ATLAS Searches for Resonances Decaying to Boson Pairs

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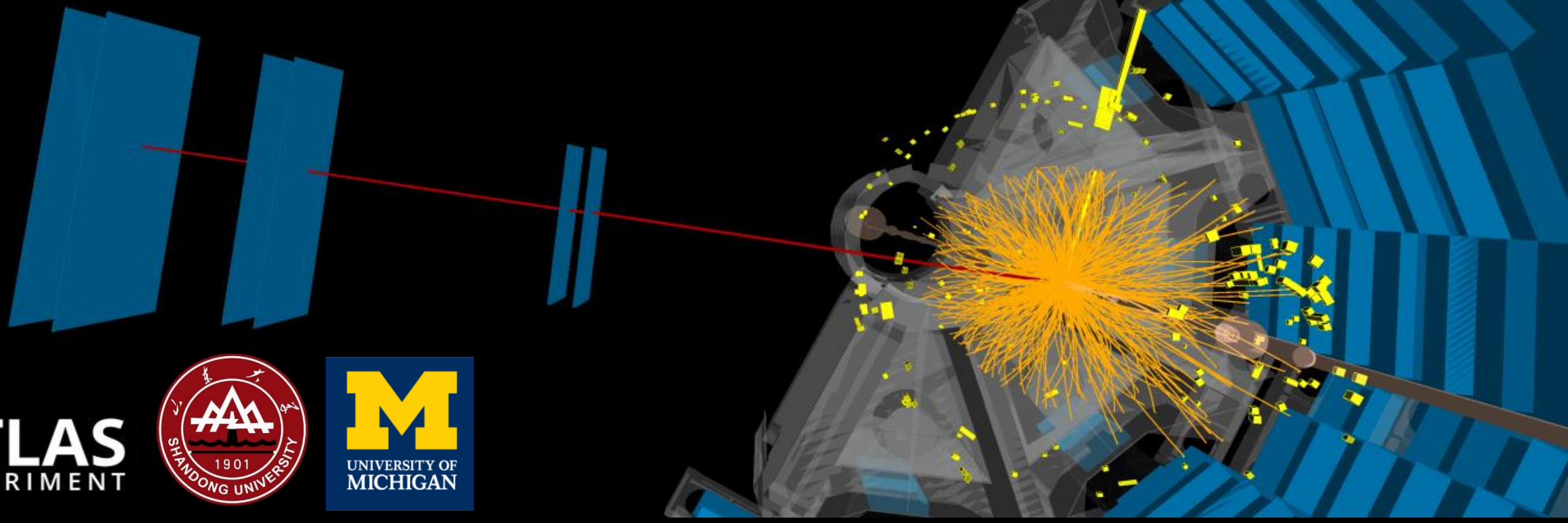
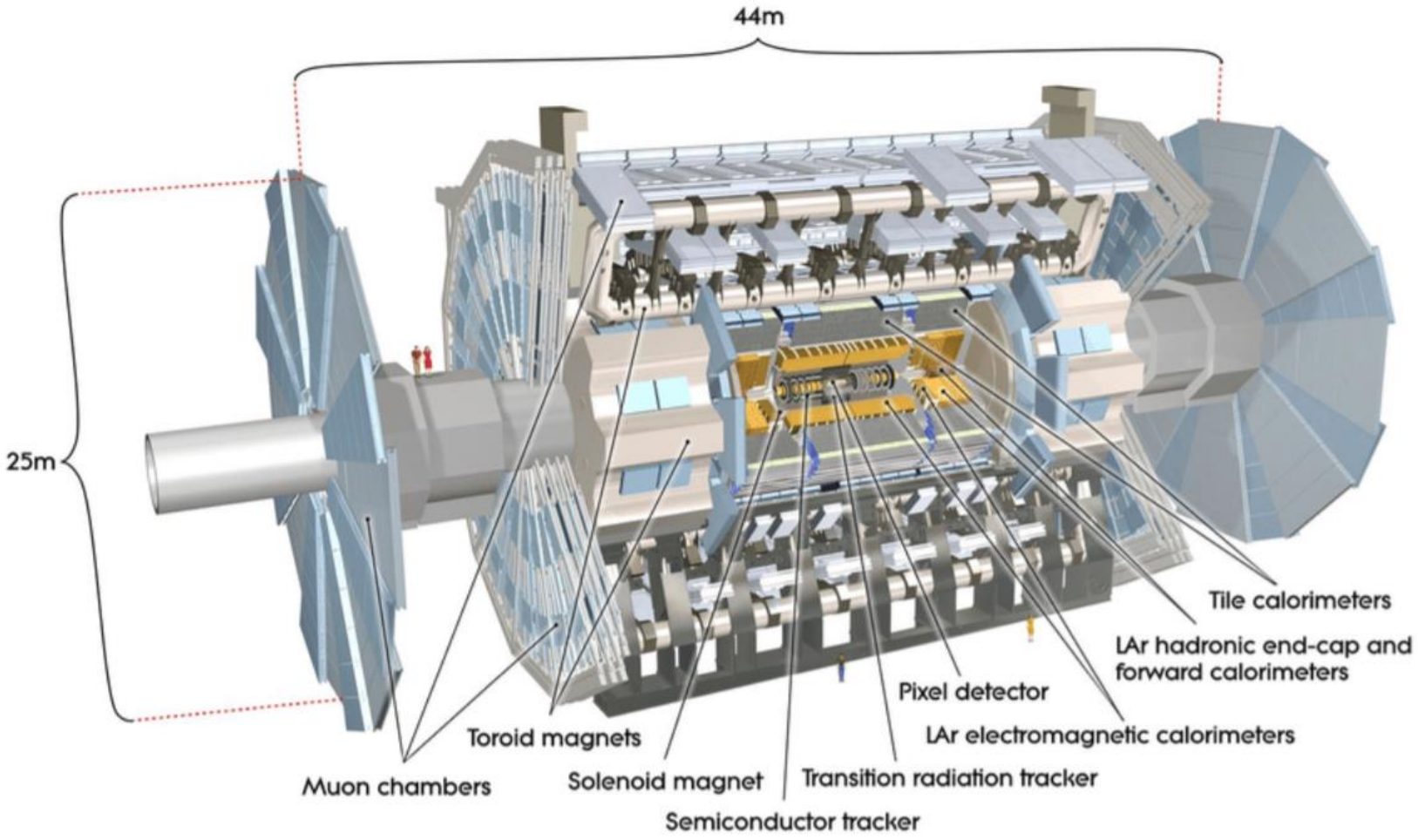
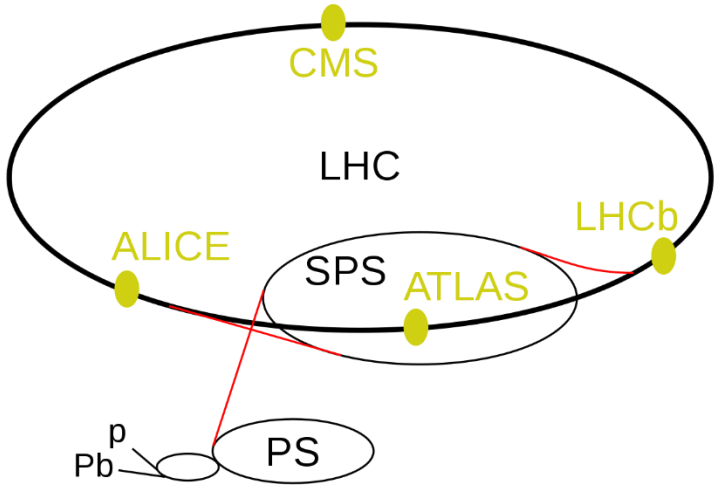


ATLAS detector



Overall weight 7000 tonnes
~ 3000 km of cables
~ 100 million electronic channels

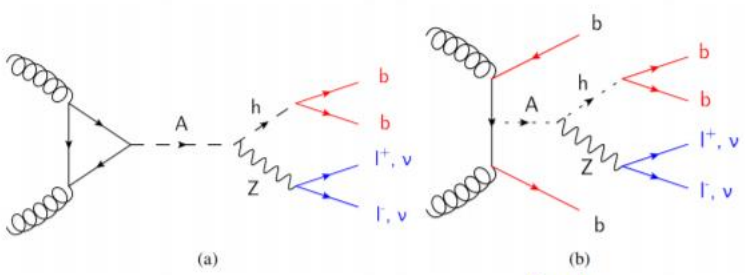


Search for heavy new particles that decay into diboson

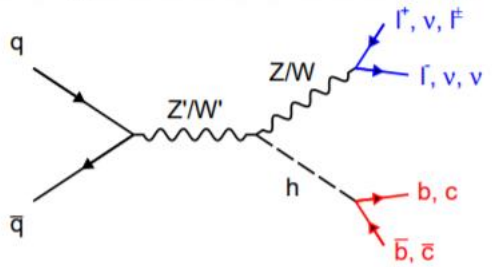
- Seek new intimations of physics Beyond the Standard Model
- Benchmark Model:
  - Two Higgs Doublet Model (2HDM)
  - Spin 1 Heavy Vector Triplets(HVT) **W'/Z'**

    Model A: extended gauge symmetry ($g_v = 1$)

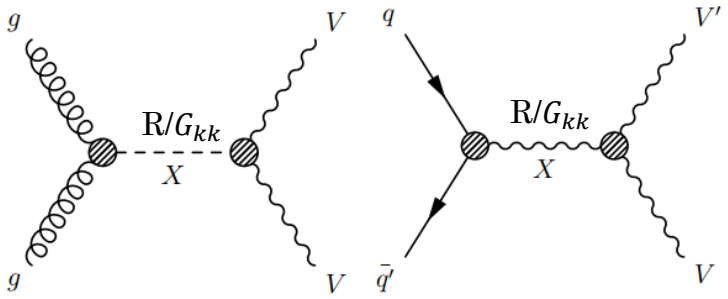
    Model B: Minimal Composite Higgs Model ($g_v = 3$)
  - Spin 0 Scalar Radion (RS Radion) **R**
  - Spin 2 Bulk Randall-Sundrum Graviton (RS Graviton) $\boldsymbol{G_{kk}}$
- Focus on VV, VH, HH, Vγ, Hγ resonances



2HDM



HVT

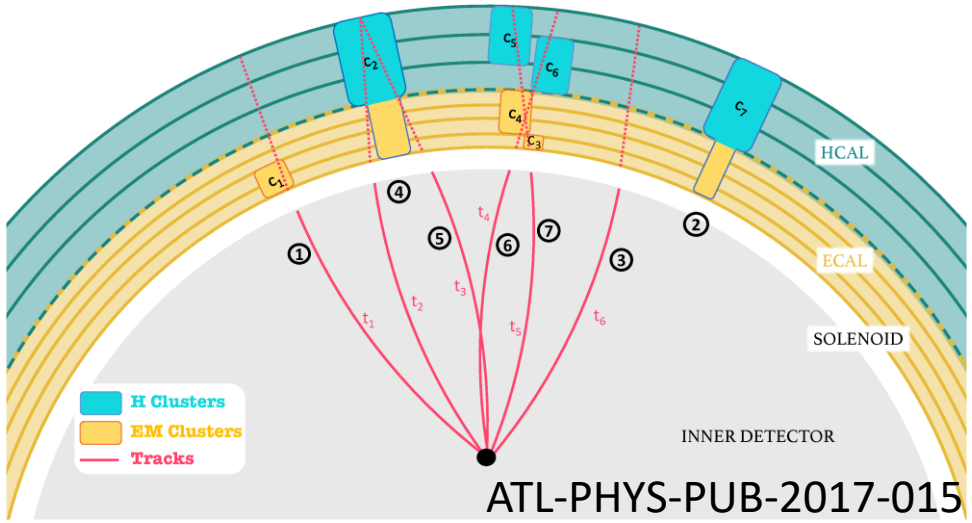


Radion/ Graviton

Search for heavy new particles that decay into diboson

- Decent improvement comes from new jet reconstruction algorithm -Track-CaloCluster (TCC)
  - Combine track and calorimeter information on jet reconstruction
  - **TCC** jets shows 100% improvement on jet substructure resolution (D2*) on high pT w.r.t **LC Topo** jets
  - Many searches benefit significantly from boson tagger optimization with better D2 resolution

*JHEP12(2014)009



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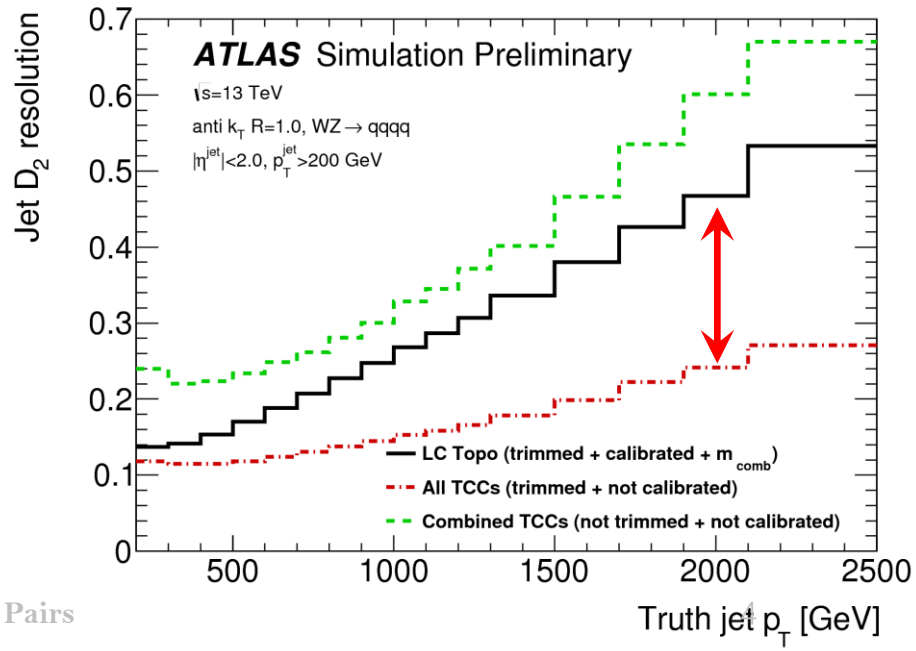


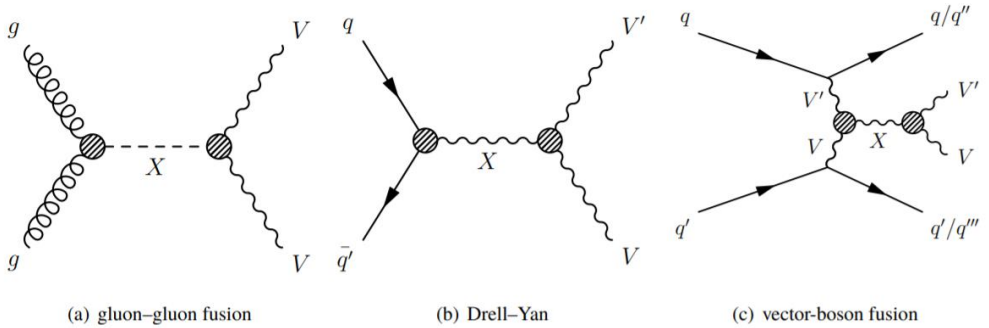
VV,VH Searches

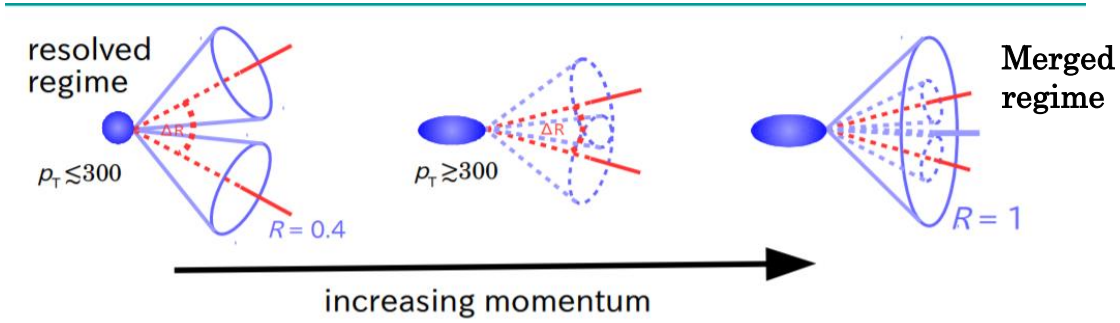
Analysis	Latest Result	Dataset
VV Semileptonic	arXiv:2004.14636	2015~2018(139 fb^{-1})
VV All hadronic	PhysRevLett.121.191801	2015~2018(139 fb^{-1})
WZ->lvll	j.physletb.2018.10.021	2015+2016(36.1 fb^{-1})
VH Semileptonic	ATLAS-CONF-2020-043	2015~2018(139 fb^{-1})
Heavy resonance combination	Phys. Rev. D 98 (2018) 052008	2015+2016(36.1 fb^{-1})

VV Resonance Semileptonic

arXiv:2004.14636

- Target signature: WW/WZ/ZZ resonance with semi-leptonic decay
  - One vector boson always decay hadronically, the other leptonically
  - Leptonic side: three sub-channels by lepton(el,mu) multiplicity $Z\rightarrow \nu\nu$ (0 lepton)/$W\rightarrow \ell\nu$ (1 lepton) /$Z\rightarrow \ell\ell$ (2 lepton)
  - Hadronic side:
    - Resolved: W/Z boson reconstructed by 2 small-R calo jets
    - Merged: W/Z boson reconstructed by 1 large-R TCC jets
- Analysis Update
  - Track-CaloCluster jet introduced for large-R jet
  - Recurrent neutral network(RNN) based ggF/VBF categorization
  - New multi-jet estimation based on template method

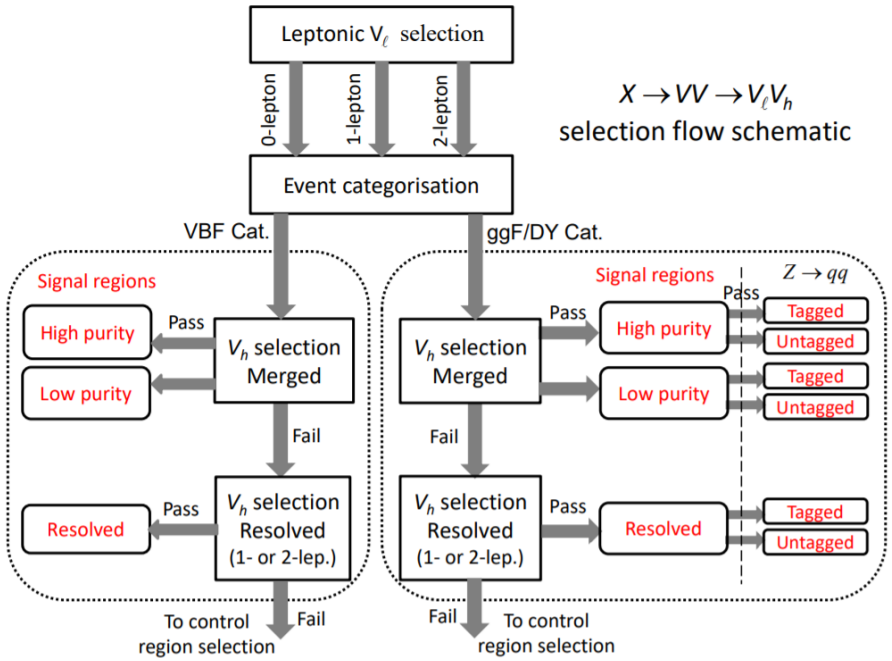


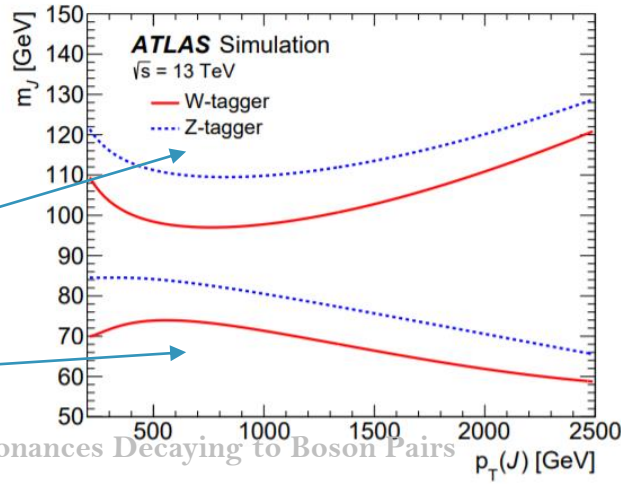


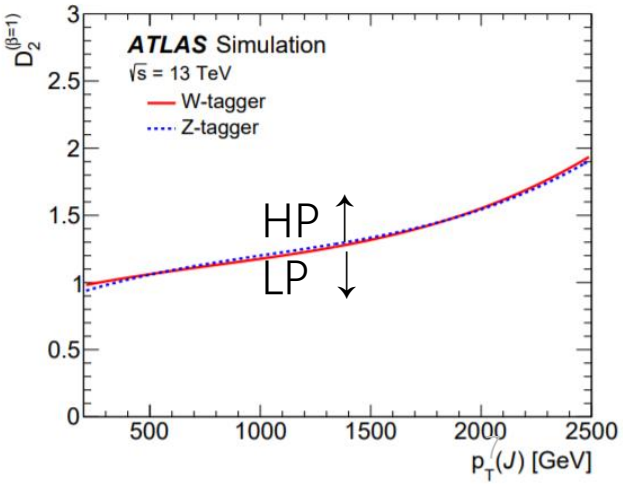
VV Resonance Semileptonic

arXiv:2004.14636

- Event Selection
  - 0/1/2 tight(loose) lepton & veto extra-lepton
  - RNN ggF/VBF Categorization
  - hadronic V reconstruction
    - Jet kinematics selection: pT ratio w.r.t mVV
    - Jet topologic selection: relative angle between MET & lepton
- SR/CR definition
  - No extra bjets
  - Merged:
    - pT dependent mass windows
    - Jet substructure D2 dependent HP/LP
  - Resolved
    -Z->jj $m \in [62,97]\ GeV$ /W->jj $m \in [70,105]\ GeV$
  - ttbar CR
    extra b-jet requirement
  - W/Z CR
    mass sideband







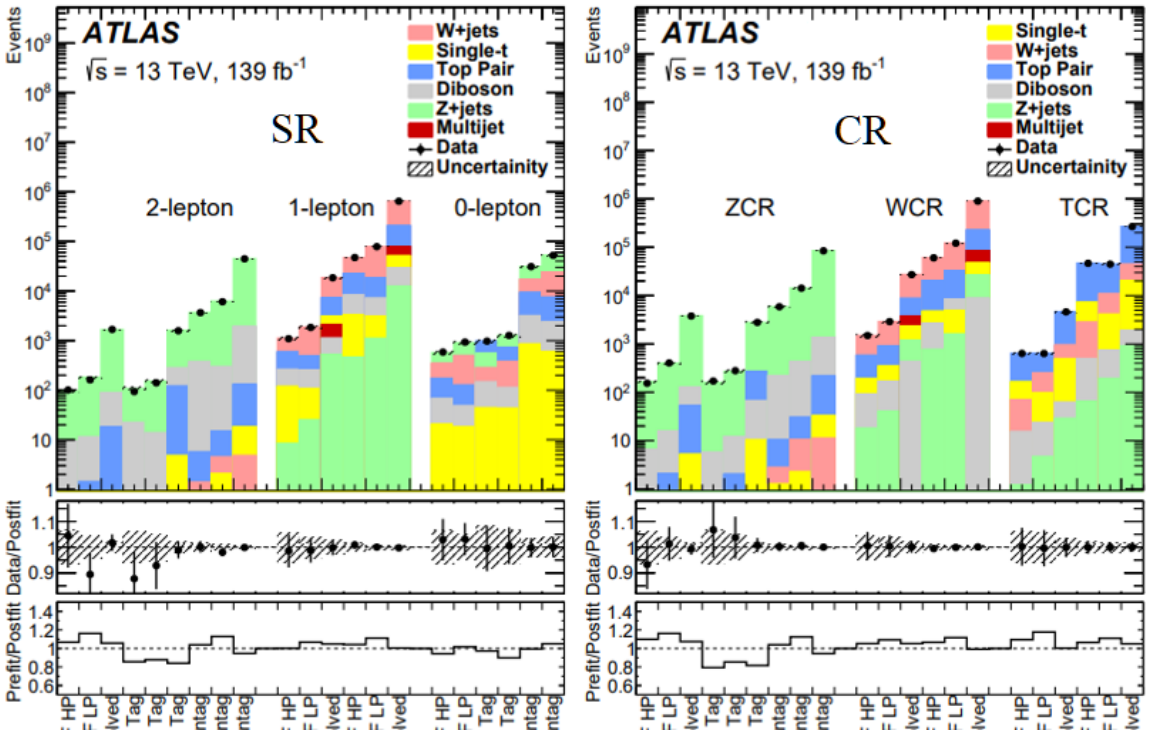
VV Resonance Semileptonic

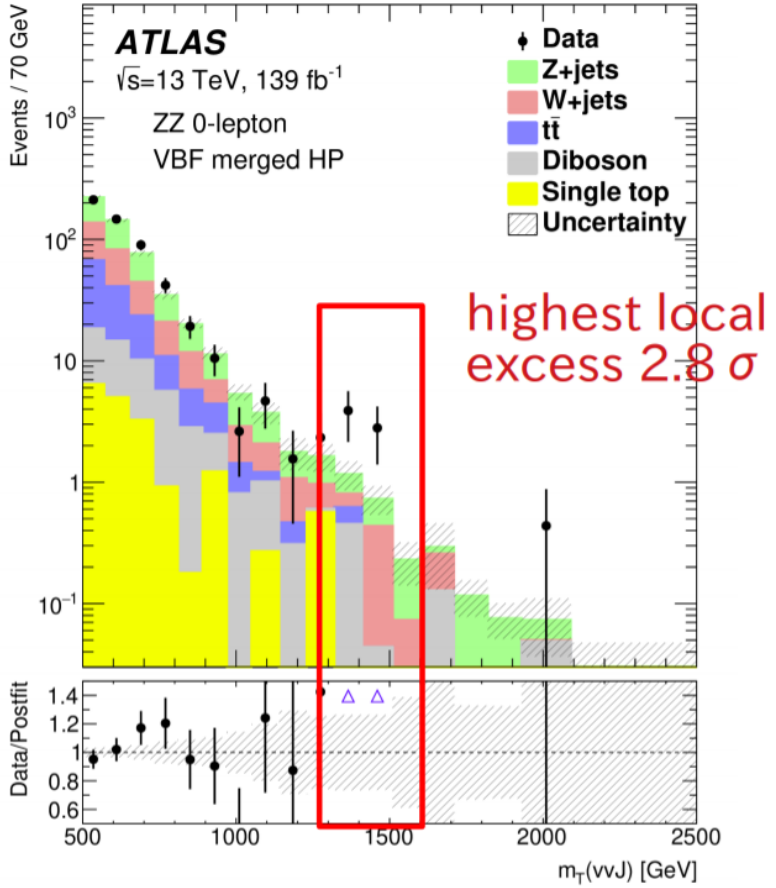
arXiv:2004.14636

Result:

-Fit on (transverse) invariant mass on 1,2 (0) lep channel, no significant excess

- 21 SRs and 21 one-bin CRs

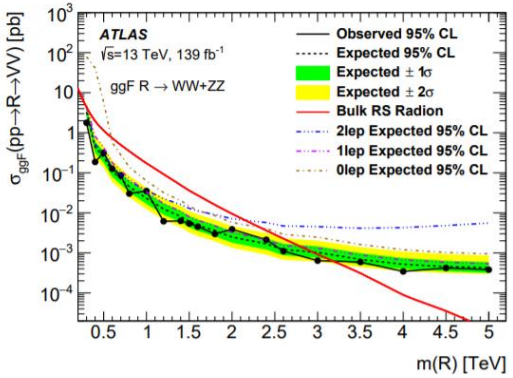


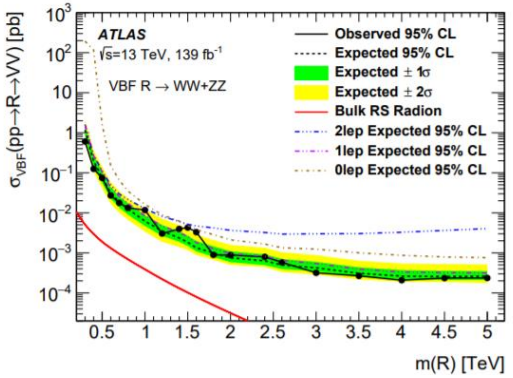


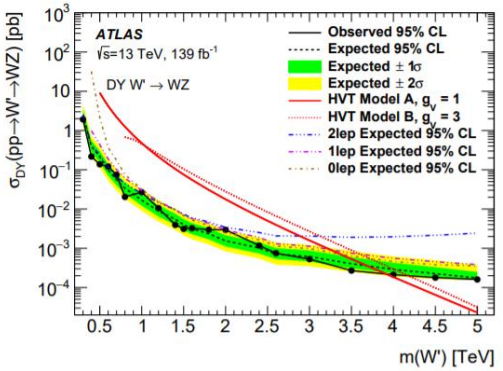
VV Resonance Semileptonic

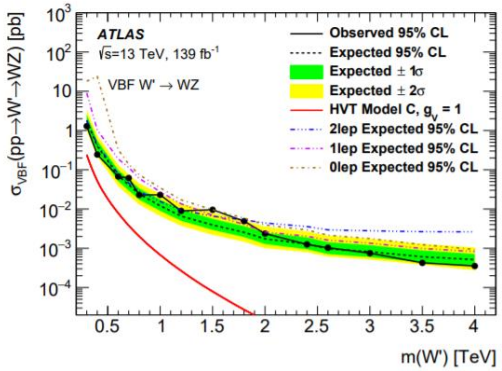
arXiv:2004.14636

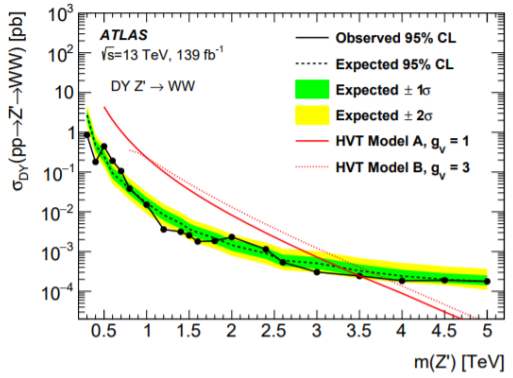
Result: Set Limit on XSec

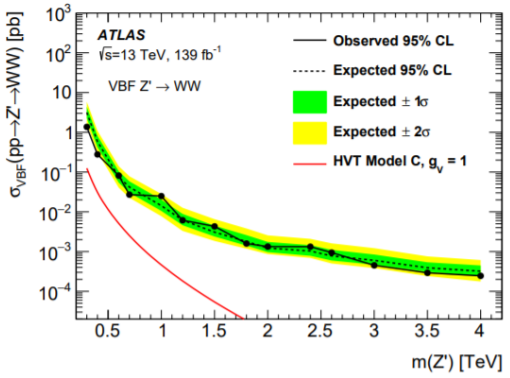


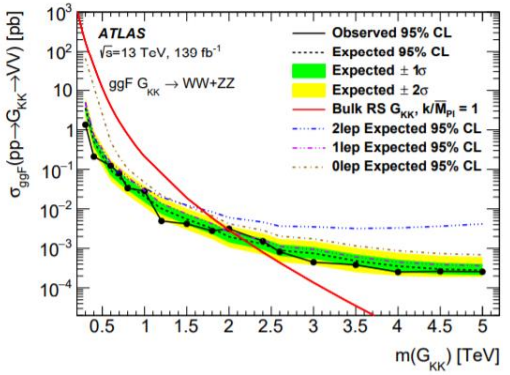


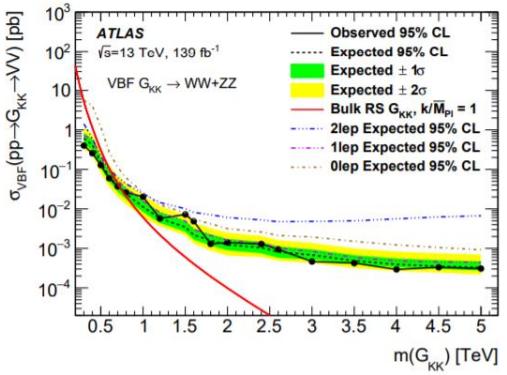












RS Radion	HVT W’
HVT Z’	RS graviton

VV Resonance Semileptonic

arXiv:2004.14636

Result: Set Limit on Xsec

- First combined result with all three different final states (vvqq, lvqq, llqq)
- Radion model result included to fill the gap from previous paper
- Limits show up to 500% improvement w.r.t separated paper with 2015~2016 dataset

Observed (expected) 95% CL lower limits on the mass, in TeV

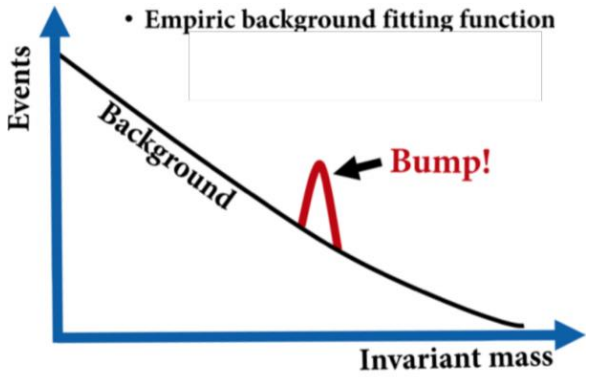
Production process	RS radion	HVT			RS graviton
			W'	Z'	
ggF/DY	3.2 (2.9)	Model A	3.9 (3.8)	3.5 (3.4)	2.0 (2.2)
		Model B	4.3 (4.0)	3.9 (3.7)	
VBF	–	Model C	–	–	0.76 (0.77)

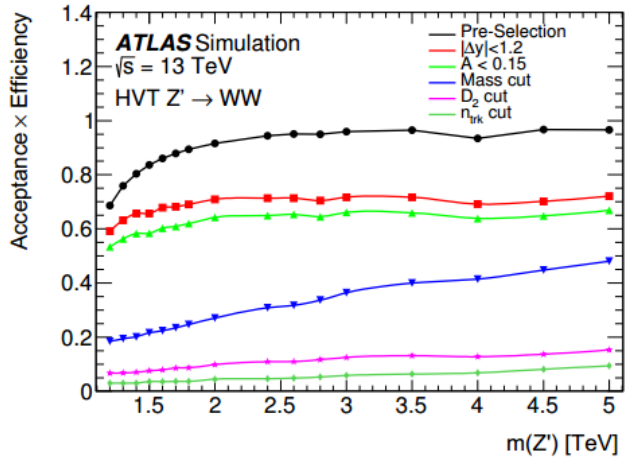
VV Resonance All-hadronic

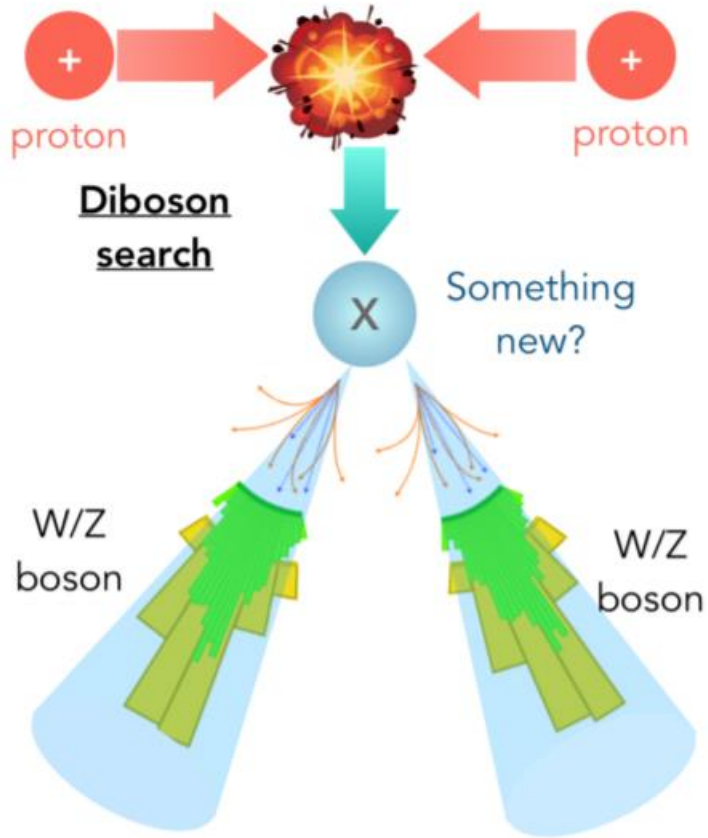
JHEP09(2019)091

Analysis strategy:

- Target: VV resonance decay into boosted jets
- Final state oriented analysis, fully data driven background estimation
- Classic bump-hunting smoothly falling di-boson invariant mass spectrum
- Main cuts listed sequentially:
  - |Δy| cut to suppress t-channel QCD
  - pT asymmetry to select well balanced events
  - cuts by boson tagging







VV Resonance All-hadronic

JHEP09(2019)091

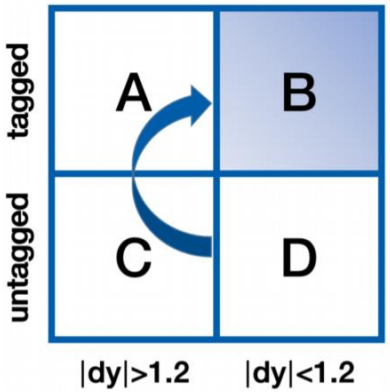
Analysis strategy:

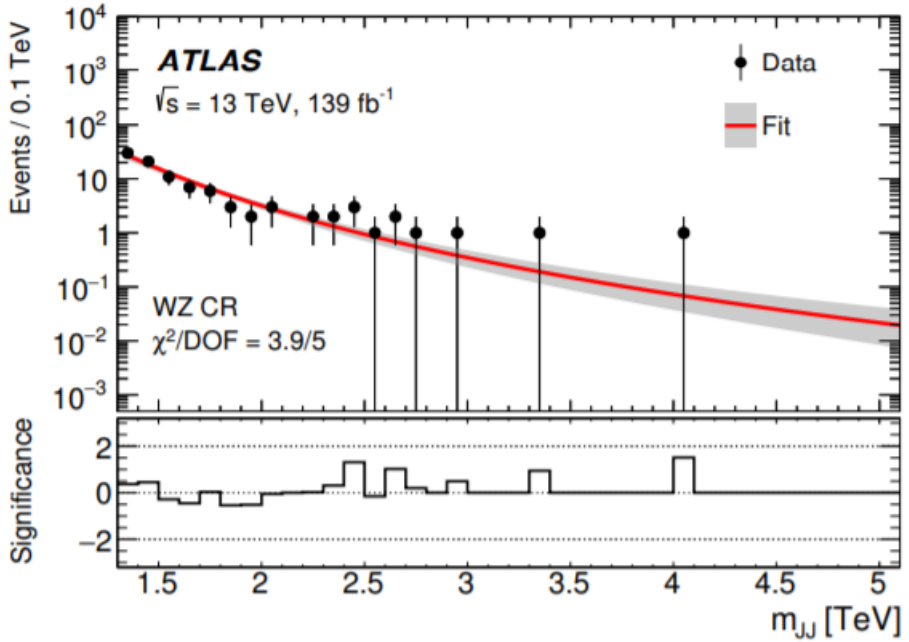
-Background Modeling

- Parametric function:

$$\frac{dn}{dx} = p_1(1-x)^{p_2-\xi p_3}x^{-p_3} \quad \text{with} \quad x = \frac{m_{JJ}}{13[Tev]}$$

- ABCD method
  - modelling of the parametric shape tested in CRs
  - Region B is nominal fit control region
  - Fit was able to describe the expected mJJ spectra in all fit control region



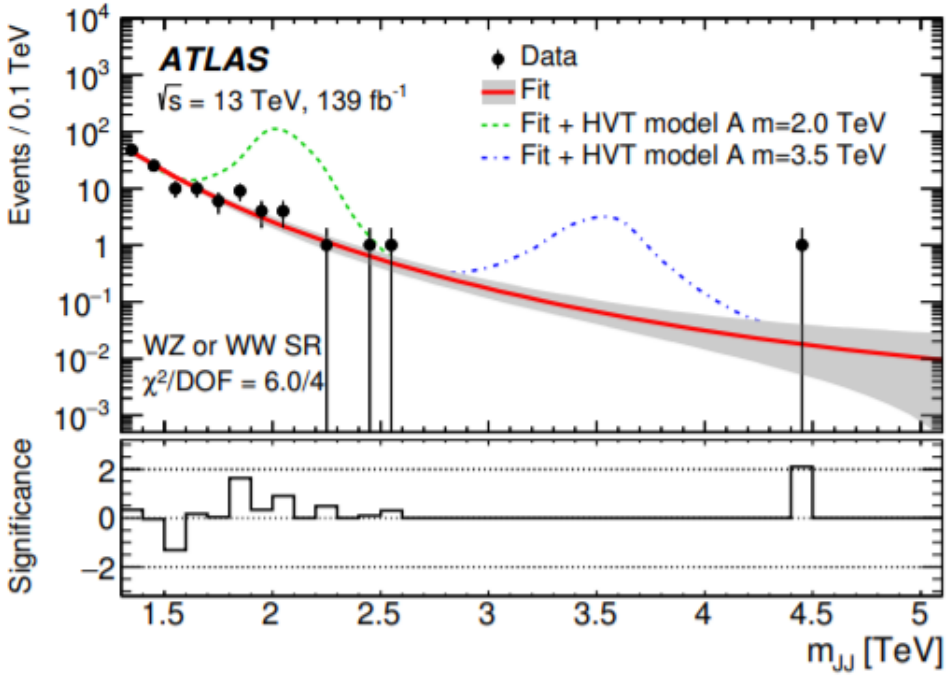


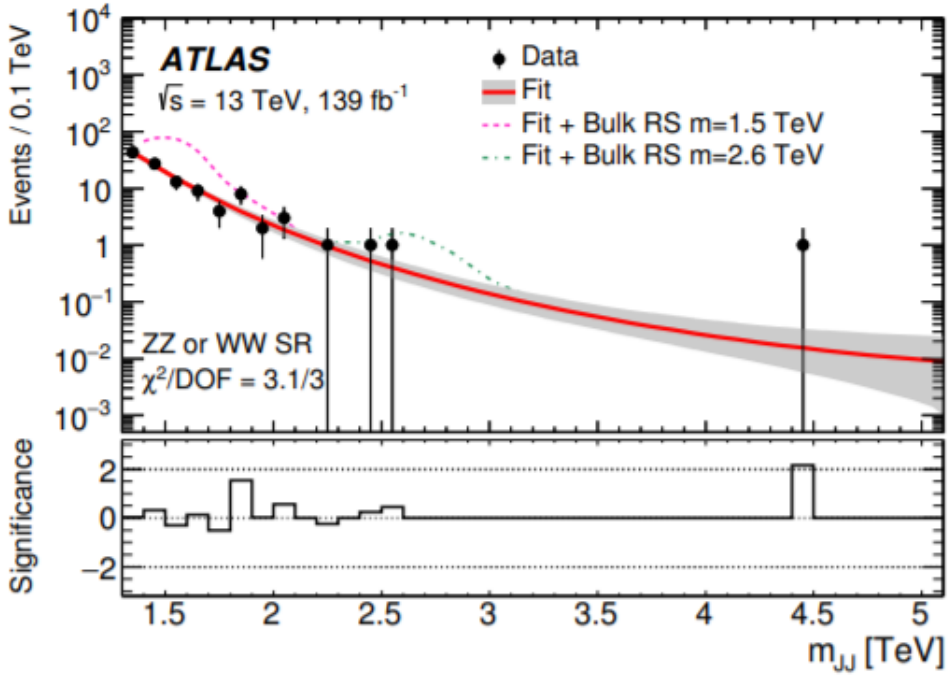
VV Resonance All-hadronic

JHEP09(2019)091

Result:

- No significant excess in any of the observed channels
- Largest excess has a local p-value of 1.8σ
- Observe an event with mJJ ≃ 4.4 TeV





VV Resonance All-hadronic

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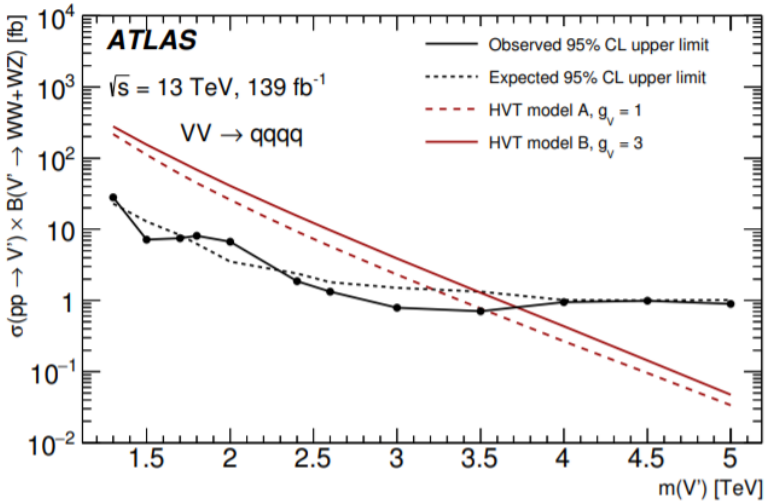
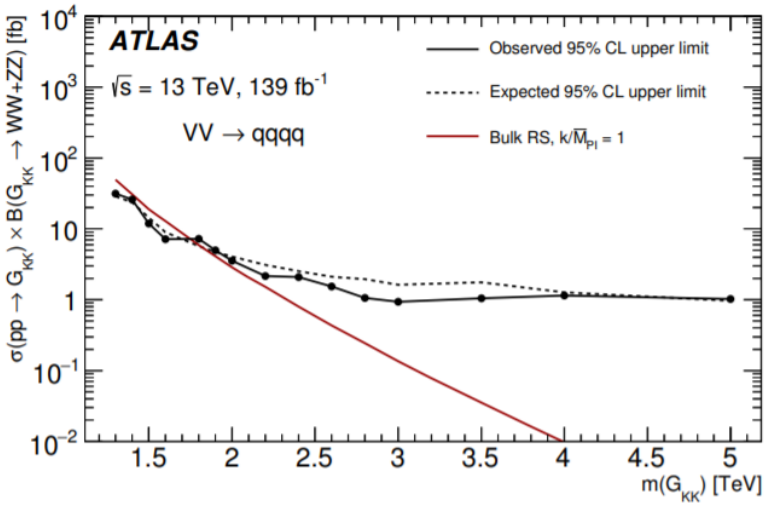




Model	Signal Region	Excluded mass range [TeV]
Radion	WW	none
	ZZ	none
	$WW + ZZ$	none
HVT model A, $g_V = 1$	WW	1.3–2.9
	WZ	1.3–3.4
	$WW + WZ$	1.3–3.5
HVT model B, $g_V = 3$	WW	1.3–3.1
	WZ	1.3–3.6
	$WW + WZ$	1.3–3.8
Bulk RS, $k/\overline{M}_{\mathrm{Pl}} = 1$	WW	1.3–1.6
	ZZ	none
	$WW + ZZ$	1.3–1.8

Result:

Wider excluded mass range on HVT model A and Bulk RS model

Previous Result:

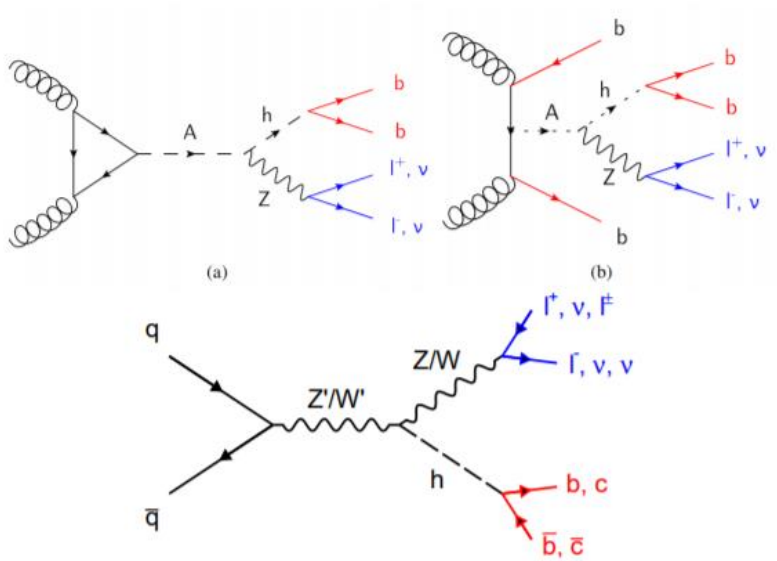
Model	Signal Region	Excluded mass range [TeV]
HVT model A, $g_V = 1$	WW	1.30 – 2.80
	WZ	1.20 – 3.10
	$WW + WZ$	1.20 – 3.40
HVT model B, $g_V = 3$	WW	1.30 – 3.10
	WZ	1.20 – 3.30
	$WW + WZ$	1.20 – 4.15
Bulk RS, $k/\overline{M}_{\mathrm{Pl}} = 1$	WW	1.30 – 1.60
	ZZ	*None*
	$WW + ZZ$	1.20 – 1.90, 2.10 – 2.30

VH Resonance Semileptonic

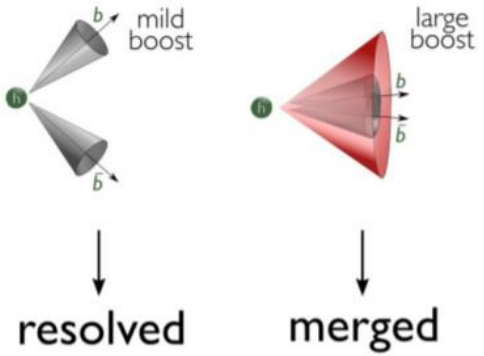
ATLAS-CONF-2020-043

Search for heavy resonances decaying into Zh or Wh

- Two Higgs Doublet Model (2HDM) and Heavy Vector Triplet (HVT)
- SM-like Higgs h → bb, W or Z decay leptonically



- 3 channels:
  - 0 lepton
  - 1 lepton (HVT only)
  - 2 leptons
- 2 regimes
  - Resolved: SM Higgs reconstructed by 2 small-R (0.4) calo jets
  - Merged: SM Higgs reconstructed by 1 large-R TCC jets with at least one associated btagged VR track jet
- Resolved prior strategy



VH Resonance Semileptonic

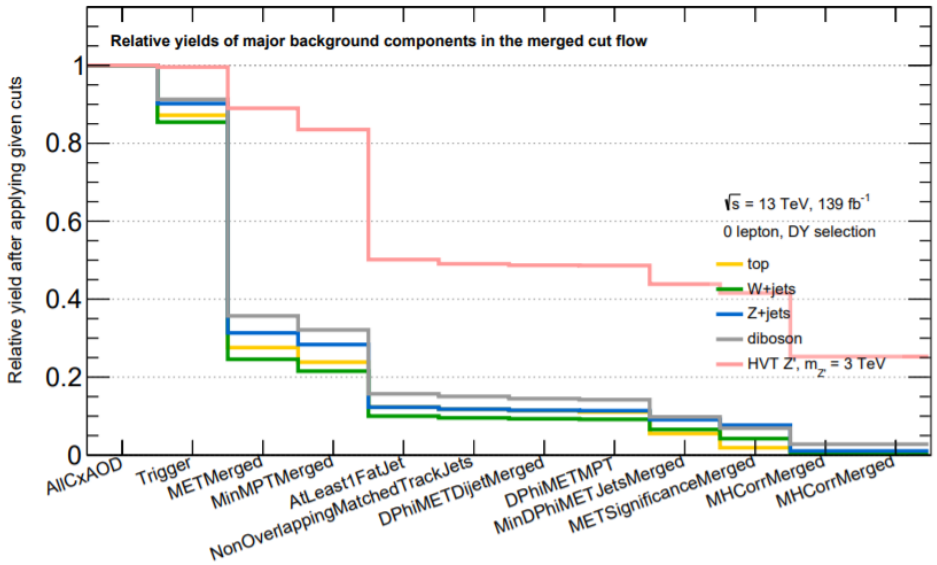
ATLAS-CONF-2020-043

Event selection:

Cuts are the same as the previous publication except:

• New MET significance cut to suppress the multi-jet background in the 0-lepton channel

• Sub-leading lepton pt changed from 7 GeV to 20 GeV to suppress the multi-jet background and W+jets background



Region definition:

-Signal region:

Resolved: $m_{bb} \in [110(100), 140(145)]\ GeV$ for 0(2)L

Merged: $m_{bb} \in [75,145]\ GeV$

-Control region:

Sideband, Top&V+jets VR, TopCR

Region	Channel	Resolved	Merged
m_{bb} sidebands:	0-lep	$50 < m_{bb} < 110$ GeV || $140 < m_{bb} < 200$ GeV	$50 < m_{bb} < 75$ GeV || $145 < m_{bb} < 200$ GeV
	1-lep		
	2-lep	$50 < m_{bb} < 100$ GeV || $145 < m_{bb} < 200$ GeV	
Top & W + jets VR	0-lep	$N^{\tau} = 1$	
		$50 < m_{bb} < 110$ GeV || $140 < m_{bb} < 200$ GeV	$50 < m_{bb} < 75$ GeV || $145 < m_{bb} < 200$ GeV
Top CR	2-lep	Different lepton-flavour	

VH Resonance Semileptonic

ATLAS-CONF-2020-043

Background Modeling

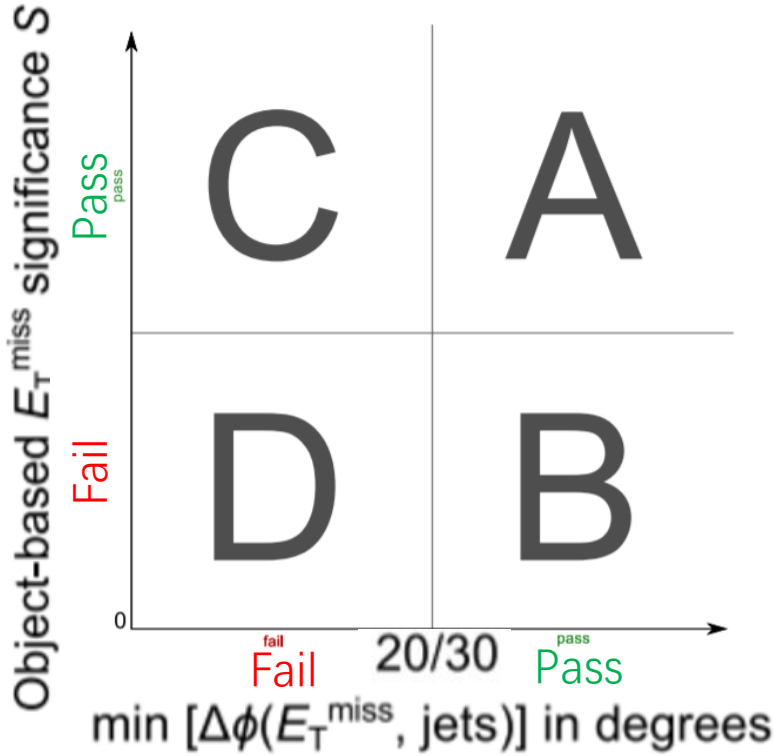
- ABCD method on 0L multijet

  Using MET significance and min[$\Delta\phi$(MET, jets)] to define control regions:

subtracting MC from data

$$N_{\text{multijet}} = \frac{N_C^{\text{data}} - N_C^{\text{MC}}}{N_D^{\text{data}} - N_D^{\text{MC}}} (N_B^{\text{data}} - N_B^{\text{MC}}).$$

- Validated with events count in the mbb sideband region



Conclusion: QCD contribution is negligible

b-tags	$N_B^{\text{data-MC}}$	$N_C^{\text{data-MC}}$	$N_D^{\text{data-MC}}$	N_{multijet}
1	3498 ± 229	288 ± 59	15072 ± 183	66.9 ± 14.5
2	758 ± 85	90.8 ± 26.8	2631 ± 72	26.2 ± 8.3

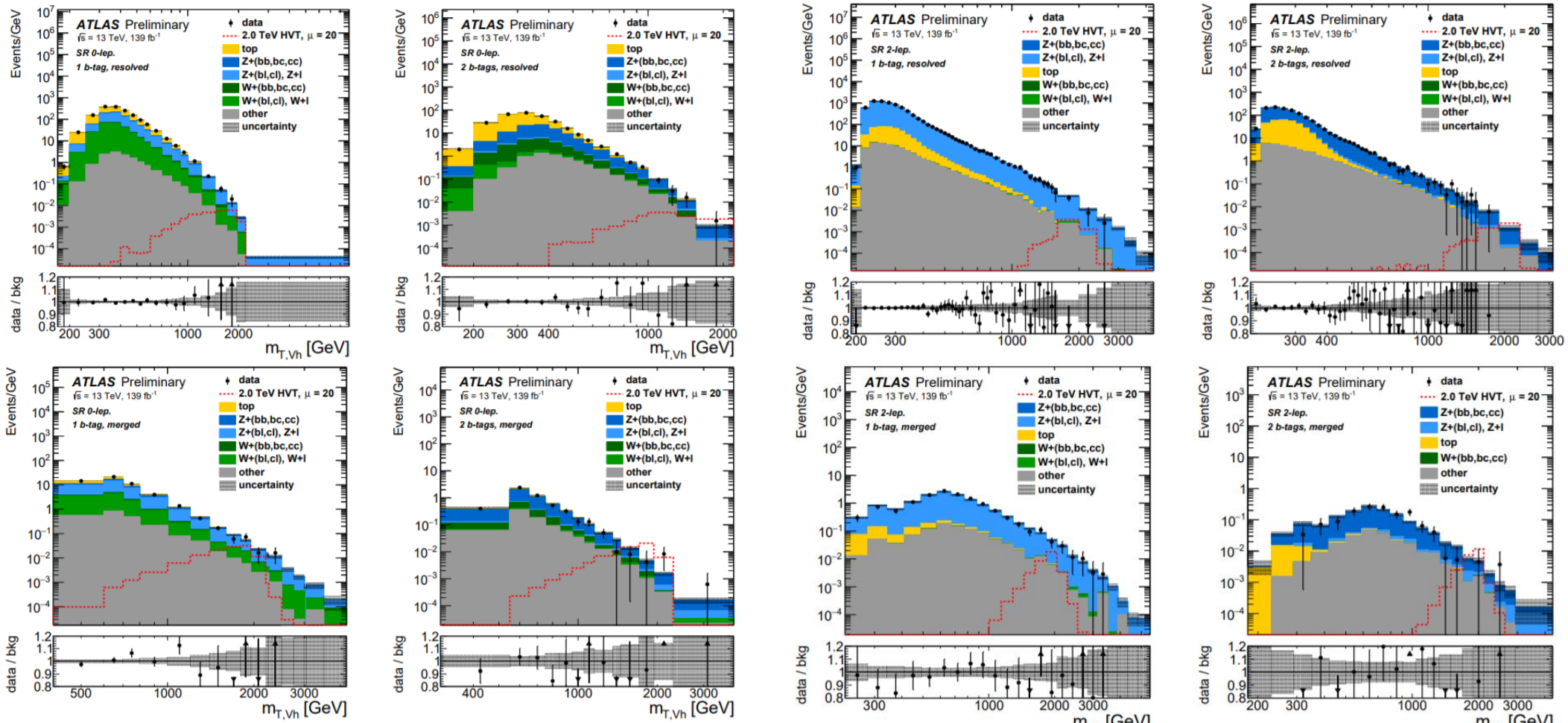
VH Resonance Semileptonic

ATLAS-CONF-2020-043

Result: Fit on (transverse) invariant mass on 2L (0L) channel, no significant excess

resolved

merged



0-lep

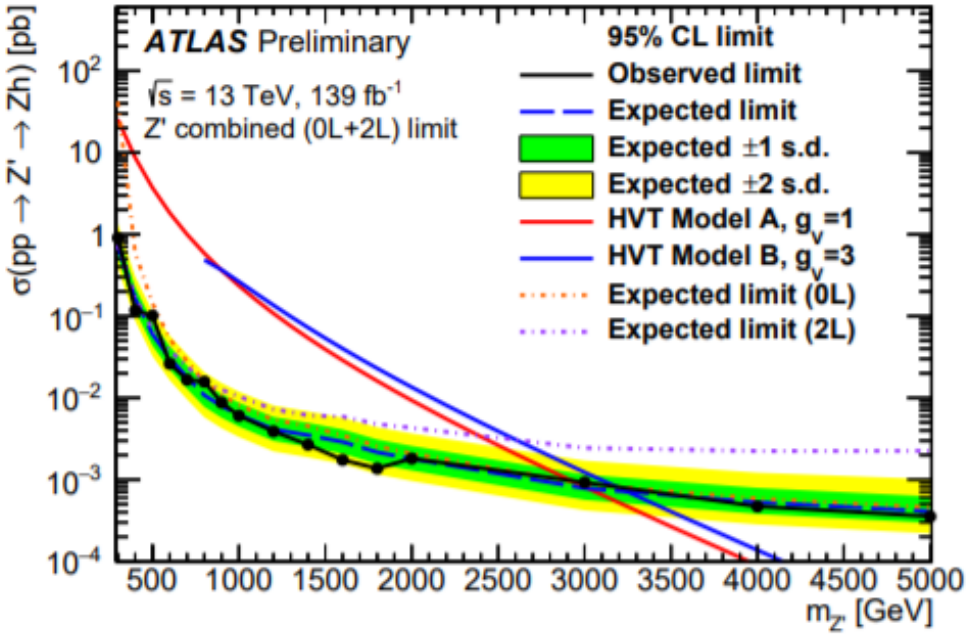
2-lep

VH Resonance Semileptonic

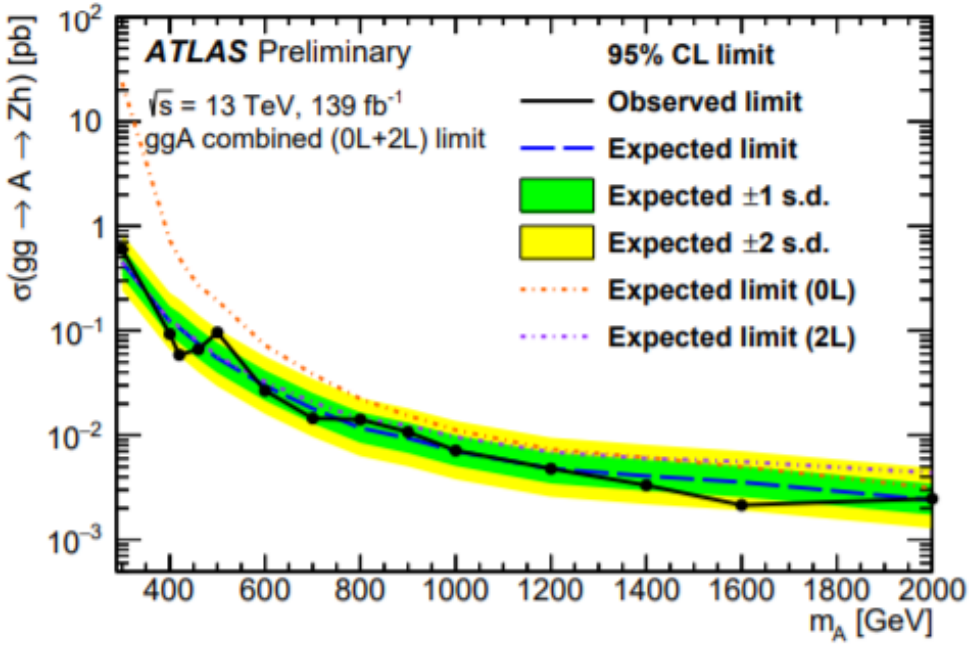
ATLAS-CONF-2020-043

Result: limit set with 95%CL

Z'



ggA



HVT Model A	HVT Model B	ggA
2.9TeV	3.2TeV	none

Improvements range from about 50% for a resonance mass of 300 GeV to about 500% for a mass of 5 TeV, w.r.t to previous analysis .(physletb.2016.11.045)

DiHiggs Searches

Analysis	Latest Result	Dataset used
HH->4b	JHEP07(2020)108	2016~2018(126 fb^{-1})
HH->bbtautau	PhysRevLett.121.191801	2015+2016(39 fb^{-1})
HH->bbVV	JHEP04(2019)092	2015+2016(39 fb^{-1})
HH->bbγγ	JHEP11(2018)040	2015+2016(39 fb^{-1})
HH->Combination	j.physletb.2019.135103	2015+2016(39 fb^{-1})

More details on Jana's talk

Resonant VBF->HH->4b

JHEP07(2020)108

Analysis Strategy:

- Target signature: “hh->4b process with 2 forward VBF jets”
- Resonant signal:

  mH = 260 – 1000 GeV

  narrow width/ board width of O(10-100) GeV
- Event selection:

  Require two other jets with VBF-like topology

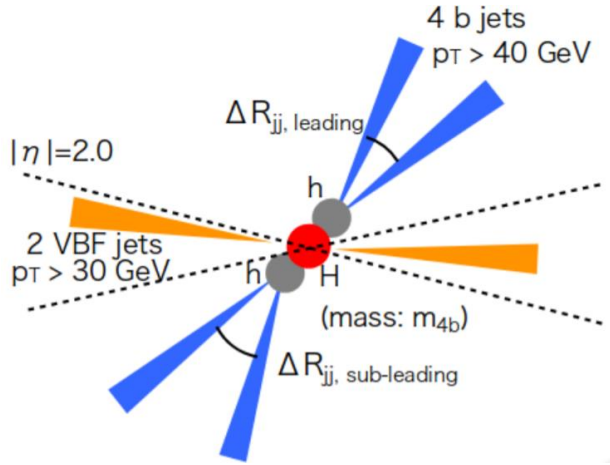
  4 b-tagged jets with pT>40GeV

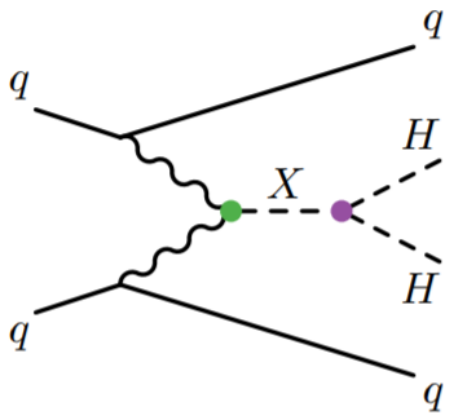
  Dijet candidate with boson-tagger

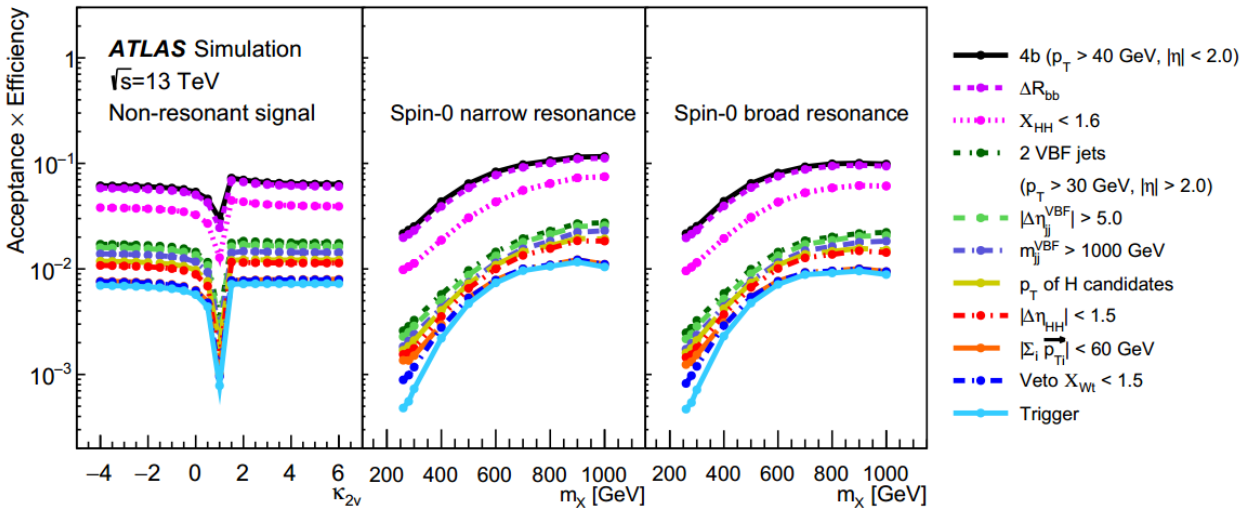
  Background cleaning cut
- Background:

  95% multijet with data-driven modeling

  5% ttbar with simulation modeling
- Analysis also includes non-resonant models







Resonant VBF->HH->4b

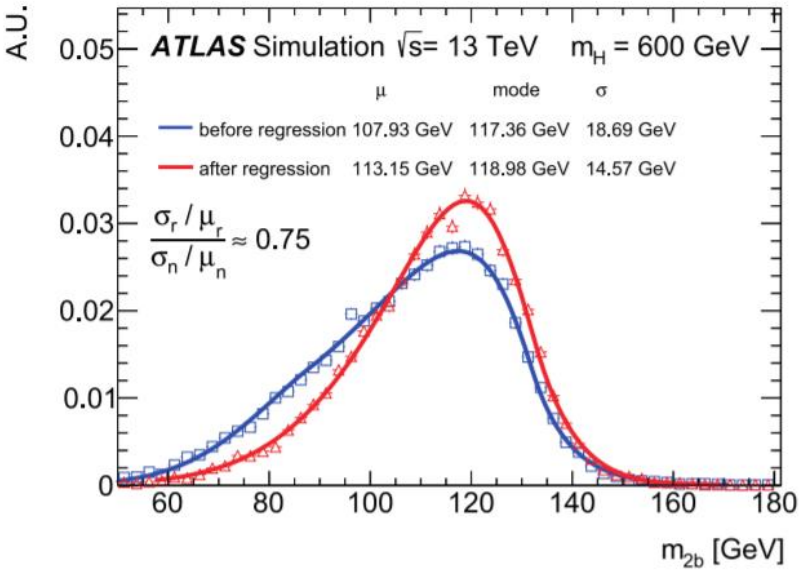
JHEP07(2020)108

Analysis Strategy:

- b-jet energy correction with BDT

  - Energy loss by semi-leptonic decays, energy leakage outside the jet cone

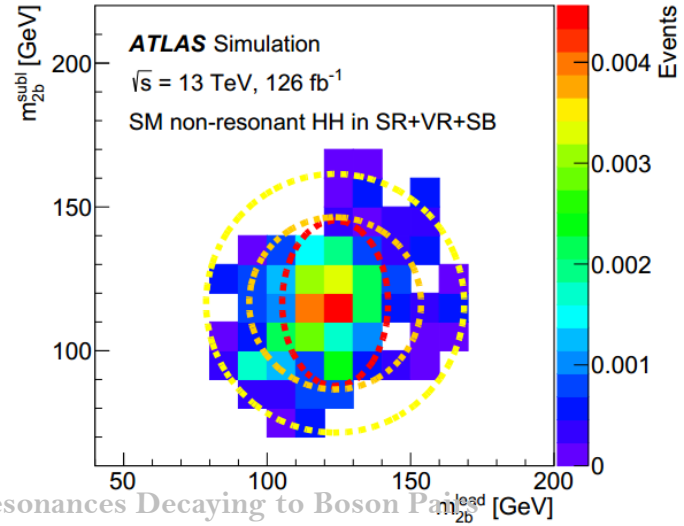
  - 10% jet energy resolution and 25% for the mX = 600 GeV signal mass distribution improvement

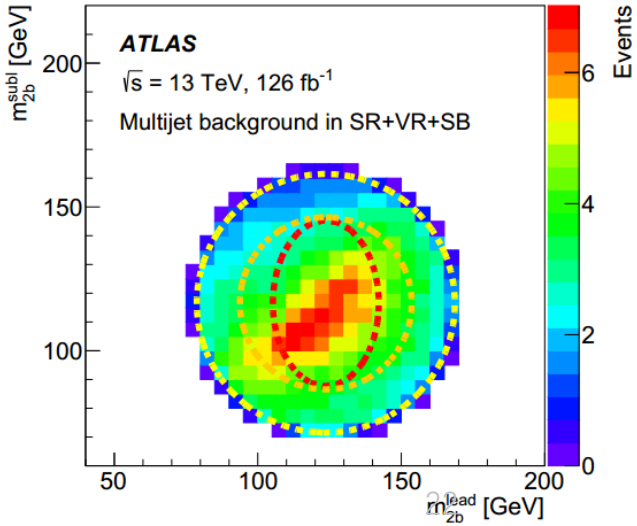


- Mass of two H candidate used to create **Signal**, **Validation**, **Sideband** Region

  - Sideband provides reweighting on multijet modeling

  - Validation Region provides normalisation on bkg





Resonant VBF->HH->4b

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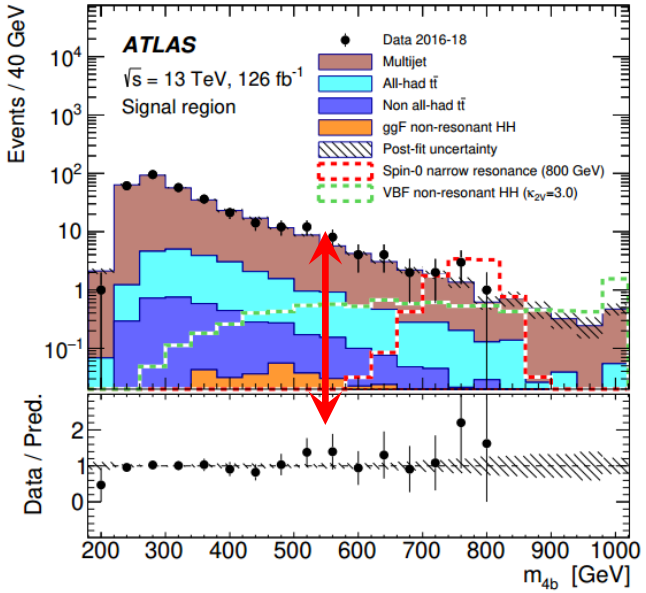
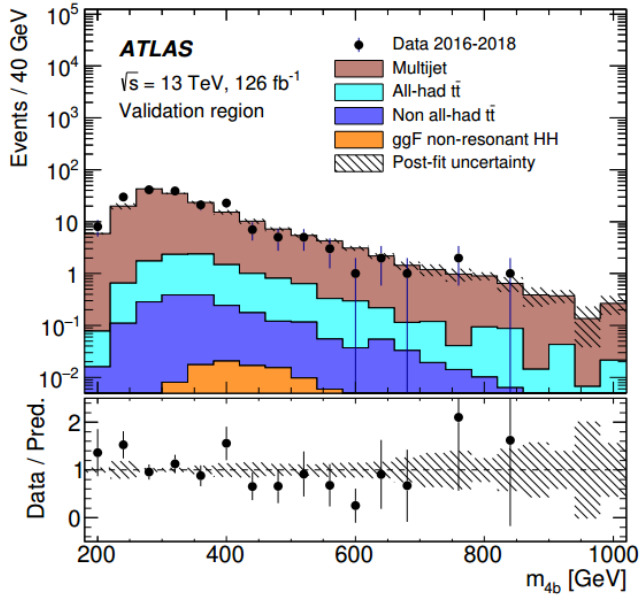
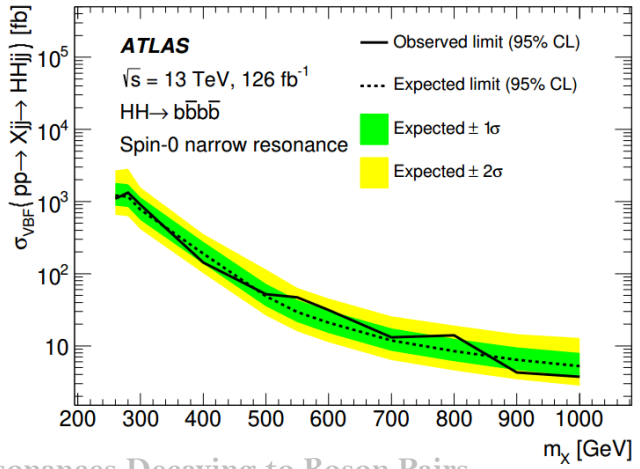
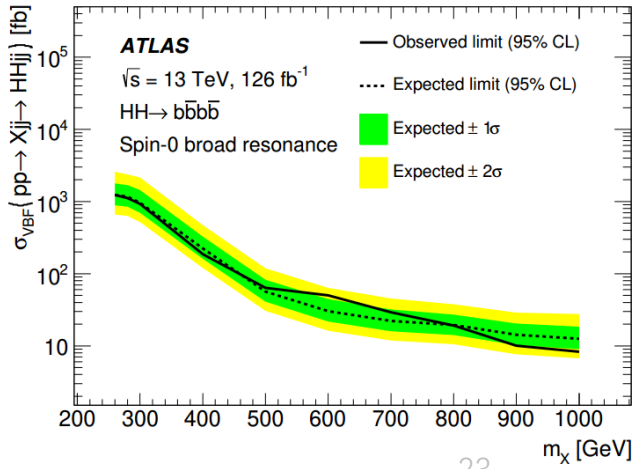
Result:

- Simultaneously fit on 4-bjets mass
- No excess covering mass range 250–1000 GeV
- The most extreme $p0$-value corresponds to a local significance of 1.5 standard deviations at 550 GeV
- Limit is set within [250,1000]GeV range and shows up to 100% improvement w.r.t 2015-2016 paper









X->Hγ

Published on Aug, 2020
axriv:2008.05928

Analysis Strategy:

- Target: Search for heavy resonance decay into H+γ using full run-II
- Only considered hadronic decay mode(H→bb ~58%) and merged regime
- Signal: spin=1 qq->X->Hγ
- Baseline Selection:

- Photons

  pT>200GeV, |eta|<1.37, Tight ID

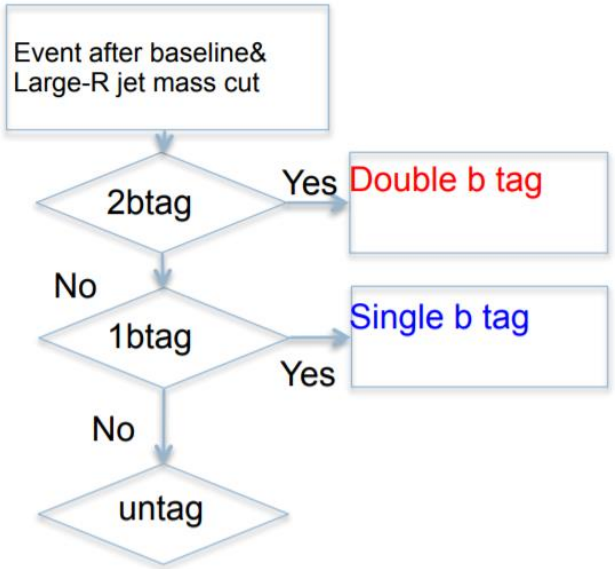
- Large-R jet (Ak10 LCTopo Jet)

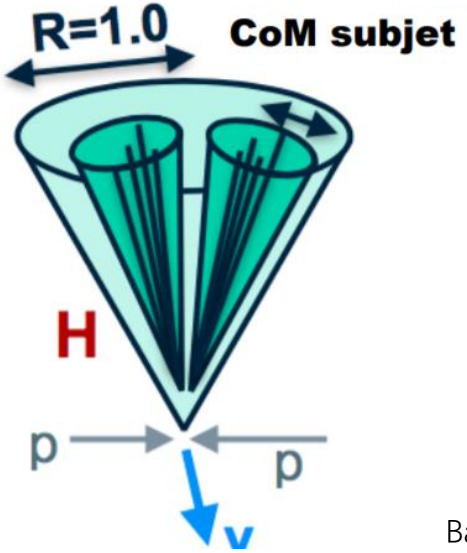
  pT>200GeV, |eta|<2.0, 50GeV <mass<200GeV

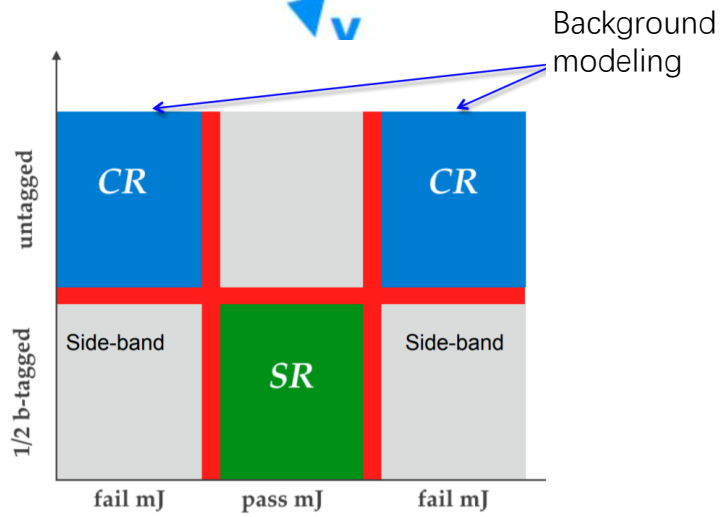
  pT dependent boson tagger

- SR: 1/2btag SR CR: untagged sideband

- Background: ttbar+γ

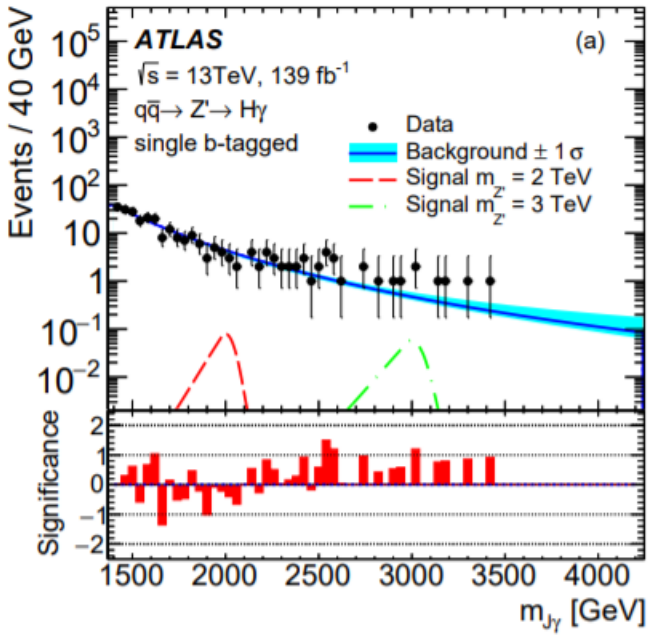


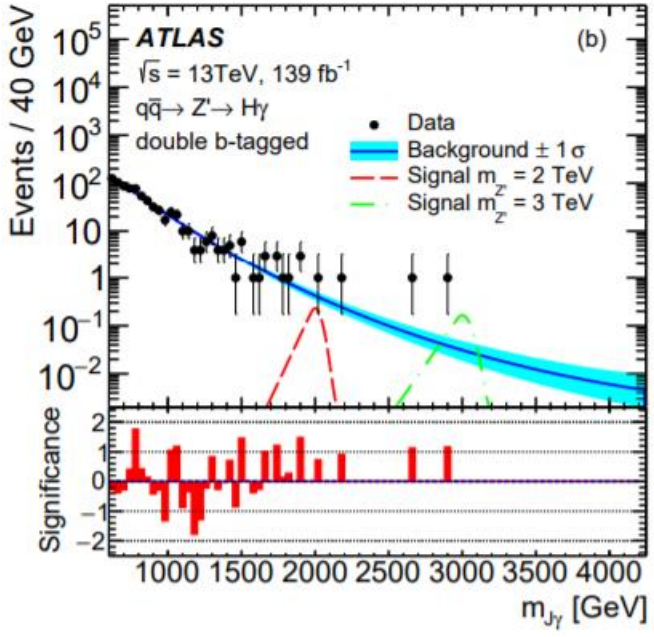


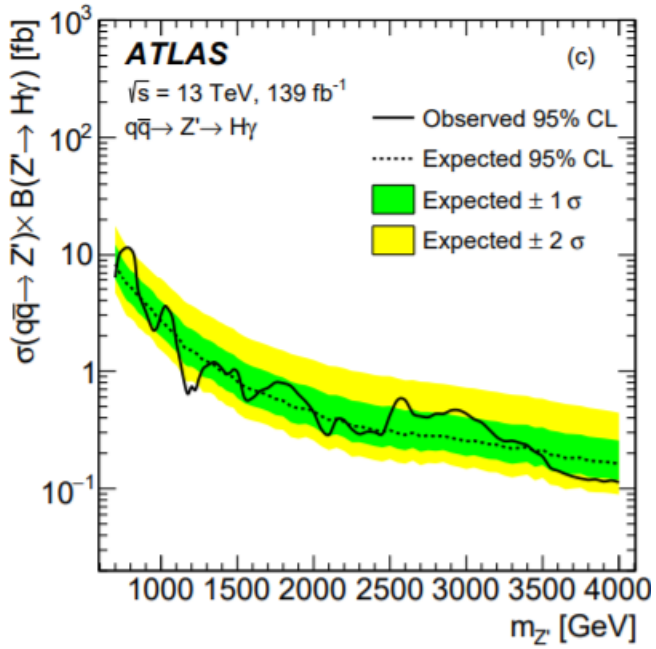


X->Hγ

axriv:2008.05928







Signal: Crystal Ball function with small Gaussian on tail

Background: $B(m_{J\gamma}) = (1-x)^{p_1} x^{p_2+p_3 \log(x)}$

$$x = m_{J\gamma}/\sqrt{s},\ \sqrt{s} = 13\ \text{TeV}$$

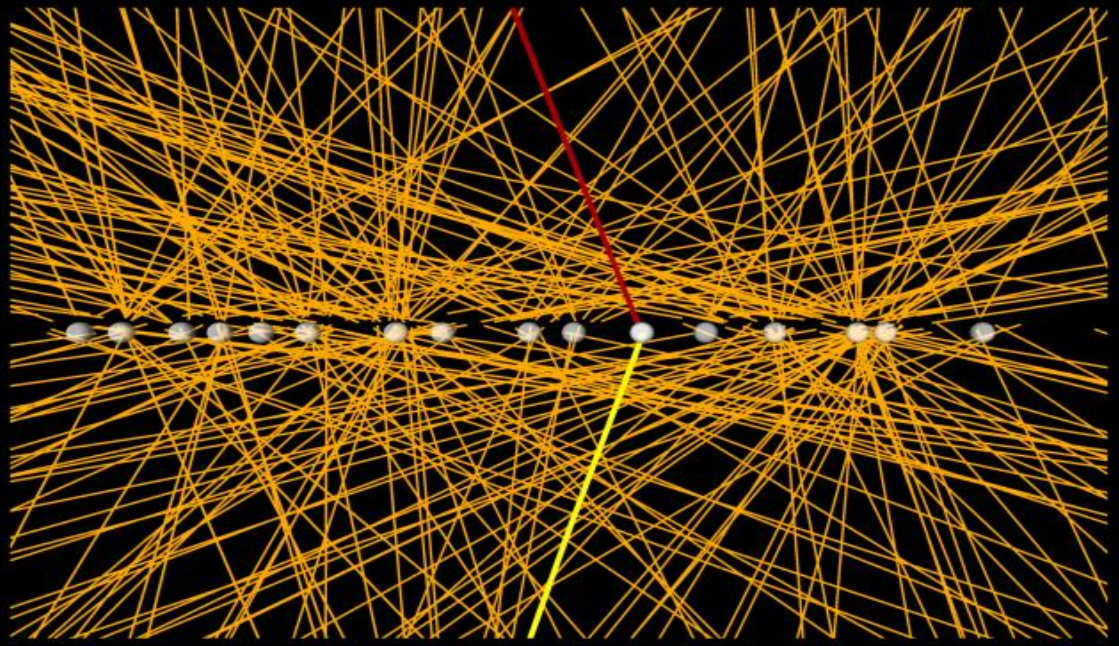
Simultaneous fit to the mJγ distributions on 1/2-btag region, no significant excess is found

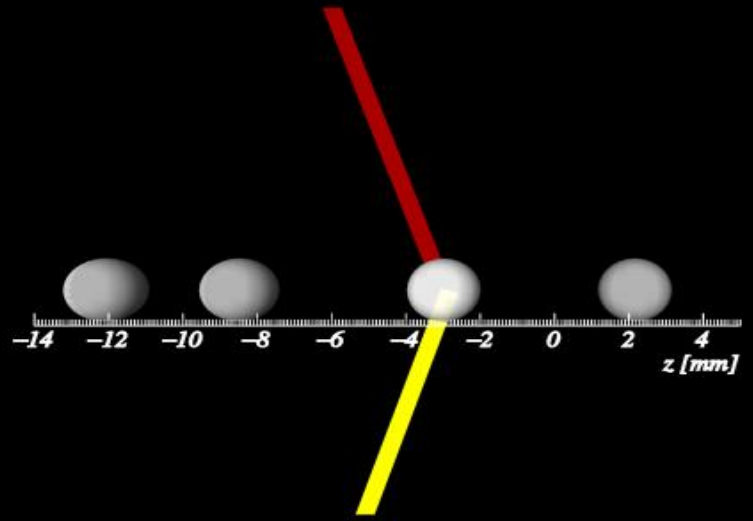
Highest local (global) significance of 2.6σ (0.22σ) at 775 GeV.

Upper limits are set with mass range from 0.7 to 4 TeV, significantly larger covering mass range than in the previous ATLAS and CMS searches.

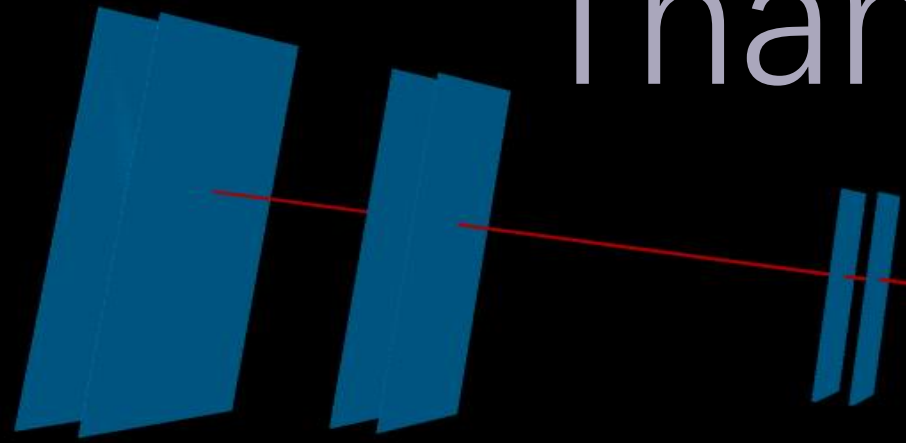
Summary

- BSM models predict new resonances in the TeV range that decay into boson pairs, many BSM diboson searches are studied on ATLAS experiment.
- New Track-CaloCluster jet results in improvements in the boson tagging performance, and guarantees better sensitivity for many diboson resonance searches.
- Some new Run 2 results on VH semileptonic, VV semileptonic, VV full-hadronic, VBF HH->4b, X->Hγ are published with new data up to 2018.
- No excess found but significantly better limit w.r.t previous run 2 study using 2015~2016 dataset.
- Plenty of studies on this topic will be coming up with exciting results in the future.





Thank you!



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