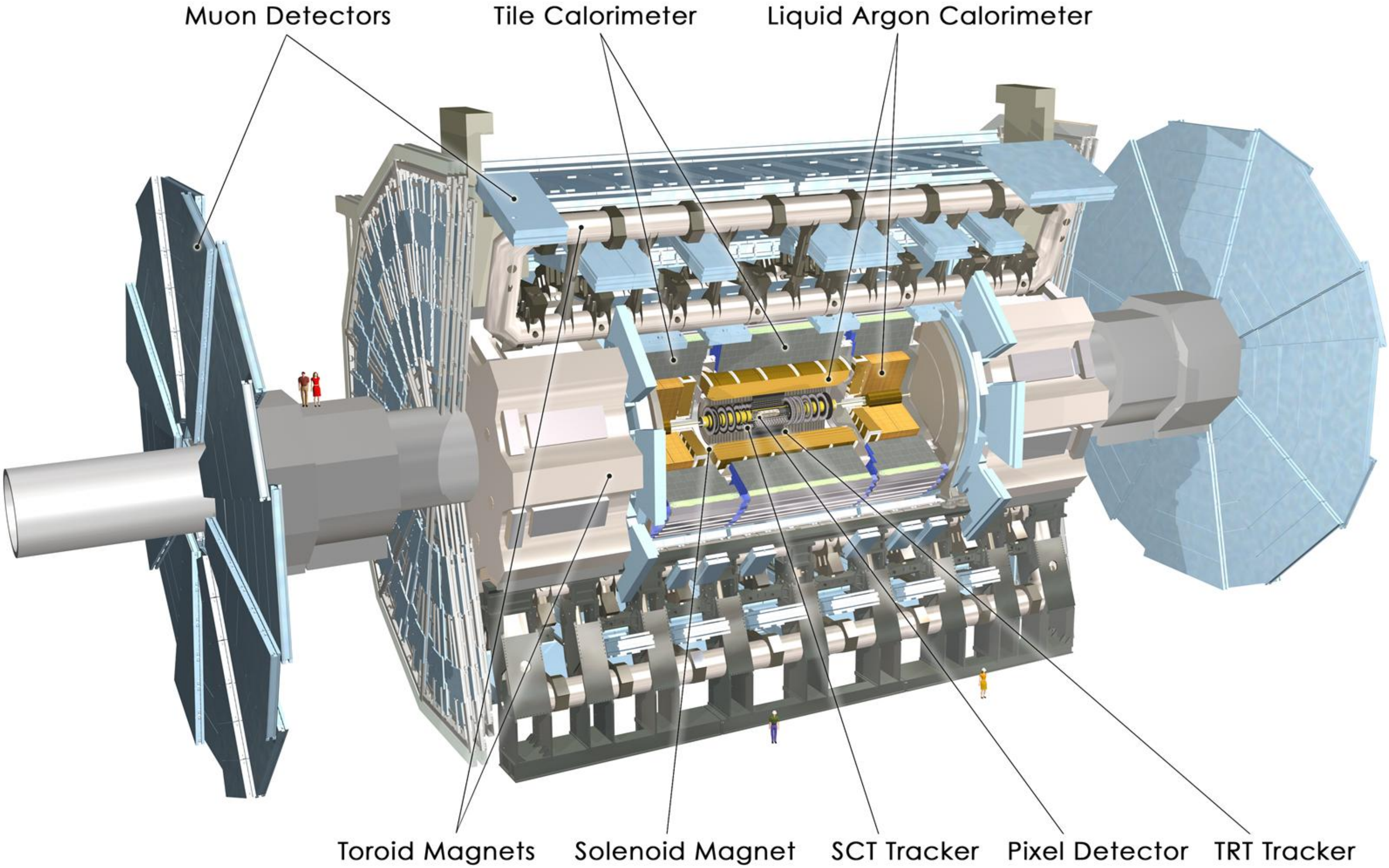
ATLAS @ LHC: status and recent results

28th International Symposium on Lepton Photon Interactions at High Energies

Sun Yat-Sen University, Guangzhou China
7 August 2017

Rob McPherson University of Victoria / IPP + TRIUMF
On behalf of the ATLAS Collaboration

The ATLAS Detector



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Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
Taiwan
Turkey
UK
USA
CERN
JINR

- **182 Institutions in 38 Countries**
  - **- Including 9 Chinese institutes**
- **~ 2900 Scientific Authors**

  ~ 1900 with PhD, contributing to M&O share

  ~ 1000 Students

Outline of Talk

- ATLAS data-taking and performance
- ATLAS recent physics analysis results
- ATLAS Upgrades
- Summary

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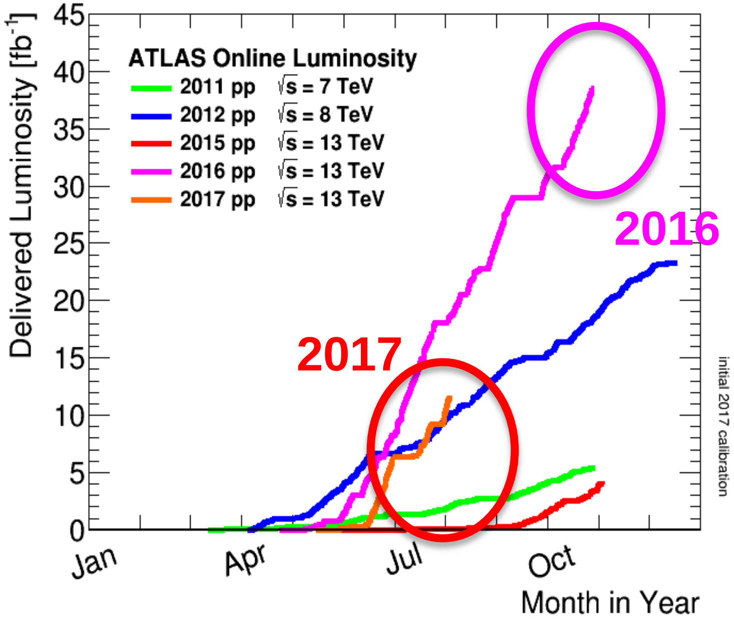
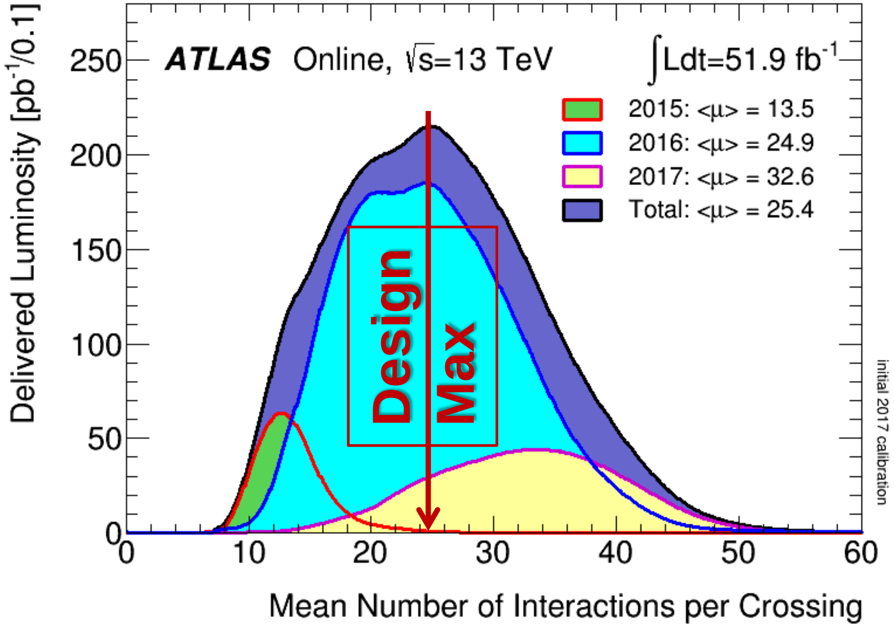
Excellent *but Challenging* LHC Performance

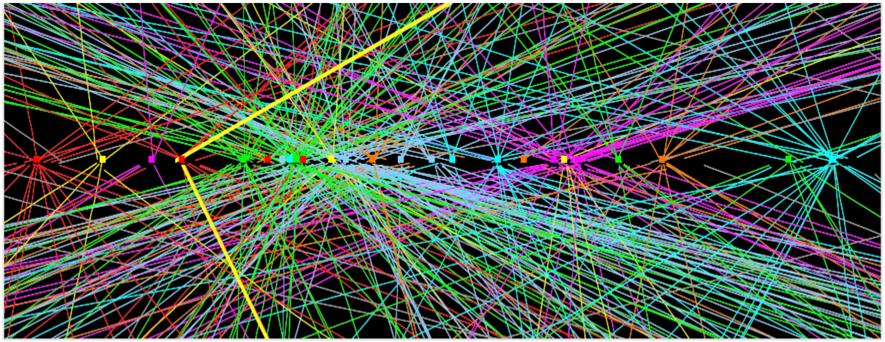
- **2016 p-p $\mathcal{L}_{PEAK}$ record ≈ 1.4x10^{34} cm^{-2} s^{-1}**
  μ (peak) ≈ 44 interactions per crossing
  $\int\mathcal{L}$ = 38.5 fb^{-1} delivered by LHC
- **2017 p-p $\mathcal{L}_{PEAK}$ already ≈ 1.7x10^{34} cm^{-2} s^{-1}**
  μ (peak) ≈ 50 interactions per crossing
  $\int\mathcal{L}$ = 11.7 fb^{-1} delivered by LHC (2017/08/04)



Pileup: average per fill

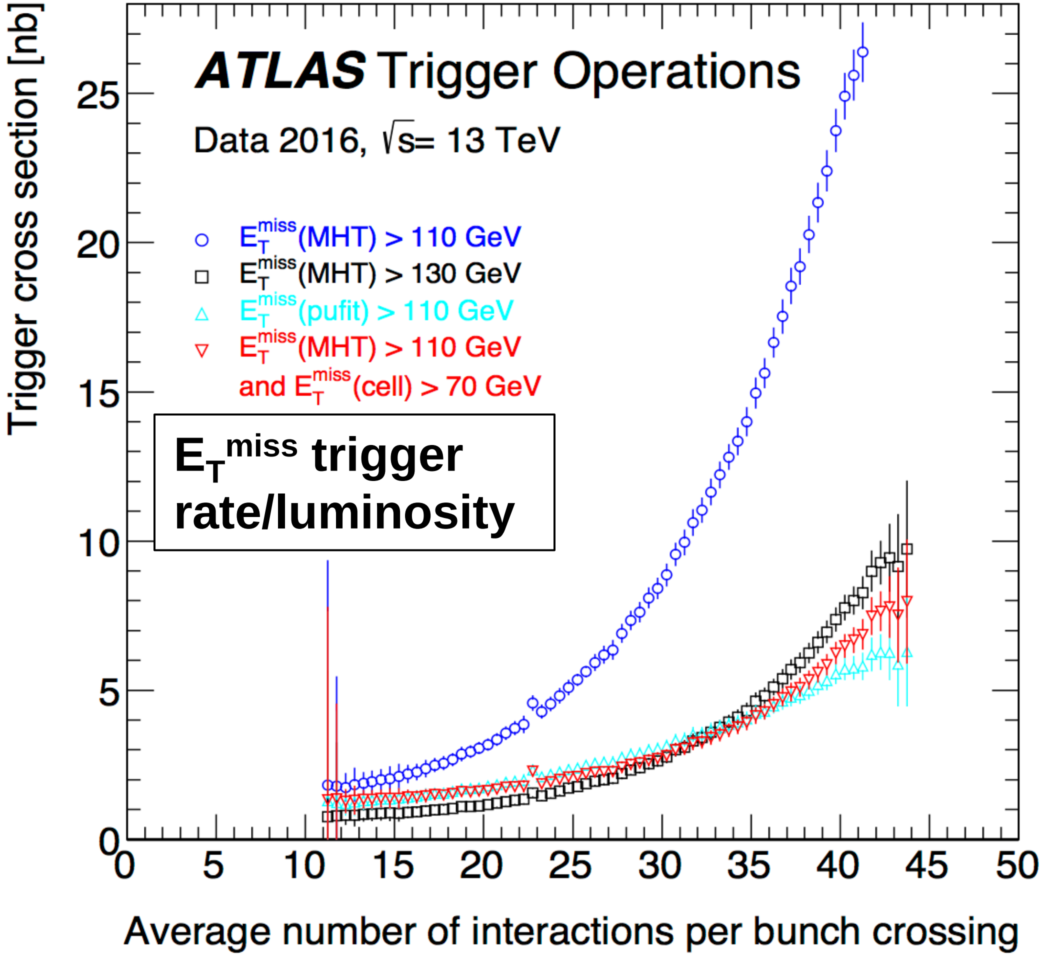


Z→μμ with 25 other interactions



Trigger Performance in 2016

- **Trigger menu: physics, monitoring, calibration requirements**
  - **~2000 active menu items**
  - **Level-1 rate: up to 100 kHz, Physics output rate ~1kHz**
  - ***Challenge: non-linear growth of trigger rates with pileup***
    - ***Eg E_T^{miss} resolution badly degraded by pileup potentially ⇒ threshold increase?***



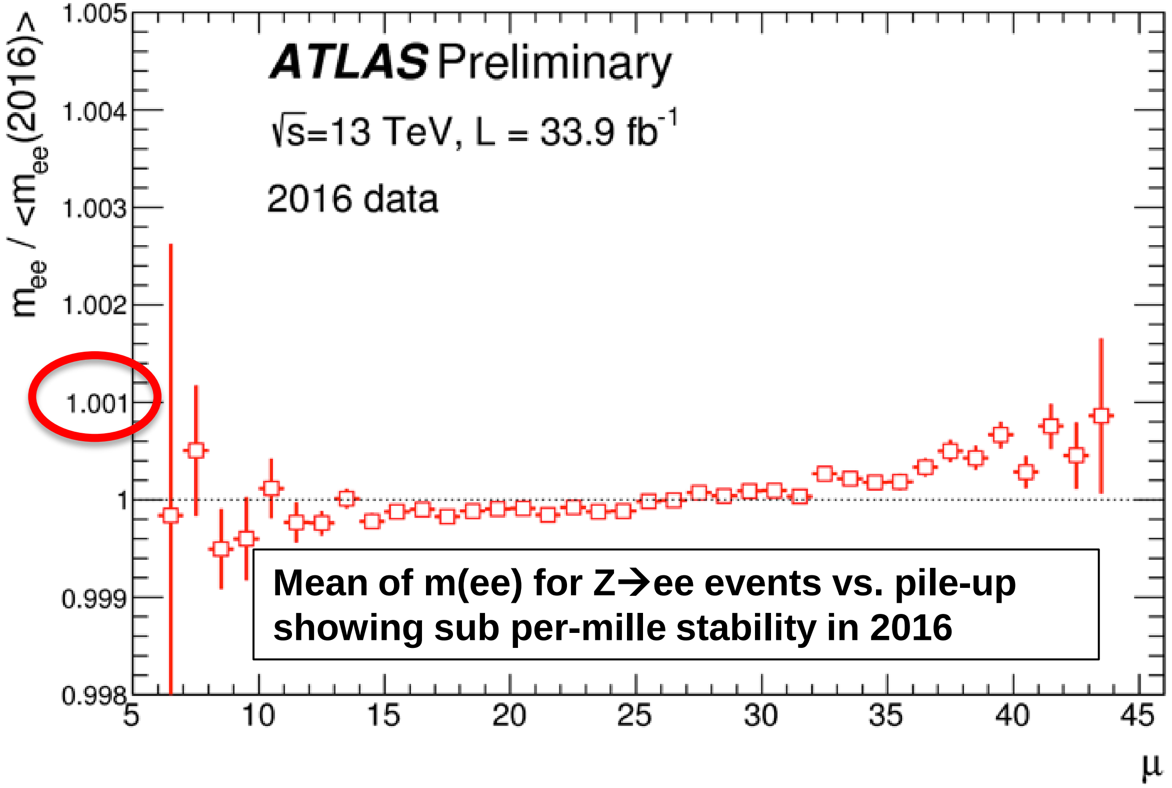
E_T^{miss} trigger rate/luminosity

Typical trigger thresholds at 1.4×10^{34} cm^{-2}s^{-1}:

- ***E_T(e) > 26 GeV***
- ***p_T(μ) > 26 GeV***
- ***E_T^{miss} > 110 GeV***
- ***E_T(jet) > 380 GeV***
- ***E_T(γ) > 140 GeV***

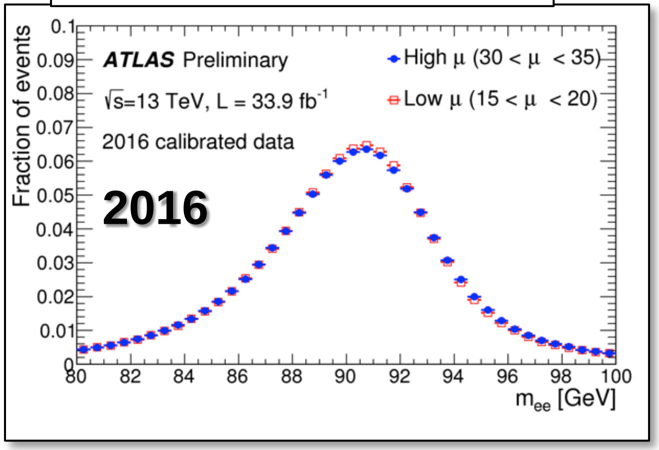
Physics Object Performance

- **Physics analyses start with detector data, then physics objects:**
  - **electrons, muons, taus, jets, b-tagged jets, E_t^{miss} etc.**
- **Huge effort throughout 2016 and early 2017 to stabilize performance**
  - **Eg: m(ee) in Z→ee:**

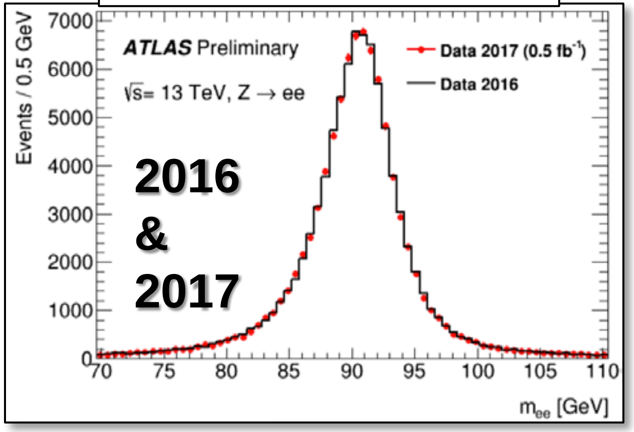


Mean of m(ee) for Z→ee events vs. pile-up showing sub per-mille stability in 2016

m(ee) at low/high pile-up



m(ee) in 2016/2017



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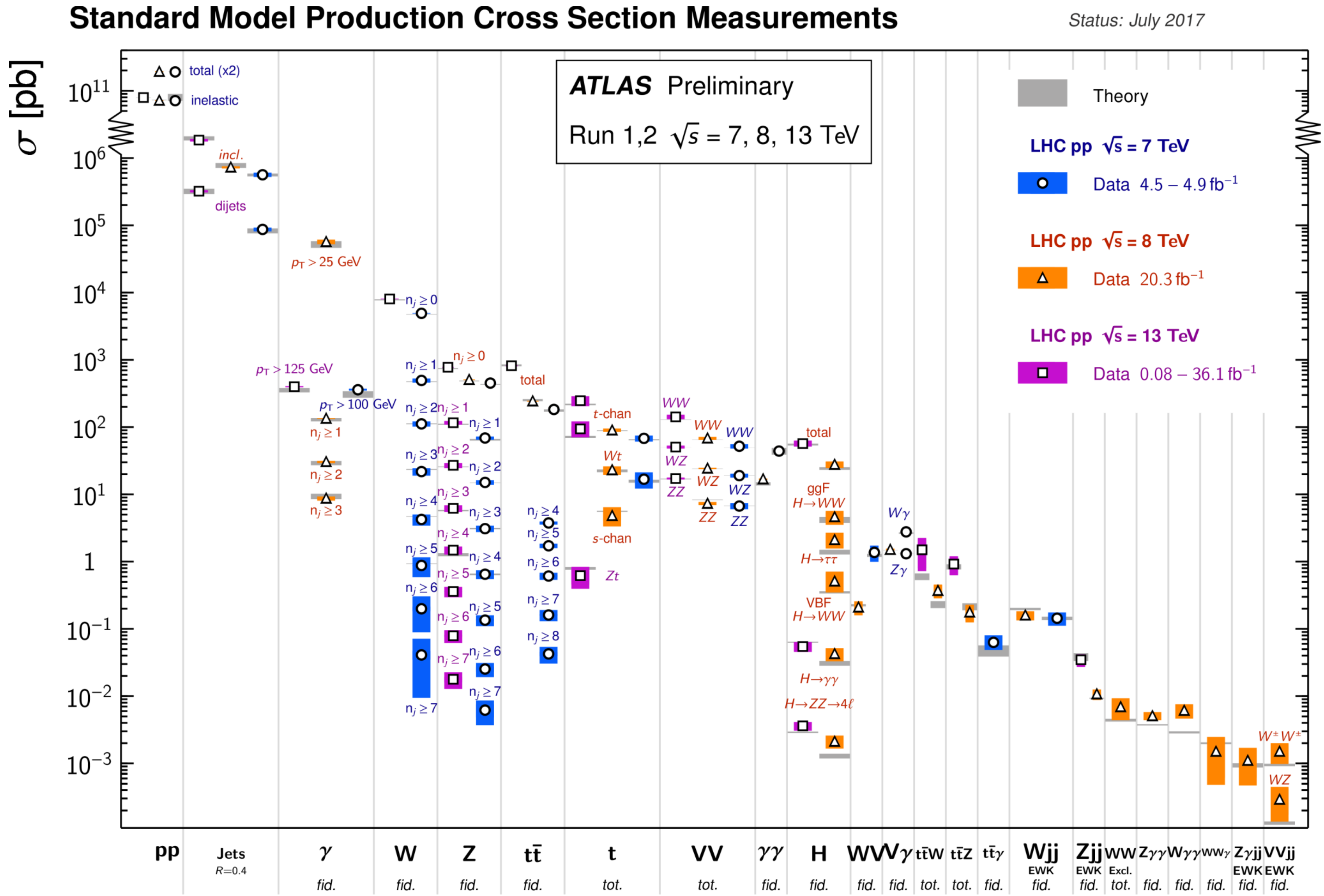
Only a few selected results presented here

Standard Model Processes

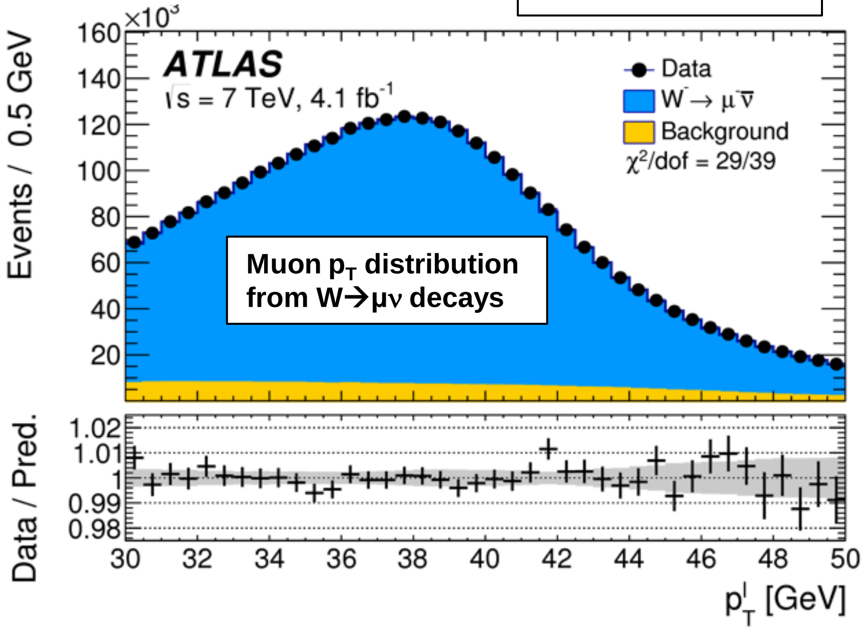


W Boson Mass Measurement

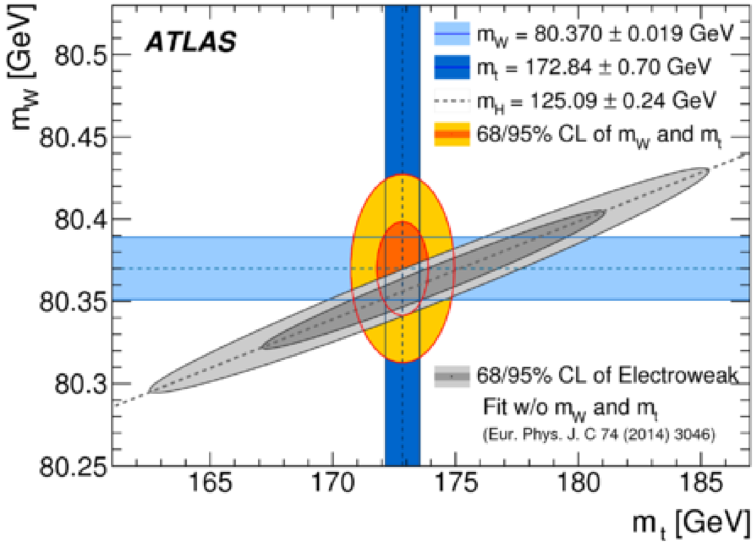
arXiv:1701.07240

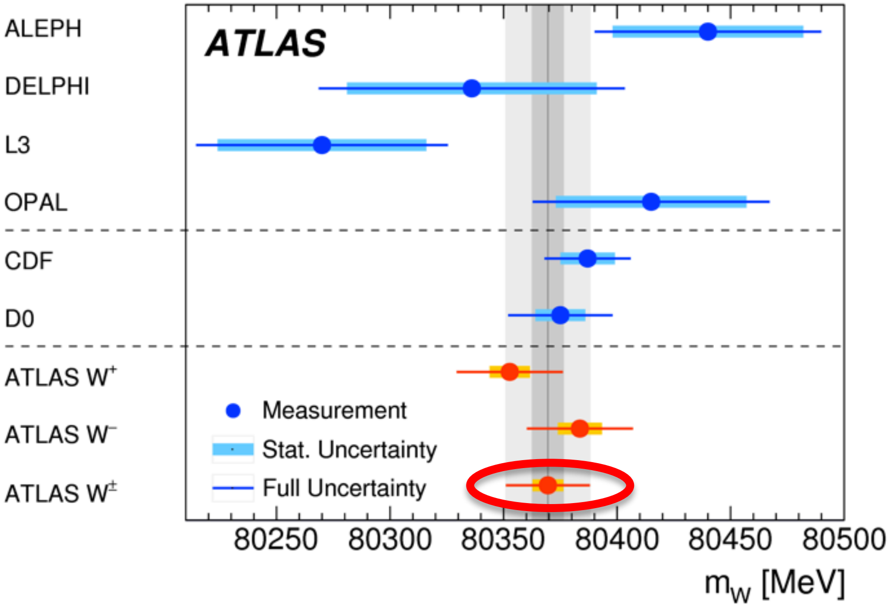
- 4.6 fb^{-1} of 7 TeV data (W→eν/μν)
- Huge amount of work since 2011 to understand detector response and modelling of kinematic quantities, e.g. lepton p_T, E_T^{miss}
  - Calibration of W recoil with Z → ℓℓ data critical
- Similar precision to best previous single experiment measurement (from CDF)
- Result consistent with SM expectation
- Further progress requires improved modelling

m_W = 80.370 ± 0.019 GeV
[± 7 MeV (stat.) ± 11 MeV (syst.) ± 14 MeV (modelling)]



Muon p_T distribution from W→μν decays

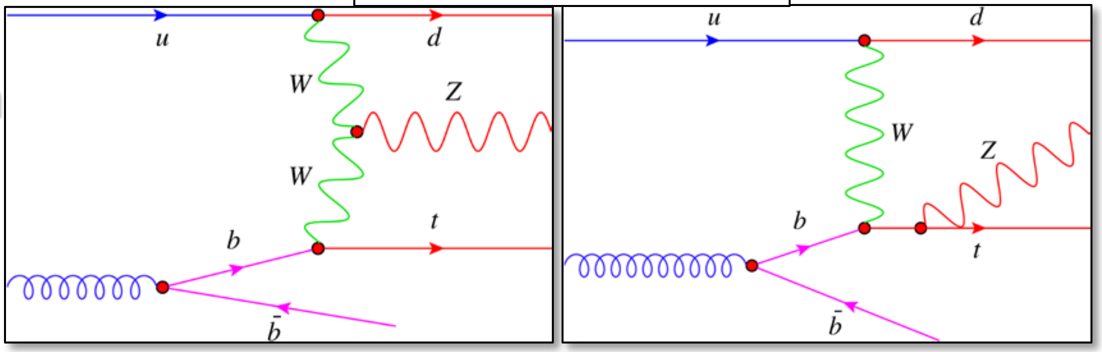




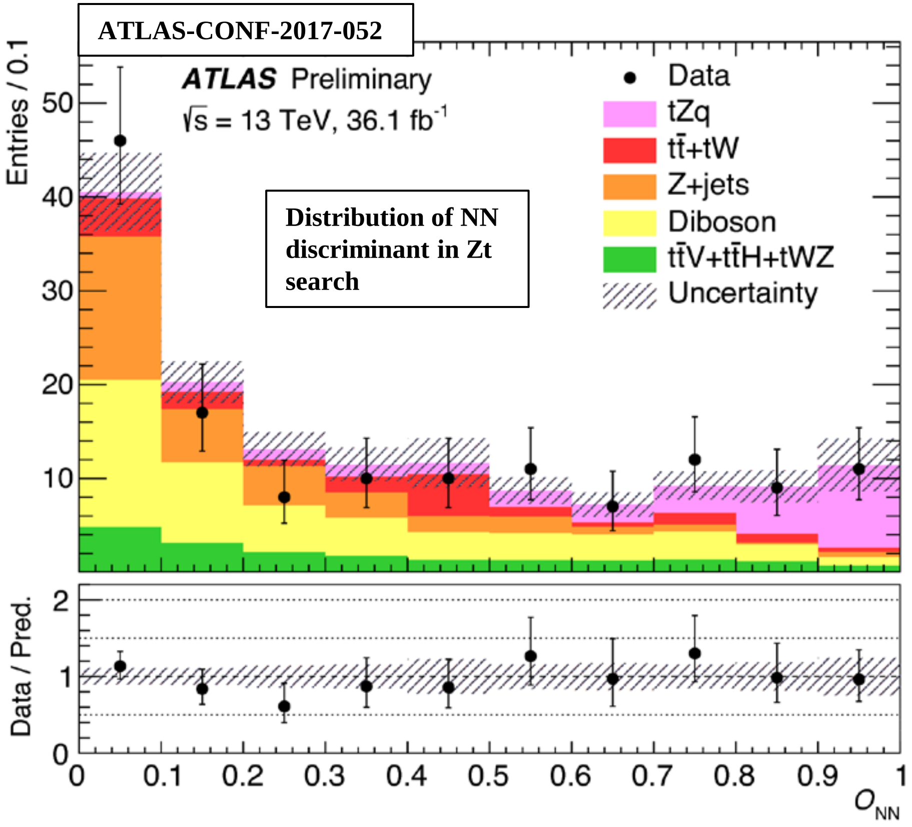
Top Quark Physics example: Zt

- **Previously evidence for single top quark production at LHC in s-channel, t-channel and Wt associated production**

Zt production diagrams



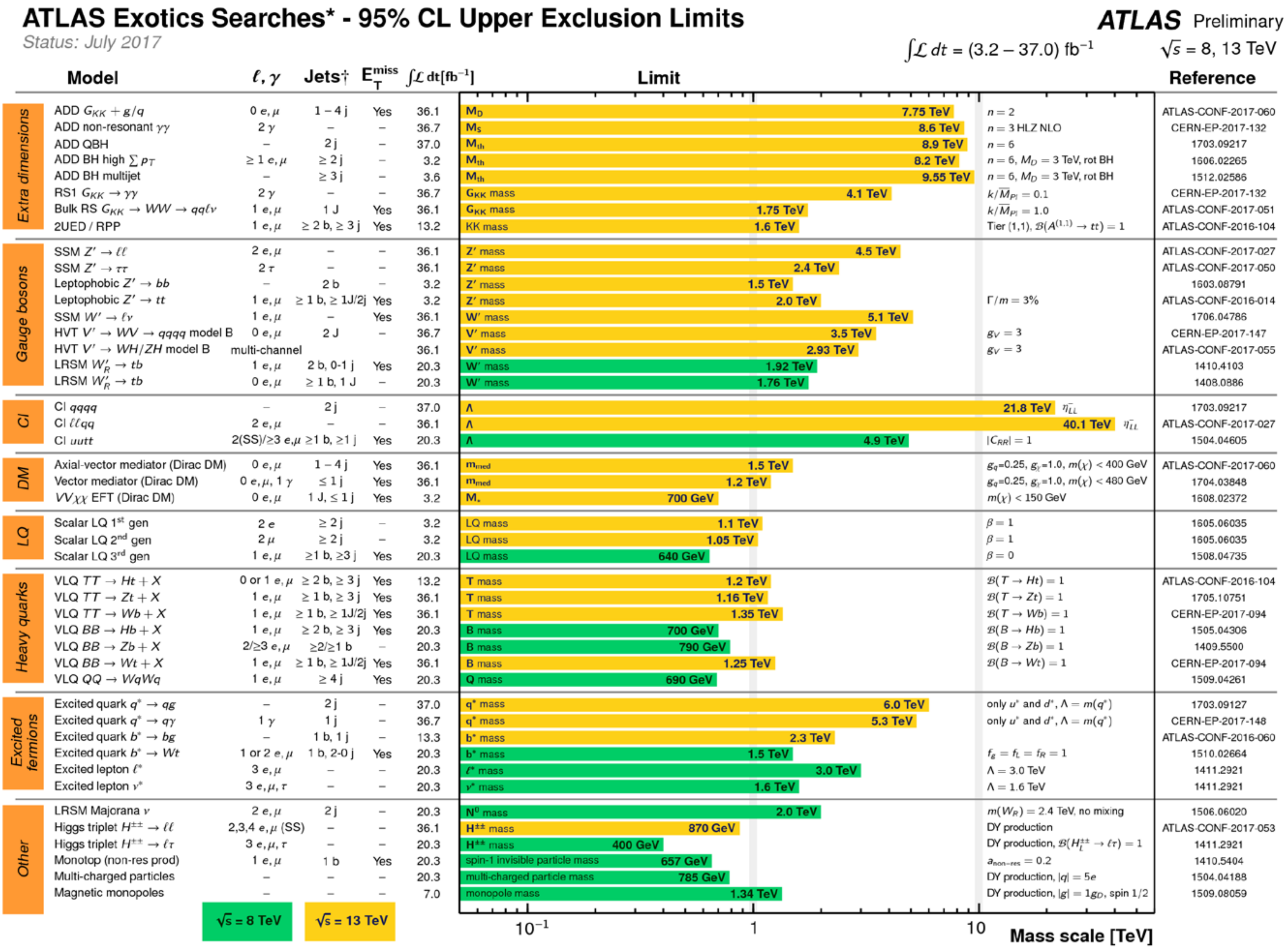
- **Now also evidence for Zt production**
  - **Significance 4.2σ (5.4σ expected)**
  - **Cross-section 620 ± 170_{stat} ± 140_{syst} fb consistent with SM expectation**
- **Also m(top), ttW, ttZ, etc.**



ATLAS-CONF-2017-052

Distribution of NN discriminant in Zt search

Searches for “Exotic” New Physics



ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

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

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

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	$0\ e, \mu$	$1 - 4$ j	Yes	36.1	🟨 M_D 7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	$2\ \gamma$	–	–	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 $\sum p_T$	$\geq 1\ e, \mu$	≥ 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 $G_{KK} \to \gamma\gamma$	$2\ \gamma$	–	–	36.7	🟨 G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	$1\ e, \mu$	1 J	Yes	36.1	🟨 G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2017-051
	2UED / RPP	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	13.2	🟨 KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt) = 1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	$2\ e, \mu$	–	–	36.1	🟨 Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	$2\ \tau$	–	–	36.1	🟨 Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	🟨 Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	3.2	🟨 Z' mass 2.0 TeV	$\Gamma/m = 3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	$1\ e, \mu$	–	Yes	36.1	🟨 W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	$0\ e, \mu$	2 J	–	36.7	🟨 V' mass 3.5 TeV	$g_V = 3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	🟨 V' mass 2.93 TeV	$g_V = 3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	$1\ e, \mu$	2 b, 0-1 j	Yes	20.3	🟩 W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	$0\ e, \mu$	≥ 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,μ	$\geq$1 b, $\geq$1 j	Yes	20.3	🟩 Λ 4.9 TeV	$\vert C_{RR}\vert = 1$	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_χ=1.0, $m(\chi) < 400$ GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	$0\ e, \mu, 1\ \gamma$	≤ 1 j	Yes	36.1	🟨 m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 480$ GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	$0\ e, \mu$	1 J, ≤ 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	$2\ \mu$	≥ 2 j	–	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	$1\ e, \mu$	$\geq$1 b, $\geq$3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	🟨 T mass 1.2 TeV	$\mathcal{B}(T \to Ht) = 1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	$1\ e, \mu$	≥ 1 b, ≥ 3 j	Yes	36.1	🟨 T mass 1.16 TeV	$\mathcal{B}(T \to Zt) = 1$	1705.10751
	VLQ $TT \to Wb + X$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 T mass 1.35 TeV	$\mathcal{B}(T \to Wb) = 1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	$1\ e, \mu$	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass 700 GeV	$\mathcal{B}(B \to Hb) = 1$	1505.04306
	VLQ $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	🟩 B mass 790 GeV	$\mathcal{B}(B \to Zb) = 1$	1409.5500
	VLQ $BB \to Wt + X$	$1\ e, \mu$	≥ 1 b, ≥ 1J/2j	Yes	36.1	🟨 B mass 1.25 TeV	$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	$1\ e, \mu$	≥ 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 $q^* \to q\gamma$	$1\ \gamma$	1 j	–	36.7	🟨 q^* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	🟨 b^* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	🟩 b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	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	LRSM Majorana ν	$2\ e, \mu$	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	ATLAS-CONF-2017-053
	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
	Monotop (non-res prod)	$1\ e, \mu$	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{\mathrm{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\vert q\vert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass 1.34 TeV	DY production, $\vert g\vert = 1g_D$, spin 1/2	1509.08059

🟩 $\sqrt{s}$ = 8 TeV

🟨 $\sqrt{s}$ = 13 TeV

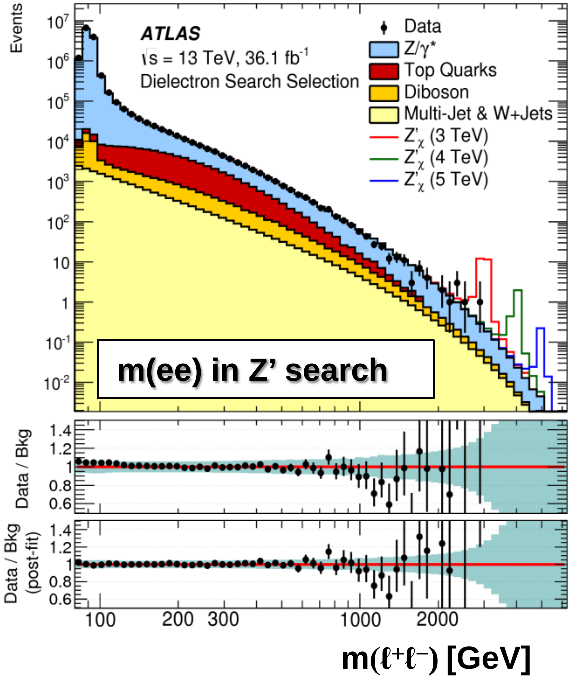
*Only a selection of the available mass limits on new states or phenomena is shown.

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

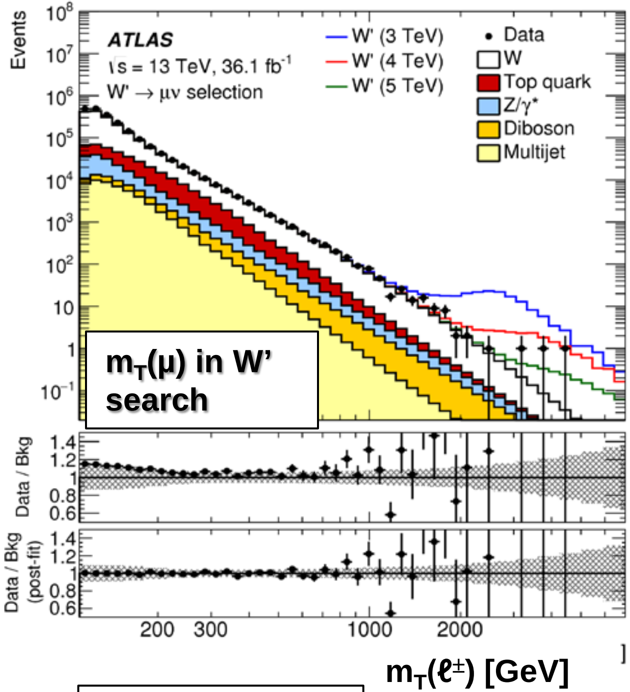
Resonance Searches - Dilepton, Lepton+E_T^{miss}

- $X \rightarrow \ell^+\ell^-$ (eg Z′)
  - $m(\ell^+\ell^-)$ Peak
- $Y \rightarrow \ell^\pm + E_t^{miss}$ (eg W′)
  - $m_T(\ell^\pm)$ Peak/edge
- No significant excess over SM expectation
- 95% CL exclusion limits extracted in various new physics scenarios

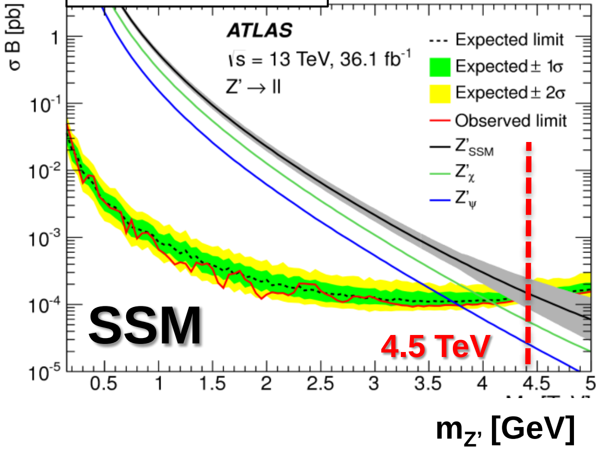
arXiv:1707.02424



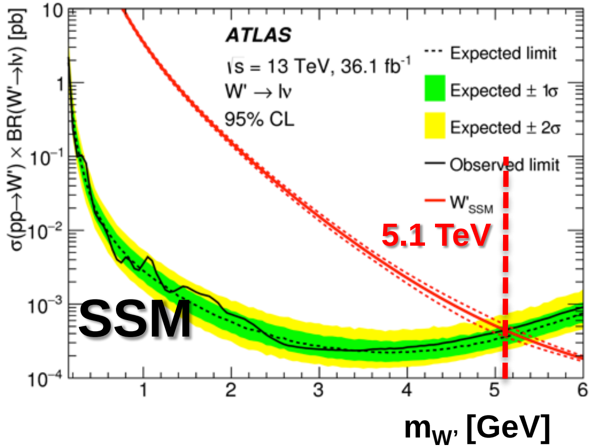
arXiv:1706.04786



Z'→ll mass limits



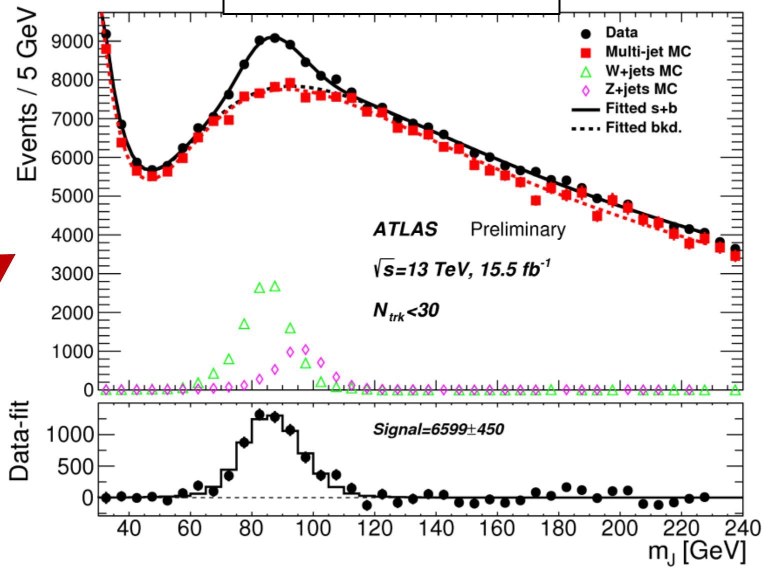
W'→lν mass limits



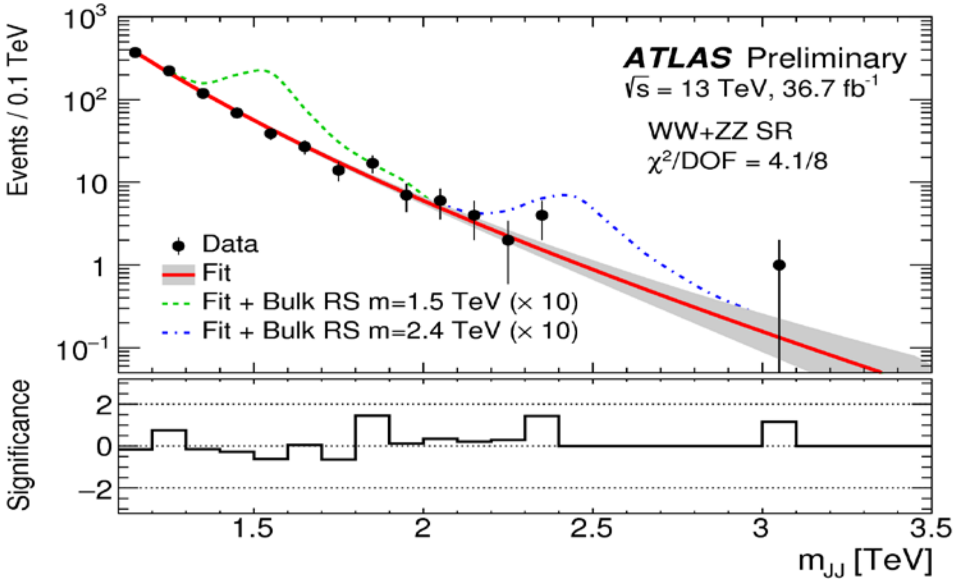
Resonance Searches - Dibosons

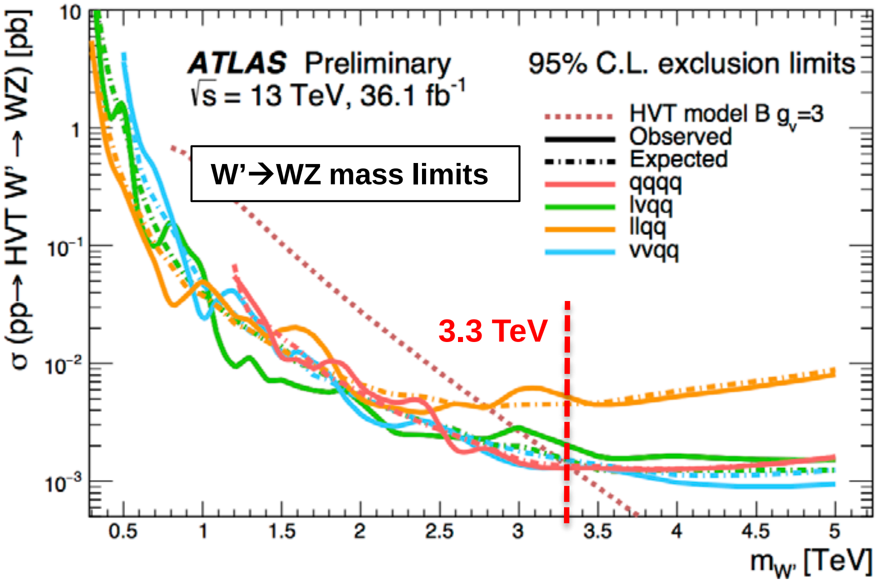
- $X \rightarrow VV, VH, HH$ (V=W/Z)
  - $VV \rightarrow qqqq / qq\ell\nu / qq\ell\ell / qq\nu\nu$
  - $VH \rightarrow bbqq / bb\ell\nu / bb\ell\ell$
  - Merged jets at high p_T using substructure
    - “boson-tagging”

ATLAS-CONF-2016-055



Dijet mass in VV→qqqq search with boson-tagged jets





W’→WZ mass limits

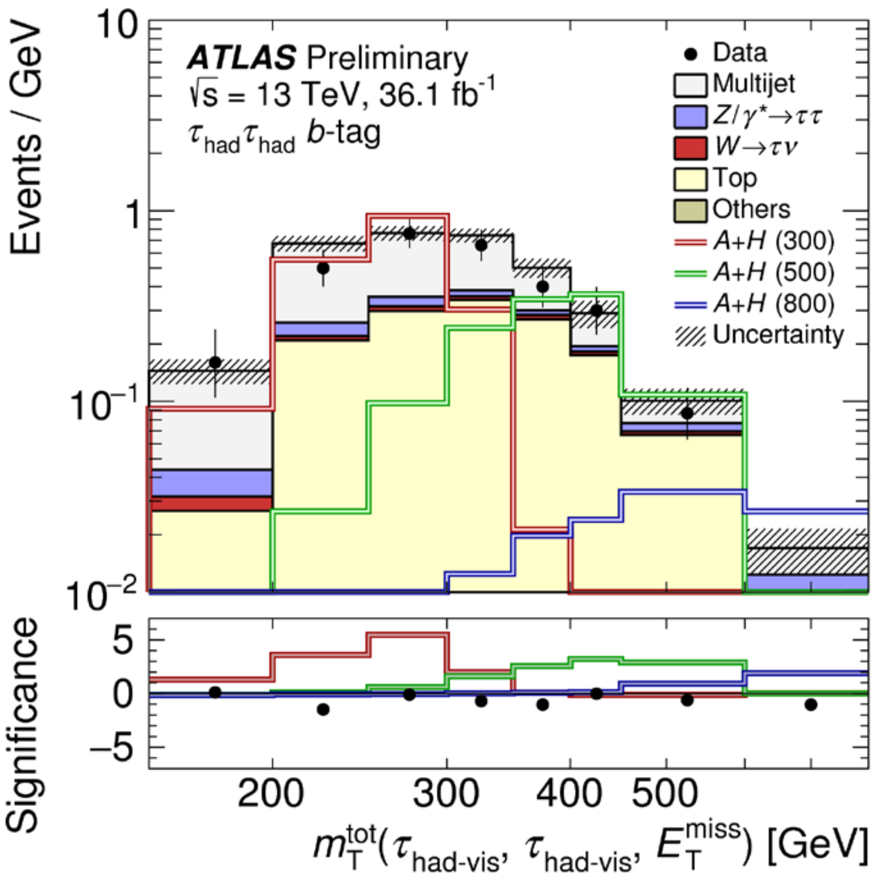
3.3 TeV

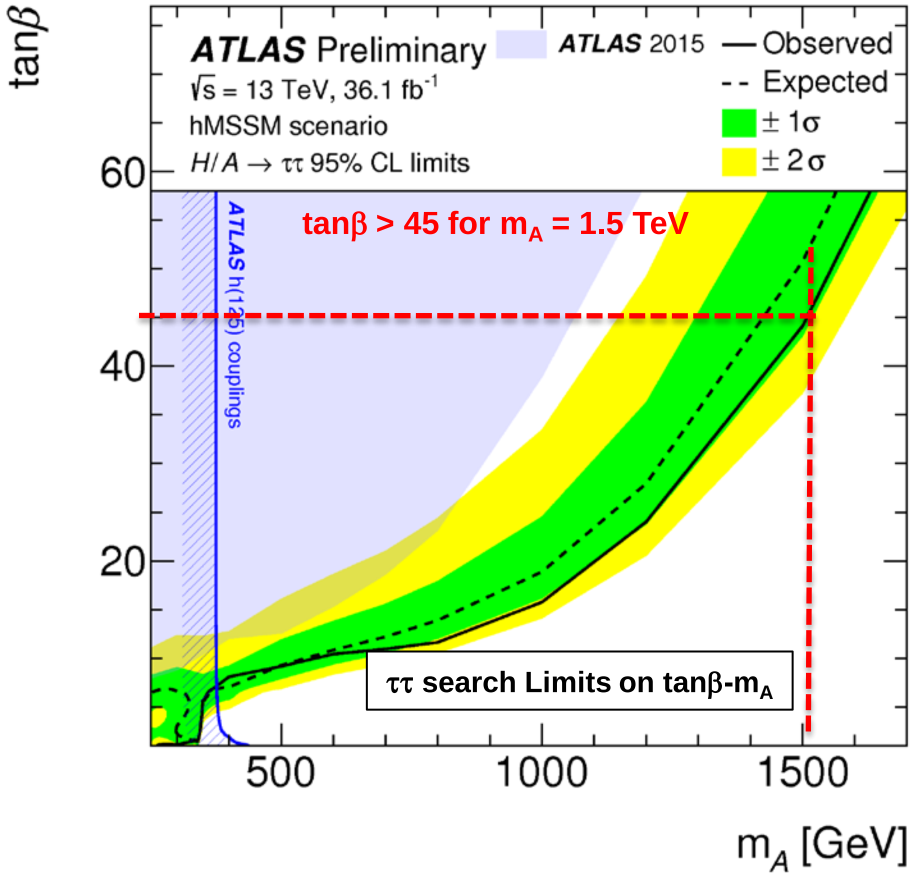
ATLAS-CONF-2017-018/051/055

Resonance Searches - $\tau^+ \tau^-$

- $X \rightarrow \tau^+\tau^-$
  - Heavy Higgs, eg from SUSY
- No significant excesses over SM expectation

ATLAS-CONF-2017-050





tanβ > 45 for m_A = 1.5 TeV

ττ search Limits on tanβ-m_A

Searches for Dark Matter (DM)

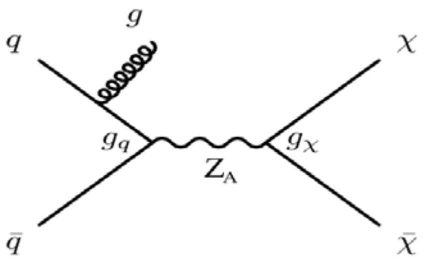
- **Something + DM where DM → E_t^{miss}**
  - **Jet(s) + E_t^{miss}**
  - **γ + E_t^{miss}**
  - **H (→γγ/bb) + E_t^{miss}**

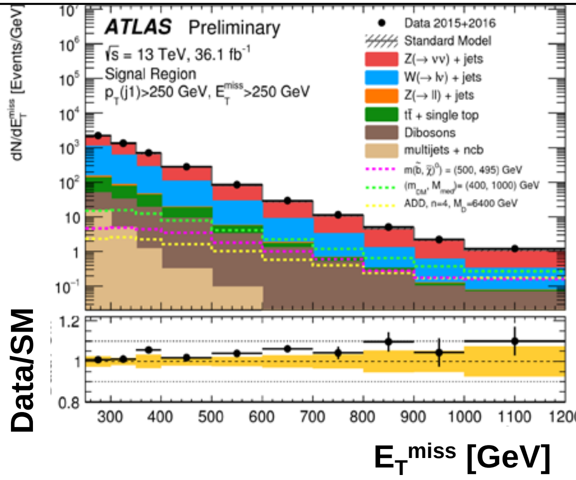
ATLAS-CONF-2017-060

E_T^{miss} distribution in monojet search

monojet + DM

(simplified model)

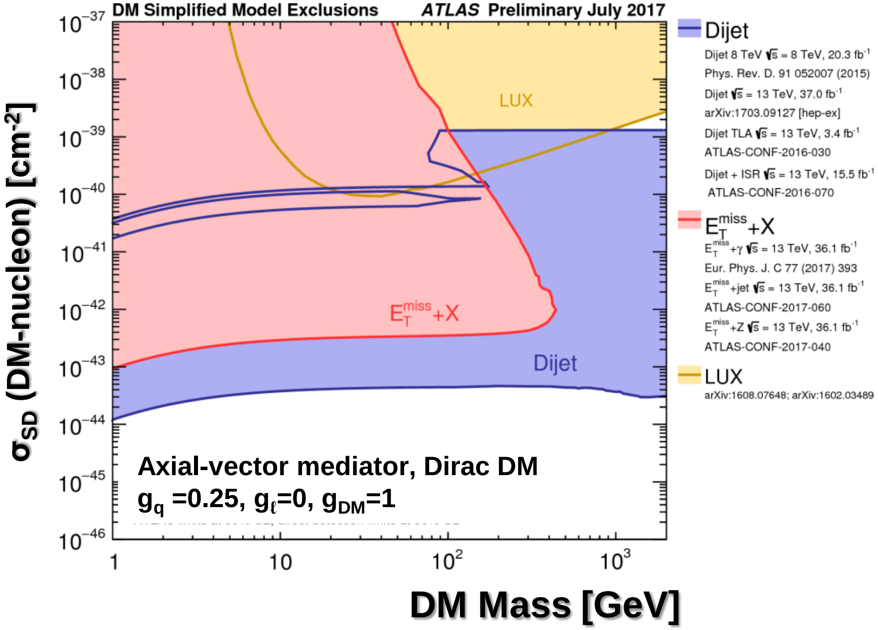




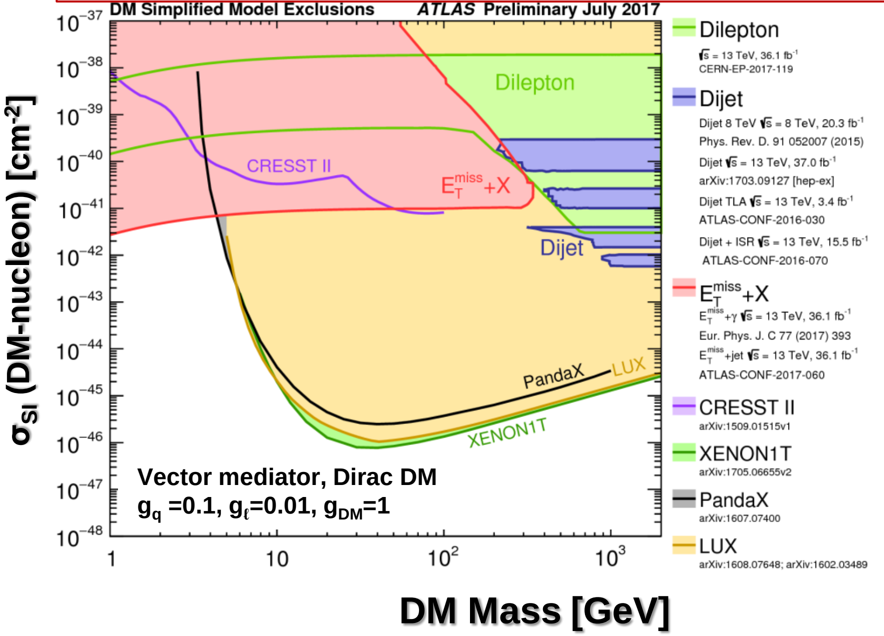
- **Complementary to direct dark matter searches**
- **Use "simplified models" to guide analyses and interpret results**

Compare to Direct Detection Experiments: Model-dependent limits in σ - m_{DM} plane using simplified models

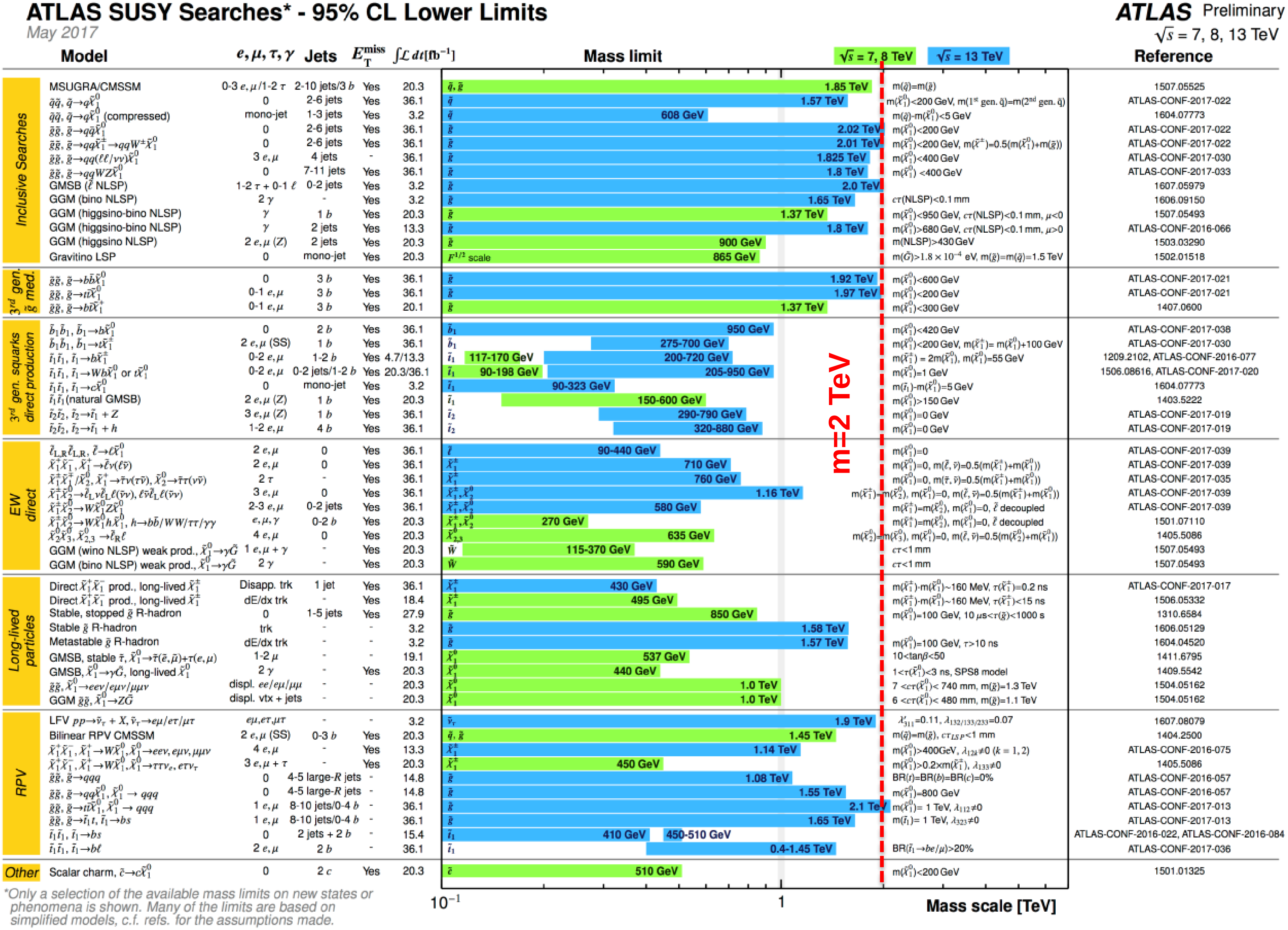
Spin-Dependent σ_{SD} - m_{DM} plane – Axial-vector Mediator



Spin-Independent σ_{SI} - m_{DM} plane – Vector Mediator



Searches for Supersymmetry



ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

🟩 $\sqrt{s}$ = 7, 8 TeV 🟦 $\sqrt{s}$ = 13 TeV

	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\text{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	🟩 $\tilde{q},\tilde{g}$ 1.85 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{q}$ 1.57 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2017-022
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}_1^0$ (compressed)	mono-jet	1-3 jets	Yes	3.2	🟦 $\tilde{q}$ 608 GeV	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)<5 GeV	1604.07773
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{g}$ 2.02 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{g}$ 2.01 TeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}^\pm$)=0.5(m($\tilde{\chi}_1^0$)+m($\tilde{g}$))	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	36.1	🟦 $\tilde{g}$ 1.825 TeV	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2017-030
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}_1^0$	0	7-11 jets	Yes	36.1	🟦 $\tilde{g}$ 1.8 TeV	m($\tilde{\chi}_1^0$) <400 GeV	ATLAS-CONF-2017-033
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	3.2	🟦 $\tilde{g}$ 2.0 TeV		1607.05979
	GGM (bino NLSP)	2 γ	-	Yes	3.2	🟦 $\tilde{g}$ 1.65 TeV	$c\tau$(NLSP)<0.1 mm	1606.09150
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	🟩 $\tilde{g}$ 1.37 TeV	m($\tilde{\chi}_1^0$)<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	🟦 $\tilde{g}$ 1.8 TeV	m($\tilde{\chi}_1^0$)>680 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	ATLAS-CONF-2016-066
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	🟩 $\tilde{g}$ 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	🟩 $F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8×10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	🟦 $\tilde{g}$ 1.92 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	36.1	🟦 $\tilde{g}$ 1.97 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	🟩 $\tilde{g}$ 1.37 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	🟦 $\tilde{b}_1$ 950 GeV	m($\tilde{\chi}_1^0$)<420 GeV	ATLAS-CONF-2017-038
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}_1^\pm$	2 e,μ (SS)	1 b	Yes	36.1	🟦 $\tilde{b}_1$ 275-700 GeV	m($\tilde{\chi}_1^0$)<200 GeV, m($\tilde{\chi}_1^\pm$)= m($\tilde{\chi}_1^0$)+100 GeV	ATLAS-CONF-2017-030
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0-2 e,μ	1-2 b	Yes	4.7/13.3	$\tilde{t}_1$ 🟩 117-170 GeV 🟦 200-720 GeV	m($\tilde{\chi}_1^\pm$) = 2m($\tilde{\chi}_1^0$), m($\tilde{\chi}_1^0$)=55 GeV	1209.2102, ATLAS-CONF-2016-077
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3/36.1	$\tilde{t}_1$ 🟩 90-198 GeV 🟦 205-950 GeV	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, ATLAS-CONF-2017-020
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet	Yes	3.2	🟦 $\tilde{t}_1$ 90-323 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)=5 GeV	1604.07773
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	🟩 $\tilde{t}_1$ 150-600 GeV	m($\tilde{\chi}_1^0$)>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	36.1	🟦 $\tilde{t}_2$ 290-790 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2017-019
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	Yes	36.1	🟦 $\tilde{t}_2$ 320-880 GeV	m($\tilde{\chi}_1^0$)=0 GeV	ATLAS-CONF-2017-019
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	36.1	🟦 $\tilde{\ell}$ 90-440 GeV	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	36.1	🟦 $\tilde{\chi}_1^\pm$ 710 GeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\to\tilde{\tau}\tau(\nu\tilde{\nu})$	2 τ	-	Yes	36.1	🟦 $\tilde{\chi}_1^\pm$ 760 GeV	m($\tilde{\chi}_1^0$)=0, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-035
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	36.1	🟦 $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 1.16 TeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0Z\tilde{\chi}_1^0$	2-3 e,μ	0-2 jets	Yes	36.1	🟦 $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 580 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0h\tilde{\chi}_1^0$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	🟩 $\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 270 GeV	m($\tilde{\chi}_1^\pm$)=m($\tilde{\chi}_2^0$), m($\tilde{\chi}_1^0$)=0, $\tilde{\ell}$ decoupled	1501.07110
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	🟩 $\tilde{\chi}_{2,3}^0$ 635 GeV	m($\tilde{\chi}_2^0$)=m($\tilde{\chi}_3^0$), m($\tilde{\chi}_1^0$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}_2^0$)+m($\tilde{\chi}_1^0$))	1405.5086
	GGM (wino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	1 e,μ + γ	-	Yes	20.3	🟩 $\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\to\gamma\tilde{G}$	2 γ	-	Yes	20.3	🟩 $\tilde{W}$ 590 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	36.1	🟦 $\tilde{\chi}_1^\pm$ 430 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)=0.2 ns	ATLAS-CONF-2017-017
	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	dE/dx trk	-	Yes	18.4	🟩 $\tilde{\chi}_1^\pm$ 495 GeV	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)~160 MeV, τ($\tilde{\chi}_1^\pm$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	🟩 $\tilde{g}$ 850 GeV	m($\tilde{\chi}_1^0$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	3.2	🟦 $\tilde{g}$ 1.58 TeV		1606.05129
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	🟦 $\tilde{g}$ 1.57 TeV	m($\tilde{\chi}_1^0$)=100 GeV, τ>10 ns	1604.04520
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	🟩 $\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	20.3	🟩 $\tilde{\chi}_1^0$ 440 GeV	1<τ($\tilde{\chi}_1^0$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	🟩 $\tilde{\chi}_1^0$ 1.0 TeV	7 <$c\tau$($\tilde{\chi}_1^0$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	🟩 $\tilde{\chi}_1^0$ 1.0 TeV	6 <$c\tau$($\tilde{\chi}_1^0$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	3.2	🟦 $\tilde{\nu}_\tau$ 1.9 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	🟩 $\tilde{q},\tilde{g}$ 1.45 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	🟦 $\tilde{\chi}_1^\pm$ 1.14 TeV	m($\tilde{\chi}_1^0$)>400GeV, $\lambda_{12k}\neq0$ ($k=1,2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\to W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to\tau\tau\nu_e, e\tau\nu_\tau$	3 e,μ + τ	-	Yes	20.3	🟩 $\tilde{\chi}_1^\pm$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^\pm$), $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	4-5 large-R jets	-	14.8	🟦 $\tilde{g}$ 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	0	4-5 large-R jets	-	14.8	🟦 $\tilde{g}$ 1.55 TeV	m($\tilde{\chi}_1^0$)=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\to qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	🟦 $\tilde{g}$ 2.1 TeV	m($\tilde{\chi}_1^0$)= 1 TeV, $\lambda_{112}\neq0$	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1t$, $\tilde{t}_1\to bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	🟦 $\tilde{g}$ 1.65 TeV	m($\tilde{t}_1$)= 1 TeV, $\lambda_{323}\neq0$	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	15.4	🟦 $\tilde{t}_1$ 410 GeV 🟦 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	36.1	🟦 $\tilde{t}_1$ 0.4-1.45 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	🟩 $\tilde{c}$ 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

*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.

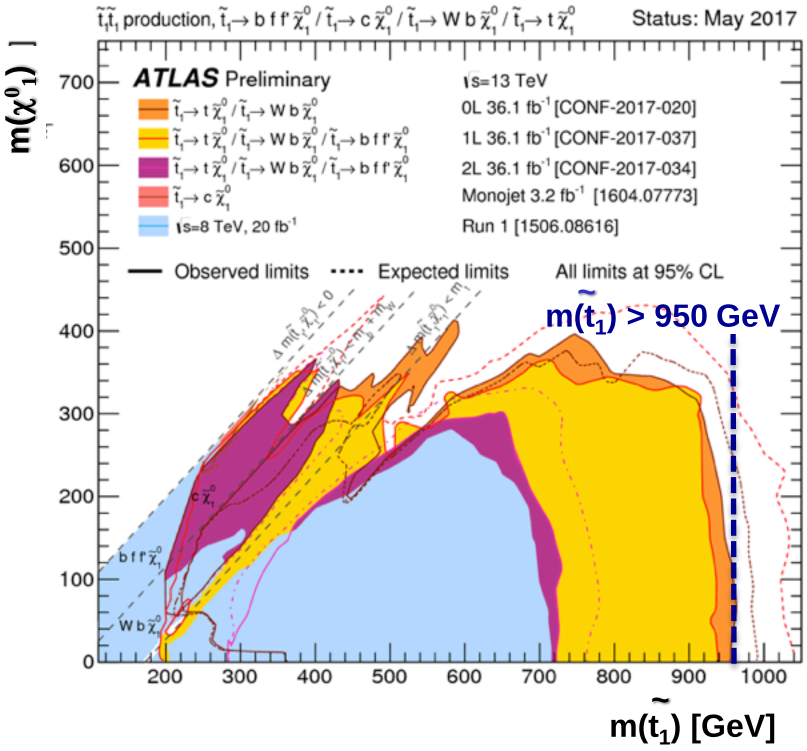
SUSY: 3rd Generation and Electroweak

- **"Natural SUSY"**
  - → light 3rd generation squarks and higgsinos cancel Higgs mass loop corrections

- **Direct stop ($\tilde{t}_1$)**
  - b-jets + E_t^{miss}
  - Many different signal regions:
    - Highly optimized

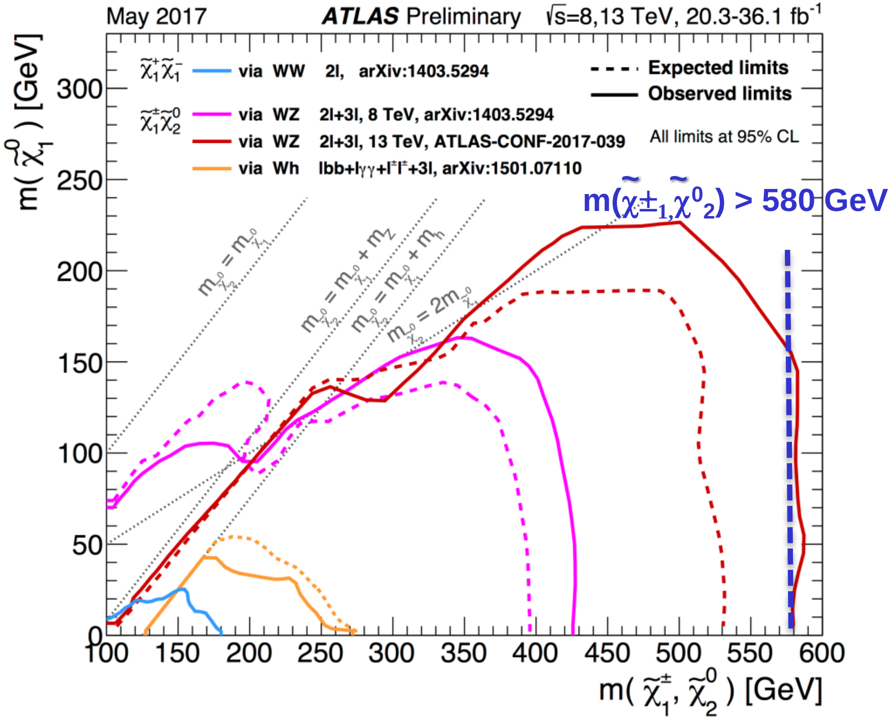
- **Direct production of charginos and neutralinos with**
  - 2 or 3 leptons + E_t^{miss}
  - Many different signal regions:
    - Highly optimized

Limits in $m(\tilde{t}_1) - m(\tilde{\chi}^0_1)$ plane



$m(\tilde{t}_1) > 950$ GeV

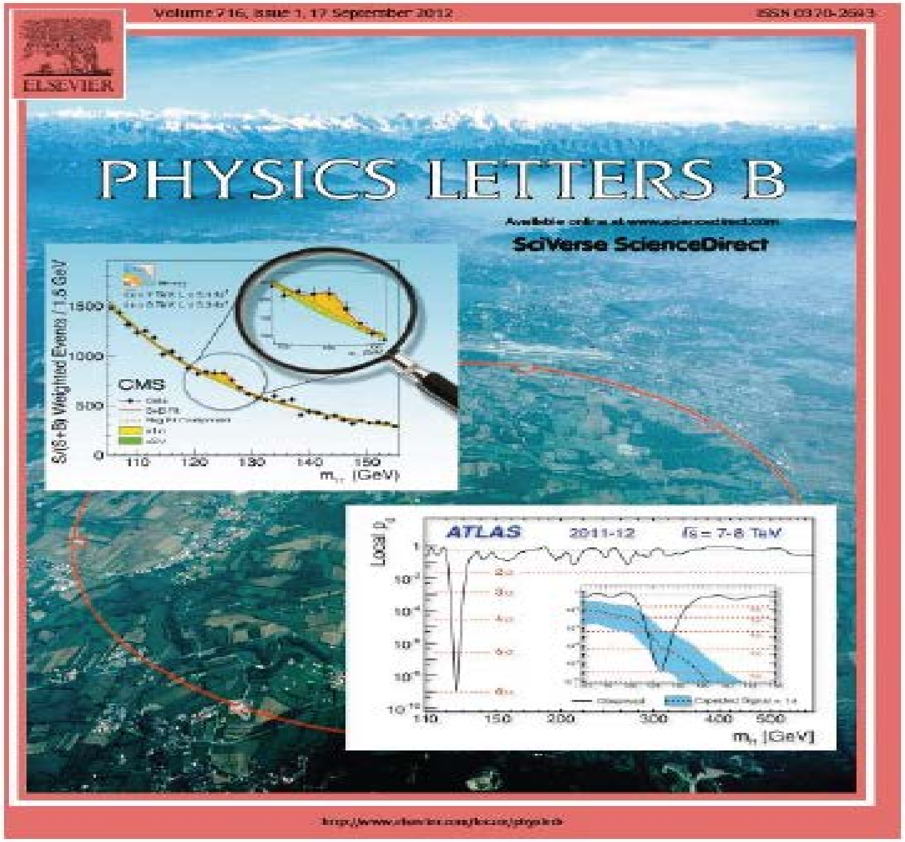
Limits on $m(\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_2) - m(\tilde{\chi}^0_1)$



$m(\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_2) > 580$ GeV

Higgs Boson Studies …

- Higgs-like particle discovery by ATLAS and CMS announced July 4th, 2012. ATLAS paper:
  - Phys. Lett. B 716 (2012) 1-29
  - 7503 citations (as of 2017-08-03)
- March 2013: key papers on particle properties
  - new particle declared “a Higgs boson”
- Citation for 2013 Nobel Prize in Physics


Volume 716, Issue 1, 17 September 2012

ISSN 0370-2693

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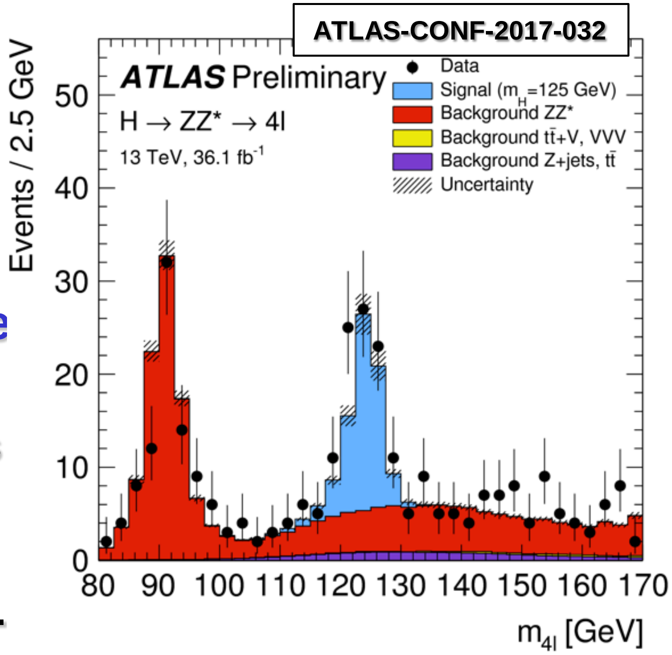
Higgs Boson Production at √s = 13 TeV

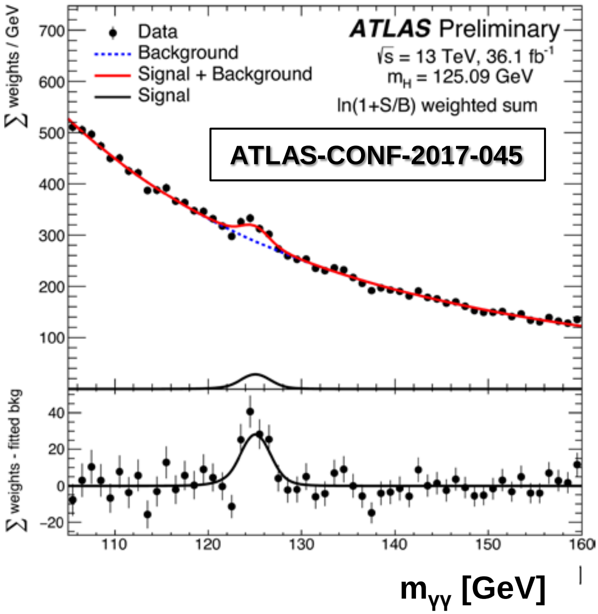
- **Measurements use $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels**
- **Larger √s & data ⇒ more measurements possible**
  - **Fiducial cross-sections**
  - **Differential cross-sections**
  - **Total production cross-sections (assumes SM branching ratios)**
- **Combined global signal strength compatible with Standard Model:**

$$\mu = 1.09 \pm 0.12$$

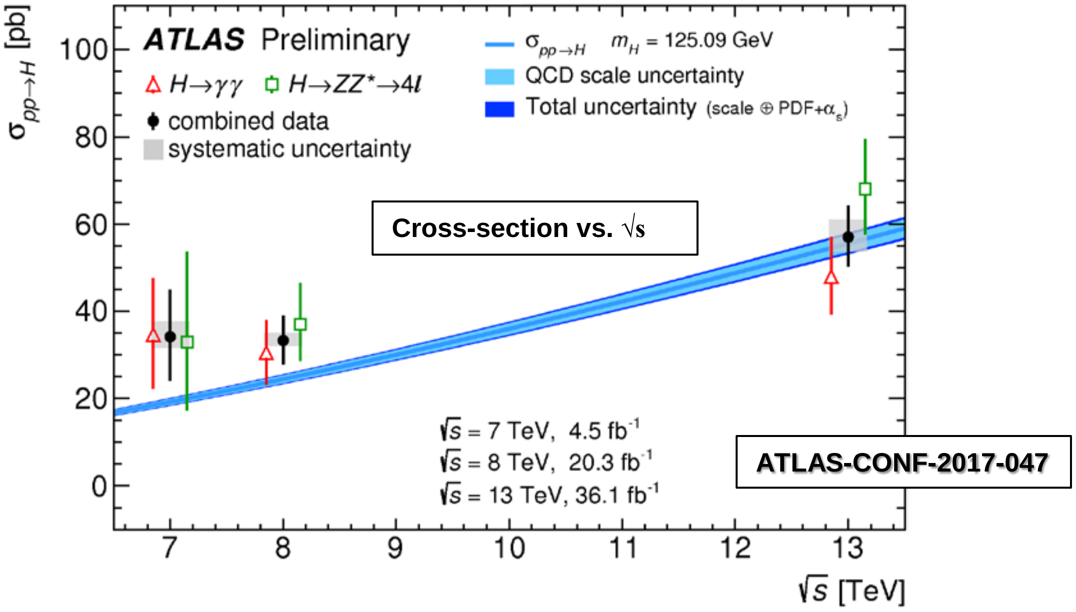
$$= 1.09 \pm 0.09\ (\text{stat.})\ ^{+0.06}_{-0.05}\ (\text{syst.})\ ^{+0.06}_{-0.05}\ (\text{th.})$$



ATLAS-CONF-2017-032



ATLAS-CONF-2017-045



Cross-section vs. √s

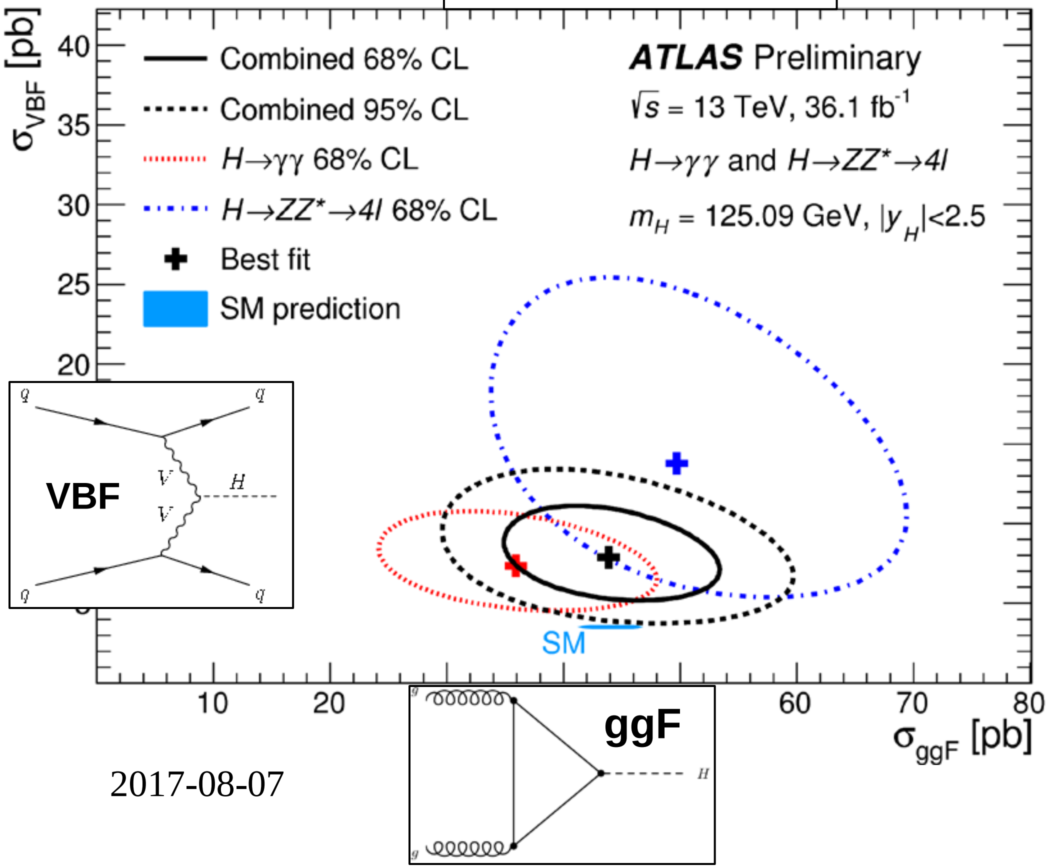
ATLAS-CONF-2017-047

Theory uncertainty reduced: N3LO ggF calculations

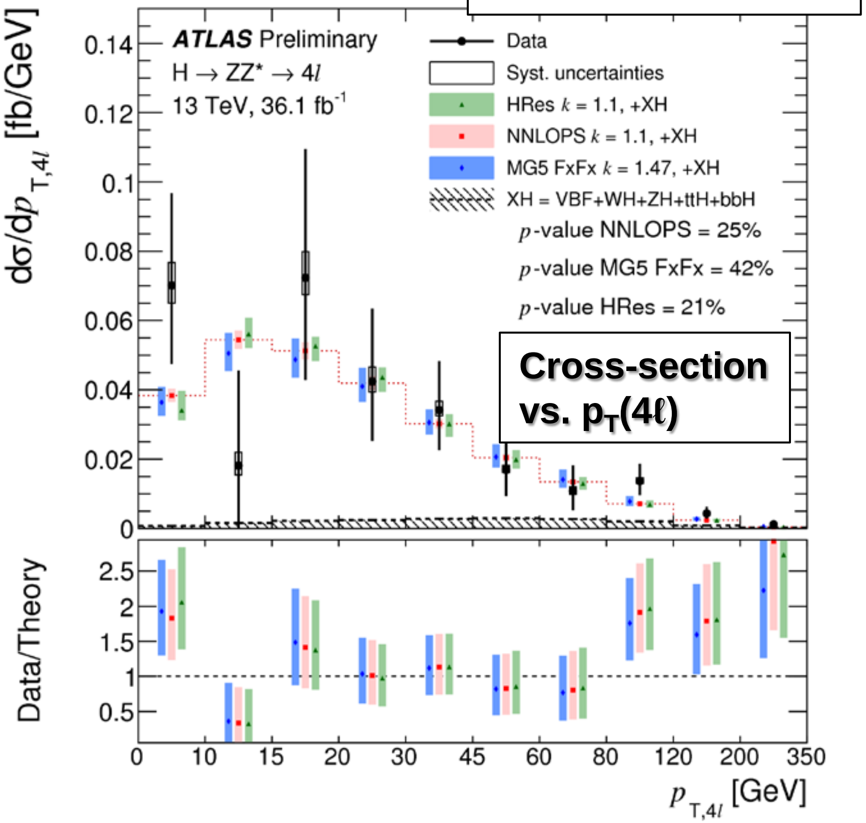
Higgs Boson Cross-Sections

- **Higgs differential cross-sections**
  - **Possible with increased data sets and √s**
- **Interpret in terms of cross-sections for production processes**
  - **ggF : gluon fusion**
  - **VBF : vector boson fusion**

ATLAS-CONF-2017-047



ATLAS-CONF-2017-032



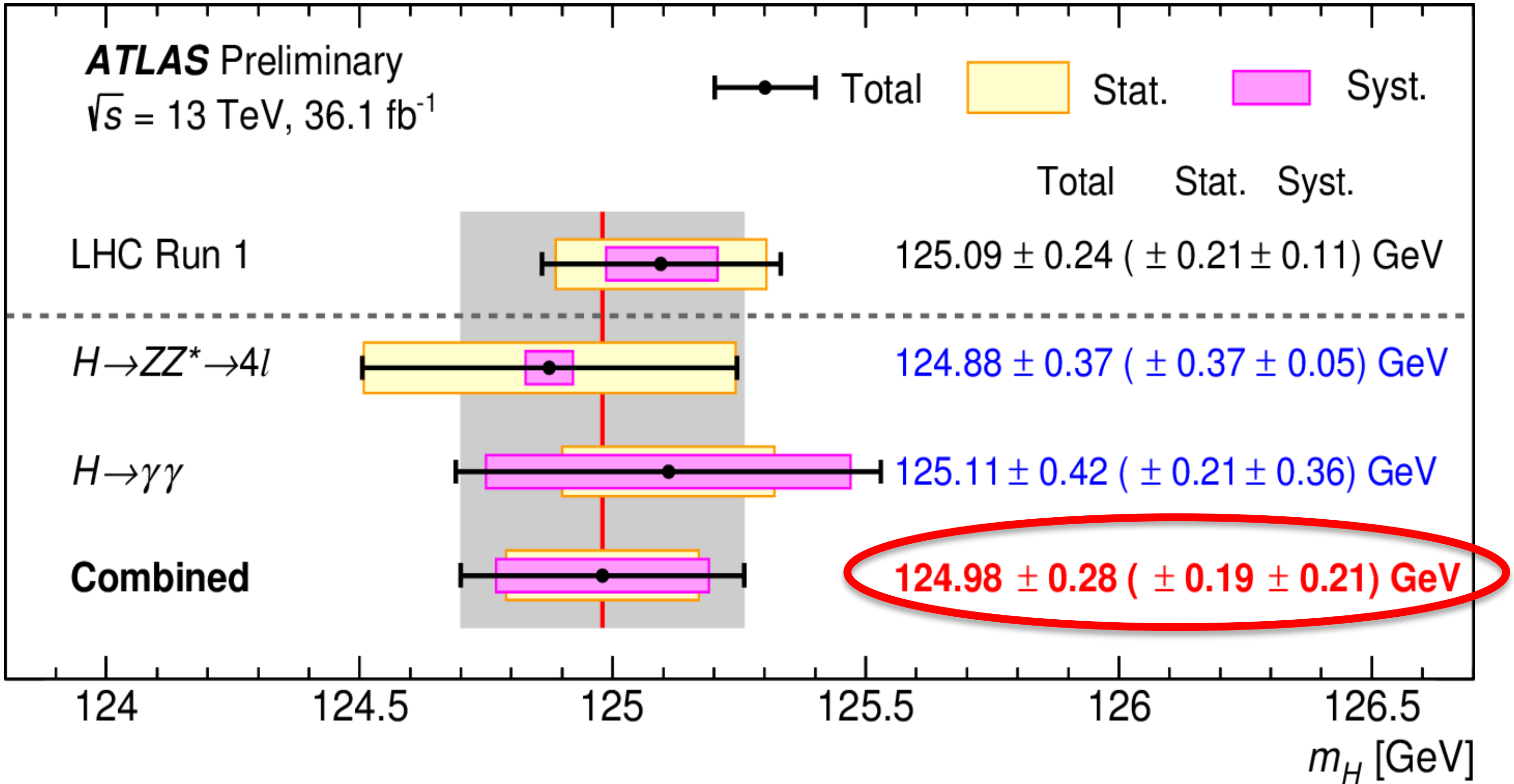
Cross-section vs. $p_T(4\ell)$

- **Higgs entering into precision measurement era with increased data sets and improved theoretical predictions**

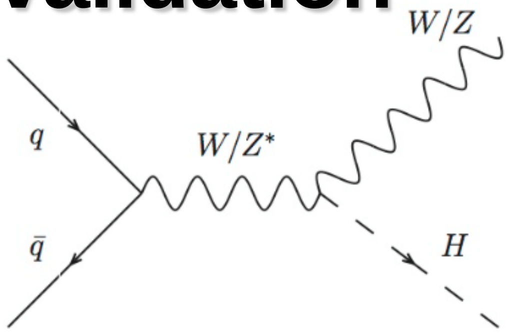
Measurement of the Higgs Boson Mass

ATLAS-CONF-2017-046

- H→ZZ*→4ℓ and H→γγ
- Measurements complementary:
  - 4ℓ channel stat uncertainty dominates with v. small systematics
    - Will continue to improve as ATLAS acquires more data even into HL-LHC era
  - γγ channel syst uncertainty dominates (photon energy scale calibration)
- In 4ℓ channel measurements consistent among electron/muon sub-channels
- 4ℓ and γγ measurements consistent
- Combined measurement consistent with Run-1



H→bb: analysis strategy and validation



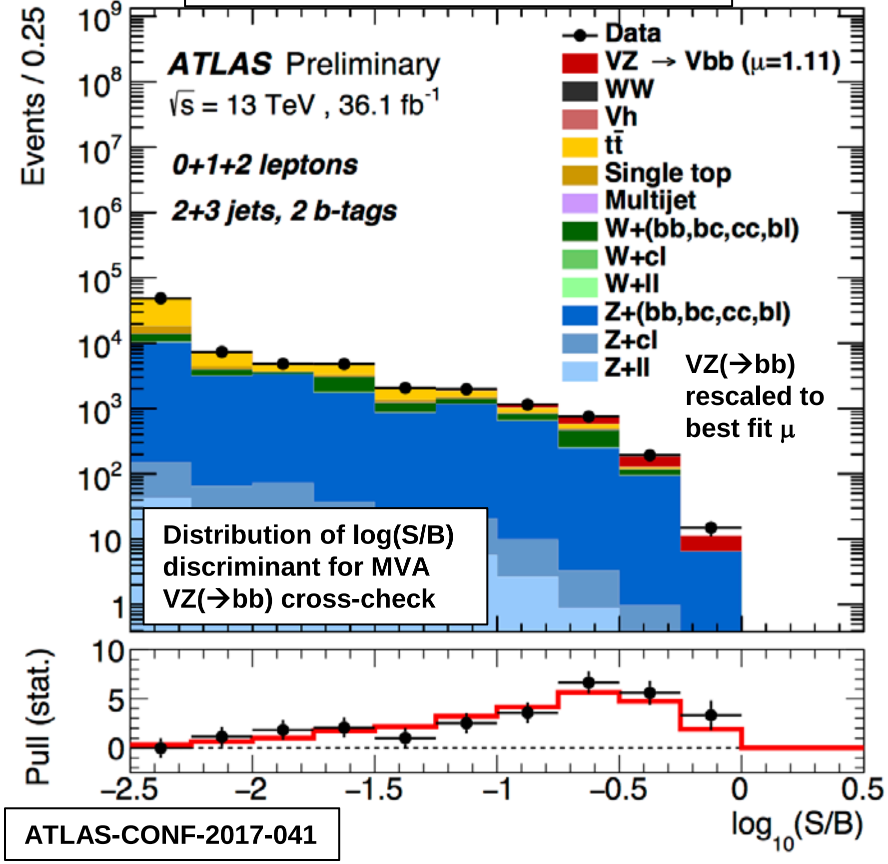
- **H→bb mode dominates Higgs decays (BR~58%)**
- **Most sensitive channel exploits VH(→bb), V=W/Z**
- **Combined Tevatron significance at m_H=125 GeV 2.8σ**
- **Combined Run-1 ATLAS+CMS significance 2.6σ**

- **ATLAS analysis combines Z and W final states:**
  - **2-lepton (Z→ℓℓ)**
  - **1-lepton (W→ℓv)**
  - **0-lepton (Z→vv)**
- **MVA-based (Boosted Decision tree), cross-checked by cut-based selection**

- **Validation of performance and systematics understanding from independent search for VZ(→bb)**
  - **Obs. (exp.) significance: 5.8σ (5.3σ)**
  - **Observed signal strength:**

$$\boxed{\mu_{VZ} = 1.11^{+0.12}_{-0.11}(\text{stat.})^{+0.22}_{-0.19}(\text{syst.})}$$

VALIDATION WITH V Z(→bb)



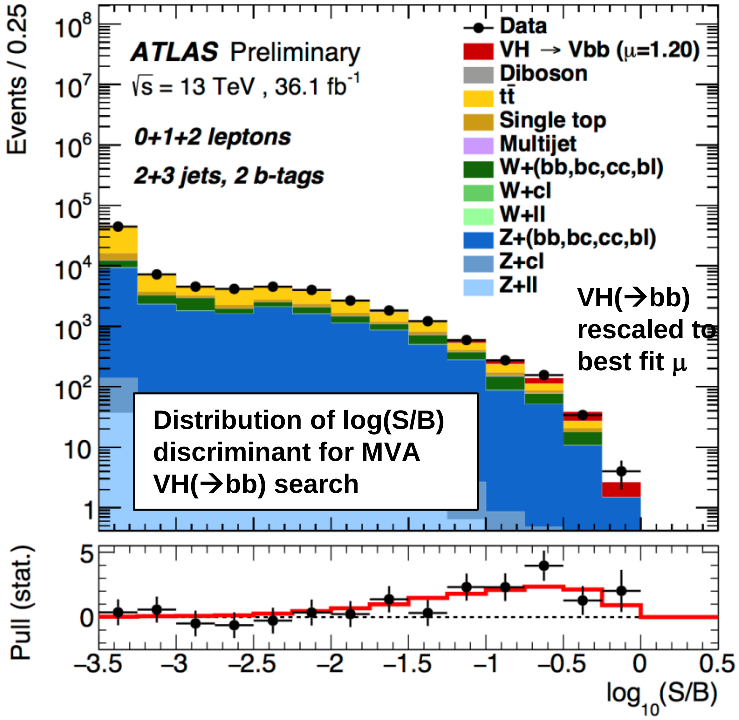
VZ(→bb) rescaled to best fit μ

Distribution of log(S/B) discriminant for MVA VZ(→bb) cross-check

ATLAS-CONF-2017-041

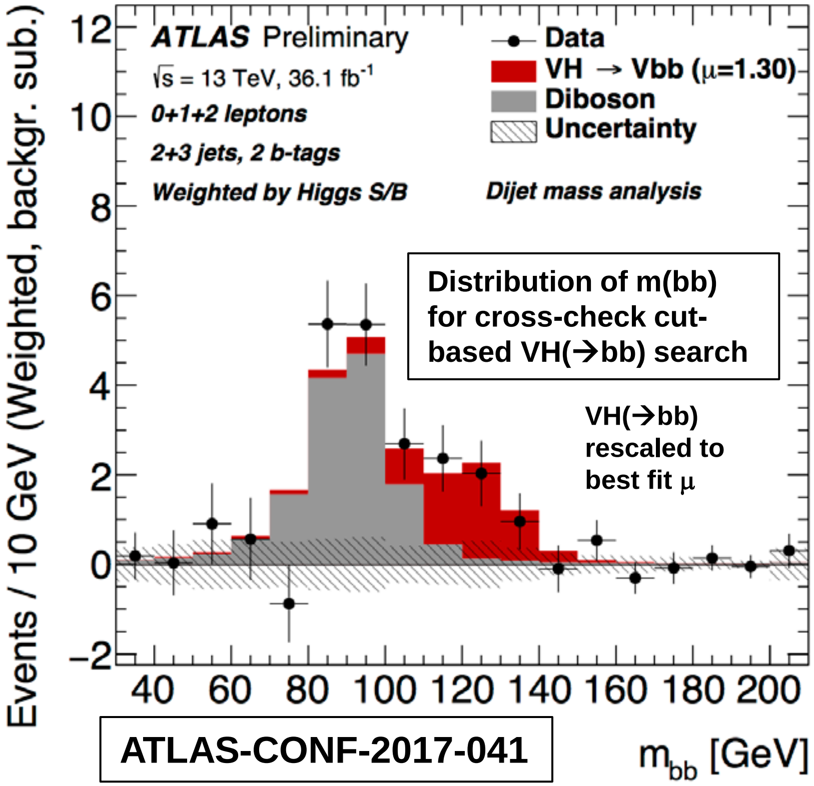
Evidence for H→bb

- BDT trained separately for VH(→bb) search
- Observed significance 3.5σ (3.0σ expected)
- Cross-check with cut-based analysis gives 3.5σ observed (2.8σ expected)
- Combination of MVA result with ATLAS Run-1 gives 3.6σ observed (4.0σ expected)
- Evidence for H→bb, consistent with SM



VH(→bb) rescaled to best fit μ

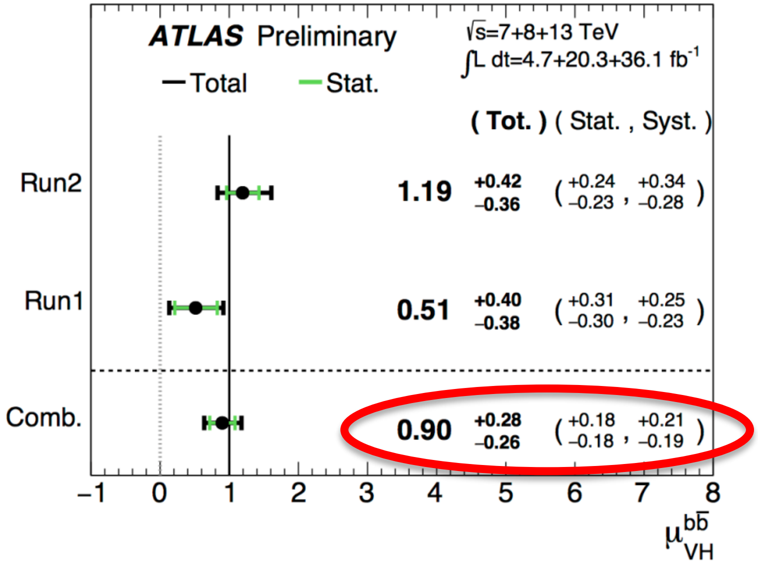
Distribution of log(S/B) discriminant for MVA VH(→bb) search



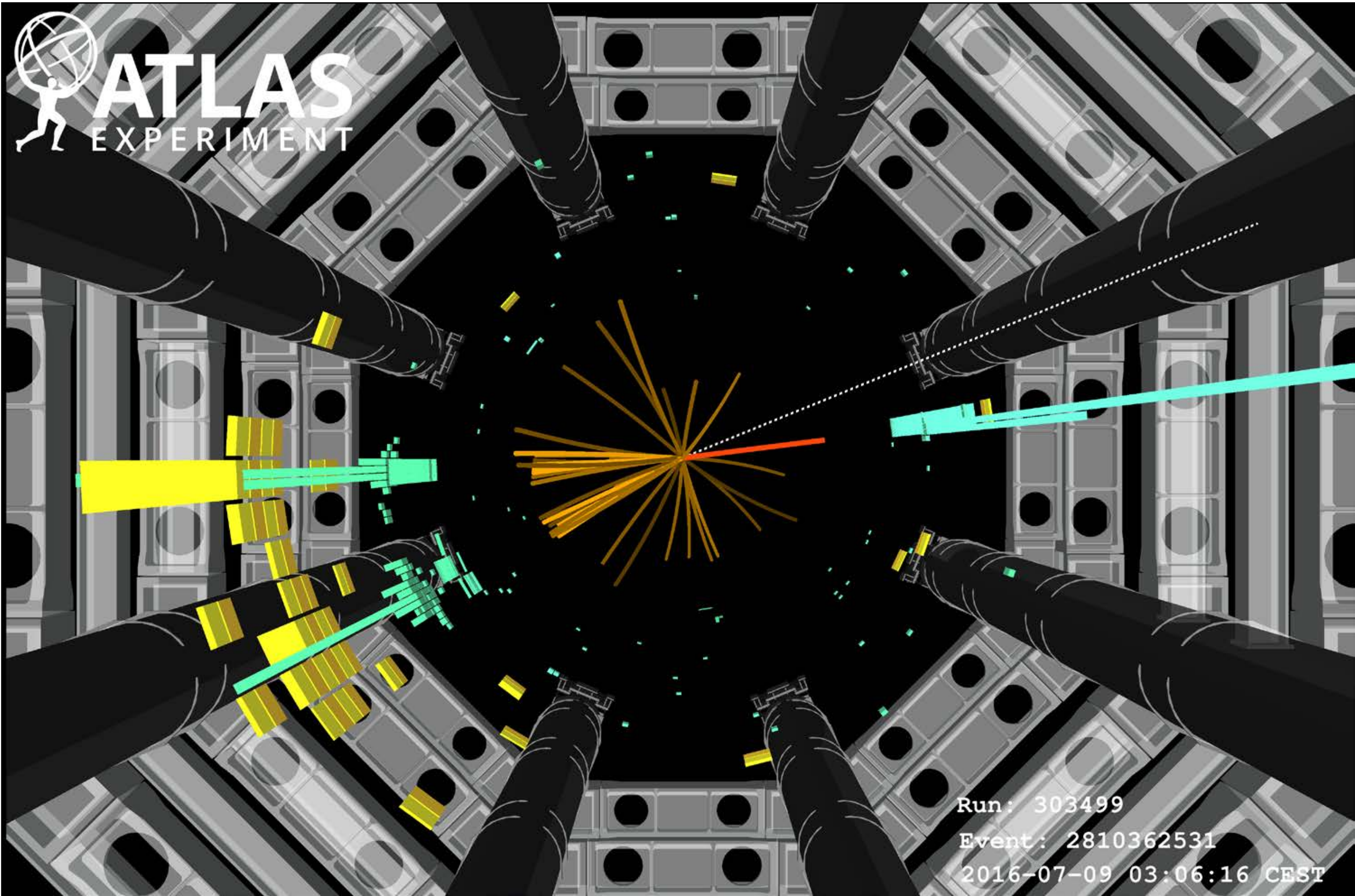
Distribution of m(bb) for cross-check cut-based VH(→bb) search

VH(→bb) rescaled to best fit μ

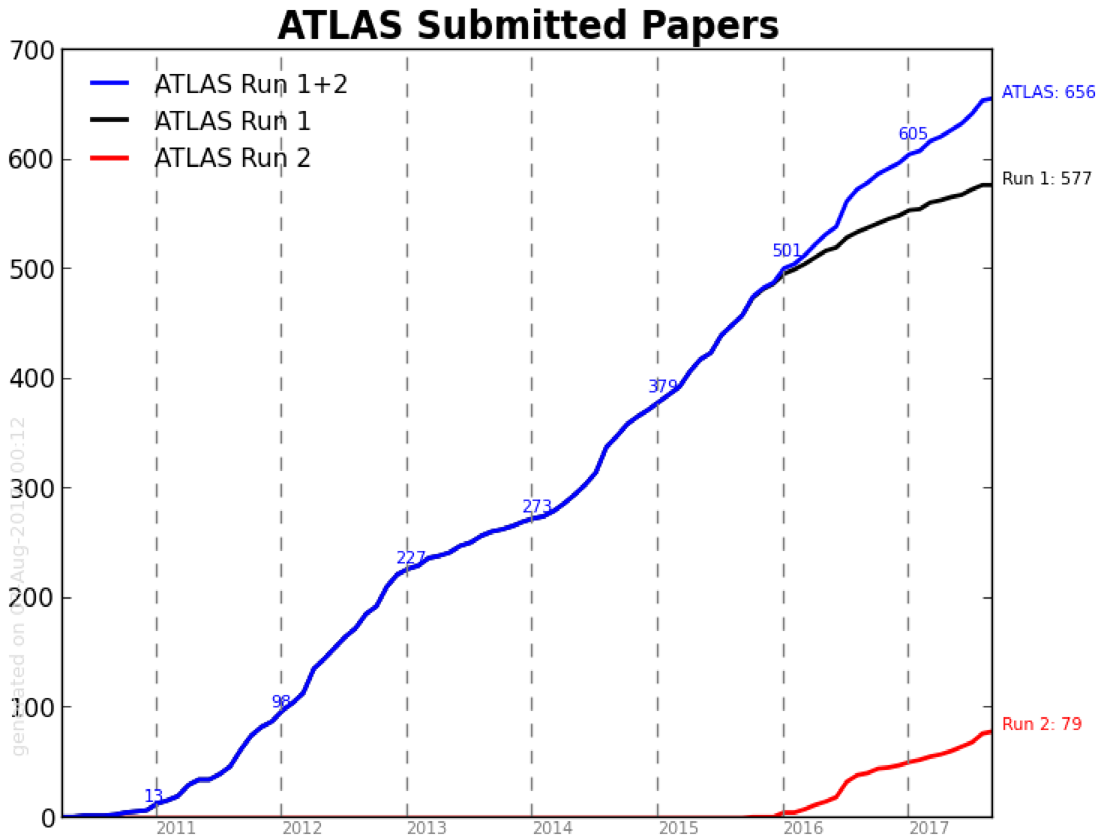
ATLAS-CONF-2017-041

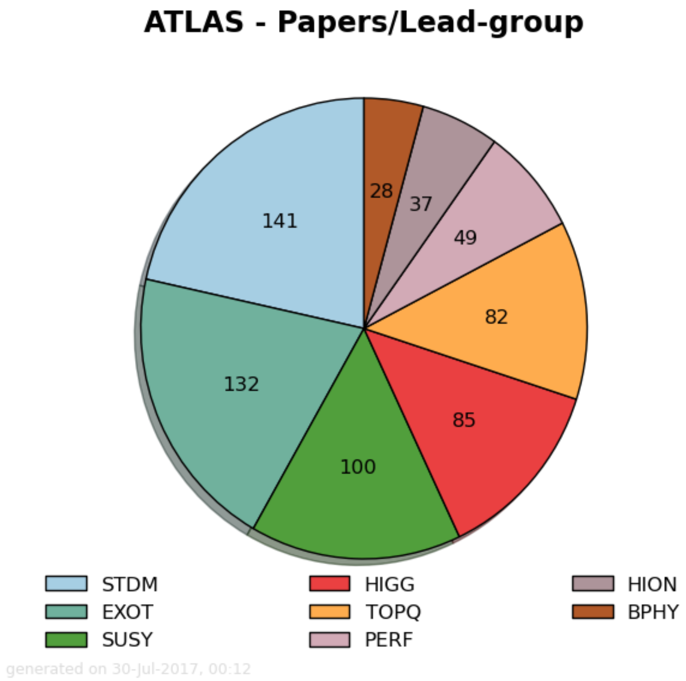


W(→eν)H(→bb) candidate



ATLAS Collision Data Papers





- **Submitted or published 656 papers (as of 4 August 2017)**
  - **Including 79 with Run II data**
  - **Still steady rate of Run I data papers (measurements)**

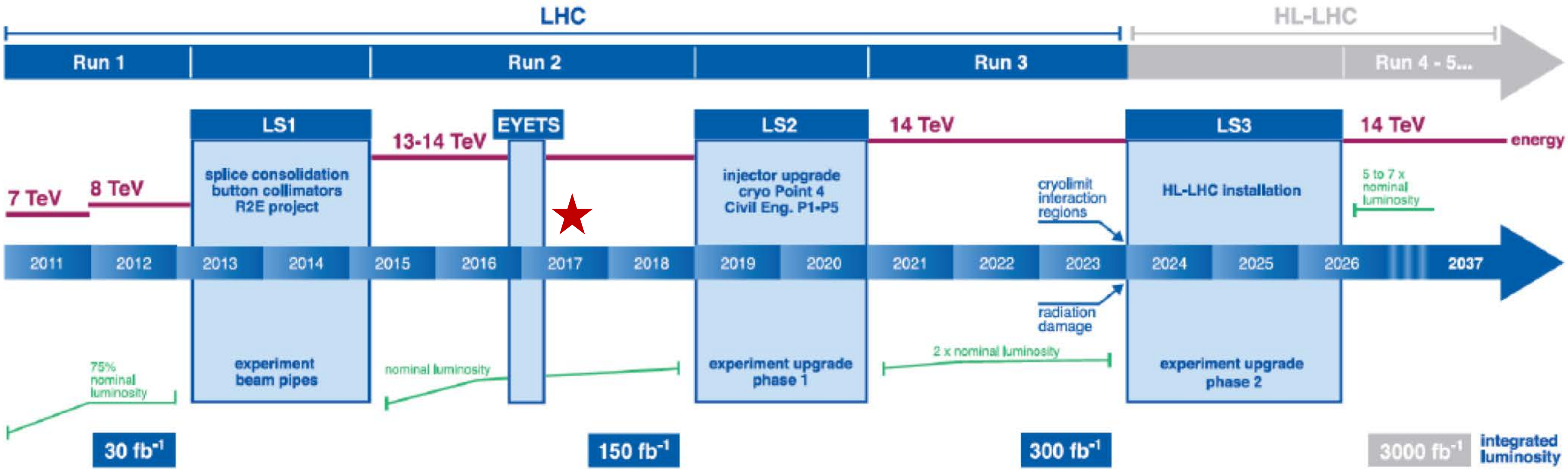
Outline of Talk

- ATLAS data-taking and performance
- ATLAS recent physics analysis results
- **ATLAS Upgrades**
- Summary

LHC / ATLAS Upgrade Timeline

HL-LHC

Run-1 LS1 Run-2 LS2 Run-3 LS3 Run-4



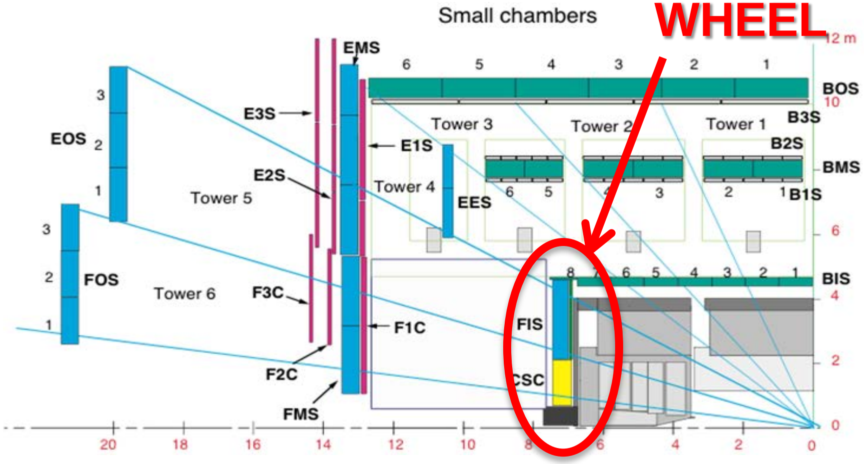
ATLAS Phase-0 Upgrades

ATLAS Phase-I Upgrades

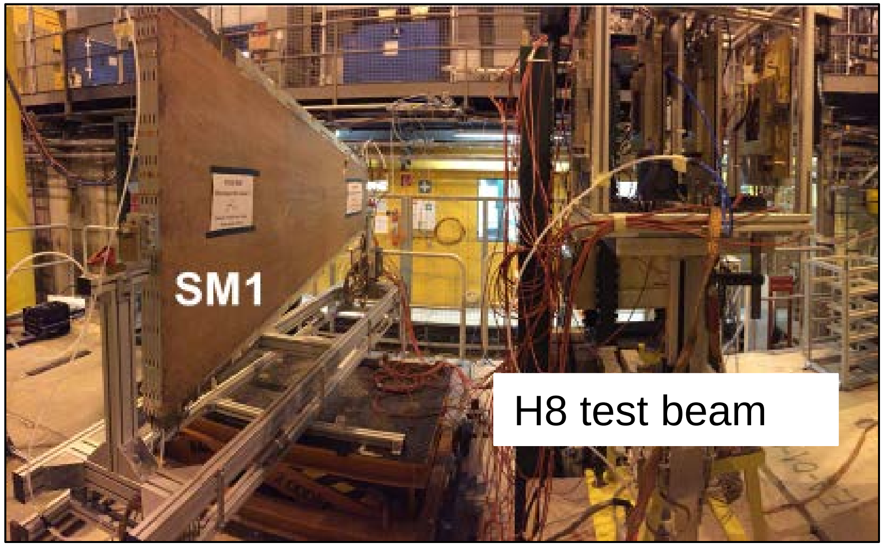
ATLAS Phase-II Upgrades

Upgrade examples in pictures

- **Phase-I: new muon small wheel**
  - **Micromegas and thin-gap chambers**

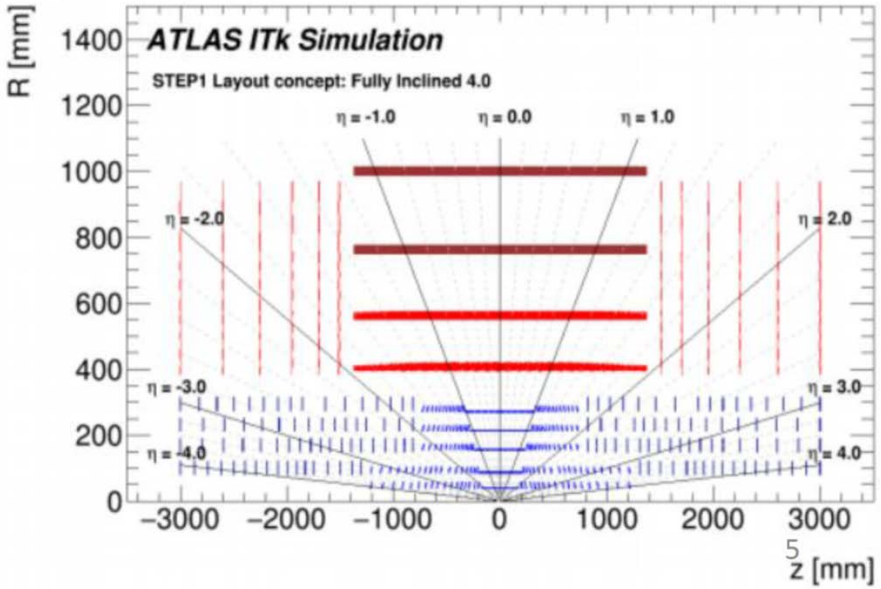


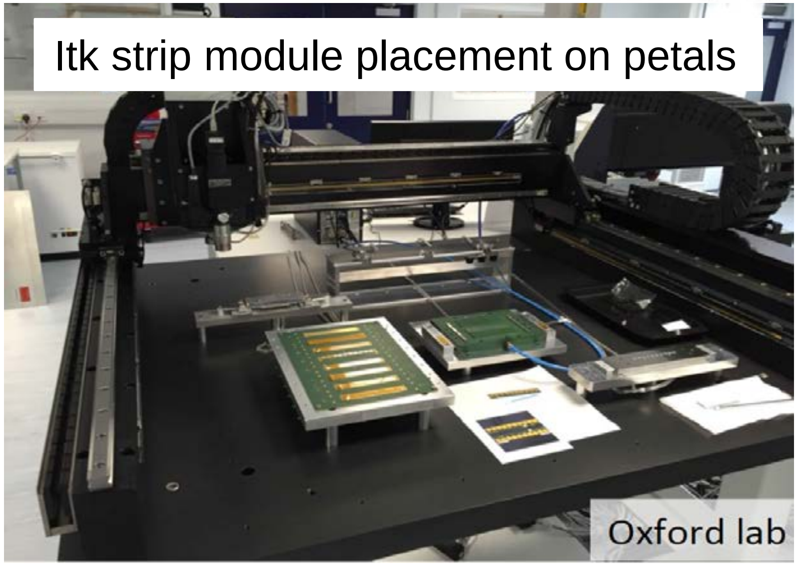
SMALL WHEEL



H8 test beam

- **Phase-II: new inner tracker**
  - **All silicon design strips and pixels**





Itk strip module placement on petals

Oxford lab

Outline of Talk

- ATLAS data-taking and performance
- ATLAS recent physics analysis results
- ATLAS Upgrades
- **Summary**

Summary

- **ATLAS detector, trigger, computing and analysis are coping well with luminosities approaching twice LHC design**
- **Many measurements from collision data**
  - **Challenging theory calculations in many final states**
  - **Entering precision measurement era for H(125)**
  - **Evidence for H→bb and closing in on rare Higgs processes**
  - **Wide spectrum of results I cannot cover – see later talks this week eg. B-hadron physics, heavy ions, QCD**
- **Huge range of searches for BSM physics**
  - **No significant excesses have persisted so far**
- **ATLAS Upgrade program also very active preparing for HL-LHC**
  - **LHC program still in its infancy. Only a ≈ percent of full data so far.**
- ***We are approaching sensitivities for new, weakly-coupled electroweak-scale physics of any form.***

- **Huge credit and thanks to the LHC and injector teams who are delivering extraordinary luminosities!**

ATLAS results

- For further ATLAS results and details of the ones shown here:
  - ATLAS public results page: https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - Talks at this symposium include the following:
    - Elisabetta Pianori: Higgs in diboson modes
    - Keti Kaadze: Higgs in fermionic modes
    - Soshi Tsuno: BSM Higgs
    - Iacopo Vivarelli: SUSY searches
    - Sunil Somalwar: Exotic Searches
    - Oliver Buchmueller: Searches for DM
    - Yuji Yamazaki: top-quark measurements
    - Qiang Li: EW measurements
    - Gabriella Pasztor: Hard QCD
    - Marek Tasevsky: Soft QCD
    - Alexander Kalweit: Experimental Heavy Ion results
    - Yuan-Ning Gao: Hadron Spectroscopy

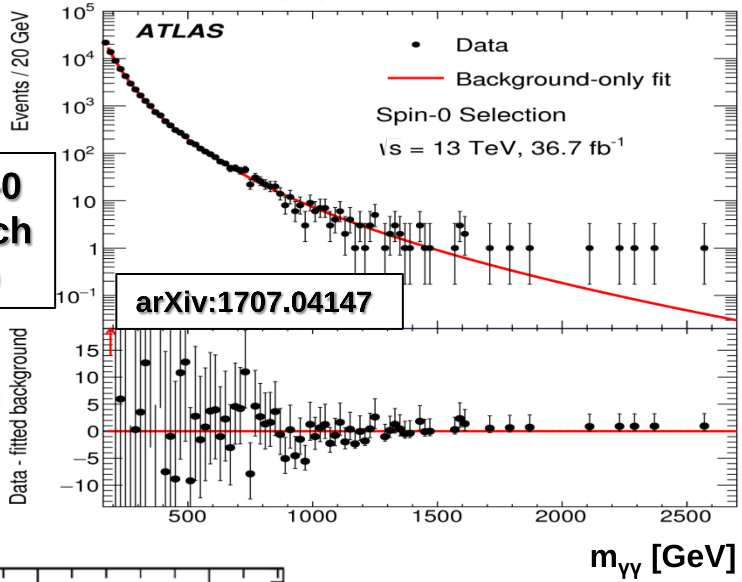
- **Additional Material**

Resonance Searches - γγ

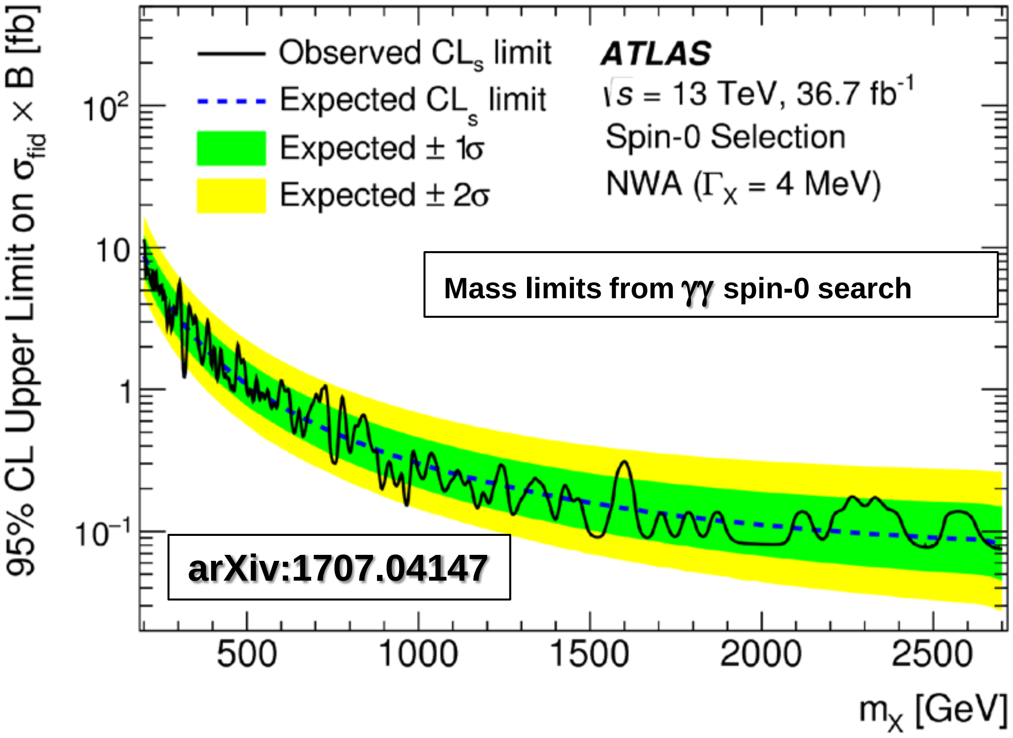
- **$X \rightarrow \gamma\gamma$**
  - **New heavy spin-0 scalars, e.g. heavy Higgs**
  - **Spin-2 (eg, gravitons)**

- **No significant excesses over SM expectation**

spin-0 search m(γγ)



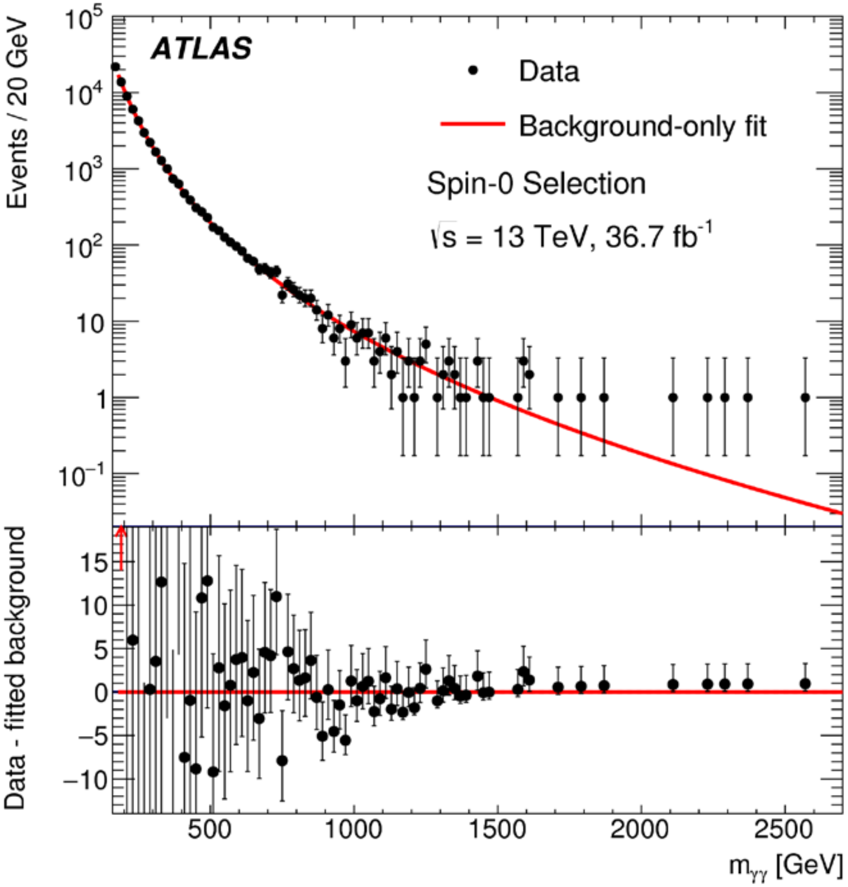
arXiv:1707.04147

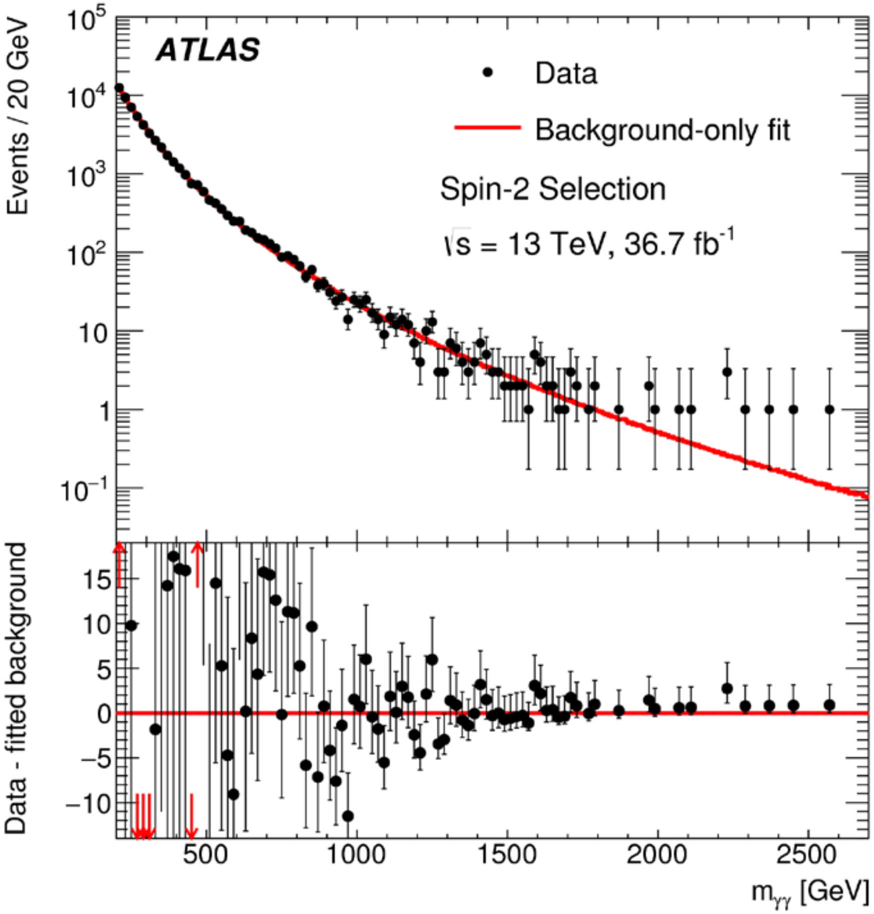


Mass limits from γγ spin-0 search

arXiv:1707.04147

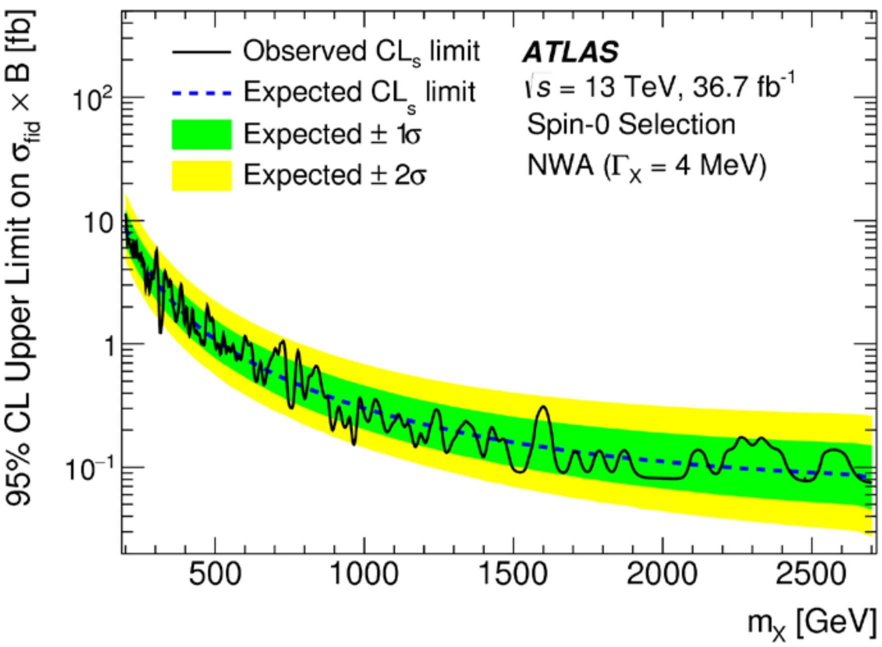
High Mass Diphoton Mass Distributions

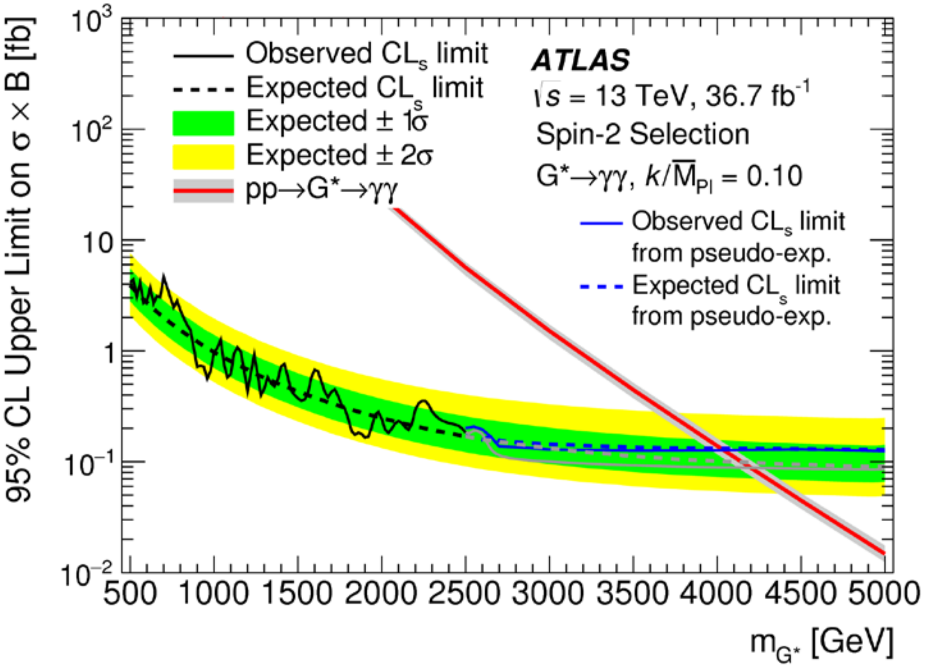




arXiv:1707.04147

High Mass Diphoton Limits



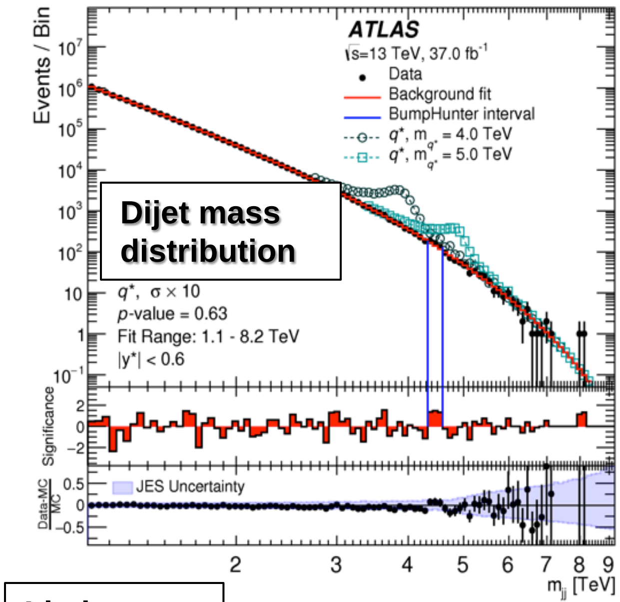


arXiv:1707.04147

Searches with Dijets

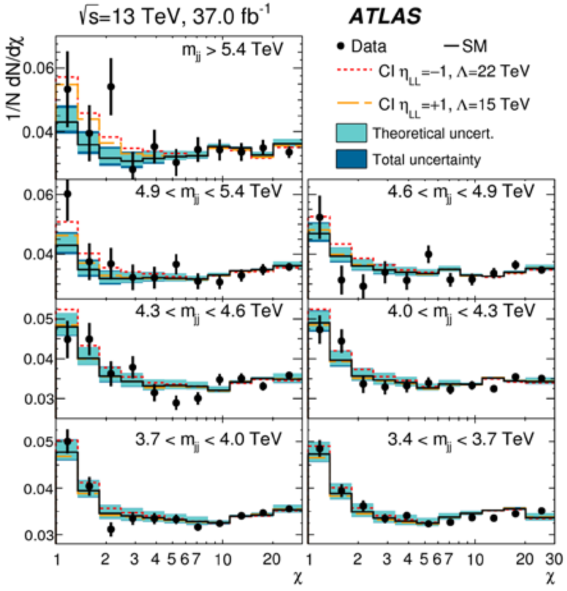
- dijet mass and angular distributions
- No significant excesses over SM expectation
- Significantly extend limits. e.g.
  - Excited quarks: m(q*) > 6.0 TeV (5.8 TeV exp.)
  - Add. gauge bosons: m(W’) > 3.6 TeV (3.7 TeV exp.)
  - Quantum Black Holes: m(BH) > 8.9 TeV (8.9 TeV exp.)
  - Contact Interactions: Λ > 13.1/21.8 TeV (η_{LL} = +1/-1)
- Limits also set on generic Gaussian resonances

arXiv:1703.09127

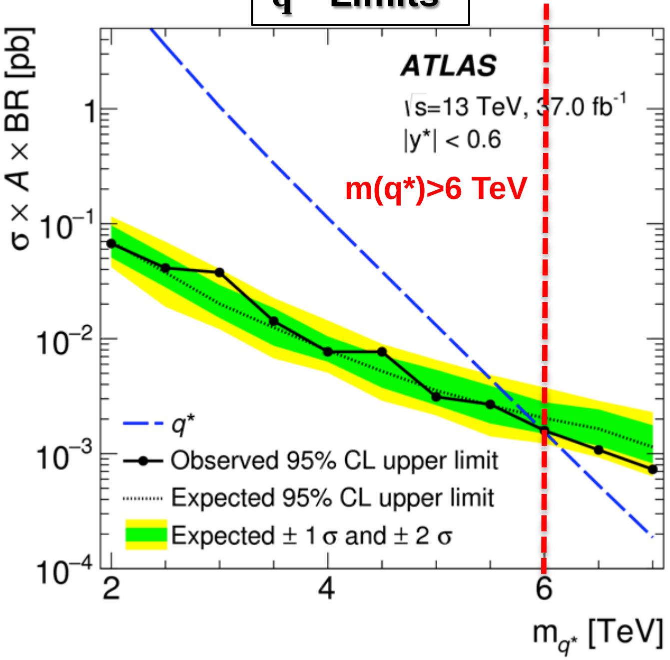


Dijet mass distribution

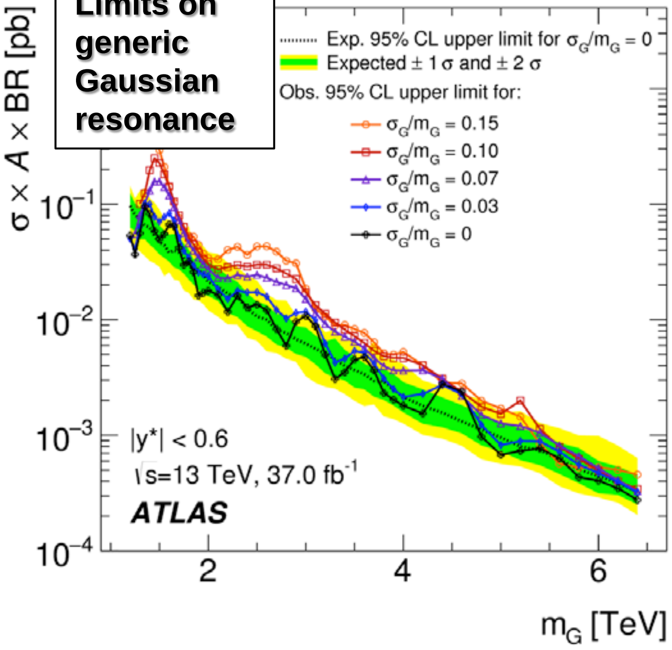
Dijet angular distributions χ=exp(2|y*|) for jet rapidity difference y*



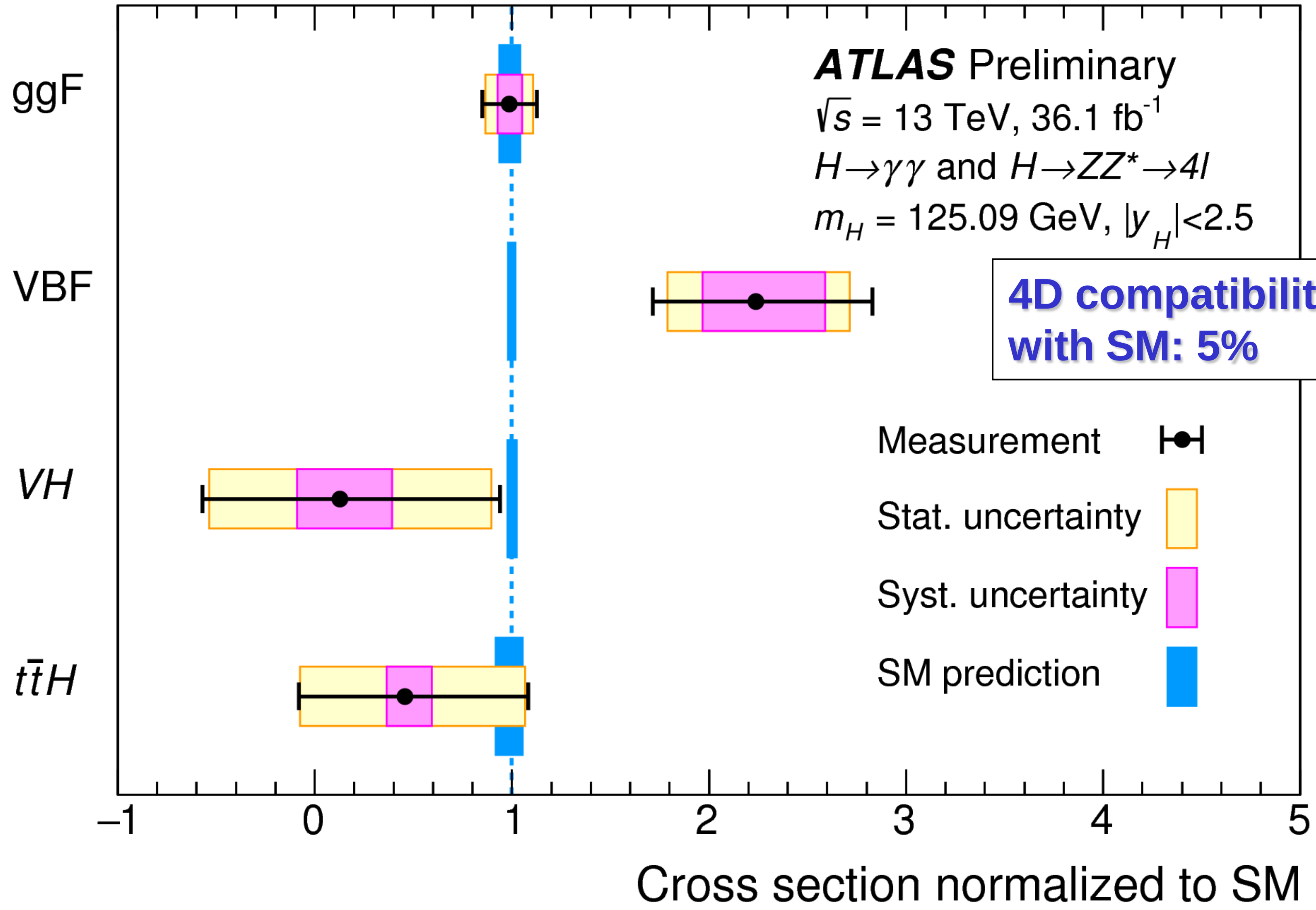
q* Limits



Limits on generic Gaussian resonance



Higgs Production Mode Signal Strength

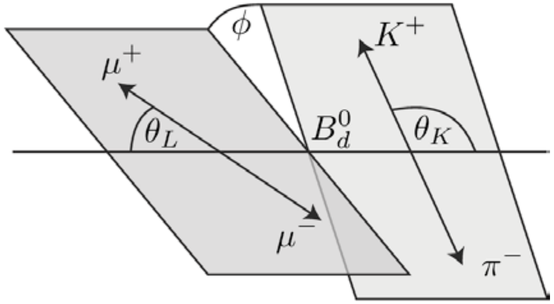


4D compatibility with SM: 5%

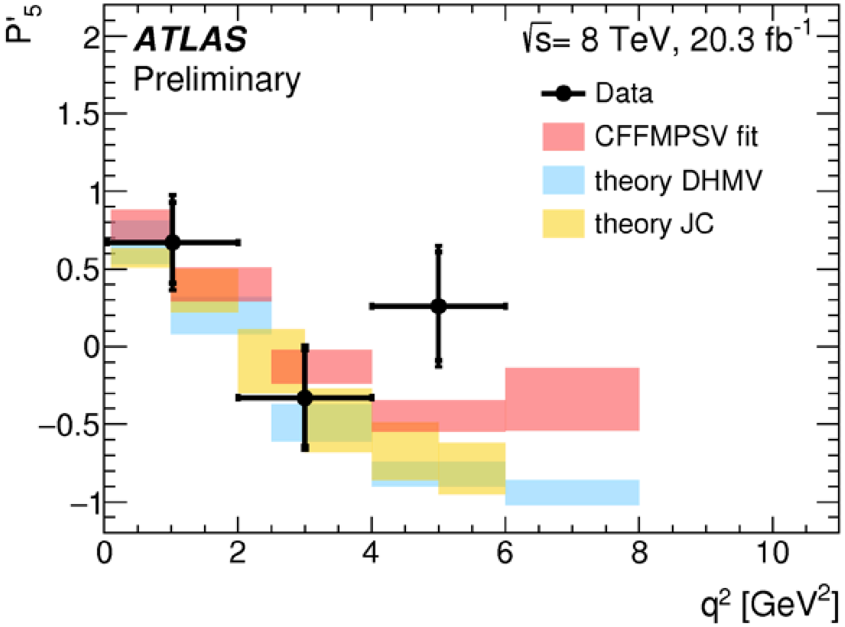
Physics with B Hadrons

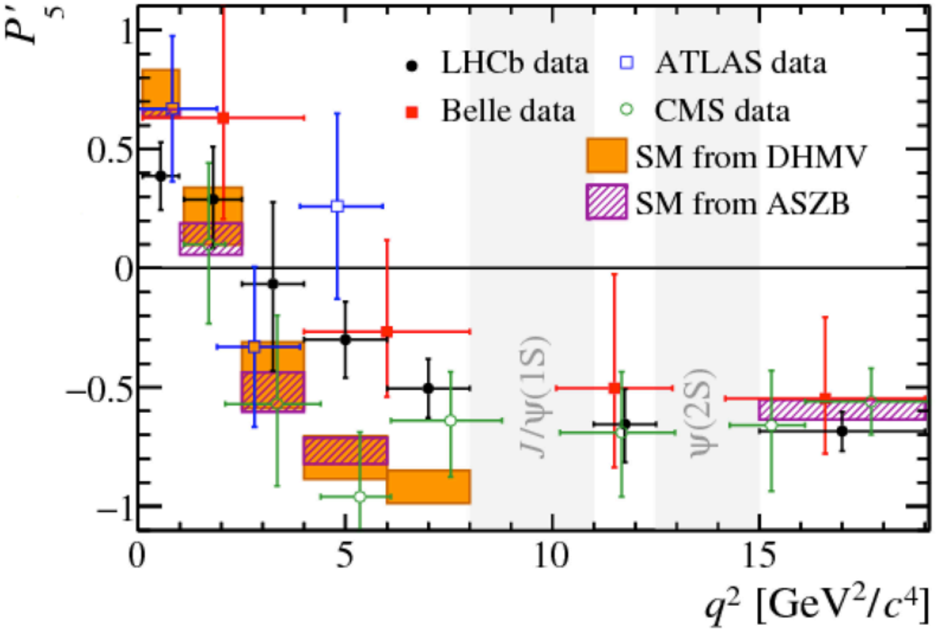
ATLAS-CONF-2017-023

- **Kinematics of products from decay $B_d^0 \rightarrow K^* \mu^+ \mu^-$ measured to constrain components of generic expression for amplitude**
- **P5' parameter (amplitude normalised by fraction of longitudinally polarised K*) measured to exceed SM expectation at moderate $q^2 = m(\mu\mu) \sim 5$ GeV^2 by LHCb and Belle**
- **ATLAS analysis with 8 TeV Run-1 data consistent with SM expectation in this bin, but also with LHCb and Belle measurements**



$$\frac{1}{d\Gamma/dq^2}\frac{d^4\Gamma}{d\cos\theta_L d\cos\theta_K d\phi dq^2} = \frac{9}{32\pi}\Bigg[\frac{3(1-F_L)}{4}\sin^2\theta_K + F_L\cos^2\theta_K + \frac{1-F_L}{4}\sin^2\theta_K\cos 2\theta_L$$
$$-F_L\cos^2\theta_K\cos 2\theta_L + S_3\sin^2\theta_K\sin^2\theta_L\cos 2\phi$$
$$+S_4\sin 2\theta_K\sin 2\theta_L\cos\phi + S_5\sin 2\theta_K\sin\theta_L\cos\phi$$
$$+S_6\sin^2\theta_K\cos\theta_L + S_7\sin 2\theta_K\sin\theta_L\sin\phi$$
$$+S_8\sin 2\theta_K\sin 2\theta_L\sin\phi + S_9\sin^2\theta_K\sin^2\theta_L\sin 2\phi\Bigg].$$

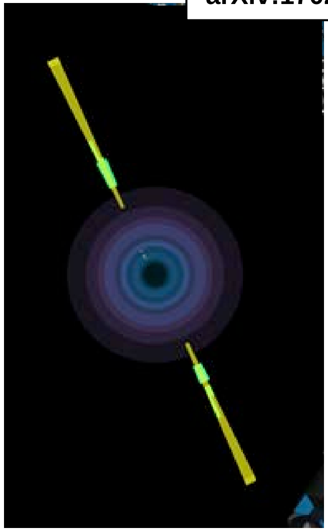


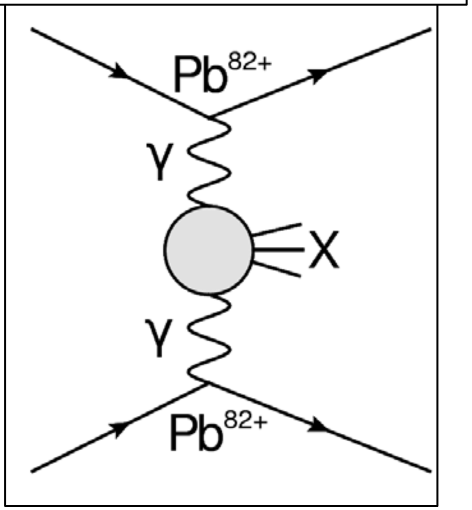


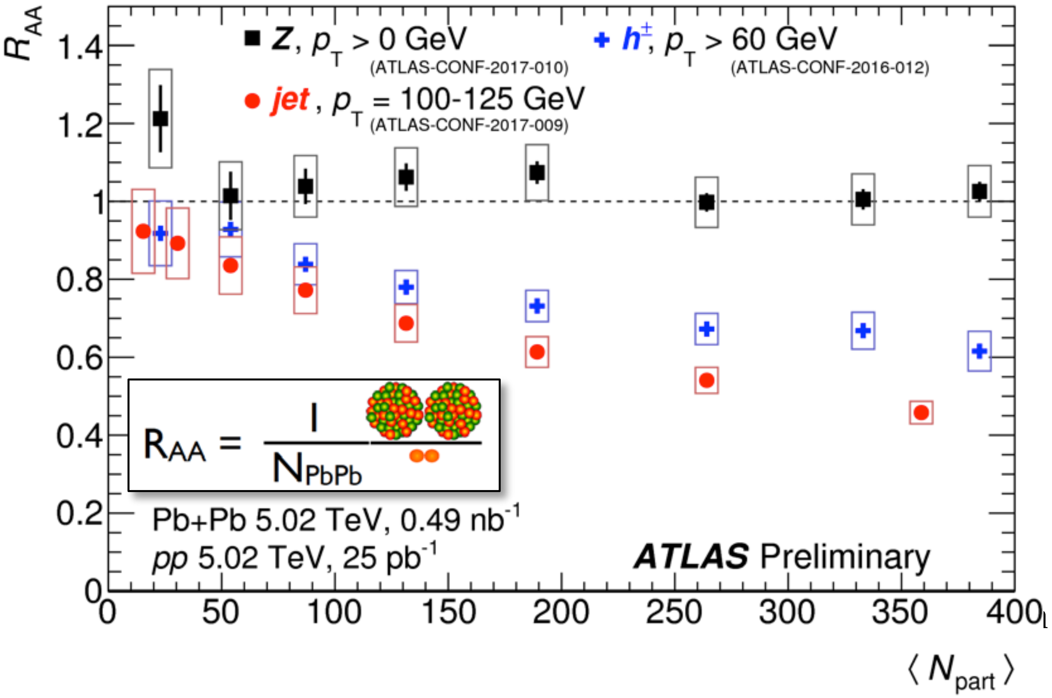
Heavy Ion Physics

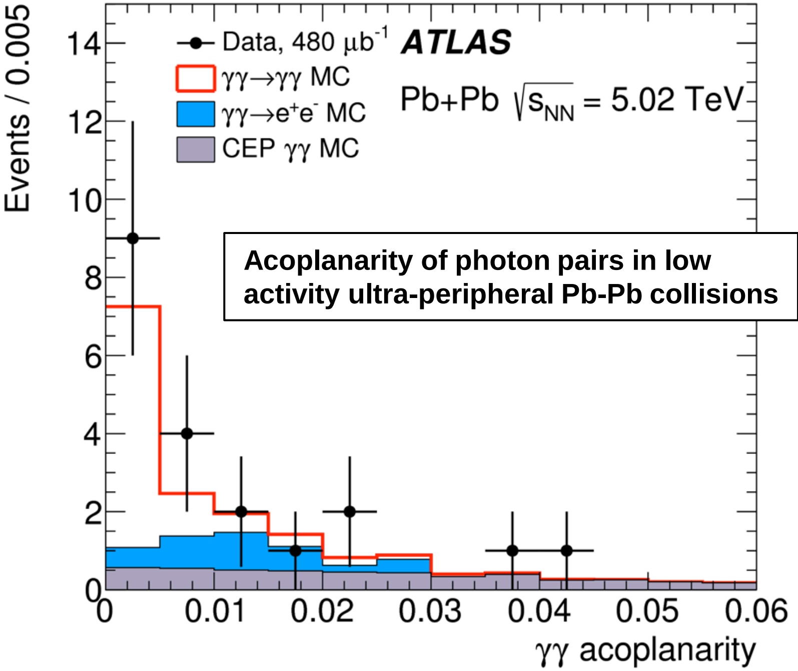
- **Evidence for light-by-light scattering $\gamma\gamma \rightarrow \gamma\gamma$ in 5 TeV Ultra-Peripheral Pb-Pb collisions**
- **Further evidence that production of strongly interacting particles is increasingly suppressed as density of nuclear medium increases.**
  - **Evidence for jet suppression up to ~1 TeV**
- **Results with novel sub-event cumulant method removing dijet contributions from pp and p-Pb elliptic flow measurements (ATLAS-CONF-2017-002)**

arXiv:1702.01625, accepted by Nature Physics





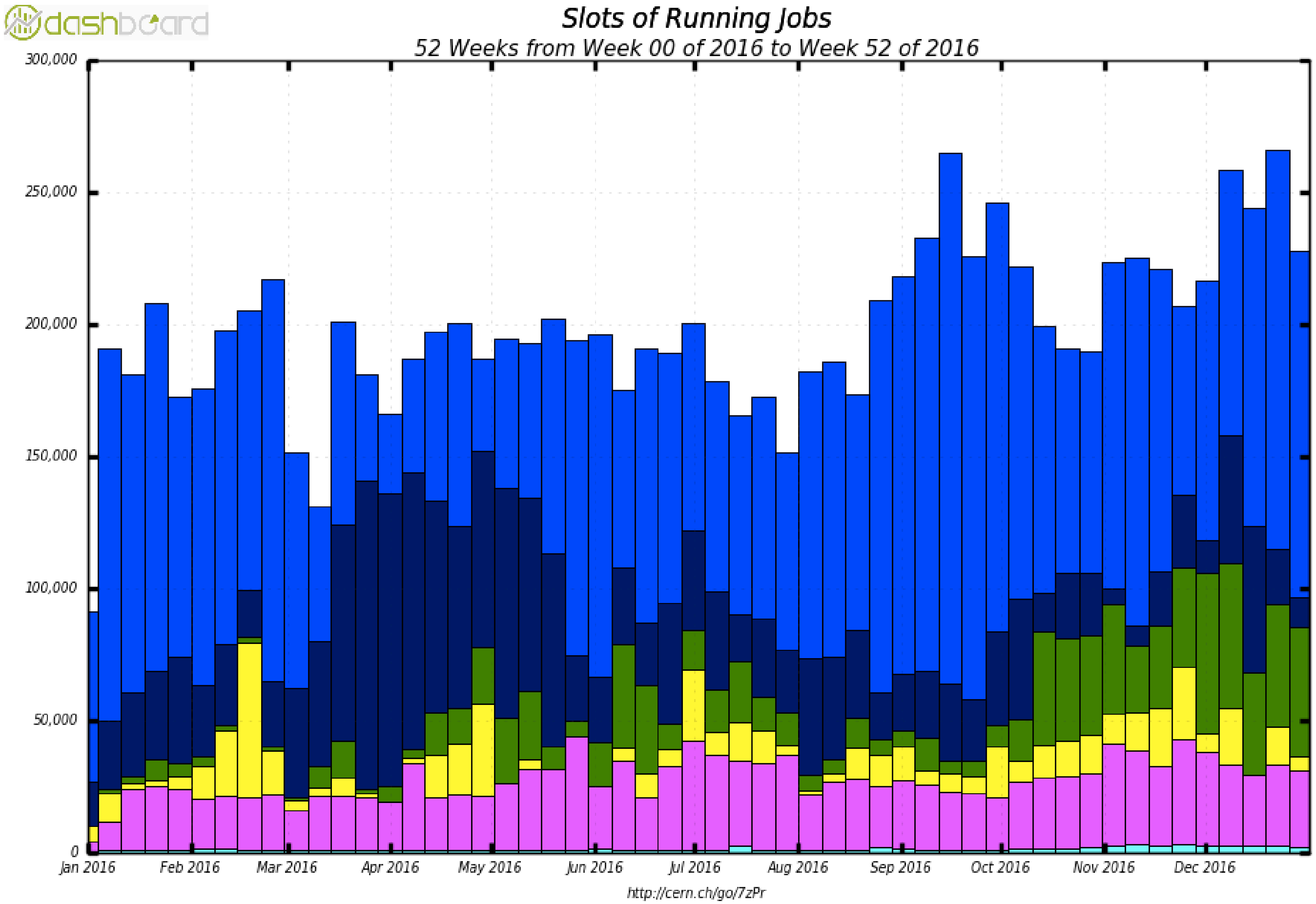




Acoplanarity of photon pairs in low activity ultra-peripheral Pb-Pb collisions

Computing

- WLCG has been fundamental to ATLAS physics analysis
  - Fully leverage all pledged resources
  - Aggressively use non-pledged CPU resources



MC Simulation

MC Reconstruction

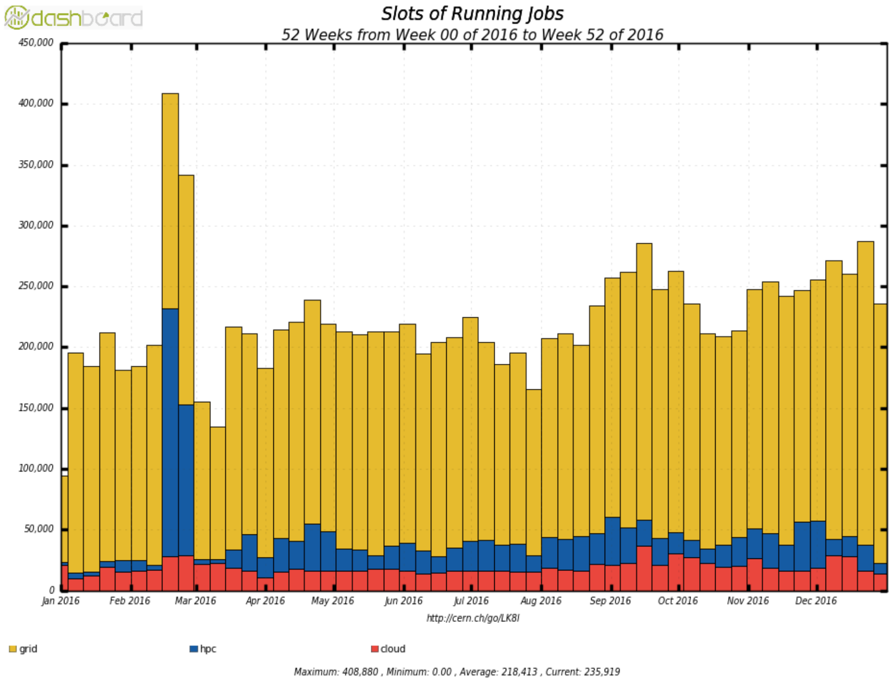
Group production

Data Processing

Analysis

High Performance Computing, Clouds

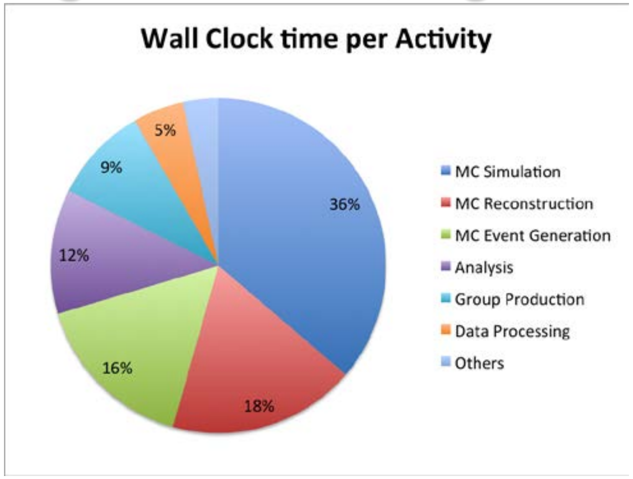
- **Increasing opportunistic use of clouds and HPCs: ~15%**
  - **event generation and Monte Carlo production**
- **Integration of non-Grid resources in ATLAS: big investment, big return**

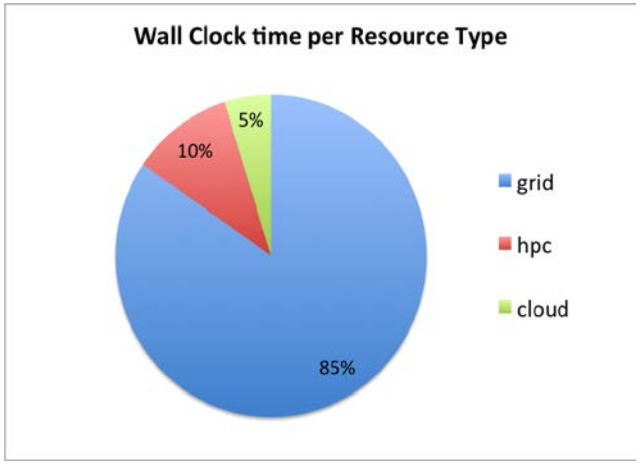


GRID

HPC

CLOUDS





ATLAS Upgrade Timelines

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

Phase 0 upgrade:

Consolidation, $\sqrt{s}=13$ TeV, 25nsec bunch spacing, $\mathcal{L}\approx 1\text{x}10^{34}$ cm^{-2}s^{-1} ($\mu\approx 30$—50)

$\int\mathcal{L}\approx 150$ fb^{-1}

- New insertable pixel b-layer (IBL)
- New Al beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation (calorimeter power supplies)
- Neutron Shielding
- Finish EE muons installation
- Upgrade magnet cryo

Phase I upgrade:

- Likely $\sqrt{s}=14$ TeV
- $\mathcal{L}\approx 2\text{x}10^{34}$ cm^{-2}s^{-1} ($\mu\approx 60$)
- $\int\mathcal{L}\approx 300$ fb^{-1}

- Topological Level-1 Trigger Processor
- New forward diffractive physics detectors AFP
- New Muon Small Wheel (NSW)
- High Precision Calorimeter Level-1 Trigger
- Fast Track Trigger (FTK)
- Trigger-DAQ

Phase II upgrade:

$\mathcal{L}\approx 7\text{x}10^{34}$ cm^{-2}s^{-1} ($\mu\approx 200$)

$\int\mathcal{L}\approx 3000$ fb^{-1}

- All new Tracking Inner Detector
- Calorimeter Electronics Upgrades
- Muon system upgrades
- Level-1 track trigger
- Trigger-DAQ
- High Granularity Timing Detector (R&D)