ATLAS Run 2 Summary

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PITT PACC Workshop

7 Apr 2021

UMass Amherst

Run 2

- Tremendous step relative to Run 1

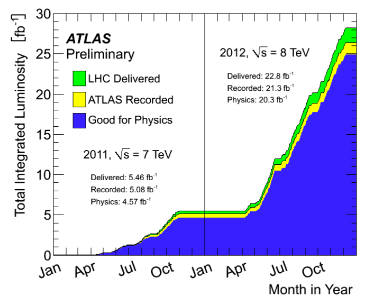
4.6 fb^{-1} @ $\sqrt{s}$ = 7 TeV

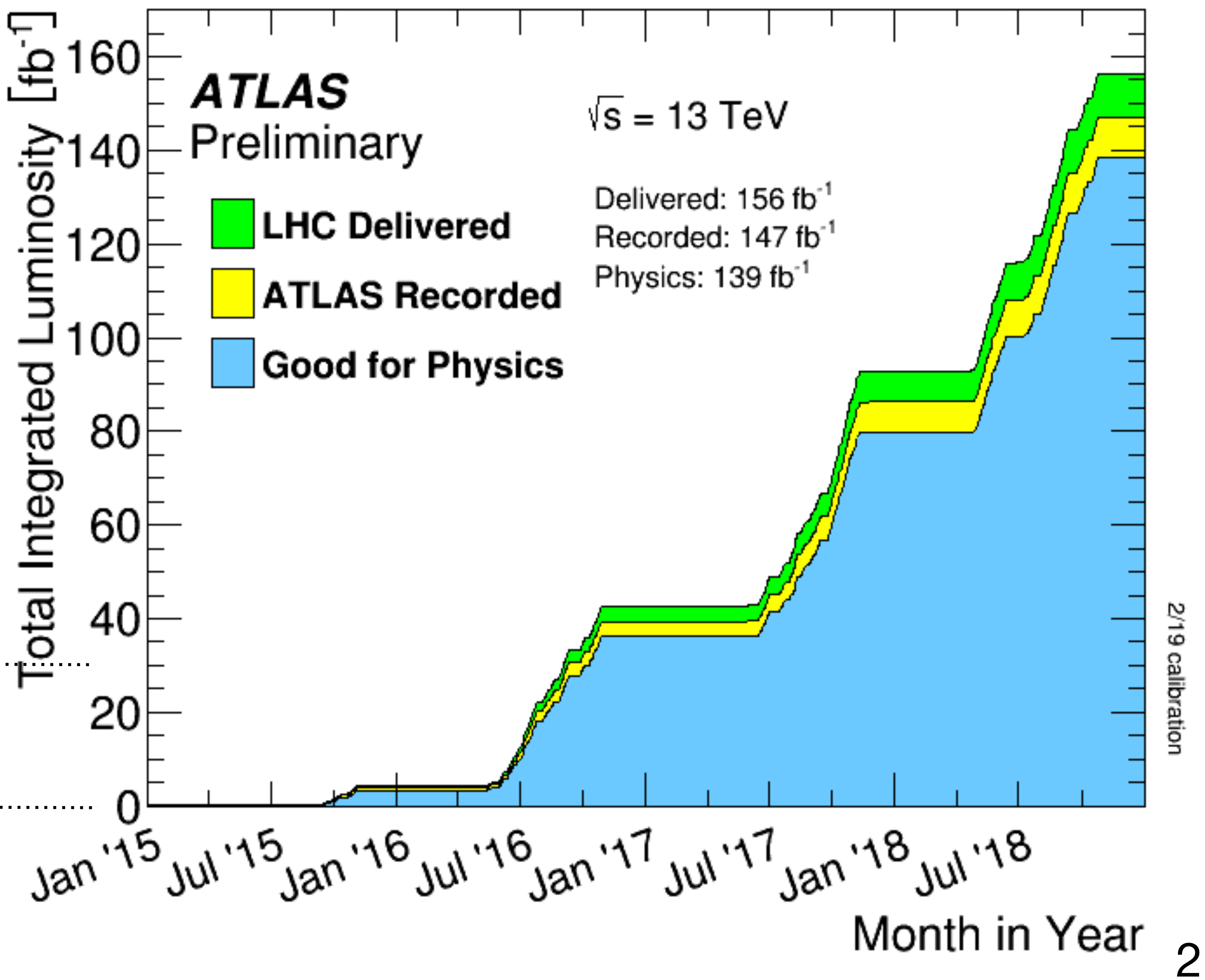
20.3 fb^{-1} @ $\sqrt{s}$ = 8 TeV

Run 1

139 fb^{-1} @ $\sqrt{s}$ = 13 TeV

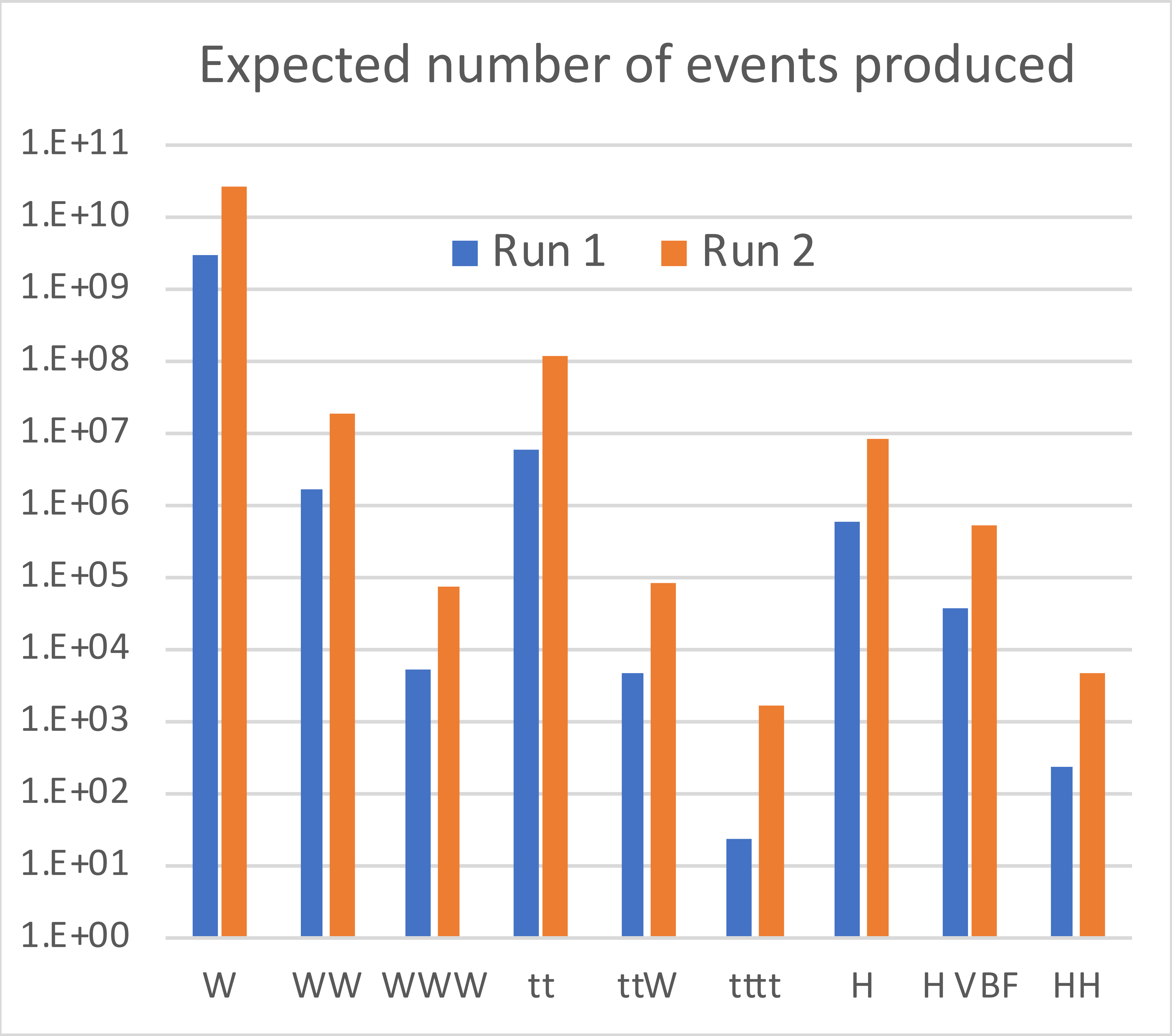
Run 2





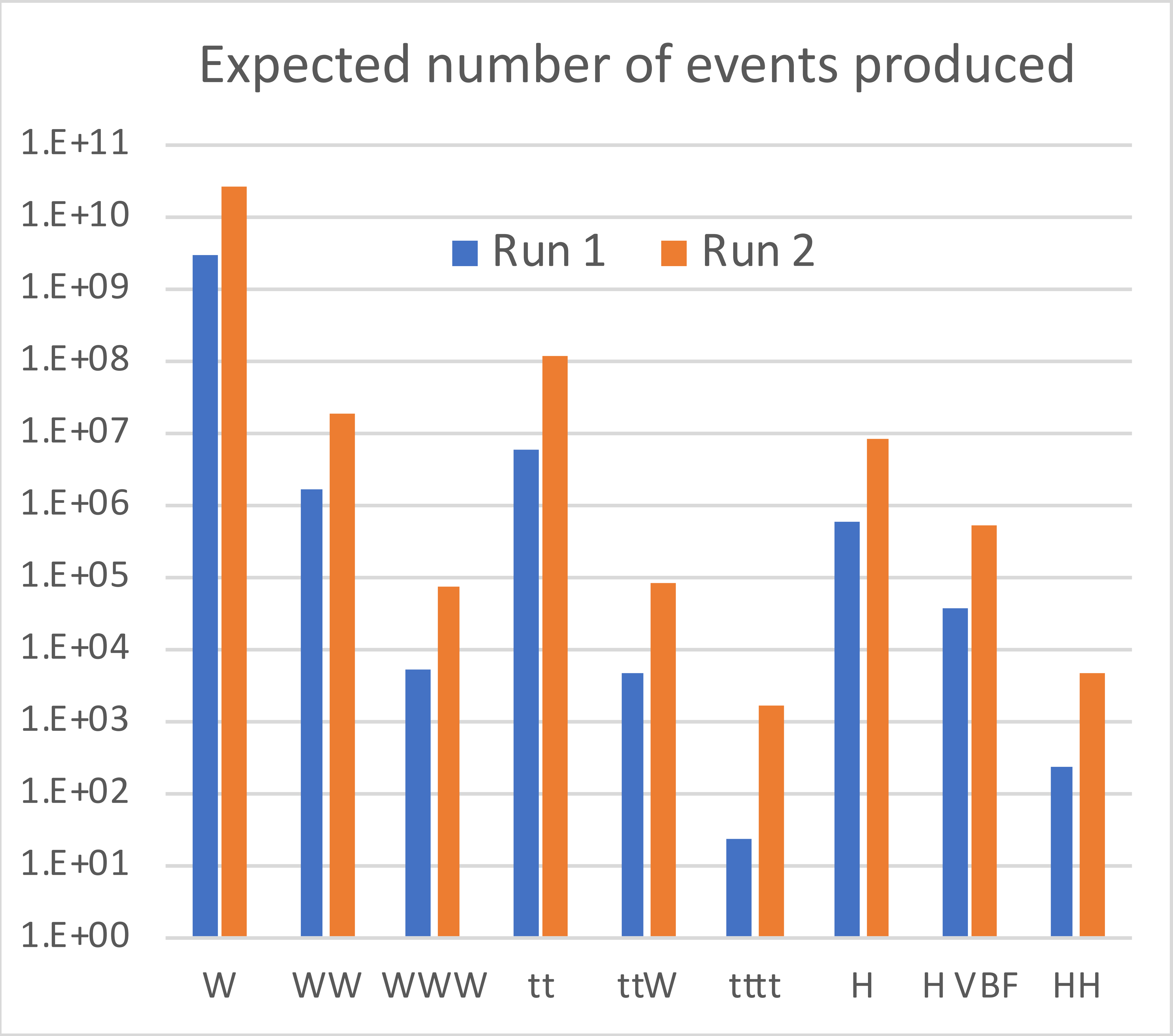
Run 2

- Number of events increase by factor of 10 - 20 relative to Run 1 for key processes
- Huge gain in BSM search sensitivity
- Much improved measurement precision
- Access to rare SM processes
- **Huge Run 2 dataset is a gold mine for physics**, for years to come
- LHC not just a proton collider but
  - a gluon/quark collider (incl. bottom, top)
  - a W and Z collider
  - a photon collider



Run 2 physics program

- Search for BSM, including
  - dark matter
  - supersymmetry
  - heavy fermions, gauge bosons
- Precision SM measurements, including
  - Higgs
  - top quark
  - electroweak sector
  - strong interactions
  - tests of flavor universality, CPV
- Rare SM processes, including
  - anomalous couplings
- Heavy ions, including
  - quark-gluon plasma
  - photon-photon collisions

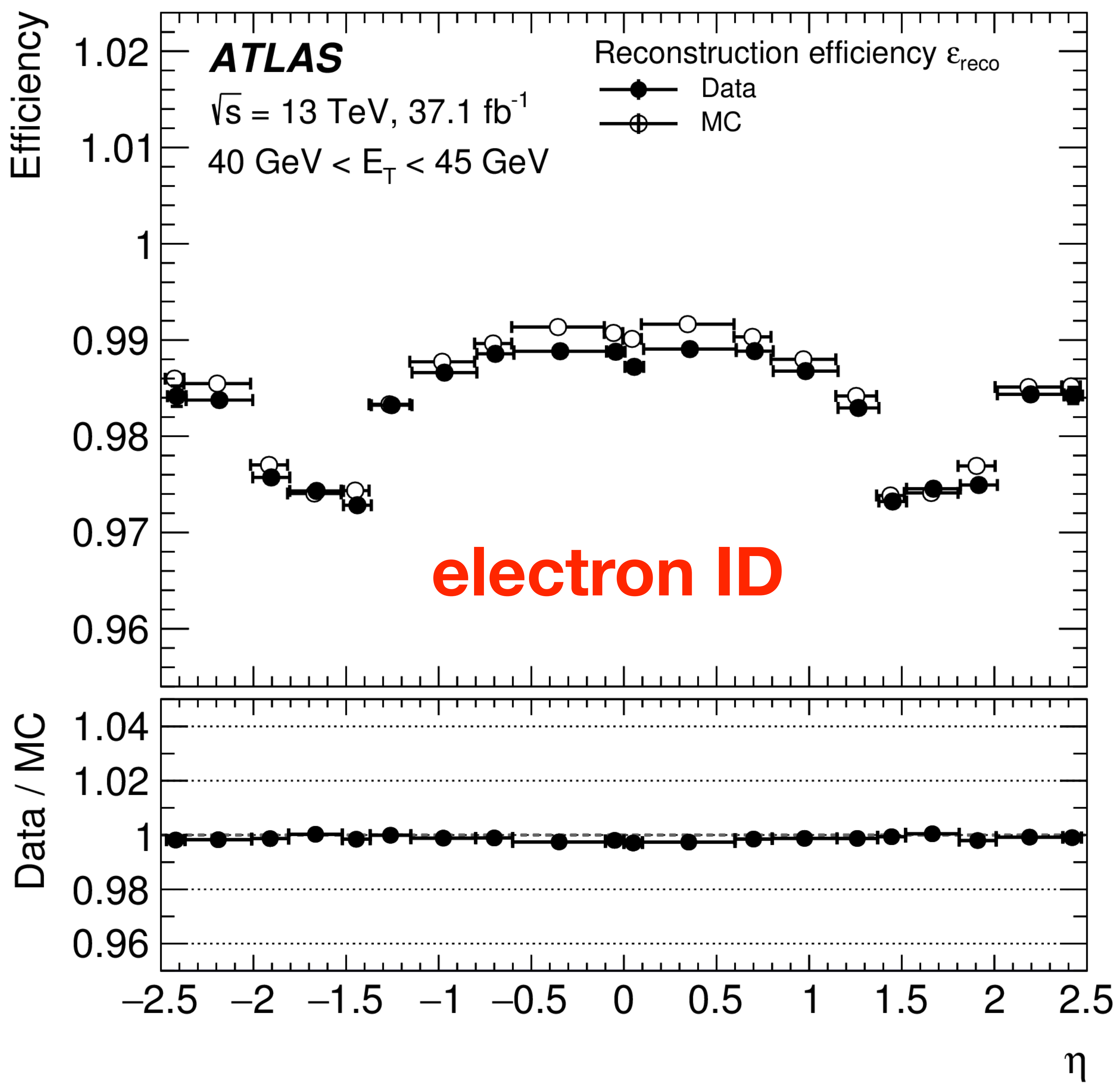


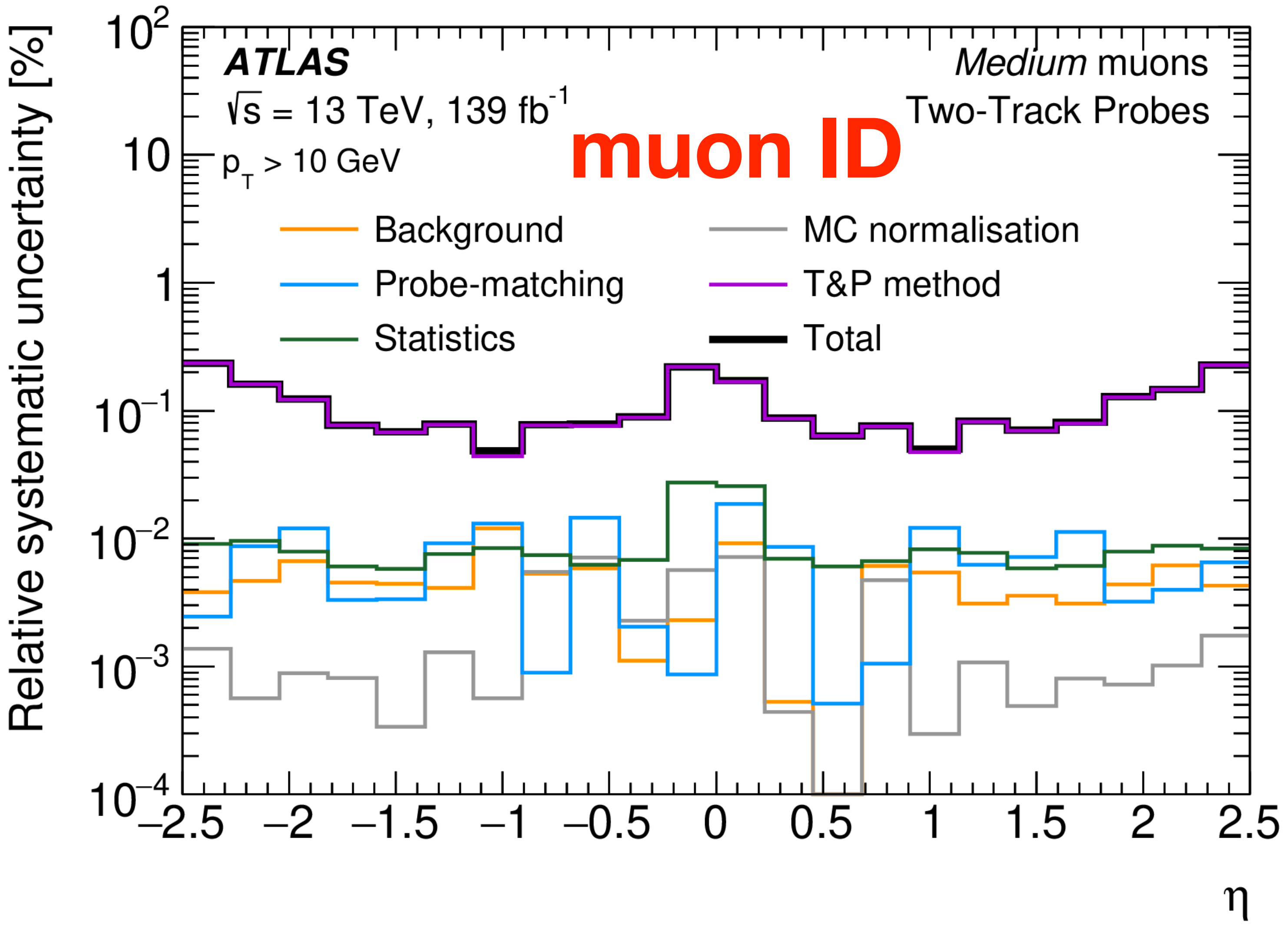
Caveat: only a glimpse of the physics program can be shown here!

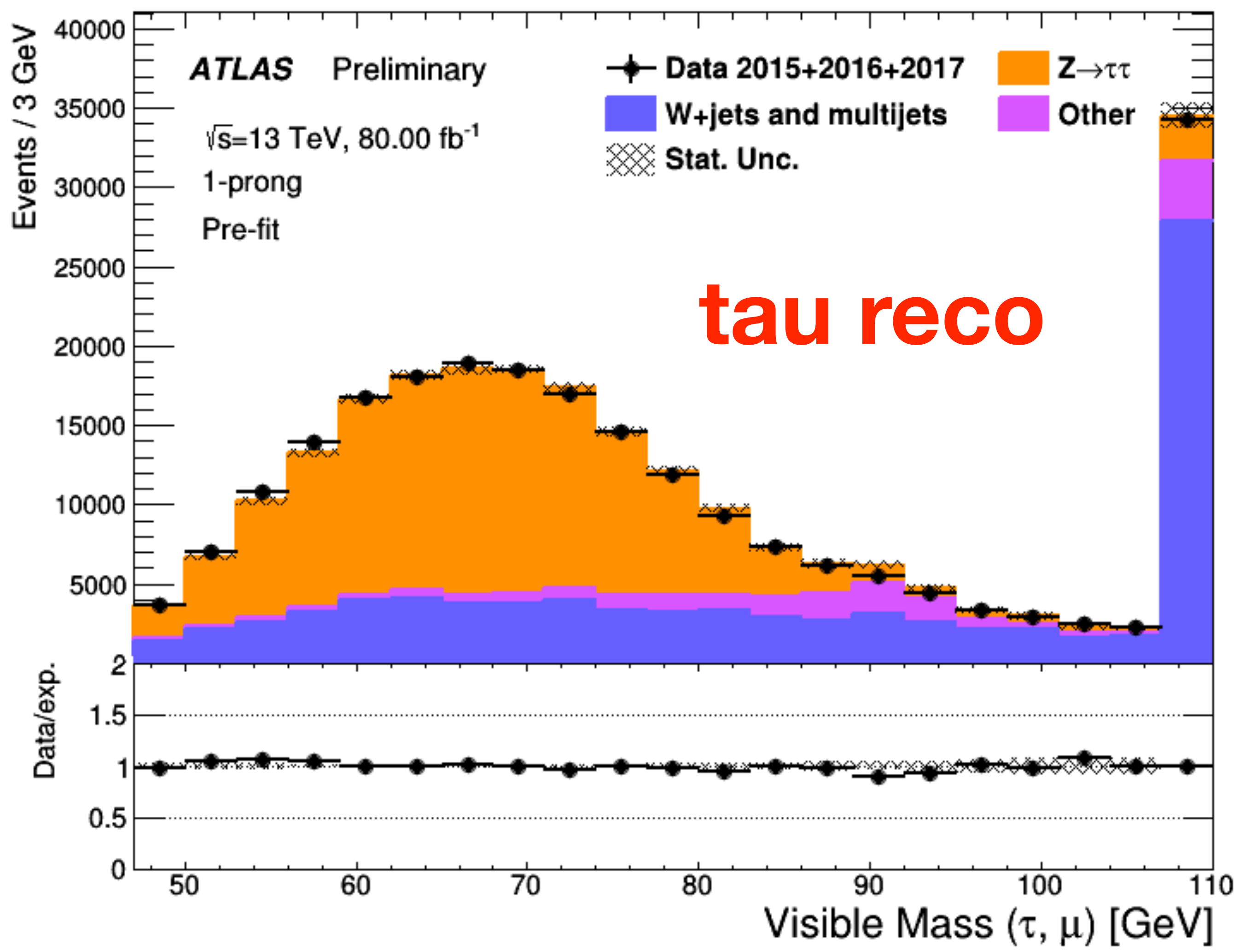
Detector reconstruction and object performance

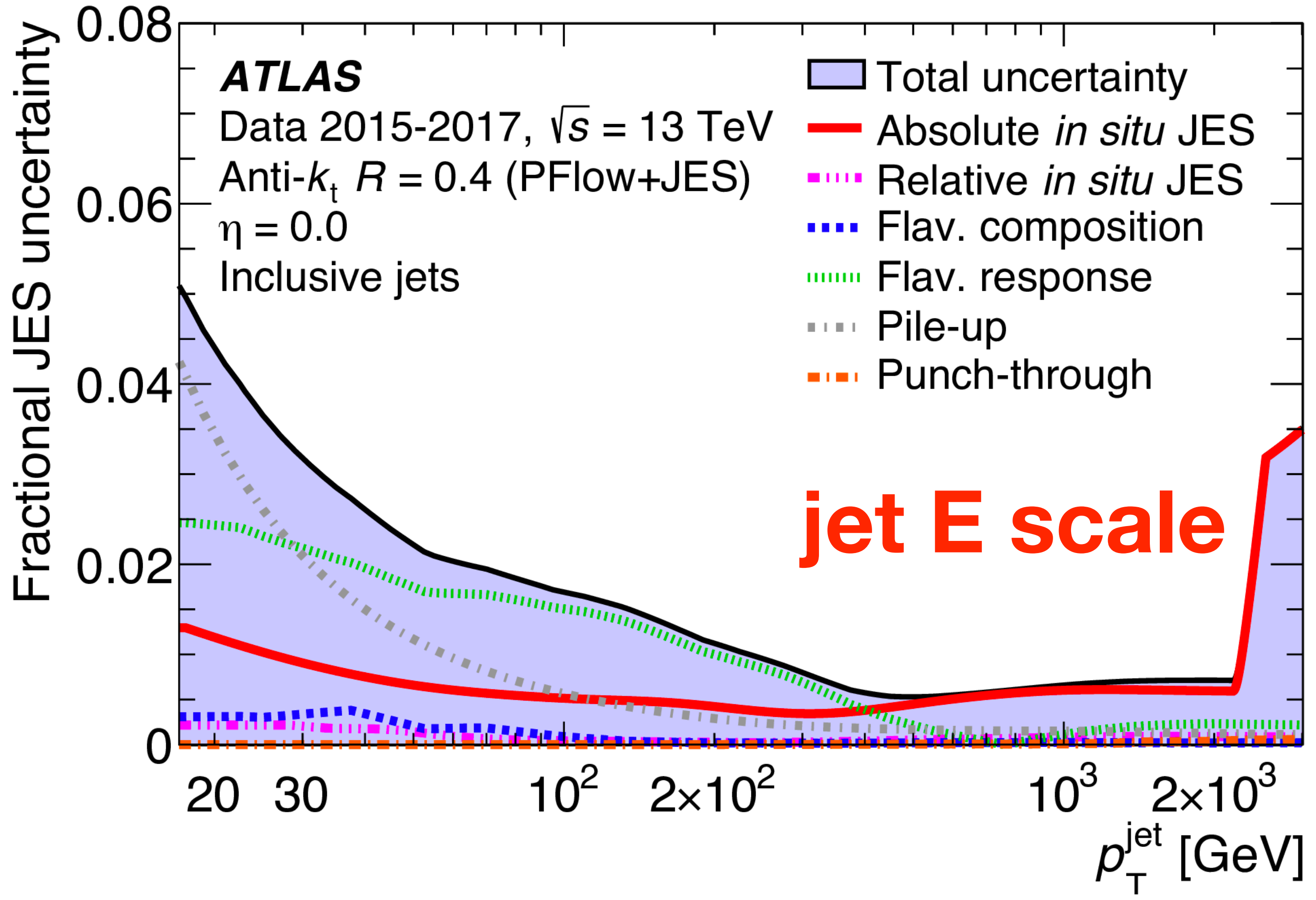
- Bumper crop of results from Run 2 only possible thanks to excellent understanding of detector performance, and development of reconstruction and identification algorithms

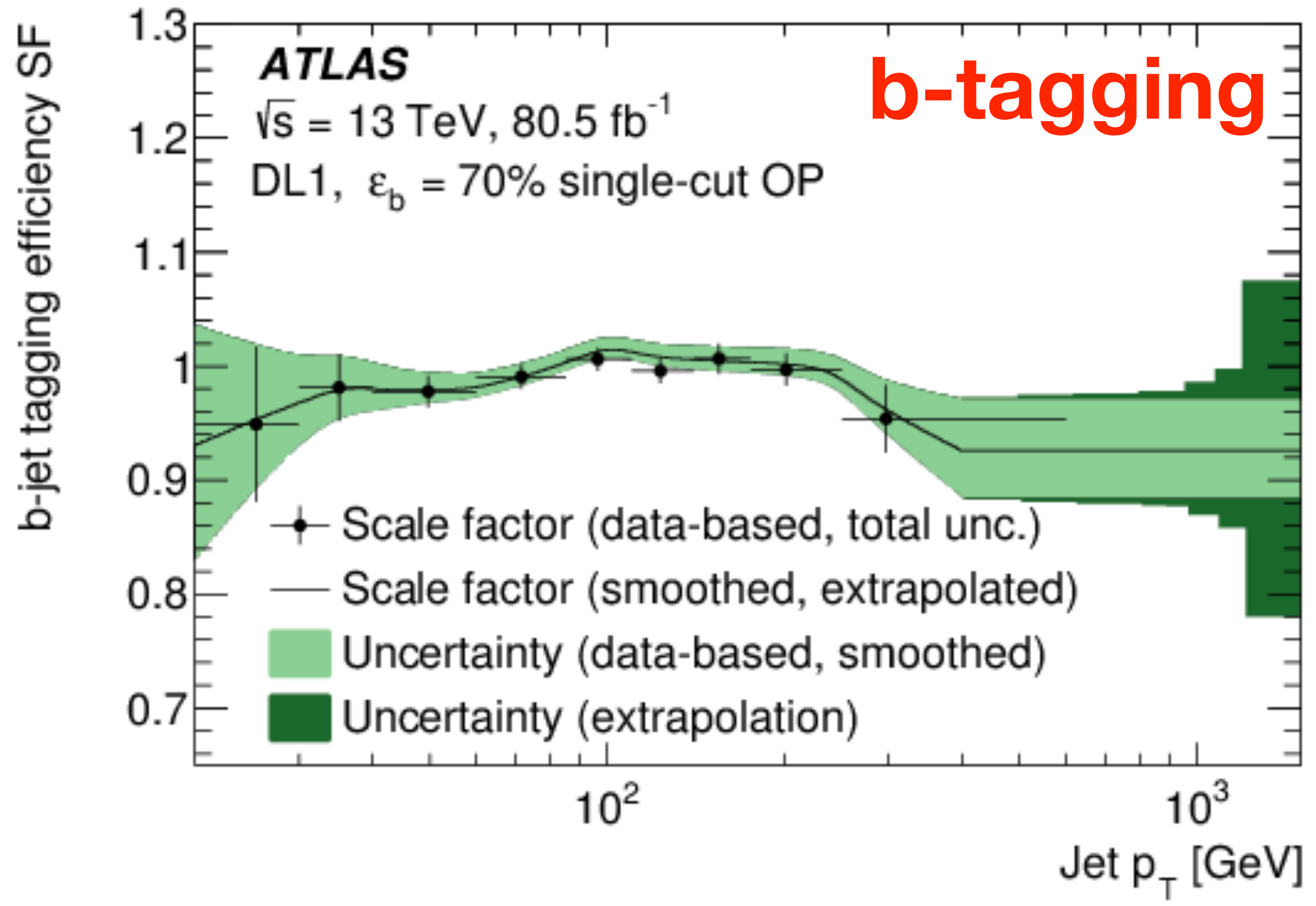
- High level of precision achieved & excellent modeling with simulation











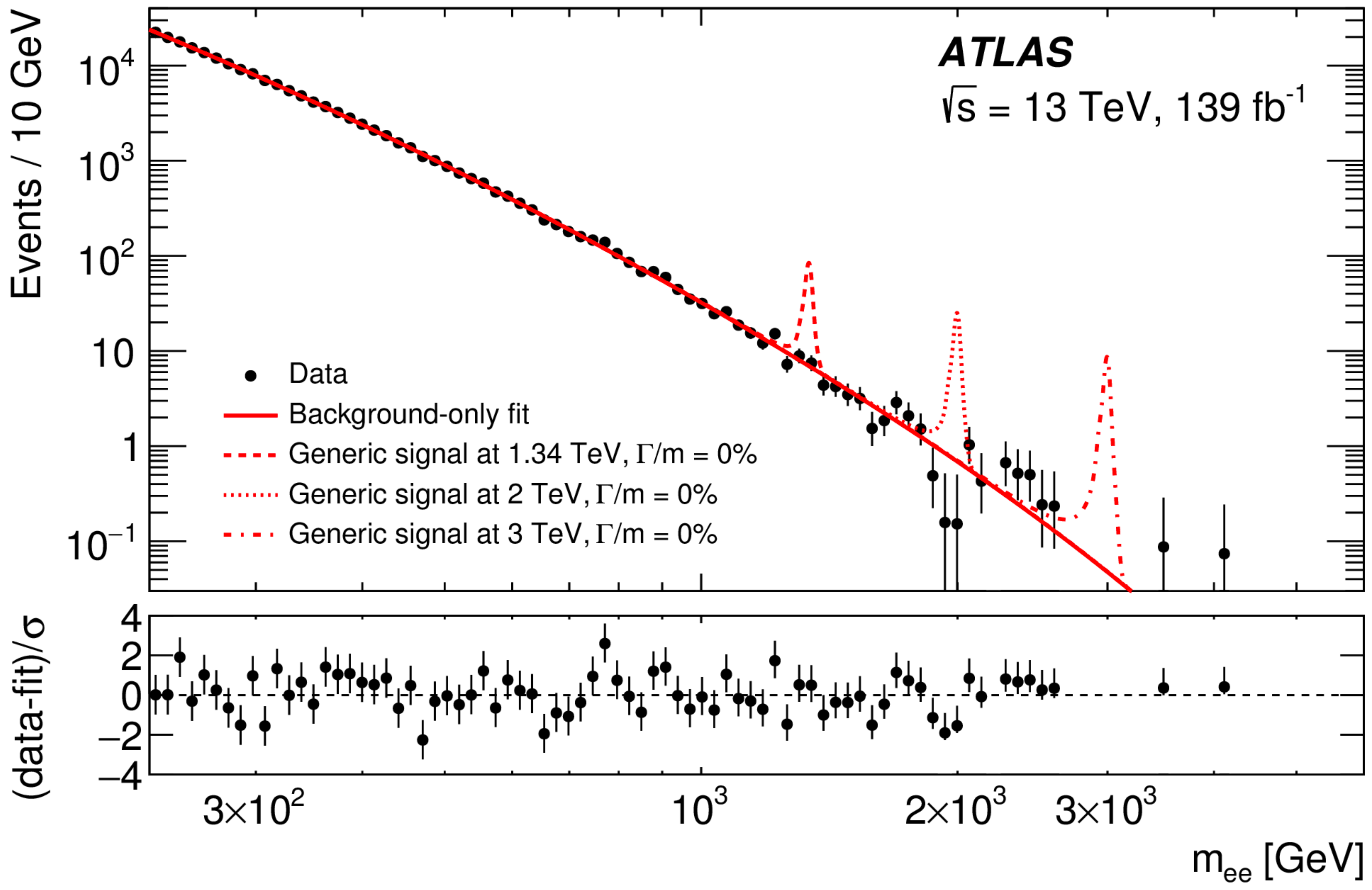
Searches at the energy frontier

- Naturalness arguments motivate search for TeV-scale new physics
- Much ground covered (a few examples here)

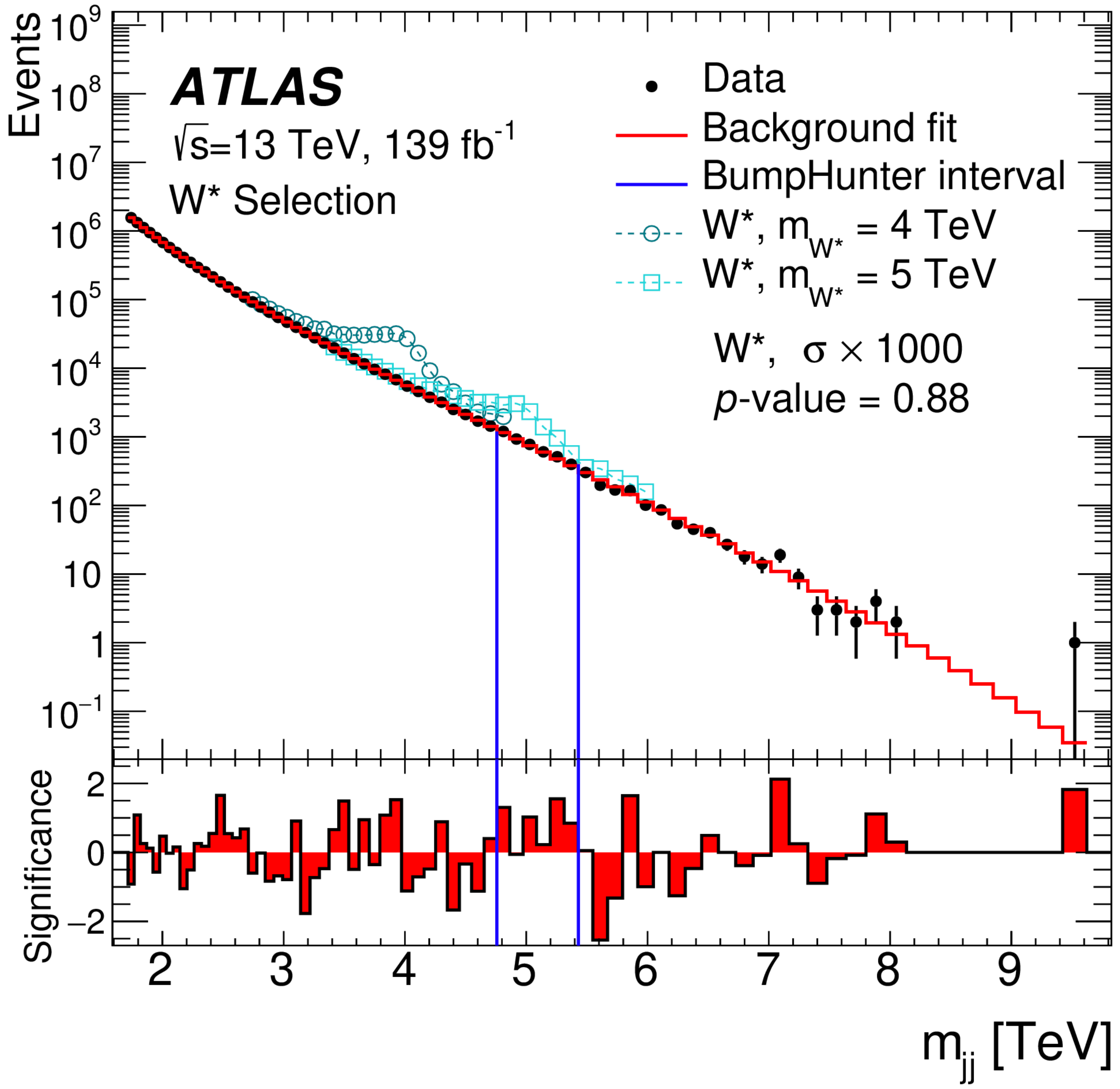
all limits in this talk at 95% CL unless indicated otherwise

- Dilepton & *lv* resonances
  - m(W'$_{SSM}$) > 6.0 TeV, m(Z'$_{SSM}$) > 5.1 TeV

arXiv:1906.05609 arXiv:1903.06248



- Dijet resonances arXiv:1910.08447
  - large kinematic reach (data up to mjj = 9.5 TeV)
  - m(q*) > 6.7 TeV, m(QBH) > 9.4 TeV, m(W') > 4.0 TeV, m(Z'$_{DM}$) > 4.6 TeV



Run: 329716
Event: 857582452
2017-07-14 10:48:51 CEST
m_{jj} = 9.5 TeV
jet1 pT = 3.0 TeV
jet2 pT = 2.9 TeV
ATLAS
EXPERIMENT

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: March 2021

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.6 - 139)\ \text{fb}^{-1}$ $\sqrt{s} = 8, 13$ 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, μ, τ, γ	1 – 4 j	Yes	139	M_D 11.2 TeV	$n = 2$	2102.10874
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO	1707.04147
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n = 6$	1703.09127
	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 γ	–	–	139	G_{KK} mass 4.5 TeV	$k/\overline{M}_{Pl} = 0.1$	2102.13405
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	1808.02380
	Bulk RS $G_{KK} \to WV \to \ell\nu qq$	1 e, μ	2 j / 1 J	Yes	139	G_{KK} mass 2.0 TeV	$k/\overline{M}_{Pl} = 1.0$	2004.14636
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	36.1	KK mass 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	1803.09678
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.42 TeV		1709.07242
	Leptophobic $Z' \to bb$	–	2 b	–	36.1	Z' mass 2.1 TeV		1805.09299
	Leptophobic $Z' \to tt$	0 e, μ	≥ 1 b, ≥ 2 J	Yes	139	Z' mass 4.1 TeV	$\Gamma/m = 1.2\%$	2005.05138
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	139	W' mass 6.0 TeV		1906.05609
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $W' \to WZ \to \ell\nu qq$ model B	1 e, μ	2 j / 1 J	Yes	139	W' mass 4.3 TeV	$g_V = 3$	2004.14636
	HVT $Z' \to ZH$ model B	0-2 e, μ	1-2 b	Yes	139	Z' mass 3.2 TeV	$g_V = 3$	ATLAS-CONF-2020-043
	HVT $W' \to WH$ model B	0 e, μ	≥ 1 b, ≥ 2 J		139	W' mass 3.2 TeV	$g_V = 3$	2007.05293
	LRSM $W_R \to tb$	multi-channel			36.1	W_R mass 3.25 TeV		1807.10473
	LRSM $W_R \to \mu N_R$	2 μ	1 J	–	80	W_R mass 5.0 TeV	$m(N_R) = 0.5$ TeV, $g_L = g_R$	1904.12679
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^-	1703.09127
	CI $\ell\ell qq$	2 e, μ	–	–	139	Λ 35.8 TeV	η_{LL}^-	2006.12946
	CI $eebs$	2 e	1 b	–	139	Λ 1.8 TeV	$g_* = 1$	ATLAS-CONF-2021-012
	CI $\mu\mu bs$	2 μ	1 b	–	139	Λ 2.0 TeV	$g_* = 1$	ATLAS-CONF-2021-012
	CI $tttt$	≥1 e, μ	≥1 b, ≥1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t} \rvert = 4\pi$	1811.02305
DM	Axial-vector med. (Dirac DM)	0 e, μ, τ, γ	1 – 4 j	Yes	139	m_{med} 2.1 TeV	g_q=0.25, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Pseudo-scalar med. (Dirac DM)	0 e, μ, τ, γ	1 – 4 j	Yes	139	m_{med} 376 GeV	g_q=1, g_χ=1, $m(\chi)$=1 GeV	2102.10874
	Vector med. Z'-2HDM (Dirac DM)	0 e, μ	2 b	Yes	139	m_{med} 3.1 TeV	$\tan\beta$=1, g_Z=0.8, $m(\chi)$=100 GeV	ATLAS-CONF-2021-006
	Pseudo-scalar med. 2HDM+a	0 e, μ	2 b	Yes	139	m_{med} 520 GeV	$\tan\beta$=1, g_χ=1, $m(\chi)$=10 GeV	ATLAS-CONF-2021-006
	Scalar reson. $\phi \to t\chi$ (Dirac DM)	0-1 e, μ	1 b, 0-1 J	Yes	36.1	m_ϕ 3.4 TeV	y=0.4, λ=0.2, $m(\chi)$=10 GeV	1812.09743
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	Yes	139	LQ mass 1.8 TeV	$\beta = 1$	2006.05872
	Scalar LQ 2nd gen	2 μ	≥ 2 j	Yes	139	LQ mass 1.7 TeV	$\beta = 1$	2006.05872
	Scalar LQ 3rd gen	1 τ	2 b	Yes	139	LQ_3^u mass 1.2 TeV	$\mathcal{B}(LQ_3^u \to b\tau) = 1$	ATLAS-CONF-2021-008
	Scalar LQ 3rd gen	0 e, μ	≥ 2 j, ≥ 2 b	Yes	139	LQ_3^u mass 1.24 TeV	$\mathcal{B}(LQ_3^u \to t\nu) = 1$	2004.14060
	Scalar LQ 3rd gen	≥ 2e, μ, ≥ 1τ	≥ 1 j, ≥ 1 b	–	139	LQ_3^d mass 1.43 TeV	$\mathcal{B}(LQ_3^d \to t\tau) = 1$	2101.11582
	Scalar LQ 3rd gen	0 e, μ, ≥ 1τ	0 – 2 j, 2 b	Yes	139	LQ_3^d mass 1.26 TeV	$\mathcal{B}(LQ_3^d \to b\nu) = 1$	2101.12527
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	1808.02343
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	1808.02343
	VLQ $T_{5/3}T_{5/3} \vert T_{5/3} \to Wt + X$	2(SS)/≥3 e, μ	≥1 b, ≥1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt)$= 1, $c(T_{5/3}Wt)$= 1	1807.11883
	VLQ $Y \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb + X$	0 e, μ	≥ 2 b, ≥ 1j	Yes	79.8	B mass 1.21 TeV	singlet, κ_B= 0.5	ATLAS-CONF-2018-024
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	139	q^* mass 6.7 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1910.08447
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1709.10440
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	36.1	b^* mass 2.6 TeV		1805.09299
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	1 e, μ	≥ 2 j	Yes	139	N^0 mass 790 GeV		20008.07949
	LRSM Majorana ν	2 μ	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	1710.09748
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $\lvert q \rvert = 5e$	1812.03673
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $\lvert g \rvert = 1g_D$, spin 1/2	1905.10130

$\sqrt{s}$ = 8 TeV | $\sqrt{s}$ = 13 TeV partial data | $\sqrt{s}$ = 13 TeV full data

10^{-1} 1 10 **Mass scale [TeV]**

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

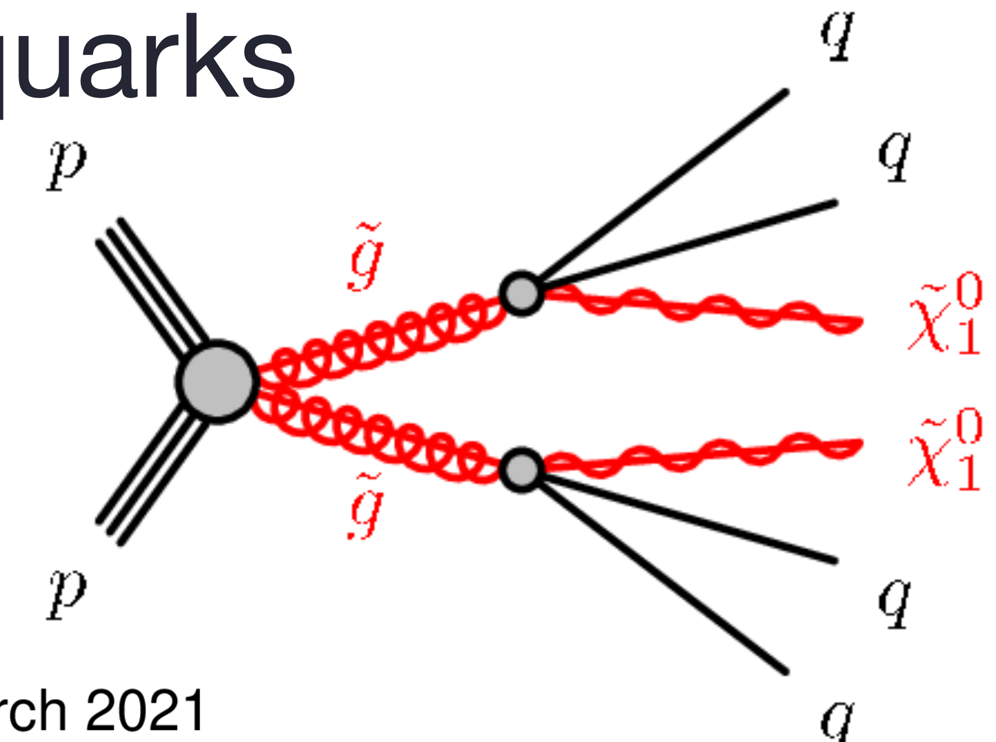
†Small-radius (large-radius) jets are denoted by the letter j (J).

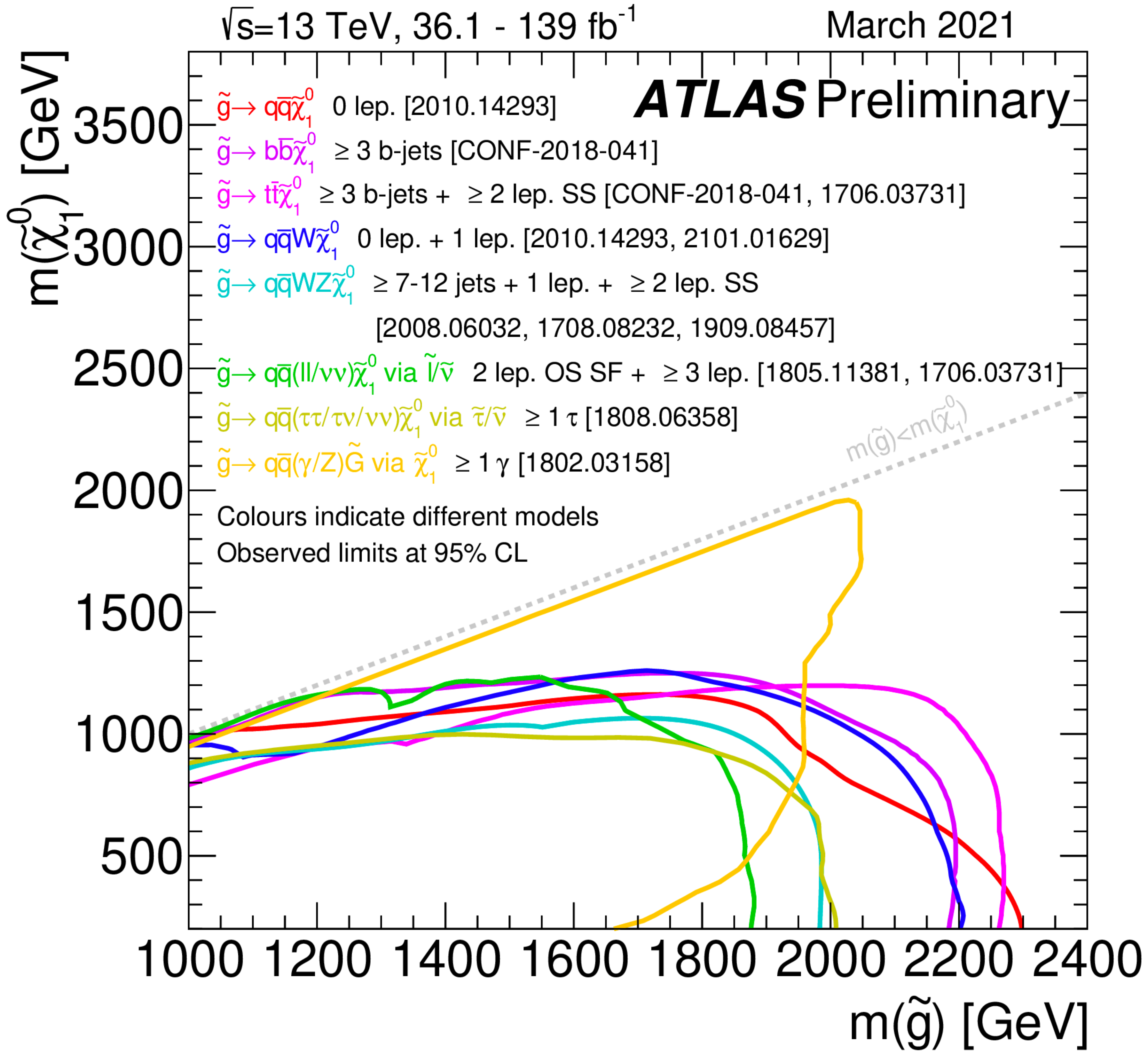
Searches at the energy frontier

- Strong production of supersymmetric partners: gluinos and squarks

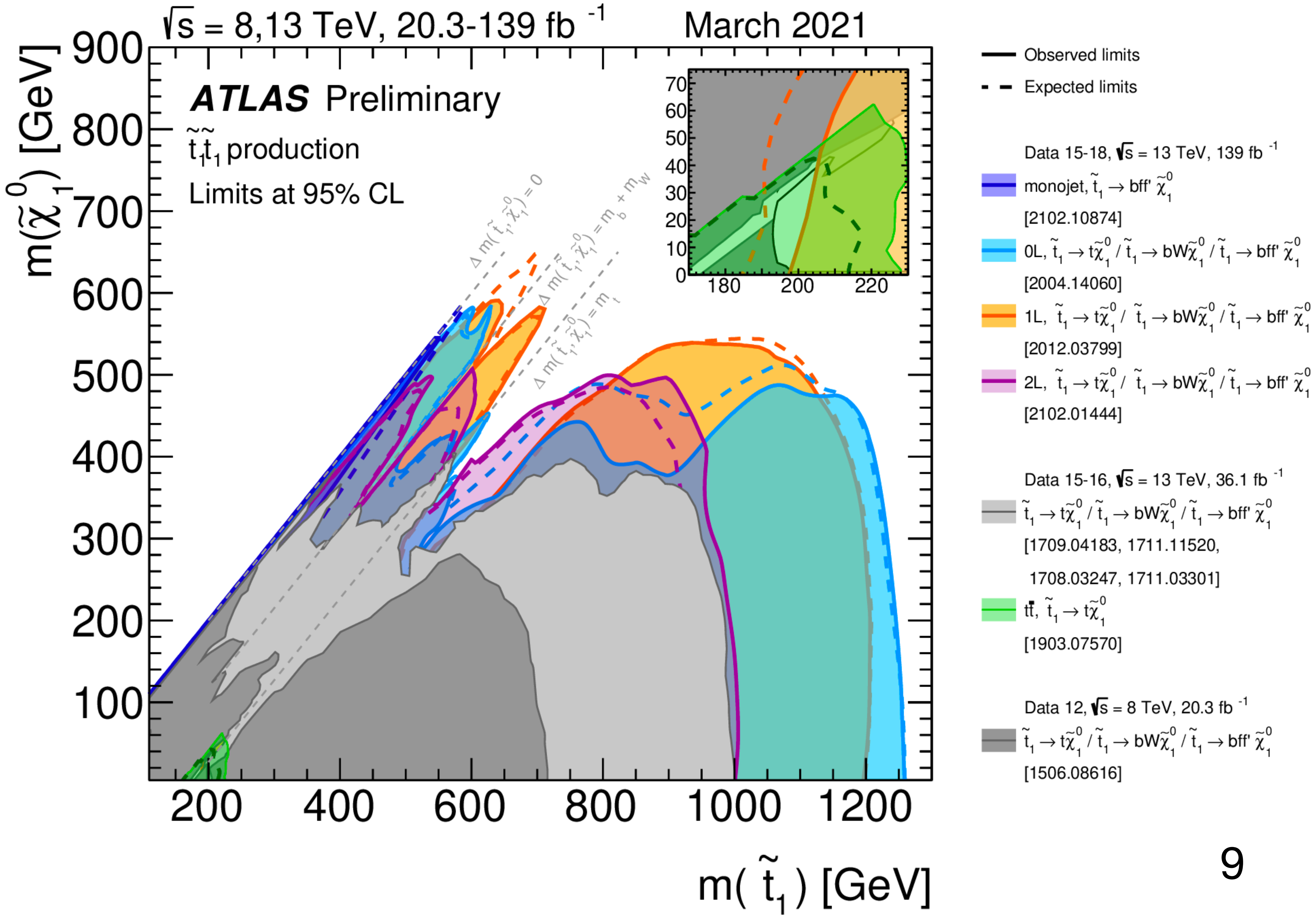
  $m(\tilde{g}) \gtrsim 2.3$ TeV

  $m(\tilde{q}) \gtrsim 1.8$ TeV





- Naturalness: TeV-scale stop and sbottom
- Dedicated object performance algorithms & analysis techniques in compressed regions
- $m(\tilde{t}) \gtrsim 1.2$ TeV



ATLAS SUSY Searches* - 95% CL Lower Limits

March 2021

ATLAS Preliminary

$\sqrt{s}$ = 13 TeV

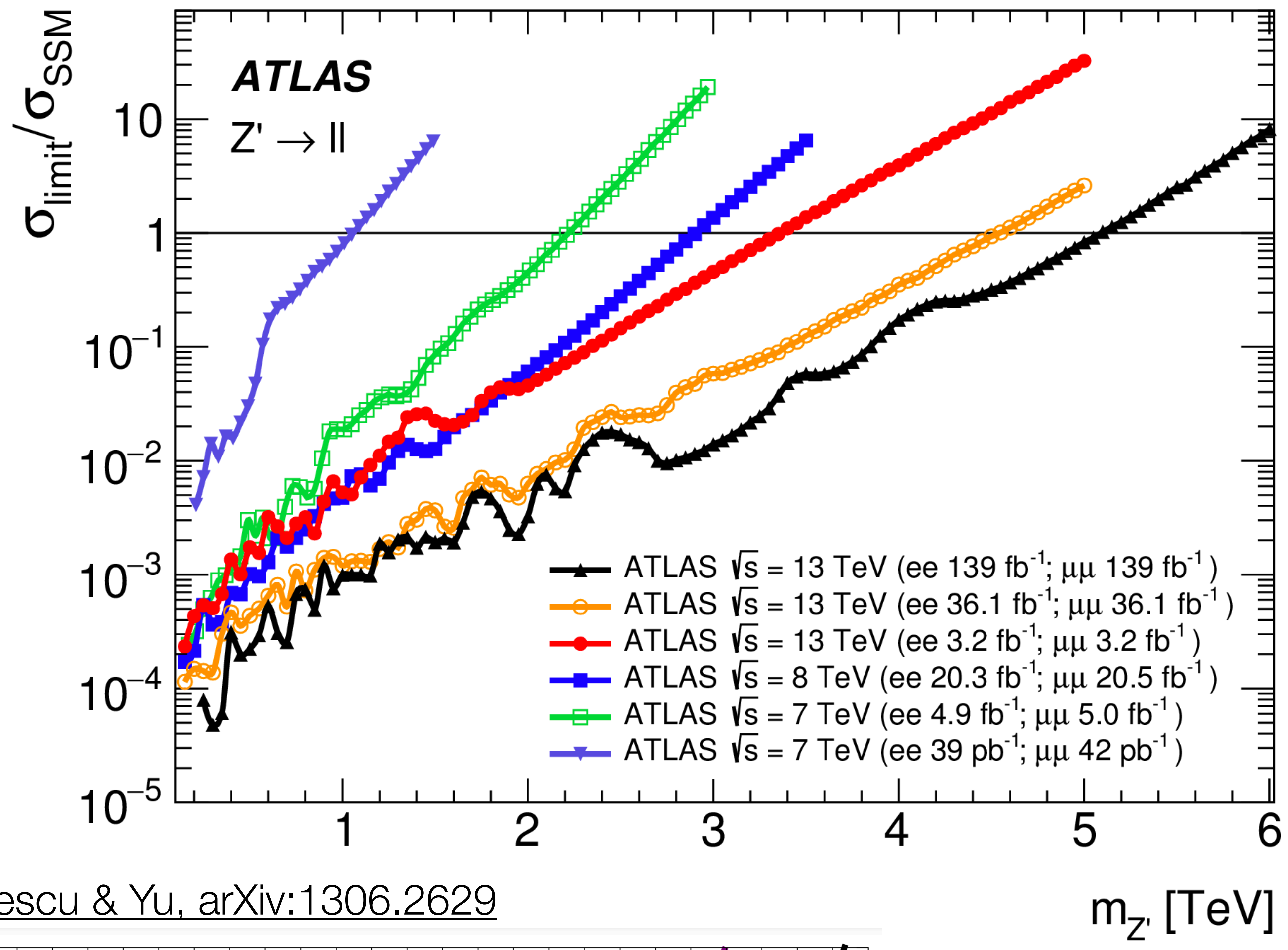
Category	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$ [fb^{-1}]	Mass limit [TeV]	Conditions	Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{q}$ [1×, 8× Degen.] 1.0, 1.85	$m(\tilde{\chi}^0_1)$<400 GeV	2010.14293
		mono-jet	1-3 jets	E_T^{miss}	36.1	$\tilde{q}$ [8× Degen.] 0.9	$m(\tilde{q})$-$m(\tilde{\chi}^0_1)$=5 GeV	2102.10874
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0 e,μ	2-6 jets	E_T^{miss}	139	$\tilde{g}$ 2.3	$m(\tilde{\chi}^0_1)$=0 GeV	2010.14293
						$\tilde{g}$ Forbidden 1.15-1.95	$m(\tilde{\chi}^0_1)$=1000 GeV	2010.14293
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}W\tilde{\chi}^0_1$	1 e,μ	2-6 jets		139	$\tilde{g}$ 2.2	$m(\tilde{\chi}^0_1)$<600 GeV	2101.01629
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}^0_1$	$ee, \mu\mu$	2 jets	E_T^{miss}	36.1	$\tilde{g}$ 1.2	$m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=50 GeV	1805.11381
	$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}^0_1$	0 e,μ	7-11 jets	E_T^{miss}	139	$\tilde{g}$ 1.97	$m(\tilde{\chi}^0_1)$ <600 GeV	2008.06032
		SS e,μ	6 jets		139	$\tilde{g}$ 1.15	$m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=200 GeV	1909.08457
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	E_T^{miss}	79.8	$\tilde{g}$ 2.25	$m(\tilde{\chi}^0_1)$<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$ 1.25	$m(\tilde{g})$-$m(\tilde{\chi}^0_1)$=300 GeV	1909.08457
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$	0 e,μ	2 b	E_T^{miss}	139	$\tilde{b}_1$ 1.255	$m(\tilde{\chi}^0_1)$<400 GeV	2101.12527
						$\tilde{b}_1$ 0.68	10 GeV<$\Delta m(\tilde{b}_1,\tilde{\chi}^0_1)$<20 GeV	2101.12527
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_2 \to bh\tilde{\chi}^0_1$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$ Forbidden 0.23-1.35	$\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=100 GeV	1908.03122
		2 τ	2 b	E_T^{miss}	139	$\tilde{b}_1$ 0.13-0.85	$\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=0 GeV	ATLAS-CONF-2020-031
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_1$	0-1 e,μ	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{t}_1$ 1.25	$m(\tilde{\chi}^0_1)$=1 GeV	2004.14060,2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ Forbidden 0.65	$m(\tilde{\chi}^0_1)$=500 GeV	2012.03799
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to\tilde{\tau}_1 b\nu, \tilde{\tau}_1\to\tau\tilde{G}$	1-2 τ	2 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ Forbidden 1.4	$m(\tilde{\tau}_1)$=800 GeV	ATLAS-CONF-2021-008
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}, \tilde{c}\to c\tilde{\chi}^0_1$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$ 0.85	$m(\tilde{\chi}^0_1)$=0 GeV	1805.01649
		0 e,μ	mono-jet	E_T^{miss}	139	$\tilde{t}_1$ 0.55	$m(\tilde{t}_1,\tilde{c})$-$m(\tilde{\chi}^0_1)$=5 GeV	2102.10874
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to t\tilde{\chi}^0_2, \tilde{\chi}^0_2\to Z/h\tilde{\chi}^0_1$	1-2 e,μ	1-4 b	E_T^{miss}	139	$\tilde{t}_1$ 0.067-1.18	$m(\tilde{\chi}^0_2)$=500 GeV	2006.05880
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1 + Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$ Forbidden 0.86	$m(\tilde{\chi}^0_1)$=360 GeV, $m(\tilde{t}_1)$-$m(\tilde{\chi}^0_1)$= 40 GeV	2006.05880
EW direct	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via WZ	3 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.64	$m(\tilde{\chi}^0_1)$=0	ATLAS-CONF-2020-015
		$ee, \mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ 0.205	$m(\tilde{\chi}^\pm_1)$-$m(\tilde{\chi}^0_1)$=5 GeV	1911.12606
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via WW	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 0.42	$m(\tilde{\chi}^0_1)$=0	1908.08215
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2$ via Wh	0-1 e,μ	2 b/2 γ	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ Forbidden 0.74	$m(\tilde{\chi}^0_1)$=70 GeV	2004.10894, 1909.09226
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 1.0	$m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}^\pm_1)$+$m(\tilde{\chi}^0_1)$)	1908.08215
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau}\to\tau\tilde{\chi}^0_1$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L, \tilde{\tau}_{R,L}$] 0.16-0.3 0.12-0.39	$m(\tilde{\chi}^0_1)$=0	1911.06660
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0 jets	E_T^{miss}	139	$\tilde{\ell}$ 0.7	$m(\tilde{\chi}^0_1)$=0	1908.08215
		$ee, \mu\mu$	$\geq$ 1 jet	E_T^{miss}	139	$\tilde{\ell}$ 0.256	$m(\tilde{\ell})$-$m(\tilde{\chi}^0_1)$=10 GeV	1911.12606
	$\tilde{H}\tilde{H}, \tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	$\geq$ 3 b	E_T^{miss}	36.1	$\tilde{H}$ 0.13-0.23 0.29-0.88	BR($\tilde{\chi}^0_1 \to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	E_T^{miss}	139	$\tilde{H}$ 0.55	BR($\tilde{\chi}^0_1 \to Z\tilde{G}$)=1	2103.11684
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	E_T^{miss}	139	$\tilde{\chi}^\pm_1$ 0.66	Pure Wino	ATLAS-CONF-2021-015
						$\tilde{\chi}^\pm_1$ 0.21	Pure higgsino	ATLAS-CONF-2021-015
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$ 2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}^0_1$		Multiple		36.1	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.05 2.4	$m(\tilde{\chi}^0_1)$=100 GeV	1710.04901,1808.04095
	$\tilde{\ell}\tilde{\ell}, \tilde{\ell}\to\ell\tilde{G}$	Displ. lep		E_T^{miss}	139	$\tilde{e},\tilde{\mu}$ 0.7	$\tau(\tilde{\ell})$ = 0.1 ns	2011.07812
						$\tilde{\tau}$ 0.34	$\tau(\tilde{\ell})$ = 0.1 ns	2011.07812
RPV	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_1$, $\tilde{\chi}^\pm_1\to Z\ell\to\ell\ell\ell$	3 e,μ			139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_1$ [BR($Z\tau$)=1, BR(Ze)=1] 0.625 1.05	Pure Wino	2011.10543
	$\tilde{\chi}^\pm_1\tilde{\chi}^\mp_1/\tilde{\chi}^0_2 \to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	E_T^{miss}	139	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2$ [$\lambda_{i33} \neq 0, \lambda_{12k} \neq 0$] 0.95 1.55	$m(\tilde{\chi}^0_1)$=200 GeV	2103.11684
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^0_1, \tilde{\chi}^0_1 \to qqq$		4-5 large-R jets		36.1	$\tilde{g}$ [$m(\tilde{\chi}^0_1)$=200 GeV, 1100 GeV] 1.3 1.9	Large λ''_{112}	1804.03568
	$\tilde{t}\tilde{t}, \tilde{t}\to t\tilde{\chi}^0_1, \tilde{\chi}^0_1 \to tbs$		Multiple		36.1	$\tilde{t}$ [λ''_{323}=2e-4, 1e-2] 0.55 1.05	$m(\tilde{\chi}^0_1)$=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t}\to b\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1 \to bbs$		$\geq 4b$		139	$\tilde{t}$ Forbidden 0.95	$m(\tilde{\chi}^\pm_1)$=500 GeV	2010.01015
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$ 0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0 1.6	BR($\tilde{t}_1\to q\mu$)=100%, $\cos\theta_t$=1	2003.11956
	$\tilde{\chi}^\pm_1/\tilde{\chi}^0_2/\tilde{\chi}^0_1$, $\tilde{\chi}^0_{1,2}\to tbs$, $\tilde{\chi}^+_1\to bbs$	1-2 e,μ	$\geq$6 jets		139	$\tilde{\chi}^0_1$ 0.2-0.32	Pure higgsino	ATLAS-CONF-2021-007

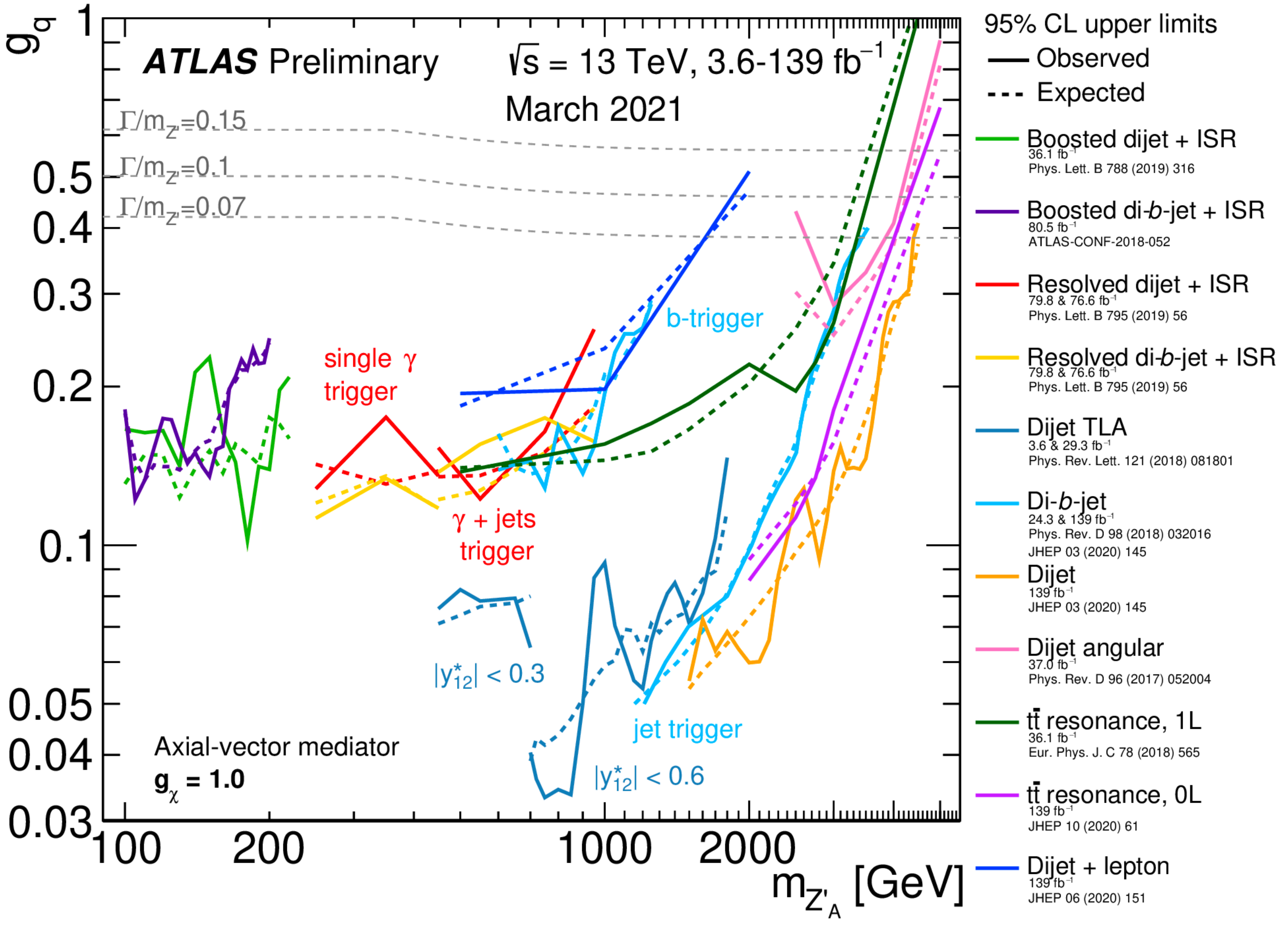
10^{-1} 1 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

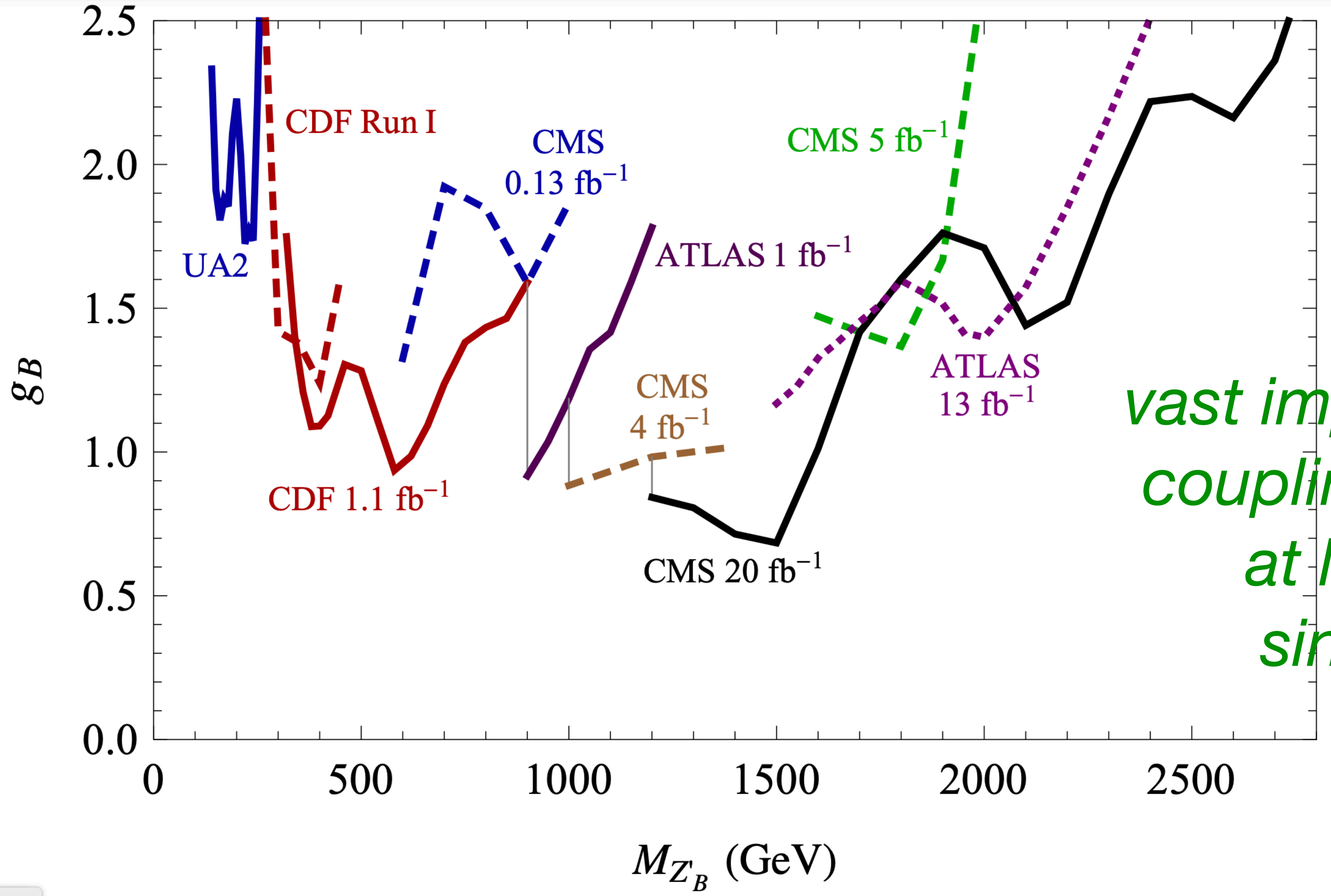
Searches at the coupling frontier

- Growing dataset provides sensitivity to weakly-coupled low-mass states
- Challenging for hadronic states due to trigger limitations
  —> alternate approaches w/ ISR jets/photons, jet substructure, trigger-level analysis





Dobrescu & Yu, arXiv:1306.2629

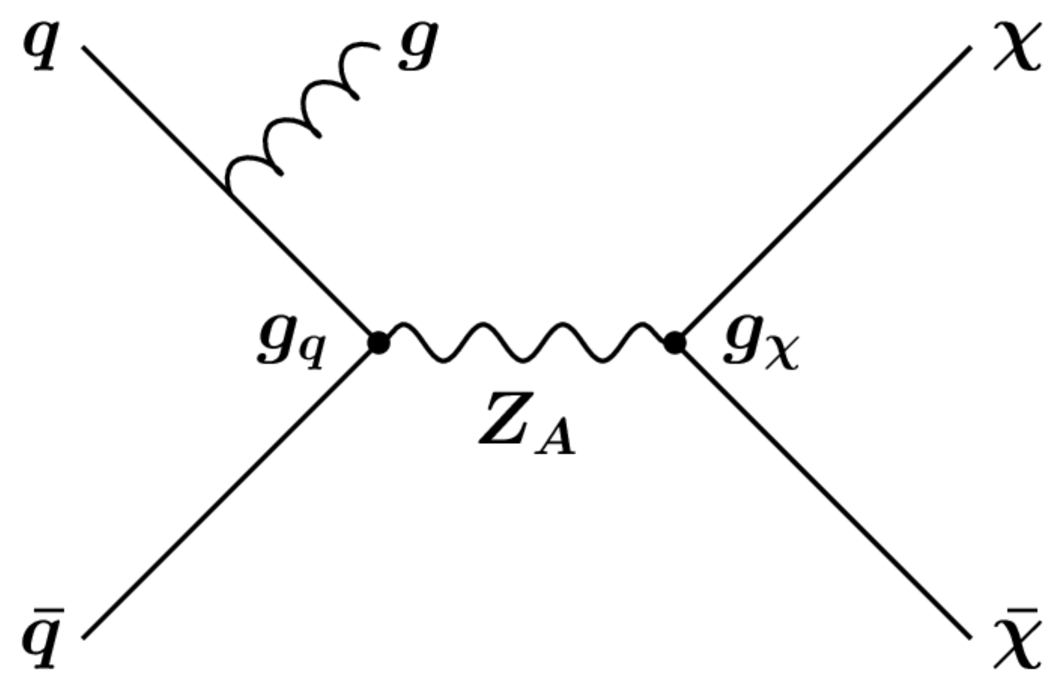


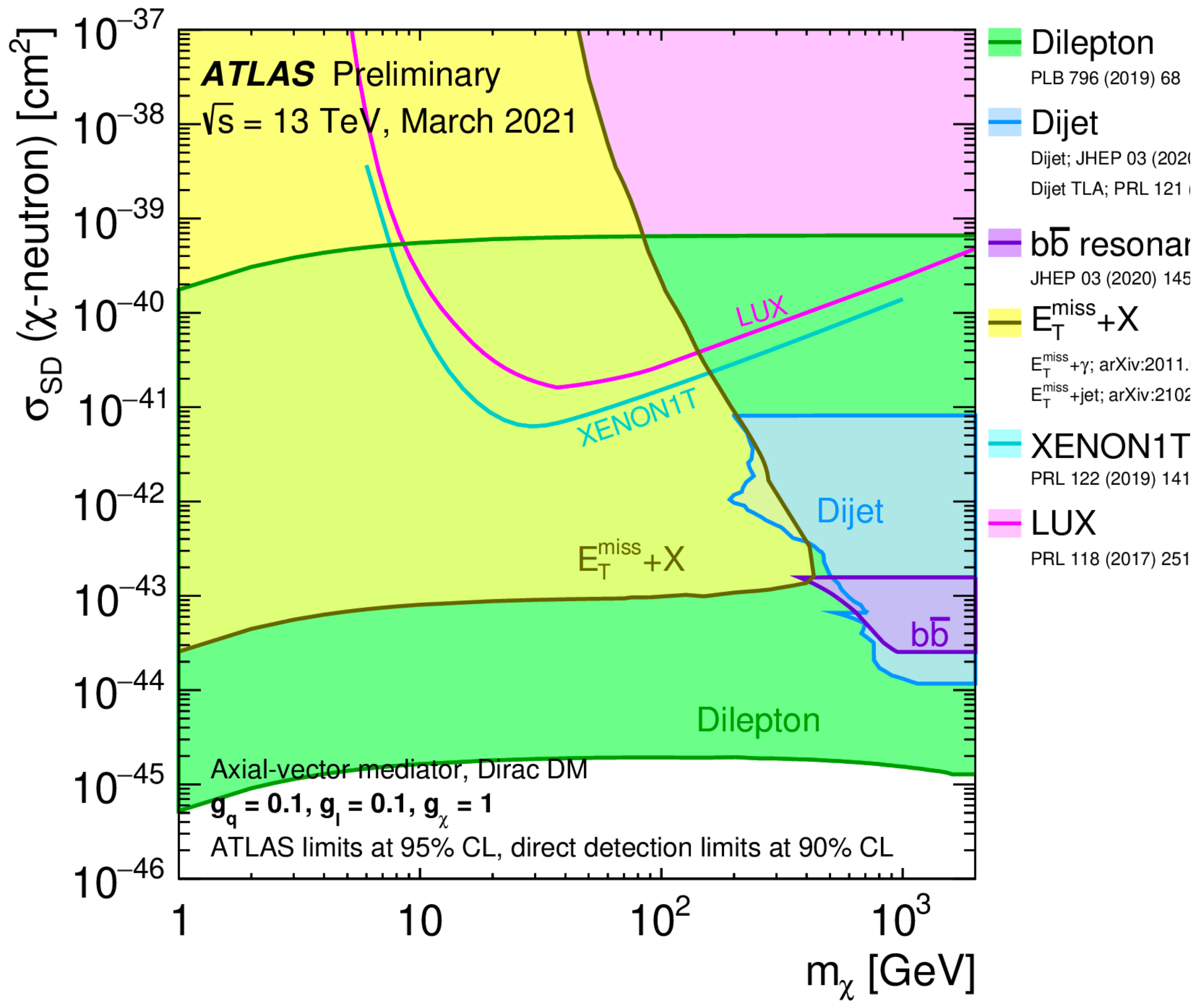
vast improvement in coupling sensitivity at low mass since 2013

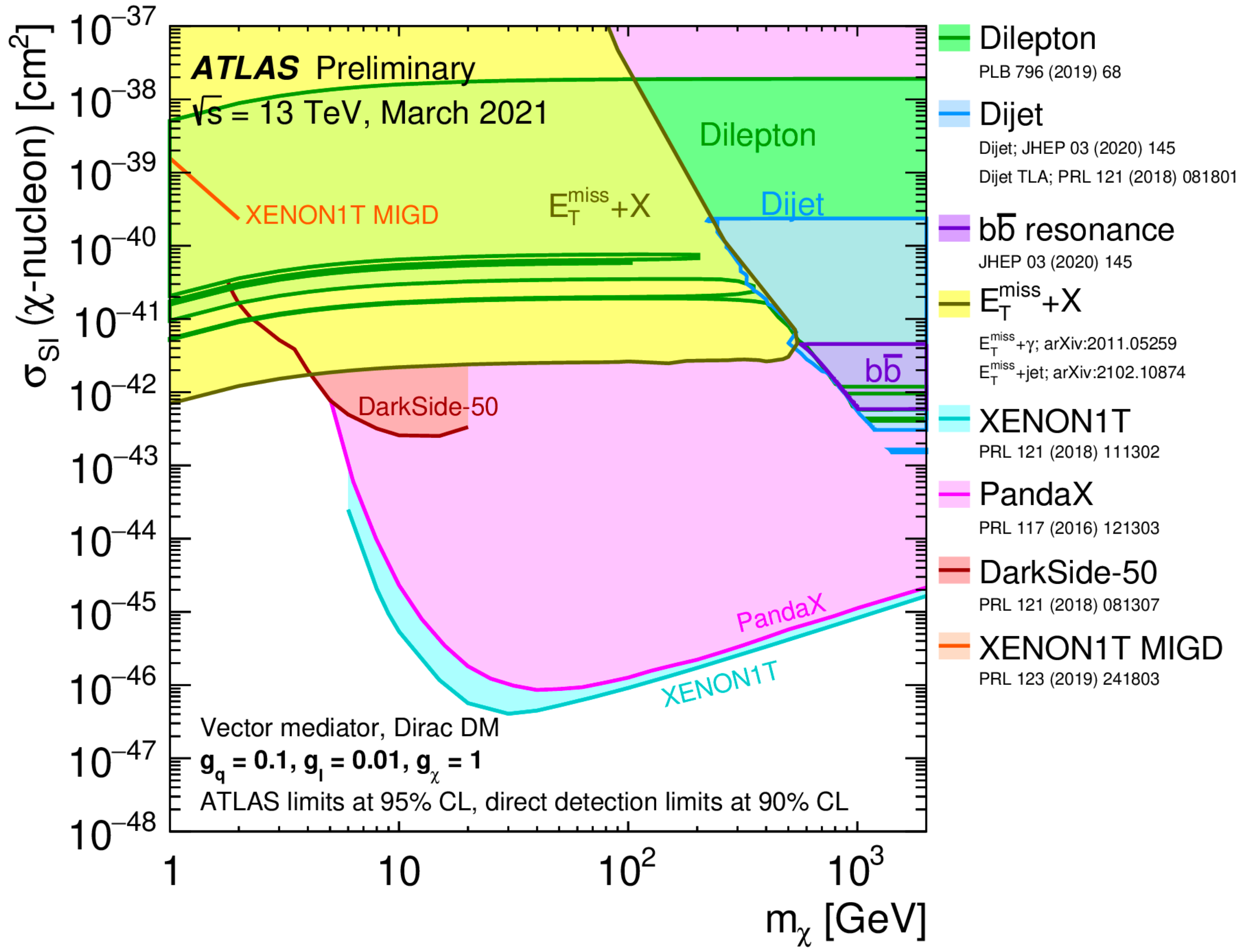
Searches for dark matter

- Multiple approaches:
  ETmiss + X with X = j, γ, W/Z, H, t
  SUSY searches

- Particularly powerful at low WIMP mass compared with direct detection expts

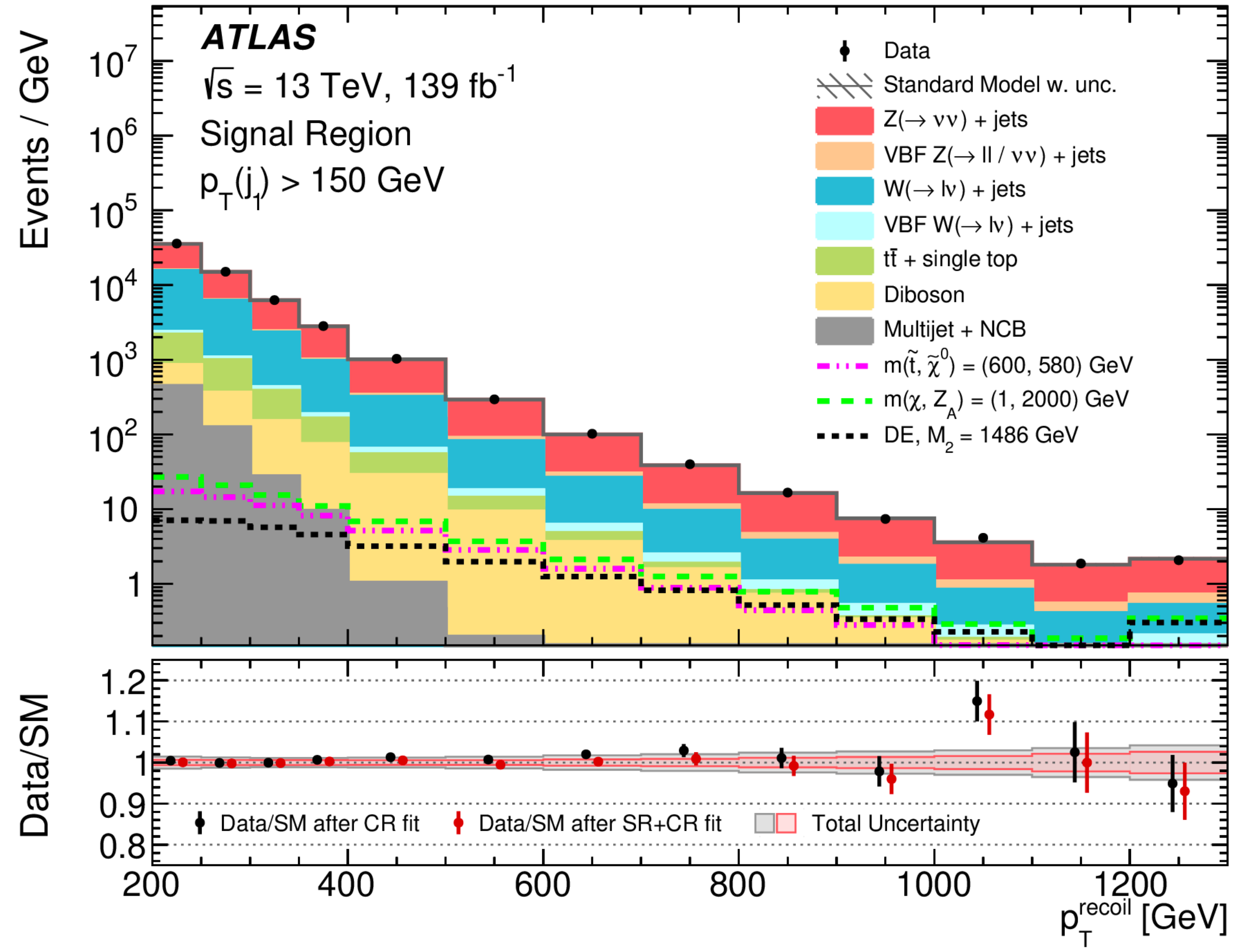


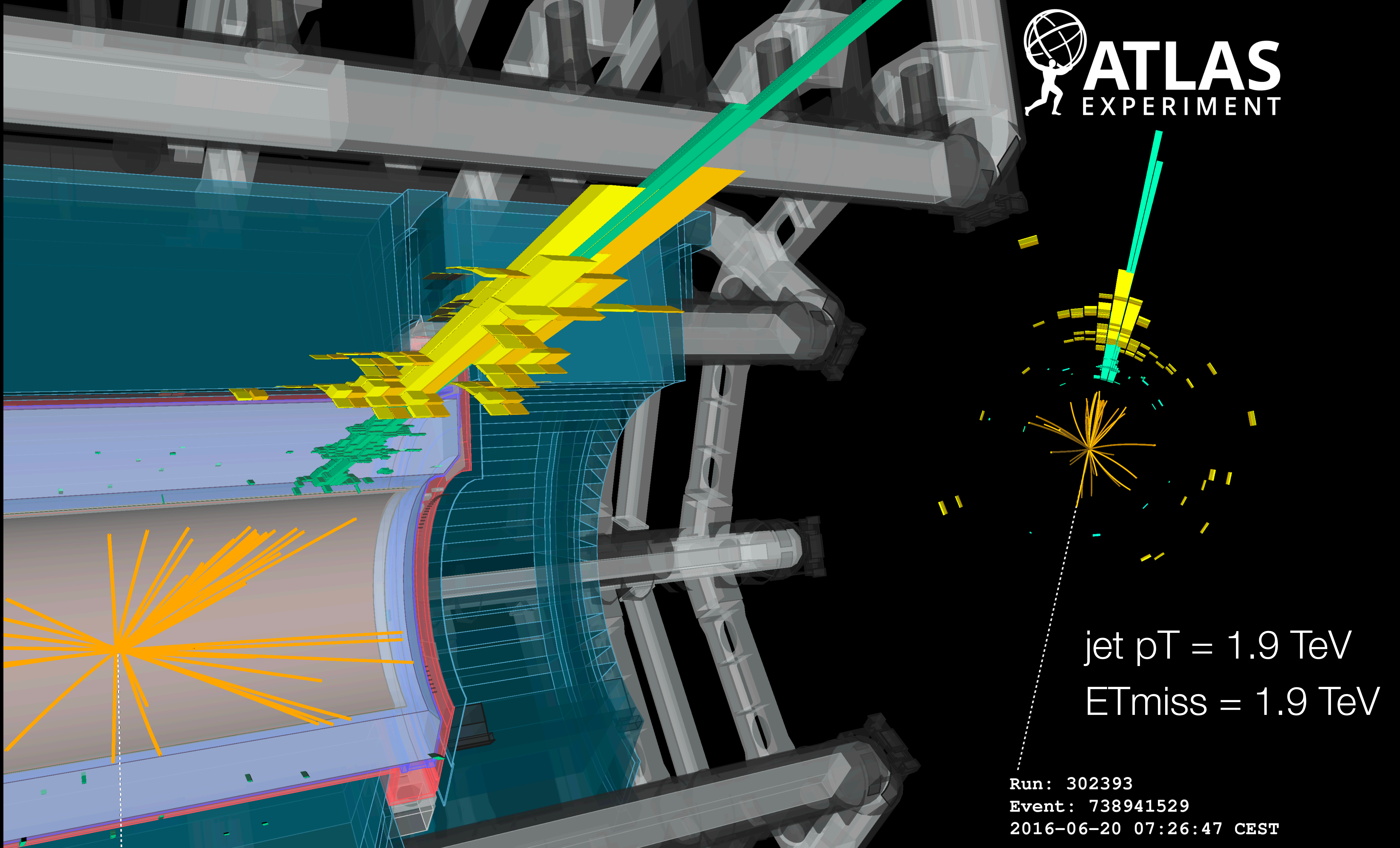




- More complete models considered beyond simplified models
  e.g. 2HDM+a —> broader phenomenology

- Monojet arXiv:2102.10874
  - high level of precision required in W/Z+jets bkg modeling (NNLO QCD and NLO EW) and lepton ID (W —> lν and Z —> ll CRs)



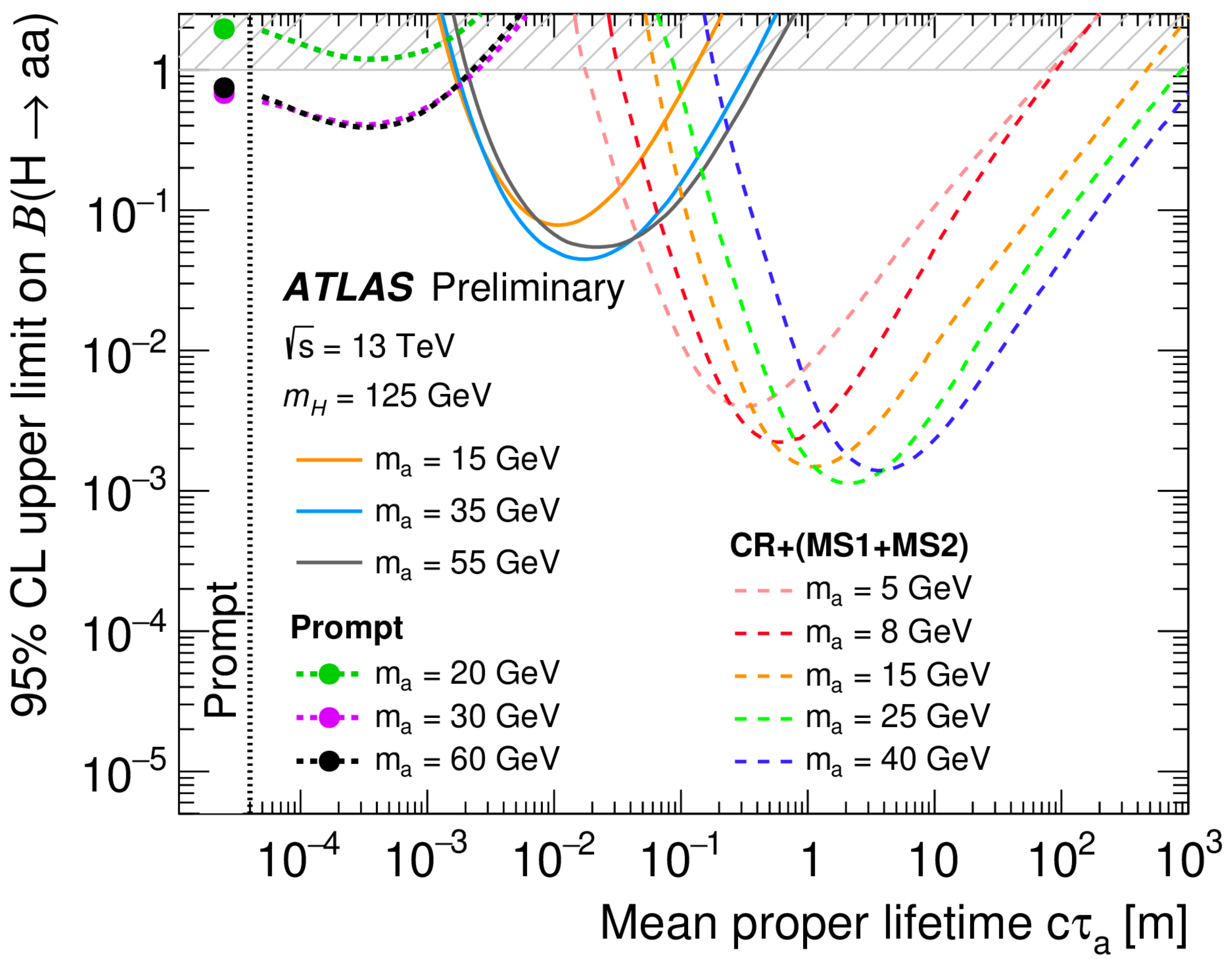

ATLAS
EXPERIMENT
jet pT = 1.9 TeV
ETmiss = 1.9 TeV
Run: 302393
Event: 738941529
2016-06-20 07:26:47 CEST

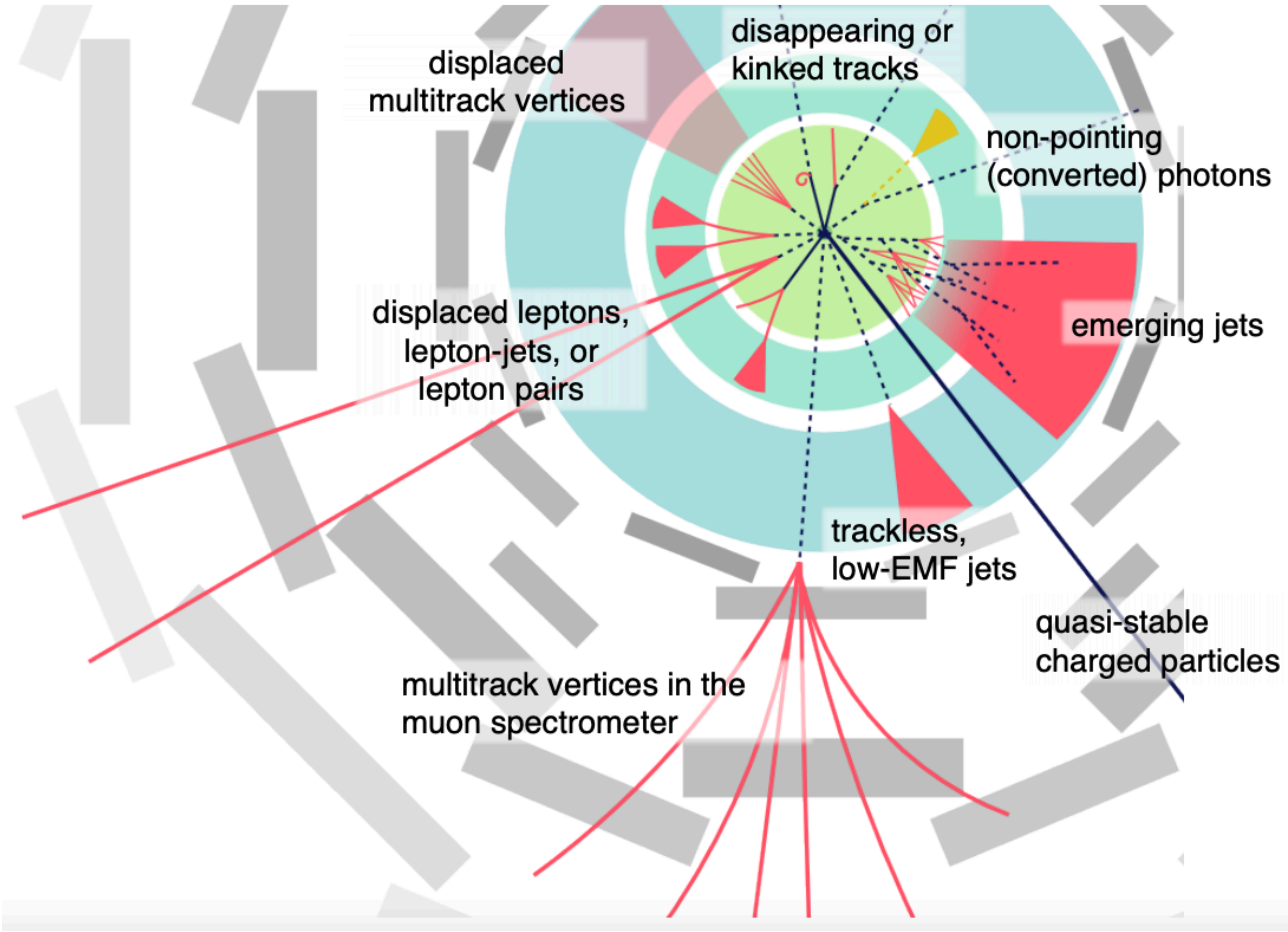
Searches for long-lived particles

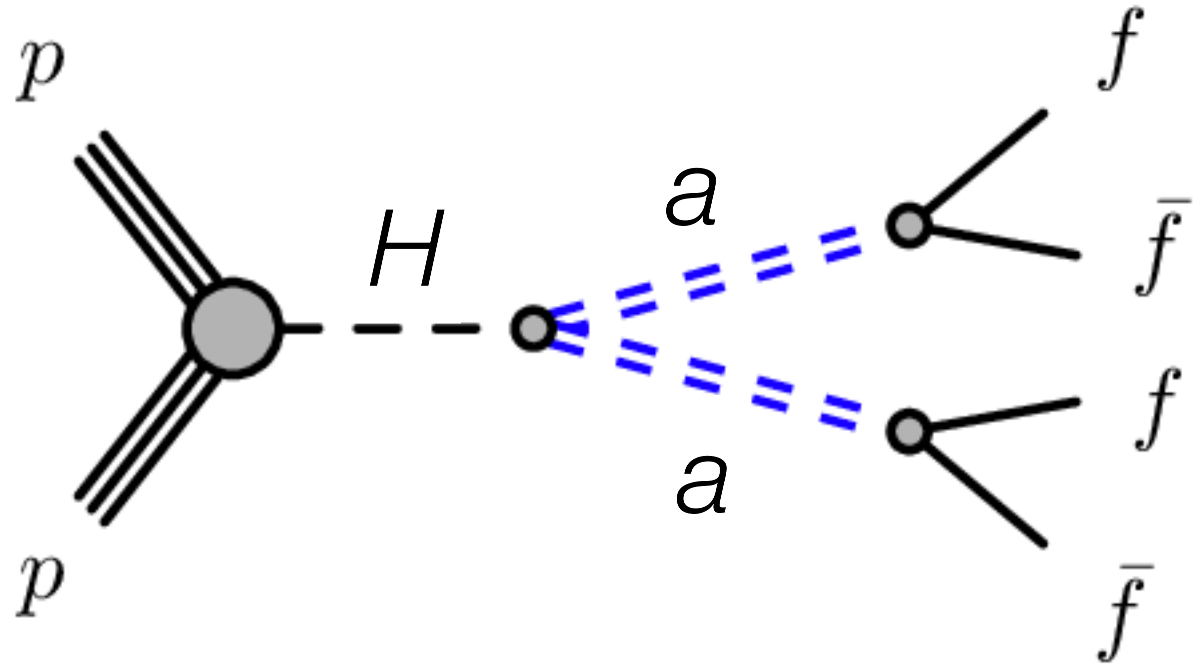
- Multiple unconventional signatures requiring dedicated triggers and/or reconstruction
- Explored lifetimes: cτ range 1 mm to >100 m
- *Example*: Higgs exotic decays to LLP
  - *ggH* or *VH* with *H* —> *aa*
  - displaced jet (in Calo) or vtx (in ID or MS)

arXiv:2102.10874

ATLAS-CONF-2021-005

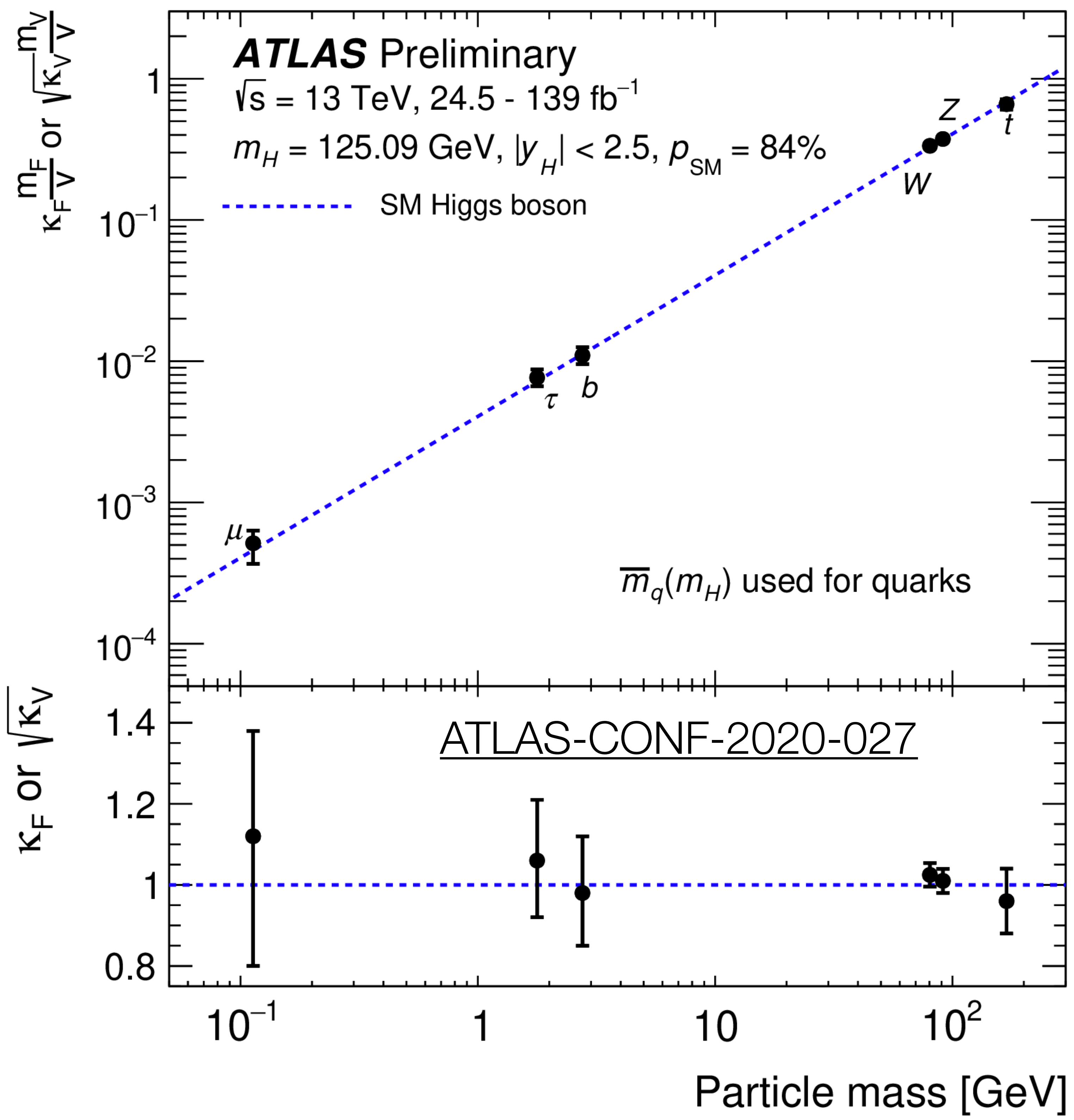


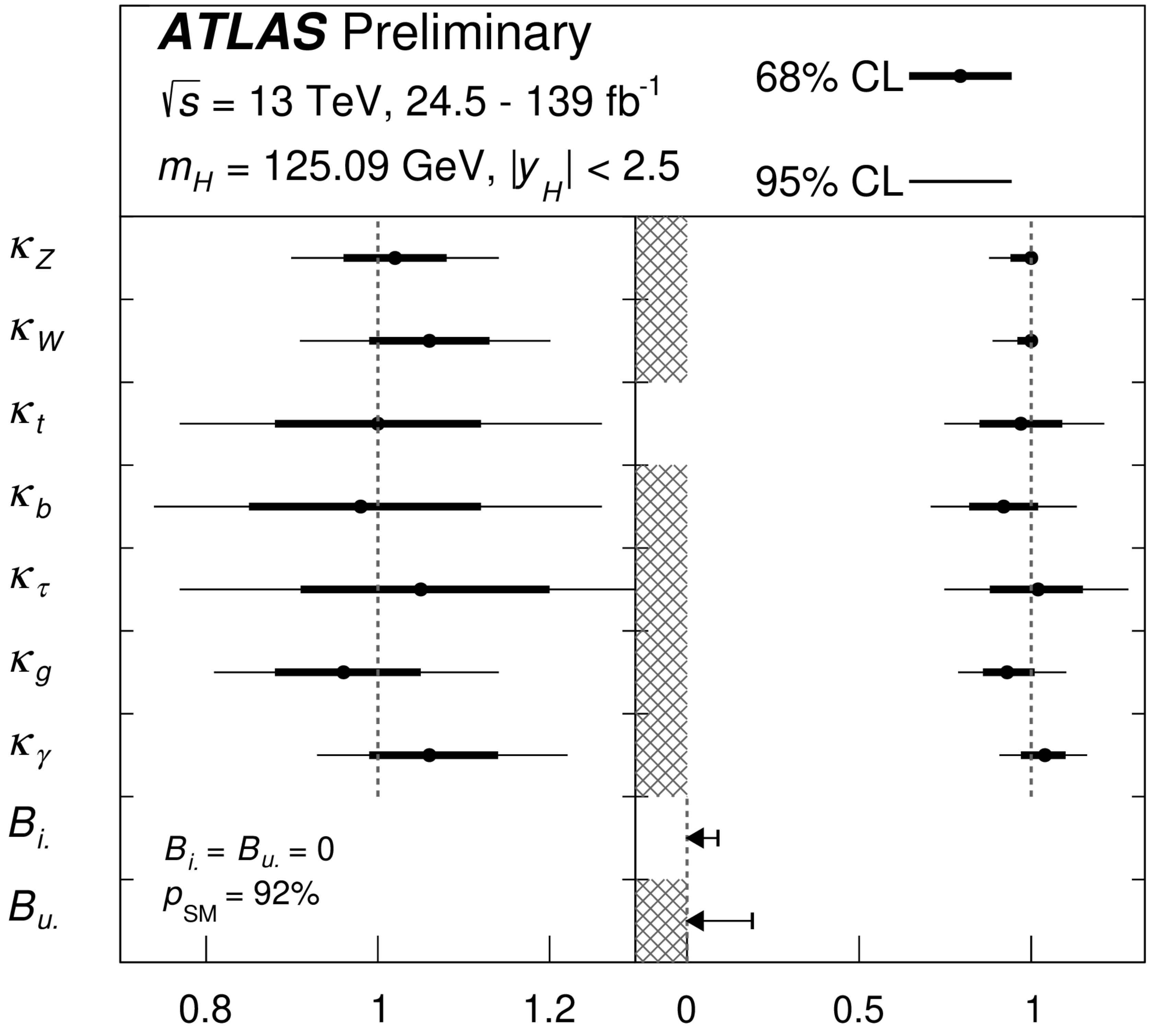


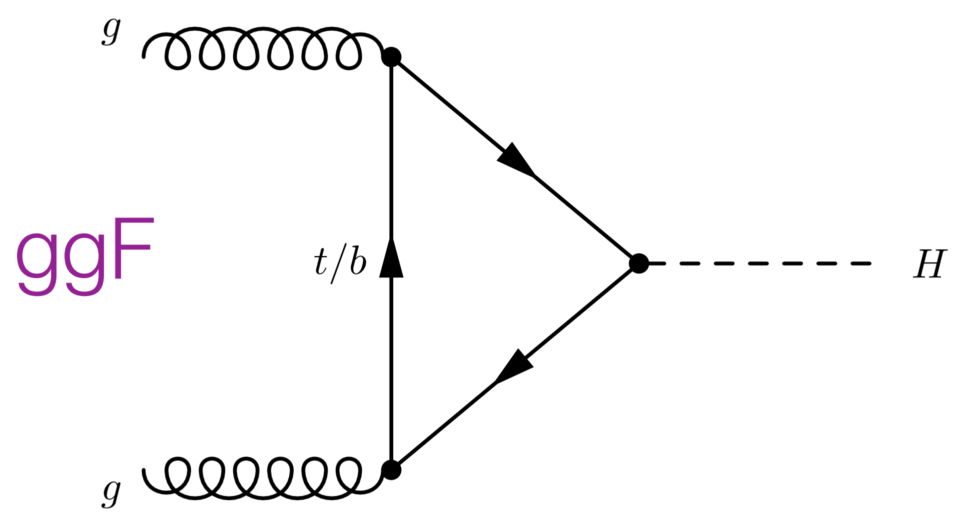


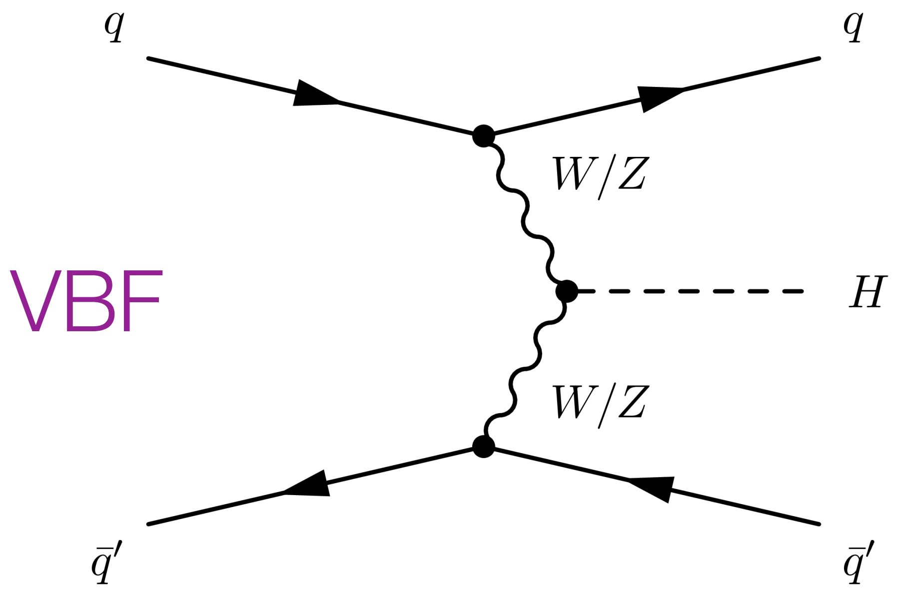
Higgs

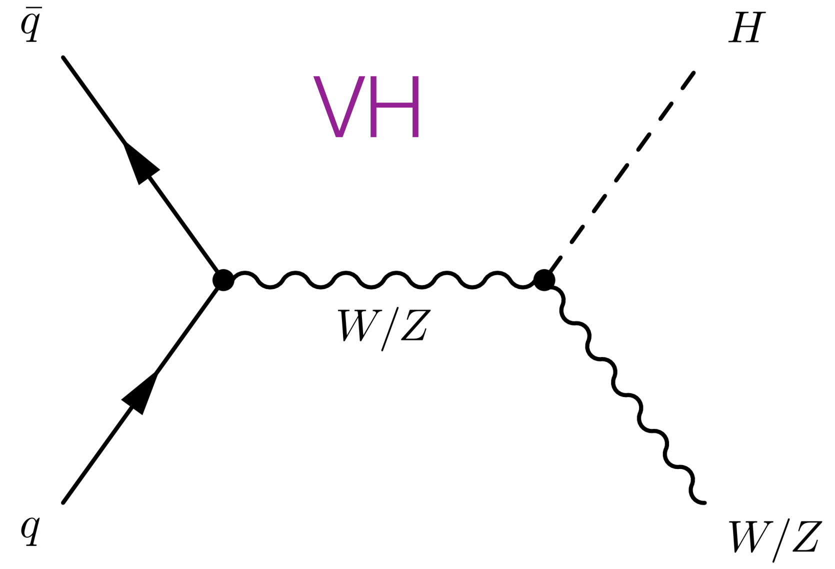
- Run 2 confirms 125 GeV Higgs boson consistent with SM
- All major production mechanisms observed
- Couplings to 3rd gen. fermions (τ, b, t) firmly established, 2σ excess for H —> μμ
- Coupling modifier $\Delta\kappa/\kappa$ = 6% for W, Z and 15% for τ

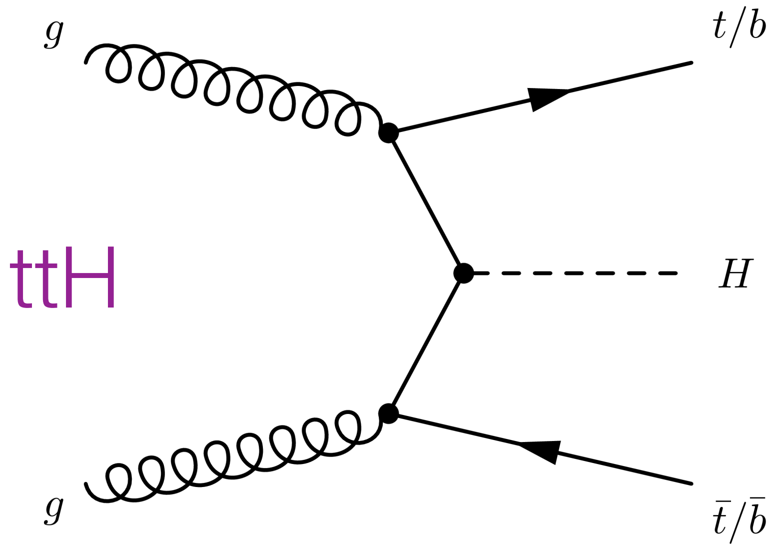










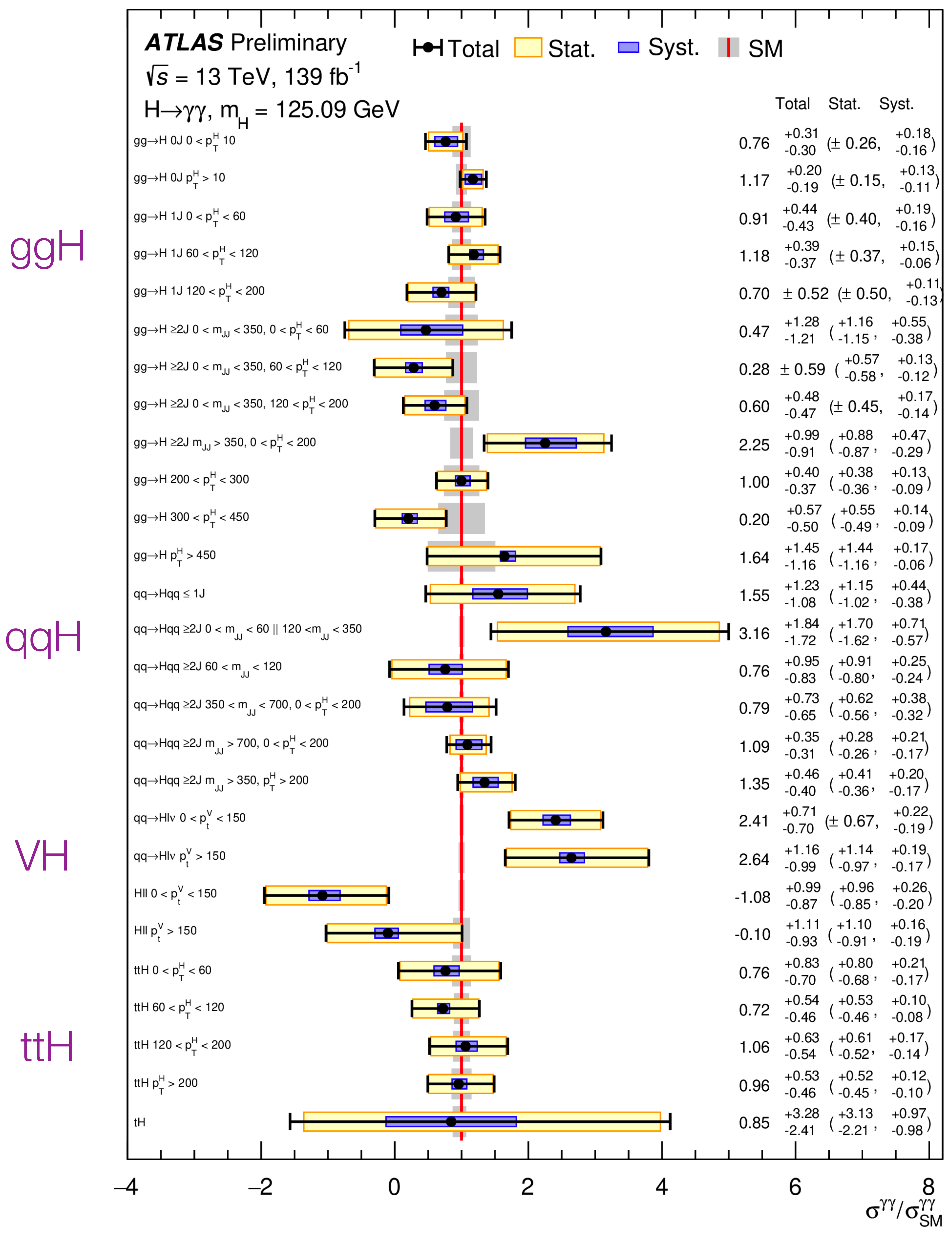


Higgs XS measurements

- Precise cross-section measurements: inclusive, differential, production mechanisms
- Kinematic distributions provide test of QCD, production mechanisms, spin-parity, BSM effects
- Simplified template cross sections (STXS):
  - XS measurements in distinct kinematic (pT(H), mjj) and topological (Njets) regions
  - some regions w/ enhanced BSM sensitivity
  - example: H —> γγ
    - 27 STXS regions!
- Broad use of MVA/ML techniques (bkg suppression, event classification)

- H —> γγ

ATLAS-CONF-2020-026

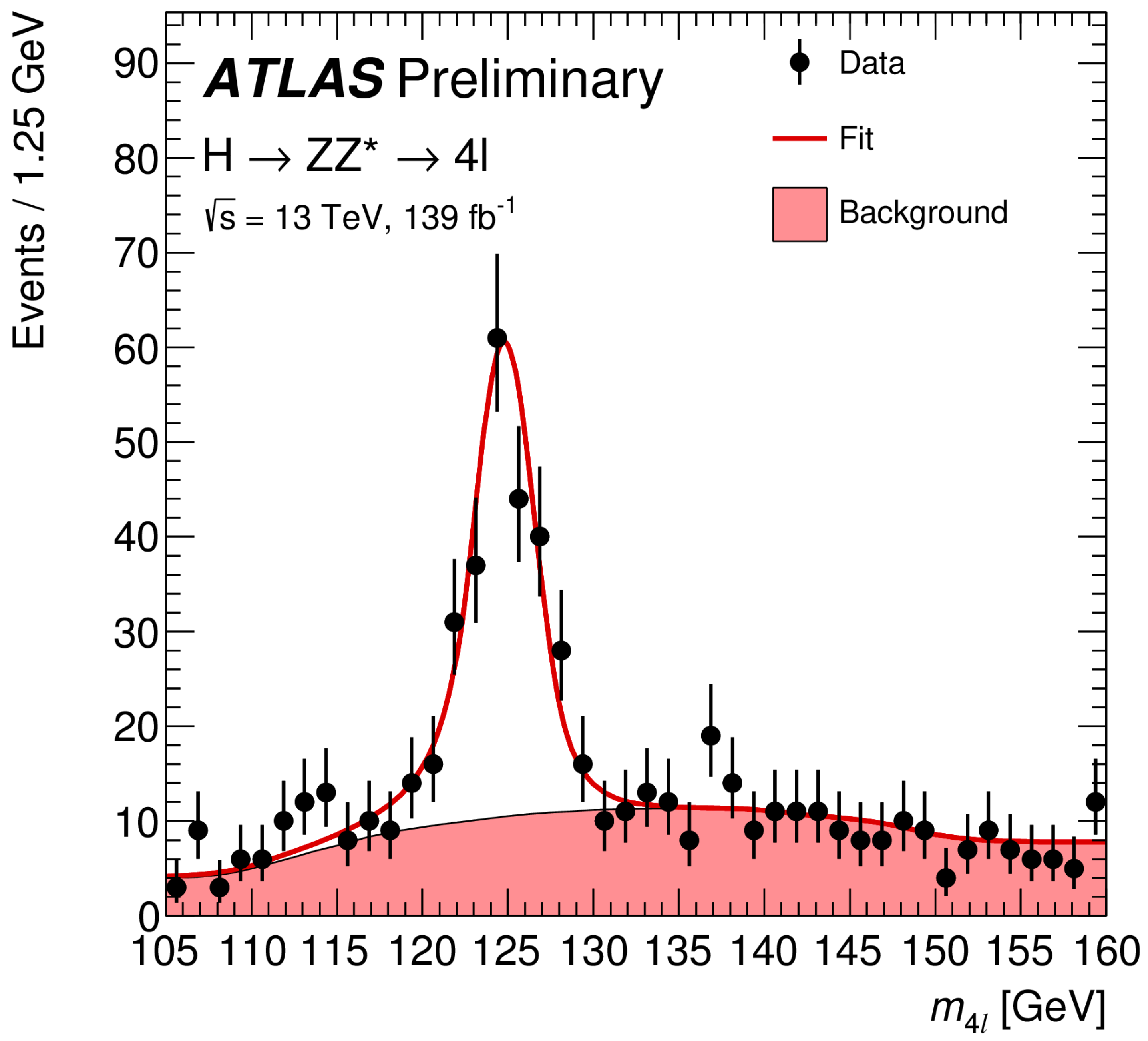


Higgs properties

- Mass $m_H^{ZZ^*} = 124.92 \pm 0.19(\text{stat})^{+0.09}_{-0.06}(\text{syst})\ \text{GeV}$

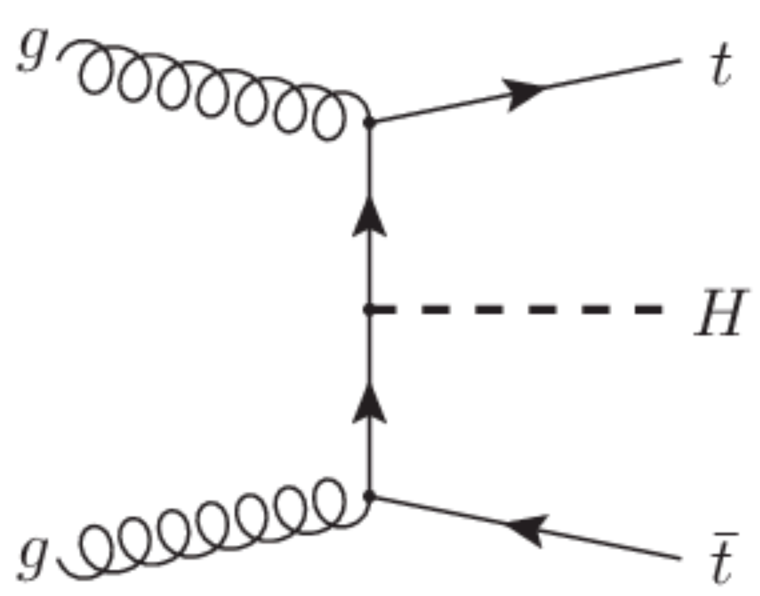
- CP structure tested in Higgs couplings to bosons & fermions

ATLAS-CONF-2020-005

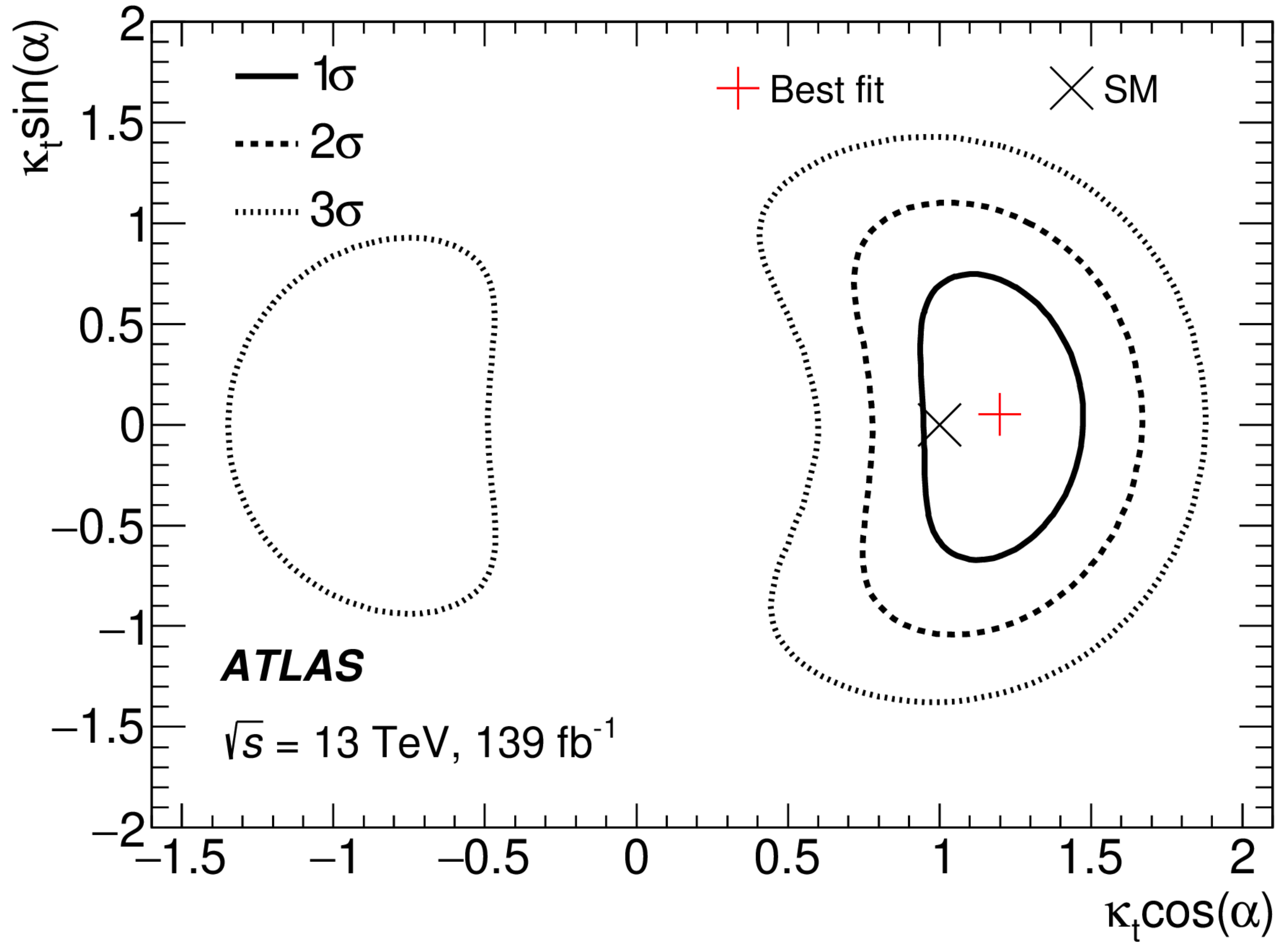


- ttH w/ H —> γγ arXiv:2004.04545
  - test of top Yukawa coupling

$$\mathcal{L} = -\frac{\sqrt{2}m_t}{v}(\bar{\psi}_t \kappa_t\,(\cos(\alpha) + i\sin(\alpha)\gamma_5)\,\psi_t)H$$



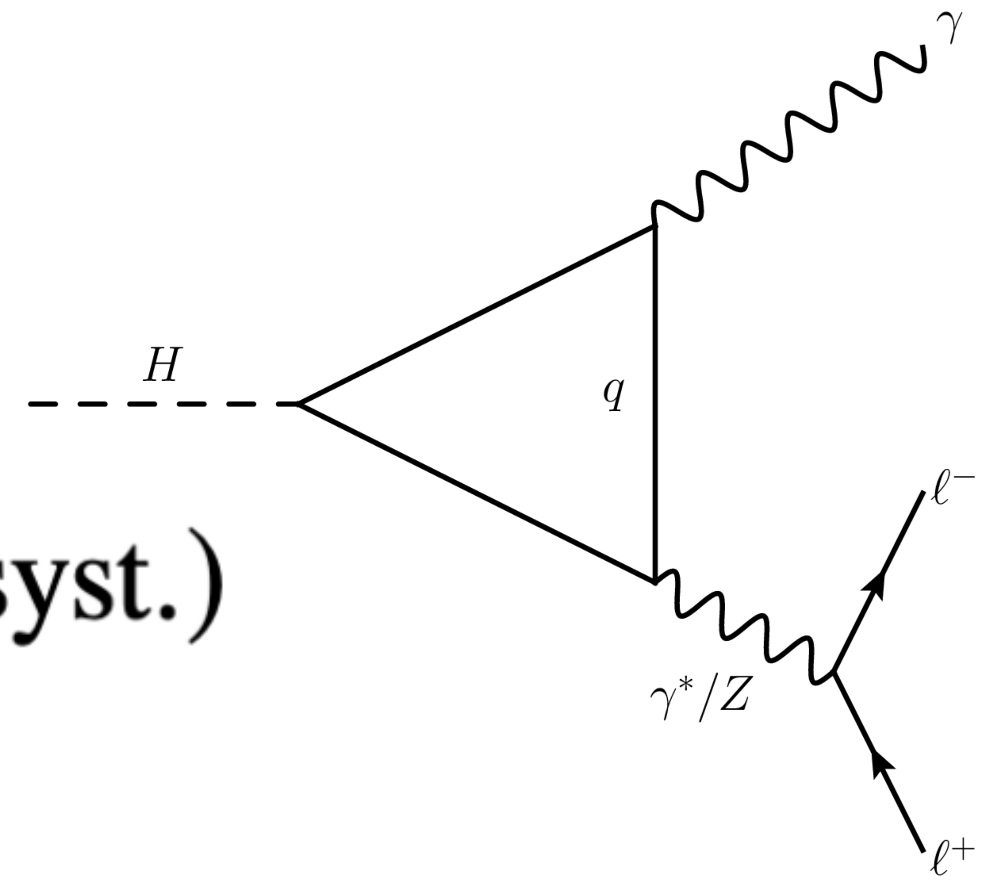
  - coupling strength κ_t (=1 in SM)
  - CP mixing angle α (=0 in SM)
  - CP odd scenario (α = 90 deg.) excluded at 3.9 σ

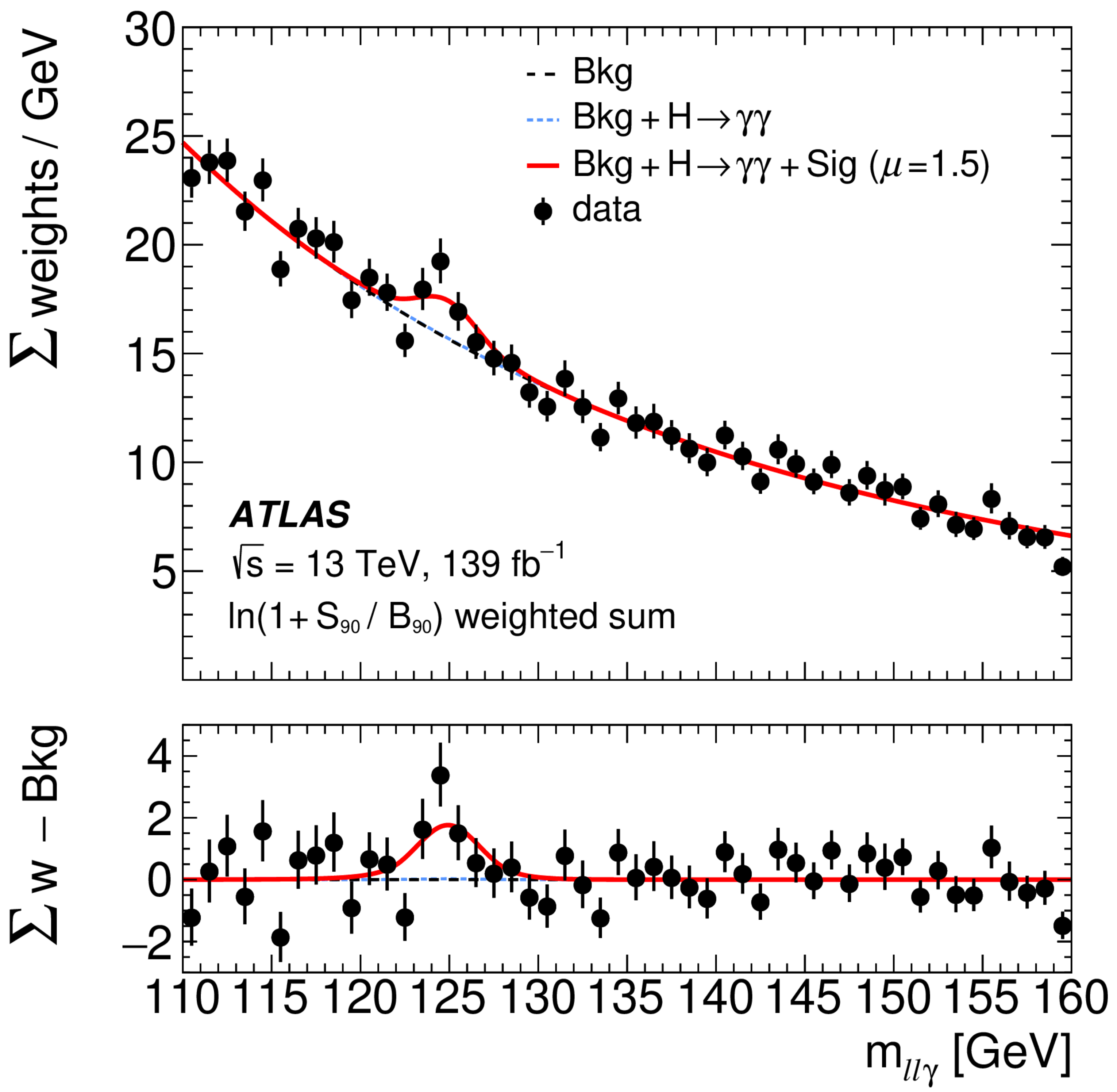


Rare Higgs processes

- **Rare decays**: Sensitive to BSM
  - first evidence for H —> $l^+l^-\gamma$ Dalitz decay arXiv:2103.10322
    - m(e+e- or μ+μ-) < 30 GeV, requires dedicated ID for merged di-electron showers
    - significance: 3.2 σ obs (2.1 σ exp)

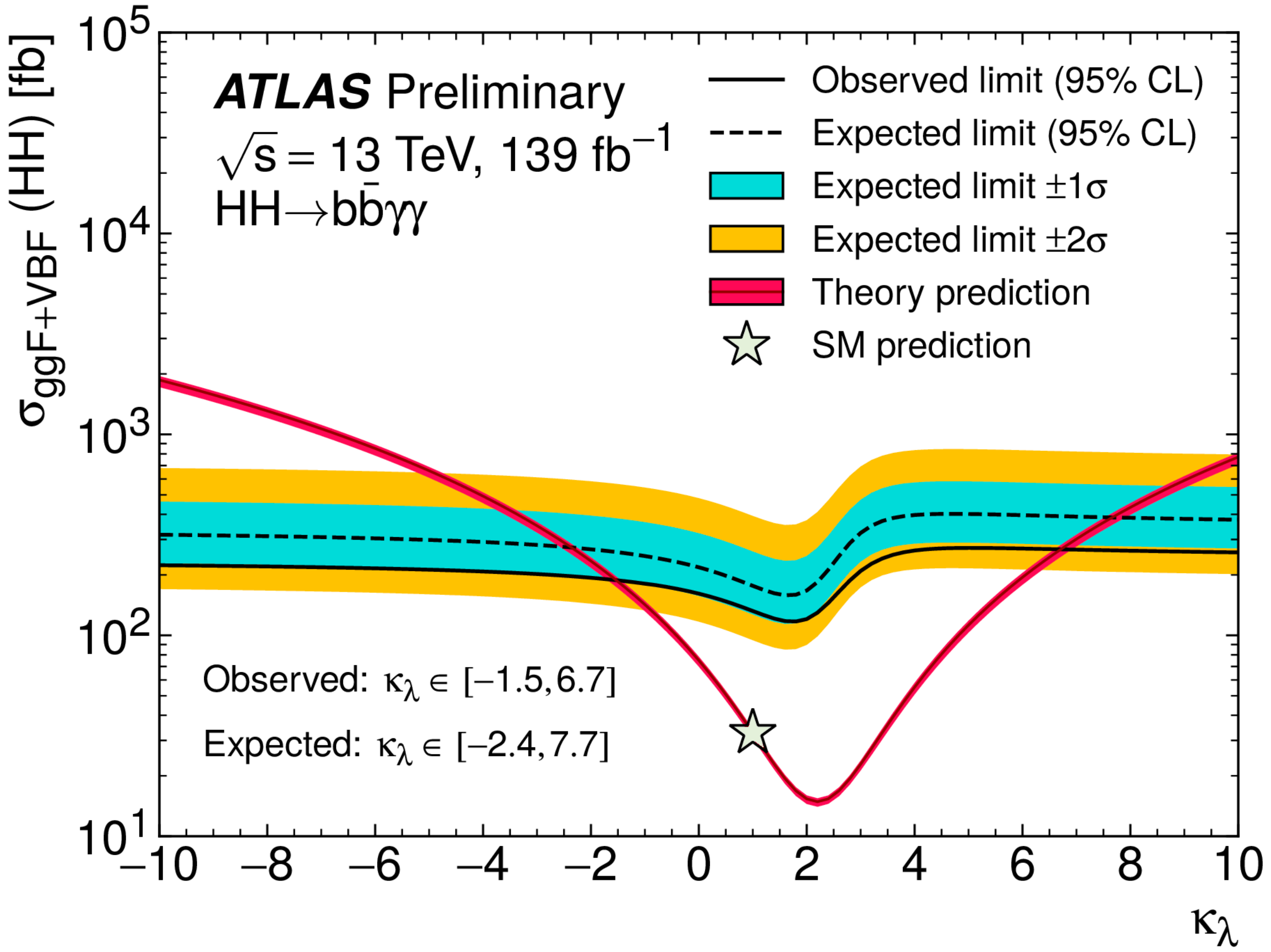
$$\mu = 1.5 \pm 0.5 = 1.5 \pm 0.5\ (\text{stat.})\ {}^{+0.2}_{-0.1}\ (\text{syst.})$$

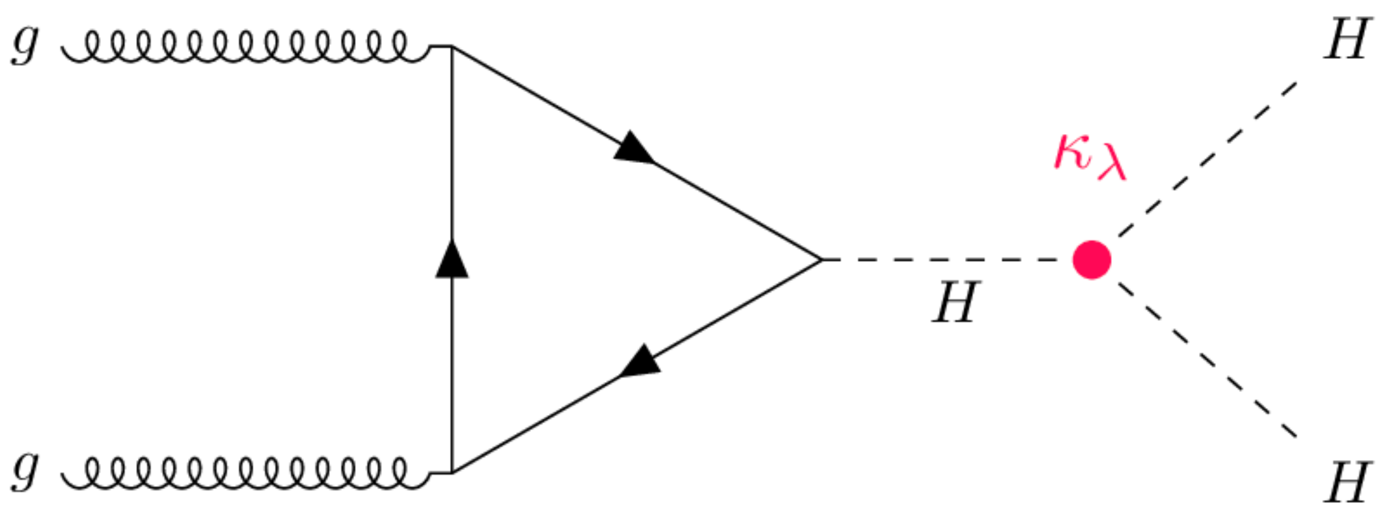




- **Di-Higgs production —> Higgs self-coupling**
  - access to Higgs potential, sensitive to BSM
  - HH —> bbγγ

ATLAS-CONF-2021-016





$$\sigma_{HH}/\sigma_{HH}^{SM} < 4.1\ (\text{exp } 5.5)^{\star}$$

self-coupling modifier κ_λ

$$\lambda_{HH}/\lambda_{HH}^{SM} \in [-1.5, 6.7]$$
$$(\text{exp } [-2.4, 7.7])$$

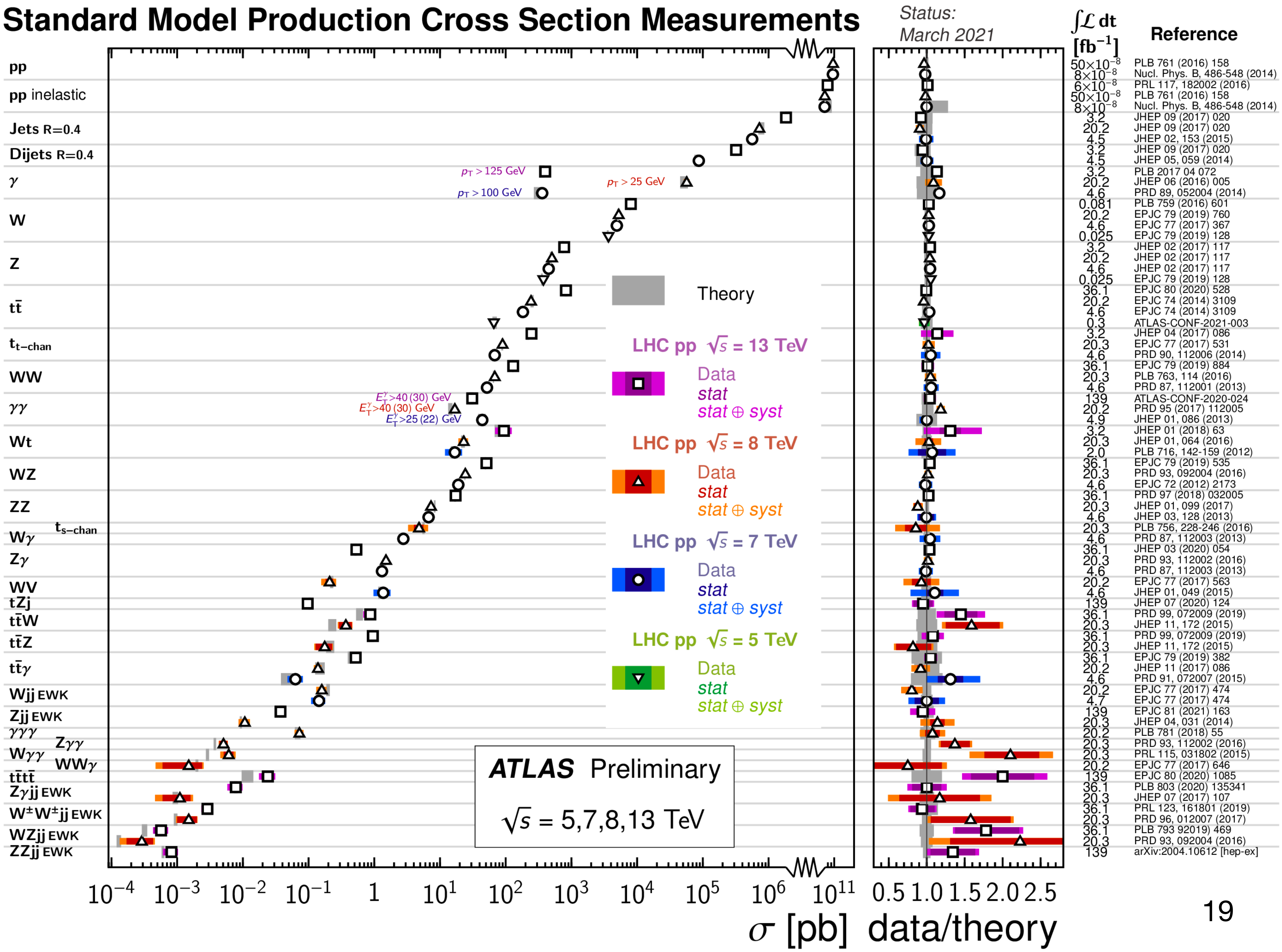
* factor of 5 improvement over 36 fb^{-1} analysis

Standard Model measurements

Stringent test of electroweak sector and QCD over 15 orders of magnitude

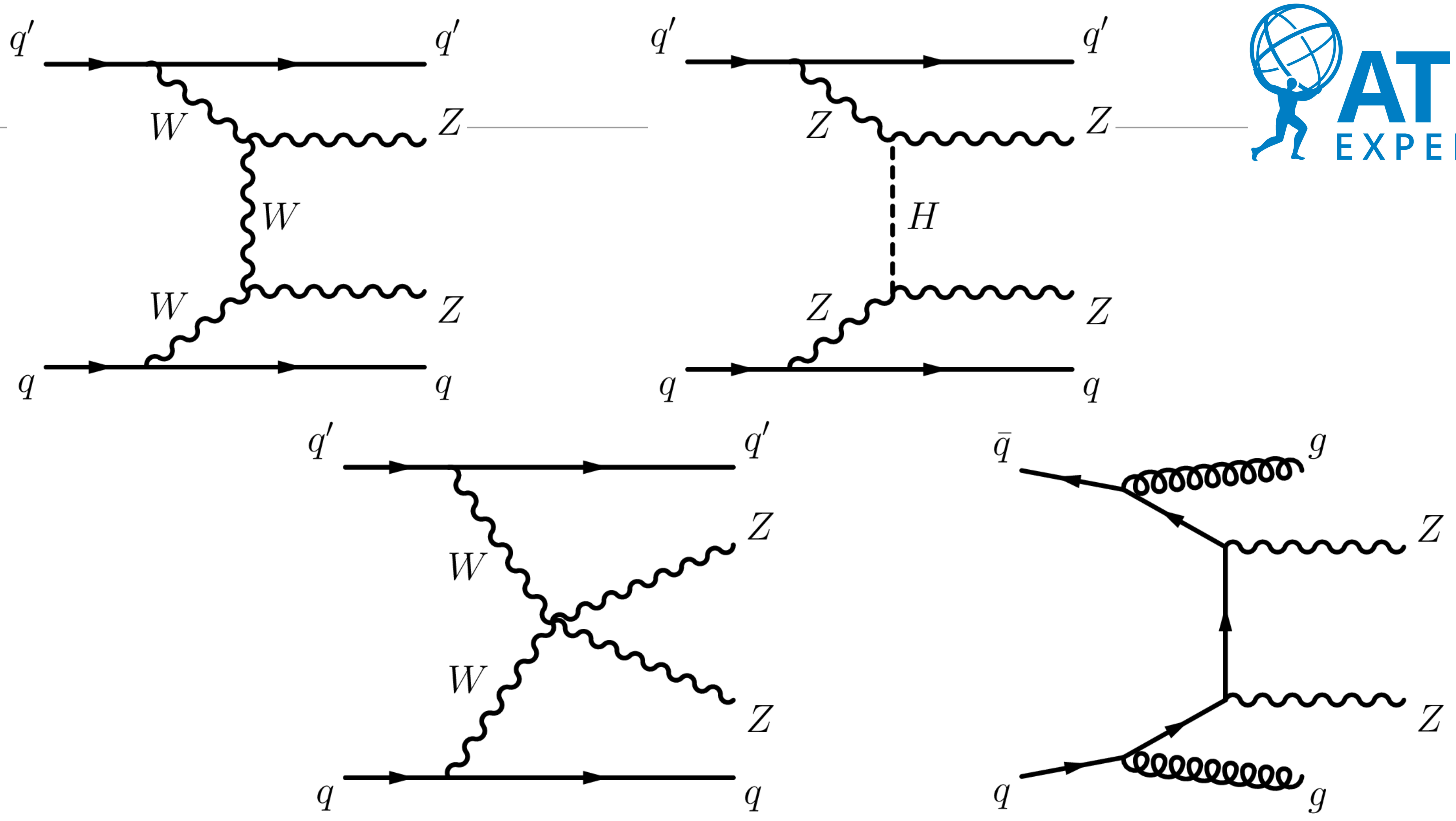
—> *passed!*

(so far…)

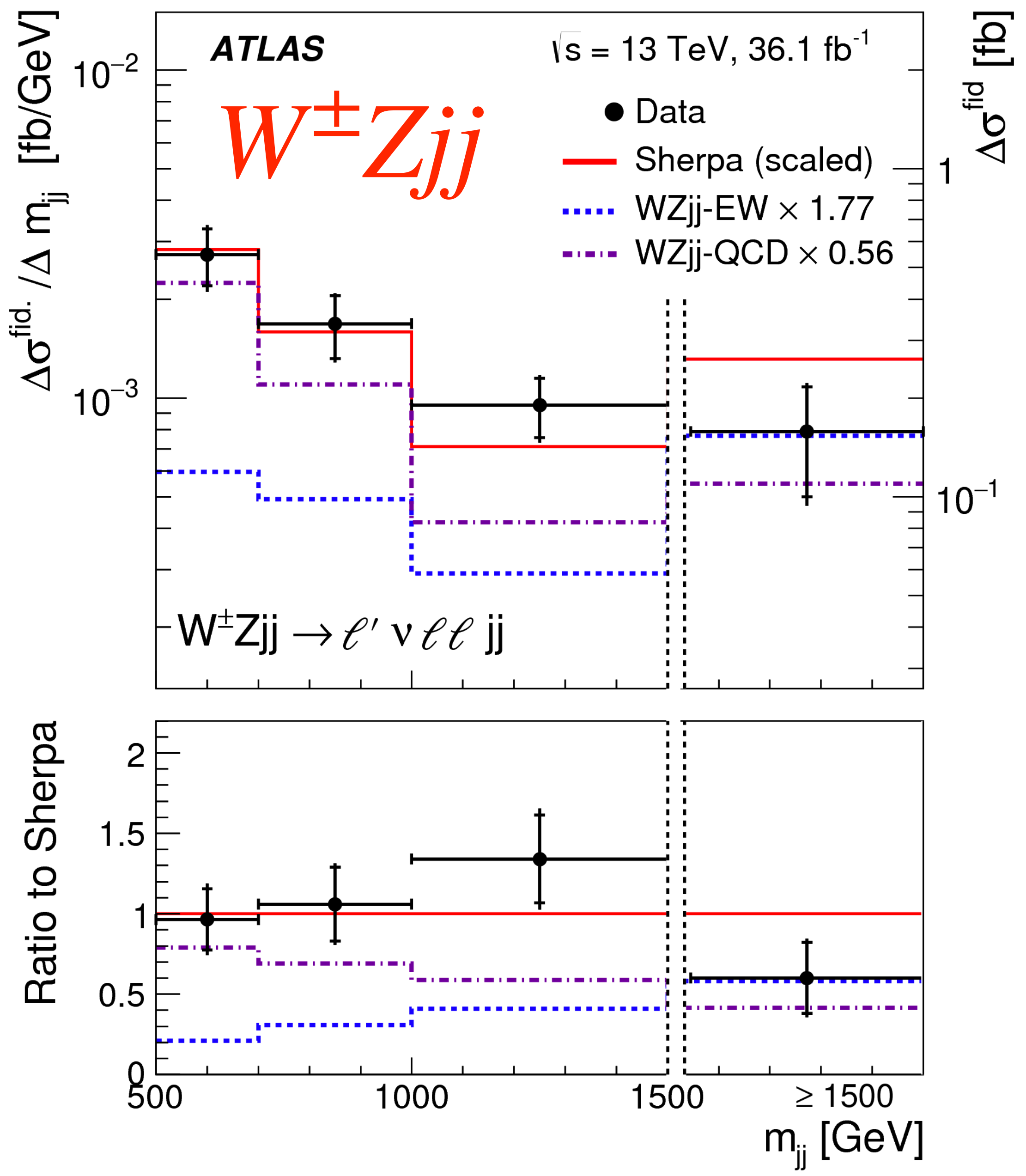


Vector boson scattering

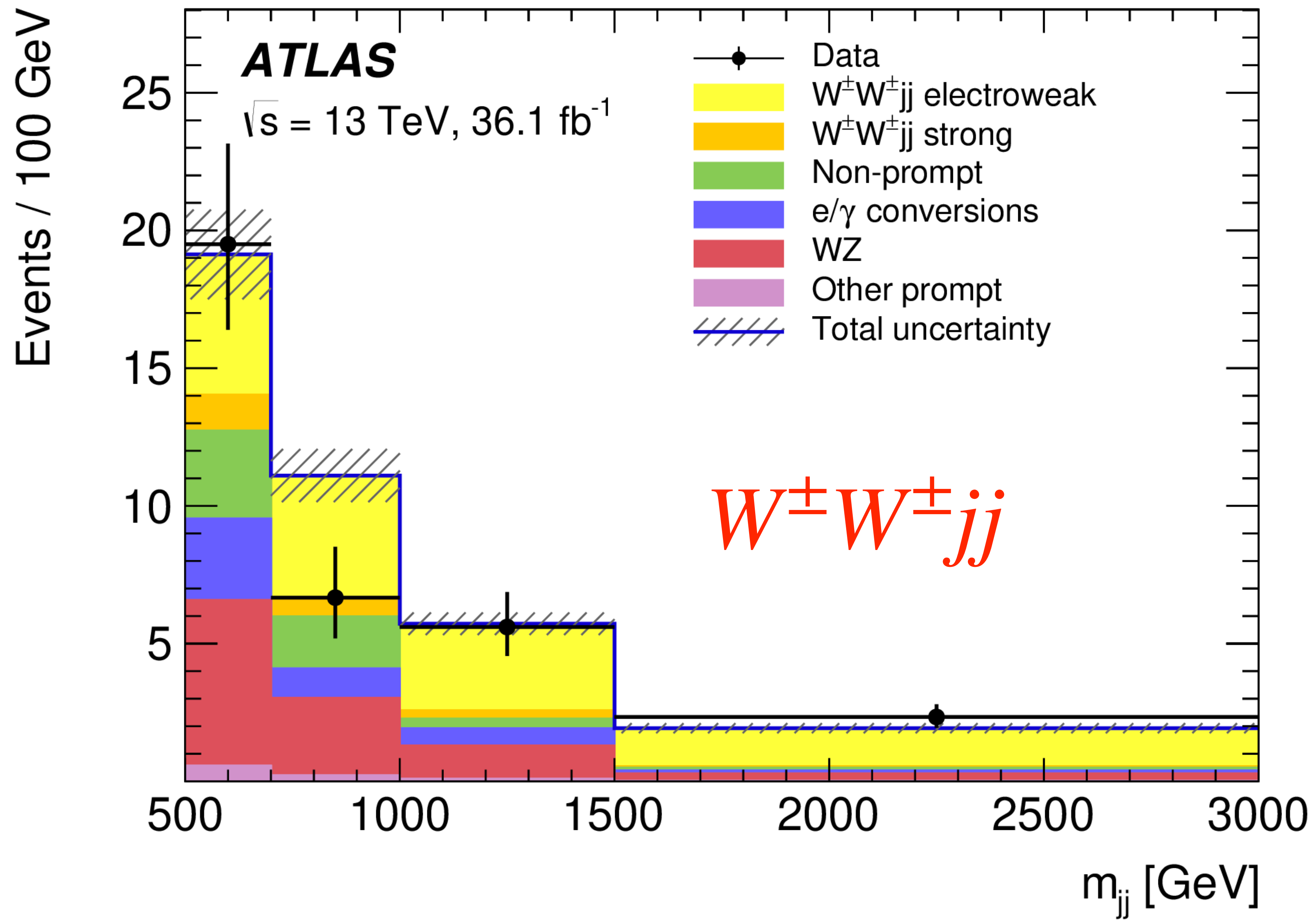
- Key test of EW symmetry —> **vector boson self-interactions** + test of EWSB (Unitarity!)
- All VVjj processes observed
  - extract EW contribution (order α^6 incl. decay) —> access cubic and quartic couplings
  - suppress QCD (order α^4 α^2_s incl. decay) —> challenging modeling (scale uncertainty)



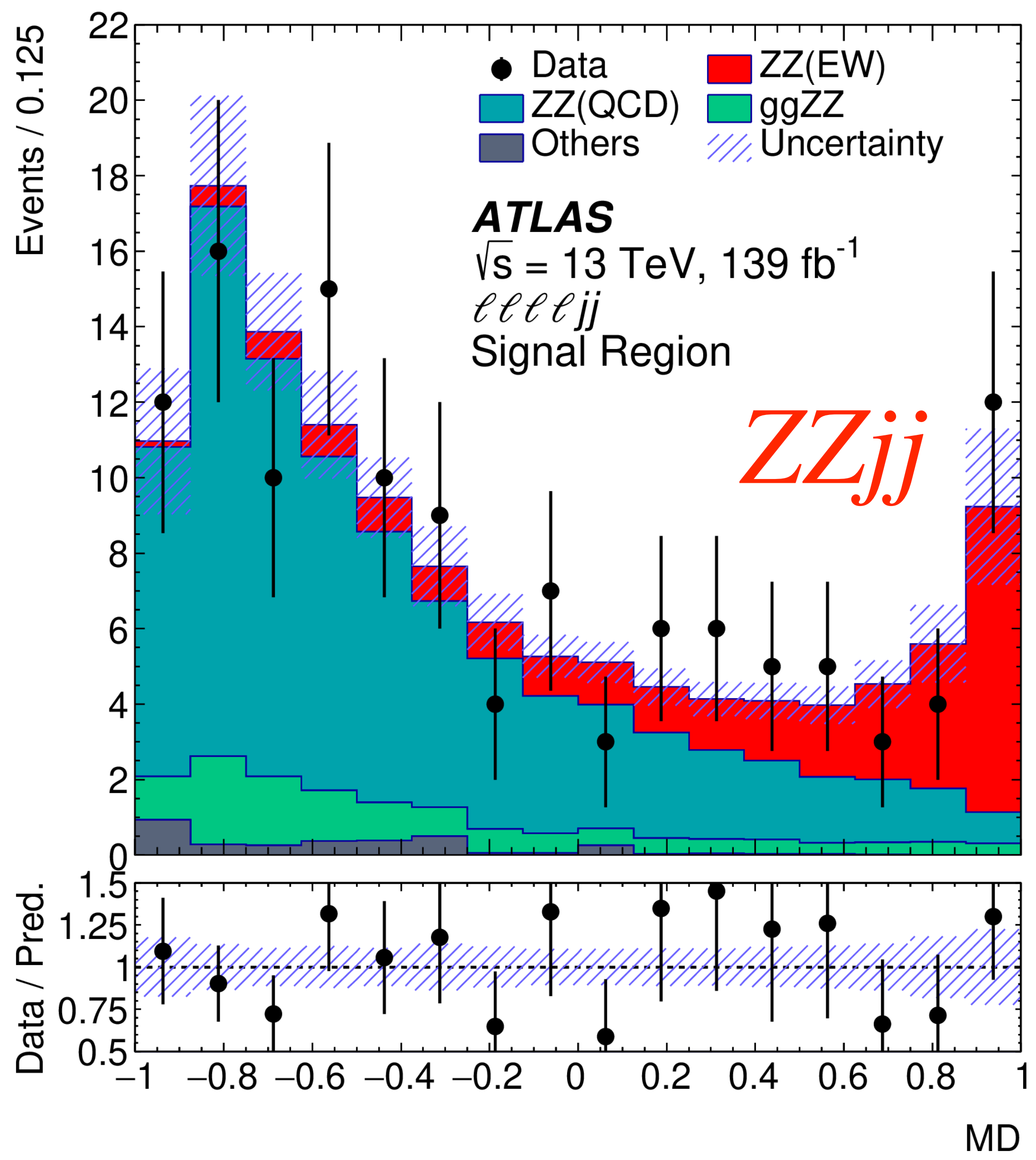
arXiv:1812.09740



arXiv:1906.03203



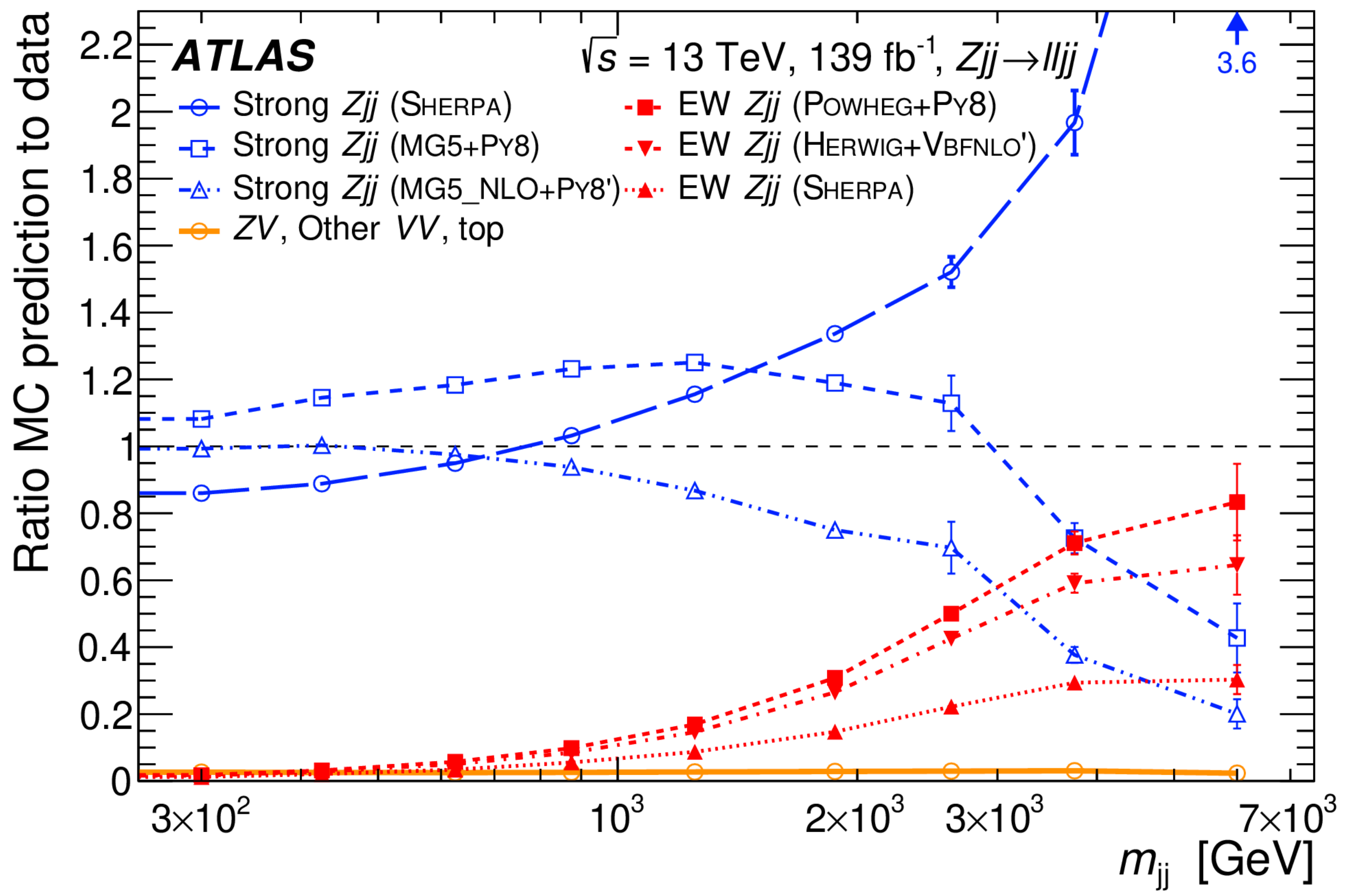
arXiv:2004.10612

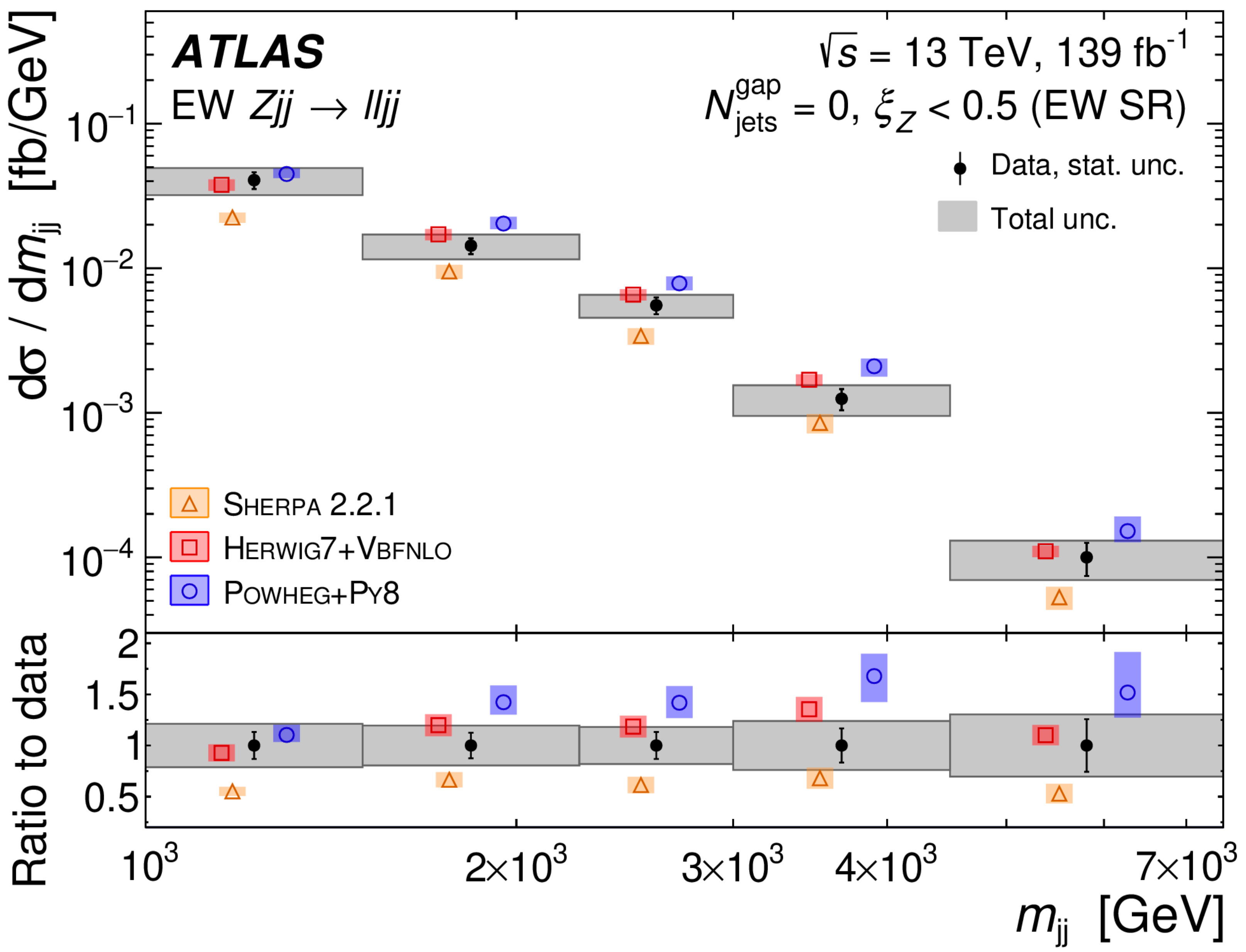


Vector boson fusion

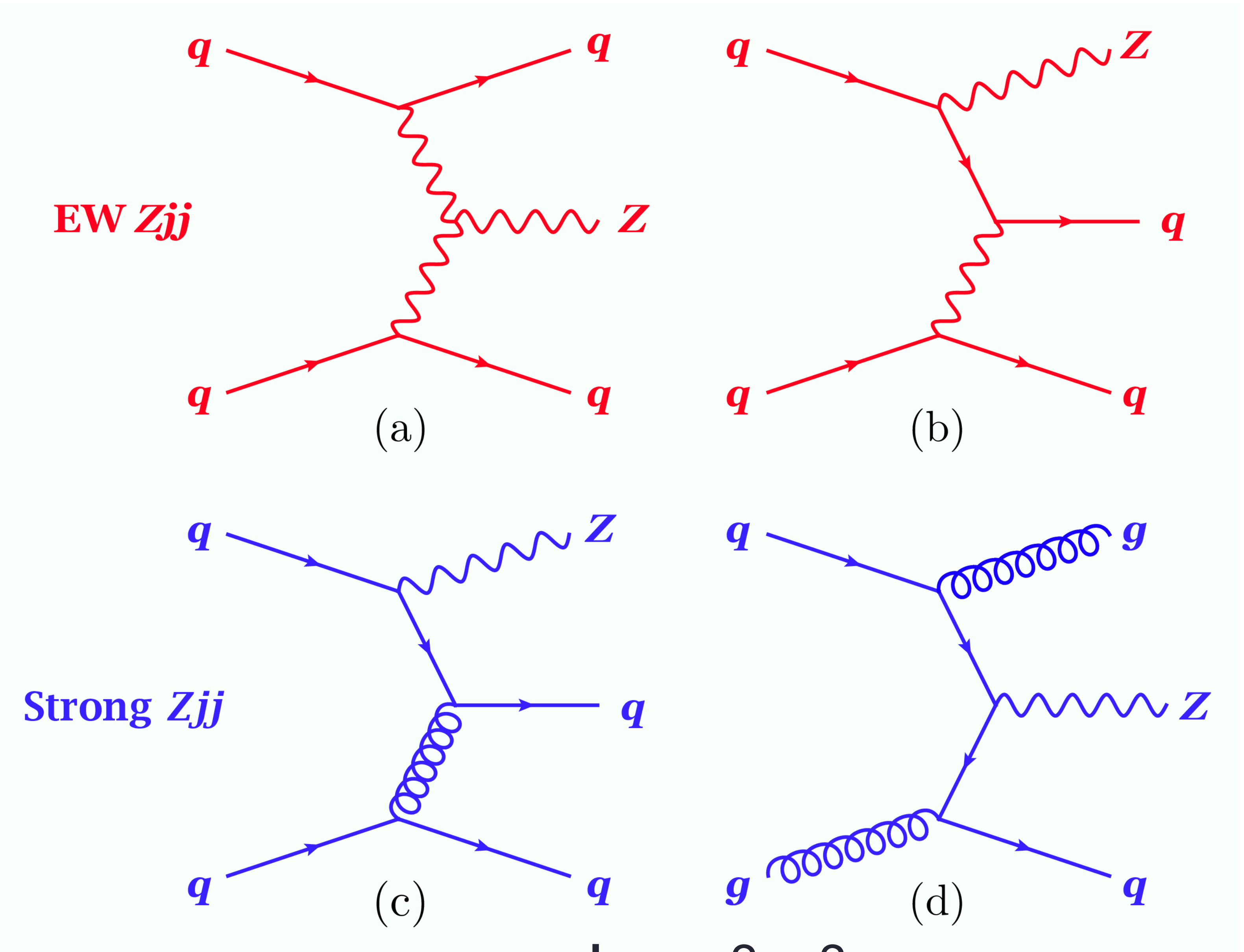
- **Zjj analysis**
  - signal vs. bkg with N_{jets} in Δy_{jj} gap and Z centrality
  - poor modeling —> data-driven QCD contribution
  - precise measurement to distinguish btw different predictions
  - sensitive to BSM —> EFT interpretation

arXiv:2006.15458





order α^4



order $\alpha^2\ \alpha_s^2$

Wilson coefficient	Includes $\lvert\mathcal{M}_{d6}\rvert^2$	95% confidence interval [TeV^{-2}] Expected	Observed	p-value (SM)
c_W/Λ^2	no	[−0.30, 0.30]	[−0.19, 0.41]	45.9%
	yes	[−0.31, 0.29]	[−0.19, 0.41]	43.2%
$\tilde{c}_W/\Lambda^2$	no	[−0.12, 0.12]	[−0.11, 0.14]	82.0%
	yes	[−0.12, 0.12]	[−0.11, 0.14]	81.8%
c_{HWB}/Λ^2	no	[−2.45, 2.45]	[−3.78, 1.13]	29.0%
	yes	[−3.11, 2.10]	[−6.31, 1.01]	25.0%
$\tilde{c}_{HWB}/\Lambda^2$	no	[−1.06, 1.06]	[0.23, 2.34]	1.7%
	yes	[−1.06, 1.06]	[0.23, 2.35]	1.6%

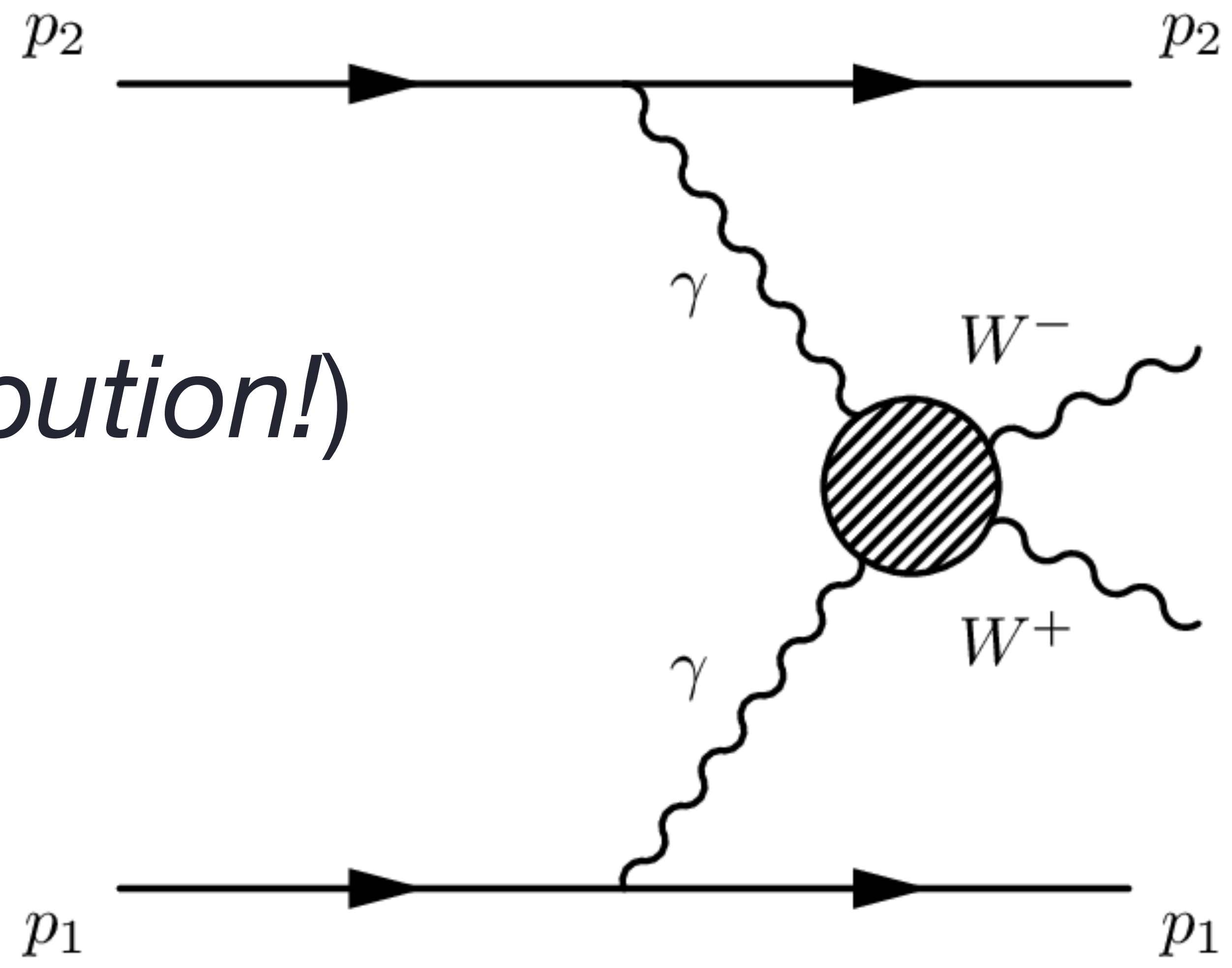
Photon collisions

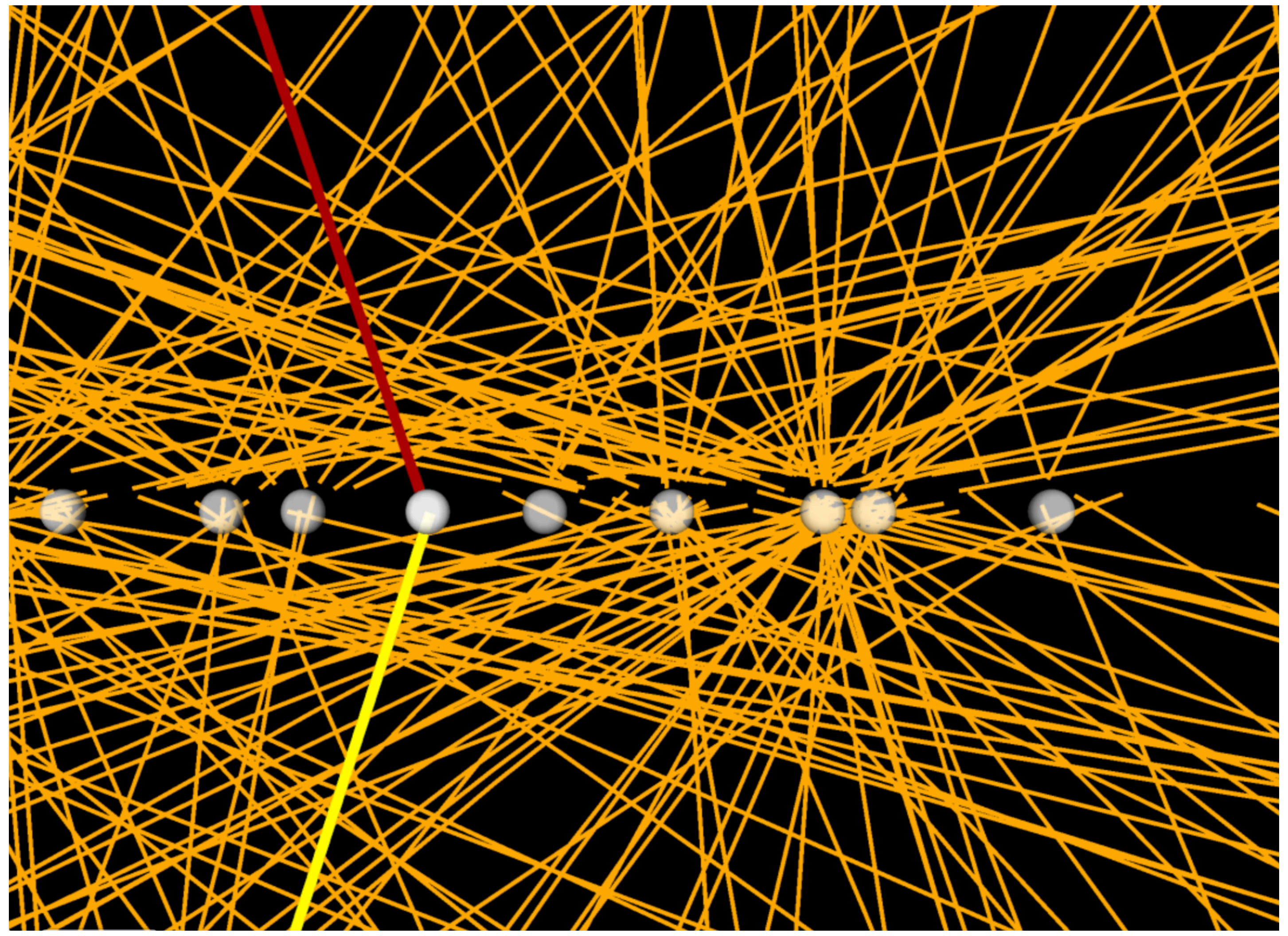
- Ultra-peripheral PbPb collisions: intense EM fields
  —> first observation of light-by-light scattering γγ —> γγ

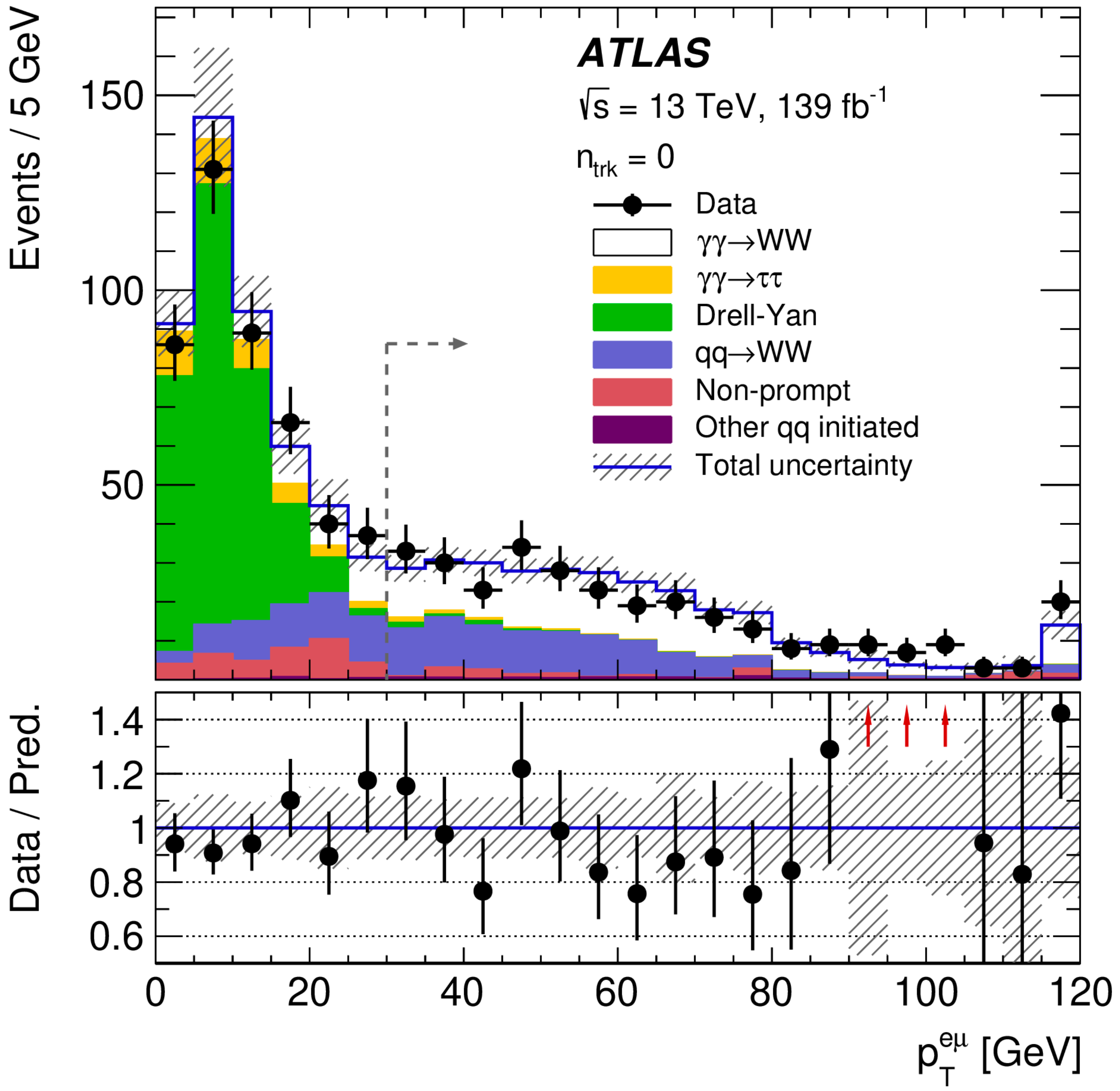
- **Two-photon interactions** in pp collisions: arXiv:2010.04019
  study of EW gauge structure in pure EW process (*no QCD contribution!*)

  - pp —> $p^{(*)}$ (γ γ —> W^+W^-) $p^{(*)}$, with W —> eν and W —> μν

  - signal: absence of fragmentation products at pp vtx







$$\sigma = 3.13 \pm 0.31\ \text{(stat)} \pm 0.28\ \text{(syst)}\ \text{fb}$$

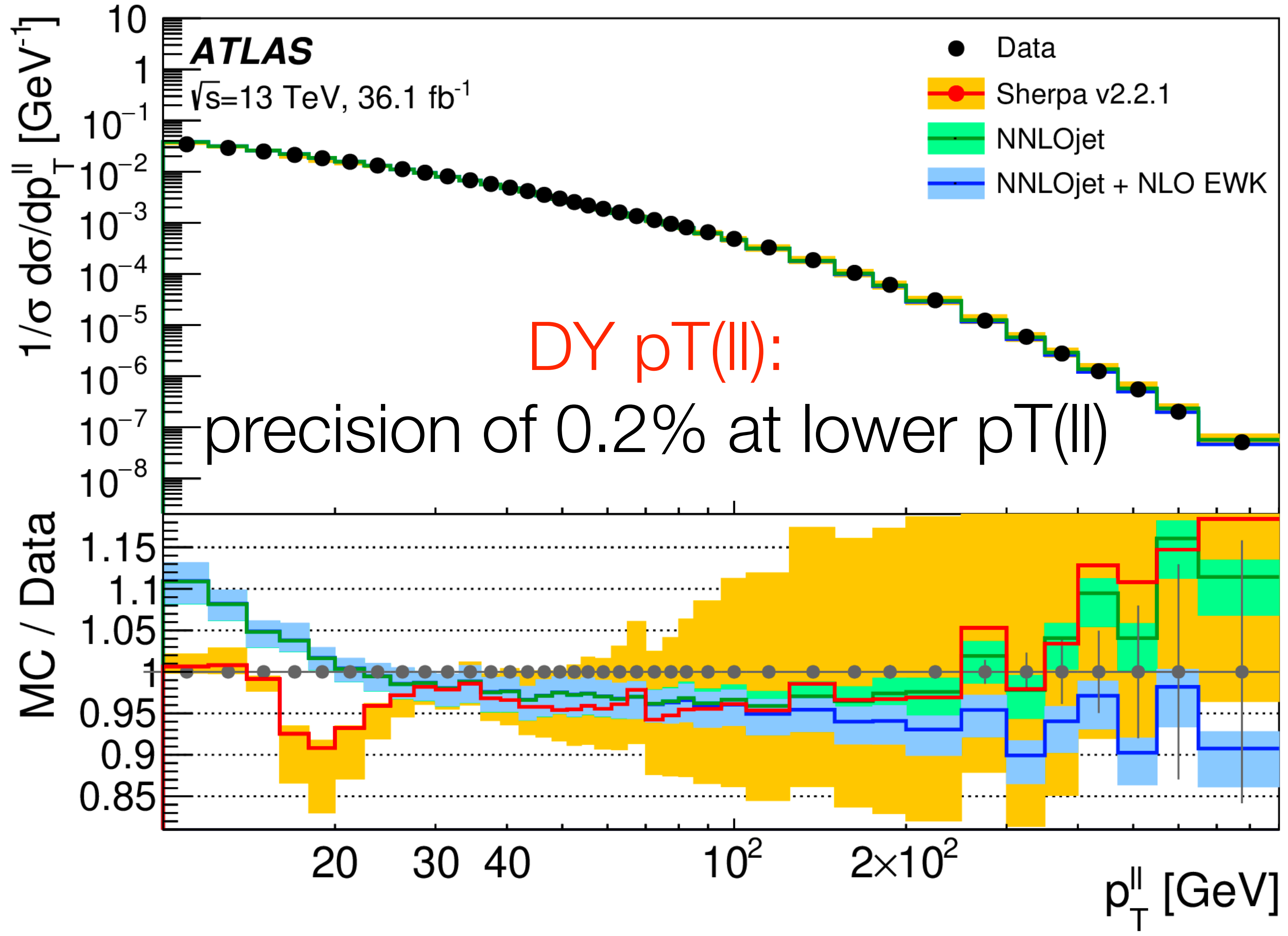
in agreement with predictions

first observation:
significance above 8 σ

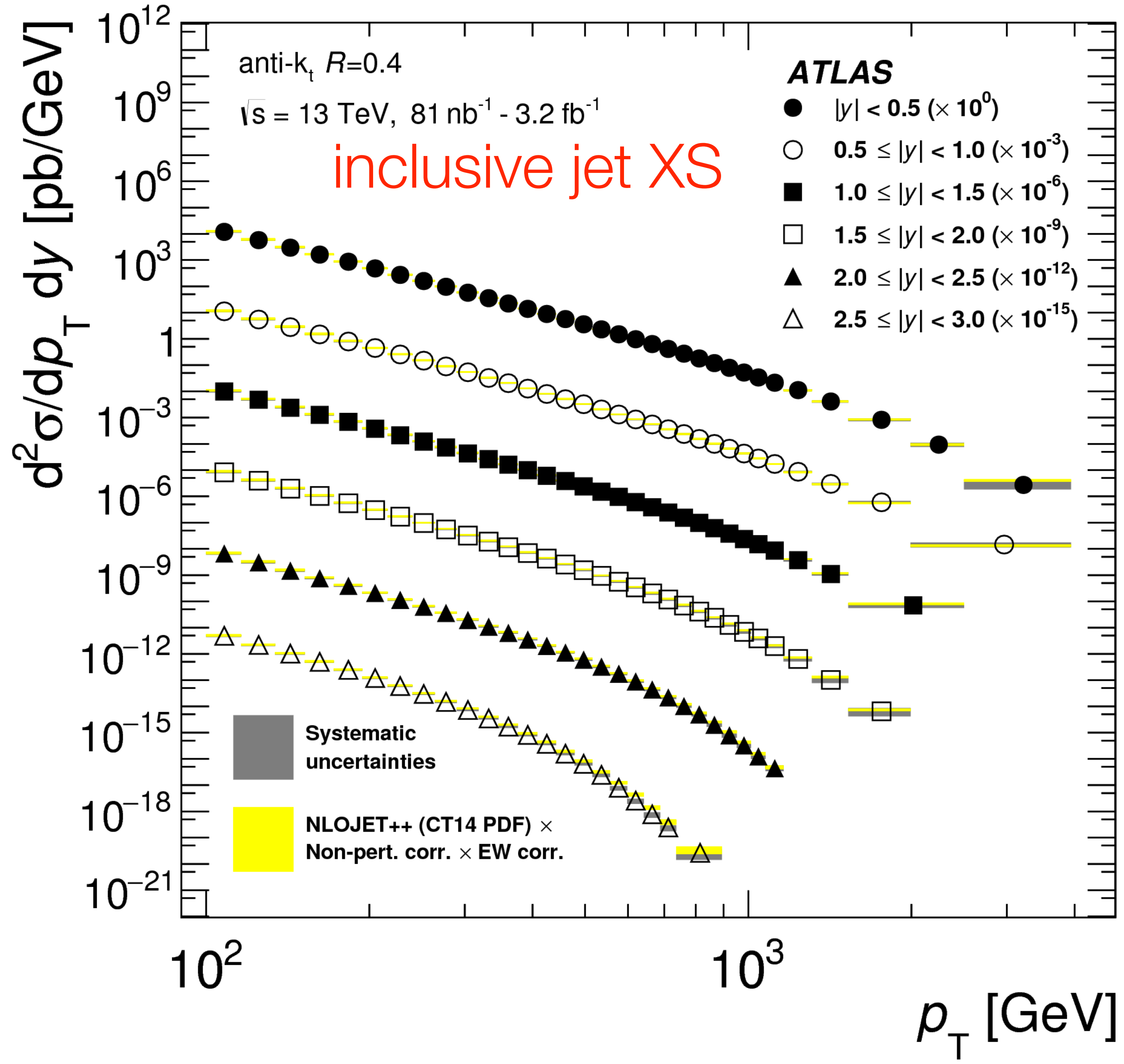
Perturbative QCD tests / Modeling of SM processes

- **Precise cross section** measurements for (di)jets, γ / W / Z / top + jets, etc.
- Confront model predictions with higher order QCD and EW corrections against data
- Sensitivity to parton distribution functions
- Improving understanding of SM processes also crucial for many searches

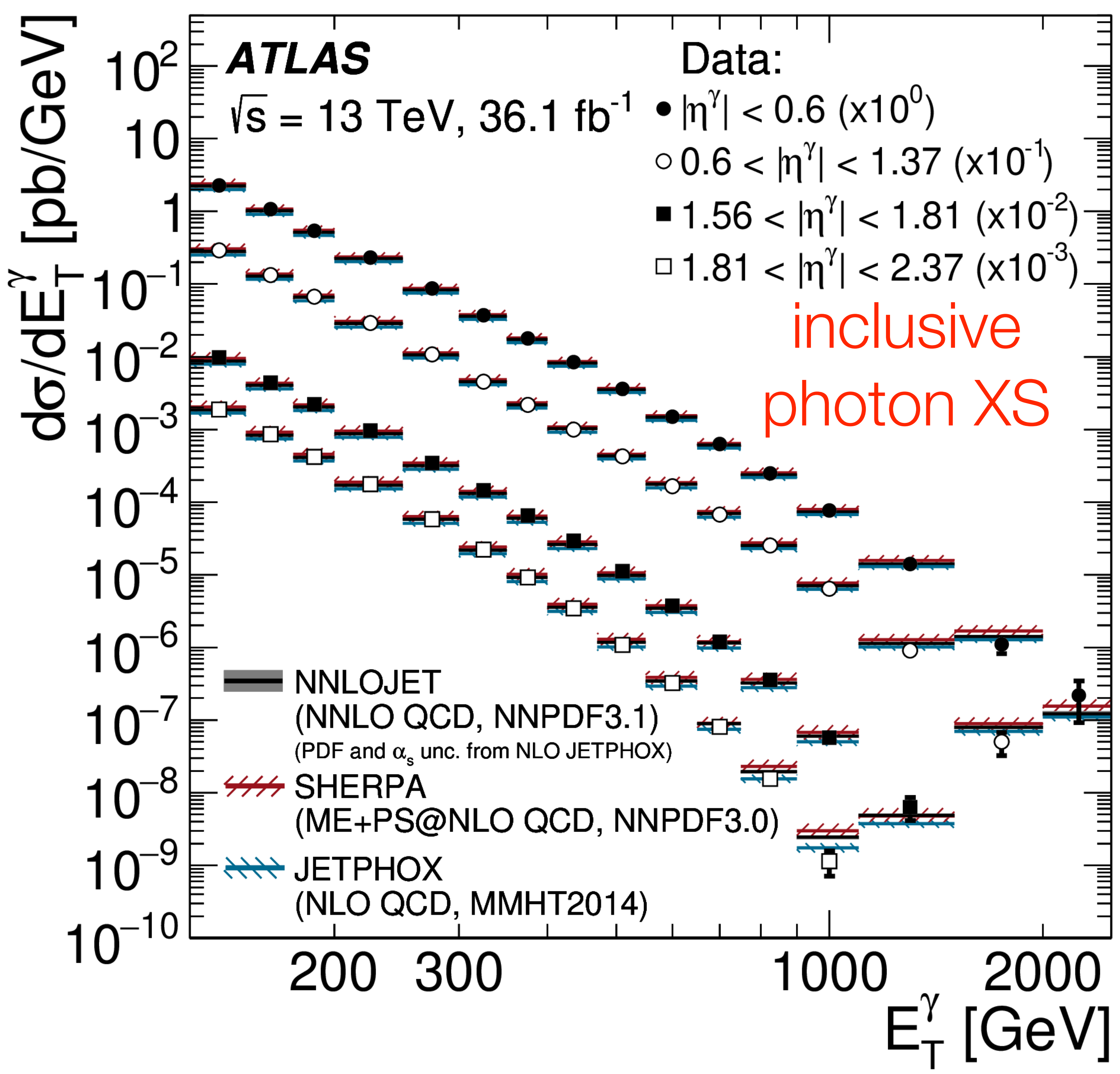
arXiv:1912.02844

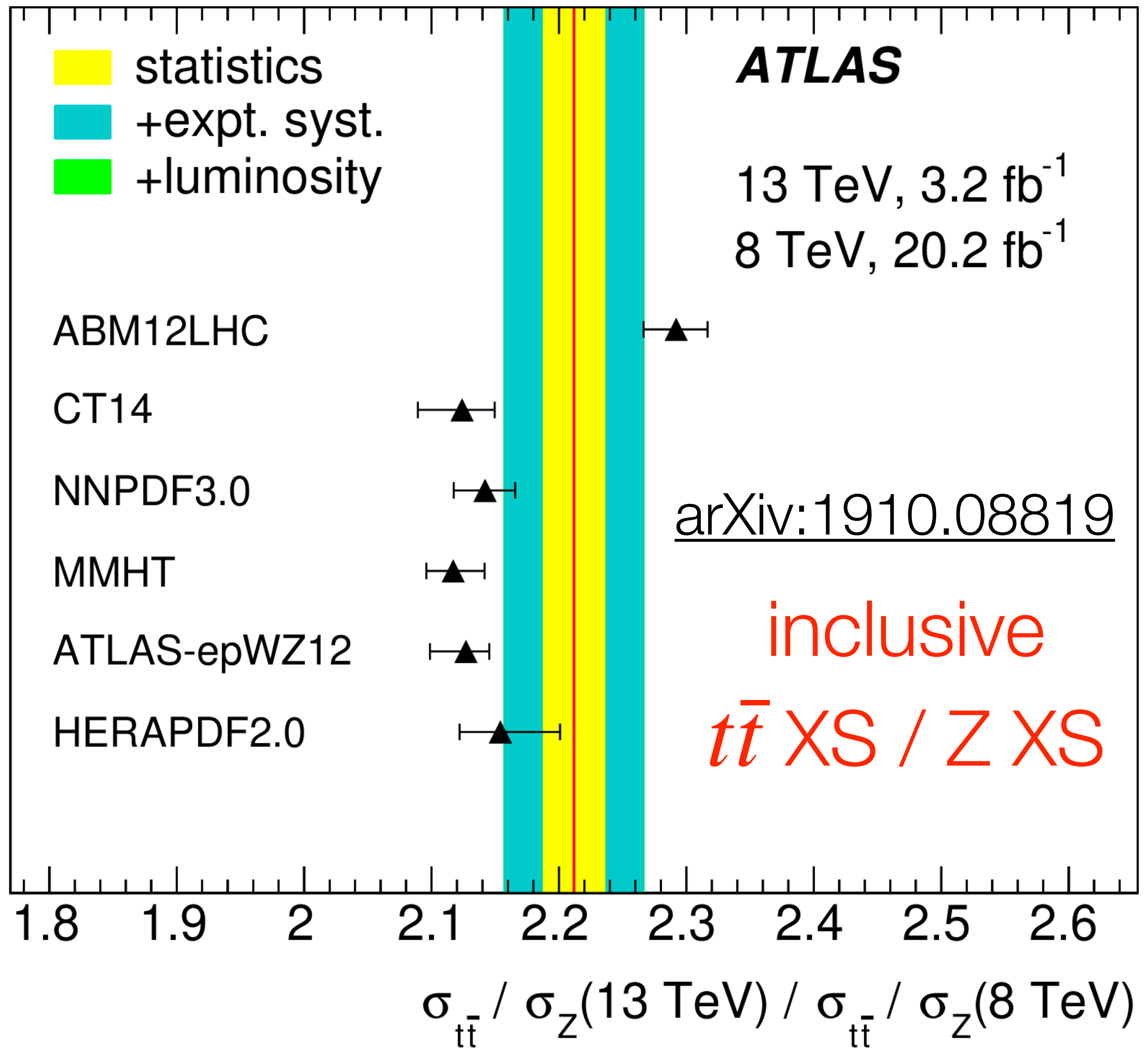


arXiv:1711.02692



arXiv:1908.02746





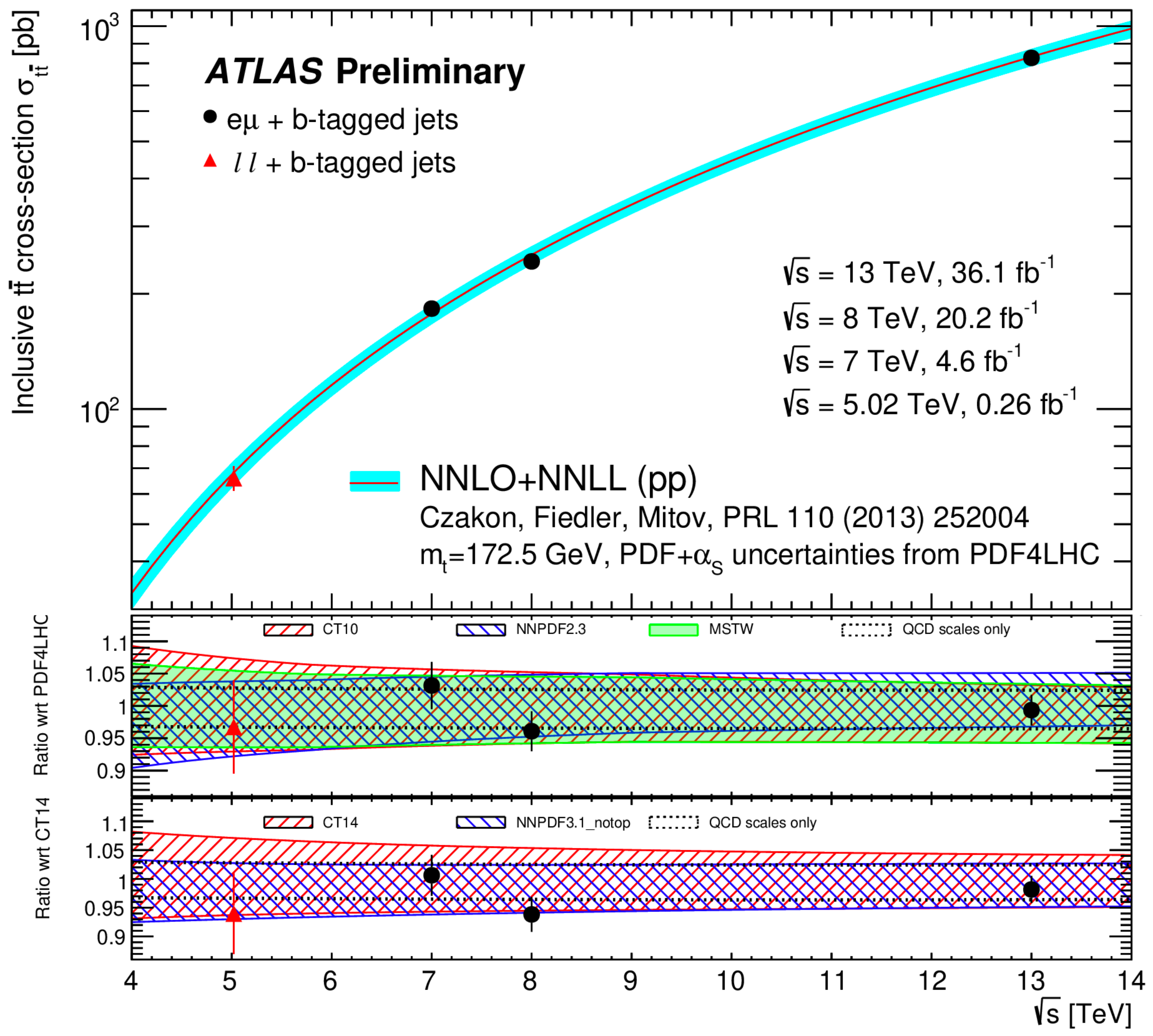
Top quark production

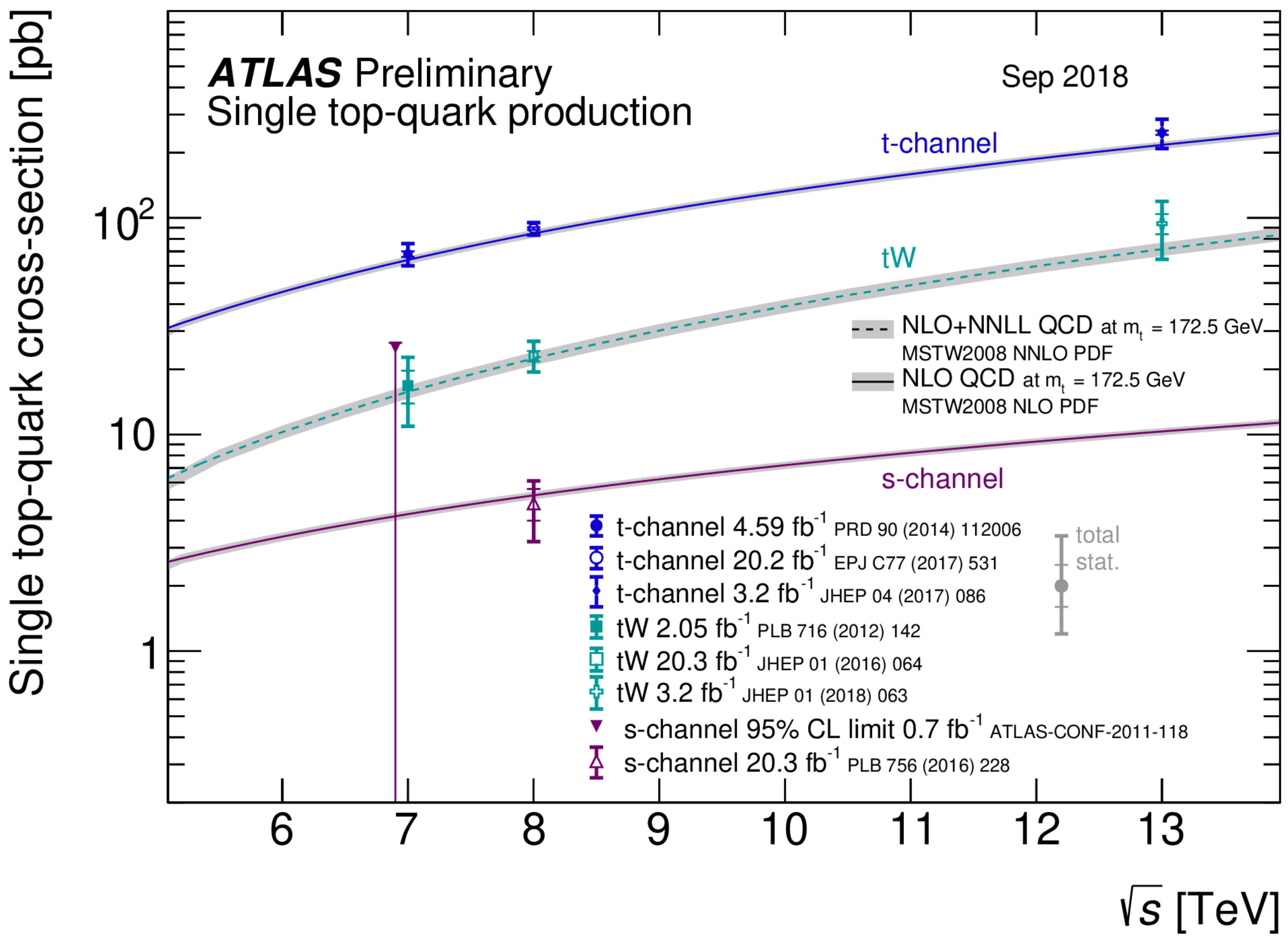
- Heaviest known particle: mass m_t ~172 GeV, Yukawa coupling y_t ~ 1; no hadronization
- **Inclusive tt and single-t cross sections** in good agreement w/ NNLO+NNLL predictions
- tt: l+jets measurement $\sigma_{t\bar{t}}^{1\ell} = 830 \pm 0.4\ (\text{stat}) \pm 36\ (\text{syst}) \pm 14\ (\text{lumi})\ \text{pb}$ 139 fb^{-1} @13 TeV

  4.5% syst. unc. from modeling and JES

  eμ measurement $\sigma_{t\bar{t}}^{e\mu} = 826.4 \pm 3.6\ (\text{stat}) \pm 11.5\ (\text{syst}) \pm 15.7\ (\text{lumi})\ \text{pb}$ 36 fb^{-1} @13 TeV

  2.4% syst. unc. from luminosity



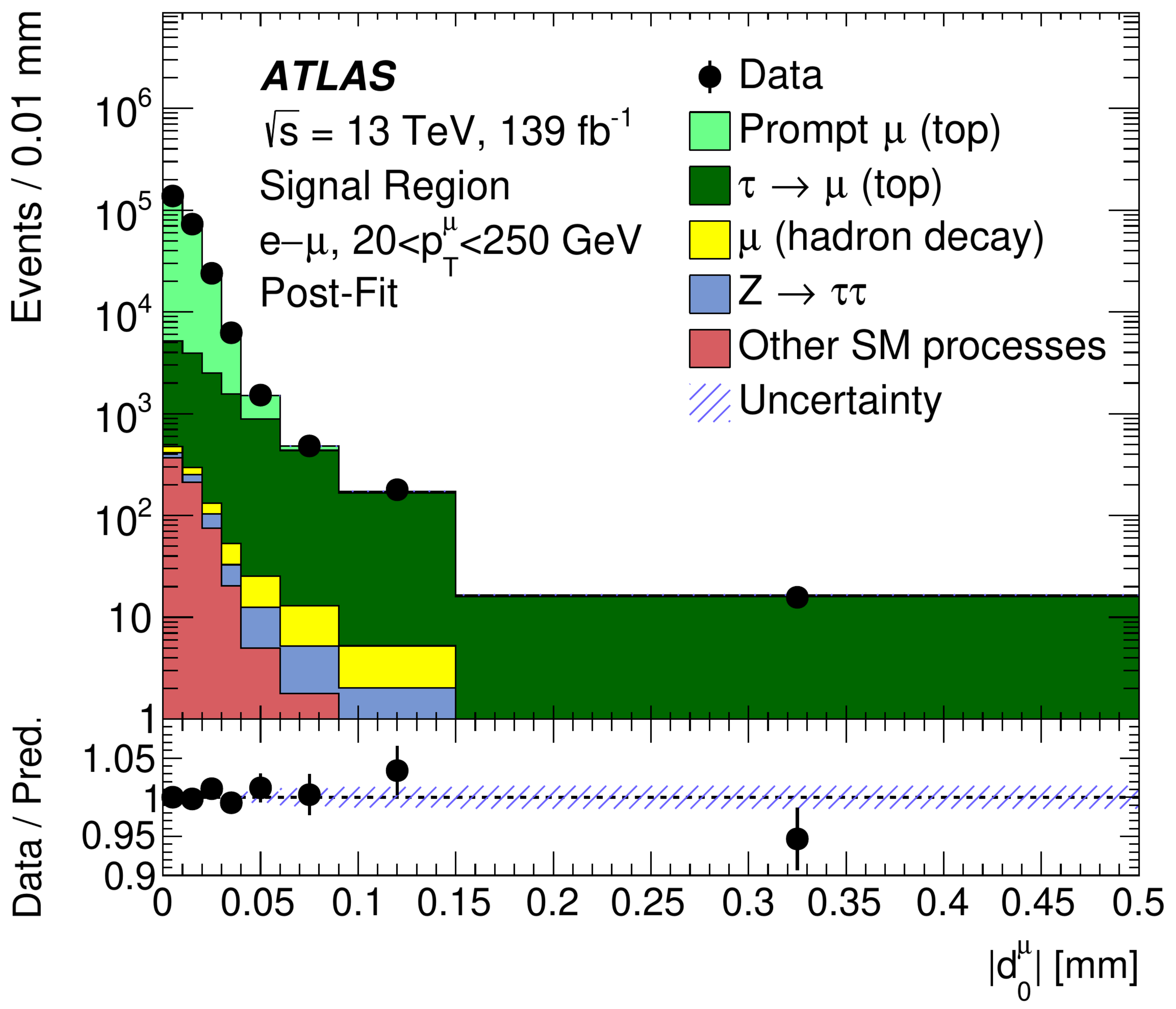


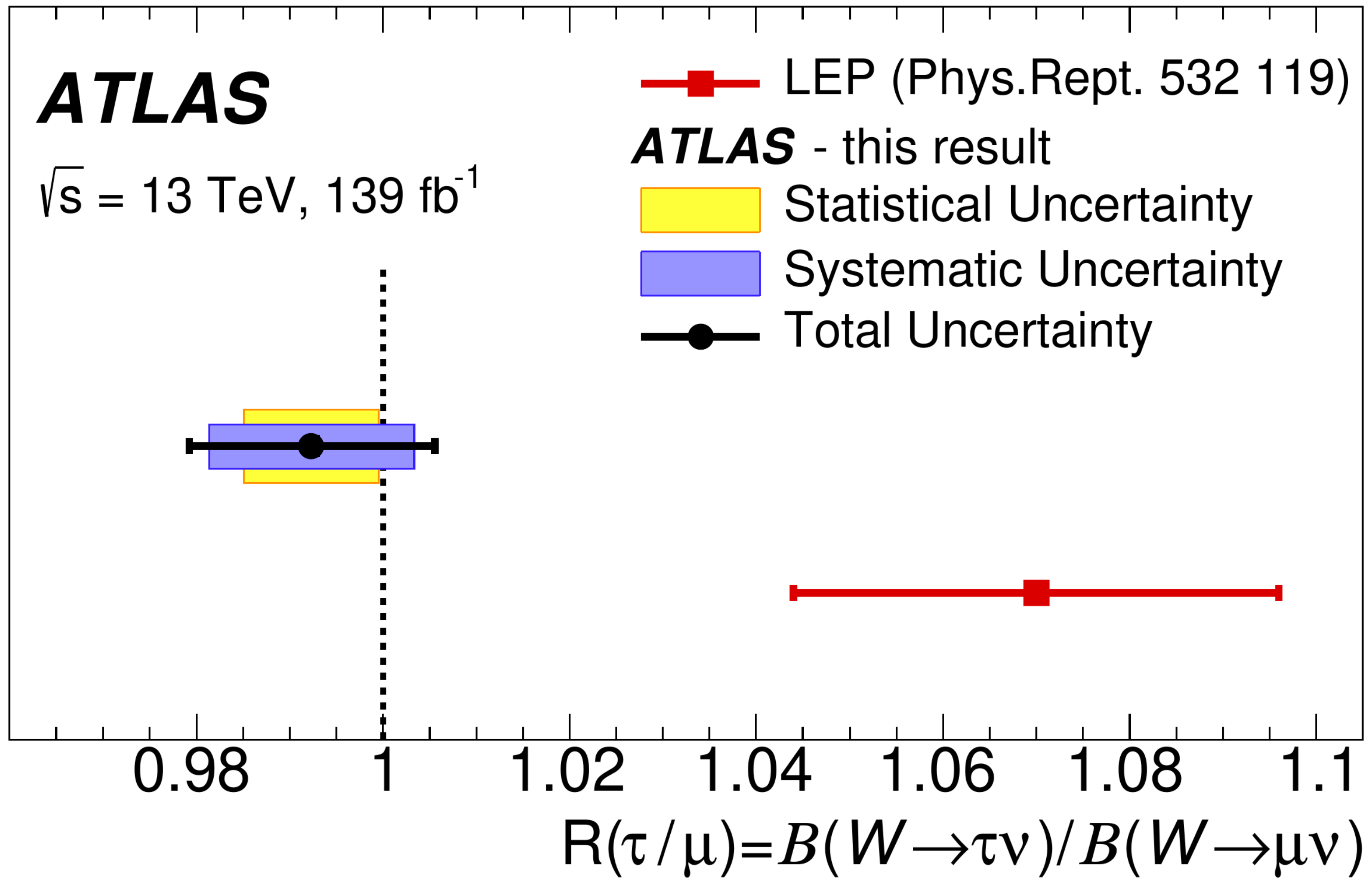
Top as a W factory: $B(W \to \tau\nu)/B(W \to \mu\nu)$

- Large sample of $t\bar{t}$ events —> abundant source of W-pair production

arXiv:2007.14040

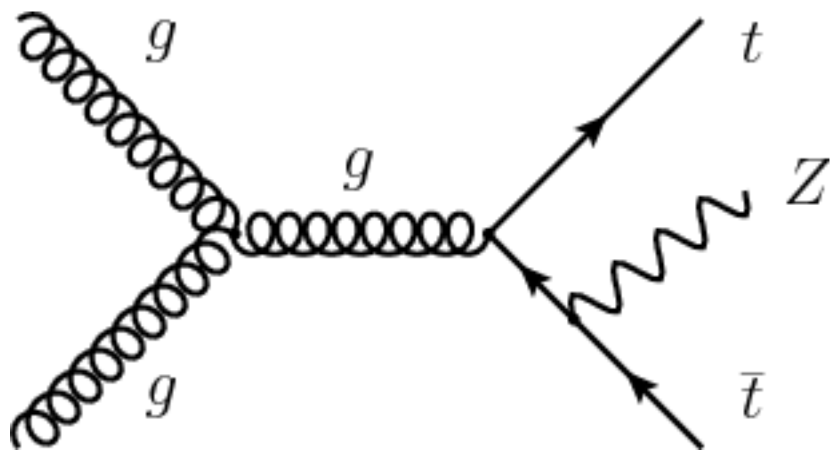
- Tag: $t \to bW \to b\ell\nu$ trigger on ℓ = e or μ
- Probe: $t \to bW$, with either $W \to \mu\nu$ or $W \to \tau\nu$ with $\tau \to \mu\nu\nu$
- Muon impact parameter and pT distributions discriminate btw two W decay modes
- Improved test of lepton flavor universality at 1% level
- Resolves 2.7 σ discrepancy from LEP era





Top quark (rare) production

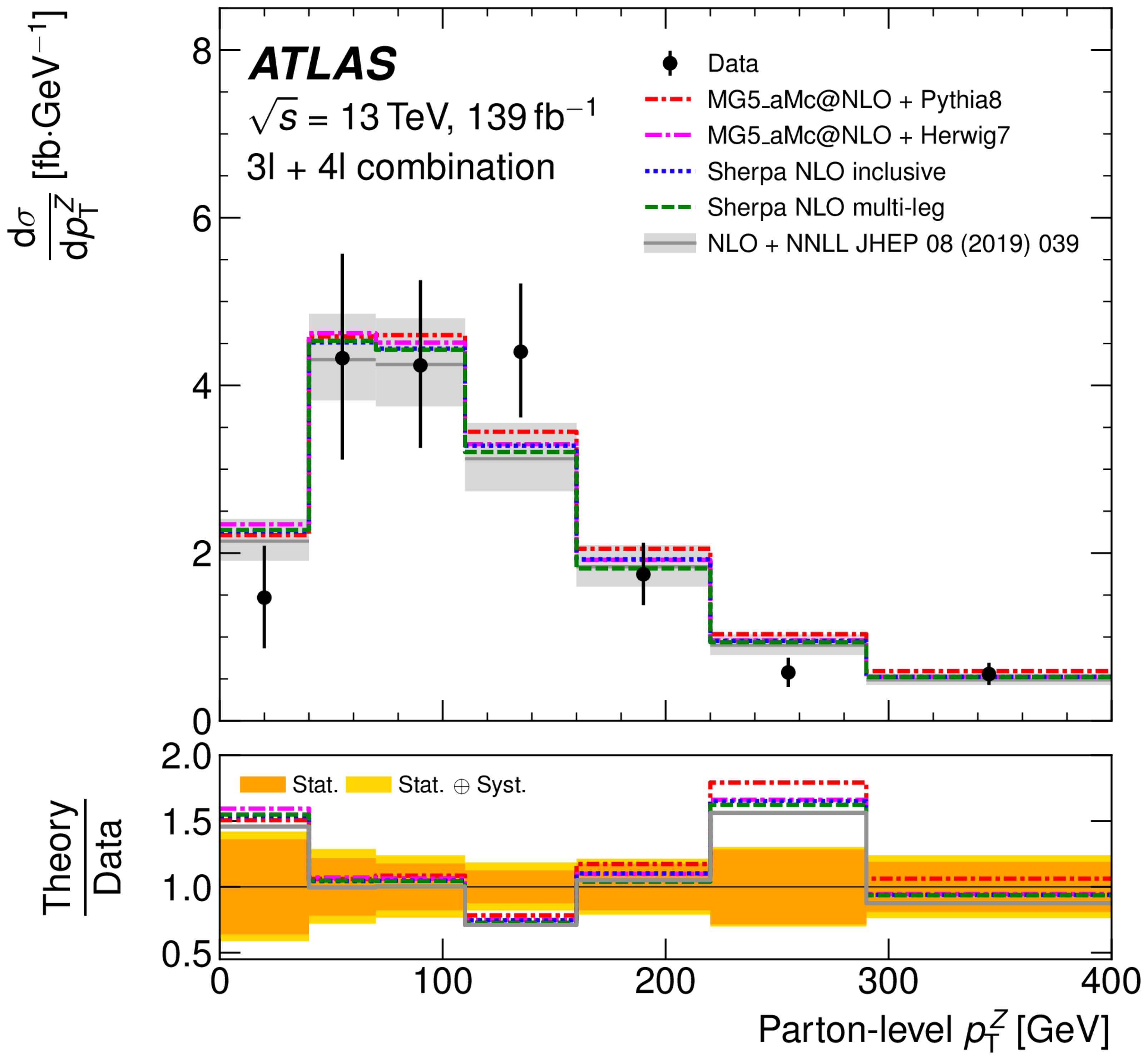
- **Measurement of t(t)+ γ / W / Z production** to test top-quark em / weak interaction



- ttZ example
  - measure

$$\sigma = 0.99 \pm 0.05(\text{stat}) \pm 0.08(\text{syst})\ \text{pb}$$

agree with NLO QCD and EW $\sigma^{\text{th}} = 0.84^{+0.09}_{-0.10}$ pb



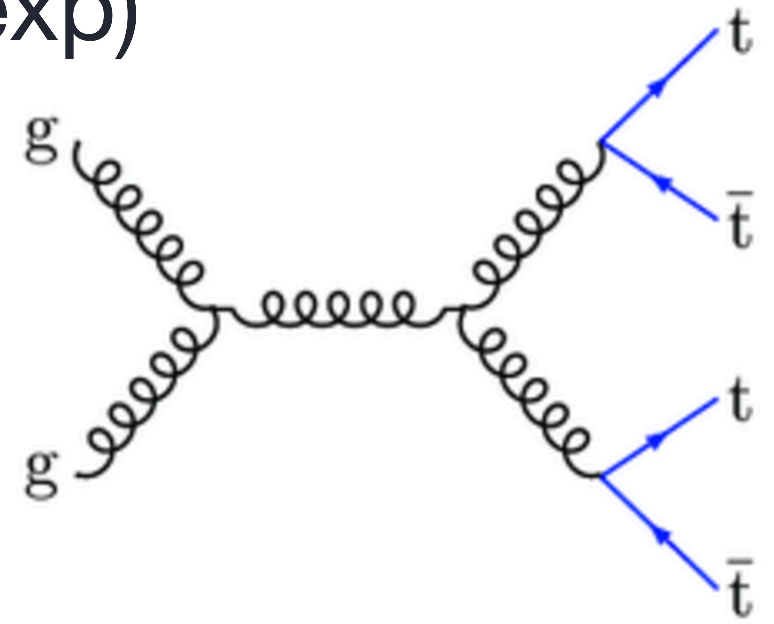
arXiv:2103.12603

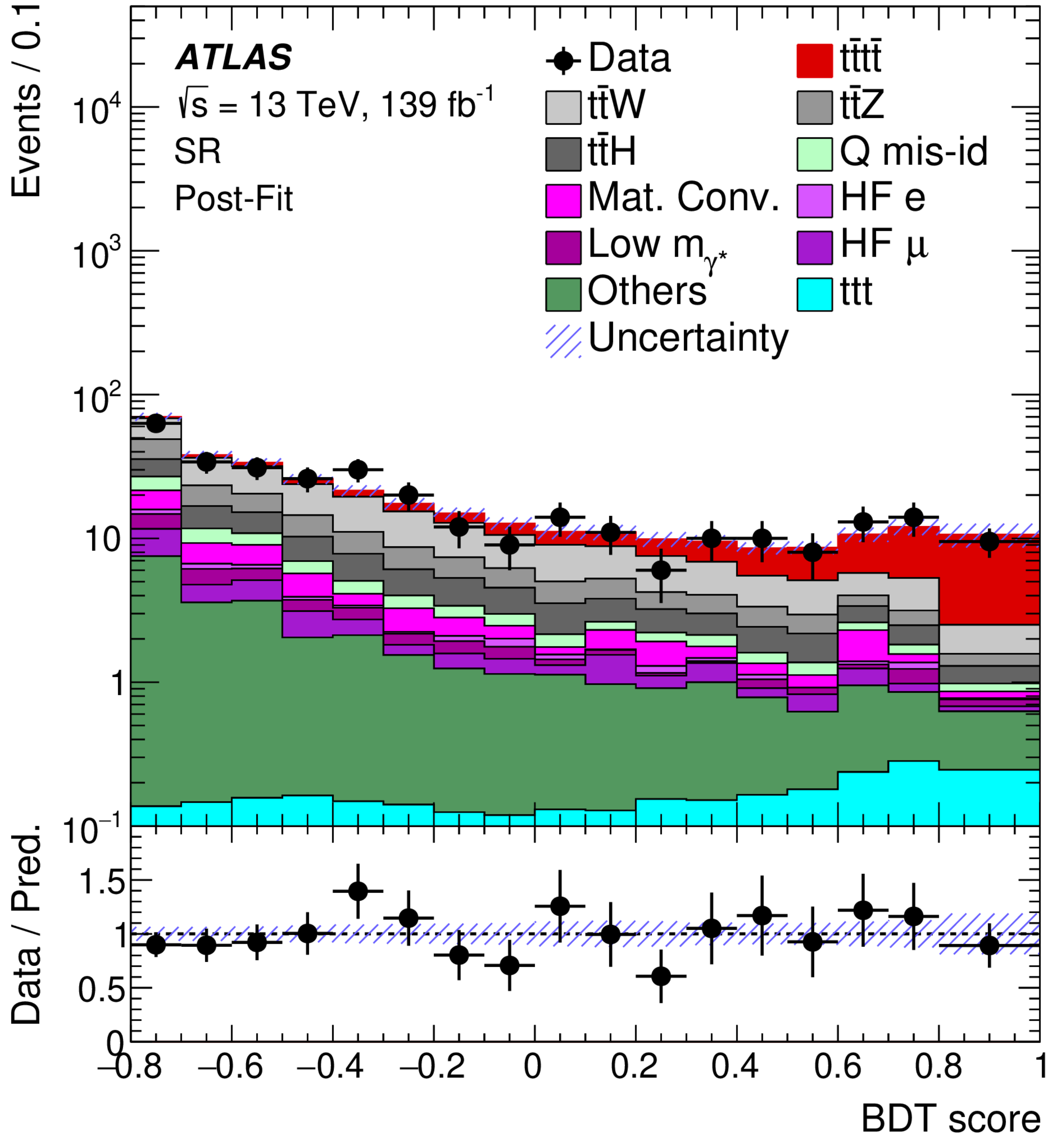
- **Measurement of $t\bar{t}t\bar{t}$ production** —> sensitive to top Yukawa & BSM
  - significance: 4.3 σ obs (2.4 σ exp)

$$\sigma = 24 \pm 5\ (\text{stat})^{+5}_{-4}\ (\text{syst})\ \text{fb}$$

agree with NLO QCD and EW

$$\sigma^{\text{th}} = 12.0 \pm 2.4\ \text{fb}$$

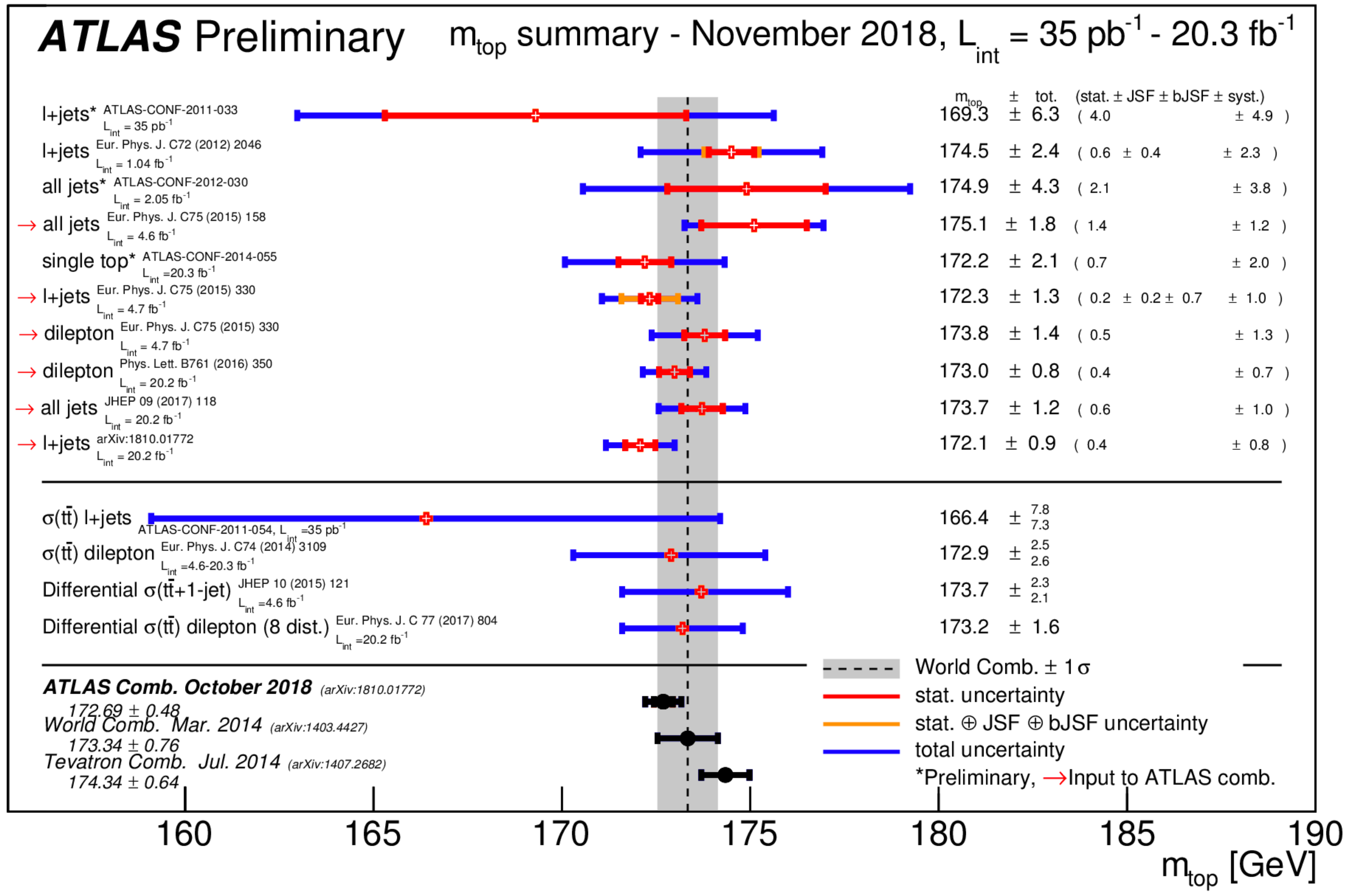




arXiv:2007.14858

Top quark properties

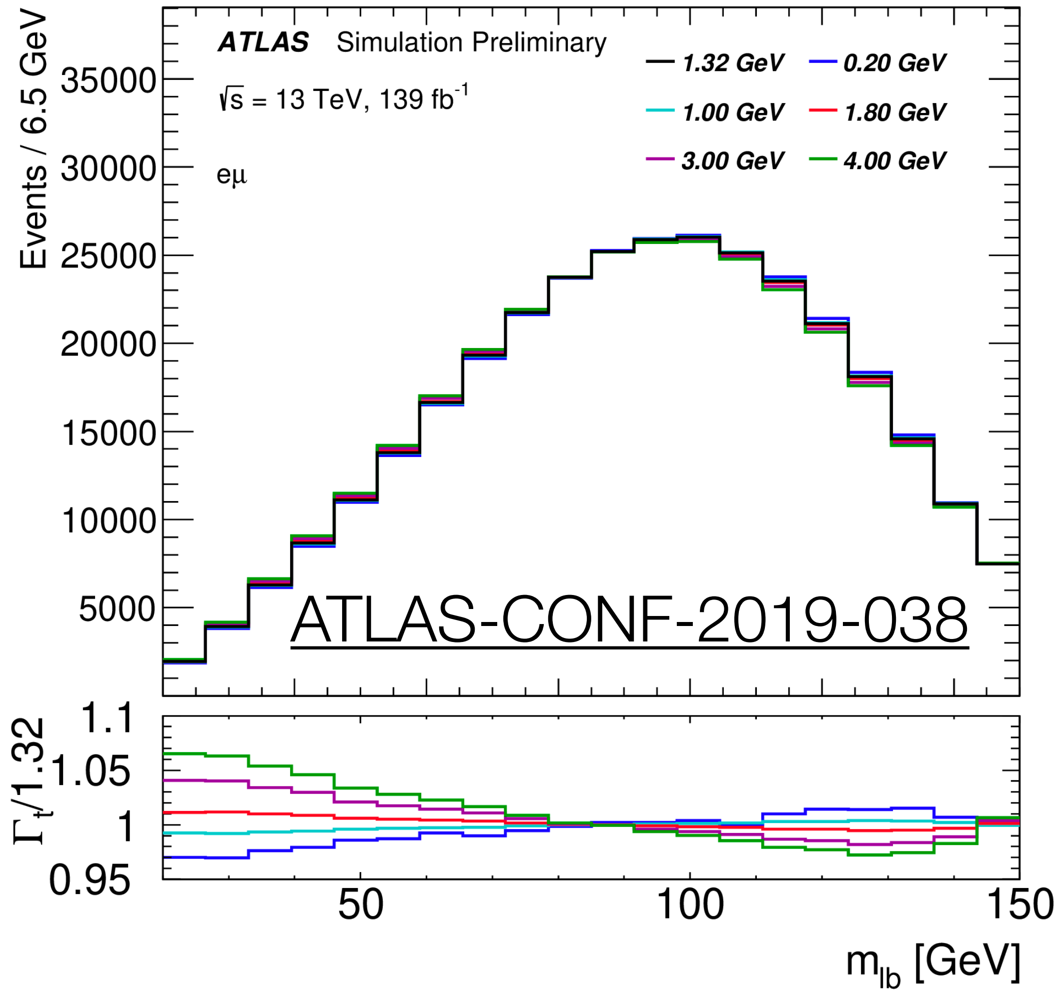
- **Top mass**: fundamental property, important for internal consistency tests of SM

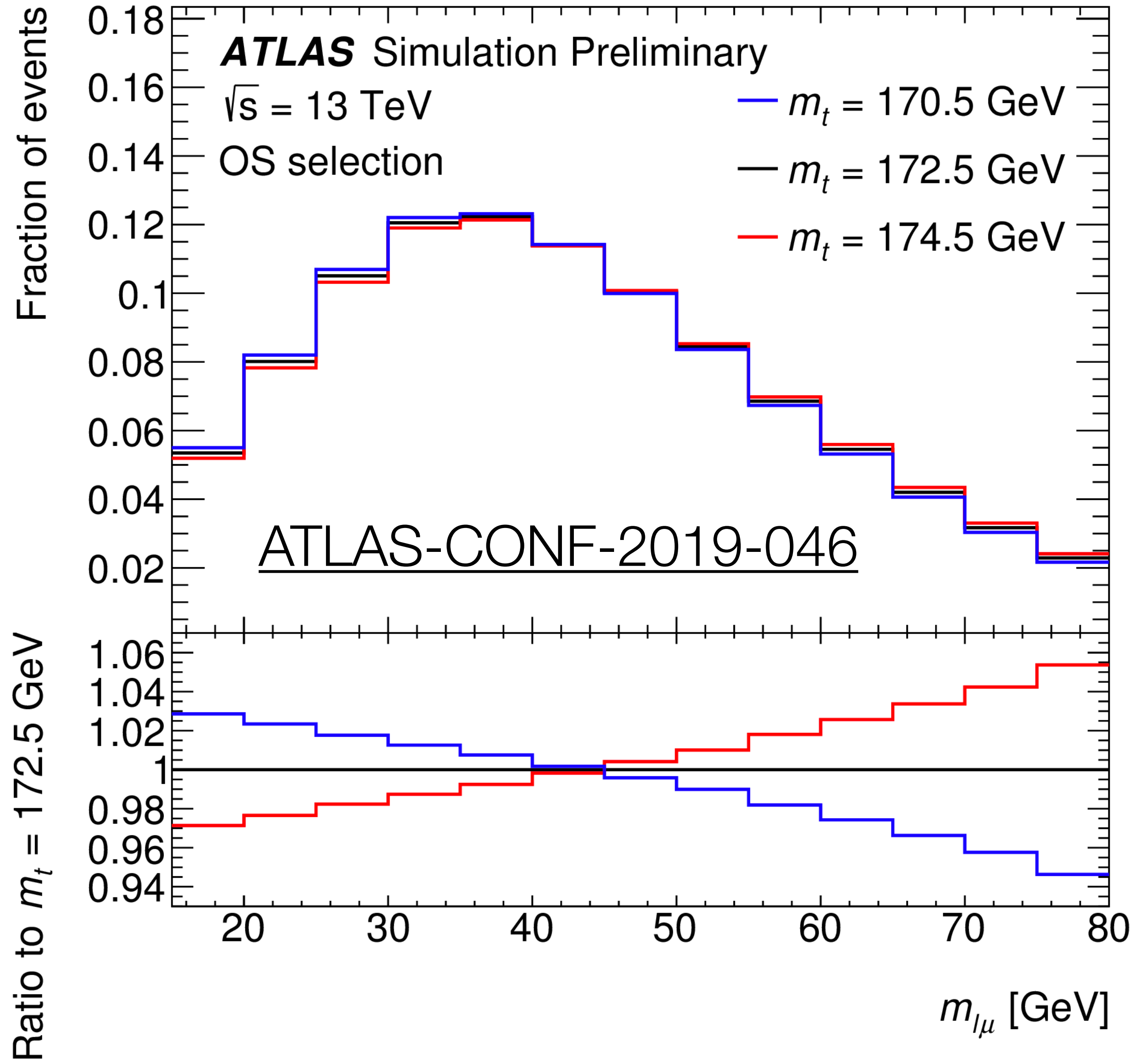


  - soft-muon tag analysis
    - sensitive variable: dilepton mass (1e/μ from W decay, 1μ from b-hadron) to reduce jet calibration unc.
    - b-/c-hadron modeling syst. unc. important

- **Top width:**
  —> sensitive to BSM
  - $\Gamma_t = 1.9 \pm 0.5$ GeV

  agree with expectation (1.32 GeV)





36 fb^{-1} @13 TeV

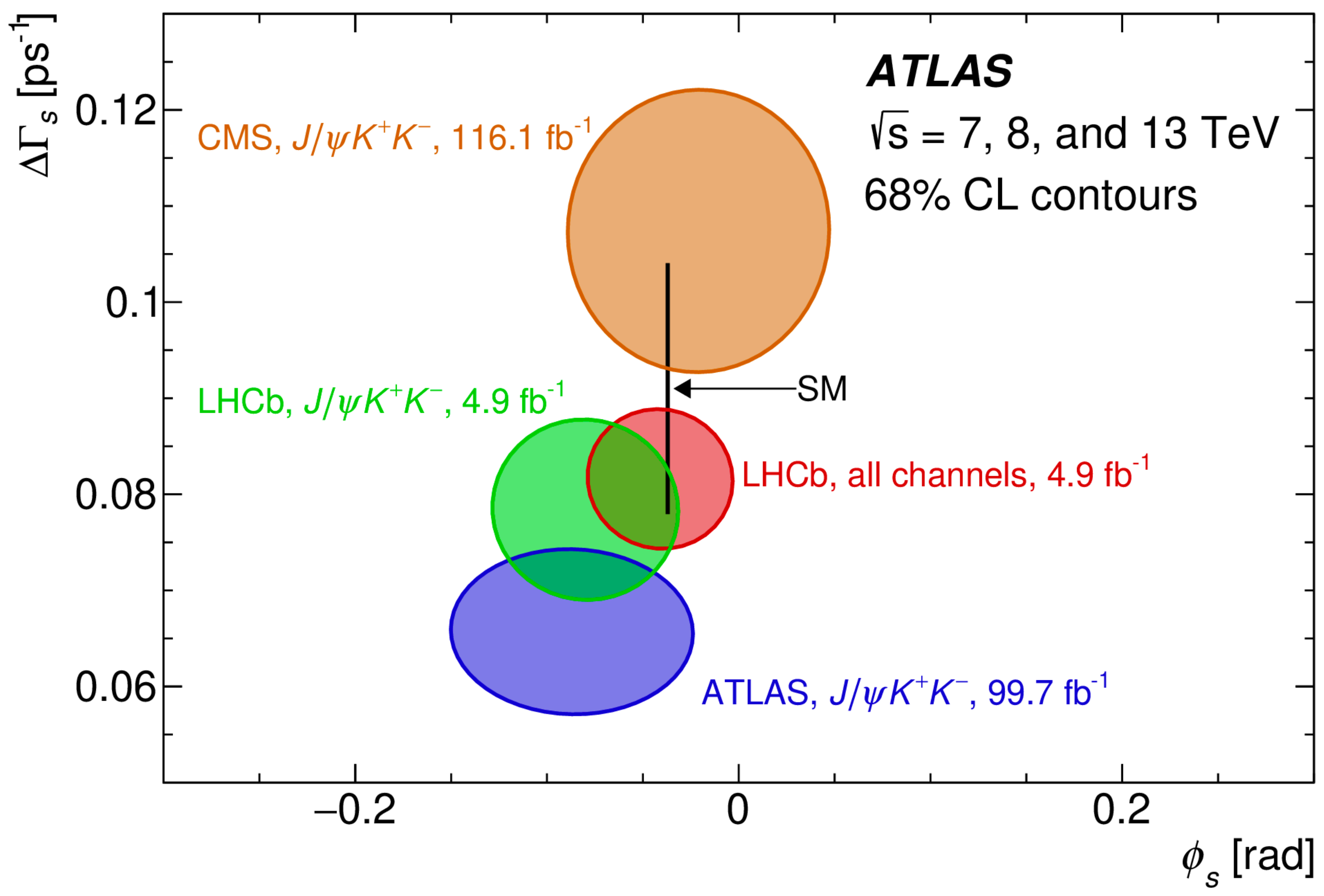
$$m_t = 174.48 \pm 0.40\,(\text{stat}) \pm 0.67\,(\text{syst})\ \text{GeV}$$

B physics

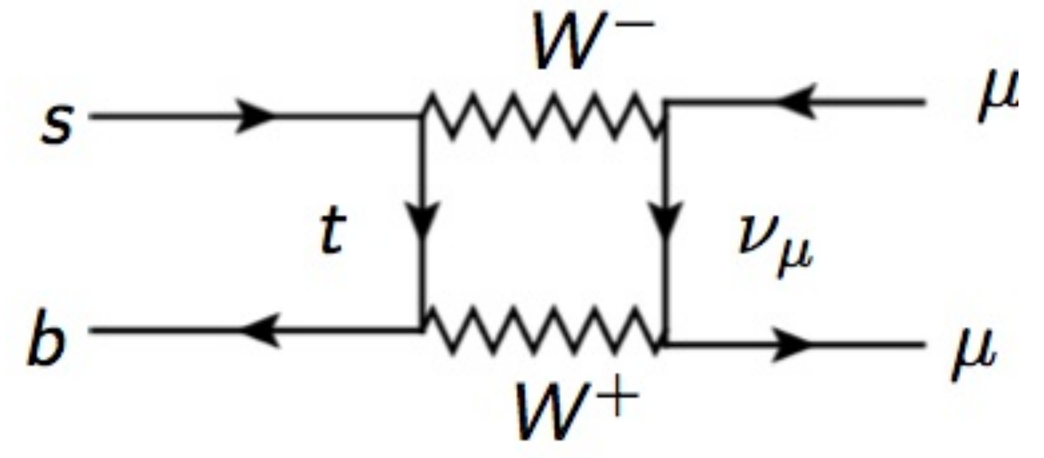
- Cross sections for J/psi production
- CP violation and rare b —> s transition measurements (relevant to lepton flavor universality): loop processes sensitive to BSM

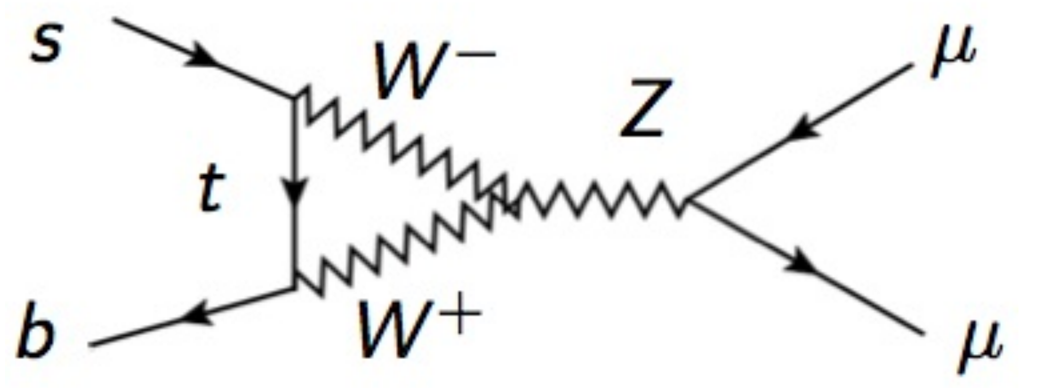
  - CPV in $B_s \rightarrow J/\psi\phi$ arXiv:2001.07115

$$\begin{aligned} \phi_s &= -0.087 \pm 0.036 \text{ (stat.)} \pm 0.021 \text{ (syst.) rad} \\ \Delta\Gamma_s &= 0.0657 \pm 0.0043 \text{ (stat.)} \pm 0.0037 \text{ (syst.) ps}^{-1} \\ \Gamma_s &= 0.6703 \pm 0.0014 \text{ (stat.)} \pm 0.0018 \text{ (syst.) ps}^{-1} \end{aligned}$$



- $B^0_{(s)} \rightarrow \mu^+\mu^-$





arXiv:1812.03017

$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = \left(2.8^{+0.8}_{-0.7}\right) \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) < 2.1 \times 10^{-10}$$

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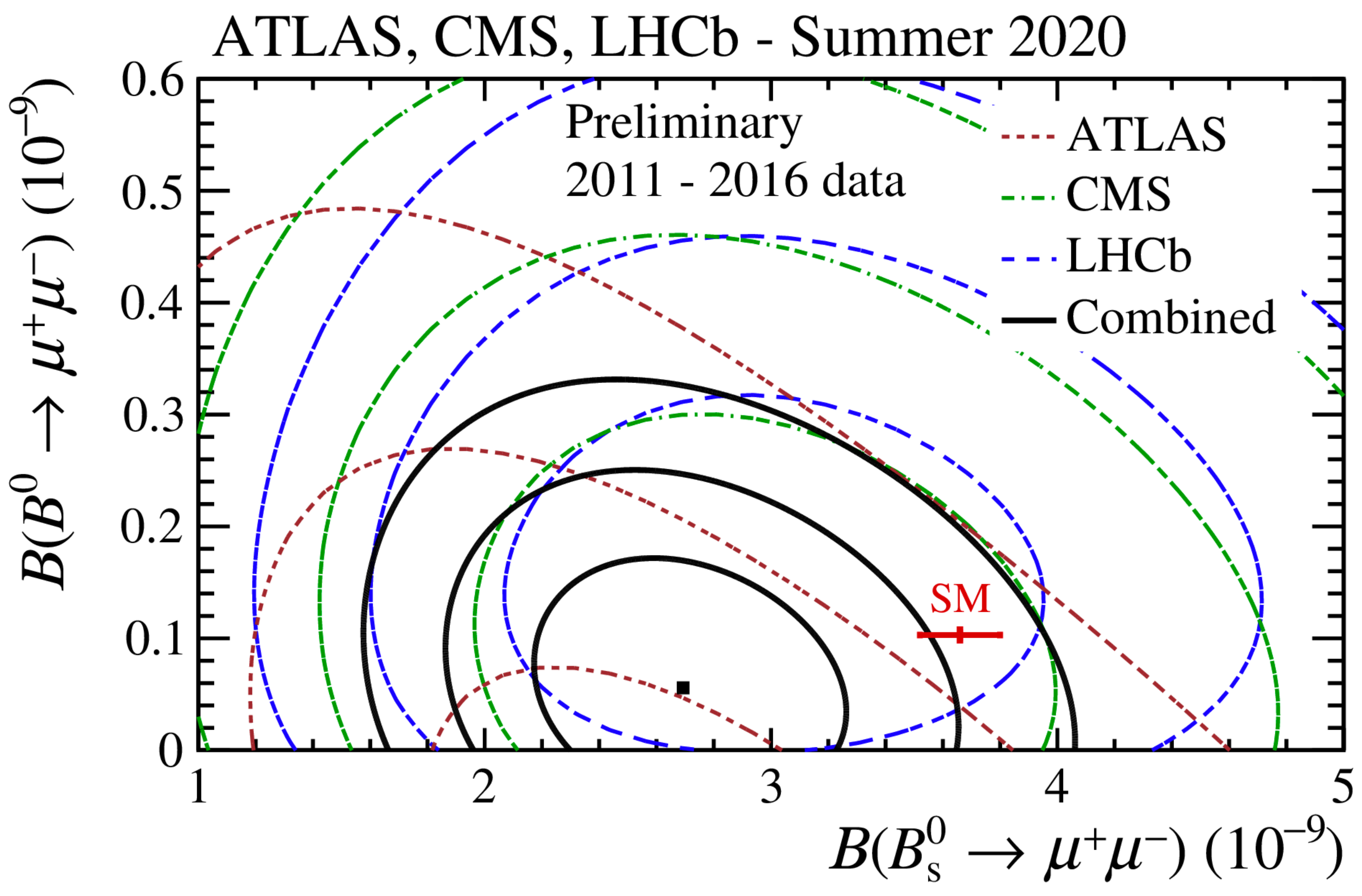
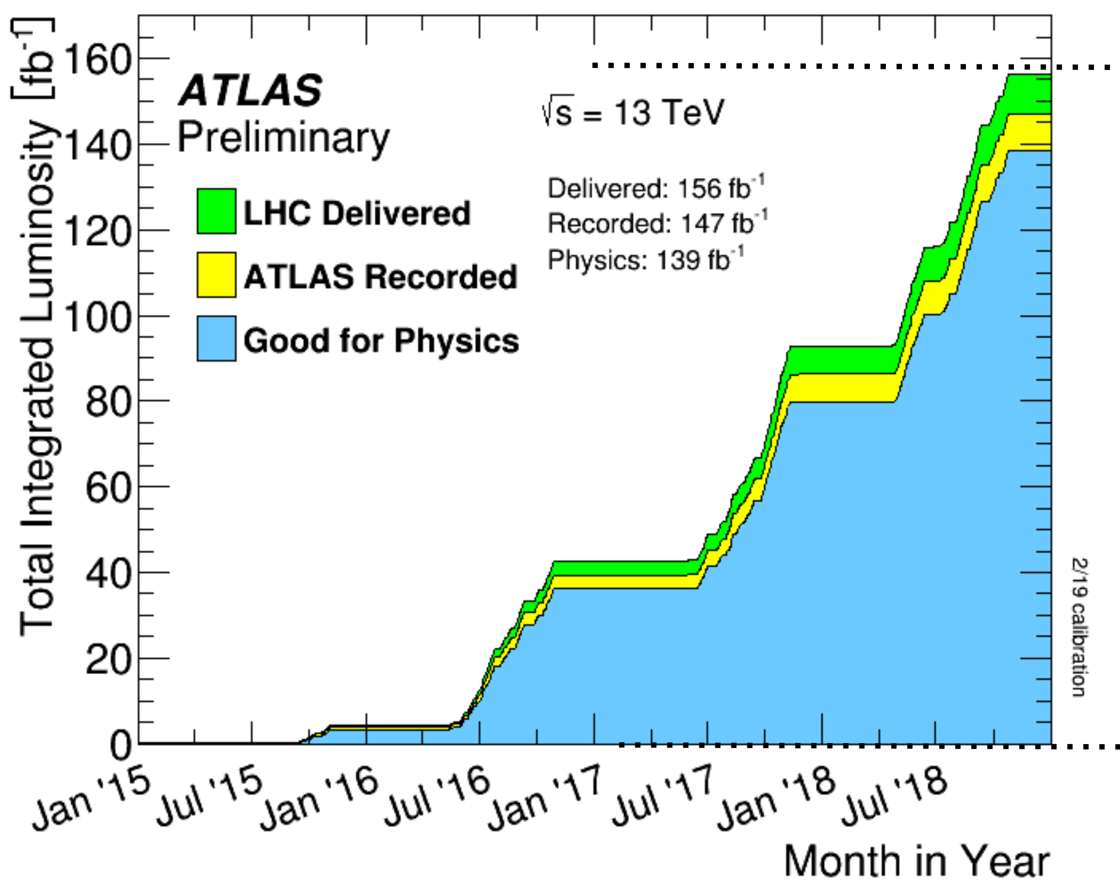


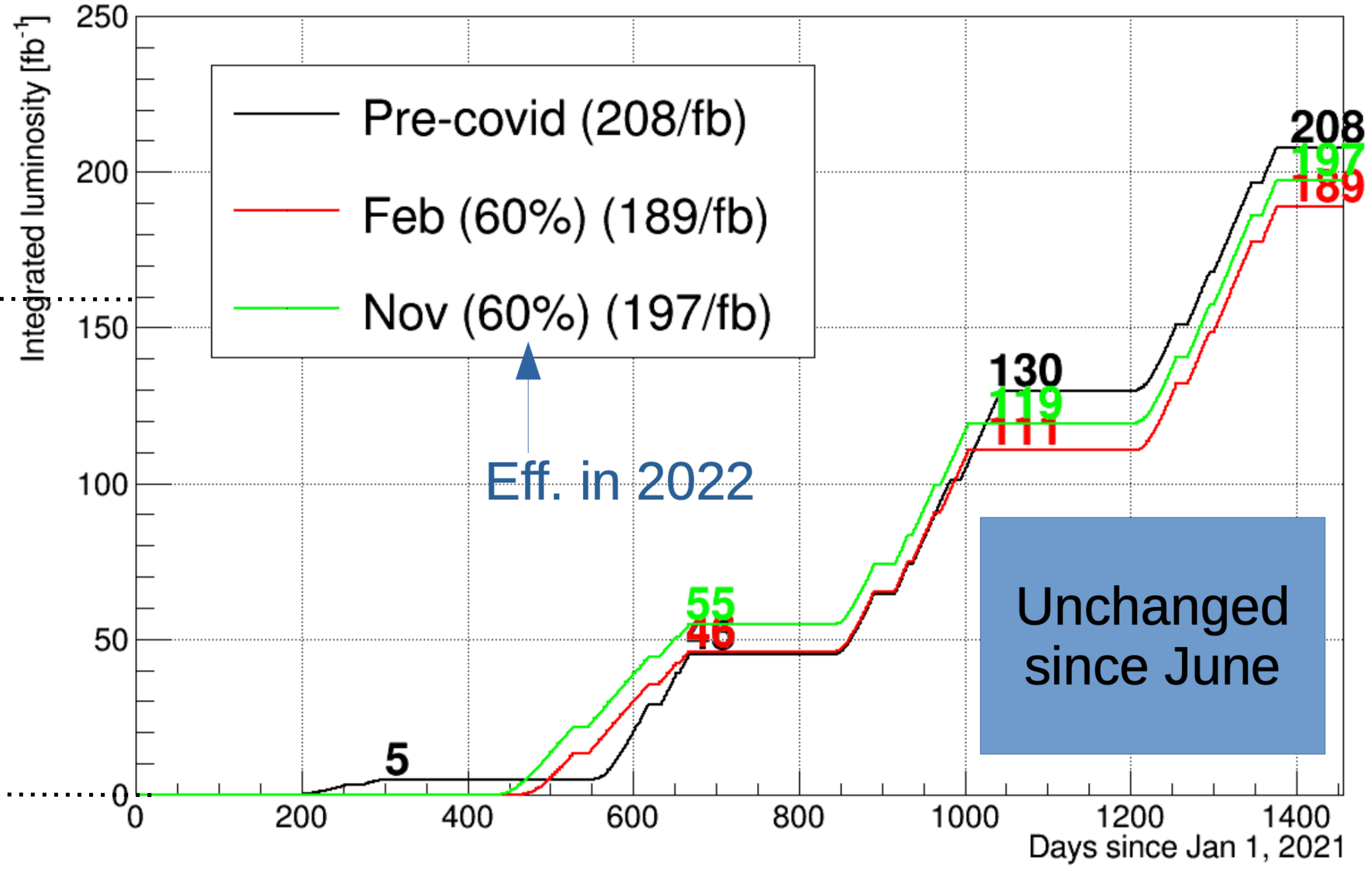
Looking ahead at Run 3

2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Run 2						magnet training + NSW	Run 3			

LS2

B. Petersen 7 Dec 2020





guesstimate: 160–220 fb^{-1} in Run 3

Beam energy to be decided after magnet training —> Sep 2021

Considerations for Run 3 physics

- At end of Run 3, the integrated luminosity for combined Runs 2 & 3 ~300-360 fb^{-1}
  i.e. factor of 2.0-2.5 increase over Run 2

- **Improvements expected on multiple fronts:**
  - trigger (open up new phase space or channels)
  - combined performance
  - analysis techniques / tools (e.g. ML, event generators)
  - new physics processes/channels or observables, expanded scope

What's new for ATLAS in Run 3?

ATLAS EXPERIMENT

- **Center of mass energy**
  - magnet training in 2021: hope for higher $\sqrt{s}$, up to 14 TeV
- **Trigger & detector system improvements**
  - L1Calo, L1Muon & NSW, and L1Topo
  - increased availability of full-scan tracking
  - AFP with time-of-flight
- **Further development of targeted trigger approaches**
  - trigger-level analysis
  - delayed stream
  - unconventional signatures

Challenges:
- increased pileup
- early commissioning

Summary / Outlook

- **Run 2 dataset: a goldmine for physics… to be extended with Run 3**
  - years of fruitful searches (more targeted) and measurements ahead
  - precision frontier to continue growing in importance (—> EFT fits)
  - further studies of rare processes
- Continue preparations for HL-LHC and 3-4 ab^{-1} @14 TeV

All ATLAS results available at
https://twiki.cern.ch/twiki/bin/view/AtlasPublic