Performance of the ATLAS track reconstruction

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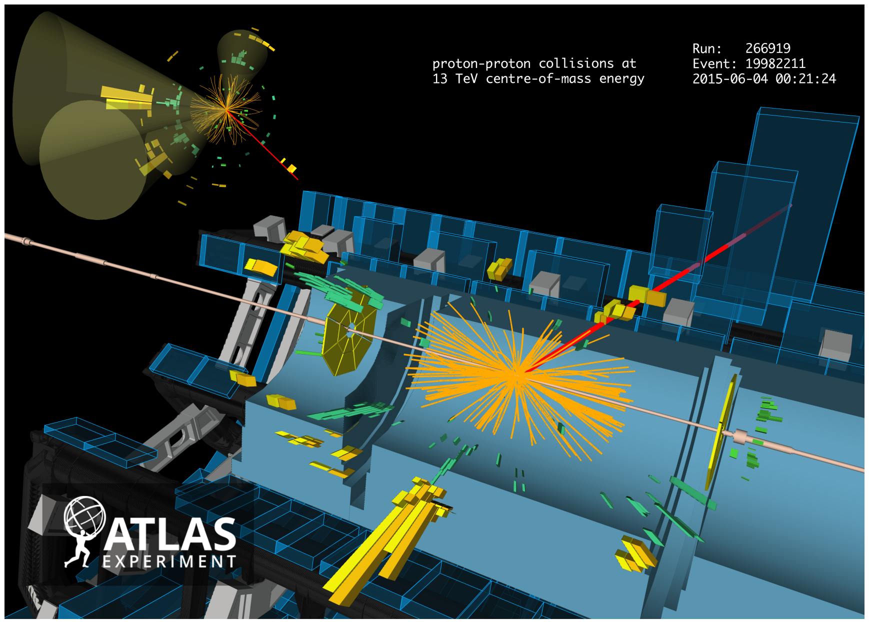
Overview

- the ATLAS detector and its tracking system
  - detector upgrade for Run2
  - software: what has been improved during LS1

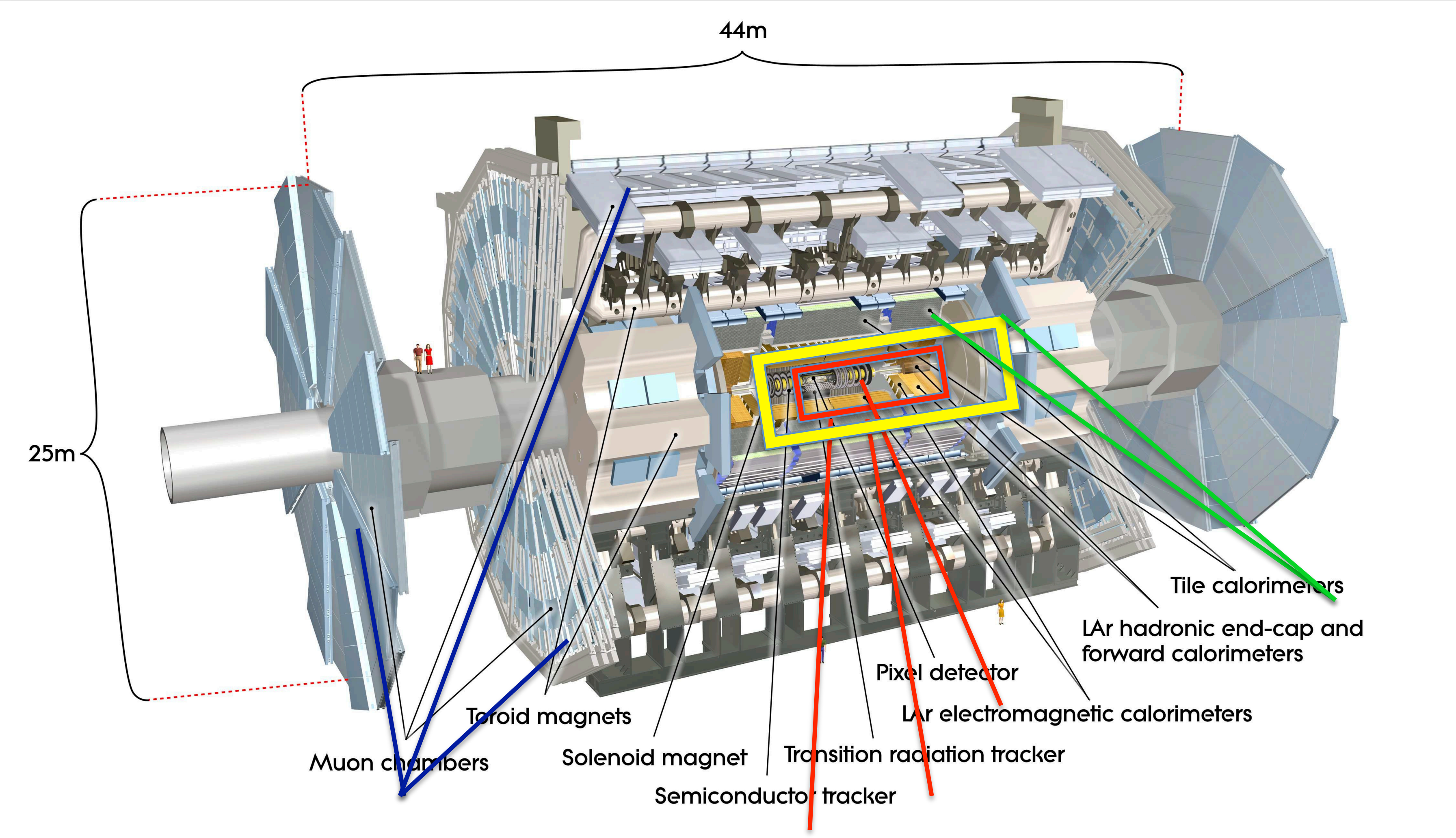
- detector commissioning with first Run 2 data:
  - cosmics
  - 13TeV collision data

- tracking performances:
  - material description
  - tracking in dense environments
  - vertexing
  - b-tagging

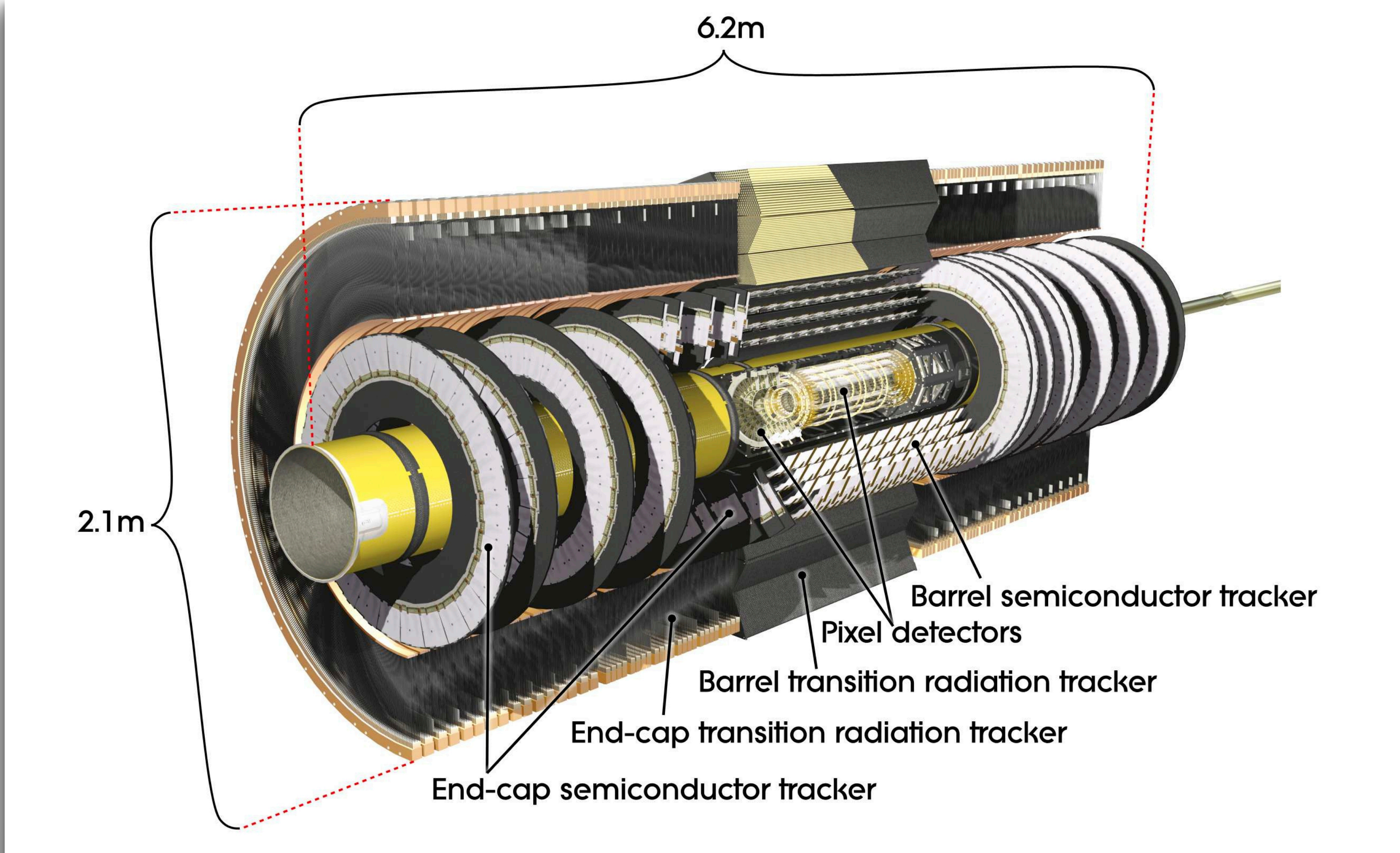
ttbar candidate@13TeV



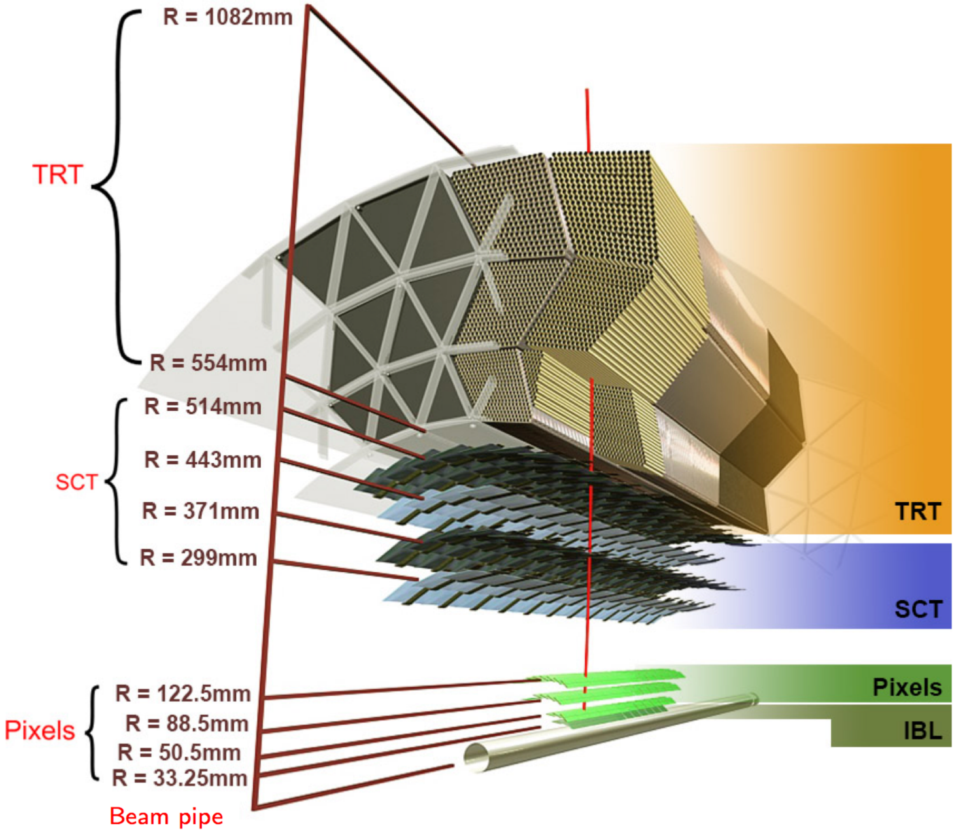
The ATLAS detector



ATLAS Inner Detector



ATLAS Inner Detector in Run 2



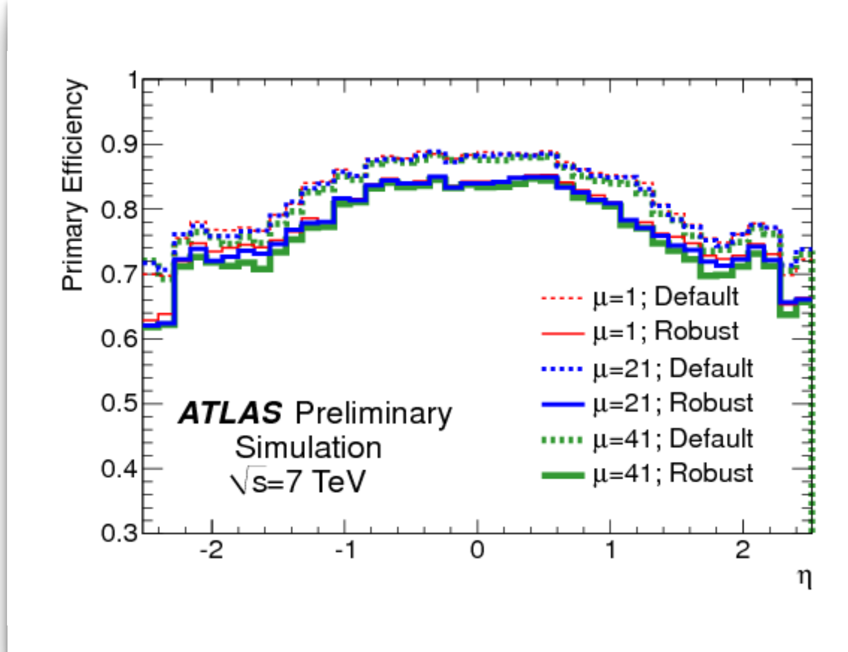
Barrel track passes:

- ~36 TRT 4mm straws
- 4x2 Si Strips on stereo modules 12cmx80mm, 285 μm thick
- 4 Pixel layers, ~250 μm thick

2T solenoidal magnetic field

robust track reconstruction against PU:

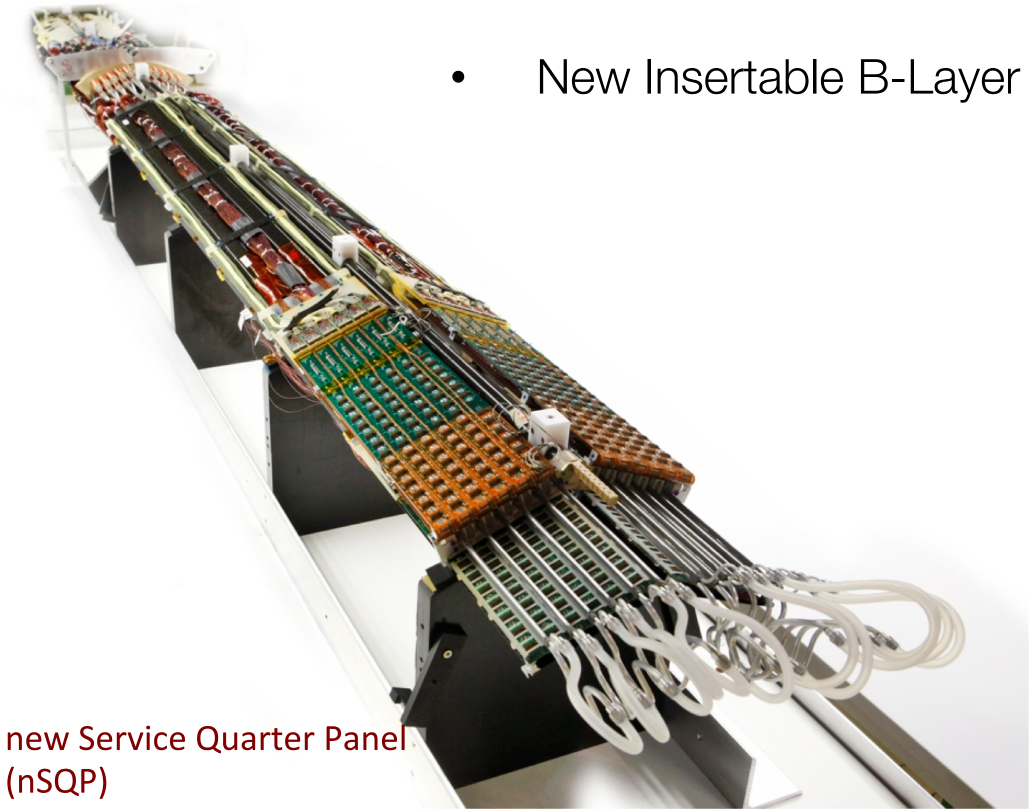
- acceptance |η|<2.5 (|η|<2 for TRT)
- track reconstruction with pT > 400 MeV (pT > 100 MeV for special fills with low pile-up)



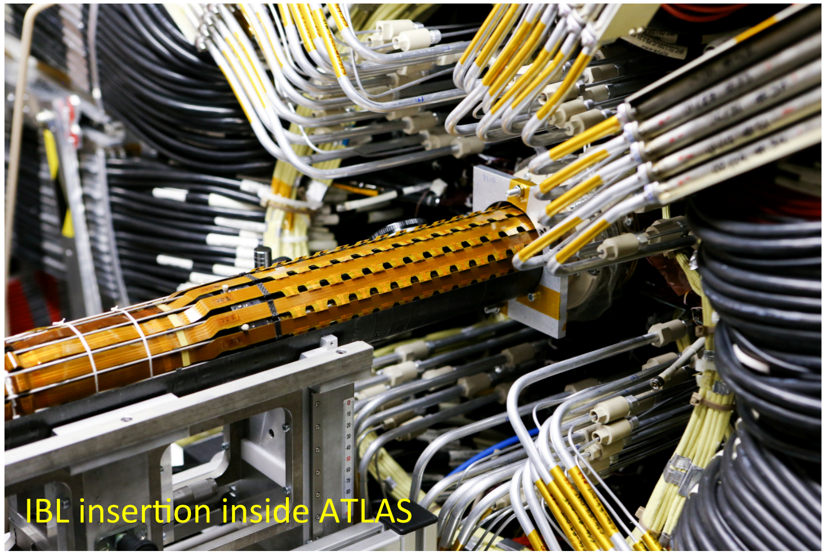
Pixel detector upgrade in LHC Long Shutdown 1 (LS1)

Major upgrade to ATLAS during LHC Long Shutdown 1

- Pixel: new services, new optical links (accessible when ATLAS open)
  - New Diamond Beam Monitor (DBM) installed in the Pixel volume
    - New Insertable B-Layer (IBL) around the beam pipe



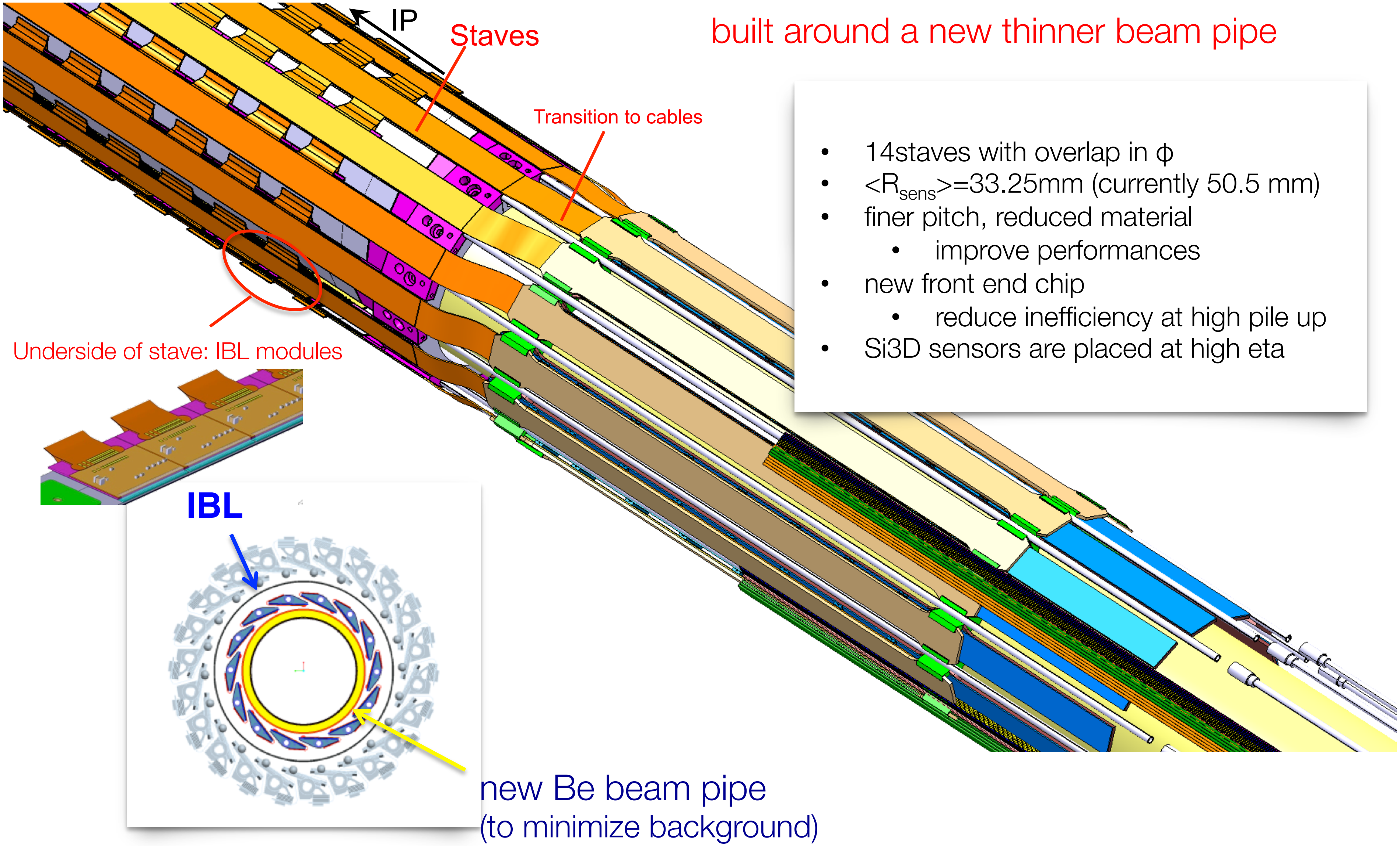
new Service Quarter Panel (nSQP)



IBL insertion inside ATLAS

Pixel detector upgrade in LHC Long Shutdown 1 (LS1)

built around a new thinner beam pipe



- 14staves with overlap in ϕ
- $<R_{sens}>$=33.25mm (currently 50.5 mm)
- finer pitch, reduced material
  - improve performances
- new front end chip
  - reduce inefficiency at high pile up
- Si3D sensors are placed at high eta

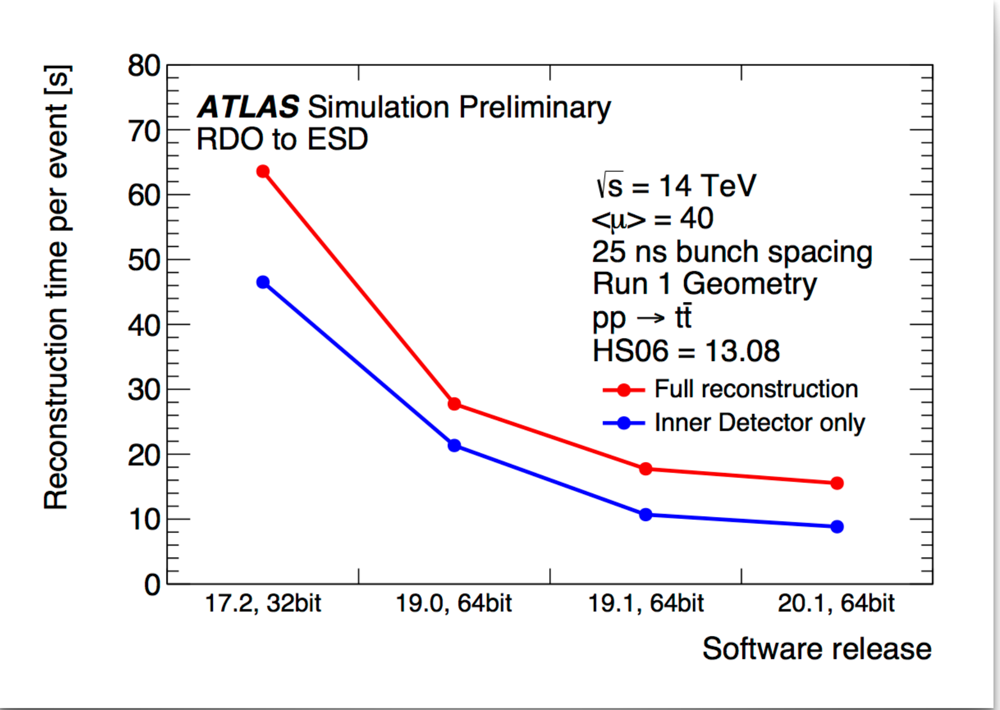
ID Tracking
software improvements during LS1

Run-2 is a challenge for the ATLAS reconstruction:

- more particles per collision: 7→13 TeV
- more collisions to process/time: increase of HLT rate 400 Hz →1kHz
- more collisions per bunch crossing: pile-up <μ>~20 → <μ>~40

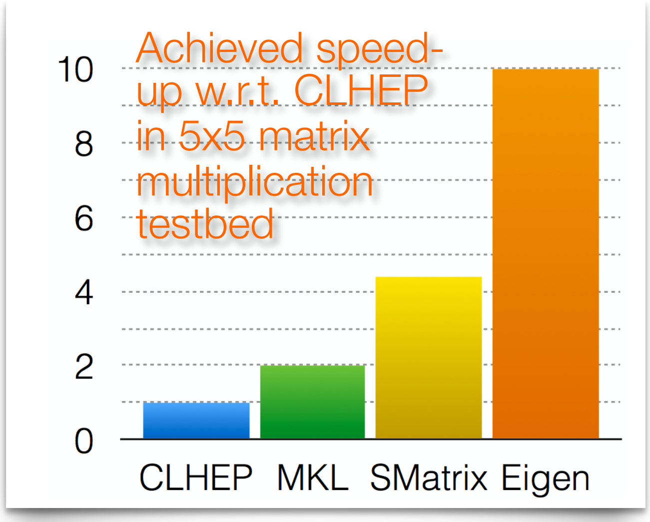
→ how to stay within resources?

during LS1 major technology and sw strategies to improve ATLAS CPU time by factor 3
(tracking factor 4 → ID track reconstruction is the dominant part)



ID Tracking
software improvements during LS1

How this CPU speed-up was achieved in tracking?



- track seeding strategy
  - optimization of seeding order (including IBL) and quality selection on seeds
- linear algebra library was changed (CLHEP bottleneck → Eigen)
  - track reconstruction makes heavy use of matrix manipulations
  - massive rework of the entire ATLAS sw (>1000 pkgs changed)
- cleaning up of the Event Data Model (EDM)
  - flattening the structure of the track reconstruction EDM
  - enormous reduction (and optimization) of code lines
- sw optimization, like B field access
  - field data from F90 → C++
  - new field service (speed-up 20% in simulation, few % in reconstruction)

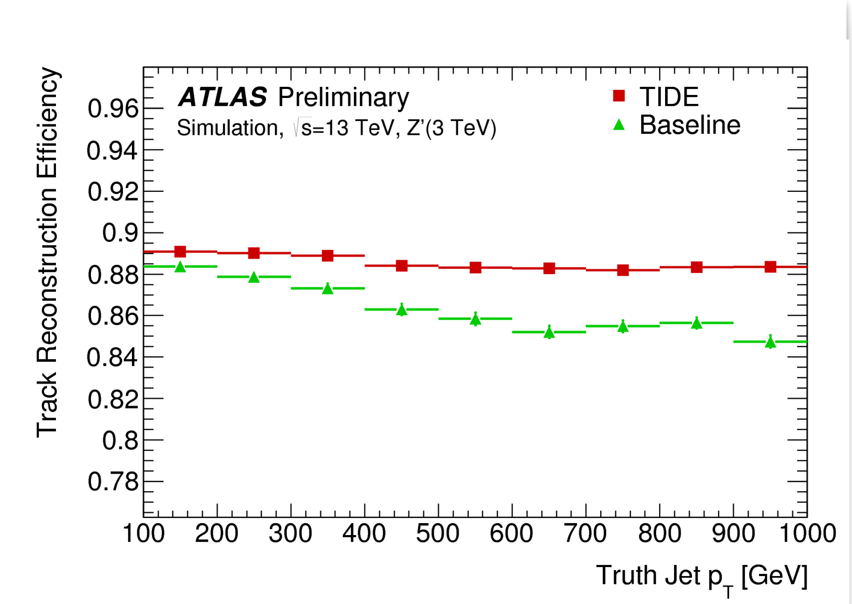
Tracking in dense environment (TIDE)

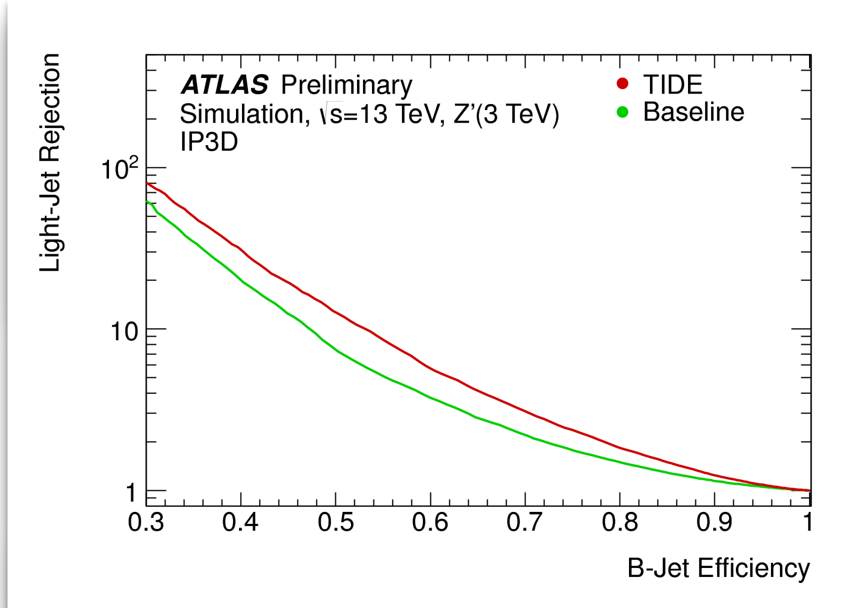
ATL-PHYS-PUB-2015-006

Cores of high pT jets and τ-leptons are environments that are characterized by charged particle separations comparable to the resolution of the Inner Detectors sensors

- an artificial neural network (NN) based approach was already introduced in 2011 to identify clusters created by multiple charged particles (arXiv: 1406.7690 [hep-ex])
- new algorithmic developments (like optimization of the ambiguity solver) to the ATLAS track reconstruction software targeting these topologies have been developed during LS1

7-13% increase in b-tagging efficiency for jets with p_T> 100GeV !





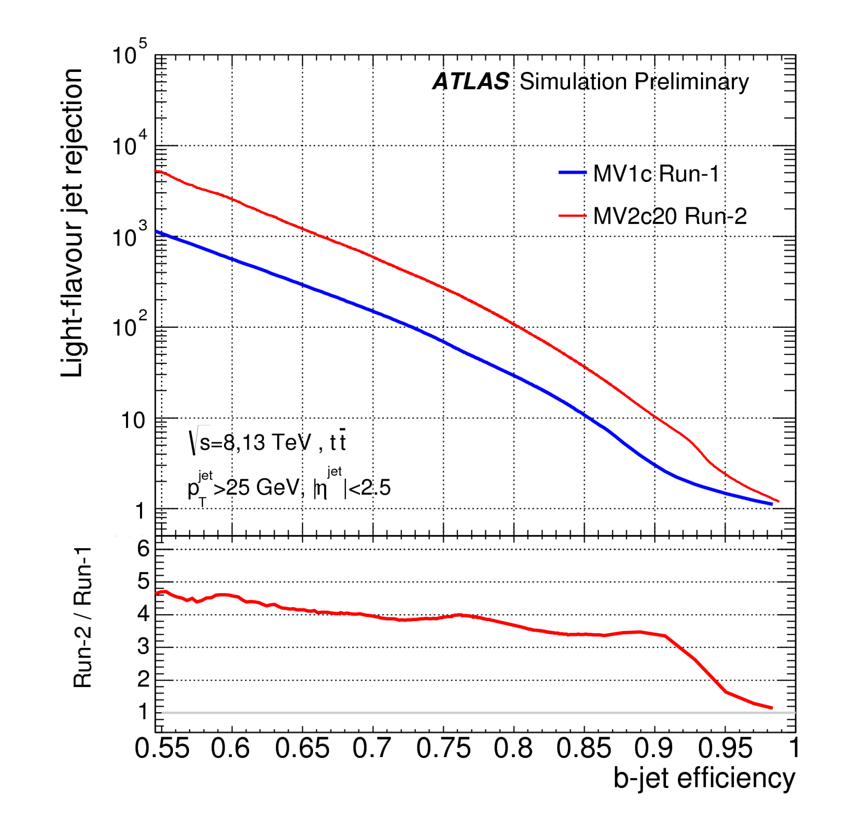
b-tagging

ATL-PHYS-PUB-2015-022

Identification of b-jets is useful for many analysis:

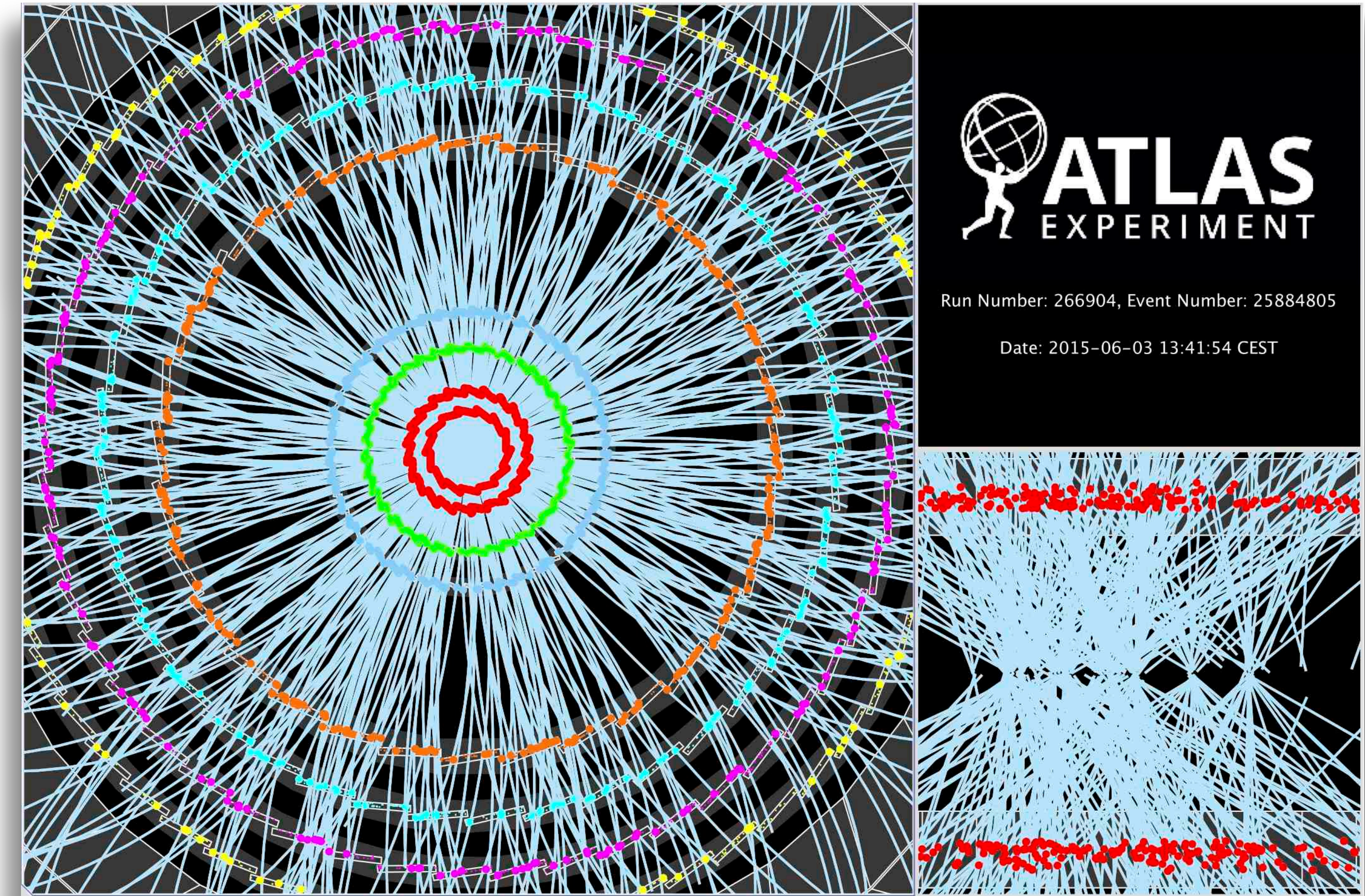
Higgs (H→bb), top(t→Wb), SUSY/Exotics (X_1→X_2b)…

- significant b-tagging performance improvement for Run 2
  (in terms of both charm and light jet rejection):
    - additional IBL info
      (extra Pixel layer closer to beam pipe)
      → improvement at low p_T
    - enhancements in tracking (see TIDE) and b-tagging algorithms
      → improvement at high p_T



- for a 70% b-tagging efficiency the light-jet rejection is increased by a factor of about 4 !
- in analyses with four b-quarks in the final state (e.g. ttH(bb)) → gain of 40-50% in signal acceptance

Run 2 is here!!!

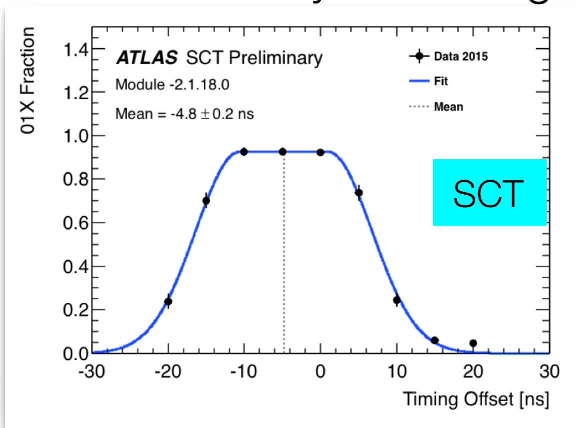


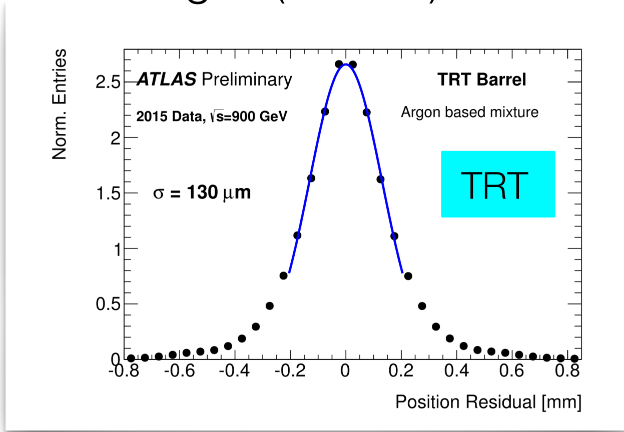
pp collision event recorded by ATLAS on 3rd June 2015, with the first LHC stable beams @ 13TeV

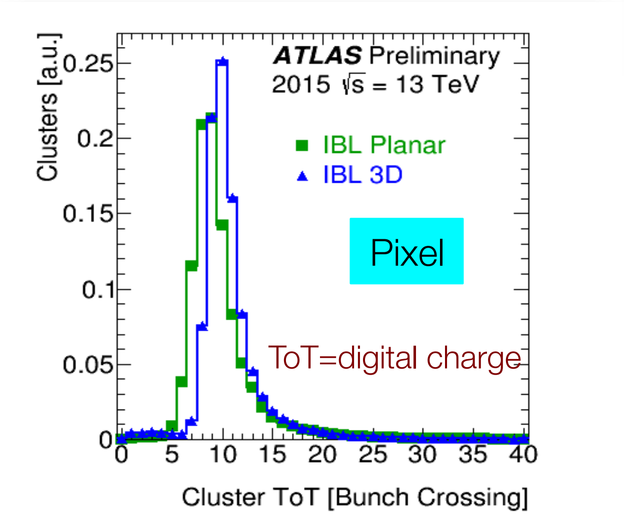
Run 2 ID detector performance

The Inner Detector had an excellent start to Run 2:

- the new 4th layer Pixels did yeld good quality data
- SCT fully operational and timed-in
- tracking performance in TRT not affected by the change of active gas (Xe→Ar)







ATLAS pp run: June-July 2015										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
97.3	99.6	100	98.4	100	100	100	100	100	100	99.3
All good for physics: 93.3%										

Luminosity weighted relative detector uptime (in percent) and good quality data delivery during 2015 stable beams in pp collisions at $\sqrt{s}$ = 13 TeV between 3 June and 16 July – corresponding to 91 pb^{-1} of recorded data.

ID Alignment

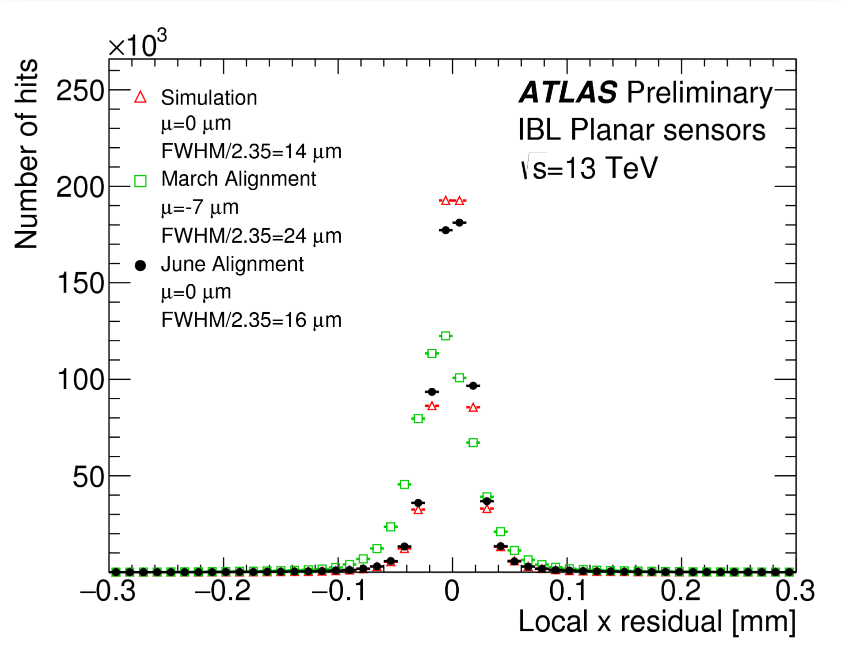
ATL-PHYS-PUB-2015-031
ATL-INDET-PUB-2015-001

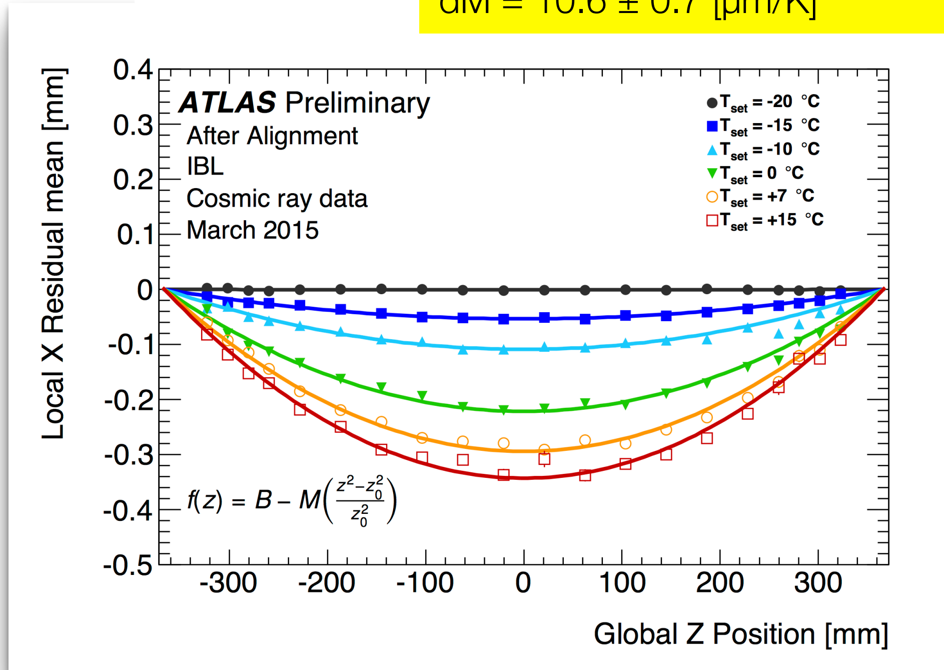
Detector alignment is a crucial aspect of tracking commissioning

- 13 TeV pp collisions (June 2015) used to update ID cosmic alignment
    - track-based algorithm
- mechanical stability of detector system over time during first LHC weeks studied
    - position of IBL staves distortions vs temperature in Φ was observed
    - reinforced monitoring of T and alignment control

→ good quality results already achieved!

local X displacement magnitude
dM = 10.6 ± 0.7 [μm/K]





ID Material description

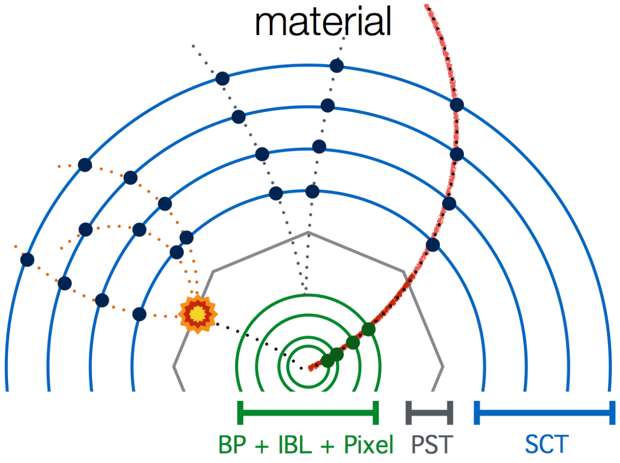
IDTR-2015-003
ATL-PHYS-PUB-2015-018

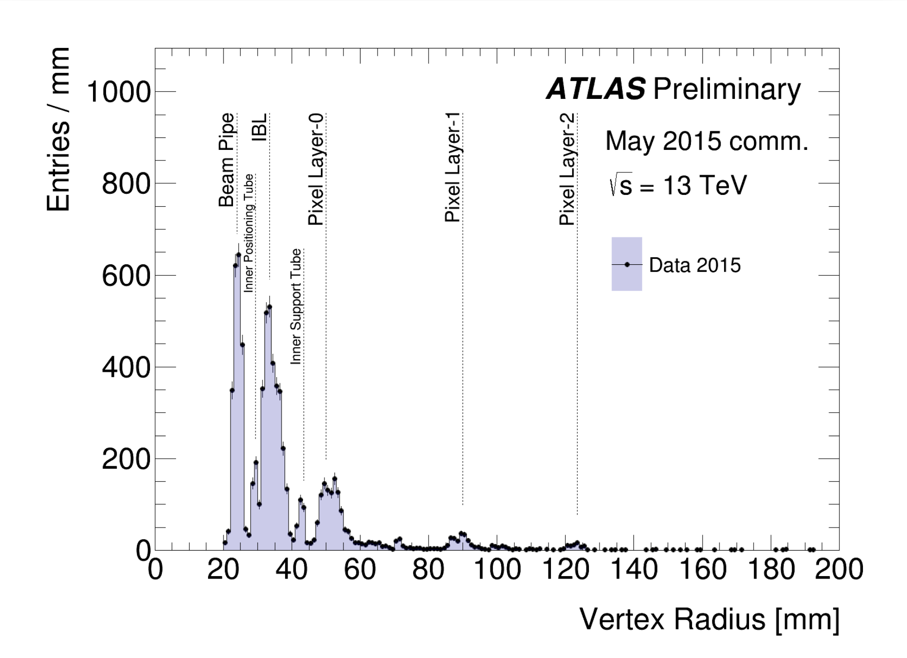
Three complementary methods to measure ID material (using 13TeV data):

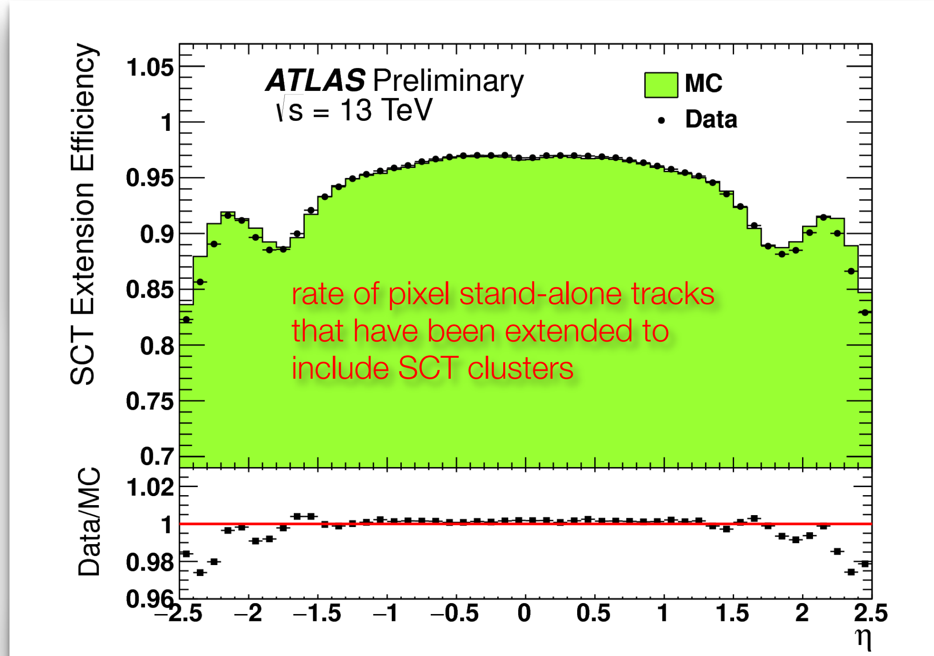
- photon conversions, hadronic interactions
- SCT extended efficiencies

agreement with simulation within a few percent

detailed studies thanks to ~130M low-μ events!



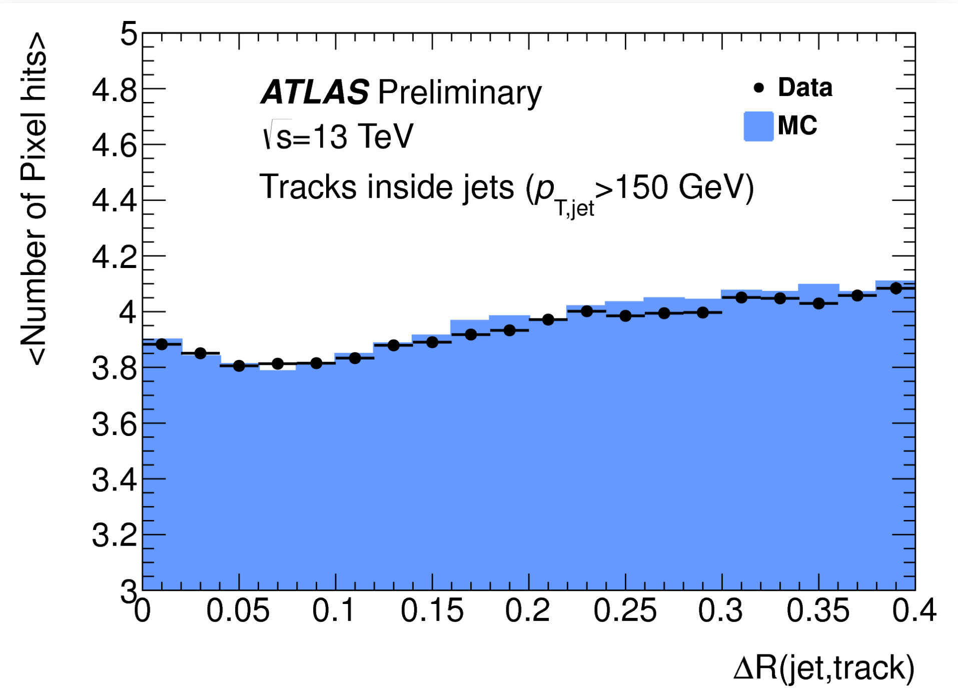


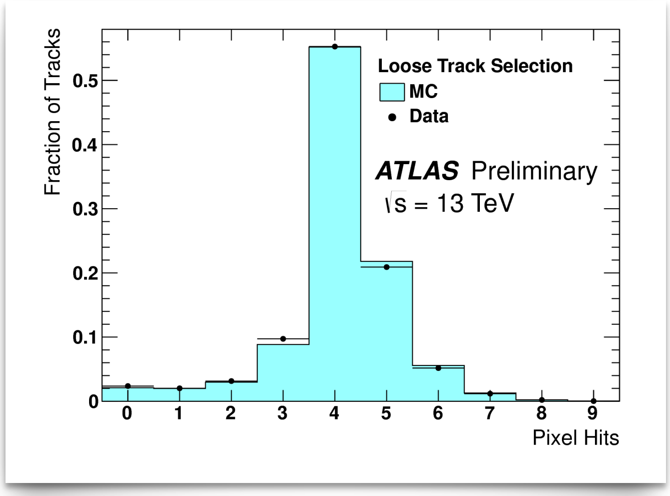


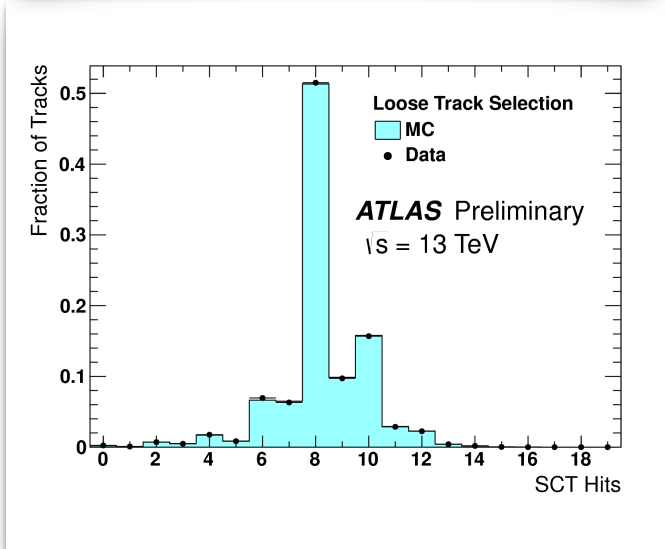
Hits on track

ATL-PHYS-PUB-2015-018

- Number of Silicon and TRT hits on track is well reproduced by the simulation
  - structures well described
  - remaining discrepancy source already identified (IBL geometry description)
- Good modeling of tracks in jets







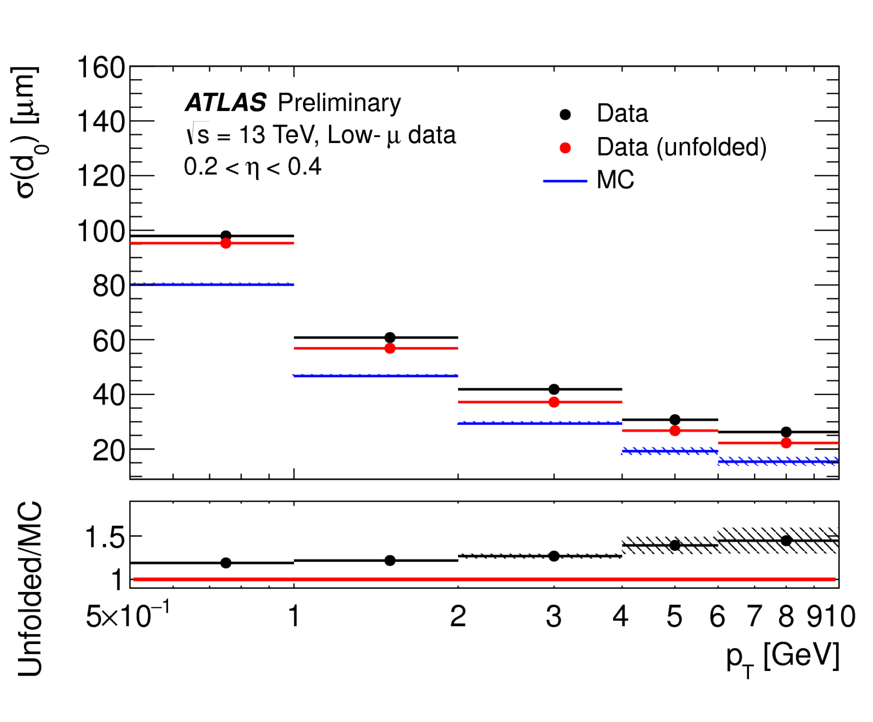
Impact parameter

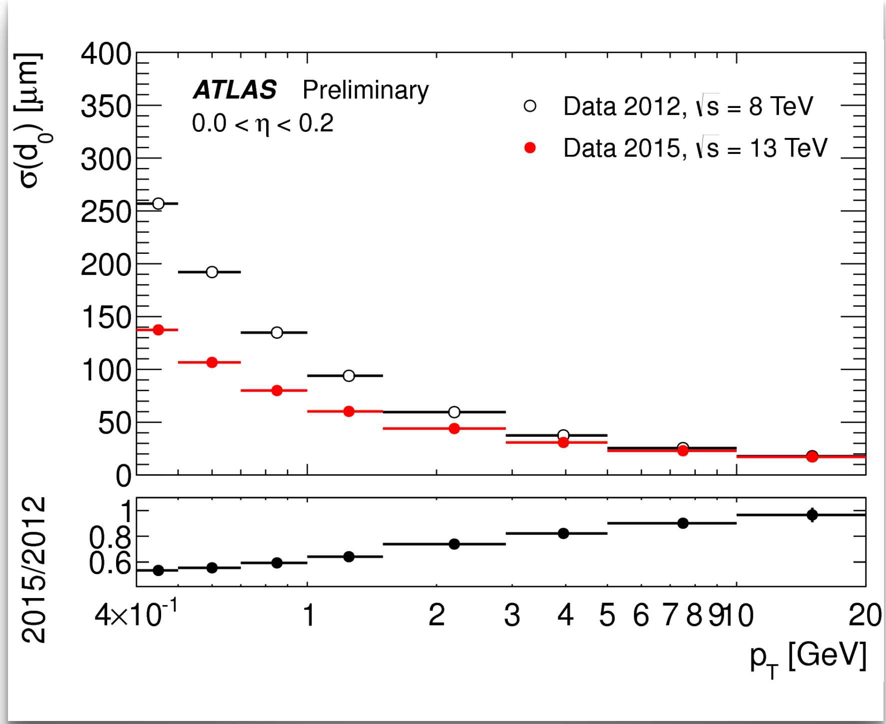
ATL-PHYS-PUB-2015-018

- Impact parameter resolution extremely sensitive to hit in first pixel layer!
  ~99.5% of tracks have a hit in the Pixel layer
- key ingredient in the reconstruction of heavy flavours (b,c,τ)
- at high p → sensitive to intrinsic detector resolution and alignment
- at low p → sensitive detector material

discrepancies due to IBL material description simulation and residual misalignment

IP resolution: improvement up to ~factor 2 w.r.t. Run1

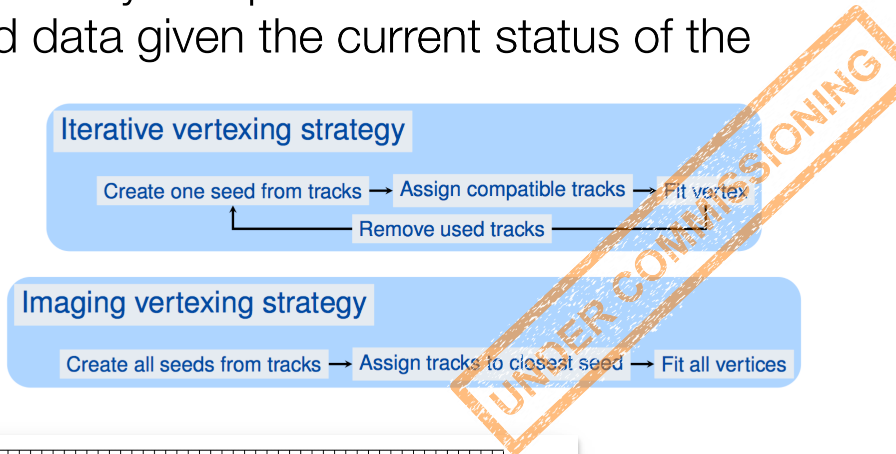


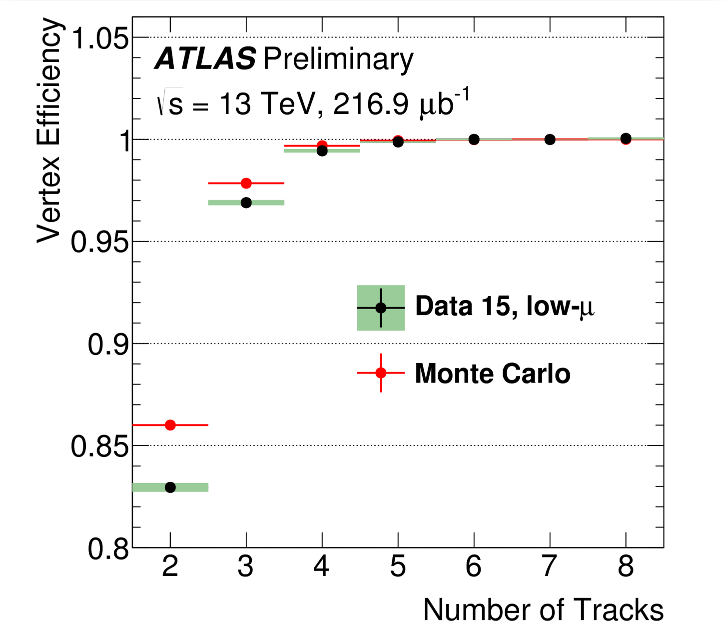


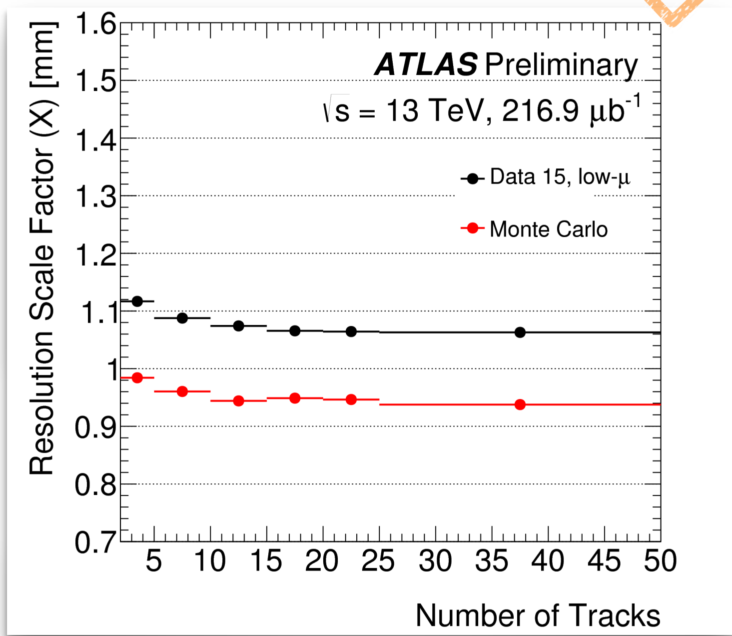
Vertexing

ATL-PHYS-PUB-2015-026
ATL-PHYS-PUB-2015-008

- first look at performances with 13TeV data: efficiency and position resolution in reasonable agreement between simulation and data given the current status of the alignment and material description
- to reduce merging of two pp interaction into one vertex, ATLAS is developing a new imaging seeding algorithm to ensure continued performance for very high numbers of simultaneous collisions in future LHC data taking







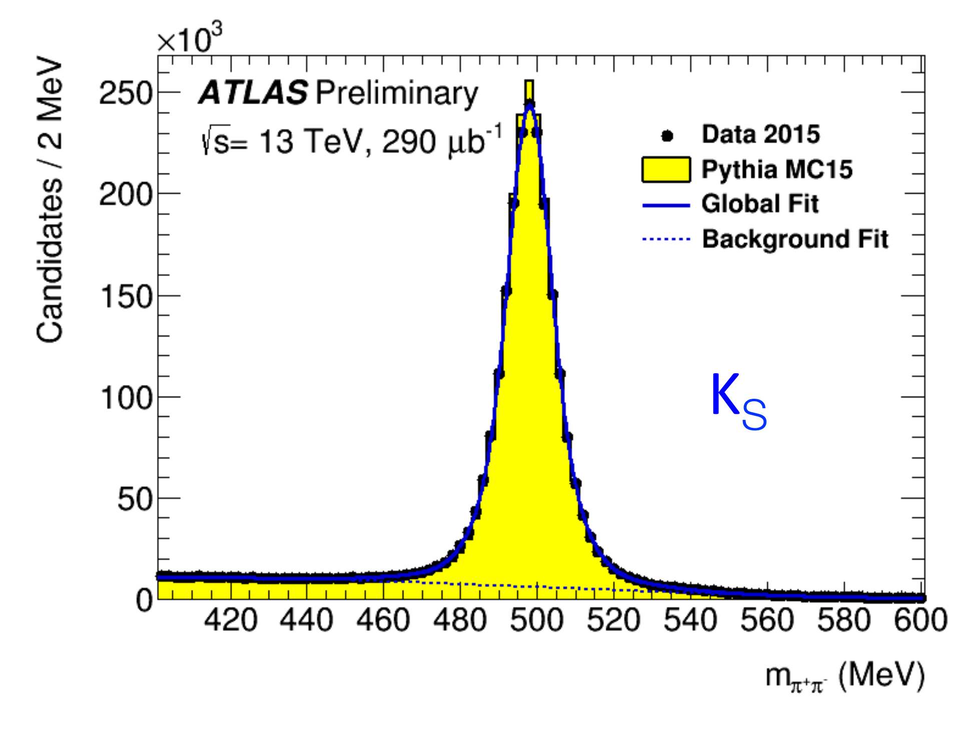
Summary

Many improvements took place during LS1 for the ATLAS tracking:

- detector side: improved Pixels with installation of an extra 4th layer
- CPU time reduction of a factor 4 thanks to technology and sw strategies
- optimization of tracking in dense environments
- improved vertex and b-tagging

Early Run 2 data have been vital for:

- alignment → approaching MC sensitivity
- improved understanding of the material of new Pixels (IBL, services)
- early measurements of IP and vertex resolution



Stay tuned, much more to come !!!!

backup

Position Reconstruction inside Pixel Detector

Up to mid-2011 run period:

If particles leave signal in more than 1 pixel → position resolution can be improved (w.r.t. a simple geometrical center of the cluster), using a charge interpolation technique

$$x_{\text{cluster}} = x_{\text{centre}} + \Delta_{\text{x}}(\phi, N_{\text{row}}) \cdot \left[\Omega_{\text{x}} - \frac{1}{2}\right]$$
$$y_{\text{cluster}} = y_{\text{centre}} + \Delta_{\text{y}}(\theta, N_{\text{col}}) \cdot \left[\Omega_{\text{y}} - \frac{1}{2}\right],$$

$$\Omega_{\text{x(y)}} = \frac{q_{\text{last row(col)}}}{q_{\text{first row(col)}} + q_{\text{last row(col)}}}$$

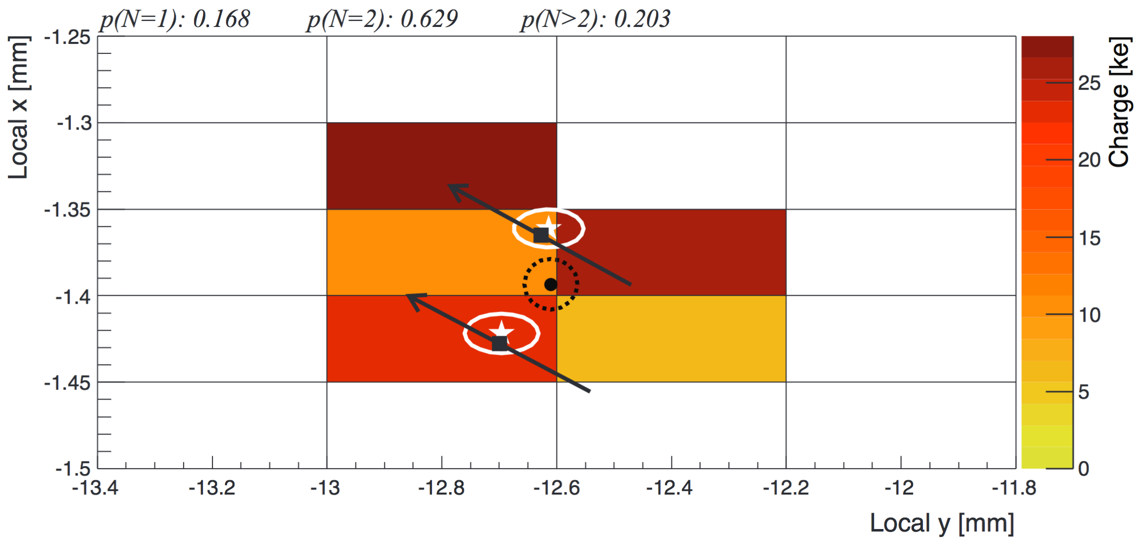
During 2011 run period: new NN cluster splitting technique became the default approach

In signatures with many collimated particles

core of very energetic jets, decay of boosted τ leptons into multiple hadrons…

shared measurements (clusters) can occur due to cluster merging

single NN to estimate cluster splitting prob
two sets of NN are then used to estimate clusters positions and uncertainties



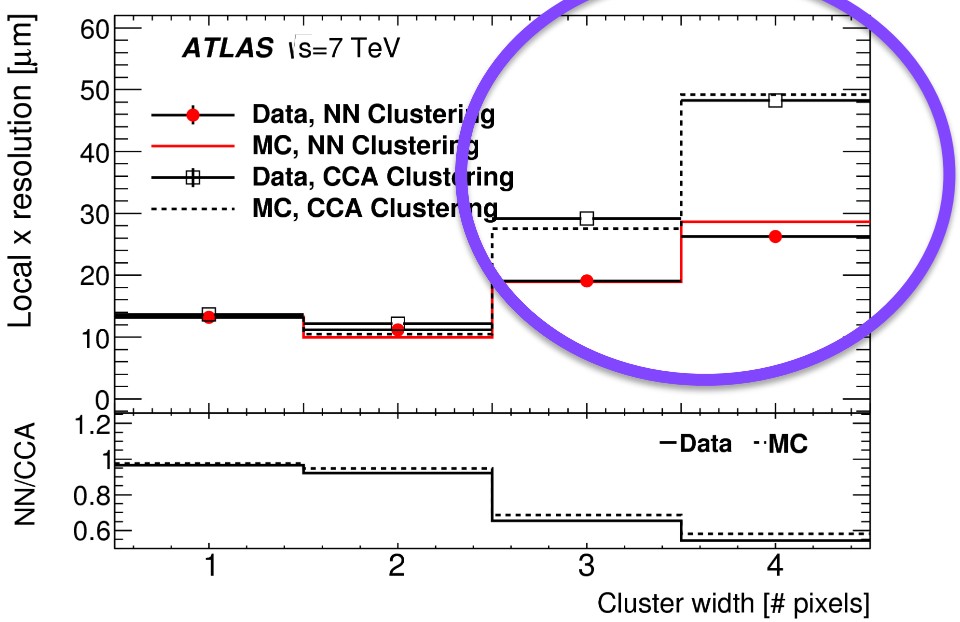
Neural Network Clustering Algorithm for the Pixel Detector

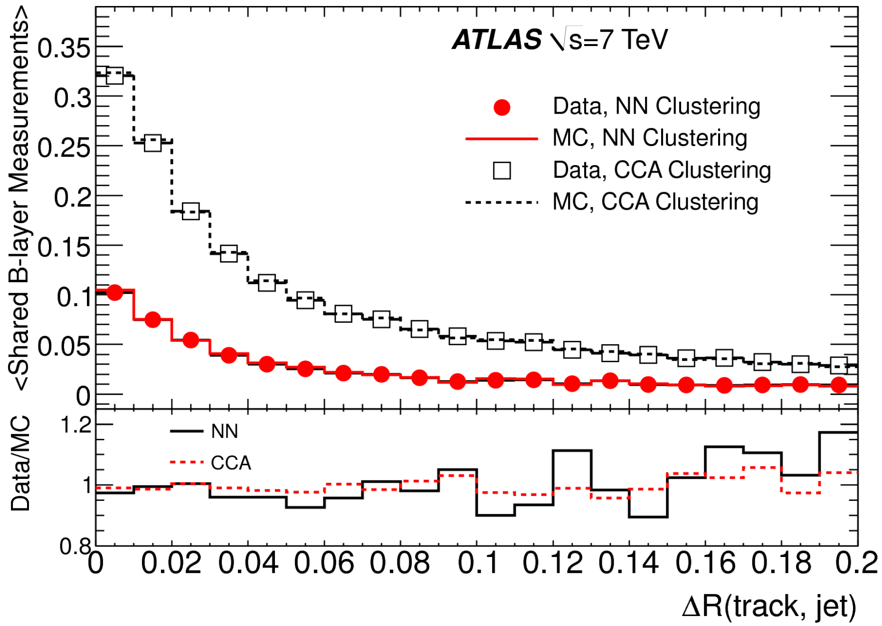
- Merged clusters, when assigned to a track → degraded position estimate (larger residuals)
- NN improves performance providing:
  - cluster splitting evaluation
  - non-linear charge interpolation
  - δ-rays handling

arXiv:1406.7690v1

in transverse direction particle usually crosses no more than 3 pix
→ in 3-4 pixel clusters likely contribution from multiple particles or δ-rays

In the jet core, the <shared measurements> is reduced by a factor 3!

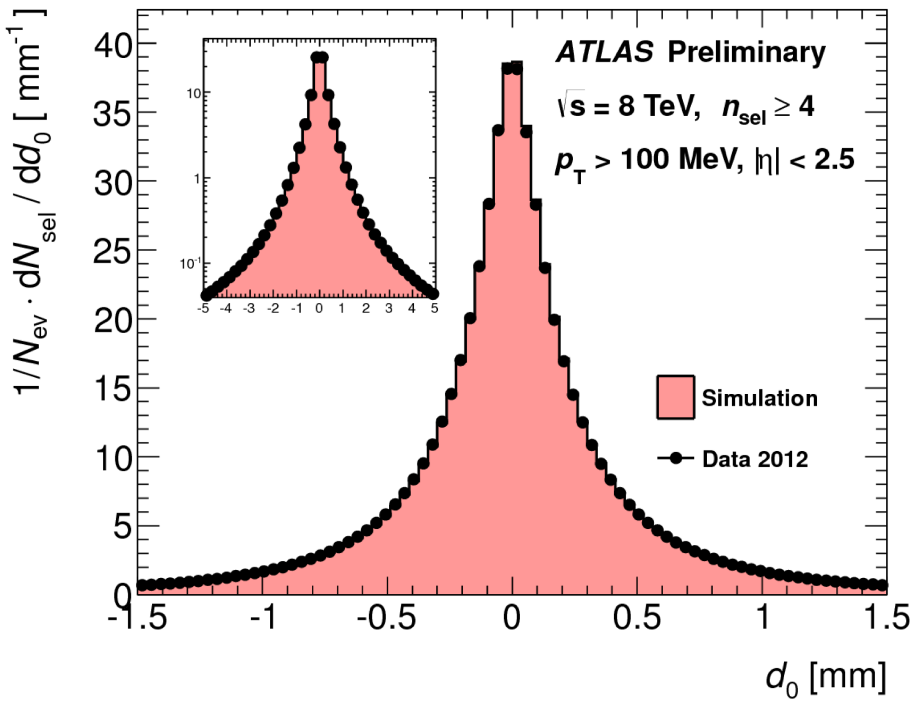


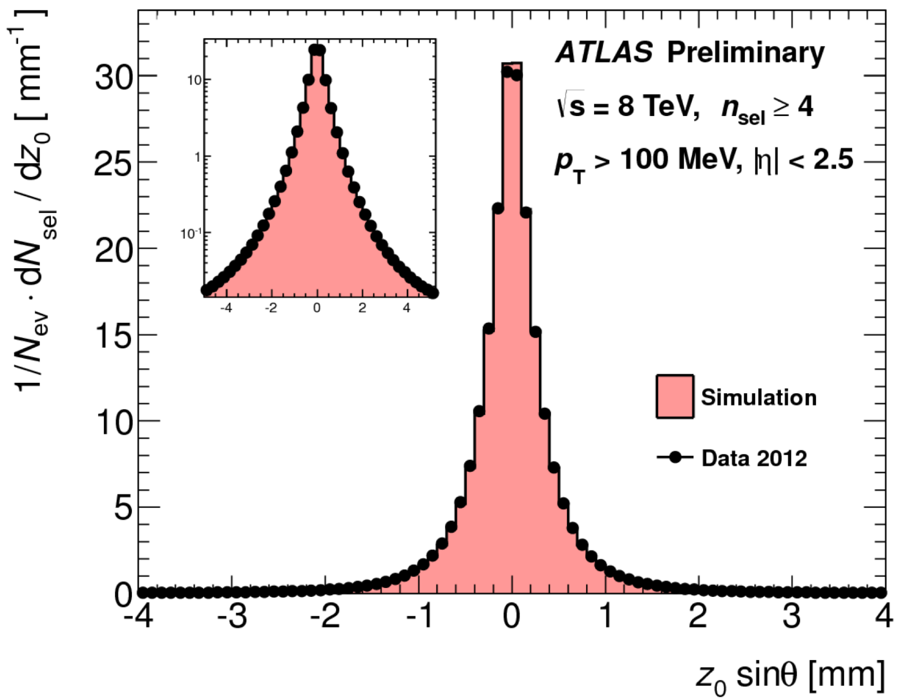


Tracking performance
Impact parameter Run 1

- resolution is dominated by the first measurement on track
  - at high p, intrinsic detector resolution and alignment (10μm resolution in barrel region)
  - at low p, detector material (material effect extremely well described)

ATL-COM-INDET-2-12-052



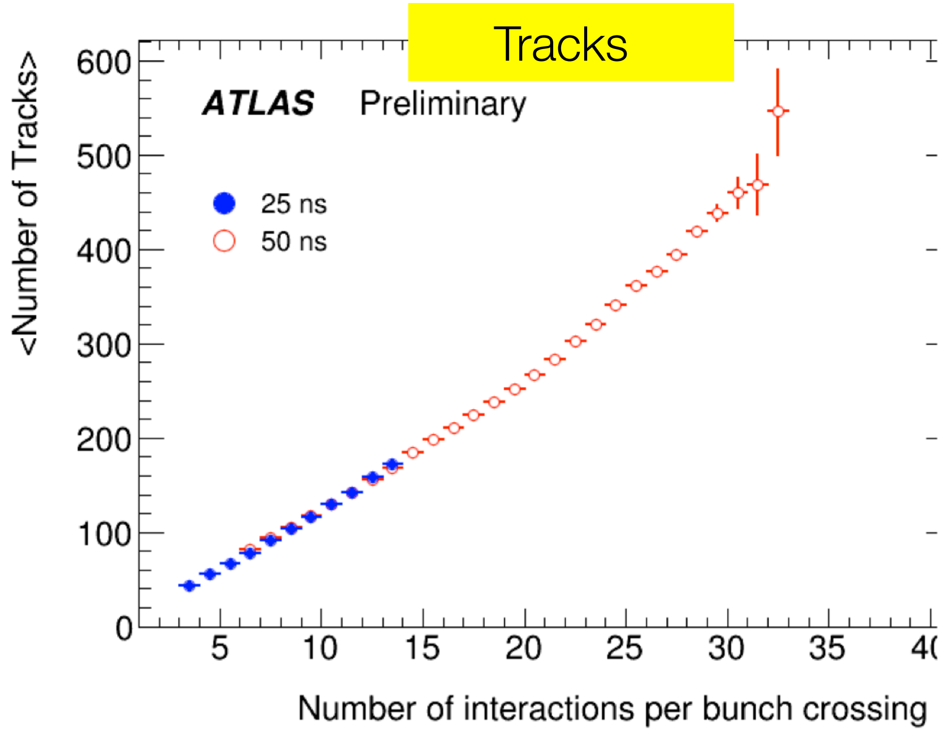


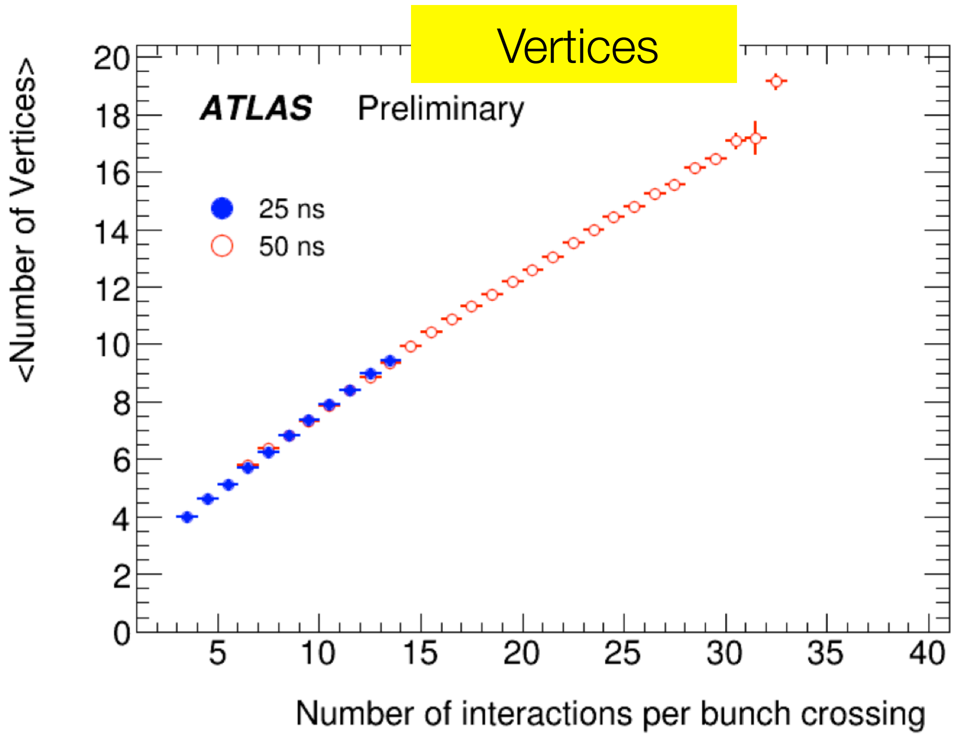
Run 2 preparation: 25 vs 50 ns

25/50 ns will need recalibration of many detector components

…nevertheless equal tracking reconstruction performance observed between 25/50 ns !

- tracking capabilities not affected by out-of-time pileup
- Inner detector seems well prepared for the 25ns setting

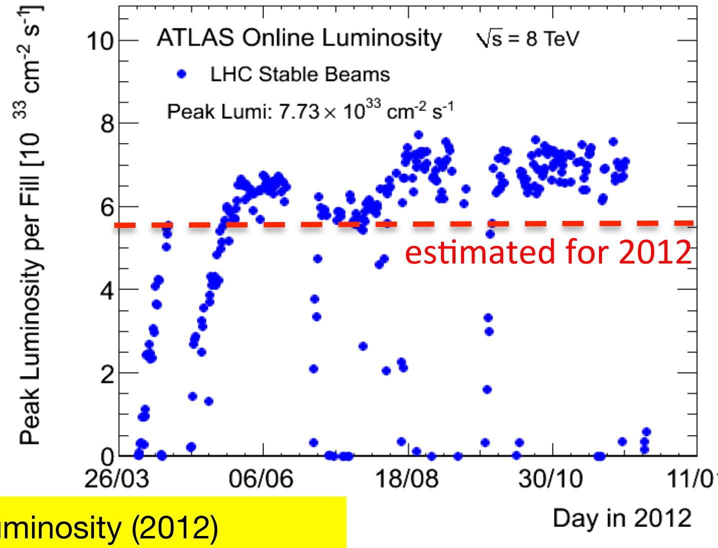


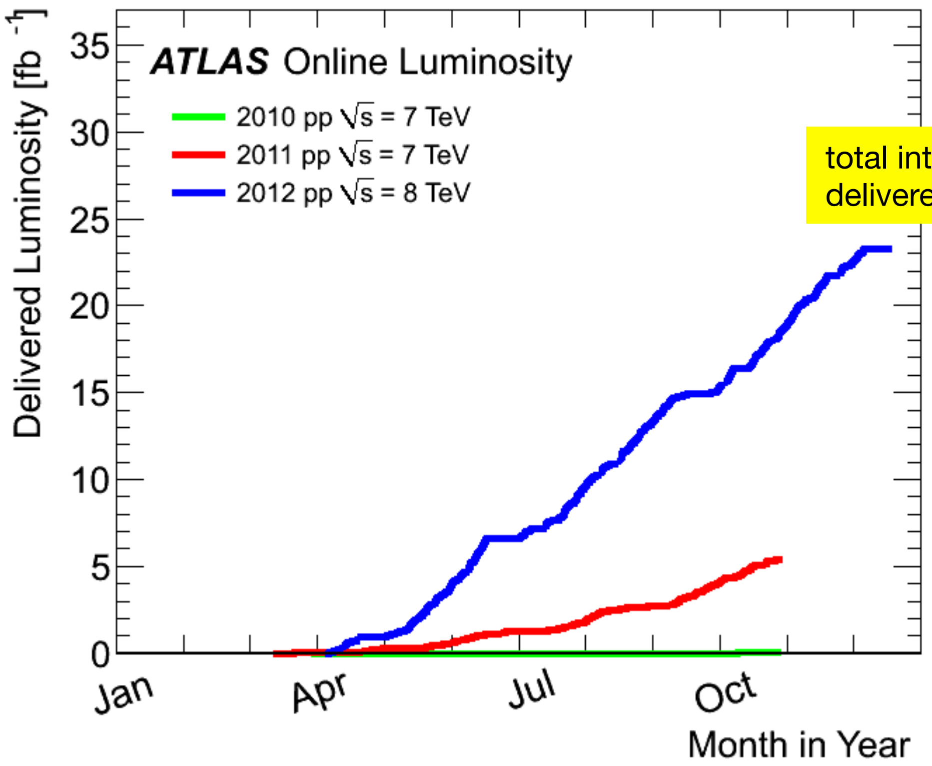


LHC and ATLAS performance in 2012

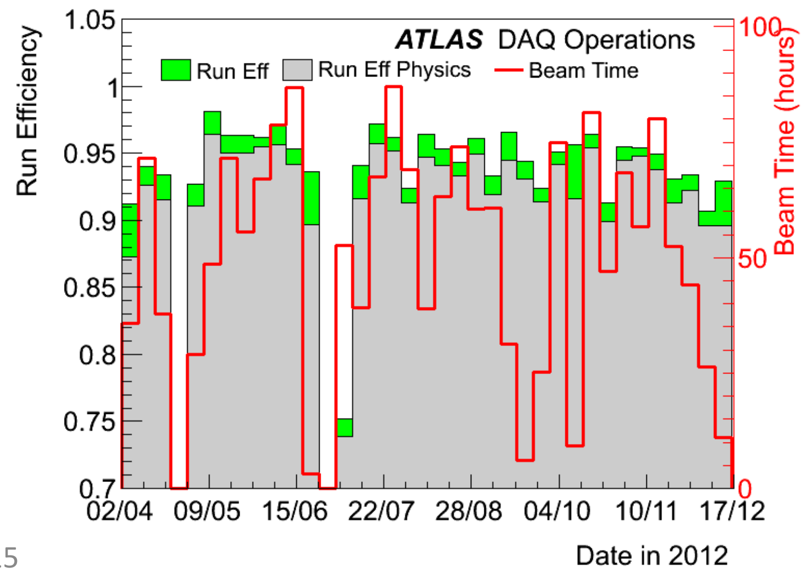
Outstanding LHC performances during 2012

- ATLAS data taking efficiency ~94%
  dominated by detector dead time
- peak luminosity routinely over 7.5 $10^{33} cm^{-2}s^{-1}$





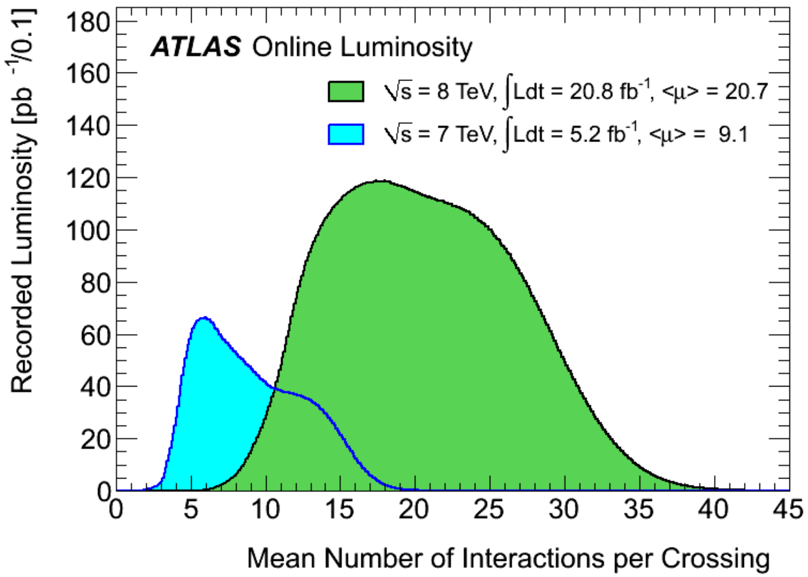
total integrated luminosity (2012)
delivered: 23.3 fb^{-1} recorded: 21.7 fb^{-1}



ATLAS performance in 2012

It was a success despite difficult conditions

- the expected in time pile up (PU) at design luminosity ($1 \times 10^{34} cm^{-2} s^{-1}$) was 23
  (25ns bunch spacing)
- in 2012 peak μ regularly over 35
  (50ns bunch spacing)



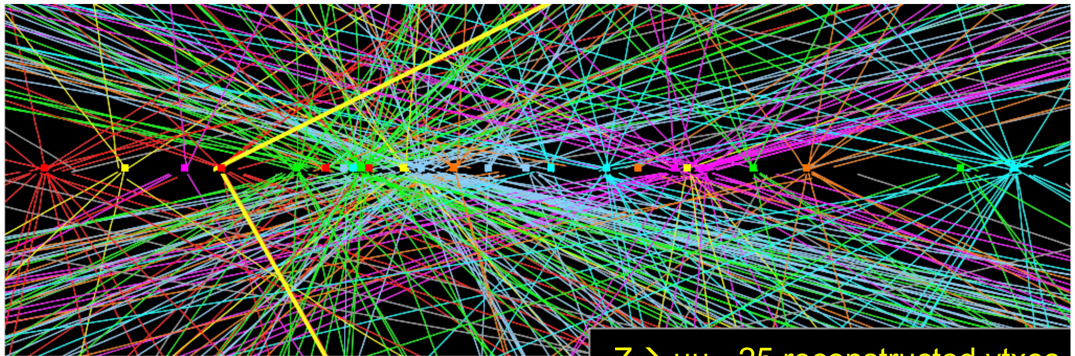
Inner Detector
- high reconstruction efficiency
  (~99% for muons)
- vertex reconstruction performing well

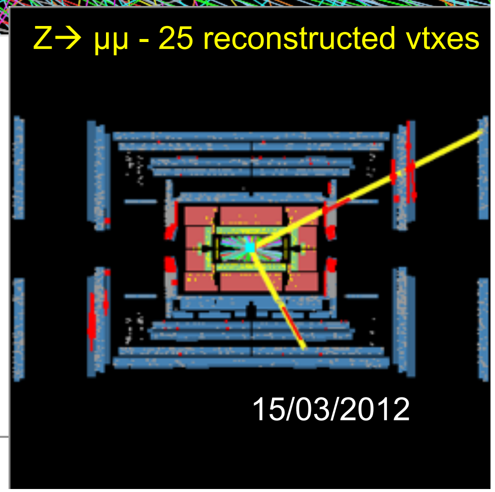
Calorimeters (e/γ performance)
- electron energy response and photon conversion reconstruction
  showed excellent stability w.r.t. increasing PU

Calorimeters (Jet/Etmis performance)
- missing Et reconstruction performing well
- stable resolution performance

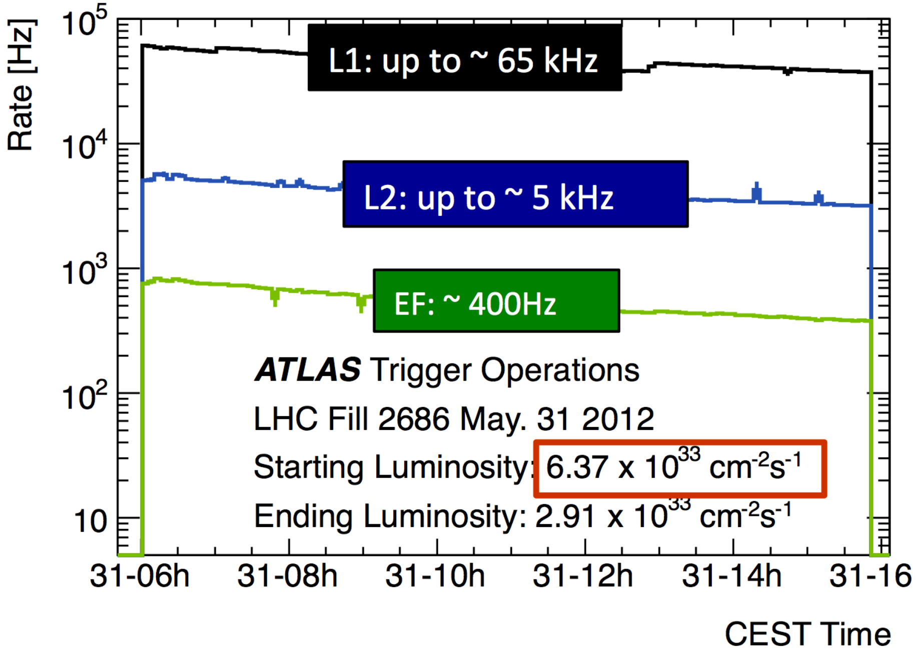
Particle Identification
- identification efficiency quite robust against PU

Trigger
- developed algorithms are robust against-pile up





Trigger and Data taking in 2012



Complicated trigger menu with >550 items!
Optimization of selections to maintain low un-prescaled thresholds

- results from 2012 operations showed trigger was coping very well (rates, efficiencies, robustness…)

Fraction of active channels was more then 95% for all systems, detector uptime > 99%

ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.4	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.8%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and December 6th (in %) – corresponding to 21.6 fb^{-1} of recorded data.

Pixel performances during Run I

excellent performances during LHC Run 1

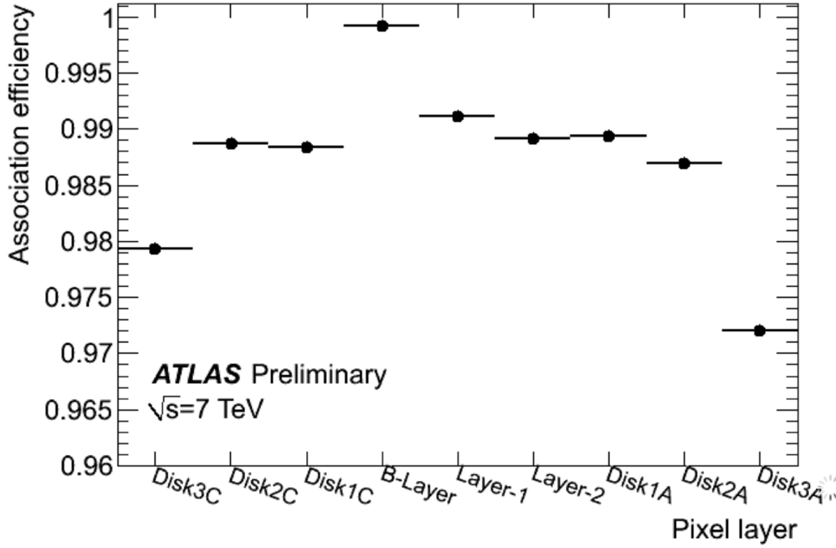
- data taking efficiency: 99.9%

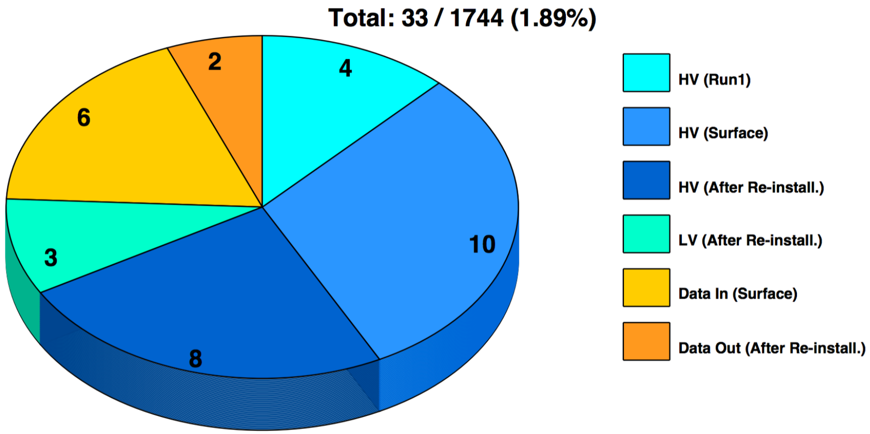
radiation effects are within expectations

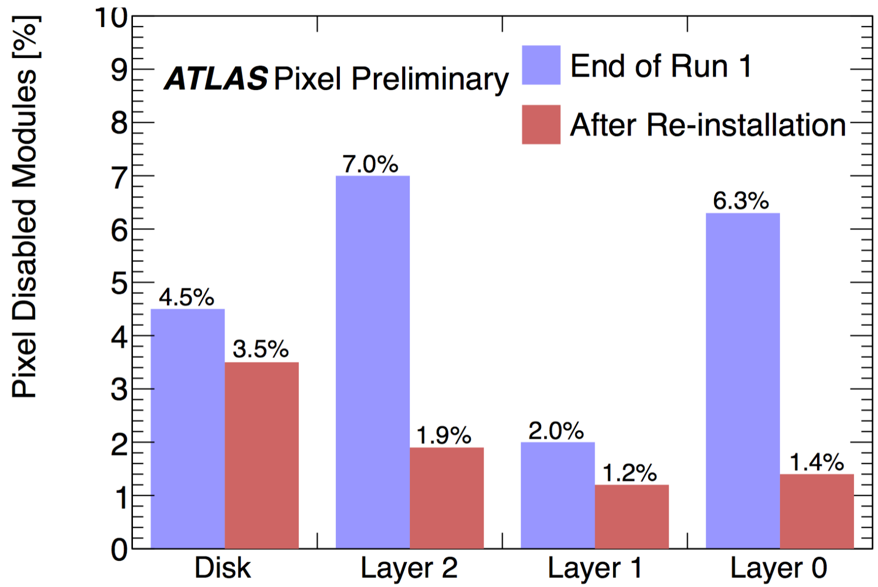
5% of pixel modules were disabled

- failures correlated with thermal cycling

During LS1 Pixel detector was extracted from The ATLAS experiment and brought on surface
→ after the LS1 installation ~98% active modules







Pixel upgrade for Run 2: the Insertable B-Layer (IBL)

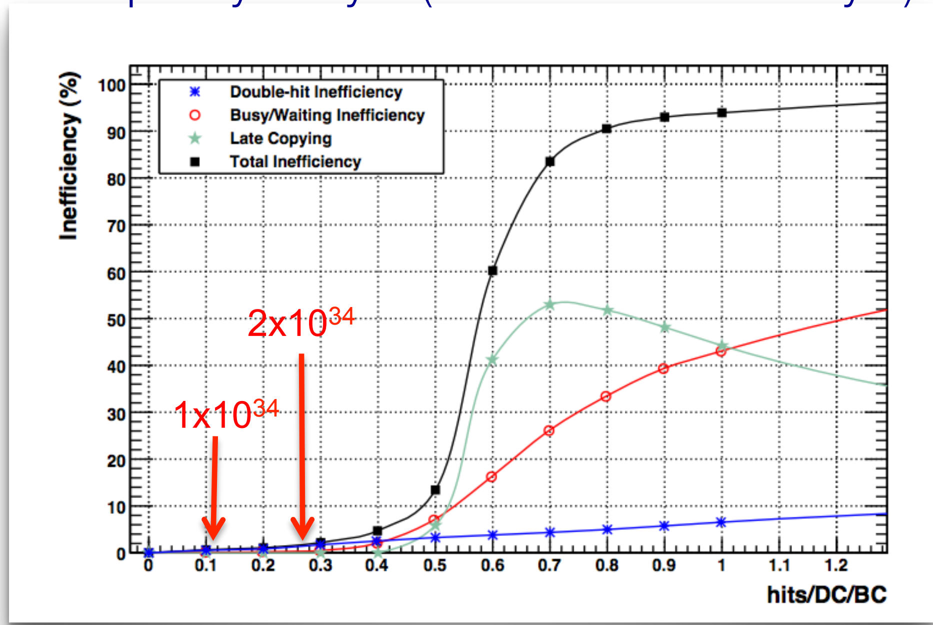
additional (4^{th}) pixel layer closer to IP

Physics motivation

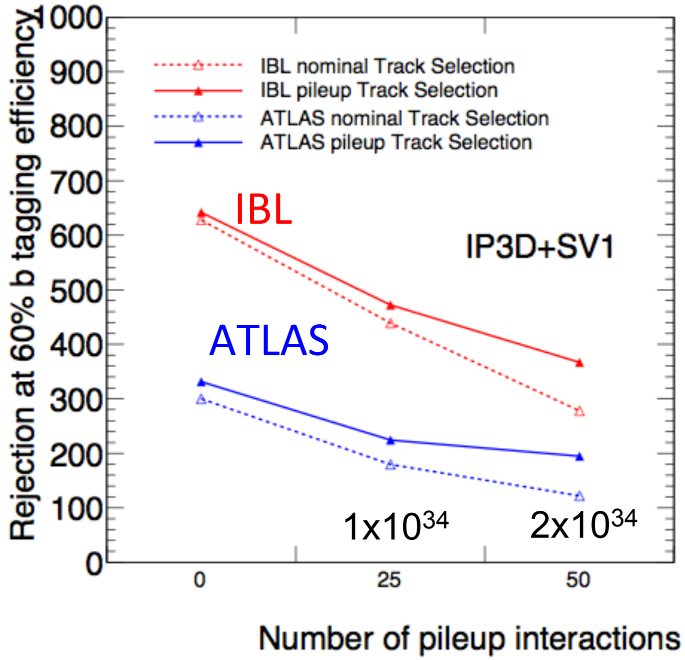
- robust tracking in case of failures in the current pixel system
- from L = 2×10^{34} $cm^{-2}s^{-1}$ b-tagging efficiency will start to degrade

  impact parameter resolution, vertexing, τ-reconstruction at high pile-up

occupancy B layer (current innermost layer)



Light jet rejection



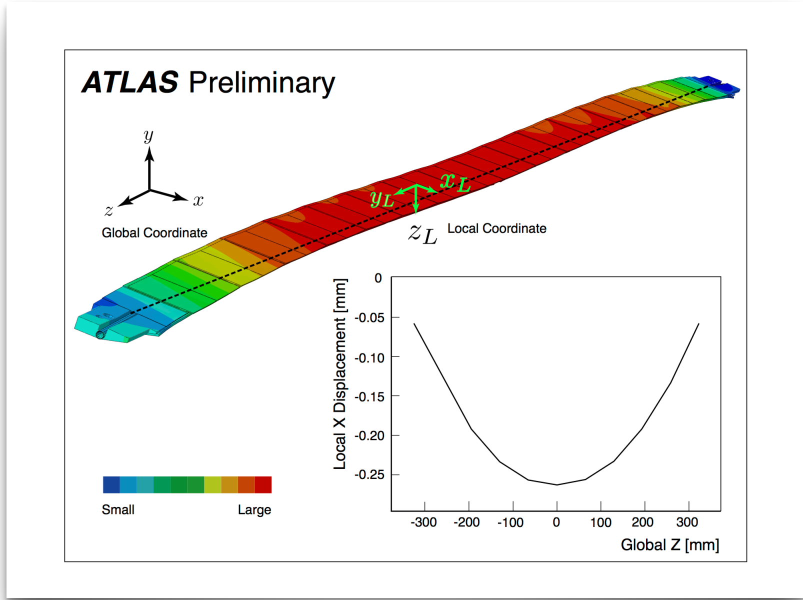
ID Alignment

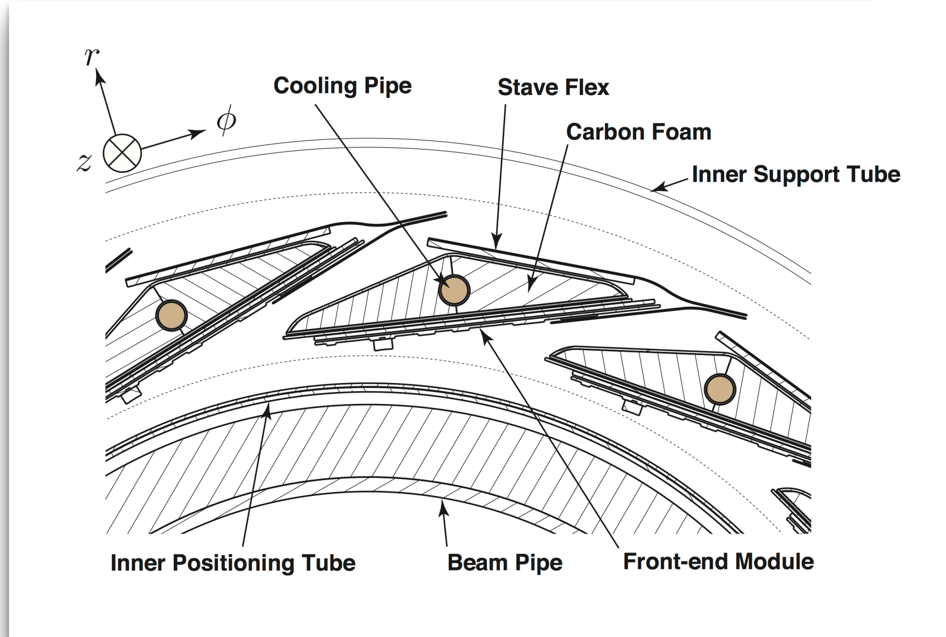
ATL-PHYS-PUB-2015-031
ATL-INDET-PUB-2015-001

Detector alignment is a crucial aspect of tracking commissioning

- first alignment using cosmic rays has been updated using 13 TeV data of June 2015
- mechanical stability of detector system over time during first LHC weeks studied
    - position of IBL staves distortions vs temperature in Φ was observed
    - reinforced monitoring of T and alignment control

→ good quality results already achieved!



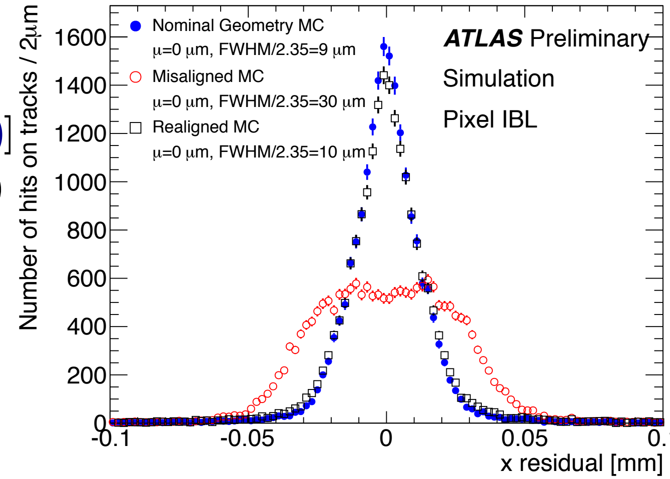


IBL integration into Pixel alignment framework

High resolution, unbiased measurement of all charged particle kinematic parameters
→ accurate invariant mass reconstruction and interaction and decay vertex finding

Alignment tools:

- assembly and survey [O(100μm)]
- time-dependent optical hardware based monitoring [O(1μm)]
- track-based alignment → minimization of χ^2 (track-hit residuals)
    - different techniques in place to eliminate syst deformations (beam spot and primary vertex constraints, info from known resonances, e^+ and e^- measured in the calo…)
    - sudden environmental changes (temperature, B field) have been taken into account in 2012
      typical resolution for barrel x,y residuals for 2012 Z->mumu events ~5μm(local x) ,50 μm (local y)



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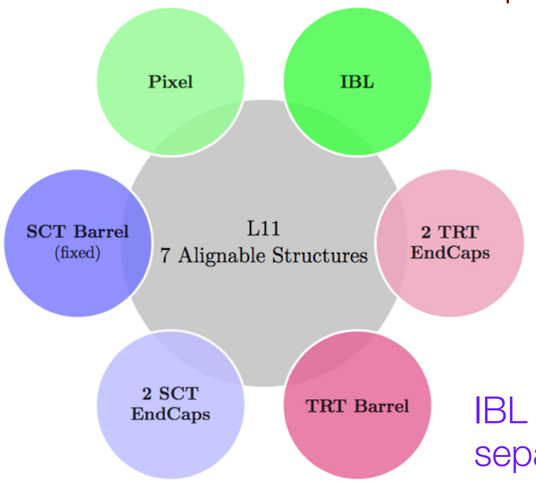

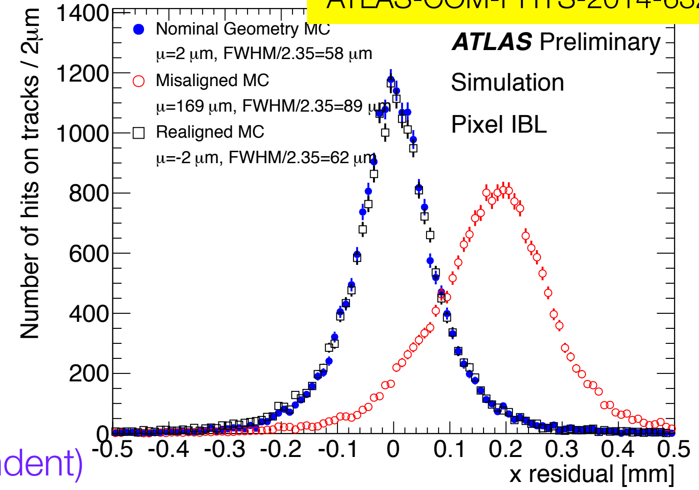

IBL considered as a whole structure separated from Pixels (mechanical independent)