

Highlight of recent ATLAS results

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14th Workshop of France China
Particle Physics Laboratory

7th of November 2023

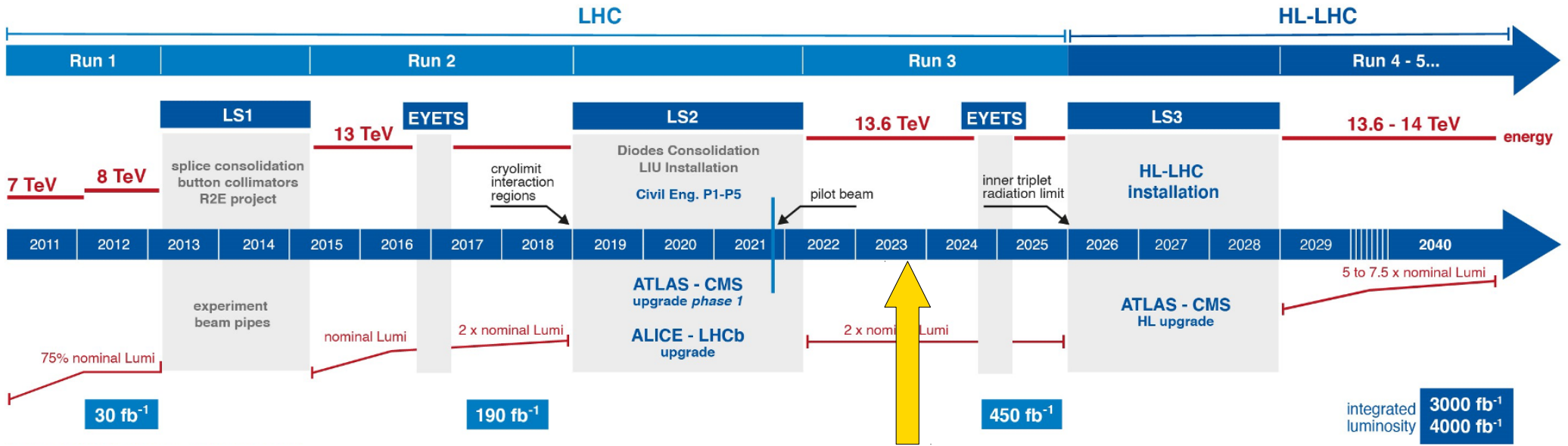
Run: 451896

Event: 349429897

2023-05-11 11:46:34 CEST



LHC program



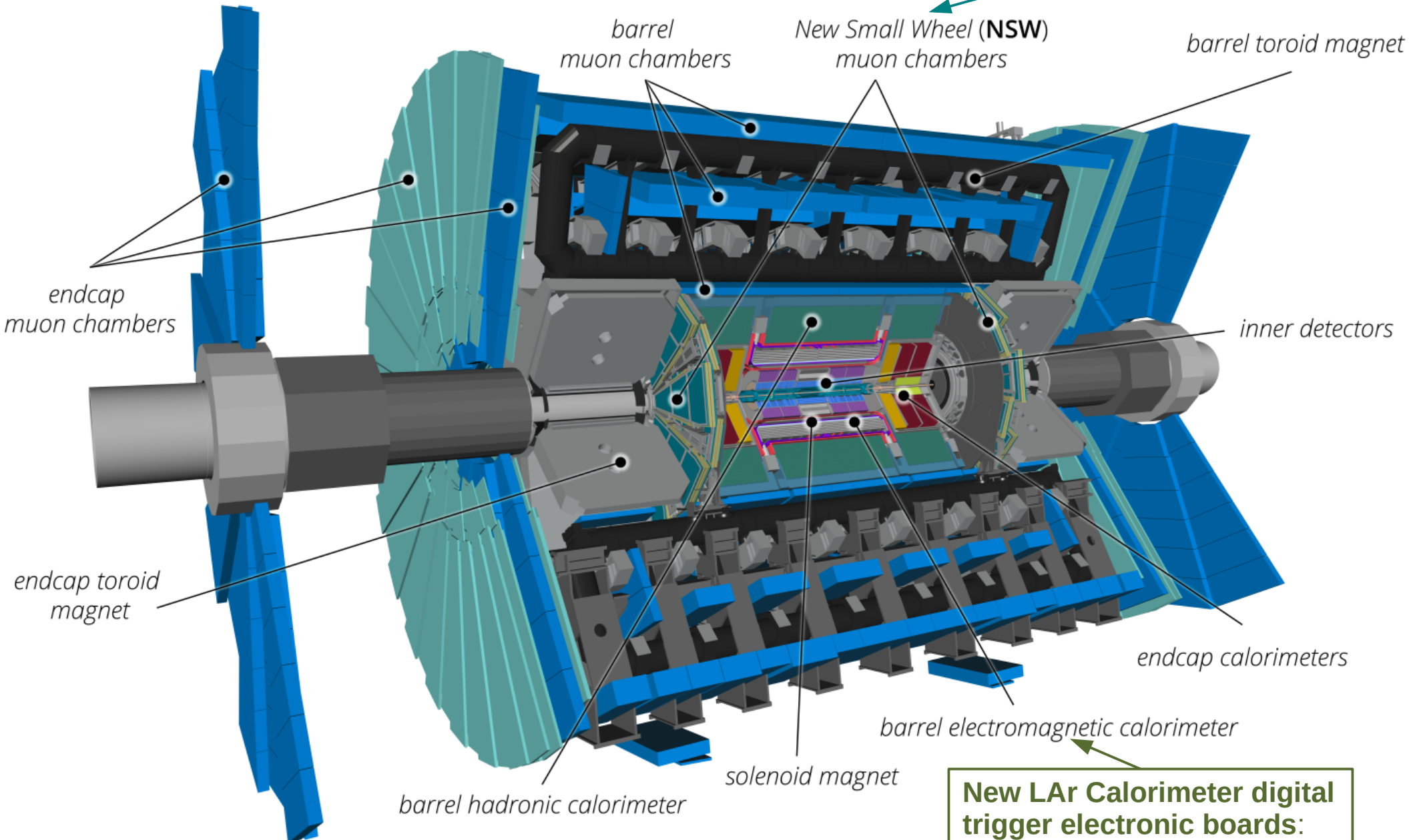


ATLAS detector in Run 3

arxiv:2305.16623

Muon New Small Wheels to replace innermost forward Muon station to

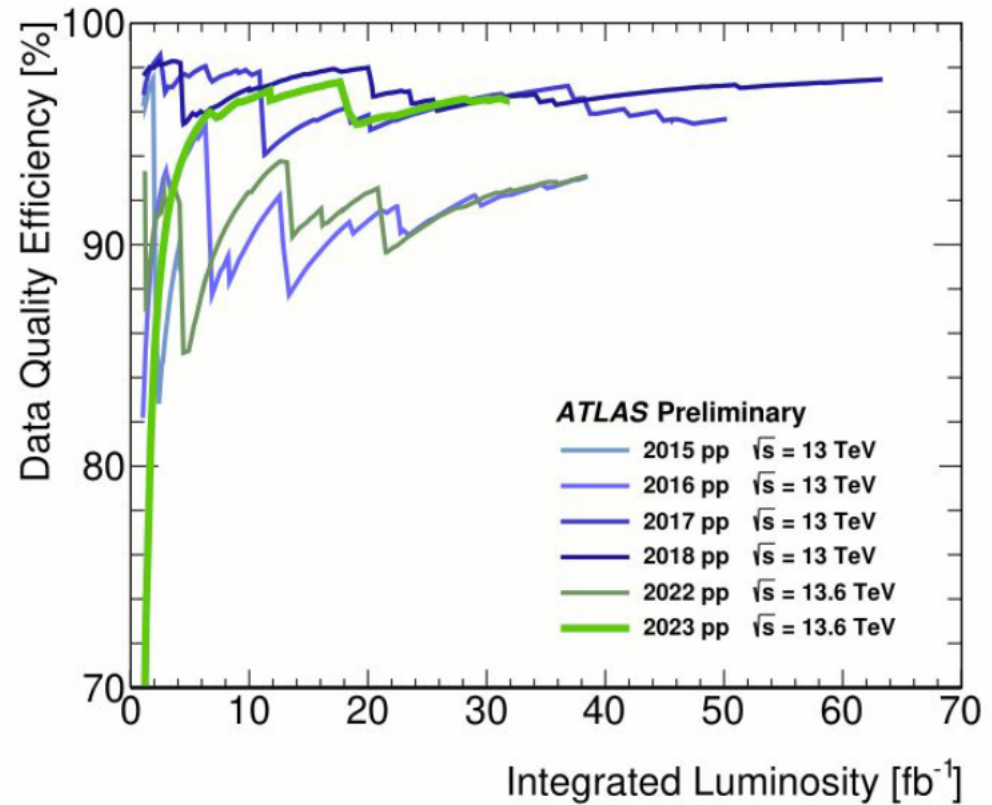
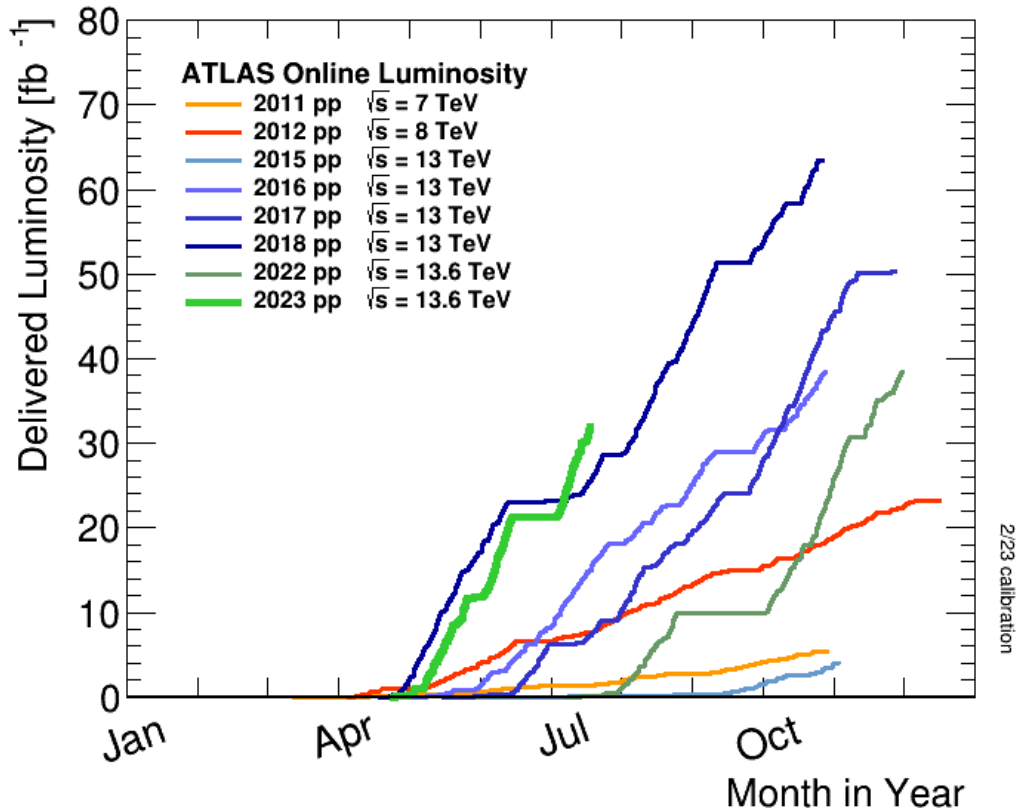
- improve Level 1 trigger
- maintain good tracking in end-cap region



New LAr Calorimeter digital trigger electronic boards:
improved trigger granularity



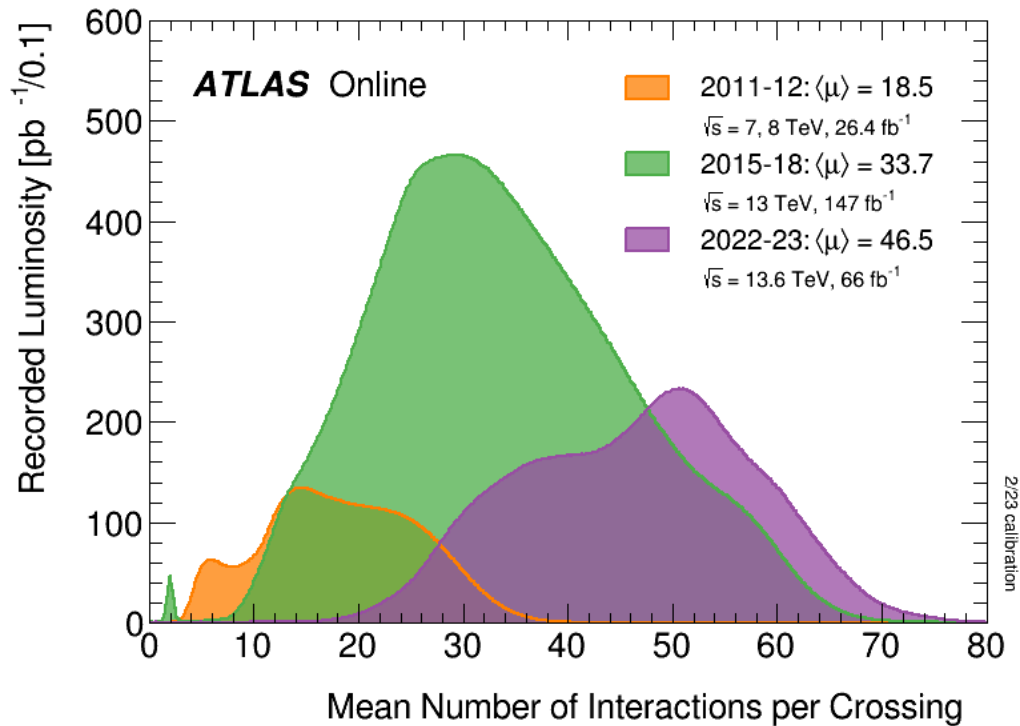
Run 3 so far (1)



- ◆ $\sim 66 \text{ fb}^{-1}$ of data recorded in Run 3
- ◆ 93(94)% data taking efficiency in 2022(2023)
- ◆ High data-quality efficiency
- ◆ Target Run2+3: 450 fb^{-1} by the end of 2025



Run 3 so far (2)



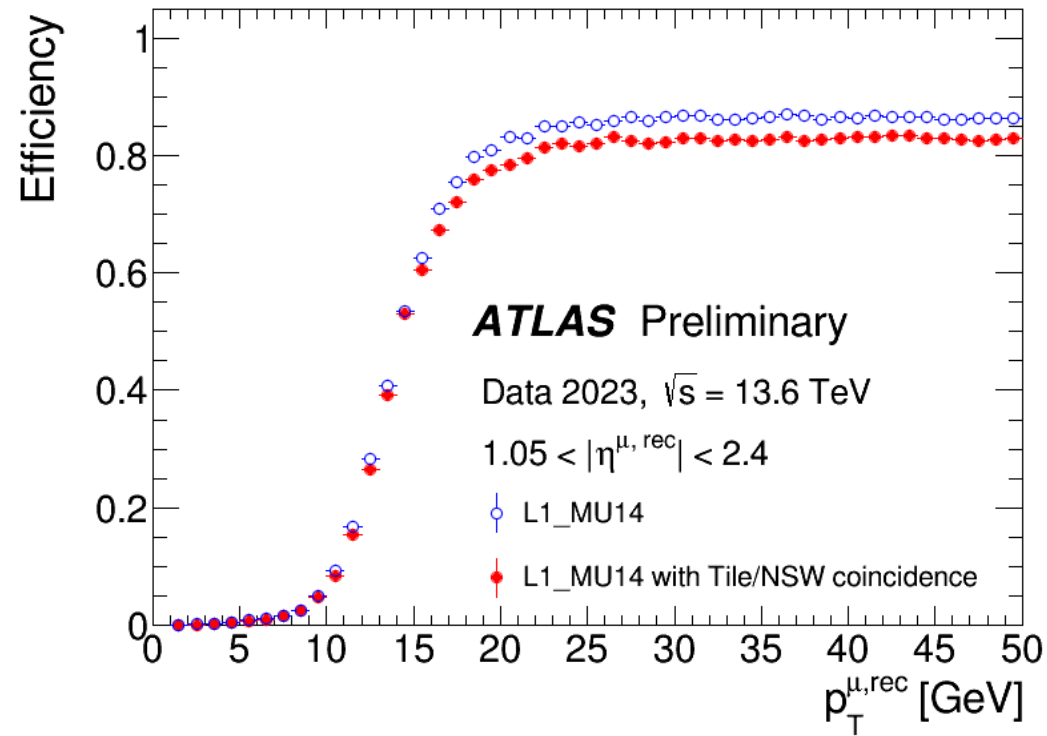
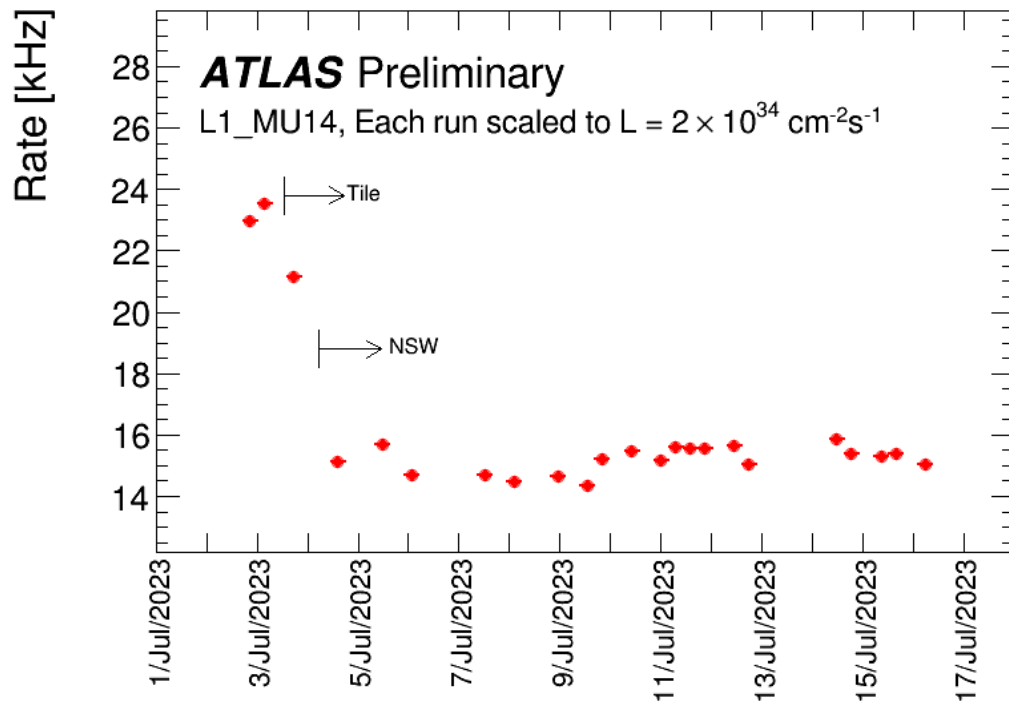
- ◆ Mean pileup increased to 60
- ◆ **Phase-1 upgrades** vital to keep trigger rate under control by reducing rate by:
 - 5 kHz by eFEX (L1Calo)
 - 6 kHz by NSW
 - 2 kHz by muon-tile coincidence
- ◆ **Pixel coping** with those conditions despite outer layers being designed for $\mu = 23$
 - optimised operational settings and new DAQ



New triggers for Run 3 (1)

◆ L1-Muon:

- decrease of rate with coincidences with Tile and NSW
- good efficiency

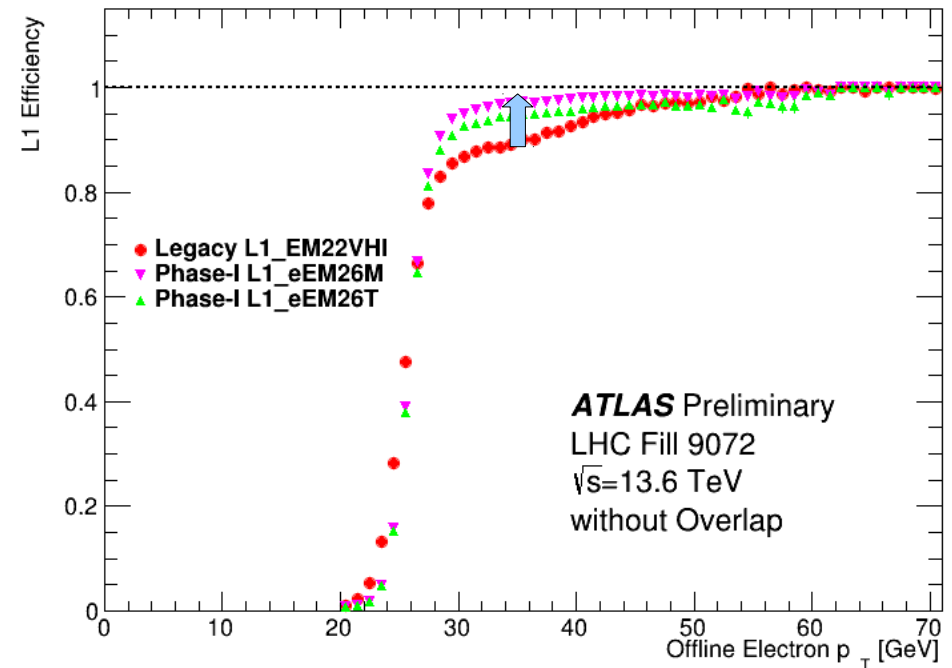
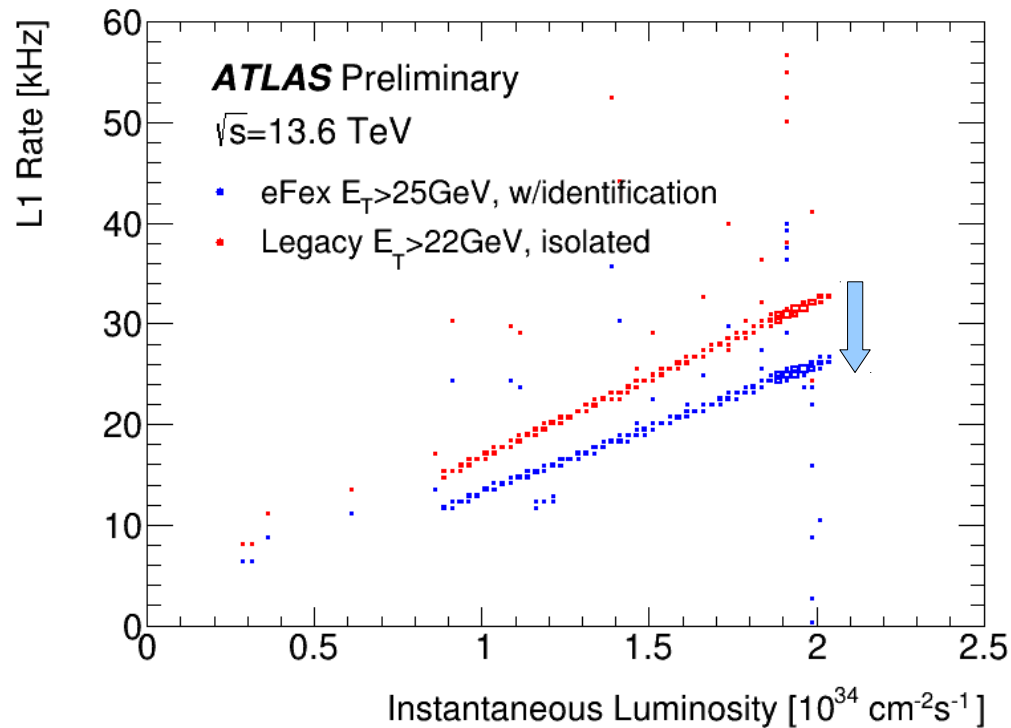




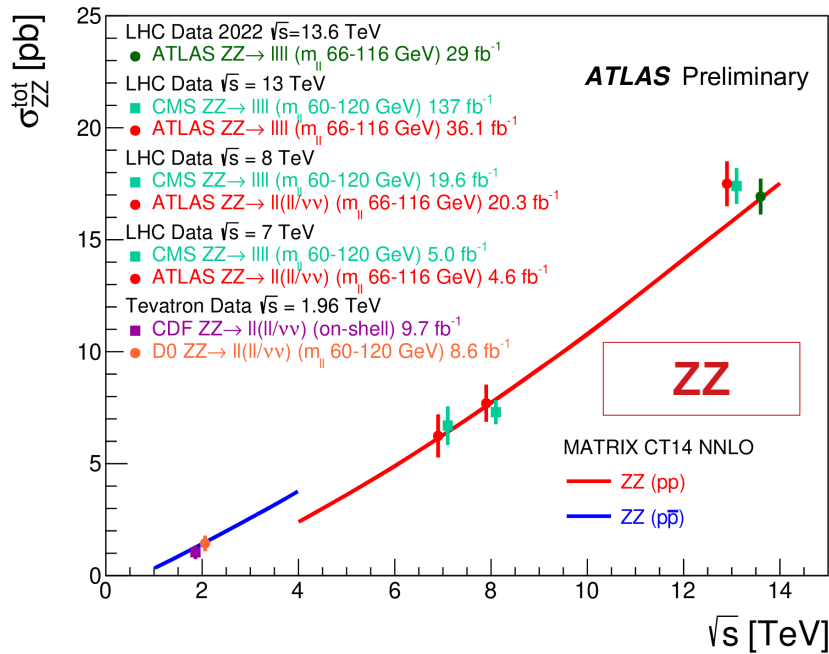
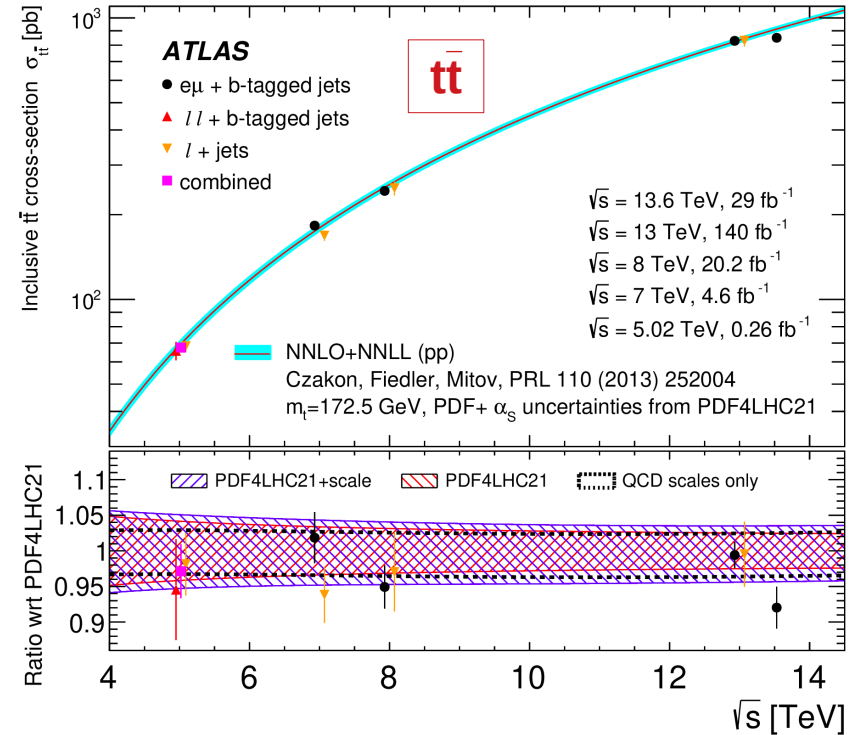
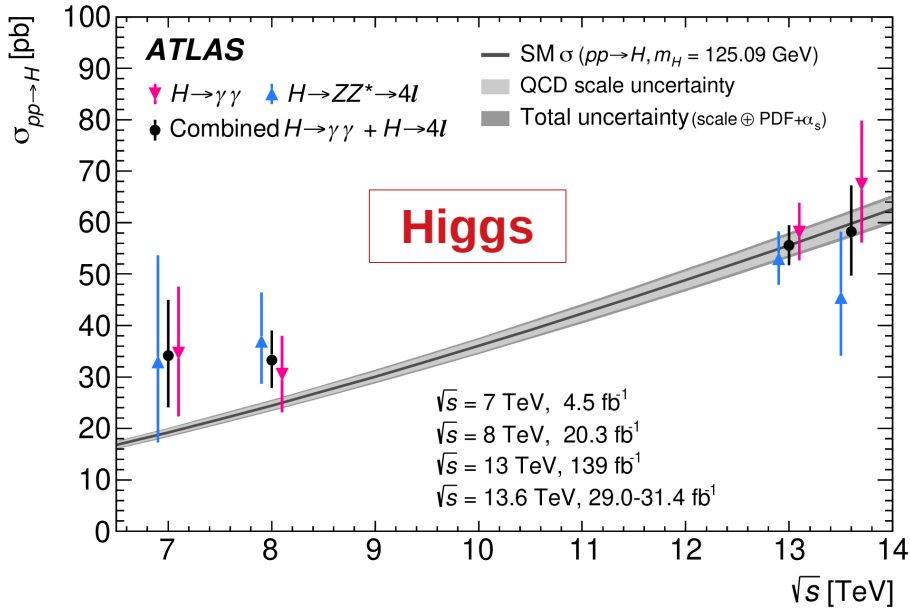
New triggers for Run 3 (2)

◆ L1-Calo:

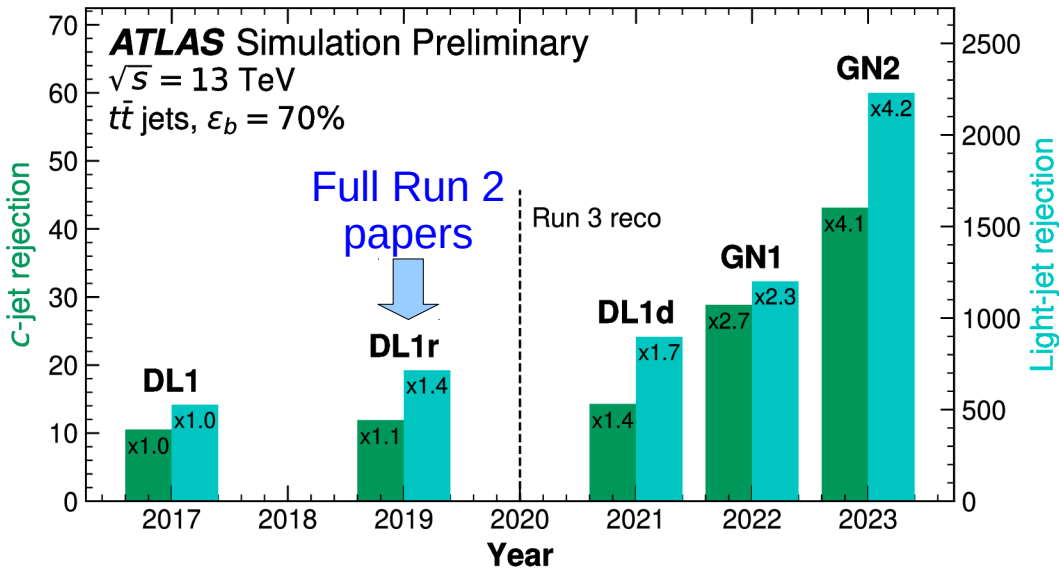
- decrease of trigger rate
- increase of trigger efficiency



Rediscovery of SM at 13.6 TeV

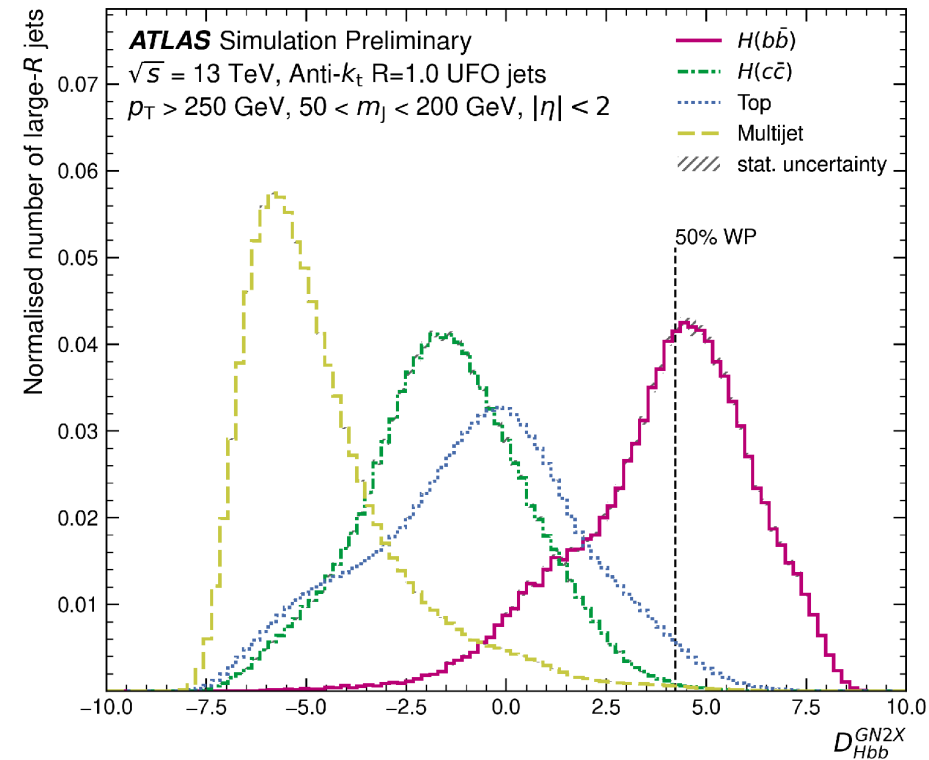


- ◆ New Graph Neural Network algorithms (GN) for Run 3
- ◆ Rejections over time for a 70% efficiency:



- ◆ Boosted $H \rightarrow b\bar{b}/c\bar{c}$ tagging:

- new algorithm using a transformer neural network architecture: GN2X

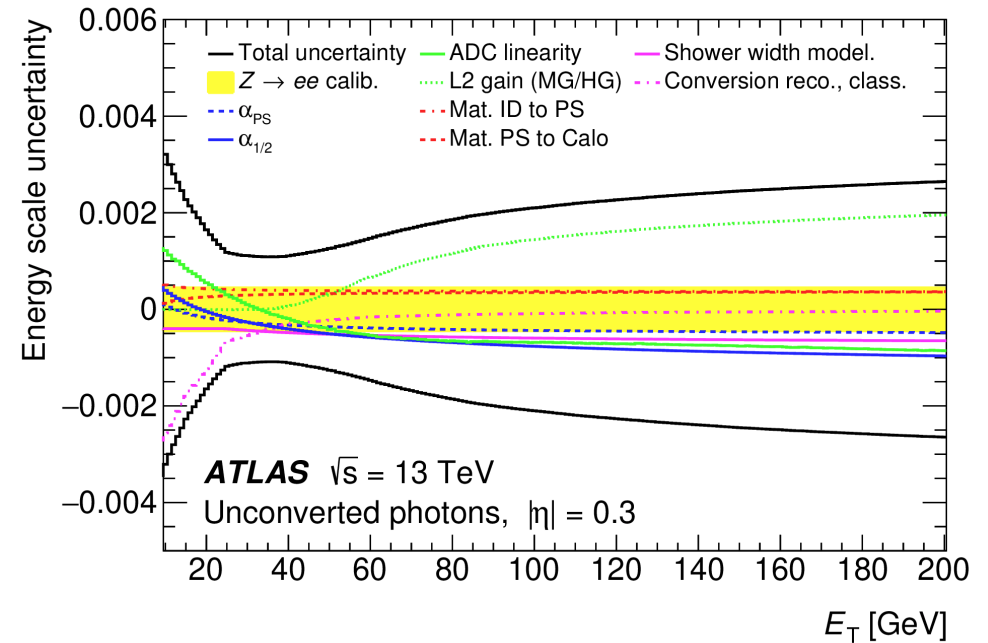
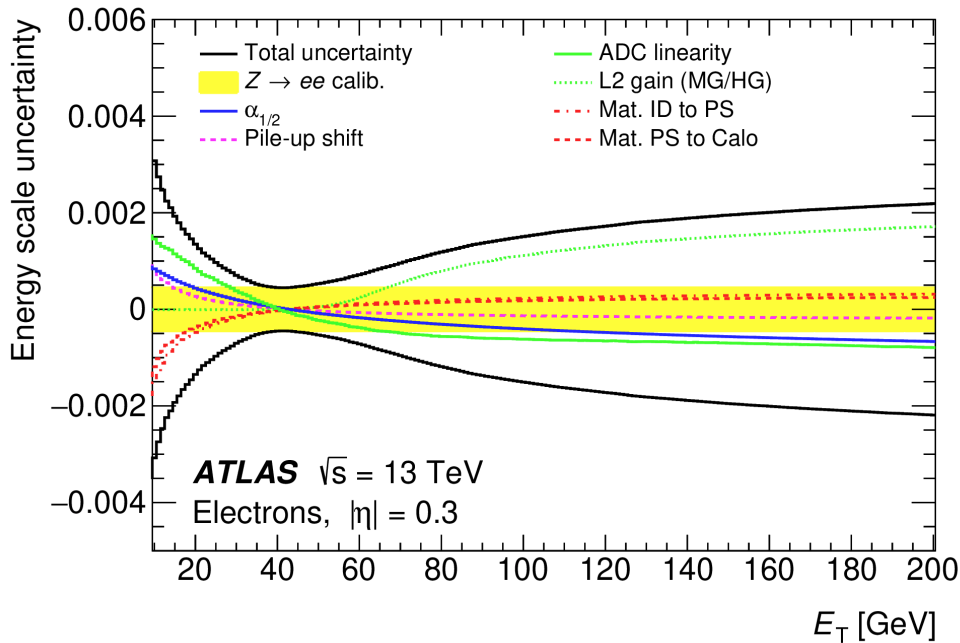


- ◆ For 50% signal efficiency:

- top rejection increased by factor 1.6
- multijet rejection by a factor 2.5



- ◆ Improved electron and photon **energy calibration**
- ◆ Energy scale: factor 2-3 with respect to previous calibration



◆ Calibration uncertainties:

- electrons: 0.4% at 10 GeV, 0.02% at Z mass, 0.3 % at 1 TeV
- photons: 0.2 % at 60 GeV



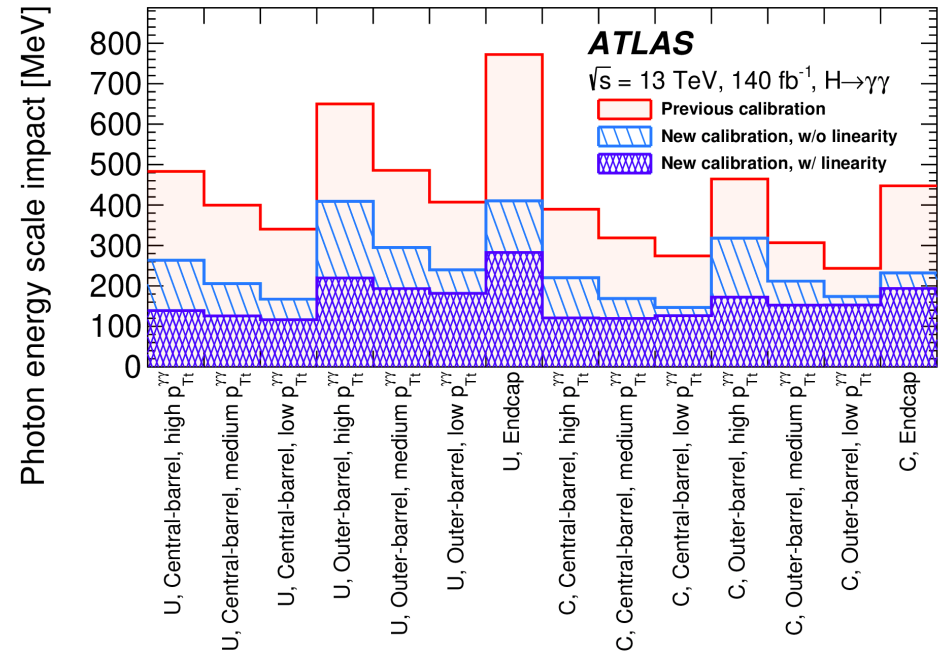
Higgs boson mass

arxiv:2308.07216

arxiv:2308.04775

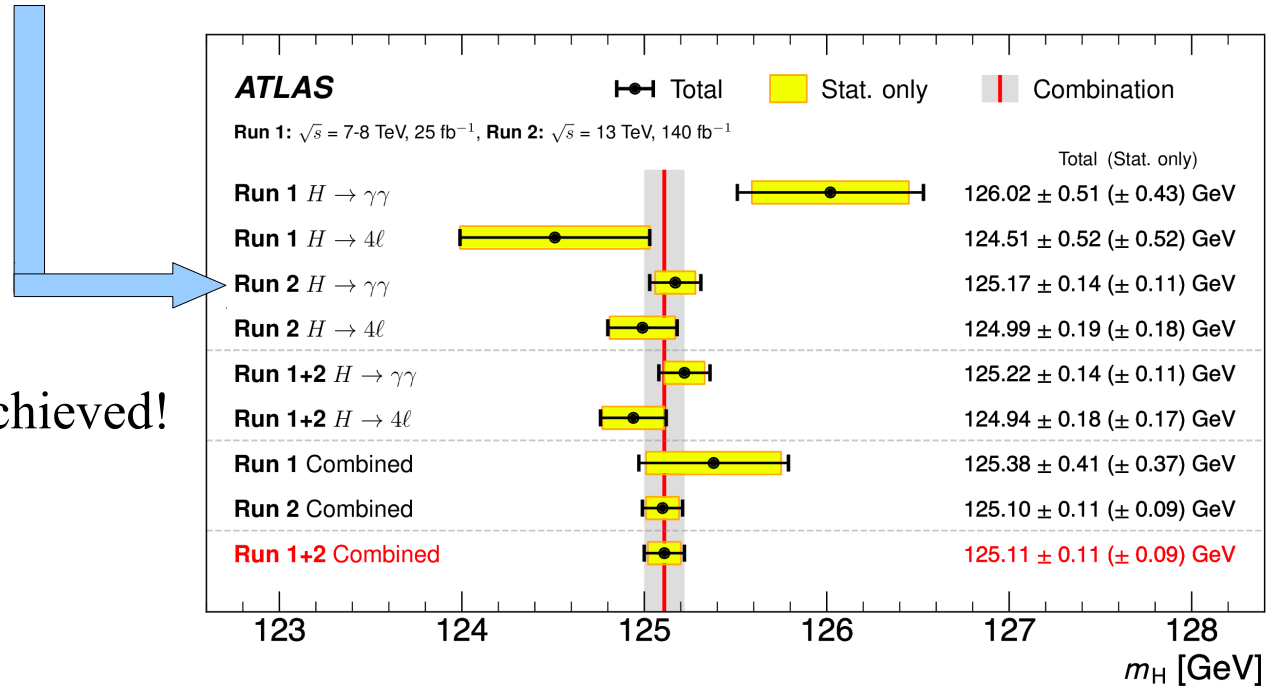
◆ $H \rightarrow \gamma\gamma$

- 30% improvement in systematics: EM calorimeter layer calibration, measure of E lost around e/γ clusters
- residual electron E scale non-linearities used for first time to constrain systematic uncertainties: further x2 improvement
- systematics reduced by factor 3: $330 \text{ MeV} \rightarrow 90 \text{ MeV}$



◆ $H \rightarrow \gamma\gamma + H \rightarrow 4l$:

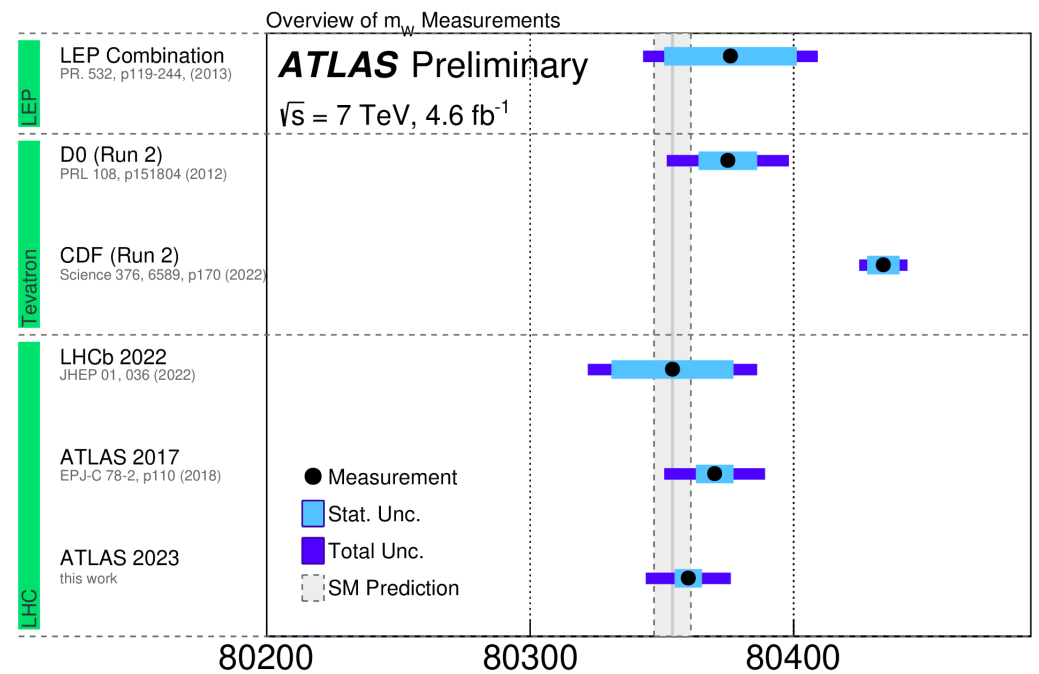
- 0.09% precision achieved!



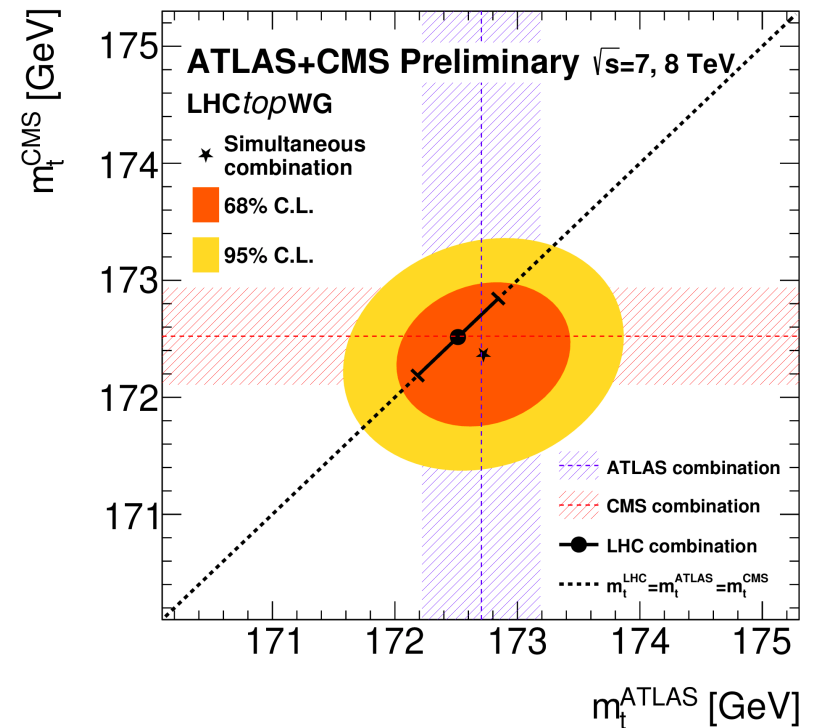
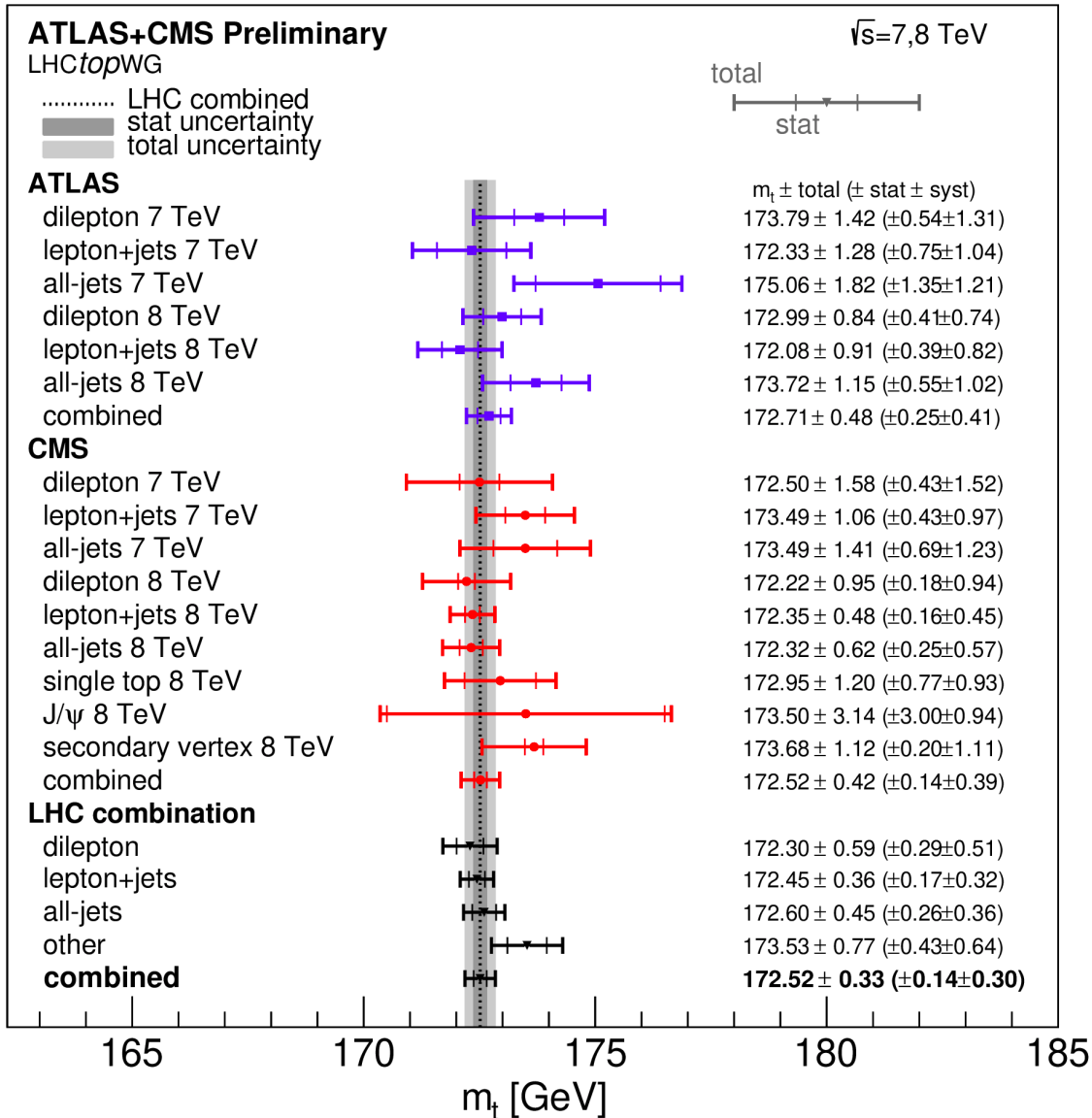


- ◆ Re-analysis of the **7 TeV dataset** with improved statistical methods and refinements in the treatment of the data
- ◆ W mass determined by fitting the kinematic distributions of the decay leptons in simulation to the data
 - new measurement simultaneously adjusts the systematic uncertainties together with the W mass: reduces several systematic uncertainties, particularly those related to the **theoretical modelling** of W-boson production and decay
- ◆ **Special low- μ run** at 5 TeV in 2017 to validate the modelling of p_T^W
- ◆ Modern **PDF** sets

◆ 2017: $m_W = 80370 \pm 19$ MeV
 \Rightarrow 2023: $m_W = 80360 \pm 16$ MeV



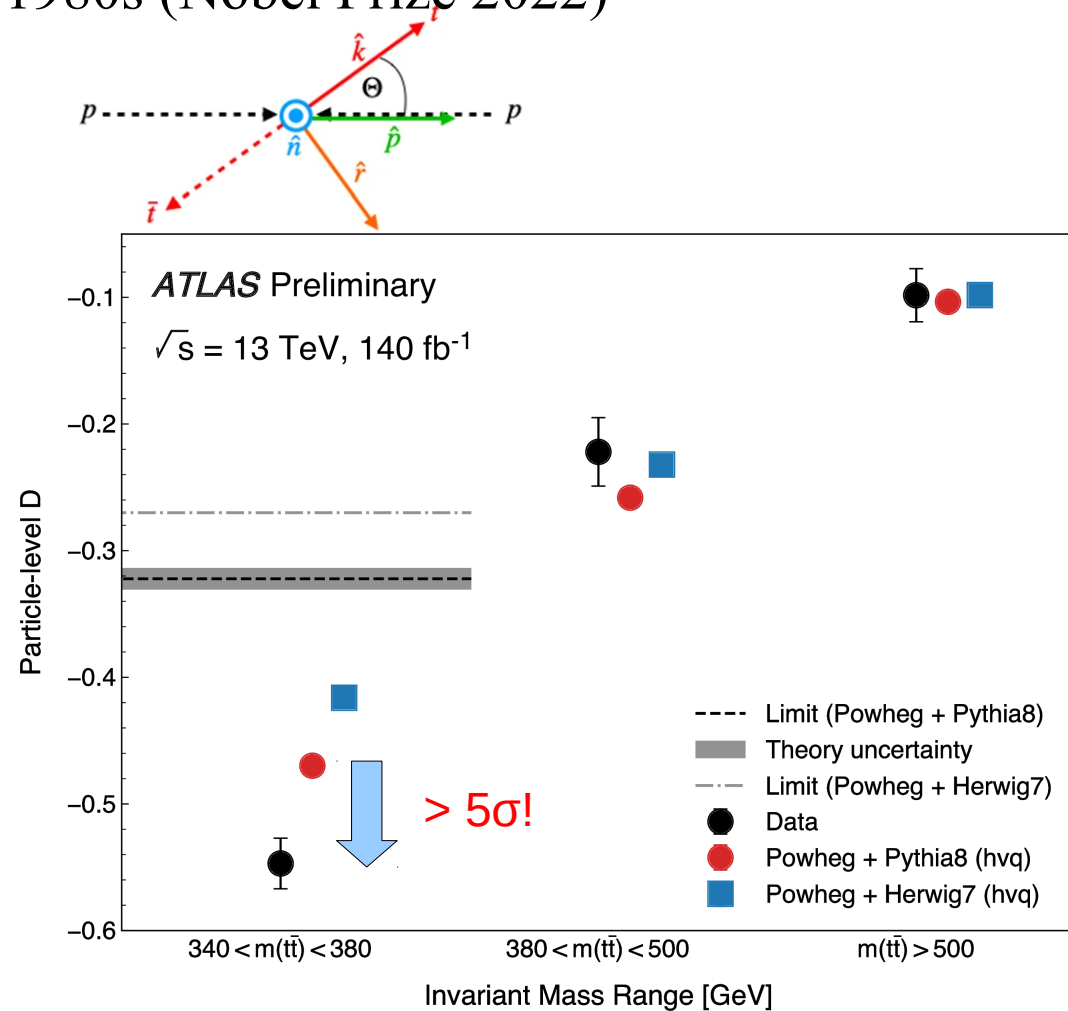
◆ Combination of 15 top quark mass measurements by ATLAS and CMS



◆ $m_{\text{top}} = 172.52 \pm 0.33 \text{ GeV}$

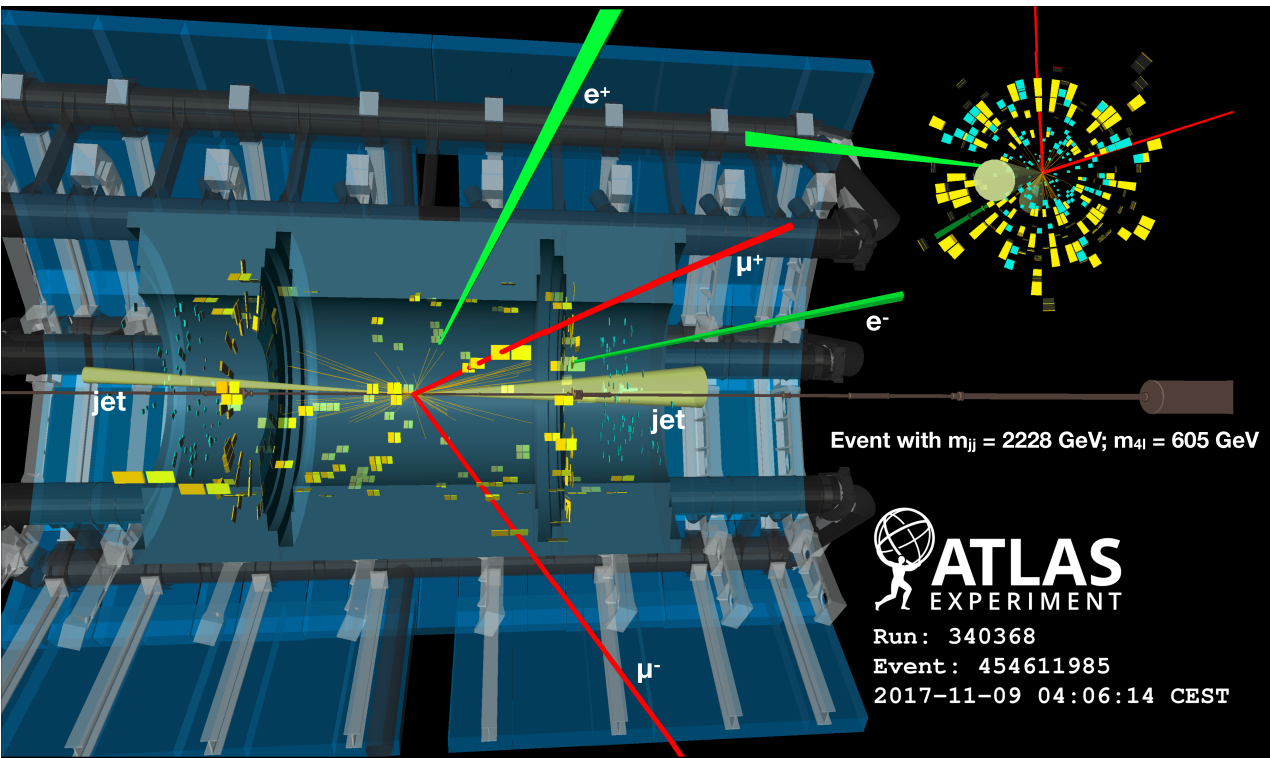
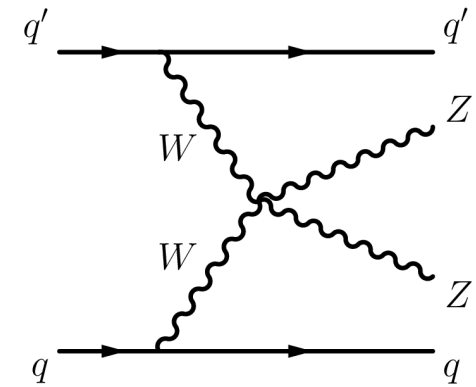


- ◆ Quantum entanglement: predicted in the 1930s, entangled pairs of non-relativistic photons measured in the 1980s (Nobel Prize 2022)
- ◆ **Top quark** decays before it has time to hadronise, transferring all of its **quantum numbers** to its **decay particles** \Rightarrow possible to reconstruct the quantum state of a top quark
 - degree of entanglement (D) from the **angular separation** of the decay products
 - $D < -1/3 \Rightarrow$ entanglement
- ◆ top-quark pairs at production threshold: max entanglement expected
- ◆ Entanglement observed with a significance of **more than 5σ**
- ◆ Highest-energy measurement ever!
 - 12 orders of magnitude above usual measurements

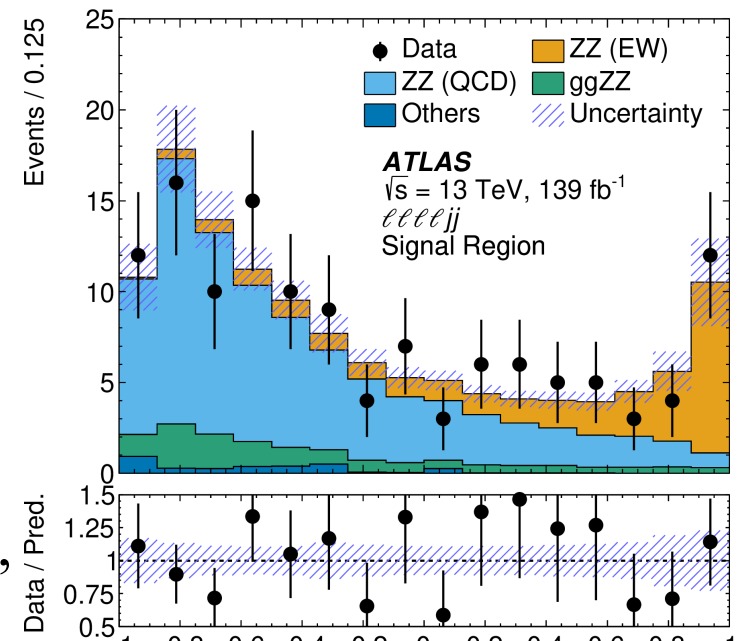




- ◆ Vector Boson Scattering: **probing EW symmetry**
 - SM only allows $WWWW$, $WW\gamma\gamma$, $WWZ\gamma$ and $WWZZ$, forbidding interactions among four neutral bosons
 - broad research programme
- ◆ Electroweak $VVjj$ production via Vector Boson Scattering:



$WWjj$: observed in 2019
 $WZjj$: observed in 2019
 $Z\gamma jj$: observed in 2022
 $ZZjj$: **observed in 2023**



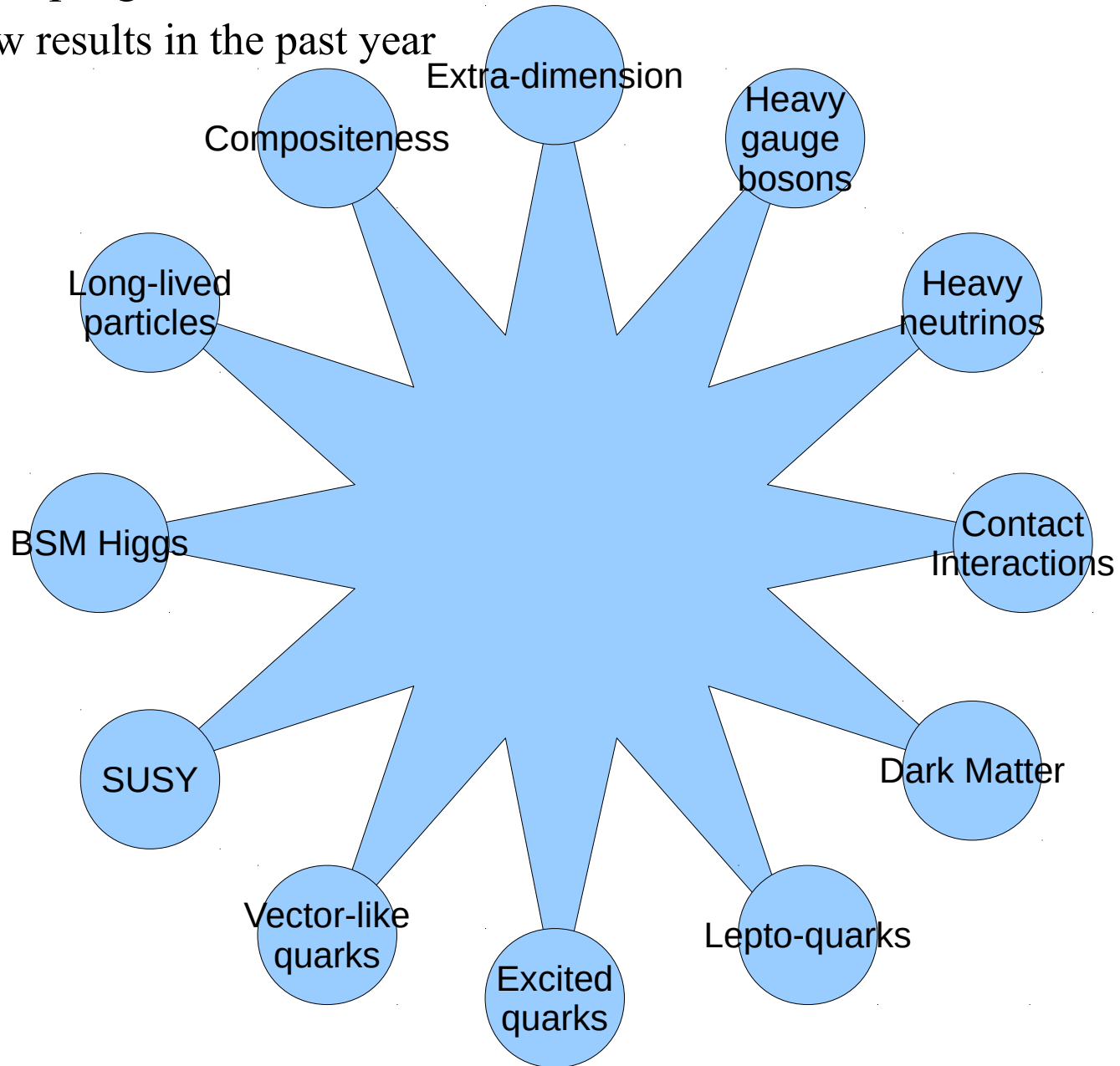
- ◆ ATLAS has **observed all relevant VBS** channels, setting constraints on anomalous couplings



BSM searches

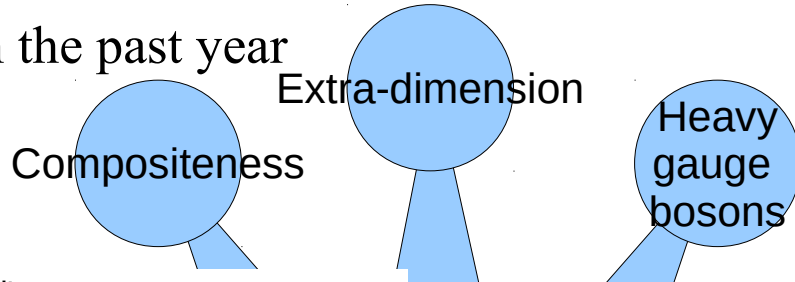
◆ Huge search program

- ~70 new results in the past year



◆ Huge search program

- ~70 new results in the past year



ATLAS Heavy Particle Searches* - 95% CL Upper Exclusion Limits
Status: March 2023

Model	ℓ, γ	Jets†	E ^{miss}	ℓ Δt (fb ⁻¹)	Limit	Reference	ATLAS Preliminary √s = 13 TeV [ℒt = (3.6 - 139) fb ⁻¹]	
								Model
Extra dimen.	ADD G _{KK} + g/q	0 e, μ, τ, γ	1-4	Yes	139	M ₀	2102.10874	
	ADD non-resonant γγ	2 γ	-	-	139	M ₀	1707.04147	
	ADD OBH	-	2 j	-	139	M ₀	1910.08447	
Gauge bosons	ADD BH multijet	-	≥3 j	-	139	M ₀	1512.02696	
	RS1 G _{KK} → γγ	2 γ	-	-	139	G _{KK} mass	2102.13405	
	Bulk RS G _{KK} → WW/ZZ	multi-channel	-	-	139	G _{KK} mass	1808.02380	
	Bulk RS G _{KK} → tt	1 e, μ, τ, γ	≥1 b, ≥1 Δt	Yes	139	G _{KK} mass	1804.10823	
	ZUED / RPP	1 e, μ, τ	≥2 b, ≥3 j	Yes	139	G _{KK} mass	1803.00678	
	SSM Z' → ℓℓ	2 e, μ	-	-	139	Z' mass	1903.08248	
	SSM Z' → ττ	2 τ	-	-	139	Z' mass	1709.07242	
	Leptophobic Z' → bb	0 e, μ, τ	2 b	-	139	Z' mass	1805.08299	
	Leptophobic Z' → tt	0 e, μ, τ	≥1 b, ≥2 j	Yes	139	Z' mass	2005.05138	
	SSM W' → ℓν	1 e, μ, τ	-	-	139	W' mass	1906.05609	
	SSM W' → τν	1 τ	-	-	139	W' mass	2207.03925	
	SSM W' → tb	1 τ	≥1 b, ≥1 j	Yes	139	W' mass	2004.14636	
	HVT W' → WZ model B	0-2 e, μ	2 j (VBF)	Yes	139	W' mass	1904.12079	
HVT W' → WZ → ℓℓ (VBF) model C	3 e, μ, τ	2 j (VBF)	Yes	139	W' mass	2105.13847		
HVT Z' → WW model B	1 e, μ, τ	2 j (1 j)	Yes	139	Z' mass	1911.02905		
LRSM W _K → μN _K	2 μ	1 j	-	30	W _K mass	1703.09127		
CI	CI qqqq	2 e, μ, τ	2 j	-	37.0	Λ	2108.12846	
	CI qqqq	2 e, μ, τ	1 b	-	139	Λ	2105.13847	
	CI eebs	2 e, μ, τ	1 b	-	139	Λ	2105.13847	
	CI μμbs	2 μ, τ	1 b	-	139	Λ	2105.13847	
DM	CI ttcc	≥1 e, μ, τ	≥1 b, ≥1 j	Yes	36.1	Λ	1811.02905	
	Axial-vector med. (Dirac DM)	0 e, μ, τ, γ	2 j	-	139	m _{DM}	2102.10874	
	Pseudo-scalar med. (Dirac DM)	0 e, μ, τ, γ	1-4 j	Yes	139	m _{DM}	2108.13391	
	Vector med. Z'-2HDM (Dirac DM)	0 e, μ, τ	2 b	Yes	139	m _{DM}	2108.13391	
LQ	Pseudo-scalar med. 2HDM+A	multi-channel	-	-	139	m _{DM}	2108.13391	
	Scalar LQ 1 st gen	2 e	≥2 j	Yes	139	LQ mass	2006.05872	
	Scalar LQ 2 nd gen	2 μ	≥2 j	Yes	139	LQ mass	2006.05872	
	Scalar LQ 3 rd gen	1 τ	2 b	Yes	139	LQ mass	2303.01294	
	Scalar LQ 3 rd gen	0 e, μ, τ	≥2 b	Yes	139	LQ mass	2004.14060	
	Scalar LQ 3 rd gen	≥2 e, μ, τ	≥1 j, ≥1 b	Yes	139	LQ mass	2101.11582	
	Scalar LQ 3 rd gen	0 e, μ, τ	≥1 τ, 0-2 j, ≥2 b	Yes	139	LQ mass	2101.12527	
	Vector LQ mix gen	multi-channel	≥1 j, ≥1 b	Yes	139	LQ mass	2101.12527	
	Vector LQ 3 rd gen	2 e, μ, τ	≥1 b	Yes	139	LQ mass	2303.01294	
	Vector LQ 3 rd gen	2 e, μ, τ	≥1 b, ≥1 j	Yes	139	LQ mass	2210.15413	
Vector-like fermions	VLO TT → Z + X	multi-channel	-	-	36.1	T mass	1808.02343	
	VLO BB → W1 Zb + X	multi-channel	-	-	36.1	T mass	1807.11882	
	VLO T ₃₃ T ₃₃ T ₃₃ → Wt + X	2(SB)/2(SM) ≥1 b, ≥1 j	Yes	36.1	T mass	2101.11961		
	VLO T → Ht Zt	1 e, μ, τ	≥1 b, ≥3 j	Yes	139	T mass	2303.01294	
	VLO Y → Wb	1 e, μ, τ	≥1 b, ≥1 j	Yes	36.1	Y mass	1812.07343	
	VLO B → Hb	0 e, μ, τ	≥2b, ≥1 j, ≥1 b	Yes	139	B mass	2303.01294	
	VLO T → Zt Ht	multi-channel	≥1 j	Yes	139	B mass	2303.01294	
	VLO T → Zt Ht	multi-channel	≥1 j	Yes	139	B mass	2303.01294	
	Excited fermions	Excited quark q* → qg	2 e, μ, τ	2 j	-	139	q* mass	1910.08447
		Excited quark q* → qγ	1 γ	1 j	-	139	q* mass	1709.10440
Excited quark q* → bγ		-	1 b, 1 j	-	139	q* mass	1910.08447	
Excited lepton ℓ*		2 τ	≥2 j	-	139	ℓ* mass	2303.09444	
Other		Excited lepton ℓ*	2 τ	≥2 j	-	139	ℓ* mass	2303.09444
	Type III Seesaw	2.3-4 e, μ, τ	≥2 j	-	139	N [±] mass	2202.00309	
	LRSM Majorana ν	2 μ	2 j	-	139	N ₀ mass	1808.11905	
	Higgs triplet H ^{±±} → W [±] W [±]	2.3-4 e, μ (SS) various	Yes	139	H ^{±±} mass	2101.11961		
	Higgs triplet H ^{±±} → ℓℓ	2.3-4 e, μ (SS)	-	-	139	H ^{±±} mass	2211.07505	
	Multi-charged particles	-	-	-	139	multi-charged particle mass	2211.07505	
	Magnetic monopoles	-	-	-	34.4	monopole mass	1906.10130	
	RPV	Excited quark q* → qg	2 e, μ, τ	2 j	-	139	q* mass	1910.08447
		Excited quark q* → qγ	1 γ	1 j	-	139	q* mass	1709.10440
		Excited quark q* → bγ	-	1 b, 1 j	-	139	q* mass	1910.08447
Excited lepton ℓ*		2 τ	≥2 j	-	139	ℓ* mass	2303.09444	
Type III Seesaw		2.3-4 e, μ, τ	≥2 j	-	139	N [±] mass	2202.00309	
LRSM Majorana ν		2 μ	2 j	-	139	N ₀ mass	1808.11905	
Higgs triplet H ^{±±} → W [±] W [±]		2.3-4 e, μ (SS) various	Yes	139	H ^{±±} mass	2101.11961		
Higgs triplet H ^{±±} → ℓℓ		2.3-4 e, μ (SS)	-	-	139	H ^{±±} mass	2211.07505	
Multi-charged particles		-	-	-	139	multi-charged particle mass	2211.07505	
Magnetic monopoles		-	-	-	34.4	monopole mass	1906.10130	

ATLAS Preliminary
√s = 13 TeV

ATLAS SUSY Searches* - 95% CL Lower Limits
August 2023

Model	Signature	ℒt (fb ⁻¹)	Mass limit	Reference
Inclusive Searches	0 e, μ, τ mono-jet	2-6 jets	140	m ₀ ≥ 480 GeV
	0 e, μ, τ mono-jet	1-3 jets	140	m ₀ ≥ 480 GeV
	0 e, μ, τ mono-jet	2-6 jets	140	m ₀ ≥ 480 GeV
	0 e, μ, τ mono-jet	1-3 jets	140	m ₀ ≥ 480 GeV
3 rd gen. squarks direct prod.	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
	t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV
t ₁ t ₁ , t ₁ t ₂ , t ₁ t ₃	0 e, μ, τ	140	m ₀ ≥ 480 GeV	
EW direct	W [±] W [±] via WZ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via WW	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via Wh	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
	W [±] W [±] via ℓℓ	Multiple ℓ/jets	140	m ₀ ≥ 480 GeV
Long-lived particles	Direct ℓ ₁ ℓ ₂ prod., long-lived ℓ ₁	Disapp. trk	140	m ₀ ≥ 480 GeV
	Stable ℓ R-hadron	pixel dE/dx	140	m ₀ ≥ 480 GeV
	Metastable ℓ R-hadron, ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
	ℓ → qqℓ	Displ. sep.	140	m ₀ ≥ 480 GeV
RPV	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓ	3 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → WZℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV
	ℓ ₁ ℓ ₂ ℓ ₃ → ℓℓℓℓ	4 e, μ, τ	140	m ₀ ≥ 480 GeV

ATLAS Preliminary
√s = 13 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).

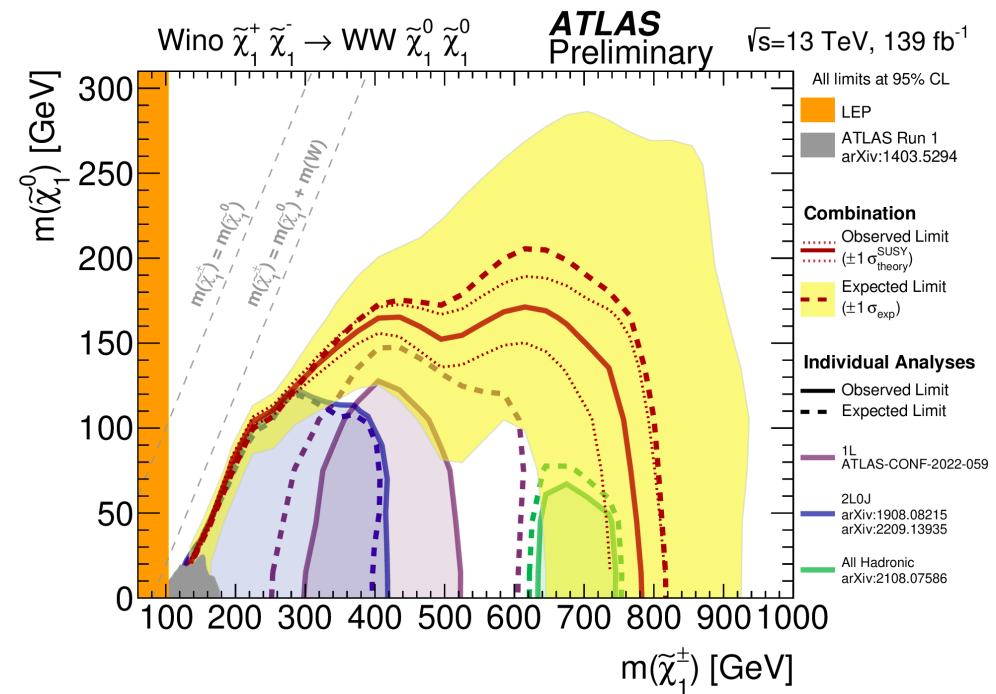
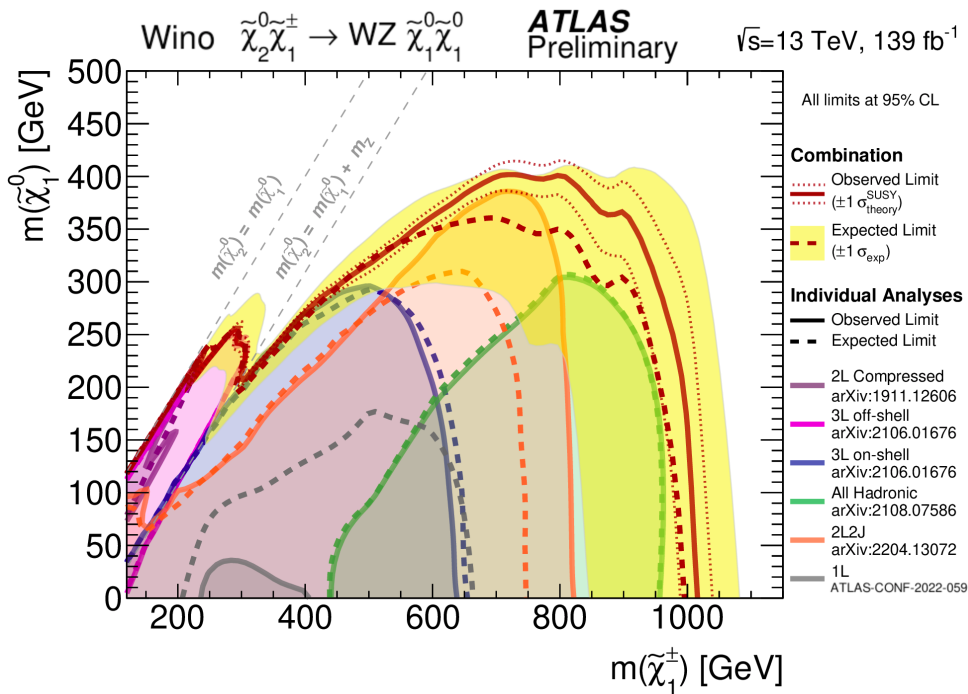
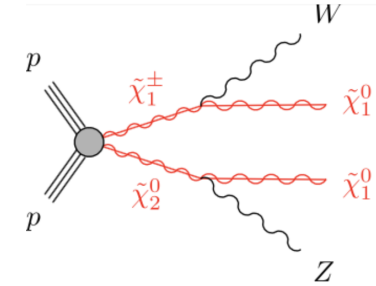
Vector-like quarks

Excited quarks

Lepto-quarks



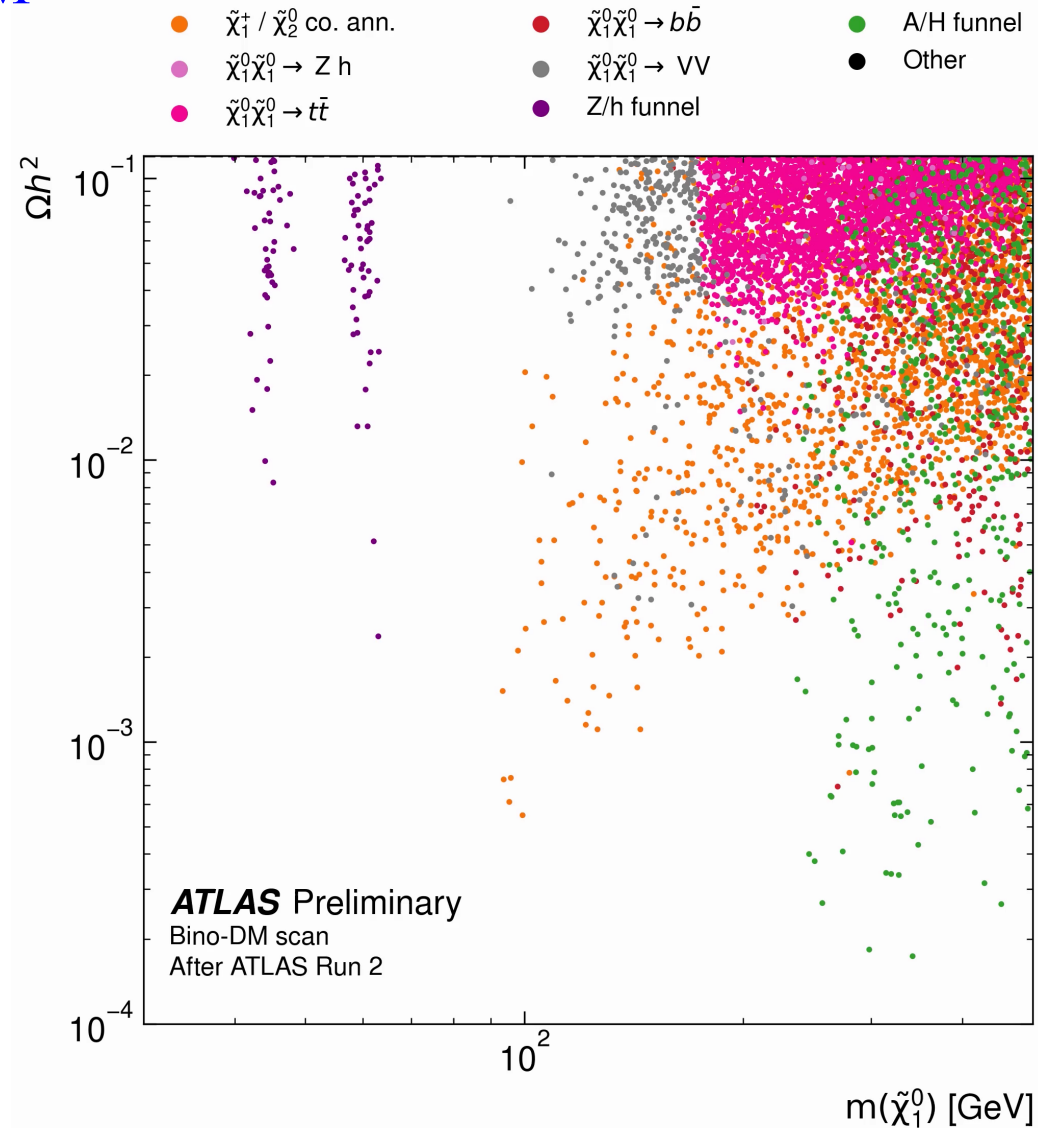
- ◆ Statistical combination of different chargino and neutralino production, decaying via W, Z and h



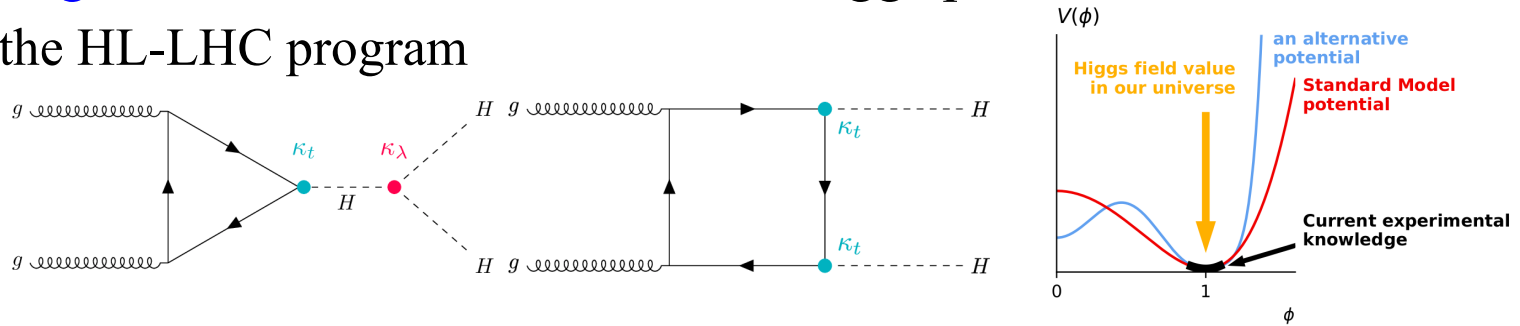
- ◆ Improves sensitivity by 15 - 40 %
- ◆ **Covers gaps** for challenging heavy-lepton scenarios



- ◆ Combination of 8 analyses in pMSSM framework
- ◆ Includes LHC (eg SUSY searches, Higgs \rightarrow invisible) and external constraints (eg dark matter direct-detection)
- ◆ Overall 12280 models tested
- ◆ Almost full exclusion of low mass neutralino region that would not oversaturate the dark matter relic abundance



- ◆ Higgs **self-coupling** can be measured from the di-Higgs production
 - main goal of the HL-LHC program

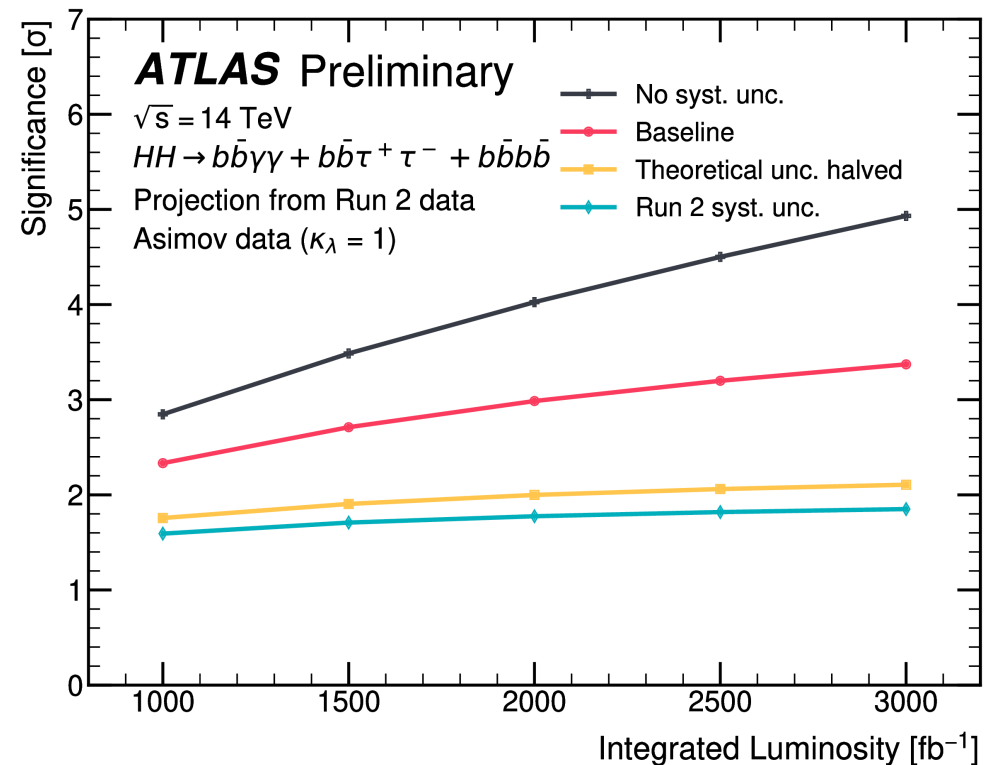


- ◆ New projection from Full Run 2 $HH \rightarrow 4b$, $b\bar{b}\tau\tau$ and $b\bar{b}\gamma\gamma$
- ◆ Expected significance:

	Stat-only	Stat+Syst
YR2019	3.5σ	3.0σ
ATL-PHYS-PUB-2022-05	4.9σ	3.4σ

- ◆ 68% Confidence Intervals on κ_λ :

	Stat-only	Stat+Syst
YR2019	[0.4 ; 1.7]	[0.25 ; 1.9]
ATL-PHYS-PUB-2022-05	[0.7 ; 1.4]	[0.5 ; 1.6]



- ◆ ATLAS-only in new prospect \approx ATLAS+CMS in 2019

- ◆ 118 new ATLAS results released since last year
- ◆ A lot of **Full Run 2** results
 - precision measurements
 - searches
 - continuous improvement of the object reconstruction/calibration and analysis techniques
- ◆ Already some Run 3 results available
 - Latest detector upgrades working well

Back-up