中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

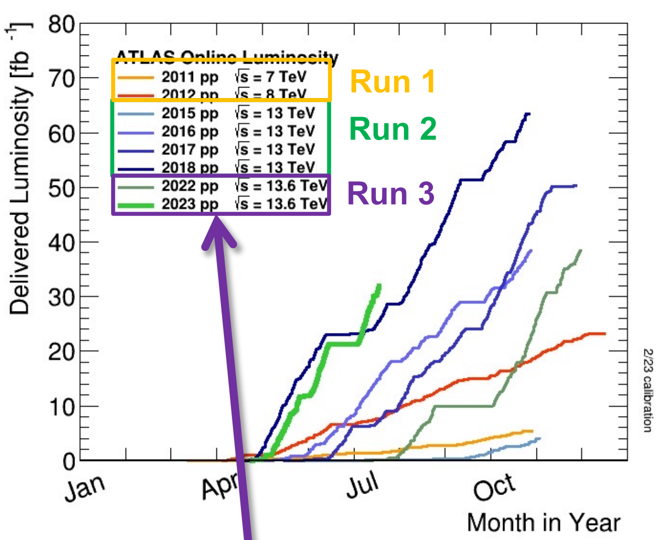
ATLAS EXPERIMENT

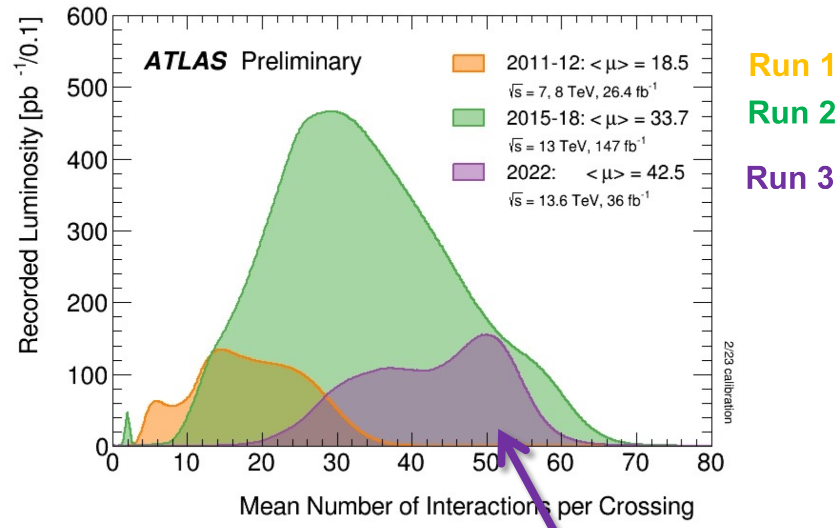
RECENT RESULTS FROM ATLAS

Xuai Zhuang (IHEP, Beijing, China)
On behalf of ATLAS Collaboration

Workshop on the Standard Model and Beyond
Corfu, Aug. 27 - Sep. 7, 2023

ATLAS experiments @LHC





Run3 is well underway and Interactions per crossing is higher as expected

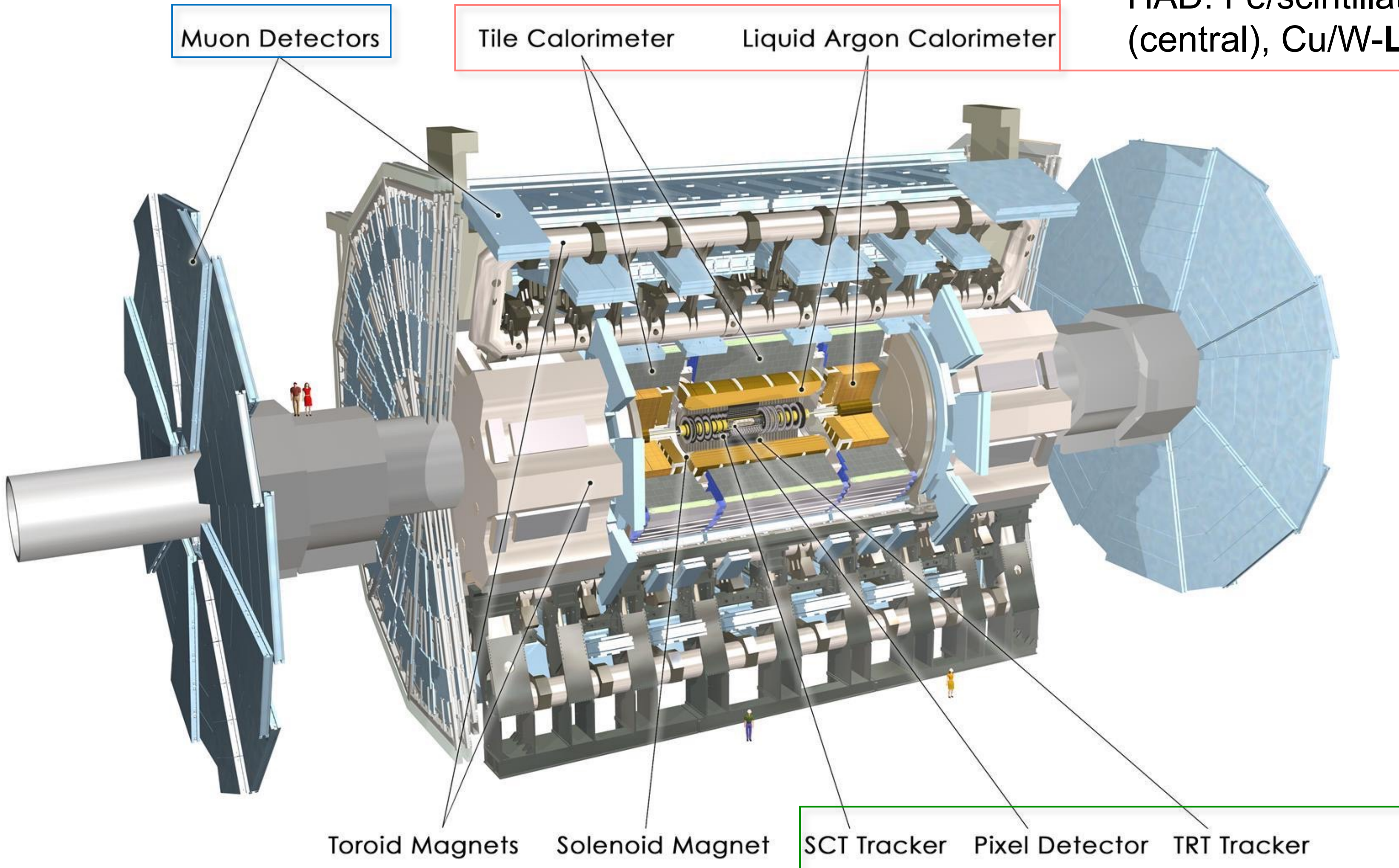
ATLAS collected an integrated luminosity good for all physics of ~139 fb^{-1} (66 fb^{-1}) at √s = 13 (13.6) TeV in Run2 (Run3).

ATLAS has released ~1200 papers, ~260 Full Run 2 and already few Run 3 results

Will highlight some recent Run2 and Run3 results in this talk.

Muon Spectrometer (|η|<2.7) :
- air-core toroids with muon chambers

Calorimetry (|η|<5) :
- EM : Pb-**LAr** Accordion
- HAD: Fe/scintillator **Tiles** (central), Cu/W-**LAr** (fwd)

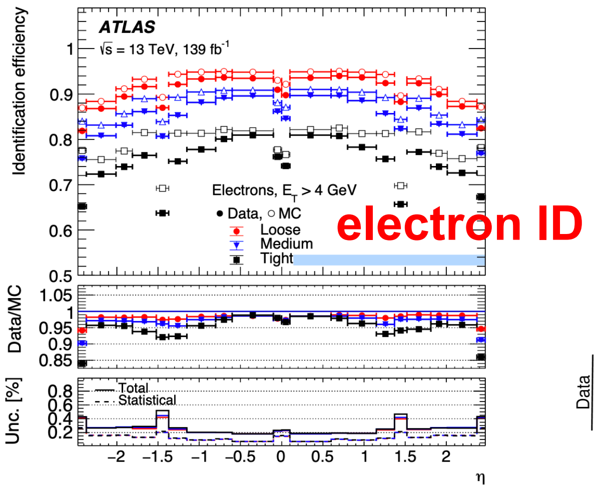


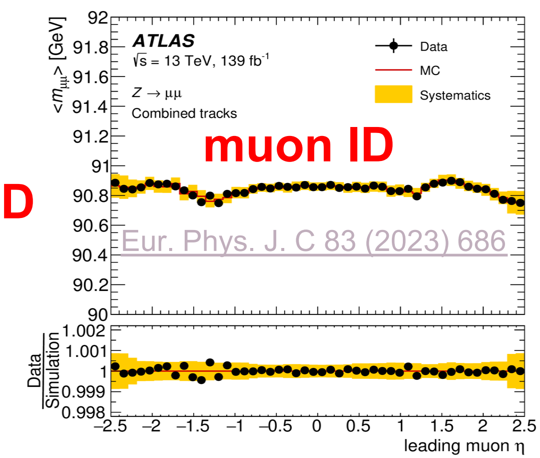
Inner Detector (|η|<2.5, B=2T) :
- Si pixels and strips (precise tracking, vertexing)
- Transition Radiation Detector (e/π separation)
- Innermost pixel layer IBL added in Run2

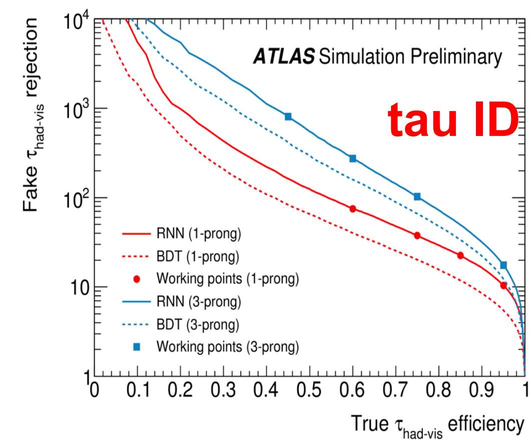
ATLAS detector

Excellent detector performance

- Thanks excellent understanding of detector performance, and development of rec. and ID algorithms
- **Precision object performance：** el-ID<0.5% (pt~4-250GeV), mu-ID<0.1% (pt<450 GeV), JES unc. ~1% (pt~100-1000GeV)







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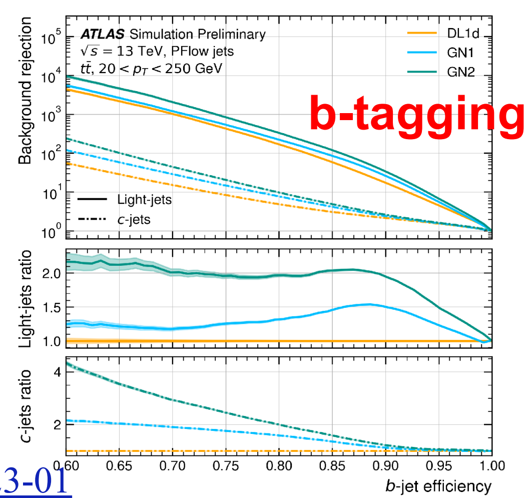

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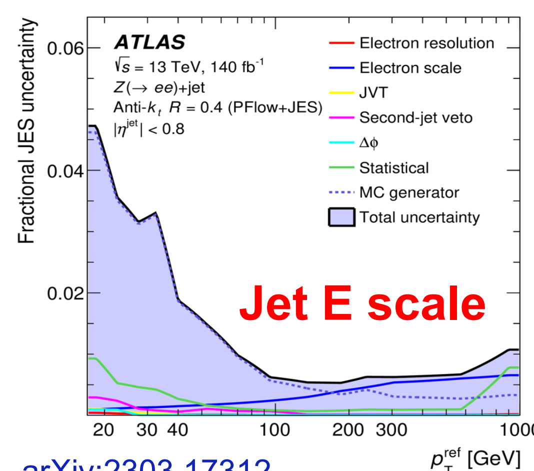


arXiv:2303.17312

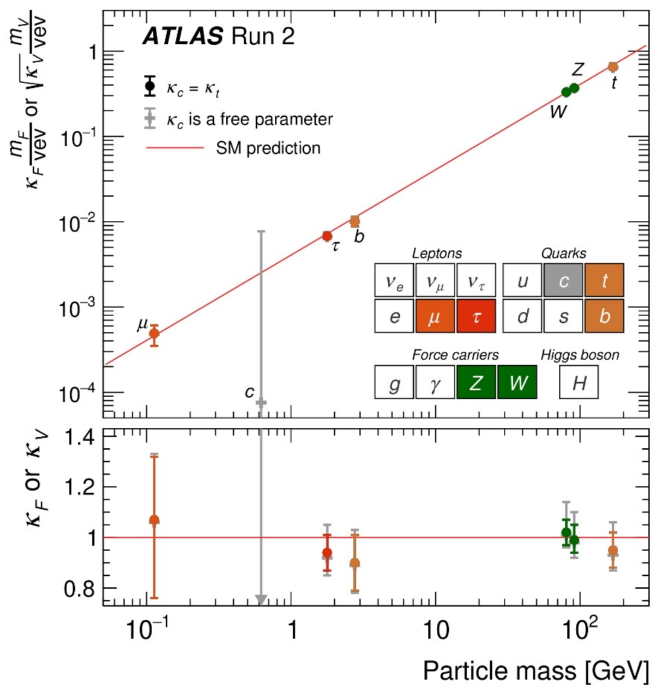
After higgs discovery in both ATLAS and CMS in 2012, the main physics purpose of LHC：

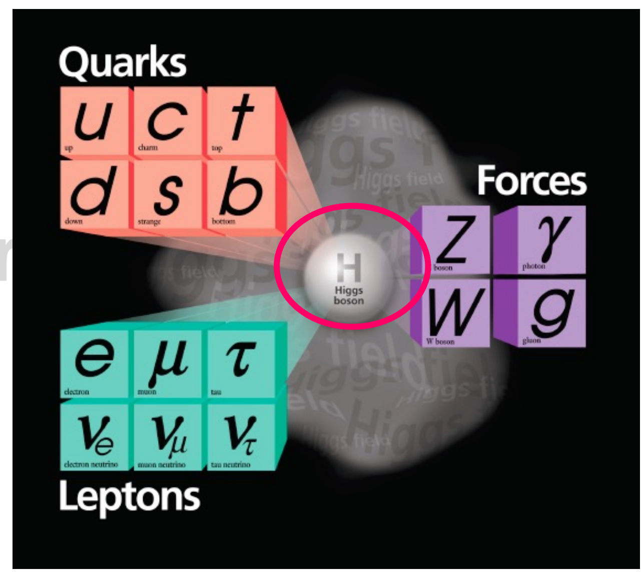
- ☞ **Higgs boson precision measurements**
- ☞ **BSM searches**
- ☞ **SM precision measurements**

Rainer Mankel's talk

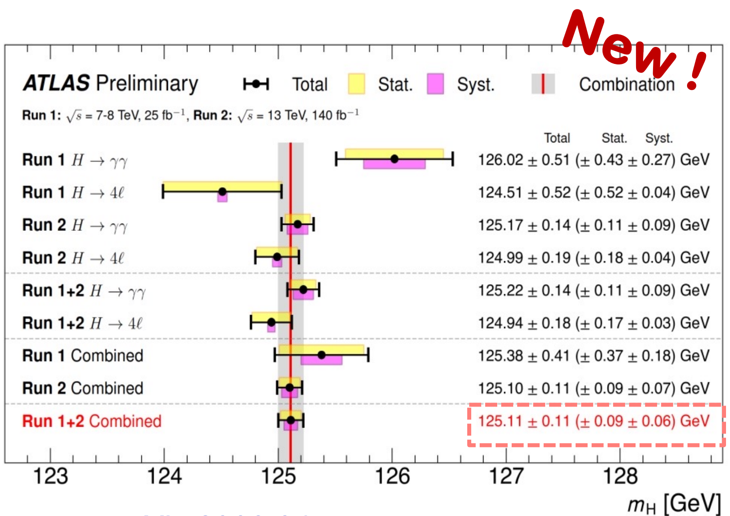
Recent physics results

☞ **Higgs boson precision measurements**





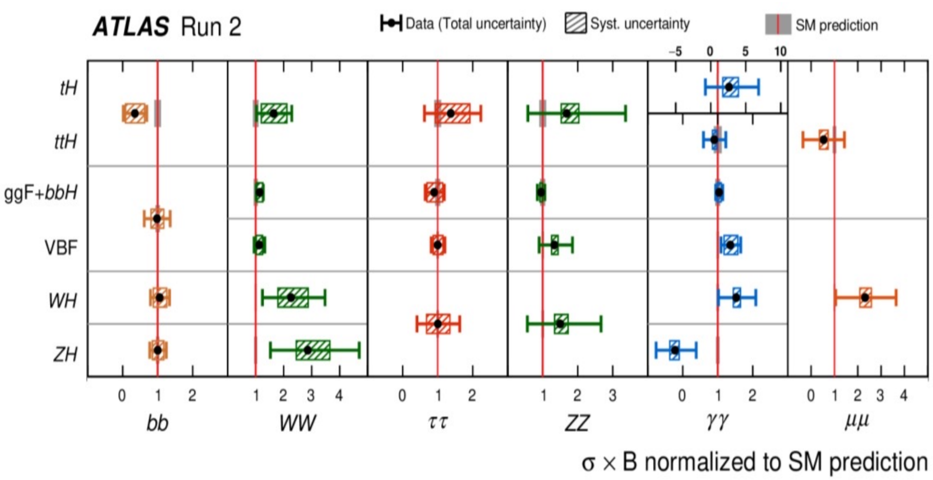
Higgs properties

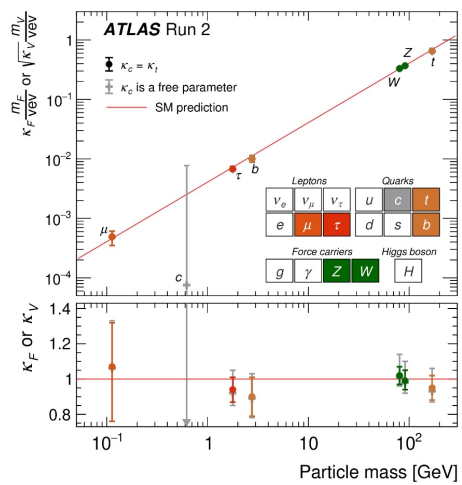


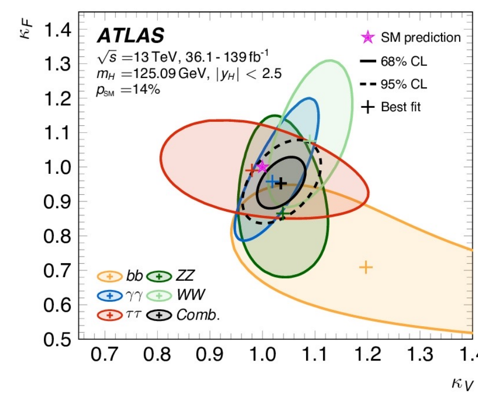
arXiv:2308.04775

Results are consistent with the SM!

- **Higgs mass:** 0.09% uncert.
  - ATLAS 4l+γγ Run1+2: 125.11 ± 0.11 GeV
- **Higgs width:**
  - ATLAS 4l+2l2ν Run2: $\Gamma_H = 4.5^{+3.3}_{-2.5}$ MeV
- **CP:** even, consistent with SM pred.
  - Pure CP odd excluded for H-tau and H-top interactions
- **Couplings: agree with SM predictions**
  - Higgs strength: μ= 1.05+0.06 5-12% uncert.

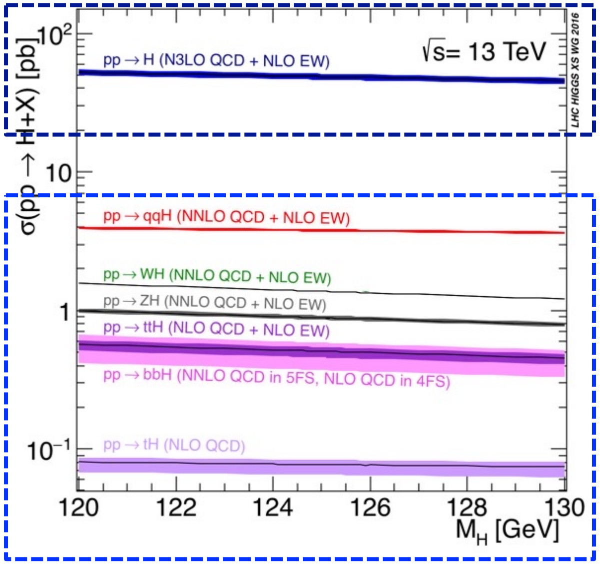


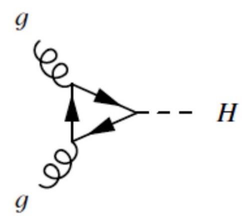




Nature 607, 52-59 (2022)

Higgs production and decays

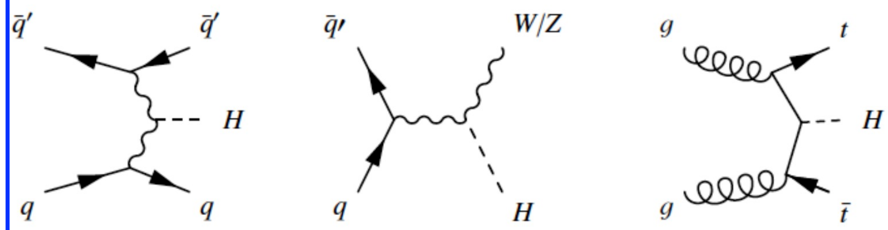




(a) $gg \to H$

$\sigma_{ggF} = 48.61$ pb

Observed in Run1



(b) VBF (c) VH (d) $t\bar{t}H$

$\sigma_{VBF} = 3.766$ pb $\sigma_{VH} = 2.238$pb $\sigma_{ttH} = 0.507$ pb

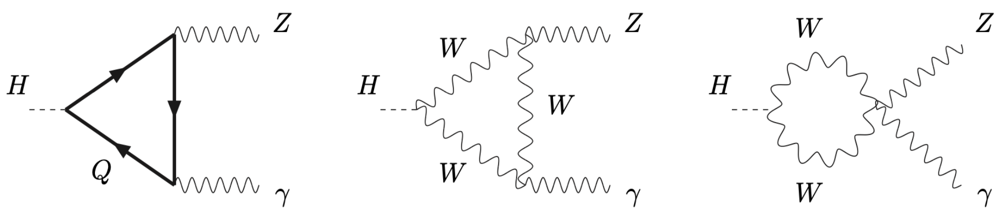
All observed in Run2

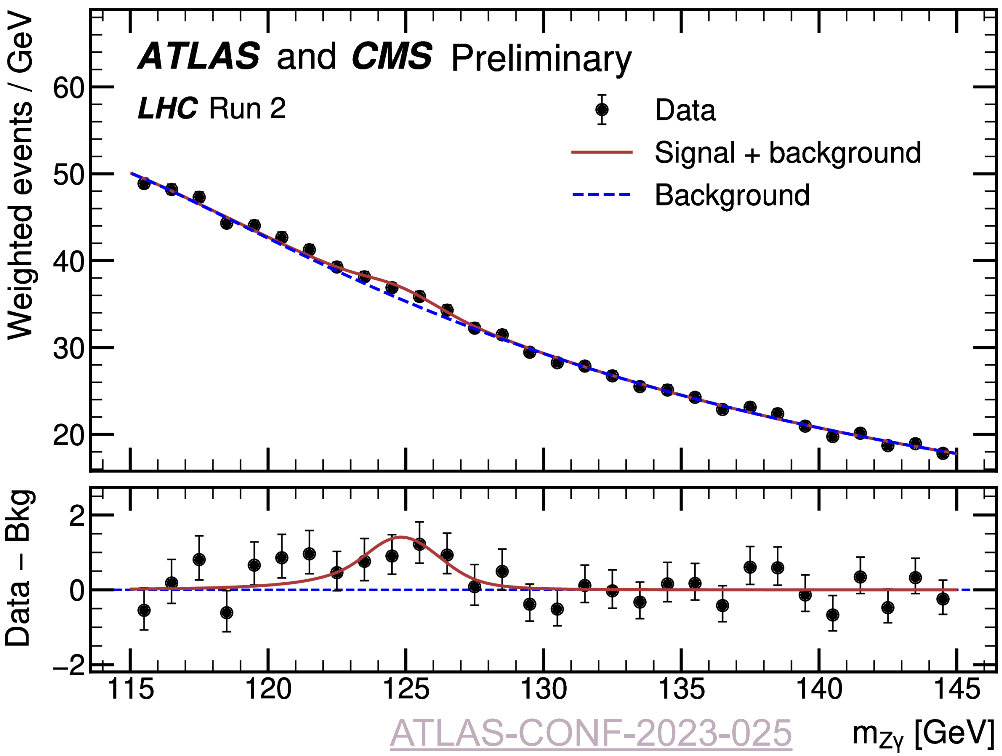
Decay mode	Br.
$H \to b\bar{b}$	57.7%
$H \to WW^*$	21.5%
$H \to \tau\tau$	6.3%
$H \to c\bar{c}$	2.9%
$H \to ZZ^*$	2.6%
$H \to \gamma\gamma$	0.23%
$H \to Z\gamma$	0.15%
$H \to \mu\mu$	0.02%
$H \to \gamma^*\gamma$	0.01%

- **All main production processes and decay channels established: move to precision measurement**
  - → Decays to **bosons** and **third-generation fermions**
- **Searches for decays to second-generation fermions and other rare decays start sensitive**
  - → **Evidence for H → μμ and H→ llγ**
  - → **First evidence for H→Zγ**
- **Searches for HH production getting closer to SM predictions → constraints on Higgs potential**

ATLAS+CMS: First evidence for H→Zγ

New !





ATLAS-CONF-2023-025

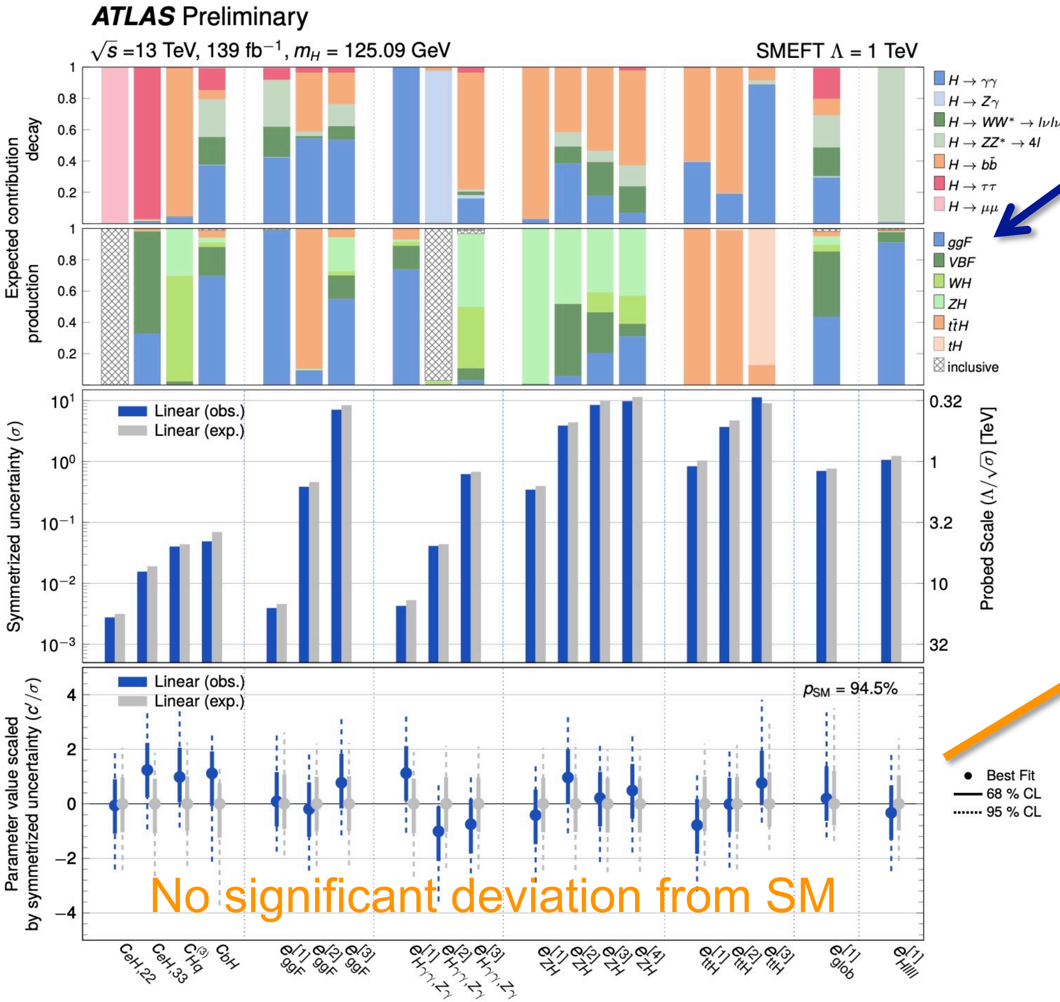
	Obs. (Exp.)	Signal strength μ
ATLAS	2.2σ (1.2σ)	$2.0^{+1.0}_{-0.9}$
CMS	2.6σ (1.1σ)	$2.4^{+1.0}_{-0.9}$
Combination	**3.4σ (1.6σ)**	**2.2 ± 0.7**

- $H\to Z\gamma$ decay has **small BR;** sensitive to many BSM scenarios with BR to diff from SM
- Using Z→ee/μμ (mll>50 GeV) + isolated photon, b/g from DY+ γ , DY+jets
- **First evidence for the $H\to Z\gamma$ process is found with 3.4σ significance** by ATLAS and CMS comb.
- Measured BR= $(3.4 \pm 1.1) \times 10^{-3}$, which is within 1.9 σ of the SM.

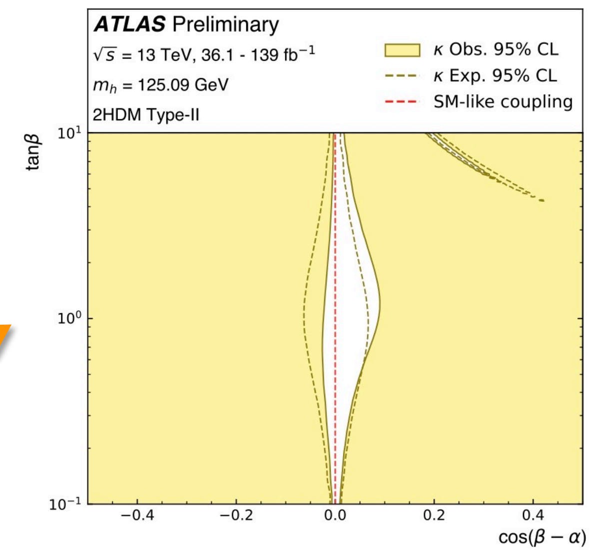
Comprehensive Higgs EFT/BSM study

New !

EFT and BSM interpretation using 10 year’s Higgs anniversary Nature 607, 52-59 (2022). In addition uses differential x-sec combined results for $H \rightarrow \gamma\gamma$ (JHEP 08 (2022) 027) and ZZ decays (EPJC 80 (2020) 942).



Various production/decay modes contribute to constrain different EFT parameters



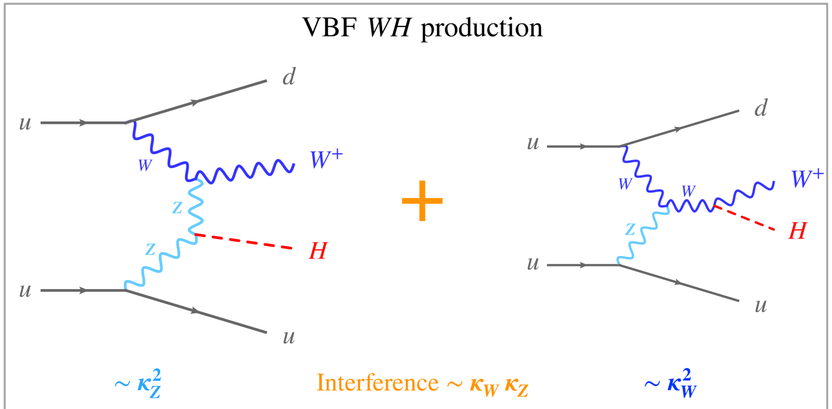
Interpreted with 2HDM and MSSM models

ATLAS-CONF-2023-052

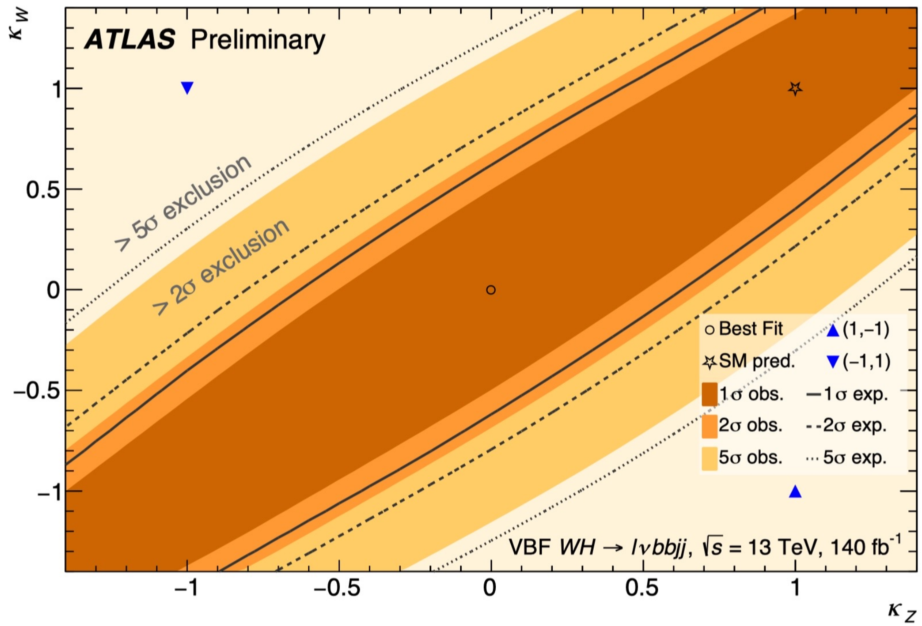
Relative sign of W/Z coupling

New !

- VBF WH process is sensitive to $\lambda_{WZ}(=\kappa_W/\kappa_Z)$ sign
  - σ(VBF,WH) enhanced by a factor of ~6 for negative λ_{WZ}
- Positive λ_{WZ} in the SM (custodial symmetry)
- Search BSM through negative λ_{WZ}



$$\sigma_{\mathrm{VBF},WH} \propto \kappa_Z^2|\mathcal{M}_Z|^2 + \kappa_W^2|\mathcal{M}_W|^2 - 2\kappa_Z\kappa_W \Re[\mathcal{M}_Z^\dagger \mathcal{M}_W]$$
$$= \kappa_Z^2|\mathcal{M}_Z|^2 + \kappa_W^2|\mathcal{M}_W|^2 - 2\kappa_Z^2 \lambda_{WZ} \Re[\mathcal{M}_Z^\dagger \mathcal{M}_W]$$



Negative λ_{WZ} excluded >8σ
→ Consistent with SM

ATLAS-CONF-2023-057

HH production

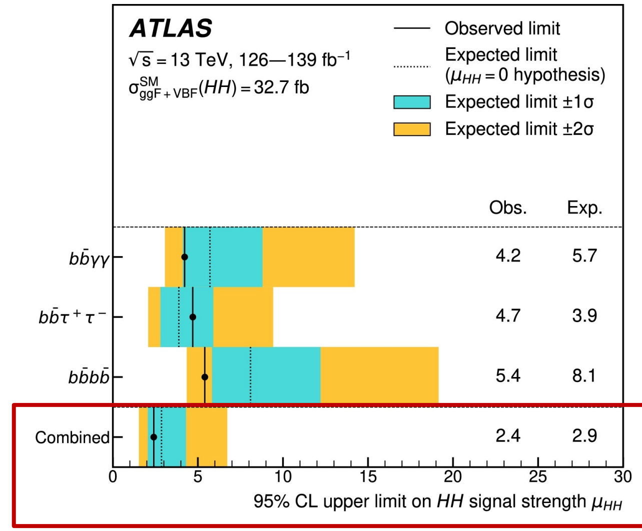
Phys. Lett. B 843 (2023) 137745

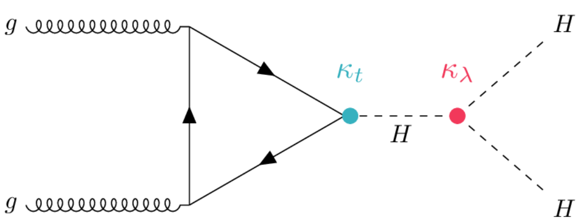
New !

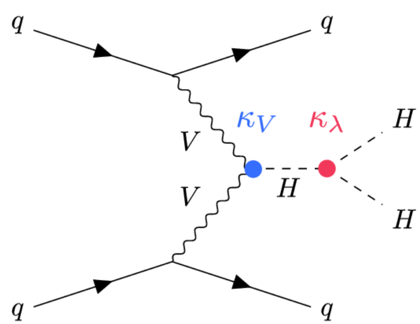
- The potential energy of Higgs field:

$$V(\Phi) = \frac{1}{2} m_H^2 \phi^2 + \sqrt{\frac{\lambda}{2}} m_H \phi^3 + \frac{1}{4} \lambda \phi^4$$

- The H self-coupling determines the shape of the potential, and has significant impact on the nature of EW symmetry breaking and the vacuum stability of the Universe
- It can be measured via Higgs pair prod.
  - 10^3 times smaller than single H process







The upper limit of signal strength is less than 3 times the SM prediction

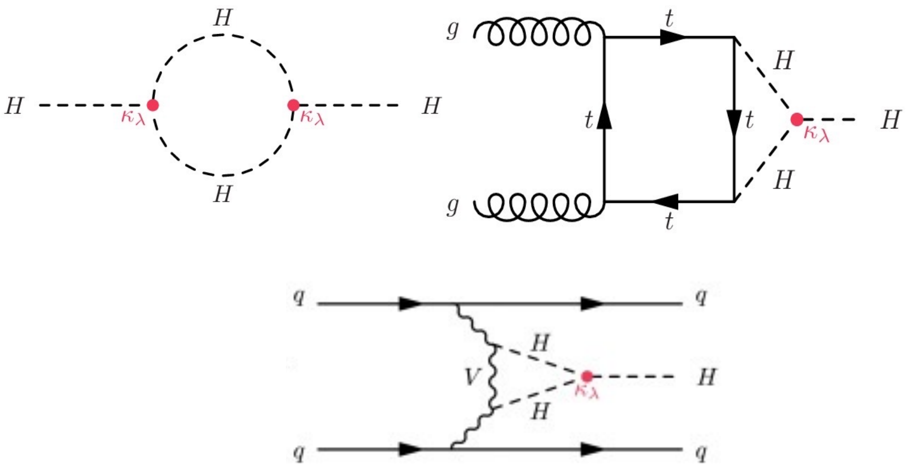
$$\kappa_\lambda = \frac{\lambda}{\lambda_{SM}} \qquad \lambda = \frac{m_H^2}{2v^2}$$

HH+H combination

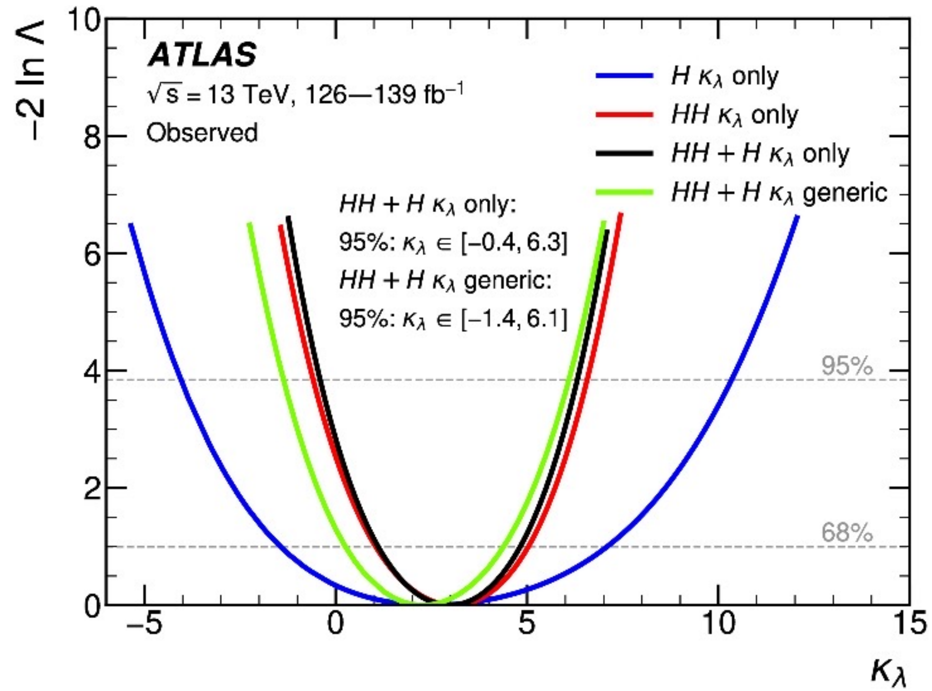
Phys. Lett. B 843 (2023) 137745

New !

- k_λ enters at **loop** level for **H** production affecting σ and kinematics



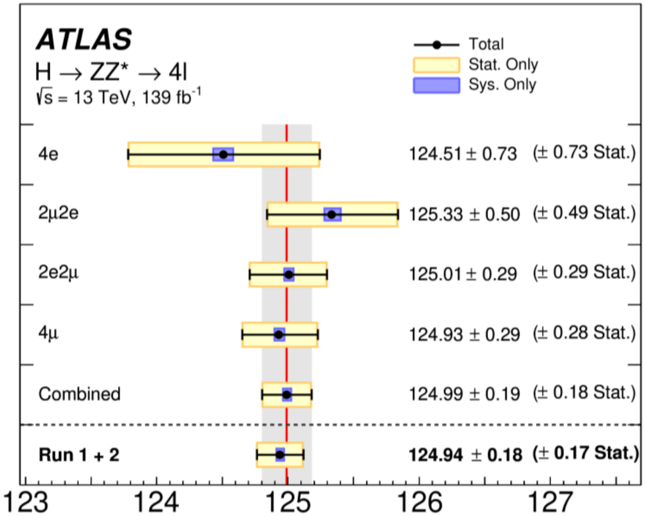
$-0.4 < \kappa_\lambda < 6.3$



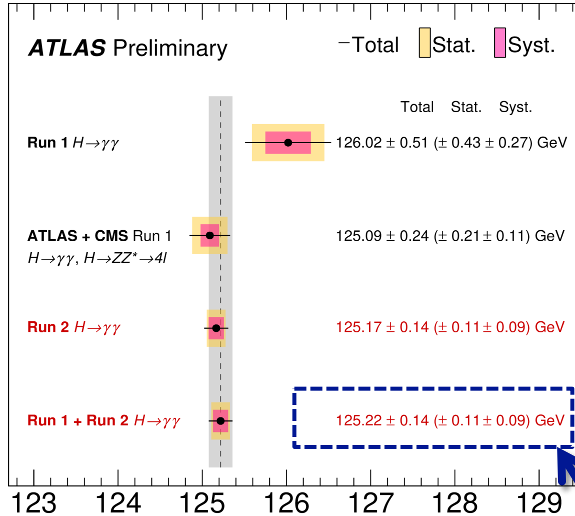
- The statistical combination of HH and H searches **achieves the most stringent constraint on κ_λ**

Higgs Mass

New !



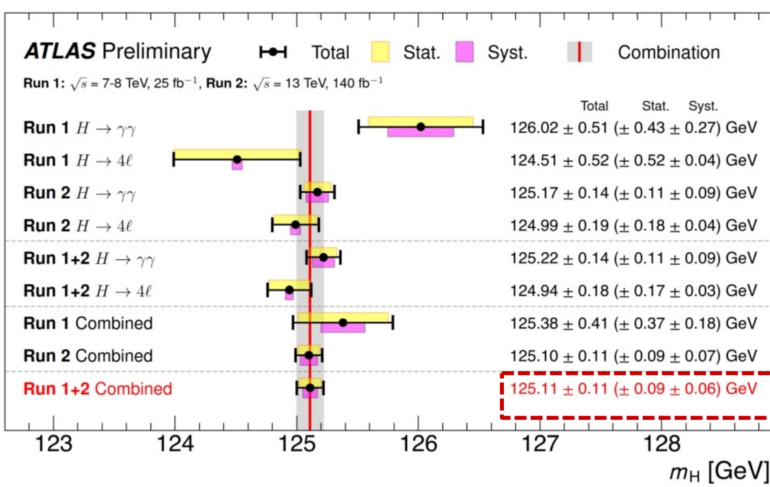
PLB 843 (2023) 137880



ATLAS-CONF-2023-036

- **Updated H→γγ and H→ZZ measurements with full Run2 data**
- **Precise photon, e, μ energy scale and resolution is critical**

arXiv:2308.04775



- **H→γγ: most precise measurement from a single channel 0.11% (improved γ energy scale measurement)**
- **New most precise measurement (0.09%) !**

Higgs Width

arXiv:2304.01532 **New !**

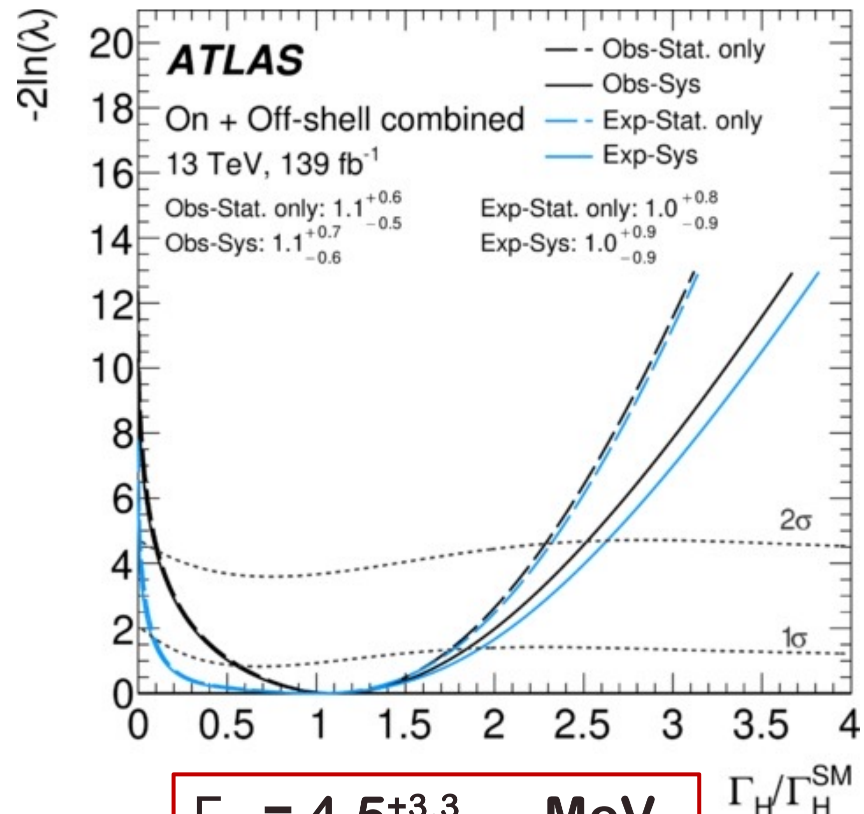
- Standard Model predicts $\Gamma_H \sim 4$ MeV
- **Direct measurement** strongly limited by experimental resolution
- Assuming equal on-shell and off-shell couplings:

JHEP 1208 (2012) 116,
PRD88 (2013) 054024

$$\sigma^{\text{on-shell}}_{gg\to H\to ZZ^*} \sim \frac{g^2_{ggH}\, g^2_{HZZ}}{m_H \Gamma_H}$$

$$\sigma^{\text{off-shell}}_{gg\to H^*\to ZZ} \sim \frac{g^2_{ggH}\, g^2_{HZZ}}{(2m_Z)^2}$$

$$\frac{\mu_{\text{off-shell}}}{\mu_{\text{on-shell}}} = \frac{\Gamma}{\Gamma_{SM}}$$



$\Gamma_H = 4.5^{+3.3}_{-2.5}$ MeV

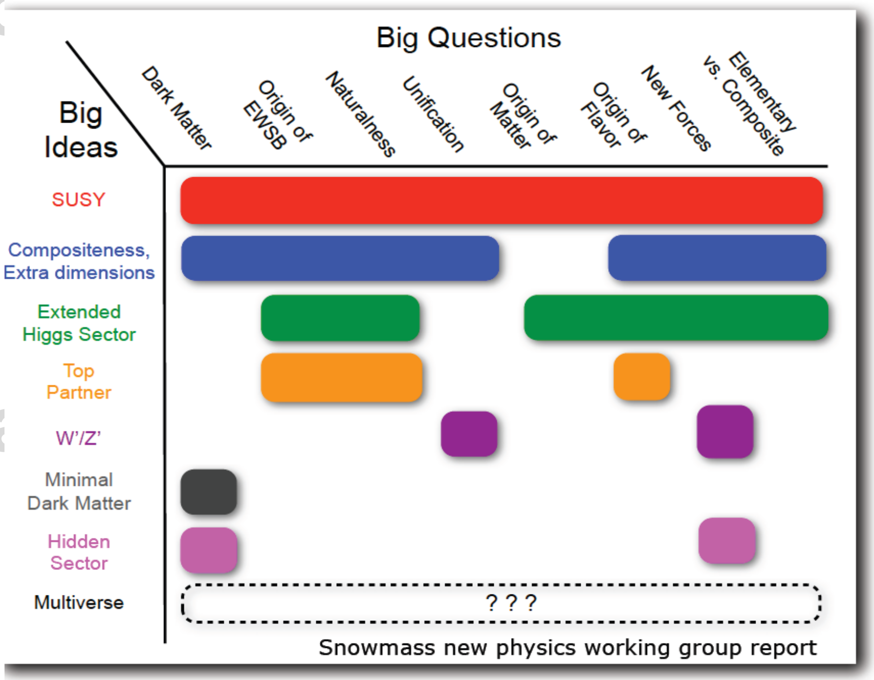
- **Indirect measurement** from the on-shell/off-shell Higgs boson production
- Measured in the $H \to ZZ(4l+2l2\nu)$ decay channels

- 3.3σ obs (2.2σ exp) exclusion of $\mu_{\text{off-shell}} = 0$
- $\mu_{\text{off-shell}} = 1.1^{+0.7}_{-0.6}$

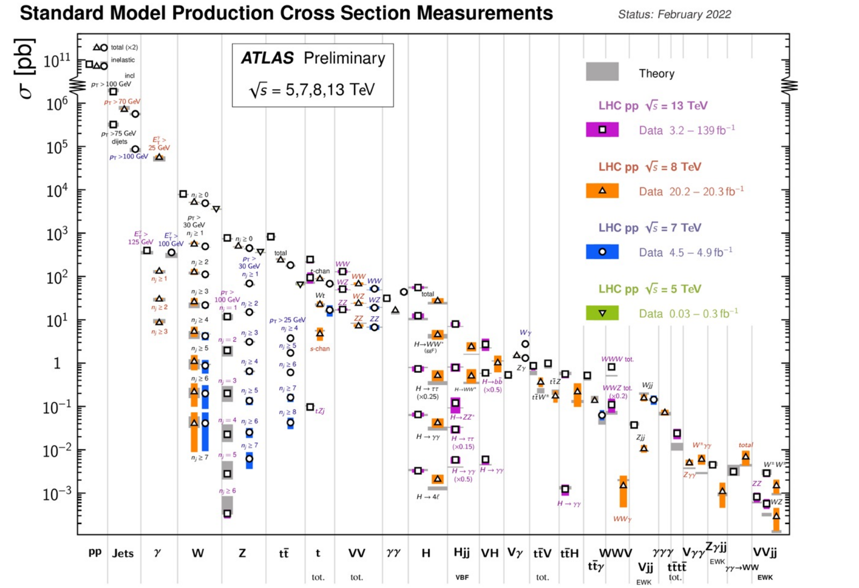
Recent physics results

- ☞ Higgs boson prec
- ☞ **BSM searches**
- ☞ SM precision mea

New Physics beyond the SM



- **SM fits the experimental data very well at EW scale, while has problem in Planck scale.**
  - Naturalness and "hierarchy" problem
  - Unification of gauge coupling
  - Dark Matter
  - ……



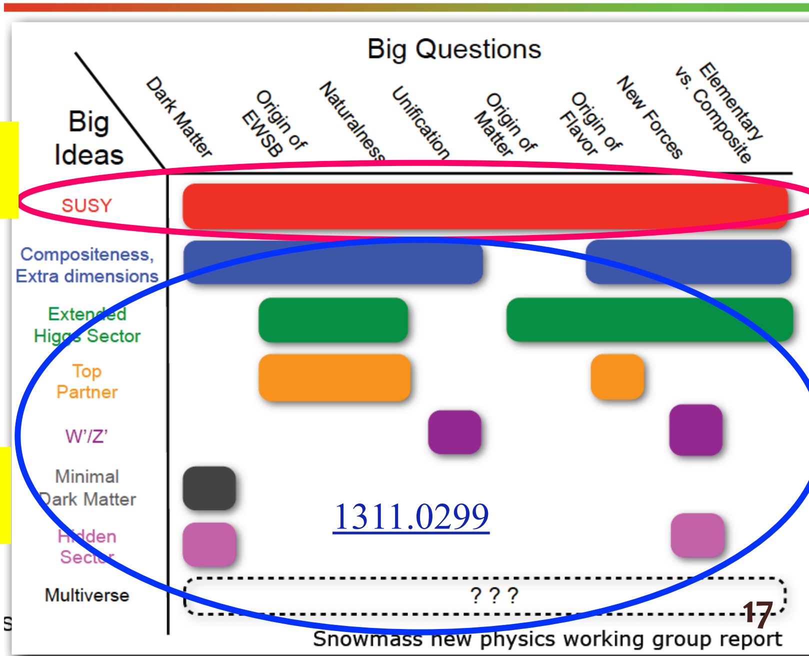
New Physics beyond the SM

SUSY

- **Need a more fundamental theory in which SM is only a low-energy approximation**

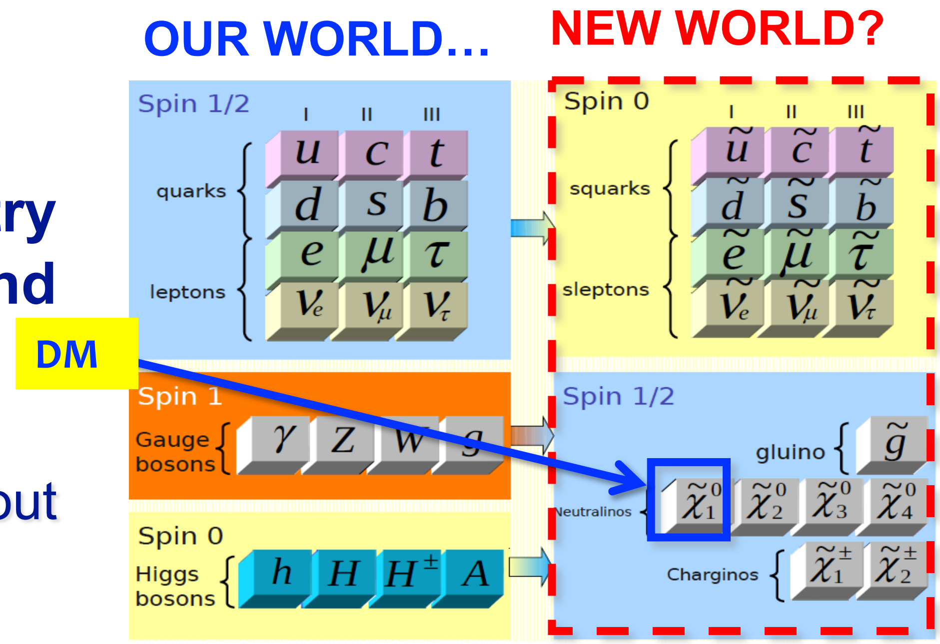
Exotics

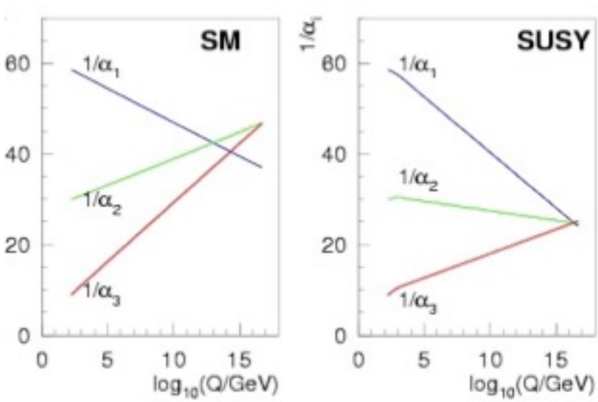
➔ **New Physics.**

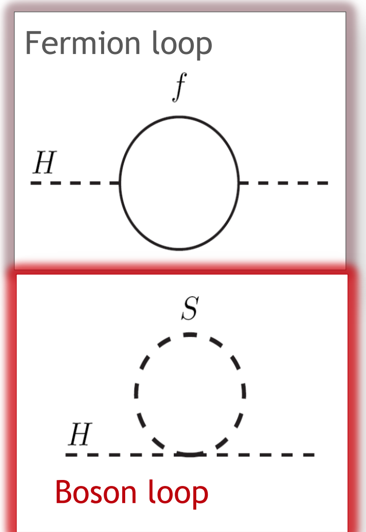


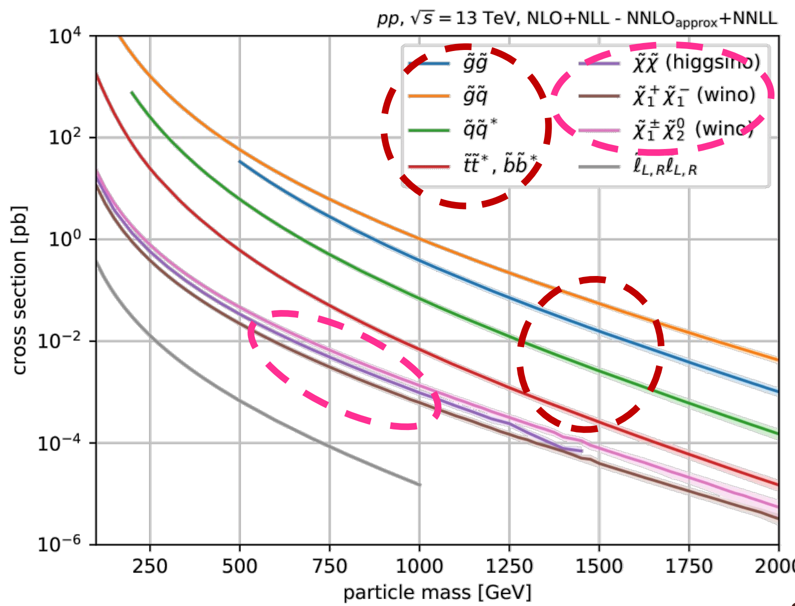
SUSY

- **SUSY establishes a symmetry between fermions (matter) and bosons (forces)**
  - Unification
  - Solve hierarchy problem without "fine tuning"
  - Provide Dark Matter candidate
  - …







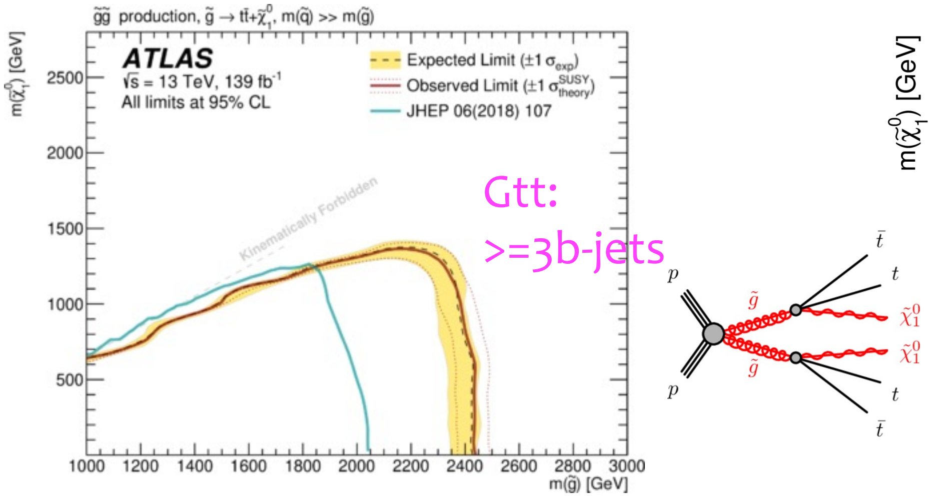


[Otilia Anamaria Ducu's talk](#)

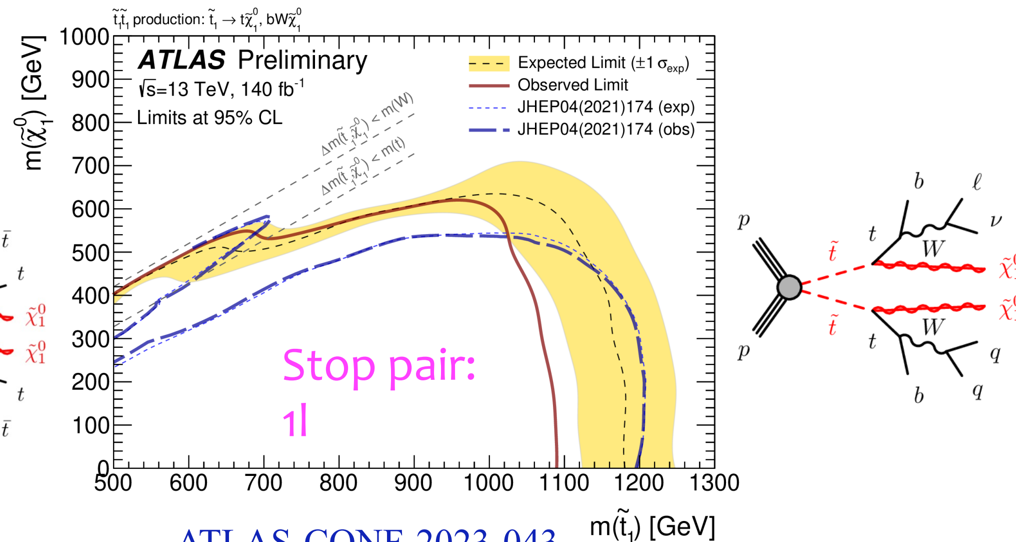
Gluino、 squark searches

- Has large xSec

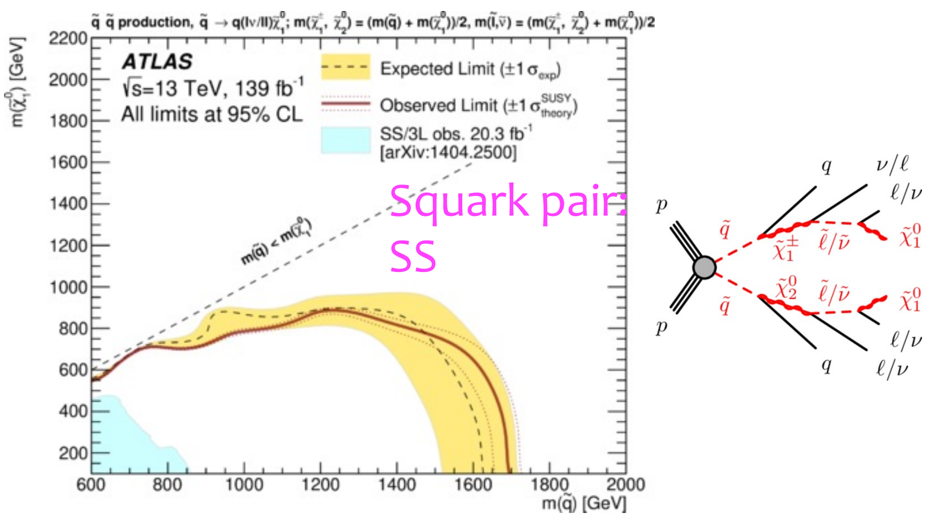
New !



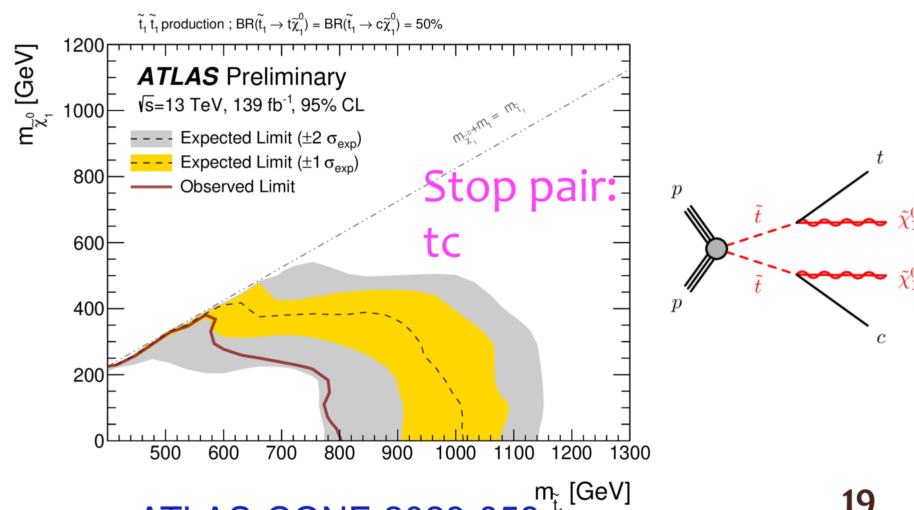
[EPJC 83 (2023) 561](#)



[ATLAS-CONF-2023-043](#)



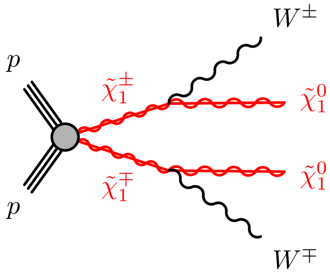
[2307.01094](#)

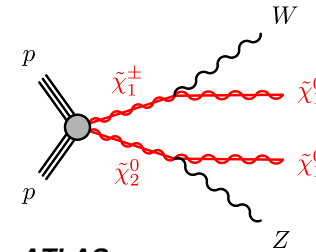


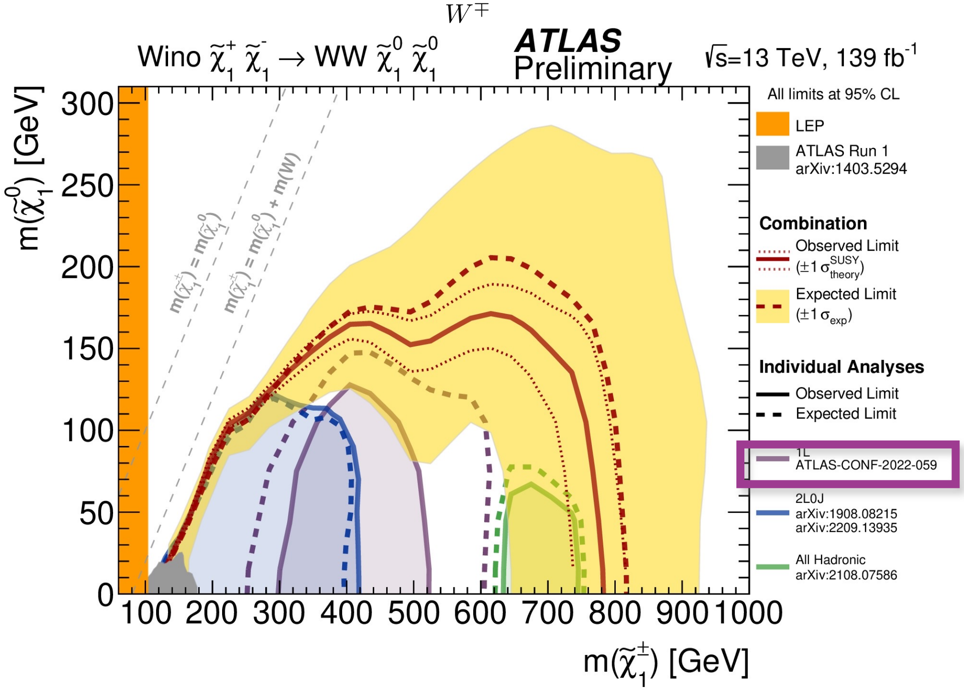
[ATLAS-CONF-2023-058](#)

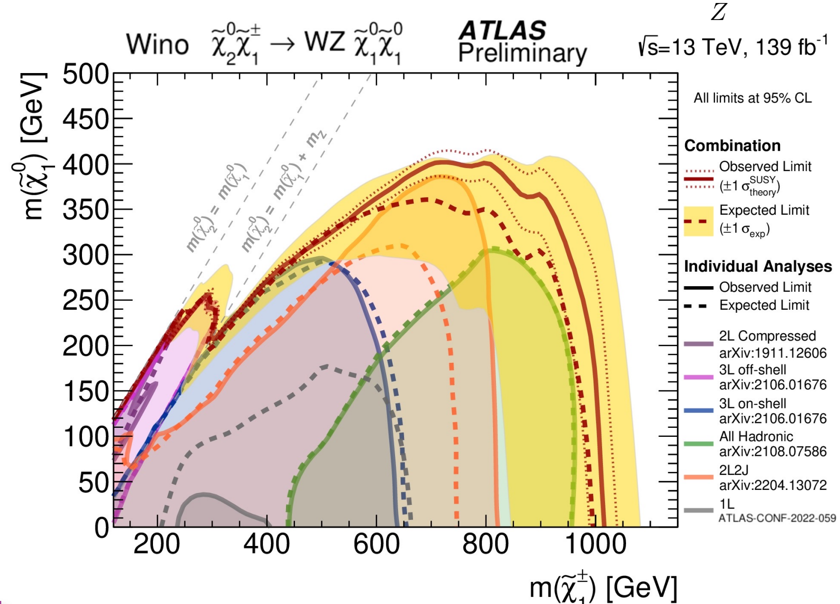
Electroweakinos via WW/WZ decay

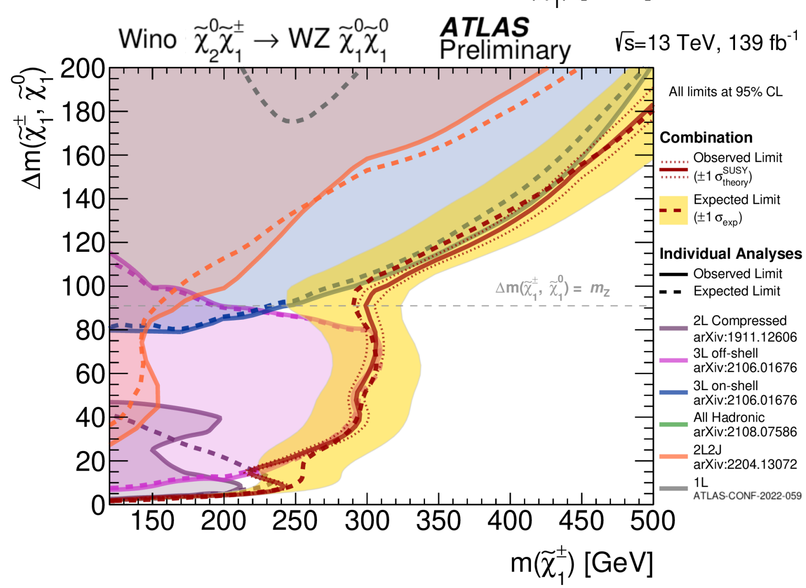
New !









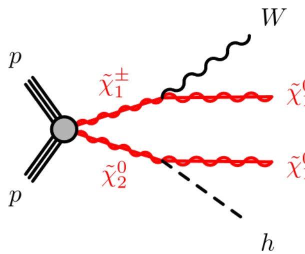


The combined results fills the gap between the individual analyses

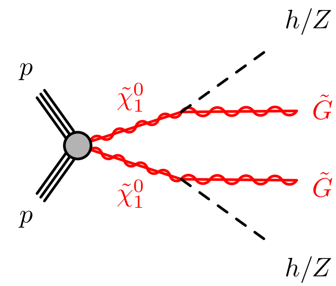
ATLAS-CONF-2023-046

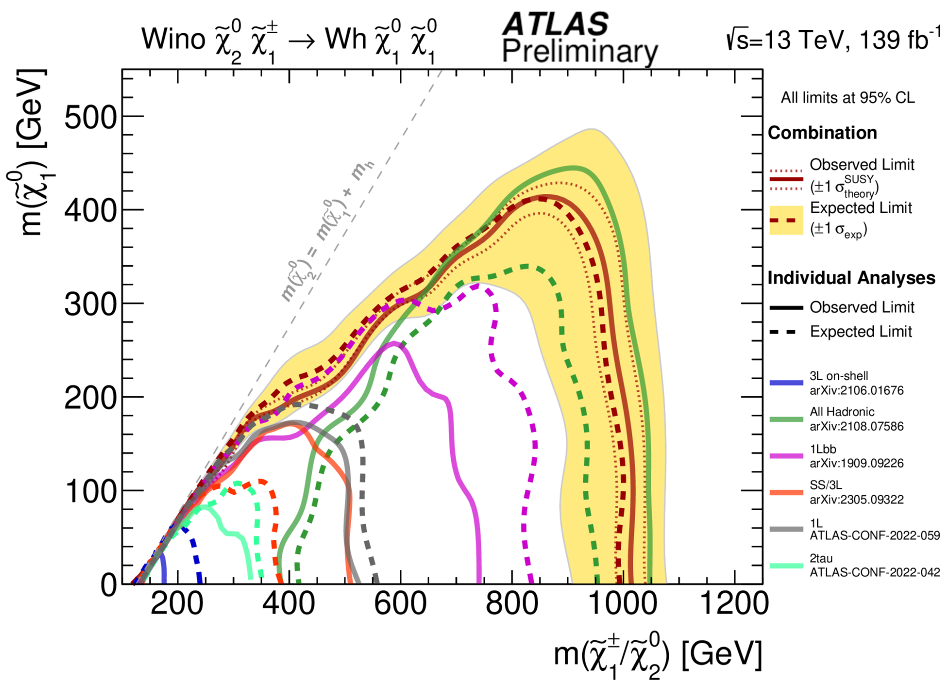
Electroweakinos via Wh/Zh/hh decay

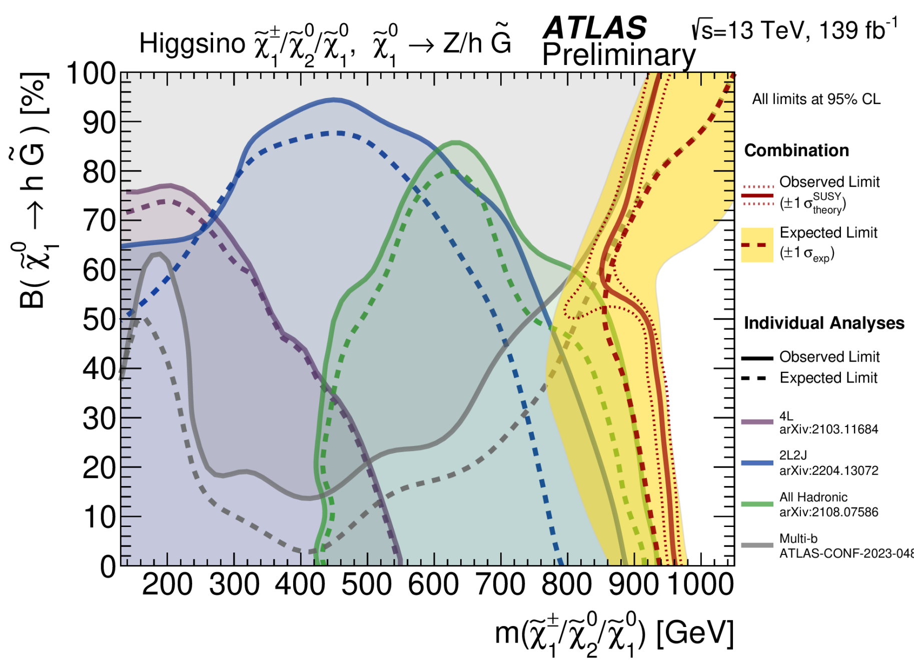
New !



Higgsino pair production via higgs or Z decay



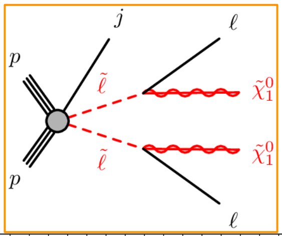


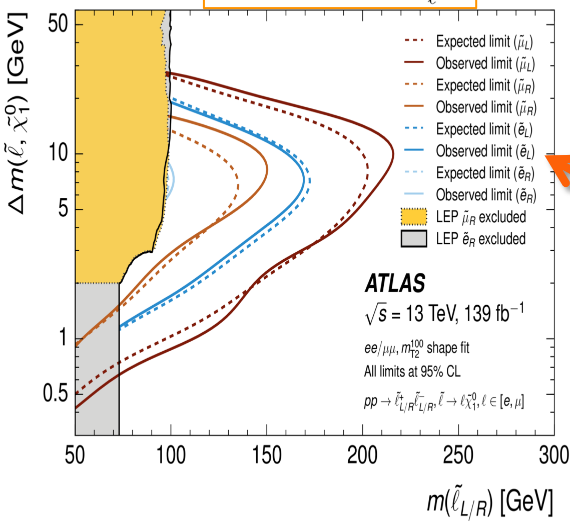


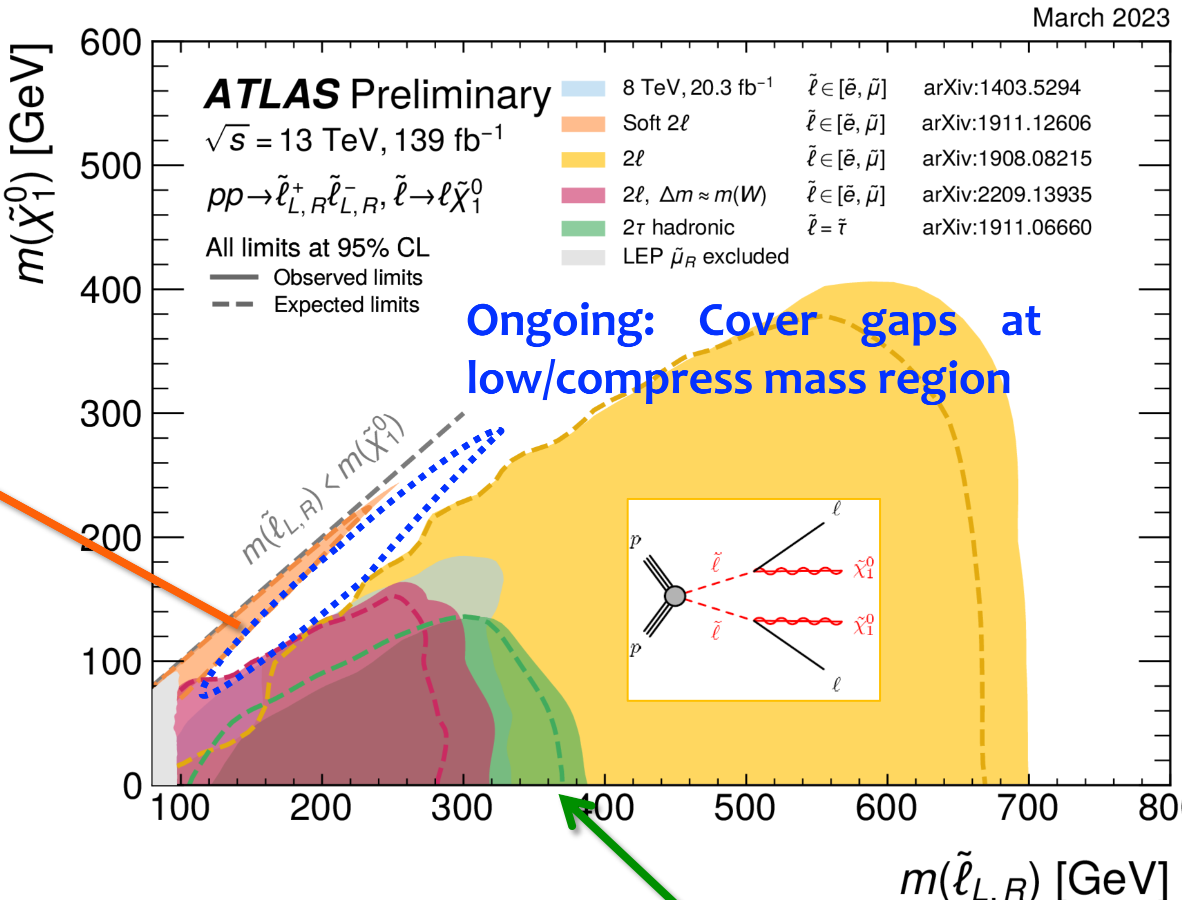
ATLAS-CONF-2023-046

Sleptons

ATL-PHYS-PUB-2023-005







Ongoing: Cover gaps at low/compress mass region

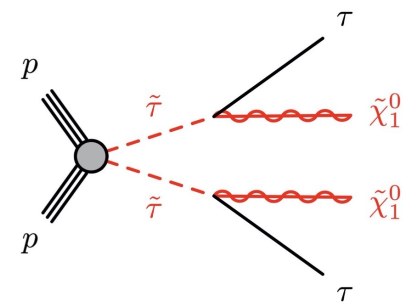
Stau updated

Limits maybe different in case of cascade decays of the sleptons into lighter electroweakino states

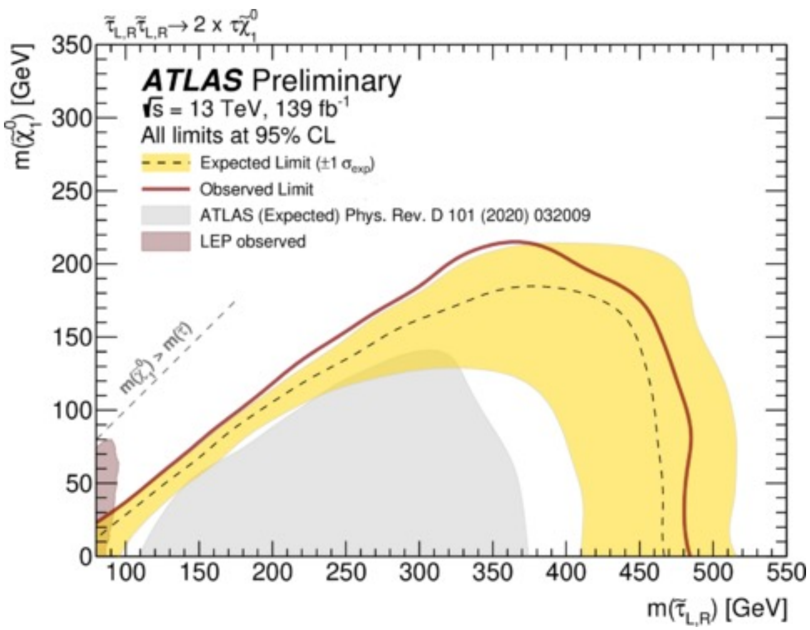
Stau search

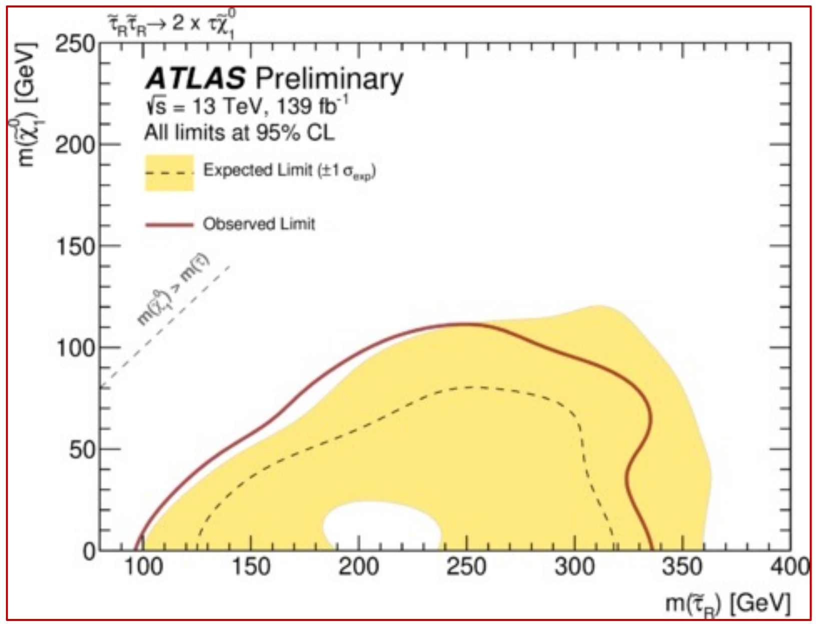
ATLAS-CONF-2023-029

- Final states with taus are challenging but interesting:
  - Dark matter probe and light sleptons could play role in neutralino coannihilation in Early Universe
- Improved **TauID** based on **Recurrent NN**
- **BDT** based on kinematic variables used to signal signal candidates



New !





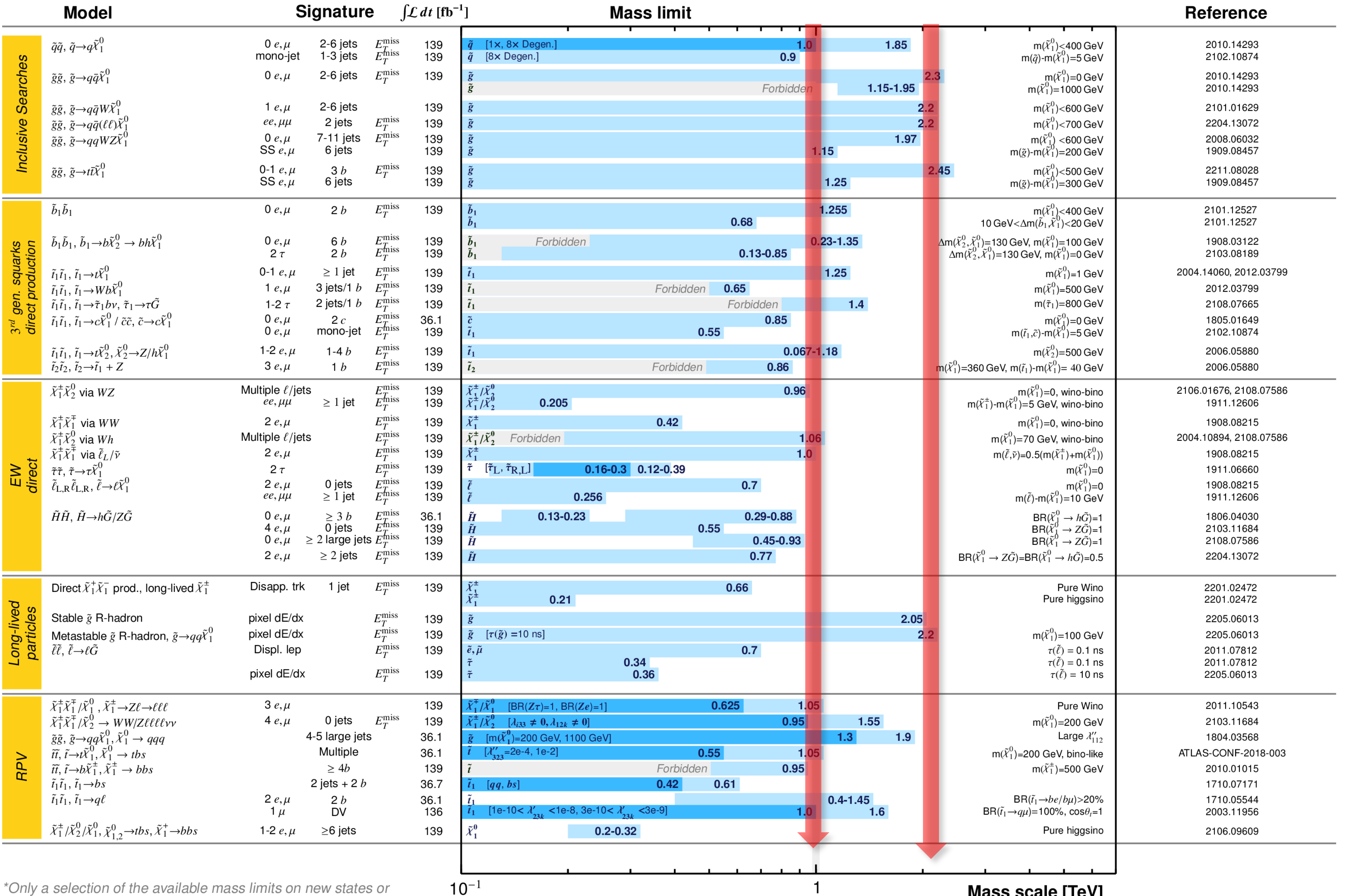
First exclusion for stau_R only at LHC (up to 330 GeV) !

ATLAS SUSY Searches* - 95% CL Lower Limits

March 2023

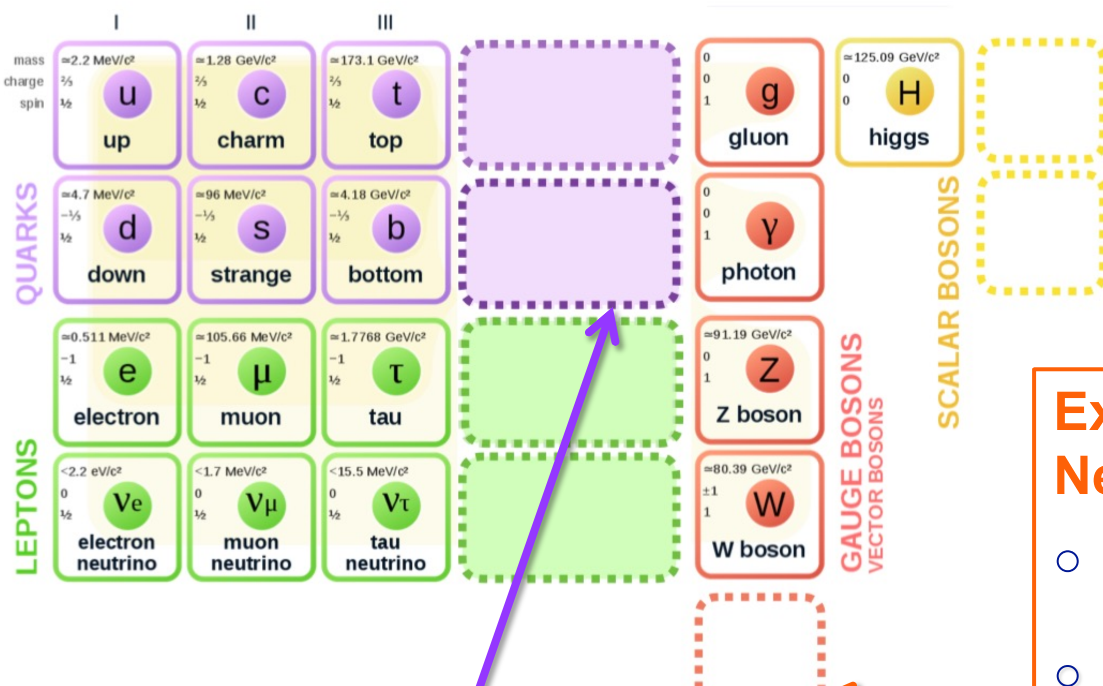
ATL-PHYS-PUB-2023-005

ATLAS Preliminary $\sqrt{s}$ = 13 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.

Exotics - various extensions of SM



Extended Higgs Sector

- A common feature in SUSY models
- Mixing with Higgs

Extended Gauge Sector / New bosons

- Extra dimension models (V KK,GKK, …)
- Grand unification theories (leptoquarks, …)
- Technicolor, composite Higgs (W', Z',…)

Extended Fermion Sector

- Heavy quarks (T, B)
- Excited fermion (q*,l*,ν* …)

Compositeness

- New forces/particles integrate out at low energies (SM)

Exotics: Jun Guo's talk; DM: Bisnupriya Sahu's talk

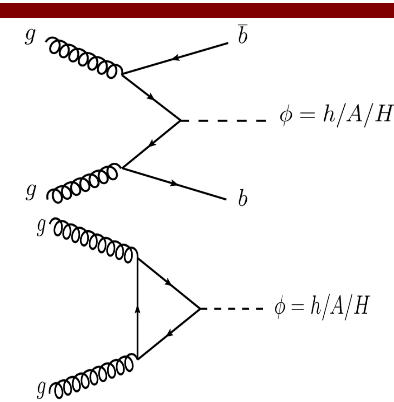
Heavy Higgs: Spyros Argyropoulos's talk

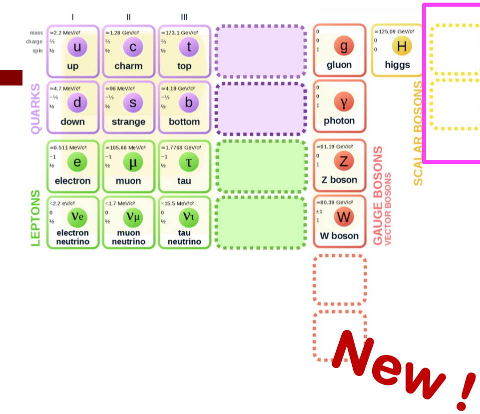
Extended Higgs sector – BSM Higgs

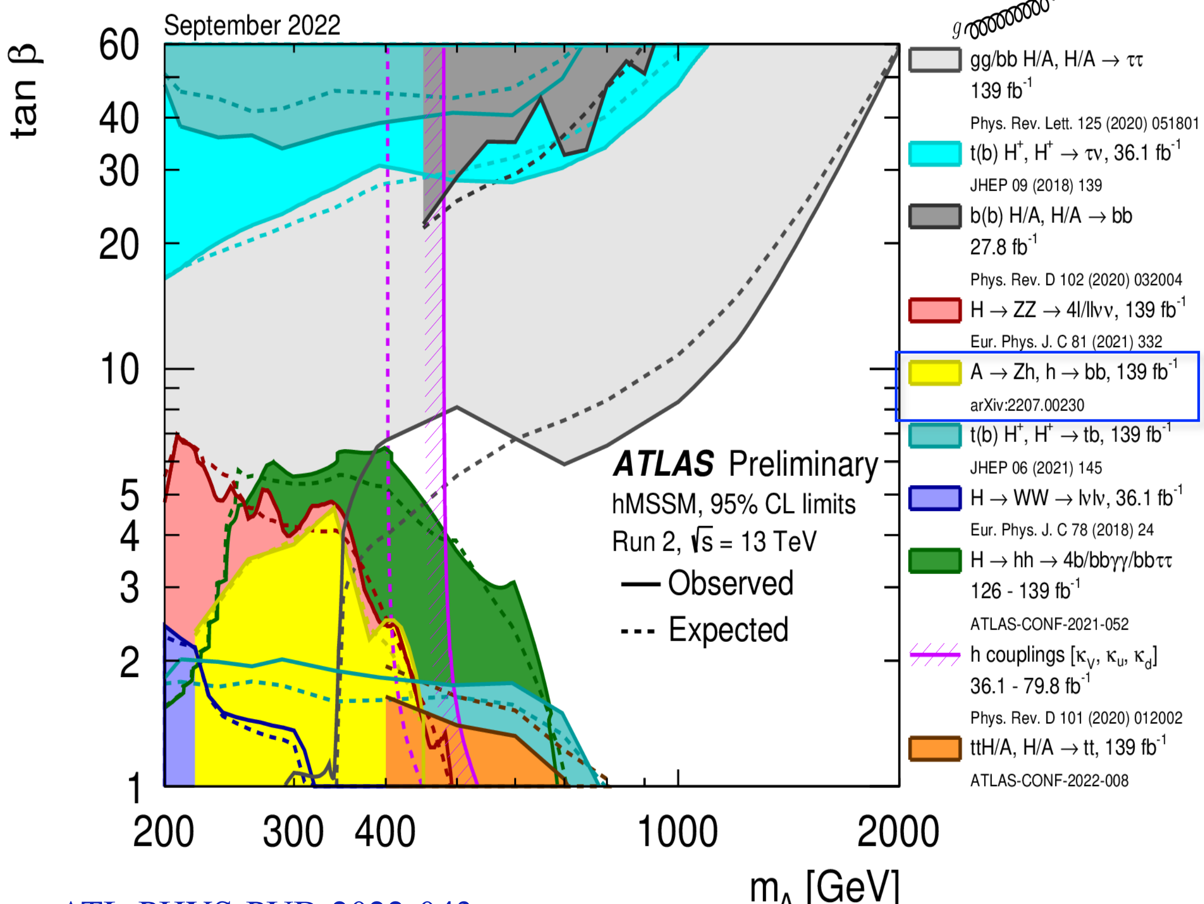
Many models: MSSM, 2HDM, etc.

☞ **Benchmark models: MSSM-like**

- **5 Higgs bosons:** h, H, A, $H^{\mp}$
- **2 free parameters at tree level:** m_A, $\tan\beta = \nu_u/\nu_d$

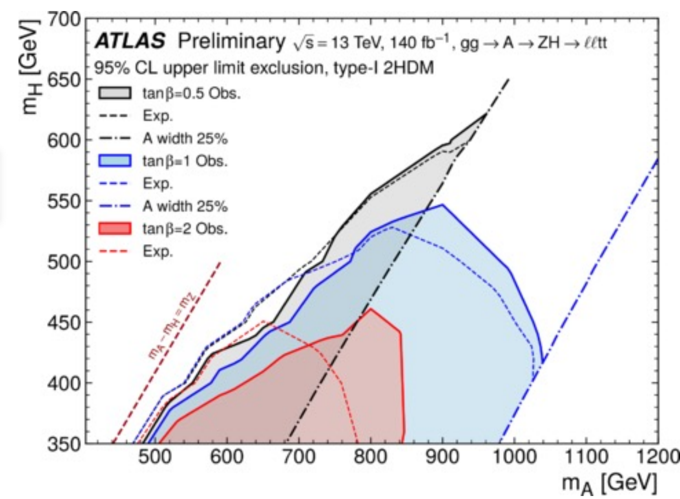






ATL-PHYS-PUB-2022-043

New channels explored:
A→ZH (lltt, ννbb)

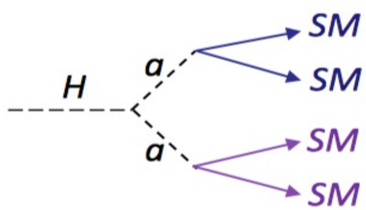


ATLAS-CONF-2023-034

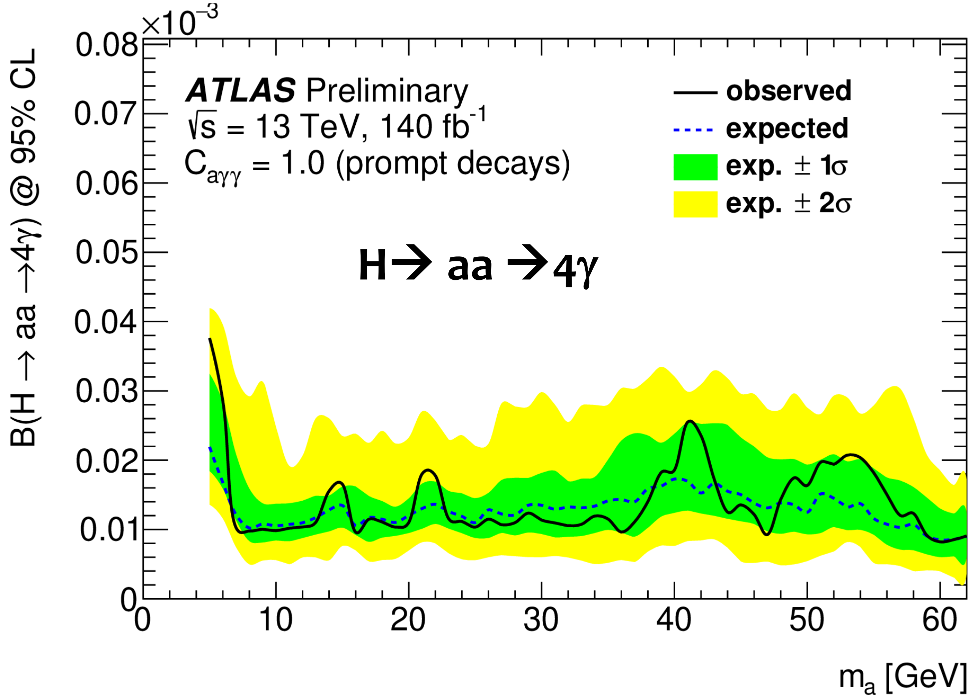
Extended Higgs sector – BSM Higgs

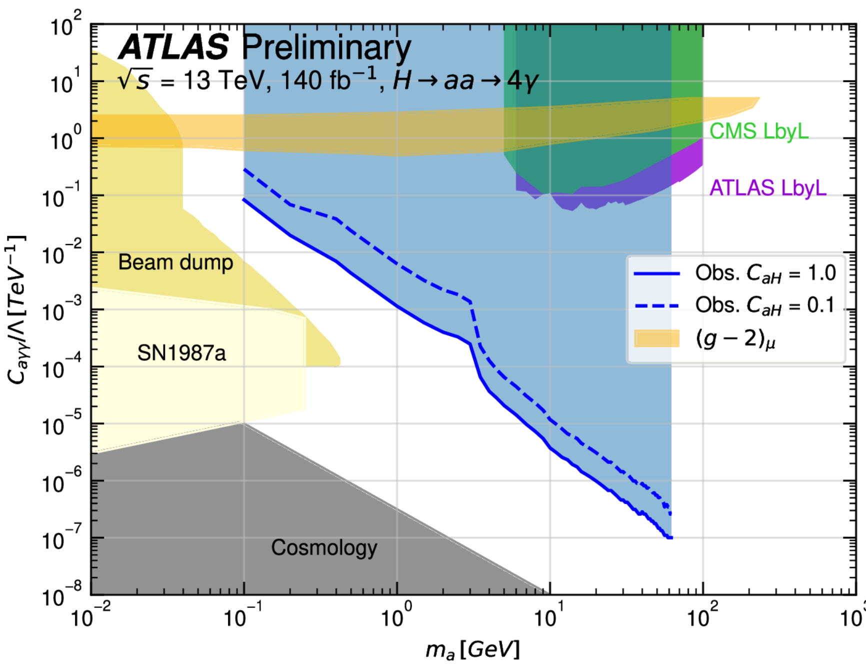
☞ 2HDM+Singlet model: Searches for H→aa→4γ

✓ Axion-like particles (ALPs) decaying into $\gamma\gamma$ is sensitive to various models that could explain $(g\text{-}2)_\mu$ discrepancy



New !





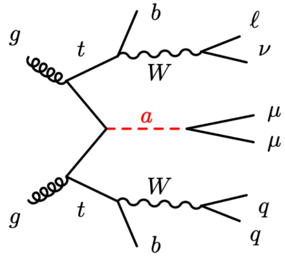
ATLAS-CONF-2023-040

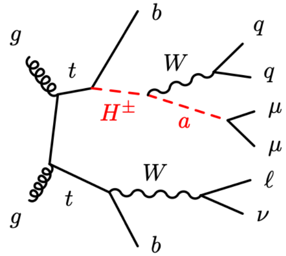
Pseudo-scalar a with top quarks

New !

Light pseudoscalar a→μμ is well-motivated

- Enables strong first-order EW phase transition
- Two searches: tta or tt with t→H⁺b, H⁺→Wa





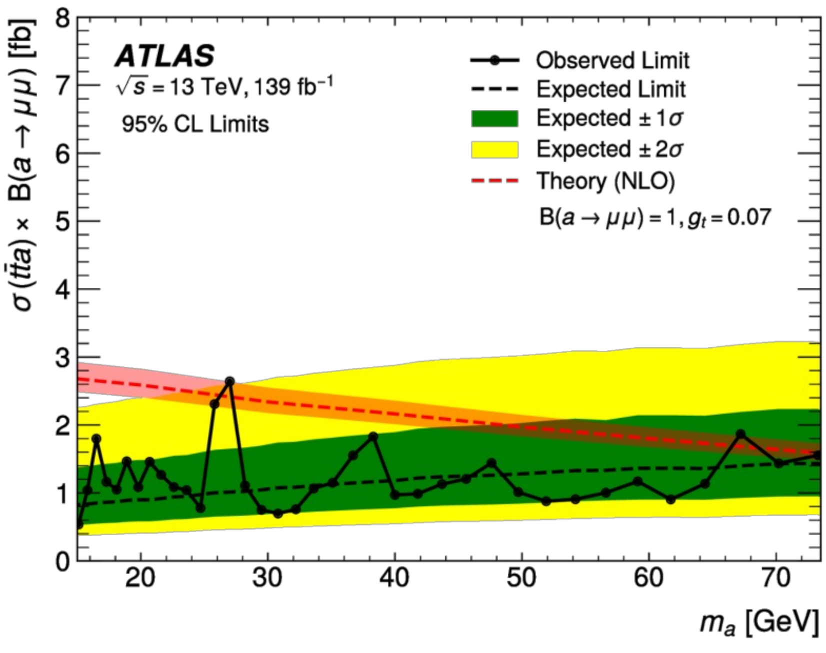
- Select eμμ or μμμ events with $12 < m_{\mu\mu} < 77$ GeV

- Limits set on σ (pp→tta)×Br(a→μμ)

  - 0.5-3 fb, **local 2.4σ excess at 27 GeV**
  - Also set limits on m_H and m_a

    $120 < m_{H+} < 160$ GeV

    15 GeV $< m_a < 72$ GeV
  - Statistically limited search → Run3 data



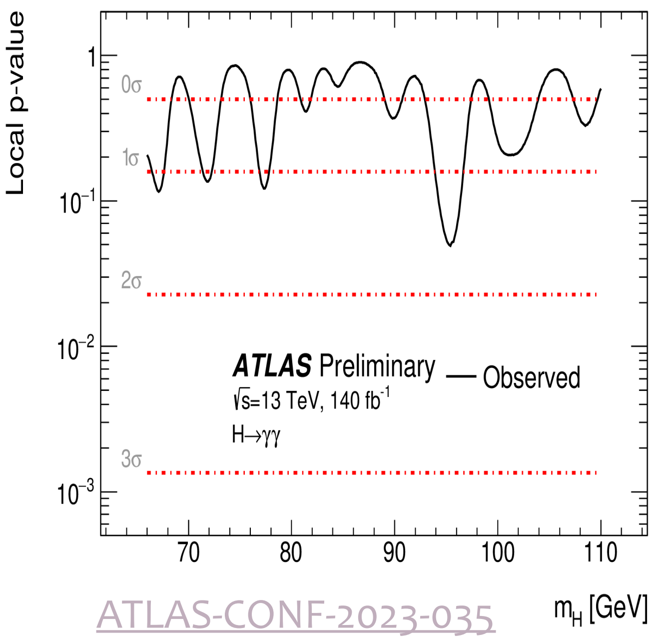
arXiv:2304.14247

Light Higgs search

New !

- 2HDM and Axion-like particle models predict light Higgs
- Two searches for γγ resonance at low mass regions

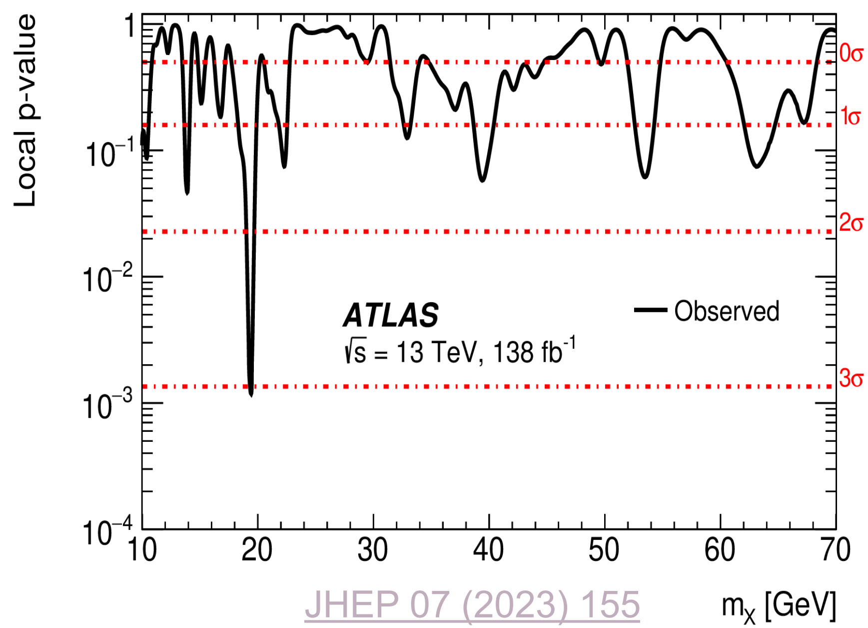
Search for γγ resonances in the mass range [65 , 110] GeV



ATLAS-CONF-2023-035

Local **1.7σ** @ m ≈ 95.4 GeV

First search for γγ resonances in the mass range [10 , 70] GeV



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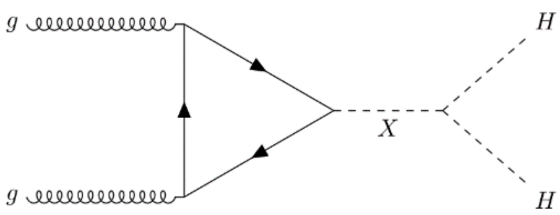
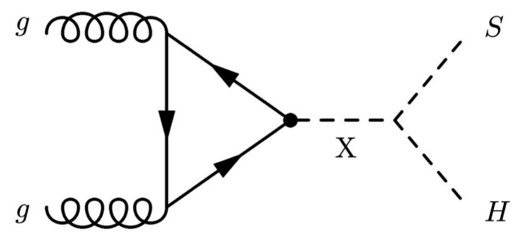
Local (global) **3.1 (1.5) σ** @ m ≈ 19.4 GeV

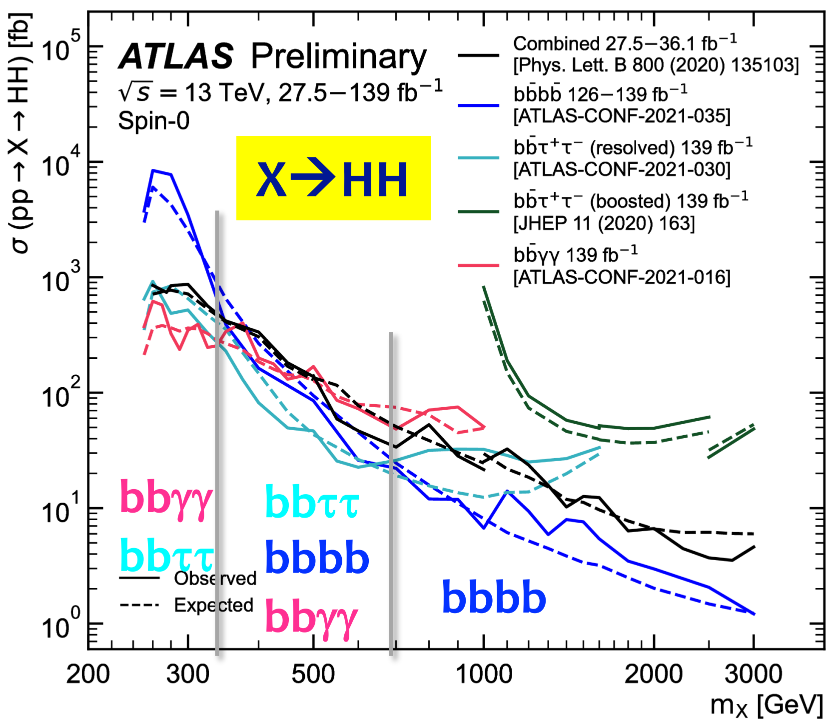
Heavy resonance X (→HH, SH)



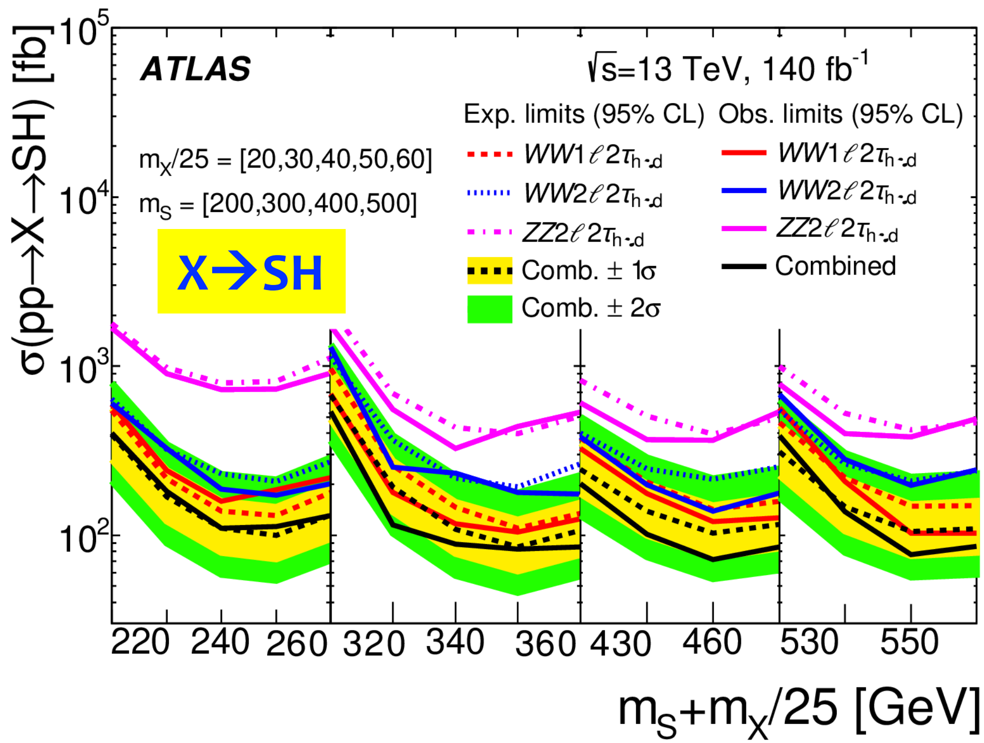


H→ττ

S →WW/ZZ → light leptons



ATL-PHYS-PUB-2021-031

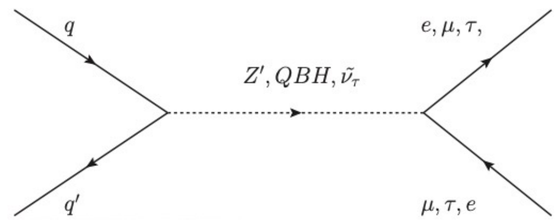


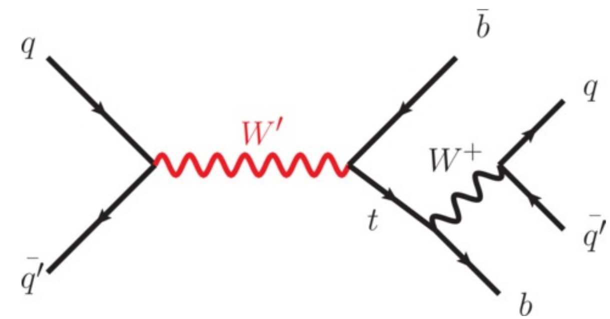
arXiv:2307.11120

Extended gauge sector – Resonance

- **Predicted by many BSM models:**
  - ED (Randall-Sundrum (RS) Graviton), Heavy Vector Triplet (HVT: W′, Z′), DM mediator, …

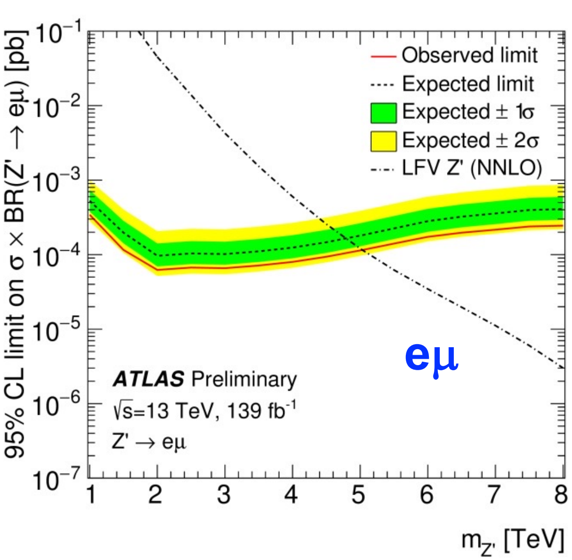
- **Search for BSM from small couplings of LFV**

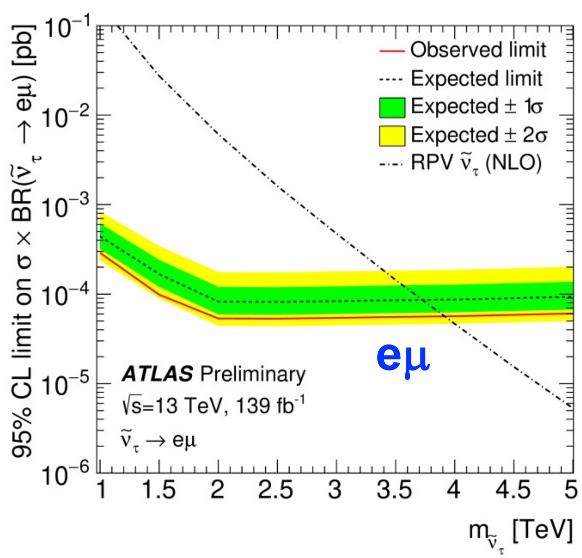


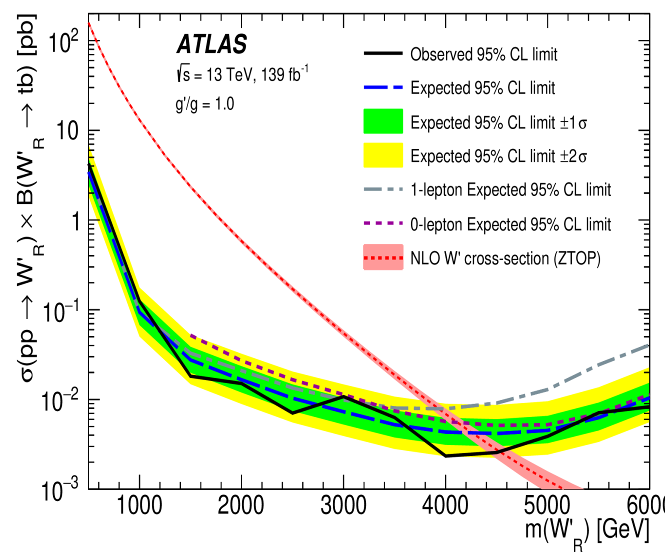


Z'→eμ

$\tilde{\nu}_\tau \rightarrow e\mu$







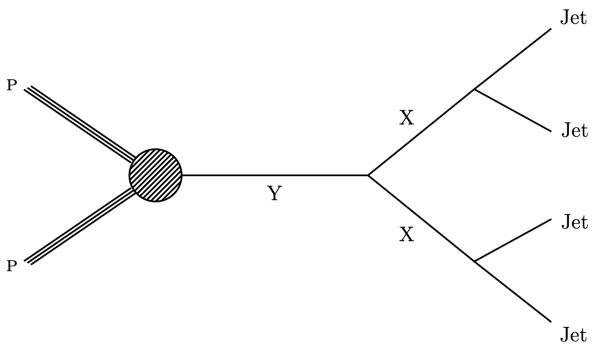
2307.08567

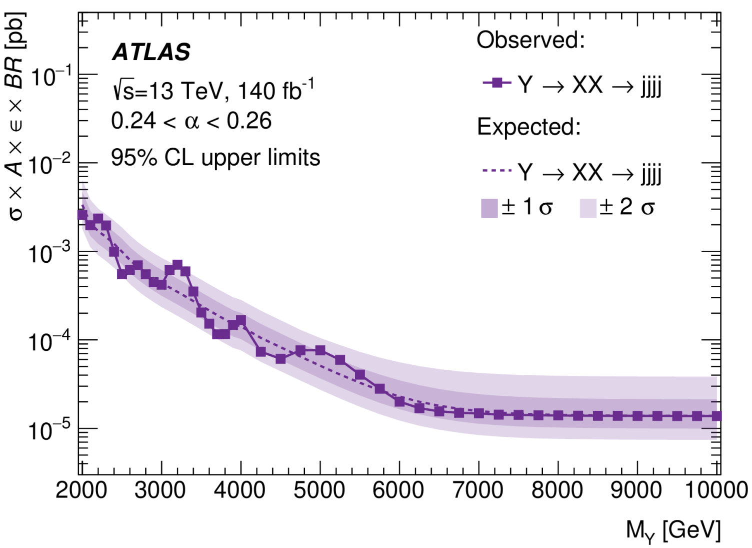
2308.08521

Extended gauge sector – Resonance

New !

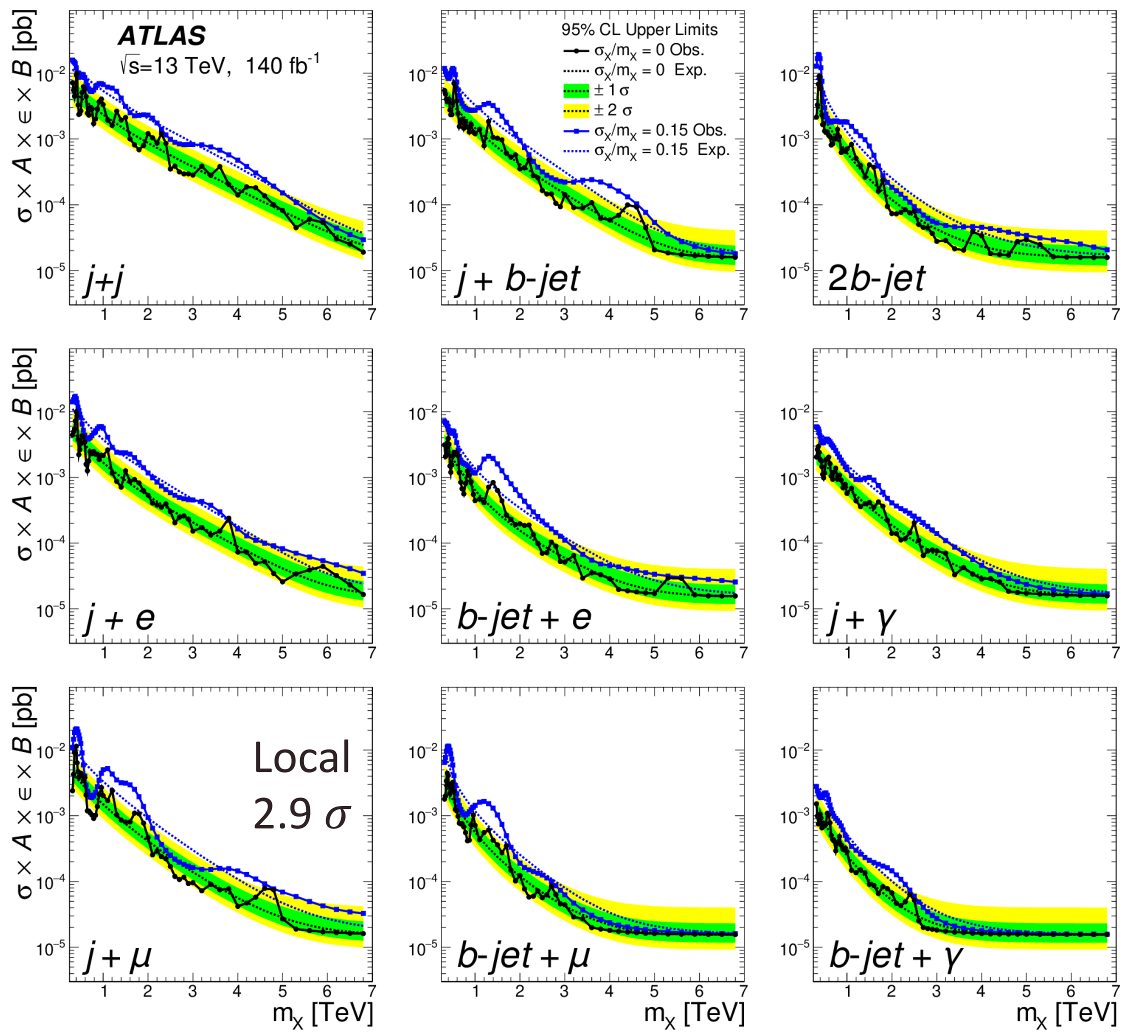
Di-jet resonance





arXiv:2307.14944

Jet+X 2body resonance



arXiv:2307.01612

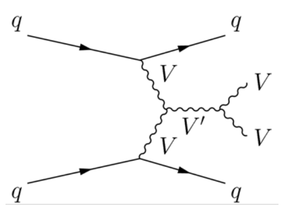
Signal width: 0%, 15%

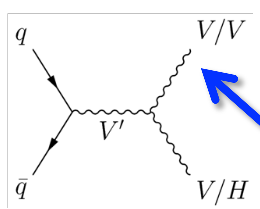
Extended gauge sector – Resonance (VV)

- **Predicted by many BSM models:**
  - ED (Randall-Sundrum (RS) Graviton), Heavy Vector Triplet (HVT: W′, Z′), DM mediator, …

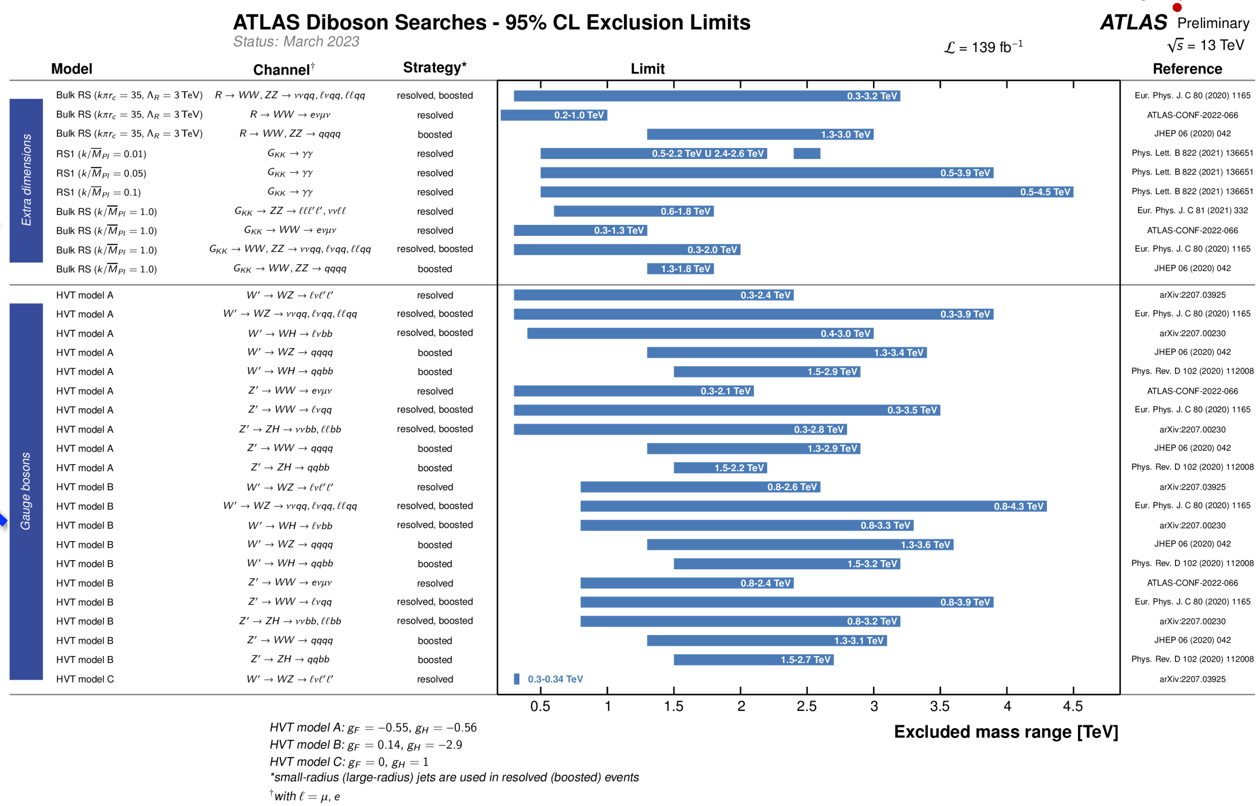
- Spin-2 bulk **RS Graviton**
  $G_{KK} \to WW/ZZ$

- Heavy Vector Triplet **(HVT)**





New !



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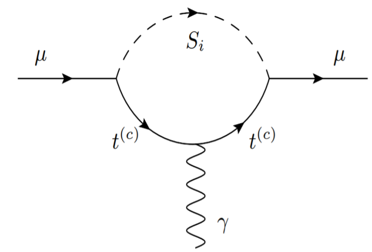
Extended gauge sector – Leptoquarks (LQ)

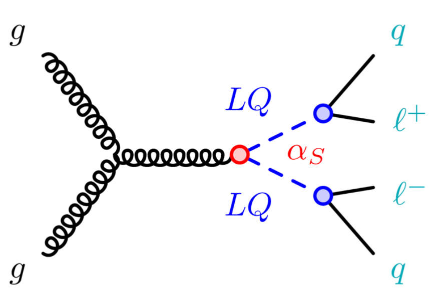
New !

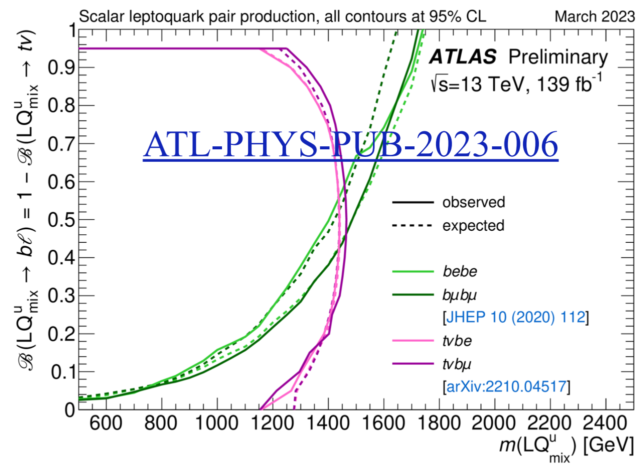
- **Leptoquarks (LQs)** arise in many models, such as grand unified theories, compositeness models and superstring theories.
- **Scale LQs: Could explain μ g-2**

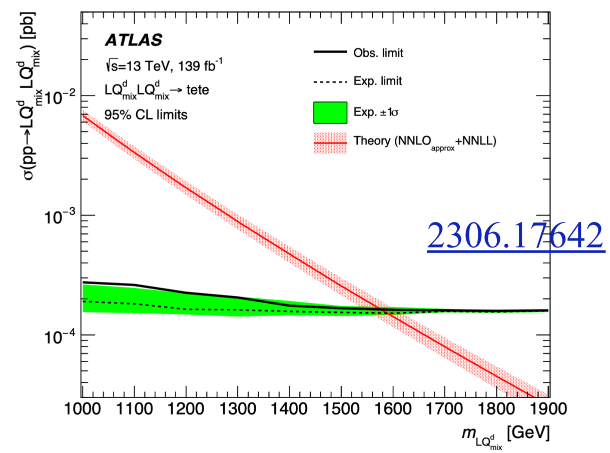


m(LQ$_{mix}$) > 1.2-1.7TeV

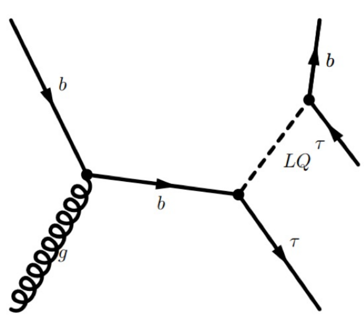
Pair LQs (top)



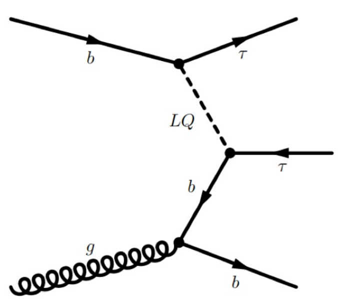


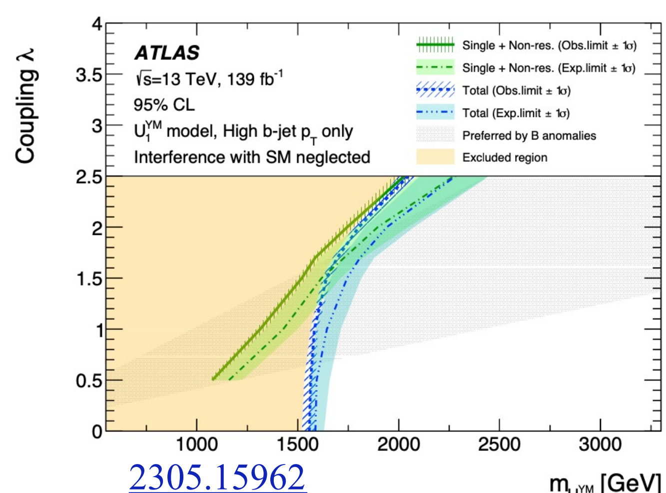


Single LQ



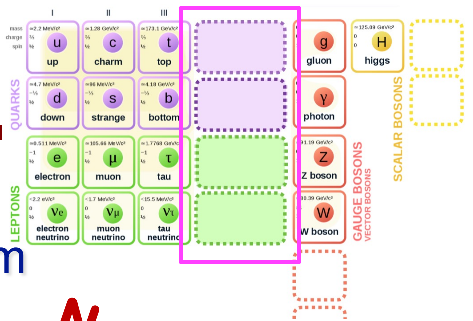
Non resonance





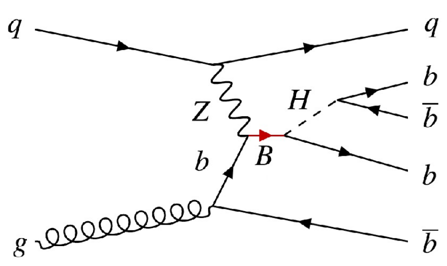
2305.15962

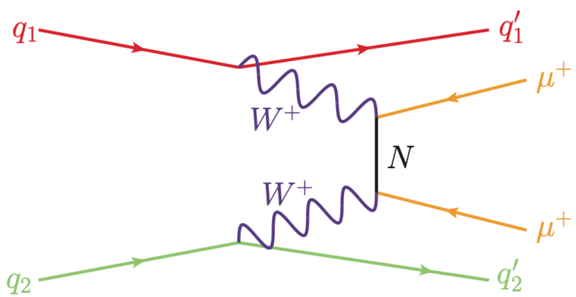
Extended fermion sector

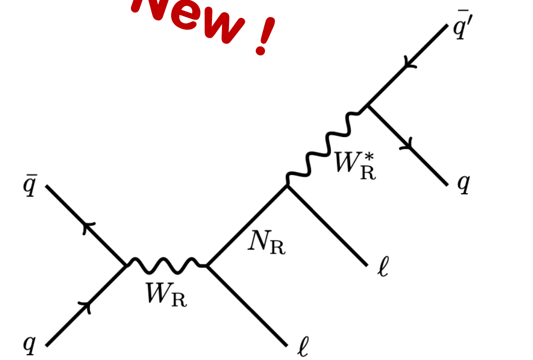


- Heavy Vector-like fermions (T, B, Tau, N …)
  - New heavy partner of top in loop to solve hierarchy problem
  - constraints on Singlet/Doublet BB, TT: 1.2-1.4 TeV
- Excited fermion (q*,l*,v* …)

New !

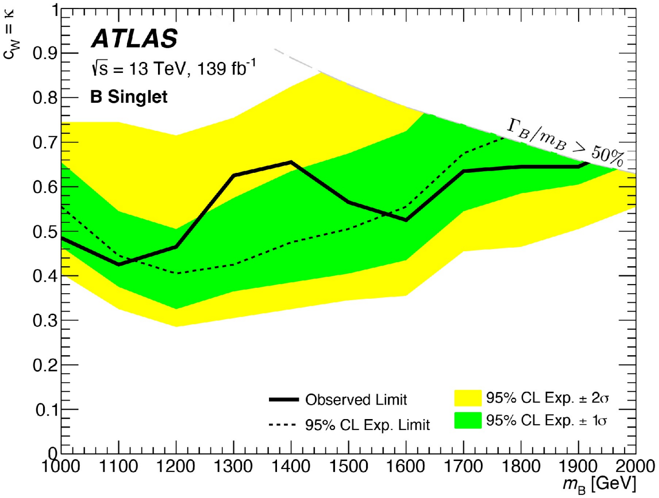


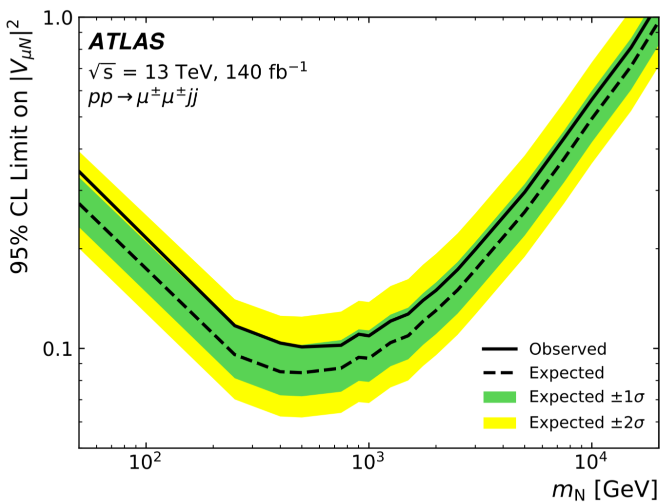


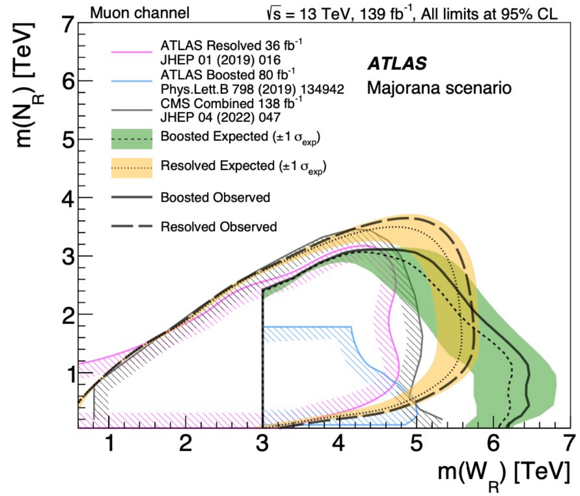


Singlet B

Heavy neutrino N







2308.02595

2305.14931

2304.09553

DM search at colliders

SUSY, simplified models,
2HDM+a, Higgs portal DM,…

Simplified models:

(mono-X: E_T^{miss}+X; mediator: resonance)

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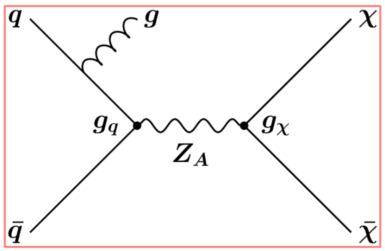
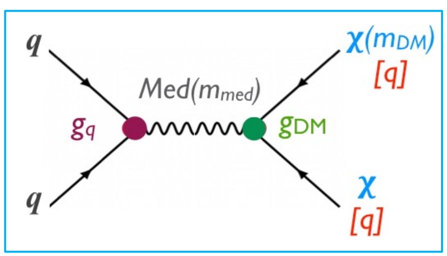
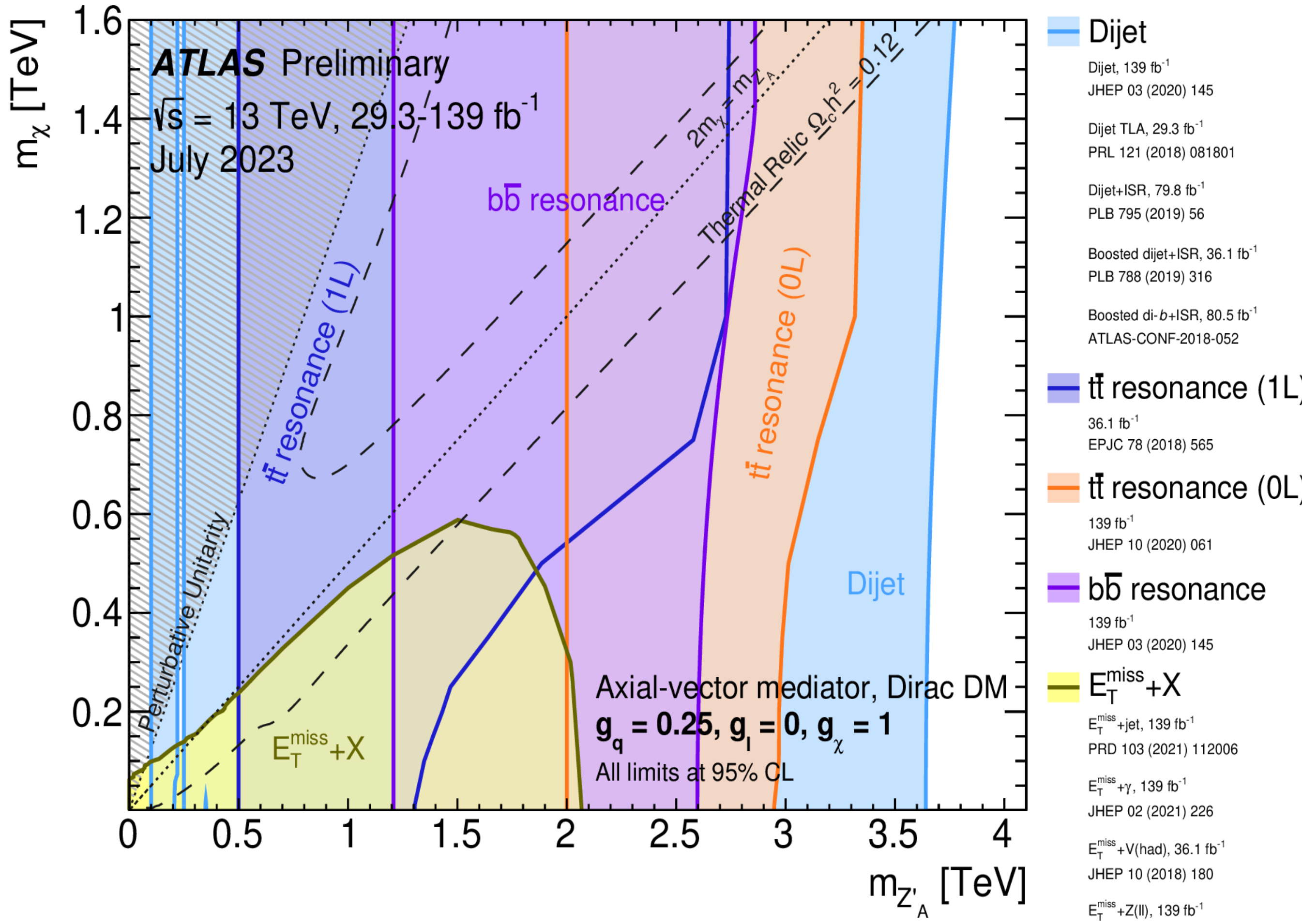


mono-X: E_T^{miss}+X
X: jet, γ, V, H …



mediator: resonance of
di-jet, bb, tt



DM search at colliders

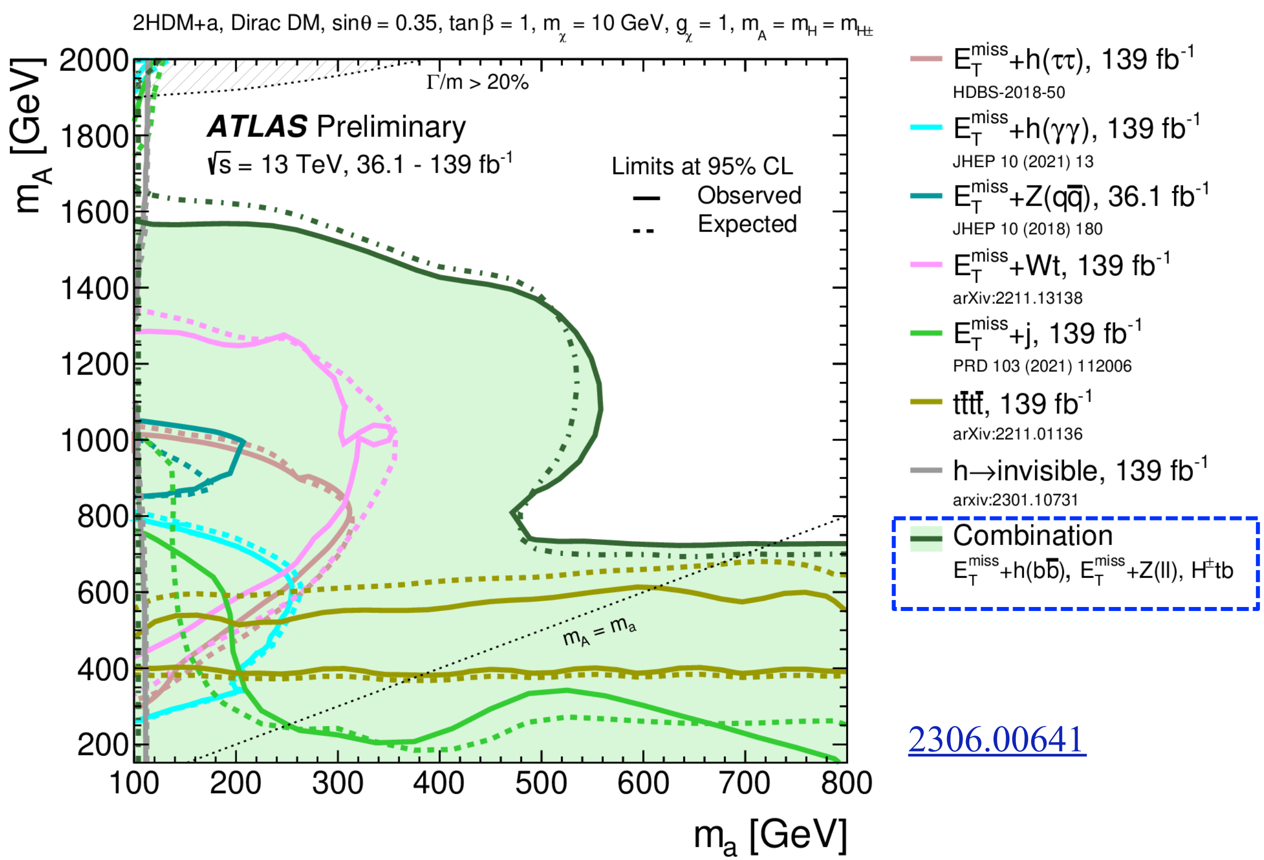
SUSY, simplified models, 2HDM+a, Higgs portal DM,…

■ 2HDM+a model:

The results w or w/o MET signatures also used to constrain a 2HDM with pseudo-scale mediator "a" model

A statistical combination of the three most sensitive searches is performed:

- MET+ $H \rightarrow bb$
- MET+leptonically decaying Z bosons
- charged Higgs bosons with top and b quarks



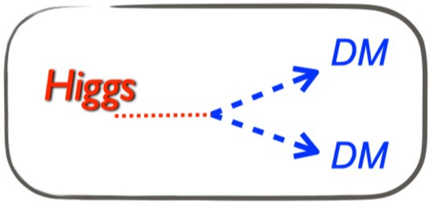
2306.00641

DM search at colliders

SUSY, simplified models,
2HDM+a, Higgs portal DM,…

Higgs portal DM:

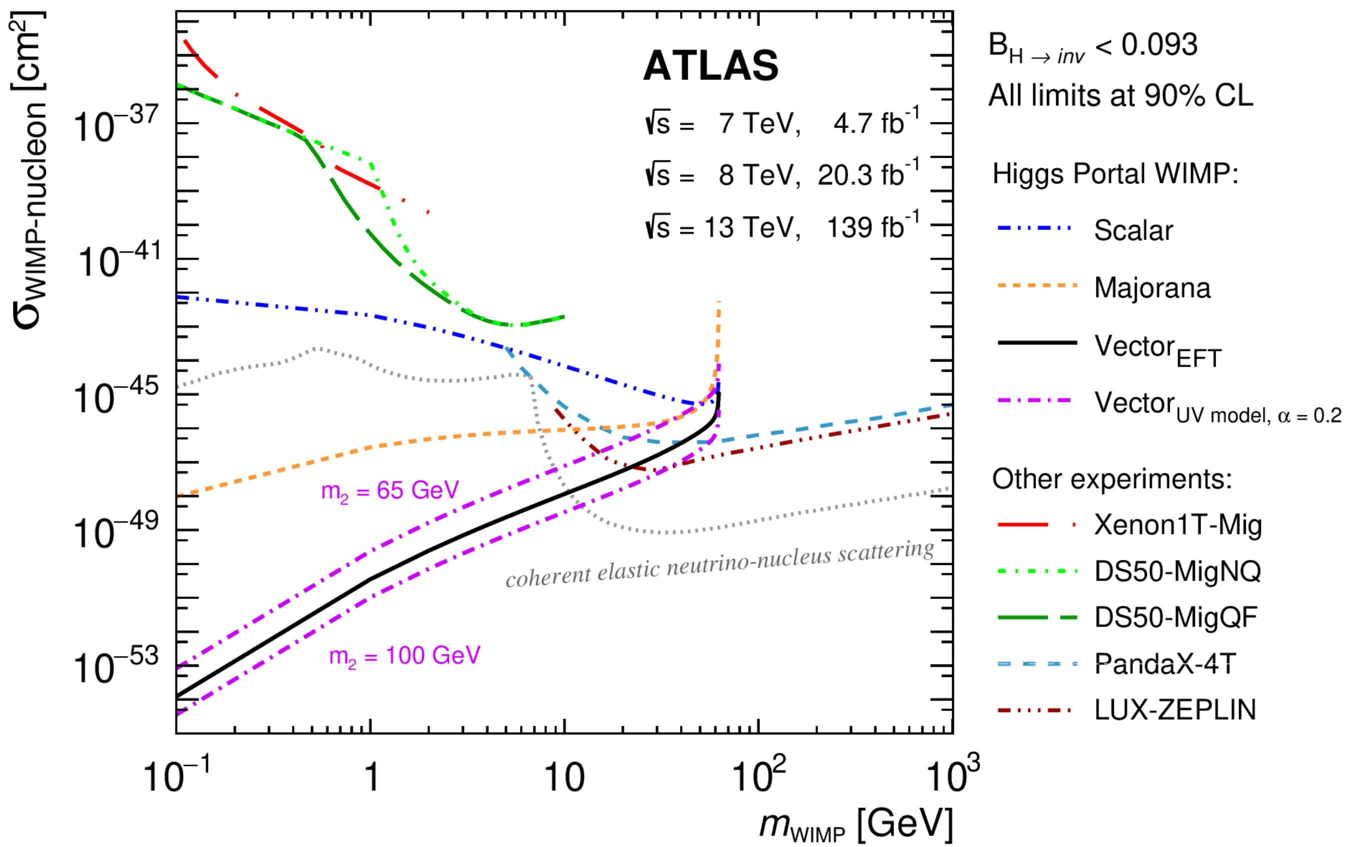
Direct coupling H-DM will enhance H invisible decays (SM ~0.1%)



Phys. Lett. B 842 (2023) 137963

- The combination of results (all H prod.) are interpretated in Higgs portal DM

- The limits setting on the scattering cross section of WIMP and nucleons

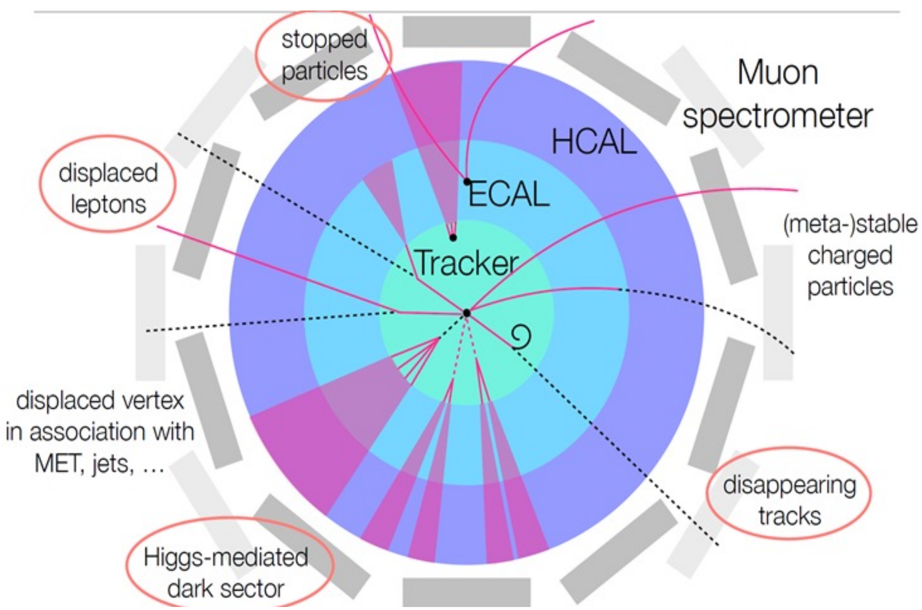


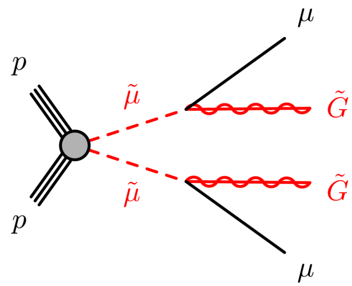
Long-lived particles

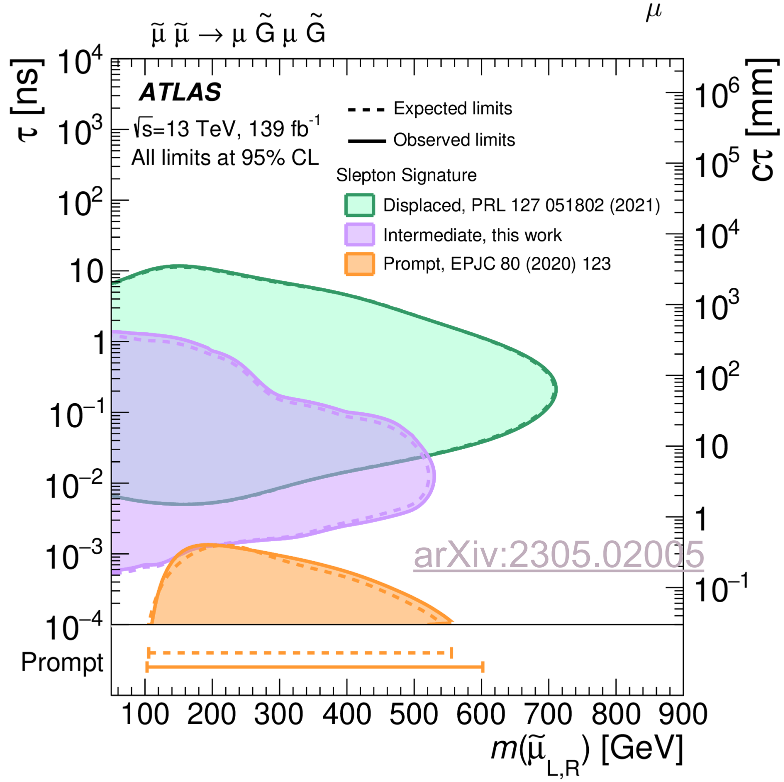
New !

Long lifetimes result from a few simple physical mechanisms:

- Small couplings (ex. RPV SUSY)
- Limited phase space: small mass splitting (ex. compressed SUSY, …)
- Heavy intermediate states
- ……





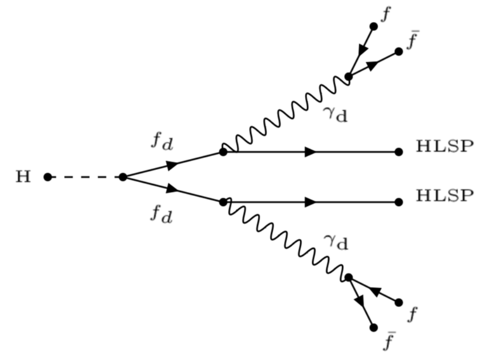


Smuon lifetimes down to 1 (10) ps are excluded for a smuon mass of 100 (520) GeV

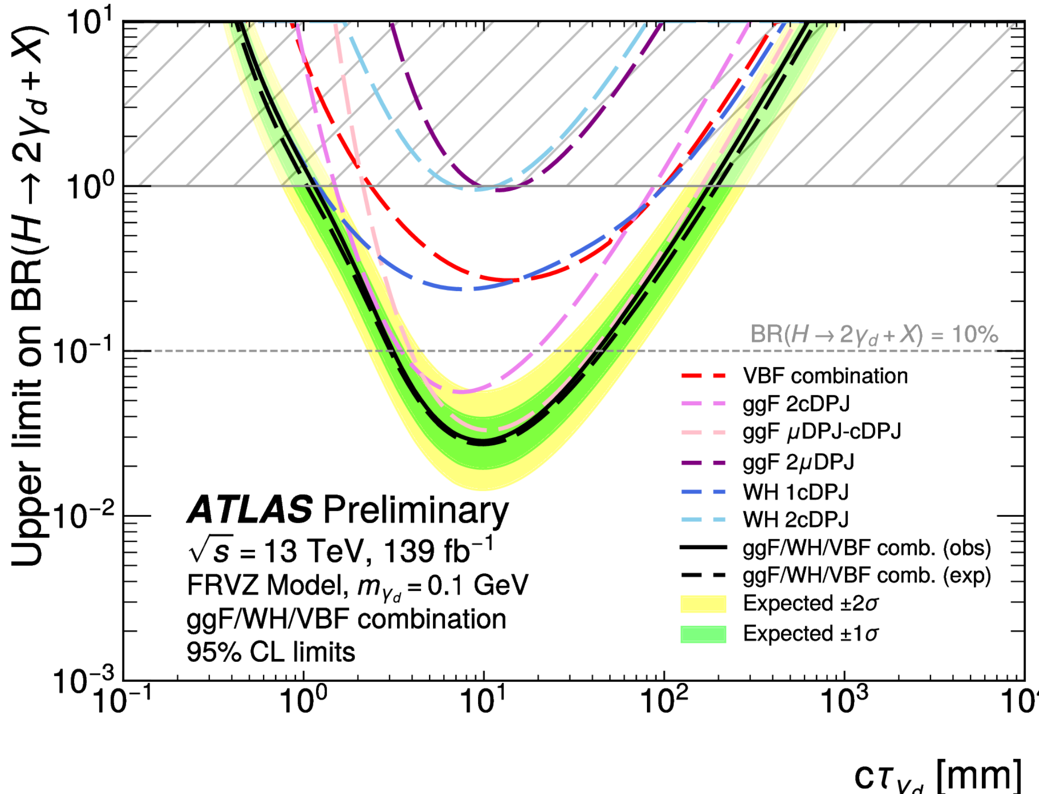
Displaced dark photon

New !

- Many BSM predict the existence of dark sectors that are weakly coupled to the SM
- The scenario where the SM and the dark sector interact through a Higgs portal to produce BSM states has been studied
- A search for **displaced dark photons** with masses between 0.1 GeV and 15 GeV
- Upper limits on the Higgs boson to dark photon BR as function of decay length



Falkowski-Ruderman-Volansky-Zupan (FRVZ) model

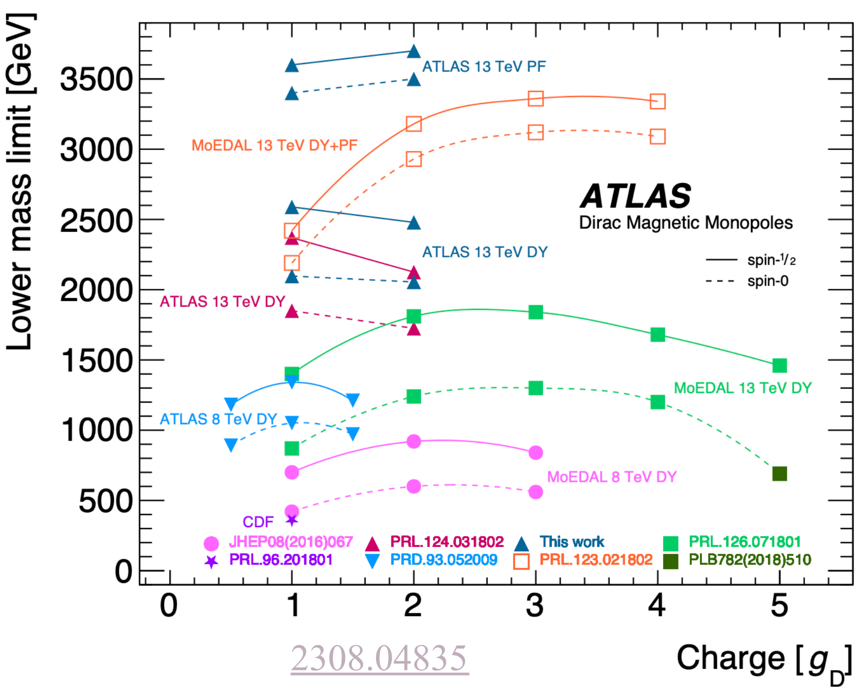


ATLAS-CONF-2023-051

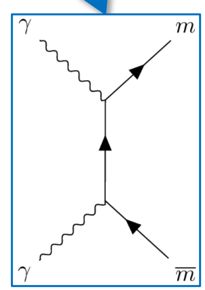
Highly ionizing particles (HIP)

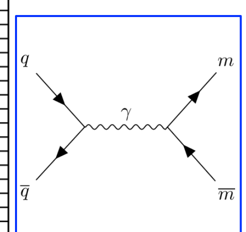
New !

- Dirac's theory of magnetic monopoles offers an explanation for the quantization of electric charge
- Search for magnetic monopoles and stable particles with high-electric-charges
  - First ATLAS limits on photon-fusion pair production mechanism
  - DY: Improves by factor 3 the previous x-section limits by ATLAS 36 fb^{-1}

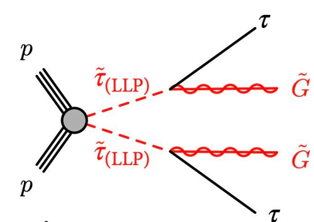


2308.04835

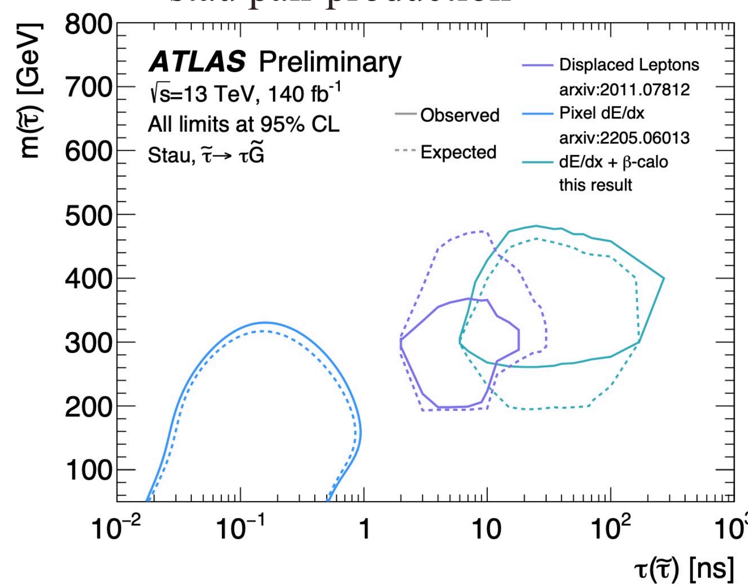




- Targeting heavy, long-lived charged particles
- Using large E depositions in pixel detector by including calorimeter ToF info



stau pair production



ATLAS-CONF-2023-044

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

Status: July 2021

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.6 - 139)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt [\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu, \tau, \gamma$	1 – 4 j	Yes	139	M_D 11.2 TeV	$n = 2$	2102.10874
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	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 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	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 $G_{KK} \to WV \to \ell\nu qq$	$1\ e, \mu$	2 j / 1 J	Yes	139	G_{KK} mass 2.0 TeV	$k/\overline{M}_{Pl} = 1.0$	2004.14636
	Bulk RS $g_{KK} \to tt$	$1\ e, \mu$	≥1 b, ≥1J/2j	Yes	36.1	g_{KK} mass 3.8 TeV	$\Gamma/m = 15\%$	1804.10823
	2UED / RPP	$1\ e, \mu$	≥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 $Z' \to \ell\ell$	$2\ e, \mu$	–	–	139	Z' mass 5.1 TeV		1903.06248
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	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 $Z' \to tt$	$0\ e, \mu$	≥1 b, ≥2 J	Yes	139	Z' mass 4.1 TeV	$\Gamma/m = 1.2\%$	2005.05138
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	139	W' mass 6.0 TeV		1906.05609
	SSM $W' \to \tau\nu$	$1\ \tau$	–	Yes	139	W' mass 5.0 TeV		ATLAS-CONF-2021-025
	SSM $W' \to tb$	–	≥1 b, ≥1 J	–	139	W' mass 4.4 TeV		ATLAS-CONF-2021-043
	HVT $W' \to WZ \to \ell\nu qq$ model B	$1\ e, \mu$	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	$0\ e, \mu$	≥1 b, ≥2 J		139	W' mass 3.2 TeV	$g_V = 3$	2007.05293
	LRSM $W_R \to \mu N_R$	$2\ \mu$	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 $\ell\ell qq$	$2\ e, \mu$	–	–	139	Λ 35.8 TeV	η_{LL}^-	2006.12946
	CI $eebs$	$2\ e$	1 b	–	139	Λ 1.8 TeV	$g_* = 1$	2105.13847
	CI $\mu\mu bs$	$2\ \mu$	1 b	–	139	Λ 2.0 TeV	$g_* = 1$	2105.13847
	CI $tttt$	$\geq 1\ e, \mu$	≥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)	$0\ e, \mu, \tau, \gamma$	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)	$0\ e, \mu, \tau, \gamma$	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)	$0\ e, \mu$	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	multi-channel			139	m_{med} 560 GeV	$\tan\beta$=1, g_χ=1, $m(\chi)$=10 GeV	ATLAS-CONF-2021-036
	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	$2\ \mu$	≥2 j	Yes	139	LQ mass 1.7 TeV	$\beta = 1$	2006.05872
	Scalar LQ 3rd gen	$1\ \tau$	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	$0\ e, \mu$	≥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	$\geq 2\ e, \mu, \geq 1\ \tau$	≥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	$0\ e, \mu, \geq 1\ \tau$	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 $TT \to Zt + X$	$2e/2\mu/\geq 3e,\mu$	≥1 b, ≥1 j	–	139	T mass 1.4 TeV	SU(2) doublet	ATLAS-CONF-2021-024
	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 $T \to Ht/Zt$	$1\ e, \mu$	≥1 b, ≥3 j	Yes	139	T mass 1.8 TeV	SU(2) singlet, κ_T= 0.5	ATLAS-CONF-2021-040
	VLQ $Y \to Wb$	$1\ e, \mu$	≥1 b, ≥1 j	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \to Wb)$= 1, $c_R(Wb)$= 1	1812.07343
	VLQ $B \to Hb$	$0\ e, \mu$	≥2b, ≥1j, ≥1J	–	139	B mass 2.0 TeV	SU(2) doublet, κ_B= 0.3	ATLAS-CONF-2021-018
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 $q^* \to q\gamma$	$1\ \gamma$	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^*	$3\ e, \mu$	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	$3\ e, \mu, \tau$	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	Type III Seesaw	2,3,4 e, μ	≥2 j	Yes	139	N^0 mass 910 GeV		ATLAS-CONF-2021-023
	LRSM Majorana ν	$2\ \mu$	2 j	–	36.1	N_R mass 3.2 TeV	$m(W_R) = 4.1$ TeV, $g_L = g_R$	1809.11105
	Higgs triplet $H^{\pm\pm} \to W^\pm W^\pm$	2,3,4 e, μ (SS)	various	Yes	139	$H^{\pm\pm}$ mass 350 GeV	DY production	2101.11961
	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 $H^{\pm\pm} \to \ell\tau$	$3\ e, \mu, \tau$	–	–	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, $\lvert g \rvert = 1 g_D$, 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.

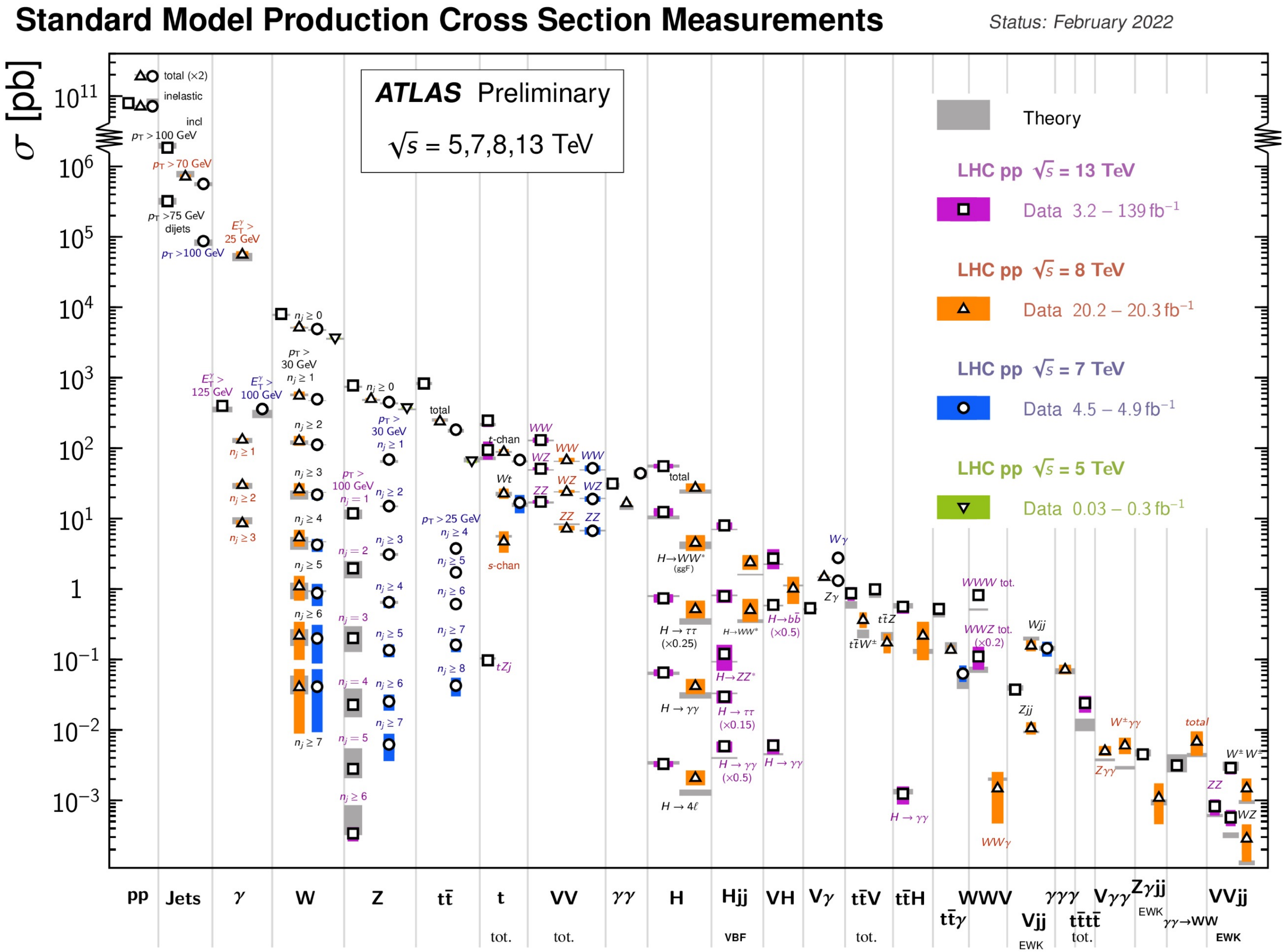
†Small-radius (large-radius) jets are denoted by the letter j (J).

Recent physics results

- ☞ Higgs boson precision measurements
- ☞ BSM searches
- ☞ **SM precision measurements**

Elvira Rossi's talk

- **SM precision measurement, Probe new physics**
- **Overall good agreement with SM**
- **Just highlight some recent results**



Vector Boson Scattering Progress

Key test of EW symmetry:

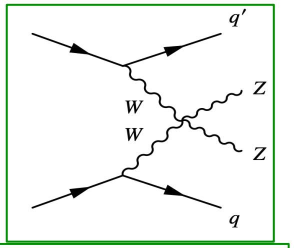
→ vector boson self-interactions

$$\mathscr{L}_{SM} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\overline{\psi}\not{D}\psi + \psi_i y_{ij}\psi_j\phi + \text{hc} + |D_\mu\phi|^2 - V(\phi)$$

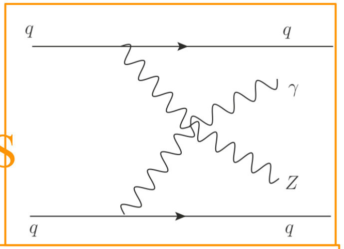
ATLAS has observed all relevant VBS channels, probing EW symmetry breaking and setting constraints on anomalous couplings

Some recent results:

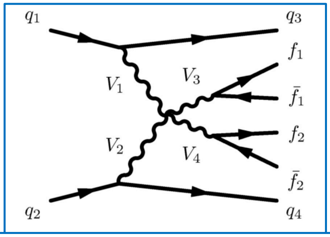
ZZjj differential measurement

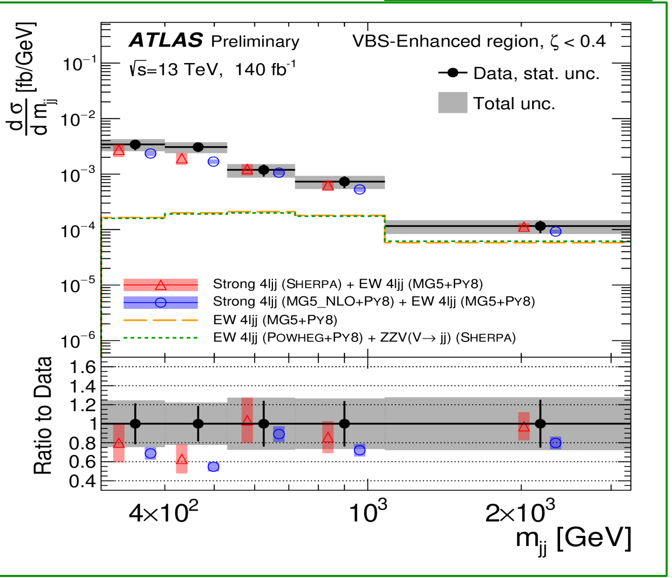


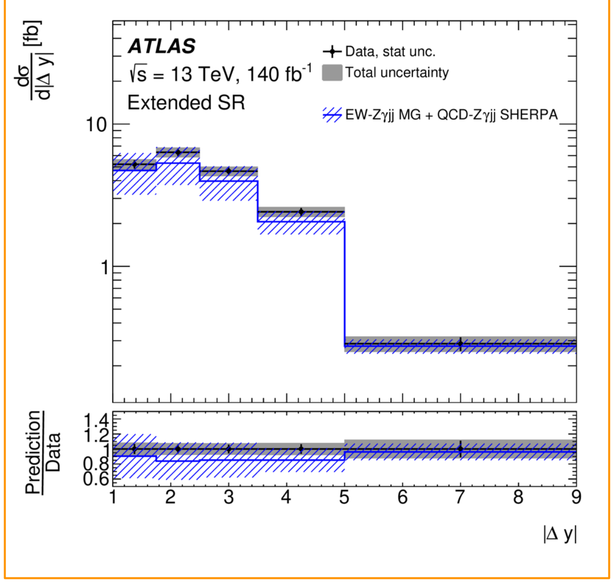
EW Zγjj differential XS

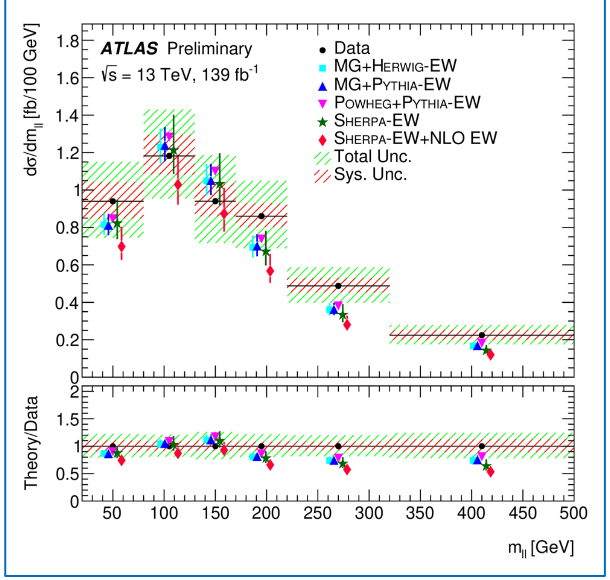


differential VBS same sign WWjj









ATLAS-CONF-2023-024

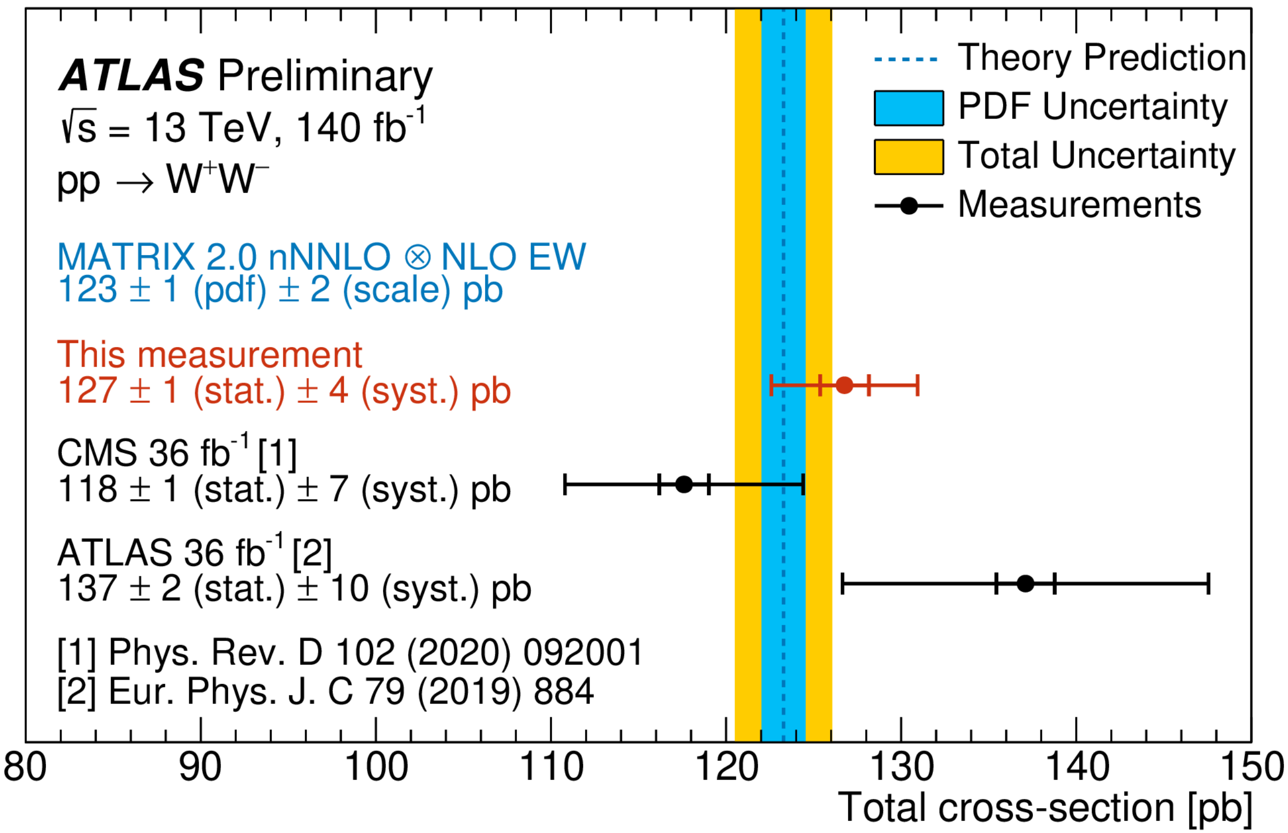
arXiv:2305.19142

ATLAS-CONF-2023-023

Inclusive WW xSec measurement

Excellent agreement with prediction is observed

New !



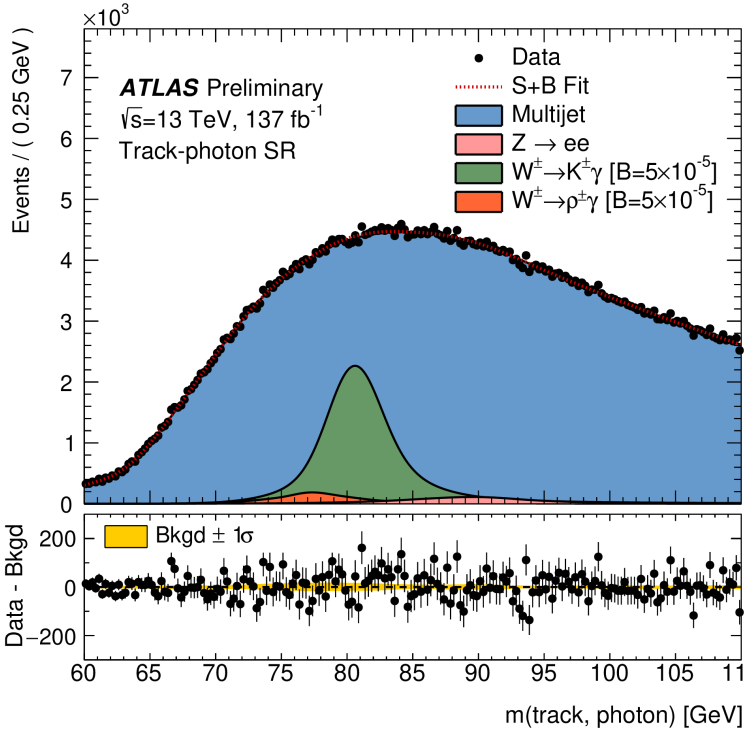
Total WW cross section: 127±4 pb (~3%)

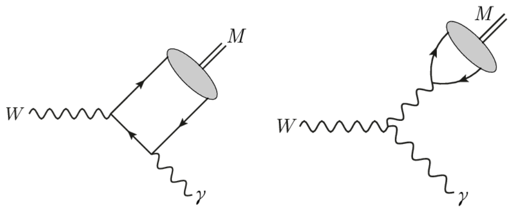
ATLAS-CONF-2023-012

W rare decays

New !

- **None of exclusive hadronic W decays** ($W\rightarrow M\gamma$ with M = {π, K, ρ}) **predicted by SM have been observed**
- **May provide novel studies of QCD factorisation.**
- **2 topologies track+γ and τ+γ studied**





Expected and observed upper limits on $W^{\pm}\rightarrow\pi^{\pm}\gamma$, $W^{\pm}\rightarrow K^{\pm}\gamma$ and $W^{\pm}\rightarrow\rho^{\pm}\gamma$ at 95% CL.

	Expected branching fraction $\times10^{-6}$	Observed branching fraction $\times10^{-6}$
$W^{\pm}\rightarrow\pi^{\pm}\gamma$	$1.2^{+0.5}_{-0.3}$	1.9
$W^{\pm}\rightarrow K^{\pm}\gamma$	$1.1^{+0.4}_{-0.3}$	1.7
$W^{\pm}\rightarrow\rho^{\pm}\gamma$	$6.0^{+2.3}_{-1.7}$	5.2

- **Best upper limit on $B(W^{\pm}\rightarrow\pi^{\pm}\gamma)$ at 95% CL**
- **First limits on $B(W^{\pm}\rightarrow\rho^{\pm}\gamma)$ and $B(W^{\pm}\rightarrow K^{\pm}\gamma)$**
- **Still far from SM (10^{-9},10^{-10})**

ATLAS-CONF-2023-056

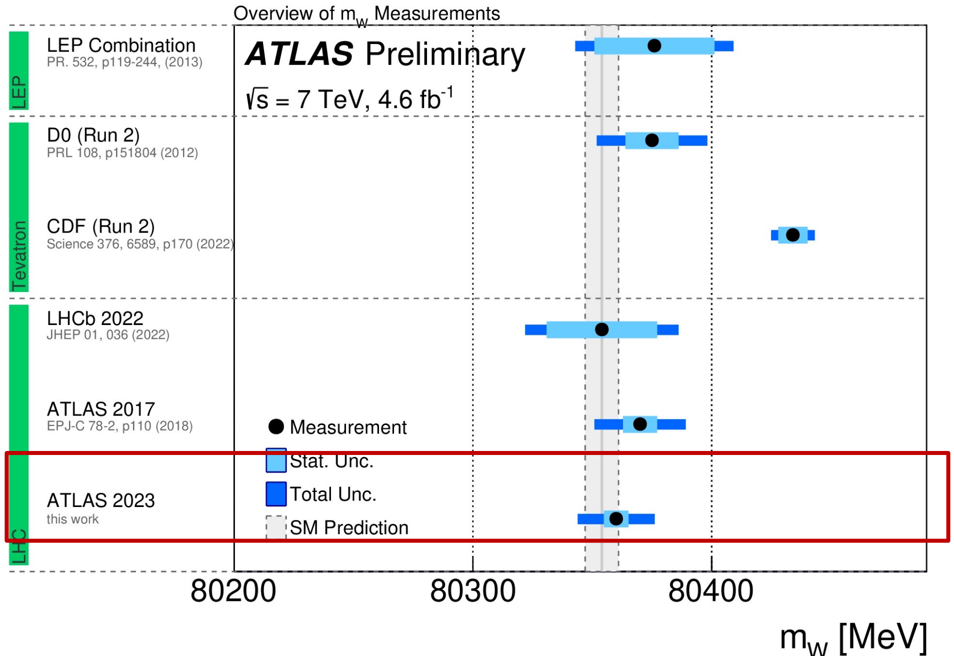
W boson mass with 7 TeV data

New !

Extremely sensitive probe of and constraint on new physics

- Revisited measurement from 2017, using the same data, but with more modern PDFs, and new log-likelihood fit to constrains systematic uncertainties with data

- Reduce systematics from 18 MeV to 16 MeV



ATLAS-CONF-2023-004

m_W = 80360 ± 5 (stat.) ± 15 (syst.) = 80360 ± 16 MeV

In agreement with SM !

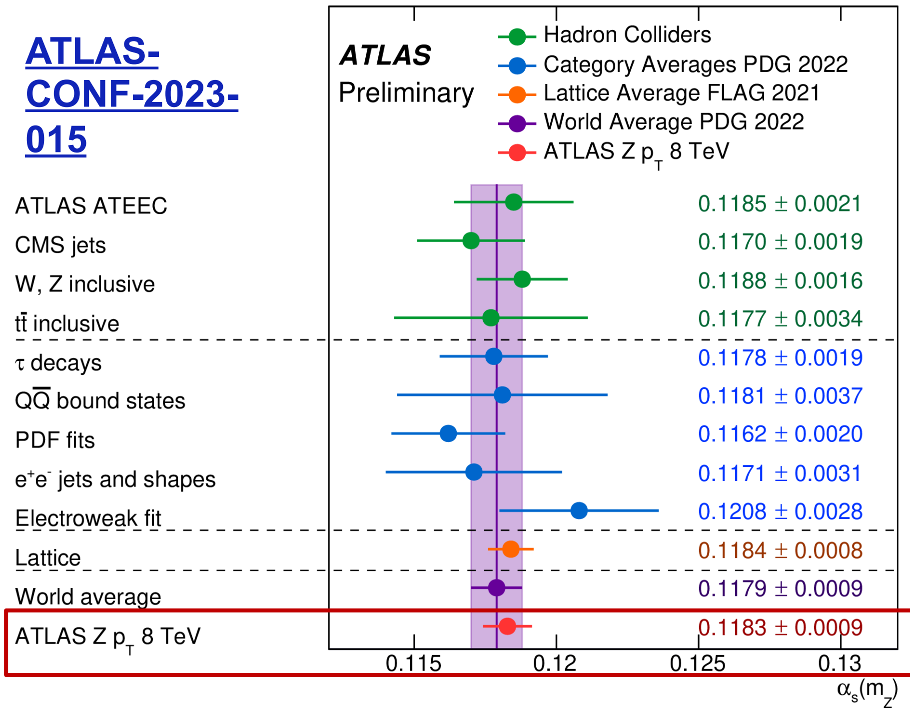
Strong coupling constant α_s

New !

- **The strong force is still not well known interaction of nature**
- **Two α_s determinations at NNLO or N3LO from ATLAS**

α_s from Z recoil

[ATLAS-CONF-2023-015]

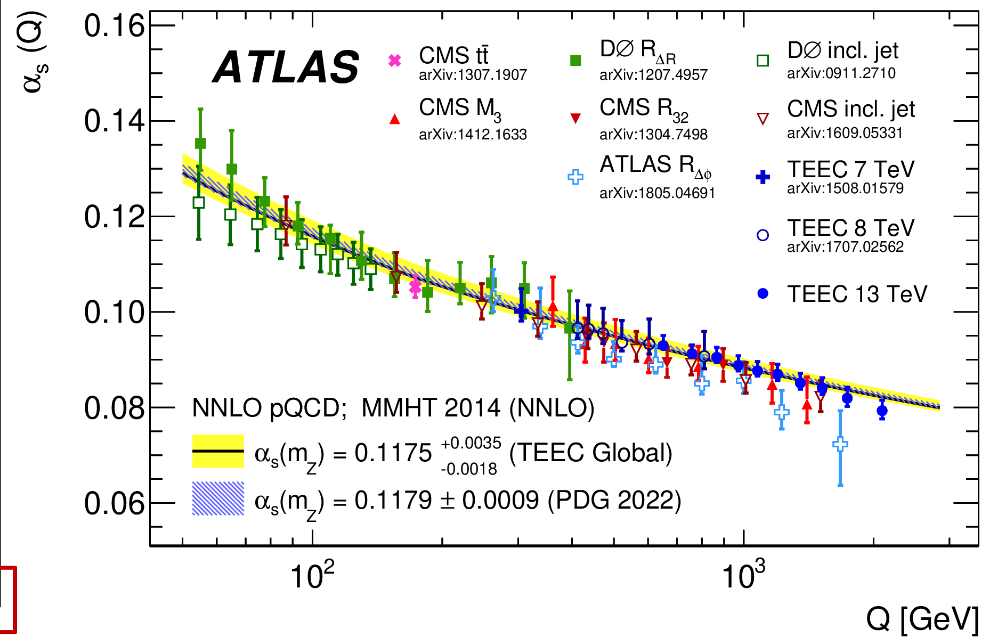


(0.7% rel.)

Most precise experimental single-measurement of α_s (m_Z) (~0.7%)

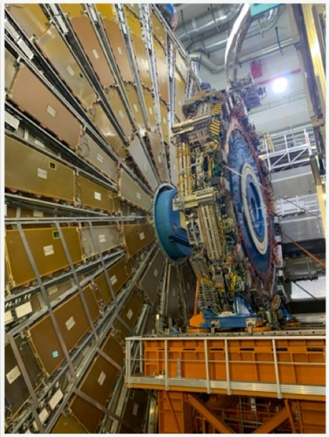
α_s from Transverse Energy-Energy Correlation (TEEC)

[JHEP 07 (2023) 85]



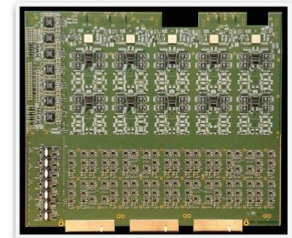
Good agreement with the renormalisation group equation and with previous analyses

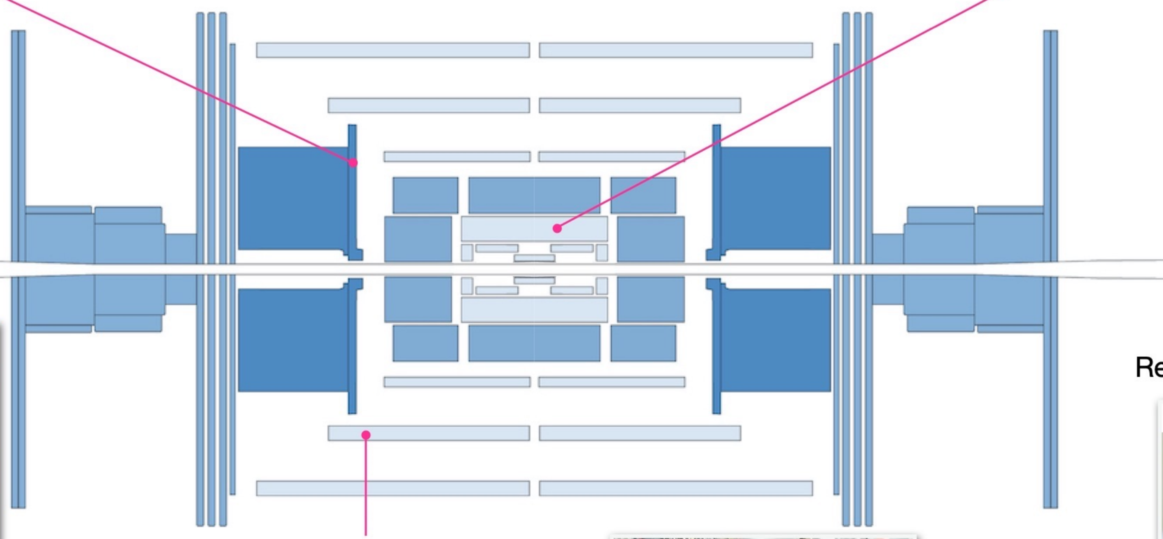
ATLAS Phase-1 upgrade (Run3)



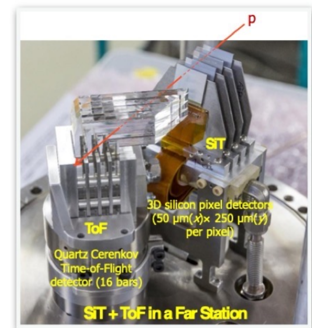
Muon New Small Wheels
Precision tracking, identification and triggering

New LAr Calorimeter digital trigger electronic boards
Improved trigger granularity
Boards installed in all FE crates!





AFP
Re-designed TOF detector



Trigger and Data Acquisition
Upgraded hardware, firmware and software for improved trigger and DAQ

TDAQ Upgrade briefing

BIS78
New Muon chambers sMDT and new generation RPC (8 chambers installed)

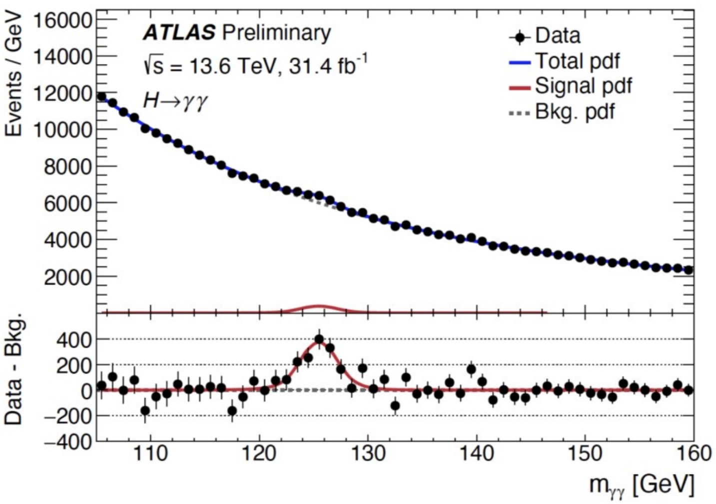
First Run3 results:

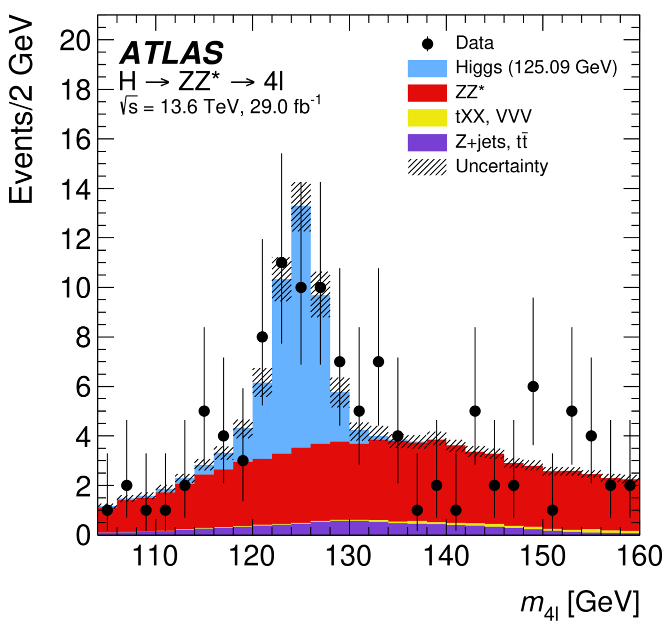
Based on ~30 fb^{-1} of data recorded by ATLAS in Run 3 (2022):

- Excellent muon, electron, photon and jet performance
- Good luminosity calibration with 31.4 ± 0.7 fb^{-1} (2.2%)
- Simplified analyses w/o categorization
- Preliminary understanding of systematics

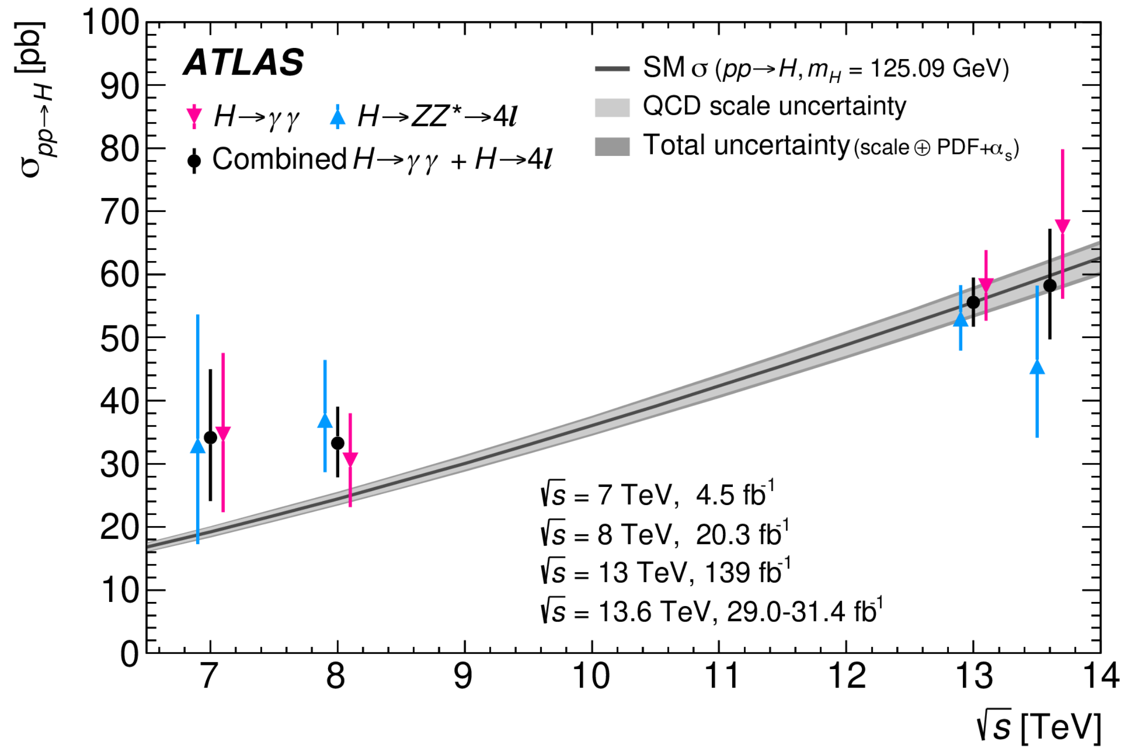
"Rediscover" Higgs at Run3

arXiv:2306.11379





New !



$\sigma^{\gamma\gamma}_{fid} = 76\,^{+14}_{-13}(67.6 \pm 3.7)$ fb $\quad \sigma^{4l}_{fid} = 2.80 \pm 0.74(3.67 \pm 0.19)$ fb

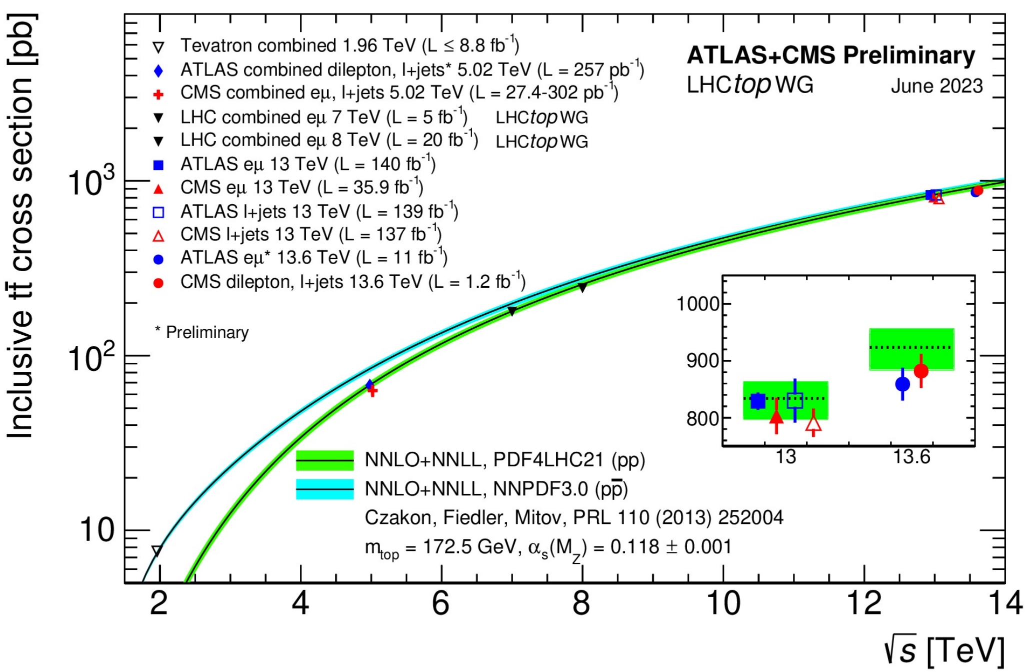
$\sigma_{tot} = 58.2 \pm 8.7(59.9 \pm 2.6)$ pb

New top and ZZ xSec. measurement at 13.6 TeV

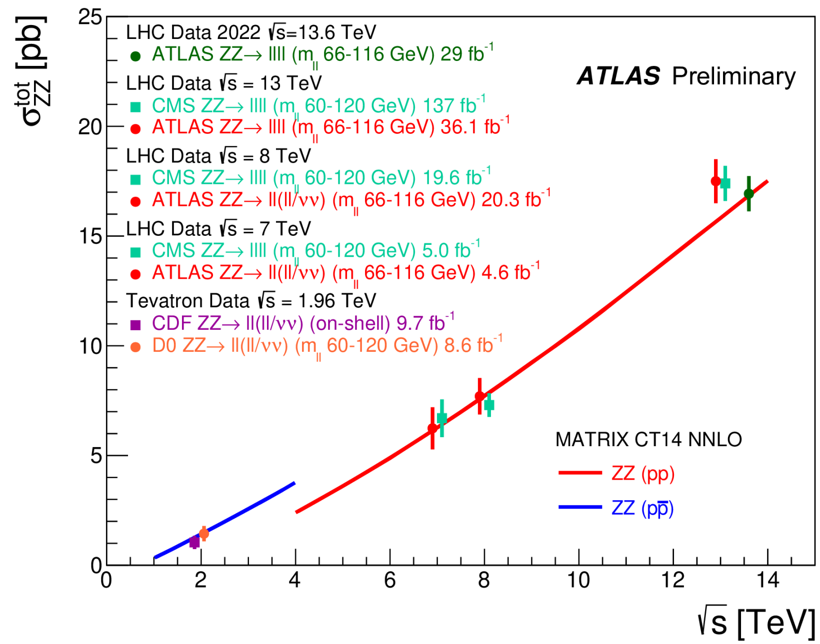
Consistent with NNLO theoretical predictions

New !

(ATLAS: eμ channel;
CMS: dilepton, lepton+jets)



[ATL-PHYS-PUB-2023-014]



[ATLAS-CONF-2023-062]

Summary and Outlook

- **Fruitful results from Run-2, thanks to the outstanding performance of the LHC and ATLAS**
  - Higgs behaves as **SM Higgs**, reaching 5–10% constraints on main H-V couplings
  - Explored **rare processes**: $Z\gamma$ (3.4σ), or HH prod. ($\sigma/\sigma_{SM} < 2.4$)
  - Wide program for **BSM search** at high-energy or through small couplings
- **Run-3 has started with $\sqrt{s}$ = 13.6 TeV**
  - Expect to collect ~double of Run-2 dataset by 2025
  - **First Run3 results** from Higgs, top and ZZ cross section measurements
  - **BSM searches with Run2+partial Run3 to be coming at next year**

Stay tuned!

Related talks at Corfu2023

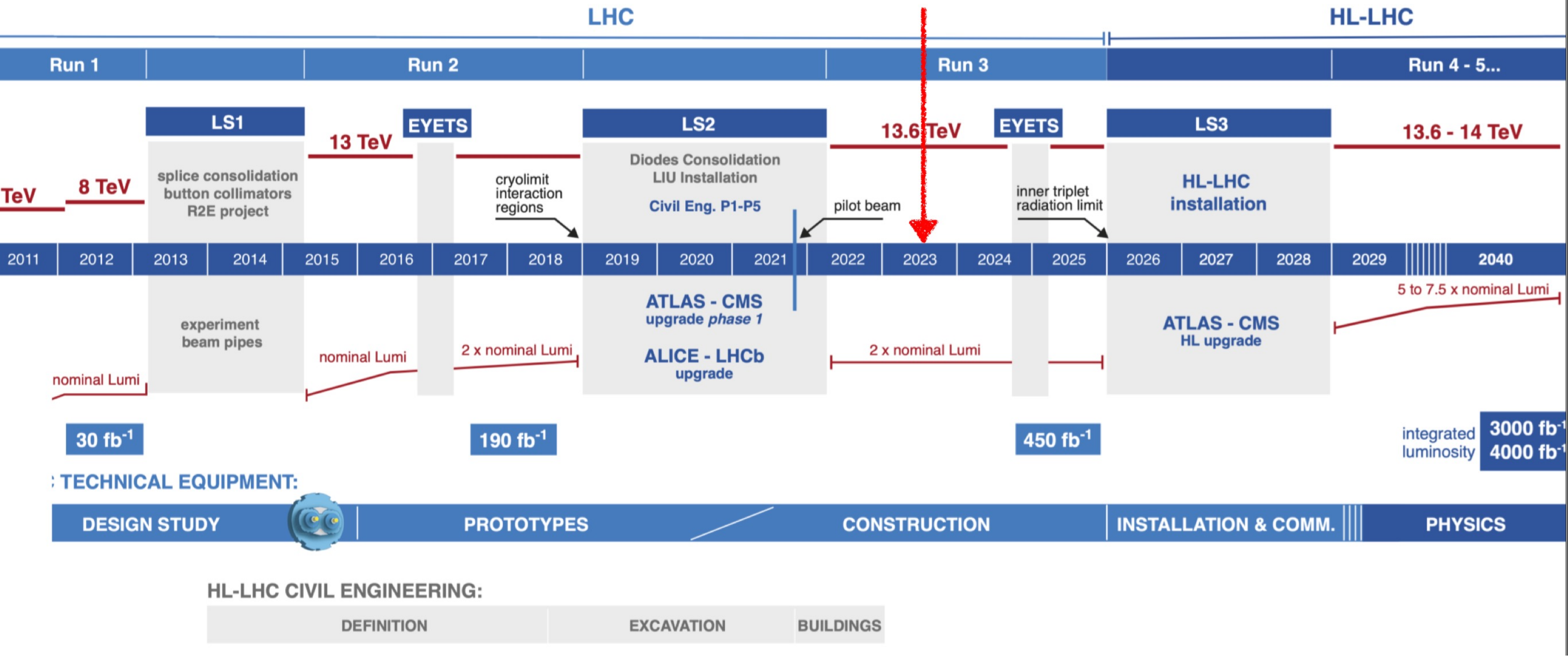
1. **Higgs physics in ATLAS and CMS**, Rainer Mankel (Mon. 28/8)
2. **SM (QCD+EW) in ATLAS and CMS**, Elvira Rossi (Tue. 29/8)
3. **Constraining EW baryogenesis with searches for decays of heavy Higgs bosons in ATLAS**, Spyros Argyropoulos (Tue. 29/8)
4. **Exotics and BSM (non SUSY, non DM) in ATLAS and CMS**, Jun Guo (Wed. 30/8)
5. **SUSY in ATLAS and CMS**, Otilia Anamaria Ducu (Wed. 30/8)
6. **Dark matter in ATLAS and CMS**, Bisnupriya Sahu (Wed. 30/8)
7. **Top physics in ATLAS and CMS**, Markus Cristinziani (Sun. 03/9)

Thanks for your attention!

backup

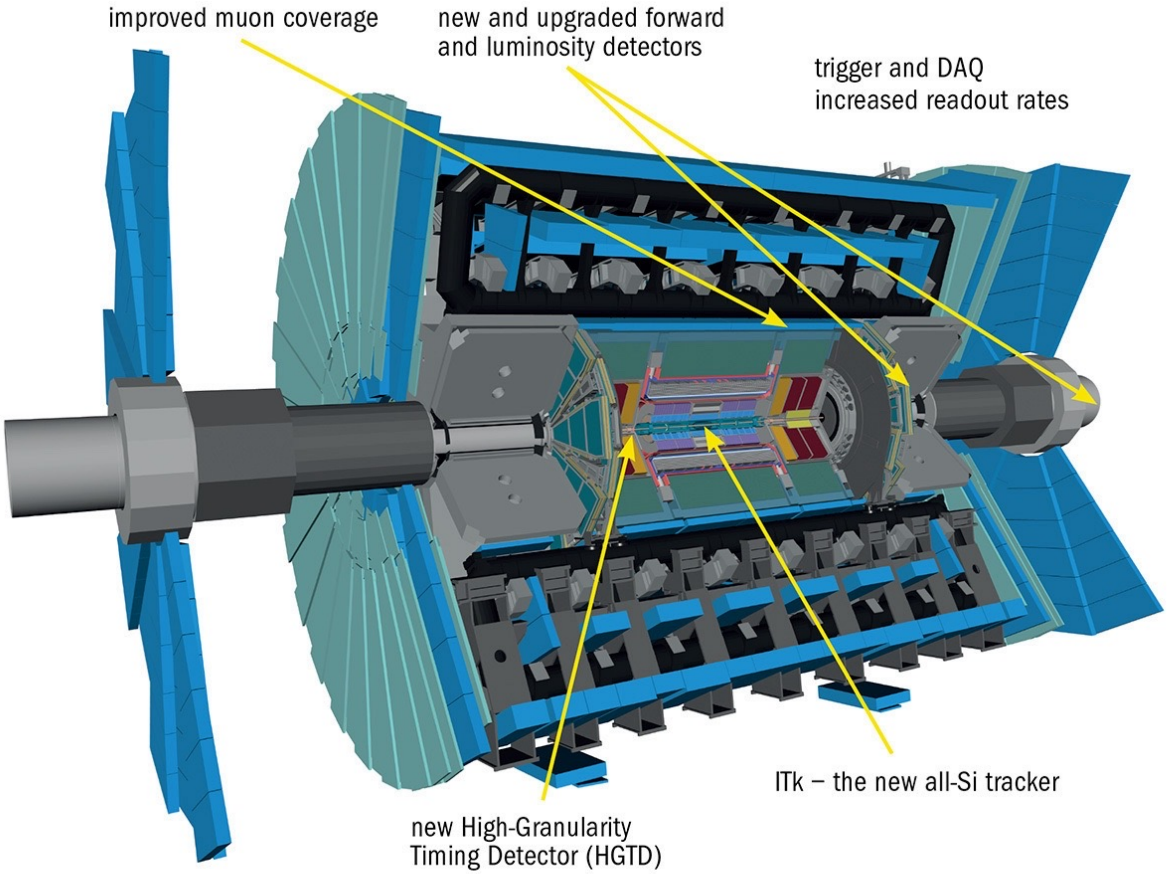
LHC / HL-LHC Plan

we are here



ATLAS Phase-2 upgrade (HL-LHC)

- **ITK**: all **silicon tracker** up to $|\eta| = 4$ with 50x increase in channels
- New **inner muon systems** for improved trigger acceptance
- New **high-granularity timing detector** for pile-up rejection
- **Trigger**: 1 MHz Level-0 rate 150 kHz full-scan tracking
- LAr/Tile/muons **electronics** upgrade
- Additional smaller upgrades



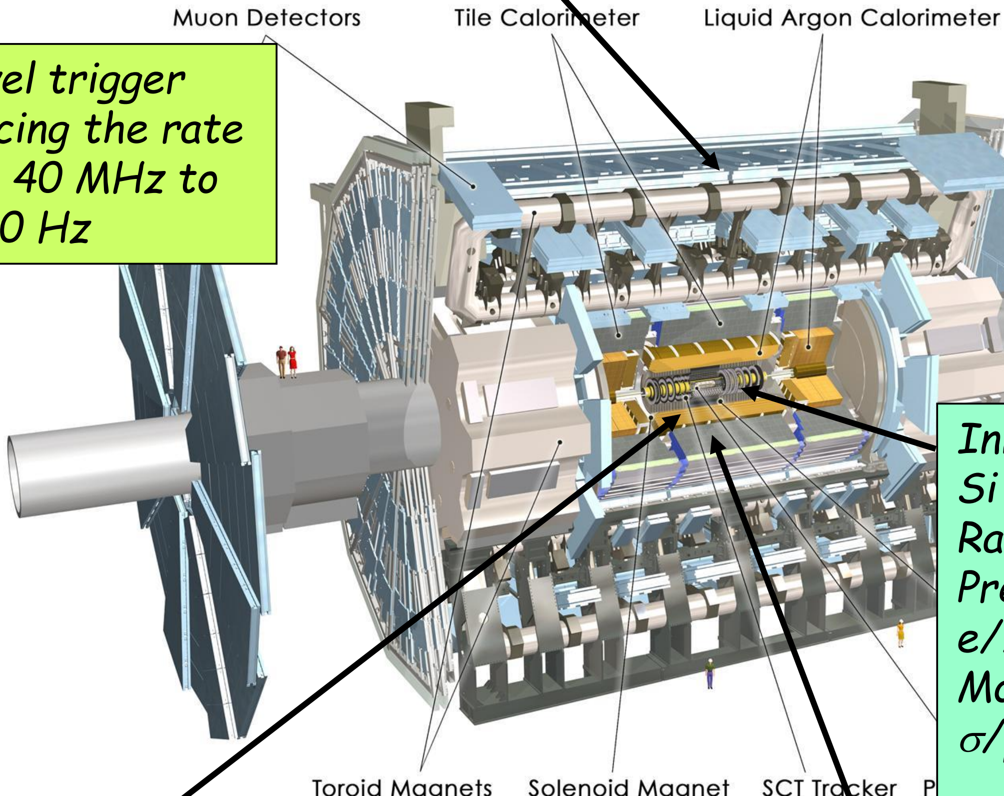
This ambitious upgrade program supports our ambitious physics goals.

Muon Spectrometer ($|\eta|$<2.7) : air-core toroids (B ~ 0.5 / 1T in barrel/ end-cap) with gas-based muon chambers Muon trigger and measurement with momentum resolution < 10% up to E_μ ~ 1 TeV

Run-1 ATLAS detector

Length : ~ 46 m
Radius : ~ 12 m
Weight : ~ 7000 tons
~10^8 electronic channels
3000 km of cables

3-level trigger reducing the rate from 40 MHz to ~1200 Hz



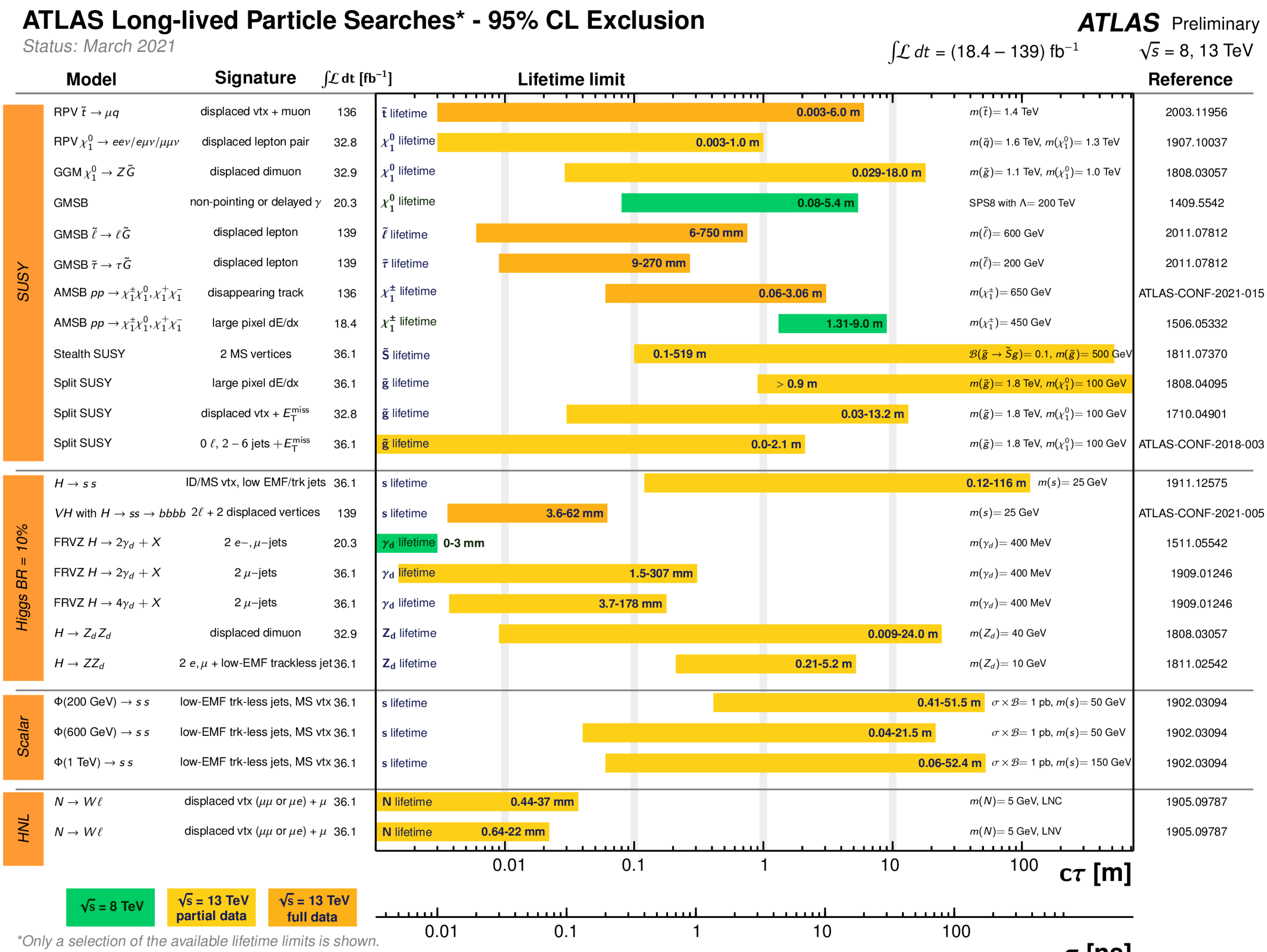
© F.Gianotti

Inner Detector ($|\eta|$<2.5, B=2T):
Si Pixels, Si strips, Transition Radiation detector (straws)
Precise tracking and vertexing,
e/π separation
Momentum resolution:
$\sigma/p_T \sim 3.8\times10^{-4}\, p_T(\mathrm{GeV}) \oplus 0.015$
(chamber resolution $\oplus$ MS)

EM calorimeter: Pb-LAr Accordion
e/γ trigger, identification and measurement
E-resolution: $\sigma/E \sim 10\%/\sqrt{E}$

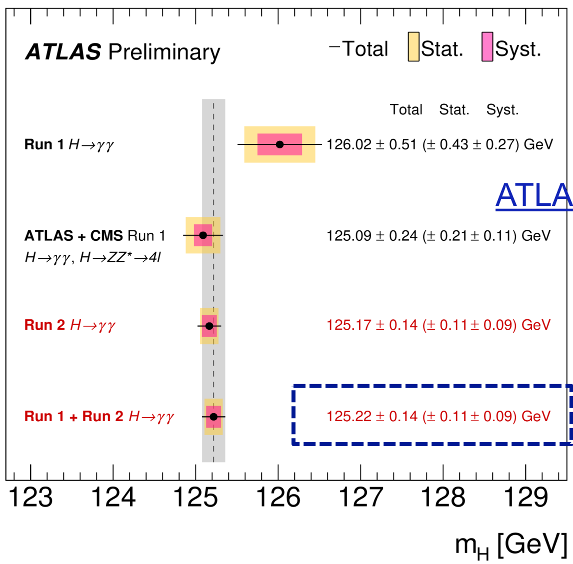
HAD calorimetry ($|\eta|$<5): segmentation, hermeticity
Fe/scintillator Tiles (central), Cu/W-LAr (fwd)
Trigger and measurement of jets and missing E_T
E-resolution: $\sigma/E \sim 50\%/\sqrt{E} \oplus 0.03$

ATL-PHYS-PUB-2021-009

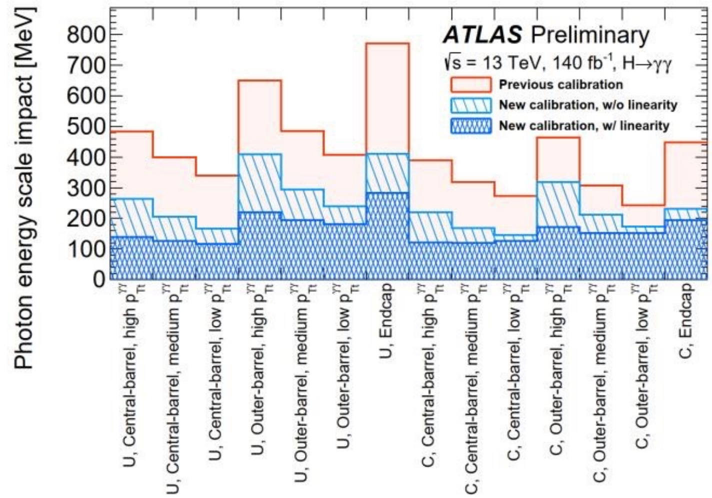


Higgs mass

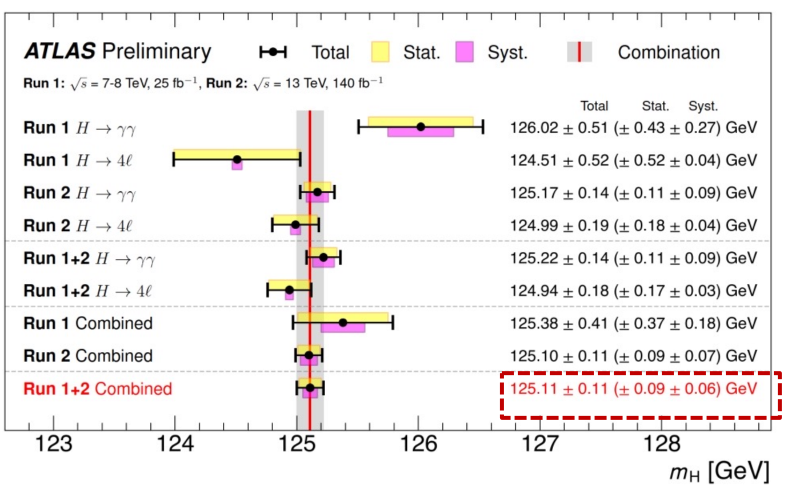
New !



ATLAS-CONF-2023-036



arXiv:2308.04775



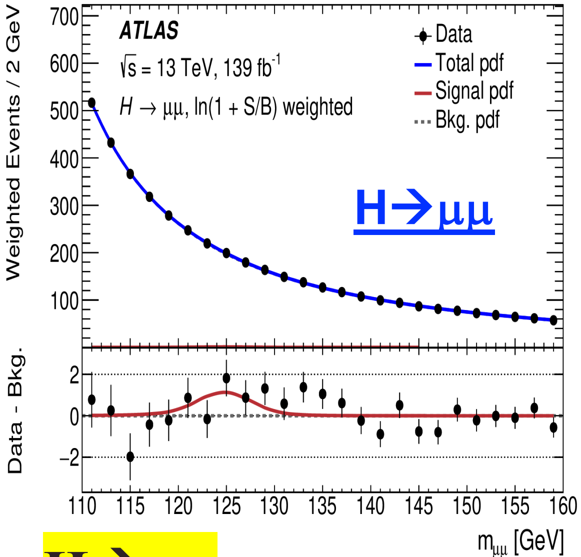
New $H \to \gamma\gamma$ measurement using full Run 2 data:

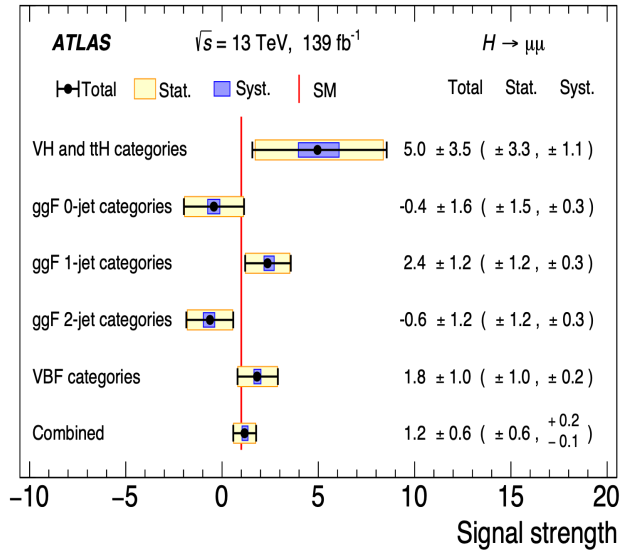
- Increased data sample (~4x)
- Improved estimation of photon energy scale with significantly reduced (~3x) uncertainties
- Optimized event classification strategy

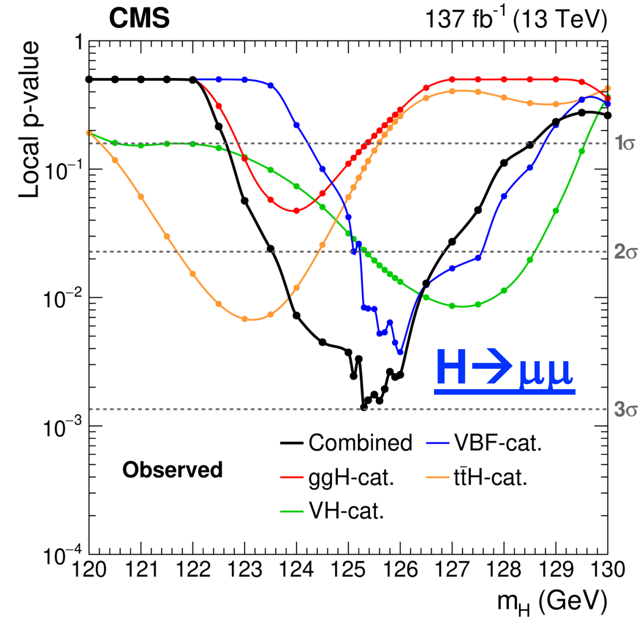
Source	Systematic uncertainty on m_H [MeV]
e/γ E_T-independent $Z \to ee$ calibration	44
e/γ E_T-dependent electron energy scale	28
$H \to \gamma\gamma$ interference bias	17
e/γ photon lateral shower shape	16
e/γ photon conversion reconstruction	15
e/γ energy resolution	11
$H \to \gamma\gamma$ background modelling	10
Muon momentum scale	8
All other systematic uncertainties	7

Evidence for H to 2nd gen. lepton

[ATLAS: JHEP 01 (2021) 148, PLB 812 (2021) 135980] [ATLAS:arXiv:2007.07830; CMS: JHEP 03 (2020) 131]





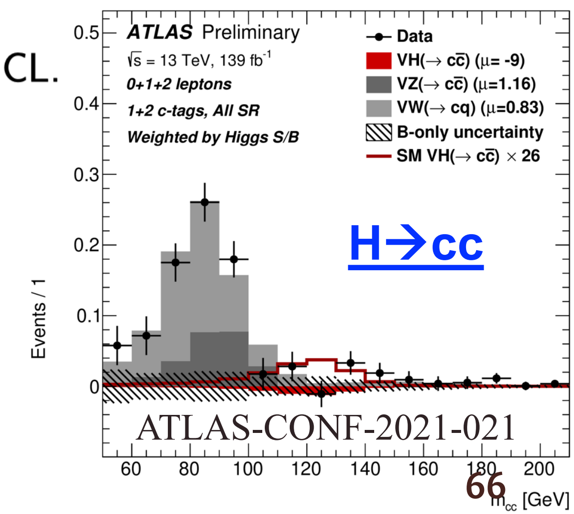


H→μμ

- **ATLAS: Signal significance: 2σ (exp. 1.7σ)**
  Signal strength $\mu = 1.2 \pm 0.6(\text{stat})^{+0.2}_{-0.1}(\text{syst})$
  Assuming SM production rate, $\mathcal{B}(\mathrm{H} \to \mu\mu) < 4.7 \times 10^{-4}$ at 95% CL.

- **CMS: Signal significance: 3σ, (exp. 2.5σ)**
  Signal strength: $\mu = 1.19^{+0.40}_{-0.39}(\text{stat})^{+0.15}_{-0.14}(\text{syst})$
  $0.8 \times 10^{-4} < \mathcal{B}(\mathrm{H} \to \mu\mu) < 4.5 \times 10^{-4}$

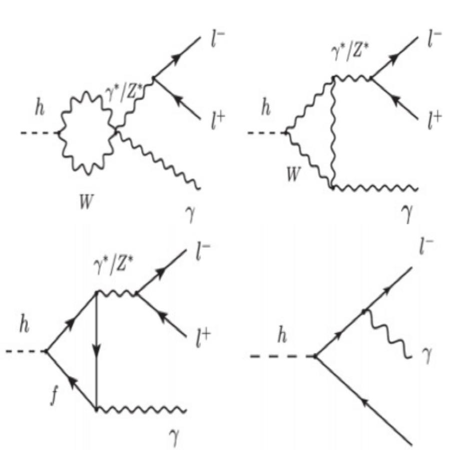
H→cc (next milestone)

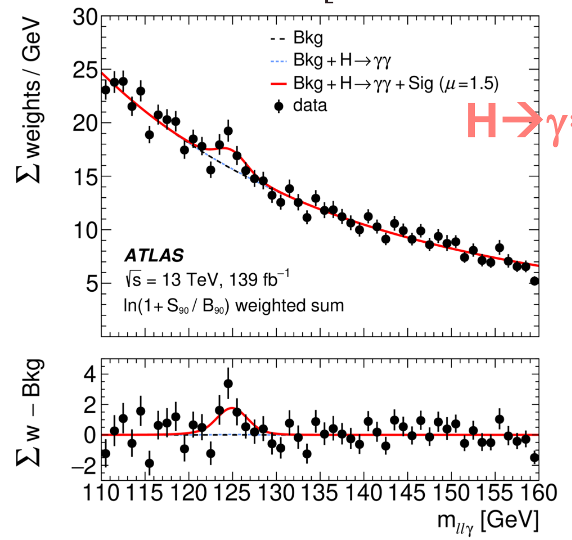


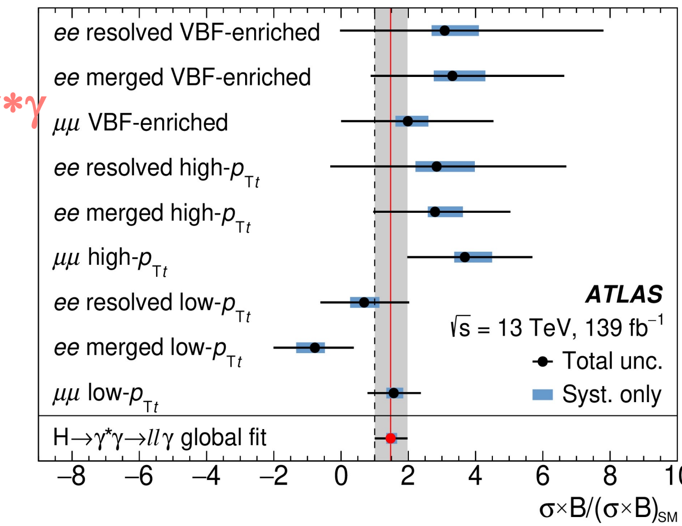
- **Limits on *VHcc@95%CL*:** $\mu_{VHcc} < 26\ (31_{-8}^{+12}) \times$ SM; $|\kappa_c| < 8.5$ (12.4) obs. (exp.)

Higgs rare decays (H→llγ)

[ATLAS: PLB 819 (2021) 136412]



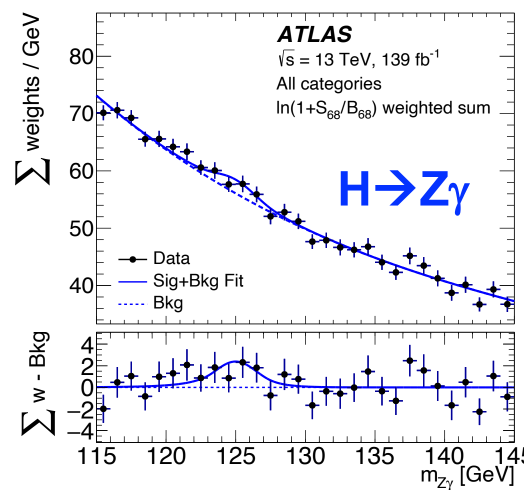




H→llγ

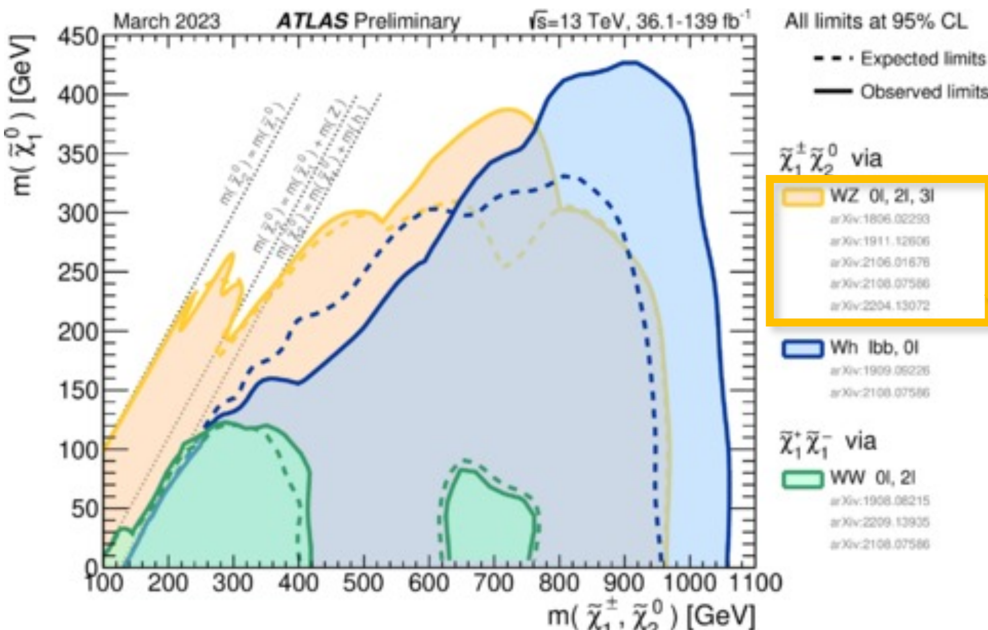
- **Low invariant mass range: dominated by H→γ*γ (mll< 30 GeV)**
  - **Significance: 3.2 σ (2.1 σ) for obs. (exp.)**

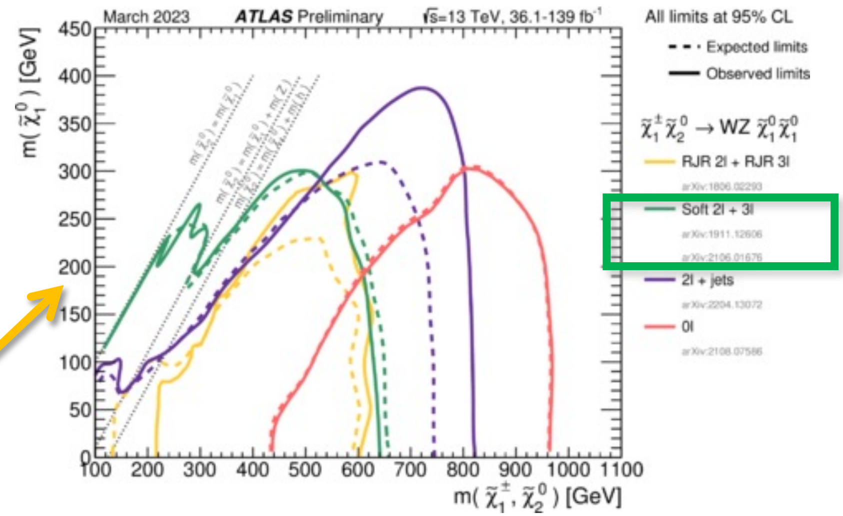
    → First evidence of H→llγ (l=e/μ)
  - Signal strength μ =1.5 ± 0.5
  - Fiducial xSec×B (H→llγ) = $8.7_{-2.7}^{+2.8}$ fb
- **Complementary result for H→Zγ (mll ~ mZ)**
  - **Significance of 2.2 σ (1.2 σ) obs. (exp.)**
  - Obs(Exp)<**3.6**(2.6)×**SM** @95%CL.

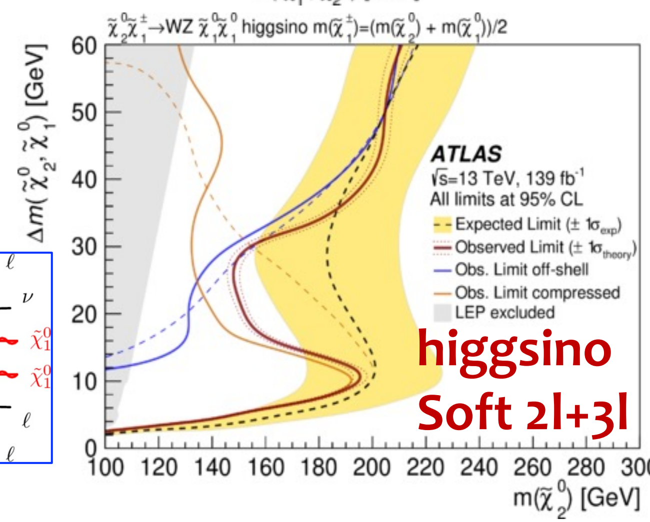


PLB, 809(2020) 135754

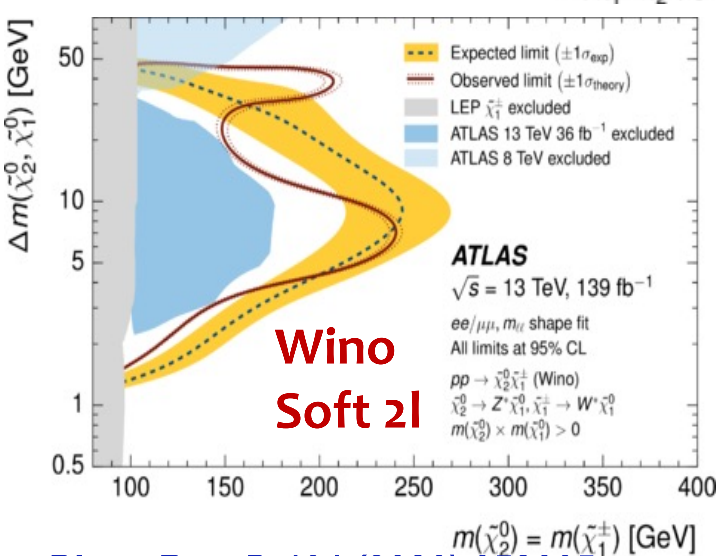
Electroweakinos

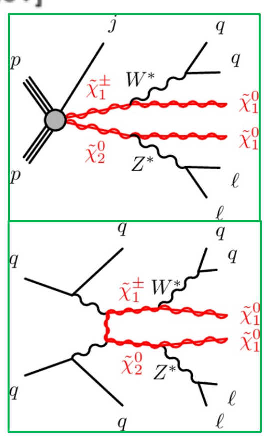


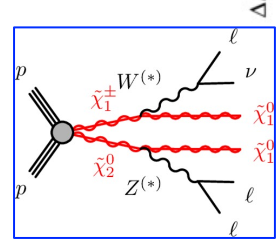




[Eur. Phys. J. C 81 (2021) 1118]







[Phys. Rev. D 101 (2020) 052005]

~ 2σ excess for wino Δm~20 GeV

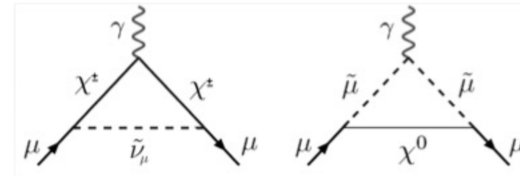
< 2σ excess for higgsino Δm~25 GeV

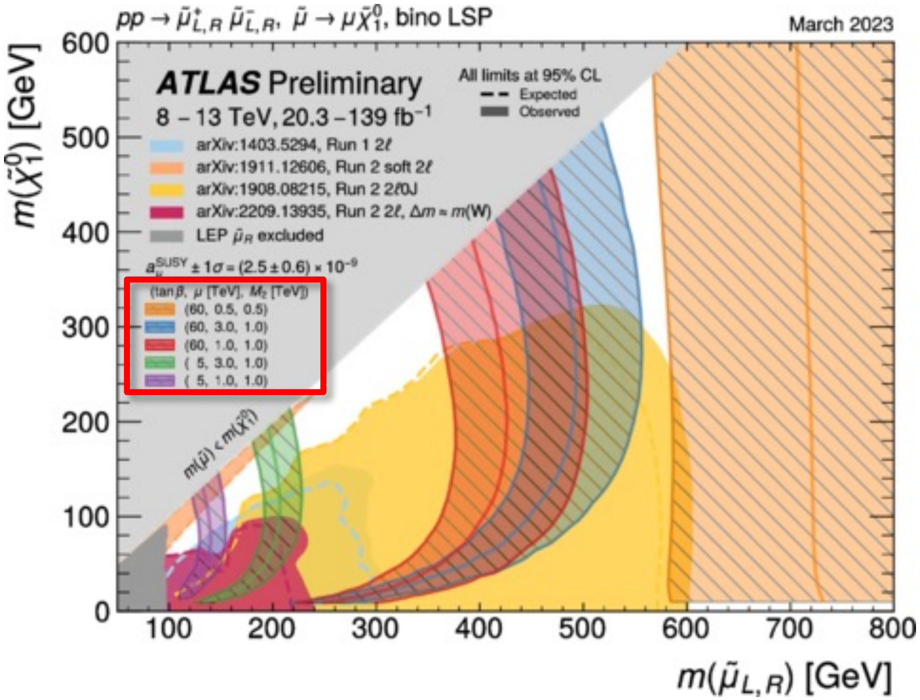
CMS: ~2σ for higgsino Δm ~ 20 GeV [JHEP 04 (2022) 091]

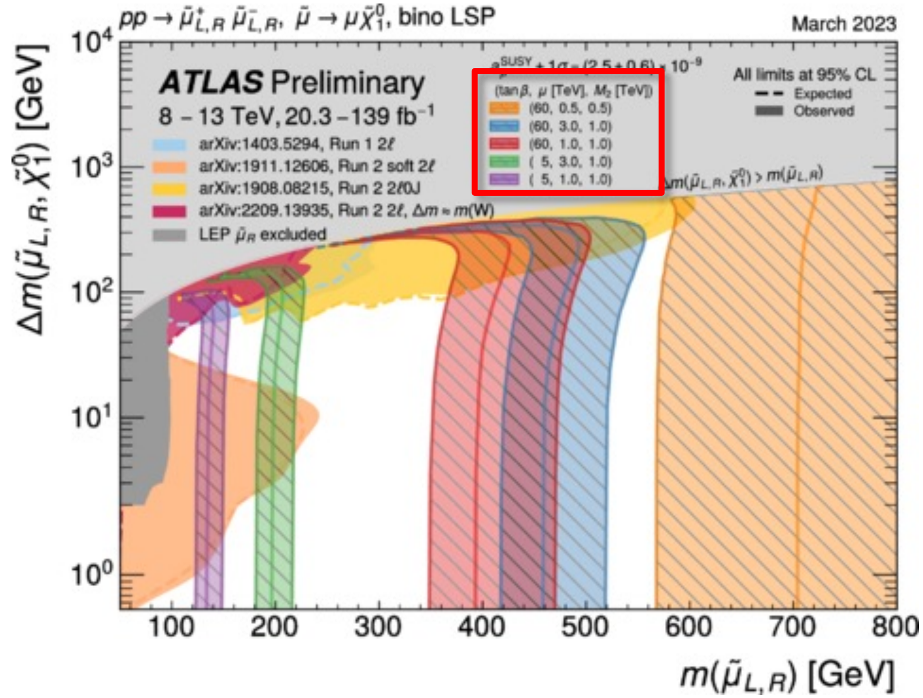
Smuon & g-2

EWKinos / sleptons contribute to muon's g-2

$\Delta a_\mu = a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (251 \pm 59) \times 10^{-11}$ (4.2σ)







ATL-PHYS-PUB-2023-005

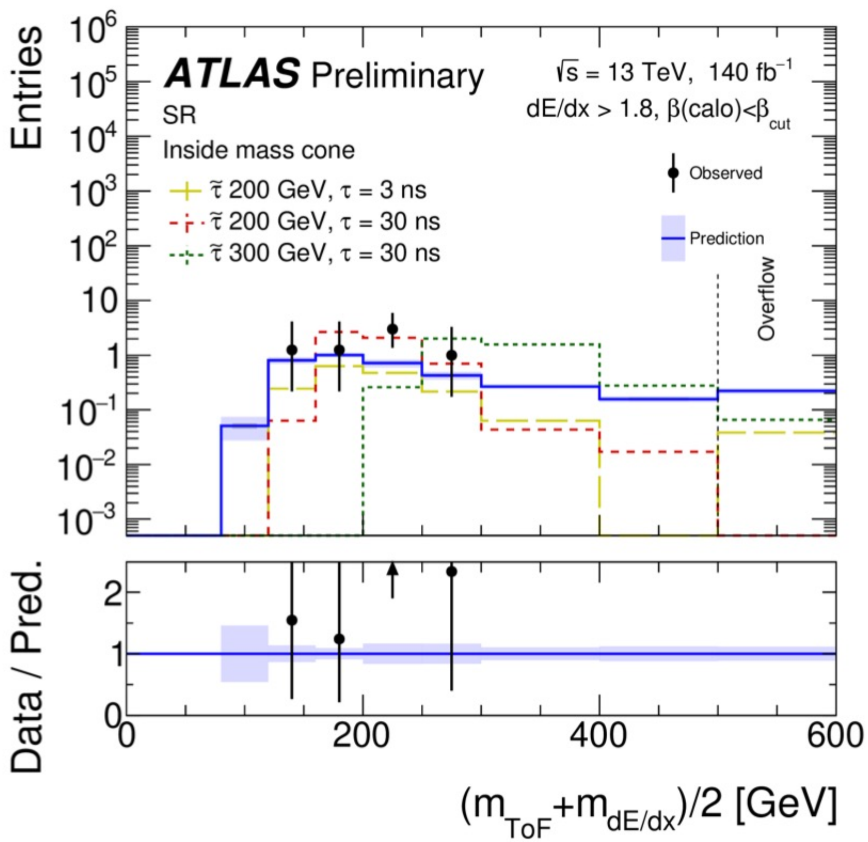
Examples of pMSSM parameters compatible with μ g-2 anomaly

To-do: Cover gaps at low/compressed mass region from experiments

NEW Search for Highly Ionizing Particles ATLAS-CONF-2023-044

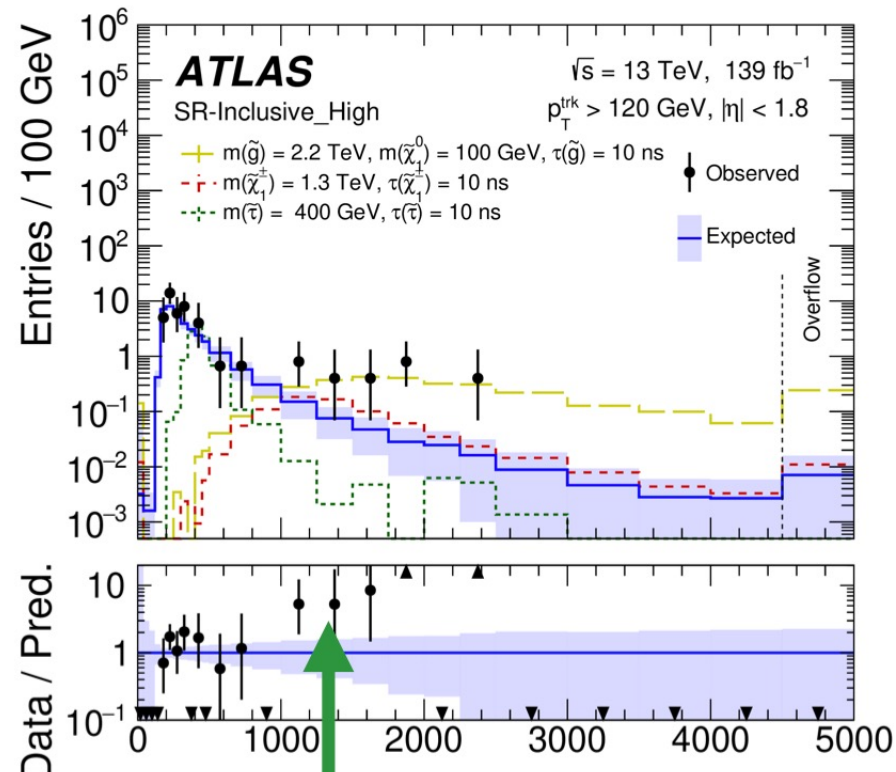
Search for heavy, long-lived, charged particles with large ionization energy loss

Mass from average of pixel dE/dx & calo ToF



Determine βγ and the mass m = p/βγ using two independent methods

Mass from pixel dE/dx



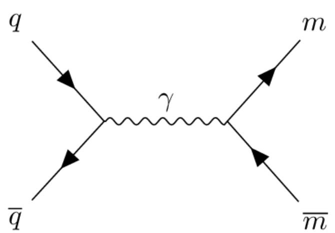
Previous result excess at high mass 3.3σ at m=1.4 TeV

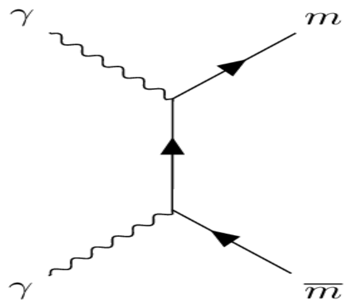
ATLAS, JHEP 06 (2023) 158

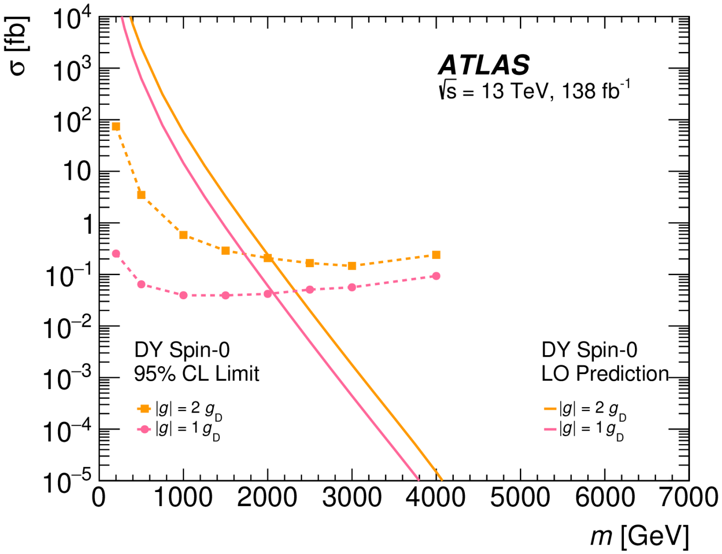
Highly ionizing particles

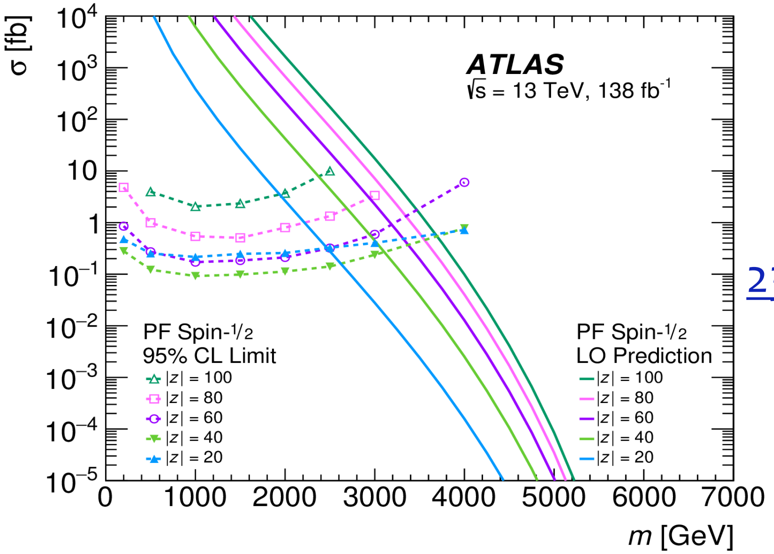
New !

- Cross-section upper limits for spin-0 (1/2) magnetic monopoles of **magnetic charge (g)** and for **high-electric-charge objects of electric charge |*z*|** (20 – 100), for masses between 0.2-4 TeV





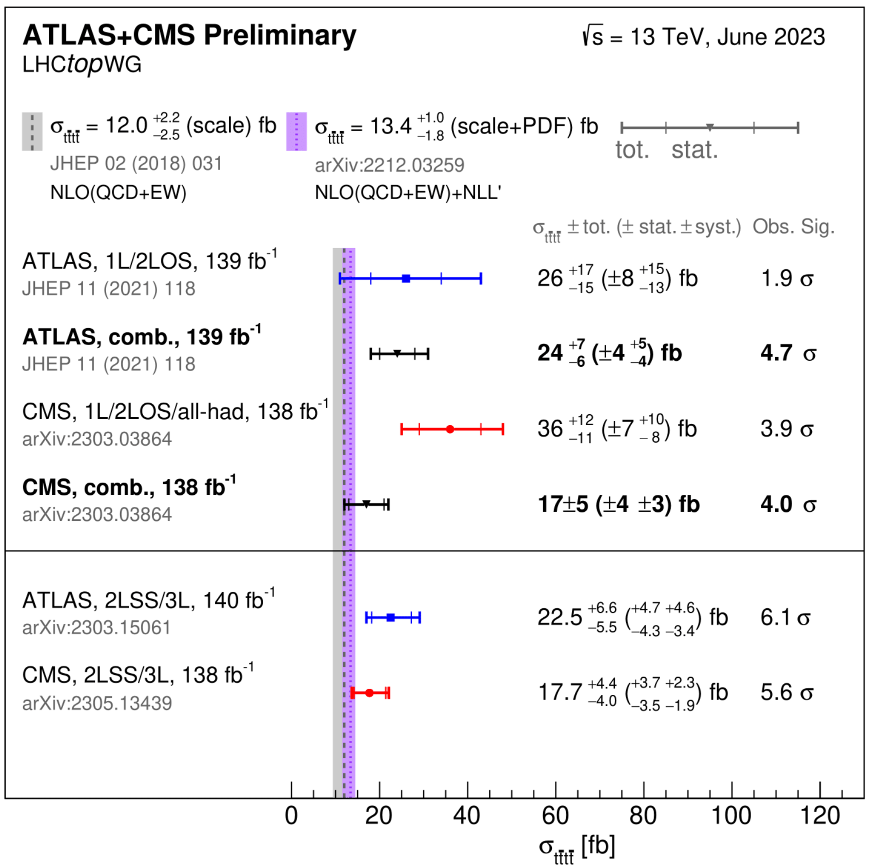




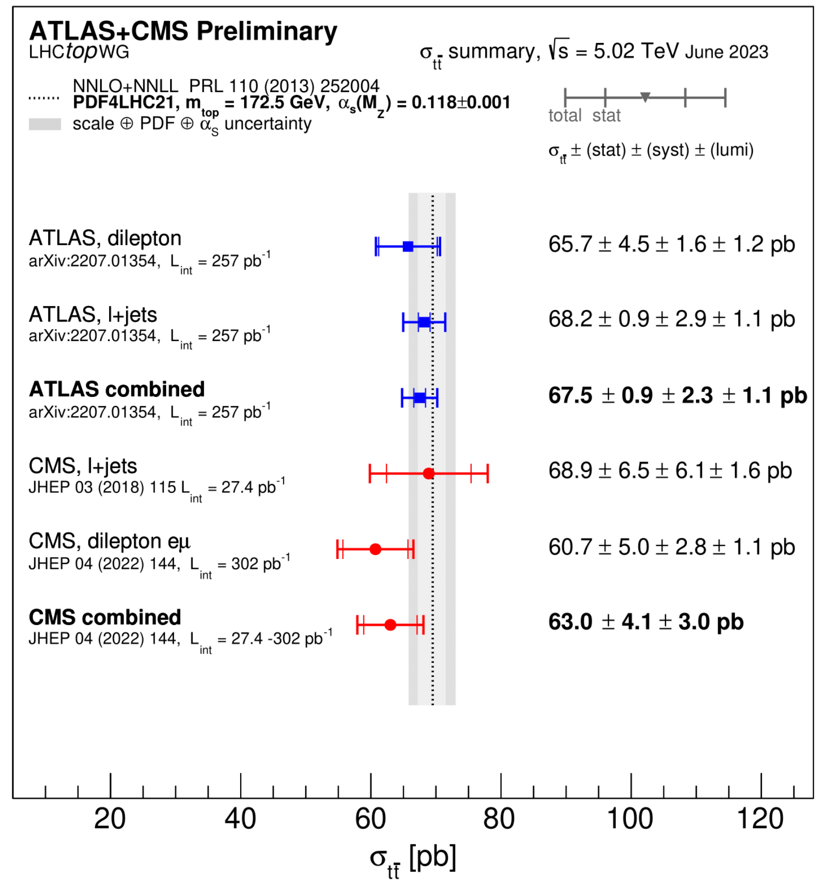
2308.04835

[LHCTopWG Summary](#)

4 top



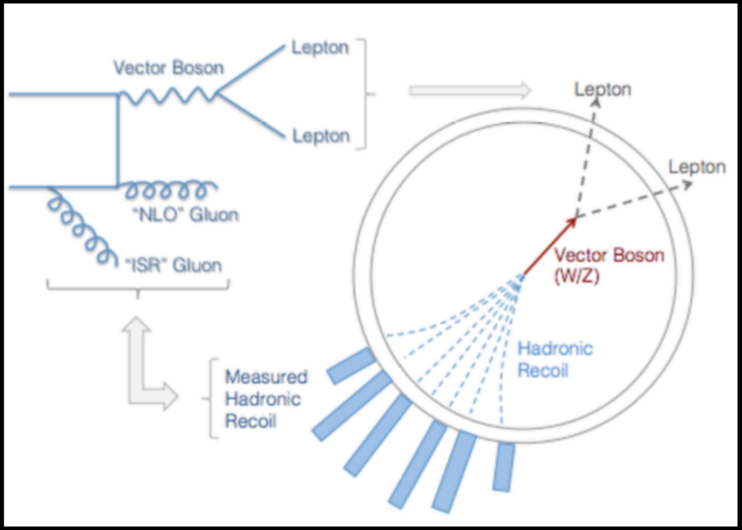
xSec -ttbar



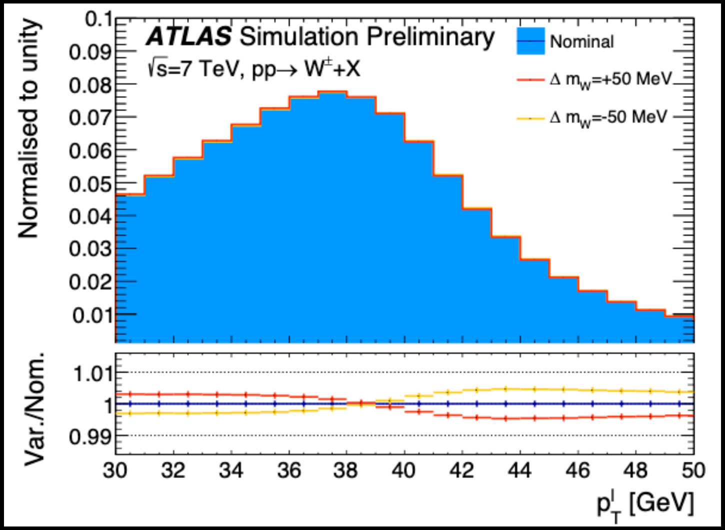
New W mass measurement from ATLAS

ATLAS-CONF-2023-004

Determine the W boson mass from the dependence of the leptonic transverse momentum (p_T) and the transverse mass (m_T)



M_W shift = ± 50 MeV



Revisited measurement from 2017, using the same data, but with more advanced physics model and profile likelihood fitting:

- **Advantage**: Reduce systematic uncertainties during the fit
- **Disadvantage**: Computational expensive, challenging to investigate systematics

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W mass: physics modeling and analysis improvements

Physics modeling

- **Baseline: Pythia AZ tune (based on Z boson)**
  - Z Boson Data, Parton Shower Variations
- **New Verifications:**
  - AZ tune describes hadronic recoil spectrum of W's in low-pileup data at 5 TeV within experimental uncertainties
  - DYTurbo (resumed calculation) also agrees with AZ Tune.
- **Treatment of angular coefficients unchanged**
- **Parton Distribution Functions:**
  - Studied full set of available PDF Sets at NNLO: CT10, CT14, CT18, MMHT2014, MSHT20, NNPDF3.1, NNPDF4.0
    - New Baseline CT18

Analysis improvements

- **Multijet Background Estimation**
  - Systematic shape variations using PCA
  - New transfer function from CR to SR
  - Reduction of uncertainty by 2 MeV
- **EWK uncertainty evaluated at detector level**
  - increase uncertainty by 1-2 MeV
- **Recovering data in the electron channel**
  - Increased statistics by 1.5%
- **Add W width as NP parameter**
- **Improving random generator setup for the electron energy calibration**

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Obs.	Mean [MeV]	Elec. Unc.	PDF Unc.	Muon Unc.	EW Unc.	PS & A_i Unc.	Bkg. Unc.	Γ_W Unc.	MC stat. Unc.	Lumi Unc.	Recoil Unc.	Total sys.	Data stat.	Total Unc.
p_T^ℓ	80360.1	8.0	7.7	7.0	6.0	4.7	2.4	2.0	1.9	1.2	0.6	15.5	4.9	16.3