The Niels Bohr Institute

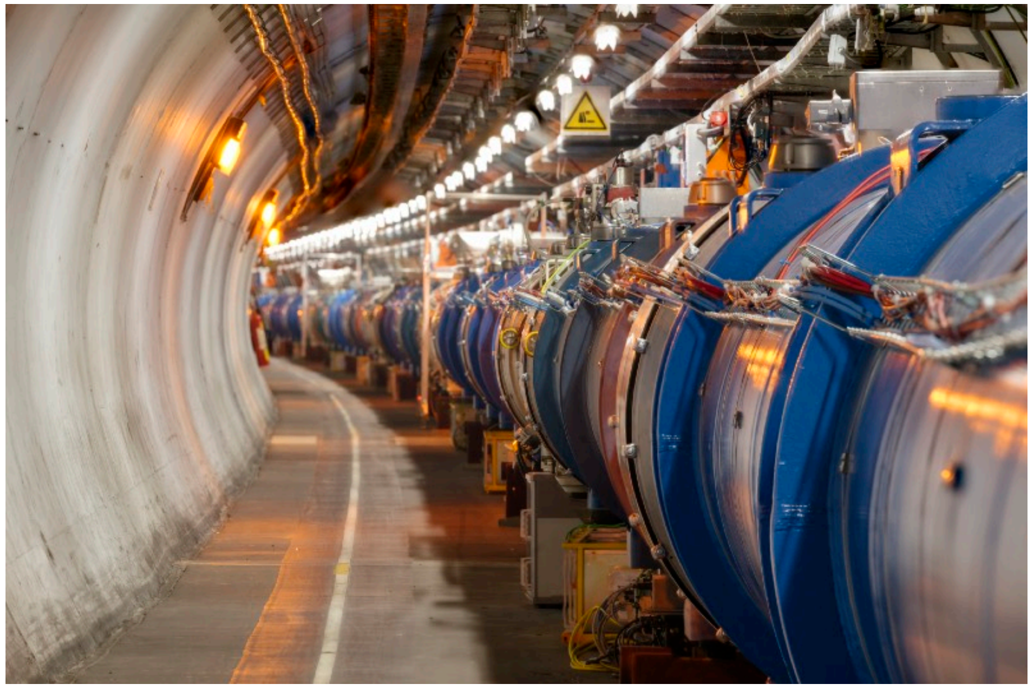
Searches for High Mass Resonances at ATLAS

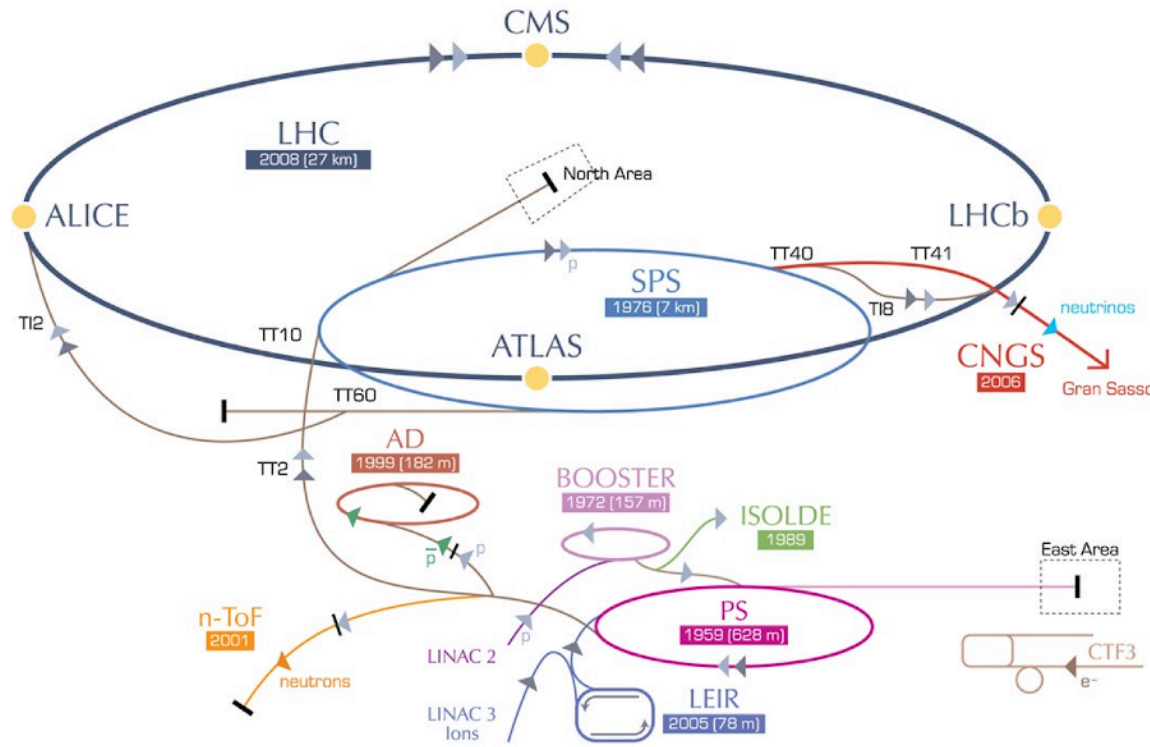
Flavia de Almeida Dias

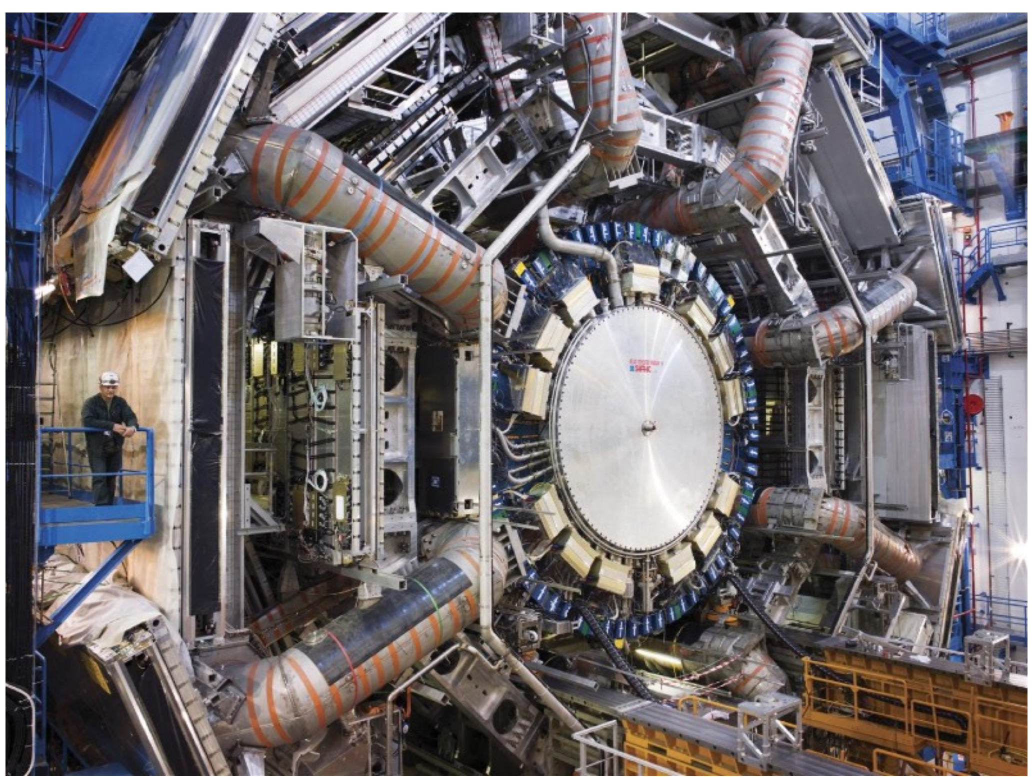
on behalf of the ATLAS Collaboration

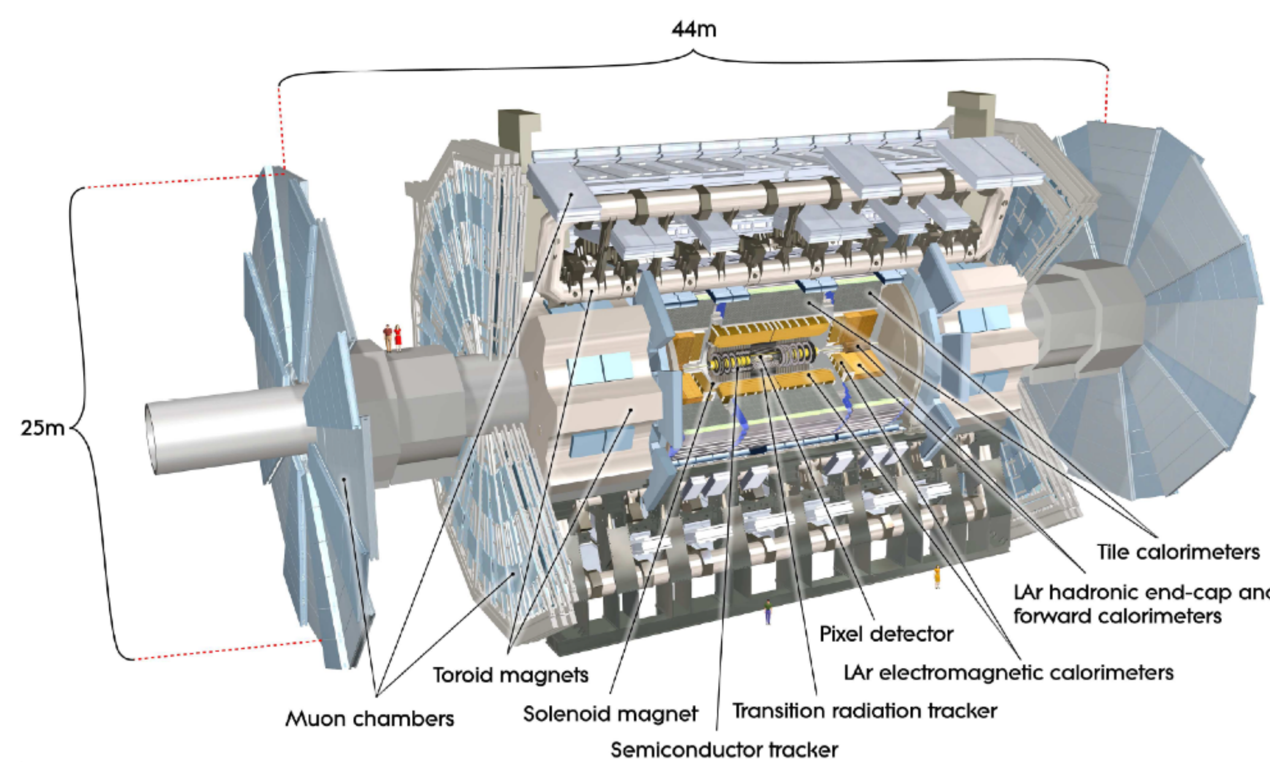
DIS2018
19 April 2018

LHC and ATLAS



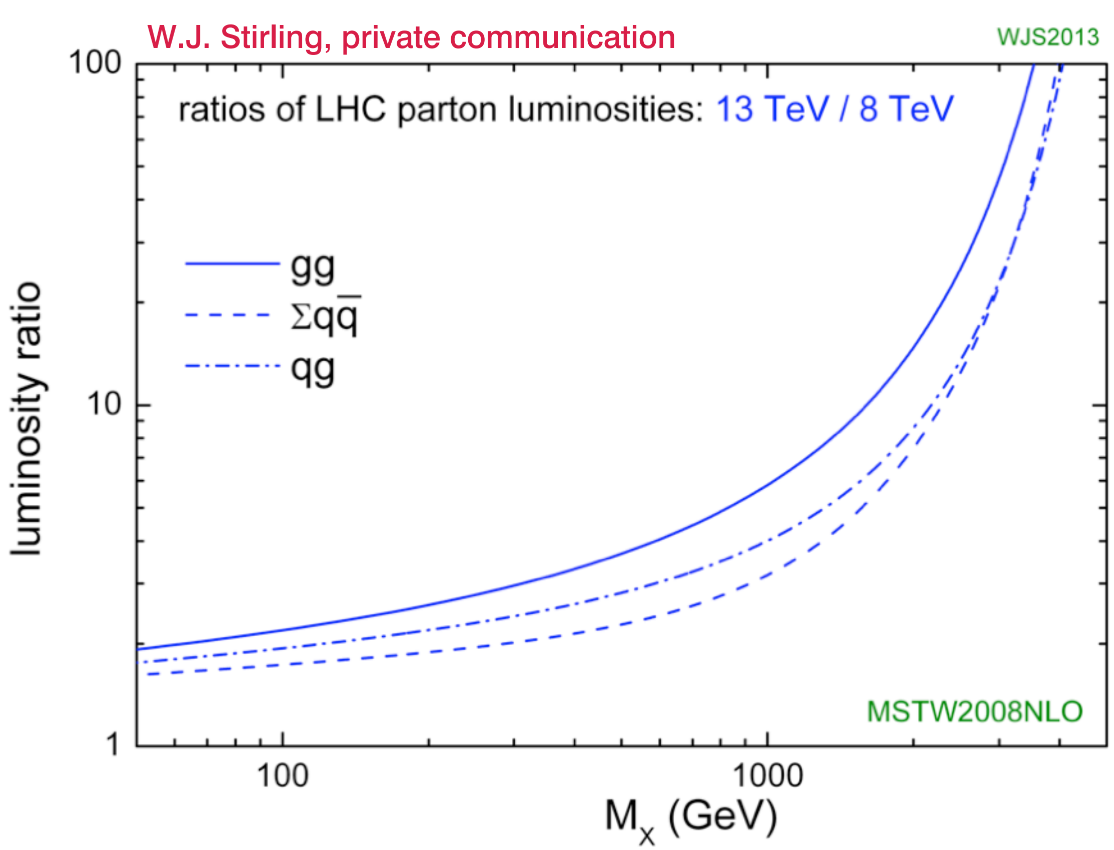


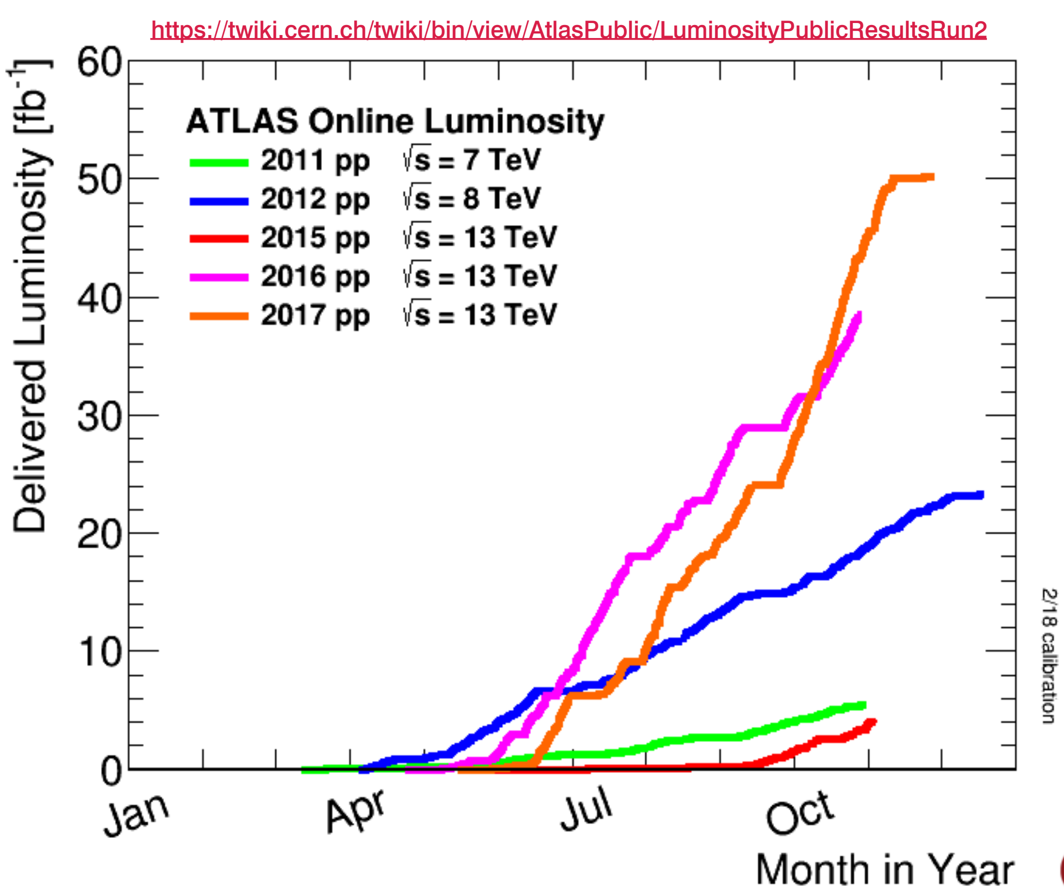




LHC Run 2

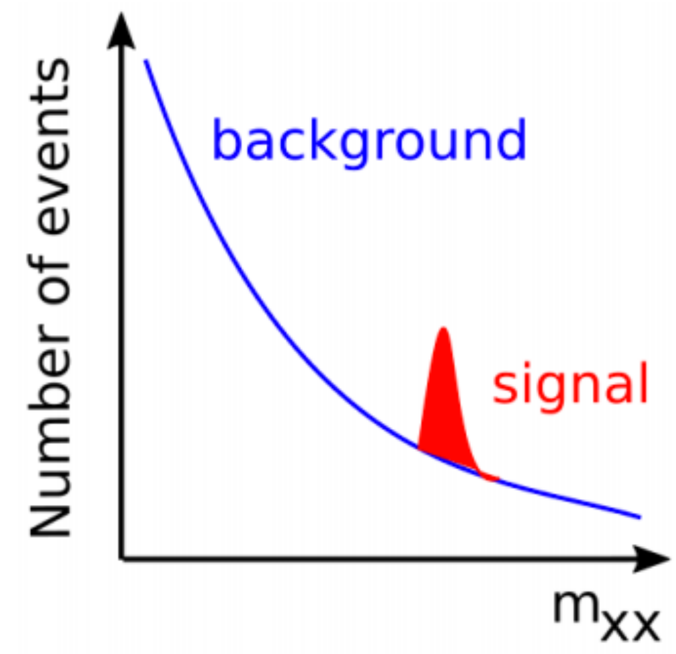
- Increase in energy from 8 → 13 TeV
- Major new-physics sensitivity has opened up, **specially at high masses**
- Exceptional LHC performance in 2016 and 2017 following 13 TeV commissioning in 2015
- Integrated luminosity so far: 86 fb^{-1} recorded (80 fb^{-1} physics)





Exotic Diboson Searches

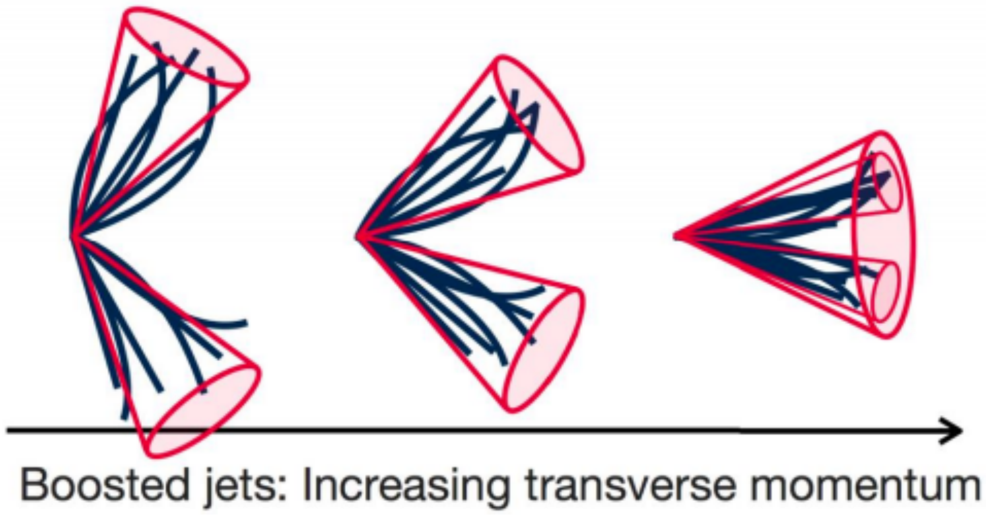
- Historically connected to electroweak symmetry breaking models
- Scenarios
  - ➡ Spin 0: Heavy scalars in extended Higgs sector
  - ➡ Spin 1: Extended gauge models (W′, Z′ in SSM/HVT)
  - ➡ Spin 2: Kaluza-Klein gravitons (bulk RS)
- Look into many final states:
  - ➡ VV, VH, HH, ZH (H≠125), XH, Vγ,γγ in leptonic, semi-leptonic and fully hadronic final states
  - ➡ Some analyses also look at different production modes (qq/ggF/VBF/VH)
  - ➡ VV, Vγ analyses assume narrow width resonances; γγ also look into larger width (4 MeV to 10% width)

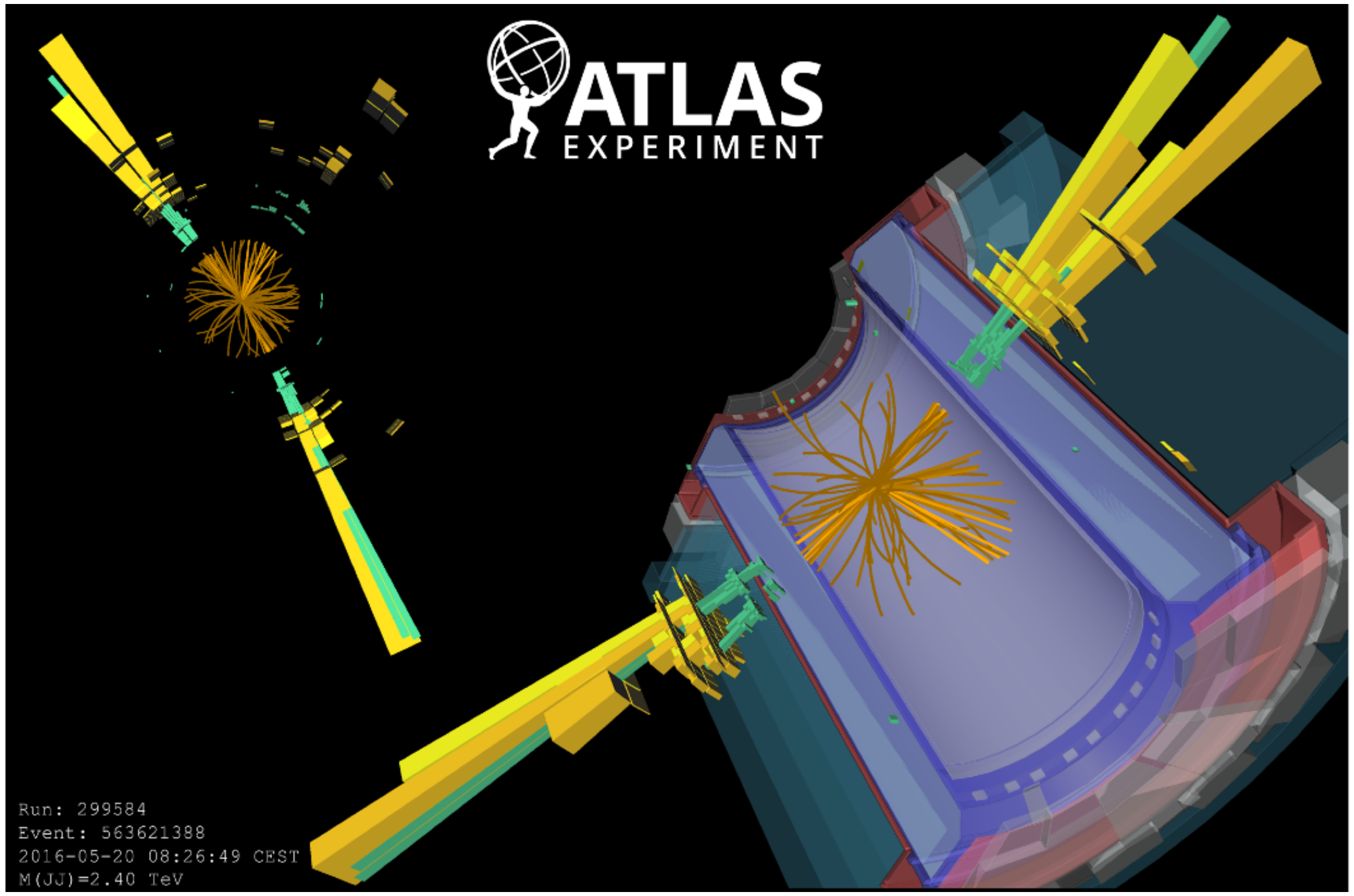


	W	Z	
Charged leptons	~33%	~10%	rare/clean
Hadrons	~67%	~70%	common/dirty
Neutrinos	-	~20%	

Boosted Boson Tagging

- Wide range of boson p_T: distinct topologies for hadronic decays
  - ➡ Resolved: 2 small R jets (jj), anti-k_t R=0.4
  - ➡ Boosted: single large R jets (J), anti-k_t R=1.0
- Jet grooming algorithm: trimming
- Boson tagging: 50% flat signal efficiency (~ 2% QCD eff.)
  - ➡ Large-radius jet mass
  - ➡ Energy correlation variable $D_2^{\beta=1}$





More on Jason Veatch's talk

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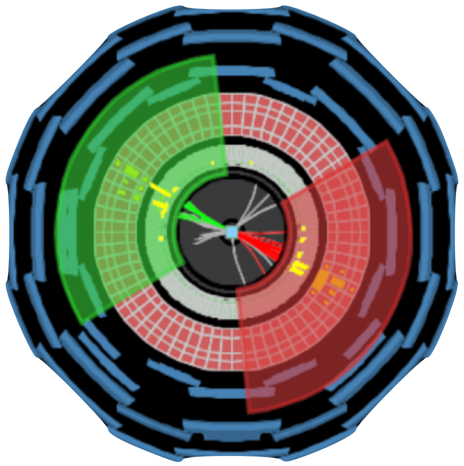
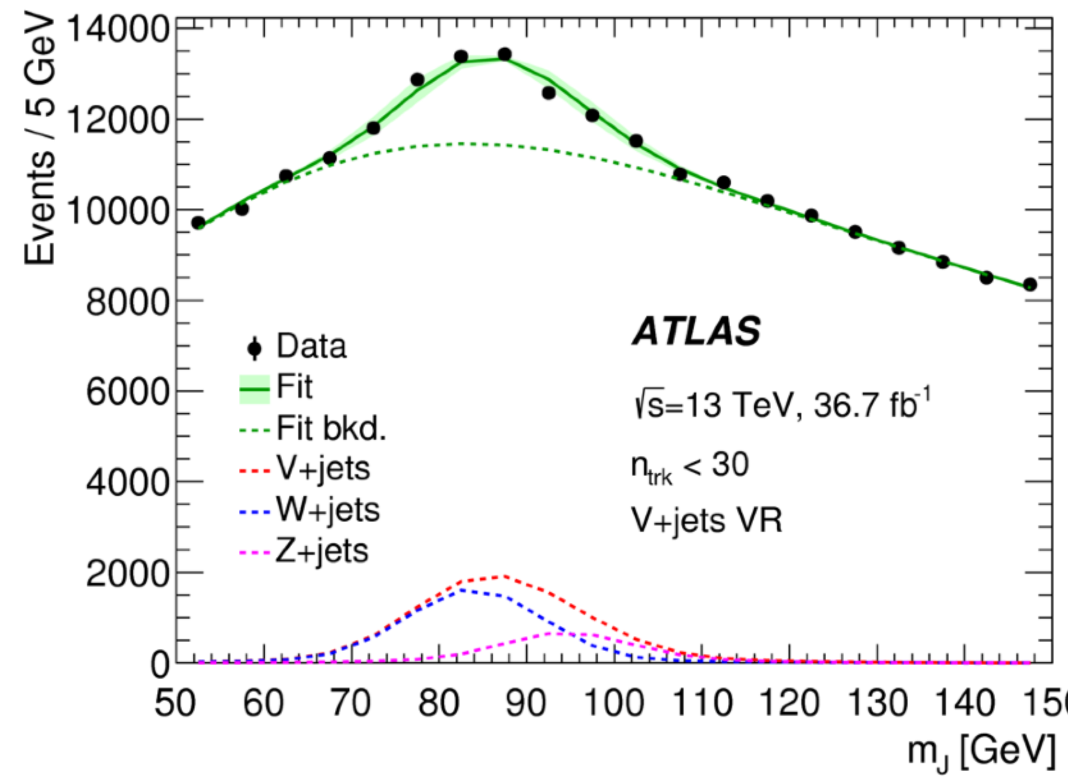
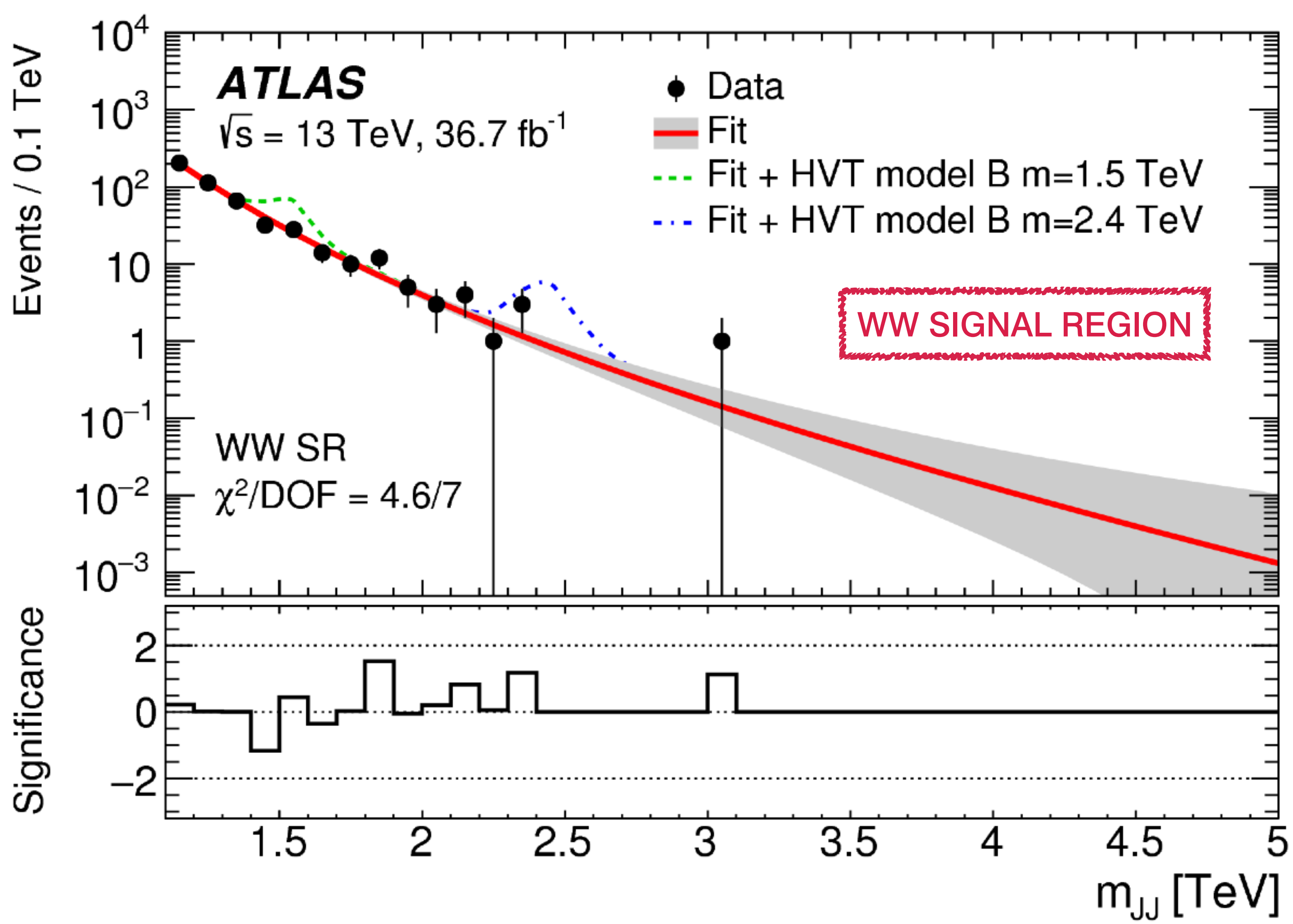
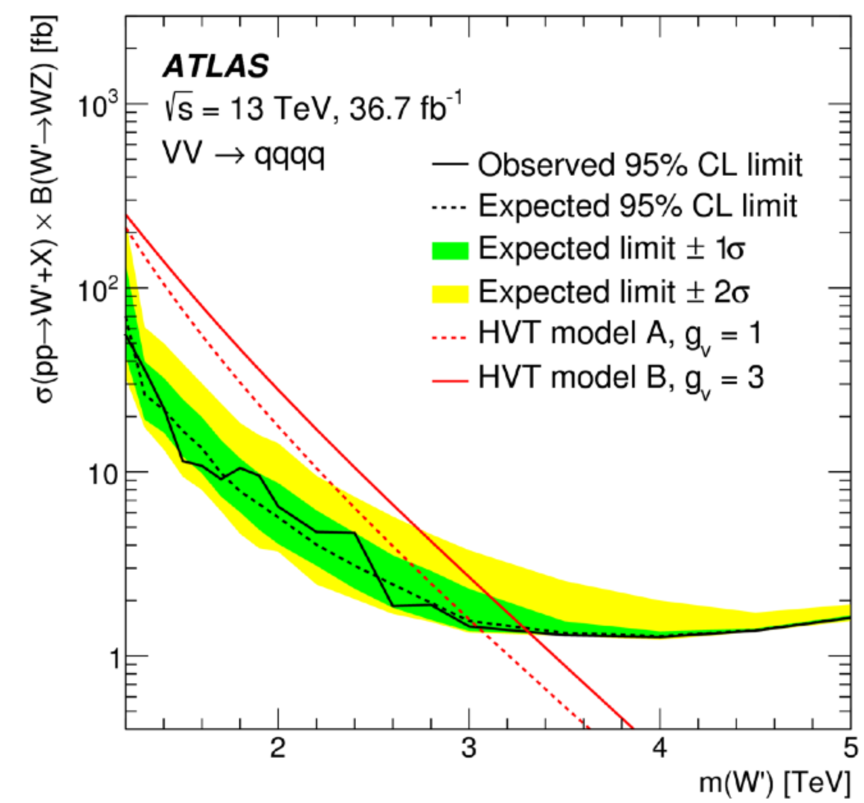
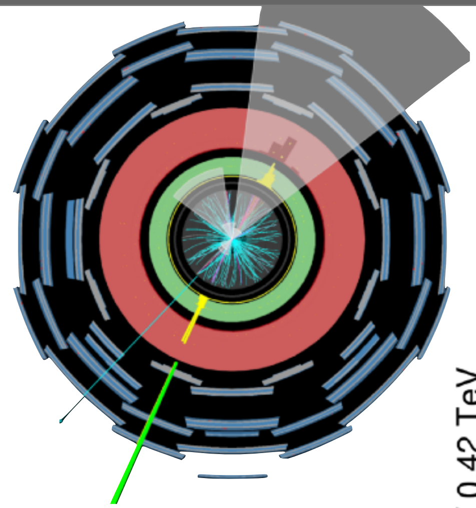


VV → JJ









VV → ℓvqq

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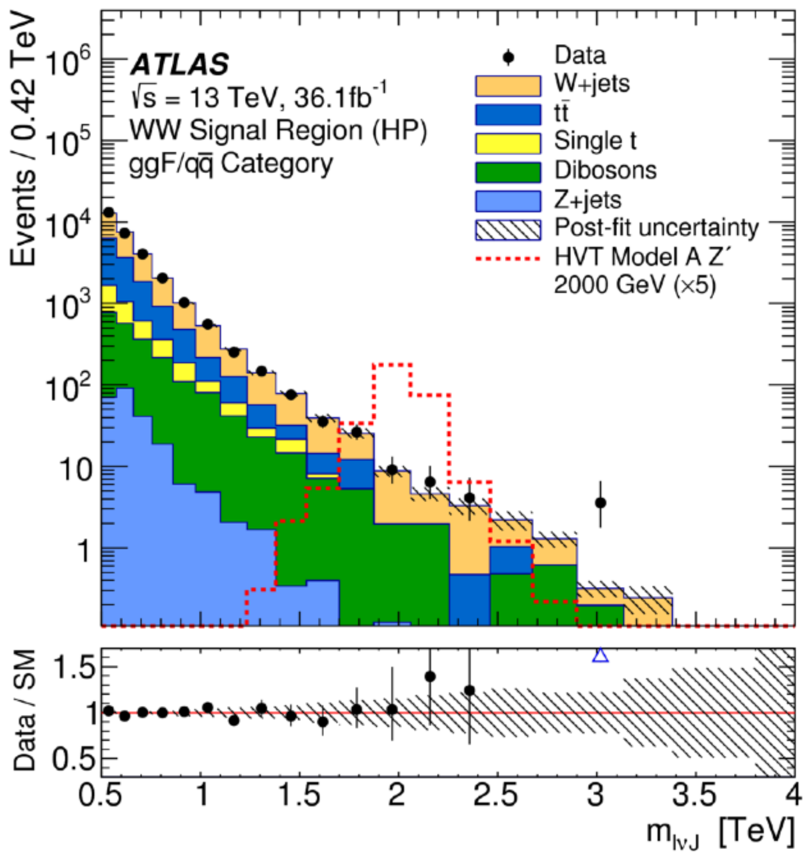
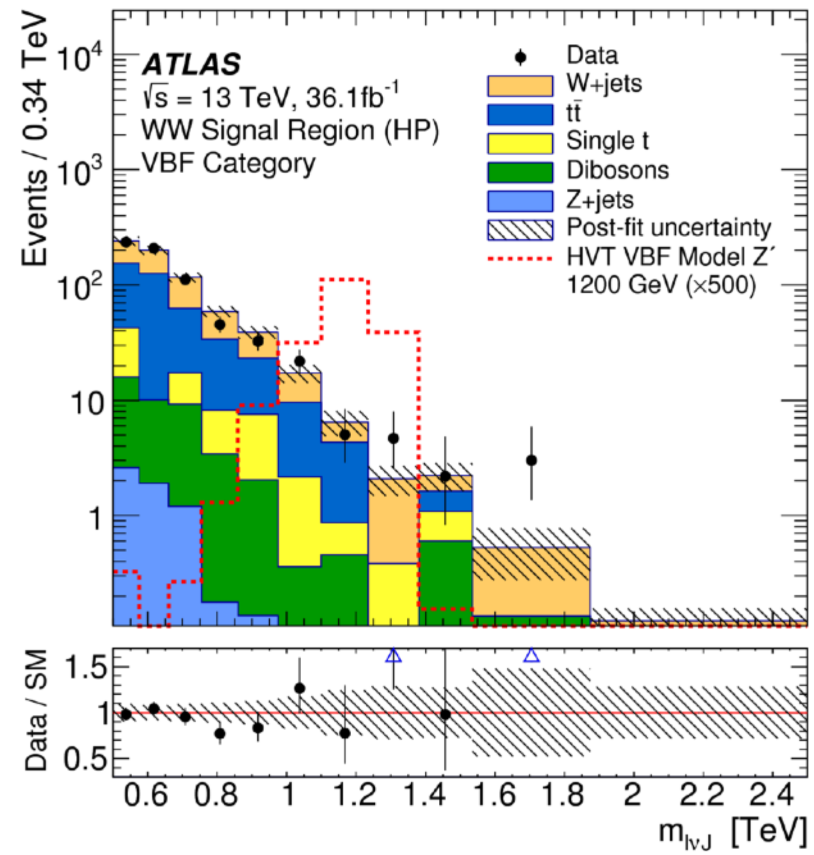
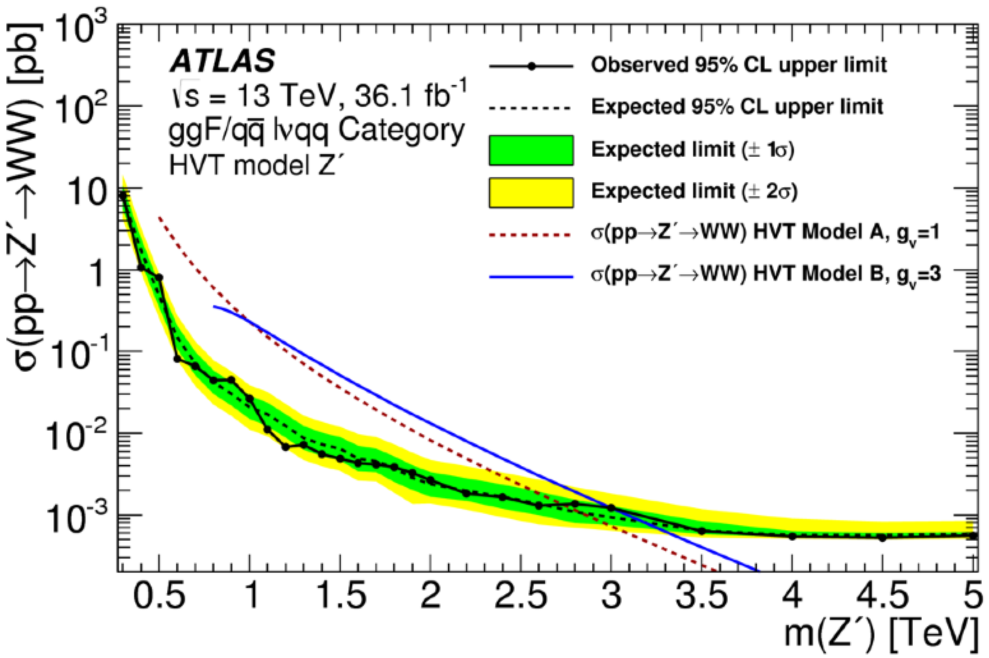
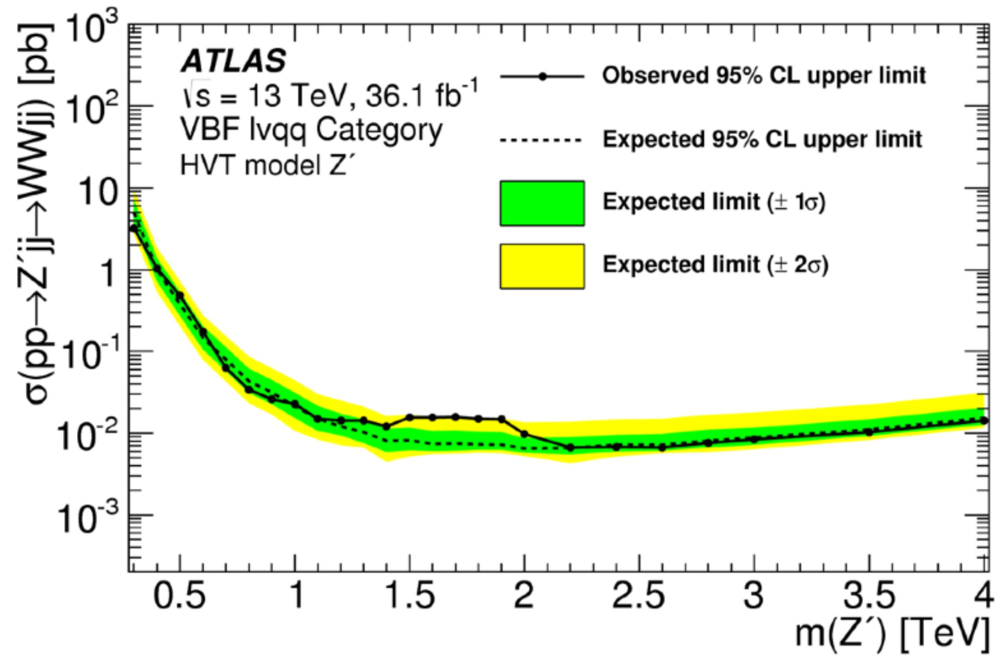
WW ggF/qq - Boosted high purity



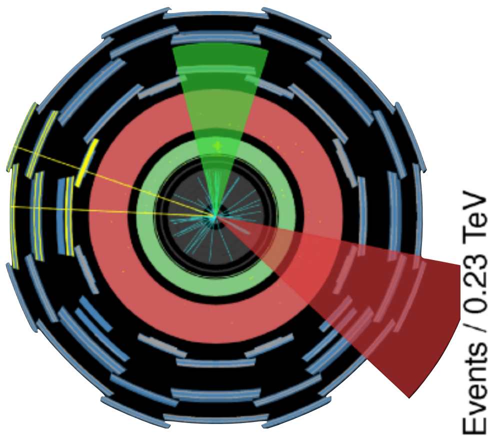
WW VBF- Boosted high purity

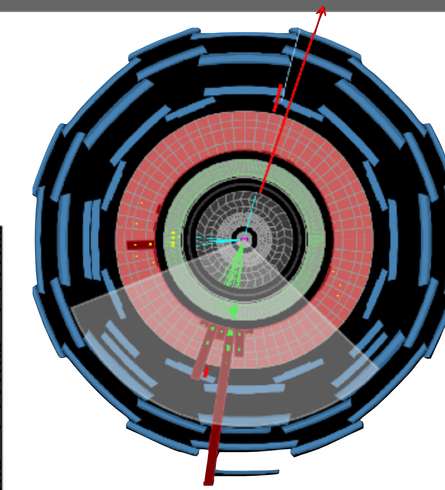


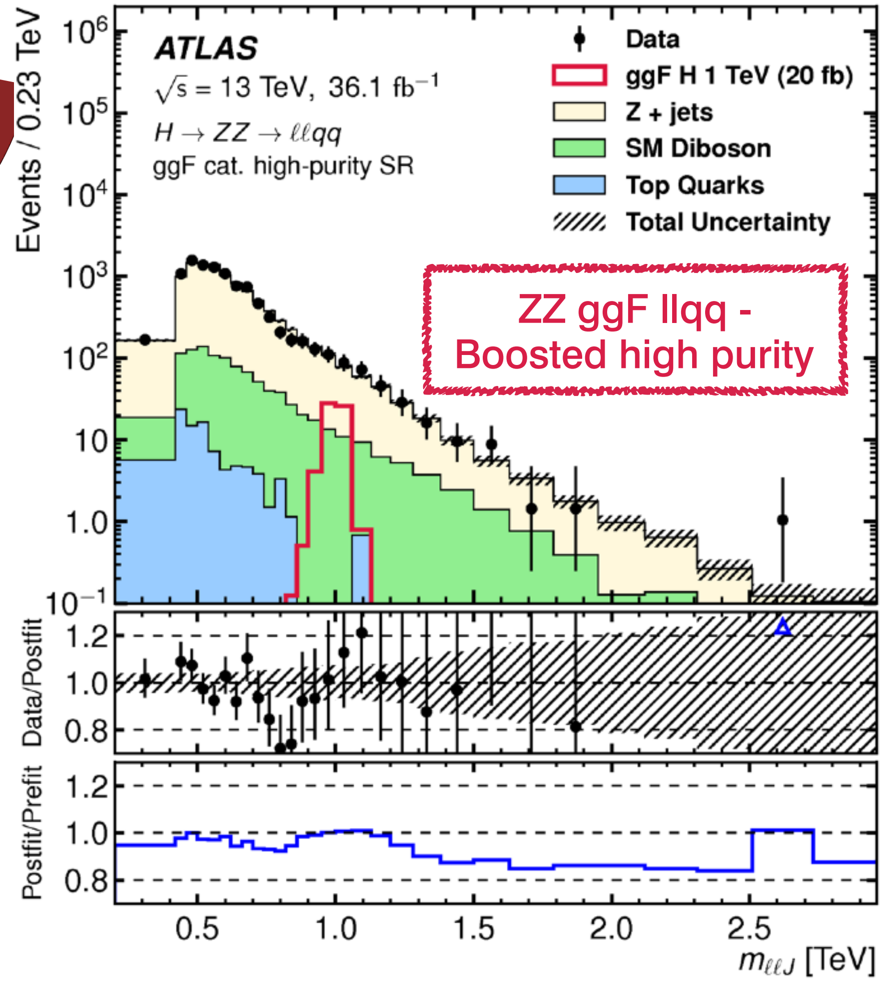


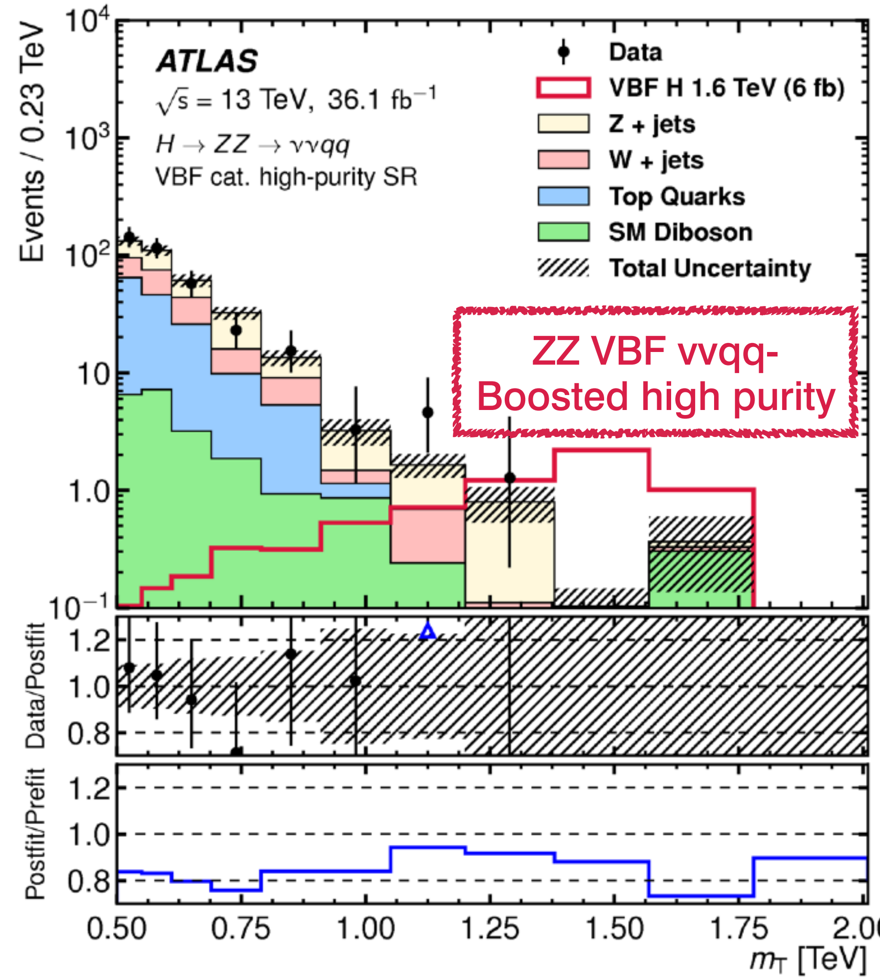


VV → ℓℓqq, ννqq









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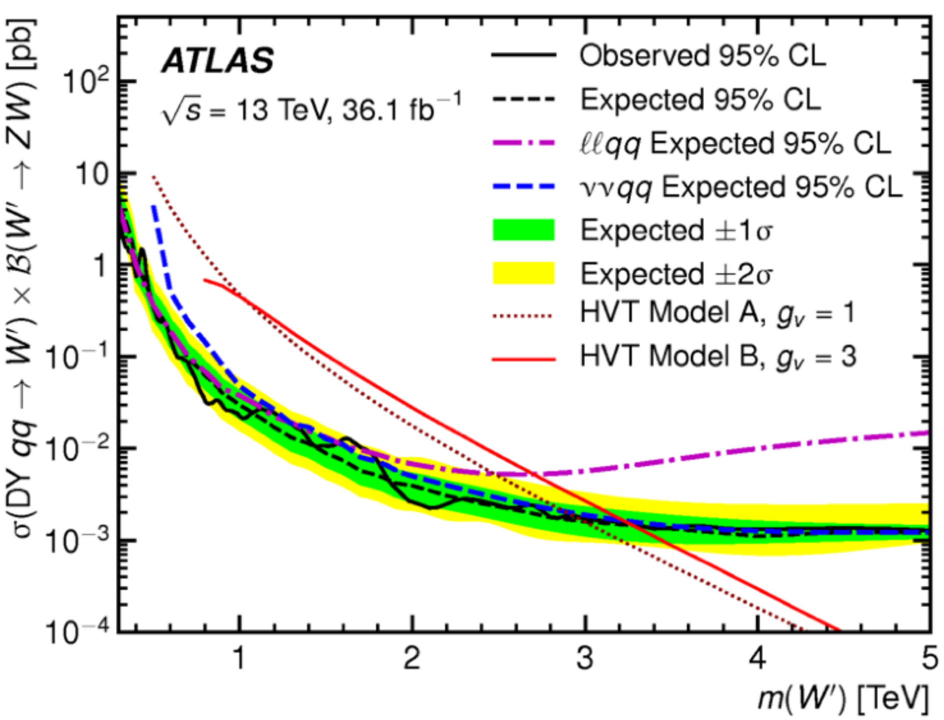
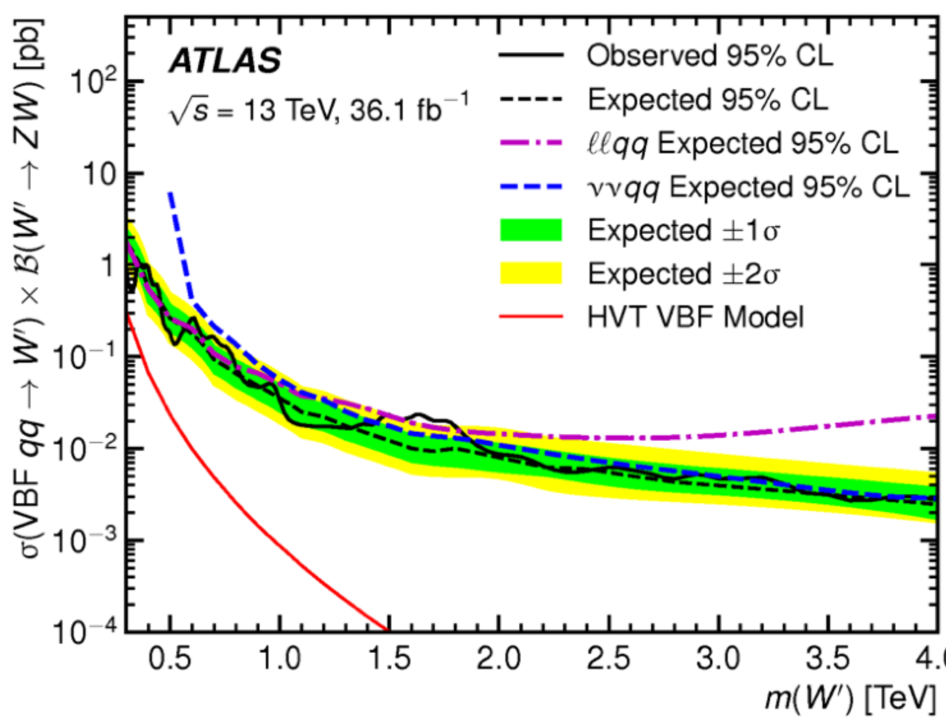
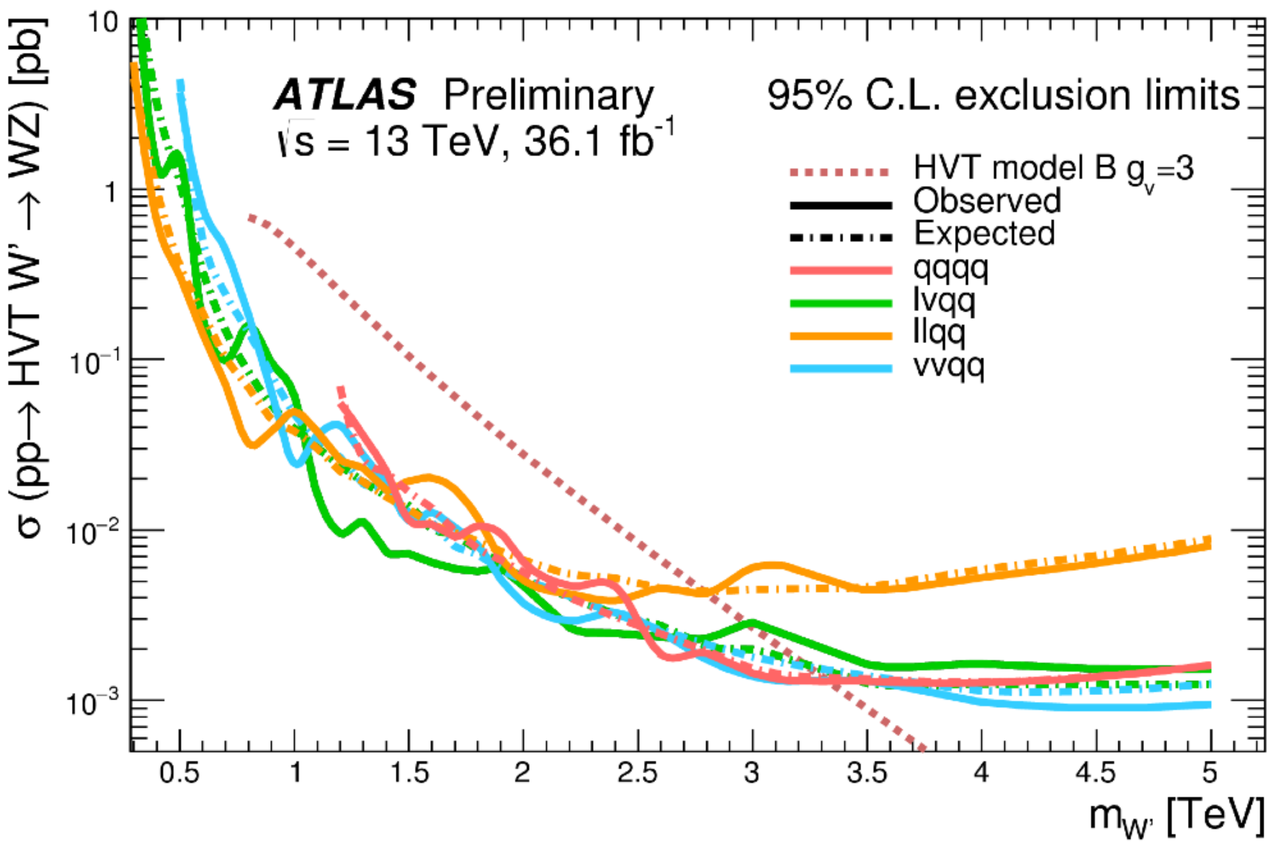
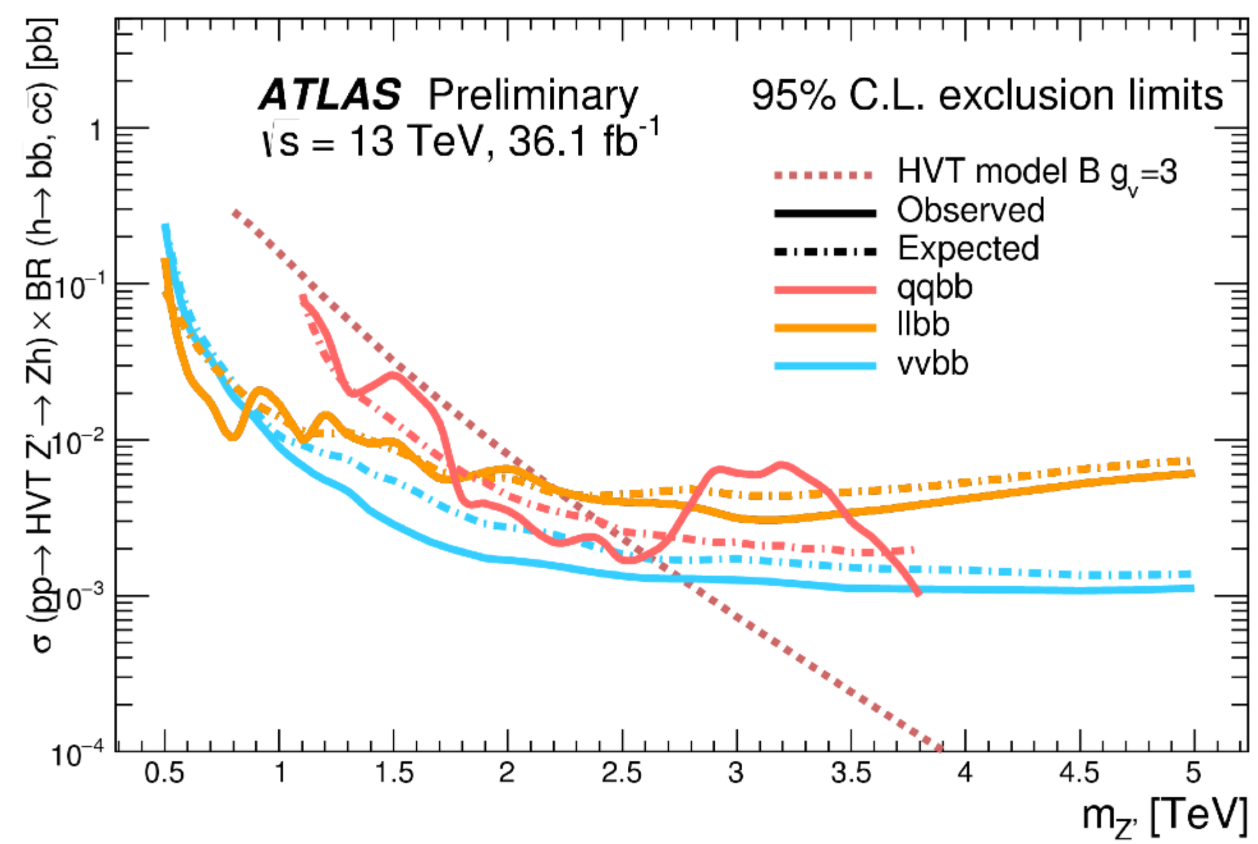




VV and VH Searches





- Complementarity in sensitivity amongst channels

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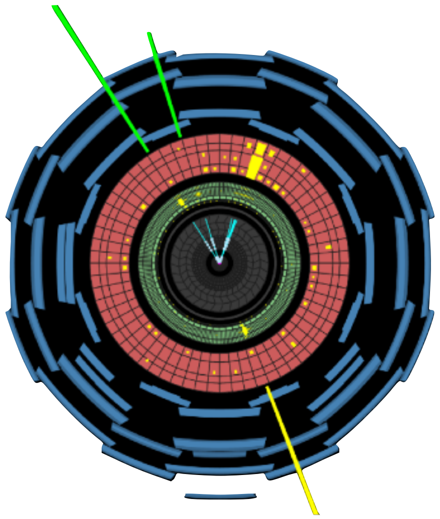
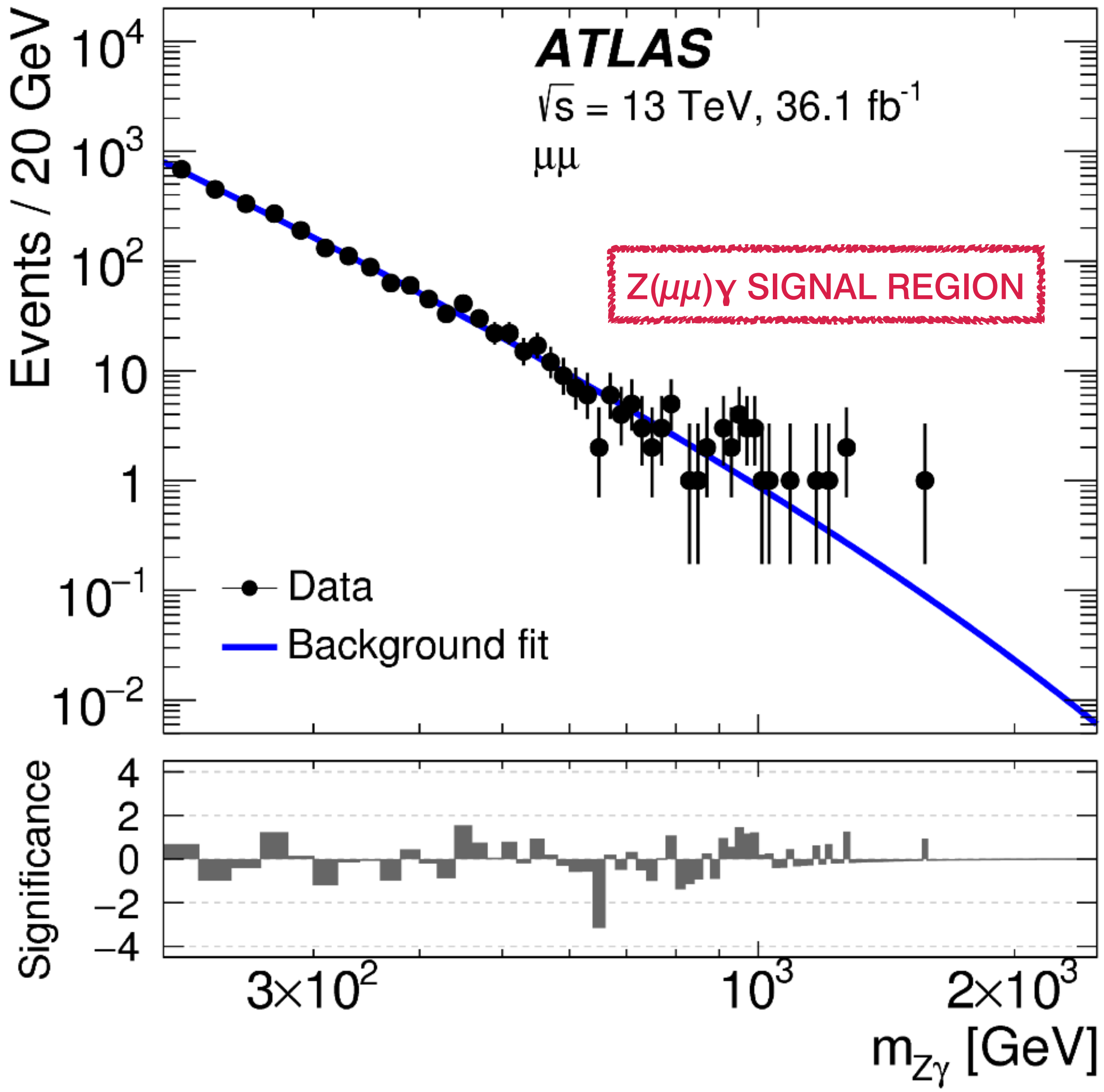
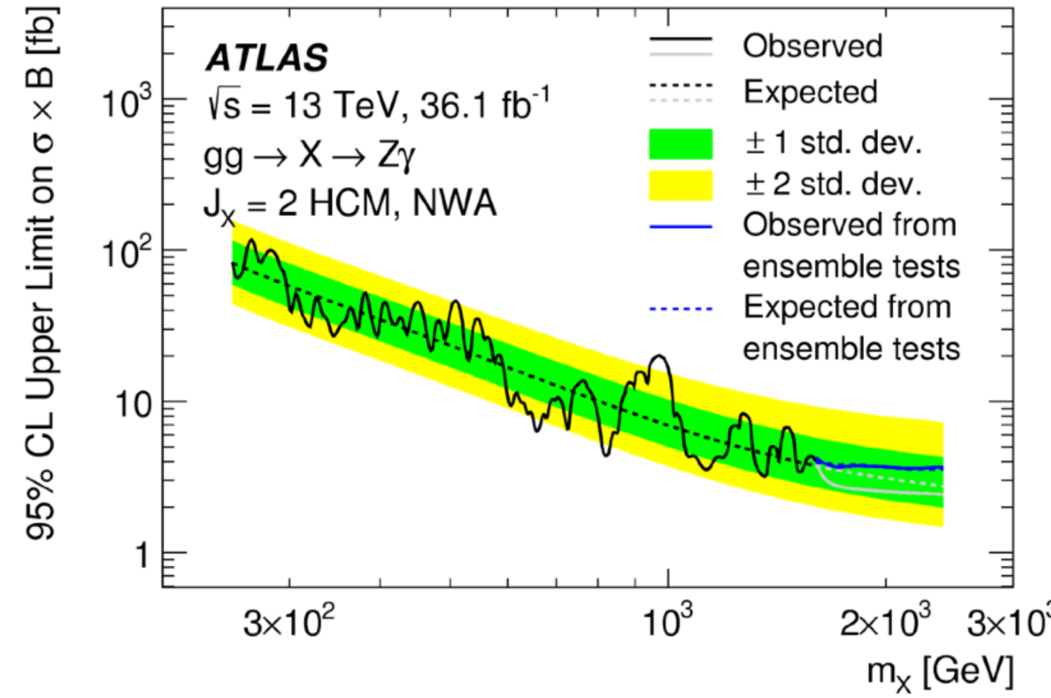
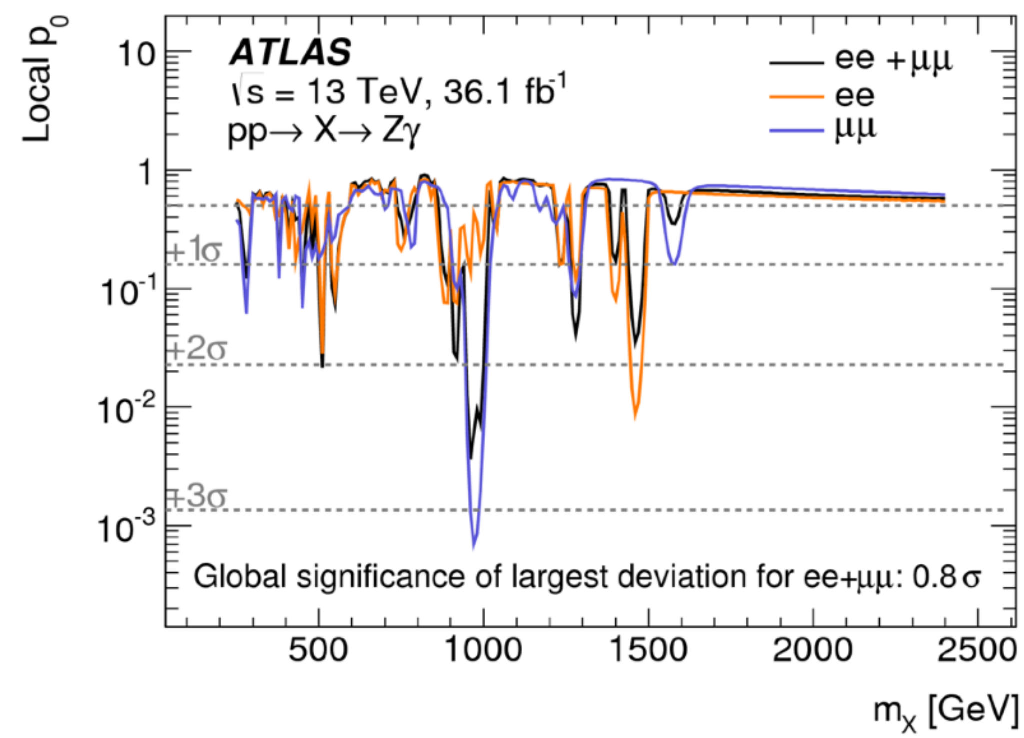
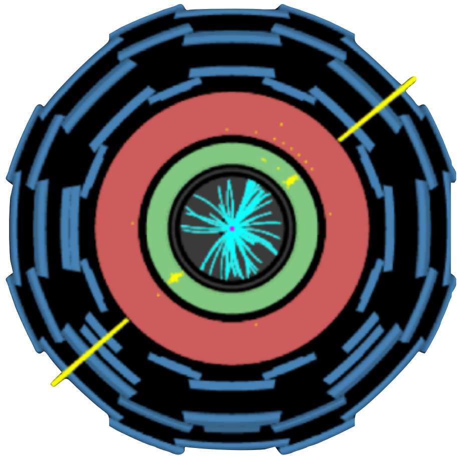


$X \to Z\gamma$









$X \rightarrow \gamma\gamma$

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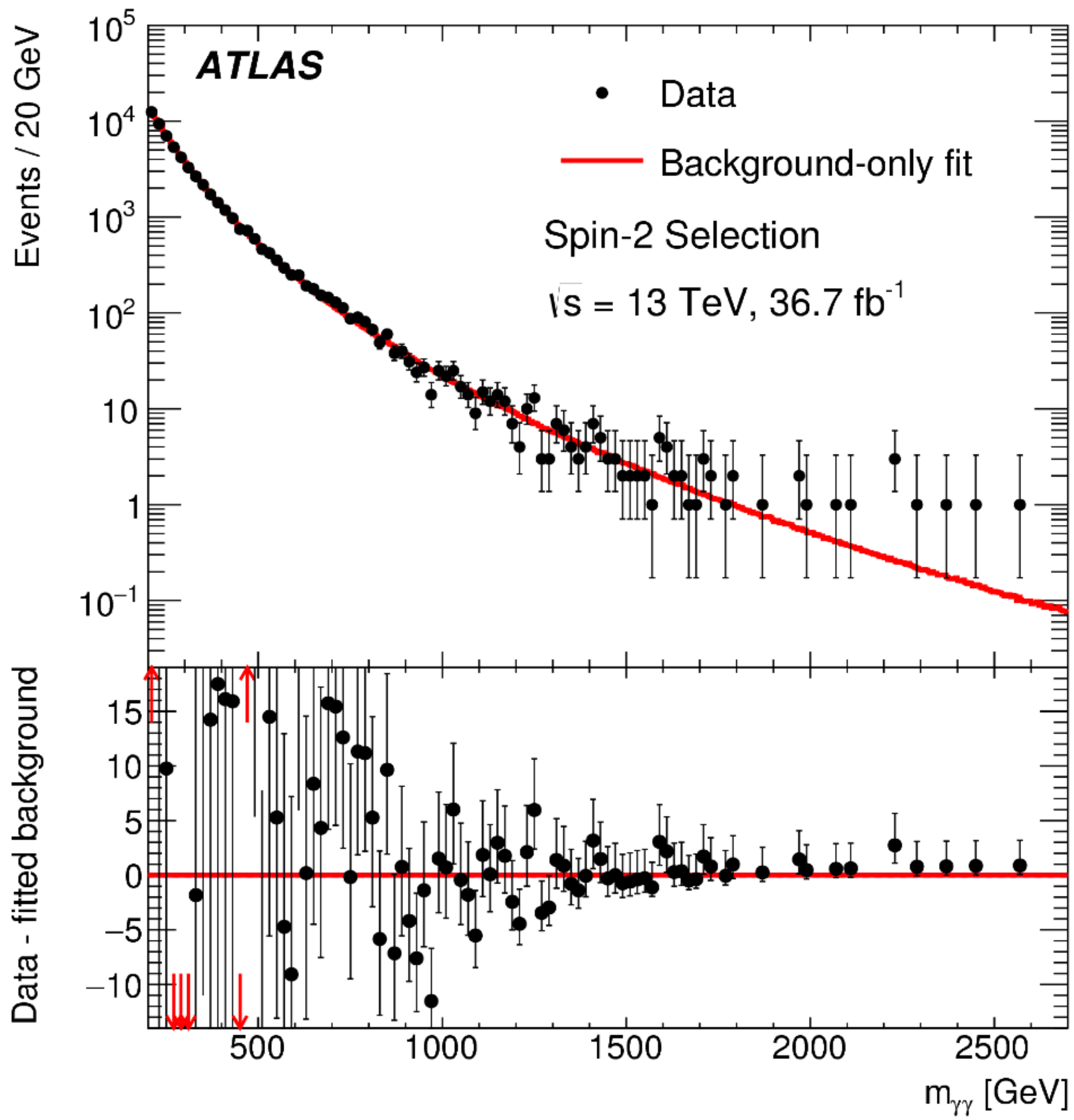
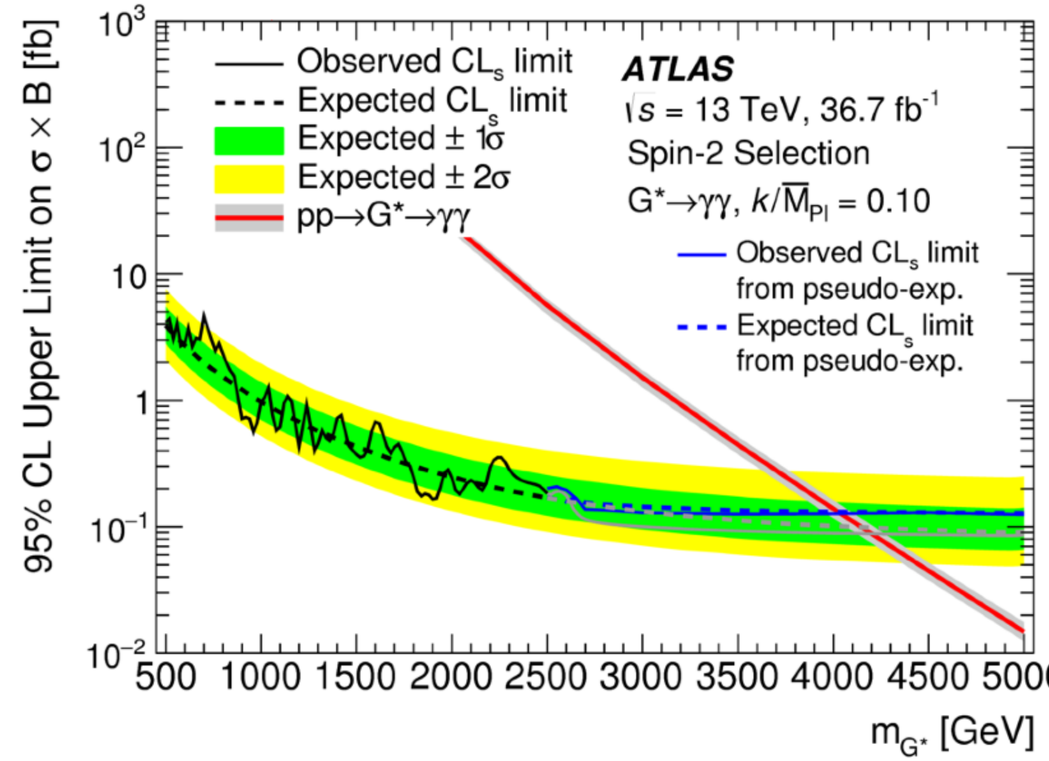
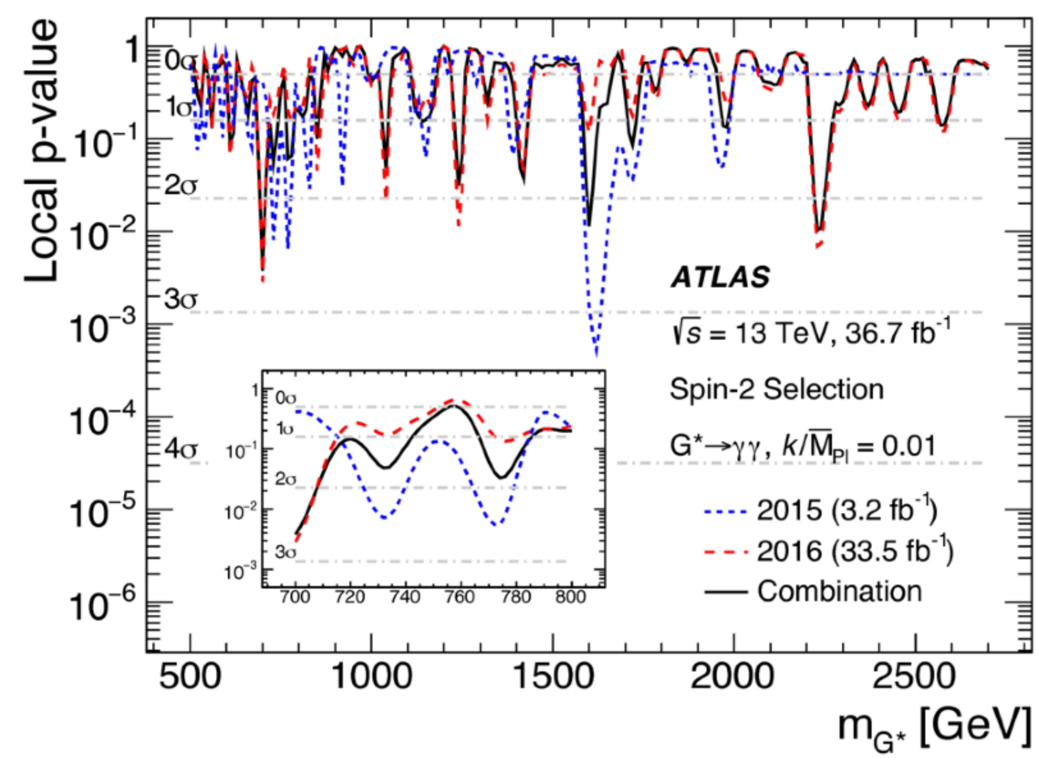
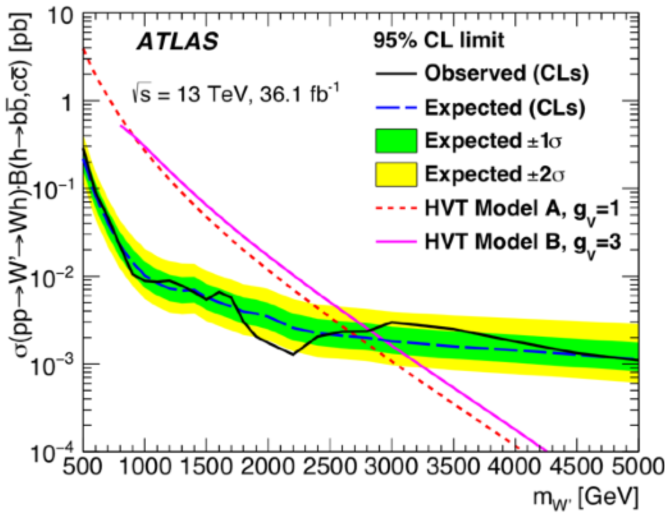
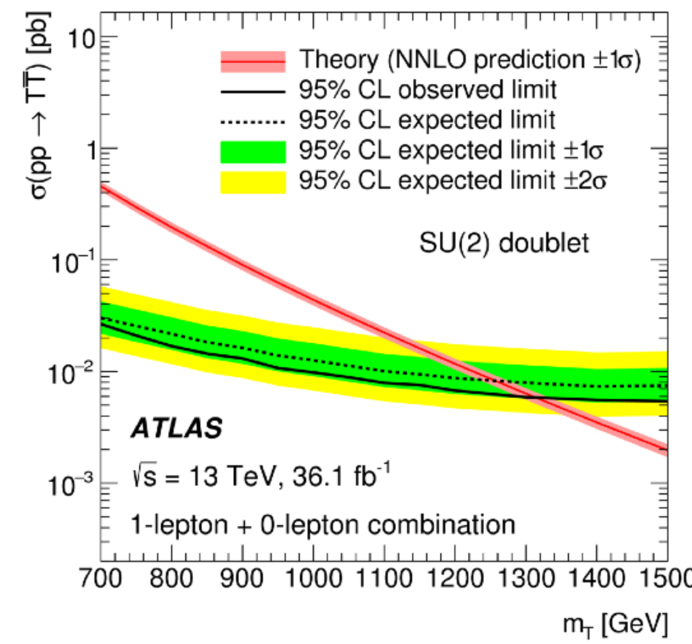


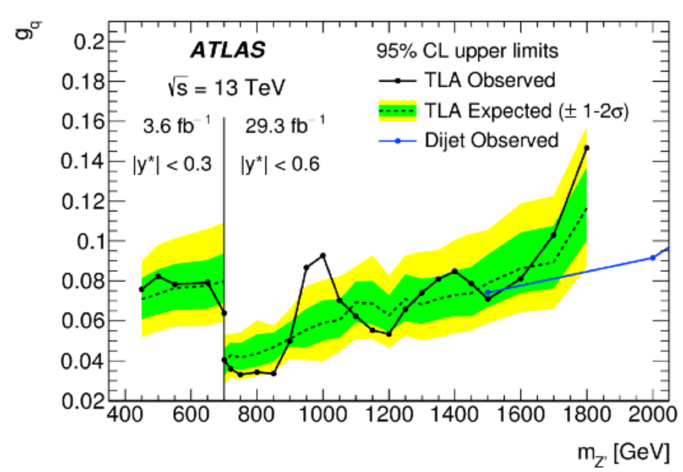


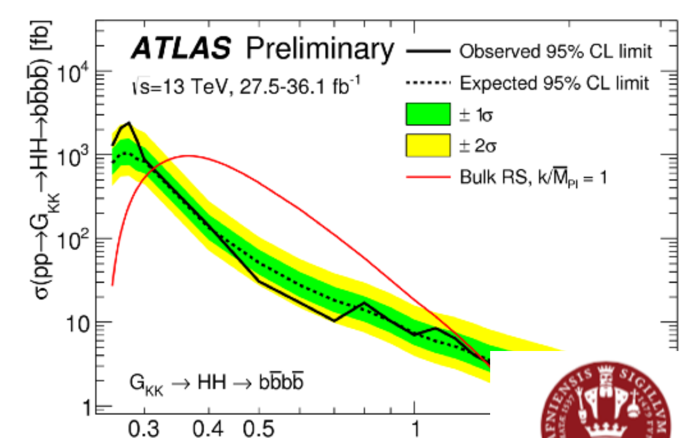


Exotic Searches in ATLAS









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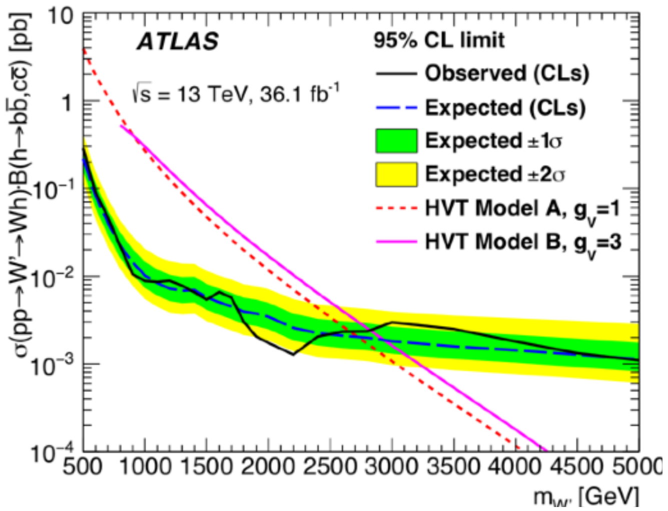

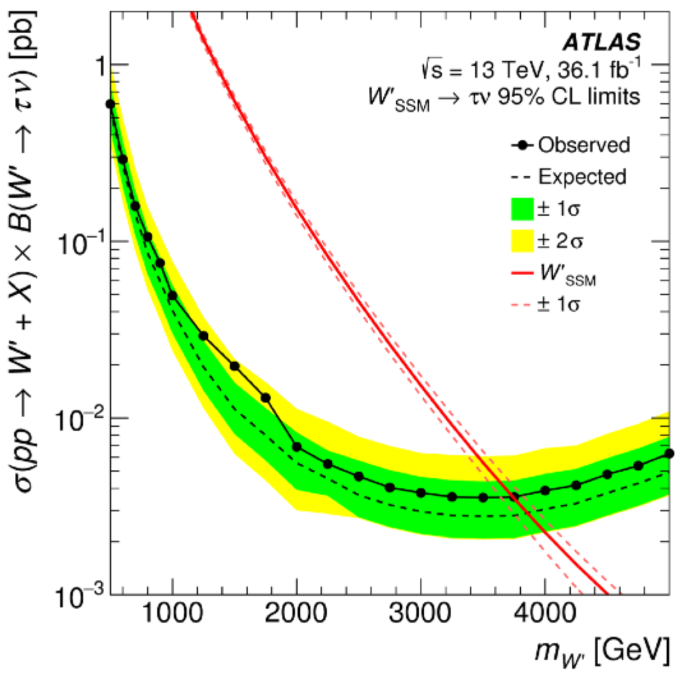

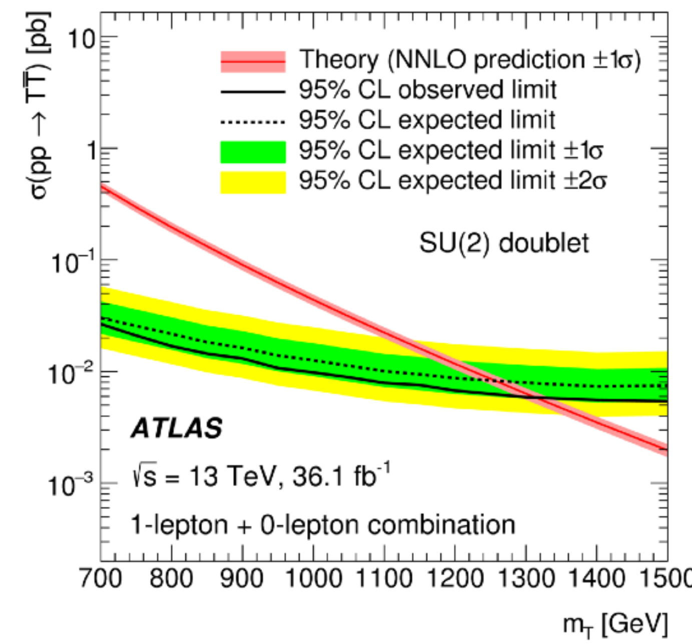

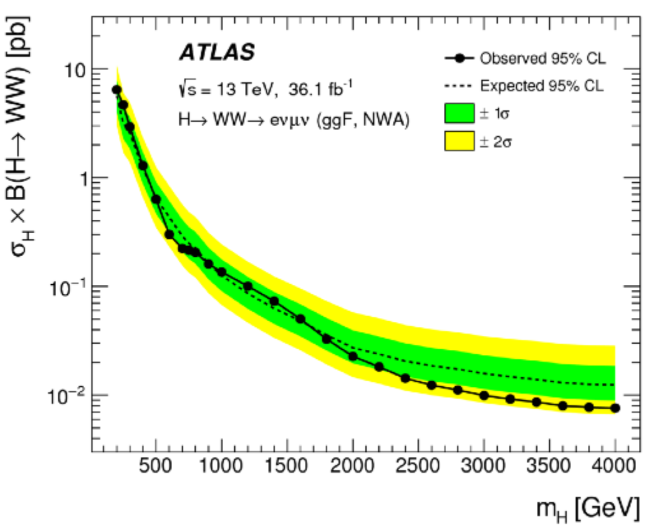

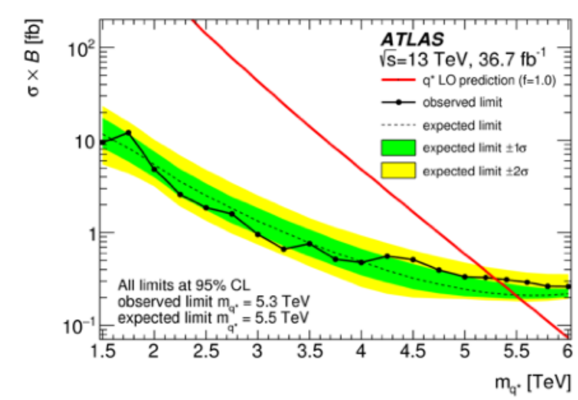

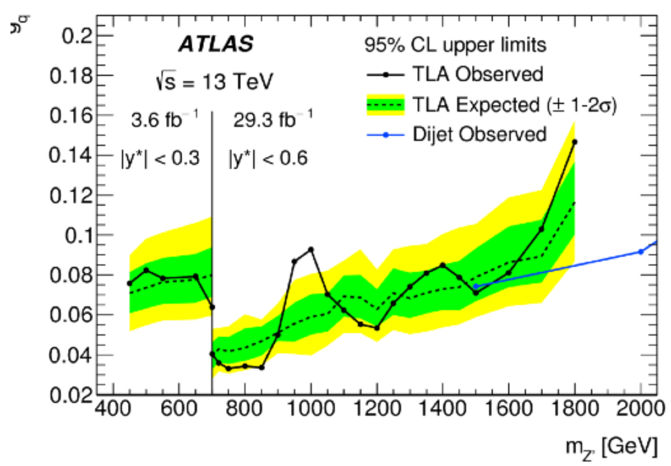

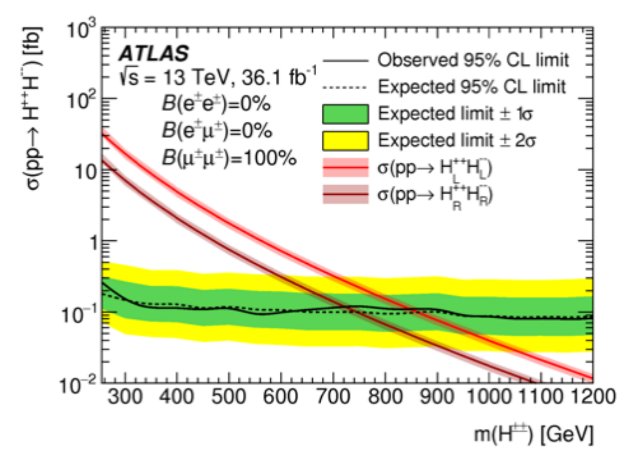

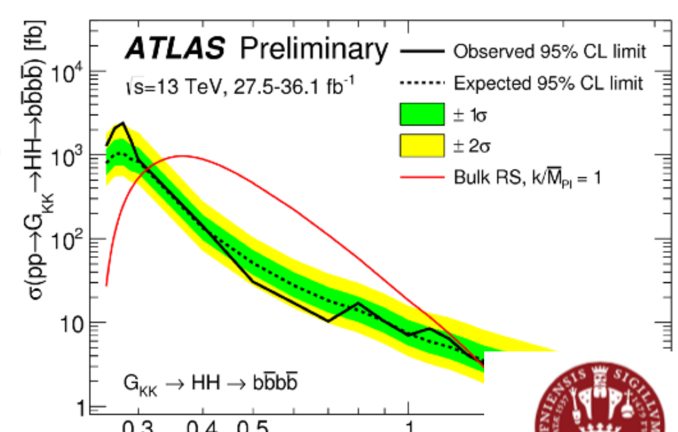

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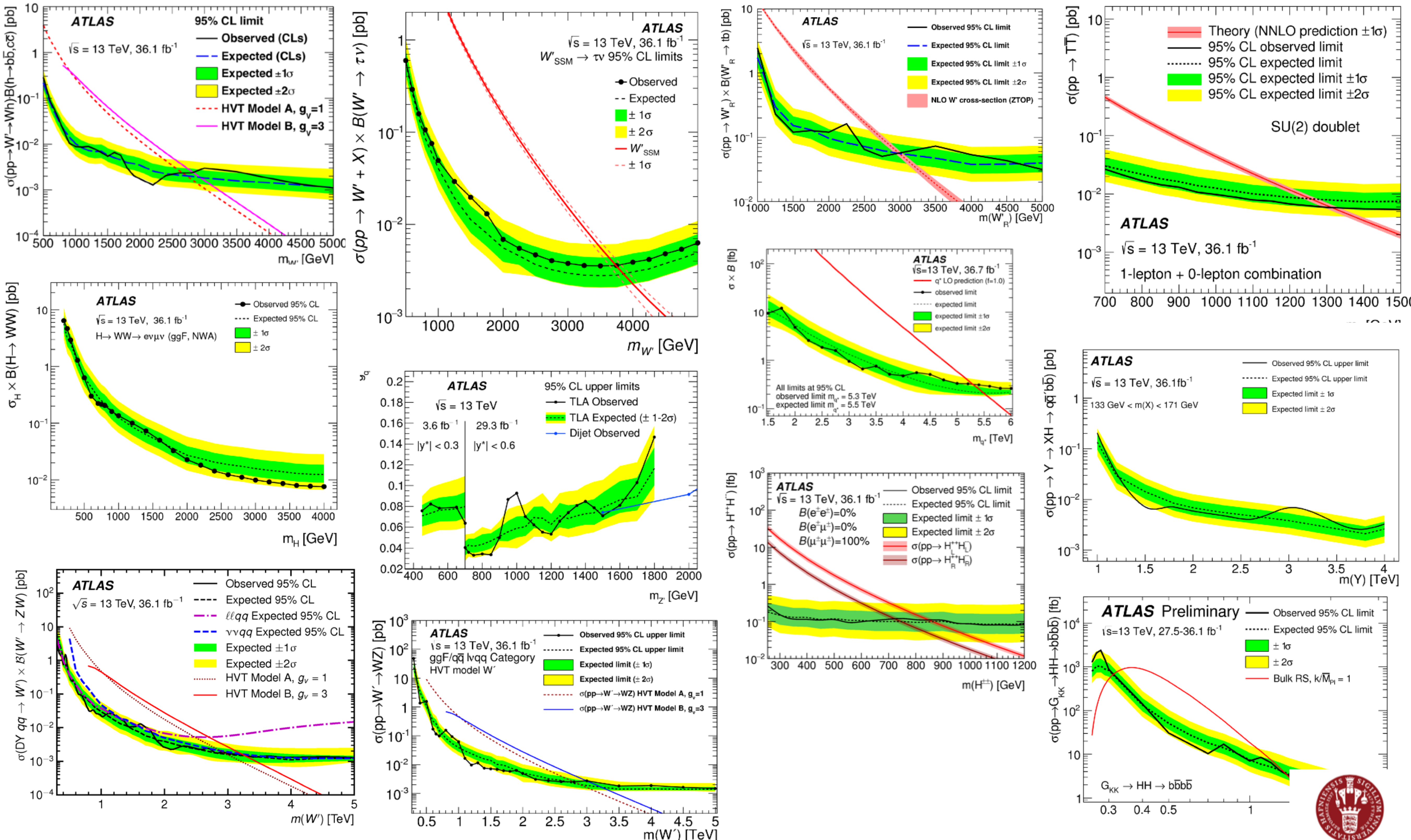

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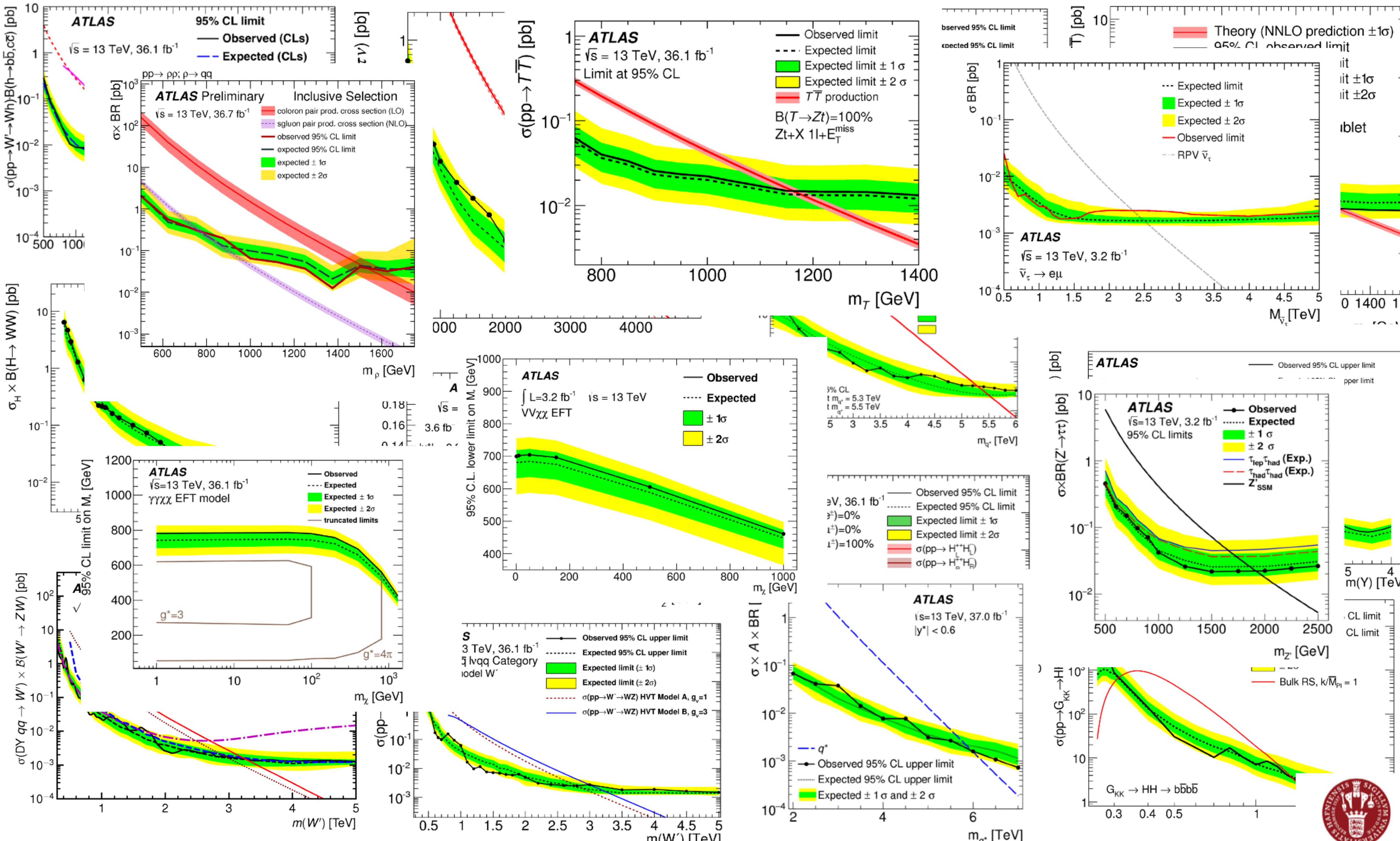


Exotic Searches in ATLAS

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int\mathcal{L}\, dt[\text{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e,\mu$	1 – 4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	$\geq 1\ e,\mu$	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\ e,\mu$	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	$1\ e,\mu$	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e,\mu$	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	$1\ e,\mu$	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	$1\ e,\mu$	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	$0\ e,\mu$	2 J	–	36.7	V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	$1\ e,\mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	$0\ e,\mu$	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^-	1703.09217
	CI $\ell\ell qq$	$2\ e,\mu$	–	–	36.1	Λ 40.1 TeV	η_{LL}^-	ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/$\geq 3\ e,\mu$	≥ 1 b, ≥ 1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	$0\ e,\mu$	1 – 4 j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	$0\ e,\mu$, $1\ \gamma$	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	$0\ e,\mu$	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	$2\ e$	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	$2\ \mu$	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	$1\ e,\mu$	≥ 1 b, ≥ 3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e,μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	$1\ e,\mu$	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	$1\ e,\mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	$1\ e,\mu$	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/$\geq 3\ e,\mu$	≥ 2/≥ 1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	$1\ e,\mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	$1\ e,\mu$	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e,μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	$3\ e,\mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e,\mu,\tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	$2\ e,\mu$	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e,μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	$3\ e,\mu,\tau$	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	$1\ e,\mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

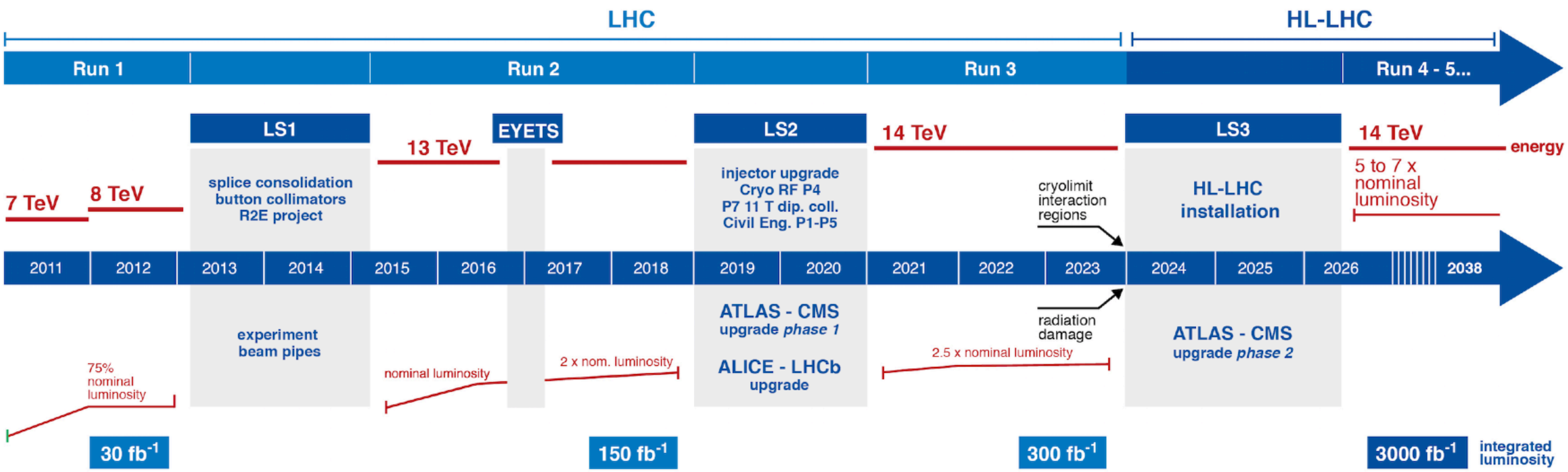
Mass scale [TeV]: 10^{-1}, 1, 10

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).

Looking ahead

- After the 8→13 TeV energy increase, no obvious new physics at high masses has been discovered so far
  - ➡ More luminosity will not add a huge sensitivity improvement for the straightforward high-mass searches
- Looking beyond means new techniques, new ideas, and increased precision in the Standard Model measurements to look for deviations



https://hilumilhc.web.cern.ch/about/hl-lhc-project

Looking Ahead - TCC jets

- Track-CaloCluster for jet substructure
  - ➡ Correlates low-level objects (tracks, calorimeter energy deposits) before running jet algorithms
    - – Different to ATLAS Particle Flow approach, which subtracts charged hadrons energy deposits
  - ➡ Improved resolution for substructure variables

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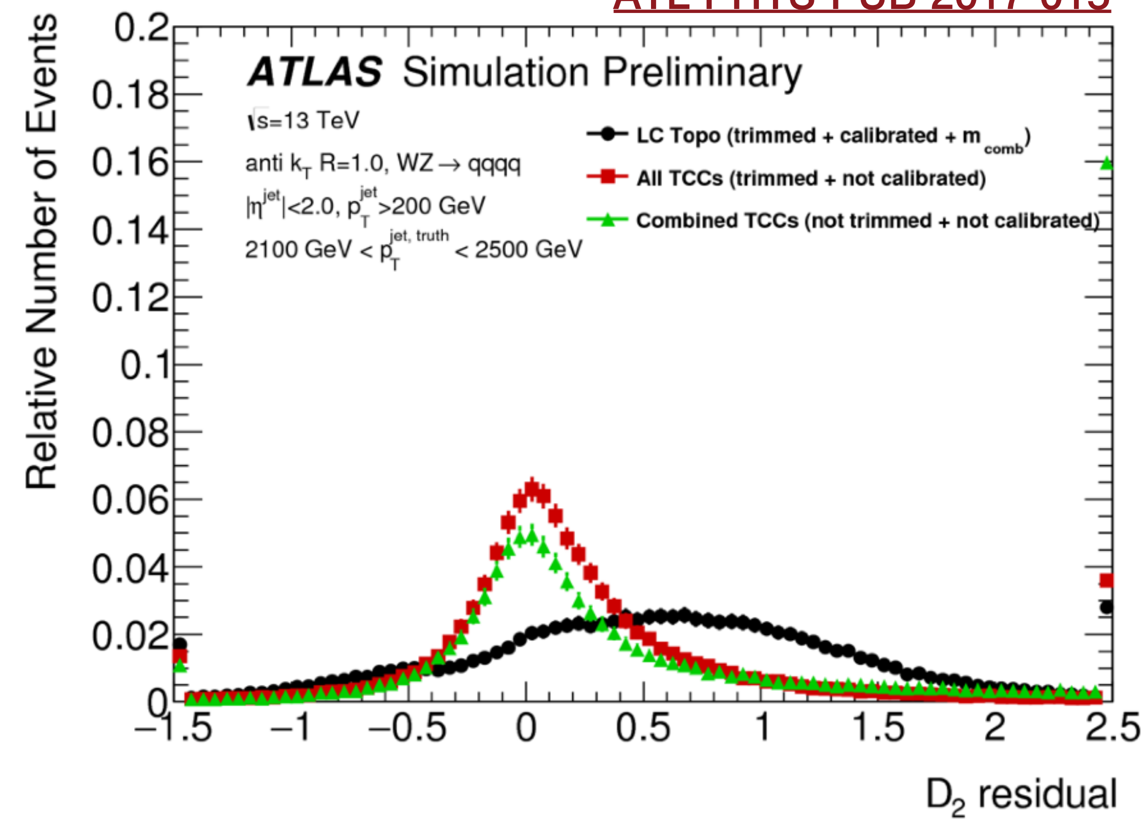

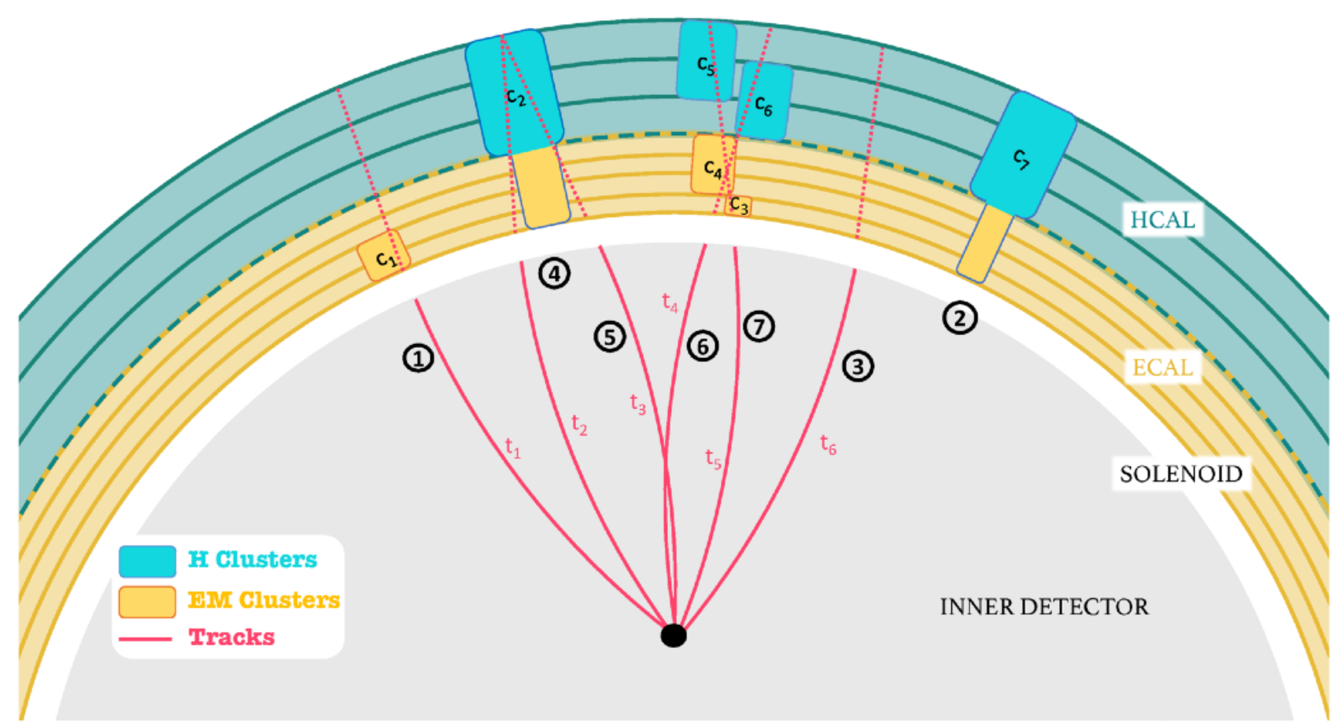

Summary and Outlook

- Wide programme of searches for high mass resonances at ATLAS
  - ➡ Probe beyond the Standard Model frontiers at multi-TeV scale
  - ➡ Many more exciting analysis not covered here, please check the ATLAS public pages
- Even higher masses and lower couplings to be probed by the end of Run 2
  - ➡ Expected luminosity ~120 fb^{-1} at 13 TeV centre-of-mass energy
  - ➡ Improvements in object reconstruction (TCC jets, new b-tag algorithms,…) and analysis techniques (machine learning, reweighting,…)
- Stay tuned for what the next years are going to unveil!