Highlights from the ATLAS experiment at Run 1

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On behalf of the ATLAS Collaboration

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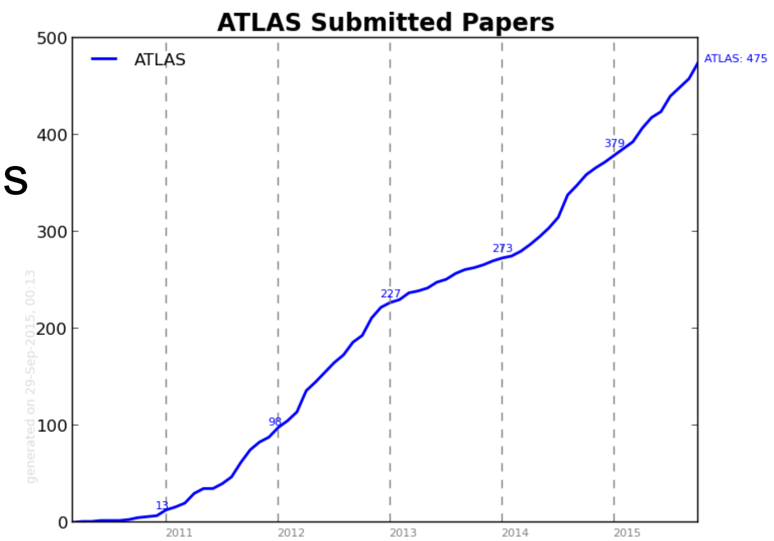
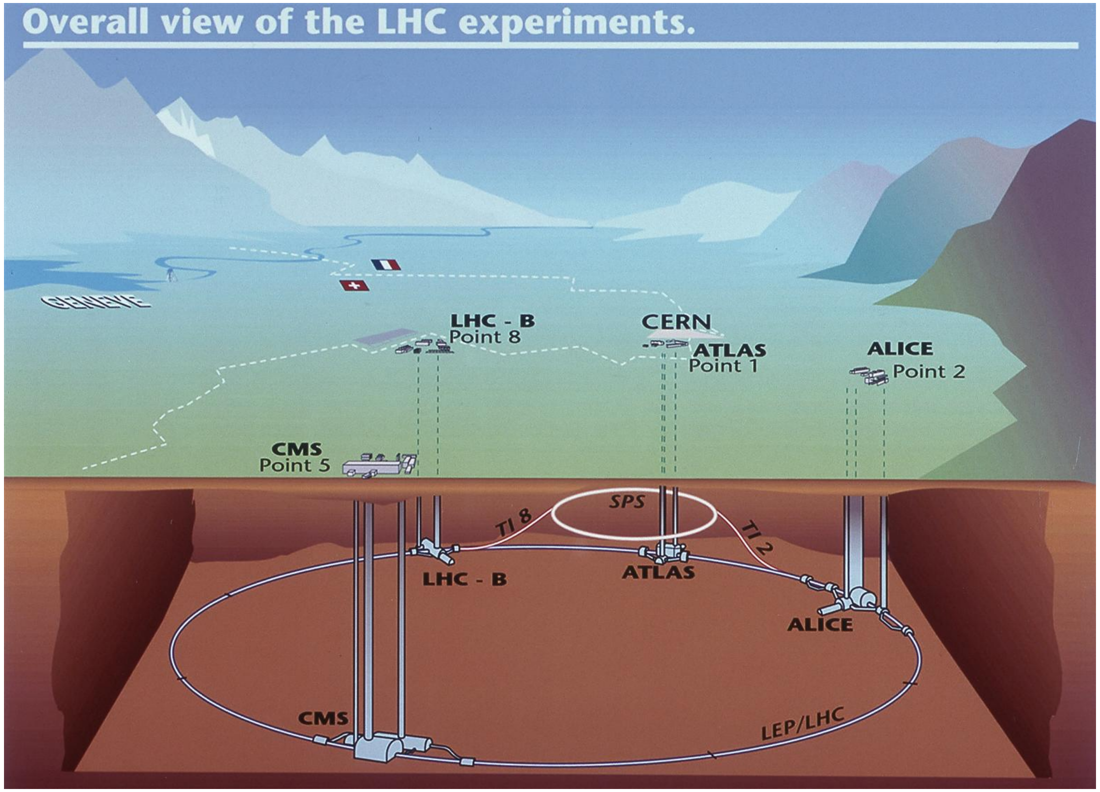
Outline

- A short description of ATLAS
  - Detectors & Data taking at Run 1
- Selected results from recent publications from :
  - Higgs
  - Top
  - SUSY searches
  - Exotic searches



https://twiki.cern.ch/twiki/bin/view/AtlasPublic (475 submitted papers and counting)

ATLAS detector at LHC



ATLAS is one of the two multi-purpose detector at the LHC proton-proton collider

ATLAS collaboration:

38 countries, ~178 institutes, ~3000 physicists

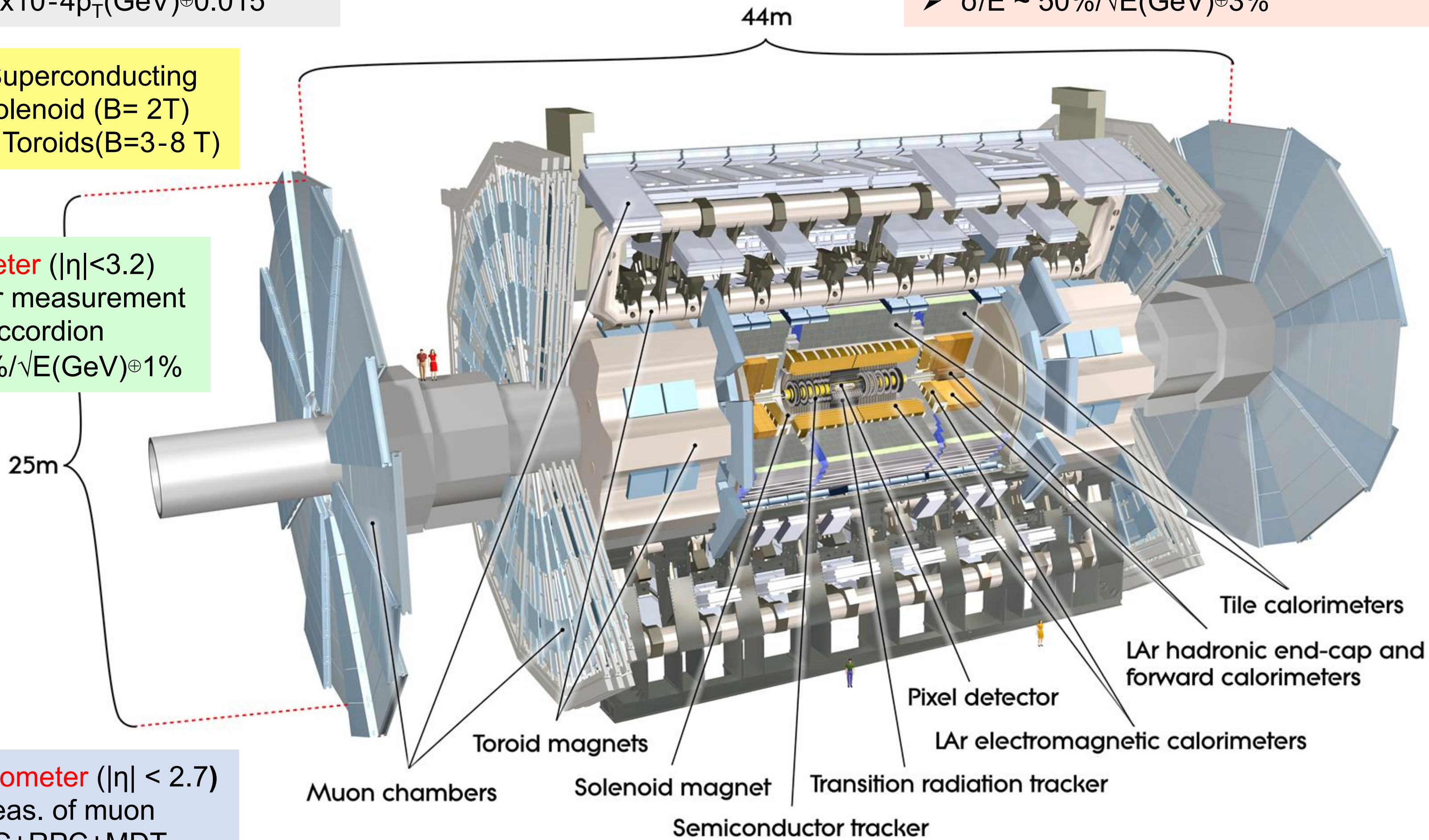
ATLAS detector at Run 1

Inner detector (|η|< 2.5, B=2T)
Tracking, vertexing, dE/dx, e/π ID
- Si pixels, Si strips, Trans. Rad. det.
- σ/p_T ~3.8x10-4p_T(GeV)⊕0.015

Hadron Calorimeter (|η|<5)
Trigger and meas. of jet/Emiss
- Fe/scintillator (central), Cu/W-LAr (fwd)
- σ/E ~ 50%/√E(GeV)⊕3%

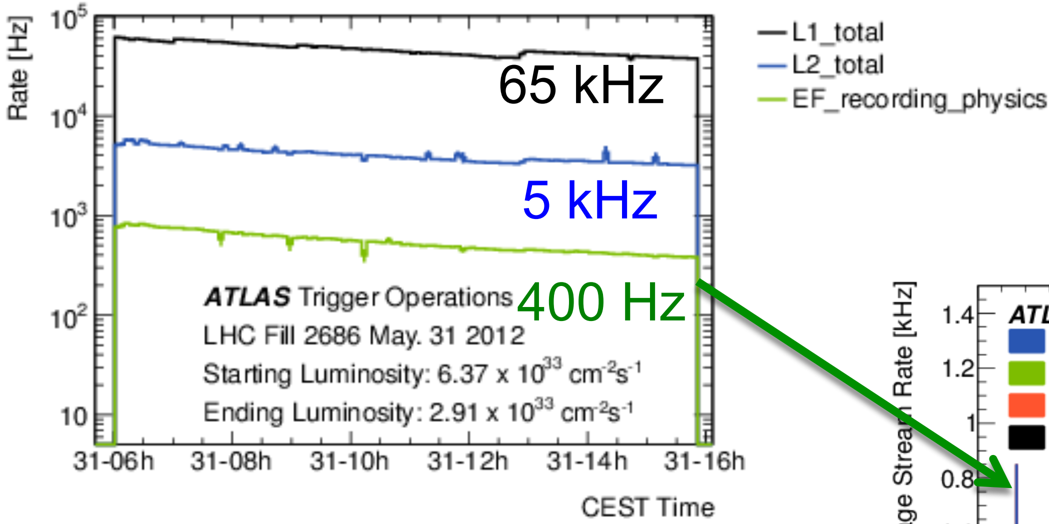
Magnets 4 Superconducting
- Central Solenoid (B= 2T)
- 3 Air core Toroids(B=3-8 T)

EM Calorimeter (|η|<3.2)
e/γ ID trigger measurement
- Pb-Lar accordion
- σ/E ~ 10%/√E(GeV)⊕1%



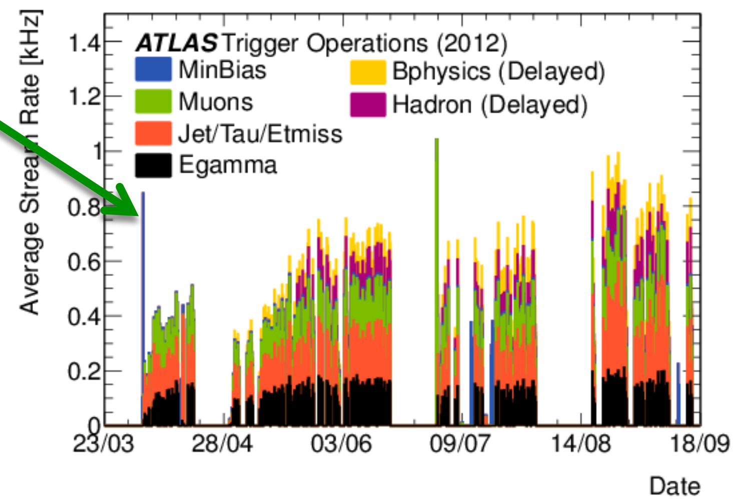
Muon spectrometer (|η| < 2.7)
Trigger & meas. of muon
- CSC+TGC+RPC+MDT
- σ/p_T <10 % up to 1 TeV

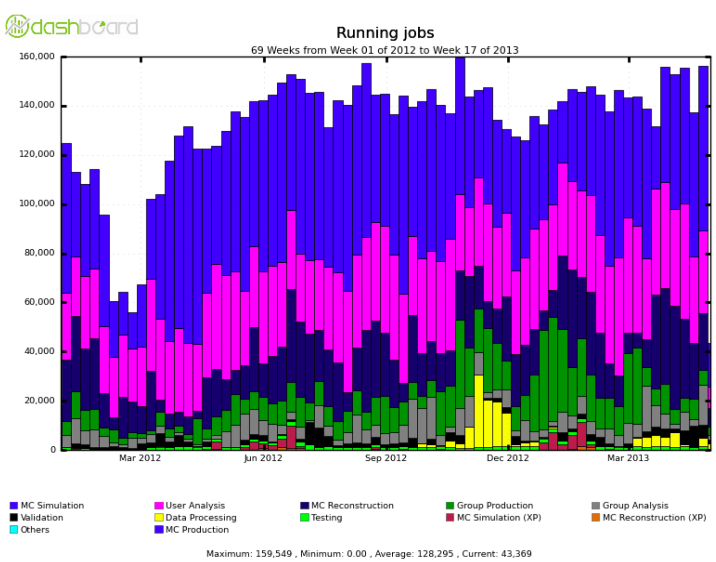
ATLAS trigger at Run 1



Using multi-level trigger system to select interesting events from O(20 MHz)

Collected events for physics analysis ~ 400 Hz

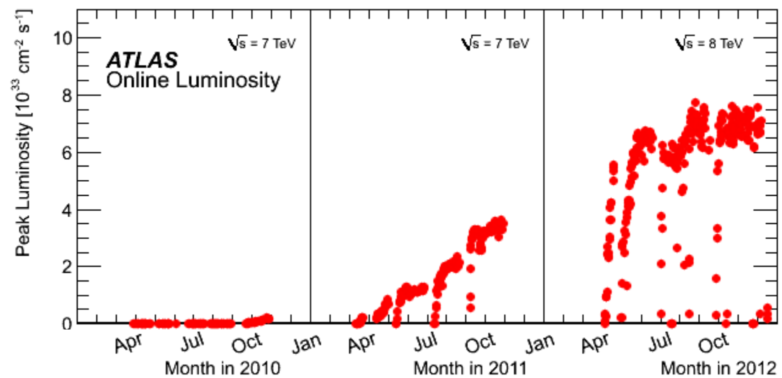


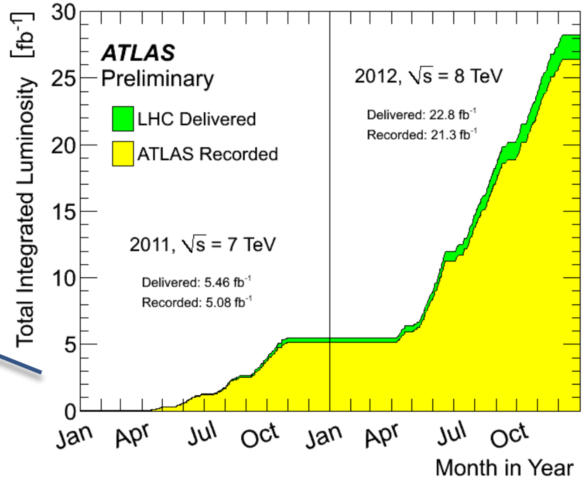


- The ATLAS Distributed Computing System manages the world-wide data processing, MC production, and user analysis jobs, running on O(150k) computing cores

Data Taking at Run 1

- LHC Run 1 schedule was from 2009 till beginning of 2013
  - 2009 – 20 μb^{-1} at $\sqrt{s}$ = 900 GeV
  - 2010 – 45 pb^{-1} at $\sqrt{s}$ = 7 TeV
  - 2011 + 2012 – 25 fb^{-1} at $\sqrt{s}$ = 7,8 TeV
    - 7.6 billion p-p events and 7.4 PB data volume





During Run 1: Excellent performance of LHC, detector and data taking

The higher the luminosity is the higher the pile-up i.e. number of interactions per bunch crossing

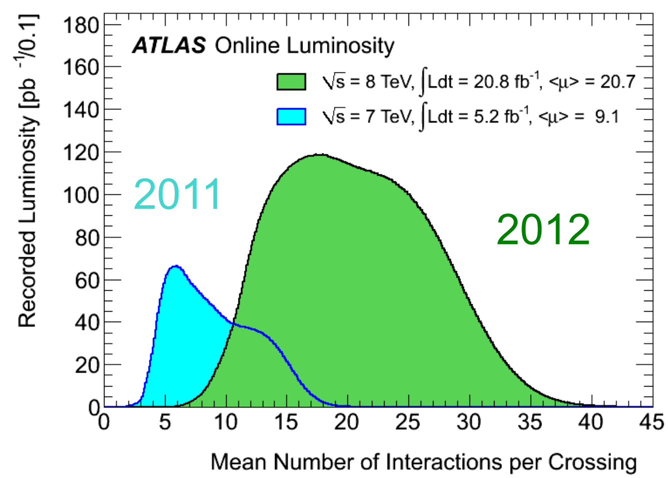
Average pile-up <μ> ~ 9 (21) at 2011 (2012)

ATLAS p-p run: April-December 2012

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.1	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5

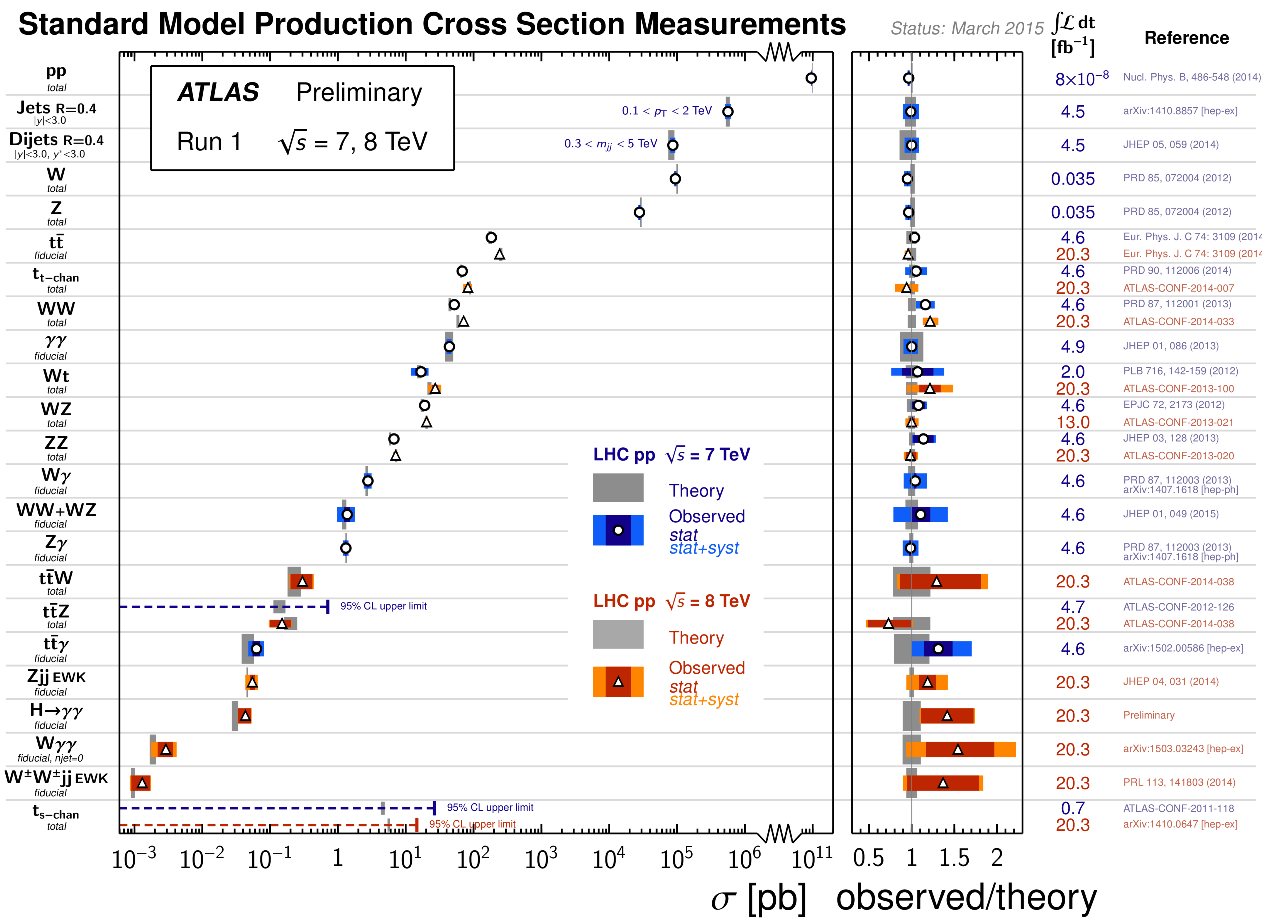
All good for physics: 95.5%

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and December 6th (in %) – corresponding to 21.3 fb^{-1} of recorded data.



Standard Model Summary

- Total or fiducial cross section measurements from inclusive W,Z production and di-bosons production:
  - Tests of the SM (at higher energy) and probing new physics
  - Backgrounds for searches and precision measurements (W/Z+jets, top pairs and di-bosons)

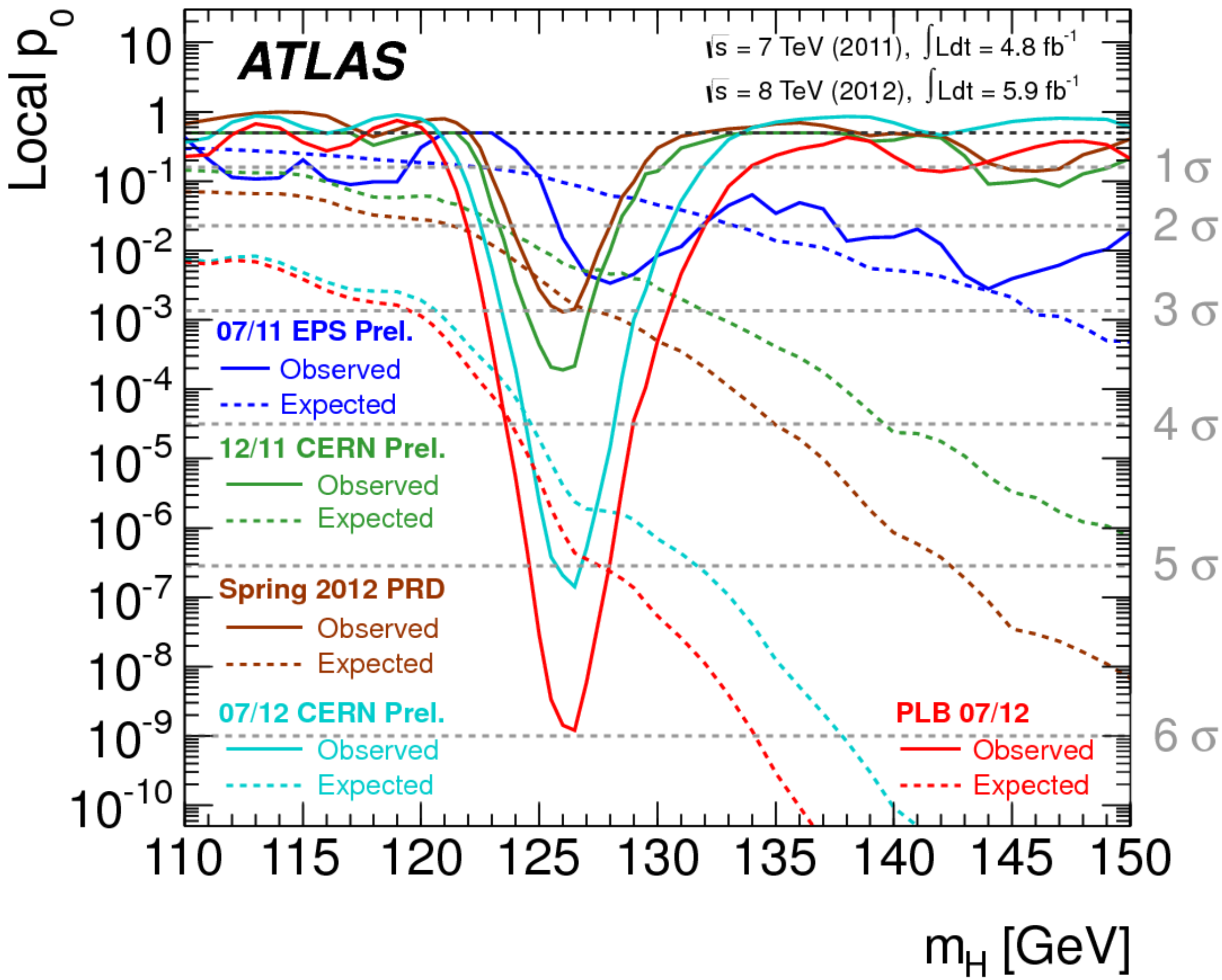


Only with 35 pb^{-1} data

Theory values at NLO or higher

Standard model scalar boson search

Phys. Lett. B 716 (2012) 1-29



- In July 2012, ATLAS and CMS announced discovery of a new particle (mass ~ 125 GeV) decaying to two bosons

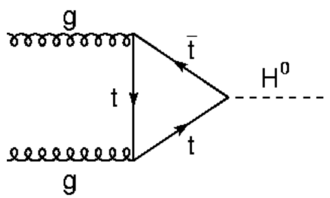
p_0 = probability that the background fluctuates more than the observed excess

3σ – evidence
5σ – discovery

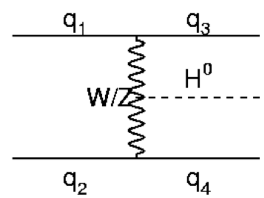
SM Higgs Production at the LHC

LHC Higgs Cross Section Working Group

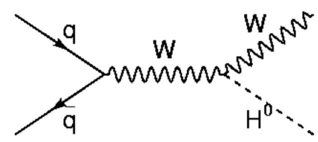
Gluon fusion process (87%)



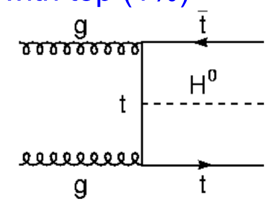
Vector Boson fusion (7%)

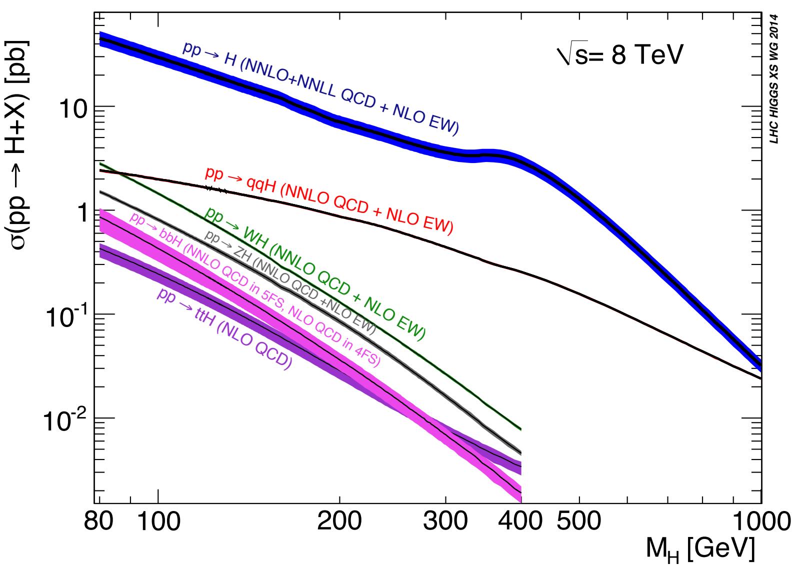


Associated production with W/Z (5%)

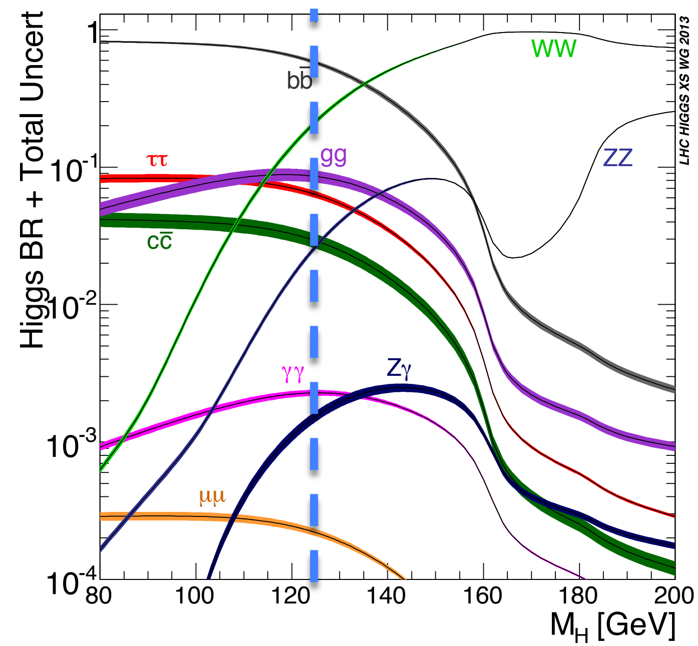


Associated production with top (1%)



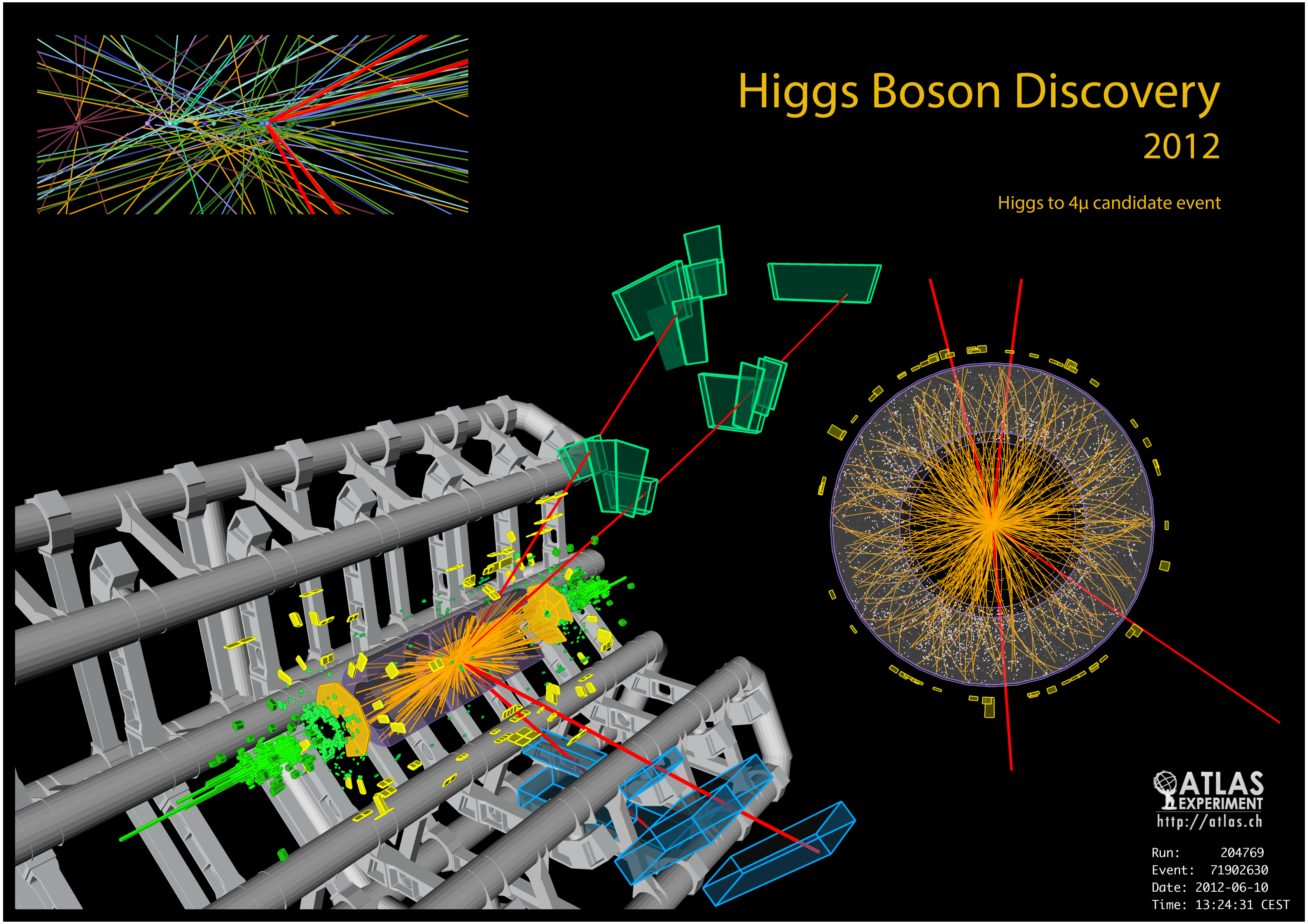


Cross section [pb] at m_H = 125.5 GeV (√s=8 TeV)				
ggF	VBF	WH	ZH	ttH
19.1	1.6	0.7	0.4	0.1



BR [%] at m_H = 125.5 GeV			
WW	ZZ	γγ	Zγ
22	2.8	0.23	0.16

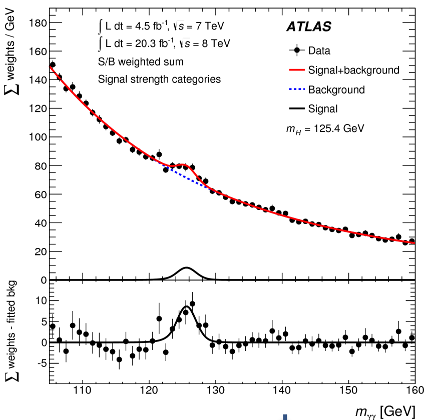
bbH cross section at 7 TeV and 8TeV is 1.1% of ggF



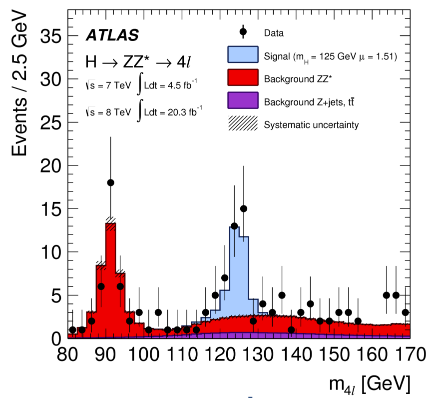
Event display of H→ZZ*→4μ candidate in ATLAS

Higgs searches in ATLAS

H→γγ : good resolution

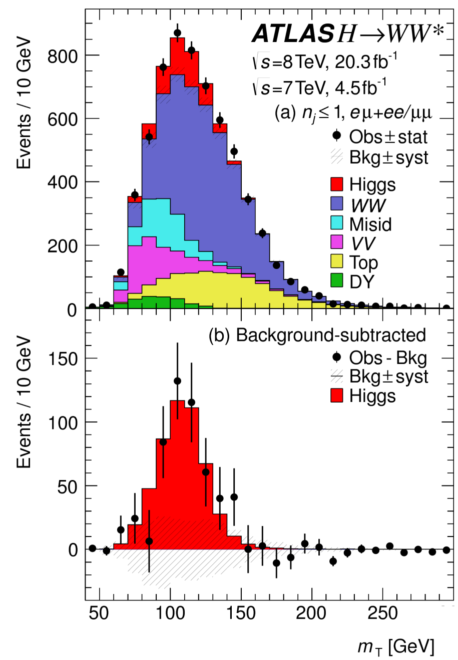


H→ZZ* → 4l: Golden channel

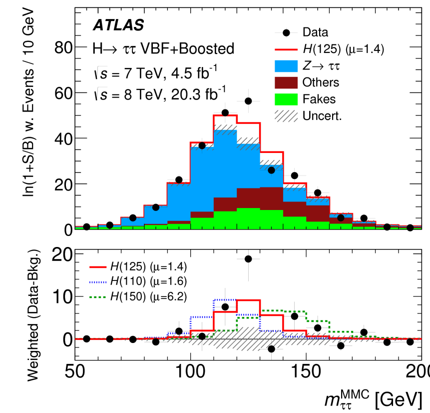


$$m_H = 125.36 \pm 0.37(stat) \pm 0.18(syst)\ \text{GeV}$$

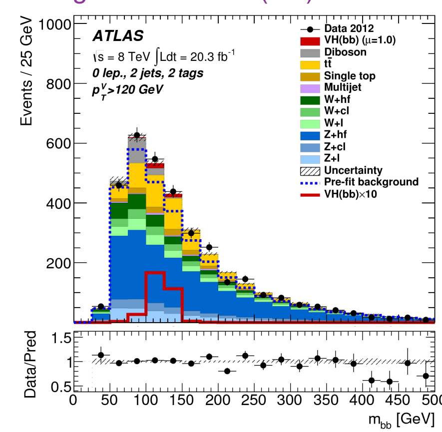
H→WW* → 4l: Good statistics, low resolution;
Observed (expected) significance : 6.1 (5.8) σ



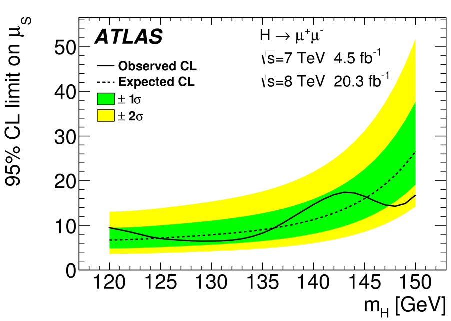
H→ τ+τ− : Best fermionic channel
Observed(expected) significance: 4.5 (3.4) σ



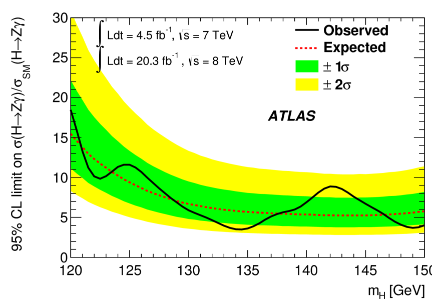
H→bb : not possible ggF (though VH)
Observed(expected) significance: 1.4 (2.6) σ



H→ µ+µ− : Clean signal
B(H→ µ+µ−) < 21.9 10^{-5}
(m_H=125 GeV)



H→ Zγ : Clean signal
B(H→ Zγ) < 1.6 10^{-3}
(m_H=125 GeV)

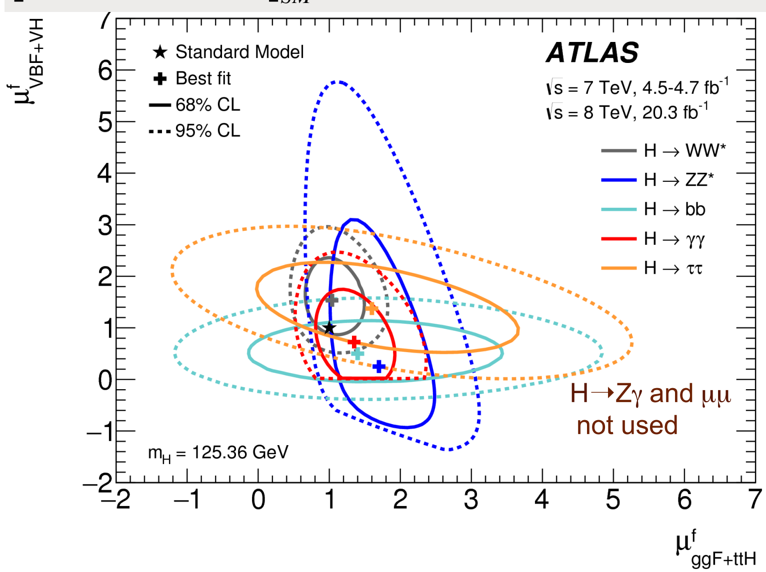


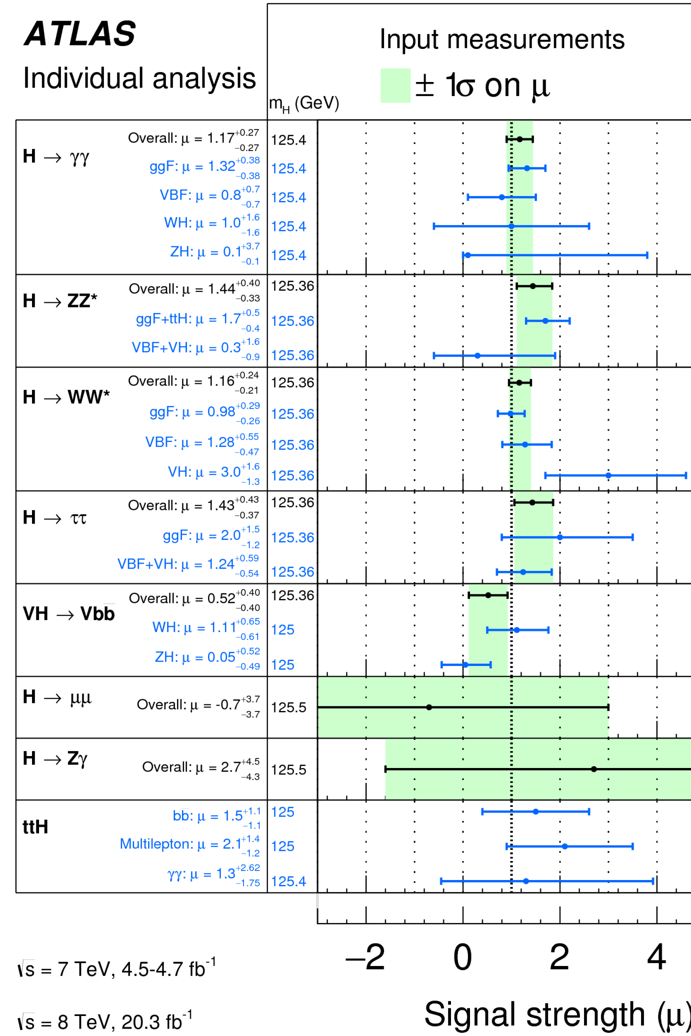
Higgs boson signal strength

arXiv:1507.04548

- With full data sets, combined results from the di-boson decays H→ZZ*→4l, WW*, γγ from the rare decays H→Zγ, bb, ττ and μμ and VH(bb), ttH
  - The signal strength, μ, is the ratio of a given Higgs boson production cross section (σ) to its SM value (σ_{SM}), $\mu = \sigma/\sigma_{SM}$
- Categorization of the production processes:
  - Couplings to fermions : ggF + ttH ($\mu_{ggF+ttH}$)
  - Couplings to vector bosons : VBF + VH (μ_{VBF+VH})

$$\frac{\mu_{VBF+VH}/\mu_{ggF+ttH}}{\left[\mu_{VBF+VH}/\mu_{ggF+ttH}\right]_{SM}} = 0.96^{+0.33}_{-0.26}(stat)^{+0.20}_{-0.13}(syst)^{+0.18}_{-0.10}(th)$$



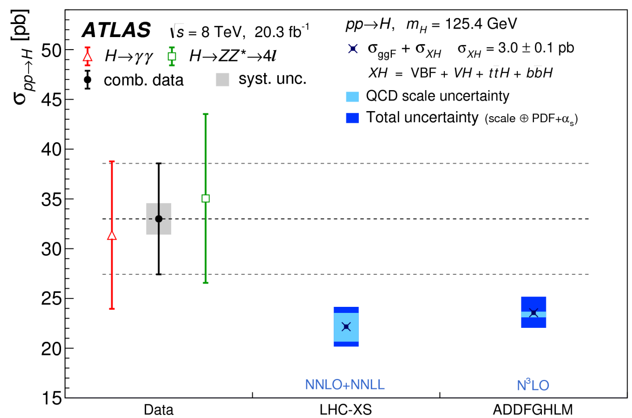


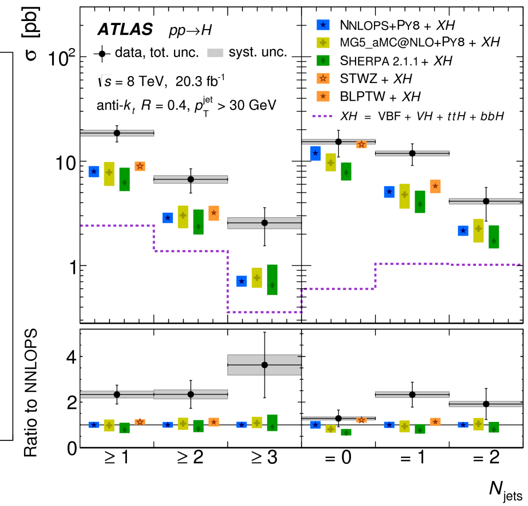
$$\mu = 1.18 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{syst})^{+0.08}_{-0.07}(\mathrm{th})$$

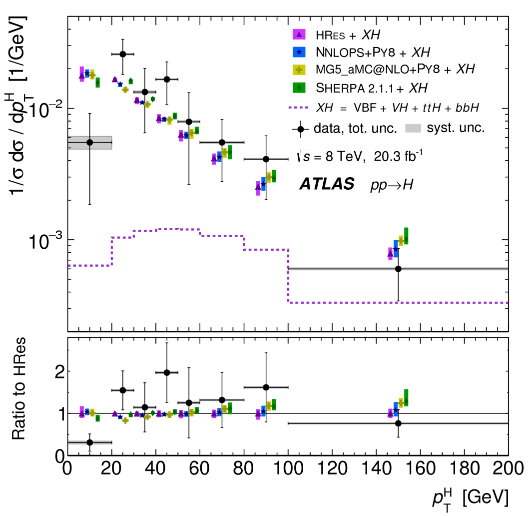
Fiducial and differential cross sections

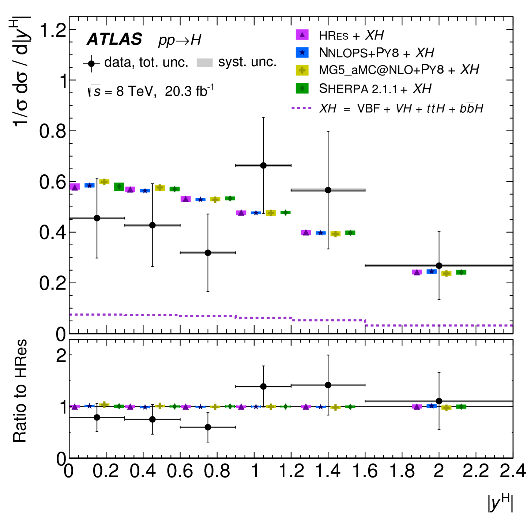
PRL 115 (2015) 091801

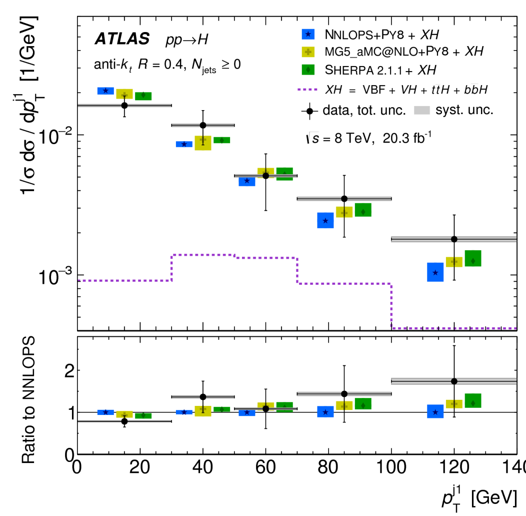
- Model independent measurement of total cross section from 8 TeV data using H→ZZ* and H→γγ
  - Observed higher cross section than theory
  - For all inclusive and exclusive jet multiplicities, data is higher
    - Least agreement is on ≥1 or =1 bins (p-value 0.1% and 3.6%)
  - Need more data to confirm
    - Results are statistically dominated











Higgs boson couplings

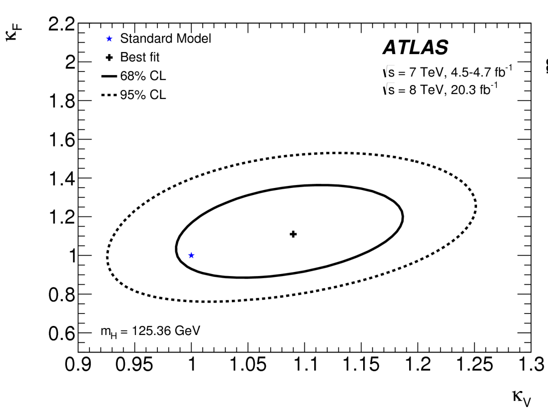
arXiv:1507.04548

- Assuming only SM contribution to the total width and no invisible or undetected H boson decays (simplest case)
  - Global fit using all data and decay channels
  - The measured fermion and vector coupling-strength scale factors are in agreement with SM

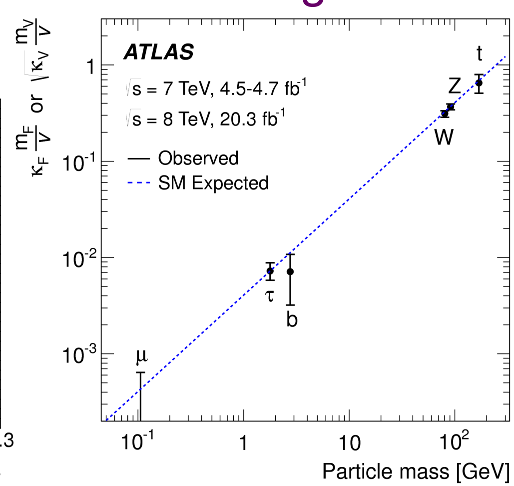
$$\kappa_V = 1.09 \pm 0.07$$
$$\kappa_F = 1.11 \pm 0.16$$

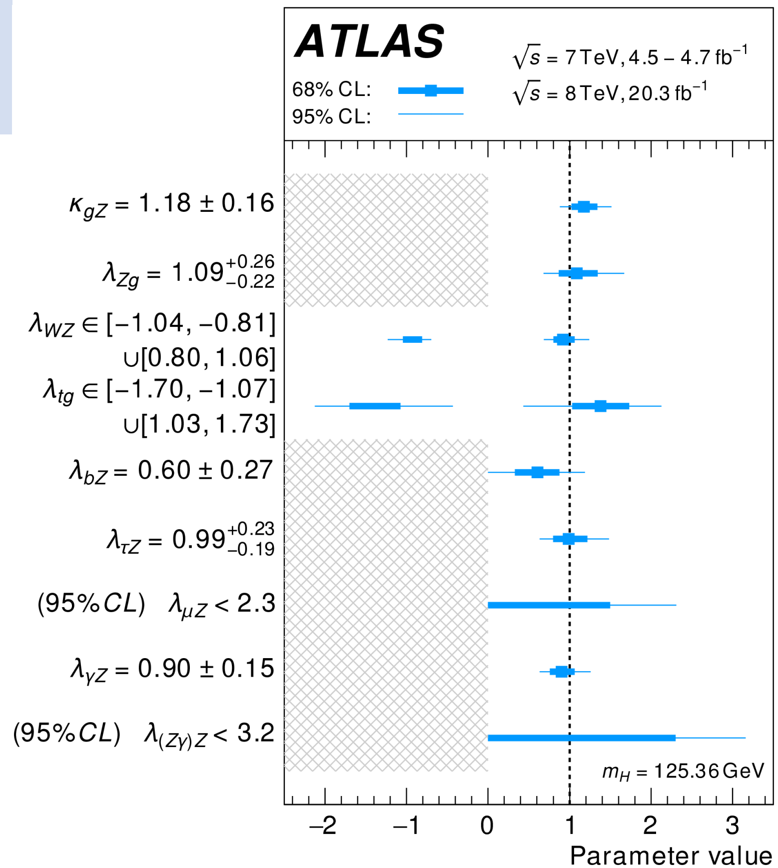
$$\kappa_i \equiv g_i / g_i^{SM}$$
$$\lambda_{ij} \equiv \kappa_i / \kappa_j$$
$$\kappa_{ij} \equiv \kappa_i \cdot \kappa_j / \kappa_H$$

- Most generic case: Allowing new particles in loops and no assumption on the total width



Testing SM



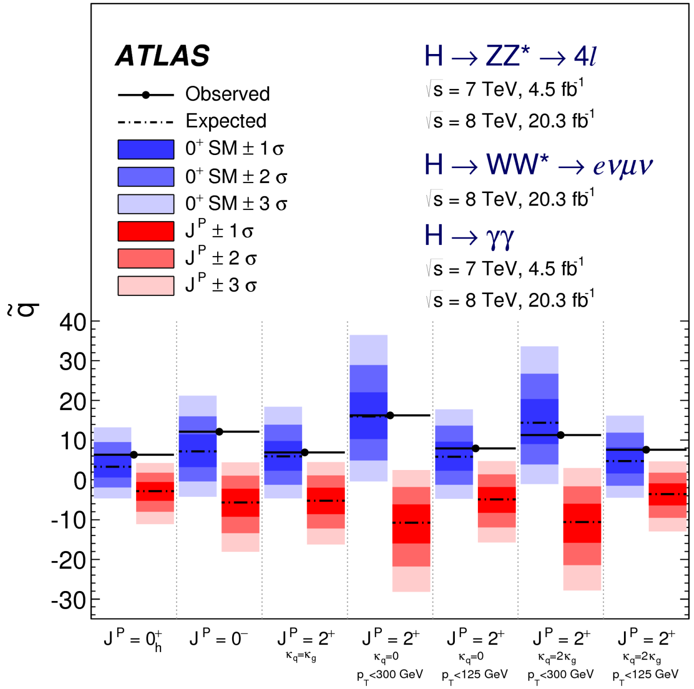


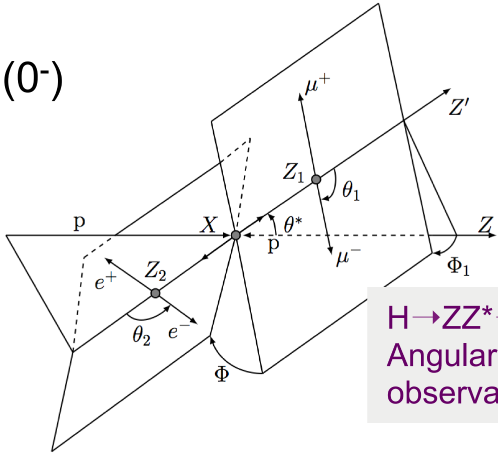
Higgs spin and parity measurement

arXiv:1506.05669

- Examining the Spin/CP nature of the Higgs boson with H→ZZ*→4l, H→WW*→eνμν and H→γγ
  - Spin-0: CP-even BSM (0^+_h) and CP-odd pseudo-scalar (0^-)
  - Spin-2: Universal couplings and κ_q/κ_g = 0 and 2
  - Exclusion determined from q: likehood ratio

to distinguish between two spin hypothesis





H→ZZ*→4l Angular observables

J^P	Model	Choice of tensor couplings			
		κ_{SM}	κ_{HVV}	κ_{AVV}	α
0^+	Standard Model Higgs boson	1	0	0	0
0^+_h	BSM spin-0 CP-even	0	1	0	0
0^-	BSM spin-0 CP-odd	0	0	1	$\pi/2$

Values of spin-2 quark and gluon couplings		p_T^X selections (GeV)	
$\kappa_q = \kappa_g$	Universal couplings	–	–
$\kappa_q = 0$	Low light-quark fraction	< 300	< 125
$\kappa_q = 2\kappa_g$	Low gluon fraction	< 300	< 125

SM is favoured and alternative models excluded > 99.9%CL_S

Higgs spin and parity measurement

- Combined fit performed on H→ZZ* and →WW* final states
  - Constraint the Spin-0 coupling ratios

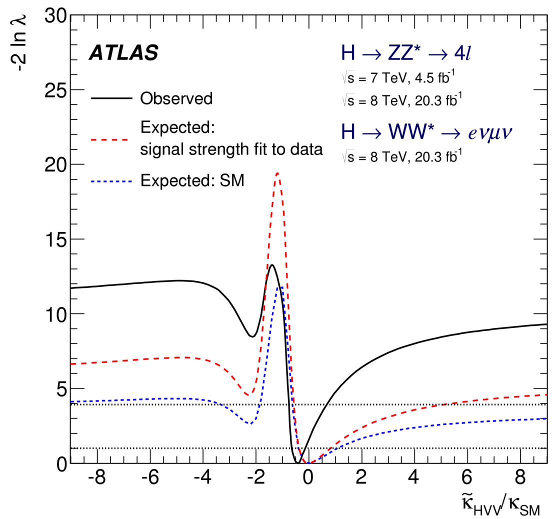
$$(\tilde{\kappa}_{AVV}/\kappa_{SM})\cdot\tan\alpha \text{ and } \tilde{\kappa}_{HVV}/\kappa_{SM}$$

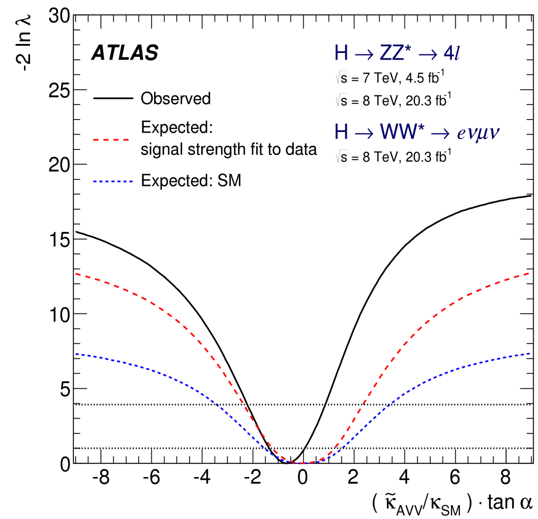
$$\tilde{\kappa}_{A(H)VV} = \frac{1}{4}\frac{v}{\Lambda}\kappa_{A(H)VV}$$

L for spin-0 particle interaction with W or Z boson

$$\mathcal{L}_0^V = \left\{\cos(\alpha)\kappa_{SM}\left[\tfrac{1}{2}g_{HZZ}Z_\mu Z^\mu + g_{HWW}W_\mu^+W^{-\mu}\right] -\tfrac{1}{4}\tfrac{1}{\Lambda}\left[\cos(\alpha)\kappa_{HZZ}Z_{\mu\nu}Z^{\mu\nu} + \sin(\alpha)\kappa_{AZZ}Z_{\mu\nu}\tilde{Z}^{\mu\nu}\right] -\tfrac{1}{2}\tfrac{1}{\Lambda}\left[\cos(\alpha)\kappa_{HWW}W_{\mu\nu}^+W^{-\mu\nu} + \sin(\alpha)\kappa_{AWW}W_{\mu\nu}^+\tilde{W}^{-\mu\nu}\right]\right\}X_0$$

Spin-even BSM contribution





Spin-odd BSM contribution

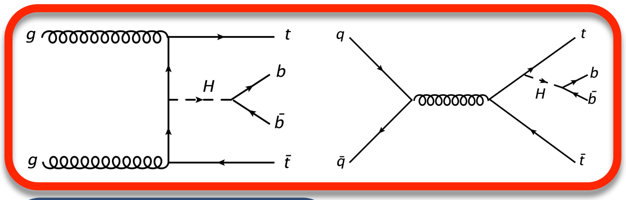
Coupling ratio	Best-fit value	95% CL Exclusion Regions	
Combined	Observed	Expected	Observed
$\tilde{\kappa}_{HVV}/\kappa_{SM}$	-0.48	$(-\infty,-0.55]\bigcup[4.80,\infty)$	$(-\infty,-0.73]\bigcup[0.63,\infty)$
$(\tilde{\kappa}_{AVV}/\kappa_{SM})\cdot\tan\alpha$	-0.68	$(-\infty,-2.33]\bigcup[2.30,\infty)$	$(-\infty,-2.18]\bigcup[0.83,\infty)$

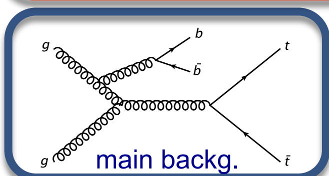
BSM to SM tensor couplings are compatible with the SM expectation

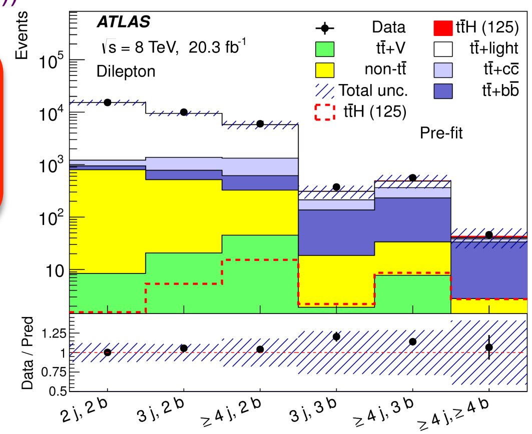
Rare processes ttH

- Higgs boson production in association with a top-quark pair
  - Direct measurement of top quark-Higgs coupling
  - ttH (H → bb / multilepton H(→ZZ, WW, ττ))

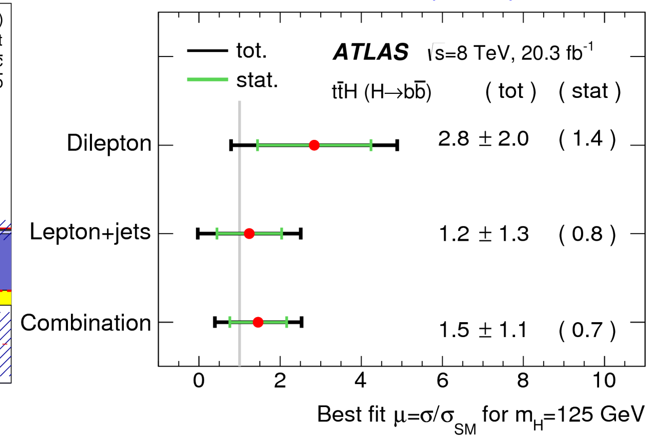
ttH (H → bb)





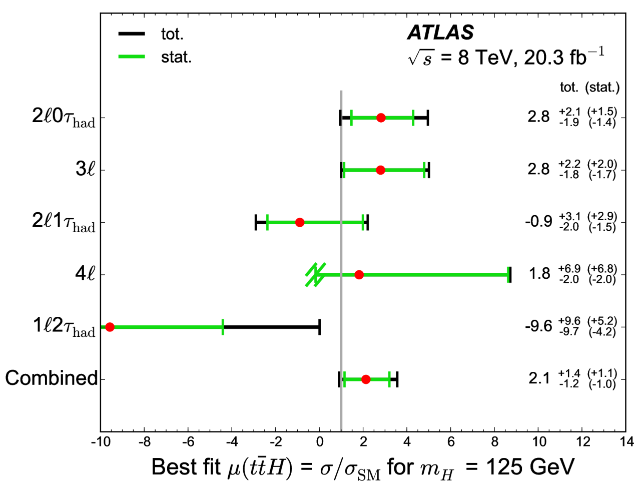


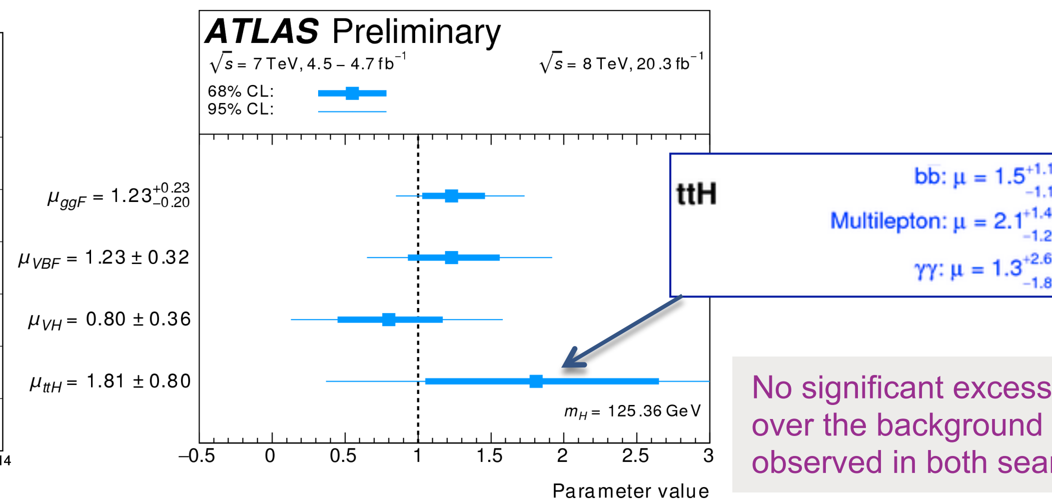
EPJC (2015) 75:349



ttH (H → multilepton)

(PLB 749 (2015) 519)

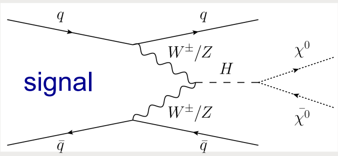


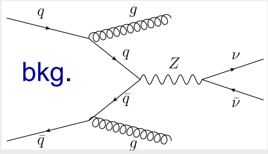


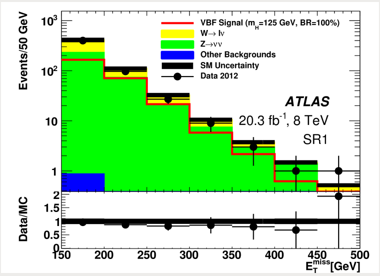
No significant excess over the background is observed in both searches

Searches for new physics with SM Higgs

Invisible Higgs decay (VBF) arXiv:1508.07869

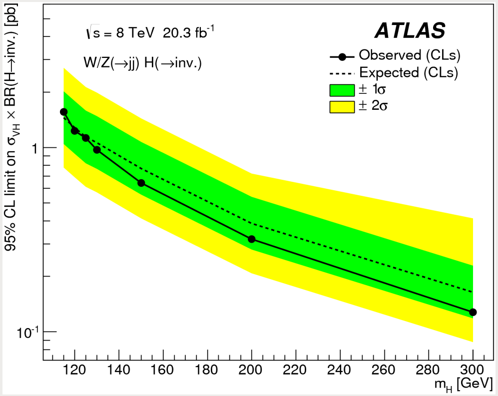






No excess over expected background
At 95% CL.
B(H→invisible) < 28 % (31%) obs (exp)

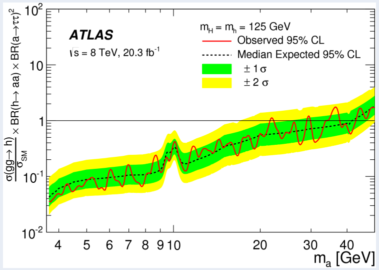
VH(W/Z→hadronic, H→invisible)

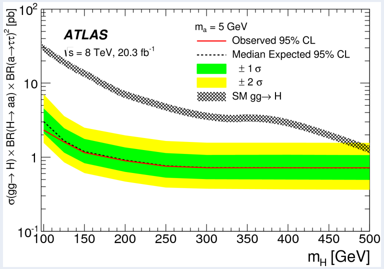


EPJC (2015) 75:337
m_H=125 GeV
B(H→invisible) < 78% (86%) obs (exp)

H→aa→μμττ (PRD 92 2015 052002)

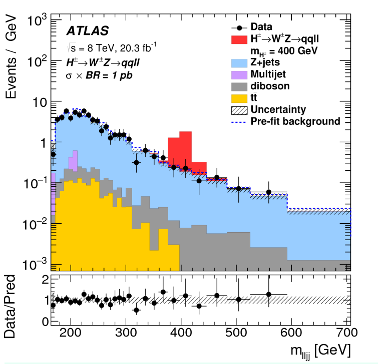
NMSSM : H decays to lightest pseudoscalar higgs

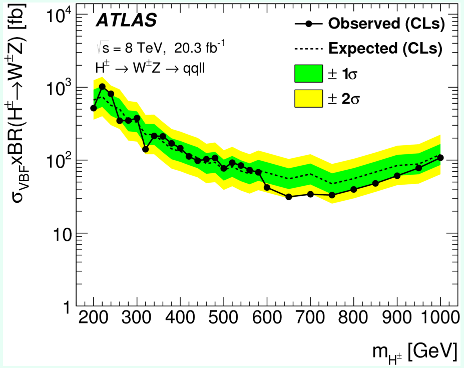




H$^{\pm}$→W$^{\pm}$Z→qqll (PRL 114 231801 (2015))

Charged Higgs boson appears in many SM extension models : 2HDM, Higgs Triplet model

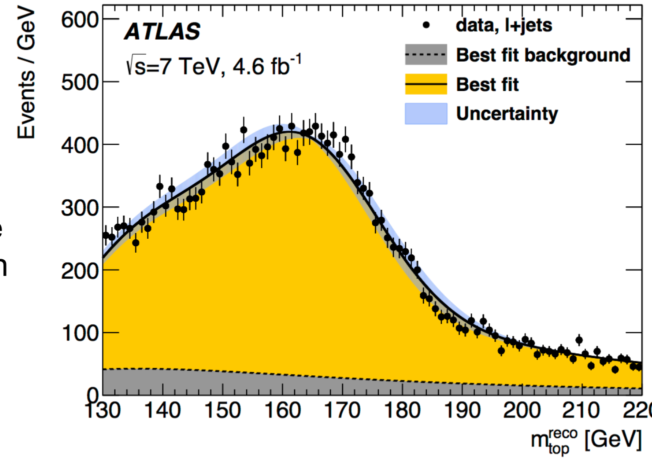


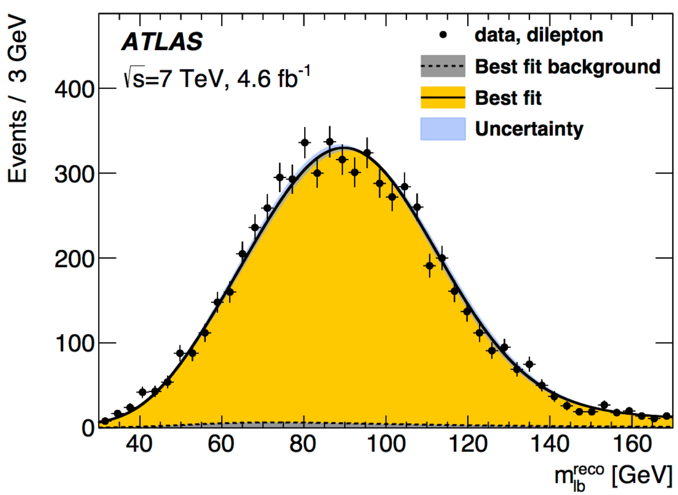


Top quark mass

EPJC (2015) 75:330

- Precise measurements of m_{top} is important - critical input to EW fits
- Top quark mass is measured in ttbar → lepton +jets (fully reconstructed) or di-lepton at 7 TeV (~5 fb^{-1})
  - Single lepton: 3D fit (m_{top}^{reco}, m_W^{reco} (hadronically decaying W) and R_{bq}^{reco}))
    - R_{bq}^{reco} : the ratio of the transverse momentum of the *b*-tagged jet to the average transverse momentum of the two jets of the hadronic *W* boson decay
    - Compared to the previous measurement (2D), 3D reduces the systematic uncertainty
  - Di-lepton : 1D fit (m_{lb}^{reco})





Dominant syst. error

	$t\bar{t}$ → lepton+jets			$t\bar{t}$ → dilepton	Combination	
	$m_{top}^{\ell+jets}$ [GeV]	JSF	bJSF	m_{top}^{dil} [GeV]	m_{top}^{comb} [GeV]	ρ
Results	172.33	1.019	1.003	173.79	172.99	
Statistics	0.75	0.003	0.008	0.54	0.48	0
– *Stat. comp. (m_{top})*	*0.23*	*n/a*	*n/a*	*0.54*		
– *Stat. comp. (JSF)*	*0.25*	*0.003*	*n/a*	*n/a*		
– *Stat. comp. (bJSF)*	*0.67*	*0.000*	*0.008*	*n/a*		
Method	0.11 ± 0.10	0.001	0.001	0.09 ± 0.07	0.07	0
Signal MC	0.22 ± 0.21	0.004	0.002	0.26 ± 0.16	0.24	+1.00
Hadronisation	0.18 ± 0.12	0.007	0.013	0.53 ± 0.09	0.34	+1.00
ISR/FSR	0.32 ± 0.06	0.017	0.007	0.47 ± 0.05	0.04	−1.00
Underlying event	0.15 ± 0.07	0.001	0.003	0.05 ± 0.05	0.06	−1.00
Colour reconnection	0.11 ± 0.07	0.001	0.002	0.14 ± 0.05	0.01	−1.00
PDF	0.25 ± 0.00	0.001	0.002	0.11 ± 0.00	0.17	+0.57
W/Z+jets norm	0.02 ± 0.00	0.000	0.000	0.01 ± 0.00	0.02	+1.00
W/Z+jets shape	0.29 ± 0.00	0.000	0.004	0.00 ± 0.00	0.16	0
NP/fake-lepton norm.	0.10 ± 0.00	0.000	0.001	0.04 ± 0.00	0.07	+1.00
NP/fake-lepton shape	0.05 ± 0.00	0.000	0.001	0.01 ± 0.00	0.03	+0.23
Jet energy scale	0.58 ± 0.11	0.018	0.009	0.75 ± 0.08	0.41	−0.23
b-Jet energy scale	0.06 ± 0.03	0.000	0.010	0.68 ± 0.02	0.34	+1.00
Jet resolution	0.22 ± 0.11	0.007	0.001	0.19 ± 0.04	0.03	−1.00
Jet efficiency	0.12 ± 0.00	0.000	0.002	0.07 ± 0.00	0.10	+1.00
Jet vertex fraction	0.01 ± 0.00	0.000	0.000	0.00 ± 0.00	0.00	−1.00
b-Tagging	0.50 ± 0.00	0.001	0.007	0.07 ± 0.00	0.25	−0.77
E_T^{miss}	0.15 ± 0.04	0.000	0.001	0.04 ± 0.03	0.08	−0.15
Leptons	0.04 ± 0.00	0.001	0.001	0.13 ± 0.00	0.05	−0.34
Pile-up	0.02 ± 0.01	0.000	0.000	0.01 ± 0.00	0.01	0
Total	1.27 ± 0.33	0.027	0.024	1.41 ± 0.24	0.91	−0.07

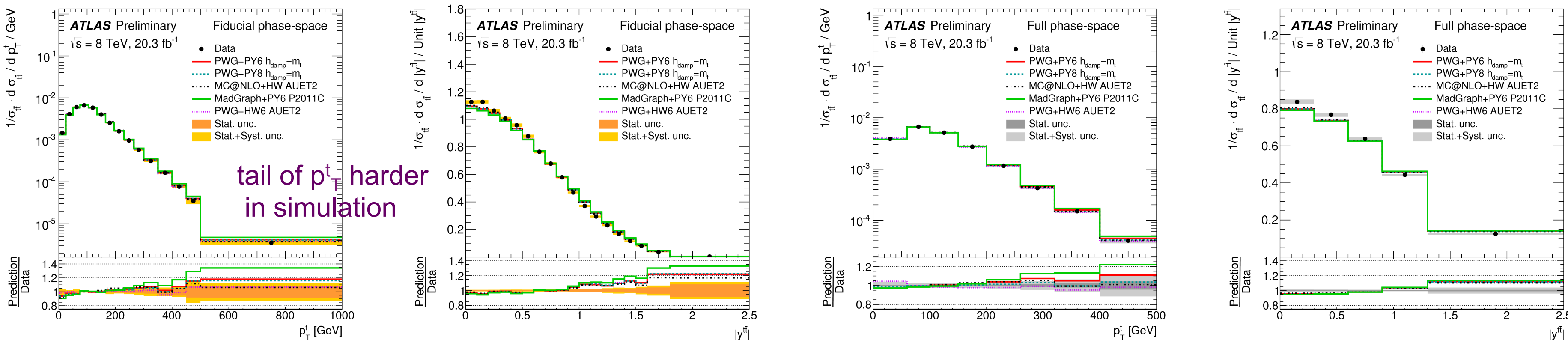
Unbinned likelihood fit data - Signal templates are from MC

$$m_{top}^{comb} = 172.99 \pm 0.48(stat) \pm 0.78(syst)\ \text{GeV} \ = \ 172.99 \pm 0.91\ \text{GeV}$$

Top-quark pair production

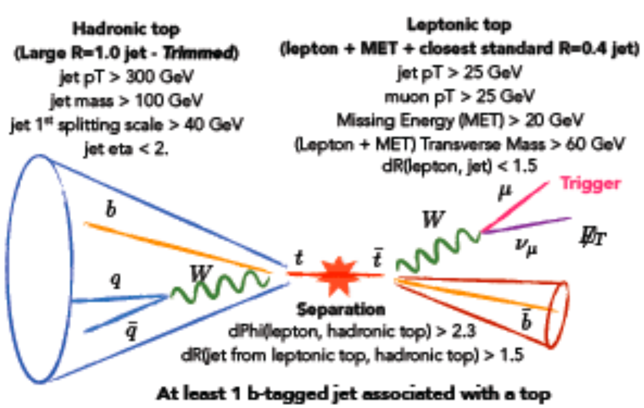
- Measure differential cross section in fiducial and full phase space as a function of observables
  - Reconstruct one top leptonically (lepton+jets) and the other one hadronically
  - Particle (parton-level) objects defined in simulated events for fiducial (full) phase space

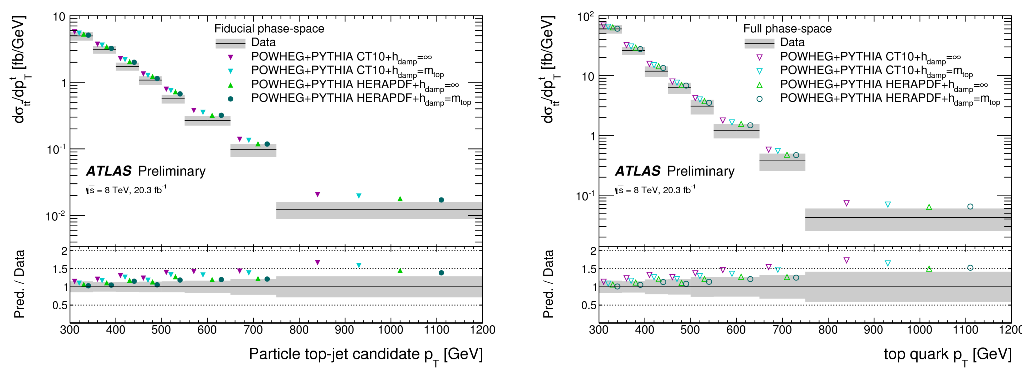
$p_T^{t}, |y^t|, m_{t\bar{t}}, p_T^{t\bar{t}}$ and $|y^{t\bar{t}}|$



tail of p_T^t harder in simulation

- Measure differential cross section of highly boosted top quarks
  - Hadronic top reconstructed as a single jet, the other top decay leptonically

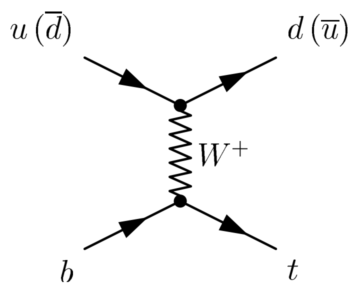




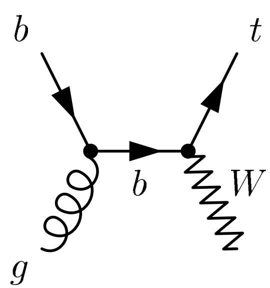
In general, simulation is higher than data

Single top production

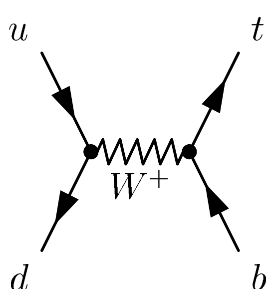
t-channel

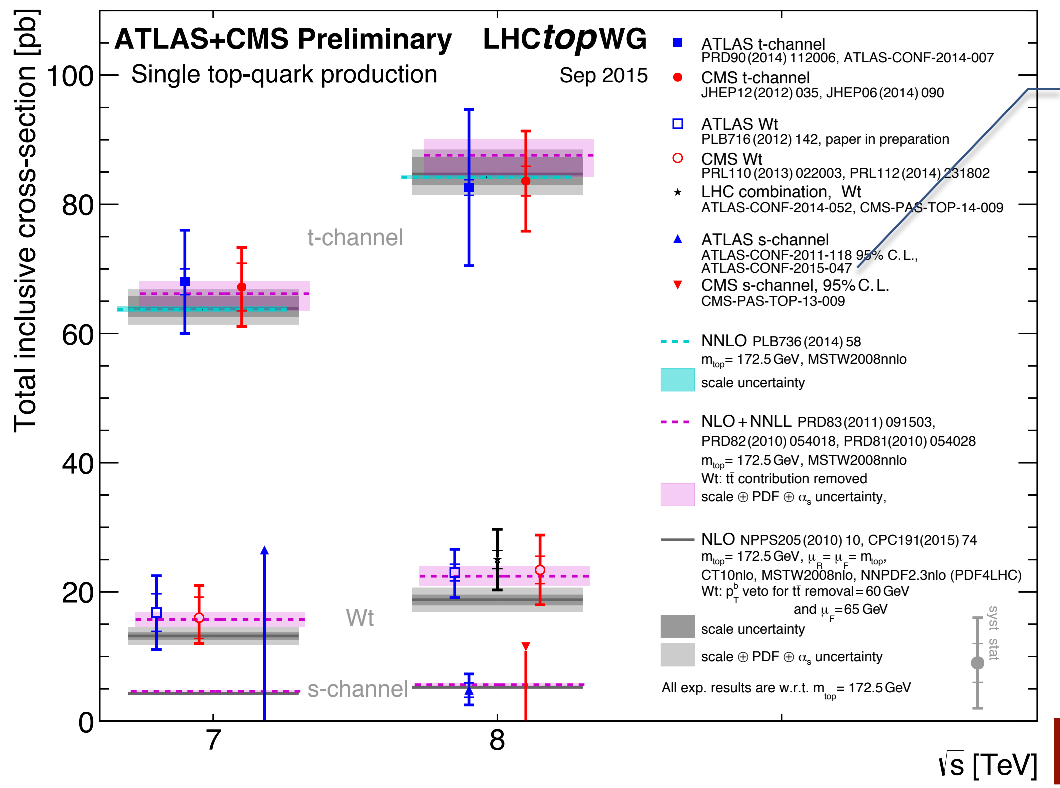


Wt-channel



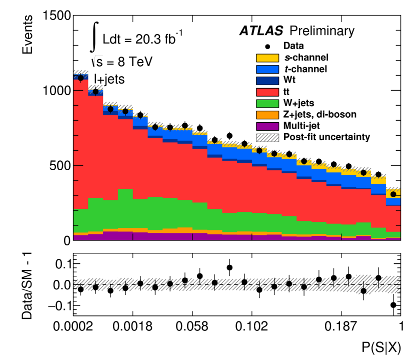
s-channel





The most recent update on s-channel by ATLAS (ATLAS-CONF-2015-047)

Signal significance observed(expected) : 3.2σ (3.9σ)



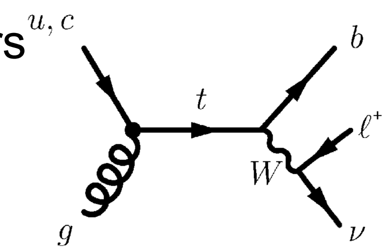
$$\sigma_S = 4.8 \pm 1.1(stat)^{+2.2}_{-2.0}(syst)\ \text{pb}$$

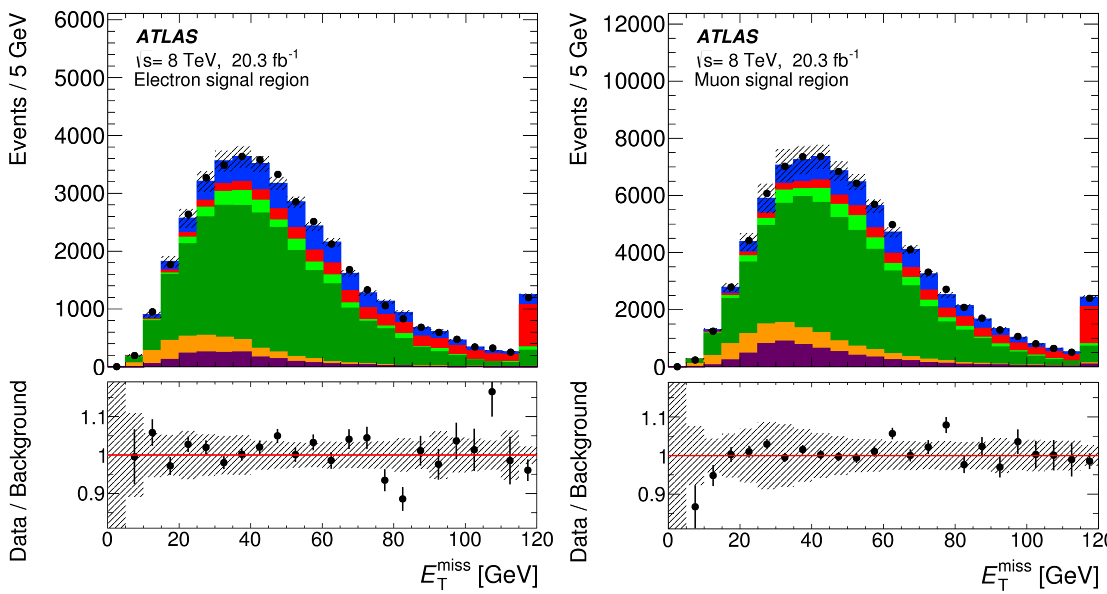
- **t-channel** : 1 isolated leptons (e / μ), one b-tagged jet, 1 forward jet, missing E_T
- **Wt channel** : 2 isolated leptons (e / μ), one b-tagged jet, missing E_T
- **s-channel** : 1 isolated lepton (e / μ), two b-tagged jets, missing E_T

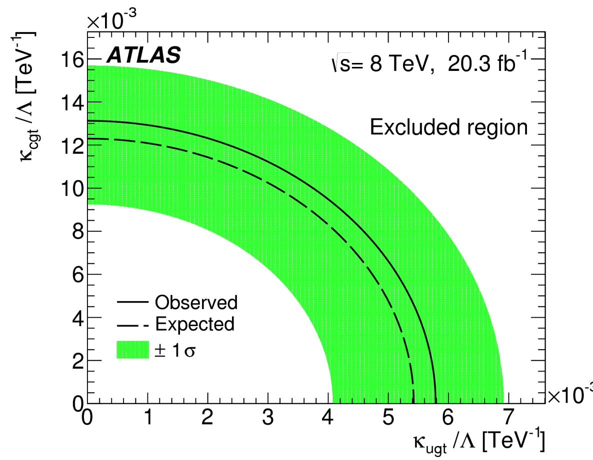
Single top production in FCNC

arXiv:1509.00294

- FCNC forbidden at tree level, suppressed at higher orders
  - Rate can be enhanced through the BSM models (B ~ 10^{-5}- 10^{-3})
- qg→t→bW (W in leptonic decay)







Upper limits on the coupling constants divided by the scale of new physics:

$$\kappa_{u(c)gt}/\Lambda < 5.8\ (13)\ \times 10^{-3}\ \text{TeV}^{-1}$$

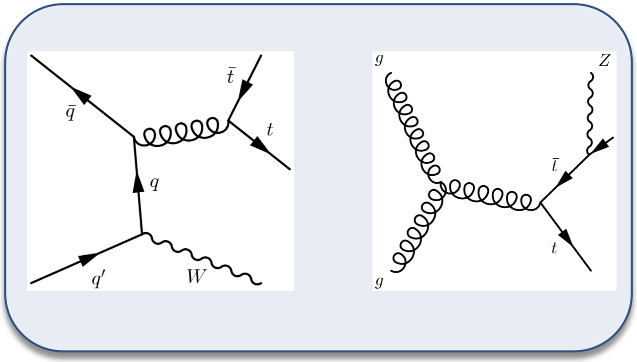
$$B\left(t \to u(c)g\right) < \ 4\ (17)\ \times\ 10^{-5}$$

No signal seen, upper limit is set at 95% CL:

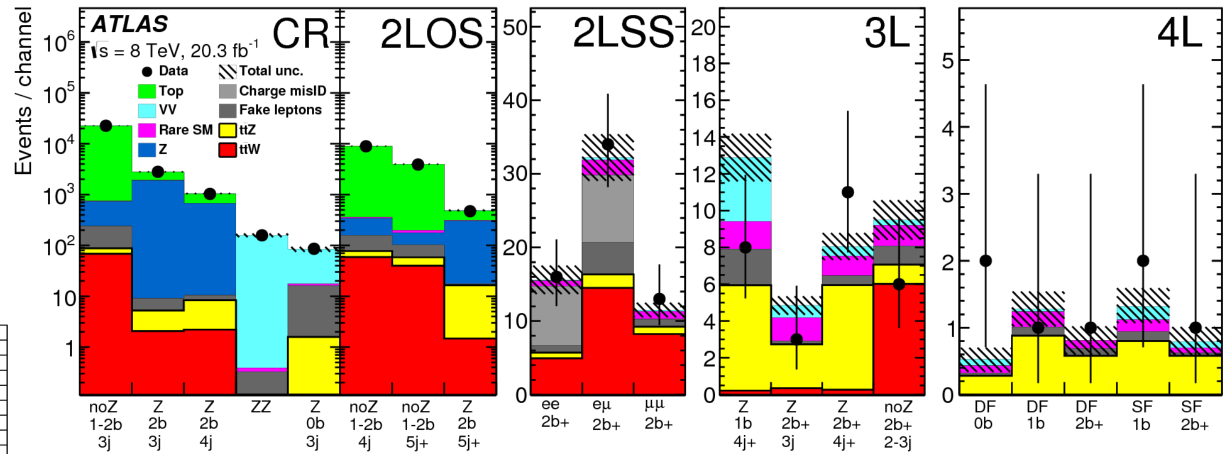
$$\sigma_{qg\to t} \times B\left(t \to bW\right) < 2.9\ \ (3.4)\ \text{pb}\ \ \text{expected(observed)}$$

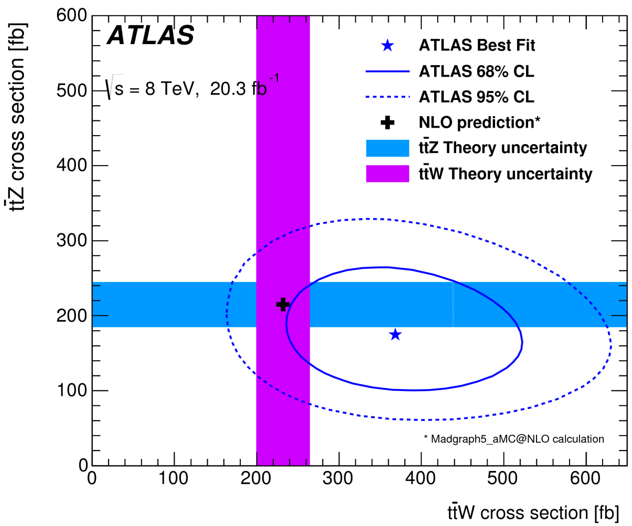
ttV (V = W,Z) productions

arXiv:1509.05276



Fit results on 15 signal and 5 control regions





Channel	$t\bar{t}W$ significance Expected	$t\bar{t}W$ significance Observed	$t\bar{t}Z$ significance Expected	$t\bar{t}Z$ significance Observed
2ℓOS	0.4	0.1	1.4	1.1
2ℓSS	2.8	5.0	-	-
3ℓ	1.4	1.0	3.7	3.3
4ℓ	-	-	2.0	2.4
Combined	3.2	5.0	4.5	4.2

$$\sigma_{t\bar{t}W} = 369^{+86}_{-79}(stat) \pm 44(syst)\ \text{fb}$$

$$\sigma_{t\bar{t}Z} = 176^{+52}_{-48}(stat) \pm 24(syst)\ \text{fb}$$

Simultaneous fit to all four channels to extract the cross sections

24

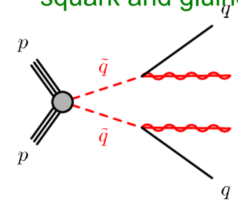
SUSY Summary

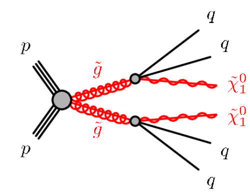
Inclusive 1st and 2nd squark and gluino

arXiv:1507.05525

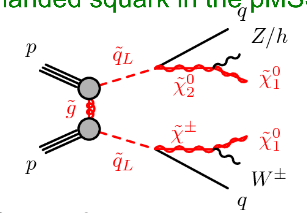
- Inclusive searches of squarks and qluinos with final states:
  - High p_T jets + MET + with or without leptons or b-jets
- Exclusion limits are set on various SUSY models
  - Simplified models (R-parity+LSP stable), mSUGRA/CMSSM, bRPV, mGMSB, nGM, NUHMG, mUED

squark and gluino pair production in the simplified models

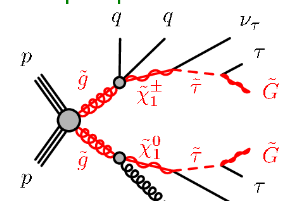




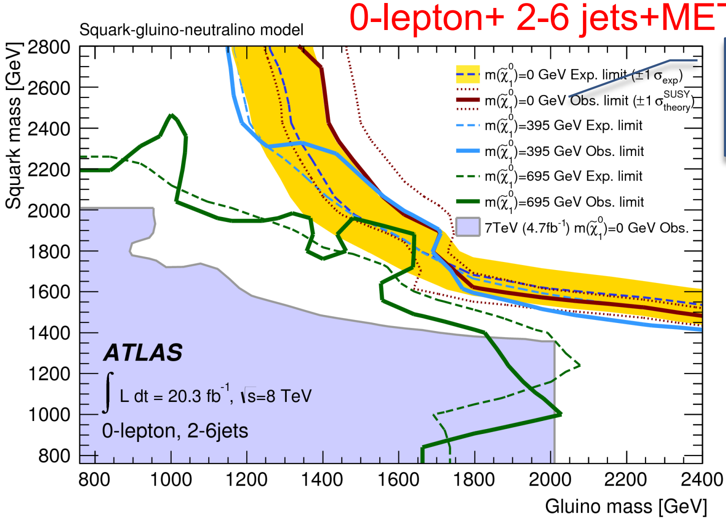
left-handed squark in the pMSSM



gluino-pair production in nGM

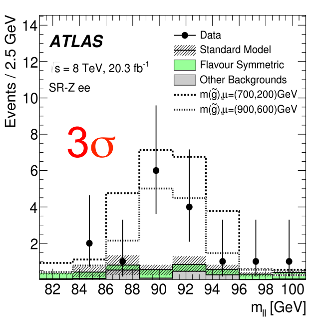


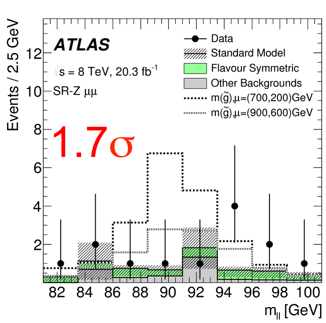
0-lepton+ 2-6 jets+MET

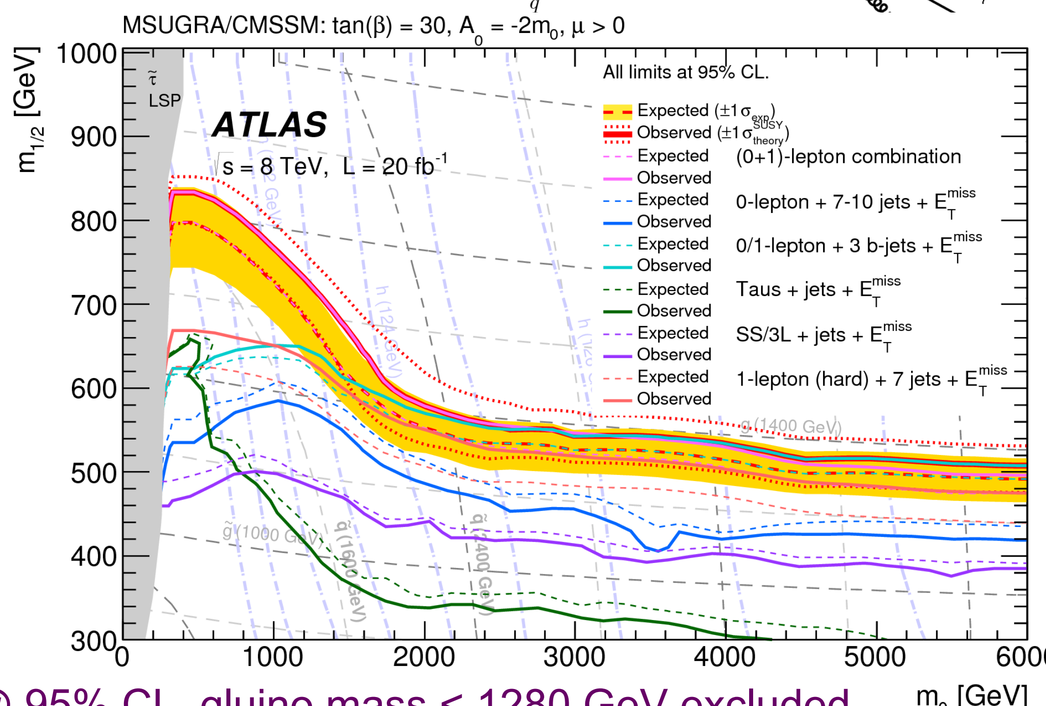


For massless neutralino, lower limit for squark and gluino is at 1650 GeV.

2-lepton+jets+MET arXiv:1503.03290







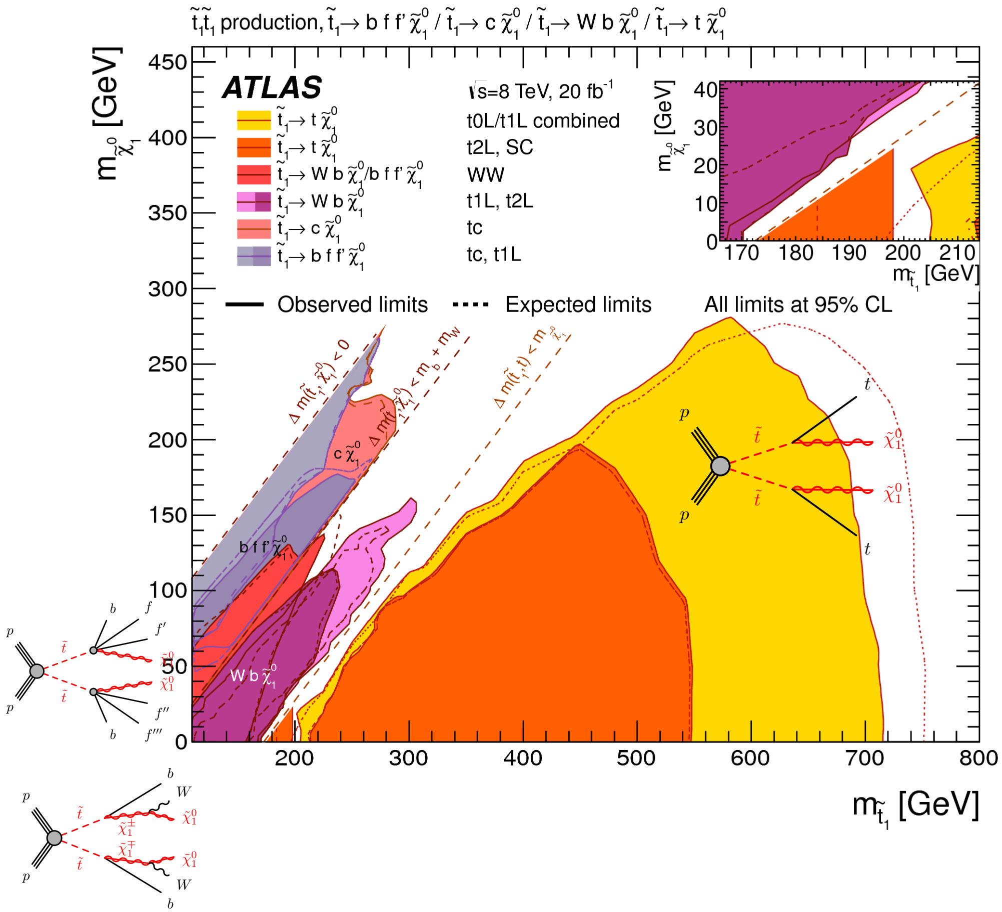
@ 95% CL. gluino mass < 1280 GeV excluded

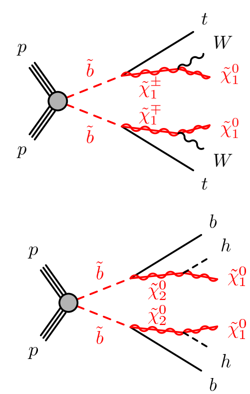
Third-generation squarks

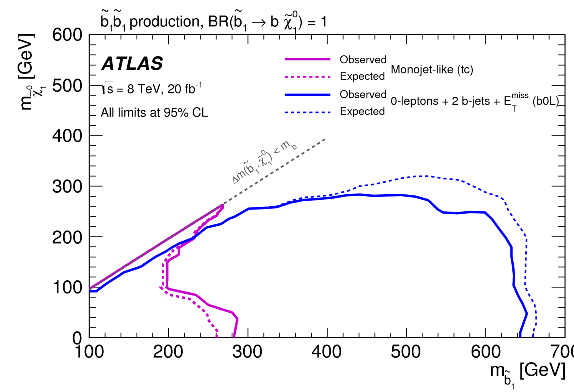
arXiv:1506.08616

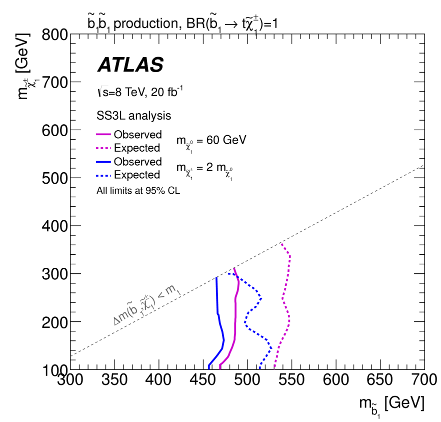
- Scalar top mass is required to be <~ TeV to solve the Higgs mass fine-tuning in SM
- Four decay modes are considered separately with a branching ratio of 100%

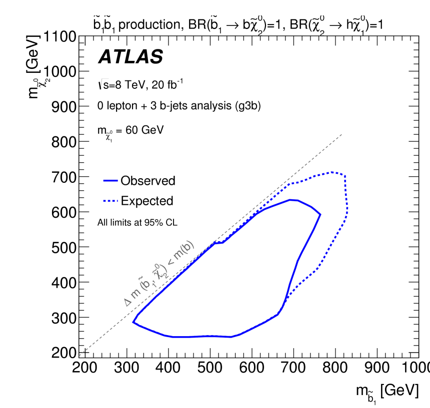
- Light stop implies light sbottom
- Three decay modes with 100% branching ratio is considered











Mass limits on SUSY searches

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: July 2015

ATLAS Preliminary

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

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.8 TeV	$m(\tilde{q})=m(\tilde{g})$	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}^0_1$ (compressed)	mono-jet	1-3 jets	Yes	20.3	$\tilde{q}$ 100-440 GeV	$m(\tilde{q})-m(\tilde{\chi}^0_1)<10$ GeV	1507.05525
	$\tilde{q}\tilde{q}, \tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$ 780 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1503.03290
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}^\pm_1\to qqW^\pm\tilde{\chi}^0_1$	0-1 e,μ	2-6 jets	Yes	20	$\tilde{g}$ 1.26 TeV	$m(\tilde{\chi}^0_1)<300$ GeV, $m(\tilde{\chi}^\pm)=0.5(m(\tilde{\chi}^0_1)+m(\tilde{g}))$	1507.05525
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.32 TeV	$m(\tilde{\chi}^0_1)$=0 GeV	1501.03555
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	$\tan\beta>20$	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.29 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}^0_1)<900$ GeV, $c\tau$(NLSP)<0.1 mm, $\mu<0$	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}^0_1)<850$ GeV, $c\tau$(NLSP)<0.1 mm, $\mu>0$	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 850 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	$m(\tilde{G})>1.8\times10^{-4}$ eV, $m(\tilde{g})=m(\tilde{q})$=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{b}\tilde{\chi}^0_1$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}^0_1)<400$ GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}^0_1)<350$ GeV	1308.1841
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}^0_1)<400$ GeV	1407.0600
	$\tilde{g}\tilde{g}, \tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}^0_1)<300$ GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}^0_1)<90$ GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}^\pm_1$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}^\pm_1)=2\, m(\tilde{\chi}^0_1)$	1404.2500
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\tilde{\chi}^\pm_1$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 110-167 GeV; 230-460 GeV	$m(\tilde{\chi}^\pm_1)=2m(\tilde{\chi}^0_1)$, $m(\tilde{\chi}^0_1)$=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-191 GeV; 210-700 GeV	$m(\tilde{\chi}^0_1)$=1 GeV	1506.08616
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}^0_1$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)-m(\tilde{\chi}^0_1)<85$ GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}^0_1)>150$ GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}^0_1)<200$ GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}^0_1)$=0 GeV	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1$ 140-465 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^\pm_1)+m(\tilde{\chi}^0_1))$	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 100-350 GeV	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}^\pm_1)+m(\tilde{\chi}^0_1))$	1407.0350
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ 700 GeV	$m(\tilde{\chi}^\pm_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^\pm_1)+m(\tilde{\chi}^0_1))$	1402.7029
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1 Z\tilde{\chi}^0_1$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ 420 GeV	$m(\tilde{\chi}^\pm_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}^\pm_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1 h\tilde{\chi}^0_1, h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}^\pm_1,\tilde{\chi}^0_2$ 250 GeV	$m(\tilde{\chi}^\pm_1)=m(\tilde{\chi}^0_2)$, $m(\tilde{\chi}^0_1)$=0, sleptons decoupled	1501.07110
	$\tilde{\chi}^0_2\tilde{\chi}^0_3, \tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}^0_{2,3}$ 620 GeV	$m(\tilde{\chi}^0_2)=m(\tilde{\chi}^0_3)$, $m(\tilde{\chi}^0_1)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}^0_2)+m(\tilde{\chi}^0_1))$	1405.5086
	GGM (wino NLSP) weak prod.	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$ 124-361 GeV	$c\tau<1$ mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}^\pm_1$ 270 GeV	$m(\tilde{\chi}^\pm_1)-m(\tilde{\chi}^0_1)\sim$160 MeV, $\tau(\tilde{\chi}^\pm_1)$=0.2 ns	1310.3675
	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^\pm_1$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}^\pm_1$ 482 GeV	$m(\tilde{\chi}^\pm_1)-m(\tilde{\chi}^0_1)\sim$160 MeV, $\tau(\tilde{\chi}^\pm_1)<15$ ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}^0_1)$=100 GeV, 10 $\mu s<\tau(\tilde{g})<1000$ s	1310.6584
	Stable $\tilde{g}$ R-hadron	trk	-	-	19.1	$\tilde{g}$ 1.27 TeV		1411.6795
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}^0_1$ 537 GeV	$10<\tan\beta<50$	1411.6795
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$ 435 GeV	$2<\tau(\tilde{\chi}^0_1)<3$ ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}, \tilde{\chi}^0_1\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}^0_1$ 1.0 TeV	$7<c\tau(\tilde{\chi}^0_1)<$ 740 mm, $m(\tilde{g})$=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}, \tilde{\chi}^0_1\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}^0_1$ 1.0 TeV	$6<c\tau(\tilde{\chi}^0_1)<$ 480 mm, $m(\tilde{g})$=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$ 1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}<1$ mm	1404.2500
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to W\tilde{\chi}^0_1, \tilde{\chi}^0_1\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 750 GeV	$m(\tilde{\chi}^0_1)>0.2\times m(\tilde{\chi}^\pm_1)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}^+_1\tilde{\chi}^-_1, \tilde{\chi}^+_1\to W\tilde{\chi}^0_1, \tilde{\chi}^0_1\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}^\pm_1$ 450 GeV	$m(\tilde{\chi}^0_1)>0.2\times m(\tilde{\chi}^\pm_1)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\tilde{g}, \tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to q\tilde{\chi}^0_1, \tilde{\chi}^0_1\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 870 GeV	$m(\tilde{\chi}^0_1)$=600 GeV	1502.05686
	$\tilde{g}\tilde{g}, \tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$ 100-308 GeV		ATLAS-CONF-2015-026
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2 c	Yes	20.3	$\tilde{c}$ 490 GeV	$m(\tilde{\chi}^0_1)<200$ GeV	1501.01325

Legend: $\sqrt{s}$ = 7 TeV, $\sqrt{s}$ = 8 TeV. Mass scale [TeV] axis: 10^{-1}, 1.

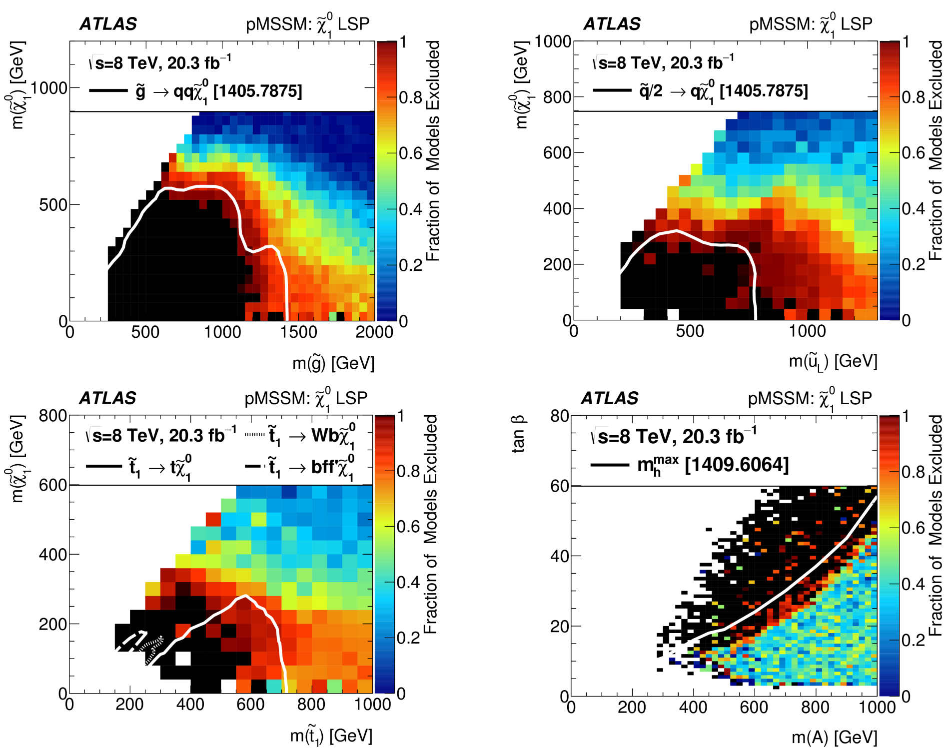
Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

No significant evidence of a SUSY signal at Run 1

Constraints in the pMSSM

arXiv:1508.06608

- MSSM has over 100 parameters to describe sparticles and masses
- Phenomenological MSSM, (pMSSM) ~ 19 parameters under the assumptions that:
  - R-parity conserved- LSP is stable, the neutralino and sparticles are produced in pairs
  - Minimal flavor violation with no new source of CP violation
  - Degenerate 1st and 2nd generation squarks and sleptons
- Re-interpret 22 ATLAS Run 1 results in pMSSM



Generate 19 pMSSM parameters within the ranges:

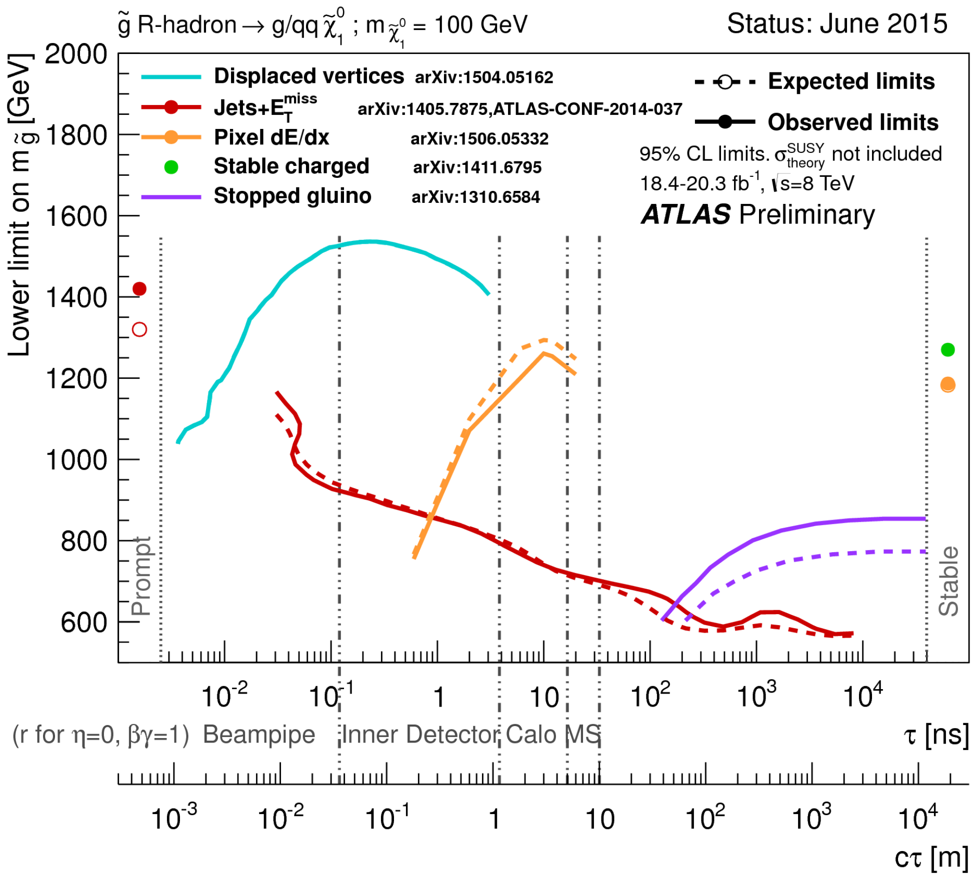
Parameter	Min value	Max value	Note
$m_{\tilde{L}_1}(=m_{\tilde{L}_2})$	90 GeV	4 TeV	Left-handed slepton (first two gens.) mass
$m_{\tilde{e}_1}(=m_{\tilde{e}_2})$	90 GeV	4 TeV	Right-handed slepton (first two gens.) mass
$m_{\tilde{L}_3}$	90 GeV	4 TeV	Left-handed stau doublet mass
$m_{\tilde{e}_3}$	90 GeV	4 TeV	Right-handed stau mass
$m_{\tilde{Q}_1}(=m_{\tilde{Q}_2})$	200 GeV	4 TeV	Left-handed squark (first two gens.) mass
$m_{\tilde{u}_1}(=m_{\tilde{u}_2})$	200 GeV	4 TeV	Right-handed up-type squark (first two gens.) mass
$m_{\tilde{d}_1}(=m_{\tilde{d}_2})$	200 GeV	4 TeV	Right-handed down-type squark (first two gens.) mass
$m_{\tilde{Q}_3}$	100 GeV	4 TeV	Left-handed squark (third gen.) mass
$m_{\tilde{u}_3}$	100 GeV	4 TeV	Right-handed top squark mass
$m_{\tilde{d}_3}$	100 GeV	4 TeV	Right-handed bottom squark mass
$\|M_1\|$	0 GeV	4 TeV	Bino mass parameter
$\|M_2\|$	70 GeV	4 TeV	Wino mass parameter
$\|\mu\|$	80 GeV	4 TeV	Bilinear Higgs mass parameter
M_3	200 GeV	4 TeV	Gluino mass parameter
$\|A_t\|$	0 GeV	8 TeV	Trilinear top coupling
$\|A_b\|$	0 GeV	4 TeV	Trilinear bottom coupling
$\|A_\tau\|$	0 GeV	4 TeV	Trilinear τ lepton coupling
M_A	100 GeV	4 TeV	Pseudoscalar Higgs boson mass
$\tan\beta$	1	60	Ratio of the Higgs vacuum expectation values

Constraints: considerations of precision EW and flavour results, dark matter relic density, and other ollider measurements

Parameter	Minimum value	Maximum value
$\Delta\rho$	-0.0005	0.0017
$\Delta(g-2)_\mu$	-17.7×10^{-10}	43.8×10^{-10}
$\mathrm{BR}(b\to s\gamma)$	2.69×10^{-4}	3.87×10^{-4}
$\mathrm{BR}(B_s\to\mu^+\mu^-)$	1.6×10^{-9}	4.2×10^{-9}
$\mathrm{BR}(B^+\to\tau^+\nu_\tau)$	66×10^{-6}	161×10^{-6}
$\Omega_{\tilde{\chi}_1^0}h^2$	—	0.1208
$\Gamma_{\mathrm{invisible(SUSY)}}(Z)$	—	2 MeV
Masses of charged sparticles	100 GeV	—
$m(\tilde{\chi}_1^\pm)$	103 GeV	—
$m(\tilde{u}_{1,2},\,\tilde{d}_{1,2},\,\tilde{c}_{1,2},\,\tilde{s}_{1,2})$	200 GeV	—
$m(h)$	124 GeV	128 GeV

Long-lived SUSY particles

- Constraints on the gluino R-hadron are set
  - R-hadrons formed from long-lived coloured sparticle (squark or gluino) and SM quarks and gluons



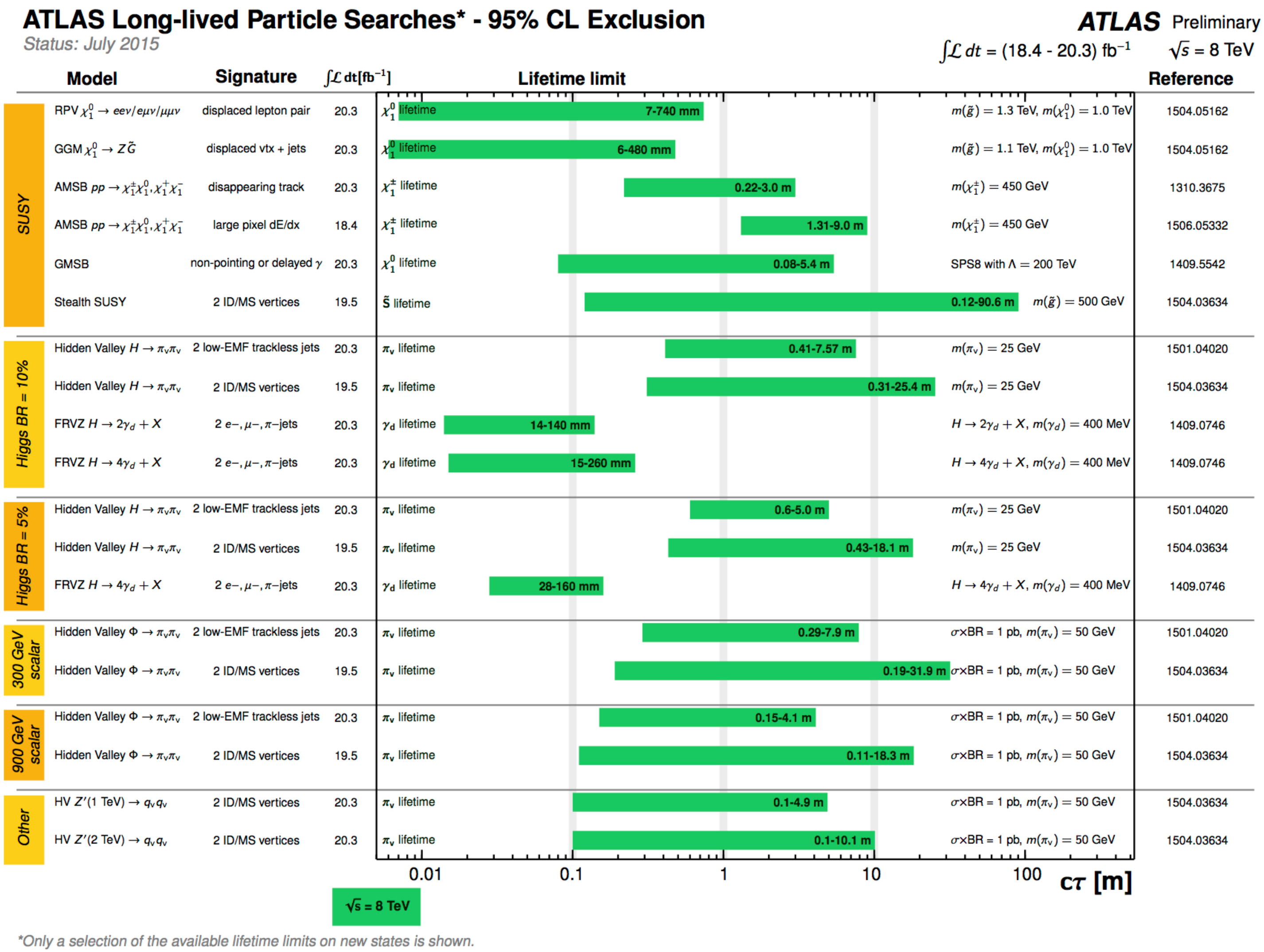
Complementary sensitivity from different searches relying on:

- reconstructed displaced vertex
- high ionization in tracker
- timing measurement in muon and calorimeters

From dE/dx study:

Gluino R-hadron with 10ns lifetime and masses up to 1185 GeV are excluded.

Long-lived particle summary

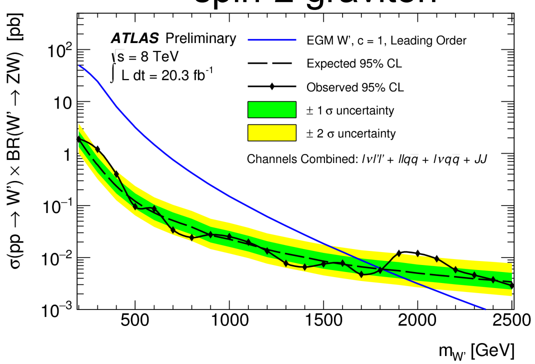


SUSY and Exotic searches

Various scenarios are considered, but no signal yet

Heavy Boson and heavy quark searches

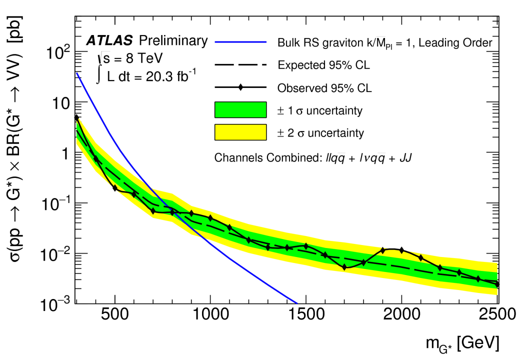
- Heavy boson decays to : WW, WZ or ZZ
  - All leptonic, semileptonic and hadronic final states are considered
  - No excess observed and limit set for the models:
    - Extended Gauge Model with a heavy W'
    - Randall-Sundrum model with a heavy spin-2 graviton



ATLAS-CONF-2015-045

EGM model exclusion limit:
Largest deviation ~2 TeV with p_0 value of 3.4σ (2.5σ) obs (exp) in JJ

@ 95% CL., $m_{W'} < 1.81$ TeV

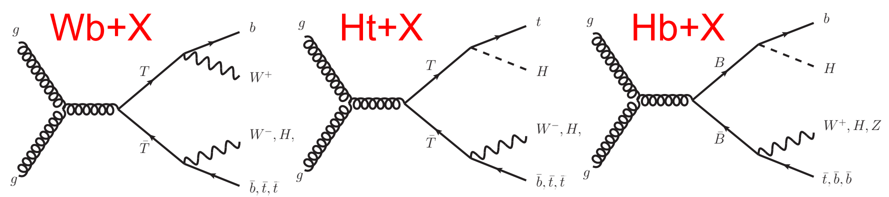


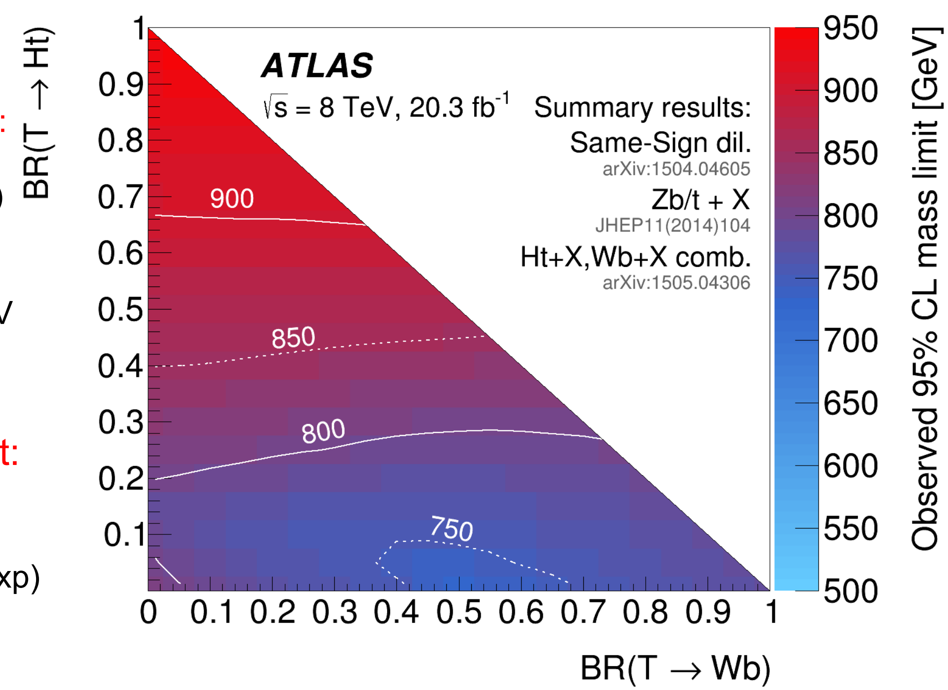
RS model exclusion limit:

@ 95% CL.
$m_{G^*} < 810$ (790) GeV obs (exp)

Best sensitivity from lνqq

- Pair production of vector-like quark (T and B)
  - T→Wb, Zt, ot Ht ; B→Wt, Zb or Hb

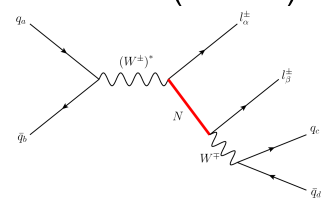




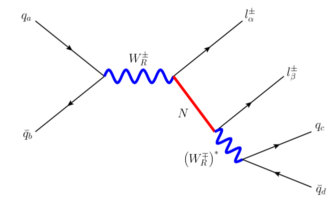
Heavy neutrino and heavy lepton searches

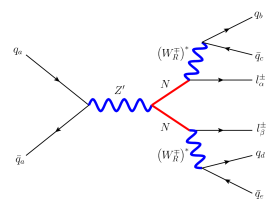
- Heavy neutrino (N) production in two models: mTISM and LRSM (JHEP 07 (2015) 162)
- Signal: two same-sign leptons and at least two high-p_T jets
- No significant excess of events is observed above the SM background

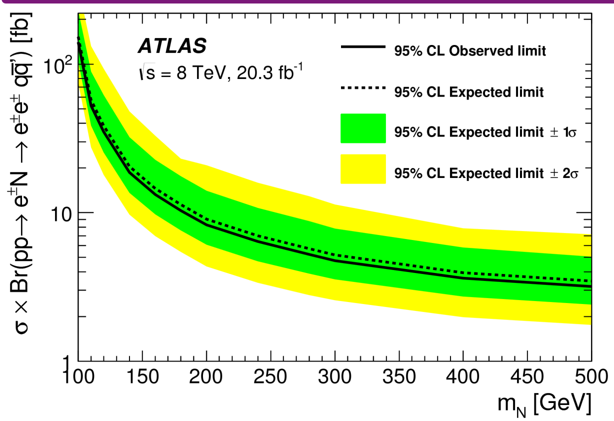
Minimal Type-I seesaw mechanism (mTISM)

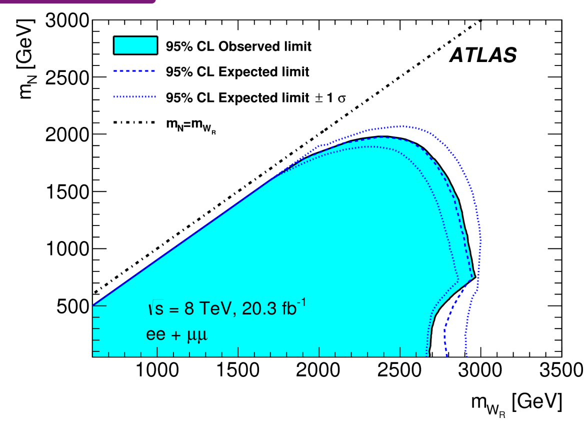


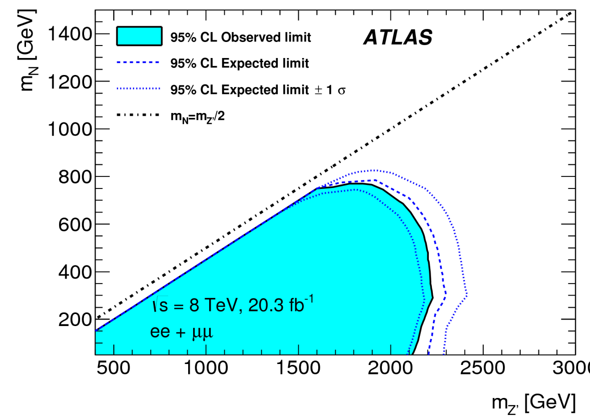
Left-Right Symmetric Model (LRSM) incldes $V_R = \{W_R, Z'\}$











Minimal Type-III seesaw heavy leptons (PRD 92, 032001 (2015))

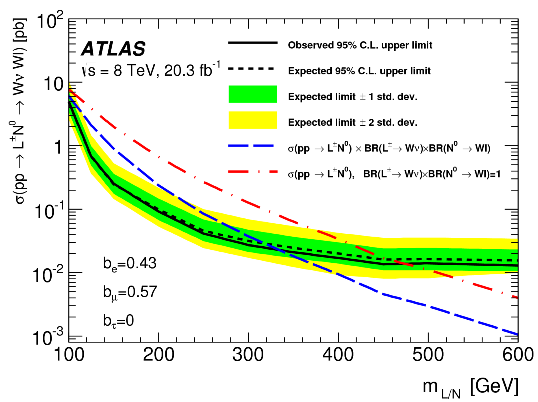
(one neutral N^0, two charged leptons, $L^{\pm}$)

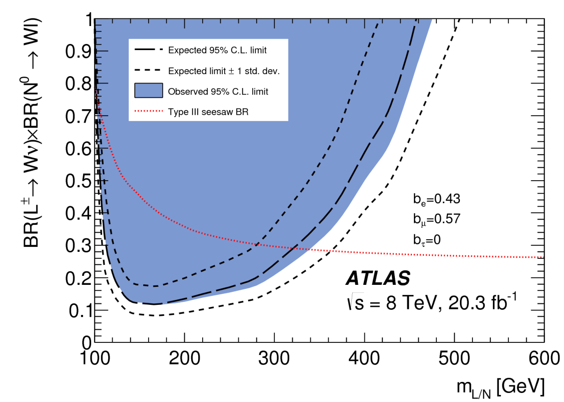
$pp \rightarrow W^* \rightarrow N^0 L^{\pm}$

($N^0 \rightarrow W^{\mp} l^{\pm}$ and $L^{\pm} \rightarrow W^{\pm} \nu$)

At 95% C.L,

$m_{L/N} < 335$ (475) GeV is excluded.



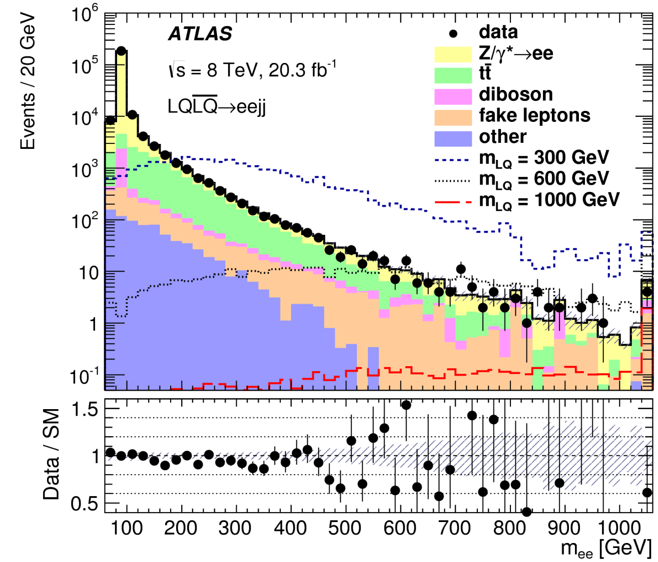


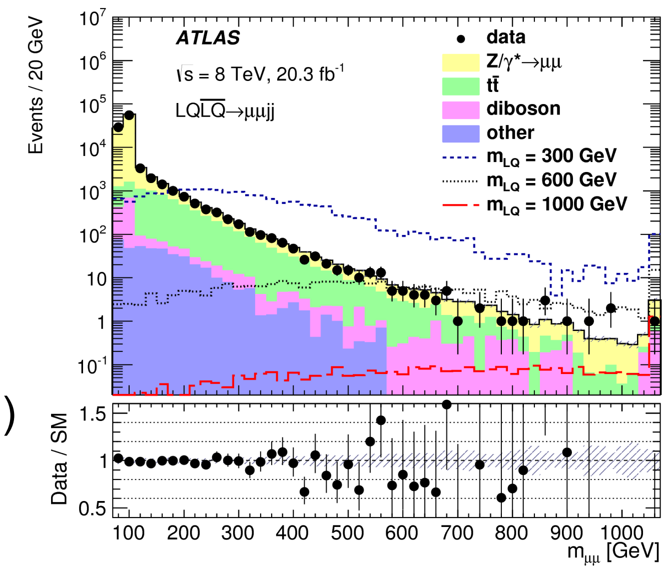
Scalar leptoquarks search

arXiv:1508.04735

- Leptoquarks (LQ) are predicted by BSM
  - LQs are colour-triplet bosons with fractional electric charge and non-zero values of both baryon and lepton number
  - Expected to decay directly to lepton–quark pairs
- First and second generation LQs (LQ1 and LQ2) are searched in 2e+2jets and 2μ+2jets,
- Third generation (LQ3) in $b\nu_\tau b\nu_\tau$, $t\nu_\tau t\nu_\tau$
  - Similar to SUSY searches such as $t\tilde{t} \to tt\tilde{\chi}_0\tilde{\chi}_0$

Excluded range at 95% CL.
m_{LQ1} < 1050 GeV
m_{LQ2} < 1000 GeV
b-channel m_{LQ3} < 640 (625) GeV expected (observed)
t-channel
200 (210) < m_{LQ3} < 685 (640) GeV expected (observed)





Exotic Summary

Extra Dimension

Gauge Boson

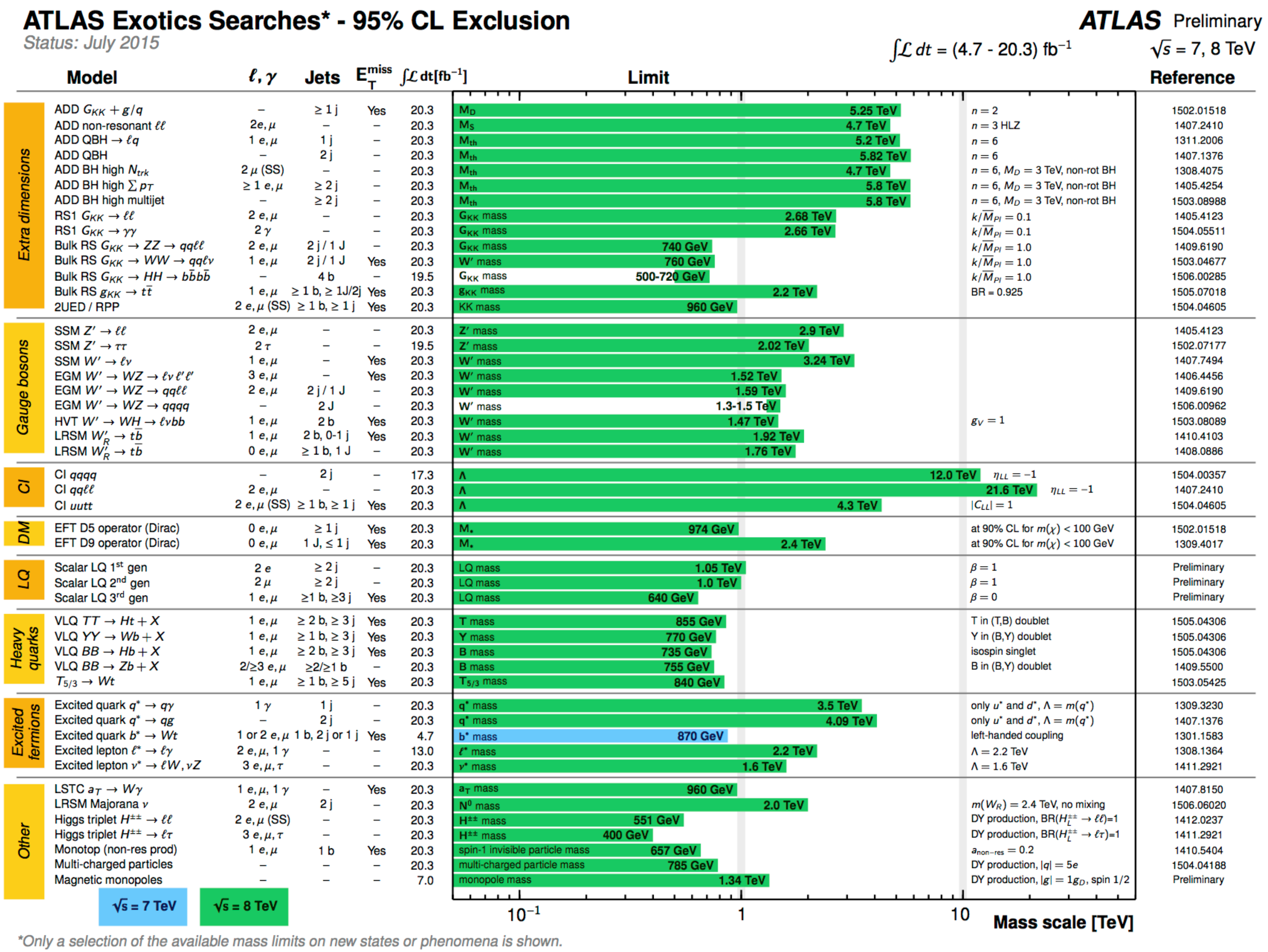
Contact Interactions

Dark Matter

Lepto Quarks

Heavy Quarks

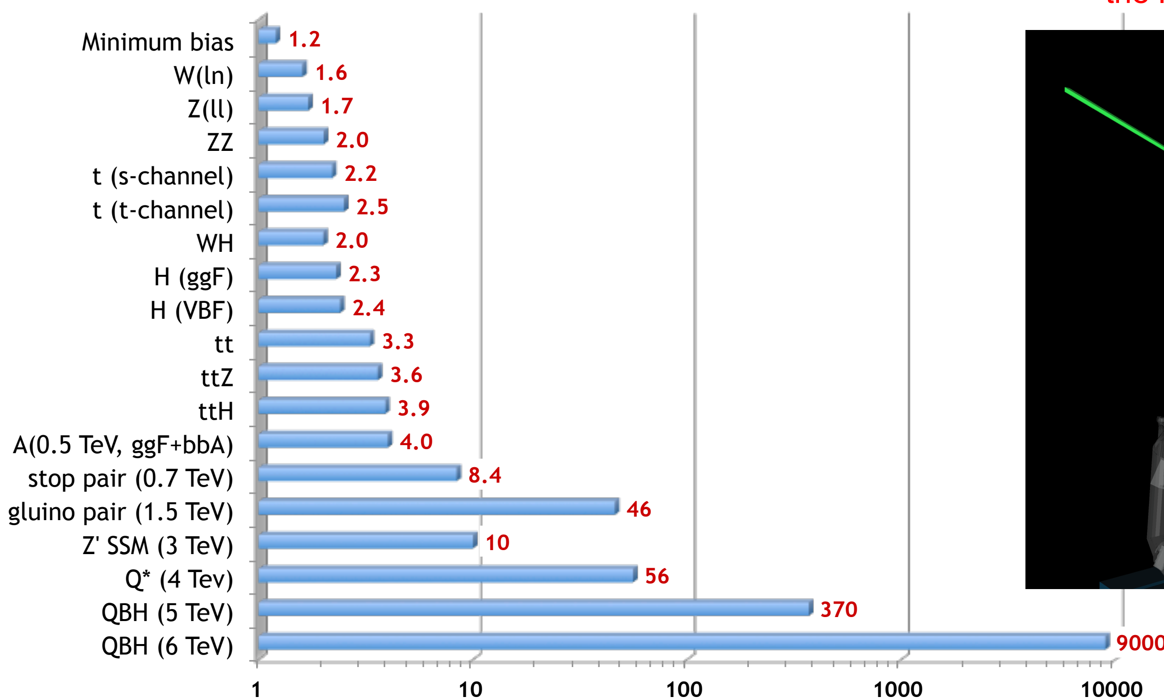
Excited Fermions



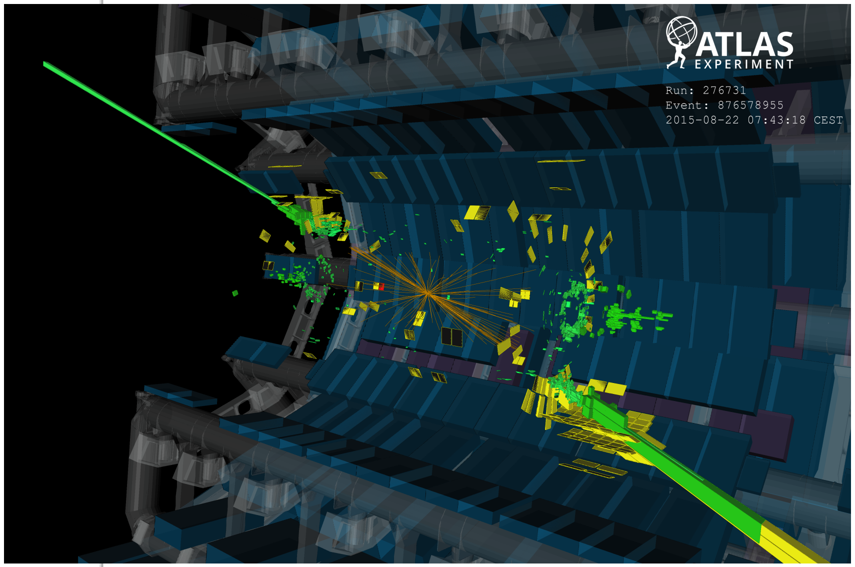
ATLAS at Run 2

- After LHC first long shutdown (LS1) , ATLAS started to take data at a higher energy of $\sqrt{s}$ = 13 TeV
- Updates for Run 2
  - A new detector (closer to beam pipe) added and upgrades to other detector components and trigger system
  - Improved online and offline reconstruction

13 TeV / 8 TeV inclusive pp cross-section ratio



two high-p_T jets with an invariant mass of 6.9 TeV
the leading and subleading jet p_T : 1.3 and 1.2 TeV



Summary

- The first running period of LHC ended successfully
  - Higgs boson is discovered and its properties measured
  - Extensive searches on BSM was done
    - No new physics observed yet
  - Number of analysis are being finalized

- ATLAS Run 2 started with higher energy and higher luminosity
  - Explore new mass ranges for new physics

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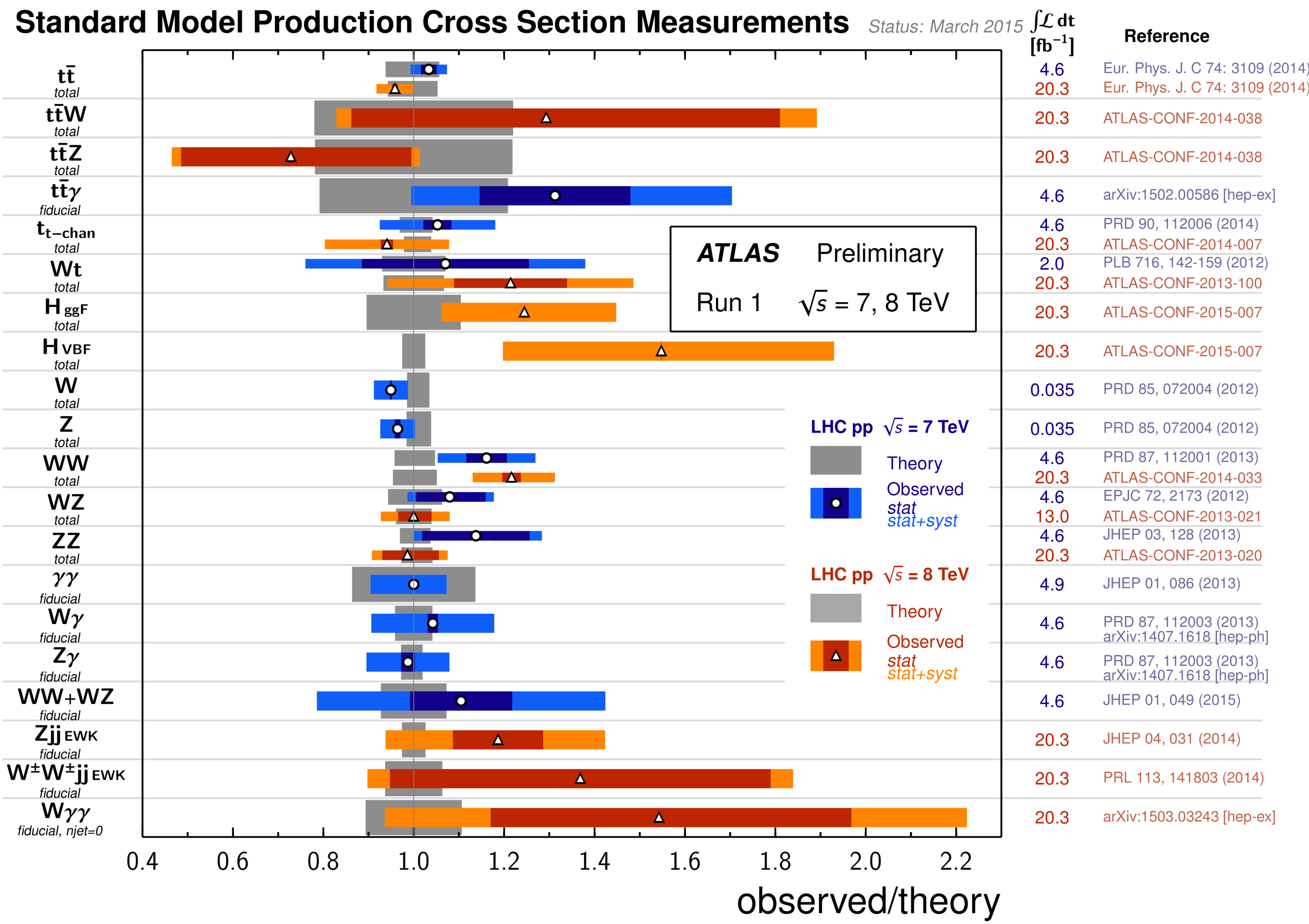
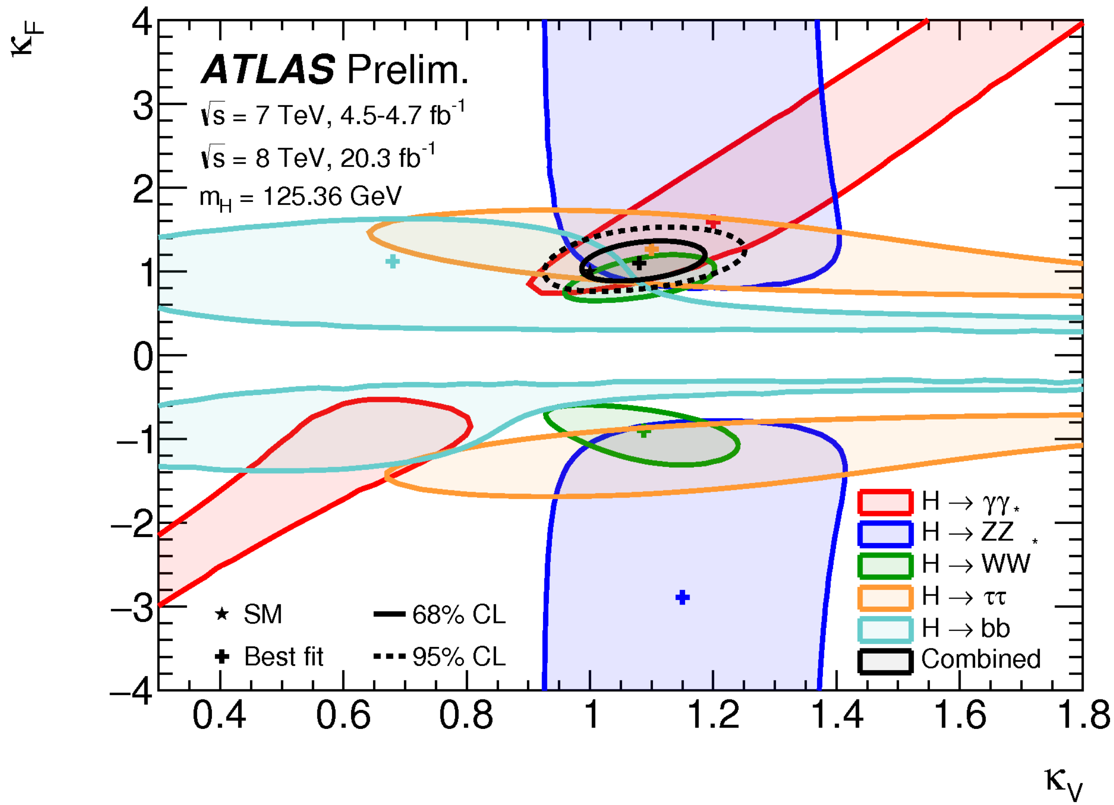
BACKUP

Standard Model Summary



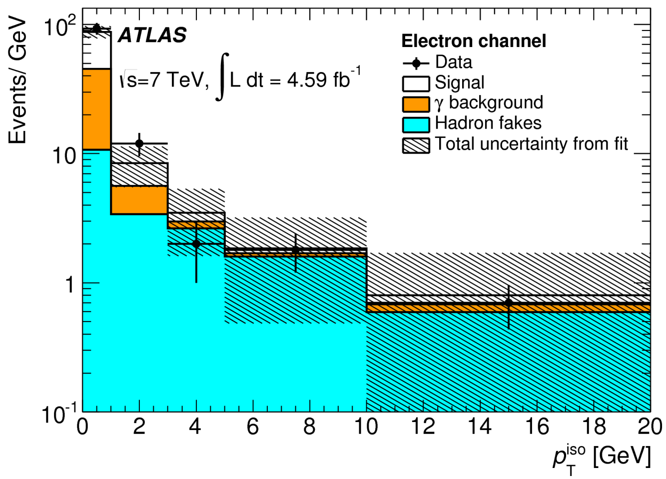
No significant discrepancy compared to the theory predictions

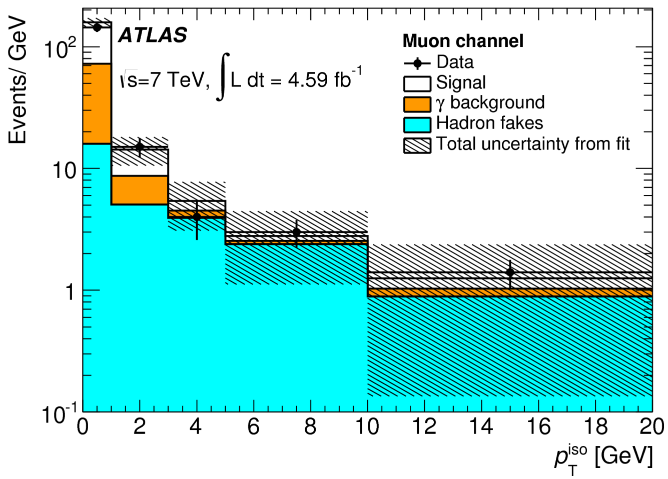
Higgs couplings from each channel



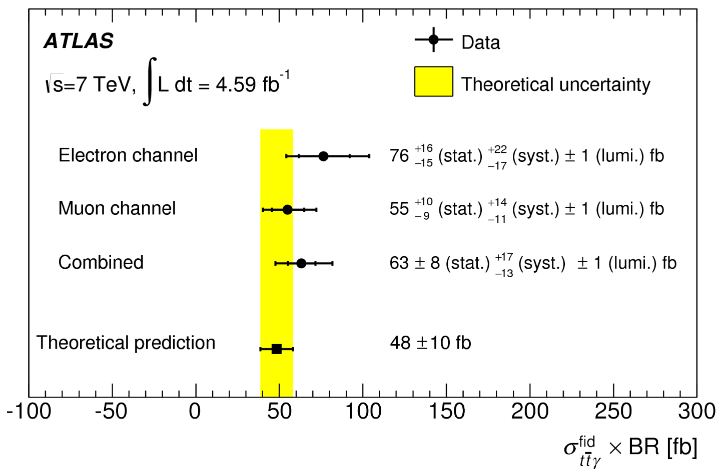
ttV (V=γ) production

- ttγ analysis (PRD 91, 072007 (2015))
  - lepton+jets (lepton electron or muon)





Combined (e and μ) value is 5.3σ away from the no-signal hypothesis



Charge asymmetry

$$A_C = \frac{N(\Delta|y| > 0 - \Delta|y| < 0)}{N(\Delta|y| > 0 + \Delta|y| < 0)}, \quad \Delta|y| = |y_t| - |y_{\bar{t}}|$$