Review of (recent) ATLAS Results

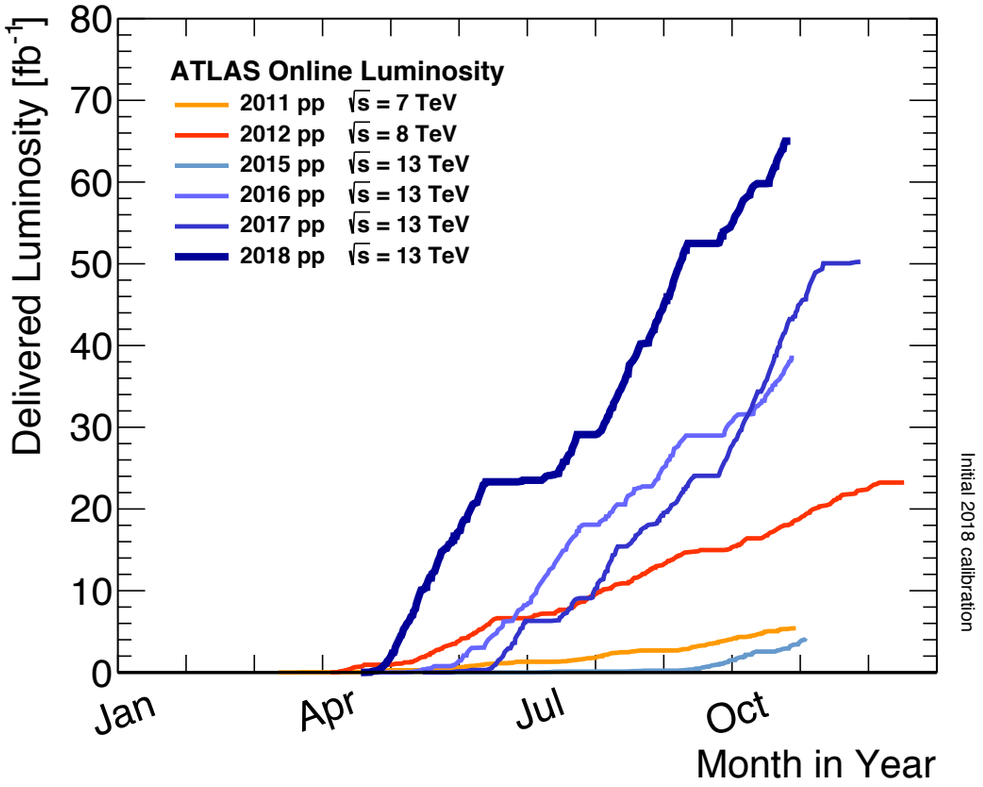
Frank Filthaut
Radboud University & Nikhef, Nijmegen
for the ATLAS Collaboration

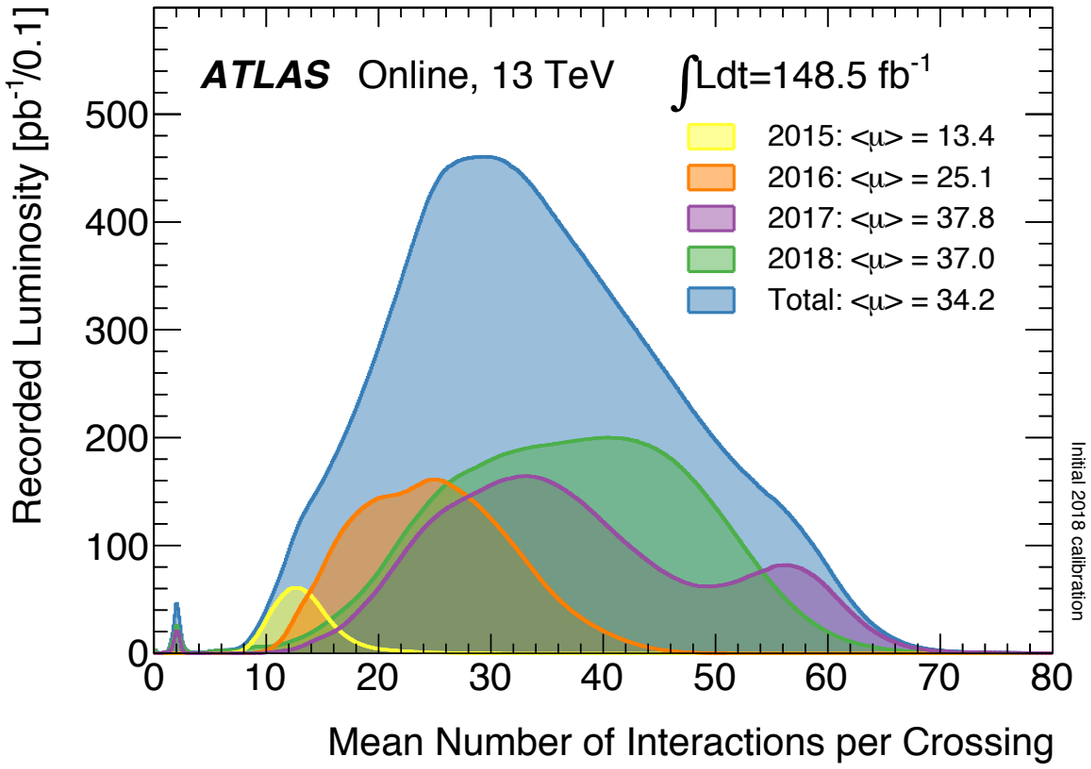
Miami 2018, 15 December 2018

Run 2 is over!

Huge thanks to the LHC division for efficient and smooth operation

- 2018: ~ 70 /fb
- Run-2 integrated: ~ 160 /fb (goal: 120 /fb)





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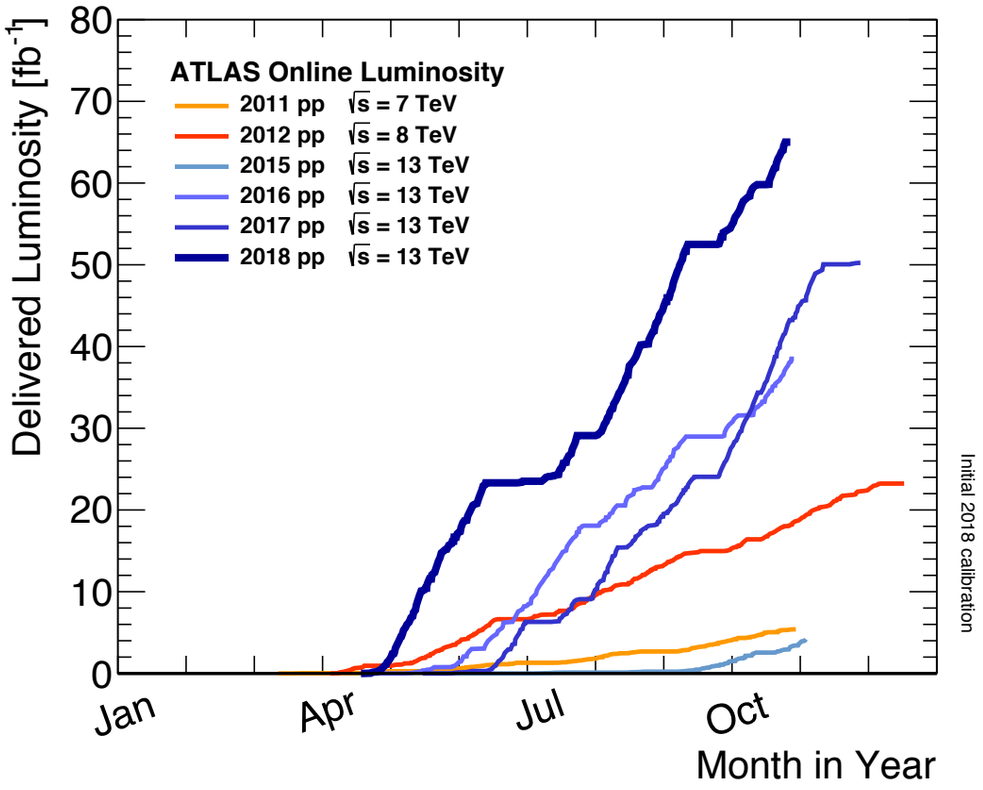
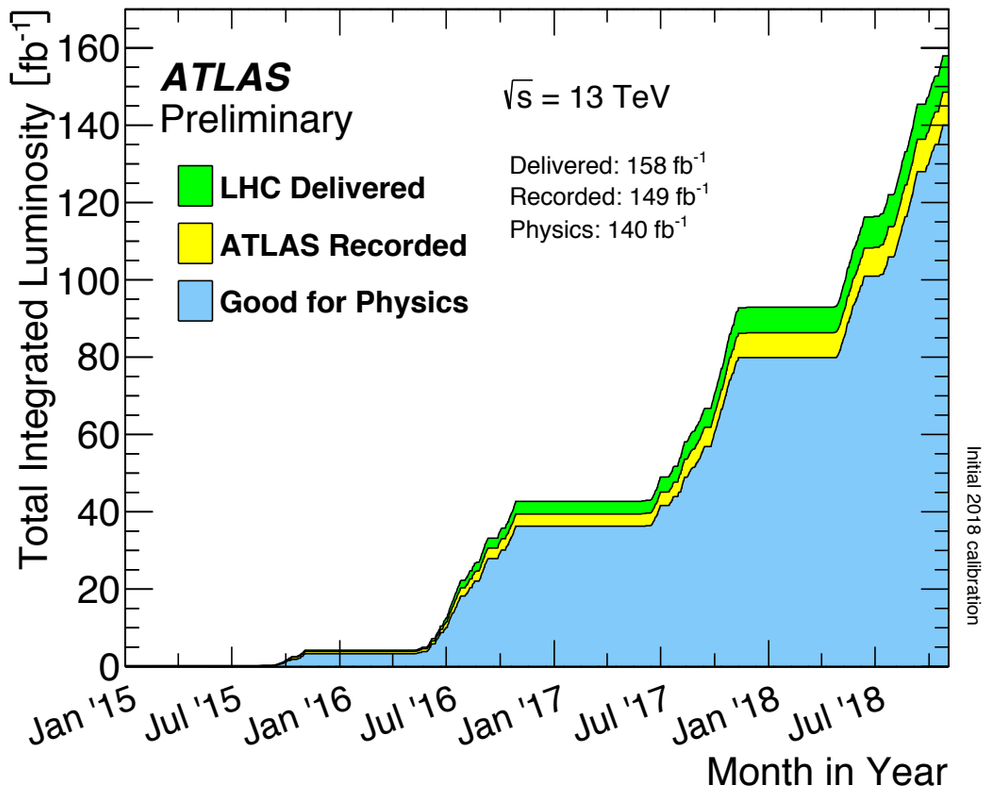




- usable for physics: ~ 140 /fb

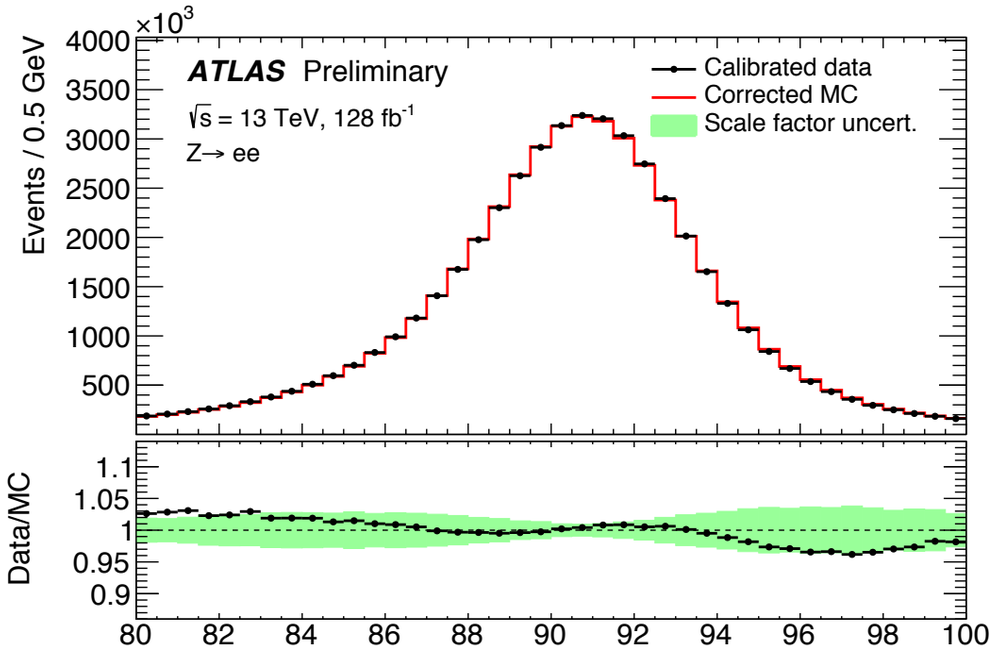
To come:

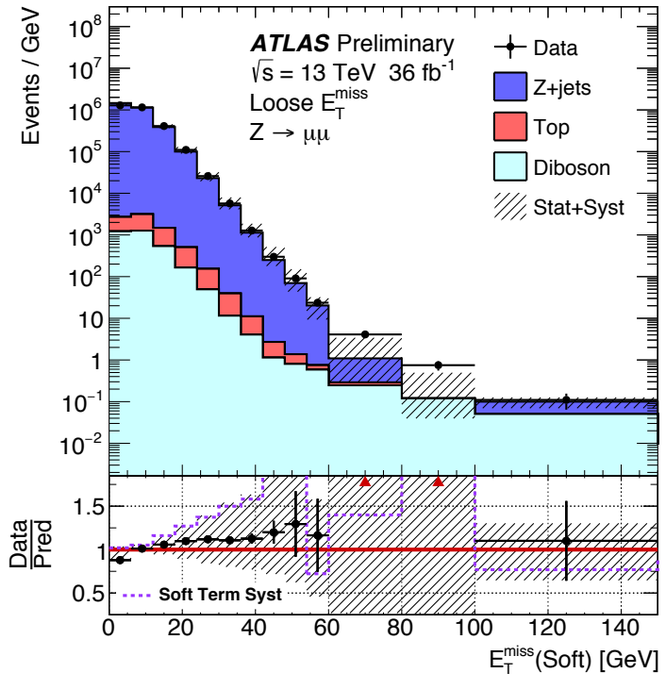
- Run 3: 2021— 2023, 150 /fb at 14 TeV
- Run 4: 2027+, 3000 /fb at 14 TeV

1808.07858

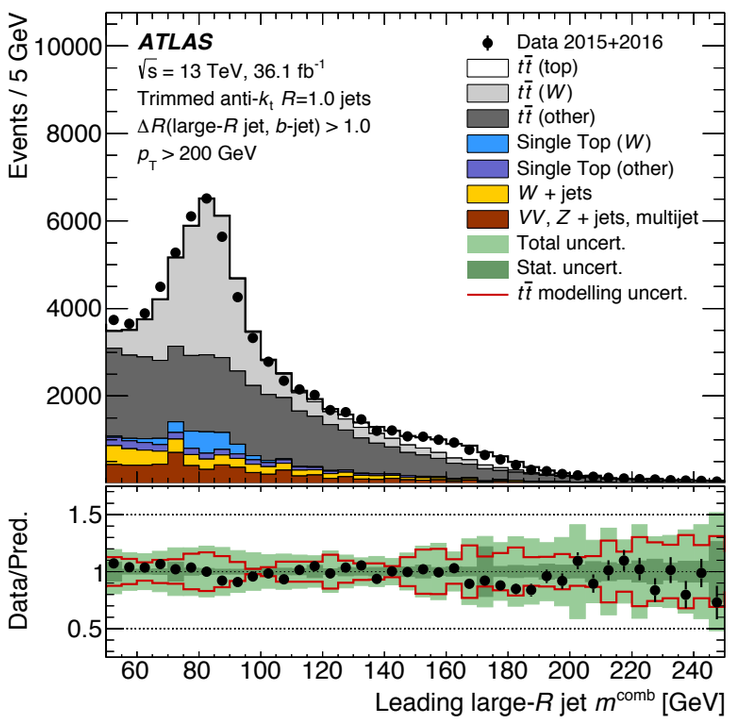
Run 2: exquisite understanding

electron momentum scale & resolution; p_T(miss) resolution

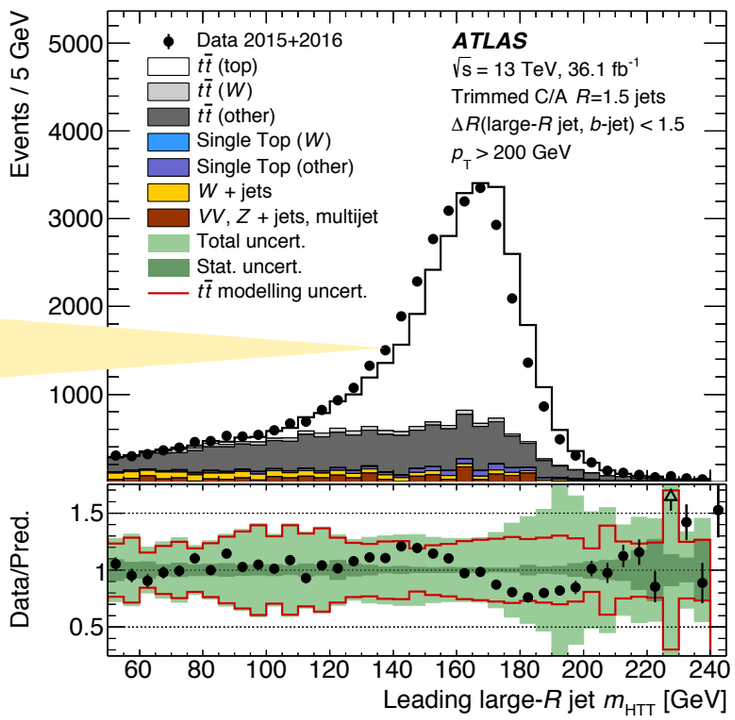




tagging (boosted) hadronic W, top decays: moving to advanced techniques



limited by parton shower & hadronisation systematics



ATLAS physics programme

Over 800 publications submitted by ATLAS in total (~100 in 2018)
Full details at https://twiki.cern.ch/twiki/bin/view/AtlasPublic

Standard Model measurements:

- electroweak measurements
- top quark physics
- flavour-changing neutral current processes

Searches for BSM physics:

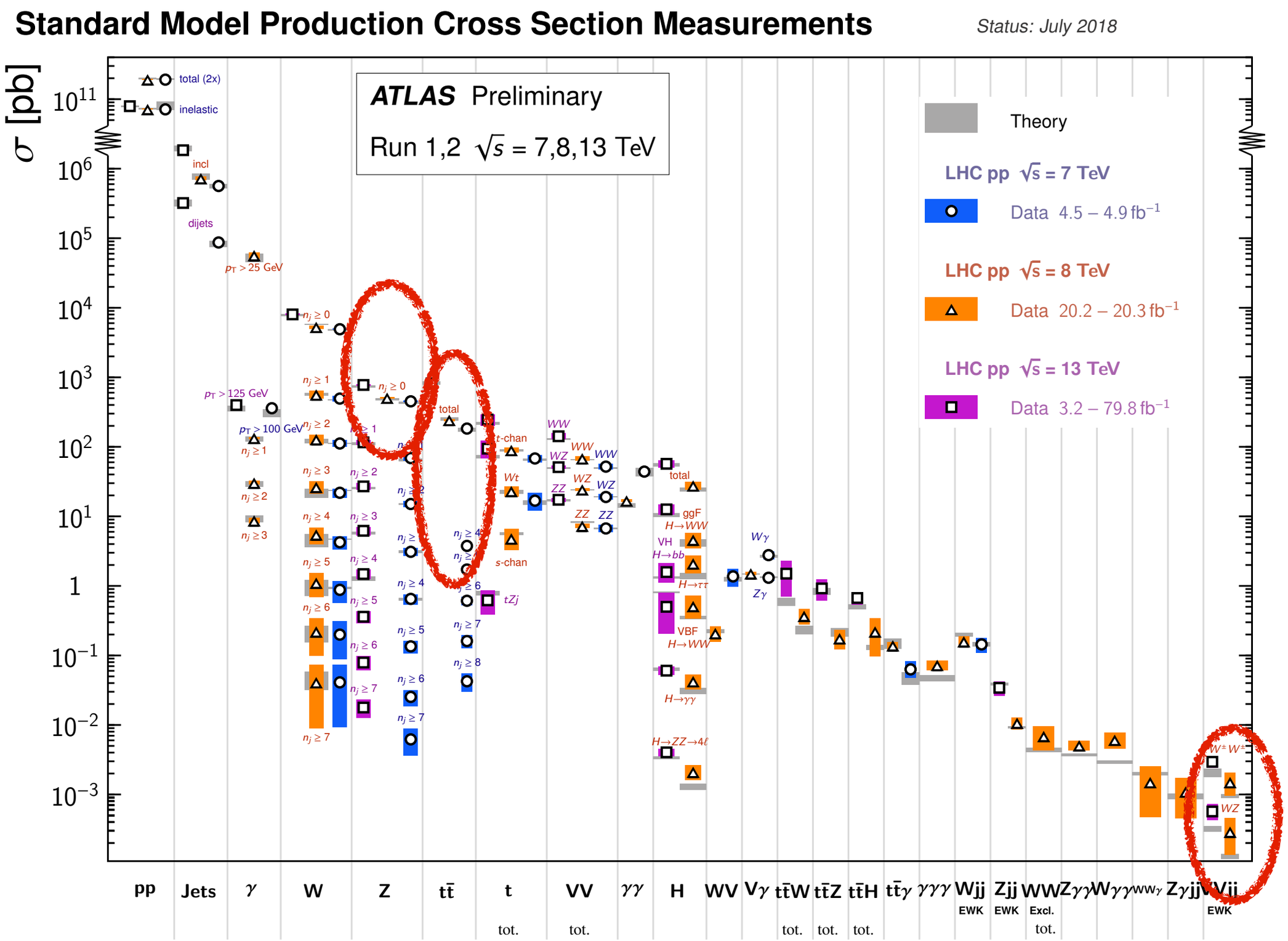
- generic SUSY
- dark matter
- exotic signatures: long-lived heavy particles

Higgs boson physics:

- H(125) properties
- search for di-Higgs production

Heavy-ion physics

Standard Model measurements



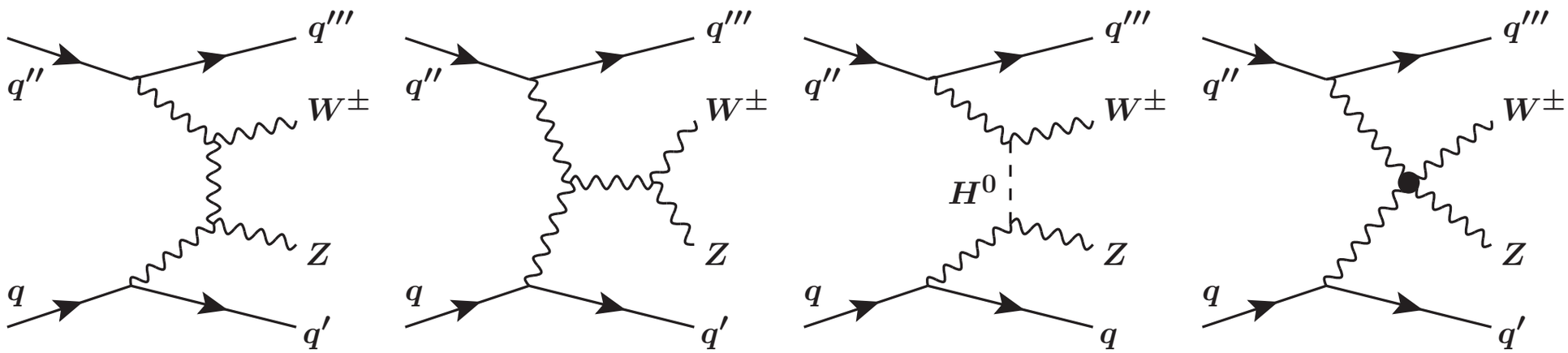
ATLAS-CONF-2018-030

ATLAS-CONF-2018-033

Observation of EW WW, WZ production

Sensitive probes of triple gauge-boson couplings

- studied for leptonic W, Z decay modes
  - WW: W^+W^+ / W^-W^- only



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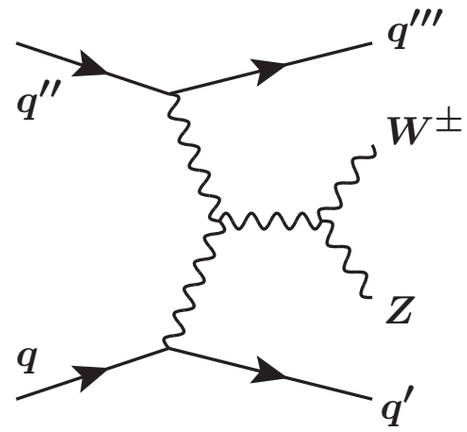
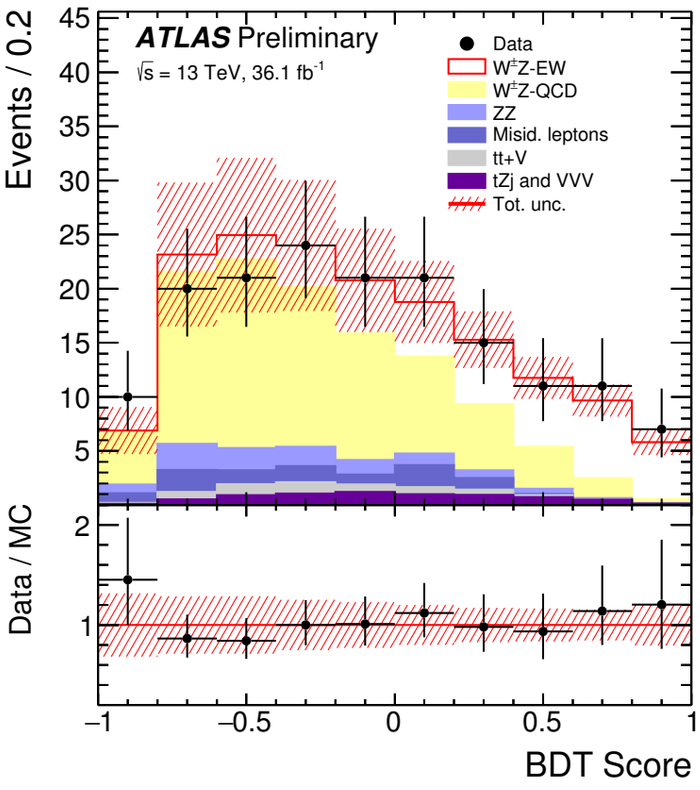
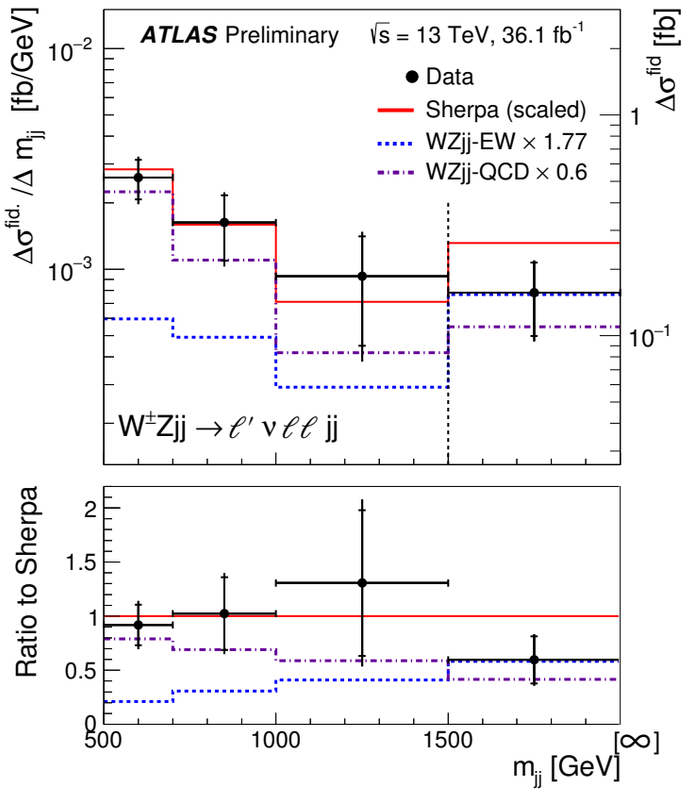
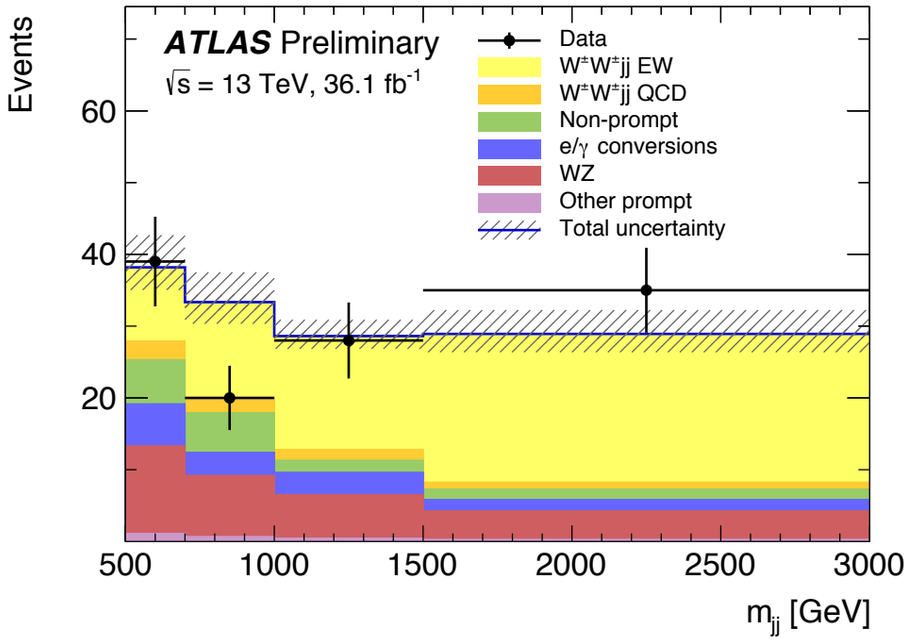






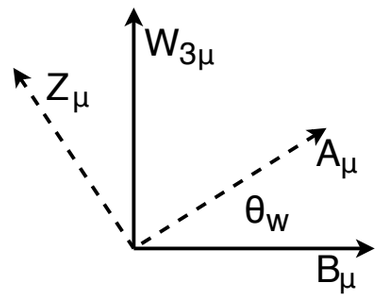


Signal significances:

- WZ: 5.6 σ observed (3.3 σ expected)
- same-sign WW: 6.9 σ observed (4.6 σ expected)

ATLAS-CONF-2018-037

Measurement of $\sin^2(\theta_W)$



Of continued importance due to tension between LEP-era measurements

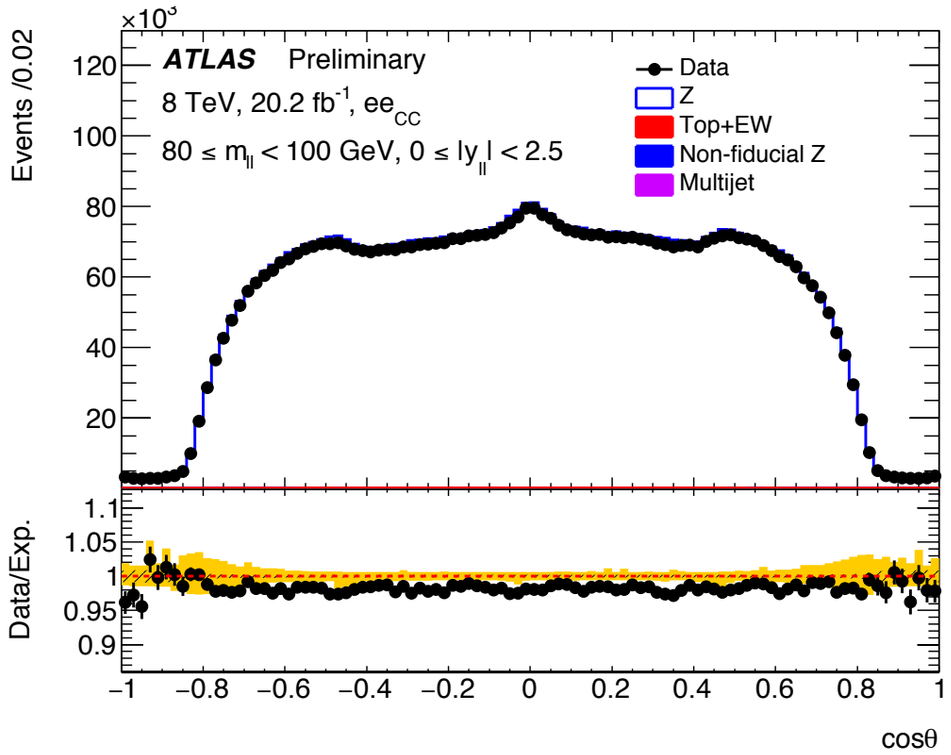
New measurement using 8 TeV data (2012)

- at LO and ignoring acceptance effects:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}y^{\ell\ell}\,\mathrm{d}m^{\ell\ell}\,\mathrm{d}\cos\theta} = \frac{3}{16\pi}\frac{\mathrm{d}\sigma^{U+L}}{\mathrm{d}y^{\ell\ell}\,\mathrm{d}m^{\ell\ell}}\left(1+\cos^2\theta + A_4\,\cos\theta\right)$$

full phase space: $A_{FB} = \frac{3}{8}A_4$

- good agreement overall between data & predictions (not using absolute rates) + cross-check with results obtained using unfolded differential dσ



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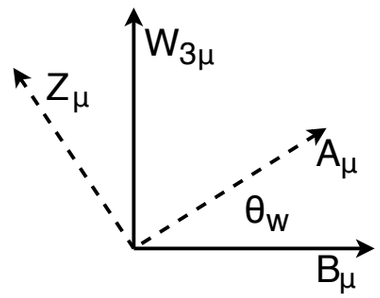

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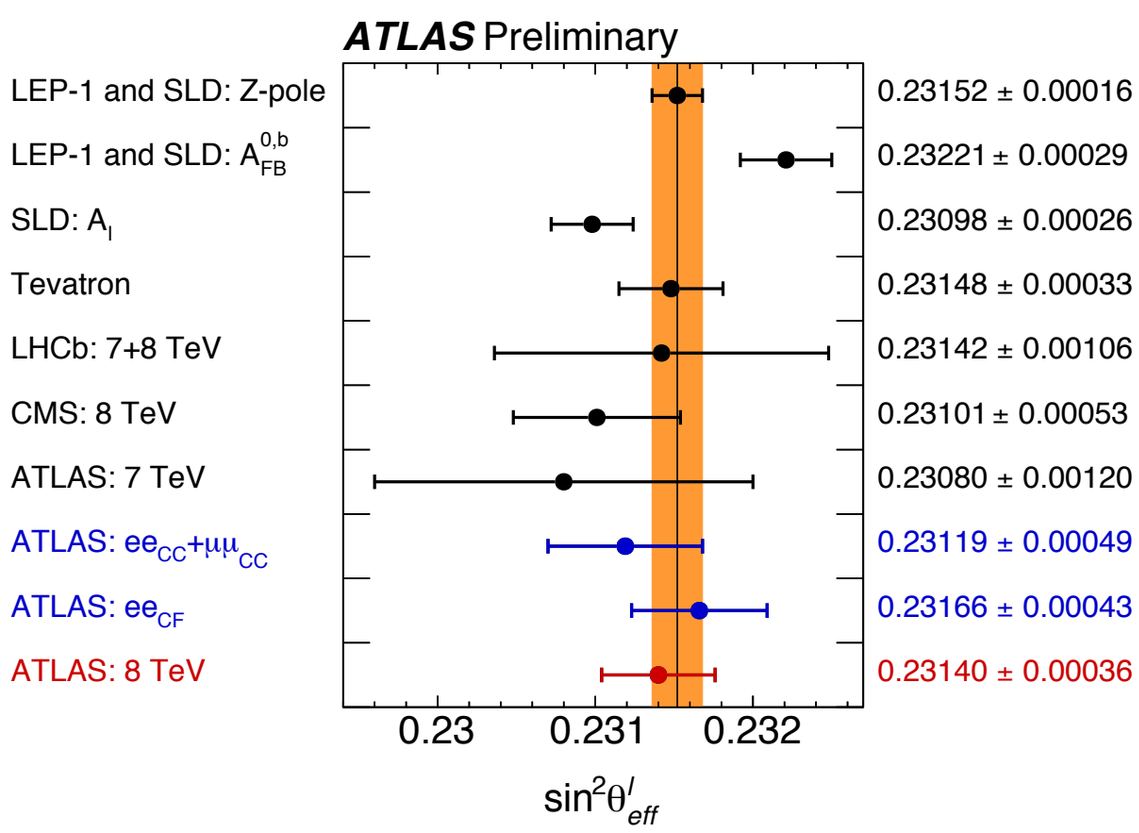


$$\sin^2\theta^{\ell}_{\text{eff}} = 0.23140 \pm 0.00021\,(\text{stat.}) \pm 0.00024\,(\text{PDFs}) \pm 0.00016\,(\text{syst.})$$

JHEP 10 (2018) 047

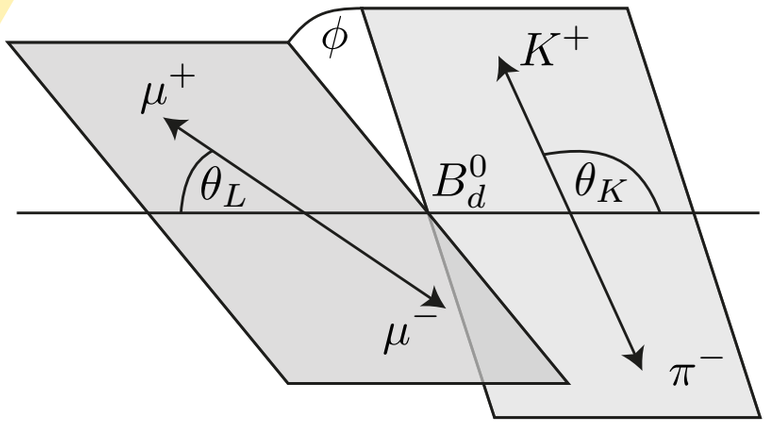
Angular analysis of $B_d \to K^* \mu^+\mu^-$ decays

FCNC process, of great (renewed) interest following LHCb 3.4 σ tension with SM predictions

$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_L\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\left(\ldots + \sqrt{F_L(1-F_L)}\,P_5'\,\sin 2\theta_K \sin\theta_L \cos\phi + \ldots\right)$$

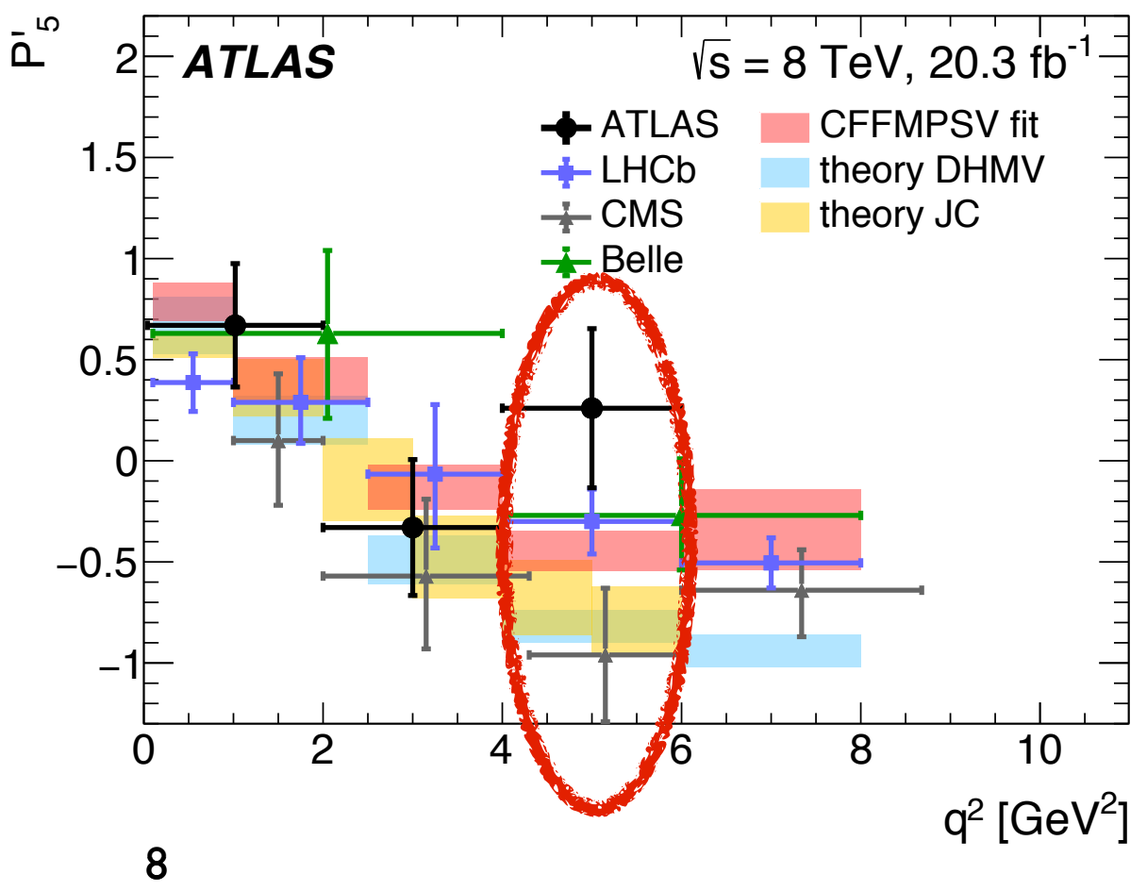
fraction of longit. polarized K*

1/7 Wilson coefficients



Measurement for $q^2 \equiv m^2_{\mu\mu} < 6\,\mathrm{GeV}^2$ (to avoid radiative J/ψ tail) in 8 TeV data

- most discrepant result for P_5' in 4 - 6 GeV² bin (2.7 σ), but not precise enough to make a firm statement
  - measurement statistically limited

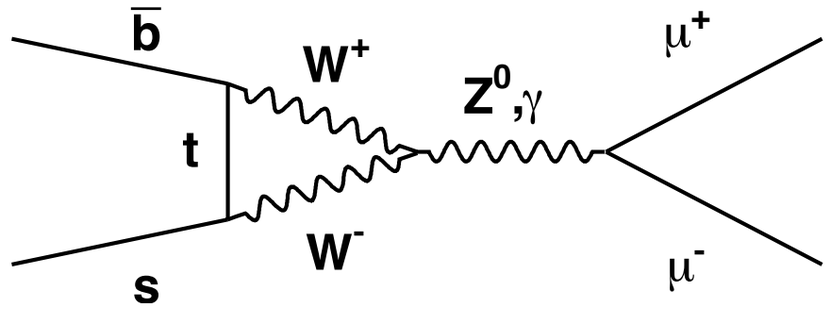


1812.03017

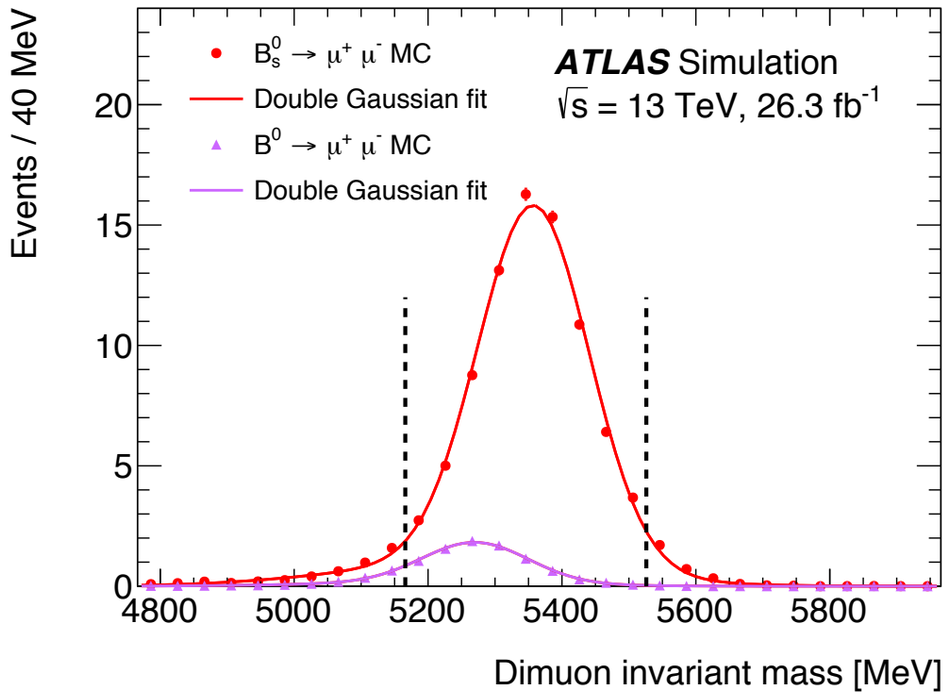
$B_{d,s} \rightarrow \mu^+\mu^-$

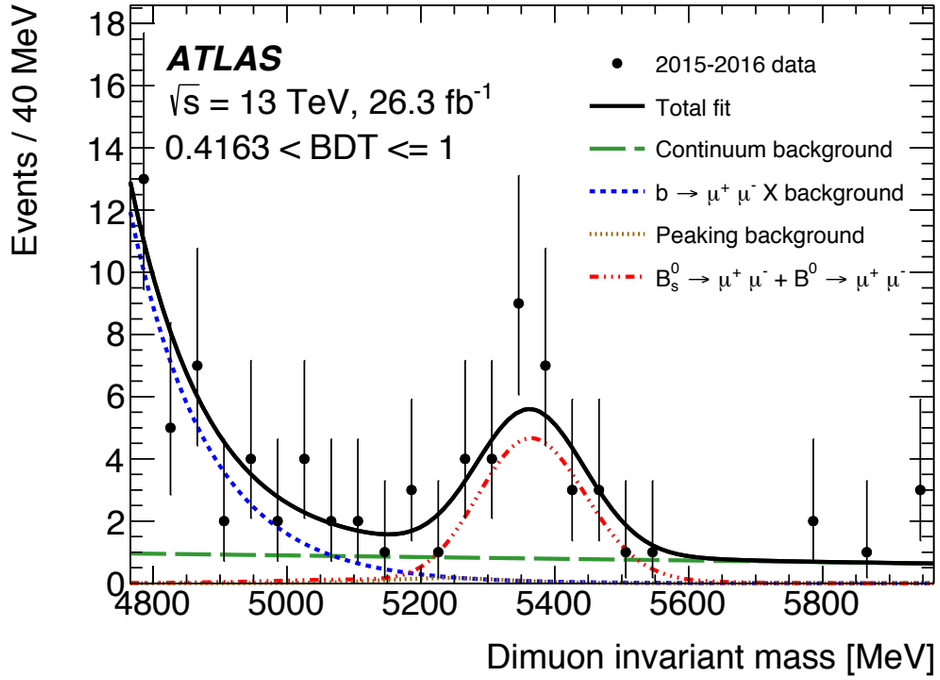
Rare FCNC decay sensitive to BSM loop contributions

Multivariate analysis (BDT) to suppress continuum bg, yields extracted from $m(\mu^+\mu^-)$ distributions in different BDT intervals



- same variables as in Run-1 analysis; BDT output not correlated with mass





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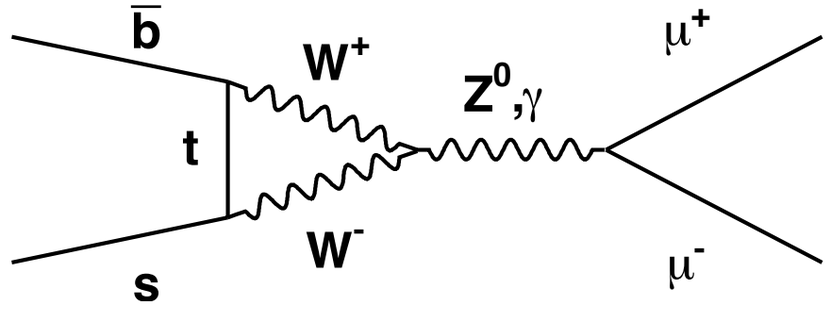
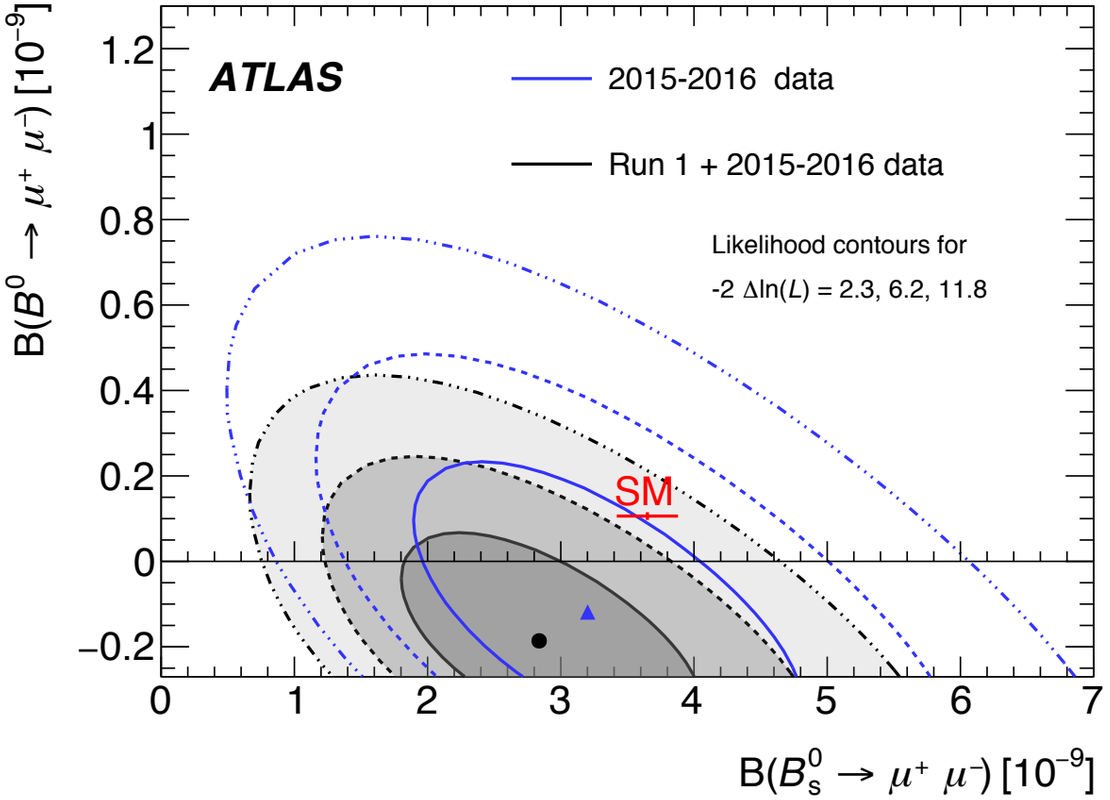


- same variables as in Run-1 analysis; BDT output not correlated with mass
- results (combined w/ Run 1):

$$B(B_s \rightarrow \mu^+\mu^-) = 2.8^{+0.8}_{-0.7} \cdot 10^{-9}$$

$$B(B_d \rightarrow \mu^+\mu^-) < 2.1 \cdot 10^{-10}$$

- SM: $(3.65 \pm 0.23) \cdot 10^{-9}$, $(1.06 \pm 0.09) \cdot 10^{-10}$



ATLAS-CONF-2018-027

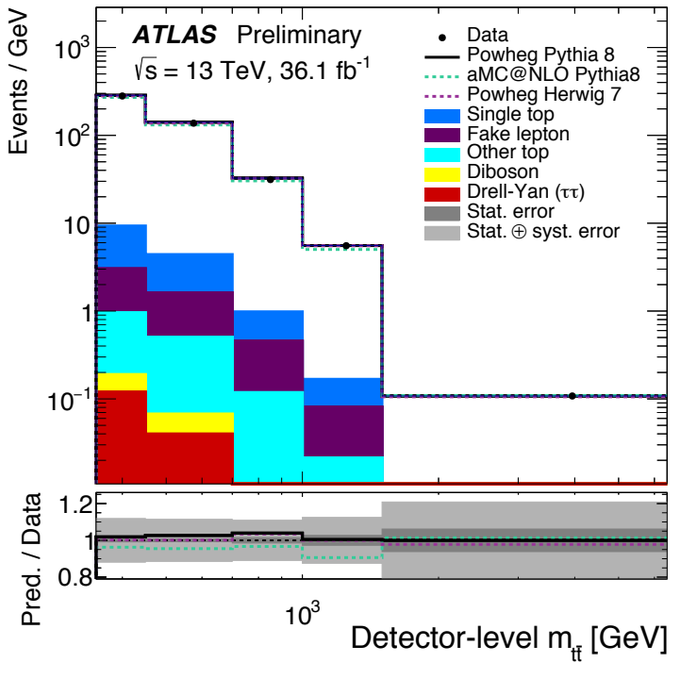
Spin correlations in tt decays

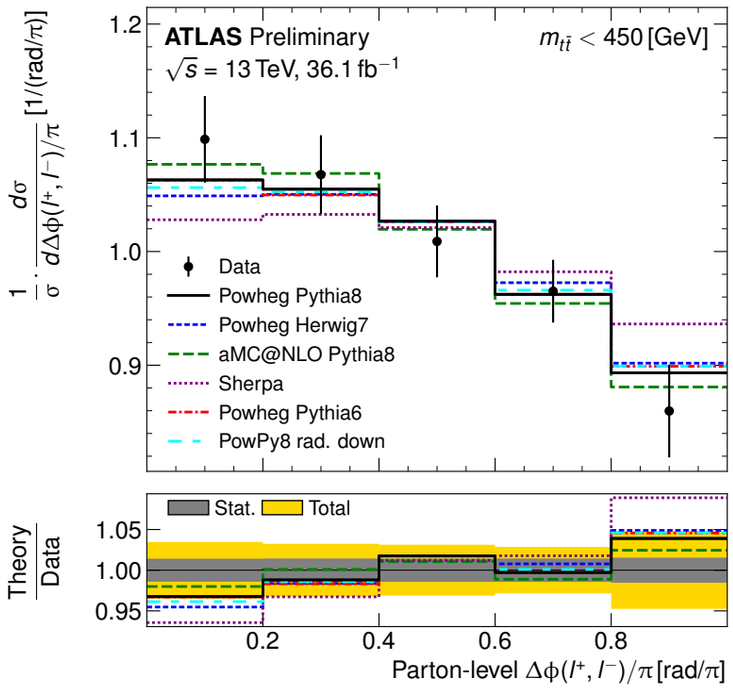
Top-quark spin transmitted to decay products, charged lepton is a sensitive probe ➠ also for spin correlations in dilepton tt events

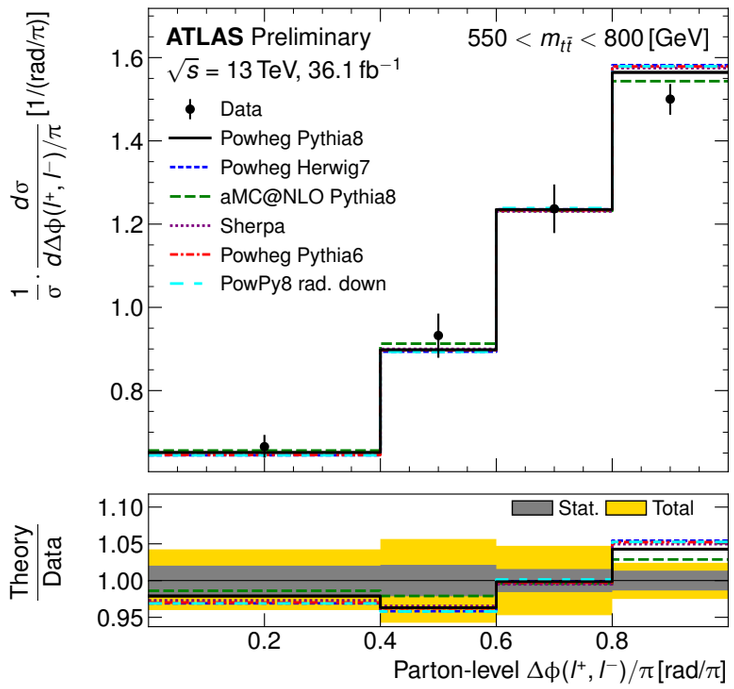
- used earlier to search for stop pair production with $m(\tilde{t}) \approx m(t)$
- consider Δφ(e,μ) in lab frame
  - integrated & in bins of m(tt)

Find stronger spin correlations than predicted by SM (3.2 σ)

- possible hint for un-understood production (e.g. $\tilde{t}\tilde{t}^* \rightarrow t\chi^0\bar{t}\chi^0$) or decay (e.g. $t \rightarrow H^+ b$) characteristics





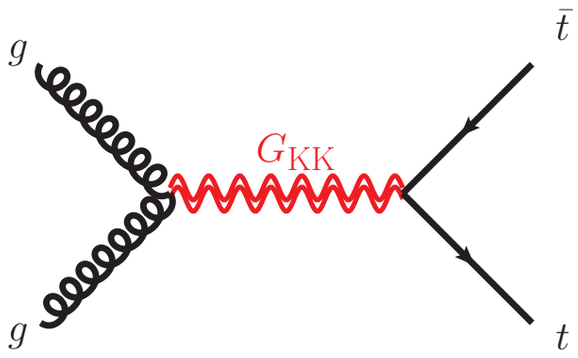


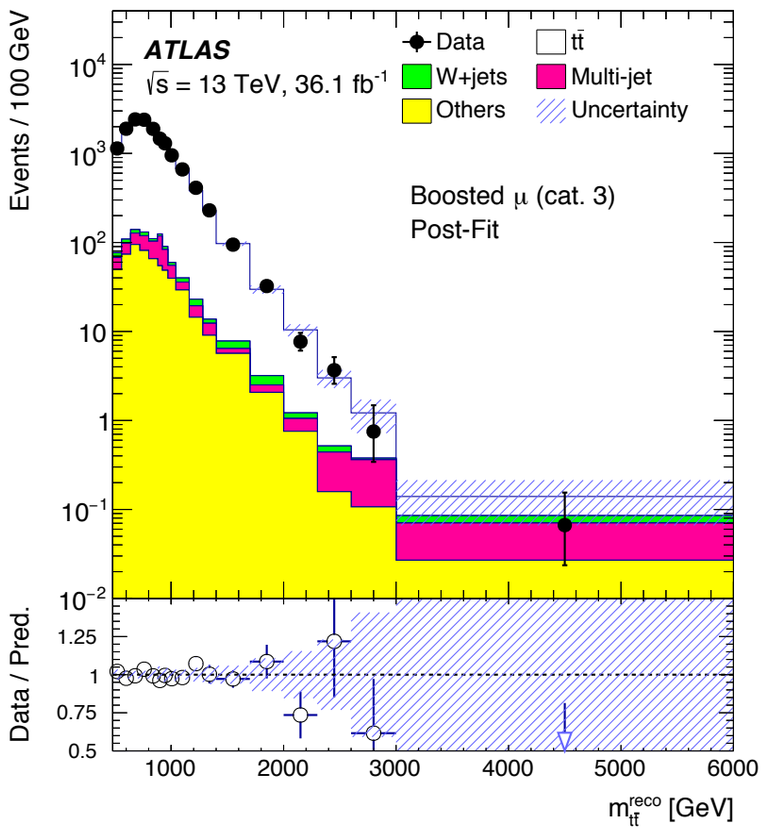
EPJ C78 (2018) 565

Search for resonances decaying to tt

Searched for in lepton+jets events

- high branching fraction, "tractable" kinematic constraints, exploit top tagging
- absence of a signal used to set limits on several benchmark signal models
  - Z' (top-colour-assisted technicolour & simplified DM models)
  - RS g_{KK}, G_{KK}





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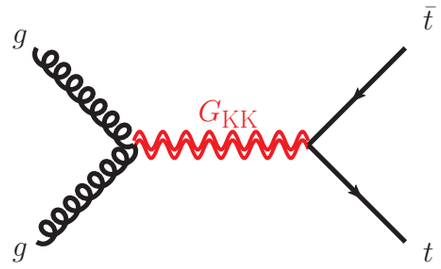
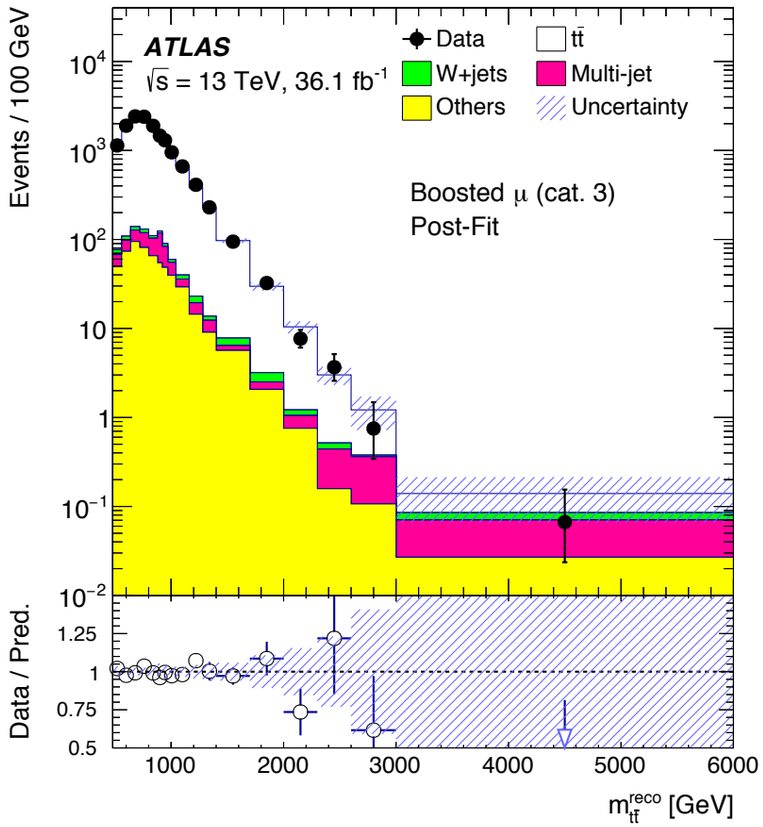
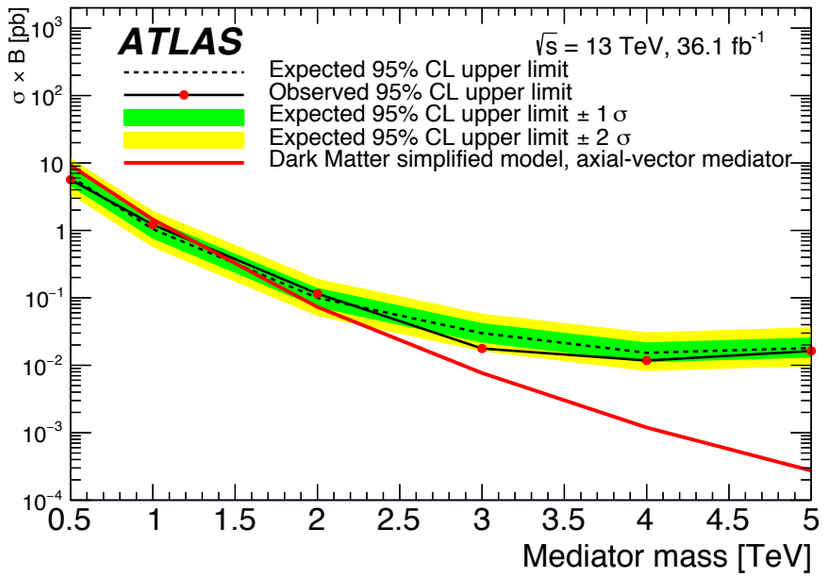
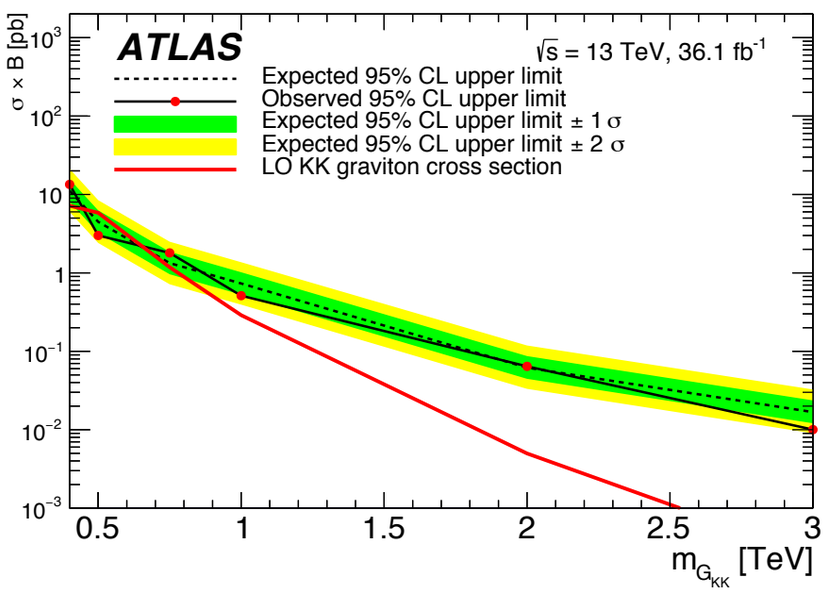








Searches for BSM physics

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2018

ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (3.2 – 79.8) fb^{-1} $\sqrt{s}$ = 8, 13 TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	M_D 7.7 TeV	$n = 2$	1711.03301
	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	$n = 6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	1707.04147
	Bulk RS $G_{KK} \to WW/ZZ$	multi-channel			36.1	G_{KK} mass 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$	CERN-EP-2018-179
	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	–	–	36.1	Z' mass 4.5 TeV		1707.02424
	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 $Z' \to tt$	1 e, μ	≥ 1 b, $\geq$ 1J/2j	Yes	36.1	Z' mass 3.0 TeV	$\Gamma/m = 1\%$	1804.10823
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	79.8	W' mass 5.6 TeV		ATLAS-CONF-2018-017
	SSM $W' \to \tau\nu$	1 τ	–	Yes	36.1	W' mass 3.7 TeV		1801.06992
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	79.8	V' mass 4.15 TeV	$g_V = 3$	ATLAS-CONF-2018-016
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V = 3$	1712.06518
	LRSM $W'_R \to tb$	multi-channel			36.1	W' mass 3.25 TeV		CERN-EP-2018-142
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV	η_{LL}^-	1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.0 TeV	η_{LL}^-	1707.02424
	CI $tttt$	$\geq$1 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	Λ 2.57 TeV	$\lvert C_{4t}\rvert = 4\pi$	CERN-EP-2018-174
DM	Axial-vector mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.55 TeV	g_q=0.25, g_χ=1.0, $m(\chi) = 1$ GeV	1711.03301
	Colored scalar mediator (Dirac DM)	0 e, μ	1 – 4 j	Yes	36.1	m_{med} 1.67 TeV	g=1.0, $m(\chi) = 1$ GeV	1711.03301
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, $\leq$ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi) < 150$ GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	$\geq$1 b, $\geq$3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht/Zt/Wb + X$	multi-channel			36.1	T mass 1.37 TeV	SU(2) doublet	ATLAS-CONF-2018-032
	VLQ $BB \to Wt/Zb + X$	multi-channel			36.1	B mass 1.34 TeV	SU(2) doublet	ATLAS-CONF-2018-032
	VLQ $T_{5/3}T_{5/3}\lvert T_{5/3} \to Wt + X$	2(SS)/$\geq$3 e,μ	$\geq$1 b, $\geq$1 j	Yes	36.1	$T_{5/3}$ mass 1.64 TeV	$\mathcal{B}(T_{5/3} \to Wt) = 1$, $c(T_{5/3}Wt) = 1$	CERN-EP-2018-171
	VLQ $Y \to Wb + X$	1 e, μ	$\geq$ 1 b, $\geq$ 1j	Yes	3.2	Y mass 1.44 TeV	$\mathcal{B}(Y \to Wb) = 1$, $c(YWb) = 1/\sqrt{2}$	ATLAS-CONF-2016-072
	VLQ $B \to Hb + X$	0 e,μ, 2 γ	$\geq$ 1 b, $\geq$ 1j	Yes	79.8	B mass 1.21 TeV	$\kappa_B = 0.5$	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	–	37.0	q^* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	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	79.8	N^0 mass 560 GeV		ATLAS-CONF-2018-020
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	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
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{non-res} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

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

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).

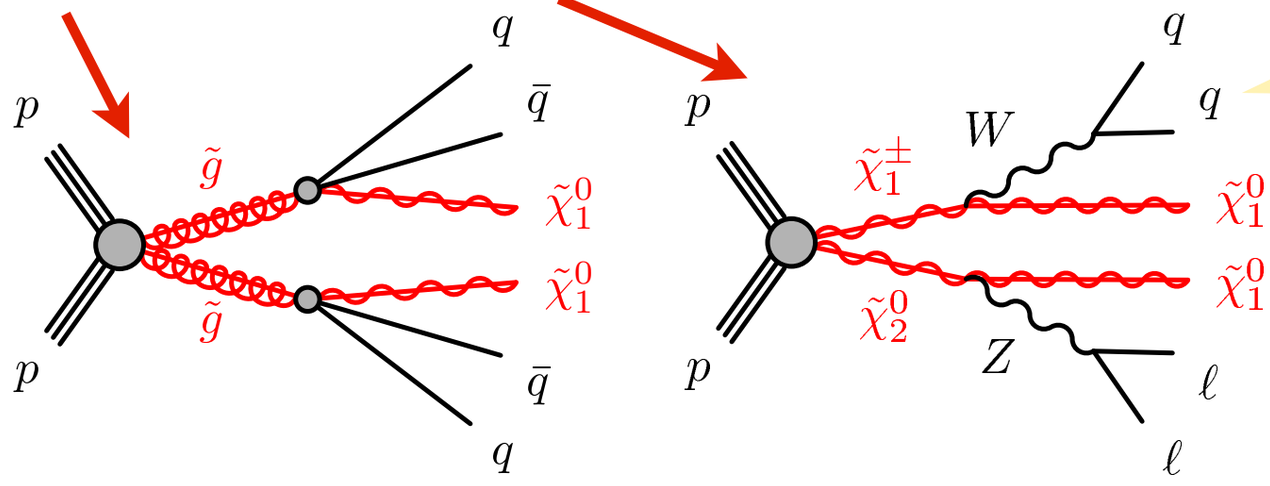
PR D97 (2018) 112001

PR D98 (2018) 092012

Searches for supersymmetry

Both for strong ($\tilde{q}\tilde{q}$, $\tilde{g}\tilde{g}$) and EW ($\tilde{\chi}^{\pm}\tilde{\chi}^{0}$) production

- also using new reconstruction techniques (RJR)



also $W \rightarrow \ell\nu$

PR D97 (2018) 112001

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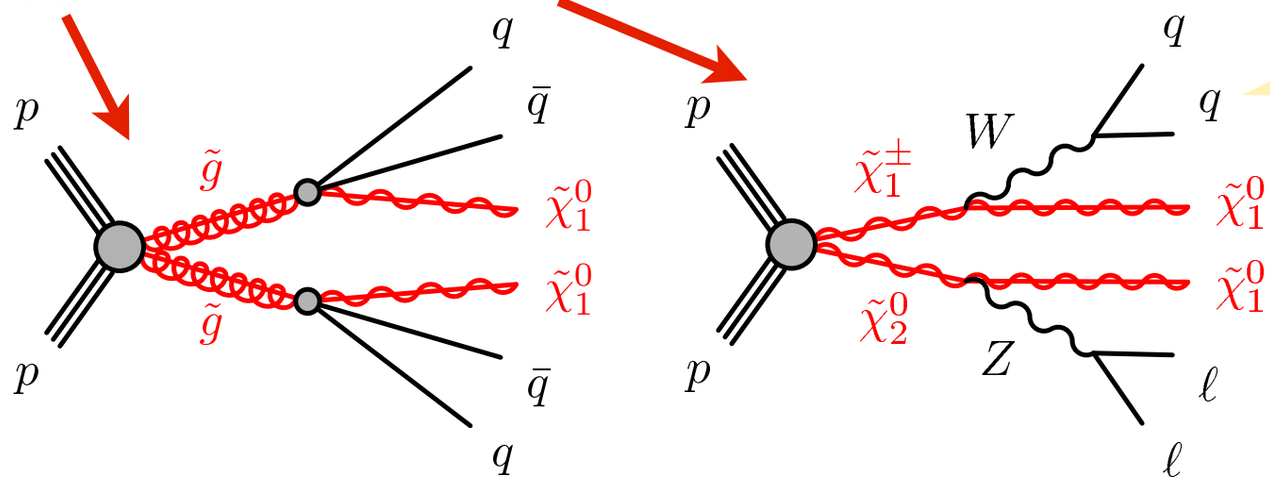
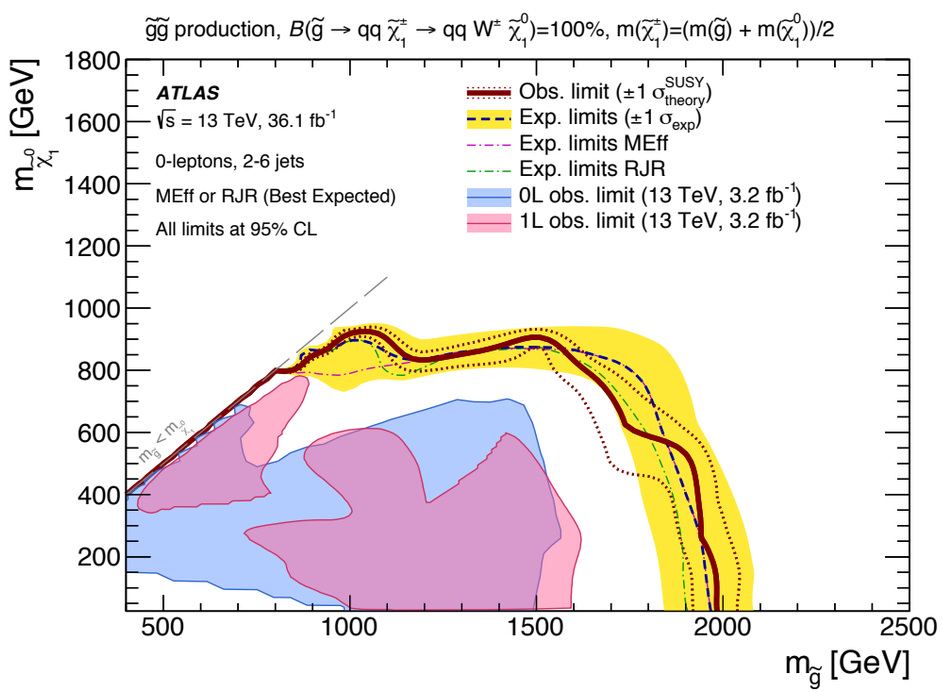
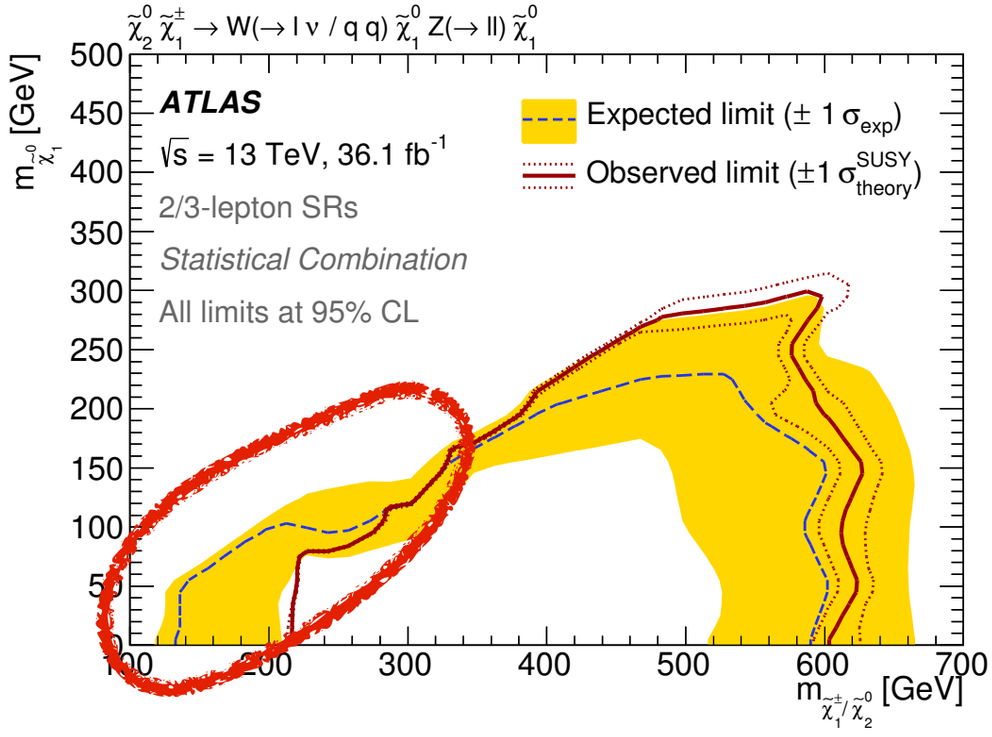


also $W \to \ell\nu$

Significantly enlarged excluded region for strong production; excess in EW search in both 2ℓ, 3ℓ regions (largest deviation: 3σ)

- compatible with compressed scenario ($m_{\tilde{\chi}_2^0,\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} \approx 100\,\text{GeV}$)



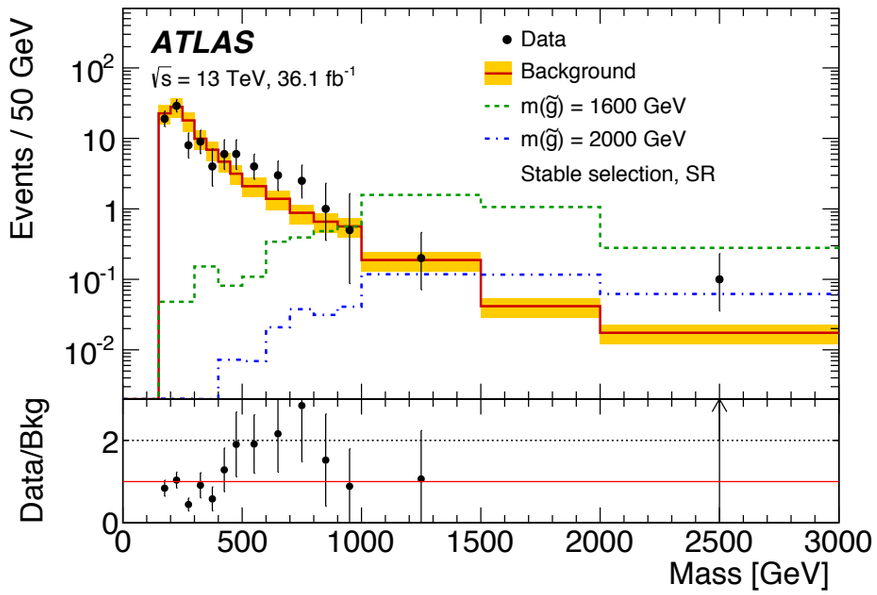


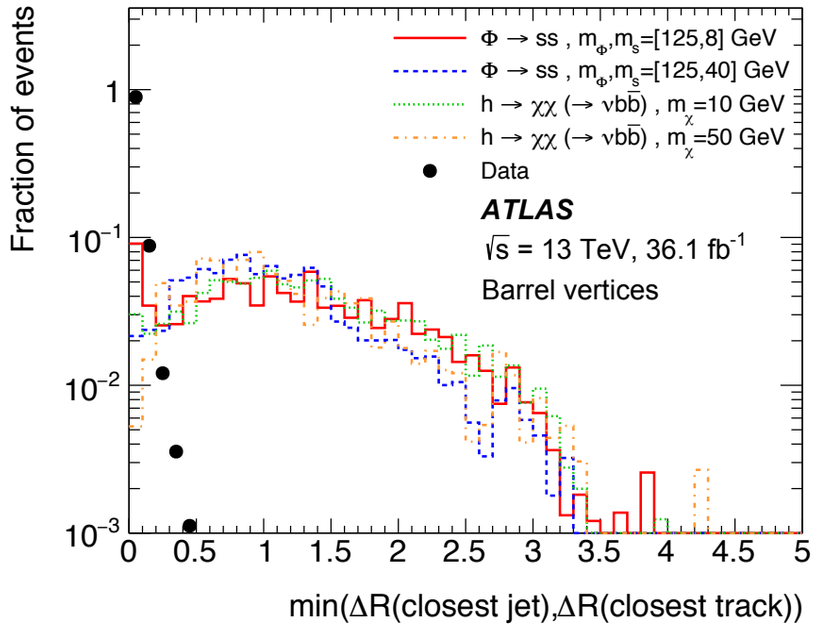
PL B788 (2019) 96 | 1811.07370

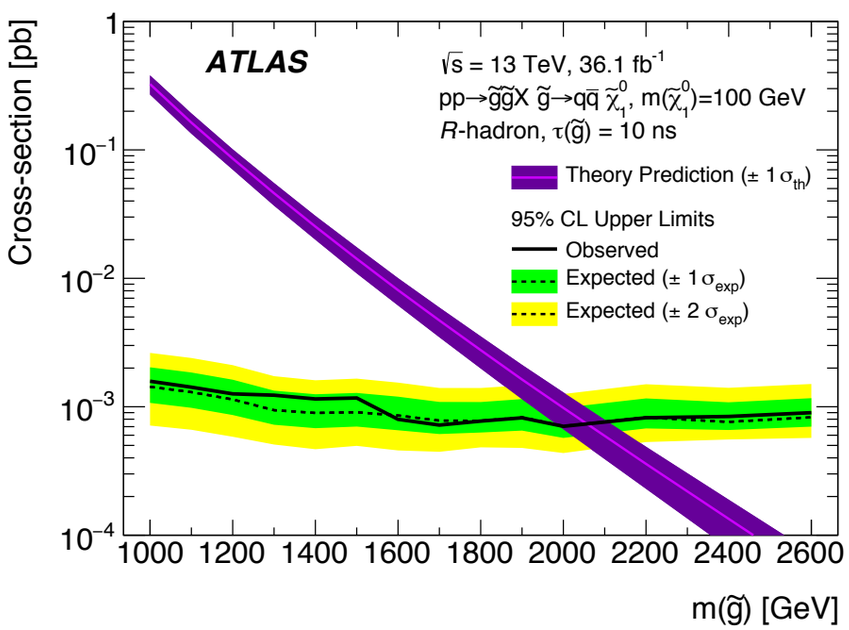
Searches for heavy, long-lived particles

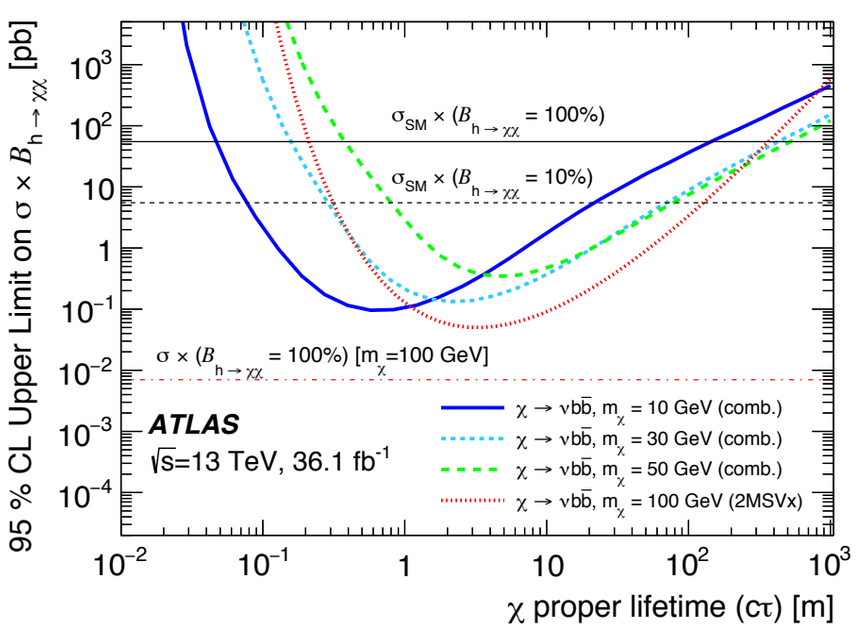
Arise in many BSM models (Hidden Valley, SUSY, …); cτ poorly constrained

ATLAS searches for both heavy charged (through dE/dx) & neutral particles (decays in Muon System)







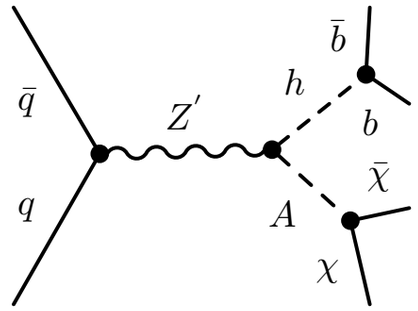


ATLAS-CONF-2018-039

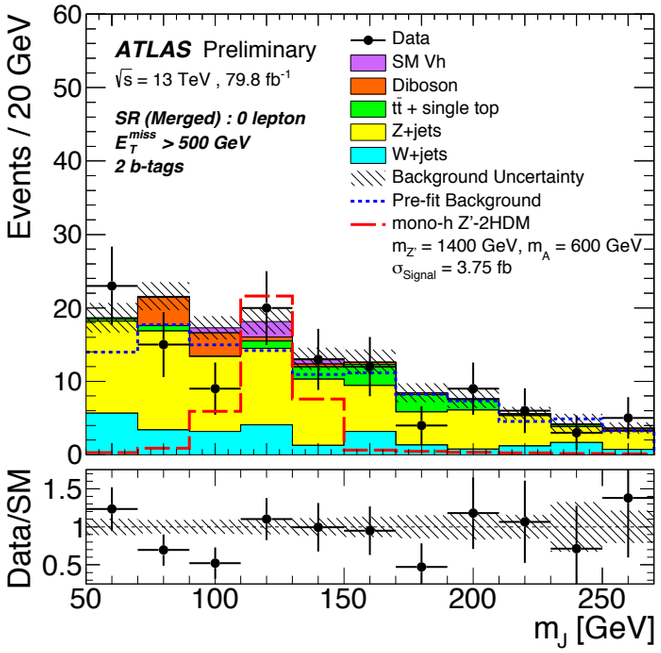
ATLAS-CONF-2018-051

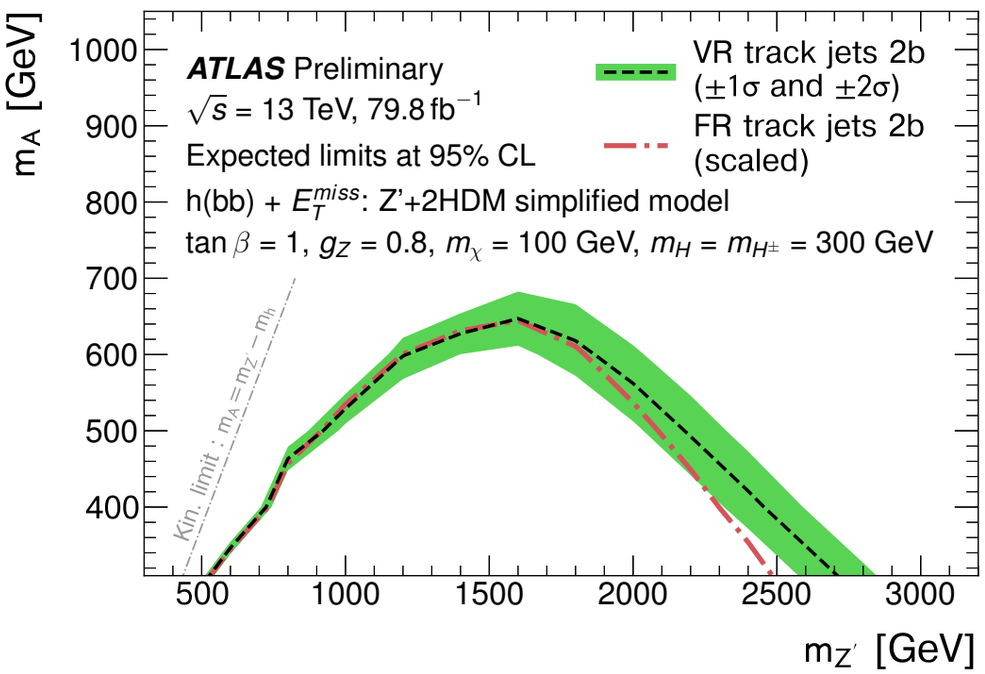
Searches for Dark Matter

Mono-H(bb) (Z'+2HDM simplified model) as a test case for reconstruction improvements



- variable-radius jets (R ~ 30 GeV/p_T) to reconstruct high-p_T H →bb as "pencil" jets inside large-R jet





ATLAS-CONF-2018-039

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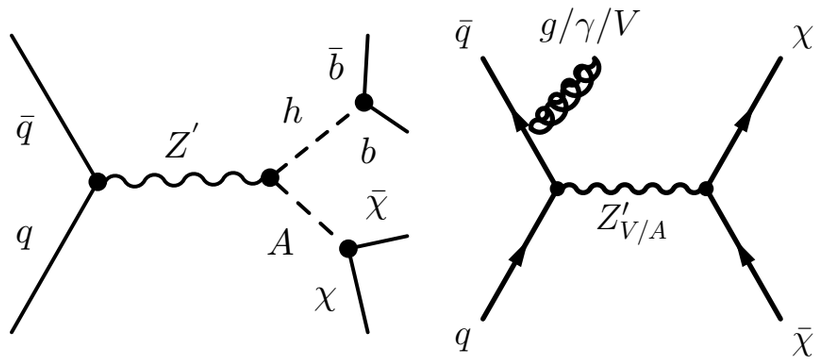
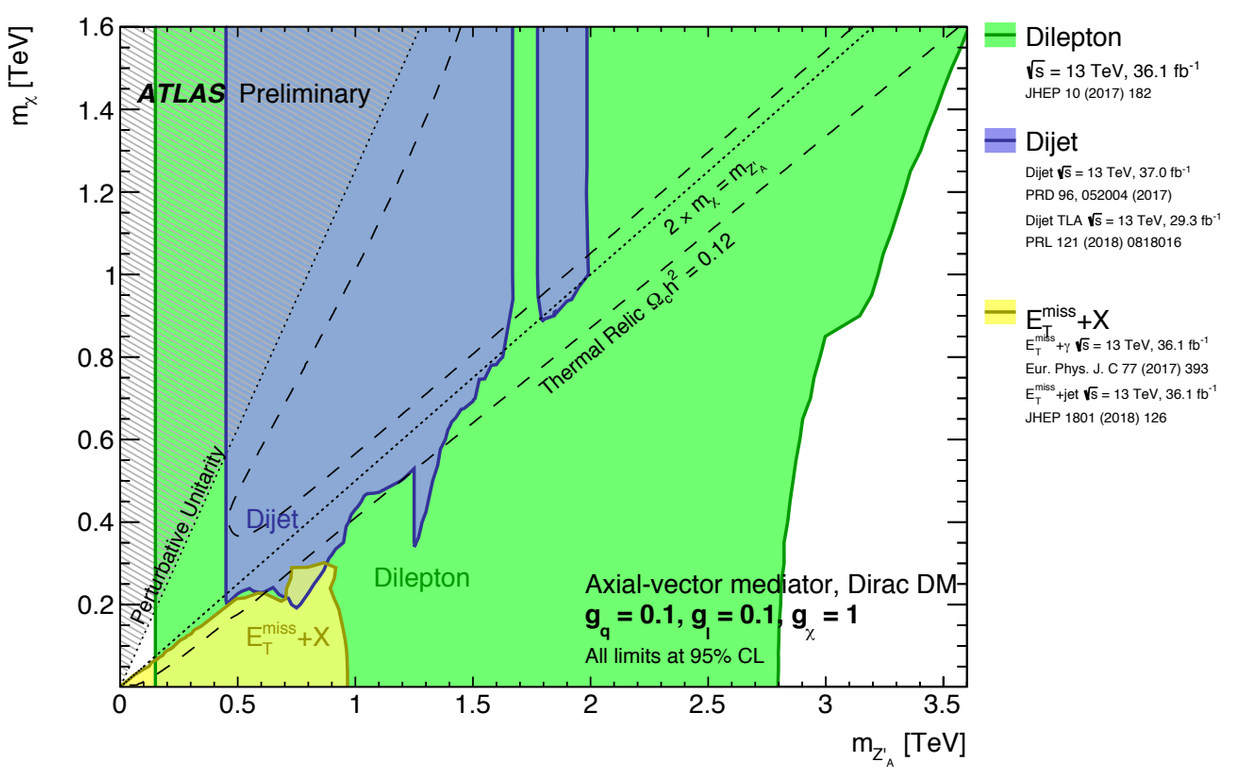
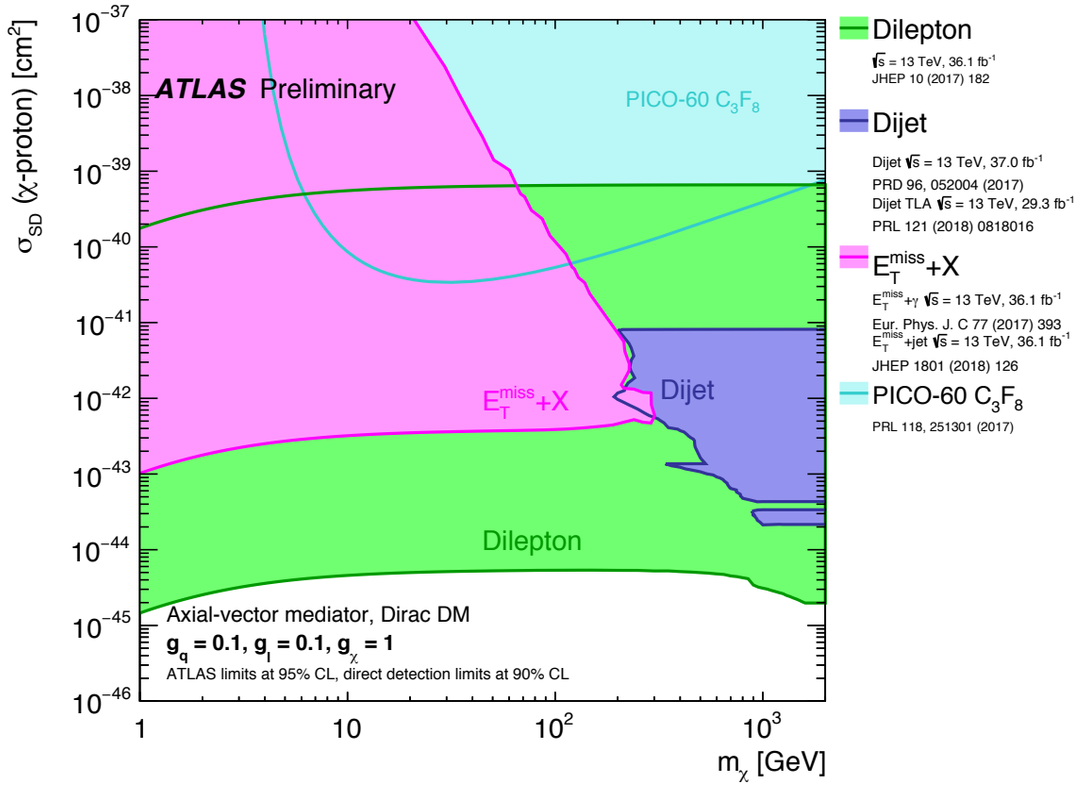
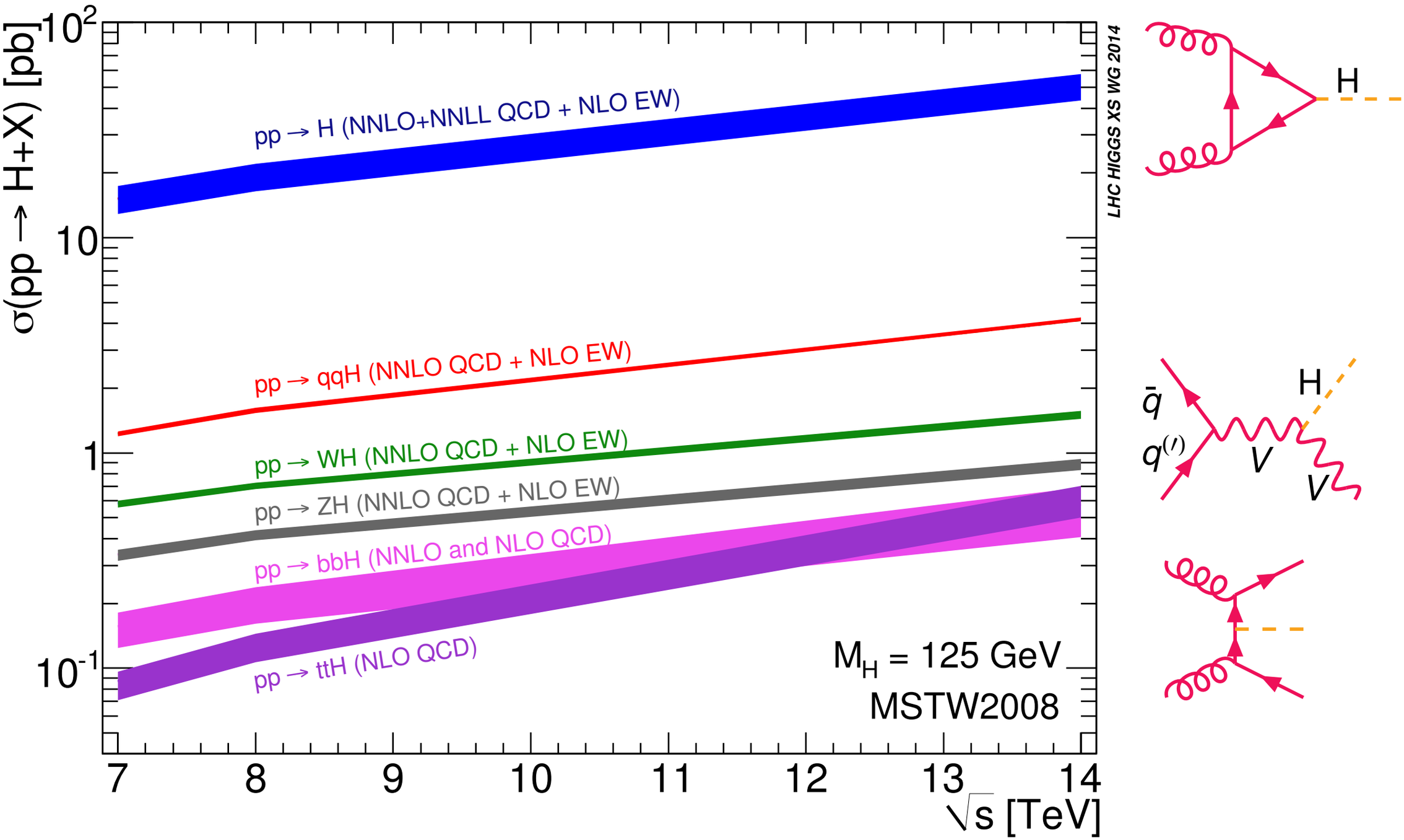


Combination of DM searches





Higgs boson physics



PL B786 (2018) 59

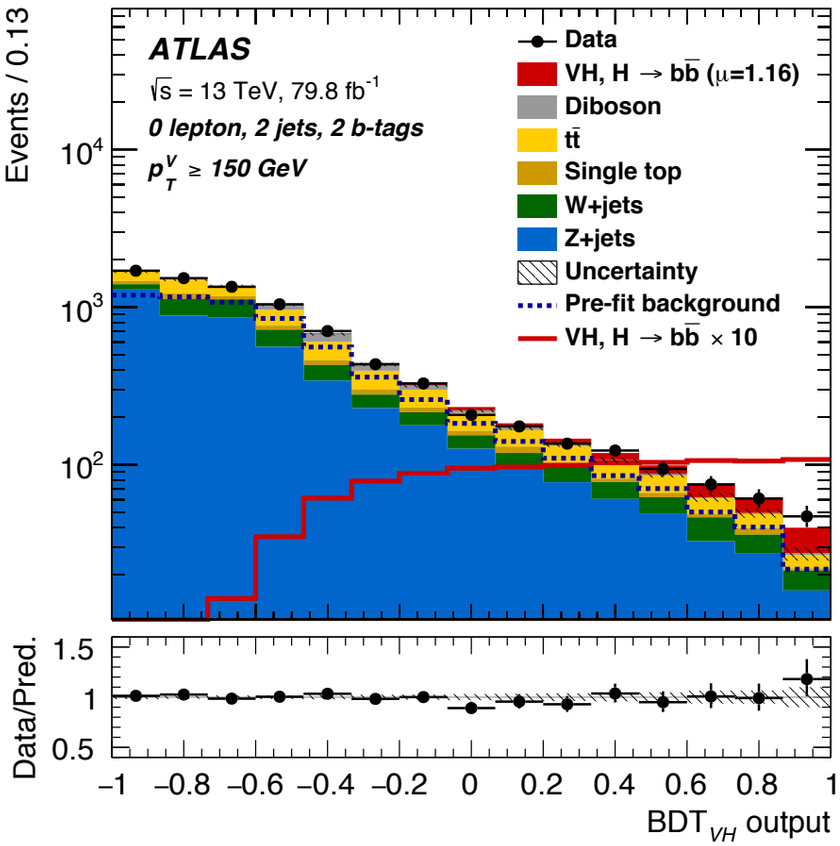
Observation of VH production, H → bb

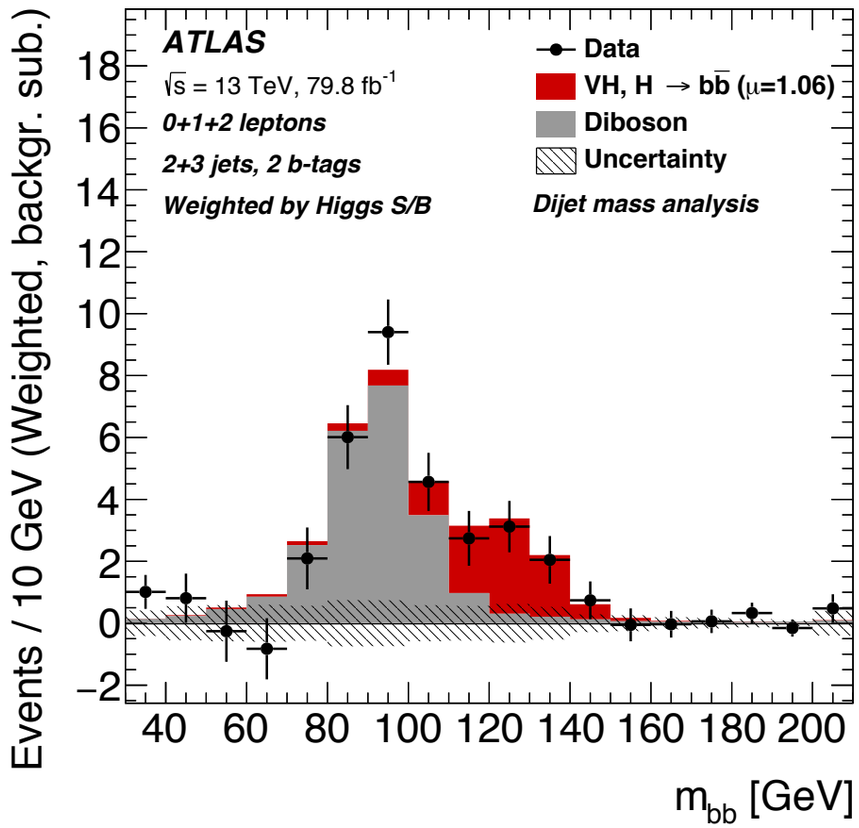
Aim: demonstrate H → bb. Evidence already last year

Analysis with 80 /fb: 4.9 σ signal (expected: 4.3 σ)

- leptonic W, Z decays

Z → bb peak as standard candle





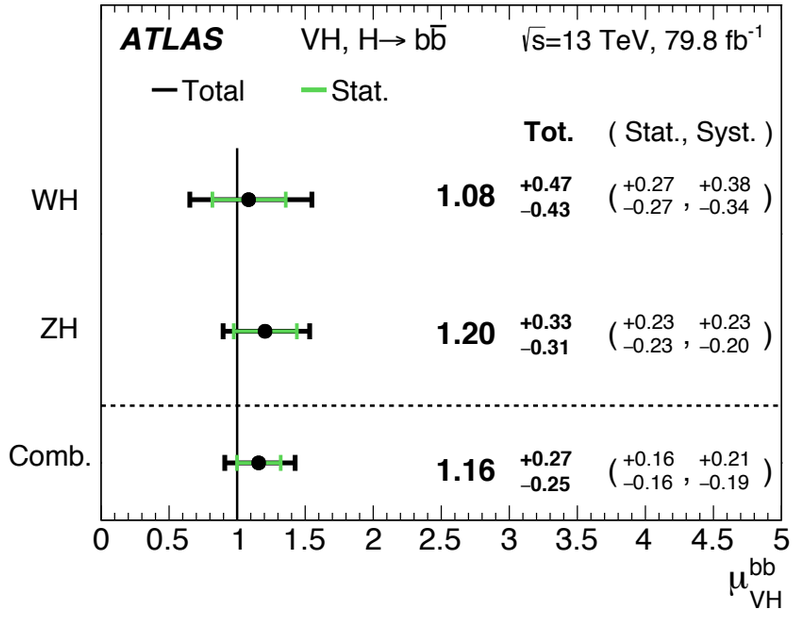
PL B786 (2018) 59

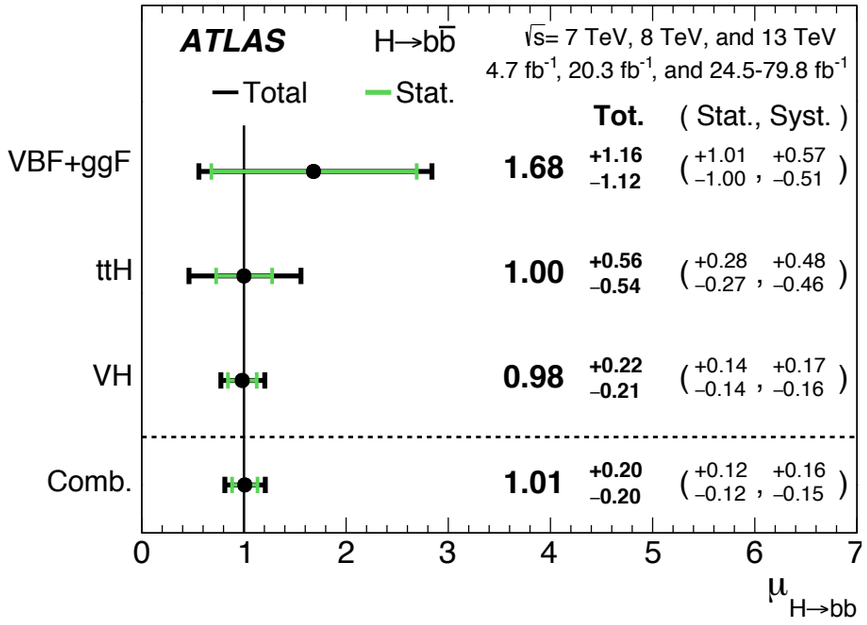
Observation of VH production, H → bb

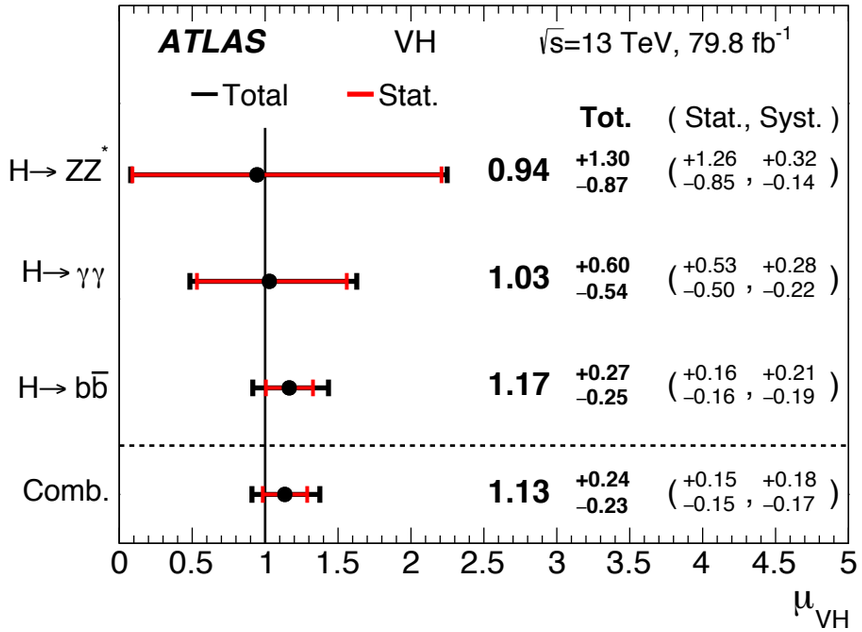
Aim: demonstrate H → bb. Evidence already last year

Analysis with 80 /fb: 4.9 σ signal (expected: 4.3 σ)

- leptonic W, Z decays
- combination with other channels suffices to claim observation
  - VH: H → ZZ* → $\ell^+\ell^-\ell'^+\ell'^-$, H →γγ
  - H → bb: ttH, VBF







H →bb: 5.4 σ (expected: 5.5) VH: 5.3 σ (expected: 4.8)

PR D97 (2018) 072003

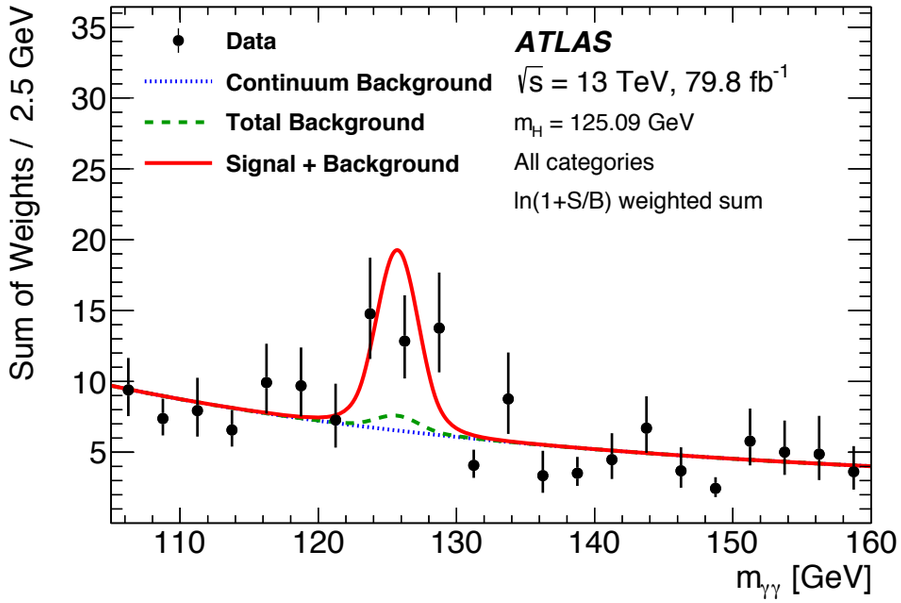
PR D97 (2018) 072016

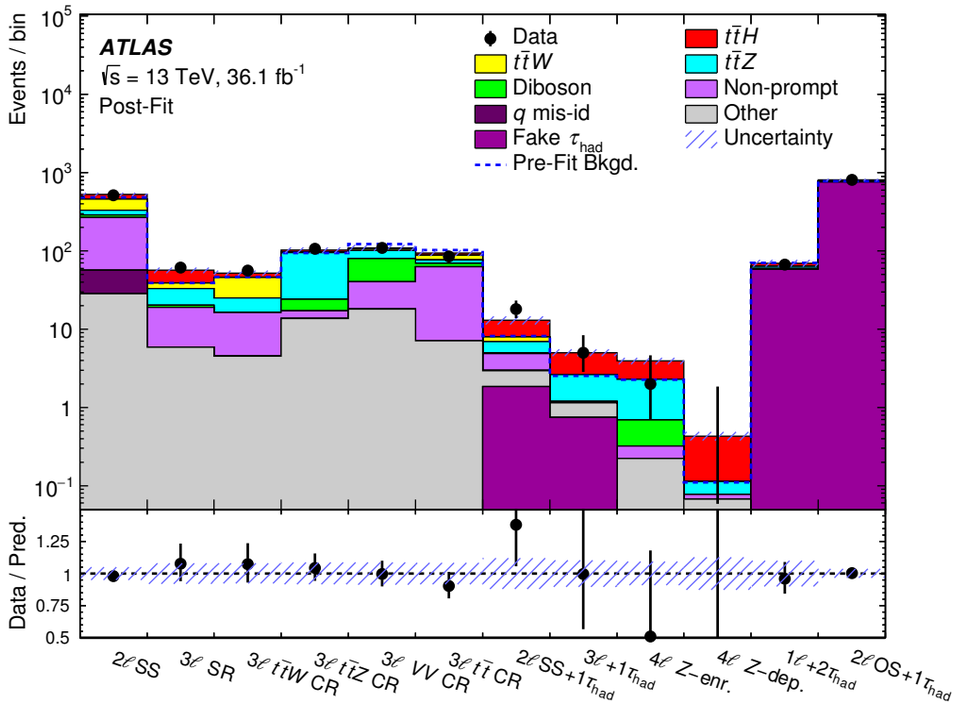
PL B784 (2018) 173

Observation of ttH production

Essential to obtain unambiguous information on y_t information (no loop contributions)

- decay modes: γγ, ZZ*→4l, bb, multi-leptons (WW, ττ)





PR D97 (2018) 072003

PR D97 (2018) 072016

PL B784 (2018) 173

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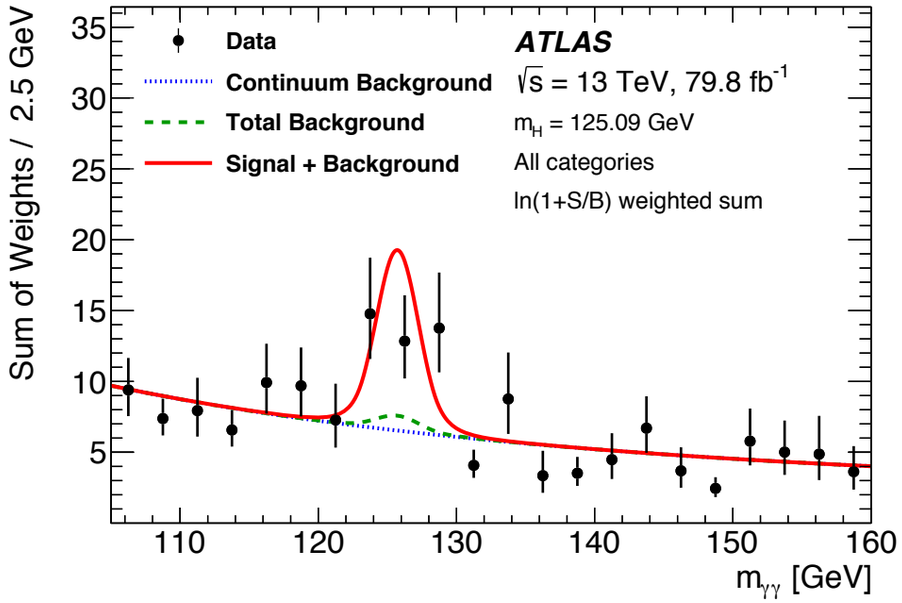
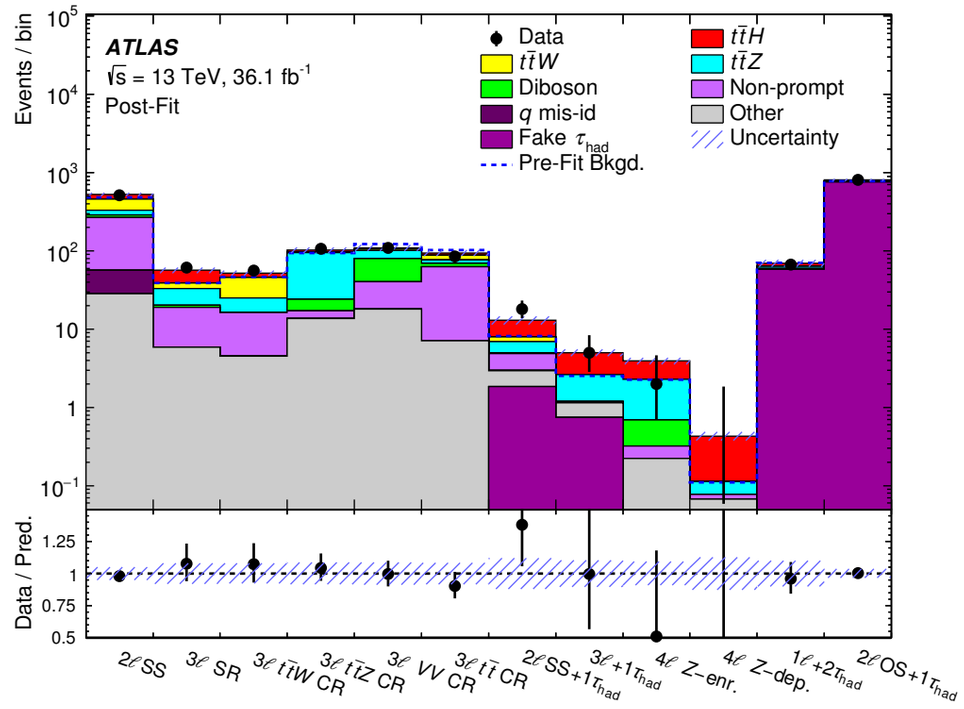
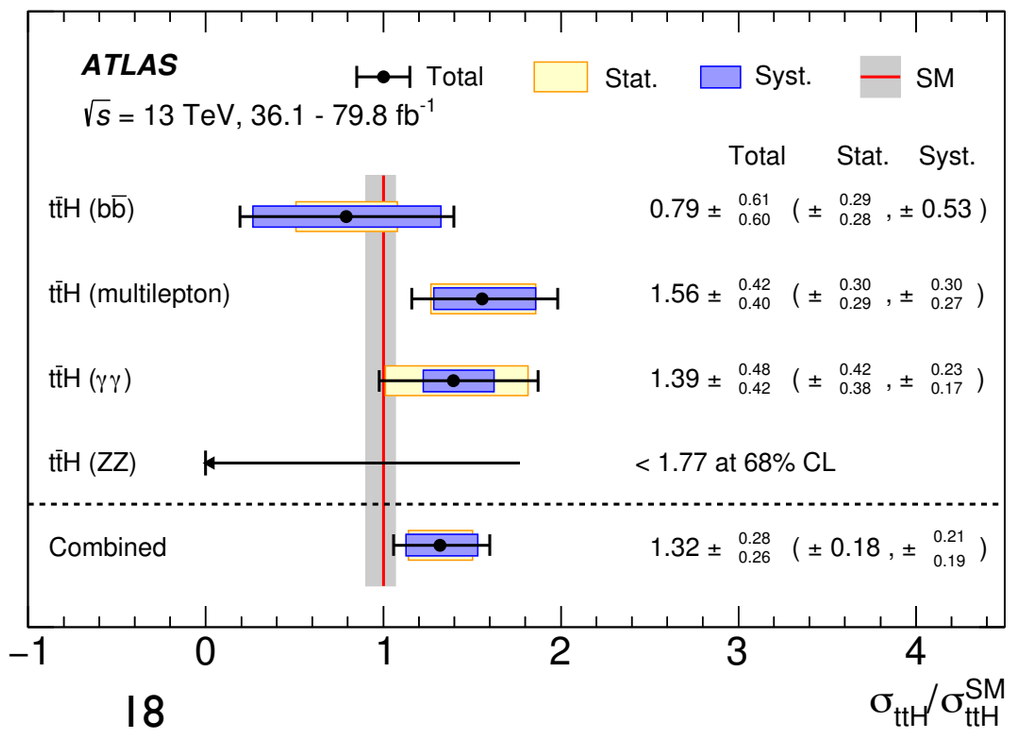




Observed significances:

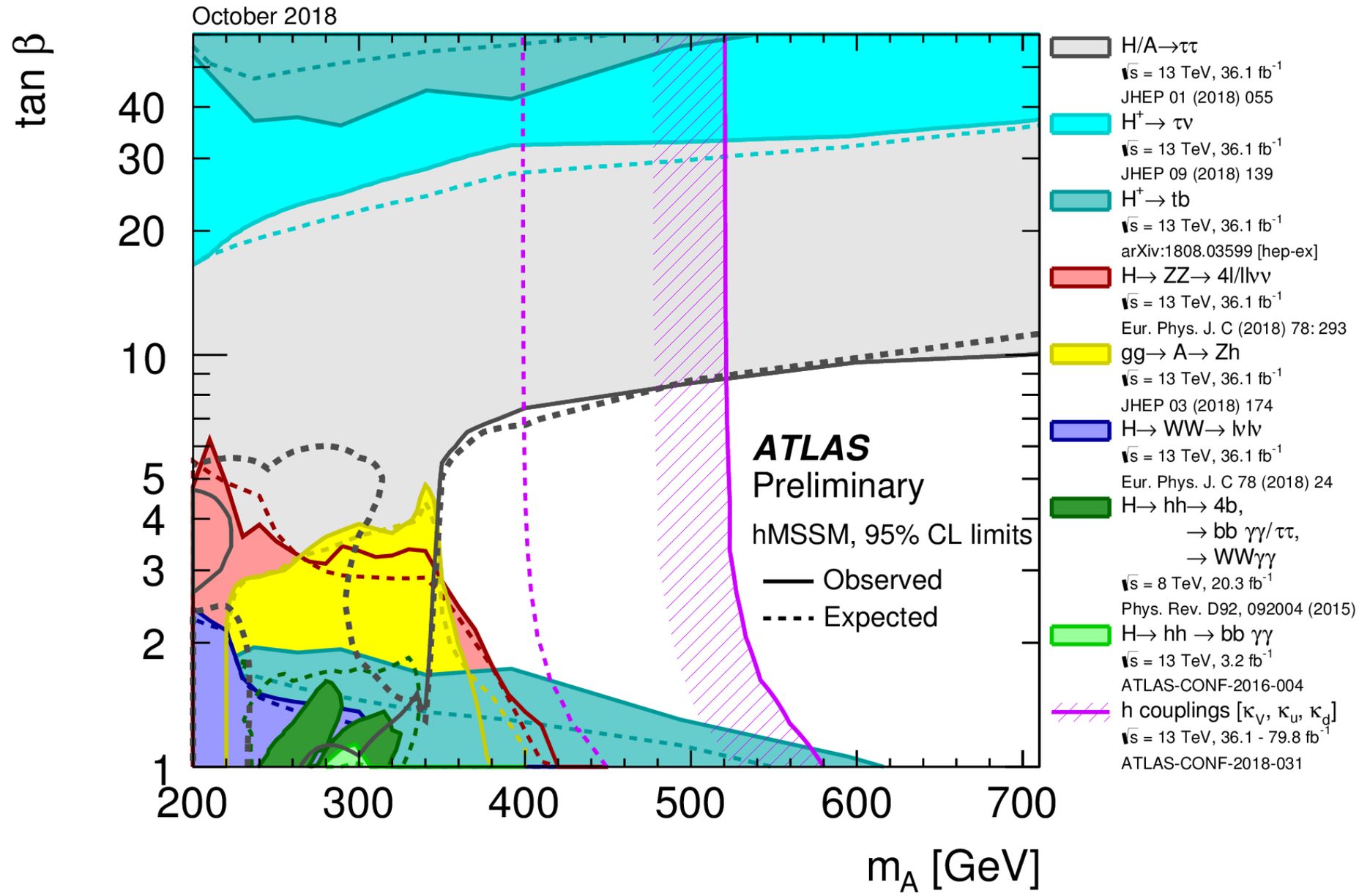
- 5.8 σ w/o (6.3 σ w/) Run-1
- expected: 4.9 σ / 5.1 σ



BSM interpretations

Constraints both from H(125) measurements, searches for other Higgs bosons

- example: hMMSM



PRL 121 (2018) 191801

JHEP 11 (2018) 040

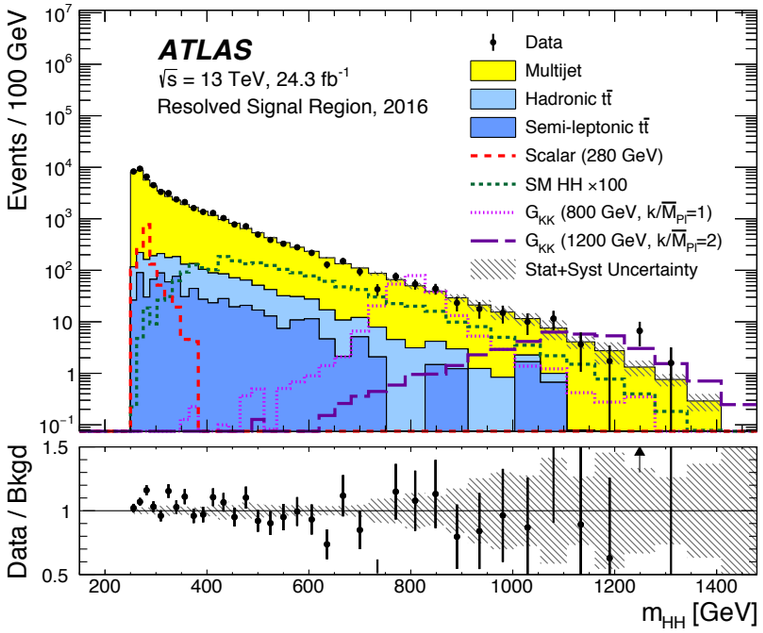
1804.06174

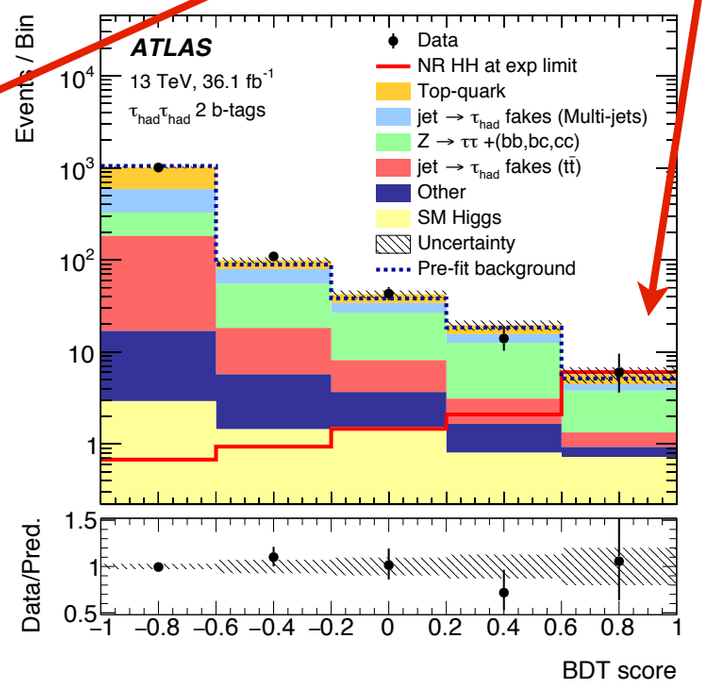
ATLAS-CONF-2018-043

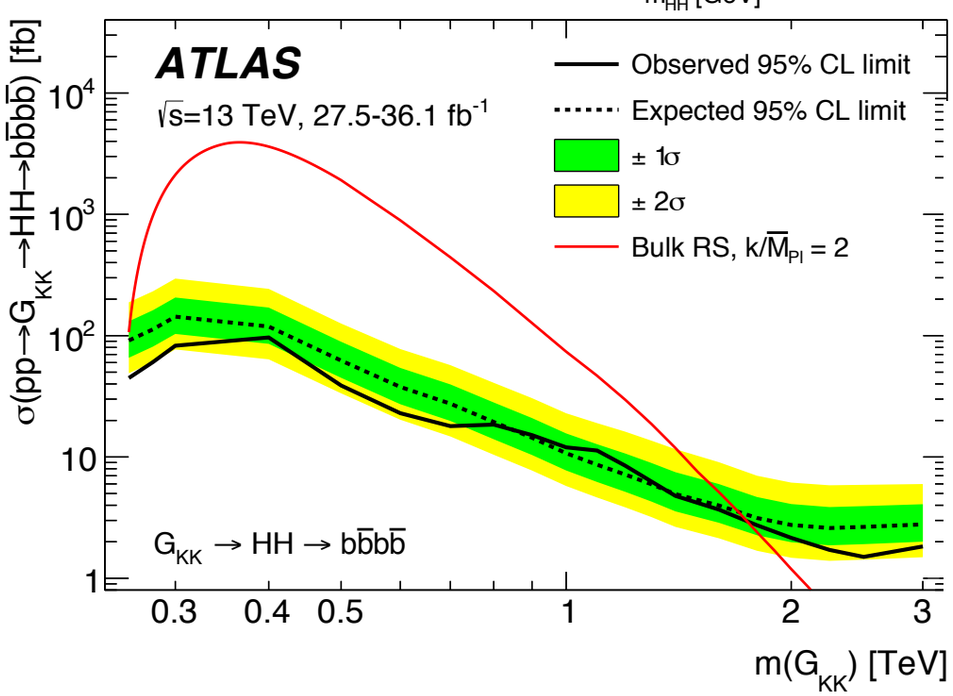
Di-Higgs production

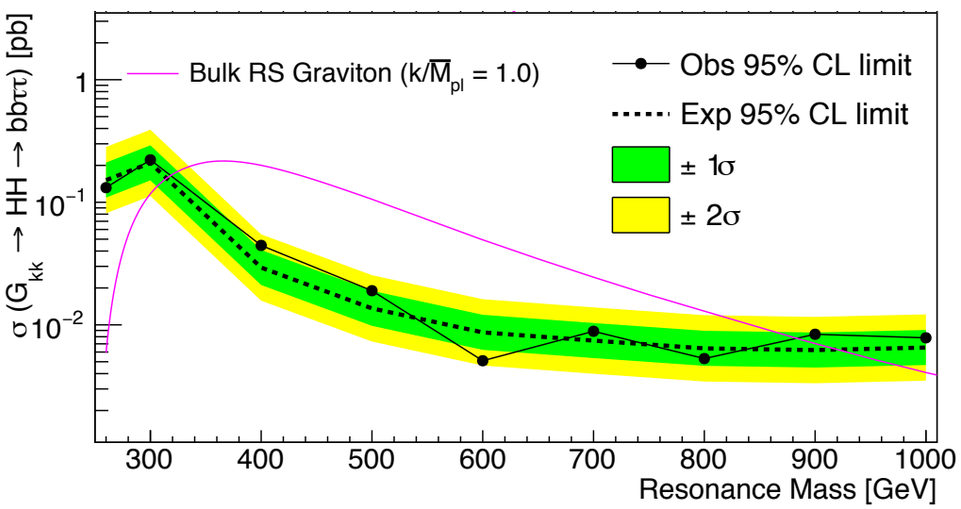
An essential step towards probing the Higgs potential

- also (alternatively) probe heavy resonance (→HH) production (G_{KK}, ..)
- highest sensitivity for at least one H → bb decay (bbbb, bbγγ, bbττ)









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ATLAS-CONF-2018-043

Di-Higgs production

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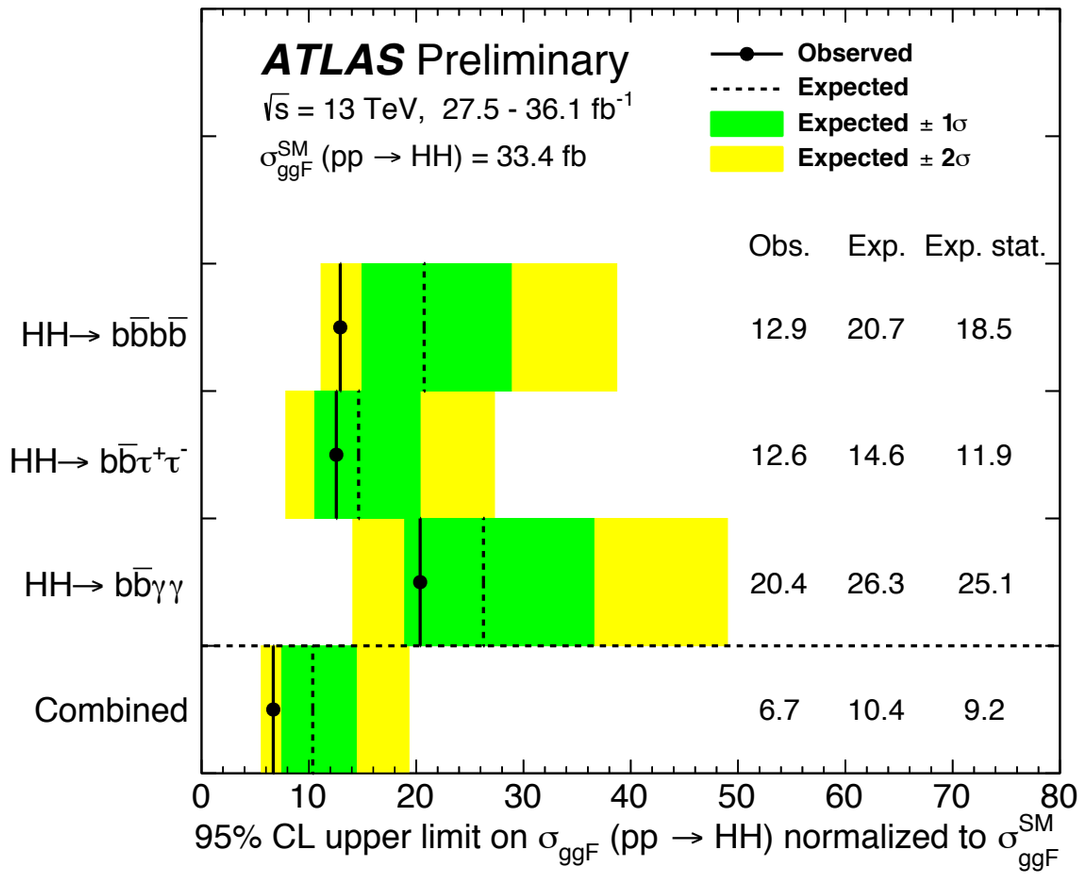
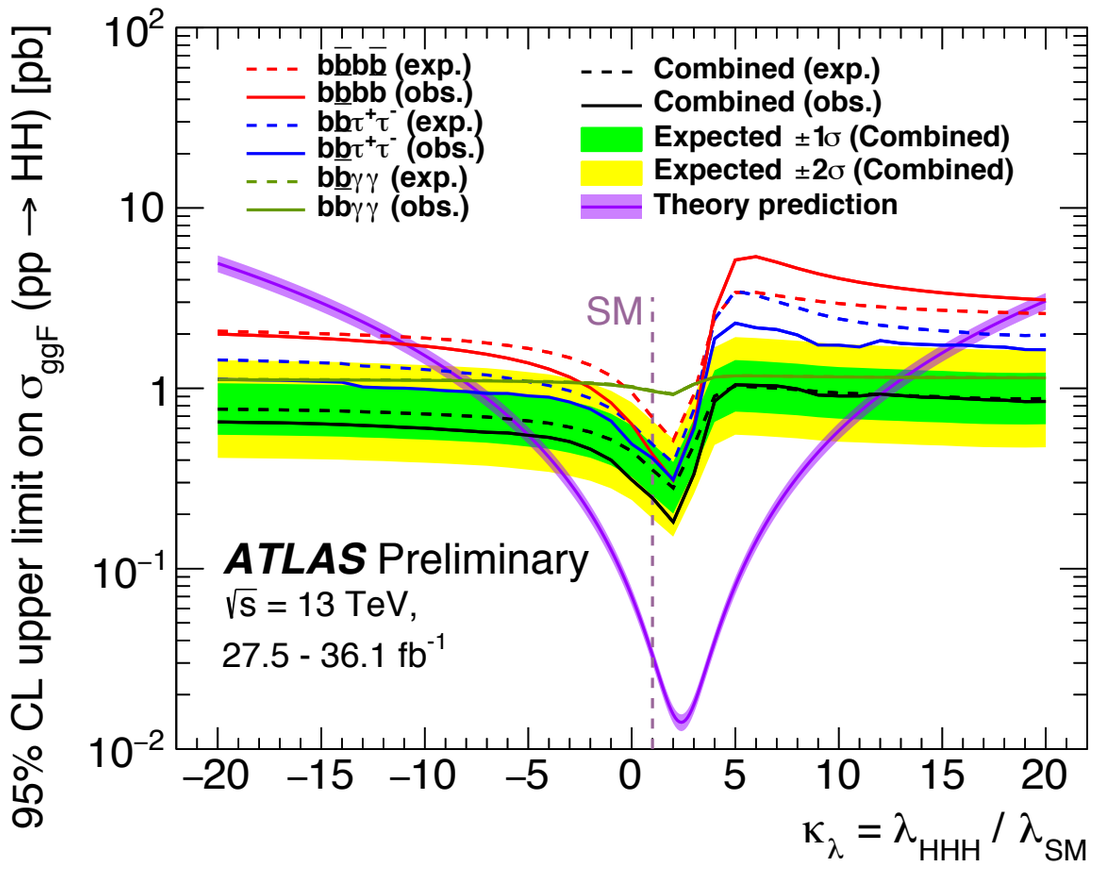
- also (alternatively) probe heavy resonance (→HH) production (G_{KK}, ..)
- highest sensitivity for at least one H → bb decay (bbbb, bbγγ, bbττ)

Combination of multiple channels starts to yield interesting results

$$-5.0 < \kappa_\lambda \equiv \lambda_{HHH}/\lambda_{HHH,\,\mathrm{SM}} < 12.1$$





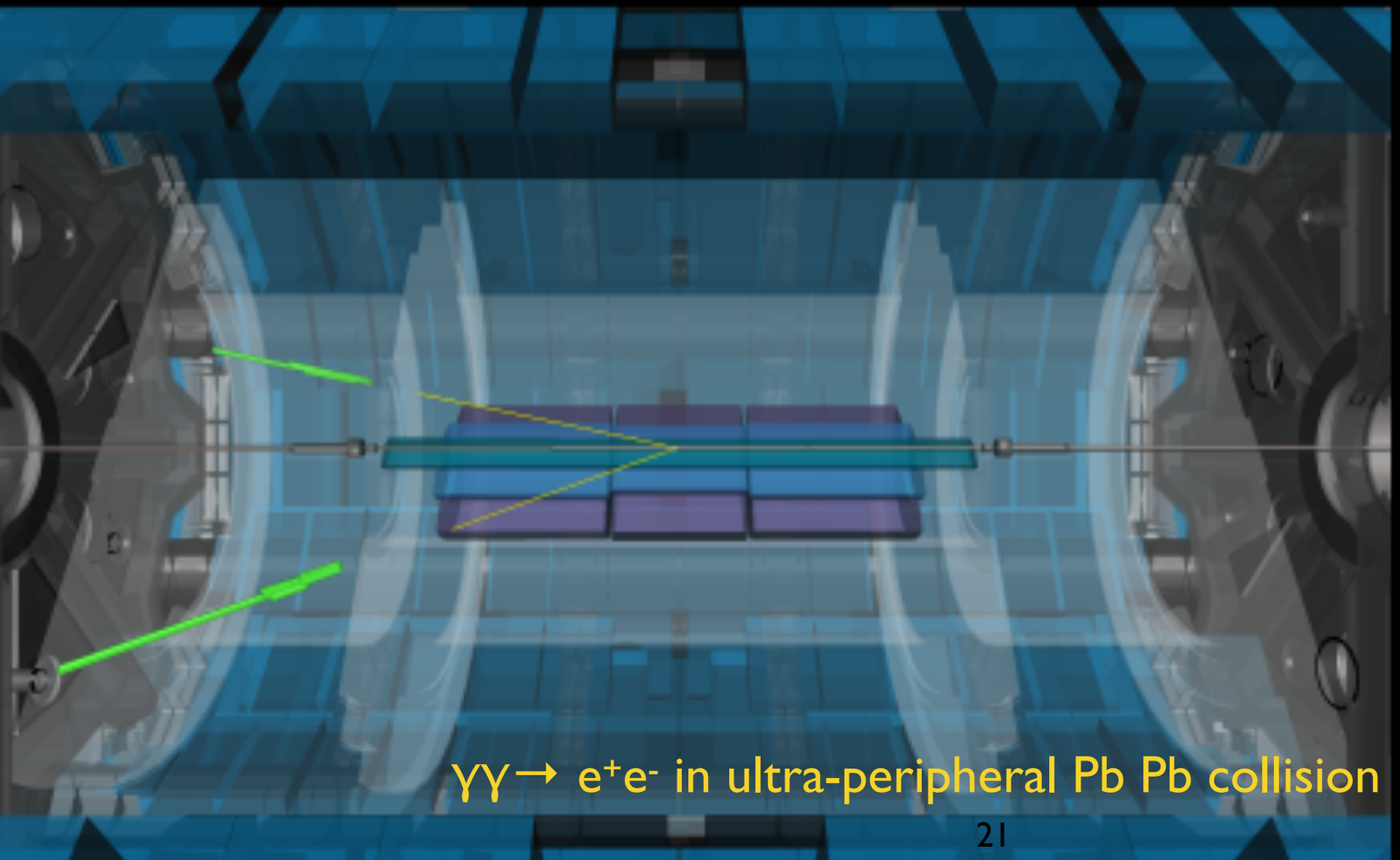
Outlook

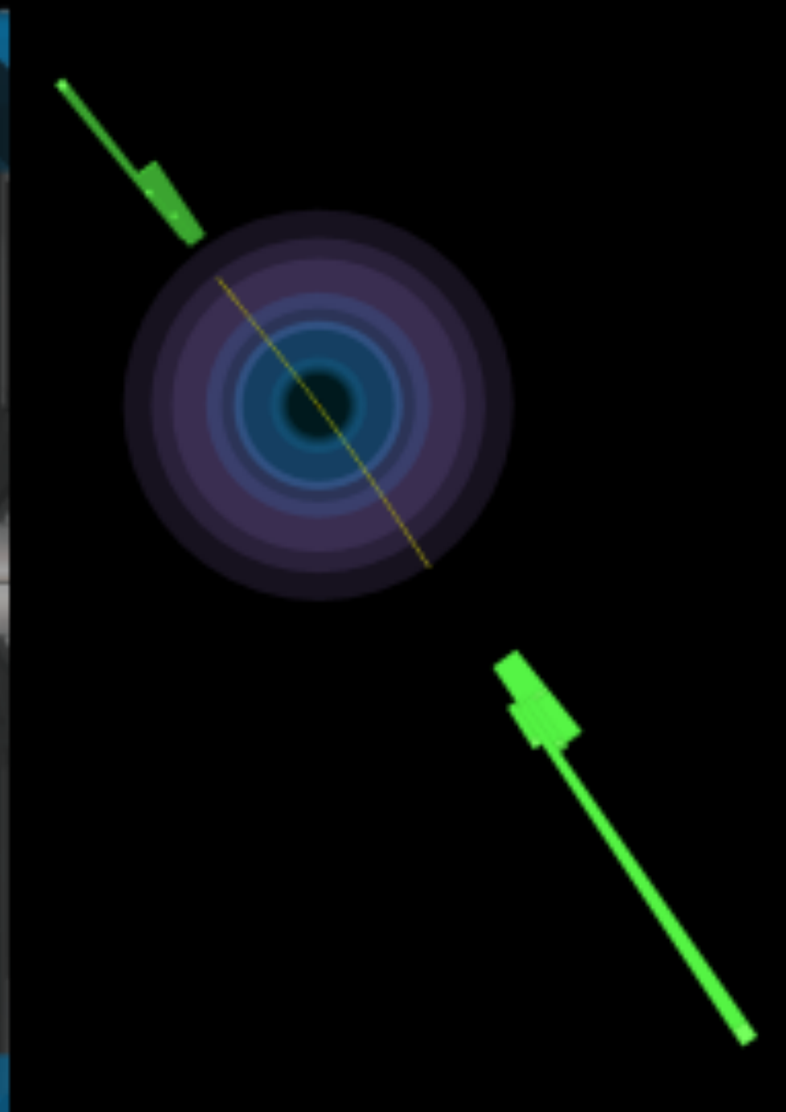
Many fresh results in both pp (and heavy ion!) collisions

- in this presentation could only cherry-pick from the highlights

Only a few results used even the 80 /fb 2015—2017 (pp) dataset

- next few years: expect many analyses to use the full Run-2 dataset..
- as well as the advances in understanding & reconstruction techniques





$\gamma\gamma \rightarrow e^+e^-$ in ultra-peripheral Pb Pb collision