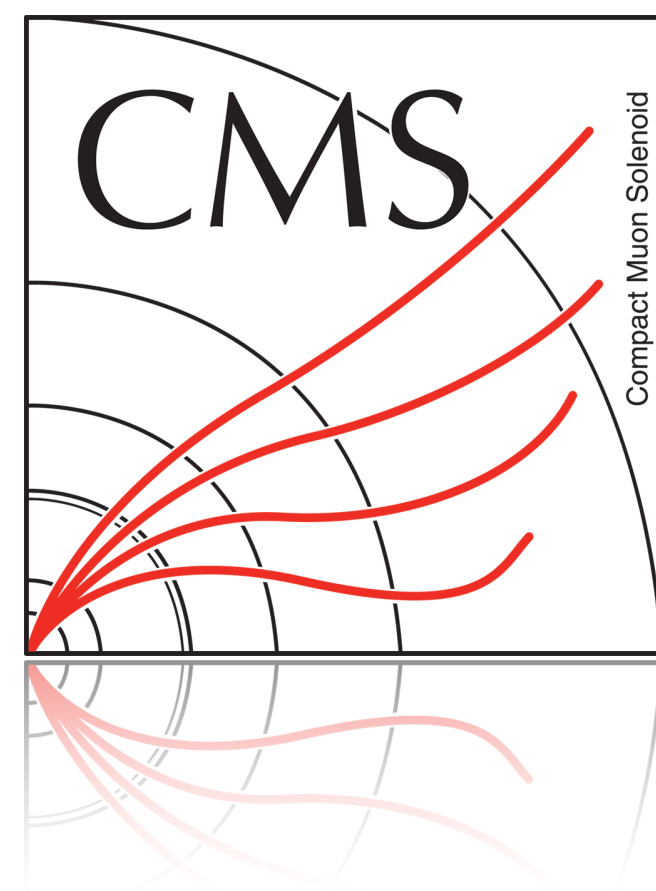


LHC anomalies: where ATLAS and CMS searches see tension with the Standard Model

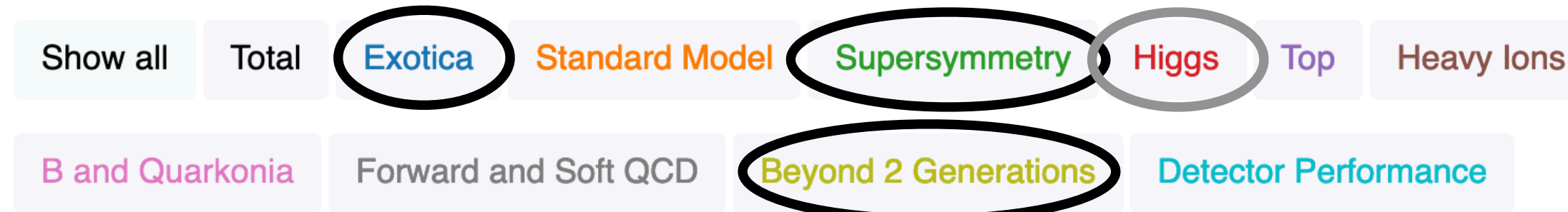
DPF-Pheno 24

May 17, 2024

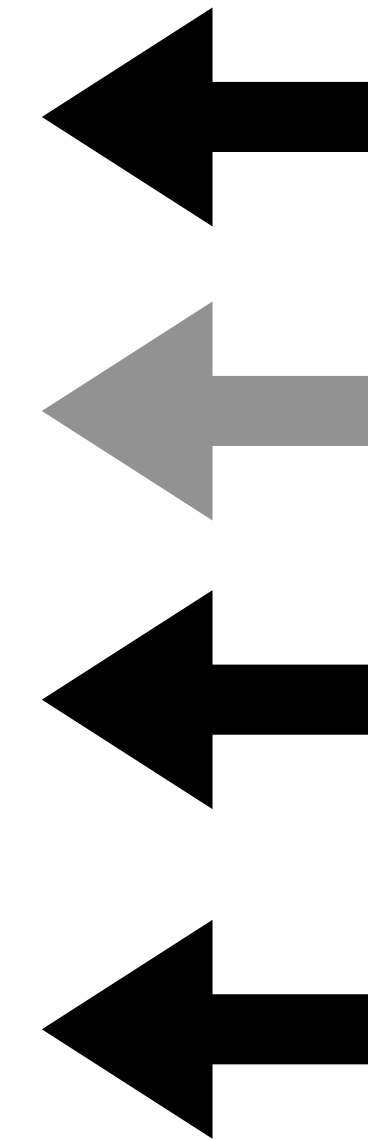
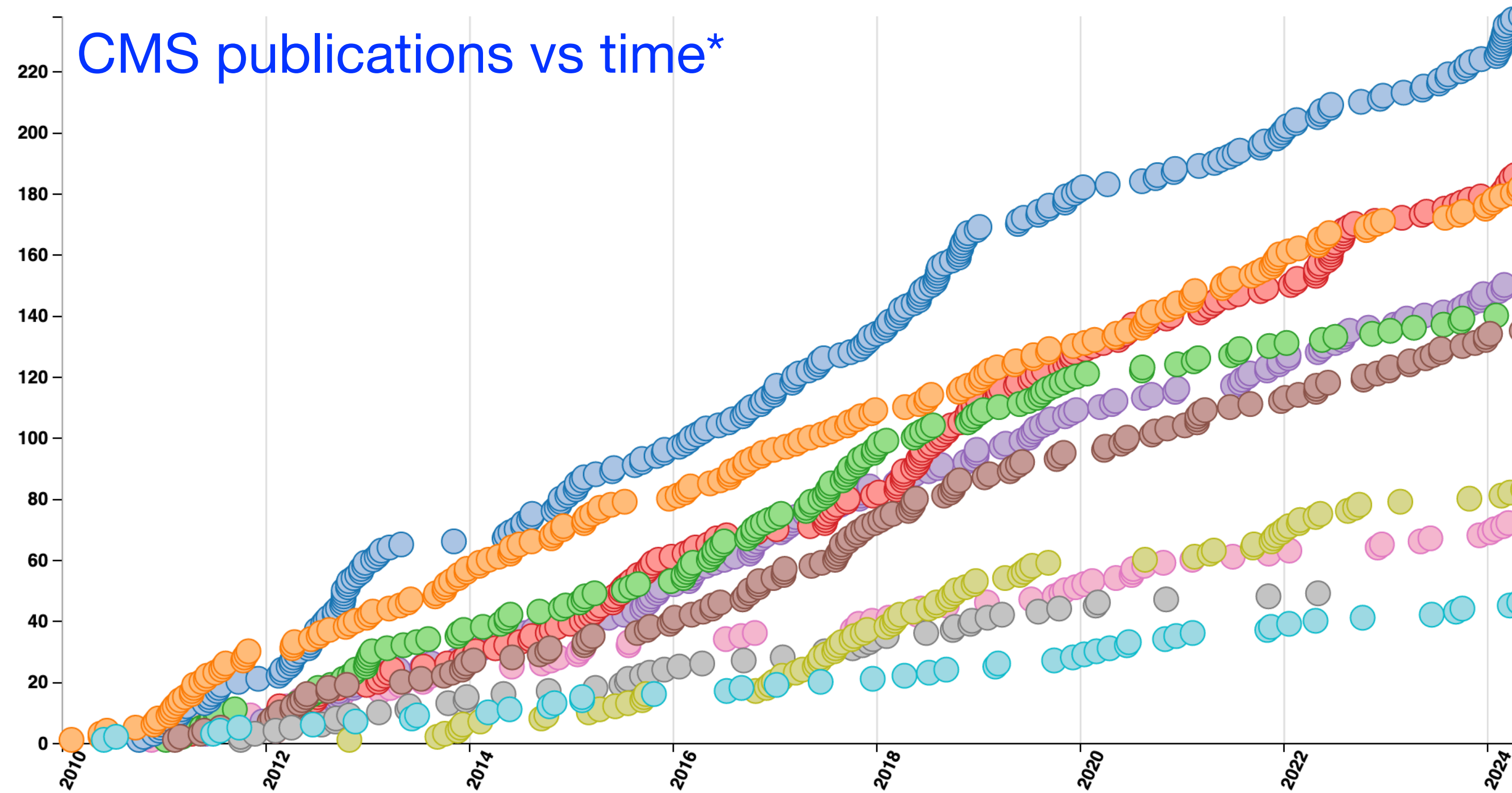
Valentina Dutta



Huge search program at the LHC!

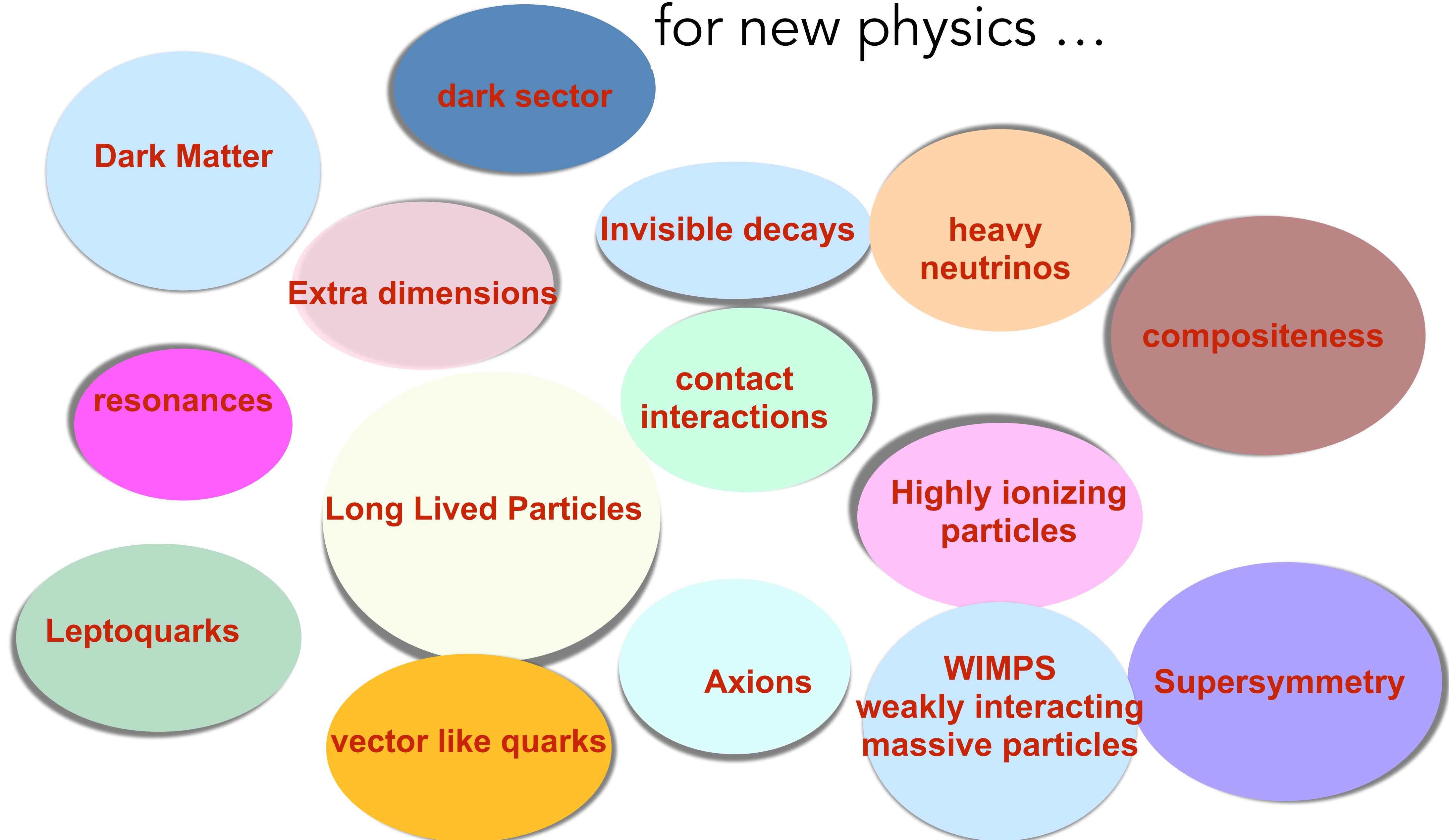


1283 collider data papers submitted as of 2024-05-10



*Similar for ATLAS!

Exploring all directions in searches for new physics ...



Covering vast range of new physics signatures

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$$

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

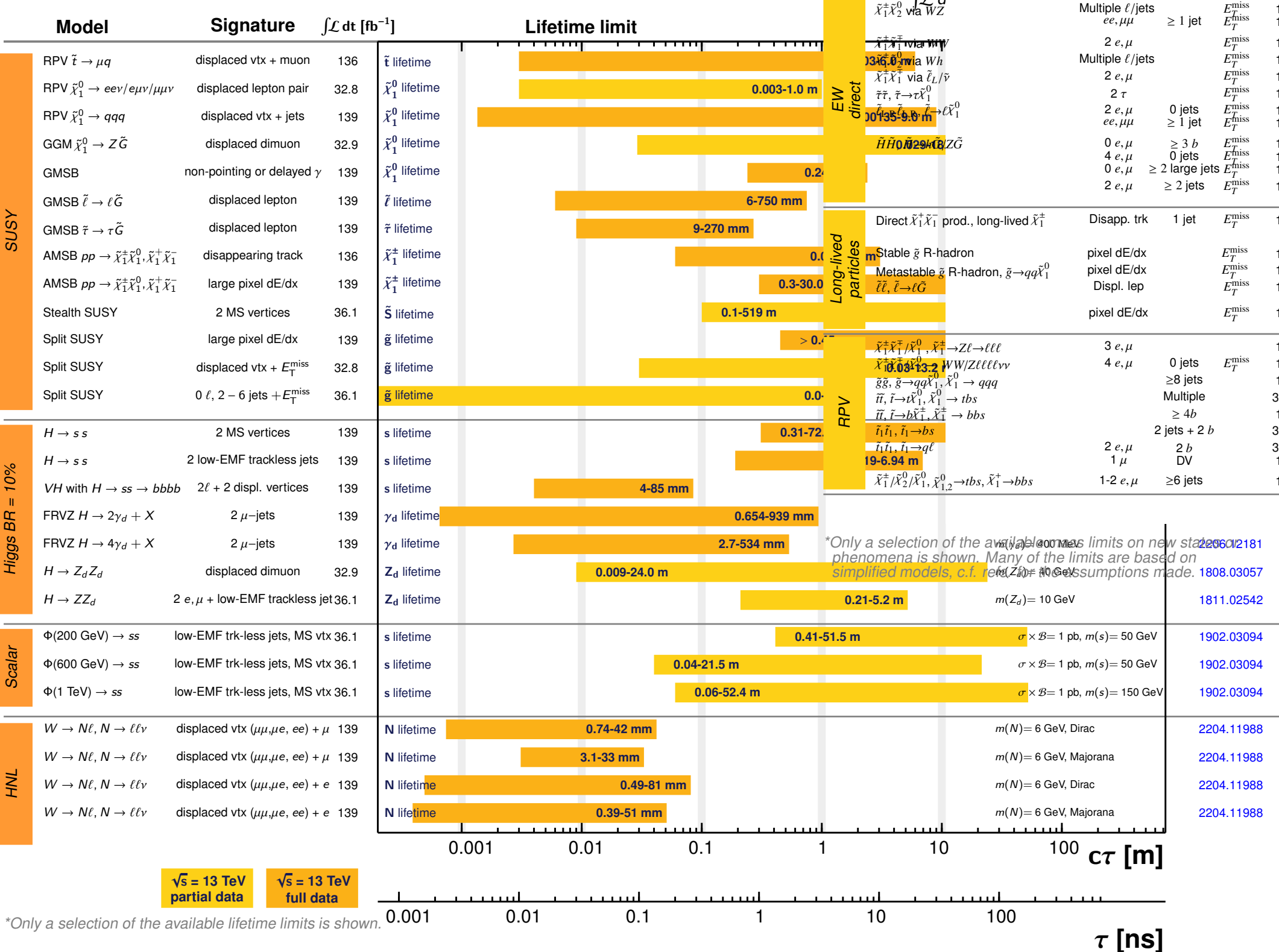
Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimen.	ADD $G_{KK} + g/q$	$0 e, \mu, \tau, \gamma$	$1-4 j$	139	M_D 11.2 TeV	$n=2$ 2102.10874
	ADD non-resonant $\gamma\gamma$	2γ	-	36.7	M_S 8.6 TeV	$n=3$ HLZ NLO 1707.04147
	ADD QBH	-	-	139	M_{th} 9.4 TeV	$n=6$ 1910.08447
	ADD BH multijet	-	$\geq 3 j$	3.6	M_{th} 9.55 TeV	$n=6, M_D = 3 \text{ TeV, rot BH}$ 1512.02586
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	139	$G_{KK} \text{ mass}$ 4.5 TeV	$k/M_{\text{Pl}} = 0.1$ 2102.13405
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	139	Z' mass 2.3 TeV	1903.06248
	SSM $Z' \rightarrow \tau\tau$	2τ	-	36.1	Z' mass 5.1 TeV	1709.07242
	Leptophobic $Z' \rightarrow bb$	-	$2 b$	36.1	Z' mass 2.42 TeV	1805.09299
	Leptophobic $Z' \rightarrow tt$	$0 e, \mu$	$\geq 1 b, \geq 2 J$	139	Z' mass 2.1 TeV	2005.05138
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes 139	W' mass 4.1 TeV	1906.05609
CI	CI $qqqq$	-	$2 j$	37.0	Λ	
	CI $\ell\ell qq$	$2 e, \mu$	-	139	Λ	
	CI $e e b s$	$2 e$	$1 b$	139	Λ	
	CI $\mu\mu b s$	2μ	$1 b$	139	Λ	
	CI $t t t t$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes 36.1	Λ	
DM	Axial-vector med. (Dirac DM)	-	$2 j$	139	m_{med}	
	Pseudo-scalar med. (Dirac DM)	$0 e, \mu, \tau, \gamma$	$1-4 j$	Yes 139	m_{med}	
	Vector med. Z' -2HDM (Dirac DM)	$0 e, \mu$	$2 b$	Yes 139	m_{med}	
	Pseudo-scalar med. 2HDM+a	-	multi-channel	139	m_{th}	
	LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2 j$	Yes 139	LQ mass
Scalar LQ 2 nd gen		2μ	$\geq 2 j$	Yes 139	LQ mass	
Scalar LQ 3 rd gen		1τ	$2 b$	Yes 139	LQ mass	
Scalar LQ 3 rd gen		$0 e, \mu$	$\geq 1 j, \geq 2 b$	Yes 139	LQ mass	
Scalar LQ 3 rd gen		$\geq 2 e, \mu, \geq 1 \tau, \geq 1 j, \geq 1 b$	-	Yes 139	LQ mass	
Vector-like fermions	VLO $TT \rightarrow Zt + X$	$2e/2\mu/3e, \mu$	$\geq 1 b, \geq 1 j$	-	T mass	
	VLO $BB \rightarrow Wt/Zb + X$	multi-channel	-	36.1	B mass	
	VLO $T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS) \geq 3 e, \mu$	$\geq 1 b, \geq 1 j$	Yes 36.1	$T_{5/3}$ mass	
	VLO $T \rightarrow Ht/Zt$	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes 139	T mass	
	VLO $Y \rightarrow Wb$	$1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes 36.1	Y mass	
Exotic ferm.	Excited quark $q^* \rightarrow qg$	-	$2 j$	139	q^* mass	
	Excited quark $q^* \rightarrow q\gamma$	1γ	$1 j$	36.7	q^* mass	
	Excited quark $b^* \rightarrow bg$	-	$1 b, 1 j$	139	b^* mass	
	Excited lepton τ^*	2τ	$\geq 2 j$	139	τ^* mass	
	Other	Type III Seesaw	$2, 3, 4 e, \mu$	$\geq 2 j$	Yes 139	N^{μ} mass
LRS Majorana ν		2μ	$2 j$	-	N_R mass	
Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm} W^{\pm}$		$2, 3, 4 e, \mu$ (SS)	various	Yes 139	$H^{\pm\pm}$ mass	
Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$		$2, 3, 4 e, \mu$ (SS)	-	139	$H^{\pm\pm}$ mass	
Multi-charged particles		-	-	139	multi-charged particle mass	
Magnetic monopoles	-	-	34.4	monopole mass		

*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).

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: March 2023



*Only a selection of the available lifetime limits is shown.

ATLAS SUSY Searches* - 95% CL Lower Limits

August 2023

ATLAS Preliminary

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

Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
Inclusive Searches	$q\bar{q}, \bar{q} \rightarrow q\bar{q}\tilde{\chi}_1^0$	$0 e, \mu$ mono-jet	E_T^{miss} 140	\tilde{q} [1x, 8x Degen.] 1.0, 1.85
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$	$0 e, \mu$ 2-6 jets	E_T^{miss} 140	\tilde{q} [8x Degen.] 0.9
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}W\tilde{\chi}_1^0$	$1 e, \mu$ 2-6 jets	E_T^{miss} 140	\tilde{g} 2.3
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}\ell\ell\tilde{\chi}_1^0$	$ee, \mu\mu$ 2 jets	E_T^{miss} 140	\tilde{g} 2.2
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}WZ\tilde{\chi}_1^0$	$0 e, \mu$ 7-11 jets	E_T^{miss} 140	\tilde{g} 1.97
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$	$0-1 e, \mu$ 3 b	E_T^{miss} 140	\tilde{g} 2.45
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$	$0 e, \mu$ 6 jets	E_T^{miss} 140	\tilde{g} 1.25
	$\tilde{b}_1\tilde{b}_1$	$0 e, \mu$ 2 b	E_T^{miss} 140	\tilde{b}_1 1.255
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0 \rightarrow b\tilde{b}\tilde{\chi}_1^0$	$0 e, \mu$ 6 b	E_T^{miss} 140	\tilde{b}_1 0.68
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	$0-1 e, \mu$ ≥ 1 jet	E_T^{miss} 140	\tilde{t}_1 1.25
3 rd gen. squarks direct production	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	$1 e, \mu$ 3 jets/1 b	E_T^{miss} 140	\tilde{t}_1 1.05
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tau b\nu, \tilde{t}_1 \rightarrow \tau\tilde{G}$	$1-2 \tau$ 2 jets/1 b	E_T^{miss} 140	\tilde{t}_1 1.4
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	$0 e, \mu$ 2 c	E_T^{miss} 36.1	\tilde{t}_1 0.85
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	$0 e, \mu$ mono-jet	E_T^{miss} 140	\tilde{t}_1 0.55
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{t}_1 \rightarrow Z/h\tilde{\chi}_1^0$	$1-2 e, \mu$ 1-4 b	E_T^{miss} 140	\tilde{t}_1 0.067-1.18
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	$3 e, \mu$ 1 b	E_T^{miss} 140	\tilde{t}_2 0.86
	$\tilde{\chi}_1^0\tilde{\chi}_2^0$ via WZ	Multiple ℓ /jets $ee, \mu\mu$	E_T^{miss} 140	$\tilde{\chi}_1^0/\tilde{\chi}_2^0$ 0.205
	$\tilde{\chi}_1^0\tilde{\chi}_2^0$ via $W\tilde{G}$	$2 e, \mu$ ≥ 1 jet	E_T^{miss} 140	$\tilde{\chi}_1^0/\tilde{\chi}_2^0$ 0.42
	$\tilde{\chi}_1^0\tilde{\chi}_2^0$ via $W\tilde{h}$	Multiple ℓ /jets	E_T^{miss} 140	$\tilde{\chi}_1^0/\tilde{\chi}_2^0$ 1.06
	$\tilde{\chi}_1^0\tilde{\chi}_2^0$ via $W\tilde{\nu}$	$2 e, \mu$ ≥ 1 jet	E_T^{miss} 140	$\tilde{\chi}_1^0/\tilde{\chi}_2^0$ 1.0
EW direct production	$\tilde{t}_1\tilde{t}_1$	$2 e, \mu$ 0 jets	E_T^{miss} 140	\tilde{t}_1 0.7
	$\tilde{t}_1\tilde{t}_1$	$ee, \mu\mu$ ≥ 1 jet	E_T^{miss} 140	\tilde{t}_1 0.26
	$\tilde{t}_1\tilde{t}_1$	$0 e, \mu$ $\geq 3 b$	E_T^{miss} 140	\tilde{t}_1 0.94
	$\tilde{t}_1\tilde{t}_1$	$4 e, \mu$ 0 jets	E_T^{miss} 140	\tilde{t}_1 0.55
	$\tilde{t}_1\tilde{t}_1$	$0 e, \mu$ ≥ 2 large jets	E_T^{miss} 140	\tilde{t}_1 0.45-0.93
	$\tilde{t}_1\tilde{t}_1$	$2 e, \mu$ ≥ 2 jets	E_T^{miss} 140	\tilde{t}_1 0.77
	Direct $\tilde{\chi}_1^0\tilde{\chi}_1^0$ prod., long-lived $\tilde{\chi}_1^+$	Disapp. trk	E_T^{miss} 140	$\tilde{\chi}_1^+$ 0.21
	Stable \tilde{g} R-hadron	pixel dE/dx	E_T^{miss} 140	\tilde{g} 2.05
	Metastable \tilde{g} R-hadron, $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$	pixel dE/dx	E_T^{miss} 140	\tilde{g} [r(g)=10 ns] 2.2
	$\tilde{\chi}_1^0, \tilde{\chi}_1^+$	Displ. lep	E_T^{miss} 140	$\tilde{\chi}_1^0, \tilde{\chi}_1^+$ 0.7
Long-lived particles	$\tilde{\chi}_1^0\tilde{\chi}_1^0$	3 e, μ	140	$\tilde{\chi}_1^0/\tilde{\chi}_1^+$ [BR(Z τ)=1, BR(Ze)=1] 0.625, 1.05
	$\tilde{\chi}_1^0\tilde{\chi}_1^+$	$4 e, \mu$ 0 jets	140	$\tilde{\chi}_1^0/\tilde{\chi}_1^+$ [BR(Z τ)=1, BR(Ze)=1] 0.95, 1.55
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow q\bar{q}q$	≥ 8 jets	140	\tilde{g} [m($\tilde{\chi}_1^0$)=50 GeV, 1250 GeV] 1.6, 2.25
	$\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t\tilde{b}s$	Multiple	36.1	\tilde{t}_1 [A ₂₂₃ =2e-4, 1e-2] 0.55, 1.05
	$\tilde{t}_1, \tilde{t}_1 \rightarrow b\tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow b\tilde{b}s$	$\geq 4 b$	140	\tilde{t}_1 0.95
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow bs$	2 jets + 2 b	36.7	\tilde{t}_1 [qq, bs] 0.42, 0.61
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow qt$	$2 e, \mu$ 2 b	36.1	\tilde{t}_1 0.4-1.45
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow q\ell$	1μ DV	136	\tilde{t}_1 [1e-10 < A ₂₂₃ < 1e-8, 3e-10 < A ₂₂₃ < 3e-9] 1.0, 1.6
	$\tilde{\chi}_1^0\tilde{\chi}_2^0/\tilde{\chi}_1^0\tilde{\chi}_1^+, \tilde{\chi}_1^0 \rightarrow t\tilde{b}s, \tilde{\chi}_1^+ \rightarrow b\tilde{b}s$	$1-2 e, \mu$ ≥ 6 jets	140	$\tilde{\chi}_1^0$ 0.2-0.32
	RPV	$m(Z_0) = 10 \text{ GeV}$	-	-
$\Phi(200 \text{ GeV}) \rightarrow ss$		low-EMF trk-less jets, MS vtx	36.1	$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 50 \text{ GeV}$ 1902.03094
$\Phi(600 \text{ GeV}) \rightarrow ss$		low-EMF trk-less jets, MS vtx	36.1	$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 50 \text{ GeV}$ 1902.03094
$\Phi(1 \text{ TeV}) \rightarrow ss$		low-EMF trk-less jets, MS vtx	36.1	$\sigma \times \mathcal{B} = 1 \text{ pb, } m(s) = 150 \text{ GeV}$ 1902.03094
$W \rightarrow N\ell, N \rightarrow \ell\nu$		displaced vtx ($\mu\mu, \mu e, ee$) + μ	139	N lifetime 0.74-42 mm 2204.11988
$W \rightarrow N\ell, N \rightarrow \ell\nu$		displaced vtx ($\mu\mu, \mu e, ee$) + μ	139	N lifetime 3.1-33 mm 2204.11988
$W \rightarrow N\ell, N \rightarrow \ell\nu$		displaced vtx ($\mu\mu, \mu e, ee$) + e	139	N lifetime 0.49-81 mm 2204.11988
$W \rightarrow N\ell, N \rightarrow \ell\nu$		displaced vtx ($\mu\mu, \mu e, ee$) + e	139	N lifetime 0.39-51 mm 2204.11988

*Only a selection of the available lower limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. [1808.03057].

Limits set on BSM physics in many, many scenarios ...

Covers vast range of new physics signatures

ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits

Status: March 2023

ATLAS Preliminary

$\int \mathcal{L} dt = (3.6 - 139) \text{ fb}^{-1}$

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

Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
ADD $G_{KK} + g/a$	$0 e, \mu, \tau, \gamma$	$1-4 j$	Yes	139	M_{Pl} 11.2 TeV	2102.10874
ADD non-resonant $\gamma\gamma$	2γ	-	-	36.7	M_S 8.6 TeV	1707.04147
ADD QBH	-	$2 j$	-	139	M_{BH} 9.4 TeV	1910.08447
ADD BH multijet	-	$\geq 3 j$	-	3.6	M_{BH} 9.55 TeV	1512.02586
RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	139	$G_{KK} \text{ mass}$ 4.5 TeV	2102.13405
Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	-	-	36.1	$G_{KK} \text{ mass}$ 2.3 TeV	1808.02380
Bulk RS $G_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2 j$	Yes	36.1	$g_{KK} \text{ mass}$ 3.8 TeV	1804.10823
2UED/RPP	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	36.1	$KK \text{ mass}$ 1.8 TeV	1803.09678
SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	139	$Z' \text{ mass}$ 5.1 TeV	1903.06248
SSM $Z' \rightarrow \tau\tau$	2τ	-	-	36.1	$Z' \text{ mass}$ 2.42 TeV	1709.07242
Leptophobic $Z' \rightarrow bb$	-	$2 b$	-	36.1	$Z' \text{ mass}$ 2.1 TeV	1805.09299
Leptophobic $Z' \rightarrow tt$	$0 e, \mu$	$\geq 1 b, \geq 2 J$	Yes	139	$Z' \text{ mass}$ 4.1 TeV	2005.05138
SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	$\geq 2 j$	Yes	139	$W' \text{ mass}$ 6.0 TeV	1906.05609
SSM $W' \rightarrow \tau\nu$	1τ	-	Yes	139	$W' \text{ mass}$ 5.0 TeV	ATLAS-CONF-2021-025
SSM $W' \rightarrow tb$	-	$\geq 1 b, \geq 1 J$	-	139	$W' \text{ mass}$ 4.4 TeV	ATLAS-CONF-2021-043
HVT $W' \rightarrow WZ$ model B	$0-2 e, \mu$	$2 j / 1 J$	Yes	139	$W' \text{ mass}$ 3.4	
HVT $W' \rightarrow WZ \rightarrow \ell\nu \ell' \ell'$ model C	$3 e, \mu$	$2 j$ (VBF)	Yes	139	$W' \text{ mass}$	
HVT $Z' \rightarrow WW$ model B	$1 e, \mu$	$2 j / 1 J$	Yes	139	$Z' \text{ mass}$	
LRSM $W_R \rightarrow \mu N_R$	2μ	$1 J$	-	80	$W_R \text{ mass}$	

ATLAS Long-lived Particle Searches* - 95% CL Exclusion

Status: March 2023

No observation of BSM physics yet 😞

ATLAS SUSY Searches* - 95% CL Lower Limits

August 2023

ATLAS Preliminary

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

Model	Signature	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$	$0 e, \mu$ mono-jet	E_T^{miss} 140	\tilde{q} [1x, 8x Degen.] 1.0, 1.85
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}\tilde{\chi}_1^0$	$0 e, \mu$ 2-6 jets	E_T^{miss} 140	\tilde{q} [8x Degen.] 0.9
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}W\tilde{\chi}_1^0$	$1 e, \mu$ 2-6 jets	E_T^{miss} 140	Forbidden 1.15-1.95, 2.3
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}(\ell\ell)\tilde{\chi}_1^0$	$ee, \mu\mu$ 2 jets	E_T^{miss} 140	2.2
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\tilde{q}WZ\tilde{\chi}_1^0$	$0 e, \mu$ 7-11 jets	E_T^{miss} 140	1.97
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	$0-1 e, \mu$ 3 b	E_T^{miss} 140	2.45
	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t\tilde{t}\tilde{\chi}_1^0$	SS e, μ 6 jets	E_T^{miss} 140	1.25
	$\tilde{b}_1\tilde{b}_1$	$0 e, \mu$ 2 b	E_T^{miss} 140	1.255
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow b\tilde{\chi}_1^0$	$0 e, \mu$ 6 b	E_T^{miss} 140	0.68
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1 \rightarrow b\tilde{\chi}_2^0 \rightarrow b\tilde{\chi}_1^0$	2τ 2 b	E_T^{miss} 140	0.13-0.85
3rd gen. squarks direct production	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_1^0$	$0-1 e, \mu$ ≥ 1 jet	E_T^{miss} 140	1.25
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow Wb\tilde{\chi}_1^0$	$1 e, \mu$ 3 jets/1 b	E_T^{miss} 140	1.05
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}b\nu, \tilde{\tau}_1 \rightarrow \tau\tilde{G}$	$1-2 \tau$ 2 jets/1 b	E_T^{miss} 140	Forbidden 1.4
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 / \tilde{c}\tilde{c}, \tilde{c} \rightarrow c\tilde{\chi}_1^0$	$0 e, \mu$ 2 c	E_T^{miss} 36.1	0.85
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	$0 e, \mu$ mono-jet	E_T^{miss} 140	0.55
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1 \rightarrow t\tilde{\chi}_2^0, \tilde{\chi}_2^0 \rightarrow Z/h\tilde{\chi}_1^0$	$1-2 e, \mu$ 1-4 b	E_T^{miss} 140	0.067-1.18
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{\tau}_1 + Z$	$3 e, \mu$ 1 b	E_T^{miss} 140	0.86
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{\tau}_1 + Z$	$3 e, \mu$ 1 b	E_T^{miss} 140	0.96
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{\tau}_1 + Z$	$3 e, \mu$ 1 b	E_T^{miss} 140	1.06
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{\tau}_1 + Z$	$3 e, \mu$ 1 b	E_T^{miss} 140	1.0

Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
CI $q\bar{q}q\bar{q}$	-	$2 j$	-	37.0		
CI $\ell\ell q\bar{q}$	$2 e, \mu$	-	-	139		
CI $e\bar{e}b\bar{s}$	$2 e$	$1 b$	-	139		
CI $\mu\bar{\mu}b\bar{s}$	2μ	$1 b$	-	139		
CI $t\bar{t}t\bar{t}$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1		
DM Axial-vector med. (Dirac DM)	-	$2 j$	-	139		
Pseudo-scalar med. (Dirac DM)	$0 e, \mu, \tau, \gamma$	$1-4 j$	Yes	139		
Vector med. Z' -2HDM (Dirac DM)	$0 e, \mu$	$2 b$	Yes	139		
Pseudo-scalar med. 2HDM+a	multi-channel	-	-	139		
LQ Scalar LQ 1st gen	$2 e$	$\geq 2 j$	Yes	139		
Scalar LQ 2nd gen	2μ	$\geq 2 j$	Yes	139		
Scalar LQ 3rd gen	1τ	$2 b$	Yes	139		
Scalar LQ 3rd gen	$0 e, \mu$	$\geq 2 j, \geq 2 b$	Yes	139		
Scalar LQ 3rd gen	$\geq 2 e, \mu, \geq 1 \tau, \geq 1 b$	$\geq 1 j, \geq 1 b$	-	139		
Scalar LQ 3rd gen	$0 e, \mu, \geq 1 \tau, 0-2 j, 2 b$	-	Yes	139		
Vector LQ mix gen	multi-channel	$\geq 1 j, \geq 1 b$	Yes	139		
Vector LQ 3rd gen	$2 e, \mu, \tau$	$\geq 1 b$	Yes	139		
Vector-like fermions VLQ $TT \rightarrow Zt + X$	$2e/2\mu \geq 3e, \mu$	$\geq 1 b, \geq 1 j$	-	139	T mass	AMS13 $pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^0, \tilde{\chi}_1^+ \tilde{\chi}_1^0$
VLQ $BB \rightarrow Wt/Zb + X$	multi-channel	-	-	36.1	B mass	Stealth SUSY
VLQ $T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS) \geq 3 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	$T_{5/3}$ mass	2 MS vertices
VLQ $T \rightarrow Ht/Zt$	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes	139	T mass	Split SUSY
VLQ $Y \rightarrow Wb$	$1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	Y mass	large pixel dE/dx
VLQ $B \rightarrow Hb$	$0 e, \mu$	$\geq 2b, \geq 1j, \geq 1J$	-	139	B mass	Split SUSY
VLL $\tau^+ \rightarrow Z\tau/H\tau$	multi-channel	$\geq 1 j$	Yes	139	τ^+ mass	displaced vtx + E_T^{miss}
Excited ferm. Excited quark $q^* \rightarrow qg$	-	$2 j$	-	139	q^* mass	Split SUSY
Excited quark $q^* \rightarrow q\gamma$	1γ	-	-	36.7	q^* mass	$0 \ell, 2-6$ jets + E_T^{miss}
Excited quark $b^* \rightarrow b\gamma$	-	$1 b, 1 j$	-	139	b^* mass	
Excited lepton τ^*	2τ	$\geq 2 j$	-	139	τ^* mass	
Other Type III Seesaw	$2, 3, 4 e, \mu$	$\geq 2 j$	Yes	139	N^{μ} mass	$H \rightarrow ss$
LRSM Majorana ν	2μ	$2 j$	-	36.1	N_R mass	2 MS vertices
Higgs triplet $H^{\pm\pm} \rightarrow W^{\pm}W^{\pm}$	$2, 3, 4 e, \mu$ (SS)	various	Yes	139	$H^{\pm\pm}$ mass	2 low-EMF trackless jets
Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	-	-	139	$H^{\pm\pm}$ mass	VH with $H \rightarrow ss \rightarrow bbbb$
Multi-charged particles	-	-	-	139	multi-charged particle mass	$2\ell + 2$ displ. vertices
Magnetic monopoles	-	-	-	34.4	monopole mass	FRVZ $H \rightarrow 2\gamma_d + X$

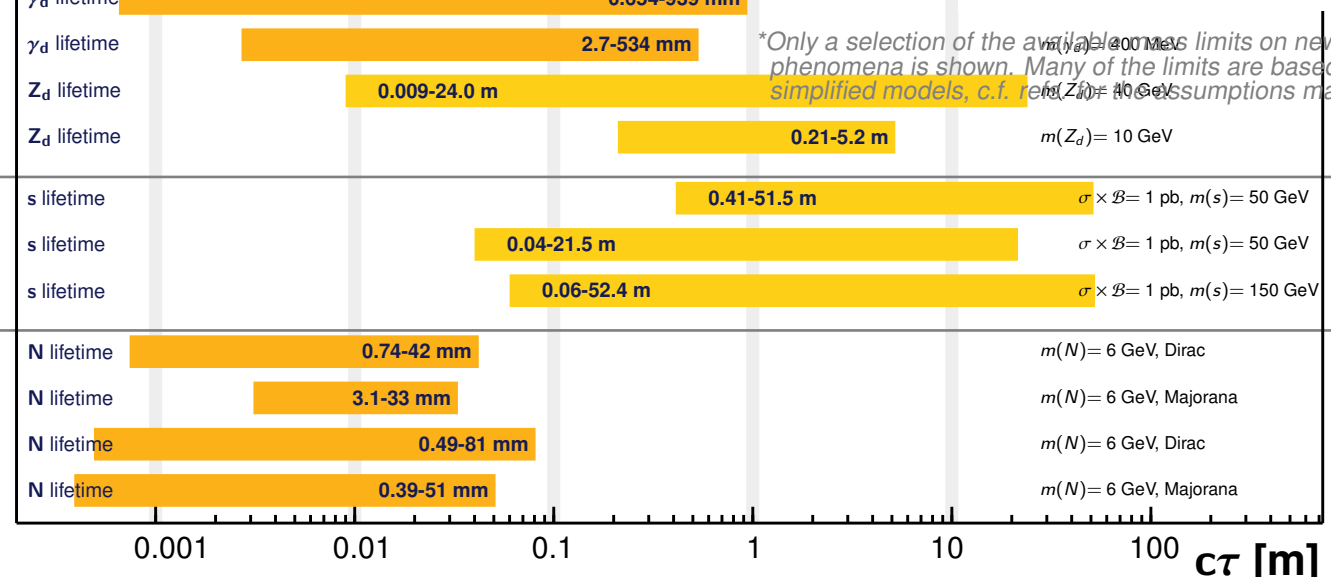
*Only a selection of the available mass limits on new states or phenomena is shown.

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

Higgs BR = 10%

Scalar

HNL



$\sqrt{s} = 13 \text{ TeV}$ partial data $\sqrt{s} = 13 \text{ TeV}$ full data

*Only a selection of the available lifetime limits is shown.

Limits set on BSM physics in many, many scenarios ...

Any hints or anomalies??



Run: 336678

Event: 1202524014

2017-09-26 18:00:56 CEST

The background features a complex, abstract visualization of particle detector components. It includes several cylindrical structures, possibly representing calorimeters or tracking chambers, with yellow and green internal structures. A central horizontal beam or pipe is visible, with various sensors and detectors attached. The overall color palette is dominated by dark blues, greys, and bright yellows/greens, creating a technical and futuristic atmosphere.

Any hints or anomalies??

This talk:

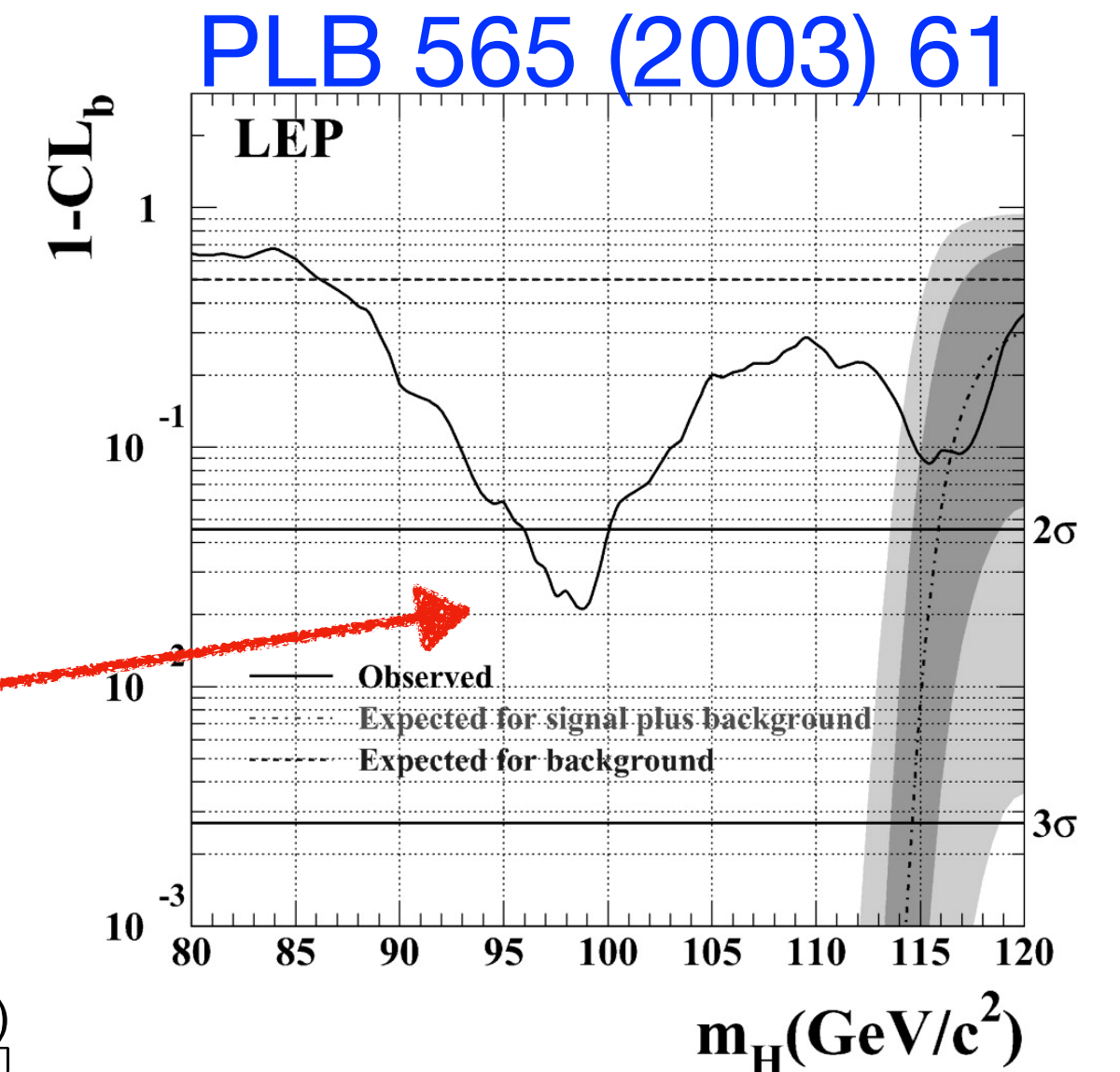
- A selection of results from ATLAS and CMS with intriguing excess of events observed with respect to the SM: especially where excess appears to be observed in multiple channels / searches or interesting in the light of other anomalies ... cases worth following up with more data / additional searches
- Compare ATLAS and CMS where available
- Results with full LHC Run 2 data set ($\sim 140 \text{ fb}^{-1}$ at $\sqrt{s} = 13 \text{ TeV}$) except where noted
- Caveat: by the nature of this talk, results shown are highly cherry-picked!

Searches for low- or high-mass resonances

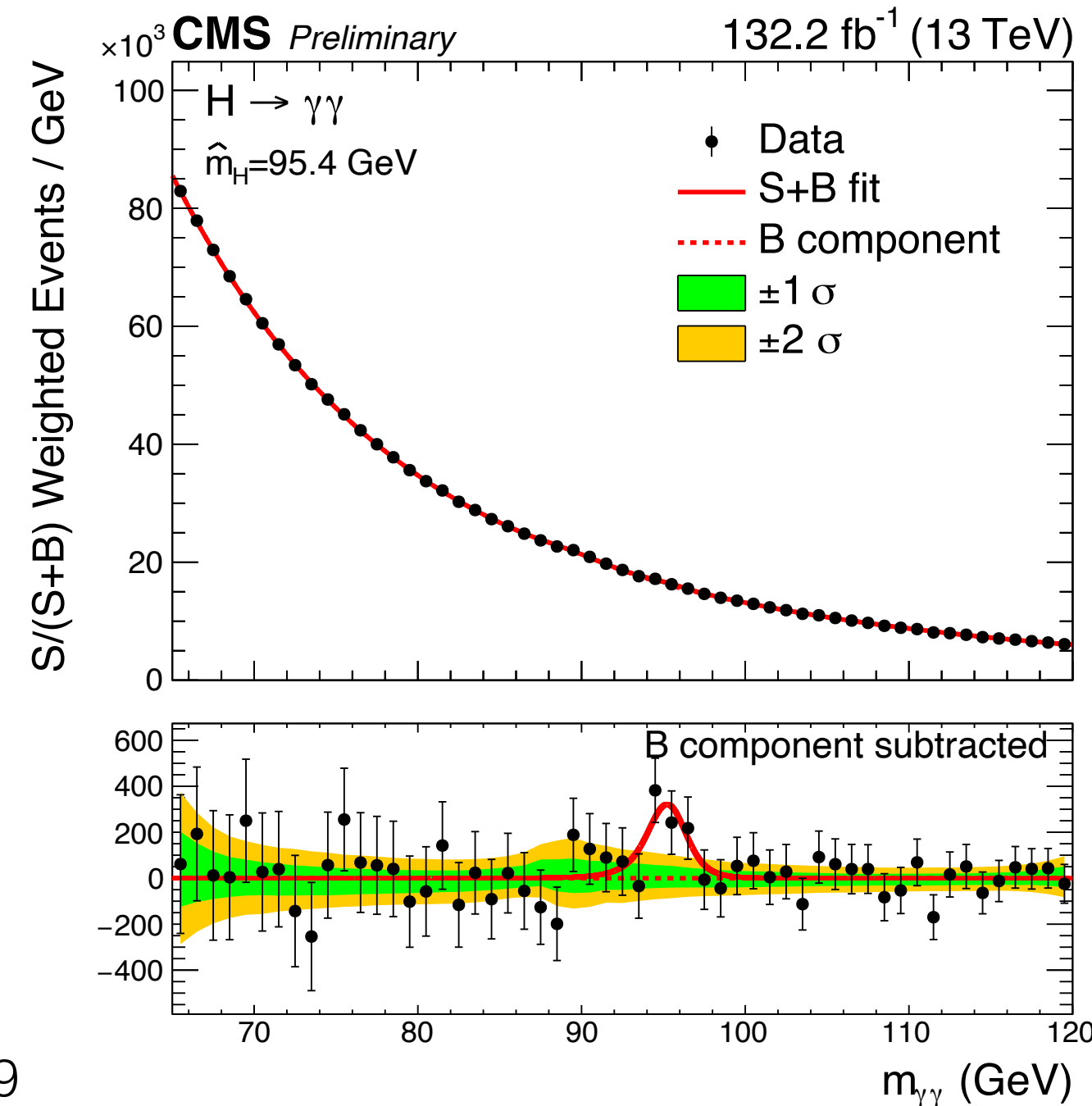
Low mass di-photon search

Search in $70 < m_{\gamma\gamma} < 110$ GeV from CMS

- Following up on previous search with $\sqrt{s} = 8$ and 13 TeV data from 2012+2016 that observed local (global) significance of 2.8 (1.3) σ (PLB 793 (2019) 320) at 95.3 GeV
- LEP saw a small excess of events ($\sim 2\sigma$) at $m_H = 98$ GeV in $H(b\bar{b})$
- In addition to continuum $\gamma\gamma$ background, contends with additional background from Drell-Yan $\rightarrow e^+e^-$ with electrons faking photons
- Kinematic diphoton BDT used for signal selection

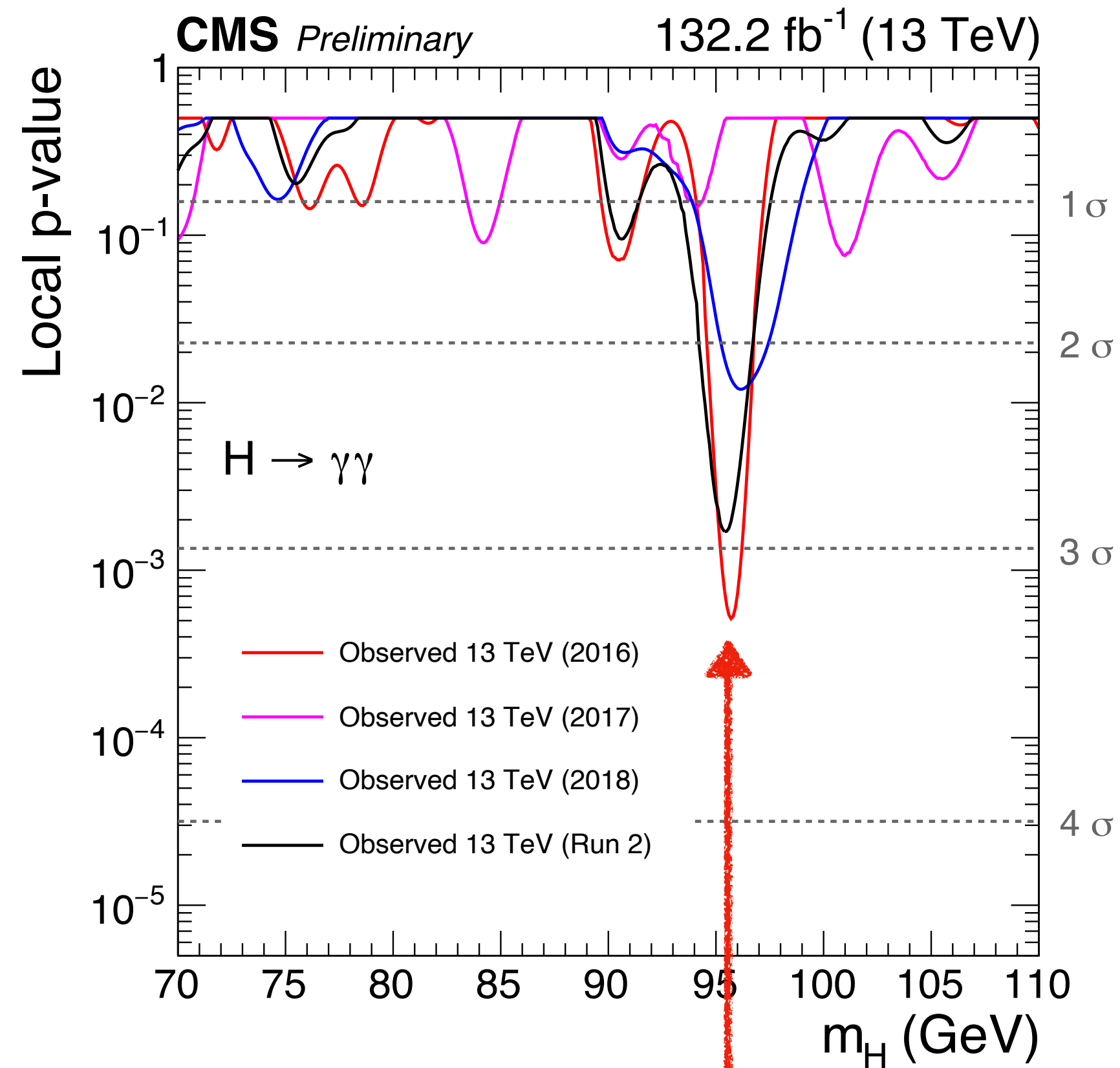


CMS-PAS-HIG-20-002

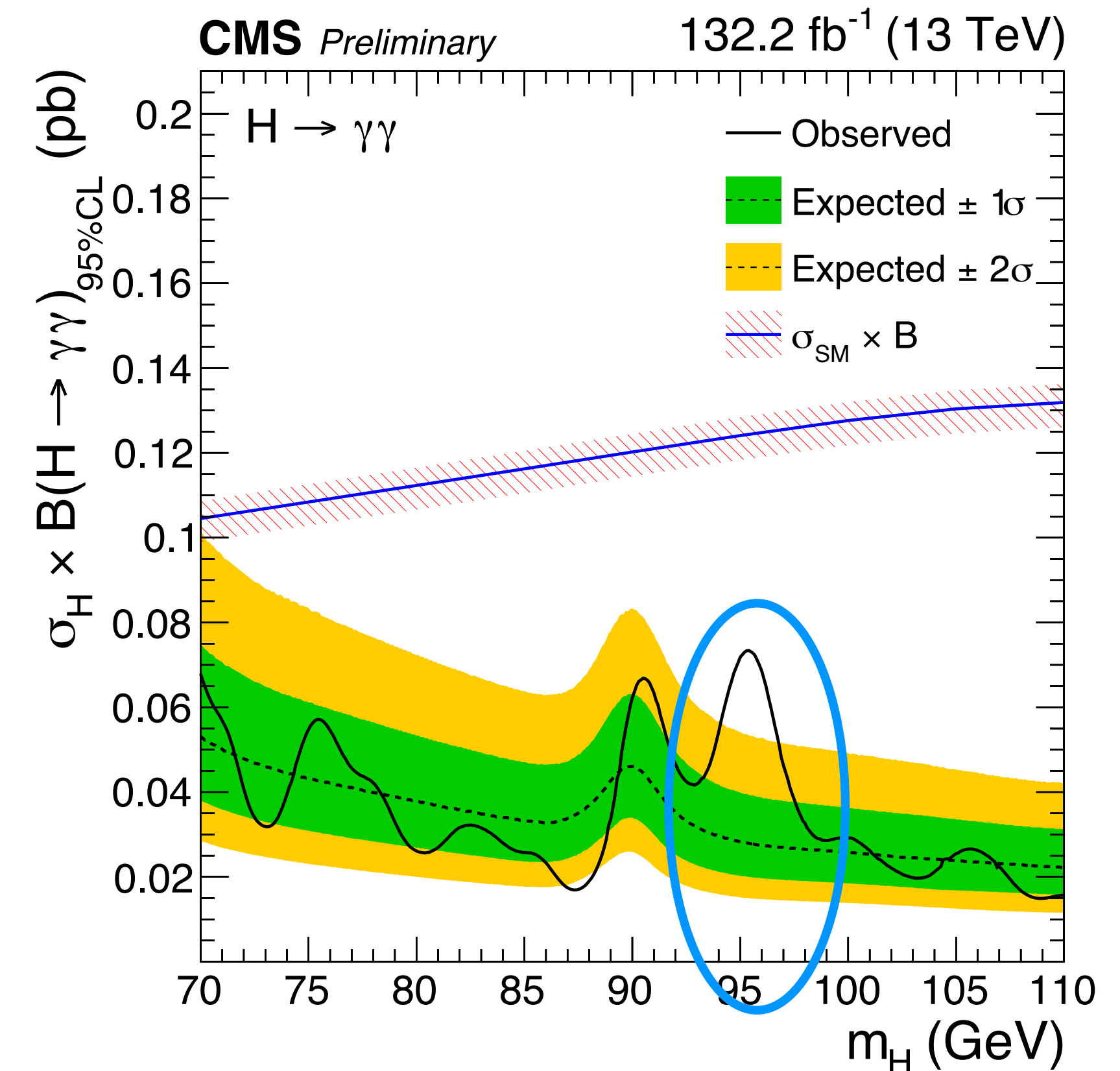


Note: LEP excess only for $E_{CM} = 189$ GeV

Low mass di-photon search



Excess previously seen in 2016 data persists, combined 2.9 (1.3) σ local (global) significance at **95.4 GeV**



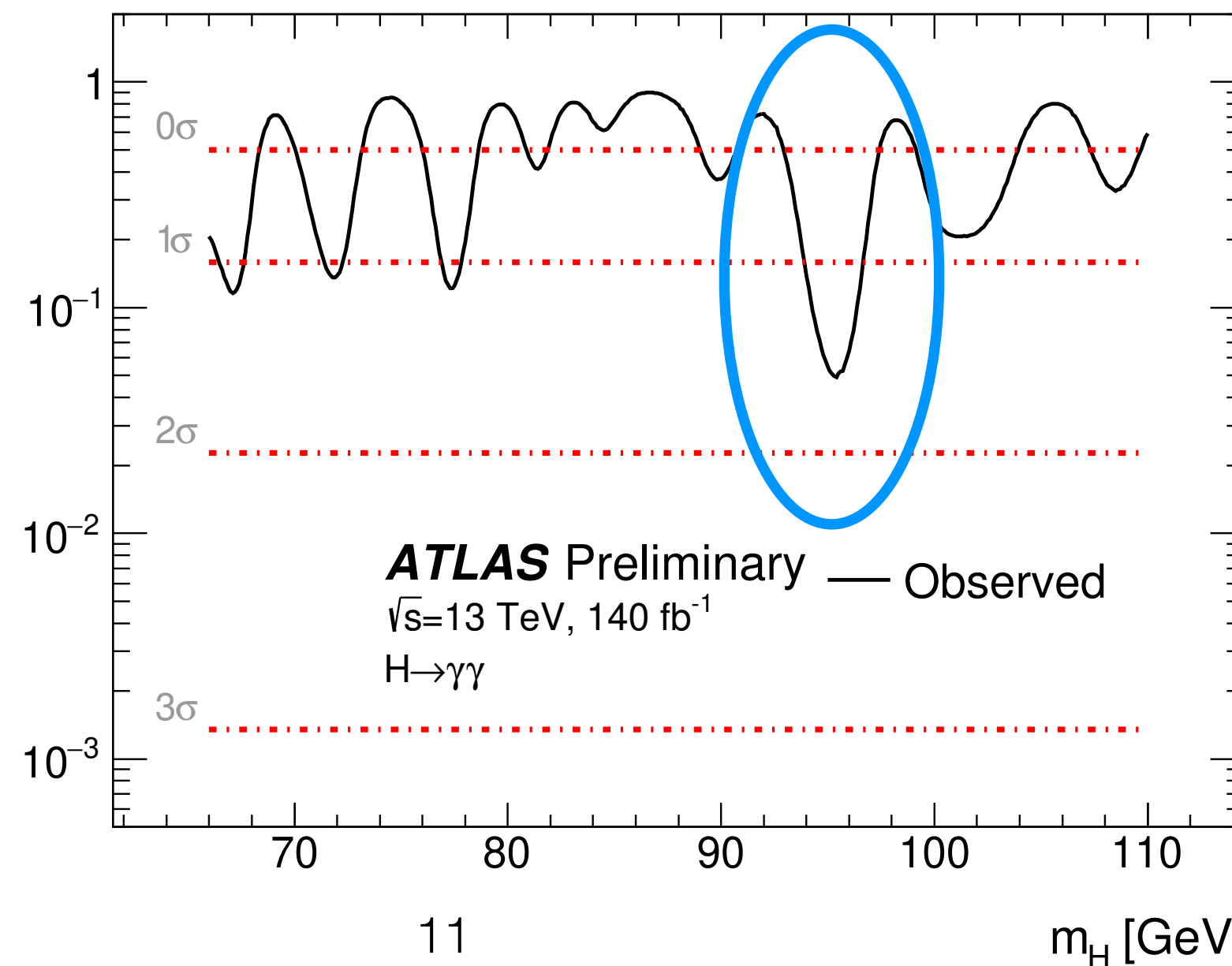
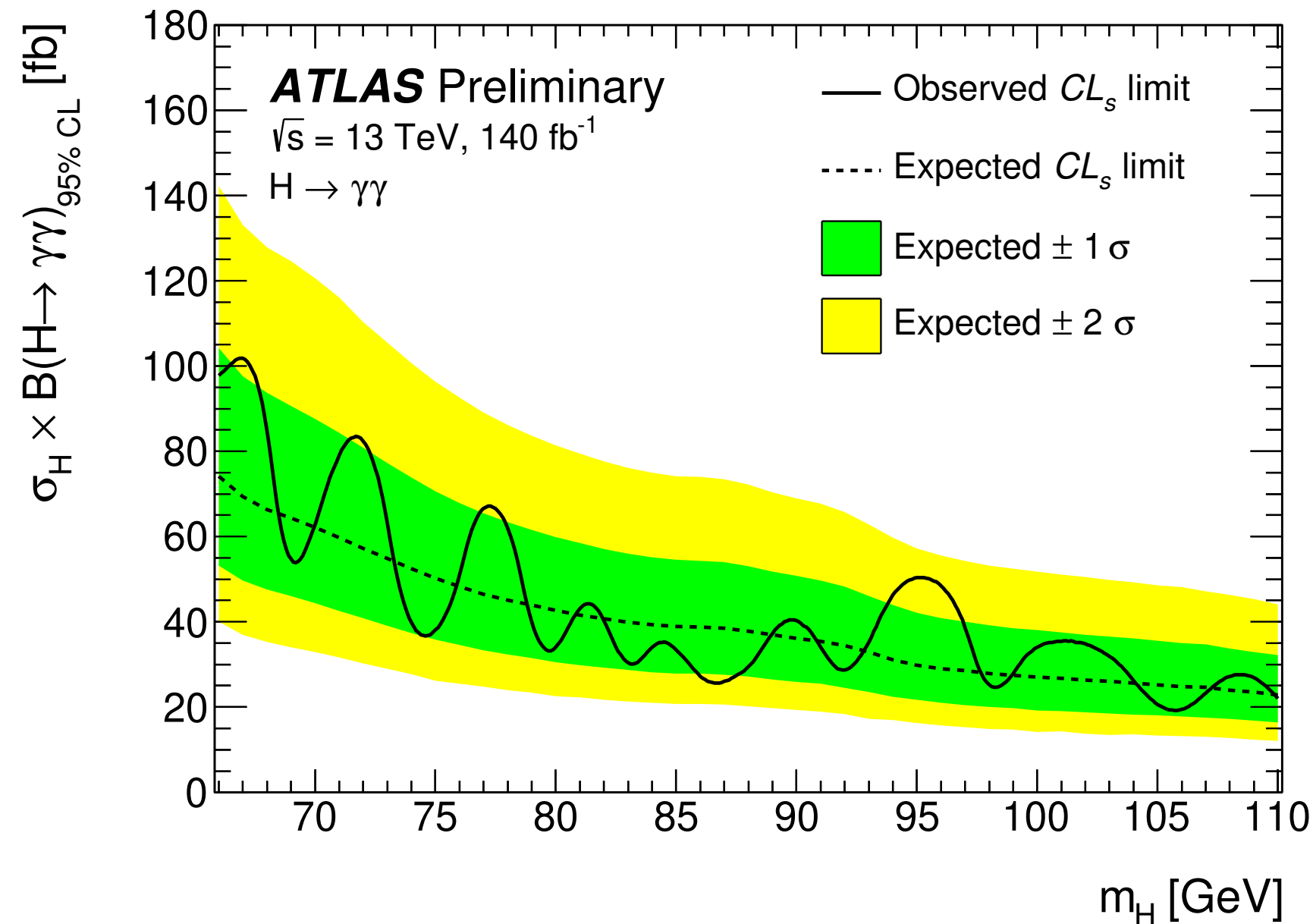
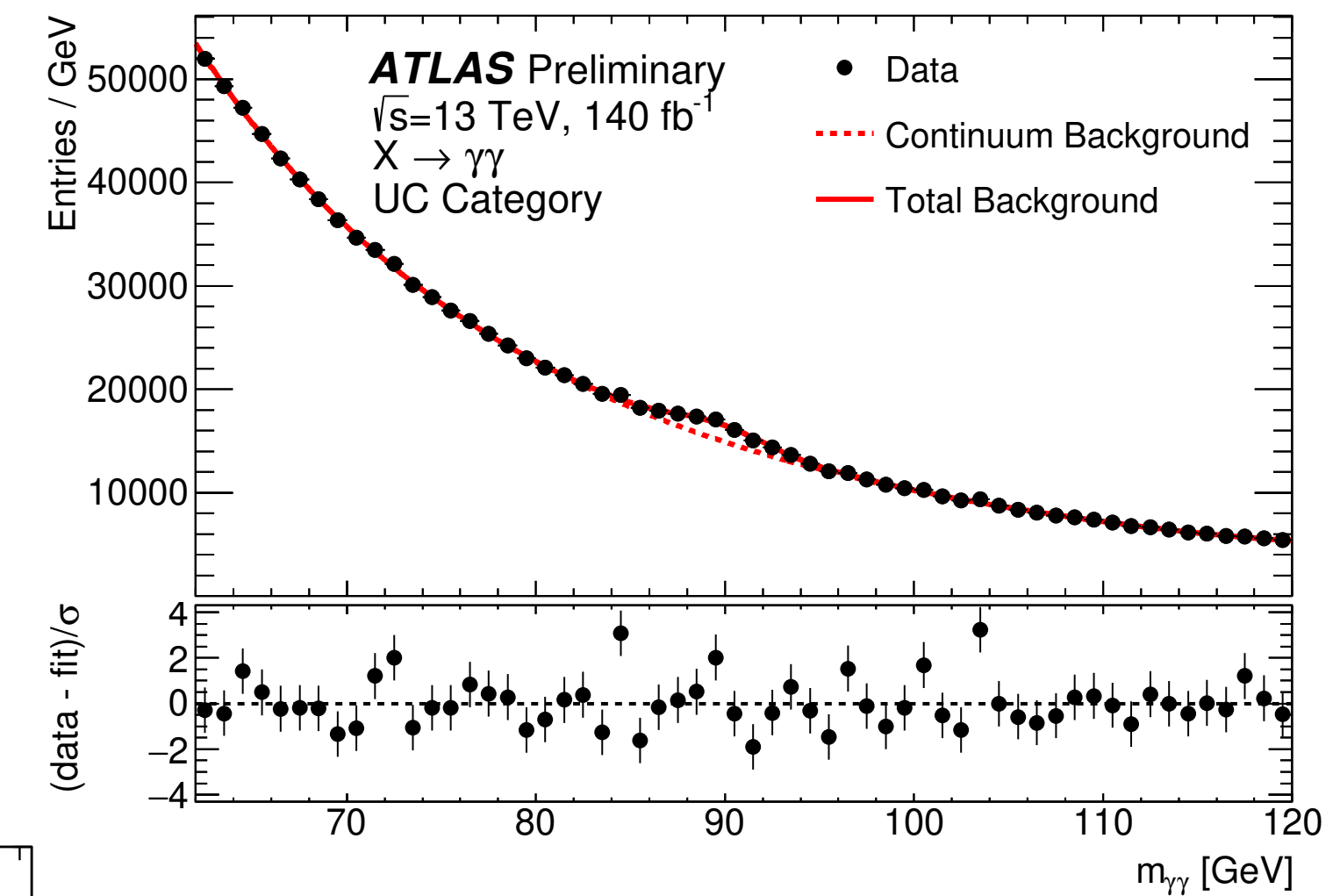
Limits also set on $\sigma_H \times B(H \rightarrow \gamma\gamma)$ for additional SM-like Higgs boson

Low mass di-photon search

ATLAS also carried out a search in $66 < m_{\gamma\gamma} < 110$ GeV

- Categorization of events based on whether photon converts to electron pair or not
- Model-dependent search uses BDT for additional event categorization

ATLAS-CONF-2023-035



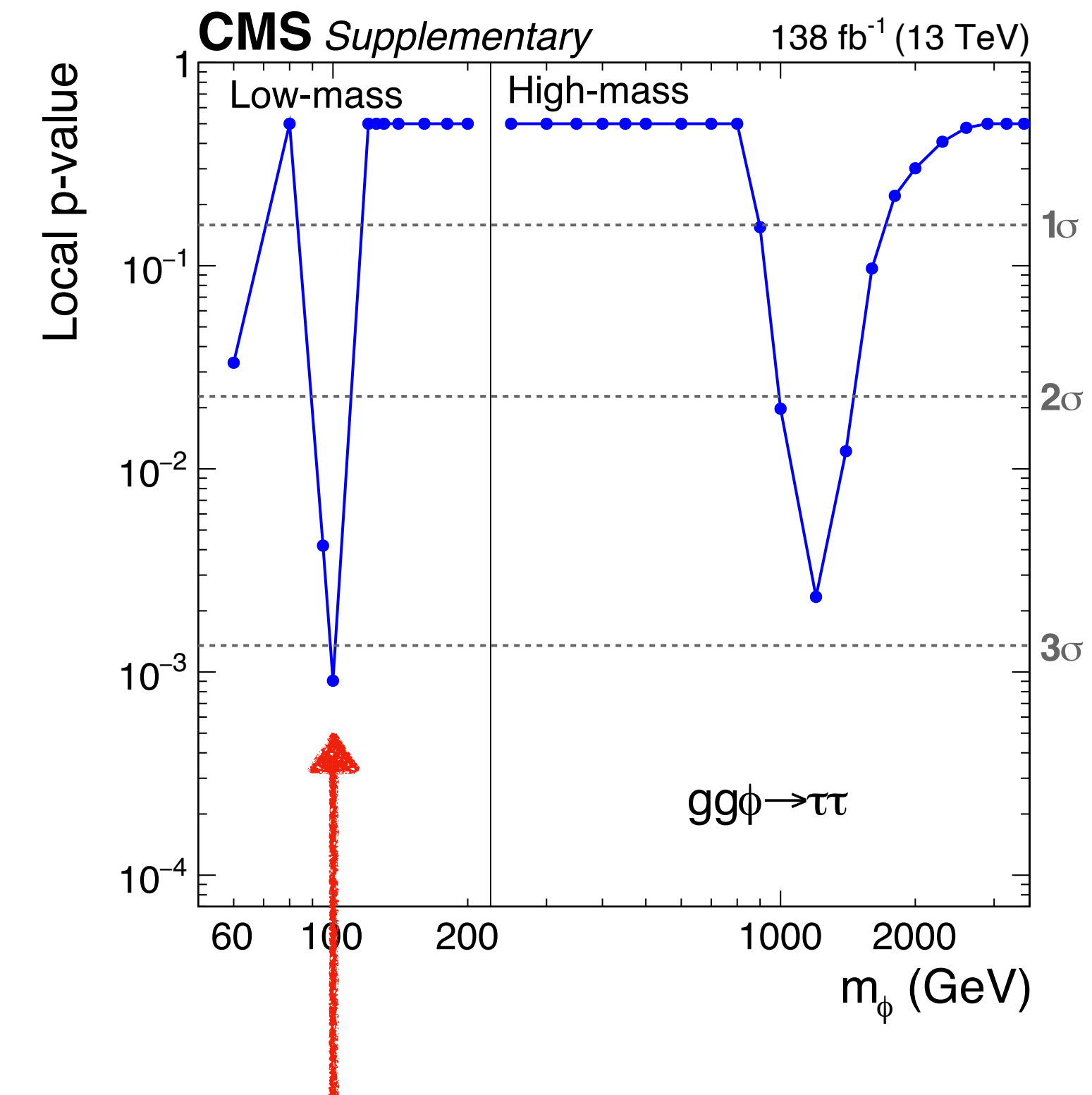
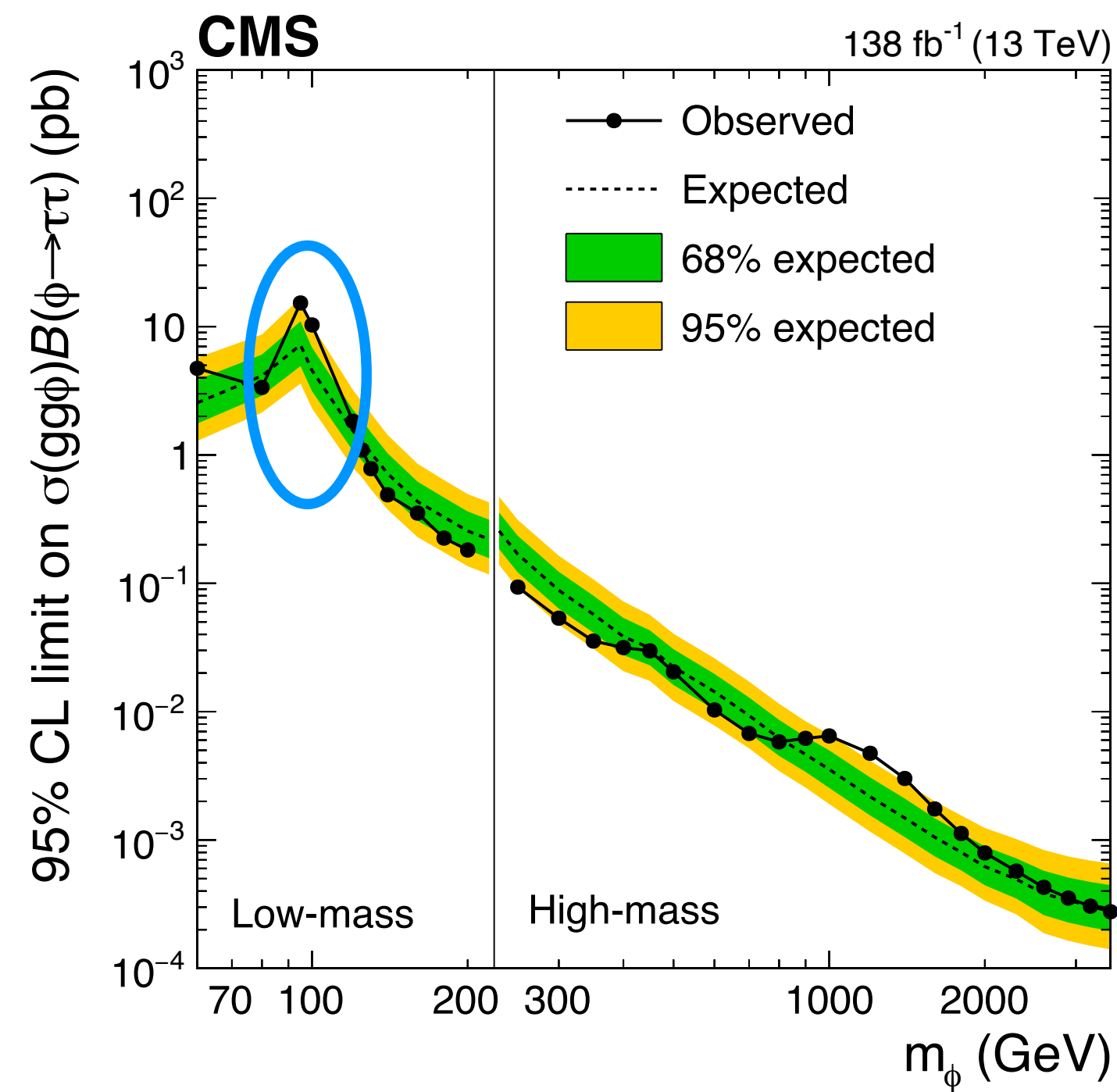
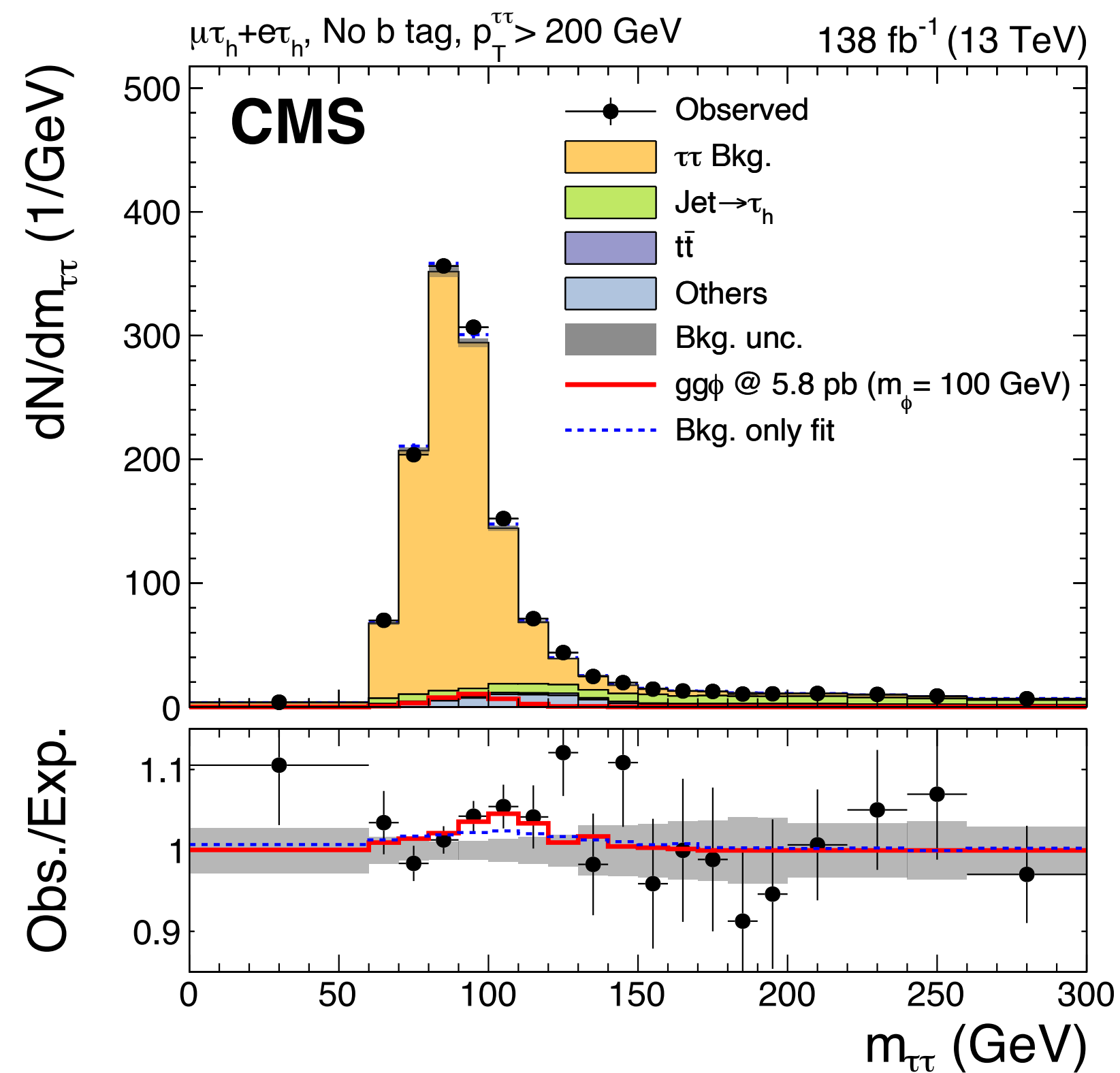
At 95.4 GeV, observe 1.7σ (local) deviation for model-dependent search

Low mass di-tau search

Search for additional Higgs bosons in $\tau\tau$ final state from CMS

- Event categorization based on b-tags, $p_T(\tau\tau)$

JHEP 07 (2023) 073



Largest deviation for $gg\phi$ production at $m_\phi = 100$ GeV with local (global) significance of 3.1 (2.7) σ
 2.6 (2.3) σ at 95 GeV

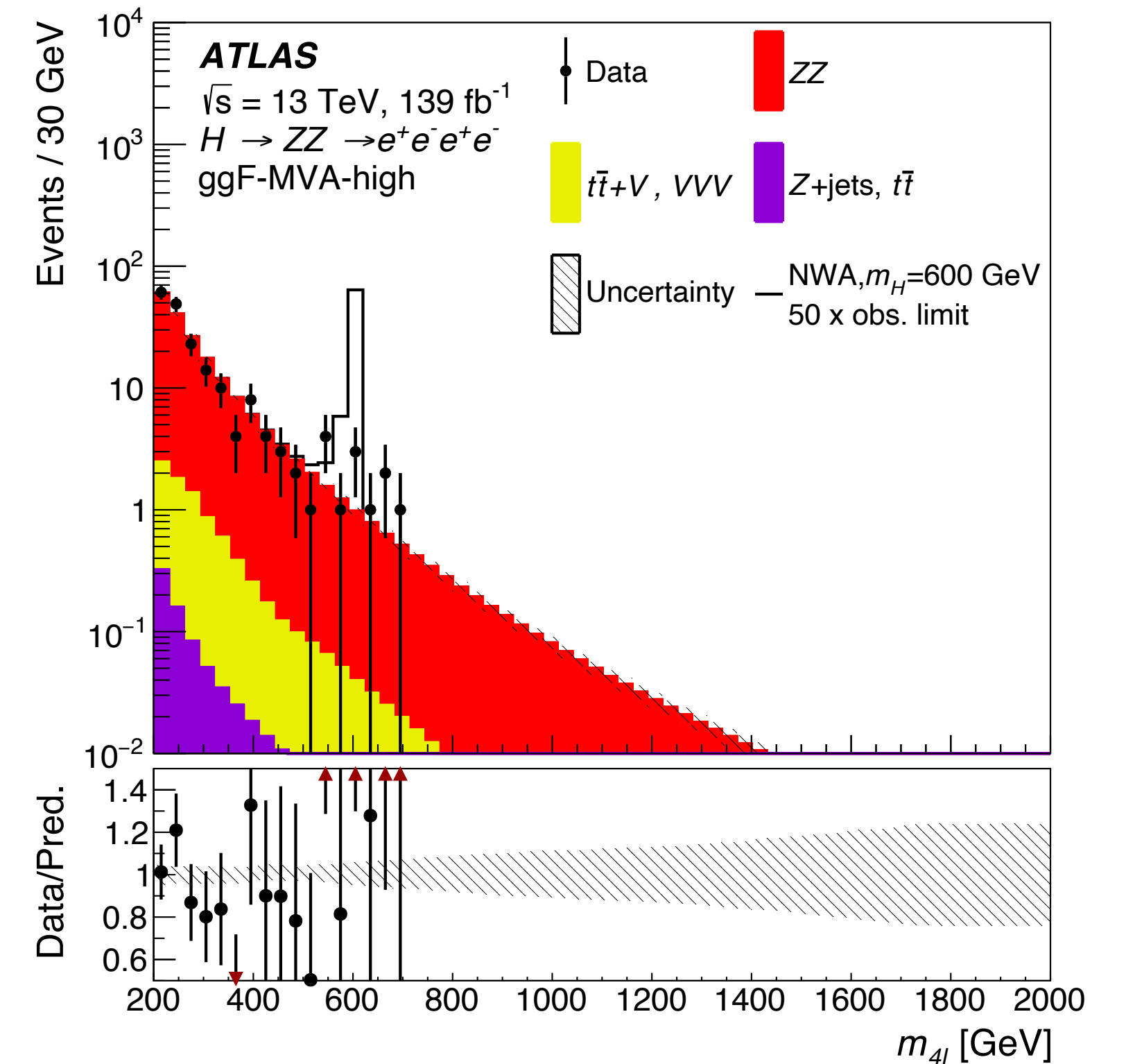
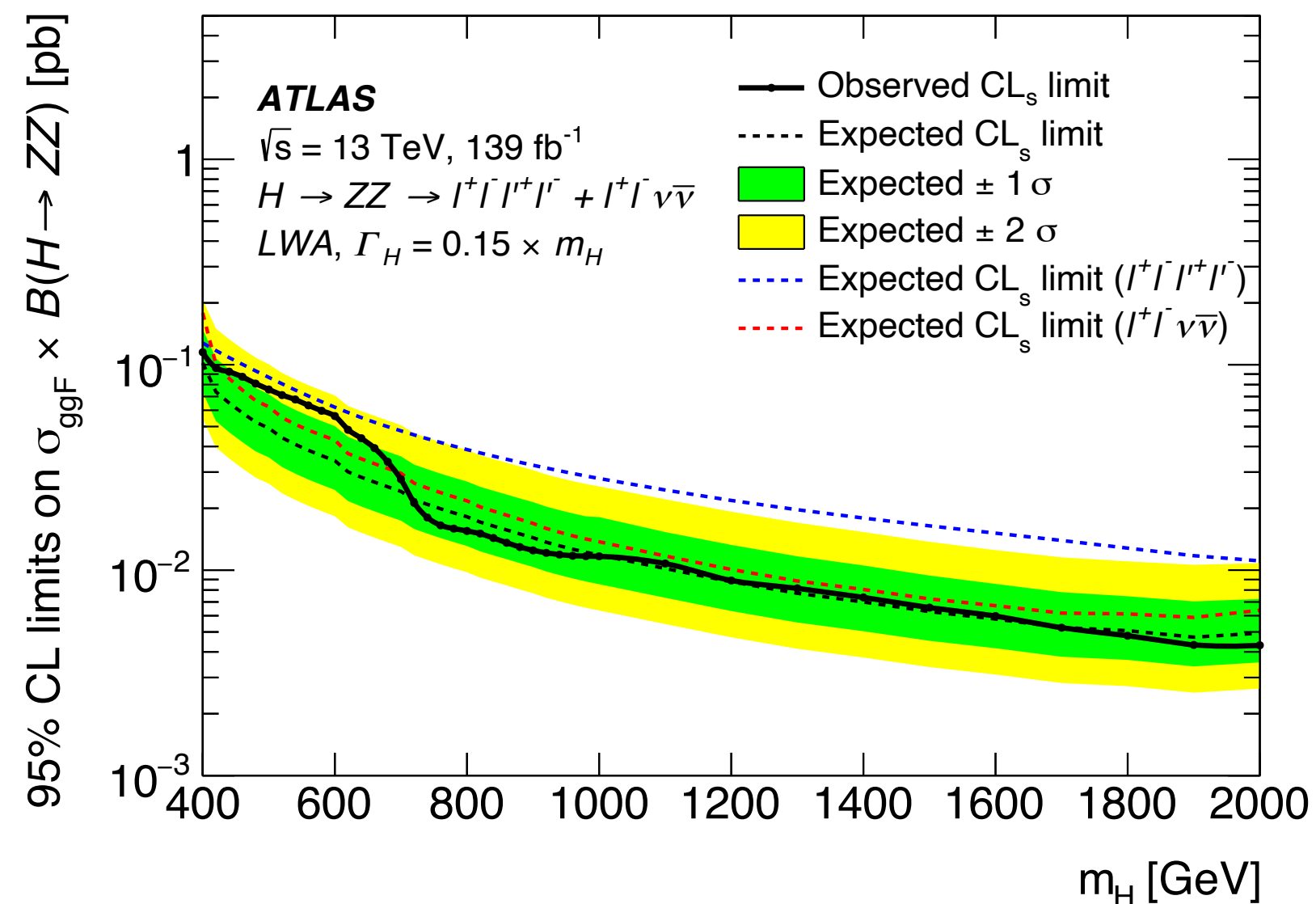
High mass ZZ search

Search for heavy resonance decaying to ZZ in $200 < m_{ZZ} < 2000$ GeV in 4l and 2l2 ν final states from ATLAS

- Considers heavy Higgs in narrow width approximation (NWA), large width assumption (LWA) as well as spin-2 resonance (KK graviton)
- Both gluon fusion (ggF) and VBF production considered for NWA

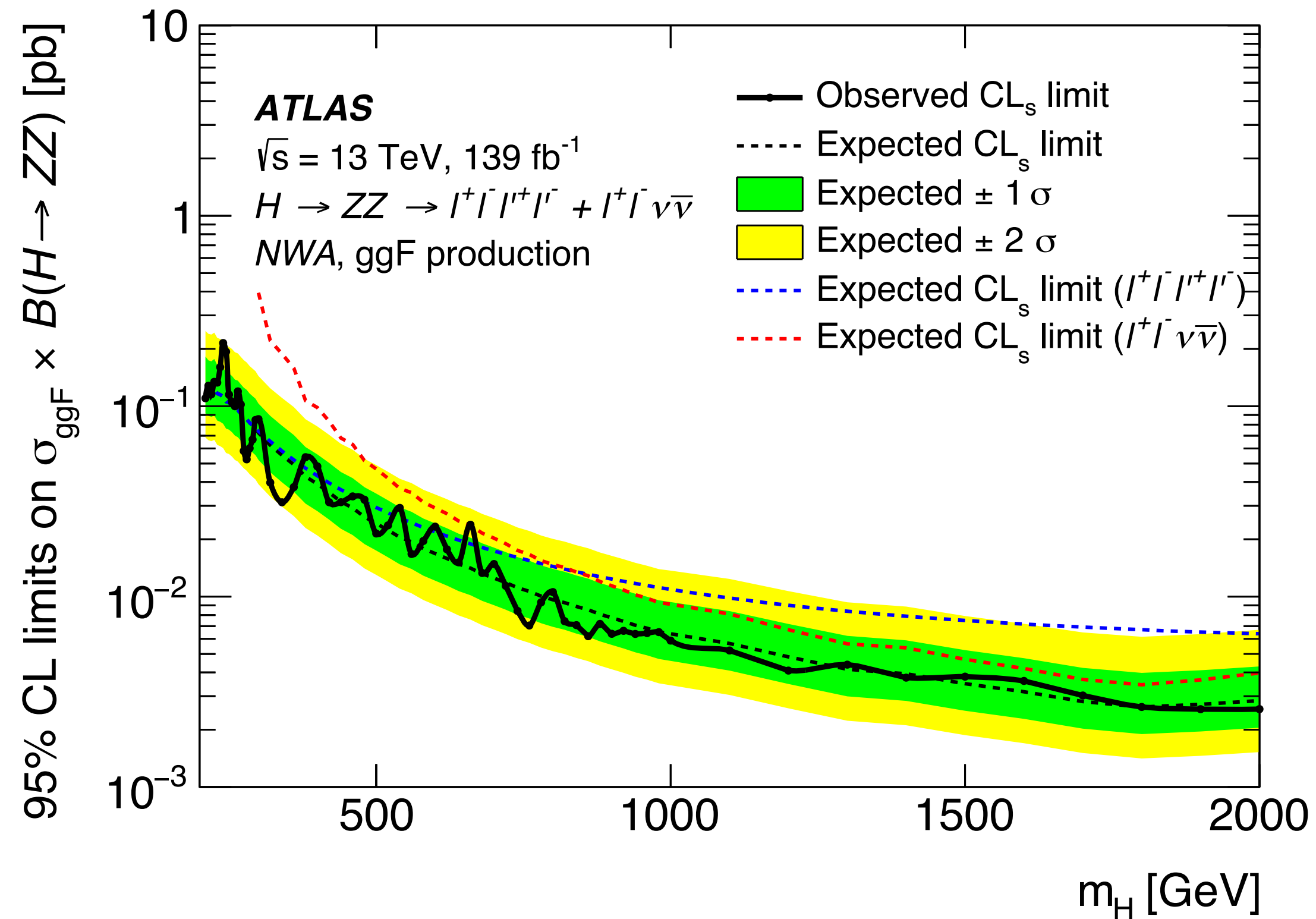
EPJC 81 (2021) 332

Results in LWA

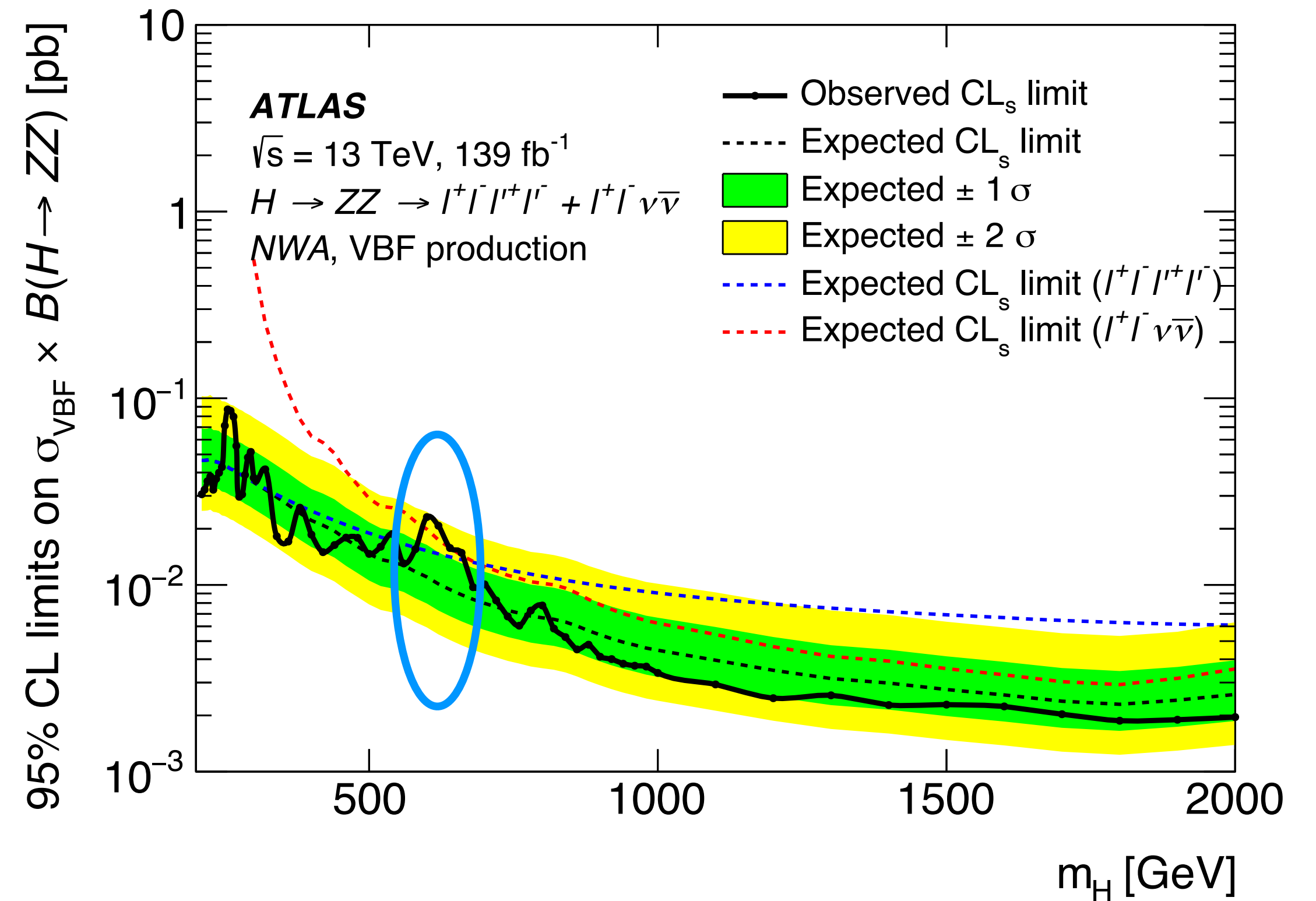


High mass ZZ search

Results in NWA



ggF: maximum deviation at **240 GeV**, with local (global) significance of 2.0 (0.5) σ

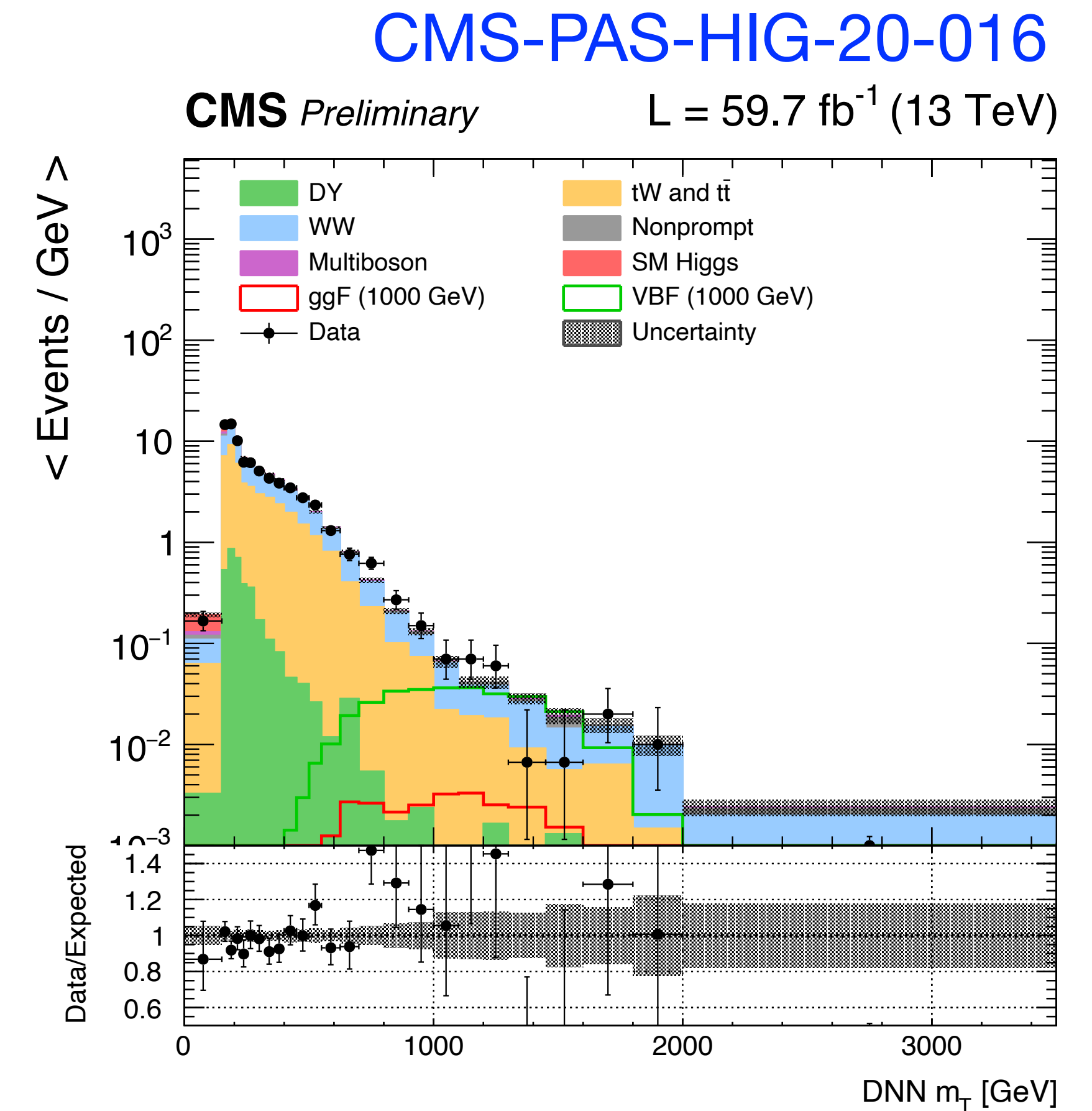


VBF: maximum deviation at **620 GeV**, with local (global) significance of 2.4 (0.9) σ

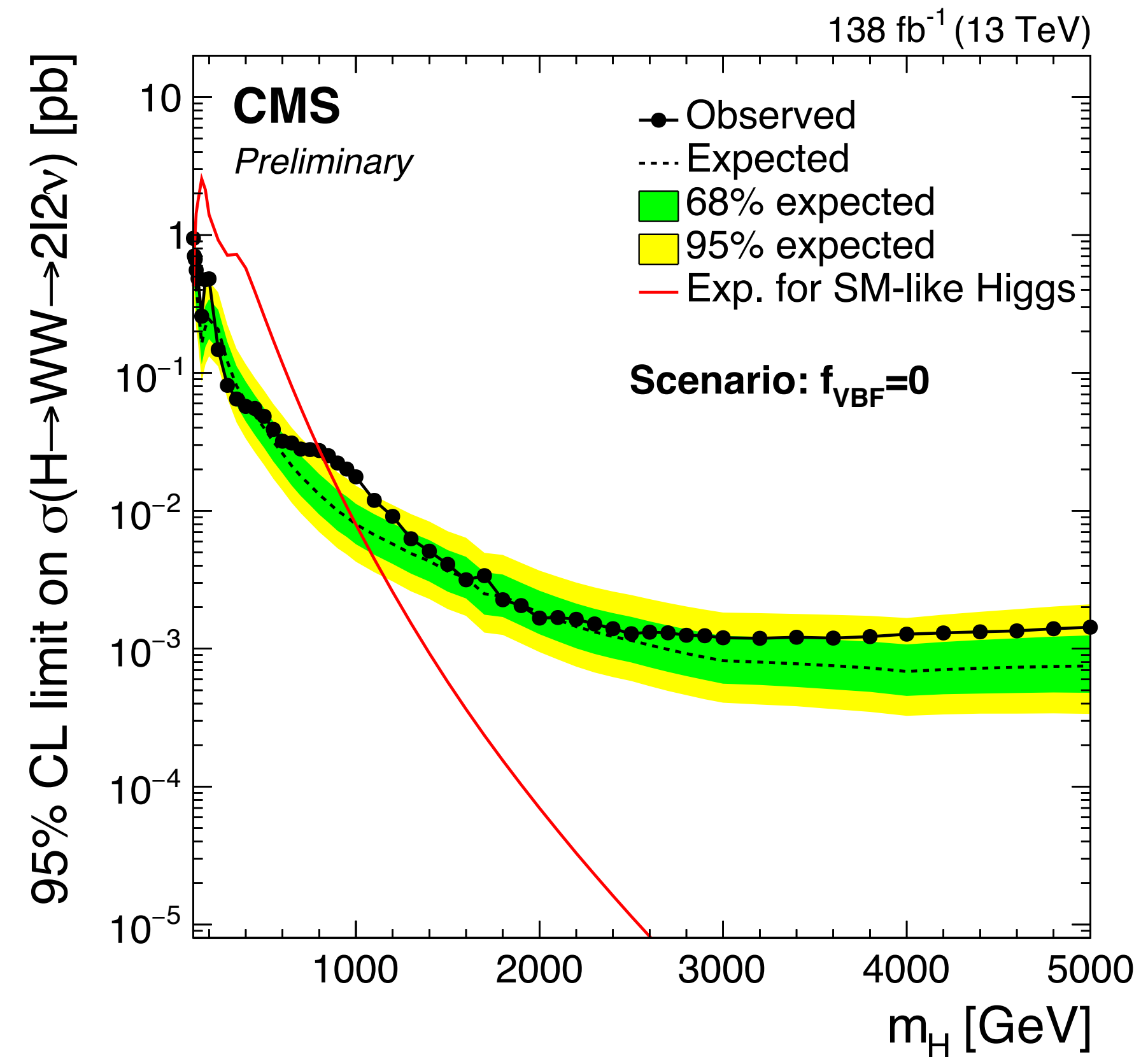
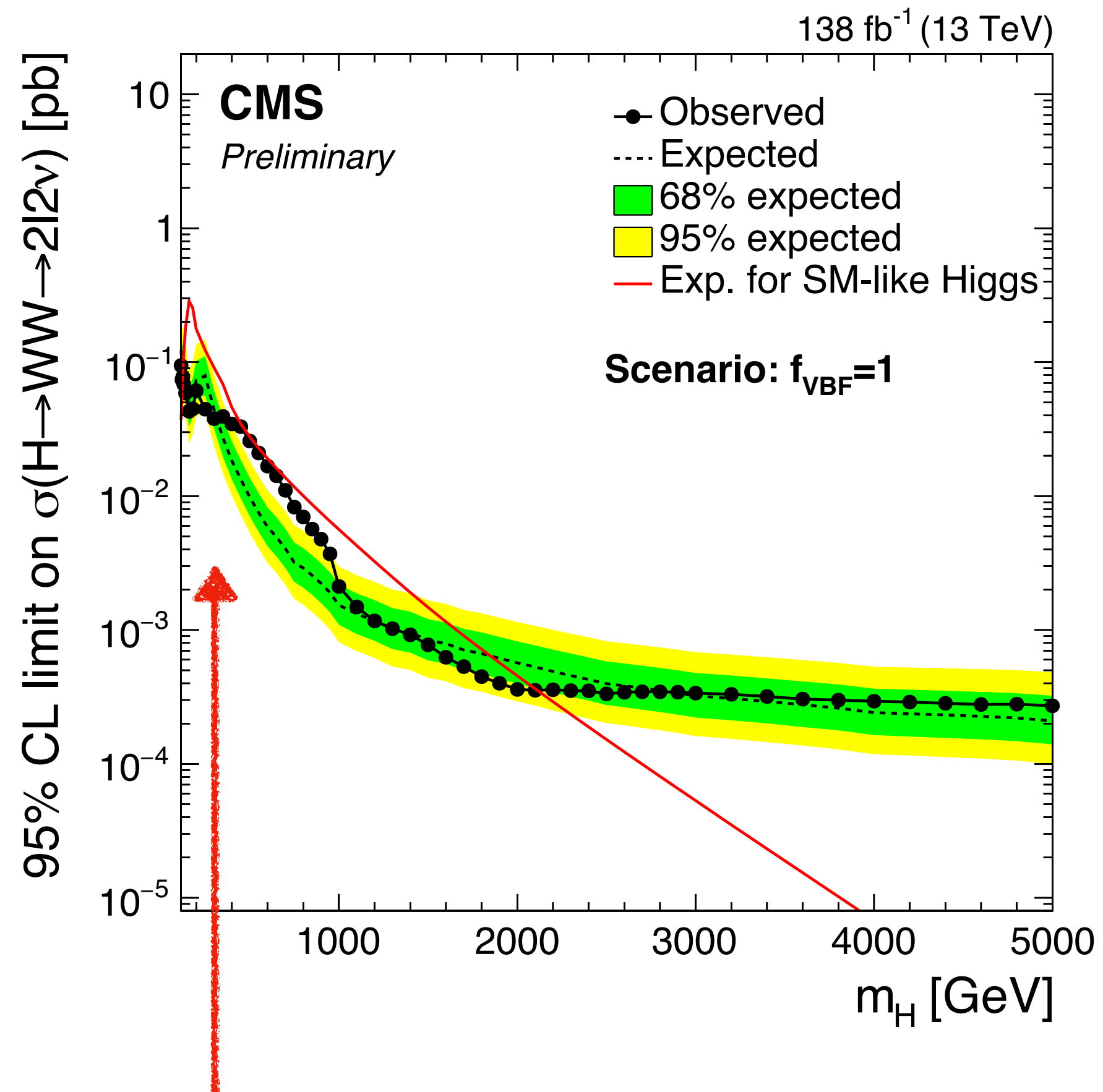
High mass W^+W^- search

Search for heavy resonance decaying to W^+W^- in $115 < m_{WW} < 5000$ GeV in $2l2\nu$ final states from CMS

- Search in final states with $ee/e\mu/\mu\mu$
- Considers range of signal width hypotheses
- Both gluon fusion and VBF production considered with different relative contributions
- Interpretation also in MSSM scenarios, 2HDM
- DNNs used for event classification, mass reconstruction



High mass W^+W^- search



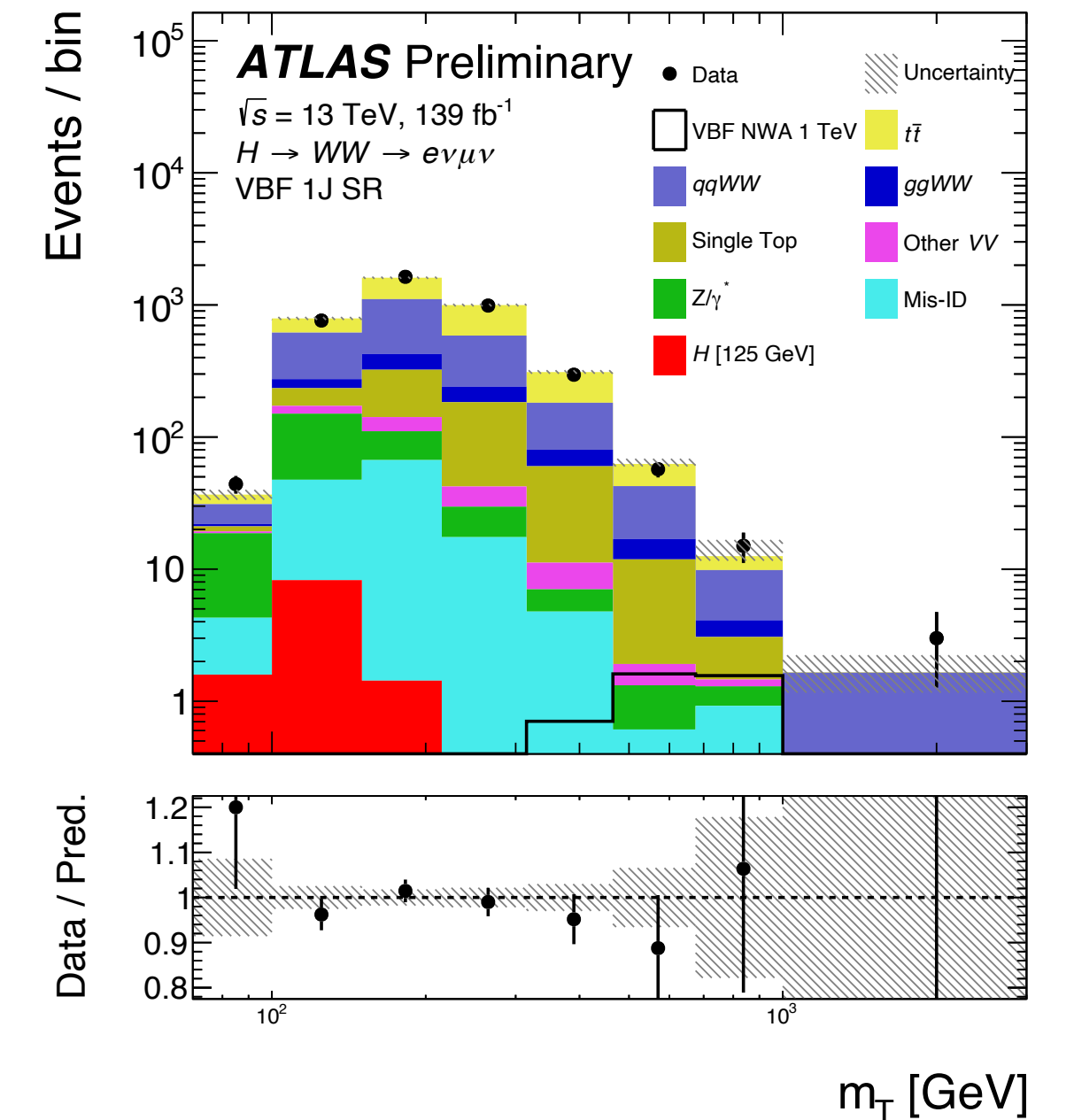
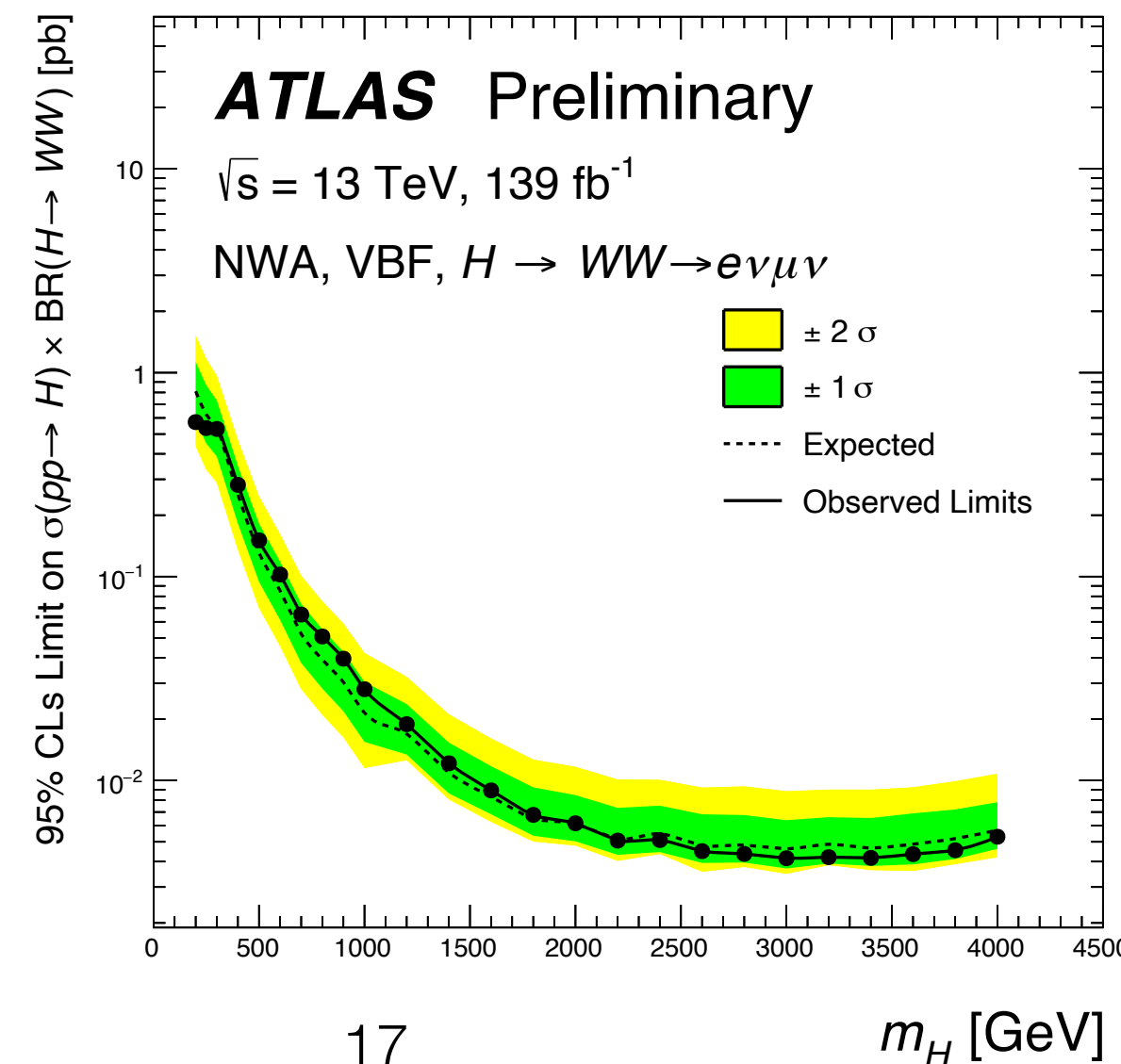
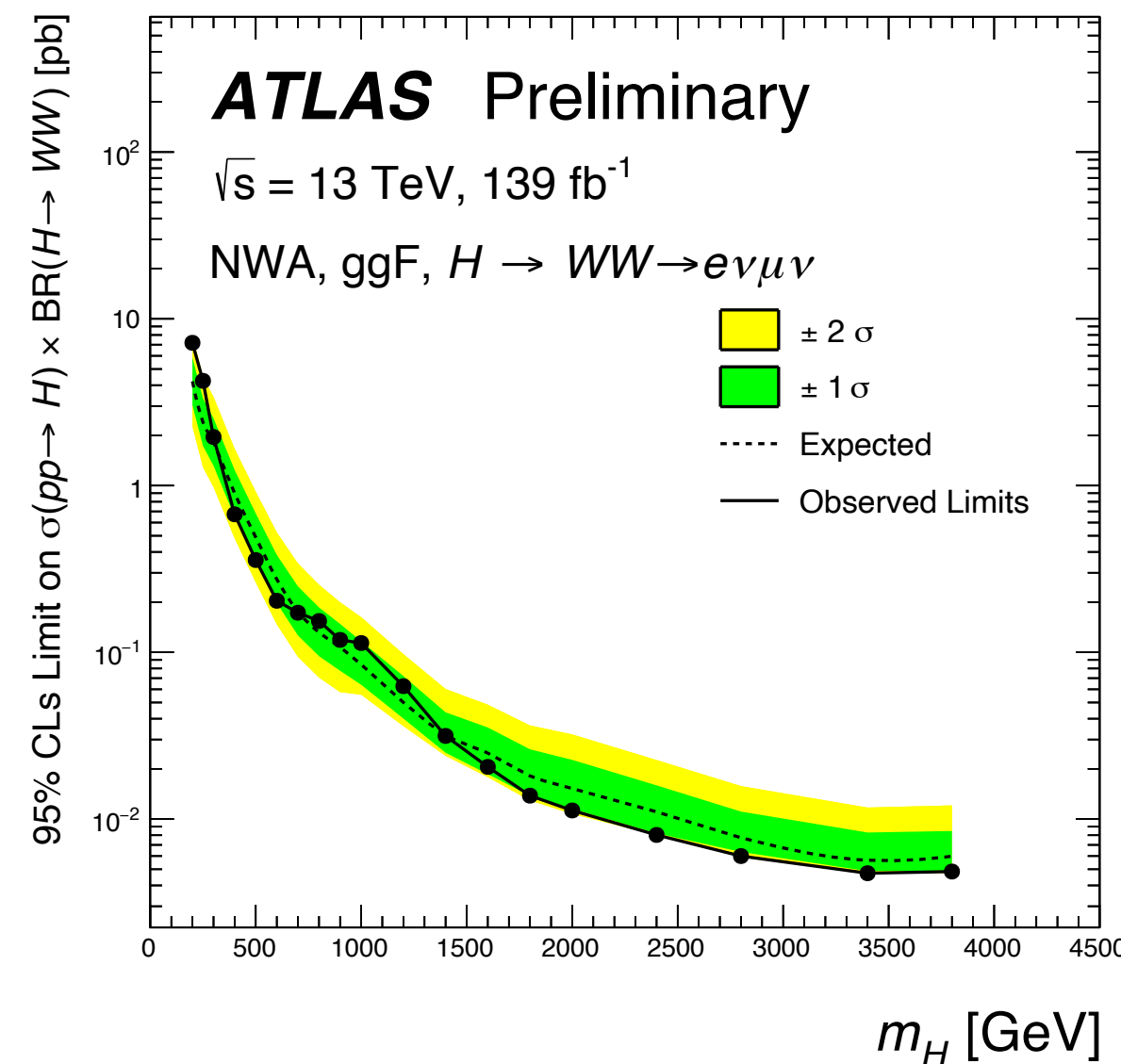
Largest local (global) significance of 3.8 (2.6) σ found for $f_{\text{VBF}} = 1$ scenario at **650 GeV**

High mass W^+W^- search

ATLAS search in $e\mu\nu\nu$ final states, $300 < m_{WW} < 4000$ GeV

- Considers additional Higgs-like resonance in NWA, and other spin 0/1/2 models
- Gluon fusion and/or VBF production considered depending on model
- Transverse mass between dilepton system and E_T^{miss} used as signal discriminant

ATLAS-CONF-2022-066



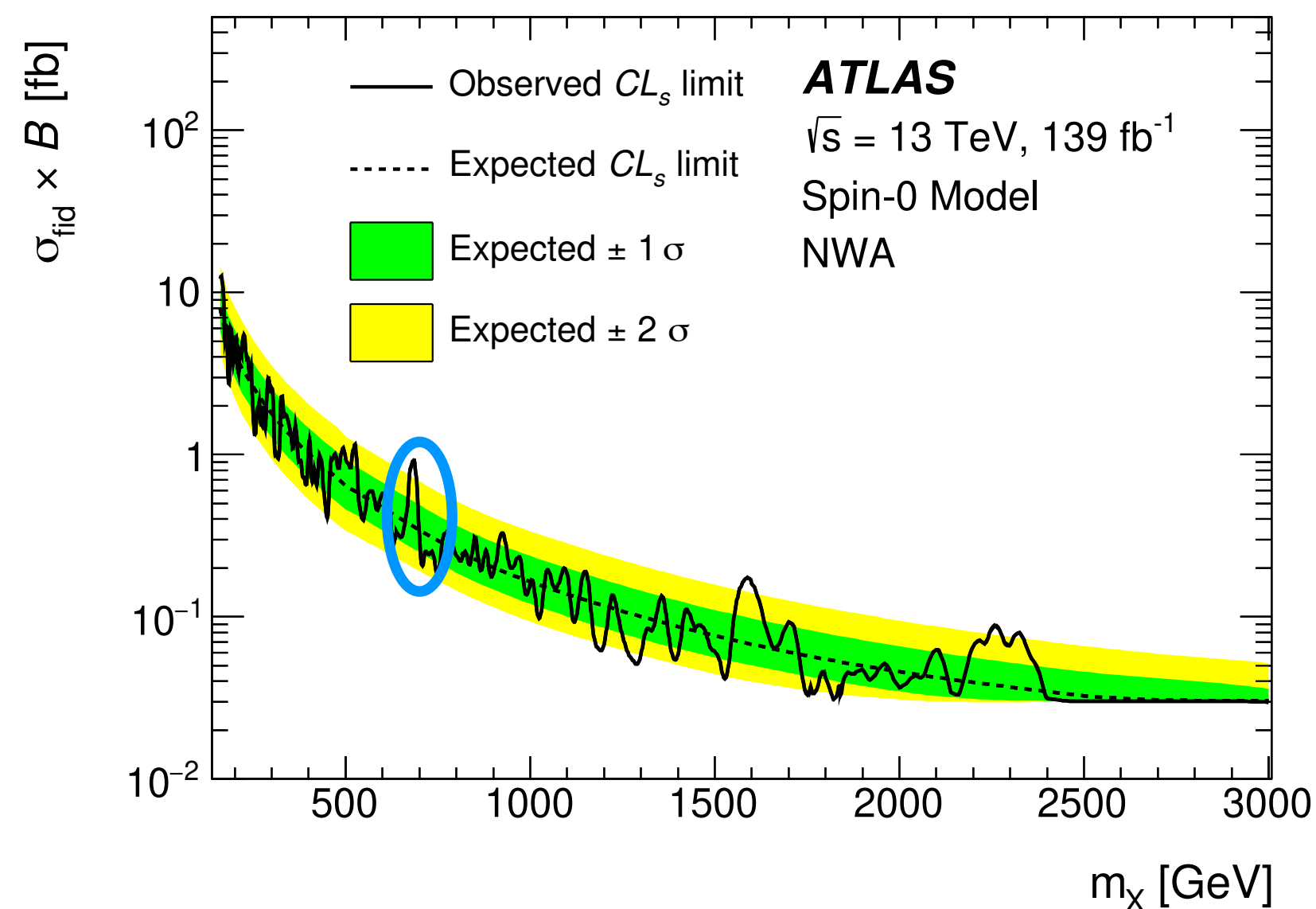
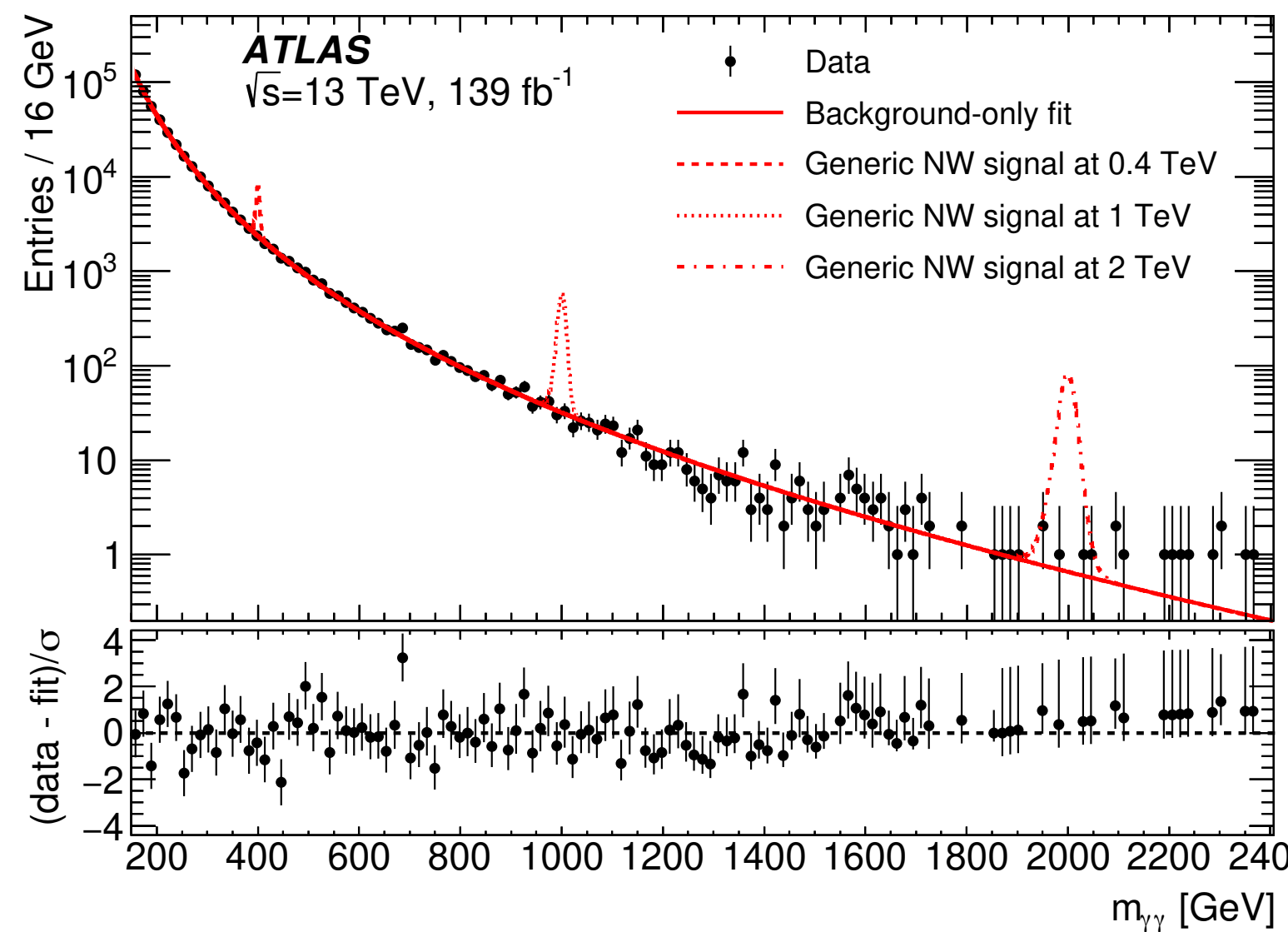
No significant excess observed!

High mass di-photon search

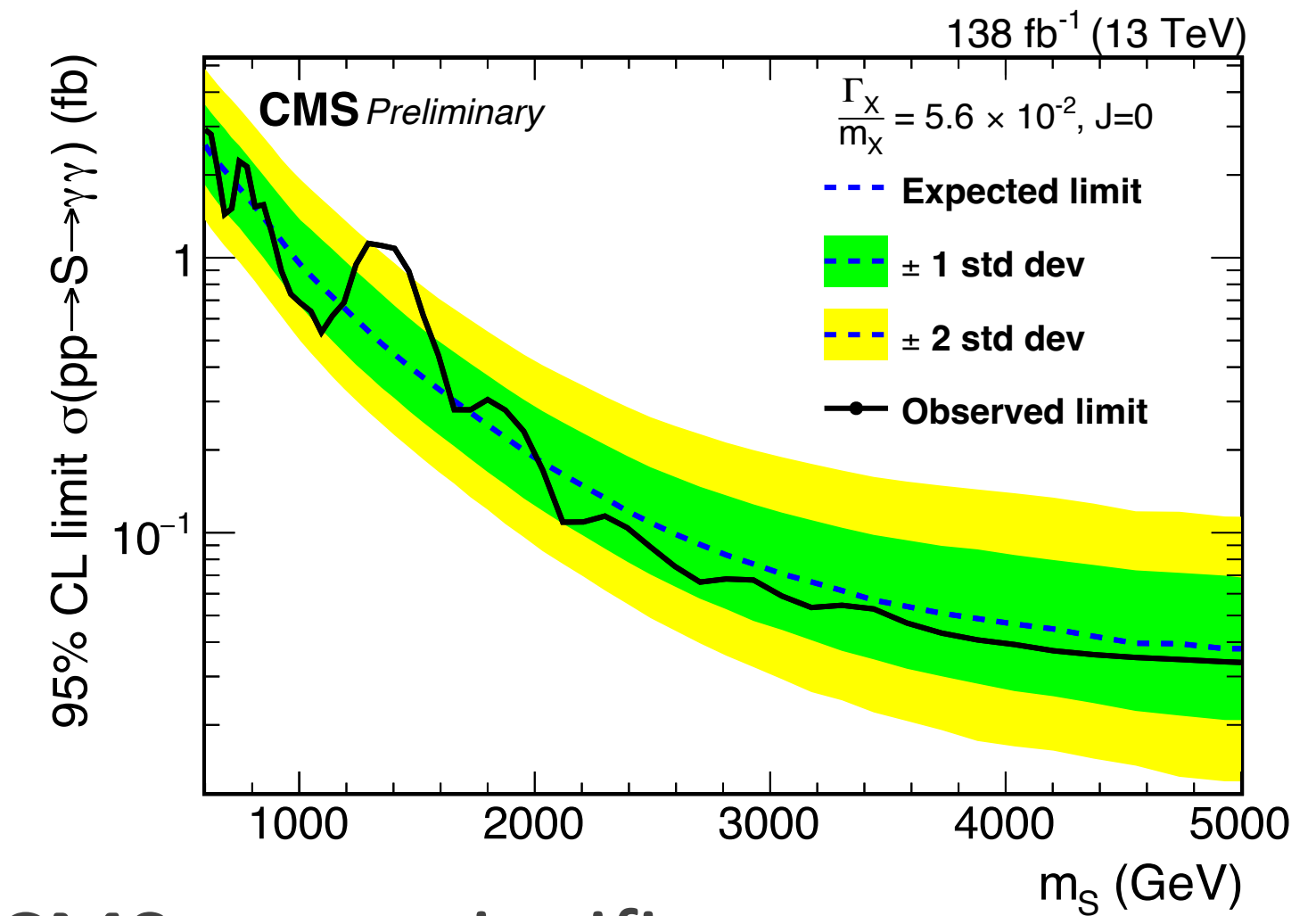
Search for resonance decaying to $\gamma\gamma$

- Searches from ATLAS and CMS consider spin-0 and spin-2 resonances
- Fit to di-photon mass spectrum

PLB 822 (2021) 136651



CMS-PAS-EXO-22-004



CMS: most significant excess at **1.3 TeV** for broad resonance model: 2.6 (0.8) σ local (global) significance

ATLAS: most significant excess at **684 GeV**: 3.3 (1.3) σ local (global) significance

Searches for heavy particles decaying to scalars

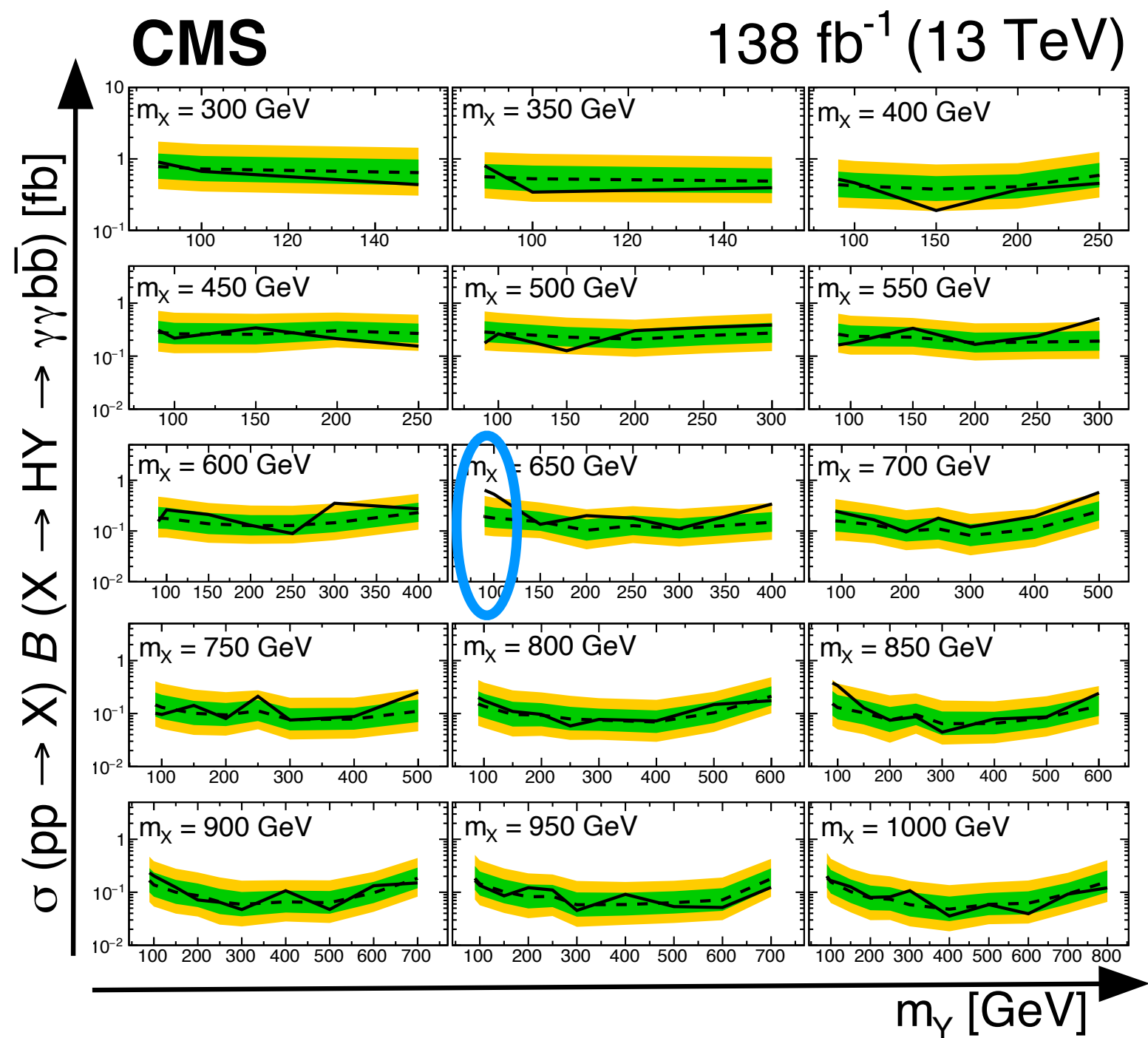
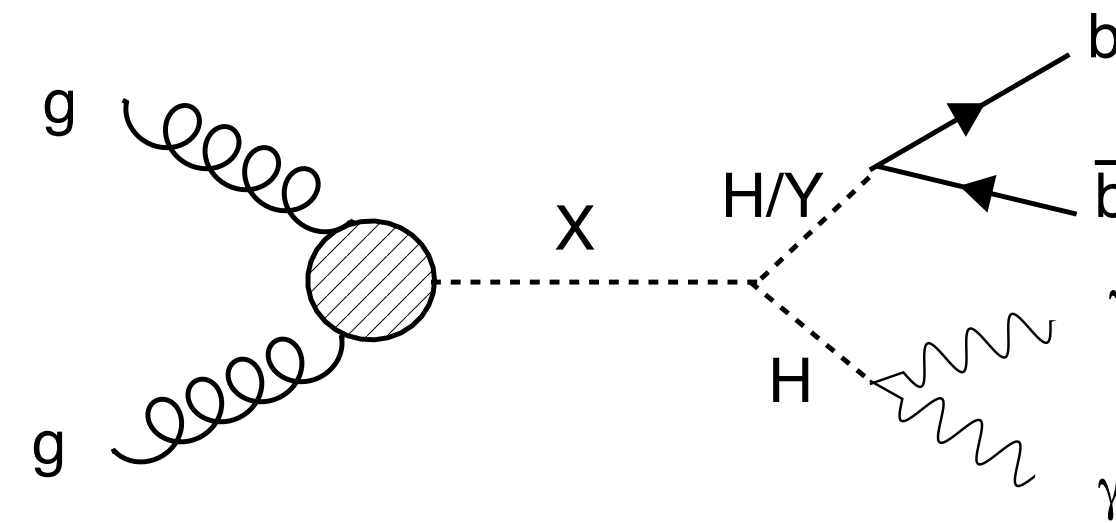
Search for heavy resonance $X \rightarrow YH$

Searches targeting resonance decaying to H and additional scalar Y

- Motivated by NMSSM, TRSM (SM extended by two real singlet fields)

CMS-PAS-HIG-22-012

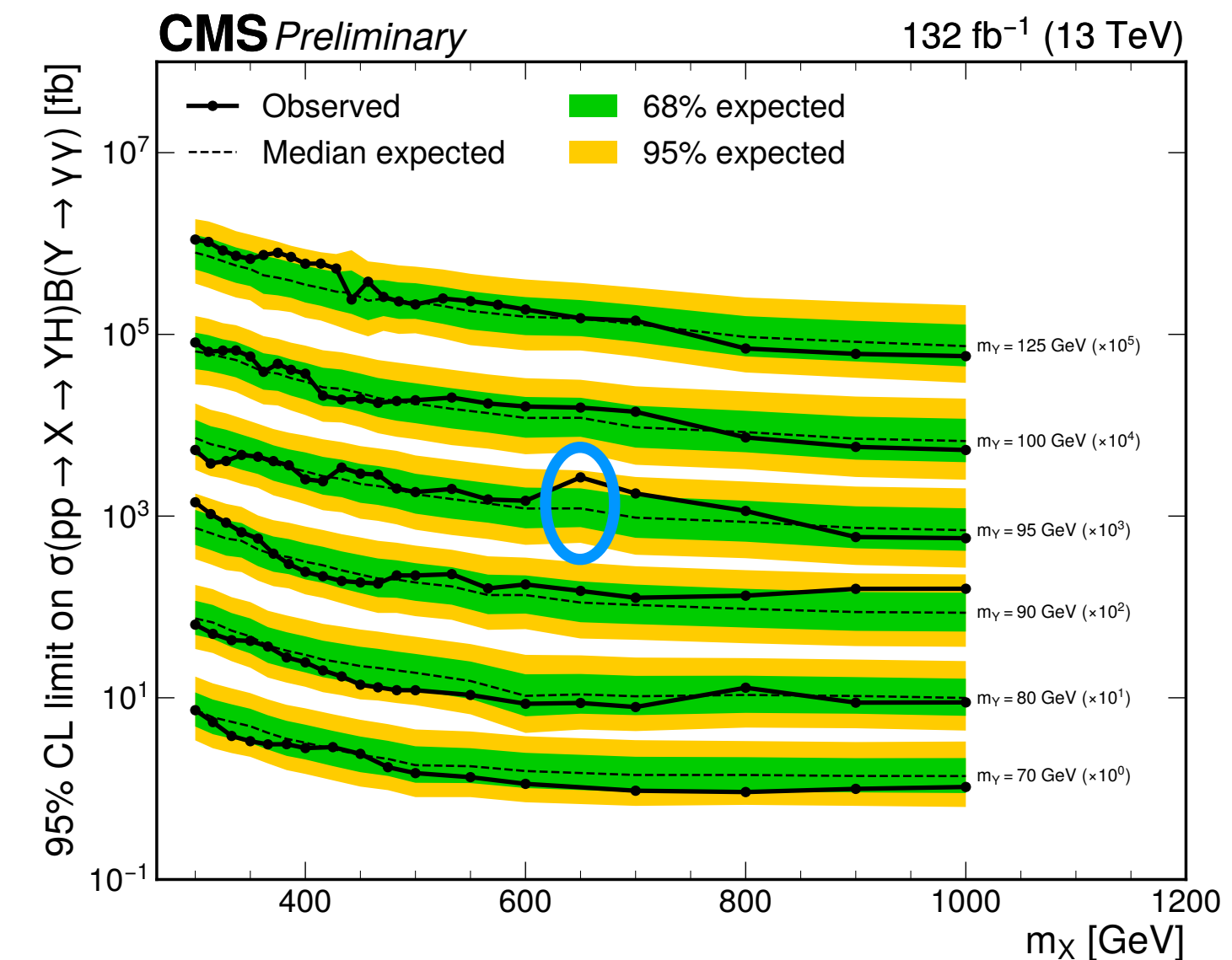
arXiv:2310.01643



(Spin-0) $X \rightarrow HY \rightarrow \gamma\gamma b\bar{b}$

■ Expected limit $\pm 1\sigma$ ■ Expected limit $\pm 2\sigma$
- - - - - Expected 95% upper limit — Observed 95% upper limit

Most significant excess at $m_X = 650$ GeV, $m_Y = 90$ GeV: 3.8 (2.8) σ local (global) significance for $Y(bb)H(\gamma\gamma)$



Mild excess seen in $Y(\gamma\gamma)H(\tau\tau)$ at $m_X = 650$ GeV, $m_Y = 95$ GeV with 2.3 σ local significance (but large LEE)

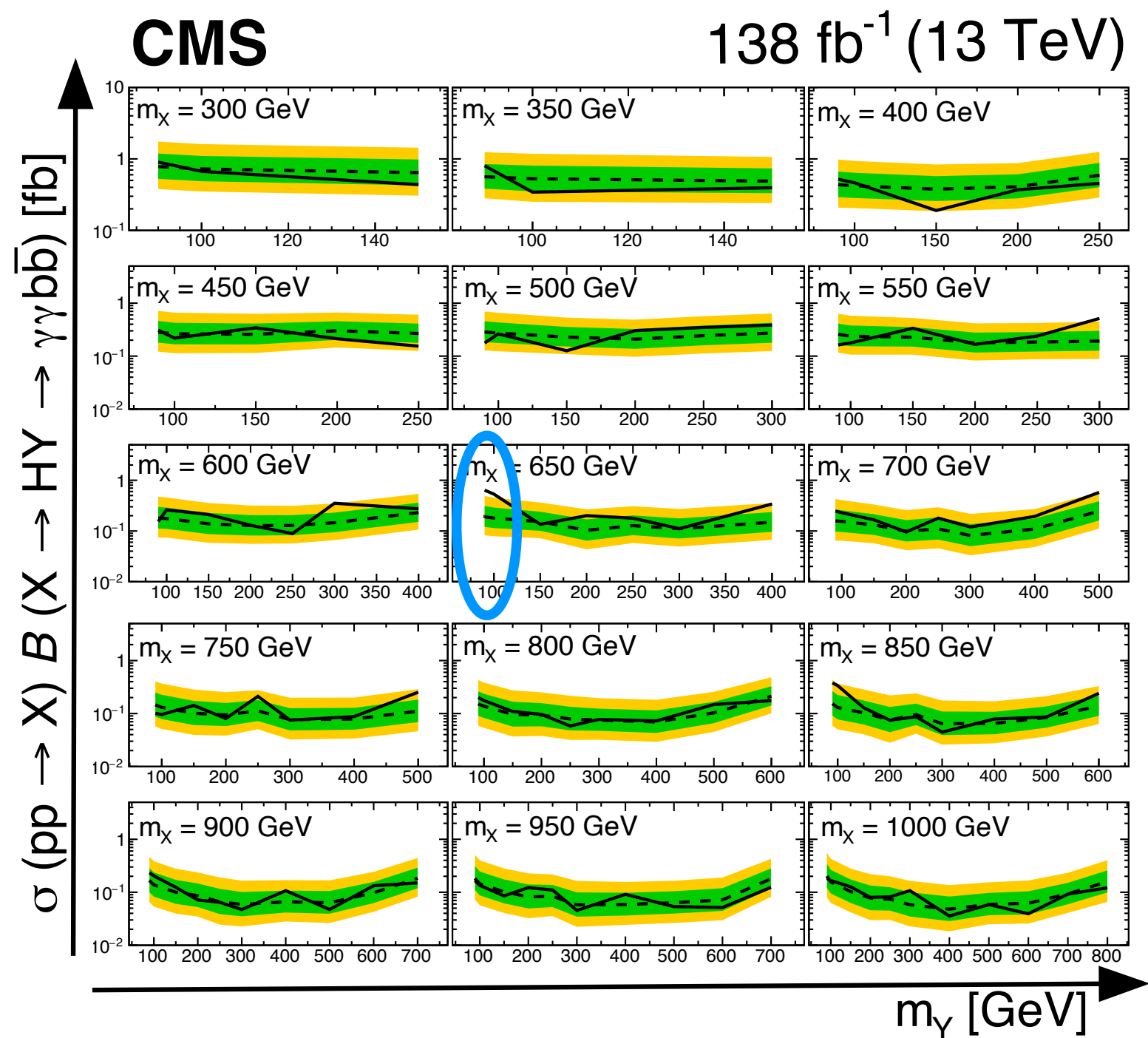
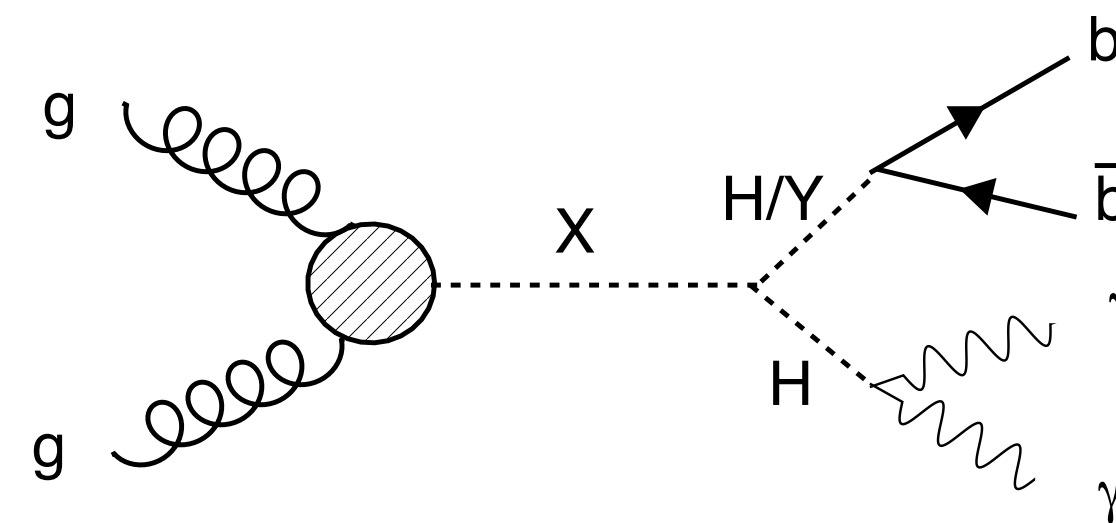
Search for heavy resonance $X \rightarrow YH$

Searches targeting resonance decaying to H and additional scalar Y

- Motivated by NMSSM, TRSM (SM extended by two real singlet fields)

arXiv:2404.12915

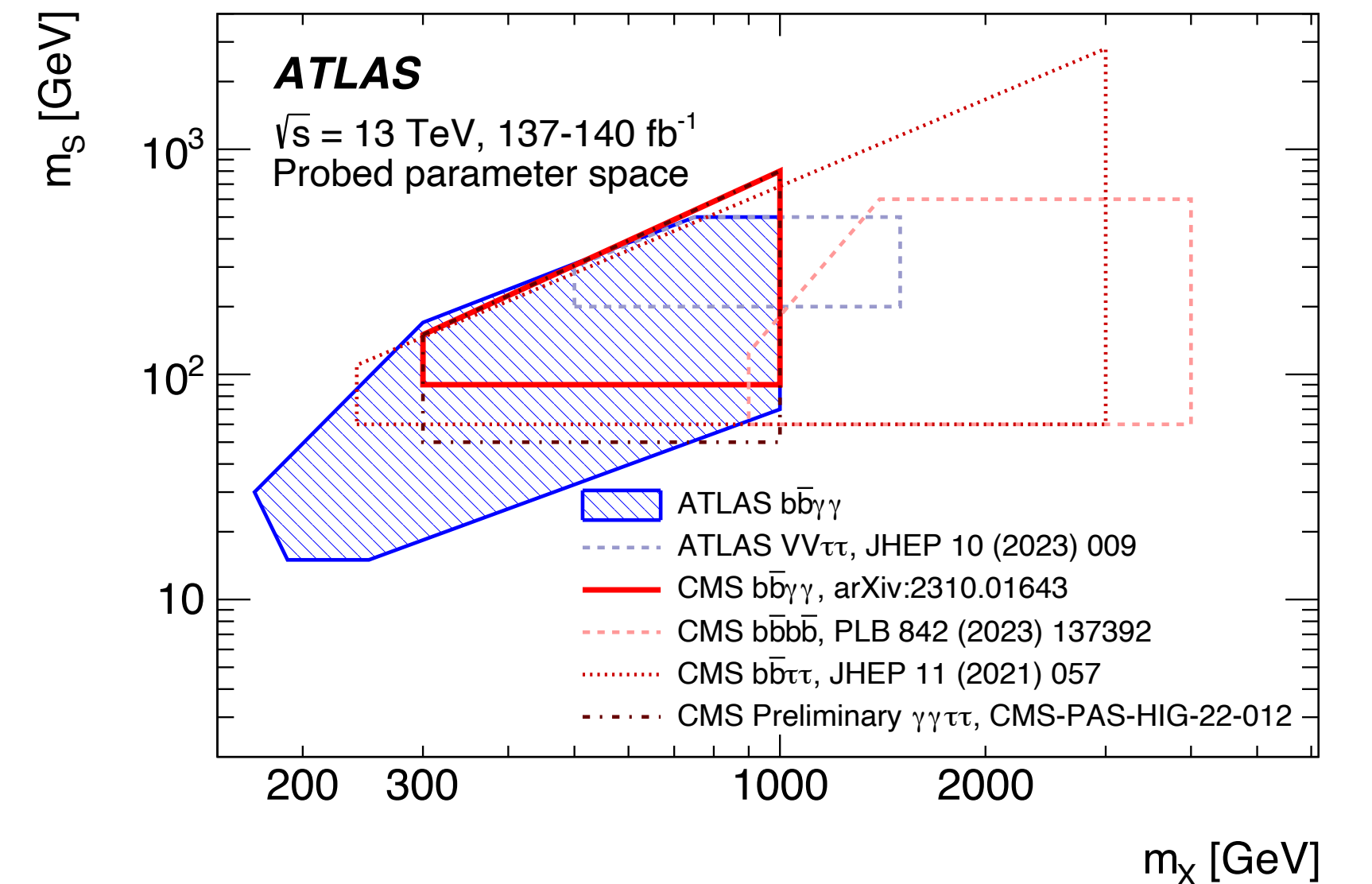
arXiv:2310.01643



(Spin-0) $X \rightarrow HY \rightarrow \gamma\gamma b\bar{b}$

■ Expected limit $\pm 1 \sigma$ ■ Expected limit $\pm 2 \sigma$
- - - - Expected 95% upper limit — Observed 95% upper limit

Most significant excess at $m_X = 650 \text{ GeV}$, $m_Y = 90 \text{ GeV}$: 3.8 (2.8) σ local (global) significance for $Y(bb)H(\gamma\gamma)$



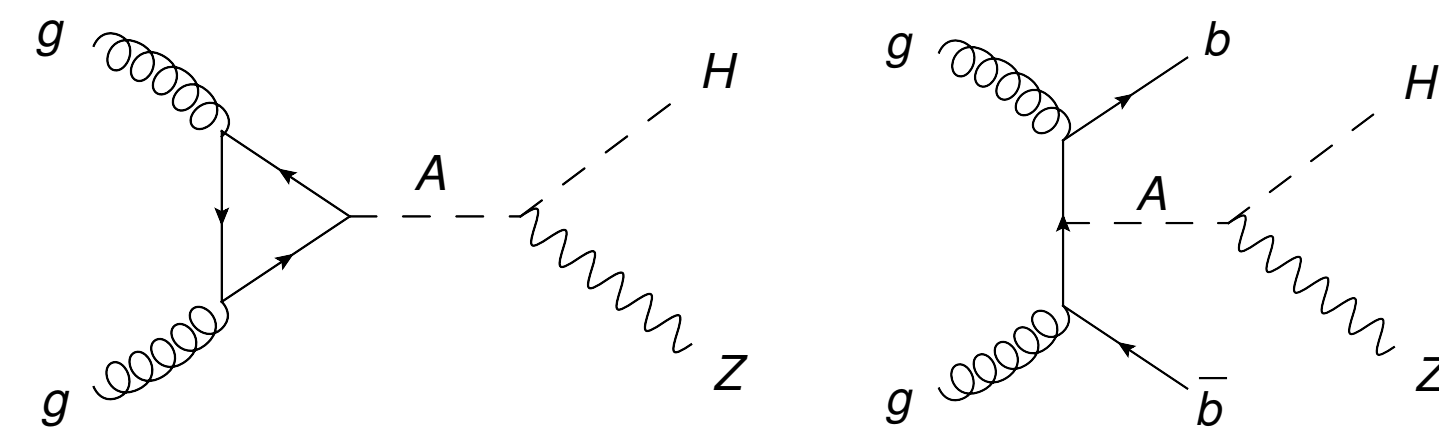
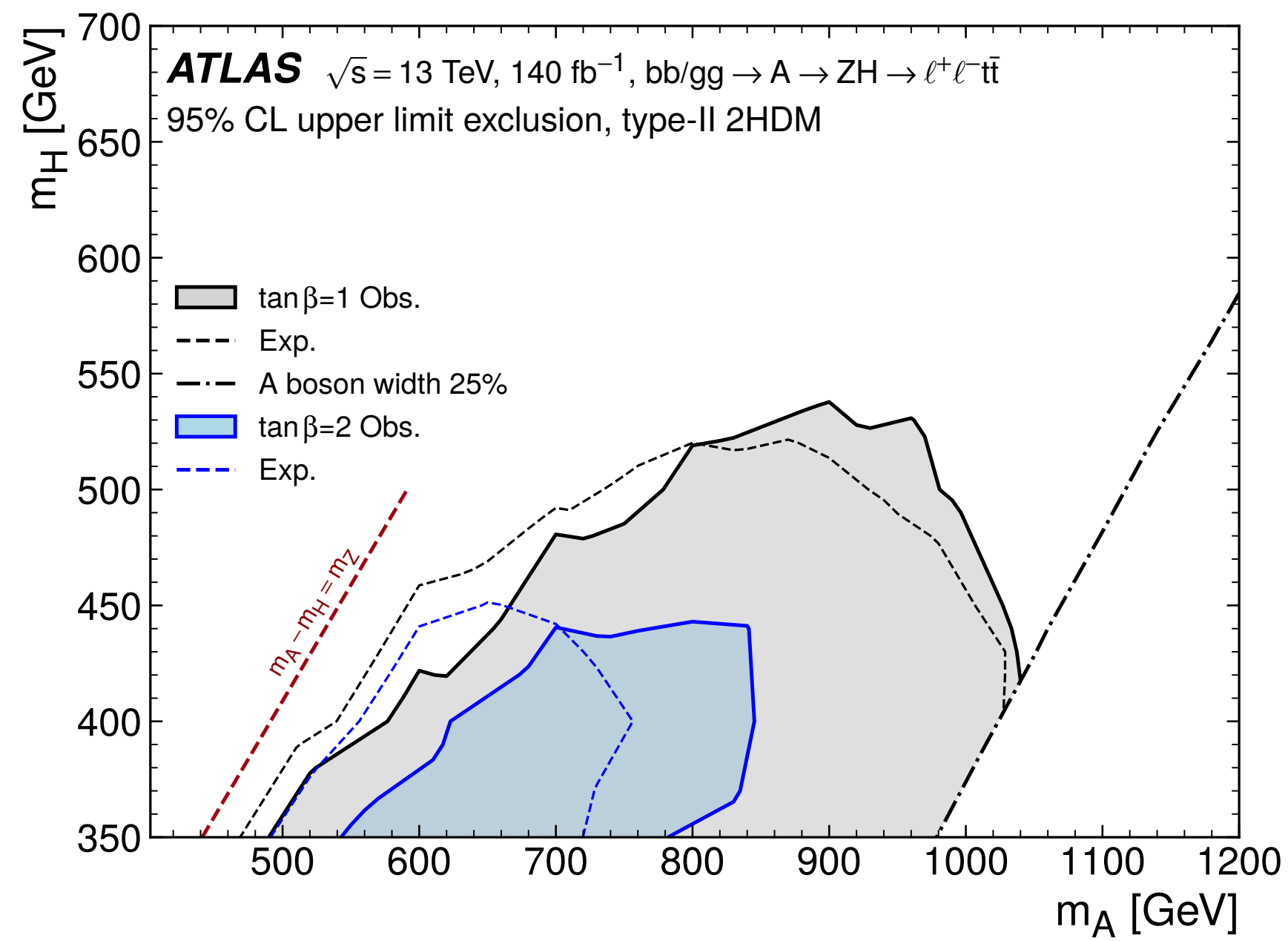
However, no excess seen by ATLAS $X \rightarrow Y(bb)H(\gamma\gamma)$ search at same masses: largest deviation at $(m_X, m_Y) = (575, 200) \text{ GeV}$ with 3.5 (2.0) σ local (global) significance)

Search for $A \rightarrow Z(\ell\ell)H(t\bar{t})$

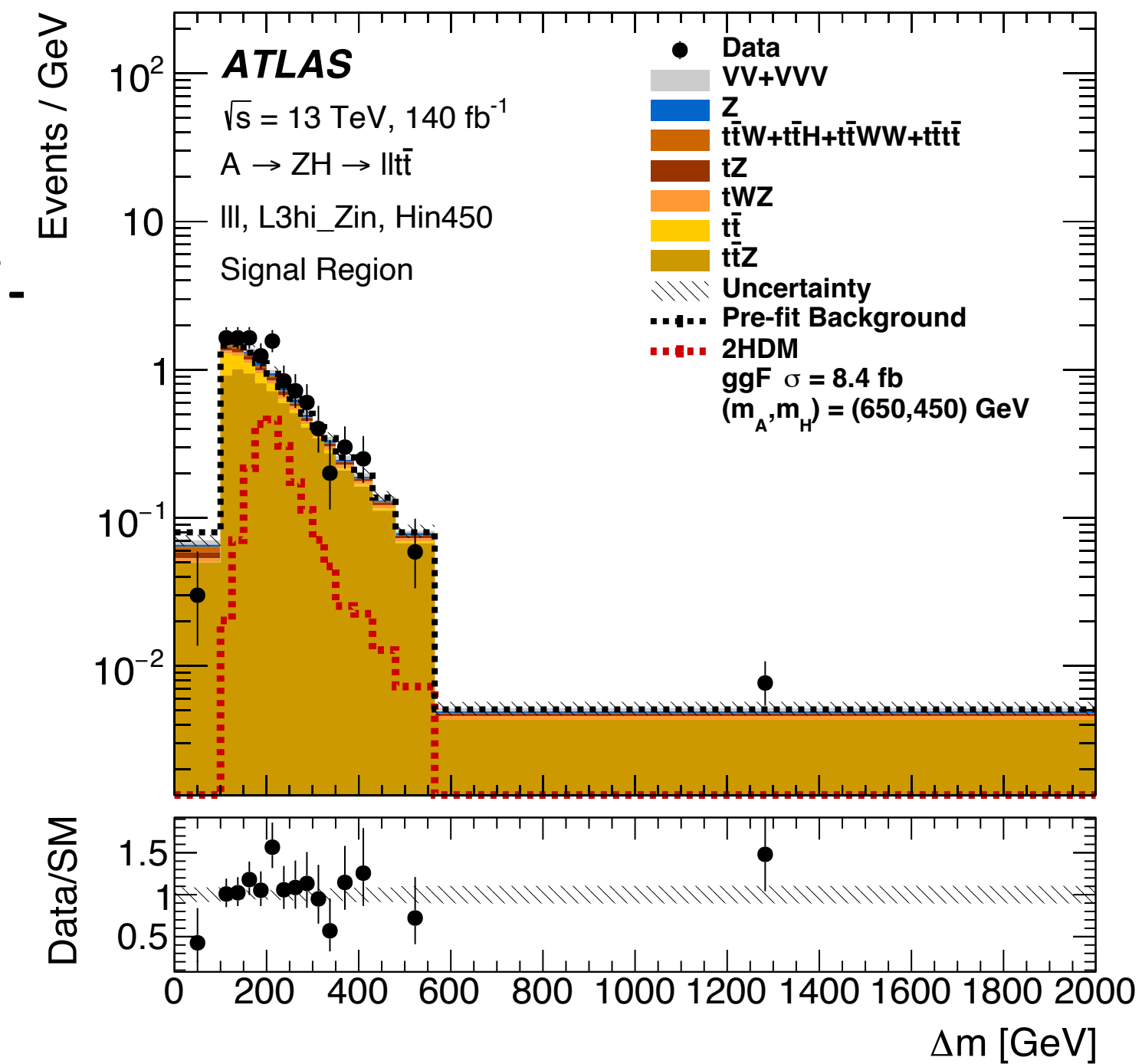
Search for CP-odd Higgs decaying to heavy CP-even Higgs and Z

- Motivated by 2HDM, $m_A > m_H$ favored by electroweak baryogenesis models featuring strongly first order EW phase transition: $A \rightarrow ZH$ dominates when $m_A - m_H > 250$ GeV
- $H \rightarrow t\bar{t}$ becomes dominant when $m_H > 2 m_t$. ATLAS search targets semi-leptonic $t\bar{t}$ decays
- Mass difference $\Delta m = m_A^{\text{cand}} - m_H^{\text{cand}}$ as signal discriminant

JHEP 02 (2024) 197



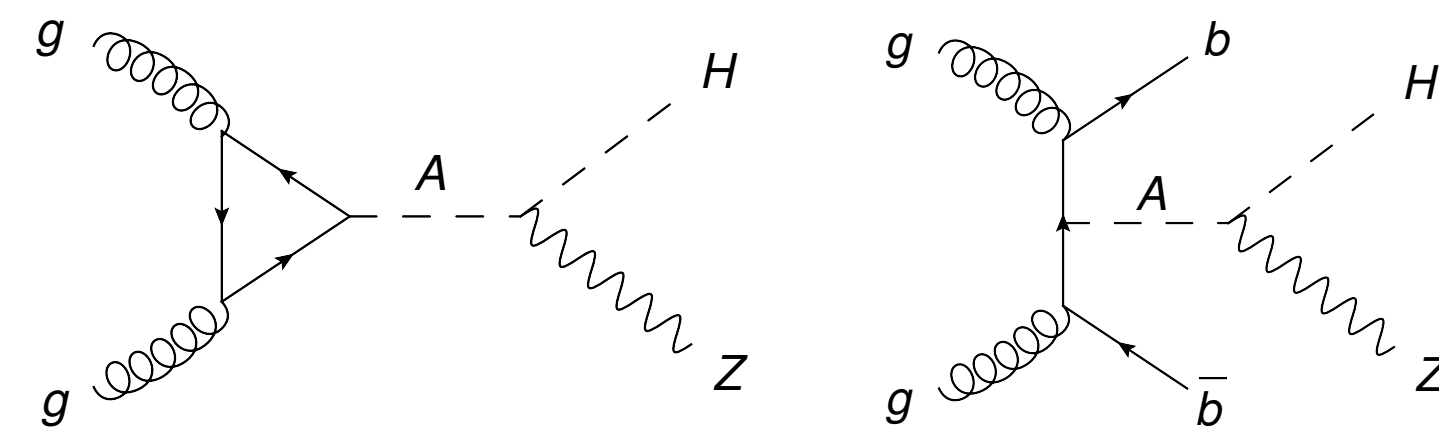
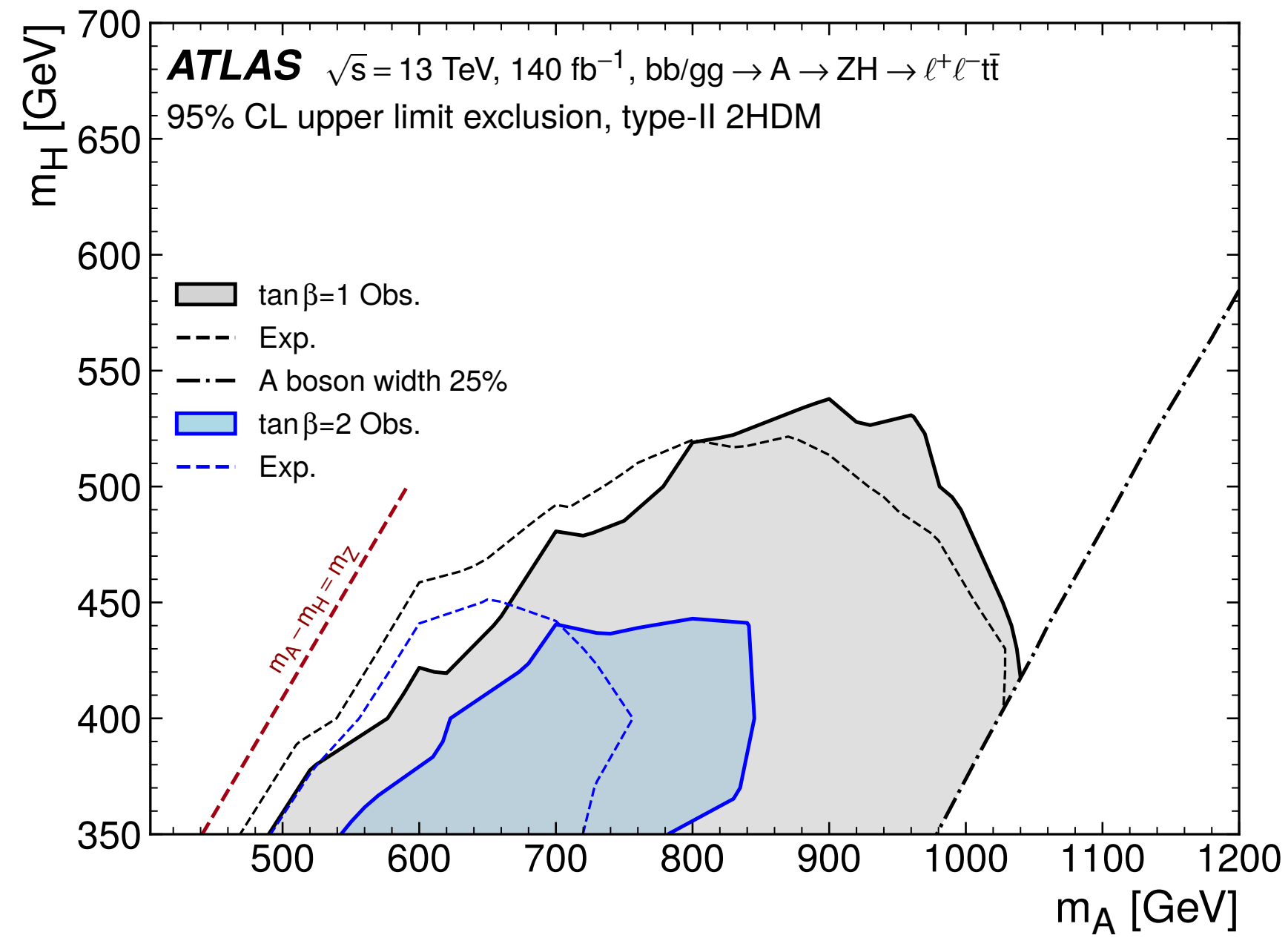
Most significant excess at $m_A = 650$ GeV, $m_H = 450$ GeV: 2.9
(2.4) σ local (global) significance



Search for $A \rightarrow Z(\ell\ell)H(t\bar{t})$

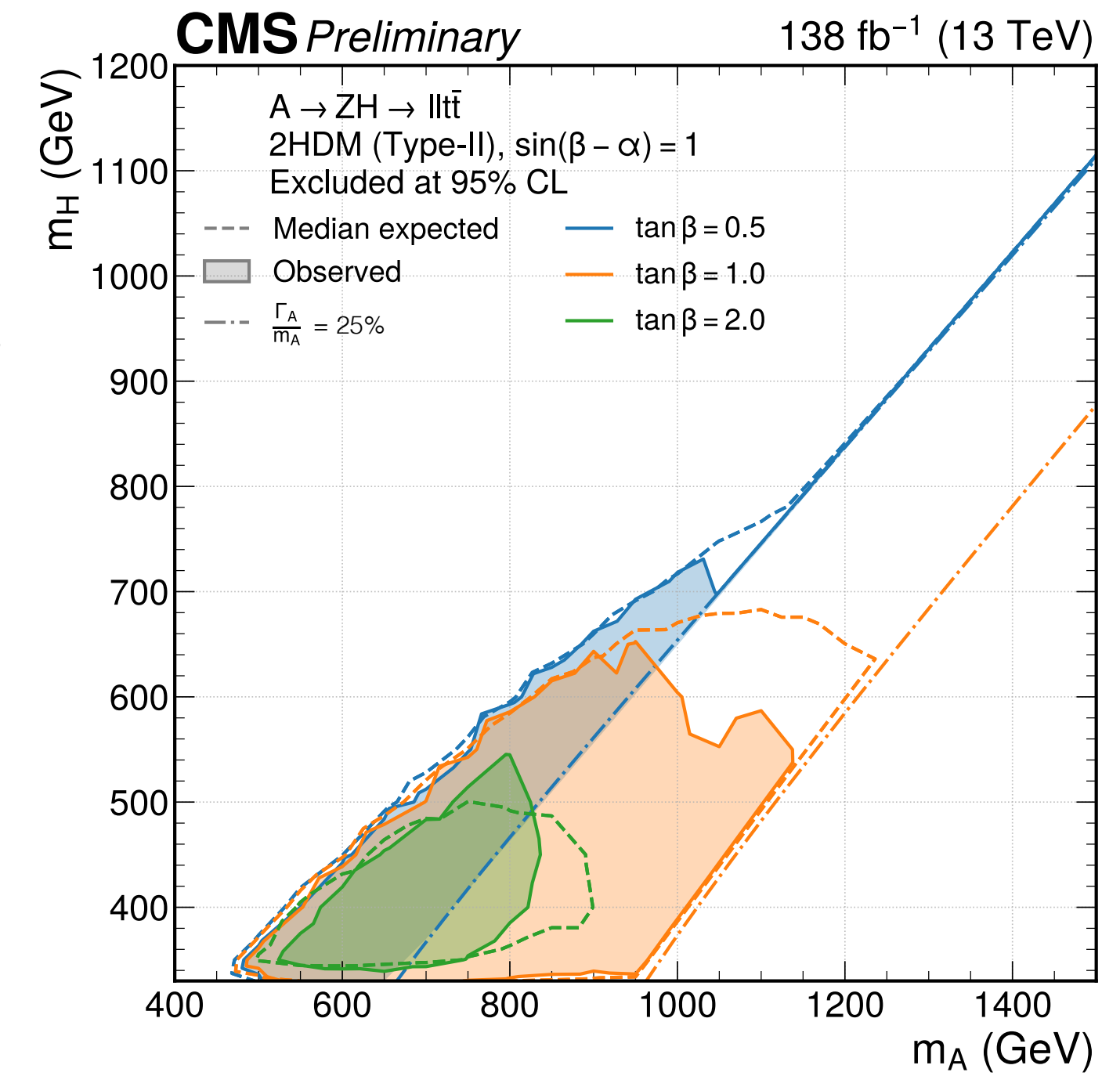
Search for CP-odd Higgs decaying to heavy CP-even Higgs and Z

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- $H \rightarrow t\bar{t}$ becomes dominant when $m_H > 2 m_t$. ATLAS search targets semi-leptonic $t\bar{t}$ decays
- Mass difference $\Delta m = m_A^{\text{cand}} - m_H^{\text{cand}}$ as signal discriminant



Most significant excess at $m_A = 650$ GeV, $m_H = 450$ GeV: 2.9 (2.4) σ local (global) significance

CMS-PAS-B2G-23-006



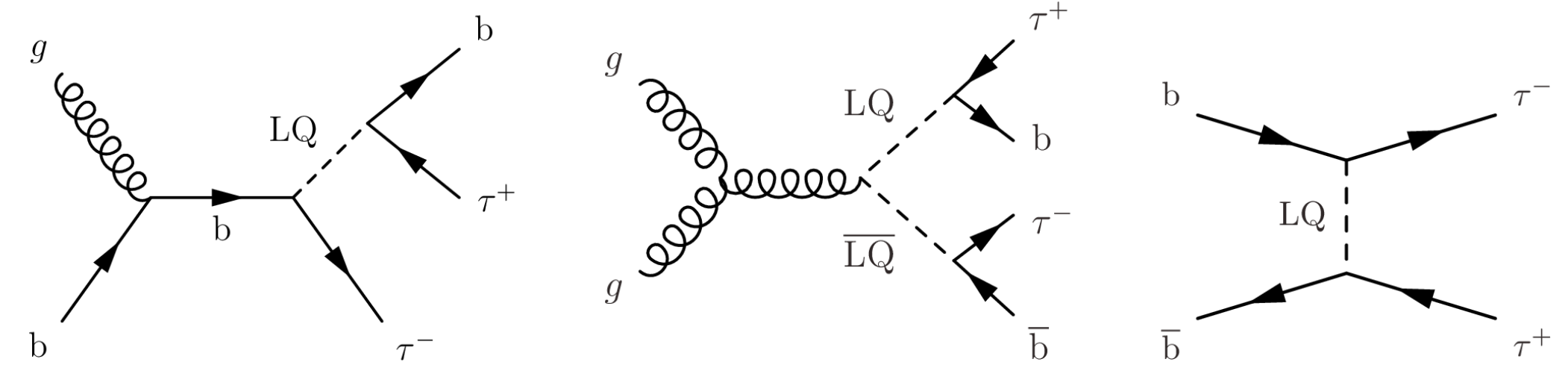
However, excess not confirmed by recent CMS search in final state with all-hadronic $t\bar{t}$ decays

**Searches in $b+\tau$ final states for leptoquarks,
vector-like leptons**

Leptoquarks coupled to 3rd generation

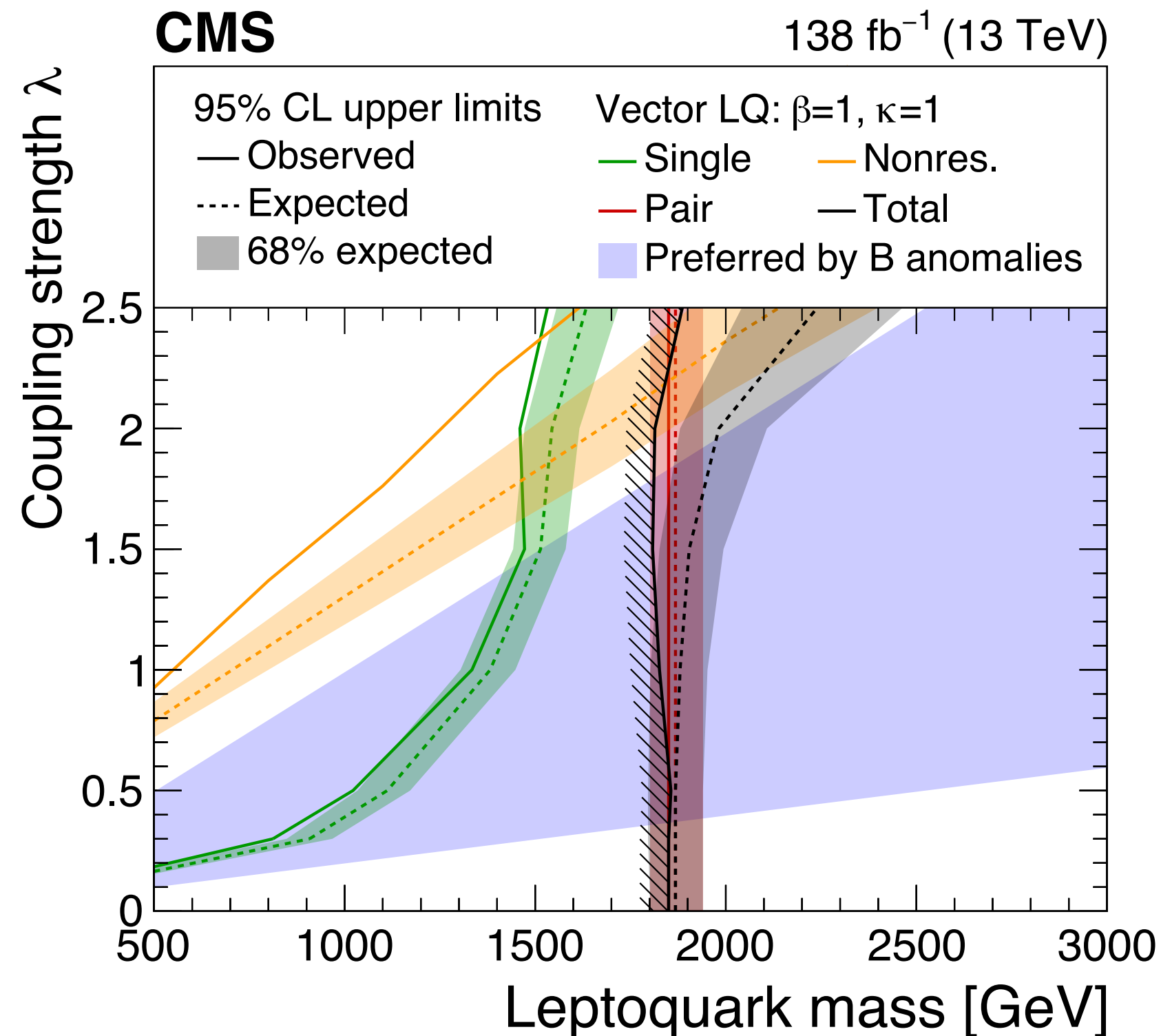
Search for $LQ \rightarrow b\tau$

- Motivated by B anomalies
- Consider single and pair production, non-resonant production

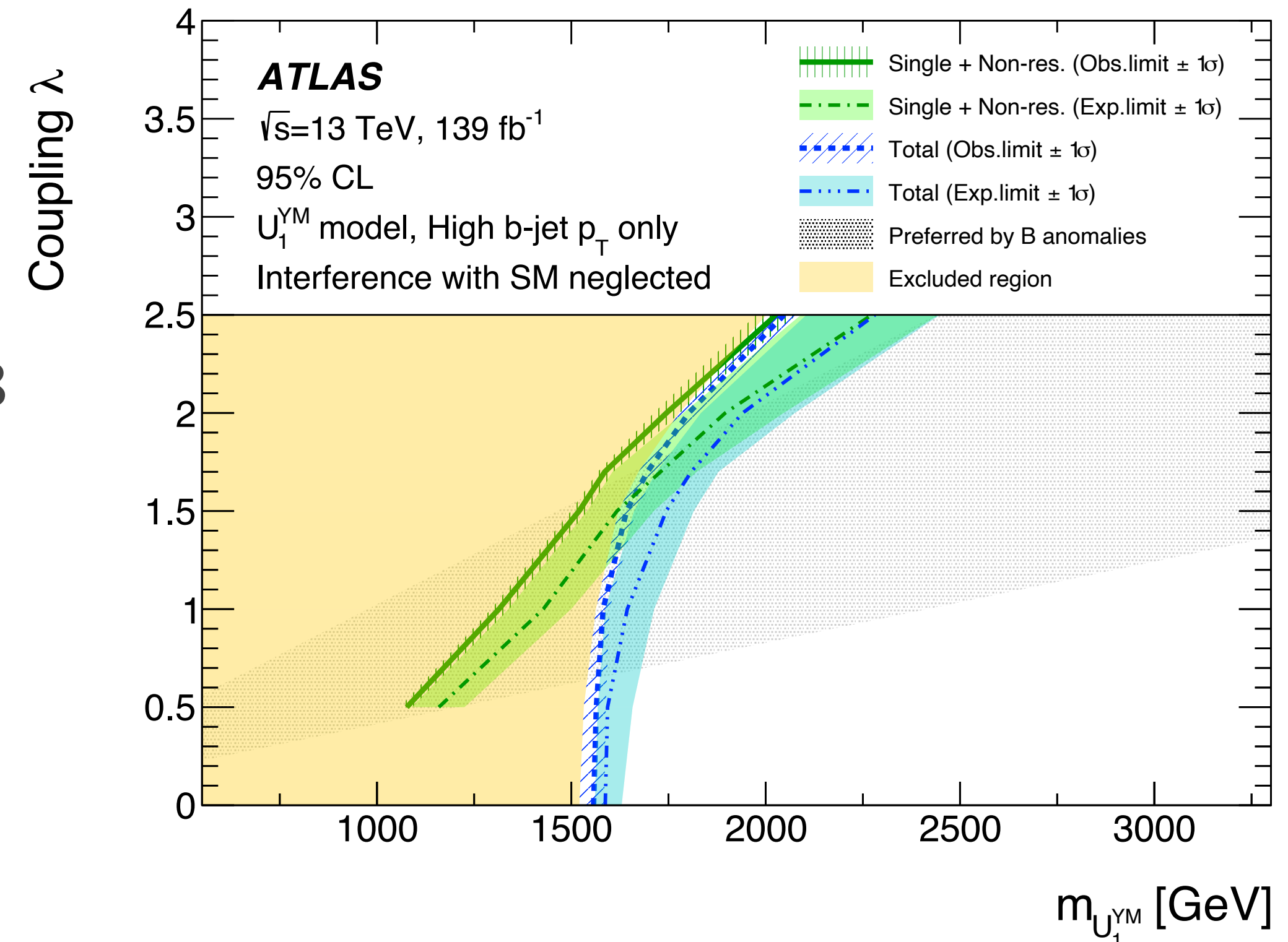


[arXiv:2308.07826](https://arxiv.org/abs/2308.07826)

[JHEP 10 \(2023\) 001](https://arxiv.org/abs/2308.07826)



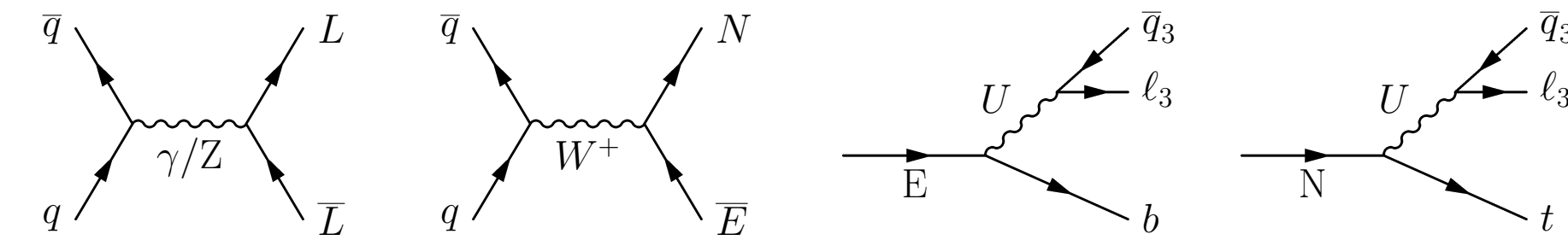
CMS observes excess with local significance 2.8σ for LQ mass **2 TeV**, coupling strength $\lambda=2.5$: excluded by ATLAS



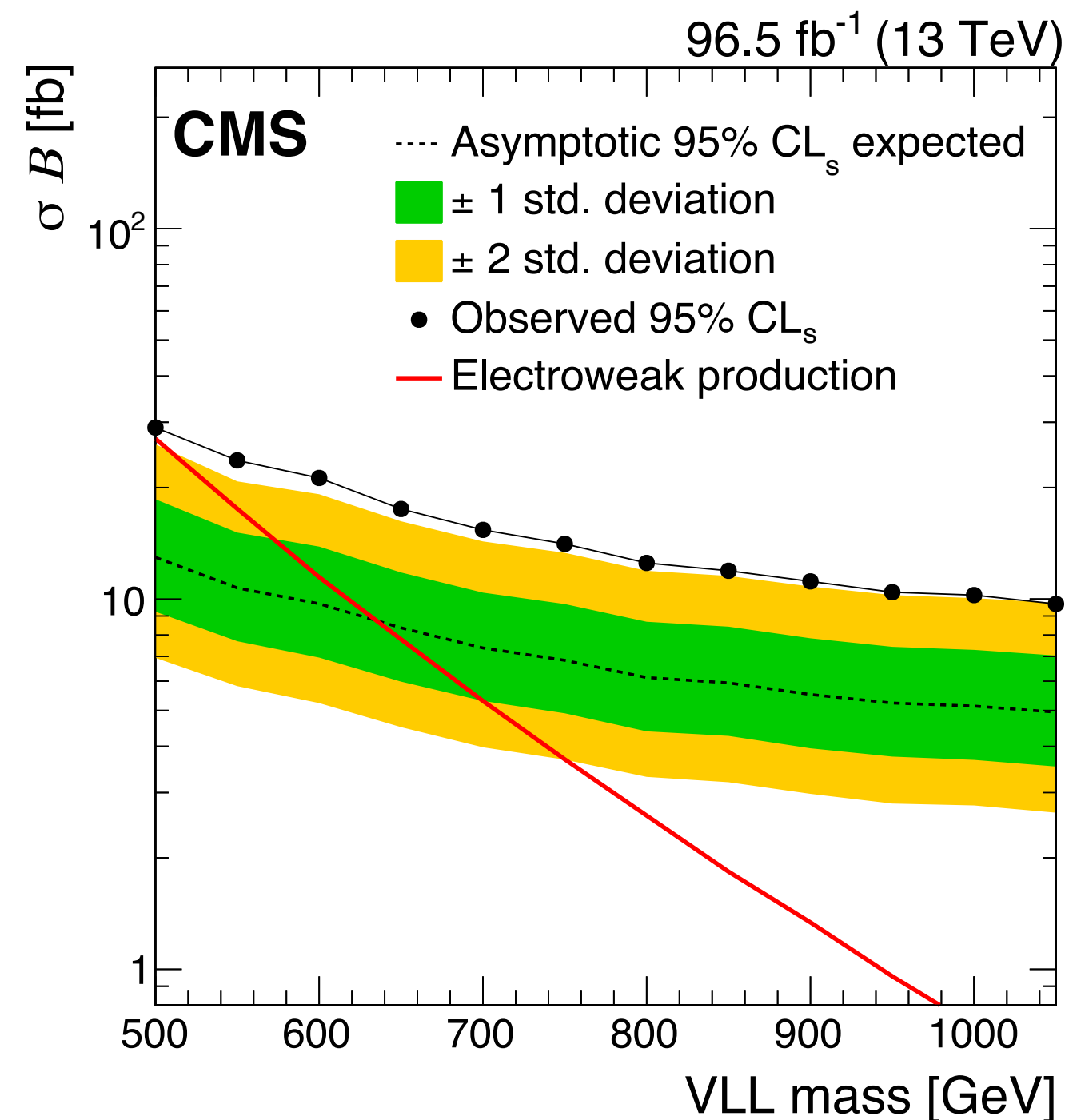
Vector-like leptons

Search for pair production of VLLs in final state with ≥ 3 b-tagged jets and upto 2 τ s with CMS 2017+2018 data

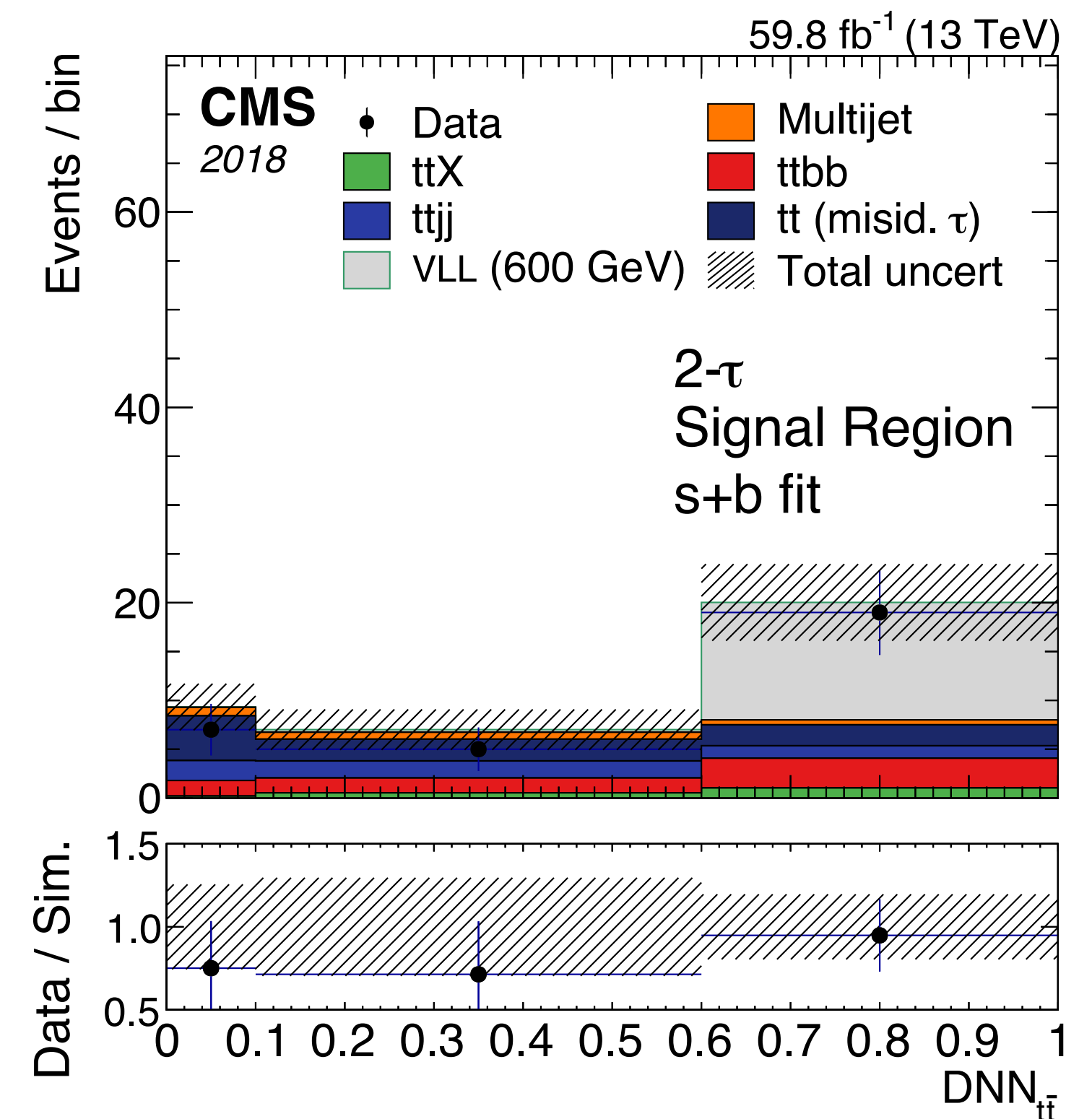
- “4321 model”, motivated by B anomalies
- EW pair production of VLLs with decay via virtual vector LQ coupled to 3rd generation
- Fit to N_{jet} or DNN distribution in different event categories



PLB 846 (2023) 137713



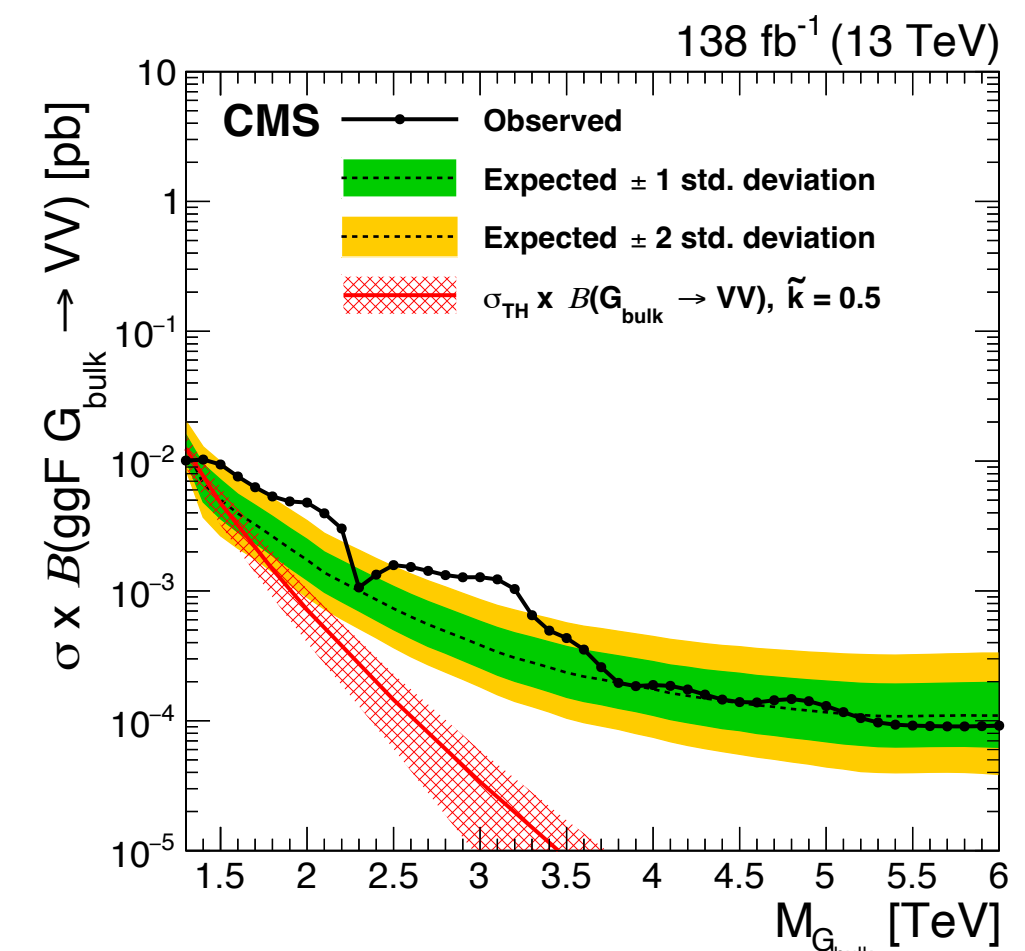
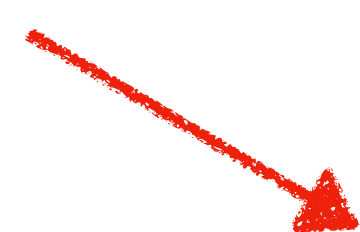
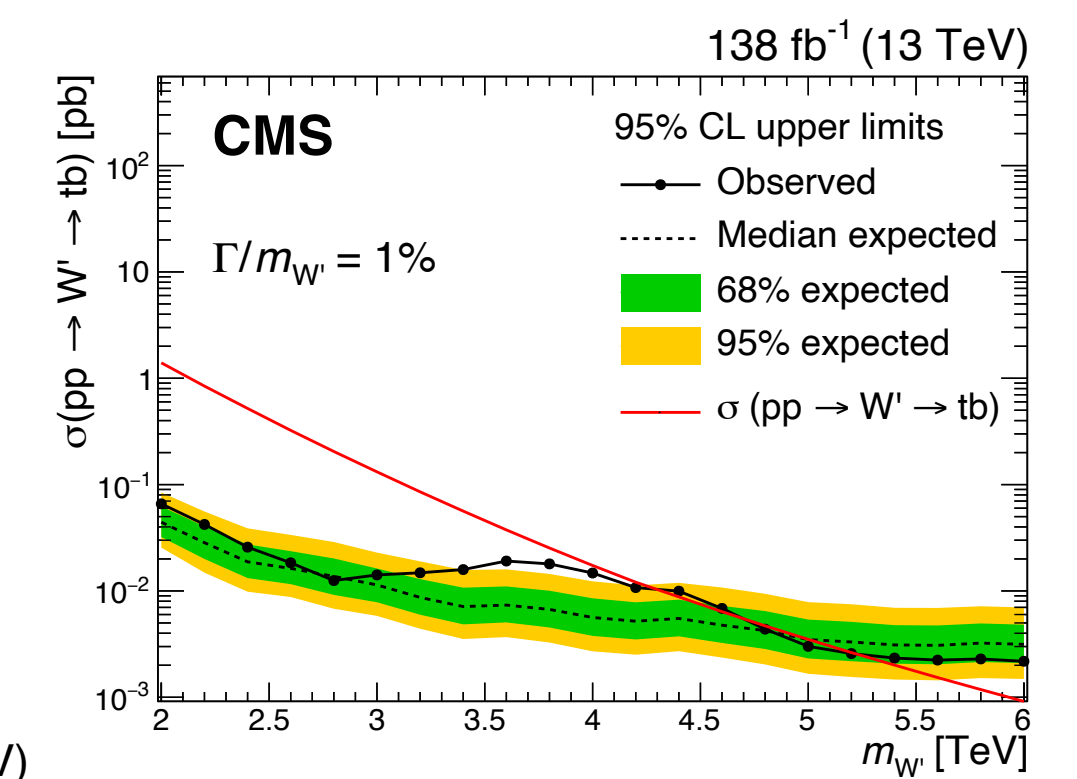
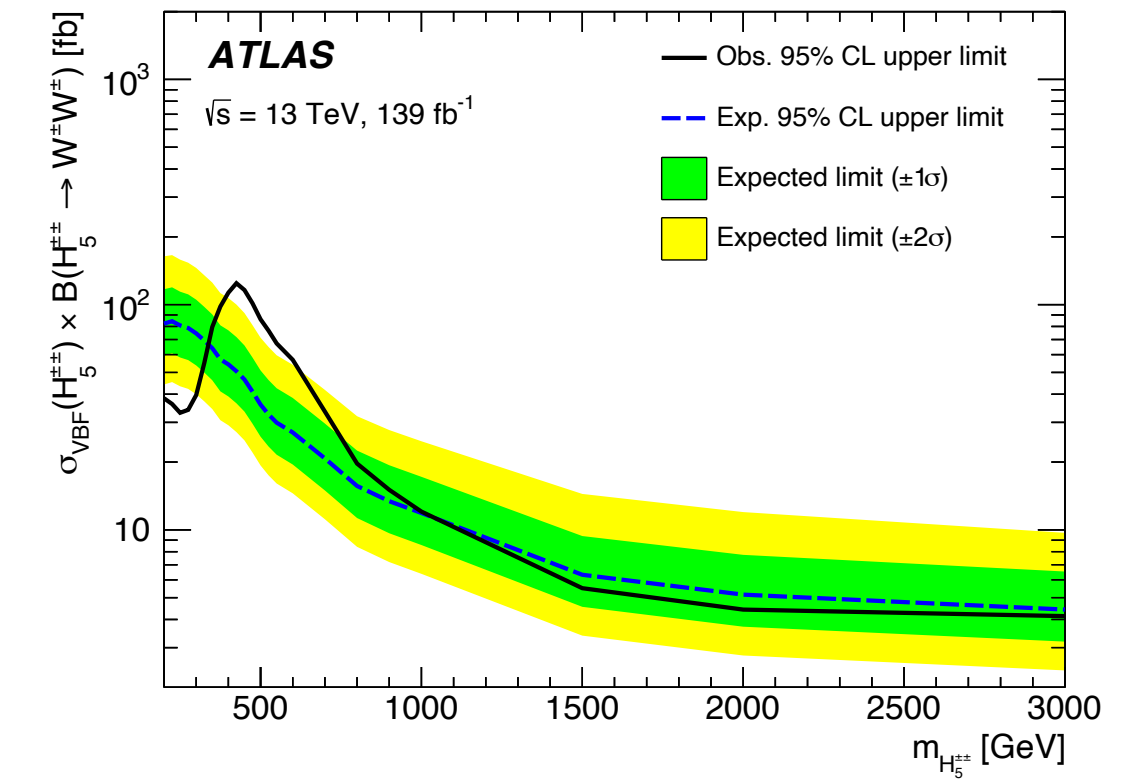
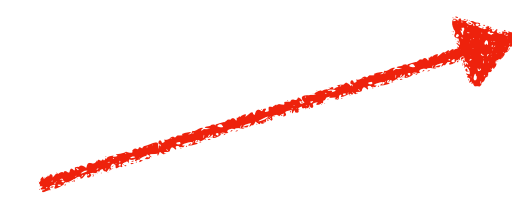
Excess with local significance 2.8σ observed for VLL mass 600 GeV



Many more interesting results ...

Did not have time to cover several others, including ...

- Doubly charged Higgs: excess of 3.3 (2.5) σ local (global) for $m_{H^{\pm\pm}} 450$ GeV (Georgi-Machacek model) in same-sign WW scattering at ATLAS ([JHEP 04 \(2024\) 026](#))
- Searches for Spin-1/Spin-2 resonances e.g.:
 - $W' \rightarrow tb$, CMS: 2.6 (2.0) σ local (global) significance for W' mass 3.8 TeV ([arXiv:2310.19893](#))
 - W'/Z' in heavy vector triplet model / spin-2 graviton in bulk model decaying to VV/VH , CMS: 3.6 (2.3) σ local (global) at 2.1, 2.9 TeV ([PLB 844 \(2023\) 137813](#))
- And more ...



Summary

Vast and rich program of experimental searches for new physics at ATLAS and CMS with LHC Run 2 data. Philosophy: leave no stone unturned!

No observation of BSM physics yet, but some intriguing excesses seen at the $2\text{-}3\sigma$ level worth following up ...

- Some excesses in extended Higgs sector searches across multiple final states ...
 - **low-mass $\gamma\gamma$, $\tau\tau$ (90-95 GeV)**
 - **high-mass dibosons (~ 650 GeV)**
- Some excesses seen in one experiment but apparently not the other ...
 - $X \rightarrow Y(bb)H(\gamma\gamma)$ at $(m_X, m_Y) = (650, 95)$ GeV in CMS (not confirmed by ATLAS)
 - $A \rightarrow Z(\ell\ell)H(t\bar{t})$ at $(m_A, m_H) = (650, 450)$ GeV in ATLAS (not confirmed by CMS)
 - $LQ \rightarrow b\tau$ at high mass in CMS (appears excluded by ATLAS)
- More searches to come with Run 2 data, and looking forward to Run 3 and HL-LHC to follow up ...

Searches using Run 3 data at $\sqrt{s}=13.6$ TeV ramping up

- Expanding sensitivity through variety of approaches: ML, new triggers and data-processing techniques, and more ...



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