The Quest for phenomena Beyond the Standard Model at ATLAS

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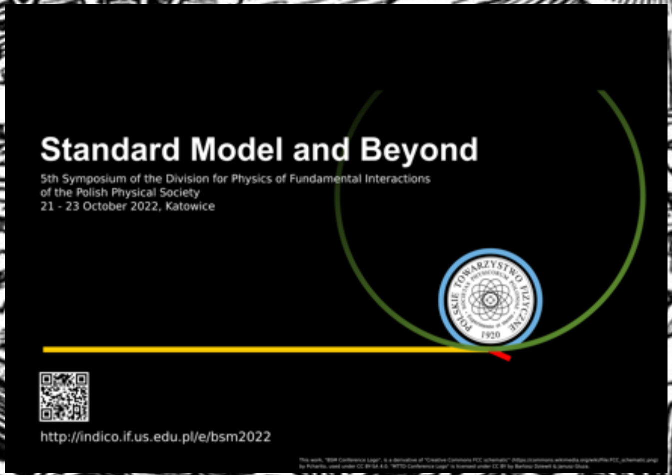
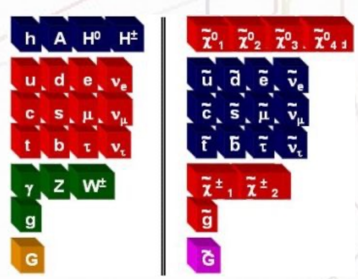


Thanks to Greg Landsberg for his lectures and healthy approach to BSM searches

How to find a black cat in a dark room
Especially when there is no cat

- Quest for new physics is not for wimps
  - A lot of searches performed by ATLAS so far, and all came empty-handed
  - A likelihood for any given search to find something interesting seems to be very small…
  - … yet, the only way to find something is to keep looking!
- And we are quite well motivated

- The SM is our best tool to understand nature but it's not the ultimate one!
  - Hierarchy problem? Dark matter? Neutrino masses? Matter/anti-matter asymmetry….
  - Tention from SM predictions in B-physics measurements, muon g-2 anomaly etc.
- Shift of paradigm: from seraches of the highest masses, and low background to searches experimentally challenging, with low couplings, low masses etc.
- This talk will present **a few** of the most recent ATLAS results from the full Run-II data



Extended scalar sector

- So far Higgs boson (125) looks like from SM, but consistent with SM ≠ incompatible with BSM

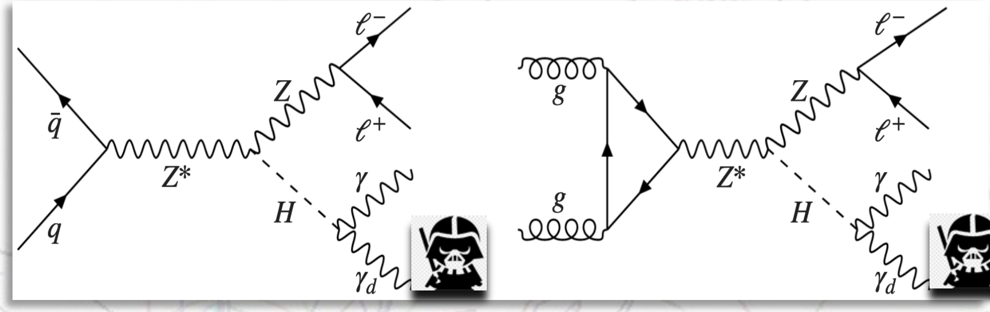
- Extended scalar sector appears in many extensions of the SM (e.g. SUSY)
- They allow for SM-like light Higgs phenomenology and bring additional Higgs bosons
- Searches often interpreted in the contest of 2HDM (MSSM)
- Rich phenomenology and final states -> also exotic Higgs decays
- Wide range of tested masses

SM Higgs doublet + Additional Field	=	Additional Higgs Bosons
EWS: Additional EW Singlet Model SM + one scaler EW singlet	=	Neutral CP Even: h, H
2HDM: Two Higgs Doublet Model SM + another Higgs doublet (MSSM)	=	Neutral CP Even: h, H; CP Odd: A; Charged: $H^{\pm}$
2HDM + Singlet (complex) Model SM + doublet & singlet (NMSSM)	=	Neutral CP Even: s; CP Odd: a; + 2HDM Higgses
Higgs Triplet Model SM + triplet	=	Double Charged: $H^{\pm\pm}$; + 2HDM Higgses

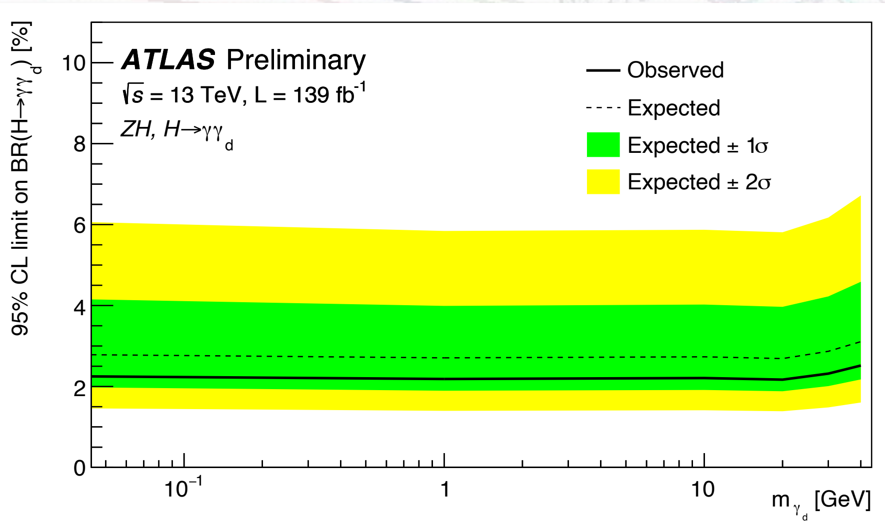
courtesy of N. Ilic

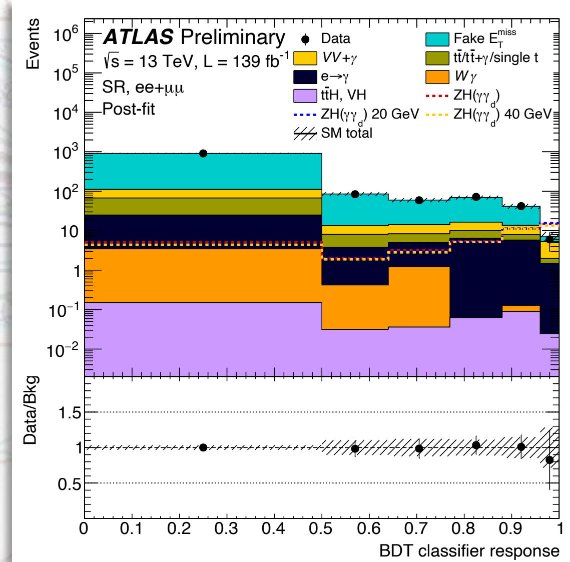
Dark photons from Higgs boson decays via ZH production

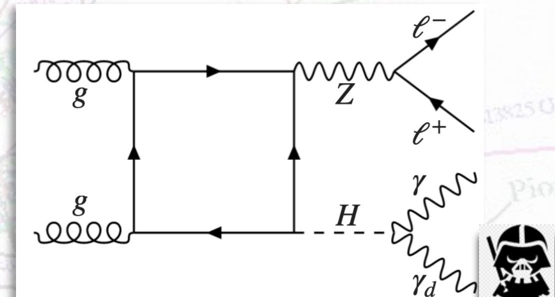
ATLAS-CONF-2022-064



- Dark photon: predicted in hidden-sector models with an unbroken dark U(1) gauge symmetry
- Model independent analysis
- Clean final state: $l^+l^-\ \gamma\ \gamma_{dark}$ (MET)
- Massless and light dark-photon (up to 40 GeV)







The BDT classifier output is used as discriminant for the final statistical analysis

$\sigma_{E_T^{miss}}$, $m_T(p_T^{\gamma}, E_T^{miss})$, $m_{\ell\ell}$, $m_{\ell\ell\gamma}$, p_T^{γ}, $\frac{|E_T^{miss}+\vec{p}_T^{\,\gamma}|-p_T^{\ell\ell}}{p_T^{\ell\ell}}$

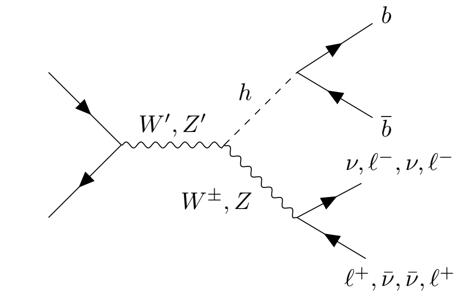
- No excess observed, limit set on BR($H\to\gamma\gamma_{dark}$)
- For massless γ_{dark}, BR($H\to\gamma\gamma_{dark}$) of 2.28% at 95% CL

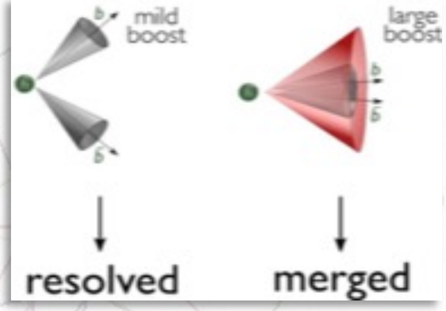
Improvement by factor 2 wrt previous (CMS) result

Heavy resonances into Z/W and Higgs boson in final states with leptons and b-jets

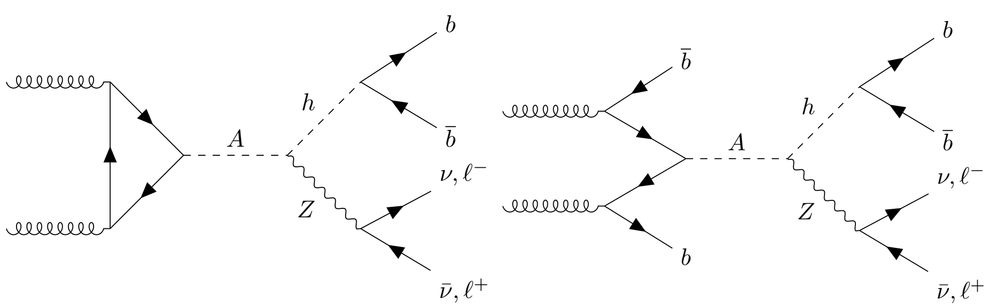
arXiv:2207.00230

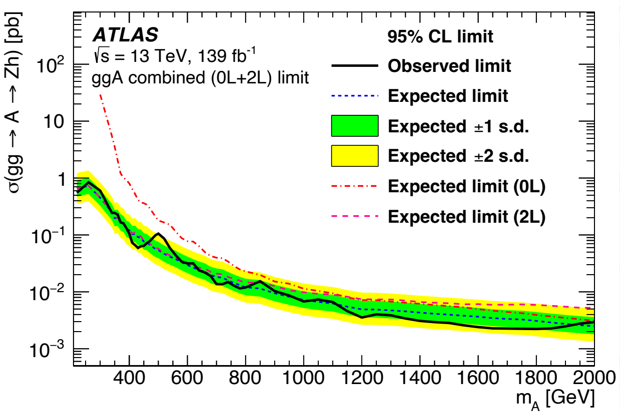
- Search for heavy pseudoscalar A or new vector boson decaying to Z/W boson and SM Higgs
  - Heavy Vector Triplet W′/Z′
  - Generic 2HDM
- Resonance mass tested: 220 GeV – 2(A)/5 (W′,Z′) TeV

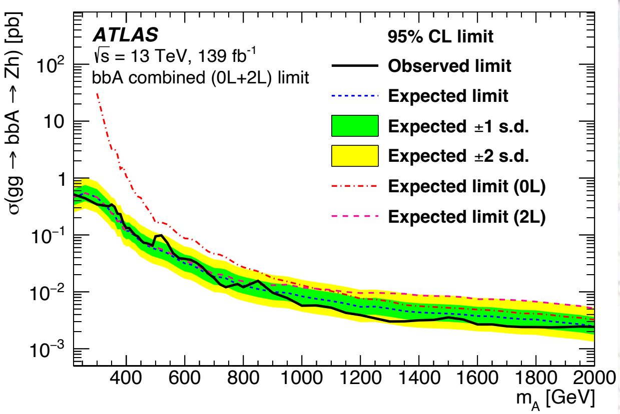


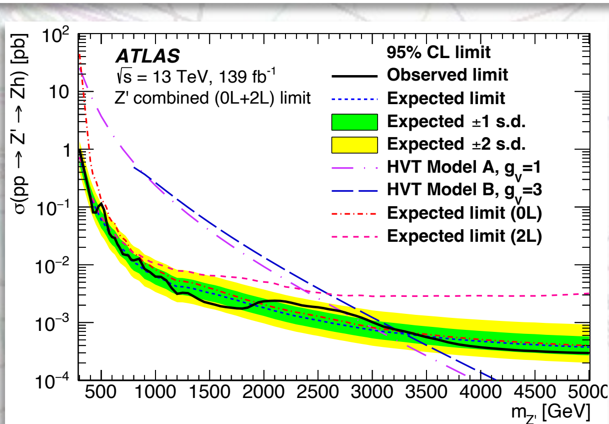


- Signal regions according to 0L/1L/2L and b-jet multiplicity
- Two event categories depending on p_T^h: resolved and merged



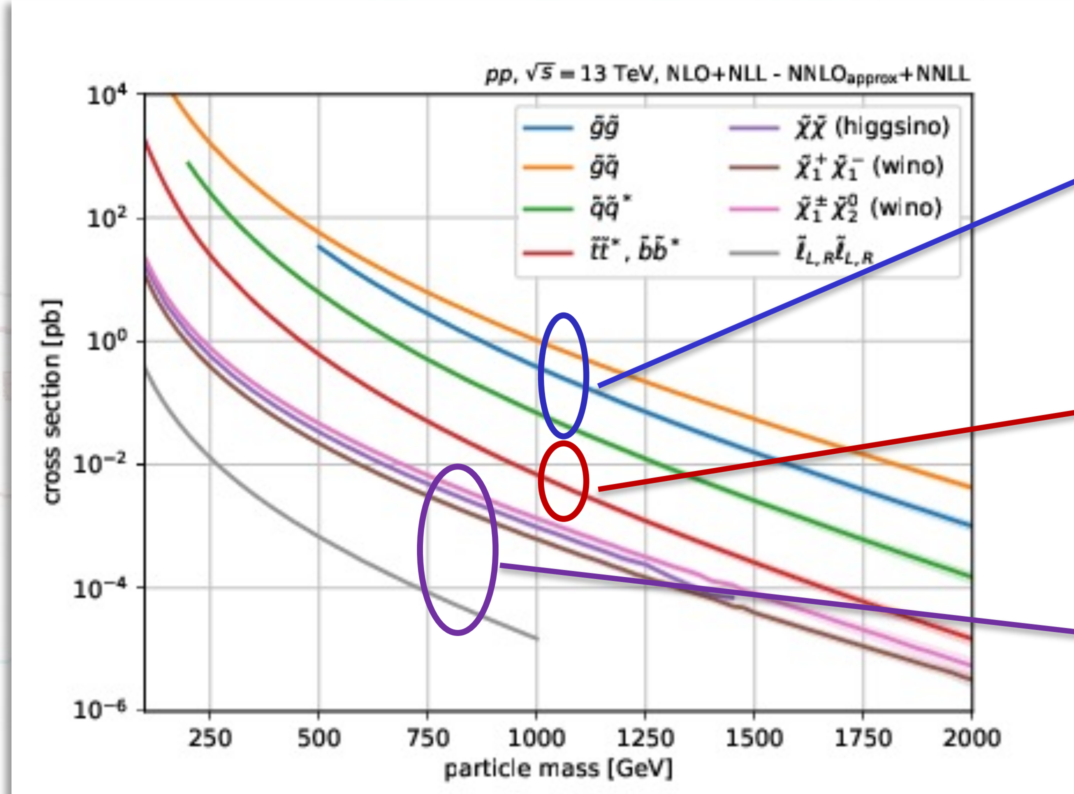






- No significant excess observed
- Largest deviation from the SM expectation found at 500 GeV in ggA and Z′, corresponding to significance of 2.1σ (1.1 σ) local (global) (1.6 σ local for bbA)

SUSY searches strategy



Strong production
- **Copious production**
- **Large MET in final state**

Third-generation sparticles
- Naturalness -> mass of ~O(TeV)
- Lighter than other squarks

Electroweak production
- Coloured spartners too heavy
- Direct gaugino/higgsino/slepton production

R-parity conservation vs RP violation
- RPC – large MET from weakly interacting LSPs
- RPV - more leptons/jets and less or no MET
- RPV – prompt or delayed LSP decay

Long lived/metastable sparticles
- Supressed (effective) coupling
- Lack of phase space, e.g.mass degeneraces (compressed searches)
- May induce non-trivial signals in detectors
  - displaced vertices
  - disappearing tracks etc.

Same-sign 2L/3L from direct production of winos and higgsinos

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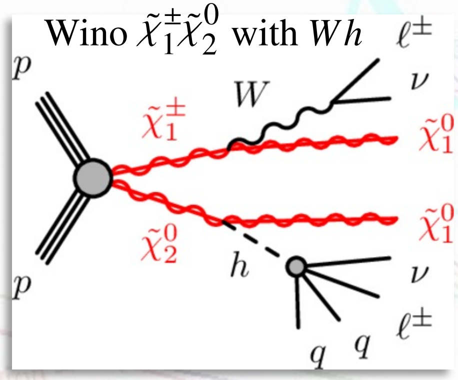
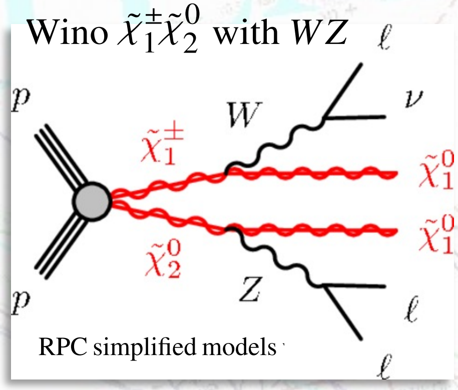
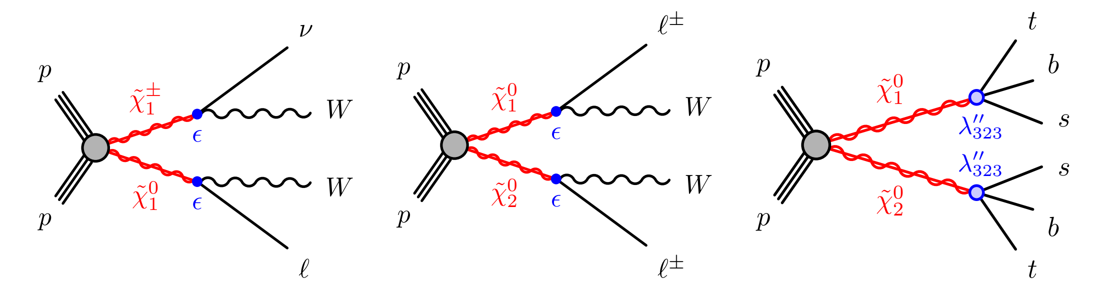


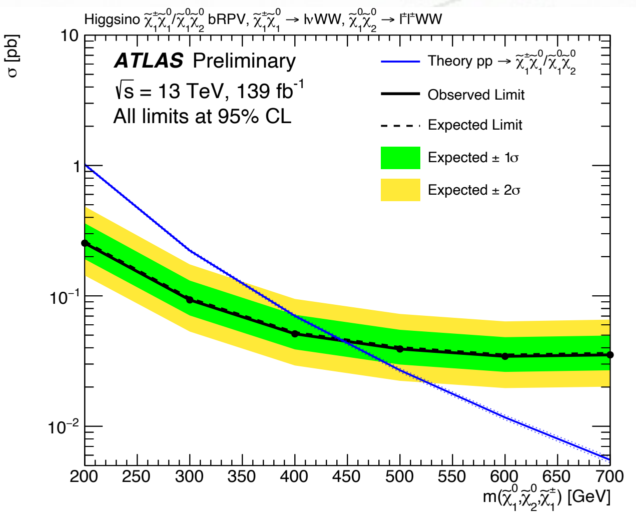


- Direct production of winos and higgsinos in final states with 2L SS (e/μ) or 3L
- Models with and without R-parity conservation, and with different RPV origin (L or B violating terms)



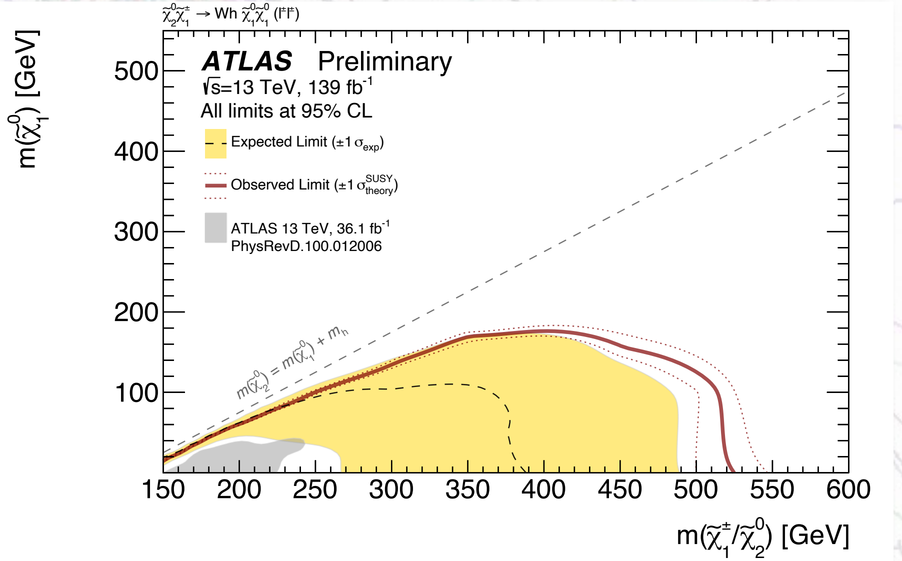
(a) Higgsino $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^0$ bRPV (b) Higgsino $\tilde{\chi}_1^0\tilde{\chi}_2^0$ bRPV (c) Higgsino $\tilde{\chi}_1^0\tilde{\chi}_2^0$ UDD RPV

- No deviations from SM predictions were observed
- For intermediate states including Wh (WZ), wino masses up to 525 GeV (260 GeV) are excluded, for a bino of vanishing mass



Higgsino masses smaller than 440 GeV are excluded in bRPV

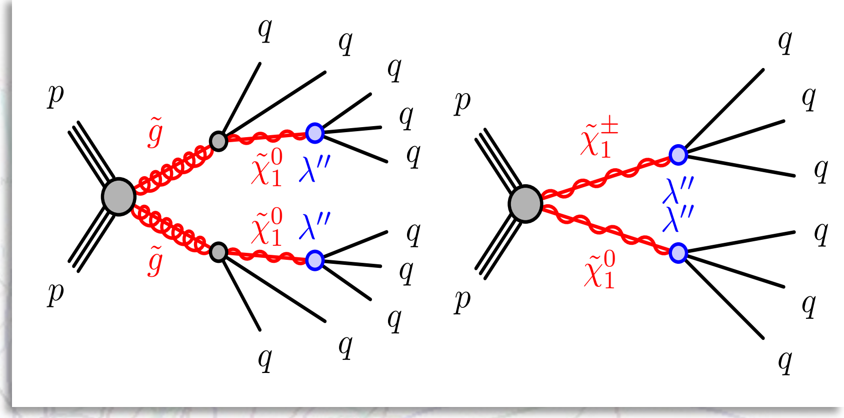
First experimental constraint on bRPV models with degenerate higgsino masses.



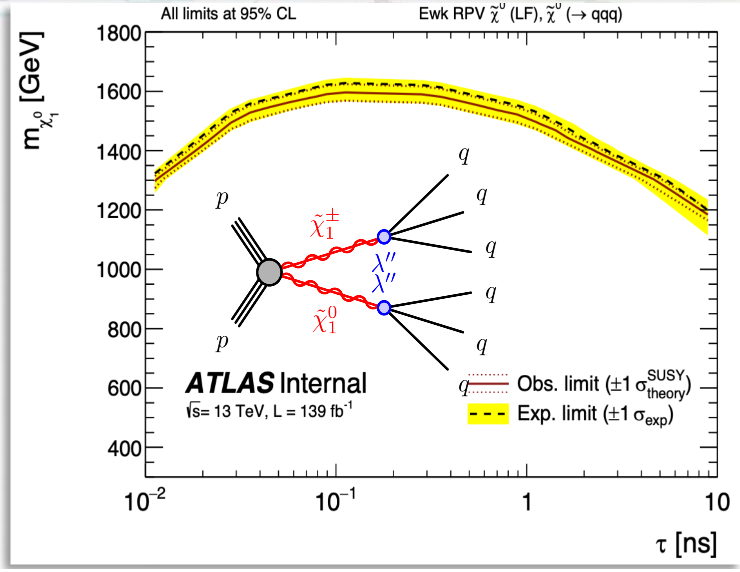
Displaced vertices + jets

ATLAS-CONF-2022-054

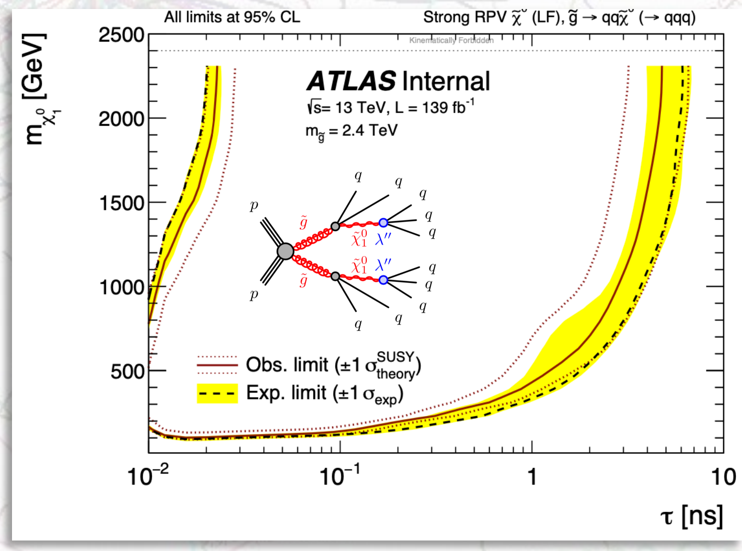
- General search for heavy LLPs decaying in hadrons
  - B-number violating RPV, gaugino->qqq
  - Lifetime O(10) ns – decaying in the ID **creating displaced verices (DV) with high mass and large track multiplicity**
- DV reconstruction possible up to 300 mm thanks to dedicted track reconstruction – Large Radius Tracking
  - Uses left-over hits after standard tracking with looser impact parameters constrains
- Dedicated secondary-vertex reconstruction algorithm
- Nearly background-free search
  - Small backgrounds from hadronic interactions and instrumental effects



Signal Region	Observed	Expected
High-p_T jet SR	1	$0.46^{+0.27}_{-0.30}$
Trackless jet SR	0	$0.83^{+0.51}_{-0.53}$



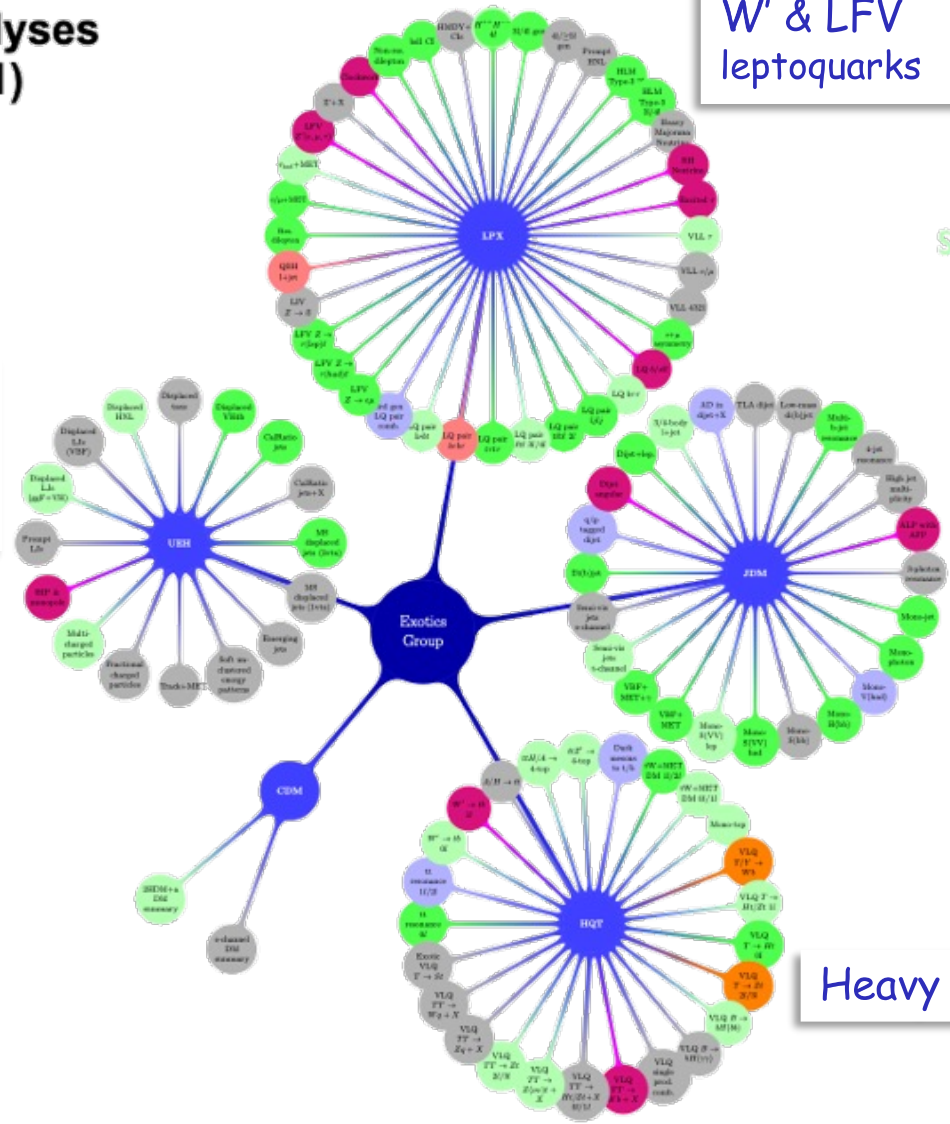
Observed limit above 1.5 TeV for lifetimes between 0.03 ns and 1 ns



Stronger limits in strong production model

Exotics (non-SUSY)

Full Run 2 analyses (Release 21)



Leptons, Z', W' & LFV leptoquarks

Unconventional signatures & Exotic Higgs

Jets & Dark Matter

Heavy Quarks & Tops

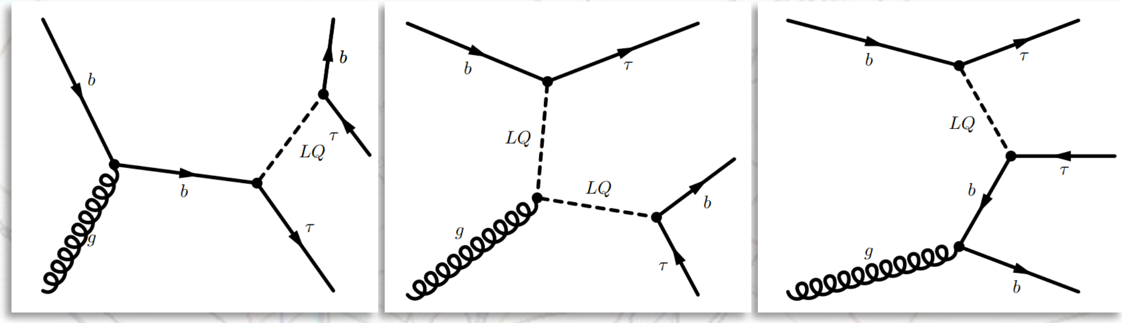
September 2022

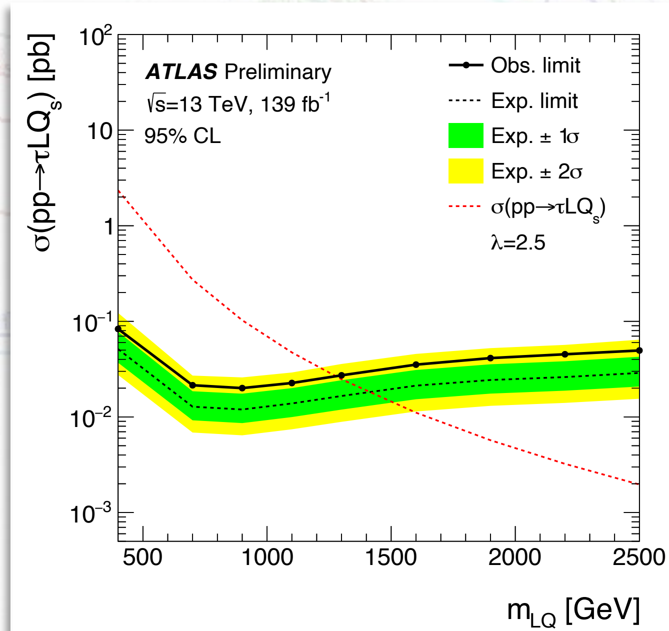
Kicked-off
With EB
In SG approval
In group approval
ATLAS circulation
Submitted / CONF-conv
Accepted / Published

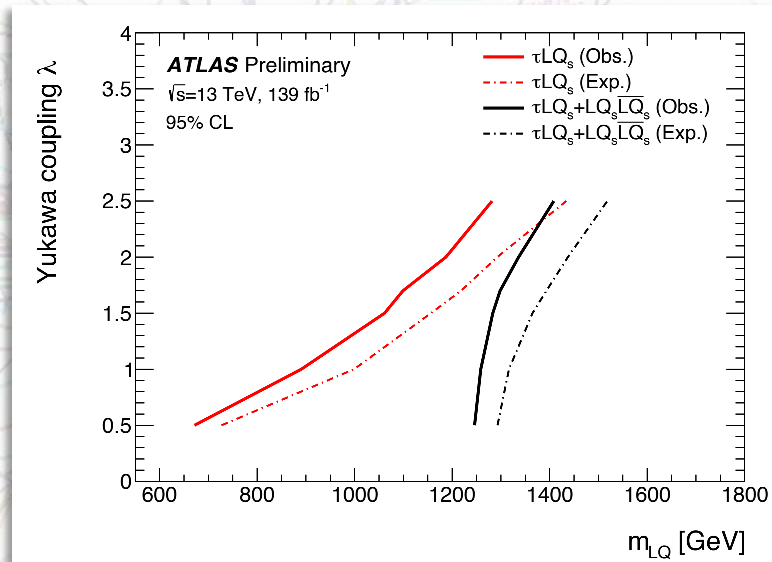
Scalar leptoquarks in bττ final state

ATLAS-CONF-2022-037

- Single scalar leptoquark production model (+4/3*e*, F=3*B* + *L* = −2)
- Decays into 3rd generation: *b*τ
- First ATLAS result for such a search
- m_{LQ} 0.4-2.4 TeV, λ 0.5-2.5







No excess:

m(*LQ*) < 1.26 TeV, 1.30 TeV and 1.41 TeV are excluded for Yukawa coupling to *b*τ of 1.0, 1.7 and 2.5, respectively

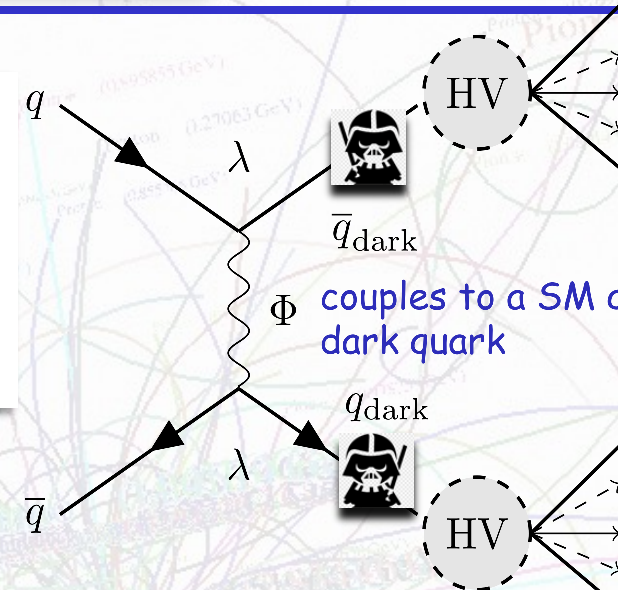
For the chosen LQ model, masses below 1.25 TeV are excluded for all λ above 0.5.

CMS excess in similar analysis CMS-PAS-EXO-19-016 => 3.4σ for LQ mass of 2 TeV and λ =2.5 but including t-channel

Semi-visible jets, t-channel

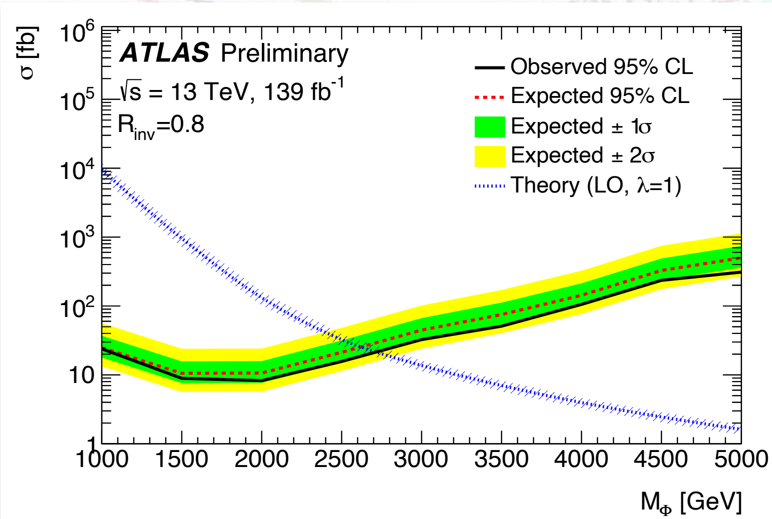
ATLAS-CONF-2022-038

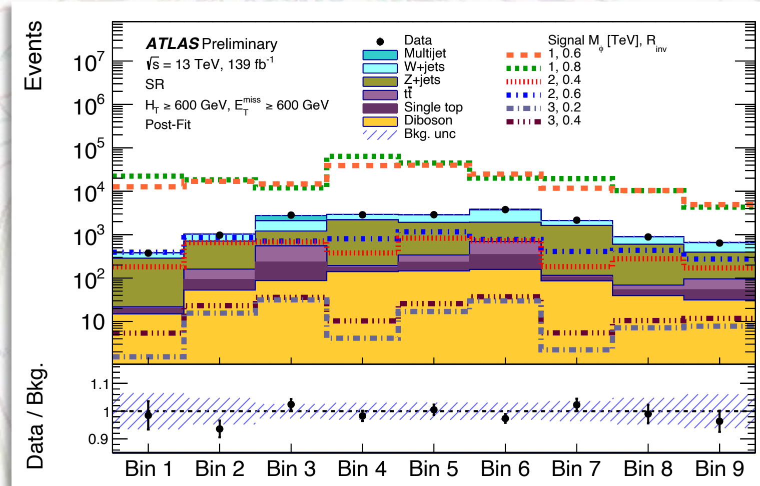
- Semi-visible jets in strongly-interacting dark sectors
- First for both experiments in t-channel (non-resonant)
- The ratio of the rate of stable dark hadrons over the total number of hadrons in the event => R_{inv} (free parameter of the model)
- Reconstructed jets geometrically encompassing the dark hadrons => semi-visible jets (SVJ)



Φ couples to a SM quark and a dark quark

final state consisting of SM hadrons and dark hadrons, governed by the R_{inv} fraction





- The first limits on the SVJ t-channel production for mediator masses ranging from 1000–5000 GeV, and for R_{inv} of 0.2–0.8.
- The observed limits increase from 2.4 TeV for R_{inv} = 0.2 to 2.7 TeV for R_{inv} = 0.8

Summary

- Several highlights presented from a broad ATLAS program searching for Physics Beyond the Standard Model:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HDBSPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

- No large deviations from Standard Model observed yet
- A lot of interesting results obtained with Run2 data, more to come
- Looking forward to taking more data with Run3 that recently started
- A discovery could be around the corner!

Beyond the Standard Slides

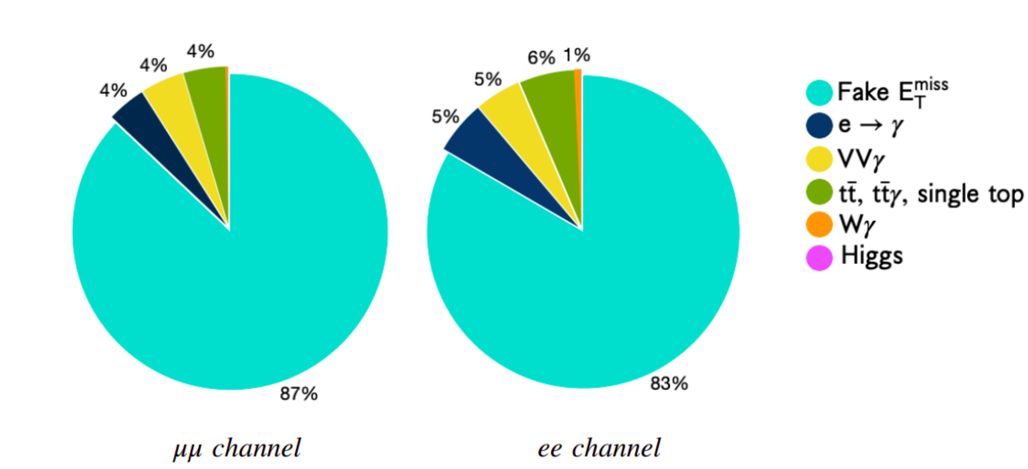
Courtesy of J. Keller

Dark photons from Higgs boson decays via ZH production

ATLAS-CONF-2022-064

Table 3: Optimised kinematic selections defining the signal region for $\ell^+\ell^-\gamma+E_T^{miss}$.

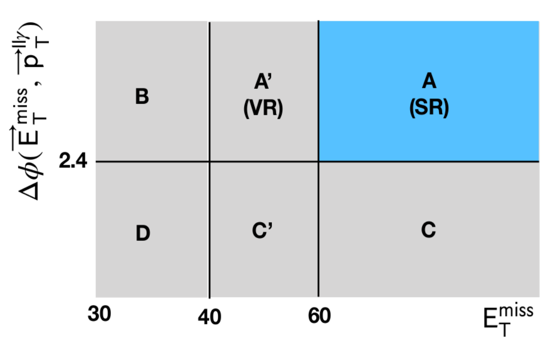
Two same flavour, opposite sign, medium ID and loose isolated leptons, with leading $p_T > 27$ GeV, sub-leading $p_T > 20$ GeV
Veto events with additional lepton(s) with loose ID and $p_T > 10$ GeV
76 GeV $< m_{\ell\ell} <$ 116 GeV
Only one tight ID, tight isolated photon with $E_T^{\gamma} > 25$ GeV
$E_T^{miss} > 60$ GeV with $\Delta\phi(\vec{E}_T^{miss}, \vec{p}_T^{\,\ell\ell\gamma}) > 2.4$ rad
$m_{\ell\ell\gamma} > 100$ GeV
$N_{jet} \leq 2$, with $p_T^{jet} > 30$ GeV, $\lvert\eta\rvert < 4.5$
Veto events with b-jet(s)



- **ABCD method**, based on E_T^{miss} and $\Delta\phi(\vec{E}_T^{miss}, \vec{p}_T^{\,\ell\ell\gamma})$ variables:

$$N_A^{fakeMET} = R\frac{N_B N_C}{N_D} \quad , \quad R = \frac{N^{MC}_{A+A'} N^{MC}_D}{N^{MC}_{C+C'} N^{MC}_B}$$

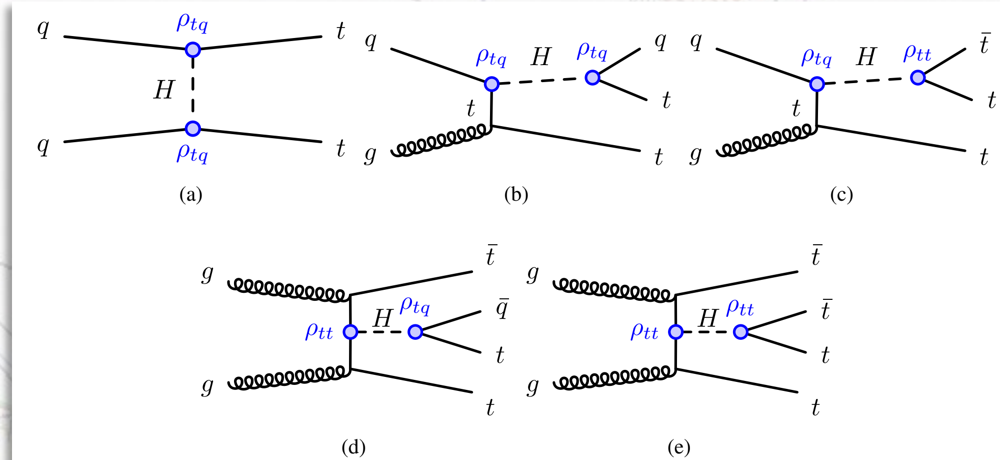
  - R takes into account possible correlation between the 2 variables
  - N_X is number observed data in region X, after subtraction of the contribution from non fake E_T^{miss} backgrounds



Heavy scalars with FV decays in final states with multiple leptons and b-jets

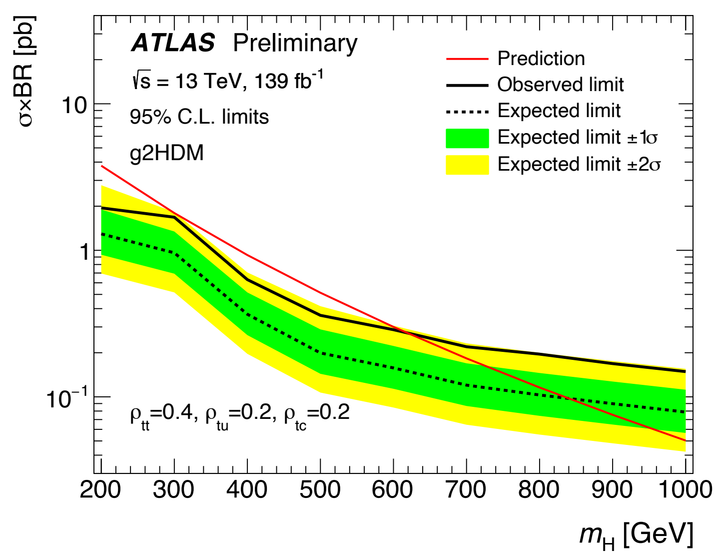
ATLAS-CONF-2022-039

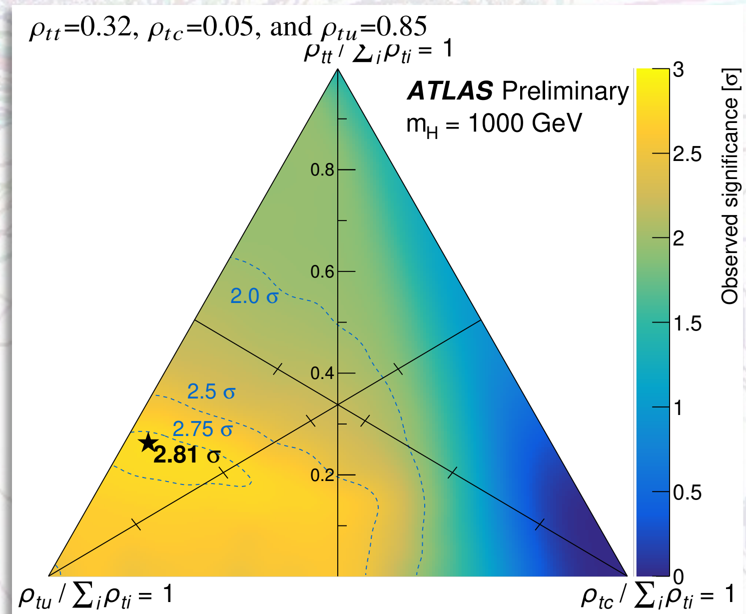
- Search for heavy scalar H from generic 2HDM (interpreted also in RPV SUSY)
- First search targeting BSM 3 top production and first with 2HDM with flavour violation
  - m_H = [200 GeV, 1 TeV]
  - tFCNC vertices allowed with Yukawa-like couplings ρ_{tt}, ρ_{tu}, ρ_{tc}



2lSS, 3l, 4l final states

- 17 Signal Regions (DNN trained to classify the different signal channels) + 10 Control Regions => 27 analysis regions
- DNN trained over each SR region to separate signal and background





Most significant deviation observed at m_H=1000 GeV with local significance of 2.81 σ

Heavy scalars with FV decays in final states with multiple leptons and b-jets

ATLAS-CONF-2022-039

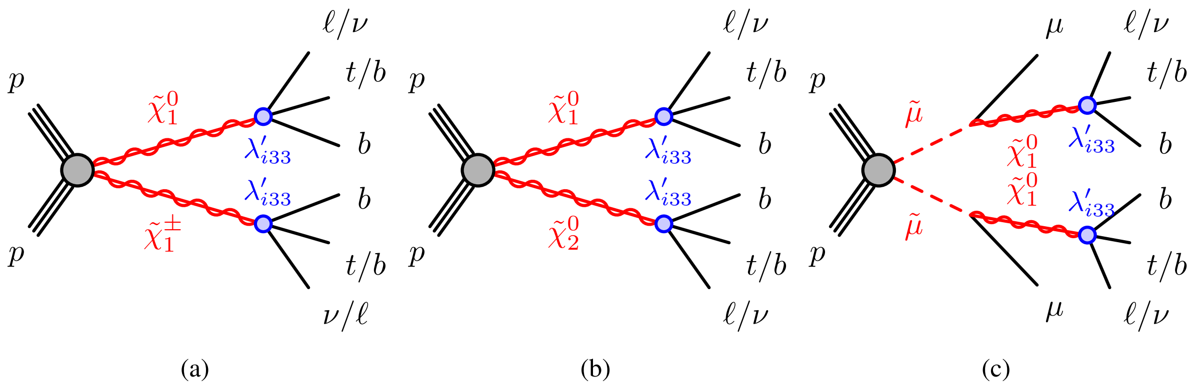


Figure 2: Signal diagrams for the RPV SUSY signals used as additional interpretation in the analysis. The subsequent decay can lead to a final state with high multiplicity of leptons and b-jets which is targeted by the search.

Table 5: Input variables to the training of the DNN^{cat} and DNN^{SB} discriminants.

Variable	DNN^{cat}	DNN^{SB}
Number of jets (N_{jets})	✓	✓
Sum of pseudo-continuous b-tagging scores of jets	✓	✓
Pseudo-continuous b-tagging score of 1st, 2nd, 3rd leading jet in p_{T}	✓	✓
Sum of p_{T} of the jets and leptons ($H_{T,jets}$, $H_{T,lep}$)	✓	✓
Angular distance of leptons (sum in the case of 3ℓ and 4ℓ)	✓	✓
Missing transverse energy	✓	✓
Leading transverse momentum of jet	-	✓
Invariant mass of leading lepton and missing transverse energy	-	✓
Di/tri/quad-lepton type variable (associated to the number of electrons/muons in event)	-	✓

Heavy scalars with FV decays in final states with multiple leptons and b-jets

ATLAS-CONF-2022-039

Table 3: Event selection summary in the signal regions. Leptons are ordered by p_T in the 2ℓSS and 4ℓ regions. In the 3ℓ regions the lepton with opposite-sign charge is taken first, followed by the two same-sign leptons in p_T order. In the lepton selection, *T, M, L* stand for Tight, Medium and Loose lepton definitions. In the region naming, the "CAT ttX" denotes the category based on the DNN^{cat} output enriched in the signal process "ttX". Each of these regions is split according to the lepton charge of the same-sign lepton pair ("++" or "- -").

Lepton category	2ℓSS	3ℓ	4ℓ
Lepton definition	(T,T) with $\geq 1\ b^{60\%}$ ‖ (T,M) with $\geq 2\ b^{77\%}$	(L,T,M) with $\geq 1\ b^{60\%}$ ‖ (L,M,M) with $\geq 2\ b^{77\%}$	(L,L,L,L)
Lepton p_T [GeV]	(20, 20)	(10, 20, 20)	(10, 10, 10, 10)
$m_{\ell^+\ell^-}^{OS-SF}$ [GeV]	–	>12	
$\lvert m_{\ell^+\ell^-}^{OS-SF} - m_Z \rvert$ [GeV]	–	>10	
N_{jets}	≥ 2		
$N_{b-\text{jets}}$	$\geq 1\ b^{60\%}$ ‖ $\geq 2\ b^{77\%}$		
Region split	(sstt, ttq, ttt, tttq, tttt) × (Q^{++}, Q^{--})	(ttt, tttq, tttt) × (Q^{+}, Q^{-})	–
Region naming	2ℓSS ++ CAT sstt	3ℓ ++ CAT ttt	4ℓ
	2ℓSS ++ CAT ttq	3ℓ ++ CAT tttq	
	2ℓSS ++ CAT ttt	3ℓ ++ CAT tttt	
	2ℓSS ++ CAT tttq	3ℓ −− CAT ttt	
	2ℓSS ++ CAT tttt	3ℓ −− CAT tttq	
	2ℓSS −− CAT sstt	3ℓ −− CAT tttt	
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Heavy scalars with FV decays in final states with multiple leptons and b-jets

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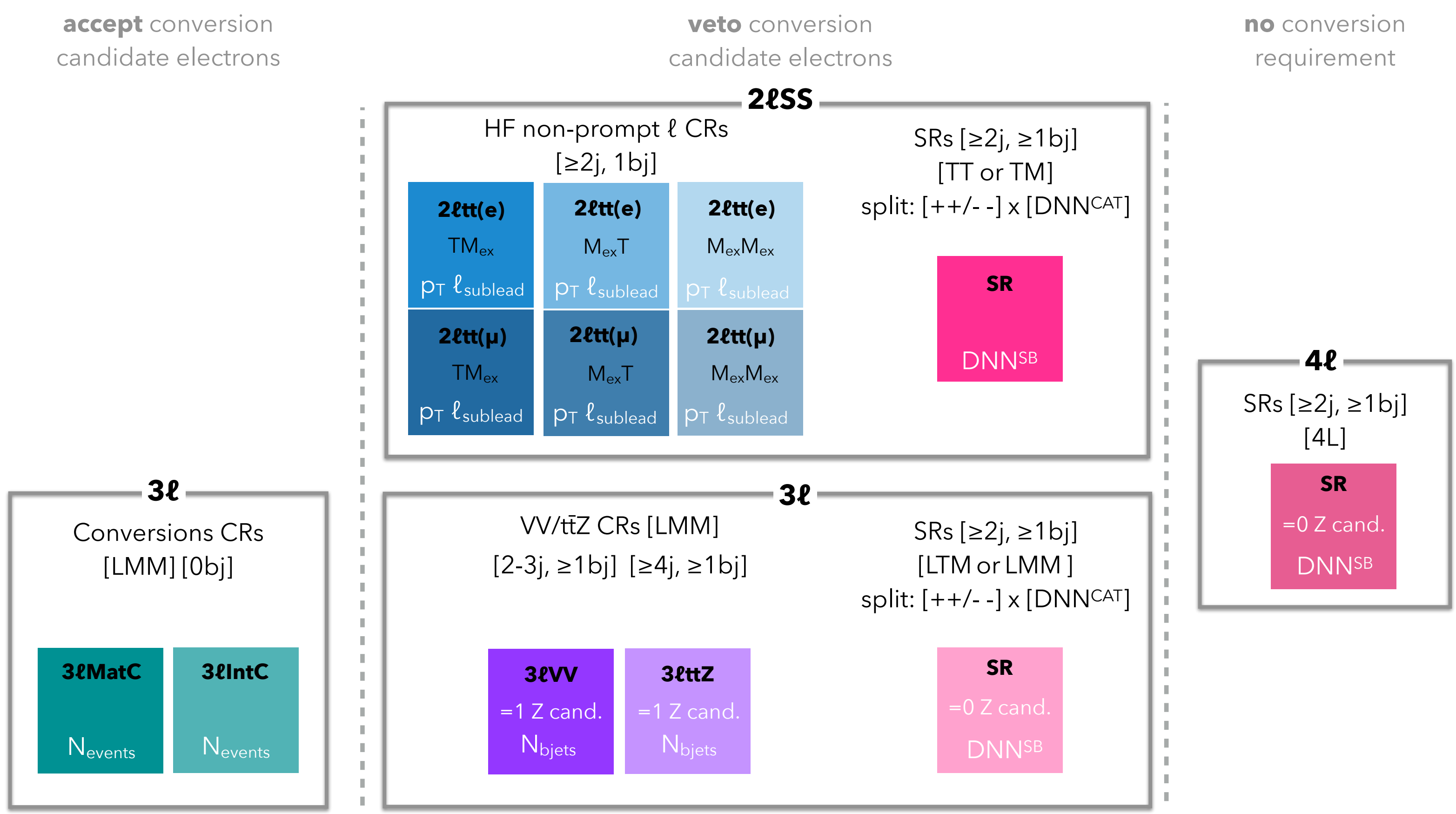

Figure 3: Illustrative sketch of the definition of the signal and control regions. At the bottom of each region box the corresponding observable used in the simultaneous fit as described in Section 8 is shown.

Heavy scalars with FV decays in final states with multiple leptons and b-jets

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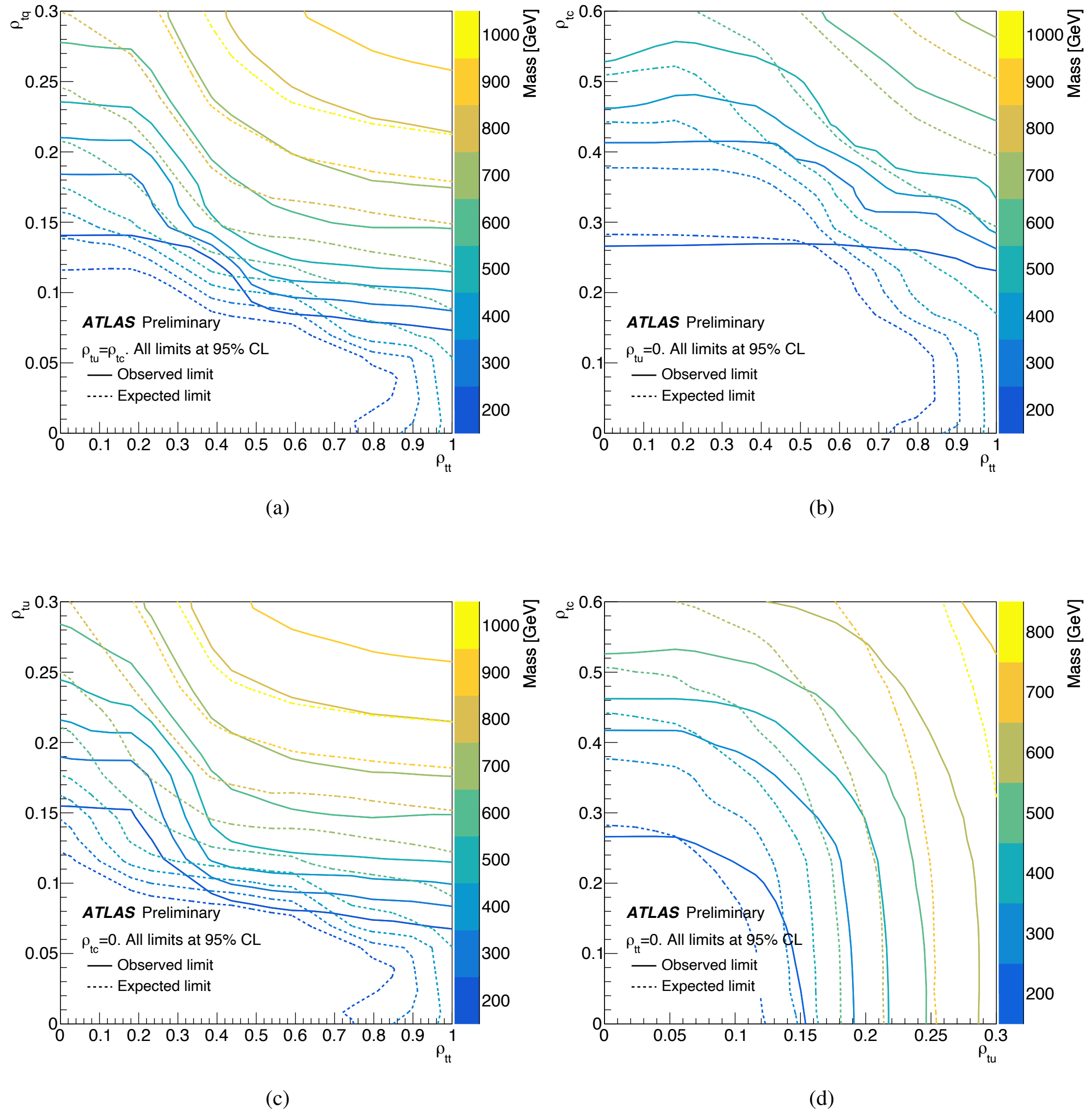


Figure 14: Observed (solid line) and expected (dashed line) exclusion limits on the scalar mass as a function of the coupling under different assumptions: (a) $\rho_{tc} = \rho_{tu}$, (b) $\rho_{tu} = 0$, (c) $\rho_{tc} = 0$, and (d) $\rho_{tt} = 0$.

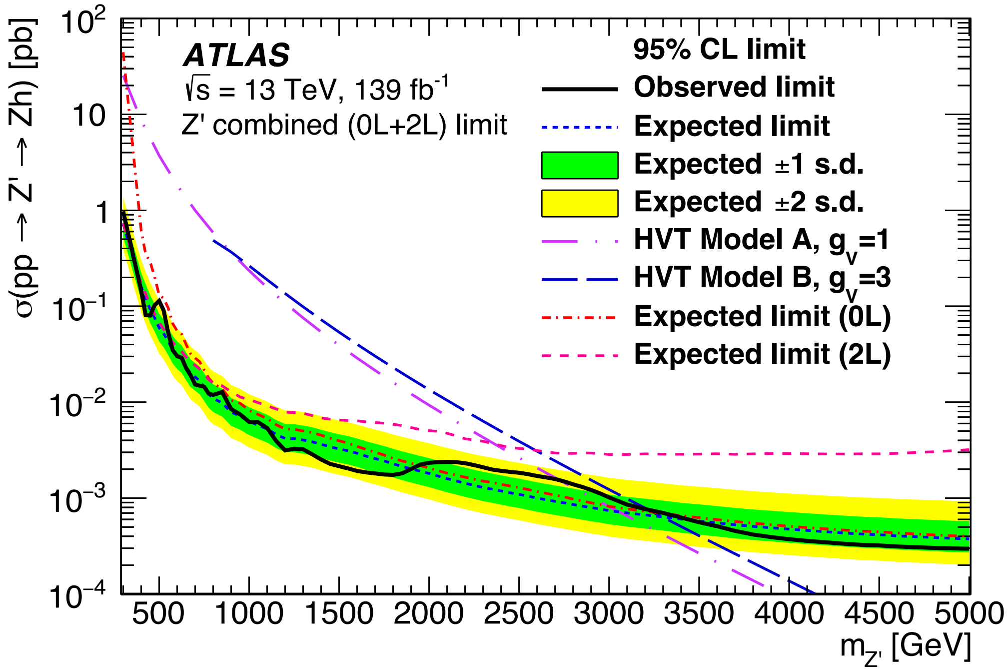
arXiv:2207.00230

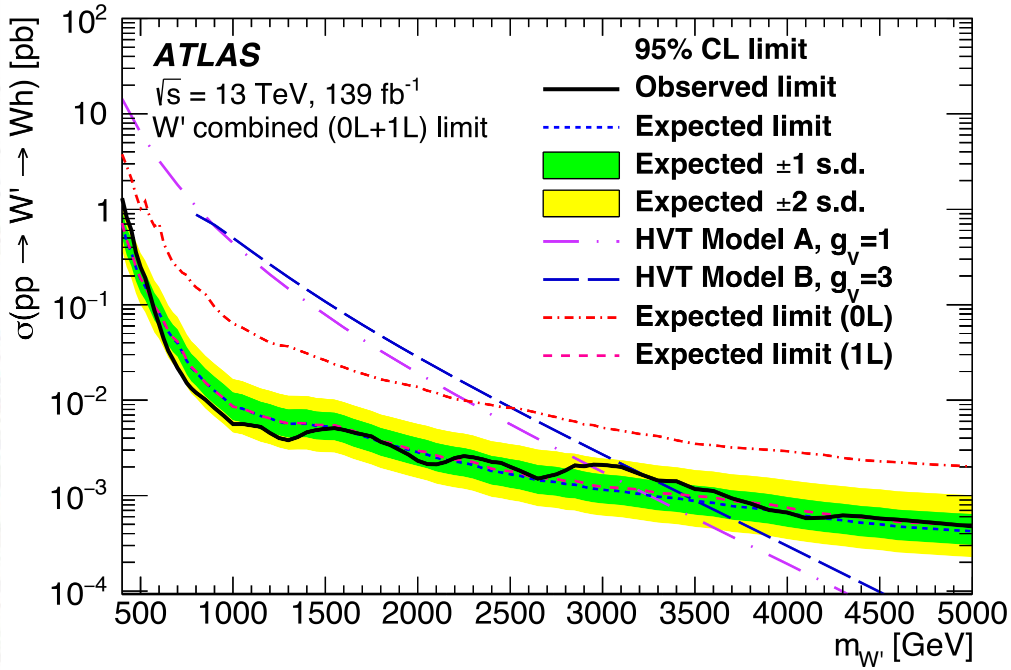
Table 2: Topological and kinematic selections for each channel and category as described in the text. $^{(*)}$ Applies in the case of only two central jets. $^{(**)}$ Applied only for the W' search. $^{(\dagger)}$ A higher threshold (80 GeV) is used for the single-electron channel. $^{(\dagger\dagger)}$ Applied only for $m_{Vh} > 320$ GeV. $^{(\ddagger\ddagger)}$ Only the two leading VR track-jets matched by ghost-association to the large-R jet are considered when classifying events into b-tag categories. Events are further classified according to the number of b-tagged jets in the events.

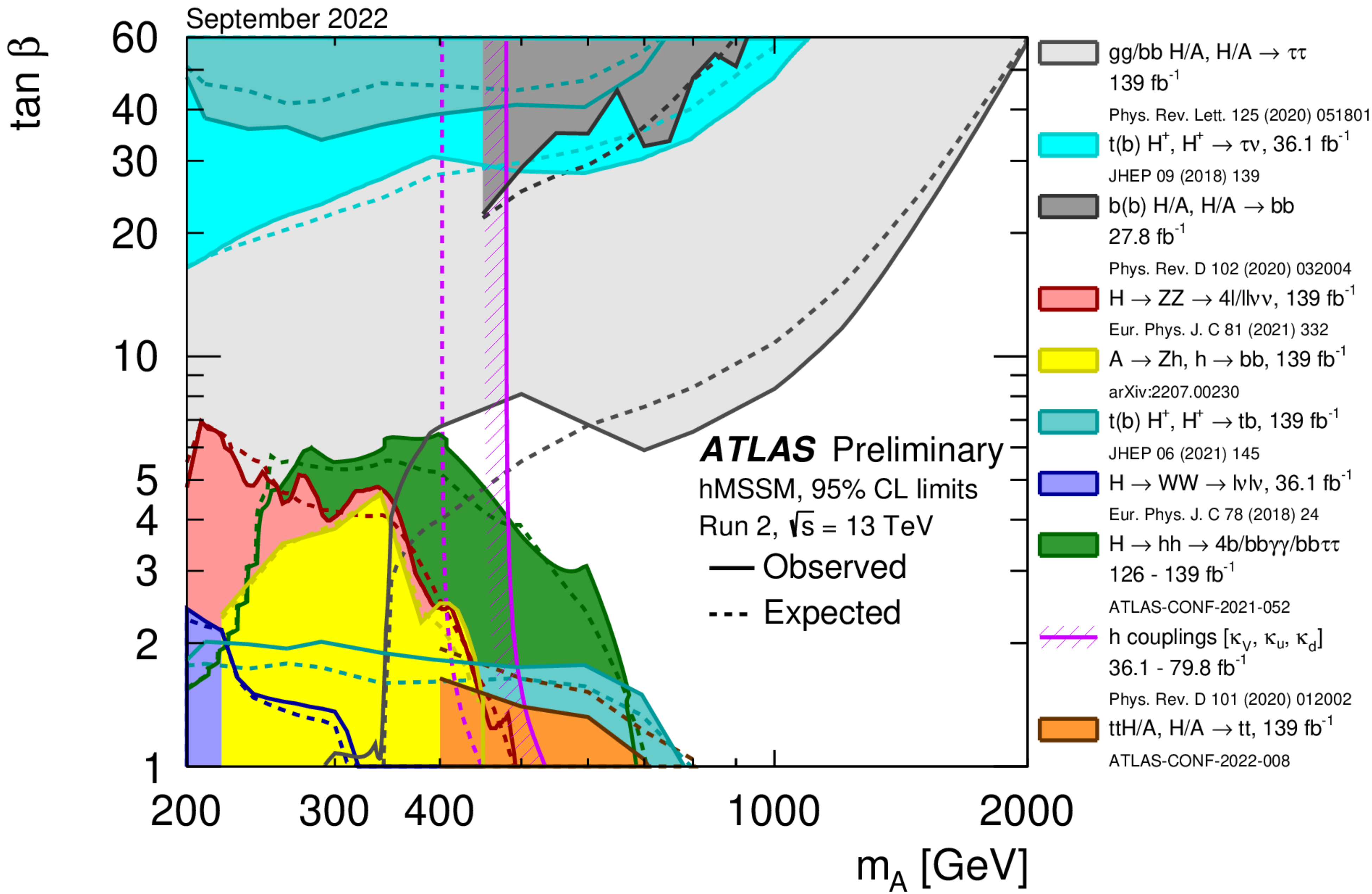
Variable	Resolved	Merged
	Common selection	
Number of jets	≥2 small-R jets (0, 2-lep.) 2 or 3 small-R jets (1-lep.)	≥1 large-R jet ≥ 1 VR track-jets (matched to leading large-R jet)‡‡
Leading jet p_T [GeV]	> 45	> 250
m_h [GeV]	110–140 (0,1-lep.), 100–145 (2-lep.)	75–145
	0-lepton selection	
E_T^{miss} [GeV]	> 150	> 200
S_T [GeV]	> 150 (120*)	–
$\Delta\phi_{jj}$	< $7\pi/9$	–
p_T^{miss} [GeV]	> 60	
$\Delta\phi(\vec{E}_T^{miss}, \vec{p}_T^{miss})$	< $\pi/2$	
$\Delta\phi(\vec{E}_T^{miss}, h)$	> $2\pi/3$	
$\min\left[\Delta\phi(\vec{E}_T^{miss}, \text{small-}R\text{ jet})\right]$	> $\pi/9$ (2 or 3 jets), > $\pi/6$ (≥ 4 jets)	
$N_{\tau_{had}}$	0 (≤ 1**)	
E_T^{miss} significance $\mathcal{S}$	$\begin{cases} > 9 & \text{if } m_{Vh} < 240\,\text{GeV}, \\ > 6.6 + 0.01 \cdot m_{Vh} & \text{if } 240\,\text{GeV} \le m_{Vh} < 700\,\text{GeV}, \\ > 13.6 & \text{if } m_{Vh} > 700\,\text{GeV}, \end{cases}$	
	1-lepton selection	
Leading lepton p_T [GeV]	> 27	> 27
E_T^{miss} [GeV]	> 40 (80†)	> 100
$p_{T,W}$ [GeV]	$> \max\left[150,\ 710 - (3.3\cdot 10^5\ \text{GeV})/m_{Vh}\right]$	$> \max\left[150,\ 394\cdot\log(m_{Vh}/(1\ \text{GeV})) - 2350\right]$
$m_{T,W}$ [GeV]	< 300	
$\Delta R(\ell, h)$	> 2.0	
	2-lepton selection	
Leading lepton p_T [GeV]	> 27	> 27
Subleading lepton p_T [GeV]	> 20	> 25
$E_T^{miss}/\sqrt{H_T}$ [$\sqrt{\text{GeV}}$]	$< 1.15 + 8\times 10^{-3}\cdot m_{Vh}/(1\ \text{GeV})$	
$p_{T,\ell\ell}$ [GeV]	$> 20 + 9\cdot\sqrt{m_{Vh}/(1\ \text{GeV}) - 320}^{\dagger\dagger}$	
$m_{\ell\ell}$ [GeV]	$\in \left[\max\left[40\,,\ 87 - 0.030\cdot m_{Vh}/(1\ \text{GeV})\right], 97 + 0.013\cdot m_{Vh}/(1\ \text{GeV})\right]$	

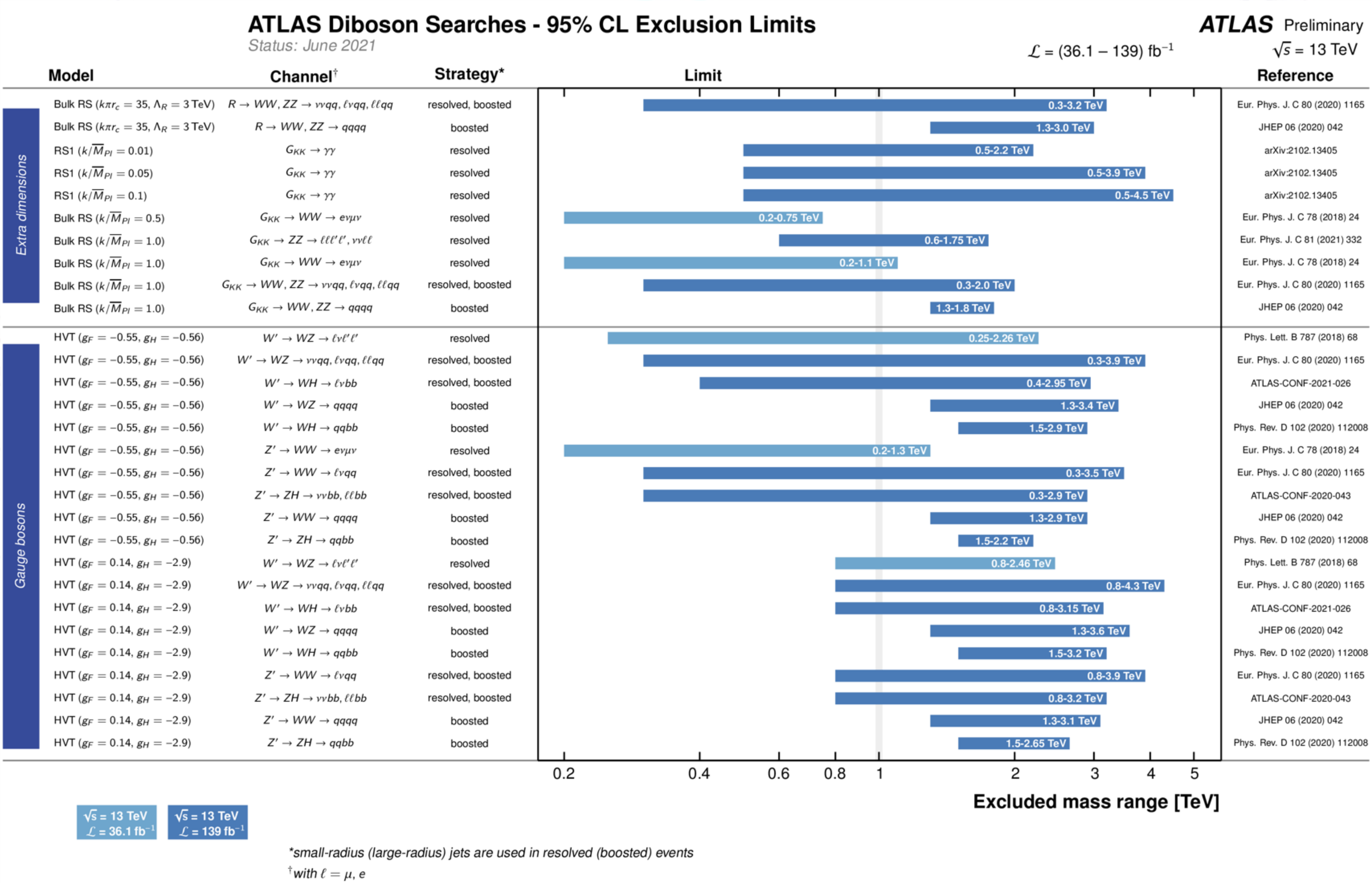
Heavy resonances into Z/W and Higgs boson in final states with leptons and b-jets

arXiv:2207.00230





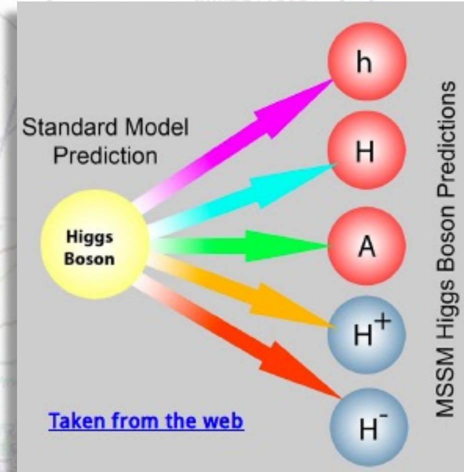

September 2022
tan β
60
40
30
20
10
5
4
3
2
1
200
300
400
1000
2000
m_A [GeV]
gg/bb H/A, H/A → ττ
139 fb^{-1}
Phys. Rev. Lett. 125 (2020) 051801
t(b) H$^+$, H$^+$ → τν, 36.1 fb^{-1}
JHEP 09 (2018) 139
b(b) H/A, H/A → bb
27.8 fb^{-1}
Phys. Rev. D 102 (2020) 032004
H → ZZ → 4l/llνν, 139 fb^{-1}
Eur. Phys. J. C 81 (2021) 332
A → Zh, h → bb, 139 fb^{-1}
arXiv:2207.00230
t(b) H$^+$, H$^+$ → tb, 139 fb^{-1}
JHEP 06 (2021) 145
H → WW → lνlν, 36.1 fb^{-1}
Eur. Phys. J. C 78 (2018) 24
H → hh → 4b/bbγγ/bbττ
126 - 139 fb^{-1}
ATLAS-CONF-2021-052
h couplings [κ_V, κ_u, κ_d]
36.1 - 79.8 fb^{-1}
Phys. Rev. D 101 (2020) 012002
ttH/A, H/A → tt, 139 fb^{-1}
ATLAS-CONF-2022-008
ATLAS Preliminary
hMSSM, 95% CL limits
Run 2, $\sqrt{s}$ = 13 TeV
Observed
Expected



ATLAS Diboson Searches - 95% CL Exclusion Limits
Status: June 2021
ATLAS Preliminary
$\mathcal{L} = (36.1 - 139)\ \text{fb}^{-1}$
$\sqrt{s} = 13$ TeV
Model | Channel† | Strategy* | Limit | Reference
Extra dimensions
Bulk RS ($k\pi r_c = 35, \Lambda_R = 3$ TeV) | $R \to WW, ZZ \to \nu\nu qq, \ell\nu qq, \ell\ell qq$ | resolved, boosted | 0.3-3.2 TeV | Eur. Phys. J. C 80 (2020) 1165
Bulk RS ($k\pi r_c = 35, \Lambda_R = 3$ TeV) | $R \to WW, ZZ \to qqqq$ | boosted | 1.3-3.0 TeV | JHEP 06 (2020) 042
RS1 ($k/\overline{M}_{Pl} = 0.01$) | $G_{KK} \to \gamma\gamma$ | resolved | 0.5-2.2 TeV | arXiv:2102.13405
RS1 ($k/\overline{M}_{Pl} = 0.05$) | $G_{KK} \to \gamma\gamma$ | resolved | 0.5-3.9 TeV | arXiv:2102.13405
RS1 ($k/\overline{M}_{Pl} = 0.1$) | $G_{KK} \to \gamma\gamma$ | resolved | 0.5-4.5 TeV | arXiv:2102.13405
Bulk RS ($k/\overline{M}_{Pl} = 0.5$) | $G_{KK} \to WW \to e\nu\mu\nu$ | resolved | 0.2-0.75 TeV | Eur. Phys. J. C 78 (2018) 24
Bulk RS ($k/\overline{M}_{Pl} = 1.0$) | $G_{KK} \to ZZ \to \ell\ell\ell'\ell', \nu\nu\ell\ell$ | resolved | 0.6-1.75 TeV | Eur. Phys. J. C 81 (2021) 332
Bulk RS ($k/\overline{M}_{Pl} = 1.0$) | $G_{KK} \to WW \to e\nu\mu\nu$ | resolved | 0.2-1.1 TeV | Eur. Phys. J. C 78 (2018) 24
Bulk RS ($k/\overline{M}_{Pl} = 1.0$) | $G_{KK} \to WW, ZZ \to \nu\nu qq, \ell\nu qq, \ell\ell qq$ | resolved, boosted | 0.3-2.0 TeV | Eur. Phys. J. C 80 (2020) 1165
Bulk RS ($k/\overline{M}_{Pl} = 1.0$) | $G_{KK} \to WW, ZZ \to qqqq$ | boosted | 1.3-1.8 TeV | JHEP 06 (2020) 042
Gauge bosons
HVT ($g_F = -0.55, g_H = -0.56$) | $W' \to WZ \to \ell\nu\ell'\ell'$ | resolved | 0.25-2.26 TeV | Phys. Lett. B 787 (2018) 68
HVT ($g_F = -0.55, g_H = -0.56$) | $W' \to WZ \to \nu\nu qq, \ell\nu qq, \ell\ell qq$ | resolved, boosted | 0.3-3.9 TeV | Eur. Phys. J. C 80 (2020) 1165
HVT ($g_F = -0.55, g_H = -0.56$) | $W' \to WH \to \ell\nu bb$ | resolved, boosted | 0.4-2.95 TeV | ATLAS-CONF-2021-026
HVT ($g_F = -0.55, g_H = -0.56$) | $W' \to WZ \to qqqq$ | boosted | 1.3-3.4 TeV | JHEP 06 (2020) 042
HVT ($g_F = -0.55, g_H = -0.56$) | $W' \to WH \to qqbb$ | boosted | 1.5-2.9 TeV | Phys. Rev. D 102 (2020) 112008
HVT ($g_F = -0.55, g_H = -0.56$) | $Z' \to WW \to e\nu\mu\nu$ | resolved | 0.2-1.3 TeV | Eur. Phys. J. C 78 (2018) 24
HVT ($g_F = -0.55, g_H = -0.56$) | $Z' \to WW \to \ell\nu qq$ | resolved, boosted | 0.3-3.5 TeV | Eur. Phys. J. C 80 (2020) 1165
HVT ($g_F = -0.55, g_H = -0.56$) | $Z' \to ZH \to \nu\nu bb, \ell\ell bb$ | resolved, boosted | 0.3-2.9 TeV | ATLAS-CONF-2020-043
HVT ($g_F = -0.55, g_H = -0.56$) | $Z' \to WW \to qqqq$ | boosted | 1.3-2.9 TeV | JHEP 06 (2020) 042
HVT ($g_F = -0.55, g_H = -0.56$) | $Z' \to ZH \to qqbb$ | boosted | 1.5-2.2 TeV | Phys. Rev. D 102 (2020) 112008
HVT ($g_F = 0.14, g_H = -2.9$) | $W' \to WZ \to \ell\nu\ell'\ell'$ | resolved | 0.8-2.46 TeV | Phys. Lett. B 787 (2018) 68
HVT ($g_F = 0.14, g_H = -2.9$) | $W' \to WZ \to \nu\nu qq, \ell\nu qq, \ell\ell qq$ | resolved, boosted | 0.8-4.3 TeV | Eur. Phys. J. C 80 (2020) 1165
HVT ($g_F = 0.14, g_H = -2.9$) | $W' \to WH \to \ell\nu bb$ | resolved, boosted | 0.8-3.15 TeV | ATLAS-CONF-2021-026
HVT ($g_F = 0.14, g_H = -2.9$) | $W' \to WZ \to qqqq$ | boosted | 1.3-3.6 TeV | JHEP 06 (2020) 042
HVT ($g_F = 0.14, g_H = -2.9$) | $W' \to WH \to qqbb$ | boosted | 1.5-3.2 TeV | Phys. Rev. D 102 (2020) 112008
HVT ($g_F = 0.14, g_H = -2.9$) | $Z' \to WW \to \ell\nu qq$ | resolved, boosted | 0.8-3.9 TeV | Eur. Phys. J. C 80 (2020) 1165
HVT ($g_F = 0.14, g_H = -2.9$) | $Z' \to ZH \to \nu\nu bb, \ell\ell bb$ | resolved, boosted | 0.8-3.2 TeV | ATLAS-CONF-2020-043
HVT ($g_F = 0.14, g_H = -2.9$) | $Z' \to WW \to qqqq$ | boosted | 1.3-3.1 TeV | JHEP 06 (2020) 042
HVT ($g_F = 0.14, g_H = -2.9$) | $Z' \to ZH \to qqbb$ | boosted | 1.5-2.65 TeV | Phys. Rev. D 102 (2020) 112008
0.2 0.4 0.6 0.8 1 2 3 4 5
Excluded mass range [TeV]
$\sqrt{s} = 13$ TeV $\mathcal{L} = 36.1\ \text{fb}^{-1}$
$\sqrt{s} = 13$ TeV $\mathcal{L} = 139\ \text{fb}^{-1}$
*small-radius (large-radius) jets are used in resolved (boosted) events
†with $\ell = \mu, e$

Two Higgs Doublet Model (2HDM)

- Generic class with second Higgs doublet. Four variants to couple SM fermions to the 2HDs (no FCNCs):
  - Type I: all quarks and leptons couple to only one doublet
  - Type II: one doublet couples to up-type quarks, the other to down-type quarks and leptons: „MSSM-like"
  - Lepton-specific: couplings to quarks as in the Type I model and to leptons as in Type II
  - Flipped: couplings to quarks as in the Type II model and to leptons as in Type I



- 5 Higgs bosons: h, H, A, H^+, H^-
- Free parameters: tanβ (ratio between the vevs of the doublets), α (mixing angle between h and H) and m_A
- Minimal Supersymmetric SM (MSSM) is a special case of 2HDM:
  - "type II" with fixed α
  - numerous benchmark models: hMSSM, m_h^{mod+}, etc.

- SM Higgs results give big constraints on 2HDM. Data prefers alignment limit: cos(β- α)=0 – h recovers properties of the SM Higgs

Phys. Rev. D 101 (2020) 012002

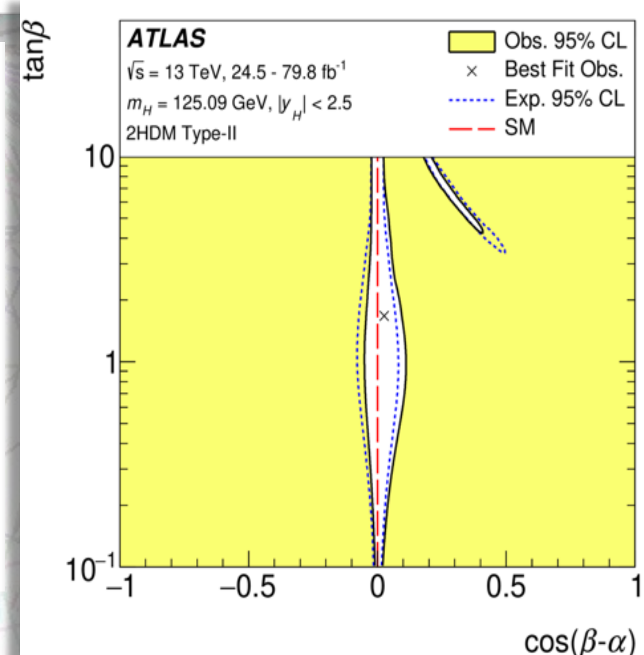


Table 1: Signal region definitions designed for the Wh model. The variables are defined in the text.

	$SR^{Wh}_{high-m_{T2}}$	$SR^{Wh}_{low-m_{T2}}$
	$e^{\pm}e^{\pm}$ | $e^{\pm}\mu^{\pm}$ | $\mu^{\pm}\mu^{\pm}$	$e^{\pm}e^{\pm}$ | $e^{\pm}\mu^{\pm}$ | $\mu^{\pm}\mu^{\pm}$
$N_{BL}(\ell)$	= 2	
$N_{Sig}(\ell)$	= 2	
Charge(ℓ)	same-sign	
$p_T(\ell)$	$\geq$ 25 GeV	
n_{jets} (p_T > 25 GeV)	$\geq$ 1	
$n_{b\text{-jets}}$	= 0	
m_{jj}	< 350 GeV	
m_{T2}	$\geq$ 80 GeV	< 80 GeV
m_T^{min}	–	$\geq$ 100 GeV
$\mathcal{S}(E_T^{miss})$	$\geq$ 7	$\geq$ 6
E_T^{miss}	$\geq$ 75 GeV	$\geq$ 50 GeV
E_T^{miss} binning (GeV)[a]	$SR^{Wh}_{high-m_{T2}}$-1: $\in [75, 125)$ $SR^{Wh}_{high-m_{T2}}$-2: $\in [125, 175)$ $SR^{Wh}_{high-m_{T2}}$-3: $\in [175, +\infty)$	–

[a] The E_T^{miss} binning applies separately to each flavour channel of $SR^{Wh}_{high-m_{T2}}$.

Table 2: Signal region definitions designed for WZ model. The variables are defined in the text.

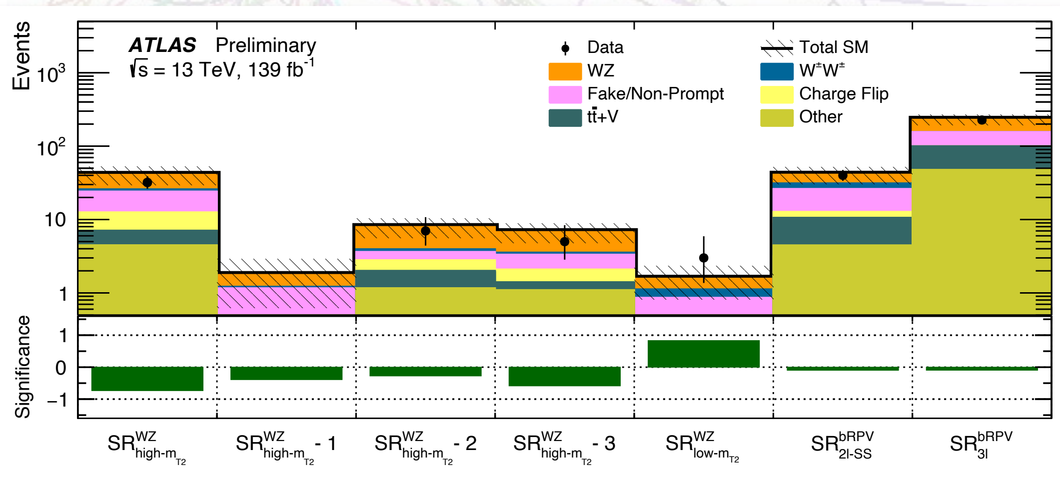
	$SR^{WZ}_{high-m_{T2}}$	$SR^{WZ}_{low-m_{T2}}$
$N_{BL}(\ell)$	= 2	
$N_{Sig}(\ell)$	= 2	
Charge(ℓ)	same-sign	
$p_T(\ell)$	$\geq$ 25 GeV	
n_{jets} (p_T > 25 GeV)	$\geq$ 1	
$n_{b\text{-jets}}$	= 0	
m_{jj}	$\leq$ 350 GeV	
m_{T2}	$\geq$ 100 GeV	$\leq$ 100 GeV
m_T^{min}	$\geq$ 100 GeV	$\geq$ 130 GeV
E_T^{miss}	$\geq$ 100 GeV	$\geq$ 140 GeV
m_{eff}	–	$\leq$ 600 GeV
$\Delta R(\ell^{\pm}, \ell^{\pm})$	–	$\leq$ 3
Bins	$\mathcal{S}(E_T^{miss})$: $\in [0, 10)$ Spread(Φ) $\geq$ 2.2 $\mathcal{S}(E_T^{miss})$: $\in [10, 13)$ $\mathcal{S}(E_T^{miss})$: $\in [13, +\infty]$ $\Delta R(\ell^{\pm}, \ell^{\pm}) \geq 1$	–

Table 3: Signal region definitions designed for bRPV model. The variables are defined in the text.

	$SR^{bRPV}_{2\ell-SS}$	$SR^{bRPV}_{3\ell}$
$N_{BL}(\ell)$	–	
$p_T(\ell)$	$\geq$ 20 GeV for (sub)leading leptons	
n_{jets} (p_T > 25 GeV)	$\geq$ 1	
$N_{Sig}(\ell)$	= 2	= 3
Charge(ℓ)	same-sign	–
m_{T2}	$\geq$ 60 GeV	$\geq$ 80 GeV
E_T^{miss}	$\geq$ 100 GeV	$\geq$ 120 GeV
m_{eff}	–	$\geq$ 350 GeV
$n_{b\text{-jets}}$	= 0	–
n_{jets} (p_T > 40 GeV)	$\geq$ 4	–
$m_{e^{\pm}e^{\mp}}$, $m_{\mu^{\pm}\mu^{\mp}}$	–	$\notin$ [81, 101] GeV

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_{T,\ell_1}(\mathbf{p}_{T,\ell_1}, \mathbf{q}_T), m_{T,\ell_2}(\mathbf{p}_{T,\ell_2}, \mathbf{p}_T^{miss} - \mathbf{q}_T)\right)\right]$$

$$m_T(\mathbf{p}_T, \mathbf{q}_T) = \sqrt{2(p_T q_T - \mathbf{p}_T \cdot \mathbf{q}_T)}.$$

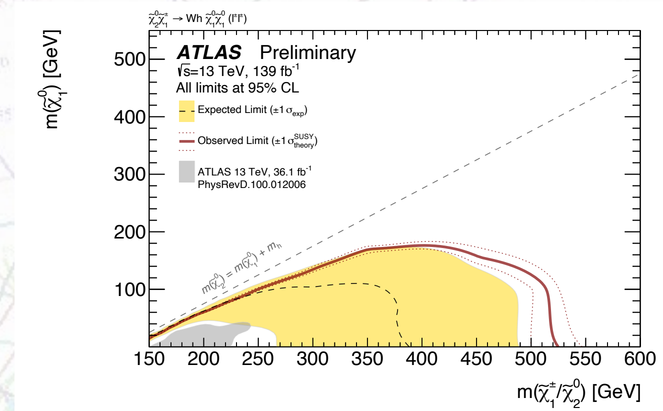


Same-sign 2L/3L from direct production of winos and higgsinos

ATLAS-CONF-2022-057

Background Type	Wino Wh	non-Wh
Irreducible	1. CR/VR defined for WZ^1 and $W^{\pm}W^{\pm}$	1. CR/VR defined for WZ^1 and VR for $t\bar{t}V$
	2. Other small backgrounds are estimated using full Monte-Carlo samples	
Reducible	3. Charge flip rates are estimated in MC and corrected using the Egamma SFs	
	4. Fakes: using Fake Factor Method	4. Fakes: using Matrix Method and MCTemplate method as a cross-check

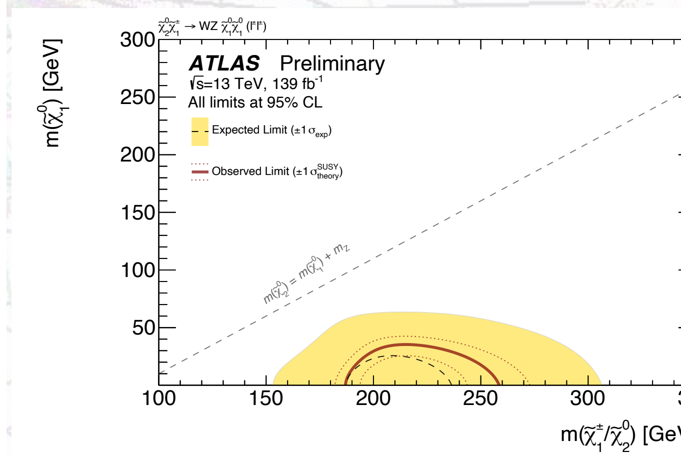
[1]. Note that the WZ would be normalised in the respective CR in Wh and non-Wh.



(a) Wino $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ with Wh

Table 7: Model-independent statistical analysis for SRs optimised for the Wh, WZ and bRPV models: 95% CL upper limits on the visible cross section, $\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$, and on the number of signal events S^{95}_{obs}. The S^{95}_{exp} is the expected 95% CL upper limit on the number of signal events, given the the expectation (and $\pm 1\sigma$ variations) of background events. The last two columns report the $\mathrm{CL_b}$ value for the background-only hypothesis, the one-sided p_0-value and the local significance Z (the number of equivalent Gaussian standard deviations).

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\mathrm{obs}}$ [fb]	S^{95}_{obs}	S^{95}_{exp}	$\mathrm{CL_b}$	p_0 (Z)
$\mathrm{SR}^{Wh}_{\mathrm{high}-m_{T2}}$	0.28	39.3	$33.9^{+14.3}_{-10.0}$	0.66	0.34 (0.41)
$\mathrm{SR}^{Wh}_{\mathrm{low}-m_{T2}}$	0.24	33.0	$29.5^{+11.7}_{-8.8}$	0.63	0.33 (0.43)
$\mathrm{SR}^{WZ}_{\mathrm{high}-m_{T2}}$	0.13	18.7	$24.4^{+6.8}_{-5.0}$	0.12	0.50 (0.00)
$\mathrm{SR}^{WZ}_{\mathrm{low}-m_{T2}}$	0.04	5.9	$4.4^{+1.8}_{-0.8}$	0.81	0.22 (0.76)
$\mathrm{SR}^{\mathrm{bRPV}}_{2\ell-\mathrm{SS}}$	0.16	22.6	$25.8^{+7.9}_{-5.8}$	0.29	0.50 (0.00)
$\mathrm{SR}^{\mathrm{bRPV}}_{3\ell}$	0.44	61.4	$93.0^{+56.0}_{-20.3}$	0.02	0.50 (0.00)



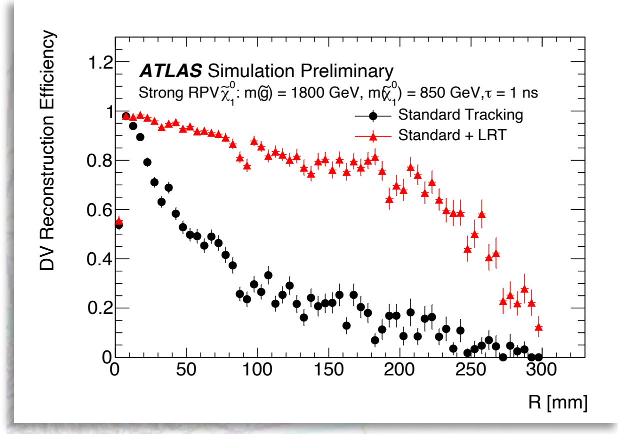
(b) Wino $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ with WZ

Displaced vertices + jets

ATLAS-CONF-2022-054

Table 2: Summary of the signal region selections. The x in the $n^{x}_{\text{jet/trackless jet}}$ notation refers to the jet p_{T} threshold in GeV. All jets are required to have $|\eta| < 2.5$.

Signal Region	High-p_{T} jet SR	Trackless jet SR
Jet selection	$n^{250}_{\text{jet}} \geq 4$ or $n^{195}_{\text{jet}} \geq 5$ or $n^{116}_{\text{jet}} \geq 6$ or $n^{90}_{\text{jet}} \geq 7$	Fail high-p_{T} jet selection, $n^{137}_{\text{jet}} \geq 4$ or $n^{101}_{\text{jet}} \geq 5$ or $n^{83}_{\text{jet}} \geq 6$ or $n^{55}_{\text{jet}} \geq 7$, $n^{70}_{\text{trackless jet}} \geq 1$ or $n^{50}_{\text{trackless jet}} \geq 2$
DV pre-selection	$R_{\text{DV}} < 300$ mm, $\lvert z_{\text{DV}}\rvert < 300$ mm, $\min(\lvert\vec{r}_{DV} - \vec{r}_{PV}\rvert) > 4$ mm, $\chi^2/n_{\text{DoF}} < 5$, $n^{\text{DV}}_{\text{Selected tracks}} \geq 2$, pass material map veto	
$n^{\text{DV}}_{\text{Tracks}}$	≥ 5	
m_{DV}	>10 GeV	



SM Decays

- SM LLP just decays naturally in flight

Hadronic Interactions (HI)

- SM LLP hits and interacts with detector material

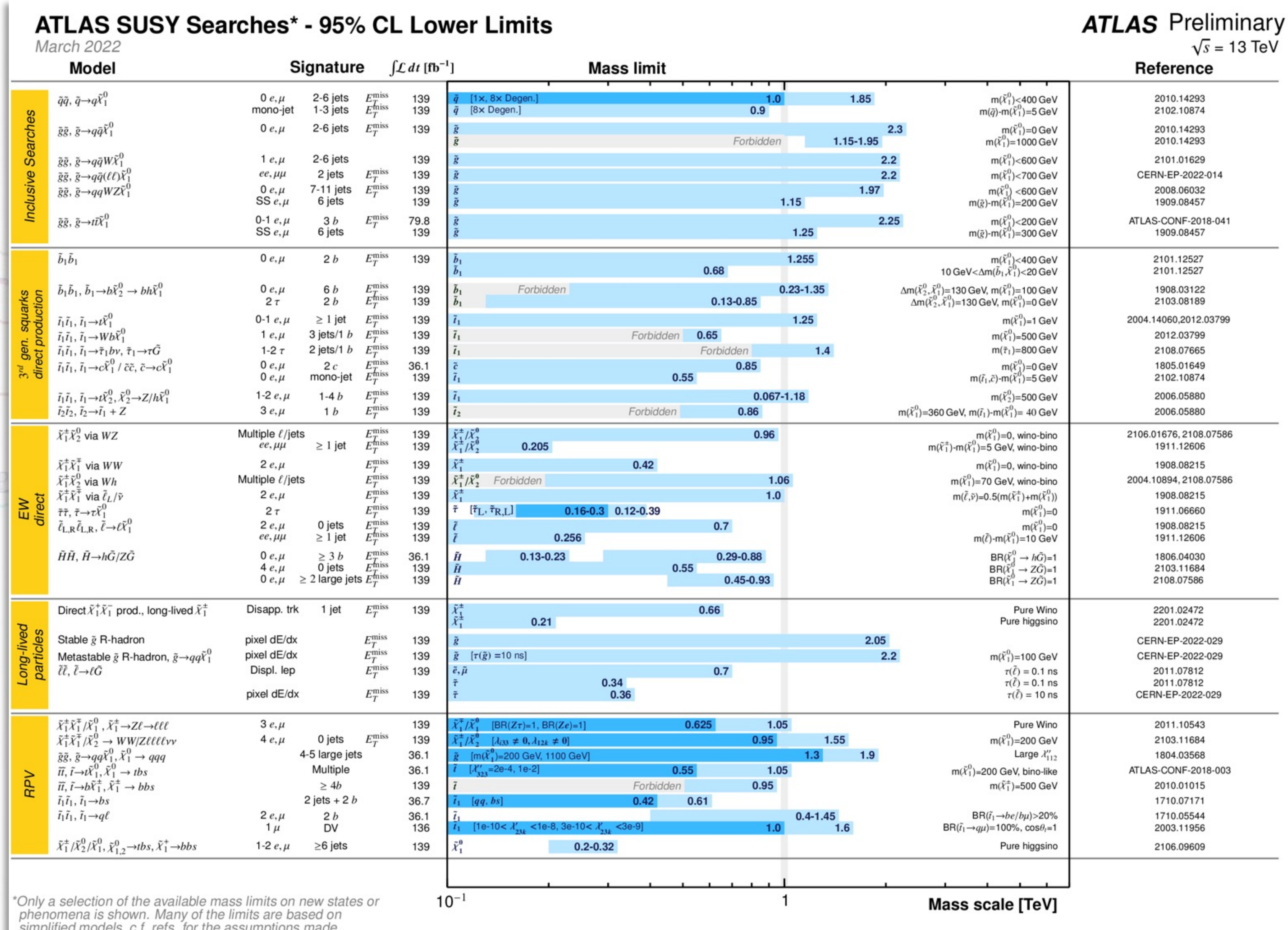
Merged Vertices (MV)

- Two DVs close together get reconstructed as a higher N, higher m DV

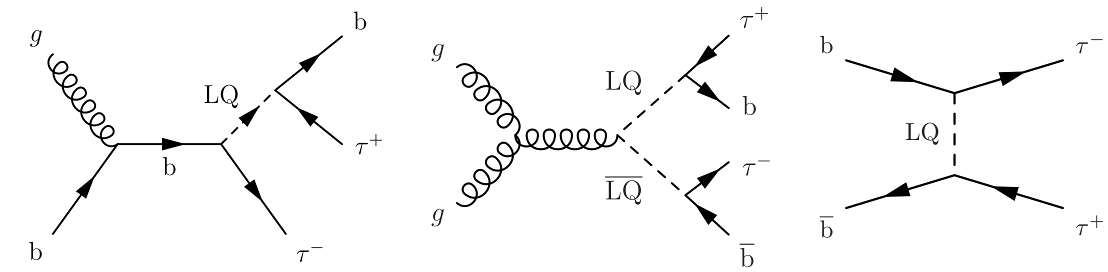
Accidental Crossings (AX)

- Random track crossing DV makes it appear higher N and higher m

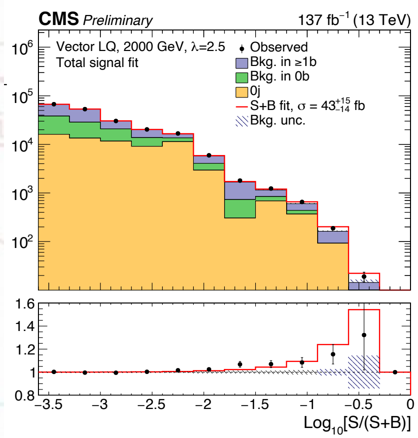
Supersymmetry – supercementary?

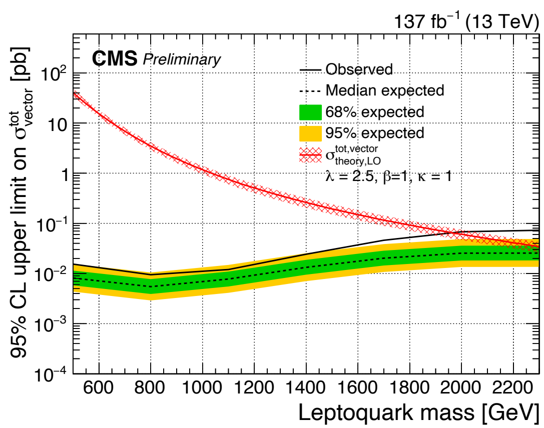


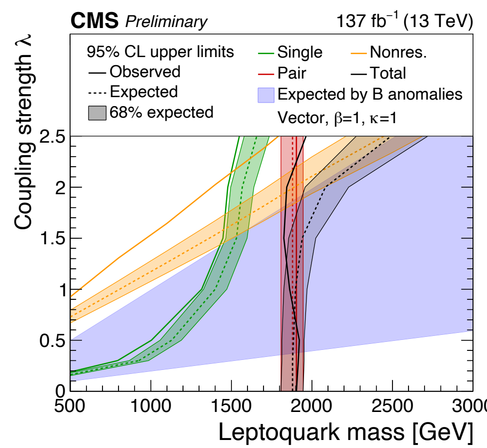
Leptoquark in $b\tau$ in $s-$ and $t-$channels CMS-PAS-EXO-19-016



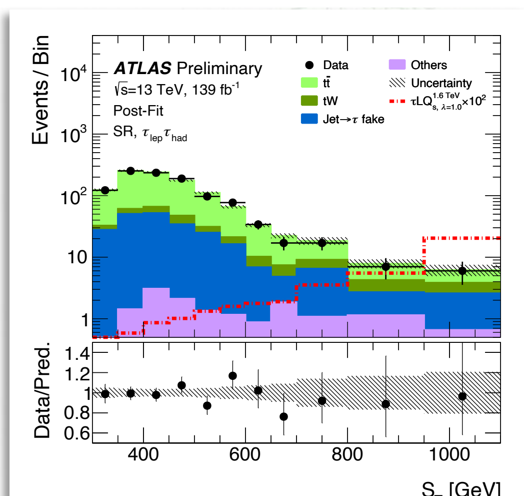
- LQ$\rightarrow$ $b\tau$ in events w/ τ and ≥ 1 b-jets
- Range of coupling strengths and masses tested

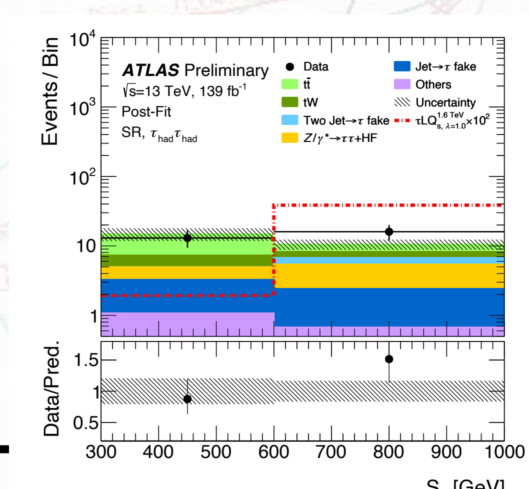






- Significant 3.4σ excess for a LQ mass of 2 TeV and $\lambda = 2.5$





S_T -scalar p_T sum of the two τ and the leading-p_T *b*-jet

Analysis preselections

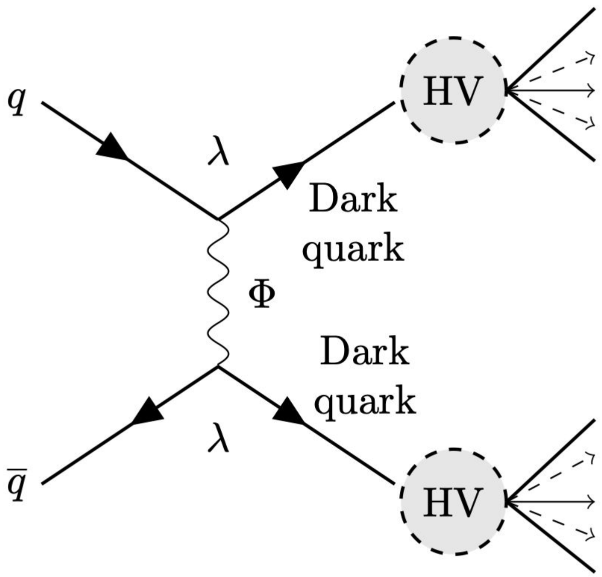
1. No electrons / muons (p_T > 7 GeV)
2. Looking at events with MET trigger (trigger is fully efficient, tests in backup slide), MET > 200 GeV
3. At least 2 jets with leading jet p_T > 250 GeV, other jet p_T > 30 GeV and |eta| < 2.8, jet cleaning LooseBad (also TightBad selection applied on data leading jet, for NCB treatment)
4. Dead-tile correction, LAr, SCT error veto
5. DeltaPhi(closest jet, MET) < 2.0
6. B-tagged jets < 2
7. Tau jets (p_T > 20 GeV) < 1

Key variables for this analysis:

- MET
- Scalar jet pT sum, HT
- DeltaPhi (closest jet, MET)
- p_T balance (between closest and farthest jet from MET)

$$\Delta_{\rm rel} p_{\rm T}(j_1, j_2) = \frac{|\vec{p_{\rm T}}(j_1) + \vec{p_{\rm T}}(j_2)|}{|\vec{p_{\rm T}}(j_1)| + |\vec{p_{\rm T}}(j_2)|}$$

- Maxminphi |Δϕ(farthest jet, MET) - Δϕ(closest jet, MET)|



The resultant MET direction is aligned along one of the jets.

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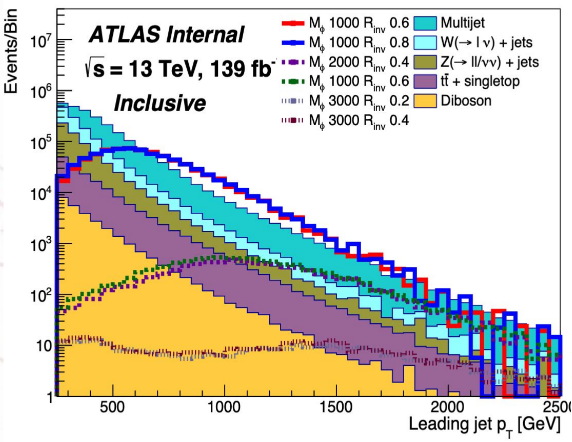
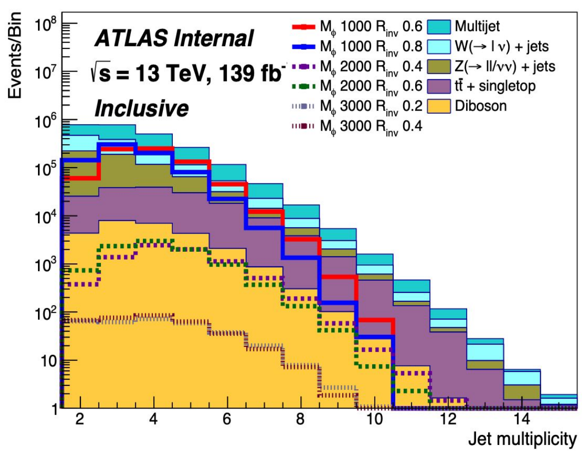
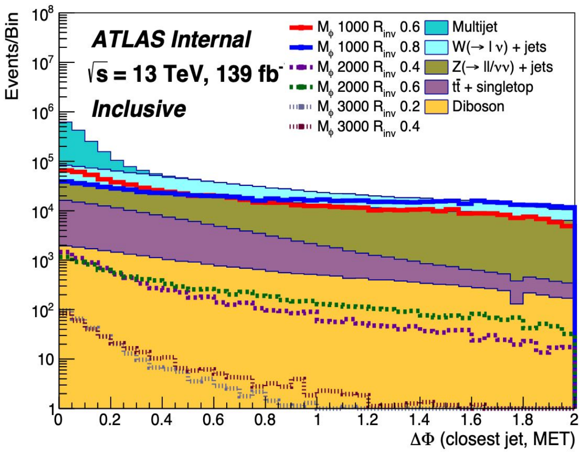
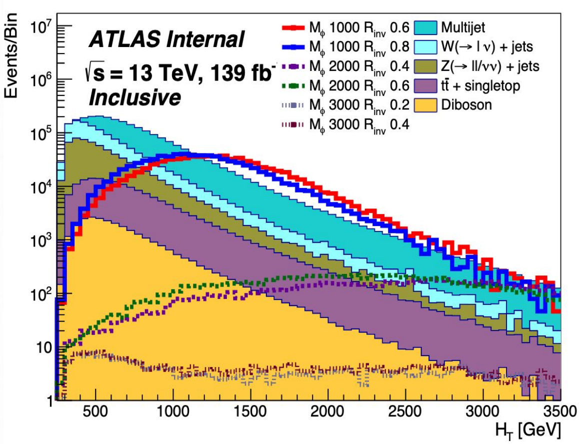
The region with MET>600 GeV and HT> 600 GeV after the pre-selection is defined as the SR.

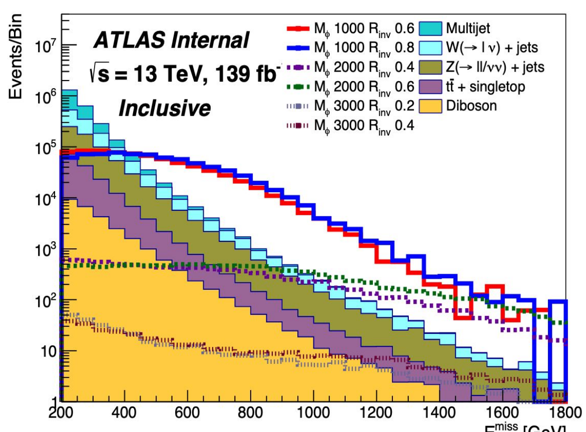
Key kinematic variables











Other signal mass points show similar trend.

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Semi-visible jets, t-channel

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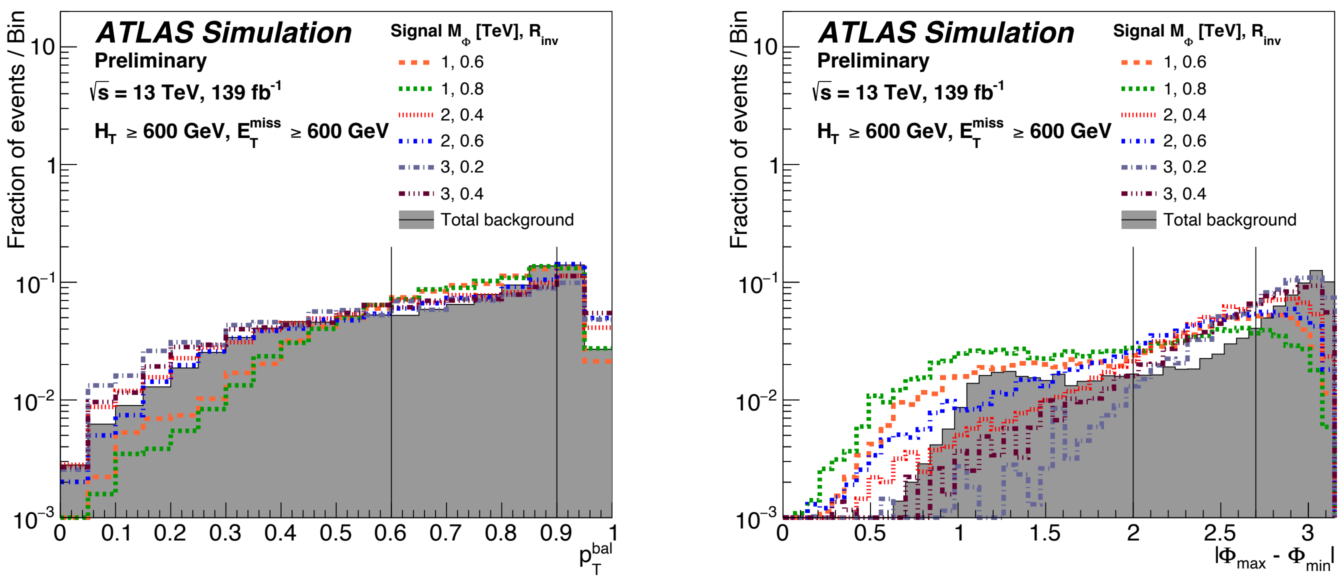

Table 2: Scale factors for each background processes obtained from simultaneous fit using SR, 1L CR, 1L1B CR and 2L CR. Top processes denotes merged contributions from $t\bar{t}$ and single top processes.

Process	k_i^{SF}
Z+jets	1.18 ± 0.05
W+jets	1.09 ± 0.04
Top processes	0.64 ± 0.04
Multijet	1.10 ± 0.04

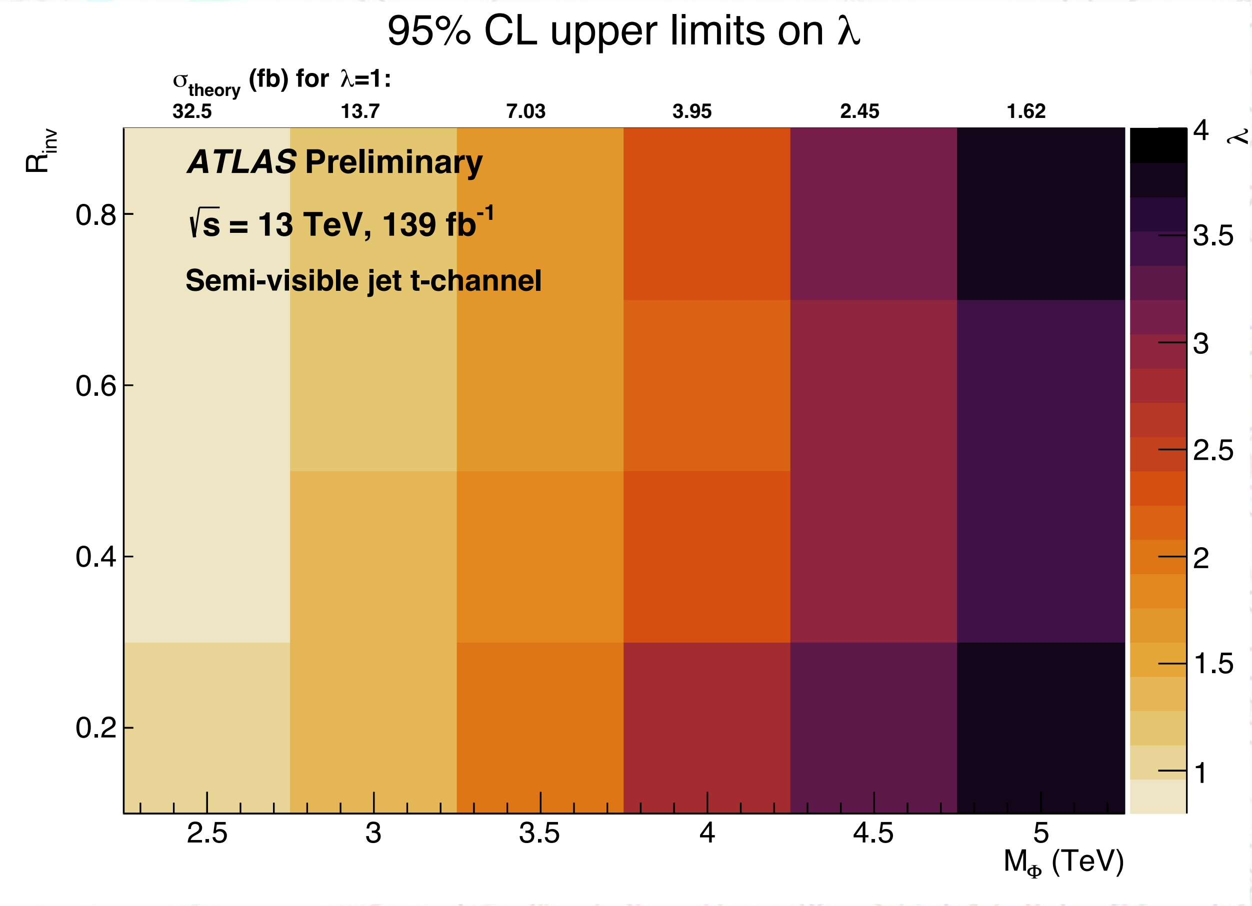

Figure 7: The grid shows the observed 95% CL upper limit on λ with M_ϕ on the x-axis, $R_{\rm inv}$ on the y axis. It also includes over each M_ϕ column the predicted cross-section for that specific mass value as a reference.