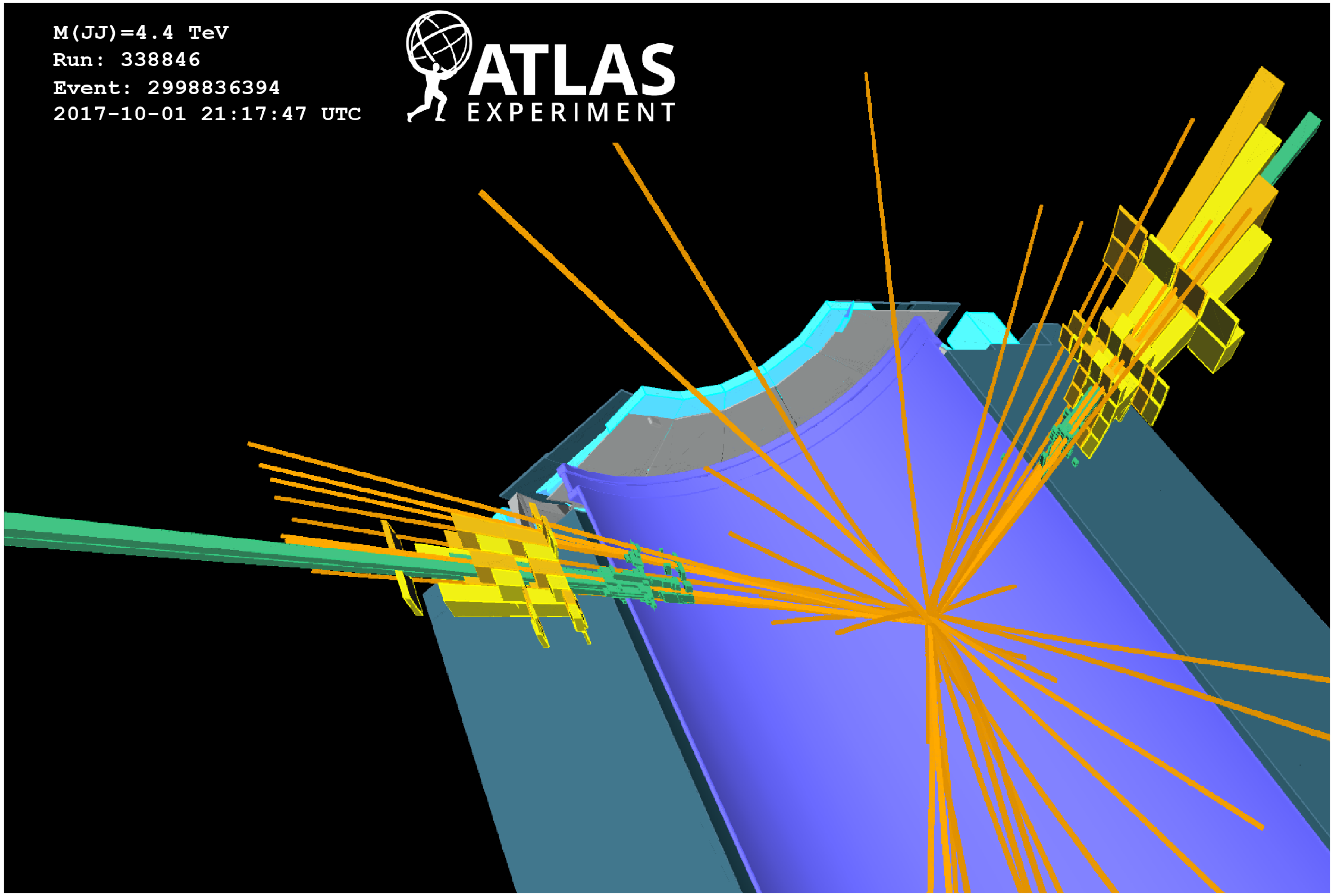

ATLAS Searches for Resonances Decaying to Boson Pairs

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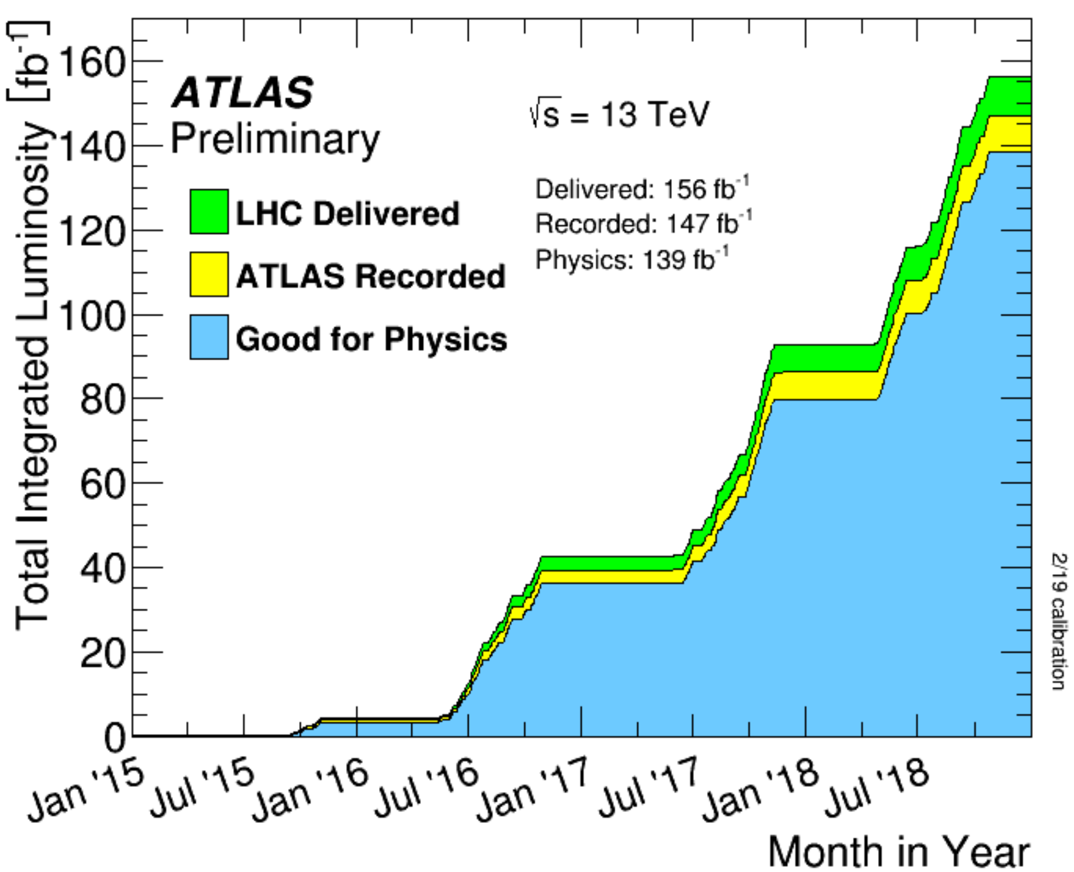
Diboson Resonances

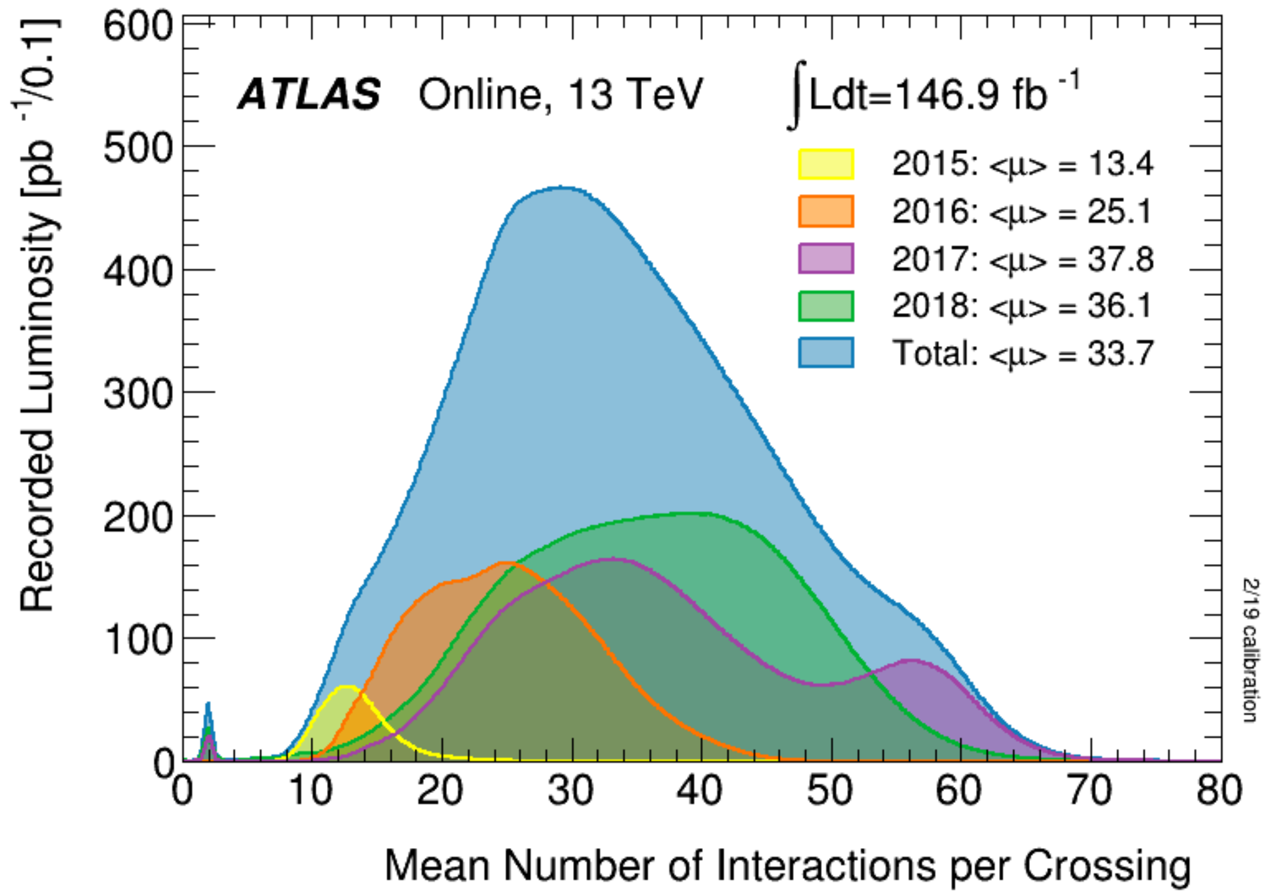
- Models trying to address the shortcomings of the Standard Model often feature new heavy resonances decaying to the Standard Model bosons
    - In many of these scenarios, the new resonances have masses in the TeV range and could be produced at the LHC
- The general idea to a search for these new resonances simply *a bump hunt*

- This talk:
    - Coherent picture emerging from the searches for new resonances decaying to bosons/leptons with 36/fb at $\sqrt{s}$ = 13TeV with ATLAS (1808.02380)
    - The VV search in hadronic final states with the full Run-2 dataset 140/fb at $\sqrt{s}$ = 13 TeV with ATLAS (1906.08589)

Dataset



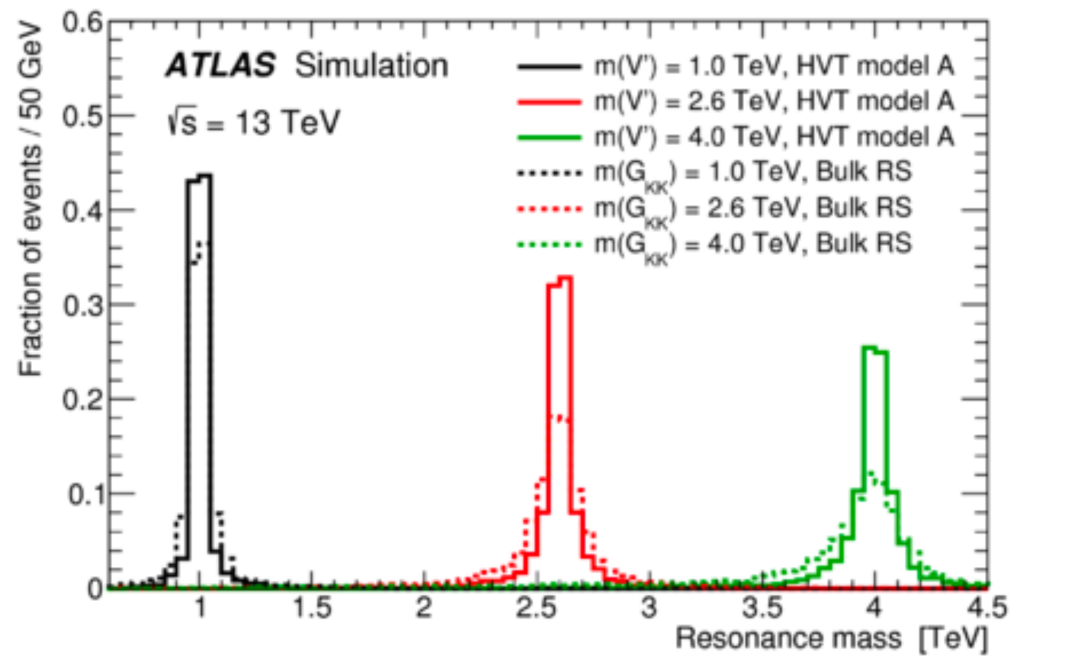
ATLAS
Preliminary
√s = 13 TeV
LHC Delivered
ATLAS Recorded
Good for Physics
Delivered: 156 fb⁻¹
Recorded: 147 fb⁻¹
Physics: 139 fb⁻¹
Total Integrated Luminosity [fb⁻¹]
Month in Year
Jan '15
Jul '15
Jan '16
Jul '16
Jan '17
Jul '17
Jan '18
Jul '18
2/19 calibration



ATLAS Online, 13 TeV
∫Ldt=146.9 fb⁻¹
2015: <μ> = 13.4
2016: <μ> = 25.1
2017: <μ> = 37.8
2018: <μ> = 36.1
Total: <μ> = 33.7
Recorded Luminosity [pb⁻¹/0.1]
Mean Number of Interactions per Crossing
2/19 calibration

Benchmarks

- Experimentally narrow
- Scalar
  - For VVJJ - Scalar Radion
- Vector Triplet
  - Production through DY or VBF
- Bulk-RS Graviton
- Vector bosons from decay are always Longitudinally polarized



Model \ Decay mode	WW	WZ	ZZ	WH	ZH	$\ell\nu$	$\ell\ell$
HVT	Z'	W'		W'	Z'	W'	Z'
Bulk RS	G_{KK}		G_{KK}				
Scalar	Scalar		Scalar				

Heavy Vector Triplet

broad phenomenological framework that a allows to explore different scenarios with new heavy boson triplets (W',Z') with approximately degenerate masses

$$\mathcal{L}_{\mathcal{W}}^{\text{int}} = -g_q \mathcal{W}_\mu^a \bar{q}_k \gamma^\mu \frac{\sigma_a}{2} q_k - g_\ell \mathcal{W}_\mu^a \bar{\ell}_k \gamma^\mu \frac{\sigma_a}{2} \ell_k - g_H \left(\mathcal{W}_\mu^a H^\dagger \frac{\sigma_a}{2} i D^\mu H + \text{h.c.} \right)$$

Model A - Weakly coupled model with extended gauge symmetry

g_H = -0.56, g_f = -0.55

Production is DY

BR(VV/VH) ~ 2% BR(lep) ~ 4%

Model B - Composite Higgs Models

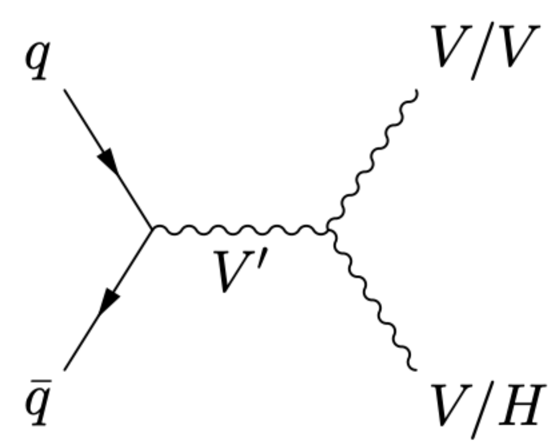
g_H = -2.9 g_f = 0.14

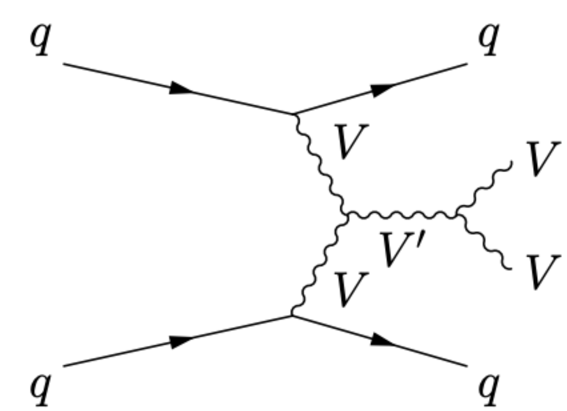
Production is DY

BR(VV/VH) ~ 50% BR(lep) ~ 0.2%

Model C - VBF

g_H=1 g_f = 0





The convention in the HVT paper

$g_H = c_H g_V$

$g_f = g^2 c_F / g_V$

	HVT model A		HVT model B		HVT model C		Bulk RS
m [TeV]	$\sigma(W')$ [fb]	$\sigma(Z')$ [fb]	$\sigma(W')$ [fb]	$\sigma(Z')$ [fb]	$\sigma(W')$ [fb]	$\sigma(Z')$ [fb]	$\sigma(G_{KK})$ [fb]
1.0	2.20×10^4	1.12×10^4	987	510	1.30	0.888	583
2.6	219	100	14.0	6.44	4.78×10^{-3}	3.14×10^{-3}	1.41
4.0	9.49	4.37	0.626	0.288	1.27×10^{-4}	7.92×10^{-5}	3.25×10^{-2}

Channels

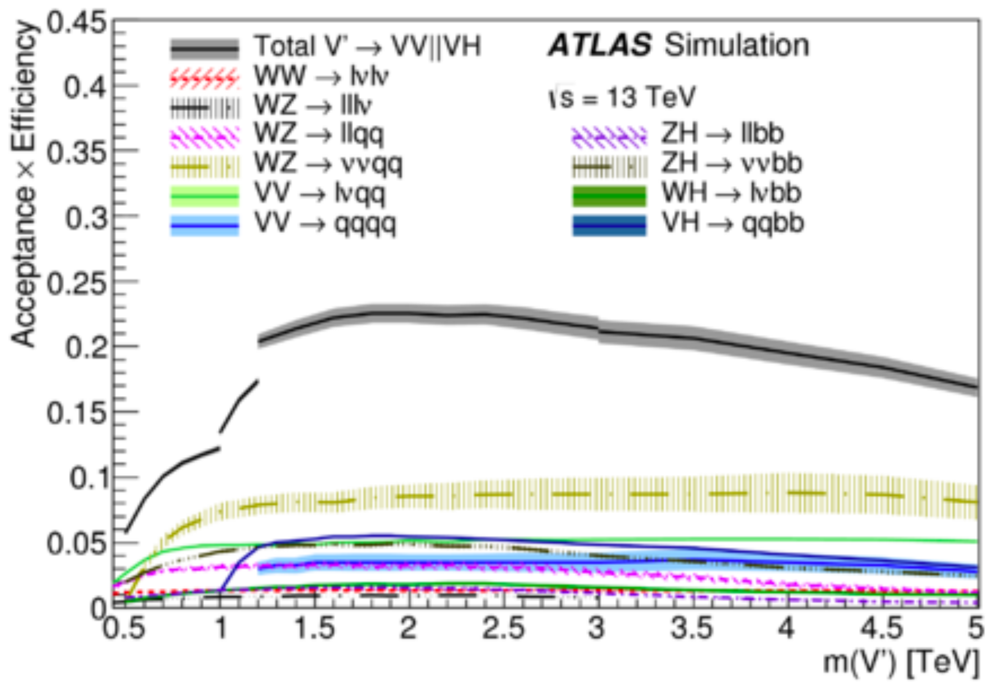
- Event selections for the different searches are orthogonal
  - leptons, jets and E_{Tmiss}
- Fully hadronic VV (two large-R jets) - Highest branching ratio, but large backgrounds, sensitive in particular at high mass
- Semileptonic VV - two leptons, or one / zero leptons with significant E_{Tmiss}, sensitive to different production mechanisms ggF/VBF
- Fully leptonic VV - clean, distinguishes ggF/VBF and sensitive at low masses
- Fully Hadronic VH - focus on m > 1 TeV, V-tagging + H-tagging
- Semileptonic VH - m > 0.5 TeV, resolved and merged H, priority to resolved. vvbb, lvbb, llbb
- Fully-leptonic - lv, ll, very clean signature - 0.2 to 5.5 TeV

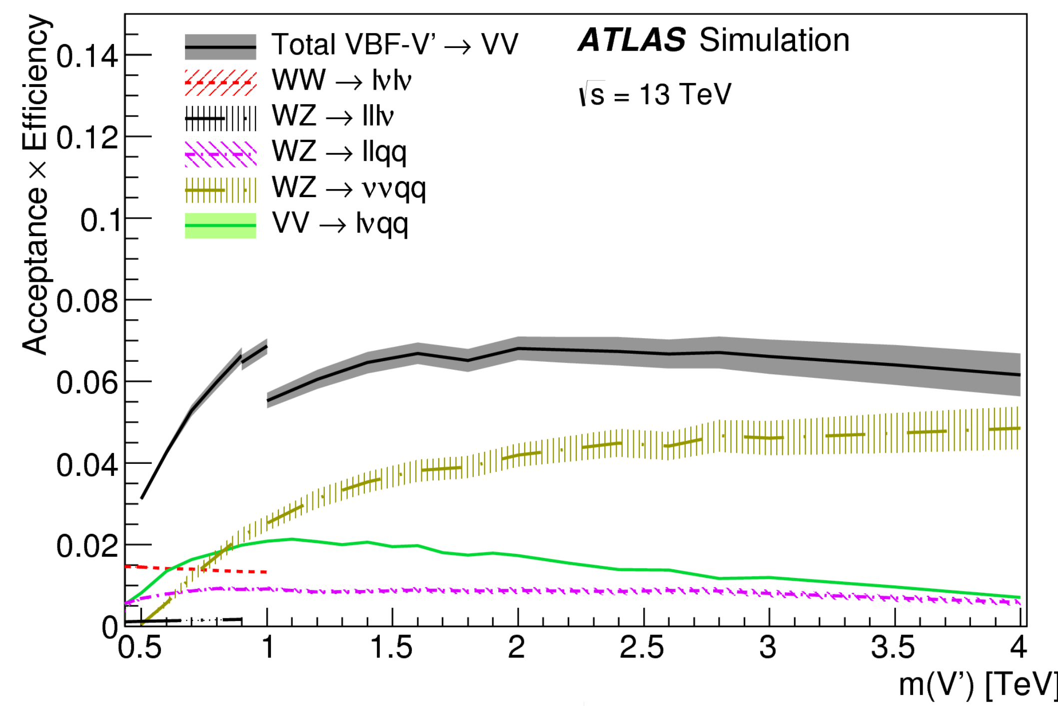
V/H Tagging

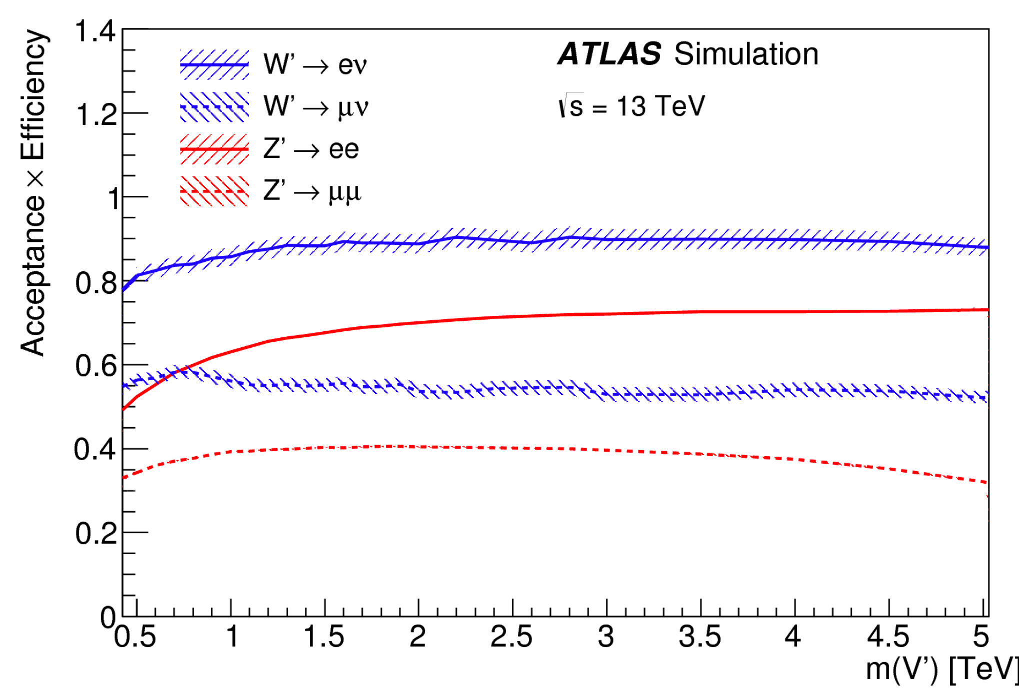
- Large-R jets are R=1.0, anti-kT, Trimmed (0.2,5%)
- V tagging - Mass and D_2
- H tagging - Mass and b-tagging on R=0.2 track jets

Channel	Diboson state	Selection				VBF ca
		Leptons	E_T^{miss}	Jets	b-tags	
$qqqq$	$WW/WZ/ZZ$	0	veto	2J	–	–
$\nu\nu qq$	WZ/ZZ	0	yes	1J	–	yes
$\ell\nu qq$	WW/WZ	$1e, 1\mu$	yes	2j, 1J	–	yes
$\ell\ell qq$	WZ/ZZ	$2e, 2\mu$	–	2j, 1J	–	yes
$\ell\ell\nu\nu$	ZZ	$2e, 2\mu$	yes	–	0	yes
$\ell\nu\ell\nu$	WW	$1e+1\mu$	yes	–	0	yes
$\ell\nu\ell\ell$	WZ	$3e, 2e+1\mu, 1e+2\mu, 3\mu$	yes	–	0	yes
$\ell\ell\ell\ell$	ZZ	$4e, 2e+2\mu, 4\mu$	–	–	–	yes
$qqbb$	WH/ZH	0	veto	2J	1, 2	–
$\nu\nu bb$	ZH	0	yes	2j, 1J	1, 2	–
$\ell\nu bb$	WH	$1e, 1\mu$	yes	2j, 1J	1, 2	–
$\ell\ell bb$	ZH	$2e, 2\mu$	veto	2j, 1J	1, 2	–
$\ell\nu$	–	$1e, 1\mu$	yes	–	–	–
$\ell\ell$	–	$2e, 2\mu$	–	–	–	–

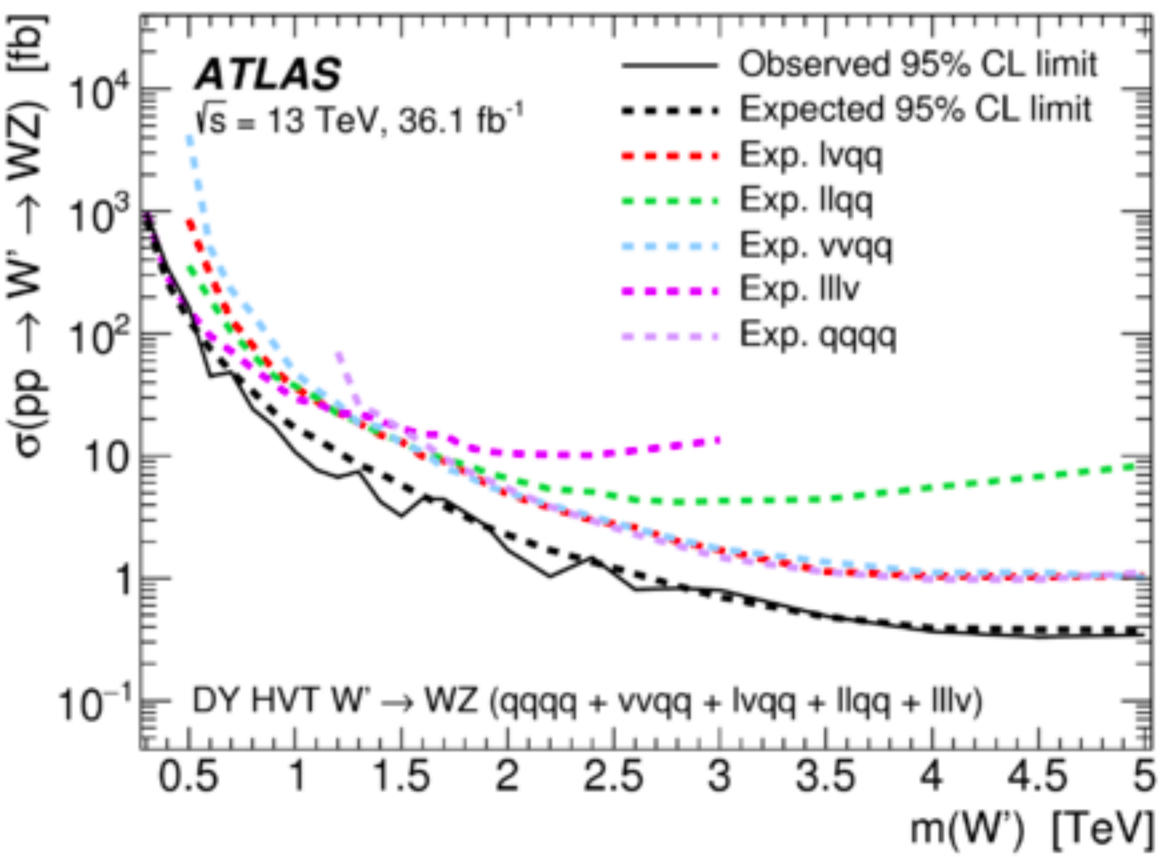
Contributions from the different channels

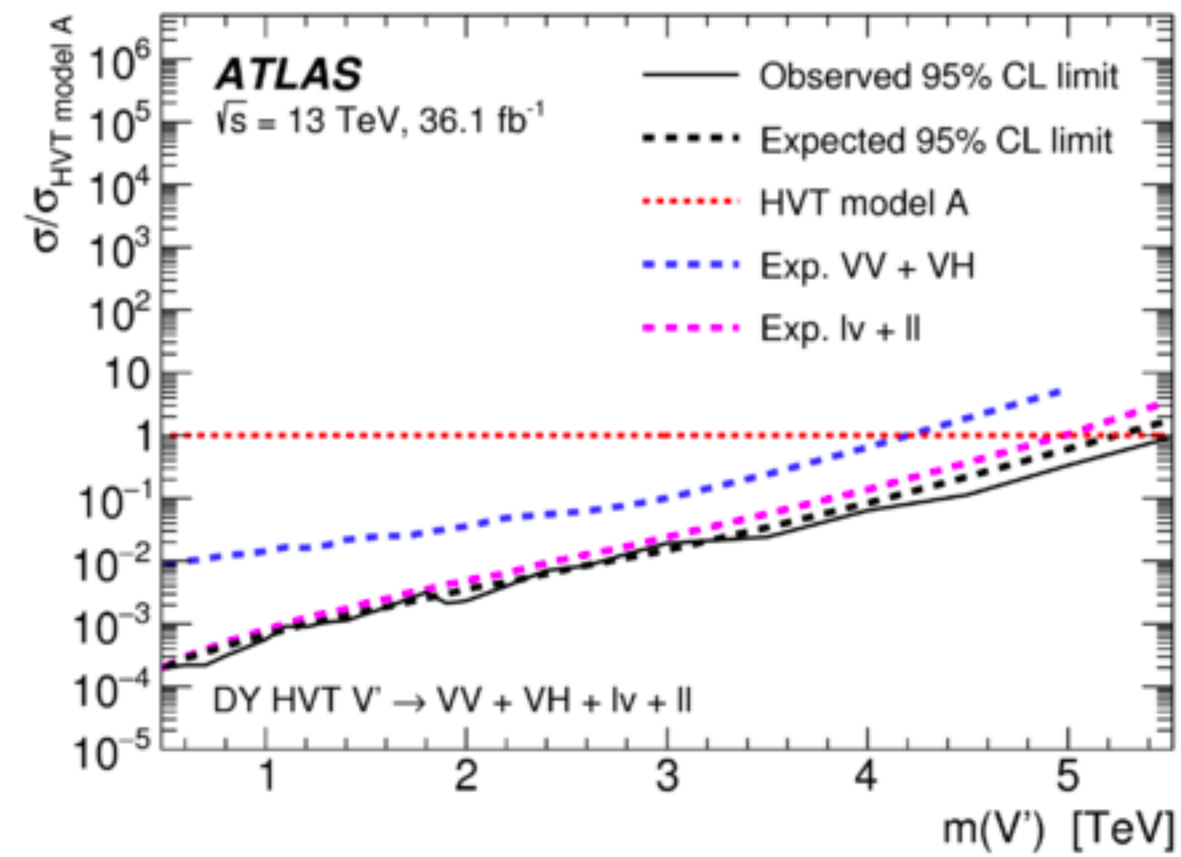






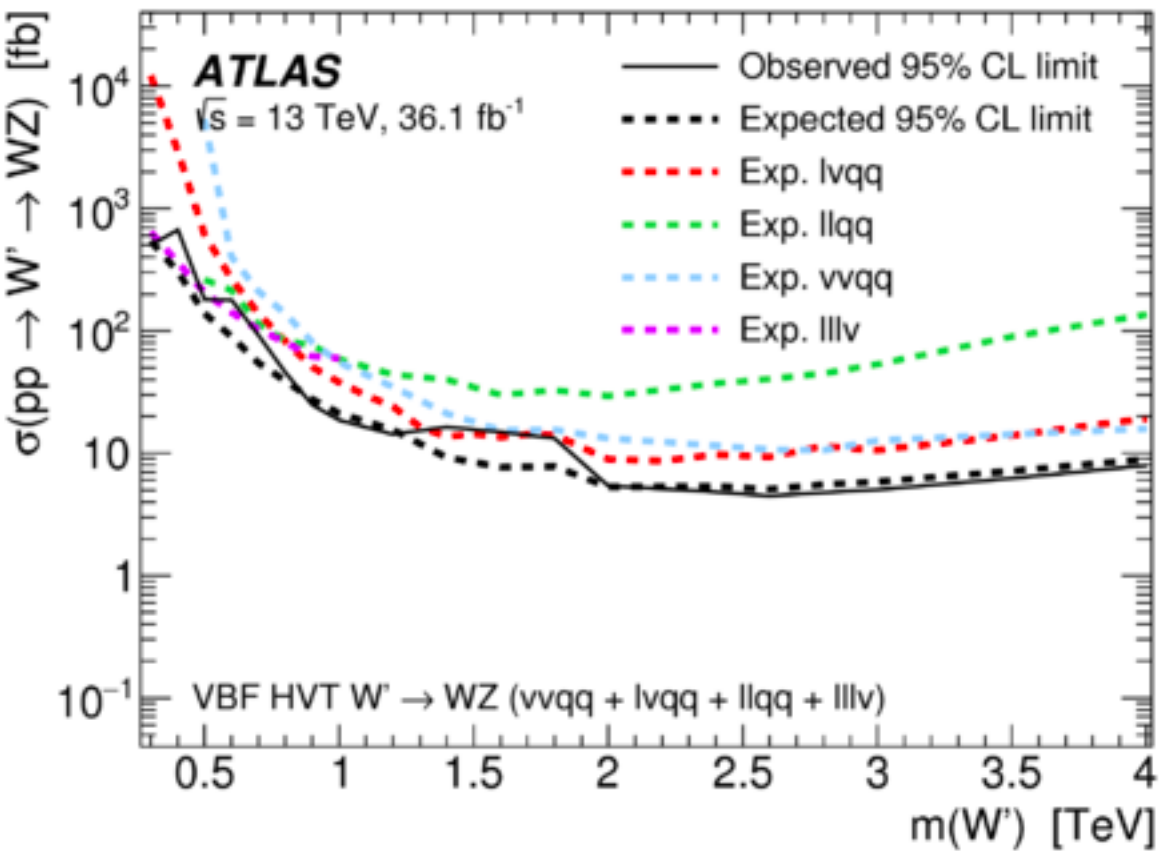
Contributions to the HVT sensitivity

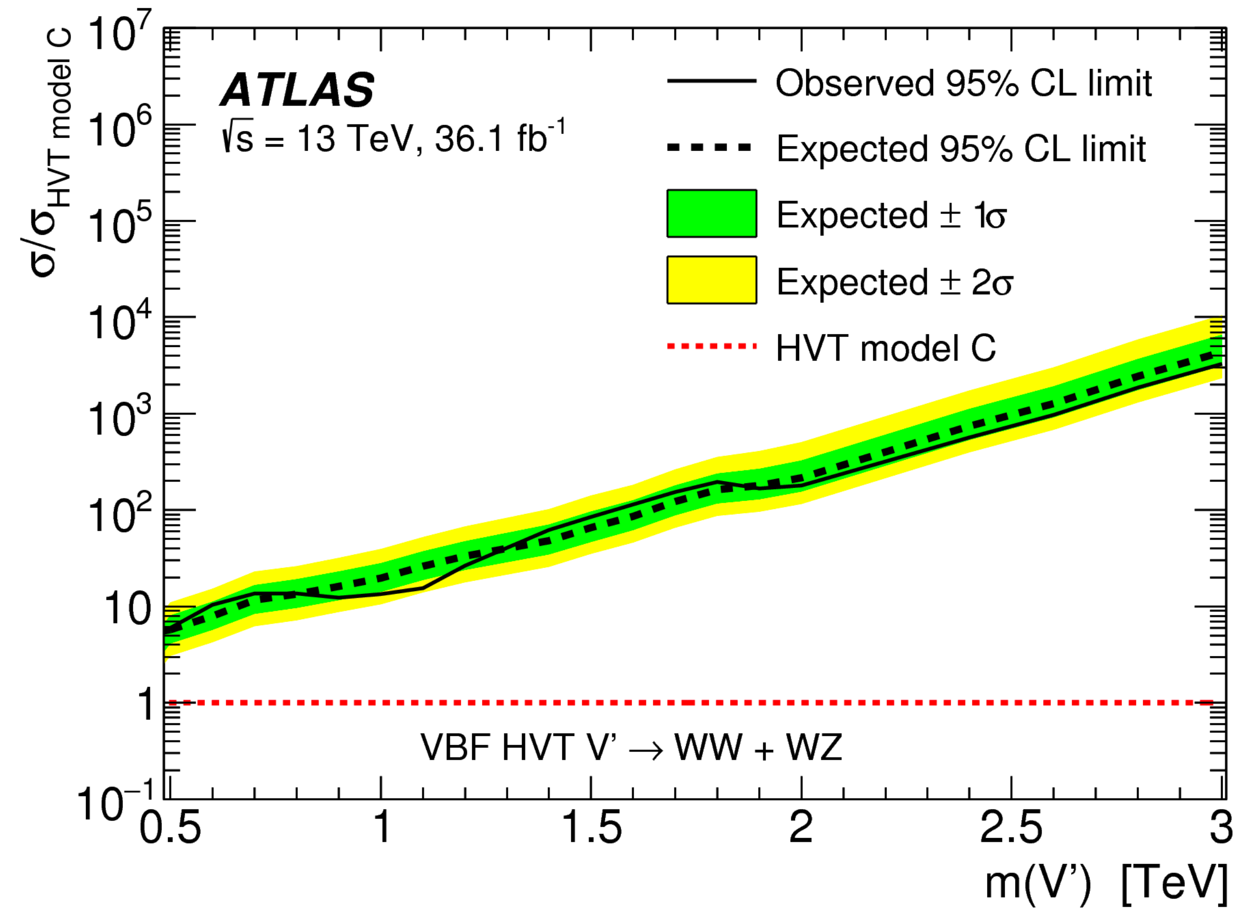


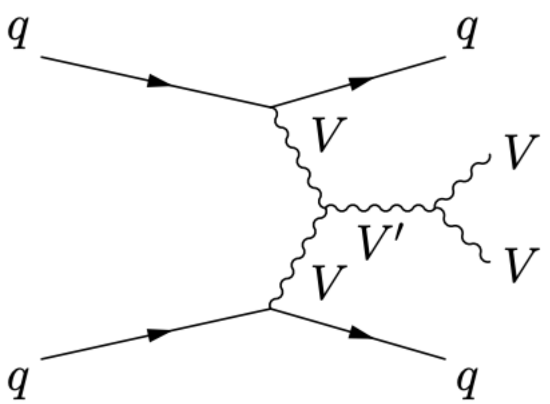


At high masses the electrons begin to merge, this degrades the semileptonic performance

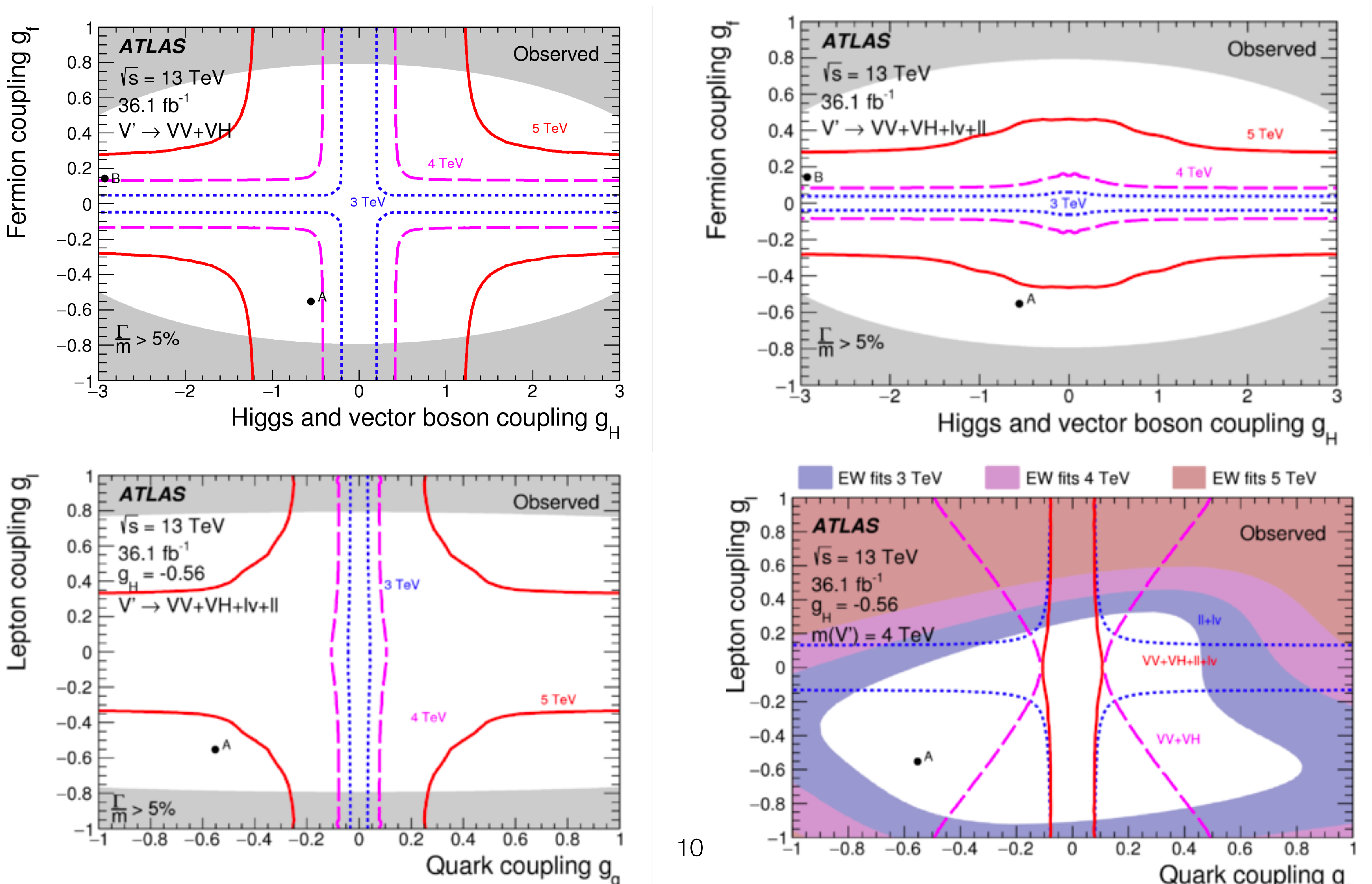
Bounds on VBF



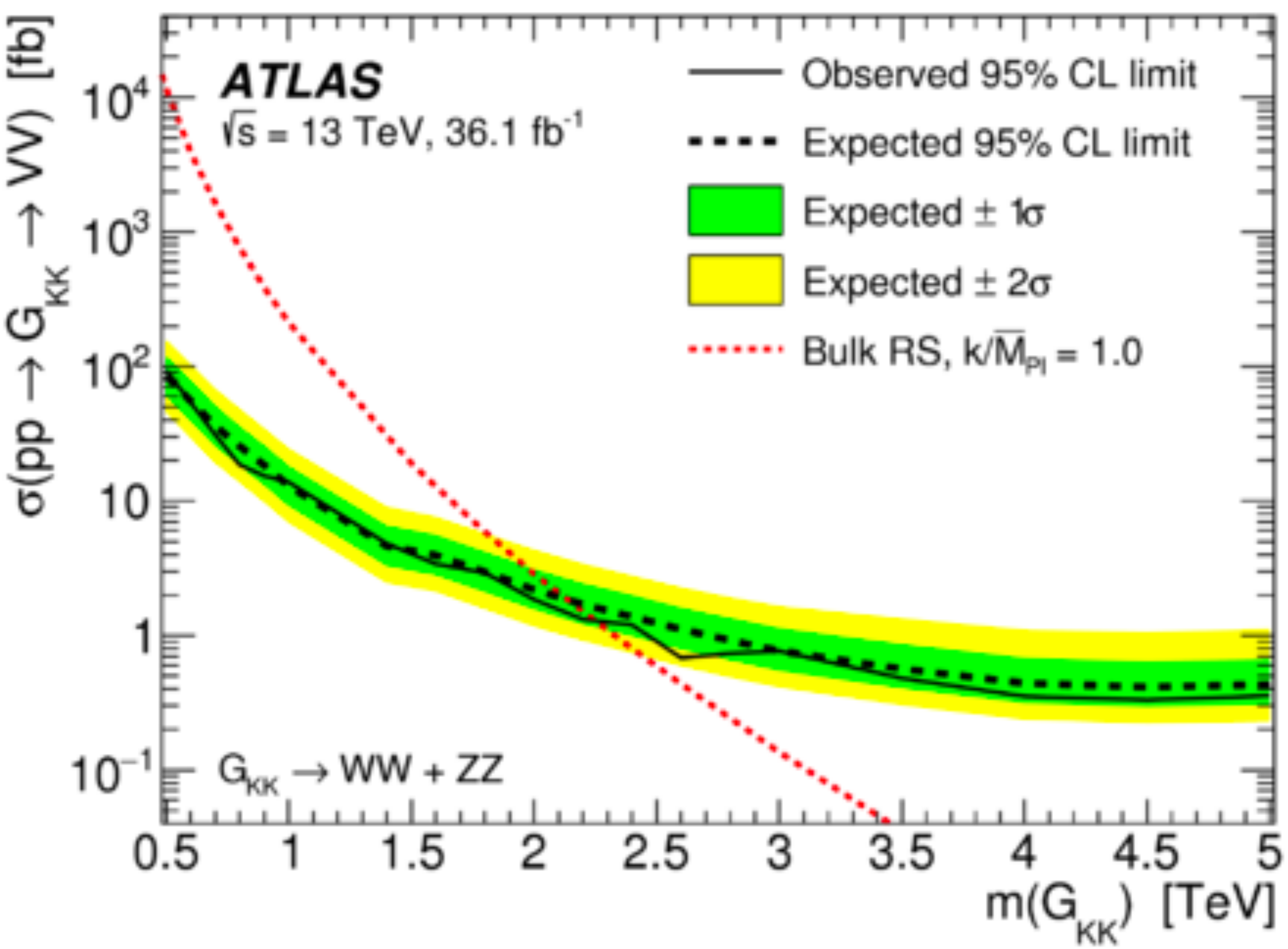




Tomography of the HVT coupling space

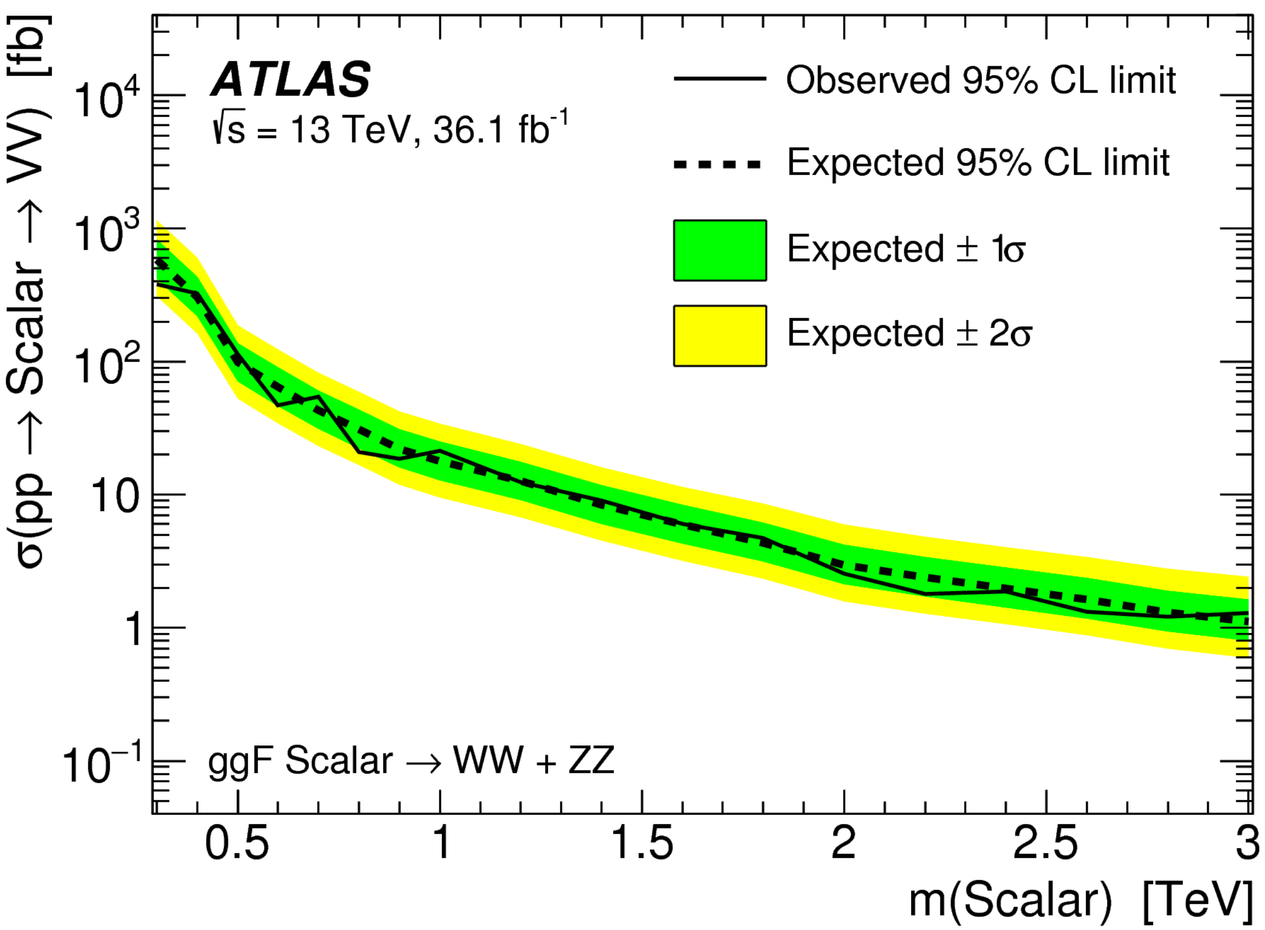


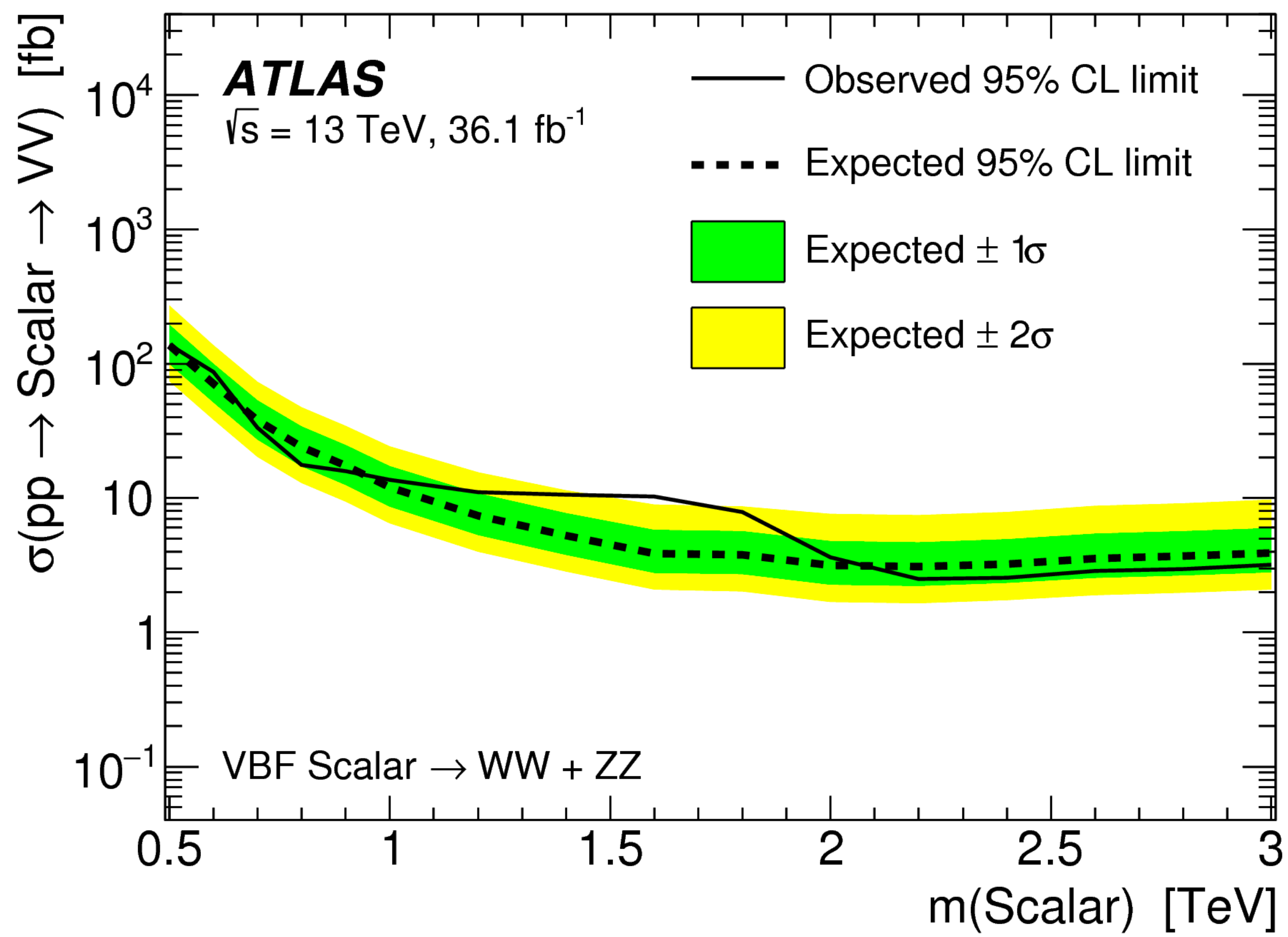
Gravitons



ATLAS
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
Observed 95% CL limit
Expected 95% CL limit
Expected ± 1σ
Expected ± 2σ
Bulk RS, $k/\overline{M}_{Pl}$ = 1.0
$G_{KK} \rightarrow WW + ZZ$
$\sigma(pp \rightarrow G_{KK} \rightarrow VV)$ [fb]
10^4
10^3
10^2
10
1
10^{-1}
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
$m(G_{KK})$ [TeV]

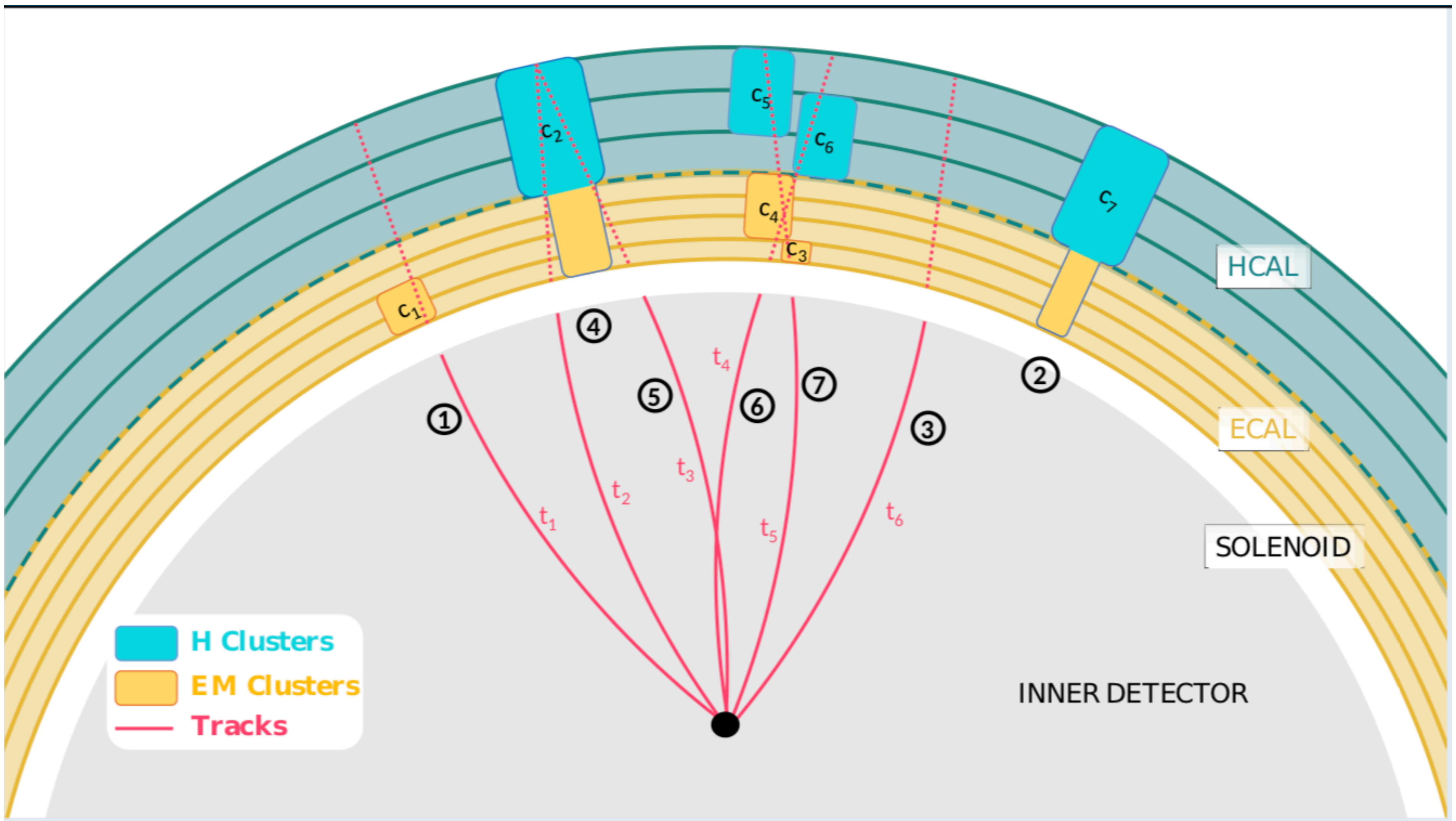
Scalars


ATLAS
√s = 13 TeV, 36.1 fb-1
Observed 95% CL limit
Expected 95% CL limit
Expected ± 1σ
Expected ± 2σ
ggF Scalar → WW + ZZ
σ(pp → Scalar → VV) [fb]
m(Scalar) [TeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Observed 95% CL limit
Expected 95% CL limit
Expected ± 1σ
Expected ± 2σ
VBF Scalar → WW + ZZ
σ(pp → Scalar → VV) [fb]
m(Scalar) [TeV]

Search for VV in fully hadronic final states with 139/fb

- Main improvement in sensitivity with respect to previous versions is due to improvements in the jets
-



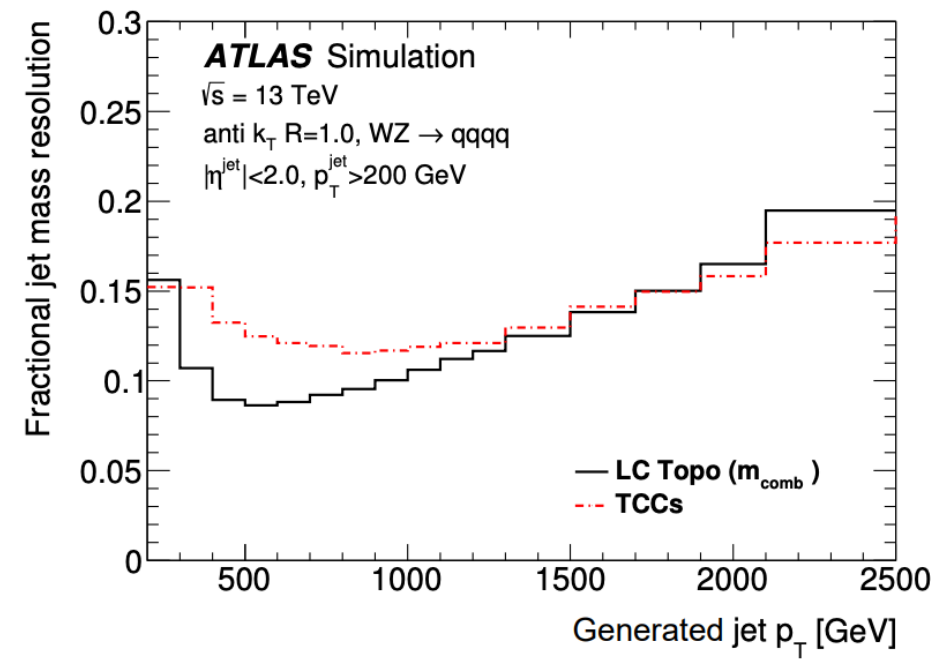
- - Multiple clusters may match a track - each cluster contributes according to its pT fraction in all clusters matching
- - Multiple tracks may match a cluster - so contribution of the cluster to a TCC is according to the relative pT fraction of a track
- - Contribution of a track to a cluster is weighed according to the fraction of all clusters matching the track

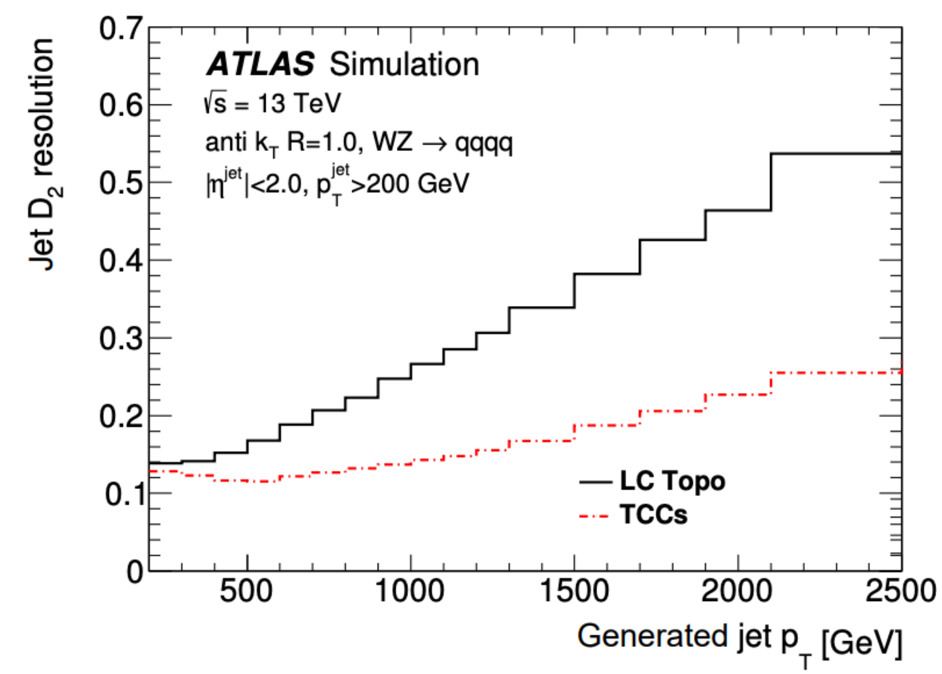
Event Selection

- Events are recorded with unprescaled high-pT jet triggers that are fully efficient in the signal region considered
- As in previous versions of the search, reject t-channel background by minimum requirement in pseudo-rapidity difference between jets $|\Delta y_{12}| < 1.2.$
- Events with badly reconstructed jets are rejected by requiring a balanced event $A = (p_{T1} - p_{T2}) / (p_{T1} + p_{T2}) < 0.15$

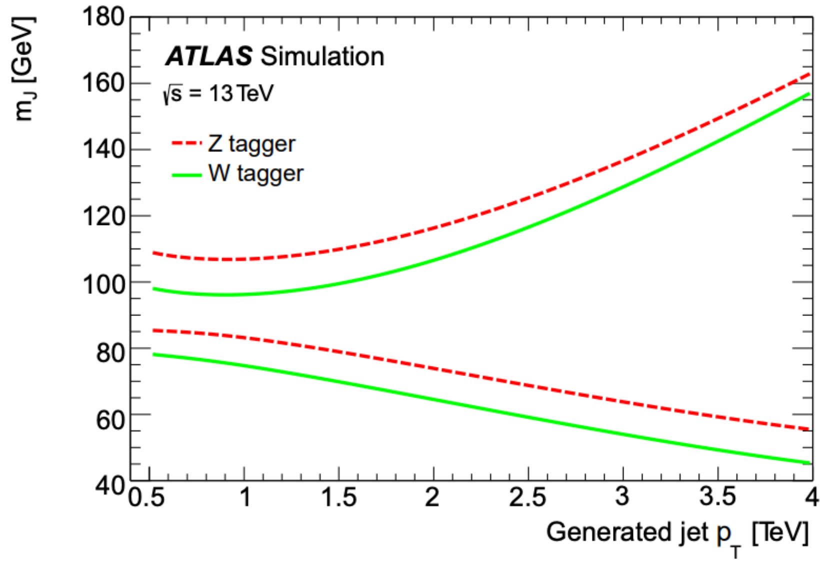
Boson Tagging - variables

- Based on three variables Mjet, D2 and n_{trk}
  - TCC inputs give huge improvement on the D2 resolution
- Optimization to maximize on significance
- n_{trk} - targeting larger number of tracks in background jets due to gluon/larger energy scale

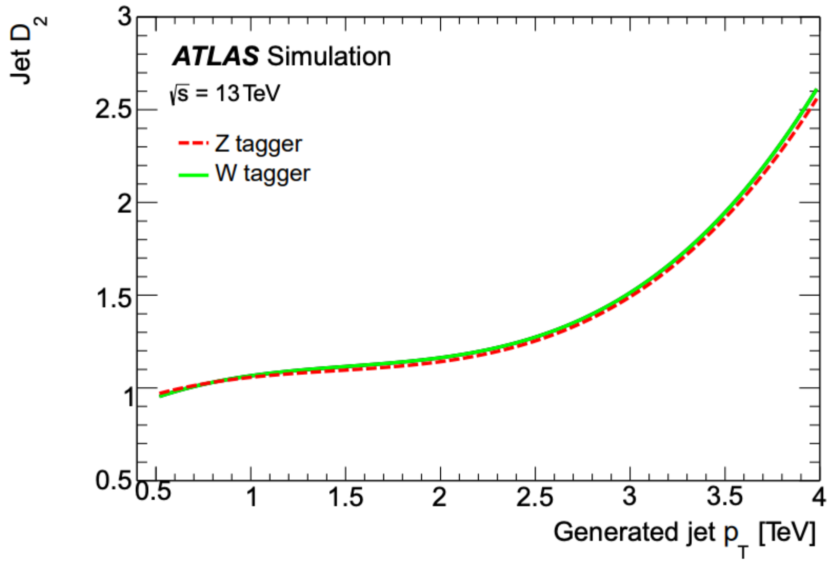




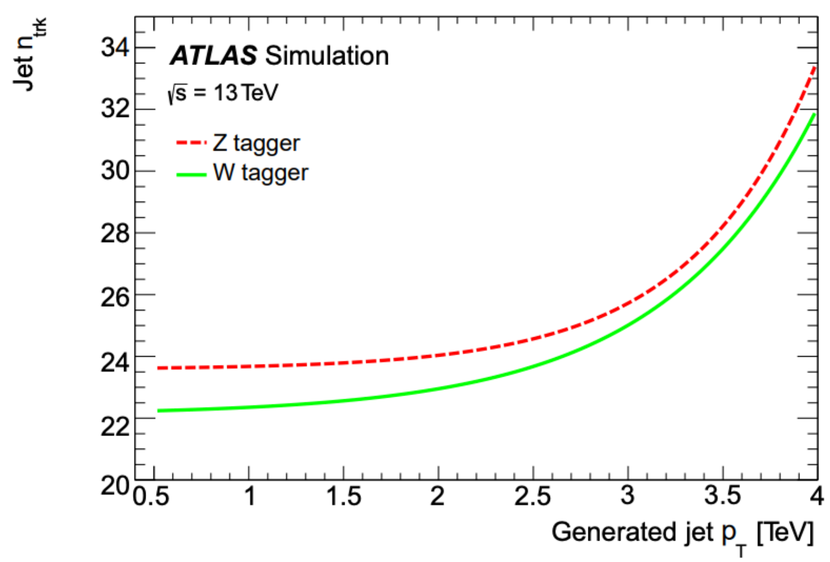
Boson tagging - selection



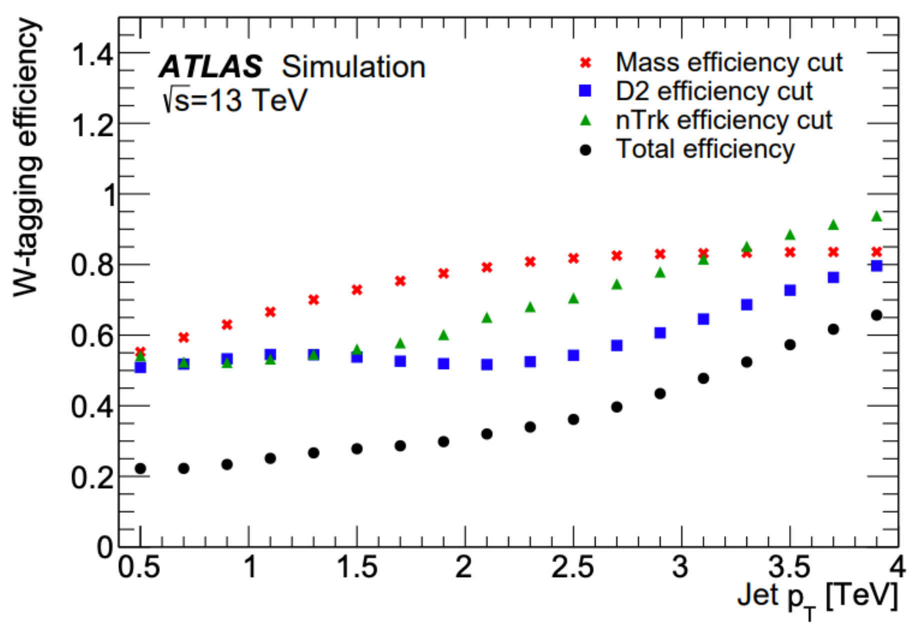
(a)



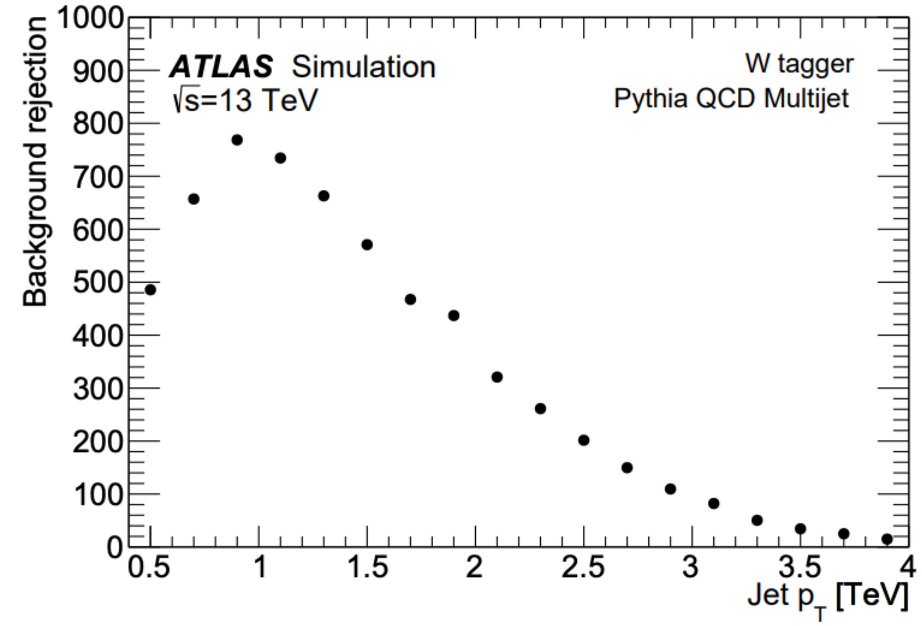
(b)



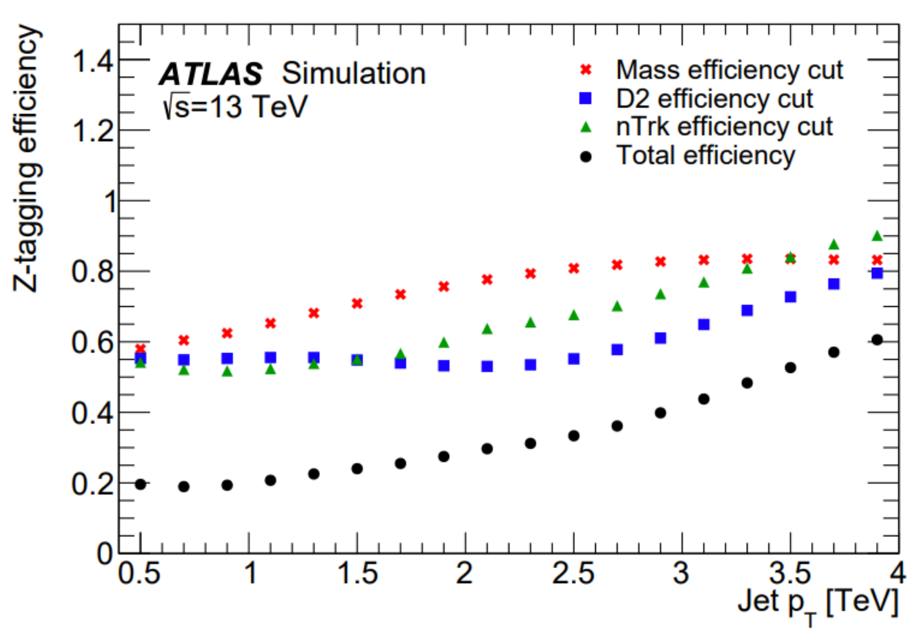
Boson Tagging - Performance



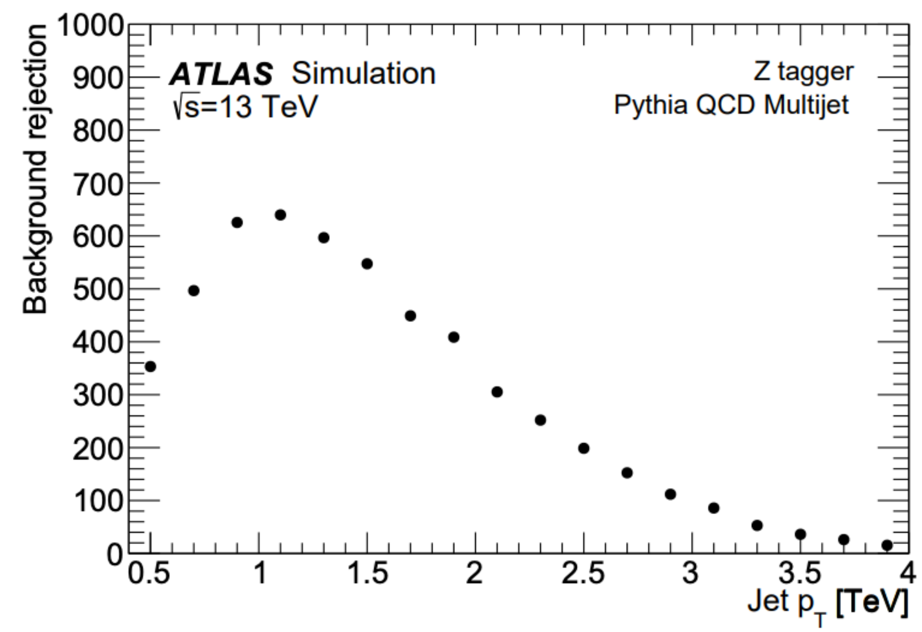
(a)



(b)



(c)



(d)

Control measurement for Tagging efficiency

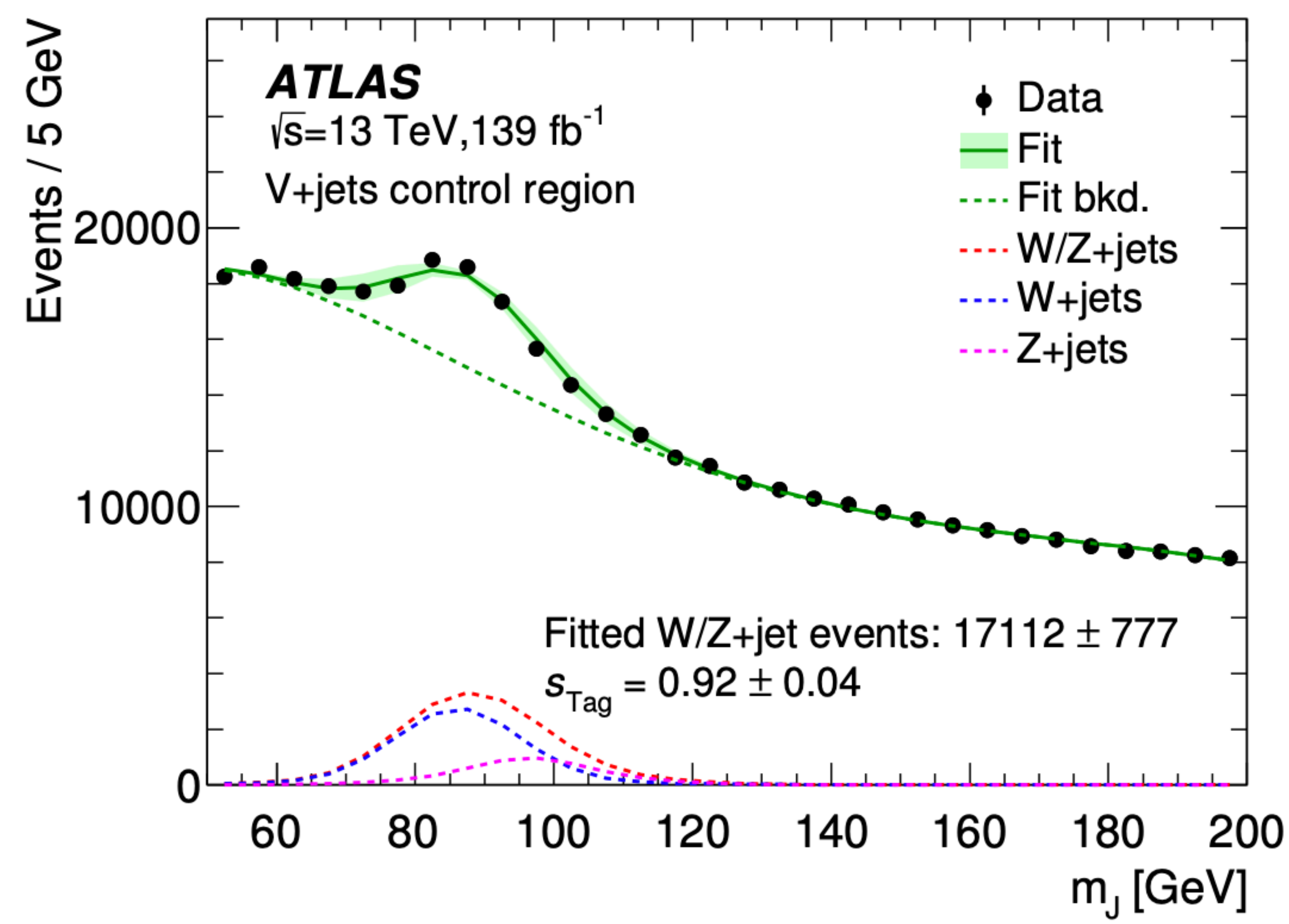
Modeling of the tagging efficiency is evaluated in a control sample of V+jets

- One jet passes the D2 and n_{trk} selection
- Second jet is anti-tagged

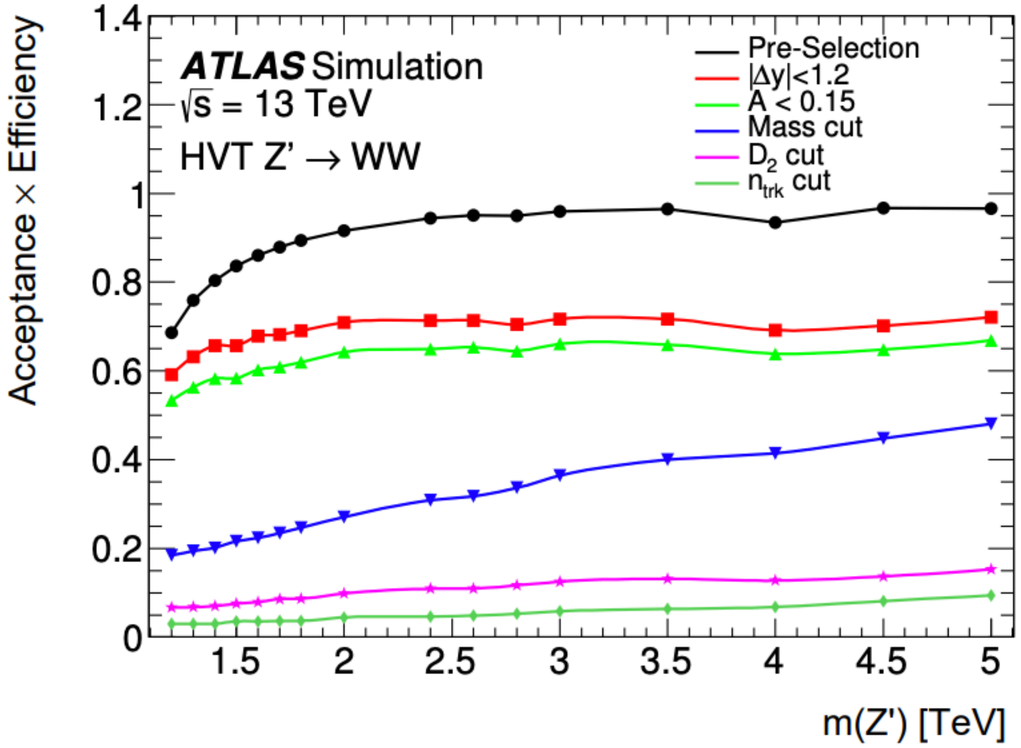
Mass distribution from 50-200 GeV is fit with S+B model

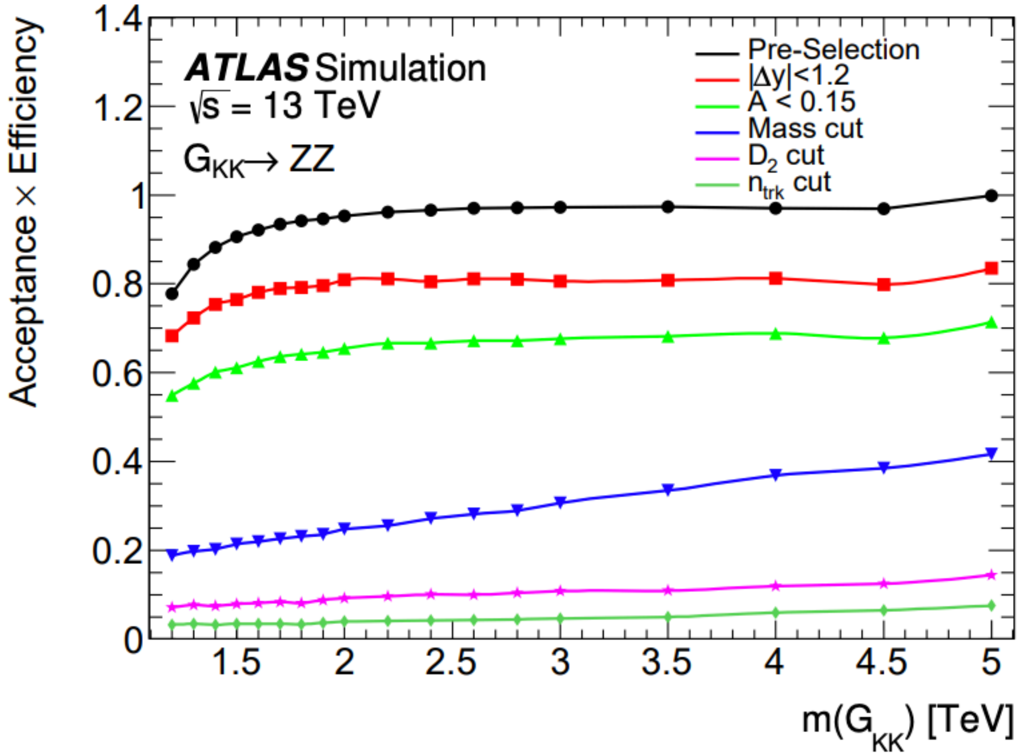
Fit extracts overall yield, width and mean of W/Z is taken from MC shapes

JMS uncertainty is checked by varying the position of the W/Z peak and checking the impact on the signal yield - found to be negligible



Overall signal efficiencies





Background estimation

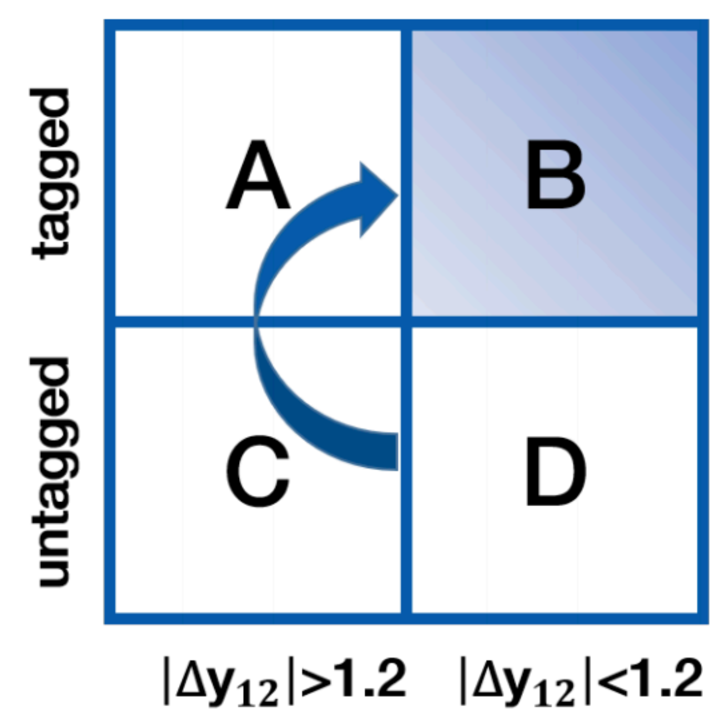
- Parametric fit of the background to avoid limitations of poor modeling or insufficient MC

$$\frac{\mathrm{d}n}{\mathrm{d}x} = p_1(1-x)^{p_2 - \xi p_3} x^{-p_3}$$

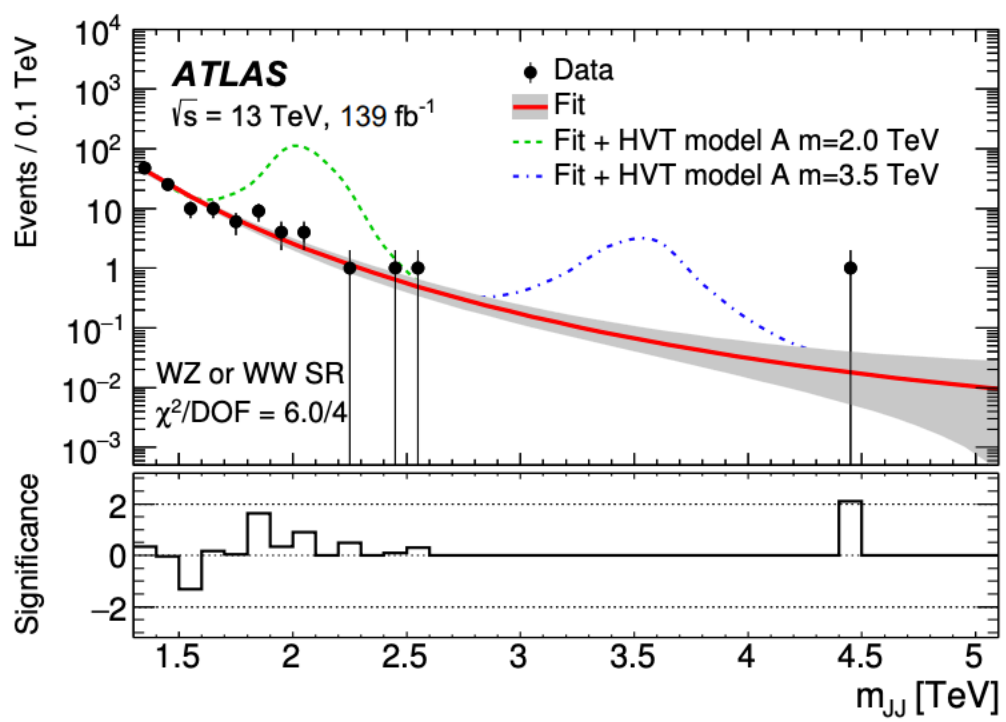
- Required model complexity is assessed using a Wilks test

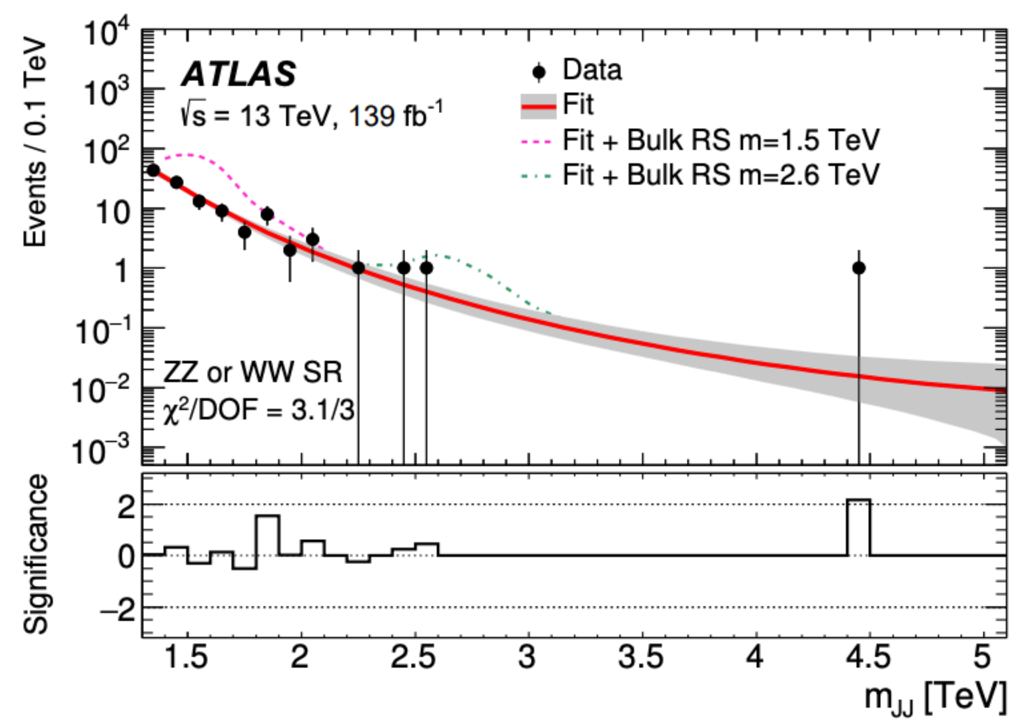
- Adequate modeling of the parametric shape is tested using control regions

- Background uncertainty driven by fit uncertainty

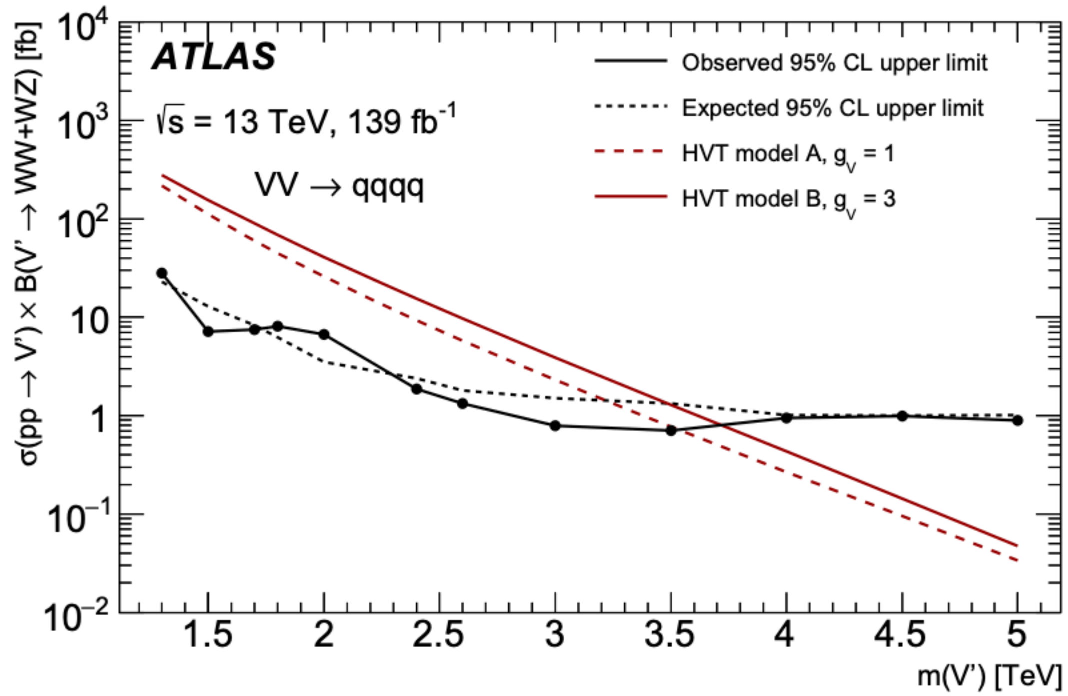


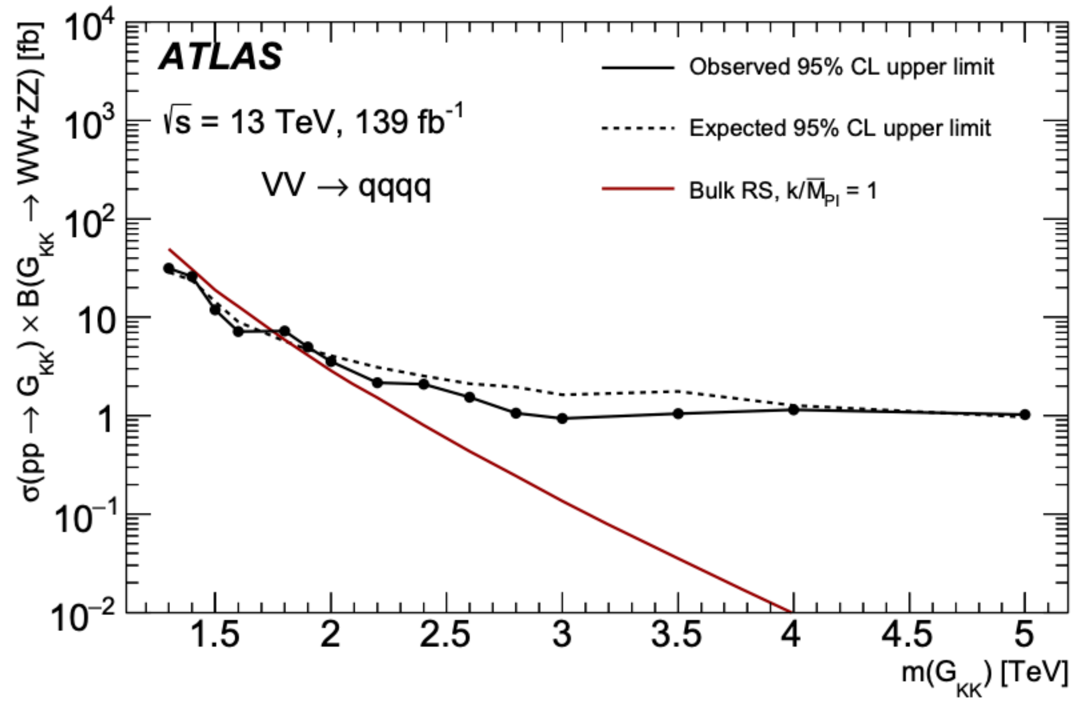
Results


ATLAS
√s = 13 TeV, 139 fb-1
Data
Fit
Fit + HVT model A m=2.0 TeV
Fit + HVT model A m=3.5 TeV
WZ or WW SR
χ2/DOF = 6.0/4
Events / 0.1 TeV
Significance
mJJ [TeV]


ATLAS
√s = 13 TeV, 139 fb-1
Data
Fit
Fit + Bulk RS m=1.5 TeV
Fit + Bulk RS m=2.6 TeV
ZZ or WW SR
χ2/DOF = 3.1/3
Events / 0.1 TeV
Significance
mJJ [TeV]

Bounds


ATLAS
√s = 13 TeV, 139 fb⁻¹
VV → qqqq
Observed 95% CL upper limit
Expected 95% CL upper limit
HVT model A, g_V = 1
HVT model B, g_V = 3
σ(pp → V') × B(V' → WW+WZ) [fb]
m(V') [TeV]


ATLAS
√s = 13 TeV, 139 fb⁻¹
VV → qqqq
Observed 95% CL upper limit
Expected 95% CL upper limit
Bulk RS, k/M̄_Pl = 1
σ(pp → G_KK) × B(G_KK → WW+ZZ) [fb]
m(G_KK) [TeV]

Summary

- Many extensions to the Standard Model predict new resonances in the TeV range that decay to boson pairs
- Unfortunately - we have not observed any evidence of such resonances
- At high masses the sensitivity to these resonances is driven by our ability to tag hadronic decays of jets
- ATLAS combination of 9 searches - gives a very complete picture on the experimental bounds on these heavy resonances at 36/fb
- At very high-masses the use of TCC results in impressive improvements to the boson tagging performance
- The Run-2 (139/fb) Fully hadronic search
    - No evidence for heavy resonances