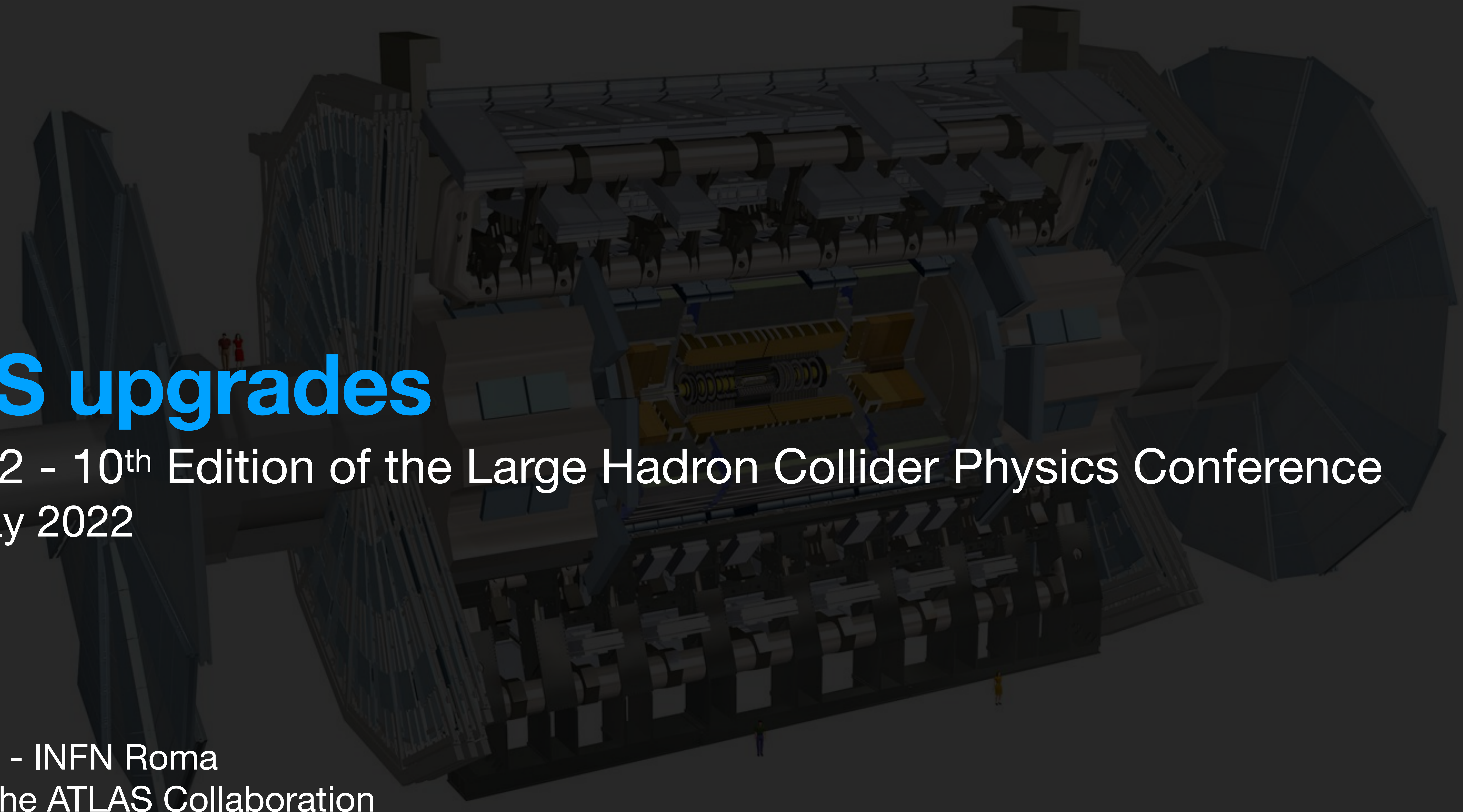


ATLAS upgrades

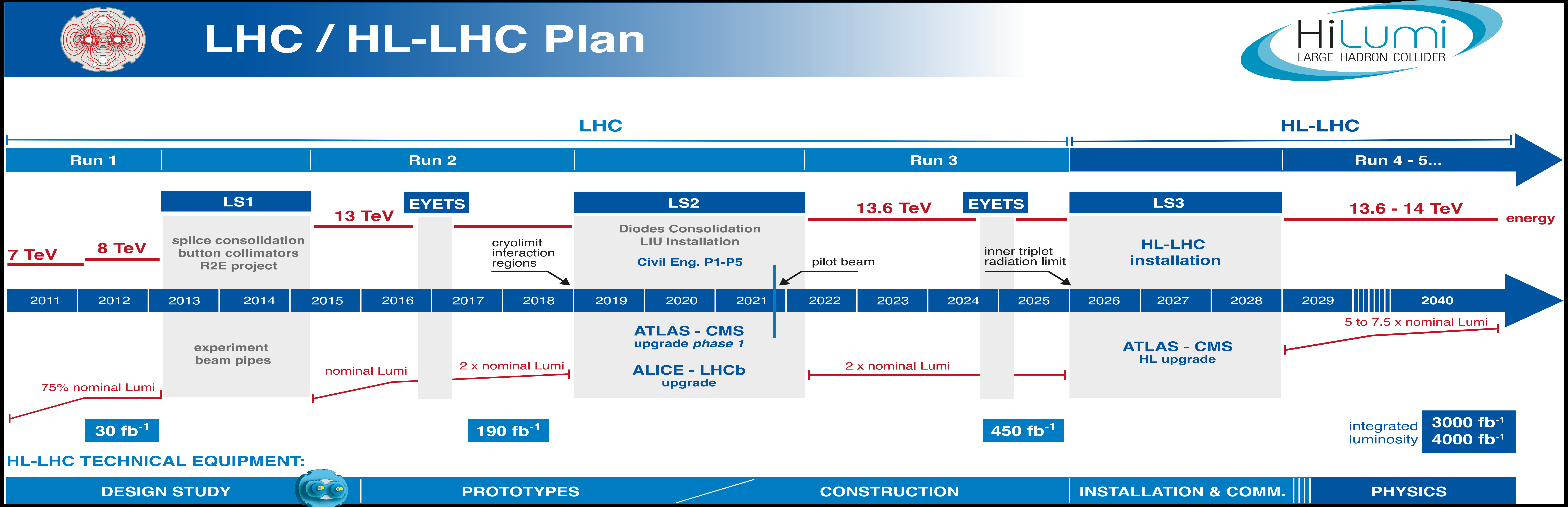
LHCP2022 - 10th Edition of the Large Hadron Collider Physics Conference

16 - 20 May 2022

Riccardo Vari - INFN Roma
on behalf of the ATLAS Collaboration

LHC and HL-LHC plans

High Luminosity LHC web page

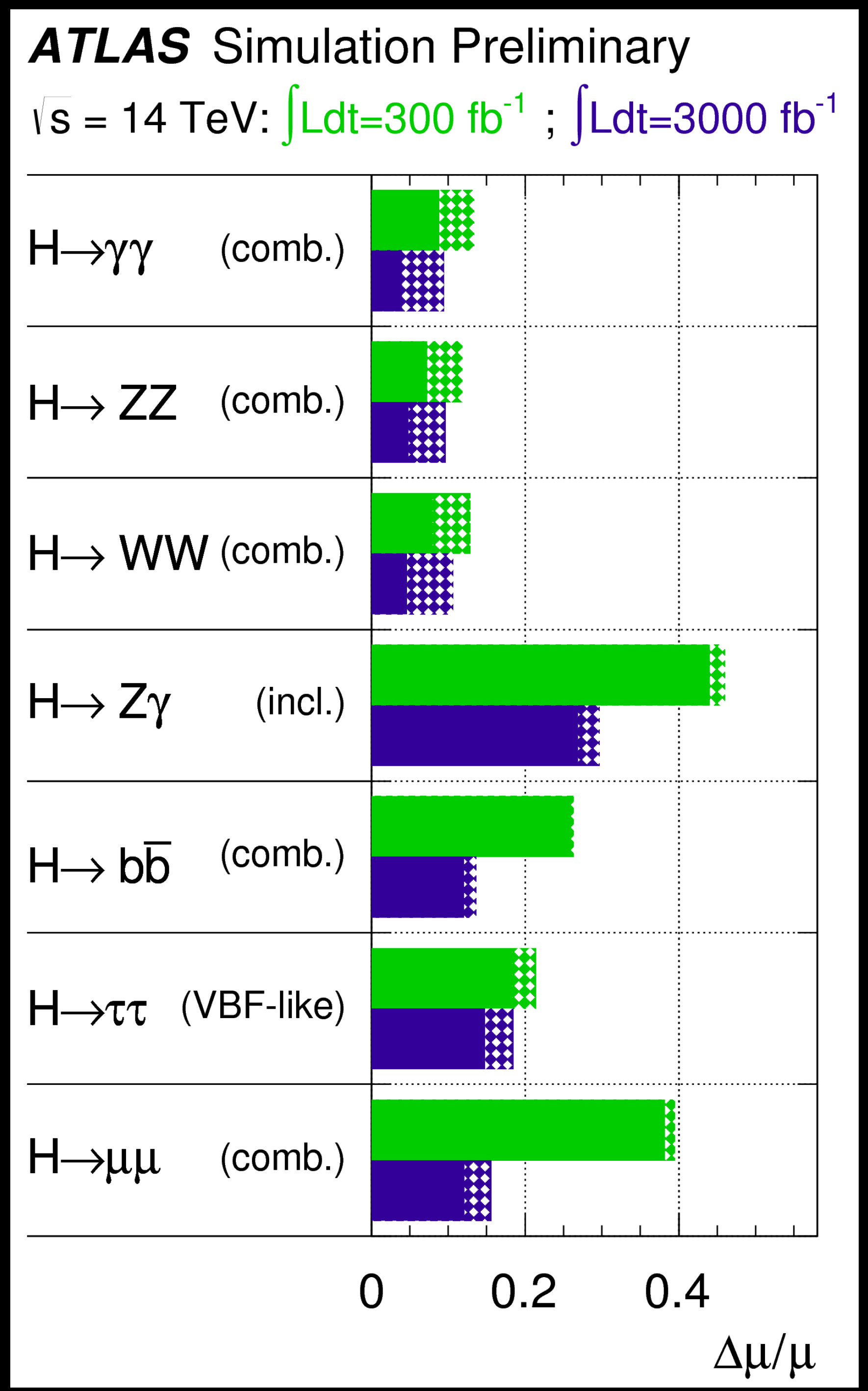


- LHC plan update (February 2022): Run3 and LS3 extended wrt previous schedule
- Run3 LHC luminosity: 2 x 10^{34} $cm^{-2}s^{-1}$ @ 13.6 TeV; integrated luminosity: 450 fb^{-1}
- Run4-Run5 HL-LHC luminosity: up to 7.5 x 10^{34} $cm^{-2}s^{-1}$ @ 14 TeV; integrated luminosity: 4000 fb^{-1}
- Technological challenge on the experiments coming from such a large dataset, rates and pile-up

ATLAS physics plans for Run3 and Run4

- Higgs boson and SM processes precision measurements
- SM rare processes measurements (H -> μμ, self-coupling Higgs from double Higgs events, …)
- High density QCD measurements (from heavy-ion and pp collisions)
- Forward physics (from exclusive production processes tagging)
- Beyond SM physics (SUSY, dark matter, long lived particles, …)
- …

ATL-PHYS-PUB-2018-010



ATL-PHYS-PUB-2013-003, 2014-007

ATLAS Mass reach for Exotic signatures

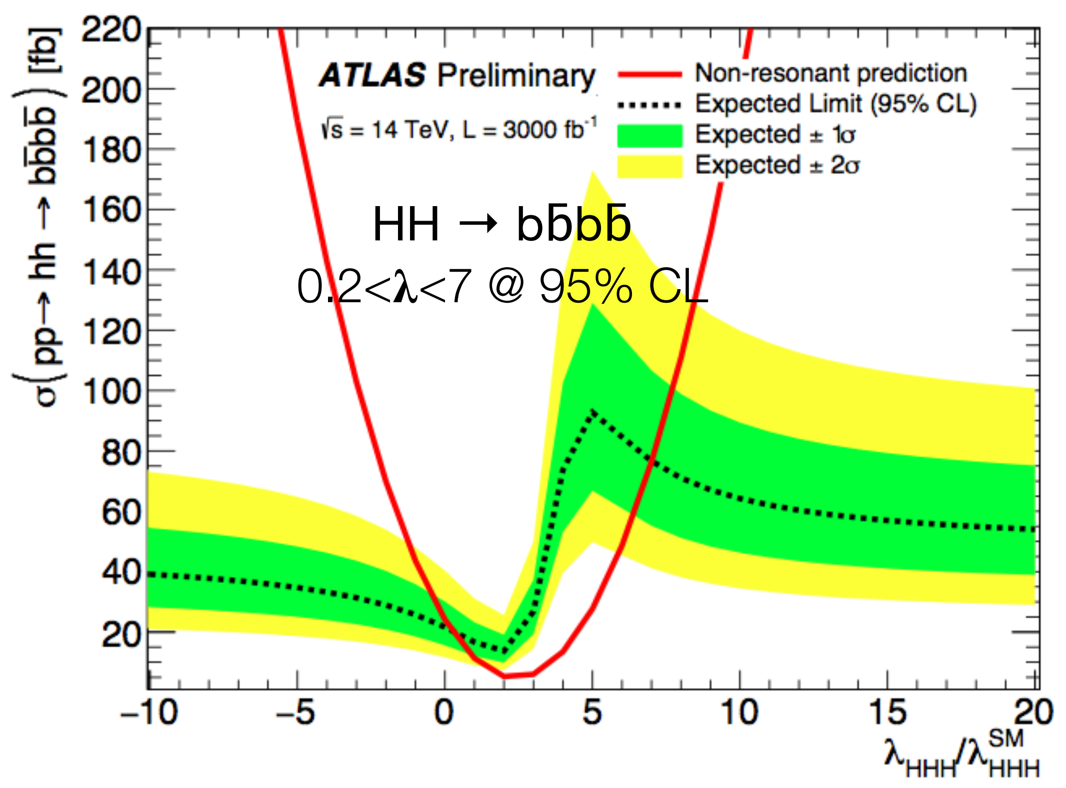
ATLAS @14 TeV	Z' → ee SSM 95% CL limit	g_{KK} → t t RS 95% CL limit	Dark matter M* 5σ discovery
300 fb^{-1}	6.5 TeV	4.3 TeV	2.2 TeV
3000 fb^{-1}	7.8 TeV	6.7 TeV	2.6 TeV

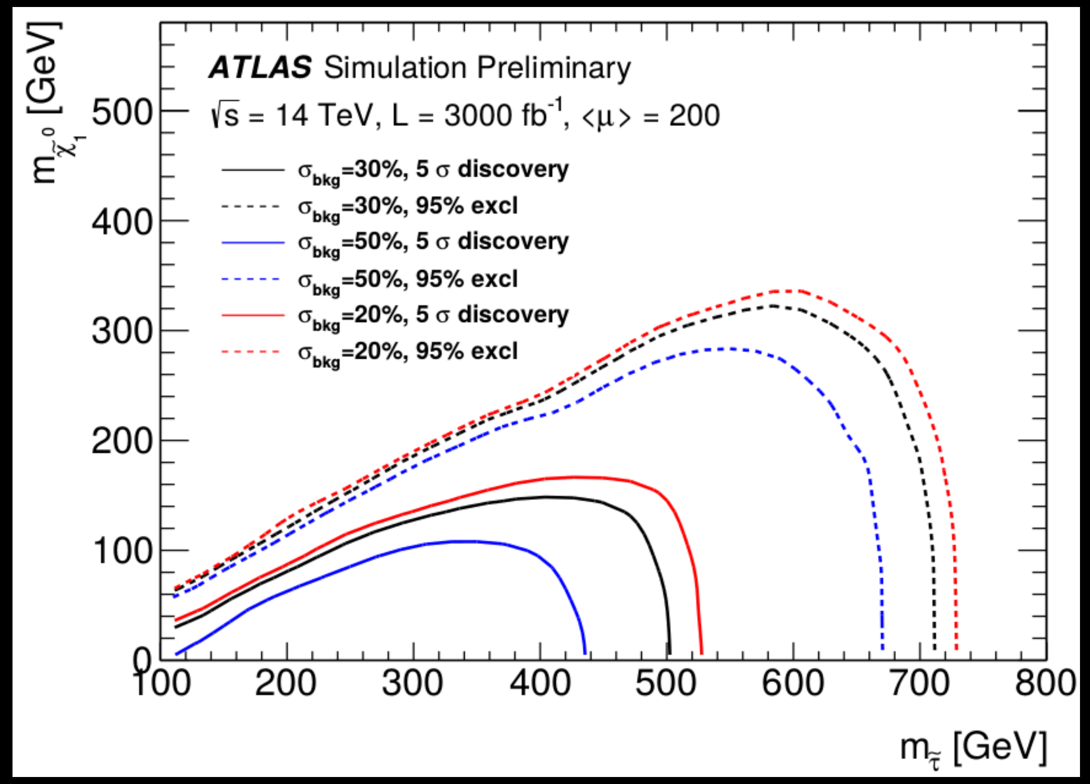
ATL-PHYS-PUB-2014-010 , 2013-011, 2015-032

ATLAS Mass reach for SUSY particles

ATLAS projection	gluino mass	squark mass	stop mass	sbottom mass	χ_1^+ mass WZ mode	χ_1^+ mass WH mode
300 fb^{-1}	2.0 TeV	2.6 TeV	1.0 TeV	1.1 TeV	560 GeV	None
3000 fb^{-1}	2.4 TeV	3.1 TeV	1.2 TeV	1.3 TeV	820 GeV	650 GeV

- Many LHCP2022 talks on ATLAS physics plans
- CERN yellow report: Report on the Physics at the HL-LHC, and Perspectives for the HE-LHC
- Snowmass White Paper contribution: Physics with the Phase-2 ATLAS and CMS Detectors



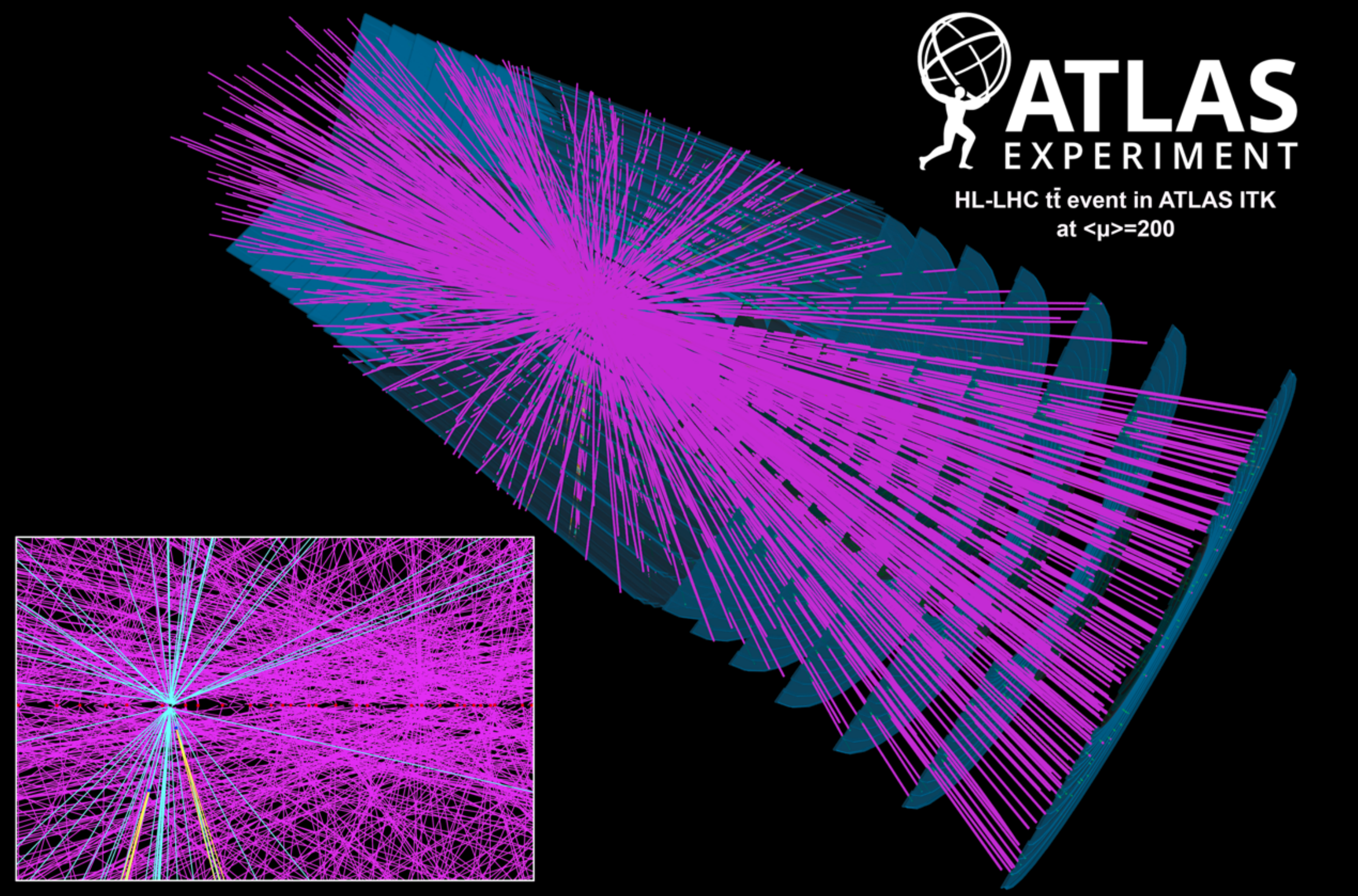


Increasing luminosity impact on ATLAS

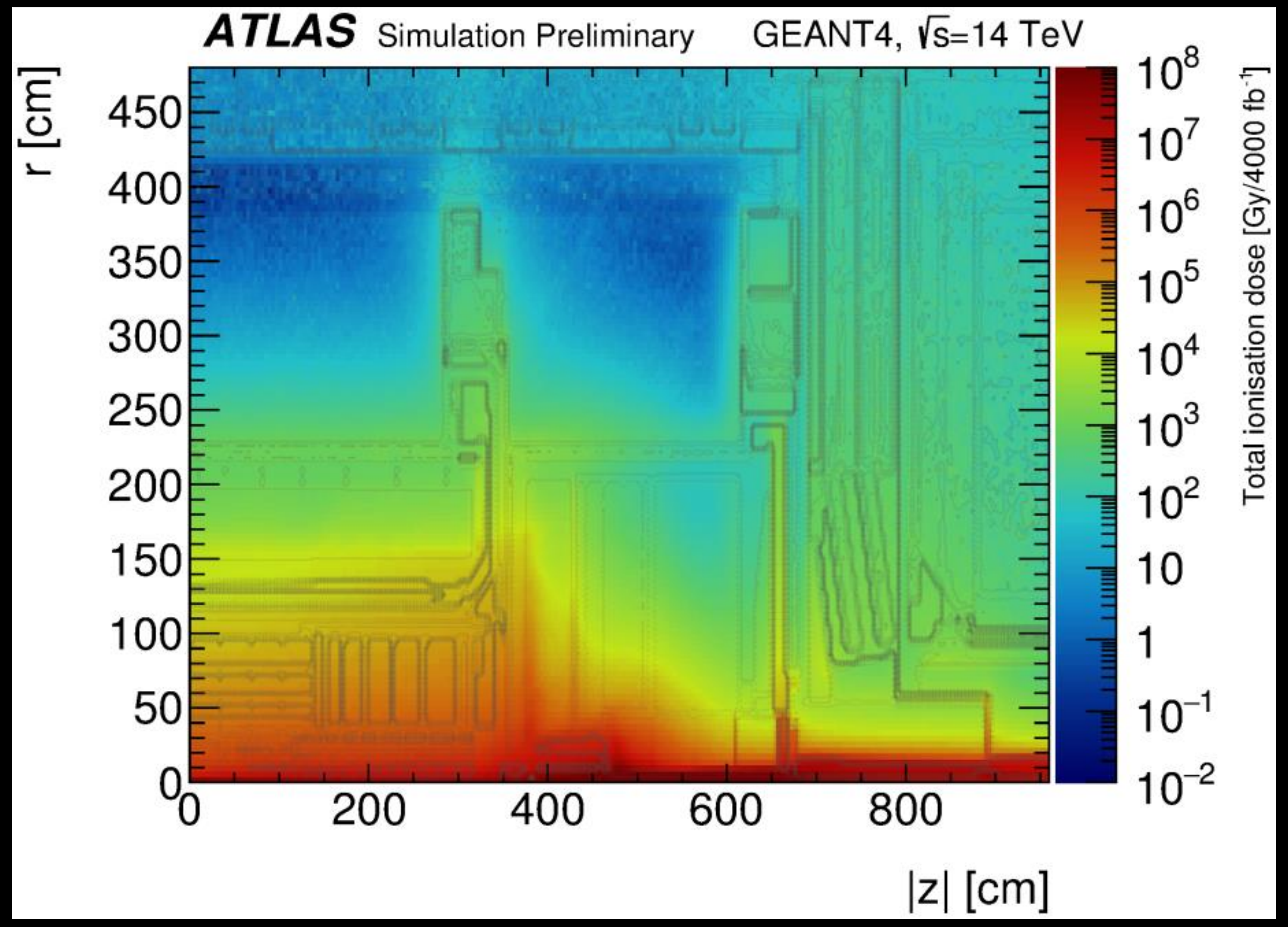
- High luminosity is needed to achieve physics goals
- The experiment has to stand the Run4 foreseen peak luminosity of 7.5 x 10^{34} cm^{-2} s^{-1}
  - high pile-up ~200 collisions/crossing
  - high radiation levels, up to ~10^{16} neq/cm^2, 10 MGy
- Requirements:
  - maintain good physics performances in the challenging environment
  - keep acceptable trigger rate for low p_T threshold
  - mitigate pile-up up to high η

ATLAS pileup for Run4

ATLAS public results

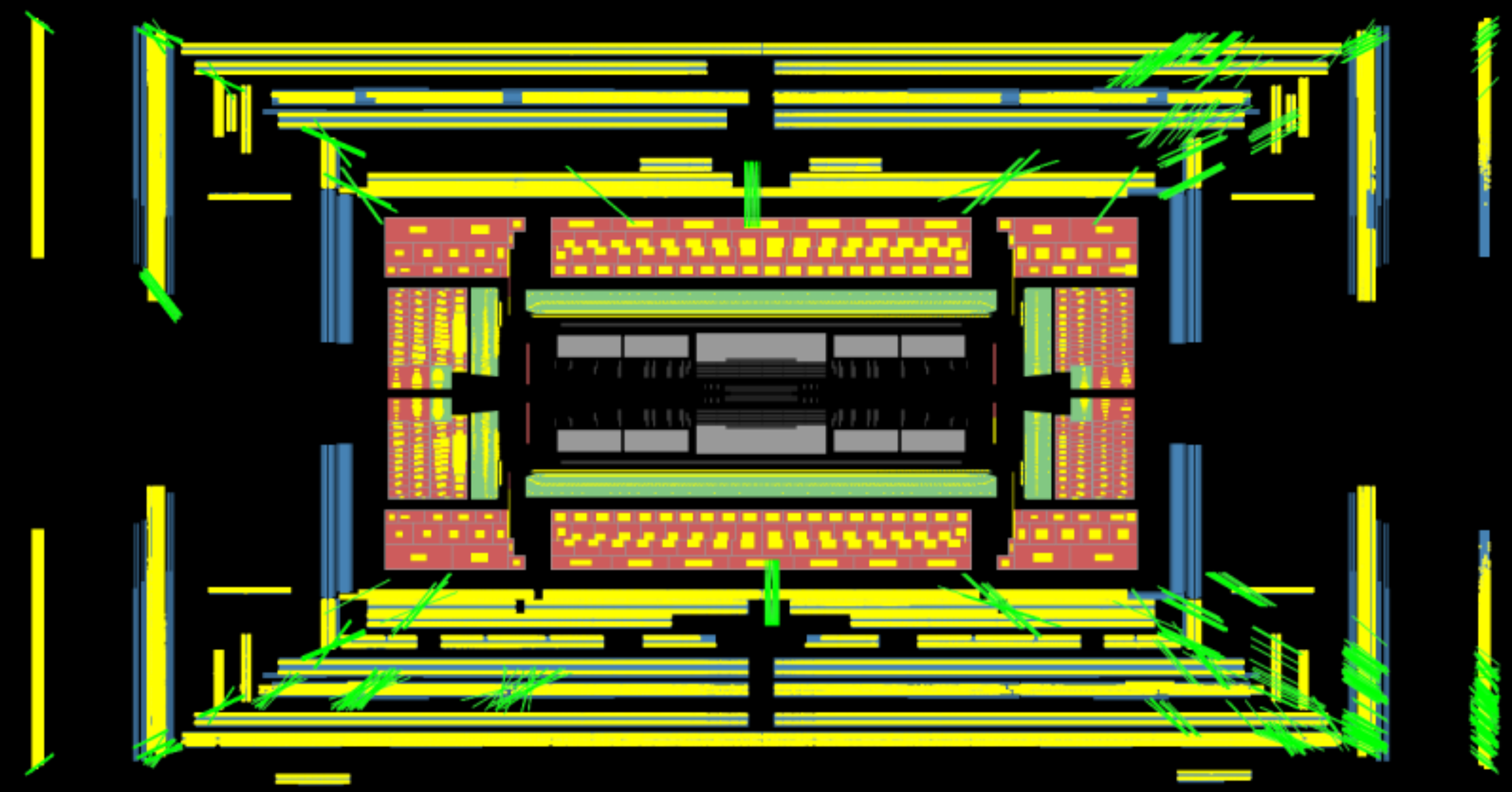


ATLAS TID radiation levels for Run4



ATLAS current upgrades for Run3

ATLAS Beam Splash Events – April 28, 2022

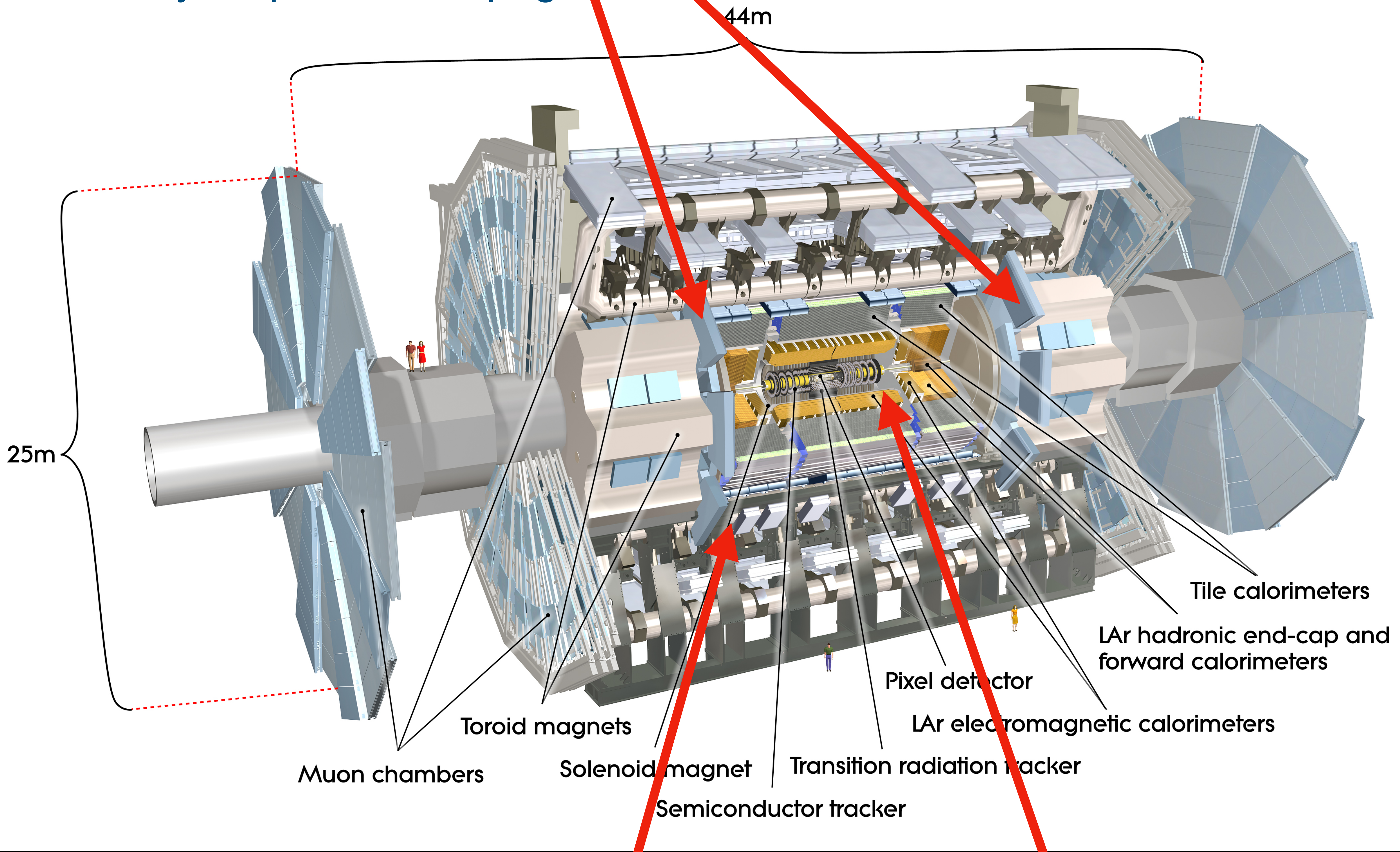


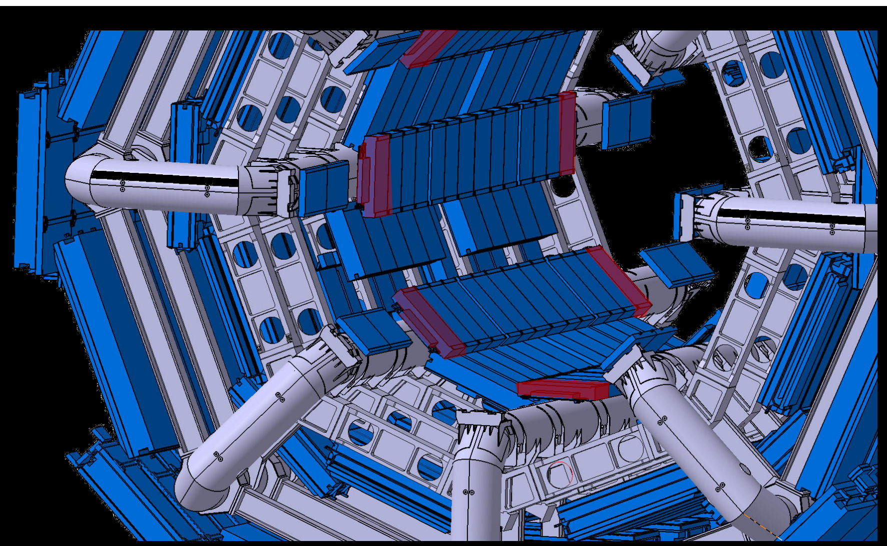
ATLAS upgrades for Run3

- Upgrades in the cavern:
  - New Small Wheel muon detector: replacement of previous end-cap CSC based detector with a sTGC+MicroMega detector for improved rate capability and performances
  - BIS78-RPC muon detector: new RPCs in the barrel to improve the rejection rate of the L1 trigger in the barrel-endcap transition region
  - LAr front-end: new electronics with higher granularity for improved performances of the detector and of the Level-1 Calorimeter electromagnetic trigger
- Upgrades in the TDAQ off-detector electronics:
  - Level-1 hardware trigger: new L1 electronics for calorimeter, topological, NSW, end-cap, MuCTPi
  - Readout: new FELIX system for NSW, BIS78, LAr, L1Calo. Hardware data router between front-end and commodity network connected to SW-RODs, DCS, TTC, busy
  - High Level Trigger: new processor cluster, improved off-line algorithms and track reconstruction, 1.5 kHz output rate

New Small Wheel muon detector (sTGC + MM)

ATLAS layout public web page



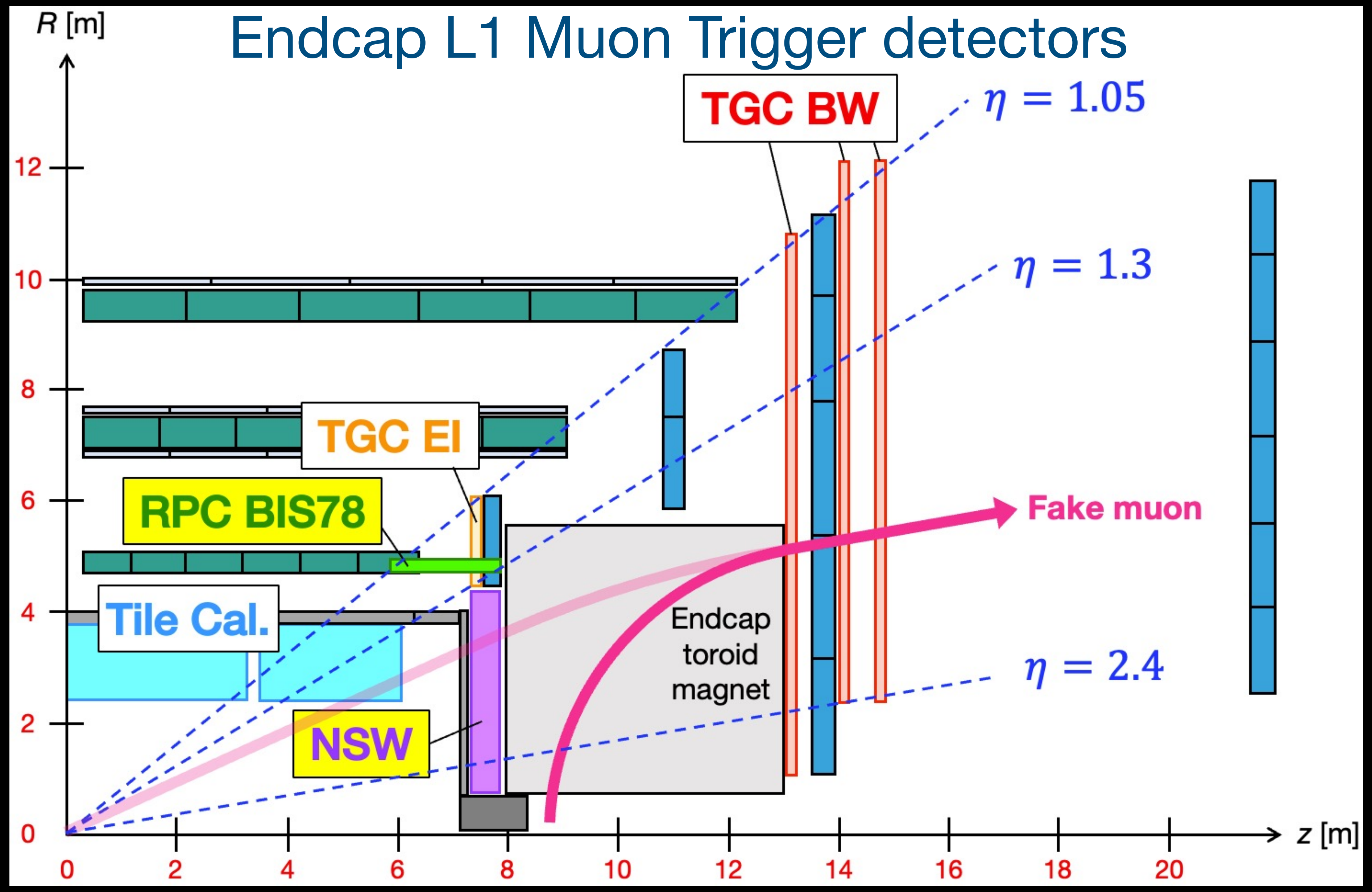


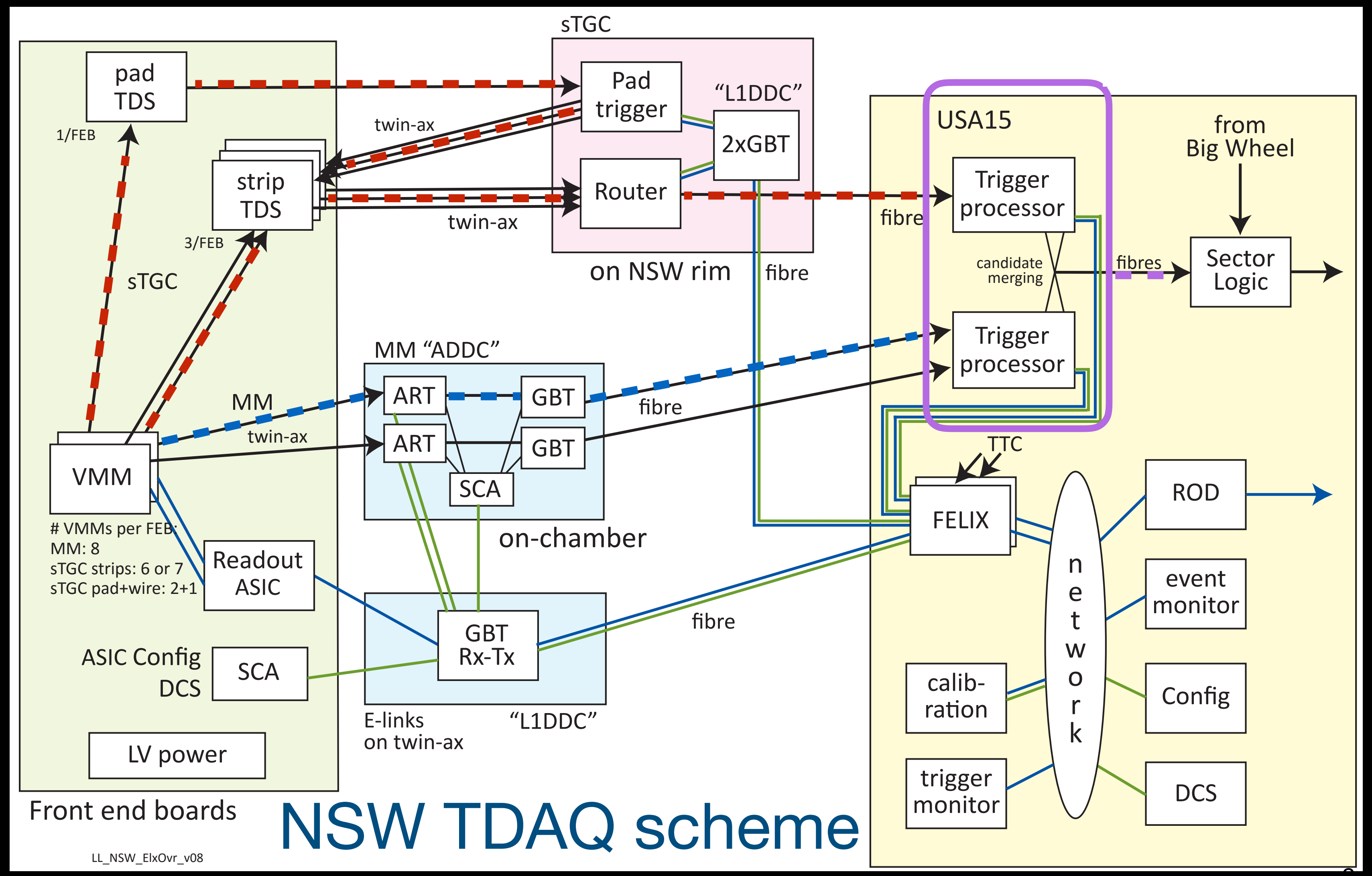
New LAr front-end electronics

New RPC muon detectors in the BIS78 region

End-cap Level-1 muon trigger upgrade for Run3

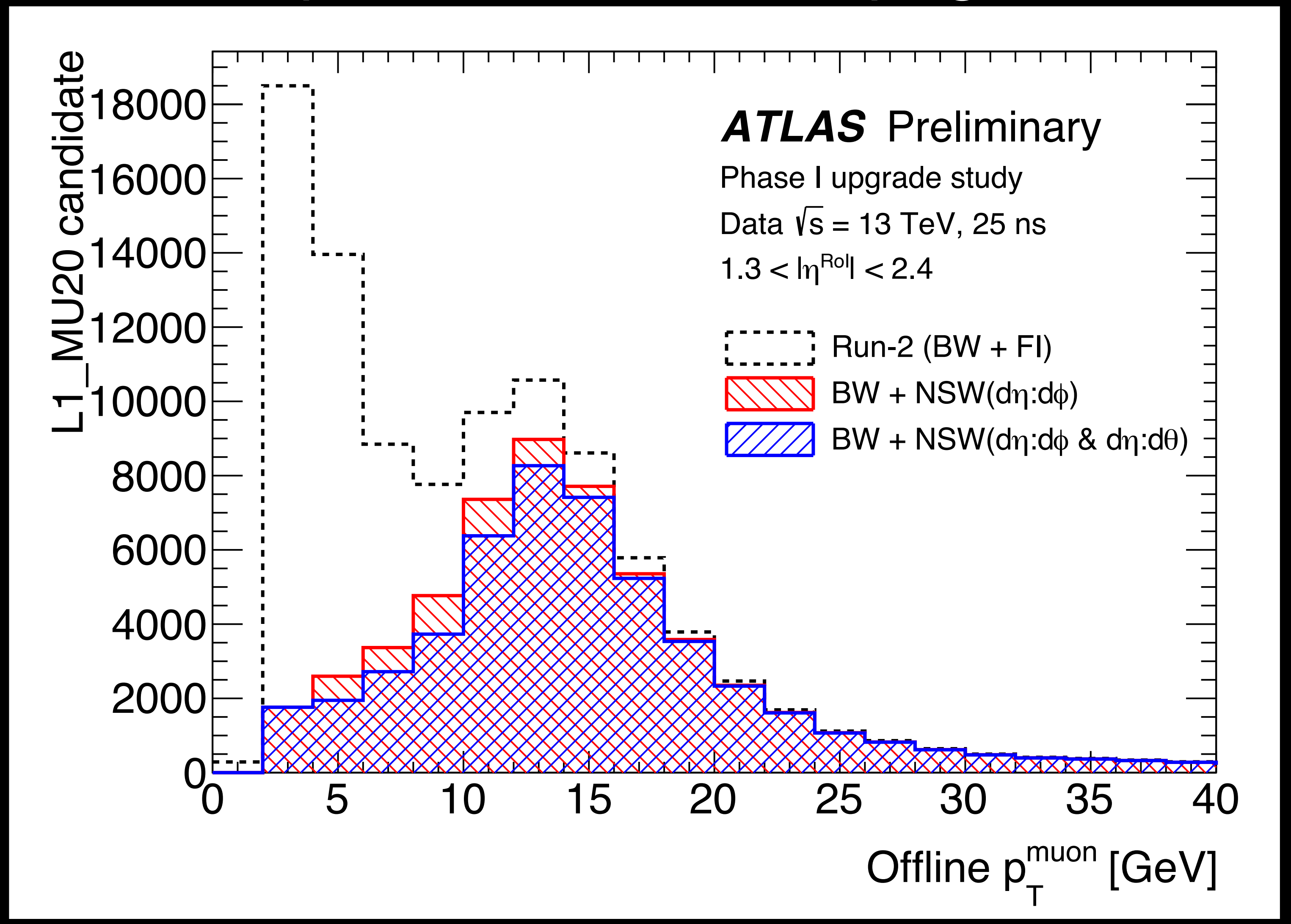
- Two 5m radius New Small Wheels in the inner end-cap region (1.3 < |η| < 2.7), each NSW is formed by:
  - 2 external sTGC quadruplets (mainly trigger, bunch ID identification + vector tracking with < 1 mrad resolution)
  - 2 internal MicroMega quadruplets (mainly tracking, geometrical resolution < 100 μm)
- New RPC triplet muon detectors in the BIS78 barrel region (reduced gas gap, higher rate capability)
- New end-cap Sector Logic board performs the coincidence within three stations of the TGC Big Wheel and the inner detectors (NSW, BIS78-RPC, EI-TGC, Tile)
- The trigger fake rate originated by low-p_T muons and background is significantly reduced (~90%)
- System currently under commissioning





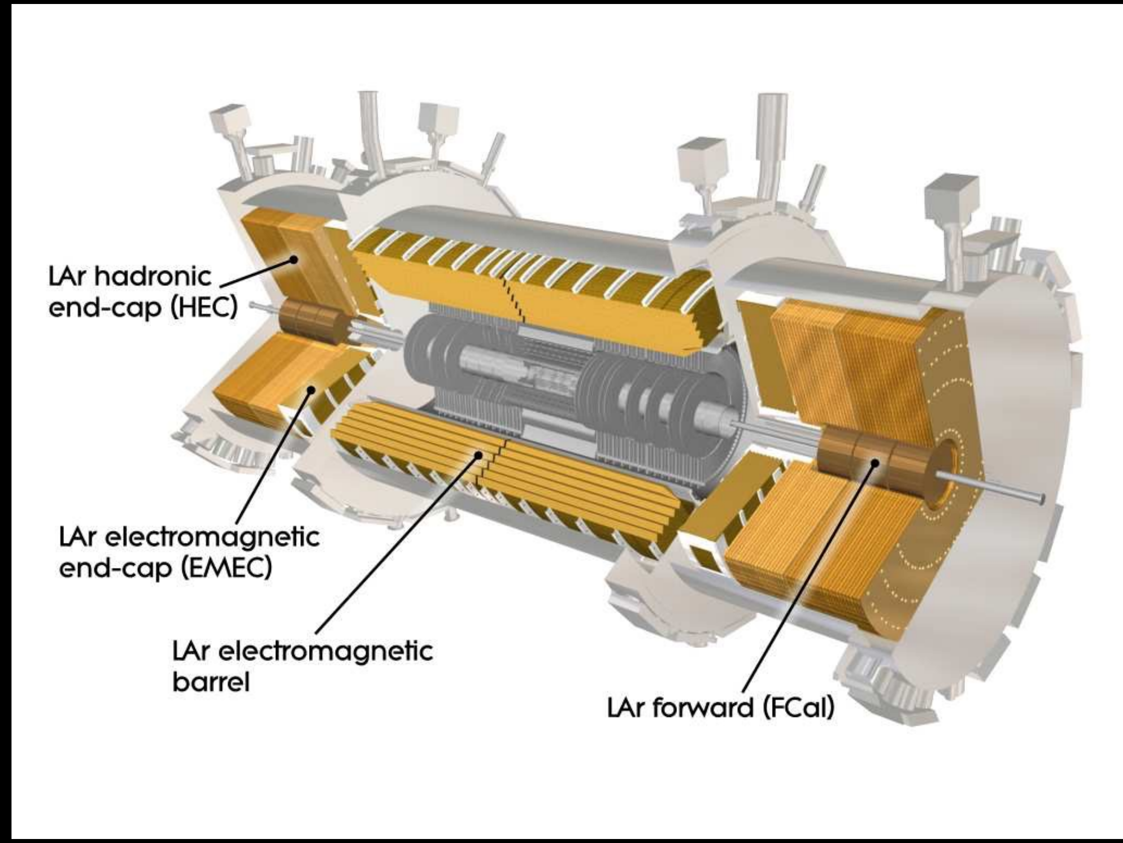
NSW TDAQ scheme

ATLAS public results web page - Muon

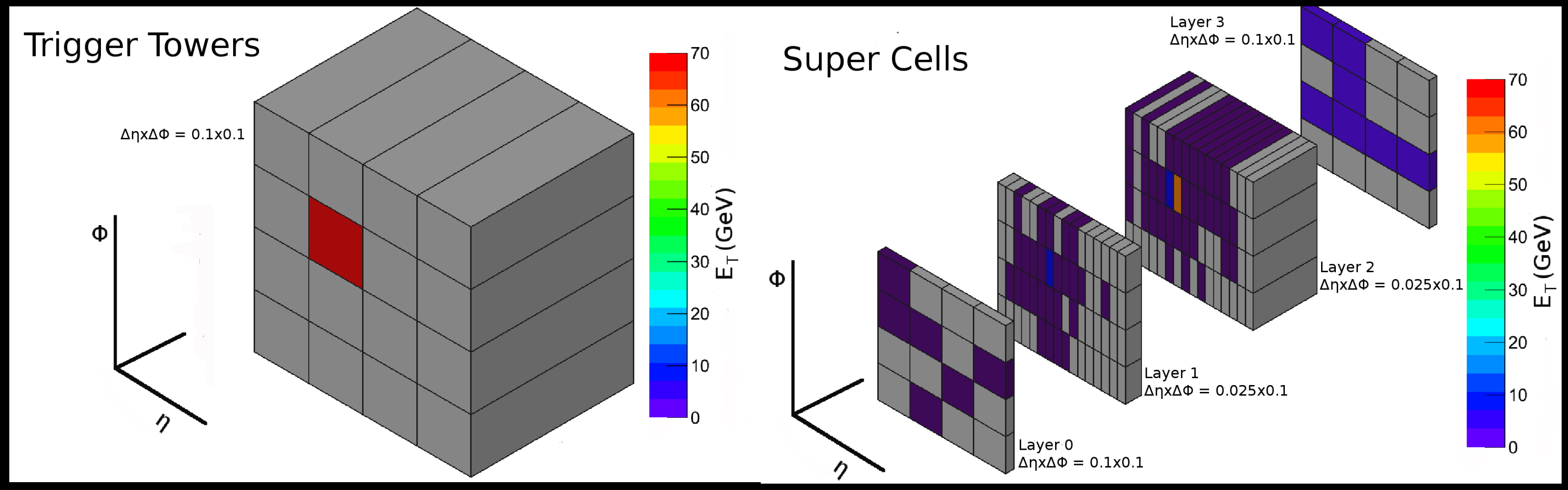


LAr calorimeter and L1Calo upgrades for Run3

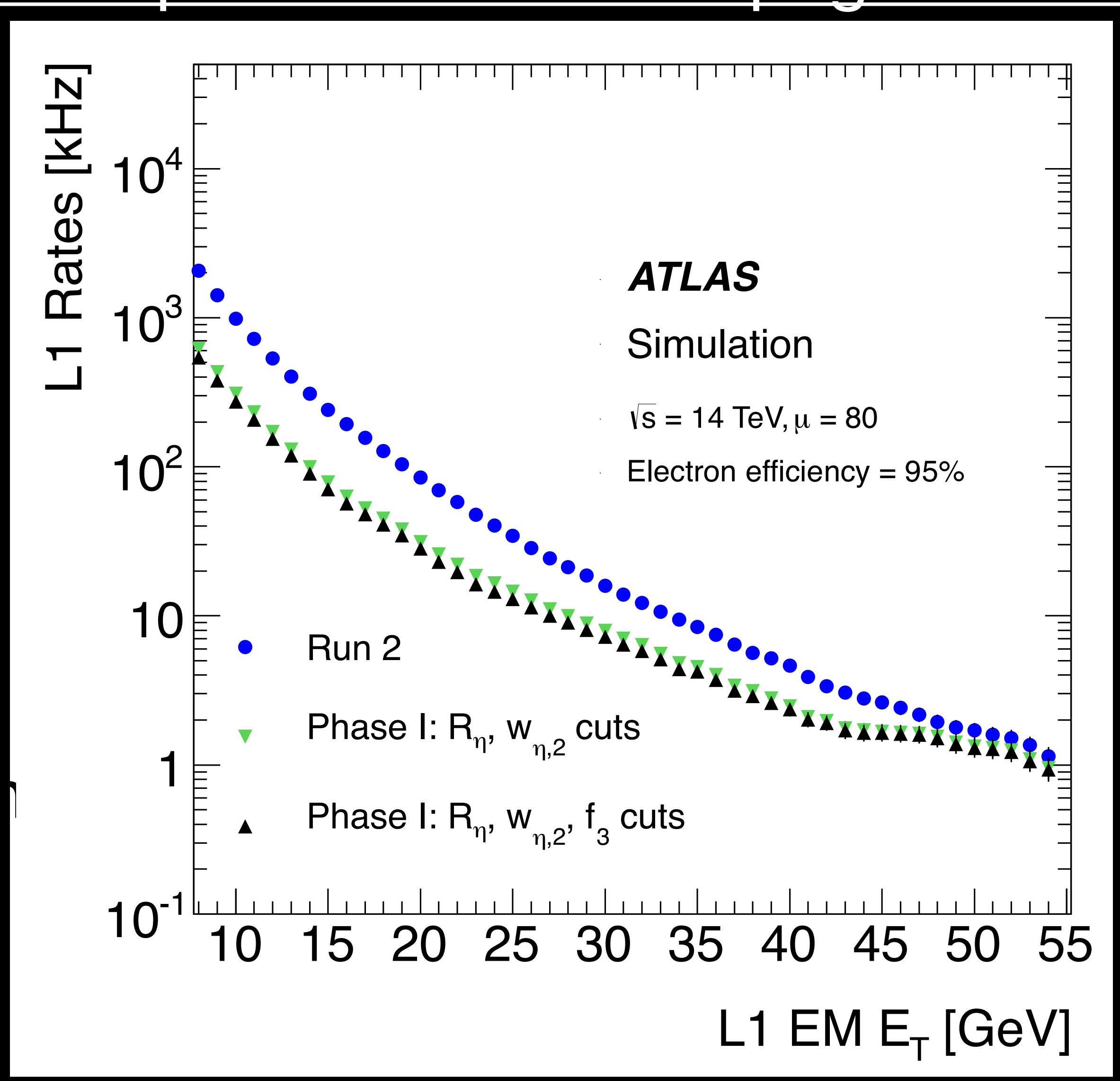
- Liquid Argon Calorimeter:
  - Measures the energy of e+, e-, ɣ (barrel and end-cap regions) and hadrons (forward region)
  - New front-end and back-end electronics with increased trigger tower granularity ($\Delta\eta \times \Delta\phi$ = 0.025x0.1) allow:
    - Low trigger rate thanks to the improved background rejection
    - Low thresholds and better turn-on curves thanks to the higher geometrical resolution
- Level-1 Calorimeter Trigger:
  - New Feature Extractor boards: eFEX, gFEX, jFex
  - More refined processing of electromagnetic calorimeter information at higher granularity
  - Better discrimination between photons, electrons, taus and jets
  - Efficient single object triggers for electroweak-scale physics
- L1Topo: new board, Level-1 topological algorithms on calorimeters and muons data
- System under commissioning



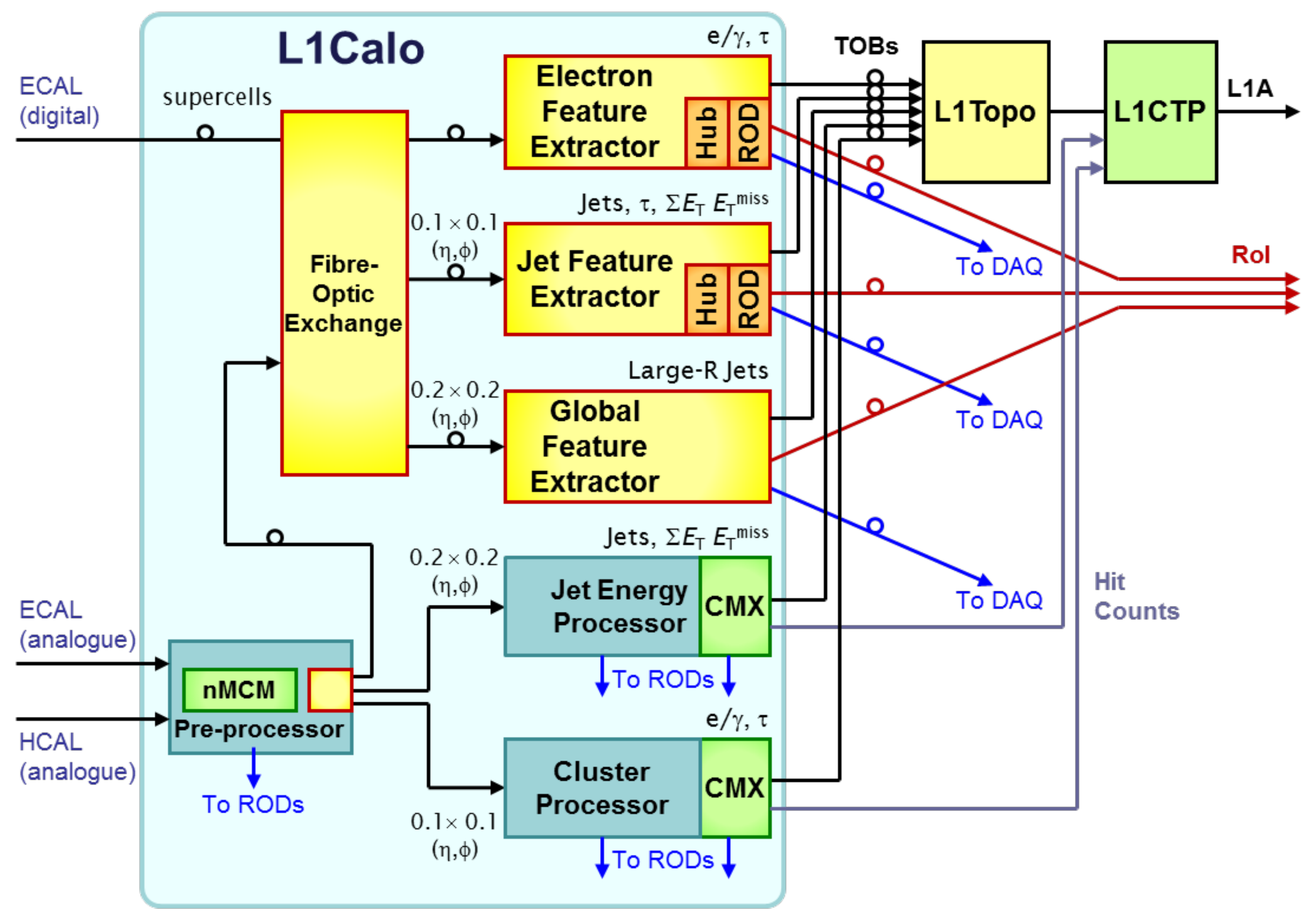
ATLAS-TDR-022-2013



ATLAS public results web page - L1Calo



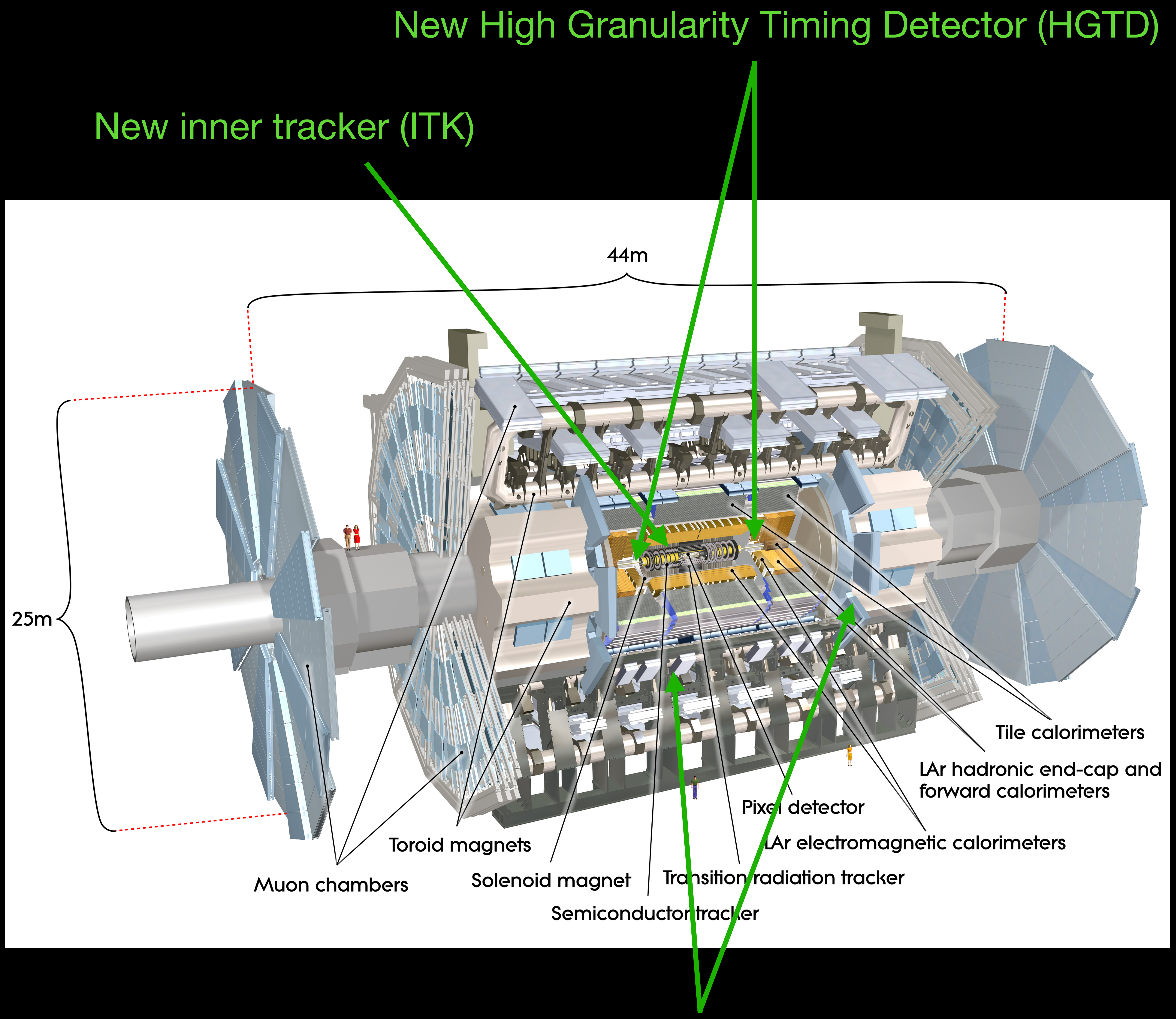
ATLAS-TDR-023-2013



ATLAS future upgrades for Run4

ATLAS upgrades for Run4

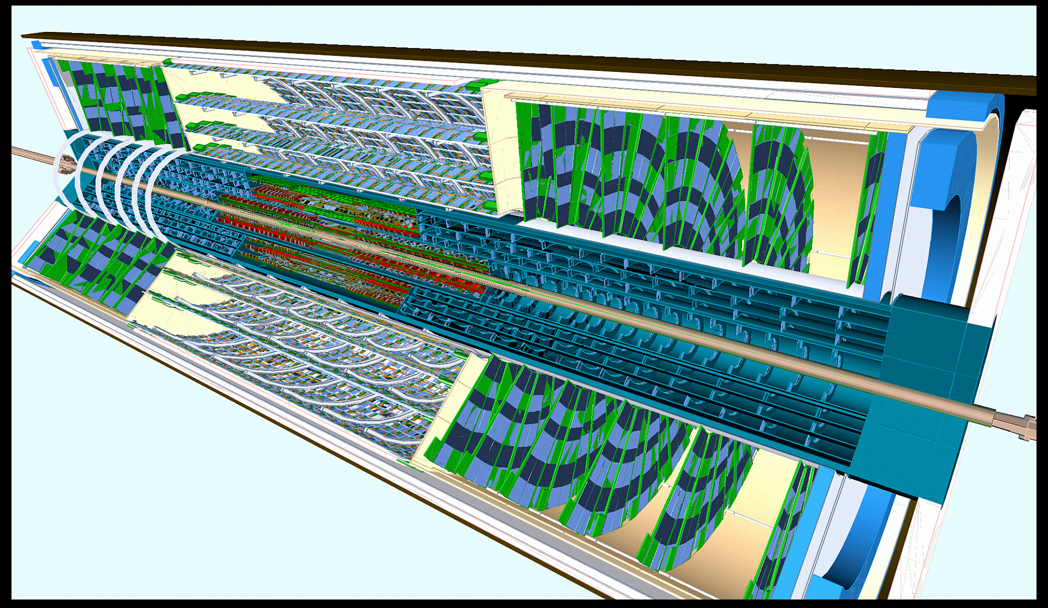
- New systems in the cavern:
  - ITk: silicon inner tracker (pixels + strip detector) with eta coverage up to 4
  - RPC and sMDT muon detector in the barrel inner region, sTGC in the end-cap inner region
  - High Granularity Timing Detector in the forward region
  - Calorimeters and muon detectors (TGC/RPC/MDT) front-end readout at 40 MHz
  - Upgrades of luminosity and forward detectors
- New TDAQ off-detector electronics:
  - Level-0 hardware trigger: calorimeter, topological, muon, global, CTP (FPGA-based boards)
  - Readout: FELIX for all ATLAS detectors
  - Event Filter processor farm and hardware tracking



Front-end replaced for calorimeters and muon detectors

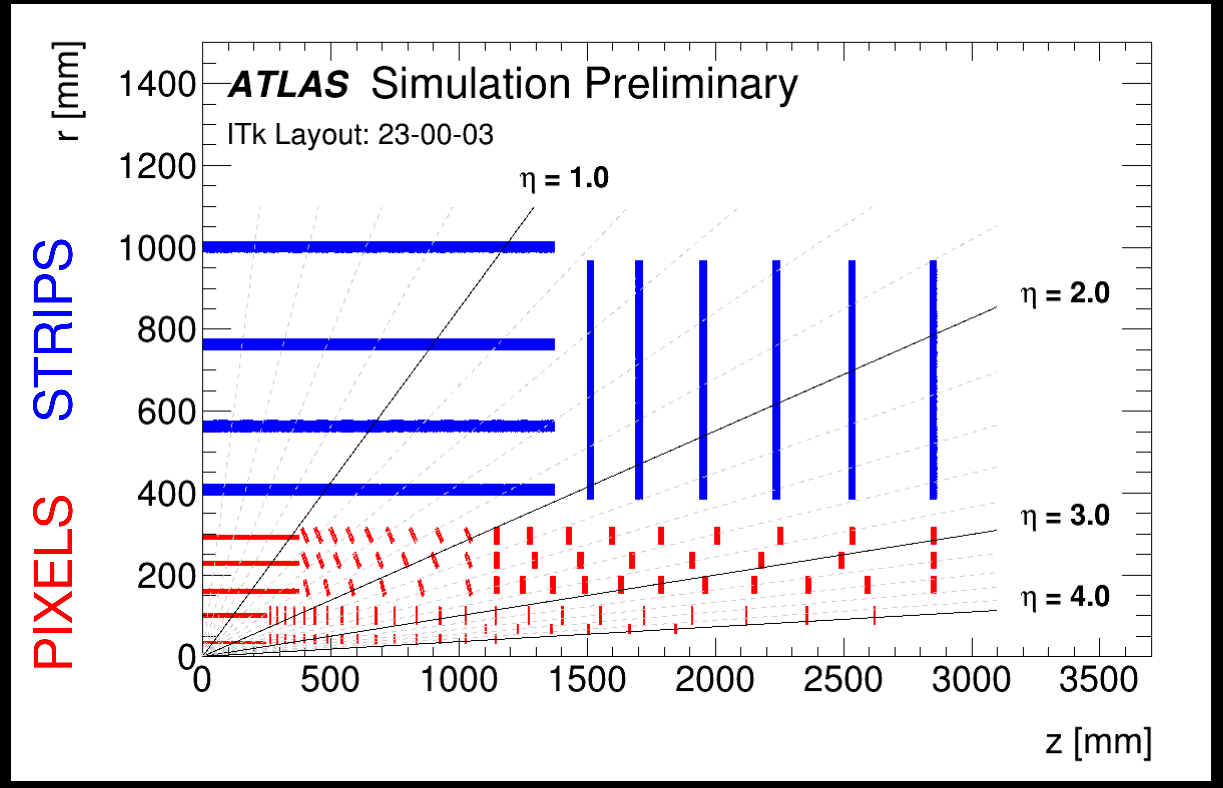
Inner Tracker

- New all-silicon tracking system, extension up to $|\eta| = 4$
- Pixel detector (25x100 μm² pixel size) at small radius close to the beam line + large area strip tracker surrounding it:
  - Pixels: $|\eta| < 4.0$, 5 barrel layers + variable number of end-cap rings, 165 m², 60 million channels, 18 thousands modules
  - Strips: $|\eta| < 2.7$, 4 barrel layers + 6 end-cap disks, 13 m², 5.1 billion channels, 9.2 thousands modules
- Increased surface and complexity with respect to the present system but reduced quantity of material
- New rad-hard (10 MGy) pixel and strip front-end readout electronics (sensor ASICs and readout modules)
- Equal or better performances than the existing detector in a much more difficult environment:
  - high tracking performances and reconstruction efficiency thanks to the improved granularity, reduced material (multiple scattering) and detector redundancy
  - > 99% efficiency for muons with p_T > 3 GeV; > 85% efficiency for pions and electrons above 1 GeV, keeping fake rates below 1%
- Entering pre-production stage for pixels and strips

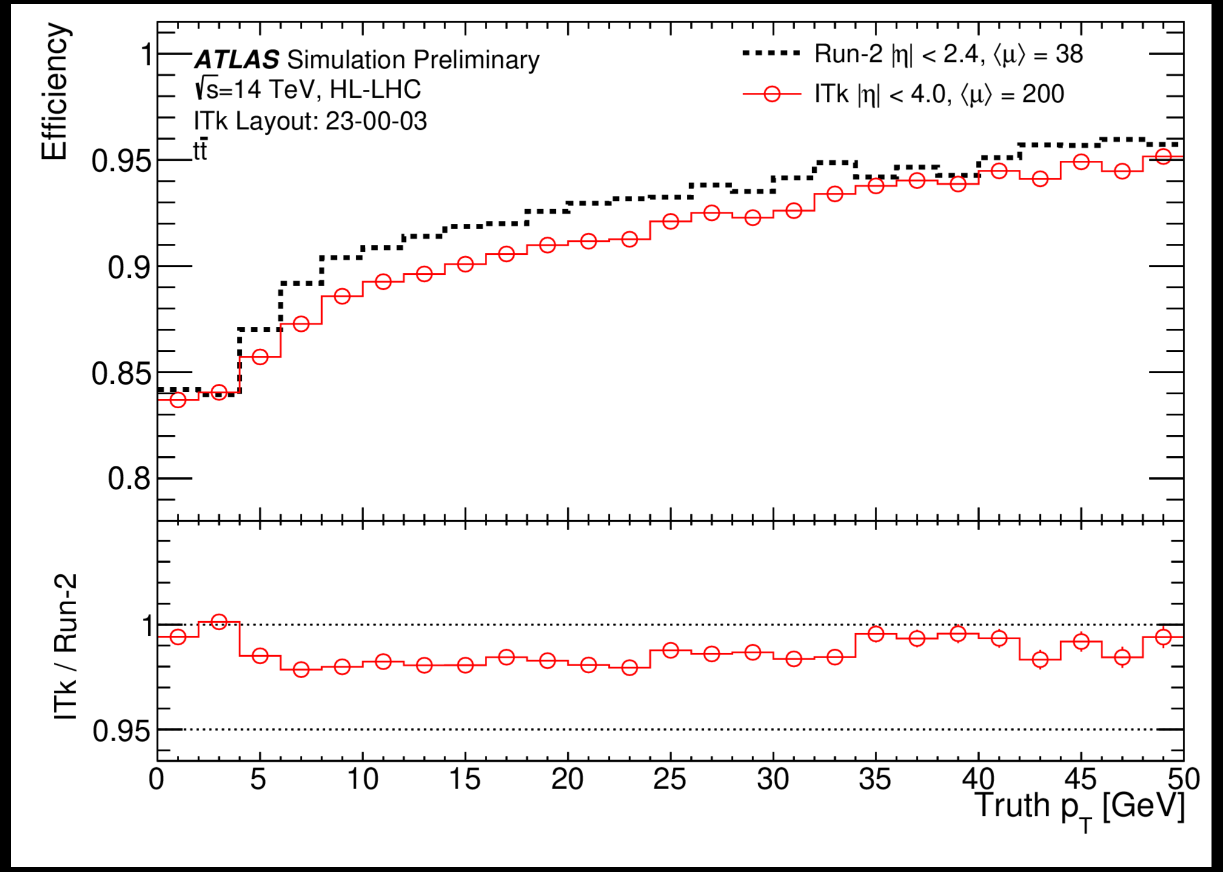


ATLAS-TDR-025-2017

ITK new layout ATL-PHYS-PUB-2021-024

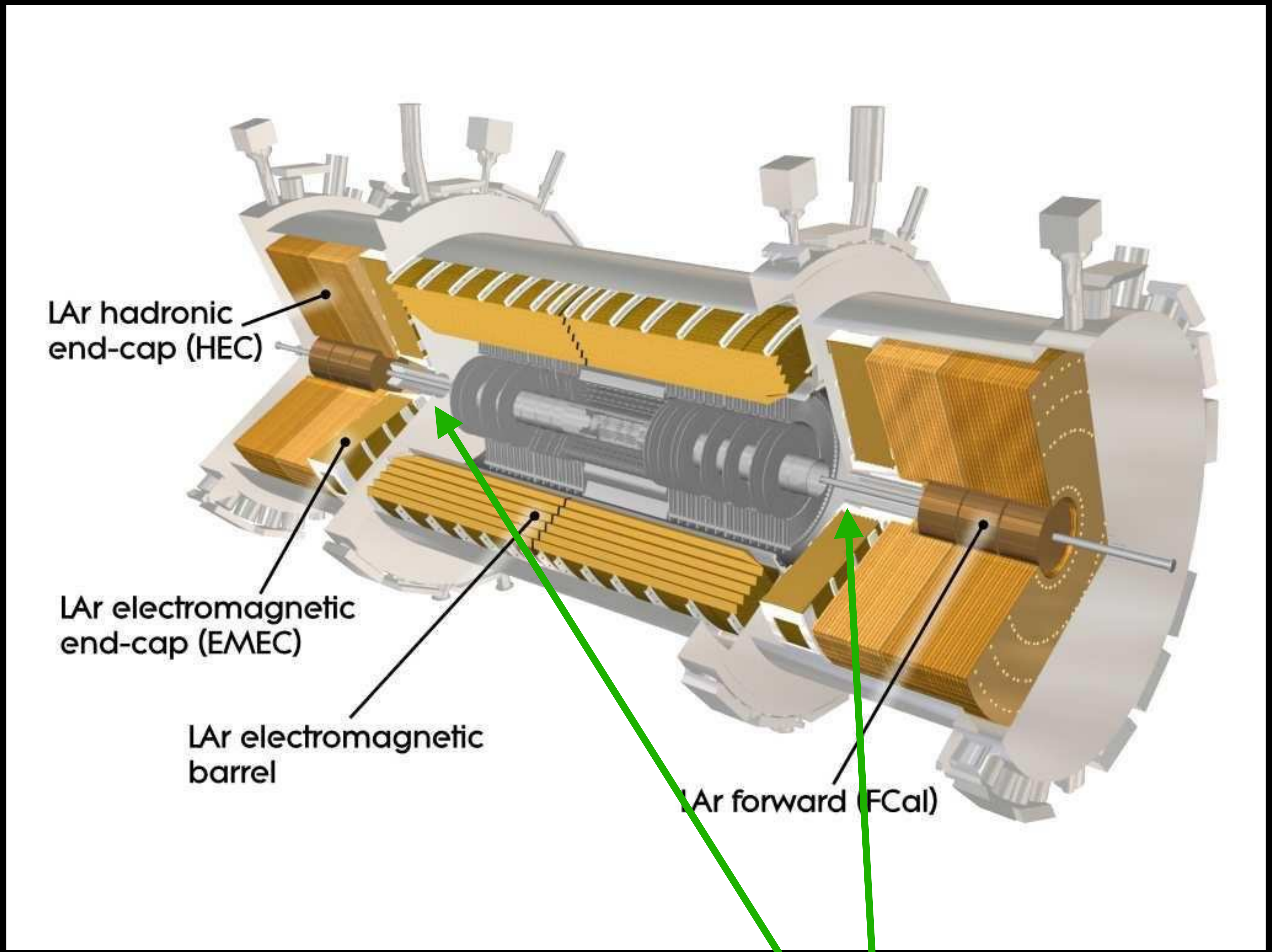


Tracking efficiency for $t\bar{t}$ events with ⟨μ⟩=200 compared with the Run2 detector

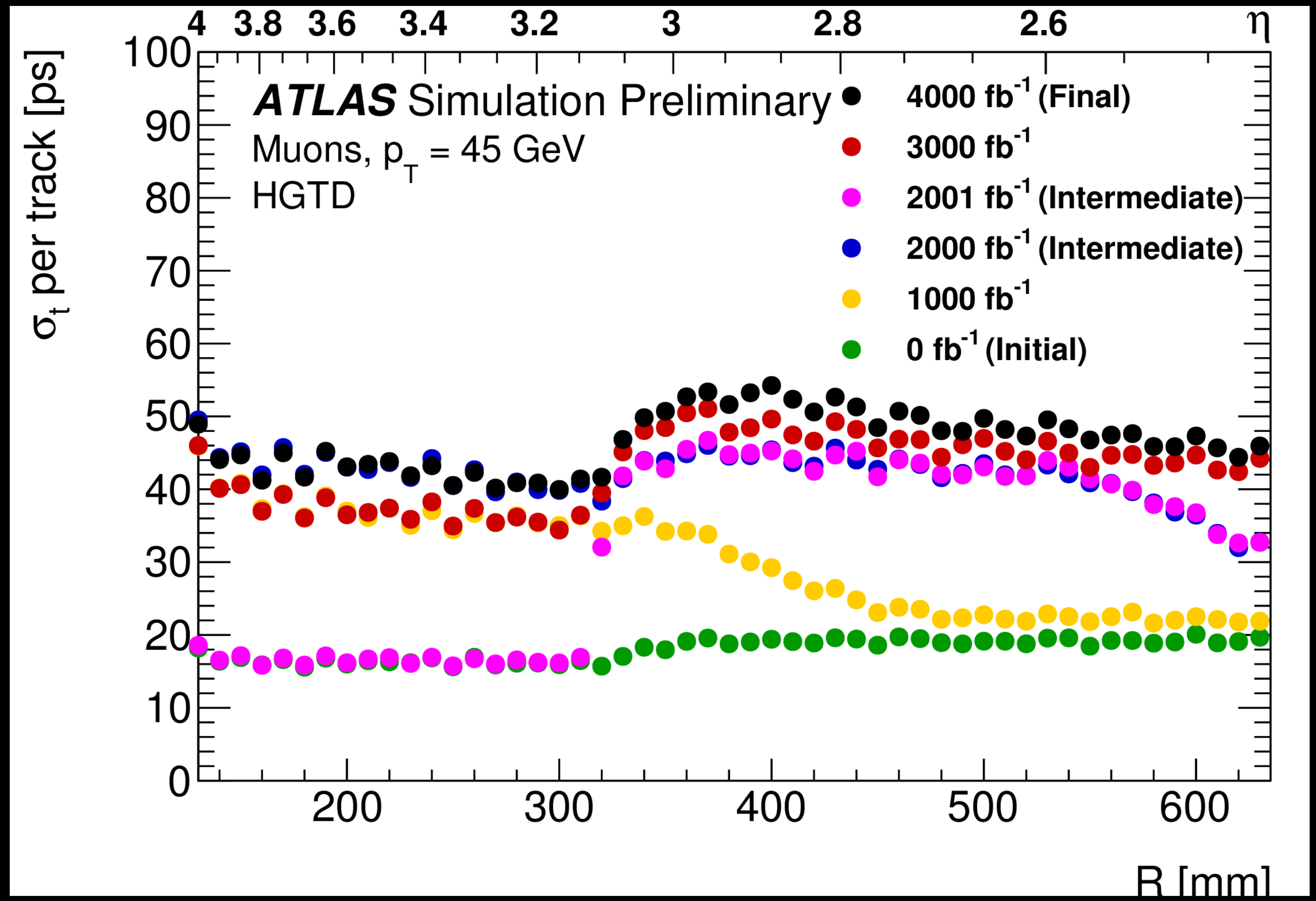


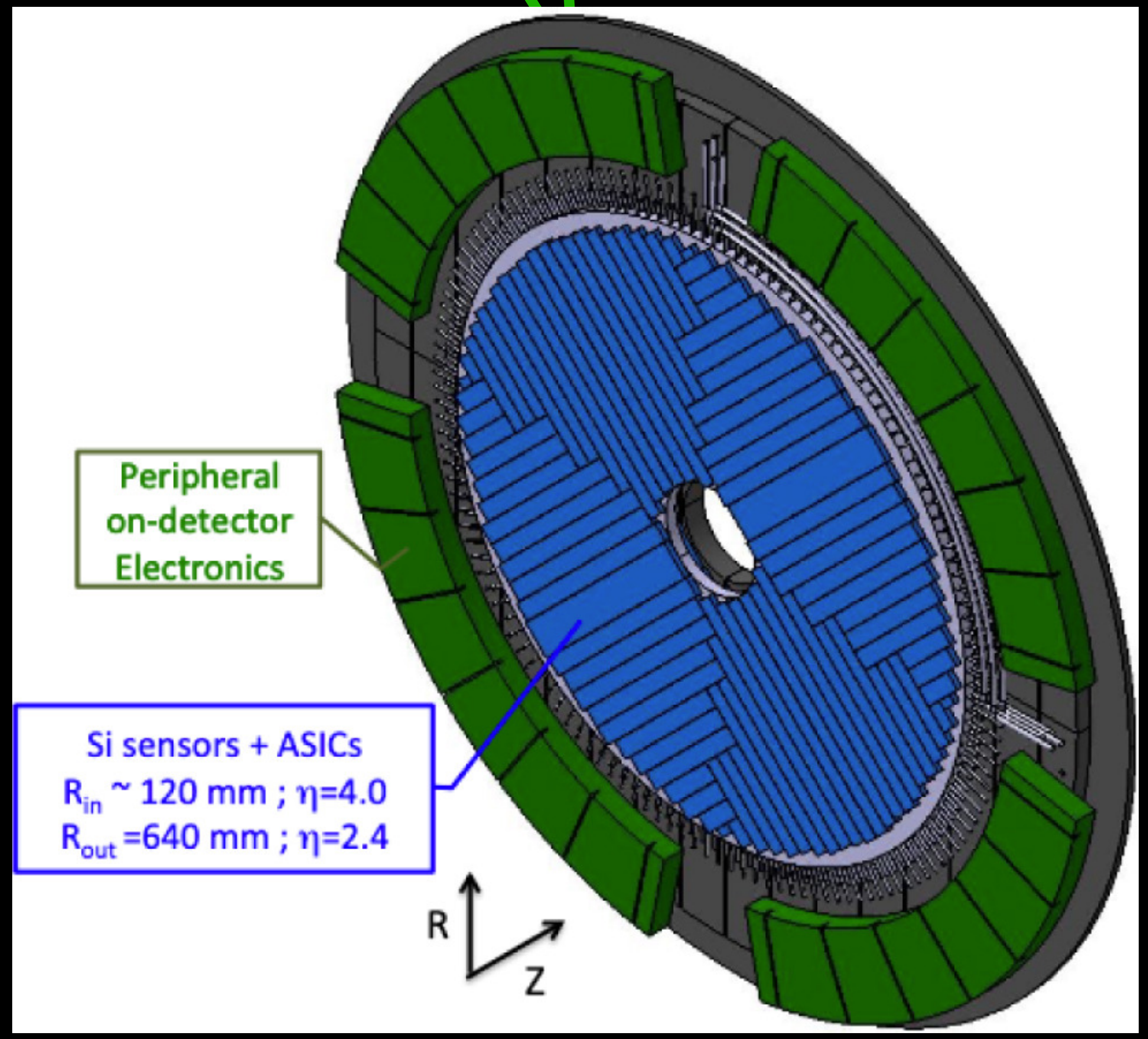
LAr calorimeter and HGTD

- Liquid Argon Calorimeter:
  - Current electronics is not compatible with Run4 (increased latency and trigger rate)
  - Radiation hardness requirements are above original design (1 kGy and 2.7 × 10^{13} neq/cm^2)
  - Run3 upgraded boards will continue to be used
  - Full replacement of readout electronics (front-end and back-end):
    - Full granularity digital data sent at 40 MHz to back-end
    - Improved algorithms to deal with overlapping events deriving from increased pile-up
    - FPGA based electronics: AI algorithms applied fo measuring the energy
- High Granularity Timing Detector:
  - Radiation-hard silicon-sensor detector, two disks per each end-cap, two sensor layers per each disk
  - Active radius from 120 mm to 640 mm, thickness < 125 mm, installed in front of the LAr end-cap calorimeters
  - Low Gain Avalanche Detectors technology, 1.3 mm x 1.3 mm readout cells, for precise timing and luminosity measurements
  - Timing resolution of ~30 ps for minimum-ionizing particles for precise vertex reconstruction and to disentangle events in high pile-up
  - Enhances ITk in region 2.4 < |η| < 4.0 (±3.5 m from the interaction point)
  - Many tests done to certify the sensor technology, recent HGTD test beam results and plots on the ATLAS public results twiki page



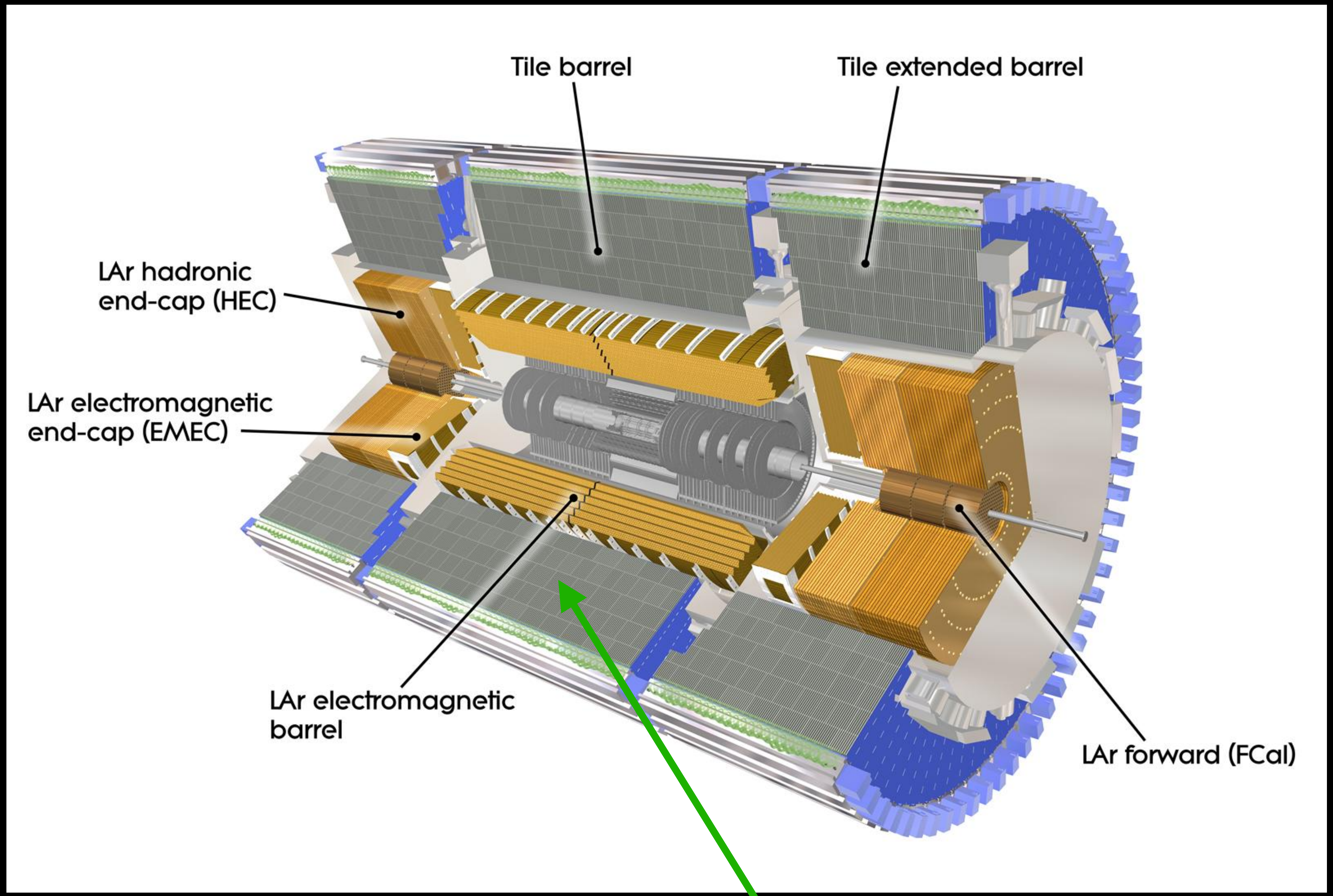
ATLAS public results web page - HGTD



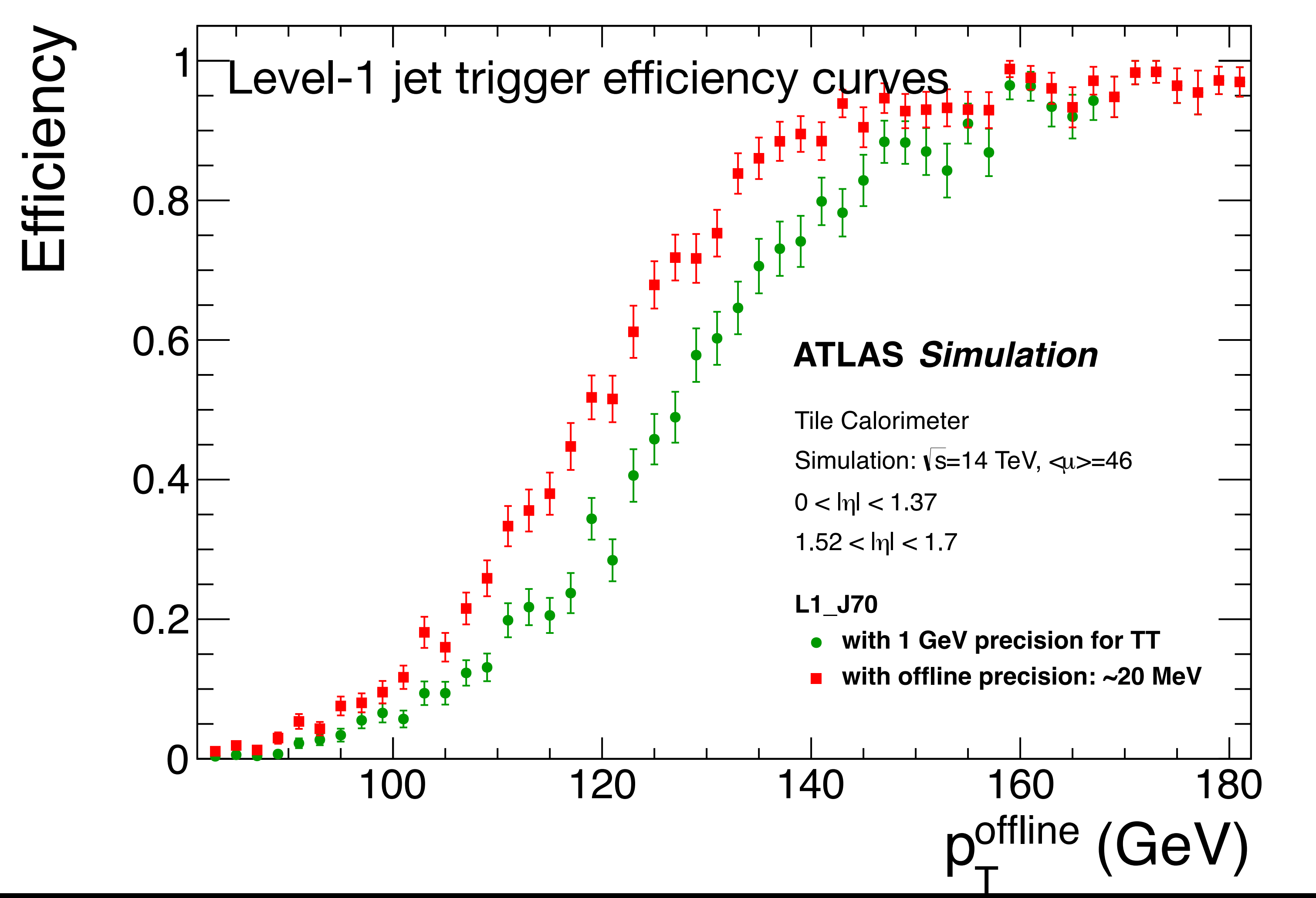


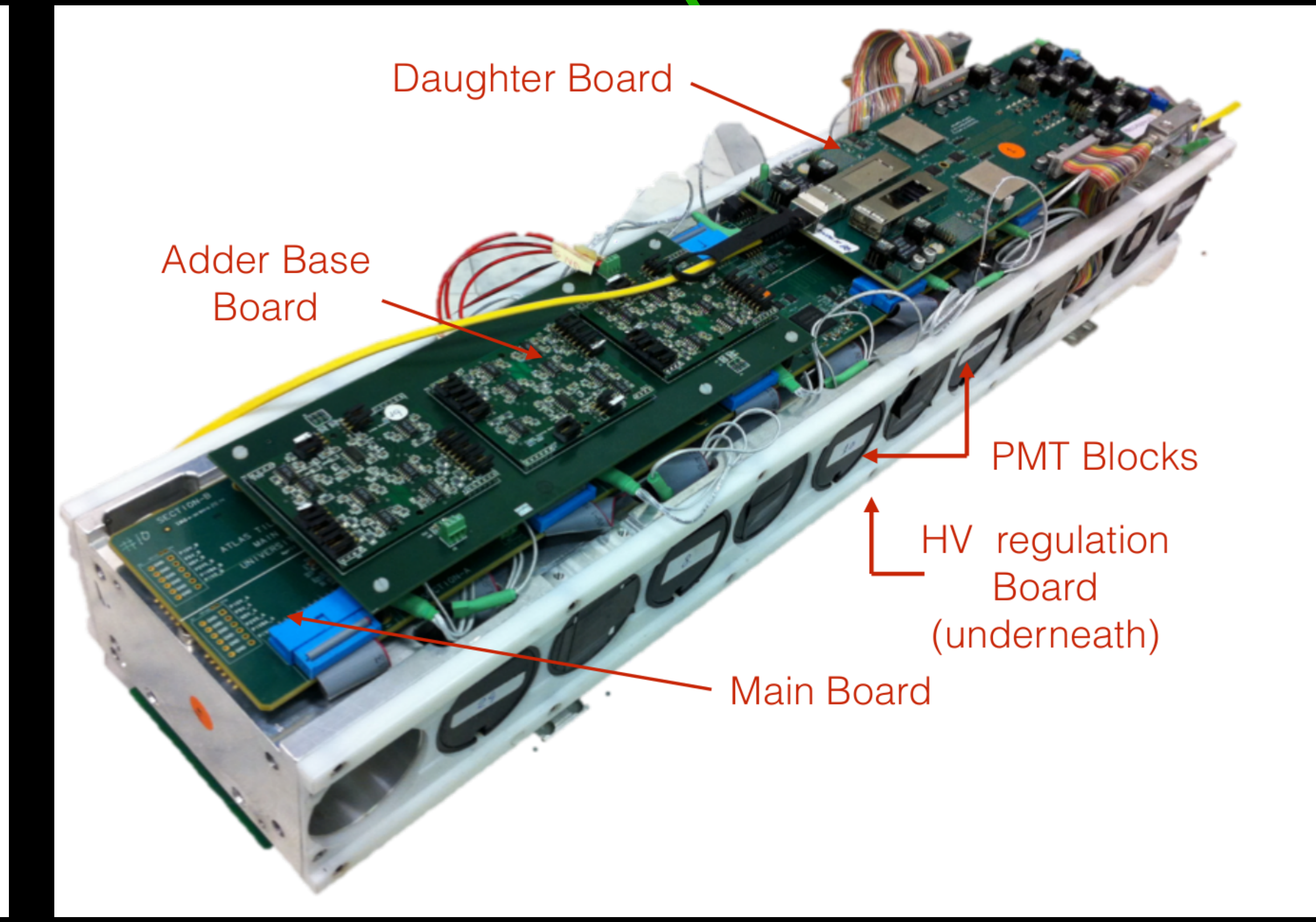
Tile calorimeter

- On-detector and off-detector electronics fully replaced to improve the radiation tolerance and the performances at high pile-up
- Front-end signals from calorimeter cells are digitized and sent directly to the back-end electronics, where the signals are reconstructed, stored, and sent to the Level-0 trigger at 40 MHz
- Better precision of the calorimeter signals used by the trigger system for more complex trigger algorithms



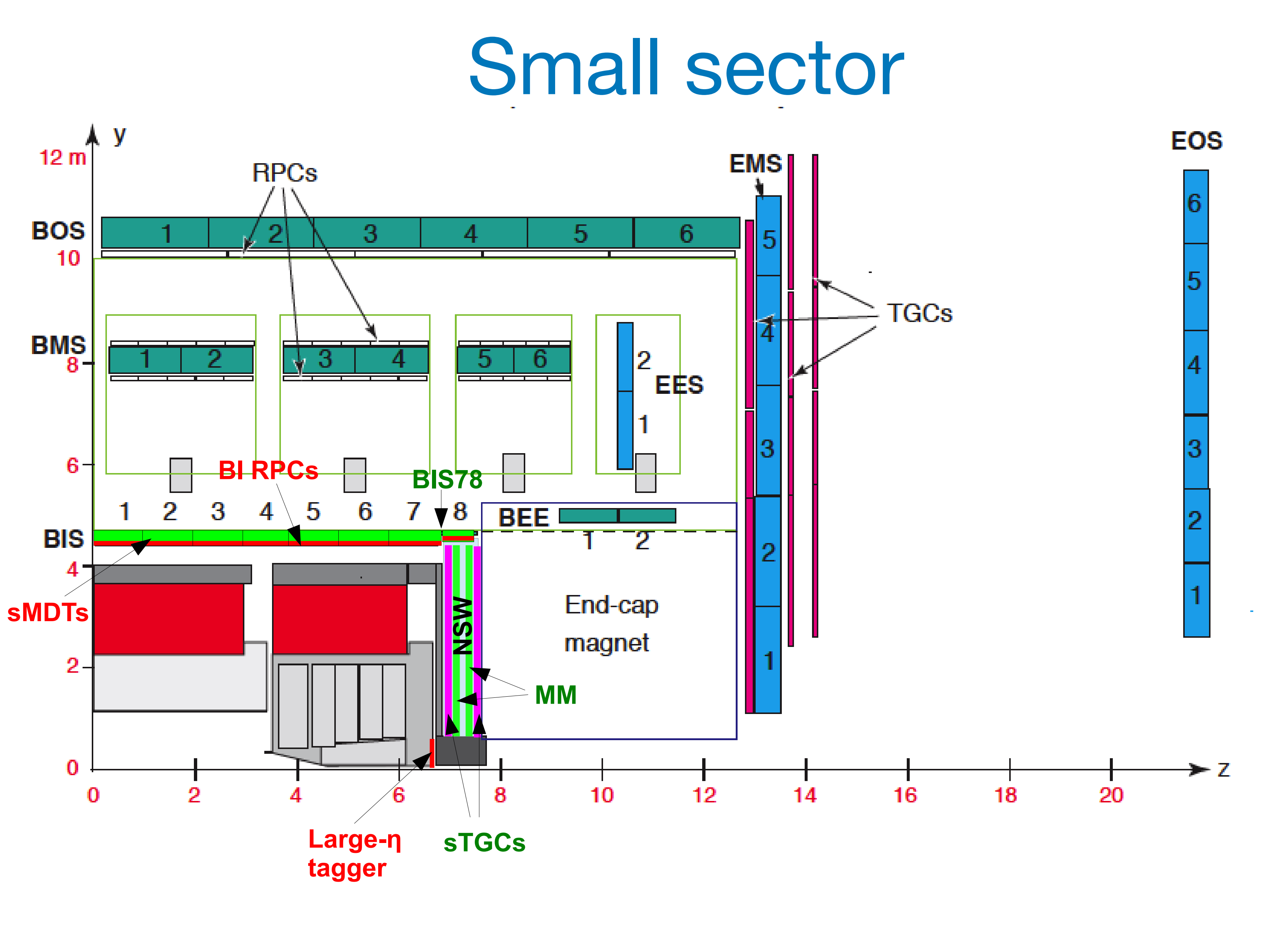
Tile Cal Phase-II TDR plots

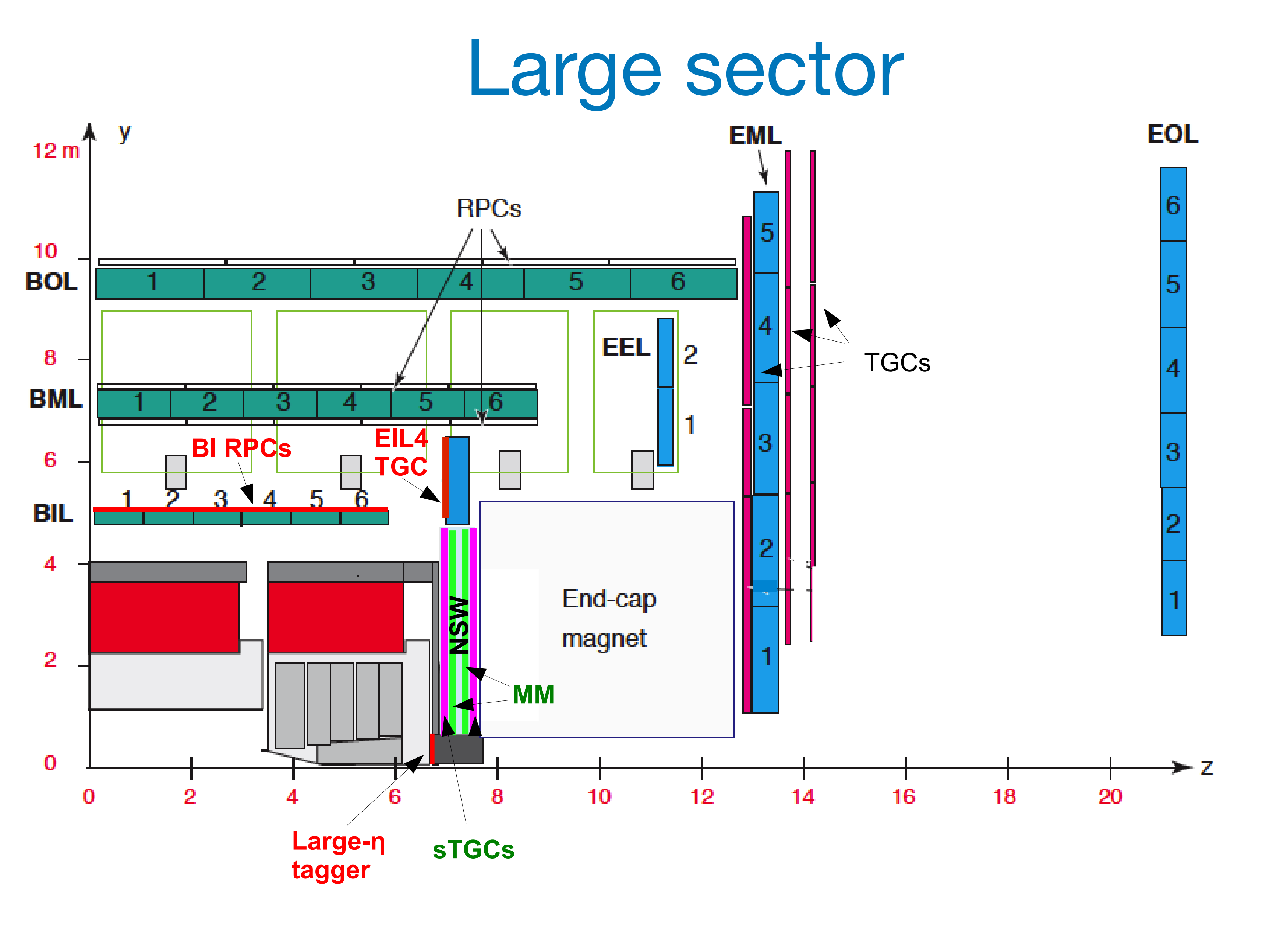




Muon detectors

- New RPC and sMDT detectors in the inner region of the barrel:
  - current BIS MDT replaced by new (sMDT + RPC)
  - new RPC triplets installed on top of the existing BIL MDT
- New sTGC triplets in the end-cap inner region EIL4
- The new detectors allow to:
  - reduce the trigger fake rate in barrel and end-cap regions
  - increase the trigger performances
  - increase the geometrical coverage in the barrel
- Detectors and front-end prototypes built, validation ongoing

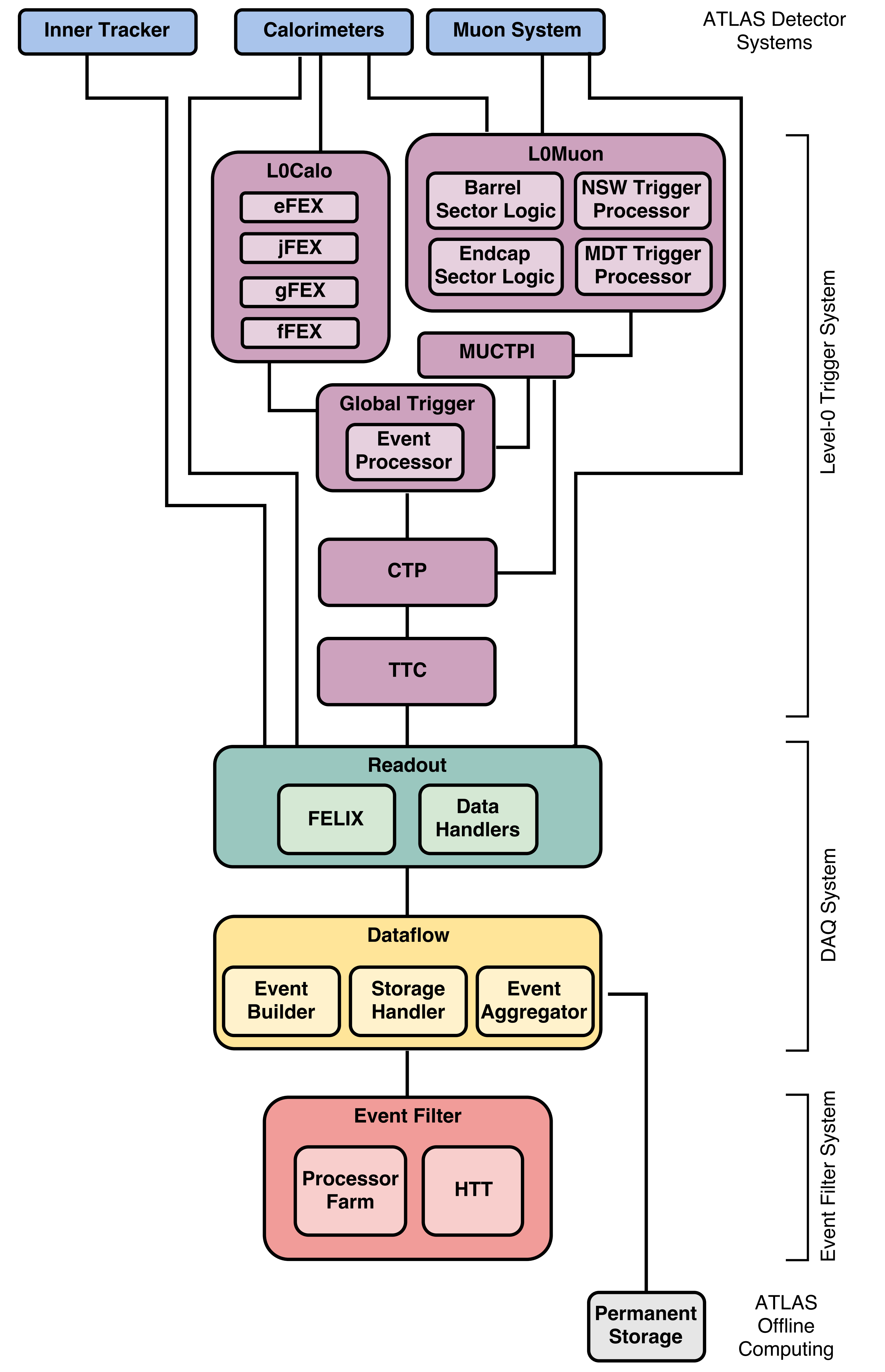




Trigger and DAQ

- Single level Level-0 hardware trigger with an output rate of 1 MHz, Level-0 readout latency is 10 μs
- Calorimeters and muons front-end full granularity readout at 40 MHz
- New Global Event processor replaces the current L1Topo and integrates topological functions with additional selection algorithms using information from muons and calorimeters
- Readout based on FELIX system for all detectors
- FPGA-based boards off-detector, on-detector where possible
- Possible hardware accelerator system for tracking at the Event Filter
- Goal of better e, γ, τ, jet identification and measurement, at hardware and software trigger levels and offline
- Event Filter output increases to 10 kHz

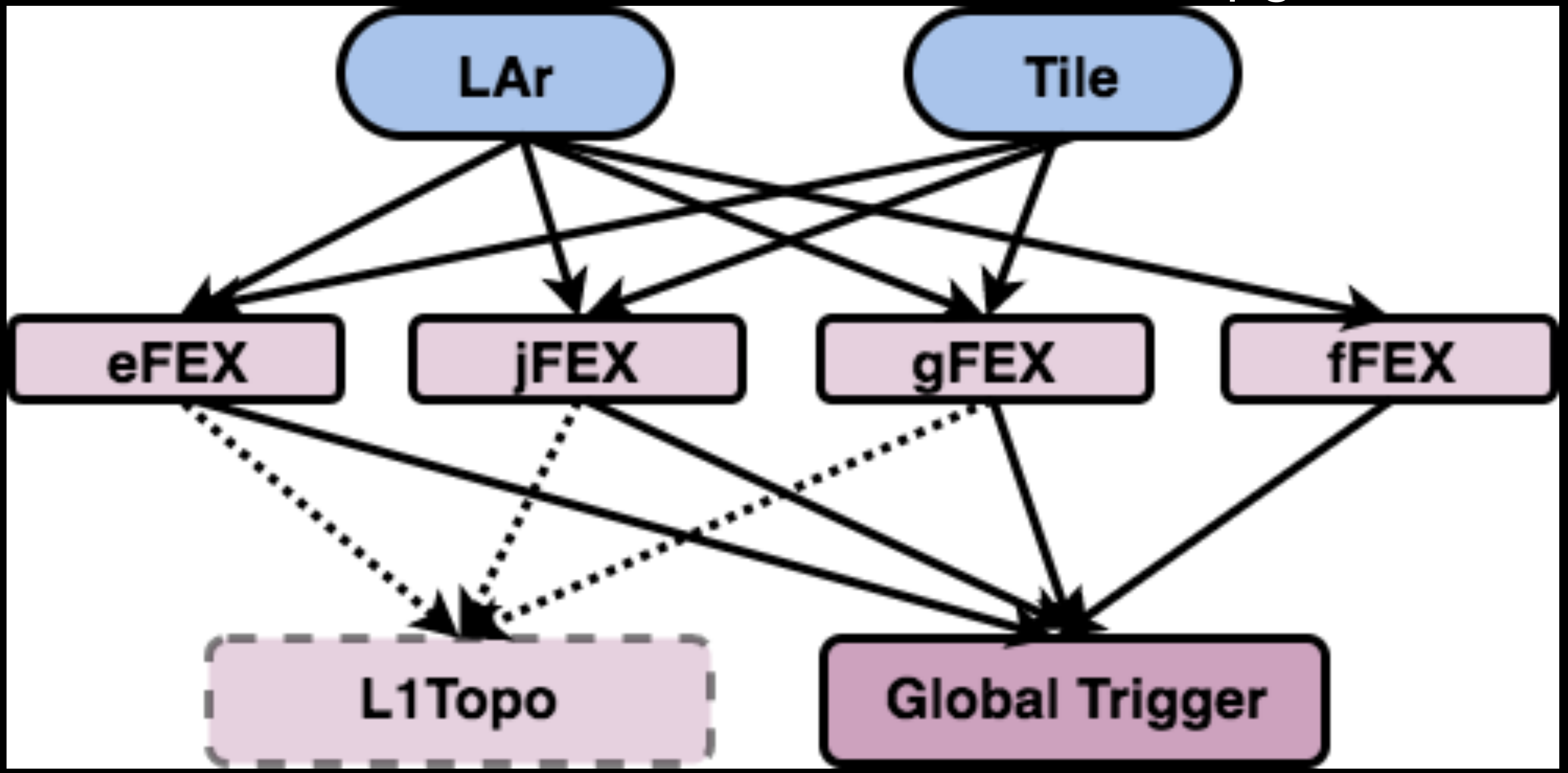
ATLAS Phase-II TDAQ Upgrade TDR

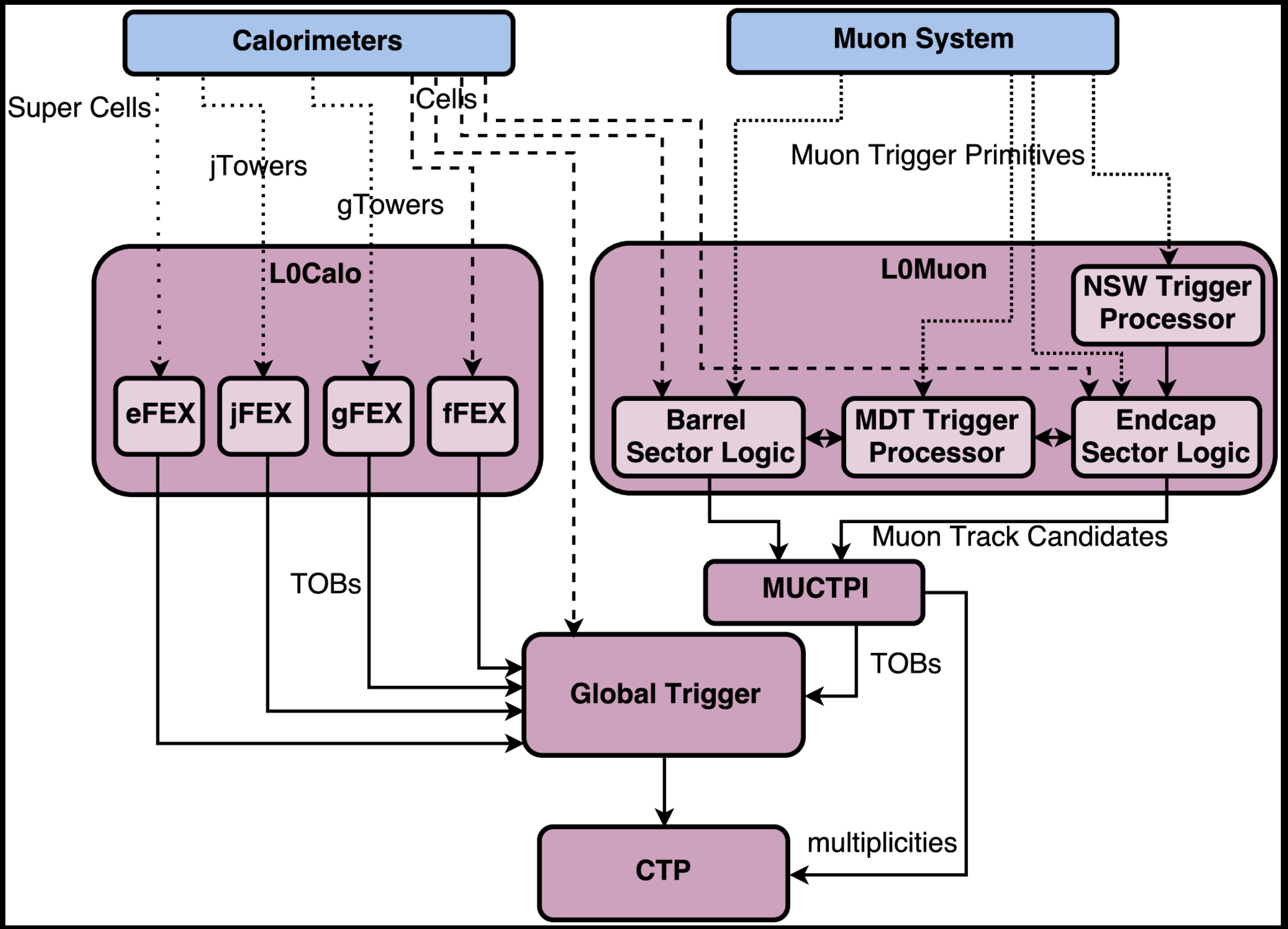


Level-0 calorimeter trigger

ATLAS TDAQ Phase-II Upgrade TDR

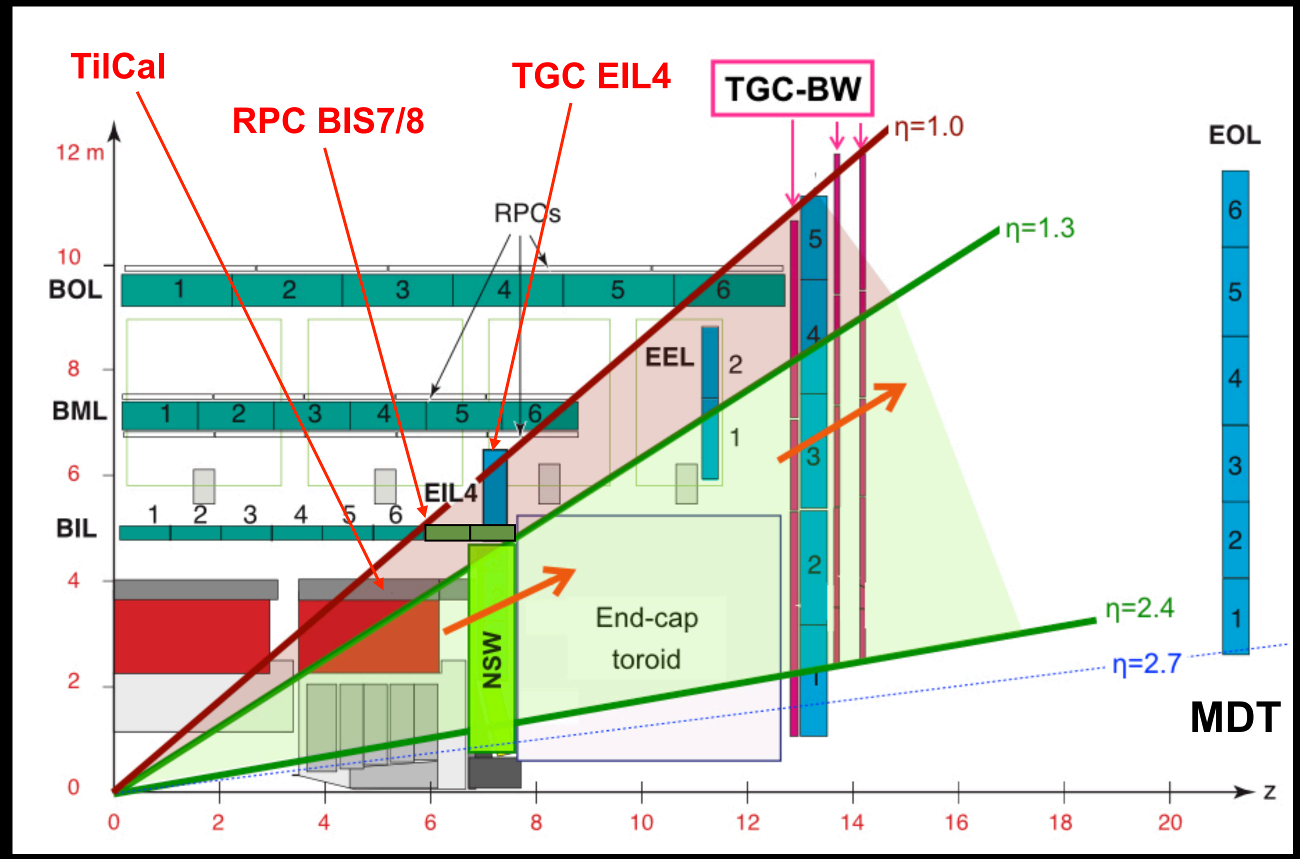
- High granularity full digital data from calorimeters sent at 40 MHz
- LAr and Tile calorimeter are sent separately to each Feature Extractor (FEX) board
- Legacy FEXs identify electron/photon/tau candidates (eFEX), jets and ETmiss (jFEX) and large-R jets (gFEX)
- New fFEX allows triggering also in the forward region (board design in progress)
- L0 Calo output to Global and Topological processors



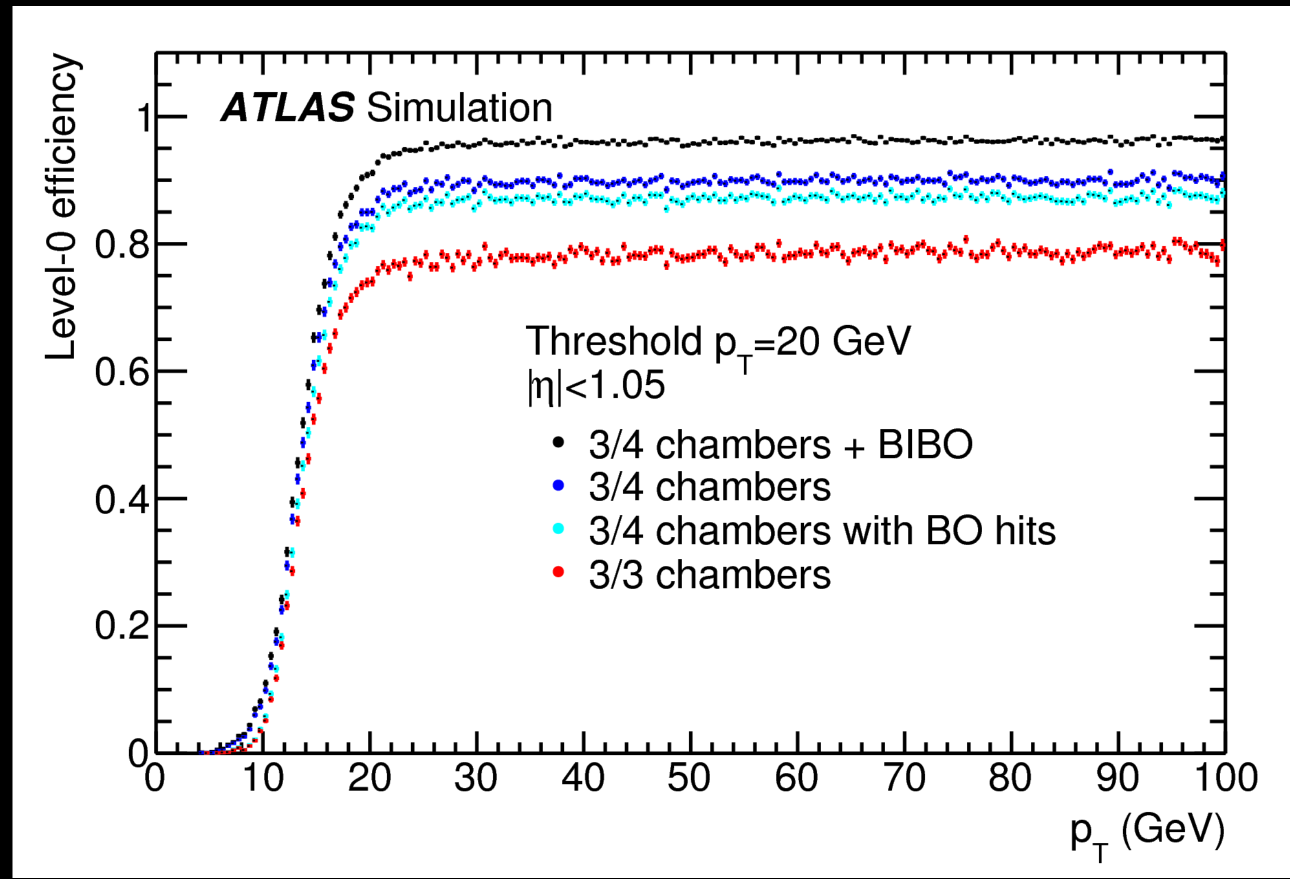


Level-0 muon trigger

- The data from the RPC, TGC, and NSW detectors used in the Run3 system will be complemented with BI RPC, Tile calorimeter and MDT
- Increased selection efficiency and reduced fake trigger rate
- New MDT trigger sharpens turn-on curve and increases the rejection power
- Possibility to loose RPC trigger selection to increase the geometrical acceptance in the barrel, from ~70% to ~95%
- Rate suppression of ~50% for muons with p_T < 20 GeV
- New on-detector electronics full digital readout to off-detector @ 40 MHz
- Barrel and end-cap new off-detector Sector Logic trigger boards perform the coincidence trigger algorithm and send the seed to the MDT Trigger Processors
- New MDT Trigger Processors match the MDT hits with the RPC/TGC seed vectors in space and time
- Large use of FPGAs on and off-detector
- Board prototypes (front-end, SL, MDT-TP) available, currently under test



ATLAS Muon Spectrometer Phase-II TDR plots



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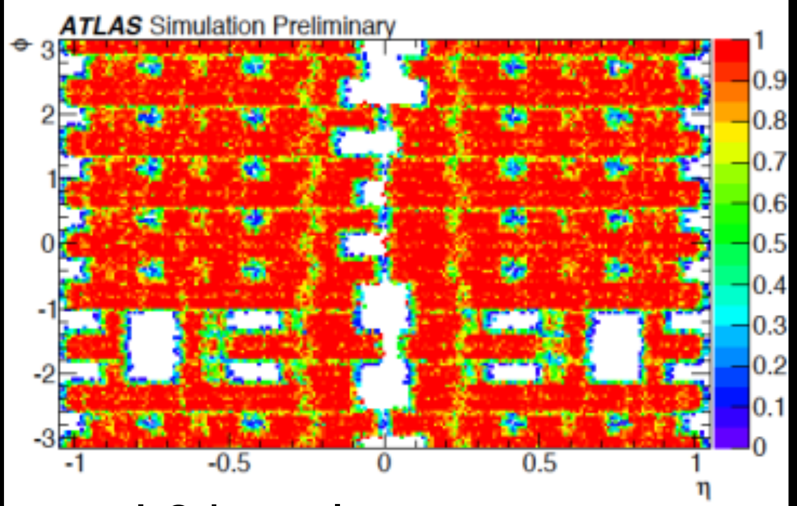
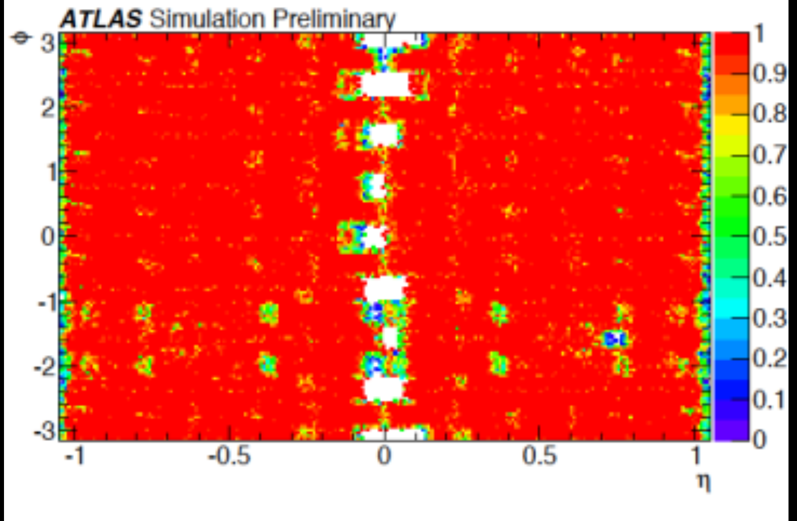
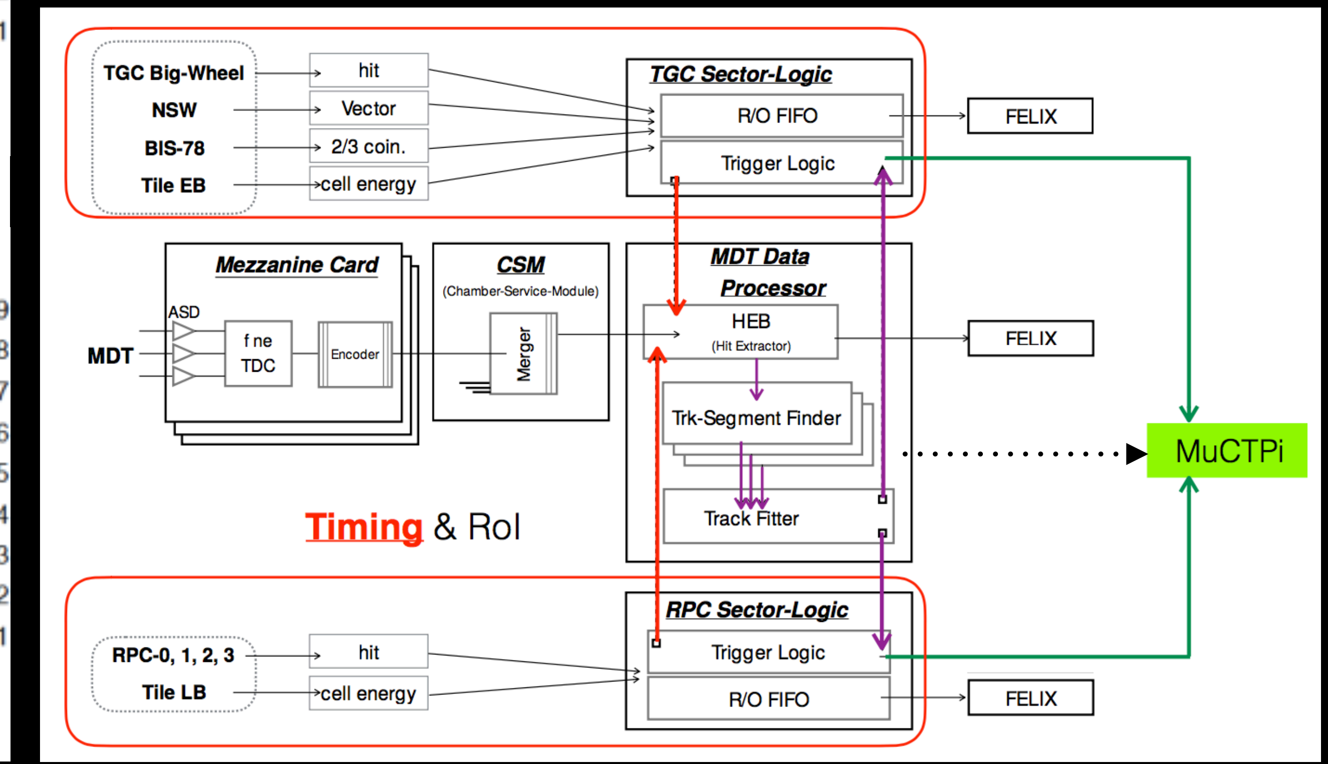


L0 barrel acceptance
Run3 vs. Run4

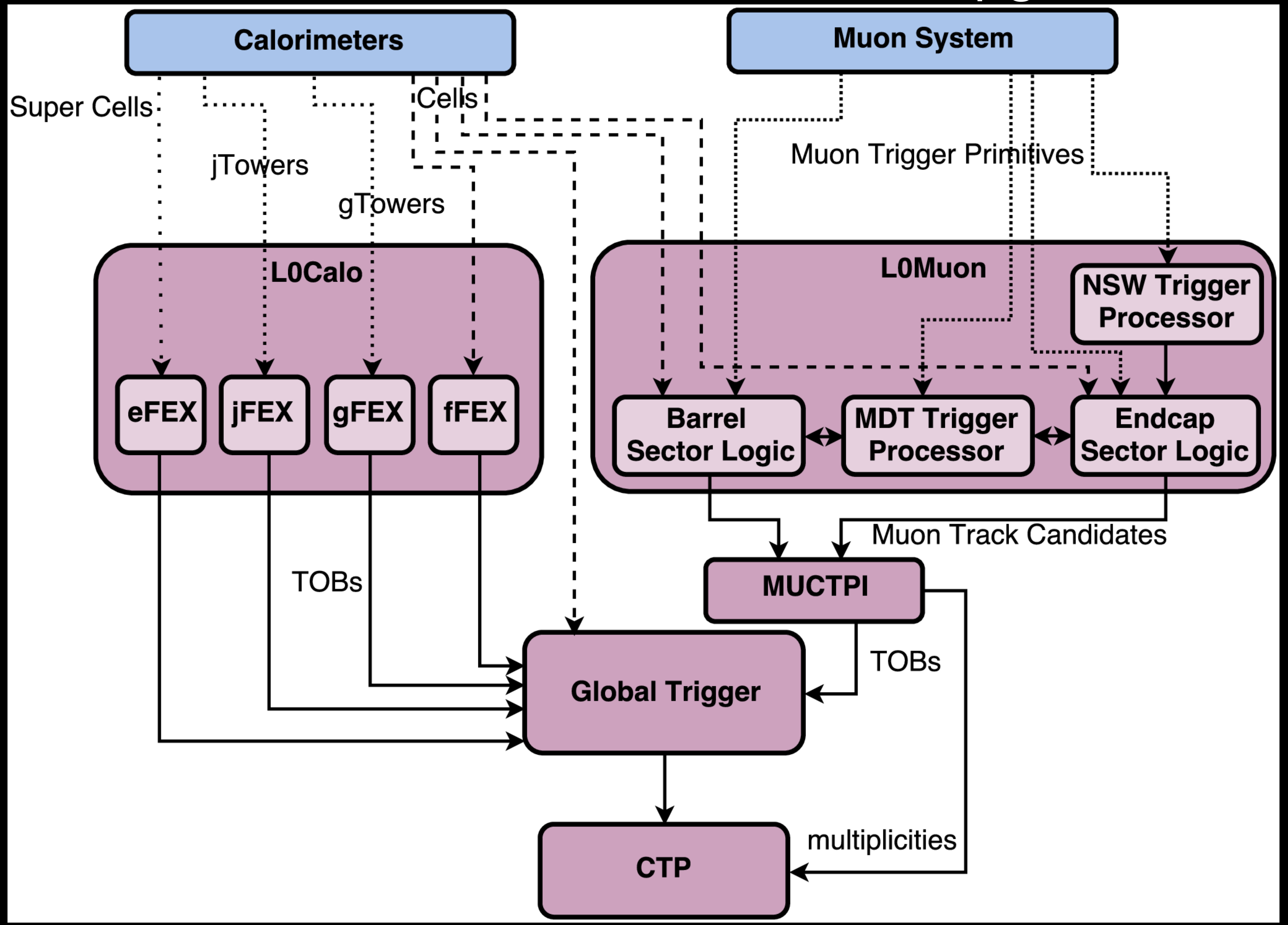


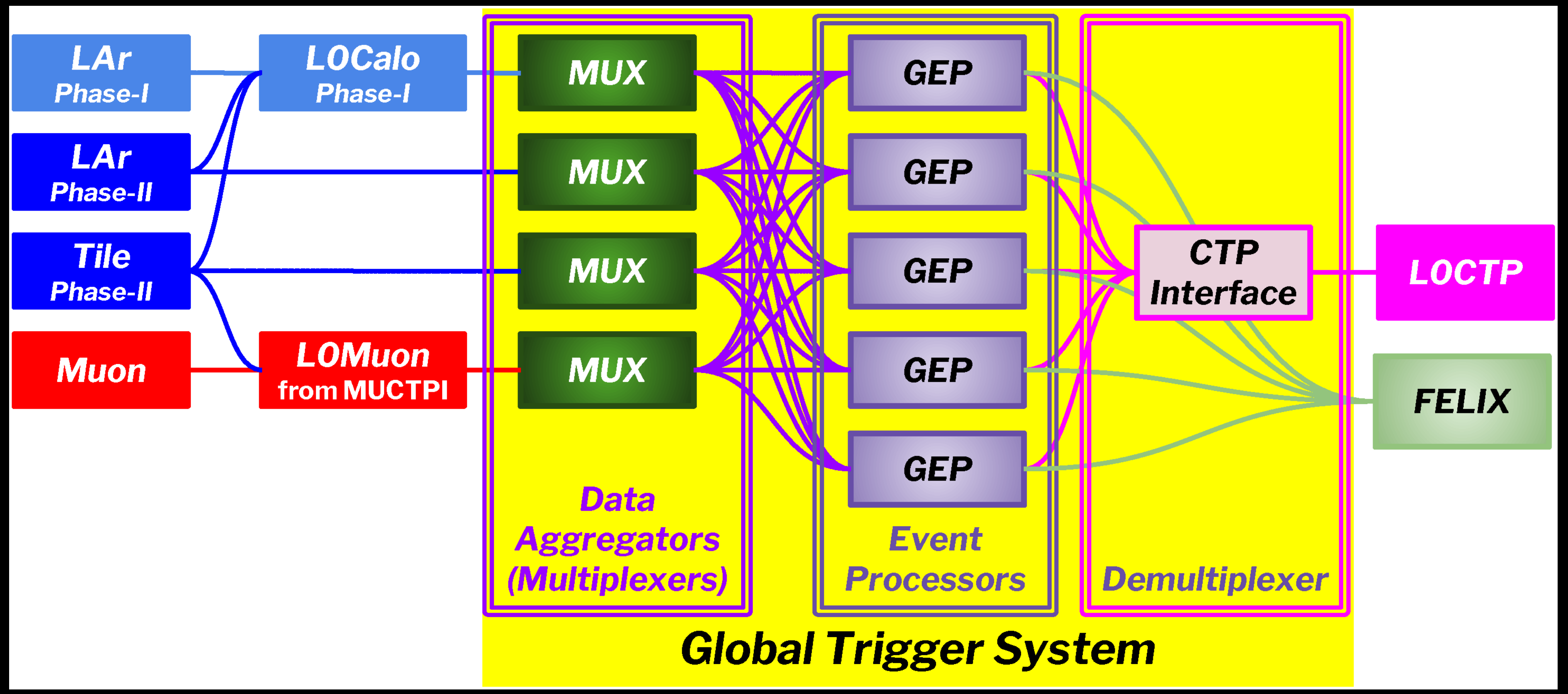


Level-0 global trigger

- Runs trigger algorithms similar to the ones in HLT, on high granularity data
- Replaces Run3 Level-1 topological trigger
- FPGA-based hardware, firmware components are:
    - MUX: data aggregator and time multiplexer of events from all sub-detectors (>50 TB/s throughput)
    - GEP: Global Event Processing and trigger algorithms
    - CTPi: Central Trigger Processor interface (takes final decision)
- Latency is a critical parameter for this project
- Board design and firmware progressing

ATLAS TDAQ Phase-II Upgrade TDR

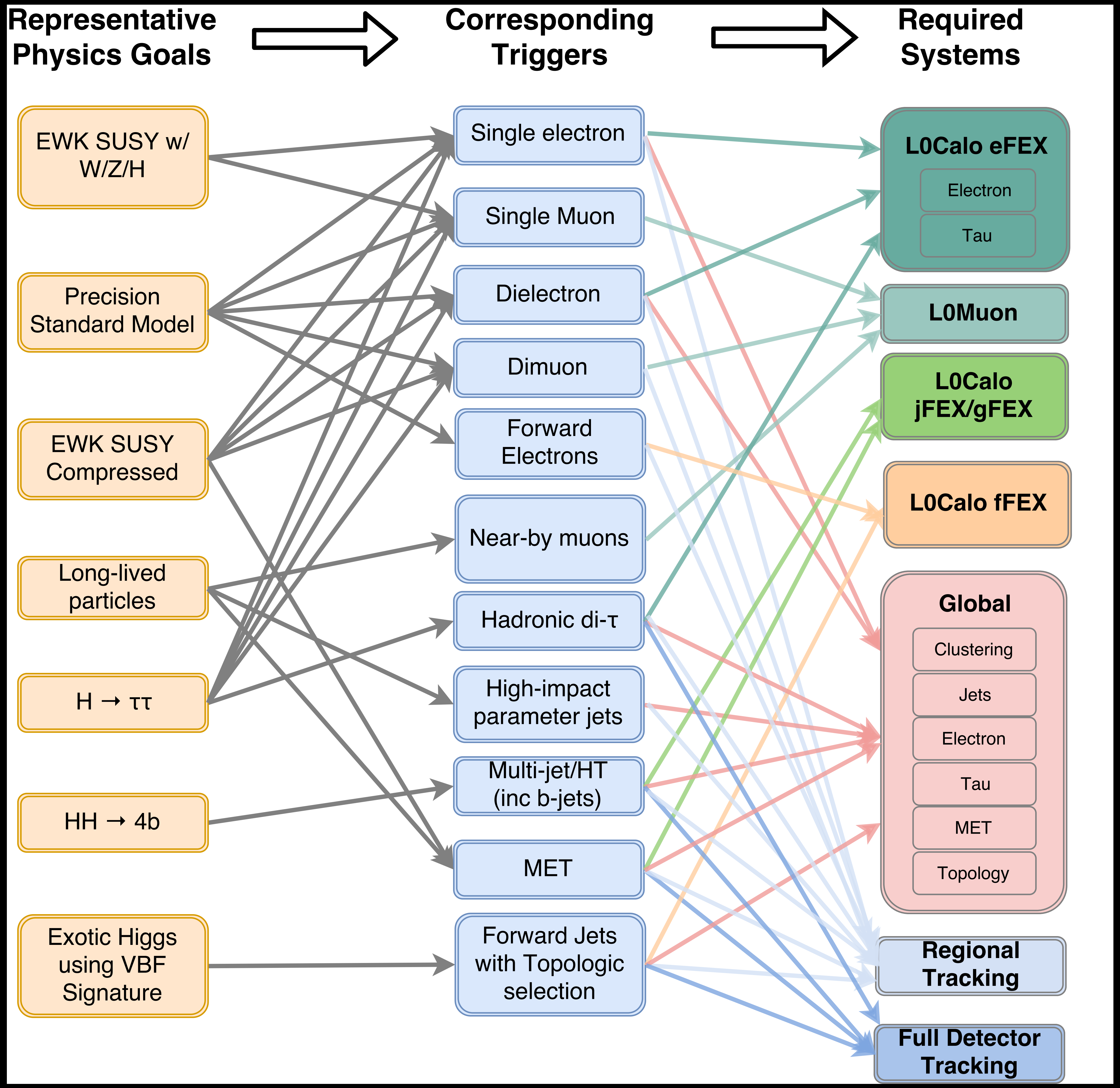




Conclusions

- The large datasets that can be collected with the High-Luminosity LHC will allow to perform Higgs and SM precision measurements, the search for rare Higgs boson decay modes and the study of low production cross section Standard Model processes, as well as the search for new phenomena beyond Standard Model
- ATLAS Run3 upgrades:
  - New detectors and new electronics improve the rate capabilities and background rejection for L = 2 x 10^{34} $cm^{-2}s^{-1}$
  - New systems are currently under commissioning
- ATLAS Run4 upgrades:
  - Designed for L = 7.5 x 10^{34} $cm^{-2}s^{-1}$ and 4000 fb^{-1}
  - Up to factor 10 increase in radiation hardness
  - Improved pile-up handling with new tracker and timing detector
  - Improved trigger and readout capabilities thanks to new detectors and new electronics
  - Detector and electronics prototypes available, moving towards pre-production
- Additional info available in the ATLAS upgrade public web page

ATLAS TDAQ Phase-II Upgrade TDR



Flow from the representative set of physics goals to the hardware systems