Trigger system in ATLAS: Prospects for Argentina to contribute with developments for the LHC Phase II upgrades.

F. Monticelli.
Coordinator of e/gamma trigger slice of ATLAS experiment
UNLP - IFLP - CONICET, ATLAS Collaboration

April 27th, 2018

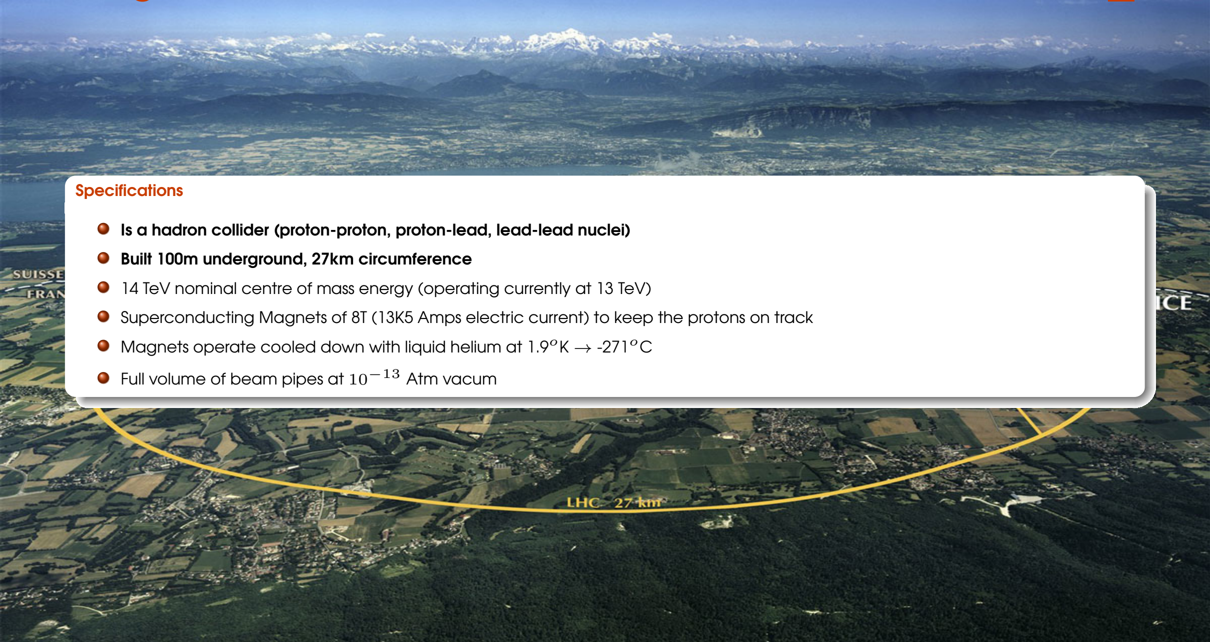
Fundamental Meets Technology

Large Hadron Collider

Large Hadron Collider

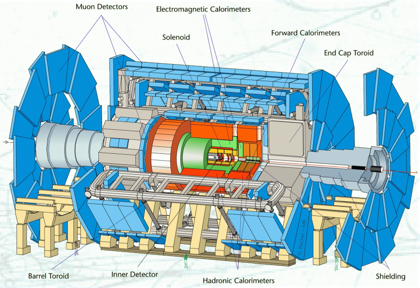
Specifications

- **Is a hadron collider (proton-proton, proton-lead, lead-lead nuclei)**
- **Built 100m underground, 27km circumference**
- 14 TeV nominal centre of mass energy (operating currently at 13 TeV)
- Superconducting Magnets of 8T (13K5 Amps electric current) to keep the protons on track
- Magnets operate cooled down with liquid helium at $1.9^oK \rightarrow -271^oC$
- Full volume of beam pipes at 10^{-13} Atm vacum



The ATLAS detector

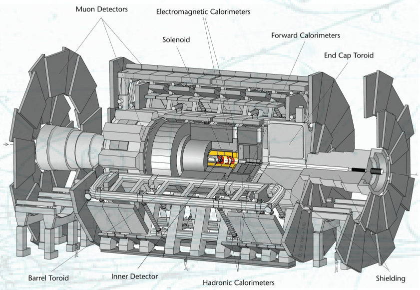
- Multipurpose detector
- 46m length x 25m diameter x 7000 Tons (the weight of the Eiffel tower)
- 100m underground at the LHC

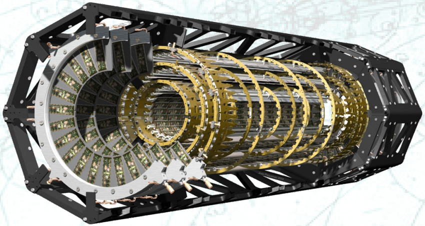


The ATLAS detector

ATLAS has different subdetectors:

- Inner detector → Tracking



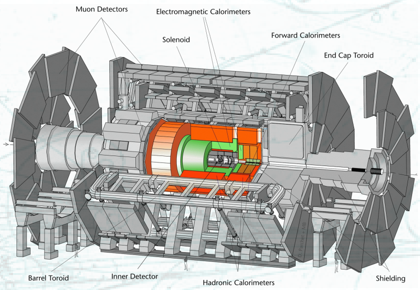


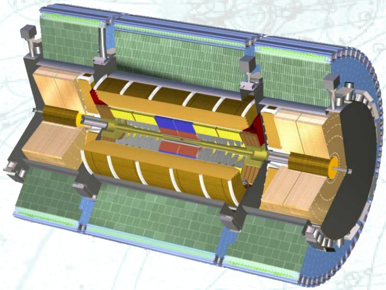
- Measure the tracks of charged particles
- More than 90M channels to read out
- IBL+pixel detector+SCT+TRT

The ATLAS detector

ATLAS has different subdetectors:

- Inner detector → Tracking
- Calorimeters



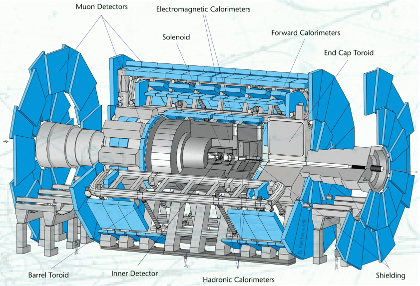


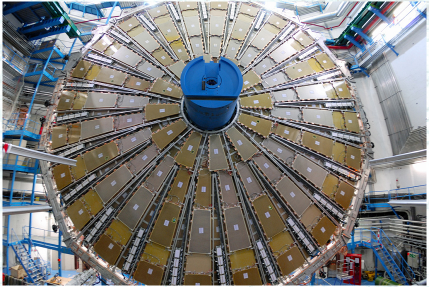
- A Lead/Liquid Argon (LAr) high granularity EM calorimeter. (absorbers/sampling material).
- High precision for electrons/photons energy/shower shape measurements
- An iron/Plastic Scintilators complemented by copper/LAr for Hadronic calorimetry.
- Tungsten/LAr covering the Forward region.
- Up to eta=4.9 coverage.

The ATLAS detector

ATLAS has different subdetectors:

- Inner detector → Tracking
- Calorimeters
- Muon detectors

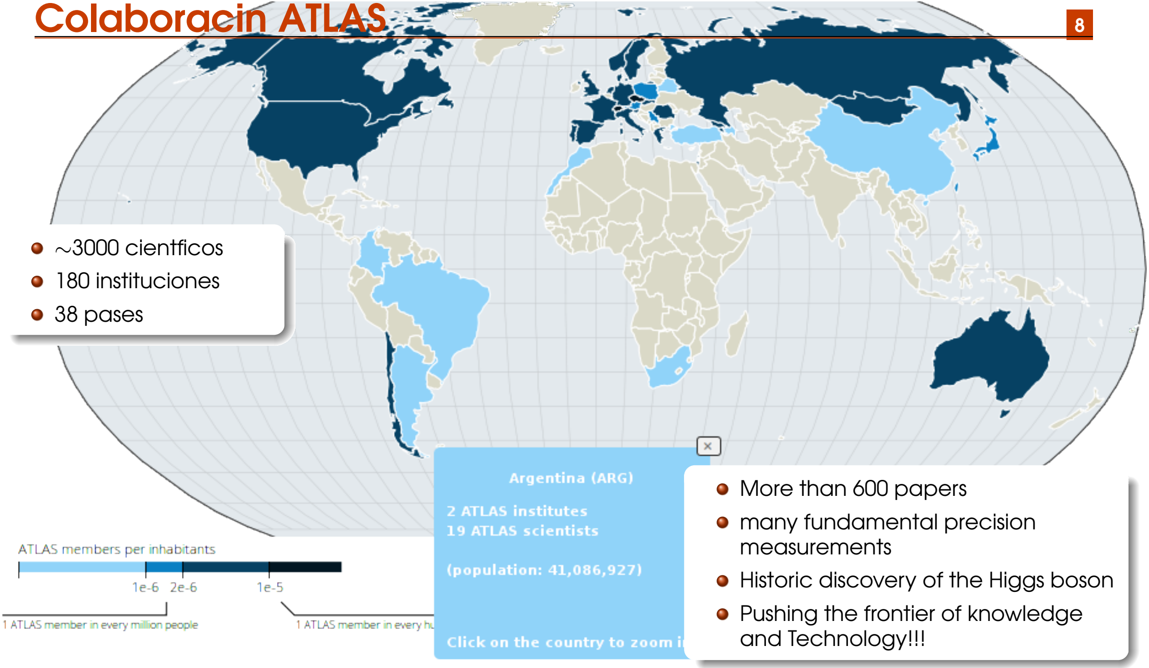




- MDT and CSC chambers plus RPC and TGC trigger

Colaboracin ATLAS

- ~3000 cientficos
- 180 instituciones
- 38 pases



- More than 600 papers
- many fundamental precision measurements
- Historic discovery of the Higgs boson
- Pushing the frontier of knowledge and Technology!!!

ATLAS trigger system

Why a trigger system?

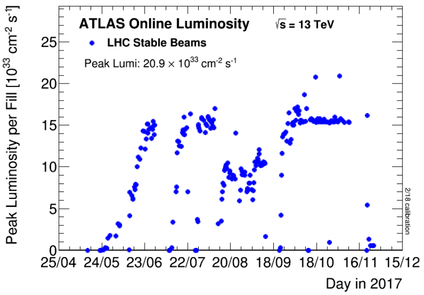
- The new physics events are very rare
- That is why the LHC makes a large number of collisions (40M/sec)
- We can only store the information of the relevan ones ($\sim$ 1000/s)

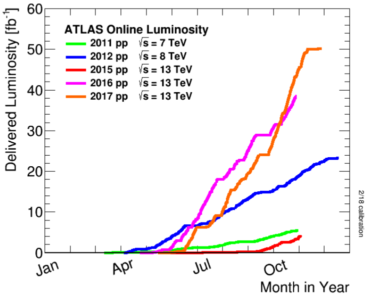
Trigger system decides online whether or not to keep an event

- Crucial impact on quality of data used in physics analysis!

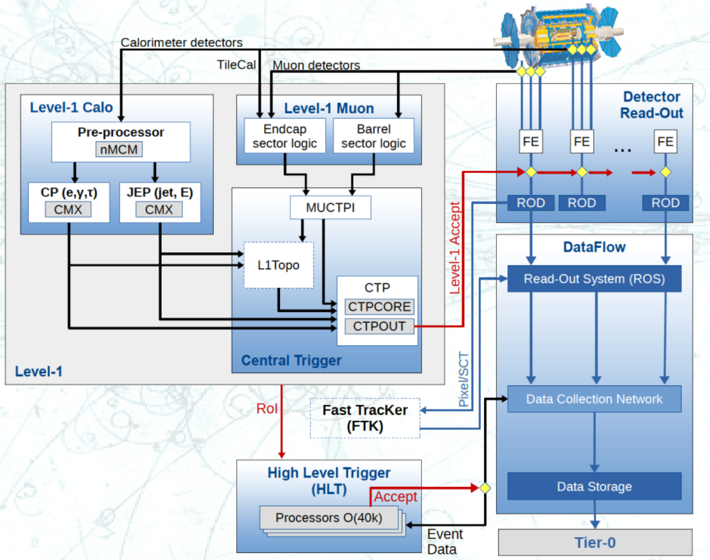
ATLAS Trigger System during Run-2 at the LHC incorporates several upgrades and improvements since Run-1 to cope with:

- Higher rates
- More interactions per bunch crossing (pile-up)
- Higher centre-of-mass energy collisions (from 7/8 TeV $\rightarrow$ 13 TeV)
- Higher instantaneous luminosty

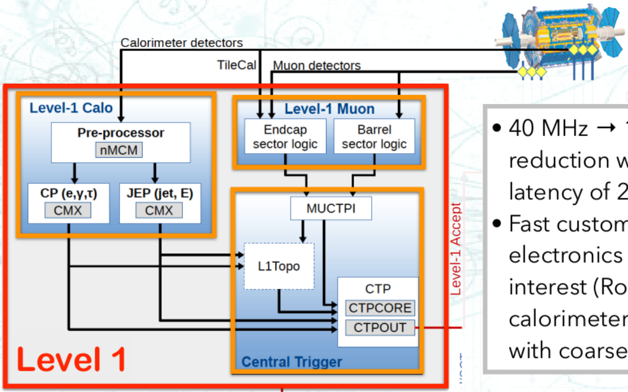




ATLAS TDAQ system



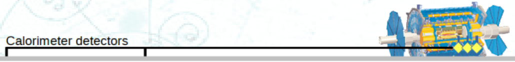
ATLAS TDAQ system



- 40 MHz → 100 kHz rate reduction with a fixed latency of 2.5 μs
- Fast custom-made electronics find regions of interest (RoIs) using calorimeter and muon data with coarse information

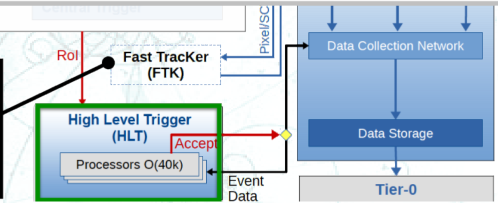
- Upgraded L1 Calo, L1 Muon and CTP (Central Trigger Processor)
  - **L1 Calo**: new Multi-Chip Module (nMCM) allows more flexible signal processing, more thresholds
  - **L1 Muon**: coincidences with inner detector, additional chambers in the feet of the barrel region and from Tile extended barrel region
  - **CTP**: more resources, support multi-partition running
- **L1Topo**
  - Allows for topological selections between L1 trigger objects (e.g. ΔR) to keep L1 thresholds low

ATLAS TDAQ system



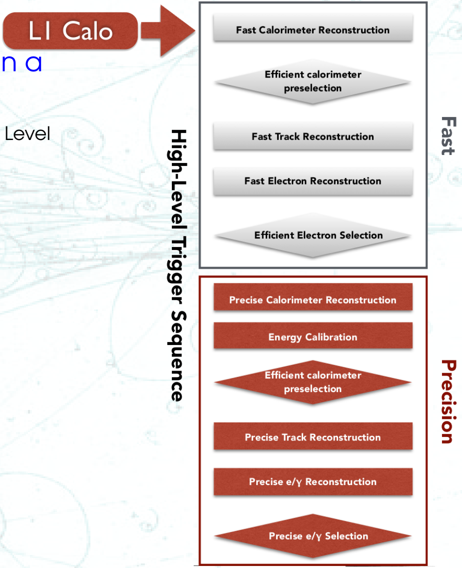
- Single farm (merged L2-EF) for better resource sharing and overall simplification
- Fast offline-like algorithms running mostly in L1 RoIs
- Average 350 ms latency
- Full upgrade of readout and data storage systems
- ~1 kHz of physics (full event building) output rate achieved
- Partial event building used for Trigger Level Analysis, detector monitoring and calibrations
- Once HLT is passed, the event is accepted and written into data streams
- Then offline software is run at Tier-0 to reconstruct the objects

FTK under commissioning
Hardware accelerated tracking: reconstructs all tracks for all L1 accepted events and provides track information to HLT



Triggering e/γ in ATLAS as a test case

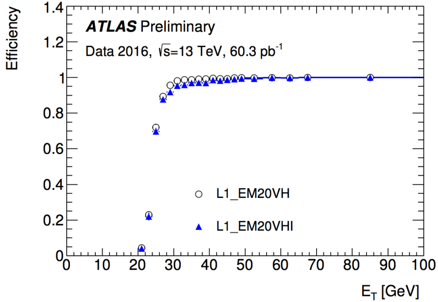
- E/γ trigger is based on reconstructing objects within a Region of Interest (RoI)
  - Level 1 Electromagnetic (L1 Calo) trigger seeds the RoI for the High Level Trigger (HLT)
- E/γ HLT algorithms reconstruct and identify
  - Clusters
  - Tracks
  - Photons Electromagnetic (EM) Cluster
  - Electrons EM Cluster + Track
- E/γ HLT algorithm flow
  - Fast algorithms rejects event early
  - Precise algorithms to efficiently identify e/γ
- E/γ Reconstruction, calibration and identification
  - Offline software and techniques



Level 1 EM trigger

Run-2

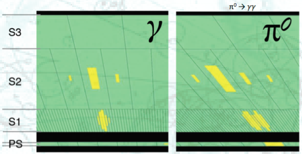
- Improved Signal Processing: new Multi-Chip-Module (nMCM)
  - Improved energy resolution (noise auto-correlation filtering)
  - Dynamical pedestal correction
- Clustering: Cluster Processor Module (CPM) firmware
  - E_T -dependent electromagnetic/hadronic isolation cuts with $\Delta E_T \sim 0.5$ GeV precision
- Counting: New extended Common Merger Module (CMX)
  - Doubles max number of E_T thresholds to 16
  - E_T thresholds can have $\Delta\eta$=0.1 in granularity



While during Run-1

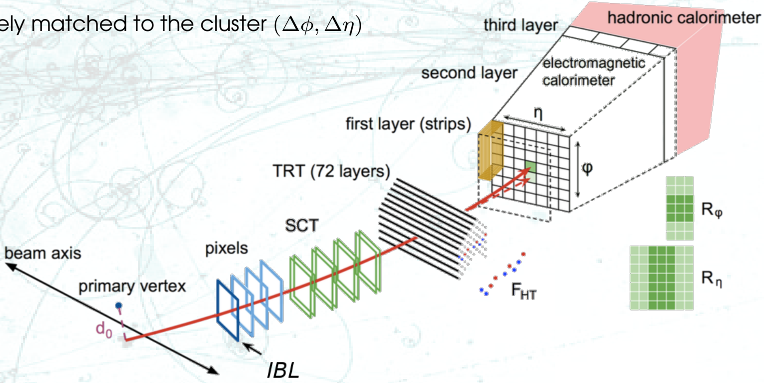
- η-dependent E_T thresholds $\rightarrow \Delta\eta$=0.4 granularity
- Fixed Isolation cut $\rightarrow$ Hadronic-core isolation H $\leq$ 1 GeV
- EM Isolation not used (but available) during Run-1

Electrons and photons at HLT



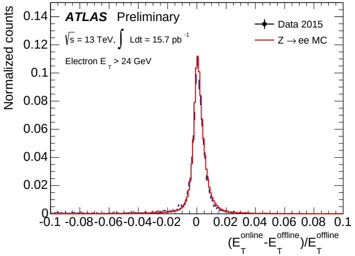
- Energy of an e/γ candidate built with cluster of cells in EM calorimeter
- Local maximum required for a cluster seed $\to$ sliding window algorithm
- Photons are reconstructed with only the cluster
- Common shower shape variables for e/γ calculated for identification

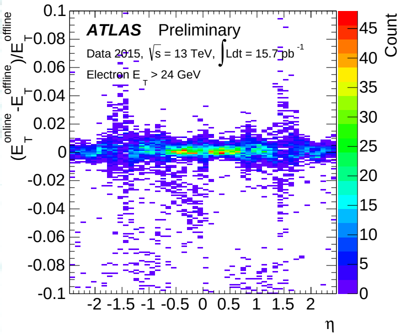
- Electron candidates have tracks loosely matched to the cluster $(\Delta\phi, \Delta\eta)$
- tracks extrapolated to 2nd EM layer
- Electrons have additional information
  - hits in the tracking detectors
  - transition radiation hit information
  - track-cluster matching $(\Delta\phi, \Delta\eta)$

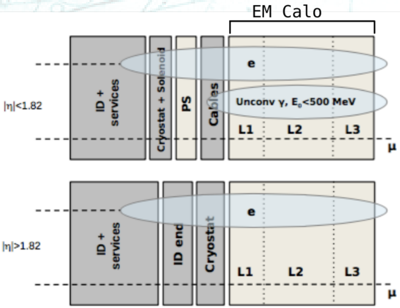


Energy Calibration at HLT

- EM cluster properties (longitudinal development) are calibrated to the original energy of the electron and photon in Monte Carlo (MC) samples
- MC samples are used to determine the e/γ response calibration where the constants are determined in a multivariate algorithm
- Good agreement between data and MC







Identifying e/γ

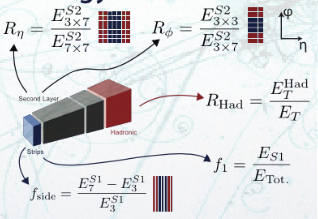
- Common set of shower shape variables used to identify electrons and photons
  - EM shower can be characterised by the longitudinal (depth) and lateral (width) shapes
  - e/γ use same variables, but different cut values

Variables and Position

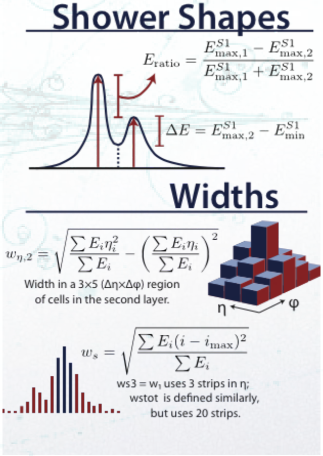
	Strips	2nd	Had.
Ratios	f_1, f_{side}	R_η*, R_ϕ	$R_{Had.}$*
Widths	$w_{s,3}$, $w_{s,tot}$	$w_{\eta,2}$*	-
Shapes	ΔE, E_{ratio}		

* Used in PhotonLoose.

Energy Ratios



- Identification of photons and electrons
  - Optimised in bins of E_T and η
  - Several levels of discrimination with higher efficiency but lower purity (loose, medium, tight)
- Electron identification incorporates tracking information
  - Transition radiation hit information
  - Track quality & Track-cluster matching



Improved Electron ID for Run-2

Rate depends strongly on Electron trigger threshold

- Physics potential suffers as threshold increases
- Run-2 improve purity and reduce background with tighter selections and multivariate techniques

Electron Likelihood (LH) Particle Identification

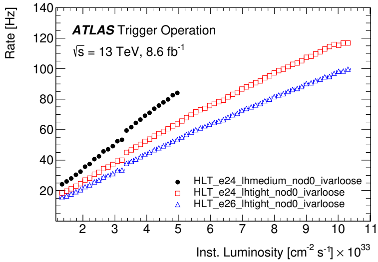
- Introduced a NN ringer algorighm for fast identification
- Same as offline ID on precise reconstruction
- Relies on same variables as cut-based selection
- LH tuned to same signal efficiency as a cut-based selection
  - Factor 2 improvement in background rejection
  - Higher signal purity
  - LH discriminant is $< \mu >$ dependent to kepp high efficiency at high pileup

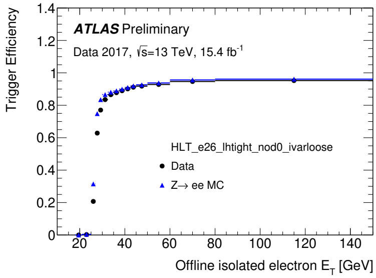
$$d\mathcal{L} = \frac{\mathcal{L}_S}{\mathcal{L}_S + \mathcal{L}_B}, \mathcal{L}(\vec{x}) = \prod_{i=1}^{n} P_{s,i}(x_i)$$

Electron Trigger Performance

Likelihood electron selection out-performs cut-based selection in Run-2

- LH selection efficiency 4-6% higher than cut-based selection
- Likelihood trigger out-performs cut-based when measured with respect to any offline identification
  - Tight selection 45% rate reduction with 7% efficiency loss w.r.t. cut-based
- Excellent Data-MC agreement

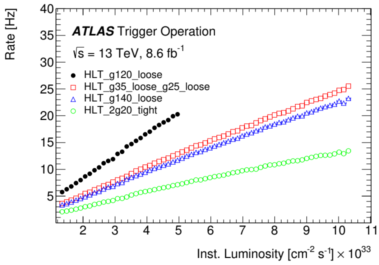


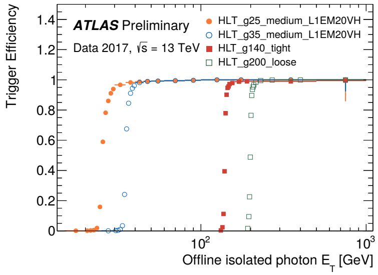


Photon Trigger Performance

Photon performance of Run-2 similar to Run-1

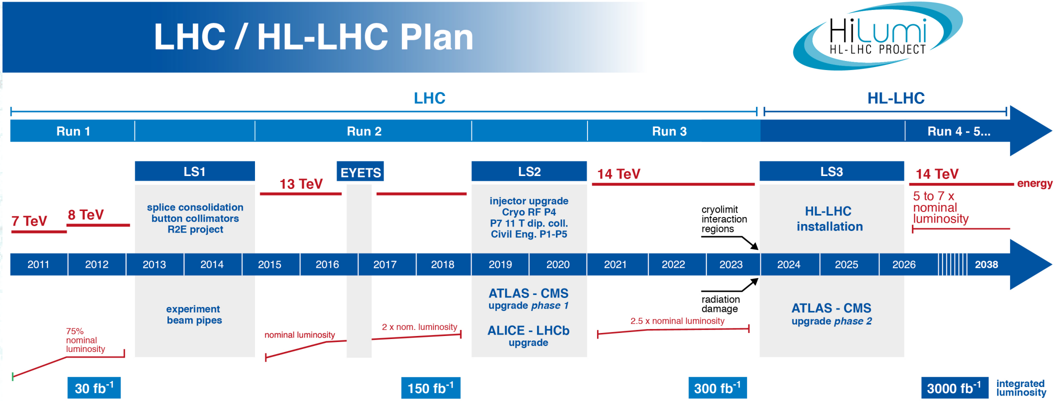
- Photon ID uses cut-base selection as in Run-1 $\rightarrow$ reoptimized for Run-2 higher $\sqrt{s}$ and instantaneous luminosity
- Incorporated *medium* Id working point at trigger level, in addition to *loose* and *tight*
  - Medium includes lateral Energy ratio in first layer to discriminate γ from $\pi^0 \rightarrow \gamma\gamma$
- Introduced topological cluster isolation for photon triggers
- Lowest threshold unprescaled triggers up to $L = 1.2 \times 10^{34} cm^{-2} s^{-1}$:
  - `g35_medium_g25_medium`
  - `g140_loose`





LHC/HL-LHC

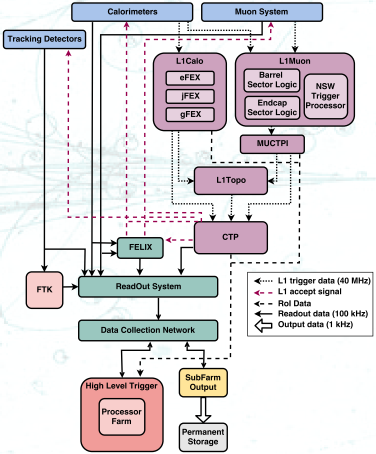
- 2019 - 2020 is LS2 to get ready for Run3: 14 TeV and higher inst luminosities → Phase-I
- The HL-LHC project is planned to begin collisions by 2026
- ATLAS will collect an integrated luminosity of 3000-4000 fb^{-1} in 10 years
- HL-LHC upgrades will happen during Long Shutdown 3 (2024-2026)



TDAQ system being updated for next run: Phase-I

Phase-I upgrade → meets the needs for Run3

- More background rejection for eγ trigger through the upgrade of the EM trigger electronics
- Better muon reconstruction and fake rejection in muon endcap by installing new precision and high efficiency detectors in a New Small Wheel
- FTK (Fast TracKer): full-event hardware-based (Associative memory and FPGAs) track reconstruction during event processing at the HLT CPU farms



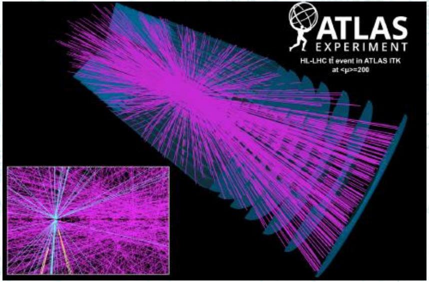
Pileup conditions at HL-LHC → 10 times more rate

Limitations of Phase-I system among others:

- The readout bandwidth is limited by the detector front-end electronics
- The Level-1 trigger rate can't go higher than 100kHz
- Phase-I system latency is insufficient to implement more powerful selection algorithms in order to reduce the trigger rate

Challenges for ATLAS @HL-LHC

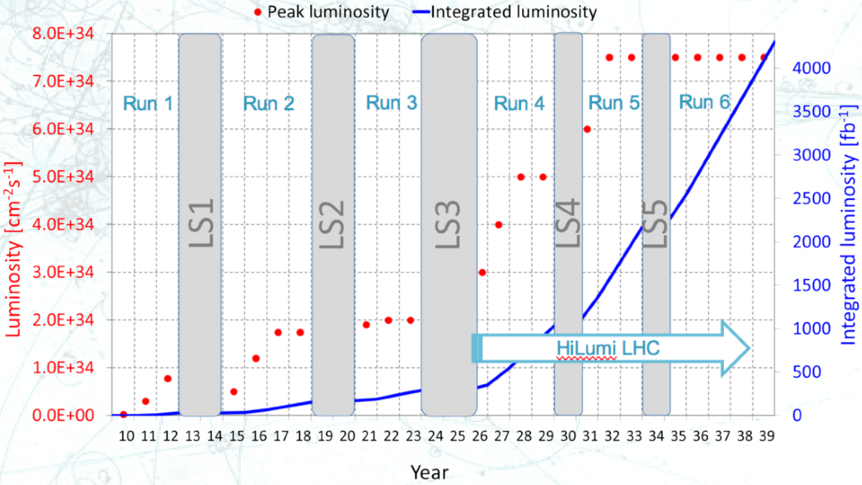
- Stand the 5-7 $10^{34}/\mathrm{cm}^2/\mathrm{s}$ instantaneous luminosity is beyond the capabilities of the current detectors
- Replace several parts (like full inner detector!) to achieve a robuster, faster, radiation harder and lighter detector.
- Goal : have the same-or better-performances in HL-LHC harsh conditions than in Run2
- Upgrade: fruit of permanent feedback between physics requirements and detectors component design



- Protect against high fluencies. Needs more radiation hard eletronics design.
- Mitigate pileup rates and occupancy
- Keep low p_{T} requirements for main triggers
- Guarantee precise measurements up to large rapidity
- Lighten the detector, dropping material

HL-LHC collisions plans

Ultimate scenario 7.5 10^{34}: 320 fb^{-1}/y for 160 days
ions collisions end at LS4
Physics days: 160 Run4 → 200 Run5→ 220 Run6



Some requirements

- TDAQ ATLAS system needs to be upgraded to cope with HL-LHC conditions
- Part of what is currently computed at the HLT would need to be achieved computed at Hardware trigger
- Some of the parameters (including contingency) required for TDAQ @HL-LHC:

Parameter	Phase-II value
Clock frequency	40.08 MHz
Level-0 trigger rate	1 MHz
Minimum interval between two L0A signals	0 BC
Consecutive Level-0 triggers	$\leq$ 4 L0A in 5 BC
Level-0 burst size	$\leq$ 8 L0A in 0.5 μs
	$\leq$ 128 L0A in 90 μs
Maximum skew between all calorimeter inputs to L0Calo FEXs	16 BC
Level-0 latency	10 μs
Calorimeter data reception in L0Calo & L0Muon processors	1.7 μs
High Granularity Calorimeter data reception in Level-0	1.7 μs
Seeding Muon detector data reception in L0Muon	1.7 μs
Precision Muon detector data reception in L0Muon	2.8 μs
Deadtime	<0.1% per detector system

TDQ Phase-II upgrade

Many complex analysis on real time at hardware trigger

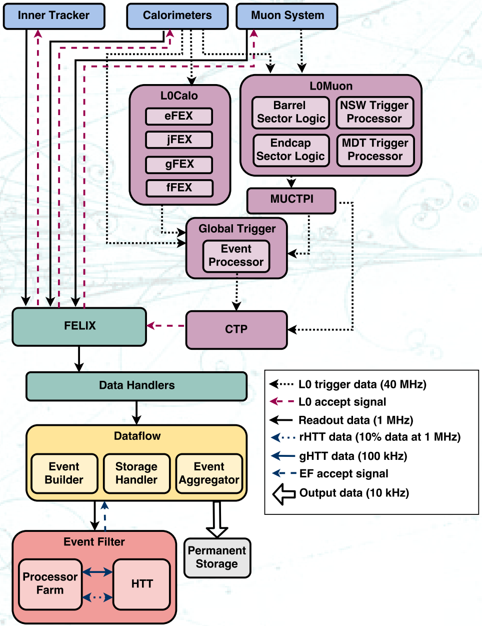
Among other aspects

- L0 Calo will include electron FeatureExtractor (eFEX), jet (jFEX), global (gFEX) and forward jet (fFEX), all implemented in FPGA hardware
- Global trigger will replace current L1-Topo, get inputs from L0 Calo and muons to make a decision
- Common hardware, specialized firmware
- Access to full calorimeter data

Not just TDAQ needs to be updated

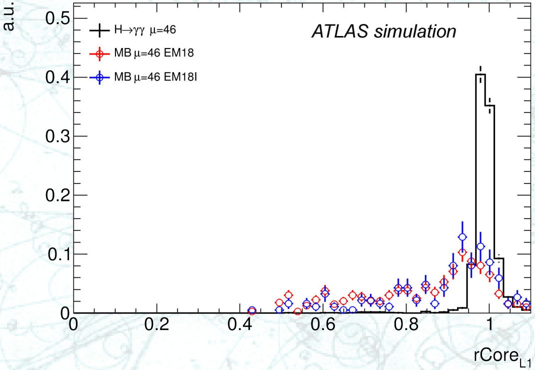
Upgrade of LAr electronics

- The LAr calorimeters themselves are expected to operate reliably during the HL-LHC data-taking period
- But the current electronics is not compatible with operations at HL-LHC
- All front-end and back-end electronics will be replaced



La Plata and the upgrades

Studies for Phase-I LoI



- We were deeply involved for Phase-I studies
- This study showed how improvement in the calorimeter granularity at L1 could lead to high efficiency and high background rejection of electron and photons

Studies for Phase-II

- Made occupancy studies of the detector at mu=200
- Under some assumptions, by merging events in 2016 data
- Estimations on rates and readout requirements (preliminary and non-public, can't be shown here)

Phase-II involvement, plans and opportunities for Argentina

Global trigger

- We are joining the effort to collaborate in development of HW/FW for the Global Trigger
- Hiring and engineer (CPA-CONICET) to full time contribute on this R&D effort
- The aim is to build hardware in Argentina, once Phase-II production starts. What and how much each institution builds is under discussion with the ATLAS collaboration, final decision during this year.
- In such case we would need to be able to produce and build multi-layer high speed boards with high-end FPGAs
- Likely, in addition, we will be responsible of R&D and production of a module of signal distribution (local industries play a role here)

New facility at new Institute building

- IFLP is moving to new building, equipped with a specific electronics lab for this project (and future ones)
- Starting to equip it. (High end Computers, high speed Oscilloscopes, high speed random signal generators and FPGA evaluation kit)

New responsibilities

- Just joint with Oregon the effort of coordinating Global Trigger algorithm developments for trigger signatures

Conclusions

Run-2

- As members of the e/gamma trigger group we have contributed with ATLAS in performance measurements, selection tuning, deployment of optimizations at the HLT and operation
- Contributed to studies for the Phase-I LoI and studies related to Phase-II

Phase-II: A step forward for Argentina contribution to ATLAS

- Provide *in kind* contribution to TDAQ Phase-II upgrade
- Full time Engineer to collaborate in Global Trigger Hardware/Firmware
- Aim is to build some of Global modules in Argentina
- In addition to some specific hardware for signal distribution

Special opportunity for local high-end electronics industry