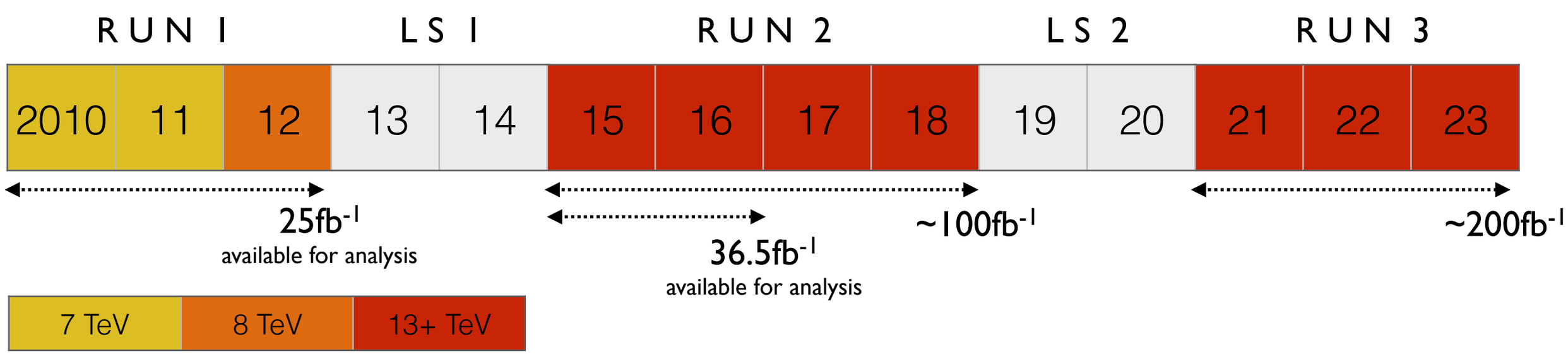
ATLAS Status Report
129th LHCC - Open Session

James Catmore (University of Oslo, Norway)
on behalf of the ATLAS Collaboration

Overview and Themes

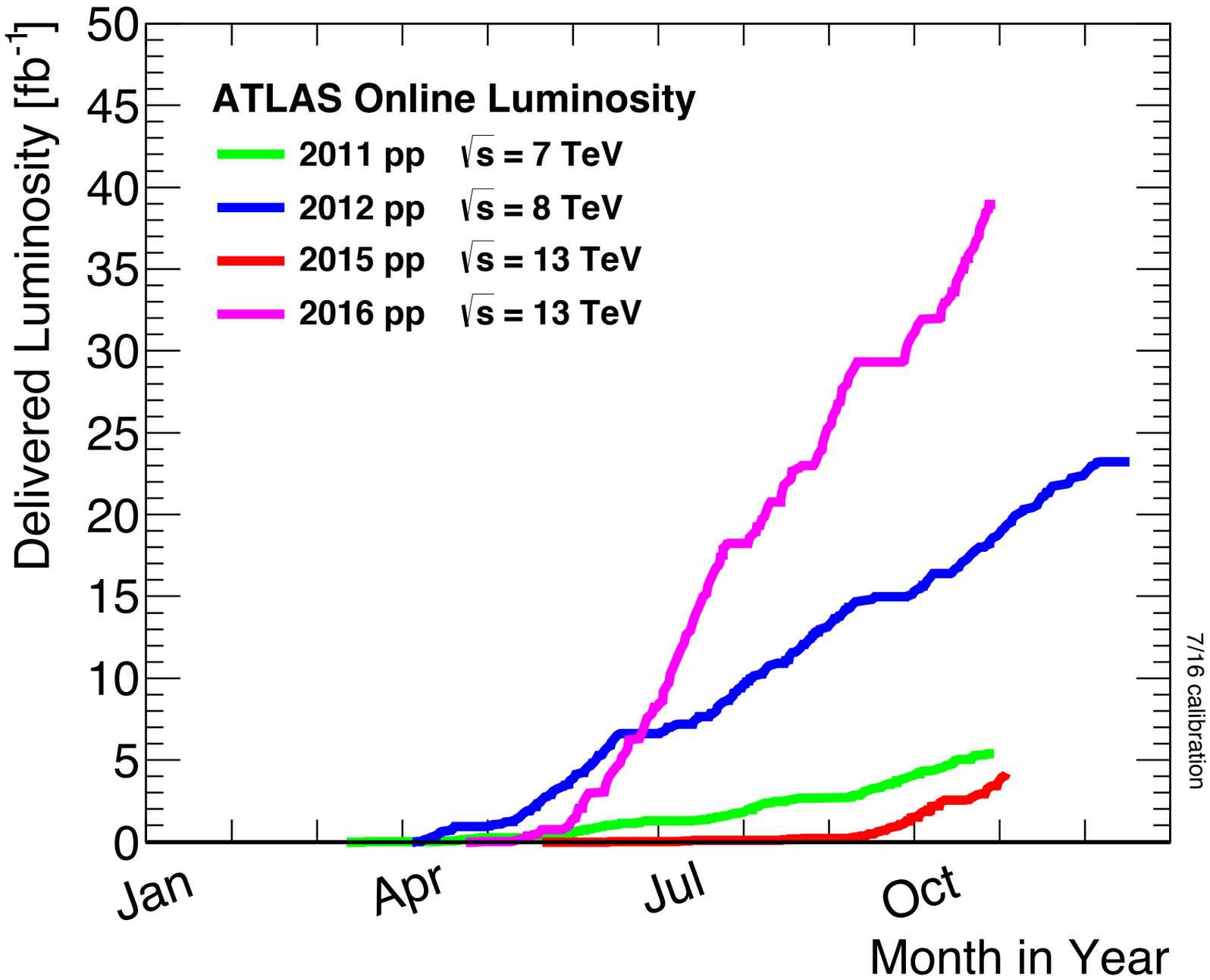
- Looking back at the 2016 data taking
- Recent physics highlights: deepening our understanding of Nature with precise measurements
  - W mass, W and Z production, W polarisation, isolated photon production
  - Heavy ion collision measurements
- Preparing for 2017 and beyond
  - Activities during the shutdown, software & computing, trigger, upgrade
- Many new results from searches for New Physics expected at the Winter Conferences



Looking back on 2016

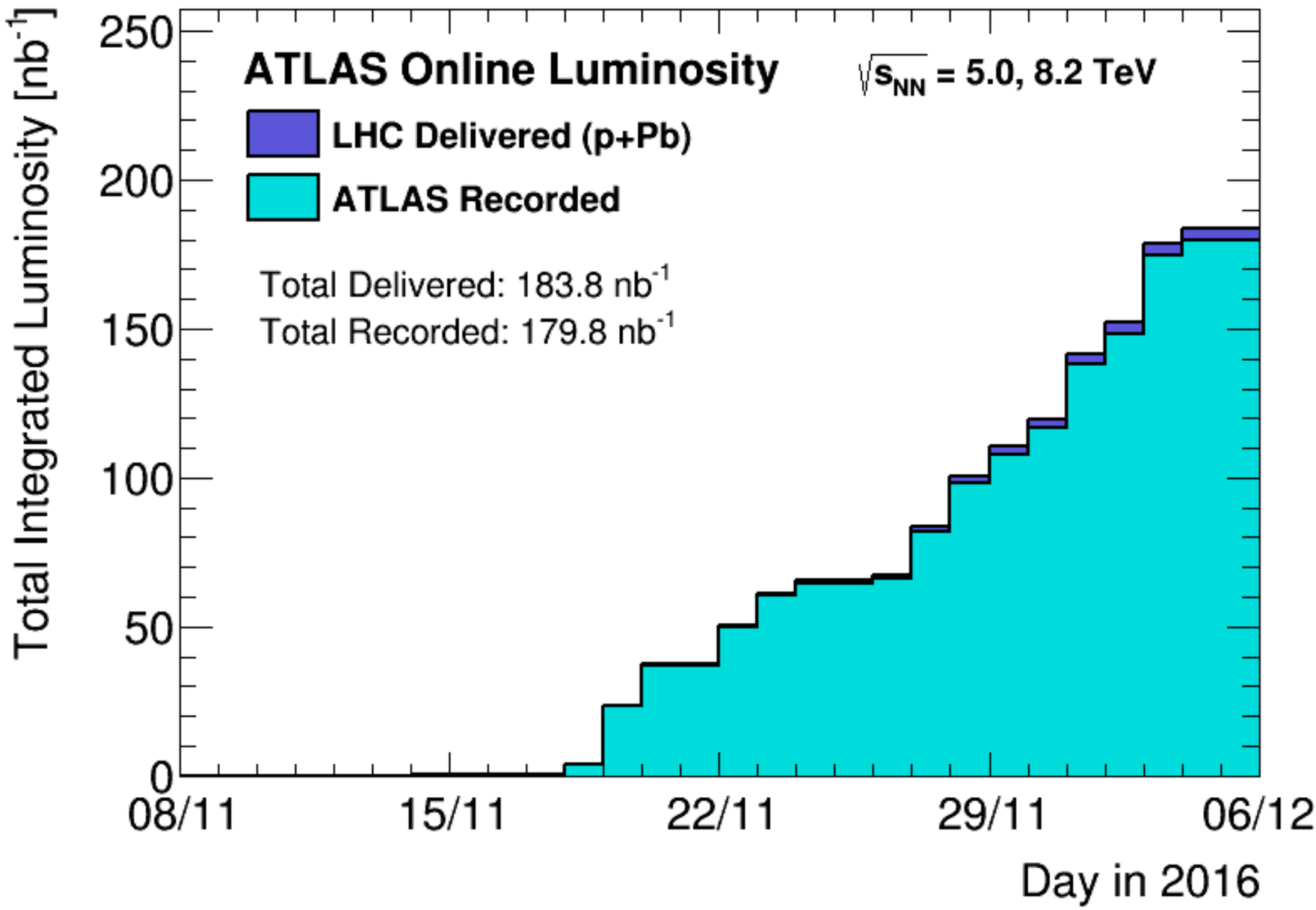
Looking back: proton data taking in 2016

- *Magnificent* LHC performance thanks to the dedication and brilliance of the people running the accelerator complex, cryogenics, electrical systems, safety, network & technical support, here at CERN
- Excellent data taking campaign for ATLAS in 2016
  - $33.3 fb^{-1}$ proton-proton data available for physics analysis, more than all previous years combined
  - Data taking efficiency 92.4%



Looking back: lead-proton data taking in 2016

- Highly successful campaign in November/ December
- Two energy points: 5 and 8 TeV
- Clockwise and anticlockwise beams used for both nuclei and protons
- Requested 100nb^{-1}, recorded 180nb^{-1}!



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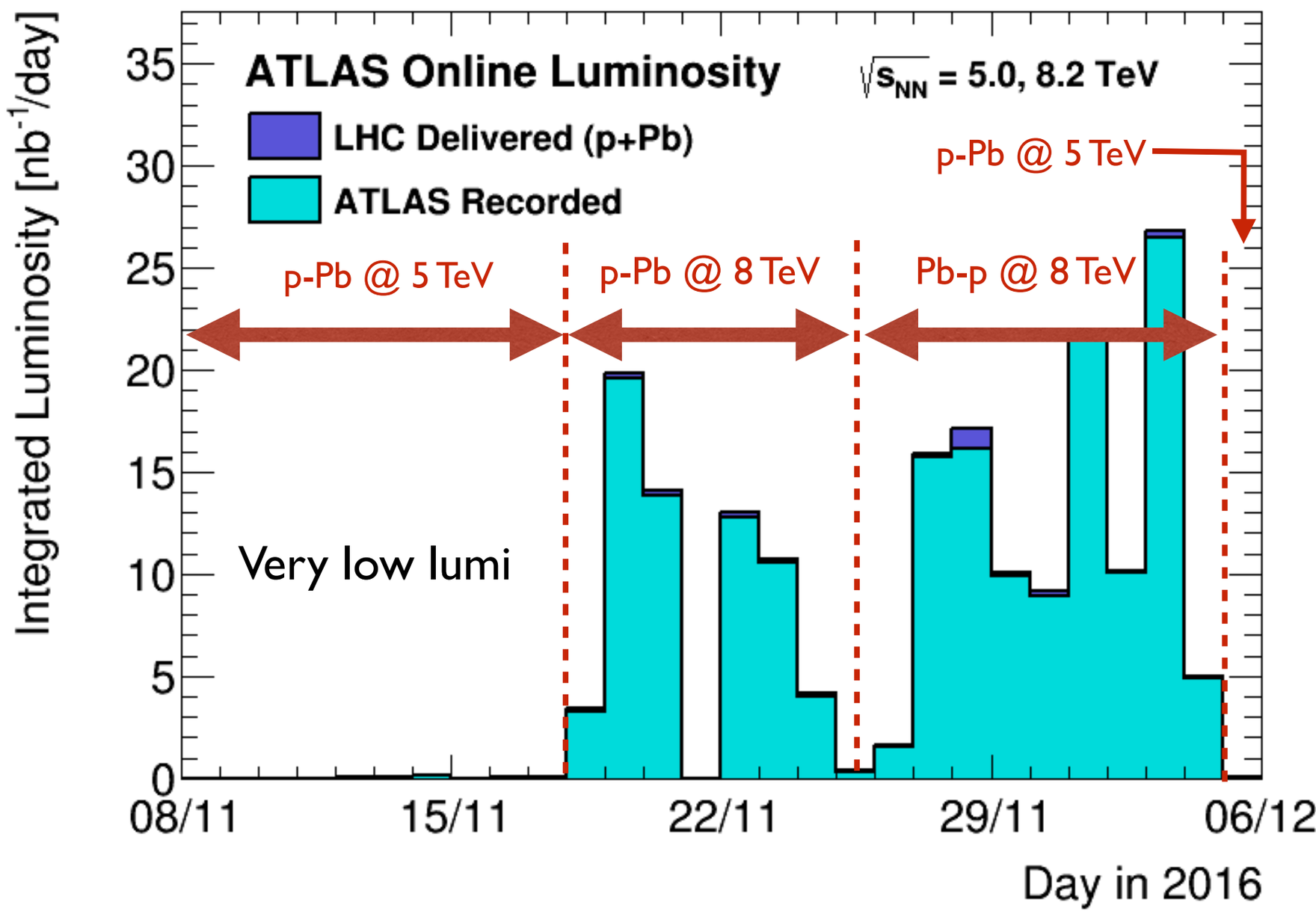
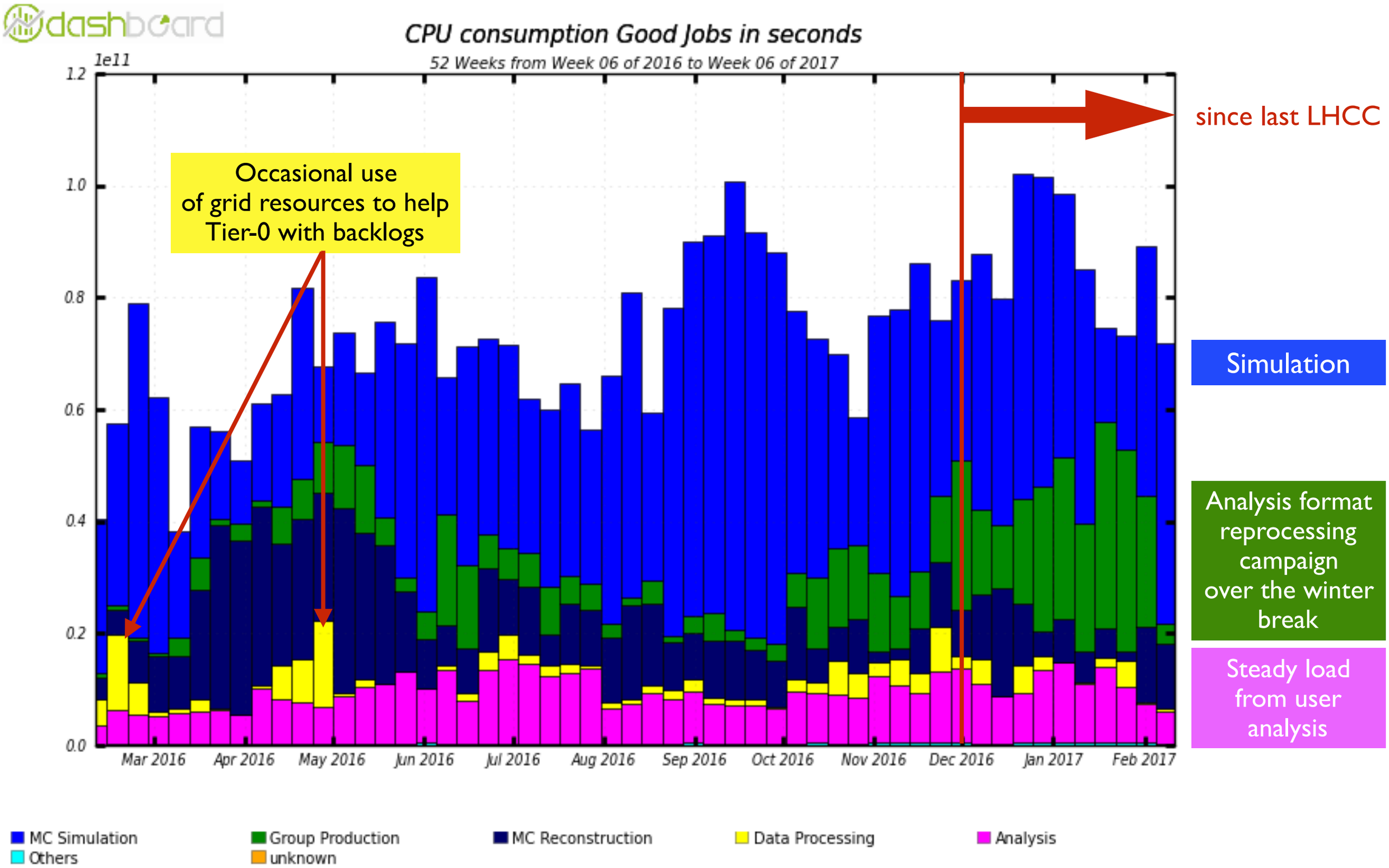
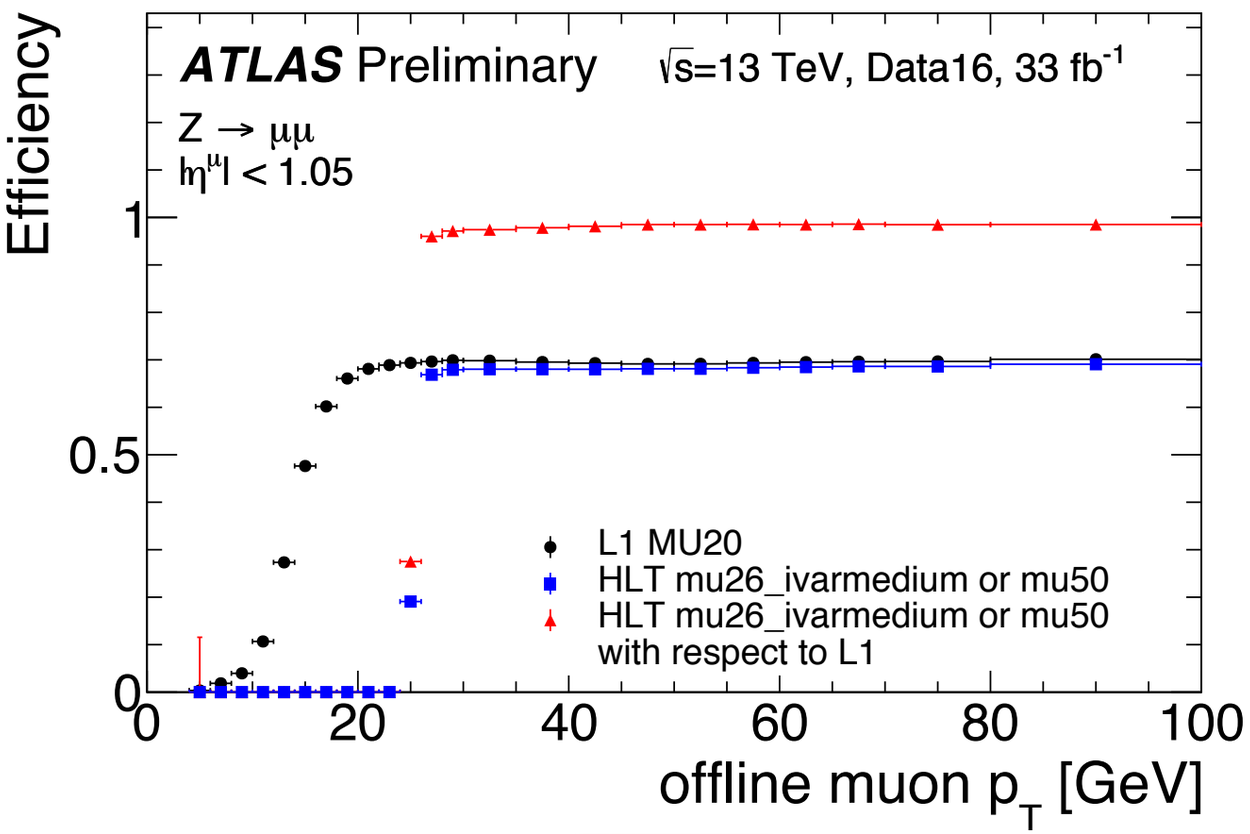


Looking back: grid computing in 2016

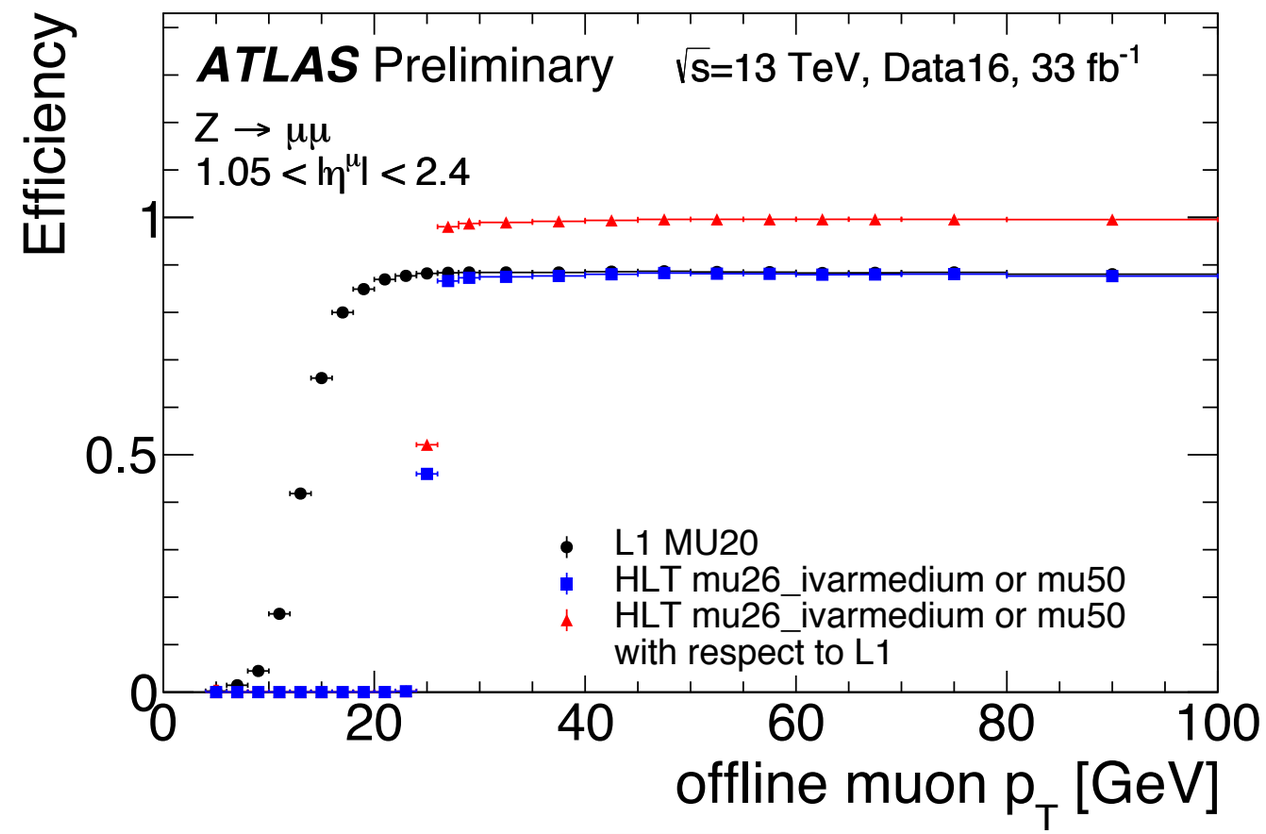


Looking back: 2016 muon trigger efficiency

Precise determination of the trigger turn-on curves;
highly efficient HLT, stable with p_T



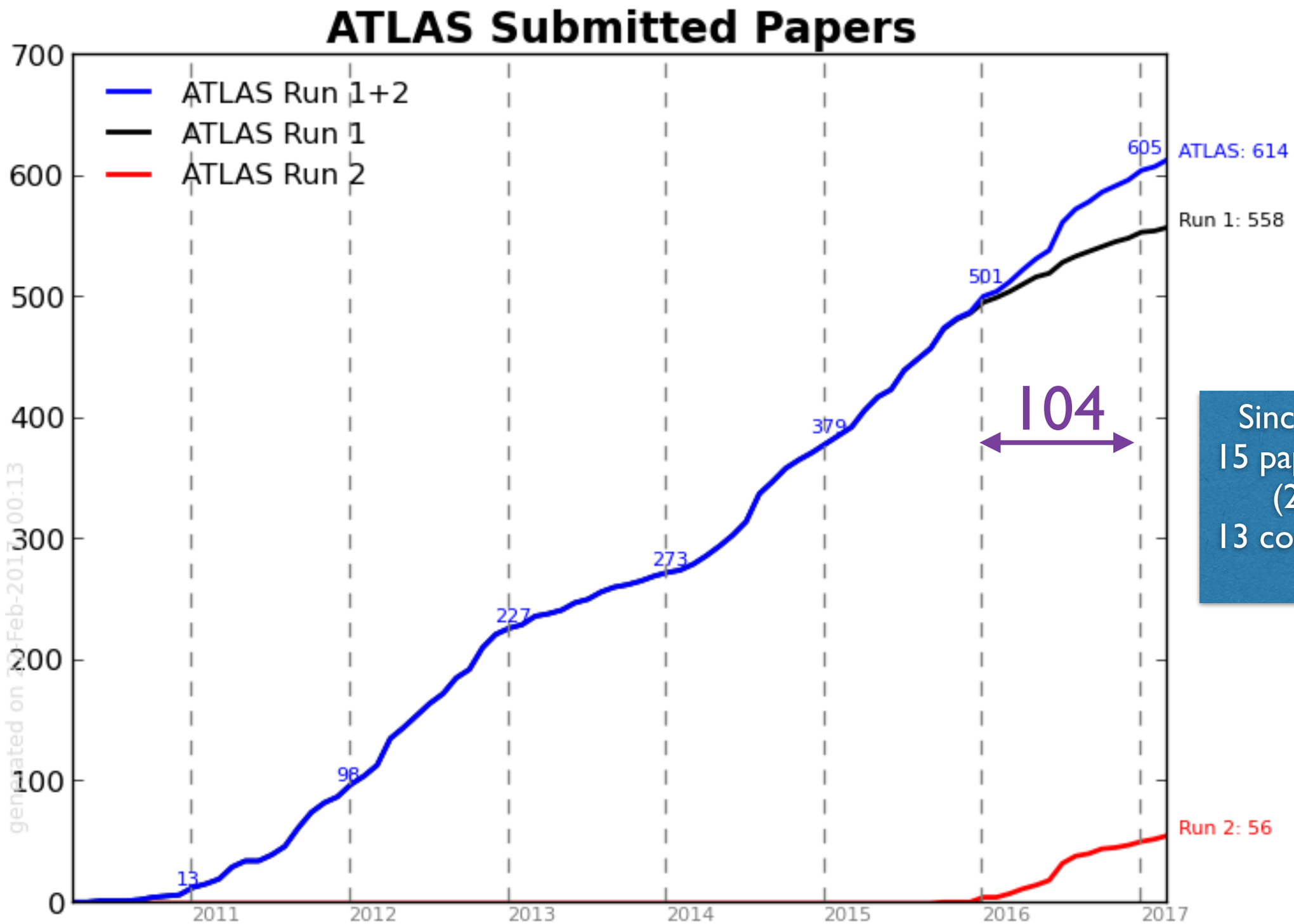
Barrel



Endcaps

Physics Highlights since the last LHCC

Publications from collision data: statistics



Since last LHCC:
15 papers submitted
(2 accepted)
13 conference notes
released

Publications from collision data: highlights

- Tests of the Standard Model through precise measurements of
  - High-precision studies of W and Z production
  - An eagerly awaited and essential measurement: the W mass
  - W polarisation in ttbar events
  - Production of isolated photons
- Many new Heavy Ion results (presented at Quark Matter two weeks ago)

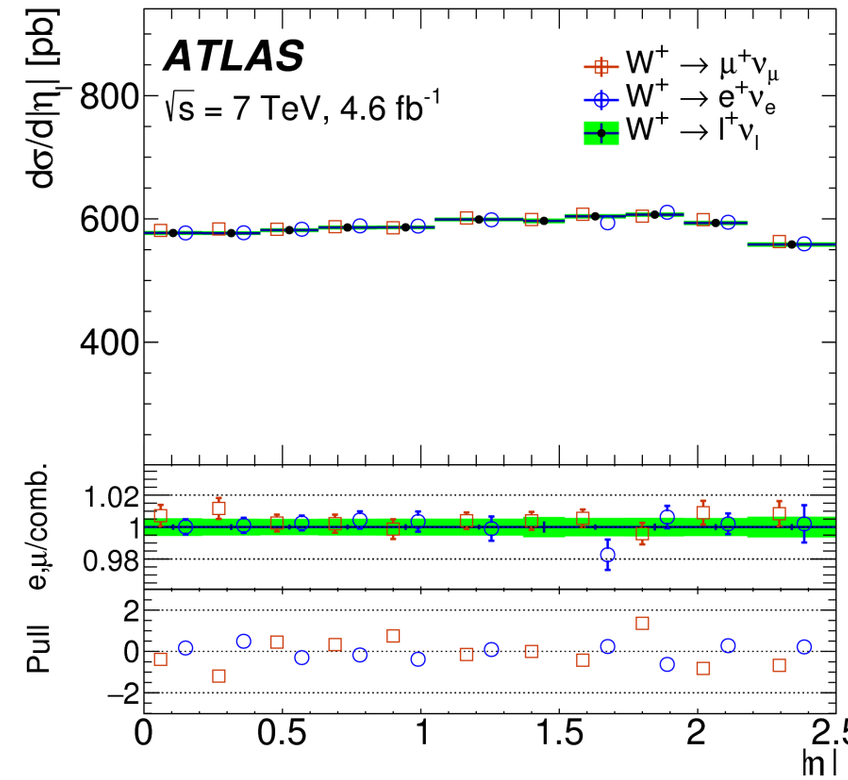
W and Z production cross sections

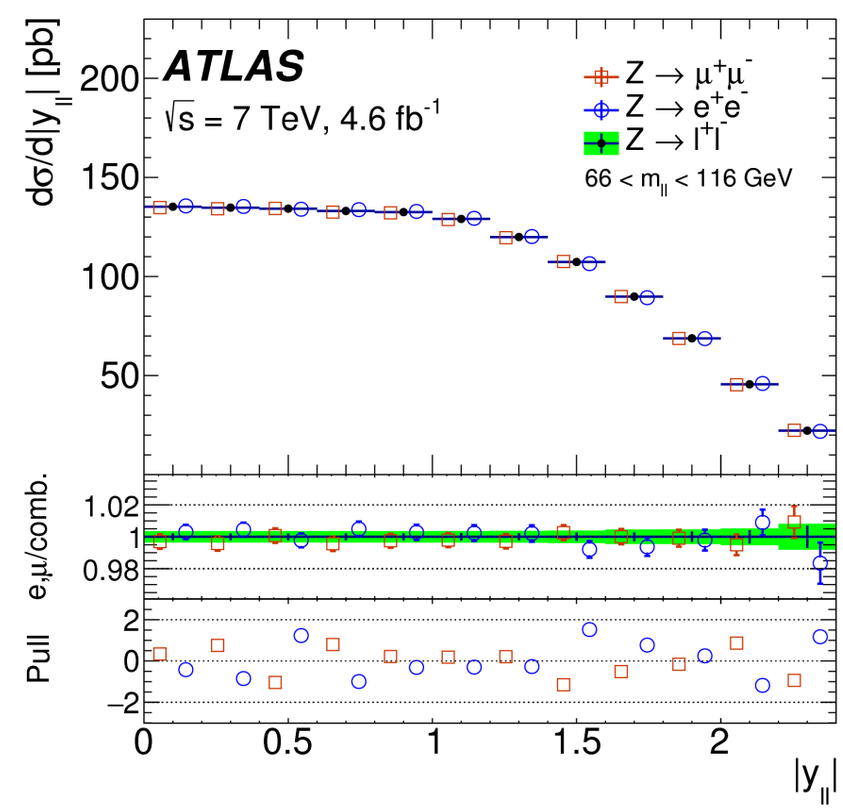
7 TeV, 4.6fb^{-1}

- Measurements of differential and integrated cross sections

	W→(e,μ)ν	Z→(ee,μμ)
Differential measurement	$\lvert\eta_{(e,\mu)}\rvert$	$\lvert y_{(ee,\mu\mu)}\rvert$, 3 mass bins

- Since 2010 measurement
  - 100x statistics
  - luminosity determination 3.5%→1.8%
  - better understanding of the triggers and the lepton reconstruction → reduced systematics

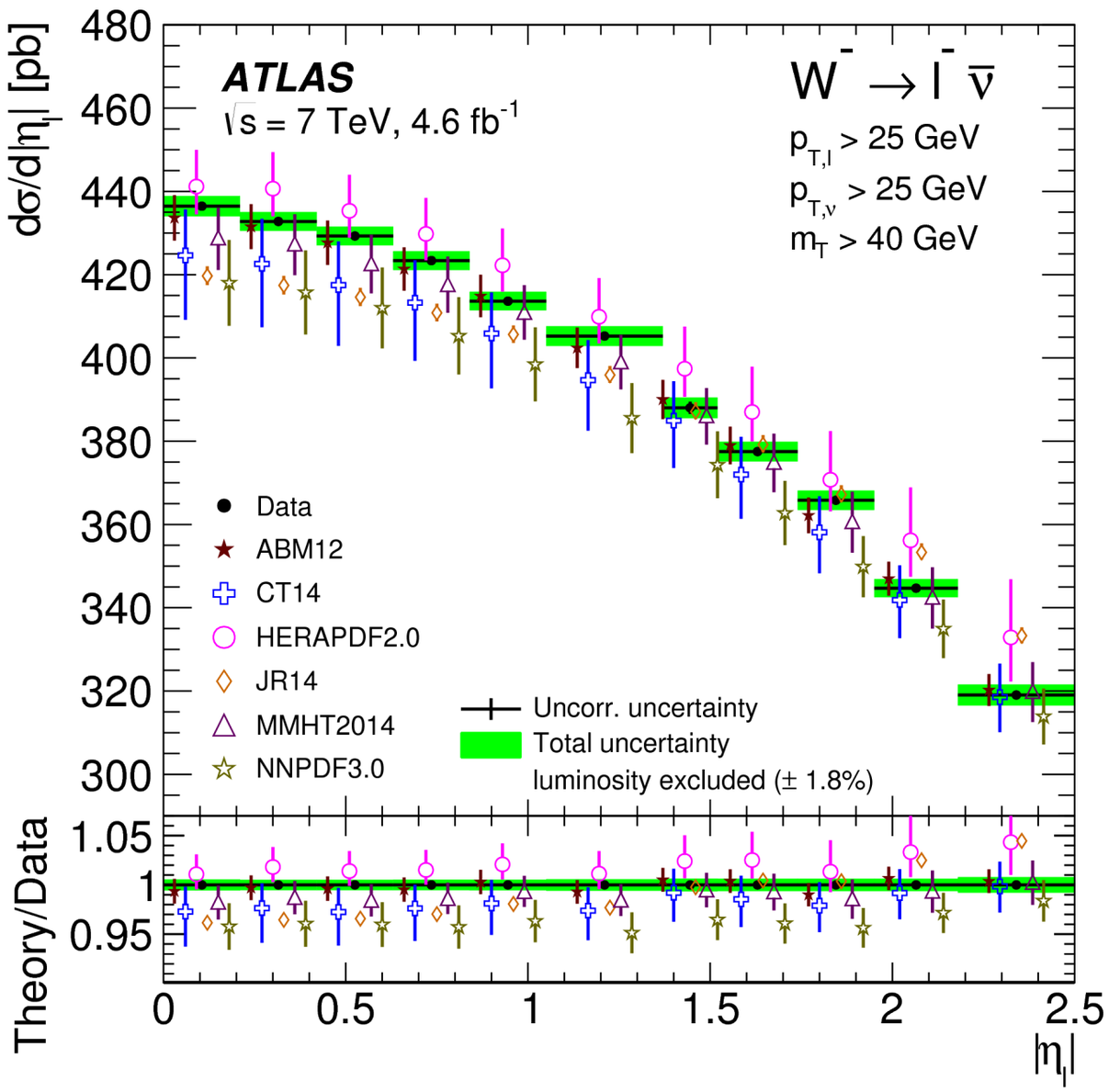


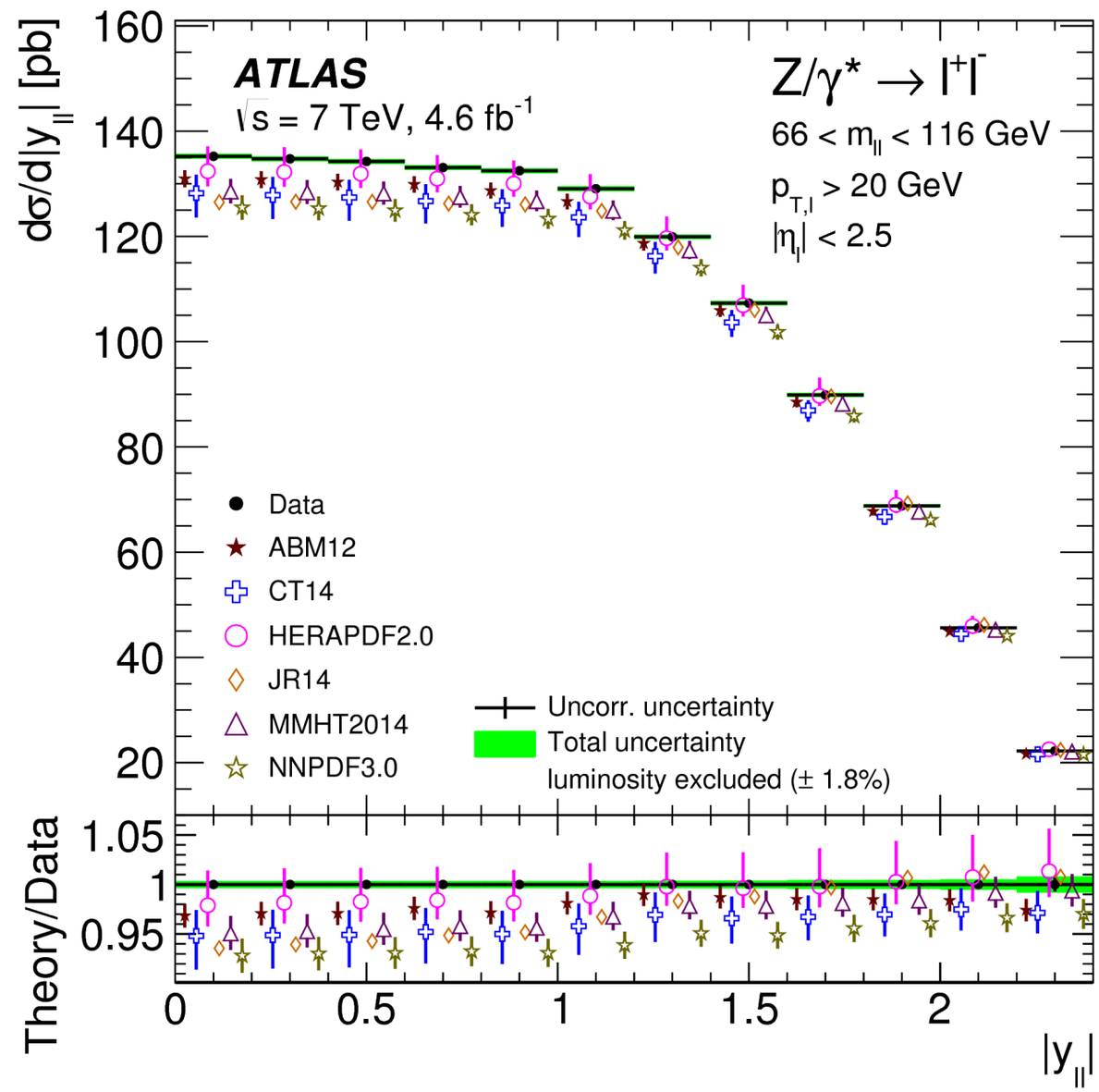


W and Z production cross sections

7 TeV, 4.6fb^{-1}

Differential cross section measured with a precision of 0.4-0.6 (exp) ± 1.8 (lumi) % for Z and W± channels → higher precision than NNLO predictions

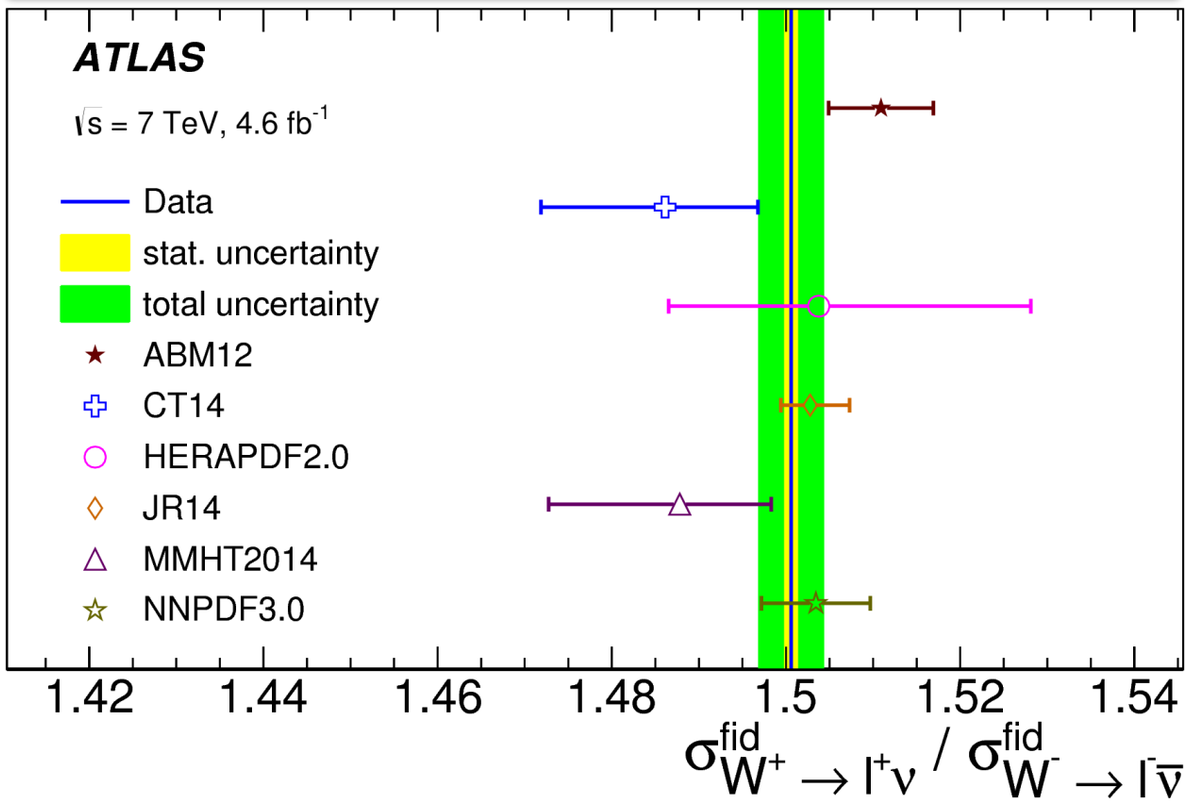




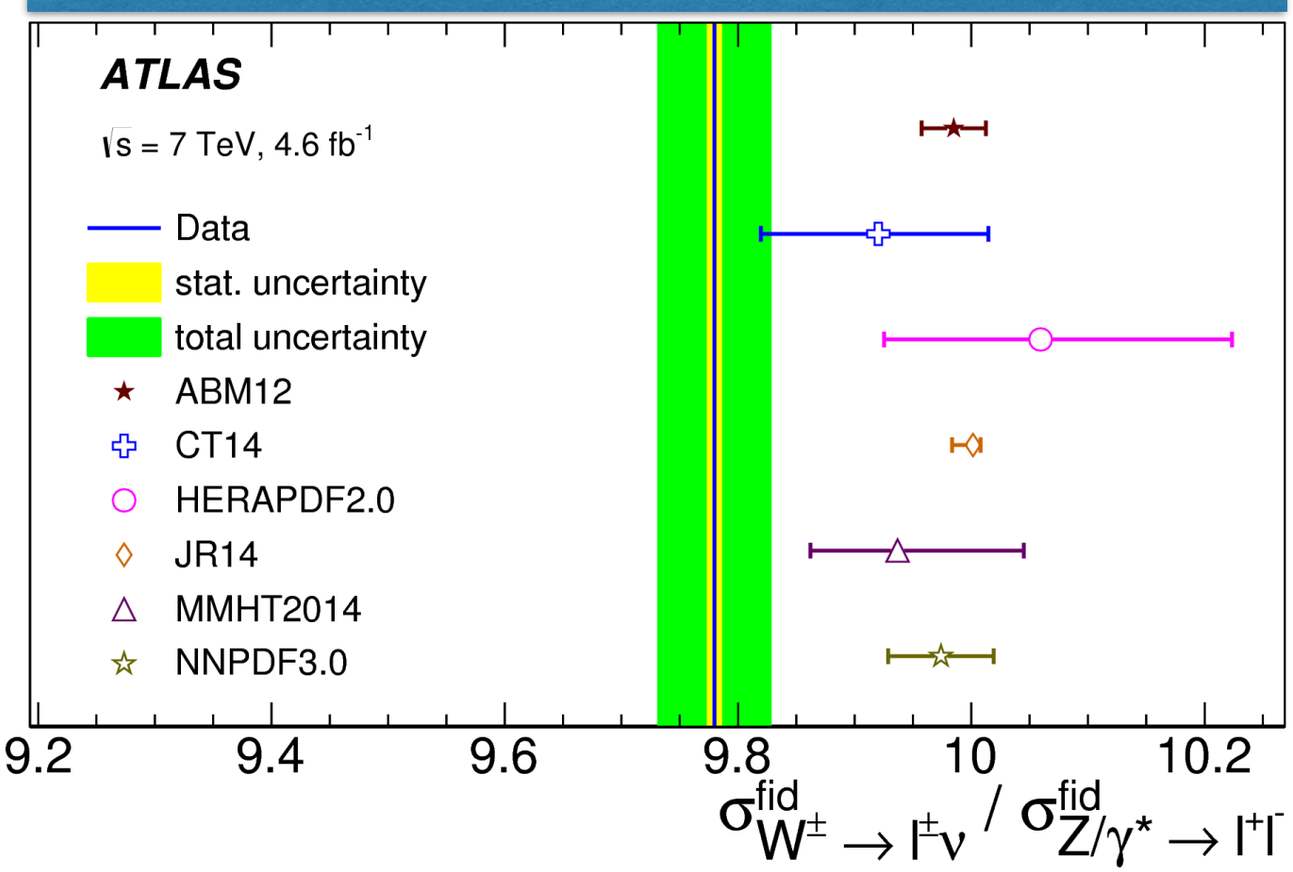
W and Z production cross sections

7 TeV, 4.6fb^{-1}

W+/W- ratio reproduced well…



…lower W/Z ratio observed…

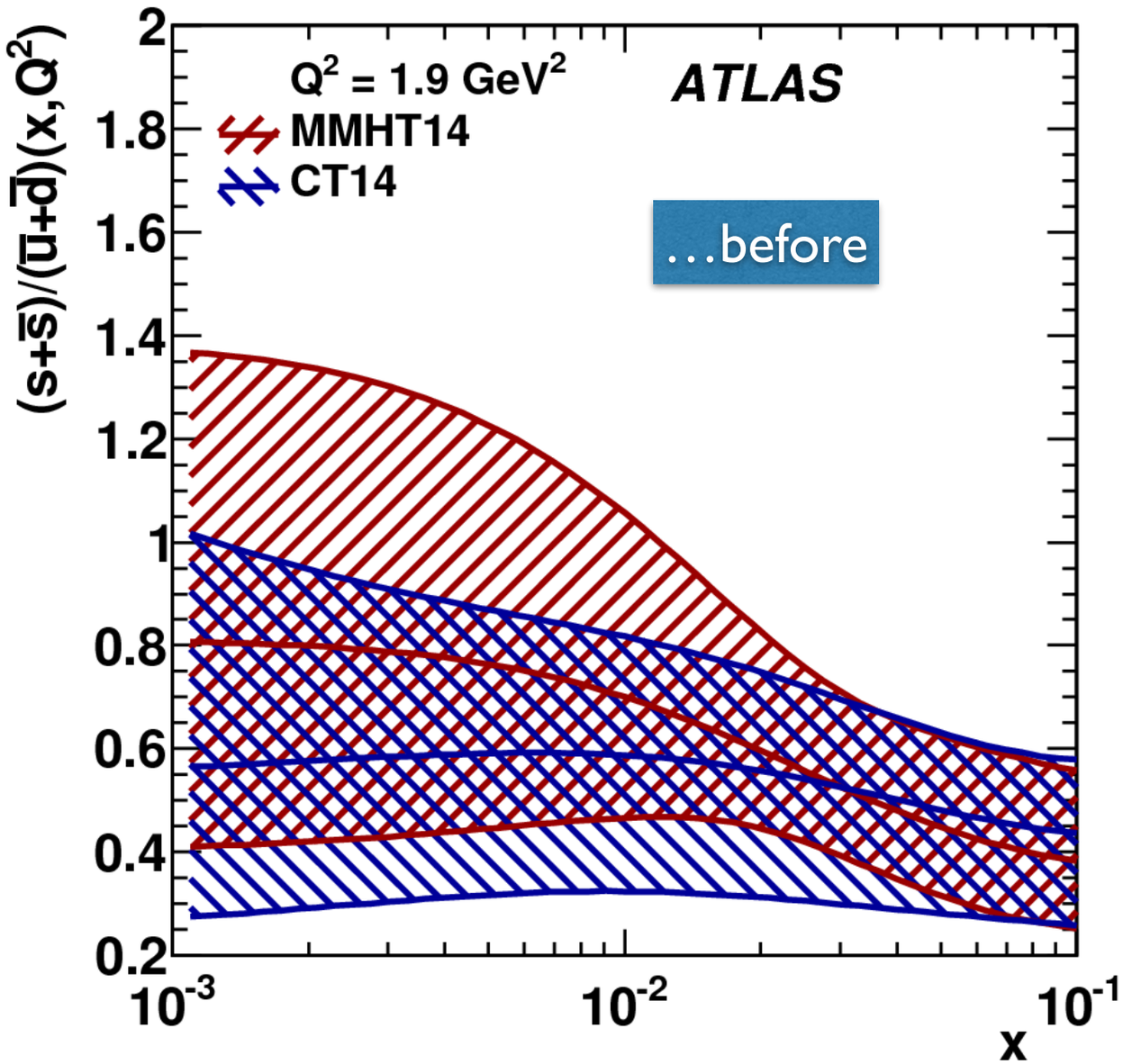


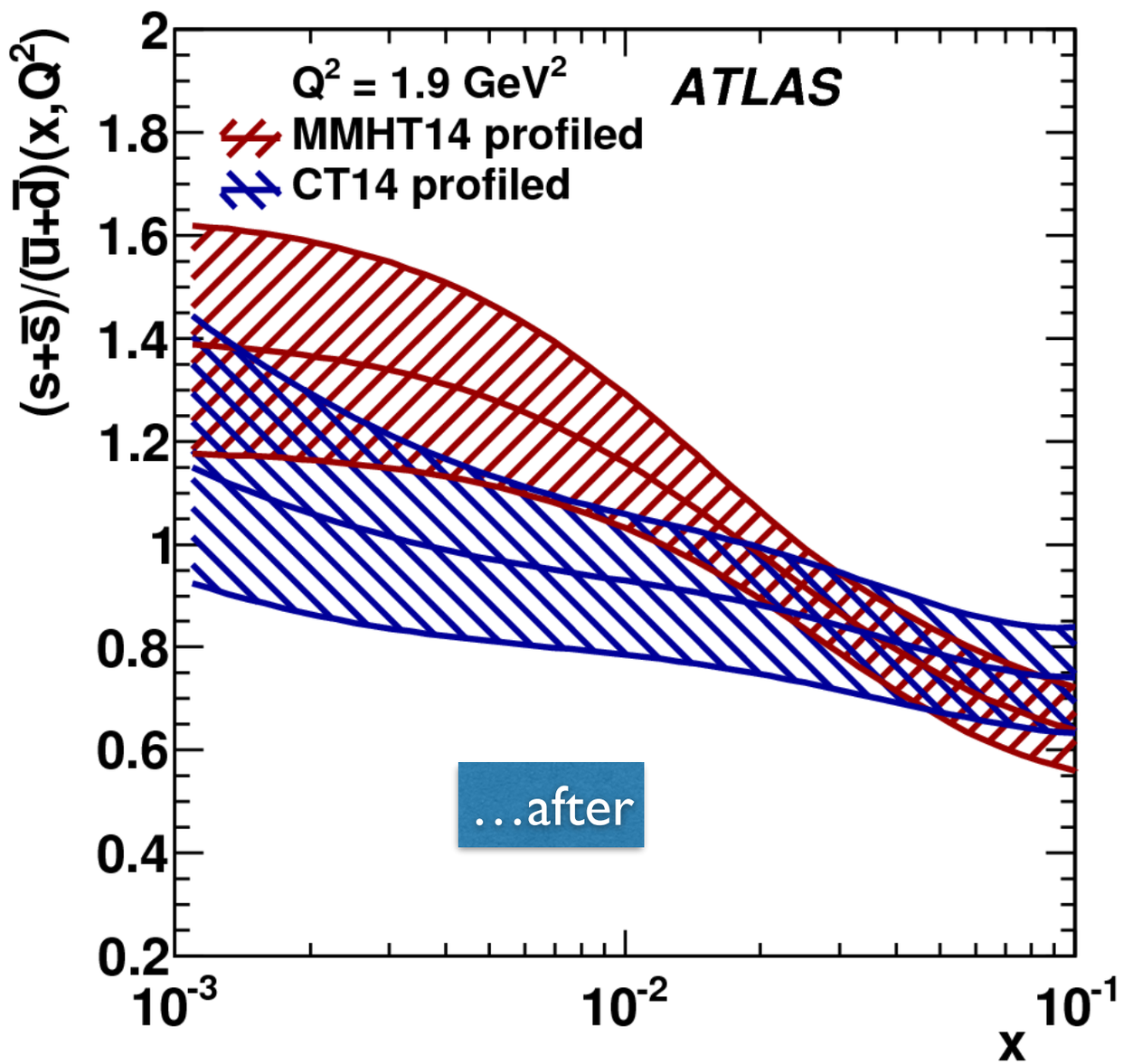
→ explore the flavour structure of the proton via the electroweak interactions

W and Z production cross sections

7 TeV, 4.6fb^{-1}

Demonstration of impact of measurement when applied to existing PDF.
Showing ratio of strange to up- and down- sea quarks before and after profiling



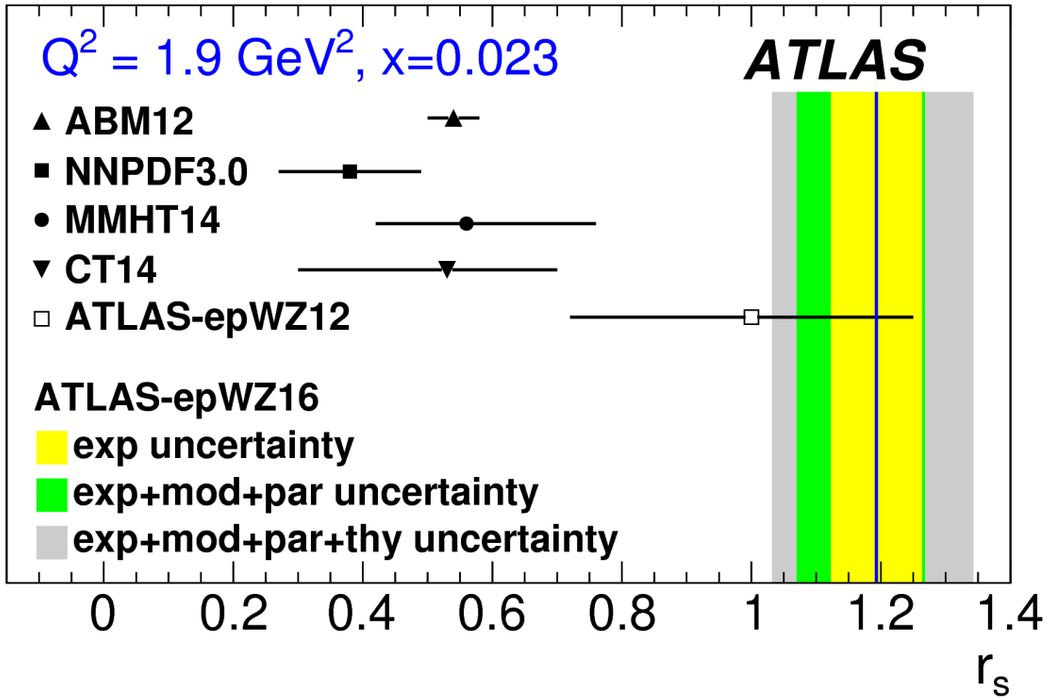


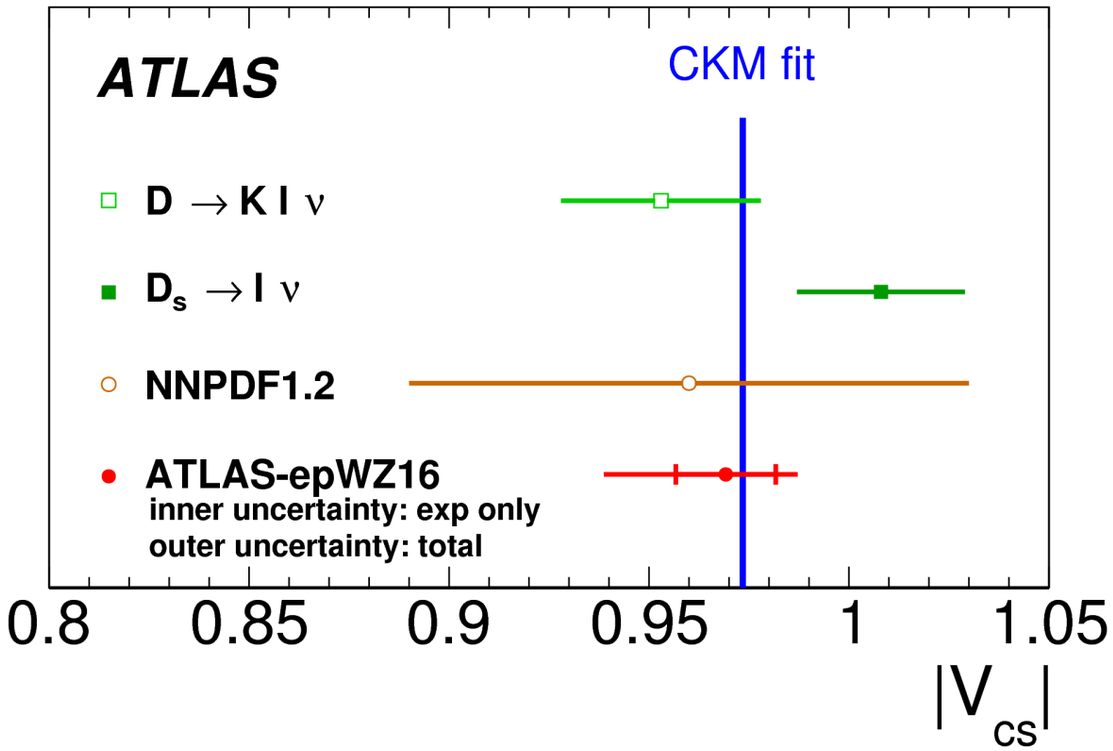
Uncertainties significantly reduced; strange quarks not suppressed w.r.t. up and down-type sea quarks

W and Z production cross sections

7 TeV, 4.6fb^{-1}

- Measurement is used together with HERA DIS data for pQCD fit
  - Improved sensitivity of flavour composition w.r.t. DIS-only fits
  - Evaluation of strange-quark distribution
  - Independent determination of the CKM matrix element $|V_{cs}|$
- Supports earlier ATLAS observation of absence of strangeness suppression
  - Experimental uncertainties reduced by factor of ~4: reached point of theory limitation
- Competitive $|V_{cs}|$ measurement





W mass

7 TeV, 4.6fb^{-1}

W MASS

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right)=\frac{\pi\alpha}{\sqrt{2}G_\mu}(1+\Delta r)$$

Higher order corrections, sensitive to the Higgs and top mass, and New Physics

Z mass: precisely measured @ LEP

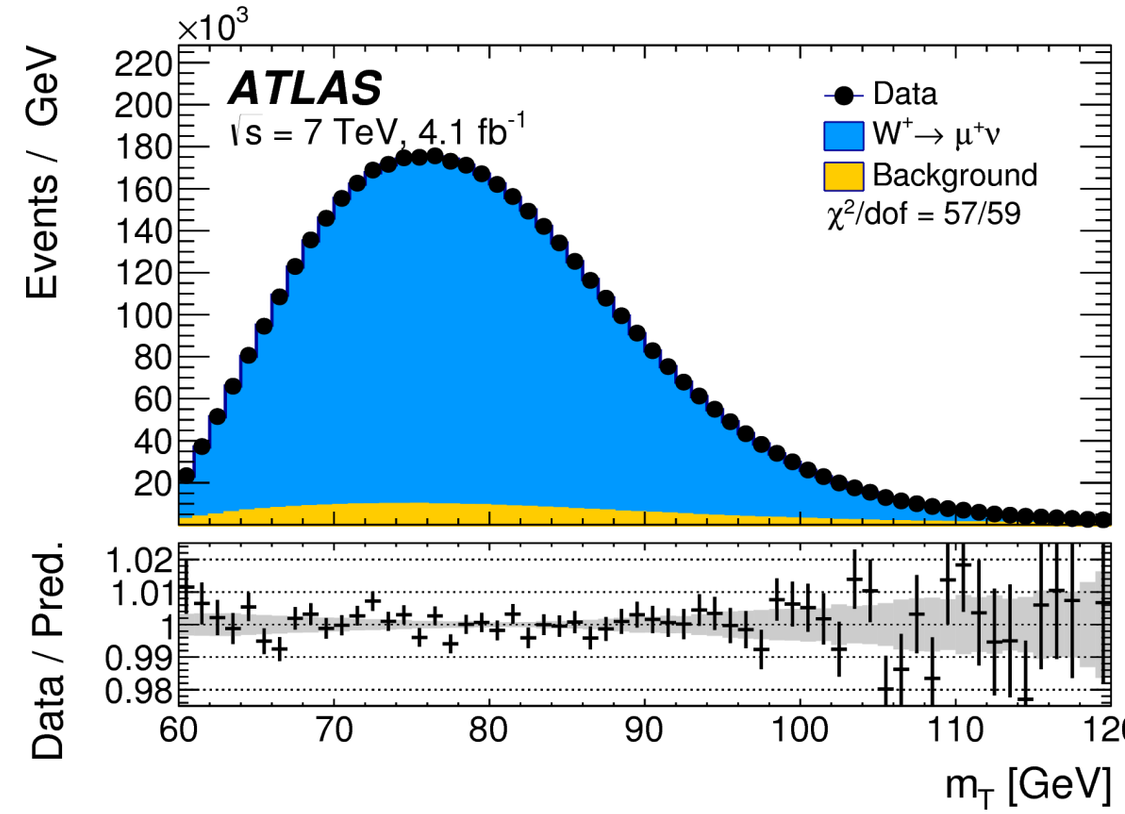
Constraints on NP effects are limited by the available precision of the measured W mass, so *improving the precision is of central importance to our field*

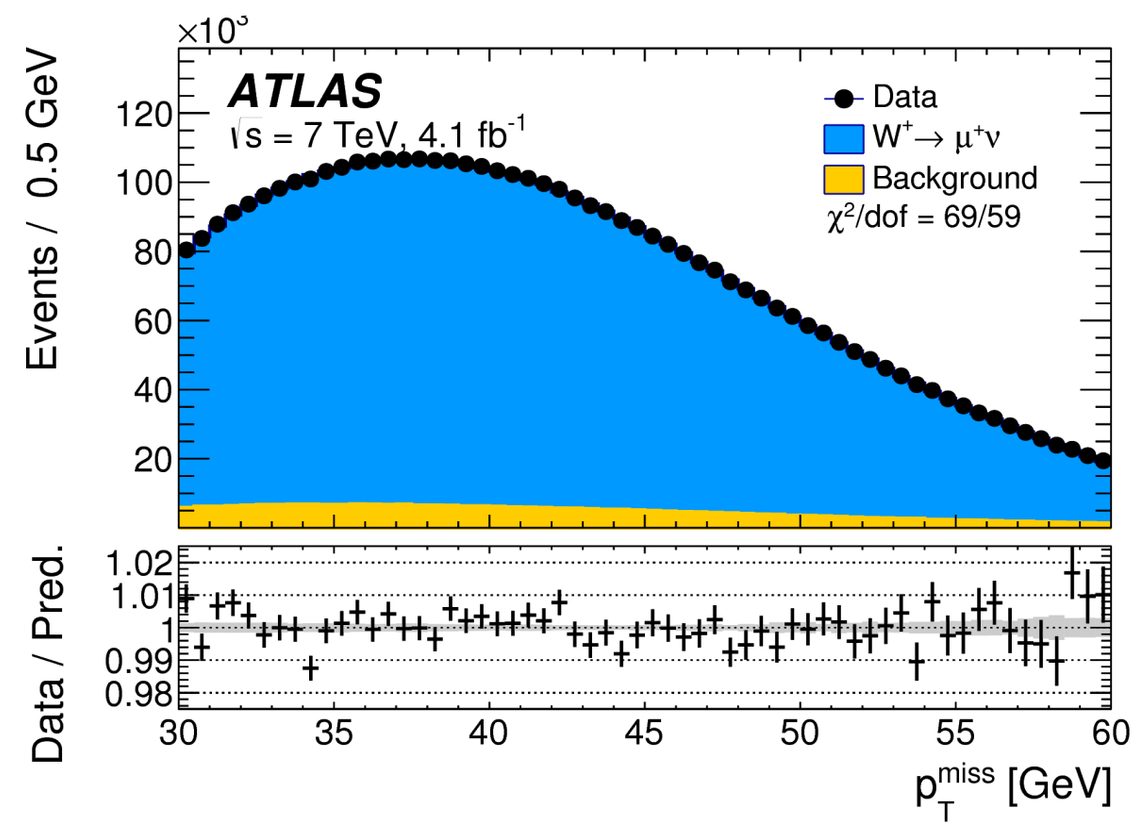
- Current best measurement is from CDF: 80387±19 MeV
- Theory uncertainty: ±8 MeV

W mass

7 TeV, 4.6fb^{-1}

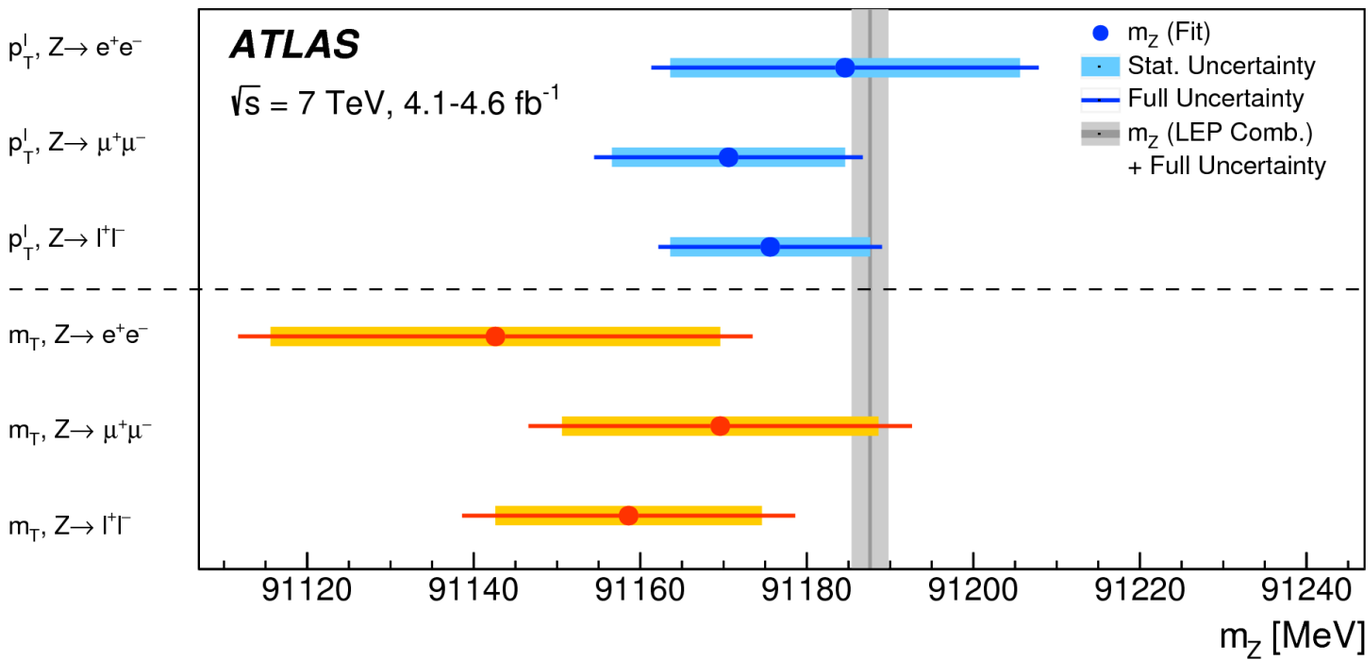
- At the LHC
  - use DY production, $W \rightarrow l\nu$
  - Extract mass from Jacobian edges of final-state kinematic distributions, e.g. $p_T(l)$ and $M_T(W)$
  - LHC benefits from huge signal and calibration statistics (10^7 W, 10^6 Z)
- Measurement relies on $Z \rightarrow ll$ for calibration
  - Modelling of $p_T(W)/p_T(Z)$ one of the main sources of uncertainty





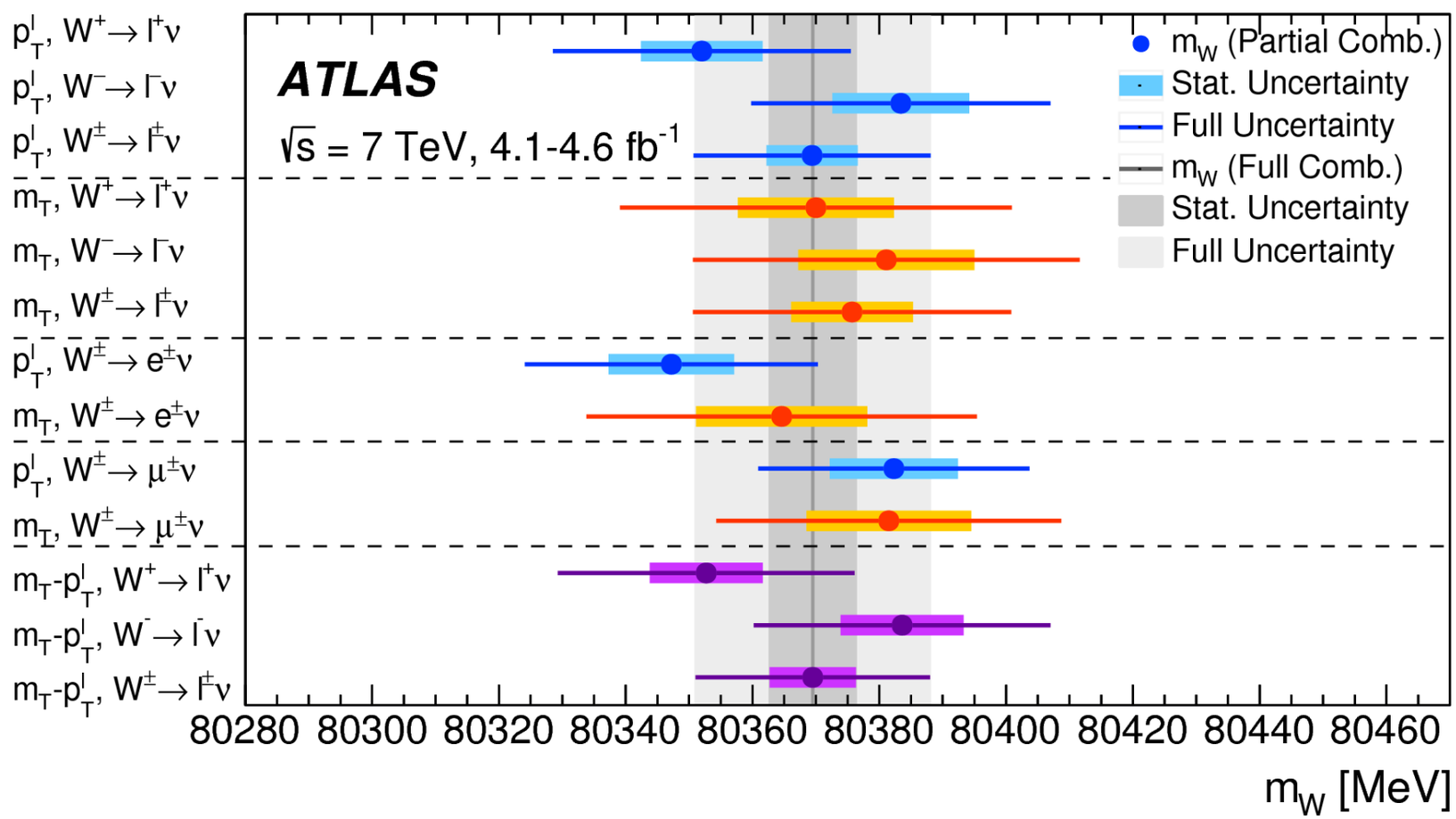
W mass

7 TeV, 4.6fb^{-1}



Closure tests with Z mass from the different kinematic distributions, e.g. extracting m_Z from m_T provides a test of the recoil calibration

Stability across a variety of analysis channels and kinematic distributions



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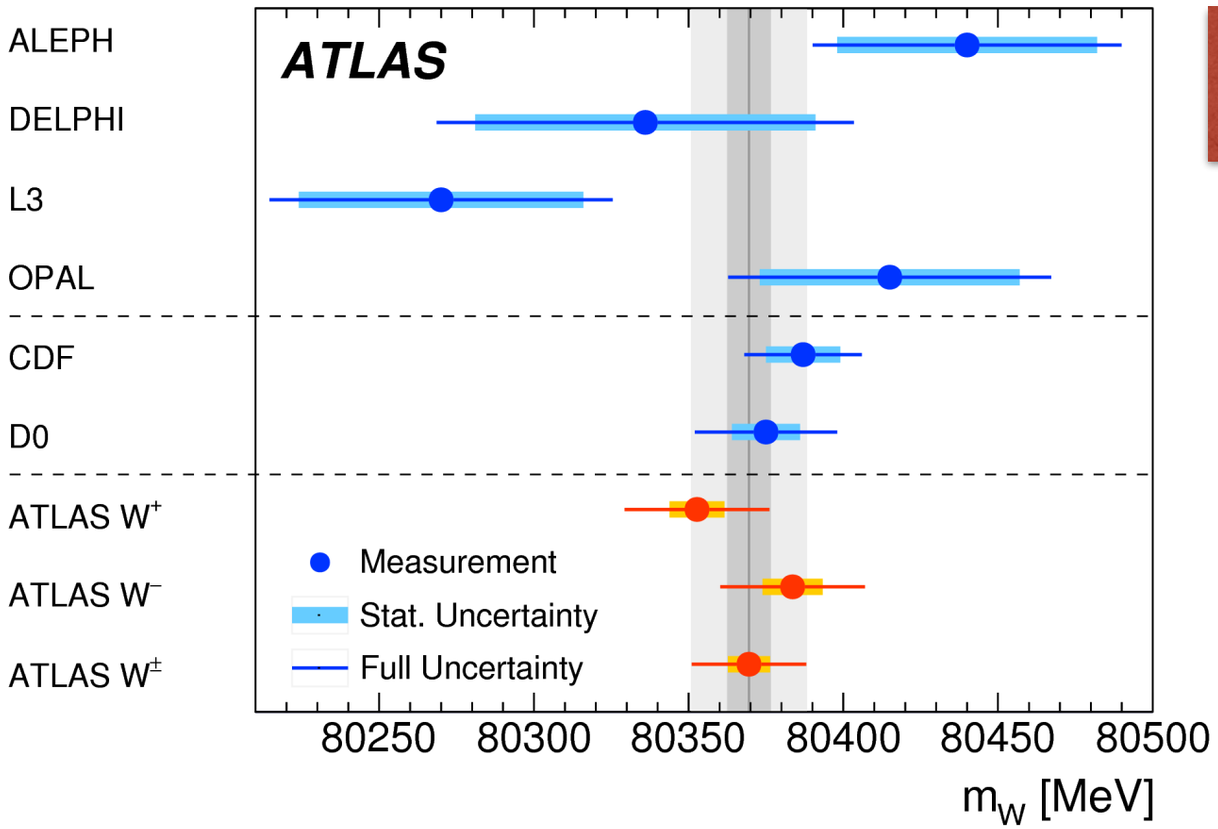
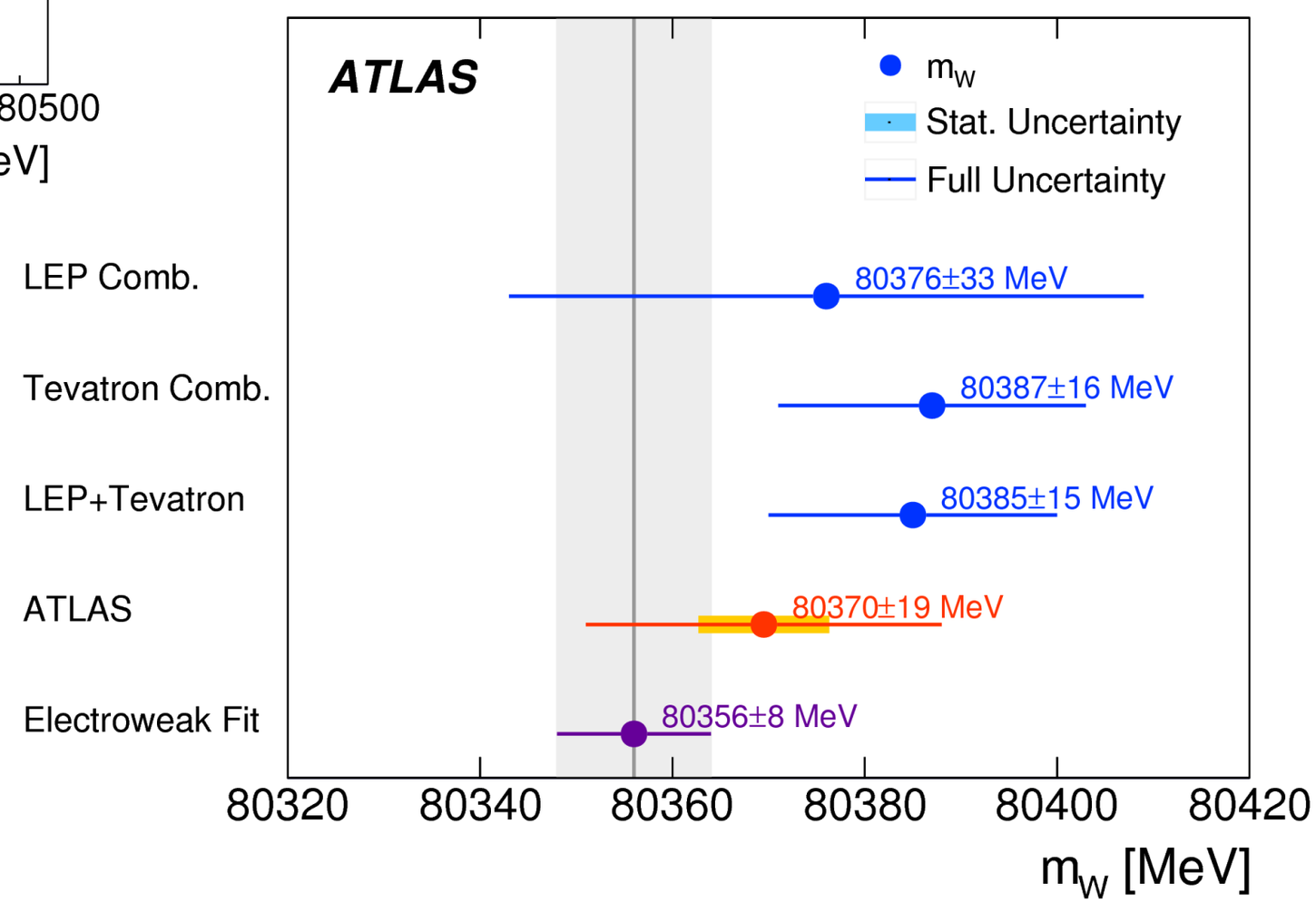


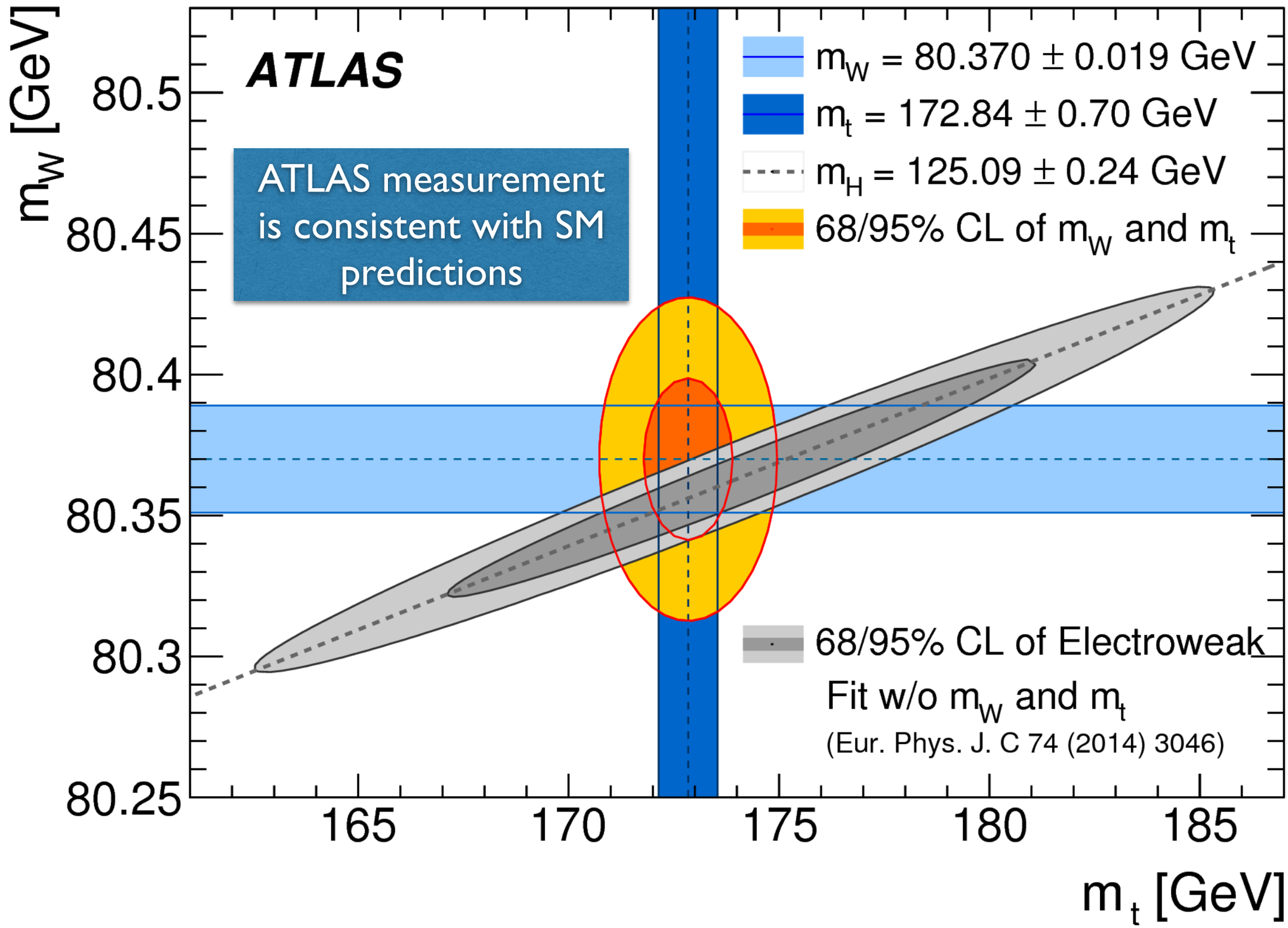
M_W = **80370 ± 19** MeV

±7 statistics
±11 systematic
±14 modelling

ATLAS measurement has similar precision to the current best measurement



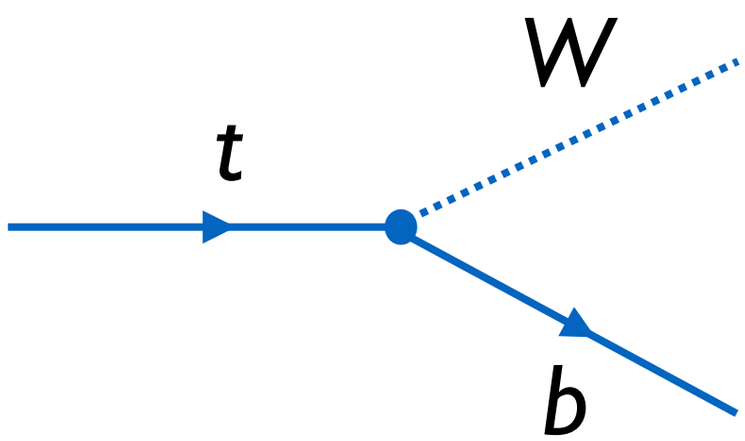
Electroweak sector consistency



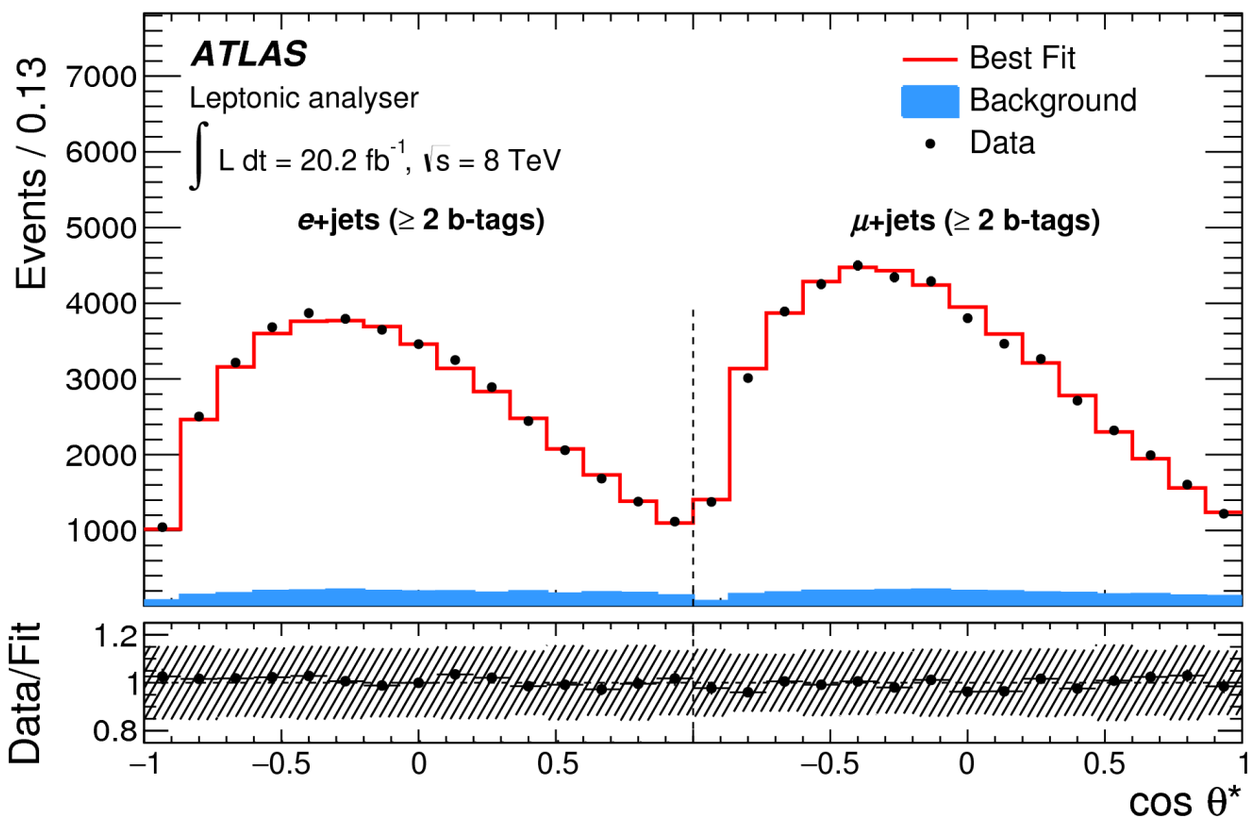
Measurement of W polarisation in $t\bar{t}$ events

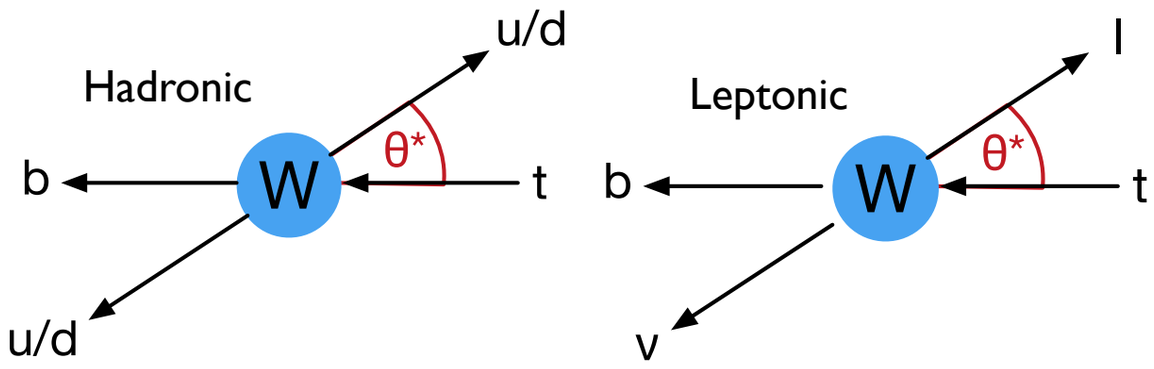
8 TeV, 20.2fb^{-1}

- Top quark decays ~100% to Wb
  - Real W boson produced with polarisation: RH, LH and longitudinal components
  - Fractions of each component can be measured to probe the nature of the Wtb vertex



- Measurement: use angular distributions from two "analysers": hadronic and leptonic
- Reached precision of 3-5%, theory in agreement with the measurement



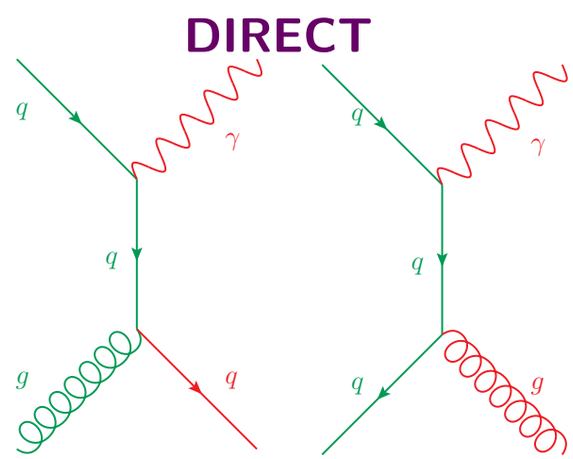


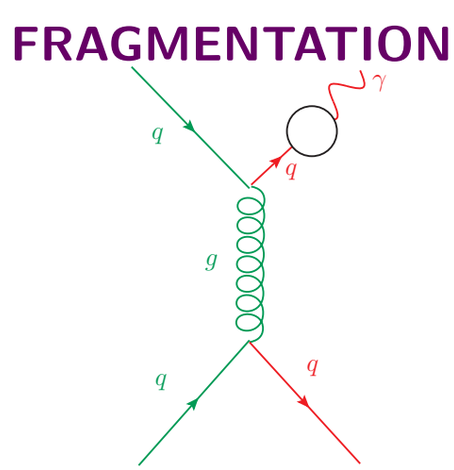
	NNLO QCD	ATLAS
F0	0.687 ± 0.005	0.709 ± 0.019
FL	0.311 ± 0.005	0.299 ± 0.015
FR	0.0017 ± 0.0001	−0.008 ± 0.014

Isolated prompt photon production

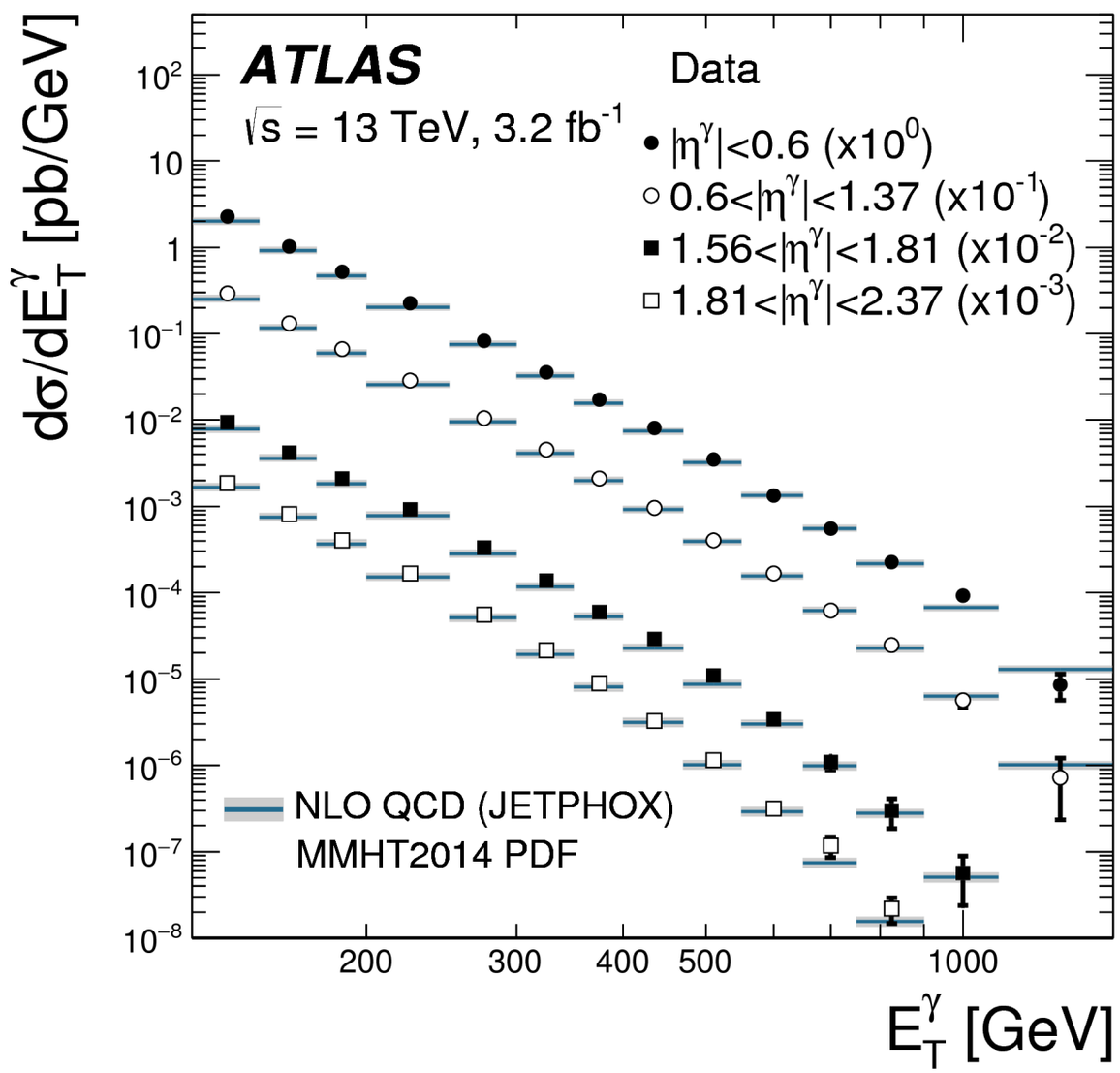
13 TeV, 3.2fb^{-1}

- pp → γ + X
  - Prompt photons: can test short-distance dynamics of quarks and gluons using a hard colourless probe.
  - Aid searches for which this process is an important background
- Measurement: differential cross sections measured for photons with $E_T(\gamma)$ > 125 GeV and $|\eta_\gamma|$ < 2.37 in four different regions of $|\eta_\gamma|$





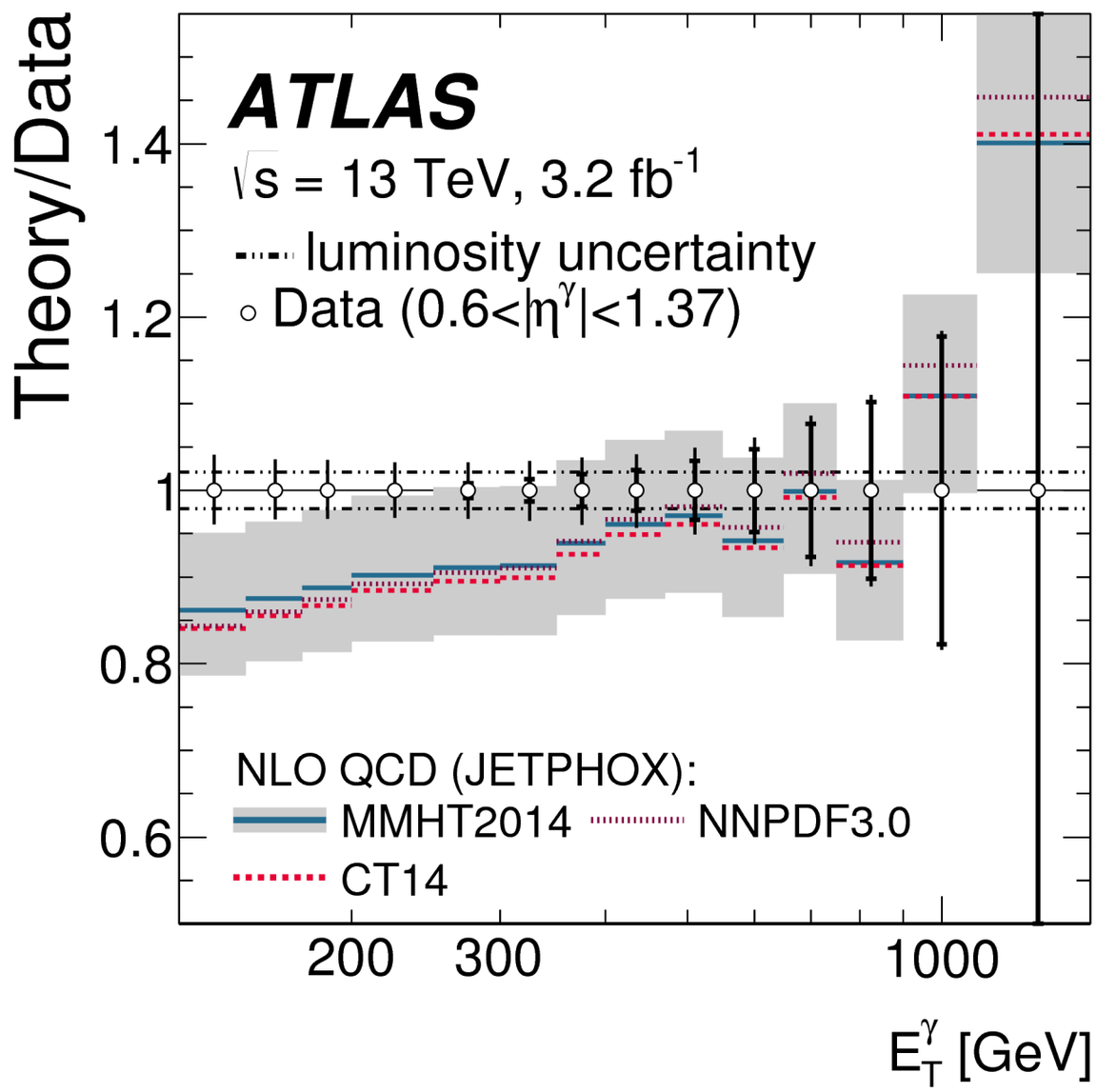
Comparisons with NLO QCD



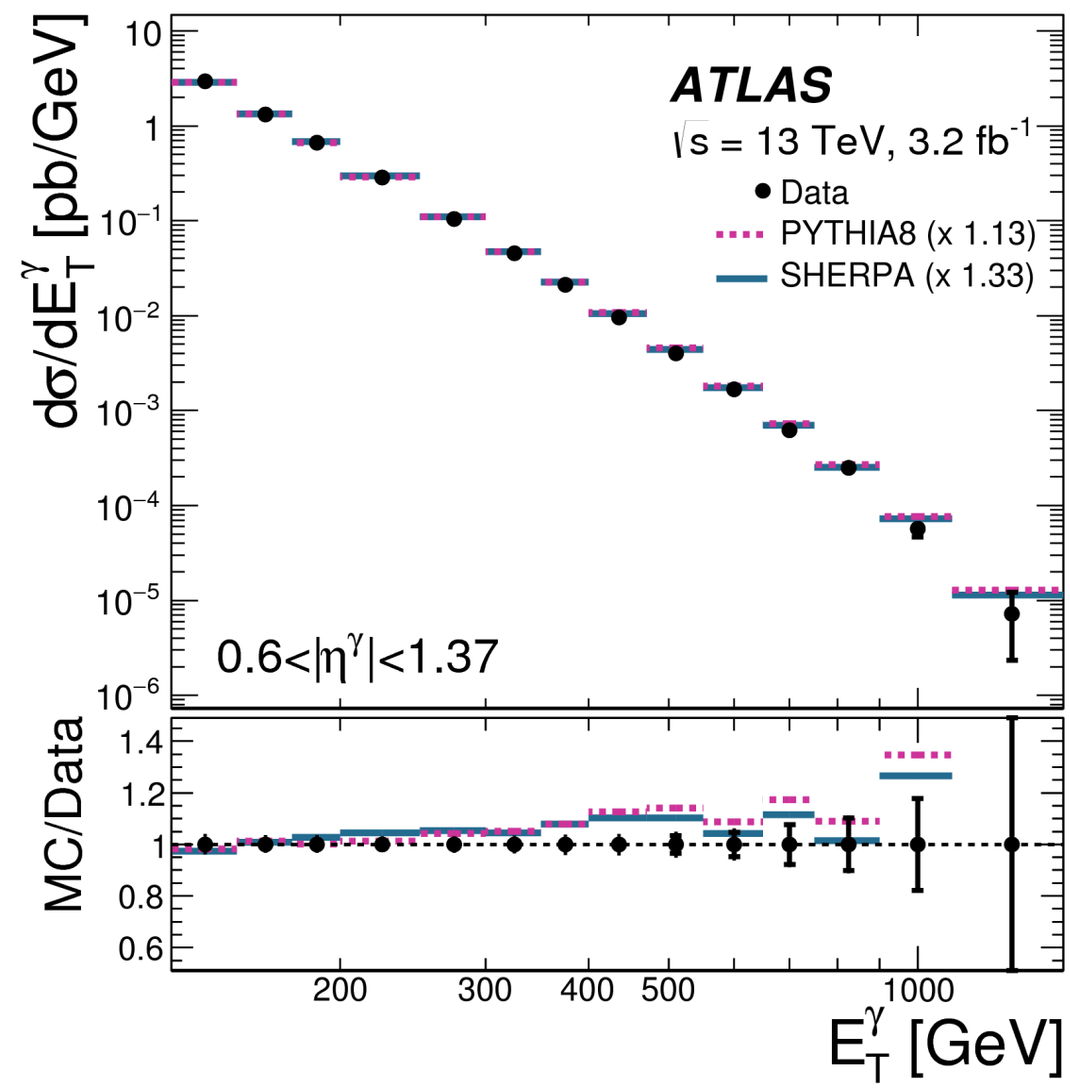
Isolated prompt photon production

13 TeV, 3.2fb^{-1}

Comparisons with NLO QCD: ratios



Comparisons with predictions from Pythia and Sherpa in one of the four η slices

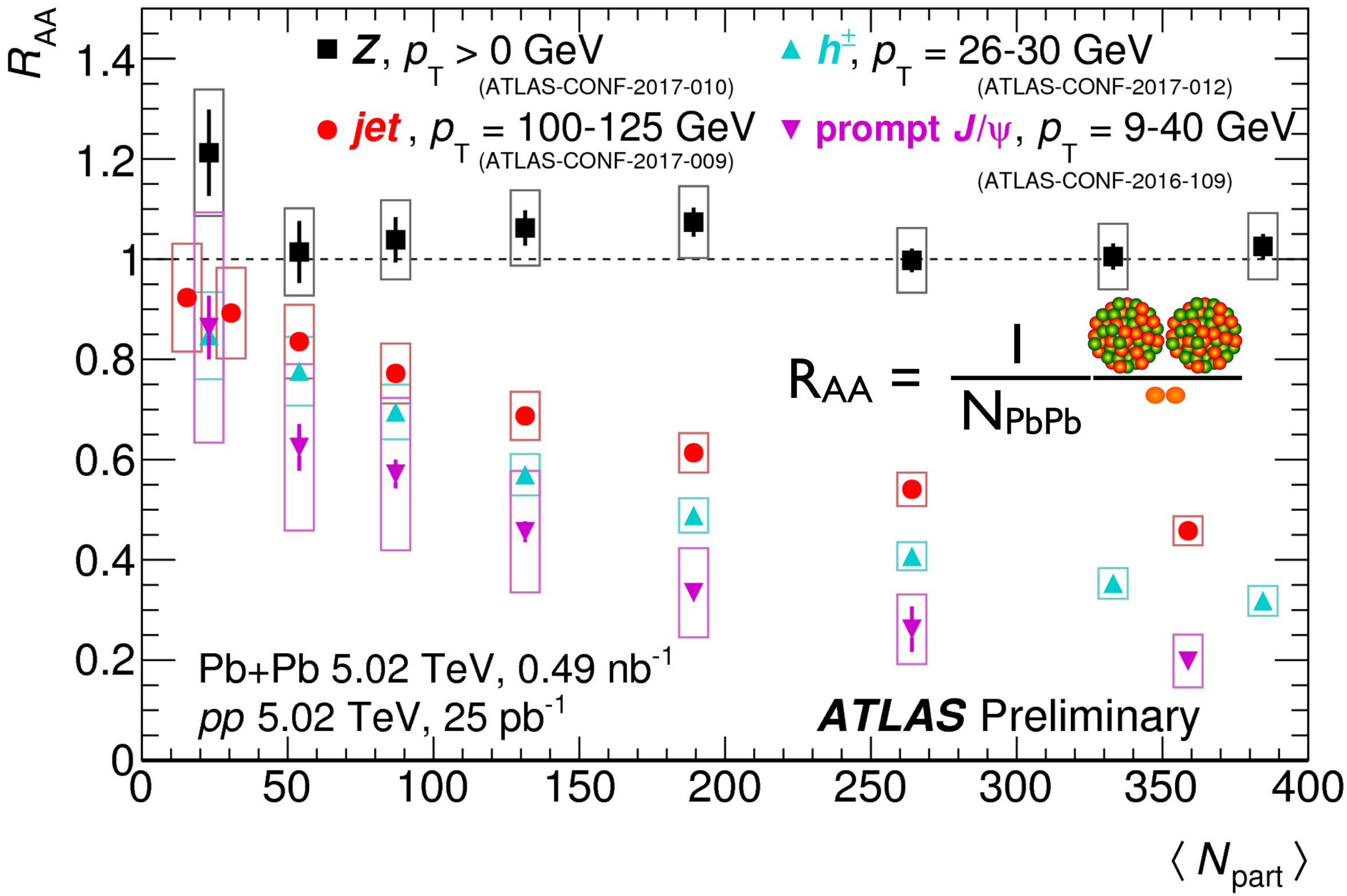


Data distributions are described adequately: experimental precision better than theory, NNLO pQCD may improve description

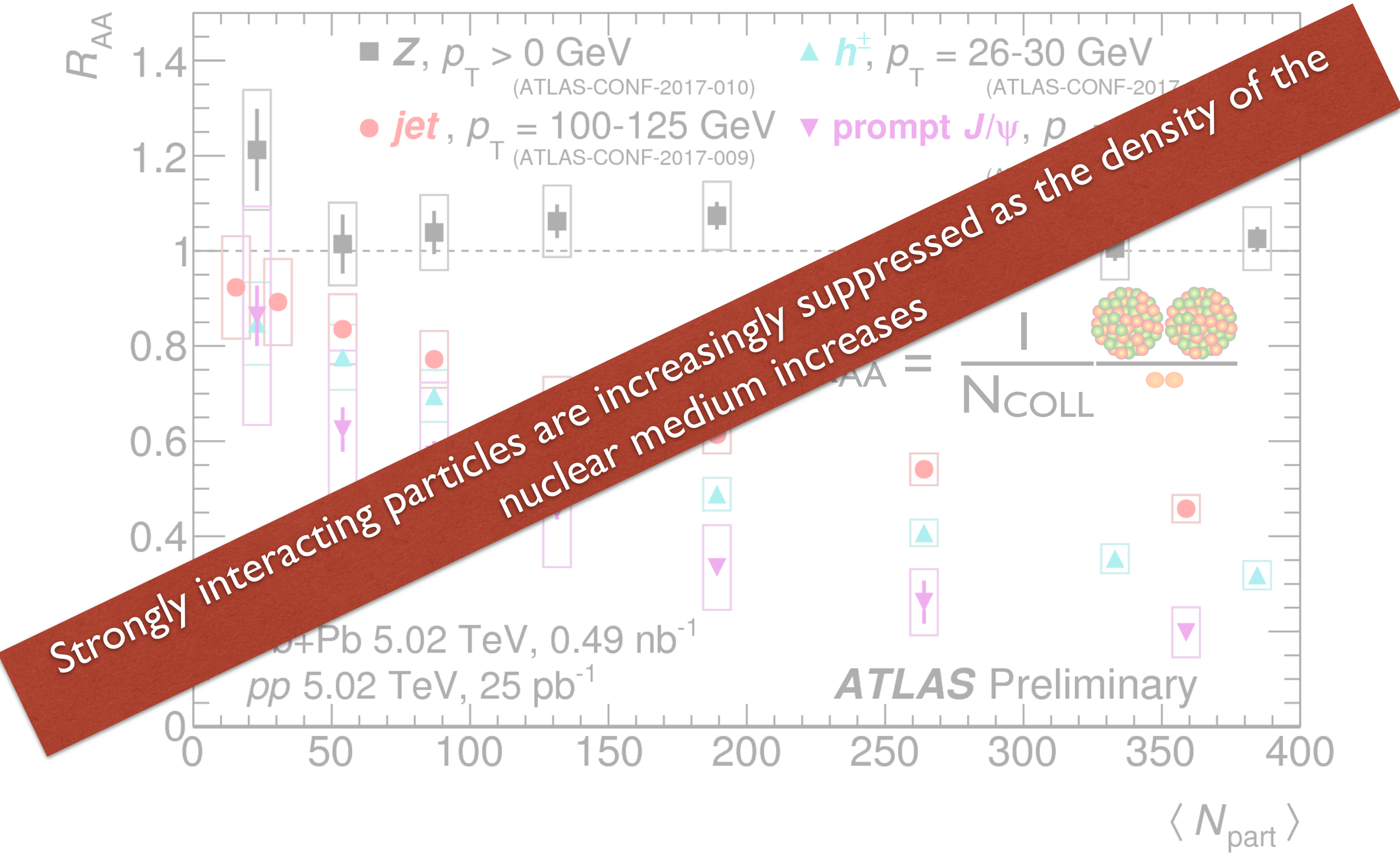
Heavy Ion physics

- Preliminary evidence for light-by-light scattering ($\gamma\gamma \rightarrow \gamma\gamma$) shown at the last LHCC
  - Since then, submitted to Nature Physics, arXiv 1702.01625
- Quark Matter 2017: major conference held in the first week of February
  - 2 papers
  - 11 preliminary results (conference notes), including 8 TeV Pb-p data
- Main highlights
  - Jet production
  - Flow in small systems

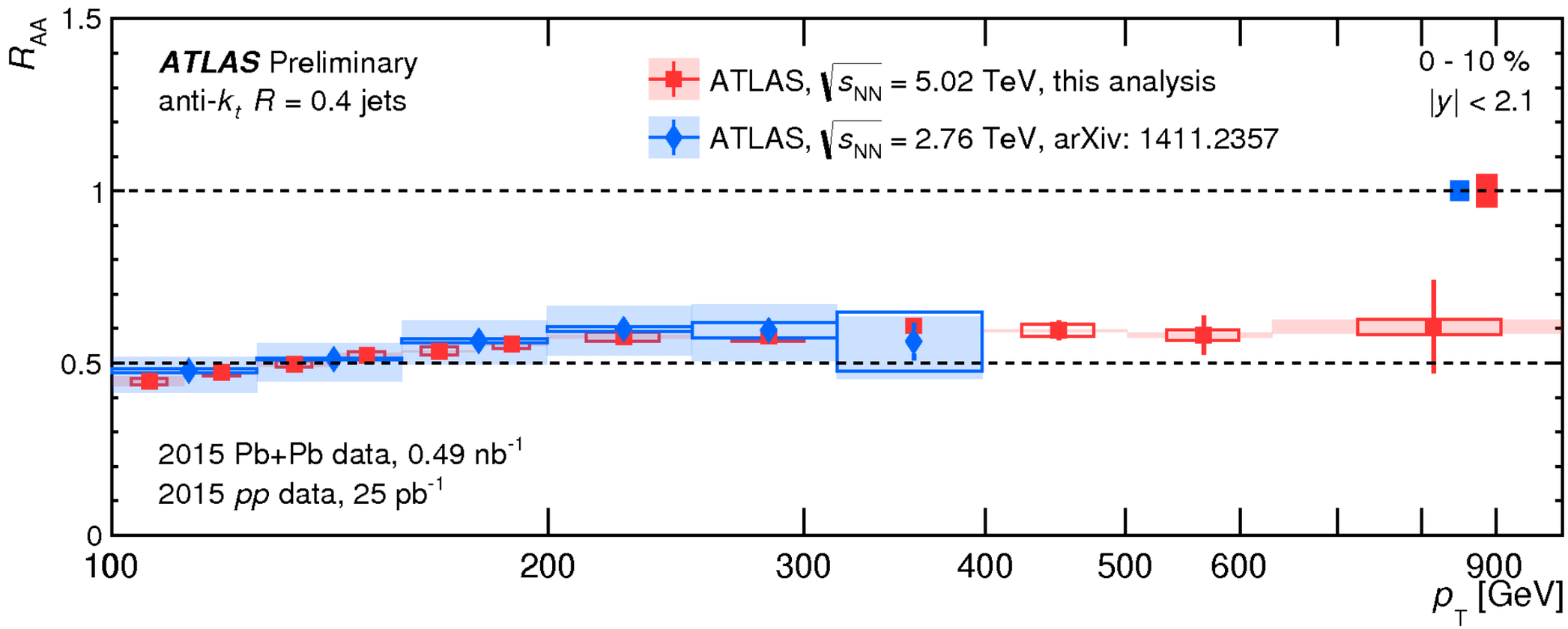
Heavy Ion physics: hard probes



Heavy Ion physics: hard probes



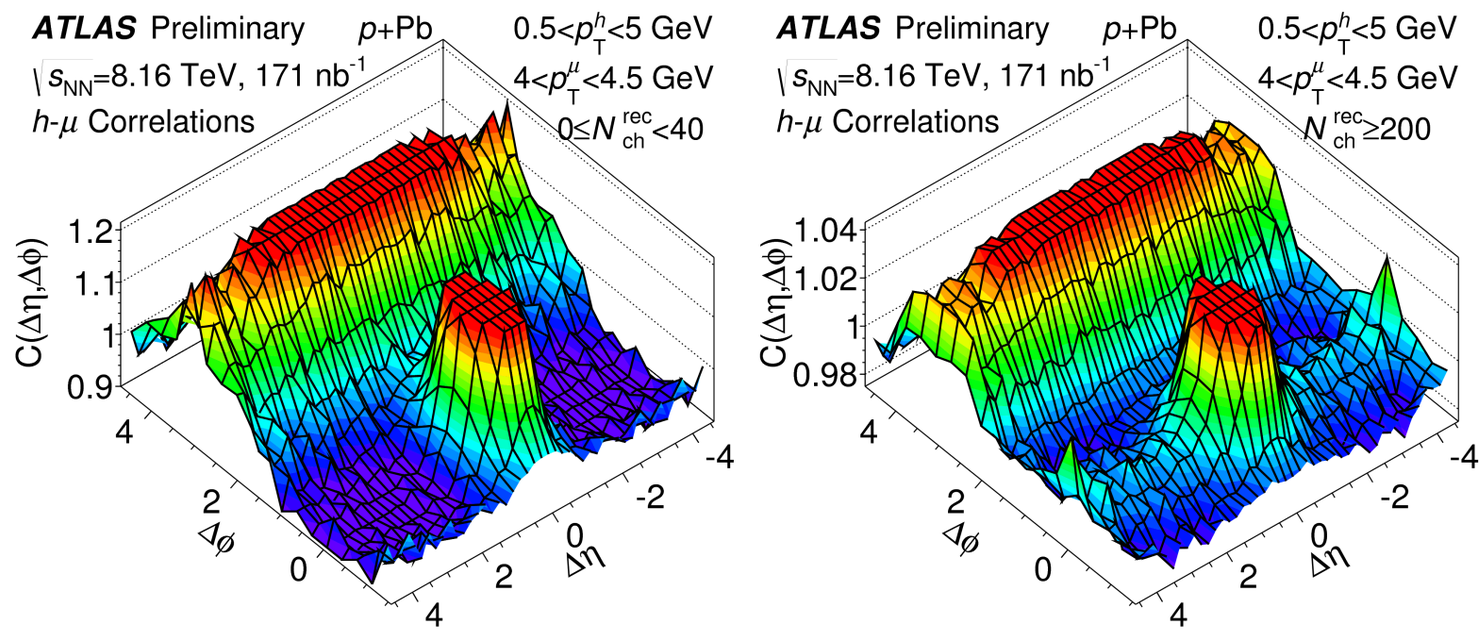
Heavy Ion physics: hard probes (jets)

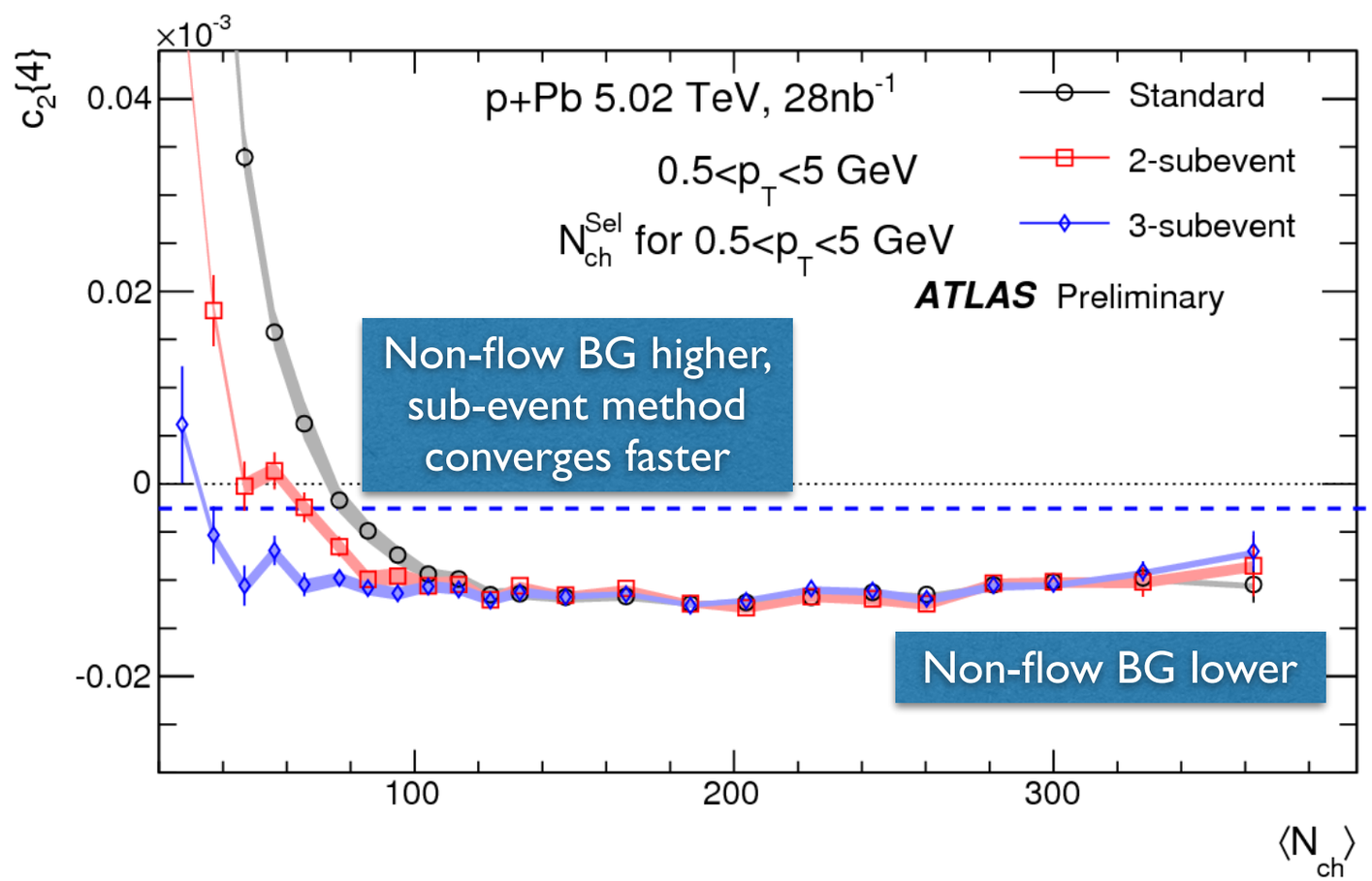


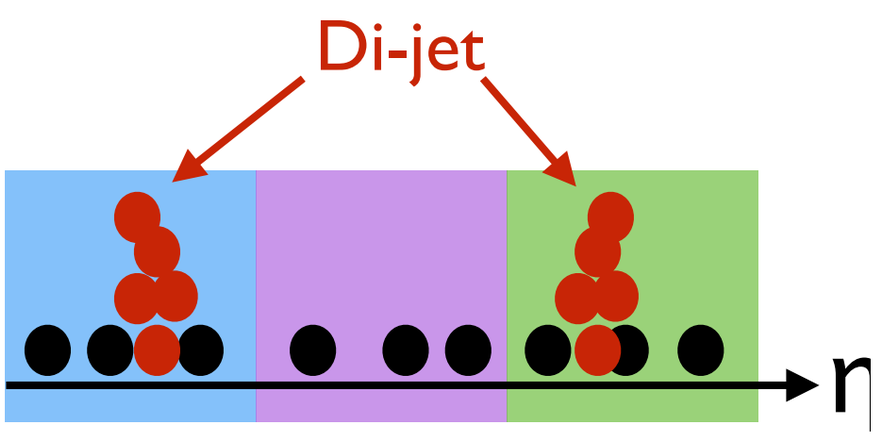
- With the new Run-2 PbPb data we can access jets to p_T ~1TeV
- Suppression pattern similar between Run-1 and Run-2 energies: slow raise and then saturation in R_{AA} above 200GeV
- Significant improvement in systematic uncertainties possible due to similar conditions of pp and PbPb data taking (Nov/Dec 2015)

Heavy Ion physics: ridge in small systems

- "Ridge" reported in small systems i.e. pp and pPb by all LHC experiments
  - Origin still debated
- ATLAS observes ridge also in muon-hadron events
  - pPb data at 8.16TeV collected in Nov/Dec 2016
- However: background from "non-flow" (correlations from di-jets and decays) is challenging in particular in pp collisions
- ATLAS developed a new method to subtract non-flow - "sub regions"





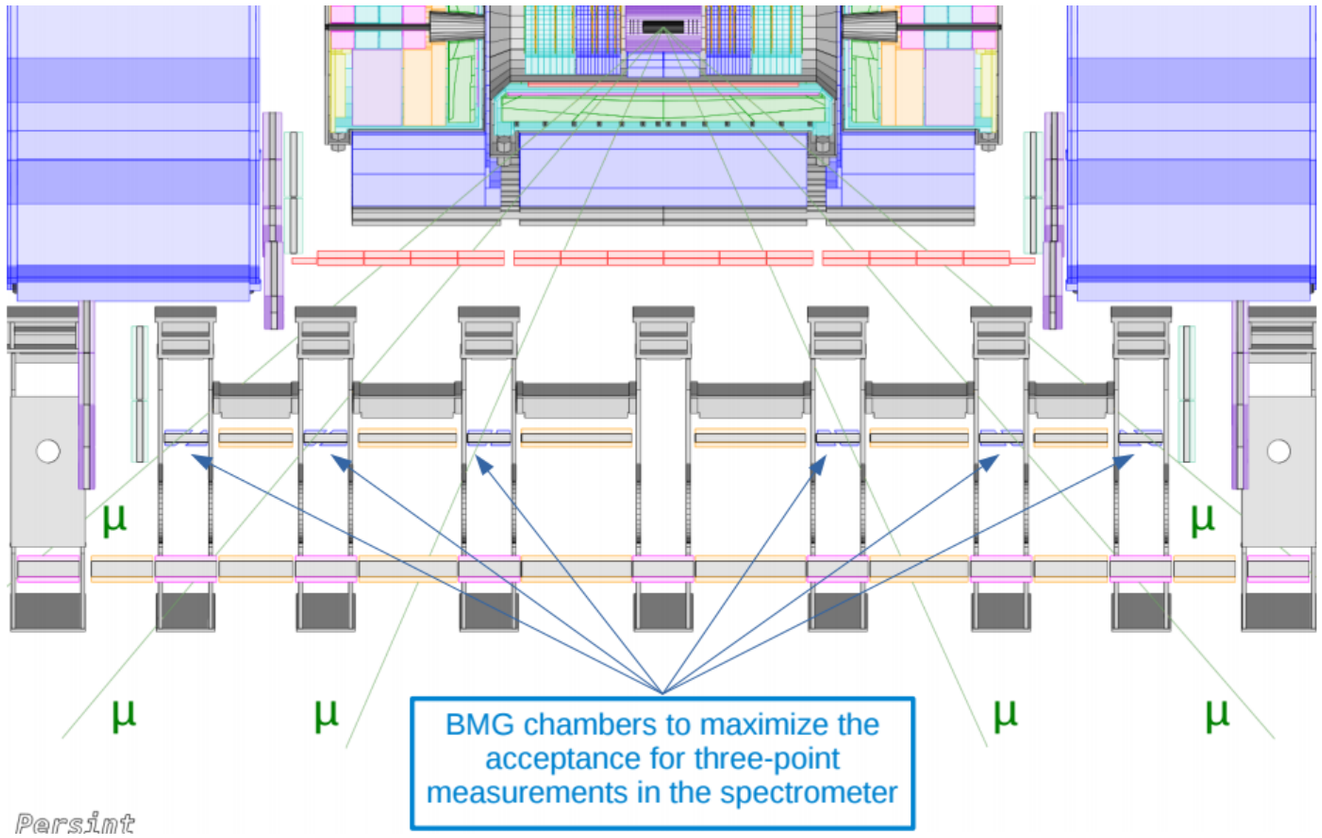


Preparing for 2017

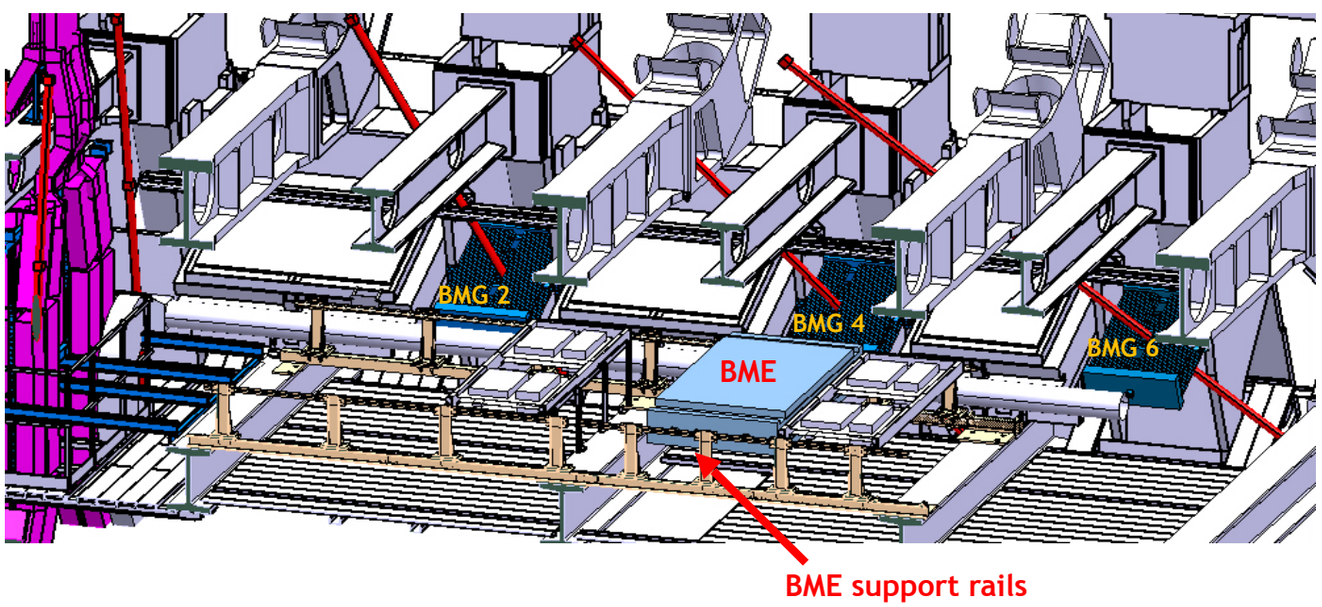
Preparing for 2017: opening of ATLAS

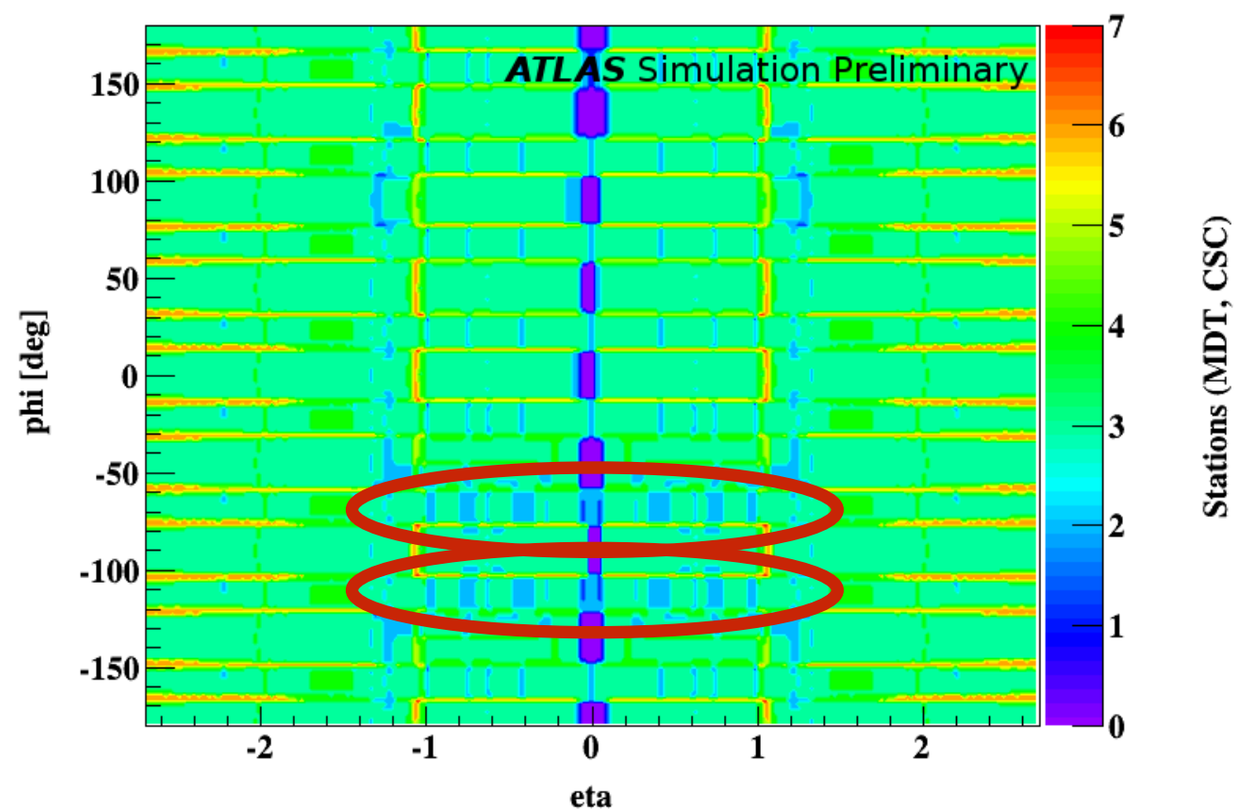
- ATLAS open for maintenance and upgrades between December 2016 and April 2017
  - General maintenance of all systems
  - Installation of new muon spectrometer components (BMGs) in the feet region, repairs to some CSC modules
  - LAr: replacing cooling manifold and HEC low-voltage power supplies
  - Tile: investigations into and repairs of the cooling loop problem
  - Installation of second arm of AFP and shielding for ALFA
- Thus far, all of the milestones have been successfully passed, on time

Preparing for 2017: BMG installation

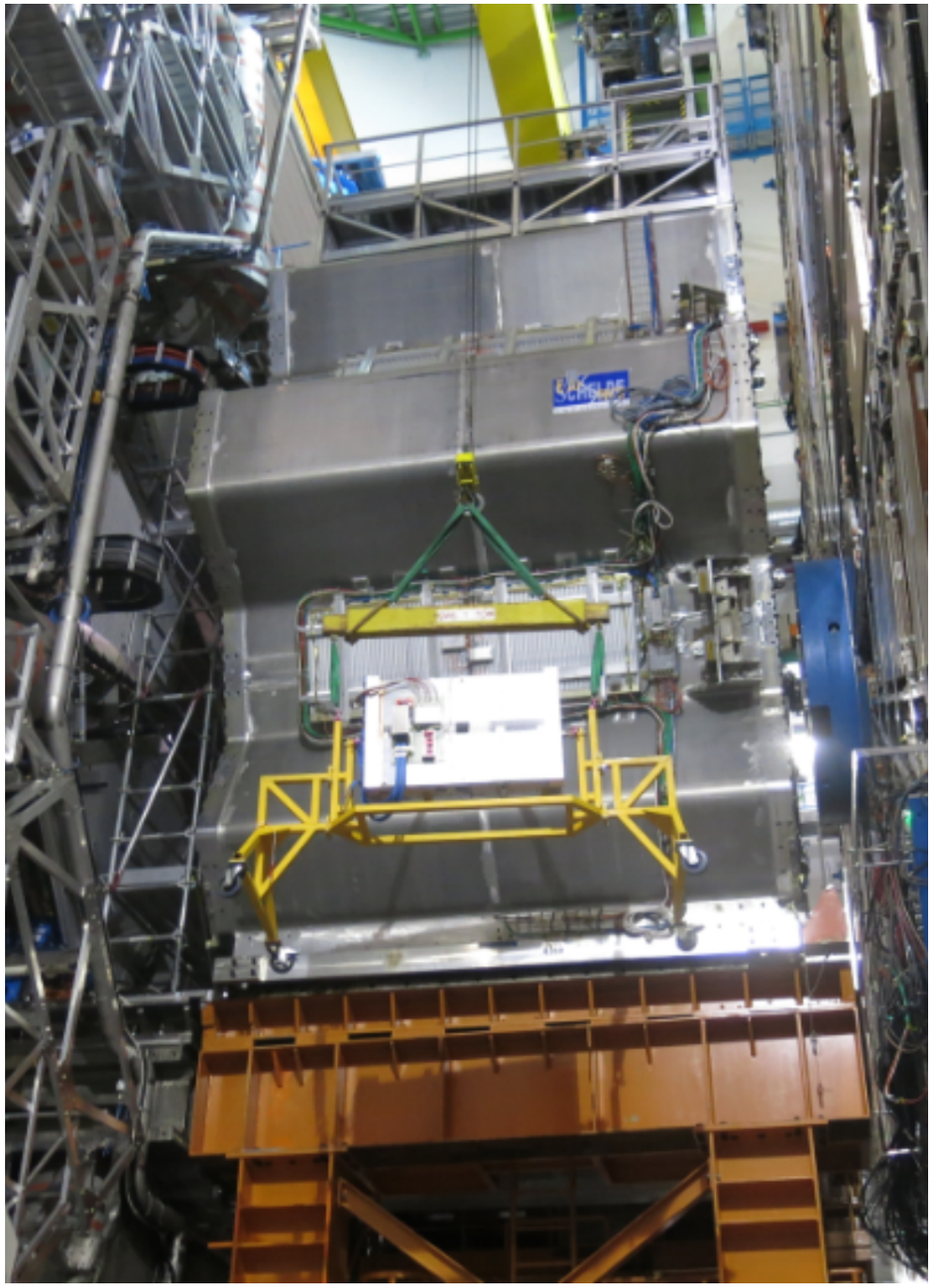


BMG: small additional barrel muon chambers in the feet of ATLAS: fill small acceptance holes in the middle station

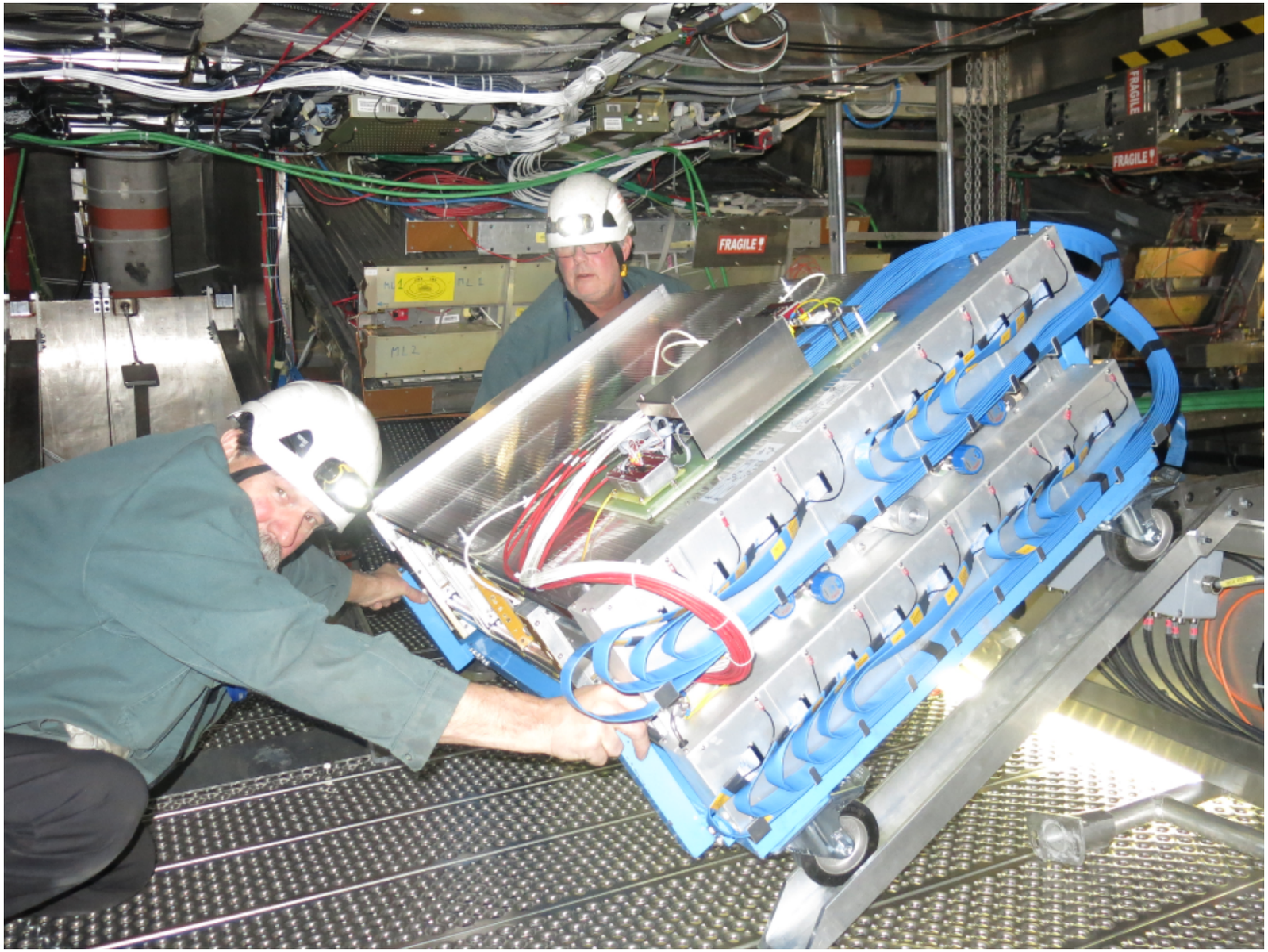


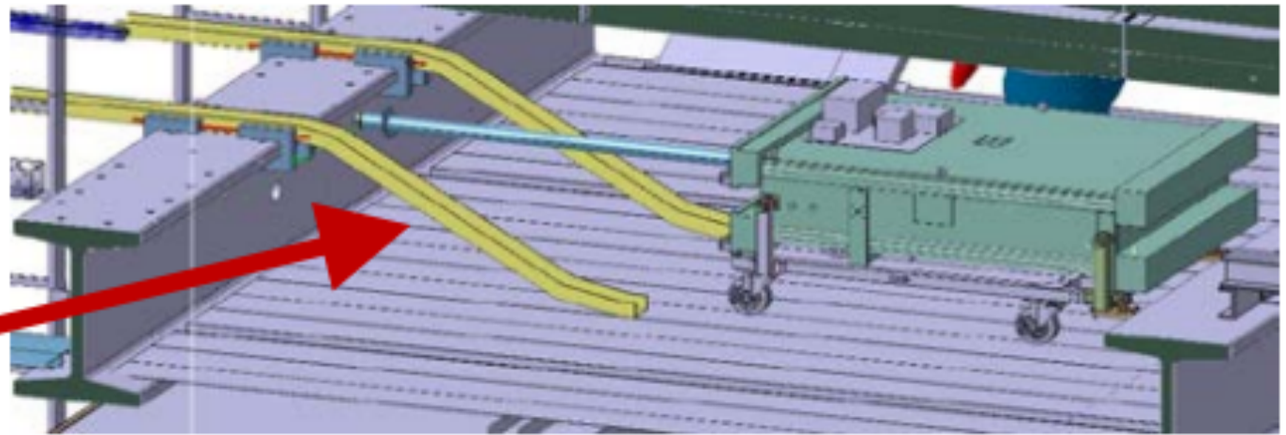


Preparing for 2017: BMG installation



Transport from surface



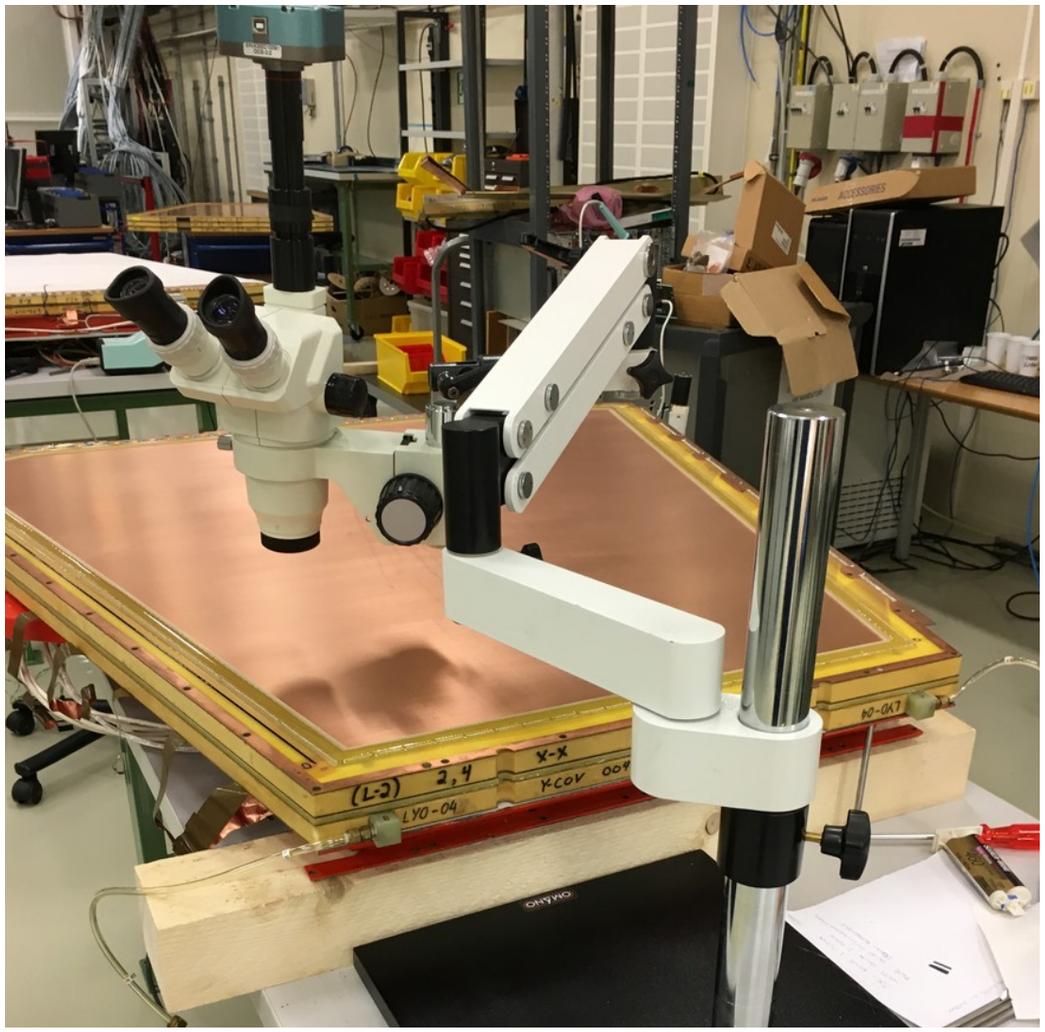


Installation rails for BMG1 and BMG2

Preparing for 2017: CSC repairs

- Two Cathode Strip Chambers with three dead layers due to broken wires (and "very sparky" other layers) have been removed, opened/repaired/closed in SR1, and re-installed

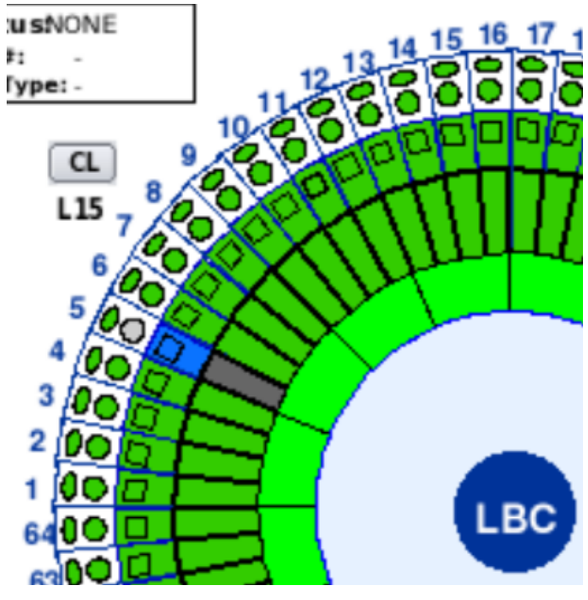
Transport to surface

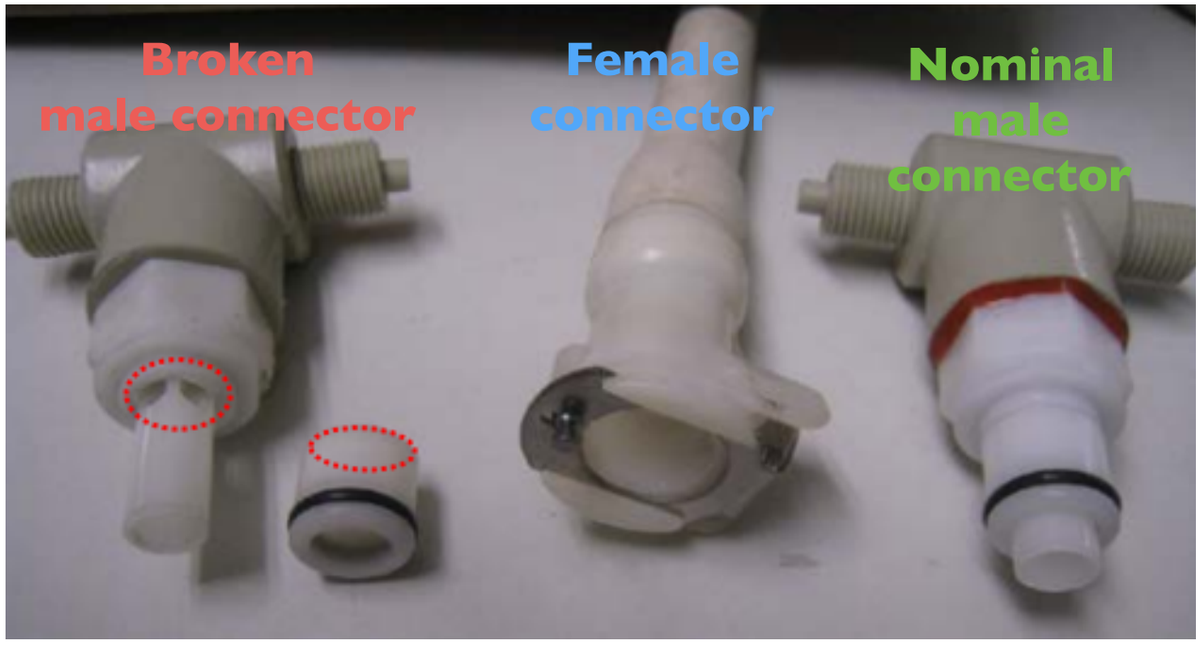


Microscope and inspection table at surface

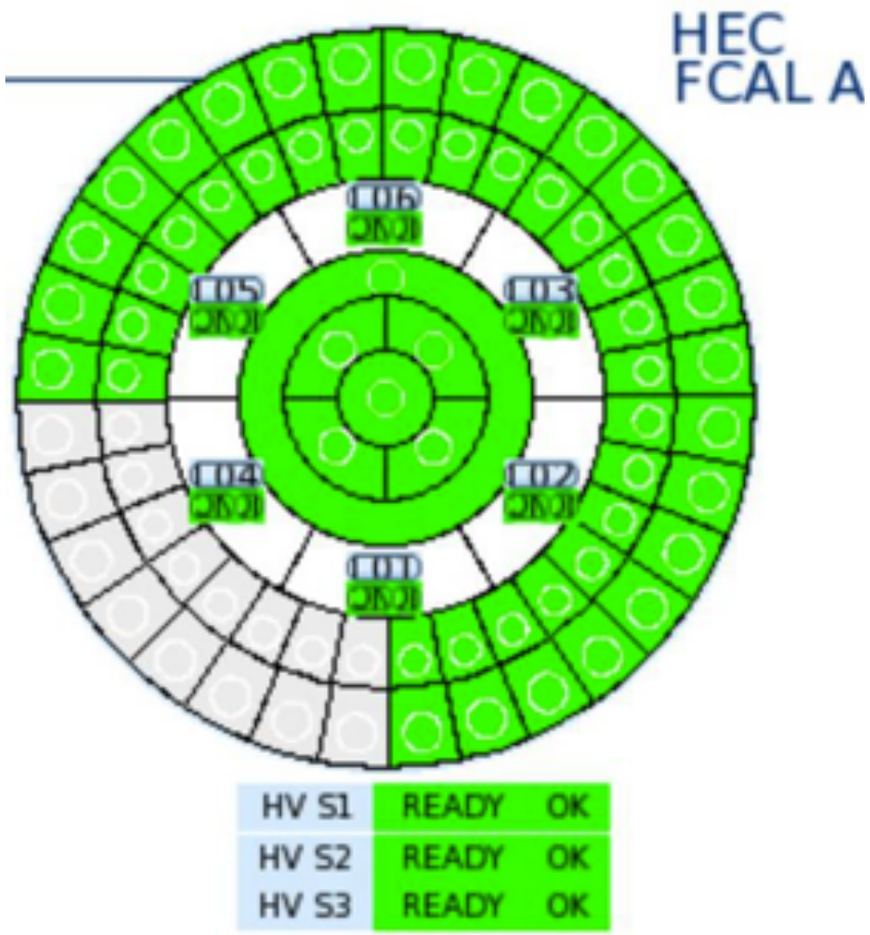
Preparing for 2017: calorimetry repairs

- Tile calorimeter
  - All main known problems for 2016/2017 maintenance already solved
  - especially: air leak into cooling system

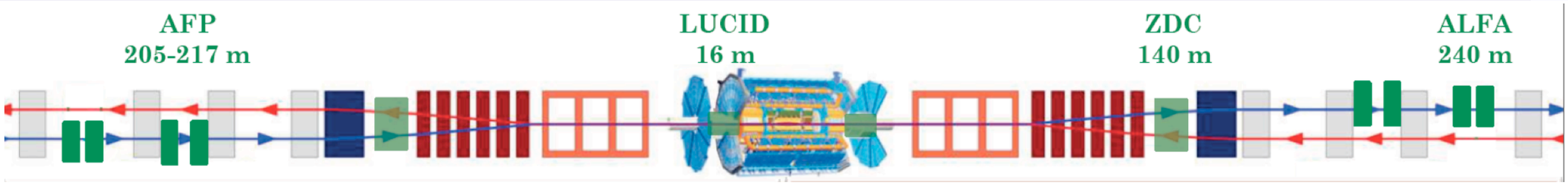


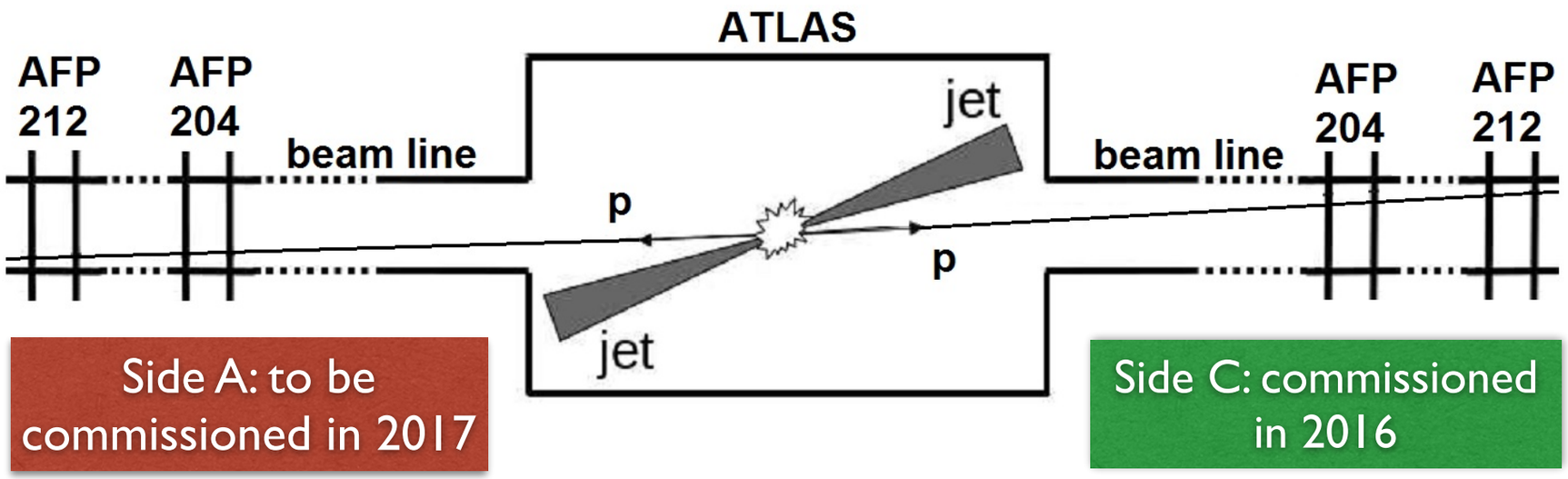


- Liquid argon
  - One quadrant of the A-side hadronic end-cap calorimeter off since October 29 (so affected Pbp/pPb runs)
  - 4 low voltage power supply boxes replaced during week of 16th January
    - 3 working but lost redundancy
    - In future, all HEC PS capacitors to be replaced

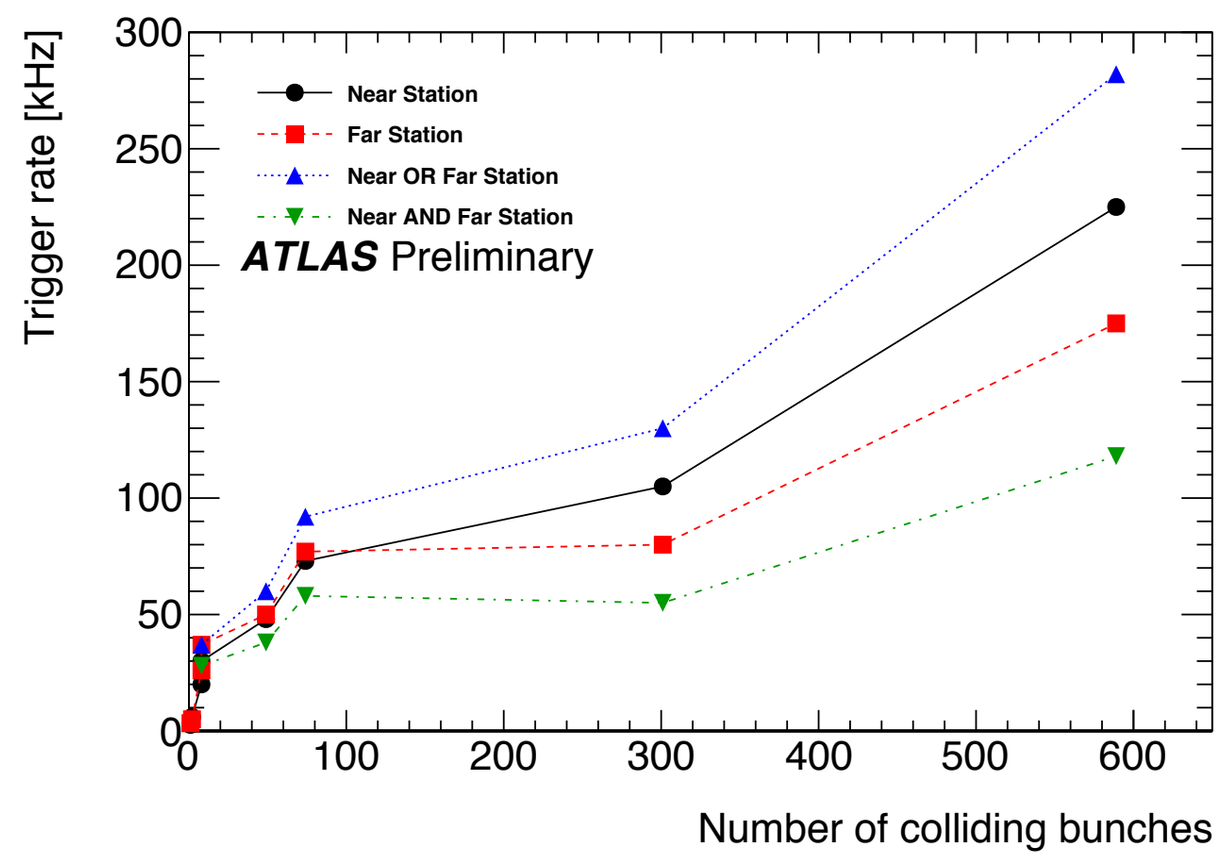


Preparing for 2017: forward detectors





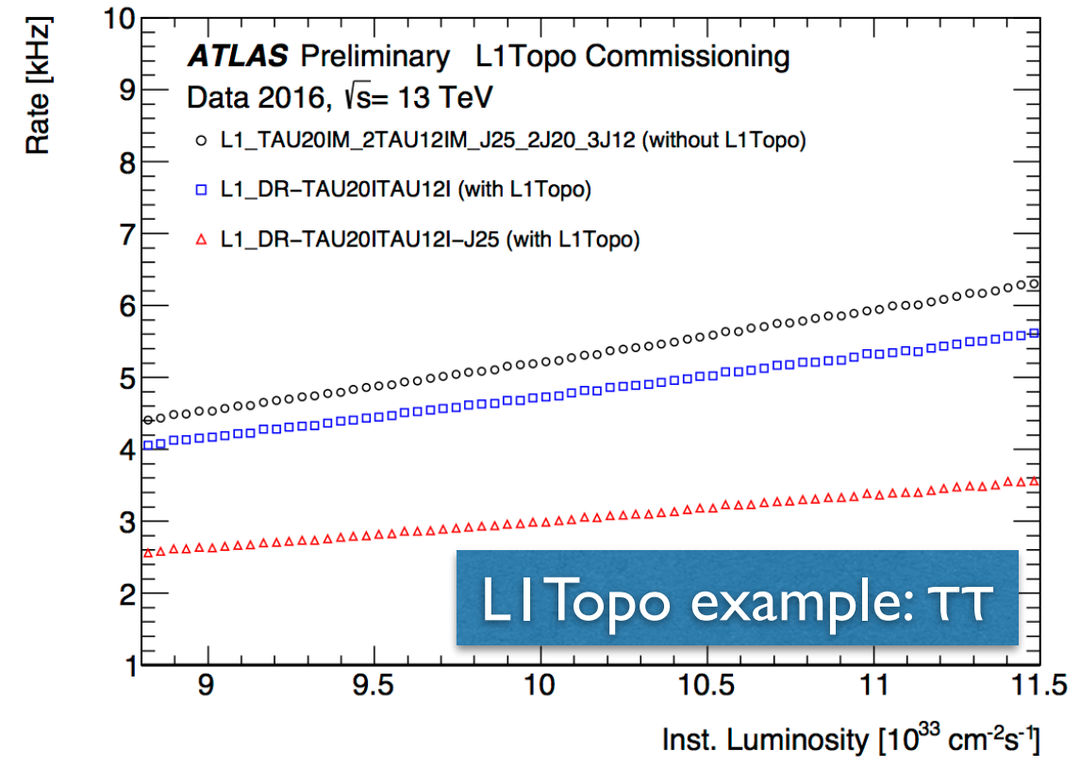
- AFP side C was fully commissioned in 2016; successfully took data in special low-luminosity runs for diffractive measurements
- Side A installed in 2017 TS, expected to be ready for data taking: plan to include AFP in high-luminosity running
  - Hard diffraction and anomalous couplings measurements



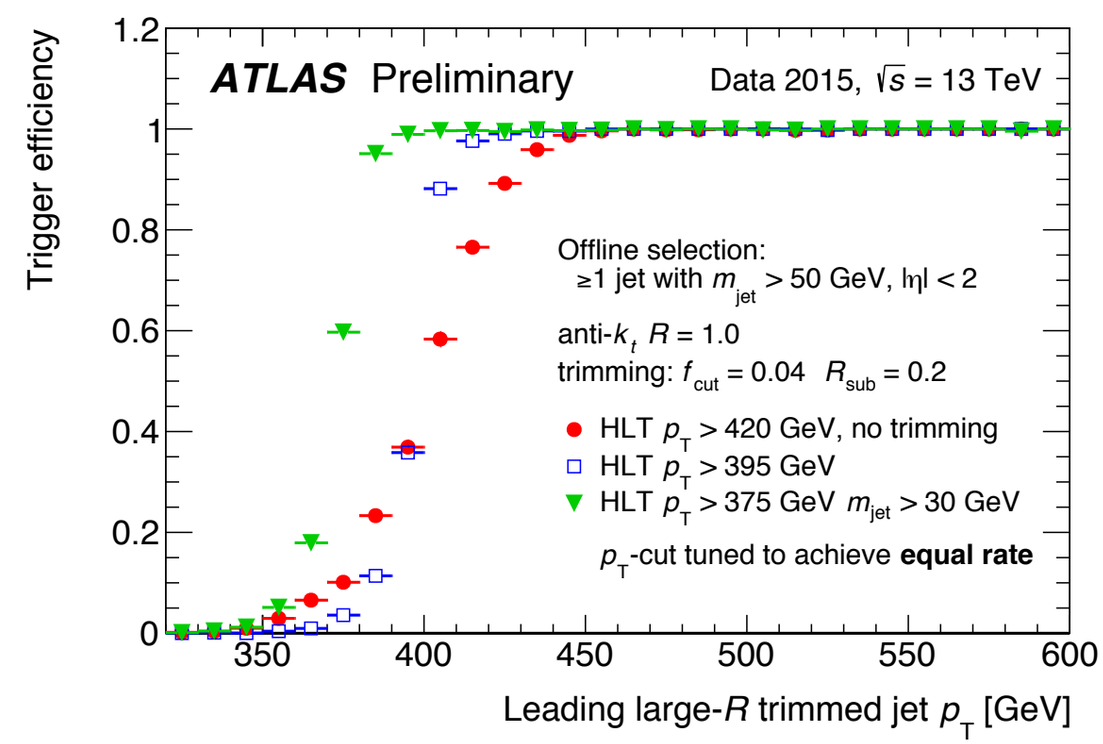
Roman Pot stations on A-side installed 12th January
Detectors & timing system in preparation

Preparing for 2017: getting ready for $2x10^{34}$ $cm^{-2}s^{-1}$

- Level 1 topological trigger
  - Apply real-time kinematic and angular cuts at L1 - reduces the L1 rate, critical for high-luminosity running
  - Hardware stable for a year, expanded menu and firmware for 2017 ready
- High Level Trigger
  - Keep thresholds as low as possible
  - Working to reduce HLT CPU use by 15-20%
  - Keep data volume manageable for offline
- ID can run at 100 kHz and mu=60 with >99% of the chips enabled
  - e.g. IBL/Pixel DAQ: significant upgrade of readout hardware (module to back-of-crate card and back-of-crate card to read out system)

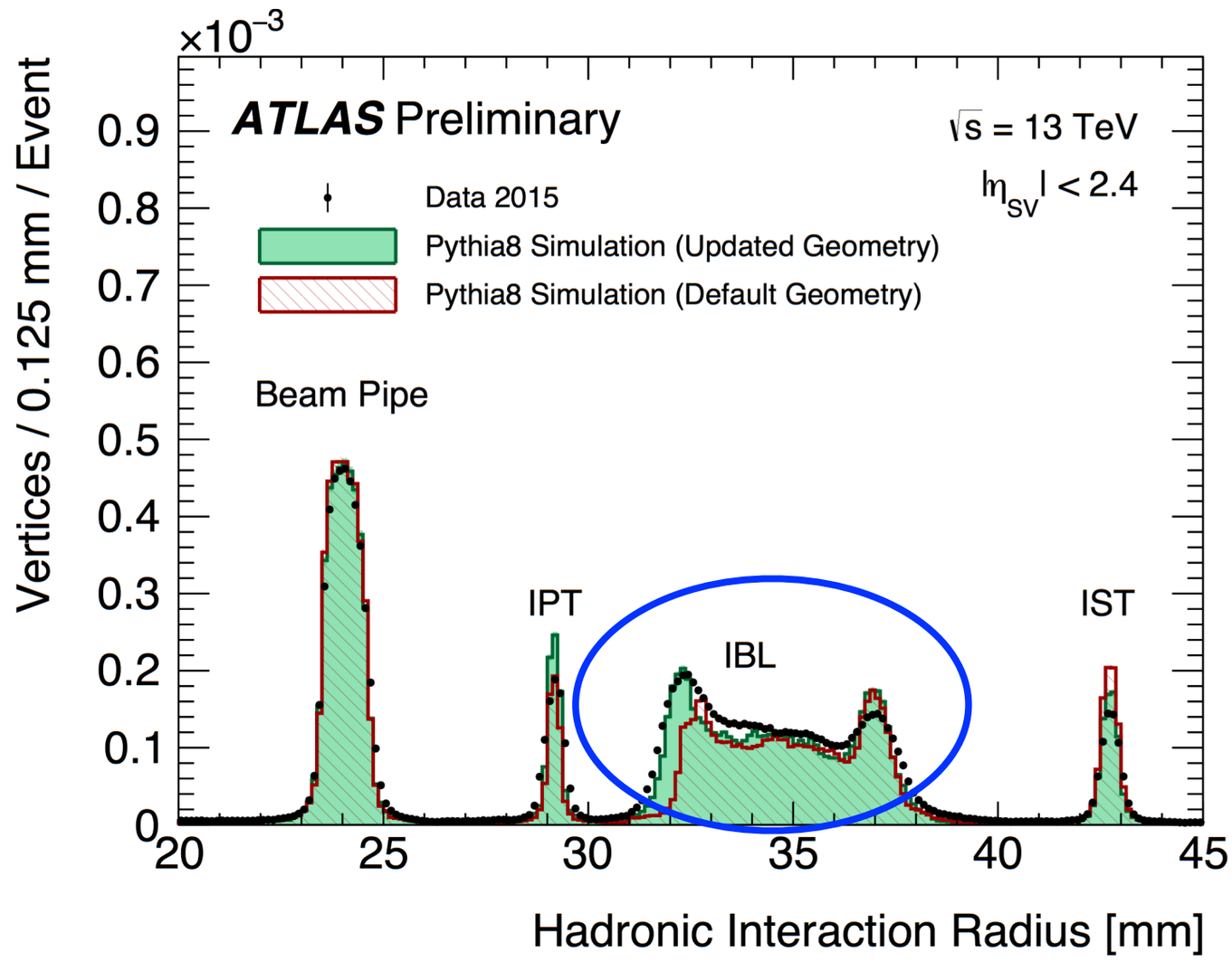


L1Topo example: ττ



Preparing for 2017: simulation and reconstruction

- Release 21: software for 2017
  - reconstruction of new data, simulation/reconstruction of MC, reprocessing of earlier Run 2 data
- Simulation
  - 15% speed-up w.r.t. previous release for full detector simulation
    - New Geant4 version, new gcc version code cleanup
  - Updated physics list and geometry



- Reconstruction
  - Numerous changes and improvements to the software, calibrations and alignments
  - Content of the reconstruction output (AOD) carefully optimized to reduce the size, achieving a slight reduction of our 2018 storage requests by moving some CPU-light reconstruction into the analysis-format building (DAODs)

Preparing for 2017: computing and software

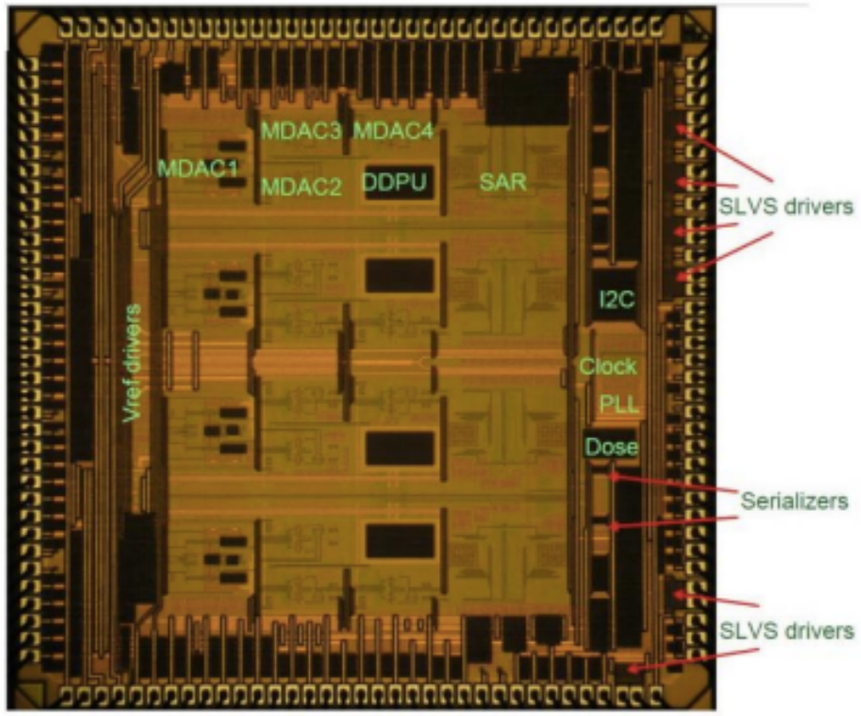
- Software management
  - ATLAS software has 4.1M lines of C++, plus python configuration
  - 2017 sees introduction of industry-standard tools and practices to manage it

	Old	New	Why?
Build system	CMT	CMake	Build speed, scale, flexibility, maintenance
Version control	Subversion (SVN)	Git GitLab	Offline working, fast, efficient, merge requesting, maintenance
Continuous integration		Jenkins	Software quality, workload reduction

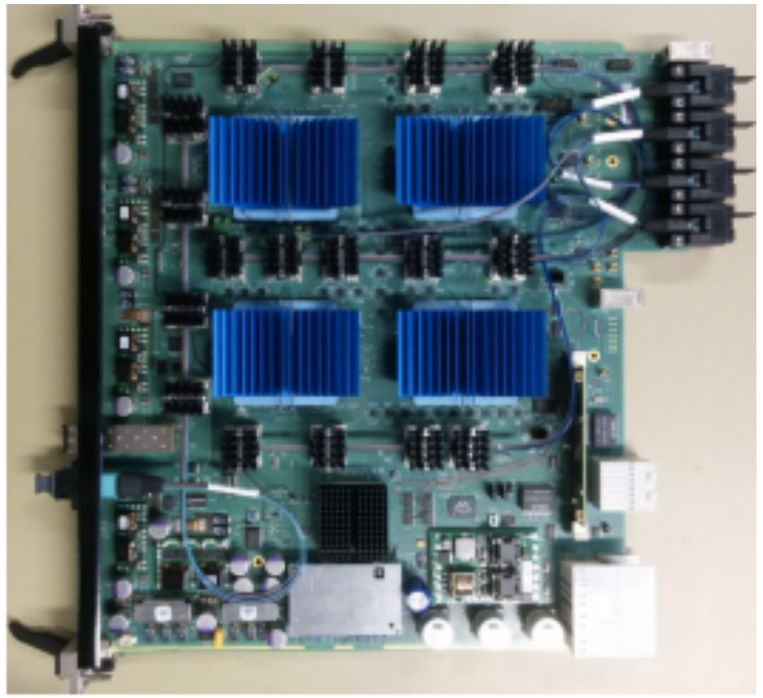
- Data analytics platform: introduction of ElasticSearch and Kibana: enable detailed monitoring and analysis of our usage of computing resources

Very brief update on Phase-1 Upgrades

(in-depth review by LHCC occurred on Monday this week)



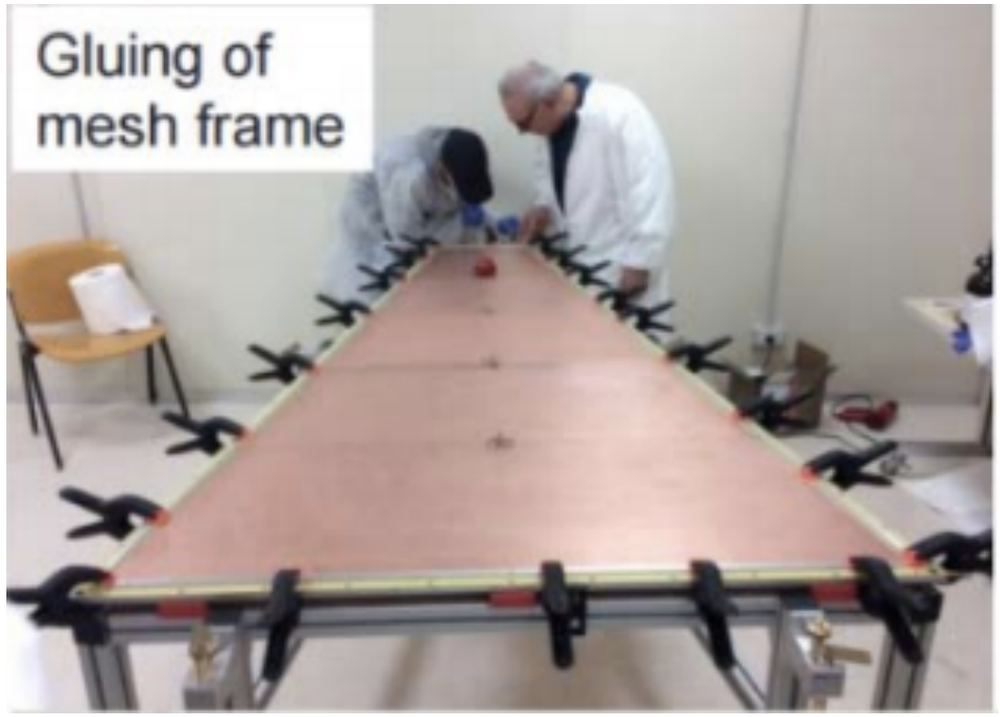
Nevis ASIC



eFEX prototype

FTK: crate at P1

Project	Status
Fast TracKer	On track (commissioning in 2017)
TDAQ	On track
LAr calorimeter	On track
New Small Wheel	Progress but delays acquired

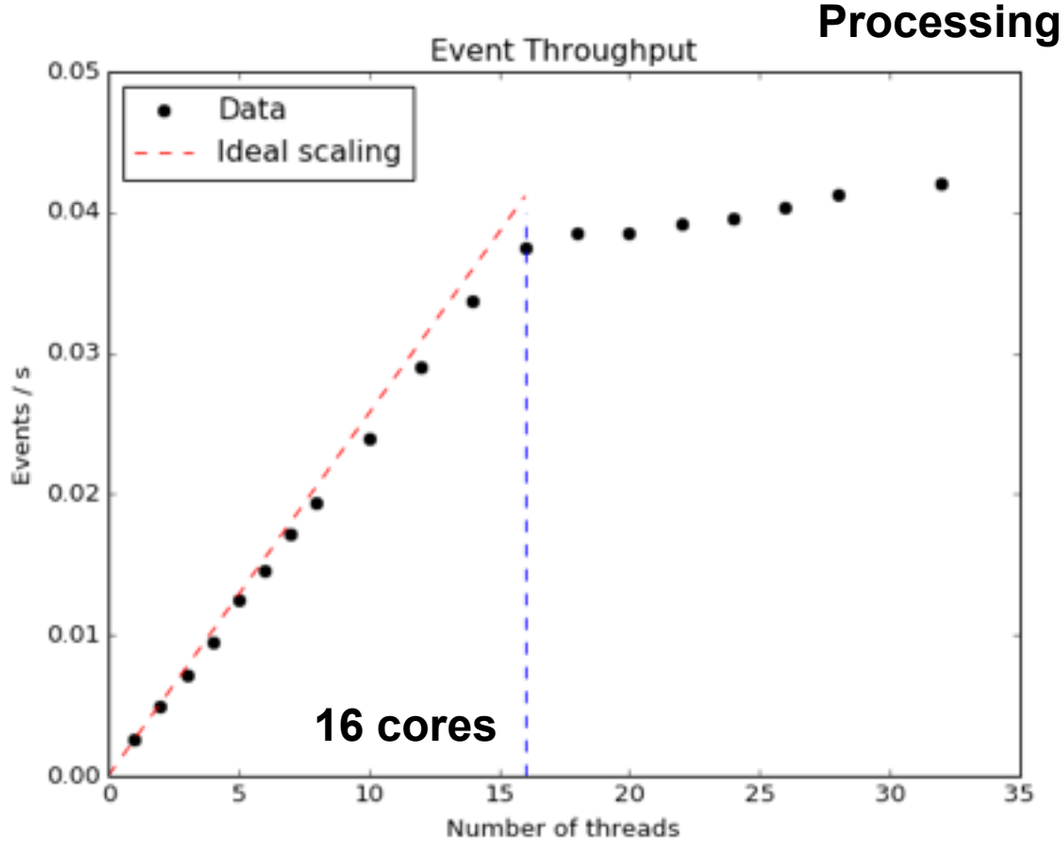


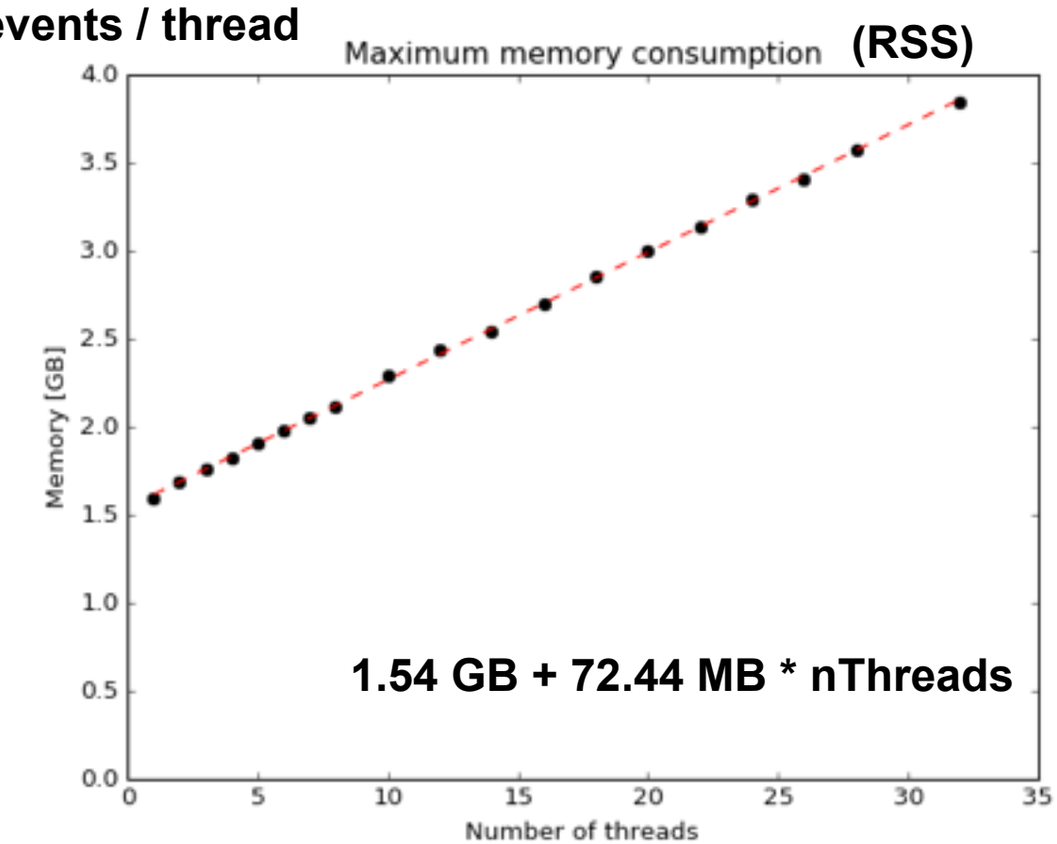
Micromegas for New Small Wheel

Preparing for Run 3: multi-threaded software

- CPUs are getting *wider* but aren't getting *faster;* memory per core isn't getting *cheaper*
- In order to make full use of new computing resources and achieve the throughput required for Run 3, we *must* use multi-threaded software (multi-processing with copy-on-write already in use)
- ATLAS software release 22 will be multi-threaded
  - Major effort involved to make all components *thread safe*
  - Algorithm migration under way; optimisation 2018, integration and full deployment during 2019

Processing 50 events / thread

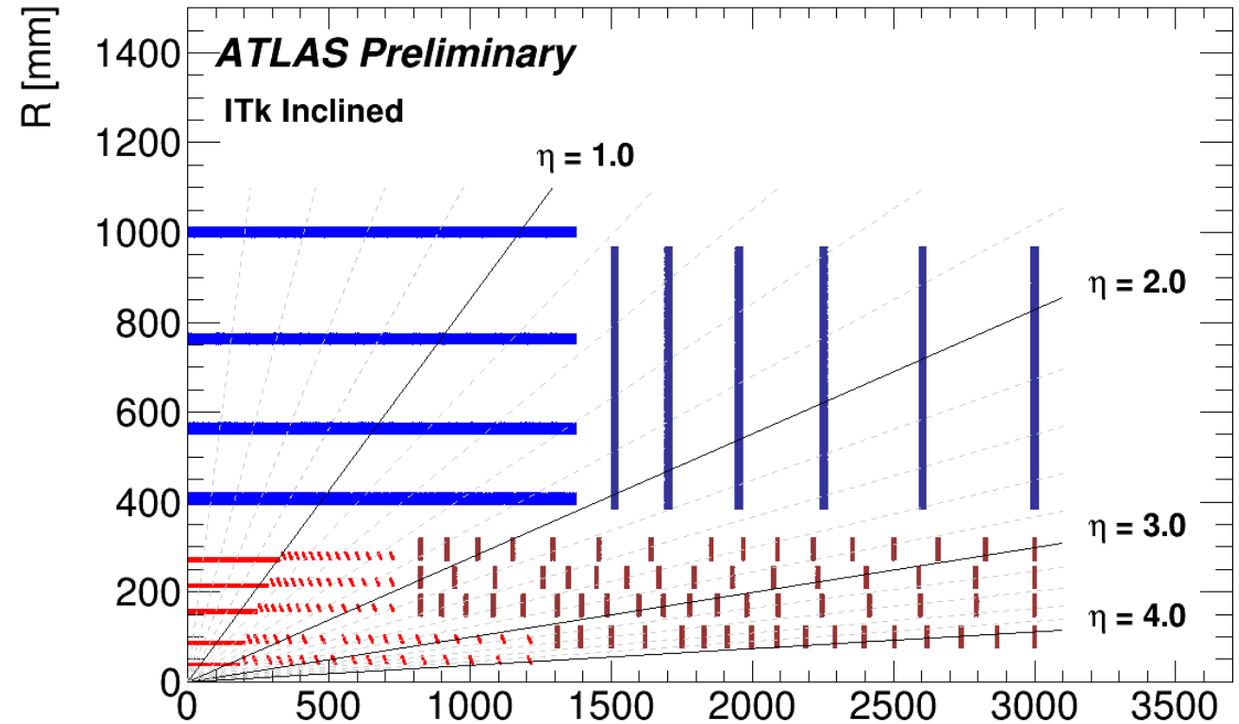


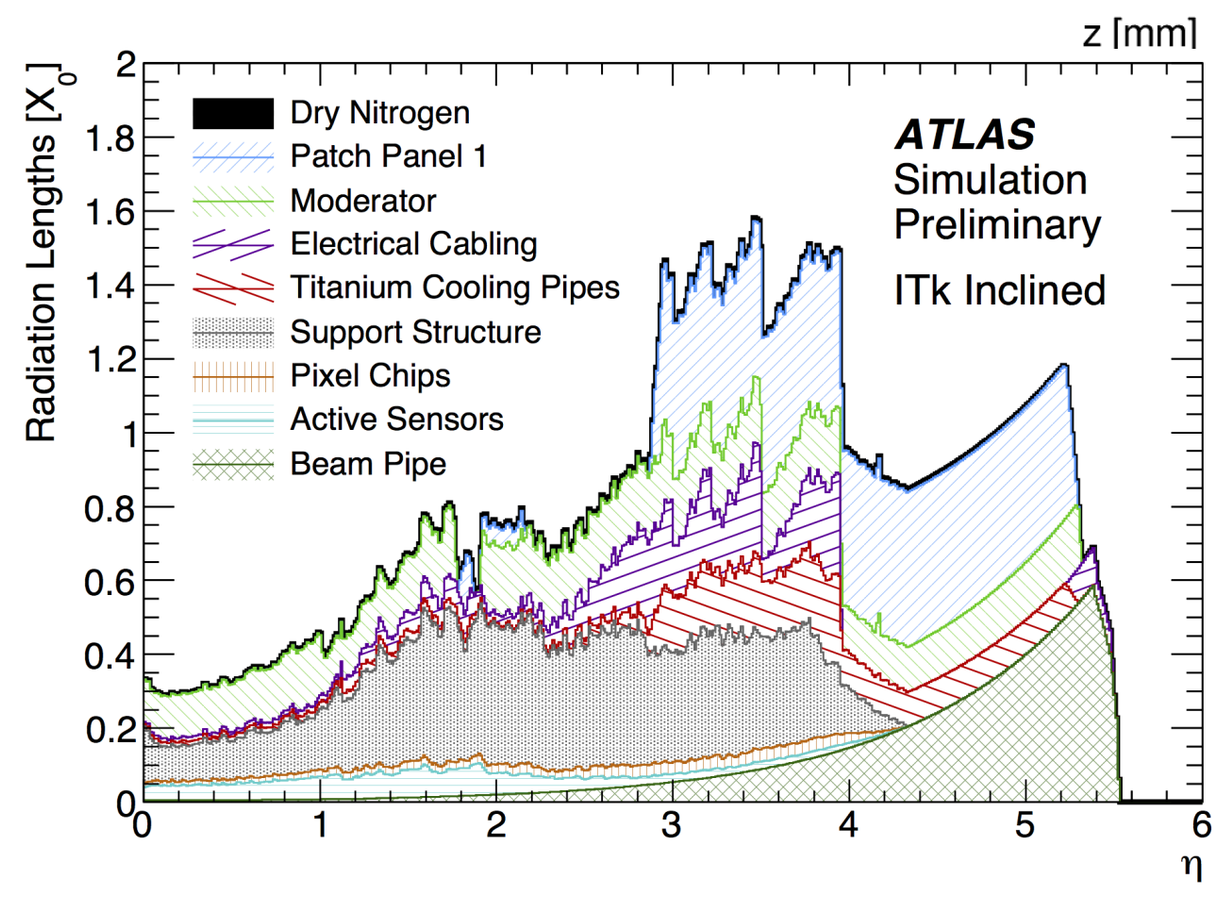


S. Farrell, CHEP 2016: Z→ττ simulation (not full ATLAS)

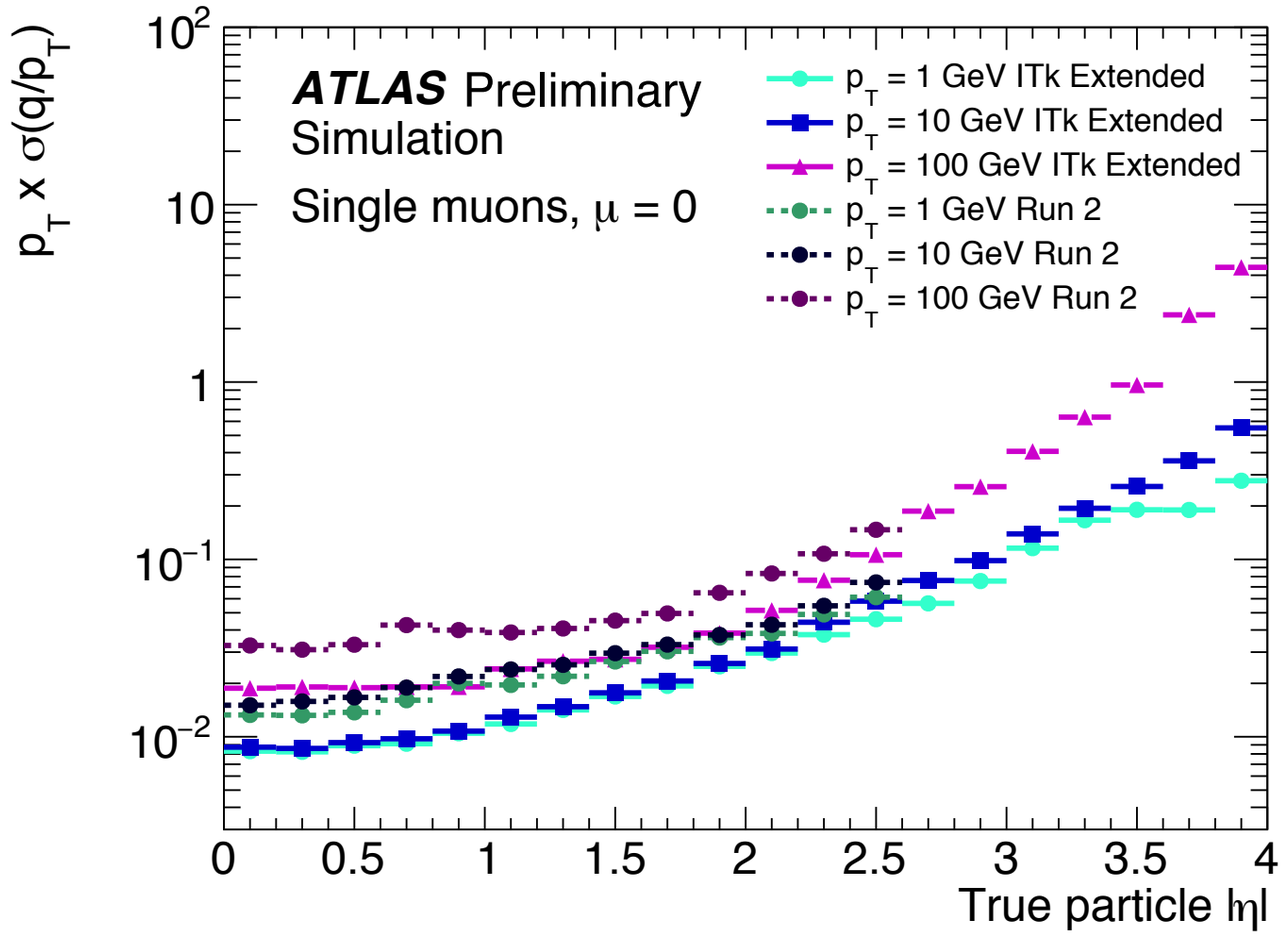
Preparing for Run 4: phase II detector upgrades

- First Phase-II TDR submitted to LHCC referees on 20 January: ITk Strip Detector
- ITk
  - Full replacement of inner tracker, all-silicon detector
    - 165 m^2 of silicon
  - Pixel system will extend to larger radii than today, with a larger coverage in the forward region
  - Minimal amount of inactive material in the tracking volume (2-3x less than in the current tracker)
  - Designed for pile-up values up to ~200
  - Optimized for high and robust tracking efficiency, track parameter resolutions, two-track separation, while minimizing fake tracks

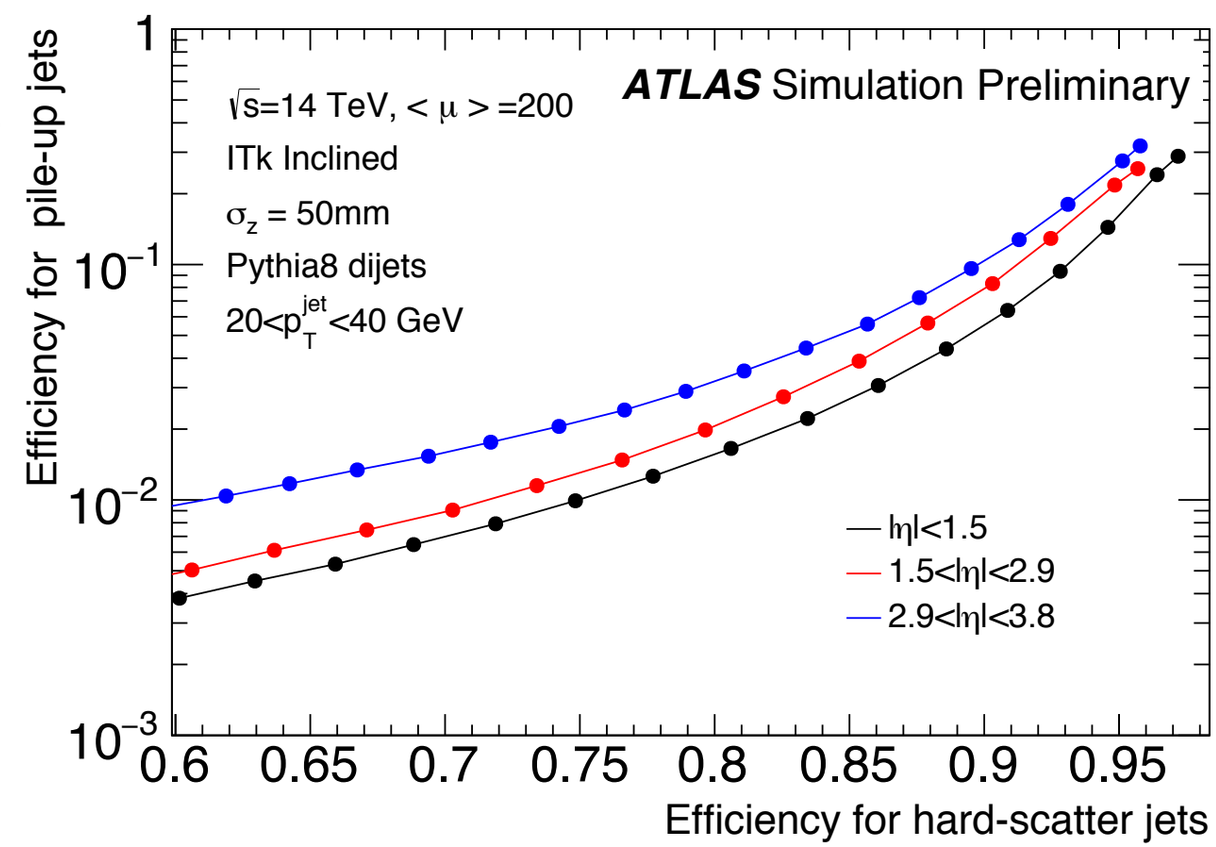




Preparing for Run 4: phase II detector upgrades



Transverse momentum resolution versus pseudorapidity for ITk and current ID (muons)



Distinguishing between hard-scatter jets and pile-up jets at high pile-up is one of the main jobs of the ITk

Summary

- The LHC and ATLAS had another superb running year in 2016
- High-precision measurements from Run 1 data have now been completed by ATLAS, in particular the W mass and the W and Z production cross sections
- The work in the ATLAS cavern during the 2016-2017 year-end technical stop is proceeding well and according to schedule
- The trigger is being prepared to face the rigours of 2017 data taking
- New software infrastructure is being put in place, and the 2017 software release is nearly ready
- Development of the multi-threaded software framework for Run 3 is well advanced, and migration of the algorithms is now beginning in earnest
- ATLAS has just submitted the TDR for the ITk Strip Detector

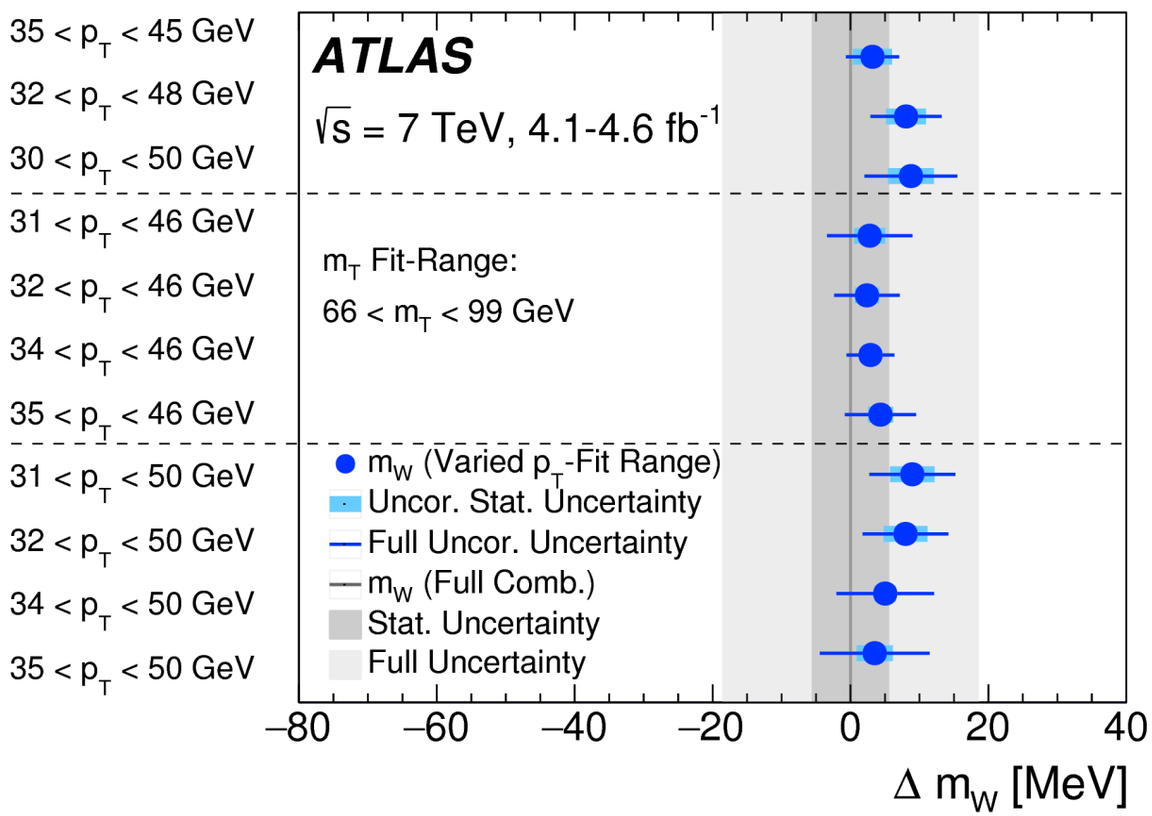
ATLAS is looking forward to the 2017 run!

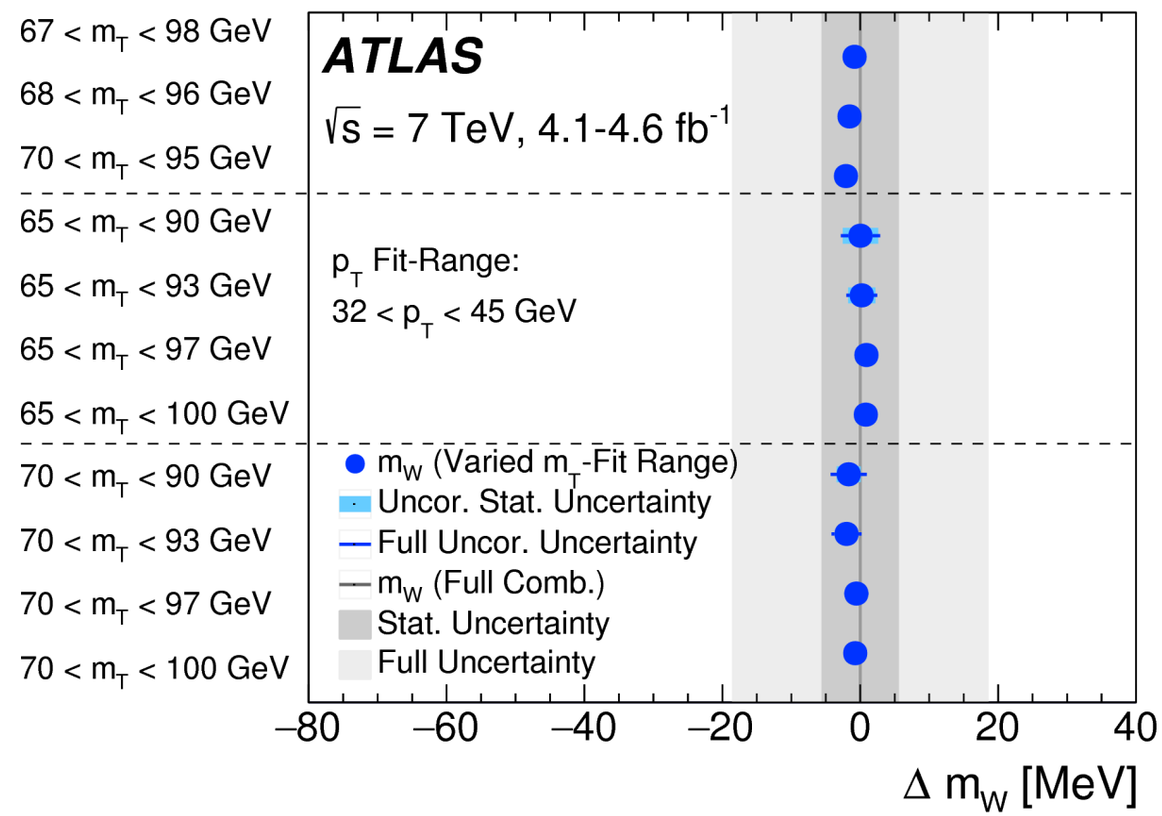
Supplementary slides

W mass

7 TeV, 4.6fb^{-1}

Stability in slices of m_T and p_T

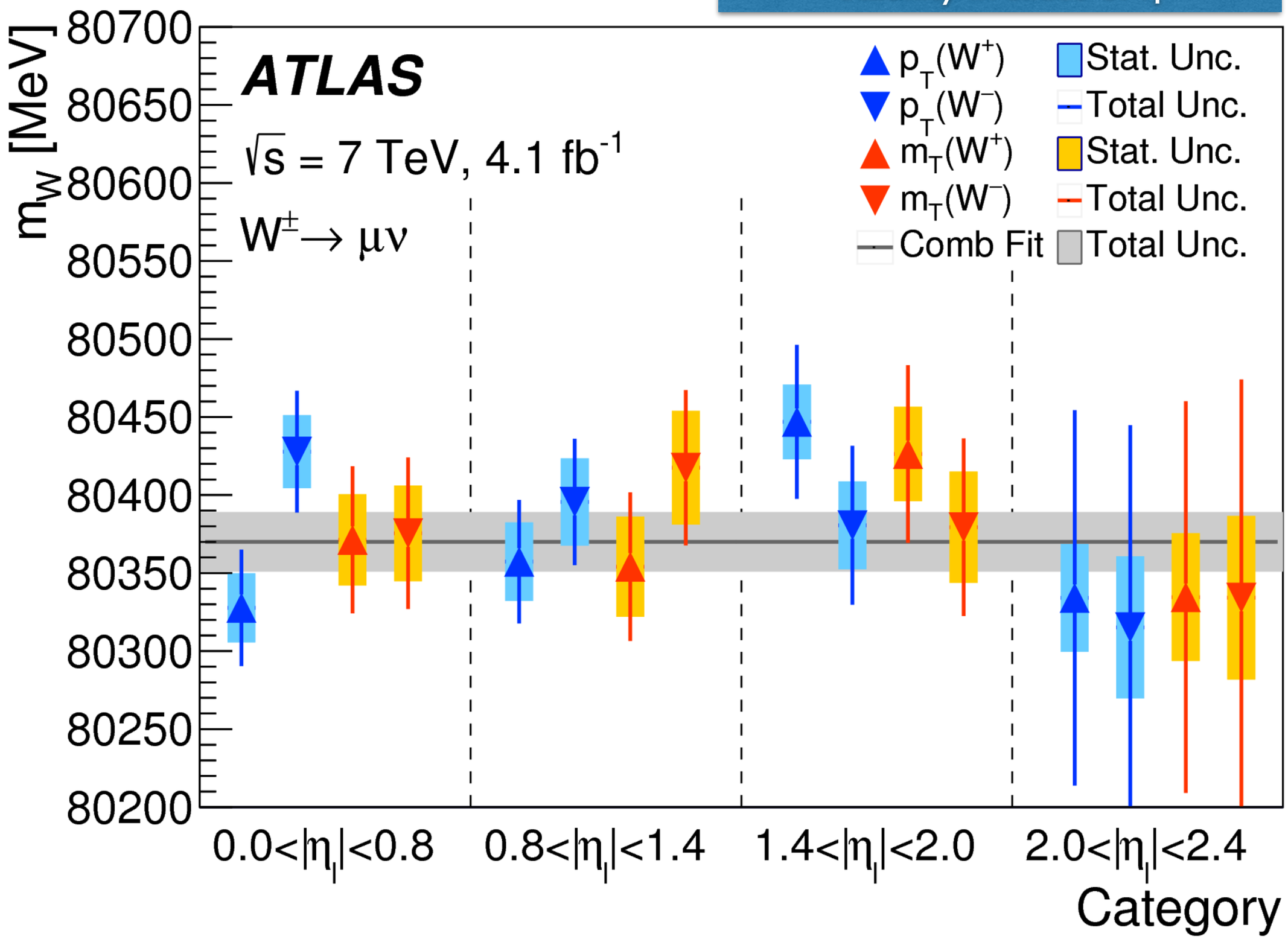




W mass

7 TeV, 4.6fb^{-1}

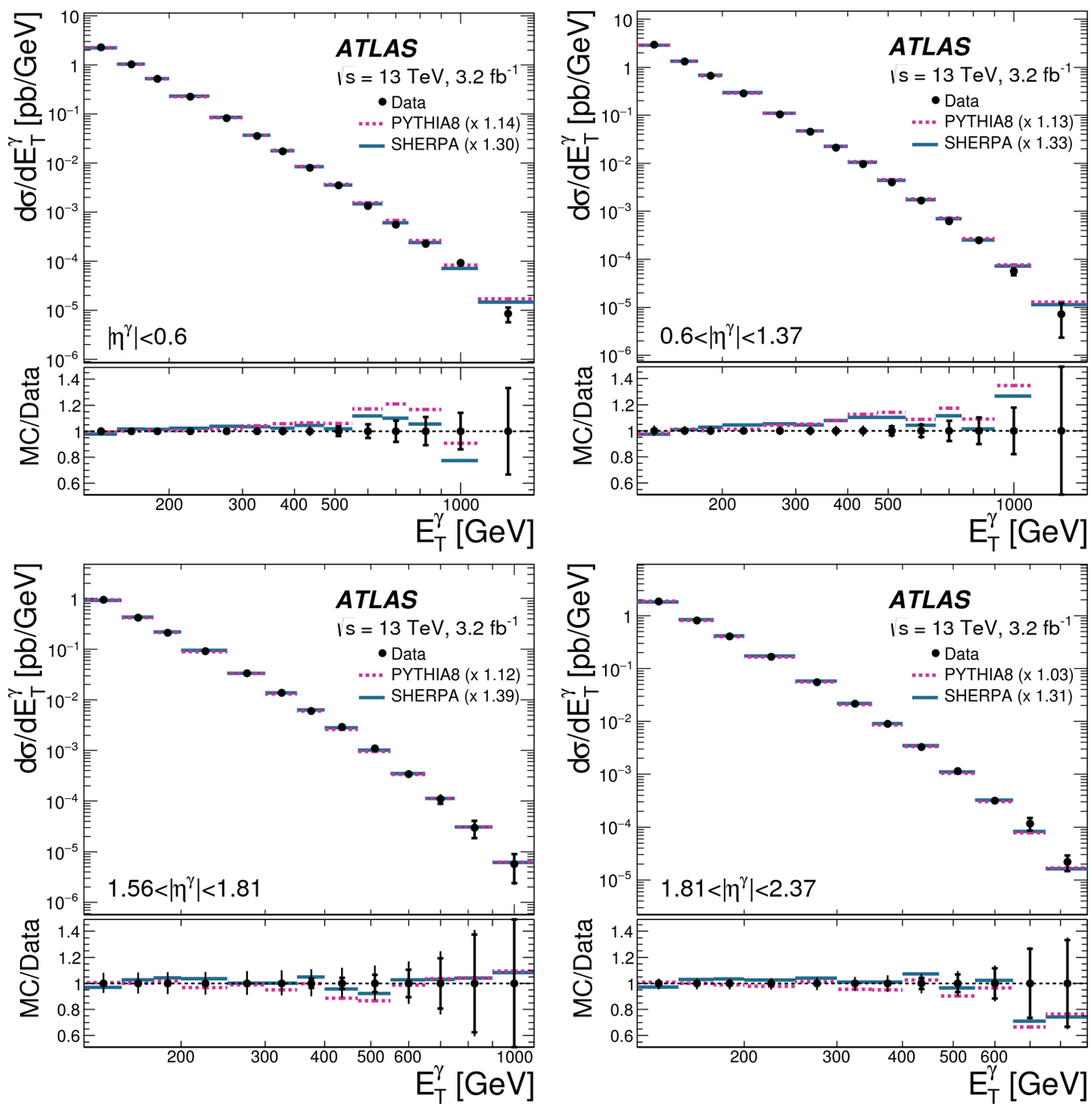
Stability in slices of η



Isolated prompt photon production

13 TeV, 3.2fb^{-1}

Comparisons with predictions from Pythia and Sherpa



W and Z production cross sections

7 TeV, 4.6fb^{-1}

- Five independent measurements of differential and integrated cross sections
  - $W \rightarrow (e,\mu)\nu$: differential in $|\eta_{(e,\mu)}|$
  - $Z \rightarrow (ee,\mu\mu)$: differential in $|y_{(ee,\mu\mu)}|$ for three mass bins
    - $Z \rightarrow ee$ central-central and central forward treated separately
- e and μ channels combined and compared to NNLO QCD
- Results used as inputs for QCD analysis → new NNLO PDF set: `ATLAS-epWZ16`
- Multi-jet backgrounds from data-driven estimation; rest from MC
- New measurement replaces 2010 data with 2011: 100x statistics, more precise luminosity determination (3.5%→1.8%), better understanding of the triggers and the performance → reduced systematics

Electron-muon universality