



LHC Status and Physics Update

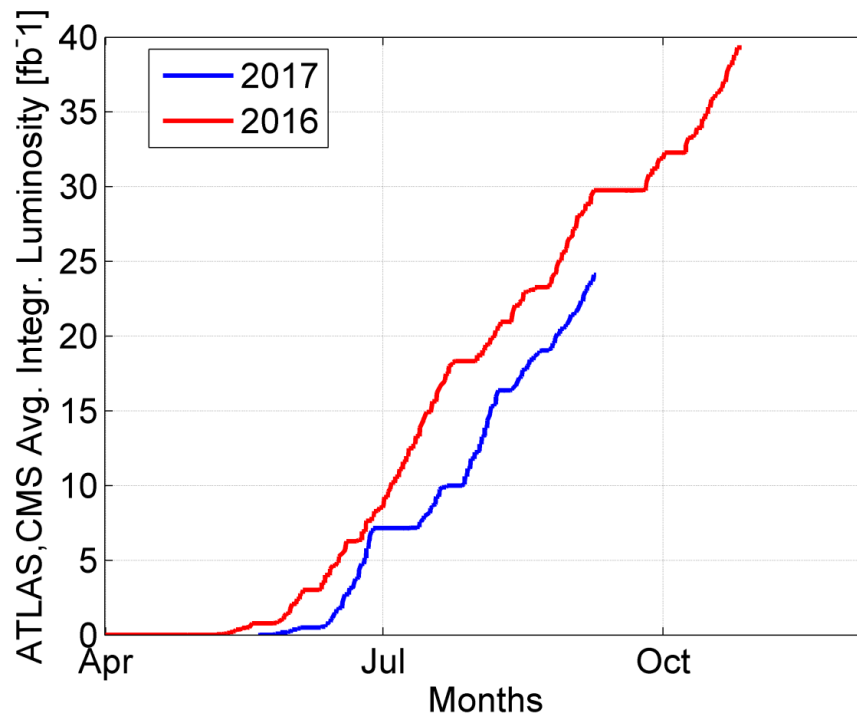
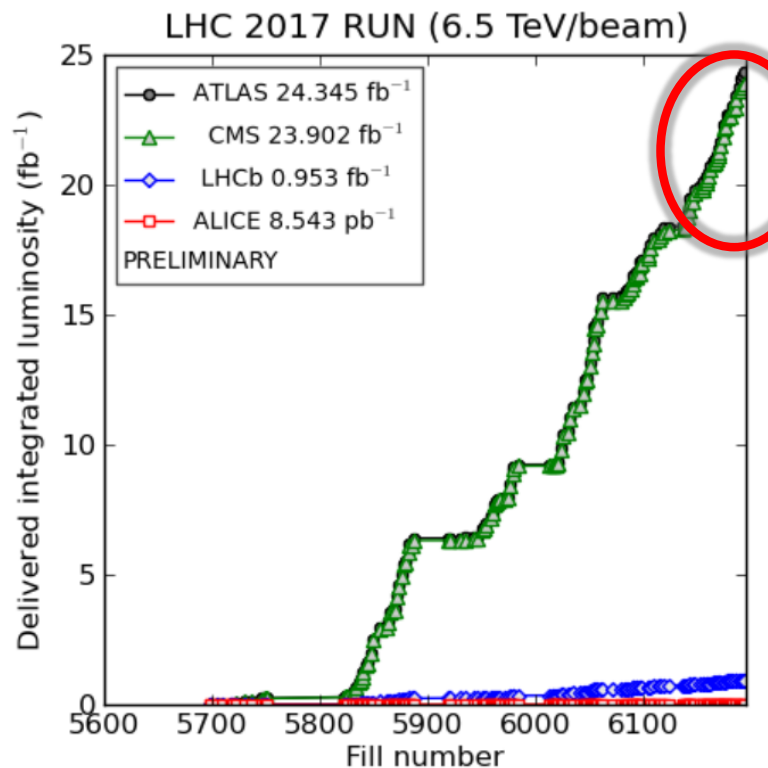
Iain Bertram

Lancaster University, 14 September 2017

GridPP39

- LHC Accelerator Update
- I will present details on recent analyses from LHC experiments (highlighting some Lancaster results and a bias towards ATLAS).
 - Higgs Production Cross Section
 - ATLAS Higgs Mass
 - ATLAS & CMS: Higgs $\rightarrow b\bar{b}$
 - CMS: Higgs $\rightarrow \tau\tau$
 - ATLAS Resonance Searches & Dark Matter
 - LHCb: Ξ_{cc}^{++}
 - LHCb: $B_s \rightarrow e\mu$
 - Alice: Hypertriton Lifetime
- Summary

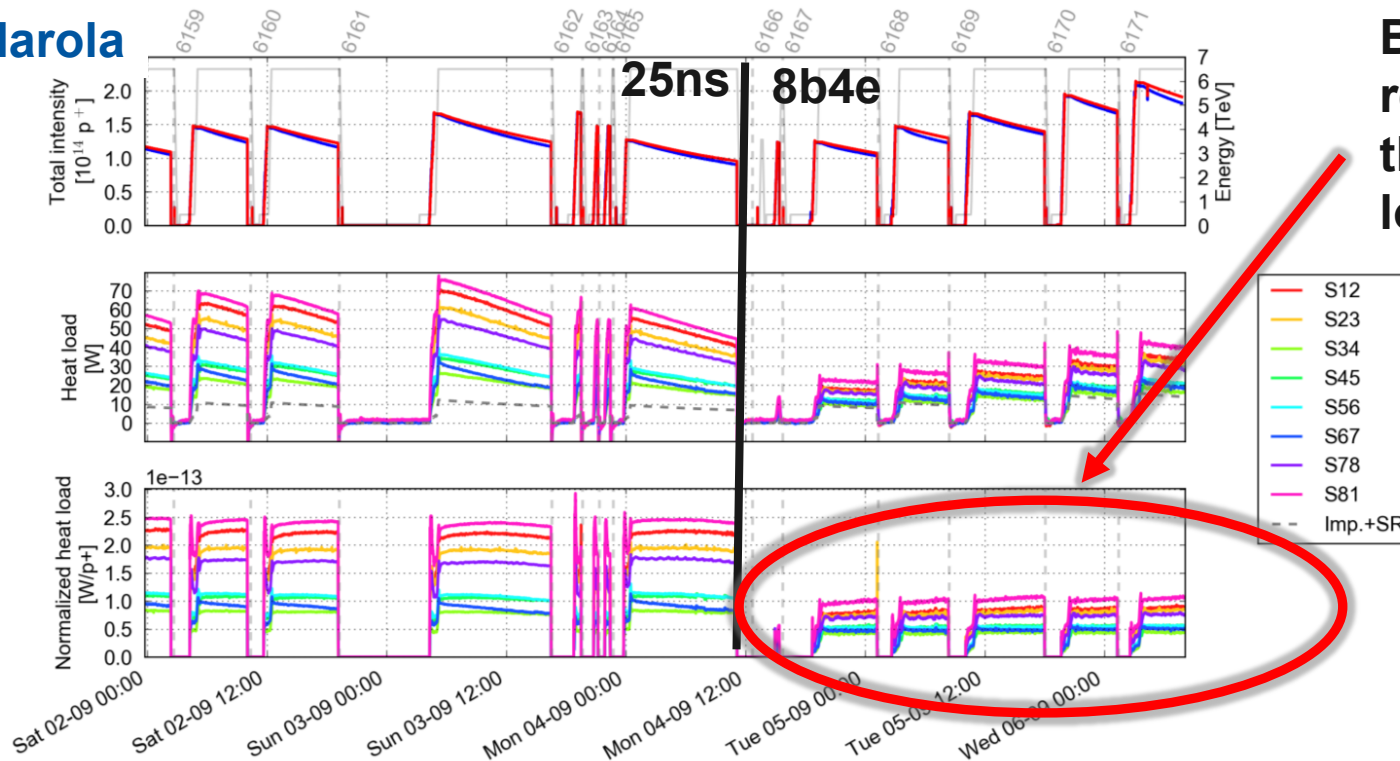
- Currently $\sim 25 \text{ fb}^{-1}$ delivered to ATLAS and CMS.
- So far it has been a difficult year for LHC
 - Many beam dumps due to issues with “16L2” group of magnets - cause unknown - has been limiting luminosity
 - Some progress, but still an ongoing problem.



Main operation limitations: Losses@16L2


- ❑ 8b4e: reduced e-cloud (induced heat-load)
 - Fast intensity ramp-up to 1916b without any dump with average intensities 1.1×10^{11} p/b
 - **However could not increase intensity more than 1.2×10^{11} p/b**
- ❑ Study is ongoing with additional diagnostics in the cell

G. Iadarola



**Big
reduction in
the heat
load**

- Target integrated luminosity of 45 fb^{-1} is still achievable.
 - Preparation of special physics runs are ongoing
 - High β^* at 450 GeV and 2.51 TeV runs
 - No special runs in 2018 — significant luminosity production to satisfy the Run-2 targets (90 fb^{-1})

	July			Aug				Sep					
Wk	27	28	29	30	31	32	33	34	35	36	37	38	39
Mo	3	10	17	24	31	7	14	21	28	4	11	18	25
Tu				MD 2								TS 2	
We	TS 1			VdM run						Jeune G			
Th											MD 3		
Fr													
Sa													
Su													

Around 11 weeks remaining

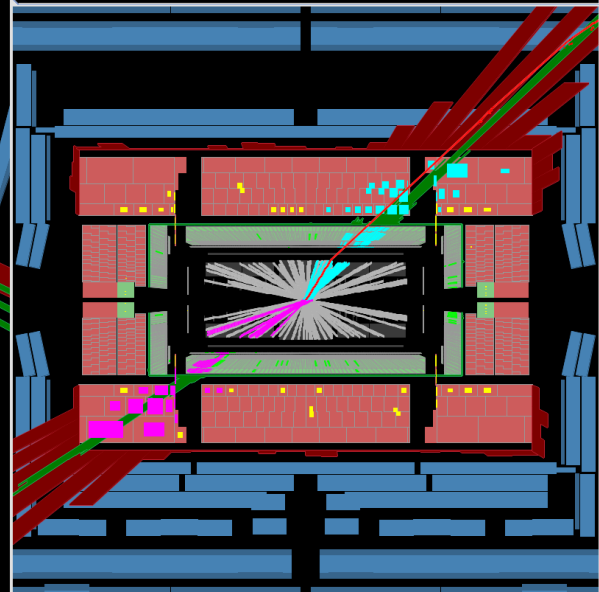
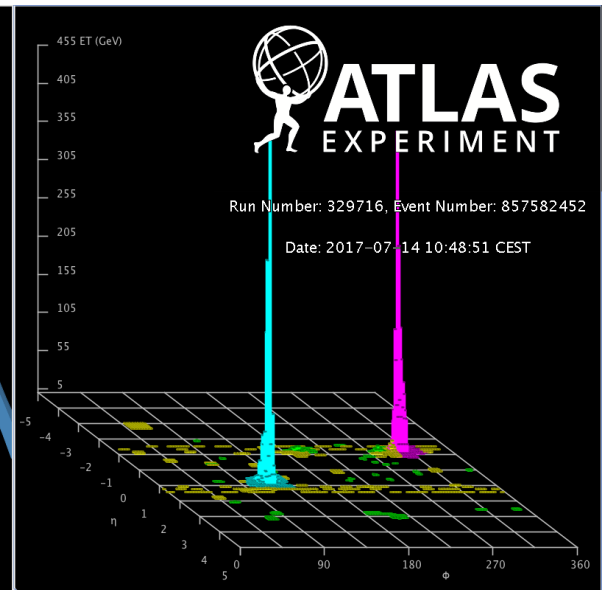
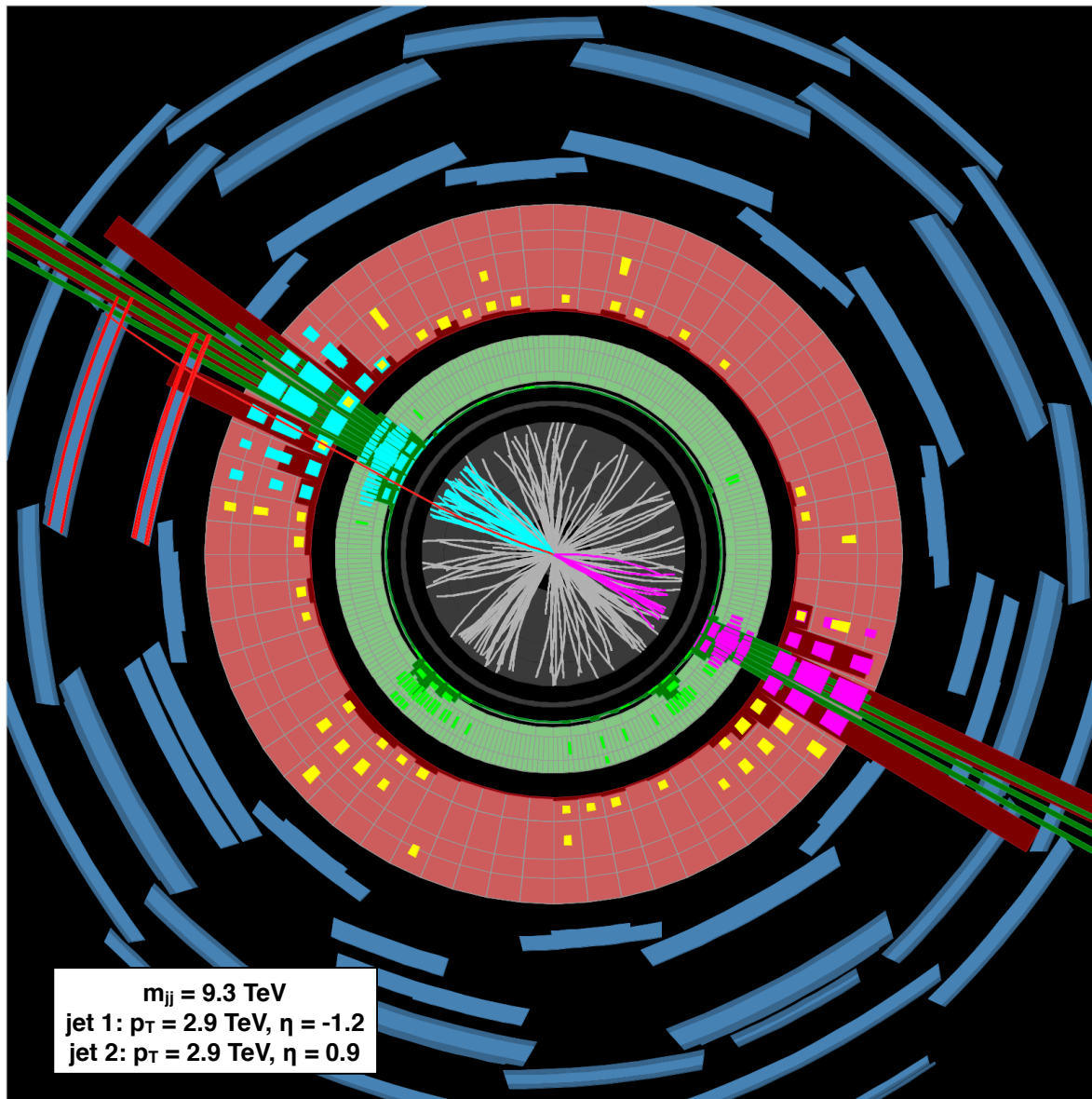
	Oct			Nov				Dec					
Wk	40	41	42	43	44	45	46	47	48	49	50	51	52
Mo	2	9	16	23	30	6	13	20	27	4	11	18	Xmas 25
Tu													
We				MD 4									
Th													
Fr													
Sa													
Su													

End of run 106:00

Special physics run

Technical stop (YETS)

Di-jet Event with $m_{jj}=9.3$ TeV

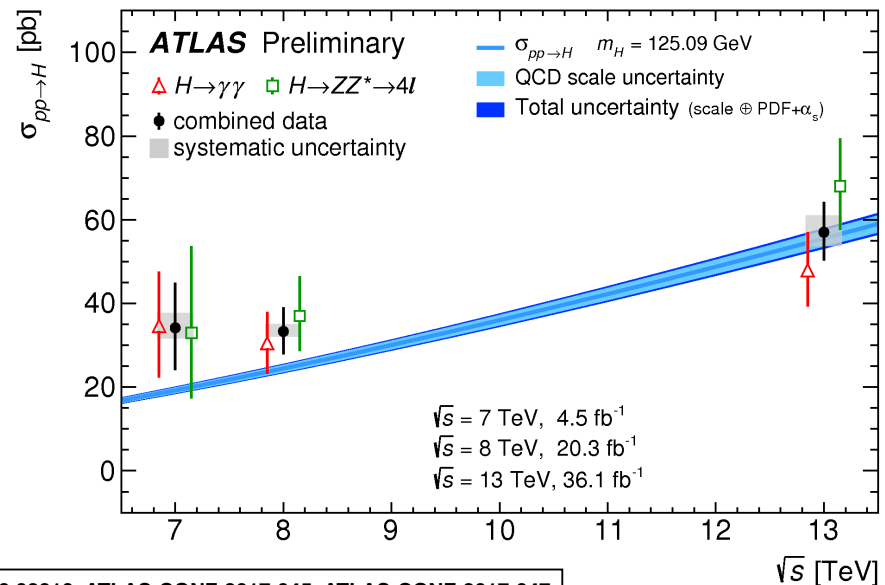
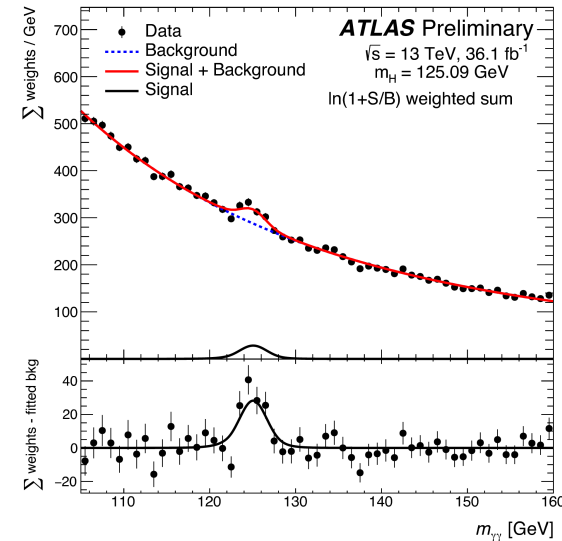
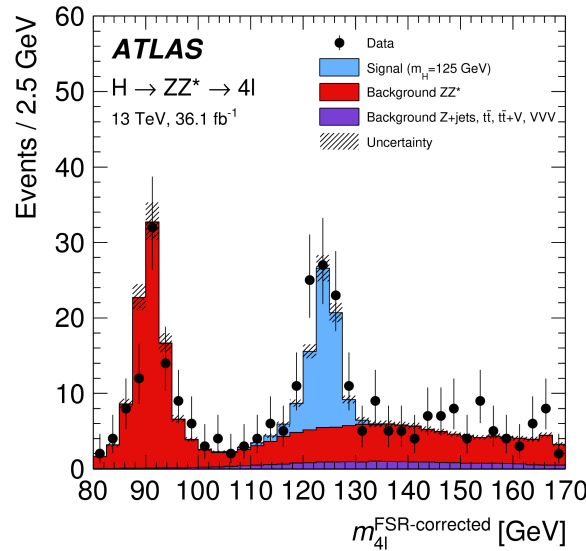


Higgs Boson Production

- New results in the $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels.
 - Combined measurements of fiducial and total production cross sections (assuming SM branching ratios).
- Combined global signal strength compatible with the Standard Model:

$$\mu = 1.09 \pm 0.12$$

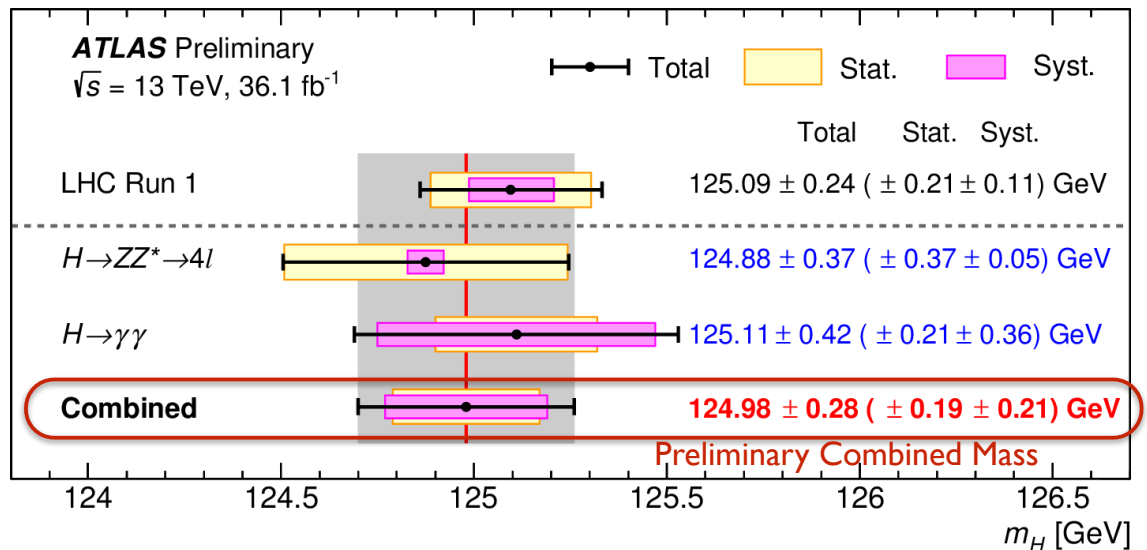
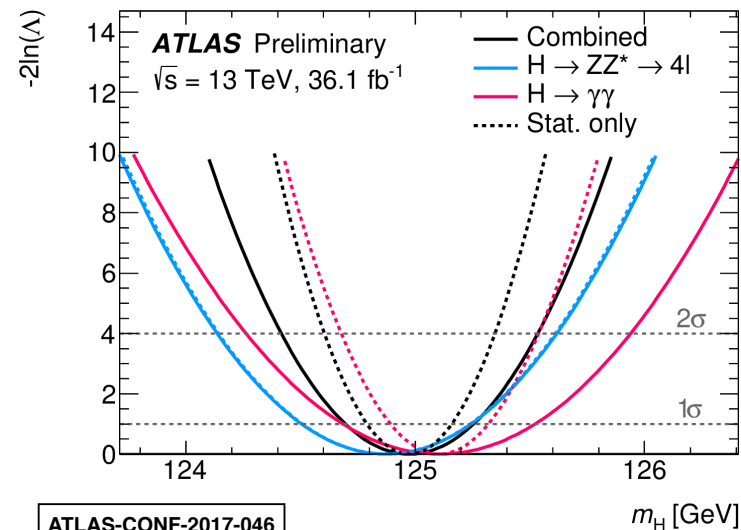
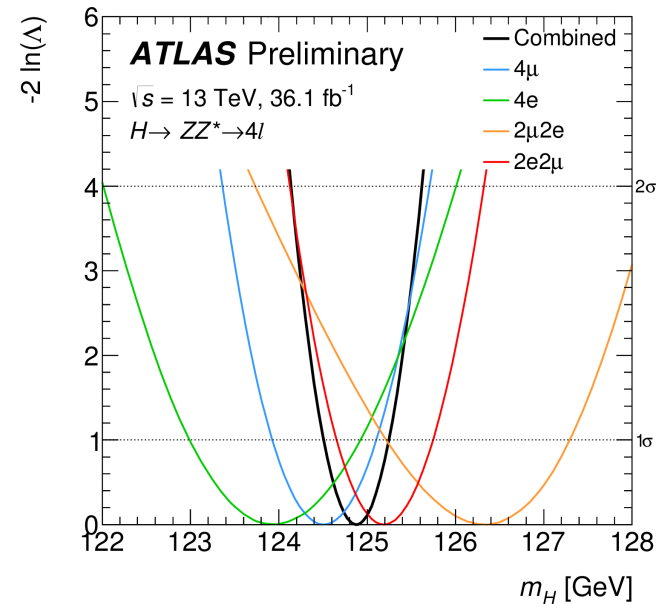
$$= 1.09 \pm 0.09 \text{ (stat.) } \begin{matrix} +0.06 \\ -0.05 \end{matrix} \text{ (exp.) } \begin{matrix} +0.06 \\ -0.05 \end{matrix} \text{ (th.).}$$



arxiv:1708.02810, ATLAS-CONF-2017-045, ATLAS-CONF-2017-047

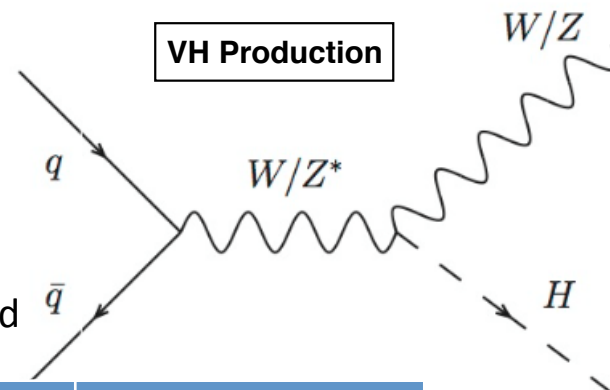
Higgs Boson Mass

- Higgs boson mass measurements in the $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels complementary:
 - 4ℓ channel the stat uncertainty dominates.
 - $\gamma\gamma$ channel dominated by syst uncertainties (most notably the γ energy scale calibration).
- Measurements consistent between sub-channels, and consistent with the Run I combined result.

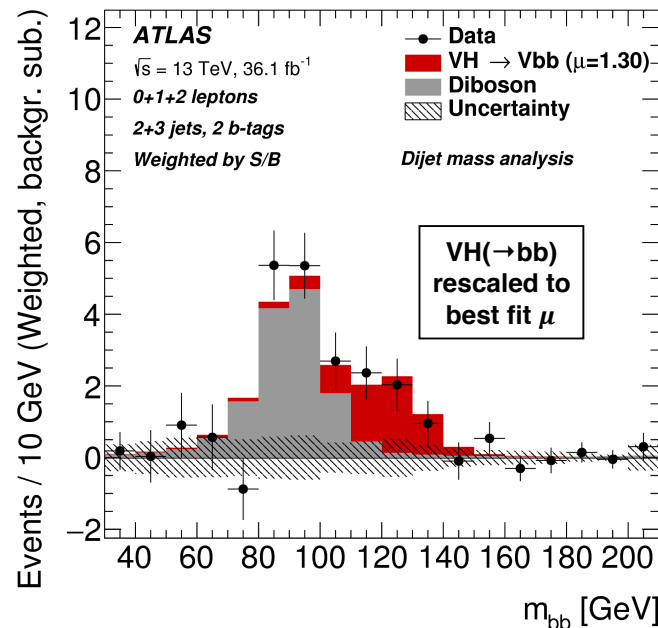
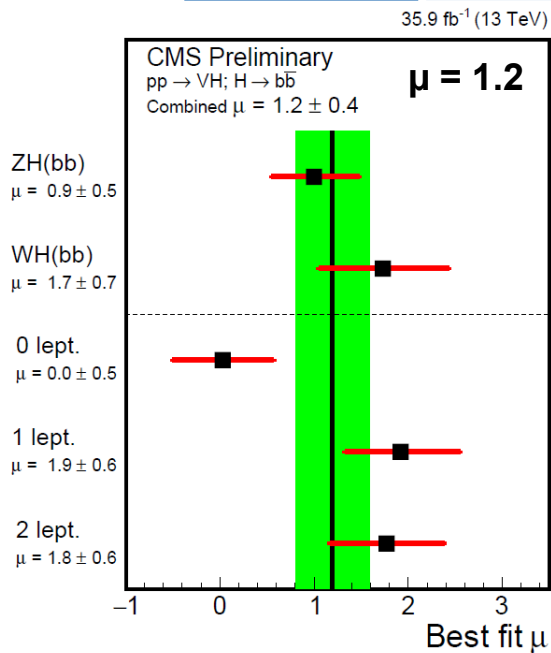


ATLAS-CONF-2017-046

- Most sensitive channel to look for the decay H → bb is associated production, VH (V=W/Z) with H → bb.
 - Largest Higgs branching ratio BR(H → bb) ≈ 58%
 - with Z → ee, μμ, νν and W → eν, μν
- CMS and ATLAS both use BDT to separate signal from background



	Expected Significance	Measured Significance	Signal Strength
ATLAS	4.0σ	3.6σ	0.90 ^{+0.28} _{-0.26}
CMS	3.8σ	3.8σ	1.06 ^{+0.31} _{-0.29}





Observation of $H \rightarrow \tau^+ \tau^-$

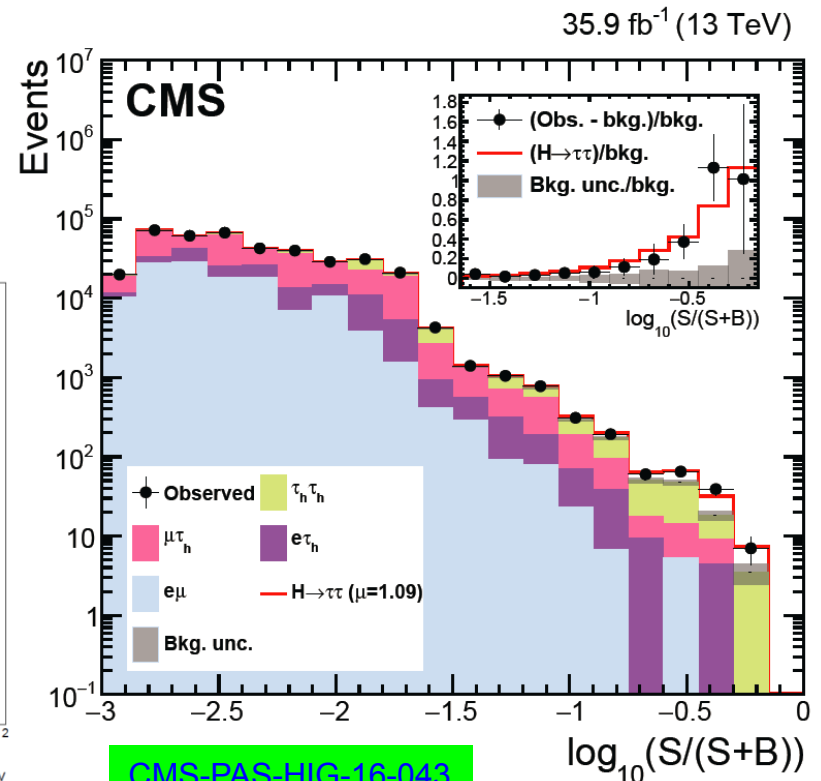
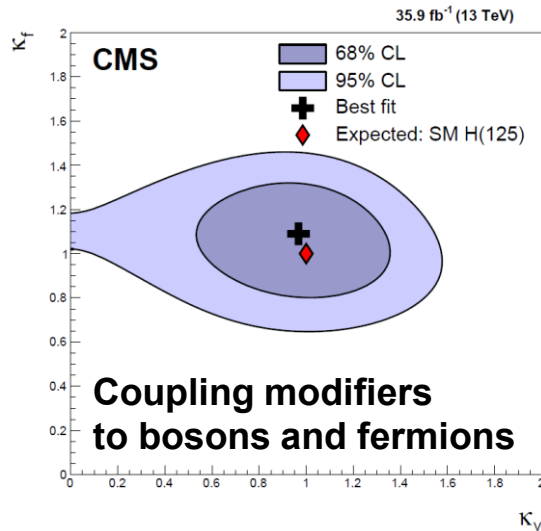
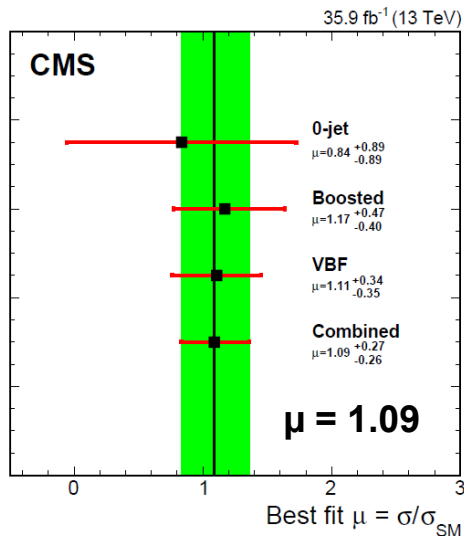


- Branching ratio (BR) = 6.3%, best channel to establish coupling of Higgs boson to fermions
- 12 categories: VBF, 0-jet (\sim gluon fusion), boosted (\sim others), for each $\tau_h \tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$
- Signal extraction from max. likelihood fits to 2D distributions in signal & control regions
- Significance of 4.9σ observed (4.7σ expected) using 13TeV data
- **Combination with 7 & 8 TeV data: 5.9σ obs. (5.9σ exp.) and $\mu = 0.98 \pm 0.18$**

First direct observation by a single experiment of coupling of H to fermions

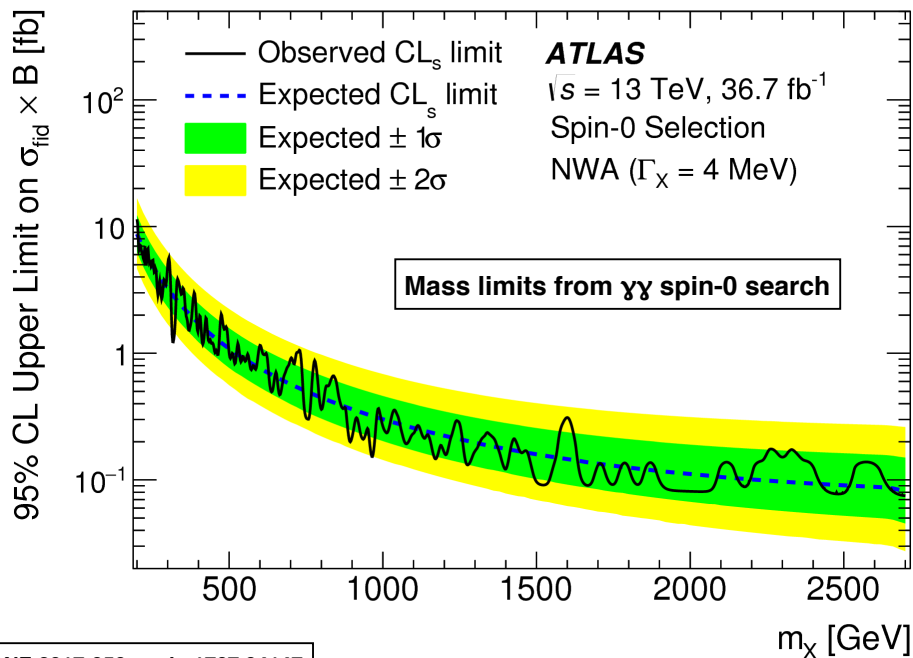
– Observed before in CMS+ATLAS combination

First direct observation of H coupling to leptons and to fermions of the 3rd generation

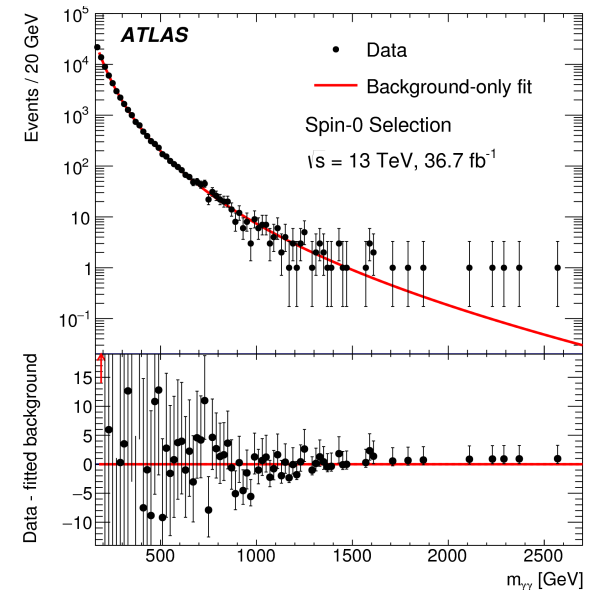
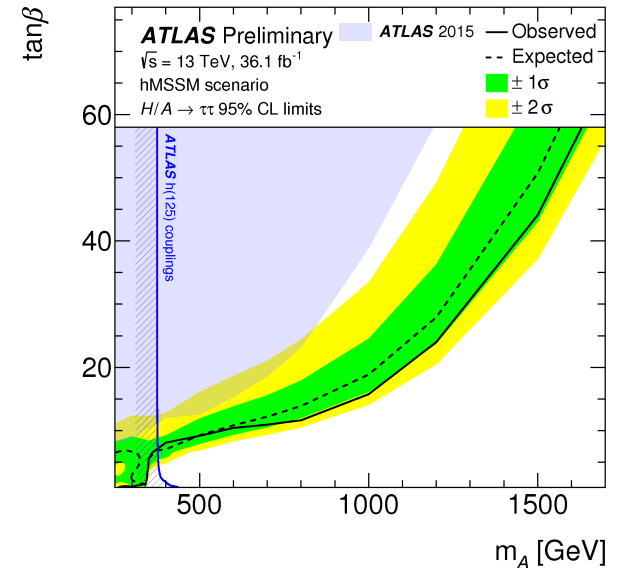


Resonance Searches ($\gamma\gamma$, $\tau\tau$)

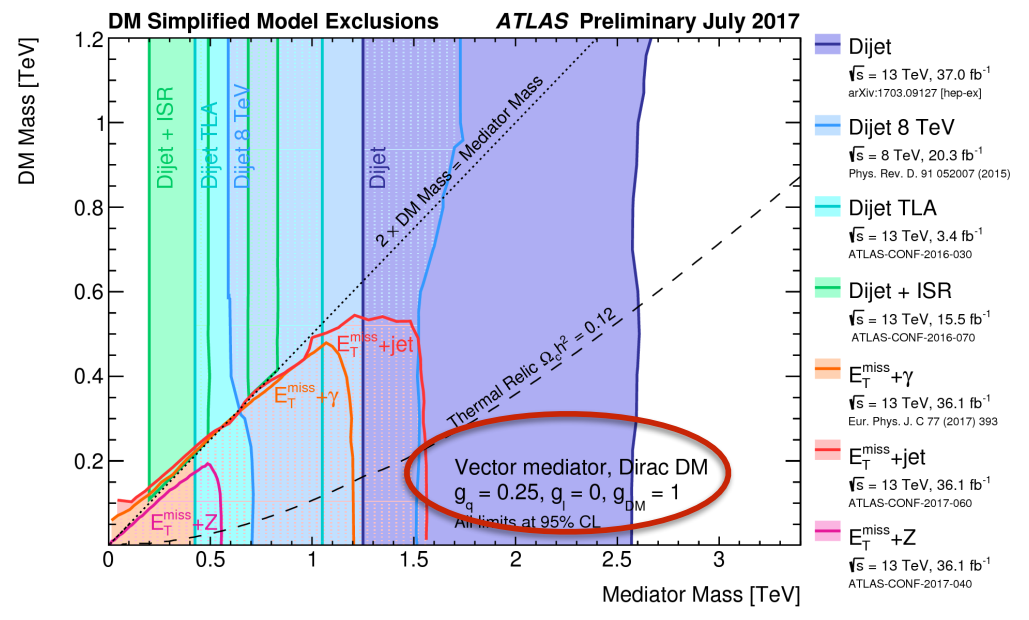
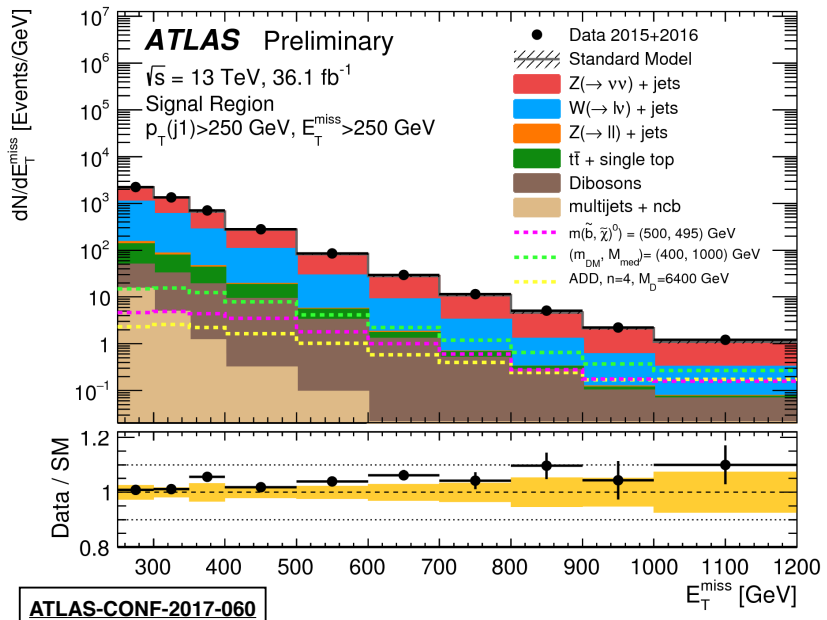
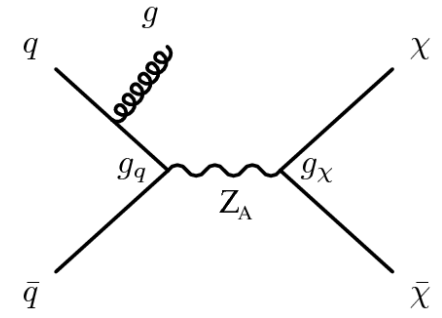
- Diphoton and ditau searches sensitive to new heavy scalars, e.g. Higgs bosons.
 - $\gamma\gamma$ search also targets spin-2 (graviton) production with a dedicated selection.
 - $\tau\tau$ searches sensitive to SUSY Higgs (H/A).
- No significant excess over the SM expectation.



ATLAS-CONF-2017-050, arxiv:1707.04147

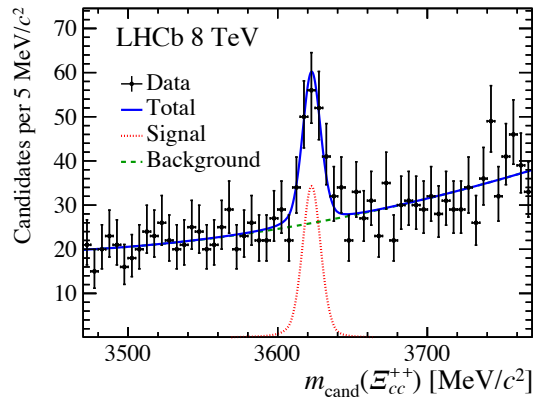
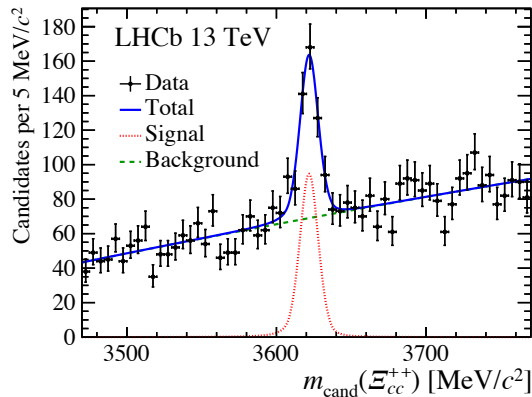


- Generic dark matter models tested with searches for mono-jet/ γ / Z / $H(\rightarrow\gamma\gamma/bb)+E_T^{\text{miss}}$, with recoil against invisible dark matter particle(s).
 - Complementary to direct dark matter searches, and direct searches for the mediator decaying to e.g. a pair of jets.
- Phenomenology depends on mass of DM, mass of heavy mediator and value and type of couplings.
- No significant excesses over the SM predictions.



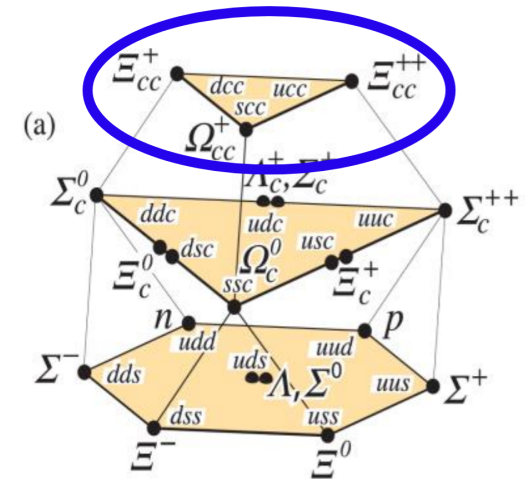
ATLAS-CONF-2017-060

- Doubly charmed baryons predicted by quark model
- Observation of Ξ_{cc}^+ claimed by SELEX [Phys. Lett. B 628 (2005) 18-24]
- No evidence observed by BaBar, FOCUS, Belle and LHCb
- Search in LHCb for $\Xi_{cc}^{++} \rightarrow \Lambda_c^+ K^- \pi^+ \pi^-$
- Data sample: 2.0 (8 TeV) + 2.0 (13 TeV) fb⁻¹

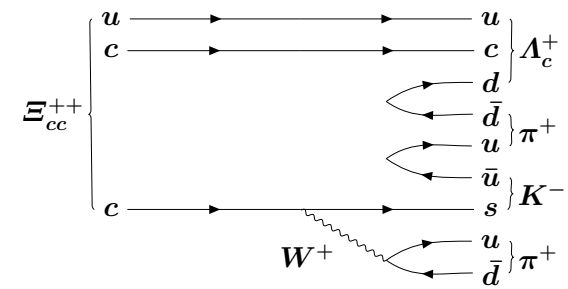


- Highly significant peak: **7.6 σ** (2012), **12.9 σ** (2016)
- Combined yield: 426 ± 39
- The mass is measured with the 2016 sample

$$m(\Xi_{cc}^{++}) = 3621 \pm 0.72 \text{ (stat)} \pm 0.31 \text{ (syst)} \text{ MeV}/c^2$$



Lattice QCD calculations
 $m(\Xi_{cc}^{++}) = 3606 \pm 11 \pm 8 \text{ MeV}/c^2$
[\[arXiv: 1704.02647\]](https://arxiv.org/abs/1704.02647)



Search for the decays $B_{(s)}^0 \rightarrow e^\pm \mu^\mp$ NEW

LHCb-PAPER-2017-031

- Lepton-flavour violating decays
- No excess of signal observed wrt background
- Put a limit to the BF

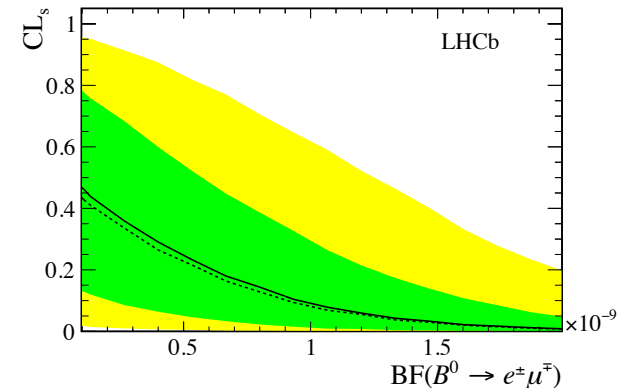
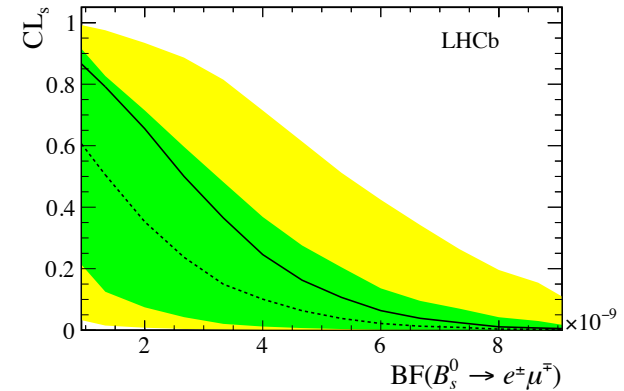
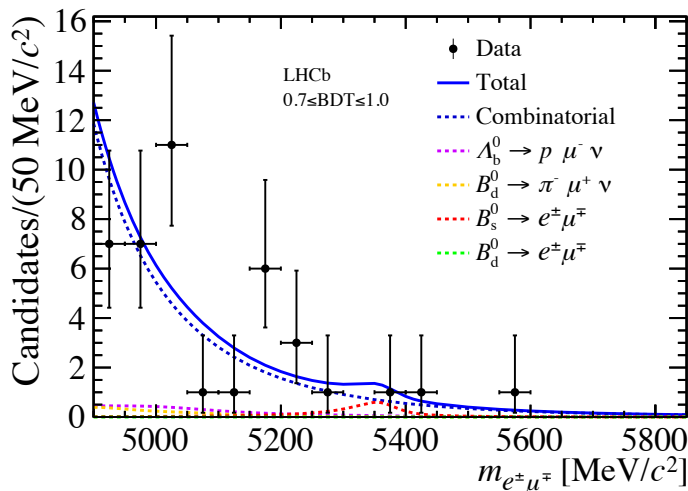
$$\mathcal{B}(B_s^0 \rightarrow e^\pm \mu^\mp) < 5.4 \text{ (6.3)} \times 10^{-9}$$

$$\mathcal{B}(B^0 \rightarrow e^\pm \mu^\mp) < 1.0 \text{ (1.3)} \times 10^{-9}$$

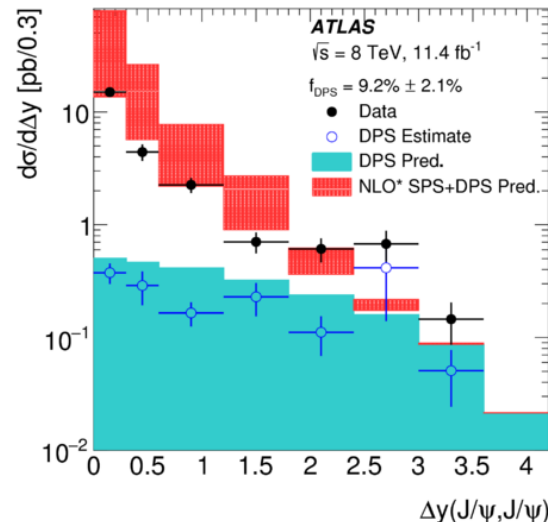
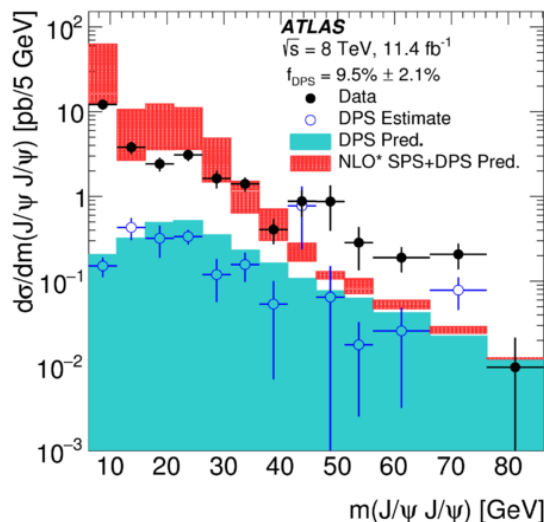
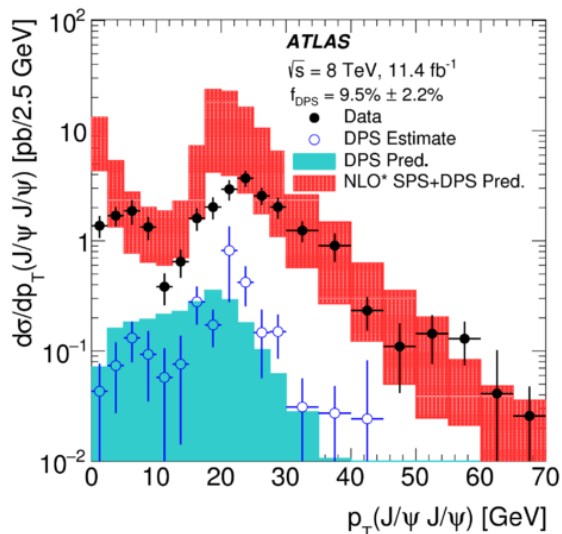
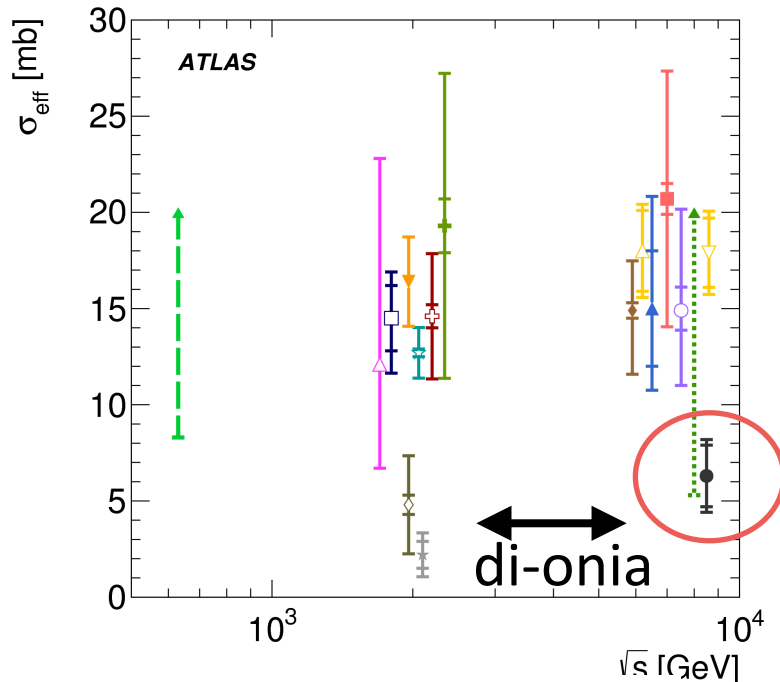
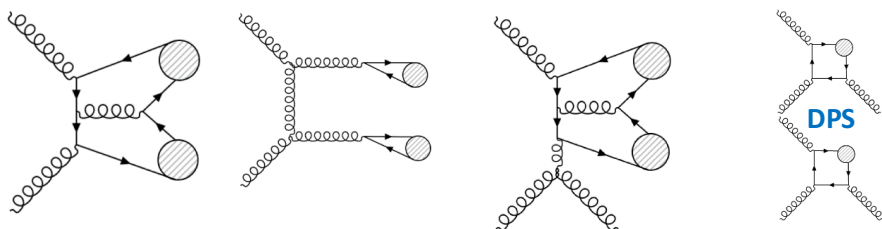
at 90 (95)% CL

- Best upper limits to date and a factor 2-3 better than the previous results from LHCb

- Data sample: 1.0 (7 TeV) + 2.0 (8 TeV) fb^{-1}



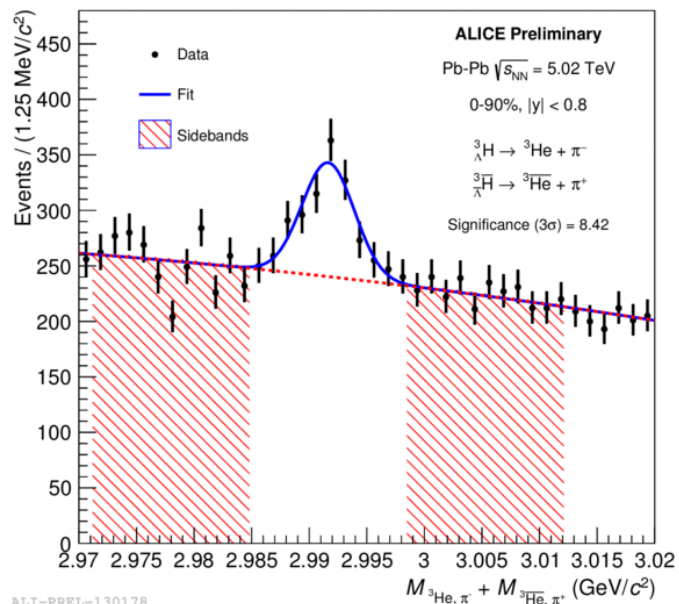
- Understanding of non-perturbative QCD, also sensitive to NLO and higher pQCD corrections
- Measure double parton scattering (DPS)
- Important background for NP searches



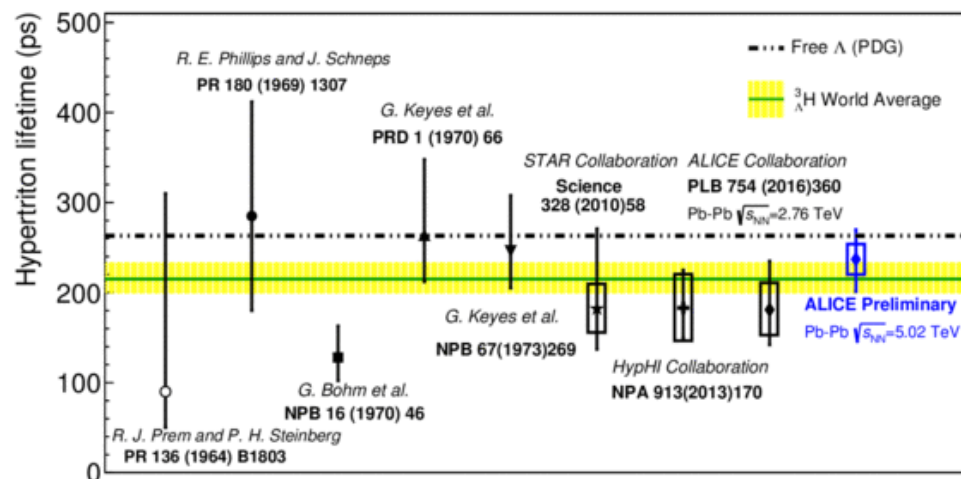


ALICE

Measurement of the (anti-)hypertriton lifetime in Pb-Pb collisions



ALI-PREL-130178



ALI-PREL-130195

$^3_{\Lambda}H$ reconstructed in the $^3He-\pi$ decay channel (3He identification via E-loss in TPC)

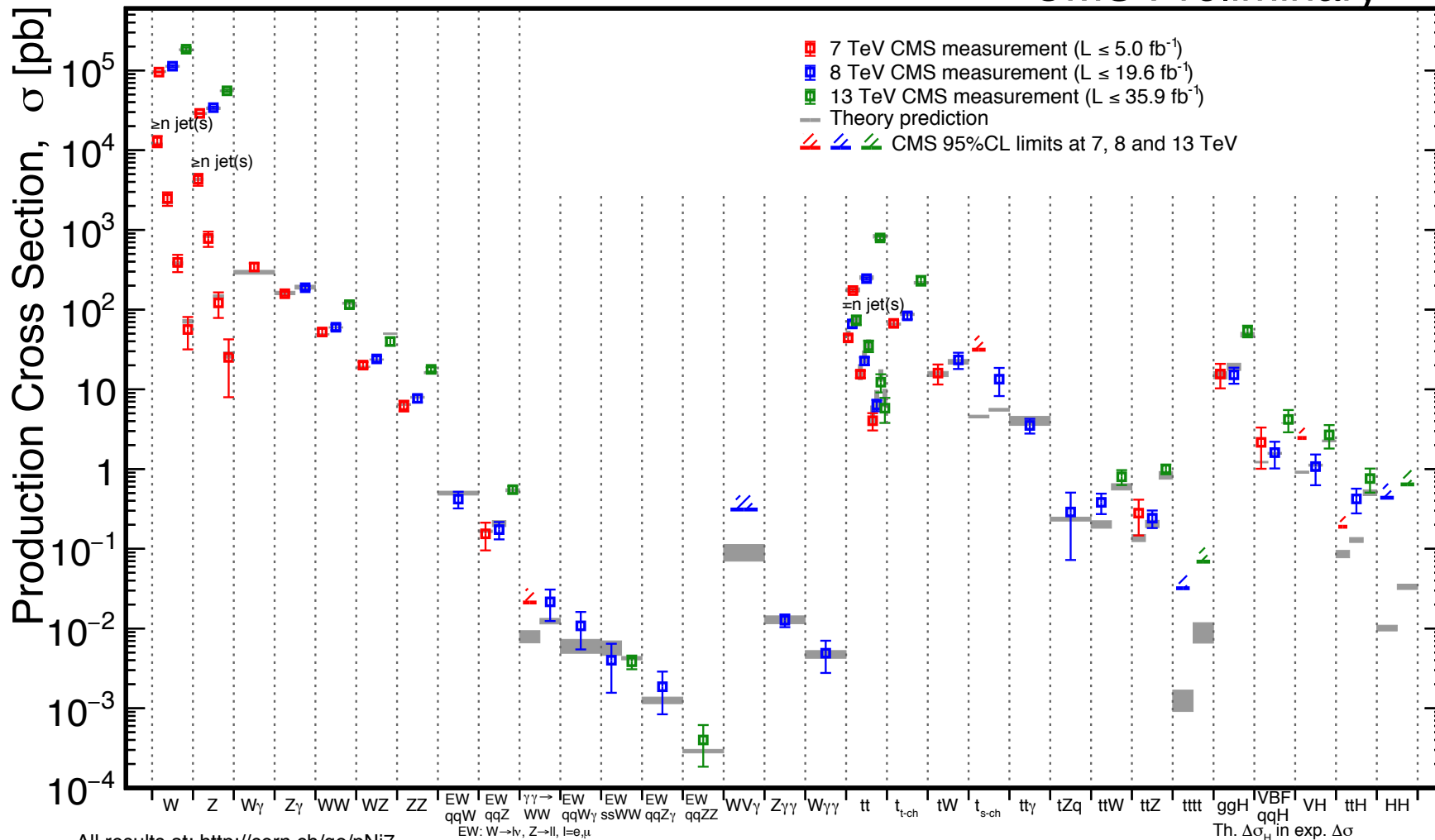
Result fully **compatible with the world-average and with the free Λ lifetime**

Significantly improved uncertainties wrt Run I

(and one of the most precise available measurements)

August 2017

CMS Preliminary



All results at: <http://cern.ch/go/pNj7>

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 37.0) \text{ fb}^{-1}$$

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

	Model	ℓ, γ	Jets [†]	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0 e, \mu$	1-4 j	Yes	36.1	M_D 7.75 TeV	$n = 2$ ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2γ	-	-	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO CERN-EP-2017-132
	ADD QBH	-	2 j	-	37.0	M_{th} 8.9 TeV	$n = 6$ 1703.09217
	ADD BH high $\sum p_T$	$\geq 1 e, \mu$	$\geq 2 j$	-	3.2	M_{th} 8.2 TeV	$n = 6, M_D = 3 \text{ TeV}$, rot BH 1606.02265
	ADD BH multijet	-	$\geq 3 j$	-	3.6	M_{th} 9.55 TeV	$n = 6, M_D = 3 \text{ TeV}$, rot BH 1512.02586
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	36.7	G_{KK} mass 4.1 TeV	$k/\bar{M}_{Pl} = 0.1$ CERN-EP-2017-132
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1 e, \mu$	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\bar{M}_{Pl} = 1.0$ ATLAS-CONF-2017-051
	2UED / PPP	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \rightarrow tt) = 1$ ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	36.1	Z' mass 4.5 TeV	$\Gamma/m = 3\%$ ATLAS-CONF-2017-027
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	36.1	Z' mass 2.4 TeV	ATLAS-CONF-2017-050
	Leptophobic $Z' \rightarrow bb$	-	2 b	-	3.2	Z' mass 1.5 TeV	1603.08791
	Leptophobic $Z' \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2j$	Yes	3.2	Z' mass 2.0 TeV	ATLAS-CONF-2016-014
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	36.1	W' mass 5.1 TeV	1706.04786
	HVT $V' \rightarrow WW \rightarrow qq\ell\ell$ model B	$0 e, \mu$	2 J	-	36.7	V' mass 3.5 TeV	$g_V = 3$ CERN-EP-2017-147
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	-	36.1	V' mass 2.93 TeV	$g_V = 3$ ATLAS-CONF-2017-055
	LRSM $W'_R \rightarrow tb$	$1 e, \mu$	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV	1410.4103
LRSM $W'_R \rightarrow tb$	$0 e, \mu$	$\geq 1 b, 1 J$	-	20.3	W' mass 1.76 TeV	1408.0886	
CI	CI $qqqq$	-	2 j	-	37.0	Λ 21.8 TeV	η_{LL} 1703.09217
	CI $\ell\ell qq$	$2 e, \mu$	-	-	36.1	Λ 40.1 TeV	η_{LL} ATLAS-CONF-2017-027
	CI $uutt$	$2(SS)/\geq 3 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	20.3	Λ 4.9 TeV	$ C_{RR} = 1$ 1504.04605
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	1-4 j	Yes	36.1	m_{med} 1.5 TeV	$g_q=0.25, g_\tau=1.0, m(\chi) < 400 \text{ GeV}$ ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	$\leq 1 j$	Yes	36.1	m_{med} 1.2 TeV	$g_q=0.25, g_\tau=1.0, m(\chi) < 480 \text{ GeV}$ 1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	$0 e, \mu$	1 J, $\leq 1 j$	Yes	3.2	M_χ 700 GeV	$m(\chi) < 150 \text{ GeV}$ 1608.02372
LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2 j$	-	3.2	LQ mass 1.1 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 2 nd gen	2μ	$\geq 2 j$	-	3.2	LQ mass 1.05 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 3 rd gen	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes	20.3	LQ mass 640 GeV	$\beta = 0$ 1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	0 or $1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \rightarrow Ht) = 1$ ATLAS-CONF-2016-104
	VLQ $TT \rightarrow Zt + X$	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \rightarrow Zt) = 1$ 1705.10751
	VLQ $TT \rightarrow Wb + X$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2j$	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \rightarrow Wb) = 1$ CERN-EP-2017-094
	VLQ $BB \rightarrow Hb + X$	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \rightarrow Hb) = 1$ 1505.04306
	VLQ $BB \rightarrow Zb + X$	$2/\geq 3 e, \mu$	$\geq 2/\geq 1 b$	-	20.3	B mass 790 GeV	$\mathcal{B}(B \rightarrow Zb) = 1$ 1409.5500
	VLQ $BB \rightarrow Wt + X$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2j$	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \rightarrow Wt) = 1$ CERN-EP-2017-094
VLQ $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4 j$	Yes	20.3	Q mass 690 GeV	1509.04261	
Excited fermions	Excited quark $q^* \rightarrow qg$	-	2 j	-	37.0	q^* mass 6.0 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1703.09127
	Excited quark $q^* \rightarrow q\gamma$	1γ	1 j	-	36.7	q^* mass 5.3 TeV	only u^* and d^* , $\Lambda = m(q^*)$ CERN-EP-2017-148
	Excited quark $b^* \rightarrow bg$	-	1 b, 1 j	-	13.3	b^* mass 2.3 TeV	ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	1 or $2 e, \mu$	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_b = f_t = f_R = 1$ 1510.02664
	Excited lepton ℓ^*	$3 e, \mu$	-	-	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$ 1411.2921
	Excited lepton ν^*	$3 e, \mu, \tau$	-	-	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
Other	LRSM Majorana ν	$2 e, \mu$	2 j	-	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4 \text{ TeV}$, no mixing 1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	-	-	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H^{\pm\pm} \rightarrow \ell\tau) = 1$ 1411.2921
	Monotop (non-res prod)	$1 e, \mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$ 1410.5404
	Multi-charged particles	-	-	-	20.3	multi-charged particle mass 785 GeV	DY production, $ q = 5e$ 1504.04188
	Magnetic monopoles	-	-	-	7.0	monopole mass 1.34 TeV	DY production, $ g = 1g_D$, spin 1/2 1509.08059

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

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

10^{-1}

Mass scale [TeV]

10 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).

- LHC Run 2 is in full swing - hundreds of results - with more expected
 - ATLAS: <https://twiki.cern.ch/twiki/bin/view/AtlasPublic>
 - CMS: <http://cms-results.web.cern.ch/cms-results/public-results/publications/>
 - LHCb: http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_all.html
 - Alice: <http://aliceinfo.cern.ch/ArtSubmission/submitted>
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- These results rely on the efforts of the Grid community and the computing resources supplied by the UK.