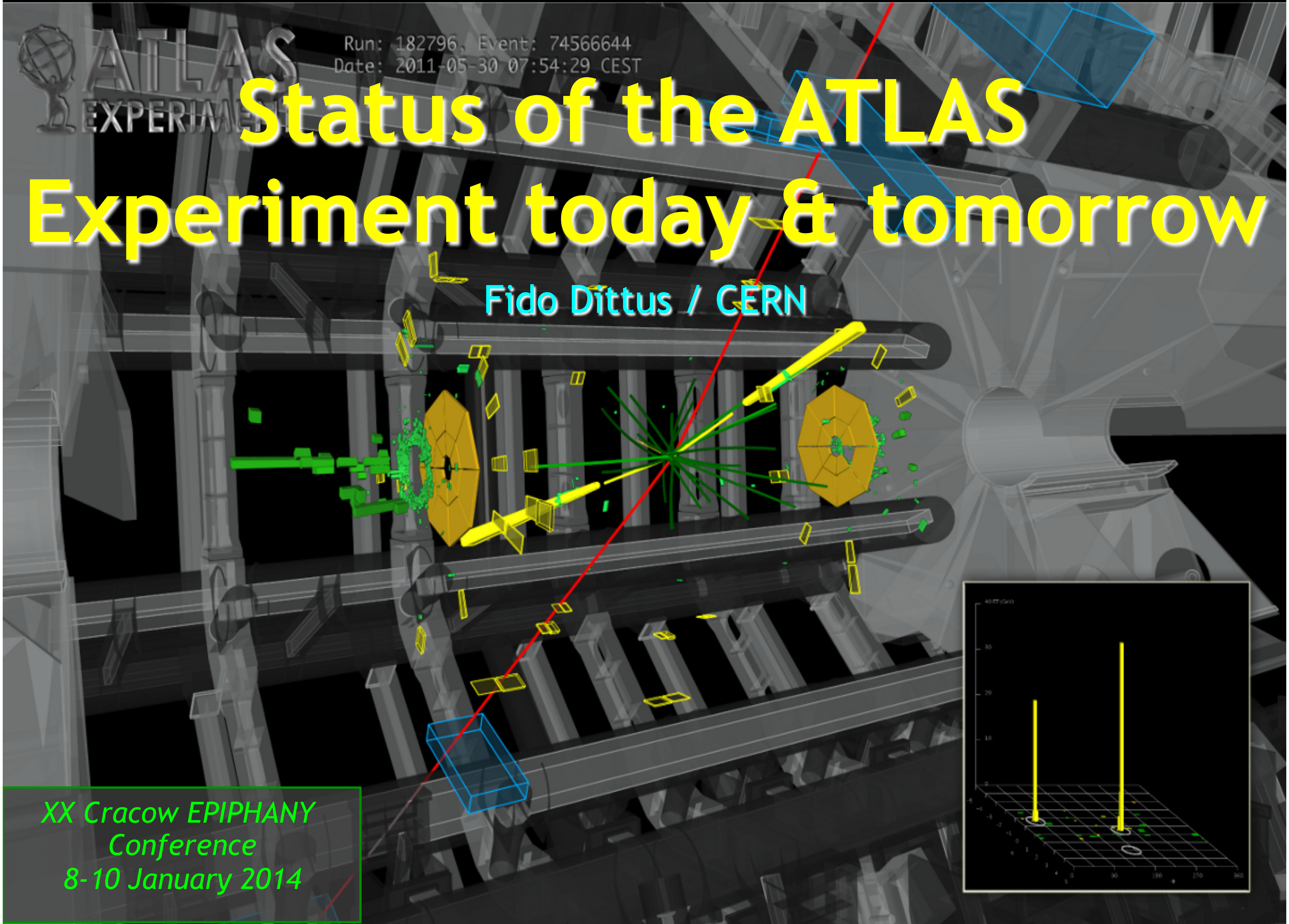
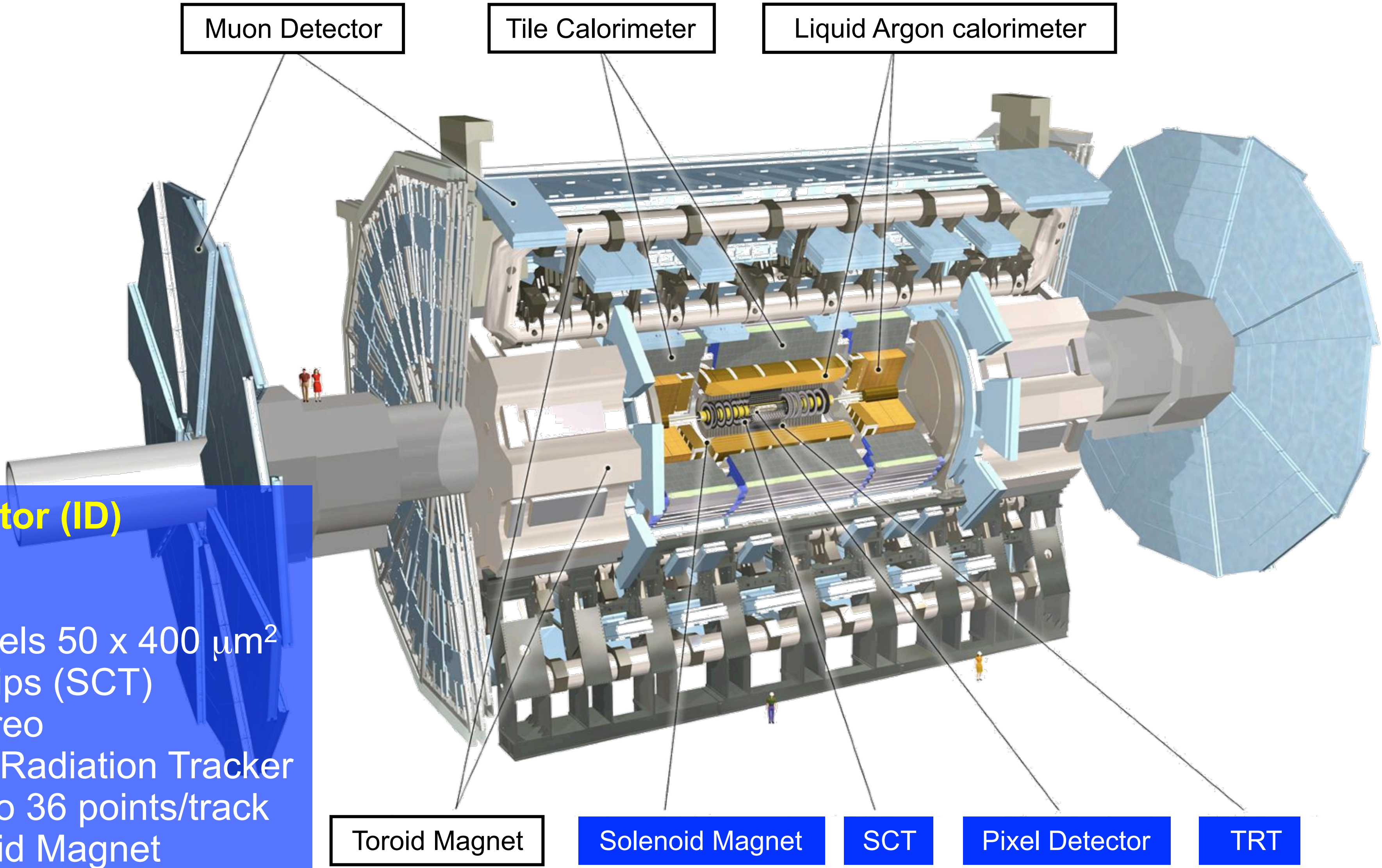
Status of the ATLAS Experiment today & tomorrow

Fido Dittus / CERN



XX Cracow EPIPHANY Conference
8-10 January 2014

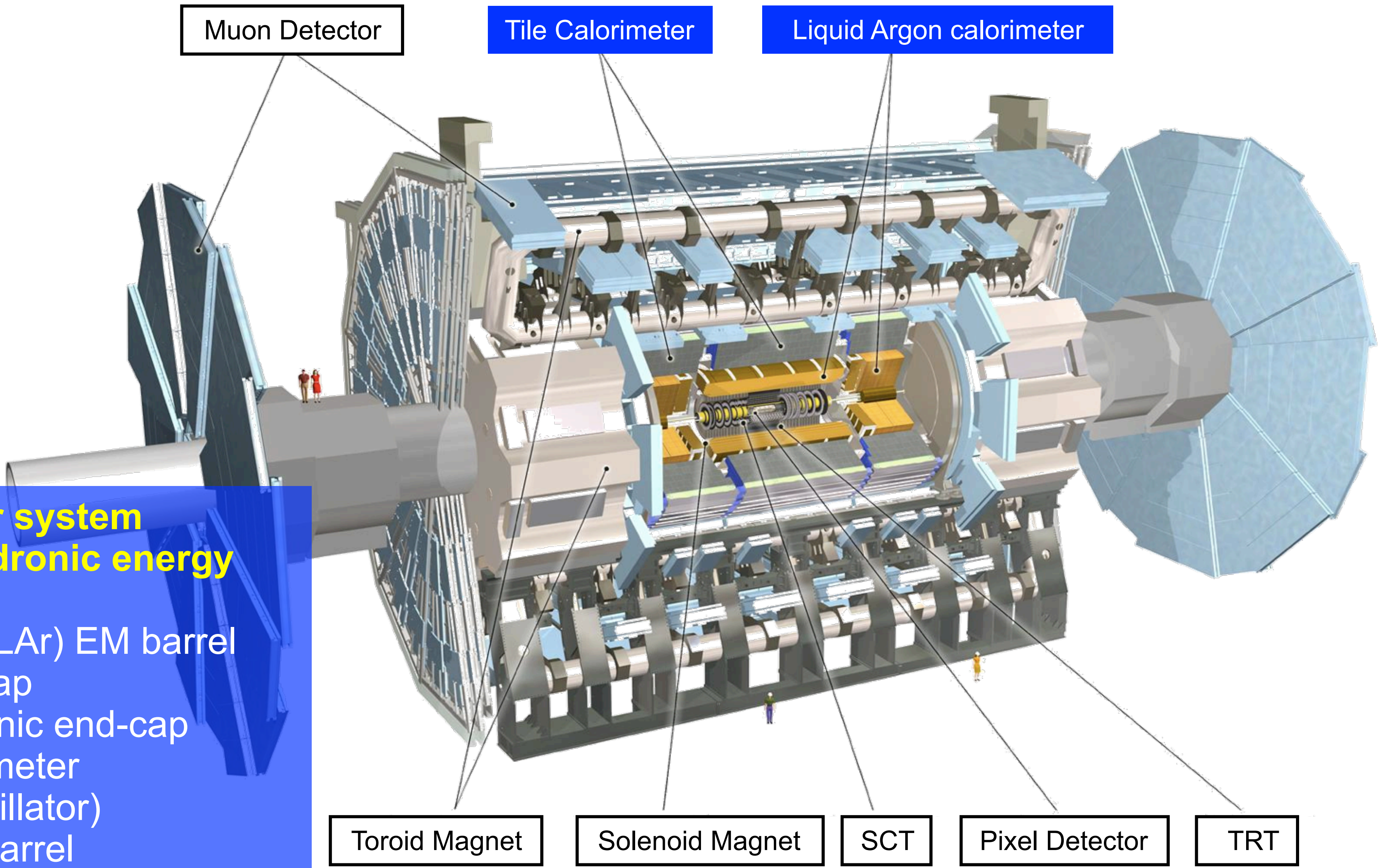
The ATLAS Detector



Inner Detector (ID) Tracking

- Silicon Pixels 50 x 400 μm^2
- Silicon Strips (SCT) 80 μm stereo
- Transition Radiation Tracker (TRT) up to 36 points/track
- 2T Solenoid Magnet

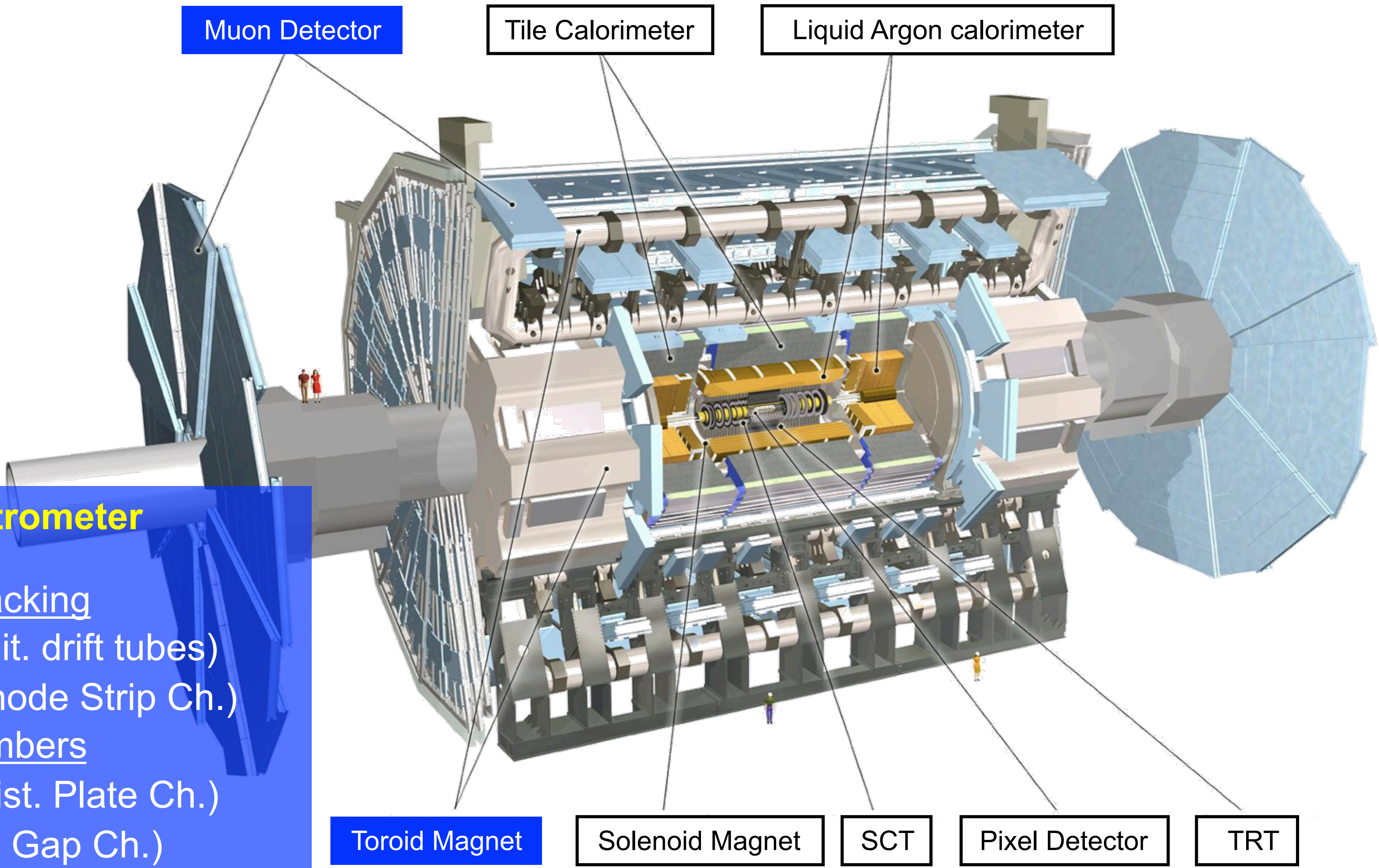
The ATLAS Detector



Calorimeter system
EM and Hadronic energy

- Liquid Ar (LAr) EM barrel and end-cap
- LAr Hadronic end-cap
- Tile calorimeter (Fe – scintillator) hadronic barrel

The ATLAS Detector



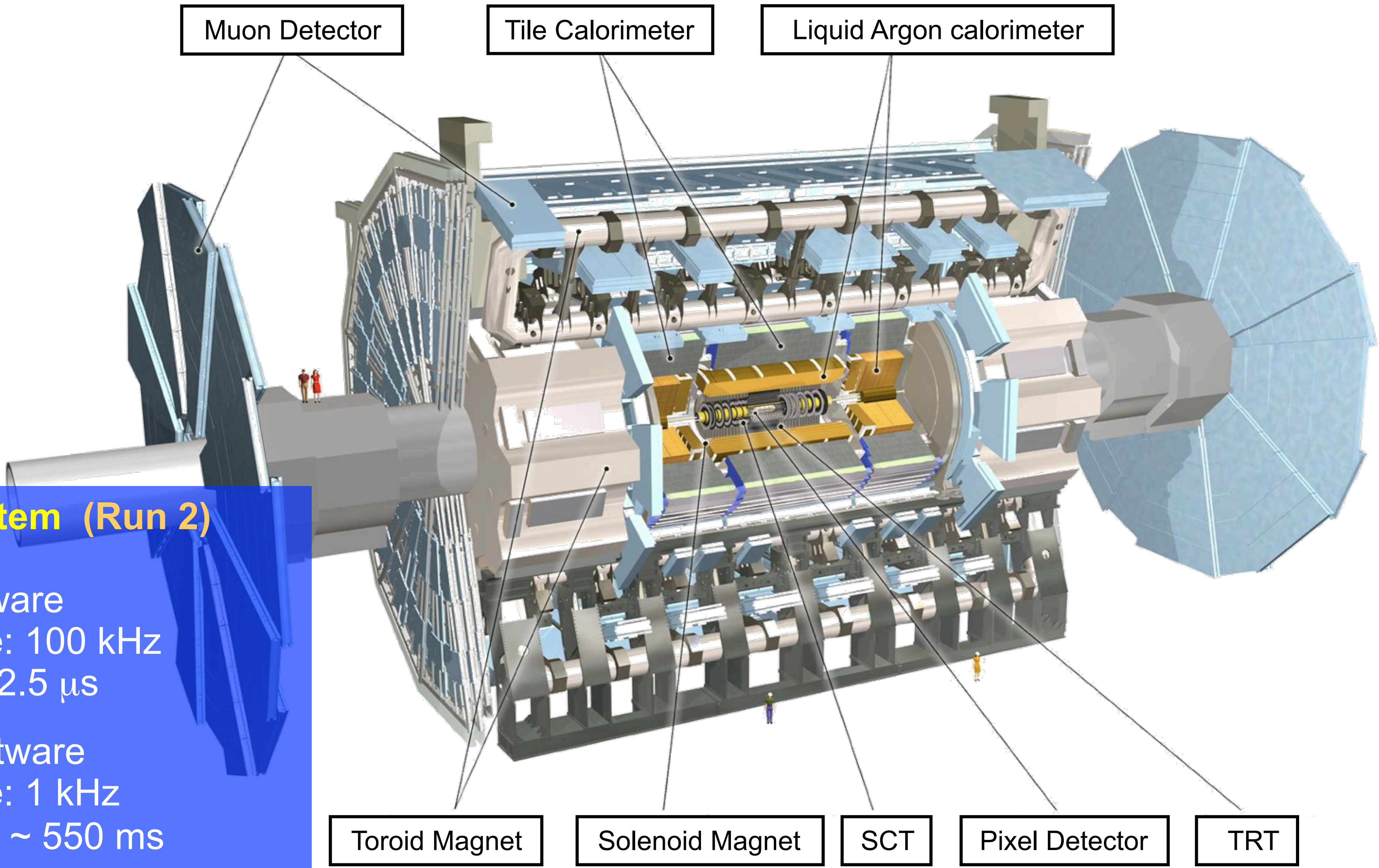
Muon spectrometer
μ tracking

Precision tracking
- MDT (Monit. drift tubes)
- CSC (Cathode Strip Ch.)

Trigger chambers
- RPC (Resist. Plate Ch.)
- TGC (Thin Gap Ch.)

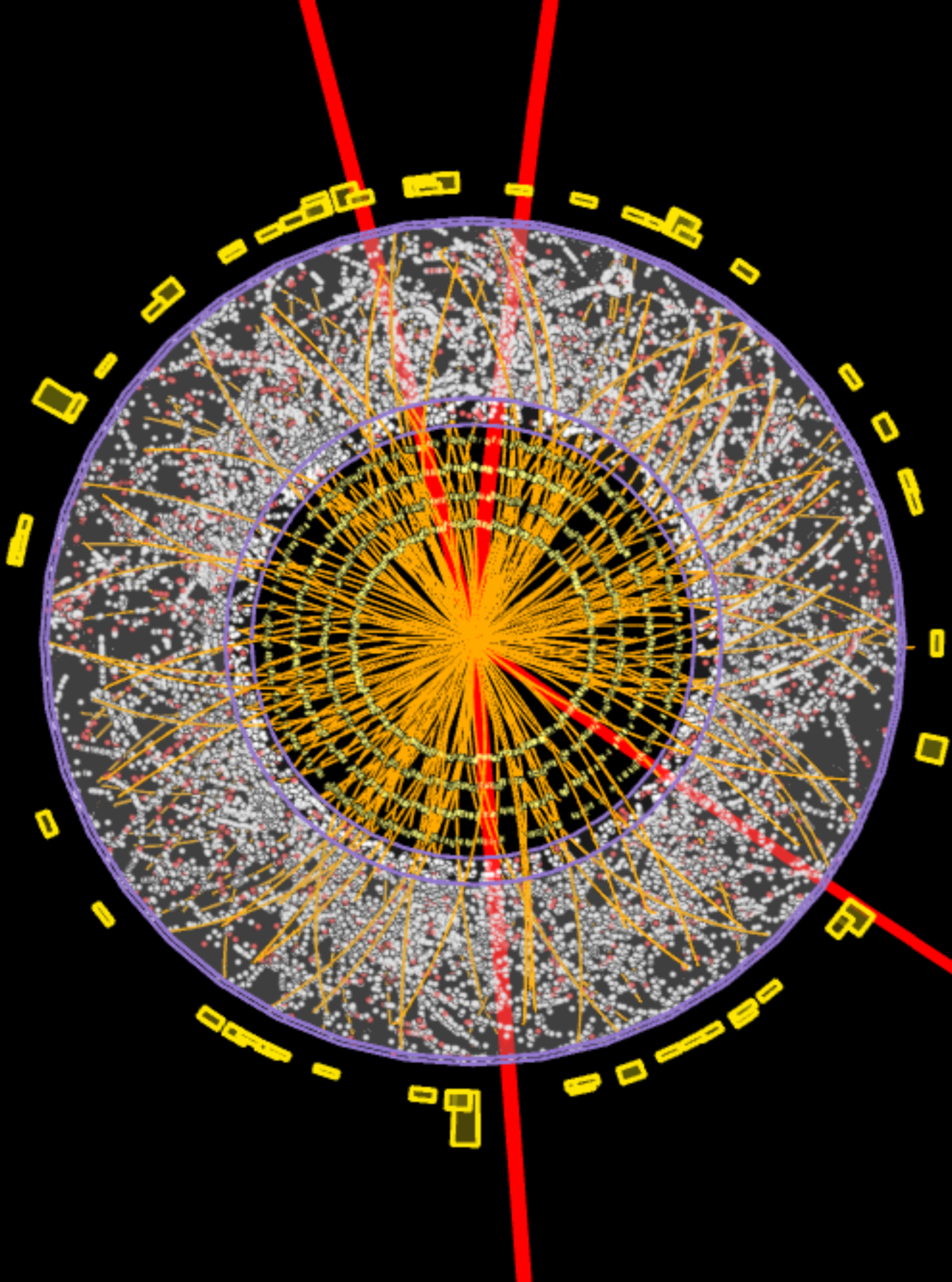
- Toroid Magnet

The ATLAS Detector



Trigger system (Run 2)

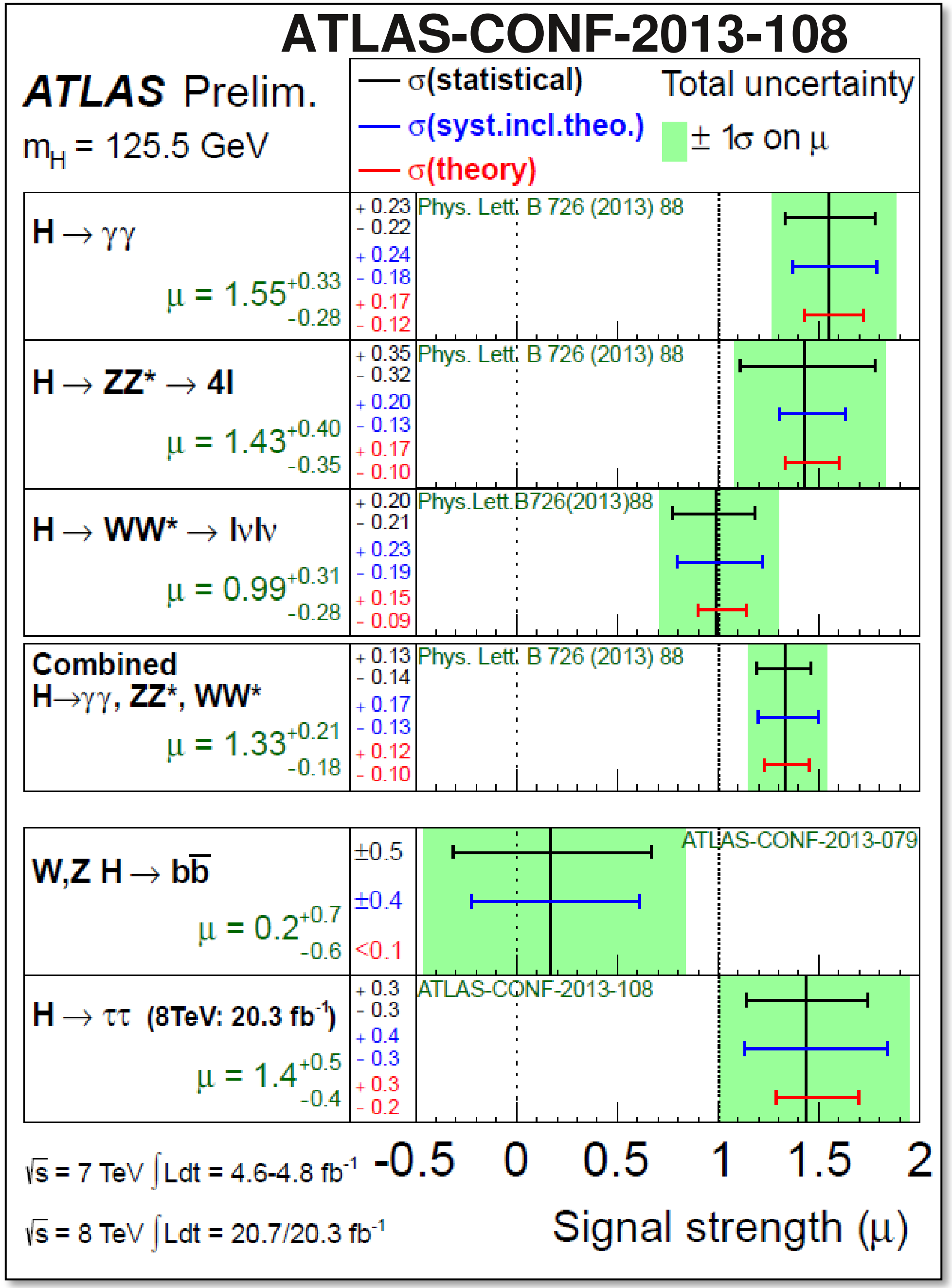
- L1 – hardware
  output rate: 100 kHz
  latency: < 2.5 μs
- HLT – software
  output rate: 1 kHz
  proc. time: ~ 550 ms

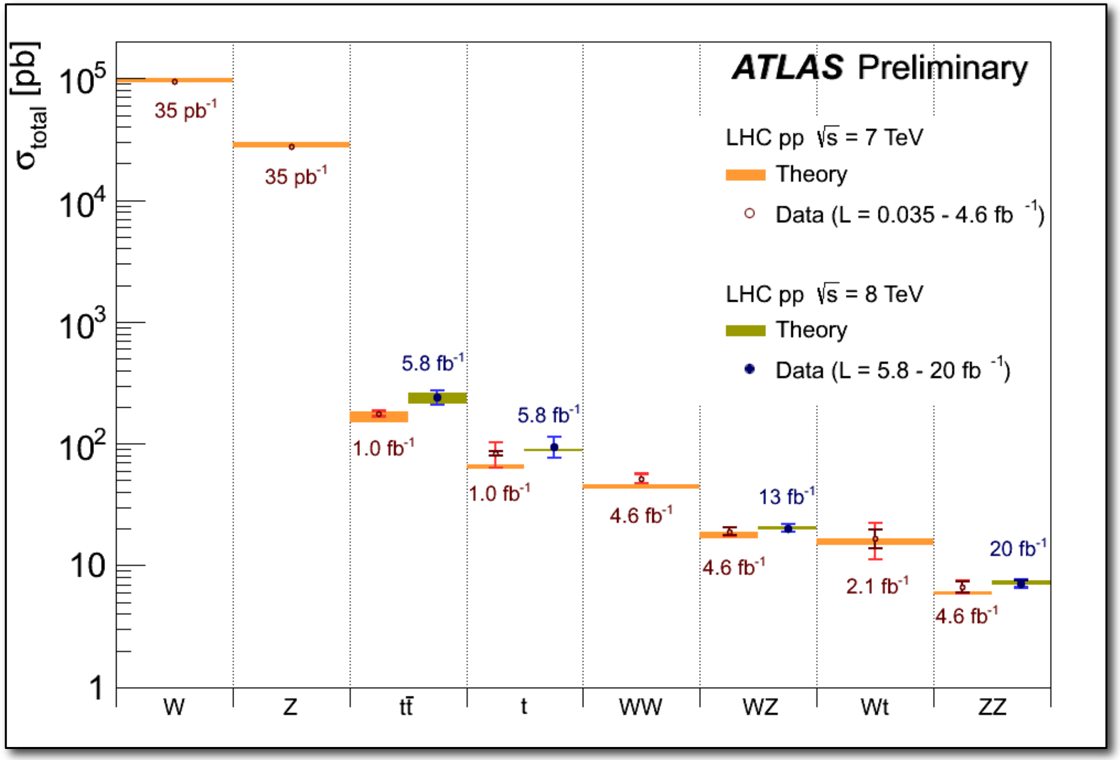


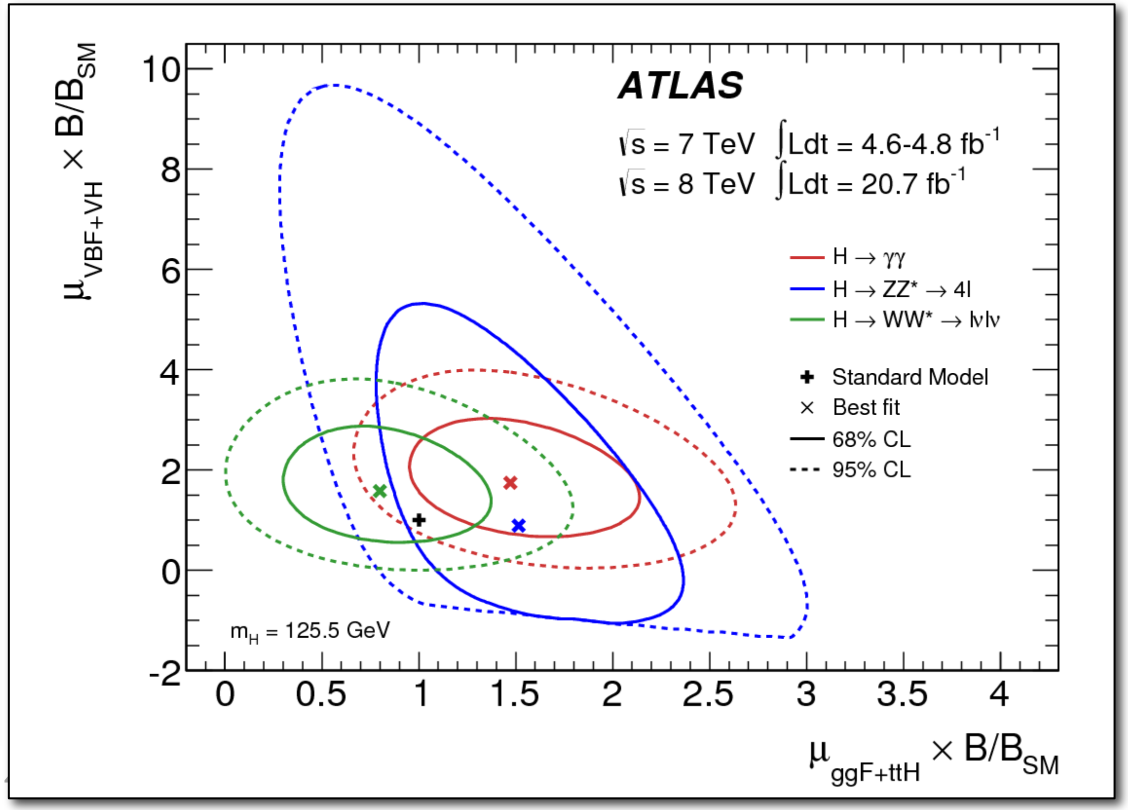
OUTLINE:

- RUN 1 Highlights
- LS1 Activities
- Phase 1 Upgrade
- Phase 2 Upgrade

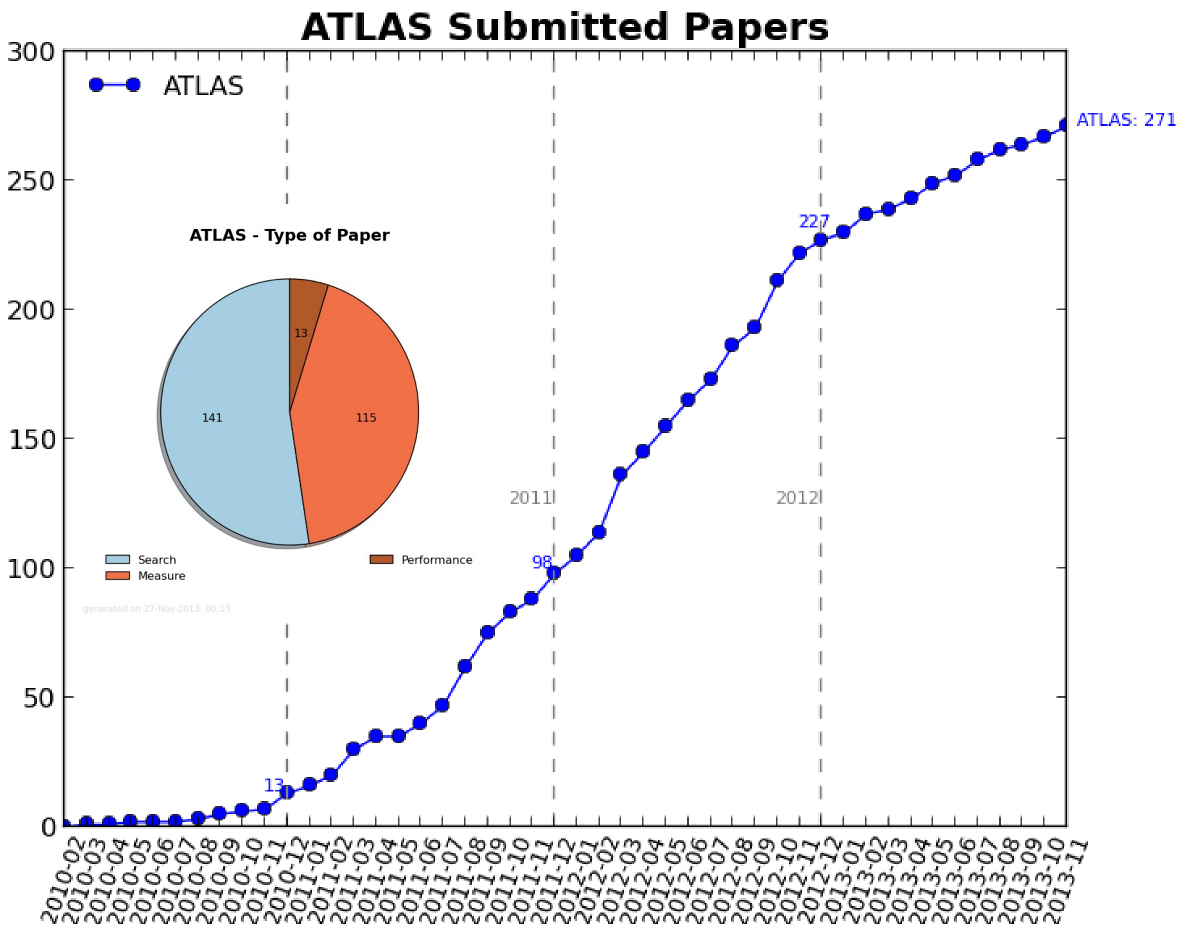
Run1 Highlights

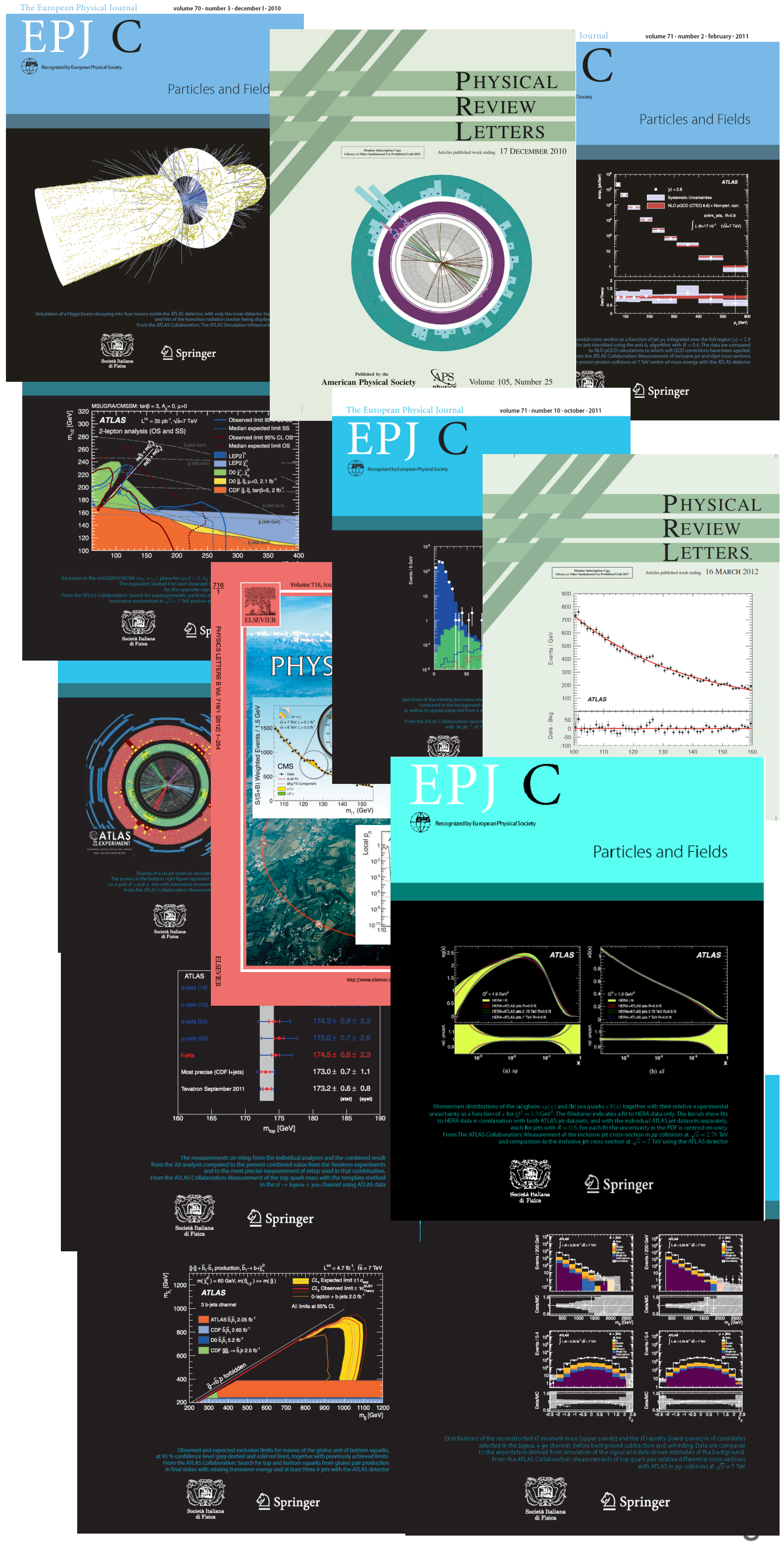






Run1 Highlights

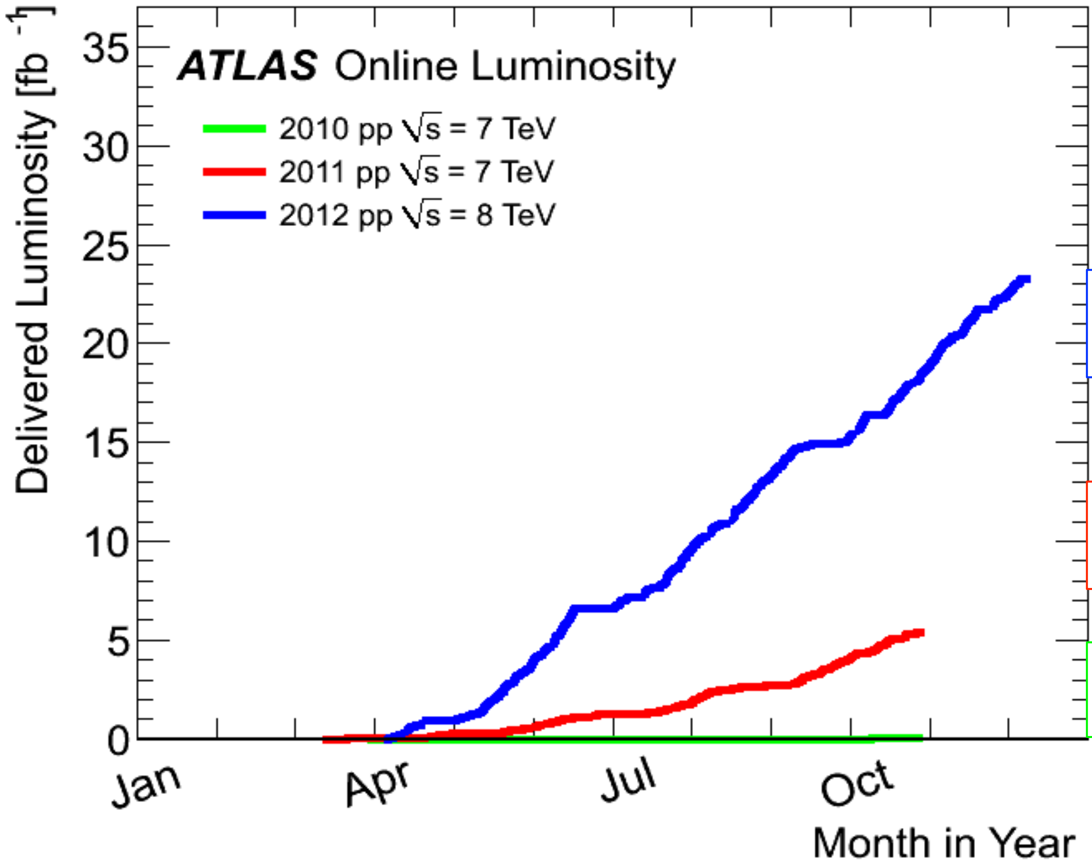




To date, 273 papers with collision data have been submitted

Sustained rate of 2.5 papers/week during 2012

In addition, 544 ATLAS CONF notes since 2010



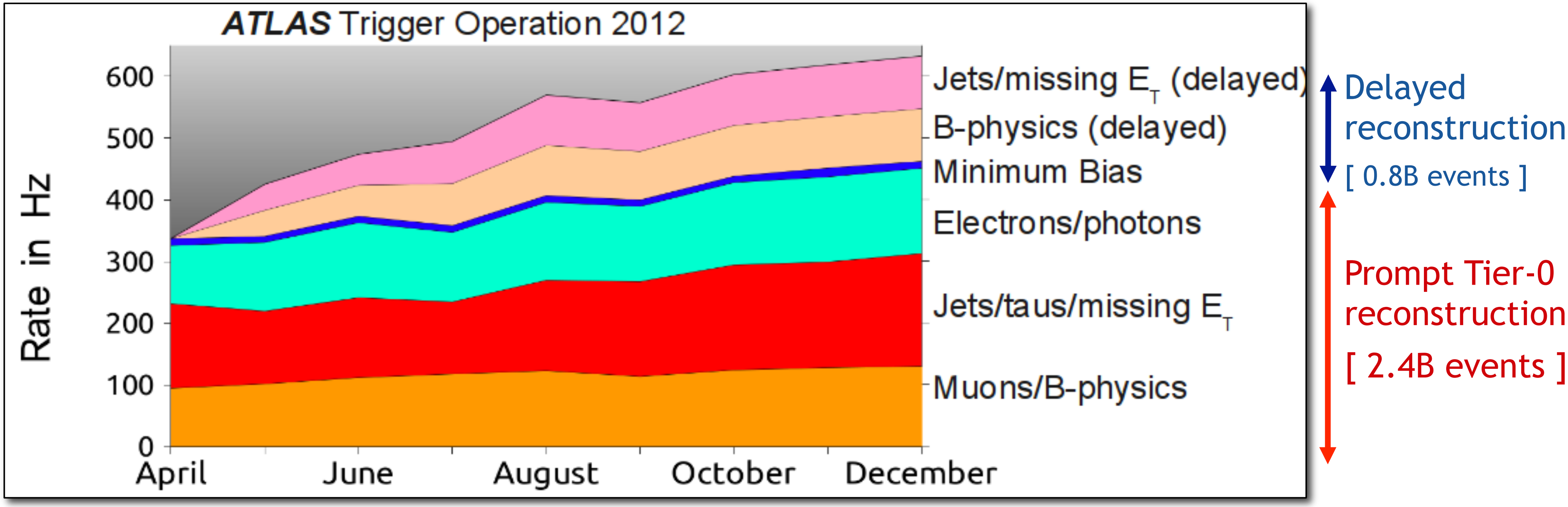
Run1 Highlights

23 fb^{-1} at $\sqrt{s}$=8 TeV

5.6 fb^{-1} at $\sqrt{s}$=7 TeV

0.05 fb^{-1} at $\sqrt{s}$=7 TeV

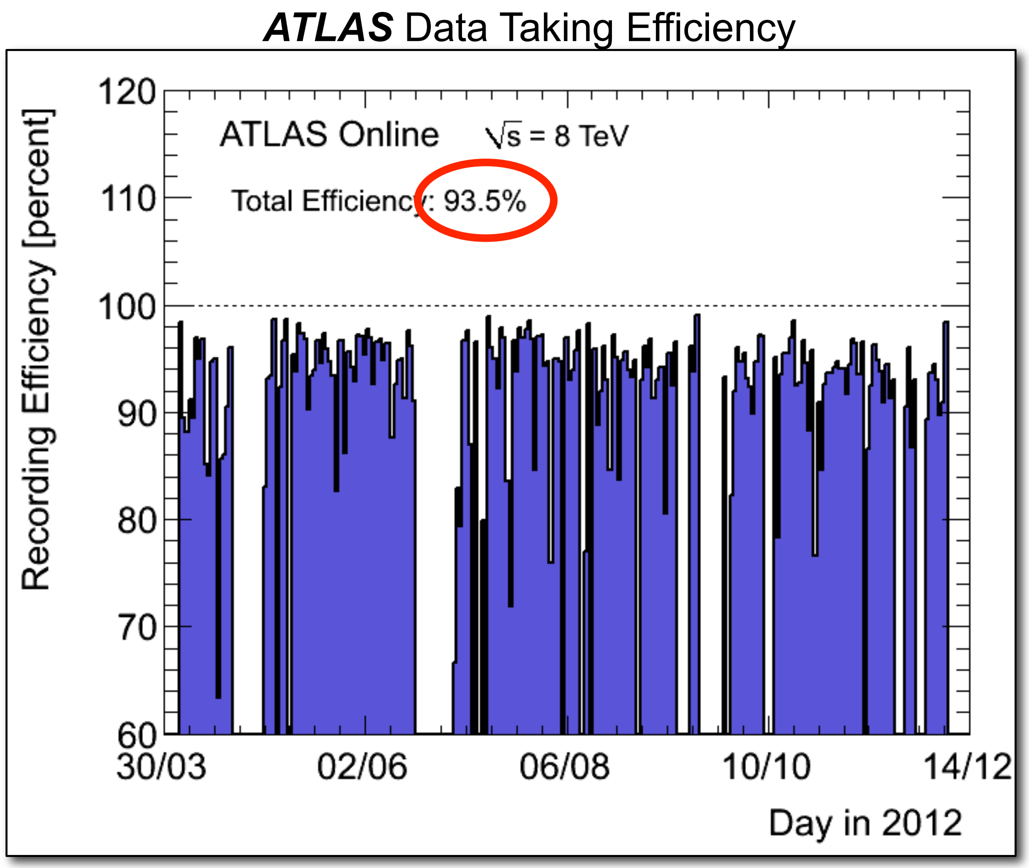
ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.4	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.8%										
Luminosity weighted relative detector uptime and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



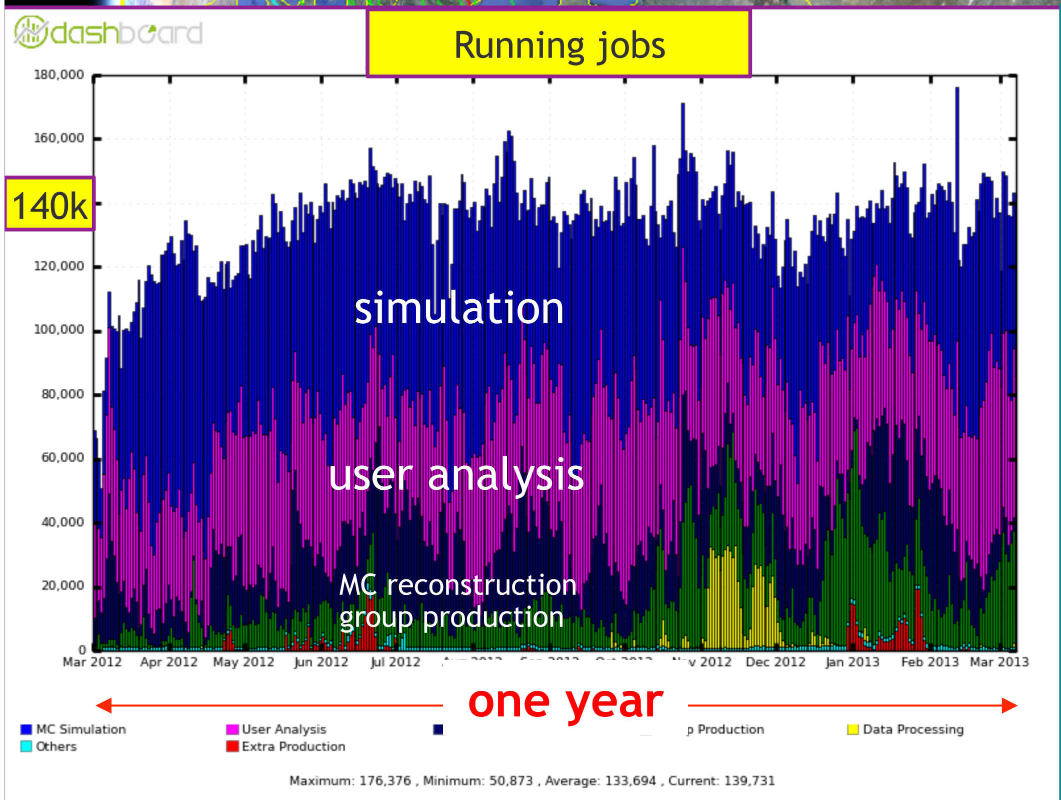
Run1 Highlights

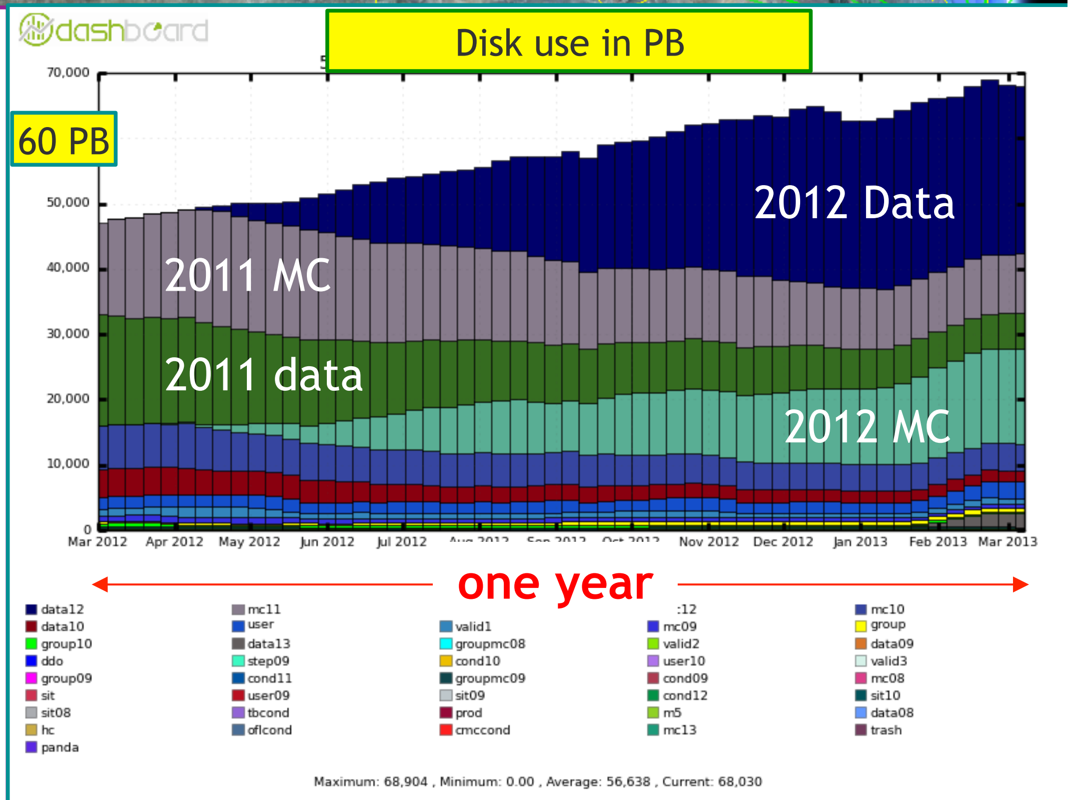
~400 Hz average rate in 2012 for prompt trigger streams (design ~ 200 Hz)

~90% of data delivered is used for analysis

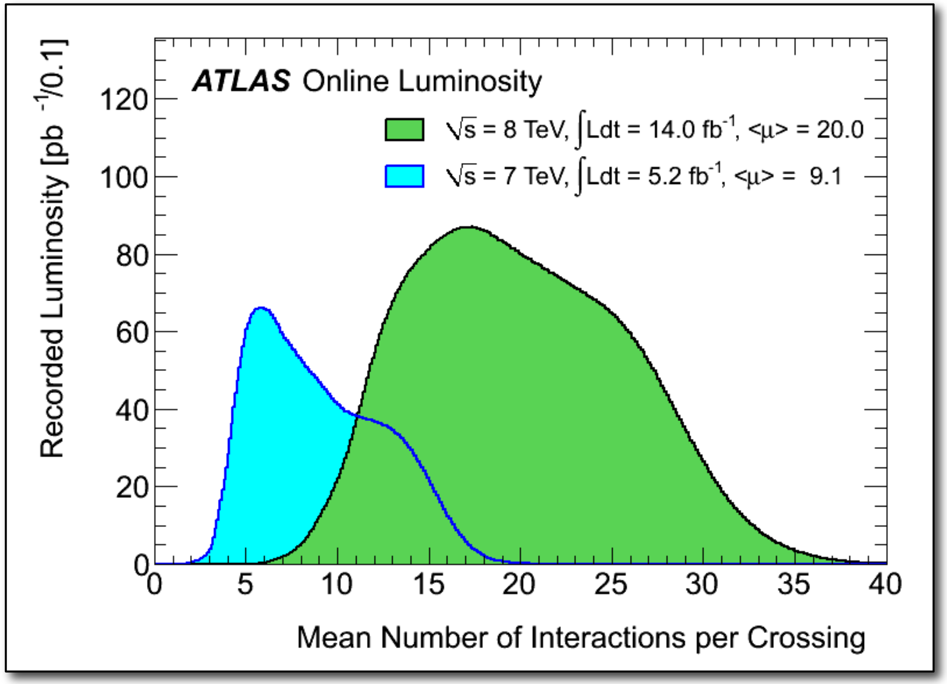


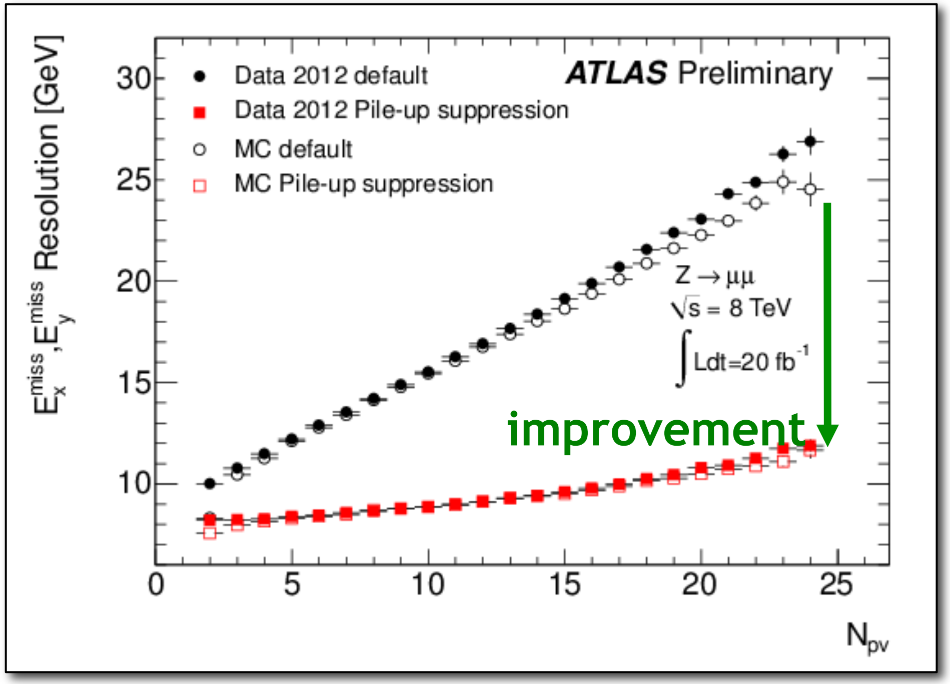

10/30/2012 6:10:31 pm
Running jobs: 243209
Transfer rate: 7.59 GiB/sec
Worldwide LHC Computing Grid
ATLAS uses 80 WLCG sites
Superb performance
Run1 Highlights

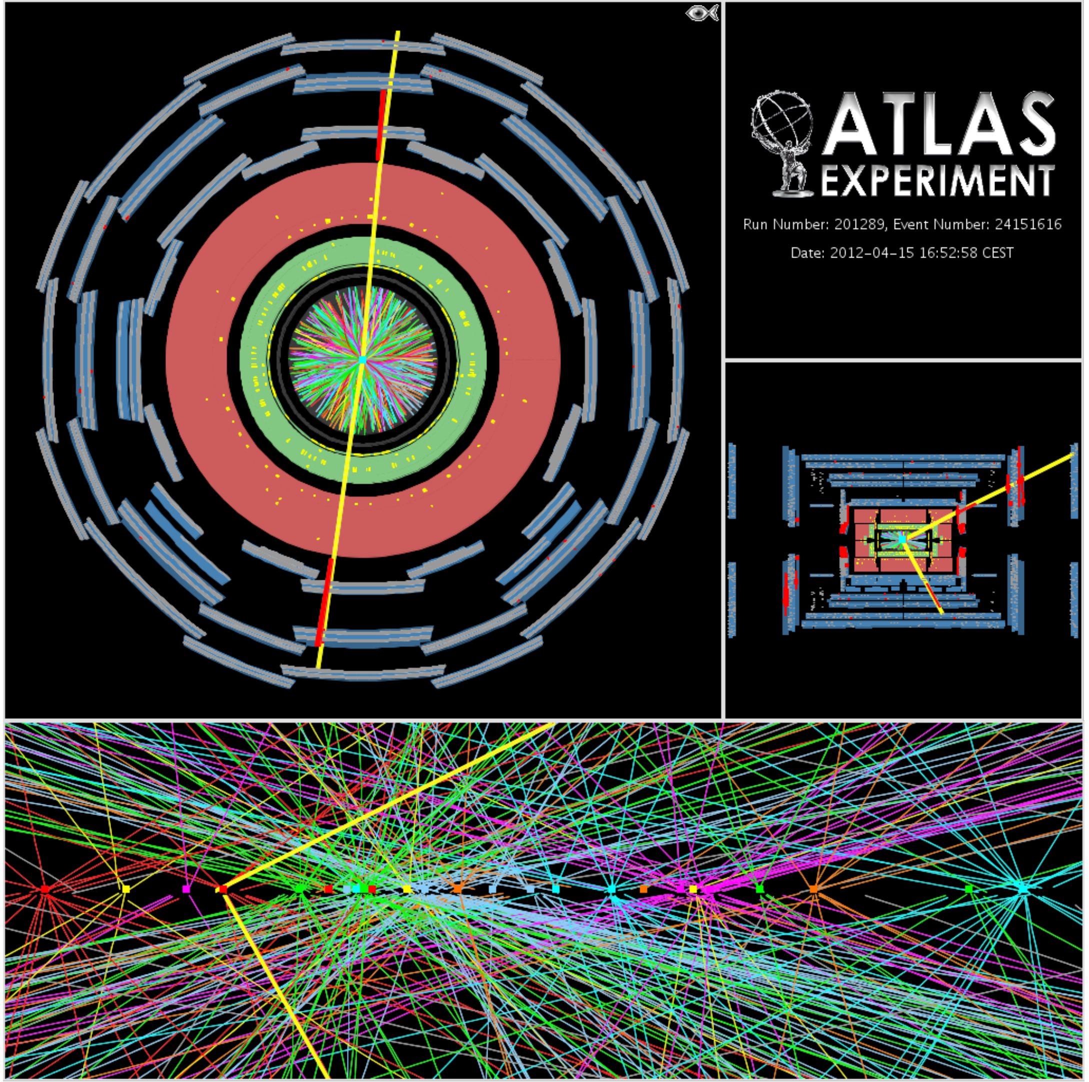

dashboard
Running jobs
140k
180,000
160,000
120,000
100,000
80,000
60,000
40,000
20,000
0
simulation
user analysis
MC reconstruction
group production
Mar 2012
Apr 2012
May 2012
Jun 2012
Jul 2012
Dec 2012
Jan 2013
Feb 2013
Mar 2013
one year
MC Simulation
Others
User Analysis
Extra Production
Data Processing
Maximum: 176,376 , Minimum: 50,873 , Average: 133,694 , Current: 139,731


dashboard
Disk use in PB
60 PB
70,000
50,000
40,000
30,000
20,000
10,000
0
2012 Data
2011 MC
2011 data
2012 MC
Mar 2012
Apr 2012
May 2012
Jun 2012
Jul 2012
Nov 2012
Dec 2012
Jan 2013
Feb 2013
Mar 2013
one year
data12
data10
group10
ddo
group09
sit
sit08
hc
panda
mc11
user
data13
step09
cond11
user09
tbcond
oflcond
valid1
groupmc08
cond10
groupmc09
sit09
prod
cmccond
mc09
valid2
user10
cond09
cond12
m5
mc13
mc10
group
data09
valid3
mc08
sit10
data08
trash
Maximum: 68,904 , Minimum: 0.00 , Average: 56,638 , Current: 68,030

Run1 Highlights







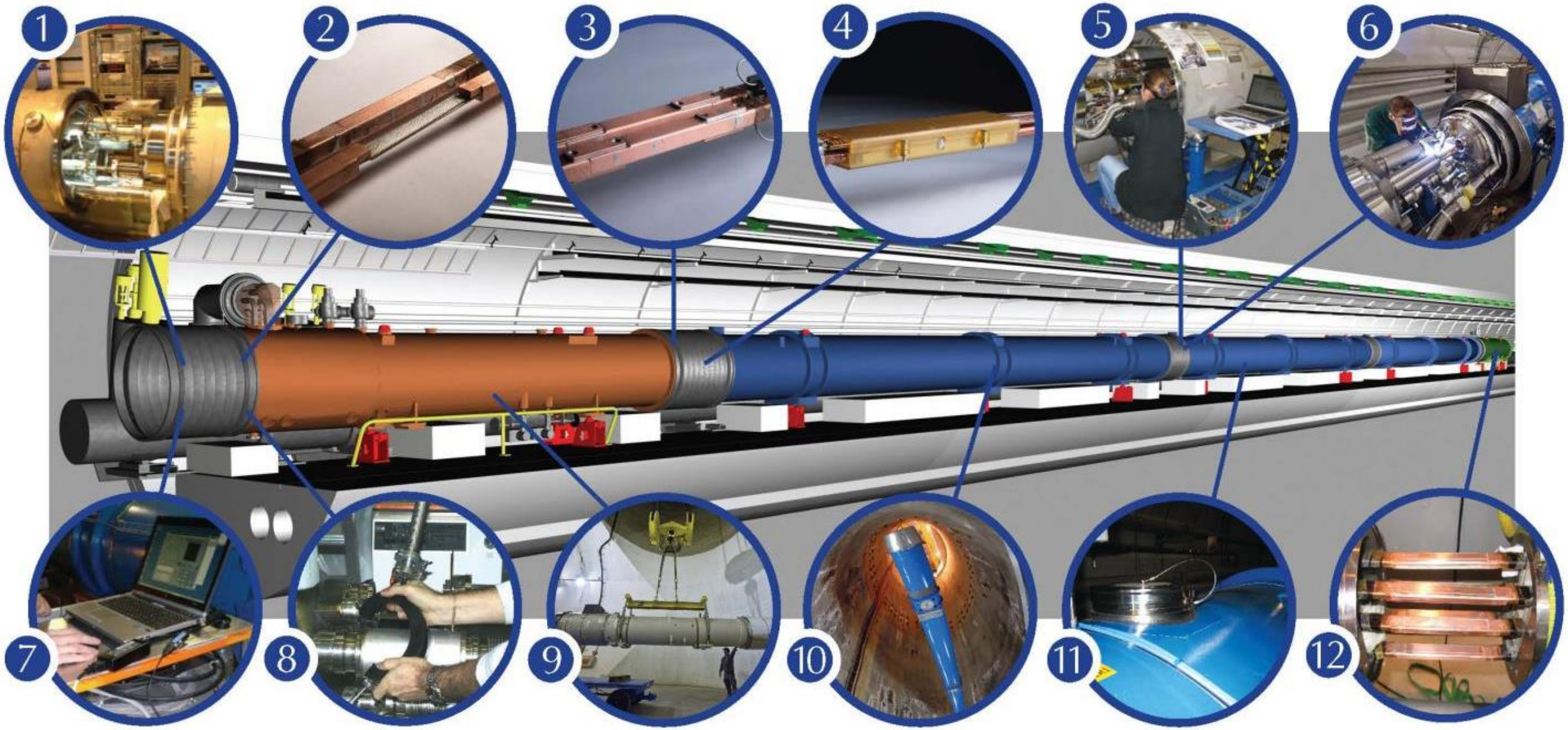
Pileup challenge:

Routinely reached 35 interactions per bunch crossing (design: $\lesssim$ 25)

With intense work and ingenuity, impact of pileup could be reduced impressively

The main 2013-14 LHC consolidations

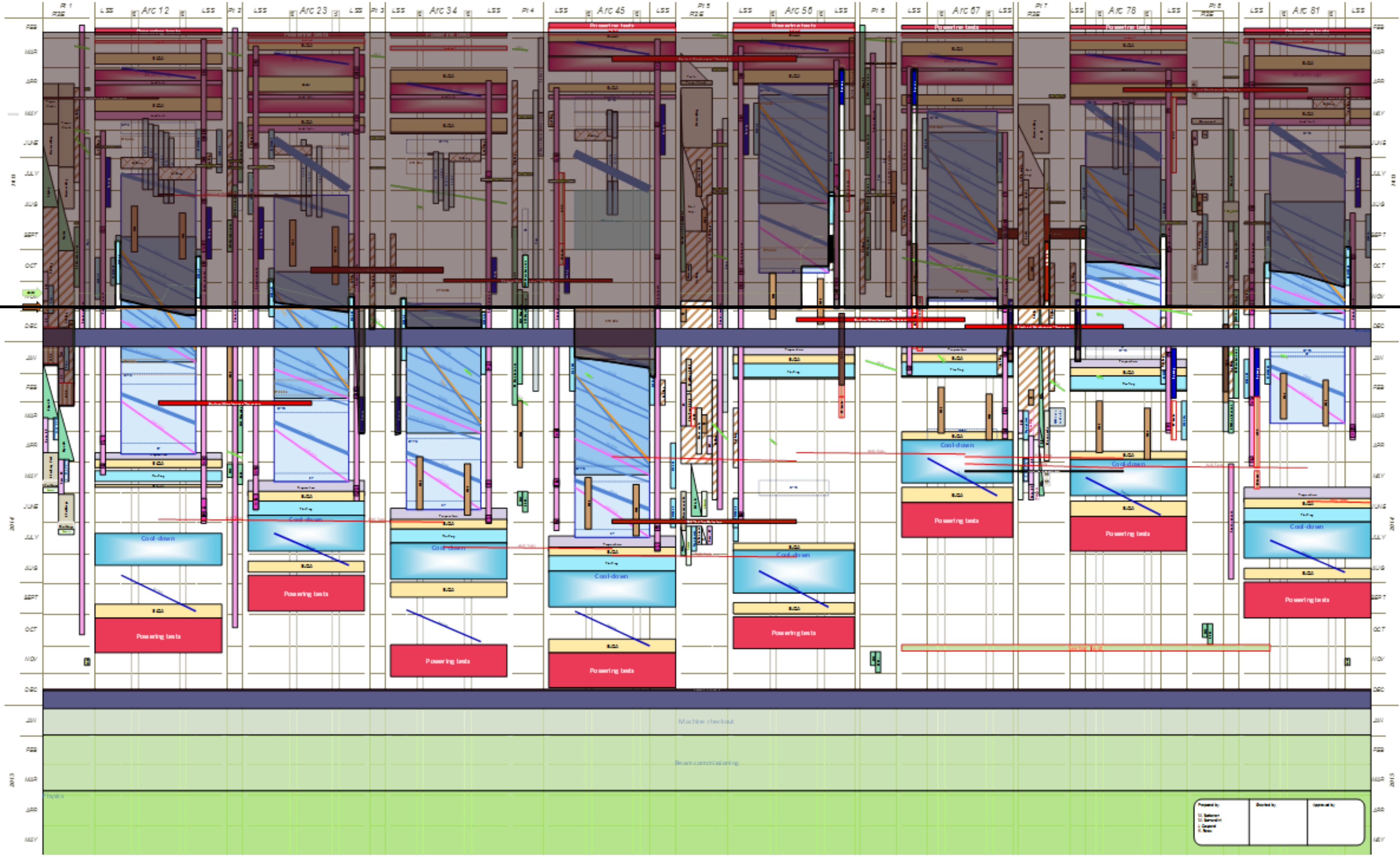
1. 1695 Openings and final reclosures of the interconnections
2. Complete reconstruction of ~~1500~~ 3000 of these splices
3. Consolidation of the 10170 13kA splices, installing 27 000 shunts
4. Installation of 5000 consolidated electrical insulation systems
5. 300 000 electrical resistance measurements
6. 10170 orbital welding of stainless steel lines



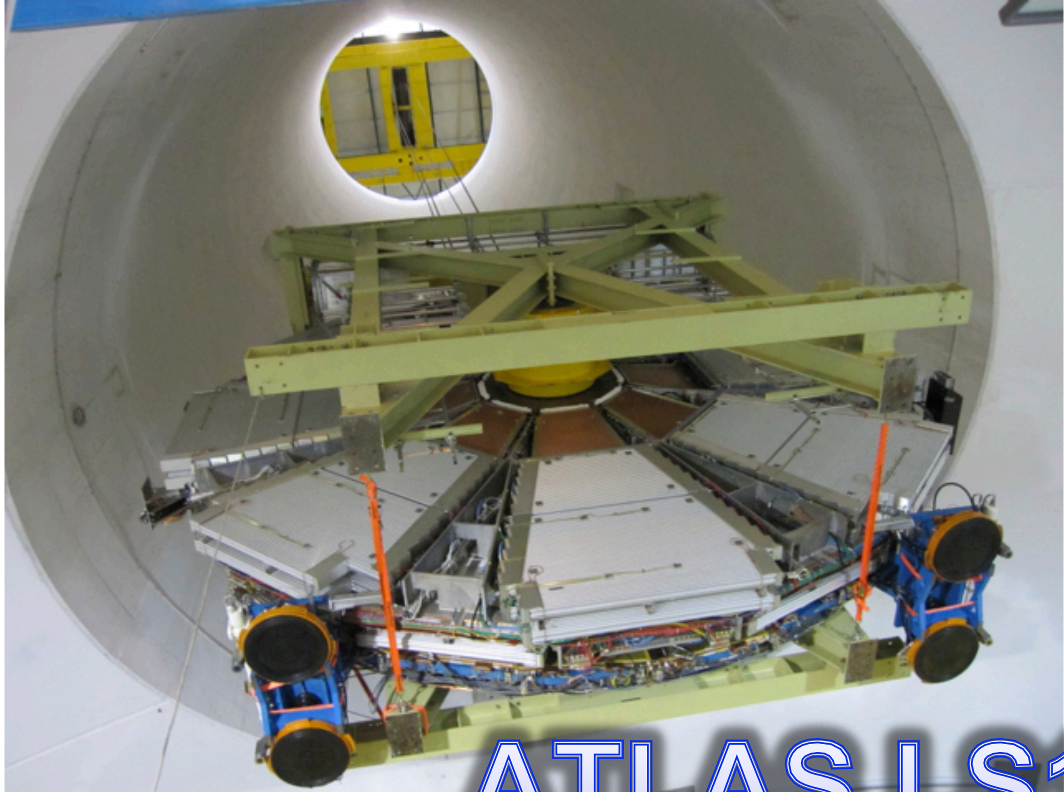
7. 18 000 electrical Quality Assurance tests
8. 10170 leak tightness tests
9. 4 quadrupole magnets to be replaced
10. 15 dipole magnets to be replaced
11. Installation of 612 pressure relief devices to bring the total to 1344
12. Consolidation of the 13 kA circuits in the 16 main electrical feedboxes

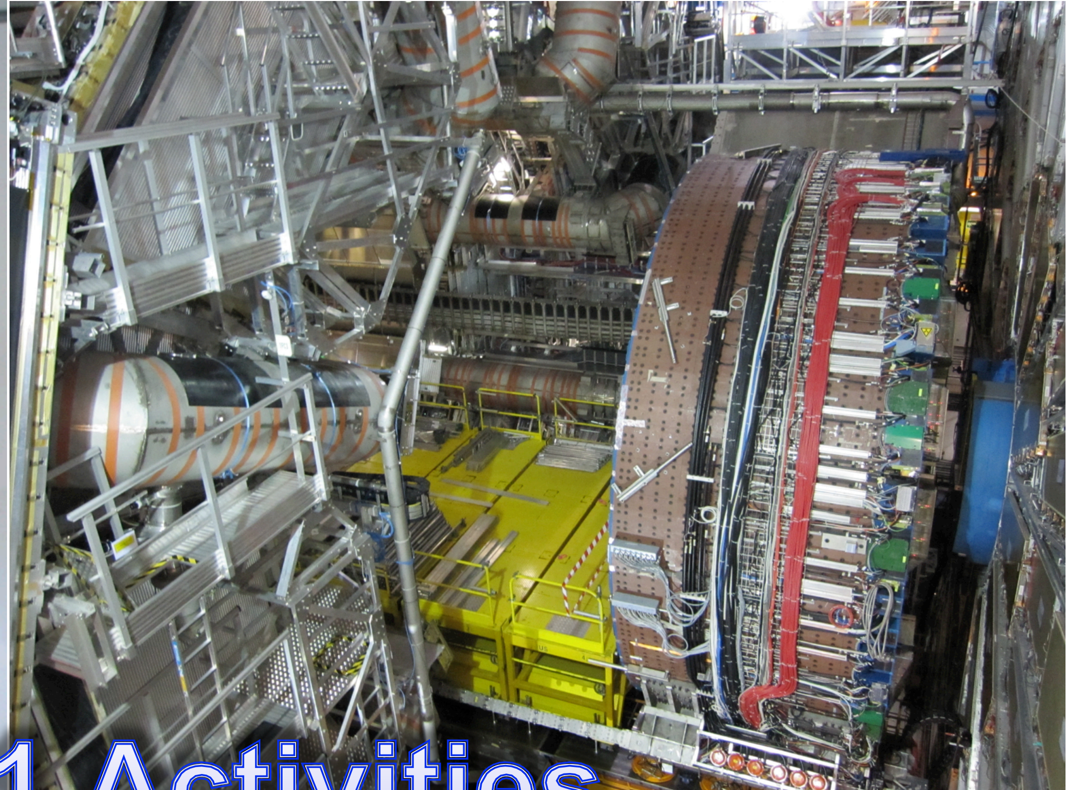
Conclusion

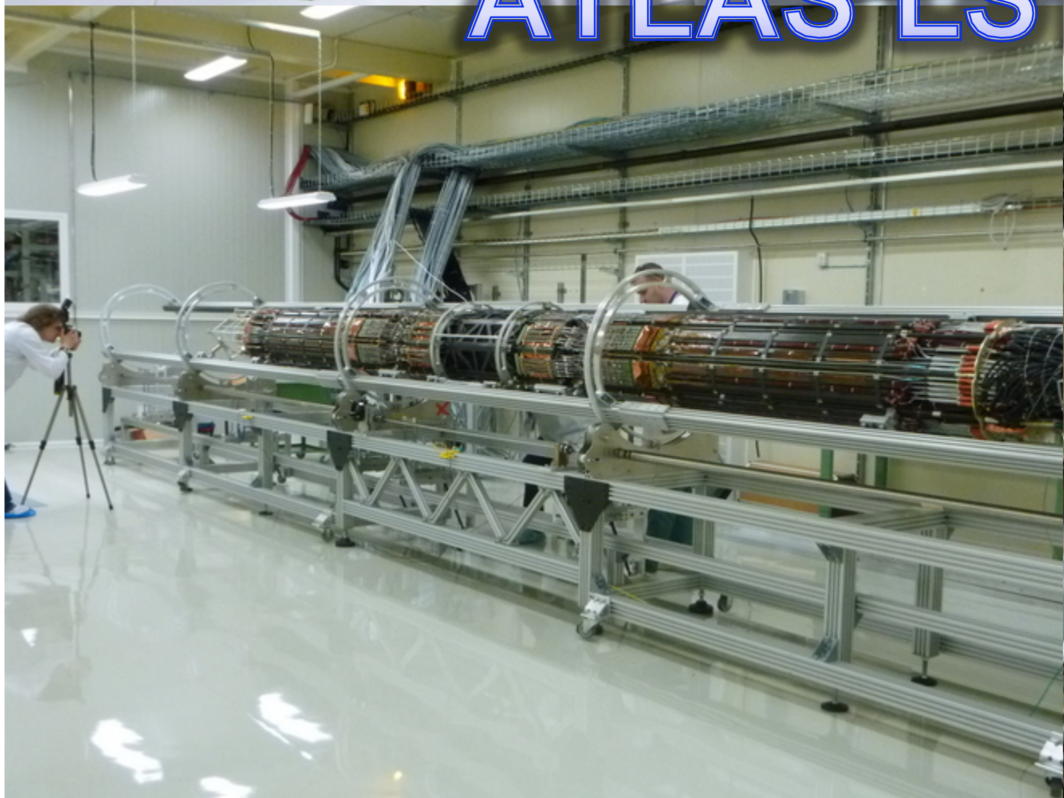
So far, LS1 is on schedule for beams in January 2015 for LHC

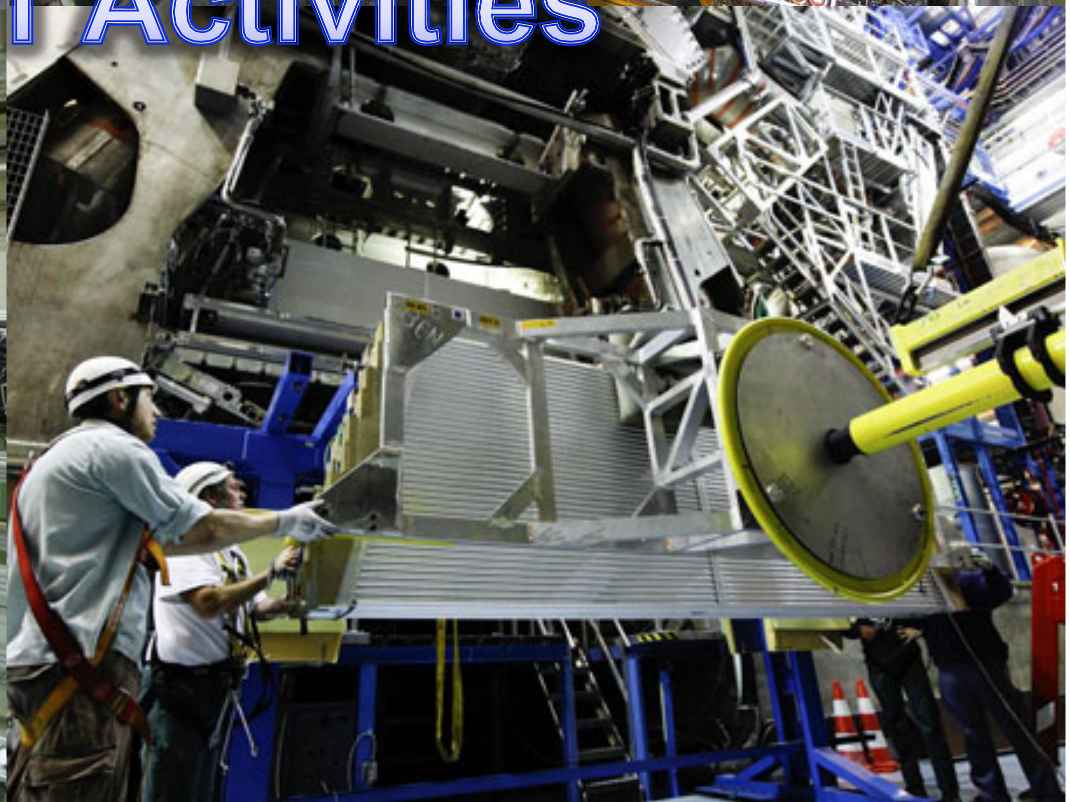


ATLAS LS1 Activities









ATLAS LS1 Activities

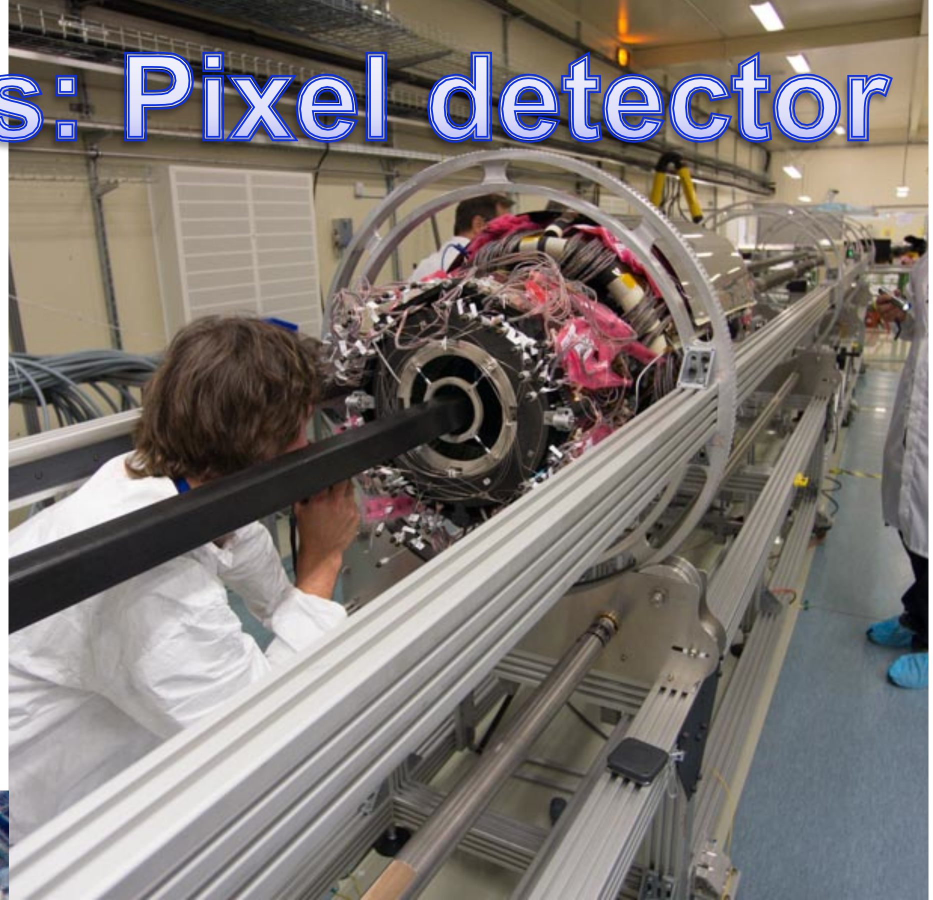
2013: focus on maintenance and consolidation of infrastructure & detector systems, and the installation of a few new systems

Detailed schedule with >250 work packages

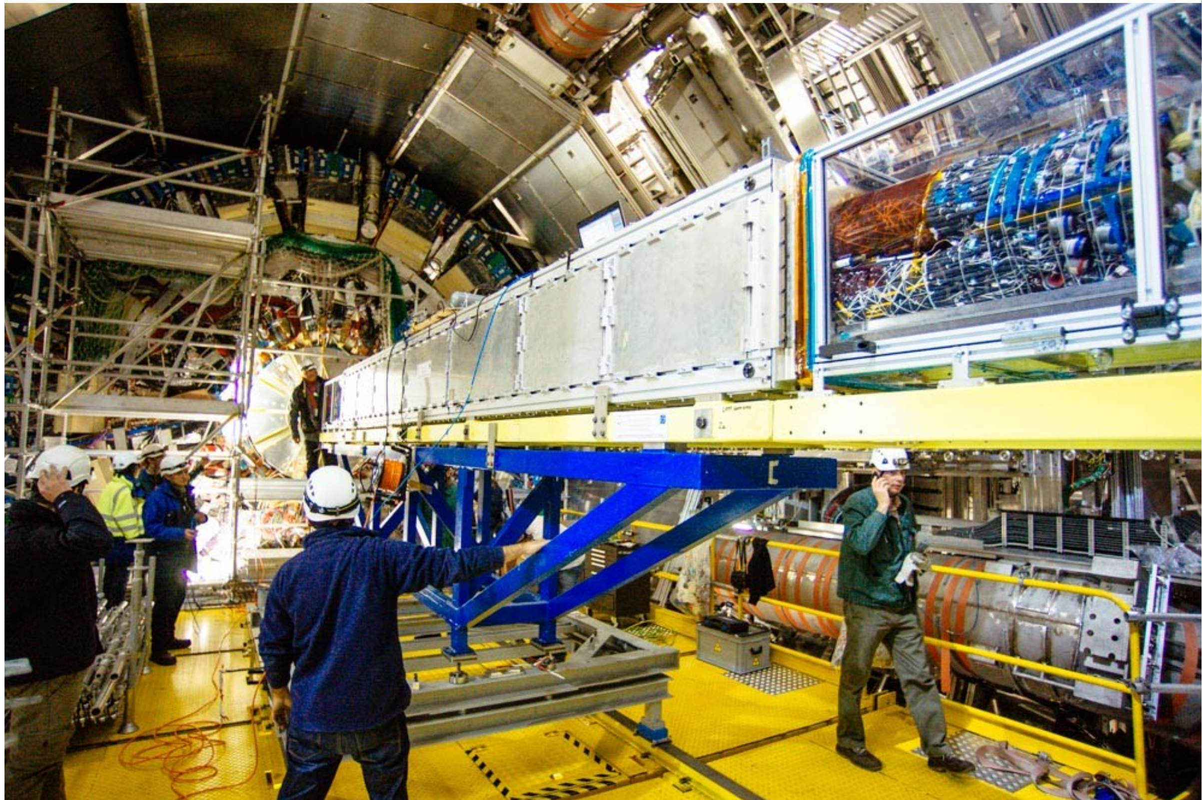
- New Al beam pipes, replacing SS pipes
- Magnet Cryogenics consolidation
- UPS to prevent down time in case of power glitches
- Thermo-siphon for the Inner Detector cooling system
- New Pixel services
- Insertable B-Layer (IBL): 4th pixel layer
- Tile & LAr calorimeter power supplies
- Tilecal readout drawers
- Gas leaks repair: TRT, RPCs
- Installation of MDT EE chambers
- TGC chamber substitution
- CSC chambers repair
- …

2014: focus on re-commissioning to be fully operational when the LHC resumes colliding beams in early 2015

ATLAS LS1 Activities: Pixel detector



- ✓ Pixel detector brought to new radiation lab on the surface – fortunately, activation was less than expected
- ✓ Old beam pipe removed
- ✓ Inner Support Tube (IST) for IBL inserted
- ✓ Old services removed, replaced with new Service Quarter Panels (nSQP), allowing upgrade to higher readout bandwidth

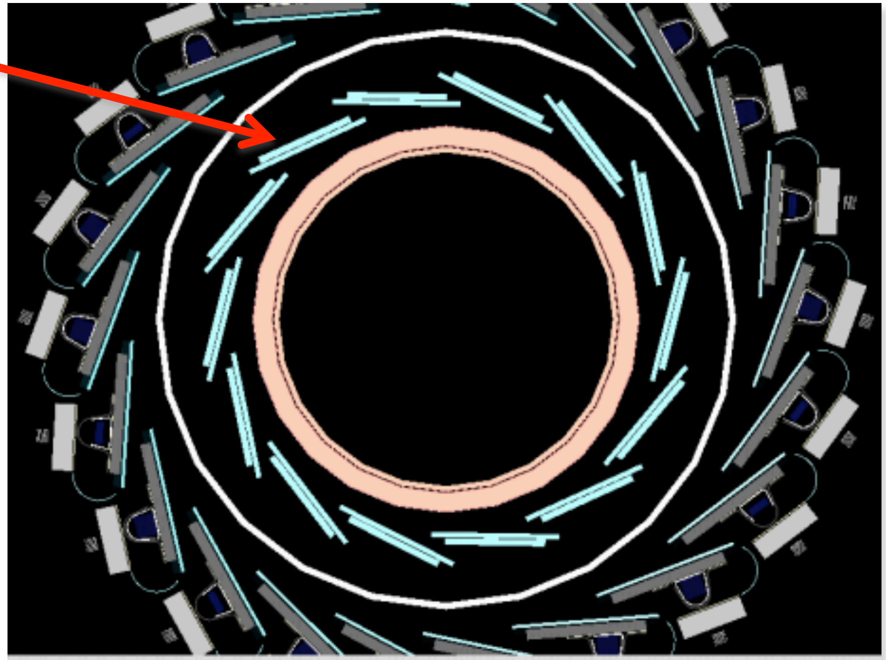


- ✓ Diamond Beam Monitor (DBM) consisting of 8 Telescopes installed (6 Diamond + 2 Si)
- ✓ Consolidated Pixel detector fully tested and re-installed in ATLAS
- ➢ **Operational fraction back to 99% (was 95% at end of Run-1 :-)**

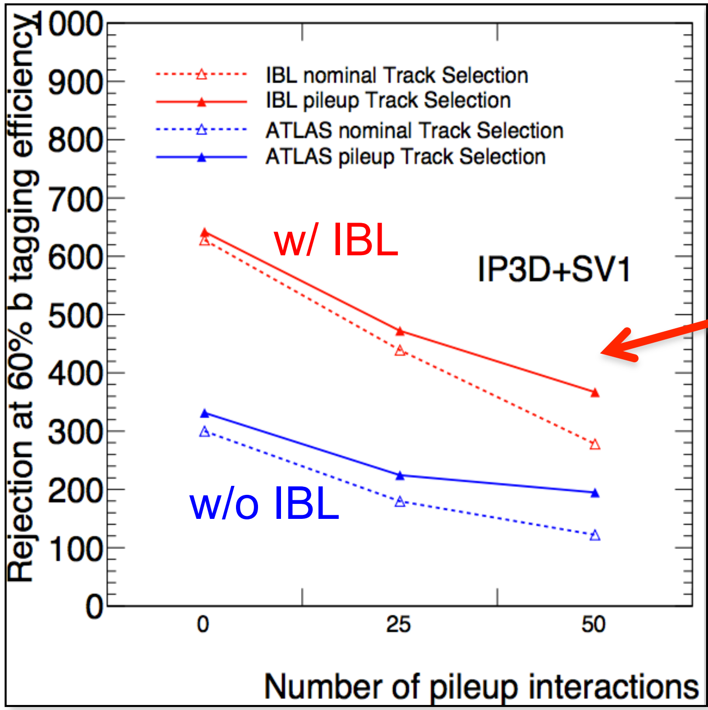
ATLAS LS1 Activities: IBL

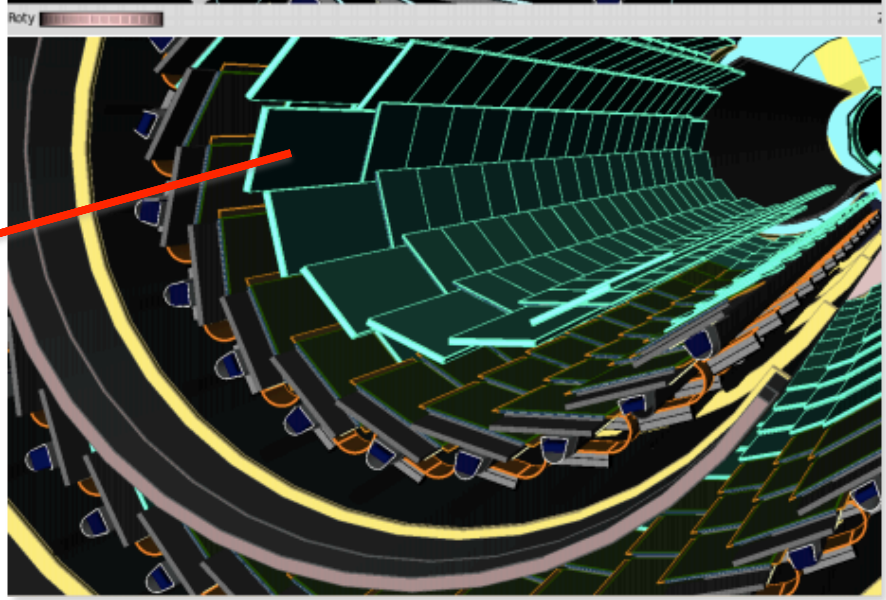
Insertable B-Layer

- New, 4th Pixel layer, mounted on new beam pipe
- Recent setback due to moisture causing wire bond corrosion
  - ➢ aggressive recovery plan implemented
- Installation in May 2014 (baseline)
- Tight schedule

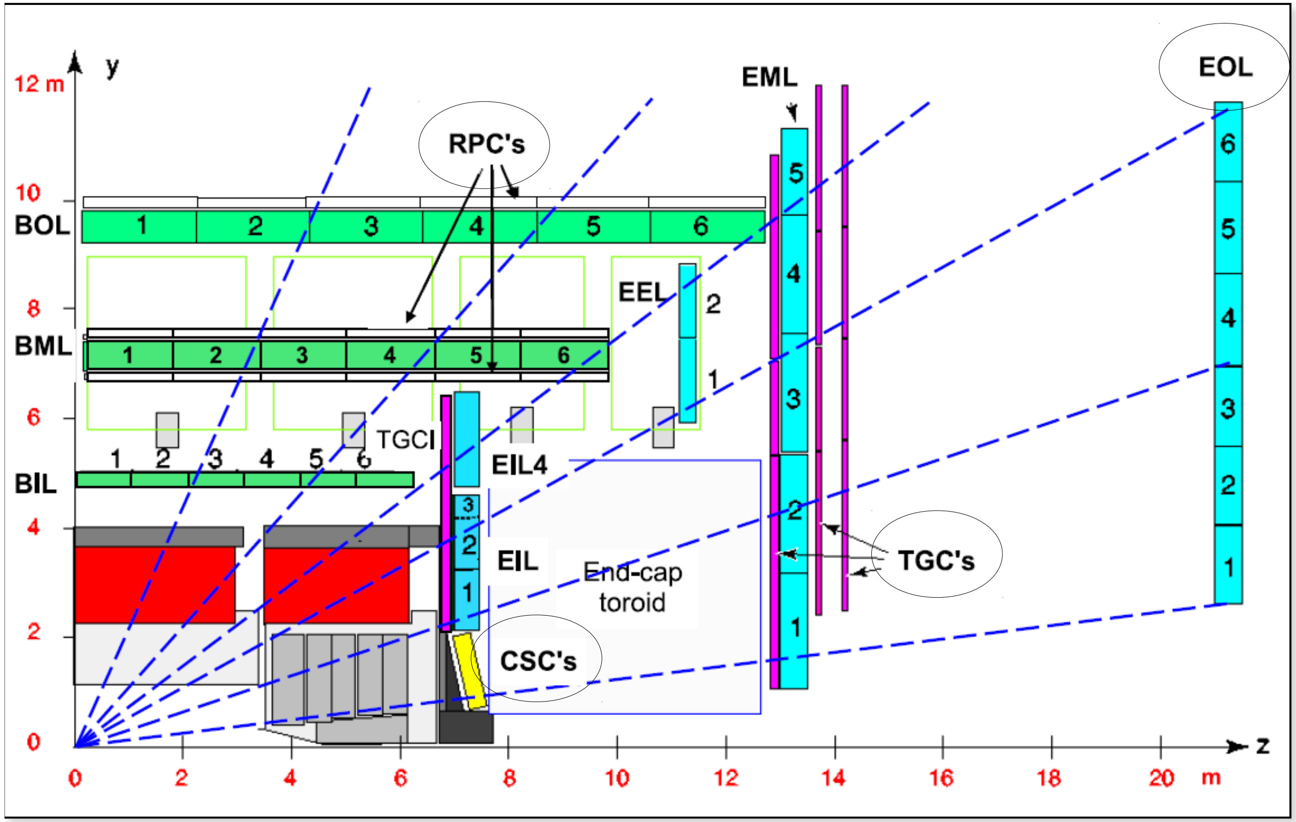


b-tagging rejection vs pileup





ATLAS LS1 Activities: Muon spectrometer



MDT: gas leak repairs on EO (Endcap Outer) chambers

RPC: ongoing leak fixing campaign, repair/replacement of gas inlets

TGC: replacing 29 of 1578 chambers; fixing readout to eliminate risk of getting stuck in "busy" state

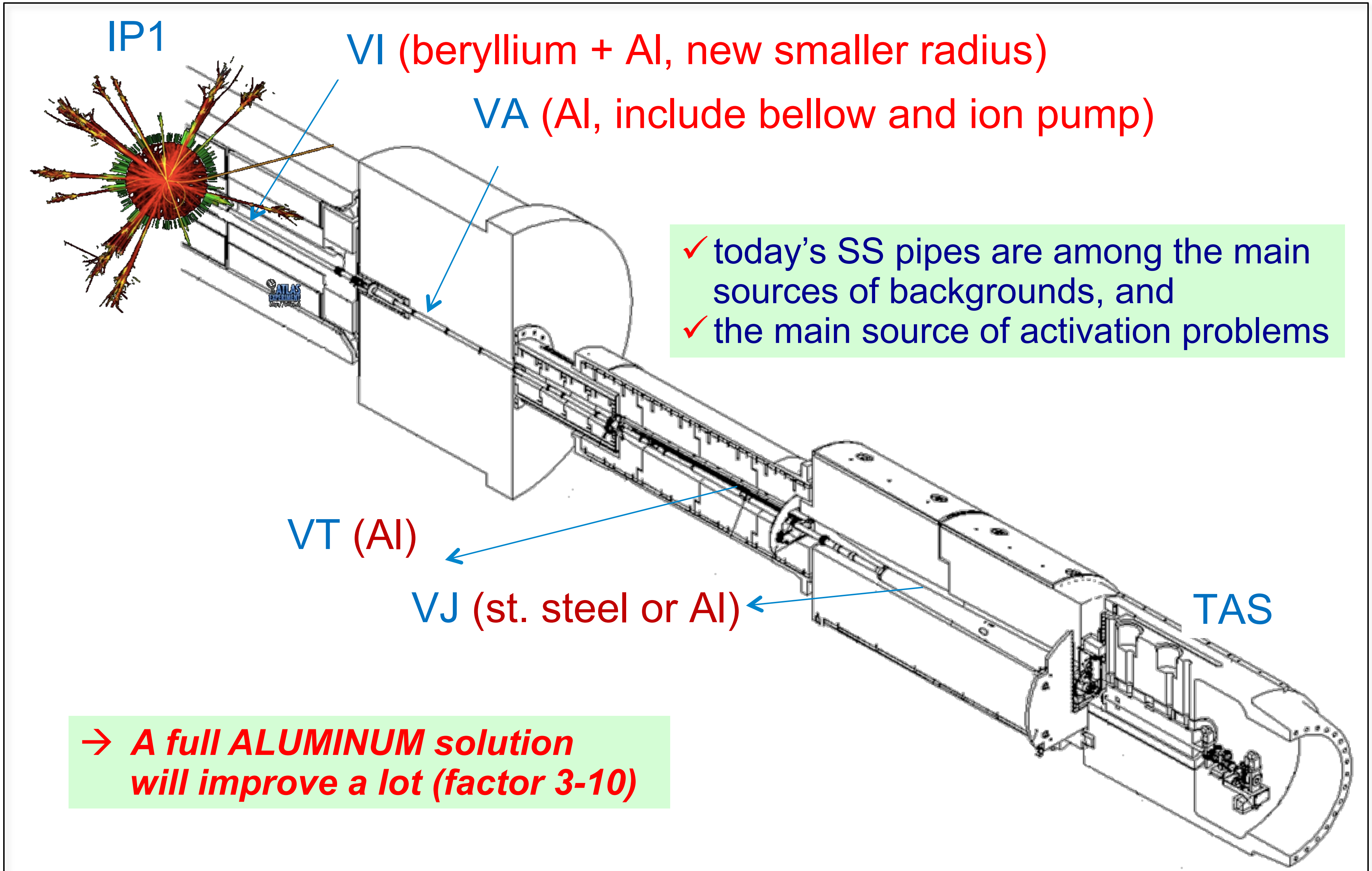
CSC: two chambers of the Small Wheel on surface repaired and re-installed

New installations: closing holes in acceptance

- EE chamber installation completed
- BOE/BME "Elevator" chambers

Alignment: sensor installation to link BEE chambers to the rest of the endcaps

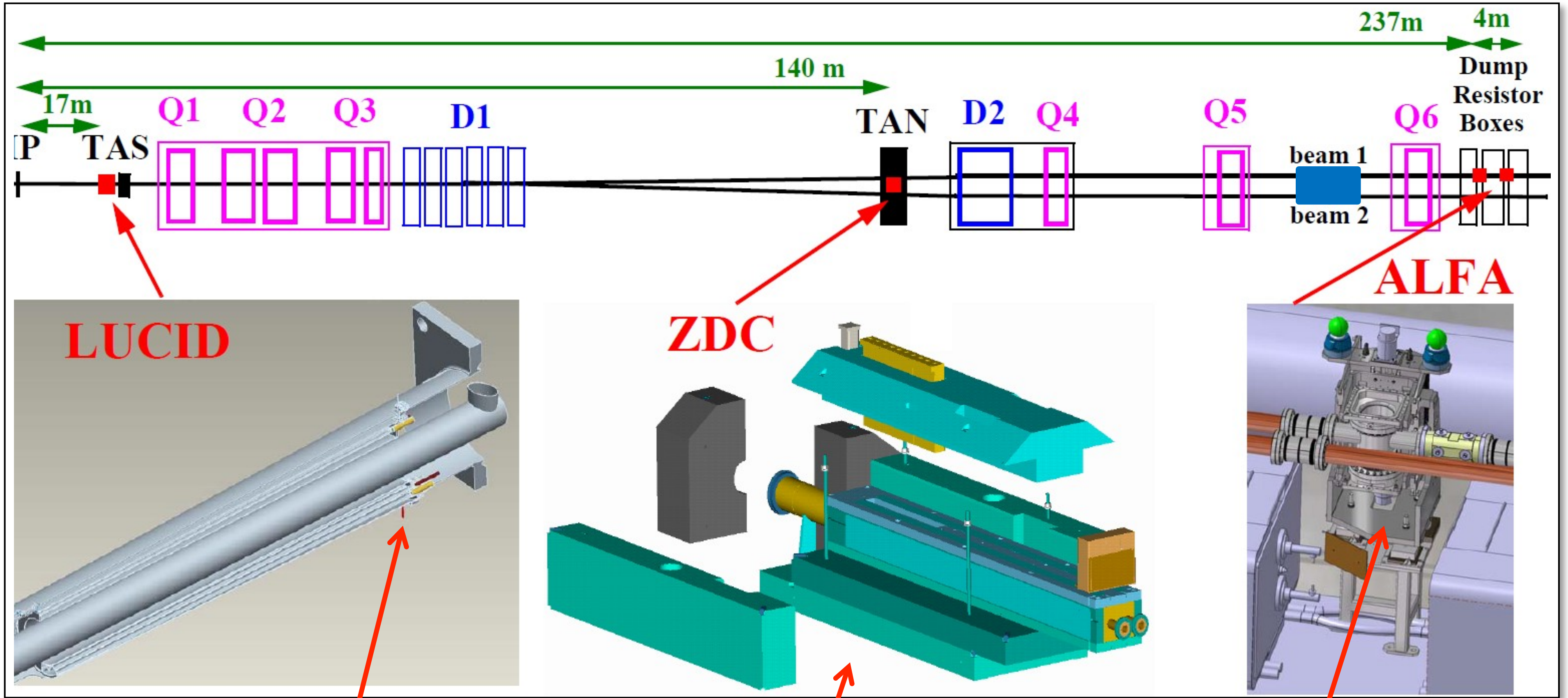
ATLAS LS1 Activities: New beam pipes



- ✓ today's SS pipes are among the main sources of backgrounds, and
- ✓ the main source of activation problems

→ ***A full ALUMINUM solution will improve a lot (factor 3-10)***

ATLAS LS1 Activities: Forward Detectors



New photomultipliers to reduce acceptance / avoid saturation

Quartz fibers suffered radiation damage upgrade under discussion

Reduce beam-induced (RF) heating with Roman Pot “fillers”

ATLAS LS1 Activities: Trigger

Level-1 Trigger upgrade:

(ATLAS-TDR-023 / CERN-LHCC-2013-018)

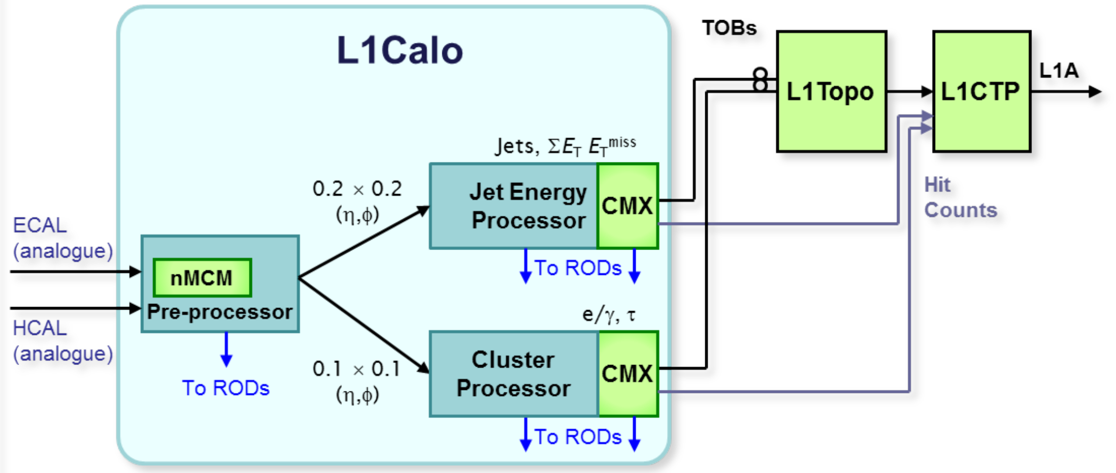


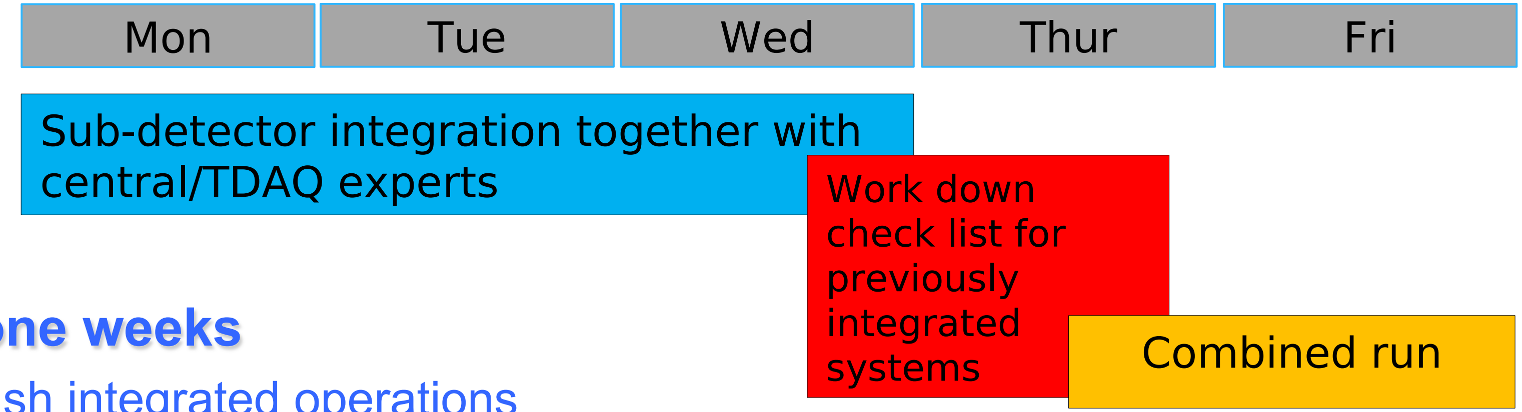
Figure 18: System Architecture during Run 2. New components are shown in green.

- New L1-Calo pre-processor modules (**nMCMs**) provide 80 MHz digitisation, lower noise and greater flexibility to handle pileup.
- The new **L1-Topo** processor allows real-time event selection based on the geometrical relationship between trigger objects, such as the angles between E_t^{miss} and jets

HLT Trigger:

- significant speed increases (>3x) achieved in several areas
- more use of offline algorithms to cope with pileup increase

ATLAS LS1 Activities: Preparations for Run-2



Milestone weeks

reestablish integrated operations with all systems and sub-detectors

- ~every 6 weeks starting in spring 2014
- Test sub-detector migration to new software and TDAQ release
- Validate combined data taking functionalities
  - configuration, state transitions, data taking recovery, high-rate stress tests, …
- Triggers
  - random triggers in first M-weeks,
  - switching to cosmic-ray triggers later
- Walk-through check-lists for all systems
  - DAQ, DCS, Expert system, Shifter Assistant rules, Data Quality

M-weeks will also be used to re-commission offline activities in 2014:

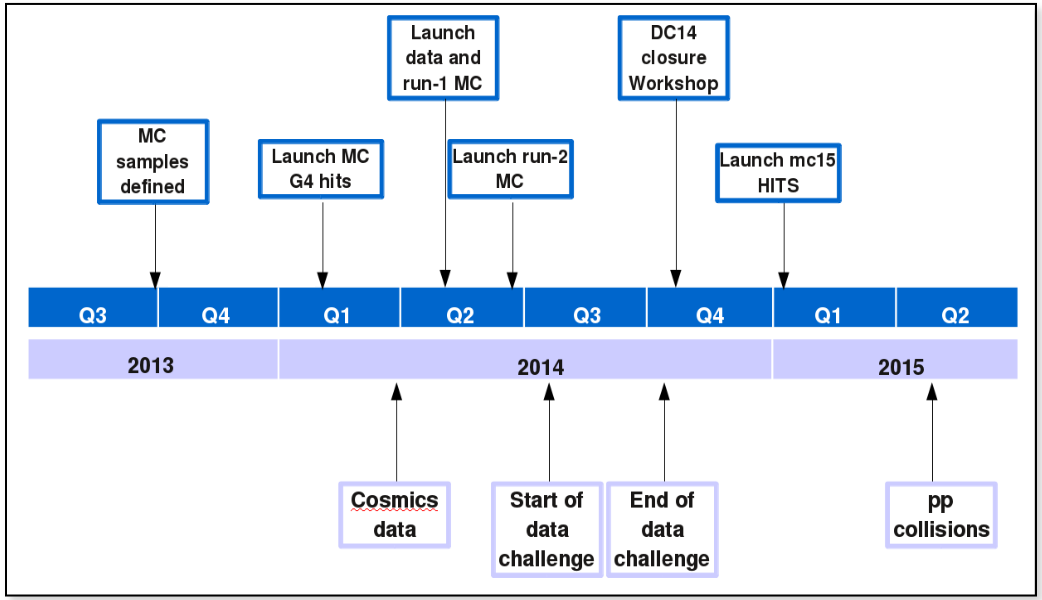
- Tier-0 operations, calibration loop, alignment, detector conditions, offline data quality
- Test and integrate offline s/w related to new detector components (e.g. IBL)

ATLAS LS1 Activities: Offline preparations for Run-2

Extensive work programme and improvements for Run-2:

- New analysis model with easier access to ATLAS data and faster turn-around
  - New Event Data Model
  - New Derivation framework
  - New Analysis framework
- New simulation framework
  - Integrated Simulation Framework (ISF)
  - Improved fast simulation
  - New Geant4 version
- New reconstruction software
  - CLHEP → Eigen migration
  - (Auto)-vectorization
  - Framework support for parallel processing
  - New/improved objects reonstruction
  - Track reconstruction optimised for IBL
- Tuning for 25ns bunch spacing
  - Analysis of 25ns data collected in 2012
  - Adjust calibrations and verify detector and physics performance

Data challenge 2014 (DC14)



- Re-test and validate the full chain of simulation and reconstruction software
  - MC production with run-1 conditions & reprocessing of a part of run-1 data
  - MC production with run-2 conditions
  - Exercise calibrations and representative analyses from combined performance and physics groups

LHC schedule beyond LS1

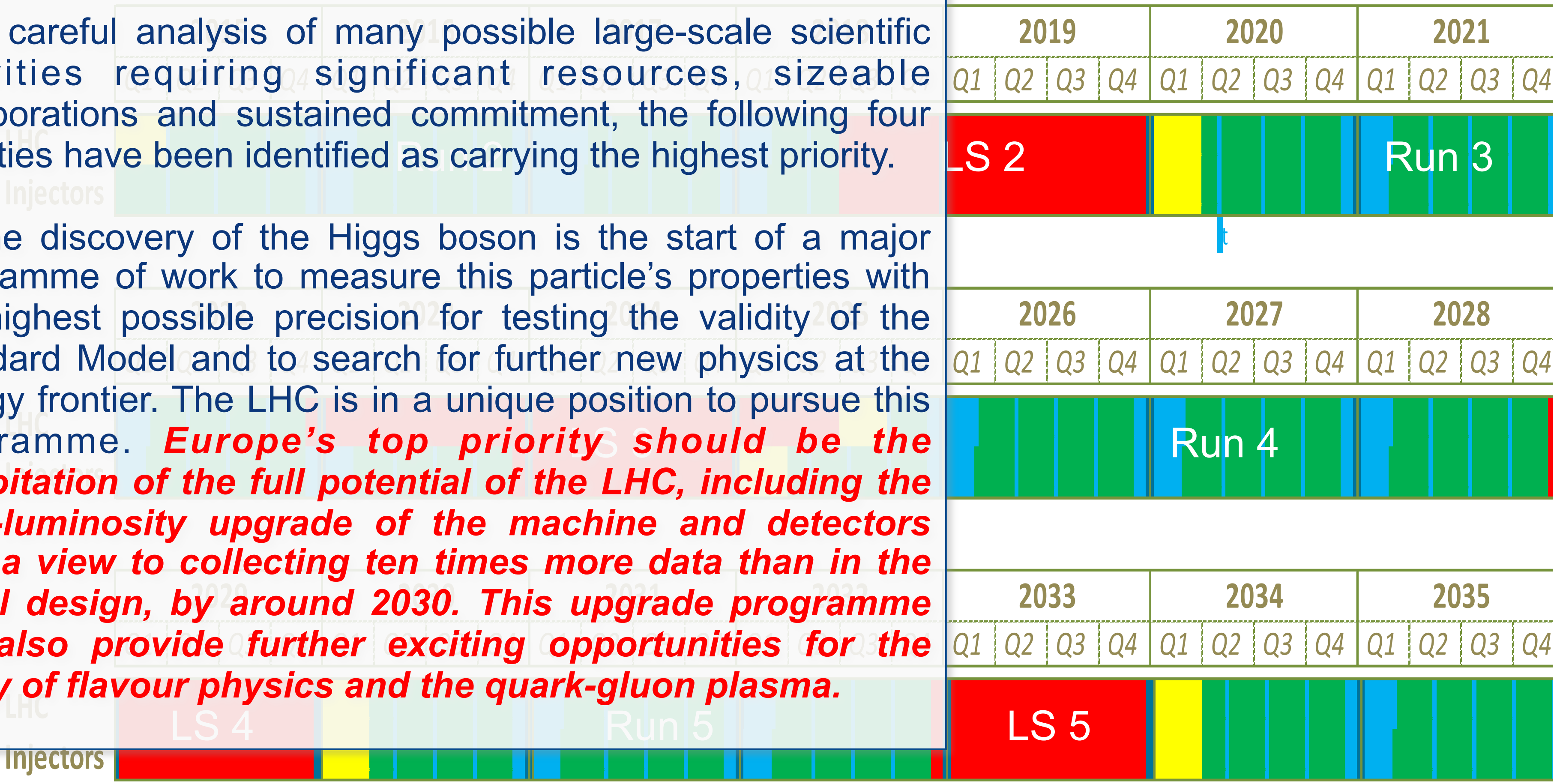
Only EYETS (19 weeks) (no Linac4 connection during Run2)
LS2 starting in 2018 (July) => 18 months + 3months BC (Beam Commissioning)
LS3 LHC: starting in 2023 => 30 months + 3 BC
injectors: in 2024 => 13 months + 3 BC

The European Strategy for Particle Physics – Update 2013

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. ***Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma.***



New LHC schedule
02/12/2013

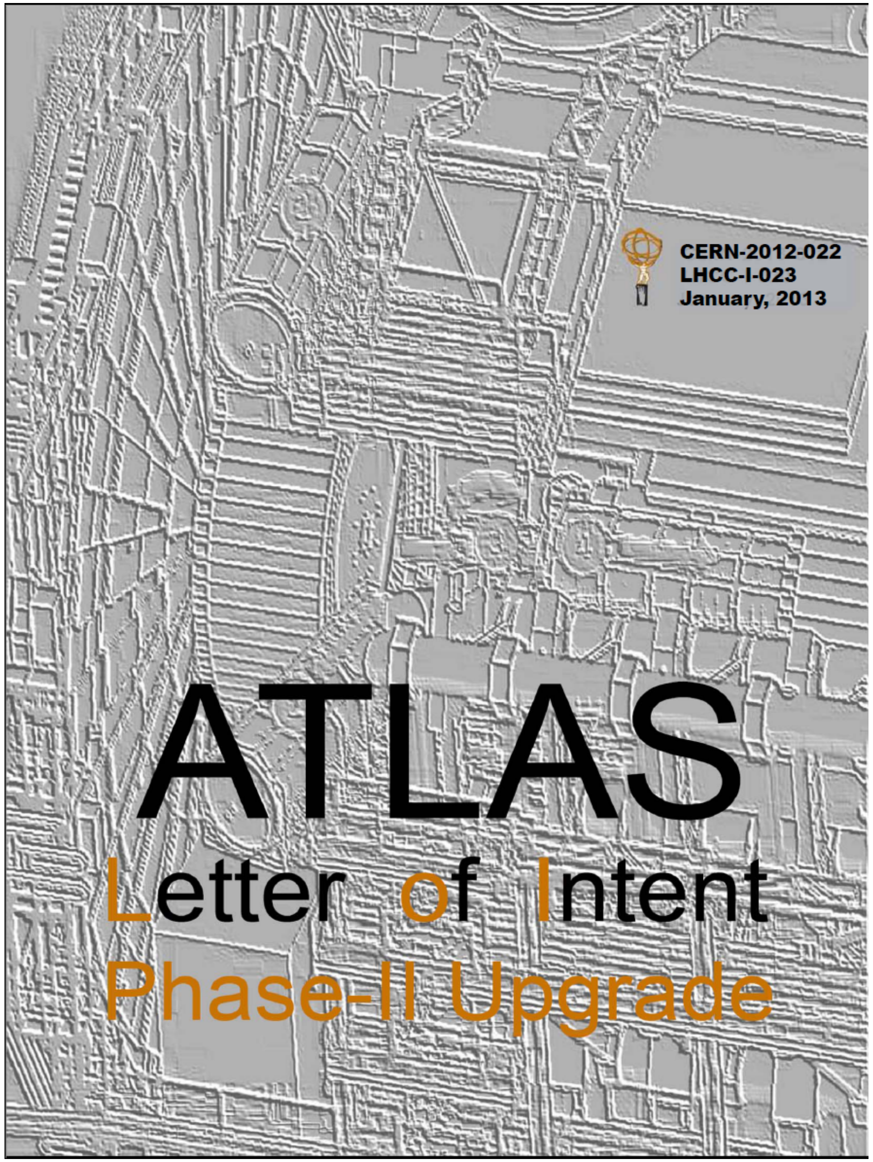
LHC ROADMAP

			pileup	Integrated luminosity
2009		✧ LHC startup, $\sqrt{s}$ = 900 GeV		
2010–2012	Run-1	$\sqrt{s}$=7~8 TeV, L=6x10^{33} cm^{-2} s^{-1}, bunch spacing 50 ns	μ < 40	~20-25 fb^{-1}
2013–2014	LS1	Go to design energy, nominal luminosity (**Phase-0**)		
2015–2018	Run-2	$\sqrt{s}$=13~14 TeV, L~1x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns	μ < 40	~75-100 fb^{-1}
2019	LS2	Injector and LHC **Phase-1** upgrade to full design luminosity		
2020–2022	Run-3	$\sqrt{s}$=14 TeV, L~2x10^{34} cm^{-2} s^{-1}, bunch spacing 25 ns	μ < 80	~350 fb^{-1}
2023–2025	LS3	HL-LHC **Phase-2** upgrade, IR, crab cavities?		
2026–2027	HL LHC	$\sqrt{s}$=14 TeV, L=5x10^{34} cm^{-2} s^{-1}, luminosity leveling	μ ~ 140 μ < 200	~3000 fb^{-1}

The ATLAS Upgrade Programme

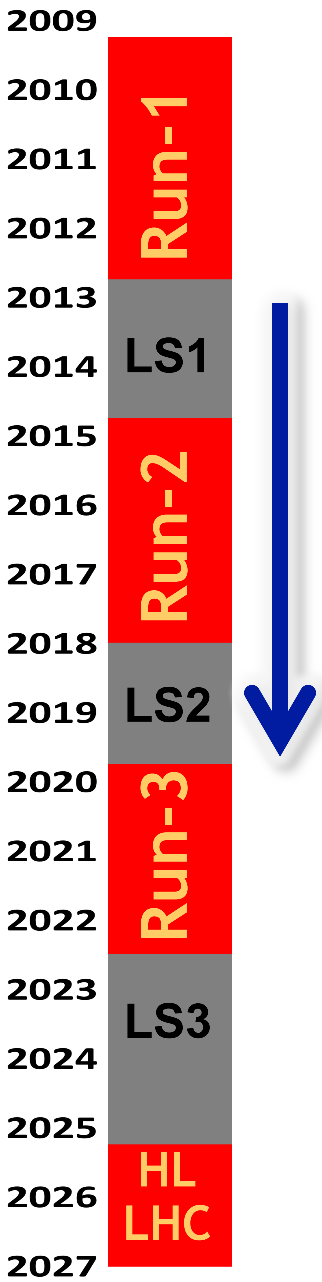
TDRs approved by LHCC last year:

- New Small Wheel
- Fast Track Trigger
- Trigger/DAQ
- LAr Trigger



ATLAS Upgrade Plan

New LHC schedule
02/12/2013



Phase-1

Improve L1 Trigger capabilities to cope with higher rates

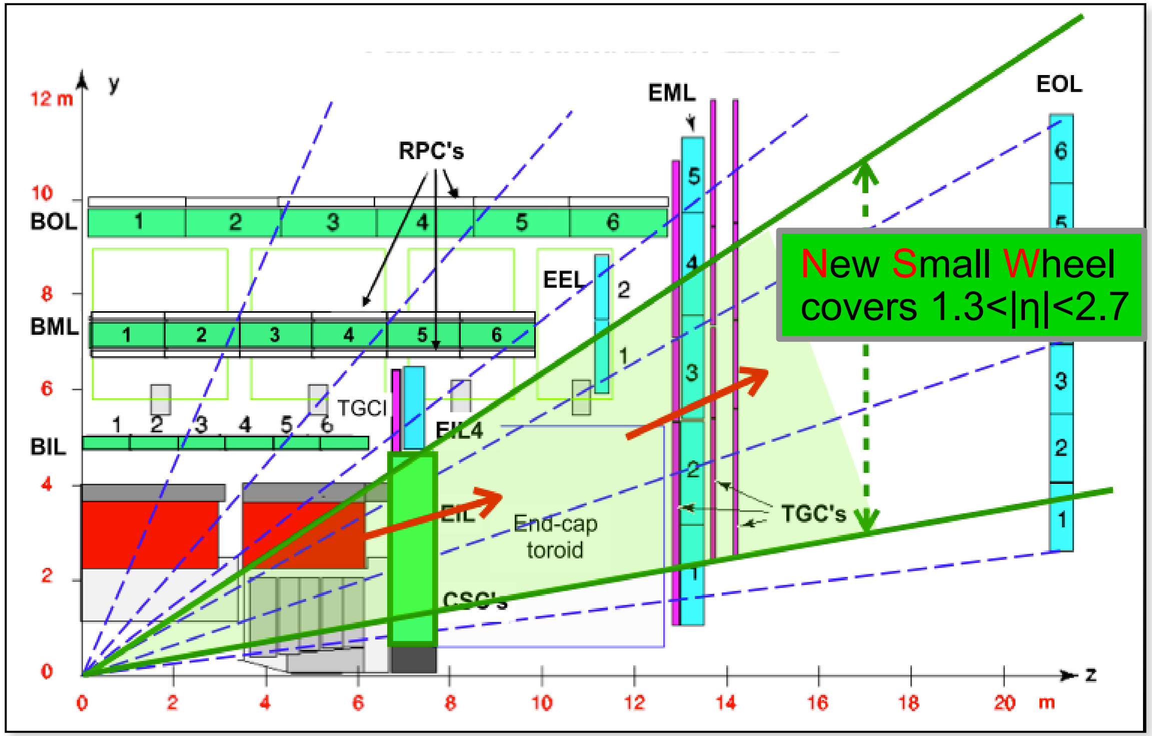
ultimate run-3 luminosity
L_{inst} ≈2-3 x10^{34} $cm^{-2}s^{-1}$ (μ≈55-81)
$\int L_{inst} \gtrsim$ 350 fb^{-1}

- 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
- Other Trigger and DAQ upgrades, e.g. Muon Trigger interface (MuCTPI)
- Under review:
  ATLAS Forward Physics (AFP), proton det. at ±210 m

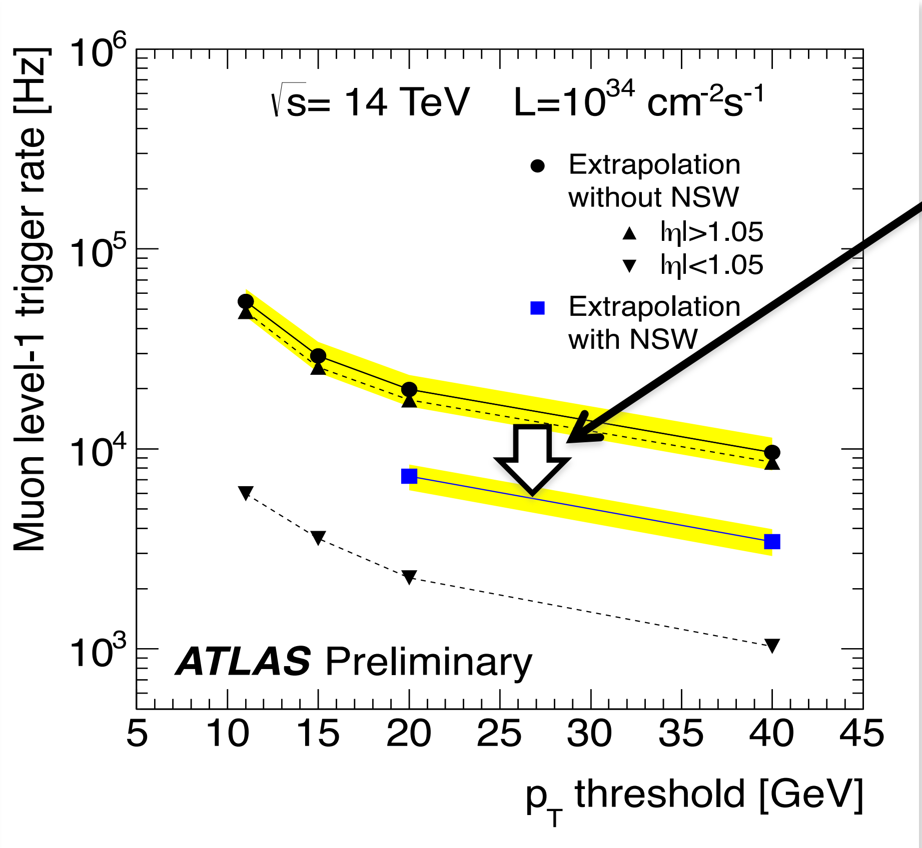
Muons: New Small Wheel

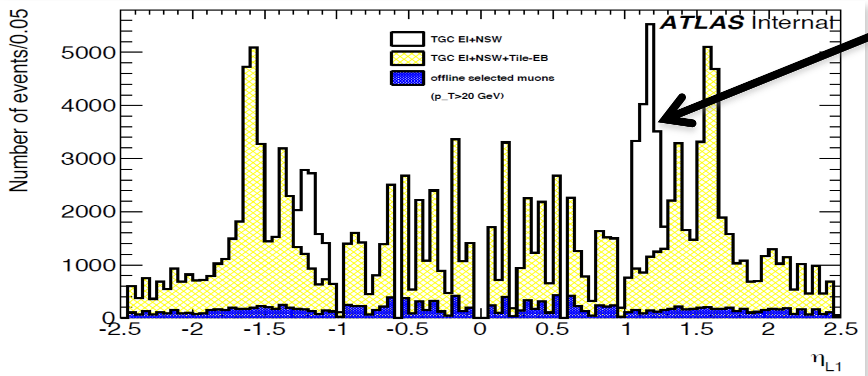
- Consequences of luminosity rising beyond design values for forward muon wheels
  - degradation of the tracking performance (efficiency / resolution)
  - L1 muon trigger bandwidth exceeded unless thresholds are raised

- Replace Muon Small Wheels with **N**ew Muon **S**mall **W**heels
  - improved tracking and trigger capabilities
  - position resolution < 100 μm
  - IP-pointing segment in NSW with σ_θ~ 1 mrad
  - Meets Phase-II requirements
    - ✓ compatible with <μ>=200, up to L~7x10^{34} cm^{-2}s^{-1}
  - Technology: MicroMegas and sTGCs



Muons: New Small Wheel cont.





- Strong reduction of muon L1 trigger rate in forward direction
  - Dominated by fakes
- Vital for running at high luminostiy
- In addition smaller improvements during phase-0
  - Additional muon chambers in barrel/end-cap overlap region
  - Coincidences with outer layers of Tile Calorimeter removes peak of muon fakes

Level-1 calorimeter trigger

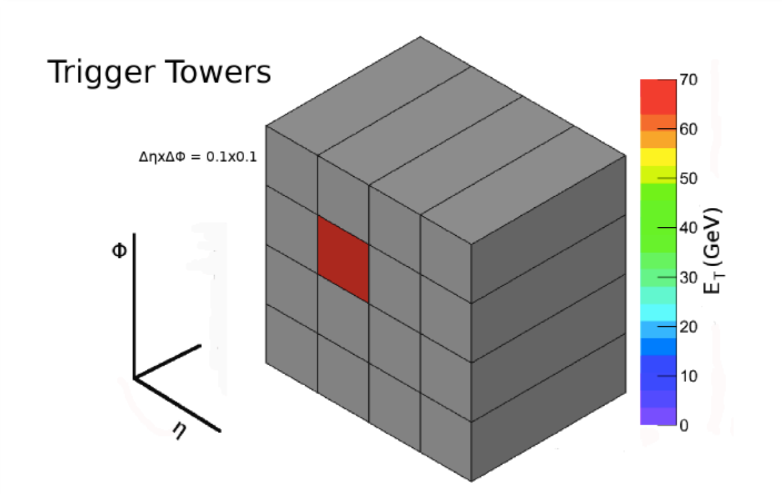
Run-1 calorimeter trigger input:
Trigger Towers $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$

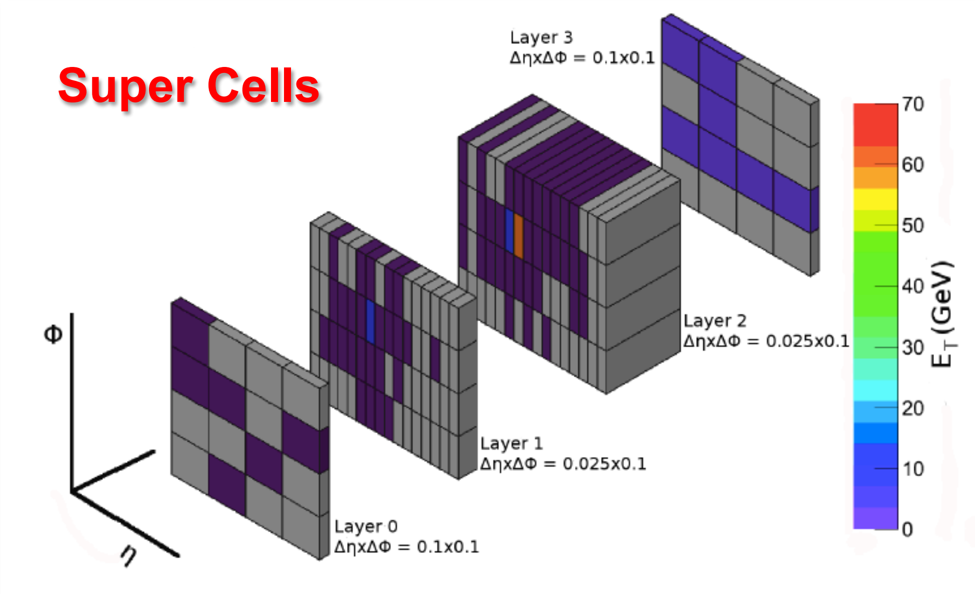
Used to calculate core energy, isolation

maintain low thresholds at an acceptable rate

↑

better granularity
better energy resolution





(b)

Run-1 trigger menu
at $L_{inst}=3 \times 10^{34}$ cm^{-2}s^{-1}

⇓

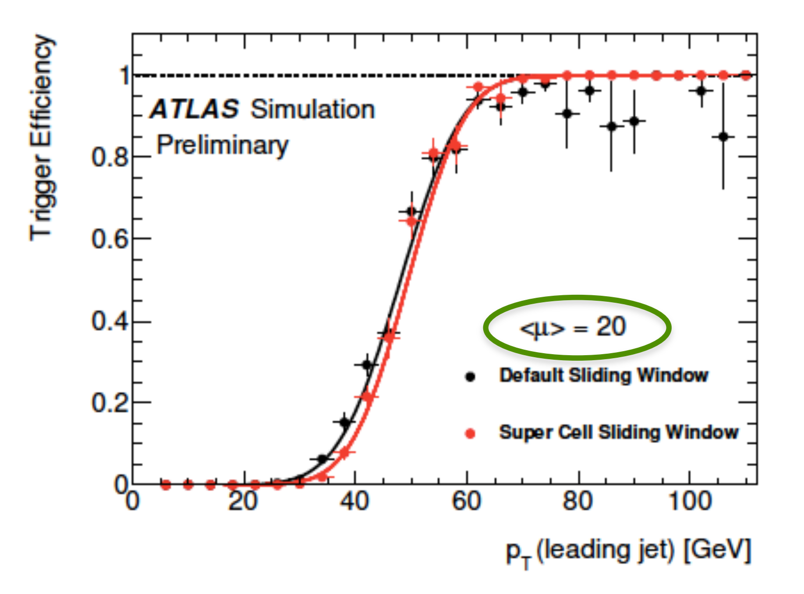
Total rate for inclusive EM triggers would be 270 kHz!
(Total L1 bandwidth is 100kHz)

⇒

Complemented by new L1Calo trigger processors eFEX and jFEX

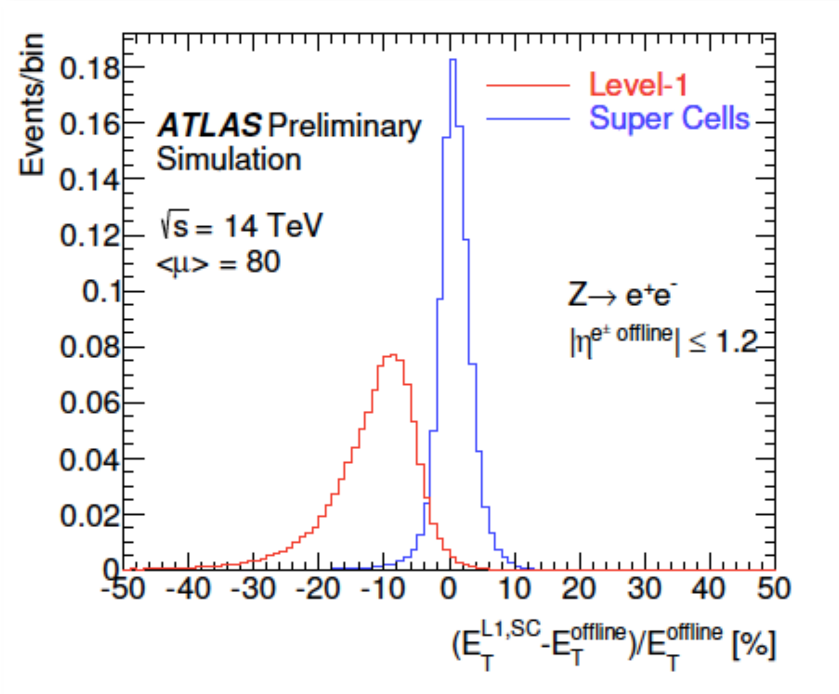
Level-1 calorimeter trigger cont.

Trigger eff. vs jet p_T



Significant degradation of the turn-on curve with pile up (<μ>=80)

- requiring much higher offline threshold (black curve)
- recovered through introduction of super-cells (red curve)



EM Triggers

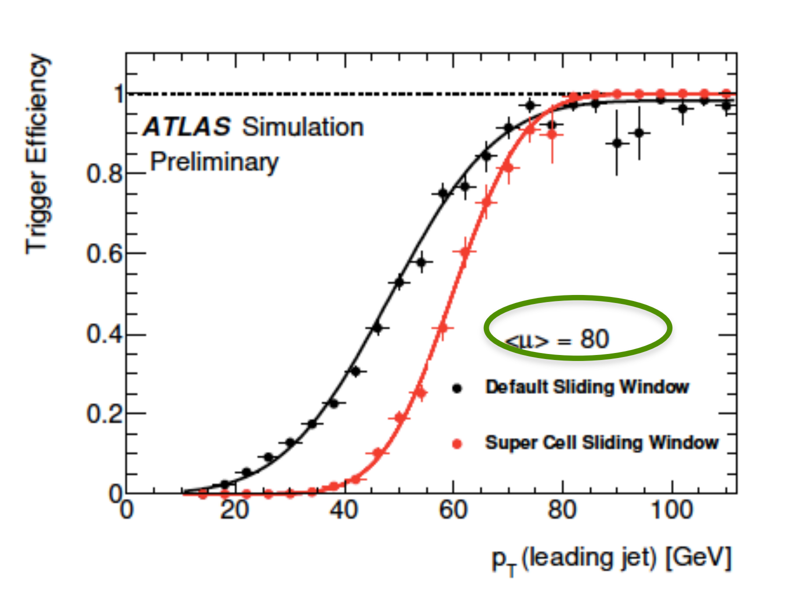
- Better shower shape discrimination
  → lower EM threshold by ~ 7 GeV at same rate
- In addition significantly improved resolution
  → lower EM threshold by another few GeV at same rate

Topological triggering

- Will feed calorimeter trigger input to L1 topological processor (already in Phase-0)

Level-1 calorimeter trigger cont.

Trigger eff. vs jet p_T



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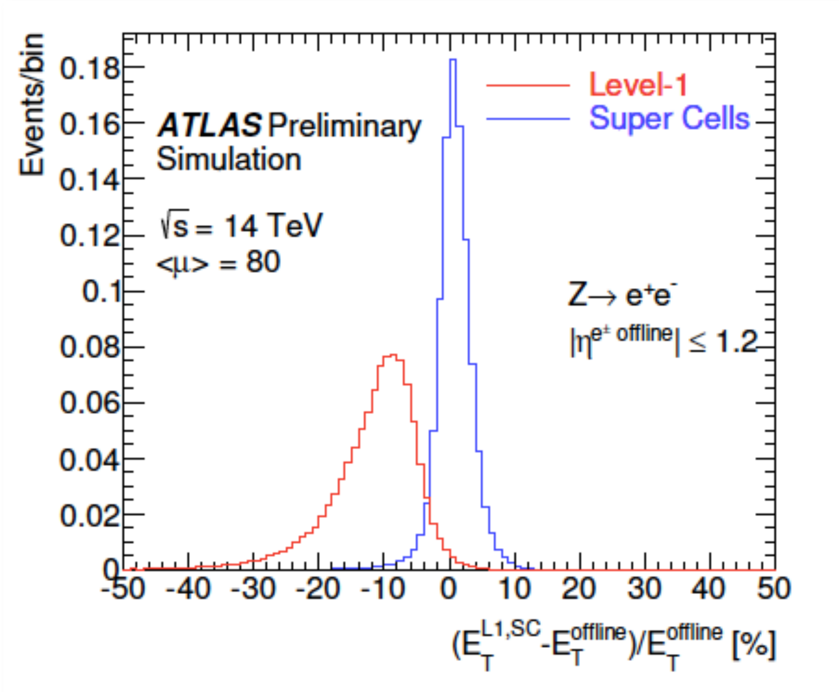


Topological triggering

- Will feed calorimeter trigger input to L1 topological processor (already in Phase-0)

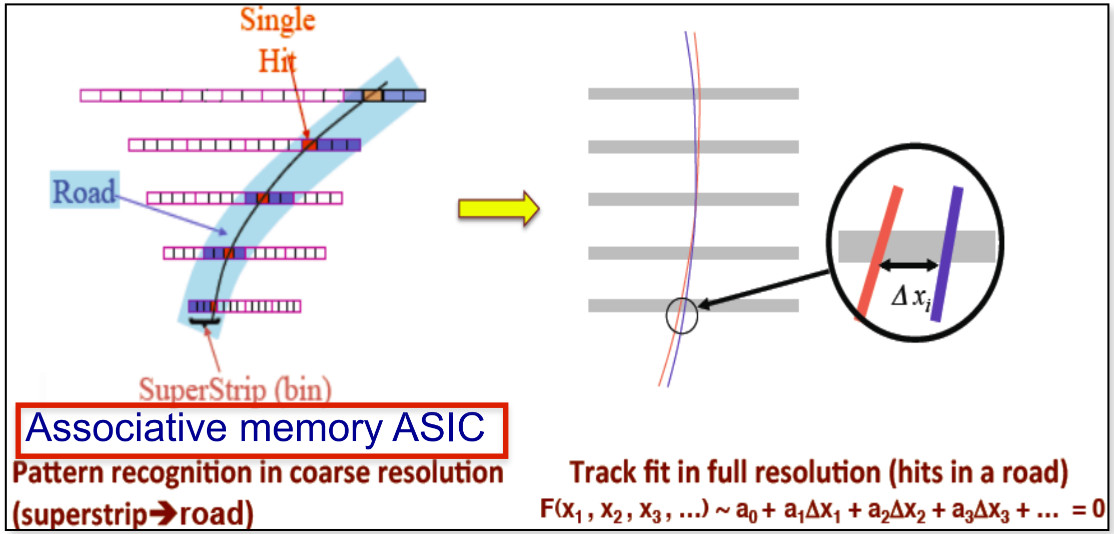
Fast TracK Trigger (FTK)

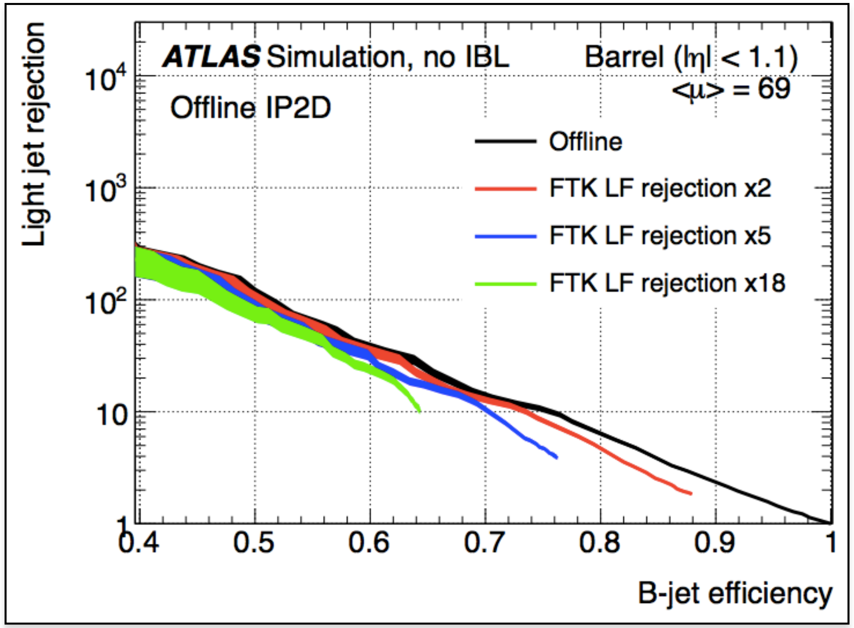
- Dedicated, hardware-based track finder
  - Runs after L1, on duplicated Si-detector read-out links
  - Provides tracking input for L2 for the full event
    - not feasible with software tracking at L2
  - Finds and fits tracks (~ 25 μs) in the ID silicon layers at an “offline precision”

- Processing performed in two steps

hit pattern matching to pre-stored patterns (coarse)

subsequent linear fitting in FPGAs (precise)





Light jet rejection using FTK compared to offline reconstruction
(further improved by addition of IBL)

New LHC schedule
02/12/2013

ATLAS Upgrade Plan

Phase-2

Prepare for <μ>=200

Replace Inner Tracker

New L0/L1 trigger scheme

Upgrade muon/calorimeter electronics

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

ultimate HL-LHC luminosity

$L_{inst} \simeq 5 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 140$) w. level.

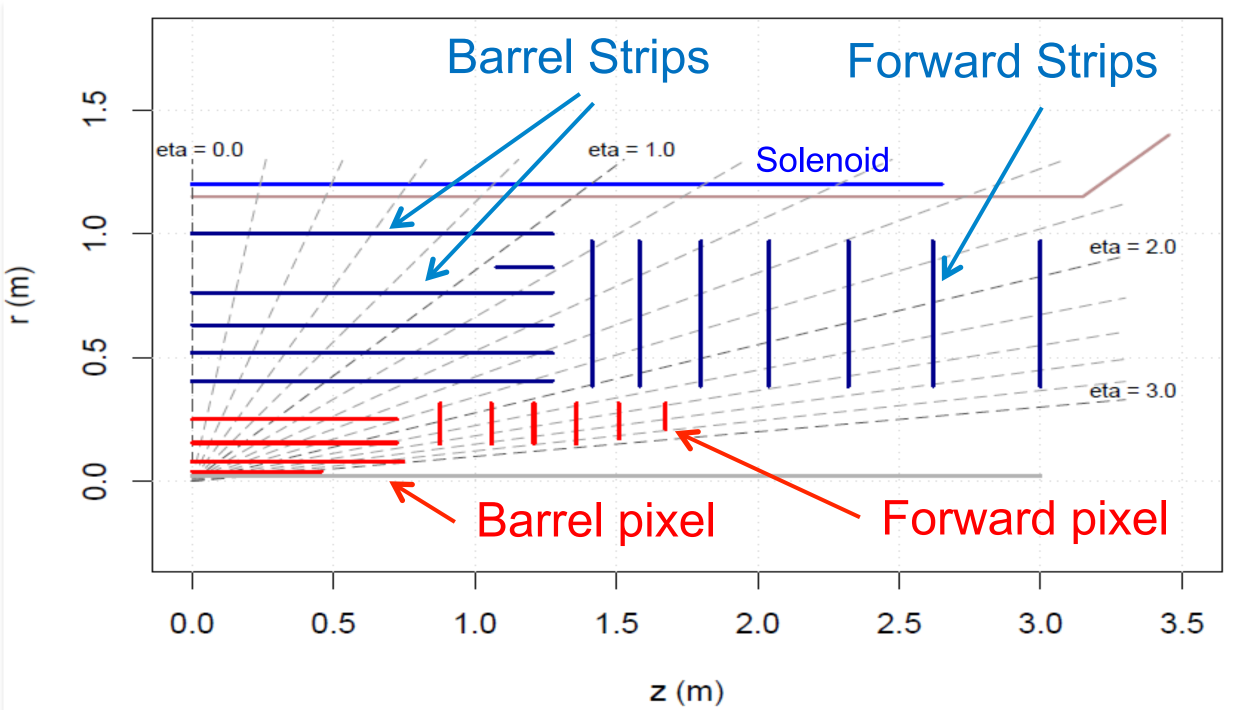
$\simeq 6\text{-}7 \times 10^{34}\ cm^{-2}s^{-1}$ ($\mu \simeq 192$) no level.

$\int L_{inst} \simeq 3000\ fb^{-1}$

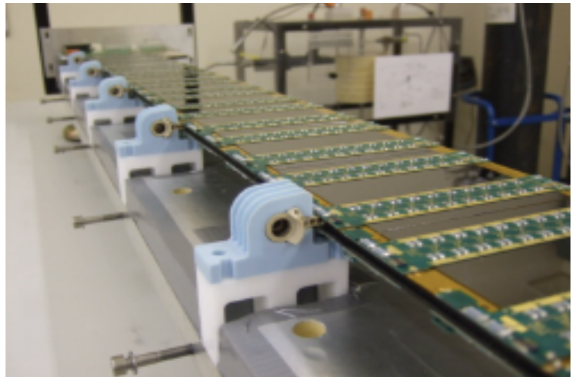
New Tracking detector

- Current Inner Detector (ID)
  - Designed to operate for 10 years at $L=1x10^{34}$ $cm^{-2}s^{-1}$ with <μ>=23, @25ns, L1=100kHz
- Limiting factors at HL-LHC
  - Occupancy
    - ➢ Bandwidth saturation (Pixels, SCT)
    - ➢ Deterioration of tracking performance (TRT, SCT)
  - Radiation damage (Pixels (SCT) designed for 400 (700) fb^{-1})

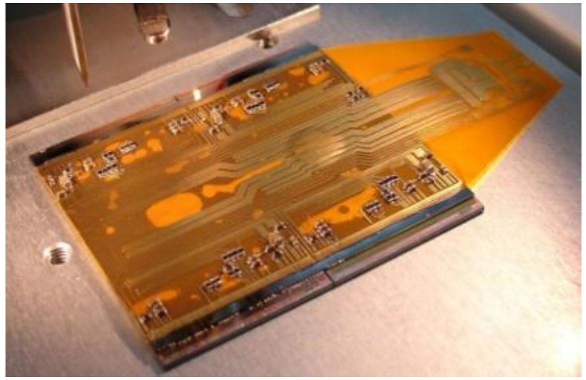
LoI layout new (all Si) ATLAS Inner Tracker for HL-LHC



Microstrip Stave Prototype



Quad Pixel Module Prototype

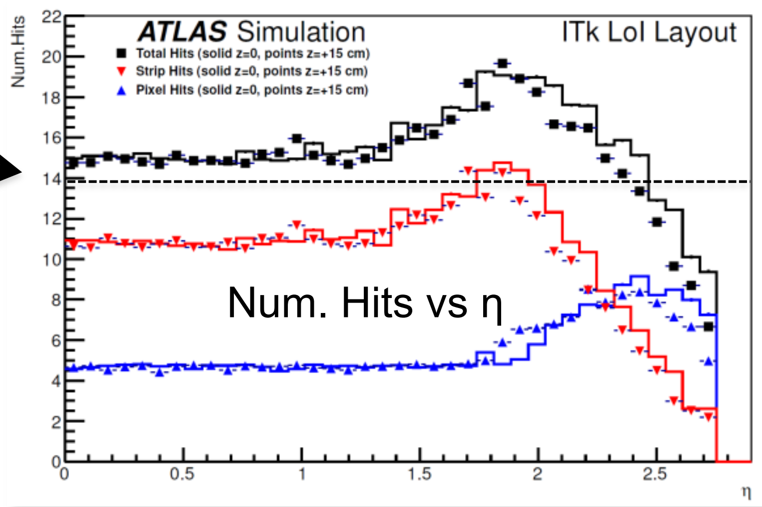


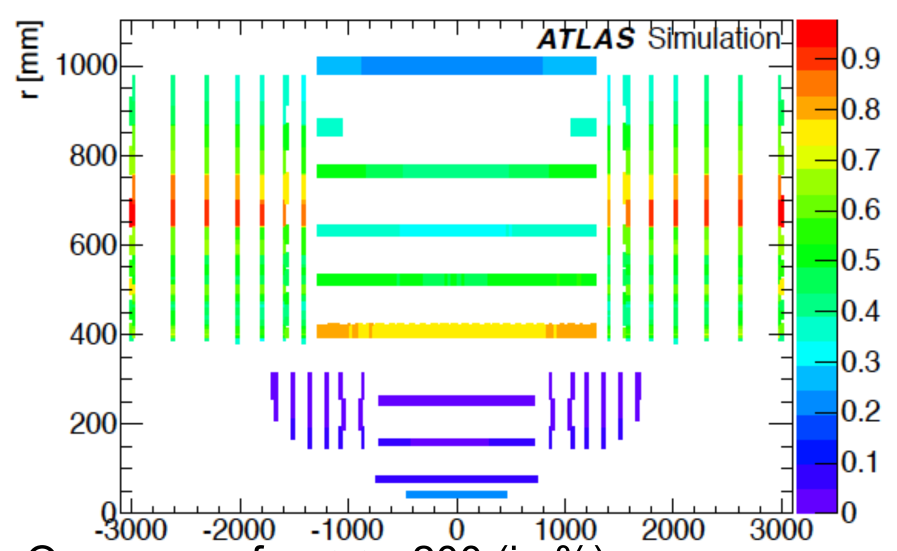
New 130nm prototype strip ASICs in production
- incorporates L0/L1 logic

Sensors compatible with 256 channel ASIC being delivered

New Tracking detector cont.

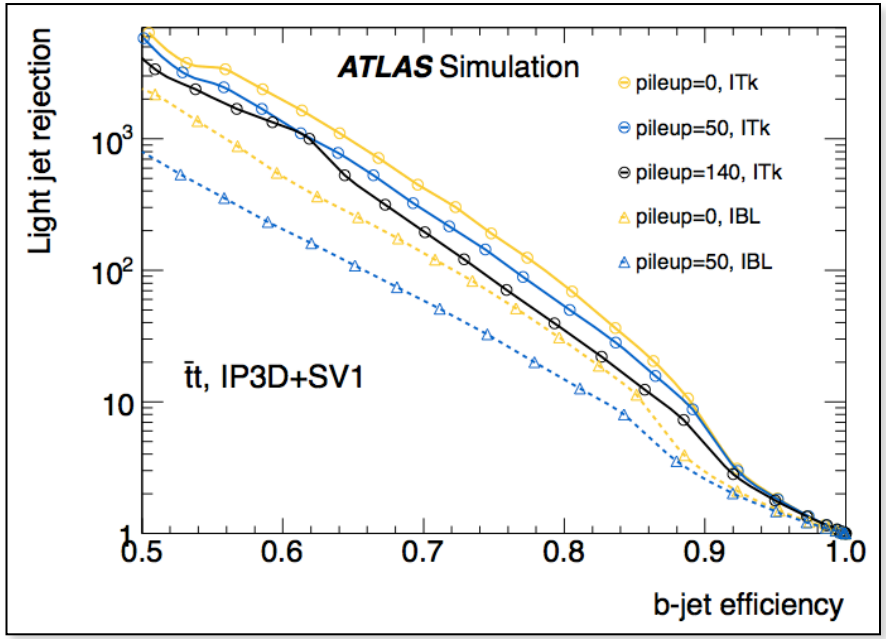
- Studies with LOI layout
  - Robust tracking (14 layers)
  - Occupancy <1% for <μ>=200
  - Reduced material wrt current ID
  - Comparable / better tracking performance at <μ>=200 as current ID at <μ>=0
- Prototypes tested to 2x HL-LHC flux
- Solid baseline design
  - working on optimisation





Occupancy for <μ>=200 (in %)

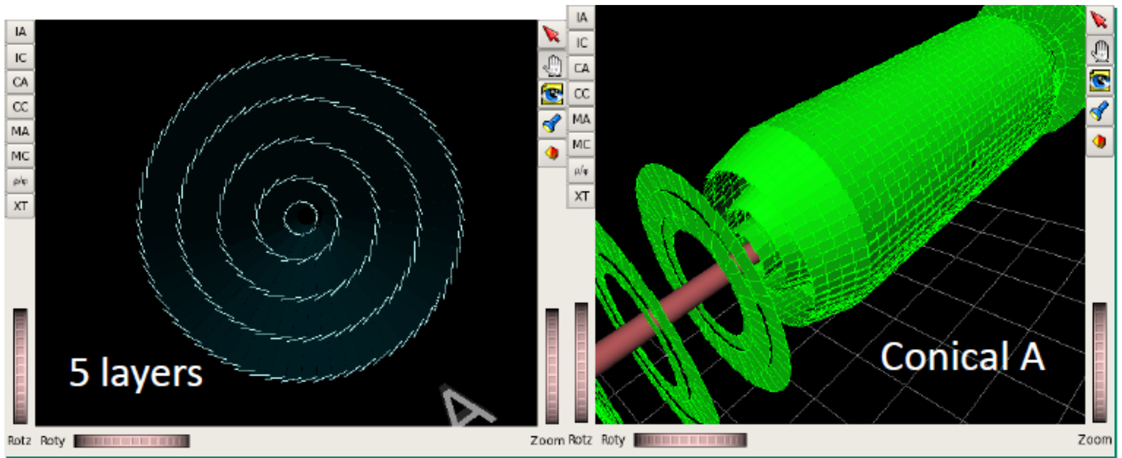
Light jet rejection, ID (w/IBL) and ITk



New Tracking detector cont.

- Many topics still to be addressed
  - How can the layout still be optimised?
  - Can all assemblies/components be qualified to the required radiation hardness?
  - How critical is the luminous beam-spot extent in z?
  - Are there physics reasons to significantly extent the coverage in η?
  - Cost / material optimisations with current technologies?
  - Alternative technologies?

- Addressing these questions now is very timely
  - note TDR of current ID was written in 1997 …



Alternative layouts being considered which include either a further pixel layer or inclined pixel

Trigger system architecture

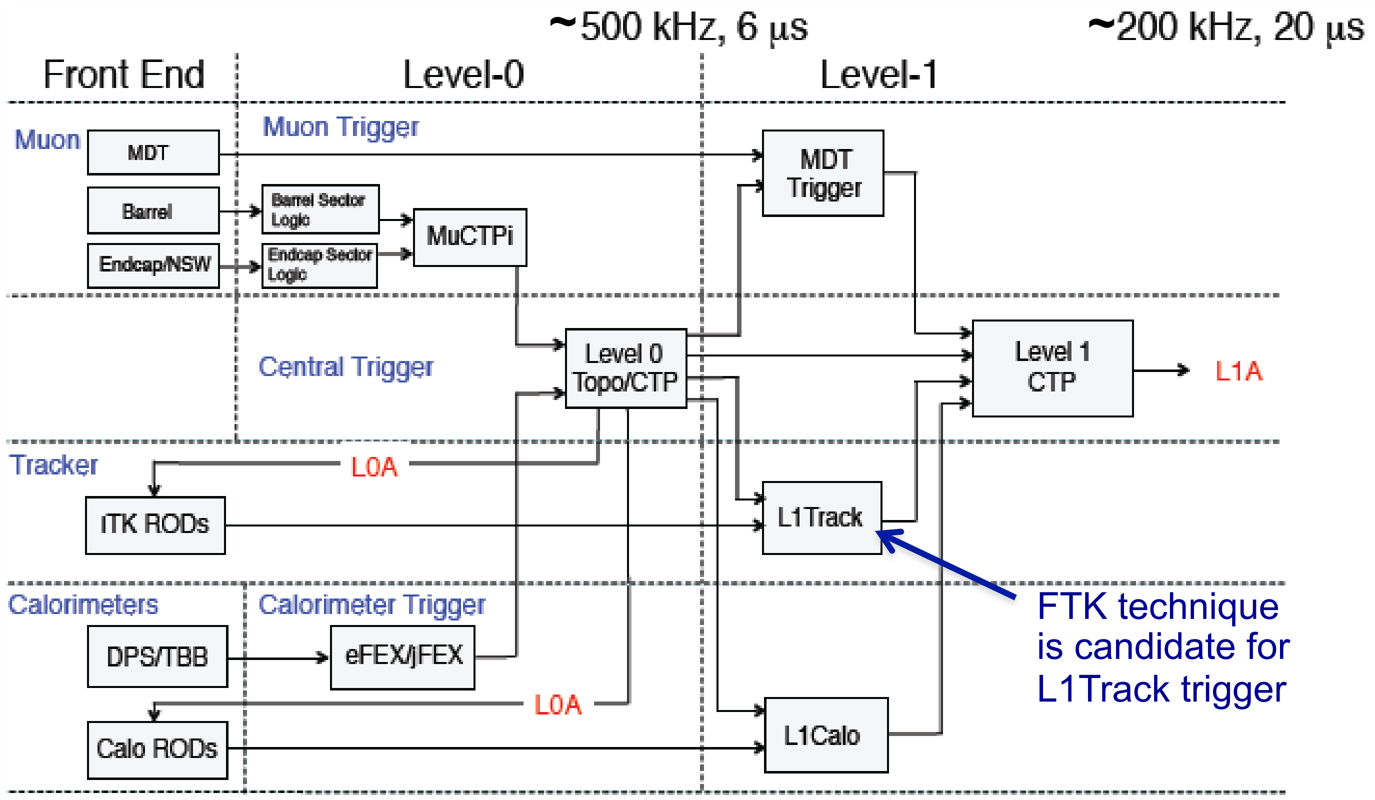
New design for Phase II

- 2-level system, Phase-I L1 becomes Phase-II L0, new L1 includes tracking
- Make use of improvements made in Phase 1 (NSW, L1Calo) in L0
- Introduce precision muon and inner tracking information in L1
    - Better muon pT resolution
    - Track matching for electrons,…

Will also have new timing/control links and LHC interface system

- Requires changes to detector FE electronics feeding trigger system

Level-0
Rate ~ 500 kHz, Lat. ~6 μs
Muon + Calo
Level-1
Rate ~200 kHz, Lat. ~20 μs
Muon + Calo + Tracks



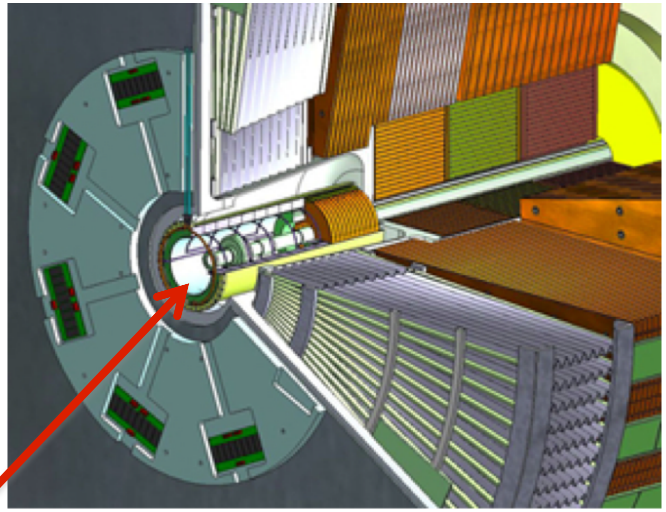
Calorimeter electronics

Tile Calorimeters

- No change to detector needed
- Full replacement of FE and BE electronics
  - New read-out architecture: Full digitisation of data at 40MHz and transmission to off-detector system, digital information to L1/L0 trigger

LAr Calorimeter

- Replace FE and BE electronics
  - Aging, radiation limits
  - 40 MHz digitisation, inputs to L0/L1
  - Natural evolution of Phase-I trigger boards



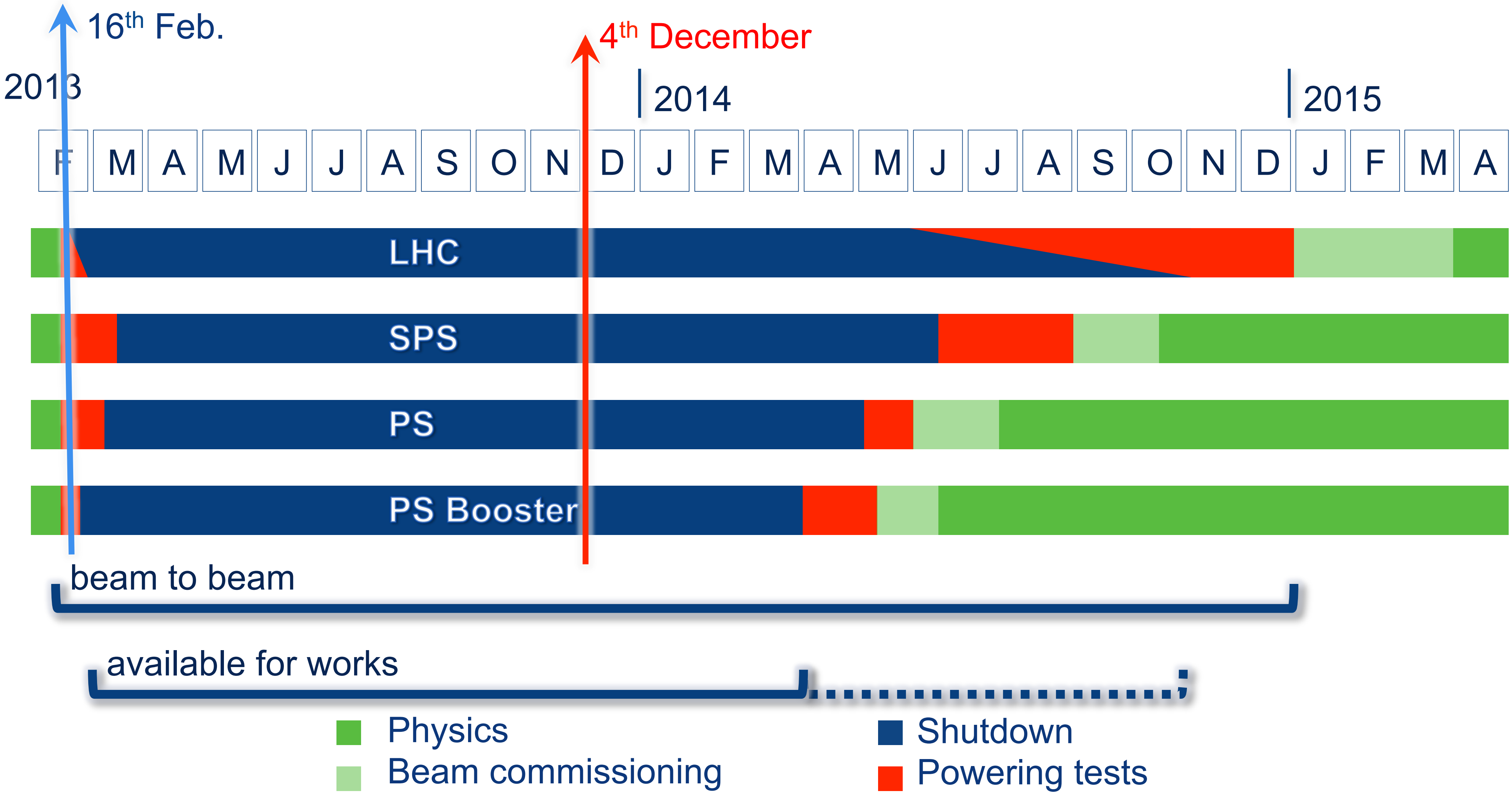
- Replace HEC cold preamps if required
  - i.e. if significant degradation in performance
- Replace Forward calorimeter (FCal) if required
  - Install new sFCAL in cryostat or miniFCAL in front of cryostat if significant degradation in current FCAL

Summary

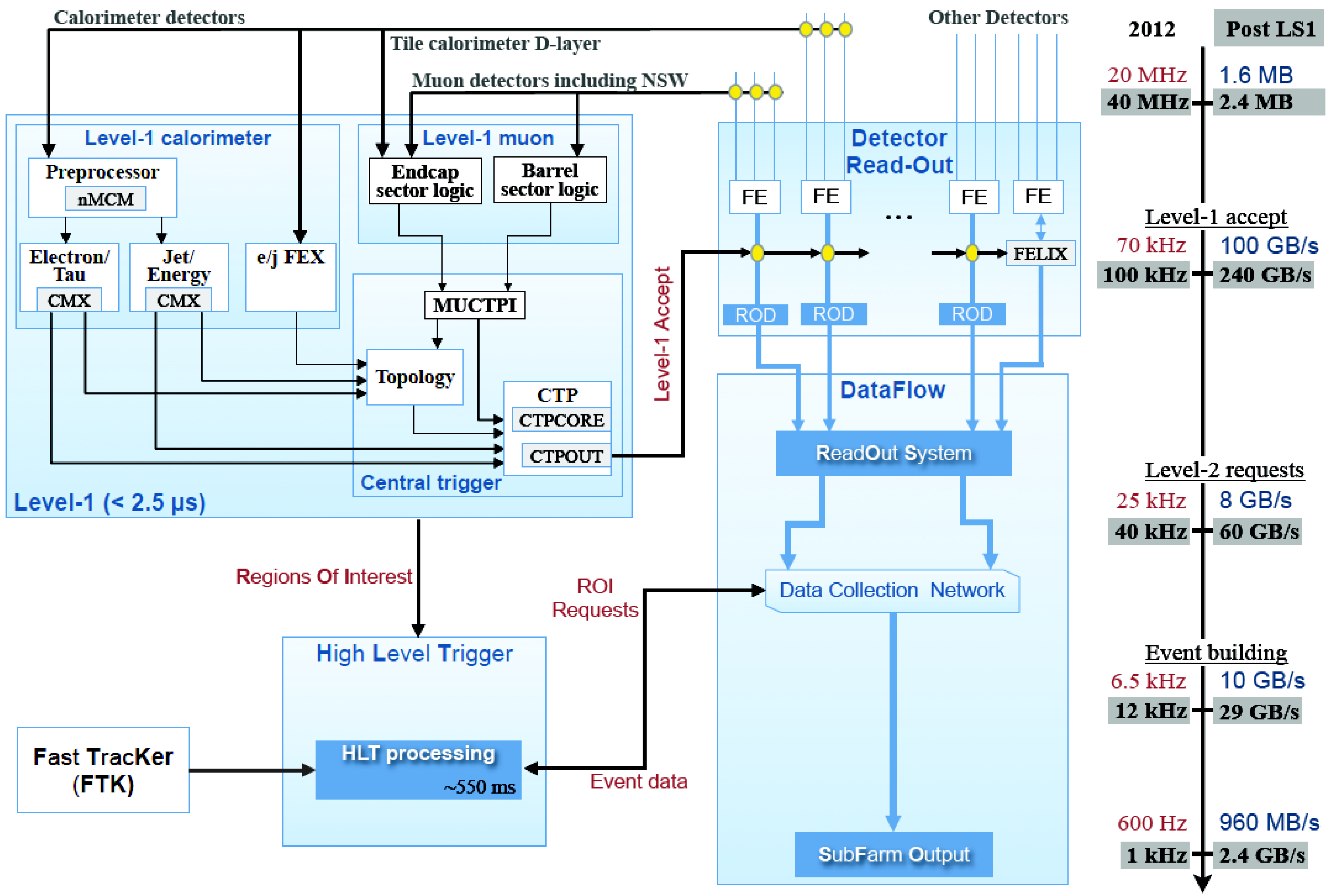
- Both the LHC and ATLAS performed superbly during Run1
  - The LHC, running at $\sqrt{s}$=7-8 TeV, has nearly reached design luminosity
  - 50 ns bunch spacing at almost nominal luminosity implied large pileup above the design value
  - The ATLAS detector recorded excellent, high-quality data with > 95% efficiency
- An intensive consolidation and upgrade programme (Phase-0) is carried out now during LS1, in preparation for Run-2
  - LHC will run with 25 ns bunch spacing at 13-14 TeV and ~1 x 10^{34} $cm^{-2}s^{-1}$
  - ATLAS will have an improved, 4-layer Pixel detector in Run 2
- Phase-1 upgrade (installation in LS2, 2018-2019) ➔ Run-3
  - Aiming to maintain excellent ATLAS performance with low threshold inclusive triggers up to 3x design luminosity and $\langle\mu\rangle$ up to 80
  - The 4 TDRs submitted to the LHCC last year were all approved
- Phase-2 upgrade (installation in LS3, 2023-2025) ➔ HL-LHC
  - $\gtrsim$5 x design luminosity, ~300 fb^{-1}/year, $\langle\mu\rangle$ = 140 (up to 200 w/o leveling)
  - New muon & calorimeter electronics, new L0/L1 trigger scheme
  - Completely new, all silicon tracker


ATLAS SurfaceBuilding
2013-04-14 CEST 15:05:02
Thank you!

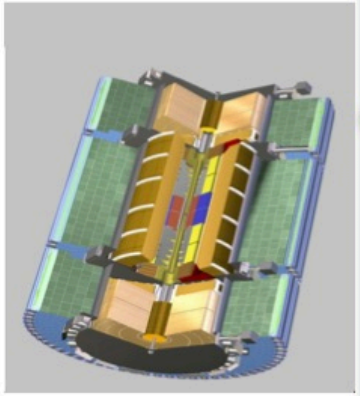
LS 1 from 16th Feb. 2013 to Dec. 2014

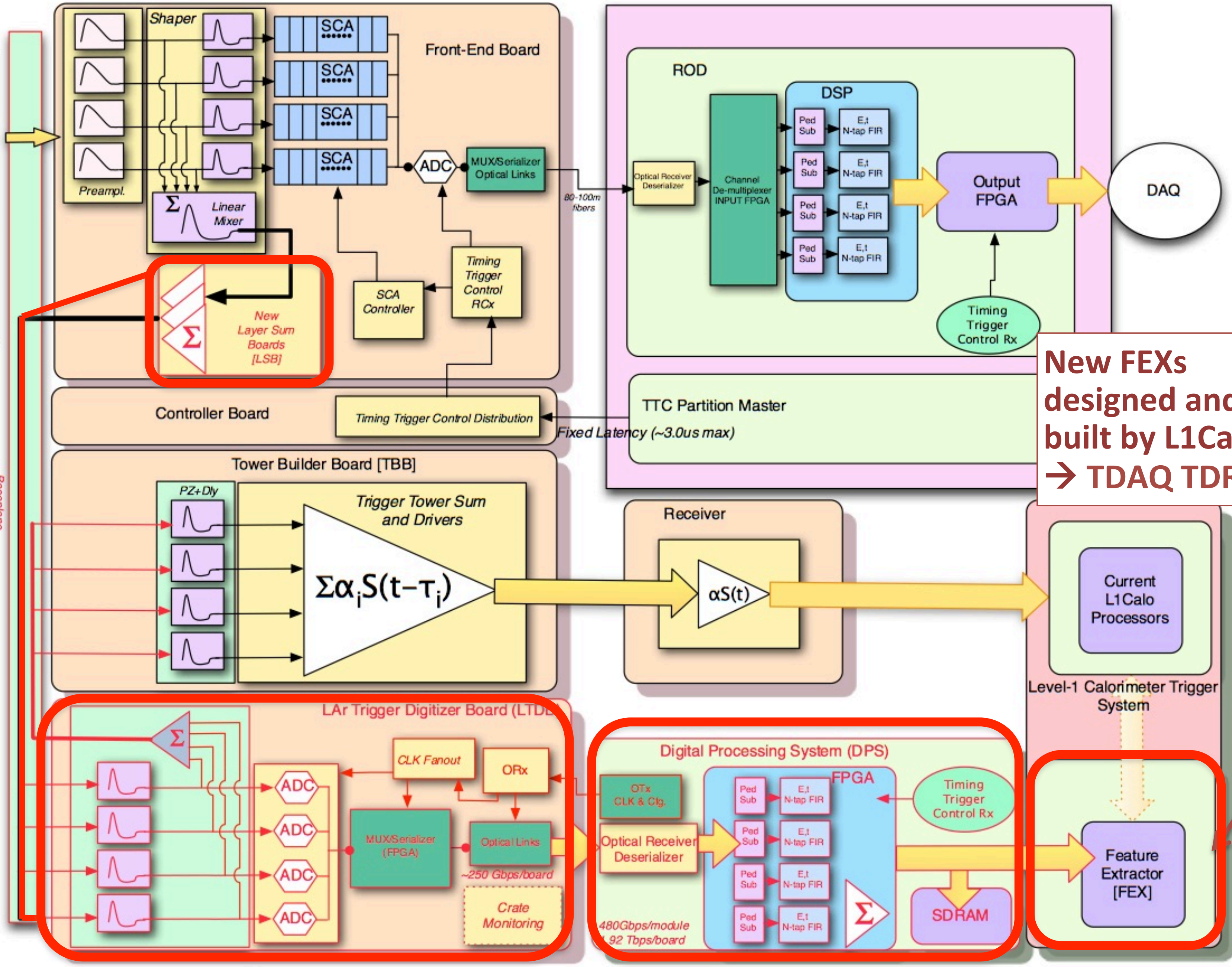


Trigger/DAQ System for Run 3



The Proposed Phase I Upgrade





New FEXs designed and built by L1Calo → TDAQ TDR

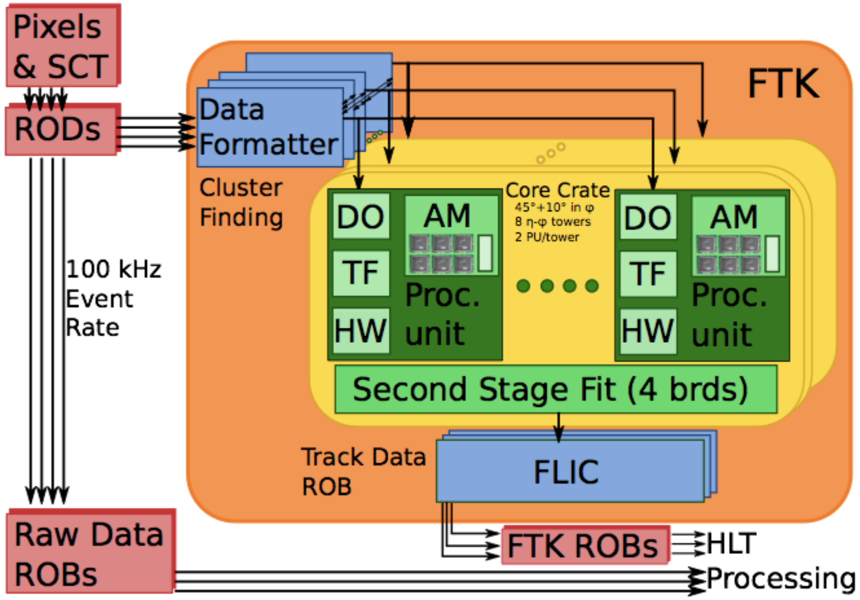
New or modified components in red → LAr TDR

Possible implementation
ΔηxΔφ=0.025x0.1 1st and 2nd layer EM
ΔηxΔφ=0.1x0.1 elsewhere

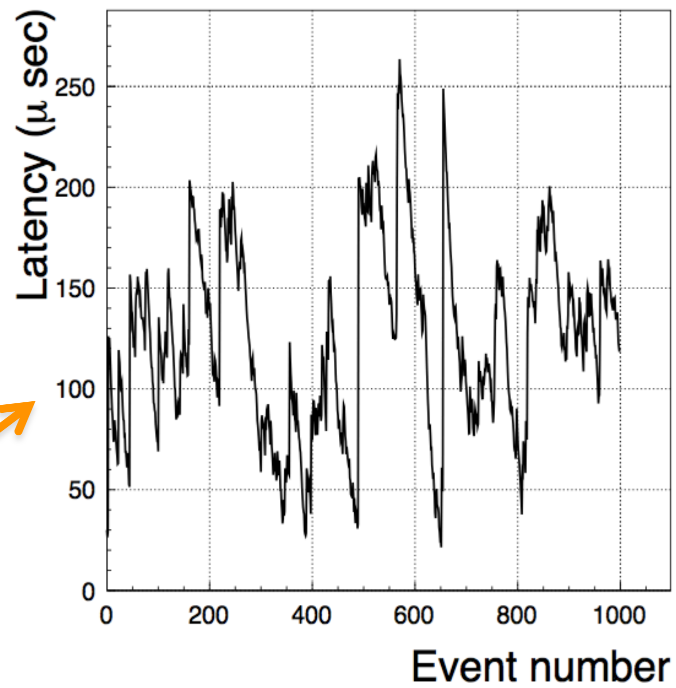
Proposed phase I upgrade fully compatible with plans for phase II upgrade

ARLAS Phase-1 Upgrade: FTK

- System of custom electronics for global track reconstruction after L1 trigger (100 kHz)
- 64 $\eta-\phi$ towers receiving and processing data in parallel
- Pattern recognition and first stage track fitting in 8 silicon layers (strips & pixels)
  - Finds hits in remaining 4 layers and performs 12-layer fits
- All tracks with p_T > 1 GeV/c are reconstructed in ~ 100 μs
- Allows selection of events with b's or τ's at rates impossible for software tracking

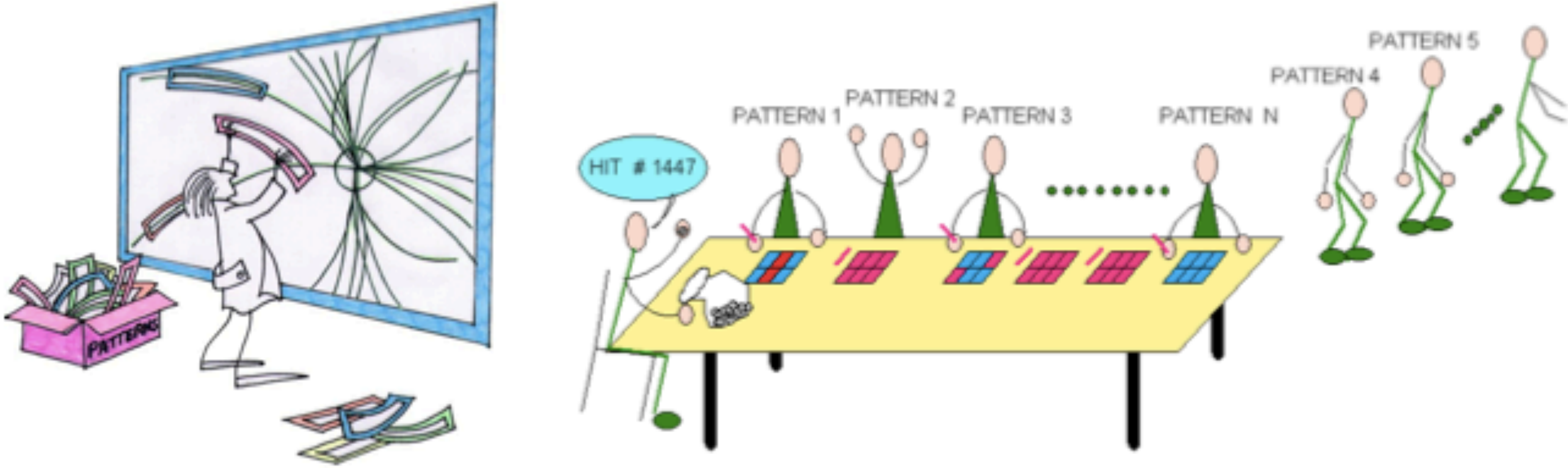


Event-by-event latency
For tt events with 69 pileup



FTK Hardware

- **Rapid pattern recognition**



  - A pattern consists of a Super-Strip in each layer (10s of pixels/strips wide).
  - Uses HEP-specific content addressable memory (CAM) custom chip.
  - Patterns determined from full ATLAS simulation.
  - ~ 10^9 patterns see each hit almost simultaneously.
  - When hits have all been sent off detector, pattern recognition is ~ done.

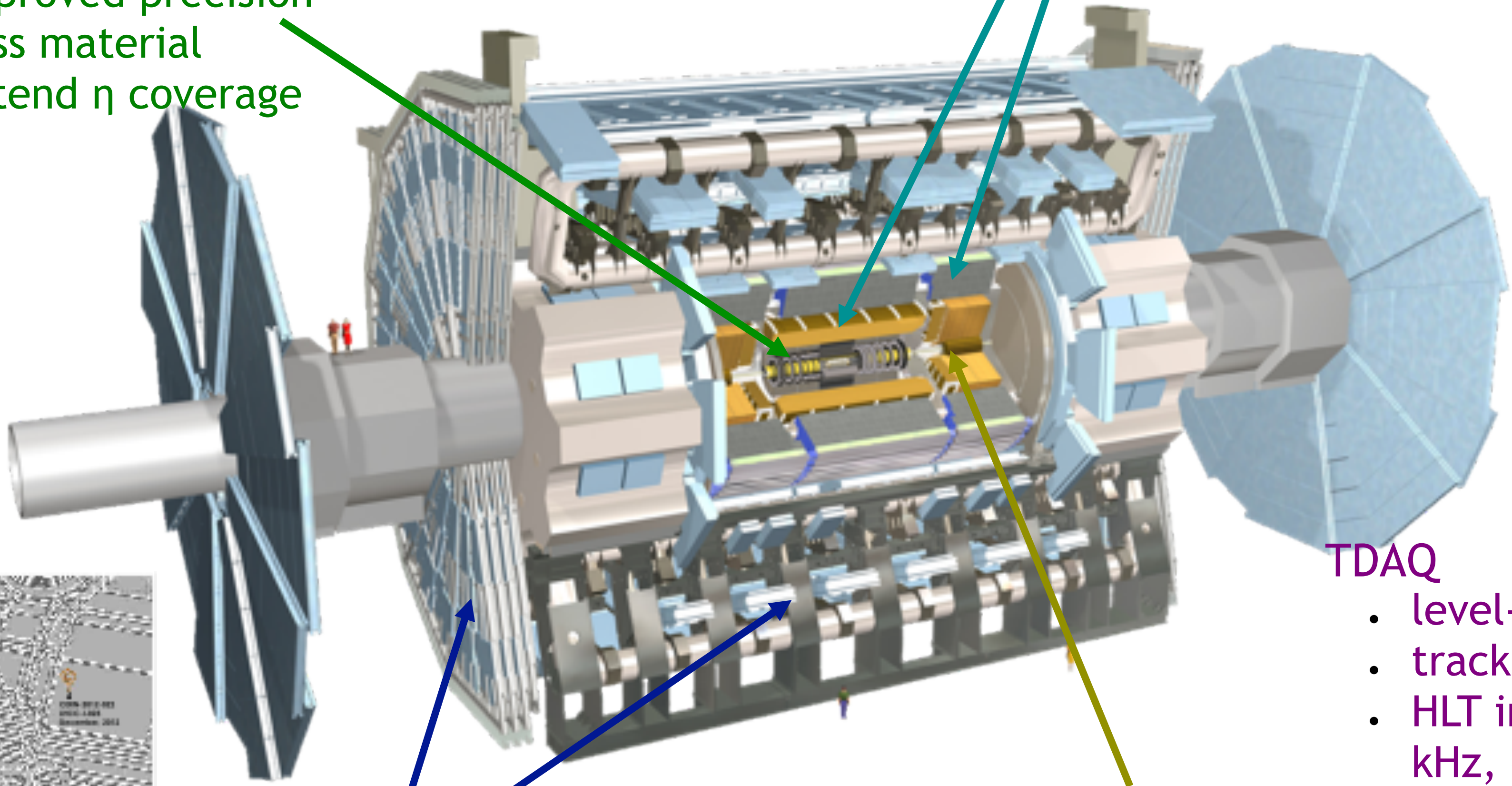
June 11, 2013 LHCC 17

Presented by M. Shochet

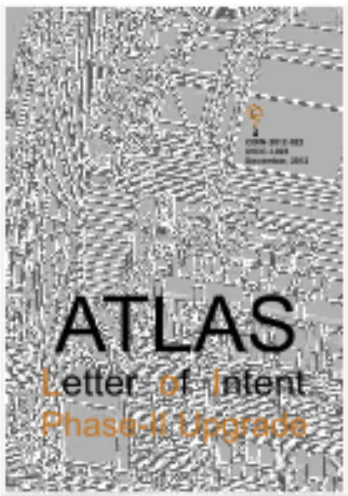
ATLAS Phase-2 Upgrades

New Inner Tracker (all silicon)
- Radiation hardness
- Better granularity and faster links
- Improved precision
- Less material
- Extend η coverage

LAr and Tile Calorimeters
- new FE and BE electronics



TDAQ
- level-0 at 0.5 MHz
- tracking at level-1
- HLT input 200 kHz, output 5 kHz?

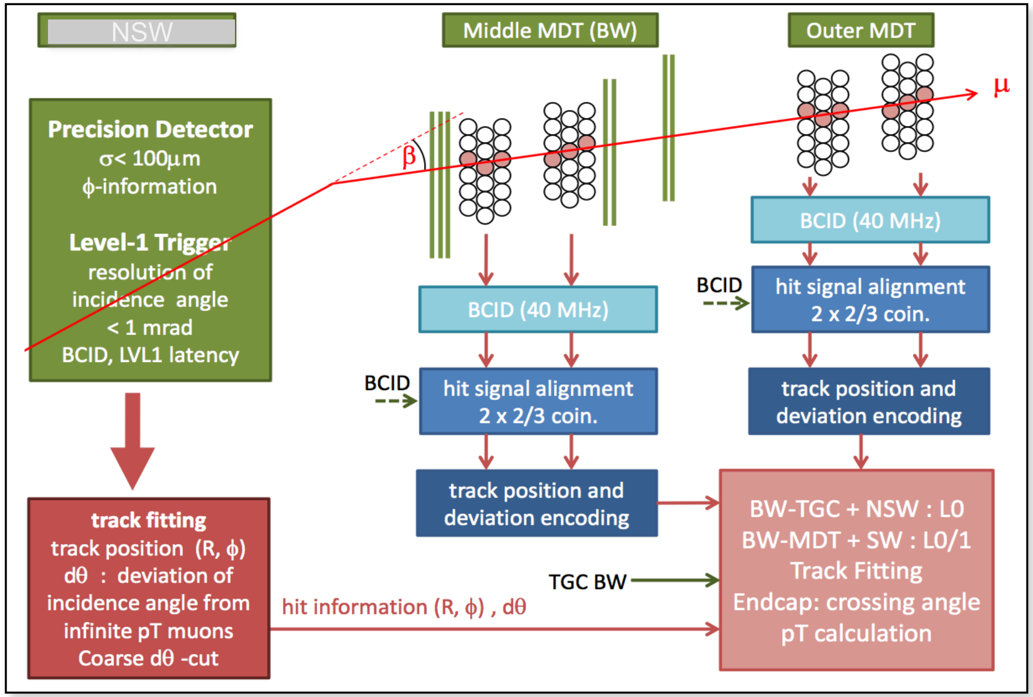


Muons
- new FE electronics
- improve resolution

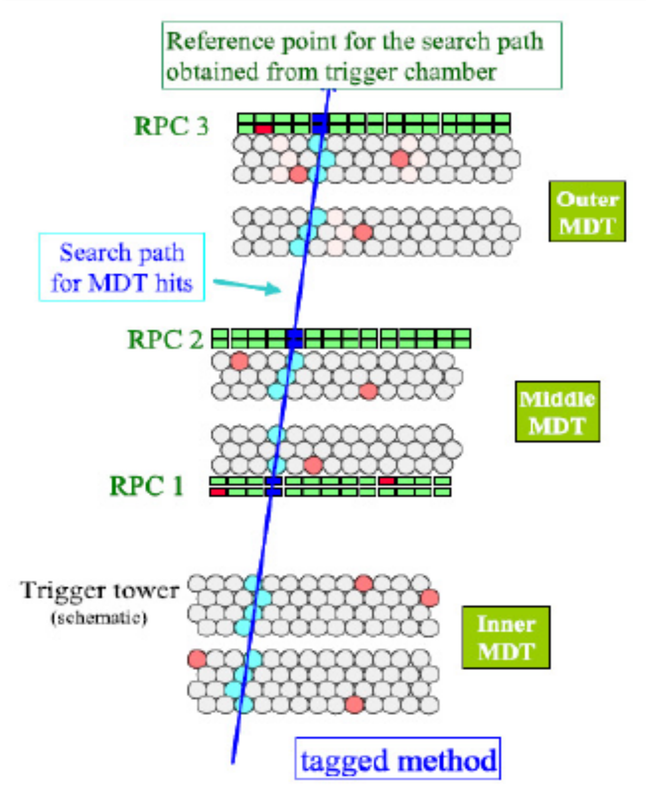
Forward Calorimeters
- Replace FCal?
- Replace endcap hadronic calorimeter cold electronics?

Muon system upgrade

- Upgrade FE electronics
  - accommodate L0/L1 scheme parameters
- Improve L1 p_T resolution
  - Use MDT information possibly seeded by trigger chambers ROIs (RPC/TGC)
  - Another option: add higher precision RPC layer at inner MDT station



Match angle measurement in end-cap MDTs to precision measurement in NSW



RoI of high-p_T track used as a search road for MDT hits of the candidate track

⇩

Combine track segments of several MDTs to give precise p_T estimate

L1Track Trigger

- Adding tracking information at Level-1 (L1)
  - Move part of High Level Trigger (HLT) reconstruction into L1
  - Goal: keep thresholds on p_T of triggering leptons and L1 trigger rates low

- Triggering sequence
  - L0 trigger (Calo/Muon) reduces rate within ~6 μs to ≳ 500 kHz and defines RoIs
  - L1 track trigger extracts tracking info inside RoIs from detector FEs

- Challenge
  - Finish processing within the latency constraints