ATLAS detector upgrades

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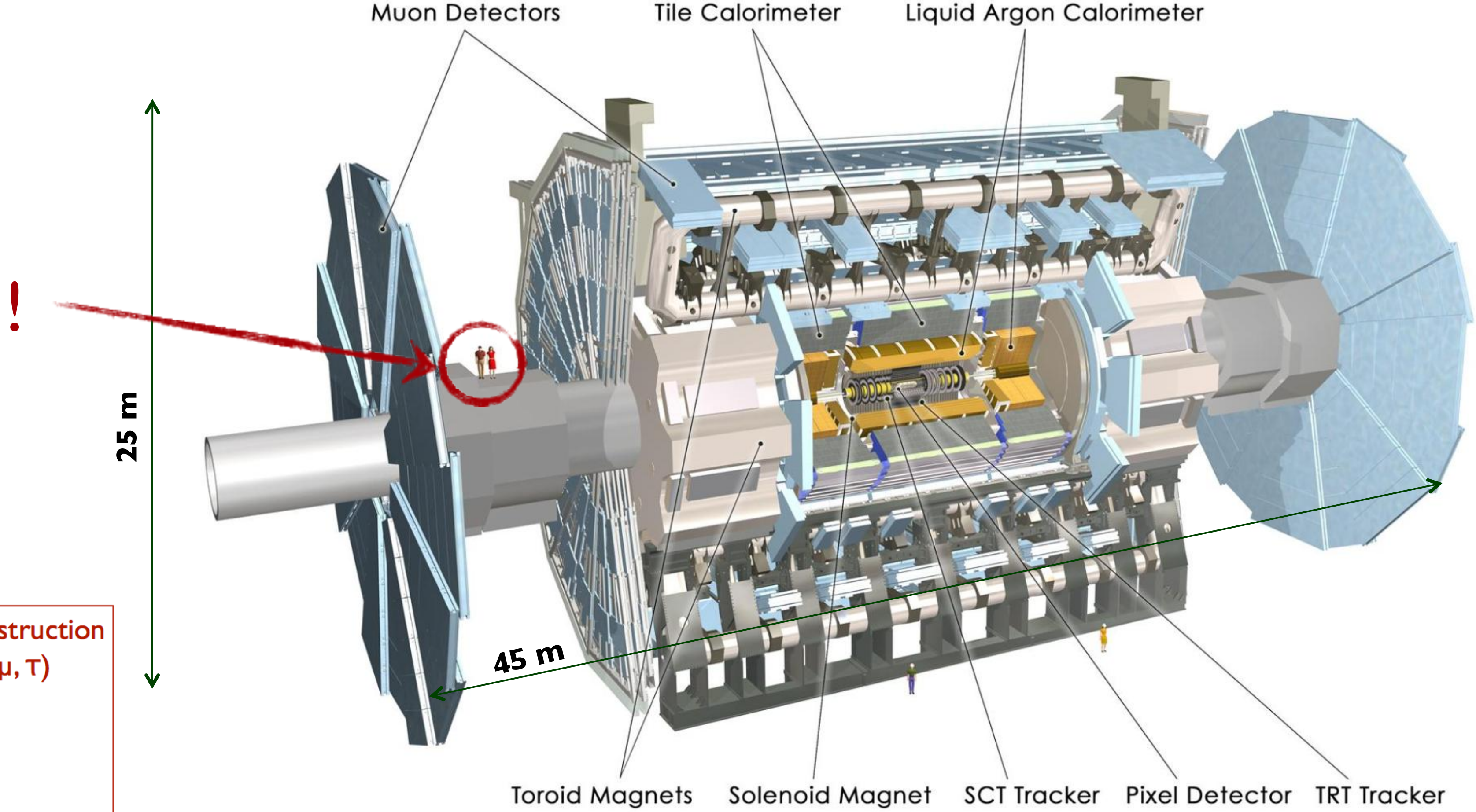
on behalf of the ATLAS collaboration

LHCP 2013

Detector Overview

Multi-purpose, high resolution and hermetic detector

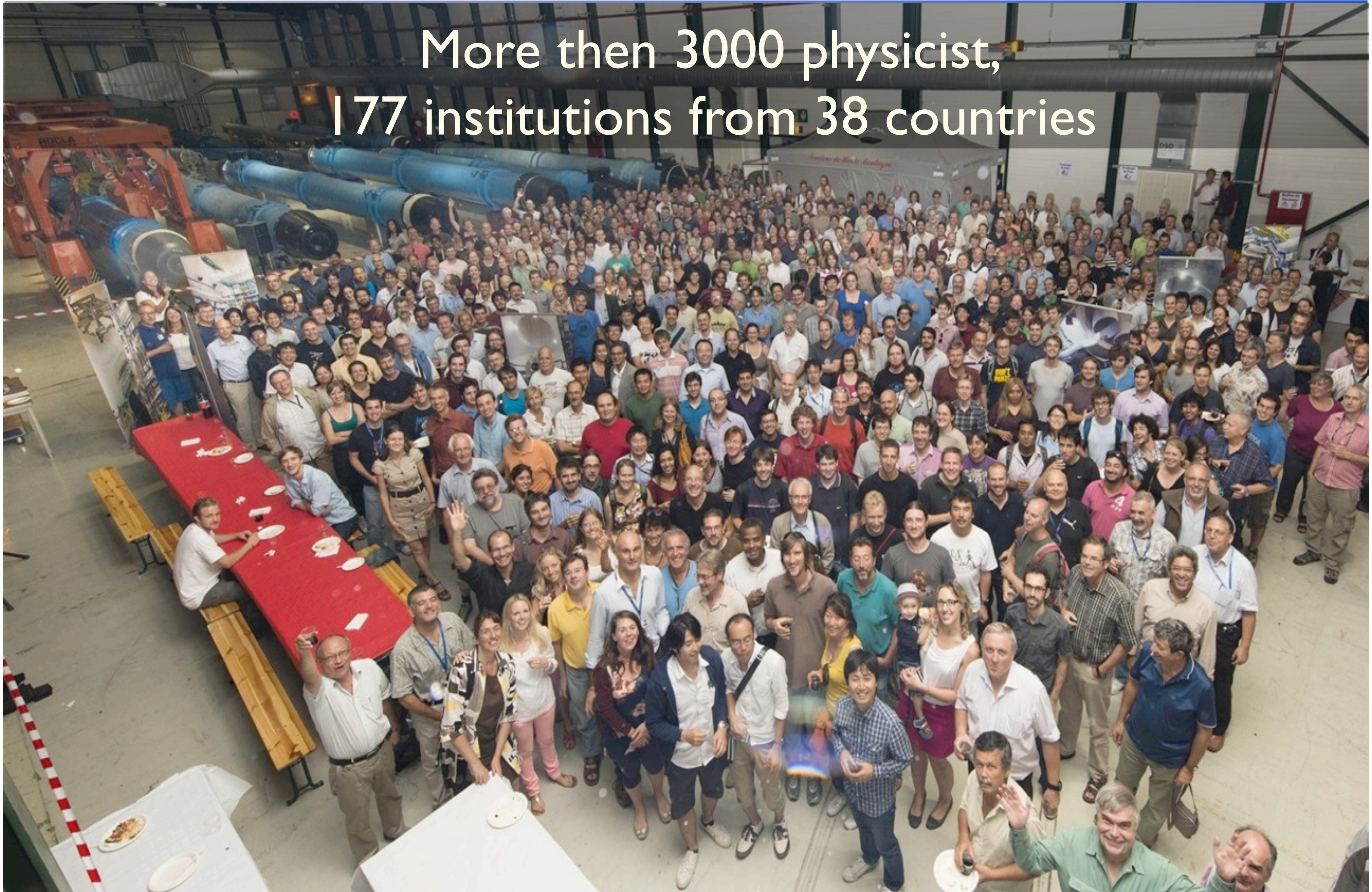
Magnets:	Central Solenoid + 3 Toroids
Tracking:	Silicon, Transition Radiation Tracker
Calorimeter:	EM (LAr), Had Cal
Muon:	Trigger + Precision chambers



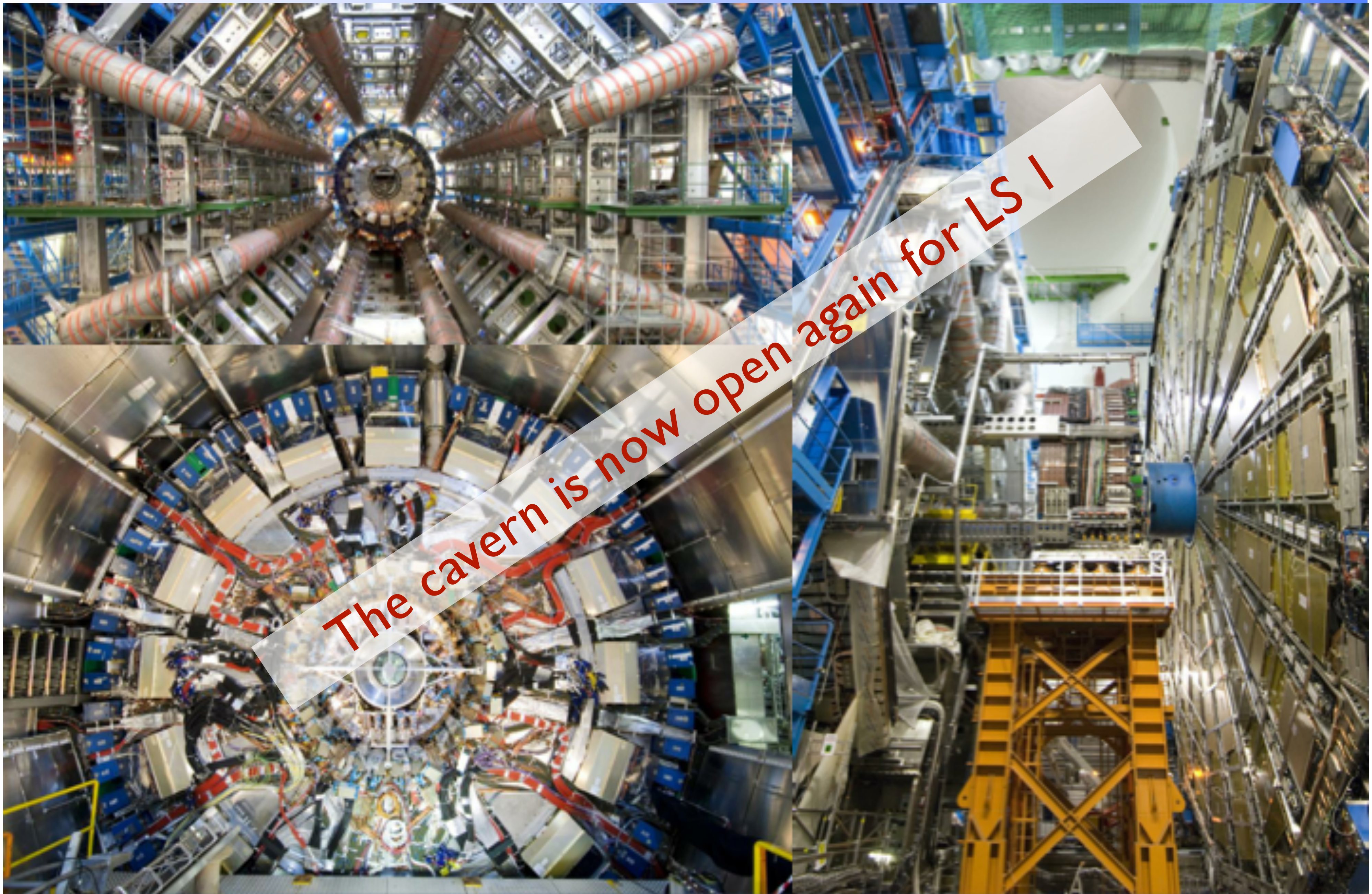
Object Reconstruction

- leptons (e, μ, τ)
- photons
- jets
- b-jets
- Etmiss

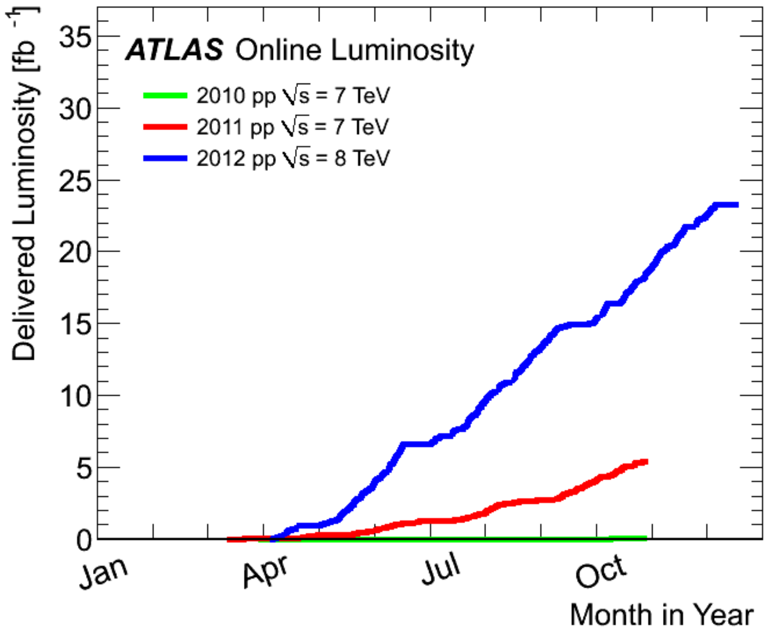
The ATLAS Collaboration

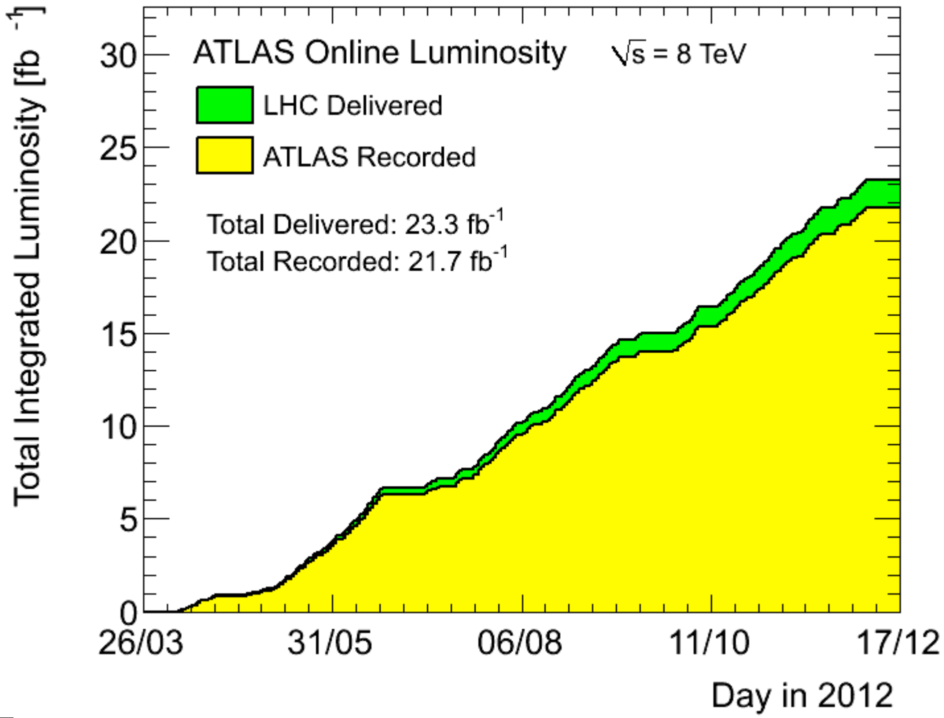


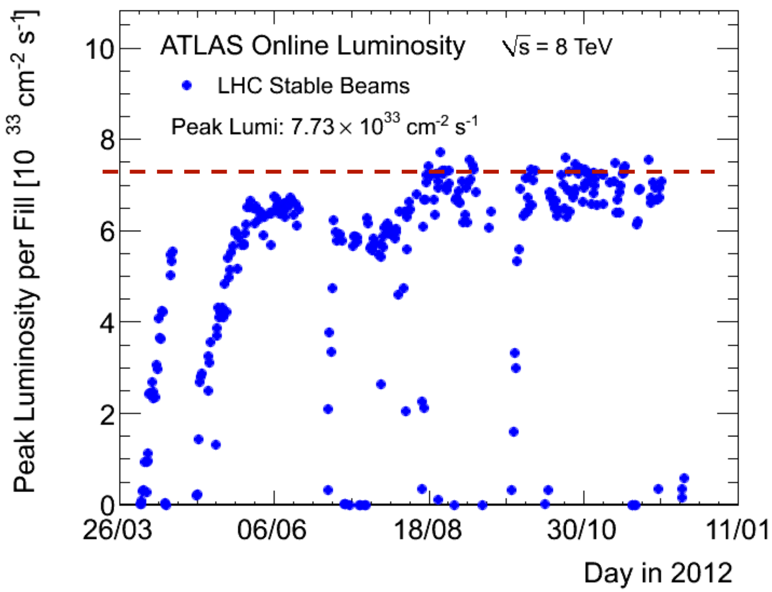
The Detector in the Cavern



2012 : Luminosity







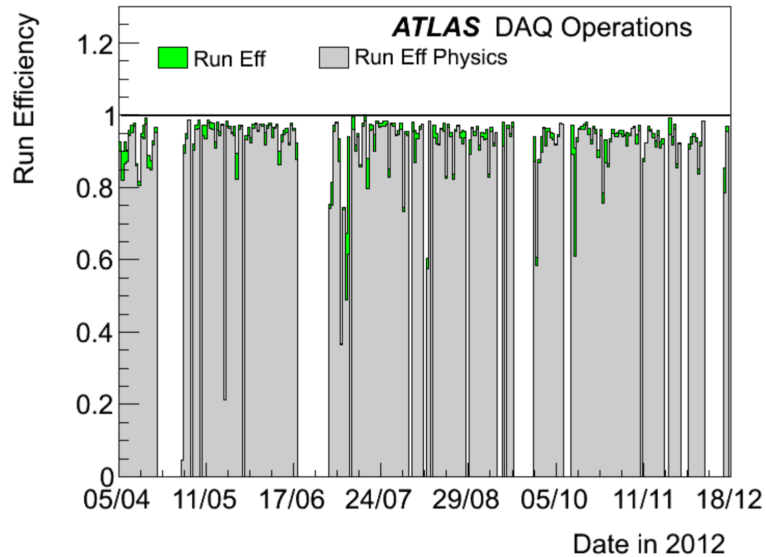
Peak luminosities routinely reaches 7.5×10^{33} cm^{-2} s^{-1}

THANK you LHC !

2012 : Overall Performance

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	95.0%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	97.5%
LAr EM Calorimeter	170 k	99.9%
Tile calorimeter	9800	98.3%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	100%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	96.0%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	98.2%

≥ 95% for all systems



Average data-taking efficiency over year ~ 93.5 %

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.

Fraction of operational channels is more then 95% for all systems, detector uptime is higher then 99% for all systems !

LAr - Performance

Electronics stable at the sub per mil level (gain stability: rms 2.6x10^{-4})

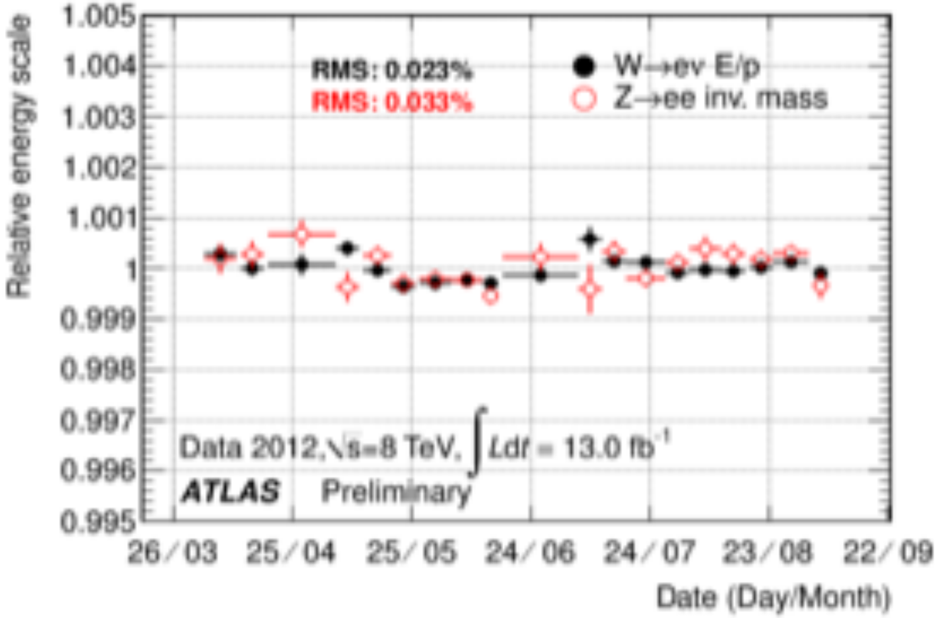
To correct for these (very small) variations: Updates of constants in DB every ≈month

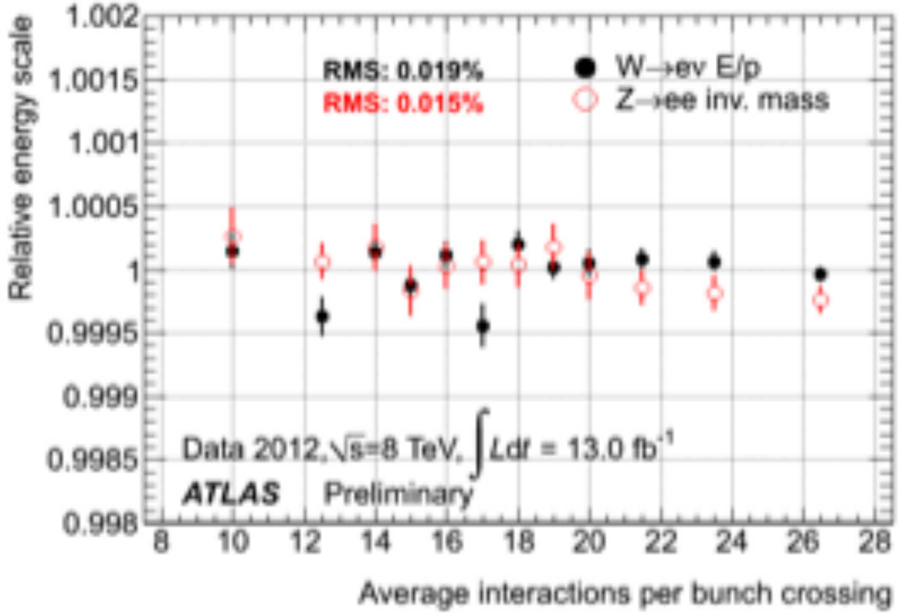
Result: The in-situ energy calibration is static with time: **no energy scale variation with time**

Also **no energy scale variation with pile-up** is observed

automatic cancellation of the in-time pile-up by the signal undershoot of the out-of-time pile-up (apart from few first bunches in a train)

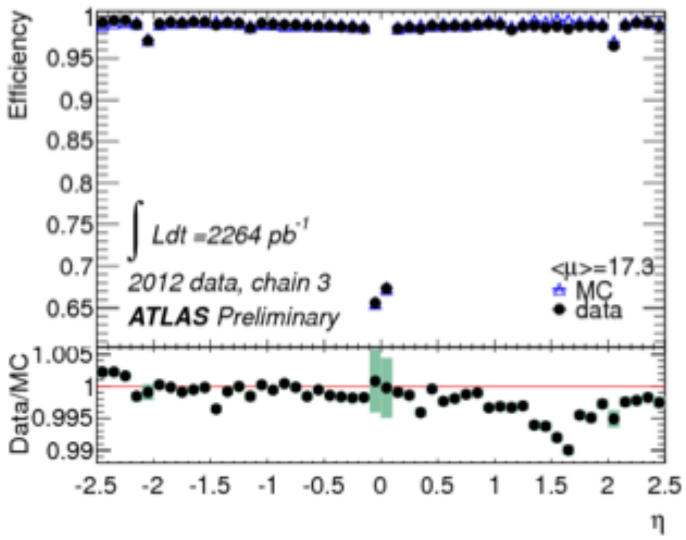
Expected for a LAr calorimeter (with stable temperature and purity)

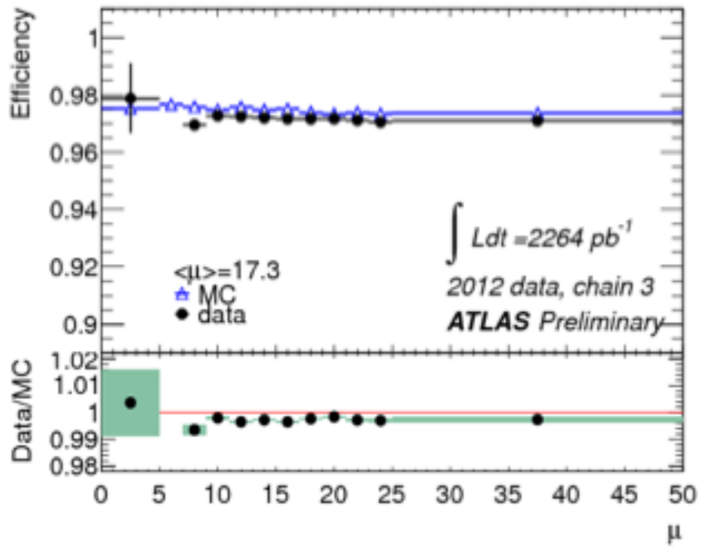




Excellent energy scale stability as a function of time and as a function of pile-up ➔ stability at the 3x10^{-4} level

Muon Performance





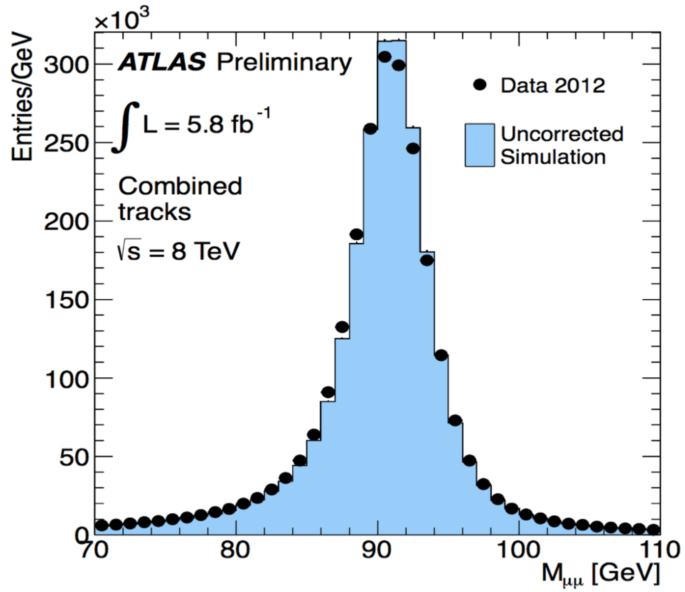
Muon reconstruction efficiency measured based on Z and J/Ψ events (Tag-and-Probe method). Efficiency studied as a function of muon η (left plot) and with different pile-up conditions (right plot). Performance is in very good agreement with simulation, and shows a negligible pile-up dependency.

Muon Momentum Resolution and Scale :

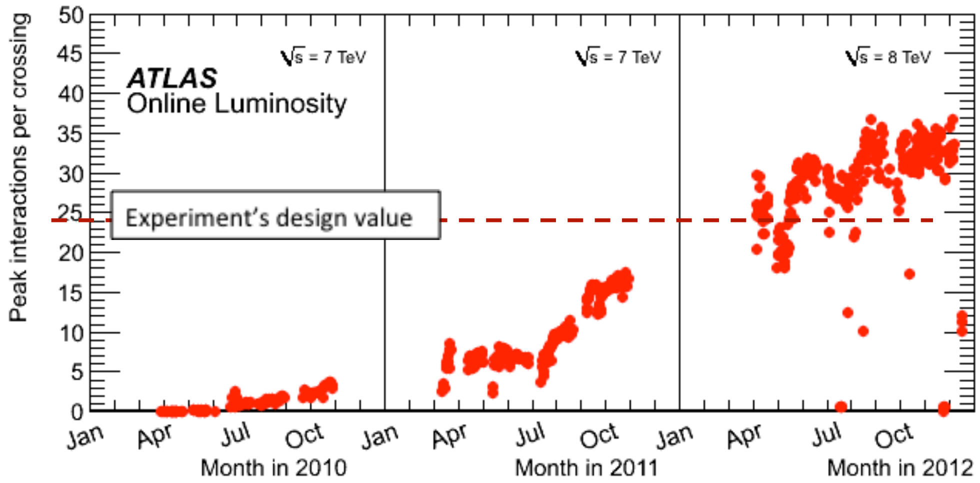
Good description of data by MC even before correction.

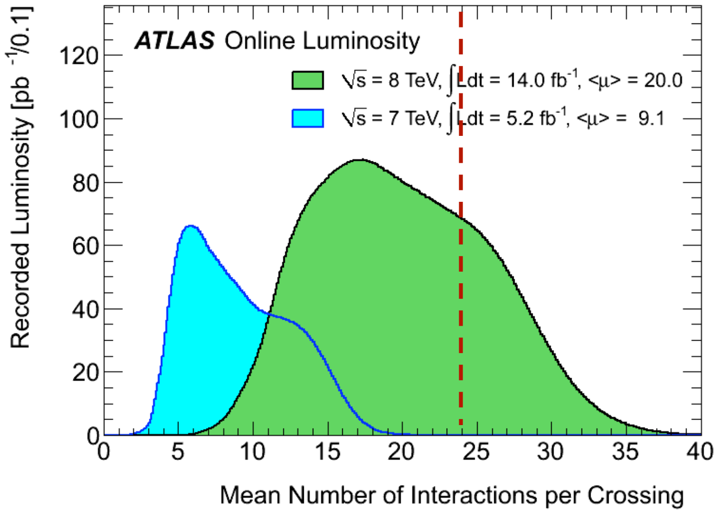
Smearing and scale corrections that have to be applied to Monte-Carlo simulations (imperfect description of the detector material) are derived via a di-muon invariant mass distribution at the Z pole region. This guarantees an accurate description of muon momentum resolution and scale.

Momentum measured independently in the MS and the ID and then combined.



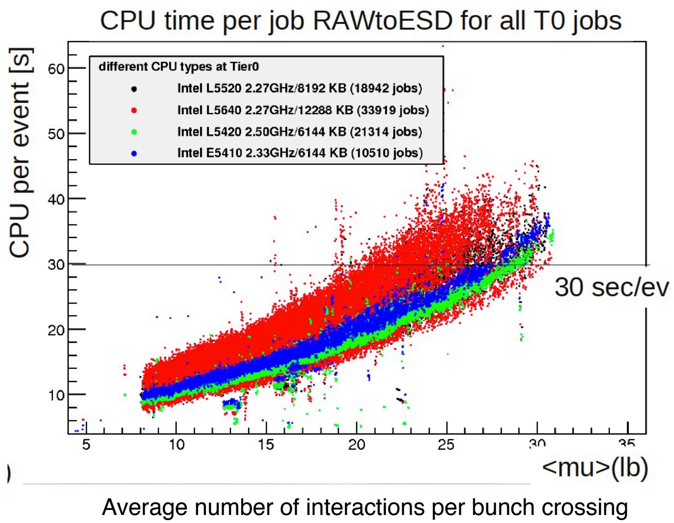
2012 : Pile Up - Challenge

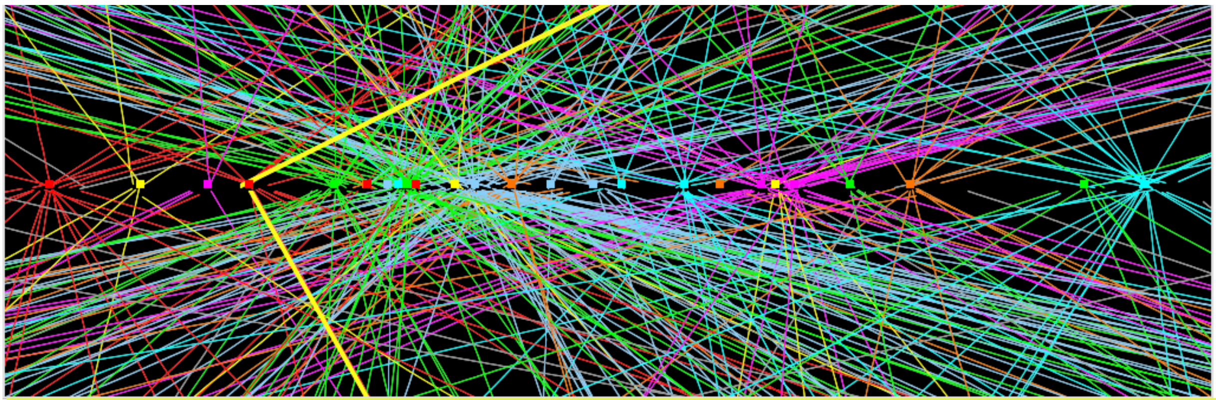




Running with 50ns (instead of 25ns) bunch spacing → double pile-up for same luminosity

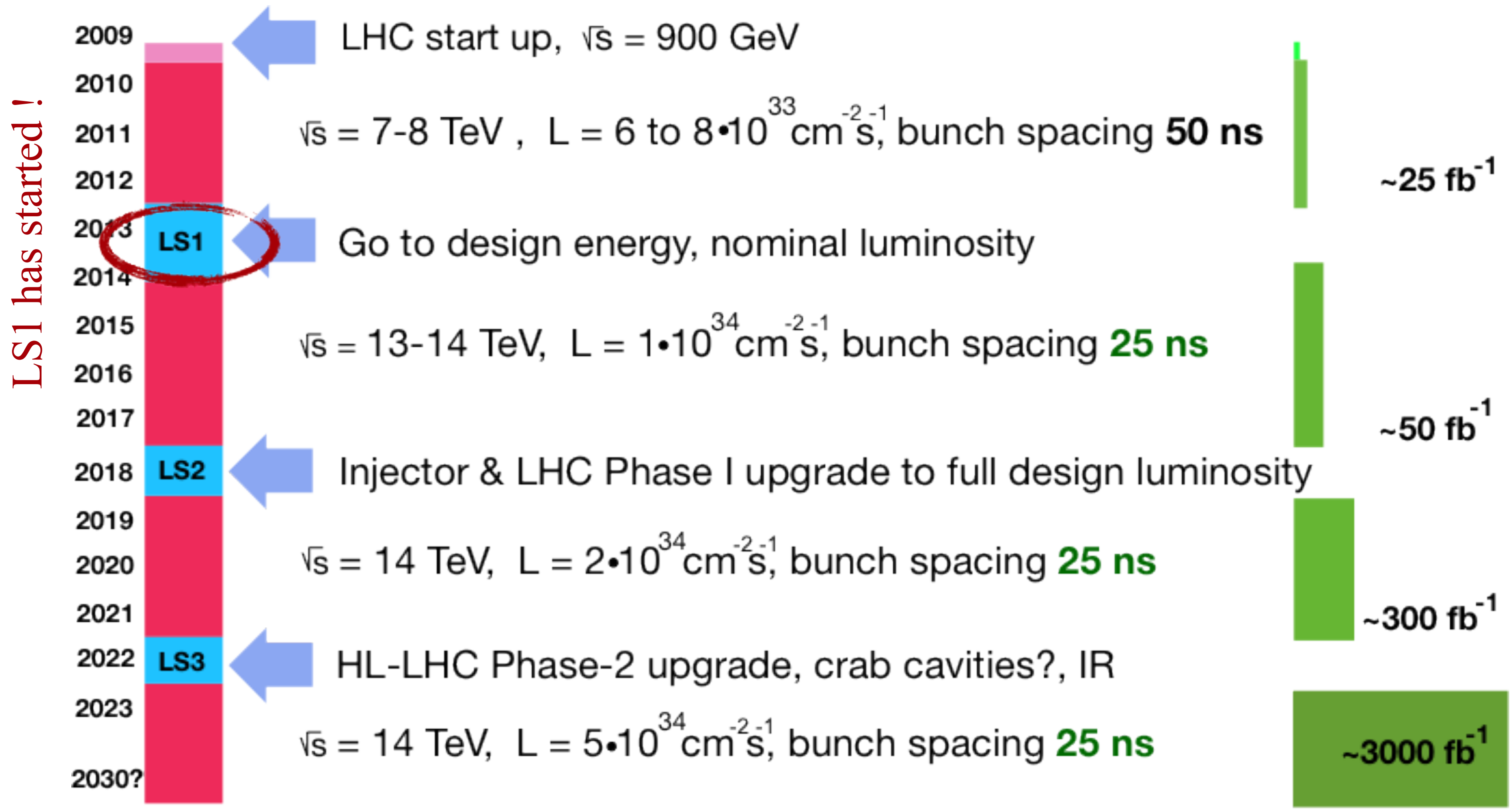
Has to be addressed at all levels : Trigger, reconstruction of physics objects, isolation cuts, data processing (CPU time)....





$Z \rightarrow \mu\mu$ event with 25 reconstructed vertices.

LHC Upgrade Schedule



ATLAS Upgrade Schedule

2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	...	2030
				LS1					LS2				LS3			

"Phase-0" upgrade: consolidation
$\sqrt{s}$ = 13~14 TeV, 25ns bunch spacing
$\mathcal{L}_{inst} \simeq 1 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 27.5$)
$\int \mathcal{L}_{inst} \simeq 50$ fb^{-1}

"Phase-I" upgrades:
ultimate luminosity
$\mathcal{L}_{inst} \simeq 2\text{-}3 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 55\text{-}81$)
$\int \mathcal{L}_{inst} \gtrsim 350$ fb^{-1}

"Phase-II" upgrades:
$\mathcal{L}_{inst} \simeq 5 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 140$) w. leveling
$\simeq 6\text{-}7 \times 10^{34}$ cm^{-2}s^{-1} ($\mu \simeq 192$) no level.
$\int \mathcal{L}_{inst} \simeq 3000$ fb^{-1}

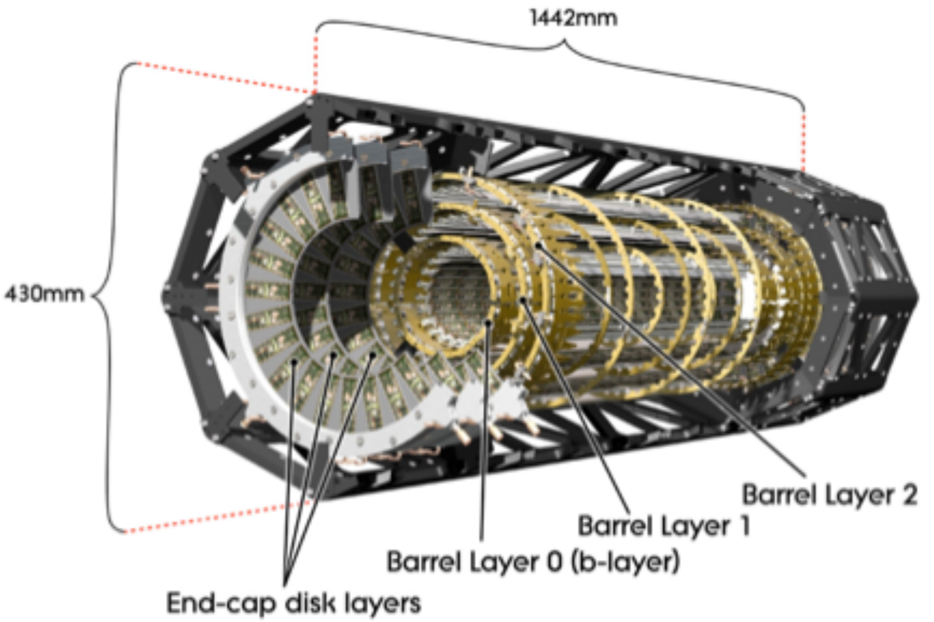
ATLAS has devised a 3 stage upgrade program to optimize the physics reach at each Phase

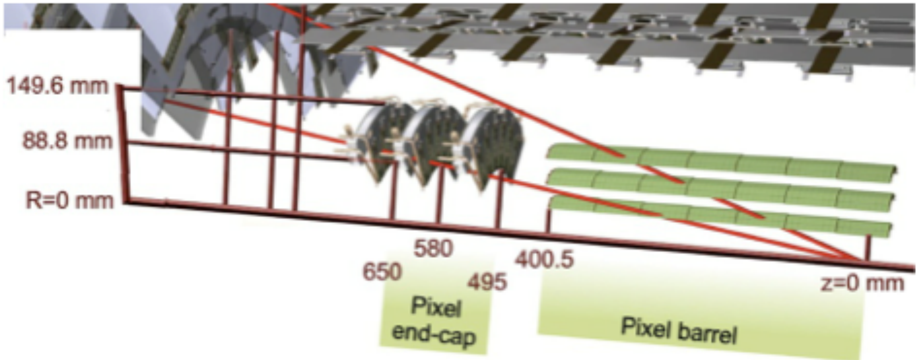
- New Insertable pixel b-layer (IBL)
- New beam pipe
- New pixel services
- New evaporative cooling plant
- Consolidation of detector elements (e.g. calorimeter power supplies)
- Add specific neutron shielding
- Finish installation of EE muon chambers staged in 2003
- Upgrade magnet cryogenics

- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter Trigger at Level-1
- Fast TracKing (FTK) for the Level-2 trigger
- Topological Level-1 trigger processors
- New forward diffractive physics detectors (AFP)

- All new Tracking Detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible Level-1 track trigger
- Possible changes to the forward calorimeters

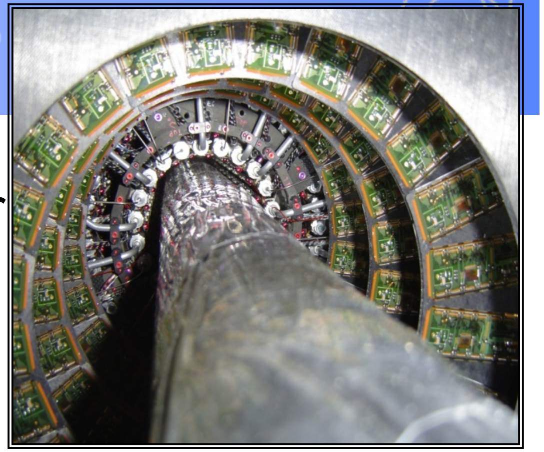
Present Pixel





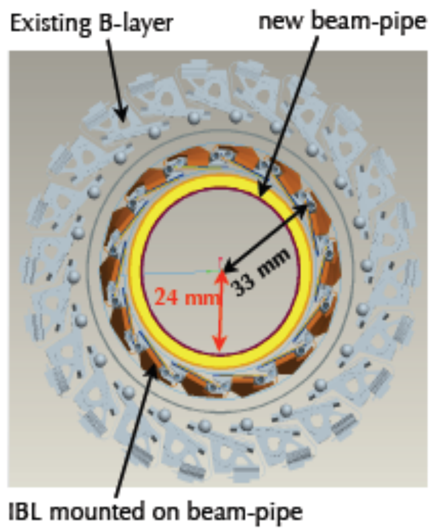
- **Three barrel layers:**
  - R= 5 cm (B-Layer), 9 cm (Layer-1), 12 cm (Layer-2)
  - modules tilted by 20º in the Rϕ plane to overcompensate the Lorentz angle.
- **Two endcaps:**
  - three disks each
  - 48 modules/disk
- **Three precise measurement points up to |η|<2.5:**
  - RΦ resolution:10 μm
  - η (R or z) resolution: 115 μm
- 1456 barrel modules and 288 forward modules, for a total of 80 million channels and a sensitive area of 1.7 m^2.
  - Environmental temperature about -10 ºC
  - 2 T solenoidal magnetic field.

Phase-0: Insertable B-Layer



New pixel layer around smaller beam pipe (ID 47mm) to allow for a 4th Pixel Layer inside the existing 3 layers

Current pixel package to be brought to surface to install new support pipes for IBL and new beam pipe



IBL modules and stave

Sensors & chips done, bump-bonding processing of sensor and electronic wafers on-going for module production –

Staves

Assembled two prototype staves to verify functionality, assembly process and to start the system-test of the full IBL system

Integration

Test stands prepared for full IBL

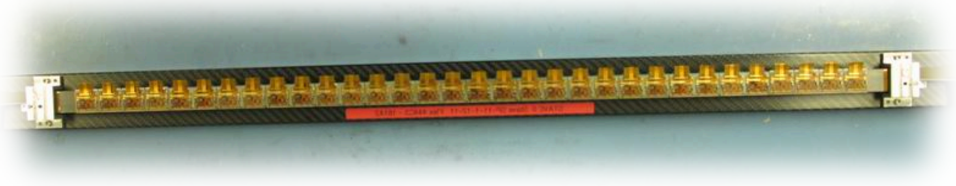
Integration tooling being finalized and surface building prepared for IBL integration

Installation

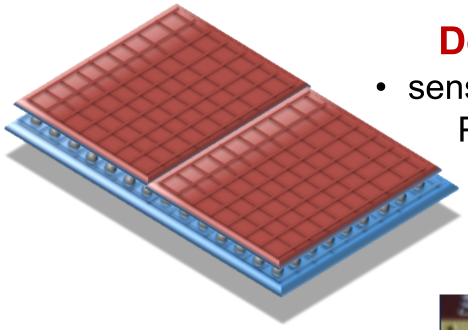
Beam pipe delivered

Installation tooling under final tests

Detailed schedule for shutdown has been prepared



Insertable B-Layer



Developments also in view of Phase II

- sensors and FEI4 chip (IBL requirements similar to Phase 2 outer layer requirements for pixel)
- Cooling with CO2 and light mechanics

-

FE-I4 Pixel Chip (26880 channels)

19 x 20 mm^2 130 nm CMOS process, based on an array of 80 by 336 pixels (each 50 x 250 μm^2)

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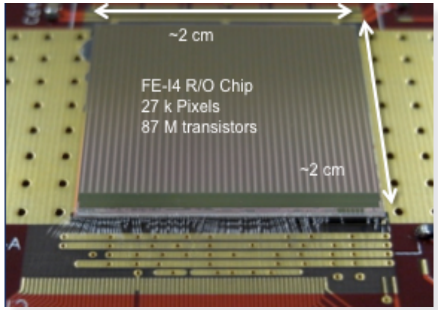
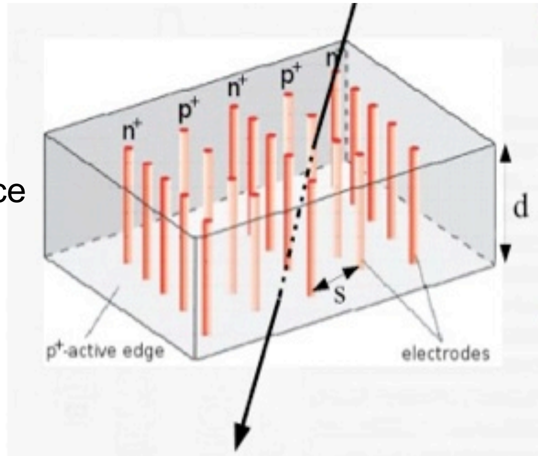


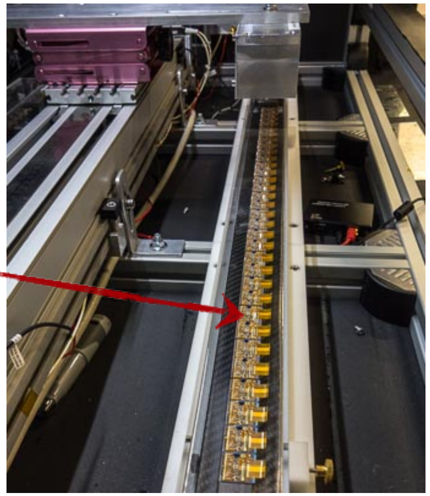
Planar Sensor

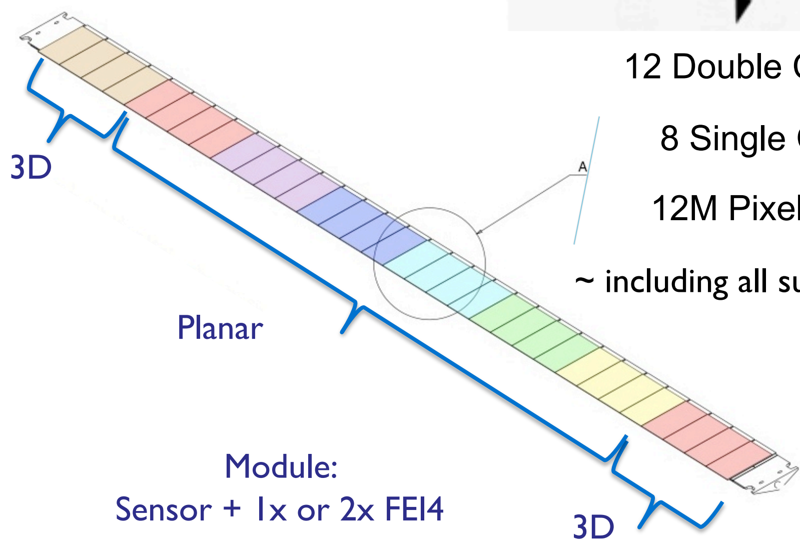
- "classic" sensor design
- oxygenated n-in-n
- 200µm thick
- Minimize inactive edge by shifting guard-ring under pixels (215 µm)
- Radiation hardness for IBL to 5×10^{15} n_{eq}/cm^2, tested up to 2.4×10^{16} p/cm^2

3D Sensor

- Both electrode types are processed inside the detector bulk
- Max. drift and depletion distance set by electrode spacing
- Reduced collection time and depletion voltage







12 Double Chip (planar)

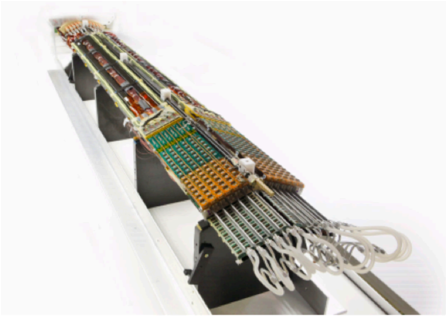
8 Single Chip (3D)

12M Pixel / 14 stave

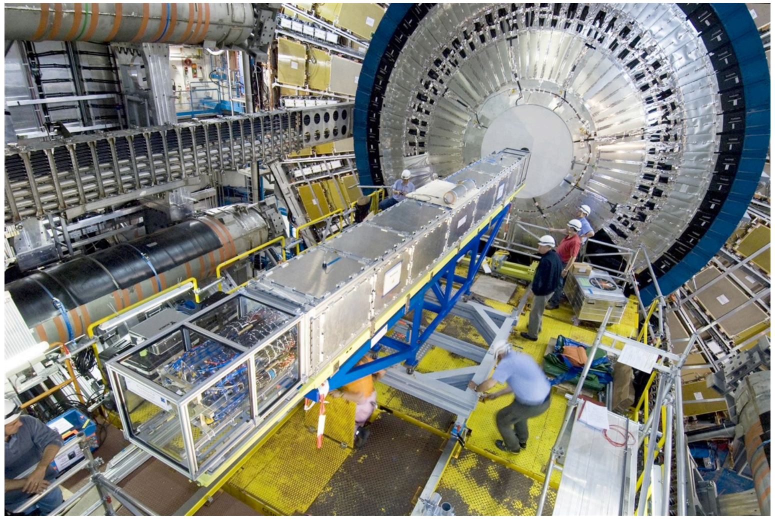
~ including all support = 1.9% X_0

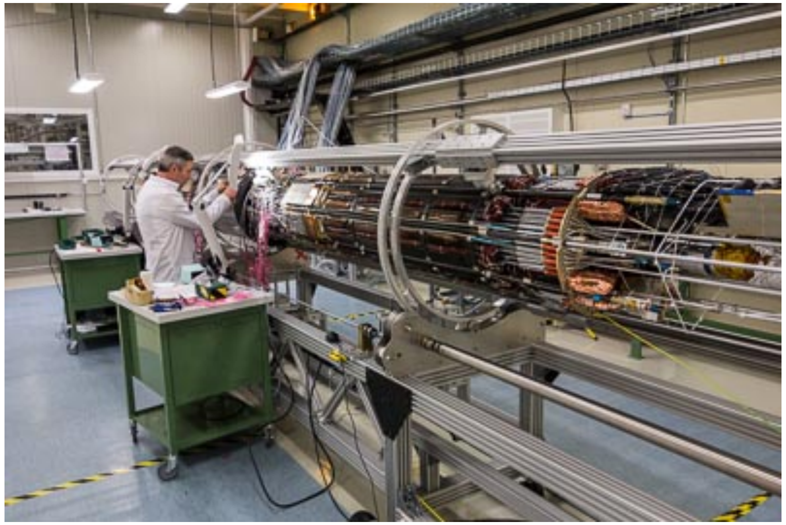
Module:
Sensor + 1x or 2x FEI4

Pixel extraction / nSQP

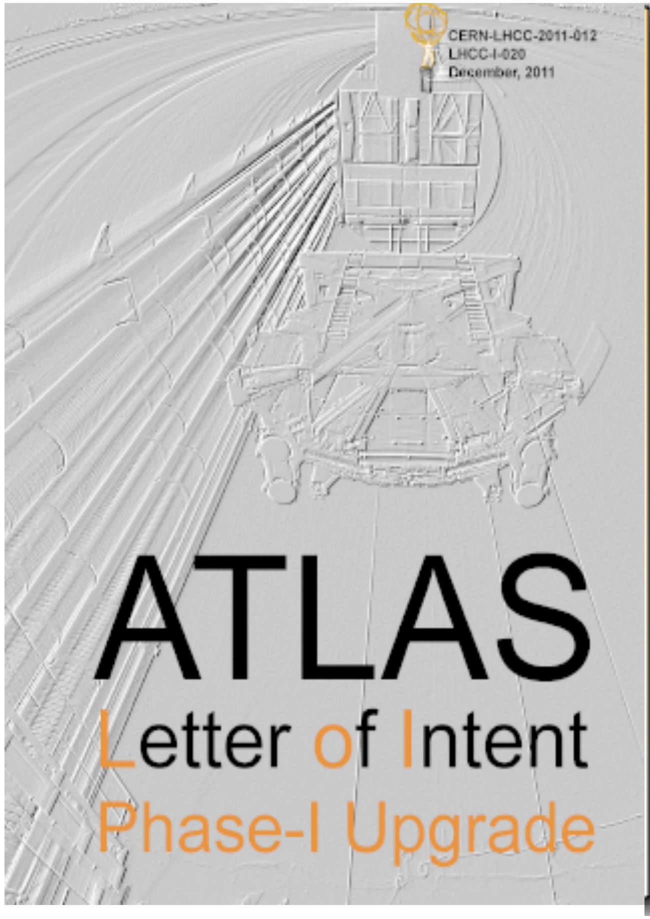


- New Service Quarter Panels (nSQP) will replace current Pixel services to move new opto-boards outside the Pixel detector volume (easier access for optical link replacement)
- Thereby also repair of Pixel RO channels, redundant links, faster, installation of Diamond Beam Monitor,...)
- Extraction of PIXEL done in April, now in SR1 clean room, un-cabling has been completed
- Re-installation in UX15 starts early 2014
- Will also upgrade Layer 2 readout system for higher throughput





Phase-I (~2018)



- New Small Wheel (nSW) for the forward muon Spectrometer
- High Precision Calorimeter Trigger at Level-1
- Fast TracKing (FTK) for the Level-2 trigger
- Topological Level-1 trigger processors
- New forward diffractive physics detectors (AFP)

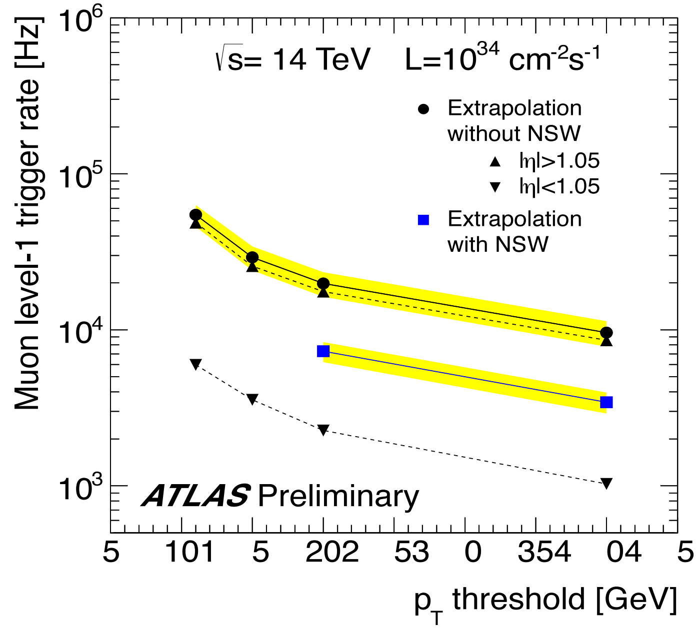
Phase 1 rate – New Small Wheel

- To maintain a L1 rate upper limit of 100kHz until Phase-II, the high luminosity requires combinations of higher thresholds, pre-scaling, multi-object/topological triggering unless **improved precision information can be made available to L1** (since backgrounds primarily from mis-measured lower P_T objects)
- Target single lepton rates each ≤~20kHz at P_T ~20 GeV as indicative of required performance to retain good sensitivity to key channels (such as those including vector bosons, like WH, WW, searches etc)
- Leads to main motivation to improve the detector resolution and background rejection in the key detector systems proving inputs to L1 in ATLAS

NSW is vital for running at high luminosity and to Allow low p_T thresholds in endcaps

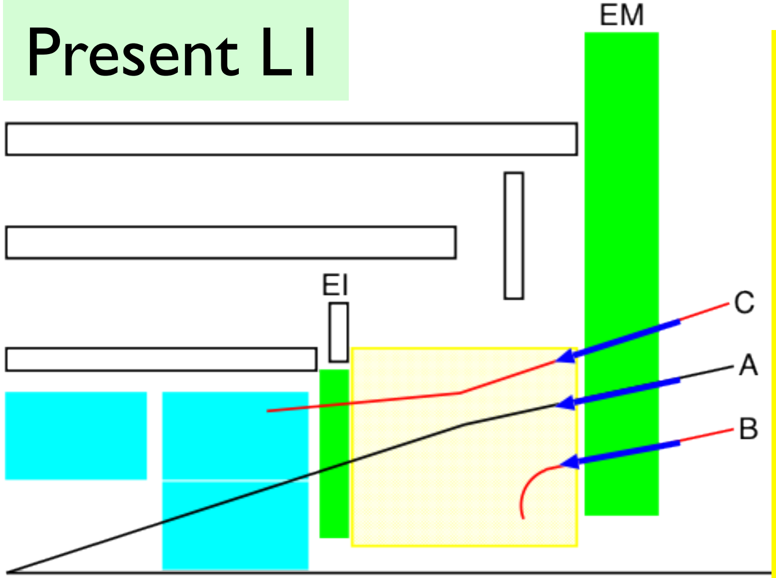
At $L = 3\times10^{34}$ Single μ L1 rate (kHz)

	Mu20	Mu40
Without NSW	60	29
With NSW	22	10
NSW + phase-0	17	8



New Small Wheel

Present L1

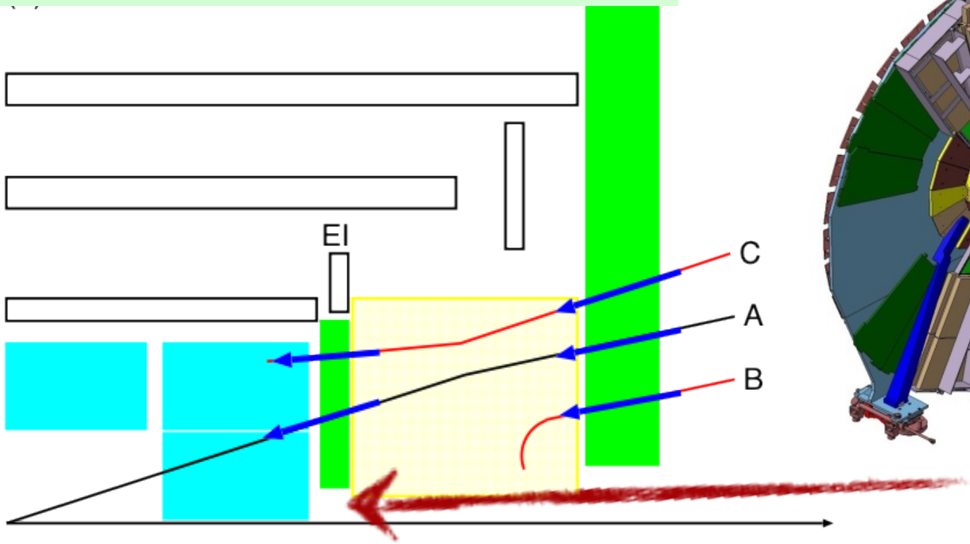


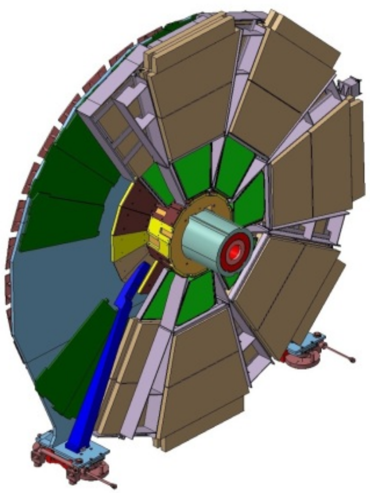
- Kill the fake trigger by requiring high quality (σ_θ~ 1mrad) IP pointing segments In New small wheels (NSW)

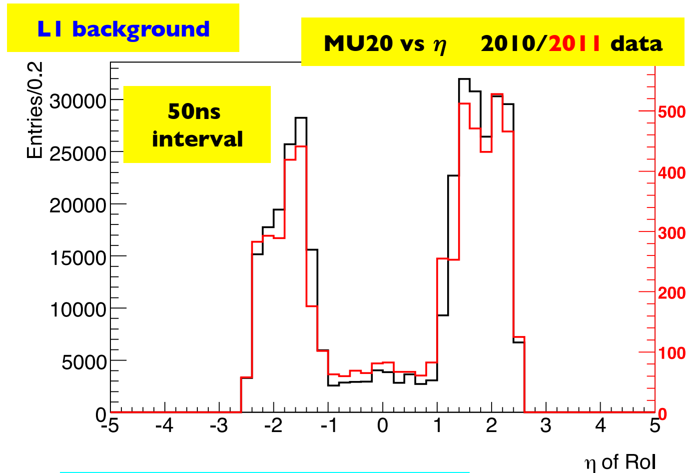
- New precision tracker in NSW that works up to the ultimate luminosity, 5-7x10^{34}, with some safety margin

New Small Wheel based on sTGC and micromegas

Upgrade L1 with NSW



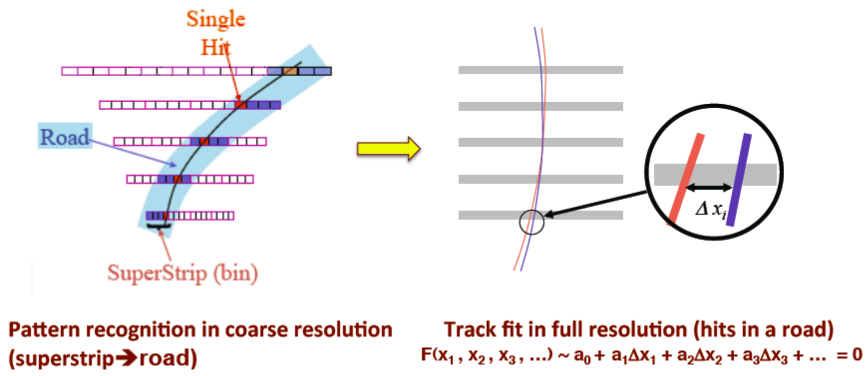




~ 6-7x higher L1 rate in End-cap than in the barrel

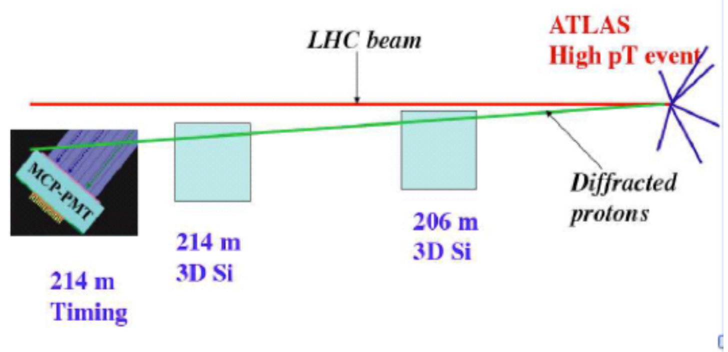
FTK and AFP

- Fast TracK (FTK): Global hardware based tracking by start of L2
  - Inputs from Pixel and SCT.
  - Data in parallel to normal read-out.
  - Provides inputs to L2 in ~ 25 μs with track parameters at ~offline precision for b tagging, tau ID and lepton isolation
  - Two phases:
    - Match hits to 10^9 stored patterns from pixel and strip layers
    - Track fitting



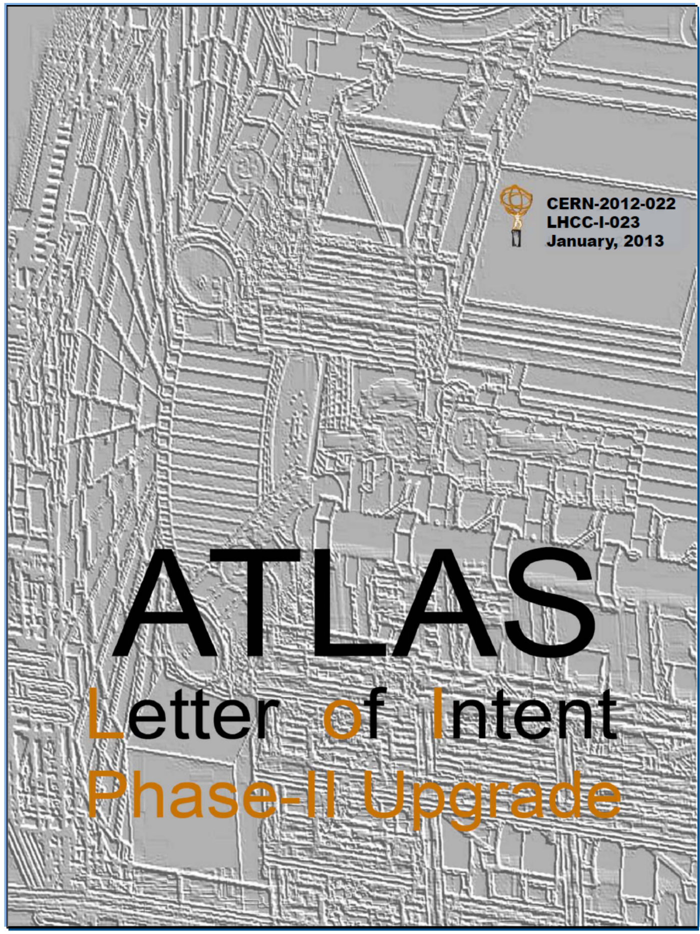
→ *New High Speed Optical link (HOLA) cards installed with dual outputs giving test of FTK functionality with real data*

- ATLAS Forward Physics (AFP)
  - Tag and measure scattered protons at ± 210m
  - Link to system triggered in central ATLAS
  - **Radiation-hard edgeless 3D silicon** developed in IBL context
  - 10ps timing detector for association with high p_T primary vertex
  - Probe hard diffractive physics and central exclusive production of heavy particles



→ *<20 ps timing per bar demonstrated at 5MHz and minimum gain loss up to ~3C/cm²*

Phase II (>2022)



- All new Tracking Detector
- Calorimeter electronics upgrades
- Upgrade part of the muon system
- Possible Level-1 track trigger
- Possible changes to the forward calorimeters

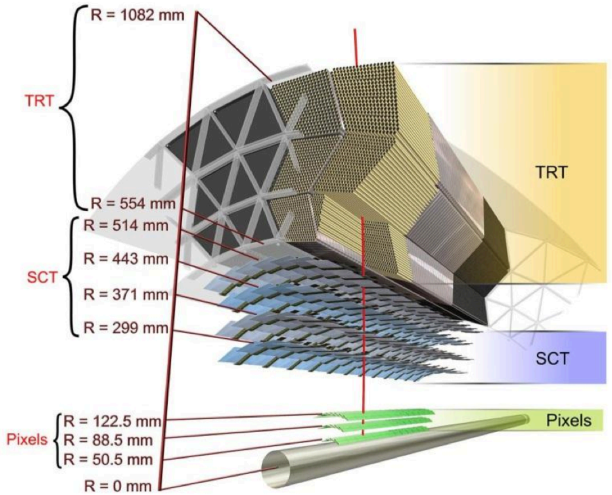
Phase II detector upgrades

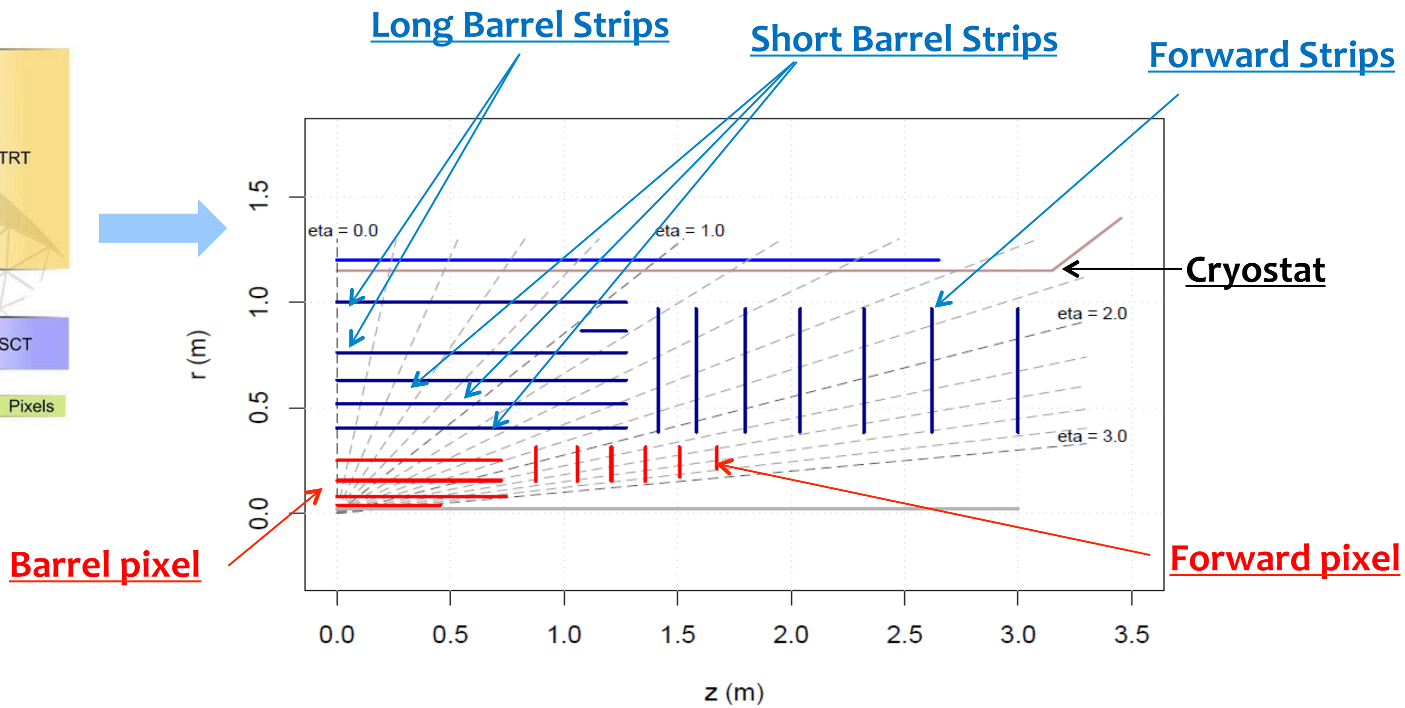
Integrated radiation levels (up to 2-3×$10^{16}n_{eq}/cm^2$) and plan to cope with μ ≈ 200.

Implications of this include:

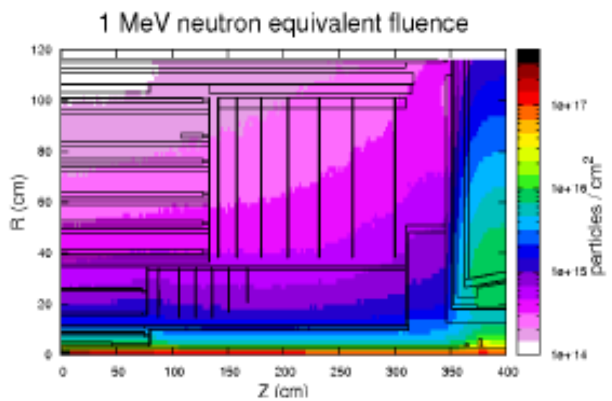
- New Inner Detector (strips and pixels)
- TDAQ upgrade
- Level 0 + Level 1 Track Trigger
- New LAr front-end and back-end electronics
- Possible upgrades of HEC and FCal
- New Tiles front-end and back-end electronics
- Muon Barrel and Large Wheel trigger electronics
- Possible upgrades of TGCs in Inner Big Wheels
- Forward detector upgrades
- TAS and shielding upgrade
- Various infrastructure upgrades
- Common activities (installation, safety, …)
- Software and Computing

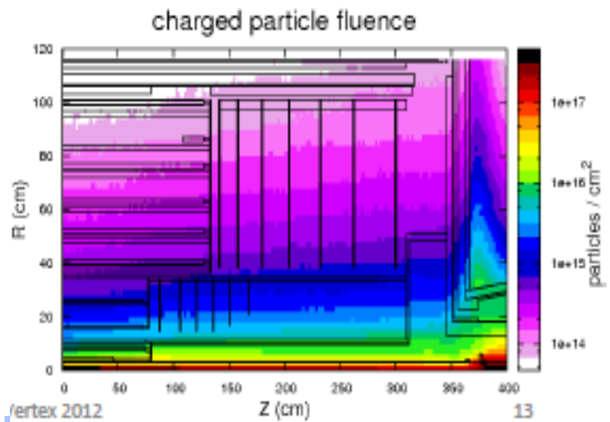
New All-silicon Inner Tracker





All Silicon tracker for Phase 2 (TRT would not cope with occupancy)
Baseline layout of the new ATLAS inner tracker for HL-LHC
Aim to have at least 14 silicon hits everywhere (robust tracking)





14 TeV collisions; integrated luminosity = 3000fb^{-1}

Tracker performance

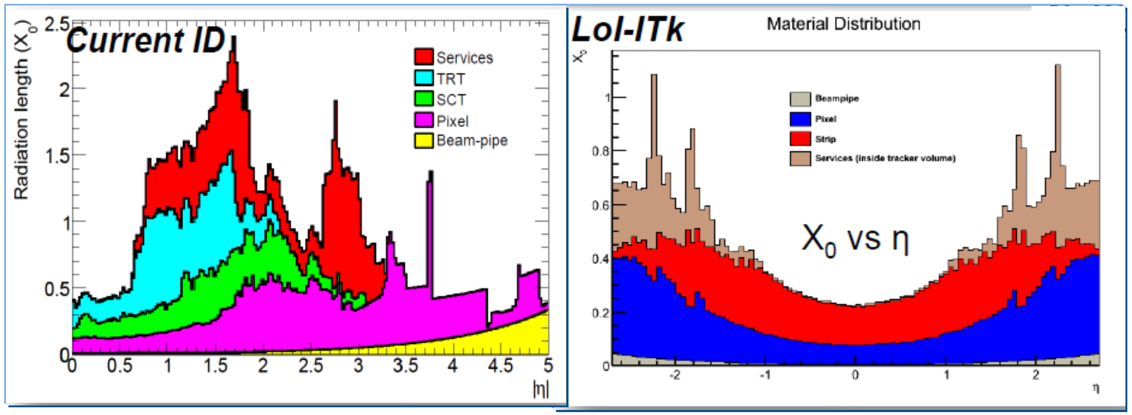
- New Inner Detector Improved granularity
  (Smaller pixels and 4.9cm and 9.8cm strips (74.5 μ m pitch)
  - Improved radiation hardness
  - Reduced material
  - Extended forward coverage
  - Robust tracking (14 layers)

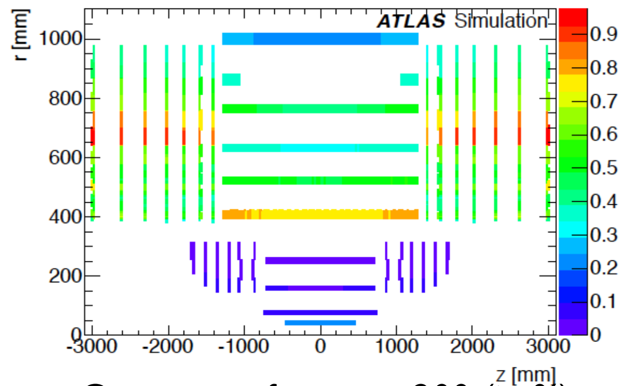
Basic numbers of baseline:

Detector:	Silicon area $[m^2]$	Channels $[10^6]$
Pixel barrel	5.1	445
Pixel end-cap	3.1	193
Pixel total	**8.2**	**638**
Strip barrel	122	47
Strip end-cap	71	27
Strip total	**193**	**74**

Tracker - now and then:

Track parameter $\lvert\eta\rvert < 0.5$	Existing ID with IBL no pile-up $\sigma_x(\infty)$	Phase-II tracker 200 events pile-up $\sigma_x(\infty)$
Inverse transverse momentum (q/p_T) [/TeV]	0.3	0.2
Transverse impact parameter (d_0) [μm]	8	8
Longitudinal impact parameter (z_0) [μm]	65	50



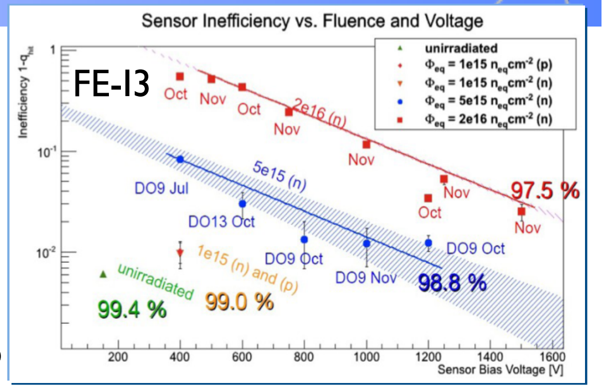


Occupancy for <μ>=200 (in %)

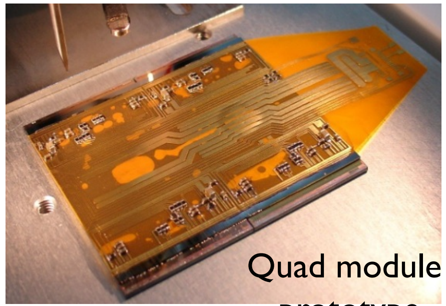
New All-silicon Inner Tracker

Pixel Detector

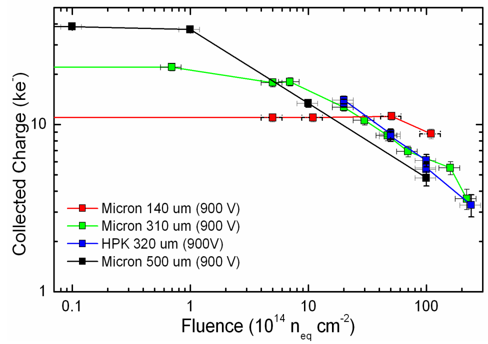
- Pixel sensors in several technologies proved to high doses (planar/3D/diamond shown to $2\times10^{16} n_{eq}/cm^2$)
- IBL pixel (50×250μm) OK for outer pixel layers, but can go down to 25μm×125μm pixels with 65 nm CMOS

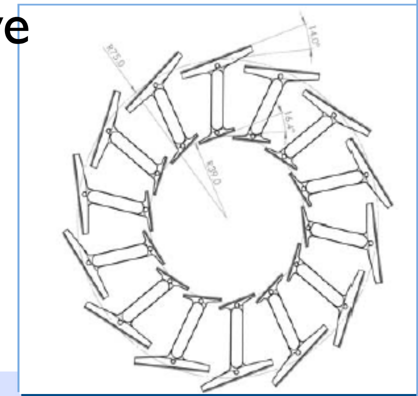


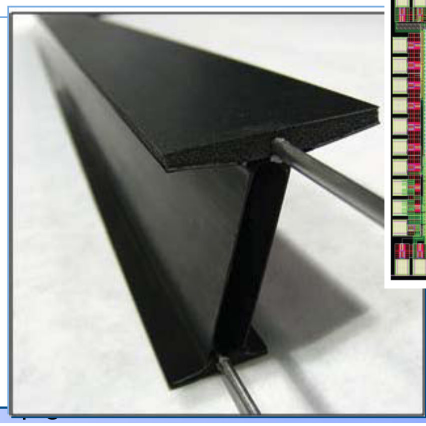
- Test structures in 65nm produced and even studies after irradiation
- Larger area sensors quads/sextuplets produced on 150mm diameter wafers with several foundries
- Quad pixel module produced, being tested and results look promising
- Prototyping of local supports for various concepts has been carried out
- A number of support designs and service routings have been studied

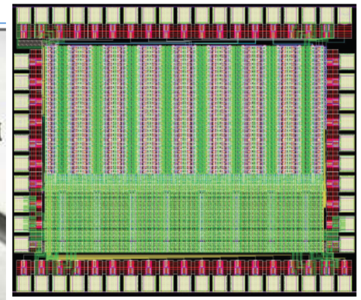


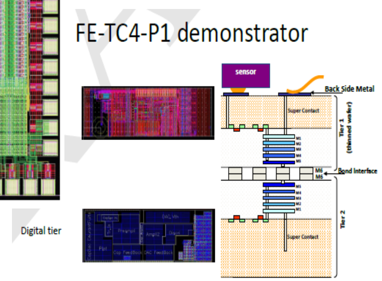
Quad module prototype







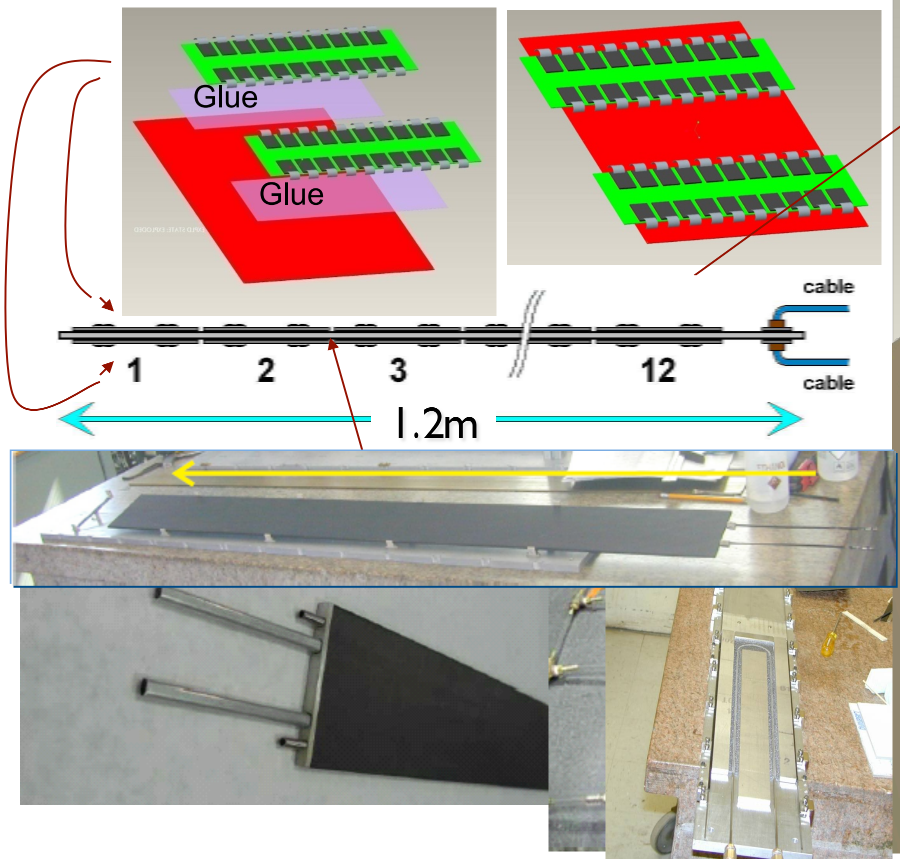


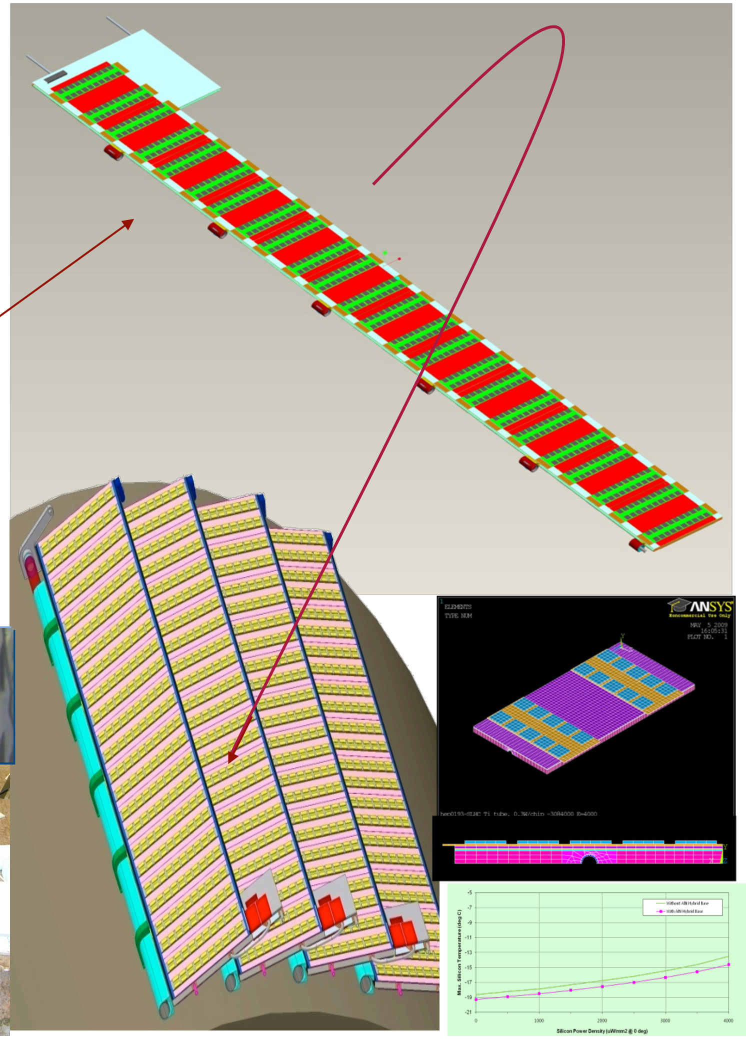


New All-silicon Inner Tracker

Strip Detector

- Strip stave = Hybrid glued to Sensor glued to bus tape glued to cooling substrate
- Barrel Stave:

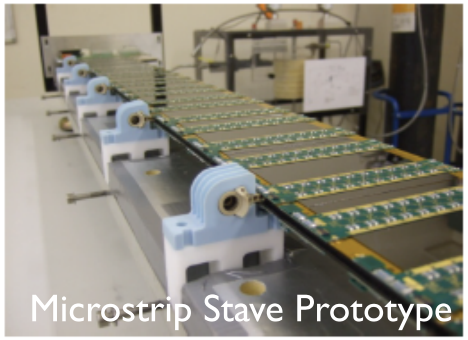


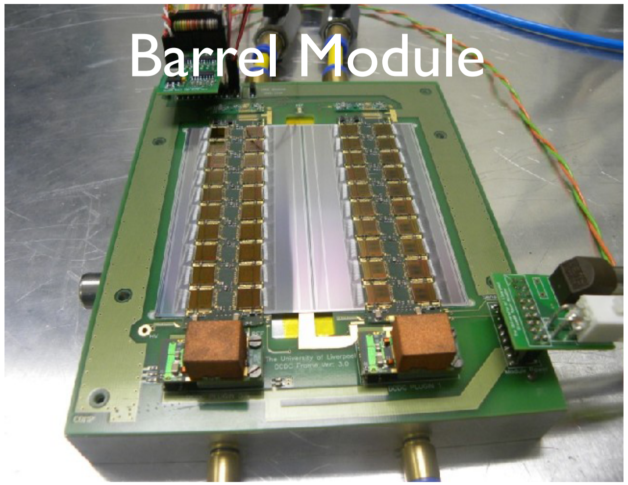


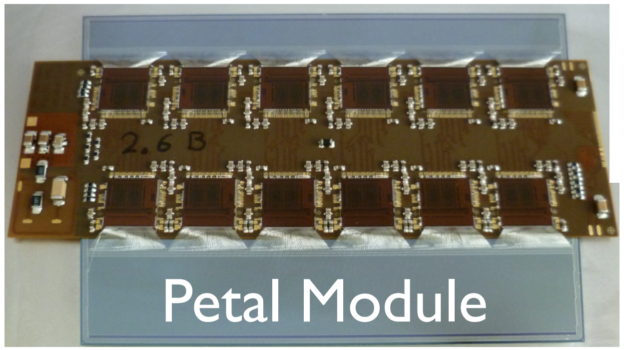
Single-sided Strip Modules

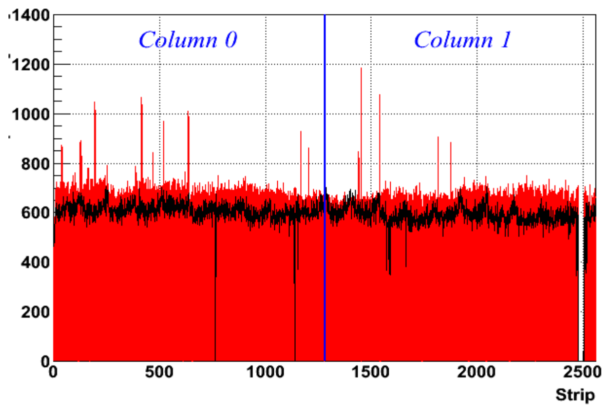
- Extensive hybrid and module construction done with 250 nm ASIC ABCn chip programme
- More than 170 hybrids and 65 barrel modules produced for stave-lets and stave-250
- First forward module recently assembled
- Studying performance, and scrutinizing properties and irradiation
- Moved to 130nm ABCN chip now

- Irradiated at CERN-PS irradiation facility
  - Module biased, powered, and clocked during irradiation
  - Total dose of 1.9×10^{15} n_{eq} cm^{-2} achieved
    - Max predicted fluence is 5.3×10^{14} n_{eq} cm^{-2} (barrel) and 8.1×10^{14} n_{eq} cm^{-2} (endcap)
- Sensor and module behave as expected









Conclusion

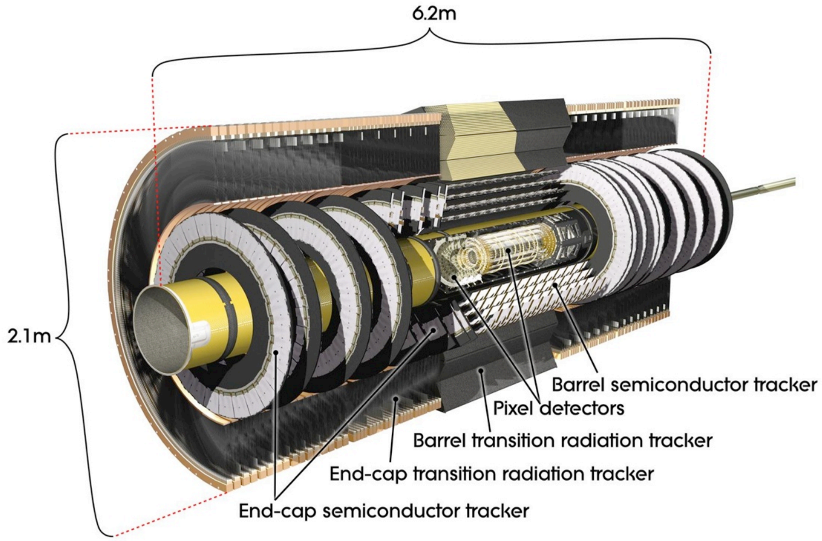
- This year has been a revolutionary one in our field!
- The machine has achieved near nominal luminosity much faster than had been originally foreseen and ATLAS performed at >95% efficiency.
- We have only just scratched the surface in terms of exploring the LHC's potential for consolidating discoveries

- The ATLAS detector upgrade is driven by maintaining and improving the performance while the luminosity (pileup) increases
- ATLAS Upgrade comes in 3 phases:
  - After LS1/2015: 4-Layer pixel
  - After Phase 1-2018 : New Small Wheel Muon detector, Trigger upgrades, FTK
  - Final Phase 2 – 2022/23 : All new tracker as well as DAQ and electronics upgrade

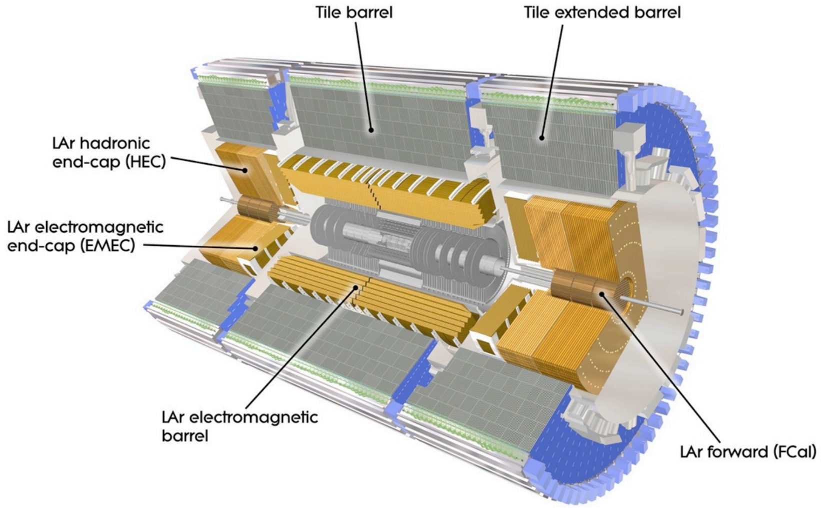
Backup slides

ATLAS Detector

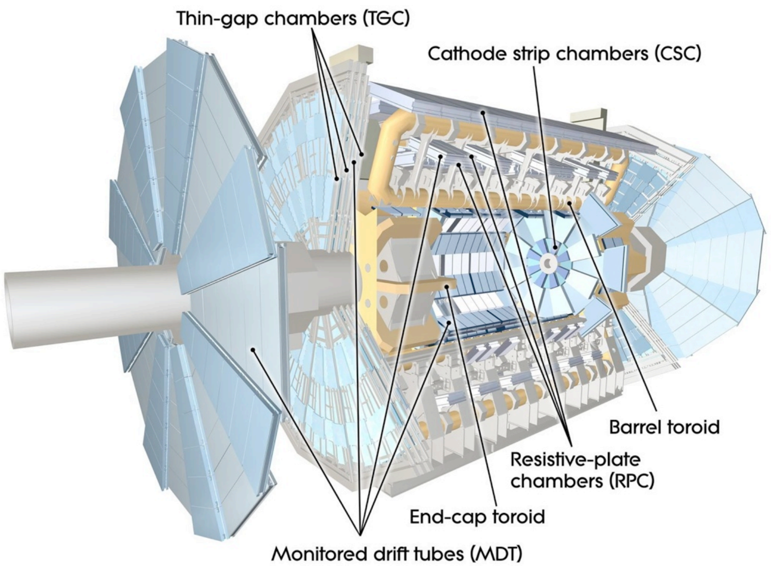
Inner Tracker



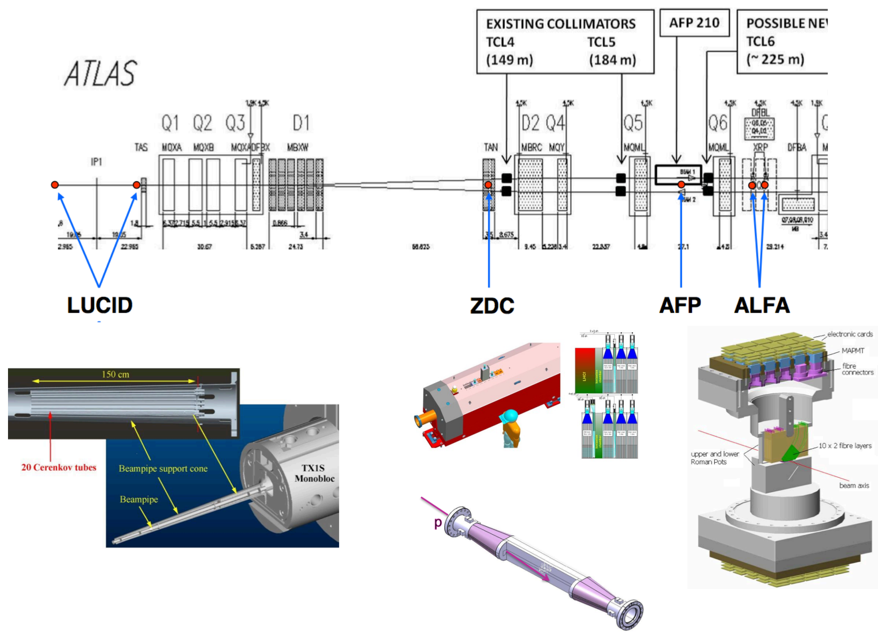
Calorimeter



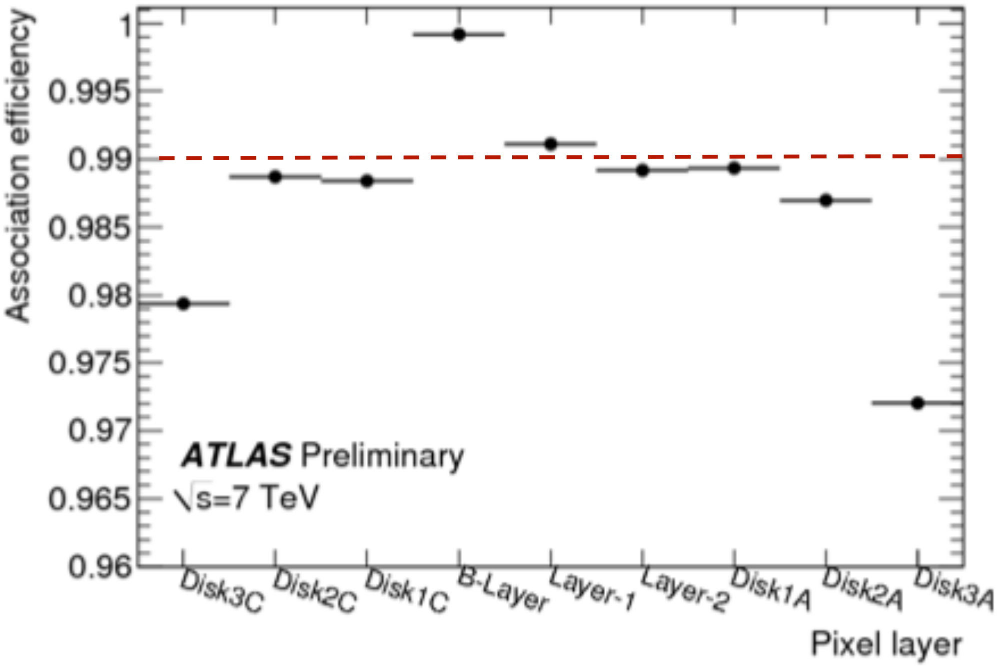
Muon Spectrometer



Forward Detectors



PIXEL - Performance

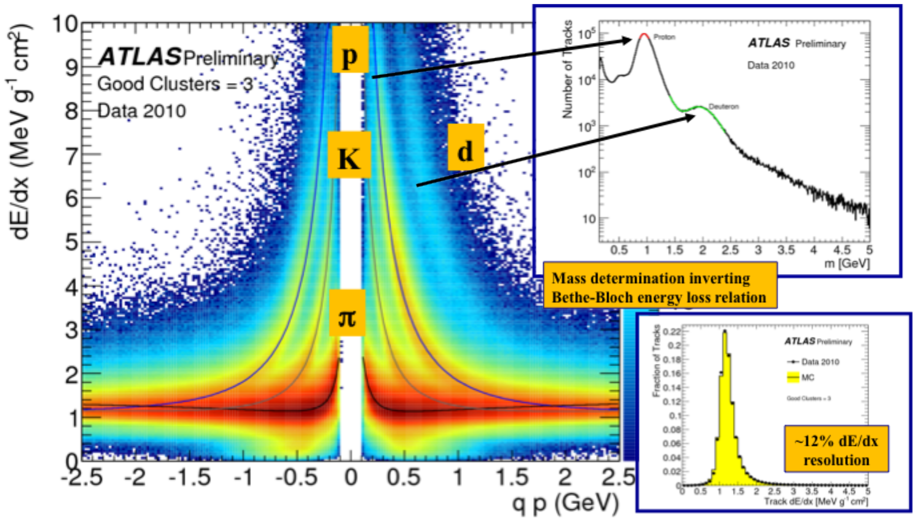


Hit-to-track association efficiency for the different parts of the detector.

Disabled modules have been excluded, dead regions not (Full efficiency of the B-layer due to track selection).

Efficiency ~99% for nearly all parts

Slightly lower efficiency in the outermost discs due to individual modules.



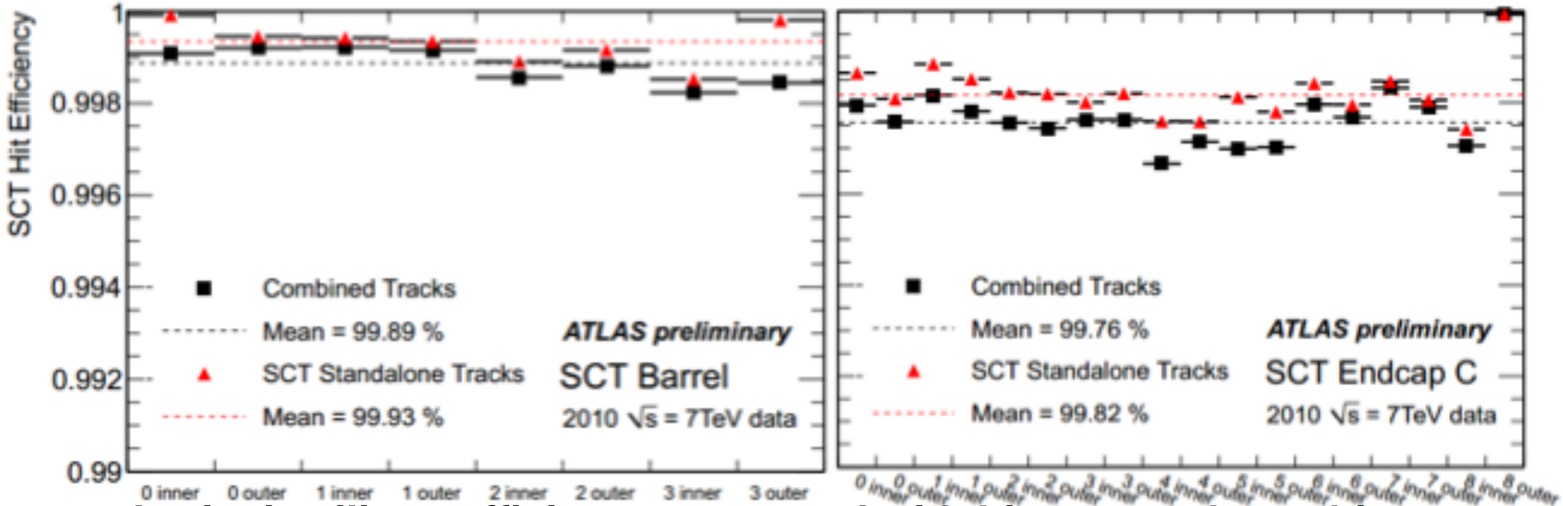
Bi-directional distribution of dE/dx and momentum.

The charge collected in each pixel is measured using the TimeOverThreshold information.

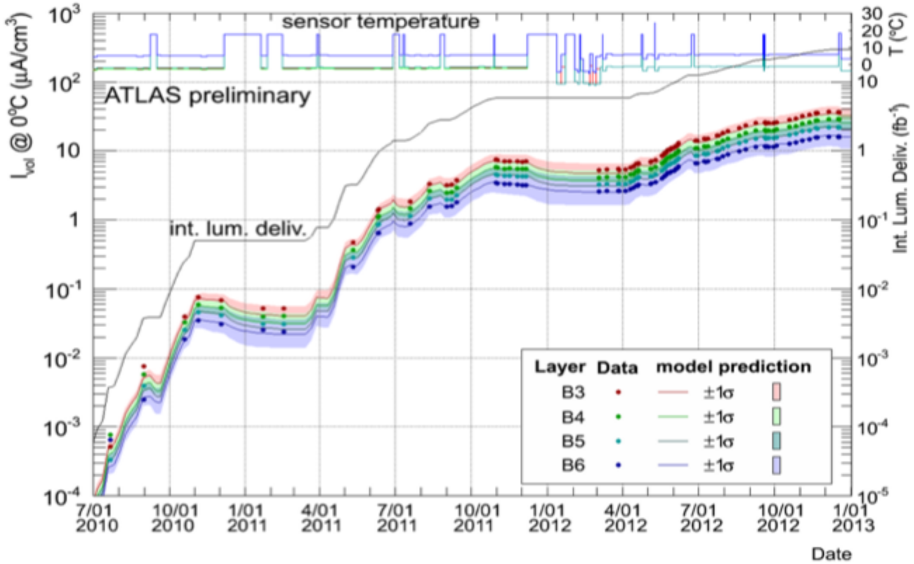
Thanks to the stability of the detection process, it allows the identification for non relativistic particles.

SCT - Performance

Intrinsic Silicon Efficiency measured in the SCT



Intrinsic silicon efficiency measured with hits on tracks : # hits per possible hit

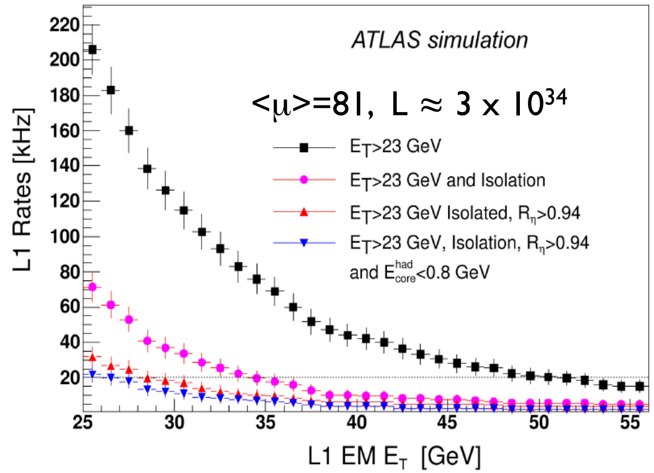


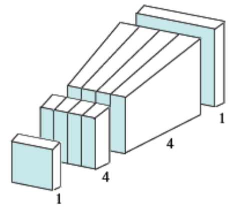
Radiation Damage in SCT Barrel

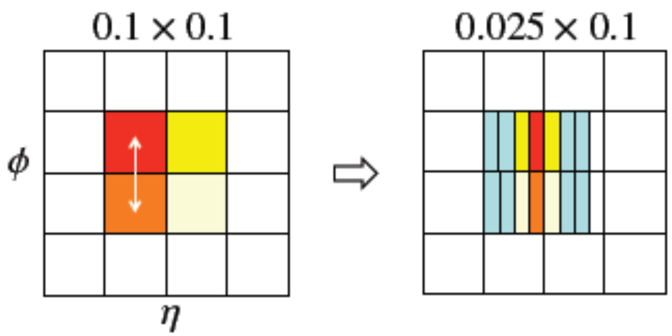
Excellent agreement over 4 orders of magnitude, need a good knowledge of inputs (L,flux,T).

- Key target (as for New Small Wheel) is to maintain high efficiency for Level-1 triggering on low P_T objects (here electrons and photons)
- In the LAr calorimeter this implies changes to the front-end electronics to allow greater granularity to be exploited at Level-1.
- Trigger upgrades include topological trigger, cluster and jet energy processor, feature extractors, muon sector logic and CTP

electron rate vs threshold







Distribution of the R_η parameter for electrons and jets, defined as the ratio of the energy in the 3x2 over the energy in the 7x2 clusters of the 2nd layer of the EM calorimeter.

Selection criteria	Rate reduction	
	Fraction of (1)	Fraction of (2)
(1): Level-1 EM $E_T > 23$ GeV	100%	-
(2): (1) and Level-1 isolation	34.9%	100%
(3): (2) and R_η	14.25%	40.8%
(4): (3) and E^{had}_{core}	11.45%	32.8%

Phase II – Split TDAQ L1

- Simulation studies show that including a track trigger complements muon and EM triggers
- Implemented as 2-level scheme reusing Phase-I L1 trigger improvements for new L0