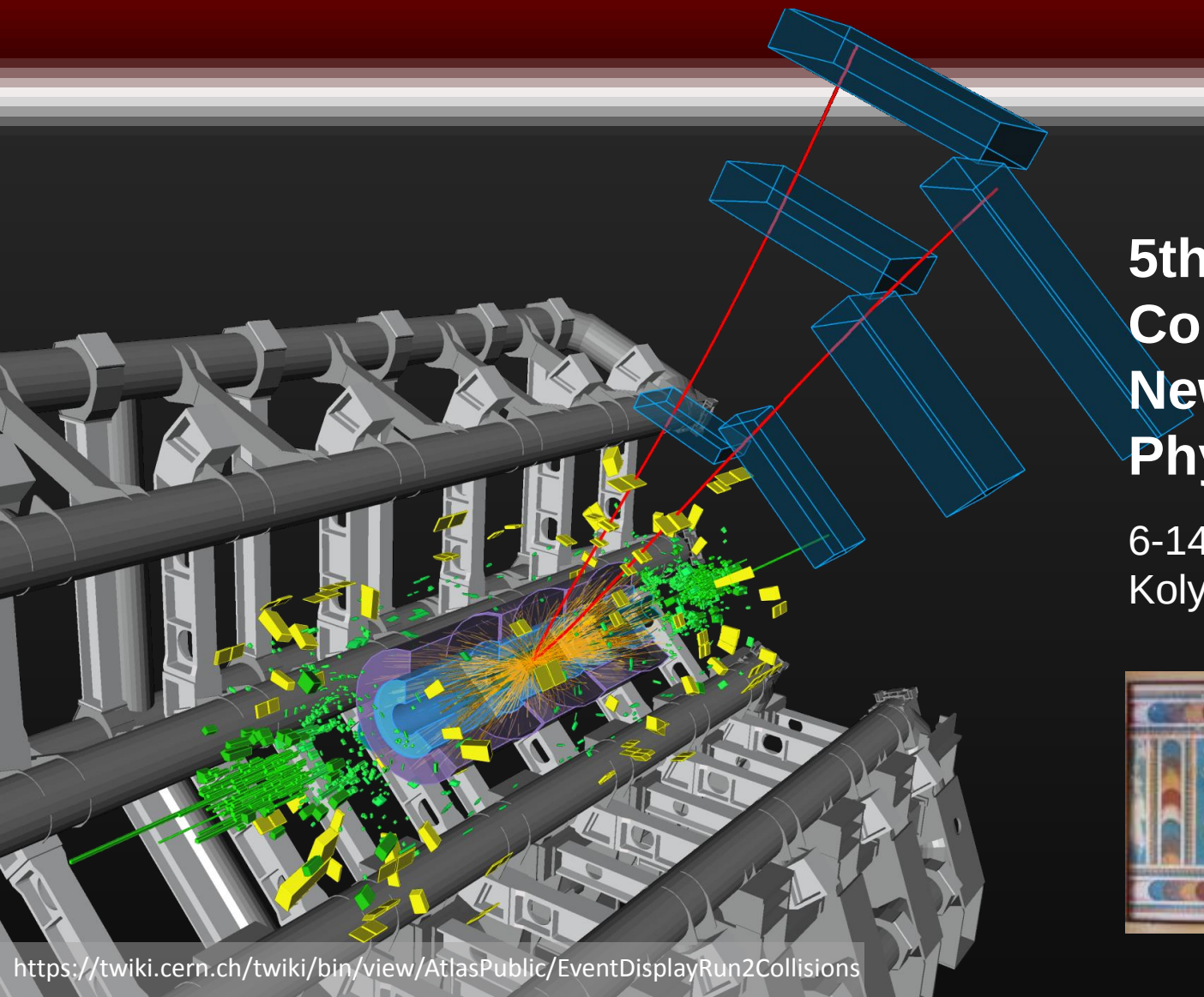
Performance of the ATLAS Detector in Run 2

Nicoletta Garelli
SLAC
on behalf of the ATLAS Collaboration



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Collisions

5th International Conference on New Frontiers in Physics

6-14 July 2016,
Kolymbari, Greece

Outline

- ATLAS upgrades during the Long Shutdown 1
- Improvements for 2016 and current status
- Detector performance in 2015

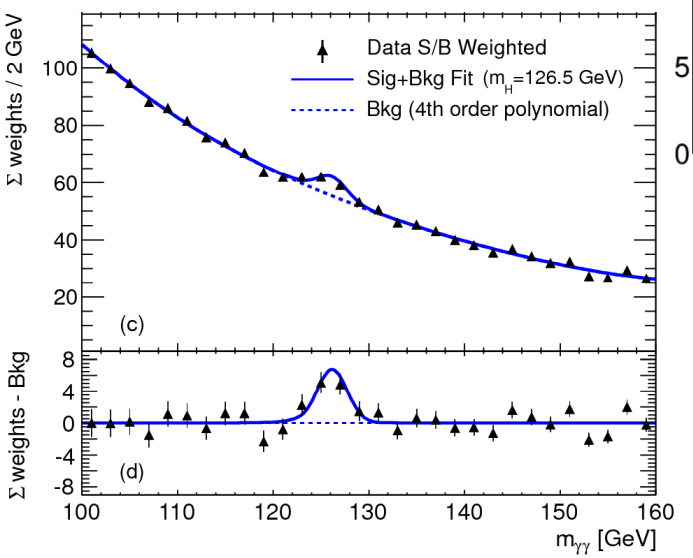
ATLAS talks @ICNFP2016 to complete the picture:

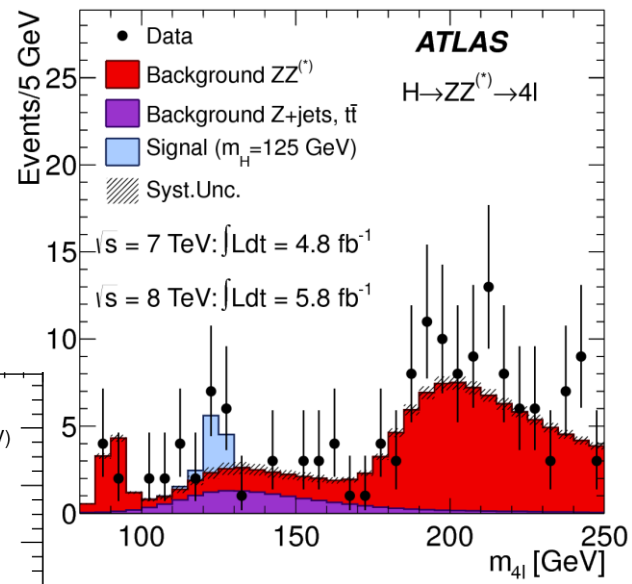
- Trigger performance by *Antonia Strubig* yesterday
- Physics performance (*Evgeny Soldatov, Fairouz Malek, Xiaohu Sun, Riccardo Maria Bianchi, James Beacham, Rachid Mazini, Bora Atlay, Ewa Stanecka, Maria Jose Costa*)
- Muon reconstruction (*Pierre-Francois Giraud*) and b-tagging (*Ian Allan Connelly*) performance
- Upgrade prospects by *Stefania Antonia Stucci* on Thursday and *Masaya Ishino* for the trigger on Wednesday

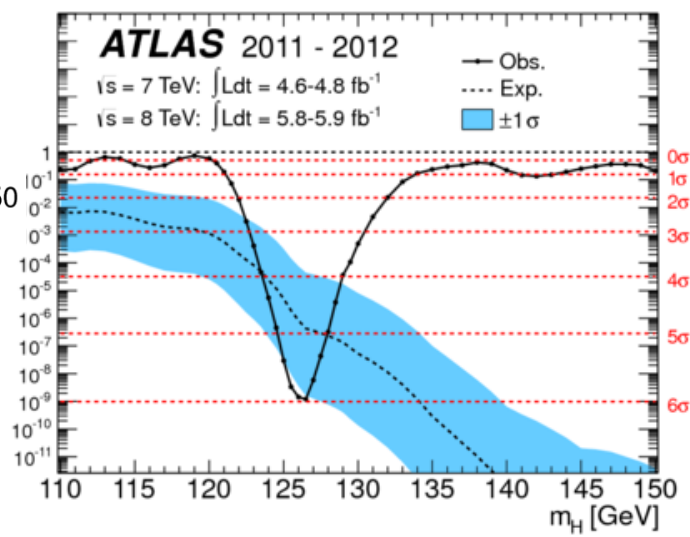
Discovery of H(251)

In 2012, with ~10 fb^{-1} of data at 7-8 TeV, a new particle observed with mass ~125 GeV in the $H \rightarrow \gamma\gamma$ and $H \rightarrow 4l$ decay channels

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

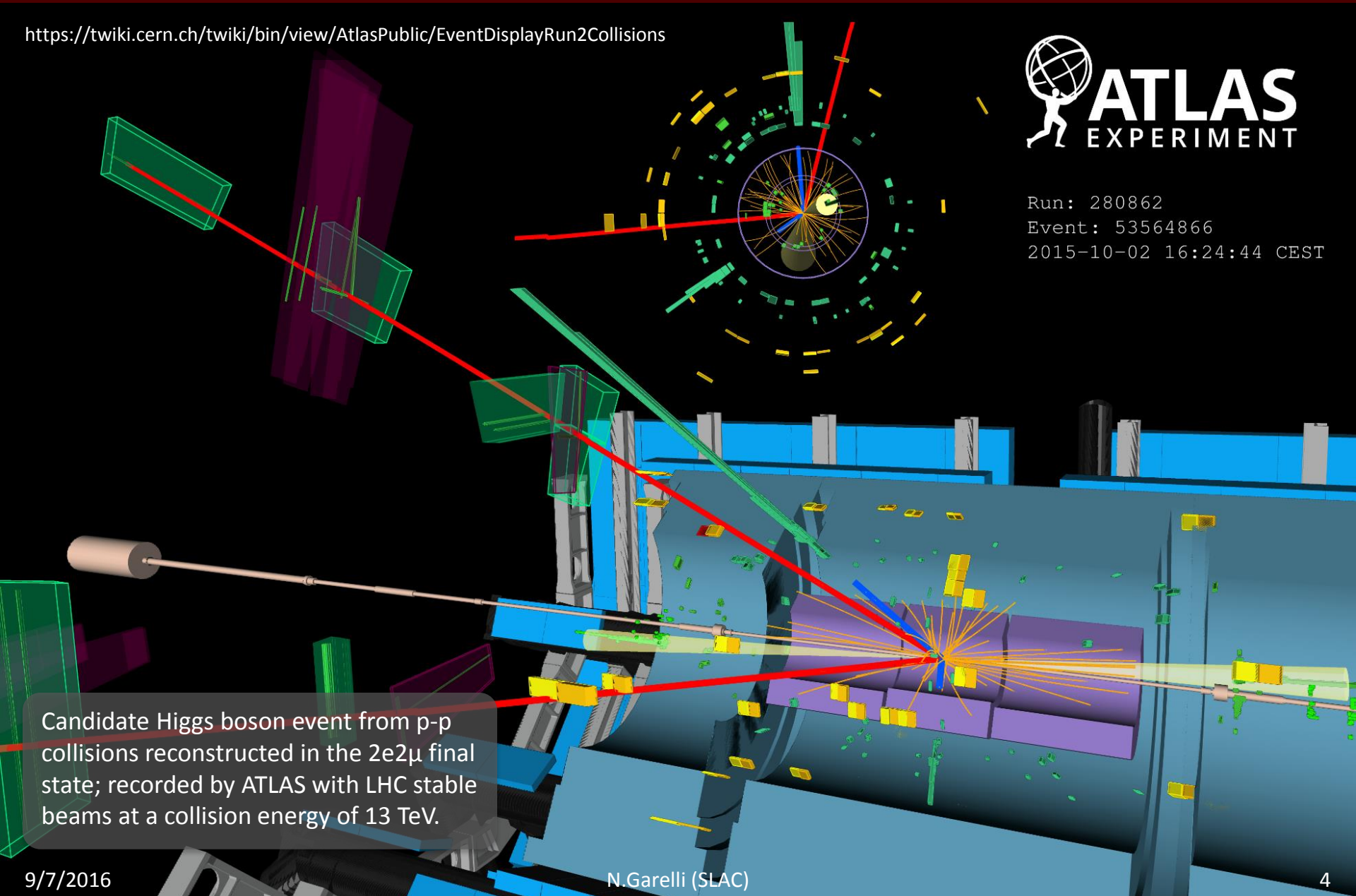






Run-2 : a New Era for HEP

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Collisions



Candidate Higgs boson event from p-p collisions reconstructed in the 2e2μ final state; recorded by ATLAS with LHC stable beams at a collision energy of 13 TeV.

Run-2 LHC Conditions

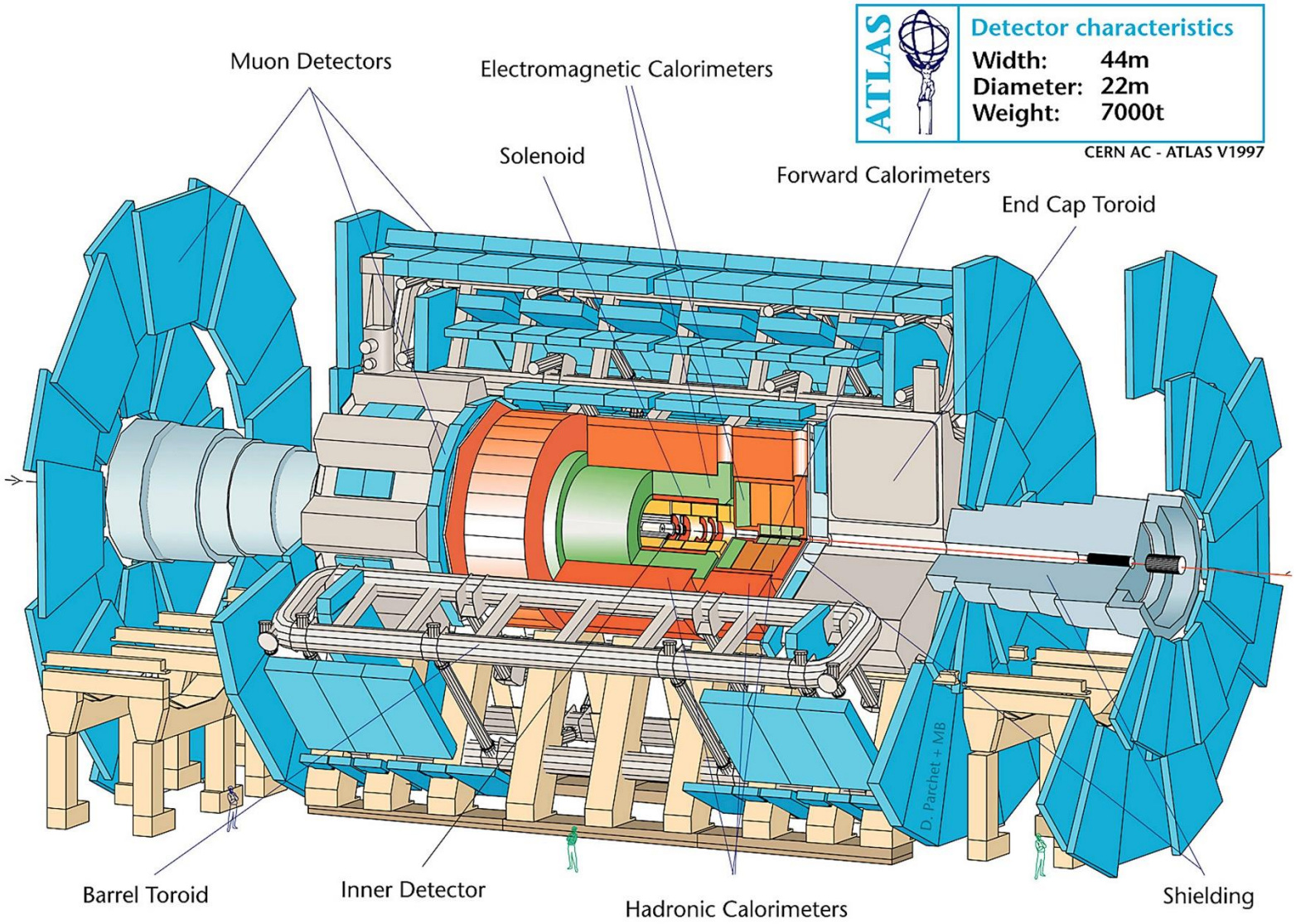
Long Shutdown 1 (LS1) = 2 years for upgrading the machine

Parameter	Run 1	Overall Run 2 (expected)	Design
Center of Mass Energy	7 (8) TeV	13 (14) TeV	14 Tev
Bunch spacing	50 ns	25 ns	25 ns
Integrated Luminosity	~ 30 fb^{-1}	~100 – 150 fb^{-1}	500 fb^{-1} (*)
Peak Instantaneous luminosity	7.5 10^{33} cm^{-2} s^{-1}	**1.3-1.5 10^{34} cm^{-2} s^{-1}**	10^{34} cm^{-2} s^{-1}
# bunches	1400	2550-2808	2808
Max pile-up	~30	**~40**	~25

LHC is working extremely well!

(*) extrapolation from integrated luminosity in Run 1, up to 2021
Numbers taken from LHC Performance Workshop (Chamonix 2014 and 2016)

The ATLAS Detector at a Glance



Detector Upgrades during LS1

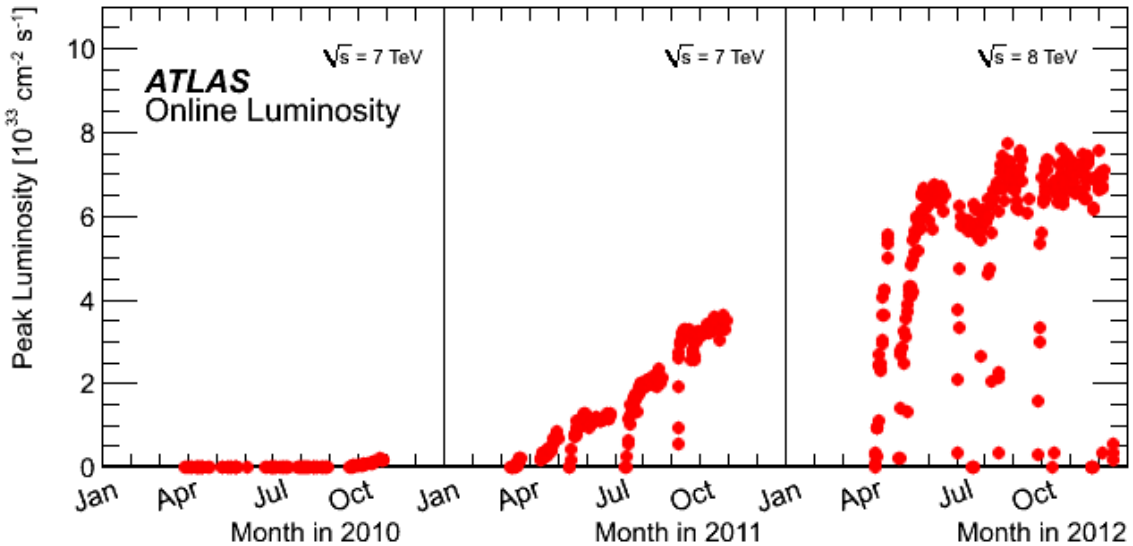
- **Remove readout limitations to sustain 100 kHz L1 rate** (75 kHz in Run-1)
  - New Cathode Strip Chambers off-detector Readout system
- **Additional 4th innermost pixel layer**
- Pixel detector brought on surface and equipped with **new service panel**
- **Gas leak repairs for Transition Radiation Tracker**
- **Replacement of on-detector power supplies for electromagnetic and hadronic calorimeters**
- **Installation of remaining and new muon chambers to close coverage holes** (sector 13 elevator shafts + feet region)
- **LUCID**: luminosity monitor, newly installed
- **Repair all accessible front-ends to improve efficiency**
  - More than 96% operational fraction across all detectors

Year-End-Technical-Stop 2015

- **New readout system for 2nd layer of Pixel detector**
- **Repair a damaged bellow of the toroid endcap magnet**
- **AFP**: new forward proton detectors installed 210 m from ATLAS, on one side

Data Taking restarted on April 25th 2016

Instantaneous Luminosity



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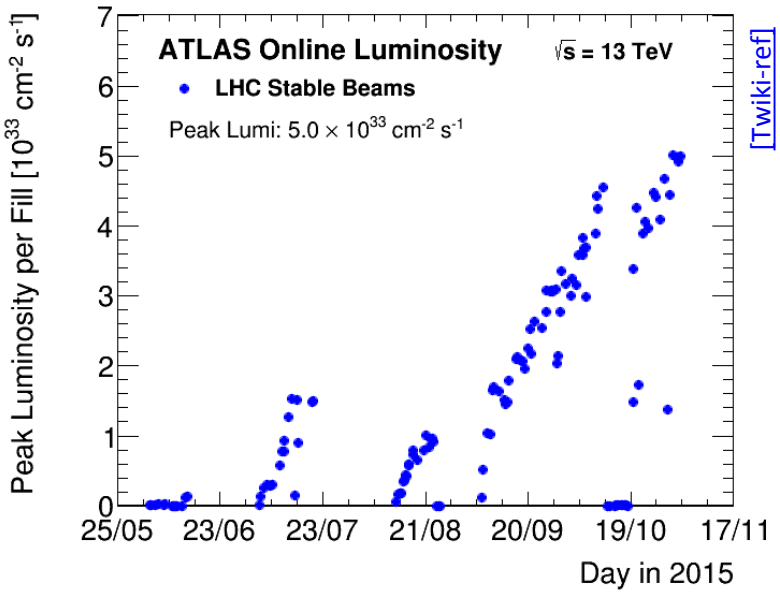
Run-1 max: 7.7e^{33} cm^{-2} s^{-1}

2015



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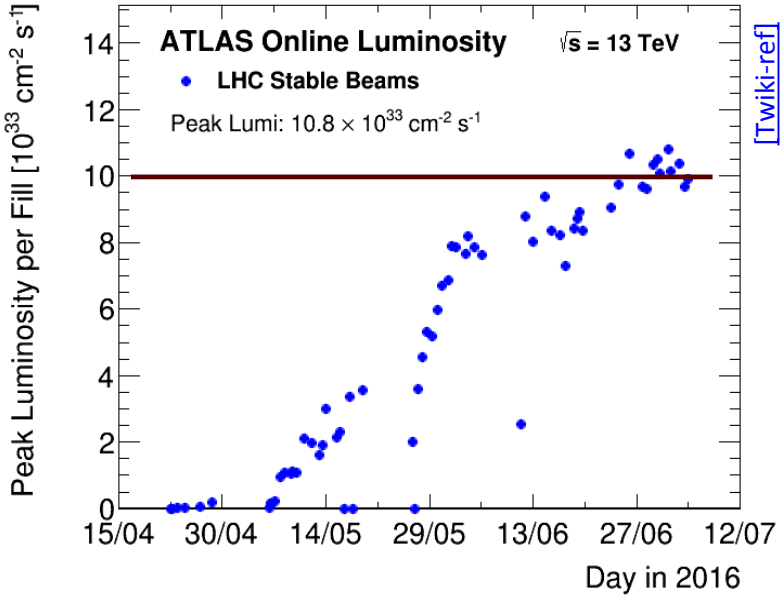
2016



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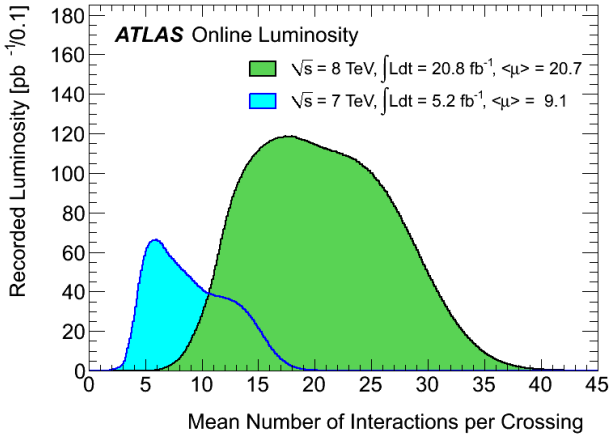
Pile-up and Integrated Luminosity

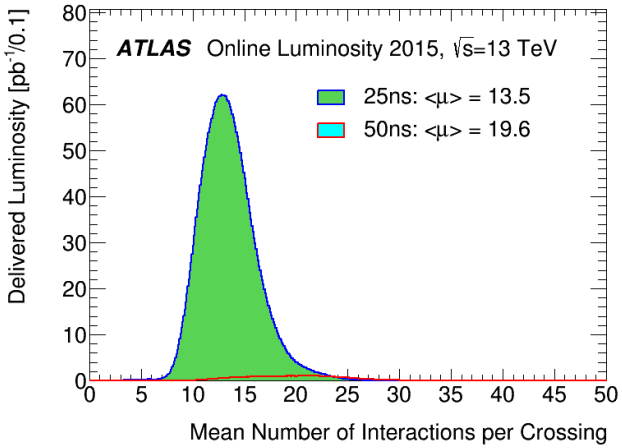
Luminosity-weighted distribution of mean number of interactions per crossing (pile-up)

[Twiki-ref]

Run-1



2015



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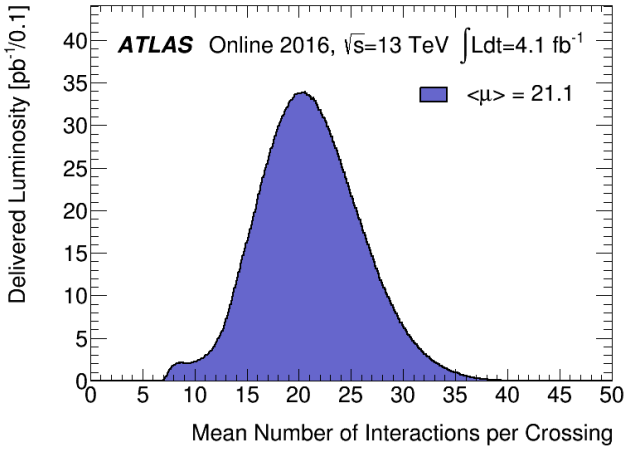
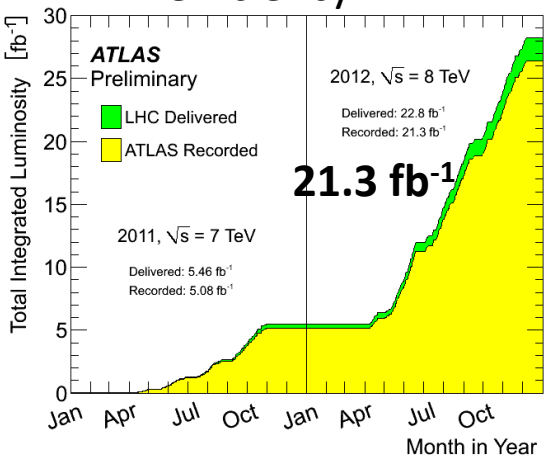
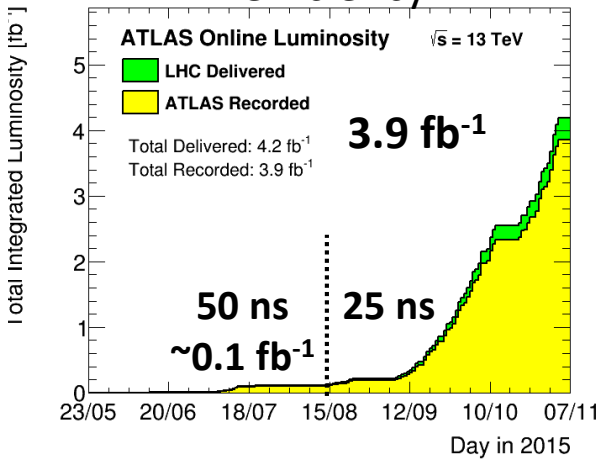
2016



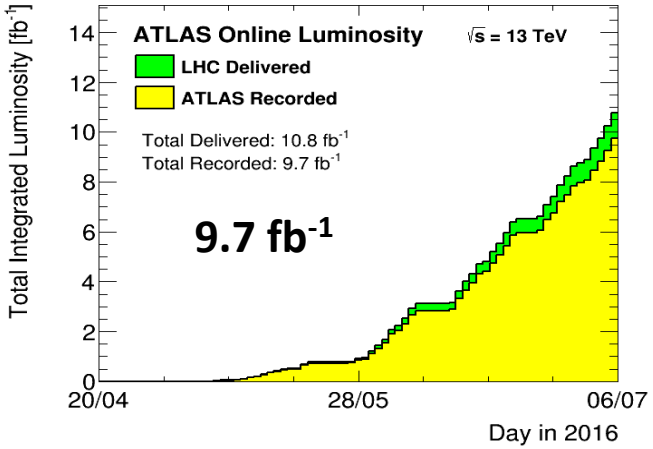
2012: **93.5%** data taking efficiency



2015: **92%** data taking efficiency



2016: **91%** data taking efficiency



Overall ATLAS Performance

ATLAS pp 25ns run: August-November 2015										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
93.5	99.4	98.3	99.4	100	100	100	100	100	100	97.8
All Good for physics: 87.1% (3.2 fb^{-1})									**95.5% in 2012**	

Luminosity weighted relative detector uptime and good data quality (DQ) efficiencies (in %) during stable beam in pp collisions with 25ns bunch spacing at $\sqrt{s}$=13 TeV between August-November 2015, corresponding to an integrated luminosity of 3.7 fb^{-1}. The lower DQ efficiency in the Pixel detector is due to the IBL being turned off for two runs, corresponding to 0.2 fb^{-1}. Analyses that don't rely on the IBL can use those runs and thus use 3.4 fb^{-1} with a corresponding DQ efficiency of 93.1%.

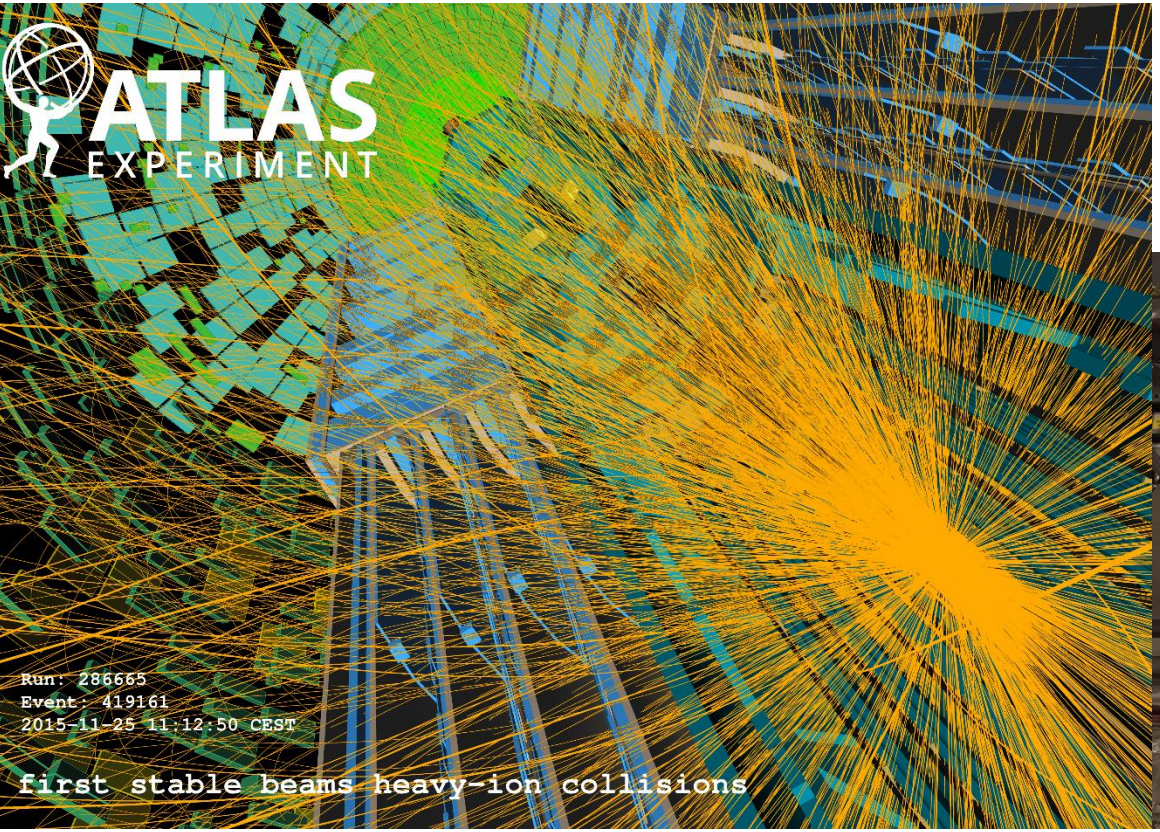
[Twiki-Results]

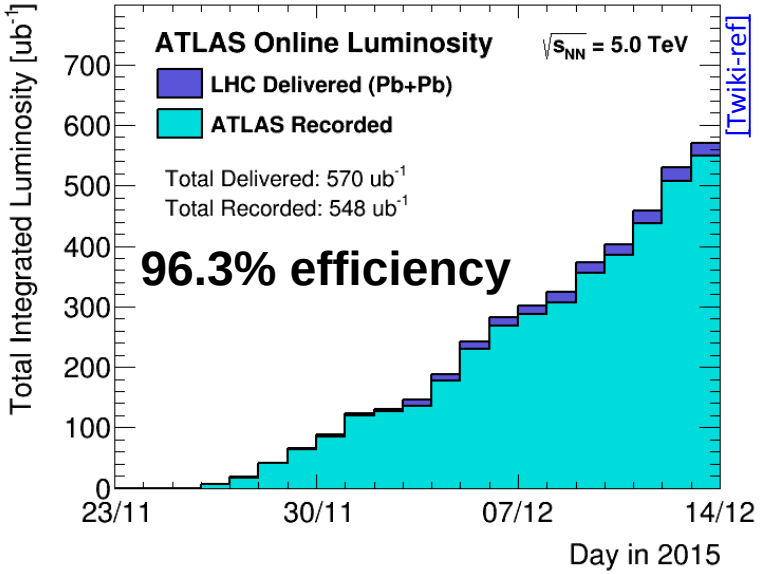
Heavy Ion Data Taking

From 23 Nov to 10 Dec 2015

- 5.02 TeV pp reference data
- $\sqrt{s_{NN}}$=5.02 TeV PbPb data
- VDM scans for both

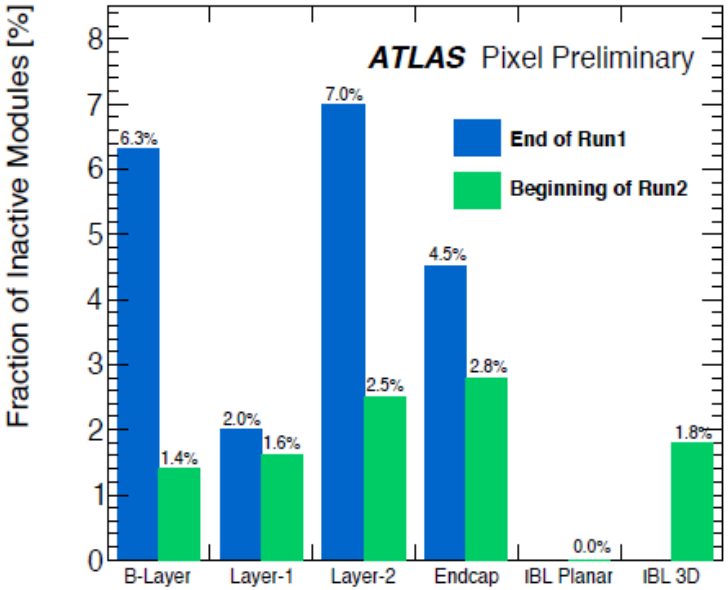
ZDC detector refurbished and re-commissioned





Inner Detector

- **Pixel**
  - More robust against optical link failures
  - New fourth layer (next slides)
  - Some readout system issues preventing the 100 kHz L1 rate → solved
- **Silicon Microstrip Tracker (SCT)**
  - All performance metrics comparable to Run-1 except small drop (~0.5%) in hit efficiency with 25ns bunch spacing
    - In line with expectations, due to veto on signal on previous BC
    - Intrinsic hit efficiency can be determined using first bunch of the train
- **Transition Radiation Tracker (TRT)**
  - Sustains 100 kHz rate at 50% occupancy
  - Allows simultaneous operations with Xe and also Ar gas mixtures
  - Leaks continued to worsen during autumn 2015, as luminosity increased



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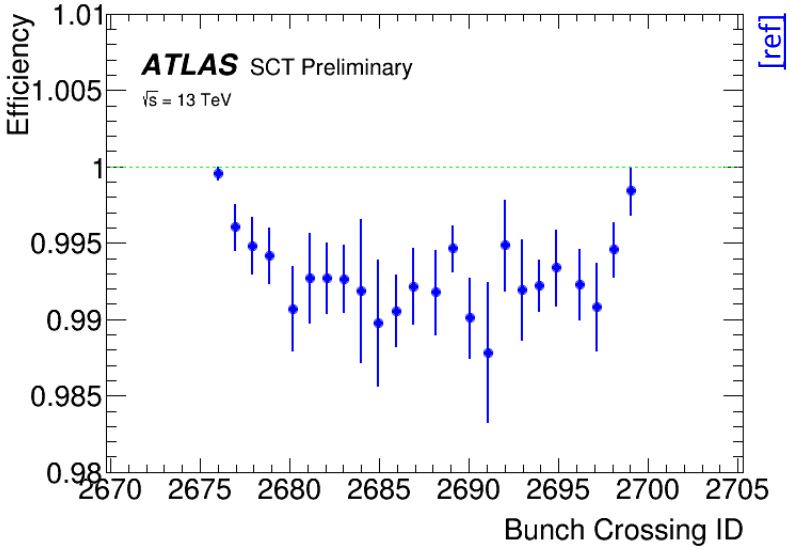

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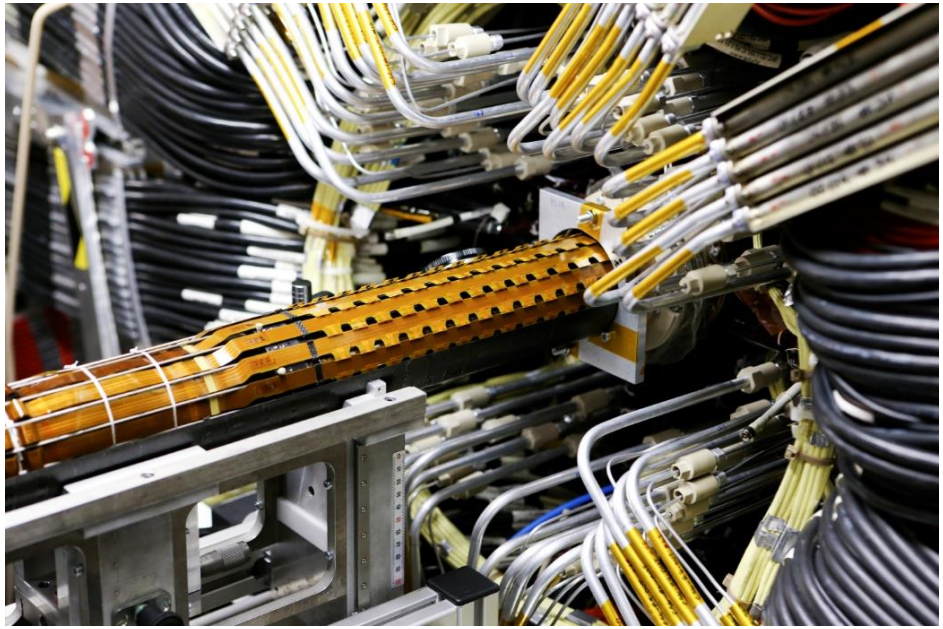
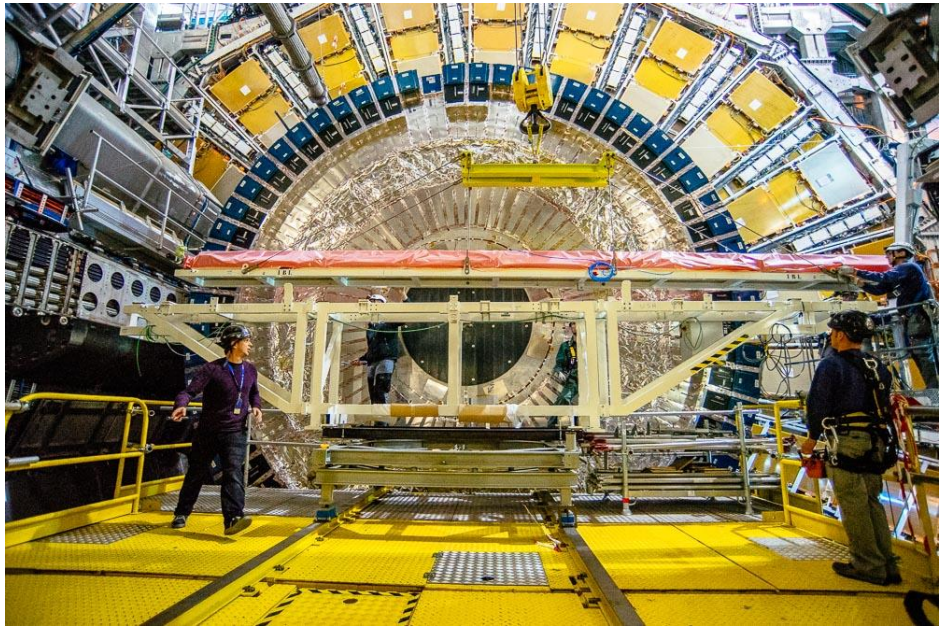
Insertable b-Layer (IBL)

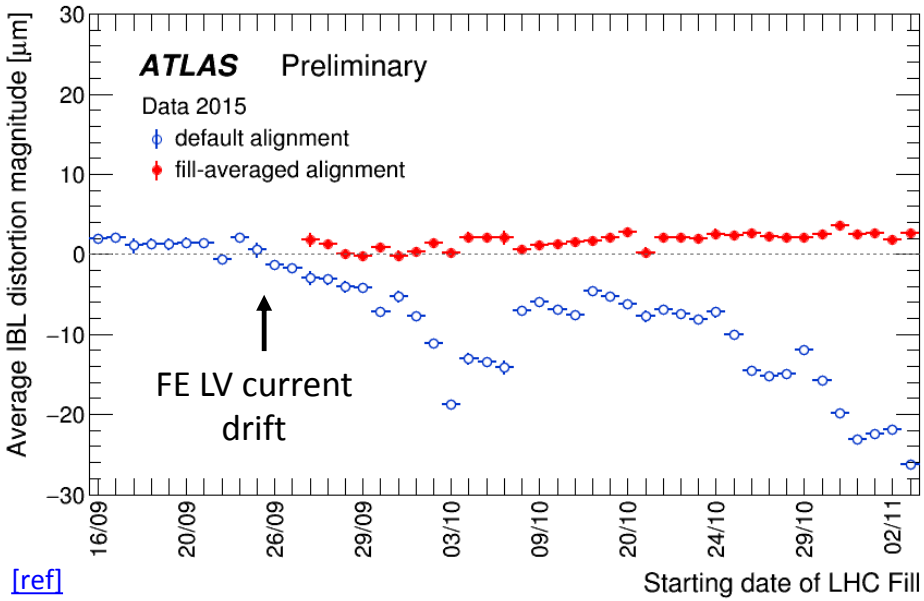
- Insertable 4th pixel layer with planar and 3D sensors
  - At R=33 mm from the beam line, mounted on the new smaller beam-pipe
  - 12M channels added to the 80M and smaller pixels cells: 50x250 μm^2 vs 50x400 μm^2
    - Improved resolution: 8 μm in rϕ and 40 (vs 75 μm) in z





IBL: some start-up issues

- **Mechanical distortion of IBL staves**
  - Cosmic ray commissioning: magnitude of distortion depends linearly on T with a gradient of ~10 μm/K
- **Increase of FE current** during October → IBL off during 2 LHC fills
  - FE transistor leakage due to defect building up at the silicon oxide interface
  - Decision to run IBL at +15° C beginning of 2016 run, +5° C now (-10°C nominal)
- **Effects regularly corrected online before reconstruction of data**
  - After alignment, no significant impact on tracking



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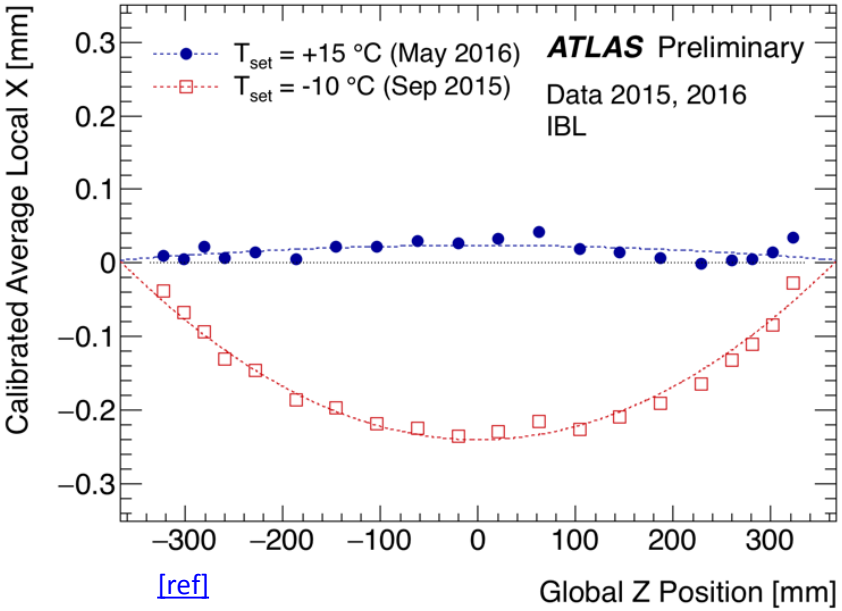
correction due to the IBL distortion



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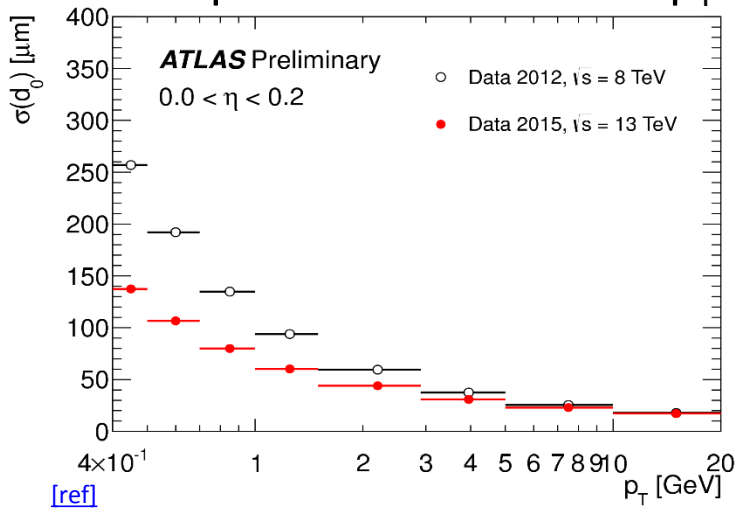
IBL Performance

- **Impact parameter significantly improved**
  - Up to a factor 2 at low p_T



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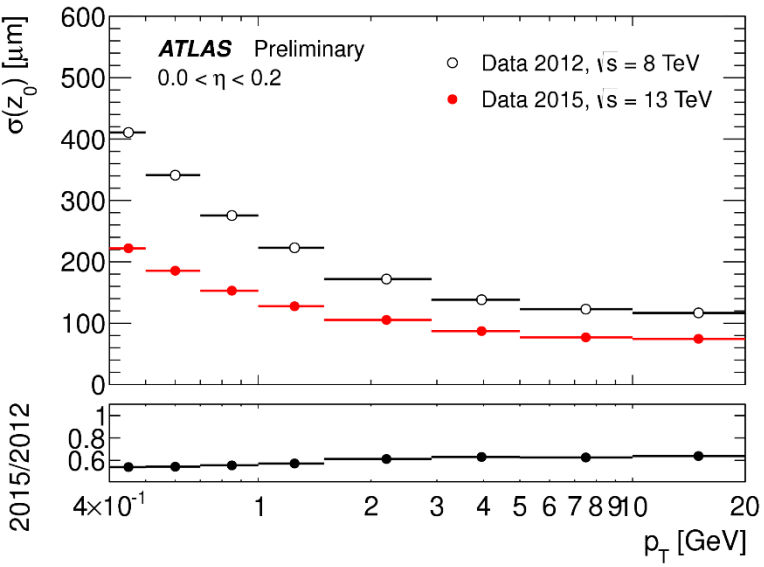
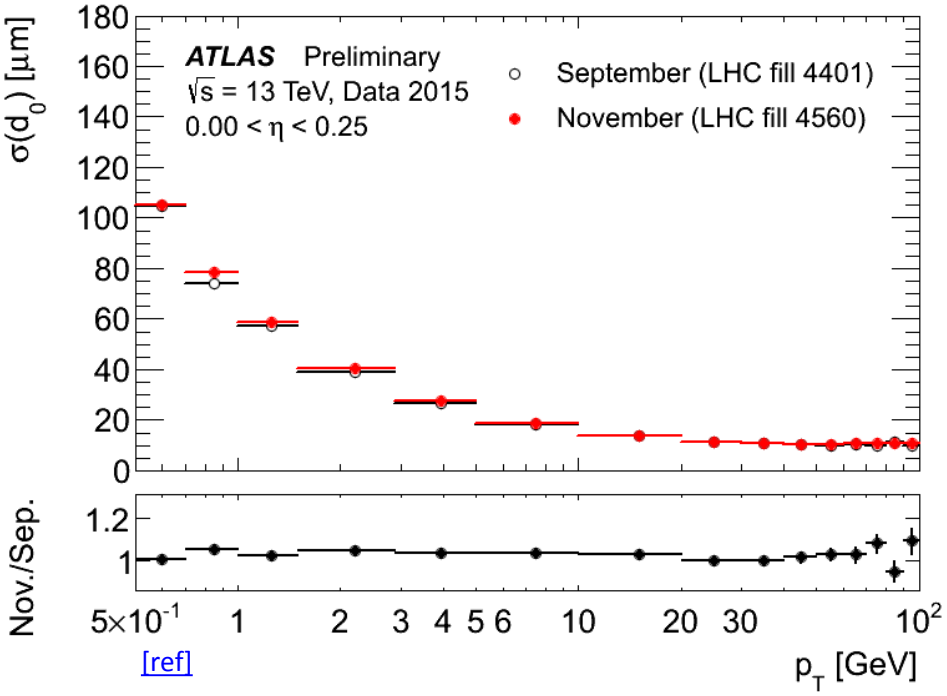


- **Mechanical distortion does not significantly impact resolution**
  - ***Black***: run <u>without</u> IBL bowing
  - ***Red***: run <u>with</u> IBL bowing and correction applied



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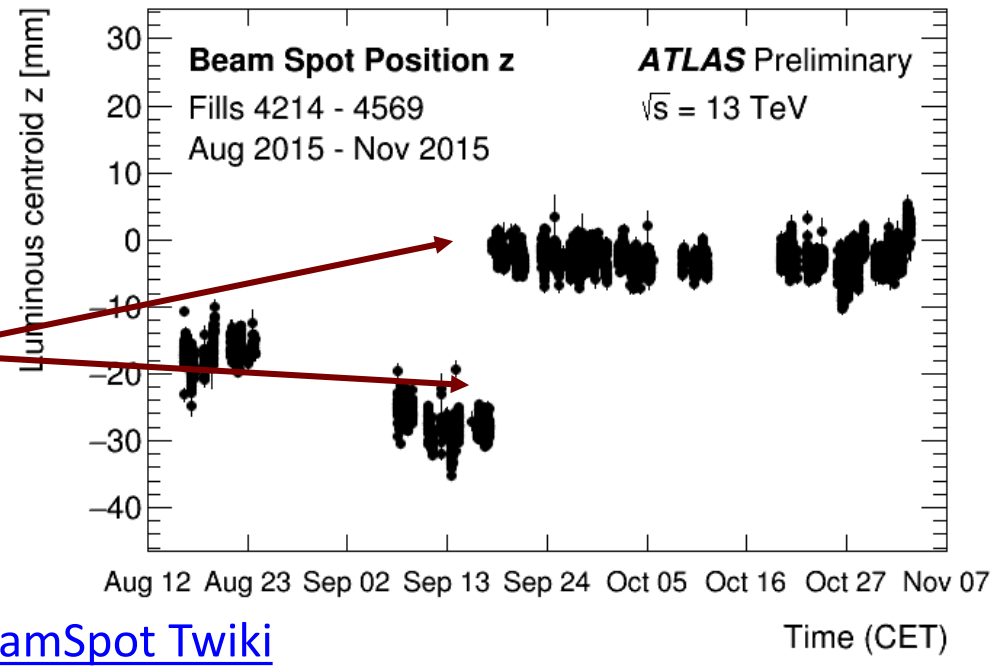
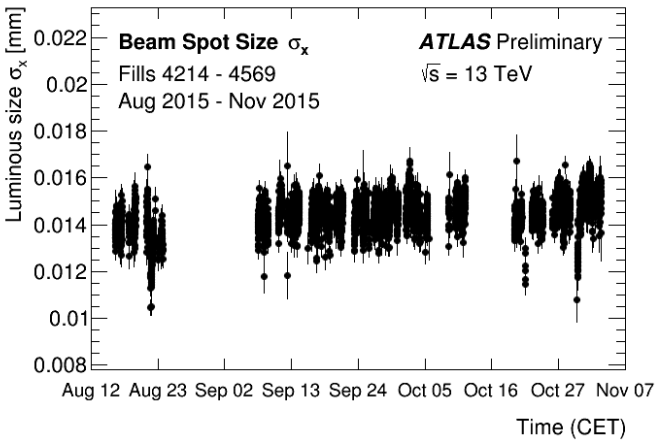
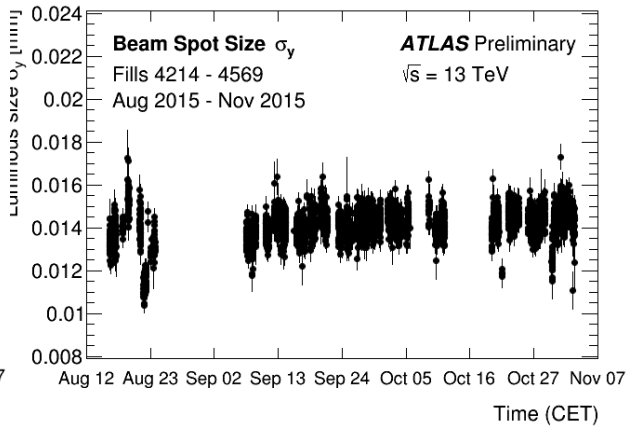
Beam Spot

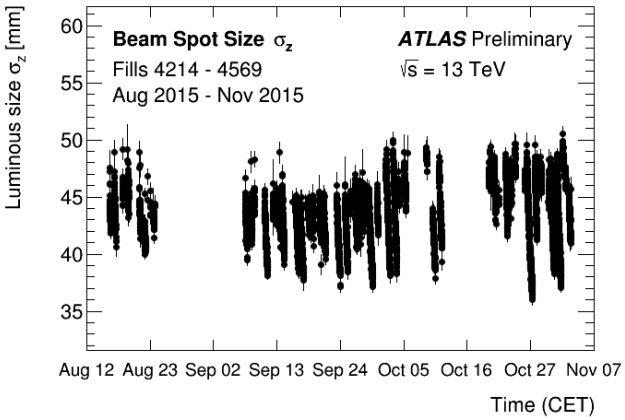
- **Very stable beam spot for all 2015**
- Tune beam once to bring collisions in nominal position
  - beam cogging on September 18th 2015
  - Longitudinal position used to be shifted by 3 cm, brought to 0
- Very stable x, y, z beam sizes



BeamSpot Twiki

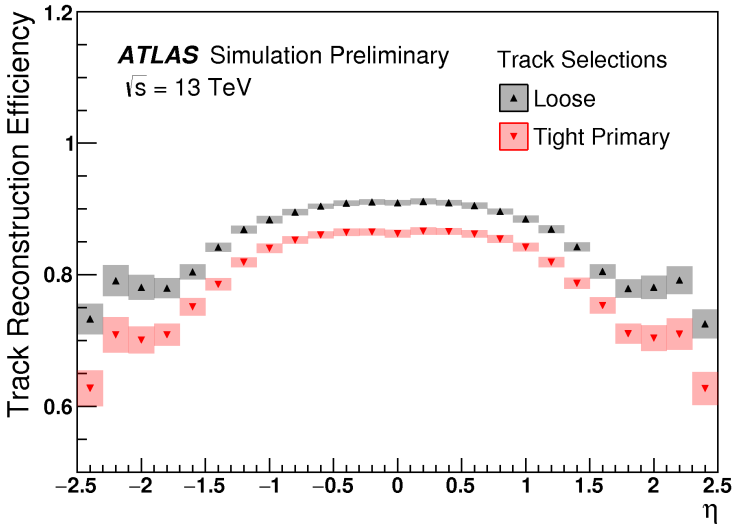






ID Tracking Performance

Tracking efficiency: 90% (85%) for Loose (Tight Primary) selections for tracks above 5 GeV



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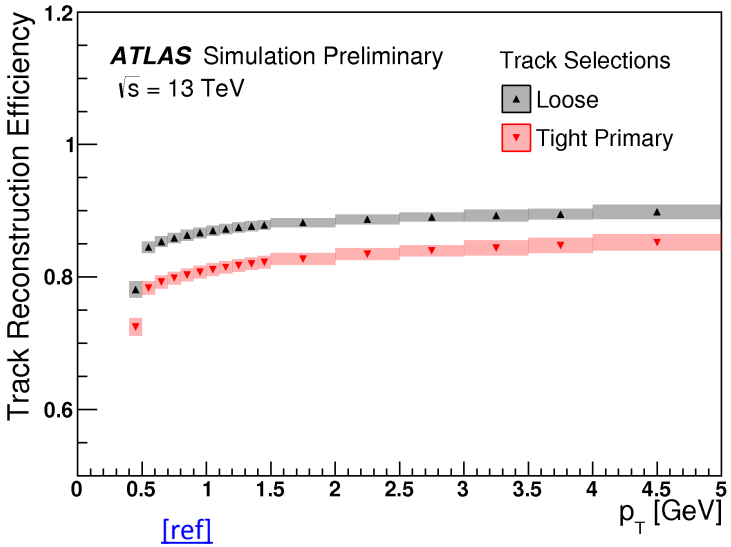

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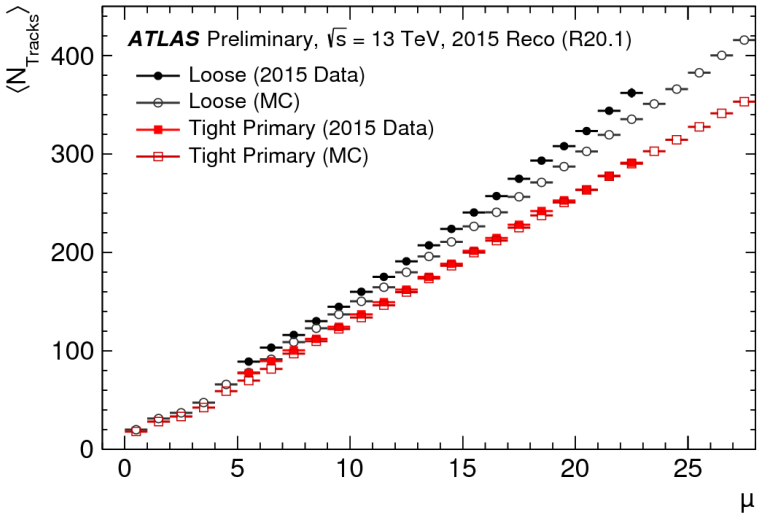
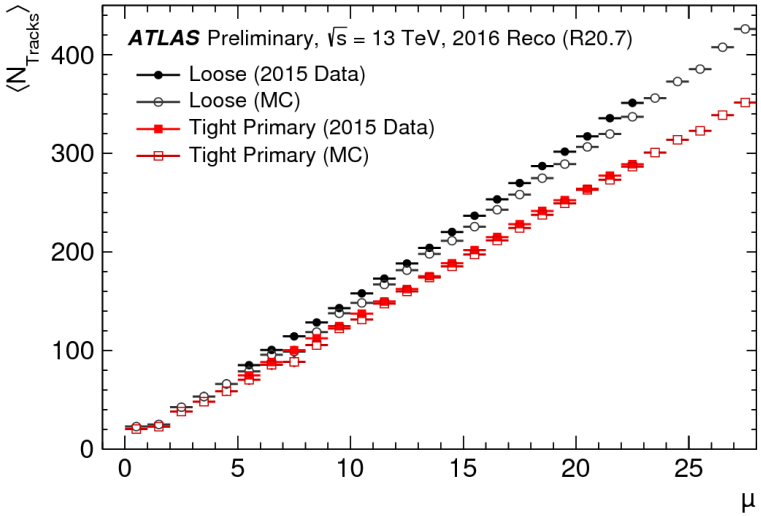
Number of Tracks vs pile-up, for Loose and Tight Primary selection with 2015 (*left*) and 2016 (*right*) reconstruction software



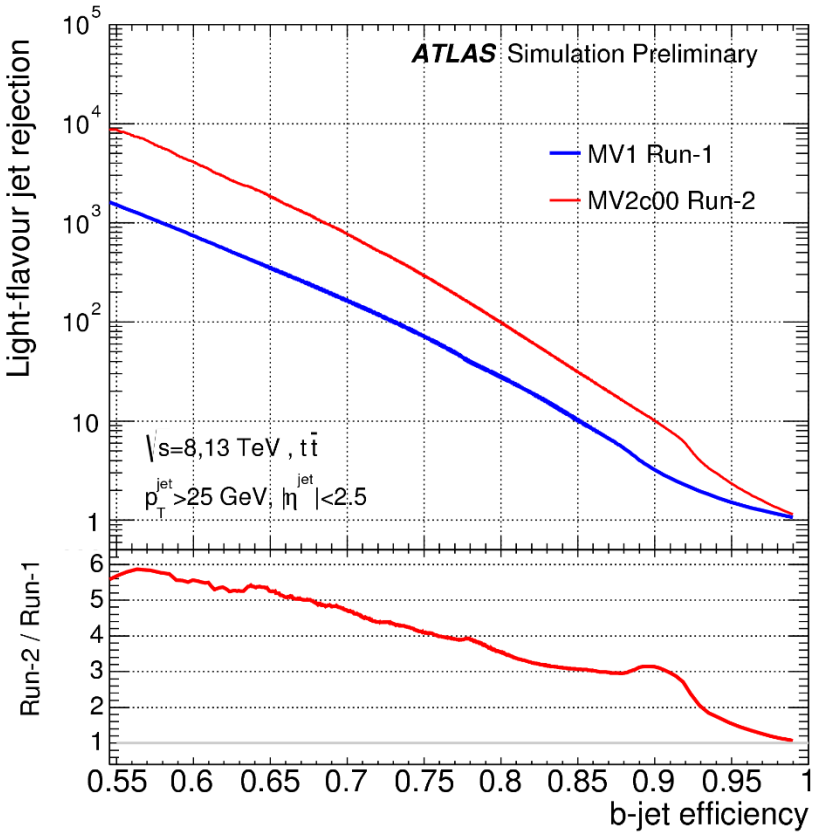


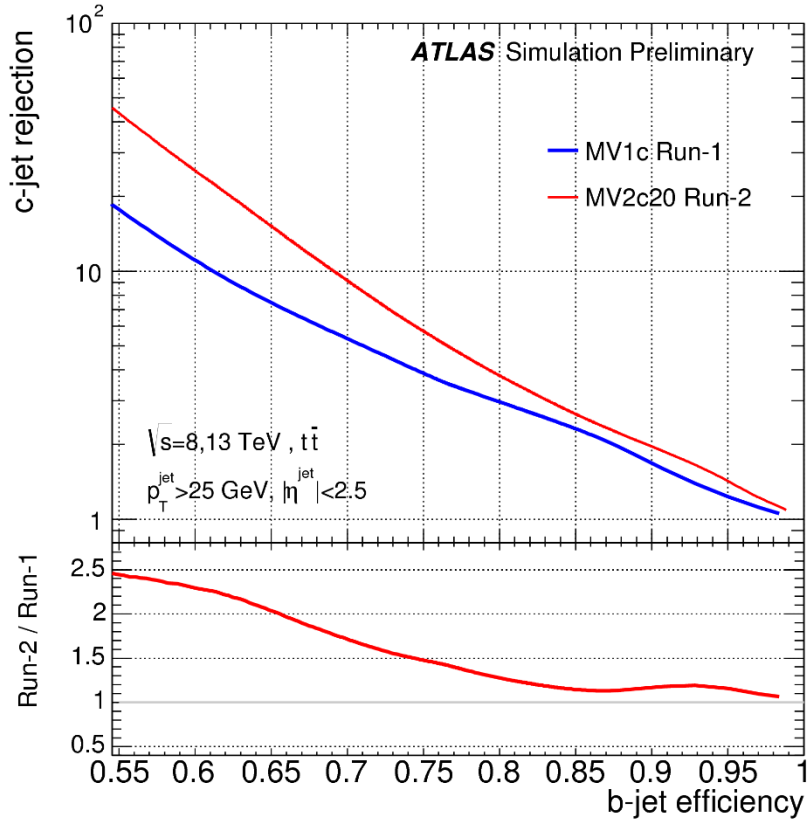
B-Tagging Performance

- **IBL**, together with several enhancements to the tracking and b-tagging algorithms, **significantly improves the b-tagging algorithms in Run-2 with respect to Run-1**

Light and c-jet rejection versus b-jet efficiency in Run-1 and Run-2.

ATL-PHYS-PUB-2015-022

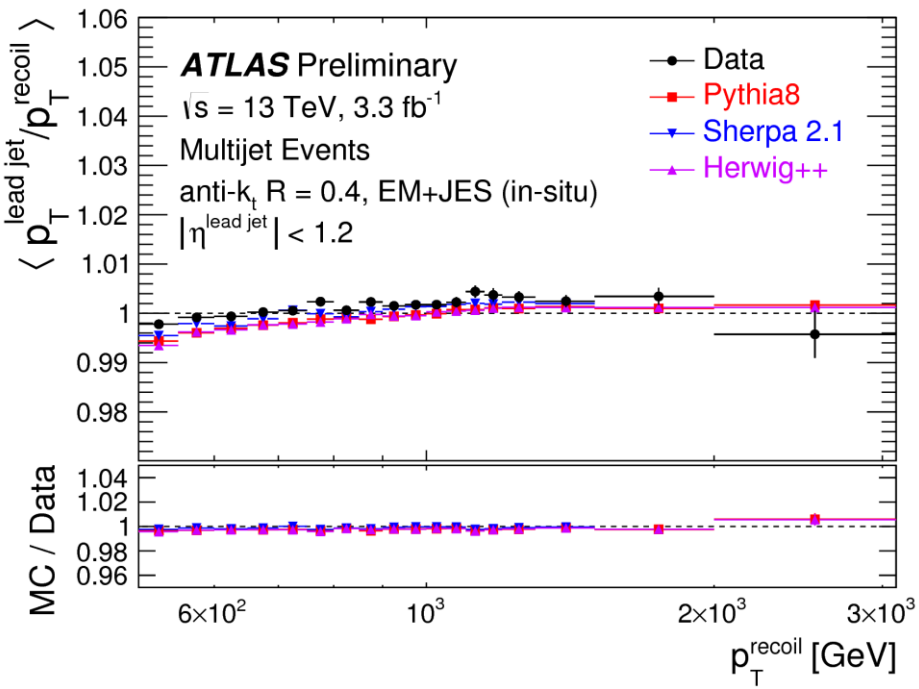




Jet Reconstruction Performance

- **Calorimeters worked extremely well in 2015**
  - Good for physics: 99.4% (Larg) and 100% (Tile)
  - LAr using 4 instead of 5 sample readout to achieve 100 kHz
- **In-situ jet energy-scale with 2015 dataset**
  - Agreement between data and MC better than 2% up to 3 TeV

[ref]



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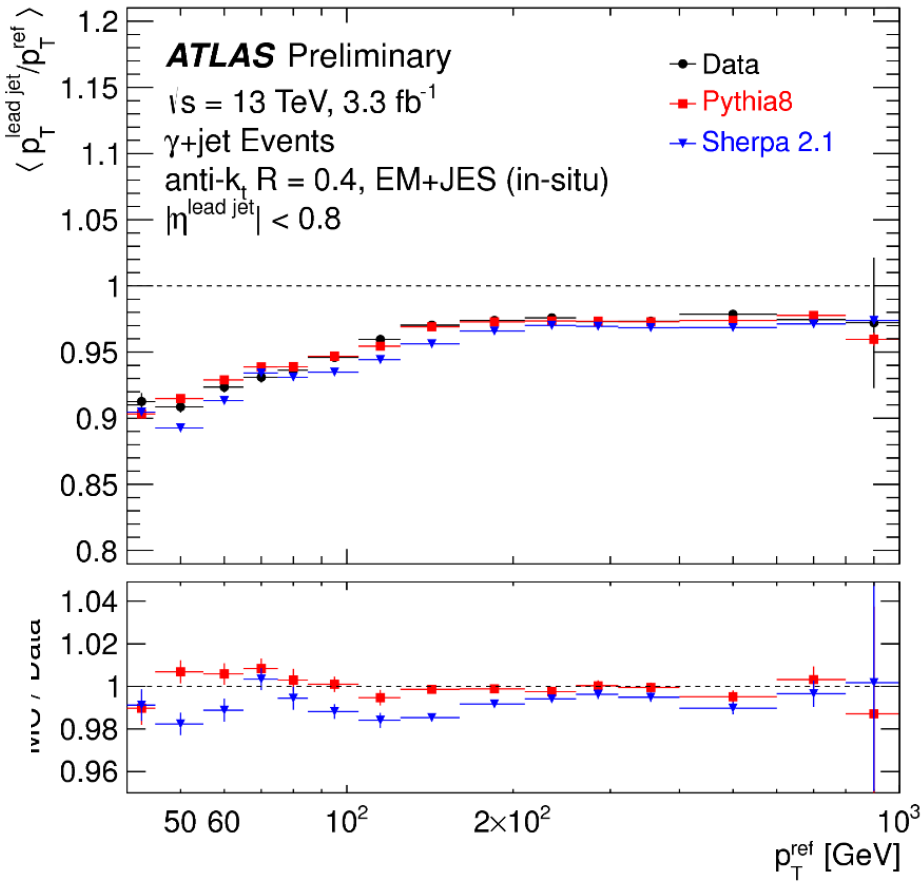
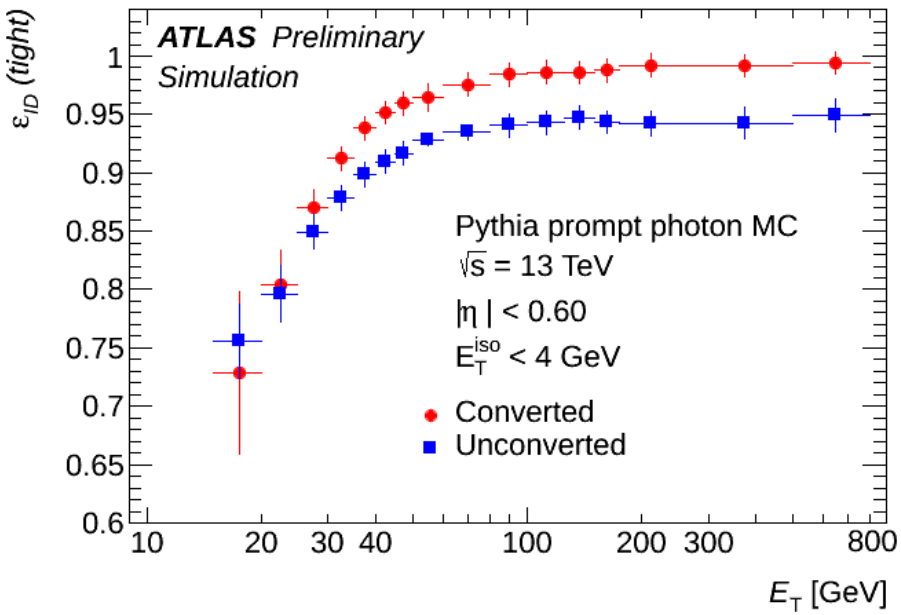


e/γ Reconstruction Performance

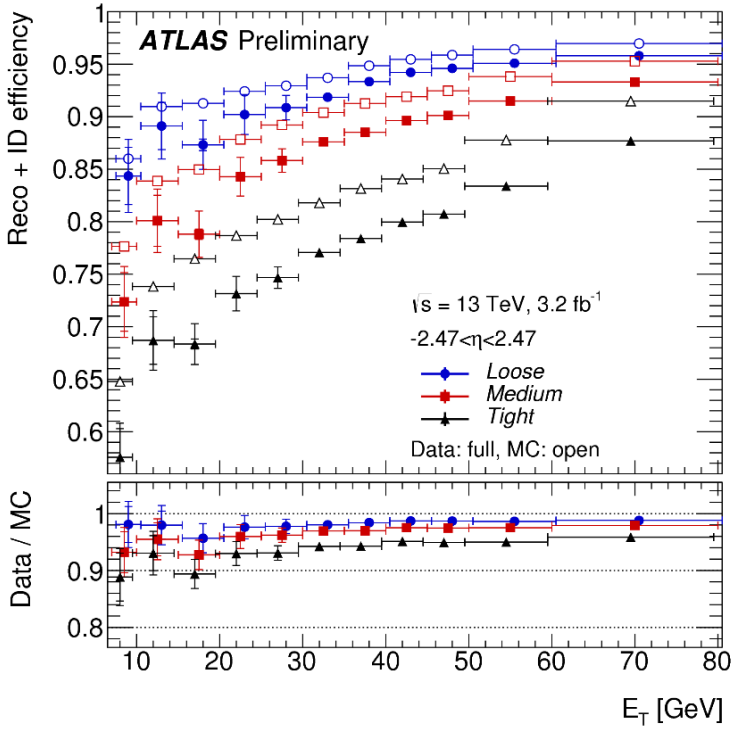
- **Electron ID**
  - number of hits in IBL used for discriminating between electrons and converted photo + new discriminating variable in the electron identification algorithms due to change in TRT gas (modifications in detector response)
  - Likelihood (LH) combining LAr shower shapes, tracking, track-cluster matching and TRT PID
- **Photon ID**
  - Using cut-based selection

Photon reconstruction (MC)



[ref]

Combined electron reconstruction and identification efficiencies in Z→ ee events

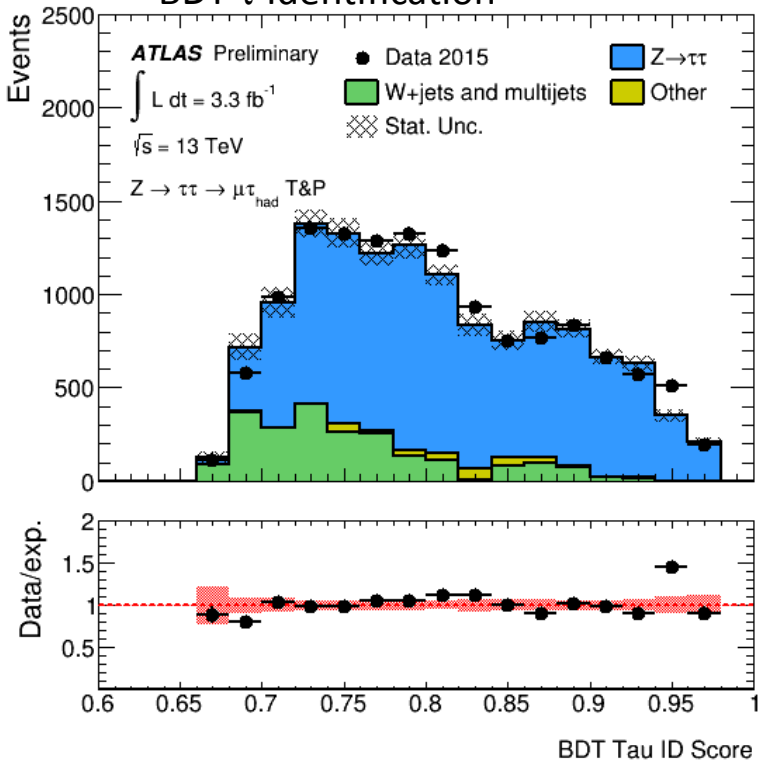


[ref]

Tau Reconstruction Performance

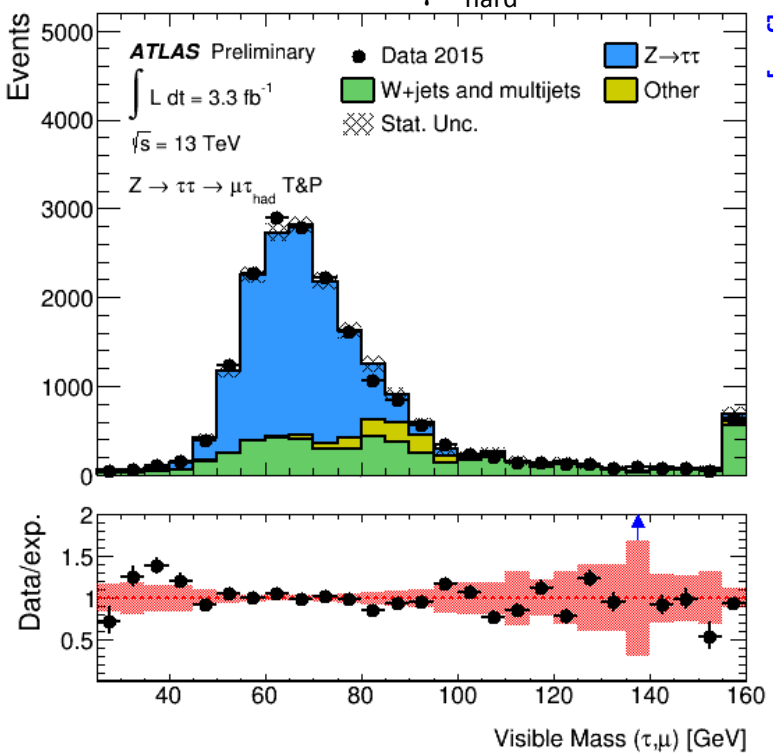
- Hadronically decaying taus identified using boosted decision tree offline and online
  - Performance measured using Z→ ττ candidates
  - Good agreement between data and simulation

BDT τ Identification



[ref]

Visible mass of the $\mu\tau_{hard}$ Z candidates



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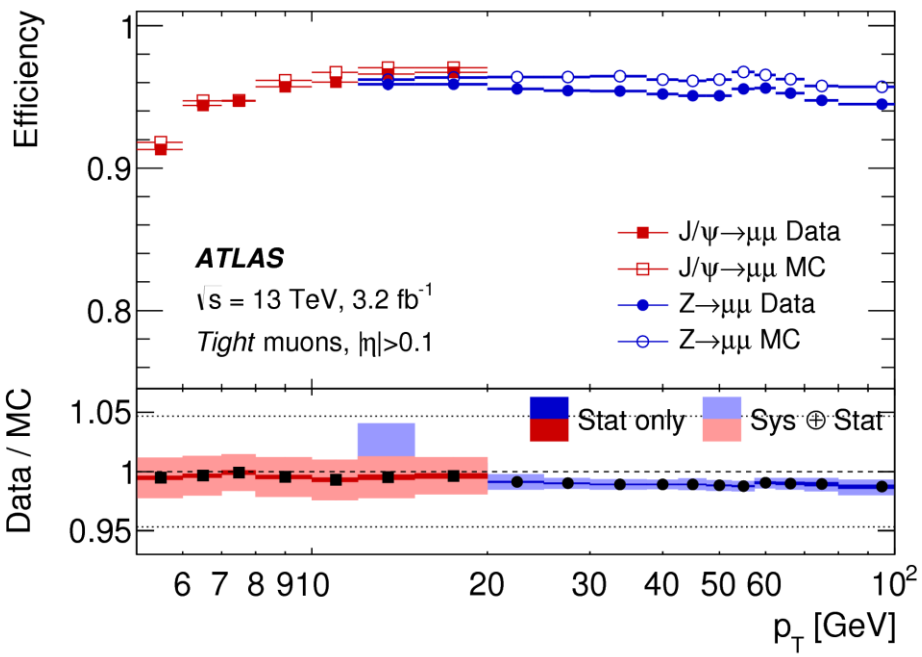
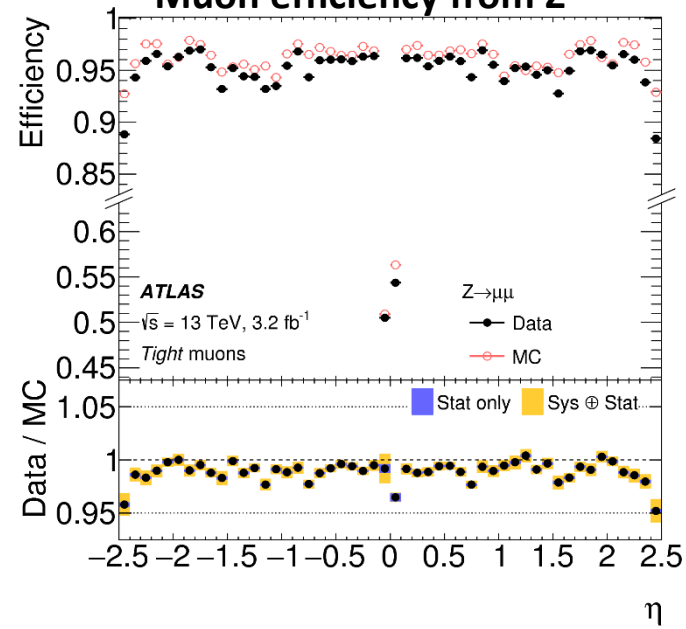
Muon System Performance

- **Muon spectrometer running smoothly**
- Alignment ~50 µm for both barrel and endcap
- Performance studies done with three main working points (Tight, medium, loose)
  - Tight presented here
- **Good agreement between data and MC**
- Ref: PERF-2015-010

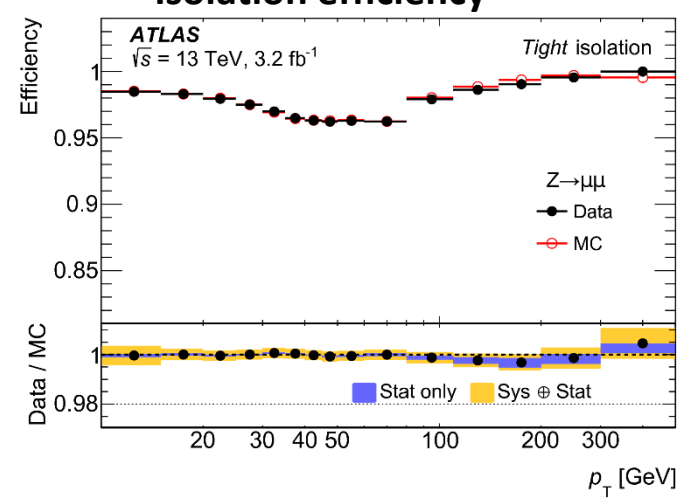
Muon efficiency from Z and J/Ψ



Muon efficiency from Z

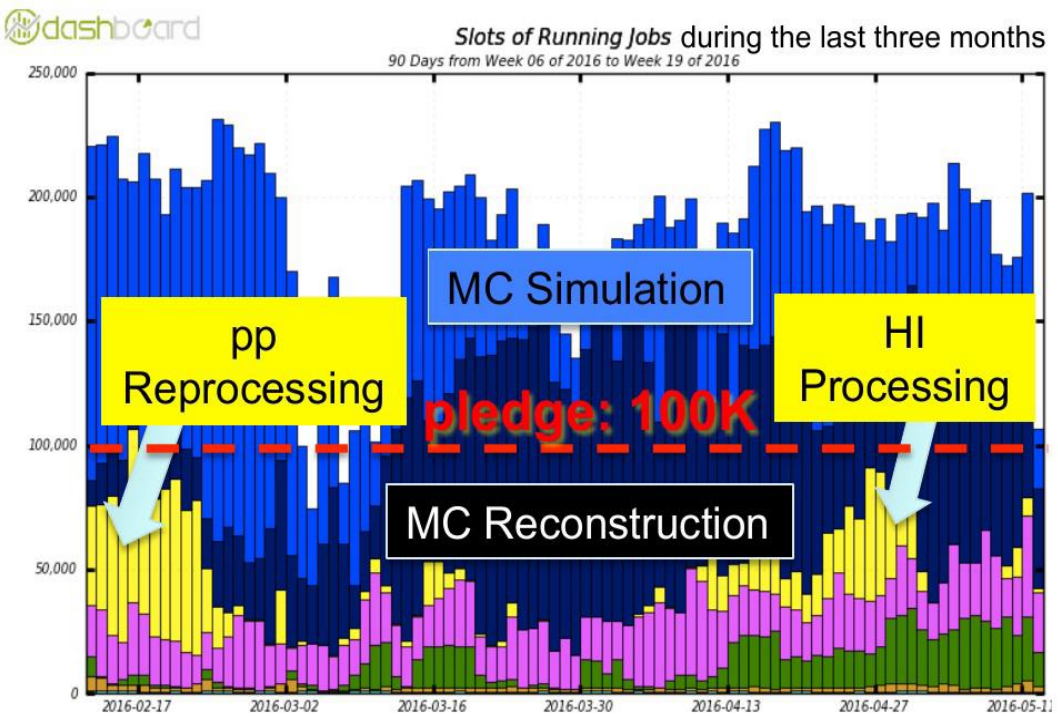


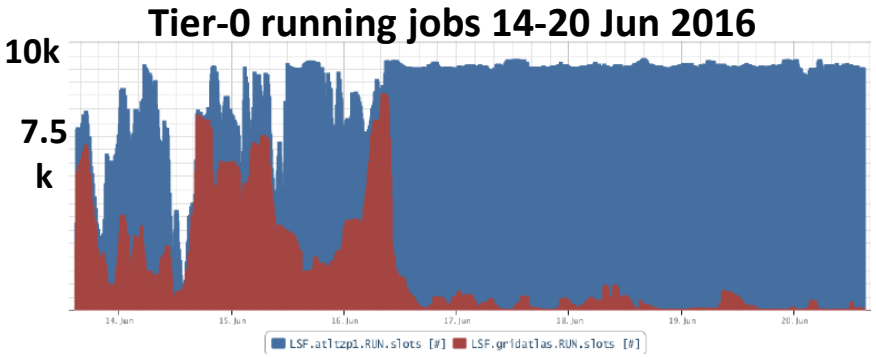
Isolation efficiency



Computing and Software

- Worldwide LHC Computing Grid (**WLCG**) backbone of ATLAS computing
  - Smooth operations
  - Dominated by MC production
- **Tier0 reconstruction**
  - 15k jobs slots
  - Used for Grid jobs if not utilized by Tier0
- **New analysis model and formats**
  - ~all analysis done via compact data format (DAOD), higher compression wrt Run 1
  - Helps in producing results quickly

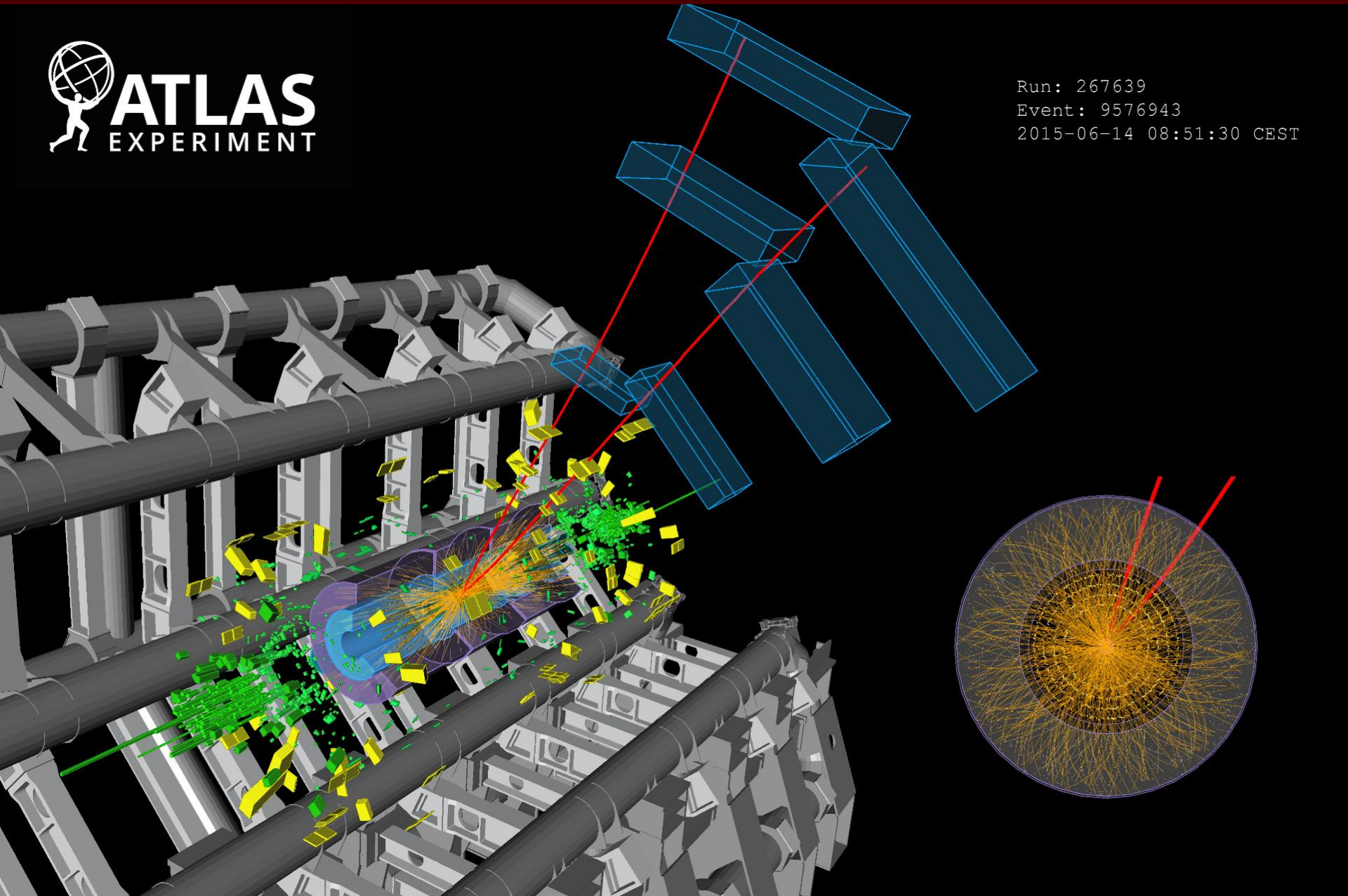




Conclusion

- **ATLAS underwent several upgrades during the LS1**
- The restart after the LS1 and the **data taking through out 2015 has been very successful**
- Despite the challenging conditions, the system stability and the data taking efficiency has quickly reached the Run-1 level
- **Detailed performance studies demonstrate good understanding of the 2015 data**
- 2016 data taking started on 25 April, **excellent LHC performance**
  - integrated luminosity already higher than in 2015
  - Instantaneous luminosity higher than in Run-1 and exceeded 10^{34} cm^{-2} s^{-1}
- **2016 will be an exciting year for HEP!**

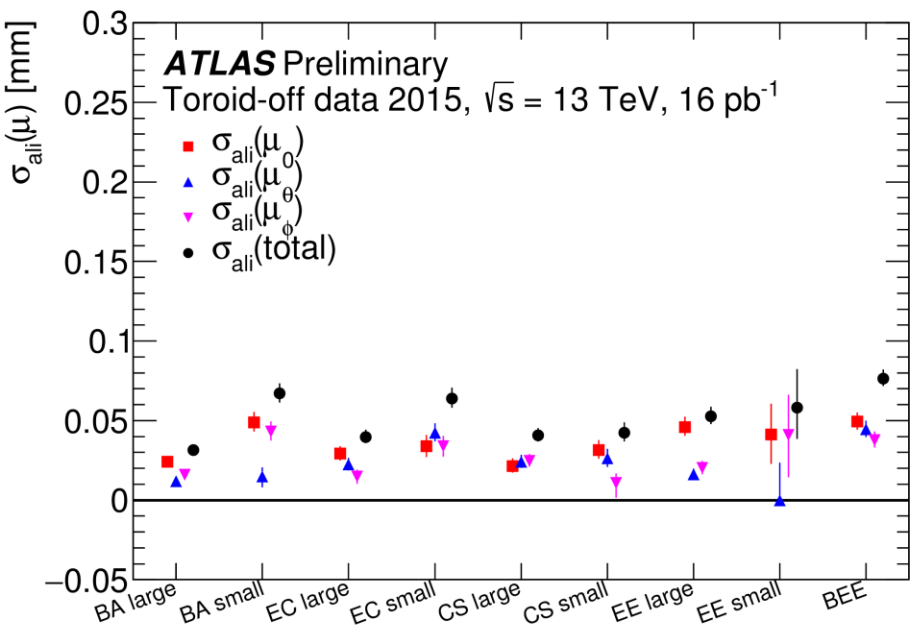
THANK YOU


ATLAS
EXPERIMENT
Run: 267639
Event: 9576943
2015-06-14 08:51:30 CEST

Backup

Muon Spectrometer Alignment

- Based on optical system
- Tracks needed for full alignment
  - Tracks in B=OFF used as re-calibration of the optical system
  - Tracks in B=ON to constrain the external alignment DoF



Sagitta alignment overall performance
MUON-2016-002

[μm]	$\sigma_{\rm ali}(\mu_0)$	$\sigma_{\rm ali}(\mu_\theta)$	$\sigma_{\rm ali}(\mu_\phi)$	$\sigma_{\rm ali}(\rm total)$
BA large	24 ± 2	12 ± 1	16 ± 2	31 ± 2
BA small	49 ± 6	15 ± 6	43 ± 6	67 ± 6
EC large	29 ± 4	22 ± 4	15 ± 4	40 ± 4
EC small	34 ± 7	42 ± 6	34 ± 7	64 ± 6
CS large	21 ± 5	24 ± 4	25 ± 4	41 ± 4
CS small	31 ± 6	26 ± 6	11^{+6}_{-9}	42 ± 6
EE large	46 ± 6	16 ± 3	20 ± 4	53 ± 6
EE small	41 ± 19	0^{+24}_{-0}	41 ± 26	58^{+24}_{-20}
BEE	49 ± 5	44 ± 5	38 ± 5	76 ± 5

IBL Start-up Issues (1)

- Mid-way during production discovered **corrosion of wire-bond**
  - Must avoid condensation at all cost!
- **Increase of FE current** during October
  - IBL turned off during 2 LHC fills
  - Effect understood: FE transistor leakage due to defect building up at the silicon oxide interface and cumulated by ionizing dose
    - Lab tests confirmed the effect relaxes after a few additional Mrad of irradiation
  - Decision taken to run IBL initially at 15°C during 2016
    - so far effect looks under control