



# The migration of the ATLAS electron photon trigger software to the AthenaMT

Debottam BakshiGupta

On behalf of the **ATLAS Collaboration**

UTA

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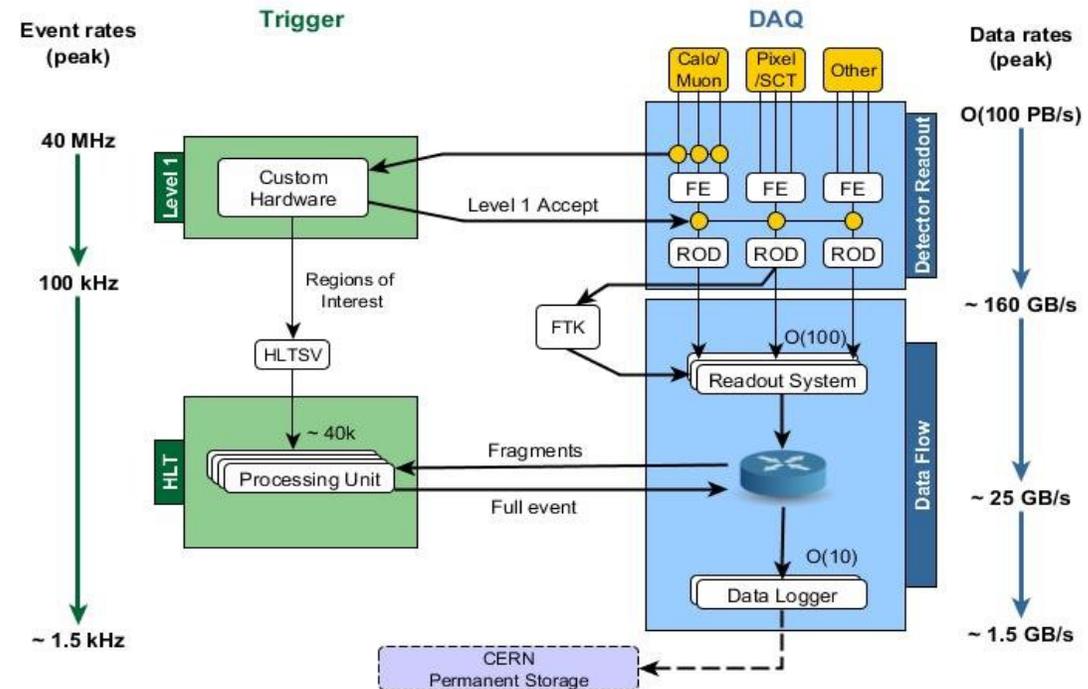
# Outline

- ATLAS Trigger System
  - Level 1
  - HLT
- Run 2 electron/photon Trigger System
  - Brief Overview
  - Sequential Athena Framework
- Run 3 electron/photon Trigger System
  - Upgrades
    - Completed
    - Under process
  - Multi Threaded Athena Frame Work (AthenaMT)
  - Migration of Offline-like Algorithms to HLT
- Outlook and Plans
- Summary
- Backup

# ATLAS Trigger System and Data Acquisition, Run 2

The ATLAS has two-level Trigger system that reduces the bunch crossing rate from 40 MHz to  $\sim 1$  kHz, of which around 20% are allocated to electron and photon triggers.

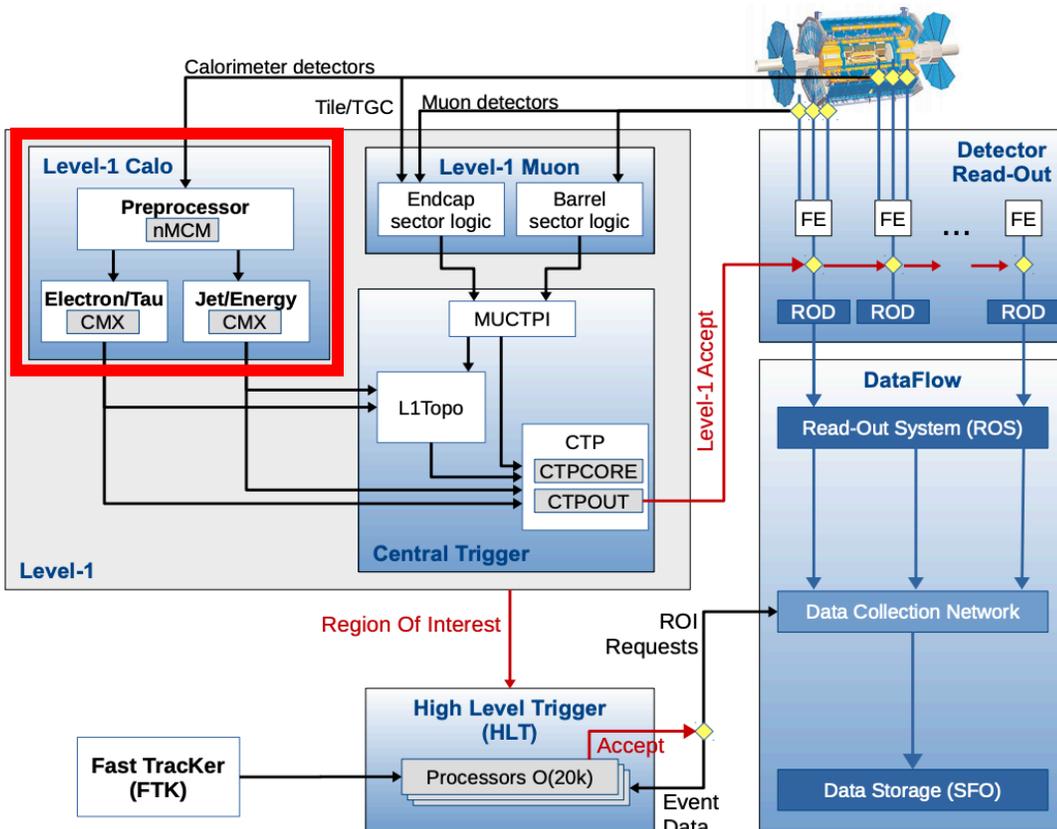
- The Level1 (L1) is hardware trigger, uses
  - low granularity data from the calorimeters (trigger towers) and the muon system to identify Regions of Interest (Rois).
  - Maximum output rate is 100 kHz.
- The High Level Trigger (HLT) is software based
  - seeded by RoIs from L1.
  - Performs reconstruction and identification similar to offline.
  - Maximum output rate is  $\sim 1.5$  kHz.



Focus of this presentation will be on the HLT and its upgrade from Run 2, specific to electron ( $e$ ) and photon ( $\gamma$ ) reconstruction and an outline of L1 readouts needed by HLT.

# Components of Trigger System related to $e/\gamma$ reconstruction ...(1)

## □ L1Calo



Trigger system used in Run 2

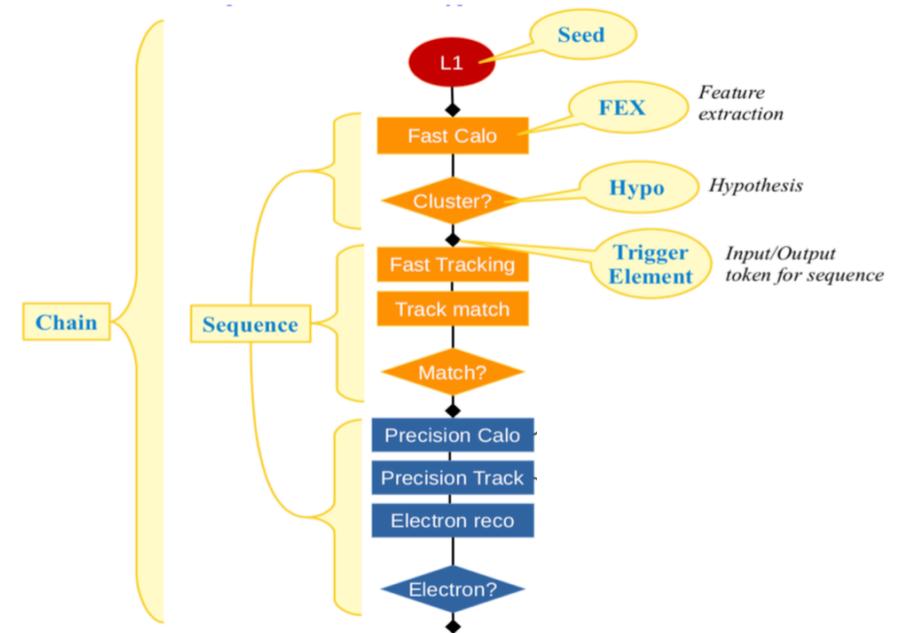
L1Calo triggers on electromagnetic (EM) objects, it has following functionalities:

- Several calorimeter cells are summed into trigger towers of reduced granularity.
- Object reconstruction (EM clusters).
- Finding local maxima via sliding window algorithm.
- Apply energy selection based on sum in trigger towers.
- Can apply additional selections.
  - EM Isolation (ring around core).
  - Hadronic Veto.
- Finally provides ROI information for the next steps of reconstruction.

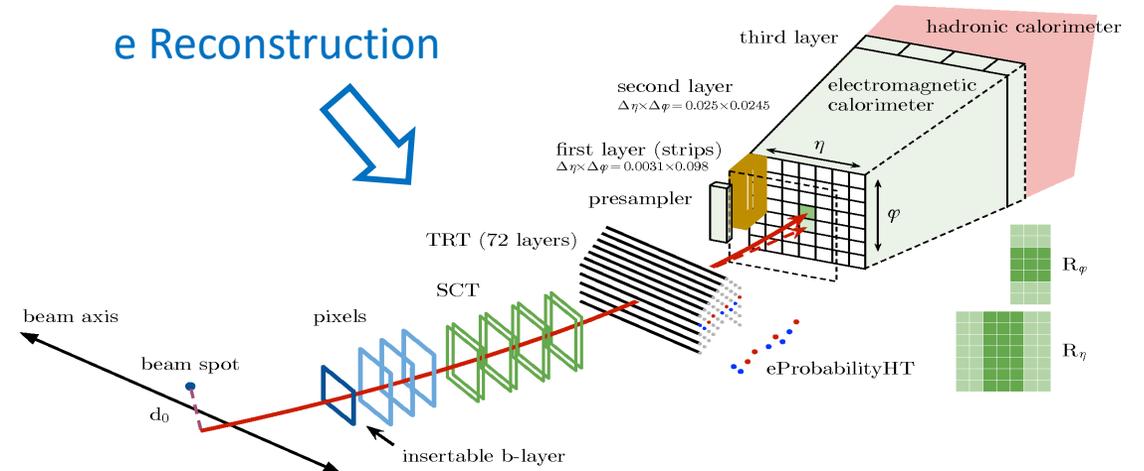
# Components of Trigger System related to e/ $\gamma$ reconstruction ... (2)

## HLT

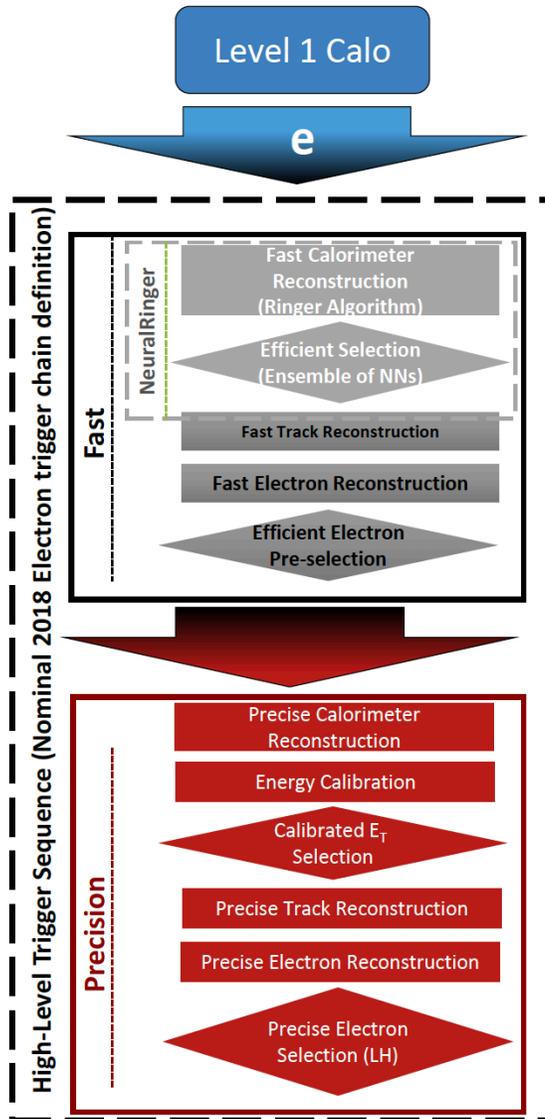
- Requires step-wise processing with early rejection
  - feature extraction (FEX)
  - hypothesis testing (Hypo)
- Two main stages of reconstruction
  - Fast reconstruction**
    - Trigger-specific or special configurations of offline algorithms.
    - Guided by L1 Rols.
  - Precision reconstruction**
    - Offline (or very close to) algorithms.
    - Can be run within Rol mode.
- HLT reconstruction stops as soon as a Hypo fails.**



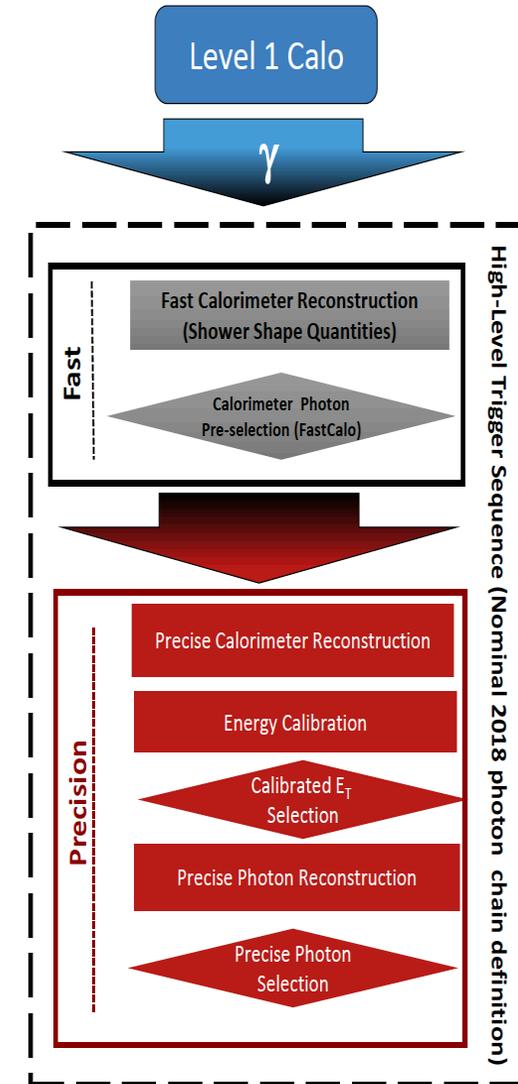
## e Reconstruction



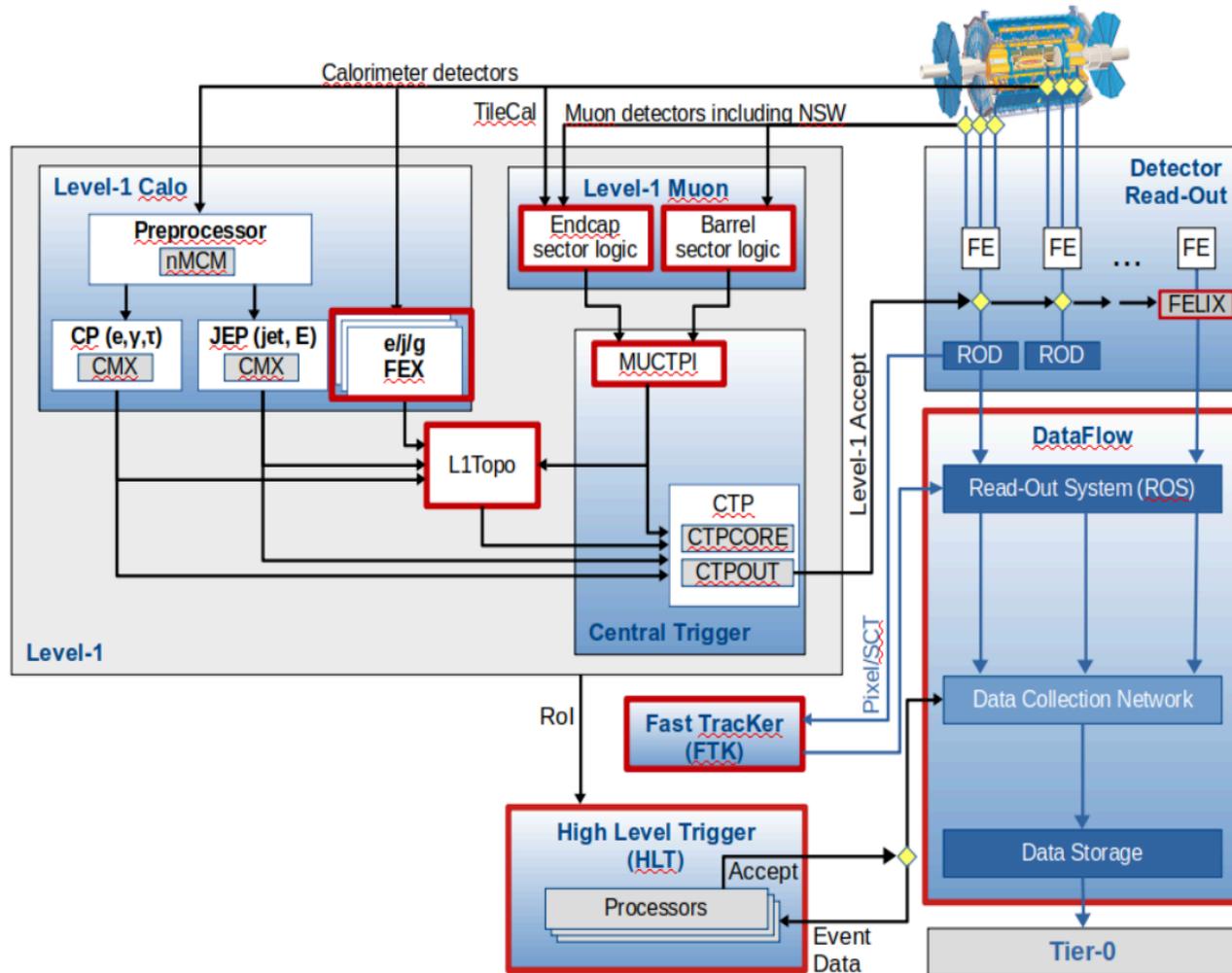
# Trigger $e/\gamma$ Sequence used in Run 2



- L1Calo trigger seeds the RoI
- Fast Reconstruction:
  - $e$  uses [NeuralRinger](#) algorithm for  $E_T > 15$  GeV, other electrons and  $\gamma$  use cut-based selection on shower shape variables.
  - Fast Track information for  $e$ .
- Precision Reconstruction
  - Offline-like.
  - Calorimeter reconstruction uses Sliding Window algorithm unlike Super Cluster used in Offline.
  - Uses Kalman filter as the electron track fitter not Gaussian Sum Filter (GSF).
  - No track or conversion vertices information for  $\gamma$ .
- Final  $e$  candidate is identified using likelihood (LH) based selection and  $\gamma$  candidates by cut based selection.



# An Overview of Run 3 Trigger Upgrades



Major upgrades in many trigger systems (see [Frank Winklmeier's talk](#) for details)

## L1Calo

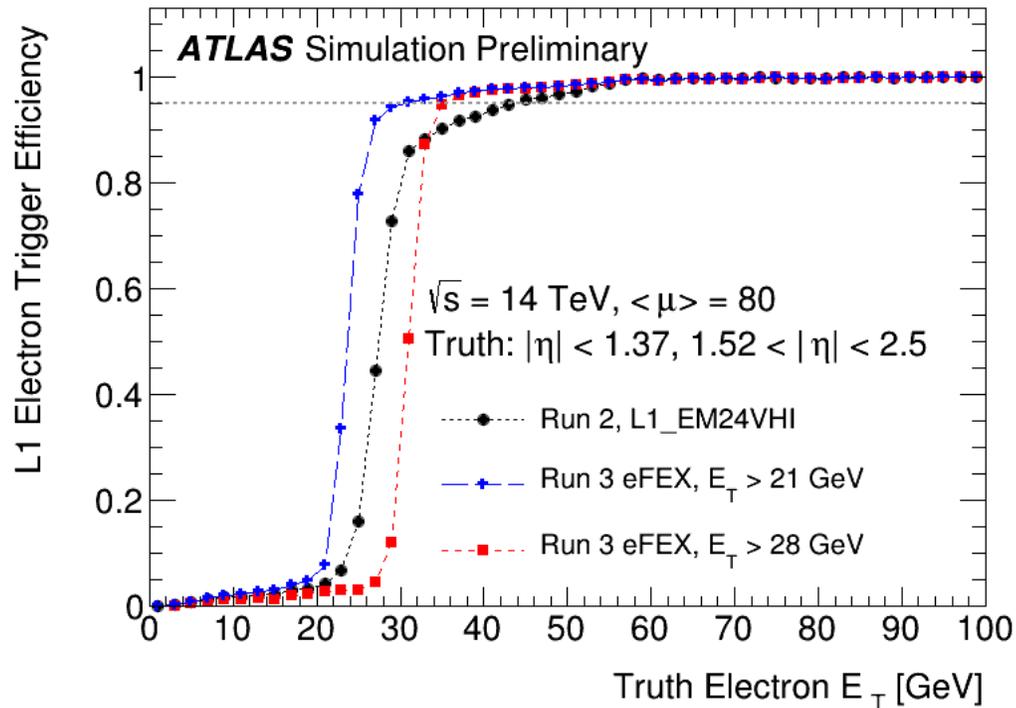
- Updated LAr electronics provides ten-fold finer granularity information to the eFex, which will allow to improve the background rejection.

## HLT

- First major framework (Athena) rewrite since Run-1: use of multi threaded framework known as AthenaMT.

# L1Calo in Run3

The Run-2 system is now the legacy system.



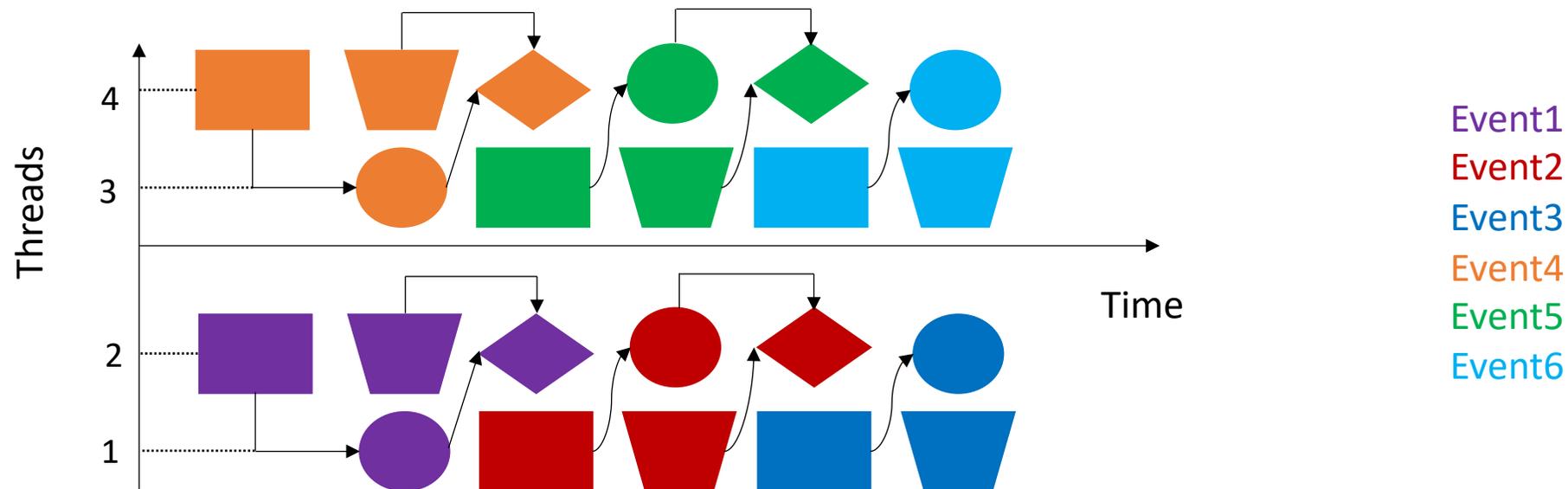
- The legacy system is expected to work in 2021, as a part of the Run-3 commissioning process.
- Possible to achieve sharper trigger turn-on curve using calorimeter's digitized readout with finer granularity.
- Allows to achieve higher background rejection earlier in the trigger sequence, which could free CPU for  $e/\gamma$  reconstruction closer to the offline one.

# Athena Multi Thread (AthenaMT): Dynamic and Parallel approach

Sequential Athena (Run 1 & 2) statically configures algorithm execution-order while AthenaMT allows dynamic and parallel execution of algorithms.

**Dynamic Execution :** Data driven execution; algorithms declare their inputs and outputs. A scheduler finds an algorithm with all its inputs available and runs it as a task

**Parallel Execution :** Use multiple event stores (“slots”). Allows flexible parallelism both within and between events.



Different shapes: different algorithms; Different colors: different events.

# Motivation Behind Migration to AthenaMT

- Expected high increase in luminosity and interactions per bunch crossing for Run 3 and the later Runs.
- AthenaMT will support both offline and HLT use-cases.
- Harmonizing offline and HLT algorithms guarantee the high trigger efficiency and event rejection factors.

## Run 2: Athena single thread environment

### HLT

- Data is analyzed in small Rols.
- Decisions are made from Rols not full event.
- Algorithms don't have direct access to Event Store, instead they get link to data through Trigger Element (TE).

### Offline

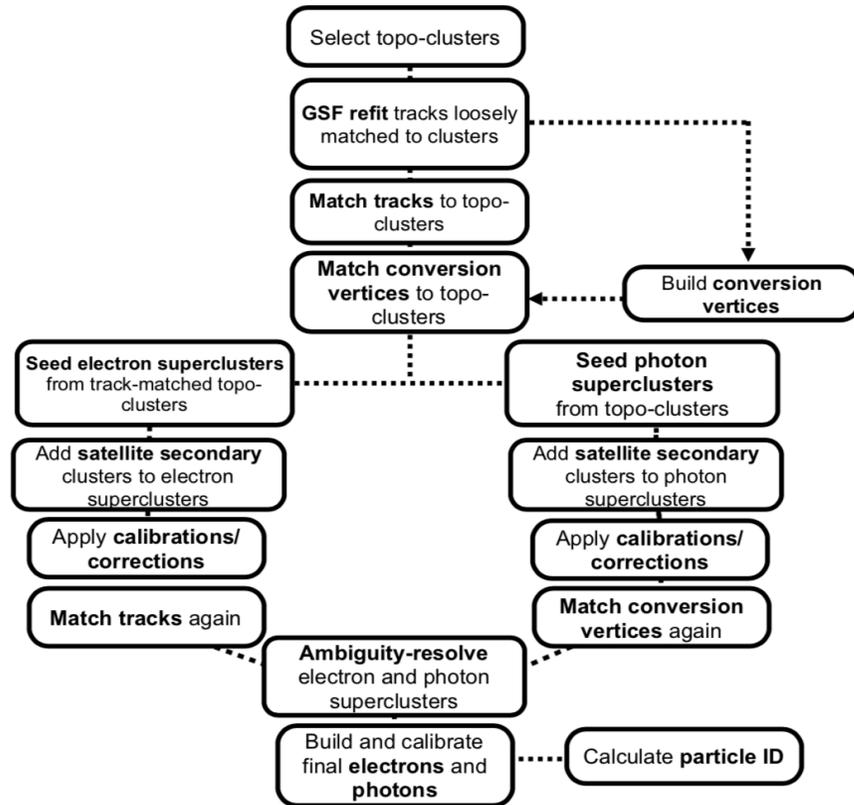
- Data is processed for entire event.
- Algorithms have direct access to event data residing in Event Store.

## Run 3: AthenaMT environment

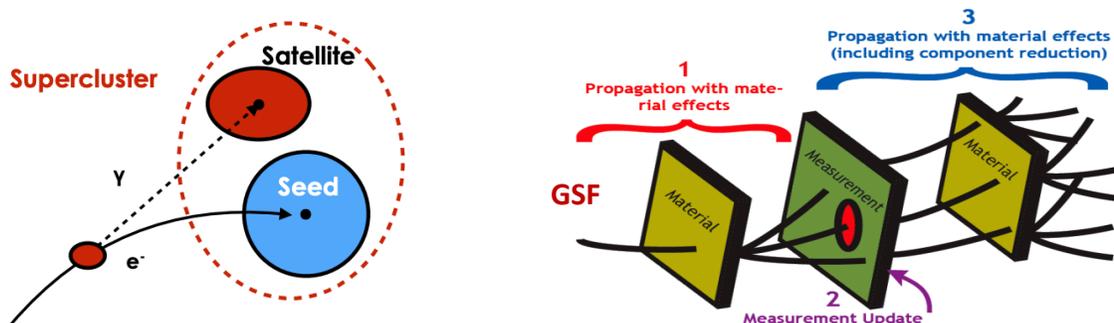
### TE has been replaced by EventView and DataHandles

- **EventView** stores data for one Rol and implements similar interface as used by offline algorithms to access Event Store : in short EventView replicates event store limited to an Rol.
- **DataHandles** are the smart pointers; property of an algorithm, it points to an EventView where the algorithm is running hence the algorithm gets direct access to the data stored in that View.

# e/ $\gamma$ Offline Reconstruction being ported to HLT

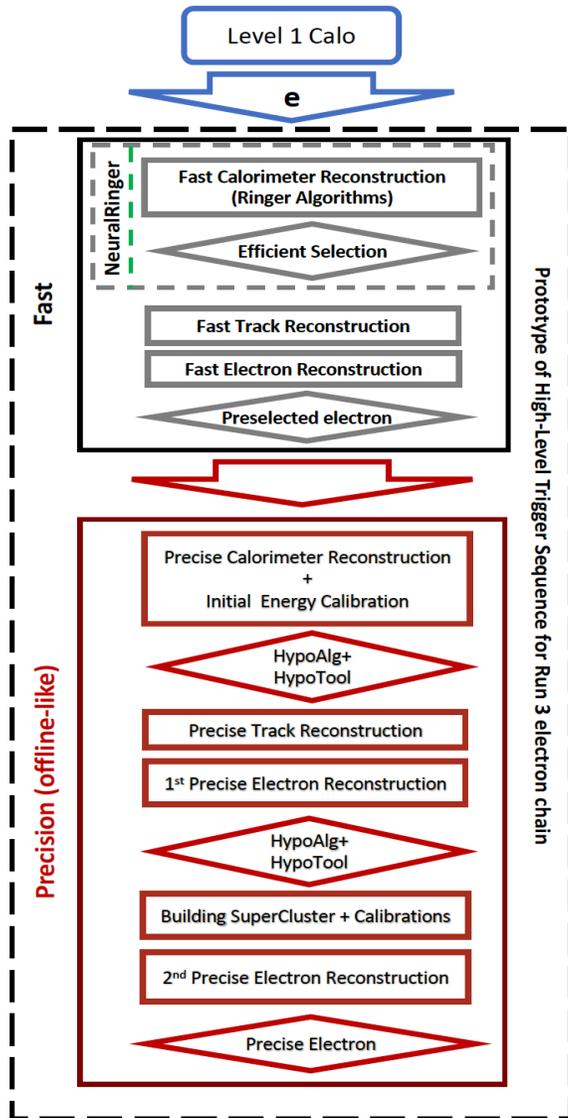


- The algorithm sequence (left) of the Offline e/ $\gamma$  reconstruction
  - GSF refit of tracks and Super Cluster (SC) building at Offline recover radiative loss in e trajectory (bremsstrahlung) and converted  $\gamma$ .
  - A similar sequence is being ported as Precision step at HLT.
- Some terminology will be used for the HLT e/ $\gamma$  sequence to avoid the details:
  - **1<sup>st</sup> Precise e/ $\gamma$  reconstruction** = Select topo-cluster + Match Tracks + Match Vertices
  - **2<sup>nd</sup> Precise e/ $\gamma$  reconstruction** = Building Super cluster + Match Tracks + Match Vertices



\*Details of GSF and SC are in the backup slides.

# Run 3 Plan for Trigger $e/\gamma$



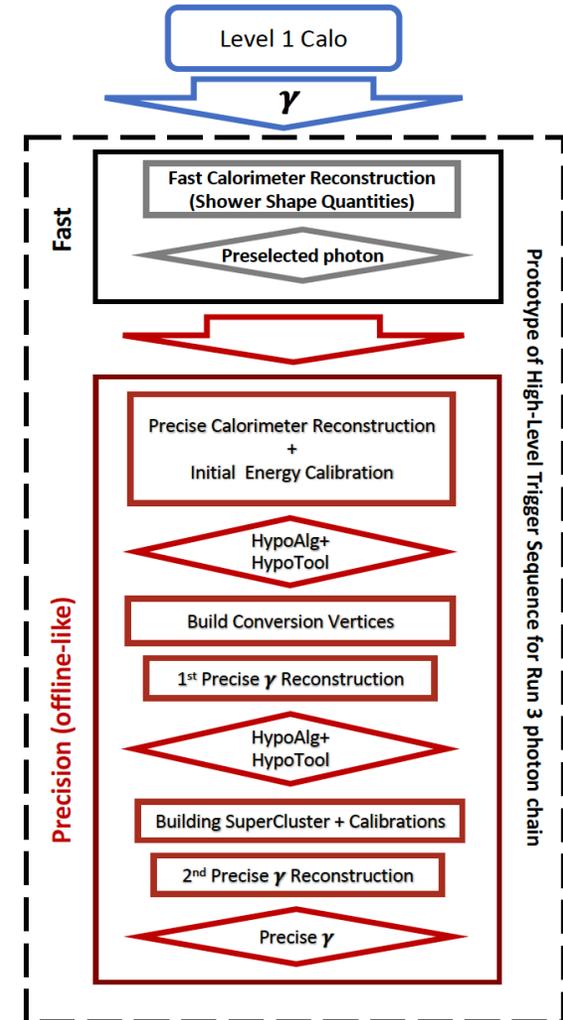
A plan of electron chain (left) and photon chain (right) for Run 3.

## Fast Step

- Trigger-specific or special configurations of offline algorithms
- Guided by L1 Rols

## Precision (offline-like)

- By using AthenaMT interfaces (DataHandles, EventView) offline algorithms will be ported directly.
- Offline algorithms don't deal with selection and rejection of events. Therefore new hypoAlgs and hypoTools will be implemented.
- Also some of the offline algorithms will need modification to serve trigger specific requirements, hence it would be just to call them “**offline-like**”.

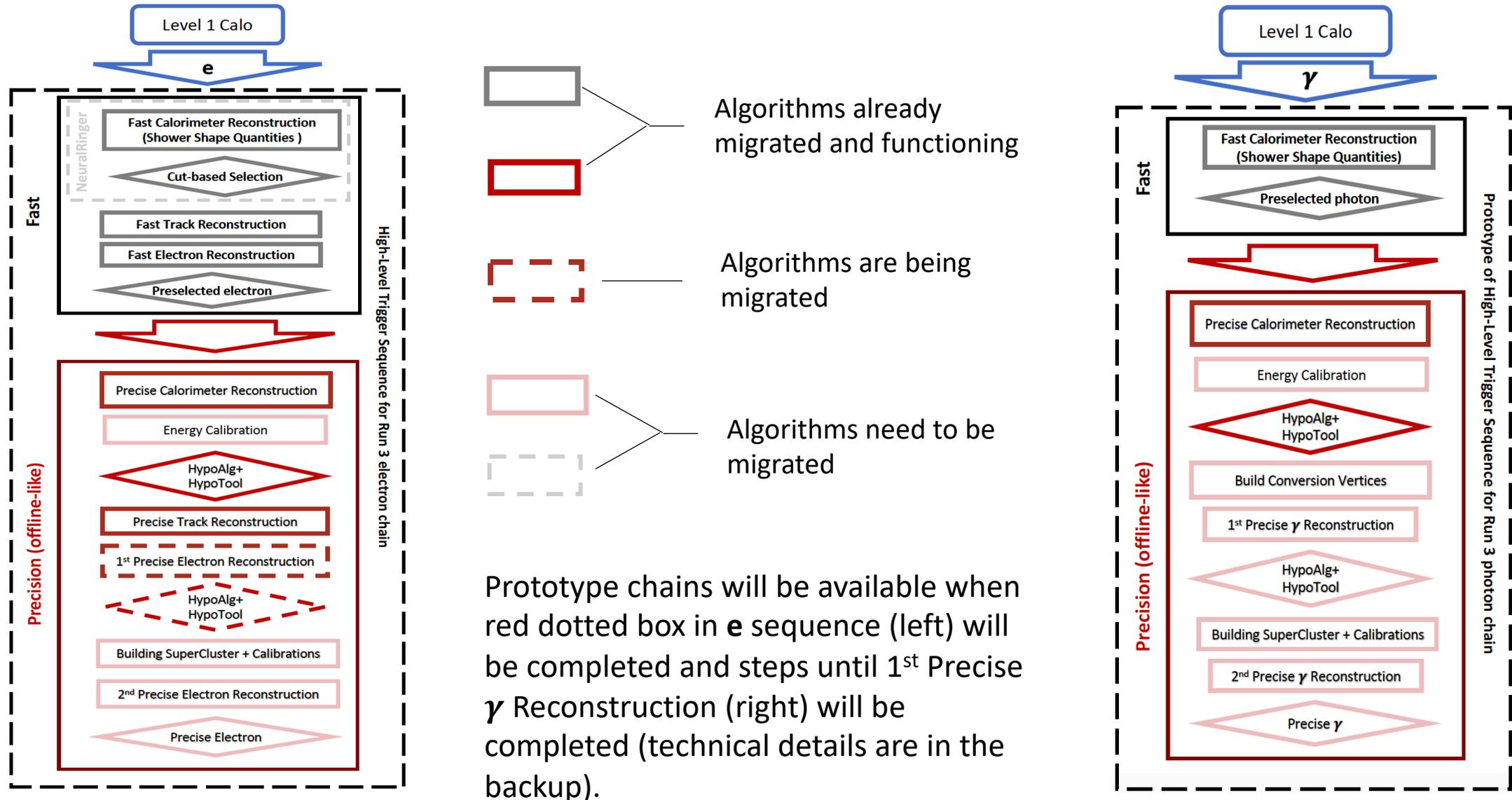


# Status of Egamma Reconstruction at AthenaMT

Stage		e	$\gamma$	Reconstruction	Comments
Fast	Calo	✓	✓	Reconstructs Fast CaloClusters for e and $\gamma$ computing shower shape variables	Migrated since last year. NeuralRinger algorithm will be implemented for e with $E_T > 15$ GeV.
	Track	✓	N/A	Reconstructs Fast Tracks and matches those with Fast CaloClusters	Migrated since last year.
Precision	Calo	✓	✓	Creates Precision CaloClusters, uses a loose $E_T$ cut selection, not all offline calibrations are applied yet.	Migrated and fully functioning
	Track	✓*	N/A	For e, Precision Track reconstruction algorithm and electron candidate builder algorithm matching Precision Tracks to Precision CaloClusters.	* Some compatibility issues (Offline to HLT) being corrected.

- **Prototype-chains** will be built first (aiming for the 1st Run 3 trigger validation round in the second half of 2019) for both electron and photon which will have following Precision sequence with existing Fast step.
  - Electron: Fast + PrecisionCalo + PrecisionTrack + Electron Candidate Builder + Selection
  - Photon: Fast + PrecisionCalo + Photon Candidate Builder + Selection

# Migration of Trigger Egamma Chain in Progress



Prototype chains will be available when red dotted box in  $e$  sequence (left) will be completed and steps until 1<sup>st</sup> Precise  $\gamma$  Reconstruction (right) will be completed (technical details are in the backup).

# Outlook and Plans

## **Default Plan:**

Once the prototype chains are ready for both Electron and Photon we will implement full Offline sequences as precision steps.

- GSF.
- SuperCluster Builder.
- All Offline Calibration and Corrections.

Investigation is needed at each step. If there is issue with CPU/timing we will work on performance optimization or special configuration which leads to following sub-plans.

## **Plan B:**

- No GSF but still keep SuperCluster with some modification to make it less CPU expensive.

## **Plan C:**

- Use Run-2-like identification at HLT: Sliding window correction and No GSF.

# Summary

- Major upgrades in many trigger systems to cope up with Run 3 requirements.
- L1Calo will have new trigger electronics which have increased ten-fold its granularity and improved background rejection.
- Sequential Athena framework will be replaced by multi threaded AthenaMT.
- HLT algorithms will have parallel and data driven execution.
- Use of Offline algorithms at HLT will provide robust reconstruction of  $e/\gamma$ .
- Offline  $e/\gamma$  algorithms being ported to HLT as Precision step.
- Prototype chains for Trigger  $e/\gamma$  will be built for the 1<sup>st</sup> round of Run 3 validation.
- Investigation on CPU cycle will be done for each offline steps ported to HLT and modification will be implemented if required.

# Backup

# Offline vs HLT reconstruction

## **Offline:**

- Refers to reconstruction algorithms.
- Runs after the data are recorded to tape.
- Uses information of entire event.
- Reconstruction process is very robust and precise, codes are written with physics performance in mind.
- CPU expenses and timing are secondary concern, takes  $> 10$  s per event.

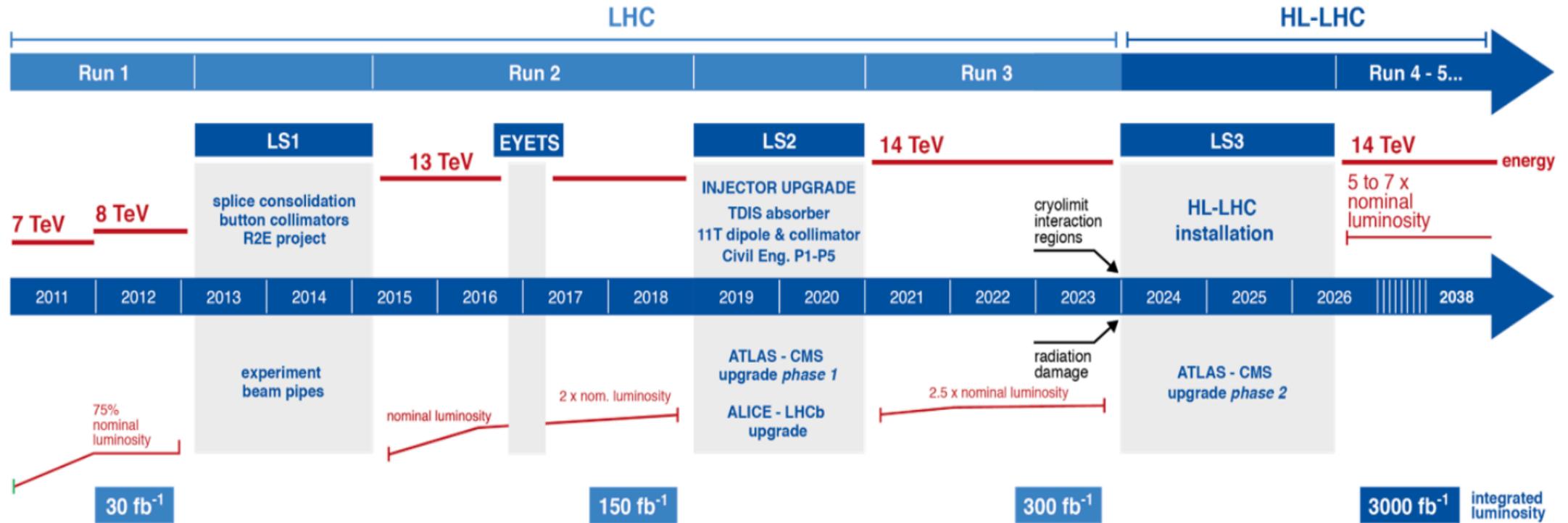
## **HLT:**

- These reconstructions are part of data taking process.
- CPU/timing is of utmost importance here; HLT needs to reconstruct and decide on an event within a few seconds.
- Offline algorithms are carefully optimized and configured to be balanced against CPU cost.

## Issues:

Due to compromise made in reconstruction at HLT could create situation where object reconstructed in offline is missed by HLT or vice versa. Thus makes it uncertain how much physics is actually being recorded.

# Run 1, Run 2, Run 3, ...



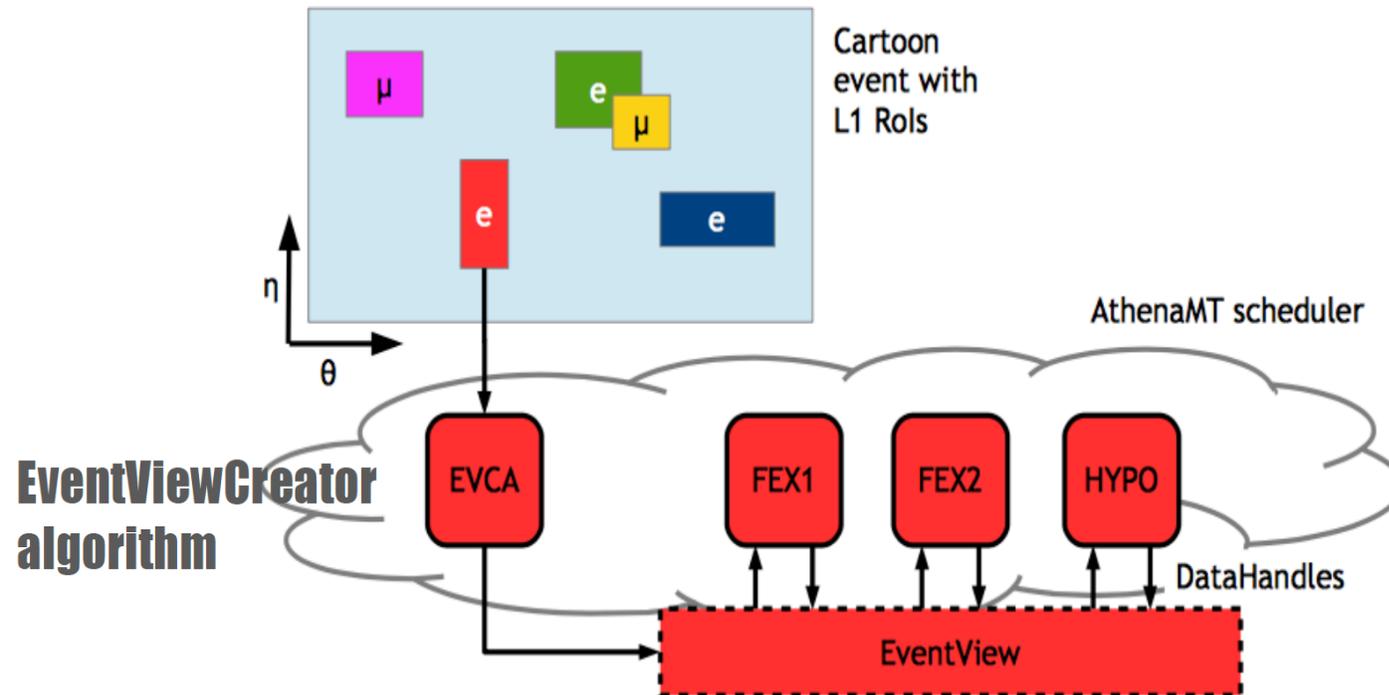
Plan for LHC/HL-LHC

# Structural Changes of TriggerSoftware Framework Run2 -> Run3

who does:	Run2	Run3
scheduling	TrigSteer specific algorithm	Gaudi
caching	TrigNavigation	Gaudi scheduler
contain trigger decision	TriggerElement	Decision (typedef TrigComposite)
navigation	TrigNavigation	Decision->ElementLink(toParent)
regional reconstruction	passing TriggerElement	creating EventView
reconstructed info linked to decision	TriggerElement → feature	Decision → ElementLink(toFeature)
reconstruction	HLT::FexAlg	InputMaker + AthAlgorithm
hypothesis algorithm	HLT::HypoAlg	HypoBase
hypo per chain step	different instantiations of HLT::HypoAlg	different HypoTools attached to same HypoAlg

# EventView and DataHandles

[Link](#) to the AthenaMT paper for detailed descriptions.



Above cartoon found as nice simplification of complex c++ technicalities, more such description can be found [here](#).

# Technical Details of ProtoType-TriggerEgammaChain

Fast Step		
Fast Calo*	Reconstruction	Selection Hypothesis
	<a href="#">FastCalorimeter-Reconstruction</a> algorithm reconstructs using L1 trigger information; produces Fast-CalorimeterClusters as output.	<a href="#">HypoAlgorithm</a> applies cut based selection (on shower shape and $E_T$ ) on the reconstructed clusters using <a href="#">HypoTool</a> .
Fast Track (electron only)	<a href="#">FastTrackFinder</a> reconstructs Fast Track and a <a href="#">FEX</a> algorithm matches tracks to Fast-CalorimeterClusters and builds Fast-Electron candidate.	A <a href="#">HypoAlgorithm</a> applies cuts on Fast-Electrons based on the transverse momentum ( $p_T$ ) of its tracks, track to cluster eta-phi difference etc. using <a href="#">HypoTool</a> .
Precision Step		
Precision Calo	A series of Precision calorimeter reconstruction algorithms ( <a href="#">CaloCellMaker</a> + <a href="#">CaloClusterMaker</a> ) create calocluster outputs. Not all offline calibrations are applied yet	<a href="#">HypoAlgorithm</a> applies an $E_T$ threshold cut** on output Caloclusters using <a href="#">HypoTool</a> .
Precision Track*** (electron only)	A series of algorithms, <a href="#">PrecisionTrackReconstruction</a> + <a href="#">TrackToClusterMatch</a> + <a href="#">PrecisionElectronBuilder</a> create 1 <sup>st</sup> Precision-Electron candidate	<a href="#">HypoAlgorithm</a> applies cut on track- $p_T$ of Precision-Electron candidate using <a href="#">HypoTool</a>

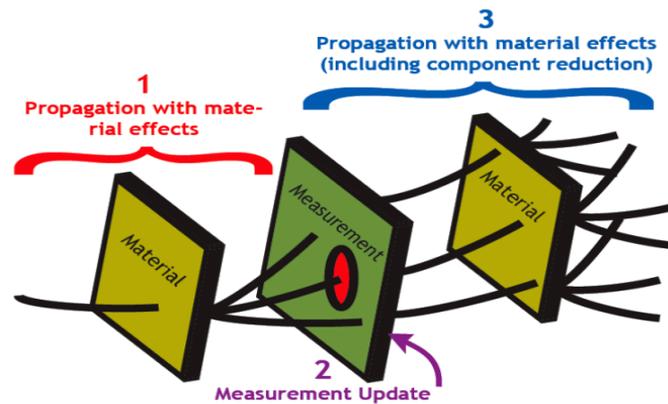
\* Currently Fast Calo is using similar reconstruction methods for both electron and photon. Electron will be using NeuralRinger for Fast Calo reconstruction in future.

\*\* Cut based selection of Precision step will be replaced by Likelihood (LH) based selection.

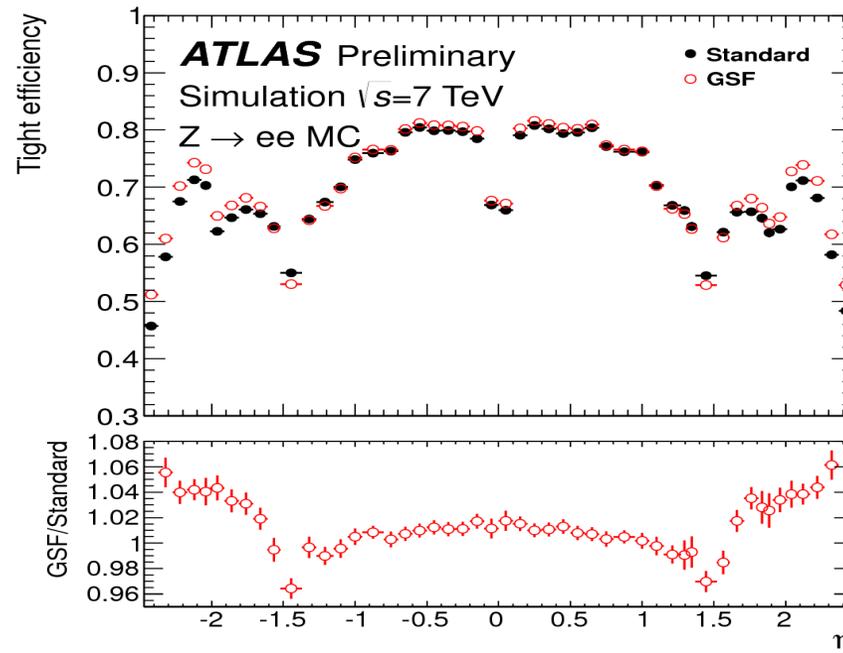
\*\*\* The Precision Track is being ported and a prototype chain for electron (Fast+Precision) will soon be available.

# Gaussian Sum Filter (GSF)

Generalization of the Kalman filter, splitting experimental noise into Gaussian components using Kalman filter to process each one (introduced offline in 2012). [Link](#) to the GSF paper.



uses a sequence of extrapolation and measurement-update steps



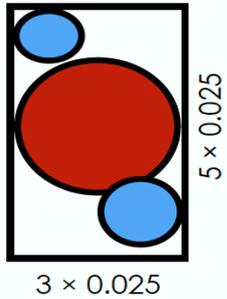
This is a tight electron identification efficiency with respect to Monte-Carlo truth information as a function of electron  $\eta$ . Electrons refitted with GSF show an improvement in the electron identification efficiency of over 5% at high  $|\eta|$ .

# SuperCluster (SC)

[Link](#) to SC paper

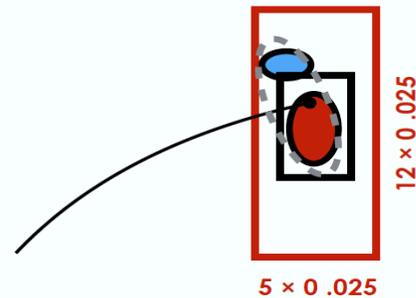
## All $e^\pm, \gamma$ :

Add all clusters within  $3 \times 5$  window around seed cluster.



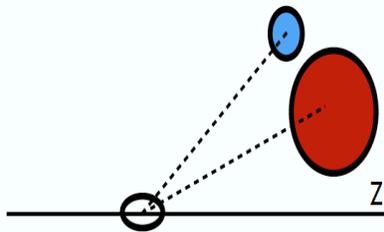
## Electrons only:

Seed, secondary cluster **match the same track.**



## Converted photons only:

Add topo-clusters that have the **same conversion vertex** matched as the seed cluster.



Add topo-clusters with **a track match** that is **part of the conversion vertex** matched to the seed cluster.

