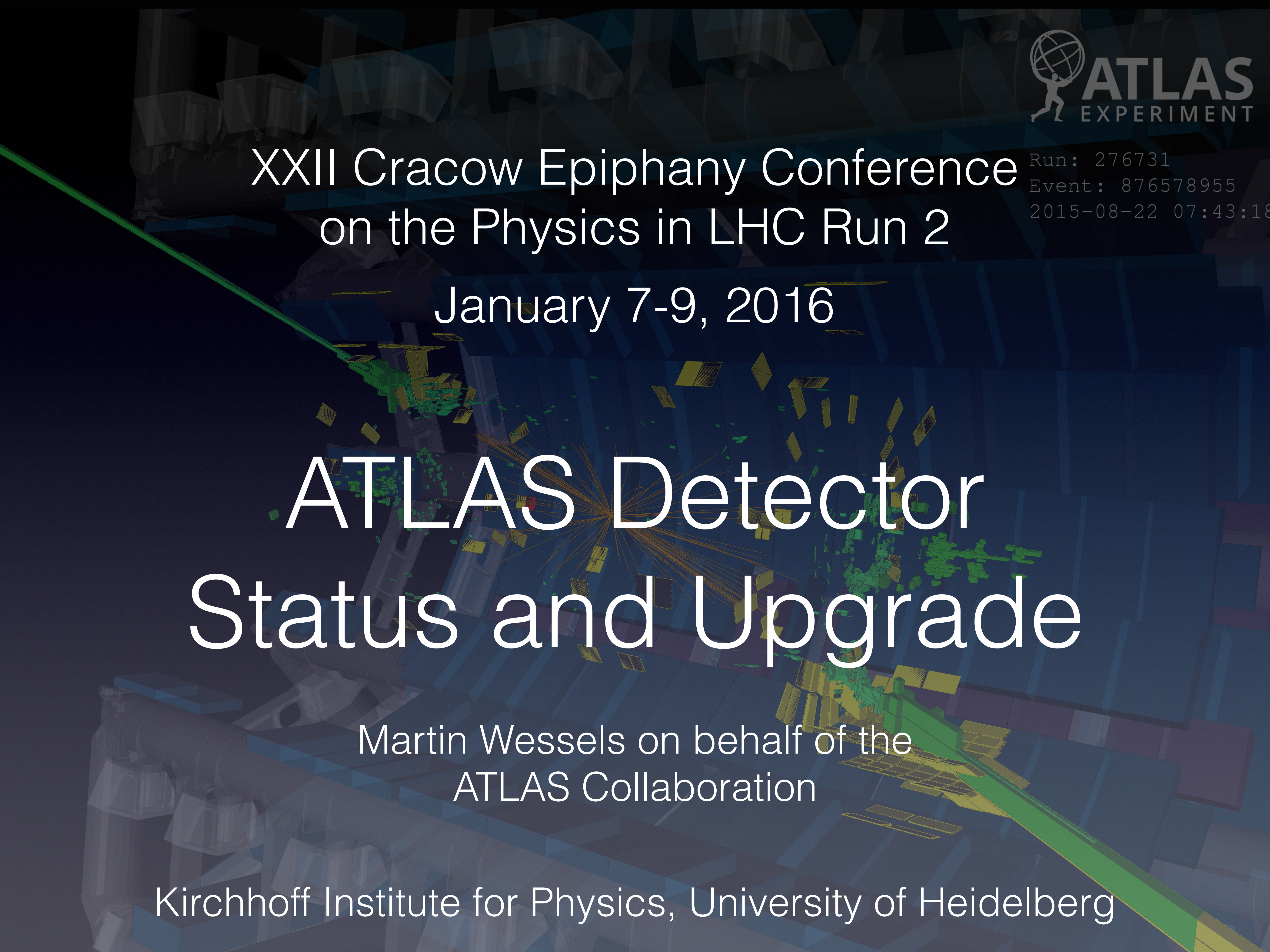
XXII Cracow Epiphany Conference
on the Physics in LHC Run 2

January 7-9, 2016

ATLAS Detector Status and Upgrade

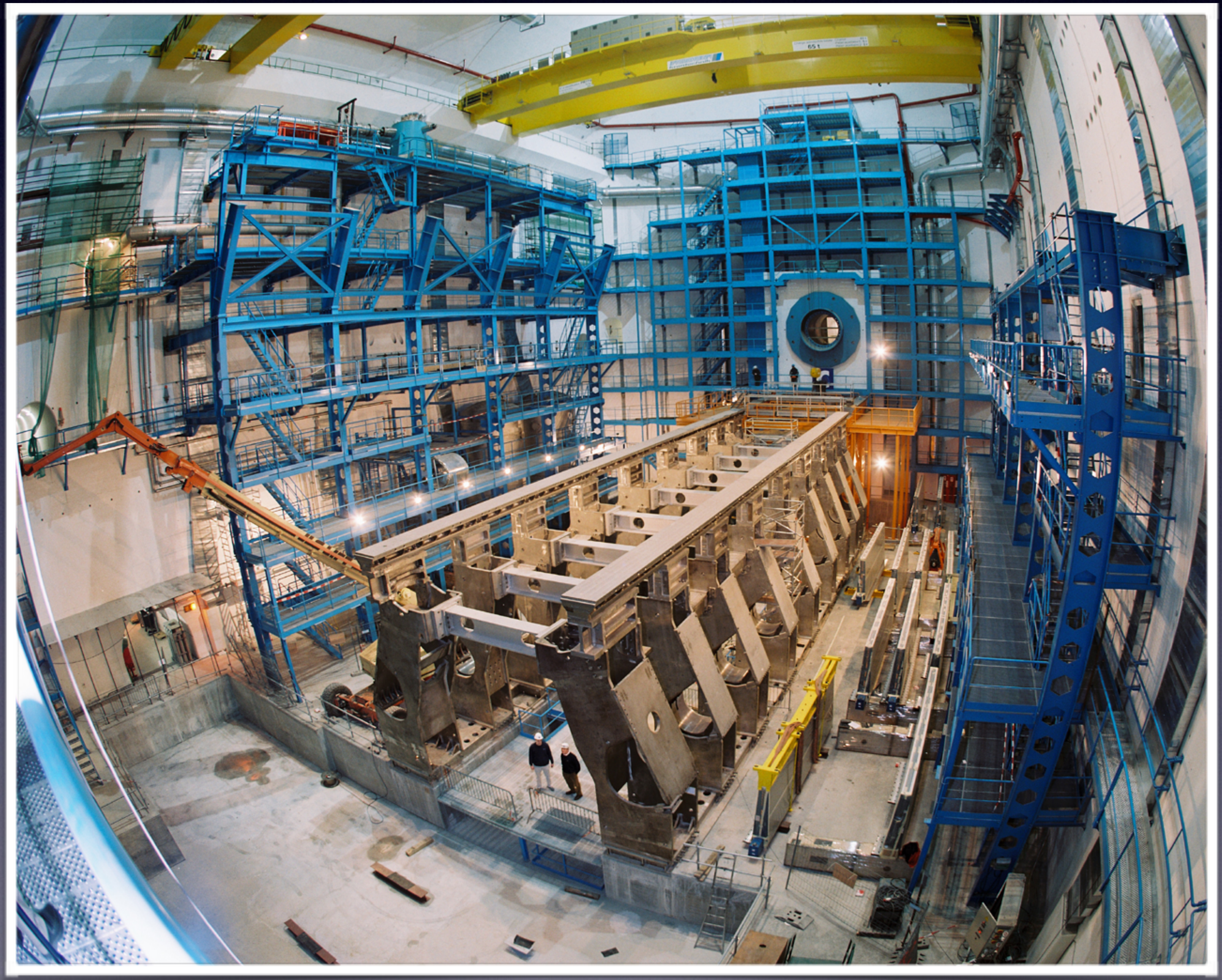
Martin Wessels on behalf of the
ATLAS Collaboration

Kirchhoff Institute for Physics, University of Heidelberg



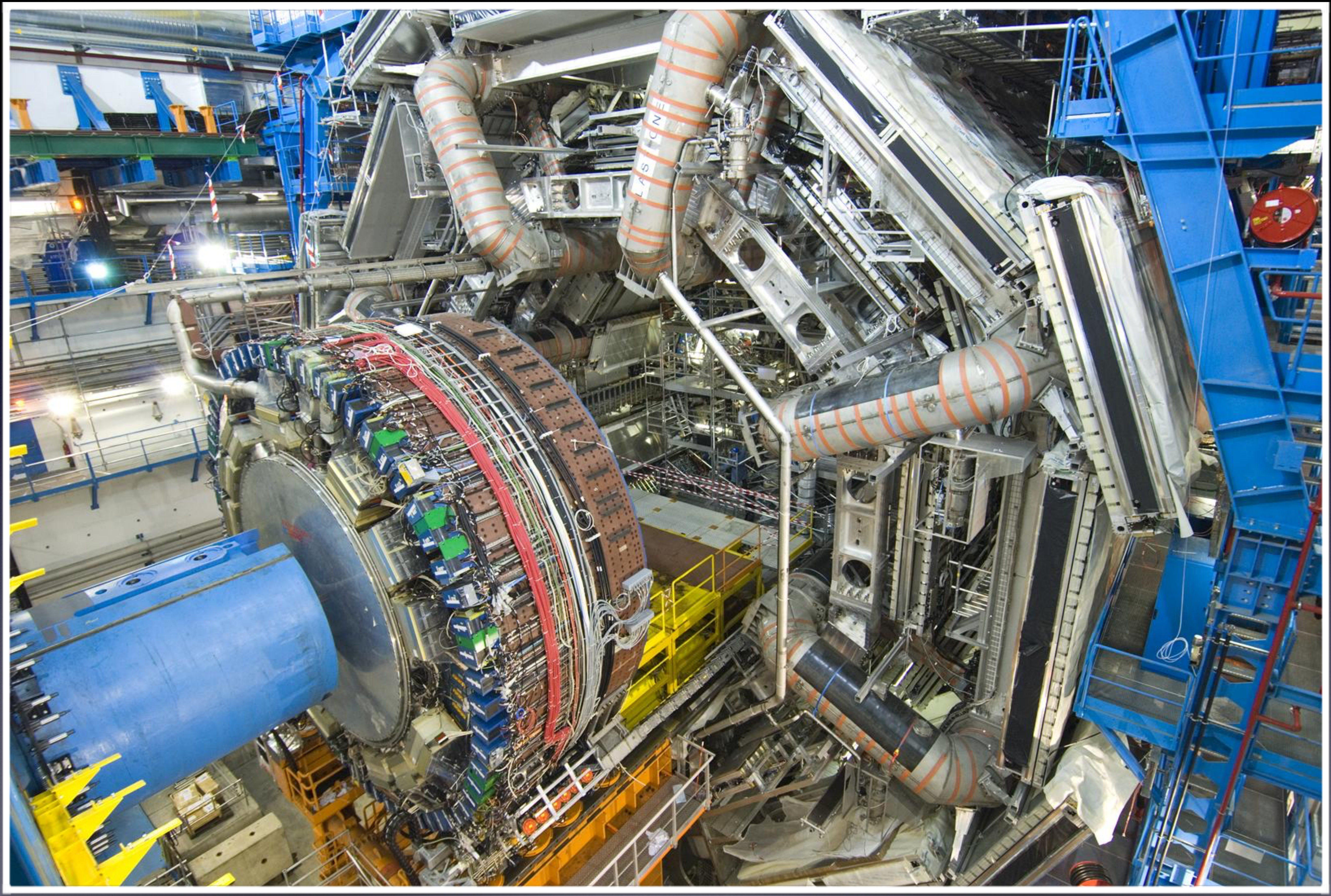
Outline

ATLAS cavern February 2004

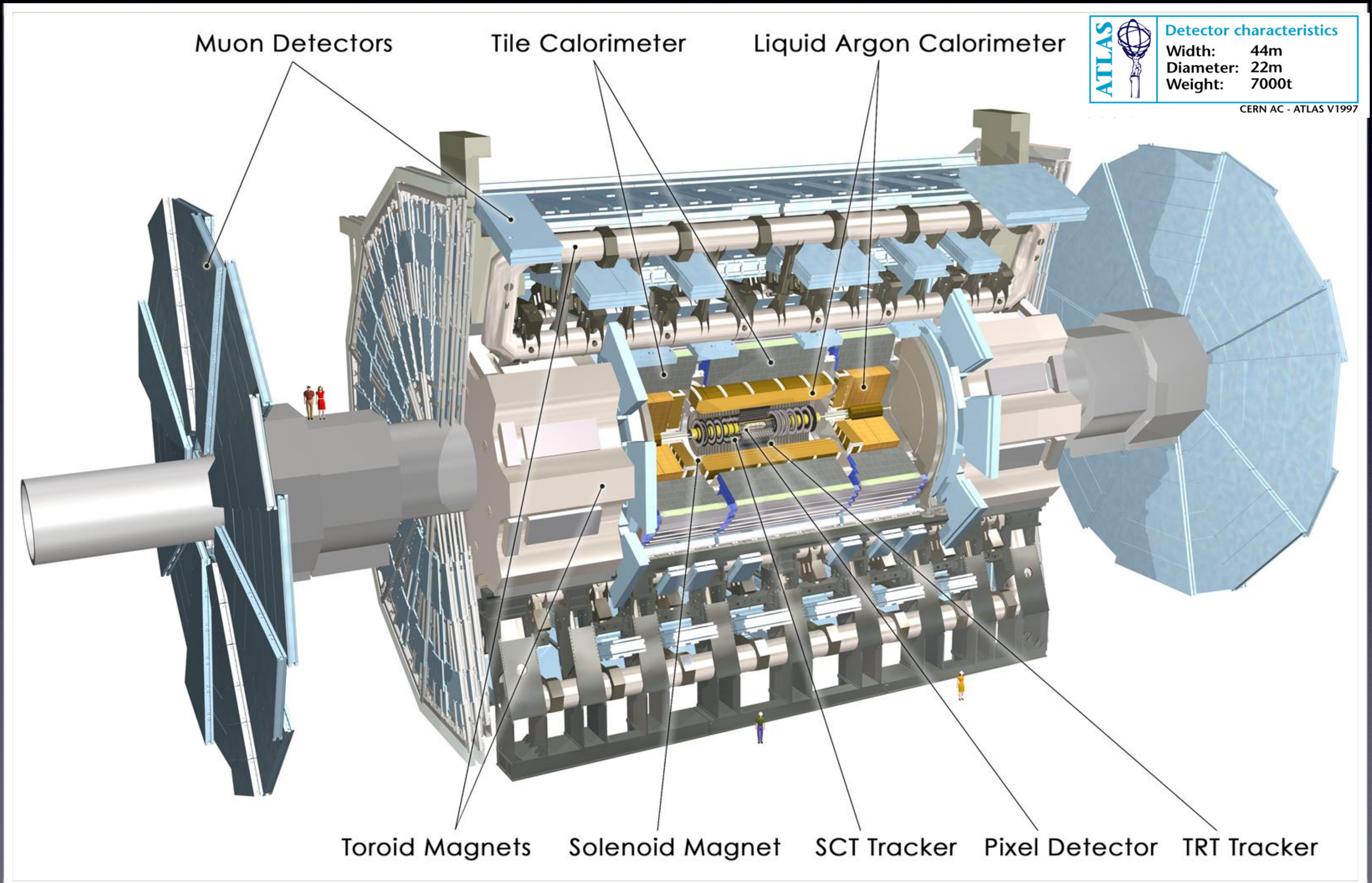


- ATLAS detector and LHC timeline
- Run 2 upgrades [and performance]
- Future upgrades for run 3 and run 4

February 2007



The ATLAS Detector



LHC Timeline

2009
2010

Run 1 — $\sqrt{s}$ = 7-8 TeV, L~0.8×10^{34} cm^{-2}s^{-1}, BS=50ns — ~20 fb^{-1}

2013
2014

LS 1 — Go to design energy and luminosity

Run 2 — $\sqrt{s}$ = 13-14 TeV, L~1×10^{34} cm^{-2}s^{-1}, BS=25ns — ~150 fb^{-1}

2019
2020

LS2 — Injector and LHC Phase-I Upgrade

Run 3 — $\sqrt{s}$ = 14 TeV, L~2×10^{34} cm^{-2}s^{-1}, BS=25ns — ~300 fb^{-1}

2024
2026

LS3 — HL-LHC Phase-II Upgrade

Run 4 — $\sqrt{s}$ = 14 TeV, L~5-7×10^{34} cm^{-2}s^{-1}, BS=25ns — ~3000 fb^{-1}

…

ATLAS Timeline

Total L1A rate limited to ≈100 kHz until LS3

Enhancements to trigger and detector

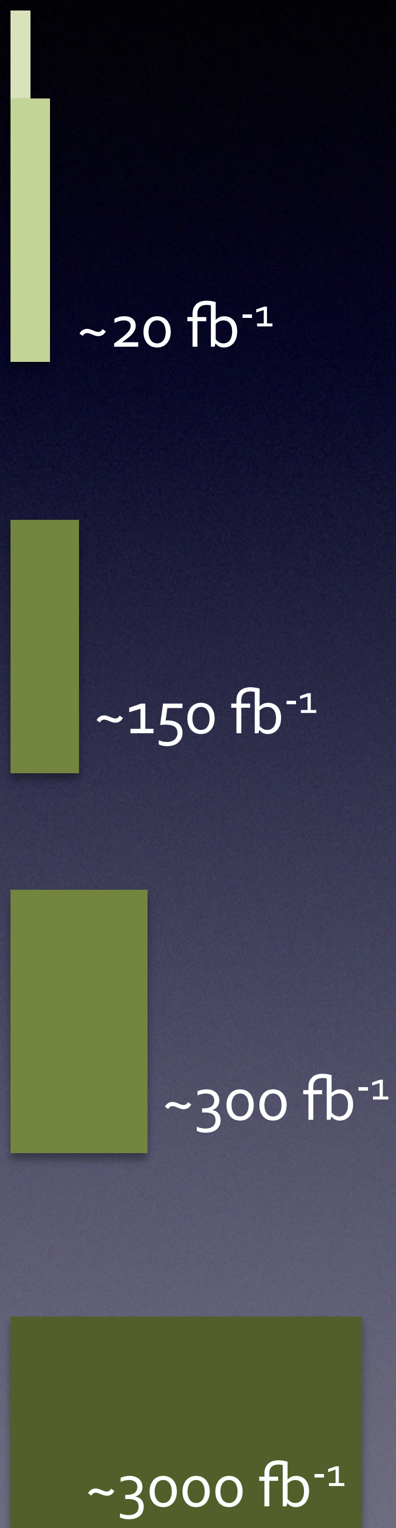
$\sqrt{s}$ = 13-14 TeV, L~1×10^{34} $cm^{-2}s^{-1}$, BS=25ns

Mainly more trigger upgrades

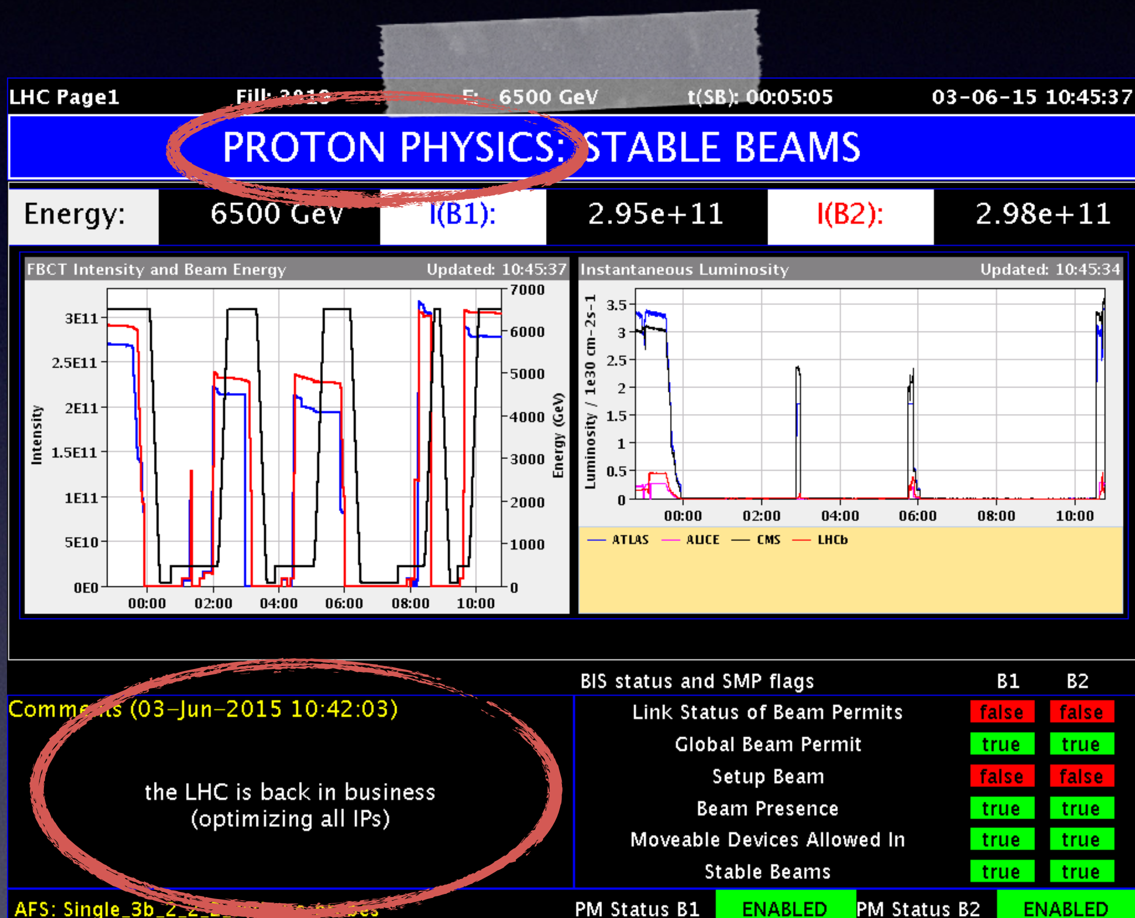
$\sqrt{s}$ = 14 TeV, L~2×10^{34} $cm^{-2}s^{-1}$, BS=25ns

Major upgrades for HL LHC

$\sqrt{s}$ = 14 TeV, L~5-7×10^{34} $cm^{-2}s^{-1}$, BS=25ns



Start of Run 2: Exciting Times

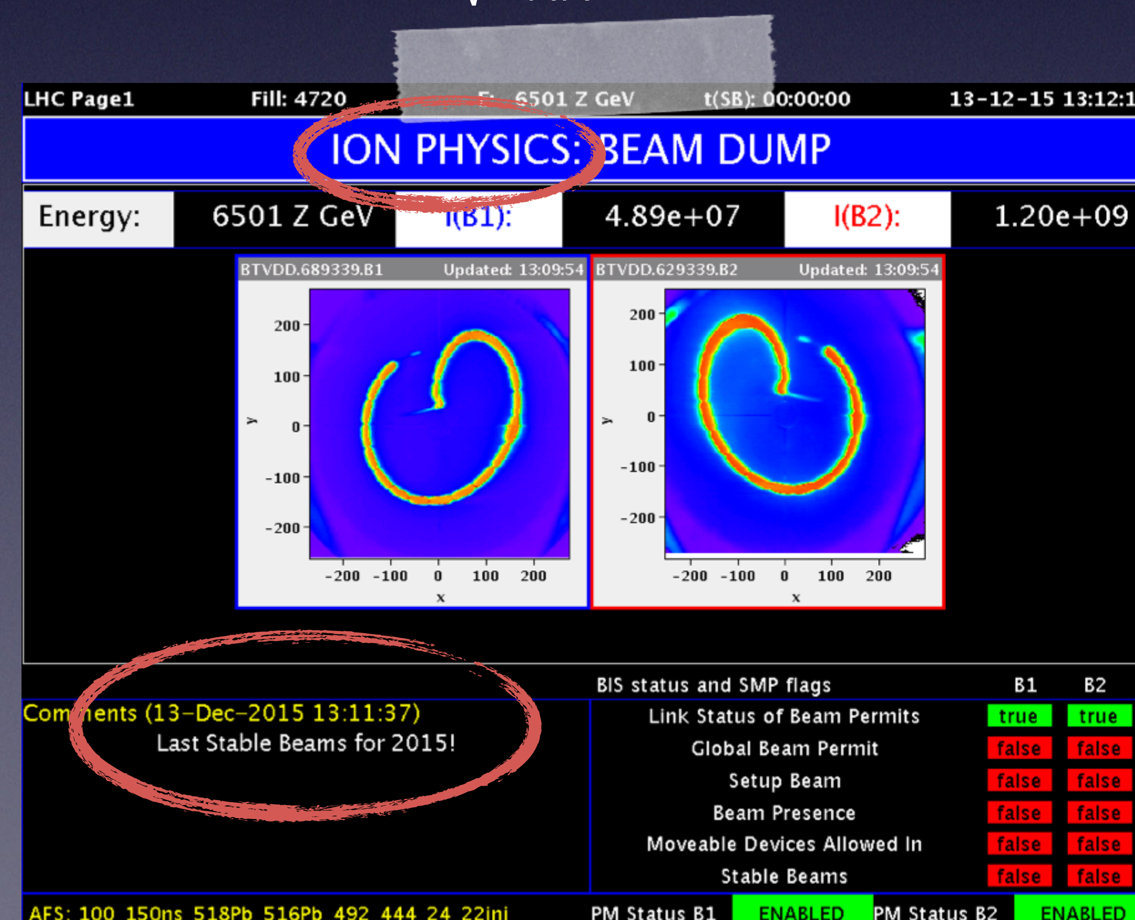


pp collisions at √s=13 TeV

- in 50ns and 25ns bunch spacing
- peak luminosity 5.1×10^{33} $cm^{-2}\,s^{-1}$

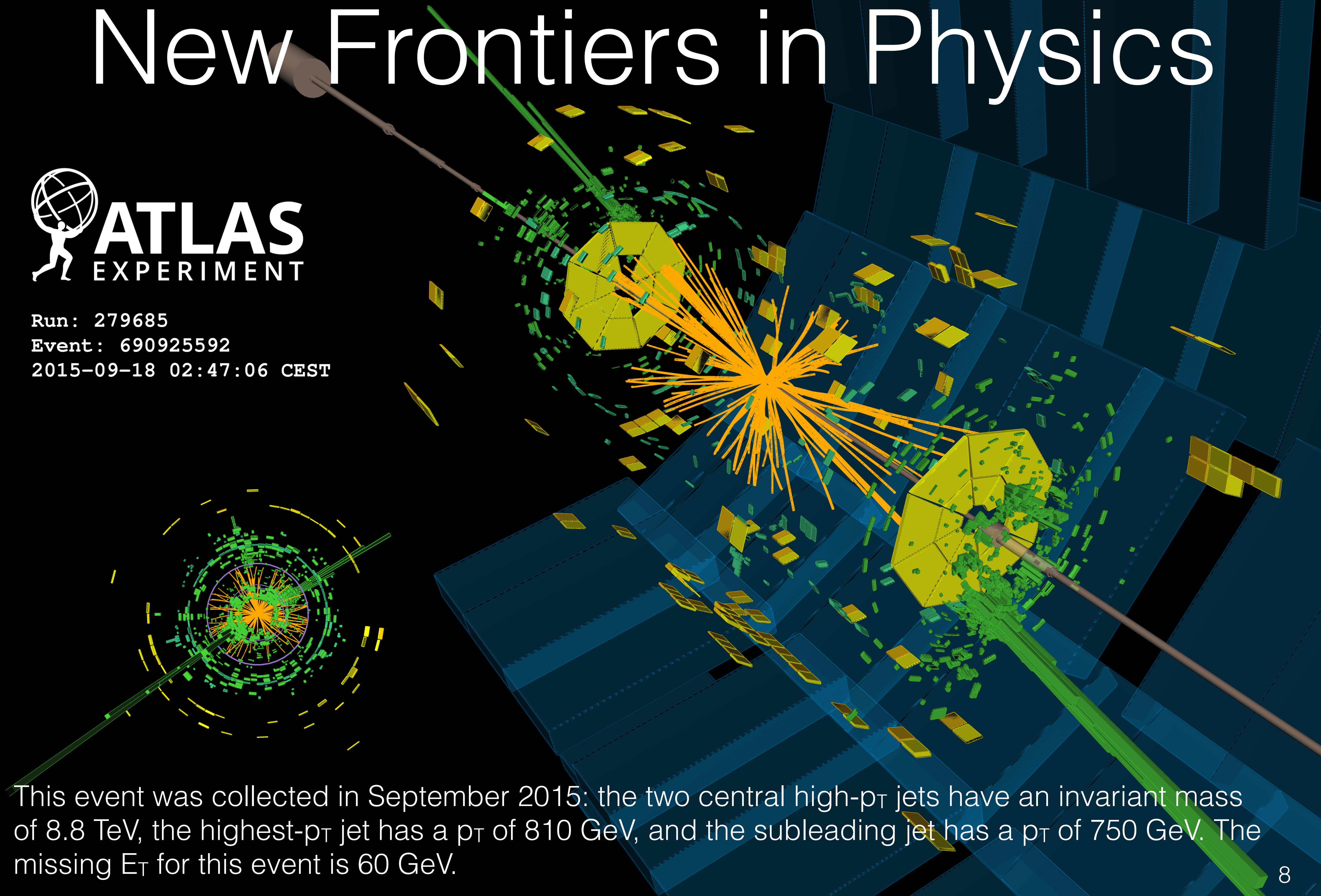
pp collisions at √s=5 TeV

Pb-Pb collisions at $\sqrt{s_{NN}}$=5 TeV



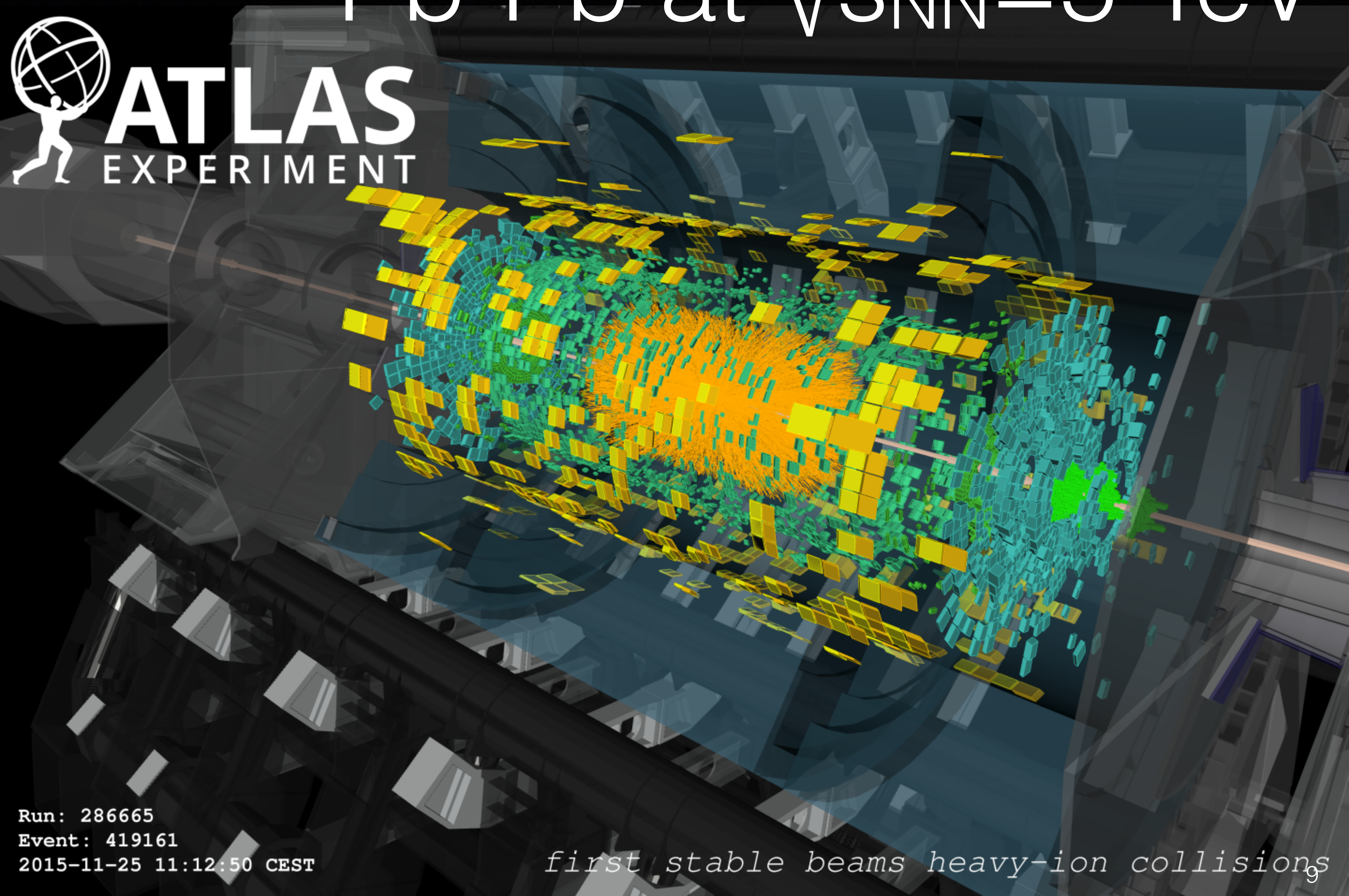
New era for proton-proton as well as heavy ion collisions

New Frontiers in Physics

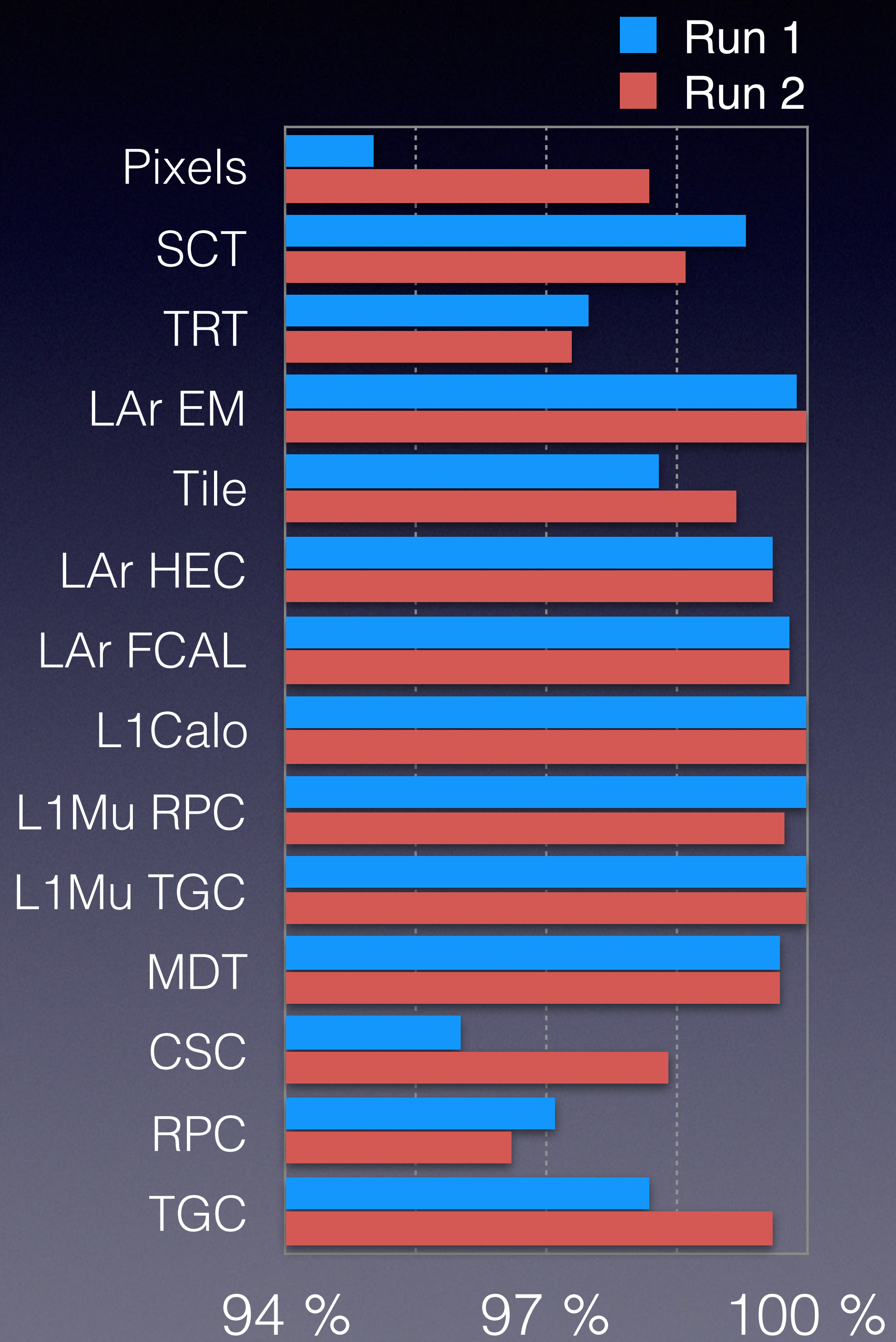


This event was collected in September 2015: the two central high-p_T jets have an invariant mass of 8.8 TeV, the highest-p_T jet has a p_T of 810 GeV, and the subleading jet has a p_T of 750 GeV. The missing E_T for this event is 60 GeV.

Pb-Pb at $\sqrt{s_{NN}}$=5 TeV



ATLAS Detector in 2015



ATLAS pp 25ns run: August-November 2015

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
93.5	99.4	98.3	99.4	100	100	100	100	100	100	97.8
All Good for physics: 87.1% (3.2 fb^{-1})										

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

- Overall smooth operation [Average recording efficiency 92.1%]
- Constant live fraction of channels
- Important re-commissioning with data
- Learned to operate “a new detector”

LS1/Run 2 Upgrades

Additional 4th silicon pixel layer [IBL]

Innermost layer at R=3.3cm

Infrastructure

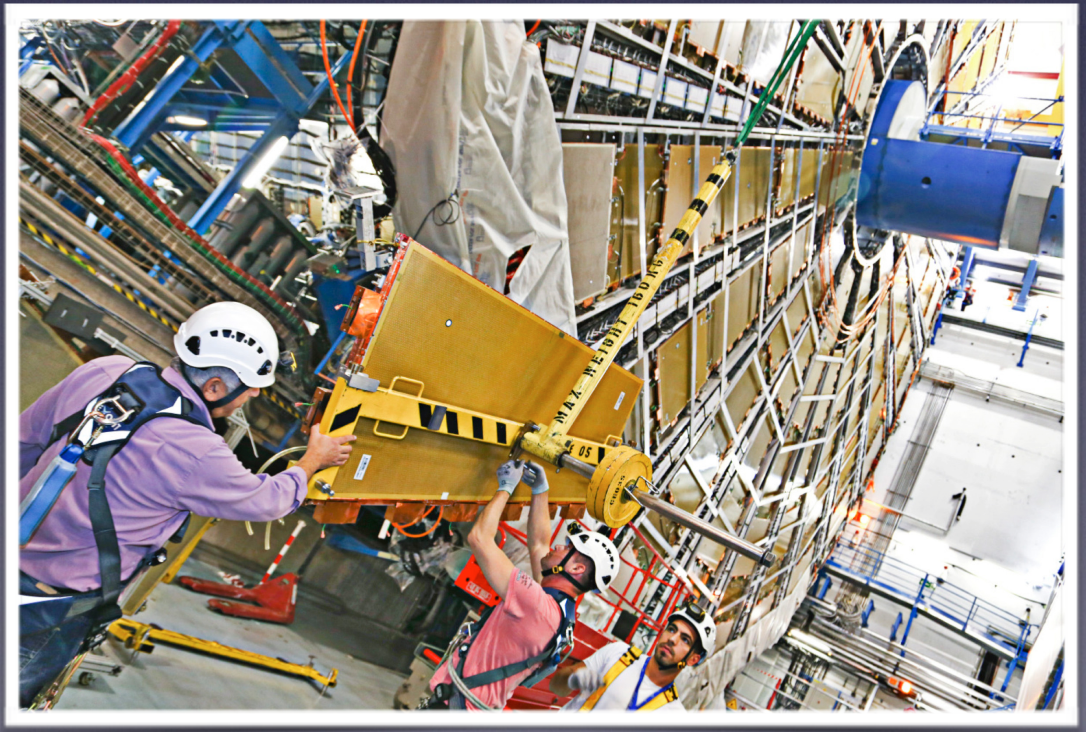
New beam pipe, improvements to magnet and cryogenic system

Detector consolidation

More muon chambers, improved readout for 100 kHz L1 rate, LAr and Tile power supply replacements, new lumi detectors, new MBTS

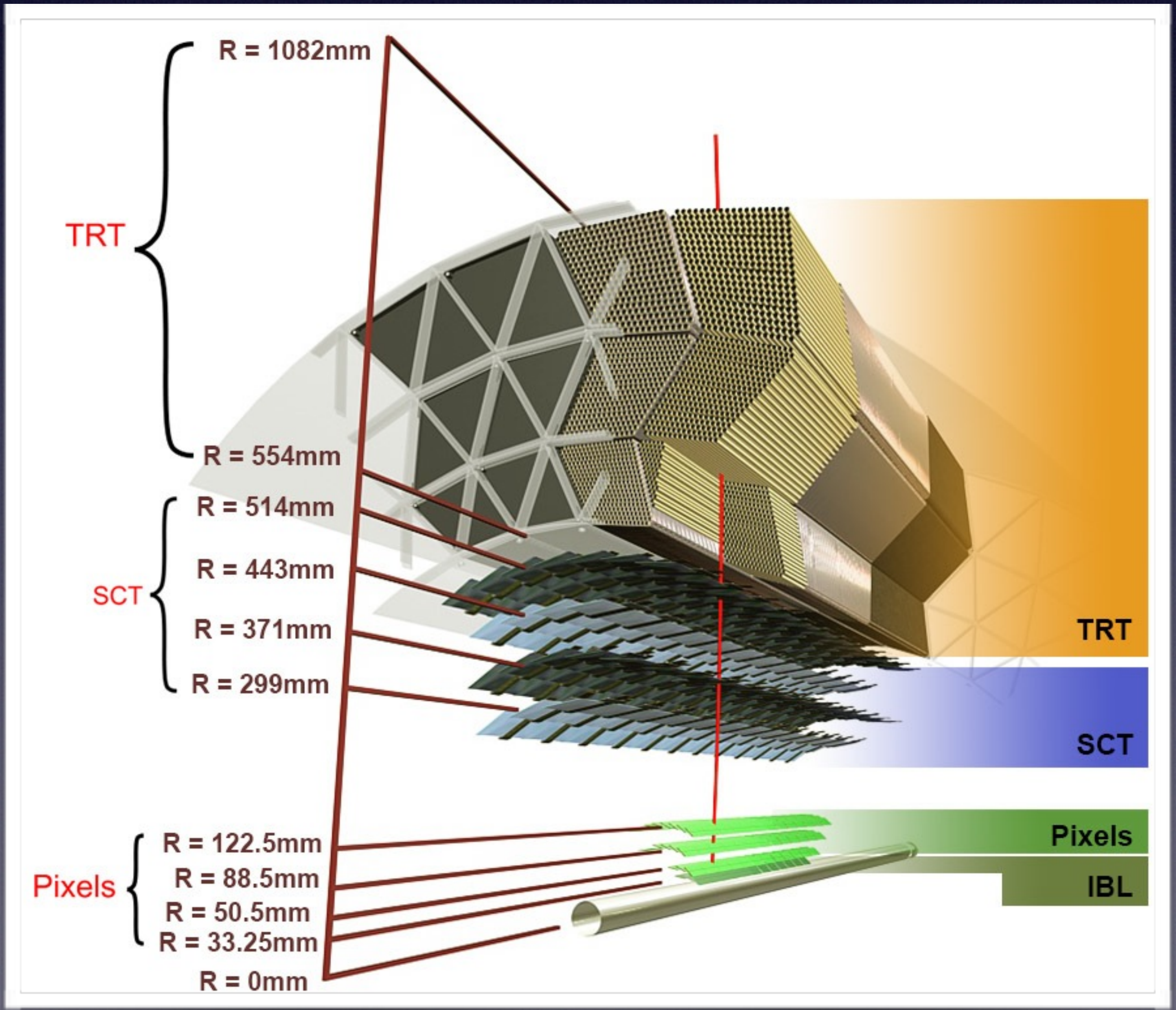
Trigger/DAQ improvements

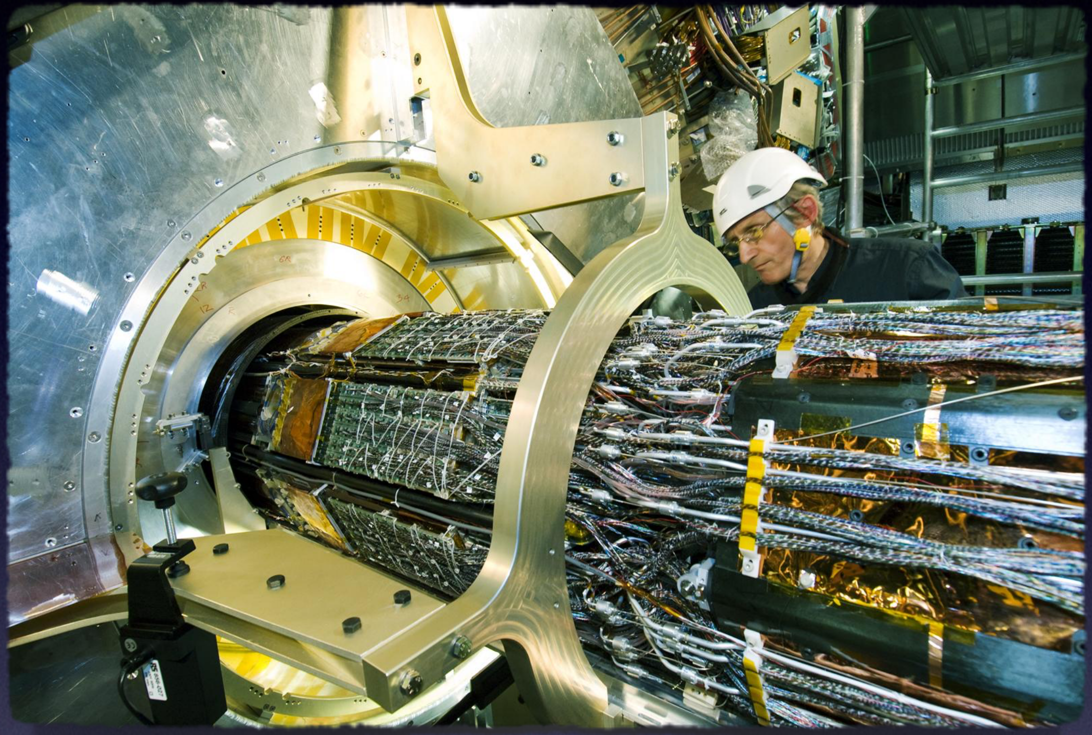
New L1 topological trigger [L1Topo], new L1 Central Trigger Processor, improved L1Calo, Tile-muon coincidence, Fast TracK Trigger [FTK], restructured High Level Trigger



Inner Detectors

Three ATLAS tracking detectors:
Pixels, SCT and TRT



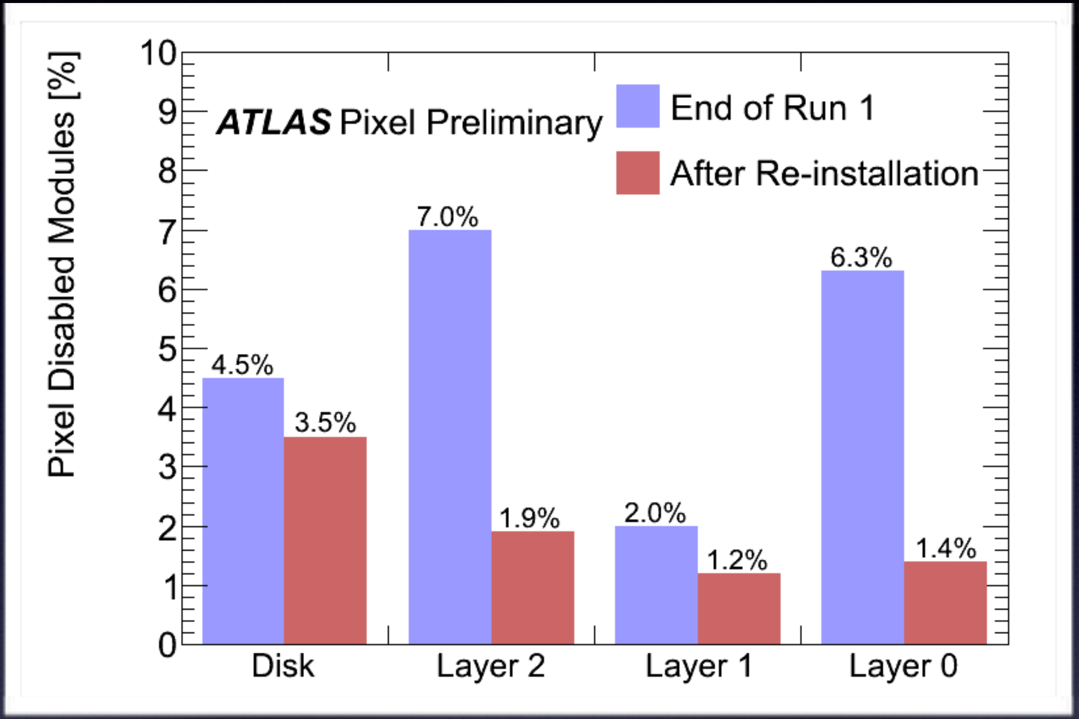


Pixel installation [Nov 2007]

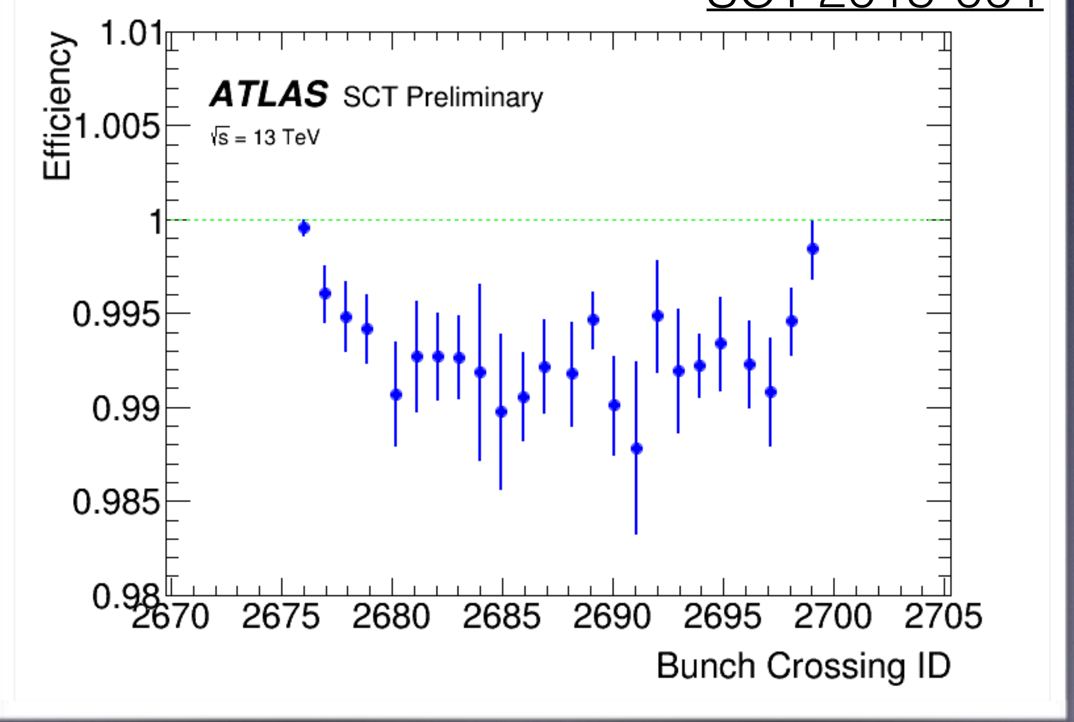
- New innermost 4th layer for the Pixel detector [IBL = Insertable B-Layer]
- Required complete removal of the ATLAS Pixel volume
- IBL fully operational

[See talk by Ewa Stanecka]

Inner Detector Performance



SCT-2015-001



Pixel Tracker

- Overall smooth operation
- More functional modules compared to run 1
- IBL enhances tracking close to IP

SemiConductor Tracker — SCT

- Stable and reliable throughout 2015
- 98.6% of 6 million strips active for tracking
- Small drop in hit efficiency with 25ns beams [Expected due to veto on hit in previous BC]

Transition Radiation Tracker — TRT

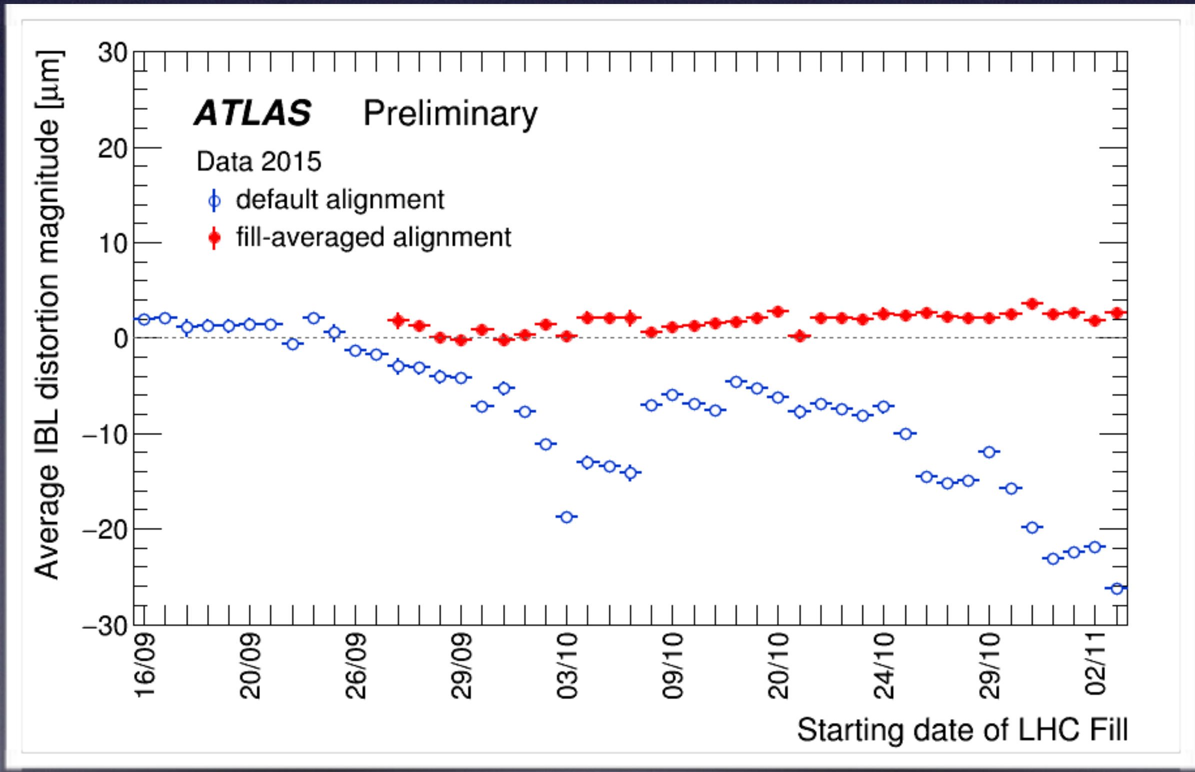
- Proved to sustain 100 kHz at 50% occupancy
- Still some gas leaks — Negligible impact on electron identification

IBL Performance

Bowing of ~10μm/K observed during cosmic ray commissioning in early 2015

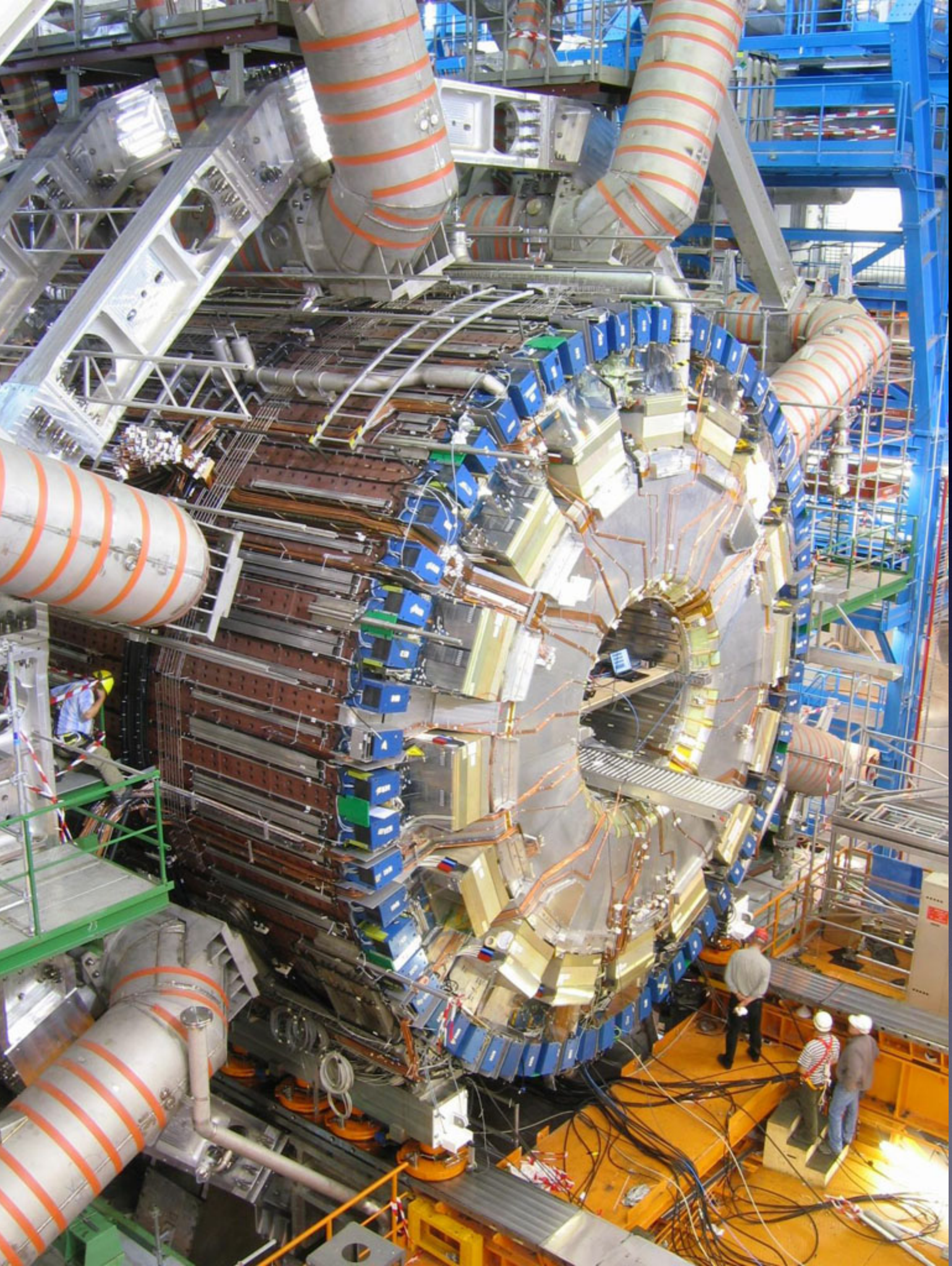
- During normal operations temperature stable to 0.2K
- Becomes an issue due to LV front-end current drifts observed during data taking
- Current drifts are understood due to radiation and expected to improve

Alignment correction applied on run-by-run basis, no significant impact left on tracking



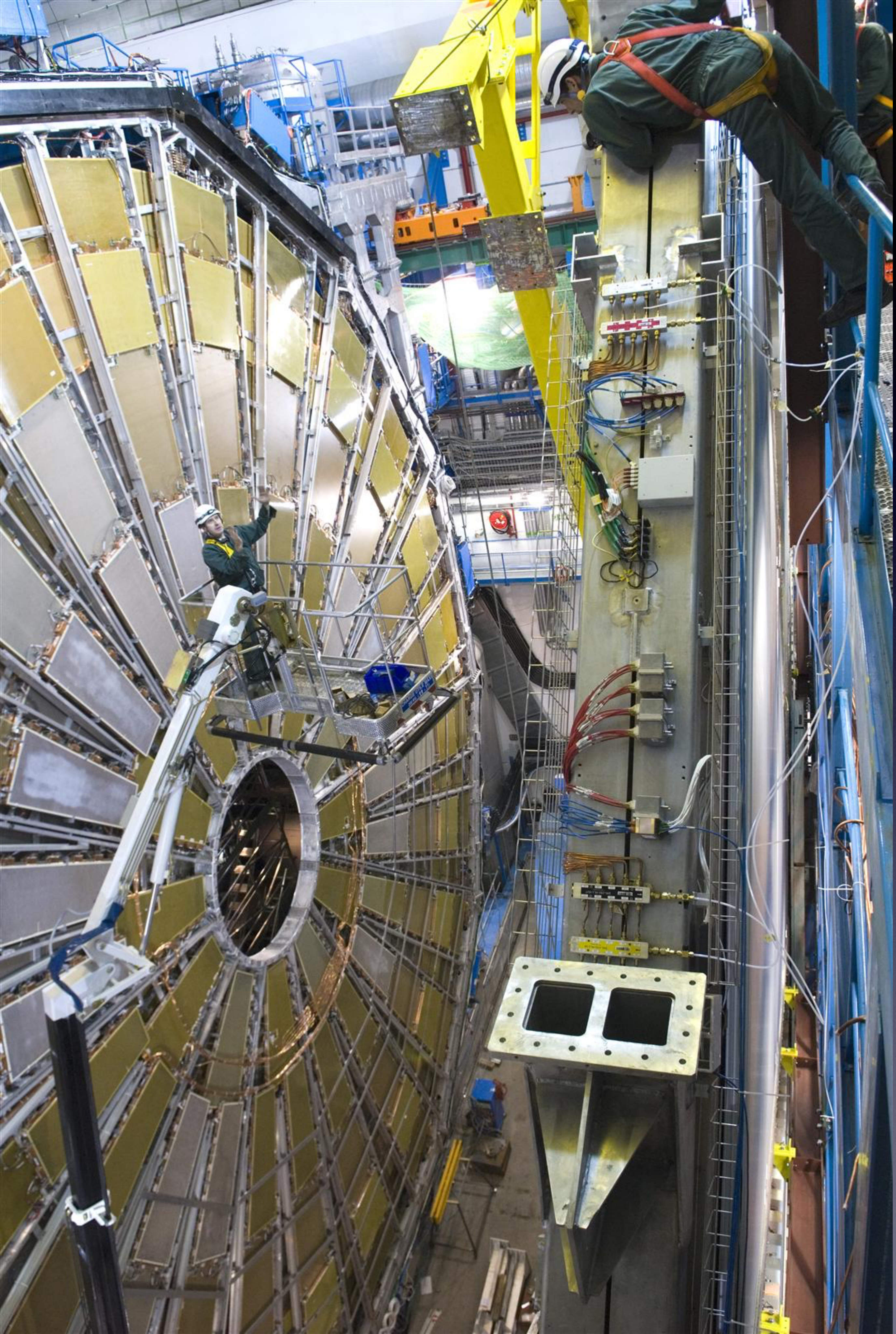
IBL significantly improves impact parameter resolution [see talk by Hong Ma later]

ATL-INDET-PUB-2015-001



Calorimeters

- Very stable performance
- Improved stability of new Tile power supplies
- Good operation efficiency: 99.4% [LAr] and 100% [Tile]
- LAr using 4 instead of 5 sample readout to achieve 100 kHz
- Physics performance, see Hong's talk later



Muon Systems

Two triggering systems

- Restive Plate Chambers [RPC]: $|\eta|<1.05$
- Thin Gap Chambers [TGC]: $1.0 < |\eta| < 2.4$

Precise muon chambers

- Monitor drift tubes [MDT]: barrel and end-cap
- For $|\eta| > 2.0$ also Cathode Strip Chambers [CSC]

Improved acceptance from additional chambers in feet and elevator regions

Physics performance, see Hong's talk

Trigger/DAQ System

- Centre-of-mass energy 8→13 TeV — 2-2.5x increase in trigger rates
- Peak luminosity 0.8→1.7×10^{34} cm^{-2}s^{-1} — ~2x higher trigger rates

Possible options:

Increase output rate

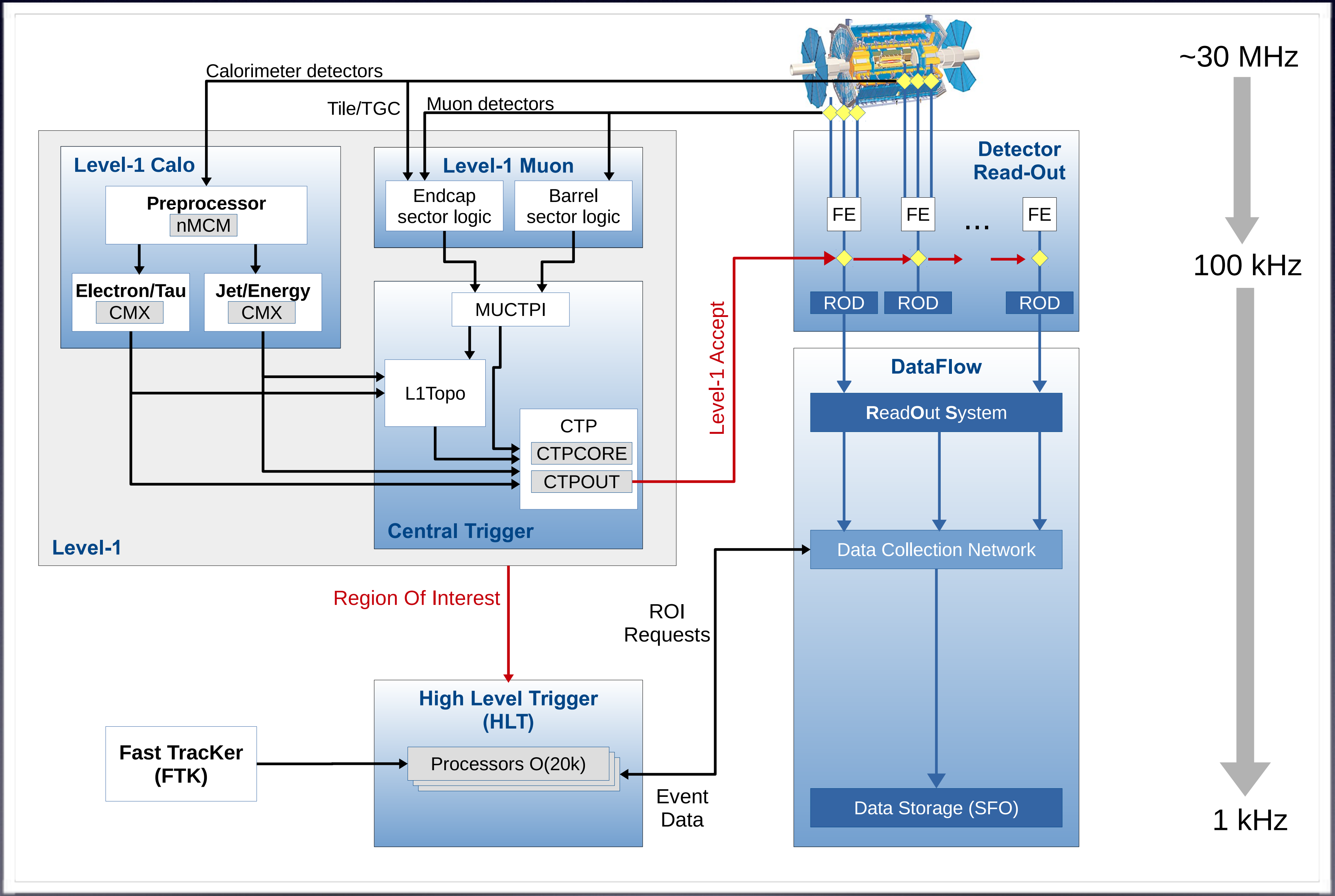
➡ Challenge for offline computing

Increase thresholds

➡ Lose interesting physics

Increase rejection

➡ Better hardware and software



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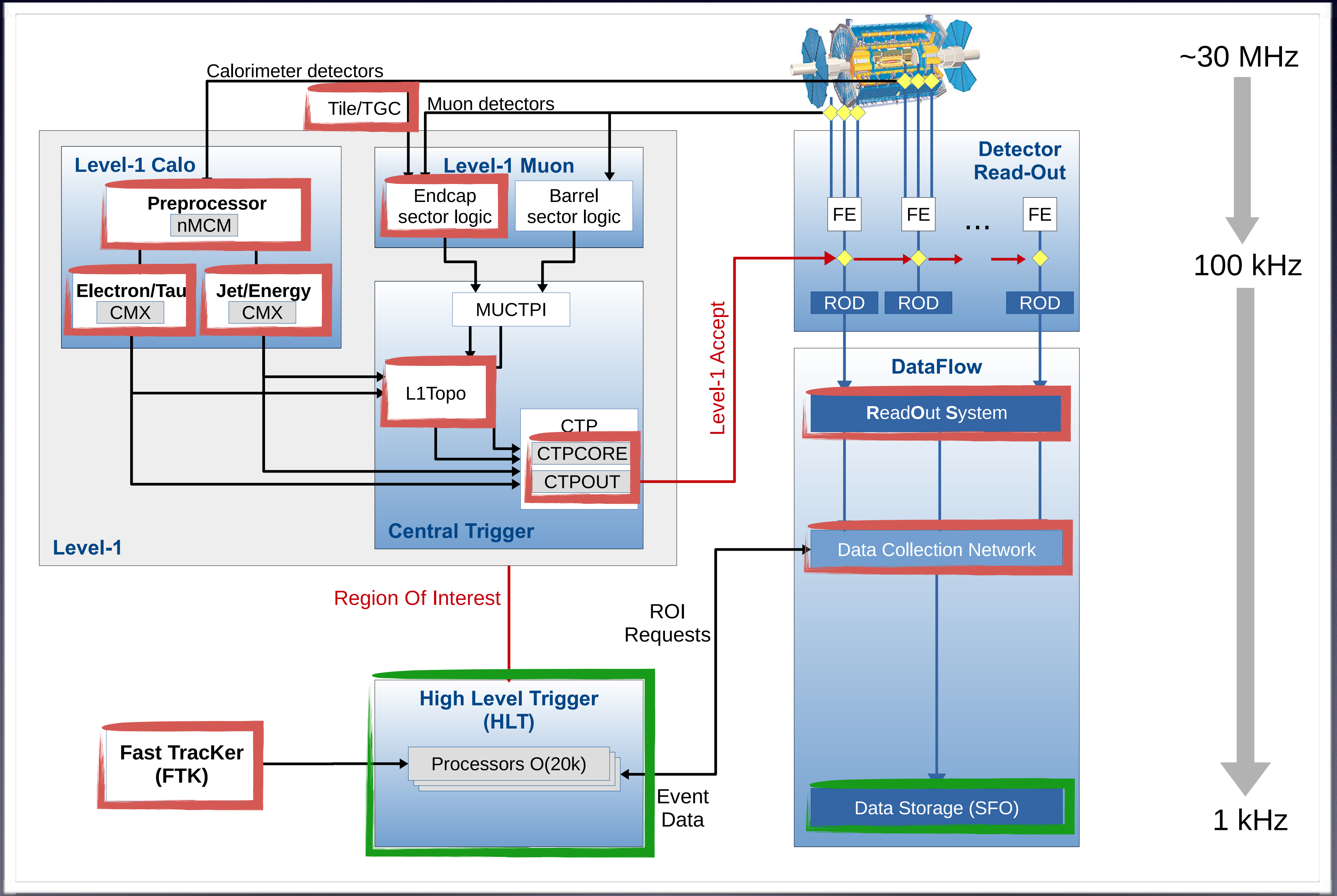
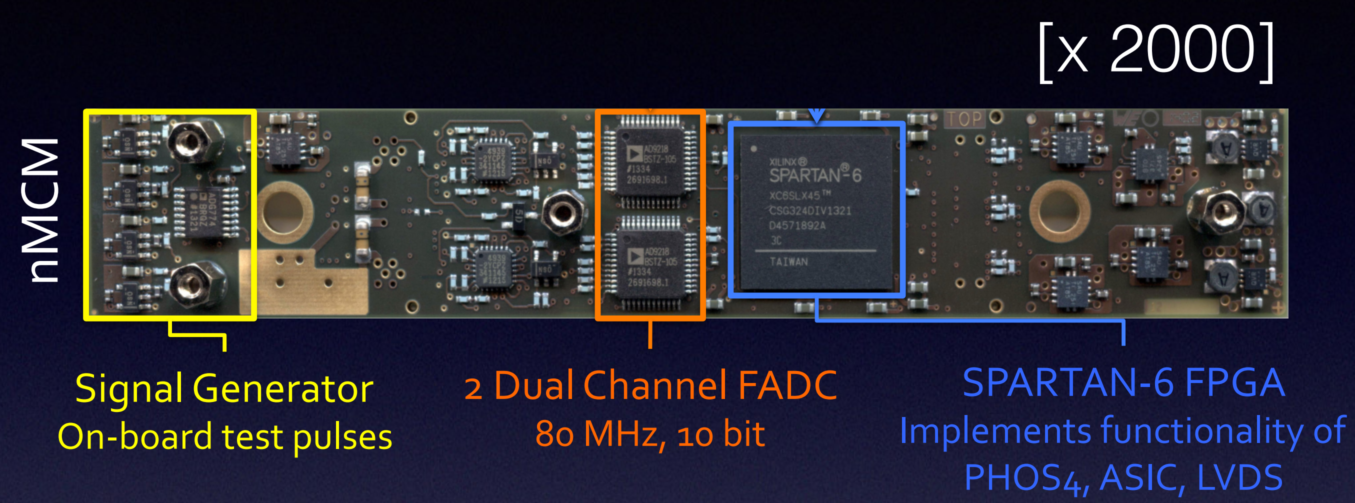
➡ Better **hardware** and **software**

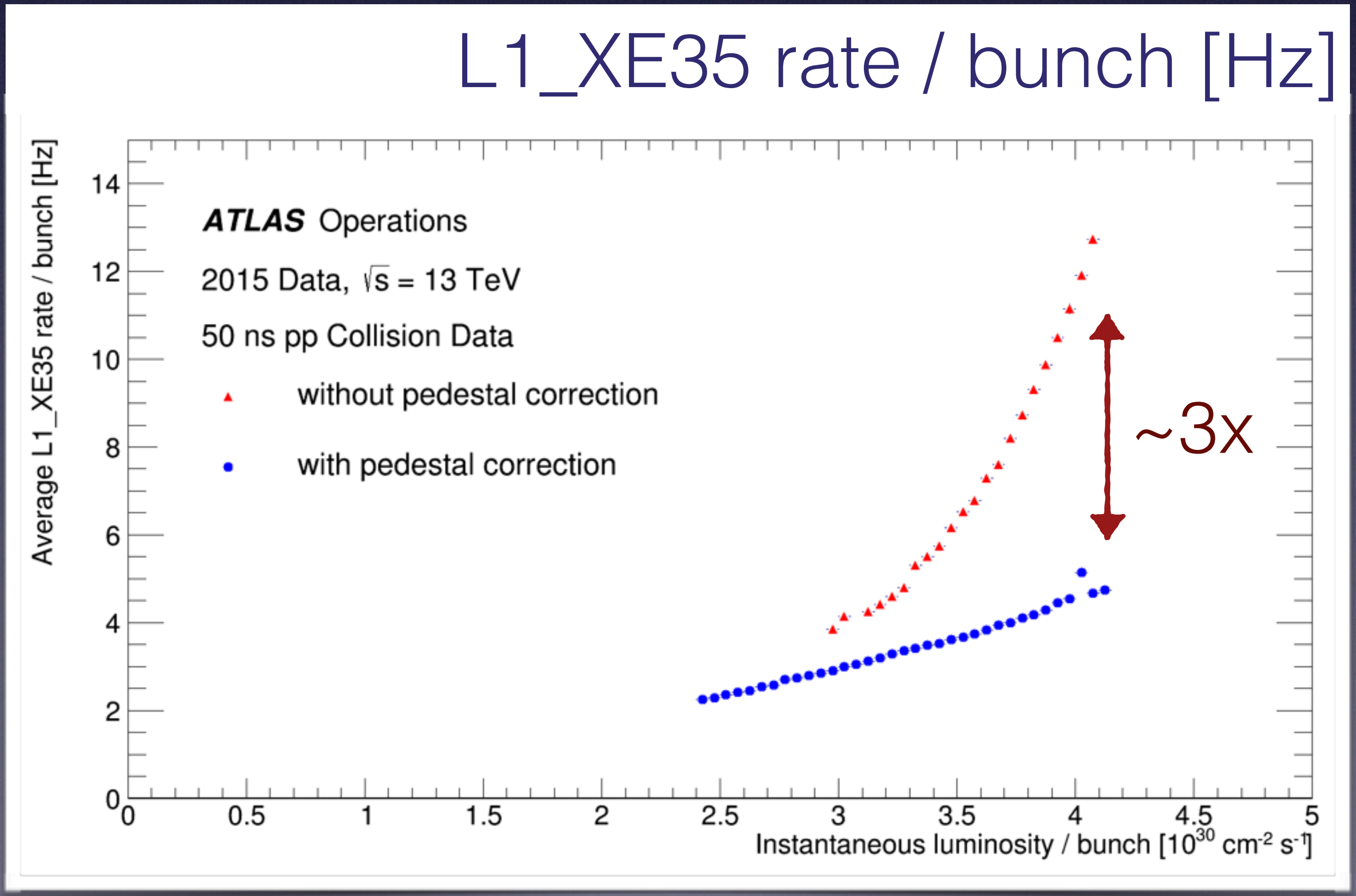


Level-1 Calorimeter Trigger

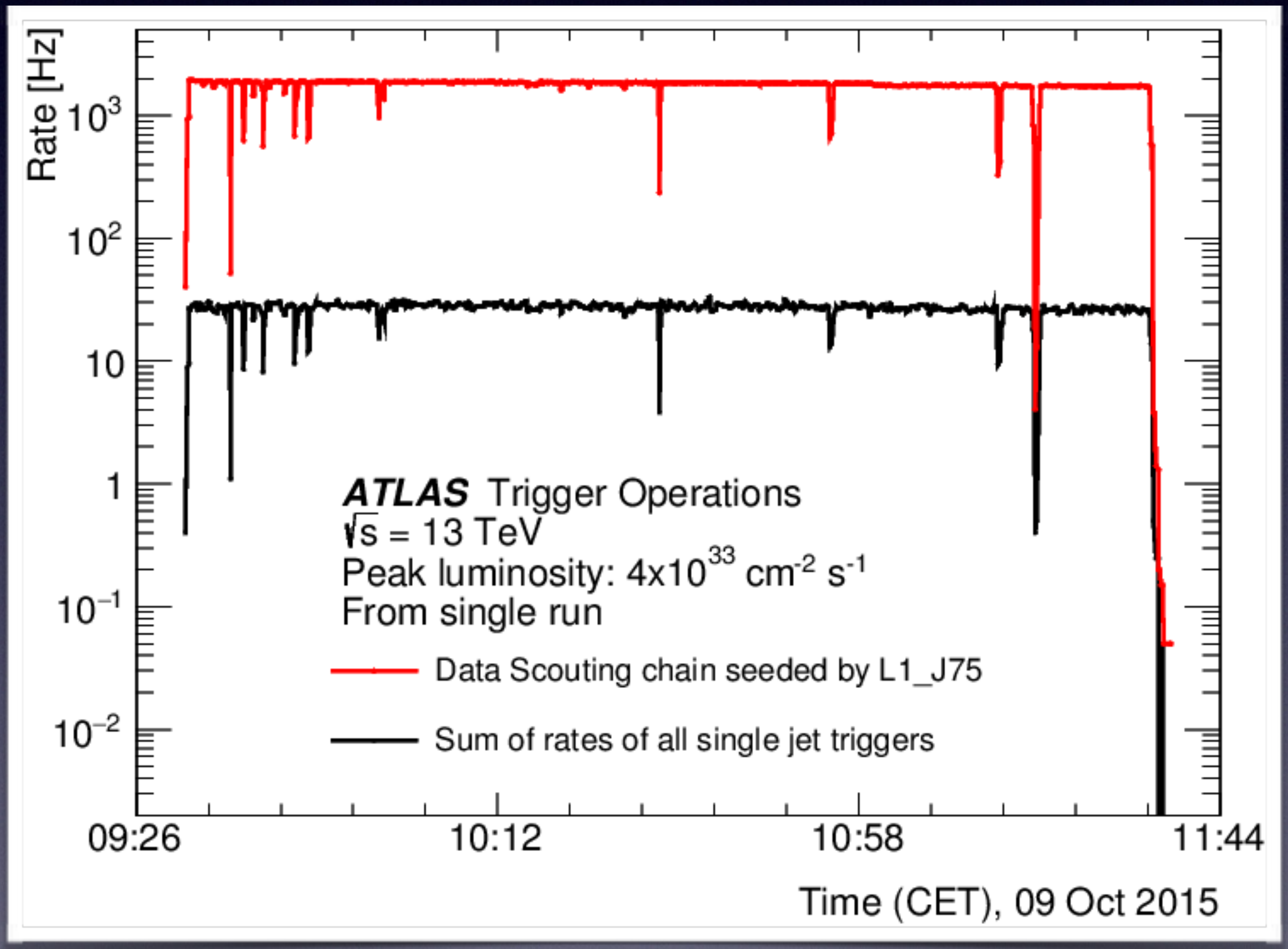


- Various upgrades applied to L1Calo
- E.g. upgrade of ~2000 Multi Chip Modules in the Preprocessor [ASIC ↔ FPGA]

- Pile-up induced pedestal fluctuations led to increased MET rates during run 1
- Dynamic pedestal correction in nMCM resulting in dramatic rate improvement



Trigger Level Analysis

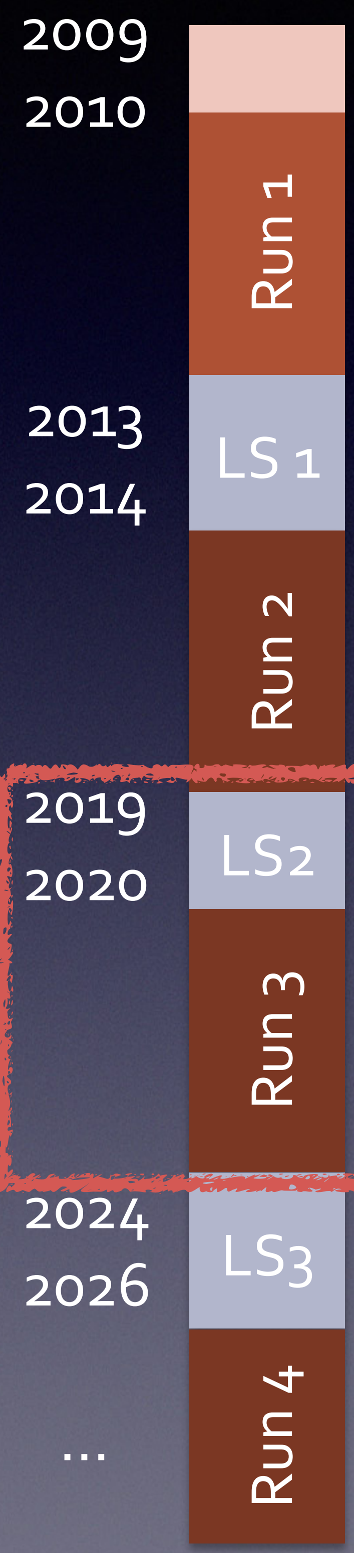


- Di-jet resonance search limited to m_{jj}>1.1TeV
- Lowest unprescaled single jet is 360 GeV
- Store only HLT jets instead of full ATLAS event

➡ 2 kHz vs 200-300 Hz

➡ Enhanced sensitivity to lower BSM mediator masses

ATLAS Timeline



Total L1A rate limited to ≈100 kHz until LS3

← Enhancements to trigger and detector

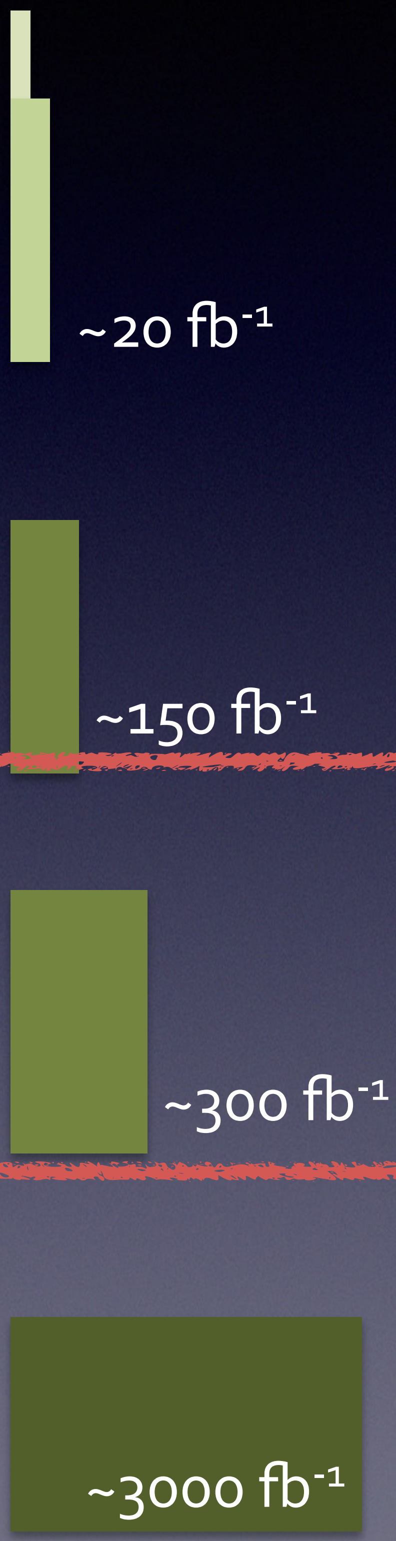
$\sqrt{s}$ = 13-14 TeV, L~1×10^{34} cm^{-2}s^{-1}, BS=25ns

← Mainly more trigger upgrades

$\sqrt{s}$ = 14 TeV, L~2×10^{34} cm^{-2}s^{-1}, BS=25ns

← Major upgrades for HL LHC

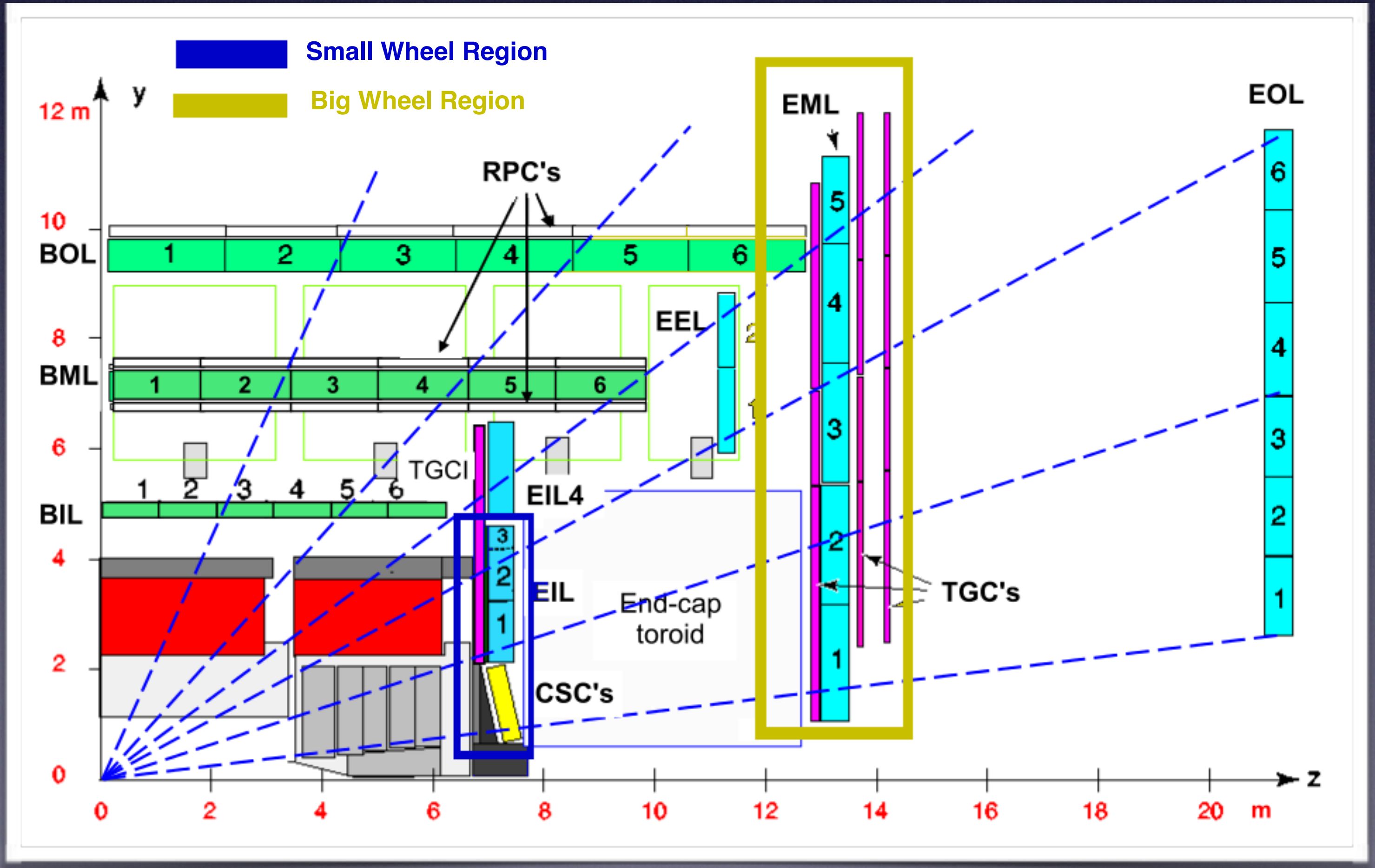
$\sqrt{s}$ = 14 TeV, L~5-7×10^{34} cm^{-2}s^{-1}, BS=25ns



Aka. Phase-I

LS2/Run 3 Upgrades

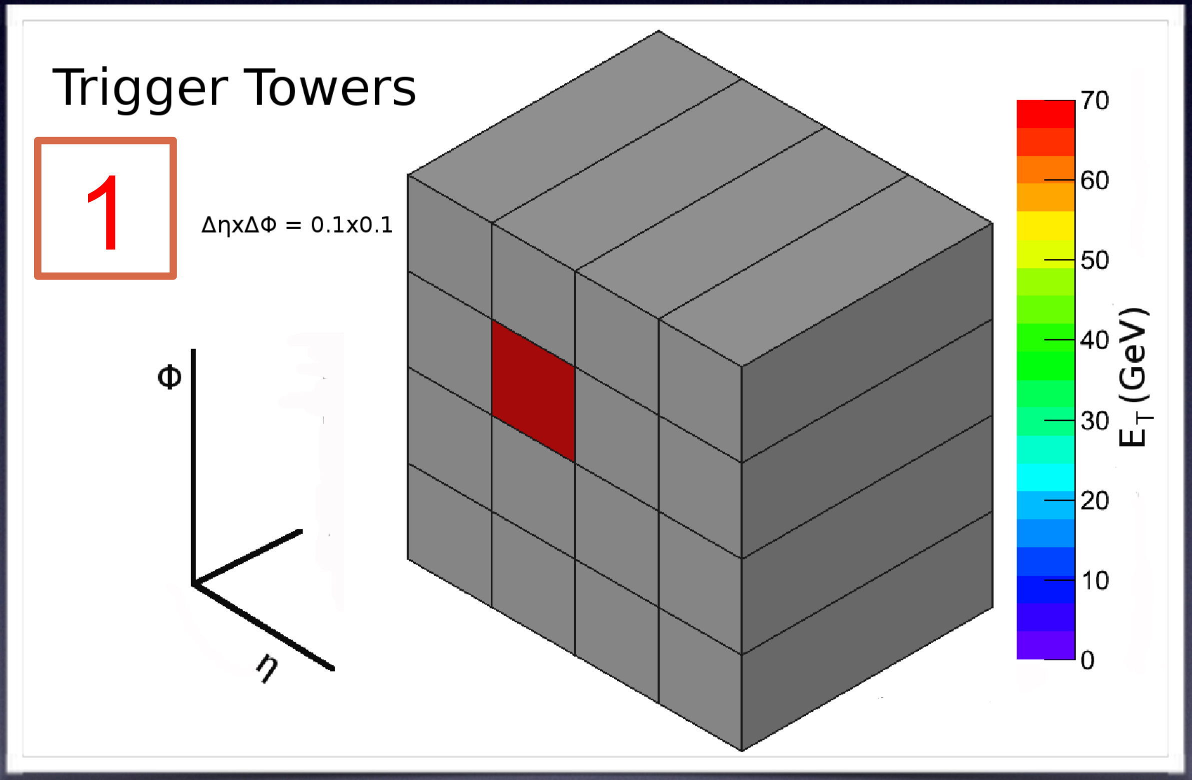
- Goal is to provide better trigger capabilities to maintain the same performance at higher pileup [μ~80]
- The four main Phase-I Technical Design Reports are approved
  - New Small Wheel for muon trigger [NSW]
  - Hardware based track trigger [FTK] for HLT
  - Finer granularity for L1Calo [LAr, TDAQ]

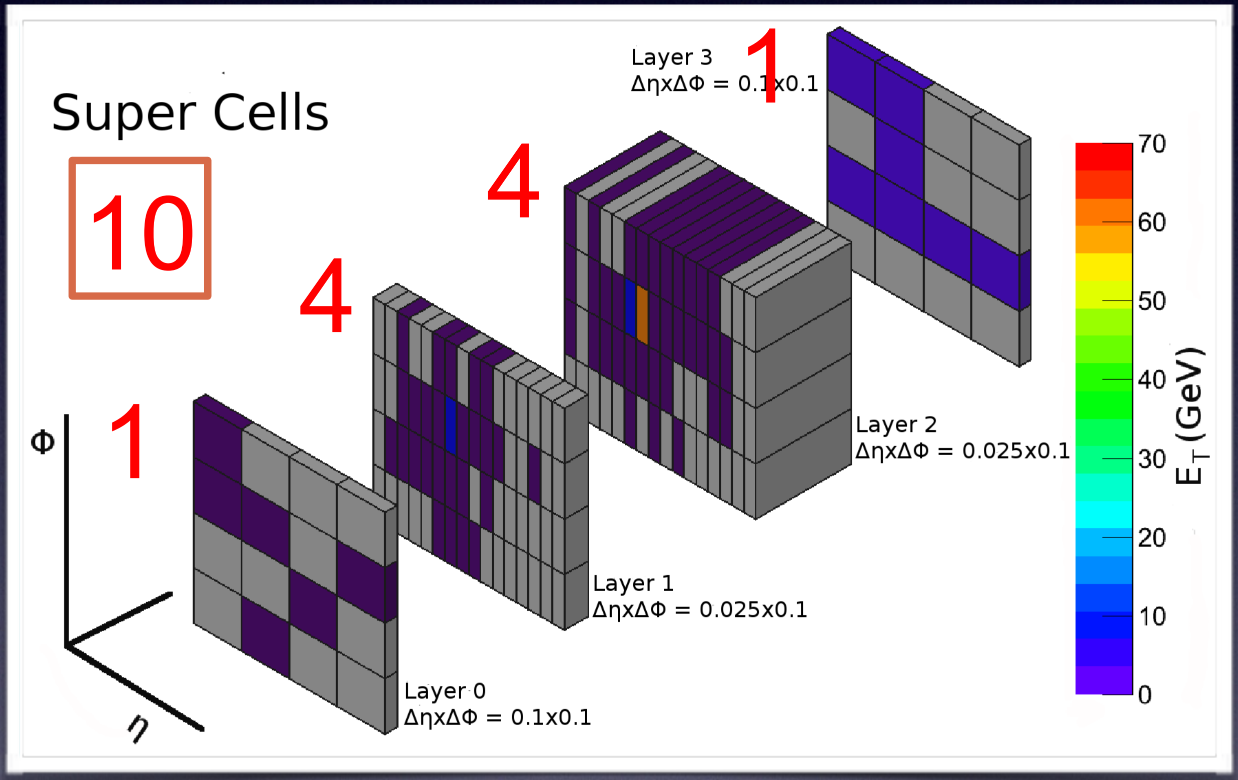


CERN-LHCC-2013-006

New LAr Trigger Signals

Electron with E_T=70 GeV as seen by run 1/2 vs. run 3 system





Trigger towers → ΔηΔΦ=0.1×0.1

Jet background most critical for electron identification

Layer information maintained

Higher eta granularity

Finer energy quantisation

ATLAS Timeline

2009
2010
Run 1

Total L1A rate limited to ≈100 kHz until LS3

~20 fb^{-1}

2013
2014
LS 1

Enhancements to trigger and detector

Run 2

$\sqrt{s}$ = 13-14 TeV, L~1×10^{34} $cm^{-2}s^{-1}$, BS=25ns

~150 fb^{-1}

2019
2020
LS2

Mainly more trigger upgrades

Run 3

$\sqrt{s}$ = 14 TeV, L~2×10^{34} $cm^{-2}s^{-1}$, BS=25ns

~300 fb^{-1}

2024
2026
LS3

Major upgrades for HL LHC

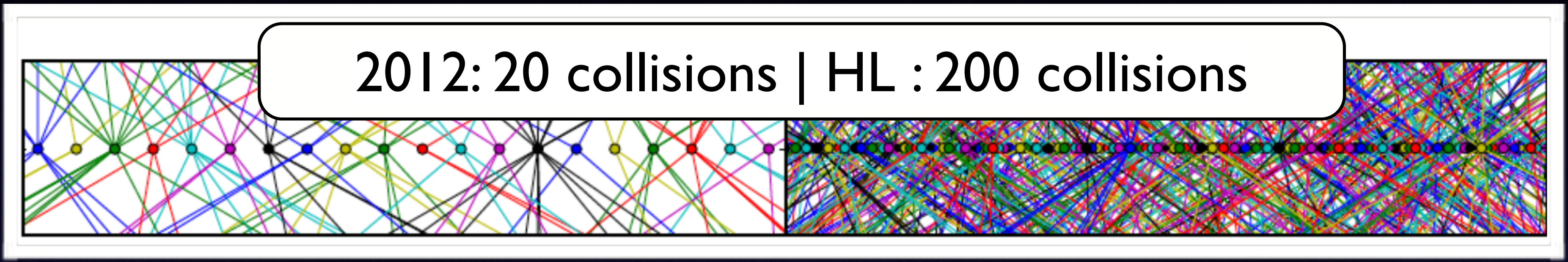
…
Run 4

$\sqrt{s}$ = 14 TeV, L~5-7×10^{34} $cm^{-2}s^{-1}$, BS=25ns

~3000 fb^{-1}

Aka. Phase-II

LS3/Run 4 Upgrades



New Phase-II Upgrade Scoping Document: CERN-LHCC-2015-020

TDAQ: Aim for 1 MHz accept rate and tracking at L1 to maintain low thresholds

- Two levels of custom-hardware triggers, L0 and L1, including new L1Track

Tracking: Need to cope with the increased pile-up and radiation

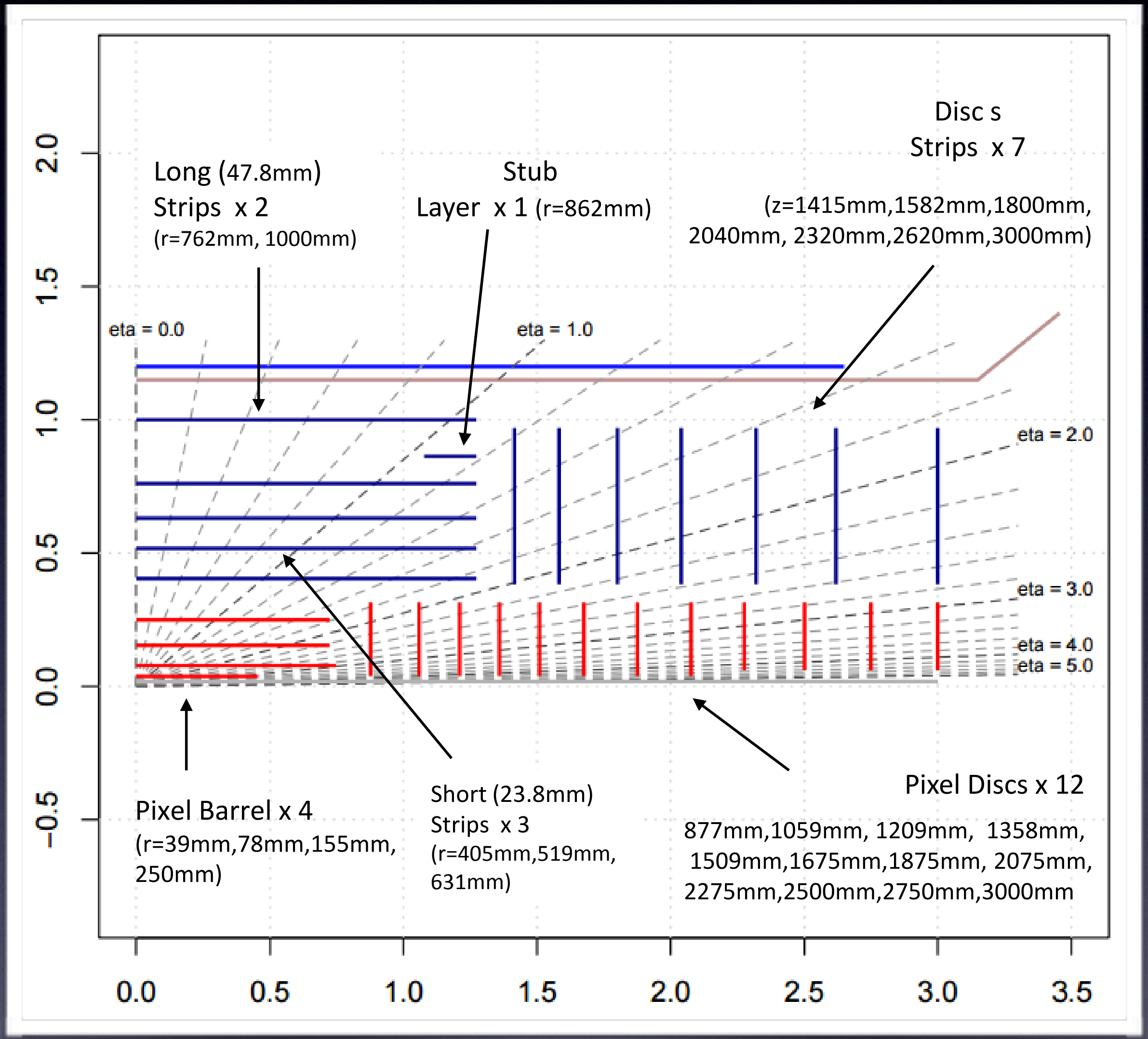
- ITK — A complete new all silicon tracker, up to $|\eta|<4.0$

Forward Calorimetry: Higher transverse granularity to cope with large energy fluctuations at very high pile-up (space charge effects, HV drops, over-heating)

- sFCAL — Design similar to that FCAL but narrower LAr gaps
- miniFCAL — In front of the FCAL

Overview of ITK Upgrade

- Need robust tracking and minimal material
- Various designs are considered, including extension to large |η|
  - Strip tracker:
    5 layers, stubs,
    7 disks on each side
  - Pixel tracker:
    4 layers, 12 disks



Track parameter $|\eta| < 0.5$	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

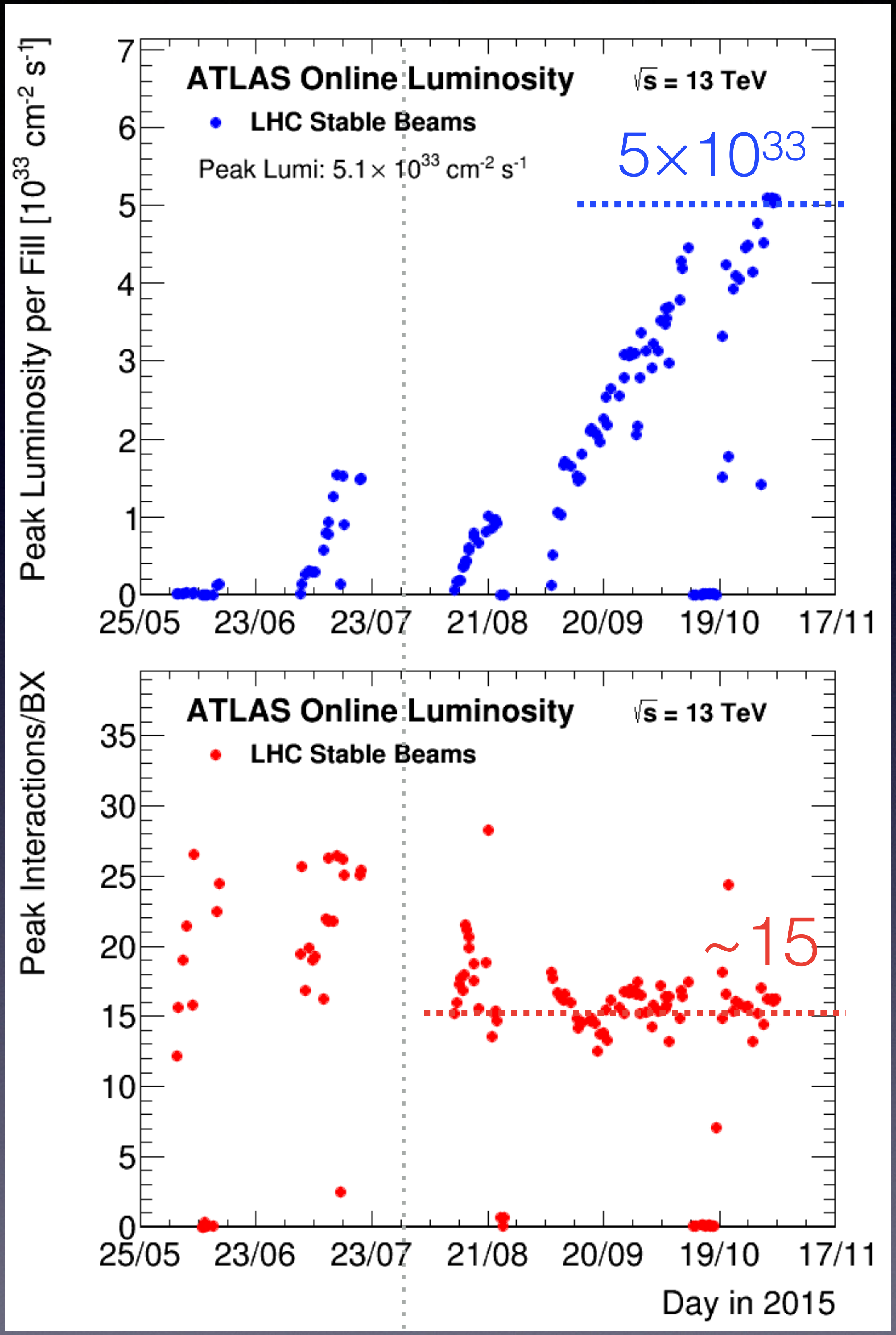
CERN-LHCC-2012-022

Conclusions

- Start of LHC run 2 — Exciting times!
  - Overall smooth commissioning and running
  - Learned to operate a new detector
- Phase I upgrade focussing on trigger
  - Maintain low thresholds at up to 2x design luminosity
- Phase II upgrade essential to operate the detector at up to 7x design luminosity

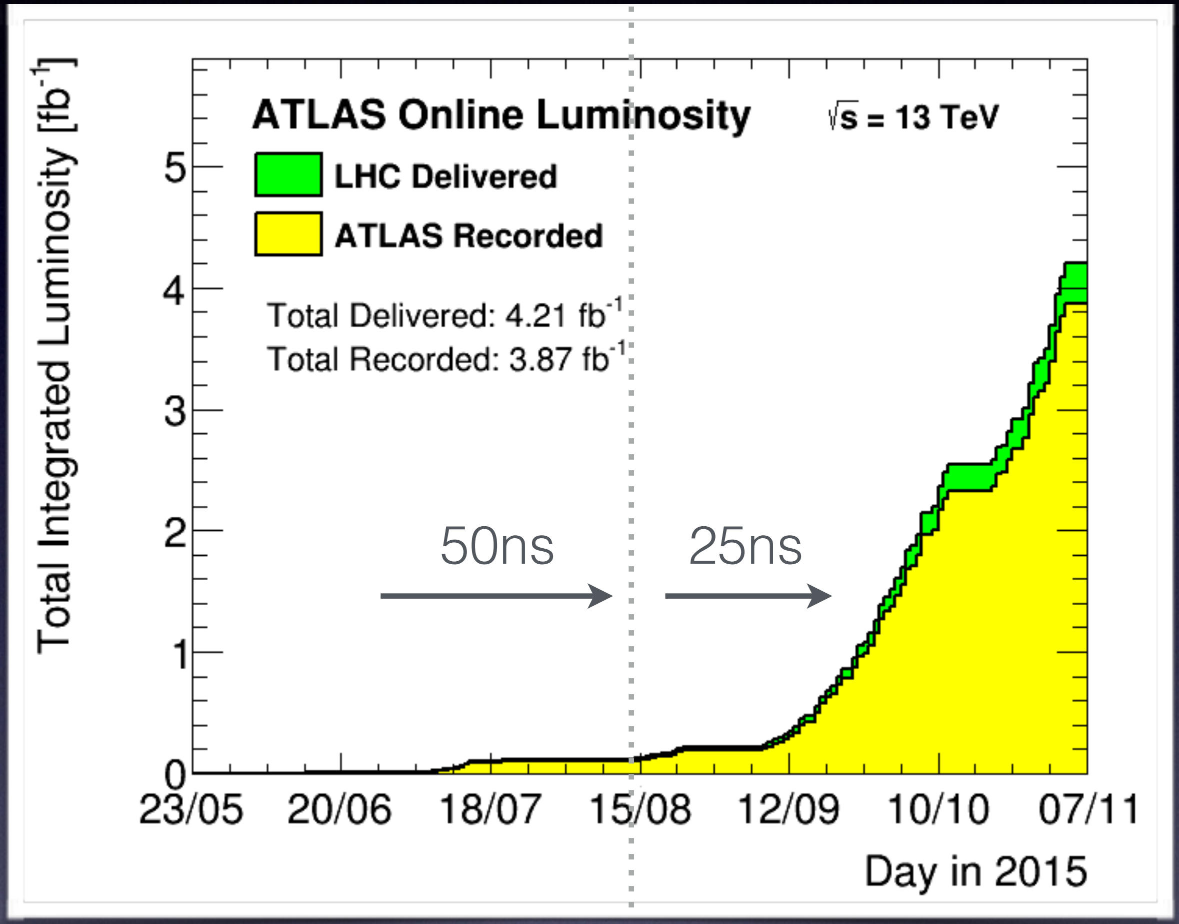
Additional Material

pp at 13 TeV



50ns Spacing

25ns Spacing

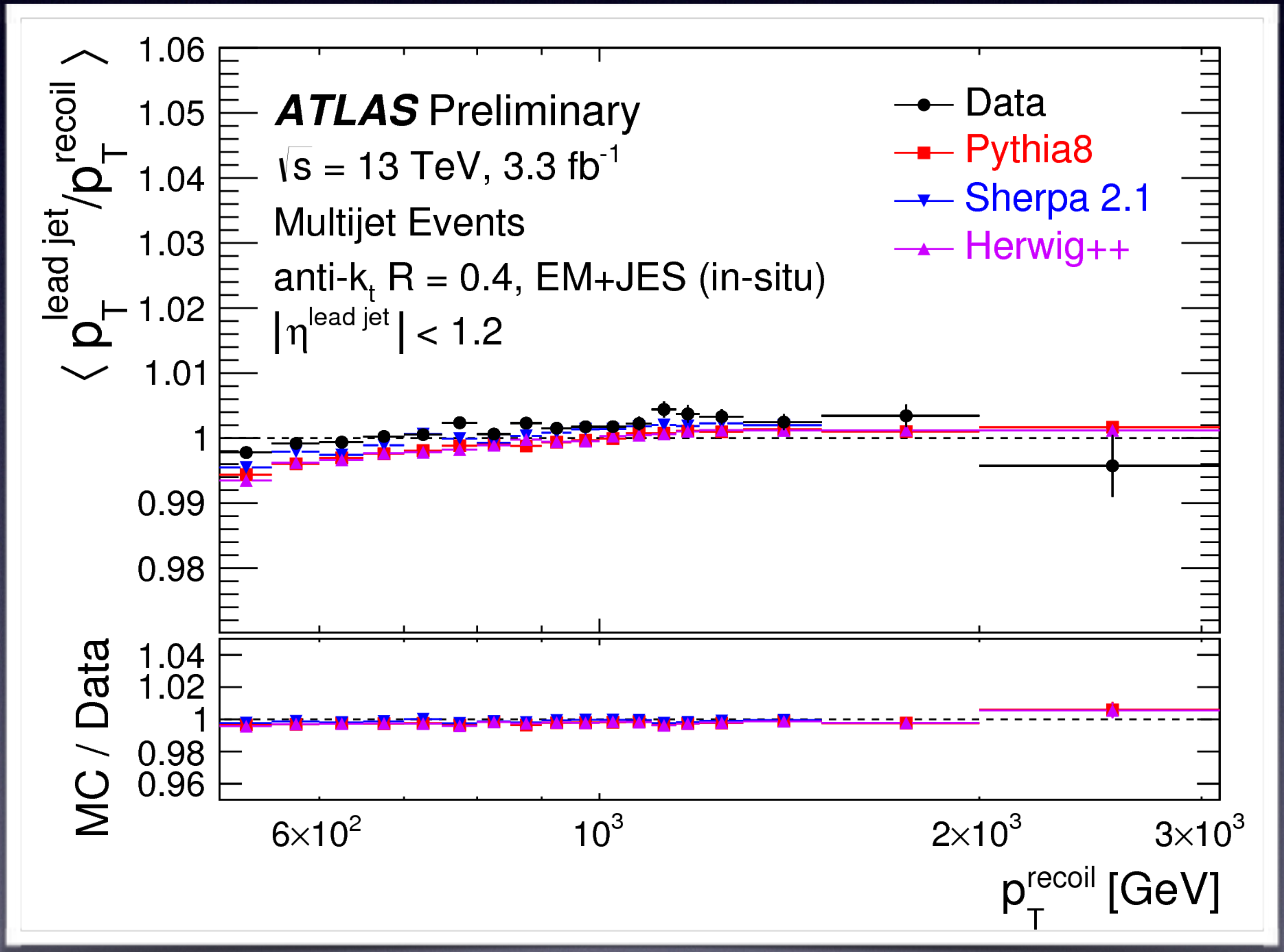


Average recording efficiency 92.1%

	Run 1 [8 TeV]	Run 2 [13 TeV]
Peak lumi [$cm^{-2}s^{-1}$]	7.7×10^{33}	5.1×10^{33}
Integrated Lumi [fb^{-1}]	22.8	4.2
Mean Interactions/BX	21	14
Data Taking Eff.	93 %	92%

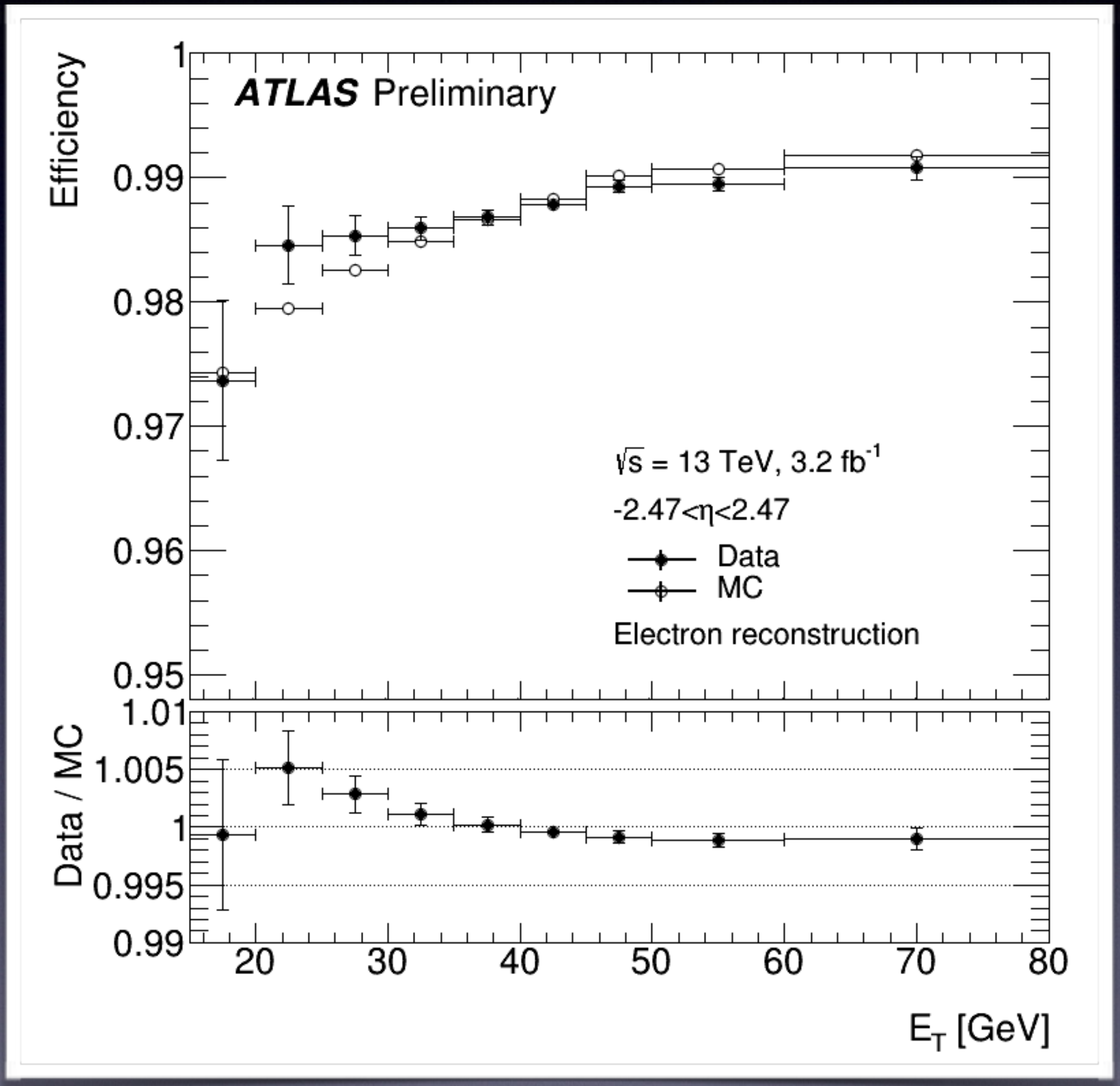
Calorimeter Performance

JETM-2015-003



P_T balance in multi-jet events [part of the in-situ JES calibration]

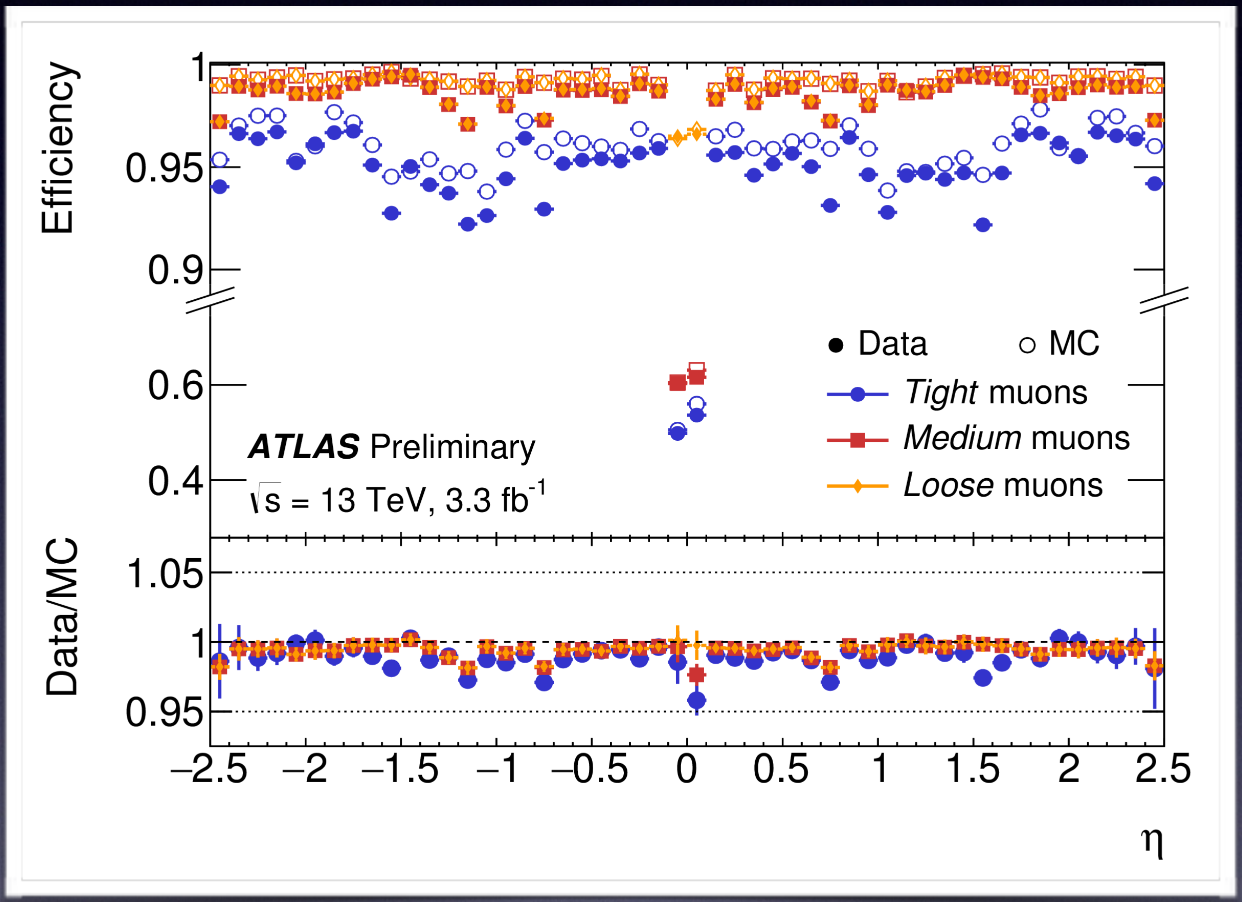
EGAM-2015-006

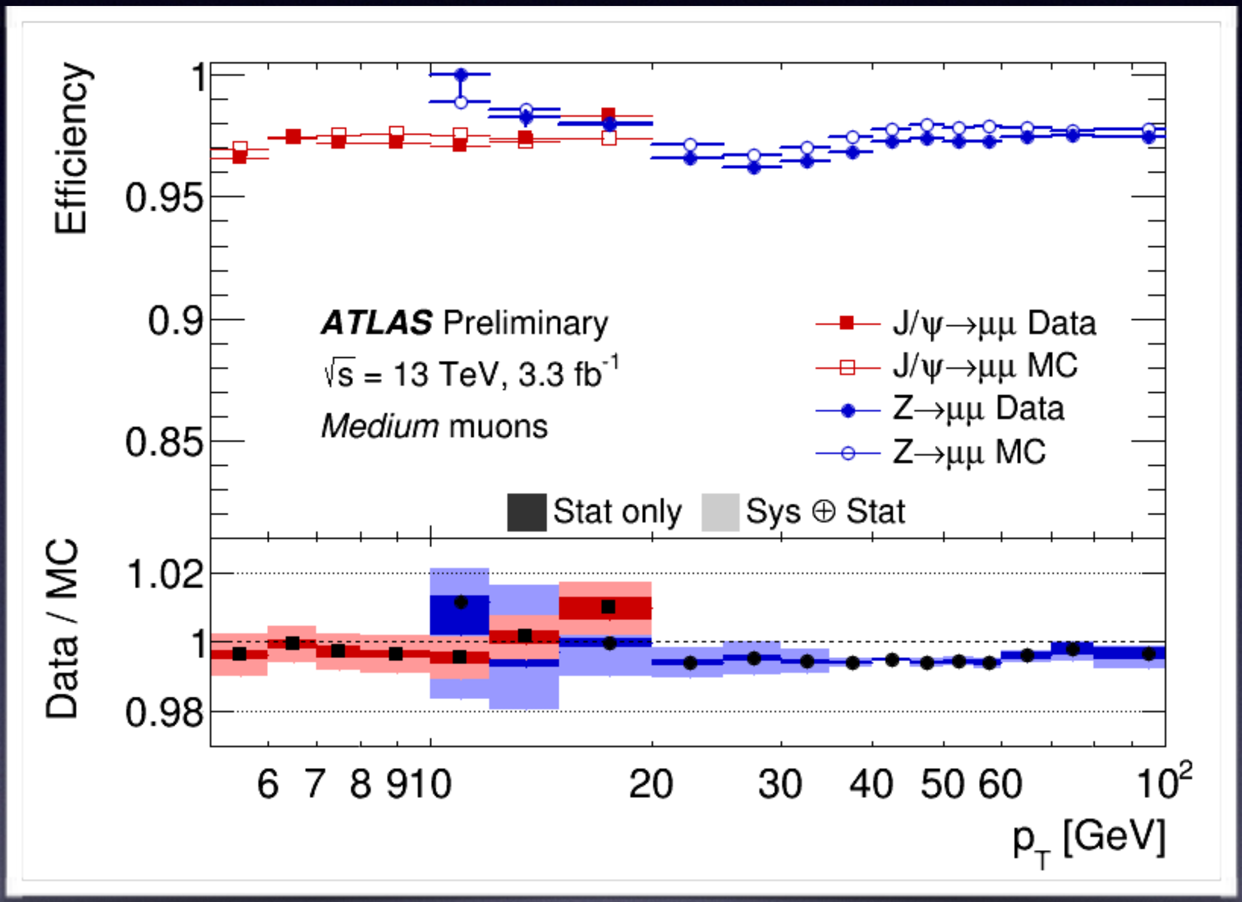


Electron reconstruction efficiency in Z→ee events [calorimeter only]

Muon System Performance

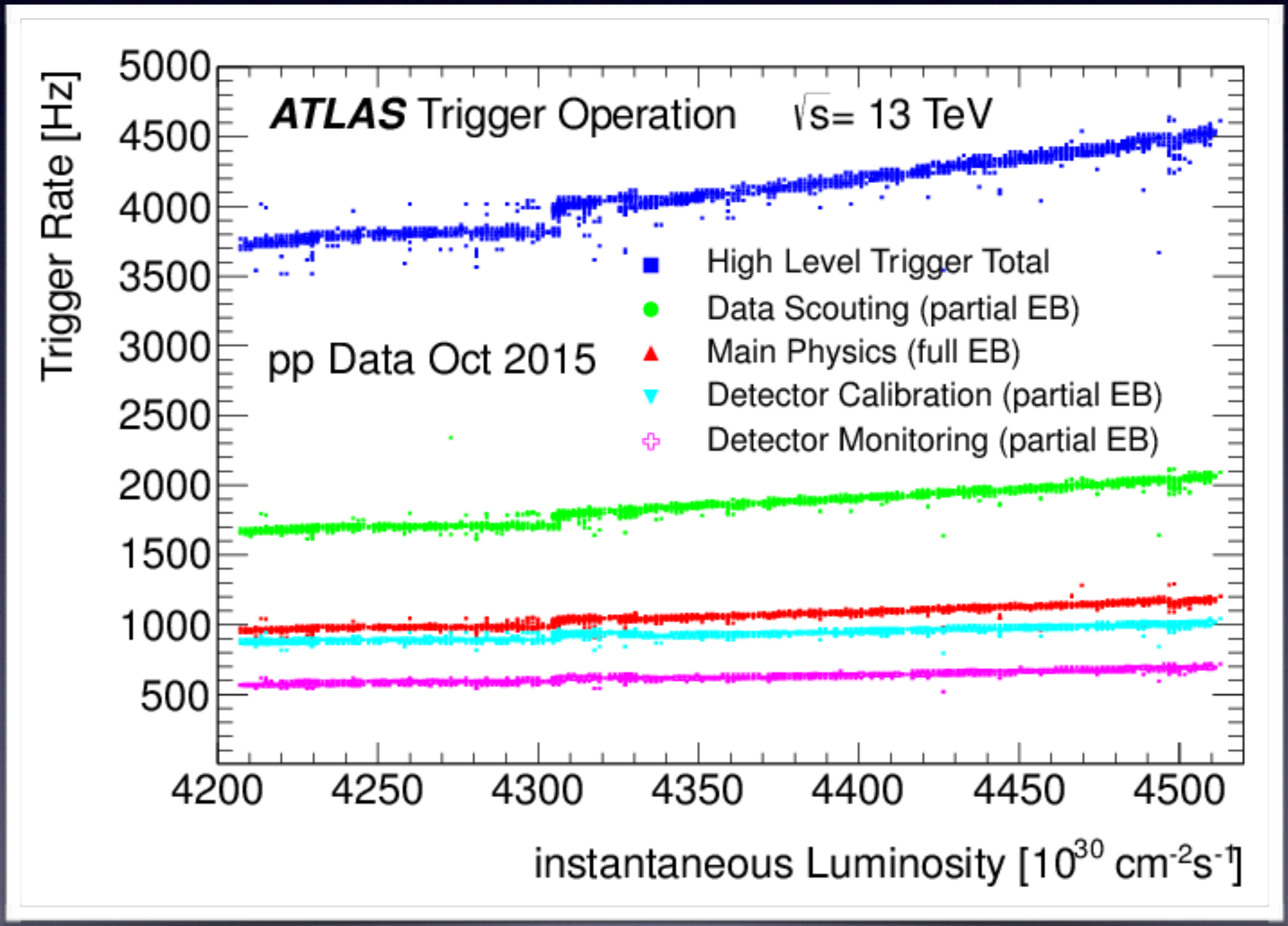
MUON-2015-004





- Muon reconstruction efficiencies for Z→μμ and J/Ψ→μμ
- Three working points
- Good agreement between data and Monte Carlo

Trigger Rates



- 1 kHz physics output rate
- 4 kHz total output rate [partial EB for calibration, monitoring and data scouting]
- Bandwidth ~1.5 GB/s [80% physics]