ATLAS EXPERIMENT

ATLAS Status Overview

A. Polini (INFN Bologna)

on behalf of the ATLAS Collaboration

Outline:

- The ATLAS detector
- Run-2 Status and Performance
- Recent Physics Highlights*
- Upgrade Plans

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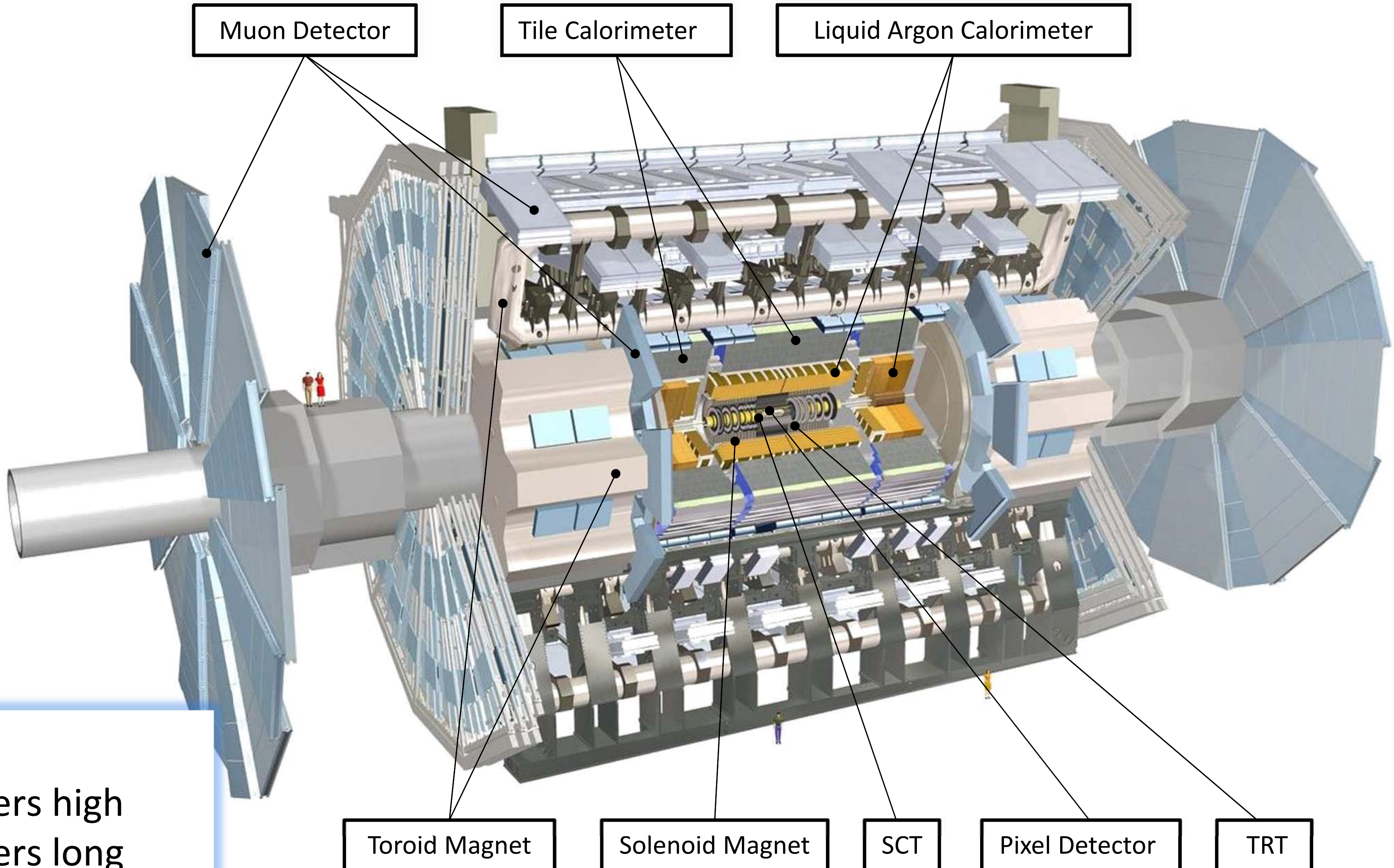
*Only few Highlights shown here:
See dedicated presentations:

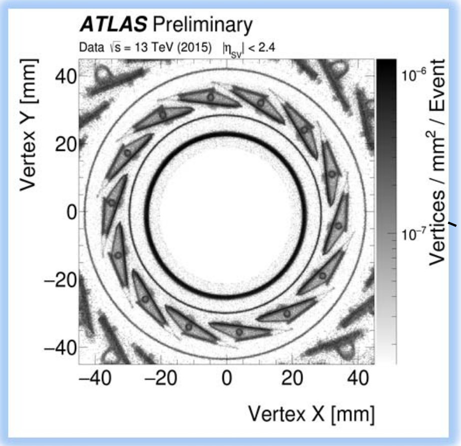
- Standard Model Physics Ludovica Aperio Bella
- New results on W boson production with the ATLAS detector, Evelin Meoni
- Exotic Higgs, Nikolina Ilic
- Higgs boson decays to fermions with the ATLAS detector, Stanley Lai
- Measurement of Higgs boson production in association with top quarks with ATLAS, John Andrew Raine
- Searches for supersymmetry in signatures with long-lived particles with the ATLAS detector, Karri Folan Di Petrillo
- Searches for squarks and gluinos with ATLAS, Antonia Struebig
- Searches for electroweak production of supersymmetric particles with ATLAS, Sarah Williams
- Dark Matter searches at the LHC, Vasiliki Kouskoura
- Exotic Searches, Adriana Milic
- ATLAS Dark Matter searches: interpretation, Darren Price
- A search for Vectorlike Quarks Erich Varnes

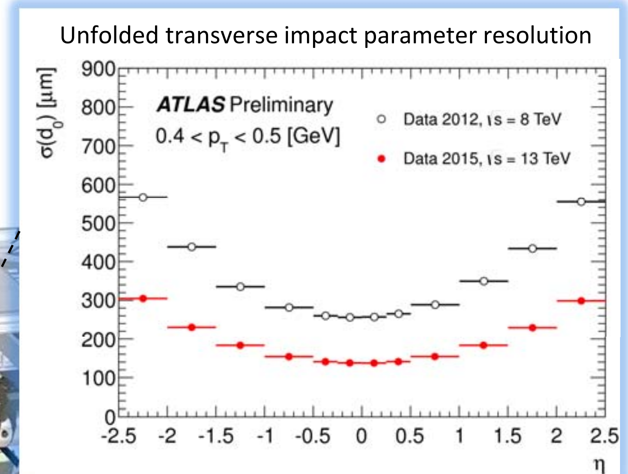
The ATLAS Detector

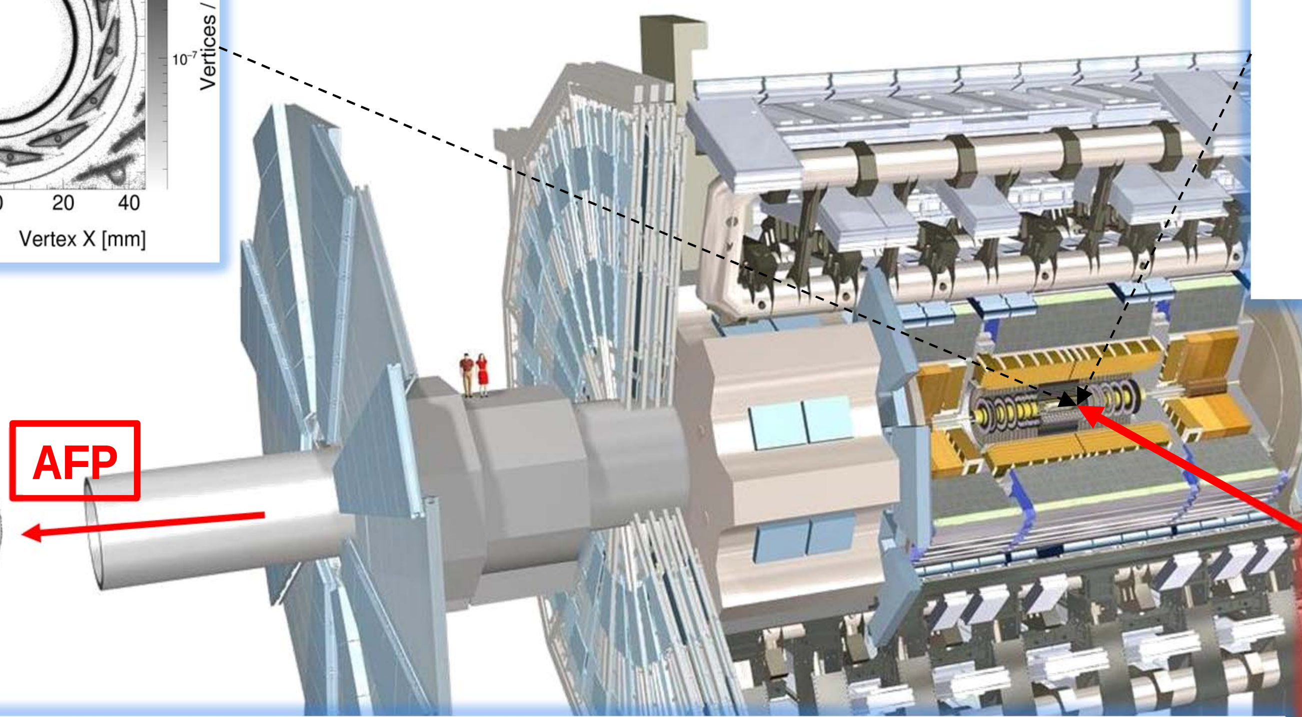


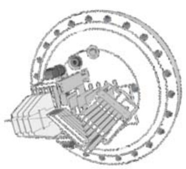
ATLAS
- 25 meters high
- 44 meters long
- Weight 7000 tons

The ATLAS Detector in Run-2 (2015-2018)





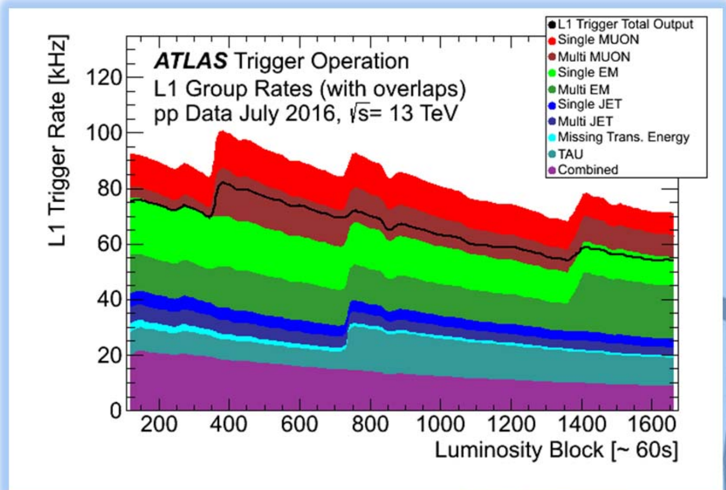


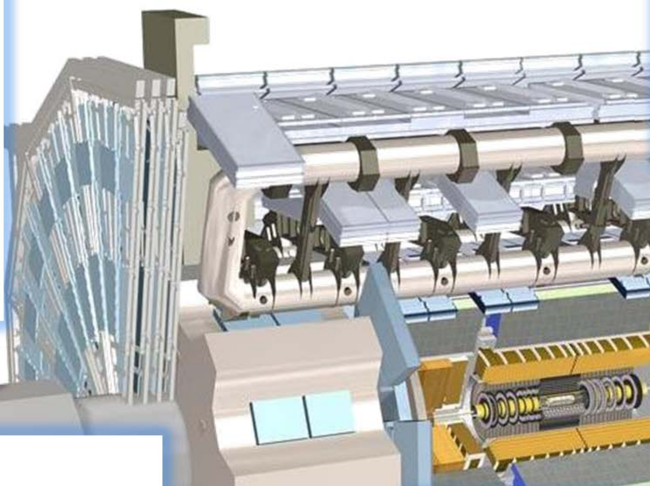


New detectors in Run-2:

- Innermost pixel layer IBL, 3.4 cm from interaction point
- Muons: MDT in $1.1 < |\eta| < 1.3$, RPC in Barrel Feet Sectors
- Forward proton detectors, AFP (one/two arms in 2016/2017, 205+217m from IP)
- In addition, **various consolidations** provide improved running at high luminosities and rates (**tracking, calorimetry, muon, luminosity measurement, etc.**)

The ATLAS Detector in Run-2 (2015-2018)



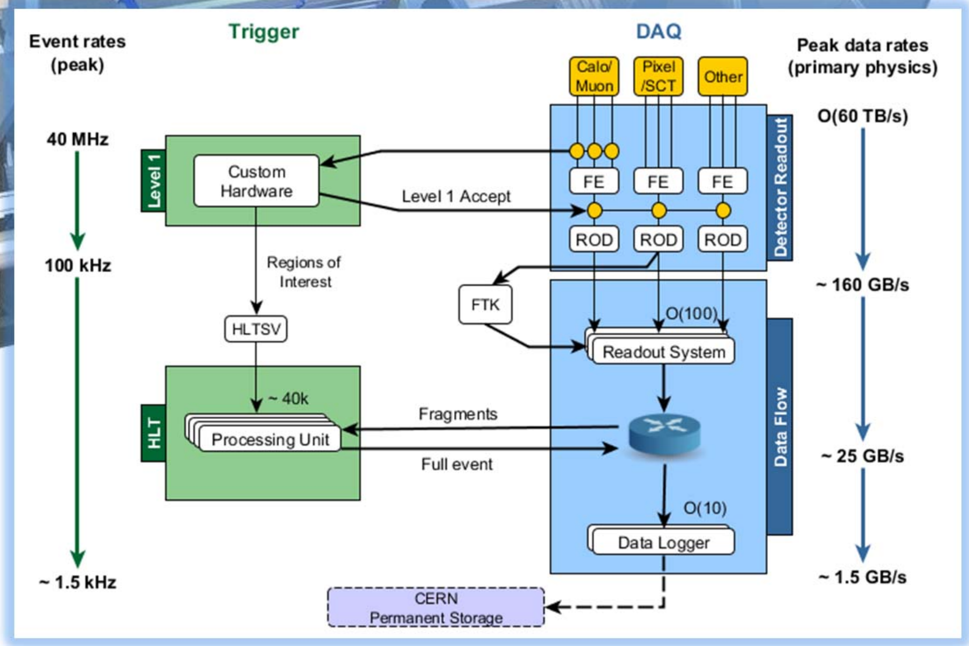


Trigger

- Menu consists of ~2000 triggers, covering a wide physics program
- Keep low threshold inclusive triggers
  - Single e/μ with p_T>26 GeV
  - E_T^{miss} > 110 GeV

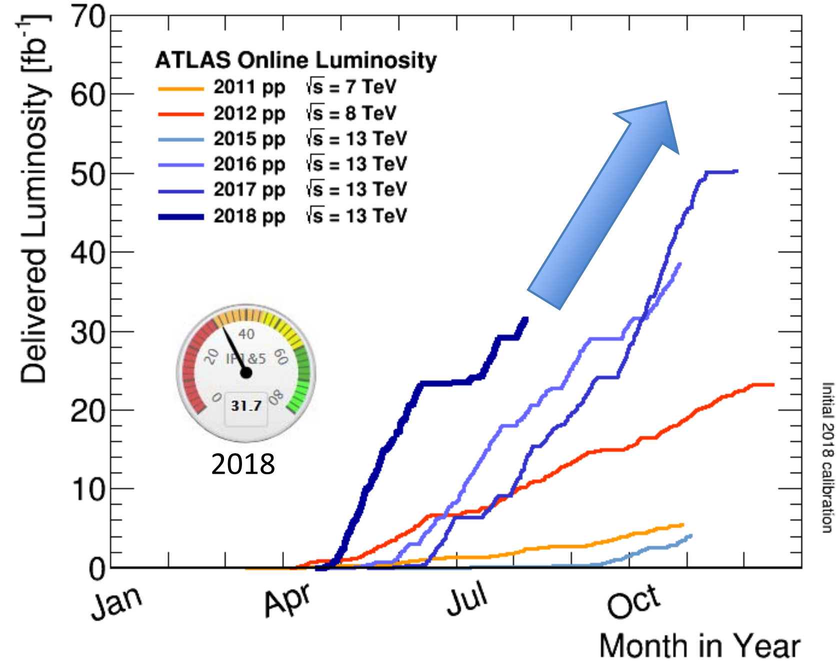
Trigger system (Run-2)

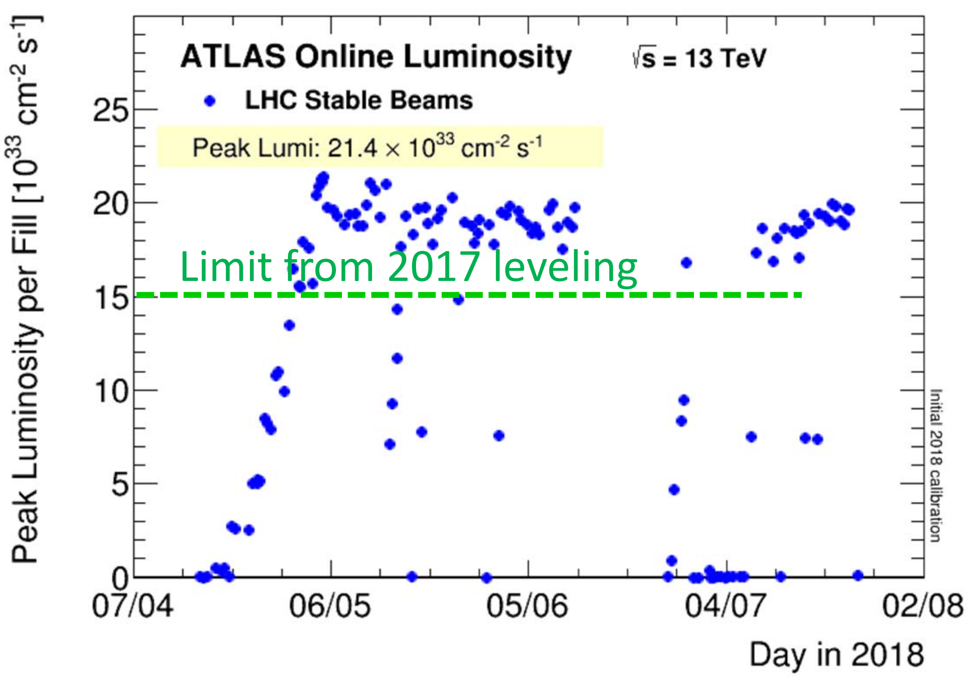
- L1 – hardware
  - output rate: 100 kHz latency: < 2.5 ms
  - New Central Trigger Processor
  - Improved resolution in calorimetry readout and trigger
  - Topological trigger at L1 (Calo+Muons)
- HLT – software
  - output rate: 1 kHz
  - proc. time: ~ 550 ms
- Wide upgrade to DAQ infrastructure

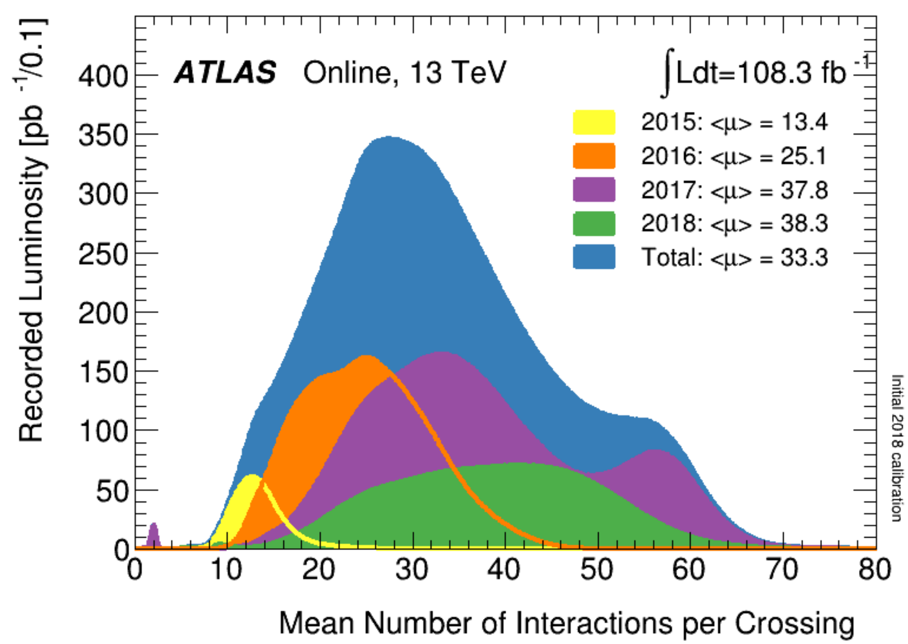


Run-2 Data Taking

- Excellent machine performance running at about double of design luminosity
- Our biggest THANKS to the LHC!
- A big experimental challenge is pile-up (multiple p-p interactions in same bunch crossing) causing:
  - Multiple vertices, many low p_T tracks
  - Underlying energy deposits in calorimeter
- Detector and data taking challenges:
  - Detector read-out with large occupancy, high rigger rates, data bandwidth, processing computing power

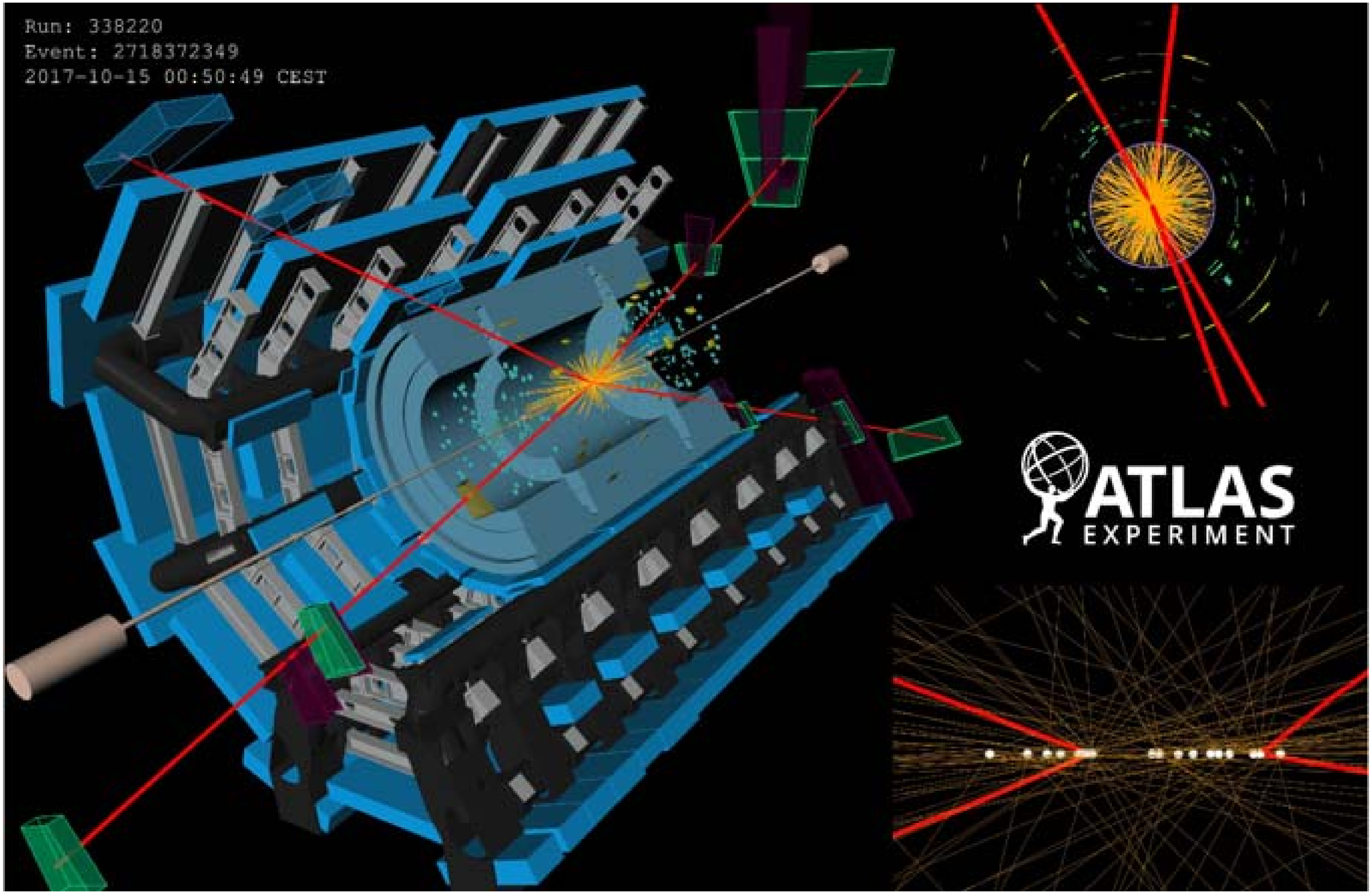




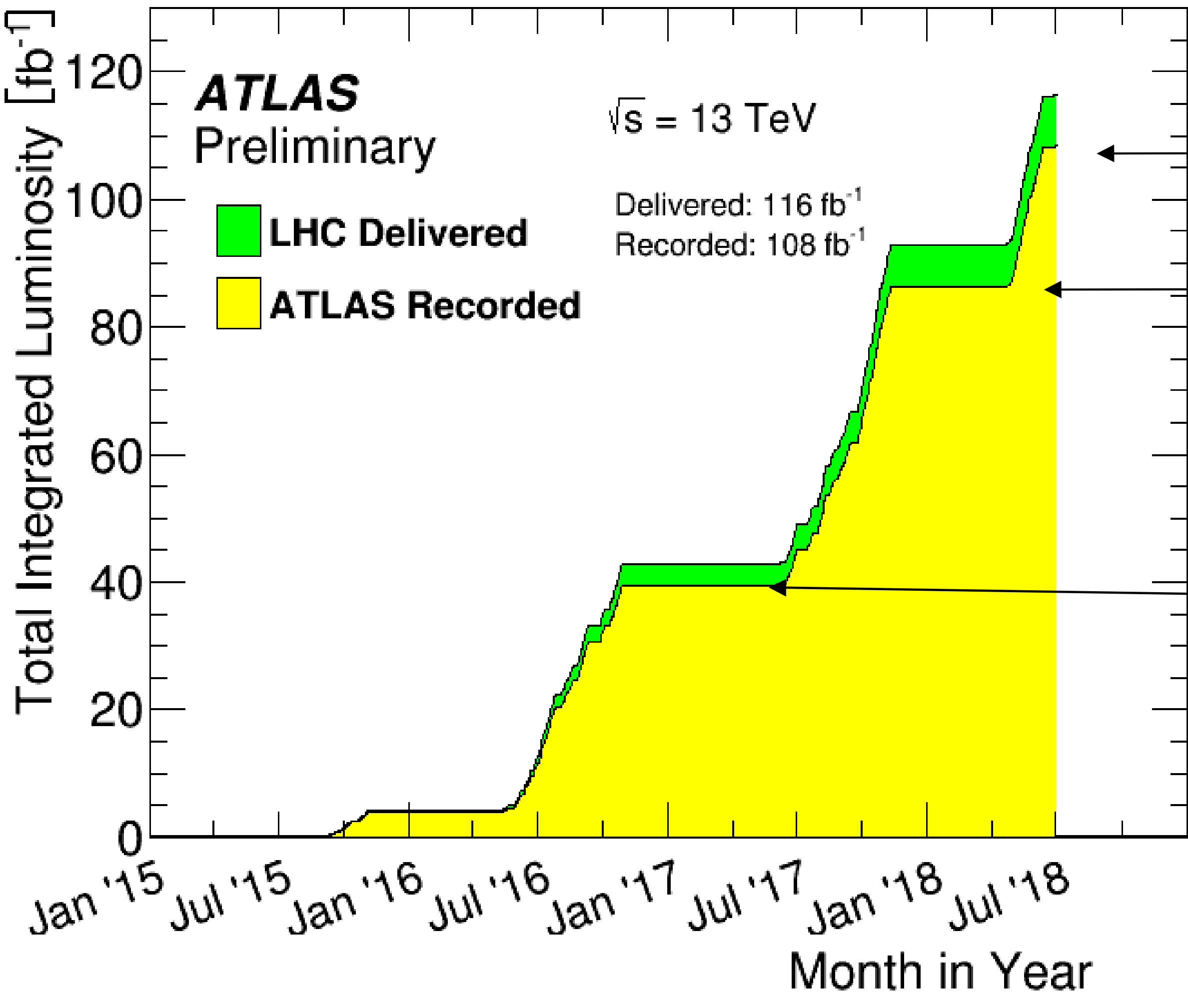


Pile-up (4 muons event)

Two $Z \rightarrow \mu\mu$ candidates from different pp interactions, but in the same bunch-crossing, observed in 2017 data ... their production vertices are separated by 67 mm ATL-PHYS-PUB-20 18-007



ATLAS Run-2 data-set



2015-2018 data-set:
L= 108 fb^{-1} recorded

2015-2017 data-set:
L = 80 fb^{-1}
13 public results

2015-2016 data-set:
L = 36 fb^{-1}
88 publications on arXiv

About a factor of 2 above LHC design luminosity.
Expect $\mathcal{L}$ = **140 - 150 fb^{-1}** for full 2015-2018 data-set.

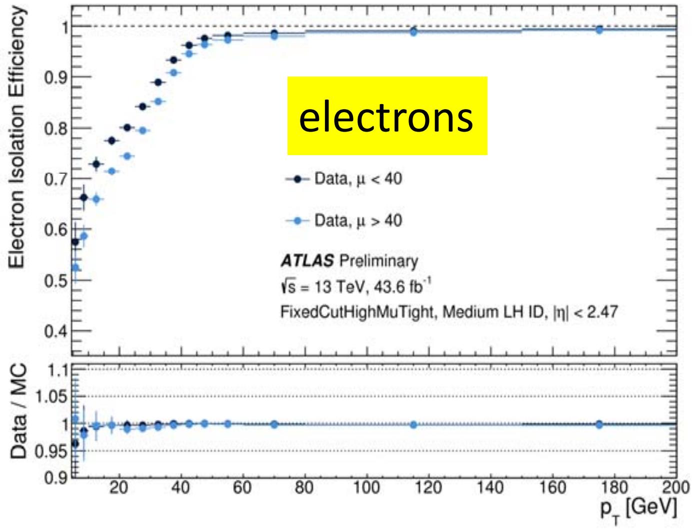
ATLAS pp 25ns run: April 25-June 11 2018

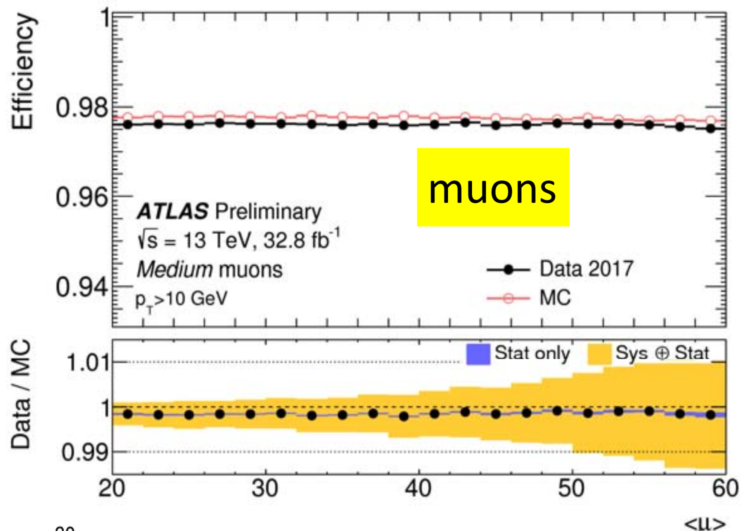
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	100	100	99.6	100	99.9	99.4	99.9	100	100	98.8

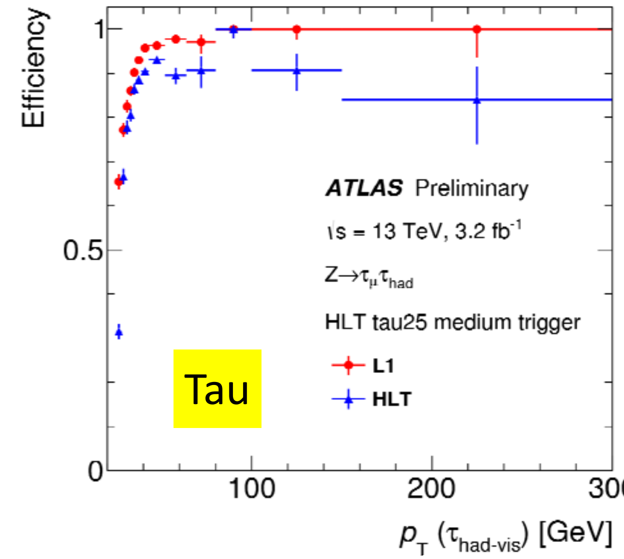
Good for physics: 96.6% (21.0 fb^{-1})

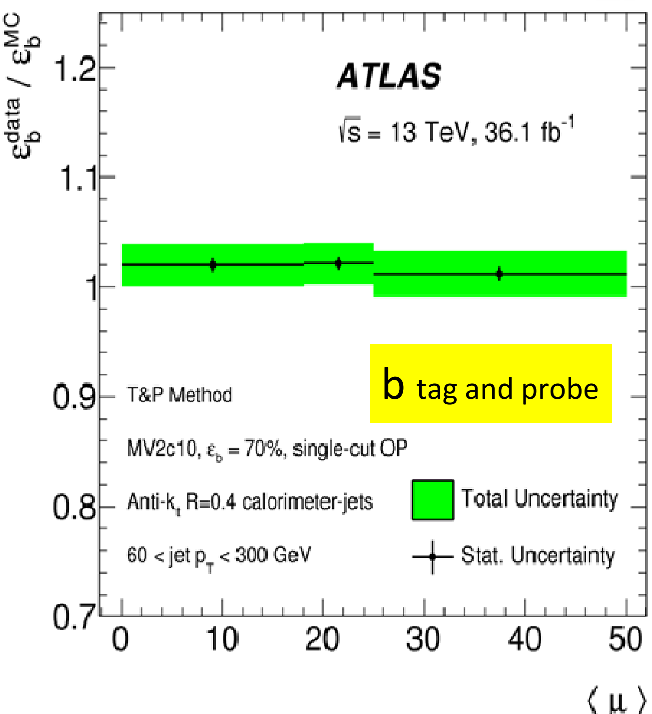
Luminosity weighted relative detector uptime and good data quality efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at $\sqrt{s}$=13 TeV between April 25 – June 11 2018, corresponding to a delivered integrated luminosity of 22.7 fb^{-1} and a recorded integrated luminosity of 21.7 fb^{-1}. Dedicated luminosity calibration activities during LHC fills used 1.0% of recorded data and are included in the inefficiency.

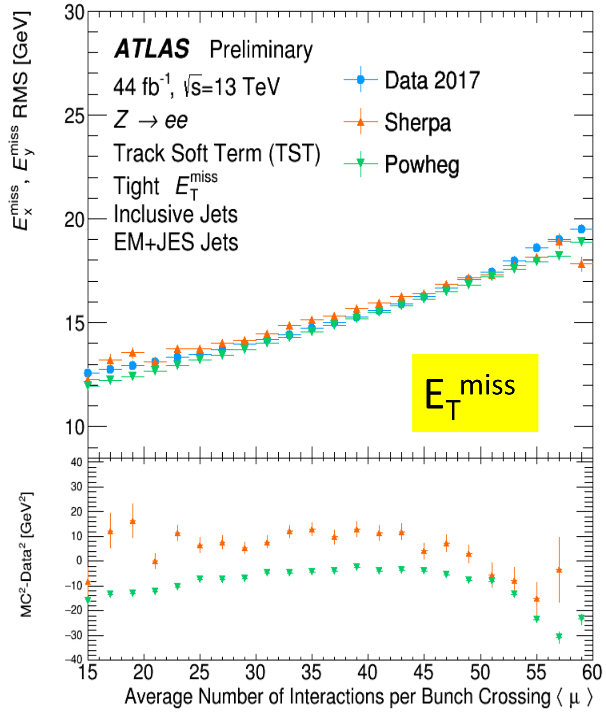
Physics Performance

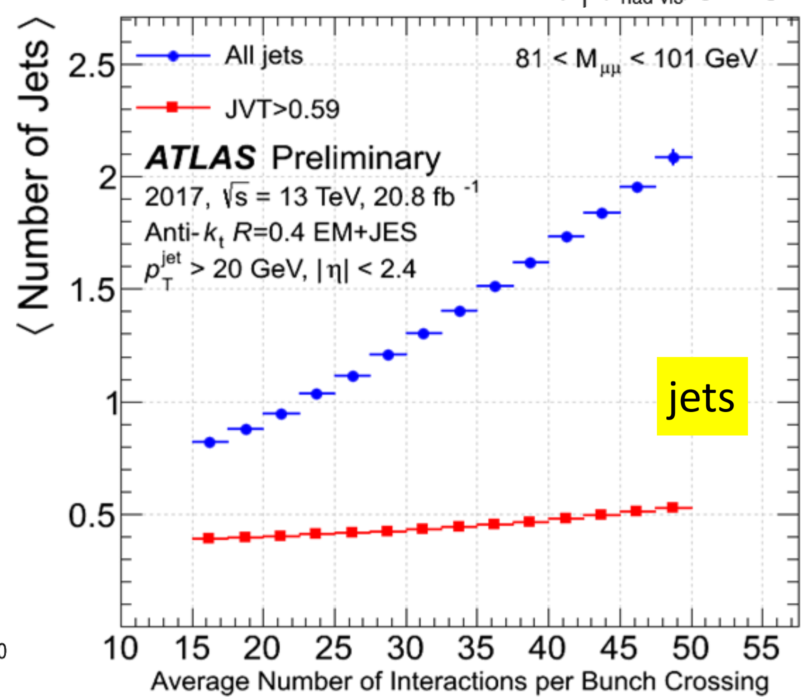






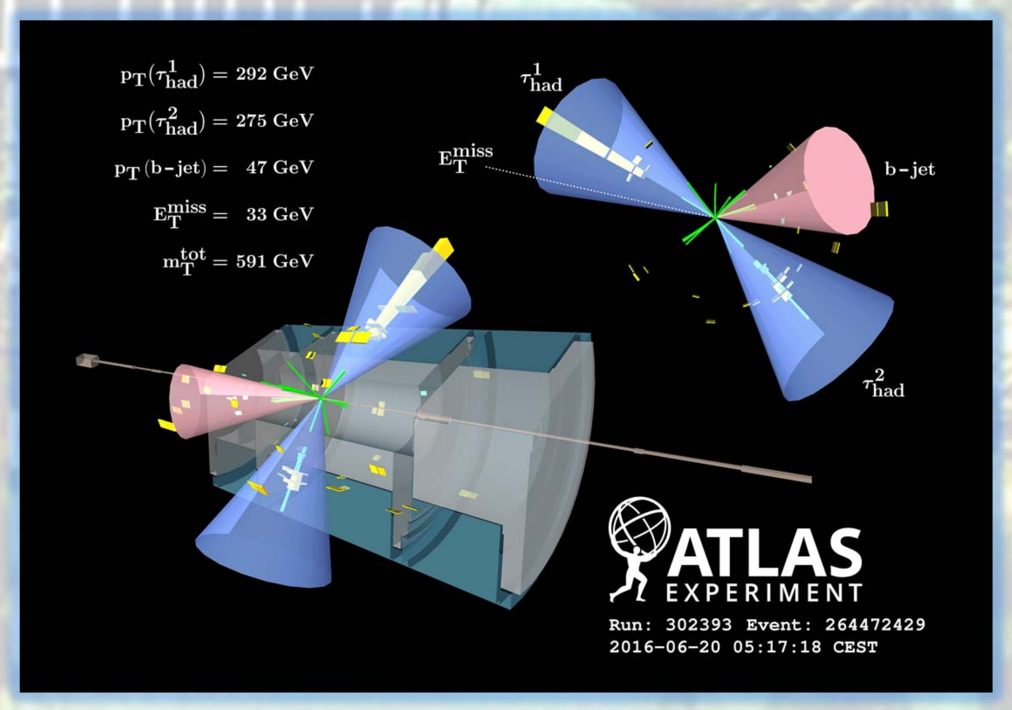


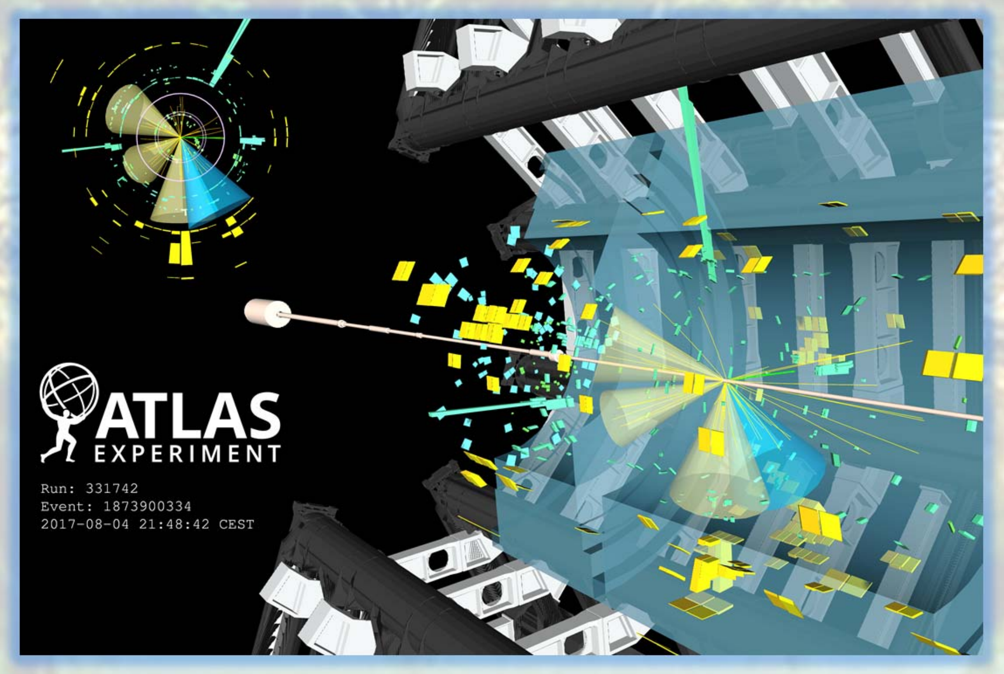




Pileup mitigation techniques e.g. subtraction, correction continuously improving and getting mature

Physics Results

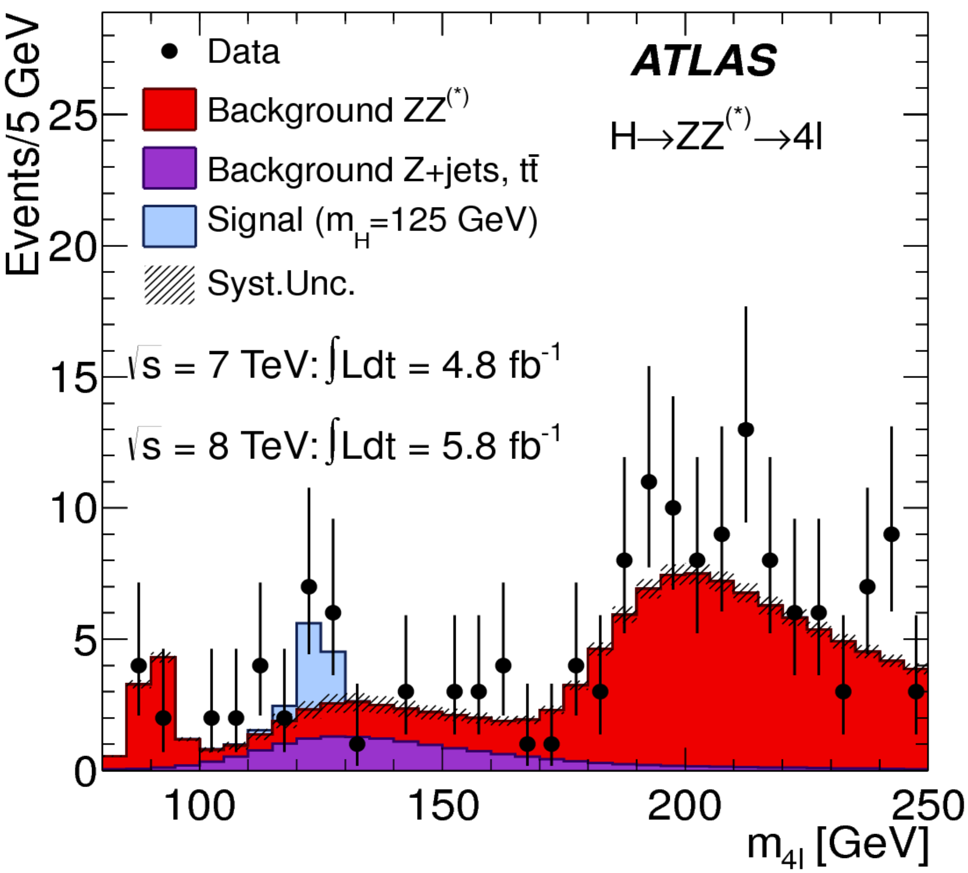




Higgs → ZZ → 4 leptons

- Higgs boson discovered in July 2012 at LHC.
- Is the new particle the SM Higgs boson ? → measure its properties
- Example for high purity but low branching fraction Higgs decay to four leptons (H→ZZ→4l):

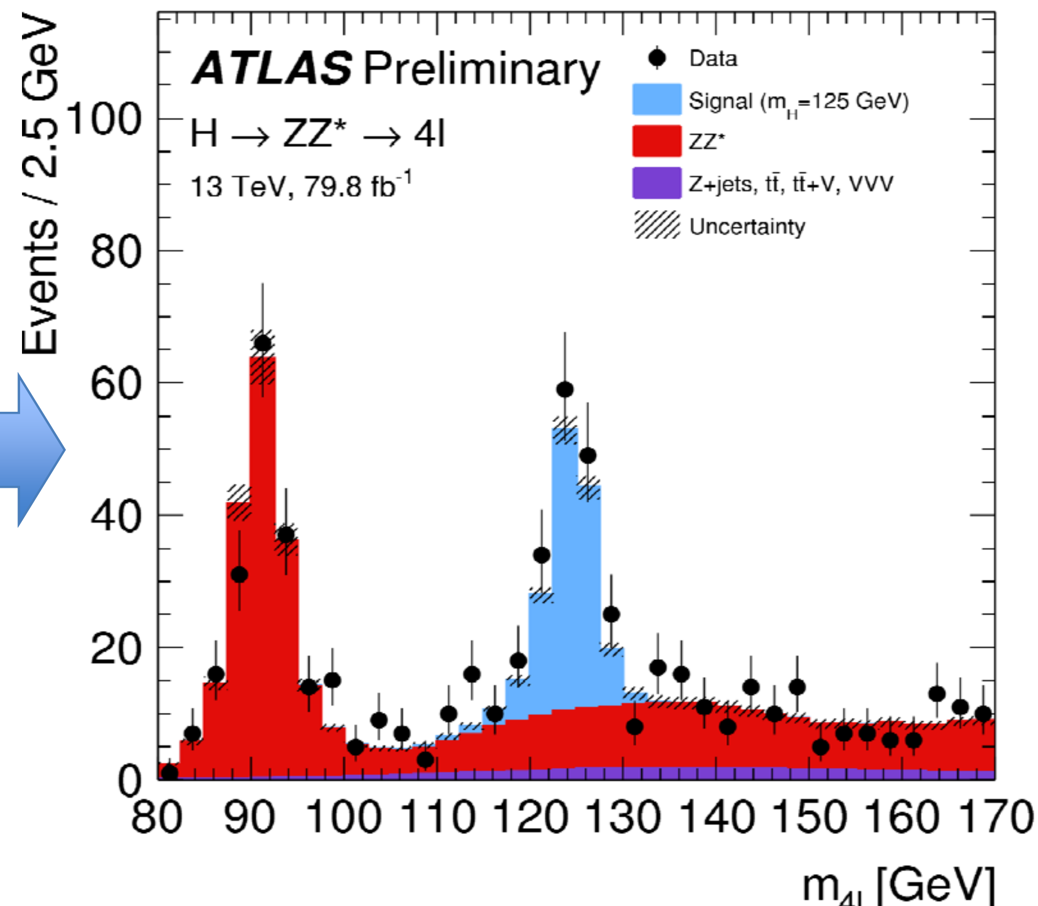
L=4.8 fb^{-1} and 5.8 fb^{-1} at 7 and 8 TeV



13 events 120< m_{4l} < 130 GeV

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

L=80 fb^{-1} at 13 TeV



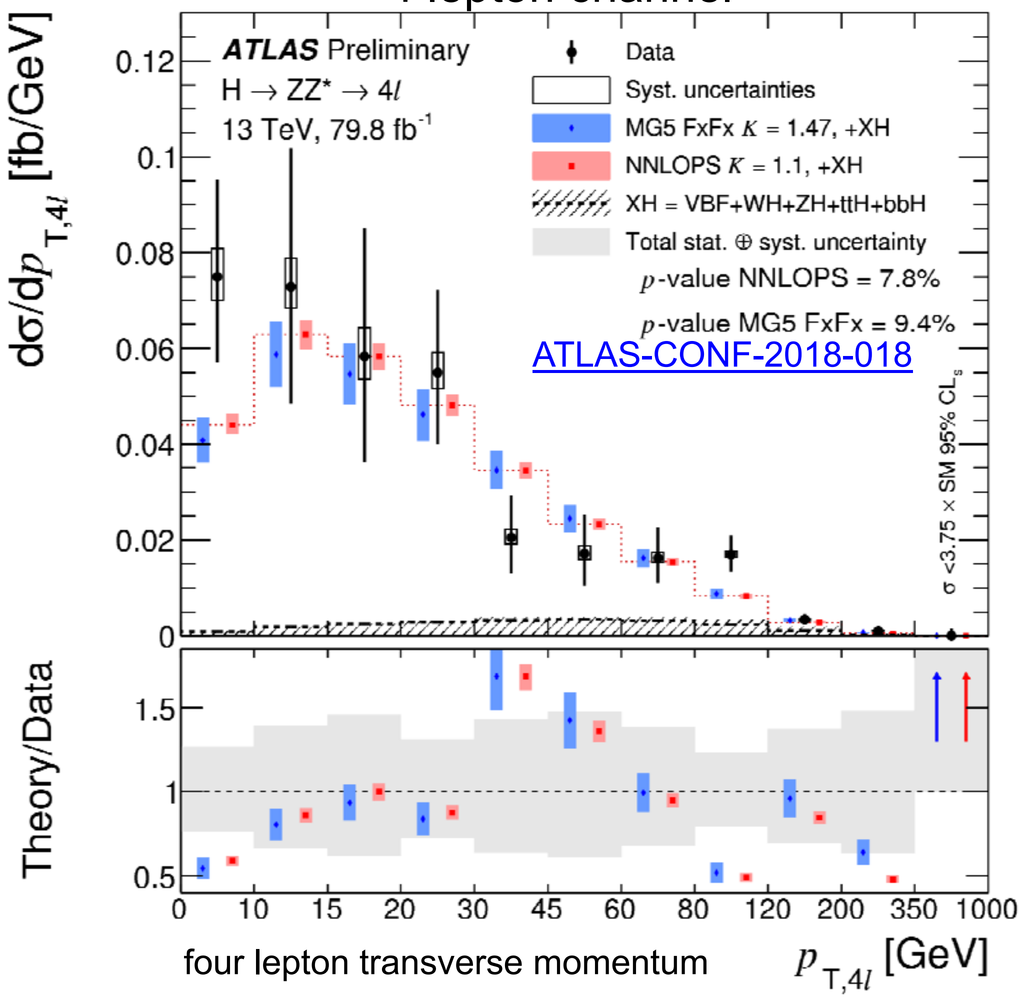
195 events for 115< m_{4l} < 130 GeV

ATLAS-CONF-2018-018

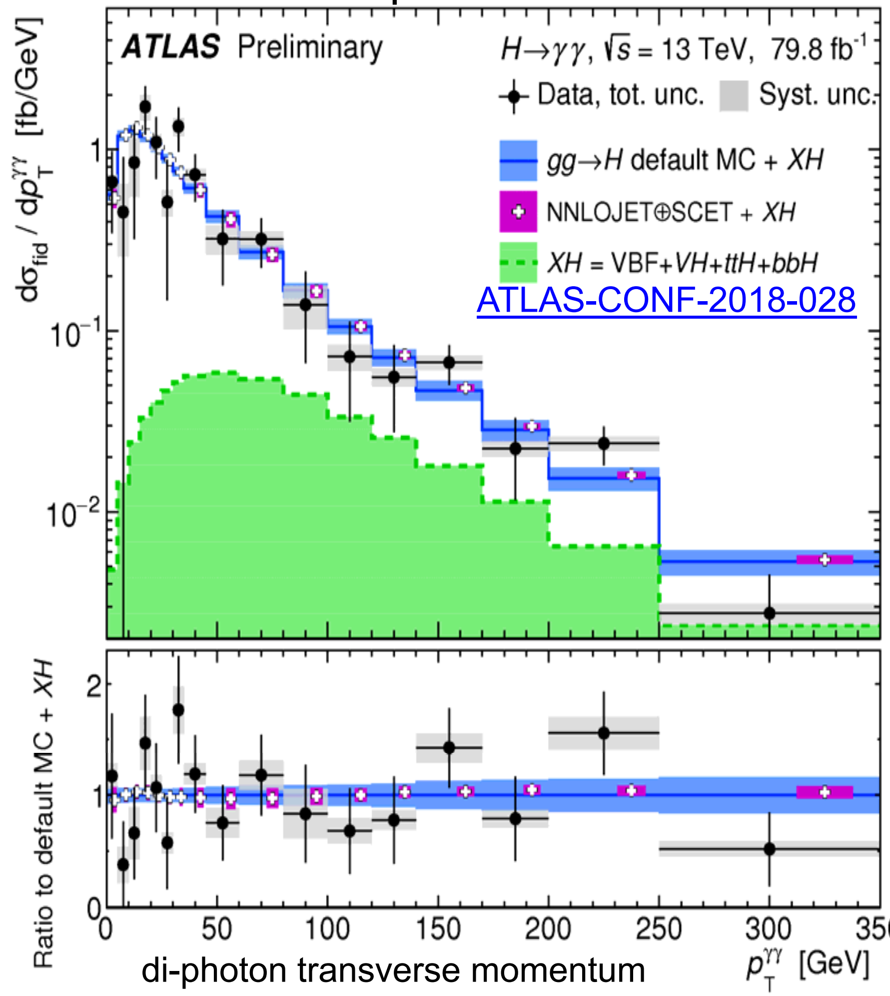
Differential cross-section using gauge boson decays

- Higgs decays to gauge bosons used for differential cross-section measurements.

4 lepton channel



2 photon channel

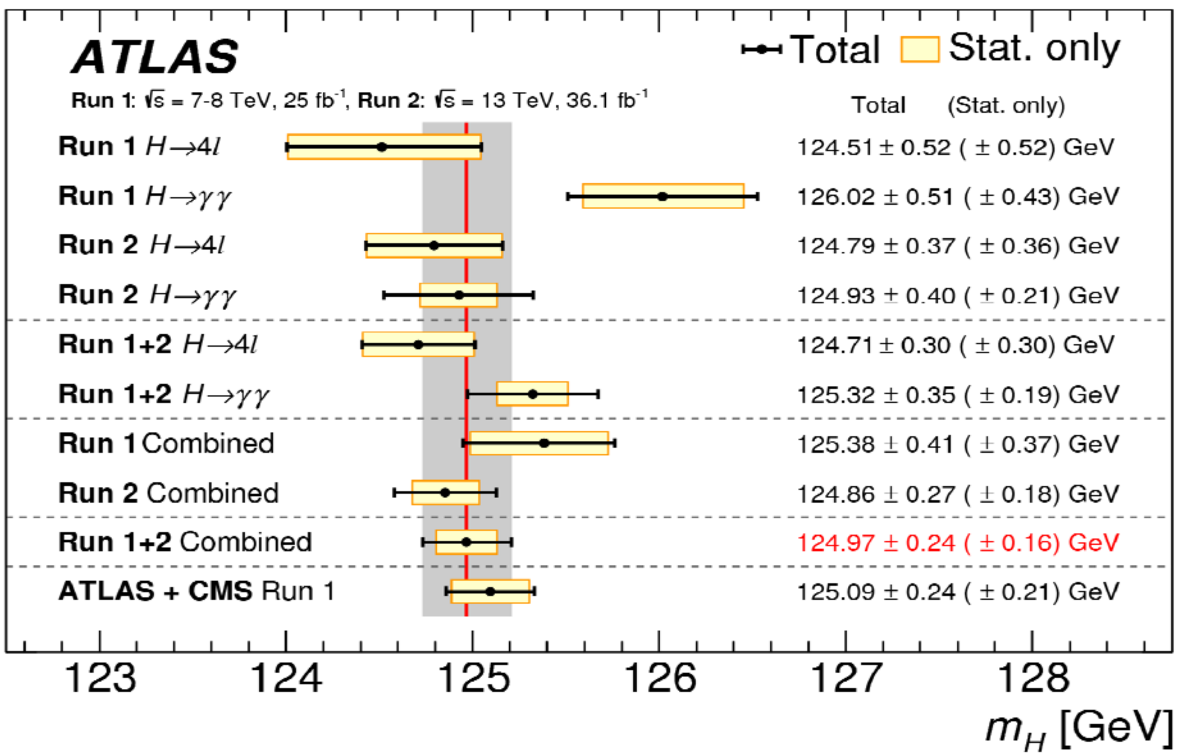


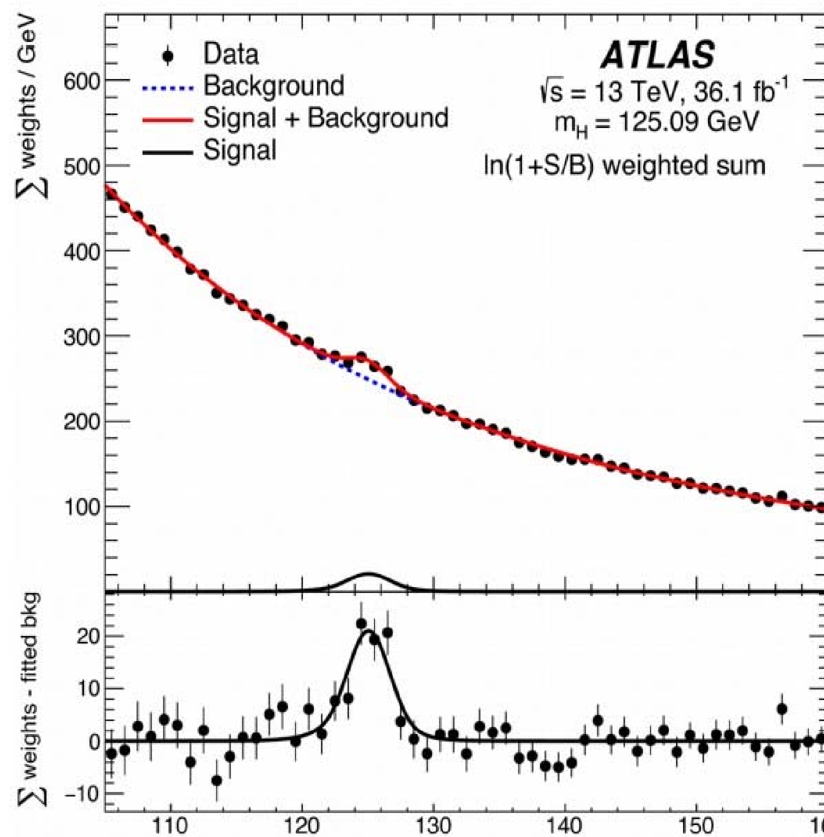
- Differential cross-section becoming more and more precise with increasing statistics.
- Data well described by recent SM predictions

Higgs Mass Measurement

- Higgs mass measured in $H \rightarrow ZZ^* \rightarrow 4l(e,\mu)$ and $H \rightarrow \gamma\gamma$ channels with 36.1 fb^{-1} @ 13 TeV
- Precision still limited by the available statistics. Prospects to determine the Higgs mass with more precision with full Run 2 data

arXiv: 1806.00242

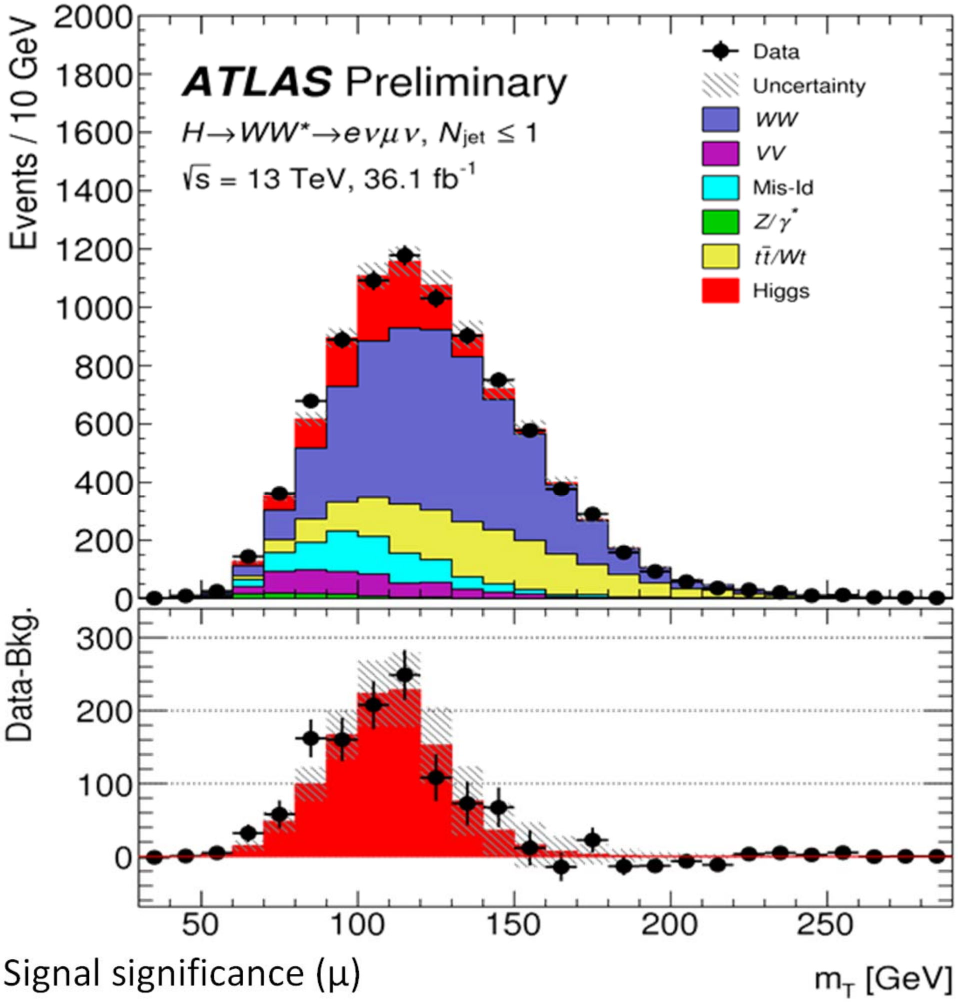




Higgs sector: $H \to WW$ and $H \to \tau\tau$

Recent 13 TeV results (2015-2016 data)

$H \to WW$ ATLAS-CONF-2018-004



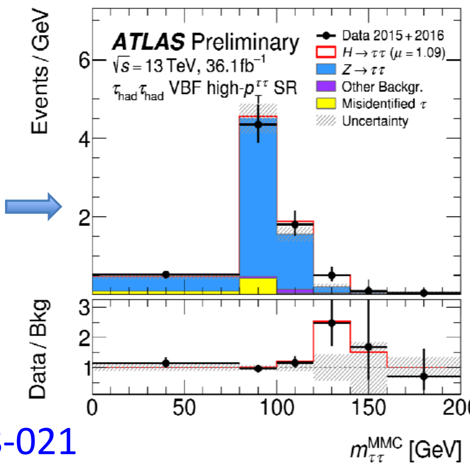
Signal significance (μ)

ATLAS

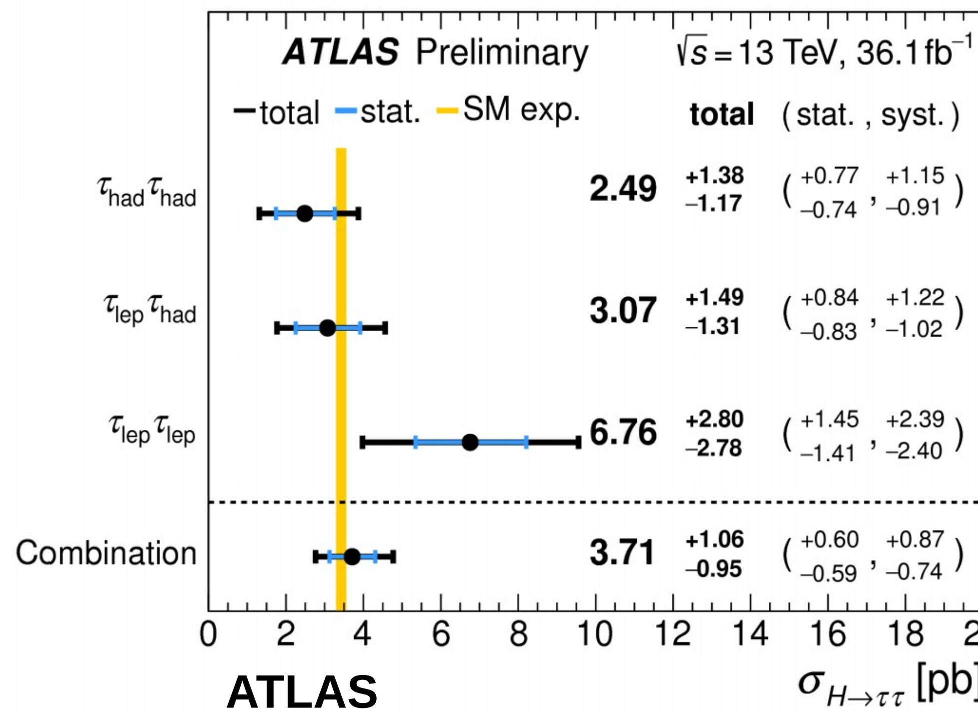
$$\mu_{ggF} = 1.21^{+0.12}_{-0.11}(\text{stat.})^{+0.18}_{-0.17}(\text{sys.}) = 1.21^{+0.22}_{-0.21}$$ 6.3 σ (5.2 σ exp.)

$$\mu_{VBF} = 0.62^{+0.30}_{-0.28}(\text{stat.}) \pm 0.22(\text{sys.}) = 0.62^{+0.37}_{-0.36}$$ 1.9 σ (2.7 σ exp.)

Example of mass dist. in 1 out of 13 signal categories



$H \to \tau\tau$ ATLAS-CONF-2018-021



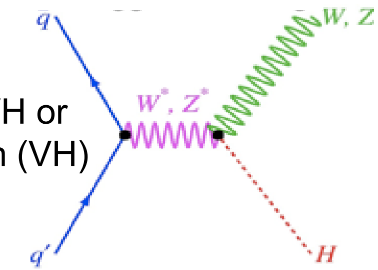
ATLAS

- 13 TeV alone: 4.4 σ (4.1 σ expected)
- 7/8/13 TeV combined: 6.4 σ (5.4 σ expected)

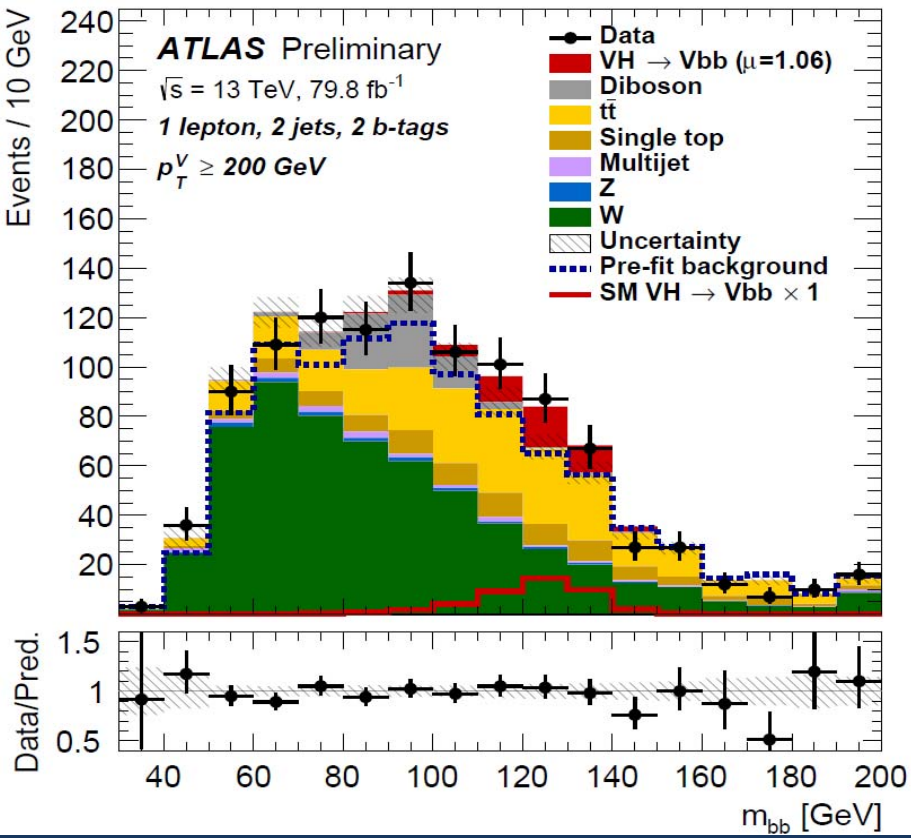
Associated VH production and $H \to bb$

- H→bb highest branching ratio: Br=58% but huge background from heavy flavor production
- Need to use exclusive (rare) production mechanism to gain sensitivity VH, $H \to bb$
- Analysis:
  - Use high-p_T boson region
  - Multi-variate analysis in 0, 1 and 2 lepton channels
  - Dijet mass analysis as cross-check

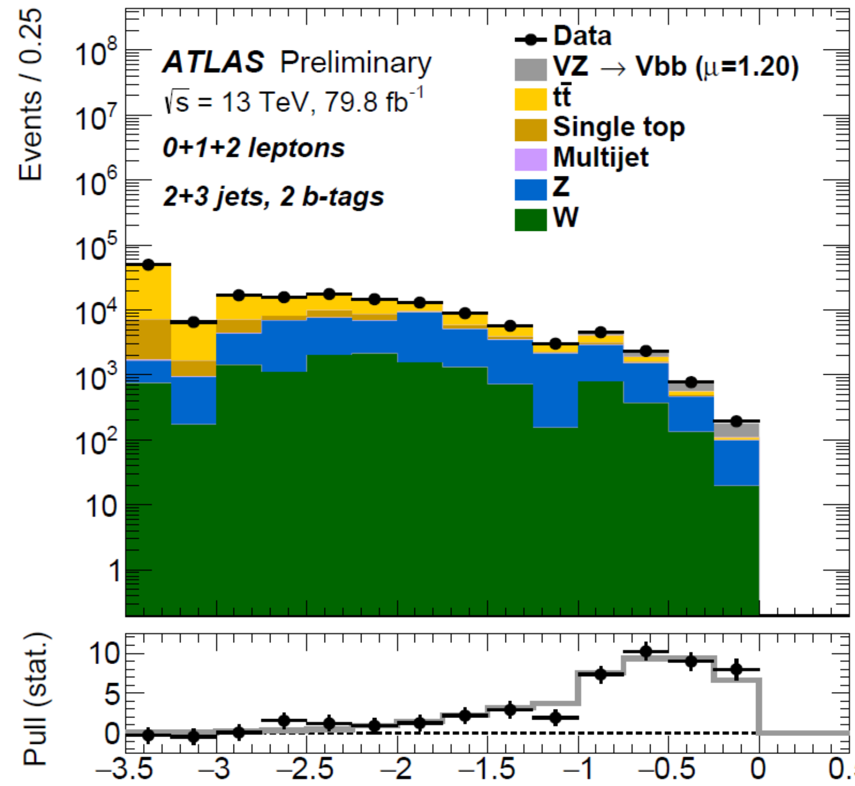
Associated WH or ZH production (VH)



Example: One input to di-jet mass analysis global fit



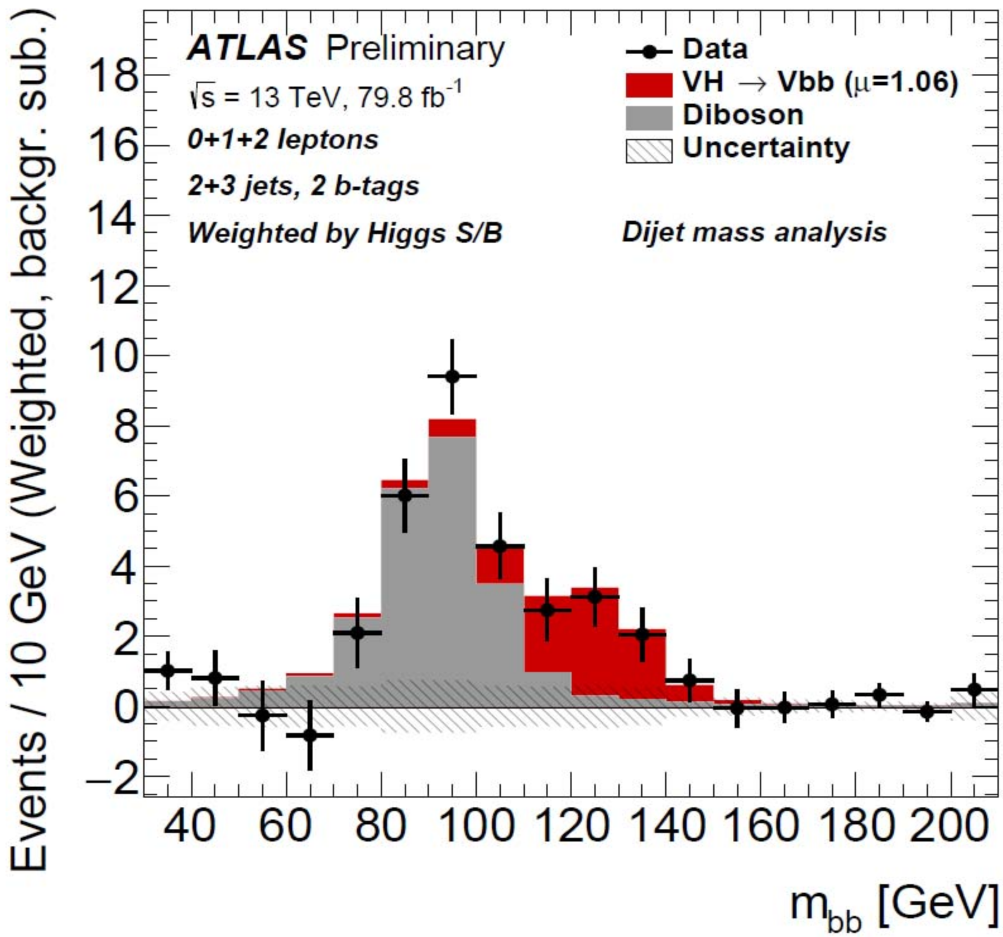
Di-boson validation analysis VZ(→bb):

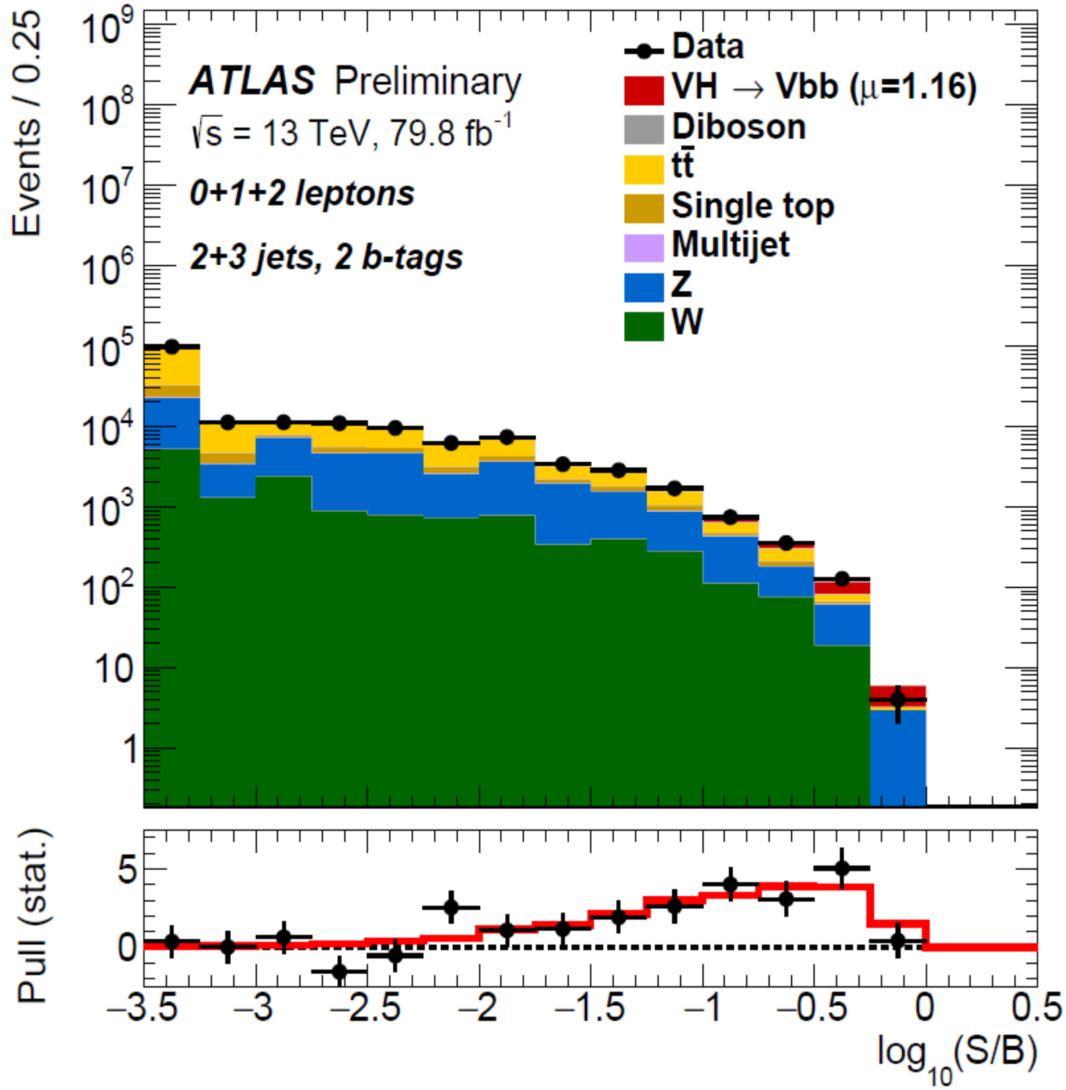


ATLAS-CONF-2018-036

Observation of $H \to bb$ decay

ATLAS-CONF-2018-036





VH alone:

- 4.9σ (4.3σ) obs (exp) (13 TeV)

Combined (7,8,13 TeV) VBF, ttH, VH:

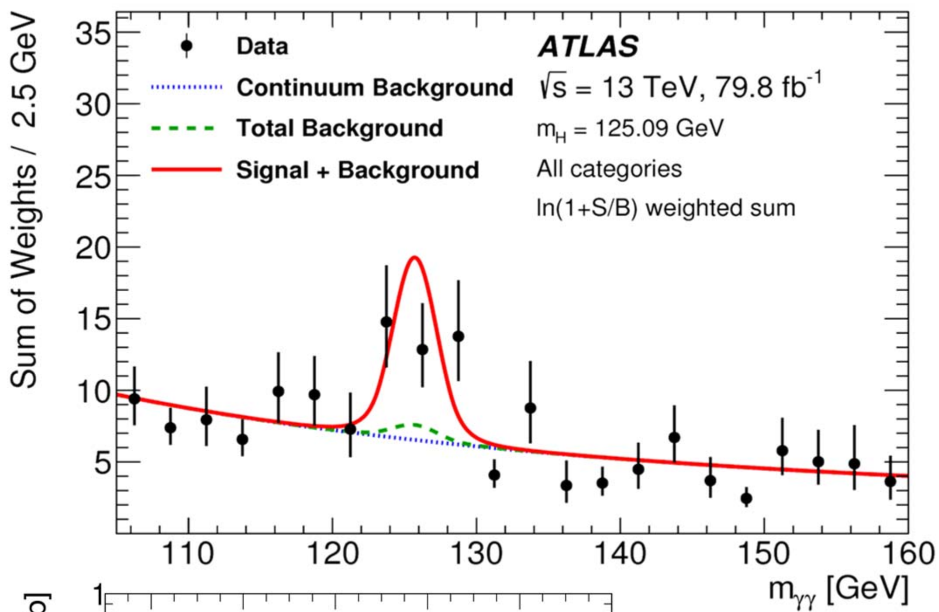
- **5.4σ** (5.5σ) obs (exp)

Observation of Higgs decay to beauty quarks !

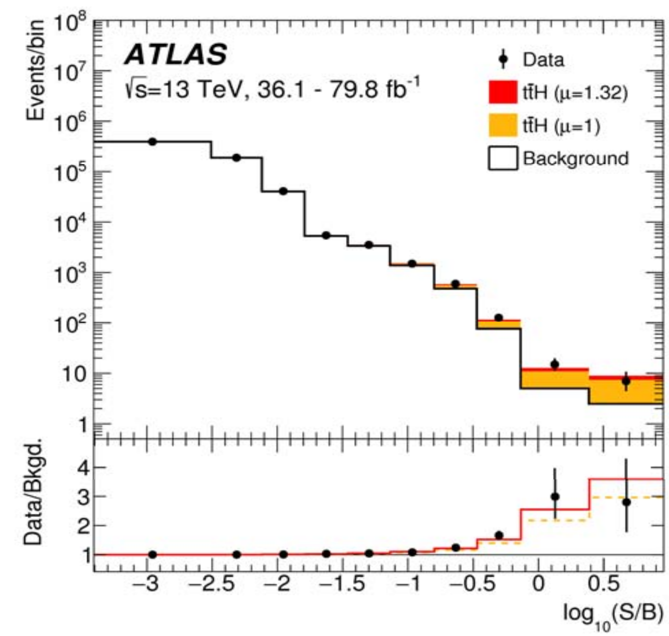
Observation of ttH production

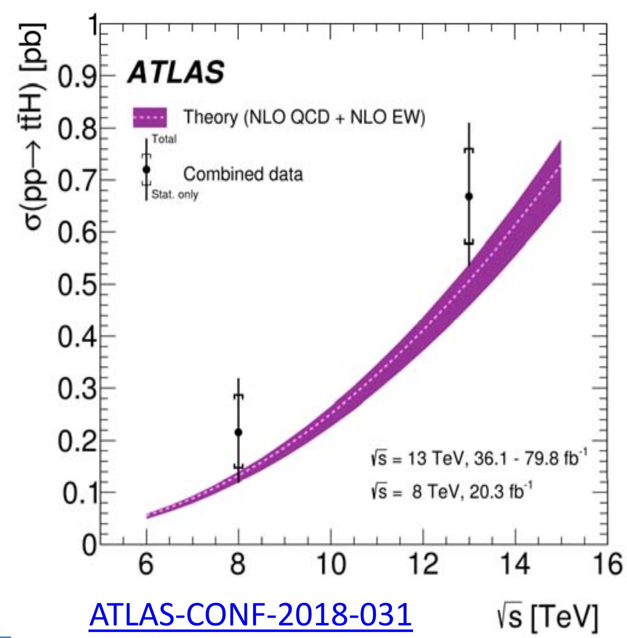
June 2018 update: $ttH(\to \gamma\gamma)$ and $ttH(\to ZZ \to 4l)$ with 80 fb^{-1}

arXiv:1806.00425



Direct observation of top Higgs coupling. Confirmation of Yukawa coupling to fermions.





ATLAS-CONF-2018-031

Analysis	Integrated luminosity [fb^{-1}]	Expected significance	Observed significance
$H \to \gamma\gamma$	79.8	3.7 σ	4.1 σ
$H \to$ multilepton	36.1	2.8 σ	4.1 σ
$H \to b\bar{b}$	36.1	1.6 σ	1.4 σ
$H \to ZZ^* \to 4\ell$	79.8	1.2 σ	0 σ
Combined (13 TeV)	36.1–79.8	4.9 σ	5.8 σ
Combined (7, 8, 13 TeV)	4.5, 20.3, 36.1–79.8	5.1 σ	6.3 σ

Inclusive ttH cross section (already 20% precision):

@ 8 TeV σ_{ttH}= 220 ± 100 (stat.) + 70 (syst.)

@ 13 TeV σ_{ttH}= 670 ± 90 (stat.) + 105 (syst.)

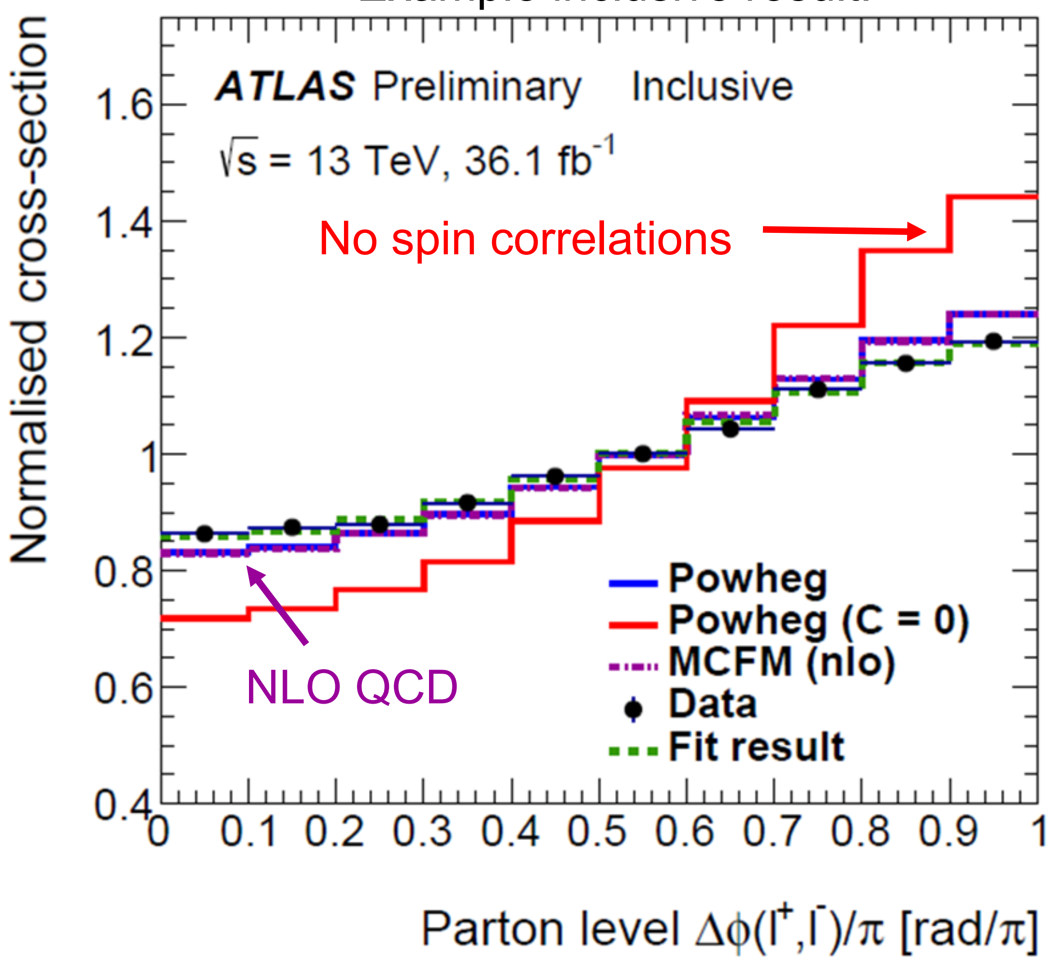
Spin correlation in top pair events

- Spin correlation for $pp \rightarrow tt \rightarrow e\mu bb$ measured between the top decay products and a spin axis.

ATLAS-CONF-2018-027

- $\Delta\Phi(e\mu)$ is a sensitive variable.

Example inclusive result:



Template fit on $\Delta\Phi(e\mu)$:

- f_{SM} fraction of expected cross-section under the SM spin hypothesis
- No spin correlation template:
- top decay with spin correlation disabled

Stronger spin correlations observed than expected by NLO QCD

Fit result: f=1.250±0.026±0.063

➔ 3.2σ discrepancy with NLO QCD

Previous analyses also measured stronger spin correlations (with large uncertainties).

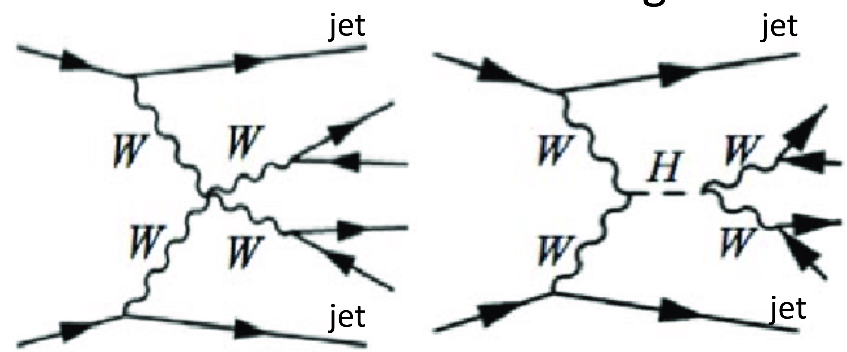
Similar results for fiducial particle-level and comparisons of ME generators.

Observation of same-sign $WWjj$

ATLAS-CONF-2018-030

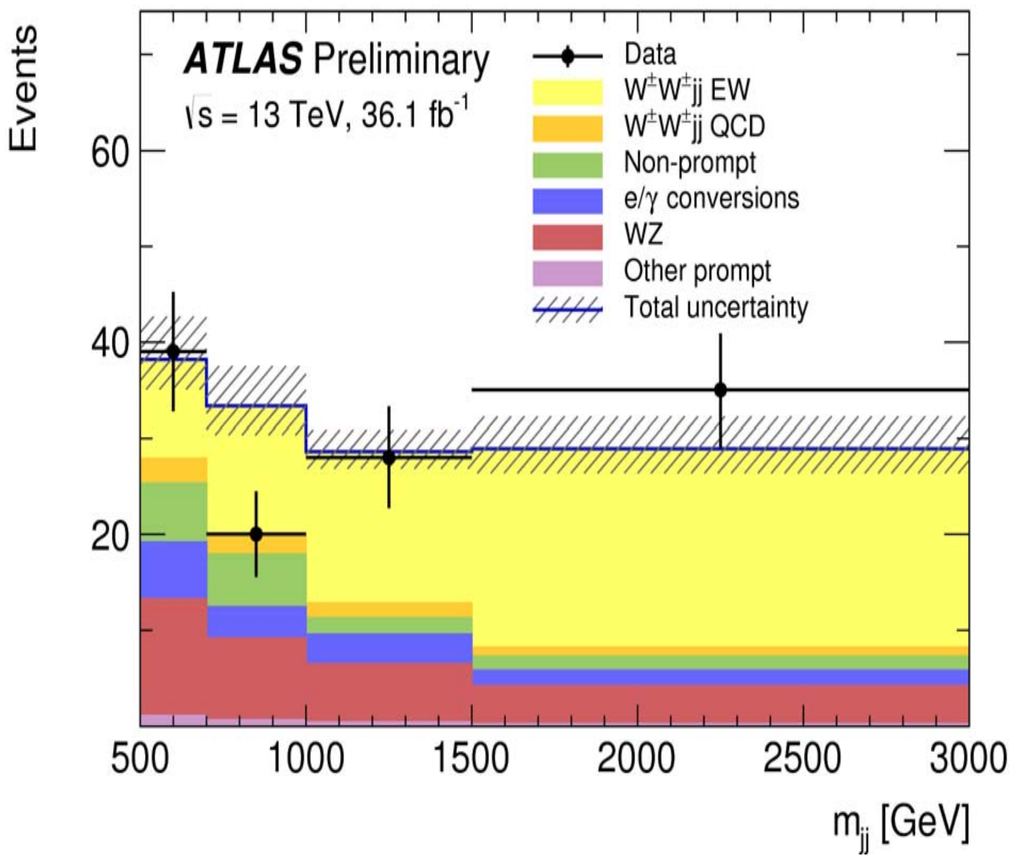
Higgs boson needed to restore unitarity of the WW scattering cross-section.

- Higgs boson leads to strong suppression via gauge cancellation of individual EW diagrams.
- Part of electroweak symmetry breaking studies.



pp → $W^{+/-}$ $W^{+/-}$ jet jet process:

- Large electroweak cross-section fraction (σ_{EW}/σ_{QCD}). and a strong background suppression.



Significance:
6.9σ (4.6σ) obs (exp)

Fiducial cross-section:

$$\sigma_{\text{fid}} = 2.91^{+0.51}_{-0.47}(\text{stat.}) \pm 0.27(\text{syst.})\ \text{fb}$$

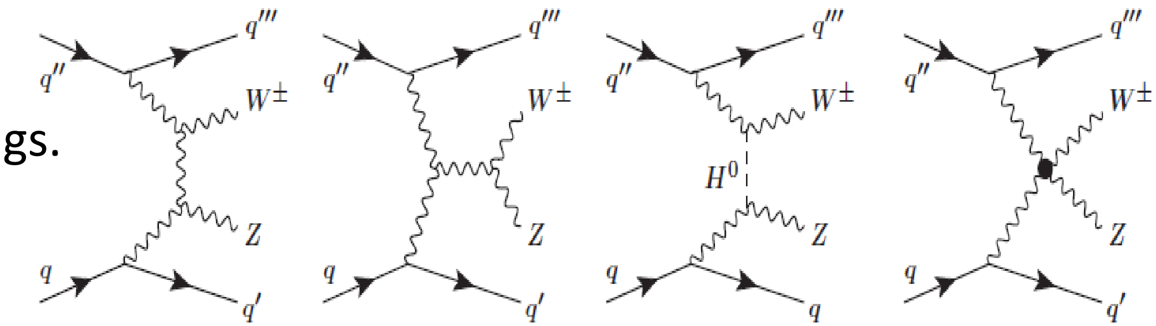
$$\sigma^{\text{Sherpa}}_{\text{fid}} = 2.01^{+0.33}_{-0.23}\ \text{fb}$$

$$\sigma^{\text{Powheg}}_{\text{fid}} = 3.08^{+0.45}_{-0.46}\ \text{fb}$$

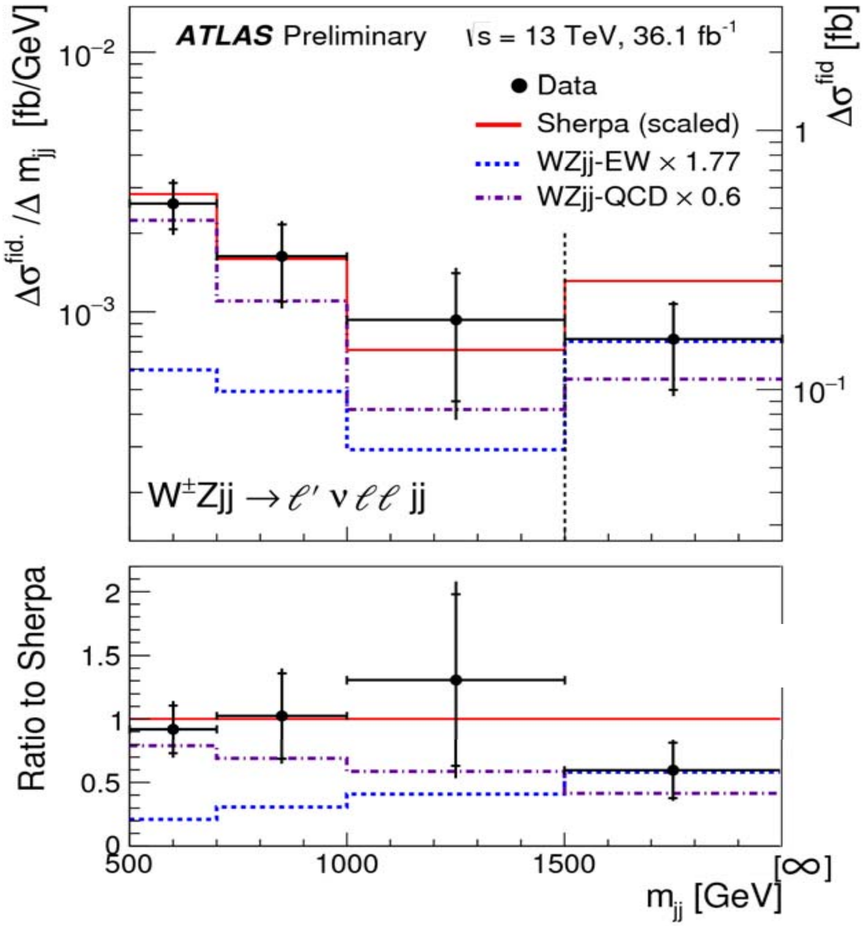
WZ and $WWjj$ production

Electroweak production of WZ boson in association with two jets pp → $W^{\pm}Z$ jet jet

Process sensitive to triple and quartic gauge couplings and anomalous couplings.



Differential EW cross-section



5.6σ (3.3σ) obs (exp)

ATLAS-CONF-2018-033

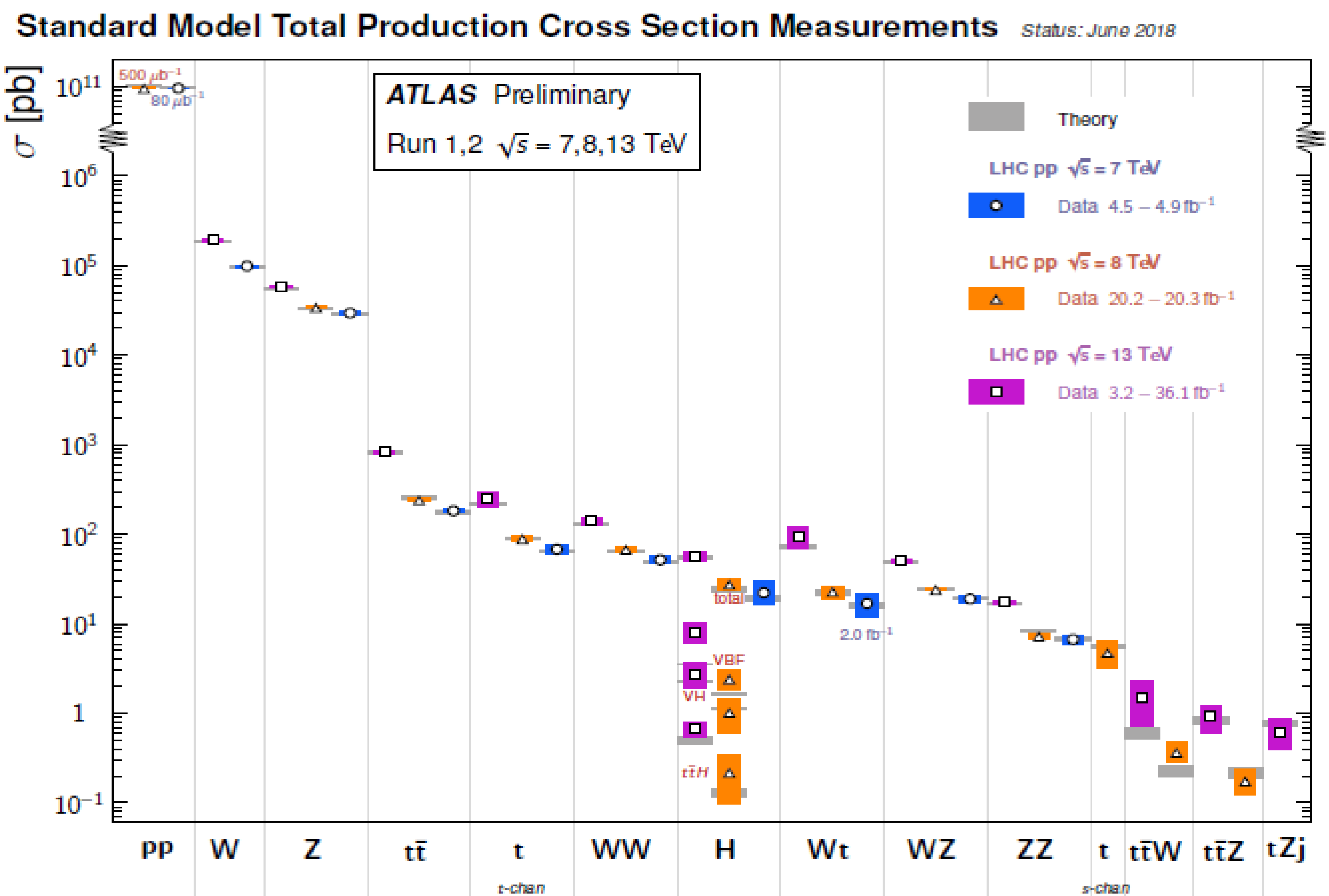
Observation of electroweak W/Z jet+jet process.

Total fiducial WZ jet jet cross section:
σ_{EW}(pp → W^{+-}Z jet jet)= 0.57 +-0.15 fb
LO (Sherpa): 0.32 +-0.03 fb

Also new results on inclusive WZ production:

- Fiducial cross-section in agreement with NNLO QCD (inclusive and differential)
- Evidence of longitudinally W polarization (4.2σ)
- Measurement of Z polarization ATLAS-CONF-2018-034

Inclusive Cross-Sections



Measurements of electroweak parameters

Measurement of electroweak mixing angle:

Drell-Yan cross-section $qq \rightarrow Z \rightarrow ll$ expanded as sum of 9 harmonic polynomials (NNLO QCD).
In LO QCD (Z-boson rest frame):

sensitive to weak mixing angle

$$\frac{d\sigma}{dy^{\ell\ell}\, dm^{\ell\ell}\, d\cos\theta} = \frac{3}{16\pi} \frac{d\sigma^{U+L}}{dy^{\ell\ell}\, dm^{\ell\ell}} \left\{(1+\cos^2\theta) + A_4 \cos\theta\right\}.$$

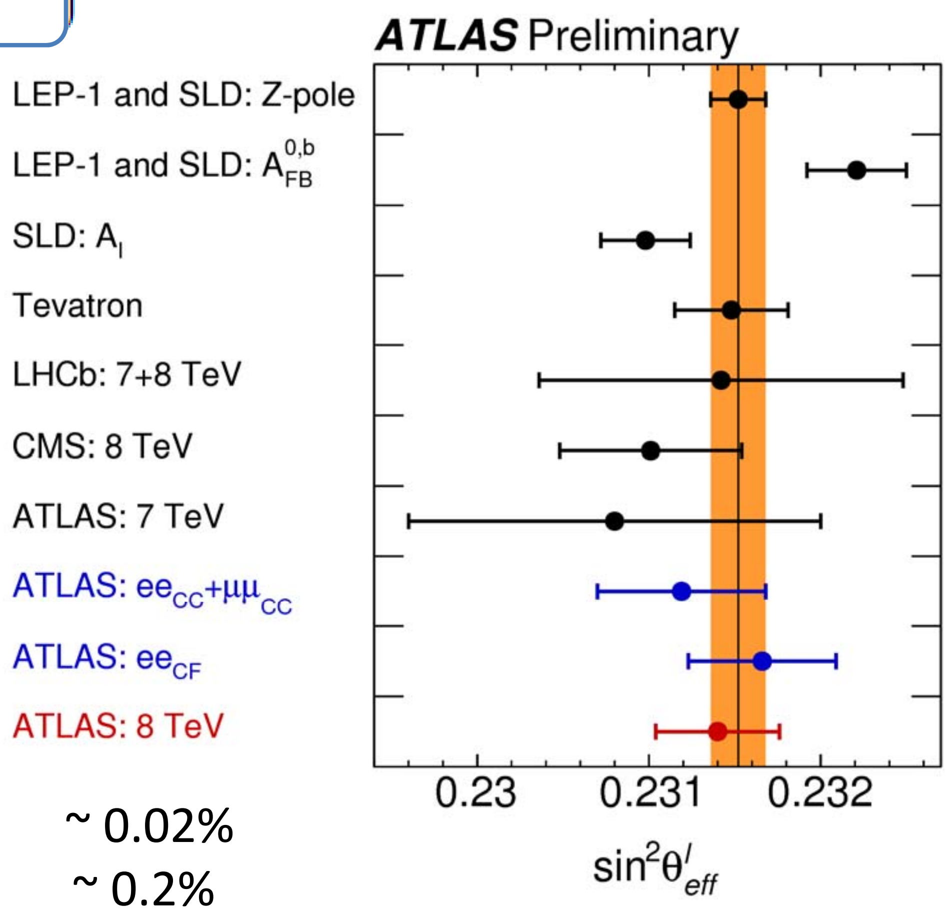
ATLAS-CONF-2018-037

A_4 measured using two leptons |η|<2.4 (cc)
and at least one forward electron 2.5<|η|<4.6 (cf).
Using 8 TeV data (2012).

$\sin^2\theta'_{eff}$=0.23140 ± 0.00036

Uncertainty break-down
0.00021 (stat) ± 0.00024 (PDF) ± 0.00016 (syst)

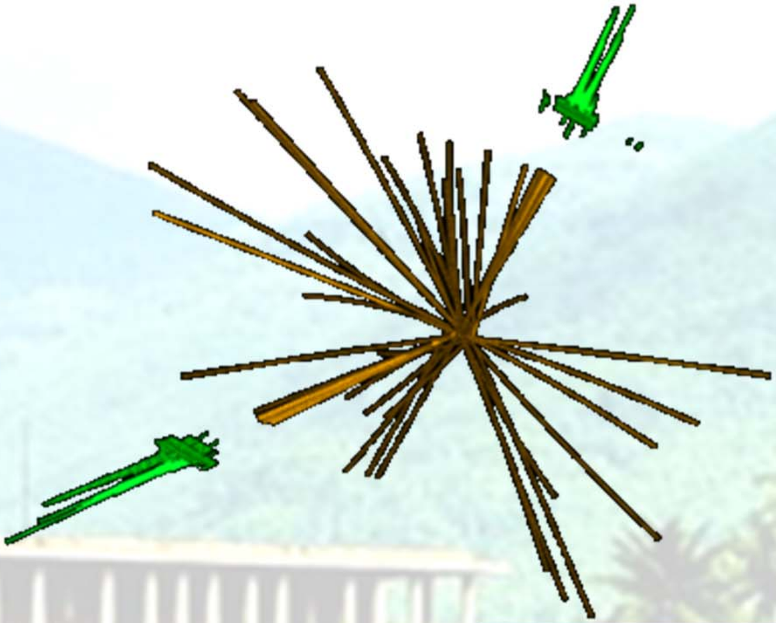
Main limitation knowledge initial quark direction



0.15% precision

Other recent electroweak measurements:

- W-mass: 80370 ± 19 MeV EPJ C78 (2018) 110 ~ 0.02%
- Higgs mass: 124970 ± 240 MeV arXiv:1806.00242 ~ 0.2%
- Top-mass: 172510 ± 500 MeV ATLAS-CONF-2017-071 ~ 0.3%

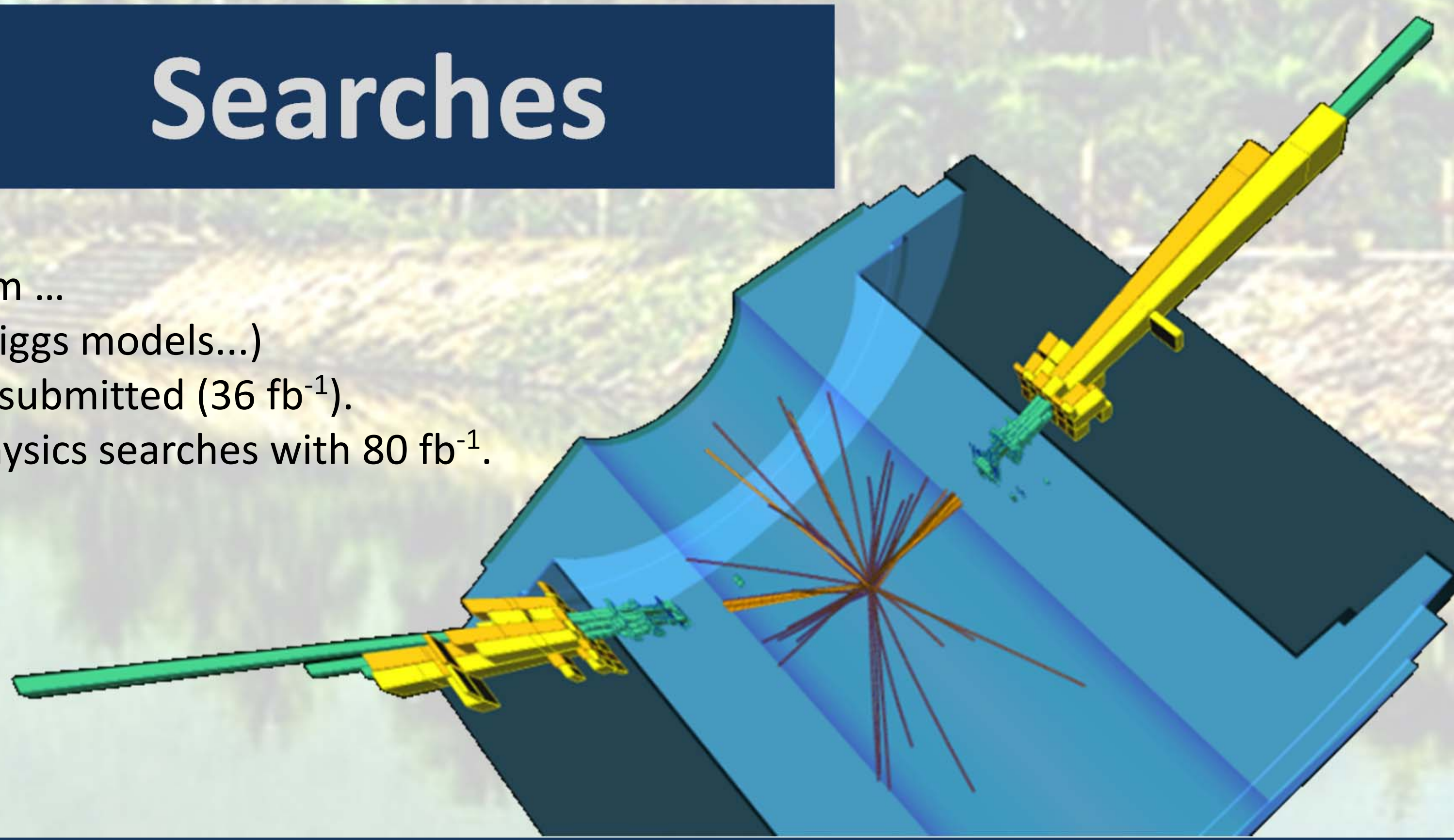


M(JJ)=5.0 TeV
Run: 307601
Event: 2054422947
2016-09-01 16:52:46 CEST

ATLAS EXPERIMENT

Searches

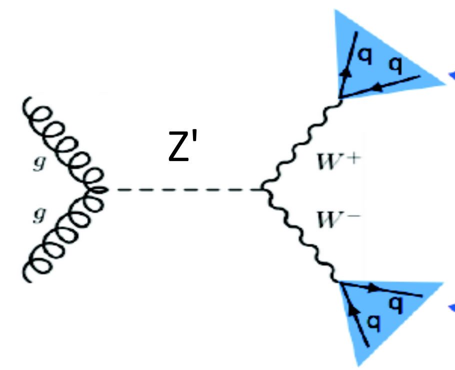
- Very active search program …
  (SUSY, dark matter, new Higgs models...)
- In total, 62 search papers submitted (36 fb^{-1}).
- 8 new preliminary new physics searches with 80 fb^{-1}.



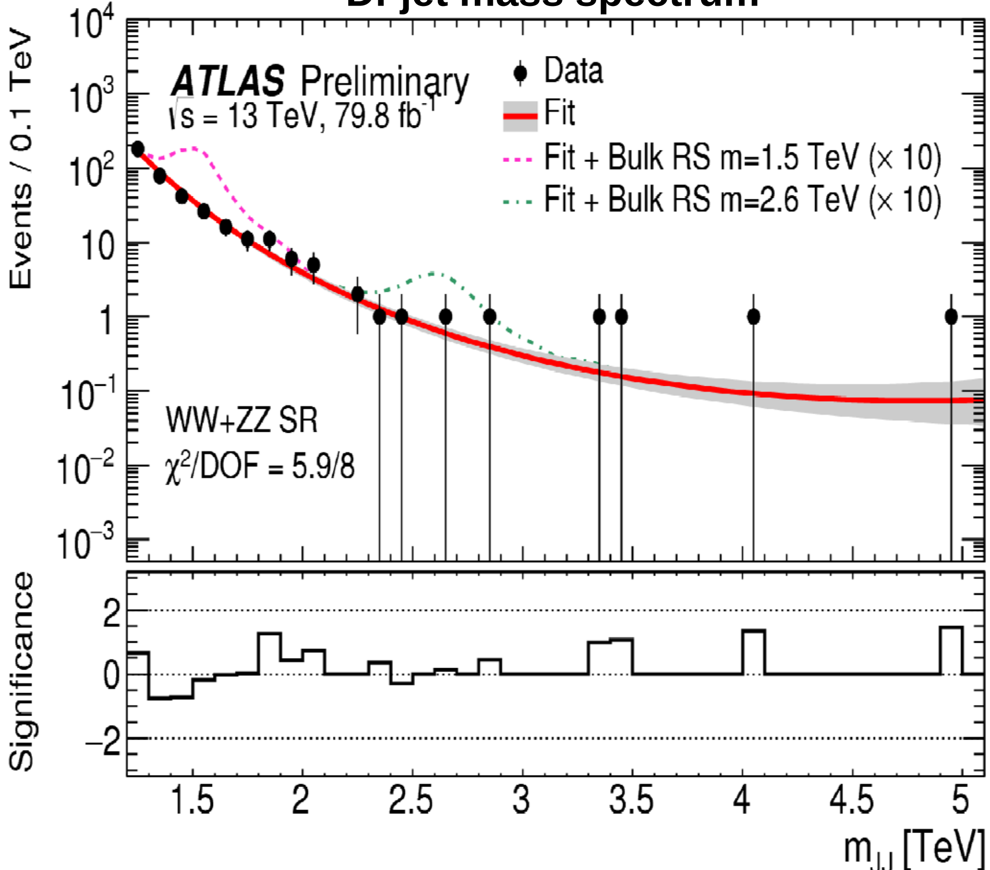
Di-boson resonance search

ATLAS-CONF-2018-016

- Select large p_t and large radius jet with boosted W-tag
- Recent improvements:
  - W and Z-boson tagging using angles from tracker and energies from calorimeter
  - Tagger working point optimization at high p_t

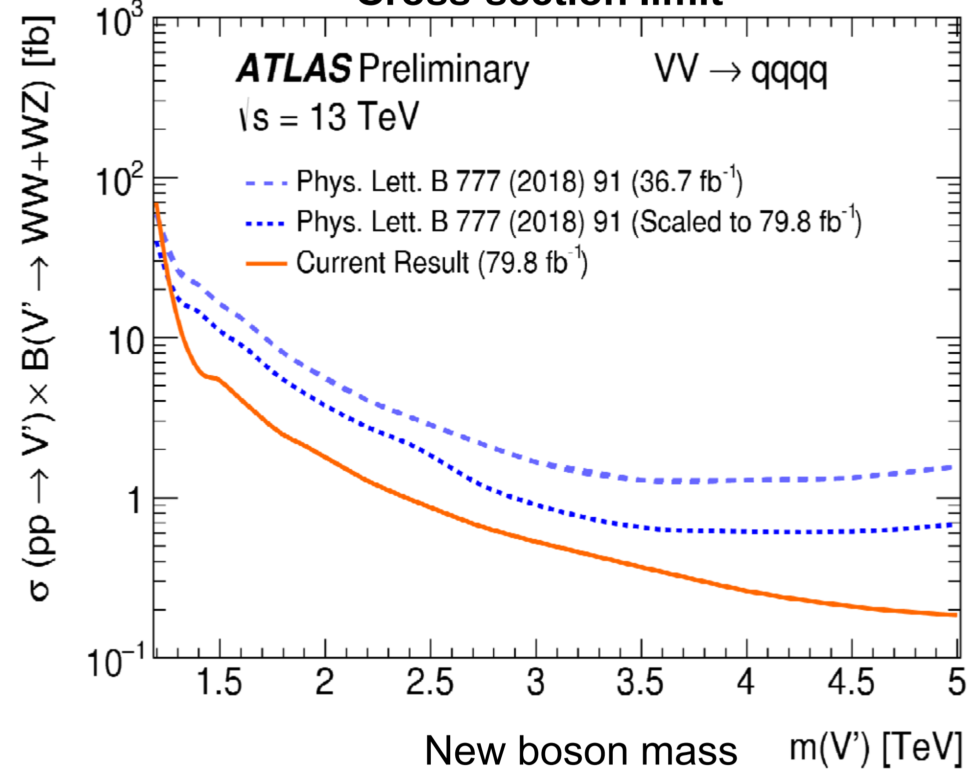


Di-jet mass spectrum



Dijet mass

Cross-section limit

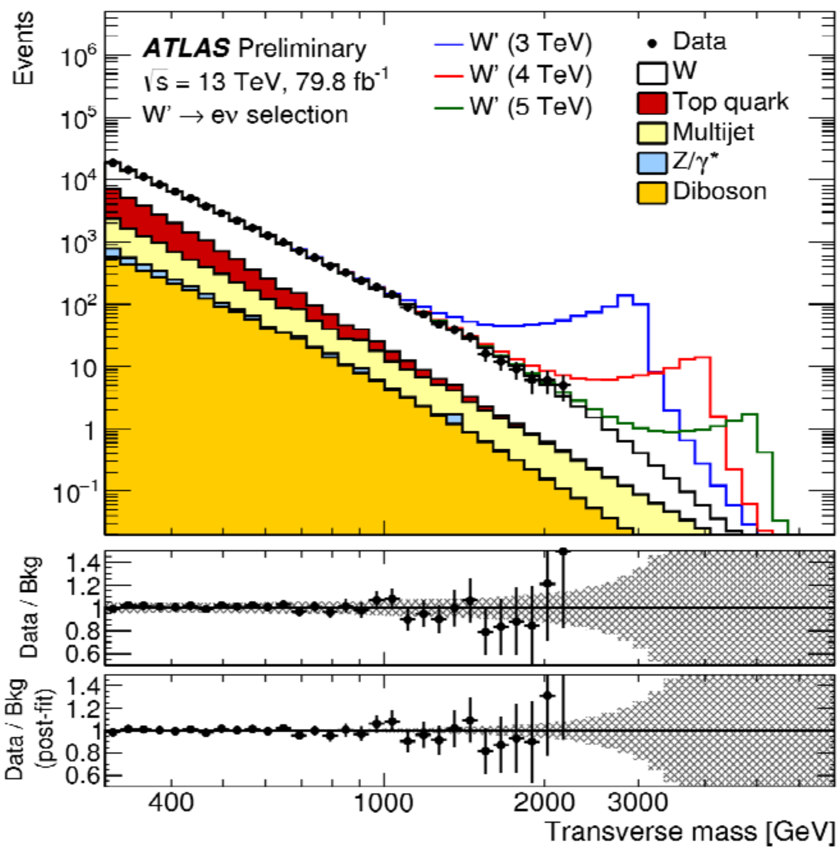


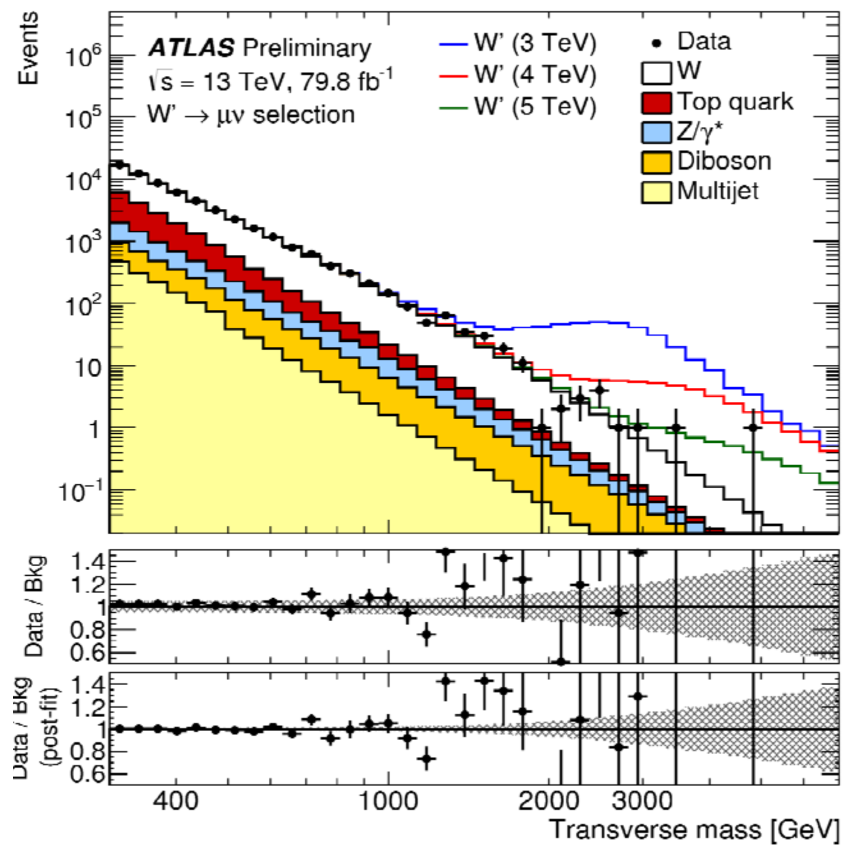
Search for new electro-weak boson

- New electro-weak gauge boson (W') decaying in context of sequential SM benchmark model.
- $W' \rightarrow e\nu$; $W' \rightarrow \mu\nu$
- Assuming SM coupling

➔ Masses below excluded at 95%CL: 5.6 TeV (80 fb^{-1})

ATLAS-CONF-2018-017





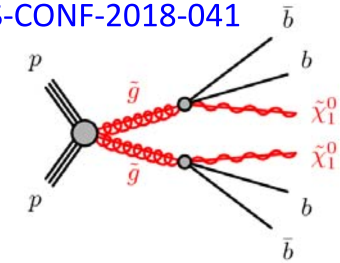
➔ Need new techniques to increase further sensitivity.

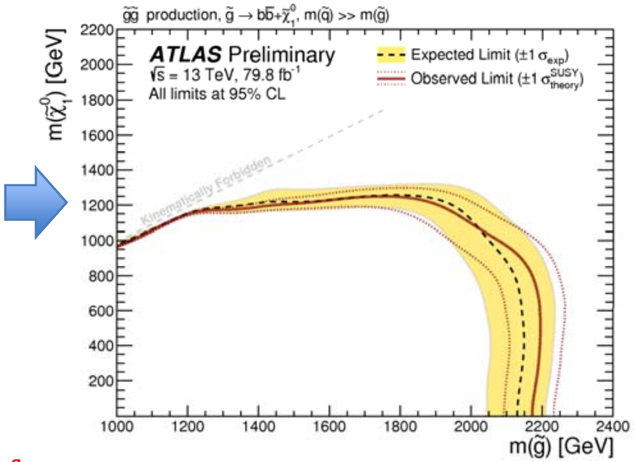
SUSY & Dark Matter

July 2018 – 4 new results based on 80 fb^{-1}

- gluino, multi-b search
  - New update w.r.t. JHEP06(2018)107 with 2017 data. Earlier 2.4 sigma deviations disappeared.
  - New limits on the $m(\tilde{g}) > 2$ TeV at 95% C.L.
- chargino decaying via W-bosons
  - New limits $m(\tilde{\chi}_1^{\pm}) > 410$ GeV 95% CL.
- bottom-squark pair production in final states Higgs
  - Seletion ≥ 6 jets > 4 b jet, no leptons, E_T^{miss}> 250 GeV
  - Use Higgs mass tagging using two b jets
  - bottom-squarks with mass below 1400 GeV are excluded at 95% C.L.
- Search for H+E_T^{miss} signature in bb decay channel.
  - Direct interaction of Higgs with DM sector.
  - New limits on M_A

ATLAS-CONF-2018-041





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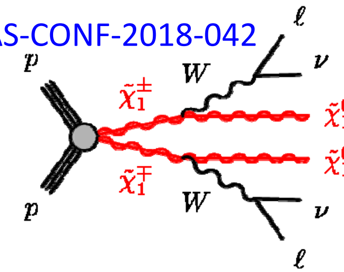

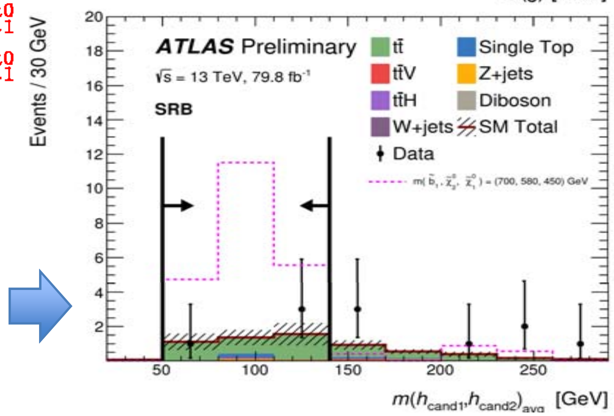

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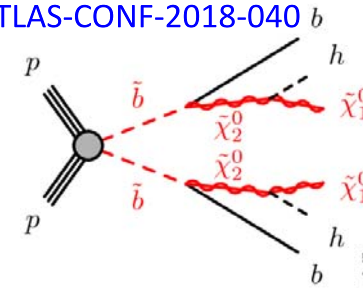

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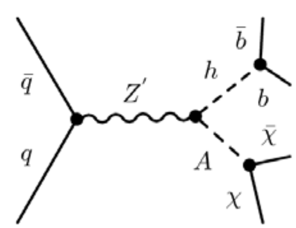
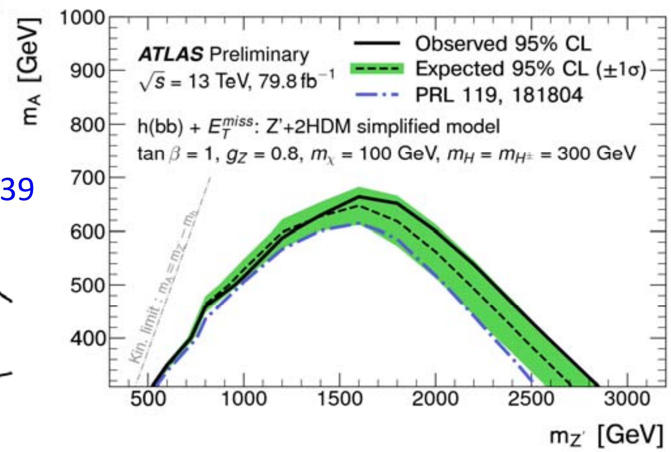
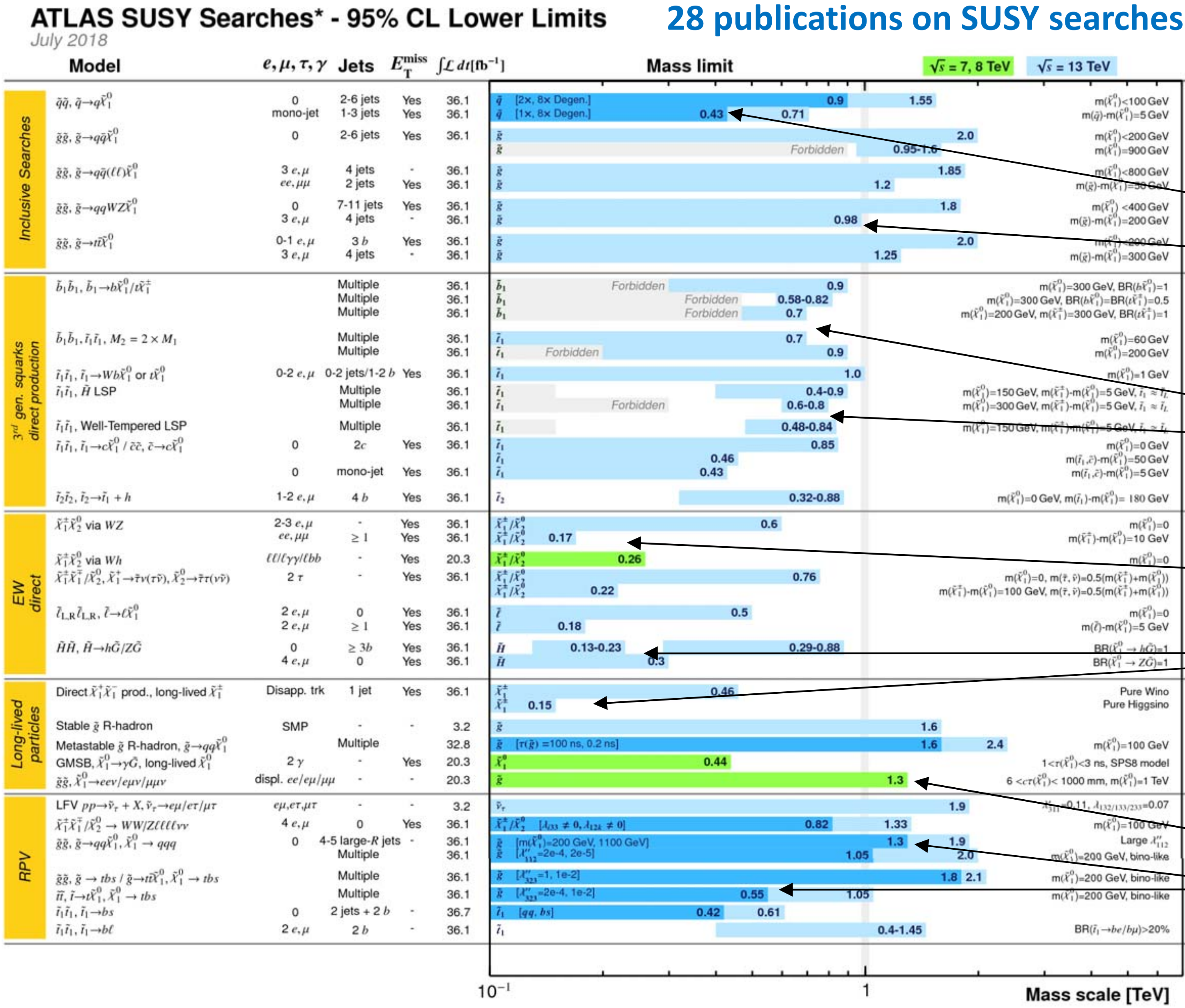




SUSY Searches



28 publications on SUSY searches with 2015-2016 data (36 fb^{-1}).

Compressed spectrum squark degeneracy:
squarks O(500 GeV)
gluinos O(1 TeV)

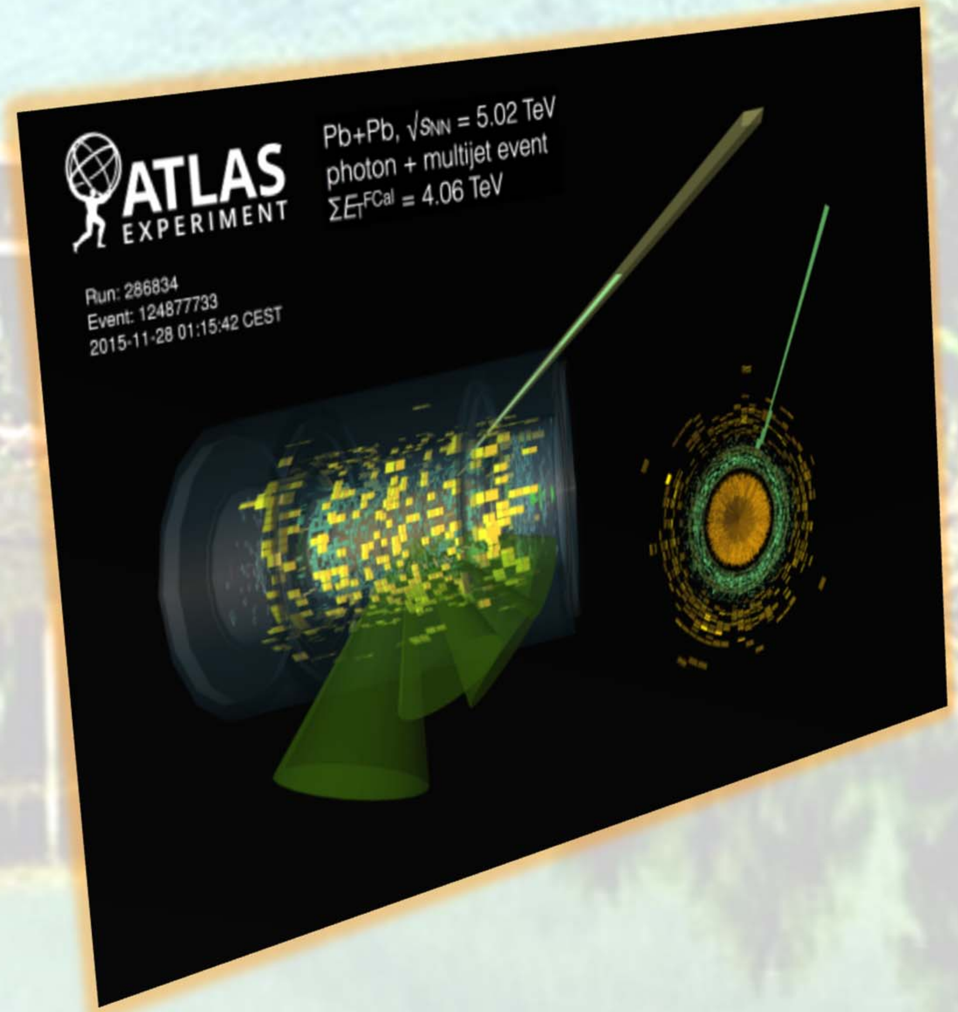
Longer decay chain more realistic models:
sbottom O(700 GeV)
stop O(700 GeV)

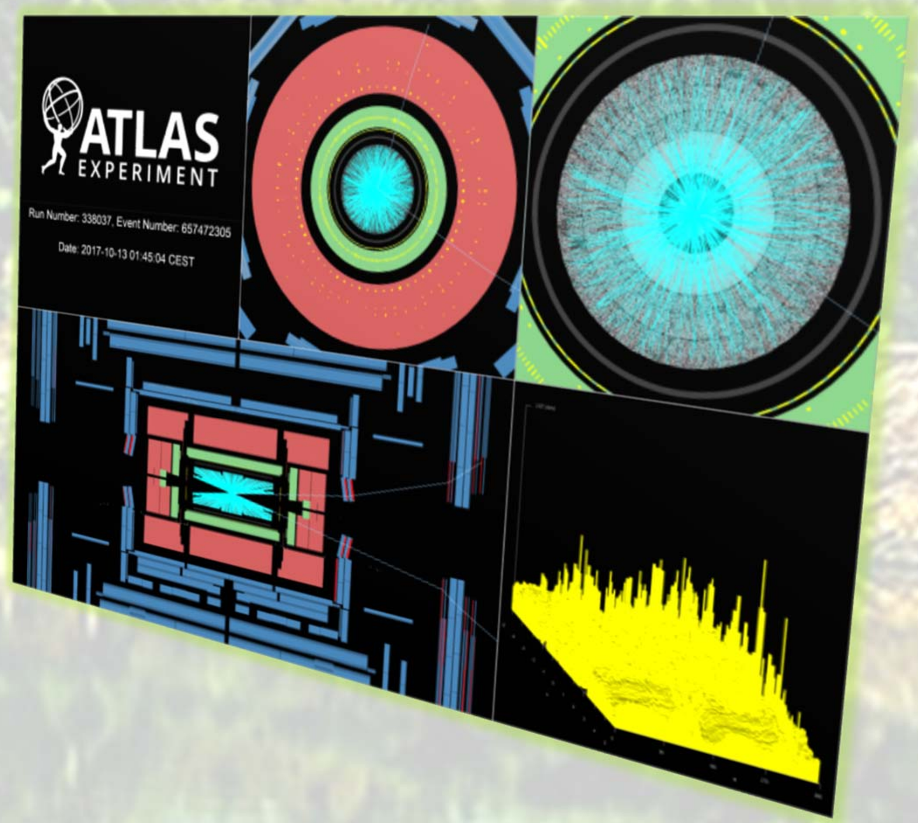
Low rate, compressed:
winos O(~100 GeV)
sleptons O(~100 GeV)
higgsino O(~100 GeV)

Complexity, long-lived:
gluinos O(1 TeV)
stop O(500 GeV)

Simplified signatures covered to high masses, but plenty of low mass unexplored model space.

Heavy Ions


ATLAS
EXPERIMENT
Pb+Pb, √sNN = 5.02 TeV
photon + multijet event
ΣET^FCal = 4.06 TeV
Run: 286834
Event: 124877733
2015-11-28 01:15:42 CEST

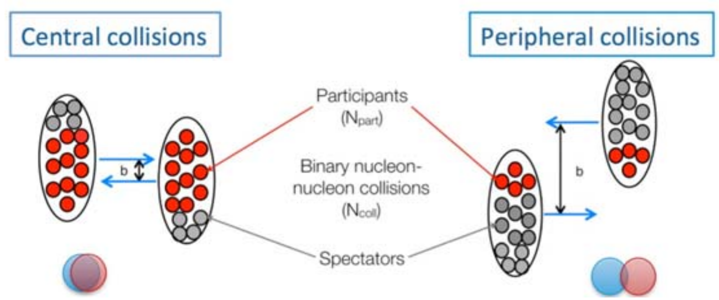

ATLAS
EXPERIMENT
Run Number: 338037, Event Number: 657472305
Date: 2017-10-13 01:45:04 CEST

Heavy Ions: not only Pb-Pb

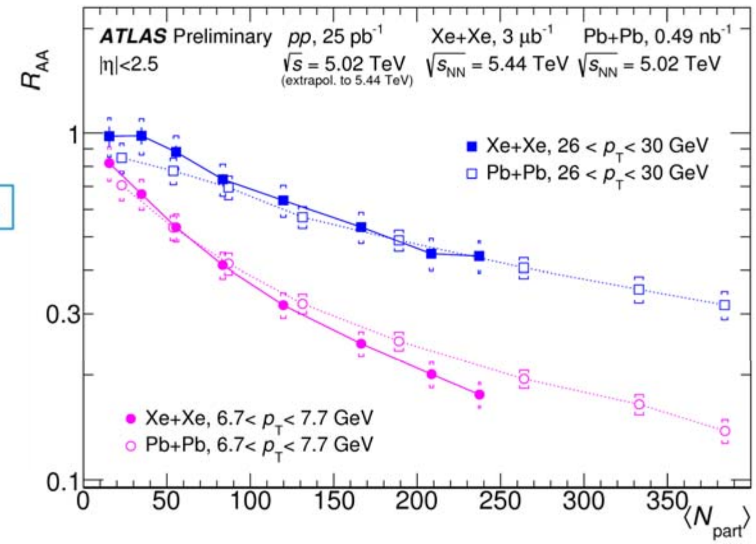
Available data sets:

- Xe+Xe data:
  - 2017, $\sqrt{s_{NN}} = 5.44$ TeV
  - $3\ \mu b^{-1}$
- Pb+Pb data:
  - 2015, $\sqrt{s_{NN}} = 5.02$ TeV
  - $0.49\ nb^{-1}$
- *pp* data:
  - 2015, $\sqrt{s} = 5.02$ TeV
  - $25.0\ pb^{-1}$

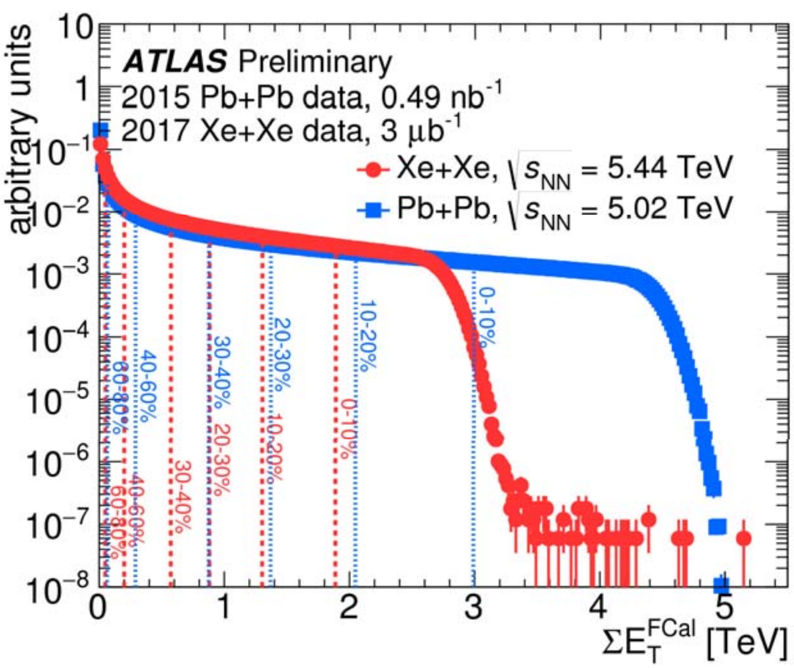
← One fill in 2017



ATLAS-CONF-2018-007

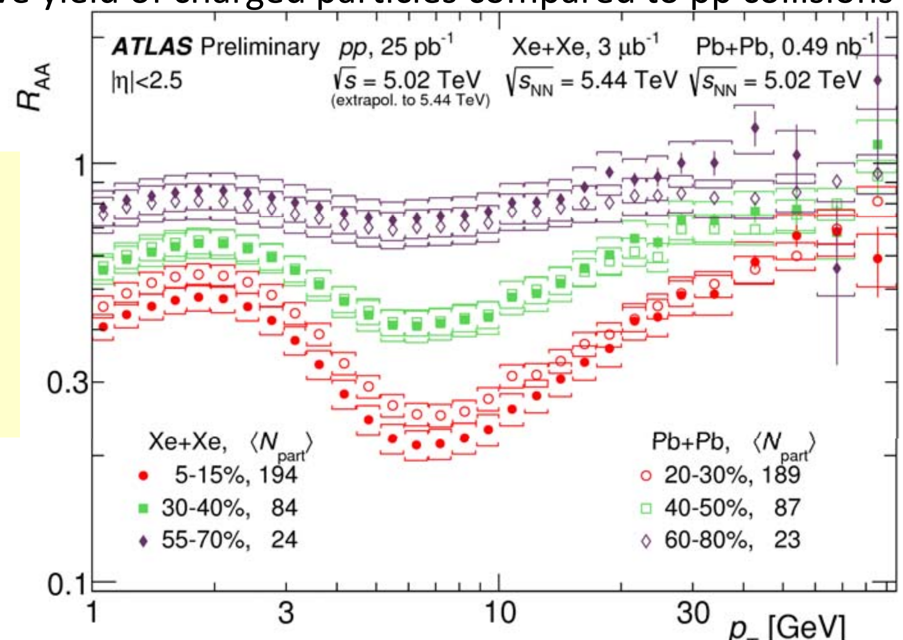


R_{AA} relative yield of charged particles compared to pp collisions



ATLAS:

- $p_T > 0.1$ GeV;
- $|\eta| < 2.5$;
- full ϕ coverage

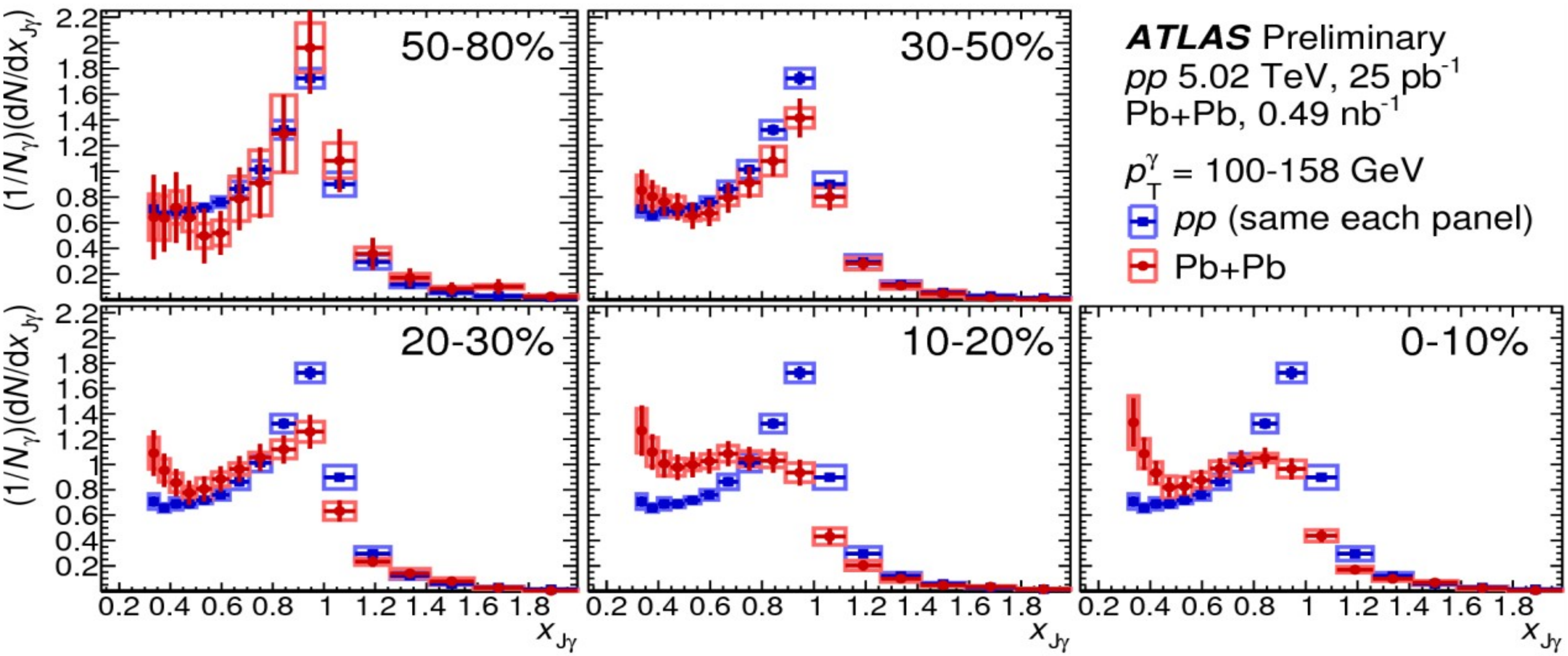


→ Similar R_{AA} distributions for events with same N_{part}

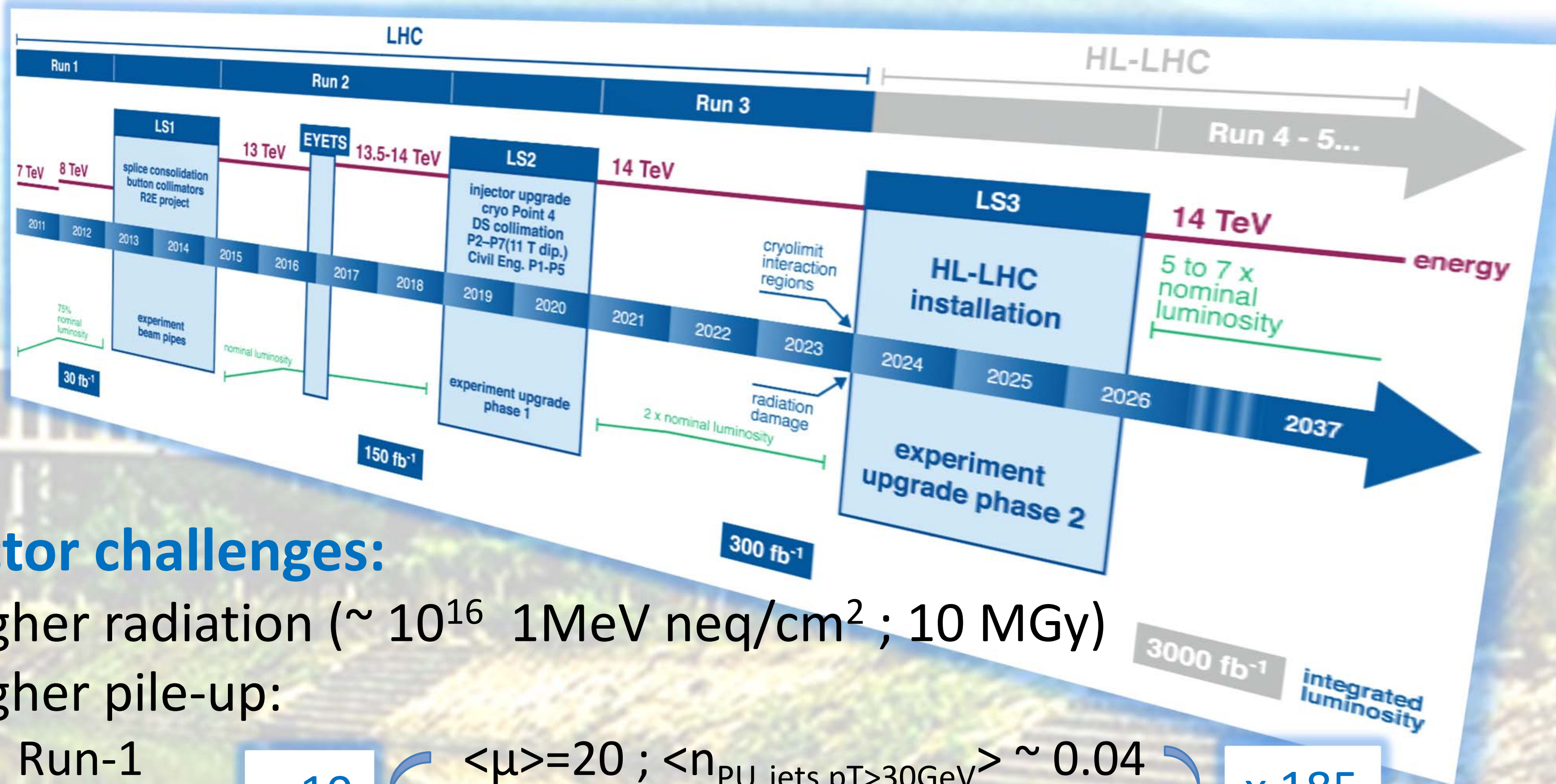
Heavy Ions: photon-jet correlations

- Photon-jet correlations:
  - To control over initial jet kinematics to see energy loss in jets
  - $x_{j\gamma}$ the transverse momentum balance between γ and jet $x_{j\gamma} = \frac{p_T^{jet}}{p_T^{\gamma}}$
- For Pb+Pb collisions, the $x_{j\gamma}$ distribution is modified with increasing centrality, consistent with the picture of parton-energy loss in the hot nuclear medium.

ATLAS-CONF-2018-009

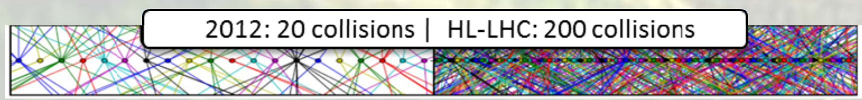


Upgrade Plans



- **Detector challenges:**
  - Higher radiation (~ 10^{16} 1MeV neq/cm^2 ; 10 MGy)
  - Higher pile-up:
    - Run-1 — $\langle\mu\rangle$=20 ; $\langle n_{PU\ jets\ pT>30GeV}\rangle$ ~ 0.04
    - HL-LHC — $\langle\mu\rangle$=200 ; $\langle n_{PU\ jets\ pT>30GeV}\rangle$ ~ 7.4

x 10 — x 185

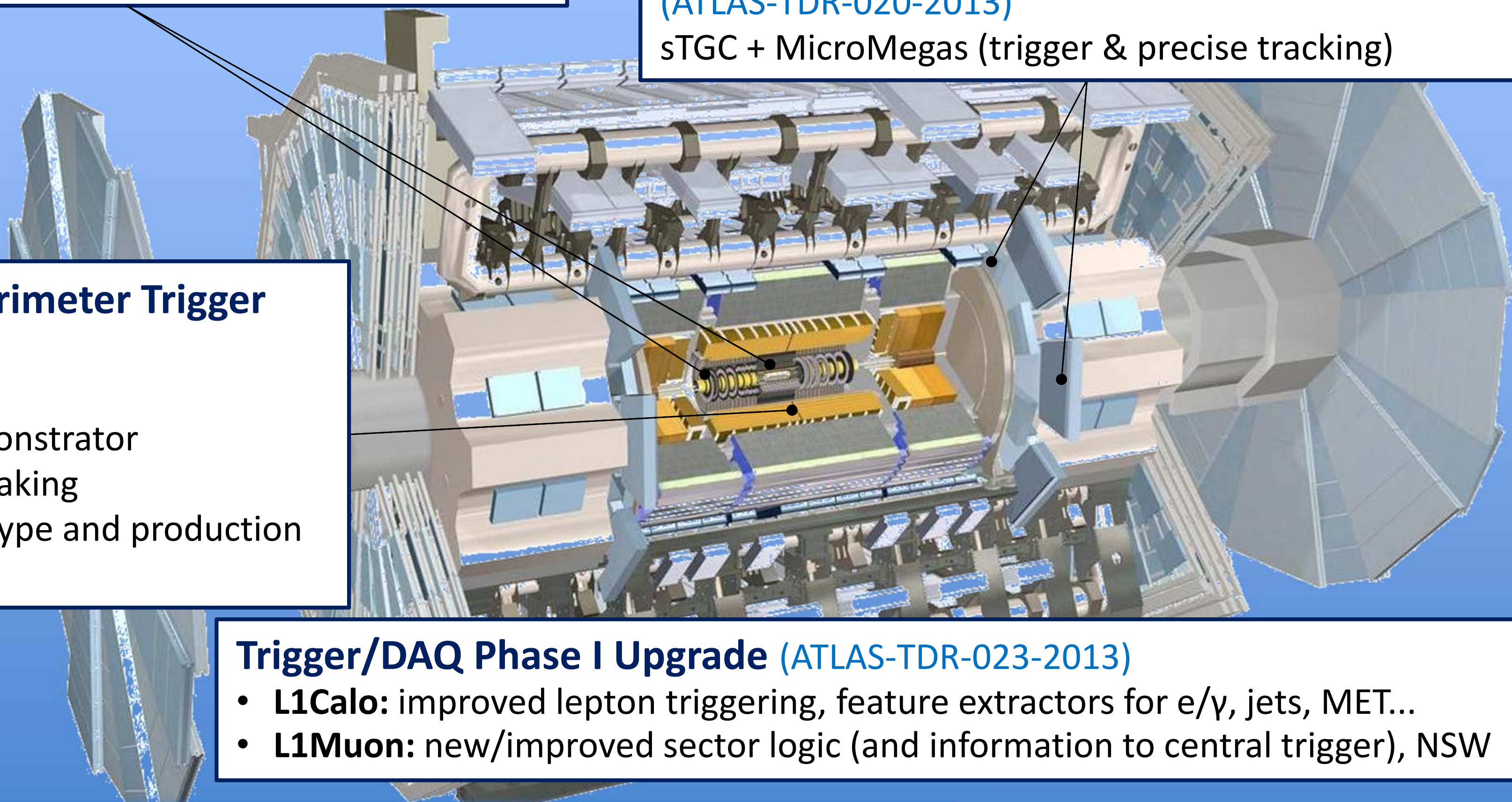


- **Upgrade goal:**
  - Keep performance (tracking, b-tag, jet/E_T^{miss}, ...)
  - Trigger rates acceptable with low P_T thresholds
  - Pile-up mitigation up to large η is needed

ATLAS Phase I Upgrades (2019-2020)

Fast Track Trigger (FTK) (ATLAS-TDR-021-2013)
HW based tracking of Si-tracking layers at "Level 1.5"
Commissioning ongoing in Run-2

Muons: New Small Wheel (NSW)
(ATLAS-TDR-020-2013)
sTGC + MicroMegas (trigger & precise tracking)



High Granular L1 Calorimeter Trigger
(ATLAS-TDR-022-2013)
Status/Plans:
- 2014: Installed FE demonstrator
- 2015: Successful data taking
- On-going: FE-BE prototype and production
- 2019: Installation

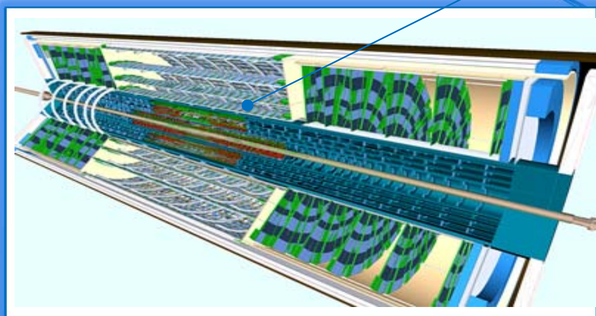
Trigger/DAQ Phase I Upgrade (ATLAS-TDR-023-2013)
- **L1Calo:** improved lepton triggering, feature extractors for e/γ, jets, MET...
- **L1Muon:** new/improved sector logic (and information to central trigger), NSW

Main Target:

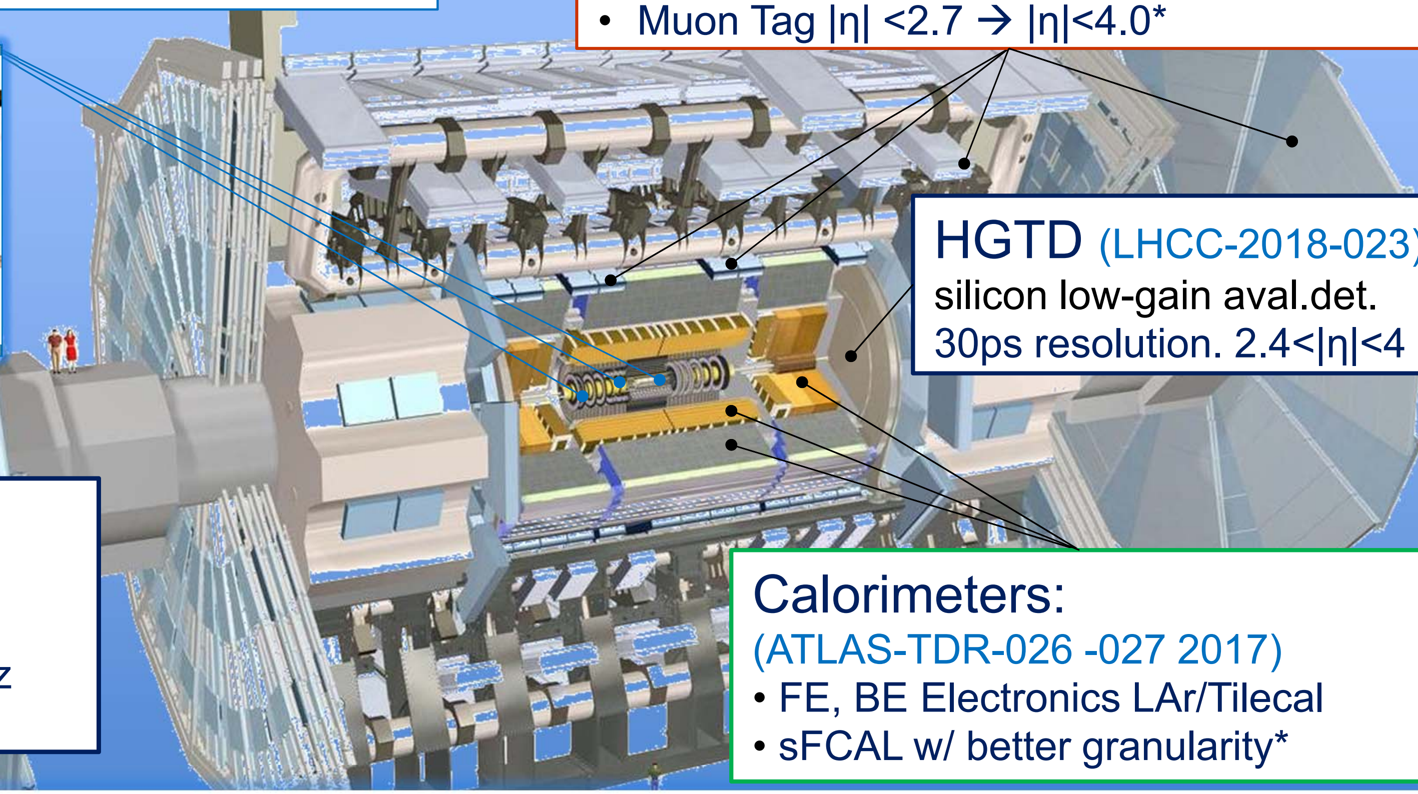
- Better trigger capabilities (efficiency, fake rejection)
- Maintain same acceptance/p_T thresholds with higher pileup.

ATLAS Phase II Upgrades (2024-2026→ HL-LHC)

ITK Inner Tracker: (ATLAS-TDR-025 -030 2017)
- Pixel + Strip
- |η| <2.7 → |η|<4.0*



Muons: (ATLAS-TDR-026 2017)
- Inner Barrel Layer (thin-gap RPC + μMDT)
- New electronics
- Muon Tag |η| <2.7 → |η|<4.0*



HGTD (LHCC-2018-023)
silicon low-gain aval.det.
30ps resolution. 2.4<|η|<4

Trigger & DAQ
(ATLAS-TDR-029 2017)
- L0 (Calo+Muon): 1 MHz
- L1 (Calo+Muon+ITK): 400 KHz
- HLT/EF: 10 KHz

Calorimeters:
(ATLAS-TDR-026 -027 2017)
- FE, BE Electronics LAr/Tilecal
- sFCAL w/ better granularity*

Path and Status:

- Phase II Letter of Interest CERN-LHCC-2012-022 + Scoping document CERN-LHCC-2015-020 (Impact of different cost scenarios on physics/performance)
- **6 Technical Design Reports released**
- **1 Technical proposal (High Granularity Timing Detector)**

Conclusions

- The LHC has gone beyond its design and is now in full production phase
- ATLAS detector and trigger system working very well
  - ATLAS coping well with pileup levels approaching twice design
- Wealth of measurements already from 13 TeV data
  - A more refined picture of the Higgs:
    - All main Higgs decays ($H \to bb$) are now observed.
    - Direct observation of Higgs coupling to top quark (via ttH).
    - Yukawa coupling to fermions established (ttH, $H \to bb$, $H \to \tau\tau$)
  - … and much more
- Extensive and active search program for full run-2 (>150 fb^{-1} achievable).
- Moreover an intense program of upgrade will allow ATLAS to run at its best as LHC and HL-LHC will deliver up to 3000 fb^{-1} of luminosity
- Huge thanks to the LHC and injector teams for the excellent performance

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More results in the several ATLAS and ATLAS+CMS talks in the coming days

Thank You!