Overview of ATLAS Results from Last Year

Detector Performance and Physics Highlights

Craig Wiglesworth – Niels Bohr Institute, University of Copenhagen

On behalf of the ATLAS Experiment

TOP 2019

UNIVERSITY OF COPENHAGEN

ATLAS EXPERIMENT

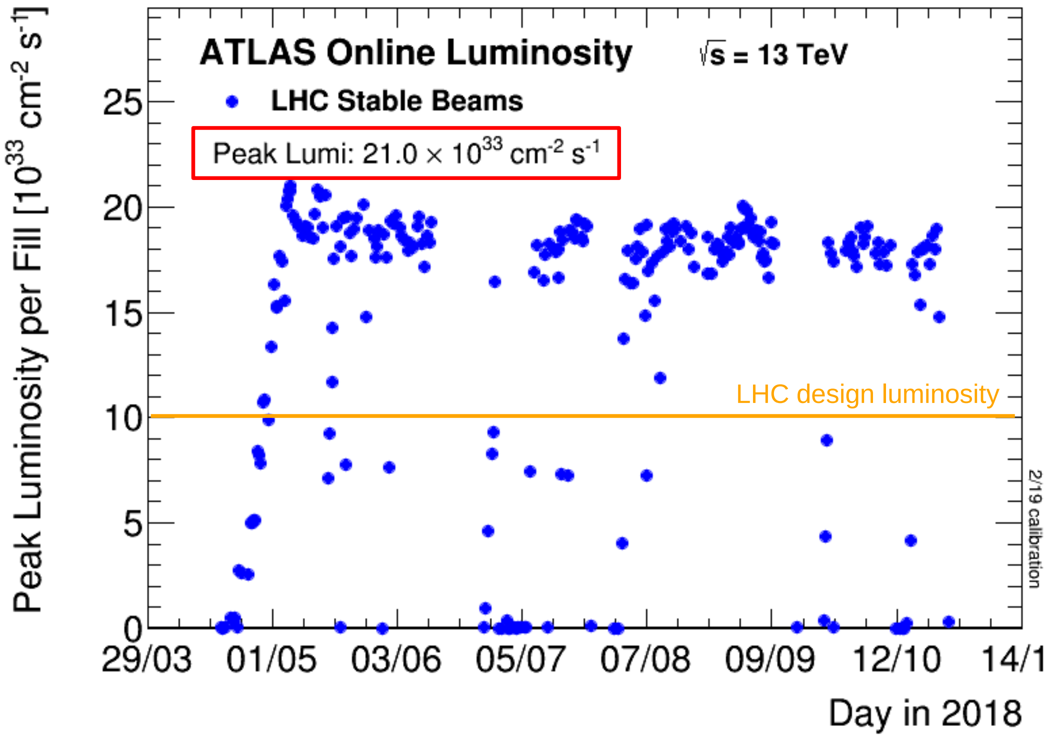
Overview

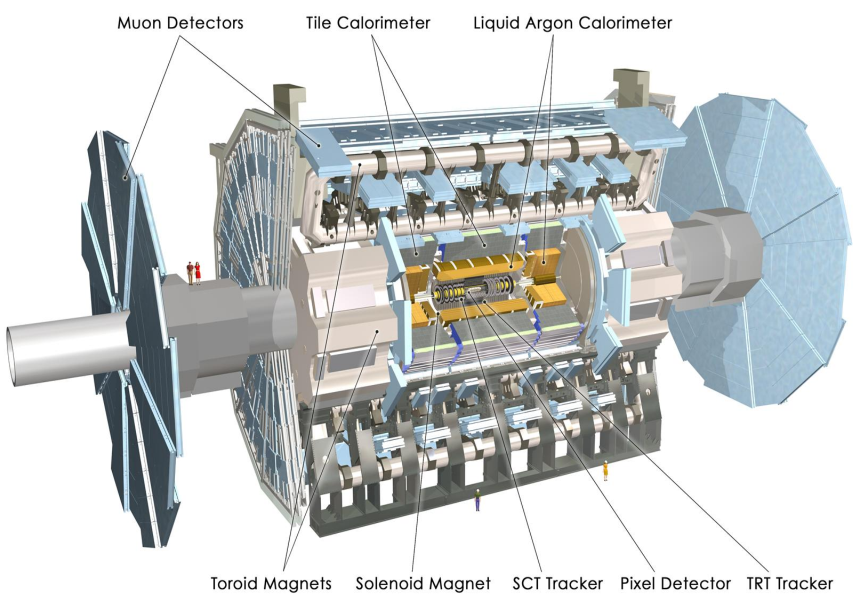
- The LHC & ATLAS Detector
- ATLAS Run 2 Datasets
- Reconstruction / Calibration
- Physics Highlights
- The Preparations for Run 3

The LHC and ATLAS Detector in 2018

- Excellent performance of the LHC in 2018 !!!
- Peak luminosity > x2 LHC design luminosity
- ATLAS performance continuously improving:

	2015	2016	2017	2018
Data Taking	92.4 %	92.5 %	93.4 %	95.7 %
Data Quality	87.1 %	92.8 %	93.6 %	97.5 %





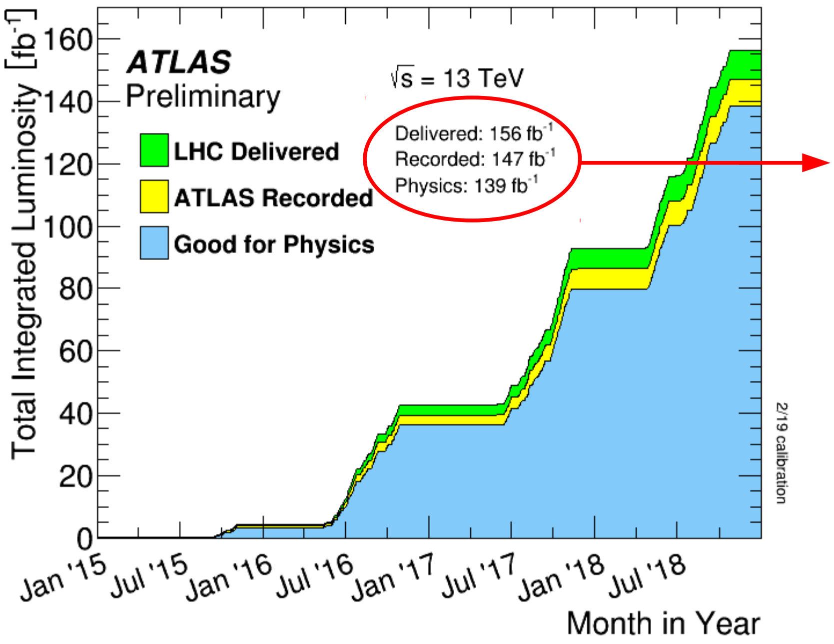
ATLAS pp data: April 25-October 24 2018

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.8	100	99.7	100	99.8	99.7	100	100	100	99.6

Good for physics: 97.5% (60.1 fb^{-1})

Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions at $\sqrt{s}$=13 TeV between April 25 – October 24 2018, corresponding to a delivered integrated luminosity of 63.8 fb^{-1} and a recorded integrated luminosity of 61.7 fb^{-1}. Dedicated luminosity calibration activities during LHC fills used 0.7% of recorded data and are included in the inefficiency. The luminosity includes 193 pb^{-1} of good data taken at an average pileup of μ=2.

ATLAS Run 2 Datasets (2015 - 2018)

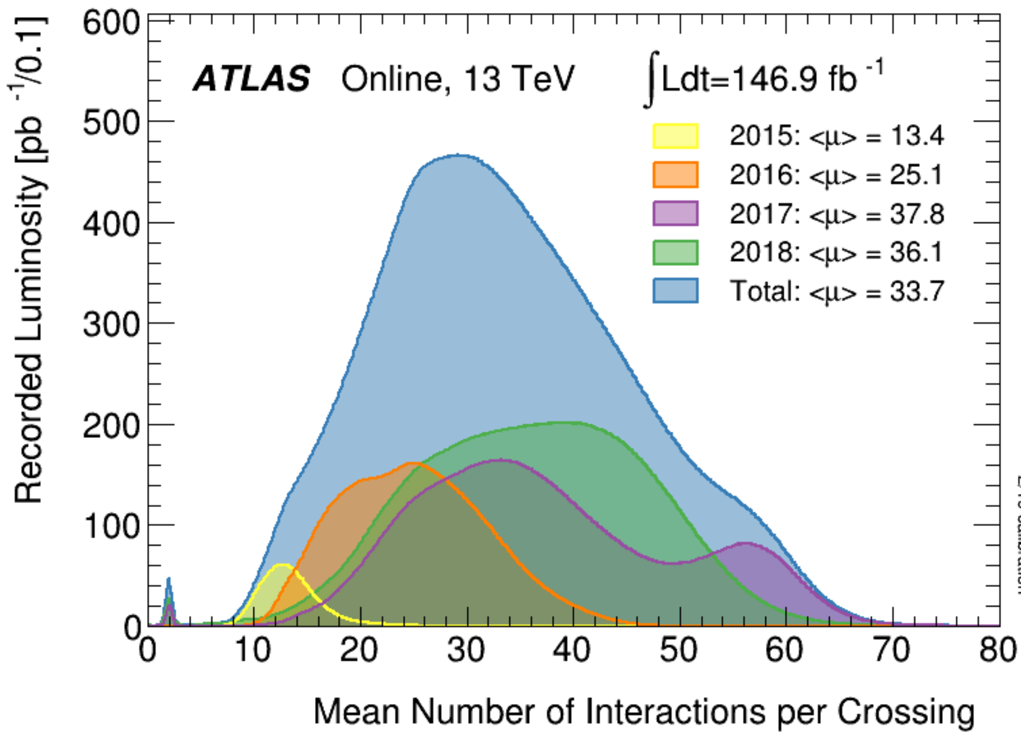


Proton-Proton √s = 13 TeV Dataset

- 156 fb^{-1} delivered – thanks to CERN accelerators team !
- 147 fb^{-1} recorded (94 %)
- 139 fb^{-1} good for physics (95 %)

Measured to a precision of 1.7 % [ATLAS-CONF-2019-021]

- Average number of interactions per bunch crossing = 34

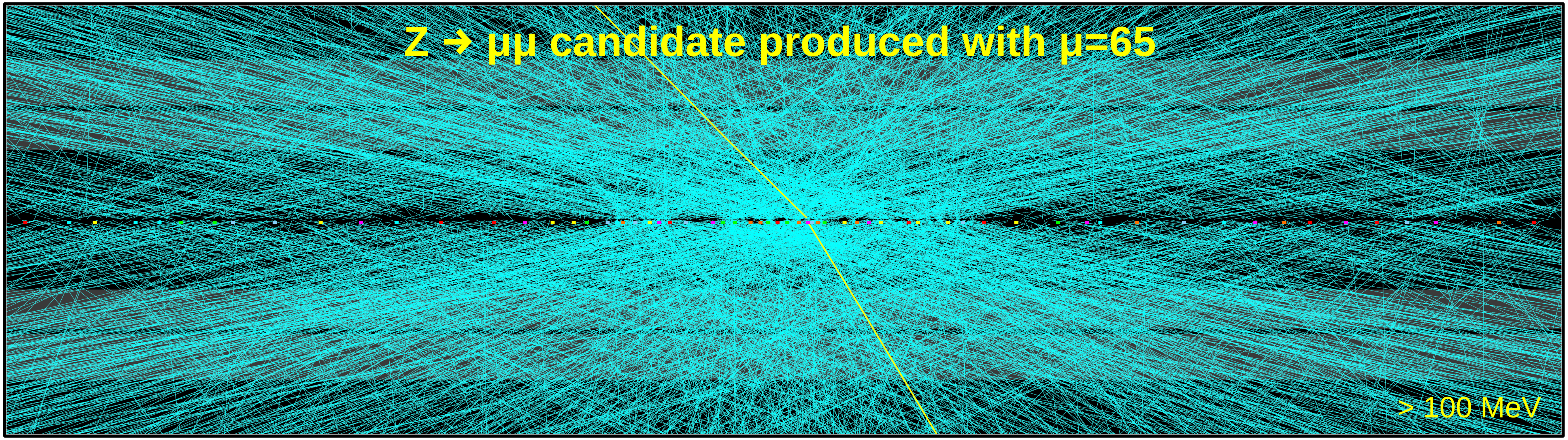


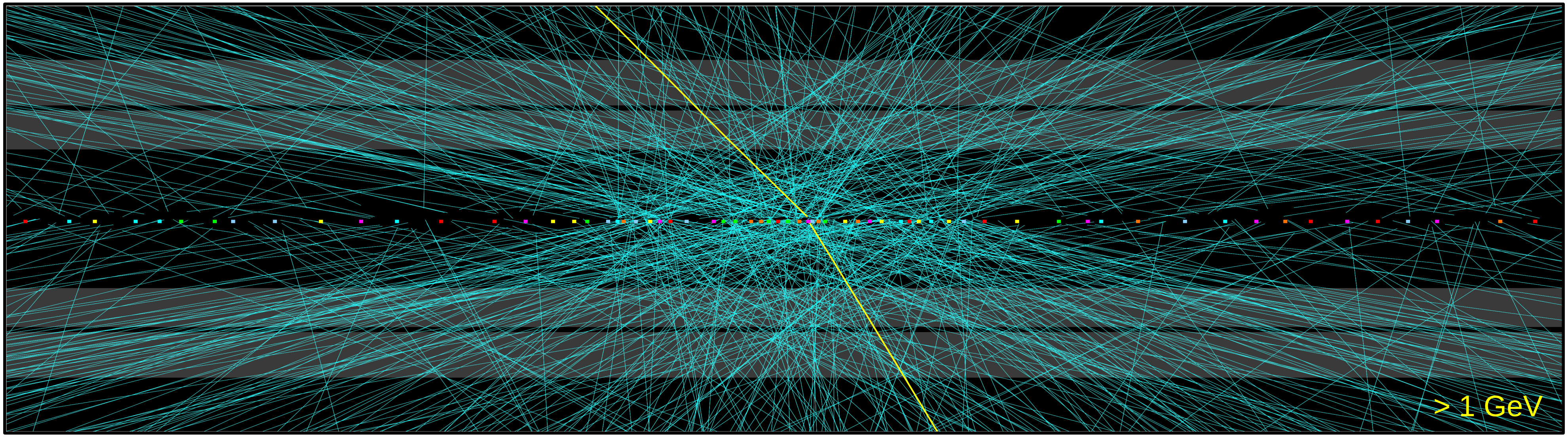
Other Datasets

- Pb-Pb, proton-Pb, Xe-Xe
- Data with low <μ> for precision W physics
- Data with different beam energies / optics for diffractive physics

The LHC is a very versatile machine !

Pile-up in Run 2

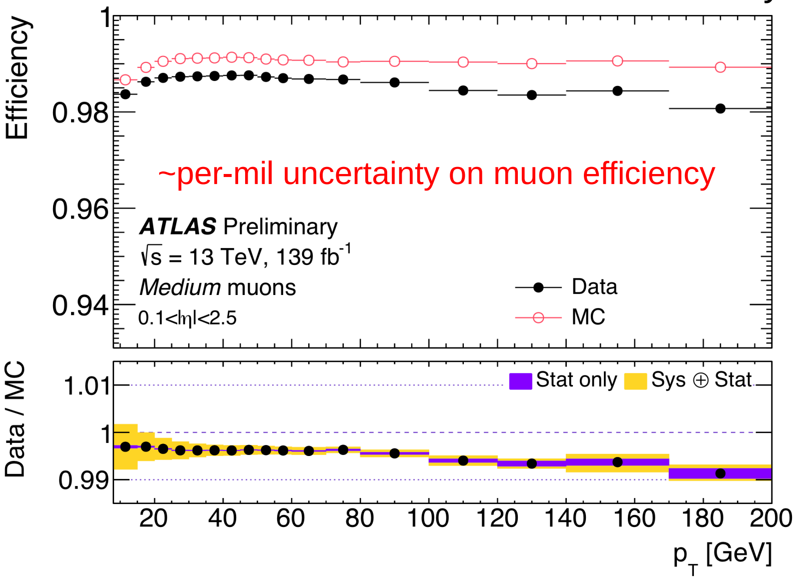




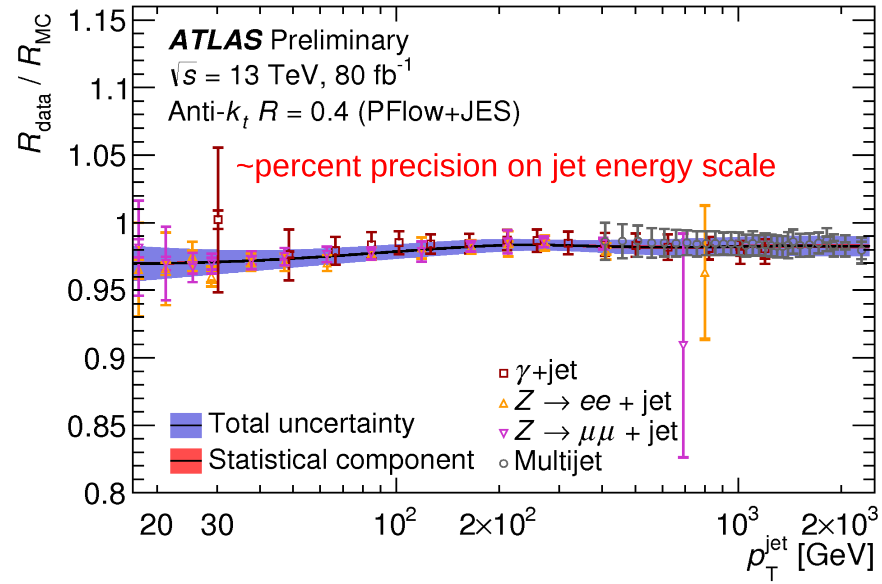
Continues to pose a number of challenges… eg. particle identification / reconstruction, trigger rates / bandwidth

Reconstruction and Calibration

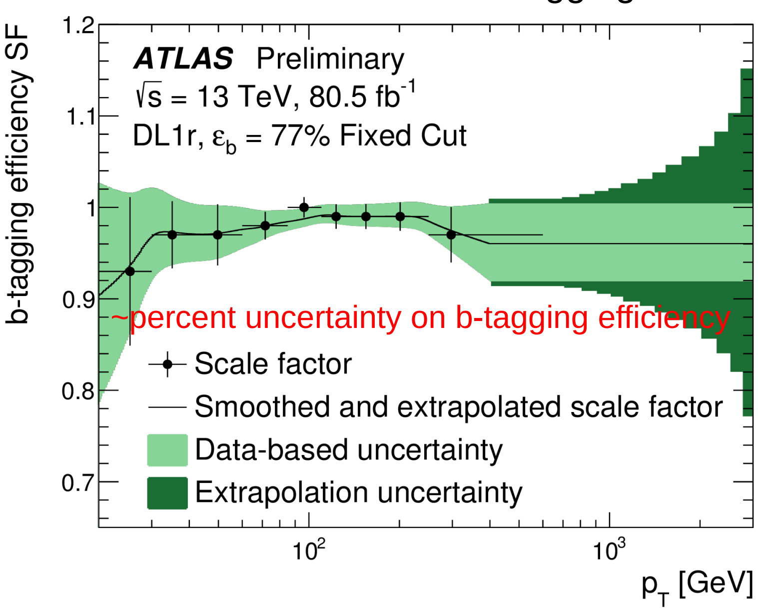
Data-driven calibration of muon efficiency



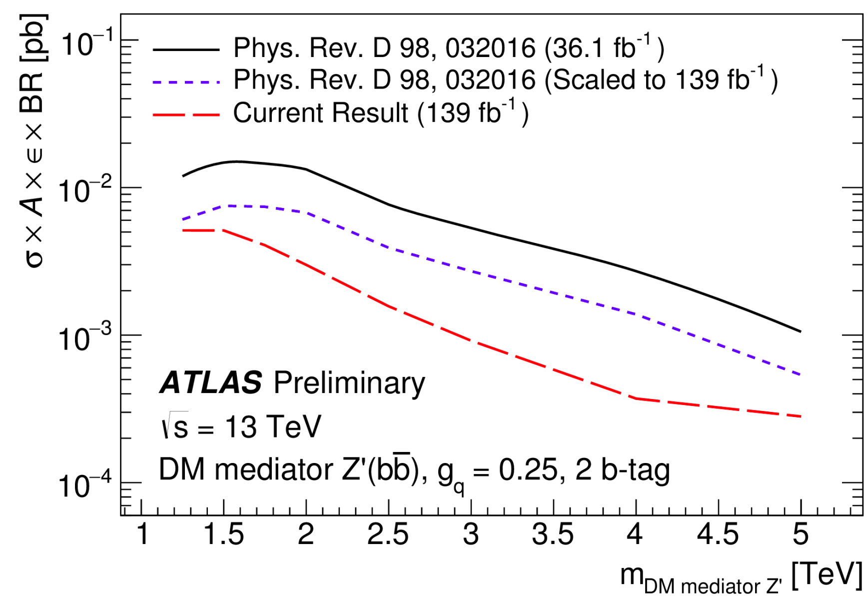
Data-driven energy calibration of jets



Data-driven calibration of b-tagging efficiency



Resonance Search (Z'→bb) [CERN-EP-2019-162]



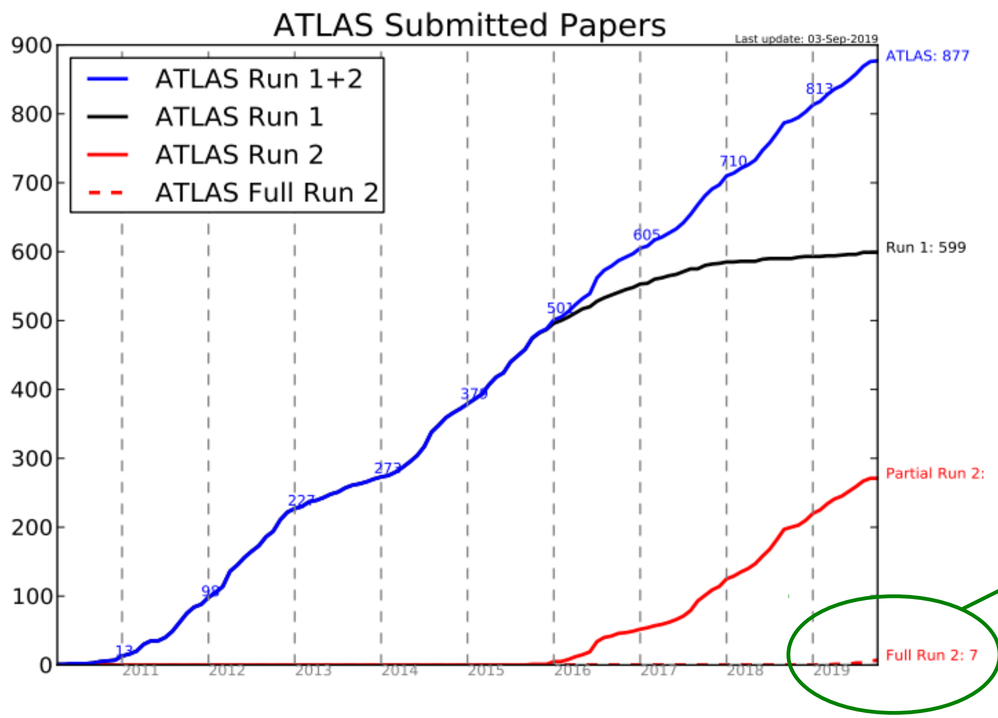
ATLAS Physics Program

The LHC is an **EVERYTHING** factory!

Large dataset facilitates a broad physics program

- Probing SM / Higgs processes with high precision
- Detecting very rare processes
- Exploring vast kinematic domain for new physics

Produced in 139 fb^{-1} @ $\sqrt{s}$ = 13 TeV	
Higgs Bosons	7.7 million
Top Quarks	275 million
Z Bosons	2.8 billion
W Bosons	12 billion
Bottom Quarks	~40 trillion

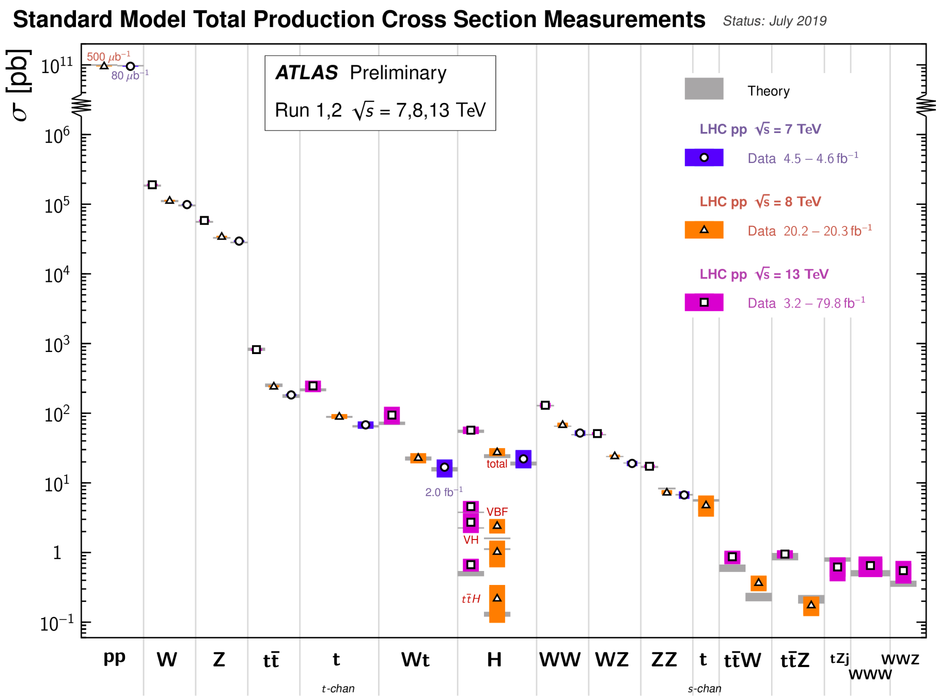


2019 has seen the first ATLAS analyses based on the full (139 fb^{-1}) Run 2 dataset

- **7** papers submitted to journals (so far)
- **26** conference notes

The following is a brief selection of these results

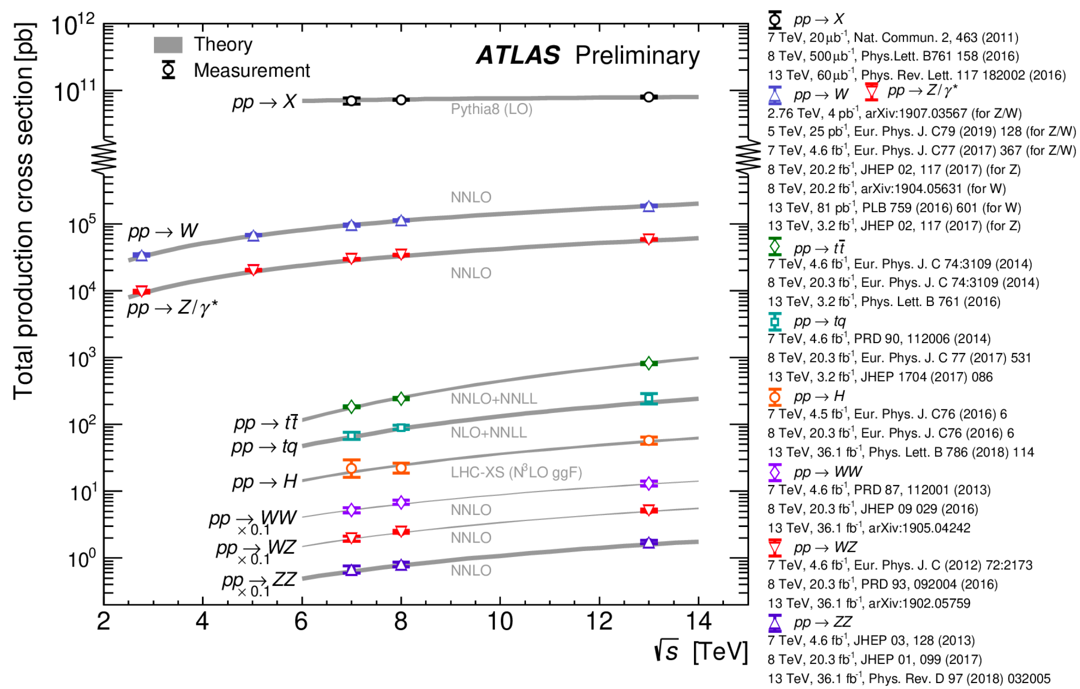
Precision Tests of the Standard Model



Many cross section measurements have been performed by ATLAS

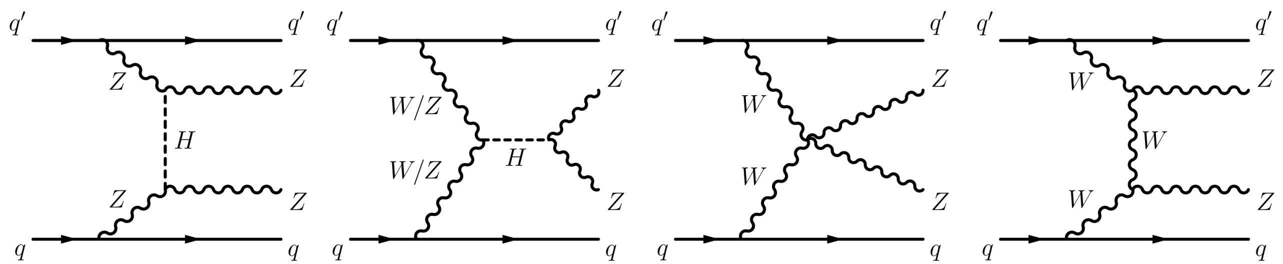
Theoretical predictions here at NLO or higher

So far... all measurements agree with SM predictions



Vector Boson Scattering

Massive VBS provides a key avenue to probe EWSB – here focus on electroweak production of ZZjj



EW WWjj (6.5σ) [arXiv:1906.03203]

EW WZjj (5.3σ) [Phys. Lett. B 793 (2019) 469]

Multivariate discriminants are used to separate signal from (irreducible) QCD background

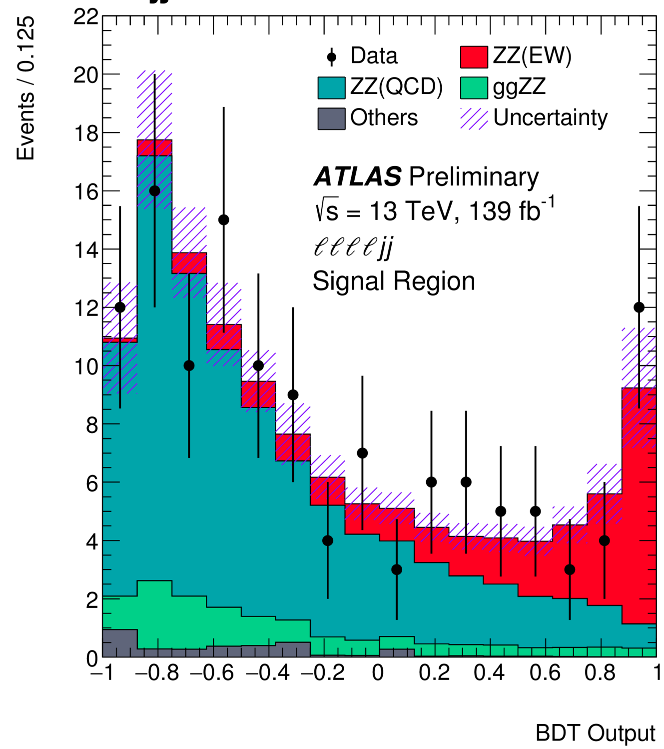
EW ZZjj

Observed with (expected) significance of 5.5σ (4.3σ)

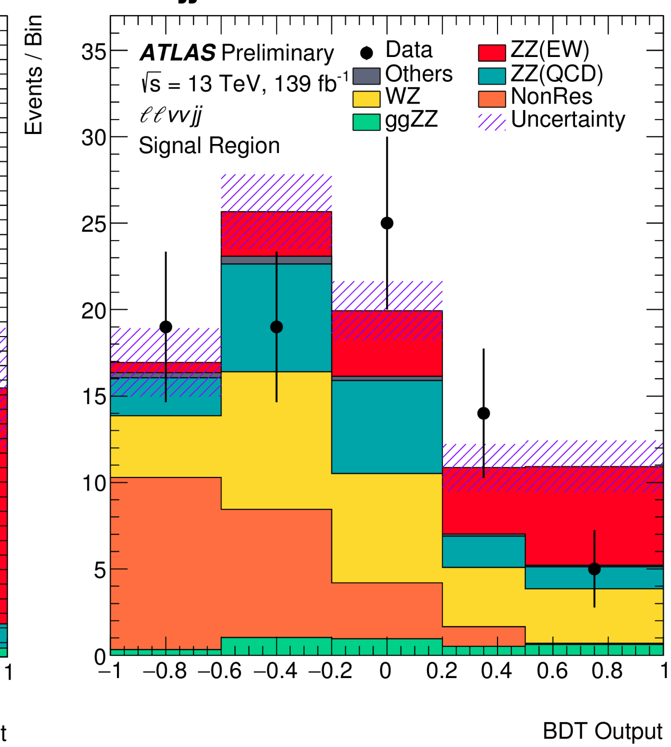
$\sigma_{fid} = 0.82 \pm 0.21$ fb
SM = 0.61 ± 0.03 fb

All VVjj processes have now been observed (>5σ) in ATLAS

llllljj



llvvjj [ATLAS-CONF-2019-033]



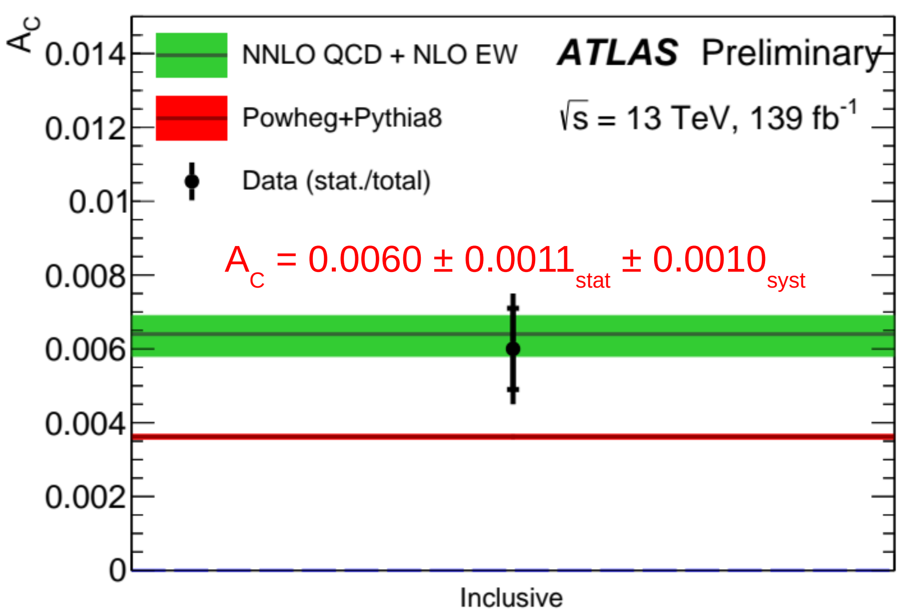
Charge Asymmetry in tt-bar

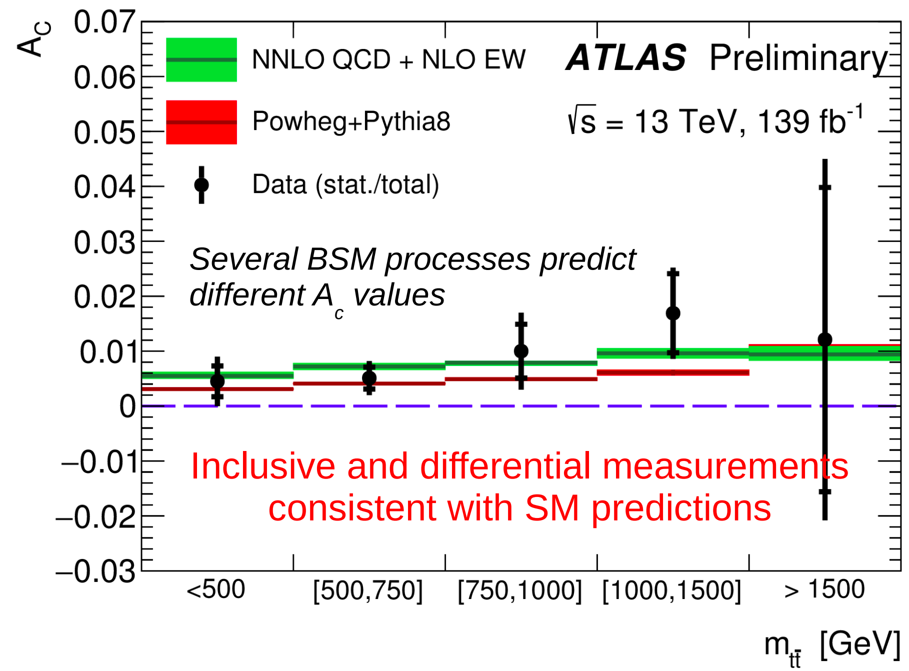
Large sample of ttbar events allows study of production asymmetry (H.O. QCD effects from qq-bar and qg)

Central-forward charge asymmetry: $$A_C = \frac{N(\Delta|y| > 0) - N(\Delta|y| < 0)}{N(\Delta|y| > 0) + N(\Delta|y| < 0)}$$

Asymmetry measured using resolved and boosted top-quark decays to lepton + jets

(Bayesian unfolding procedure used to infer A_c at parton level – correcting for detector/acceptance)



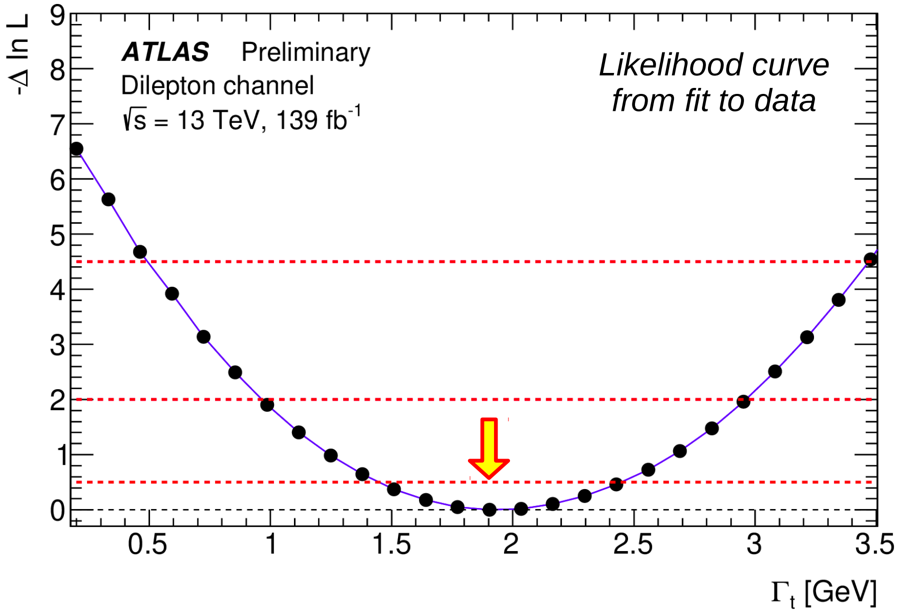


Non-zero at 4σ - first evidence of charge asymmetry @ LHC

Top-Quark Decay Width

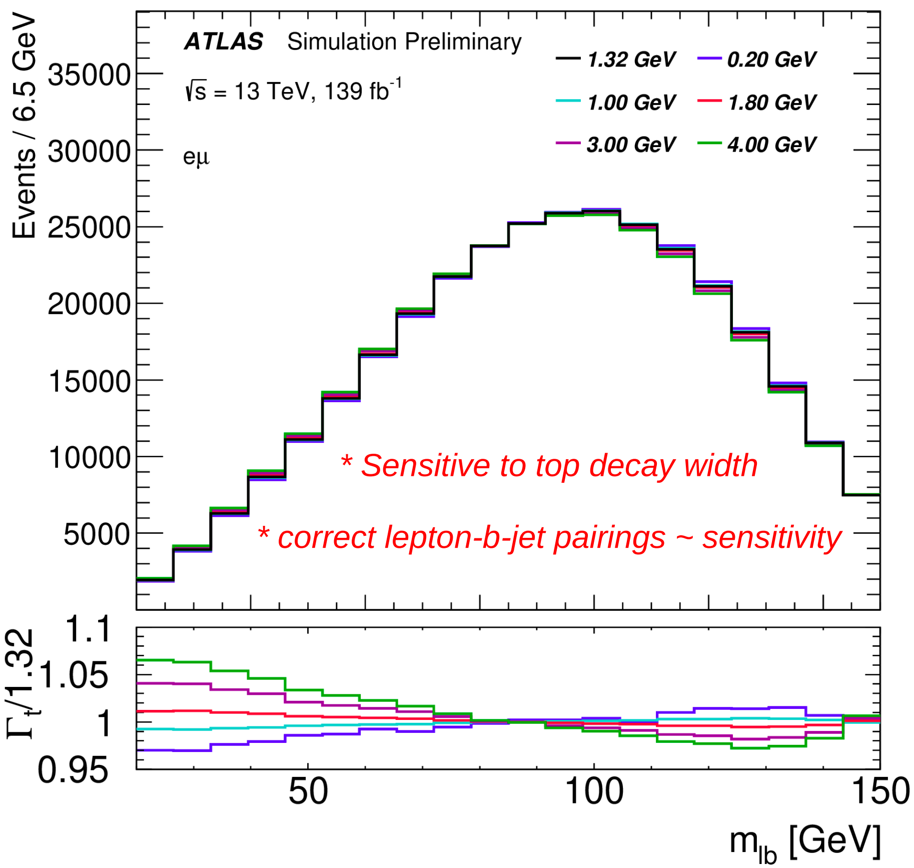
Deviations from SM prediction may hint at non SM decay channels of top-quark / modification of top quark couplings

Direct measurement of top-quark decay width Based on m(lb) distribution in dileptonic tt-bar events



Decay width extracted from profile-likelihood fit of templates representing different decay widths

[ATLAS-CONF-2019-038]

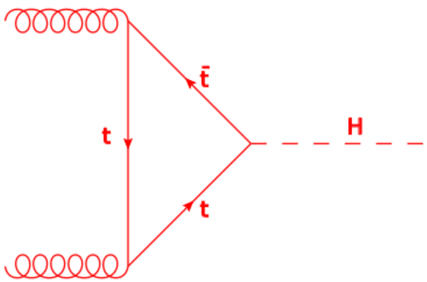


Γ_{top} = 1.9 ± 0.5 GeV

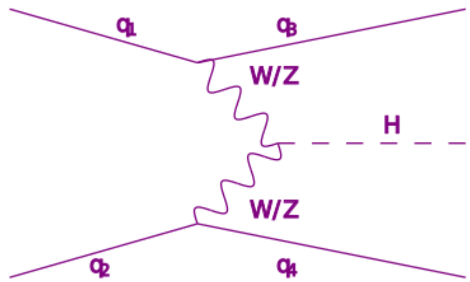
SM: 1.32 GeV @ m_{top} = 172.5 GeV

Higgs Physics in ATLAS

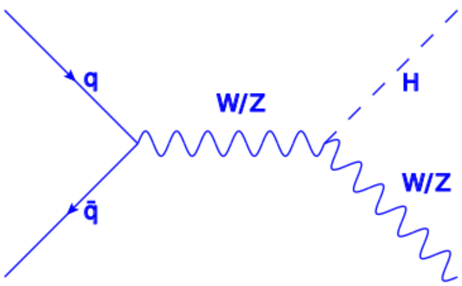
All major production / decay modes of the Higgs have been observed (≥ 5σ) in ATLAS



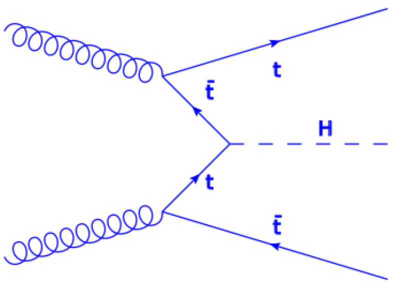
ggF
Run 1



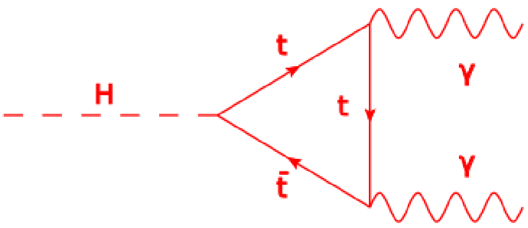
VBF
Run 1 (ATLAS + CMS)



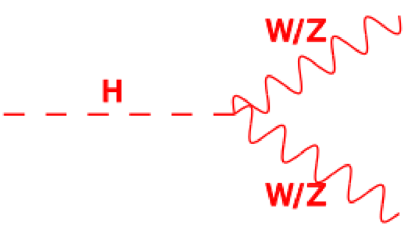
VH
2018



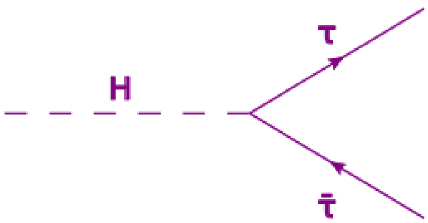
ttH
2018



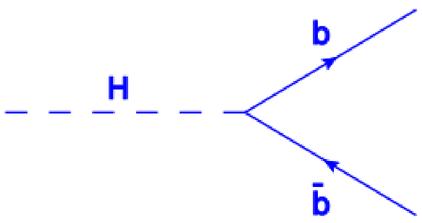
Hγγ
Run 1



HWW / HZZ
Run 1



Hττ
Run 1 (ATLAS + CMS)



Hbb
2018

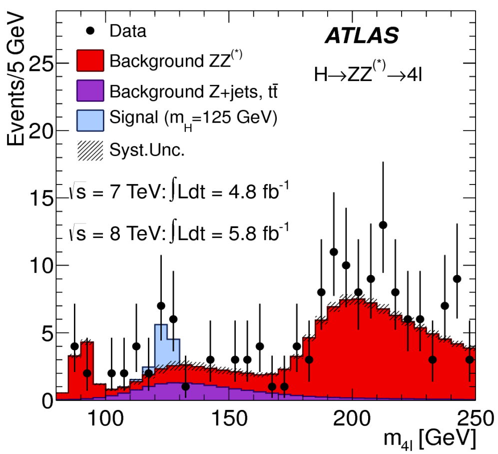
The Higgs (Re-)Discovery

Inclusive and differential cross sections measured in the $H \to ZZ^* \to 4l$ and $H \to \gamma\gamma$ channels

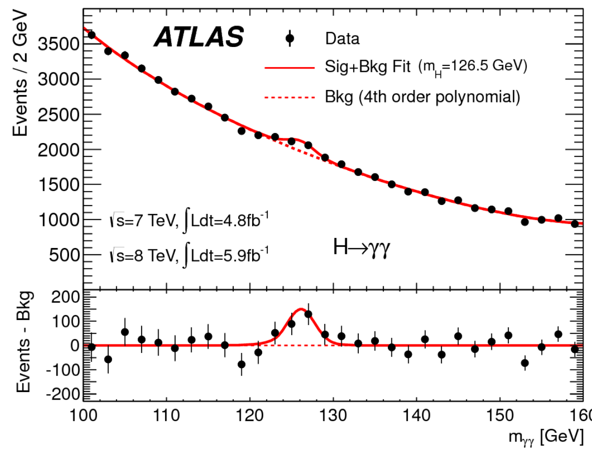
We're now moving into realm of precision Higgs physics… *(many more Higgs to play with!)*

2012

[Phys.Lett. B716 (2012) 1-29]



[Phys.Lett. B716 (2012) 1-29]



$H \to ZZ^* \to 4l$ **9%**

σ_{fid} = 3.35 ± 0.30(stat.) ± 0.12(syst.) fb
SM = 3.41 ± 0.18 fb

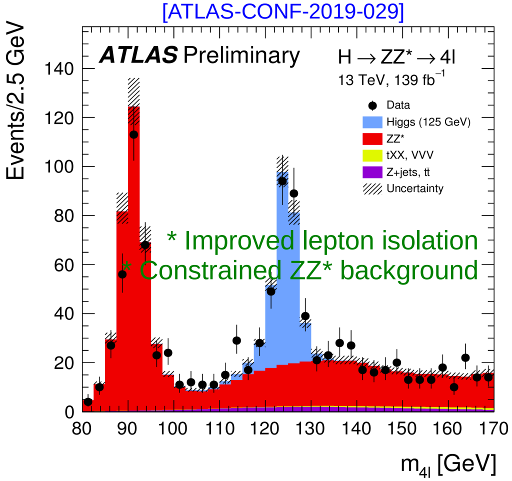
$H \to \gamma\gamma$ **11%**

σ_{fid} = 65.2 ± 4.5(stat.) ± 5.6(syst.) ± 0.3(theo.) fb
SM = 63.6 ± 3.3 fb

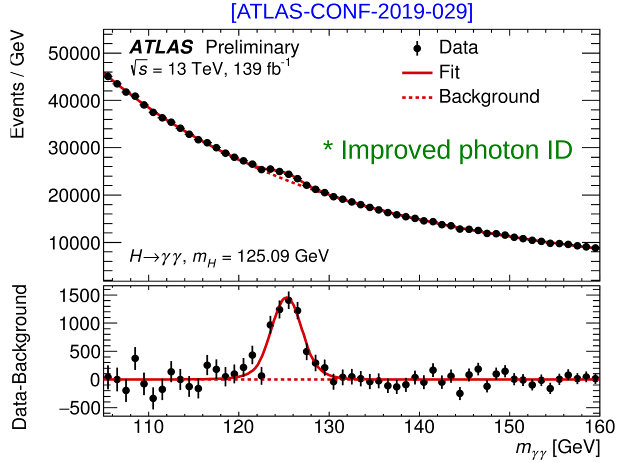
Measurements are in agreement with SM

2018

[ATLAS-CONF-2019-029]

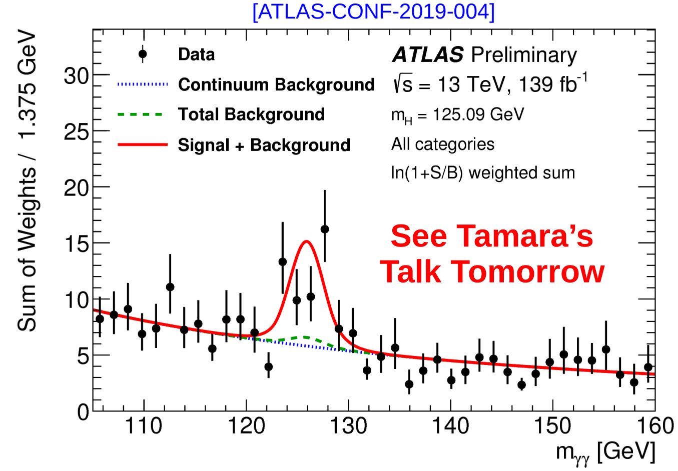


[ATLAS-CONF-2019-029]

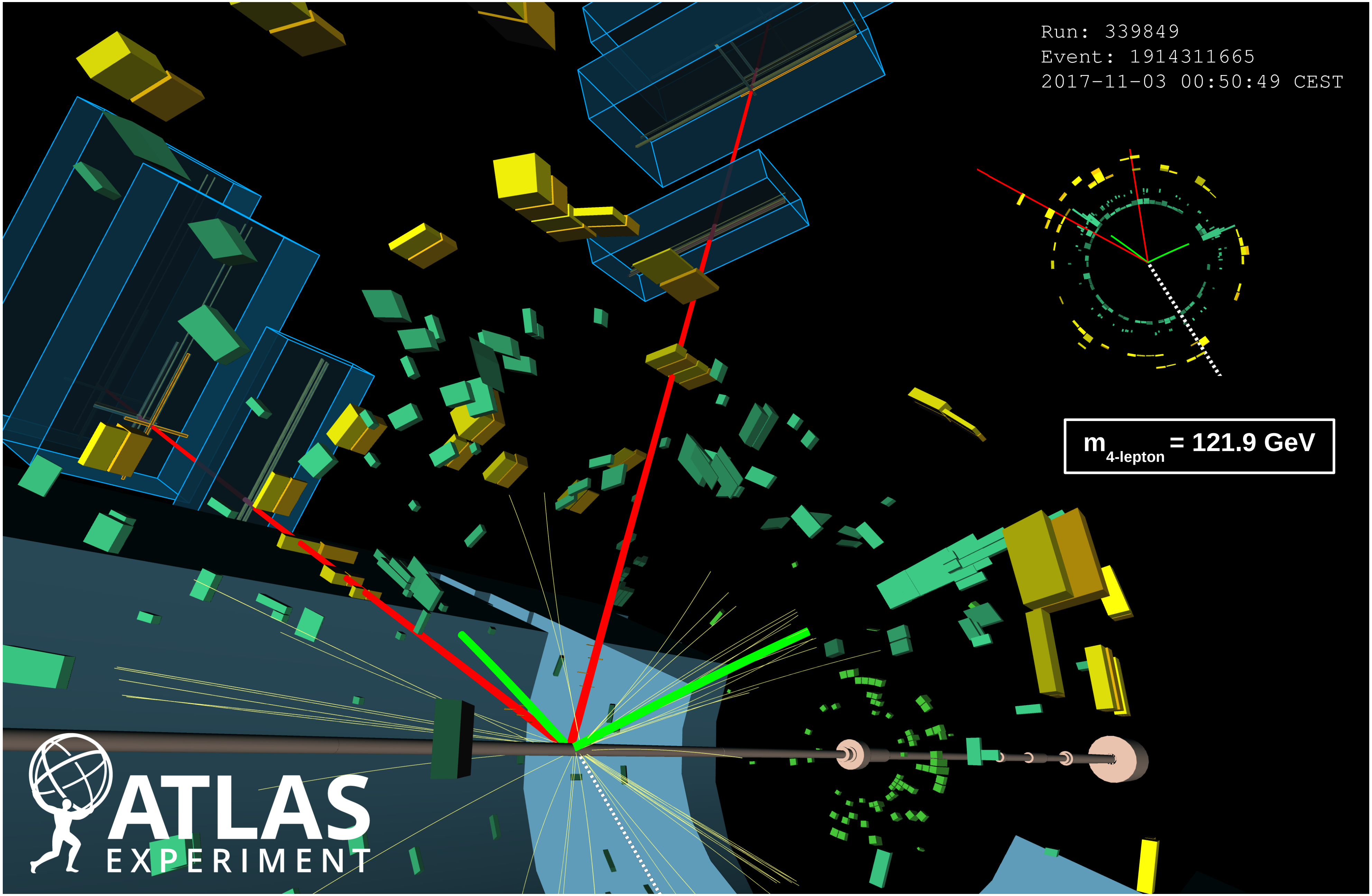


$t\bar{t}H \to \gamma\gamma$ @ 4.9σ (obs) 4.2σ (exp)

[ATLAS-CONF-2019-004]



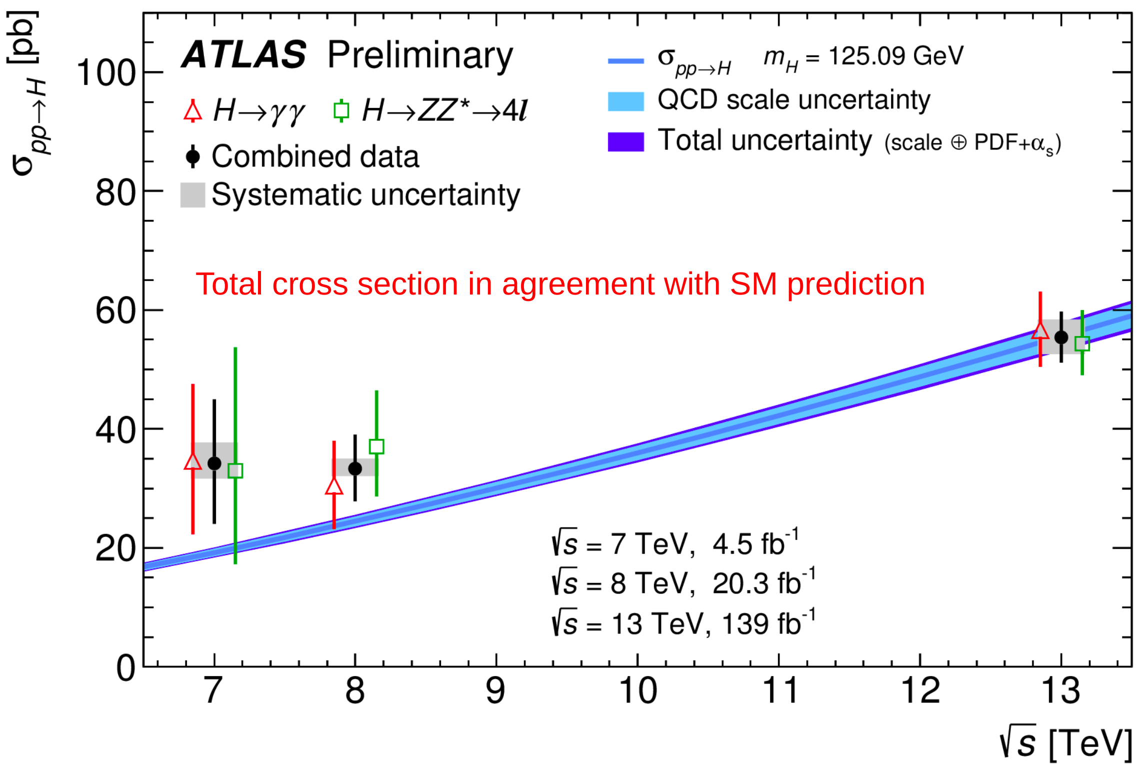
(Z)H → 4Lepton Candidate Event

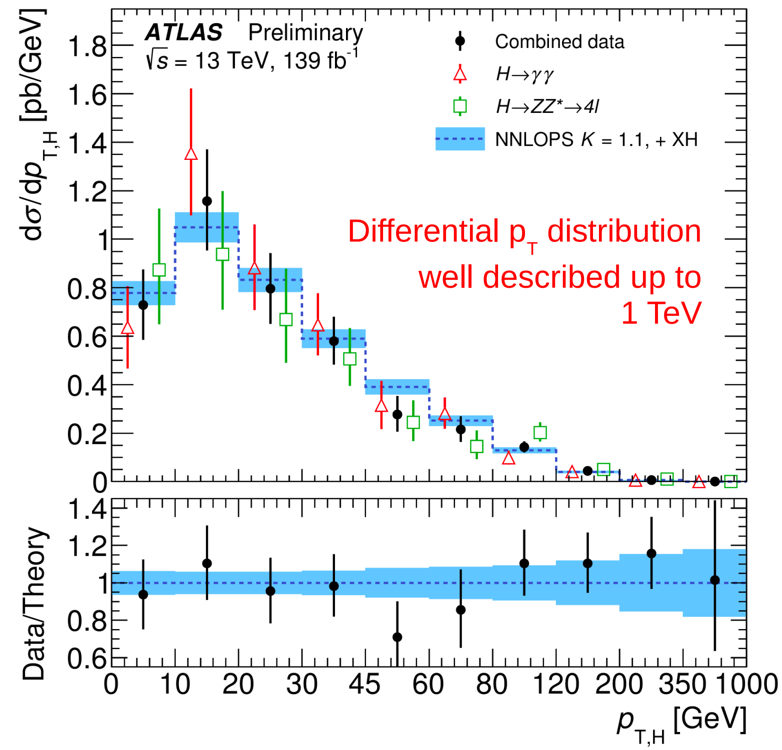


Higgs Boson Cross Sections

Statistical combination of $H\to ZZ^*\to 4l$ and $H\to\gamma\gamma$ channels provides more precise inclusive and differential cross section measurements

[ATLAS-CONF-2019-032]





Total Higgs boson production cross section: **8 % precision**

$$\sigma(pp\to H) = 56.7^{+6.4}_{-6.2}(\gamma\gamma),\ 54.4^{+5.6}_{-5.4}(4l),\ \boxed{55.4^{+4.3}_{-4.2}(\text{comb.})\ \text{pb}}$$

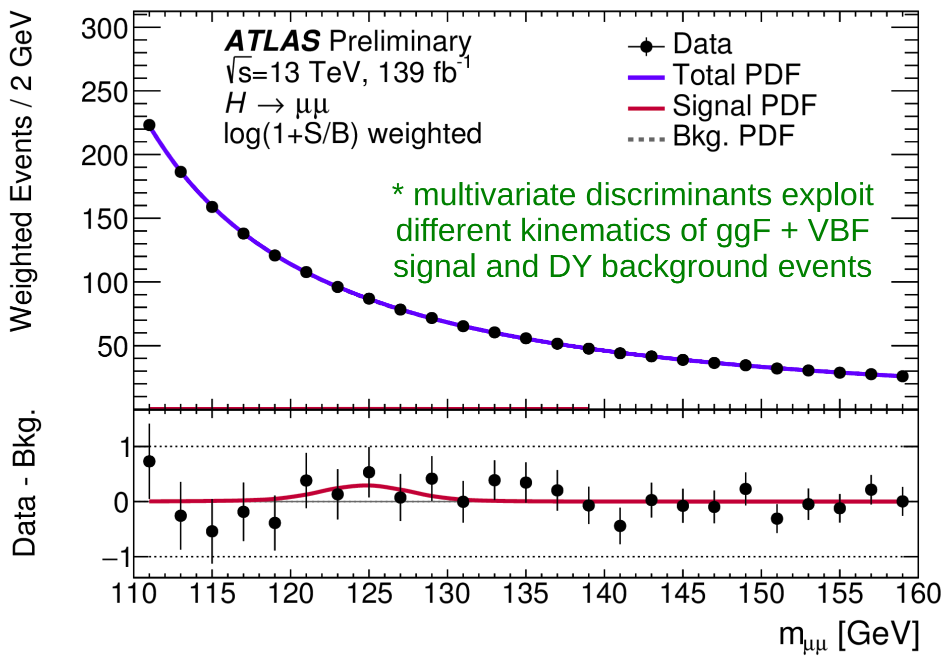
$$\sigma(pp\to H) = 55.6 \pm 2.5\,\text{pb}\,(\text{Theory})$$ *(N^3LO-NLO in QCD, NLO in EW)*

Higgs Coupling to 2nd Gen. Fermions

H→μμ

Very challenging! Small couplings in the SM
& overwhelming background from Z/γ*→μμ

[ATLAS-CONF-2019-028]



No significant excess is observed

Upper limit on BR = 3.8x10^{-4} (SM = 2.2x10^{-4})

50% improvement

Expect ~15% precision on BR with 3000 fb^{-1} [ATL-PHYS-PUB-2018-054]

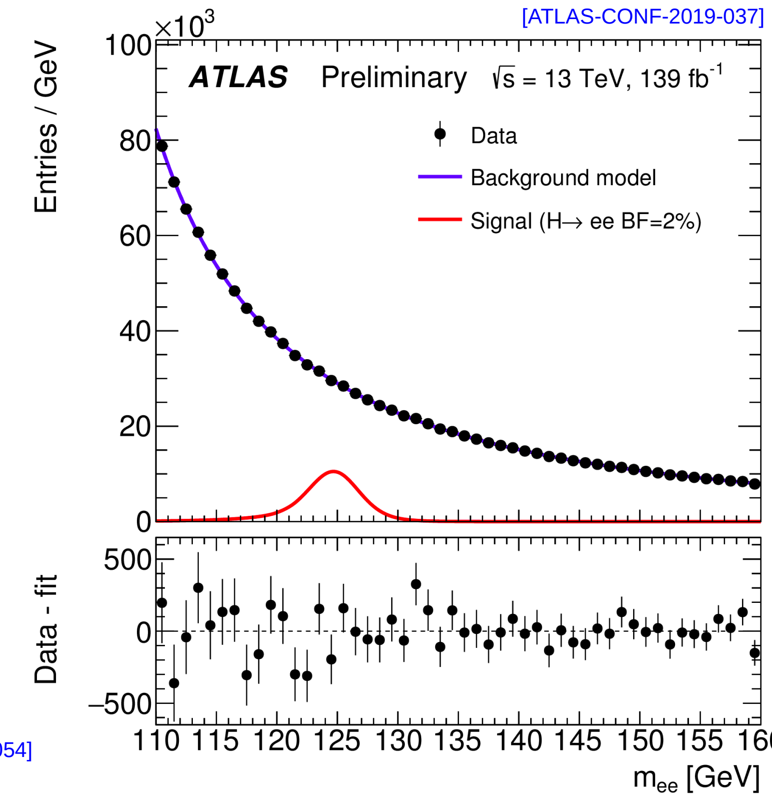
H→ee

No sensitivity at LHC to SM couplings

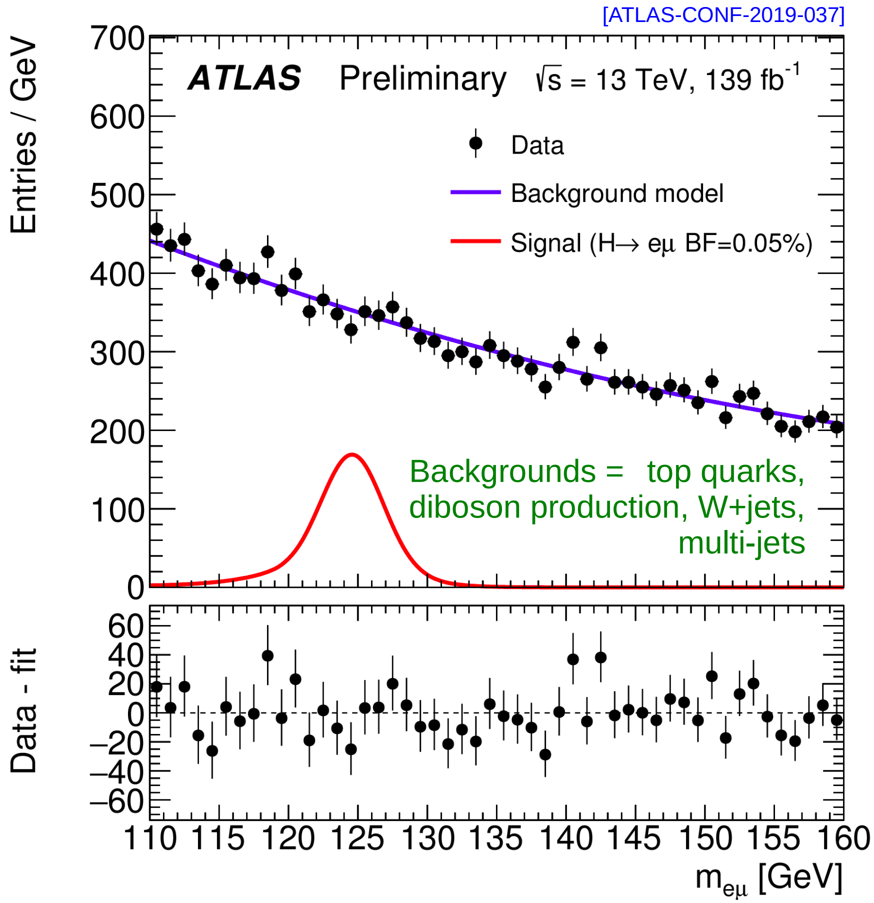
No significant excess is observed

Upper limit on BR = 3.6×10^{-4} (obs)
3.5×10^{-4} (exp) **x5 improvement**

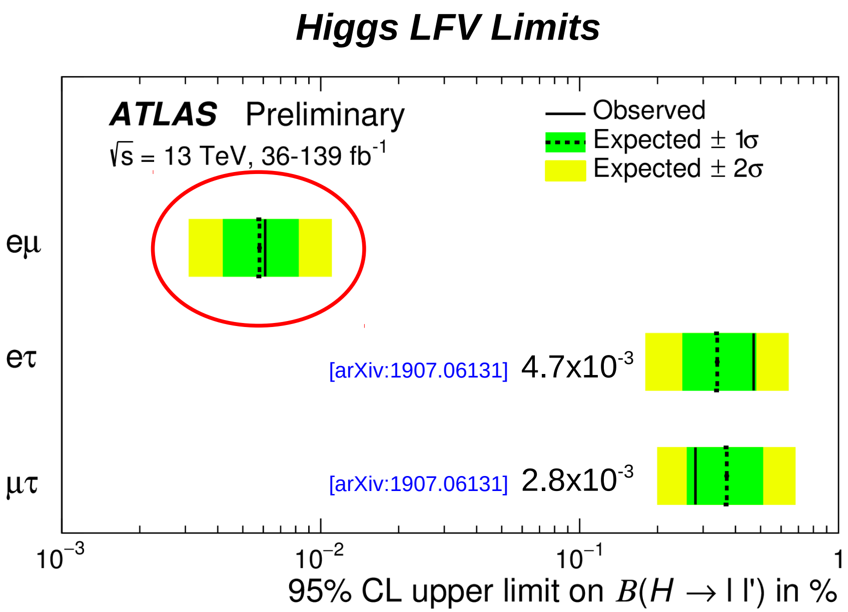
[ATLAS-CONF-2019-037]



Lepton Flavour Violating Higgs Decays



Large sample of Higgs bosons allows us to seach for non-SM decays



No significant excess observed

Upper limit on BR = 6.1×10^{-5} (obs) 5.8×10^{-5} (exp)

x6 improvement on previous limit (CMS 2016) [Phys. Lett. B763(2016) 472]

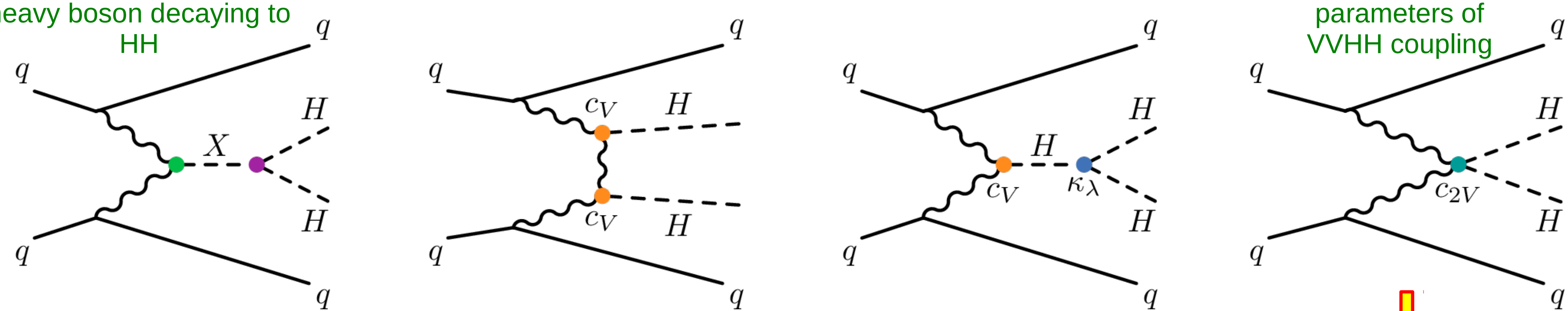
Di-Higgs Production

Search for Higgs boson pair production via vector boson fusion, where HH→bbbb

Signature = 4 b-jets + 2 jets with large Δy

Sensitive to production of heavy boson decaying to HH

Can help constrain parameters of VVHH coupling



No significant excess is observed

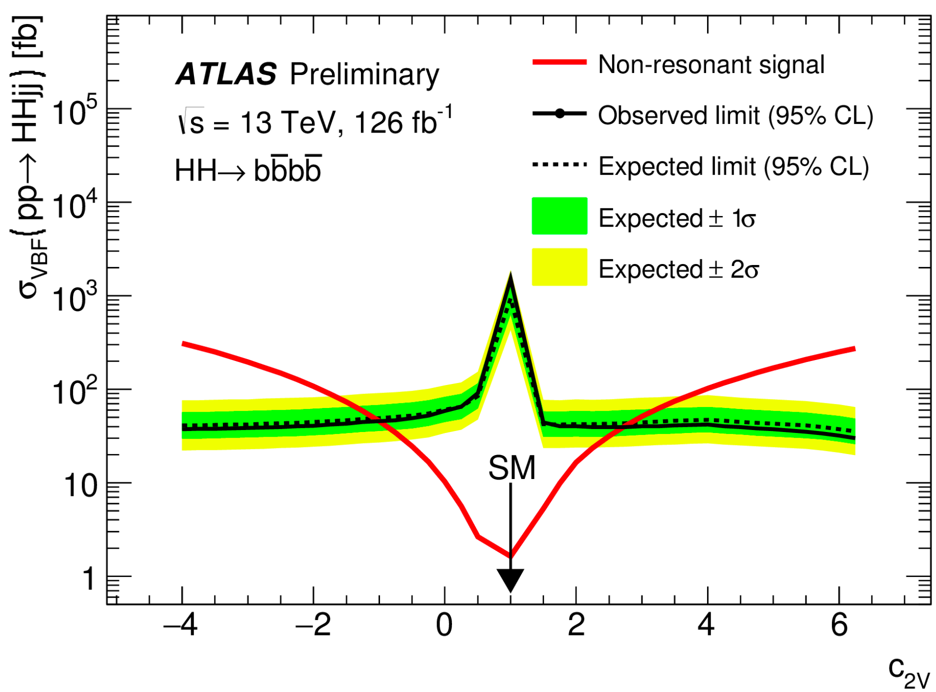
Upper limit on non-resonant production cross-section is 1600 fb (obs) 1000 fb (exp)

The excluded region corresponds to…

c_{2V} < -1.02 and c_{2V} > 2.71 (obs)

c_{2V} < -1.09 and c_{2V} > 2.82 (exp)

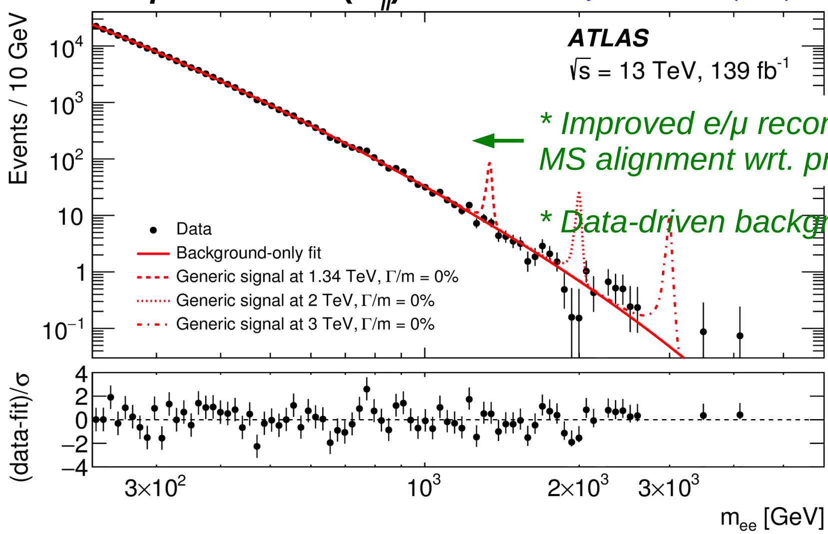
Observation of Di-Higgs would require HL-LHC



Searches for High-Mass Resonances

Here we're looking for a resonance / bump on top of a smoothly falling background distribution

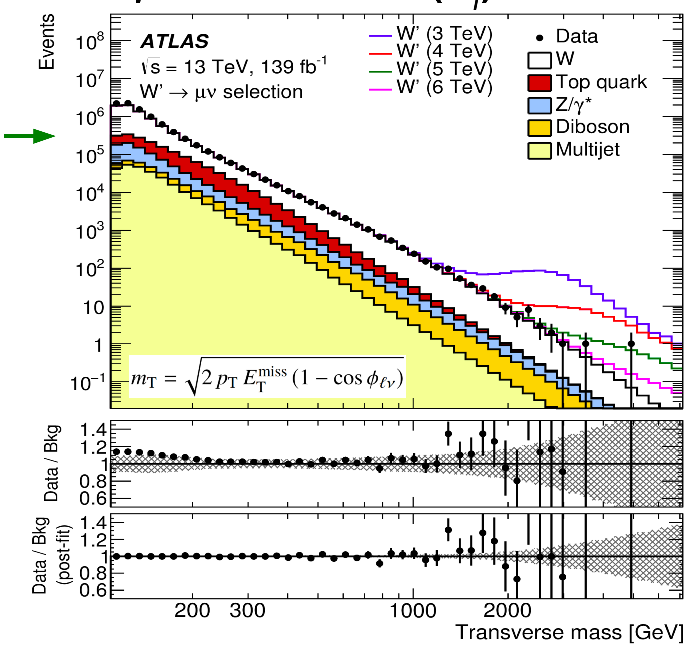
dilepton search (m_{ll}) Phys. Lett. B 796 (2019) 68



* *Improved e/μ reconstruction and ID-MS alignment wrt. previous searches*

* *Data-driven background estimate*

lepton + MET search (m_T) arXiv:1906.05609



No significant excess observed in either search

Model	Lower limits on $m_{Z'}$ [TeV]					
	ee		$\mu\mu$		$\ell\ell$	
	obs	exp	obs	exp	obs	exp
Z'_ψ	4.1	4.3	4.0	4.0	4.5	4.5
Z'_χ	4.6	4.6	4.2	4.2	4.8	4.8
Z'_{SSM}	4.9	4.9	4.5	4.5	5.1	5.1

+700 GeV

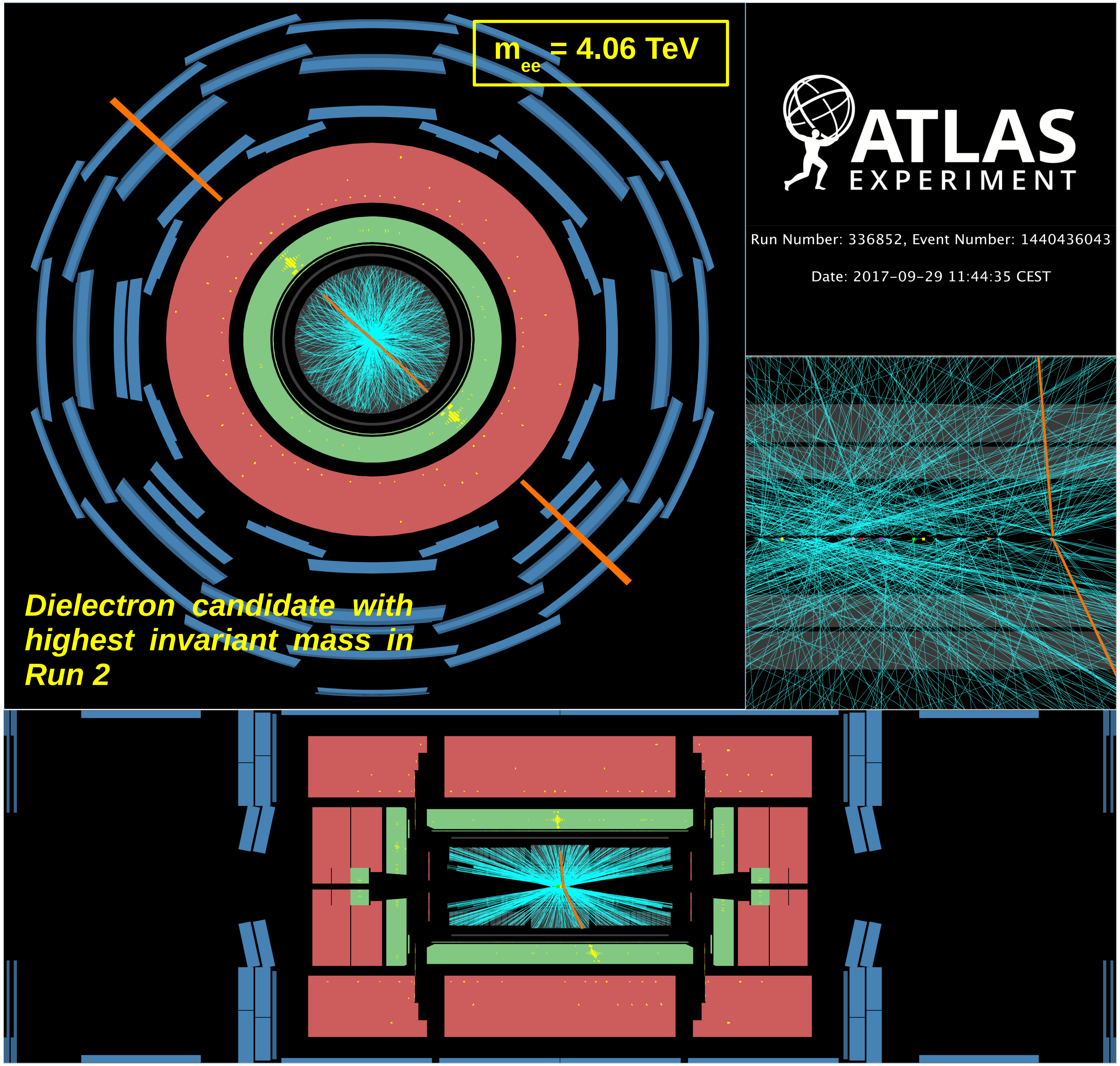
Sequential SM

Decay	$m(W')$ lower limit [TeV] Observed	Expected
$W' \to e\nu$	6.0	5.7
$W' \to \mu\nu$	5.1	5.1
$W' \to \ell\nu$	6.0	5.8

+800 GeV ($W' \to e\nu$)
+200 GeV ($W' \to \mu\nu$)

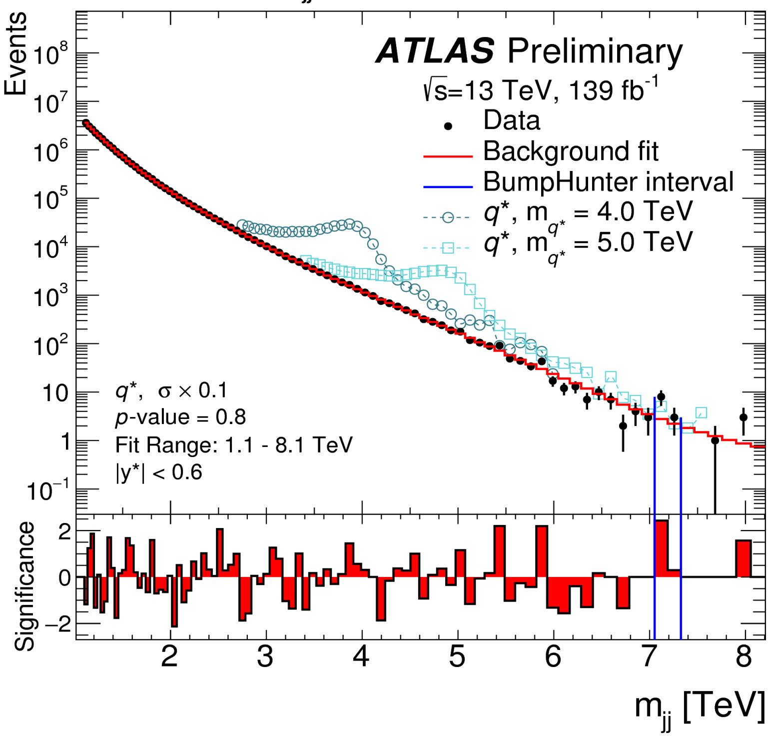
Upper limits on cross-section are also provided for generic resonances with fixed Γ / m (to allow for reinterpretation)

Dielectron Candidate Event



Searches for High-Mass Resonances

dijet search (m_{jj}) [ATLAS-CONF-2019-007]



No significant excess observed in either search

Upper limits on cross-section are also provided for generic resonances with fixed Γ / m values

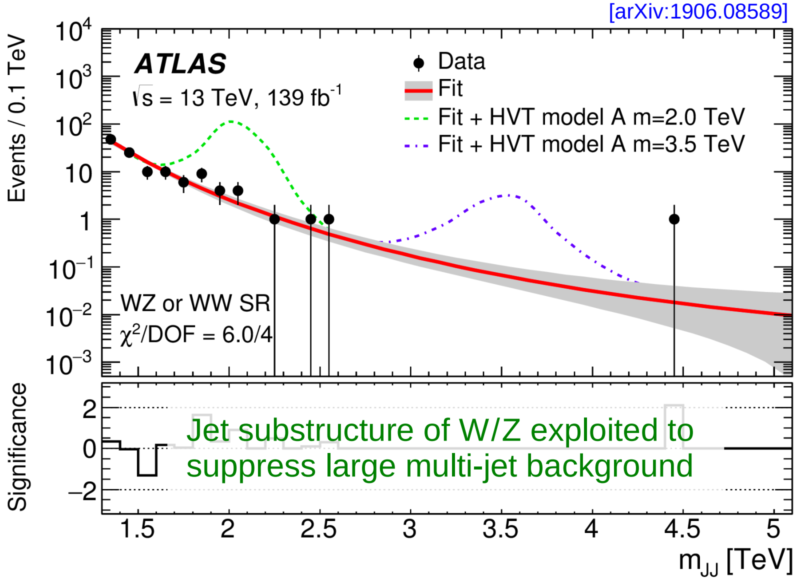
Lower mass limit for q*: 6.7 TeV (obs) 6.4 TeV (exp)

(boosted) diboson search

Search for narrow resonances decaying to WW, WZ, ZZ in fully hadronic final states

Signature = Two high-p_T, large-radius jets

[arXiv:1906.08589]

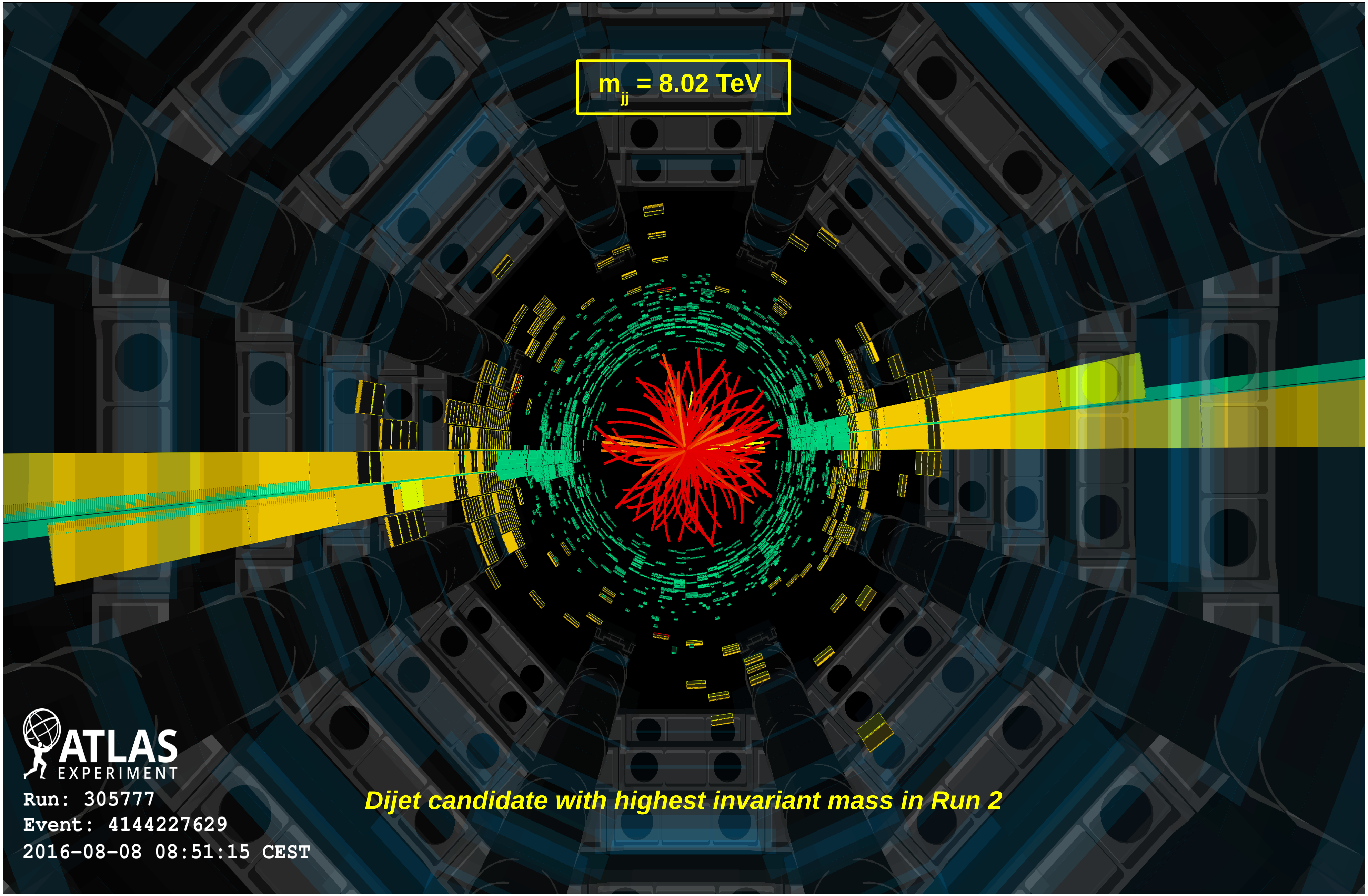


Jet substructure of W/Z exploited to suppress large multi-jet background

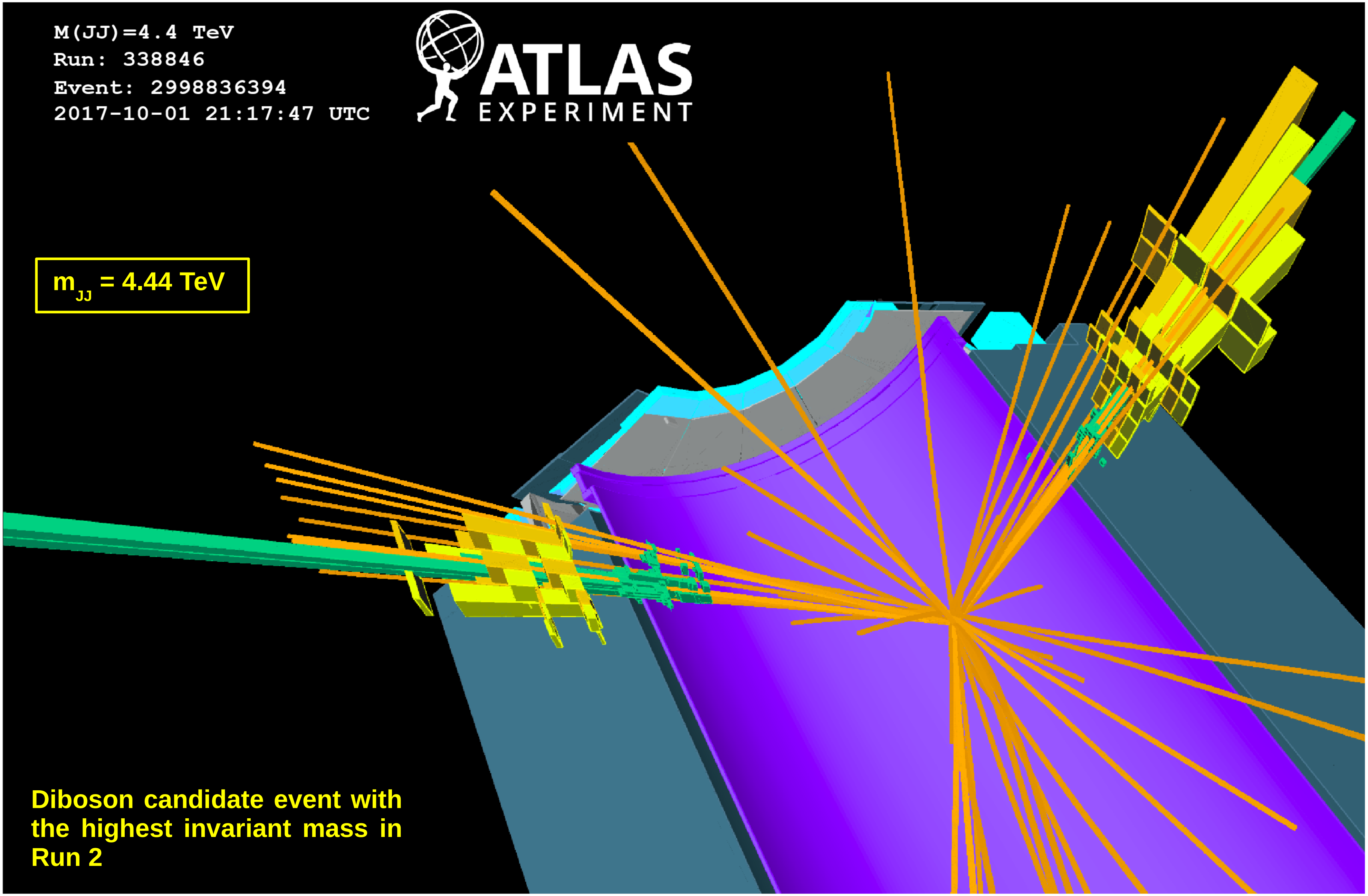
* Track-calo-clusters, 3D boosted boson tagger

Model	Signal Region	Excluded mass range [TeV]
	WW	1.3–2.9
HVT model A, $g_V = 1$	WZ	1.3–3.4
	$WW+WZ$	1.3–3.5
	WW	1.3–3.1
HVT model B, $g_V = 3$	WZ	1.3–3.6
	$WW+WZ$	1.3–3.8
	WW	1.3–1.6
Bulk RS, $k/\overline{M}_{Pl} = 1$	ZZ	none
	$WW+ZZ$	1.3–1.8

Dijet Candidate Event

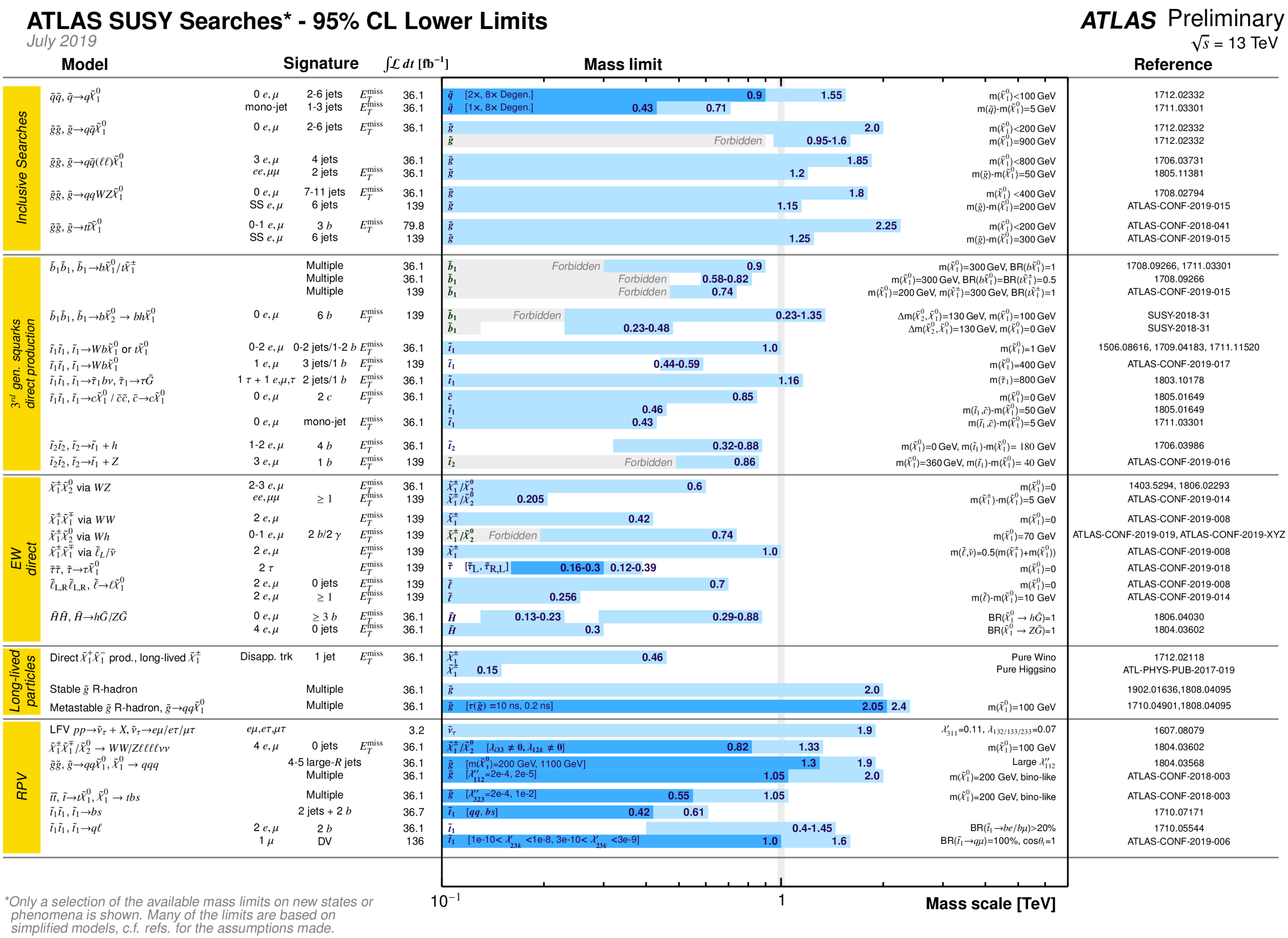


Diboson Candidate Event



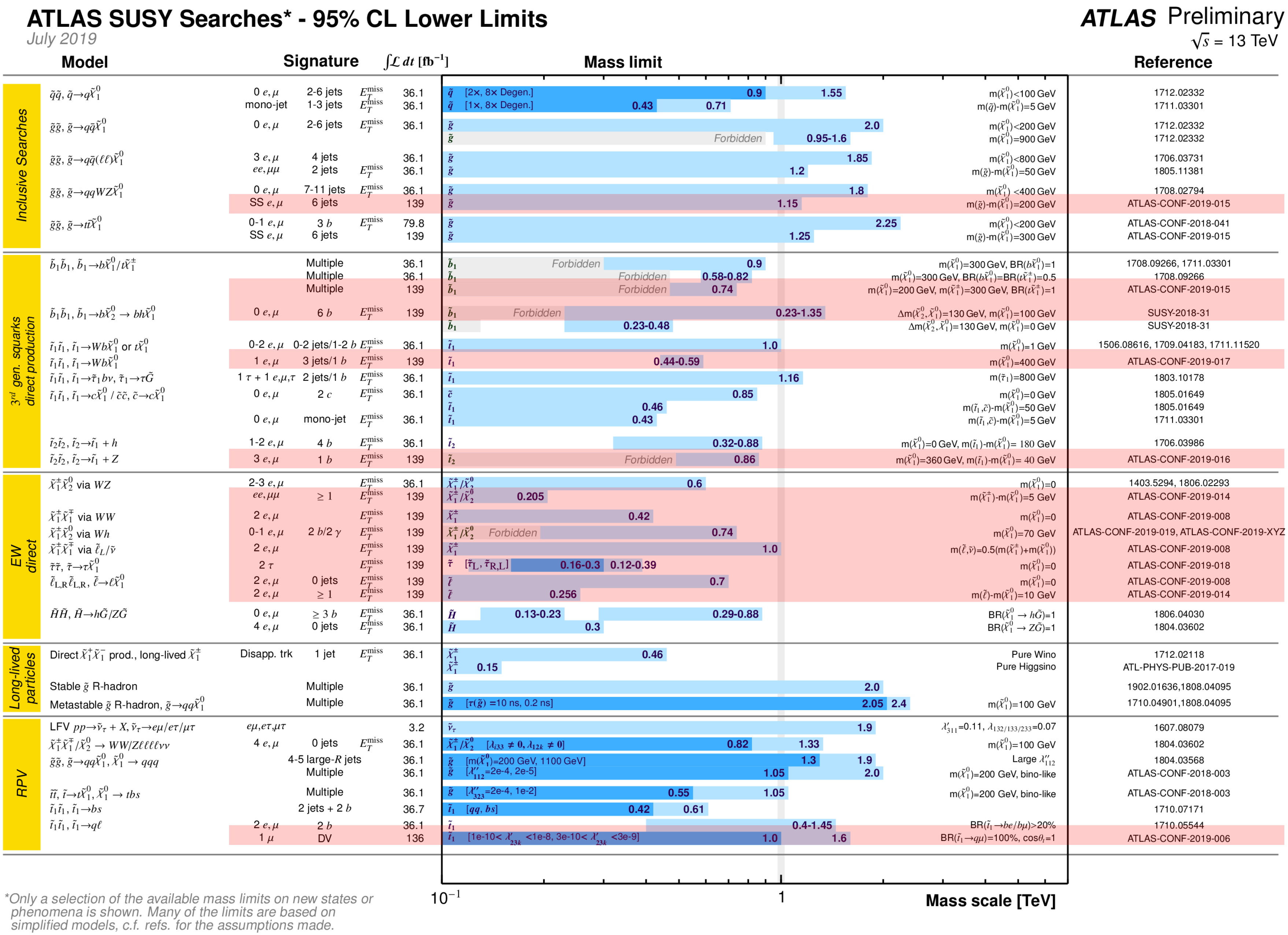
Searches for SUSY

[https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2019-022/]



Searches for SUSY

[https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2019-022/]



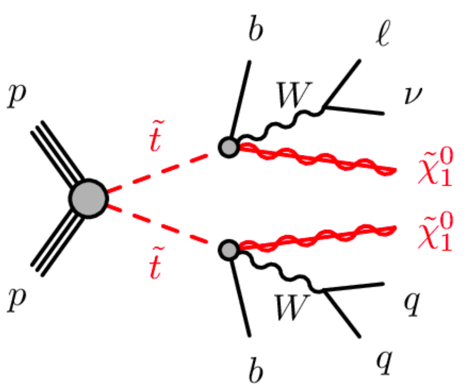
Search for Strong SUSY

Stop Pair Production (3 body decay)

Looking for some specific signatures in some difficult channels

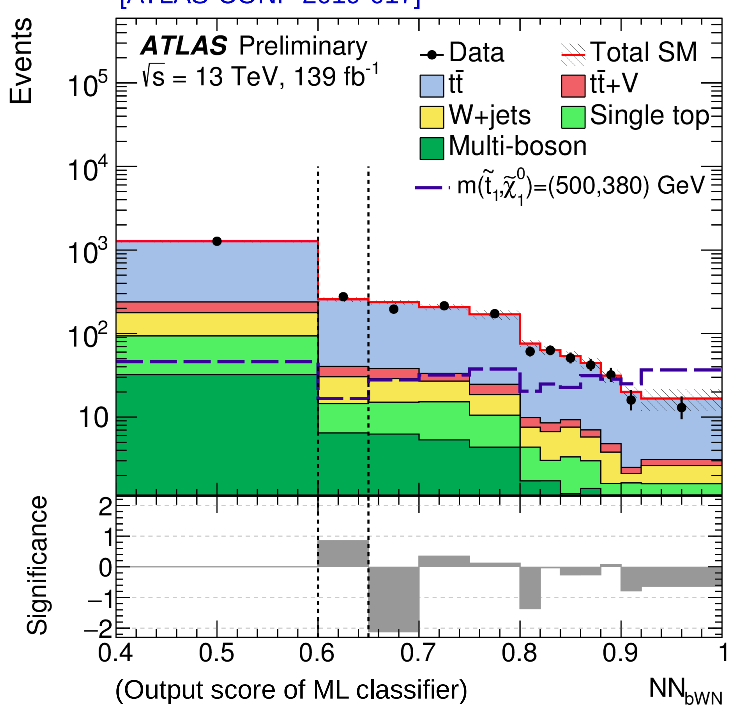
A machine learning approach is used to discriminate the signal from the large dominant tt-bar background

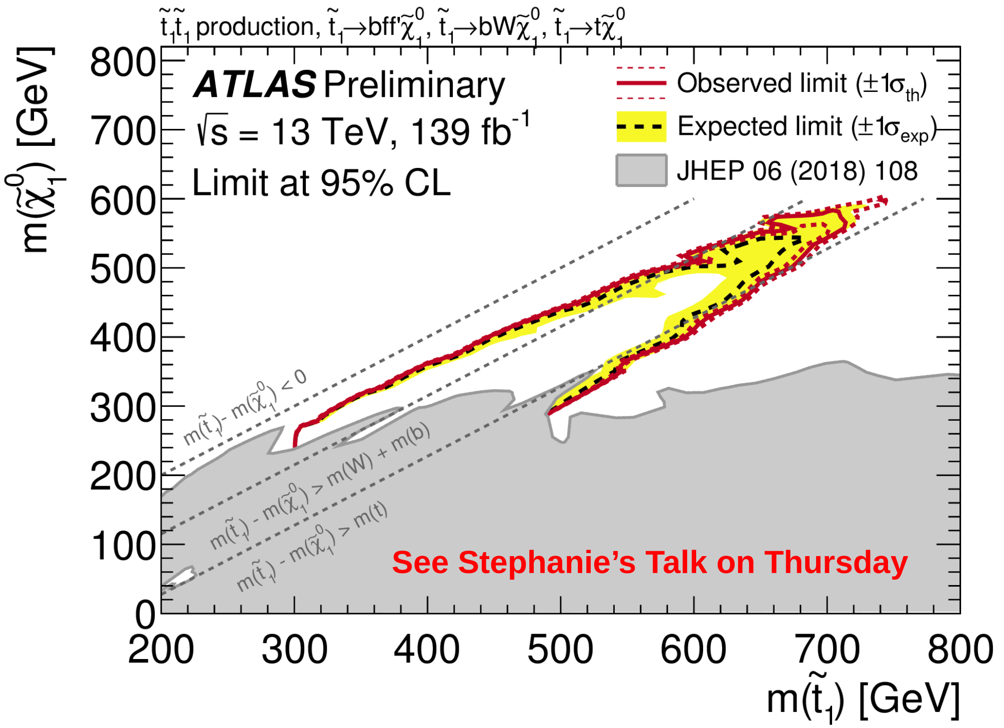
Extends the limits on top squark masses to 720 GeV (with neutralino masses up to 580 GeV).



Signature = one (isolated) lepton + high-p_T jets + MET

[ATLAS-CONF-2019-017]





Search for Electroweak SUSY

Stau Pair Production

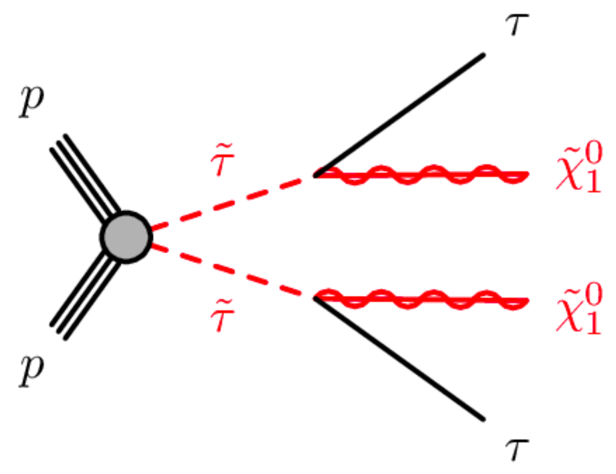
Staus theoretically interesting (eg. a light stau / DM) but experimentally challenging due to...

* Extremely low production rate

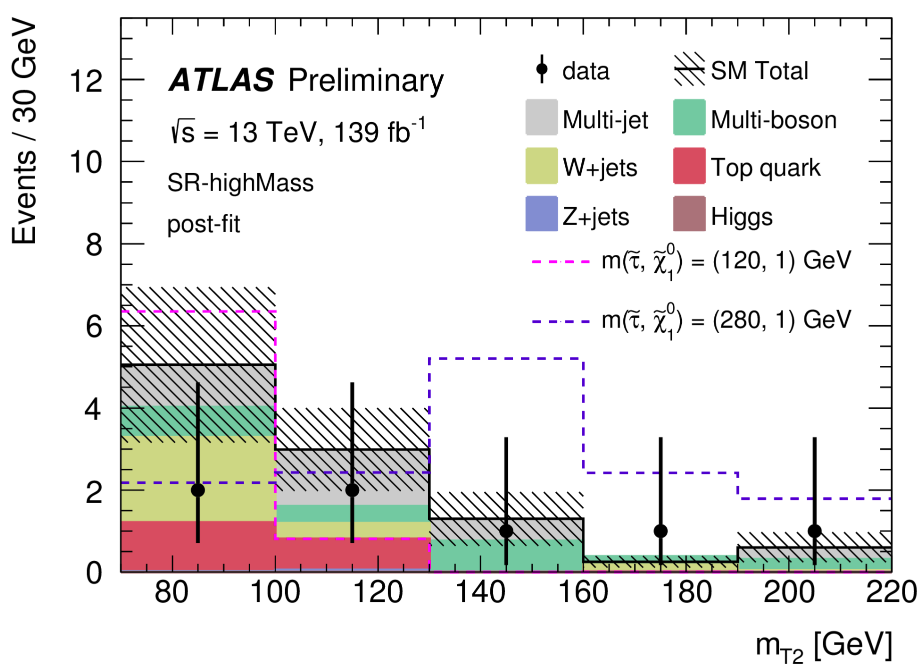
* Difficulties in reconstructing tau decays at the LHC

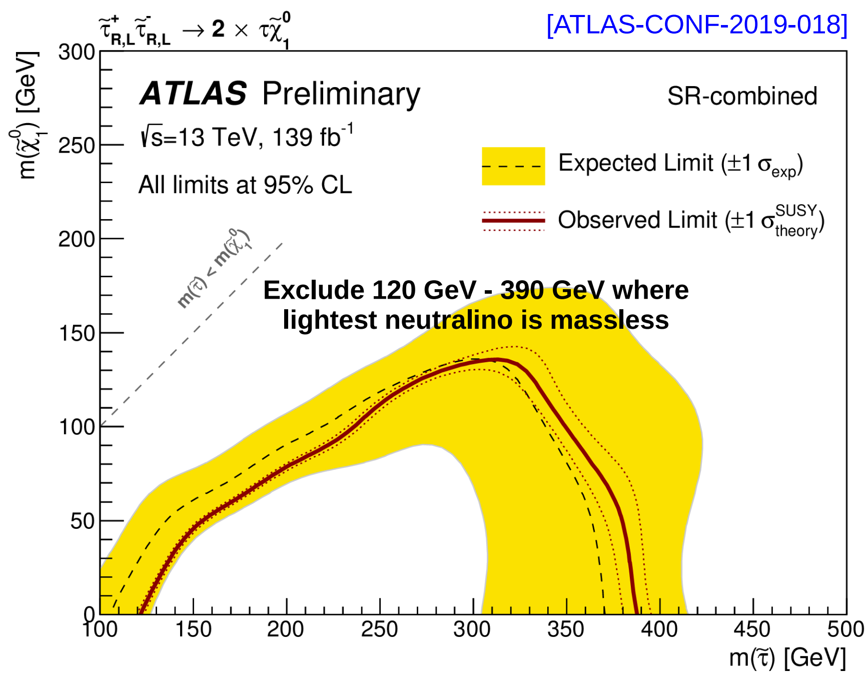
First time sensitivity in ATLAS!

Extends the LEP limit of around 90 GeV

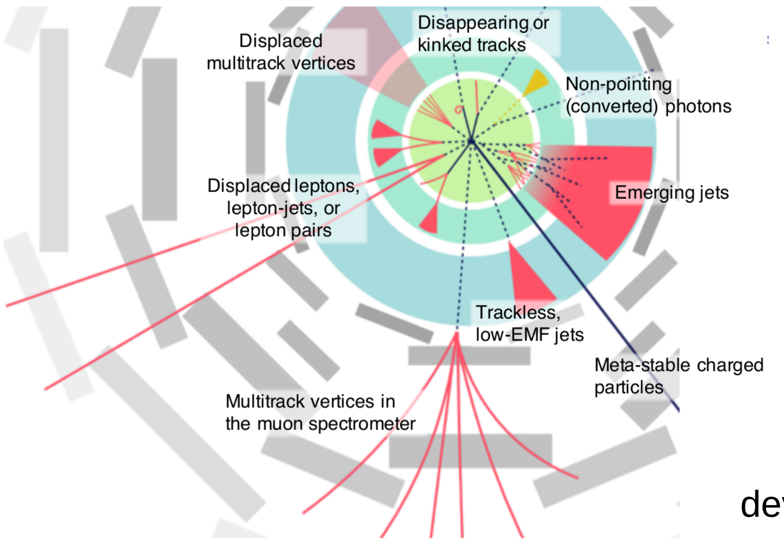


Signature = two (hadronic) taus + MET



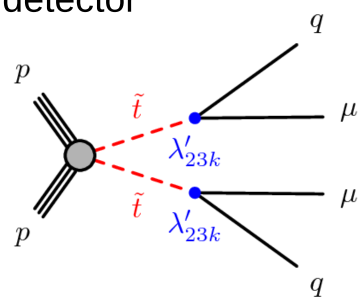


Long Lived Particles



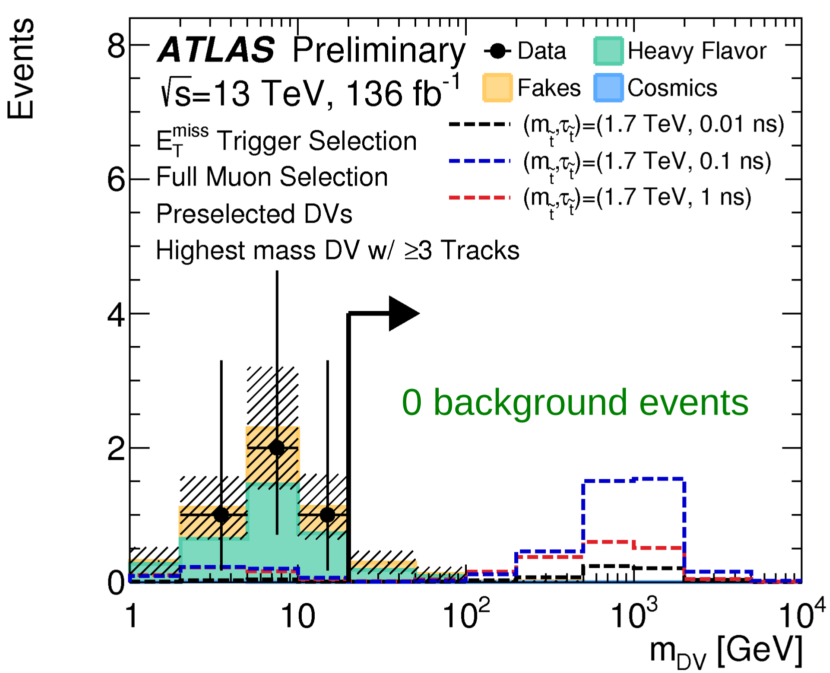
Many BSM models predict long lived (weakly interacting) particles → displaced objects in detector

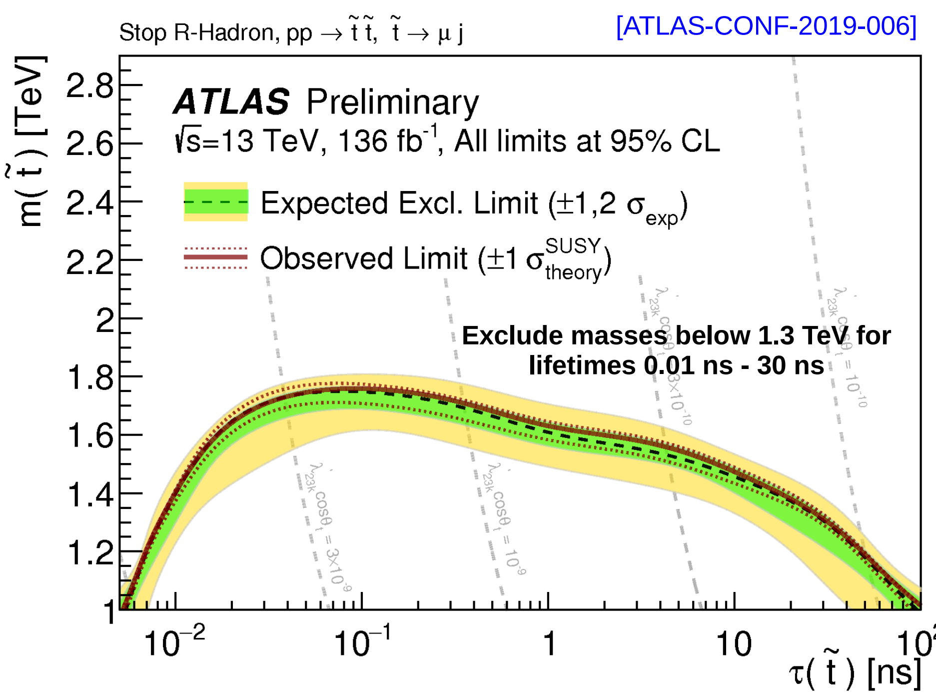
eg. a top squark with a particular RPV coupling



Signature = displaced muon + displaced vertex

Reconstructing these events required developing dedicated techniques for displaced muons/vertices



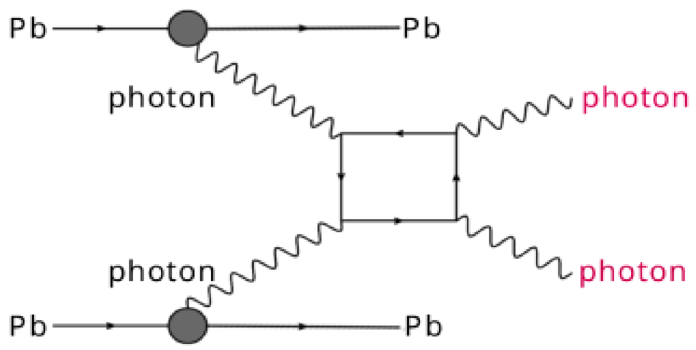


Light-by-Light Scattering

Observation of light by light scattering ($\gamma\gamma \rightarrow \gamma\gamma$) in ultra-peripheral collisions of Pb+Pb @ 5.02 TeV

(For UPCs impact parameter > x2 radius of ions)

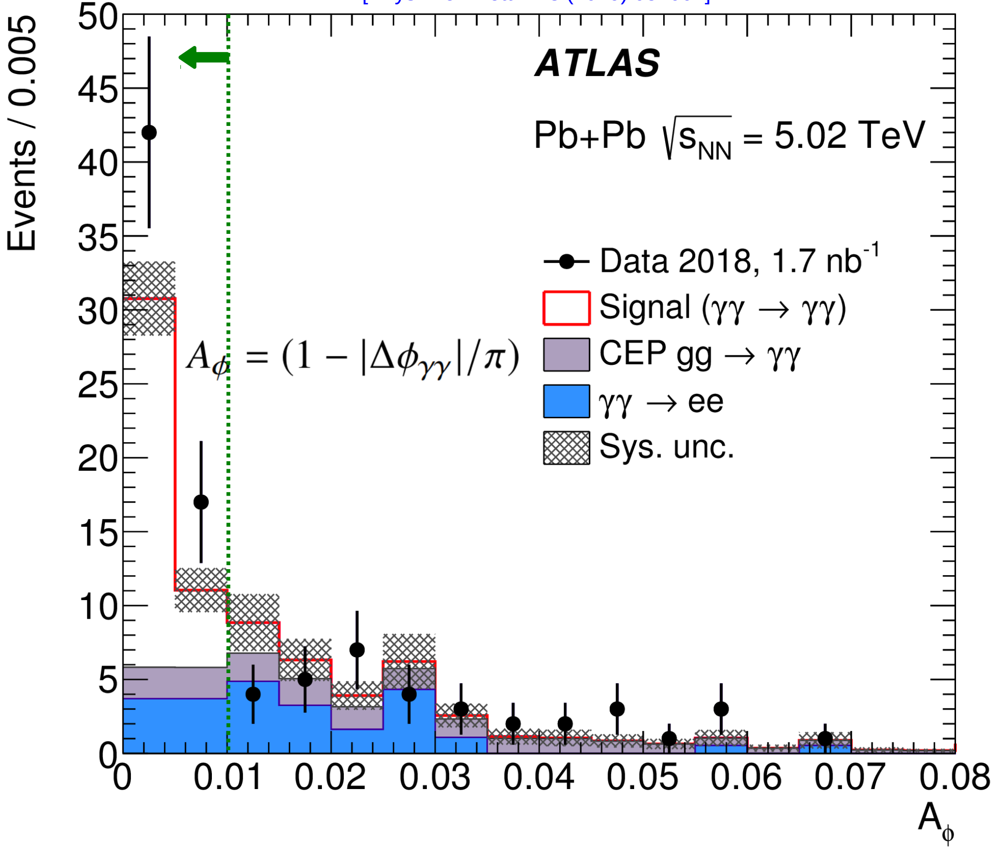
Very rare process – sensitive to new physics



Signature = Exclusive production of two low E_T, back-to-back photons in otherwise empty event

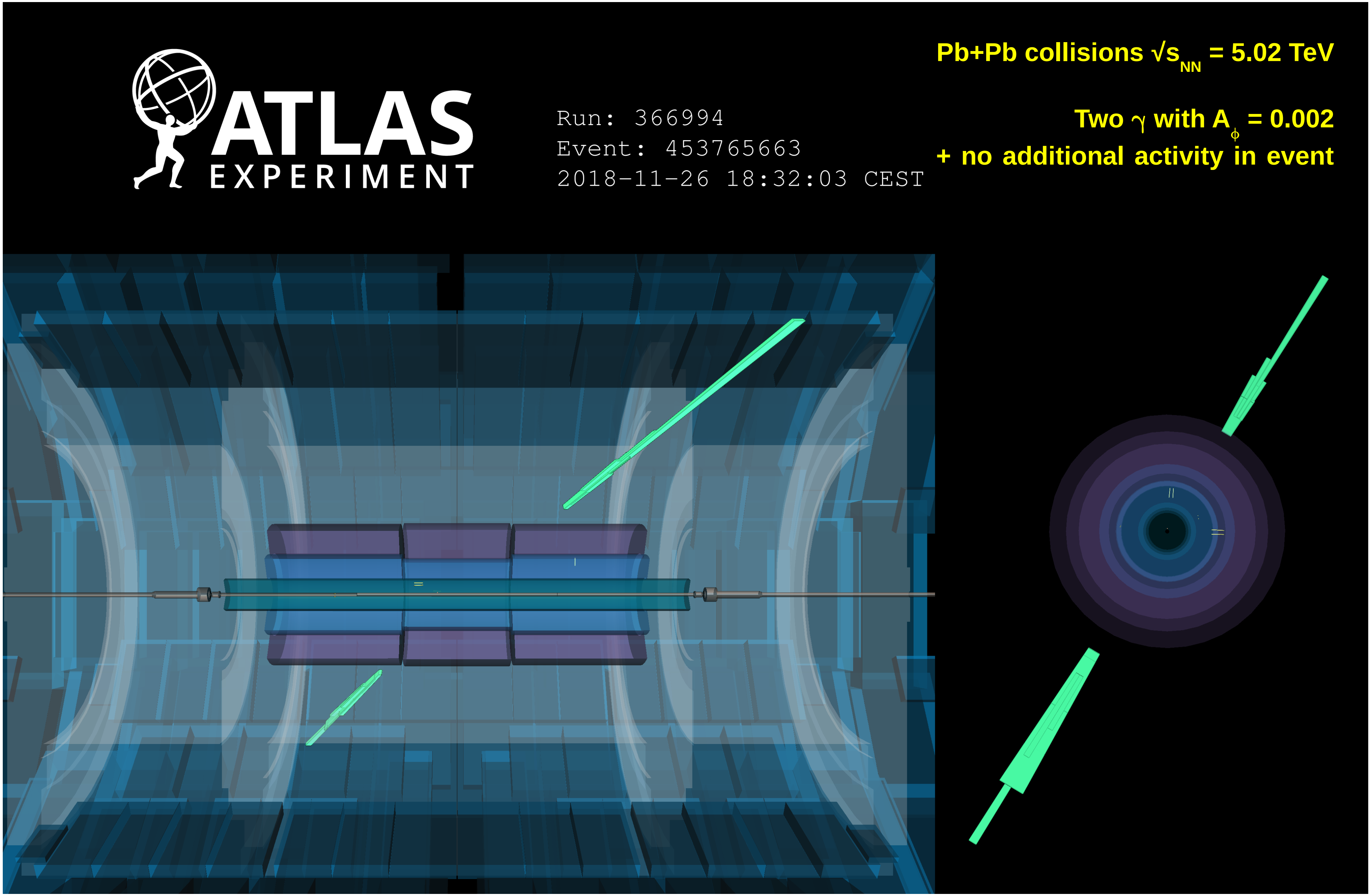
59 candidate events observed for 12 ± 3 events expected from background (8.2σ)

[Phys. Rev. Lett. 123 (2019) 052001]



This result demonstrates the power and flexibility of the ATLAS detector

$\gamma\gamma \rightarrow \gamma\gamma$ Candidate Event



Other New ATLAS Results

ATLAS EXPERIMENT — PUBLIC RESULTS

Summary of ATLAS 13 TeV results using the full 2015−2018 (Run 2) dataset

This page provides a compact summary of published and preliminary ATLAS physics and performance results on 13 TeV proton–proton collision data based on the Run-2 data-set taken between 2015 and 2018. For questions, please, contact the ATLAS physics coordinators. See the central publications page for other results from ATLAS.

This page also provides links to ATLAS Physics Briefings for specific results. These are intended to provide a general introduction to ATLAS physics results for a non-specialist audience.

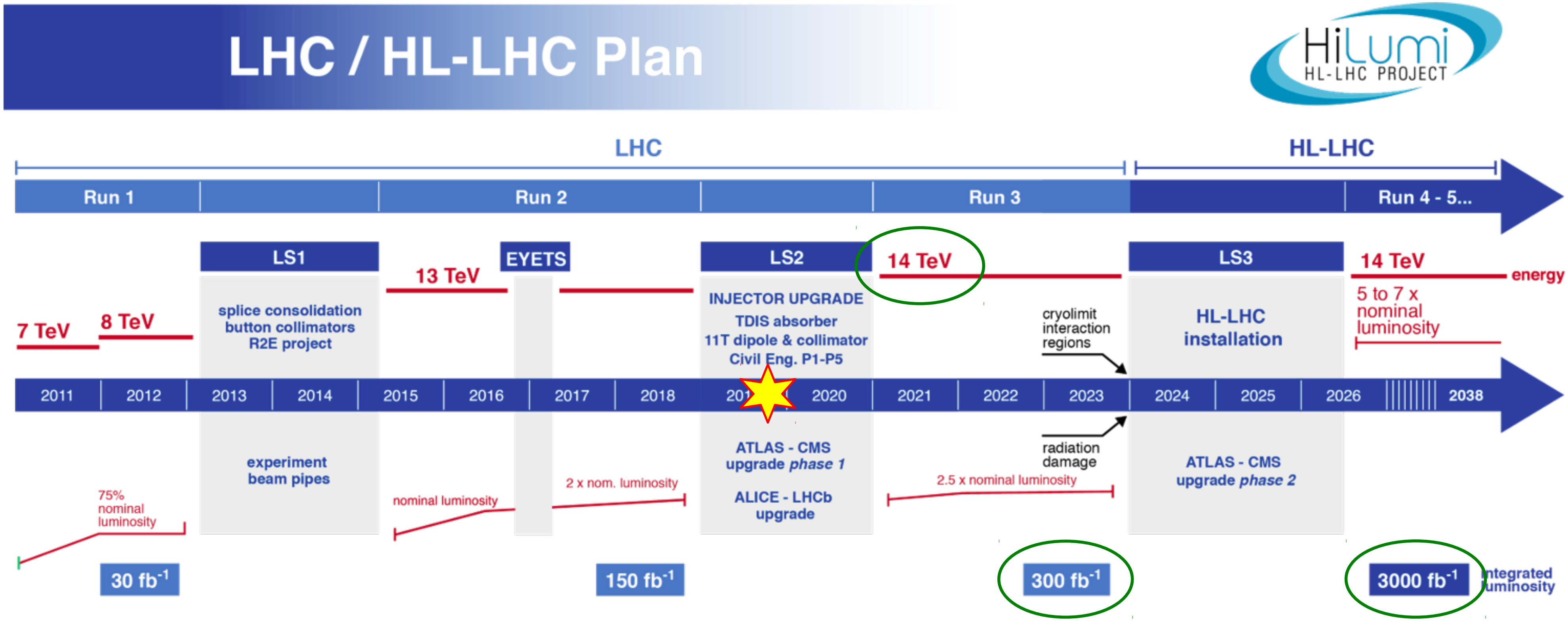
Physics results

33 documents (Papers published: 1, accepted: 2, submitted: 4; Conference notes: 26)

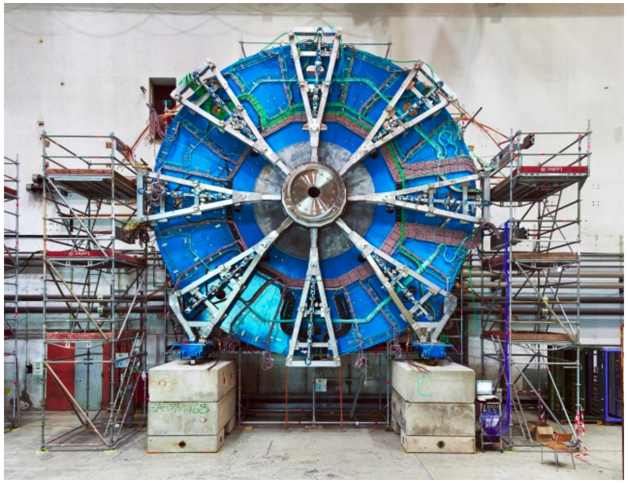
Group	Format	Short Title	Date	√s (TeV)	L	Links
TRIG	Paper	Performance of the electron and photon triggers of the ATLAS experiment during LHC Run-2 NEW	02-SEP-19	13	146 fb^{-1}	Documents | 1909.00761 | Inspire Internal
SUSY	Paper	Chargino pair, slepton pair; 2 leptons NEW	21-AUG-19	13	139 fb^{-1}	Documents | 1908.08215 | Inspire Internal
HDBS	Paper	HH->bb WW-> bblvlv NEW	19-AUG-19	13	139 fb^{-1}	Documents | 1908.06765 | Inspire Internal
SUSY	Paper	Sbottom; b-jets	08-AUG-19	13	139 fb^{-1}	Documents | 1908.03122 | Inspire Internal
HIGG	Conference note	Search BSM H(125)->emu lepton flavor violating decay and H(125)->ee	05-AUG-19	13	139 fb^{-1}	Documents | Briefing | Internal
SUSY	Conference note	Gluino pair; squark pair; gluino-squark; 0-lepton	05-AUG-19	13	139 fb^{-1}	Documents | Internal
TOPQ	Conference note	Top width measurement in dilepton ttbar	02-AUG-19	13	139 fb^{-1}	Documents | Internal
HDBS	Conference note	Dimuon search + b-jet at 8 and 13 TeV	31-JUL-19	13	139 fb^{-1}	Documents | Internal
STDM	Conference note	Lund Plane measurement with charged particles	24-JUL-19	13	140 fb^{-1}	Documents | Internal
STDM	Conference note	Observation of electroweak production of two jets in association with a Z-boson pair	12-JUL-19	13	139 fb^{-1}	Documents | Internal
STDM	Conference note	Z(-->ll) gamma cross section at 13TeV	12-JUL-19	13	139 fb^{-1}	Documents | Internal
FTAG	Conference note	Soft b-hadron tagging for compressed SUSY scenarios	11-JUL-19	13	139 fb^{-1}	Documents | Internal
HDBS	Conference note	VBF HH to 4b	11-JUL-19	13	126 fb^{-1}	Documents | Internal
HIGG	Conference note	H(125) combination differential cross-sections gamma gamma and 4l	11-JUL-19	13	139 fb^{-1}	Documents | Briefing | Internal
HIGG	Conference note	H(125)->gammagamma differential cross sections	11-JUL-19	13	139 fb^{-1}	Documents | Briefing | Internal
HIGG	Conference note	Search H(125)->mumu	11-JUL-19	13	139 fb^{-1}	Documents | Briefing | Internal
SUSY	Conference note	Chargino-neutralino pair; Higgs boson in final state, 2 b-jets and 1 lepton	10-JUL-19	13	139 fb^{-1}	Documents | Internal
HIGG	Conference note	h(125)->4l STXS and differential cross sections	09-JUL-19	13	139 fb^{-1}	Documents | Briefing | Internal
TOPQ	Conference note	Measurement of ttbar charge asymmetry at 13 TeV in l+jets	09-JUL-19	13	139 fb^{-1}	Documents | Briefing | Internal

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ResultswithData2018

Preparations for Run 3 (and Beyond)



Upgrade Phase 1	• New LAr calorimeter electronics • New small wheels for muon system • TDAQ upgrades (wrt. above items)
Upgrade Phase 2	• New all-silicon inner tracker • New electronics in calorimeter / muon systems • TDAQ upgrades (HPC, parallelization, GPUs?)



Summary

Excellent performance of LHC and ATLAS detector $\rightarrow$ Run 2 dataset of 139 fb^{-1}

- High precision measurements of Higgs, multi-boson and top quark properties
- Progress in some very rare physics searches
- Searches for new physics through new signatures and improved sensitivities

No significant deviations from SM predictions… so far!

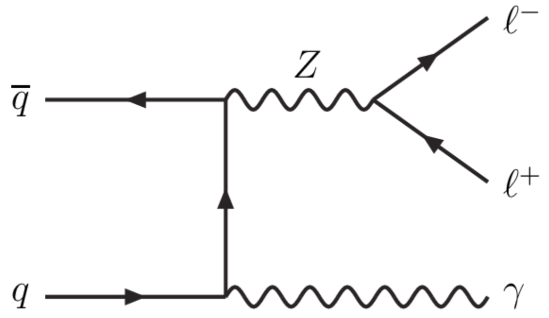
Improvements/repairs to ATLAS detector are ongoing for Run 3 (and HL-LHC)

Much more to come… stay tuned!

Backup Slides

Zɣ→llɣ **Production**

Provides tests of EW sector of SM / sensitive to new physics effects (eg. direct couplings of Z to photons)



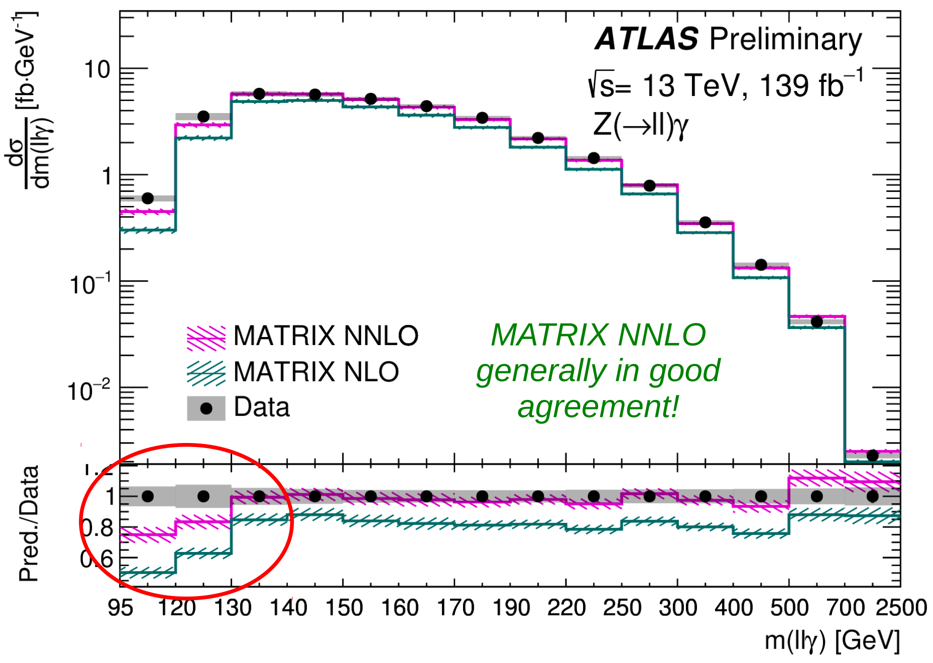
FSR and q/g fragmentation processes removed

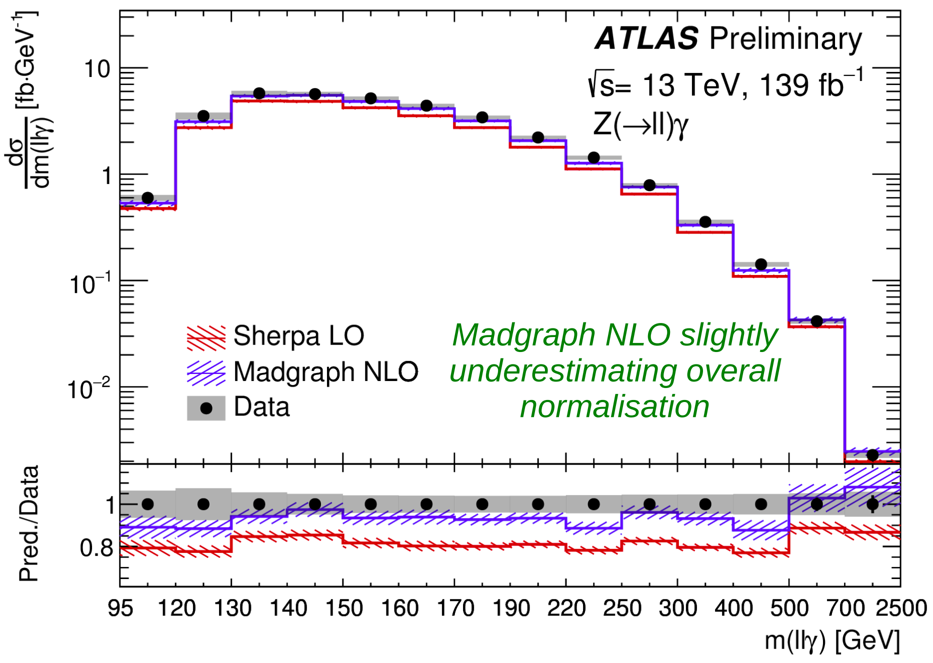
Differential cross sections measured wrt. the llɣ system

Precision better than 5% in most measurement bins

compared with parton shower MC generators and parton-level generator Matrix (corrected to particle level).

[ATLAS-CONF-2019-034]

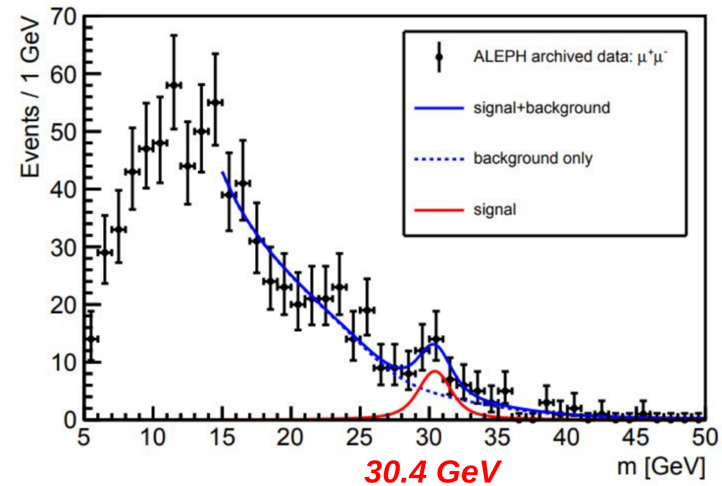




Resonance Search in bjμμ Final State

Recent result on archived LEP data reported excess in dimuon invariant mass spectrum in events with a b-quark – with a local (global) significance of 5.0σ (2.6σ)

[arXiv:1610.06536]



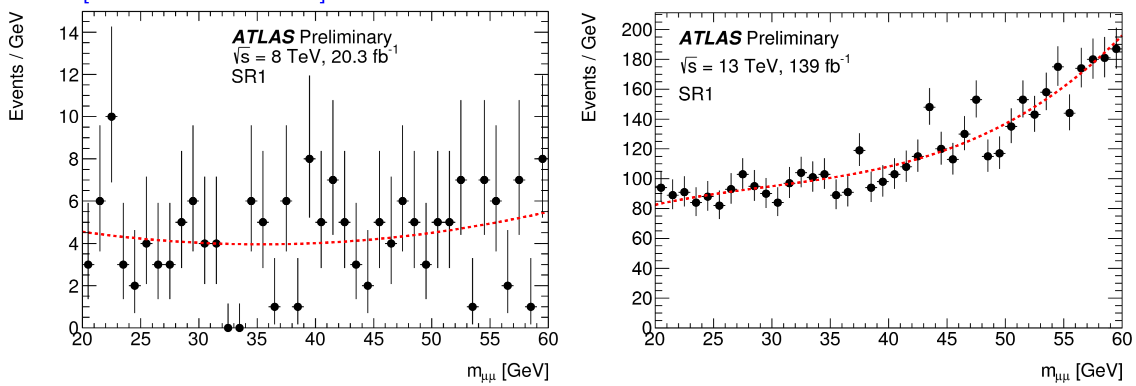
CMS reported excess at 28 GeV in 8 TeV data: [JHEP 1811 (2018) 161]

@ 8 TeV		@ 13 TeV	
SR 1	SR 2	SR 1	SR 2
4.2σ	2.9σ	2.0σ	1.4σ deficit

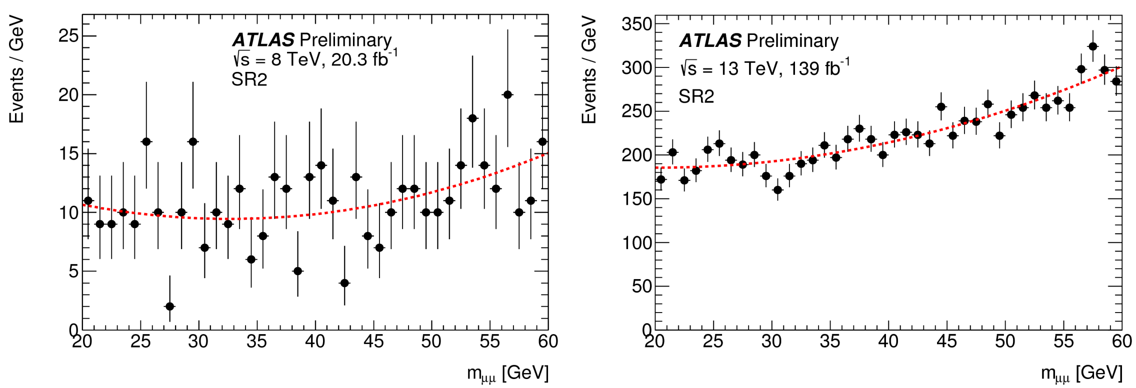
ATLAS has since targeted the same topology using Run 1 & Run 2 data:

[ATLAS-CONF-2019-036]

Central – Forward



Central – Central



	8 TeV		13 TeV	
Region	SR1	SR2	SR1	SR2
Local significance (28 GeV)	0.5	0.5	0.7	0.2
Max. significance	0.9 (29.5 GeV)	1.1 (29.5 GeV)	0.8 (27.5 GeV)	2.1 (26 GeV)

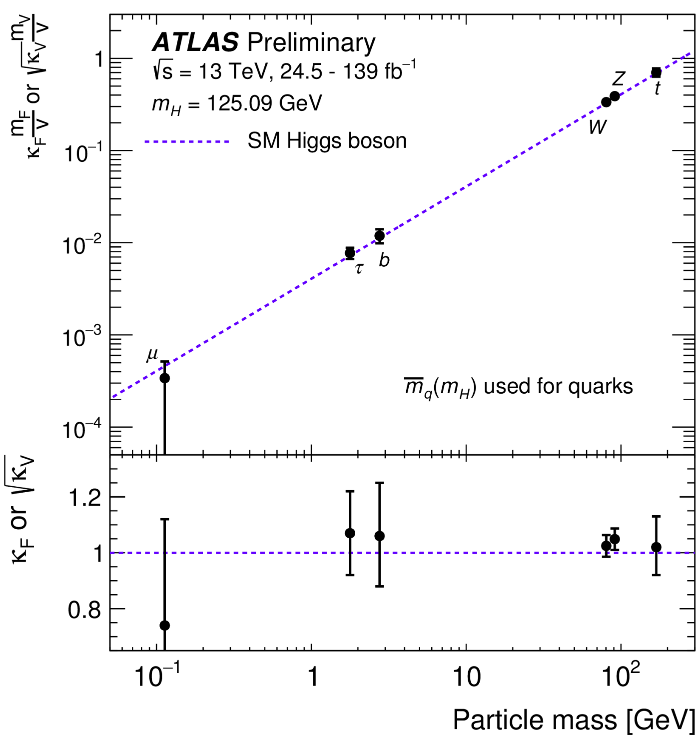
No significant excess is observed

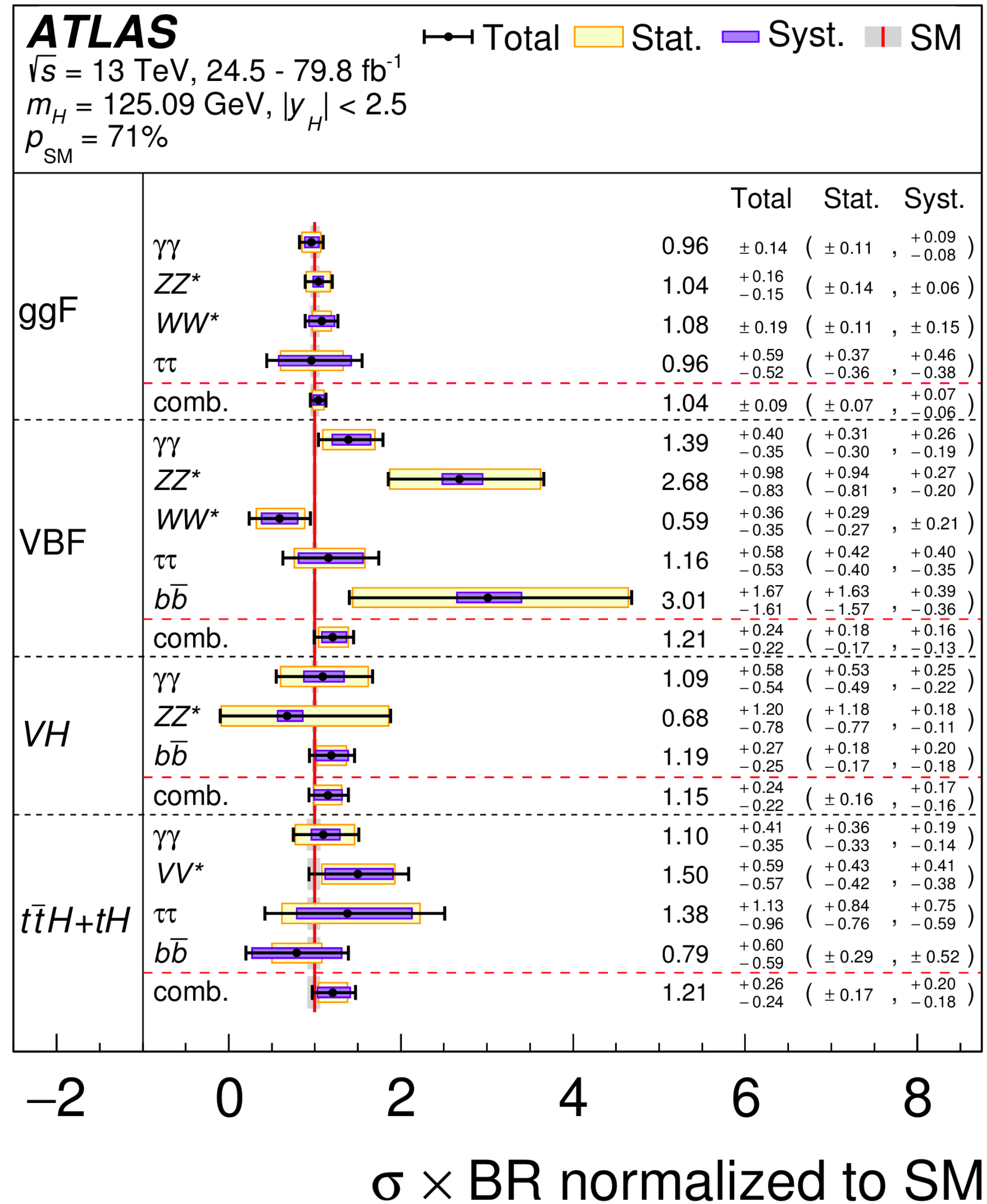
Higgs Combined Measurements

global signal strength
μ = 1.11 (+0.09)(−0.08)

[arXiv:1909.02845]

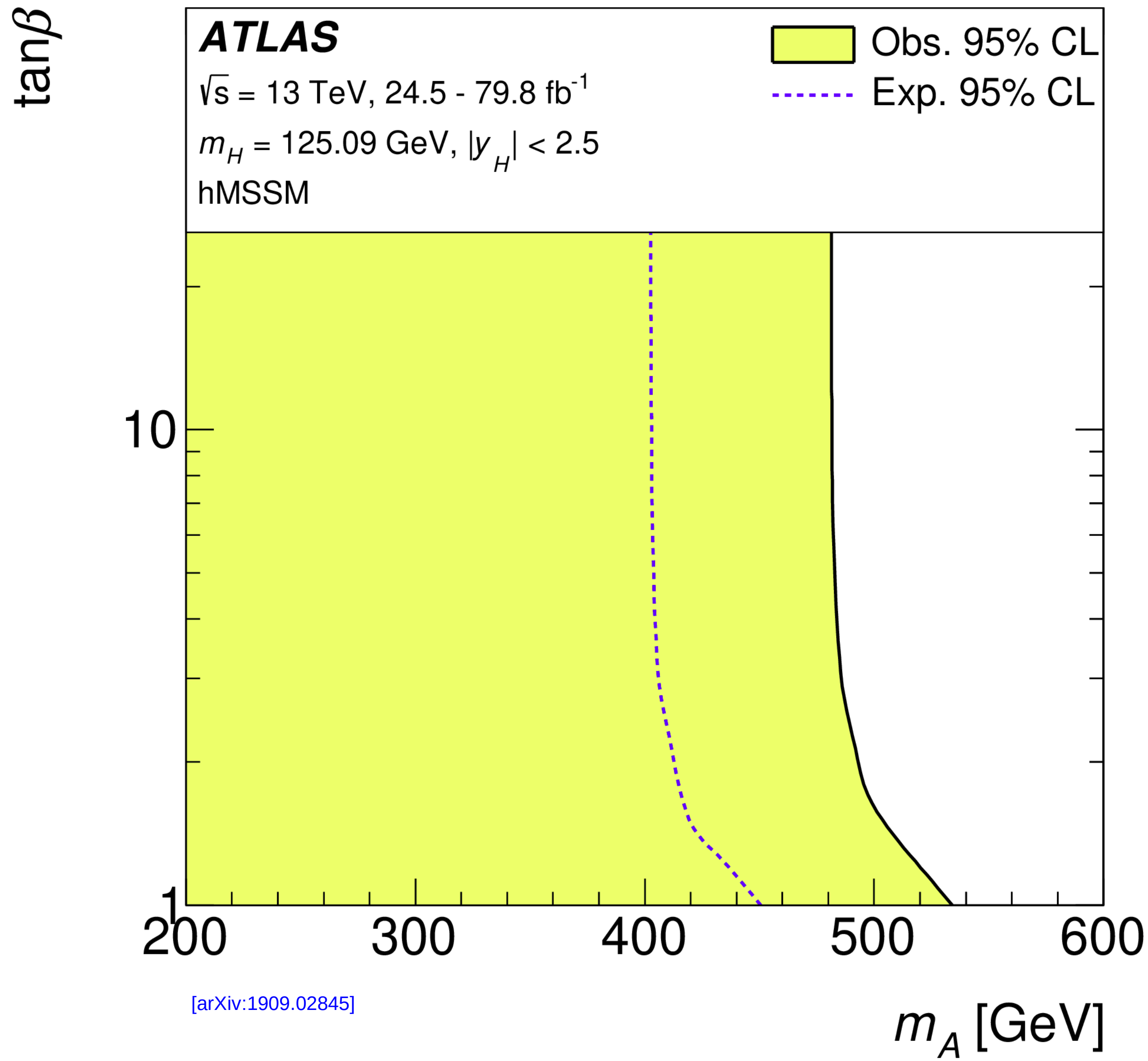
Uncertainty source	$\Delta\mu/\mu$ [%]
Statistical uncertainty	4.4
Systematic uncertainties	6.2
Theory uncertainties	4.8
Signal	4.2
Background	2.6
Experimental uncertainties (excl. MC stat.)	4.1
Luminosity	2.0
Background modeling	1.6
Jets, E_T^{miss}	1.4
Flavor tagging	1.1
Electrons, photons	2.2
Muons	0.2
τ-lepton	0.4
Other	1.6
MC statistical uncertainty	1.7
Total uncertainty	7.6





Higgs Combined Measurements

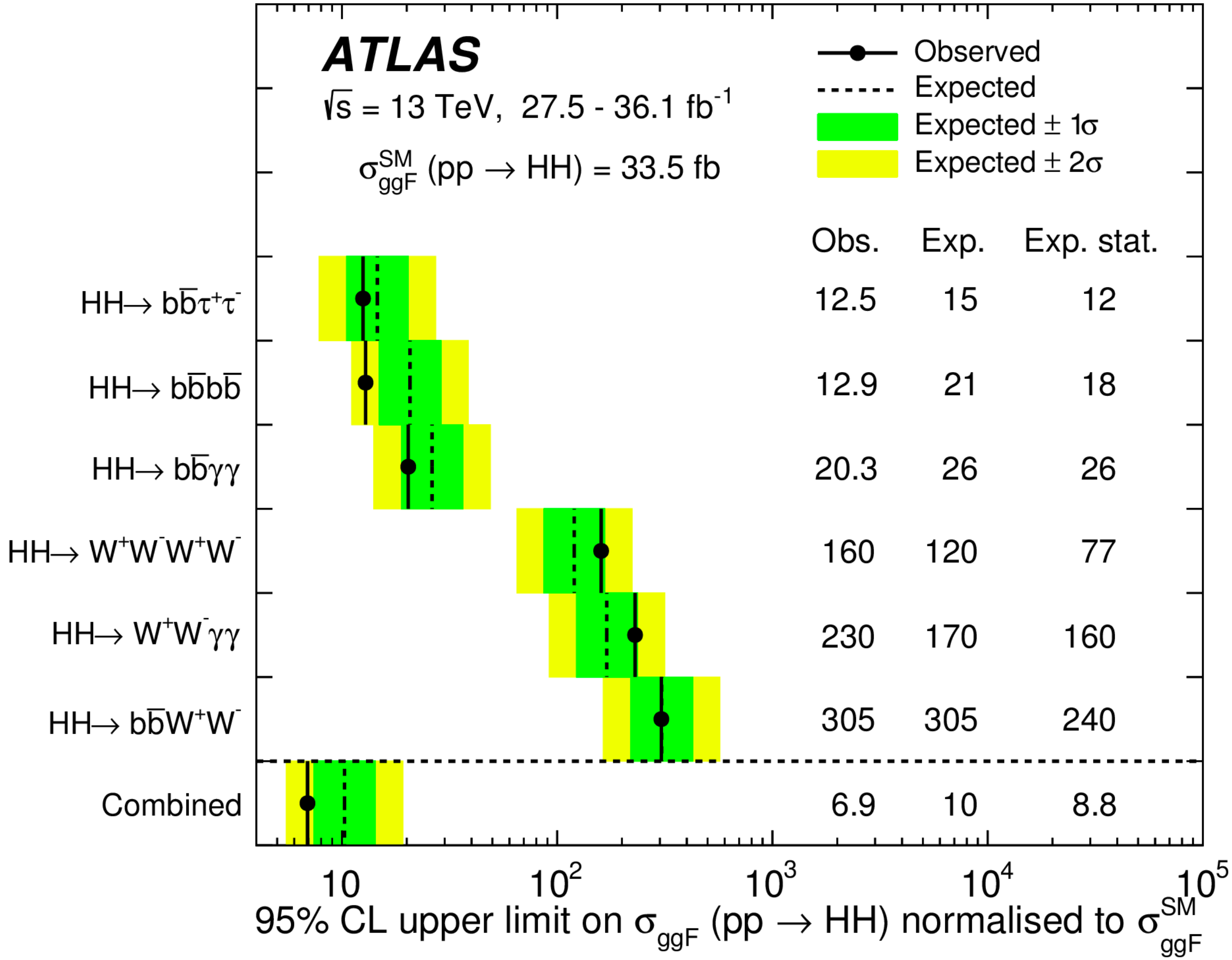
BSM Higgses searched for both directly and indirectly → couplings measurement provides indirect limit on m_A (hMSSM)



[arXiv:1909.02845]

Di-Higgs Combined Measurements

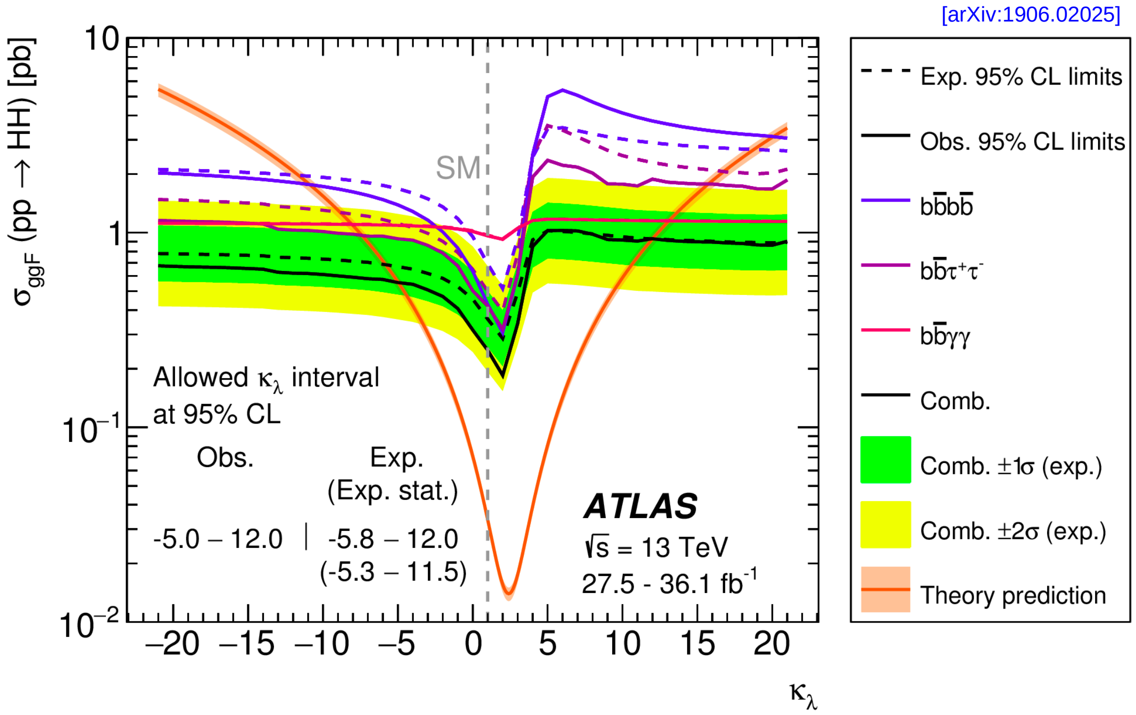
[arXiv:1906.02025]



Non-resonant Higgs boson pair production cross-section is 6.9 x σ_{SM} @ 95% CL

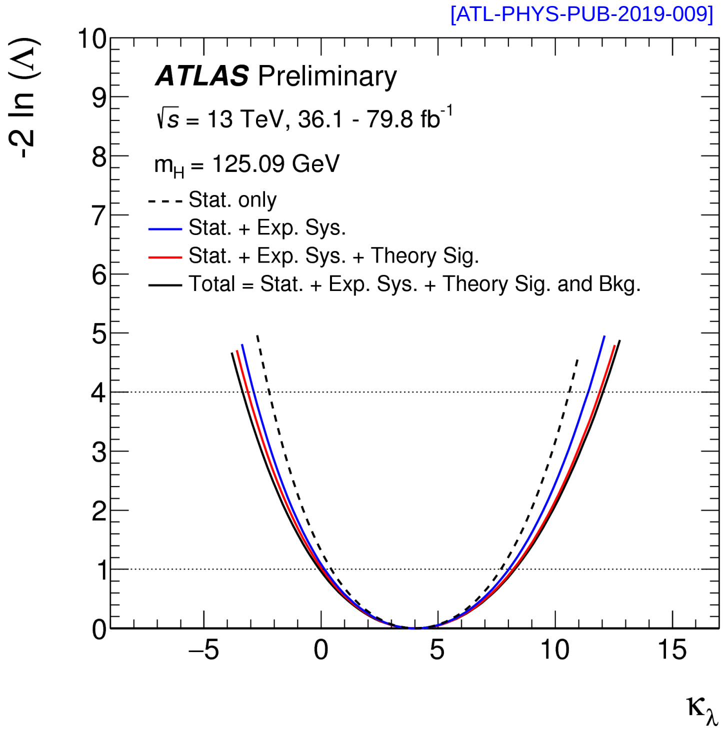
Higgs Self-Coupling Constraints

(Direct) HH



$-5.0 < \kappa_\lambda < 12.0$ @ 95% CL

Single H



$-3.2 < k_\lambda < 11.9$ @ 95 % CL

λ(HHH) contributes to single Higgs processes at NLO EW via Higgs self energy loop correction (+ additional diagrams).

Therefore an indirect constraint on λ(HHH) can be extracted by comparing precise measurements of production yields and SM predictions.