The ATLAS Detector
- Triggering -

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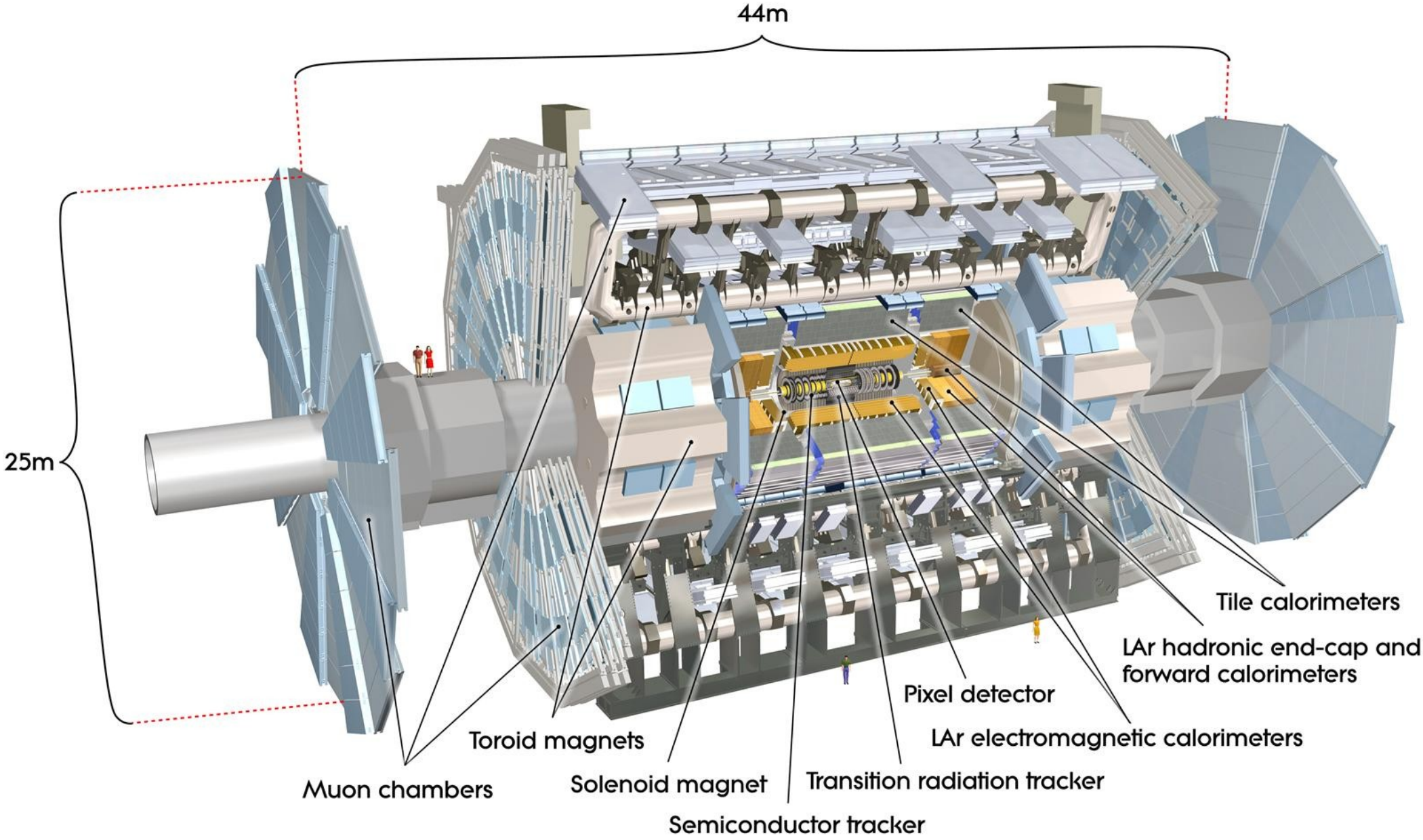
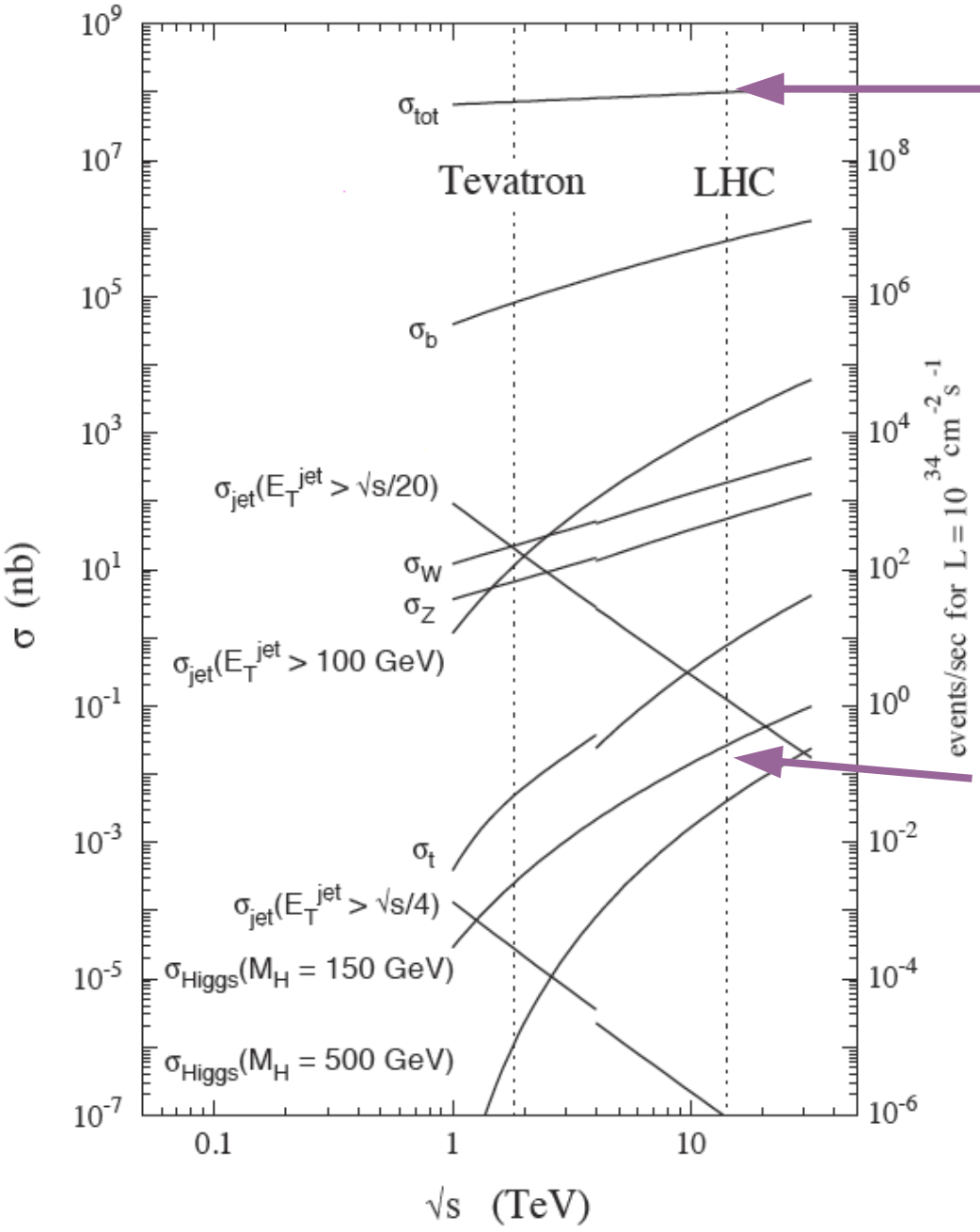
Outline:
1st lecture: The Detector
2nd lecture: The Trigger
3rd lecture: The Analysis (mine)

Reminder


44m
25m
Tile calorimeters
LAr hadronic end-cap and forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Transition radiation tracker
Muon chambers
Solenoid magnet
Semiconductor tracker

Production Probability



All SM processes combied:

10^9 events / sec

Size ~ 1 Mbyte / event

~ 10^{10}

Need efficient rate reduction

"Interesting" / new physics:

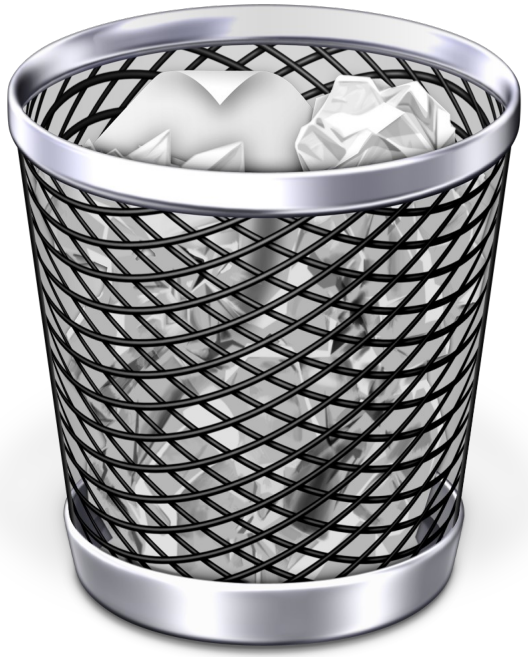
10 events / min

→ need to decide what is worth looking at!

Trigger

“A trigger is a mechanism that actuates the firing of firearms” - Wikipedia

- Decides which events will be read out and which



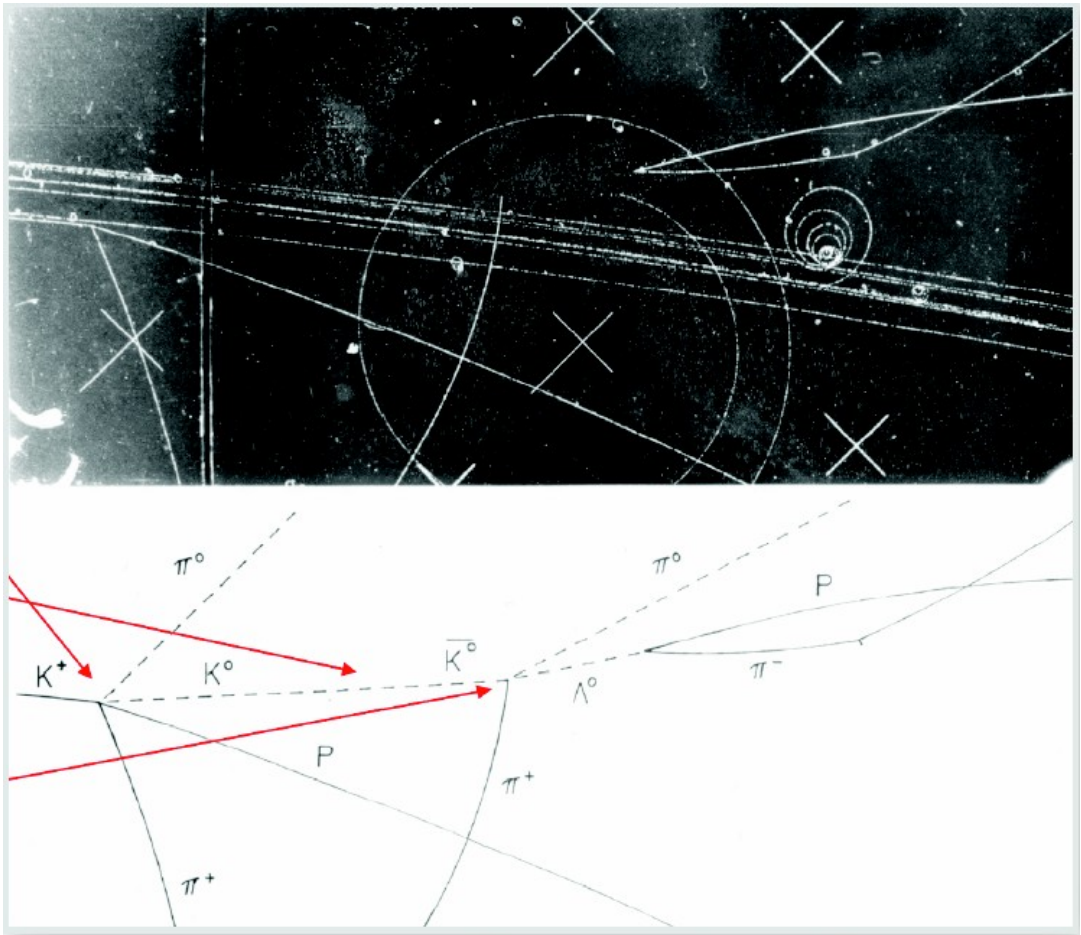
Selection necessary as

- cannot read out all events
  - limited storage
  - limited bandwidth
- new physics events much rarer than e.g. di-jet production

Trigger - History

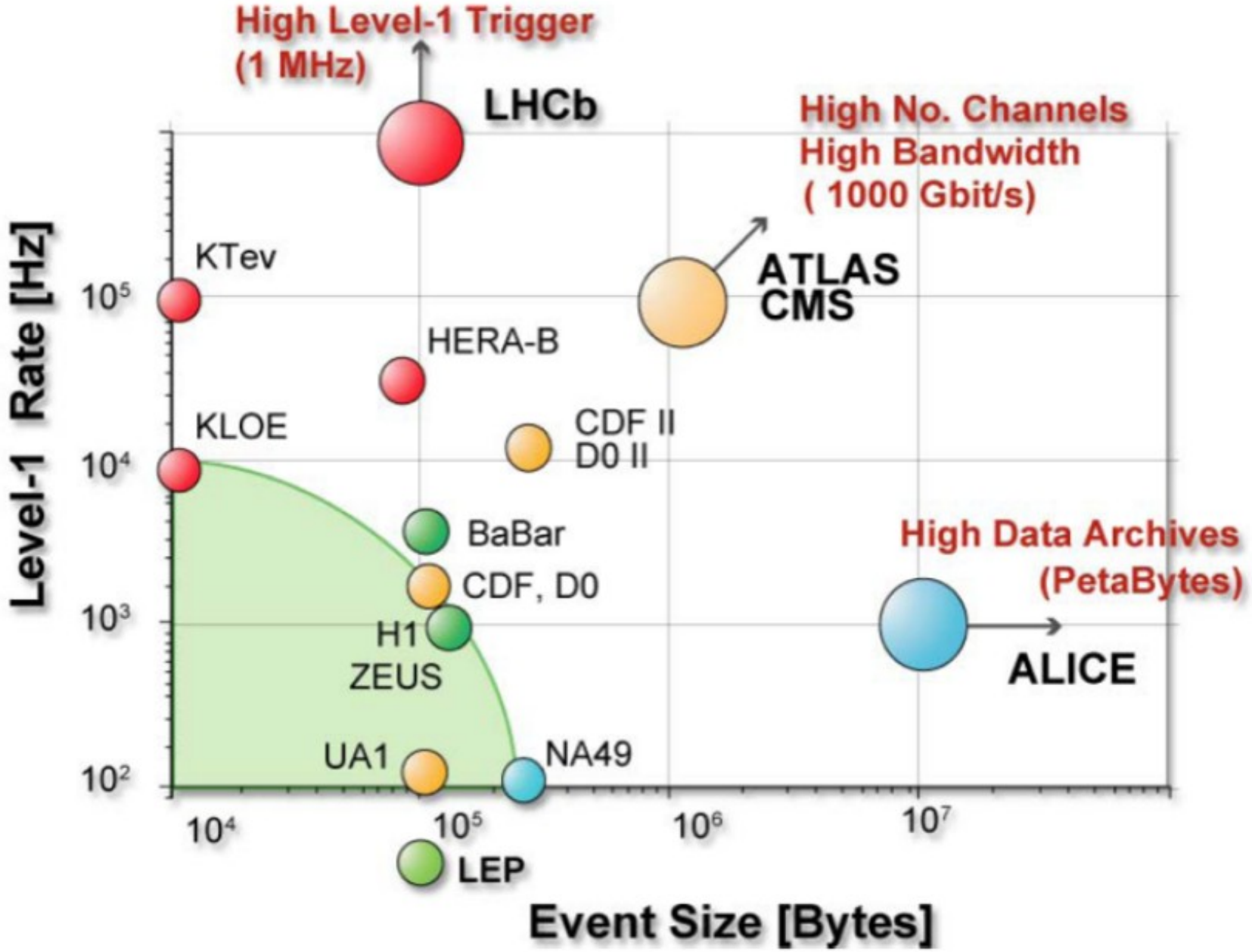
Bubble Chambers, Cloud Chambers, etc:

- Each expansion was photographed - corresponds to data acquisition (DAQ)
- Trigger was electronic signal to release camera
- slow operation rate
- only processes with high cross-section observable

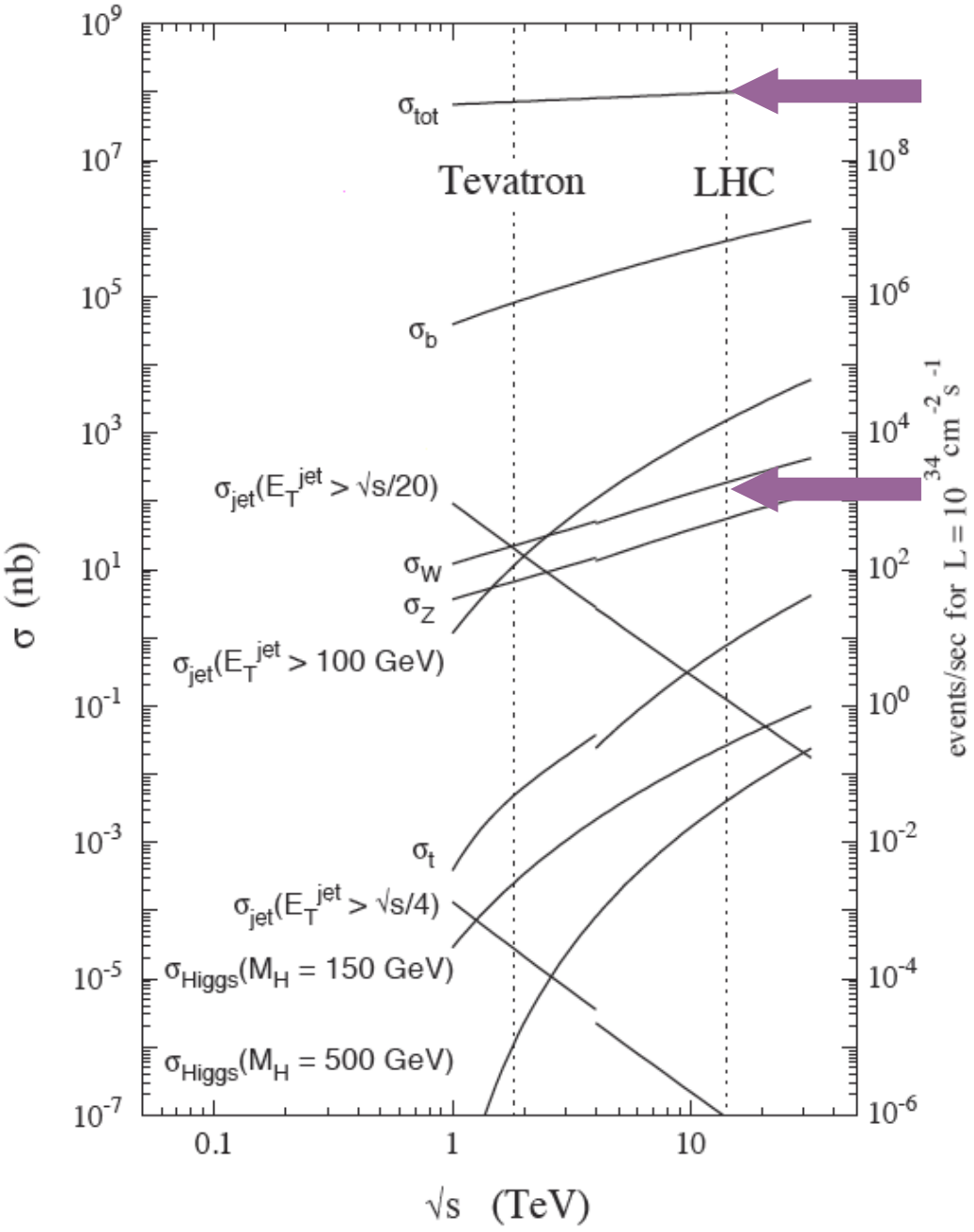


K^0 mixing event, Graham Thompson, 1971

Trigger - Requirements



Trigger - Requirements



Interaction rate ~ 1 GHz

must be reduced to

mass storage rate ~ 500 Hz

by trigger → reduction by 10^7

Trigger must be highly selective but remain efficient for rare events

Trigger - Implementation

Big task → share work: Define two trigger levels:

- Level-1: reject some events to gain time

  needs to be fast, short latency, high efficiency, low bandwidth

  ATLAS uses Muon and Calorimeter information

- High level trigger: reject most events to have efficient storage, etc.

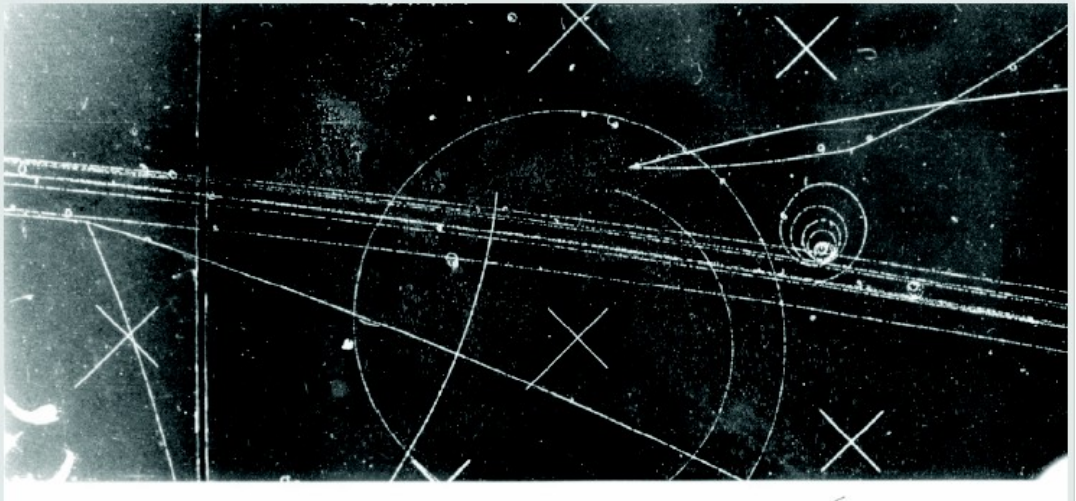
  Fine grained selection and improved rejection

  ATLAS uses all detector systems, but divides HLT into Level-2 Trigger and Event Filter

Large events size requires powerful network and computing resources

Trigger - History

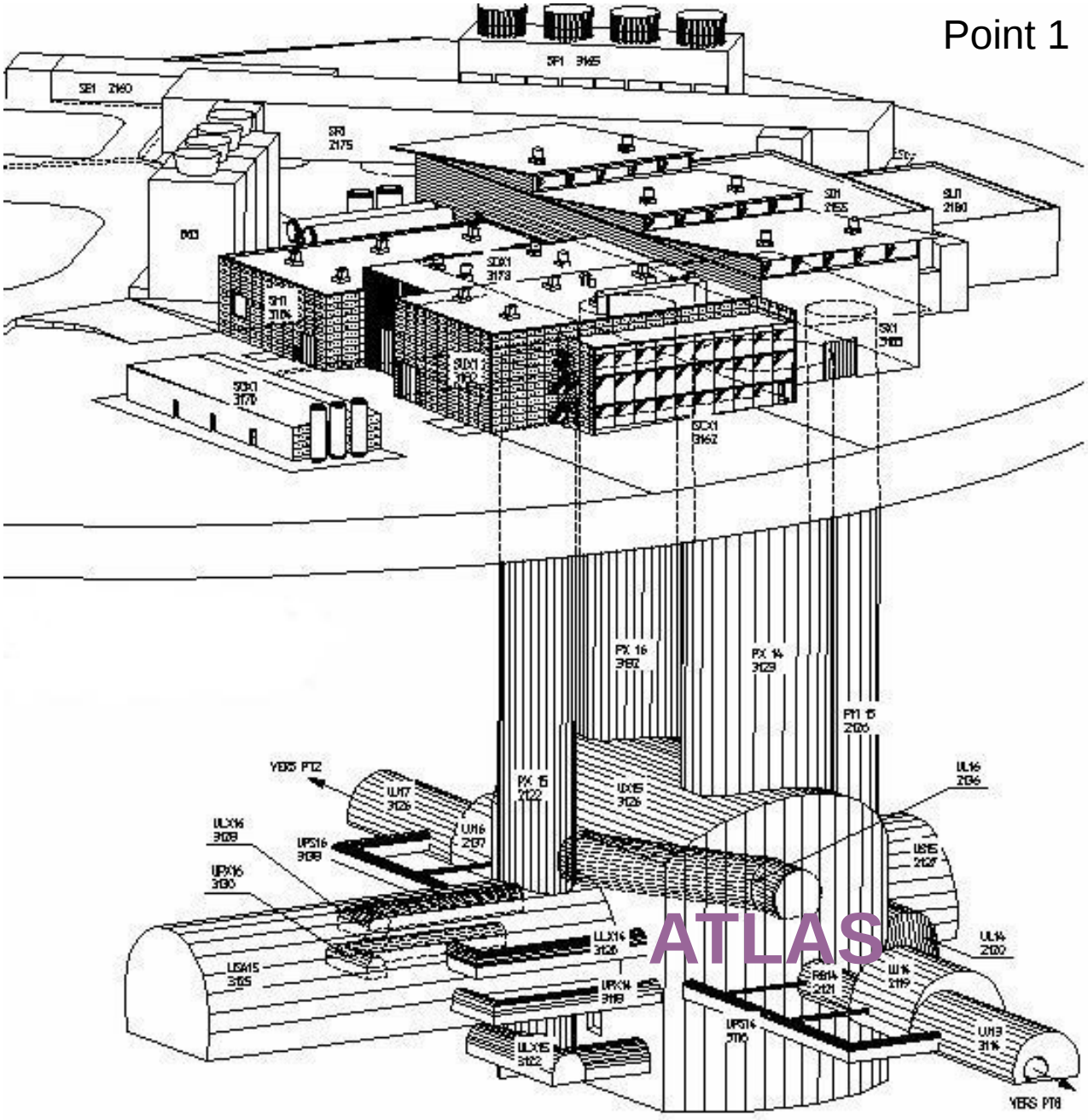
Bubble Chambers, Cloud Chambers, etc:



- First level trigger was electronic signal to release camera
- High level trigger consisted of human scanning teams

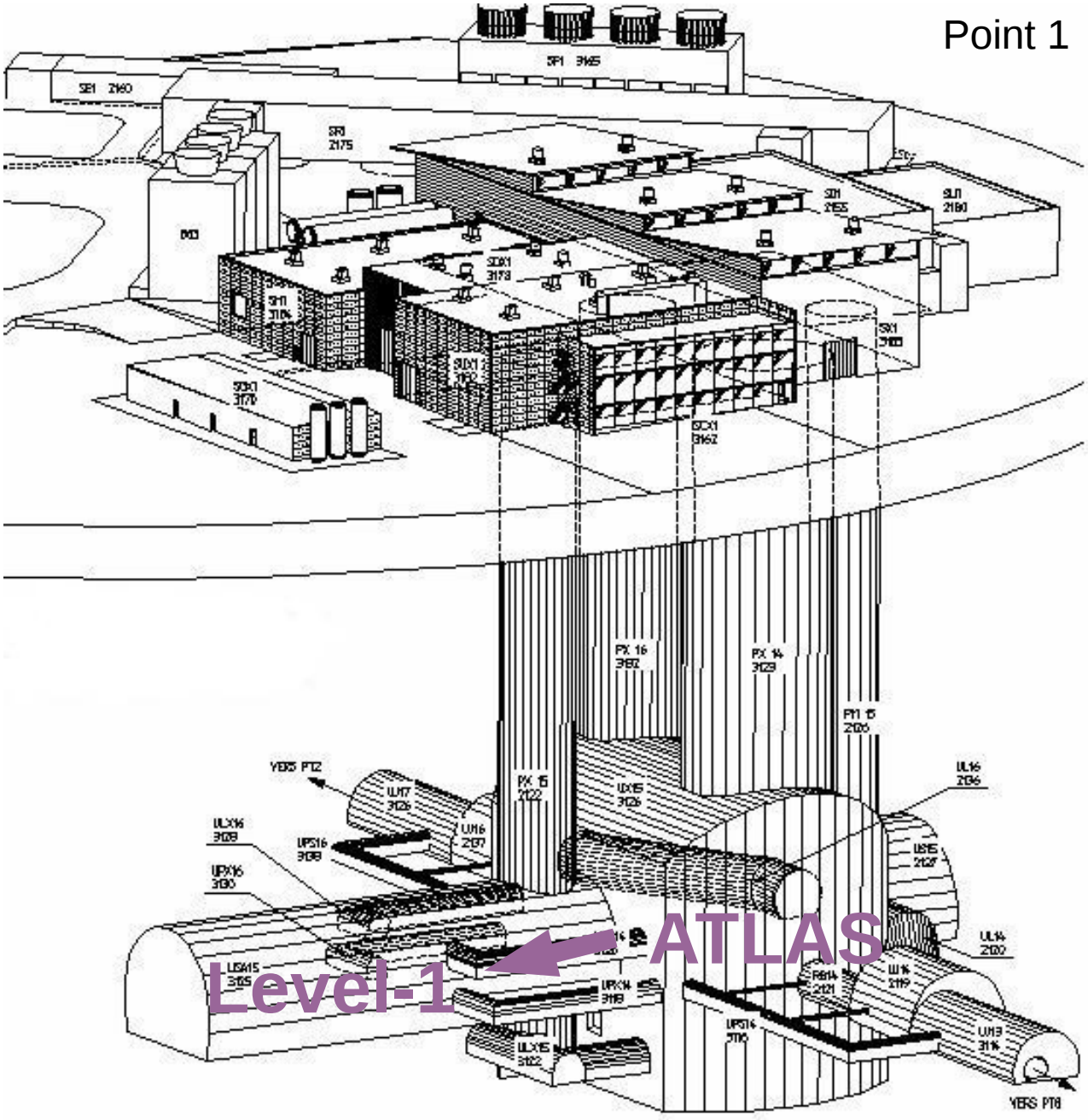
Data in ATLAS

- t = 0: Collision



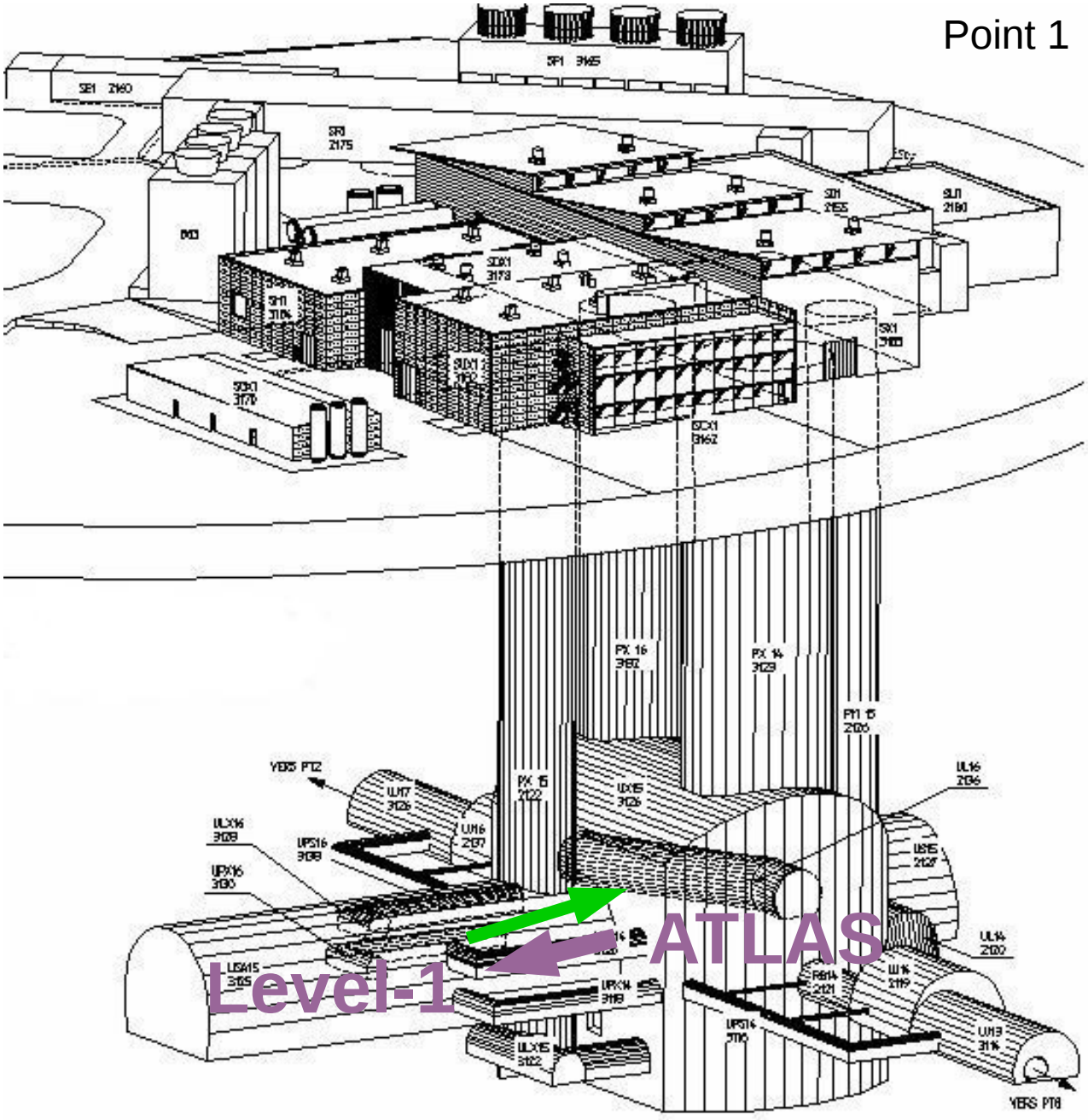
Data in ATLAS

- t = 0: Collision
- t < 2.5 µs: Level-1



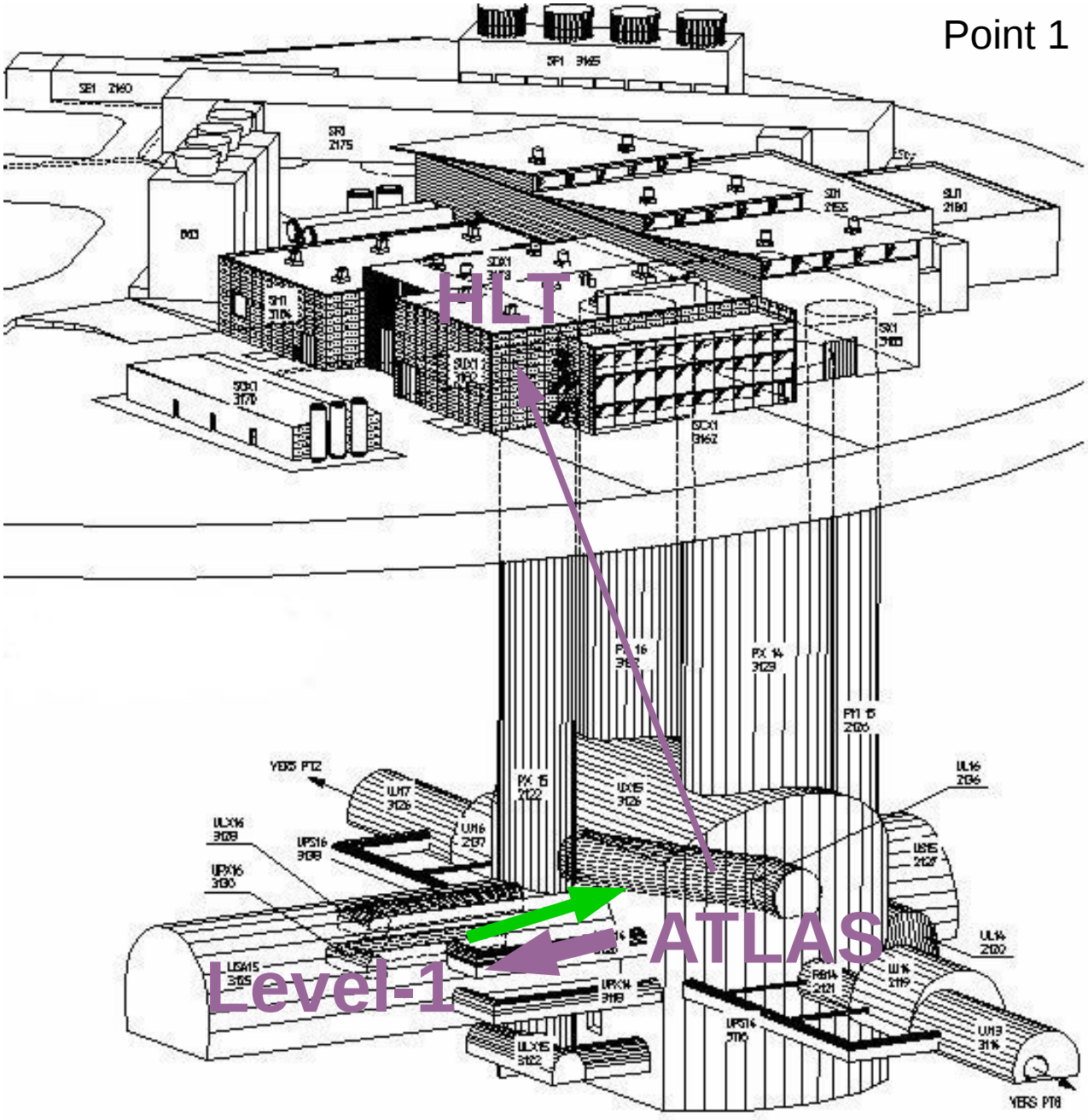
Data in ATLAS

- t = 0: Collision
- t < 2.5 µs: Level-1
- t ~ 2.5 µs: Central Trigger Processor



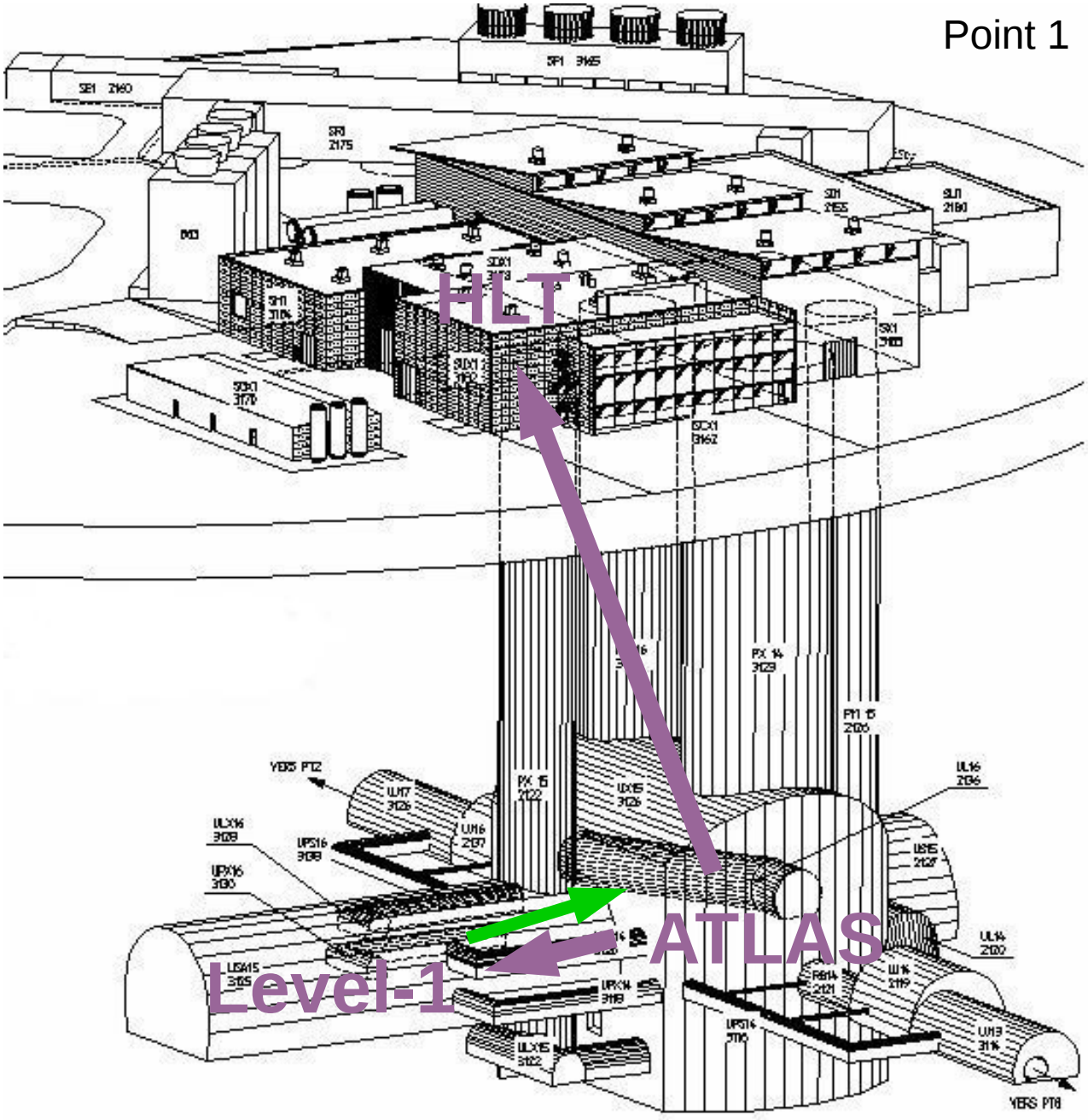
Data in ATLAS

- t = 0: Collision
- t < 2.5 µs: Level-1
- t ~ 2.5 µs: Central Trigger Processor
- t < 40 ms: Level-2



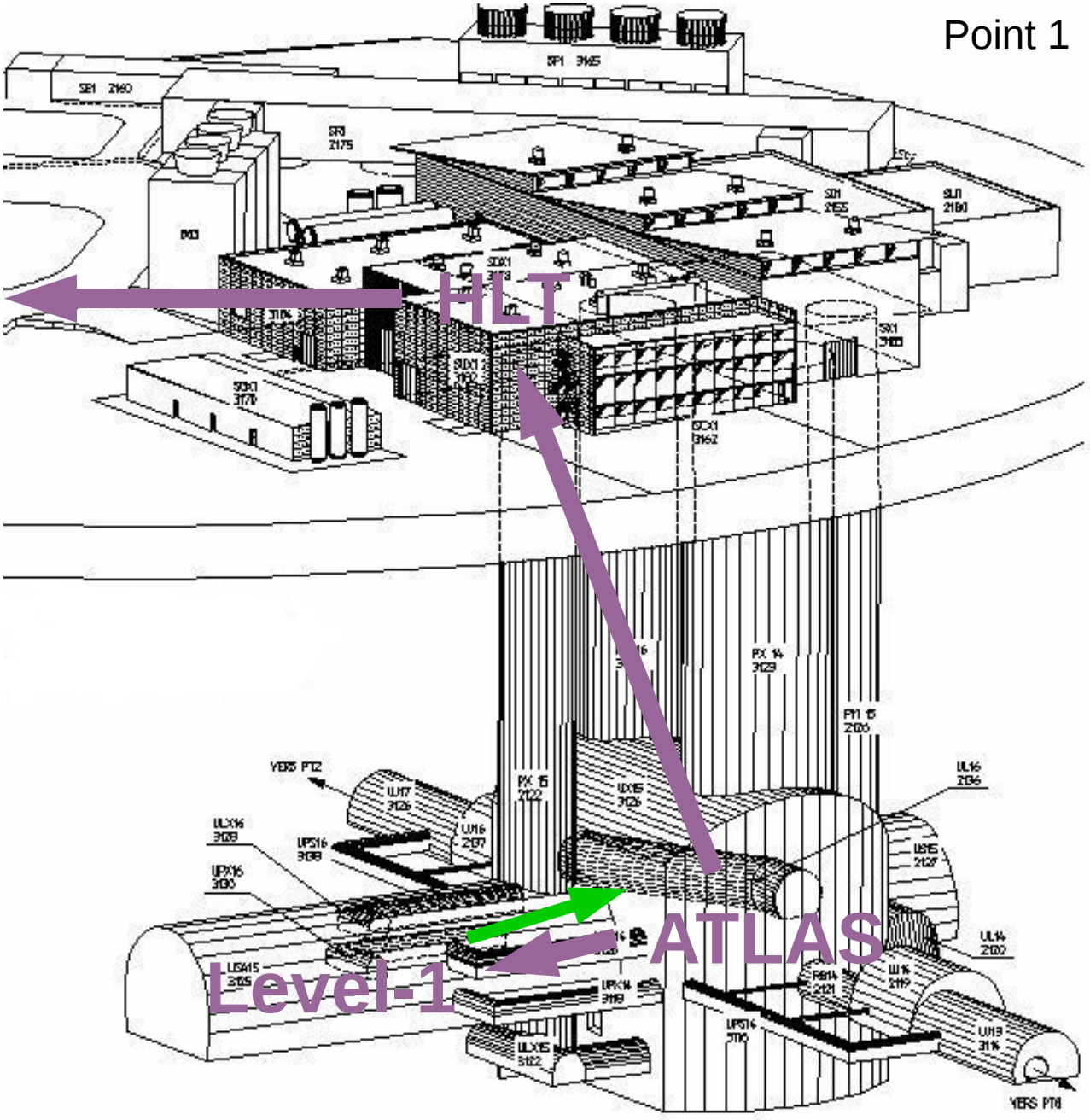
Data in ATLAS

- t = 0: Collision
- t < 2.5 µs: Level-1
- t ~ 2.5 µs: Central Trigger Processor
- t < 40 ms: Level-2
- t < 4 s: Event filter



Data in ATLAS

- t = 0: Collision
- t < 2.5 µs: Level-1
- t ~ 2.5 µs: Central Trigger Processor
- t < 40 ms: Level-2
- t < 4 s: Event filter
- t > 4 s: Tier 0 (at CERN main cite)



Data in ATLAS

- t = 0: Collision – particles arrive at detector

  electronic signals are measured
- t < 2.5 µs: Level-1 – L1 Calo and L1 Muon investigate

  data stored on front-end electronics
- t ~ 2.5 µs: Central Trigger Processor

  – Computes Level-1 decission

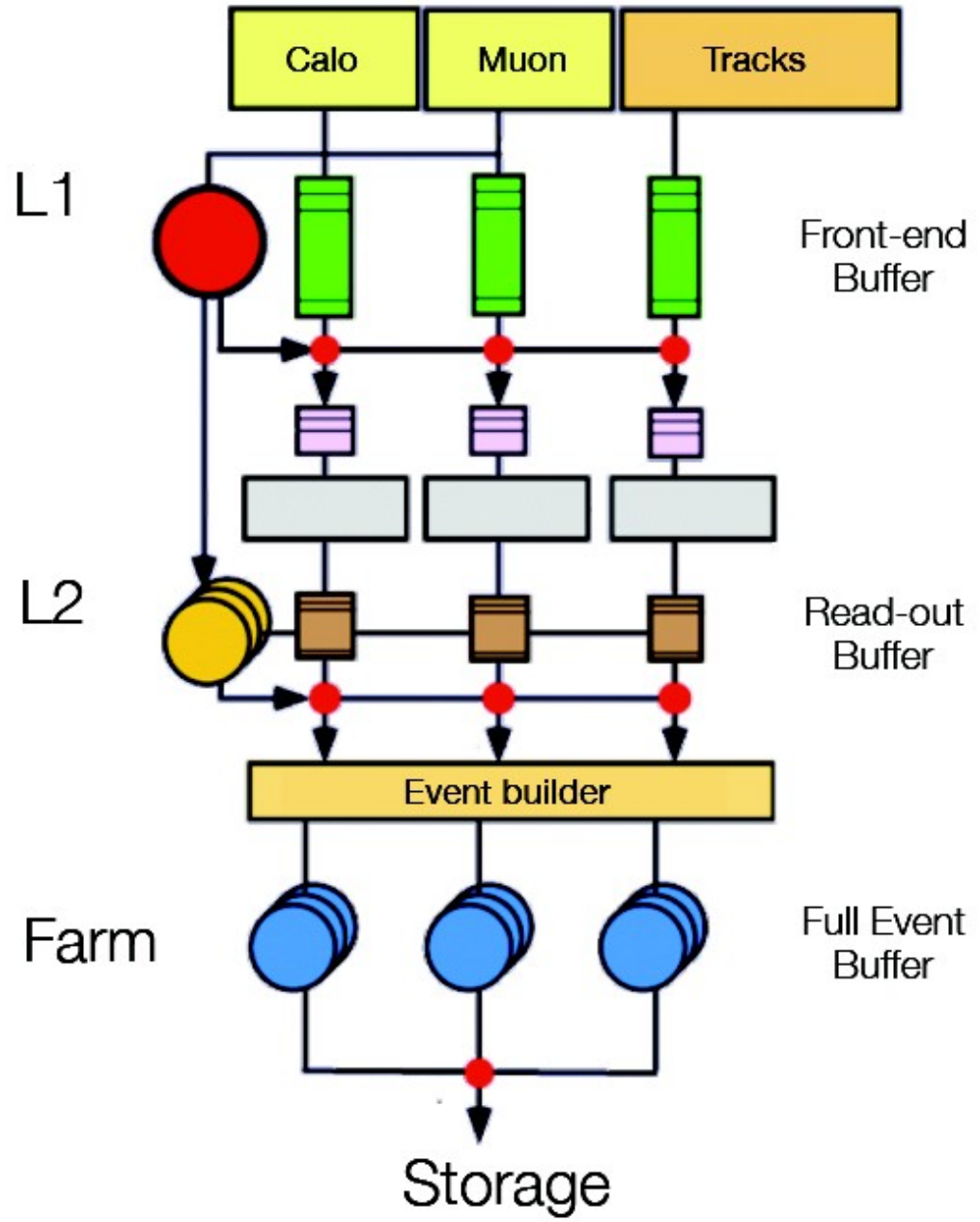
  if accepted, data transferred to read-out buffers
- t < 40 ms: Level-2 – Refines L1 decision using only part of detector

  Subset of data transferred to HLT CPUs
- t < 4 s: Event filter – Final decision using full detector information

  full data tranfered to CPUs
- t > 4 s: Tier 0 (at CERN main cite)

  – All data persistently available, ready for reprocessing / data analysis

Triggering in ATLAS



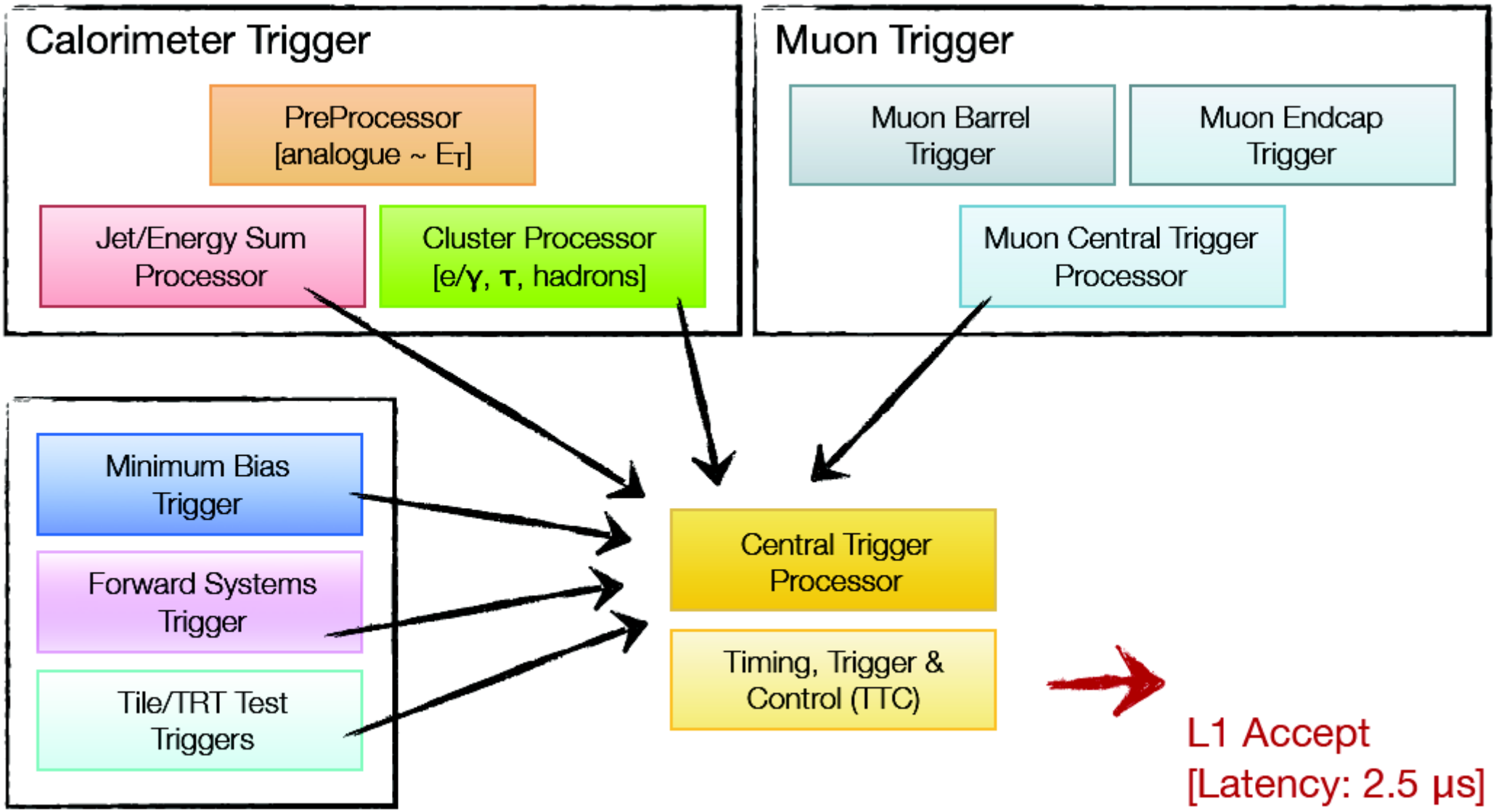
40 MHz

LEVEL-1 TRIGGER

- Hardware-Trigger [FPGAs & ASICs]
- Information from calorimeters & muon systems; low granularity
- 2 µs latency [2.5 µs pipelines]

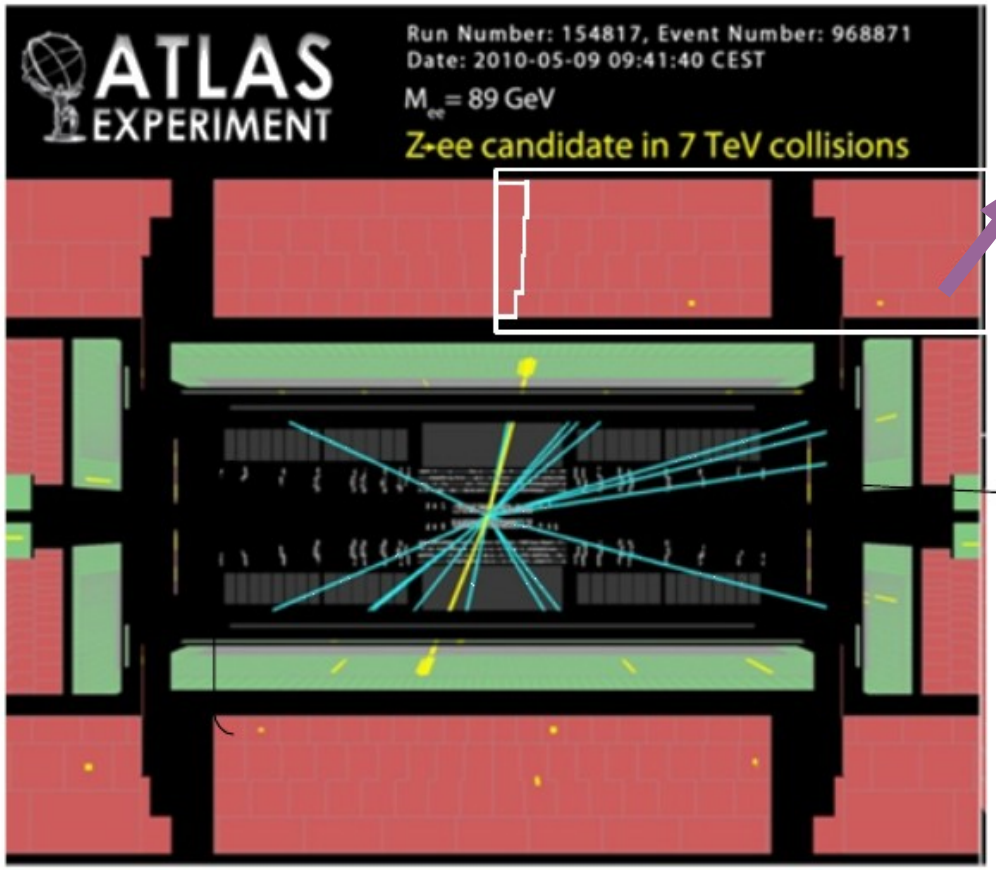
~75 kHz

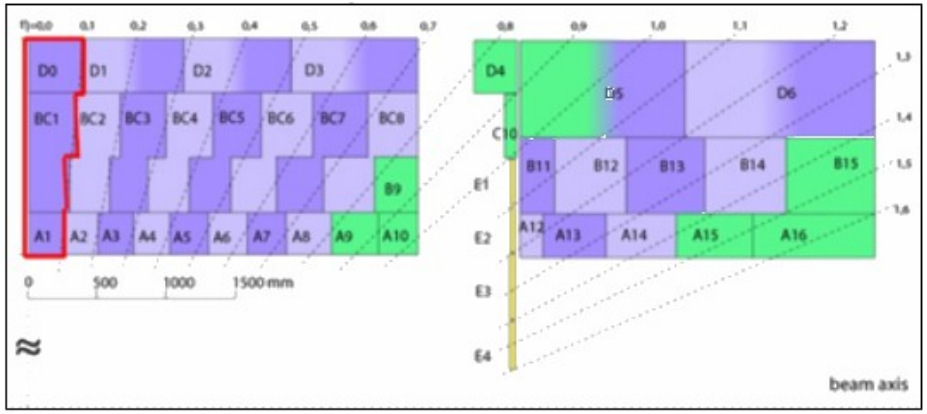
Level-1 Trigger

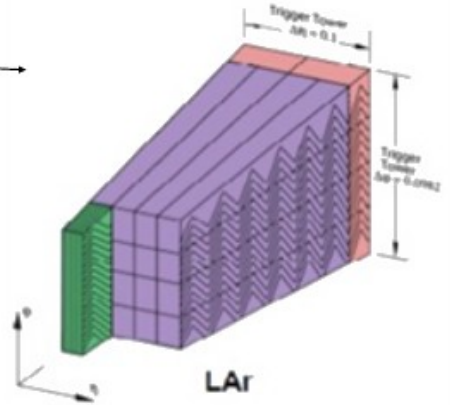


Level-1 Calorimeter Trigger

- Decision based on information from ATLAS calorimeters
- calorimeter cells are summed → no segmentation in radial direction apart from EM and hadronic calorimeter



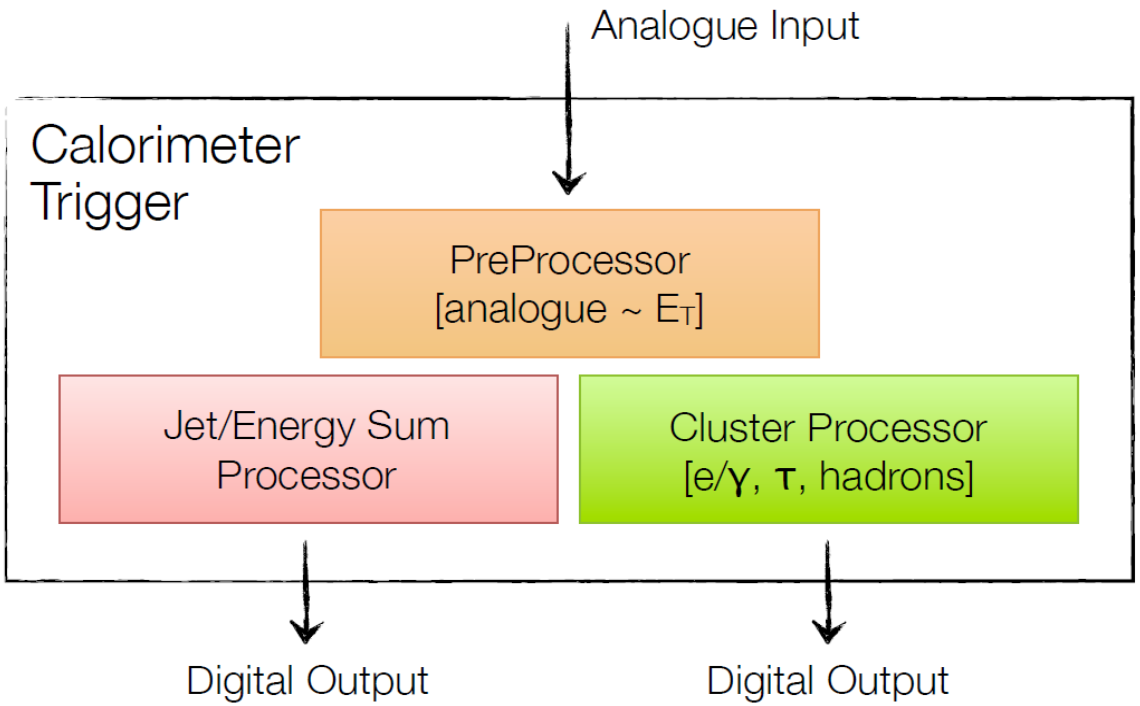




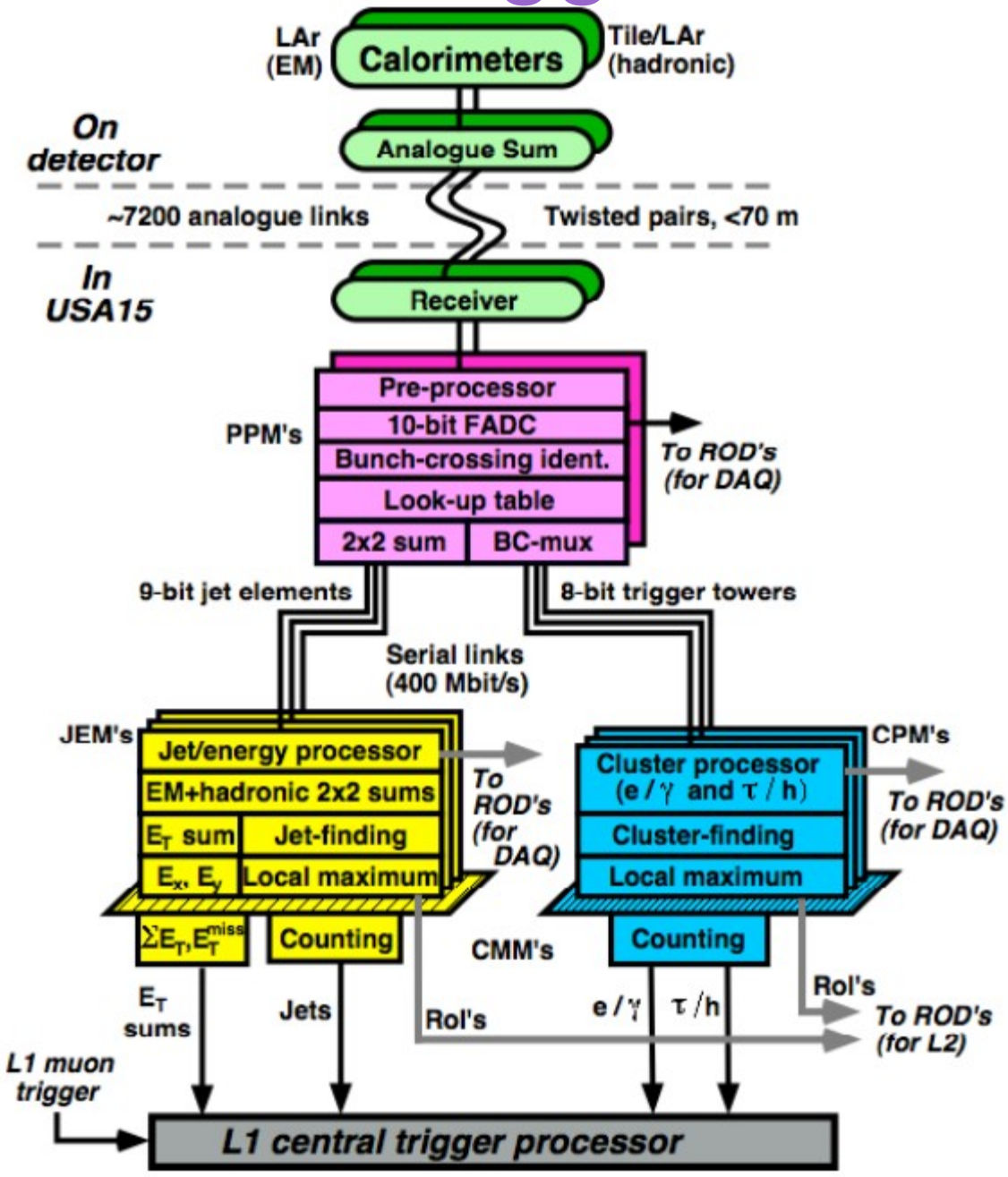
~ 250k calorimeter cells summed on detector to 7168 projective triggger towers

Level-1 Calorimeter Trigger

- Decision based on information from ATLAS calorimeters
- calorimeter cells are summed → no segmentation in radial direction apart from EM and hadronic calorimeter
- 2 independent processor subsystems (CP/JEP)



Level-1 Calorimeter Trigger



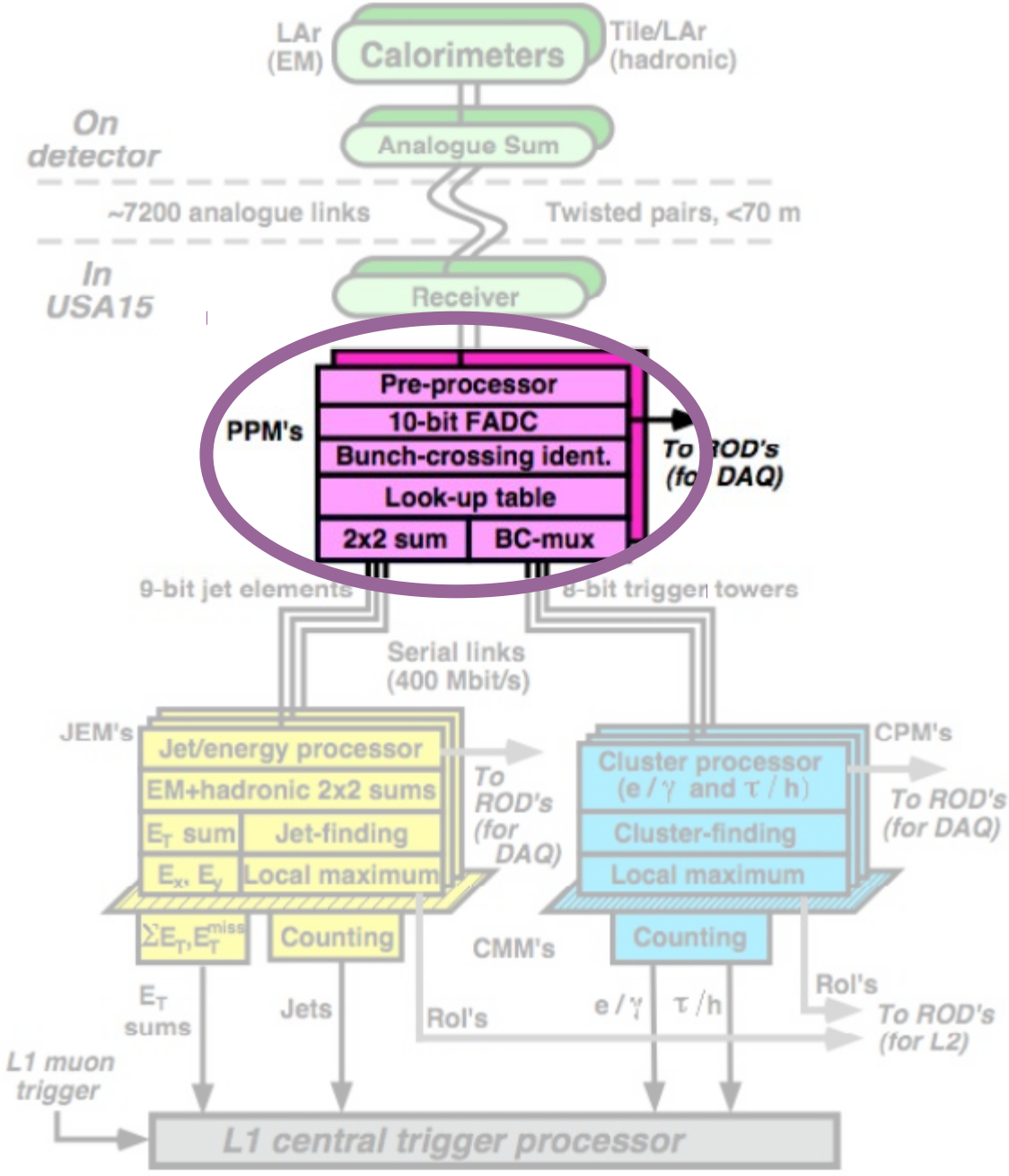
L1 Calo PreProcessor

Pre-processor module

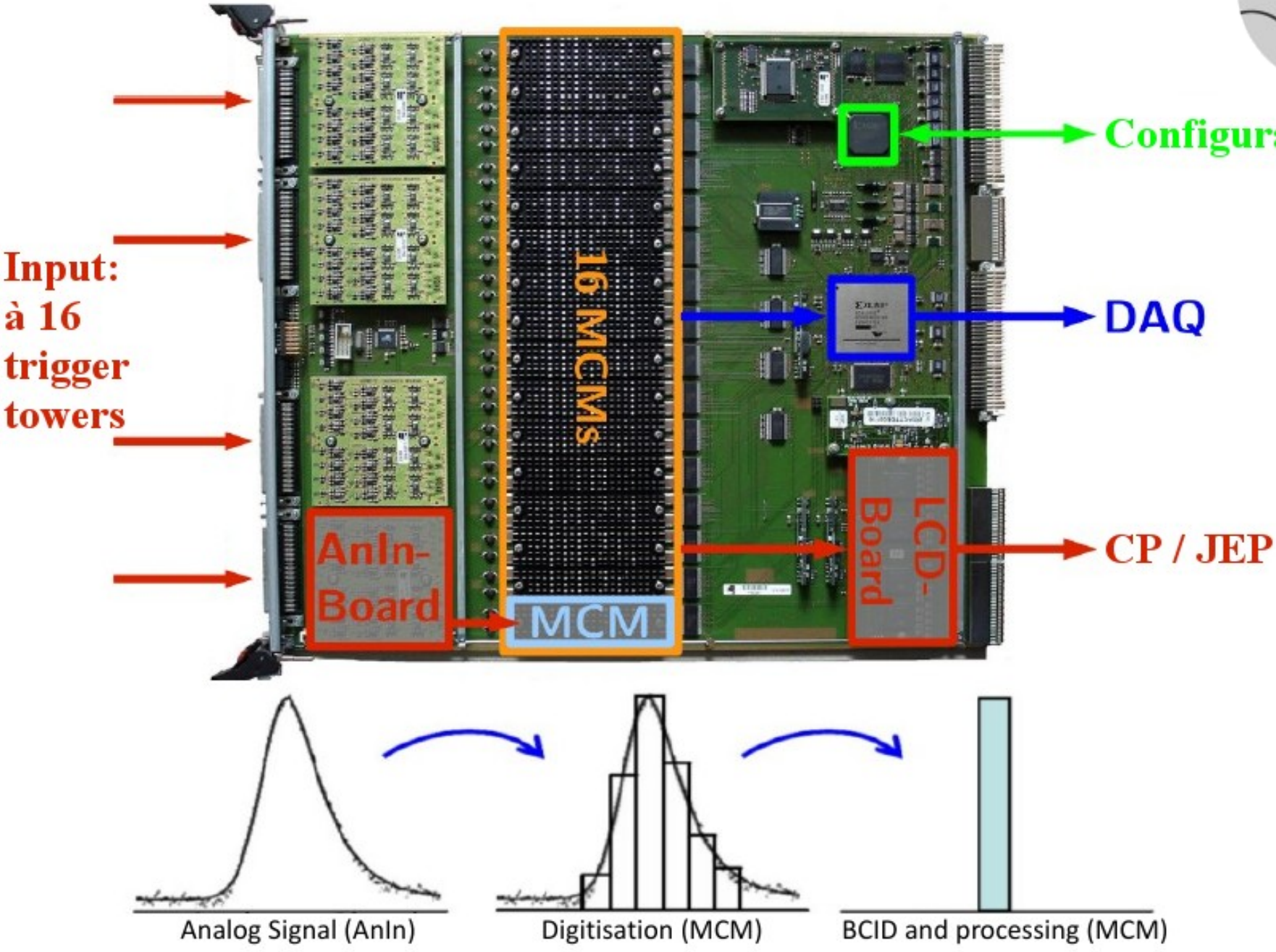
Receives analogue input pulses from calorimeters

- digitises and synchronises them
- identifies bunch crossing the pulses originate from
- performs E_T calibration
- prepares digital signals for serial transmission

The PPr serves JEP and CP systems



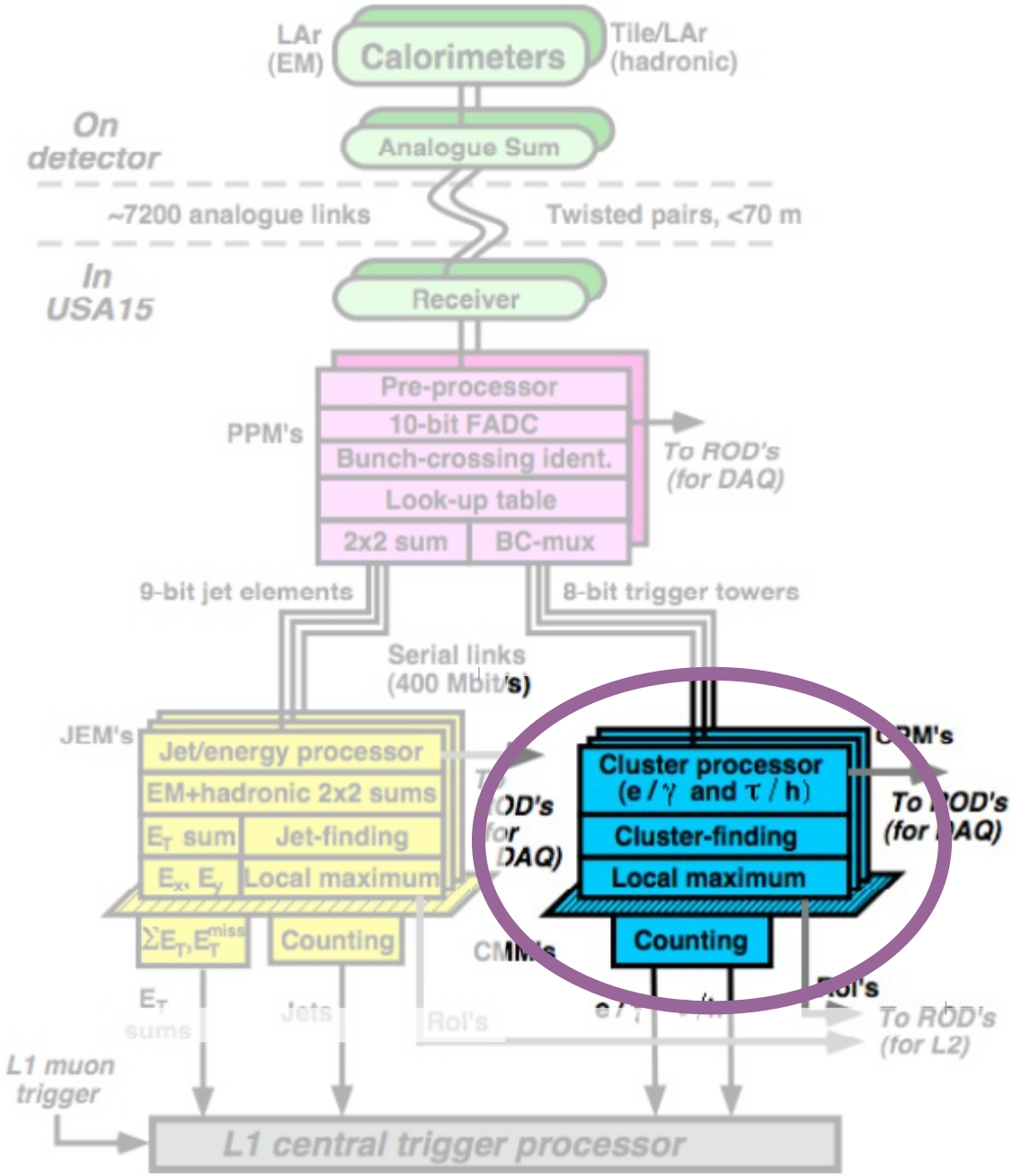
L1Calo PreProcessor



L1Calo Cluster Processor

Cluster Processor

Identifies objects with energy depositions in narrow calorimeter regions (e, γ, τ)

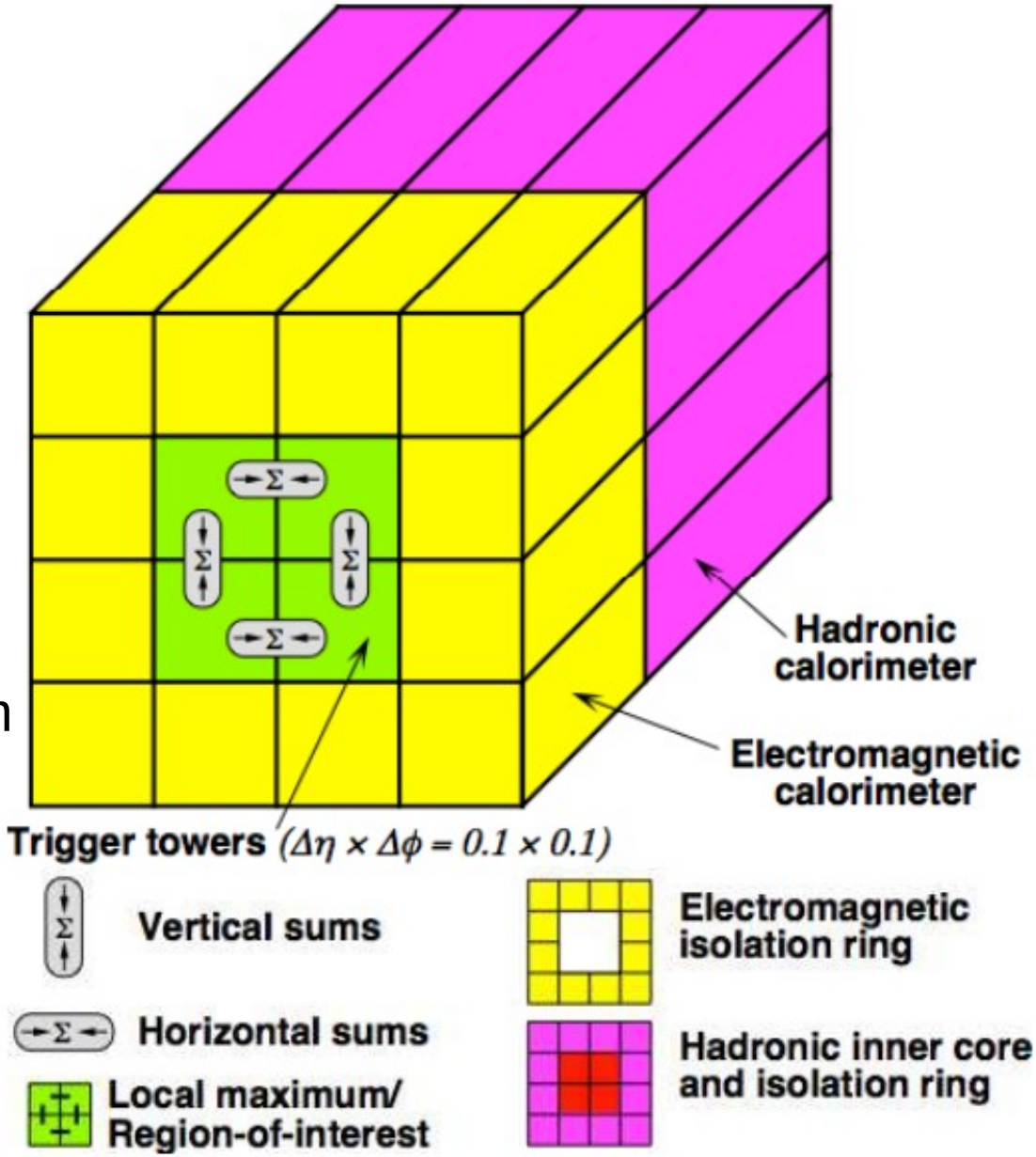


L1 Calo Cluster Processor

electron, photon and tau trigger elements based on 4×4 sliding windows of trigger towers

- energy threshold programmable (16 available) for central cluster
- Surrounding ring used for isolation requirement
- Also available: information from hadronic layer (use for veto for electrons and photons)

- Upgrade: increase number of energy thresholds

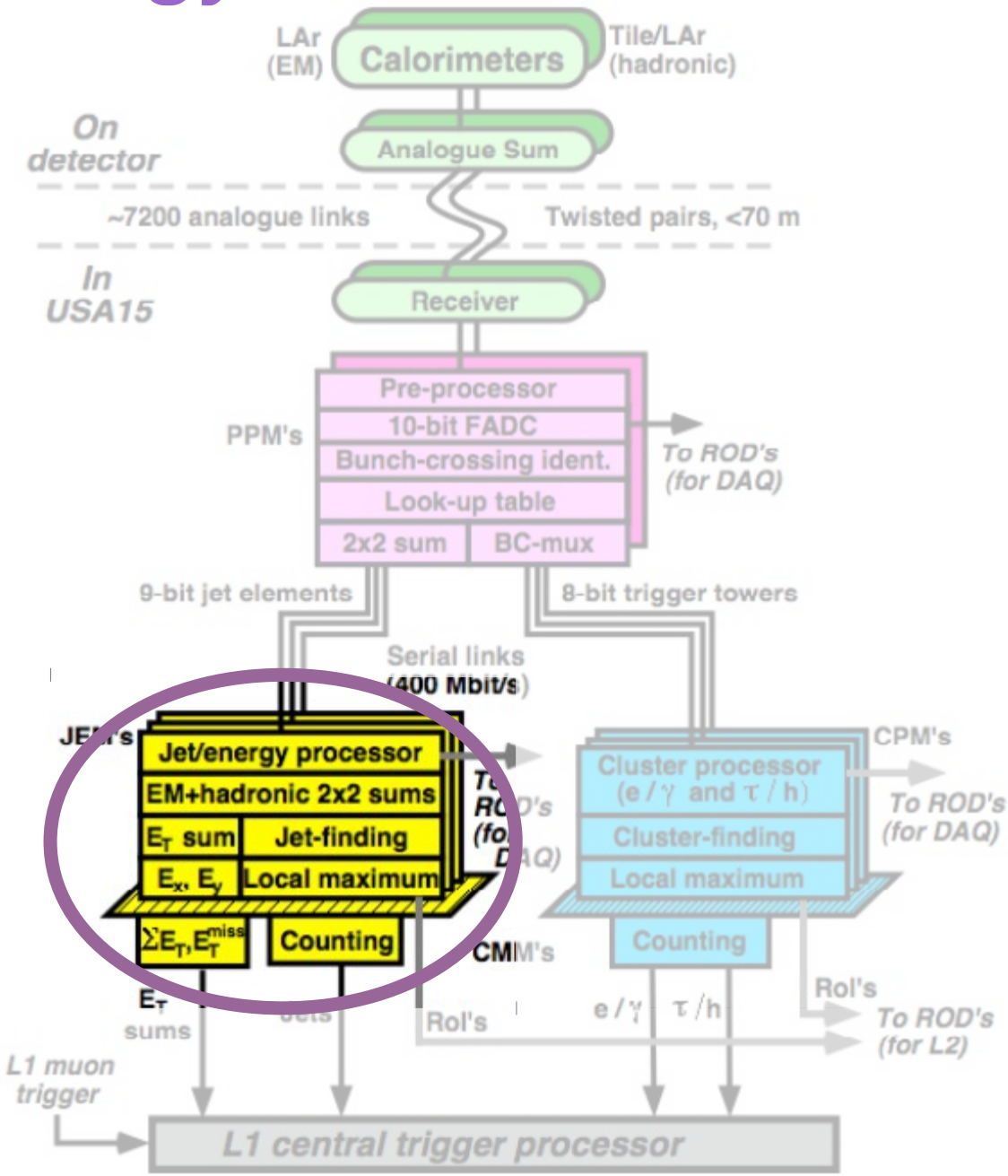


L1Calo Jet Energy Processor

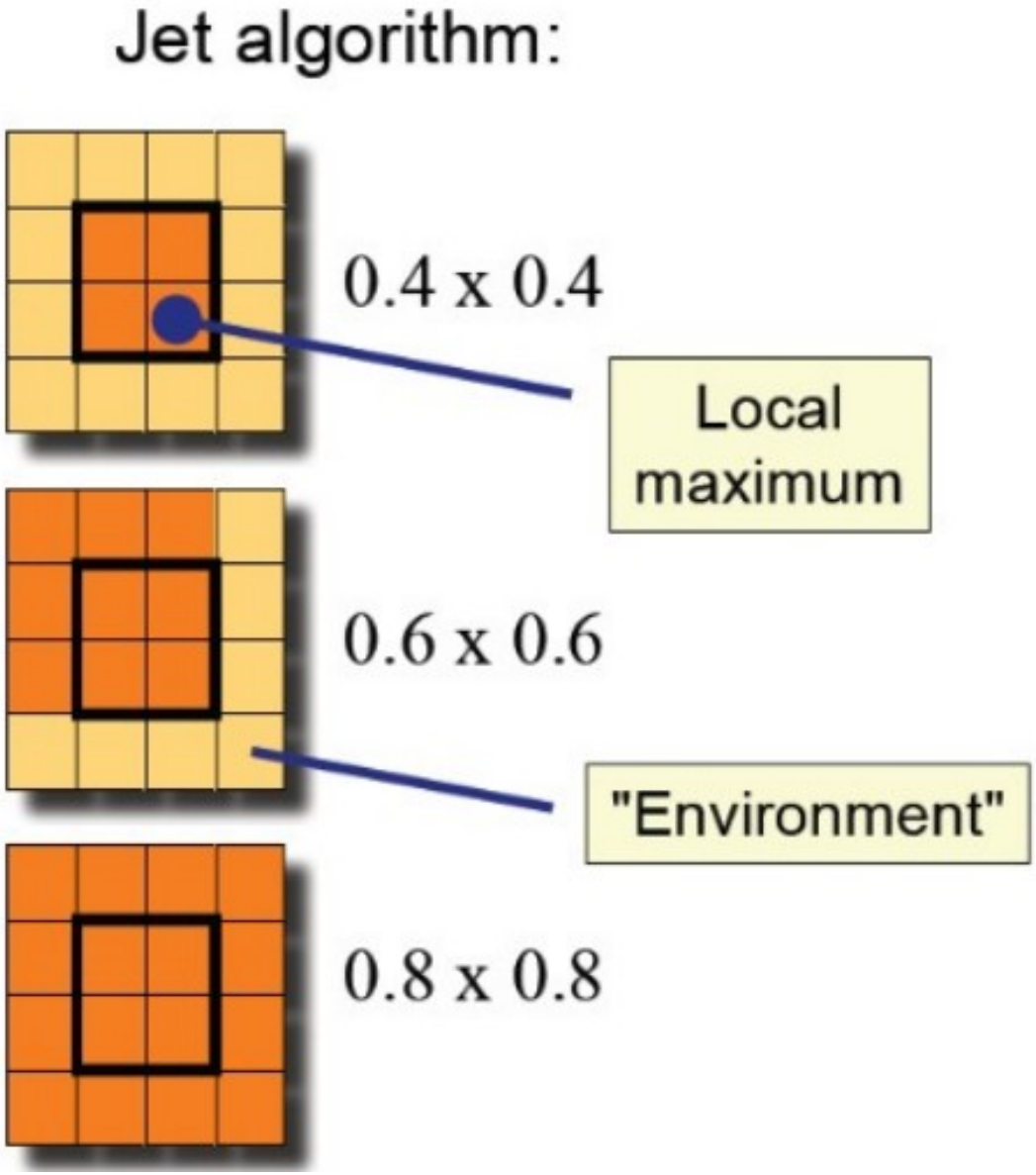
Jet Energy Processor

Looks for extended “jet-like” objects in calorimeters and for sum of transverse energy.

Receives towers with coarser granularity from PPM



Jet Energy Processor



Jet triggers can have varying sliding window sizes

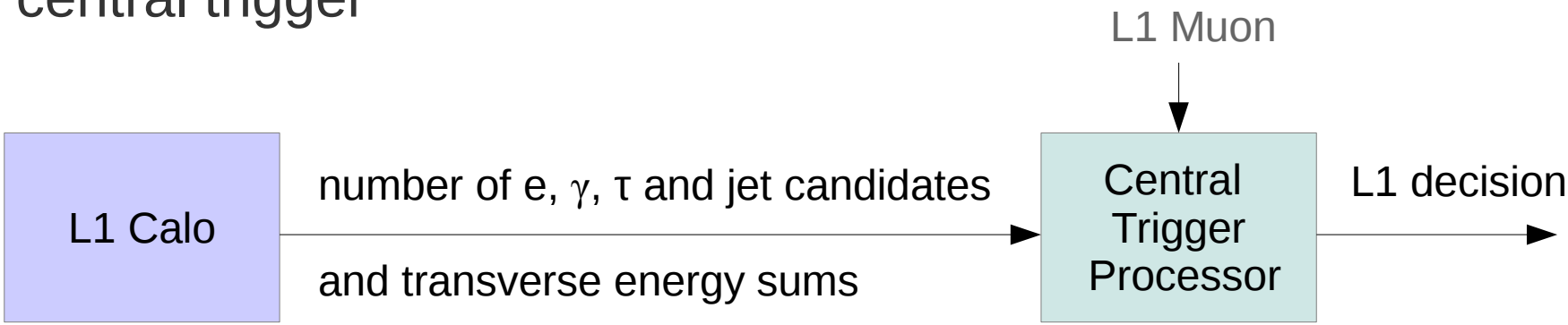
- Even more reduced granularity: Jet element instead of trigger tower:
  - Size: 0.2 x 0.2
  - No segmentation in R (energies in EM and hadronic layer summed)
- Programmable window size
- Total energy must be over threshold (8 available)

- Upgrade: increase number of thresholds

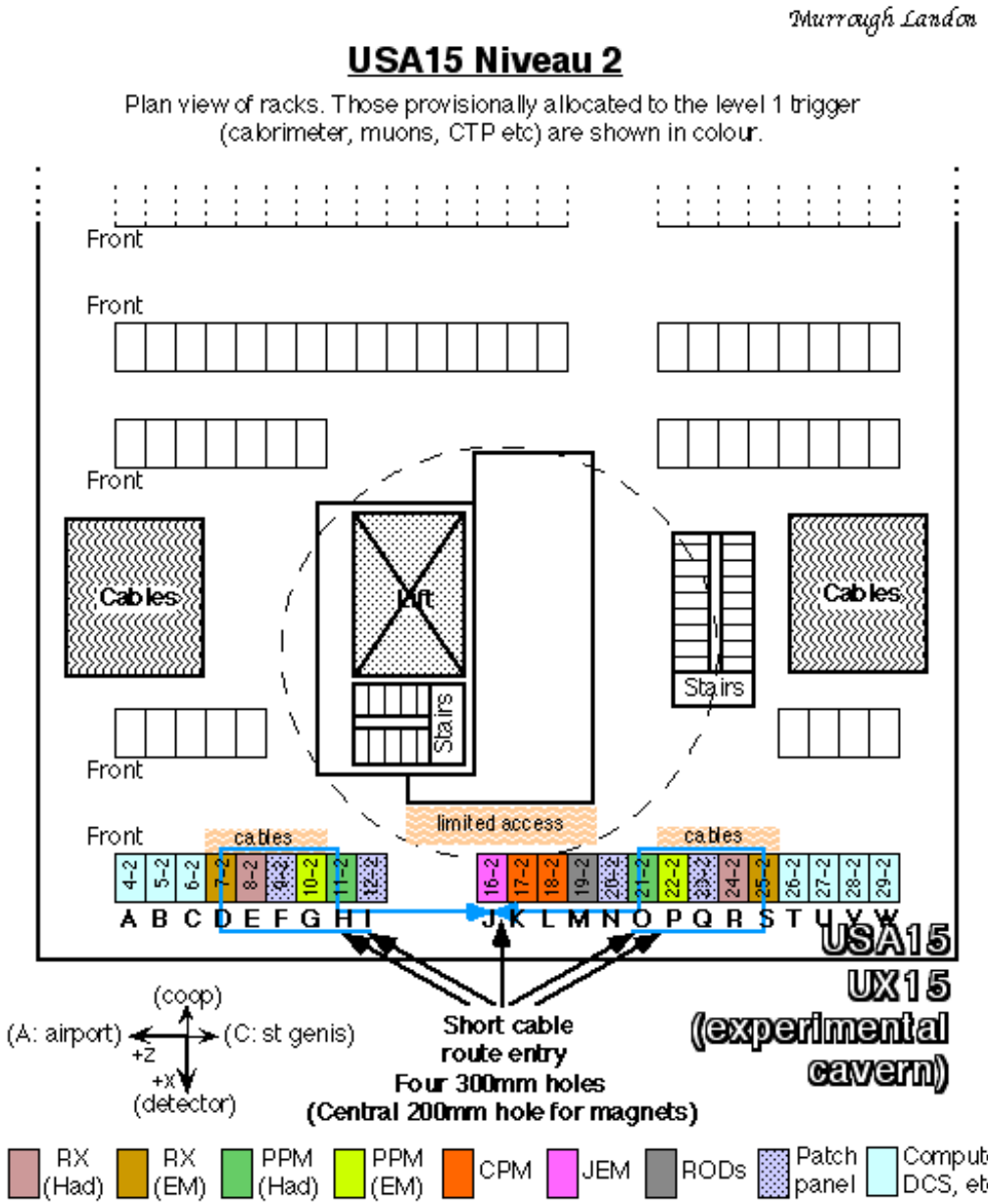
Level-1 Calorimeter Trigger

- Decision based on information from ATLAS calorimeters
- calorimeter cells are summed → no segmentation in radial direction apart from EM and hadronic calorimeter
- 2 independent processor subsystems (CP/JEP)

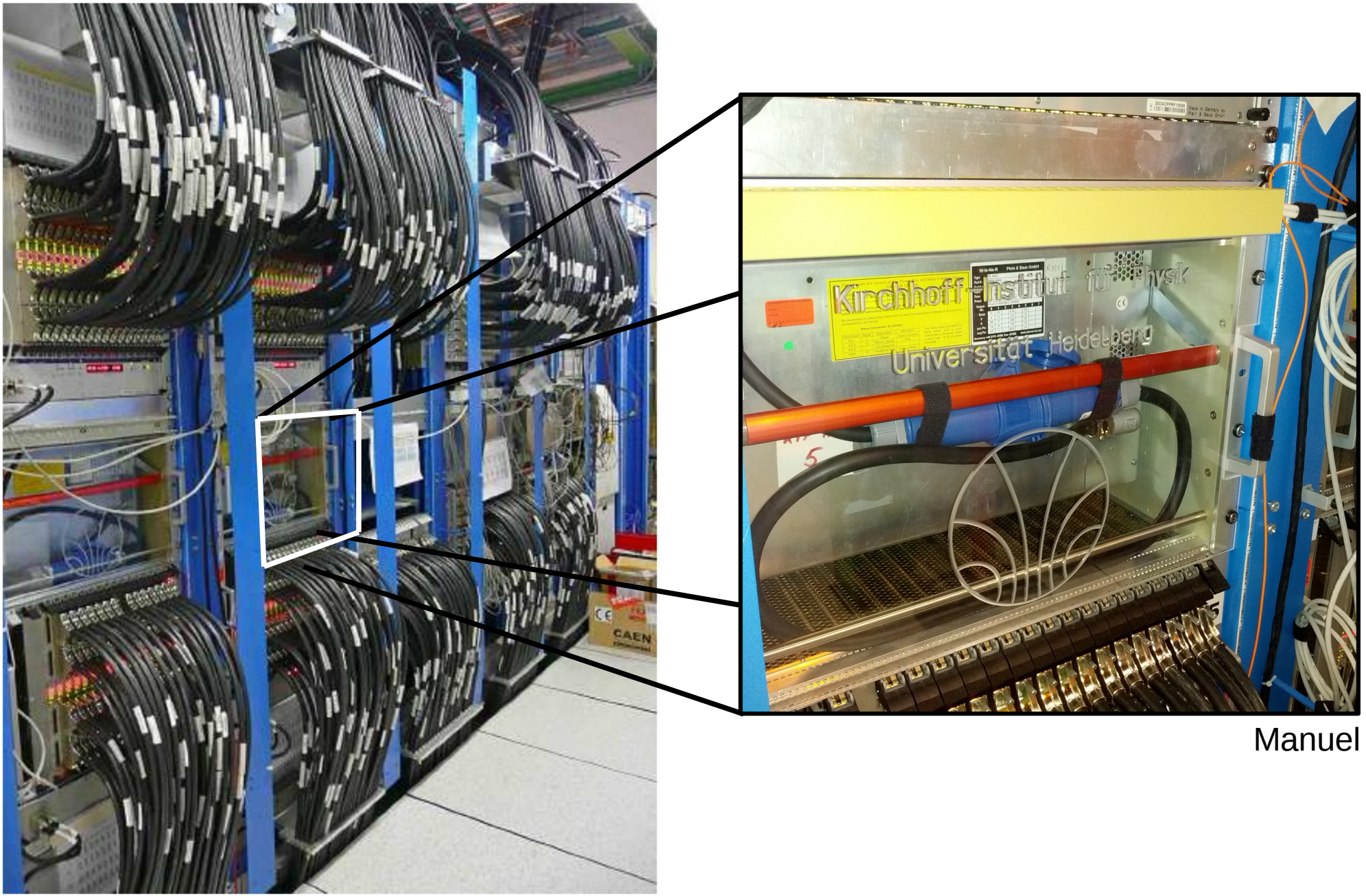
- Search for local (isolated) maxima using sliding windows
- Multiplicities of programmable thresholds (hit counts) transferred to central trigger



Level-1 Calorimeter Trigger

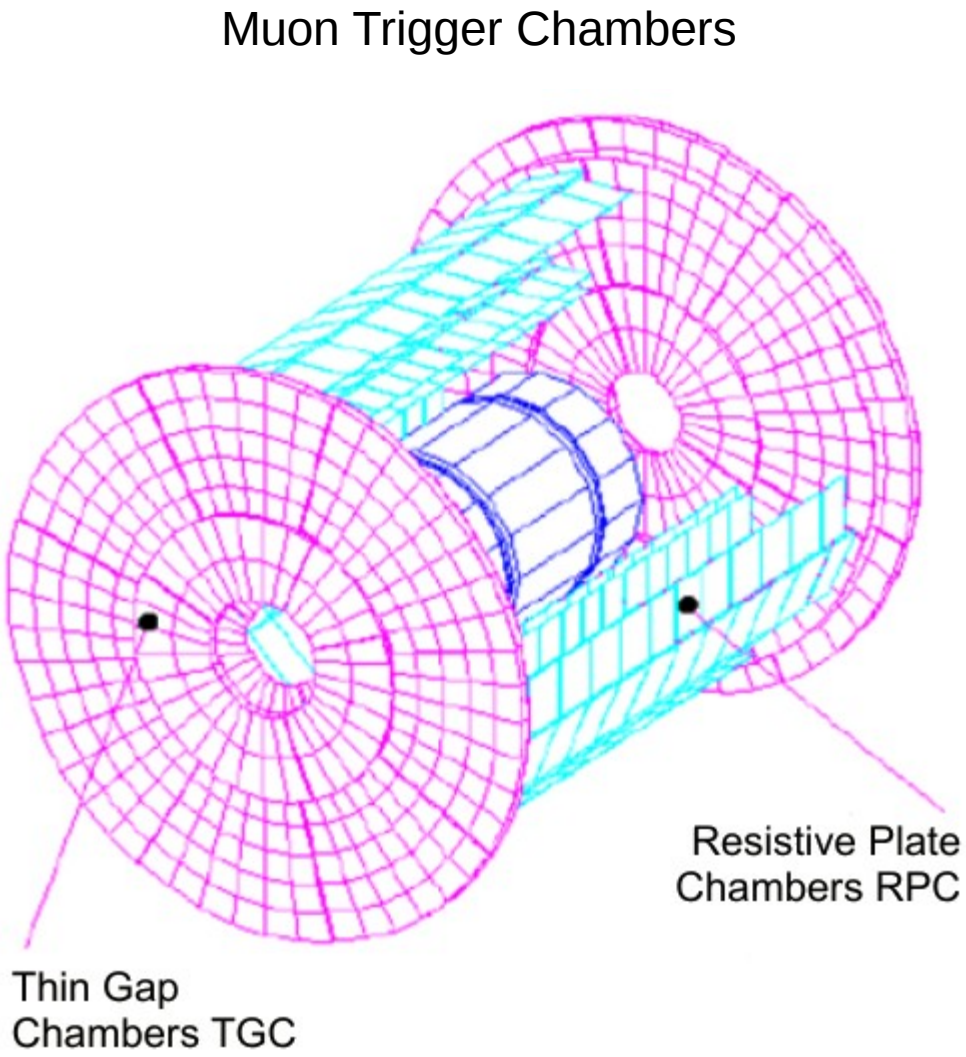


Level-1 Calorimeter Trigger



Manuel

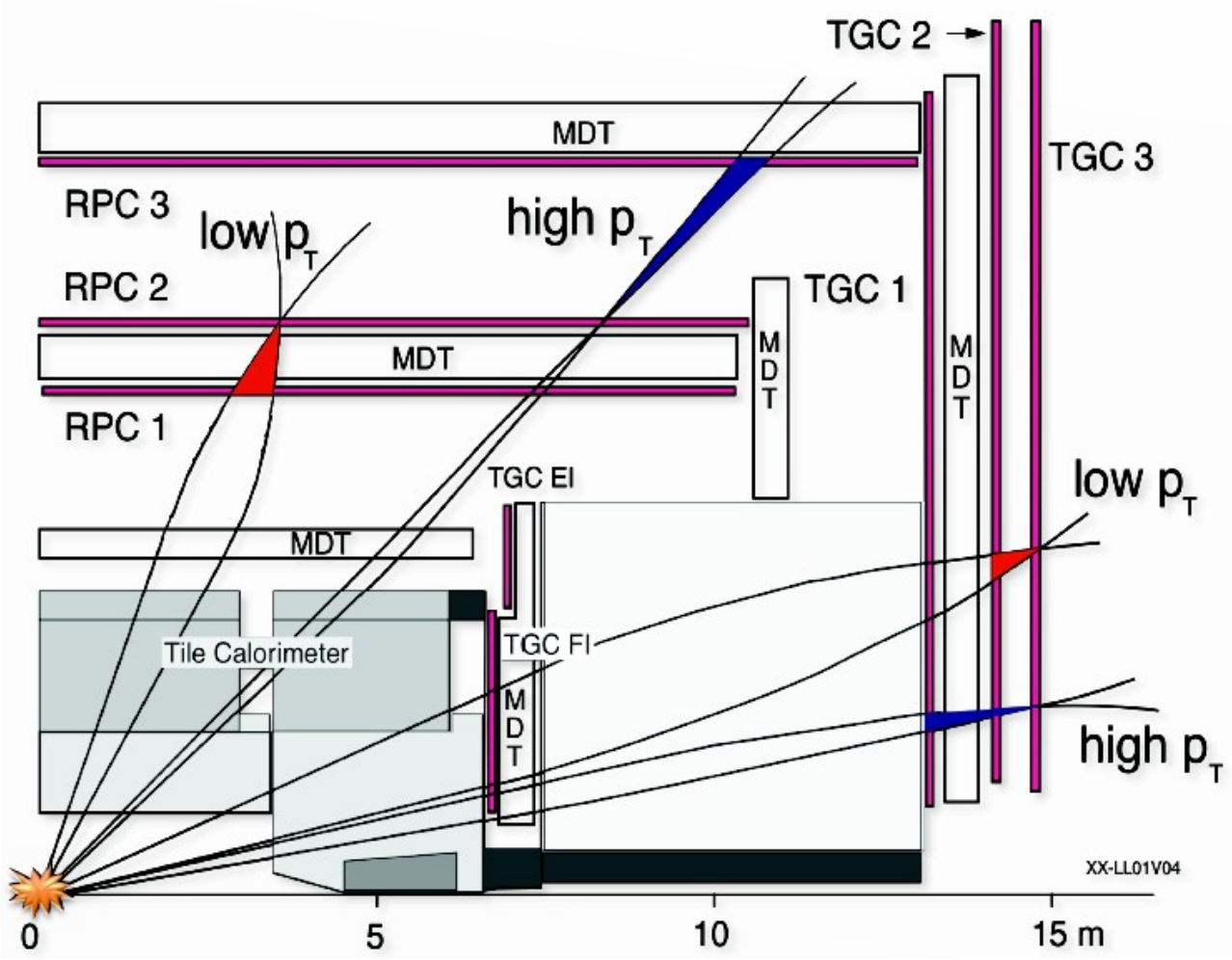
Level-1 Muon Trigger



Dedicated trigger chambers with good timing resolution, divided into 208 sectors

- TGC: Multi wire proportional chamber with narrow distance between anode and cathode
- RPC: Parallel plates of electrodes with gas filled gaps
  – passing muon will create charge avalanche

Level-1 Muon Trigger



Level-1 Muon Trigger requires coincident hits in different RPC (barrel) or TGC (endcap) layers

Muon momentum measured with simple tracking in few planes of trigger chambers

MuCTPI collects sector muon candidates, removes overlaps and forms total muon multiplicities at 6 different P_T thresholds

→ send to CTP

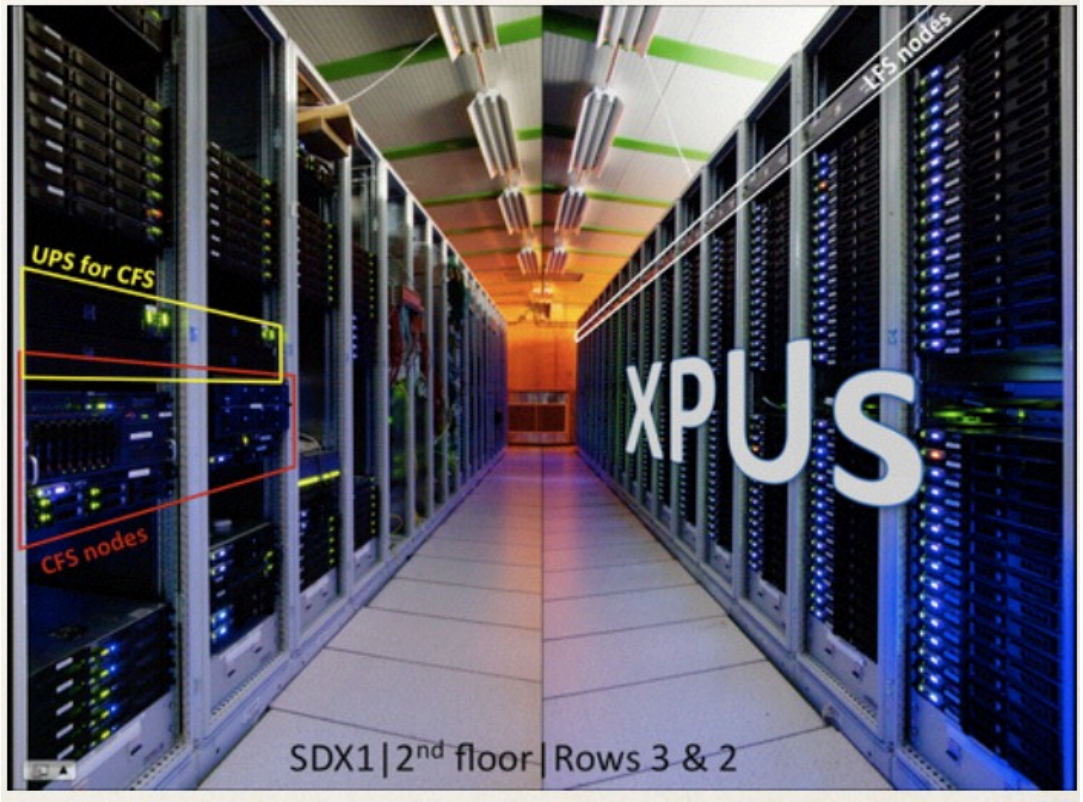
Level-1 Trigger Decision

Central Trigger Processor receives signals from Level-1 subsystems and combines them based on a "trigger menu" (defined by analysis)

- 256 trigger items available, e.g. EM20, XE50, JET100, 2EM6_MU6
- Level-1 decision is OR of actual trigger items

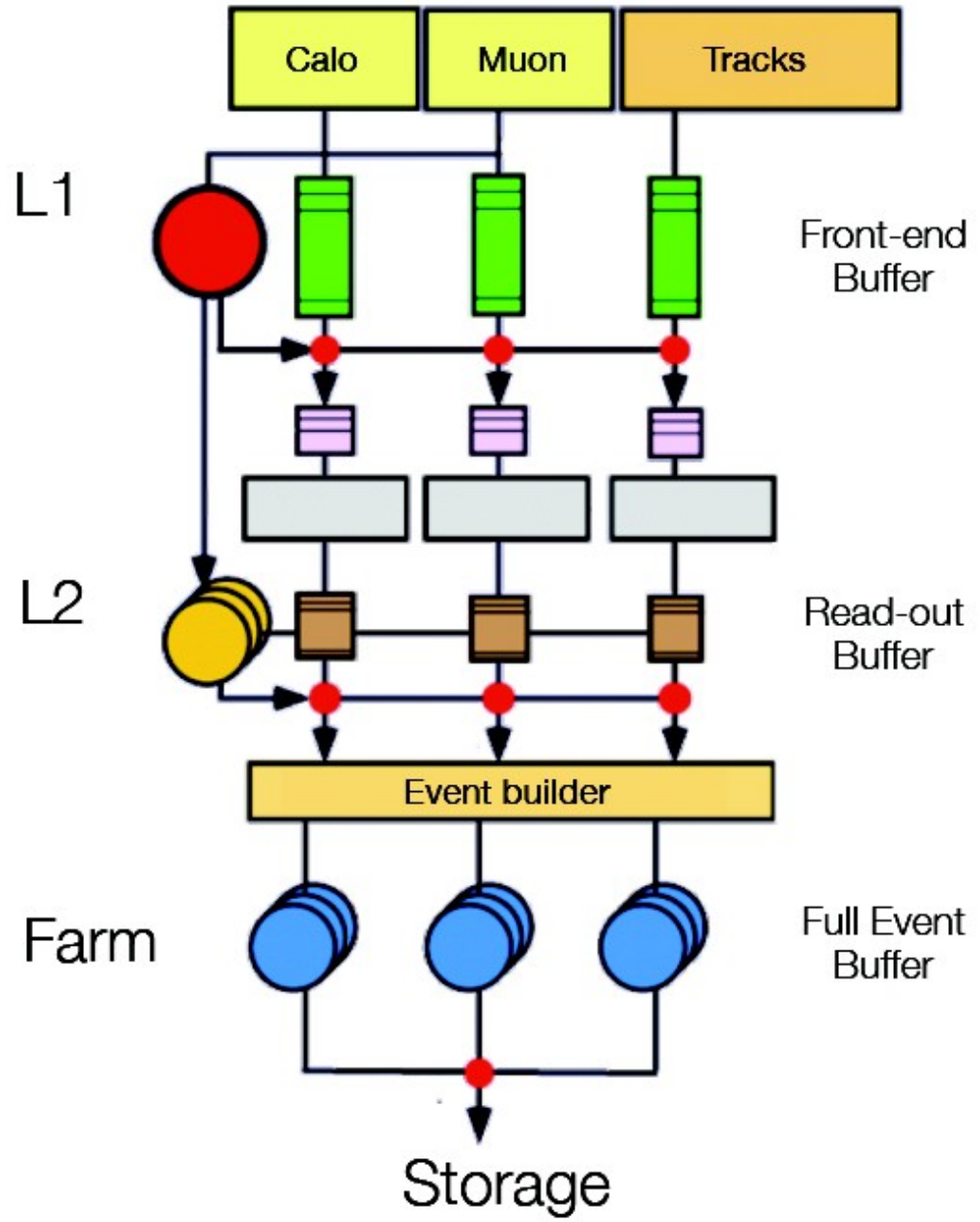
High Level Trigger

- fully realised in software
- consists of 2 systems:
  - Level-2 Trigger
  - Event Filter
- uses full detector granularity and information
- HLT Reduction methods:



  - Muons: Sharpen P_T threshold using full muon and inner tracking information
  - Electrons: Match inner track, higher granularity information
  - Photons: Inner track veto, higher granularity information
  - Energy sums: Correct L1 saturation, correct muon P_T in L1 missing E_T

Triggering in ATLAS



40 MHz

LEVEL-1 TRIGGER

- Hardware-Trigger [FPGAs & ASICs]
- Information from calorimeters & muon systems; low granularity
- 2 µs latency [2.5 µs pipelines]

~75 kHz

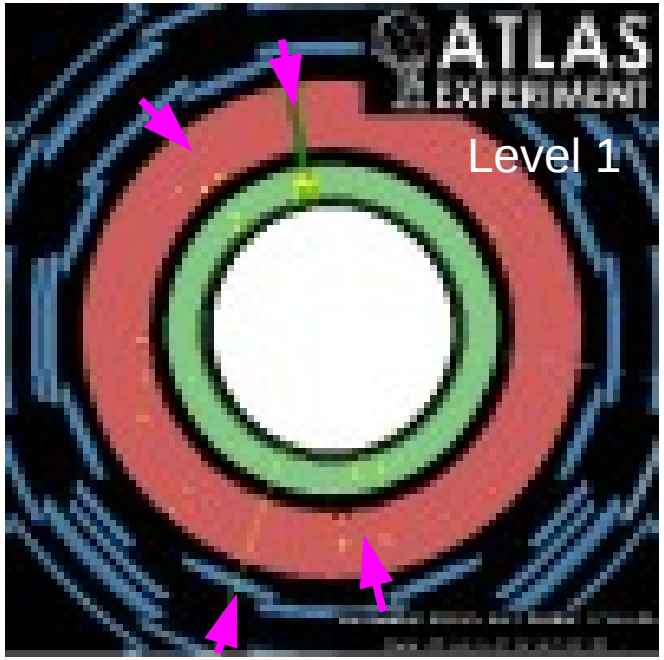
LEVEL-2 TRIGGER

- Regions-of-Interest
- In principle full information of all subdetectors; high granularity
- Decision time: O(10 ms)

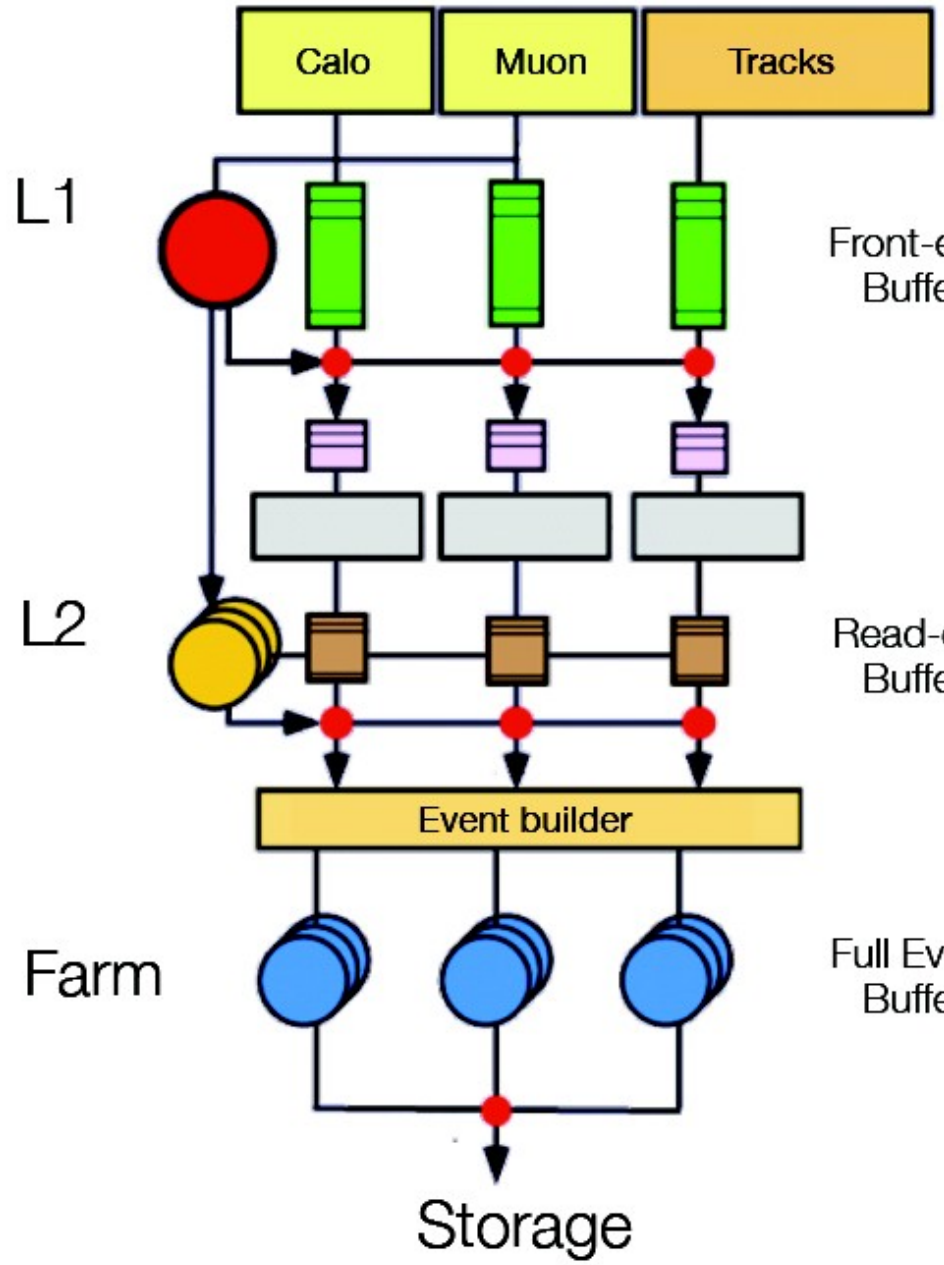
~4 kHz

Level-2 Trigger

- uses Level-1 “region-of-interest”:
  - only detector information from these regions is considered
  - uses full granularity in these regions
- uses fast reconstruction algorithms
- reduces data bandwidth



Triggering in ATLAS



Front-end Buffer

Read-out Buffer

Full Event Buffer

40 MHz

LEVEL-1 TRIGGER

- Hardware-Trigger [FPGAs & ASICs]
- Information from calorimeters & muon systems; low granularity
- 2 µs latency [2.5 µs pipelines]

~75 kHz

LEVEL-2 TRIGGER

- Regions-of-Interest
- In principle full information of all subdetectors; high granularity
- Decision time: O(10 ms)

~4 kHz

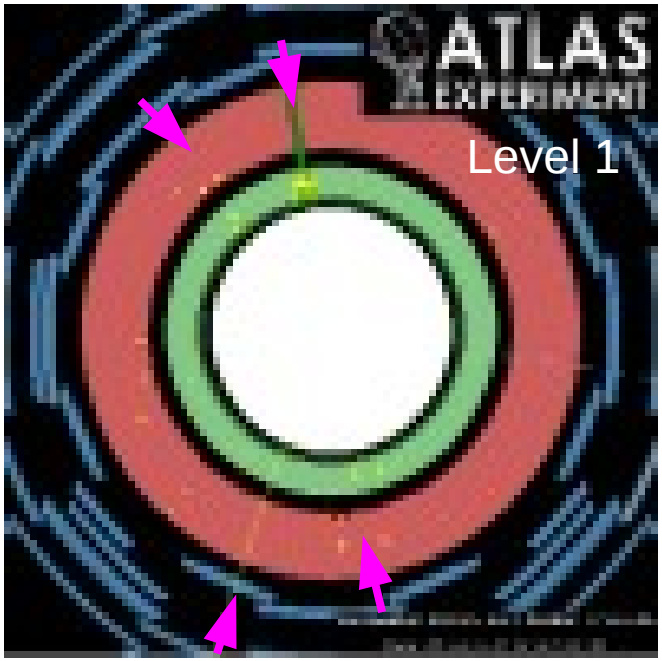
EVENT FILTER

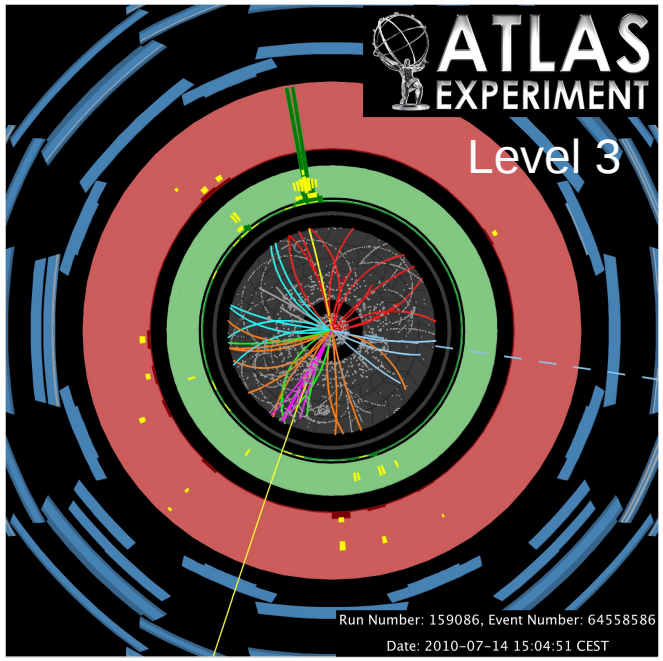
- Complete detector information
- Full event reconstruction
- Decision time: O(1 s)

~ 500 Hz

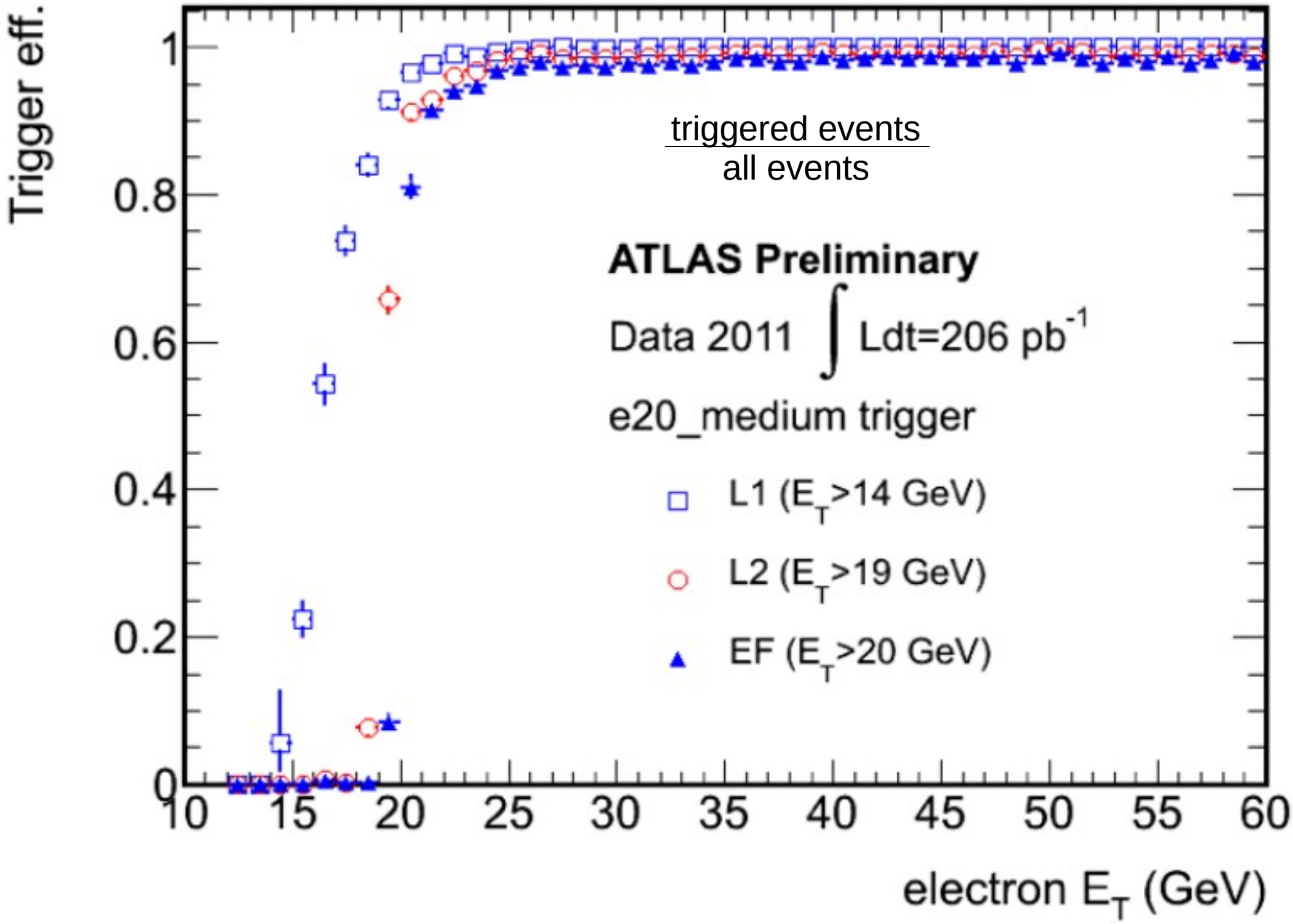
Event Filter

- fully realised in software: CPUs
- rebuilds complete event with full granularity and all subdetectors
- uses full blown offline reconstruction algorithms: refined alignment and calibration
- has ~ 1 s to decide what physics analyses will be studying (next week)

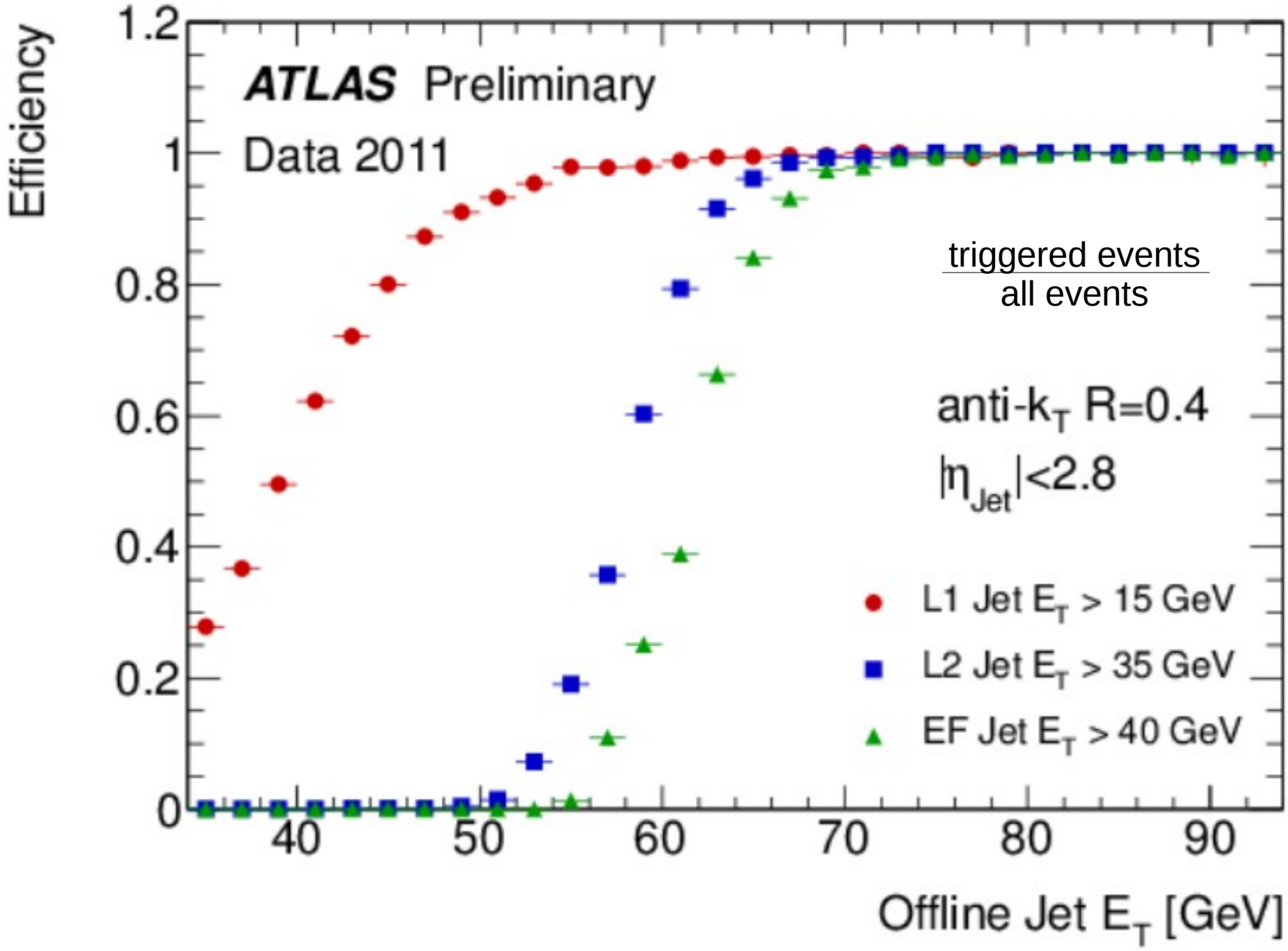




Trigger Efficiencies



Trigger Efficiencies



Summary

- Triggering important to find interesting events
- Online selection necessary due to
  - limited storage capabilities
  - limited bandwidth for persistent storage

- ATLAS has a 3 leveled trigger system to reduce event rate by factor of ~ 10^9:
  - Level-1, Level-2 and Event Filter

- Detector upgrade will bring more features:
  e.g. topology or track based Level-1 trigger

Thank you!

Sources

- The ATLAS Level-1 Calorimeter Trigger, R. Achenbach et al 2008 JINST 3 P03001
- Lectures from H.-C. Schultz-Coulon

  http://www.kip.uni-heidelberg.de/~coulon/
- Lectures from Monica Dunford

  http://results-lhc.physi.uni-heidelberg.de/Lectures/
- Lectures from Andreas Hoecker (CERN) at HCPSS 2009