ATLAS
Trigger & Data Acquisition
Upgrades for the High Luminosity LHC

CHEP2019

Adelaide, Australia, 7th Nov 2019

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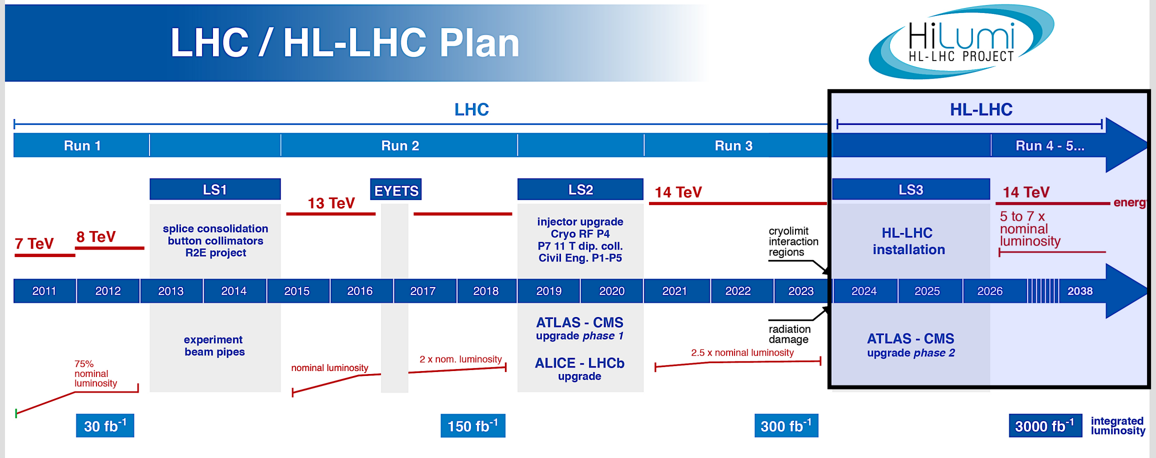
On behalf of the ATLAS collaboration

Outline:

- HL-LHC implications
  - ATLAS
  - TDAQ (Trigger & Data Acquisition)

- TDAQ Phase-II
  - Operation algorithm
  - Subsystems

ATLAS in the HL-LHC



→ Up to 200 events per pp bunch-crossing
→ total pp-dataset of $4000\ fb^{-1}$

- ATLAS preparations for the HL-LHC:
  - *New sub-detectors are being introduced*
  - *Remaining sub-detectors will be upgraded*

New inner tracker: ITk Pixel Detector, ITk Strip Detector
Higher radiation tolerance: LAr Calorimeter, Tile Calorimeter
Improved trigger chambers: Muon Spectrometer
Discussed in this presentation: TDAQ

*Detector System	Upgrade scope	CDS Reference
ITk Pixel Detector	Sensors, modules, mechanics, FE electronics	CERN-LHCC-2017-021
ITk Strip Detector	Sensors, modules, mechanics, FE electronics	CERN-LHCC-2017-005
LAr Calorimeter	FE and BE electronics	CERN-LHCC-2017-018
Tile Calorimeter	Mechanics, FE and BE electronics	CERN-LHCC-2017-019
Muon Spectrometer	FE electronics Inner Barrel MDT chambers Inner Barrel RPC stations	CERN-LHCC-2017-017
TDAQ	On-detector readout and trigger electronics (this document)	CERN-LHCC-2017-020

HGTD (High Granularity Timing Detector) – TDR in preparation. Proposal: CERN-LHCC-2018-023

*Forward detectors not mentioned here, yet are included in the ATLAS upgrade plan

Implications on TDAQ

Detector System	Upgrade scope	CDS Reference
ITk Pixel Detector	Sensors, modules, mechanics, FE electronics	CERN-LHCC-2017-021
ITk Strip Detector	Sensors, modules, mechanics, FE electronics	CERN-LHCC-2017-005
LAr Calorimeter	FE and BE electronics	CERN-LHCC-2017-018
Tile Calorimeter	Mechanics, FE and BE electronics	CERN-LHCC-2017-019
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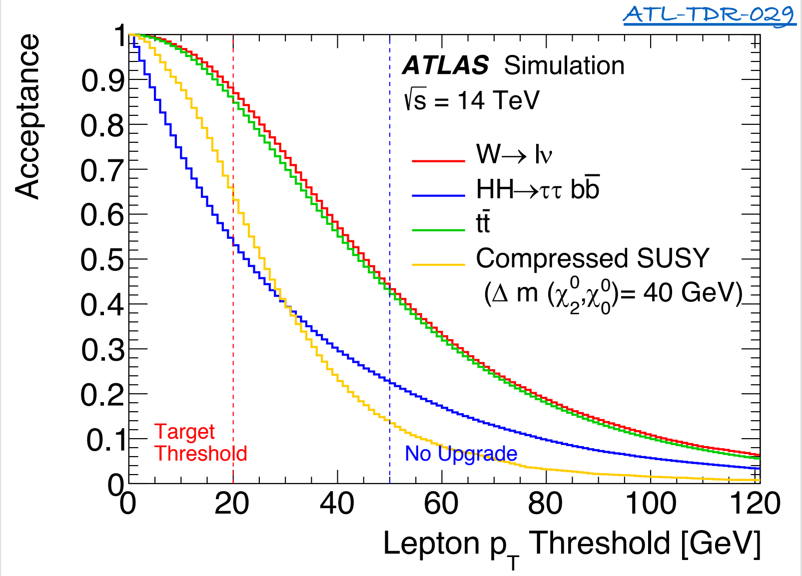
TDAQ	On-detector readout and trigger electronics (this document)	CERN-LHCC-2017-020

- High luminosity & pileup ($\langle\mu\rangle \sim 200$ vs 40)
  - → *need to 'scan' more complex events*
- Accommodating the new subdetectors: ITk, HGTD
  - → *support the sub-detectors electronics constraints (e.g. no. of channels to read-out)*
- Full granularity to the L0Trigger provided by the detectors (LAr, Tile, Muon System)
  - → *exploiting the data for better triggering while dealing with bigger event sizes (5 vs 2 MB)*
- Identification of low pT objects is still required
  - → *maintaining low pT threshold in the trigger menu*
- Would need to deal with an order of magnitude higher data volume through the system
- → *maintaining low trigger rates in order to keep only relevant events*

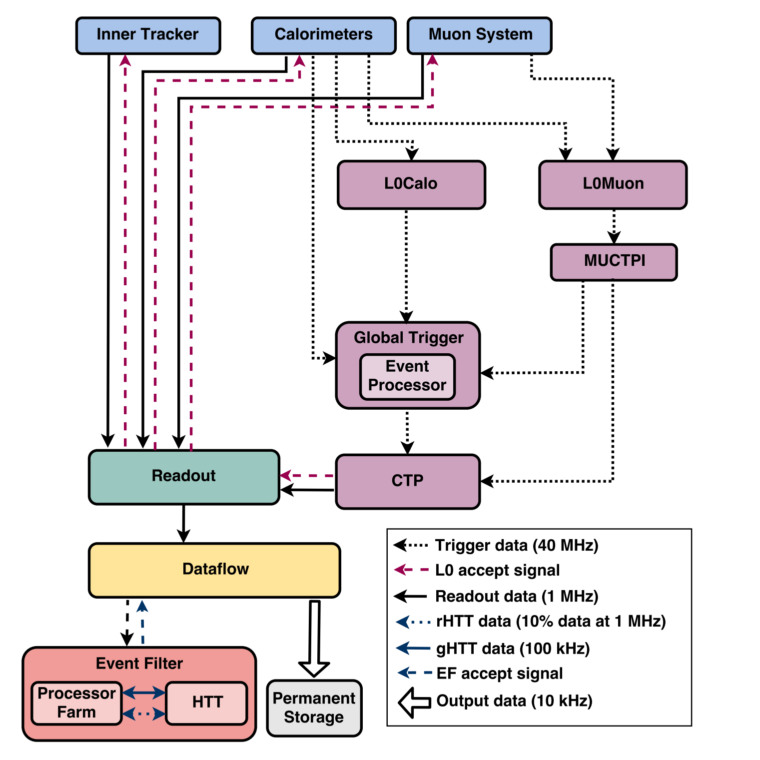


The Phase-II TDAQ upgrade would enable lowering the single lepton Level-0 threshold to 20 GeV from 50 GeV, the projected threshold without the upgrade.

TDAQ Phase-II

Operation algorithm:

- 3 systems:
  - *Level-0 Trigger*
  - *Readout & Dataflow*
  - *Event Filter*



- Data flow from the **detectors** and **into** the **L0Trigger** systems – *at40 MHz*

- * The **L0Trigger:** *within 10 µs (2.5 µs today)*
  → **identifies** physics objects and **calculates** event-level physics quantities
  → **forms** Trigger Objects (**TOBs**)
  → **makes** trigger decision - **L0Accept** (L0A)
  → **sends back** to the **detectors** L0A – signals

  ** In the evolved scenario an addition of L1track is added before L0A (see back-up)*

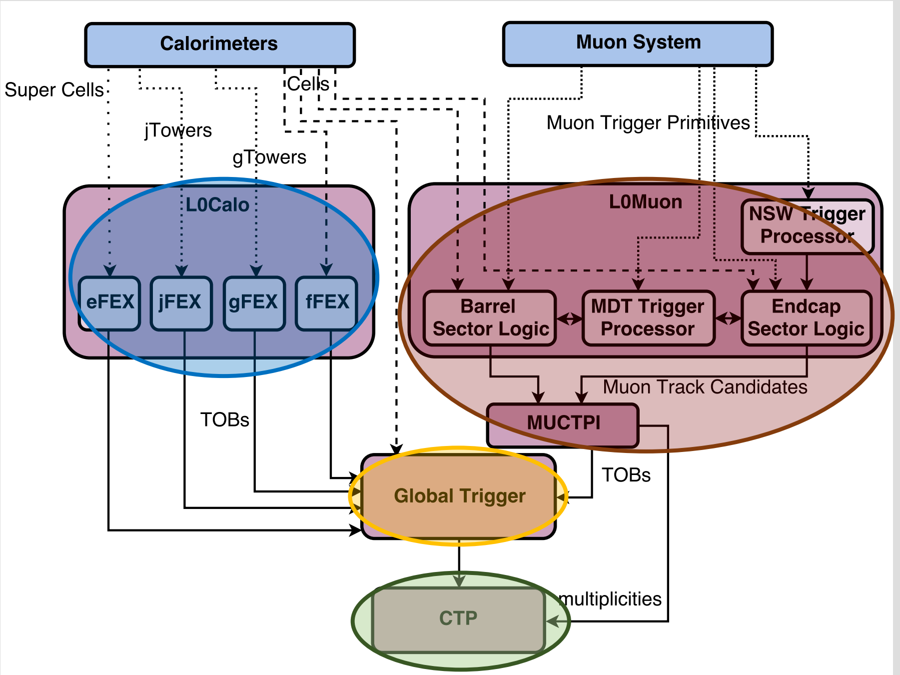
- Complete event-data **from** the **detectors** & **triggers** are then **transmitted** through the **Readout** & **Dataflow** systems for formatting & buffering, etc… and eventually **into** the **Event-Filter** – *at 1 MHz (100 kHz today)*

- The **Event Filter** performs event **reconstruction** & **selection** based on additional info from HW-based tracking (HTT). The final selected events *(5 vs 2 MB today)* are then **transferred** to **permanent storage** of the ATLAS offline computing system – *at 10 kHz (1 kHz today)*

L0 Trigger

Composed of 4 main systems:

- *L0Calo*
- *L0Muon & MUCTPI*
- *Global trigger*
- *Central Trigger (CTP)*



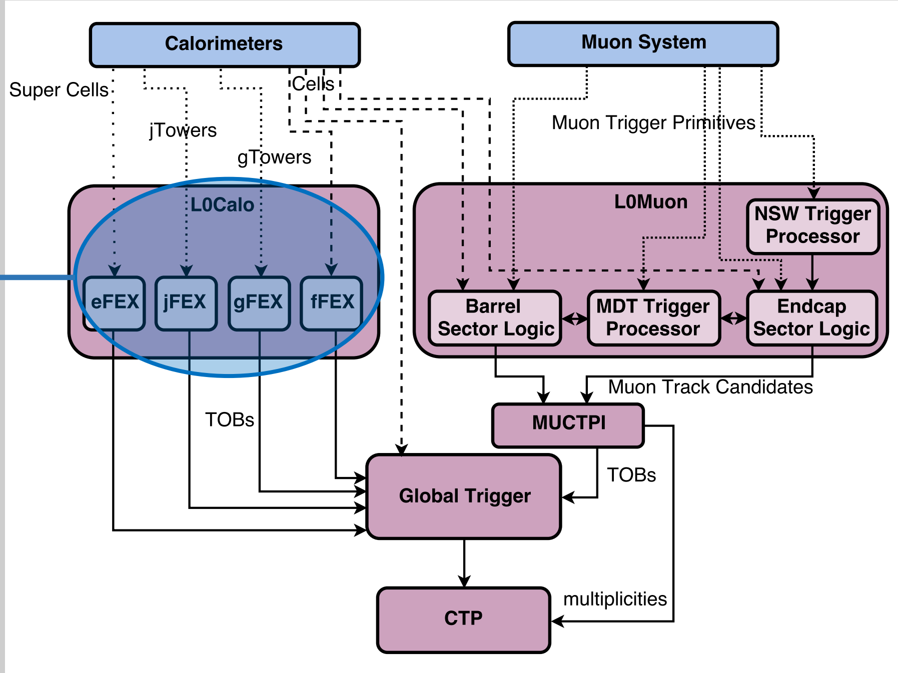
- ATCA-based architecture:
  - ***FPGAs** used for running algorithms*
  - *Data I/O Via **optical links** at 9-25 Gb/s*
- Functionality:
  - ***Identifying** physics objects*
  - ***Calculates** physics quantities*

Form Trigger Objects (TOBs)

L0Calo

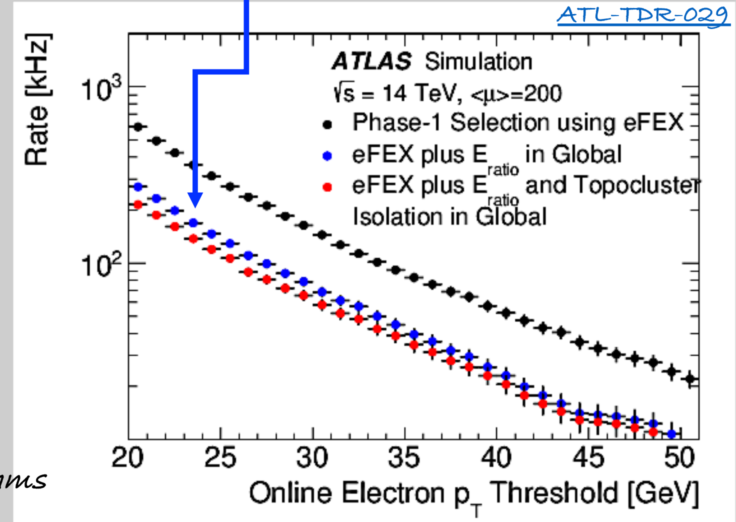
Composed of 4 main systems:

- *L0Calo*
- *L0Muon & MUCTPI*
- *Global trigger*
- *Central Trigger (CTP)*



Combined selections of eFEX and Global reduces the trigger rates for the essential low p_T thresholds

ATL-TDR-029



- **Composed of** 4 **Feature EXtractors** (FEXs)
  - *electron-FEX, jet-FEX, global-FEX and forward-FEX*
- *Mostly **Phase-I legacy**:
  - *Upgraded firmware for phase-II algorithms*
  - **Additional triggering coverage – forward-FEX*
- *Use **coarse-granularity calorimeter** data
  - **The forward-FEX will use full-granularity*
- **Identify** physics objects (e, γ, τ, jets) and **calculate** E_T^{miss}
- Final **Trigger Objects** are **sent to the Global Trigger** for further processing

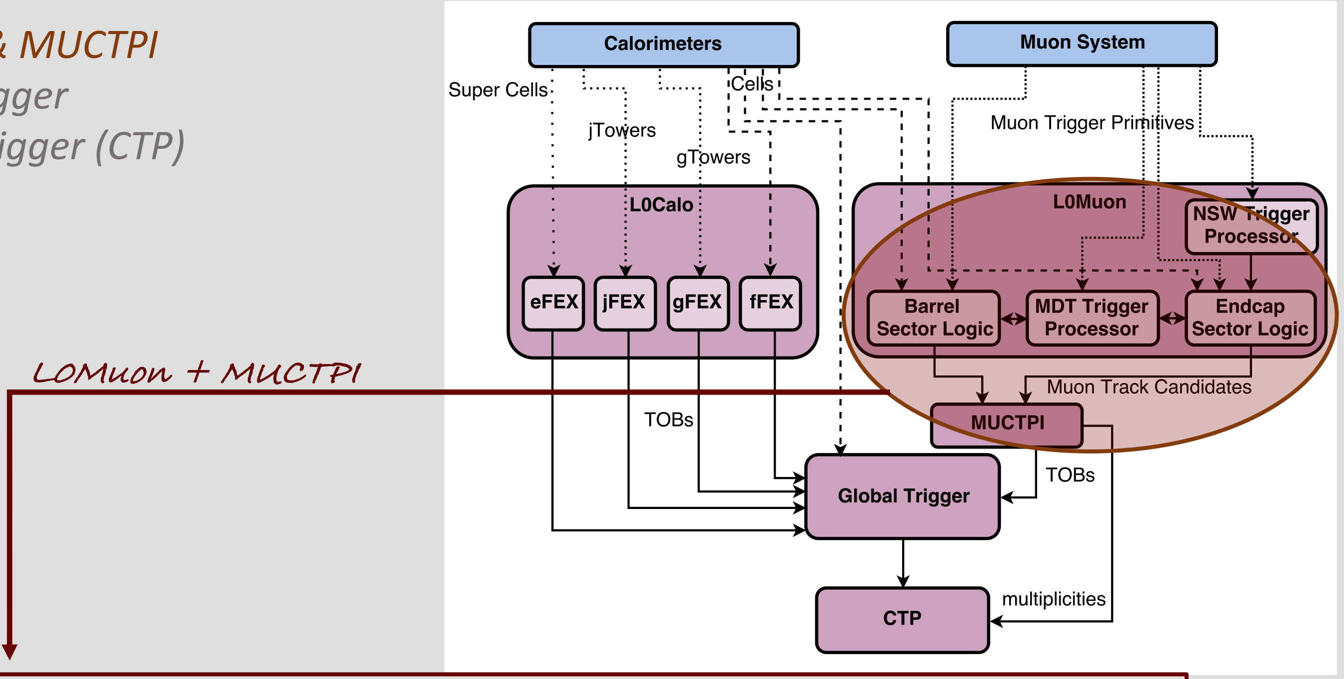
Inputs to the algorithms

Subsystem	Trigger Object	Approximate Granularity	Coverage $\|\eta\|$
eFEX	$e/\gamma, \tau$	Super Cells (10 in 0.1×0.1)	< 2.5
jFEX	τ, jet, E_T^{miss}	0.1×0.1	< 2.5
jFEX	τ, jet, E_T^{miss}	0.2×0.2	$2.5 - 3.2$
jFEX	τ, jet, E_T^{miss}	0.4×0.4	$3.2 - 4.9$
gFEX	Large-R jet, E_T^{miss}	0.2×0.2	< 3.2
gFEX	Large-R jet, E_T^{miss}	0.4×0.4	$3.2 - 4.9$
fFEX	e/γ	Full detector EMEC, HEC, FCal	$2.5 - 4.9$
fFEX	jet	Full detector FCal	$3.2 - 4.9$

L0Muon & MUCTPI

Composed of 4 main systems:

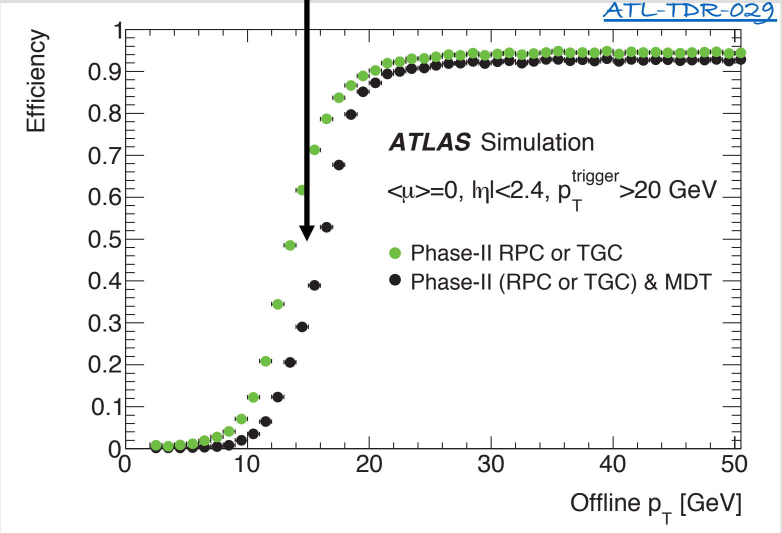
- L0Calo
- L0Muon & MUCTPI
- Global trigger
- Central Trigger (CTP)



- *Upgraded **muon** trigger system, **composed of 4 trigger-processors**
  - *RPC, TGC, NSW as legacy*
  - **MDT TP a new addition*
- Receive **full granularity data** inputs from:
  - *all Muon subsystems*
  - *subset of Tile data*
- **Higher quality** trigger **candidates** due to:
  - ***Increased detector acceptance** (additional RPC chambers providing further hits)*
  - ***Additional processing of the MDT data**, seeded by both barrel & end-cap information, forming pattern recognition & tracking*
- The **MUCTPI** (Muon to CTP interface) **combines information** for final refined selection
  - *Forming final TOBs sent to the Global Trigger for further processing*

Including MDT info in the Muon triggers:
- provides better sensitivity to muon candidates
- while still keeping the trigger eff. high

ATL-TDR-029

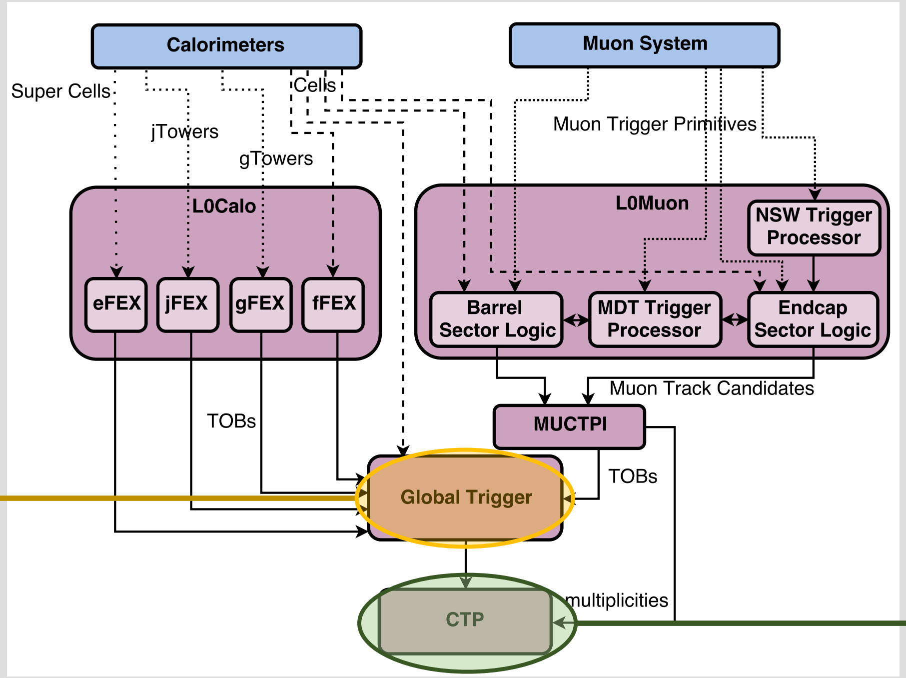


Subsystem	Granularity	Coverage $|\eta|$
NSW processor	Full NSW detector	1.3 – 2.4
MDT processor	Full MDT detector	< 2.4
Barrel Sector Logic	Full RPC and Tile, MDT	< 1.05
Endcap Sector Logic	Full TGC, Tile, RPC, NSW, MDT	1.05 – 2.4

Global & Central Triggers

Composed of 4 main systems:

- L0Calo
- L0Muon & MUCTPI
- Global trigger
- Central Trigger (CTP)

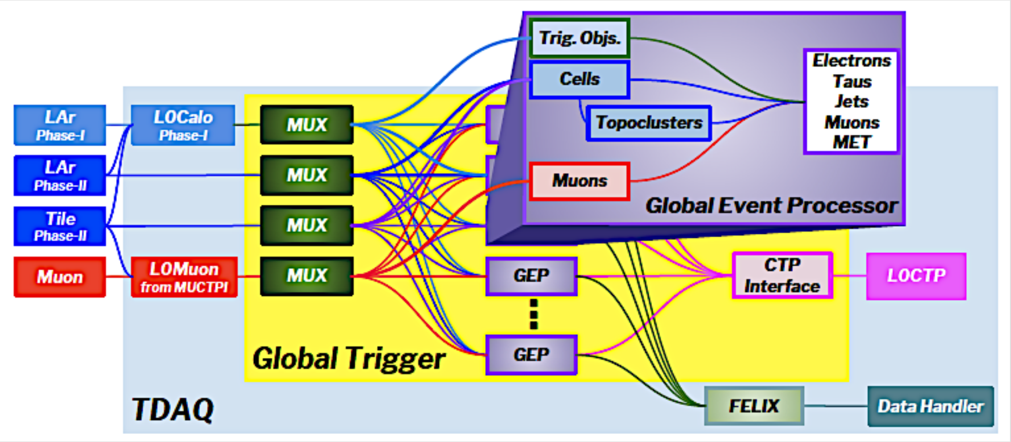


Global

- Receive **inputs** from:
  - ***Global*** *trigger*
  - ***MUCTPI***
- **Functionality**:
  - ***Align & combine*** *digital trigger inputs*
  - *Makes final* ***L0Accept decision*** *(considering trigger menu configuration, prescale factors and dead-time)*
  - ***Transmitters the L0A*** *signal to the subdetectors through* ***FELIX*** *(see next slide)*

CTP

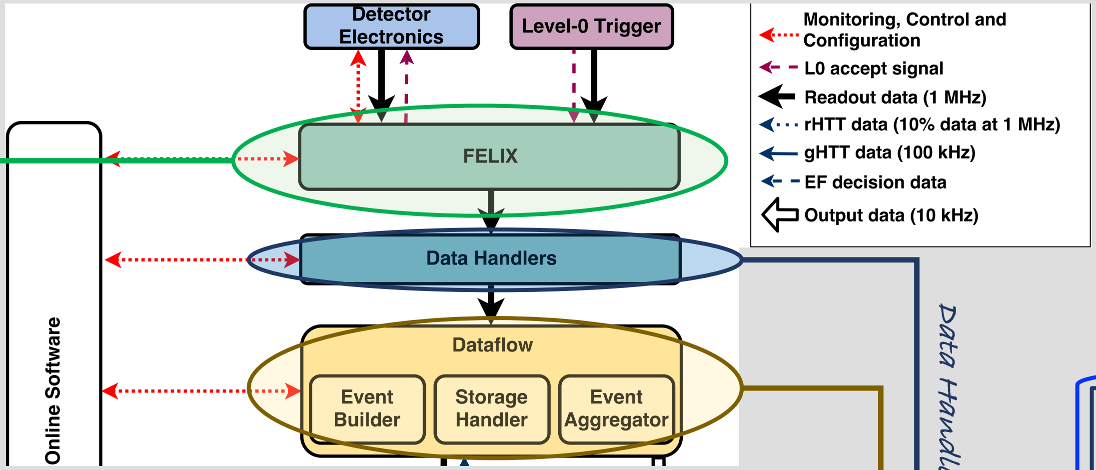
- **Composed** of 3 main components, (same hardware platform):
  - ***MUX*** *– time* ***multiplexing*** *serial* ***inputs****:*
    - ***L0Calo*** *systems*
    - ***Calorimeter*** *pre-processors*
    - ***MUCTPI***
  - ***GEP*** *(Global Event Processor) – execute* ***processing algorithms****:*
    - ***Topological*** *clustering*
    - *Refined candidate (e, γ, τ, jets)* ***identification***
    - ***Topological*** *selections to TOBs*
  - ***CTP interface*** *- routes the results to the CTP and generates TTC signals*



Readout & Dataflow

Composed of 3 main systems:

- *FELIX*
- *Data Handlers*
- *Dataflow*



Data Handlers

Data handlers:

- **Receive** the data from the subdetectors over the network at 1 MHz
- Total bandwidth of 5.2 TB/s
- Performs **data formatting** before sending to the dataflow system

FELIX

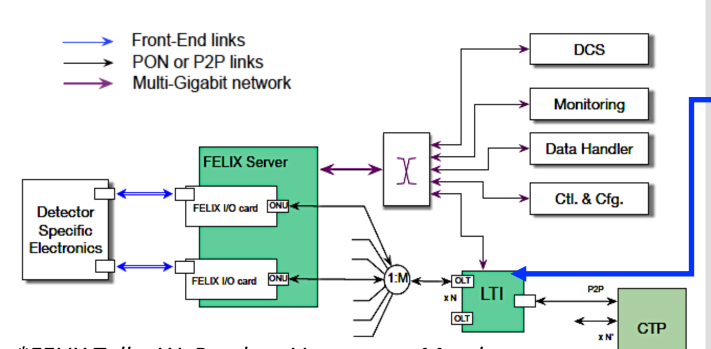
- Front-End LInk eXchange (FELIX):
  - *provides common* ***interface*** *between the subdetectors and the DAQ system*
- **Composed** of:
  - ***PC*** *hosting custom* ***FPGA*** *I/O cards*
- **Functionality**:
  - ***Propagating trigger & command*** *signals (i.e L0A, TTC) to the subdetectors*
  - ***Transmits*** *the full detector data up to the DAQ system*

Commodity PC servers

Dataflow

Dataflow:

- **Buffers**, **transports**, **aggregates** & **compress** event data
- Data buffering before/while/after Event-Filter decision
- Provides **access** to the **event data**
- **transfers** data to permanent **storage**



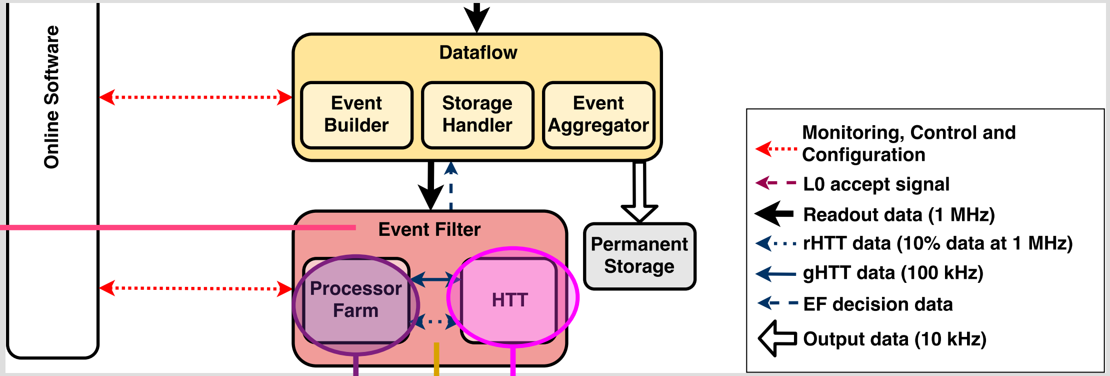
**FELIX Talk - W. Panduro Vazquez on Monday*

The LTIs provide an interface for the TTC signals between the CTP and subdetector front-end electronics via FELIX

Event Filter

Composed of 2 main systems:

- *Processor Farm*
- *Hardware Tracking Trigger (HTT)*



Event Filter (EF)

- **1 MHz data input** rate from the DAQ system
- **Runs reconstruction algorithms** (similar to offline reconstruction)
- **Final event selection** (according to the trigger menu) should be at maximum **10 kHz rate**

HTT

- Process ITk hits information and form tracks
- ATCA technology based design
- Blades mounted with different mezzanines:
  - *Associative Memory (AM) ASICs – pattern recognition*
  - *FPGAs – track reconstruction & fitting*

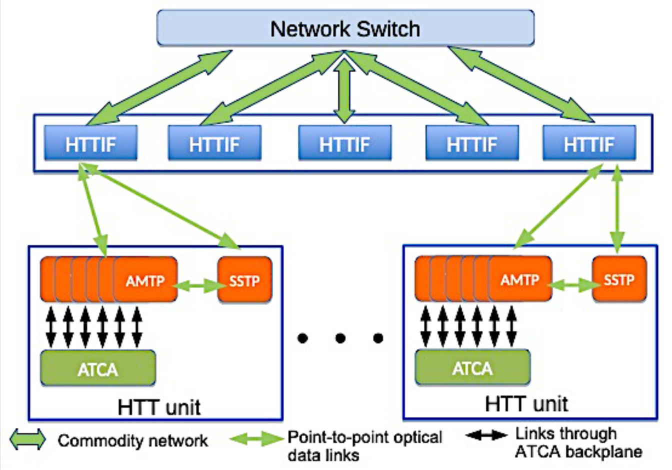
**HTT poster – A. Boveia (Tuesday)*

Processor Farm

- Composed of **commodity CPU**-servers
- CPU-based event processing for reconstruction & final event selection

HTT Interface (HTTIF)

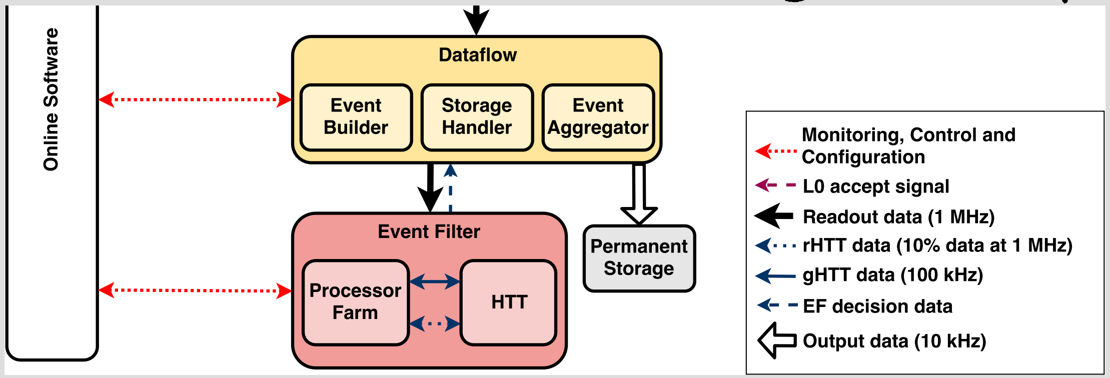
- Receives:
  - *EF requests (commodity network)*
  - *ITk data and propagates (optical links) it to the relevant HTT-unit*
- Composed of PC servers with PCIe cards

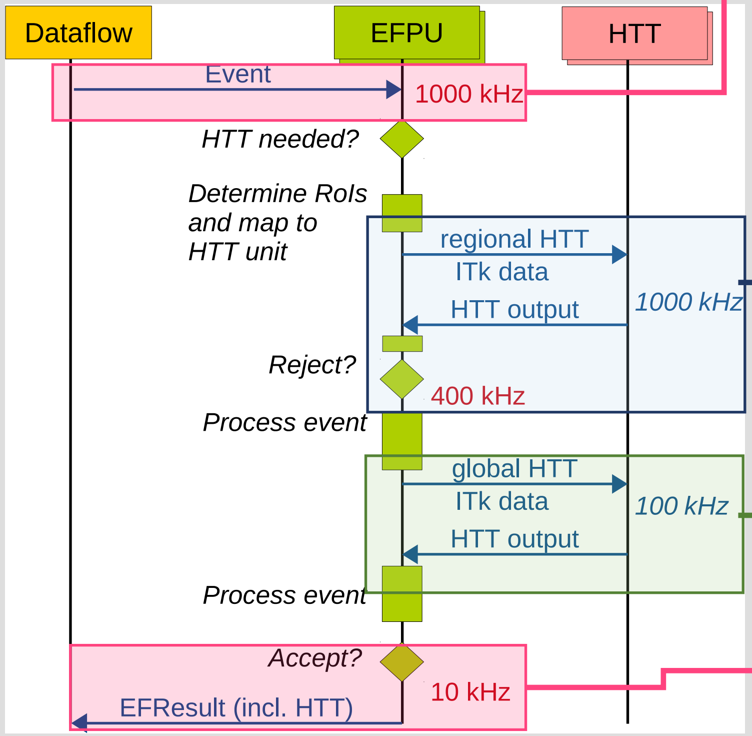


Event Filter → Tracking work flow

Composed of 2 main systems:

- Processor Farm
- Hardware Tracking Trigger (HTT)





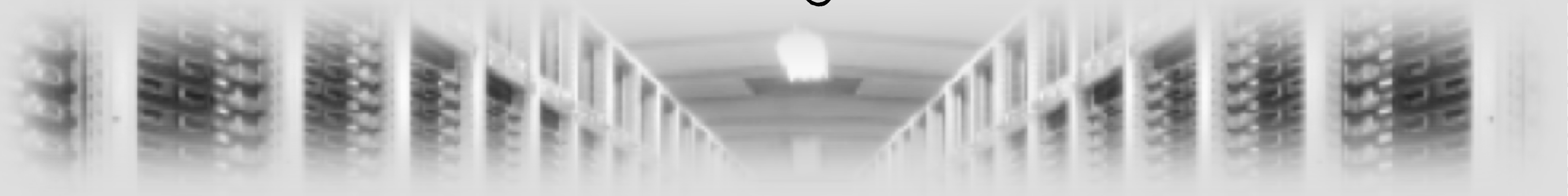
- 1st step: *determine Region of Interest (RoI) and initial reconstruction*
  - ***Retrieve detector data of L0trigger*** *accepted events at 1MHz rate from the DAQ system*
  - ***Determine RoIs*** *based on combined information from L0Trigger*

- 2nd step: *is HTT info needed for completing the reconstruction?*
  - regional (*needed in most cases, except γ, and μs*):
    - *The EF sends to the **RoI-dependent** ITk data to the **regional-HTT (rHTT)***
    - ***rHTT** forms track with $p_T > 2\ GeV$*
    - *The EF combines the L0Global topological info + **rHTT** info*
    - *reduced rate to **400 kHz***
  - global:
    - *The EF sends **full ITk** data to the **global-HTT (gHTT)***
    - ***gHTT** forms global track with $p_T > 1\ GeV$ and send them back to the **EF***
    - *The EF combines the L0Global topological info + **rHTT** info*
    - *reduced rate to **100 kHz***

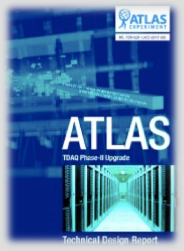
- 3rd step: *Further **software reconstruction and selection***
- **Final event selection → 10 kHz rate**

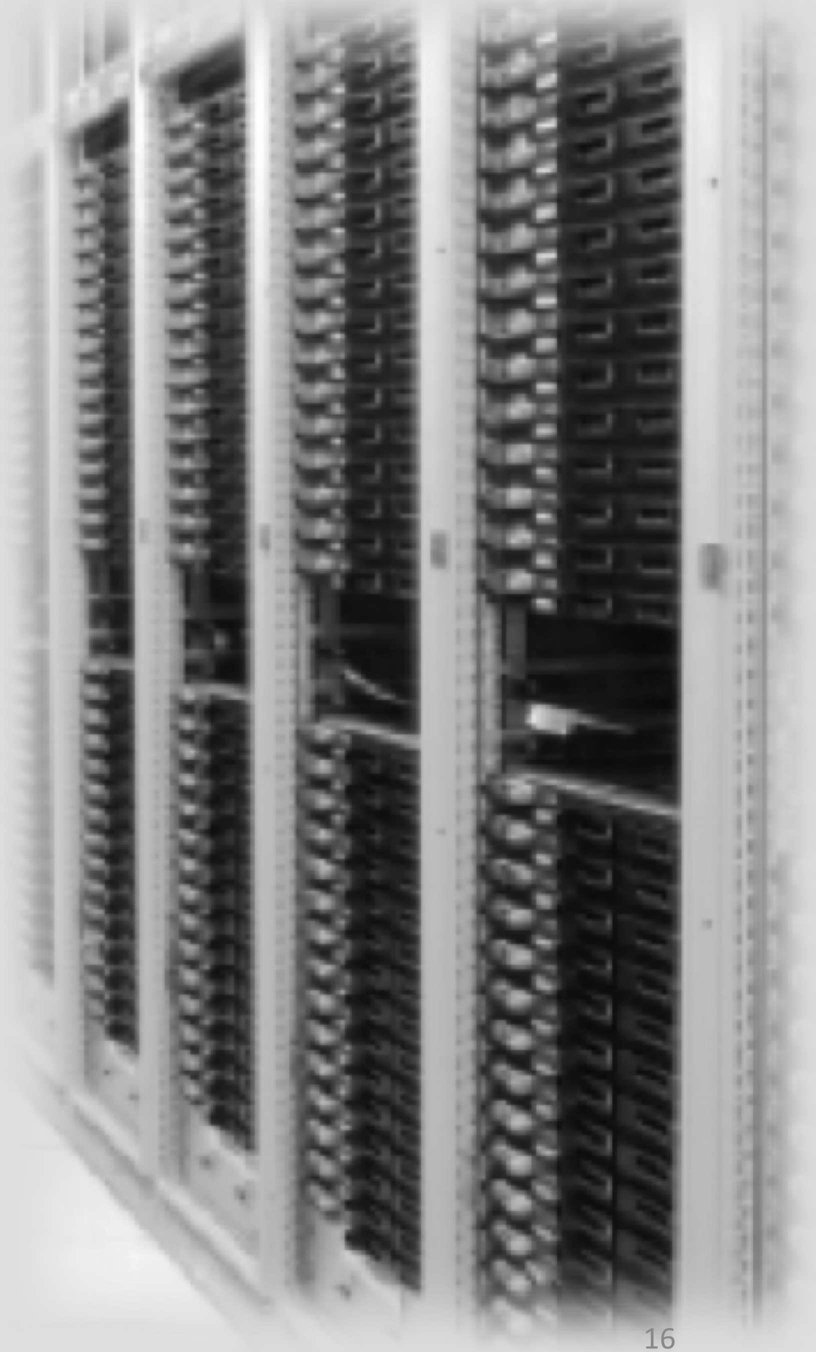
Summary

Summary:



- TDAQ is committed to enable the ATLAS HL-LHC physics program:
  - Implement sophisticated algorithms for better triggering & reconstruction
  - Combine information with the L0Global trigger for refined selection and trigger rate reduction
  - Improve reconstruction and reducing event rates by:
    - *Including more subdetectors information at the trigger level (e.g. MDT, NSW)*
    - *Increase detector coverage and high granularity data events (e.g. RPC, fFEX)*
    - *combining software & hardware tracking triggering (e.g. EF + HTT)*
  - Benefit from conclusions deduced from previous runs along with the current Phase-I upgrade experience
  - All requirements on TDAQ are being taken into account and evaluated:
    - *Maintaining close contact with other subdetectors (e.g. ITk)*
    - *Frequent study groups and brainstorming (e.g. simulations, trigger HW design)*
  - TDR – preliminary roadmap and plans were published 15th of June 2018 ATL-TDR-029 / LHCC-2017-020

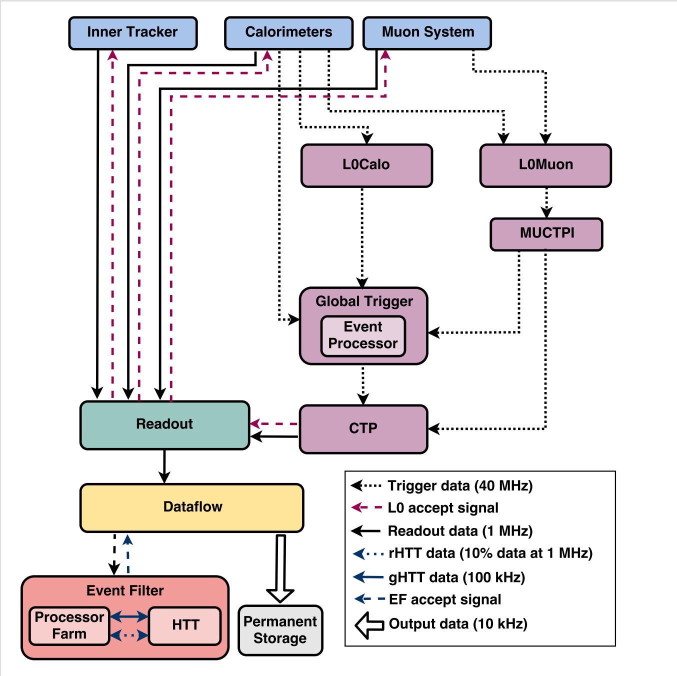




Backup...

Scenarios

Plan A: Baseline



- 3 systems:
  - *Level-0 Trigger – 4 MHz*
  - *Readout & Dataflow*
  - *Event Filter – 10 kHz*

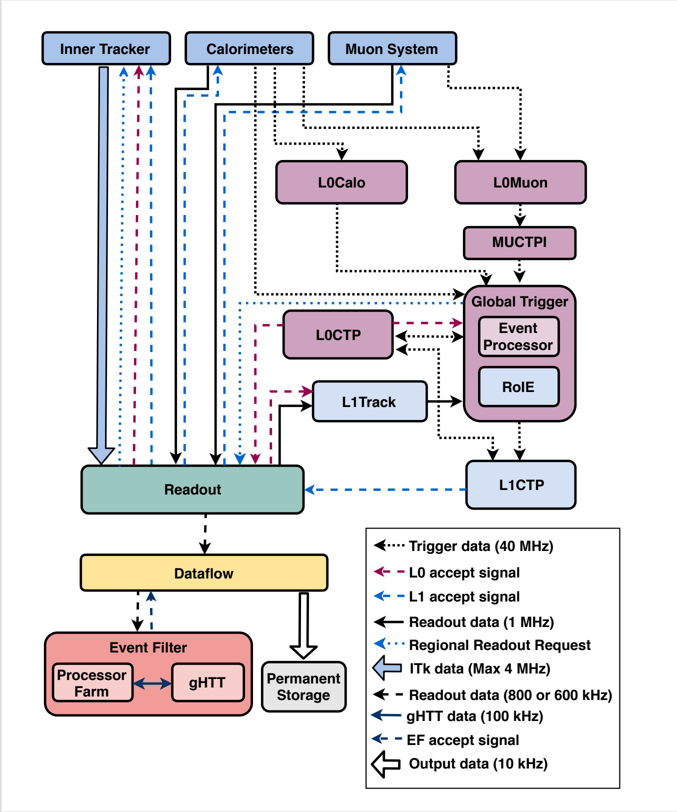
Hadronic trigger rates

manageable | Too high

ITk- pixel detector layer occupancies

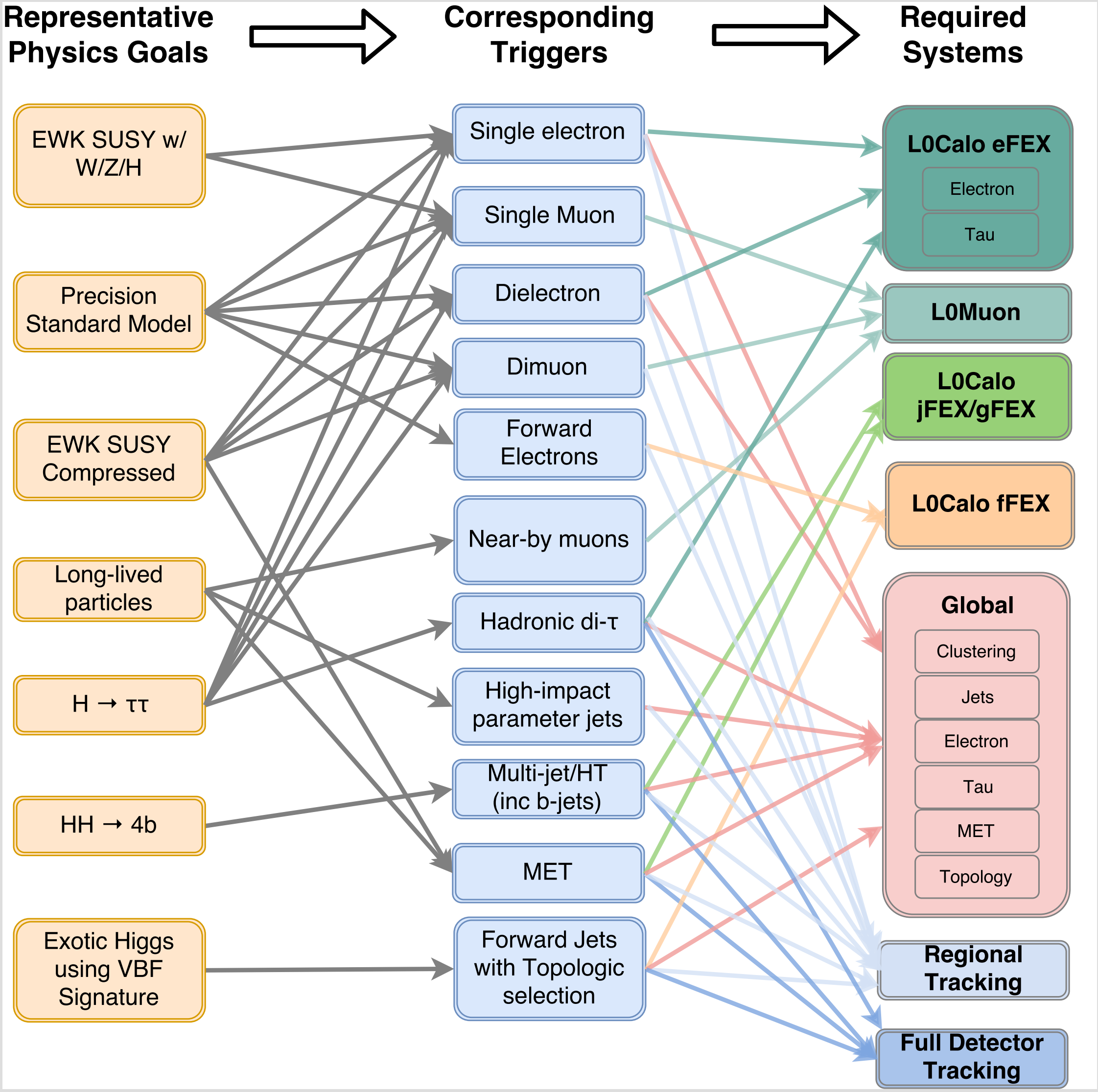
As expected | Too high

Plan B: Evolved



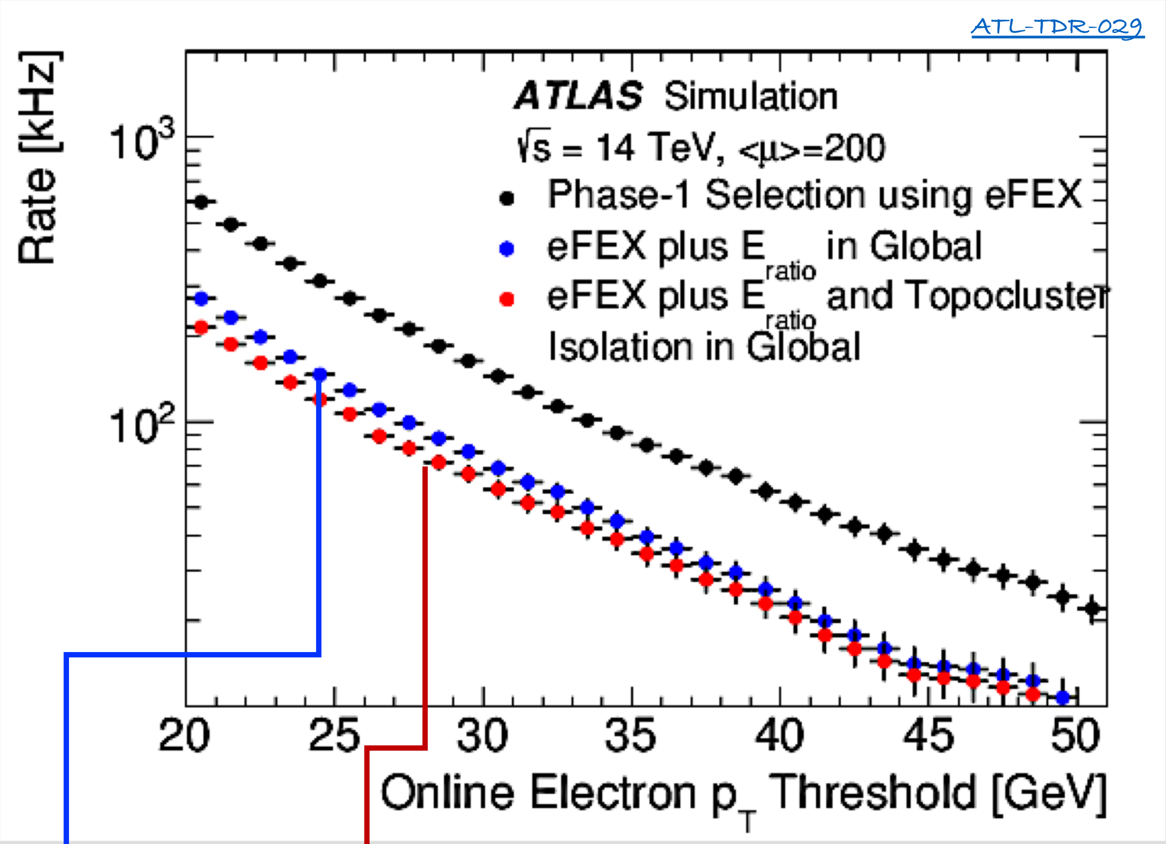
- 4 systems:
  - *Level-0 Trigger – 4 MHz*
  - *Level-1 Trigger – 1 MHz*
  - *Readout & Dataflow*
  - *Event Filter – 10 kHz*

Physics to Hardware flow



Single electron trigger rates as a function of leading electron p_T

ATL-TDR-029



- E_{ratio} - usage of the 1st layer of the LAr, that is not available in eFEX but will be available in Global

$$E_{ratio} = \frac{E_{\text{highest energy cell}} - E_{\text{2nd local maximum energy cell}}}{E_{\text{highest energy cell}} + E_{\text{2nd local maximum energy cell}}}$$

Including E_{ratio} reduces the rate by 50% at 20 GeV

Including E_{ratio} + topocluster isolation reduces the rate by ~70% at 20 GeV