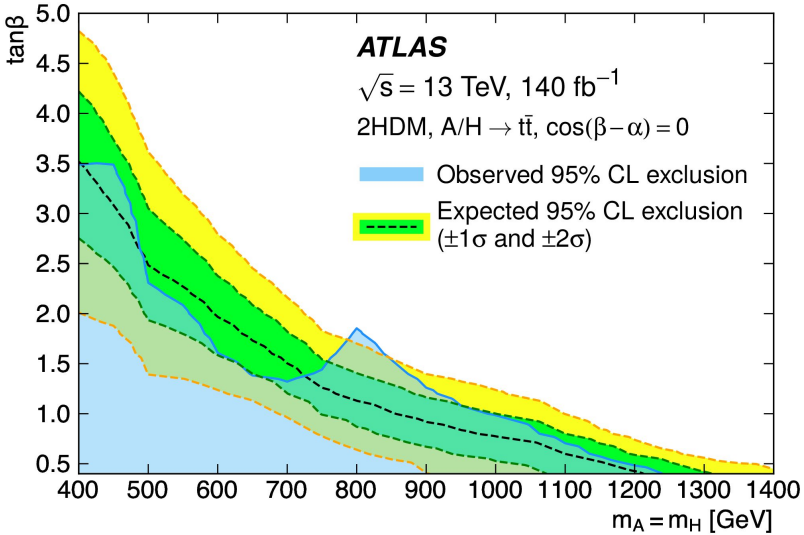
PRIORITY

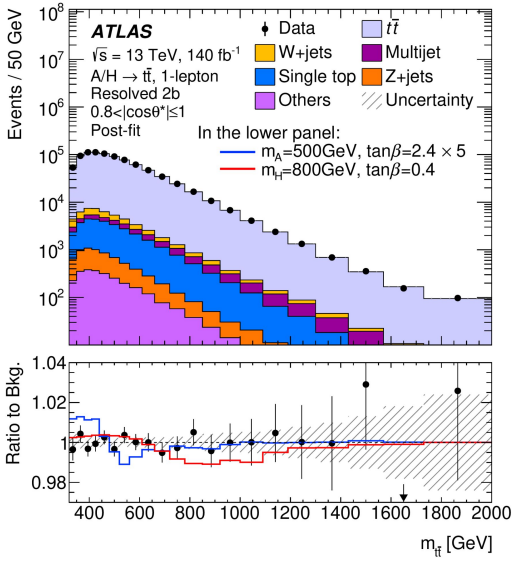
Priority given to the merged selection

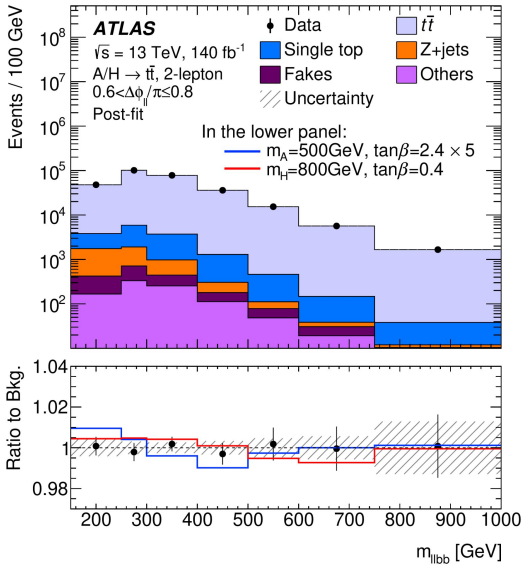
A/H->ttbar search

2404.18986

16 SR built by using angular variables cos θ^* and $\Delta\varphi_{ll}$ and the number of b-jets







Good agreement in general, with small excess (2.3σ for a 10% width resonance) around 800 GeV

Limits are set for different models, with most stringent 2HDM constraints for high m_A and low tanβ to date !

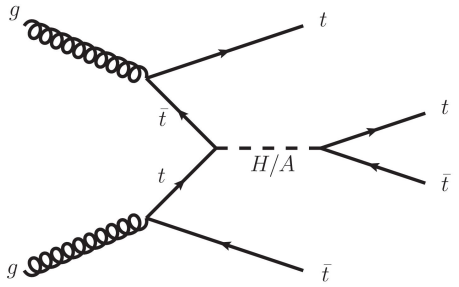
Interference contribution taken into account within the statistical analysis.

Other models in backup

4 top search

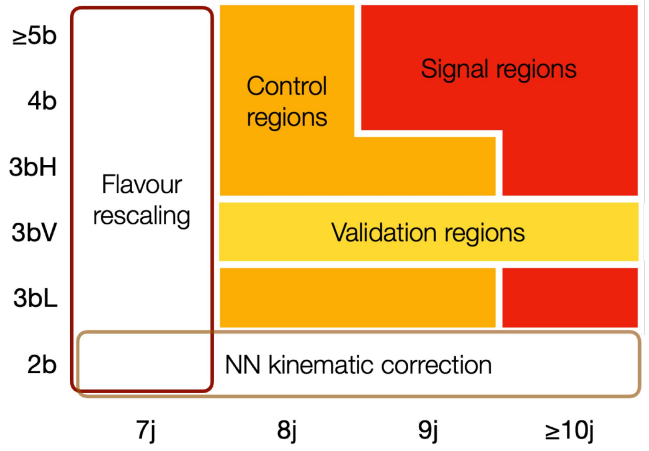
ATLAS-CONF-2024-002

Associated production: Interesting in scenarios with preferred or exclusive coupling to top quarks

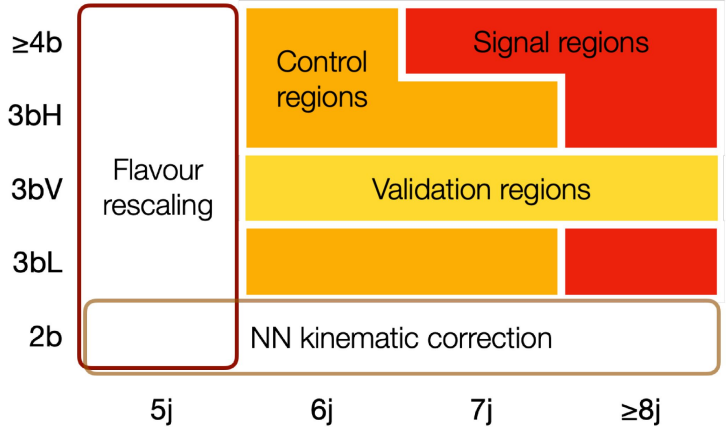


Selection and signal definition based on the number of isolated leptons, number of jets and b-jets

1L channel.



2LOS channel.

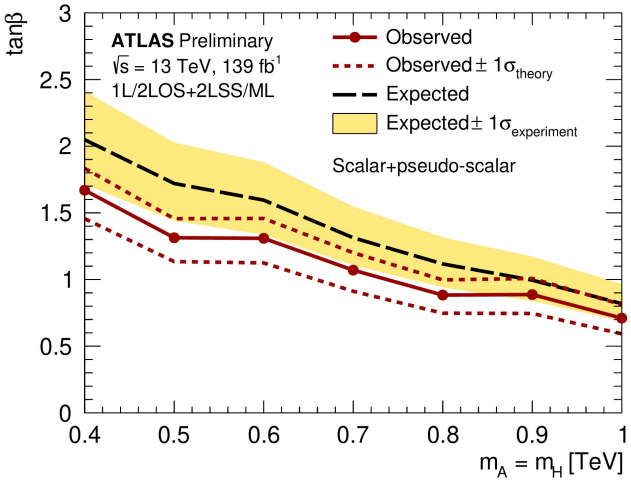


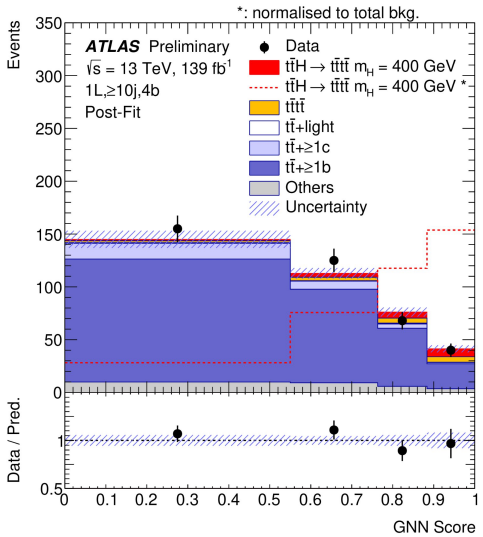
10 signal regions with large number of jet and b-jet multiplicity. Other regions used to obtain or control background estimation

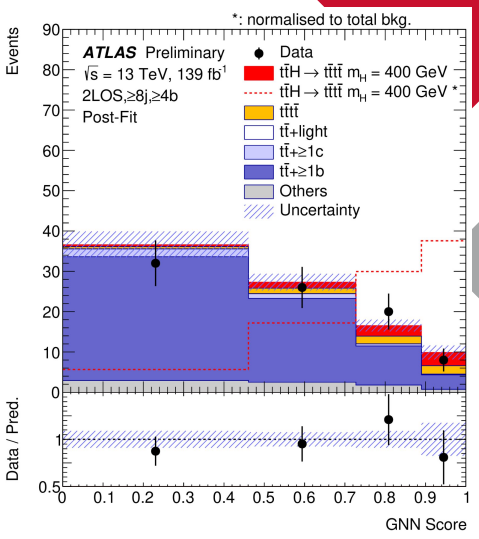
4 top search

ATLAS-CONF-2024-002

Two graph neural networks (GNN), trained in each channel, used to separate signal and the dominant ttbar + jets background.







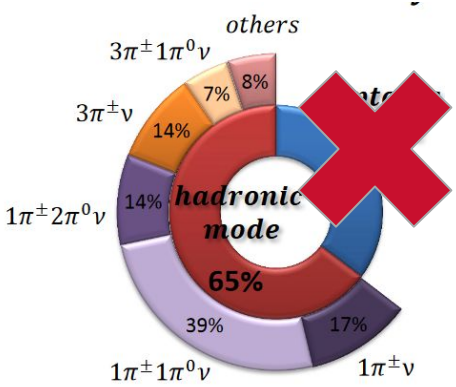
Reasonable agreement between data and MC in the GNN score. With a small excess of ~ 1.7/2.1 sigma depending on the mass

Limits in the context of the 2HDM models are set independently and in combination with the 2LSS/ML analysis.

Colour octet scalar limits in backup

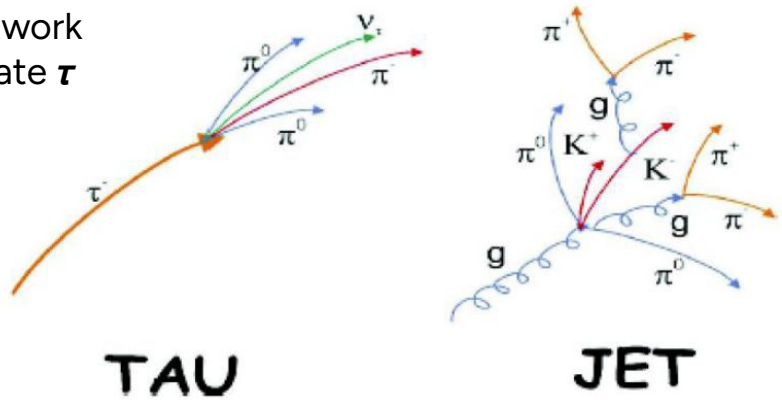
Searches with τ-leptons

τ-lepton final states appear in many BSM models. Models with preferential couplings to third generation, Leptoquark models, supersymmetry, etc...



In ATLAS τ-lepton analysis typically refer to hadronically decaying τ. Leptonically decaying τ are implicitly included in light-lepton focused analyses

A Recurrent Neural Network (RNN) is used to separate τ from QCD jets

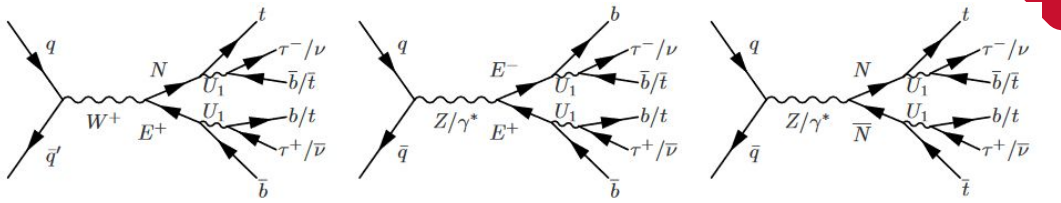


A set of BDTs is used to choose the tracks associated to calorimeter jets corresponding to the charged pions. Together they define the visible tau component $\tau_{\text{had-vis}}$

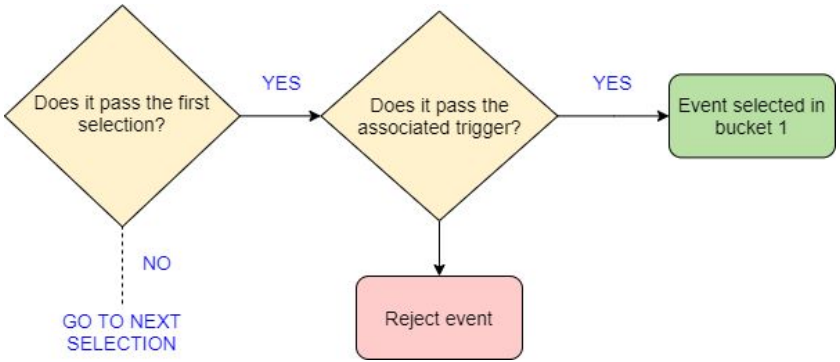
Vector like lepton (VLL) search

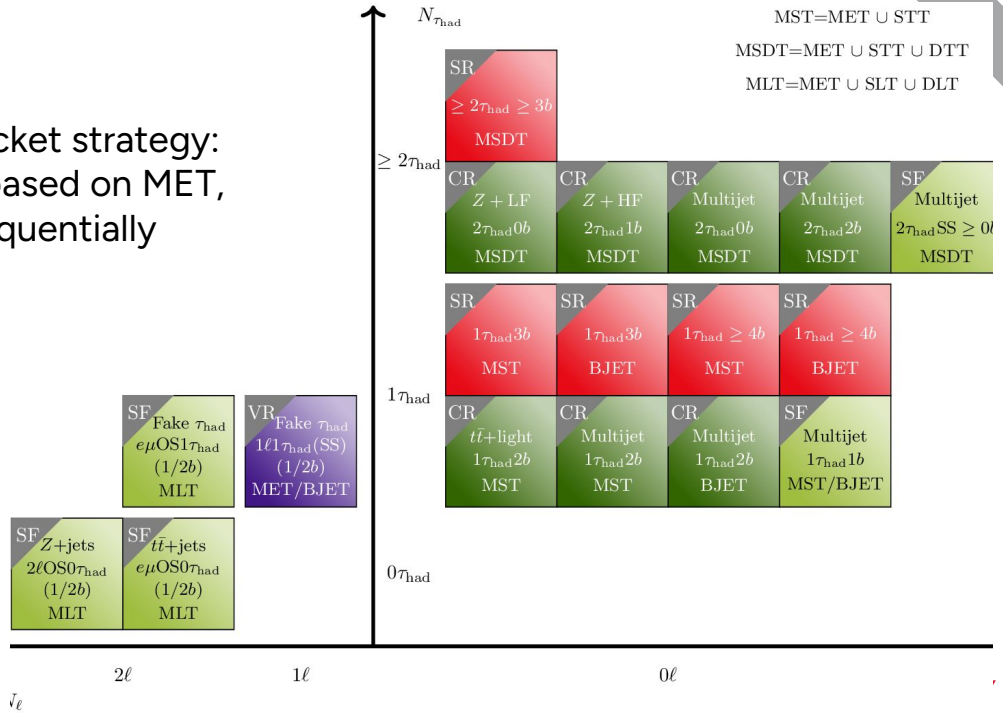
ATLAS-CONF-2024-008

Vector-like (non-chiral) charged and neutral leptons search focused on the 4321 model



Selection optimized using a trigger bucket strategy: Orthogonal offline+trigger selections based on MET, single-τ, di-τ and b-jet checked sequentially

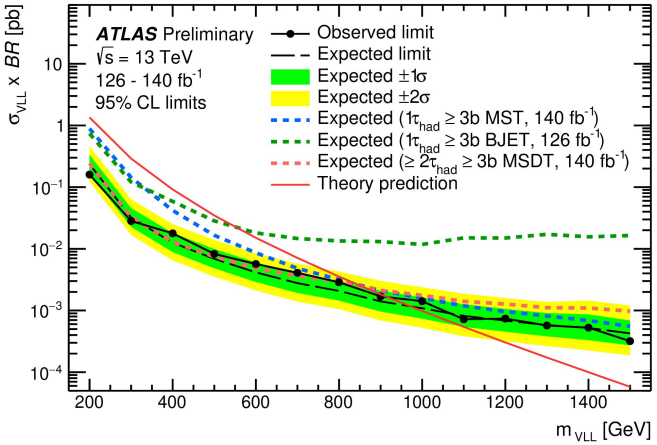


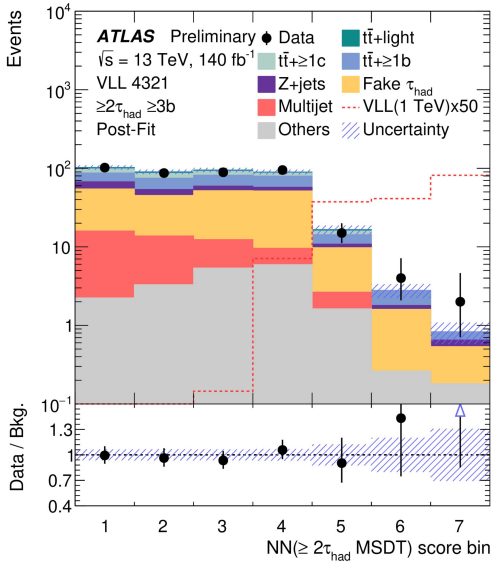


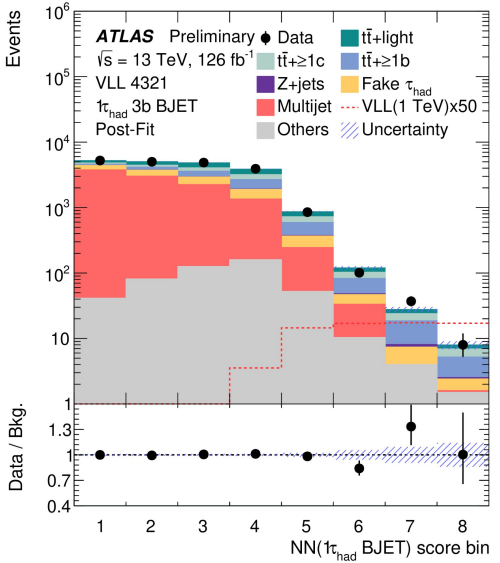
Vector like lepton (VLL) search

ATLAS-CONF-2024-008

Statistical analysis is done in the output of three parametrized (as a function of the mass) NN trained in different selections against the relevant background combination







Good agreement is found in all regions. Limits are set in the context of the 4321 model. Masses up to 970 GeV are excluded. Results disfavor the 2.8σ excess reported by the CMS Collaboration in 2022

See the excellent poster by Gabriel Olivera for more details

Resonant search with τ and missing transverse momentum

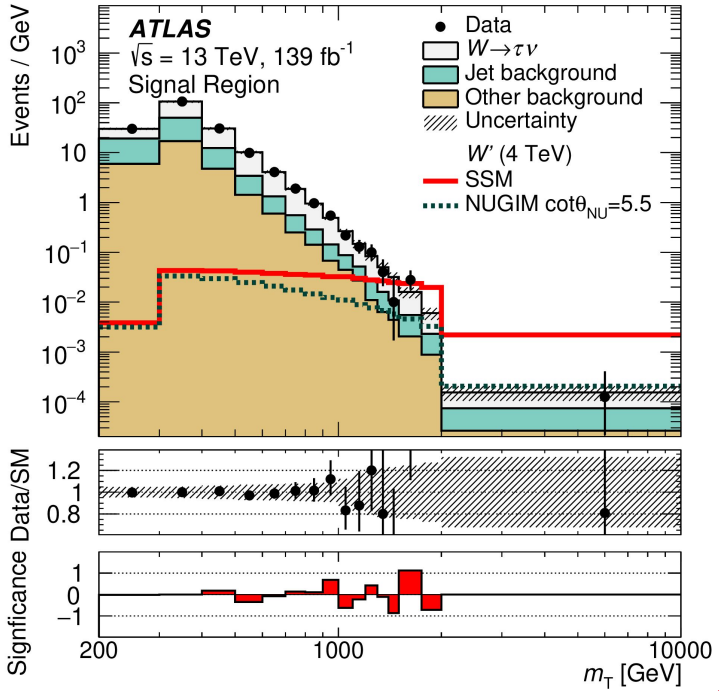
2402.16576

Search for the direct decay of a new gauge boson W' into a tau-lepton and a neutrino

Selection based on the presence of significant MET and a back-to-back hadronic tau.

Multijet background is the main challenge and is estimated using a data driven method that relies on three orthogonal control regions with looser tau ID or MET selections

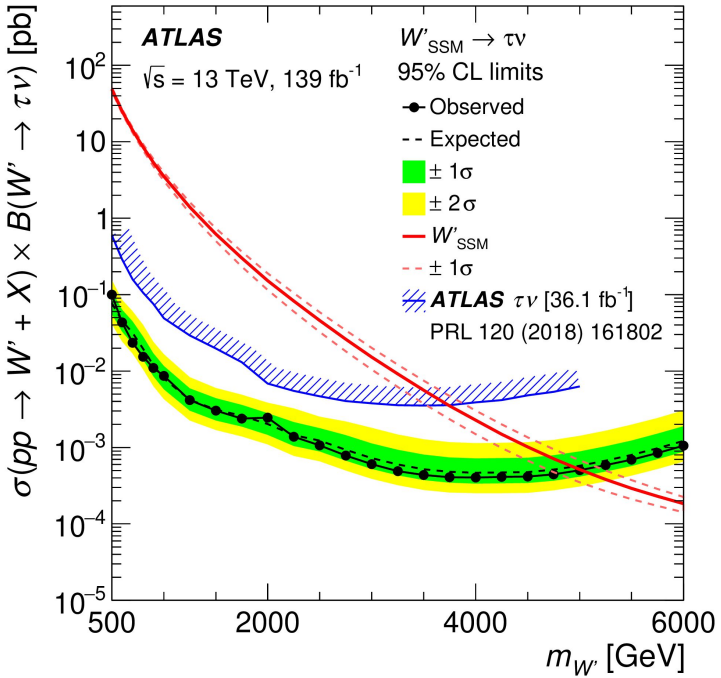
Good agreement between background estimation and data up to a large M_T value !

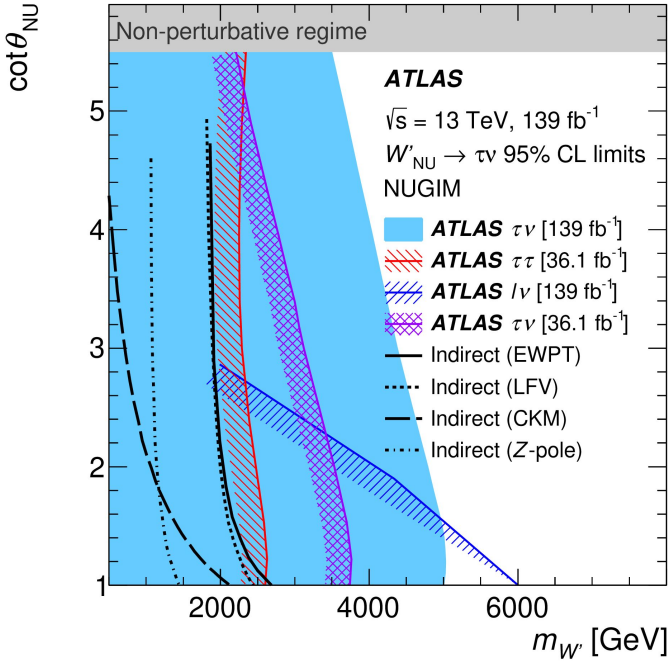


Resonant search with τ and missing transverse momentum

2402.16576

Limits are set on the SSM model and in models with non-SM 3rd generation couplings. Masses below 5 TeV are excluded.





Model independent limits in backup

Summary

- **Showed few recent BSM searches highlights from the ATLAS Collaboration**
  - **A/H->ttbar search** 2402.10607
  - **4-top resonant search** ATLAS-CONF-2024-002
  - **VLL search (4321 model)** ATLAS-CONF-2024-008
  - **τ-lepton + MET final state** 2402.16576
- **Lots of analyses performed during Run 2, with sadly, no hints of new physics**
  - Many ideas being explored to extract as much as possible from the ongoing Run 3 and leave **no stone unturned** !

OTHER BSM talks from ATLAS @ICHEP

supersymmetry (non-minimal)
supersymmetry (EW)
supersymmetry (strong)
VLQ and LQ
Hadronic final states
Dijet searches
Long-lived particles
Dark matter searches

BACKUP

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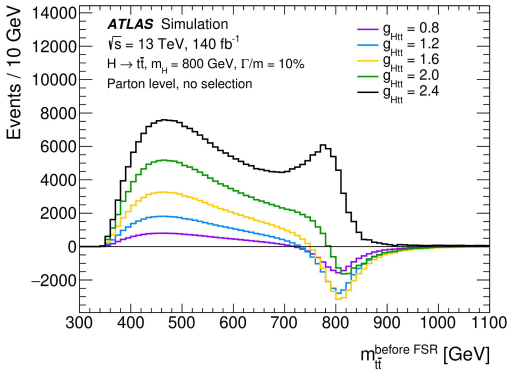
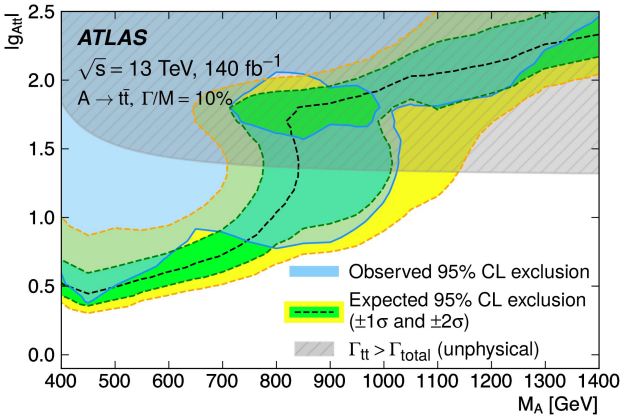
A/H->ttbar search





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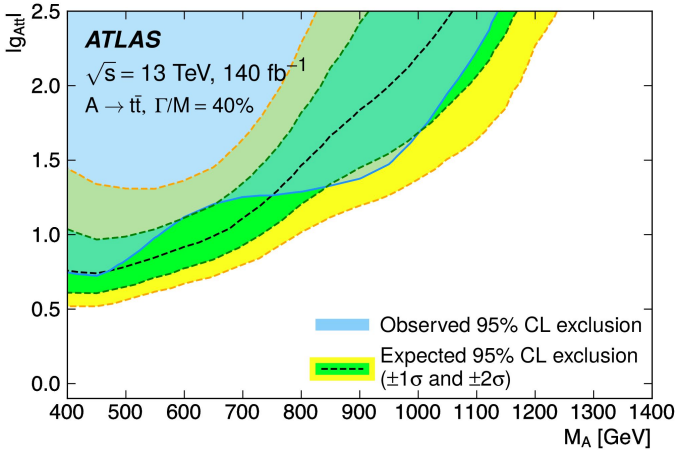
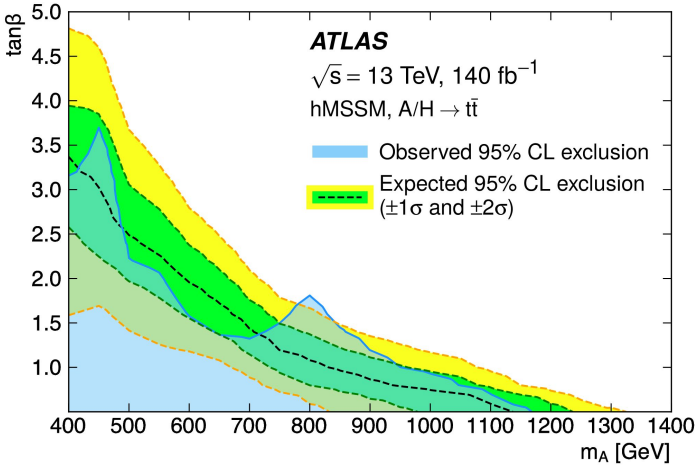
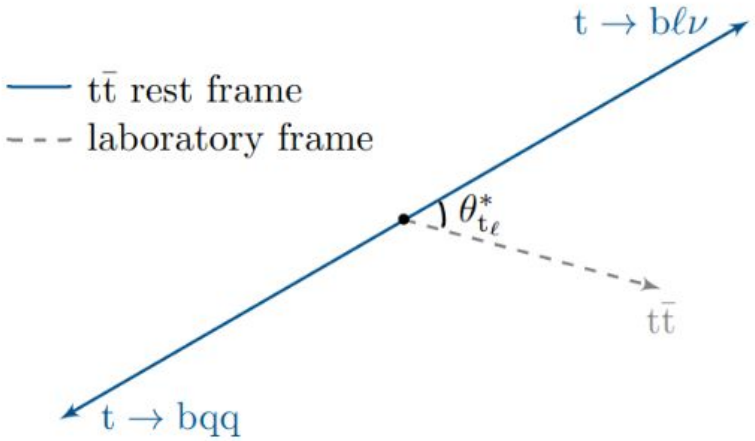




A/H->ttbar search

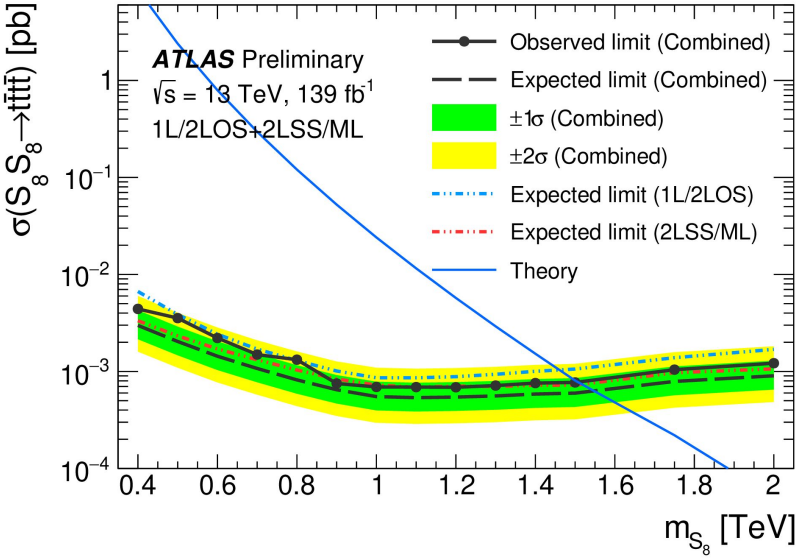
2404.18986

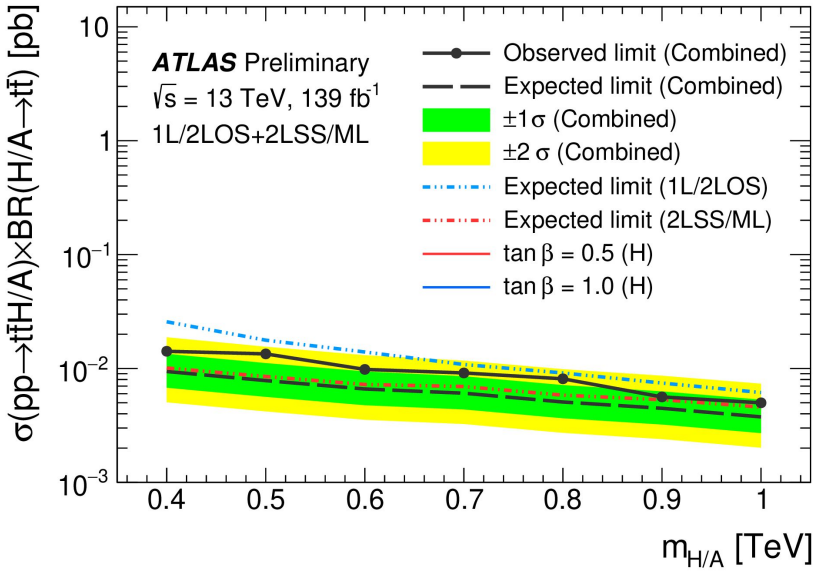


Distribution sensitive to the nature of the exchanged particle. SM ttbar production peaks at cos |cos θ^*| =1

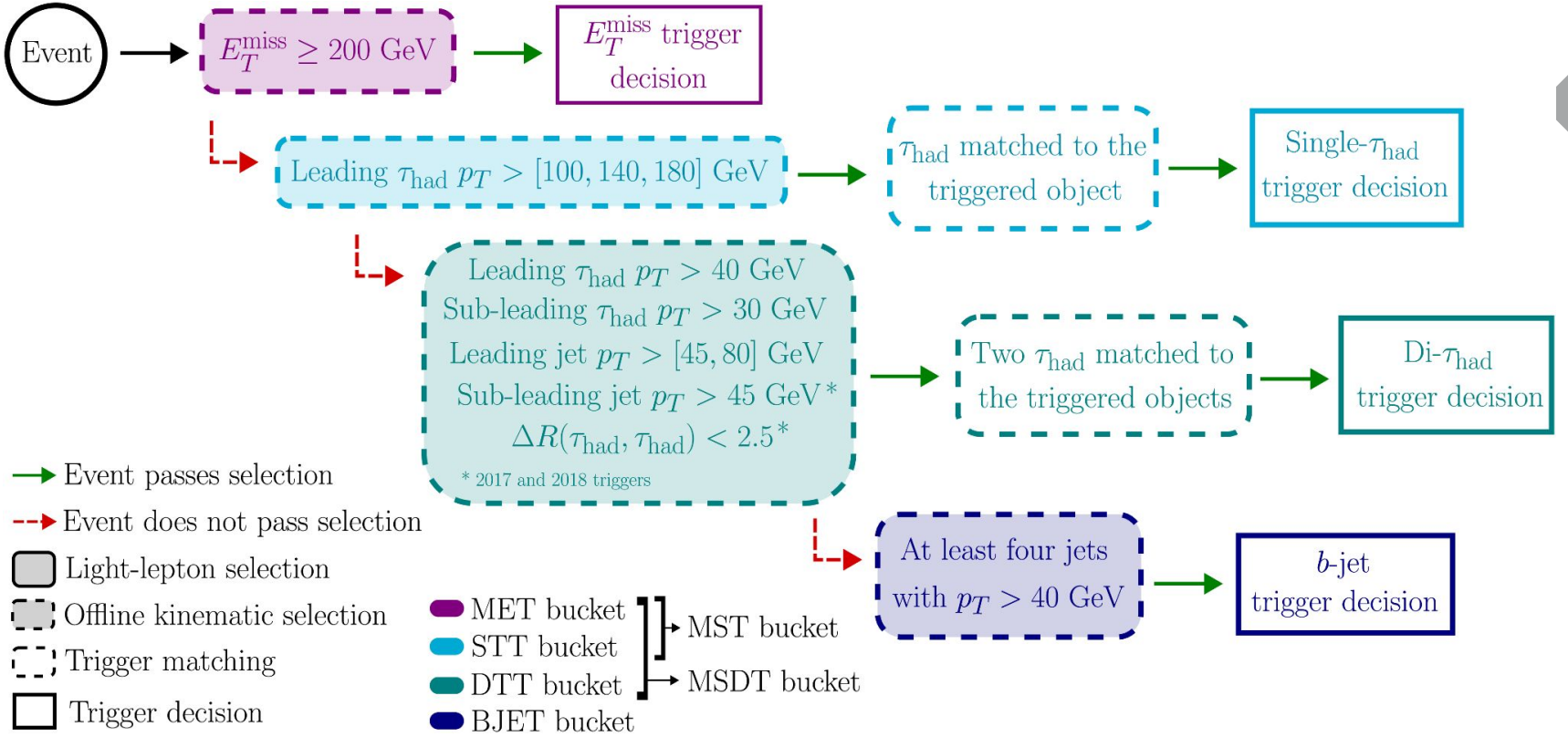
4-top search

ATLAS-CONF-2024-002



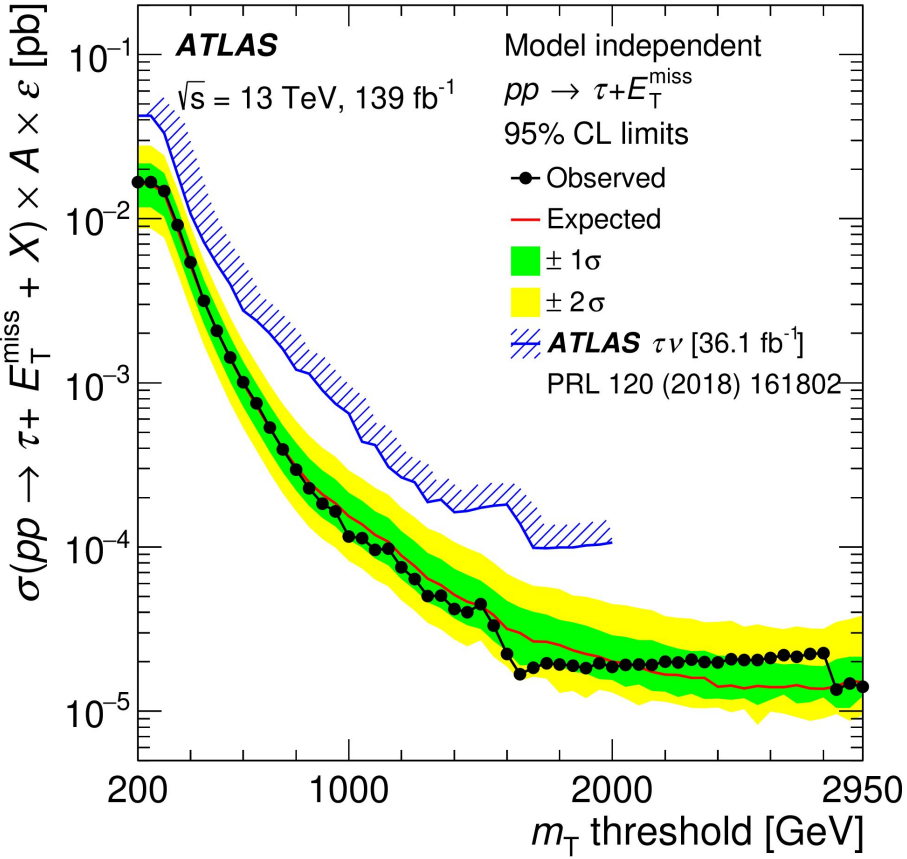


Vector like lepton (VLL) search



High-mass resonances with τ and missing transverse momentum

2402.16576



Using different M_T thresholds to set model independent limits

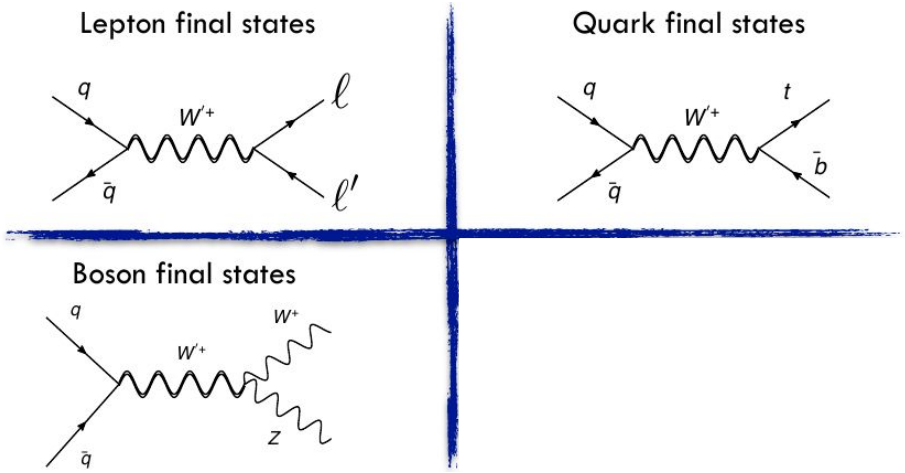
Combinations: the 1 slide version

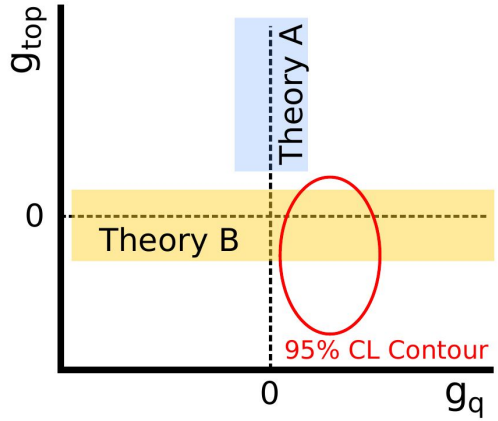
What do I mean by combination?

Statistical combination of **several analyses with a common underlying model** or production mechanism

Realistic models have a varied phenomenology

- Access to discovery via **small compatible excesses**
- Additional axes in **N-dimensional parameter space**

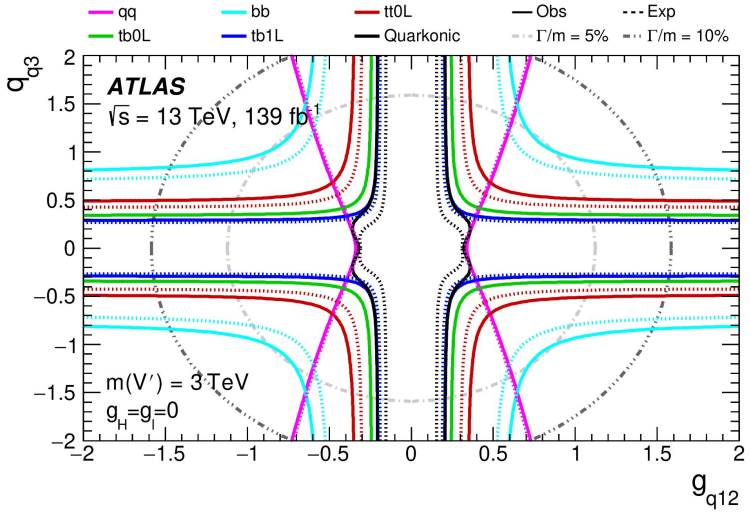




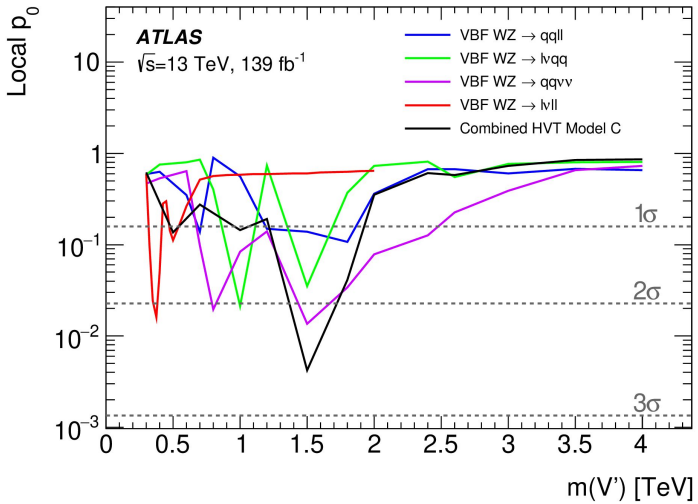
Next slide: 18 different searches combined in a single framework ! Interpreted in the context of the Heavy Vector Triplet (HVT) model, using the multidimensional coupling space to different fermions/bosons to obtain contours in several 2D planes

ATLAS Spin 1 resonance combination 2402.10607

Couplings to quarks, lepton and the Higgs boson (possible to also separate the third generation quark coupling) used to build several 2D planes. Also interpreted for few interesting HVT benchmarks (Specific coupling values)



Only one example, more can be found in backup. Improvement with respect to individual channels across the board



Combination of small excesses around 1.5 for VBF searches increased significance when combined. HVT model C corresponds to g_H=1.0 and g_f=0.0. No fermion couplings !

ATLAS Spin 1 resonance combination 2402.10607

Most analyses are orthogonal by construction, but some additional requirements were implemented to ensure it when necessary

Bosonic decays

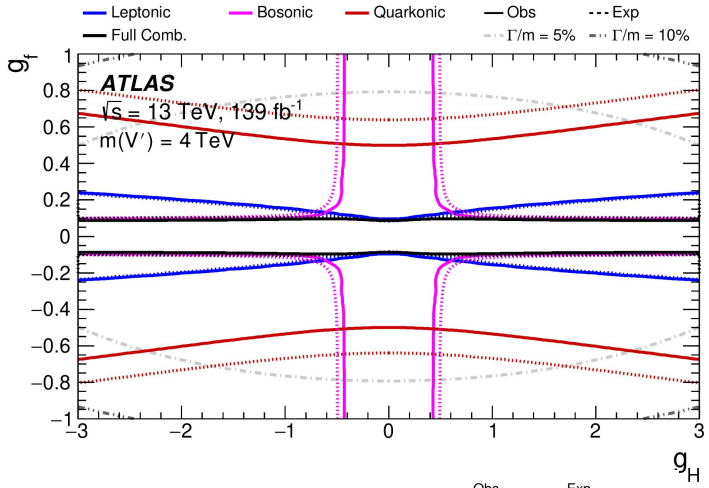
Leptonic decays

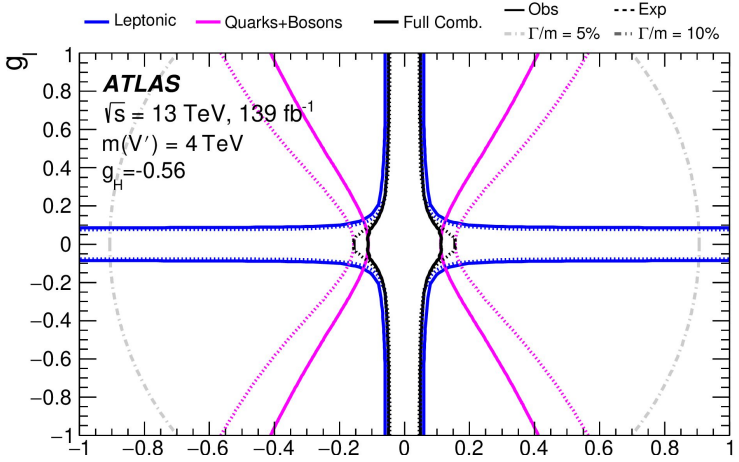
Quarks decays

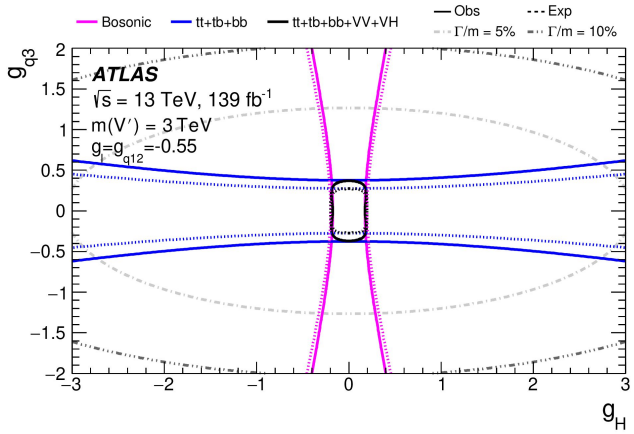
Analysis	Leptons	$E_{\mathrm{T}}^{\mathrm{miss}}$	Jets	b-tags	Top-tags	VBF
$WW/WZ \to qqqq$	0	Veto	$\geq$2J	-	-	-
$WW/WZ \to \ell\nu qq$	1e, 1μ	Yes	$\geq$2j, $\geq$1J	0, 1, 2	-	Yes
$WZ \to qq\nu\nu$	0	Yes	$\geq$1J	0	-	Yes
$WZ \to qq\ell\ell$	2e, 2μ	-	$\geq$2j, $\geq$1J	0	-	Yes
$WZ \to \ell\nu\ell\ell$	3 $\subset$ (e, μ)	Yes	-	0	-	Yes
$WH/ZH \to qqbb$	0	Veto	$\geq$2J	1, 2	-	-
$ZH \to \nu\nu bb$	0	Yes	$\geq$2j, $\geq$1J	1, 2	-	-
$WH \to \ell\nu bb$	1e, 1μ	Yes	$\geq$2j, $\geq$1J	1, 2	-	-
$ZH \to \ell\ell bb$	2e, 2μ	Veto	$\geq$2j, $\geq$1J	1, 2	-	-
$\ell\nu$	1e, 1μ	Yes	-	-	-	-
$\tau\nu$	1τ	Yes	-	-	-	-
$\ell\ell$	$\geq$2e, $\geq$2μ	-	-	-	-	-
$\tau\tau$	0, 1e, 1μ	Yes	-	0, $\geq$1	-	-
tt0L	0	-	2J	1, 2	2	-
tb0L	0	-	$\geq$(1j+1J)	$\geq$1	1	-
tb1L	1e, 1μ	Yes	2j, 3j	1, 2	-	-
qq	0	-	2j	0	-	-
bb	0	-	2j	1, 2	-	-

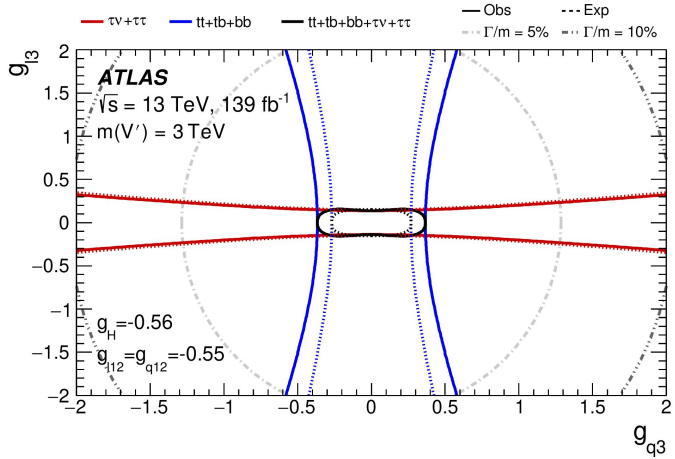
ATLAS Spin 1 resonance combination

2402.10607





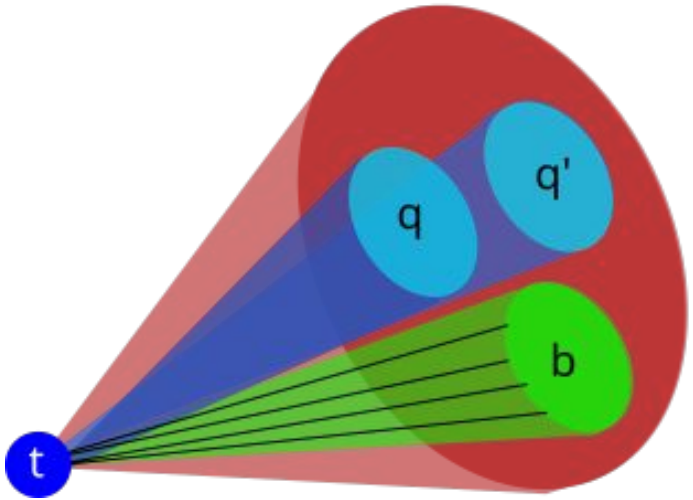




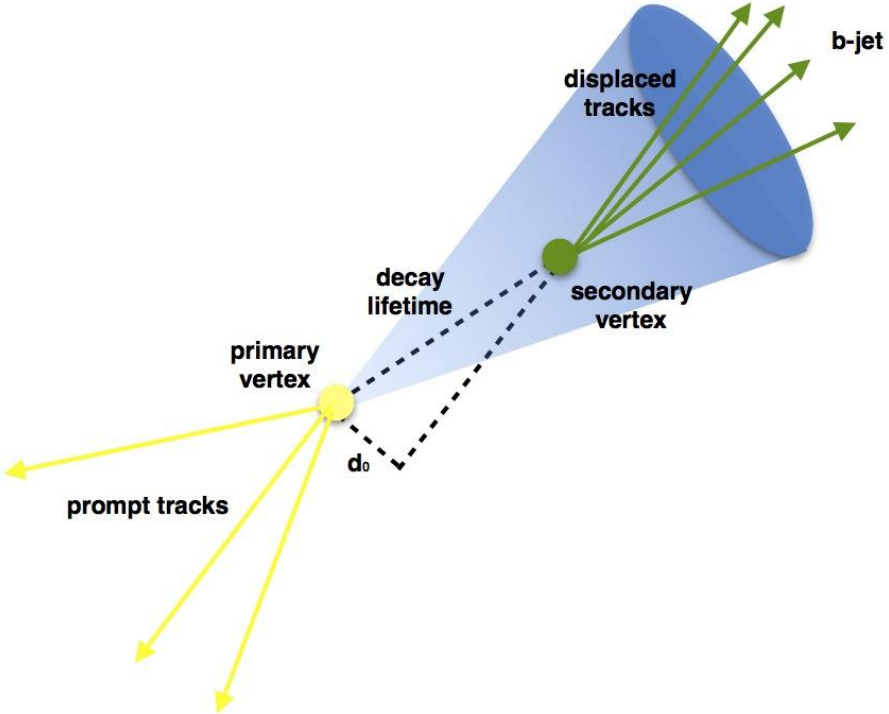
More on top tagging

Substructure variables [1808.07858]

Observable	Variable	Used for
Calibrated jet kinematics	p_T, m^{comb}	top,W
Energy correlation ratios	e_3,C_2,D_2	top,W
N-subjettiness	τ_1,τ_2,τ_{21} τ_3,τ_{32}	top, W top
Fox–Wolfram moment	R_2^{FW}	W
Splitting measures	z_{cut} $\sqrt{d_{12}}$ $\sqrt{d_{23}}$	W top, W top
Planar flow	$\mathcal{P}$	W
Angularity	a_3	W
Aplanarity	A	W
KtDR	$KtDR$	W
Qw	Q_w	top



Flavor tagging



Combination of different ML methods to identify jets originating from b-quarks using variables and objects related to displaced tracks and displaced vertices

2211.16345