Performance of ATLAS Detector with Start of Run 3

ICNFP 2022 – International Conference on New Frontiers in Physics

Pawel Klimek
on behalf of the ATLAS Collaboration

CERN

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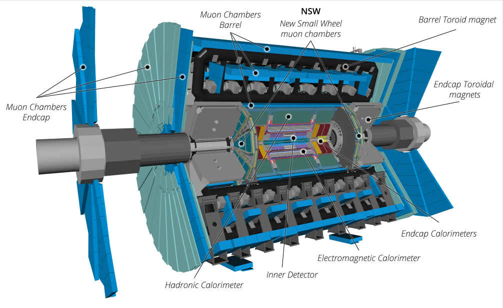
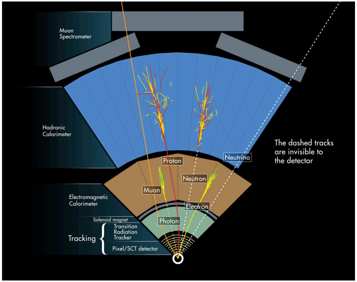
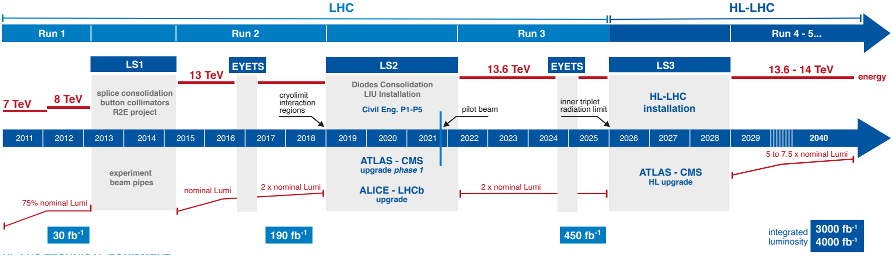
The ATLAS Detector

- A Toroidal LHC ApparatuS
- General purpose detector at the LHC
- Detector characteristics
  - Width: 44 m
  - Diameter: 25 m
  - Weight: 7000 t
- Subdetectors
  - Inner Detector
  - Calorimeters
  - Muon Spectrometer





LHC Schedule



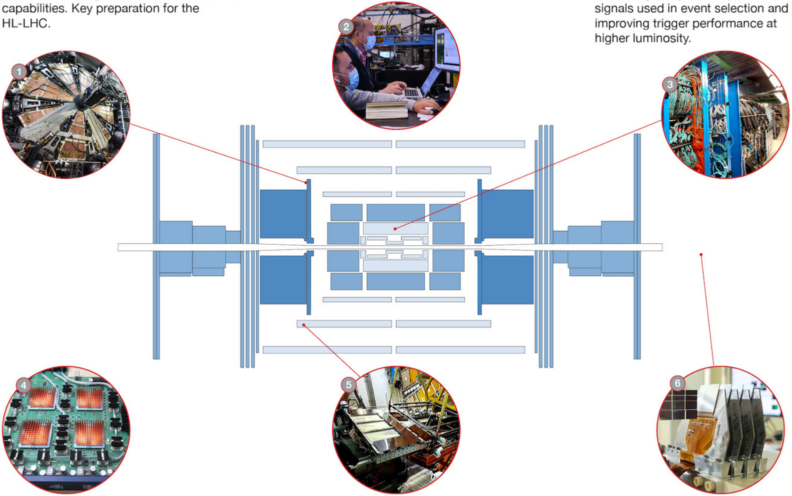
- Successful Run 2 ended in 2018
- Long shutdown 2 (LS2) took place on 2019–2022 to upgrade the machine and the detectors (phase 1 upgrade)
- Run 3 has just started now and will continue until 2025
  - Central mass energy for pp collisions of 13.6 TeV
  - Instantaneous luminosity of 2×10^{34} cm$^-2$s$^-1$
  - Integrated luminosity of 450 fb^{-1}
  - Average pile-up of $\mu = 60$

ATLAS Upgrade During Long Shutdown 2

MUON NEW SMALL WHEELS (NSW)
Installed new muon detectors with precision tracking and muon selection capabilities. Key preparation for the HL-LHC.

NEW READOUT SYSTEM FOR THE NSWs
The NSW system includes two million micromega readout channels and 350 000 small strip thin-gap chambers (sTGC) electronic readout channels.

LIQUID ARGON CALORIMETER
New electronics boards installed, increasing the granularity of signals used in event selection and improving trigger performance at higher luminosity.



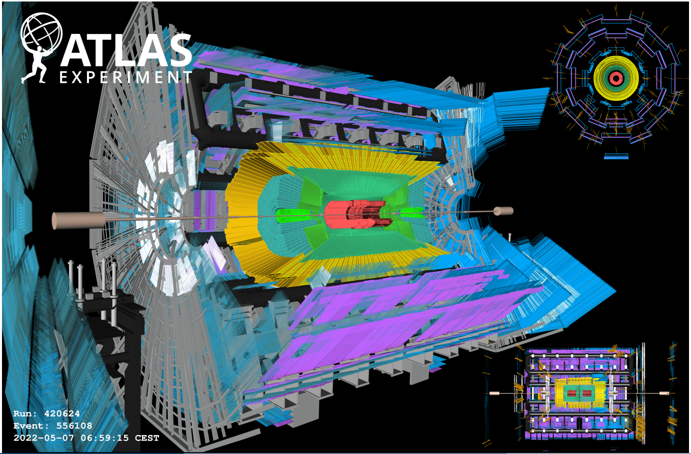
TRIGGER AND DATA ACQUISITION SYSTEM (TDAQ)

NEW MUON CHAMBERS IN THE CENTRE OF ATLAS

ATLAS FORWARD PROTON (AFP)

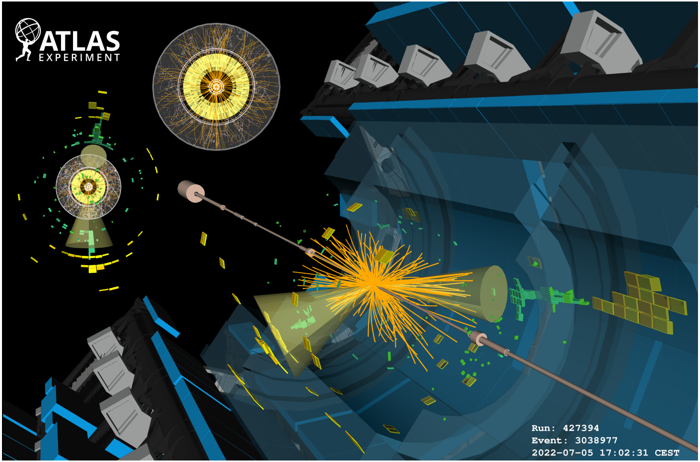
Beam Splashes

- In preparation for Run 3, special splash runs taken (Oct. 2021 – May 2022)
- In the beam splash, a single proton beam from the LHC hits a collimator placed in the beam-line 140 m in front of the ATLAS interaction point, generating a spray of particles, traveling through the detector
- They are used to probe the operation of the ATLAS detector as a whole



The Run 3 Has Started

- On July 5 at 16:47 CET, stable proton–proton collisions at 13.6 TeV delivered by LHC were recorded by ATLAS
- The LHC Run 3 has officially started
- One of the first events (dijet) recorded by ATLAS experiment in Run 3



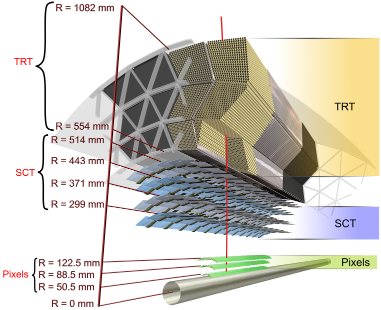
Inner Detector

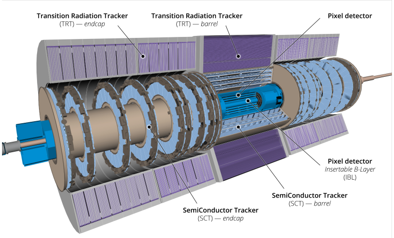
- The Inner Detector provides:
  - Precise measurement of charged particle trajectories
  - Particle identification
  - Vertex reconstruction
  - b-jets tagging

- Pixel Detector
  - 92M pixels in 4 barrel layers and 3 disks in each end-cap ($|\eta < 2.5|$)

- Semiconductor Tracker (SCT)
  - 6.3M strips in 4 barrel layers and 9 disks in each end-cap ($|\eta < 2.5|$)

- Transition Radiation Tracker (TRT)
  - 300k straws ($|\eta < 2.0|$)

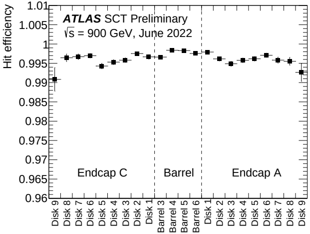


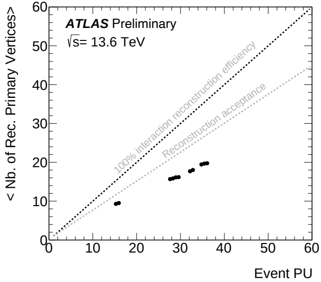


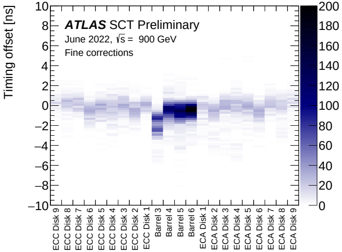
Inner Detector

- Average number of reconstructed primary vertices as a function of the number of interactions per bunch crossing in pp data
- Time corrections compensate for the length of the trigger optical fibres, delays in trigger electronics and for the time-of-flight of particles from the interaction point
- Time corrections measured in pp data
- Very high hit efficiency, $\epsilon > 99\%$

$$\epsilon = \frac{N_{\text{clusters}}}{N_{\text{clusters}} + N_{\text{holes}}}$$

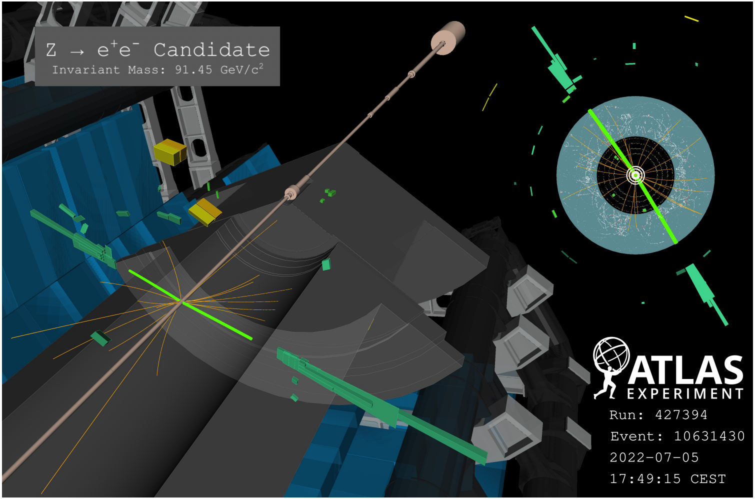






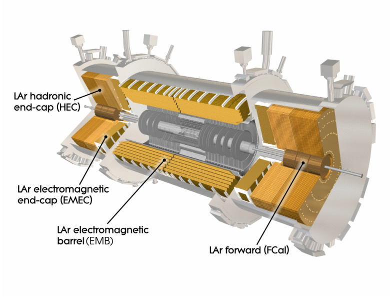
Event Reconstructed by Inner Detector

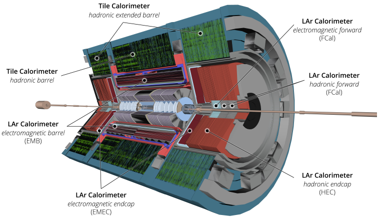
- The $Z \rightarrow ee$ candidate recorded by ATLAS in pp collisions at energy of 13.6 TeV during the first day of Run 3
- The dielectron event is reconstructed by Pixel, SCT and TRT detectors



Calorimeters

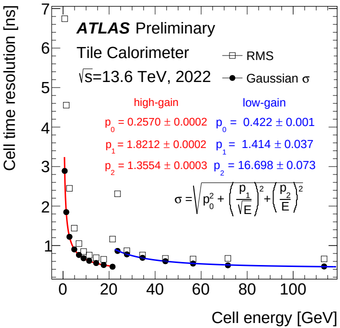
- Used to measure electrons, photons, jets, missing transverse energy and in the ATLAS Level-1 trigger
- Sampling calorimeters
- LAr
  - Electromagnetic calorimeter ($|\eta| < 3.2$)
  - Hadronic calorimeter ($1.5 < |\eta| < 4.9$)
  - steel/copper/tungsten and LAr
  - ~183000 channels
  - New front-end electronics for finer granularity inputs to L1Calo trigger
- Tile
  - Central hadronic calorimeter ($|\eta| < 1.72$)
  - Steel and scintillating plastic tiles
  - ~10000 channels
  - New crack scintillators with extended geometry



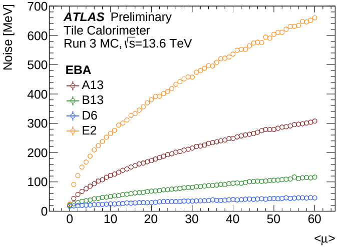


Tile Calorimeter: Timing and Noise

- Time calibration adjusts sampling clock to the peak of signal of particle traveling from the interaction point at the speed of light
- Large phases result in underestimated reconstructed amplitude
- Calculated using splash events and first pp collisions. Monitored with laser.
- Resolution is better than 1 ns for $E > 4$ GeV



- The noise in Run 3 conditions
- Modelling important for jet reconstruction
- Total noise is dominated and increase with pile-up
- The largest noise values are in the regions with the highest exposure

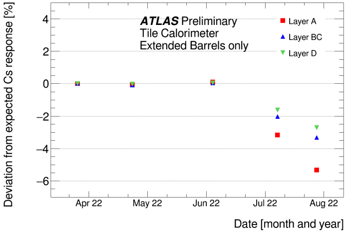


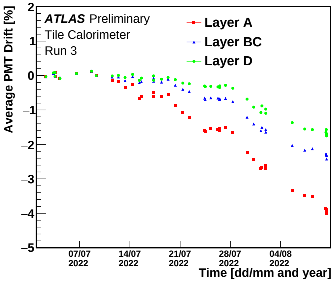
Tile Calorimeter: Cell Response

- Deviation of the cell response in time caused by the PMT gain variation and scintillator degradation due to the exposure to beam

- Tile cell response measured by caesium and laser calibration systems
  - Caesium system calibrates optical components and PMT gains with 0.3% precision. Calibration done few times per year.
  - Laser system calibrates variations due to electronics and PMTs with 0.5% precision. Calibration done weekly.

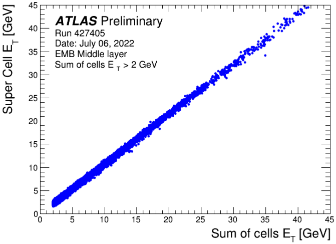
- The maximal down-drift is observed in cells with highest energy deposits (Layer A)

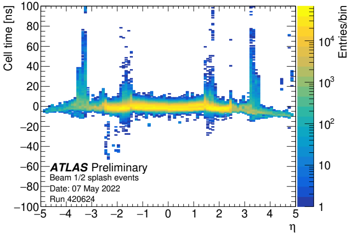


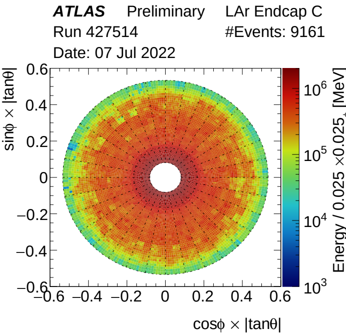


LAr Calorimeter

- Upgraded trigger system based on super cells (SC) provides 10 times finer granularity
- Both legacy (analog) and upgraded (digital) trigger system will be running in early Run 3
- Good agreement between supercell and summed cell energy from the main readout
- Using beam splash to align the timing for the full LAr system
- Main readout aligned to ns level
- End-cap cell energy depositions during pp collisions

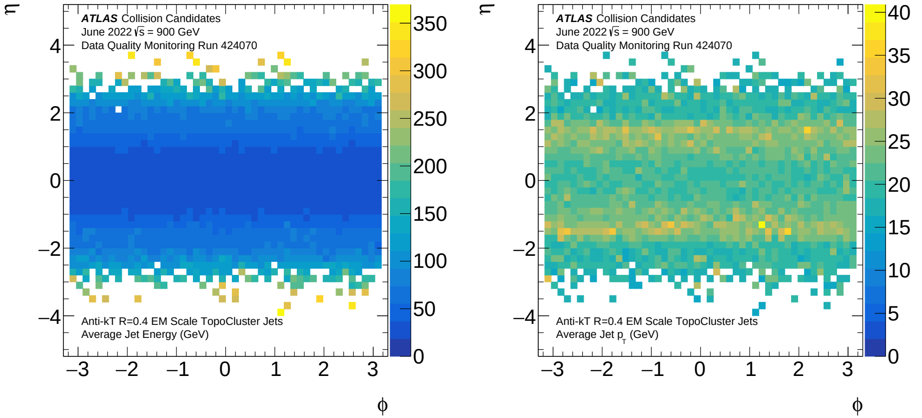






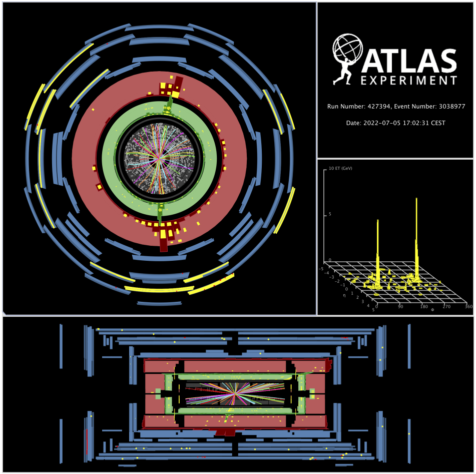
Calorimeters' Combined Performance

- The average energy and p_{T} of jets reconstructed at the EM scale as anti-k_t, $R = 0.4$ calorimeter topological cluster jets versus η and ϕ as gathered by data quality monitoring in pp collisions



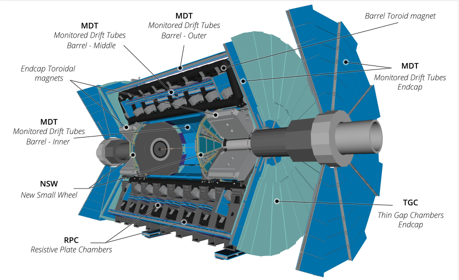
Event Reconstructed by Calorimeters

- The dijet event recorded by ATLAS in pp collisions at energy of 13.6 TeV during the first day of Run 3
- The energy deposited in the electromagnetic LAr and hadronic Tile calorimeters are shown



Muon Spectrometer

- Used for identification, precise momentum and direction measurement of muons, and in the ATLAS Level-1 trigger
- Based on deflection of muon tracks in magnetic filed



Precision chambers:

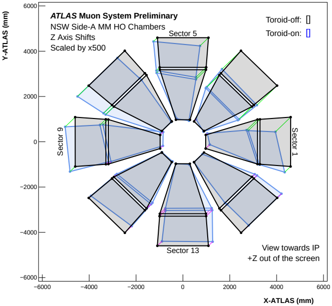
- Monitored Drift Tube (MDT)
  - 3 barrel layers and
    2 discs in each end-cap
    ($|\eta| < 2.7$)
- New Small Wheel (NSW)
  Micromesh Gaseous Structure Detector (MicroMegas)
  - 1 disc in each end-cap ($|\eta| < 2.7$)

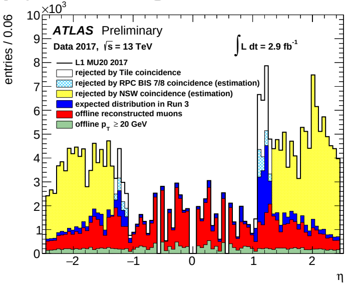
Trigger chambers:

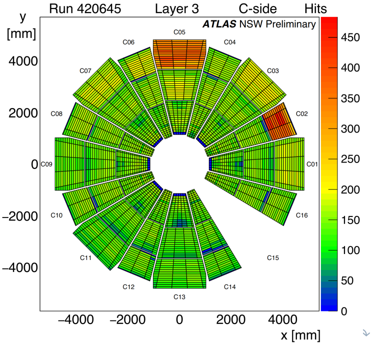
- Resistive Plate Chambers (RPC)
  - 3 barrel layers ($-1.05 < \eta < 1.3$)
- Thin Gap Chambers (TGC)
  - 3 discs in each end-cap
    ($1.05 < |\eta| < 2.7$)
- New Small Wheel (NSW)
  Small-strip Thin Gap Chamber (STGC)
  - 1 disc in each end-cap ($|\eta| < 2.7$)

New Small Wheel

- NSW was the main upgrade project during LS2 in order to provide precision trigger and tracking for muons in the forward region
- Allows background and trigger rate rejection
- An optical based alignment system allows tracking the movement, deformation of NSW
- Example of NSW shifts in z-direction measured by the alignment system
- Occupancy plot showing recorded hits during splashes

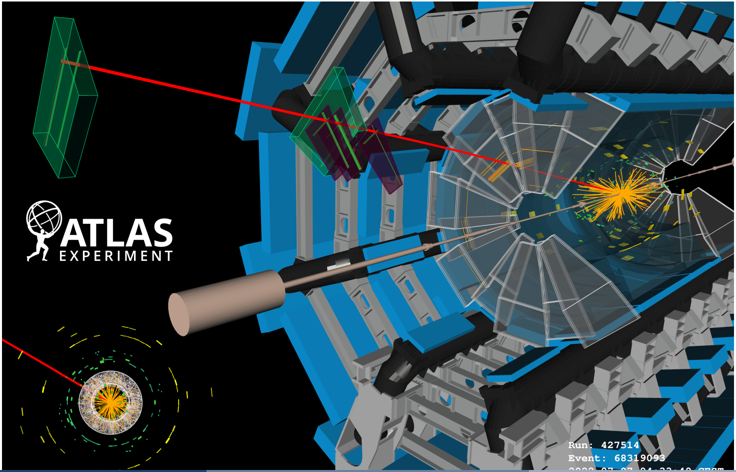






Event Reconstructed by New Small Wheel

- The muon candidate recorded by ATLAS in pp collisions at energy of 13.6 TeV
- It was among the first muon candidates reconstructed using hits in the Micromegas chambers of the New Small Wheel

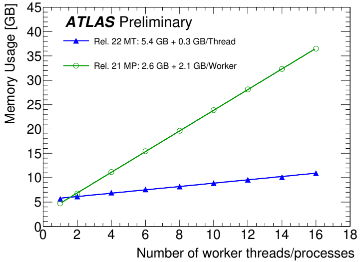


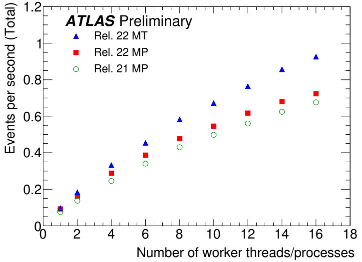
ATLAS Detector Status at the Start of Run 3

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	96.7%
SCT Silicon Strips	6.3 M	98.3%
TRT Transition Radiation Tracker	350 k	96.6%
LAr EM Calorimeter	170 k	100%
Tile Calorimeter	5200	99.2%
Hadronic End-Cap LAr Calorimeter	5600	99.9%
Forward LAr Calorimeter	3500	99.8%
LVL1 Calo Trigger	7160	99.9%
LVL1 Muon RPC Trigger	383 k	99.8%
LVL1 Muon TGC Trigger	312 k	100%
MDT Muon Drift Tubes	344 k	99.7%
MicroMegas NSW	2.1 M	98.0%
STGC NSW	358 k	99.2%
RPC Barrel Muon Chambers	383 k	87.7%
TGC End-Cap Muon Chambers	312 k	99.4%
ALFA	10 k	100%
AFP	430 k	100%
LUCID	2x16	100%
ZDC	2x20	100%

Computing and Software

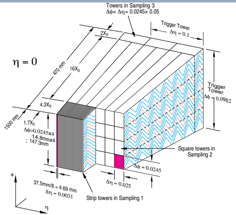
- For Run 3, ATLAS has migrated its standard reconstruction software to a multi-threaded framework (Rel. 22)
- In multi-process (MP) parallelism used in Run 2 (Rel. 21), workers are forked from the primary process at a pre-configured stage
- In multi-thread (MT) parallelism, there is no forking of worker processes from the primary. Instead, threads are spawned and assigned some work. There is a single pool of heap memory that is shared across all threads. Much more challenging to implement.
- Memory consumption per worker thread in MT is significantly lower and scales linearly
- Significant improvement of the total throughput of the jobs

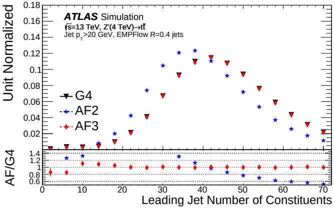


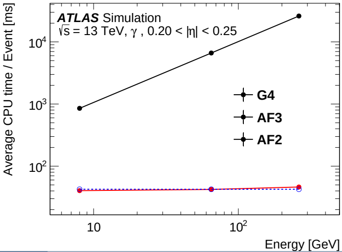


Computing and Software

- Precision measurements and searches for new particles require large and accurate MC
- Detector simulation with Geant4 is accurate but requires significant CPU resources
- Most CPU intense is calorimeter shower simulation due to accordion geometry of the EM calorimeter - 80% of the simulation time
- ATLAS has developed fast simulation tools
- Recent AtlFastII relies on parametrised fast simulation of the calorimeters
- New AtlFast3 combines updated fast calorimeter simulation with machine-learning (Generative Adversarial Networks)
- AtlFast3 significantly improves modelling of jet substructure with the same CPU performance as AtlFastII







Conclusions & Summary

- ATLAS underwent several upgrades during the Long Shutdown 2
- All legacy and upgraded components (re)commissioned using splashes and pp collision data
- The LHC delivered the stable proton–proton collisions at 13.6 TeV, on July 5, starting the Run 3
- Performance and stability ensured by continuous monitoring
- All subsystems, including the upgraded components, perform very well
- Stay tuned for new Run 3 ATLAS results

Other ATLAS Talks

- ATLAS highlights (Bill Murray)
- First glance on ATLAS data with Run 3 (Stefano Rosati)
- Celebrating 10 years of Higgs boson physics at ATLAS (Brian Moser)
- The ATLAS Experiment upgrade program (Geoffrey Mullier)
- Jet and MET reconstruction and calibration in ATLAS (Romain Bouquet)
- Boosted W/Z boson and top tagging in ATLAS (Qibin Liu)
- Electron efficiency in LHC Run 2 with the ATLAS experiment (Otilia Ducu)
- Many interesting physics results from ATLAS
  (Martin Spousta, Alex Wang, Brian Le, Josu Garcia, Shuhui Huang, Noemi Cavalli, Haifeng Li, Wasikul Islam, Kock Gan, Soshi Tsuno, Elvira Rossi, Georges Aad, Otilia Ducu, Chenliang Wang, Adam Rennie, Alkaid Cheng, Umberto De Sanctis, Joel Foo, Meng-Ju Tsai, Eirik Gramstad, Mariia Didenko, Alessandra Betti, Yasuyuki Horii, Ivan Yeletskikh, Peter Berta, Theodota Lagouri)

The Run 3 Event in ATLAS

- The $t\bar{t}$ candidate with dilepton ($e\mu$) final state recorded by ATLAS in pp collisions at energy of 13.6 TeV