The ATLAS Inner Detector operation, data quality and tracking performance.

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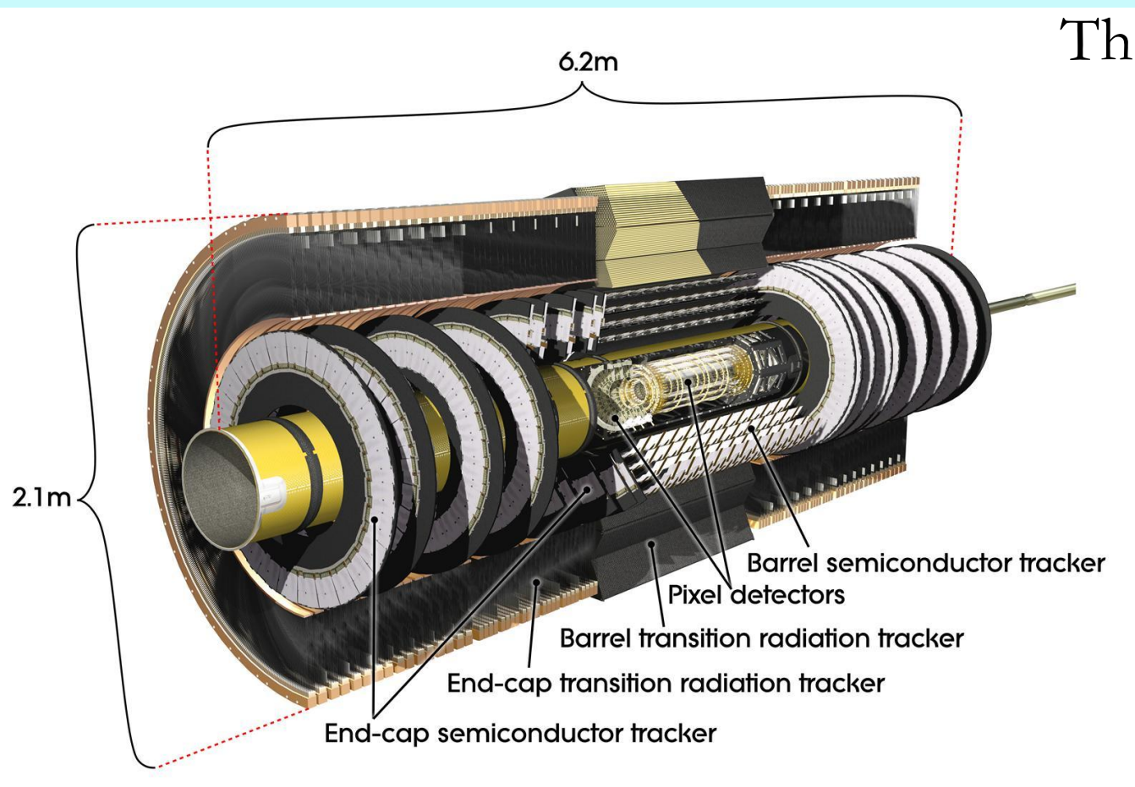
The ATLAS Inner Detector



The ID is composed of three Sub-detectors, of different technologies:

Transition Radiation Tracker (TRT):

- consisting of a barrel and two end-cap partitions
- 353 536 x 4mm-diameter Kapton straws filled with Xe/CO2/O2 gas
- good single point resolution ~130 μm in Rϕ
- continuous tracking (typically > 30 hits per track)
- high tolerance against radiation doses

Semi-Conductor Tracker (SCT)

- 4 barrel layers, 9 disks per end-cap
- 4088 modules, 6.3M channels (61 m^2)
- Intrinsic Resolution = 17 μm / 580 μm (Rϕ/z)
- Operational T = -8ºC to ~5ºC
- C3F8 Evaporative Cooling, in common with Pixel detector

Pixel detector:

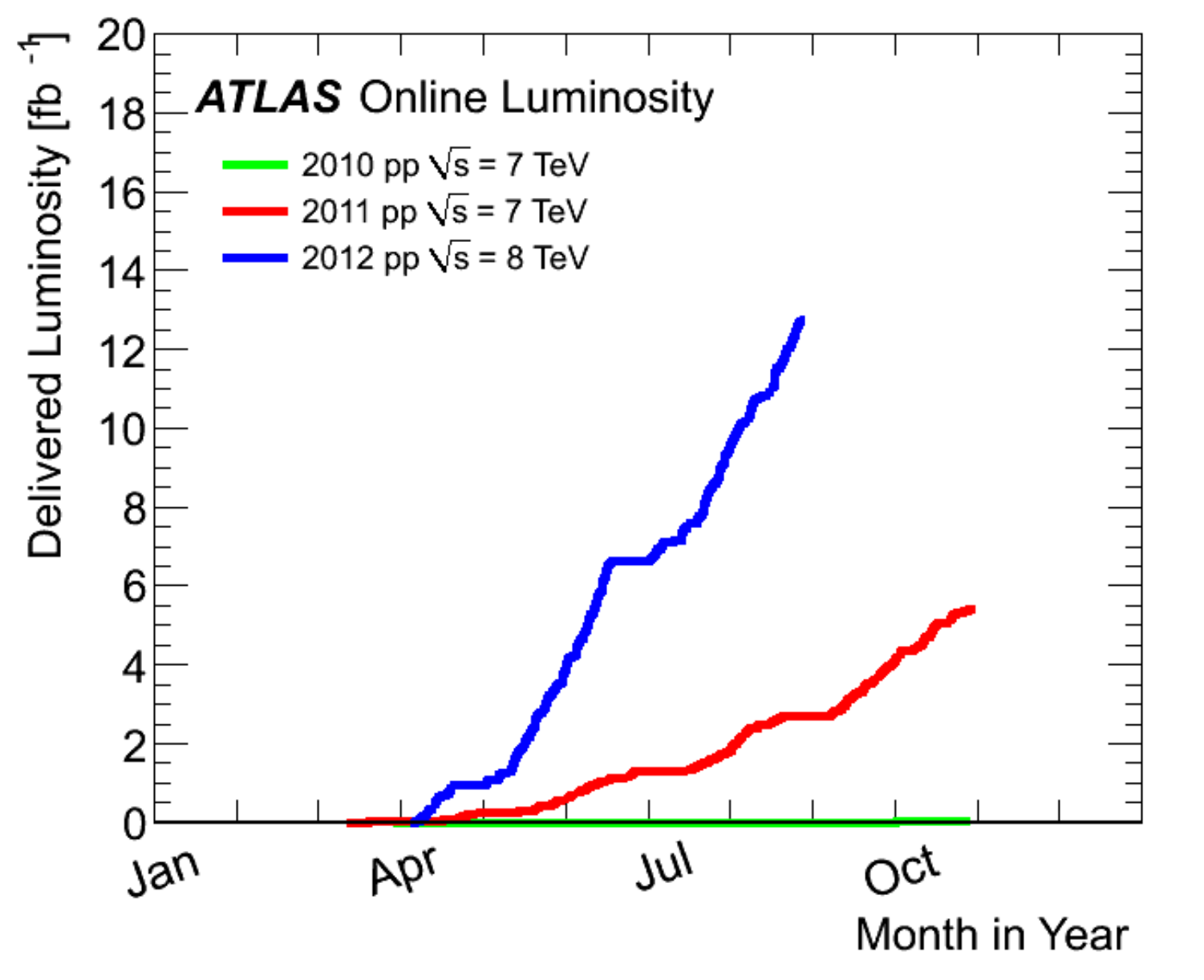
- 3 barrel layers, 2 x 3-layer end-cap disks
- 1744 pixel modules, 80M+ channels
- Intrinsic Resolution = 10 μm/115 μm (Rϕ/z)
- Cooled to average T = -13ºC
- C3F8 Evaporative Cooling, reliable (barring power cuts)

Immersed in a solenoid field of 2 Tesla the Inner Detector provides:

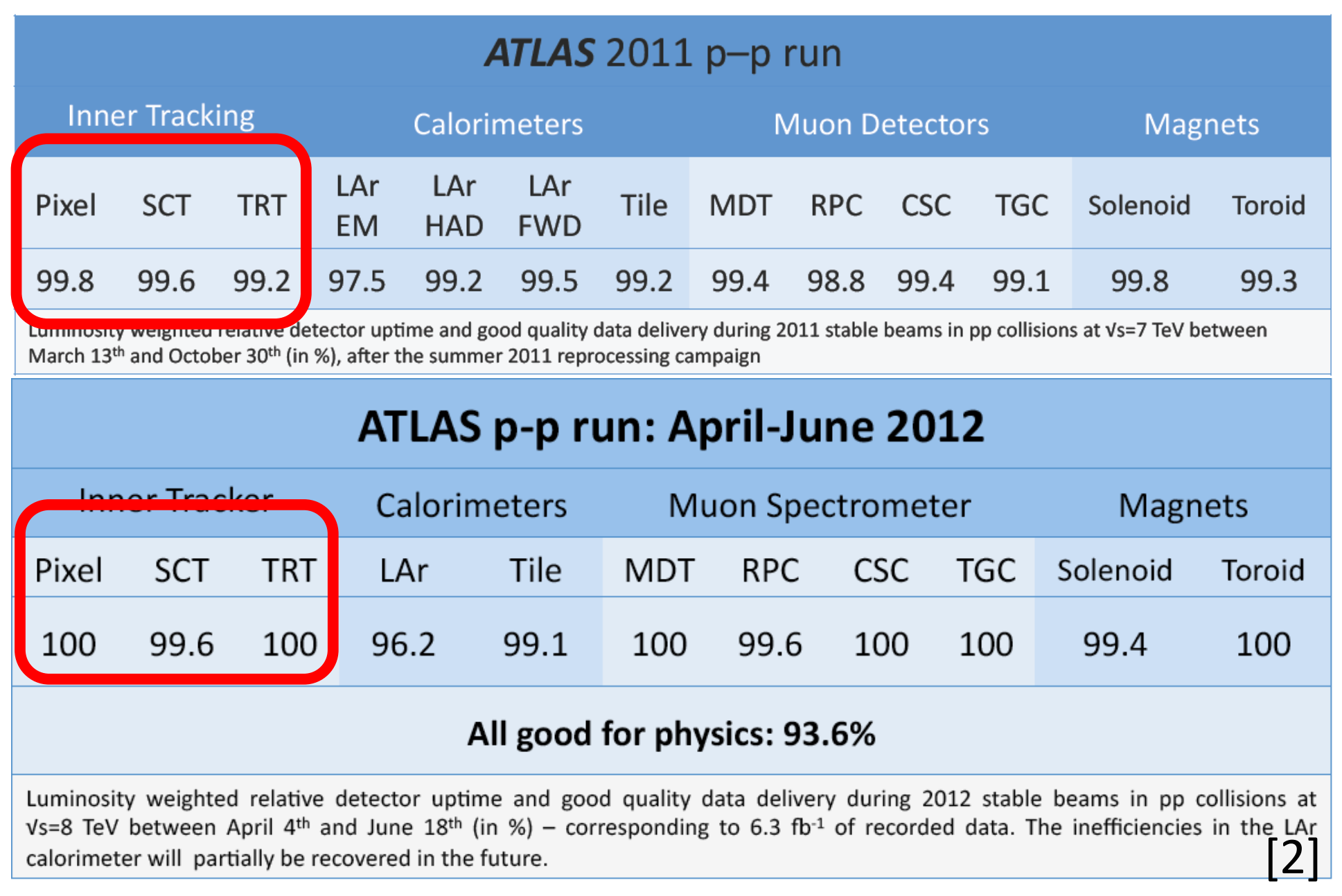
- Precision tracking at LHC luminosity over 5 units in η
- Precise primary/secondary vertex reconstruction
- Excellent b-tagging in jets
- Electron, muon, tau, b- and c-hadron reconstruction
- Transition radiation in the TRT for electron identification
- covers : |η| < 2.5 (2.0 for TRT)

Data Taking and Data Quality

The LHC delivered an integrated luminosity of 5.6 pb^{-1} at $\sqrt{s} = 7$ in 2010-2011. In 2012 the centre-of-mass energy was increased to 8 TeV , and the LHC luminosity was upgraded significantly.



The figure above presents cumulative luminosity versus day delivered to ATLAS during stable beams and for p-p collisions. This is shown for 2010 (green), 2011 (red) and part of 2012 (blue) running.[1]



***ATLAS* 2011 p–p run**

Inner Tracking			Calorimeters				Muon Detectors				Magnets	
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.8	99.6	99.2	97.5	99.2	99.5	99.2	99.4	98.8	99.4	99.1	99.8	99.3

Luminosity weighted relative detector uptime and good quality data delivery during 2011 stable beams in pp collisions at √s=7 TeV between March 13th and October 30th (in %), after the summer 2011 reprocessing campaign

ATLAS p-p run: April-June 2012

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
100	99.6	100	96.2	99.1	100	99.6	100	100	99.4	100

All good for physics: 93.6%

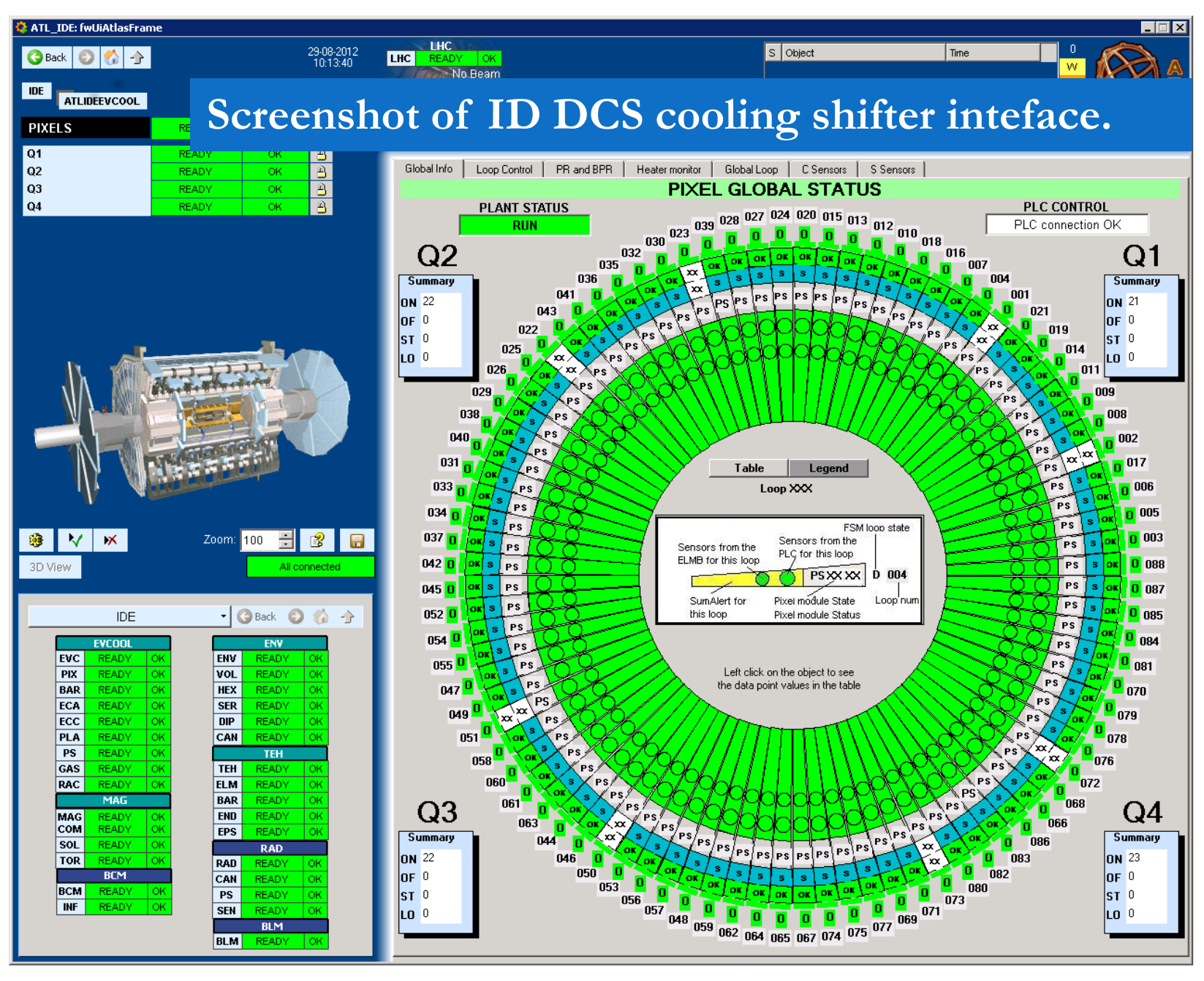
Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and June 18th (in %) – corresponding to 6.3 fb^{-1} of recorded data. The inefficiencies in the LAr calorimeter will partially be recovered in the future. [2]

Excellent data taking performance, for all ID detectors during 2010, 2011 and 2012. Close to 100% availability.

Detector Operation

The SCT Data Acquisition (DAQ) enhancements to maximise data taking efficiency:

- "stopless" reconfiguration/reintegration of RODs(Read-Out Driver) in case of BUSY
- online monitoring of chip errors in the data and automatic reconfiguration of modules which shows errors
- Auto reconfiguration of the entire SCT every 30 minutes as a precaution against Single Event Upset - spontaneous corruption of module configuration

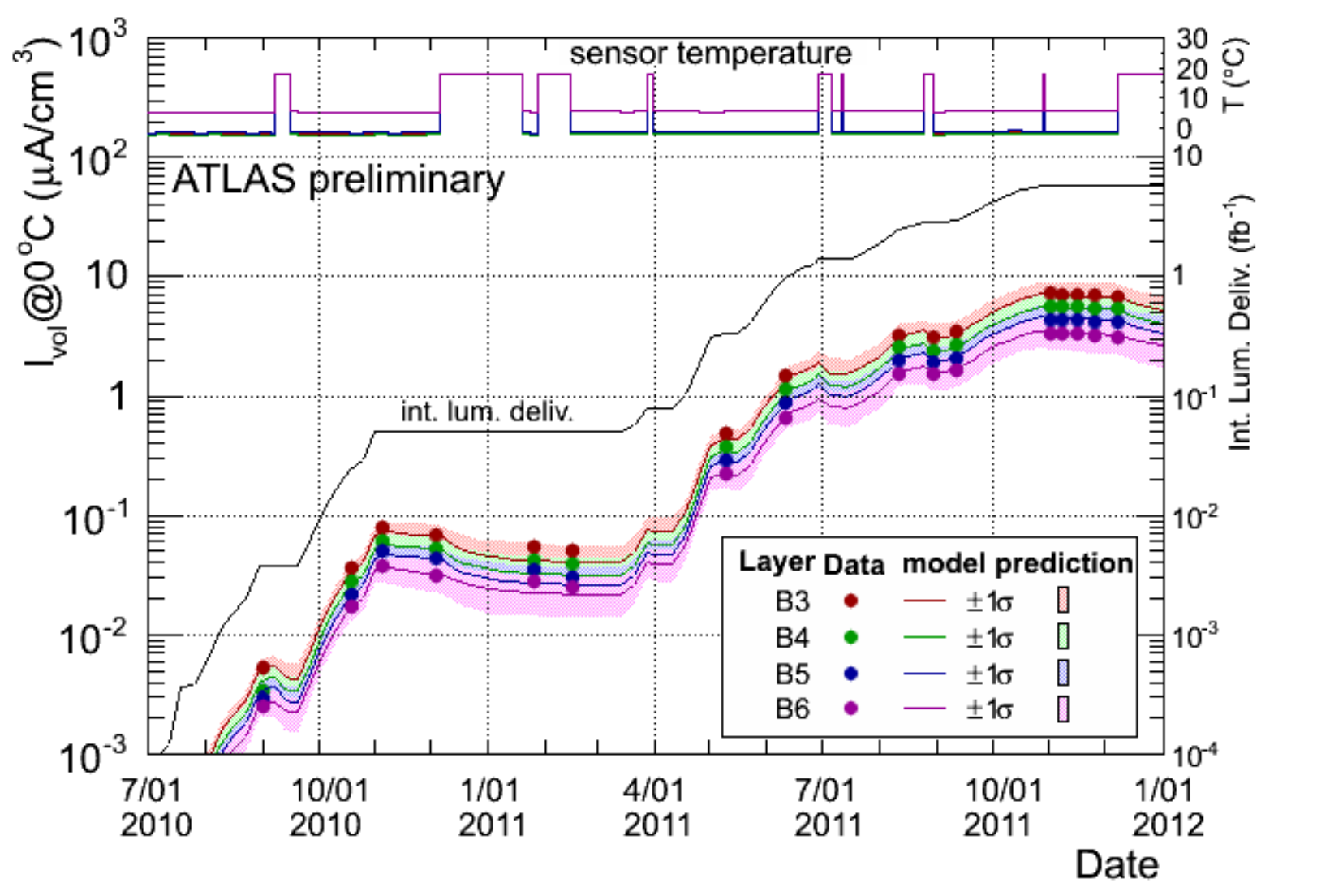


Screenshot of ID DCS cooling shifter inteface.

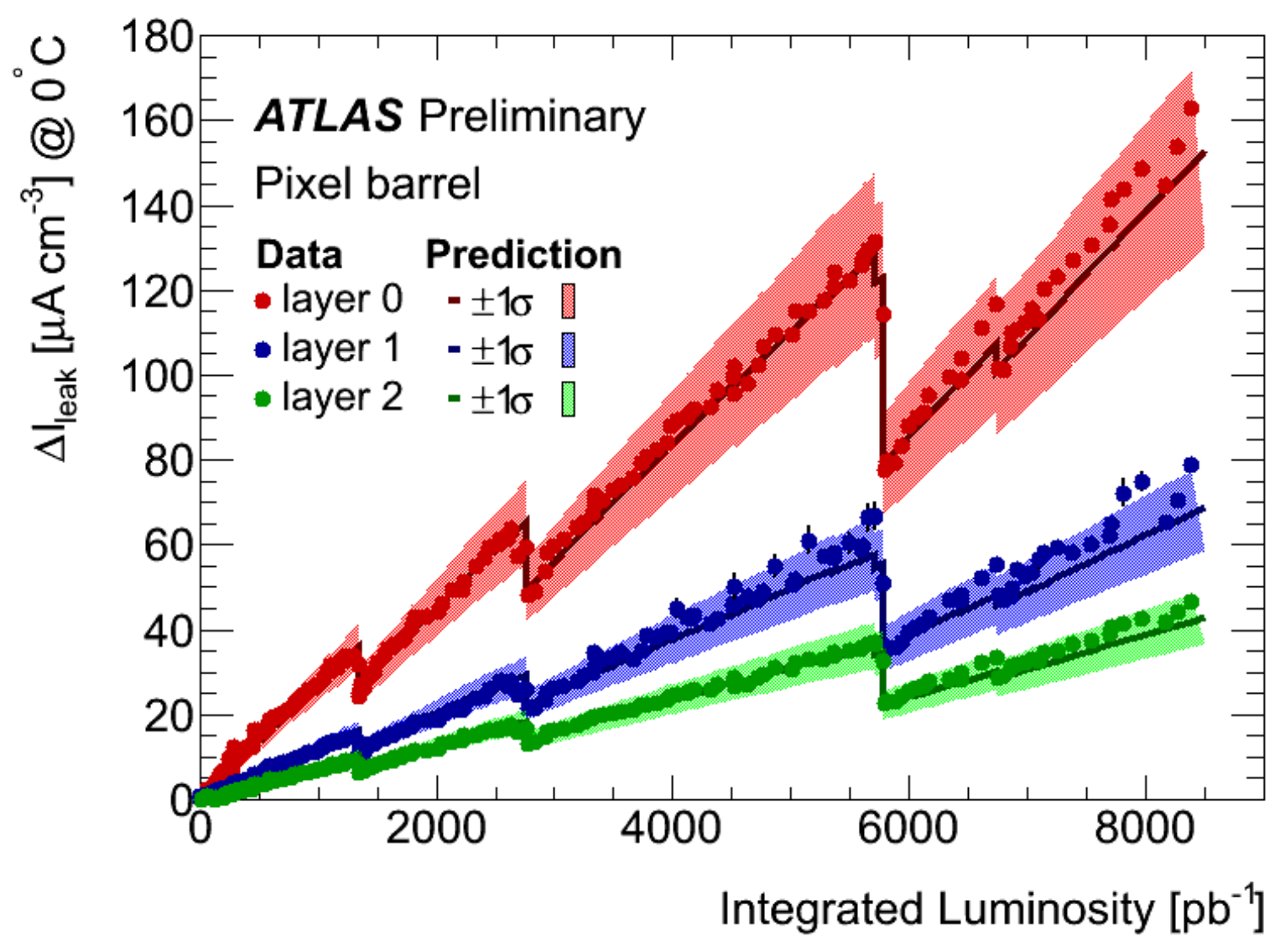
- **The Detector Control System (DCS)** supervises ID detector components, provides information about conditions inside the detector, assures optimal working conditions and provides protection mechanisms. The main ID DCS subsystems are: Evaporating Cooling to keep silicon detector cooled (~-10ºC), Heater Pad systems that ensures thermal shield between silicon detectors and TRT operating in room temperature, Radiation Monitor measuring radiation doses inside ID volume.
- In Pixel and SCT DCS the automatic turn-on (high voltage ramp from stand-by state to nominal value) was implemented in order to maximise time of data taking. Detectors are set to ready-for-data-taking state immediately after stable beams are declared by LHC and beam parameters measured in ID are correct. Typical time to ready for data-taking in SCT is ~1 minute.

Radiation Damage

- Radiation damage effects in SCT and Pixel became visible in 2011 and they are increasing with luminosity and time.
- Monitoring of radiation damage via the increase of sensor leakage current



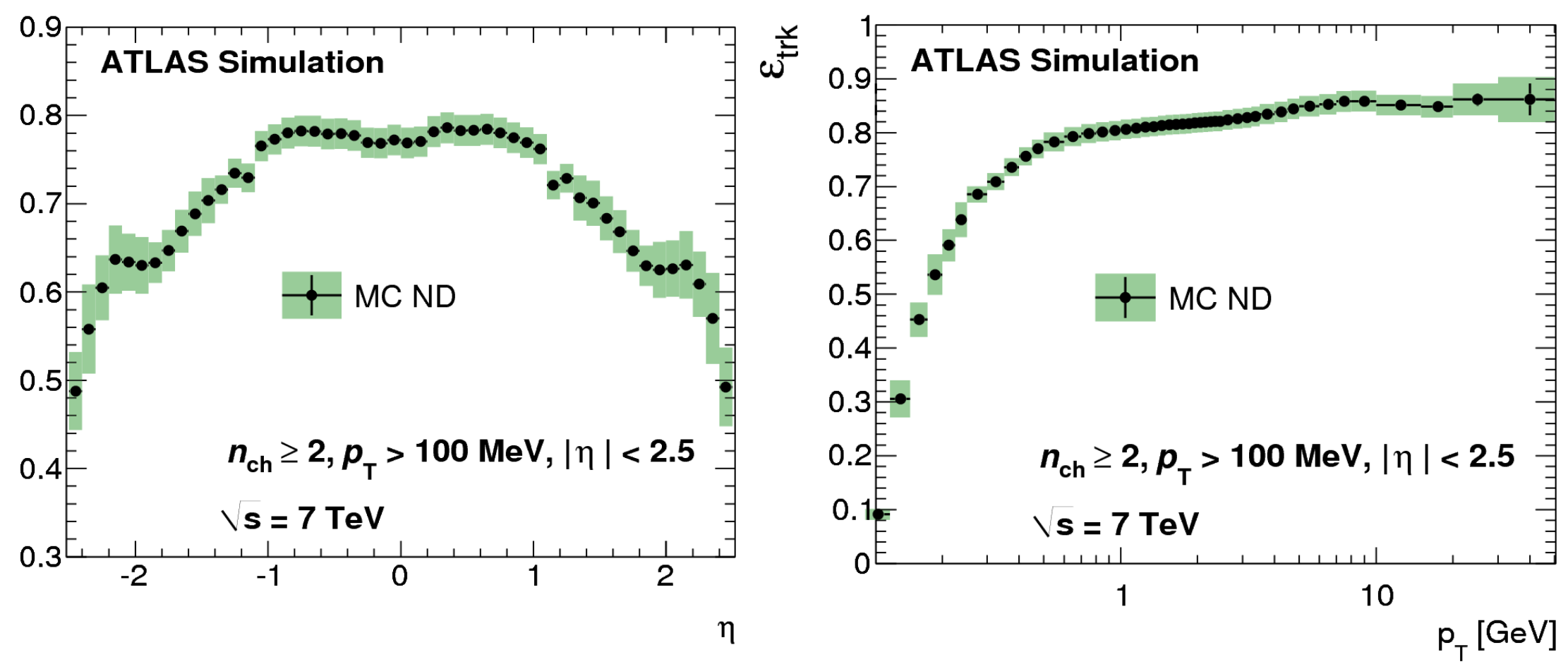
SCT barrel leakage currents during 2010 and 2011, showing correlations with delivered luminosity and temperature, compared to predictions from Monte Carlo. Dependence of leakage current on luminosity is well-understood and agrees with predictions of the Hamburg model.



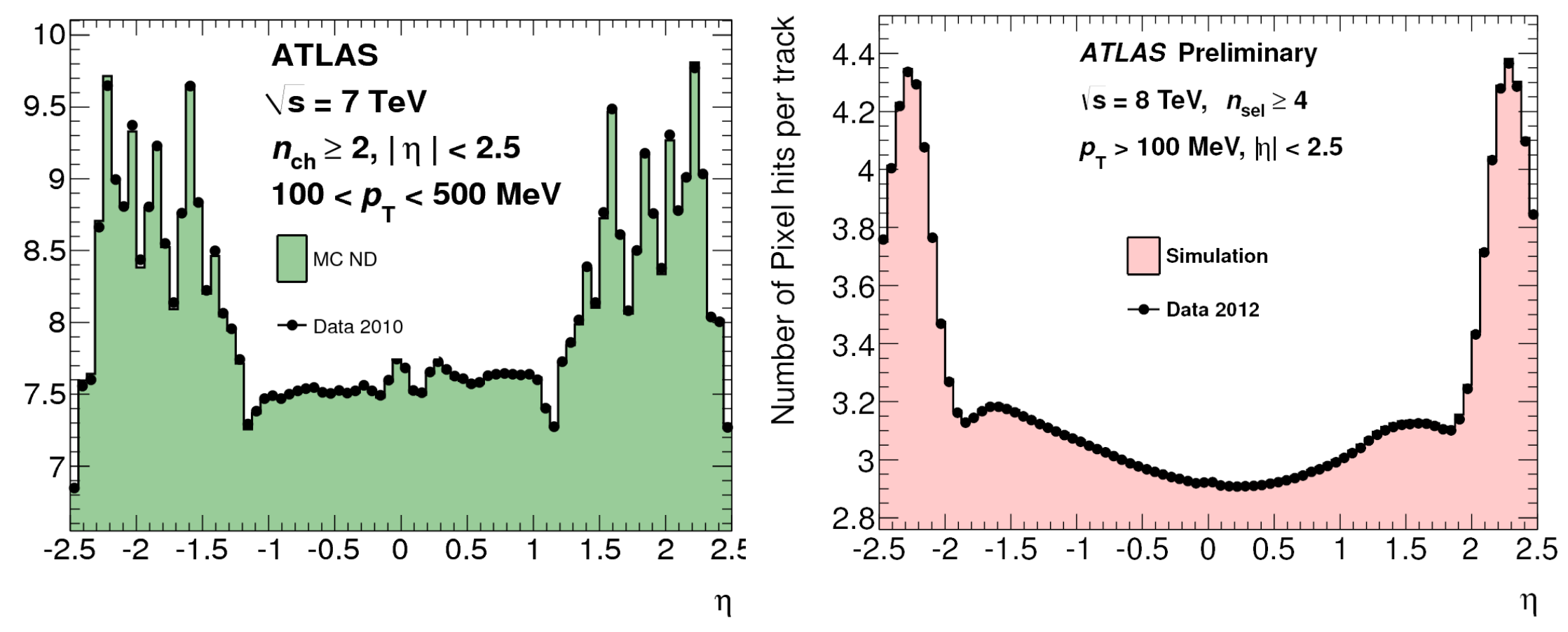
The averaged high voltage current for all Pixel modules in the different Barrel layers as a function of the integrated luminosity.

Track and Vertex Reconstruction Performance

- Tracks are reconstructed offline within the full acceptance range | η | < 2.5 of the Inner Detector.
- Multi-stage track indentification algorithms:
  - **inside-out** algorithm starts from Pixel seeds and adds hits moving away from the interaction point. The track candidates found in the silicon detectors are then extrapolated to include measurements in the TRT. Reconstructs most primary tracks.
  - **outside-in** algorithm starts from segments reconstructed in the TRT and extends them inwards by adding silicon hits. Reconstructs secondary tracks eg. conversions, hadronic interactions, V^0 decays

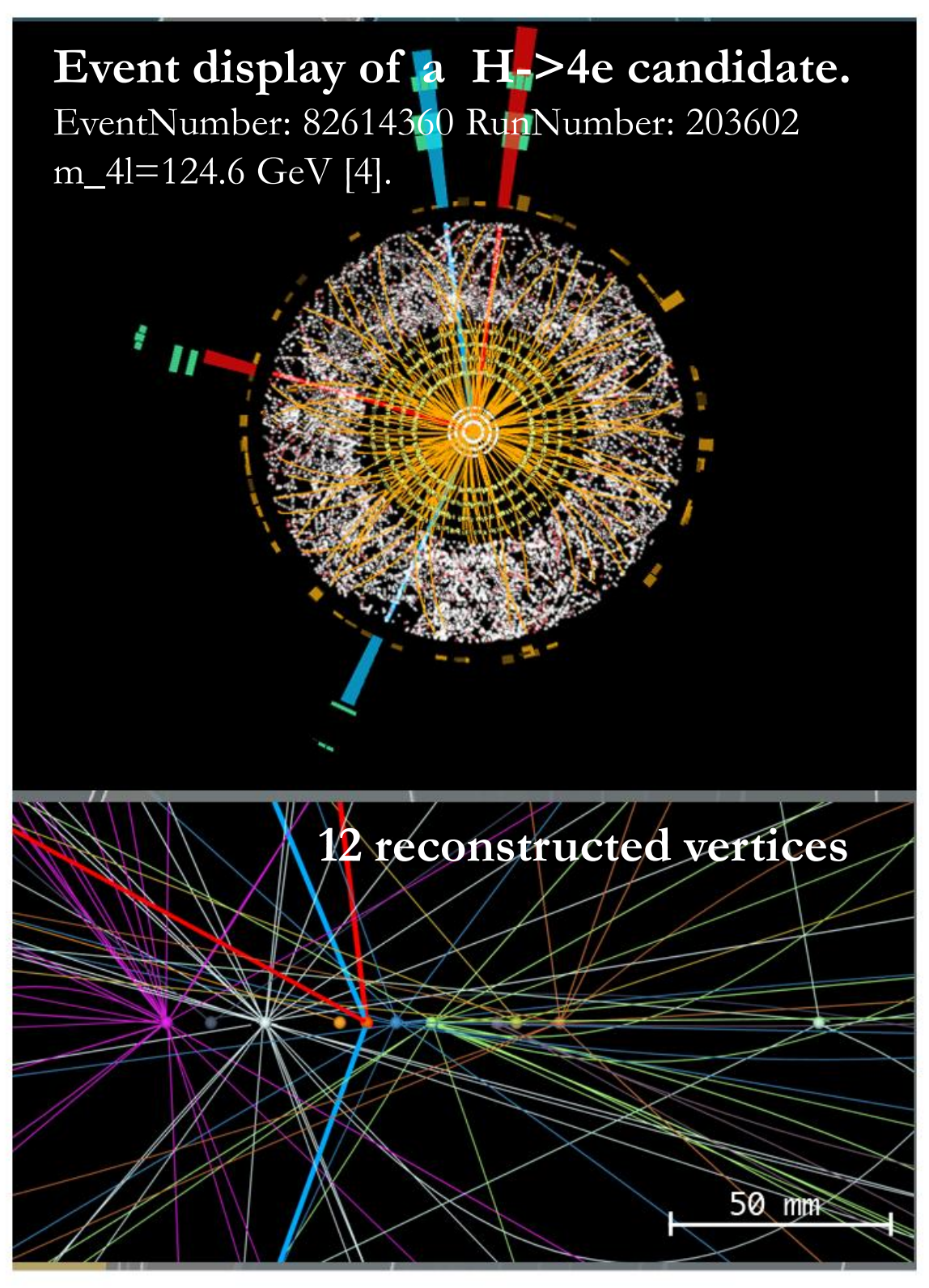


Tracking efficiency for minimum bias analysis derived from simulation is presented above. Efficiency is highest at midrapidity and for tracks with high tranverse momentum [3].



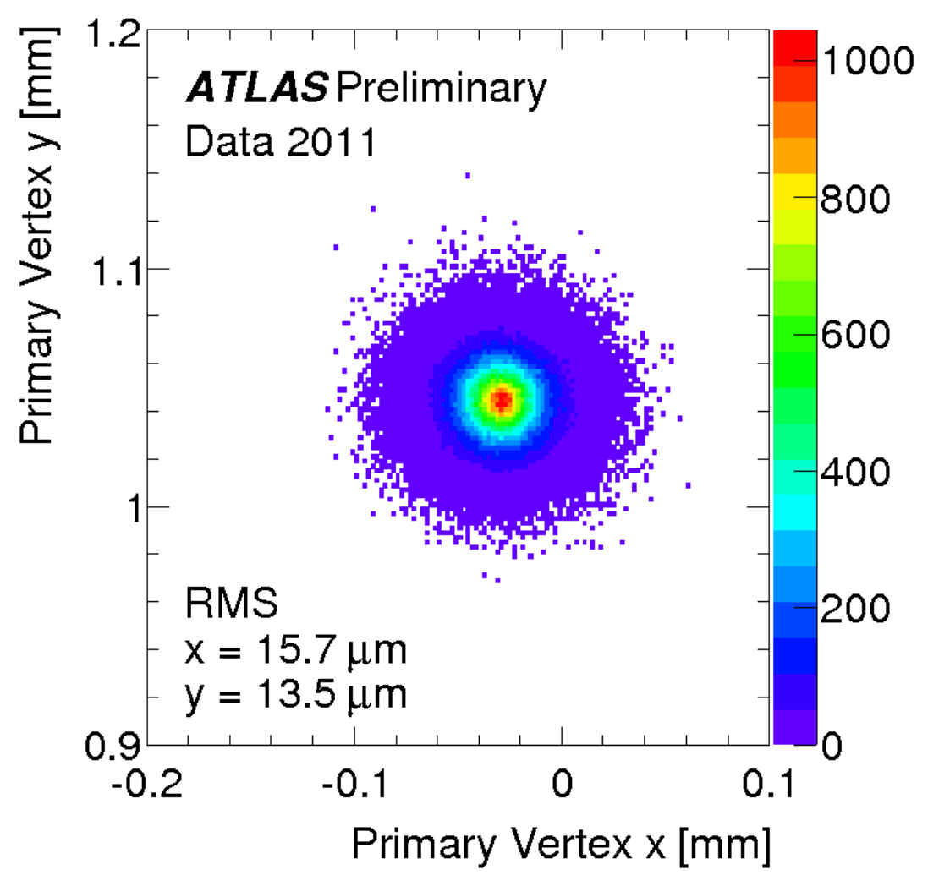
The figures above highlight **very good agreement** between data and simulation, examples for the average number of hits in SCT on reconstructed track as a function of η (left)[3] and the average number of Pixel hits as a function of η (right) [7]

- Primary vertices are reconstructed using iterative vertex finder algorithm. Vertex seeds are obtained from the z-position at the beamline of the reconstructed tracks. An iterative χ^2 fit is made using the seed and nearby tracks.
- Routinely determine the beam spot from average vertex position over a short time period.
- The beam spot position is used as a three-dimensional constraint.
- Vertex resolution determined from data using split vertex technique
- Described in simulation at the 5% level

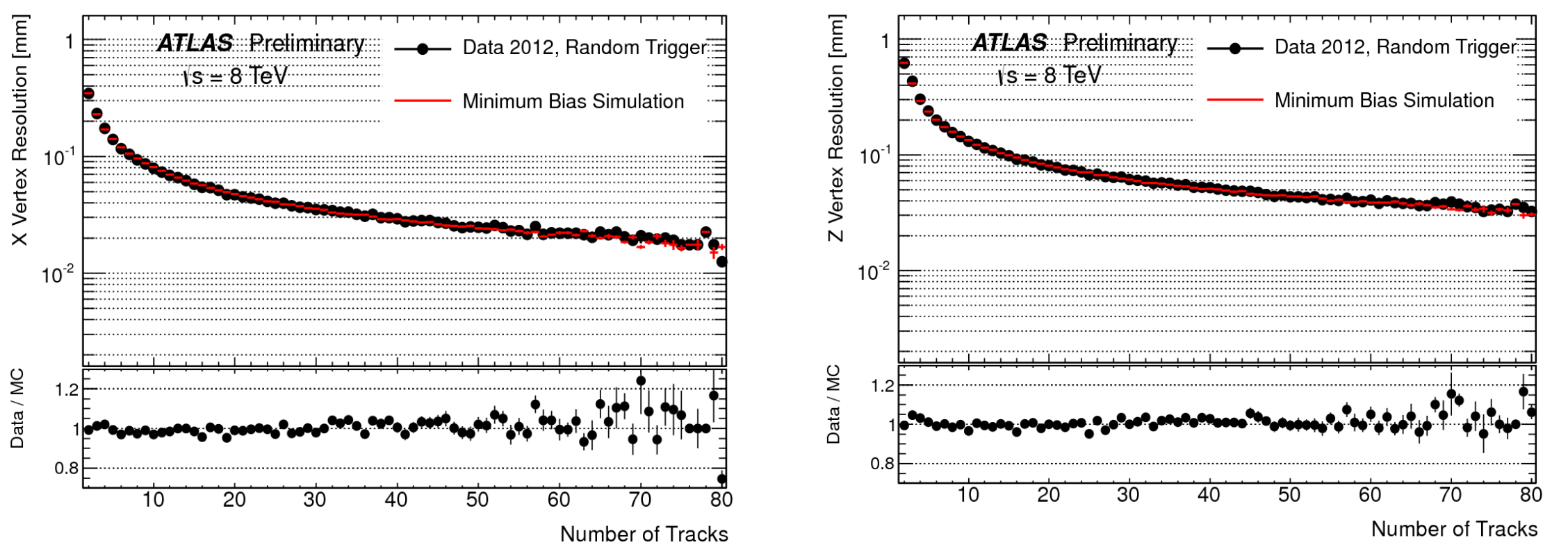


Event display of a H->4e candidate.
EventNumber: 82614360 RunNumber: 203602
m_4l=124.6 GeV [4].

12 reconstructed vertices



Two dimensional distribution of reconstructed primary vertices with NTrk > 3 in the transverse (x-y) plane in 7 TeV data of 2011.



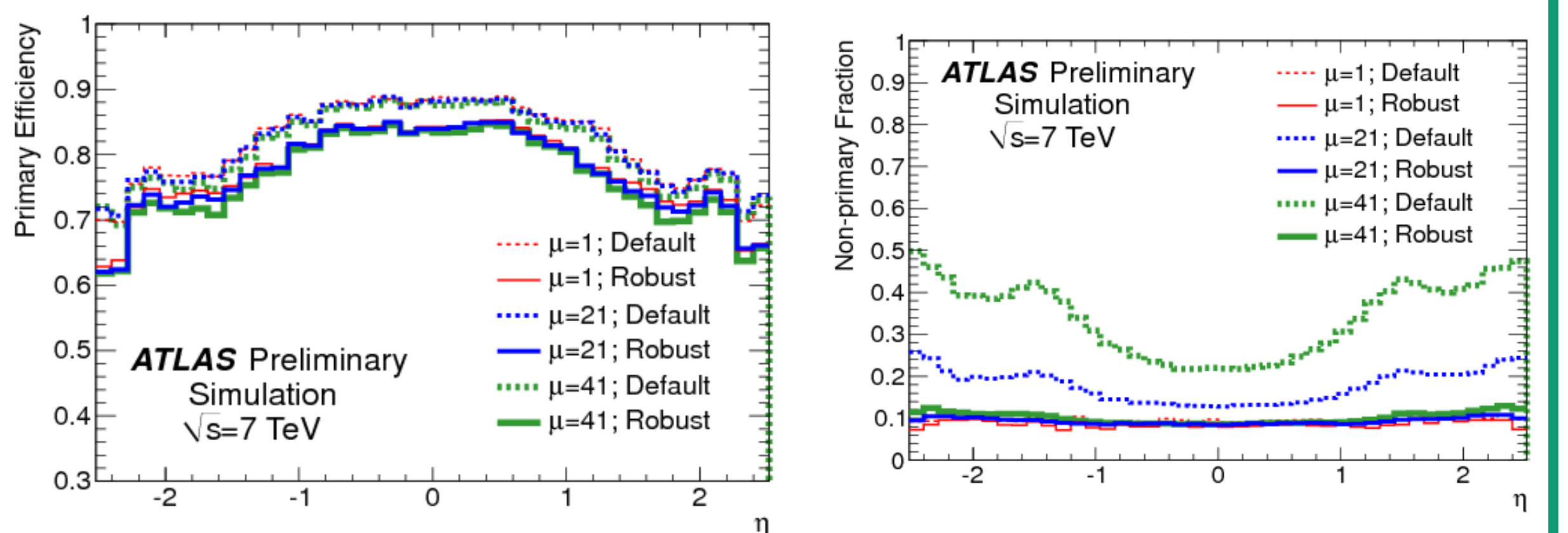
Vertex position resolution (with no beam constraint) in data (black) and MC (red). The resolution is shown for the transverse (left) and longitudinal(right) coordinate as function of the number of tracks in the vertex fit [6].

Tracking in High Pile-up

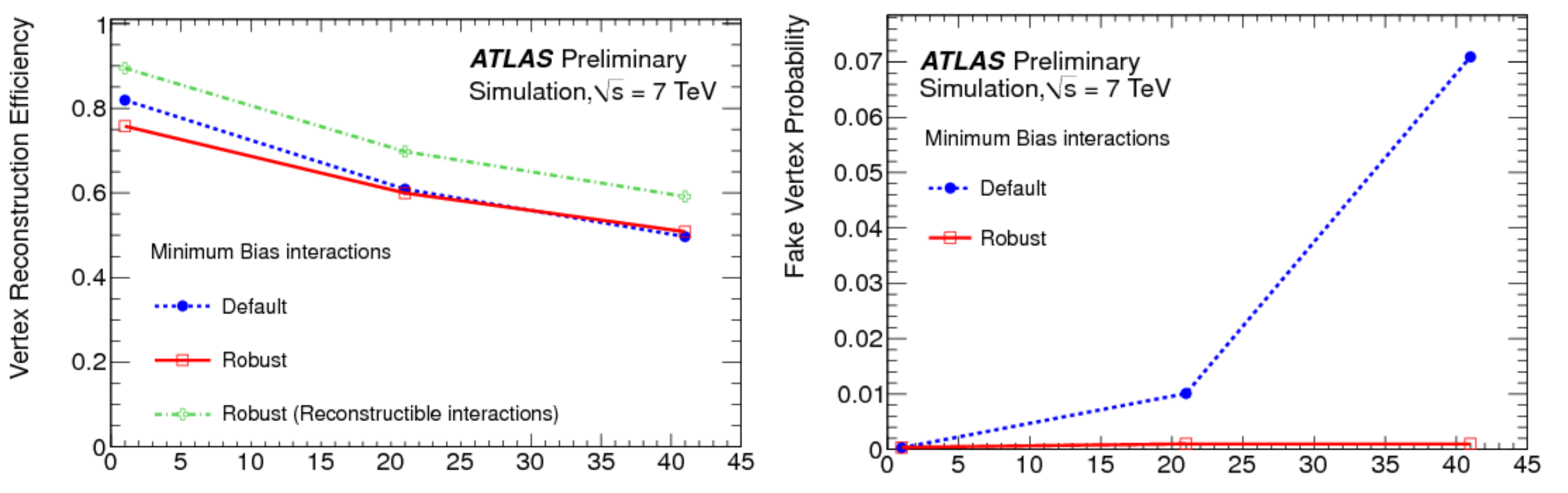
The luminosity delivered by LHC is currently the biggest challenge for ID tracking and vertexing. The increased detector occupancy can result in degraded track parameter resolution due to incorrect hit assignment, decreased efficiency and fake tracks from random hit combinations. This in turn impacts vertex reconstruction, resulting in a lower efficiency and an increased fake rate.

In order to minimise pile-up impact on tracking prformance, in 2012 „robust track selection" was defined

- Moderate drop in primary track reconstruction efficiency (~2-5%) for significant reduction in fake track fraction
- Negligible fake primary vertex probability



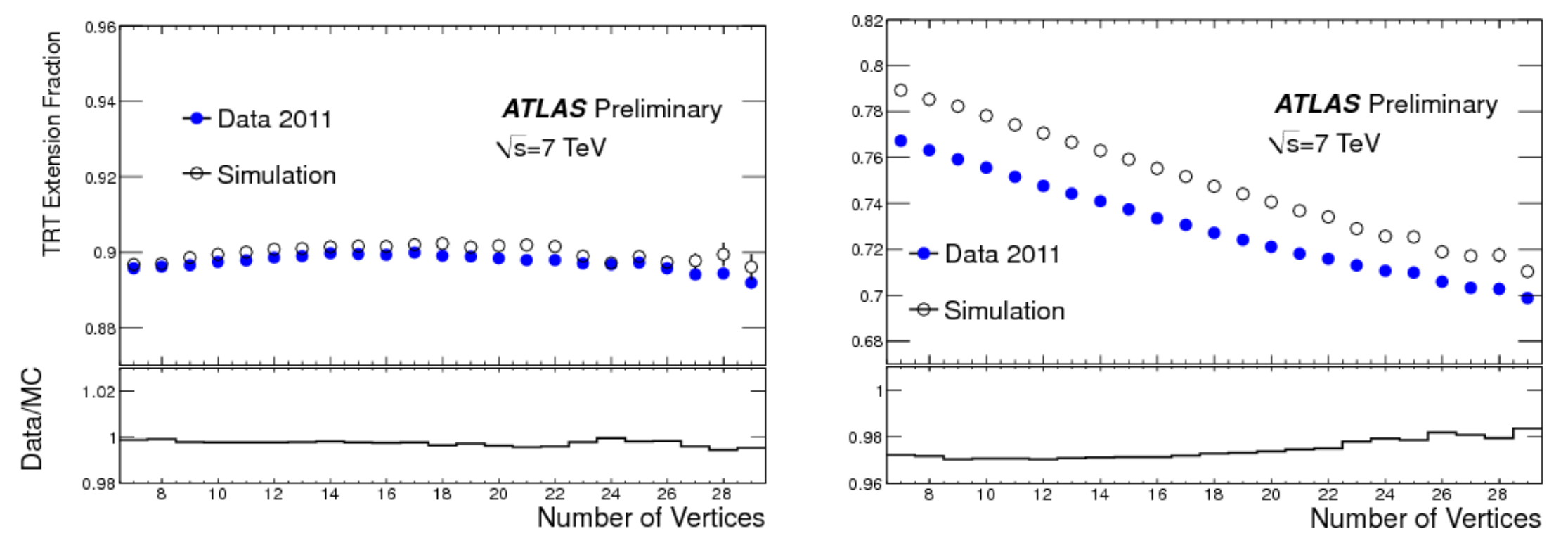
The primary track reconstruction efficiency (left) and the non-primary fraction(right) in minimum bias Monte Carlo samples containing exactly one or on average 21 or 41 interactions[5].



The vertex reconstruction efficiency (left) and fake probability (right) as a function of the average number of interactions in minimum bias Monte Carlo simulation. For default track selection (blue, dashed) and with the robust track requirements (red, solid).

Despite high pile-up conditions, the TRT is continuing to **perform well** in tracking

- the TRT extension efficiency is stable as a function of pile-up
- the number of TRT preciscion hits falls slightly

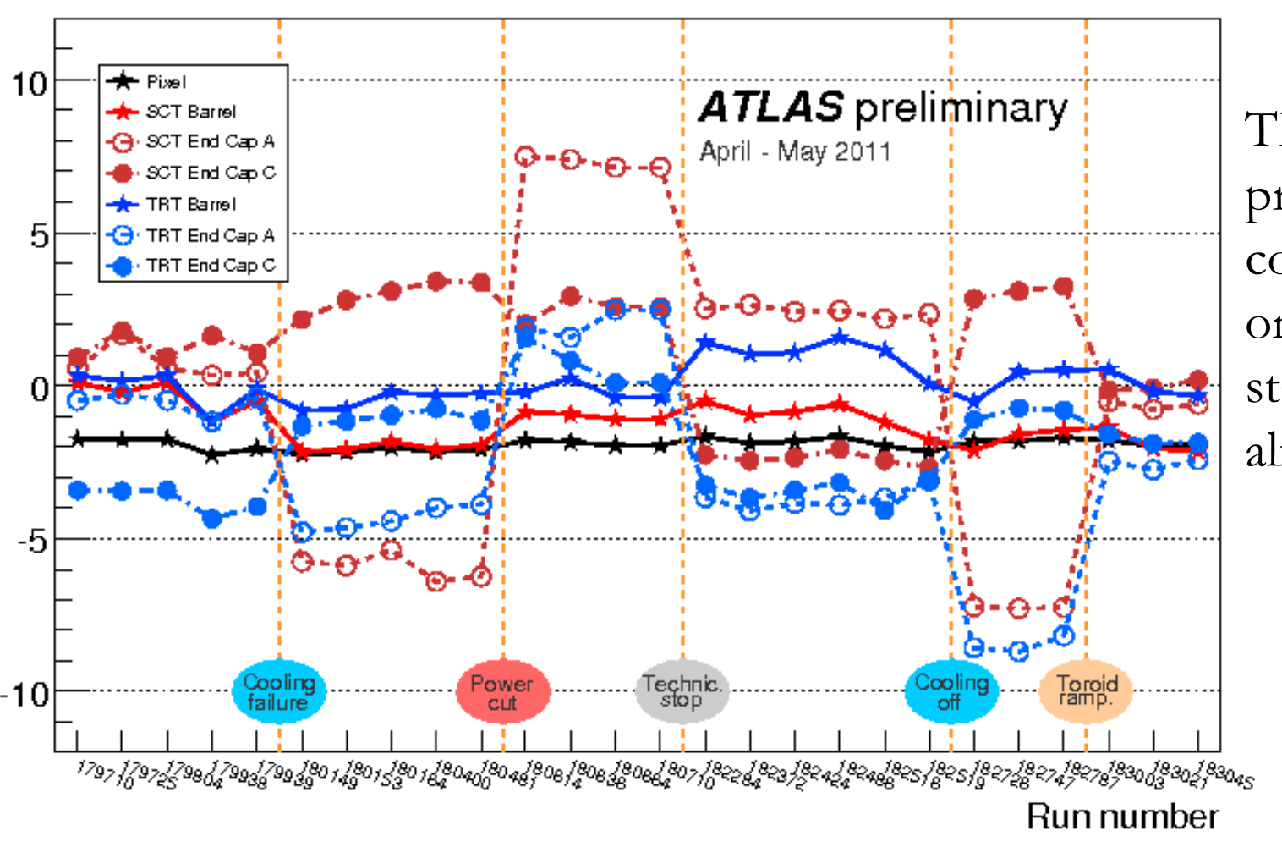


The fraction of tracks found in the silicon that have extensions in the TRT (left) and the fraction of hits on track in the TRT that are precision hits (right) as a function of the average number of vertices per bunch crossing [5].

ID alignment

Precise detector alignment is required to obtain ultimate track parameter resolution

- Align at different levels of granularity
  - Level 1 (entire sub-detector barrel & end-caps)
  - Level 2 (silicon barrels and discs, TRT barrel modules and wheels)
  - Level 3 (silicon modules, TRT straws ~700,000 DoF's)
- Level 1 alignment performed automatically for each run at Tier0.
- At the module level the detector is stable to better than 5μm.
- 2011 data studies show limited movements of Level 1 structures which usually can be correlated to sudden change in detector conditions.
- Advanced alignment using Z resonance and E/p for electrons removes residual biases on momentum reconstruction.



The figure on the left presents Level 1 alignment corrections performed on a run by run basis starting from a common set alignment constants[8].

Bibliography

[1] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResults
[2] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/RunStatsPublicResults2010
[3] The ATLAS Collaboration, *Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC. New J. Phys. 13 (2011) 053033*
[4] The ATLAS Collaboration, *Observation of an excess of events in the search for the Standard Model Higgs boson in the H ! ZZ() ! 4` channel with the ATLAS detector,* ATLAS-CONF-2012-092(Jul 2012), https://cdsweb.cern.ch/record/1460411
[5] The ATLAS collaboration, *Performance of the ATLAS Inner Detector Track and Vertex Reconstruction in the High Pile-Up LHC Environment*, ATLAS-CONF-2012-042(March2012), https://cdsweb.cern.ch/record/1435196
[6] http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/IDTRACKING/PublicPlots/ATL-COM-PHYS-2012-474/
[7] http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/IDTRACKING/PublicPlots/ATL-COM-INDET-2012-052/
[8] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/InDetTrackingPerformanceApprovedPlots

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