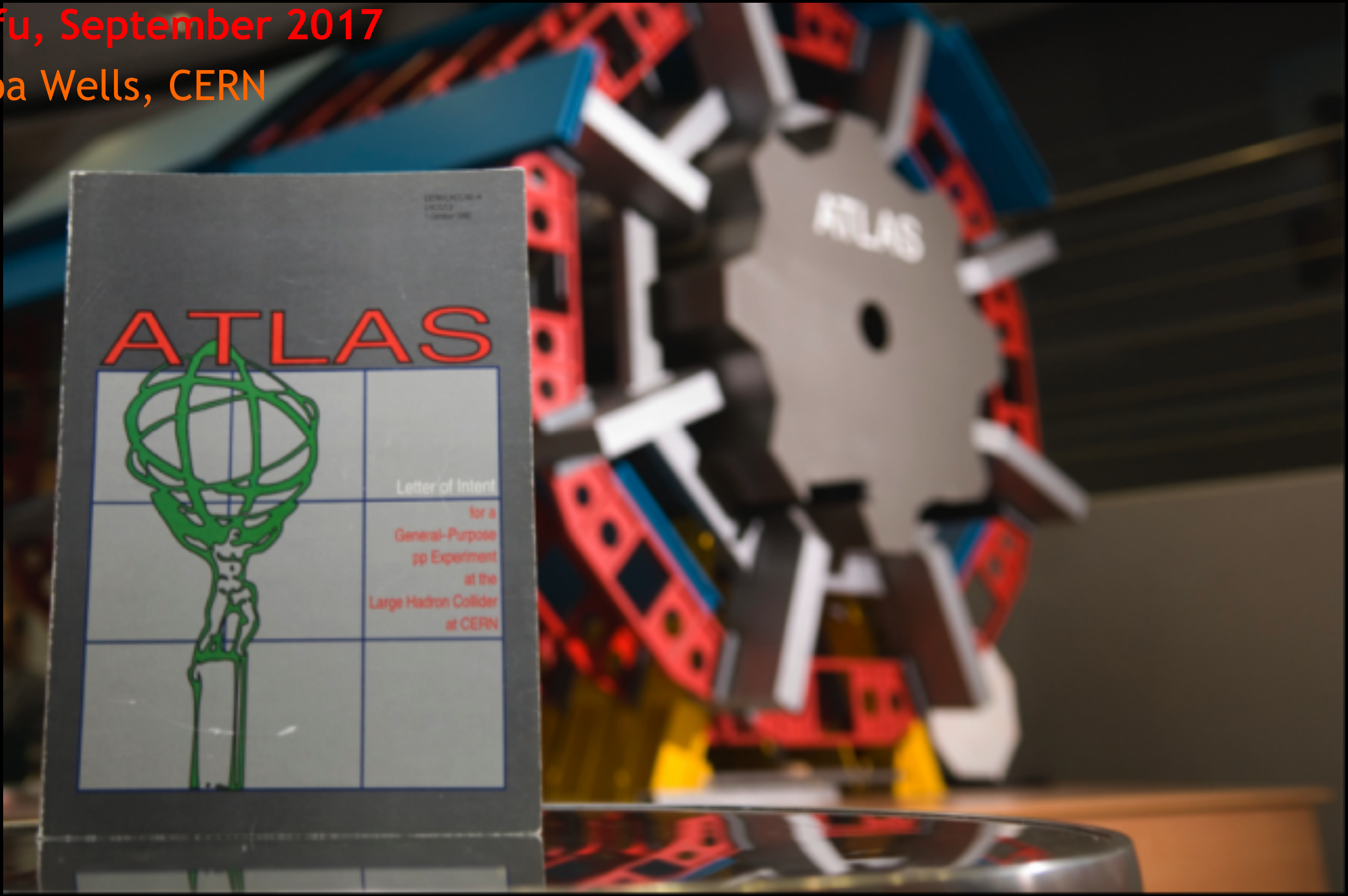
ATLAS latest results and future prospects

Corfu, September 2017

Pippa Wells, CERN



ATLAS Letter of Intent. 1 October 1992

Introduction

- This talk covers selected highlights of ATLAS results
    - More details in many other dedicated talks during this workshop [see next slide]

- Running conditions and performance in Run 2
    - Pileup mitigation
- Measurements
    - Electroweak, QCD, top physics, Higgs boson.
    - Emphasis on some personal favourites
- Searches for SUSY and other BSM physics
    - Spoiler: no new hints of signals

- Future prospects with upgrades
    - More pileup!

More information

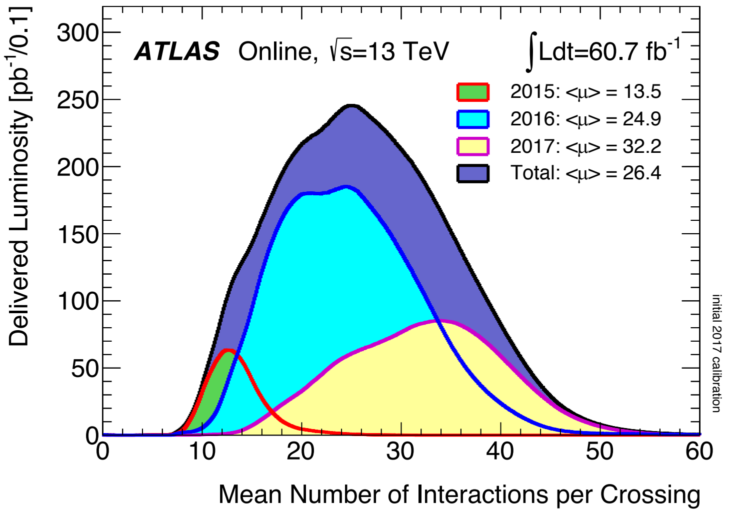
- ATLAS Public Results https://twiki.cern.ch/twiki/bin/view/AtlasPublic

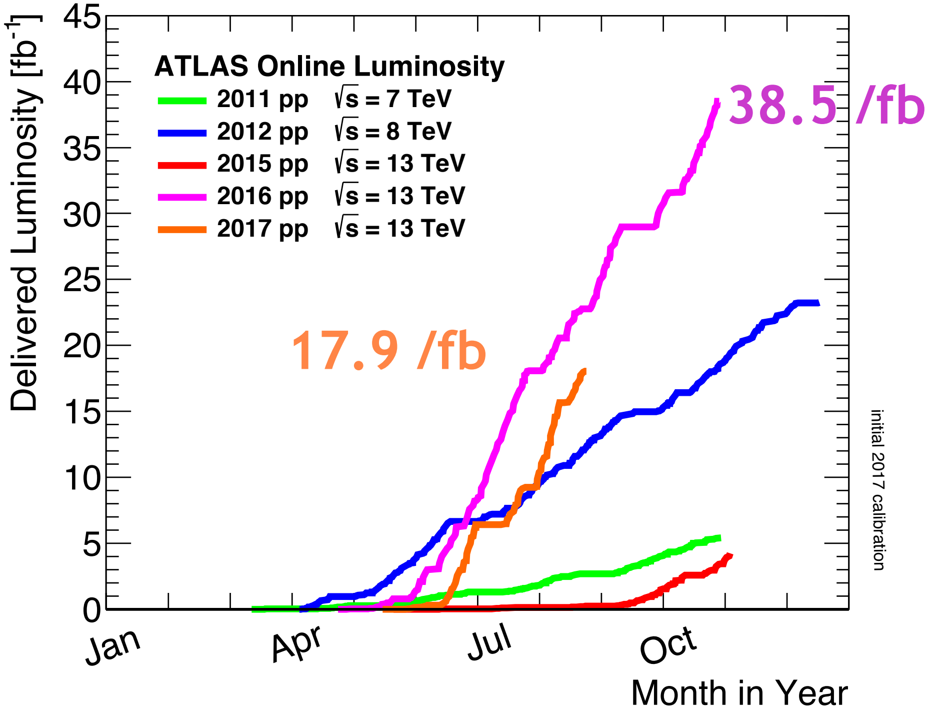
- Overview talks including ATLAS results
  - Recent Standard Model results in ATLAS and CMS (Beauchemin)
  - Top physics in ATLAS and CMS (Diez Pardos)
  - Higgs (SM and BSM) in ATLAS and CMS (Coadou)
  - Physics Prospects for HL-LHC with the ATLAS detector (Iconomidou-Fayard)
  - Recent SUSY results in ATLAS (Mamuzic)
  - Recent Exotics and beyond the SM results in ATLAS and CMS (Pigazzini)

- ATLAS young Scientist talks
  - Search for ttH production in the 3 lepton final state at ATLAS (Wang)
  - Search for dark matter in the jet+missing transverse momentum topology with ATLAS (Ratti)
  - Measurement of the W-boson mass at the ATLAS experiment (Kivernyk)
  - Measurement of $H \rightarrow \tau\tau$ in the semileptonic final state using the ATLAS detector (De Maria)

LHC and ATLAS performance

- Peak lumi in 2017 1.74x10^{34}cm^{-2}s^{-1}
- 2016: 1.38x10^{34}cm^{-2}s^{-1}
- Goal for 2017 and 2018: 45/fb per year at 13 TeV with ~50% stable beam time
- Design pileup <μ>~23





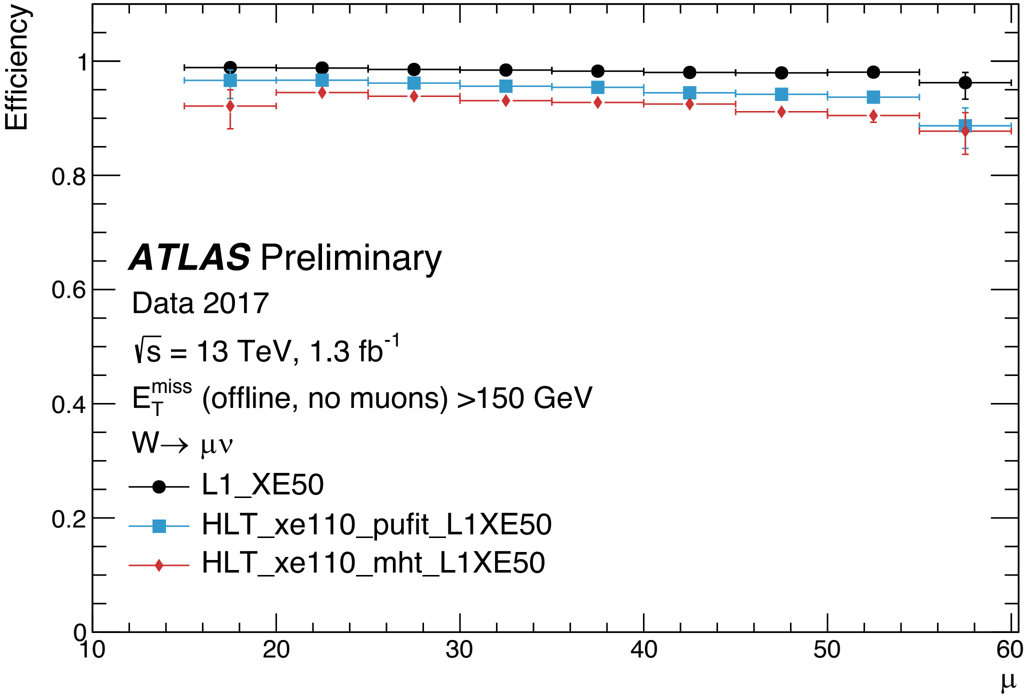
38.5 /fb

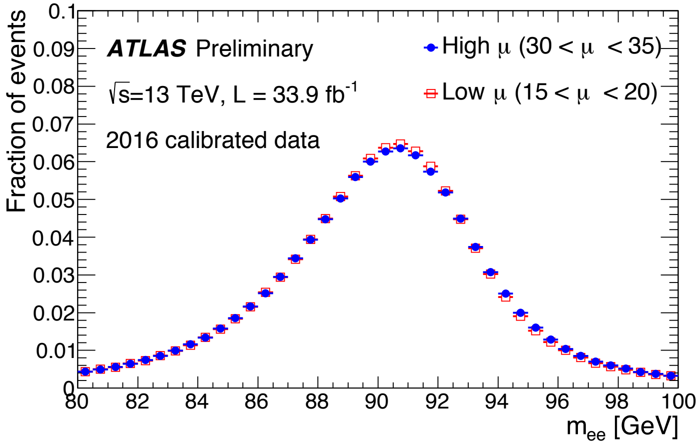
17.9 /fb

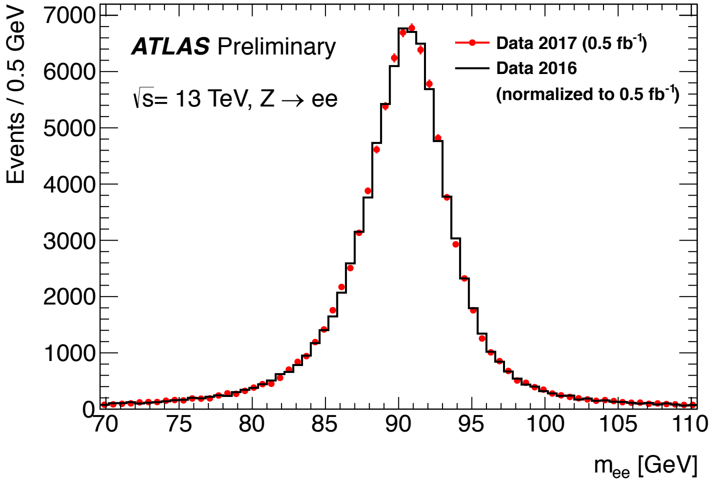
- Algorithms for pileup mitigation needed at trigger level to keep low thresholds

Physics object performance with pileup

- Continuous work to refine calibrations and trigger performance
  - Examples: Level 1 and high level trigger E_T^{miss} in W→μν events (2017)
  - Mass of Z→ee events (2016 high vs. low μ and 2017 vs. 2016)



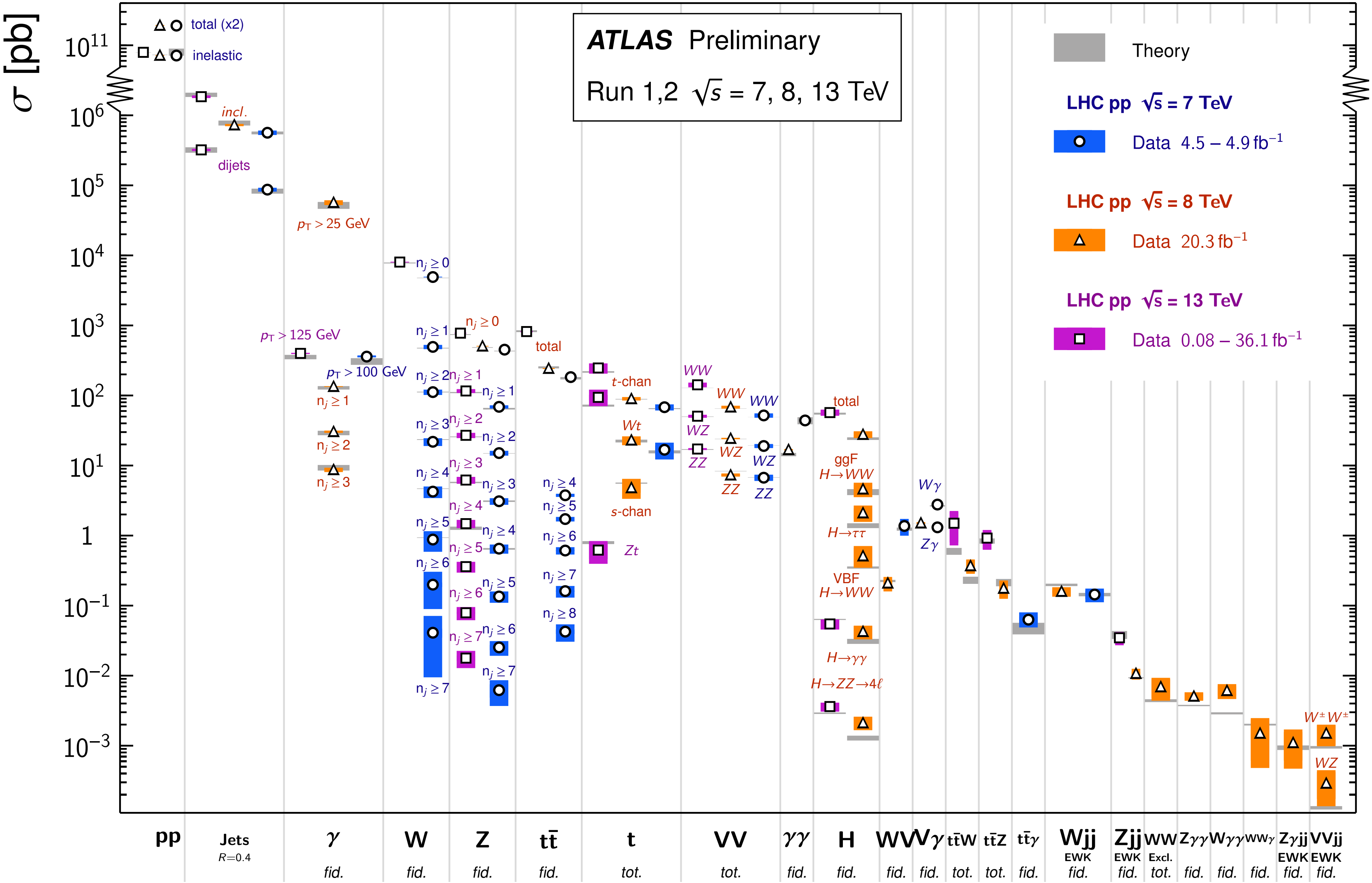




Standard Model measurements

Standard Model Production Cross Section Measurements

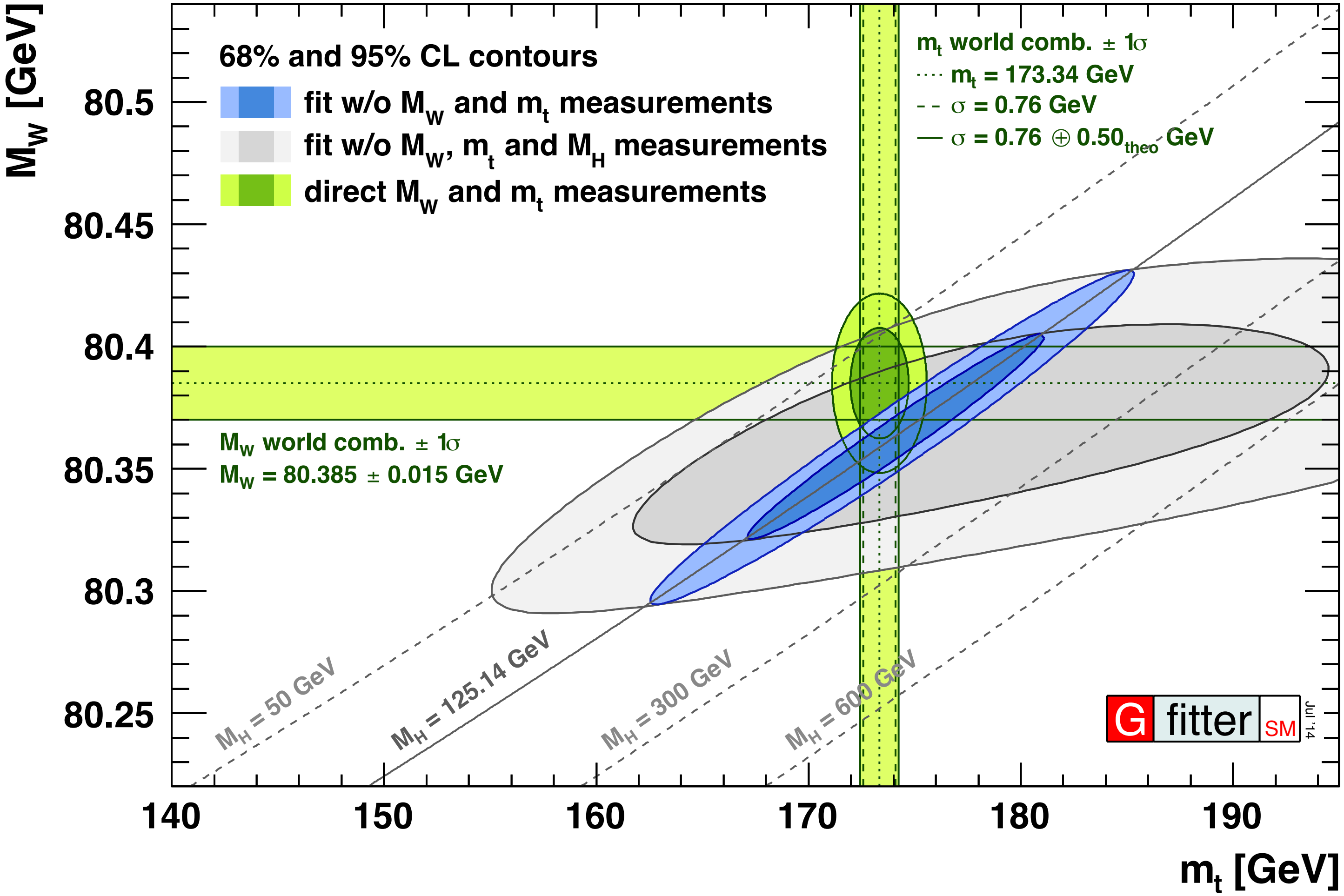
Status: July 2017



arXiv:1407.3792

Electroweak standard model

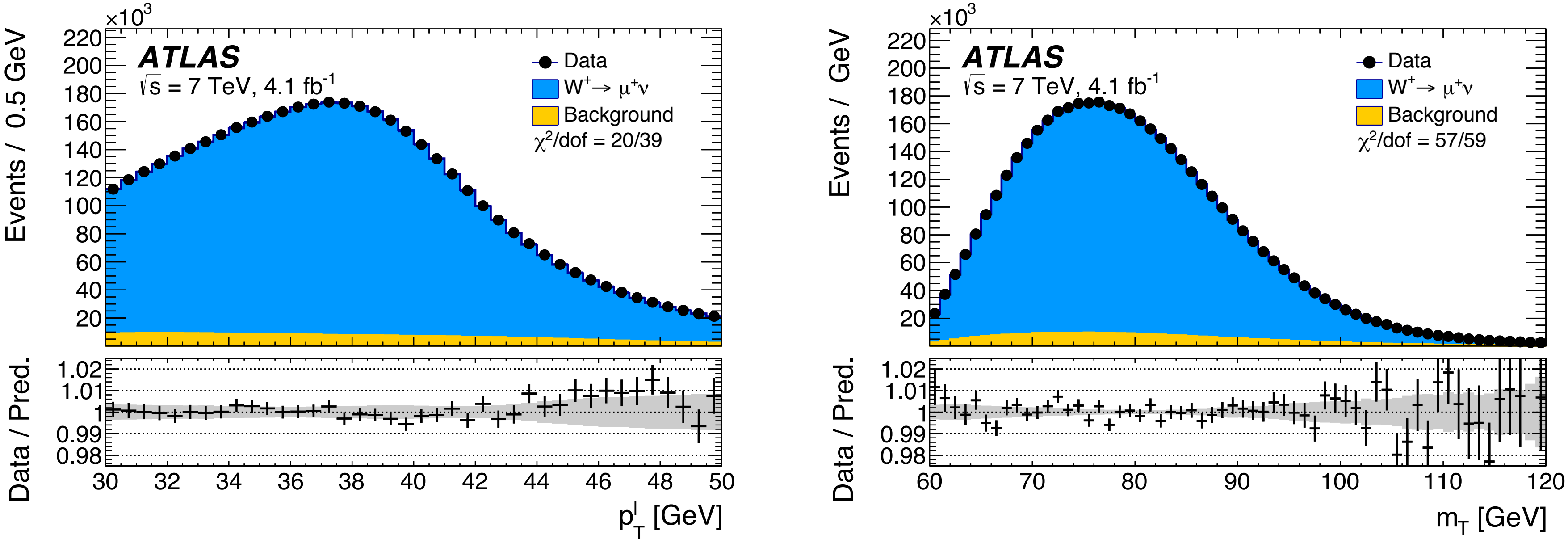
SM prediction is more precise than direct W mass measurement



arXiv:1701.07240

New W mass from ATLAS

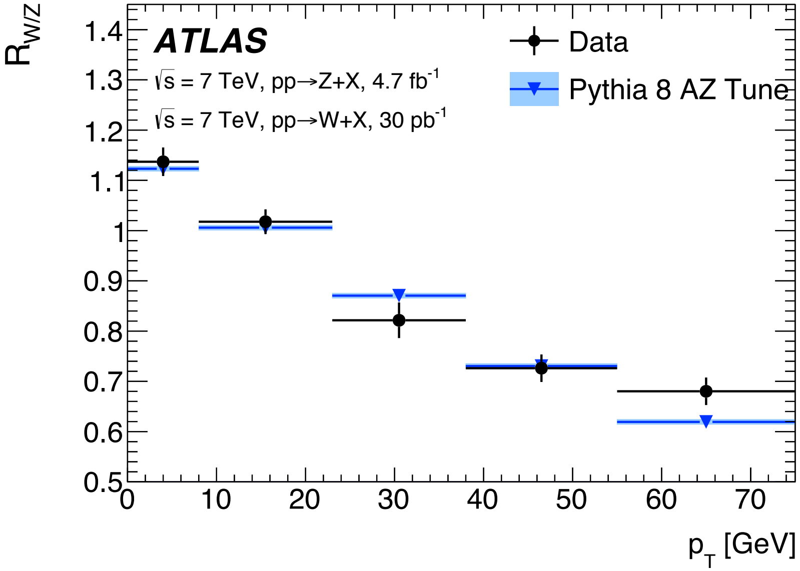
- Template fits to lepton p_T or transverse mass of lν system (7 TeV pp)
  - Z→ll events also used for calibration
  - Experimental challenge – calibrate leptons and hadronic recoil
  - Multijet background from fits in bins of lepton isolation
- Physics modelling uncertainties dominate
- Closure tests: comparison of W+,W-,e,μ, p_T fit or m_T fit

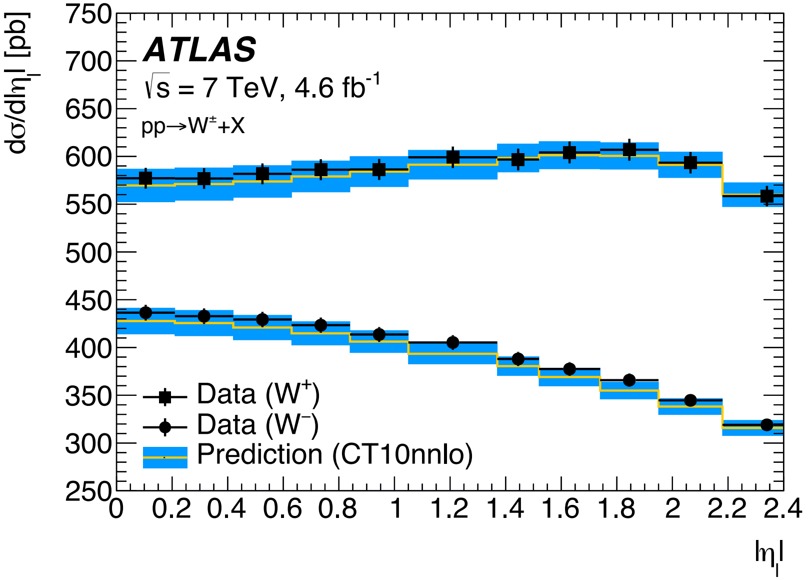


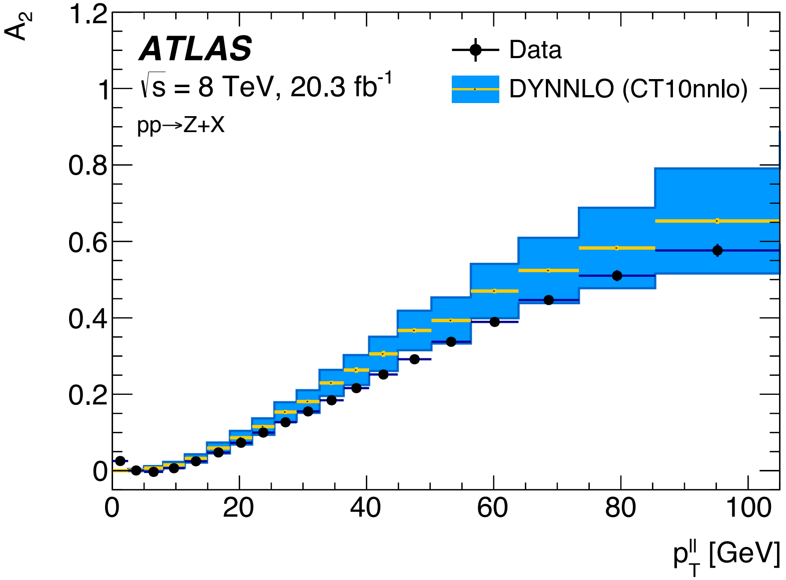
arXiv:1701.07240

Physics modelling for W mass

- Uncertainties constrained from data (including Z at 8 TeV)
  - p_T^W from PYTHIA 8 with AZ tune, after fit to Z data
  - Reweight rapidity distribution and angular variables to NNLO
  - Validate angular variables with Z data



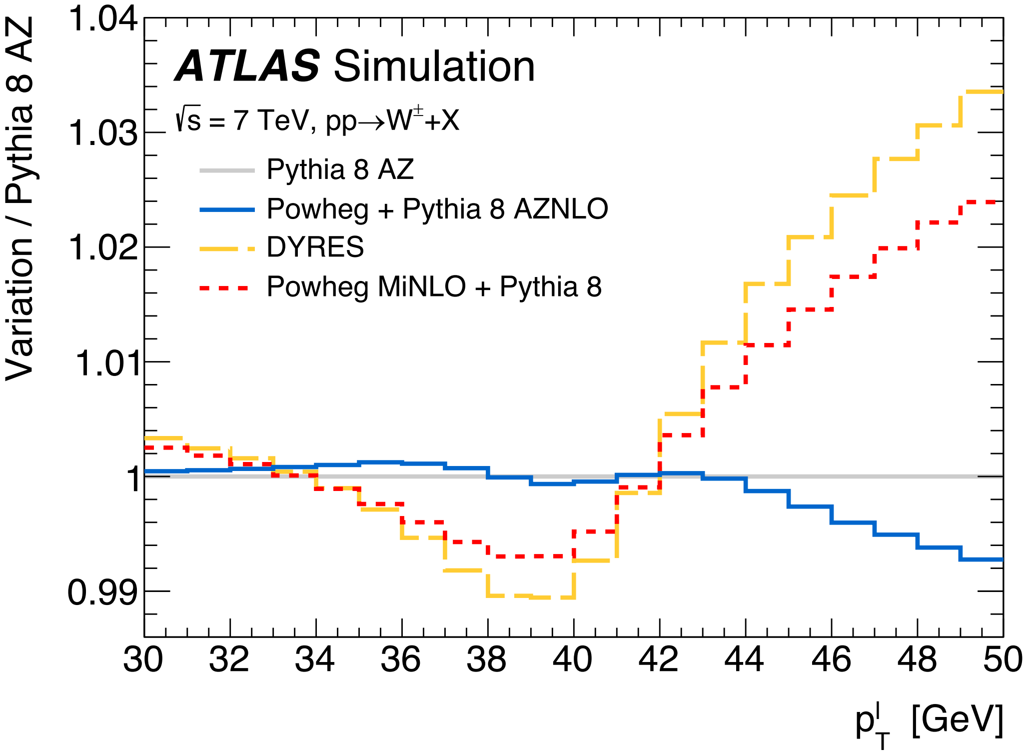




arXiv:1701.07240

W mass uncertainties

- Alternative p_T^W models are not used



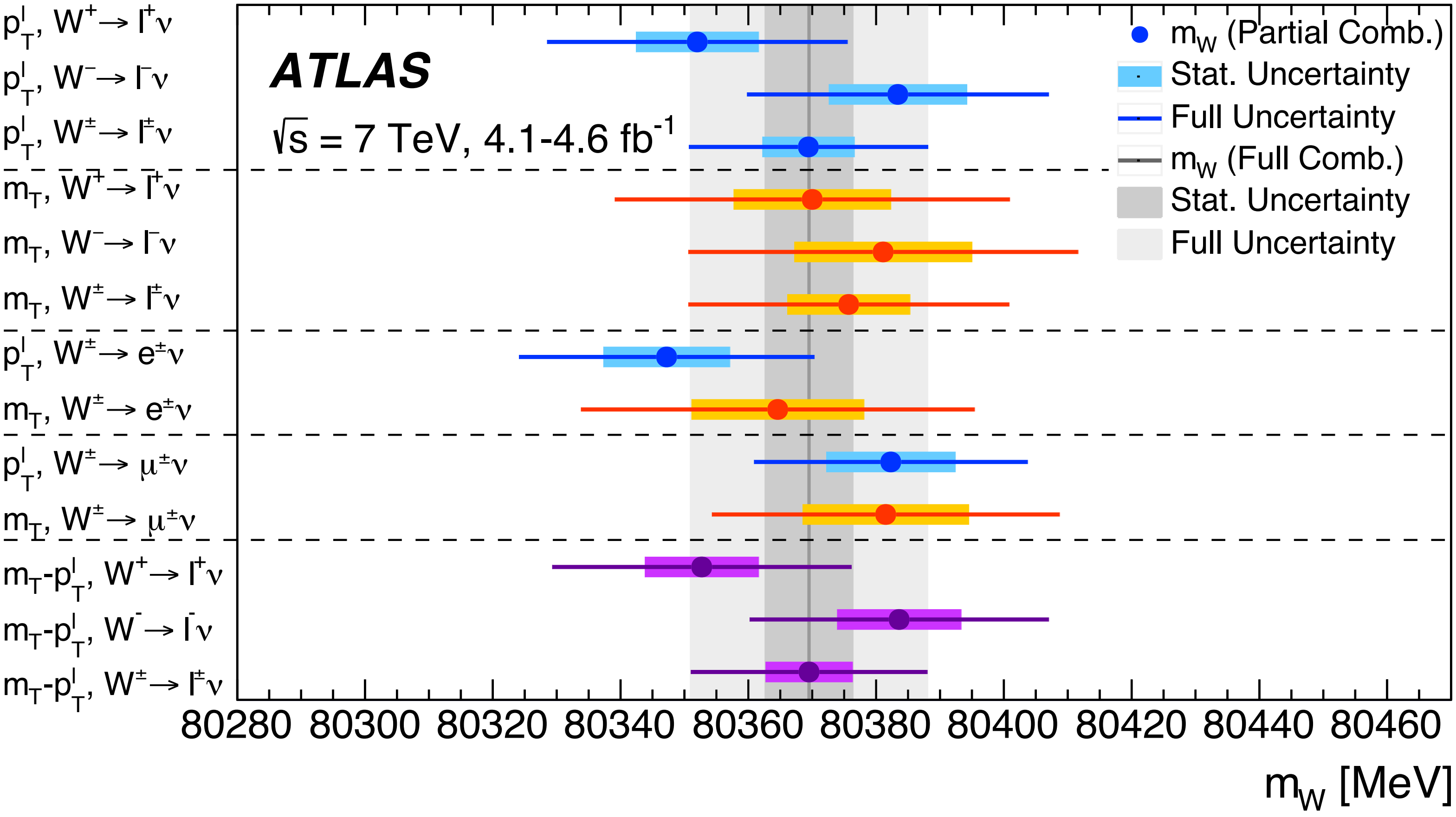
- Total uncertainties

Uncertainty	[MeV]
Statistical	7
Experimental systematic	11
QCD	8
PDF	9
QED	6
$p_T(W)$	n/a

arXiv:1701.07240

W mass result

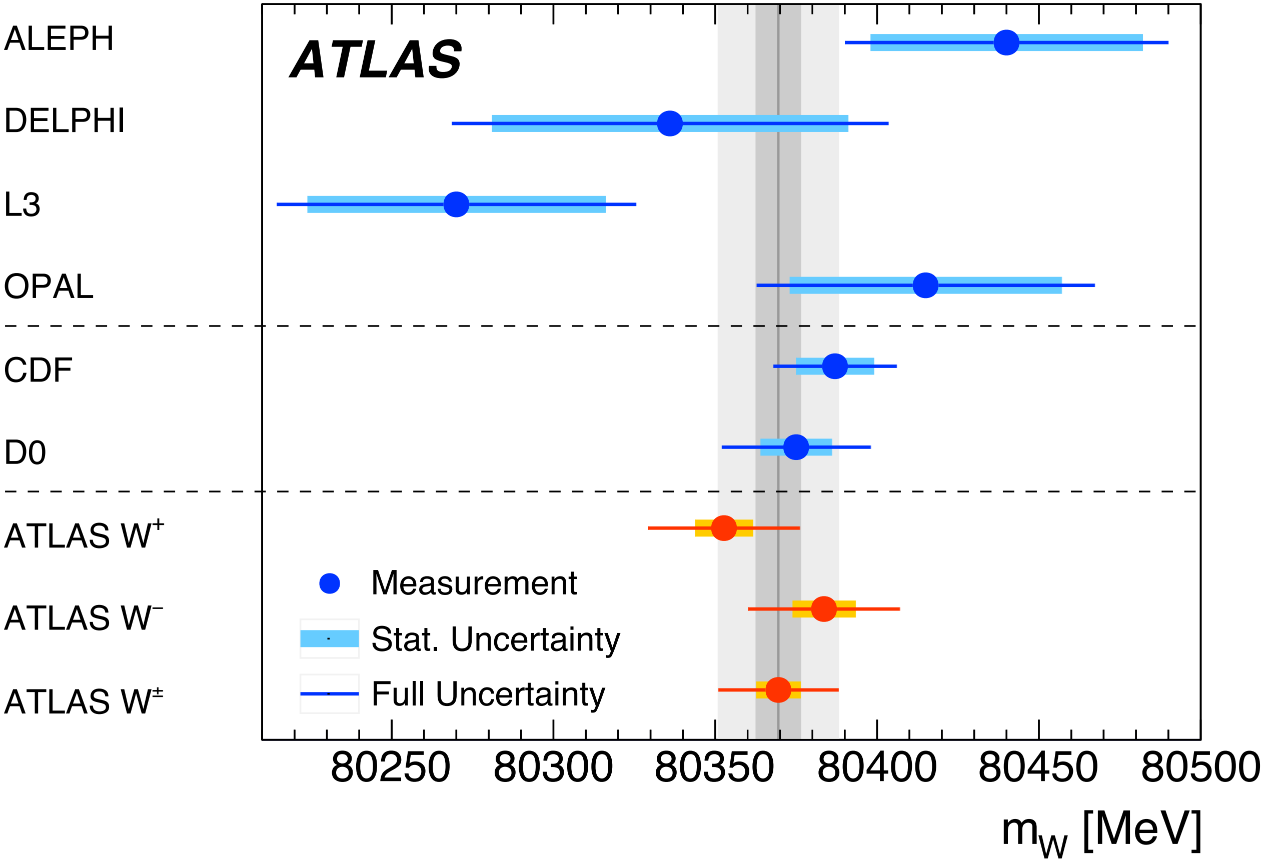
- Combined result:
  m_W = 80370±7(stat)±11(exp)±14(mod) = 80370±19 MeV



arXiv:1701.07240

W mass result

- Combined result:
  m_W = 80370±7(stat)±11(exp)±14(mod) = 80370±19 MeV
- Compare total uncertainty: CDF ±19 MeV, D0 ±23 MeV

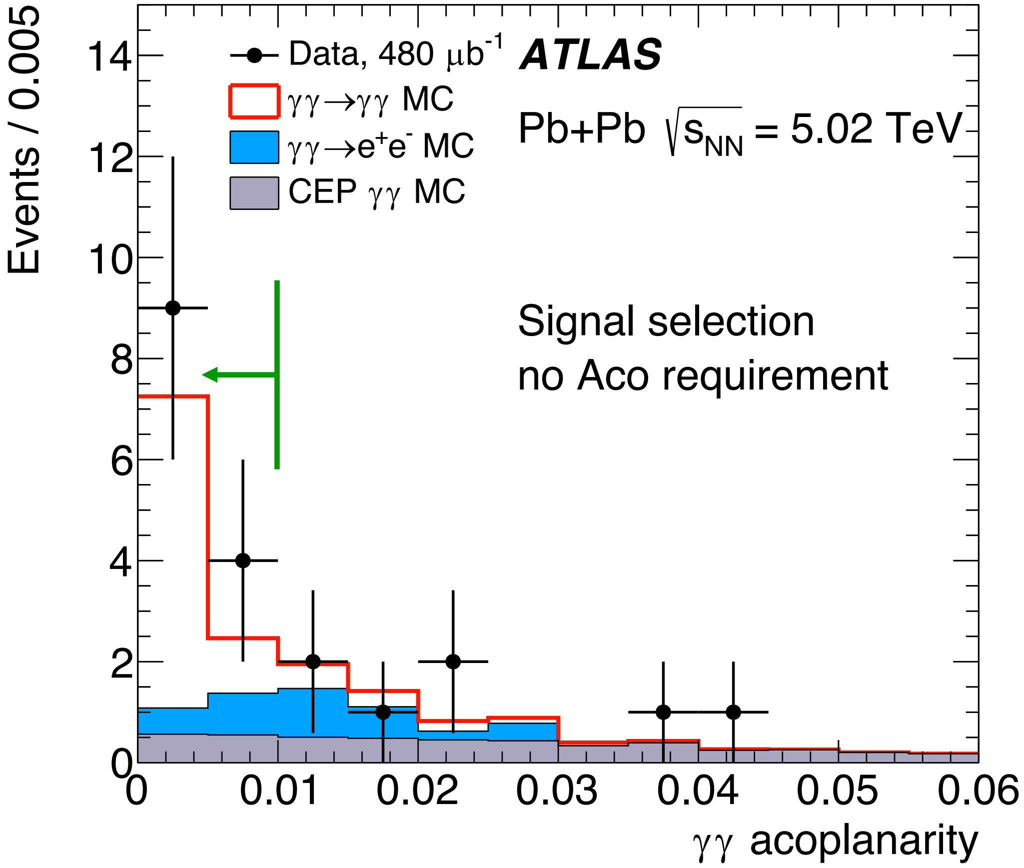


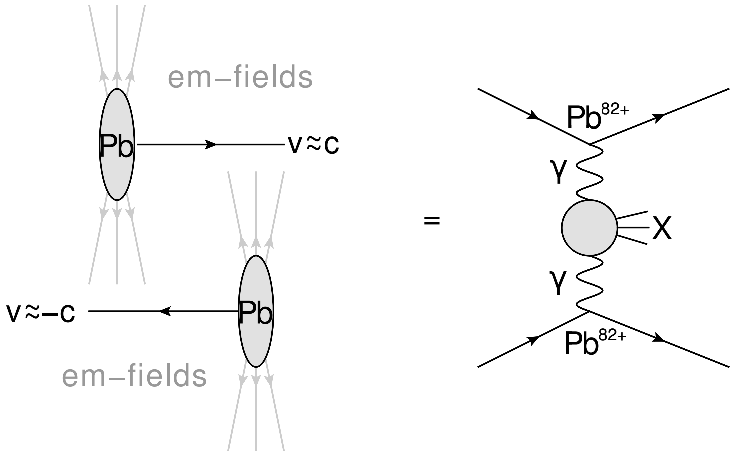
https://www.nature.com/nphys/journal/vaop/ncurrent/full/nphys4208.html

arXiv:1702.01625

Light-by-light scattering

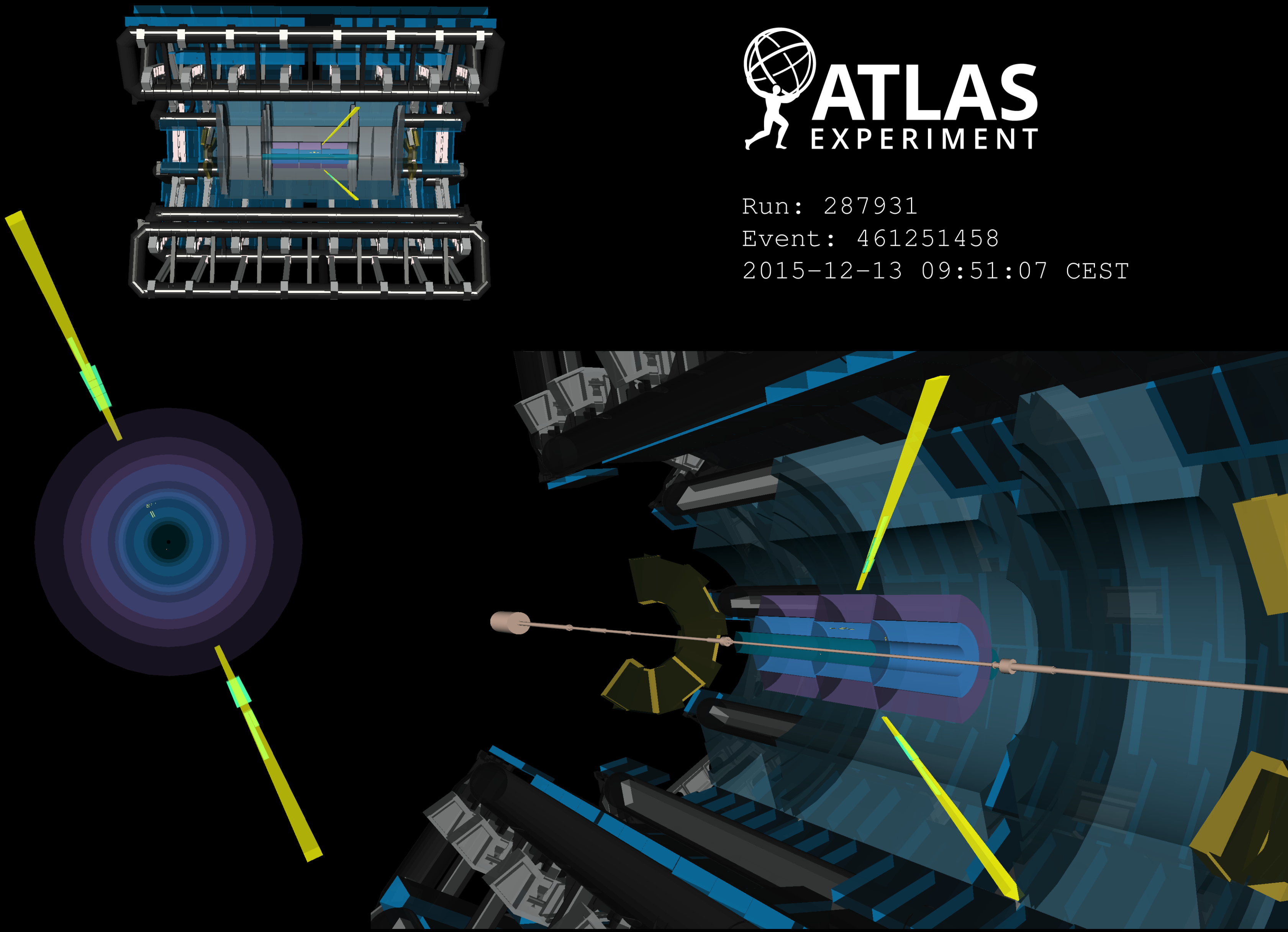
- Evidence for γγ→γγ in the large electromagnetic fields of colliding lead ions at $\sqrt{s_{NN}}$=5.02 TeV
    - 13 events with 2.6±0.7 background; 4.4σ significance





Ultraperipheral events, with only two photons in the final state

Ultra peripheral Pb-Pb collision

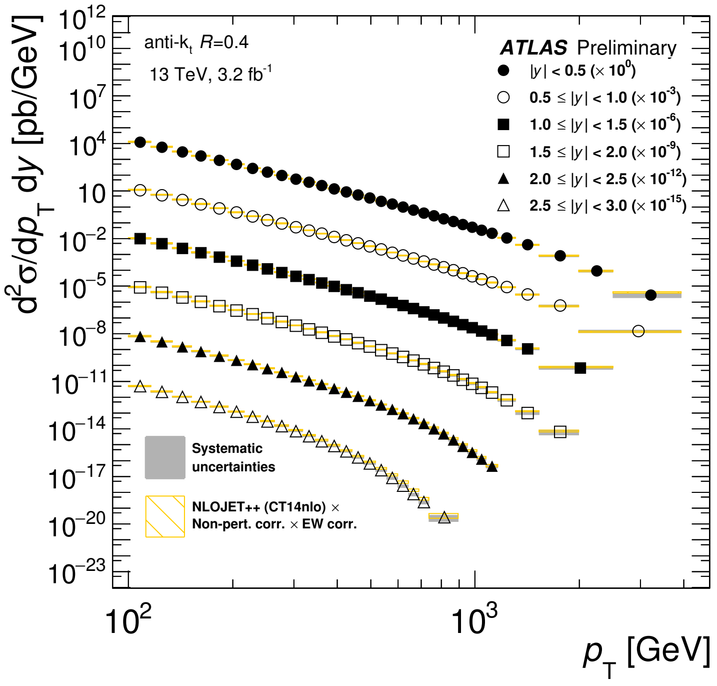


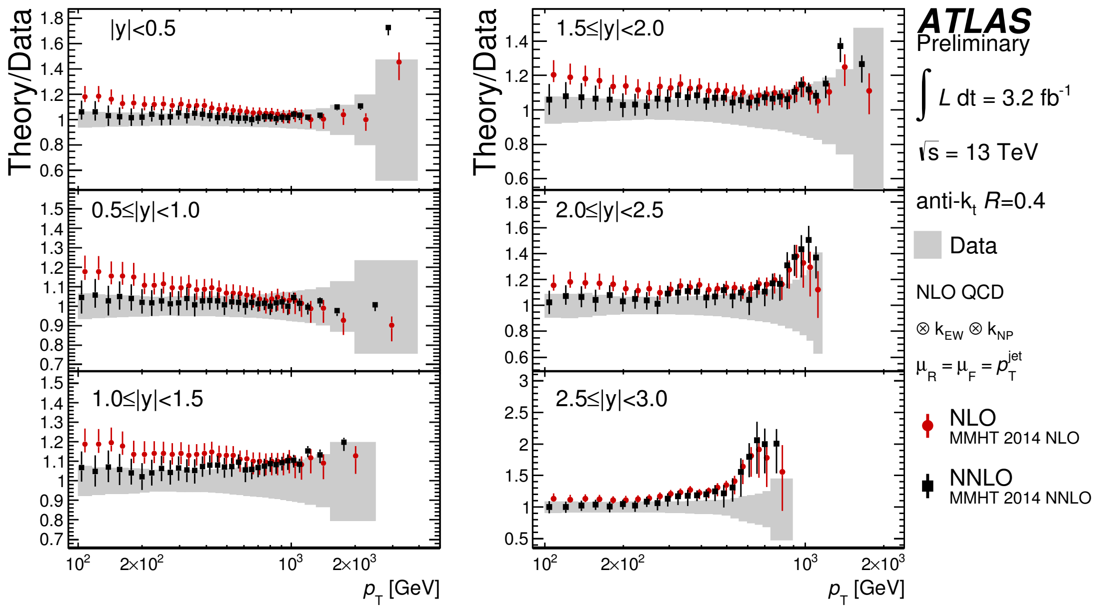
Run: 287931
Event: 461251458
2015-12-13 09:51:07 CEST

ATLAS-CONF-2017-048

Jets at 13 TeV

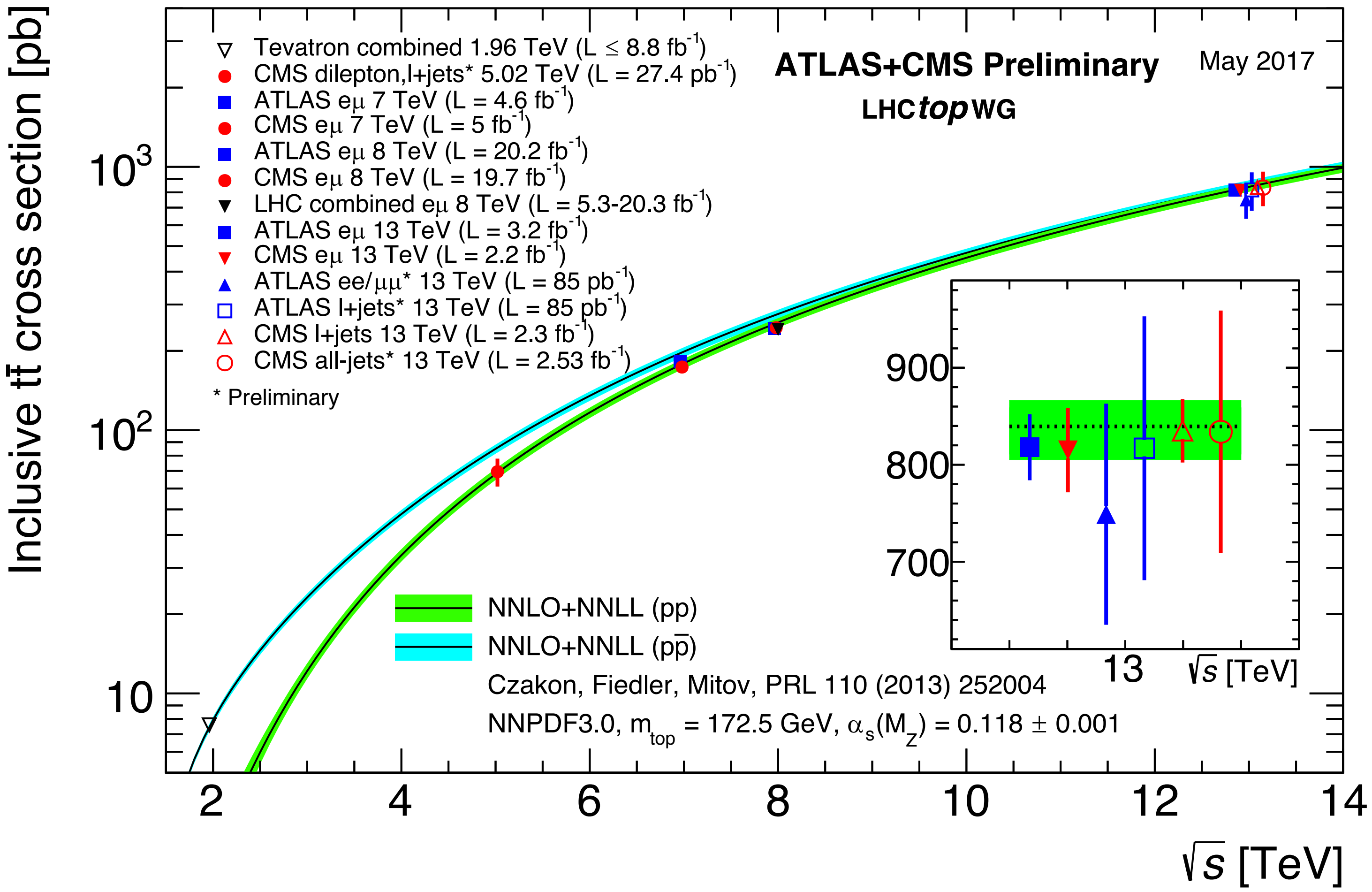
- Double differential inclusive and dijet cross sections from 2015 data
  - Compared to NLO pQCD predictions with different PDFs & scales
  - Inclusive cross sections also compared to NNLO (level of agreement depends on choice of scale).





- Dijet distributions also used in searches – see later

tt(+X) inclusive cross-section



Measured in eμ channel at 13 TeV with 2015 data

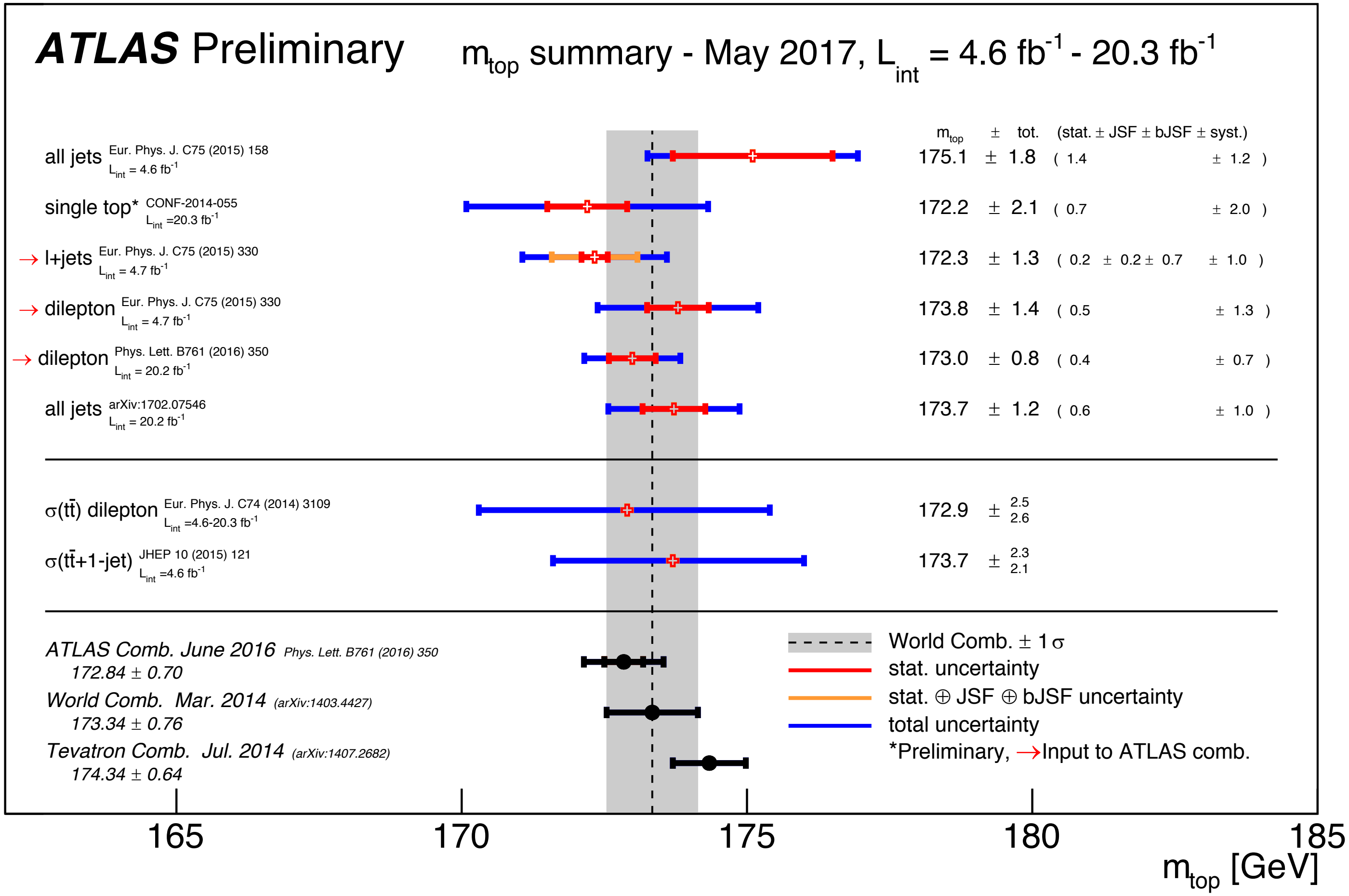
Also differential measurements eg. pT(t), pT(tt), m(tt)

Top mass

Direct

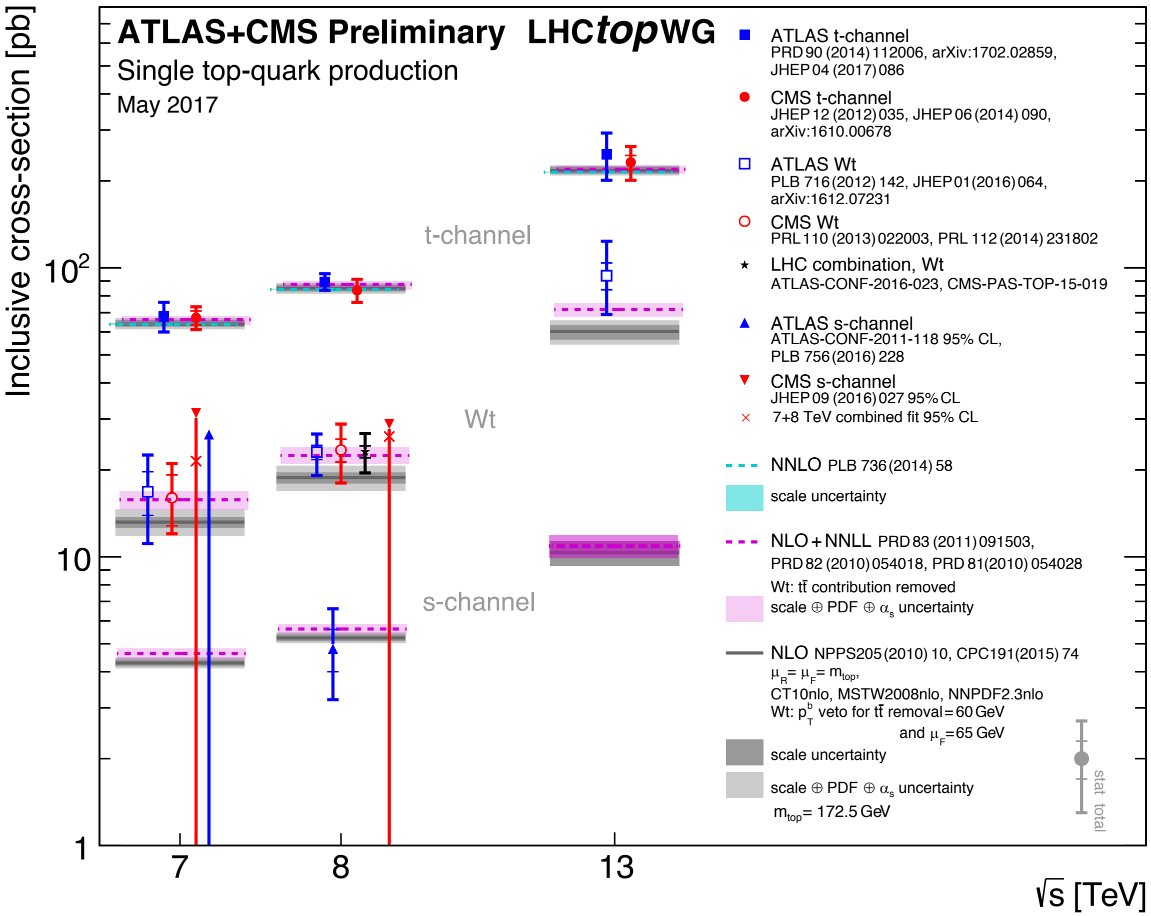
In comb.

Pole



- Latest measurements from Run 1
    - Sub GeV precision from 8 TeV dilepton result
    - Compare pole mass from cross-section measurements

Single top quark production

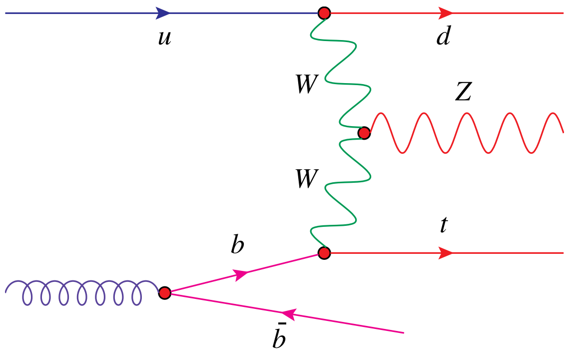


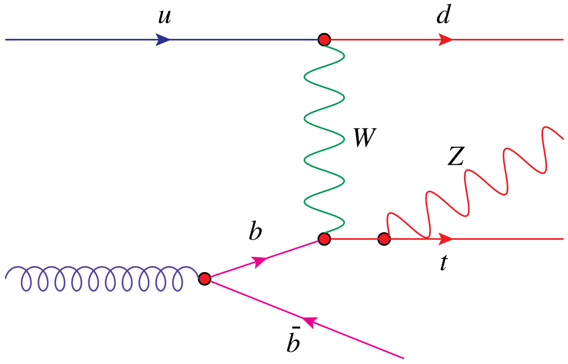
- Cross-sections agree with SM prediction, $|V_{tb}|$ consistent with 1
- t-channel, Wt and s-channel shown here

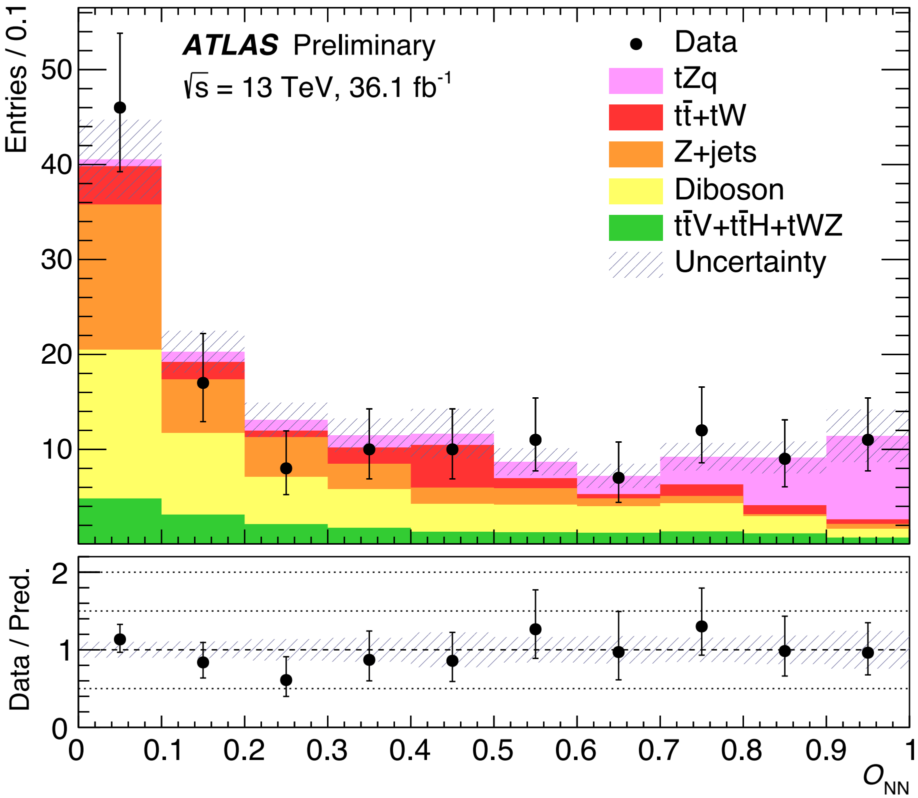
ATLAS-CONF-2017-052

Single top with a Z

- Events with 3-leptons, two jets – one tagged as b-jet
- Several kinematic variables in neural net
- Signal significance 4.2 σ observed (5.4 σ expected)
- Cross section 600 ± 170 (stat) ± 140 (syst) fb

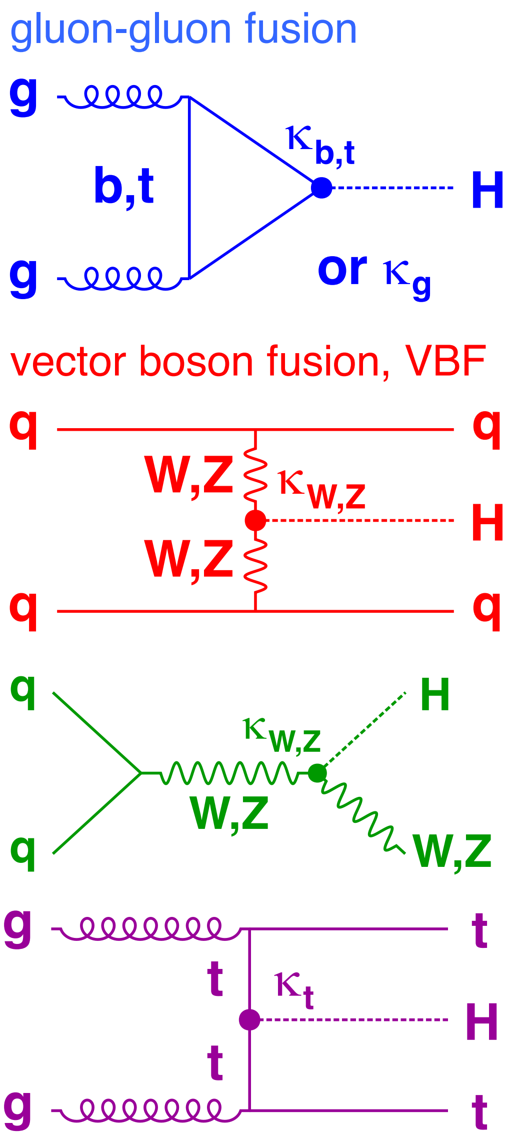


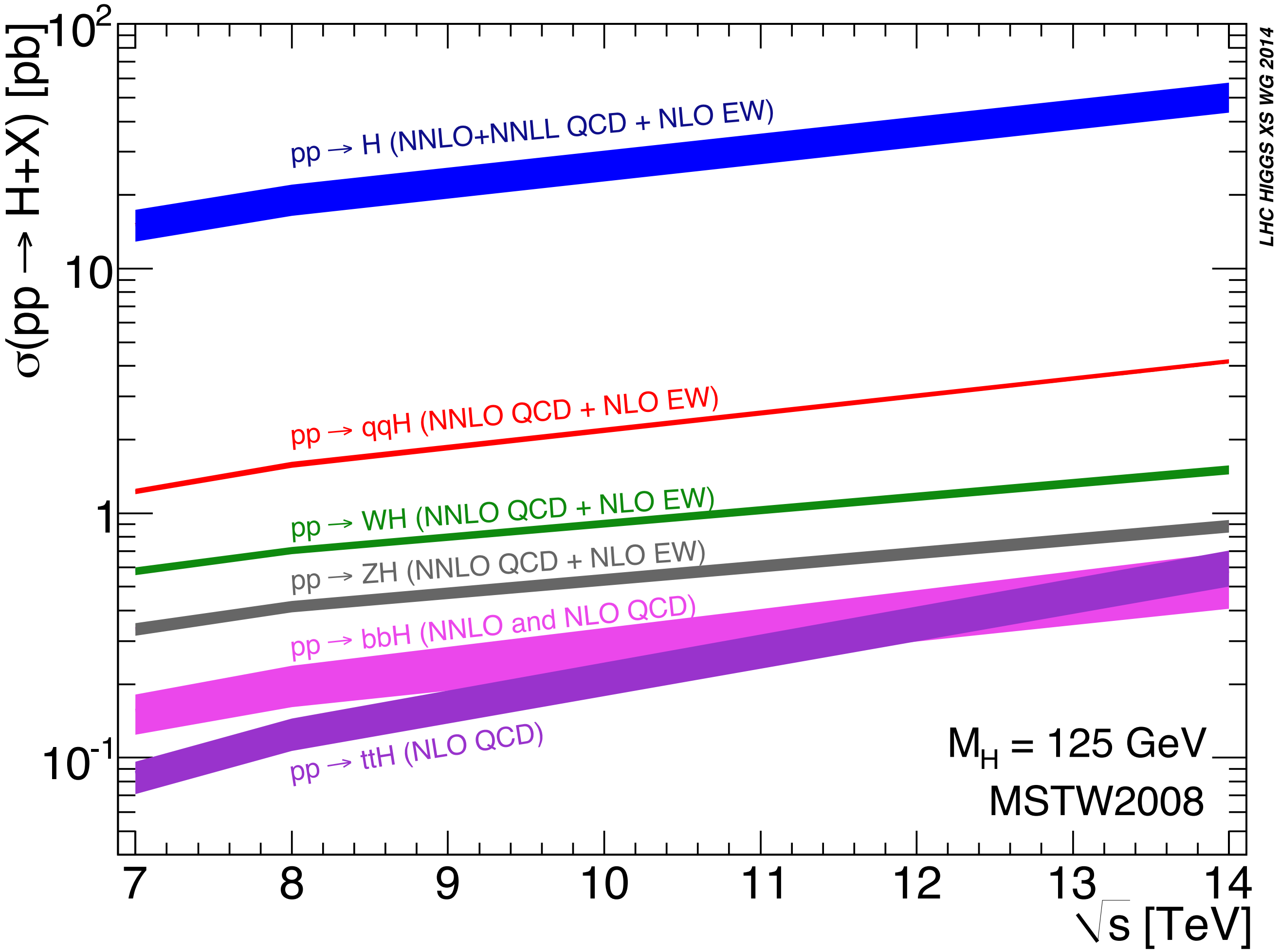




Higgs boson measurements

Higgs Boson Production

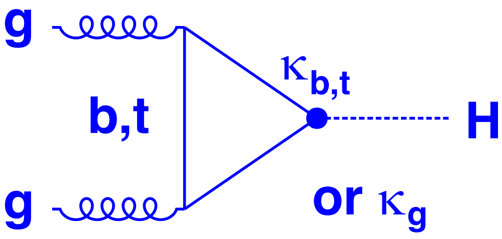




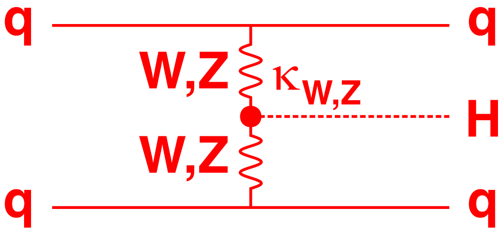
- Measure associated production with jets, leptons… to distinguish production modes

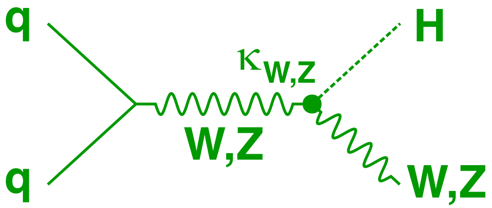
Higgs Boson Production & Decay

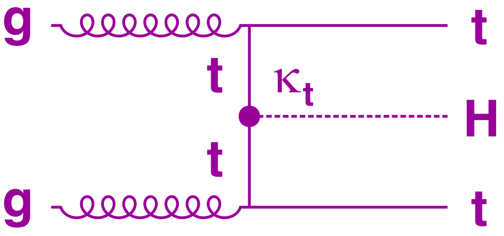
gluon-gluon fusion

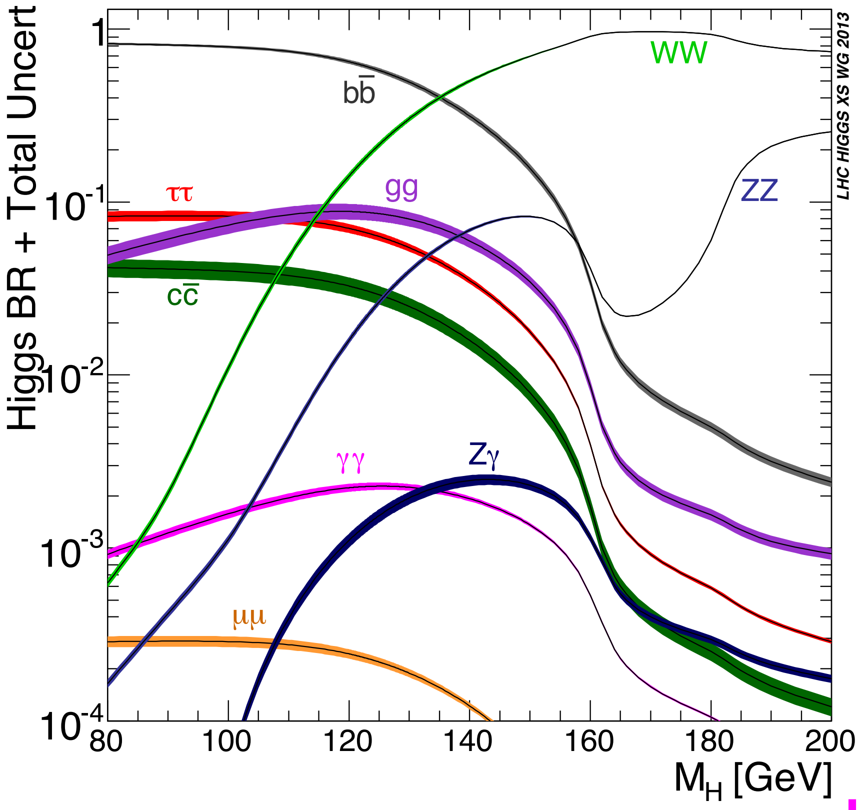


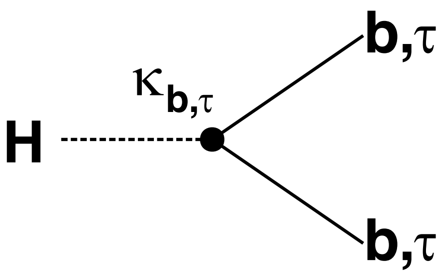
vector boson fusion, VBF

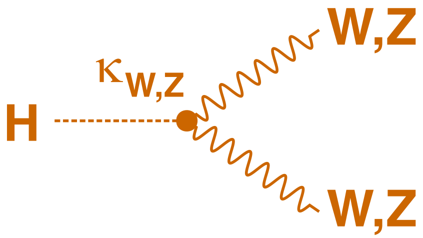


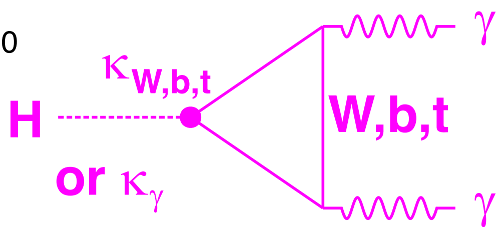












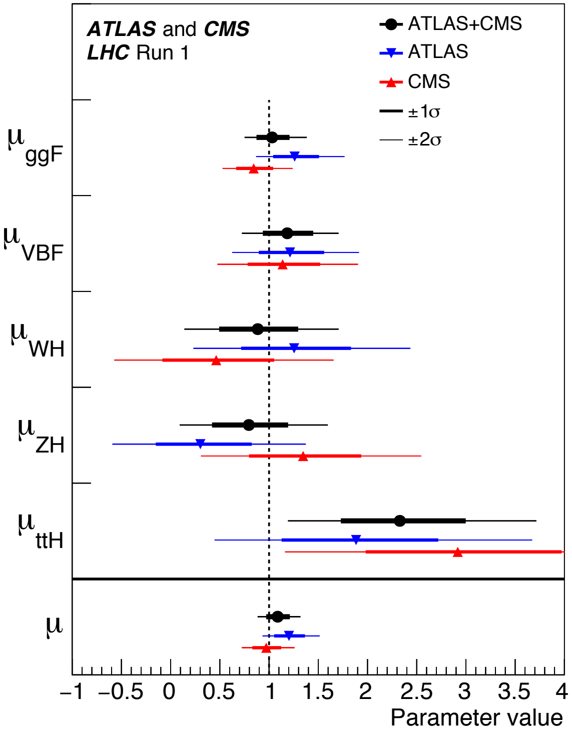
- Measure cross-section times branching ratio to different final states

Status at the end of Run 1

- Run 1 legacy – overall production rate known to 10%
  - $\mu=\sigma/\sigma_{SM}=1.09\pm0.11$
  - VBF and H→ττ observed when combining ATLAS and CMS
  - Want to establish ttH and H→bb with Run 2 data

μ_{VBF}

μ_{ttH}



Signif obs (exp)

VBF: 5.4σ (4.6σ)

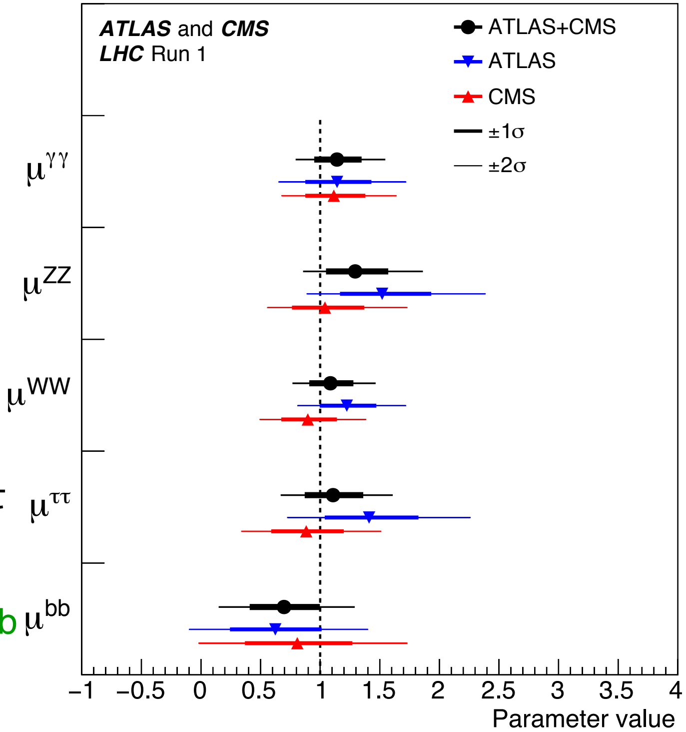
H→ττ: 5.5σ (5.0σ)

ttH: 4.4σ (2.0σ)

H→bb: 2.6σ (3.7σ)

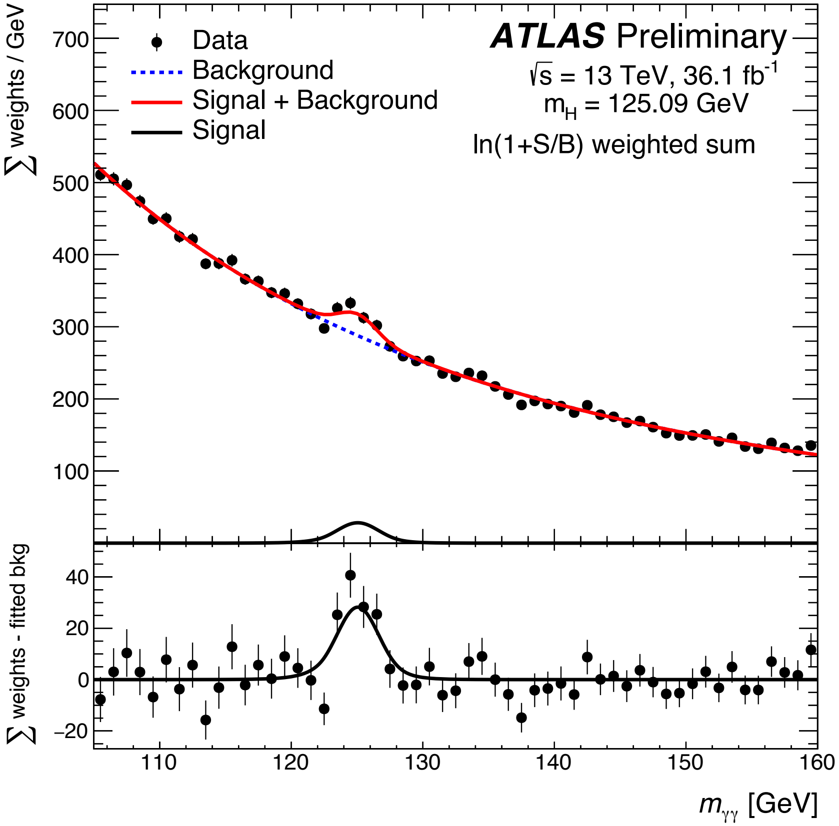
$\mu^{\tau\tau}$

μ^{bb}

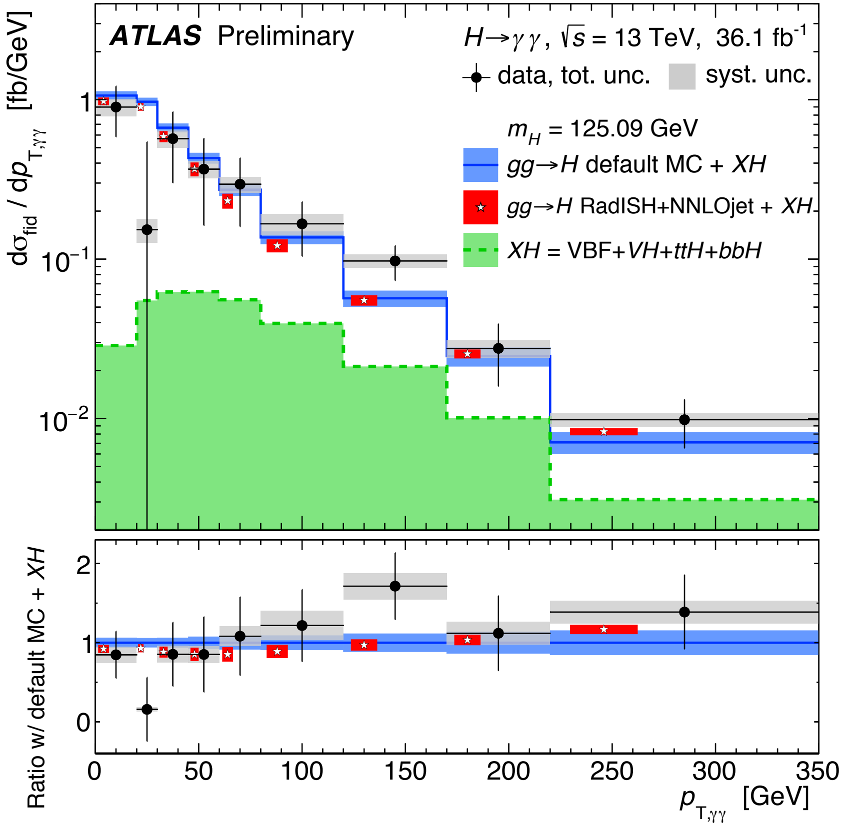


H→γγ

- Full 2015+2016 data
- Total rate, also fiducial and differential cross sections



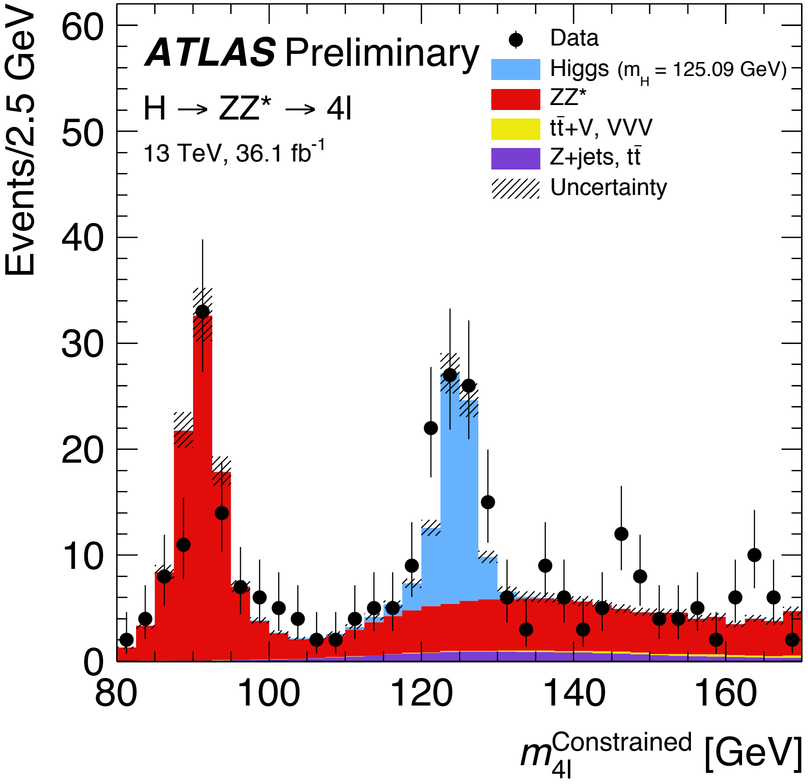
m(γγ)

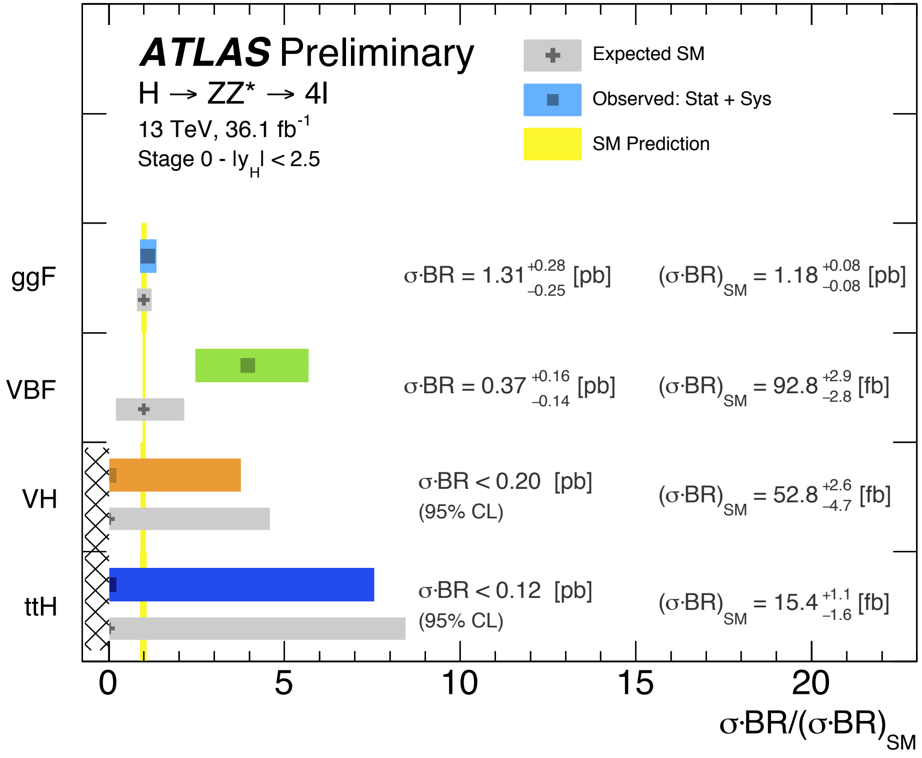


$p_T(\gamma\gamma)$

H→ZZ→4l

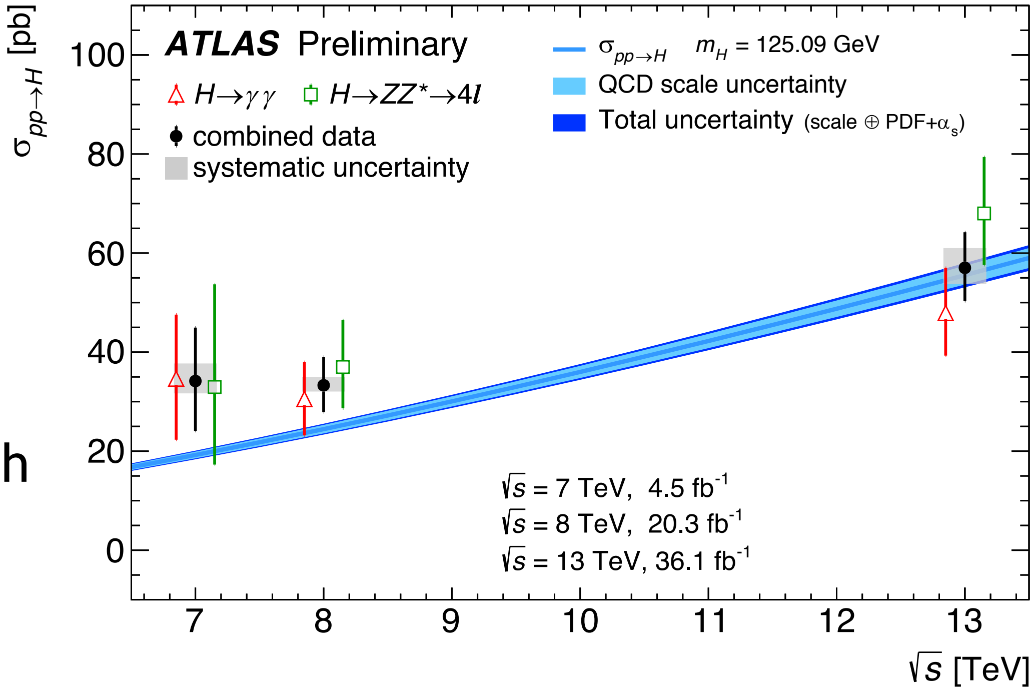
- Divided into categories to fit production modes.



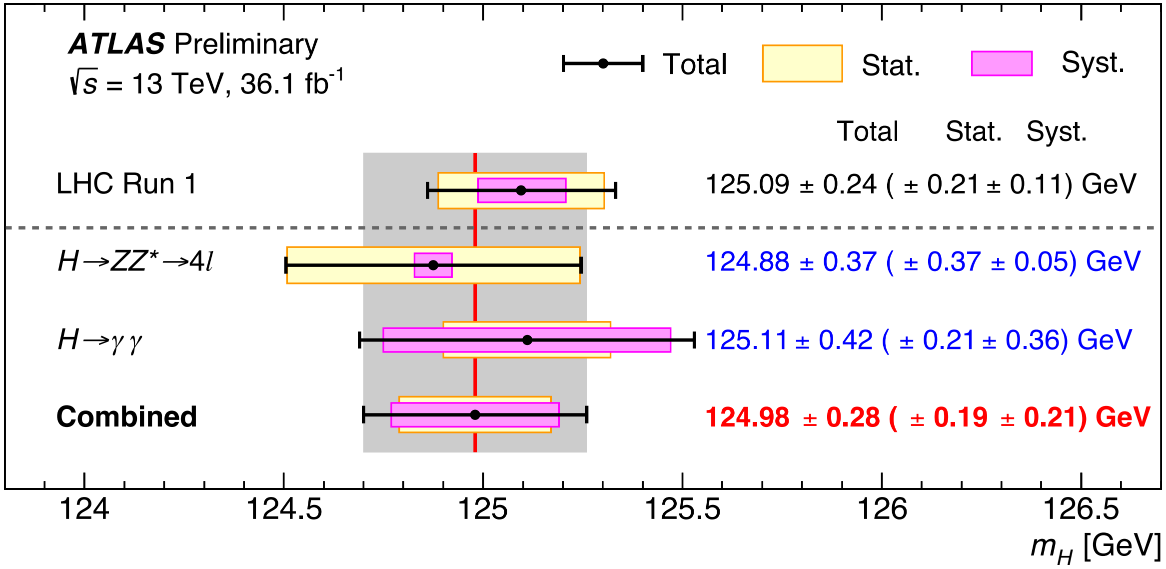


Combined

- H→γγ and ZZ→4l cross section
  - Compared to N3LO prediction
  - Global signal strength μ=1.09±0.12



- New mass measurement



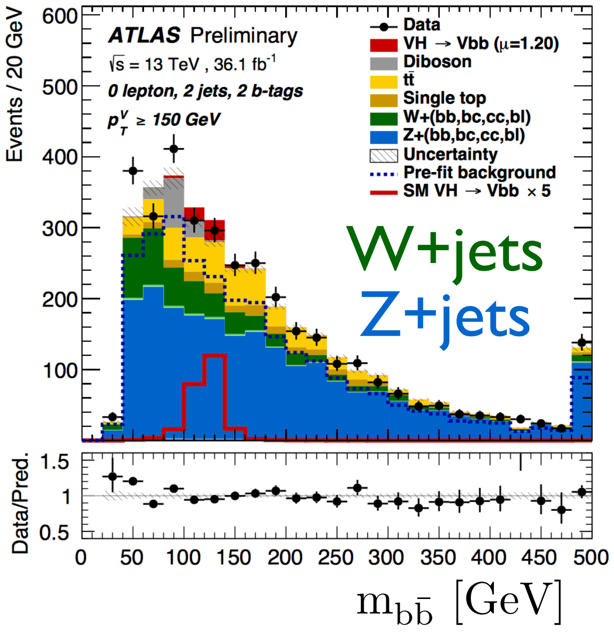
ATLAS-CONF-2017-046
ATLAS-CONF-2017-047

arXiv:1708.03299

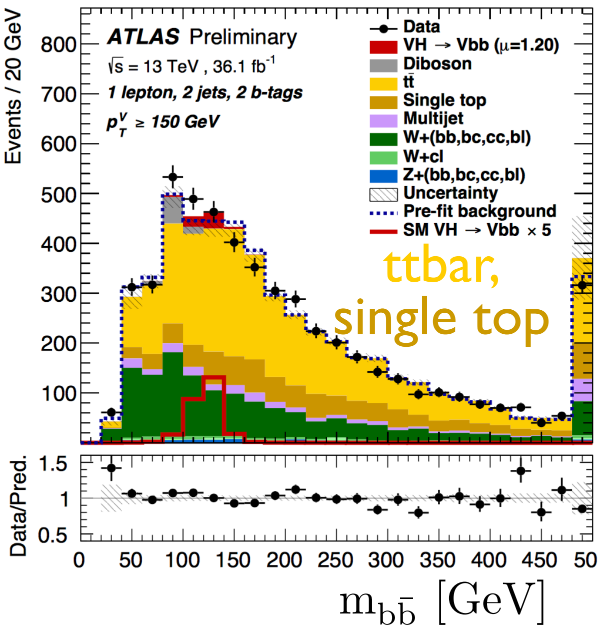
Evidence for H→bb

- Search for VH with H→bb and Z→νν, W→νl or Z→ll
  - Variables such as m(bb), $p_T(V)$ included in BDT
- Simultaneous fit to signal and control regions to constrain background processes
  - Eg. High p_T signal regions - m(bb) distribution

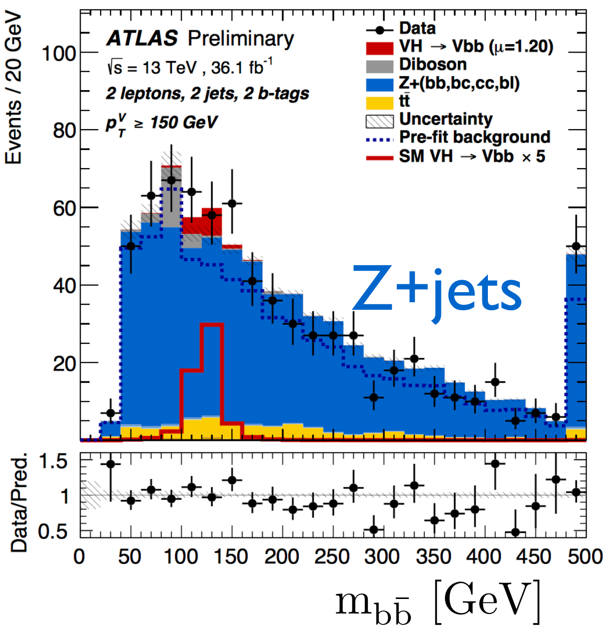
0-lepton



1-lepton



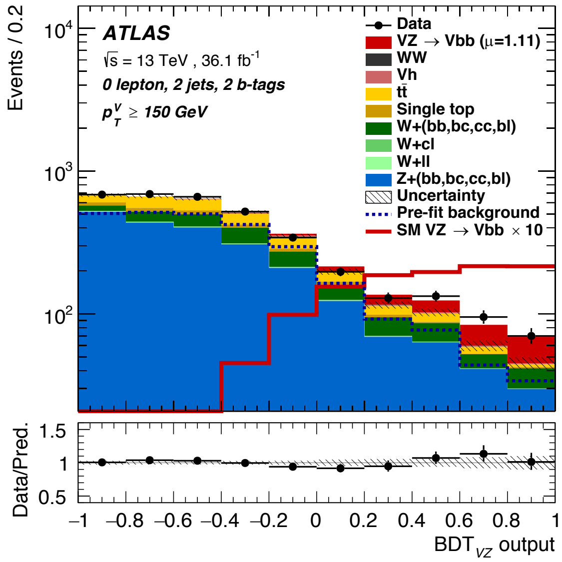
2-lepton

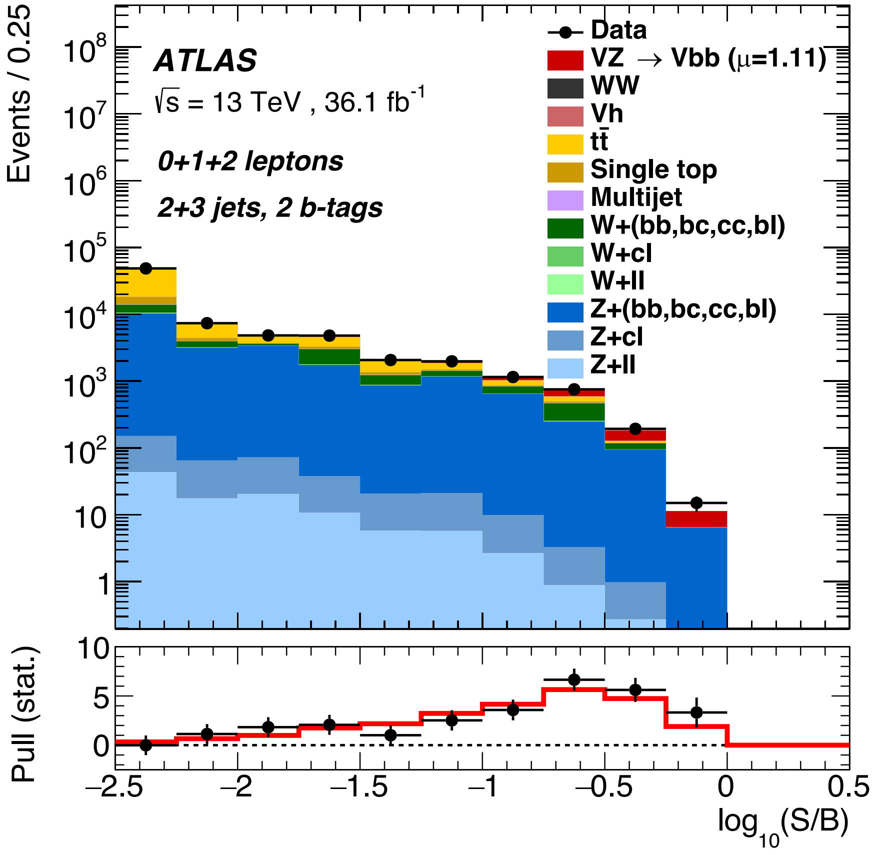


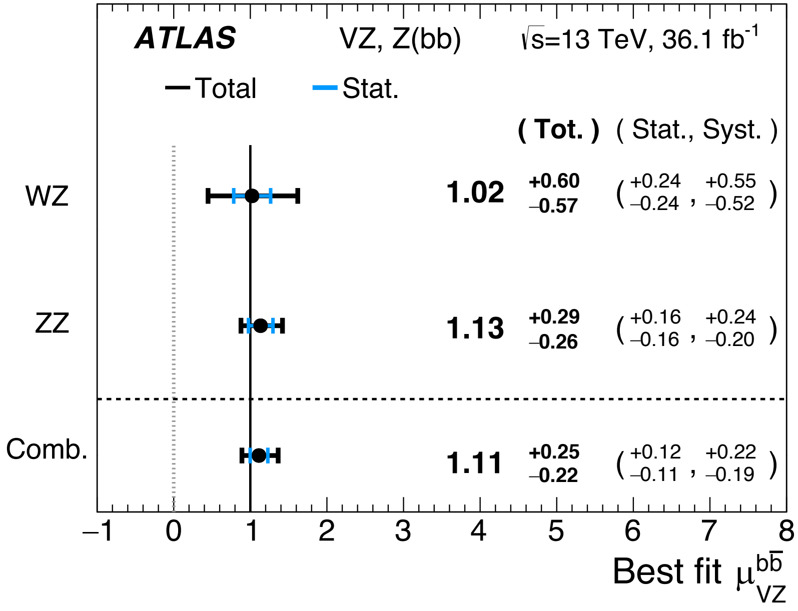
arXiv:1708.03299

Cross check of VZ, Z→bb

- BDT tuned for each region
- Combined yield as a function of S/B
- Clear excess: Obs. 5.8 σ (expected 5.3 σ)



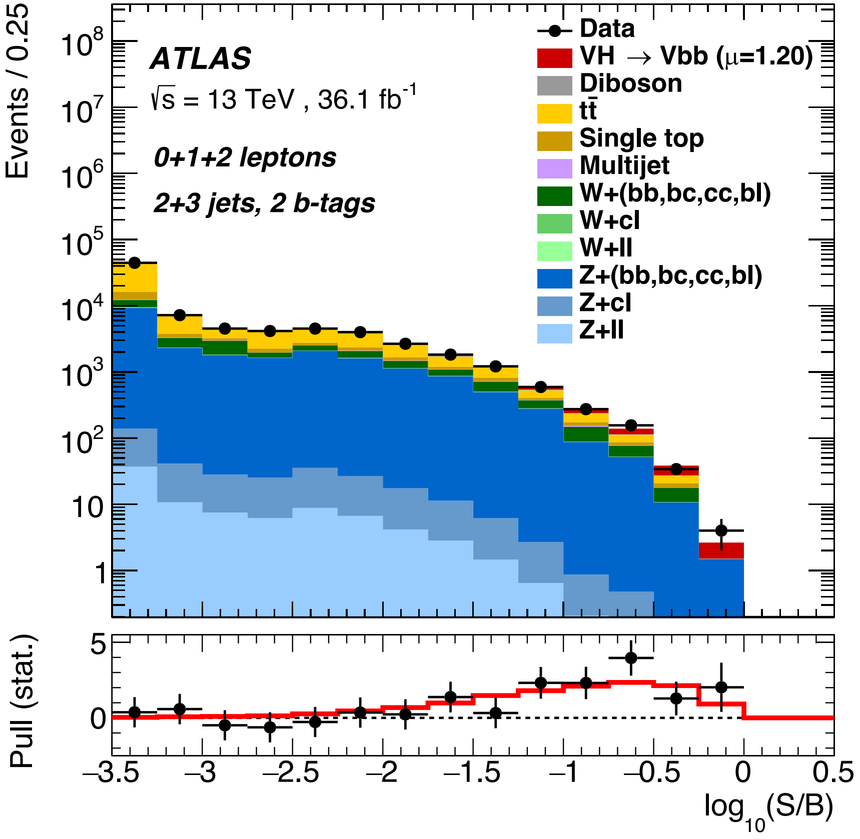




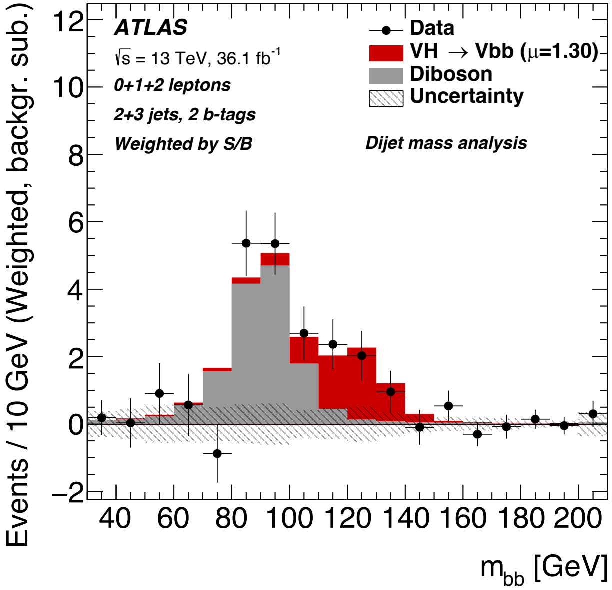
arXiv:1708.03299

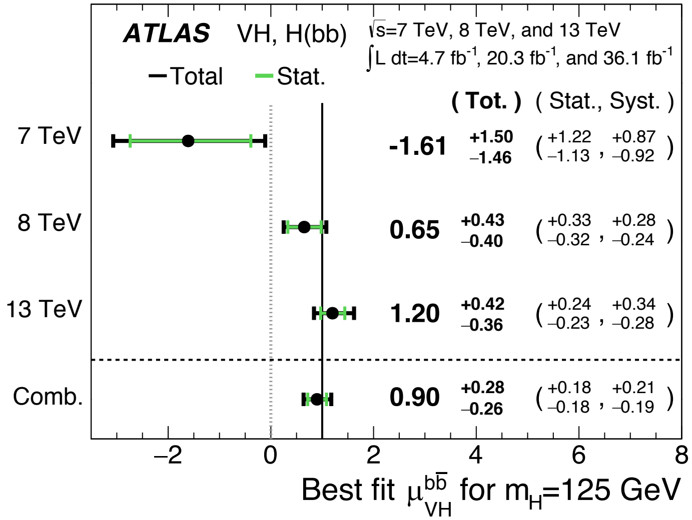
VH, H→bb result

- Run 2 significance observed 3.8 σ, expected 2.8 σ
- With Run 1: 3.6 σ (obs) 4.0 σ (exp)

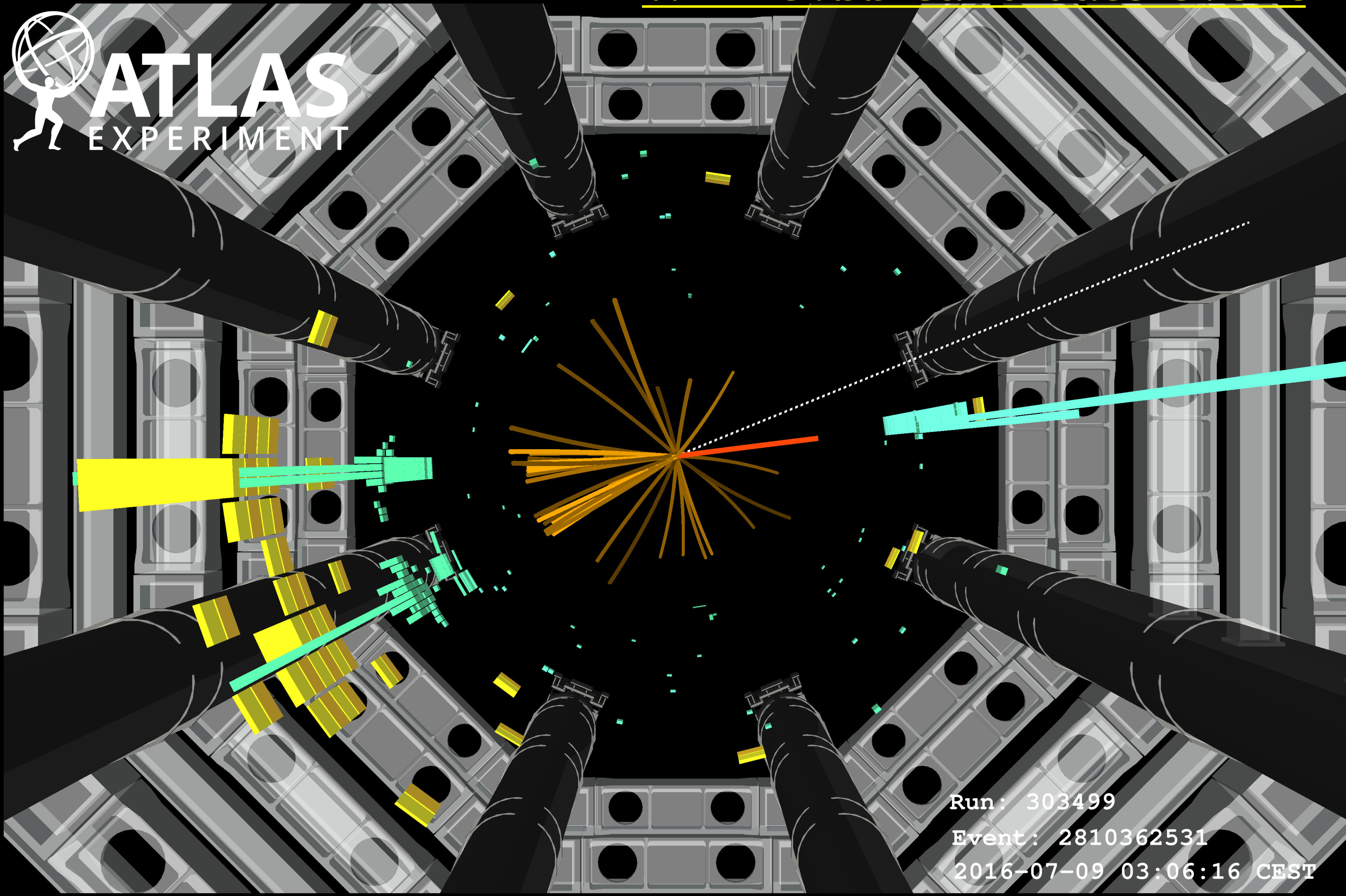


Cross-check m(bb) fit





WH→evbb candidate event

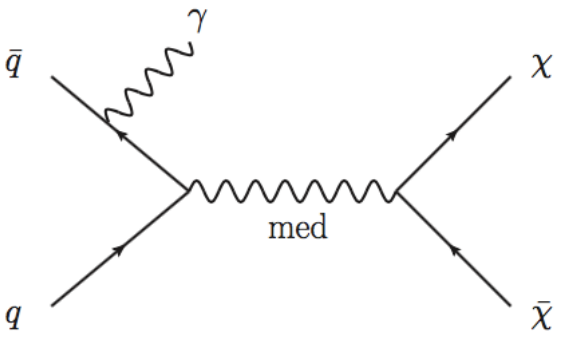


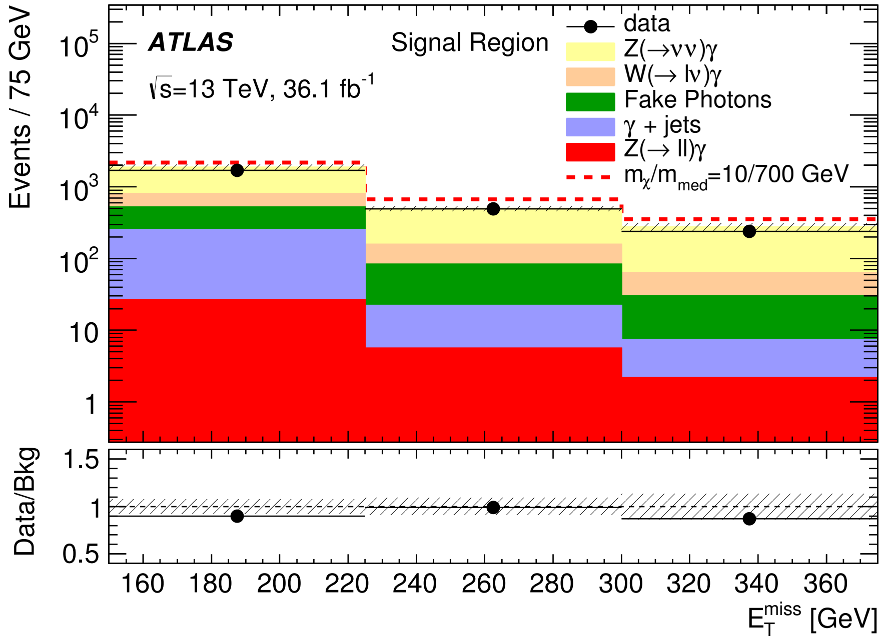
New Phenomena

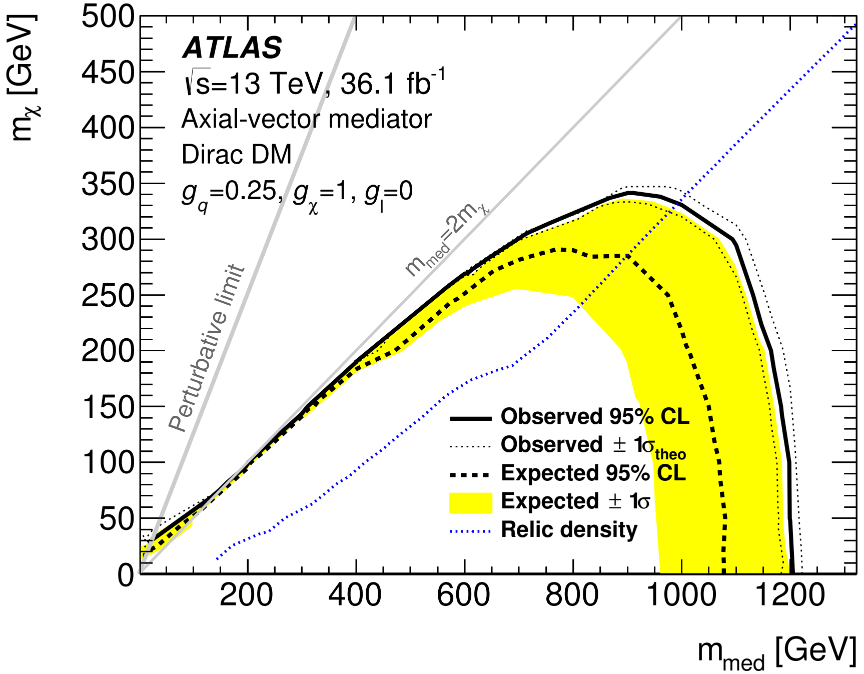
arXiv:1704.03848

Dark matter searches

- Search for SM particle + E_T^{miss}
  - Photon, vector boson, Higgs boson
  - High p_T jet, b/bb etc.
- Example, E_T^{miss} in mono-γ events
  - Main backgrounds Z/W+γ
  - Interpretation in simplified models vs. mediator and DM masses

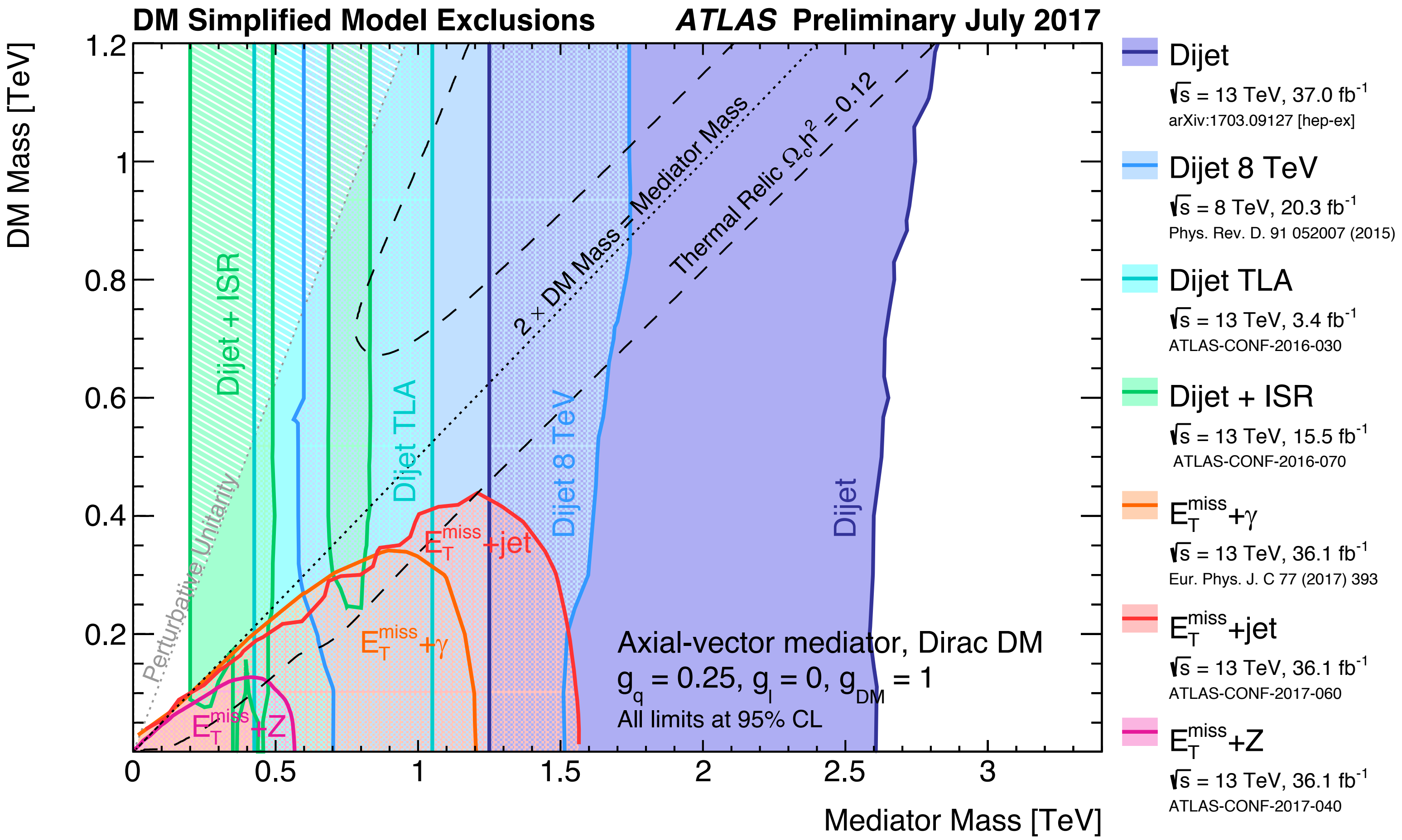






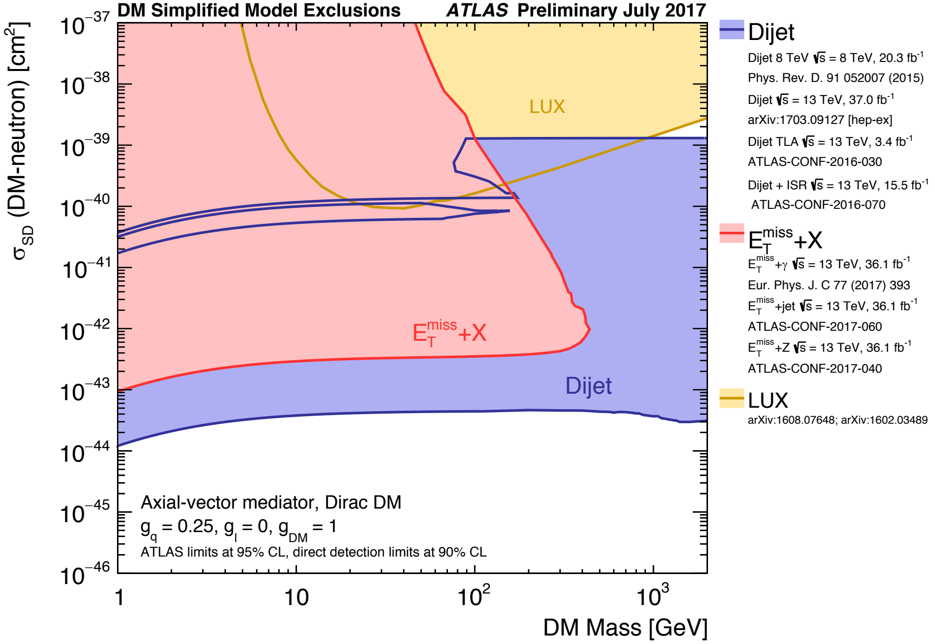
Dark matter in dijet decays

- Dijet bump searches re-interpreted as constraint on mediator mass
  - Trigger level analysis (TLA) to extend to lower mass region
  - Recoil of dijet against ISR jet for the lowest masses

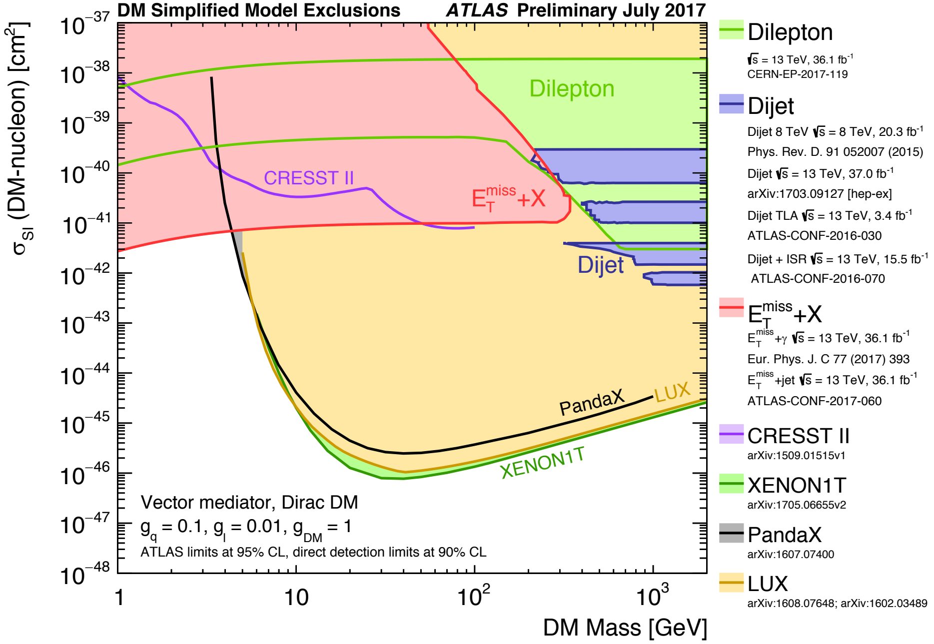


Comparison with DM direct searches

- Model dependent DM-nucleon cross-section to compare with direct searches
    - Spin dependent or Spin-independent
    - Couplings of mediator to DM



Hadronic only



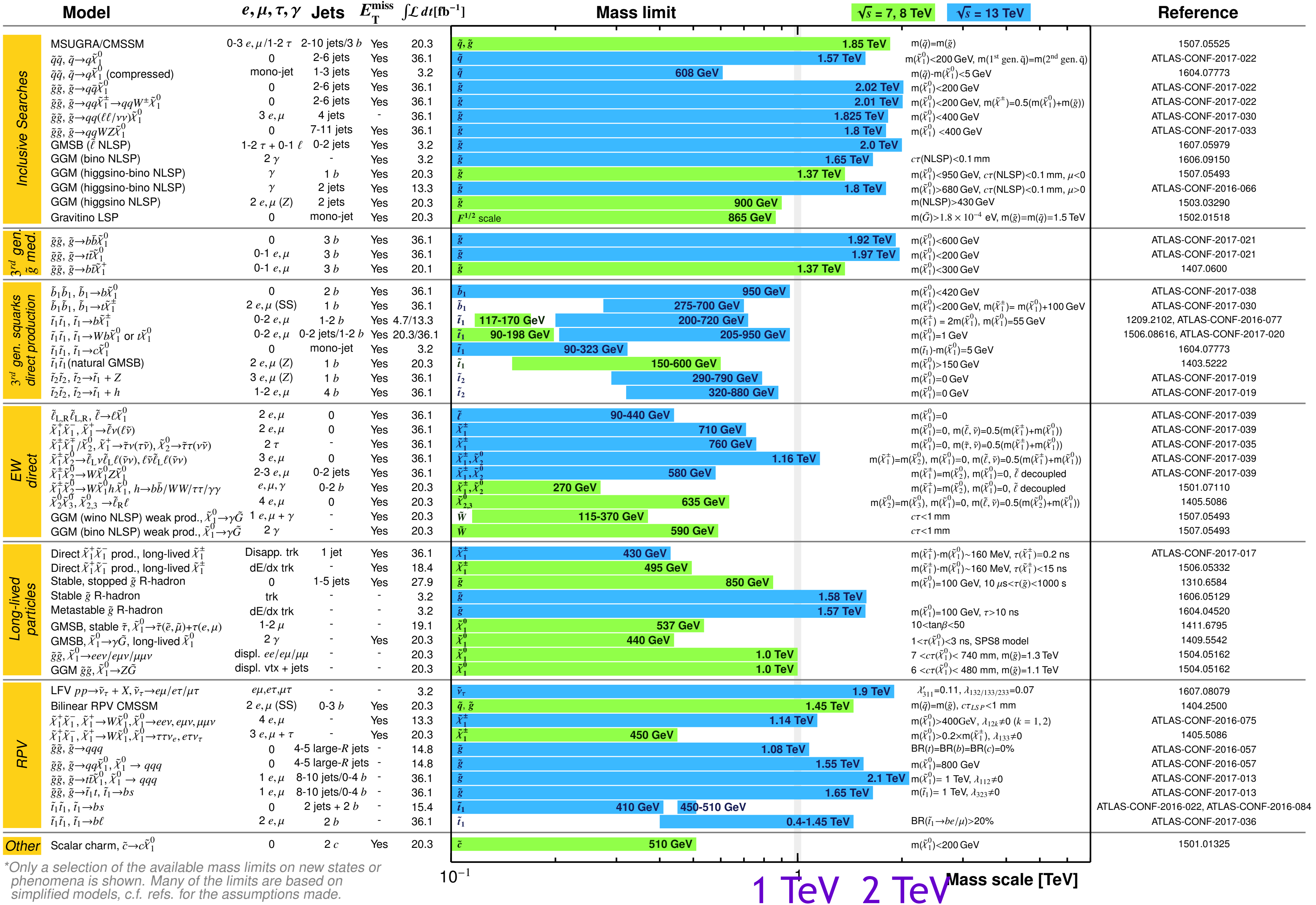
Lepton couplings in addition

ATLAS SUSY Searches* - 95% CL Lower Limits

May 2017

ATLAS Preliminary

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



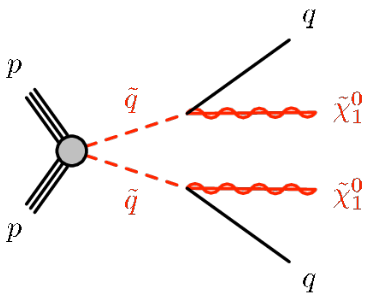
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	🟩 $\tilde{q}, \tilde{g}$ 1.85 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$	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
	$\tilde{q}\tilde{q}$, $\tilde{q}\rightarrow q\tilde{\chi}_1^0$ (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
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	36.1	🟦 $\tilde{g}$ 2.02 TeV	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2017-022
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	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
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq(\ell\ell/\nu\nu)\tilde{\chi}_1^0$	3 e,μ	4 jets	-	36.1	🟦 $\tilde{g}$ 1.825 TeV	m($\tilde{\chi}_1^0$)<400 GeV	ATLAS-CONF-2017-030
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qqWZ\tilde{\chi}_1^0$	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
3^{rd} gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	36.1	🟦 $\tilde{g}$ 1.92 TeV	m($\tilde{\chi}_1^0$)<600 GeV	ATLAS-CONF-2017-021
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	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
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	🟩 $\tilde{g}$ 1.37 TeV	m($\tilde{\chi}_1^0$)<300 GeV	1407.0600
3^{rd} gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	36.1	🟦 $\tilde{b}_1$ 950 GeV	m($\tilde{\chi}_1^0$)<420 GeV	ATLAS-CONF-2017-038
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$ 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
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	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
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1 + Z$	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
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\rightarrow\tilde{t}_1 + h$	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	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	36.1	🟦 $\tilde{\ell}$ 90-440 GeV	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2017-039
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}/\tilde{\chi}_2^0$, $\tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$, $\tilde{\chi}_2^0\rightarrow\tilde{\tau}\tau(\nu\tilde{\nu})$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	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
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$, $h\rightarrow b\bar{b}/WW/\tau\tau/\gamma\gamma$	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
	$\tilde{\chi}_2^0\tilde{\chi}_3^0$, $\tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	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., $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$	1 e,μ + γ	-	Yes	20.3	🟩 $\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
	GGM (bino NLSP) weak prod., $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$	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 $\tilde{\tau}$, $\tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	🟩 $\tilde{\chi}_1^0$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, 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
	$\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\rightarrow eev/e\mu\nu/\mu\mu\nu$	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 $\tilde{g}\tilde{g}$, $\tilde{\chi}_1^0\rightarrow Z\tilde{G}$	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 $pp\rightarrow\tilde{\nu}_\tau + X$, $\tilde{\nu}_\tau\rightarrow e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	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
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow ee\nu, e\mu\nu, \mu\mu\nu$	4 e,μ	-	Yes	13.3	🟦 $\tilde{\chi}_1^{\pm}$ 1.14 TeV	m($\tilde{\chi}_1^0$)>400GeV, λ_{12k}≠0 ($k = 1,2$)	ATLAS-CONF-2016-075
	$\tilde{\chi}_1^+\tilde{\chi}_1^-$, $\tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow\tau\tau\nu_e, e\tau\nu_\tau$	3 e,μ + τ	-	Yes	20.3	🟩 $\tilde{\chi}_1^{\pm}$ 450 GeV	m($\tilde{\chi}_1^0$)>0.2×m($\tilde{\chi}_1^{\pm}$), λ_{133}≠0	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qqq$	0	4-5 large-R jets	-	14.8	🟦 $\tilde{g}$ 1.08 TeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow qq\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow qqq$	0	4-5 large-R jets	-	14.8	🟦 $\tilde{g}$ 1.55 TeV	m($\tilde{\chi}_1^0$)=800 GeV	ATLAS-CONF-2016-057
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$, $\tilde{\chi}_1^0\rightarrow qqq$	1 e,μ	8-10 jets/0-4 b	-	36.1	🟦 $\tilde{g}$ 2.1 TeV	m($\tilde{\chi}_1^0$)= 1 TeV, λ_{112}≠0	ATLAS-CONF-2017-013
	$\tilde{g}\tilde{g}$, $\tilde{g}\rightarrow\tilde{t}_1 t$, $\tilde{t}_1\rightarrow bs$	1 e,μ	8-10 jets/0-4 b	-	36.1	🟦 $\tilde{g}$ 1.65 TeV	m($\tilde{t}_1$)= 1 TeV, λ_{323}≠0	ATLAS-CONF-2017-013
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow bs$	0	2 jets + 2 b	-	15.4	🟦 $\tilde{t}_1$ 410 GeV 450-510 GeV		ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\rightarrow b\ell$	2 e,μ	2 b	-	36.1	🟦 $\tilde{t}_1$ 0.4-1.45 TeV	BR($\tilde{t}_1\rightarrow be/\mu$)>20%	ATLAS-CONF-2017-036
Other	Scalar charm, $\tilde{c}\rightarrow c\tilde{\chi}_1^0$	0	2 c	Yes	20.3	🟩 $\tilde{c}$ 510 GeV	m($\tilde{\chi}_1^0$)<200 GeV	1501.01325

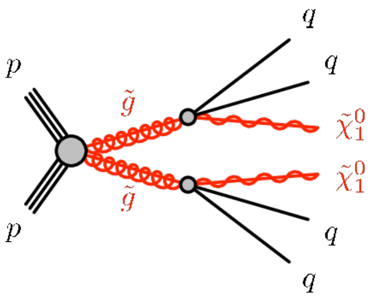
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

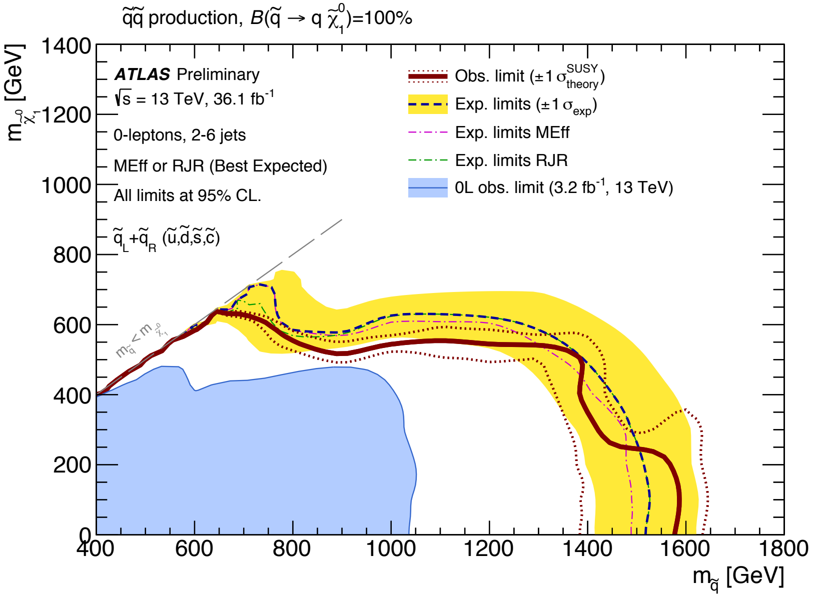
ATLAS-CONF-2017-022

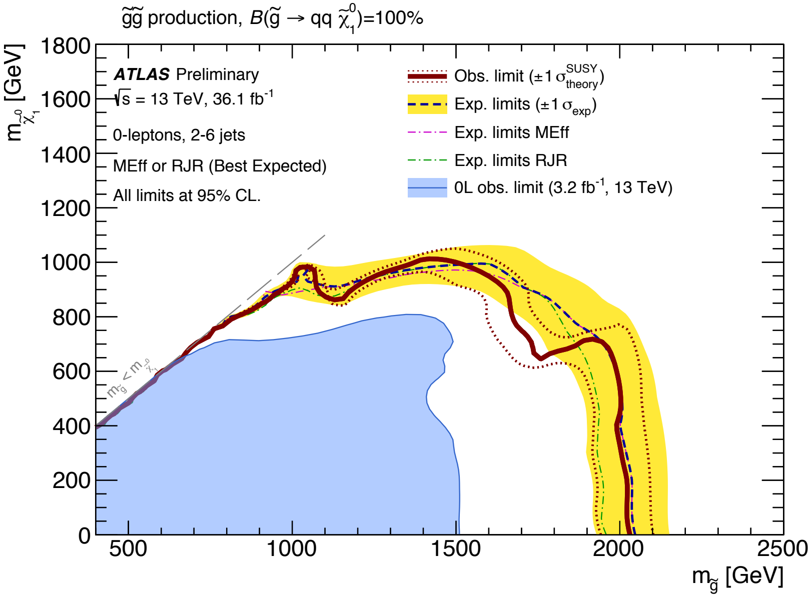
SUSY searches - squarks and gluinos

- "Classic" SUSY search with 0 lepton, 2-6 jets and E_T^{miss}
- Squarks up to 1.6 TeV and gluinos up to 2.0 TeV excluded



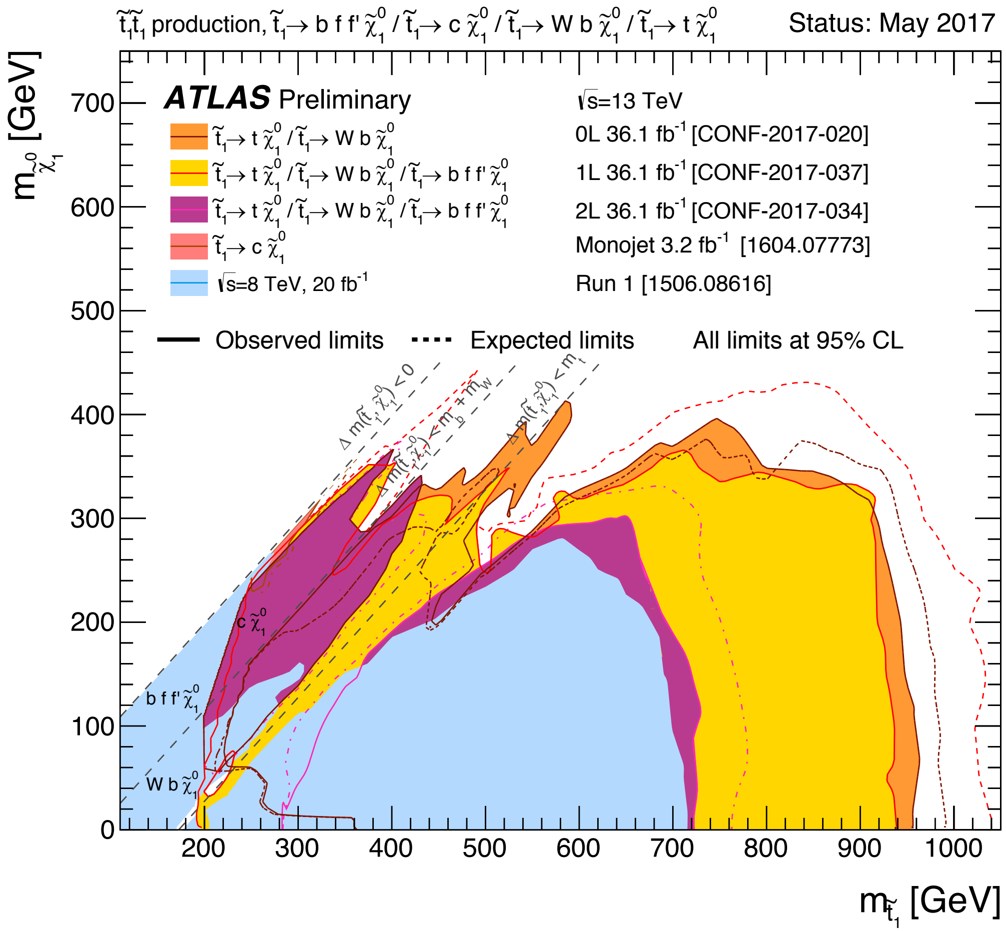






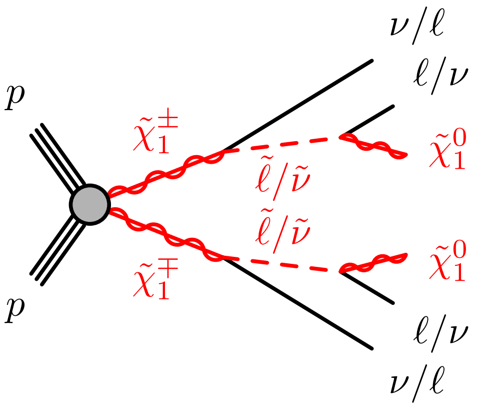
SUSY third generation

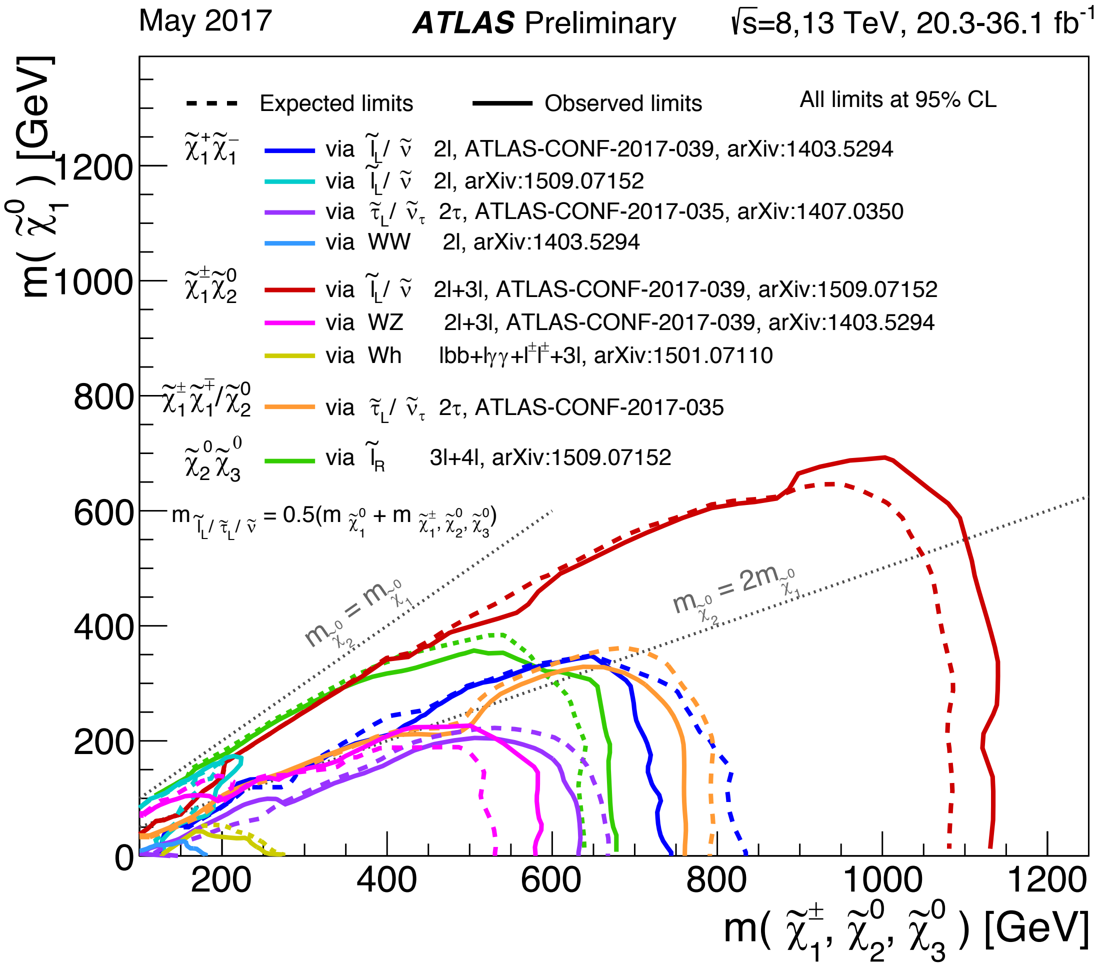
- Higgs mass can be protected with a light scalar top quark
- Many dedicated searches to cover stop-LSP mass ranges
- Many t/b quarks in the final state
- Probing scalar top mass up to 950 GeV



SUSY electroweak production

- Benefits more from increasing luminosity (lower cross section)
- Leptons and E_T^{miss} in the final state



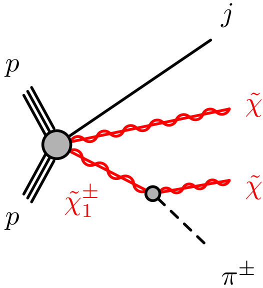


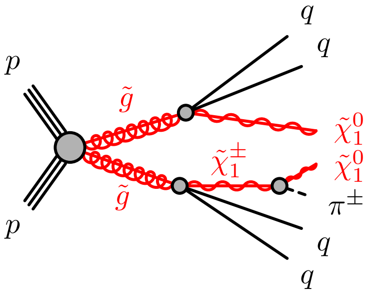
- Consider different mediators resulting in different final state combinations

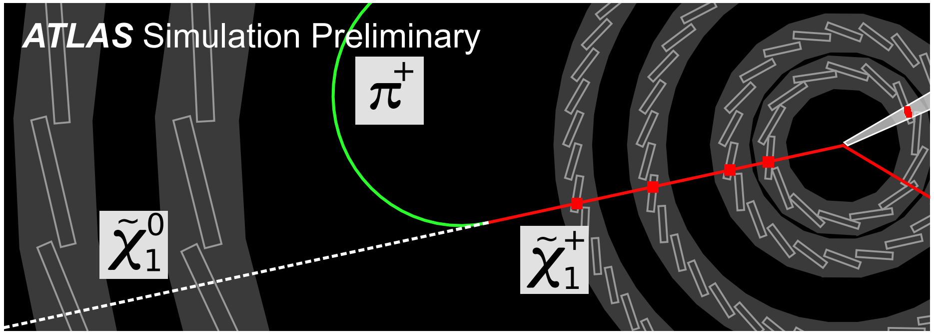
ATLAS-CONF-2017-017

Long lived particles

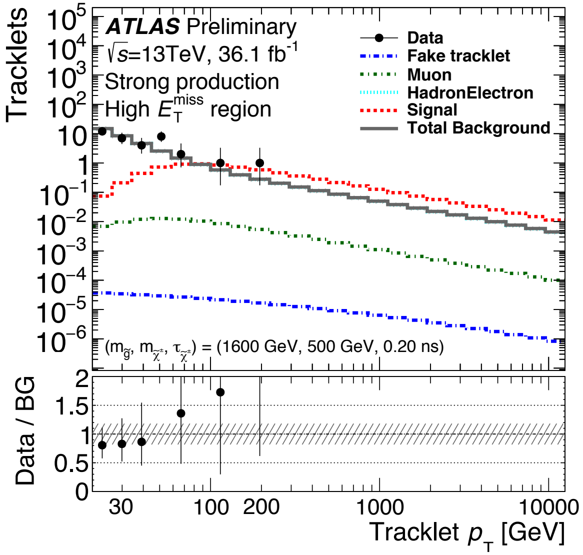
- Compressed spectra and/or RPV can give rise to long lived particles eg. Disappearing tracks from chargino decay.

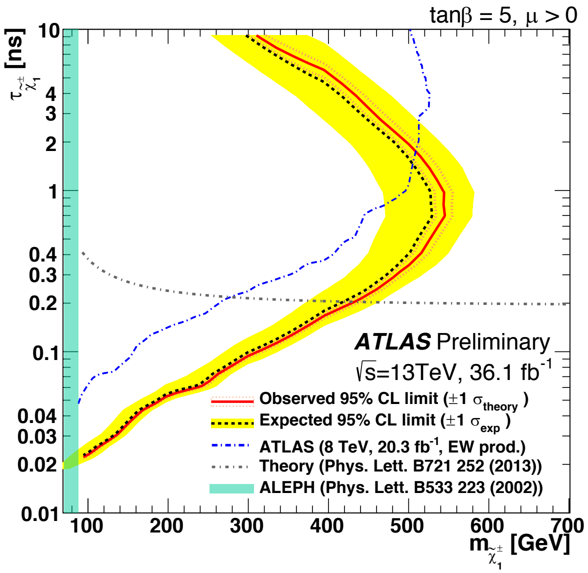






- Pixel tracklets with r<12cm
- Exclusion depends on lifetime
- Electroweak prod – chargino < 430 GeV
- Strong production – gluino < 1.6 TeV



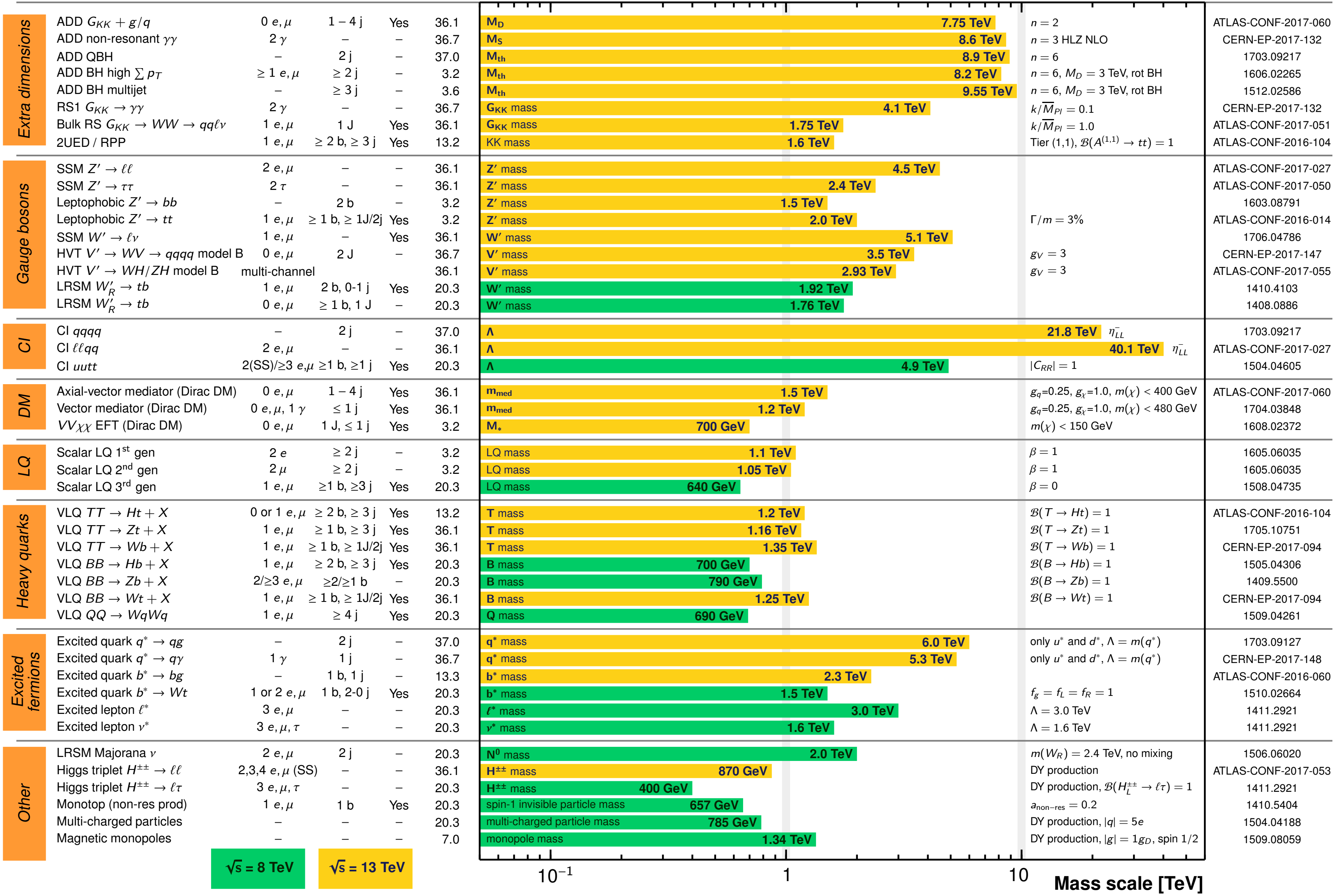


ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int\mathcal{L}\,dt = (3.2 - 37.0)\ \text{fb}^{-1}$ $\sqrt{s}$ = 8, 13 TeV



	Model	ℓ, γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt[\text{fb}^{-1}]$	Limit			Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	1 – 4 j	Yes	36.1	🟨 M_D	7.75 TeV	$n = 2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	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 $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th}	8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	🟨 M_{th}	9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	🟨 G_{KK} mass	4.1 TeV	$k/\overline{M}_{Pl} = 0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	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, μ	≥ 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, μ	–	–	36.1	🟨 Z' mass	4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	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, μ	≥ 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, μ	–	Yes	36.1	🟨 W' mass	5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	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, μ	2 b, 0-1 j	Yes	20.3	🟩 W' mass	1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 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, μ	–	–	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	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	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, μ, 1 γ	≤ 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, μ	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 μ	≥ 2 j	–	3.2	🟨 LQ mass	1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	$\geq$1 b, $\geq$3 j	Yes	20.3	🟩 LQ mass	640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	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, μ	≥ 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, μ	≥ 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, μ	≥ 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, μ	≥ 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, μ	≥ 4 j	Yes	20.3	🟩 Q mass	690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	🟨 q^* mass	6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	🟨 q^* mass	5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	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, μ	–	–	20.3	🟩 ℓ^* mass	3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν^* mass	1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	–	20.3	🟩 N^0 mass	2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	🟨 $H^{\pm\pm}$ mass	870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	🟩 $H^{\pm\pm}$ mass	400 GeV	DY production, $\mathcal{B}(H_L^{\pm\pm} \to \ell\tau) = 1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass	657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass	785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass	1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

🟩 $\sqrt{s}$ = 8 TeV

🟨 $\sqrt{s}$ = 13 TeV

*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).

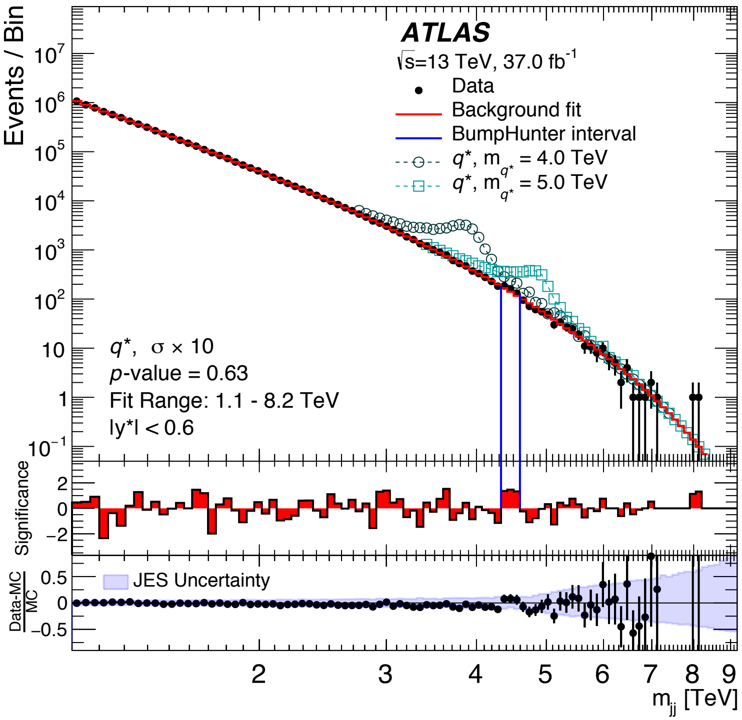
1 TeV

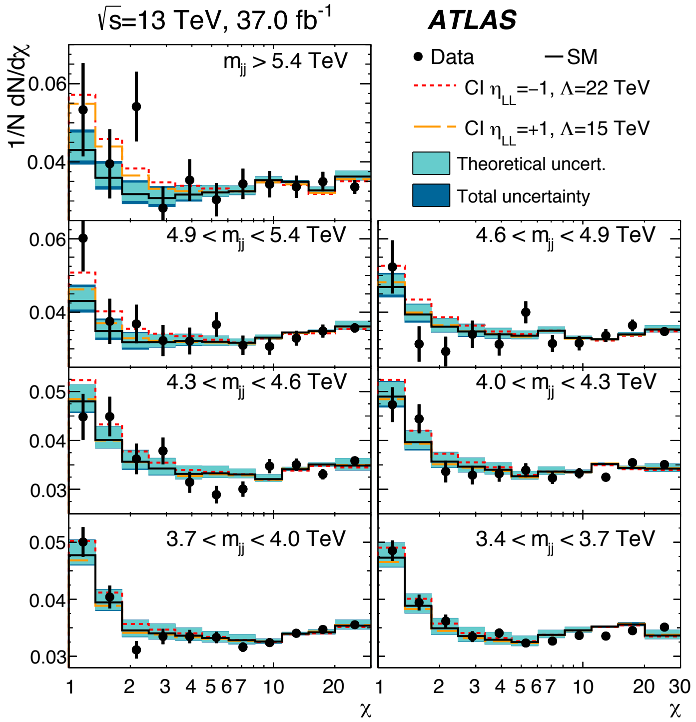
10 TeV

arXiv:1703.09127

High mass resonances with ATLAS

$$\chi = e^{\,y*} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$



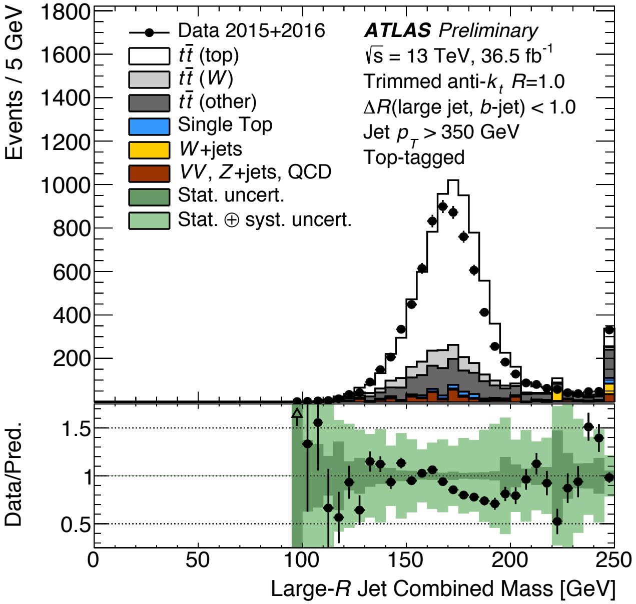


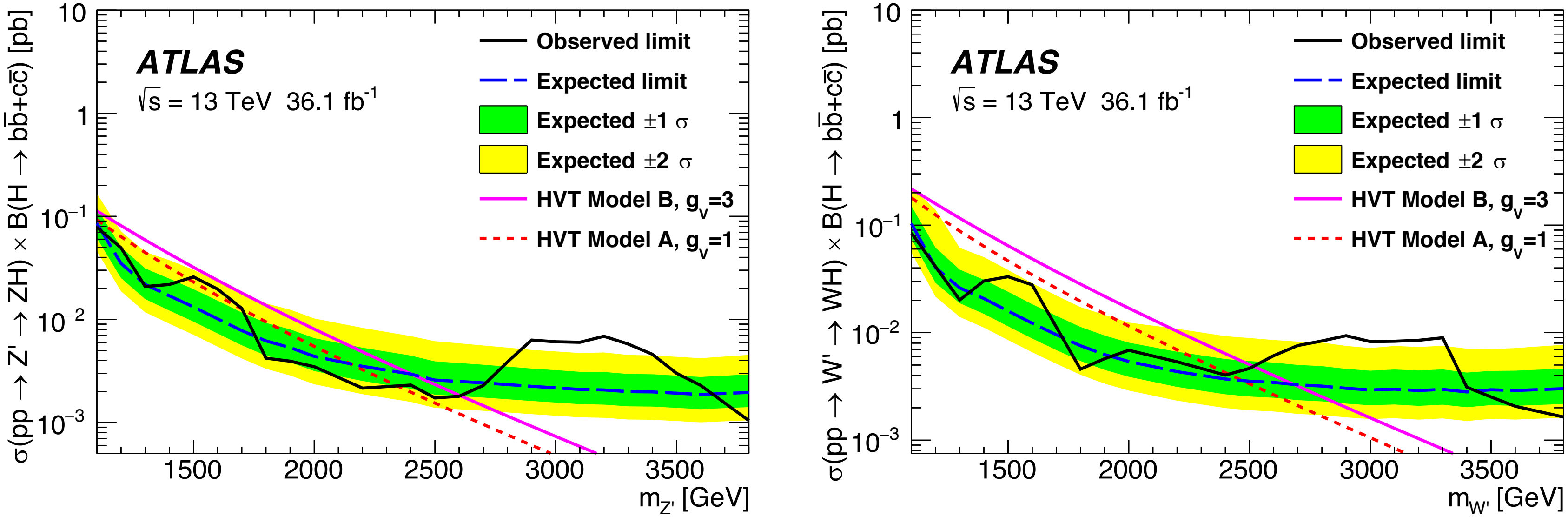
- dijet mass and angular distributions show no deviations (37/fb)
  - QBH>8.9 TeV. q*>6.0 TeV, W'>3.7 TeV
  - Contact interaction scale Λ > 13 – 29 TeV
- W' → lν, M(W')>5.1 TeV, Z' → ll, M(Z')>3.4 – 4.1 TeV (13/fb)
  - Contact interaction scale Λ > 17 – 25 TeV (3.2/fb)

arXiv:1707.06958

Boosted hadronic decays

- Low backgrounds for high mass objects. Exploit hadronic decays.
  - Jet substructure (and b-tagging) to tag top quarks, W/Z and Higgs bosons
  - eg. Jet mass of top-tagged sample
- Search for heavy resonance decaying to VH
  - ATLAS 3.3σ local, 2.1σ global excess around 3 TeV in qqbb channel
  - Not seen in VH→leptons+b-jets

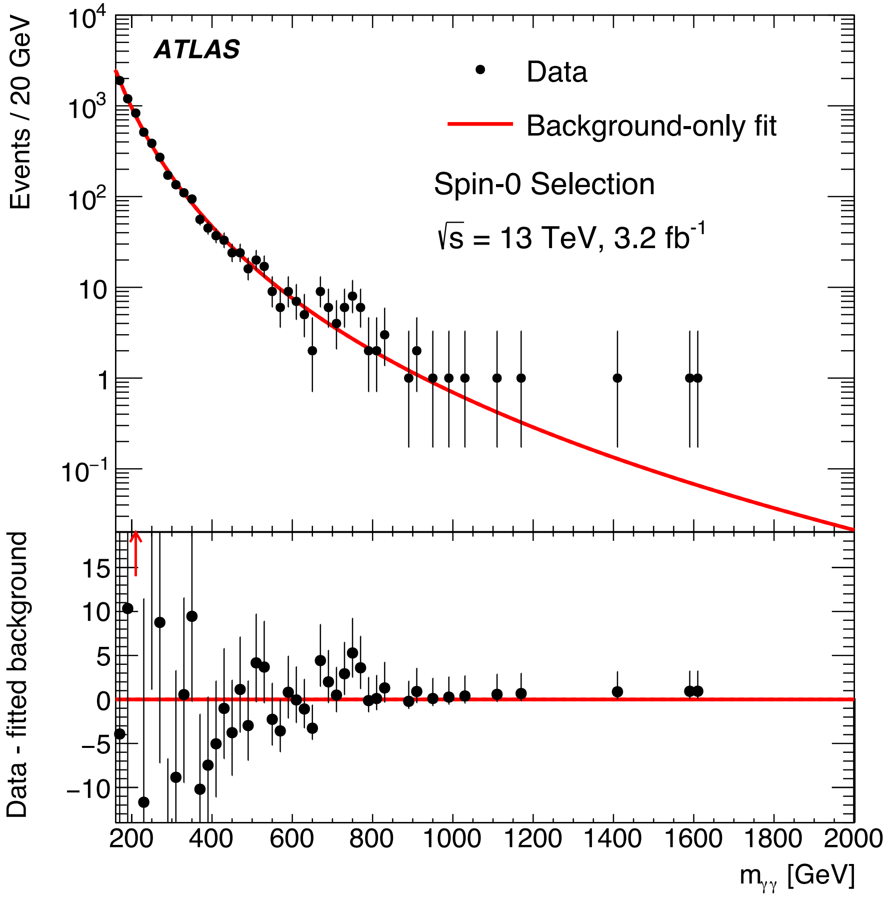


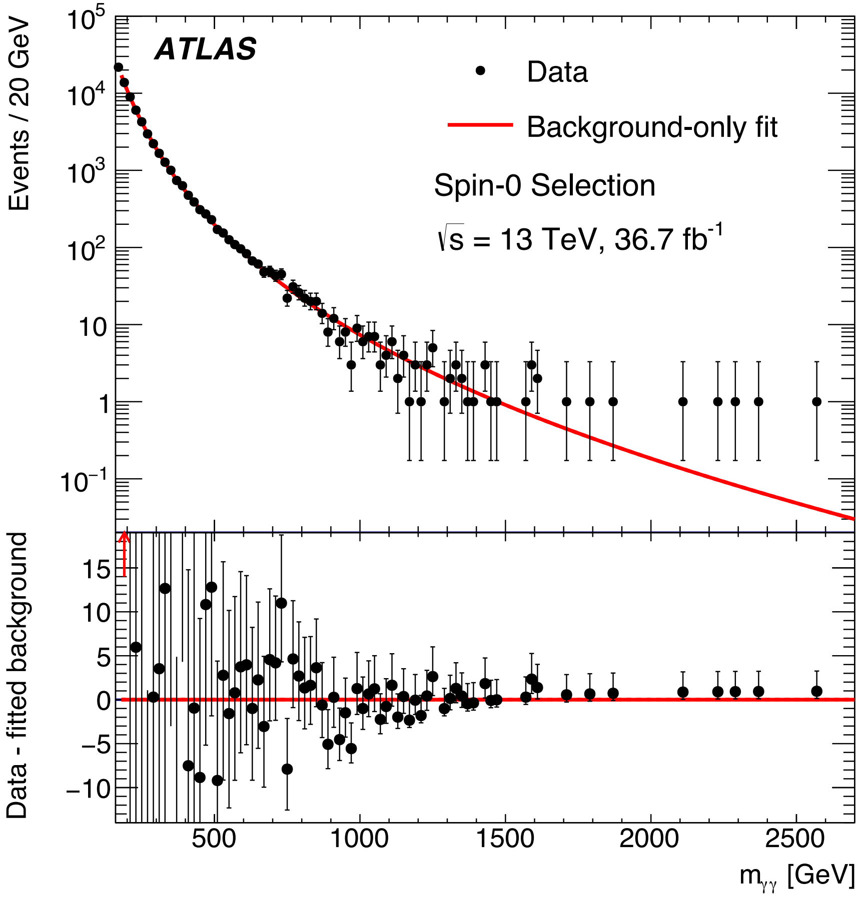


JHEP 09 (2016) 1
arXiv:1707.04147

High mass di-photon resonance

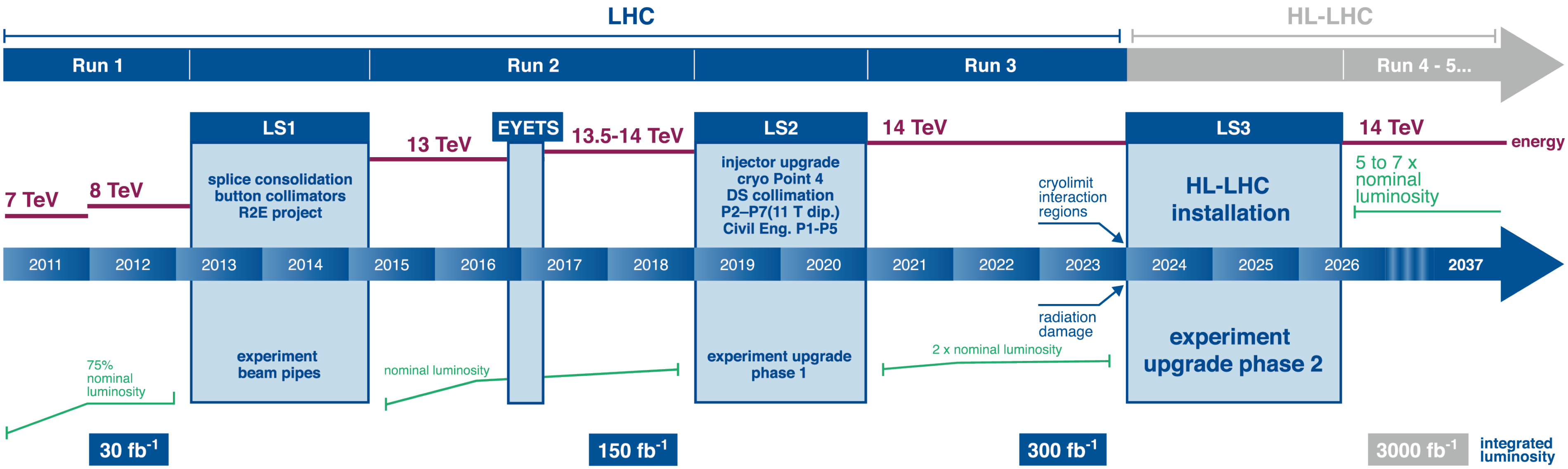
- The hint that went away





The future - near and far

LHC / HL-LHC Plan



Run 1

Magnet
splice
update

Run 2 at
~full design
energy

Phase I
upgrades
(injectors)

Run 3 →
original
design lumi

Phase II
upgrades
(final focus)

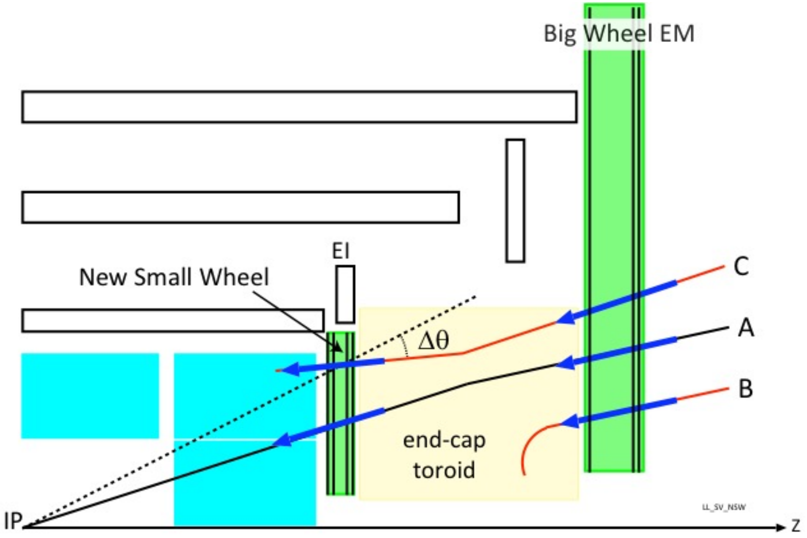
HL-LHC:
ten times
design lumi

Full exploitation of LHC is top priority in Europe & US for high energy physics

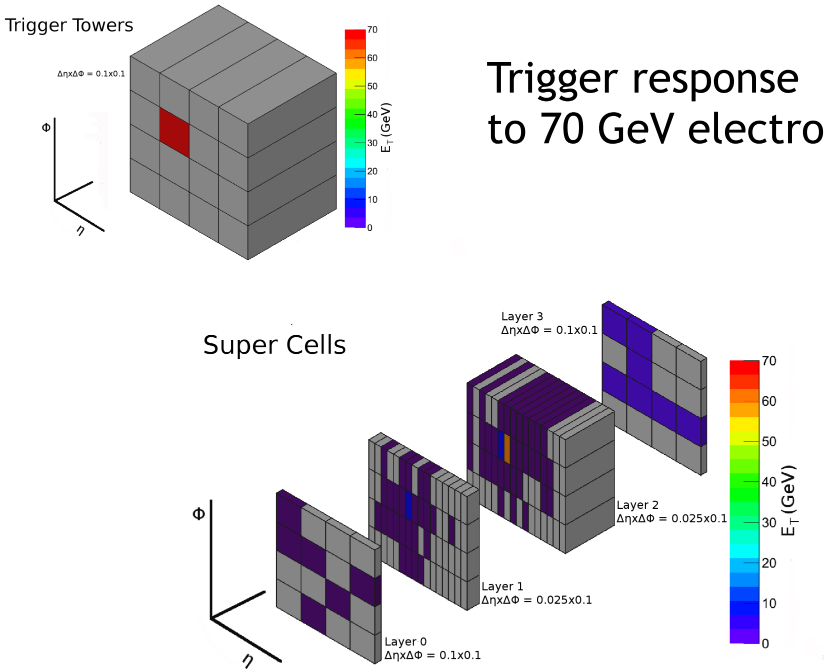
Operate HL-LHC with 5 (nominal) to 7.5 (ultimate) $x10^{34}cm^{-2}s^{-1}$ to collect 3000/fb in order ten years.

ATLAS Phase 1 upgrades

- Phase 1 (for Run 3, after LS2)
    - FTK (fast track trigger - gradual implementation)
    - NSW (muon new small wheel – reject background in trigger)
    - L1 calo (finer granularity for trigger)
    - Trigger-DAQ upgrades (trigger, higher through put)



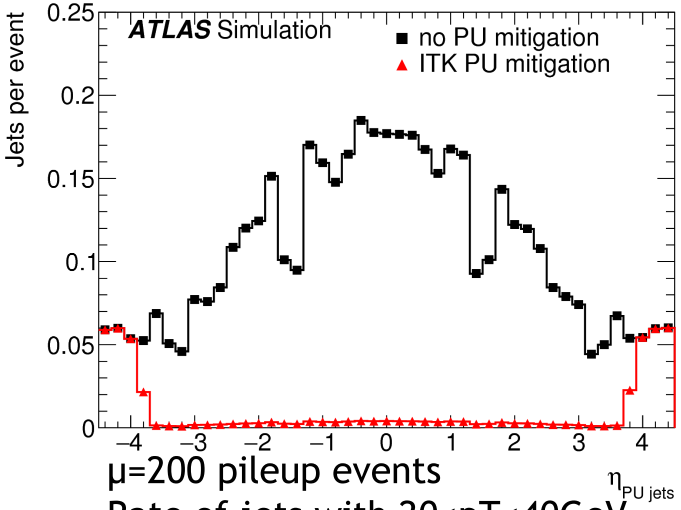
B and C rejected with NSW



Trigger response to 70 GeV electron

Phase 2 for HL-LHC

- New all-silicon tracker ITk
    - Extending to |η|< 4.0
    - L1 track trigger
- Calorimeter electronics upgrade (full info at trigger level)

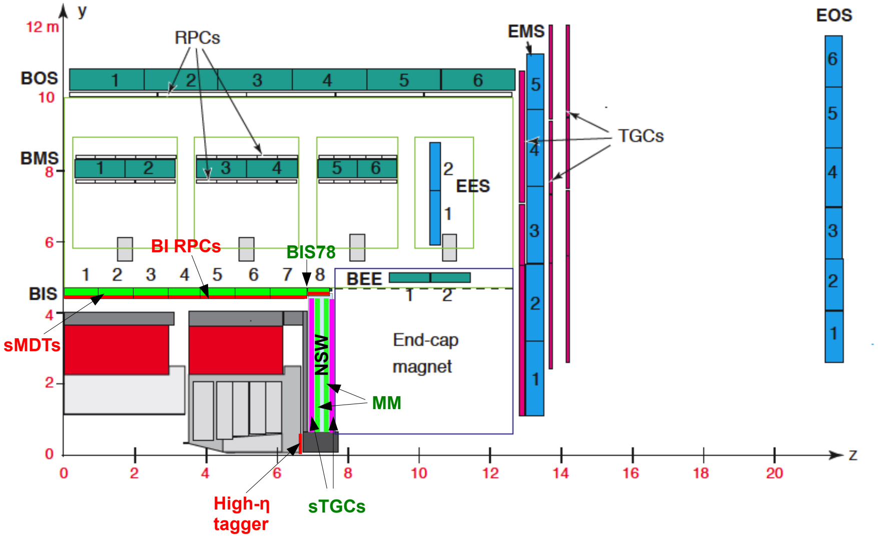


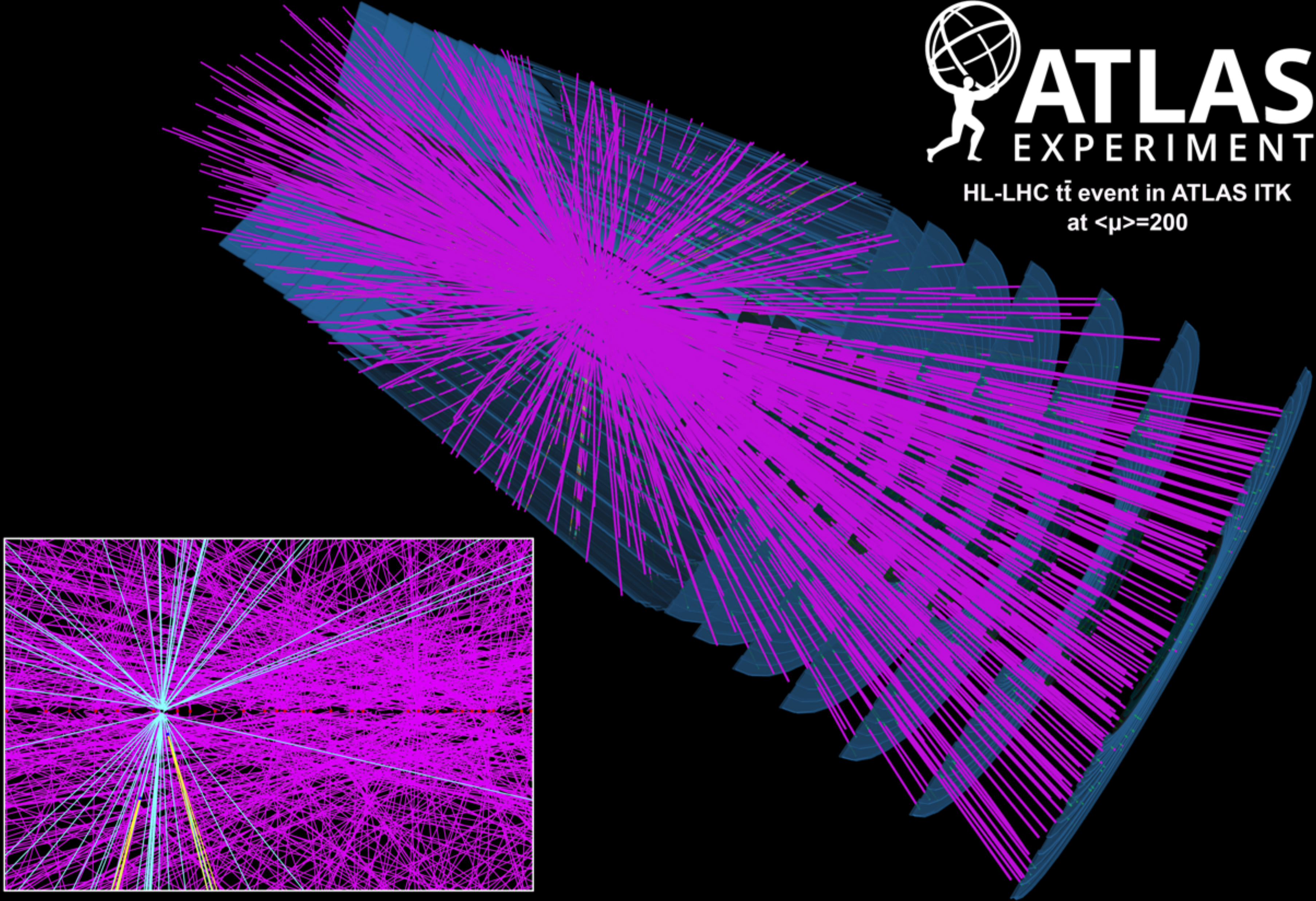
μ=200 pileup events
Rate of jets with 20<pT<40GeV

- Muon system upgrades (fill gaps in trigger coverage with new inner barrel chambers; new front-end electronics)

- Trigger-DAQ upgrades

- Options:
    - High granularity timing detector for the forward region
    - Muon high-η tagger





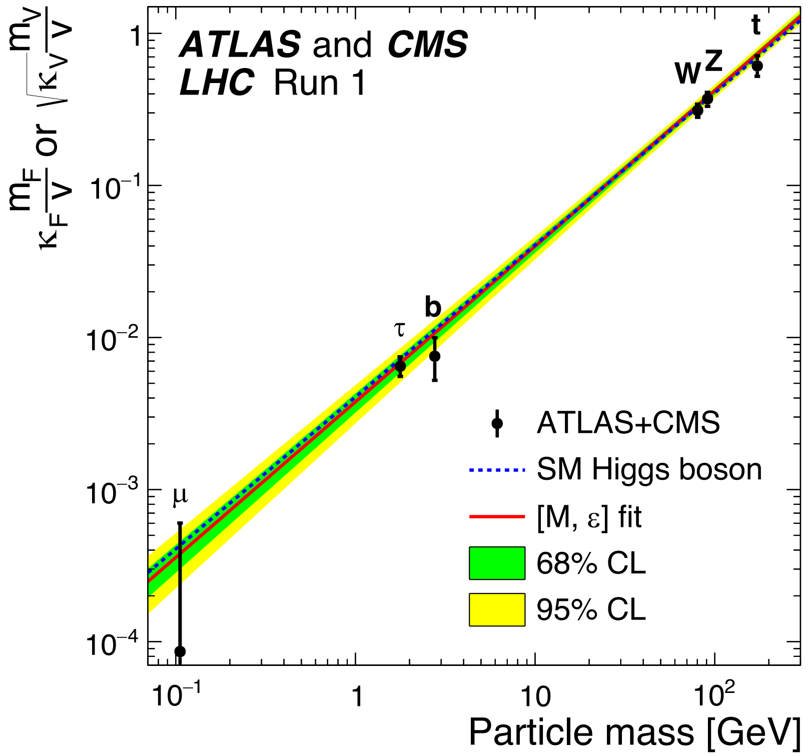
ATLAS EXPERIMENT

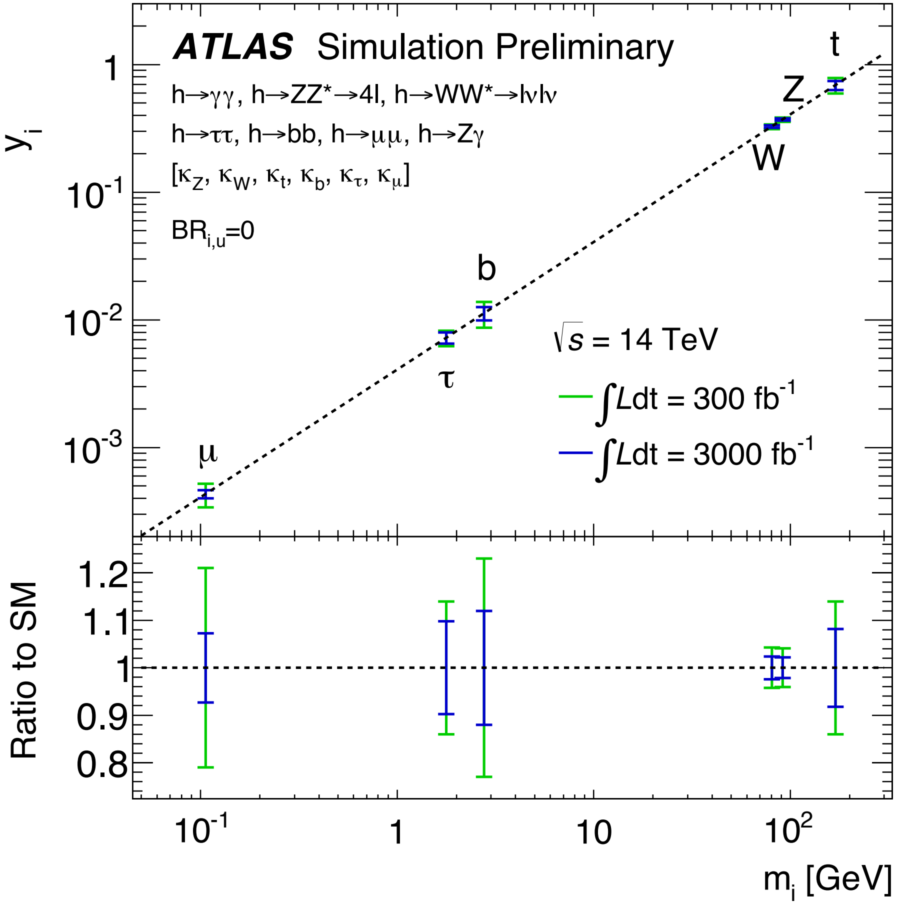
HL-LHC $t\bar{t}$ event in ATLAS ITK
at $\langle\mu\rangle=200$

JHEP 08 (2016) 045
ATL-PHYS-PUB-2014-016

Higgs boson

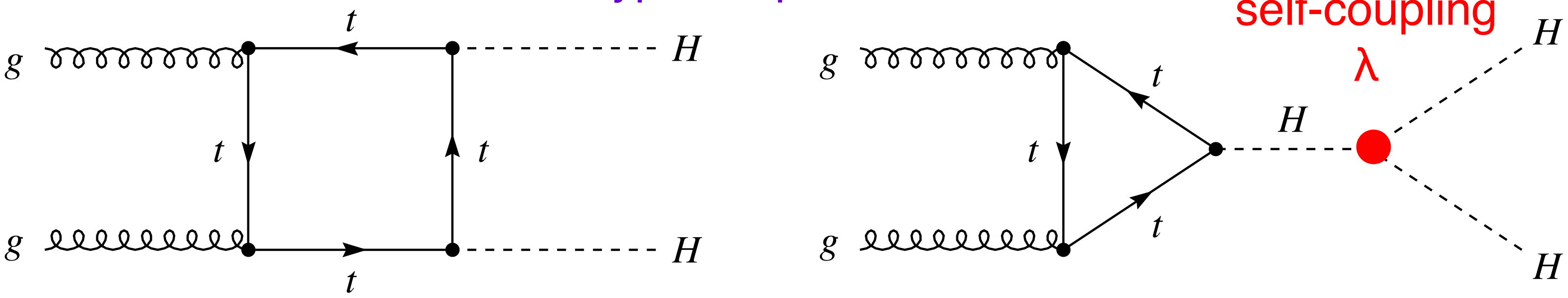
- Example coupling plots from Run 1 and for HL-LHC
  - Typical precision improves from 10% (300/fb) to 4% (3000/fb)
  - H→μμ observed with >7σ significance





Higgs boson pair production

- Higgs boson pair production includes destructive interference between two types of processes:



Higgs triple self-coupling λ

- ~factor 2 increase in cross section if λ→0

NNLO σ^{SM}=40.8 fb

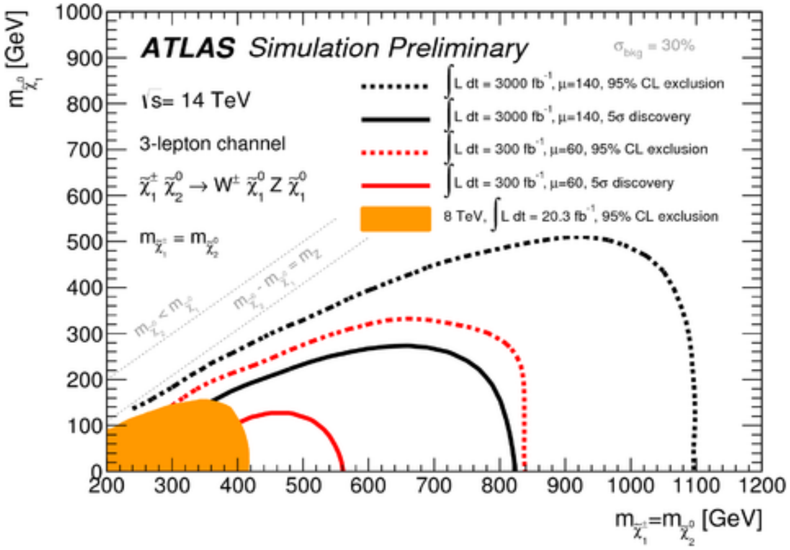
- Will have to combine several decay modes and both experiments to have evidence

- More generally – explore electroweak symmetry breaking in Vector Boson Scattering

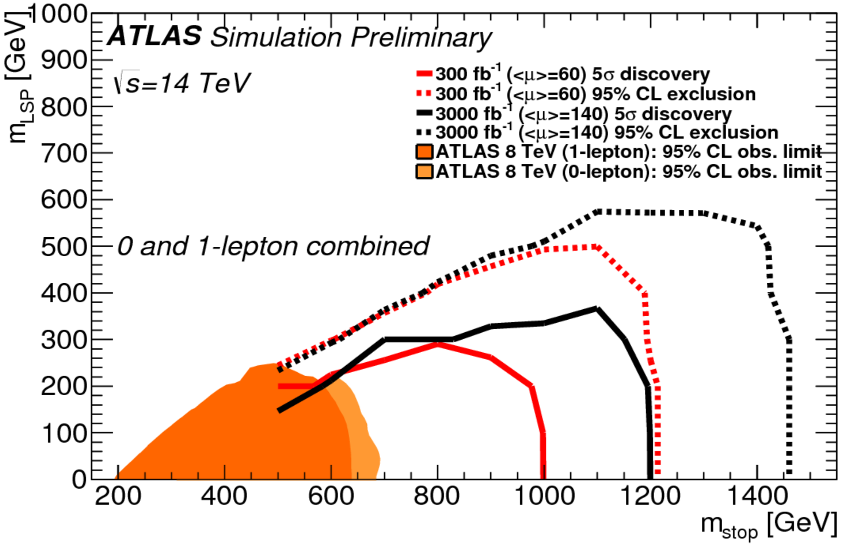
Channel	Events in 3/ab	Significance for HH (λ=1)
bbbb	40000	0.6 σ
bbWW	30000	(ttbar backgr)
bbττ	9000	0.6 σ
WWWW	6000	
γγbb	320	1.05 σ
γγγγ	1	

Search reach (300/fb vs 3000/fb)

- Electroweak SUSY, extend from 500-600 GeV to 800-900 GeV
- Scalar top/bottom, few 100 GeV increase in reach



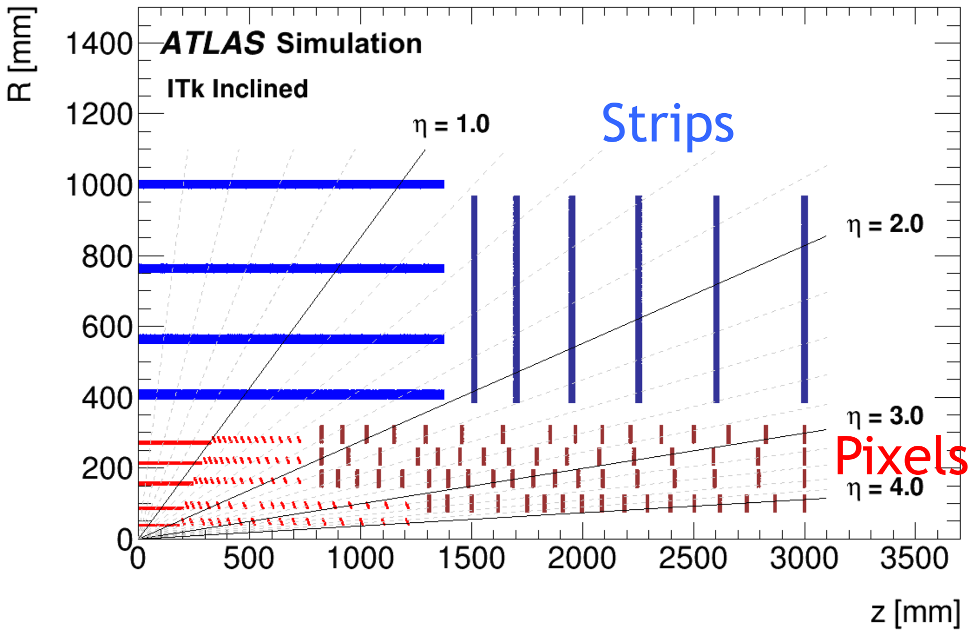
ATL-PHYS-PUB-2014-010, 2015-032

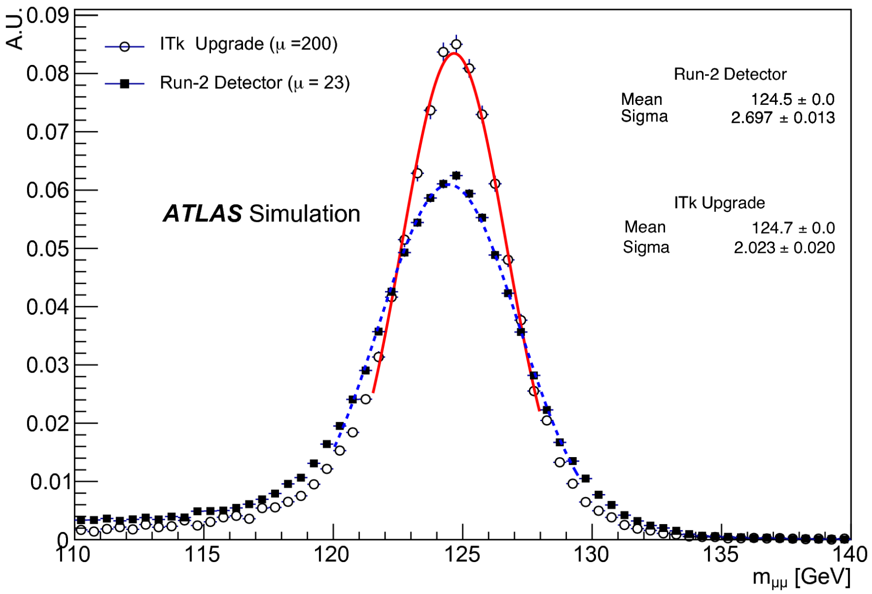


ATL-PHYS-PUB-2013-011

HL-LHC studies in progress

- Present efforts are focussing on TDRs for each Phase 2 upgrade
  - Demonstrate that the detector and trigger choices meet the required performance
  - ITk layout from the Strip TDR improves in H→μμ mass resolution





- More comprehensive physics prospects planned for Update of European Strategy for Particle Physics

Conclusions

- Measurements – recent highlights include
  - W mass measurement with 7 TeV data – 19 MeV precision
  - Evidence for light-by-light scattering in Pb-Pb
  - Evidence for H→bb decays
- Searches
  - SUSY being probed up to 2 TeV
  - No hints yet of BSM new physics
- Future prospects
  - Well defined path for experiment upgrades to match (HL-)LHC
  - Precise measurements of Higgs boson properties. Probe electroweak symmetry breaking.
  - Increase reach for high mass or weakly coupled new particles

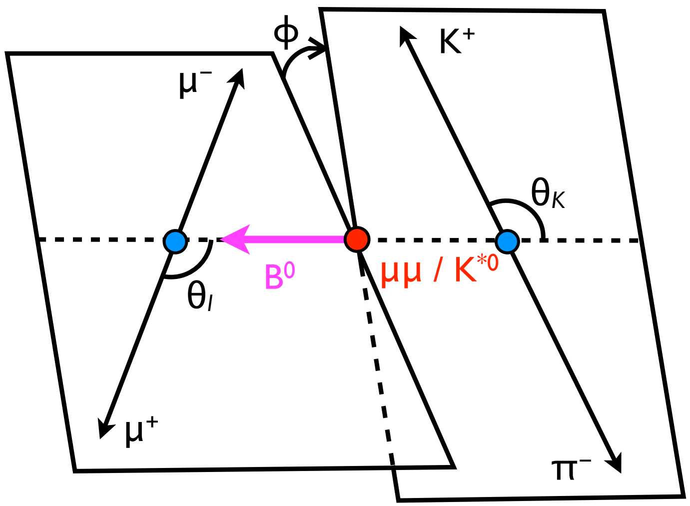
- A rich and diverse programme to keep us busy for years and even decades to come

Extras

Heavy Flavours

B→K*μμ angular analysis

- Multiparameter fit to B→K*μμ, K*→Kπ as a function of lepton pair invariant mass squared (q^2)
- P'_5 should be less sensitive to hadronic uncertainties



$$\frac{1}{\mathrm{d}\Gamma/\mathrm{d}q^2}\frac{\mathrm{d}^4\Gamma}{\mathrm{d}q^2\mathrm{d}\cos\theta_l\mathrm{d}\cos\theta_K\mathrm{d}\phi}$$

S-wave and S&P-wave interference

$$=\frac{9}{8\pi}\left\{\frac{2}{3}\left[(\boxed{F_S}+\boxed{A_S}\cos\theta_K)(1-\cos^2\theta_l)+\boxed{A_S^5}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]+(1-\boxed{F_S})\left[2\boxed{F_L}\cos^2\theta_K(1-\cos^2\theta_l)+\frac{1}{2}(1-\boxed{F_L})(1-\cos^2\theta_K)(1+\cos^2\theta_l)+\frac{1}{2}\boxed{P_1}(1-\boxed{F_L})(1-\cos^2\theta_K)(1-\cos^2\theta_l)\cos 2\phi+2\boxed{P'_5}\cos\theta_K\sqrt{\boxed{F_L}(1-\boxed{F_L})}\sqrt{1-\cos^2\theta_K}\sqrt{1-\cos^2\theta_l}\cos\phi\right]\right\}$$

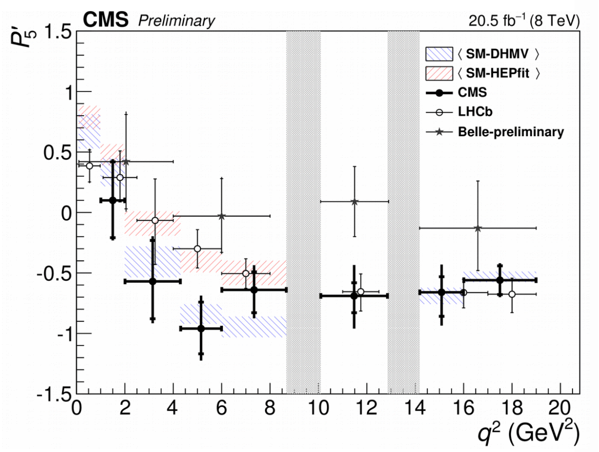
P-wave

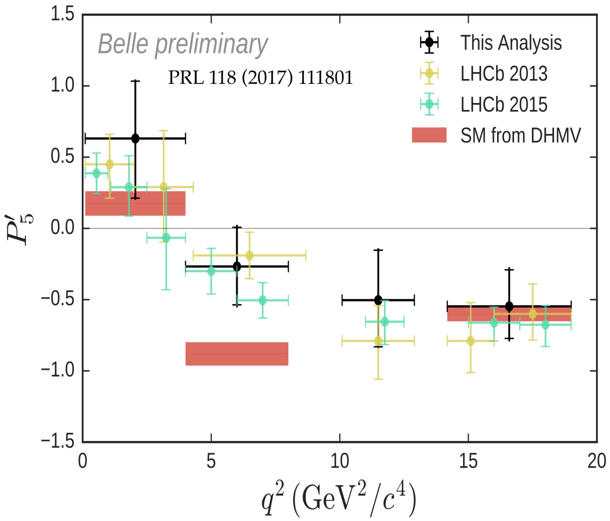
(artwork from talk by Mauro Dinardo @ Moriond-EW)

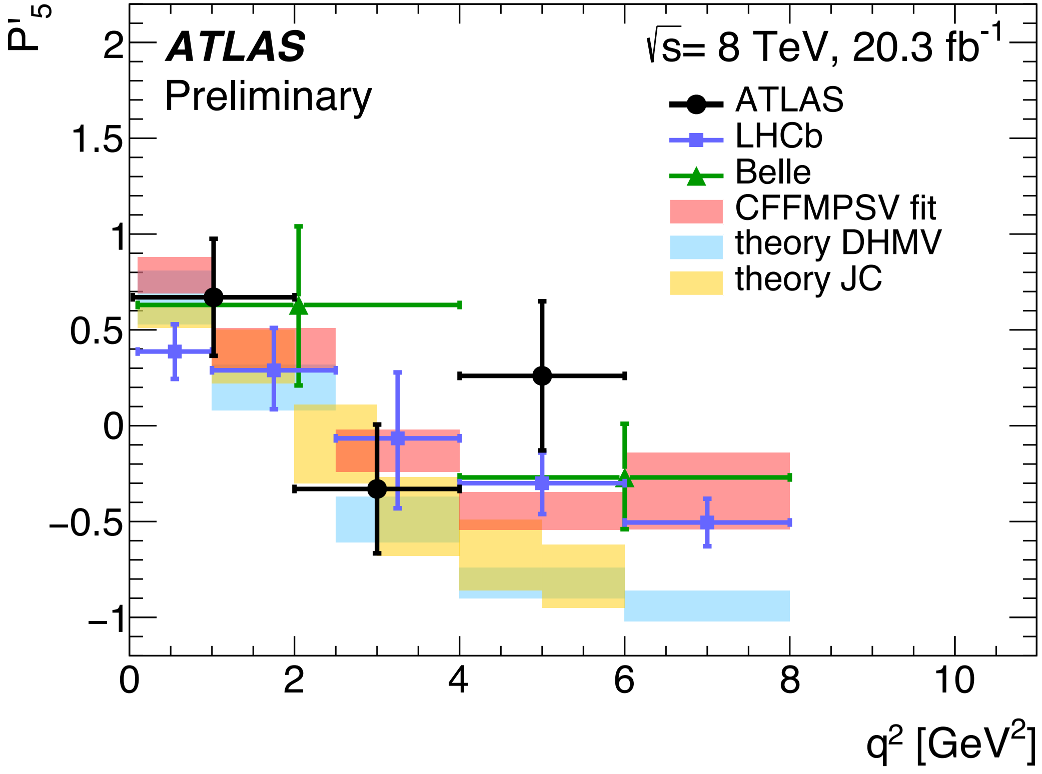
ATLAS-CONF-2017-023

B→K*μμ angular analysis

- New results from ATLAS in the region q^2<6 GeV^2





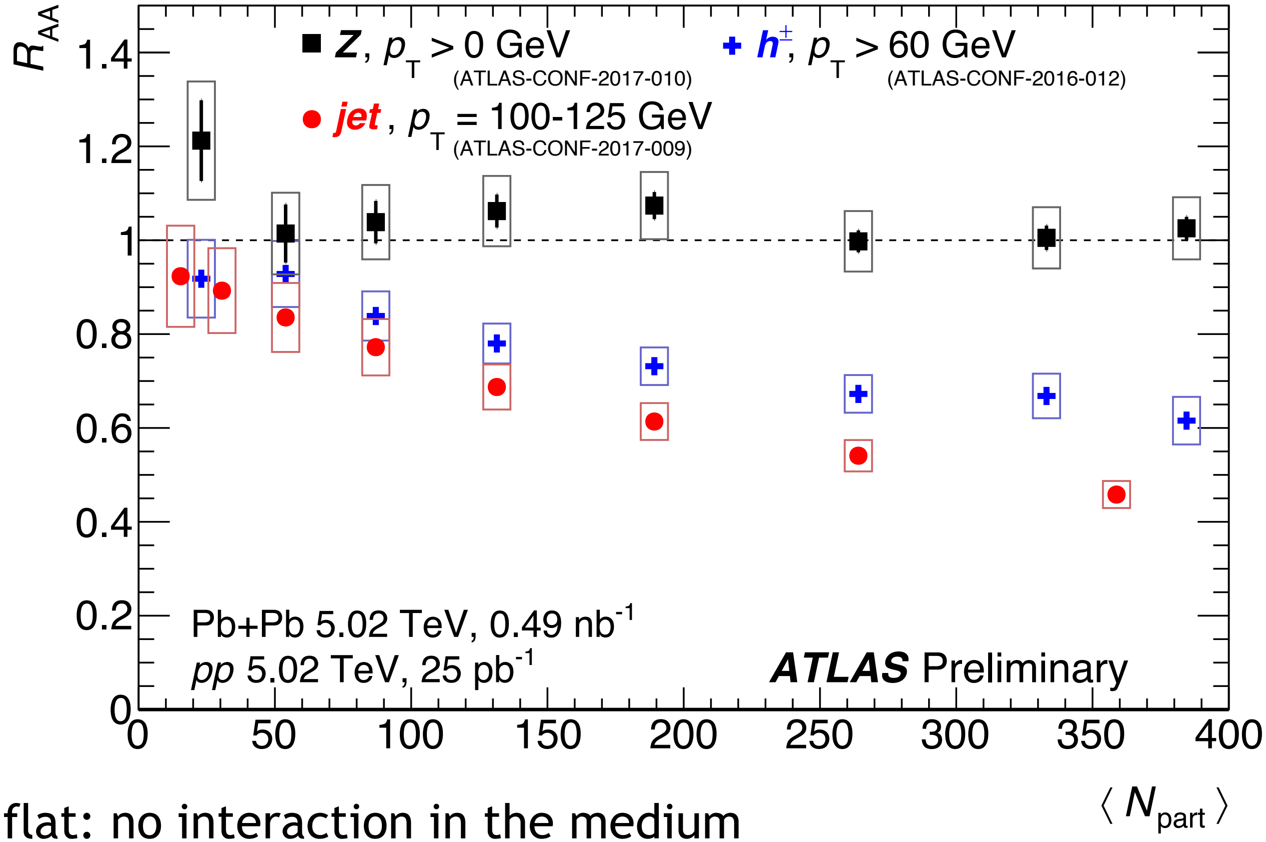


Heavy Ion collisions

Heavy Ion collisions

- Hard probes created in the early stage of collision may be modified by the Quark Gluon Plasma

$$R_{AA} = \frac{1}{N_{coll}} \frac{Y(AA)}{Y(pp)}$$



- R_{AA} for Z bosons – flat: no interaction in the medium
- R_{AA} for jets and hadrons: significant suppression