The ATLAS experiment Phase-I upgrades for the LHC Run-3

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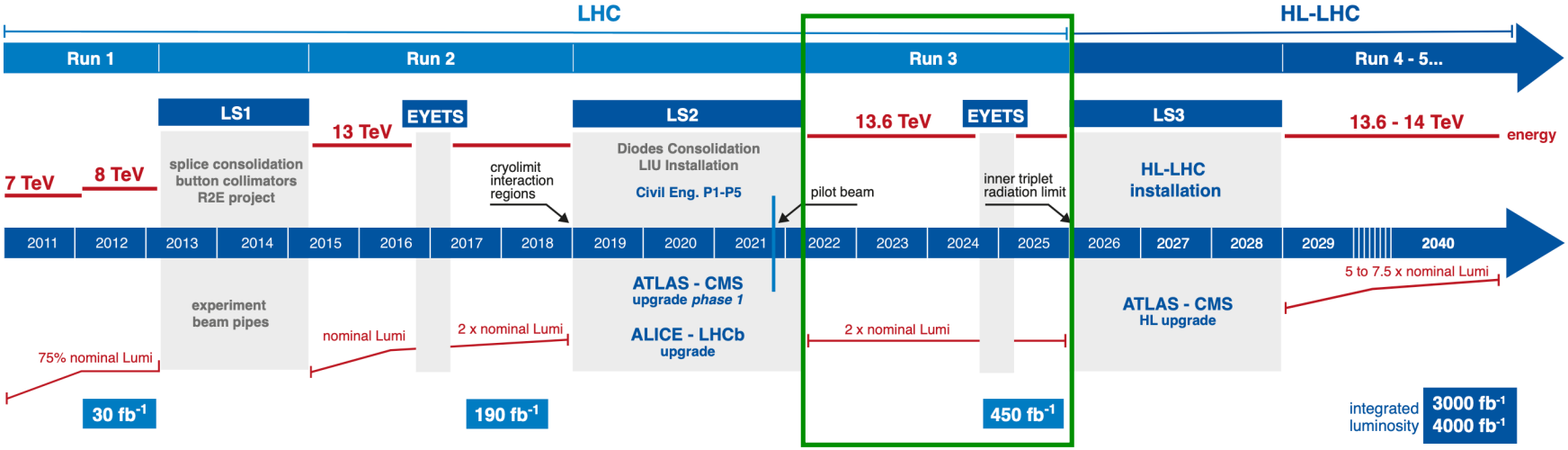
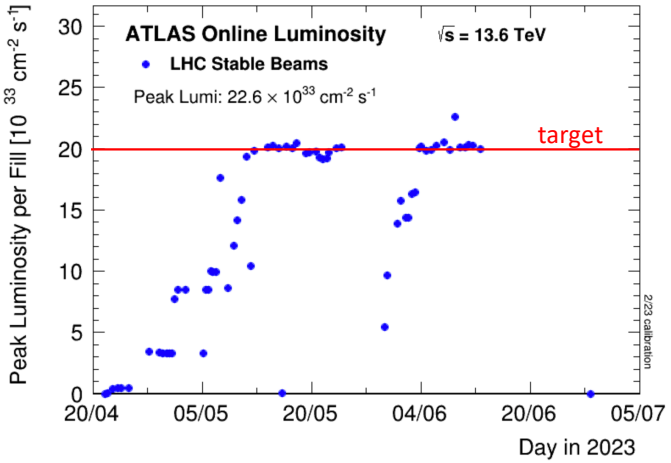
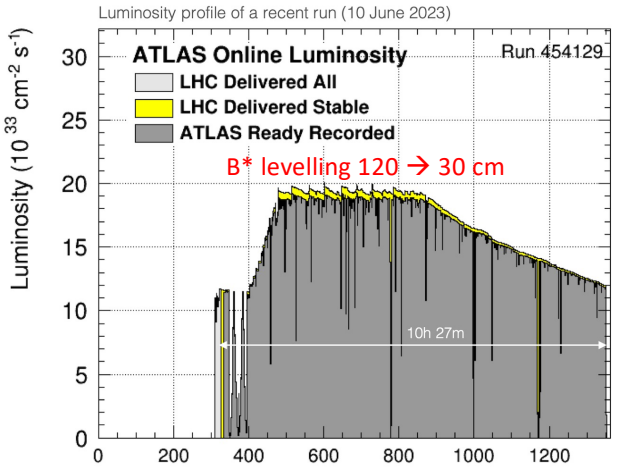
On behalf of ATLAS Collaboration

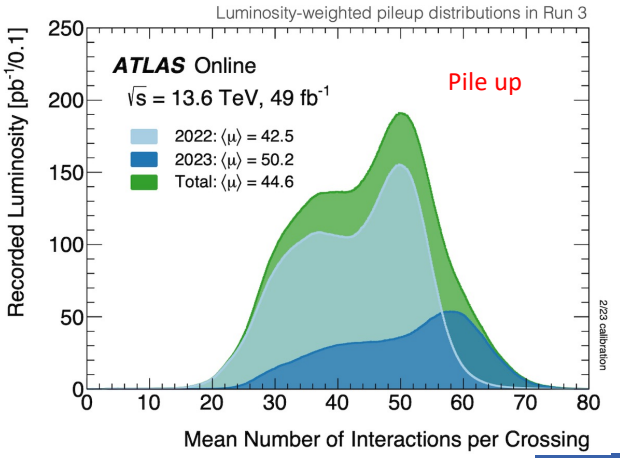
INFN

LHC: Run-3 (and HL-LHC Plans)







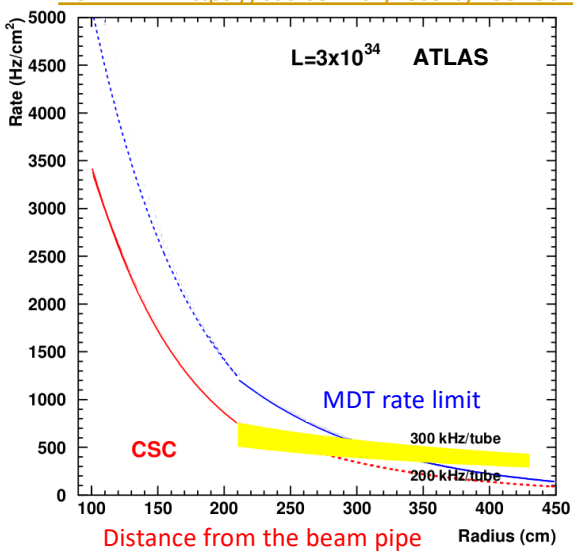


Implications on the Atlas detector

- **Unsustainable particle flux in some detectors.**
  - This is an example of the particle rate in the MDT tubes and CSC of “old” small wheel extrapolated to high luminosity from the 2010 data.

NSW TDR: https://cds.cern.ch/record/1552862

Extrapolated rate per cm^2 in the MDT or in the CSC.

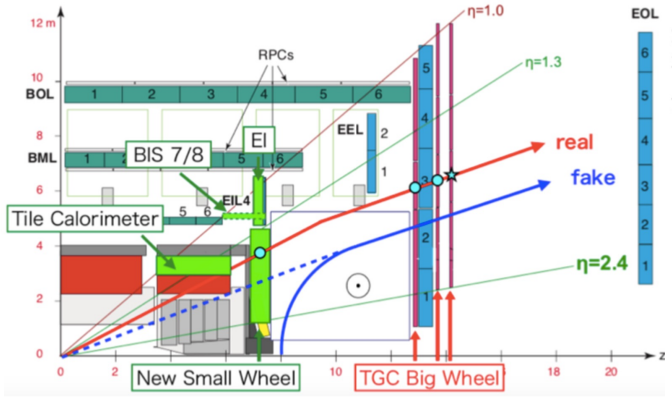


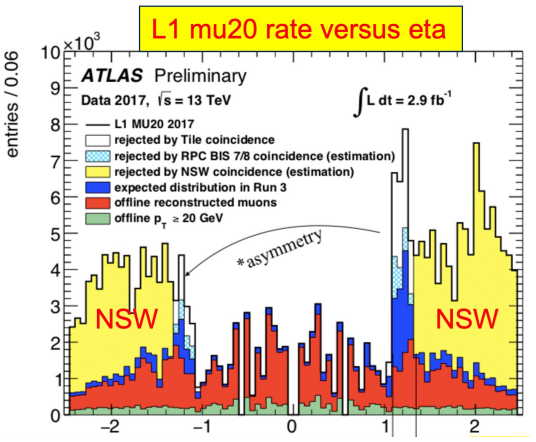
Small Wheel should be replaced by a NEW Small Wheel

- **Unsustainable Level-1 trigger rate.**
  - Target L1 rate is around 93 kHz, otherwise the protective dead time for the readout will be too high (it is 2-3% at 93 kHz).
  - A possible handle to reduce the L1 rate is to increase the single lepton thresholds (20 GeV for muons and 27 GeV for electrons), that we don’t want to do .

We need to reduce those rates without increasing the thresholds

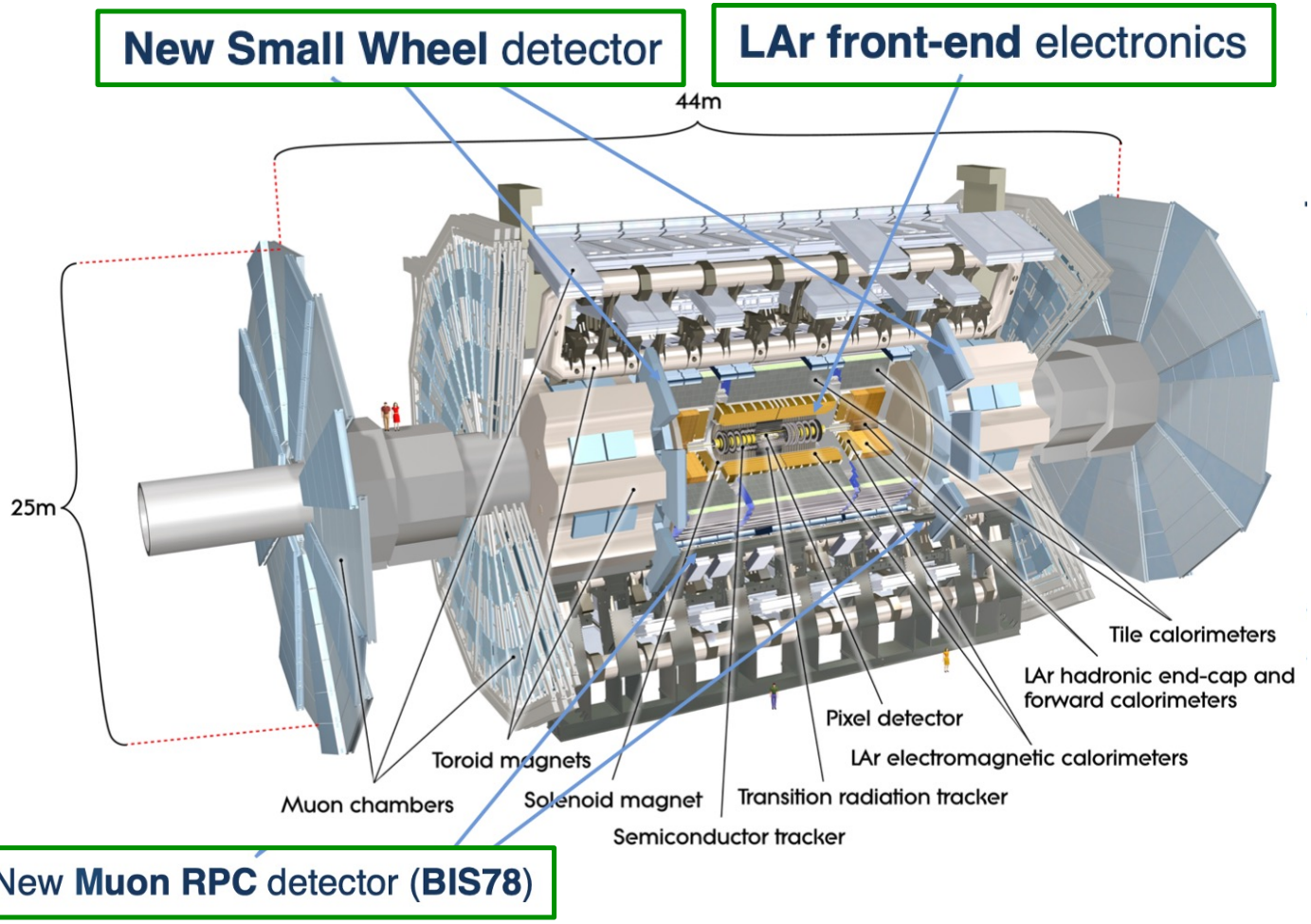
Example of how to reduce the muon trigger rate in the endcap region





Particles (protons) are bent by the toroid field faking a muon coming from the interaction point

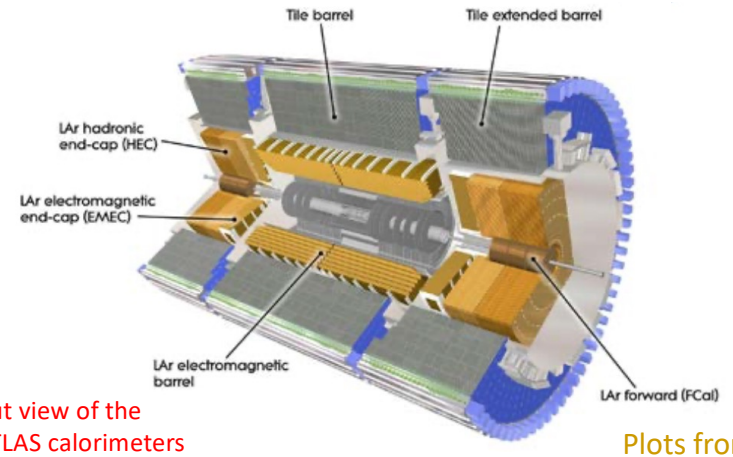
ATLAS Phase-I Upgrades



TDAQ off-detector electronics:

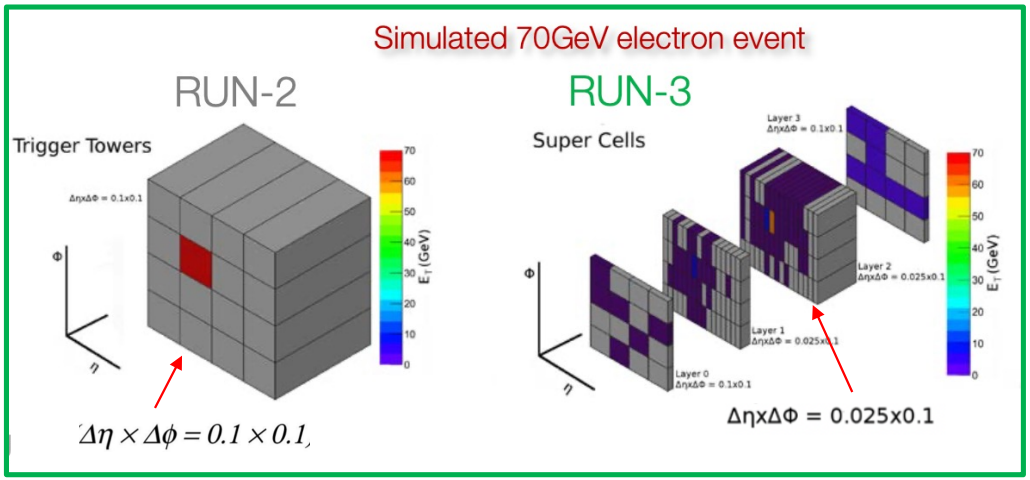
- **L1 hardware trigger**:
  - L1 calorimeter
  - L1 topological
  - L1 NSW trigger
  - L1 endcap trigger
  - L1 MuCTPi
- **Readout system**
- **HLT**

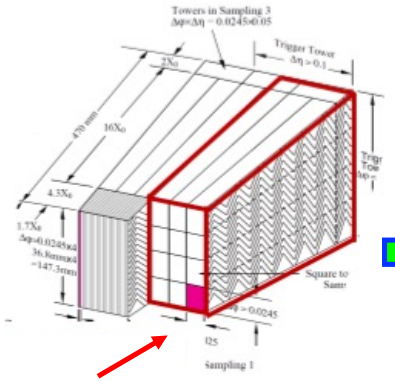
LAr Digital Trigger Upgrade



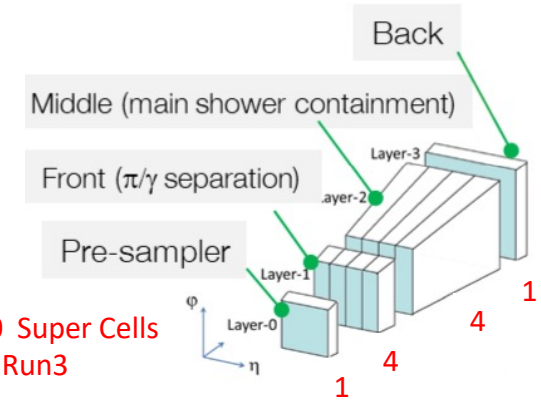
Cut view of the ATLAS calorimeters

Plots from LAr Phase1 TDR

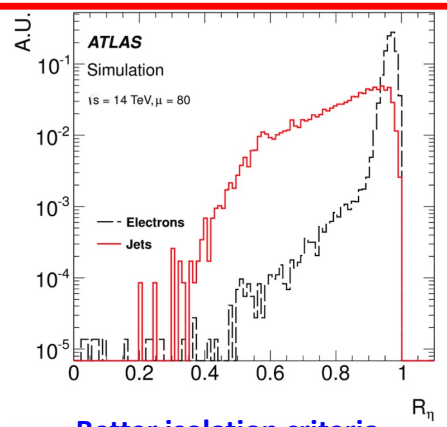




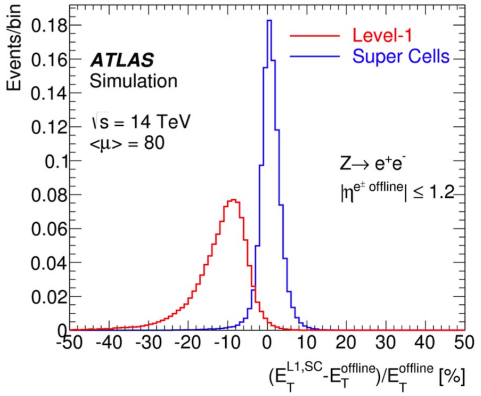
1 Lar Trigger Tower in Run2



10 Super Cells in Run3

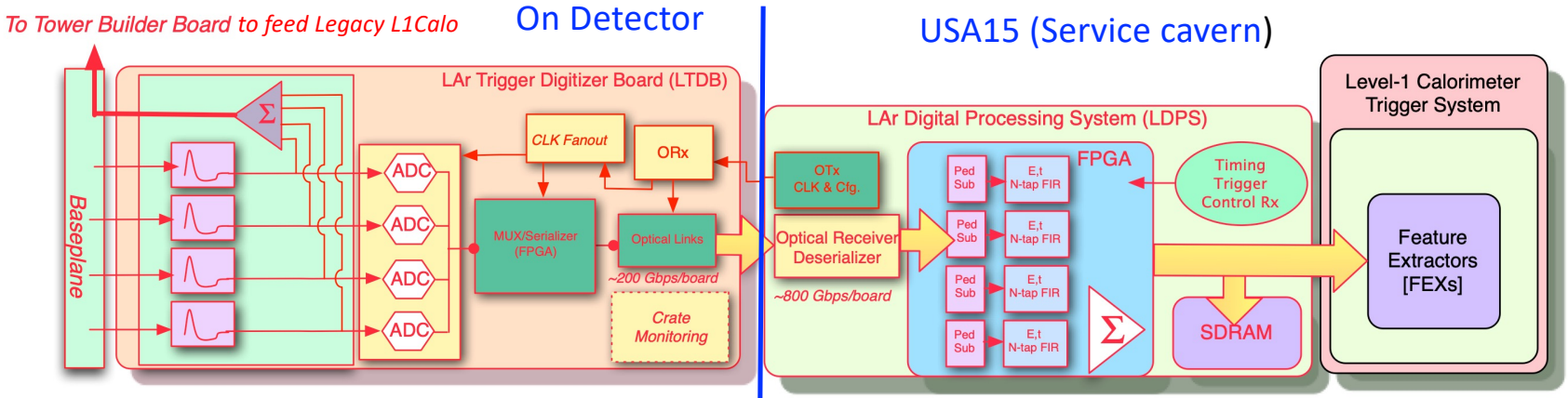


Better isolation criteria



Better energy resolution

Lar Digital Trigger- Implementation



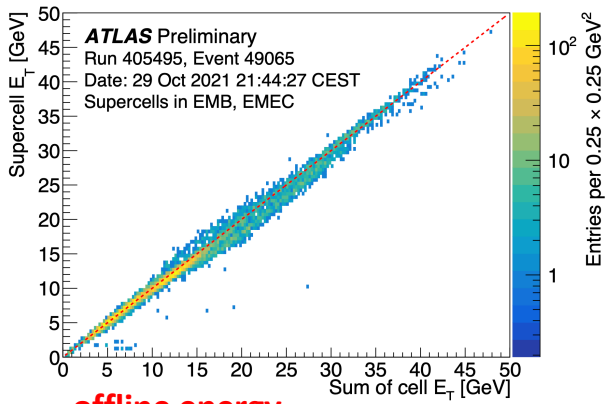
Schematic block of the Lar Trigger Digitizer Board (LTDB);
Super Cells energy is digitised and then sent off detector

Schematic block of the Lar Digital Processing System (LDPS);
reconstructs $E_T^{\text{Super Cell}}$ and transmits the results to L1-Calo.

New Hardware

114 New Baseplanes
2968 New Layer Sum Board
(to build Super Cell Energy)
124 LTDB
116 LDPS

Super Cell energy

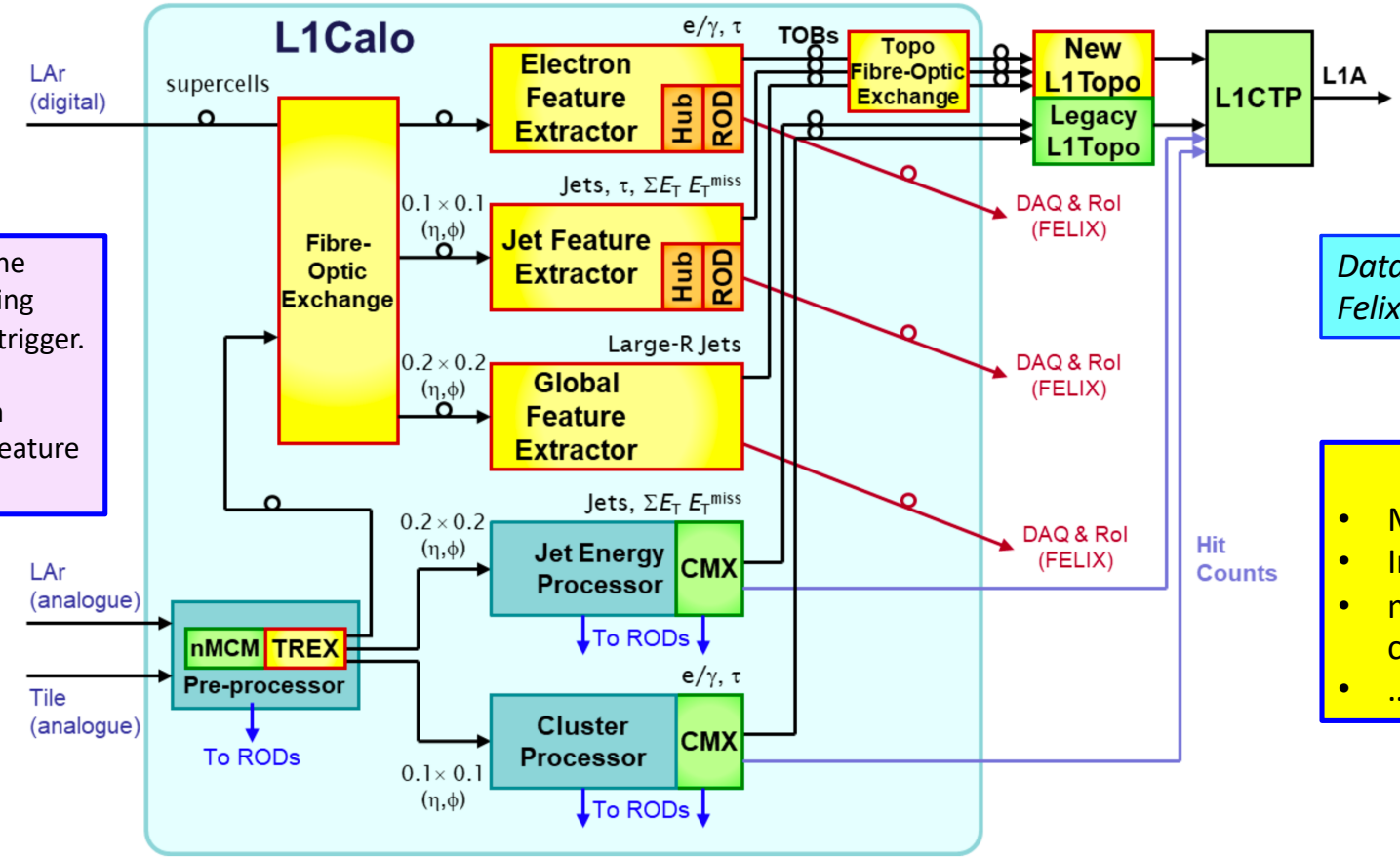


offline energy

L1Calo Upgrade - Overview

The Legacy L1Calo and the Legacy L1 Topo are running in parallel with the new trigger.

Very recently it has been activated the electron Feature Extractor (eFEx).



New for Run 3

Legacy: Run 1

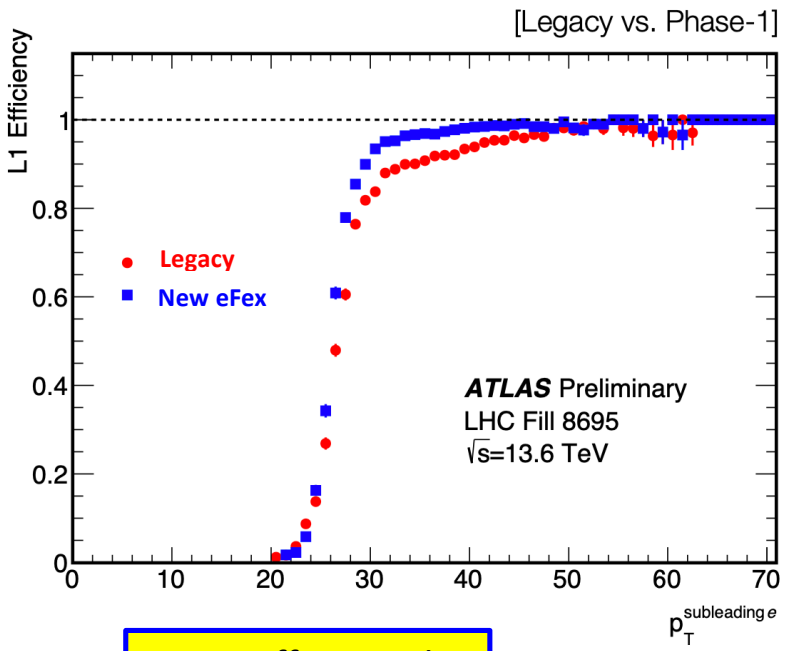
Legacy: Run 2

Data are red through Felix cards

L1 Topo

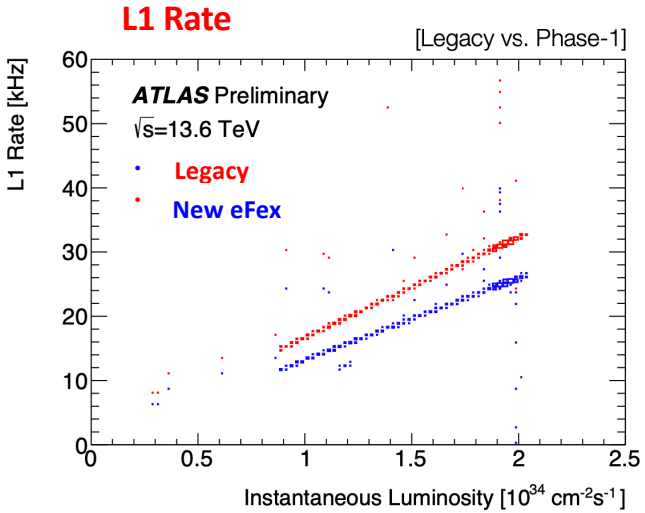
- Multiplicities
- Inviariant mass
- muon-calorimeters correlation
- .....

eFex is providing primary electron trigger



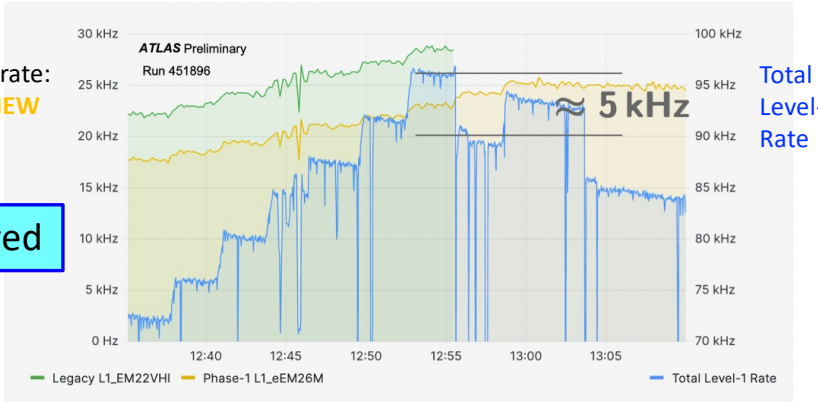
Better efficiency !
… and smaller rate !

Legacy Isolation → Shower Shape Variables



About 5 kHz saved

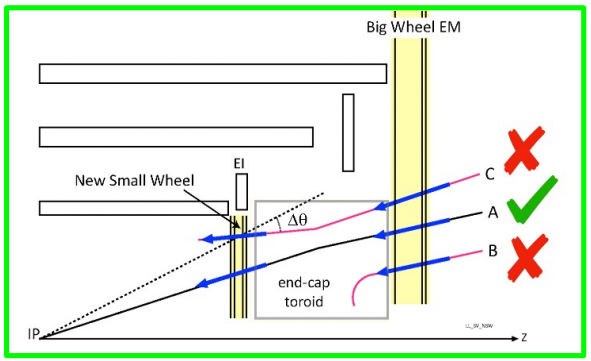
Single electron rate: OLD vs NEW

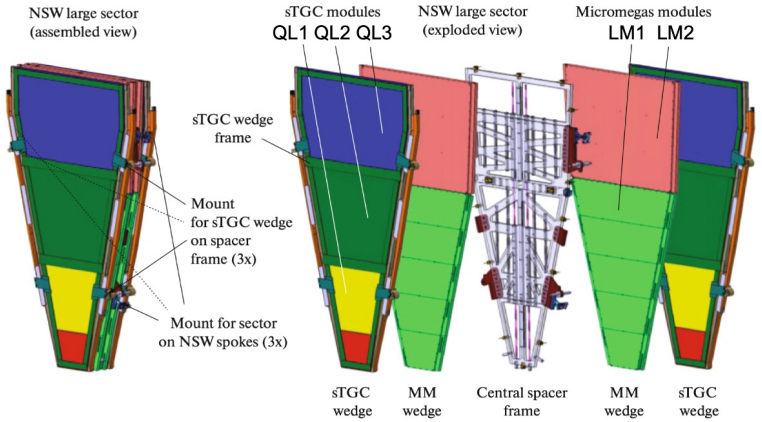


Total Level-1 Rate

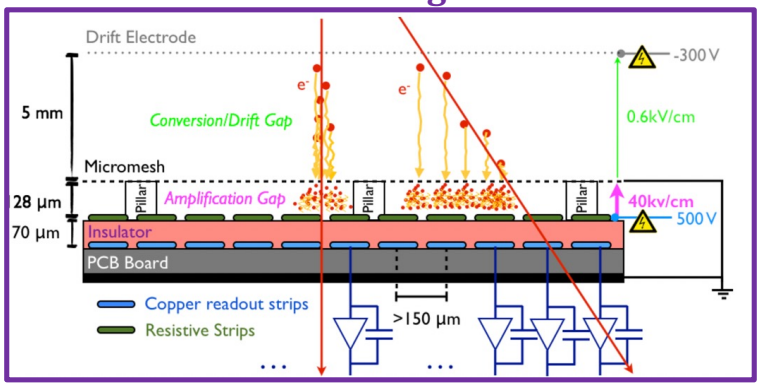
The New Small Wheel

- Replacement of inner endcap wheel by the **New Small Wheels**
  - **Small-strip Thin Gap Chambers**
    - Primary trigger
    - Track segment with < 1 mrad resolution
  - **MicroMegas**
    - Primary precision tracking
    - Spatial resolution < 100 μm
  - System redundancy
    - Both technologies used for trigger and precision measurements.
    - Total of 16 space points: 8 MM + 8 sTGC



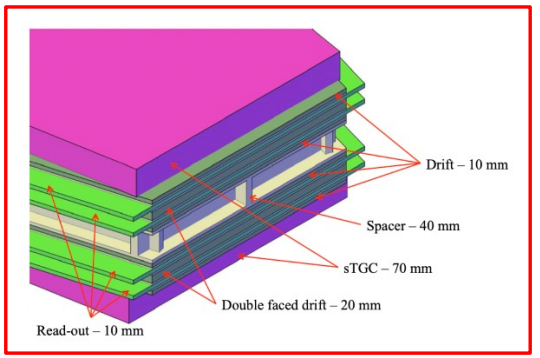


MicroMegas



Novel detector technology based on MicroPattern Gaseous Detectors (MPGD), used for the first time in such a large scale and at high-rate environment.

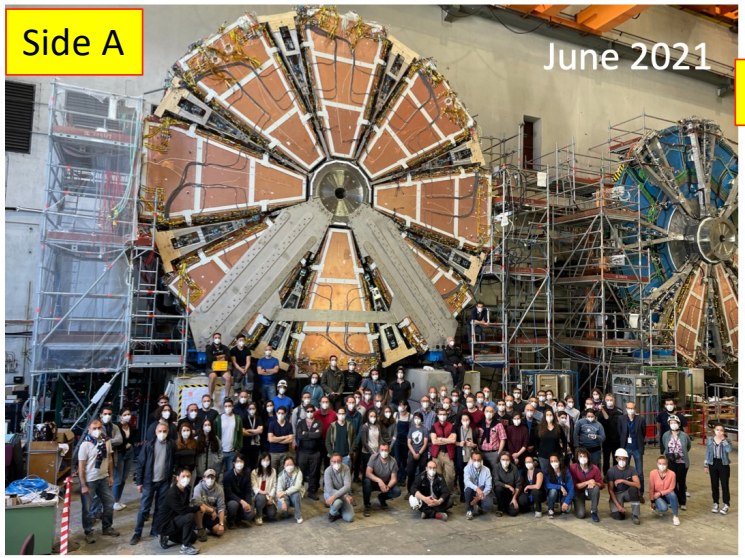
sTGC



Evolution of the current TGC detector with better tracking capabilities

NSW Construction

- Design study started in 2010, project fully defined in 2013.
- It was a huge project, supposed to be completed by 2020, before the end of LS2.
- We got some delays along the way; at a certain point it was clear that was not possible to lower both wheels in time.
- … then LS2 was delayed by one year because of the covid19 .. and NSW people made an extra effort to complete both wheels.

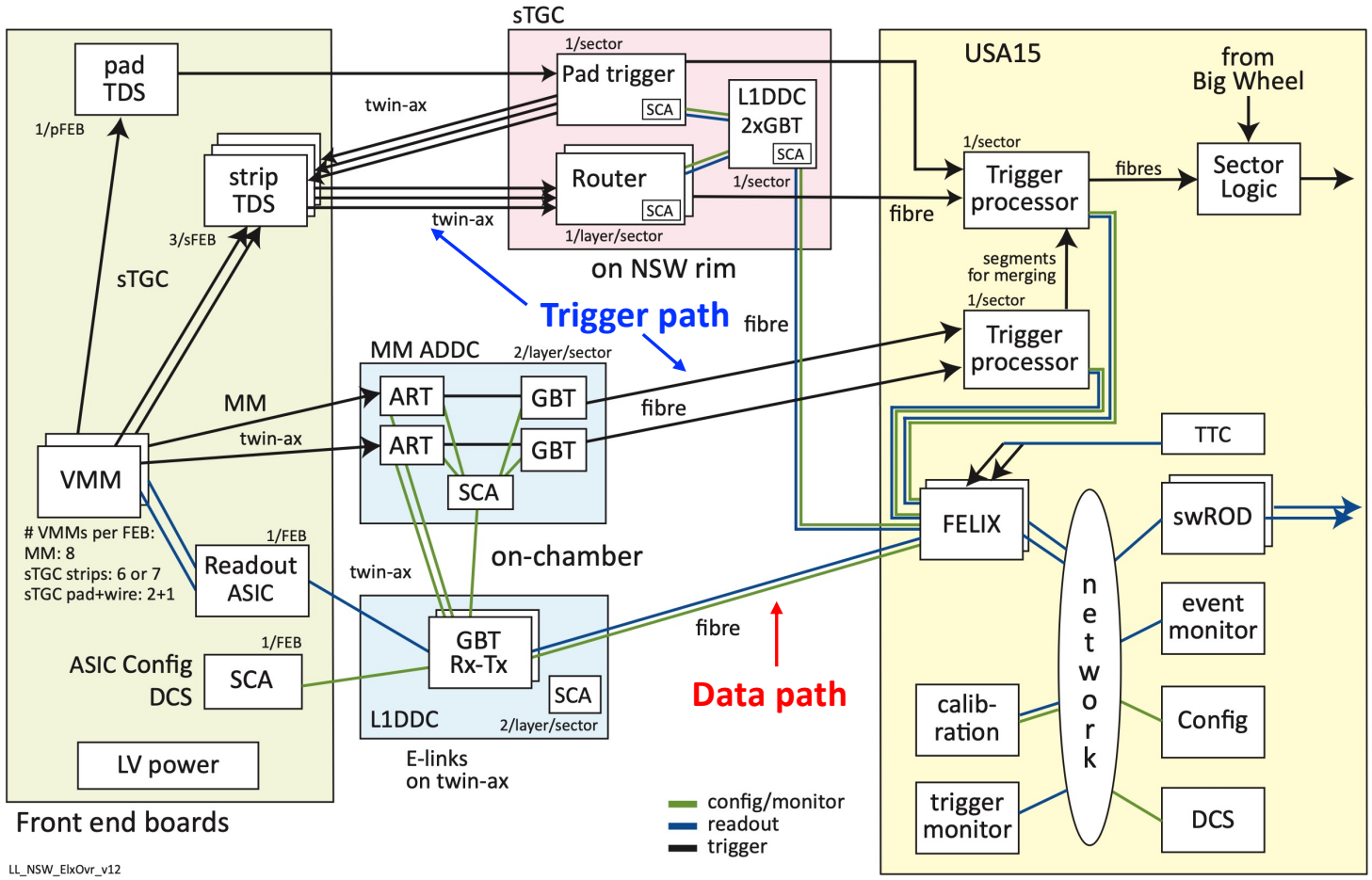


Sectors on NSW structure in B191

NSW arriving at Point 1: 6/7/2021 (NSW-A) / 14/10/2021 (NSW-C)*

We made it!

NSW DAQ and Trigger path using Felix



Felix is a unified backend electronics, based on custom PCIe FPGA cards instead of VME-based readout boards.

FELIX Prototype

ROD VME boards to buffer data and send them to ROS (and then HLT farm) are replaced by software ROD (swROD).

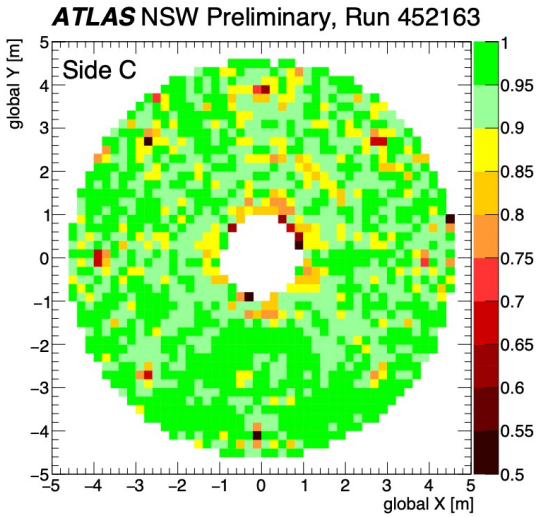
Felix performs three operations:

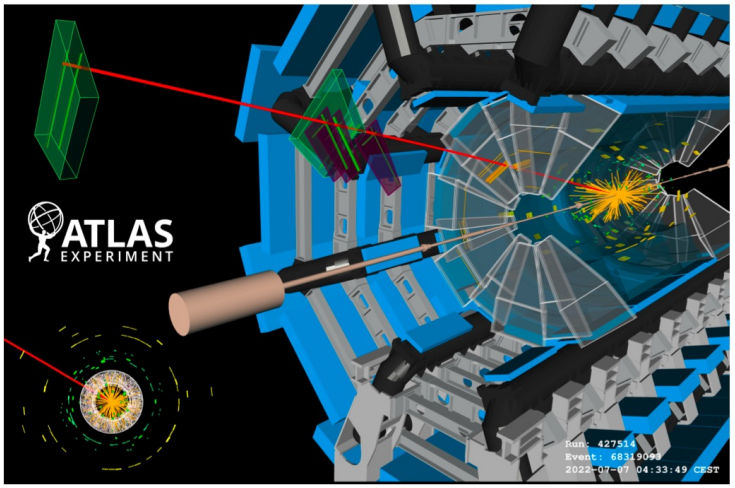
1. TTC signals transmission
2. Data Readout
3. DCS Readout and FE confi-guration.

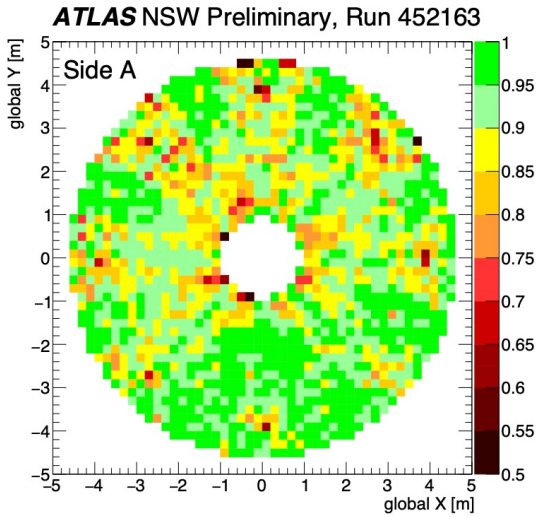
It will be the standard Phase-2 Readout

NSW current status

- 2022 was mainly devoted to commissioning the DAQ part, gradually introducing in the ATLAS running more and more sectors, while the detector commissioning was done mainly in standalone runs
- In 2023, the NSW is fully integrated in ATLAS, with a lot of work still ongoing to improve the DAQ stability and data quality (automatic resynchronisation, etc…)



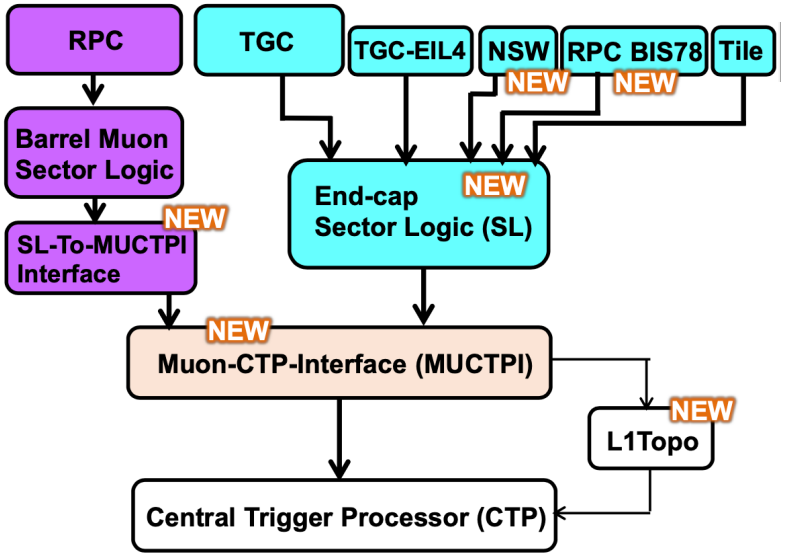




- 2023 focus is on the trigger commisioning. Very recently the coincidence between Big-Wheel and a few sectors of the NSW have been activated, bringing a significant reduction of the L1Muon Rate.
- The goal is to activate all sectors as soon as possible.

Overview of the L1-Muon Trigger Upgrade

The L1Muon system searches for a coincidence of hits across multiple layers of RPC (barrel) and TGC (endcap), which are consistent with the combination of hits expected from muons from IP.



New L1-Muon endcap trigger hardware was fully installed by December 2019 … then the commissioning was done from remote.

Contrary to L1calo, no legacy hardware was left in place, so the L1muon trigger had to function since the start of Run3.

Concidence between TGC and Inner Detectors

- **TileCal-TGC coincidence activate the first week of June** (it was already working in Run-2)
  - Activated only sectors with good efficiency (98%): 77 trigger sectors (out of 96)
  - Rate reduction about 1-1.5 kHz at L=2.0x10^{34} cm^{-2} s^{-1}
  - The rest of trigger sectors will be activated once good and stable efficiency is reached.

- **NSW-TGC coincidence activated middle of June.**
  - We are commissioning at the moment the coincidence with the sTGC pad path which have a coarse granularity.
  - Currently, we are giving priority to efficiency rather than rate reduction.
  - Activated so far only trigger sectors with good efficiency (~95%): 107 trigger sectors (out of 144).
  - Rate reduction about 5-6 kHz at L=2.0x10^{34} cm^{-2} s^{-1} observed; aiming at 8 kHz
  - A lot of work is ongoing in the NSW trigger side to include all sectors and then include also the MMG in the trigger path.

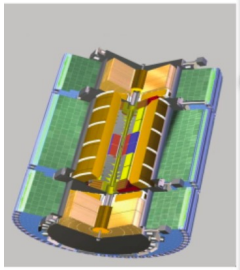
Conclusion

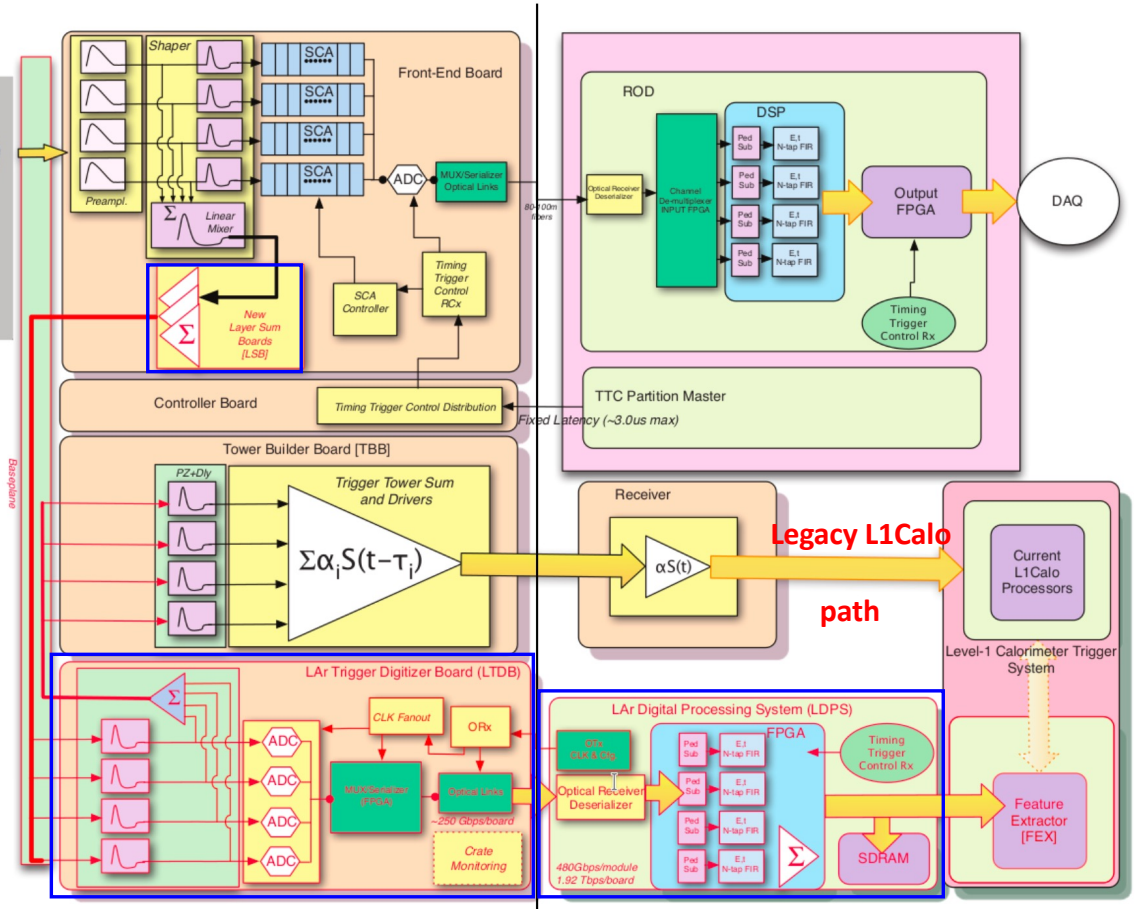
- Unprecedented high-luminosity and pileup conditions for Run3; L1 rate target: ~ 93 kHz.
- 2022 has been a commissioning year for the atlas phase-1 upgrades, in particular for the new readout system.
- In 2023 most of upgrades have been included in the standard Atlas running.
- The primary goal of these upgrades is to be able to operate Atlas at a luminosity of 2.0×10^{34} cm^{-2} s^{-1} and it has been achieved.
- To be mentioned: New L1Calo Trigger is providing the primary trigger for electrons.
- NSW detectors (MMG and sTGC) are working well and they are used to reconstruct muon tracks in the atlas forward region.
- NSW trigger is in full swing and it is already contributing to the rate reduction of the L1-Muon Endcap trigger.

Back Up Material

Lar Digital Trigger- Implementation

On Detector In USA15





114 New Baseplanes

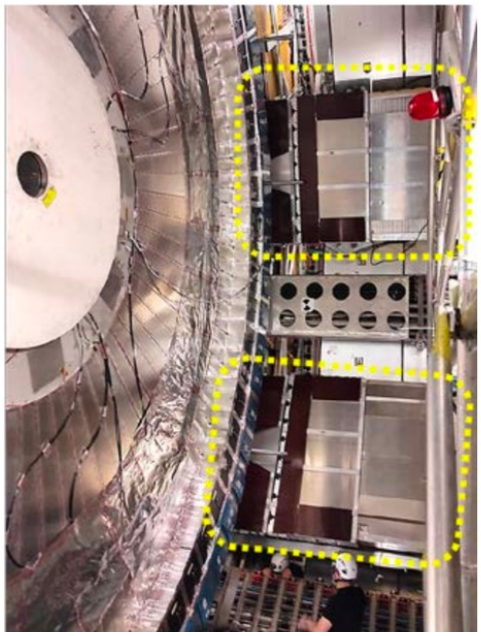
2968 New Layer Sum Board

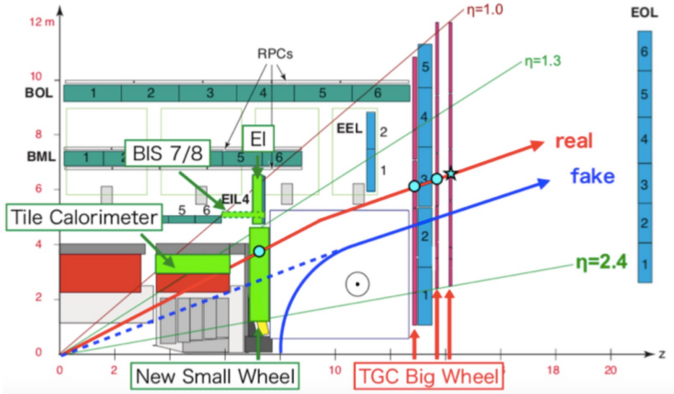
124 LTDB: digitize Supercell signals

116 LDPS: Et, timing and send data to L1Calo

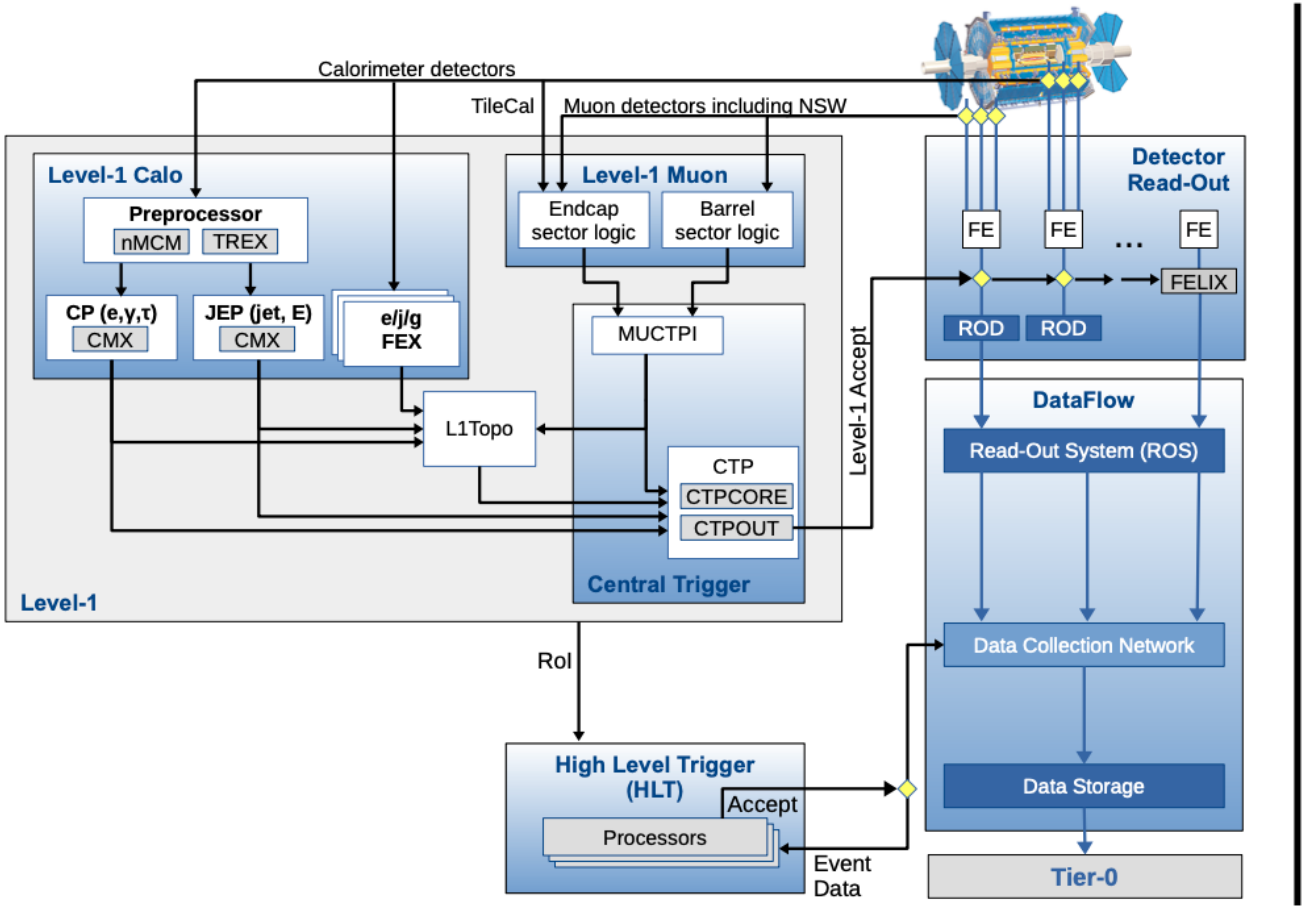
BIS78

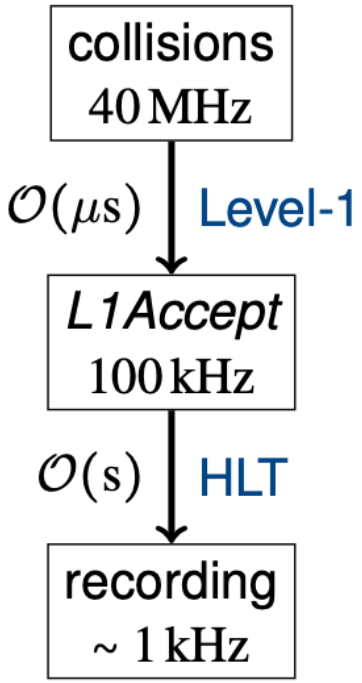
- Pilot for Muon Phase-2 BI
- MDT → sMDT compactification
- RPCs added to improve trigger coverage in transition region
- 8 sectors (A side) + related TDAQ installed & powered on
- Standalone data taking ✔
- sMDT included in regular operations
- Challenges:
  - Stable data taking in ATLAS
  - Person power for Trigger Pad firmware





Overview TDAQ System





L1Topo (Phase-1)

- Very comprehensive view of events @ Lvl1
  - Inputs from MUCTPI & all FEXes
- Topo1: Multiplicities (excl. muons), E_T^{miss}, $\sum E_T$
  - Combined "cTAU" = eTAU(E_T) + jTAU($E_{T,\text{isolation}}$)

  Topo2+3: Topological algorithms (invM, $\Delta\phi_{ij}$, ...)
- Fully installed ✔
- Algorithmic firmware generated from menu ✔
  - Close interaction with menu experts
  - Menu-side flexibility without firmware changes
  - Goal: same firmware for pp + HI
    (re-build = extensive re-validation!)
    Mainly for Topo1 → stable "bulk" triggers
- $\mathcal{O}(70)$ different algorithms → plenty to validate
  - multiplicity: object specific
  - sort/select: object specific
  - decision (topological): mostly generic