Trigger Systems at Hadron Super-Colliders

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INTRODUCTION

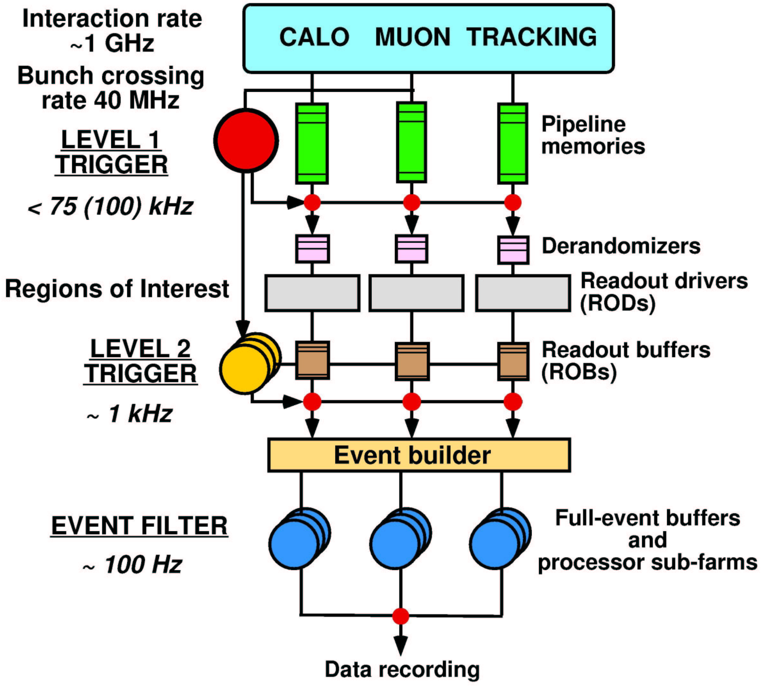
Approach followed in this talk

- Review some basic ideas about triggering
- Describe how triggers are done in general-purpose experiments at LHC (i.e. ATLAS and CMS)
- In doing so, identify issues to be addressed for experiments at a hadron Super-Collider
  - Resulting from:
    - Higher energy
    - Higher luminosity
    - Reduced bunch-crossing interval
    - More complex detector systems (needed to cope with the experimental conditions at a Super-Collider)
  - Indicate areas where R&D would be required

General trigger requirements

- The role of the **trigger** is to make the online selection of particle collisions potentially containing interesting physics
- Need **high efficiency** for selecting processes of interest for physics analysis
  - Efficiency should be precisely known
  - Selection should not have biases that affect physics results
- Need **large reduction of rate** from unwanted high-rate processes (capabilities of DAQ and also offline computers)
  - Instrumental background
  - High-rate physics processes that are not relevant for analysis
- System must be **affordable**
  - Limits complexity of algorithms that can be used
- Not easy to achieve all the above simultaneously!

Why do we need *multi-level* triggers?



Example: ATLAS

- Multi-level triggers provide:
  - Rapid rejection of high-rate backgrounds without incurring (much) dead-time
    - Fast first-level trigger (custom electronics)
      - Needs high efficiency, but rejection power can be *comparatively* modest
      - Short latency is essential since information from all (up to $O(10^8)$ already at LHC) detector channels needs to be buffered (often on detector) pending result
  - High overall rejection power to reduce output to mass storage to affordable rate
    - Progressive reduction in rate after each stage of selection allows use of more and more complex algorithms at affordable cost
    - Final stages of selection, running on computer farms, can use comparatively very complex (and hence slow) algorithms to achieve the required overall rejection power

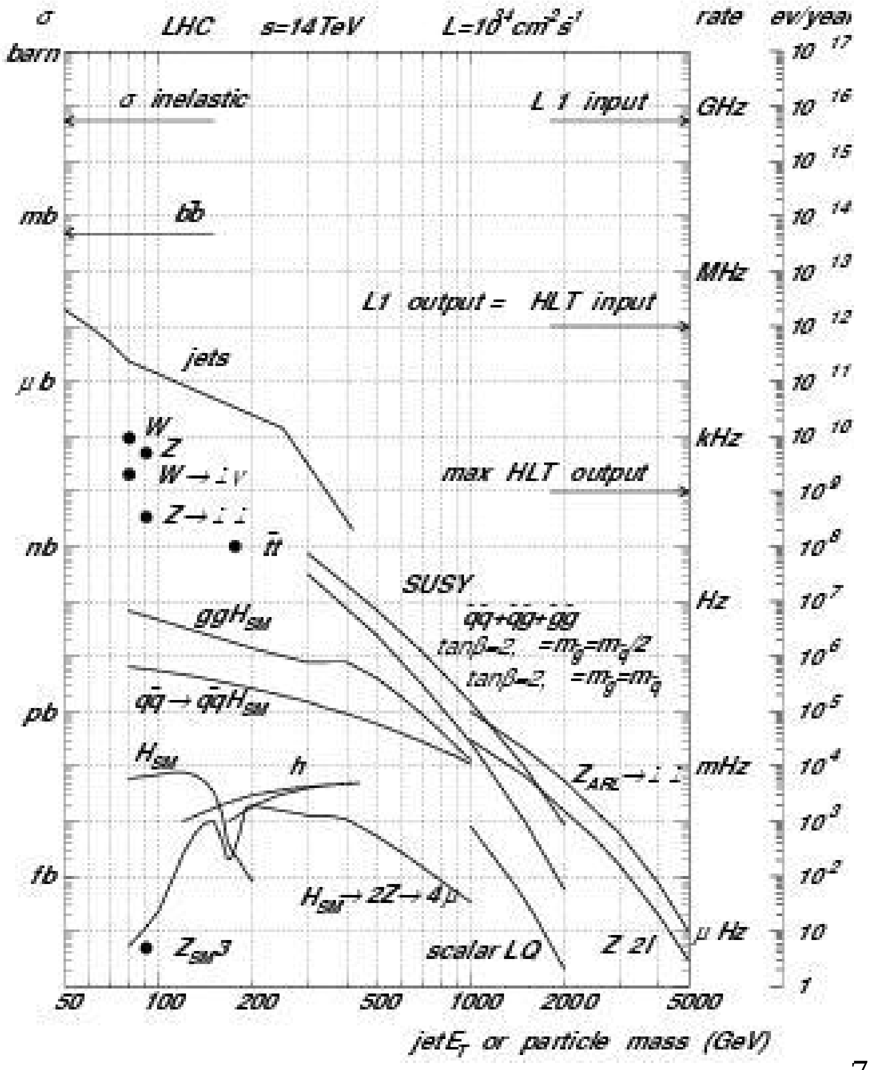
Requirements from physics perspective

- Typically, trigger systems select events according to a "trigger menu", i.e. a list of selection criteria
  - An ***event*** is selected by the trigger if one or more of the criteria are met
    - I use the term "event" to mean the record of the activity in a given bunch crossing — typically an event contains many proton–proton interactions
      - First-level trigger has to identify the BC of interest
  - Different criteria may correspond to different signatures for the same physics process
    - Redundant selections lead to high selection efficiency and allow the efficiency of the trigger to be measured from the data
  - Different criteria may reflect the wish to concurrently select events for a wide range of physics studies
    - HEP "experiments" — especially those with large general-purpose "detectors" (detector systems) — are really experimental facilities
- Remember that events rejected by the trigger are lost forever!
  - In contrast to offline processing and physics analysis, there is no possibility of a second chance!

Super-Collider physics

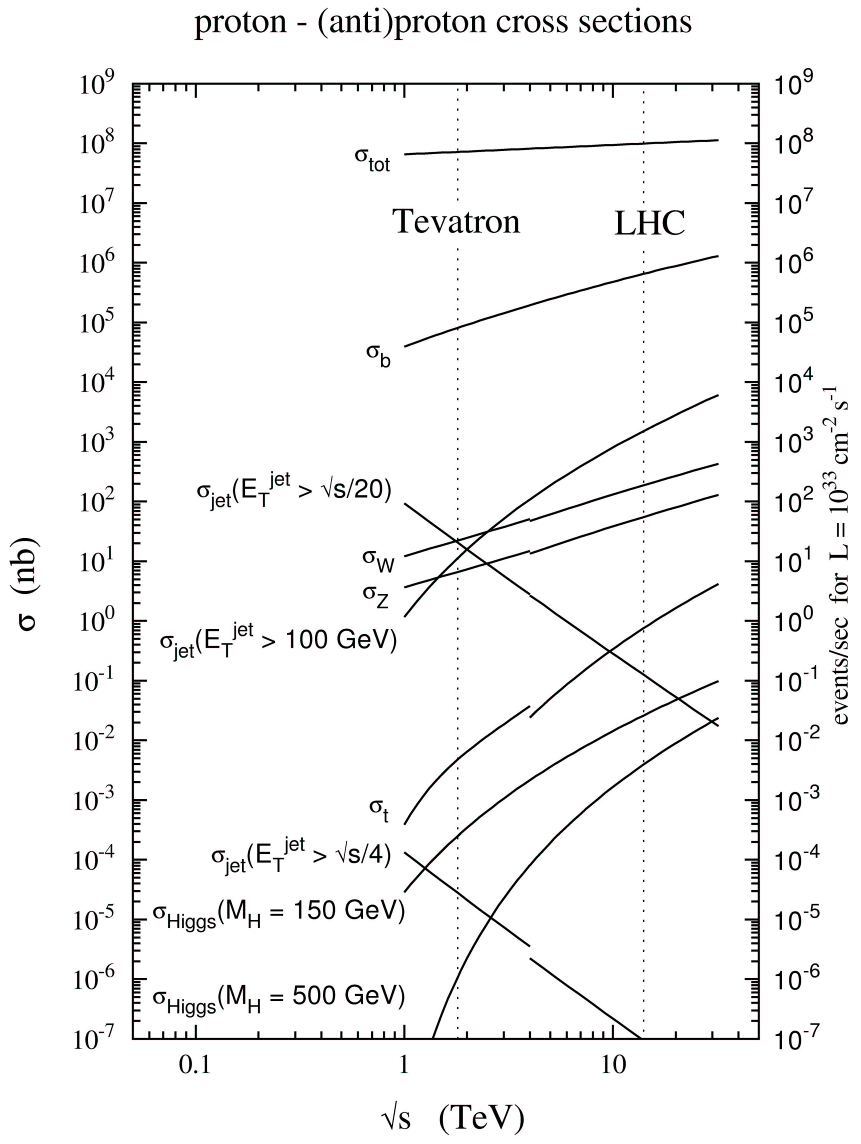
- Discovery physics is the main emphasis for ATLAS, CMS, and future hadron-Super-Collider experiments
  - Huge range of predicted new physics processes with diverse signatures
    - Very low signal rates expected in some cases (as little as 10^{-16} of total rate)
  - But should also try to be sensitive to new physics that has not been predicted!
  - Super-Collider would operate after LHC
    - Discovery of very high-mass objects (i.e. those beyond reach of LHC)
    - Precision measurements of lower-mass objects already discovered at LHC
  - At LHC, aim for storage rate *O*(100) Hz
    - i.e. *O*(10^{-7}) of interaction rate
    - Event size ~ 1 MB

Cross-sections and rates at LHC



Super-Collider backgrounds

- Huge rate of Standard Model physics backgrounds
  - Rate of proton–proton collisions up to 10^9 Hz at LHC, even more for hadron Super-Colliders
    - Rates (and pile-up and detector occupancy) obviously increase with luminosity
    - Total cross-section grows only slowly with energy
    - Cross-sections for new physics and also for SM backgrounds (jets, W, Z) increase more rapidly with energy
  - Much lower rates predicted for instrumental backgrounds such as beam–gas interactions



Physics signatures

- The trigger will have to retain as many as possible of the events of interest for the diverse physics programmes of Super Collider experiments, including:
  - Higgs searches (Standard Model and beyond)
    - E.g. $H \to ZZ \to$ leptons (e or μ), $H \to \gamma\gamma$; also $H \to \tau\tau$, $H \to bb$
  - SUSY searches
    - E.g. producing jets and missing E_T
  - Searches for other new physics
    - Using inclusive triggers that one hopes will be sensitive to unpredicted new physics
  - Studies of Standard Model processes which must be understood as backgrounds to new physics
    - W and Z bosons, top and beauty quark production

Physics signatures (continued)

- In contrast to the particles produced in typical pp collisions (typical hadron $p_T \sim 1$ GeV), the products of new physics are expected to have large transverse momentum, p_T
  - E.g. if they were produced in the decay of new heavy particles such as the Higgs boson; e.g. $m \sim 100$ GeV $\Rightarrow p_T \sim 50$ GeV
- Typical examples of first-level trigger thresholds for LHC at 10^{34} $cm^{-1}s^{-1}$ luminosity are:
  - Single muon $p_T > 20$ GeV (rate ~ 10 kHz)
    - Pair of muons each with $p_T > 6$ GeV (rate ~ 1 kHz)
  - Single e/γ $p_T > 30$ GeV (rate ~ 20 kHz)
    - Pair of e/γ each with $p_T > 20$ GeV (rate ~ 5 kHz)
  - Single jet $p_T > 300$ GeV (rate ~ 200 Hz)
    - Jet $p_T > 100$ GeV and missing-$p_T > 100$ GeV (rate ~ 500 Hz)
    - Four or more jets $p_T > 100$ GeV (rate ~ 200 Hz)

LHC and hadron Super-Colliders

- LHC (proton–proton)
  - Centre-of-mass energy
    - 14 TeV
  - Luminosity
    - 10^{34} cm^{-2}s^{-1}
  - Bunch-crossing interval
    - 25 ns
  - Interactions per BC
    - ~25

- Hadron Super-Collider
  - Higher energy?
    - Very interesting from the point of view of accessing physics at high mass scales
    - Requires completely new machine — expensive and long-term
  - Higher luminosity?
    - Could be achieved via upgrade of LHC machine and experiments — "Super-LHC" might reach 10^{35} cm^{-2}s^{-1}
  - Shorter bunch-crossing interval?
    - Short to minimize pile-up, e.g. 12.5 ns considered for Super-LHC

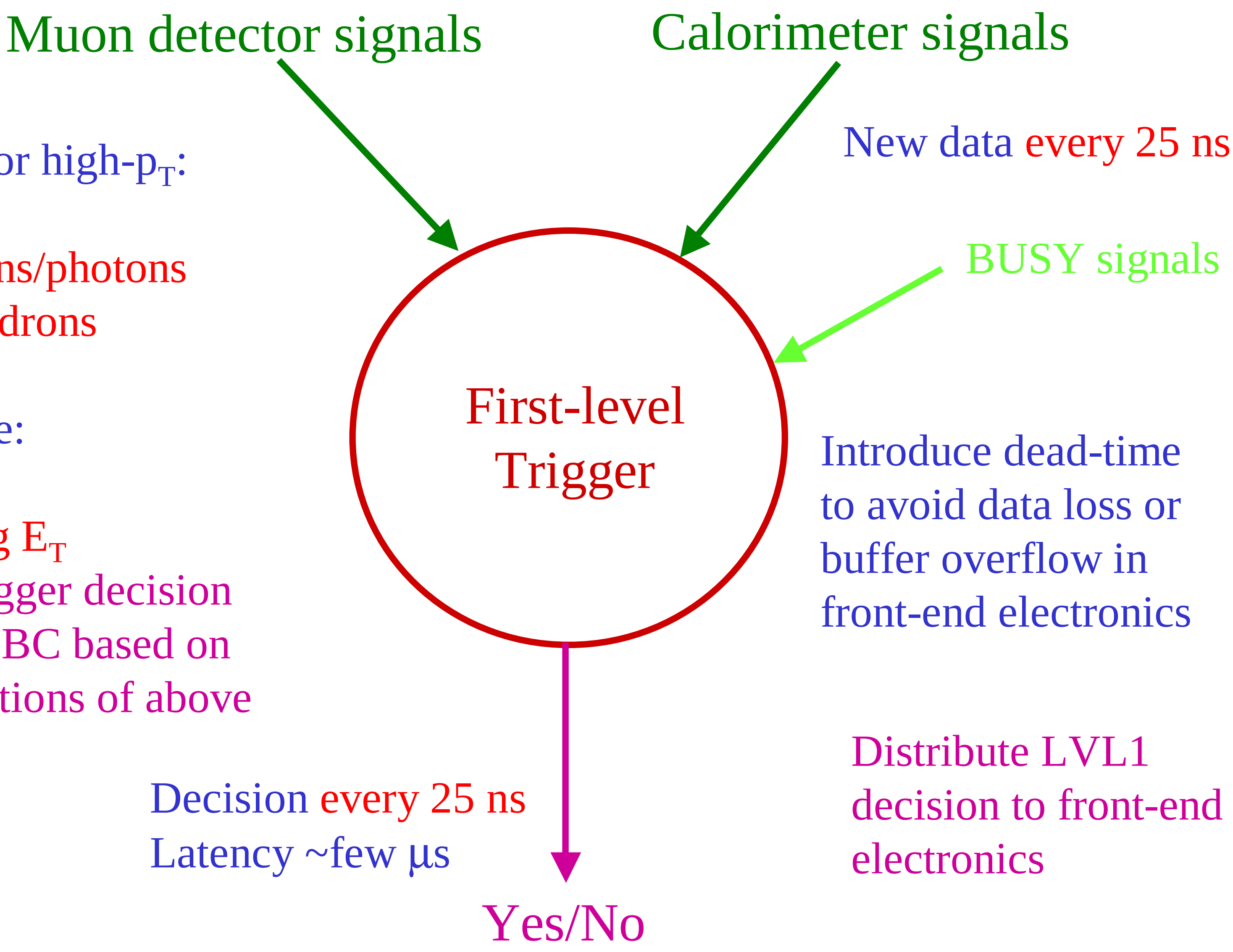
Super-LHC (SLHC) possibilities addressed in:
Physics potential and experimental challenges of the LHC luminosity upgrade, hep-ph/0204087

Bunch-crossing interval

- The BC interval is a key parameter for LHC and future hadron Super-Collider experiments
  - In particular, it profoundly affects the LVL1 trigger design
- Interaction rate much larger than BC rate
  - Pile-up is important consideration for analysis and also in trigger
  - Use detectors with time resolution comparable with BC interval
    - Assuming detectors resolve different BCs, average number of interactions "piled-up" ~ interaction rate × BC interval
      - e.g. $10^9 \times 25 \times 10^{-9} \sim 25$ at LHC
        - » $10^{10} \times 12.5 \times 10^{-9} \sim 125$ at SLHC
  - (At LHC) LVL1 trigger must uniquely identify BC of interest
    - Simplifies detector front-end electronics and readout
      - Also minimizes event size
- Very different situation to e^+e^- machines where interaction rate is typically tiny in comparison to BC rate

FIRST-LEVEL TRIGGERS
“LVL1”

First-level trigger overview (LHC)



Muon detector signals

Calorimeter signals

Search for high-p_T:

- muons
- electrons/photons
- taus/hadrons
- jets

Calculate:

- ΣE_T
- missing E_T

Form trigger decision for each BC based on combinations of above

New data every 25 ns

BUSY signals

First-level Trigger

Introduce dead-time to avoid data loss or buffer overflow in front-end electronics

Decision every 25 ns
Latency ~few µs

Yes/No

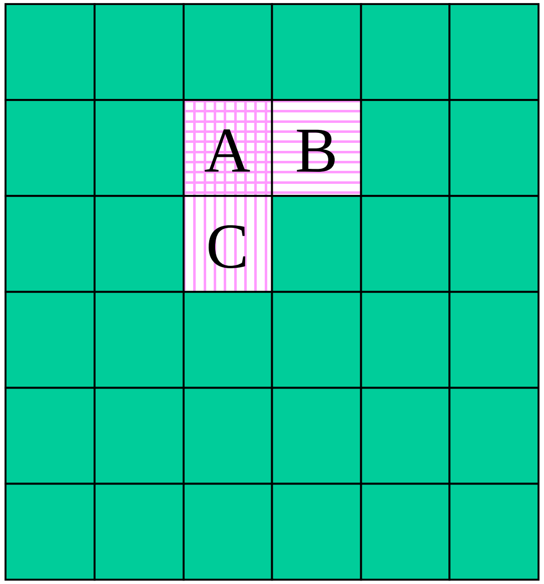
Distribute LVL1 decision to front-end electronics

Pipelined first-level triggers

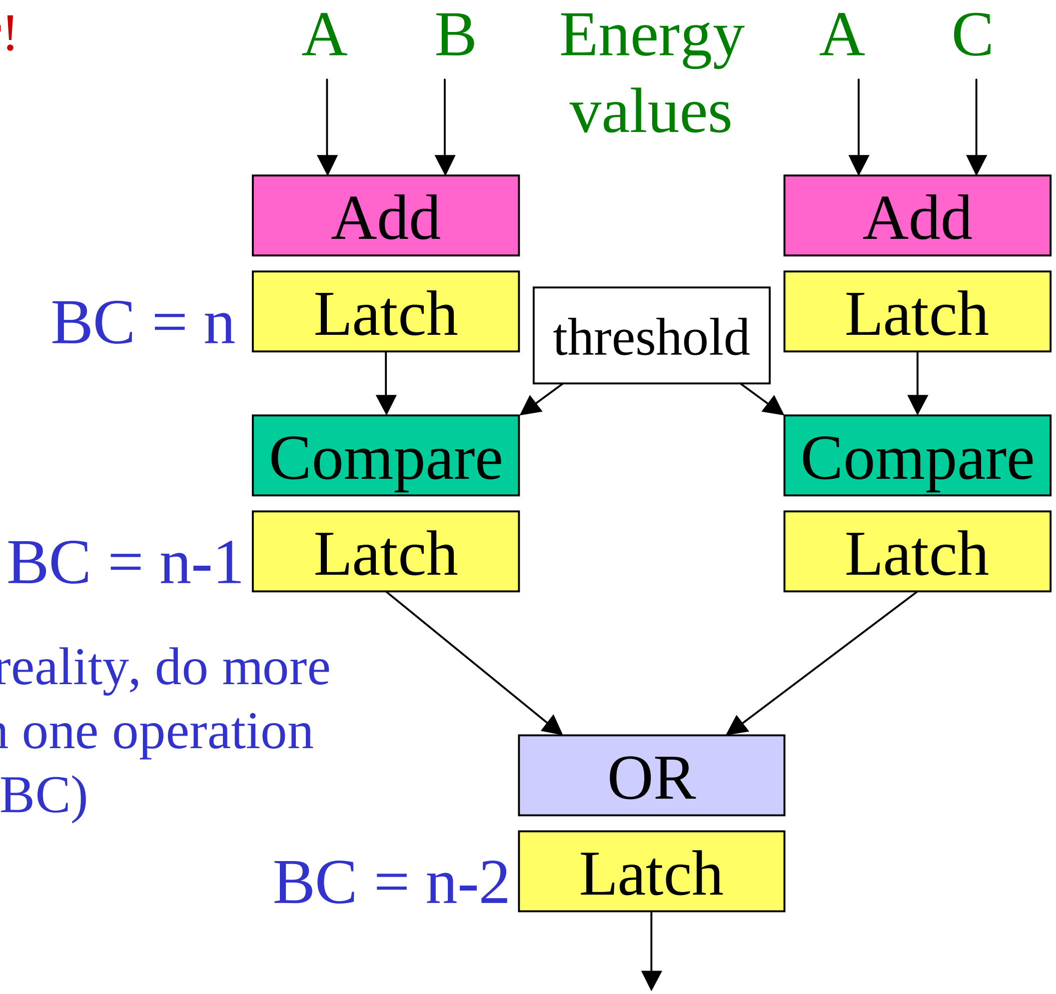
- First-level trigger has to deliver a new decision every BC, but the trigger latency is much longer than the BC period
  - First-level trigger must concurrently process many events
  - This can be achieved by “pipelining” the processing in custom trigger processors built using modern digital electronics
    - Break processing down into a series of steps, each of which can be performed within a single BC period
    - Many operations can be performed in parallel by having separate processing logic for each one
  - Note that the latency of the trigger is fixed
    - Determined by the number of steps in the calculation plus the time taken to move signals and data to and from the components of the trigger system
      - Signals have to pass from the detector to the trigger electronics and back, with a round trip distance of about 200 m (1 μs delay)

Pipelined first-level trigger (illustration)

Note that logic must be duplicated for all ~3500 positions in calorimeter!



EM Calorimeter
(~3500 trigger towers)



A B Energy values A C

Add
Latch
Compare
Latch

threshold

Add
Latch
Compare
Latch

OR
Latch

BC = n

BC = n-1

BC = n-2

(In reality, do more than one operation per BC)

Data-processing technologies

- FPGAs (and other programmable devices) now play a very important role
  - Large gate count and many I/O pins available; operate at 40 MHz and above; performance sufficient for implementing many trigger algorithms
    - Offer huge flexibility
    - Possibility to modify algorithms as well as parameters of algorithms once experiments start running
- ASICs used for some applications
  - More cost effective in some cases (e.g. large number of devices)
  - Can offer higher speed performance than FPGAs
  - Can have better radiation tolerance and lower power consumption for on-detector applications

Data-movement technologies

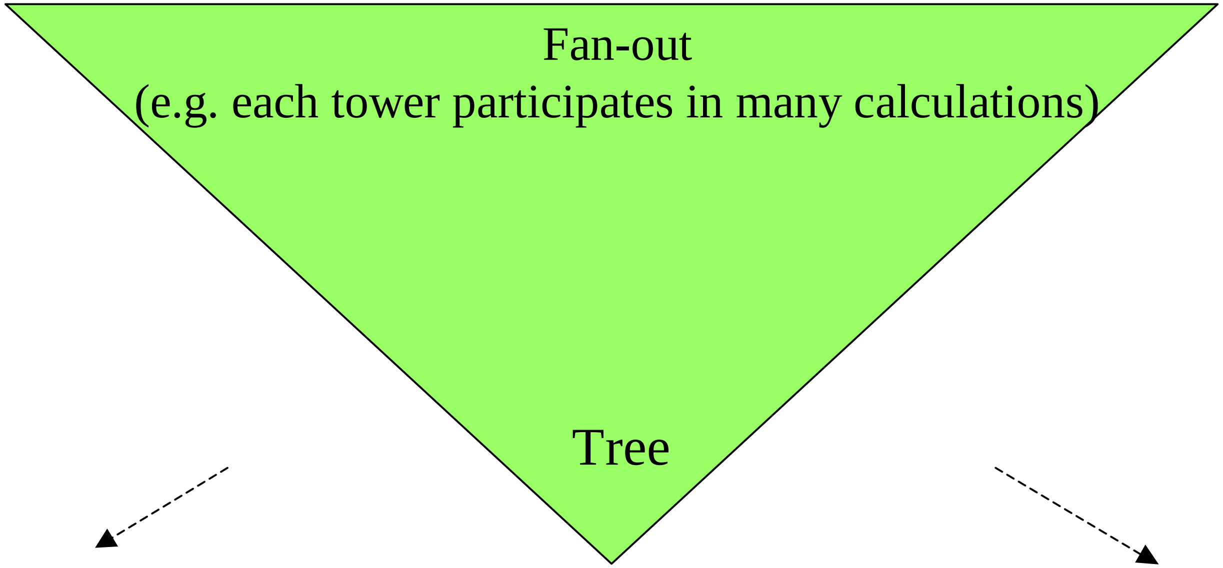
- High-speed serial links (electrical and optical)
  - Comparatively inexpensive and low-power LVDS links for electrical transmission at ~400 Mbit/s over distances up to ~10 m
  - Products such as HP G-link and Vitesse chipsets for Gbit/s transmission; using optical transmission for longer distances
- Very high-density custom backplanes
  - High pin counts (up to ~800 per 9U board)
  - Data rates per (point-to-point) connection ~160 Mbit/s
    - Multiplex data beyond 40 Mbit/s to reduce connectivity problem to a level that can be managed
- Use large (9U) boards
  - Easier to handle interconnections on board than between boards

LVL1 data flow

Many input data

Energies in calorimeter towers
(e.g. ~7000 trigger towers in ATLAS)

Pattern of hits in muon detectors
(e.g. $O(10^6)$ channels in ATLAS)



Fan-out
(e.g. each tower participates in many calculations)

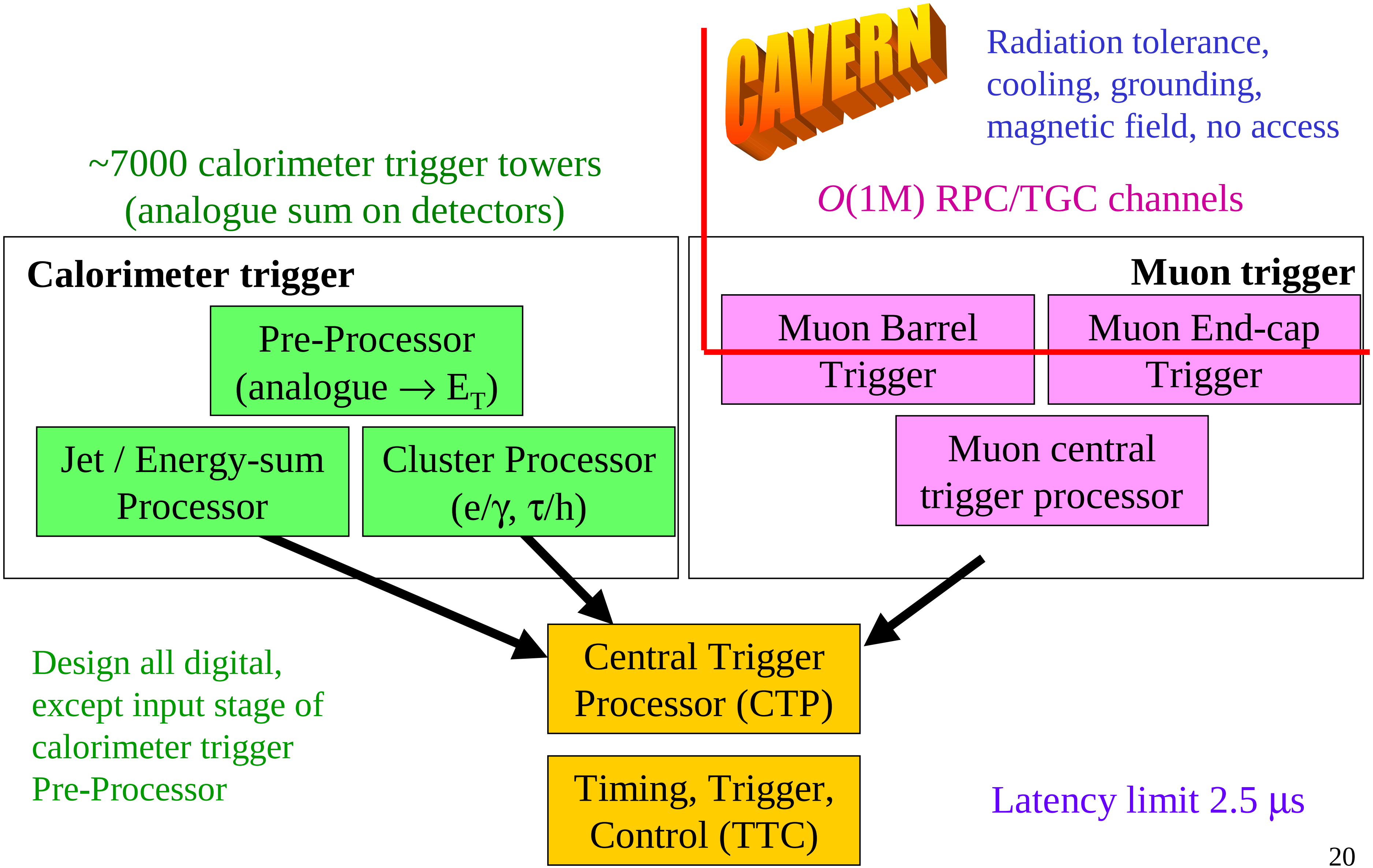
Tree

(Data for monitoring)

1-bit output
(YES or NO)

(Information to guide
next selection level)

Overview of ATLAS first-level trigger



Radiation tolerance,
cooling, grounding,
magnetic field, no access

~7000 calorimeter trigger towers
(analogue sum on detectors)

O(1M) RPC/TGC channels

Calorimeter trigger

Pre-Processor
(analogue → E_T)

Jet / Energy-sum
Processor

Cluster Processor
(e/γ, τ/h)

Muon trigger

Muon Barrel
Trigger

Muon End-cap
Trigger

Muon central
trigger processor

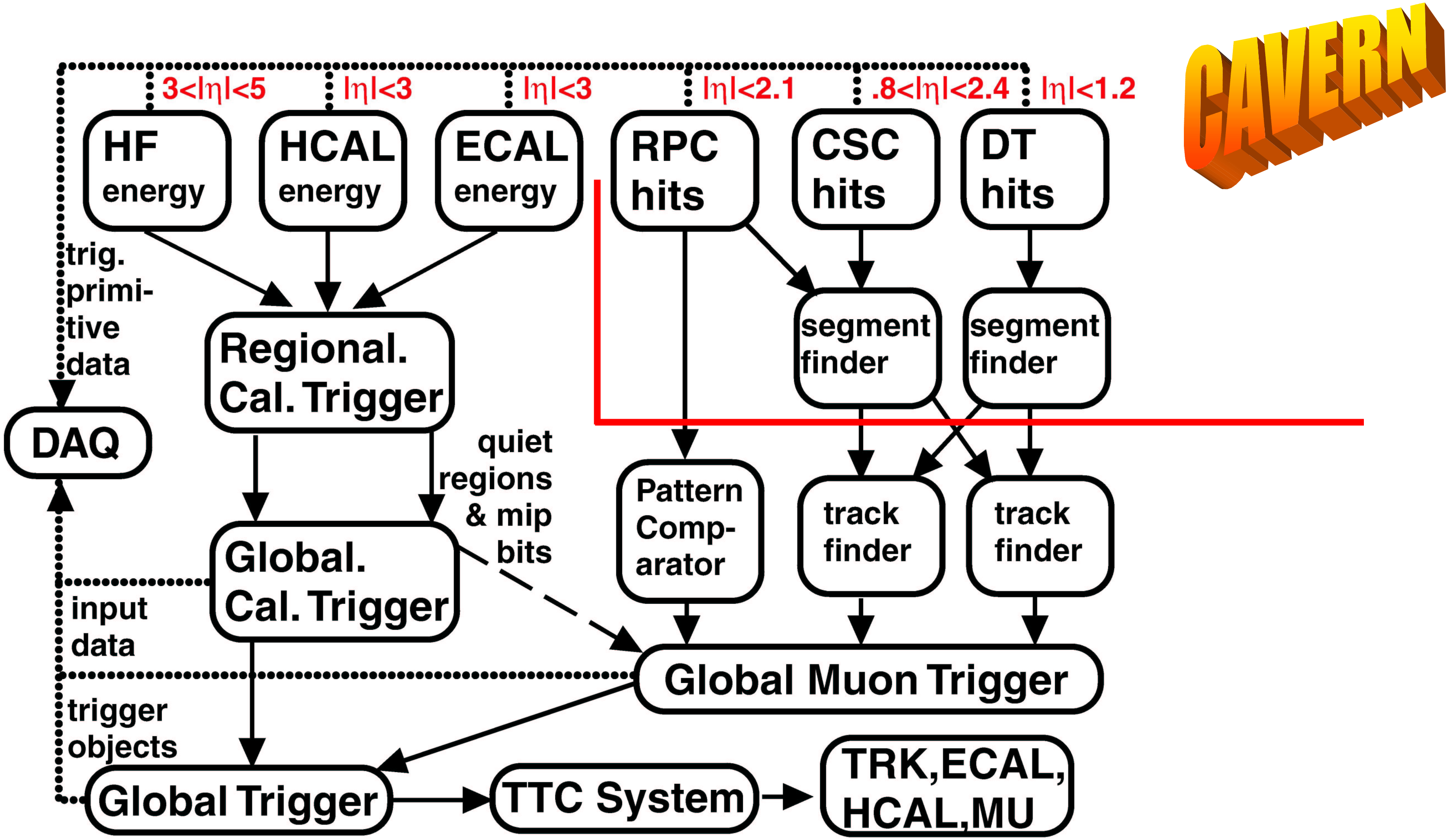
Central Trigger
Processor (CTP)

Timing, Trigger,
Control (TTC)

Design all digital,
except input stage of
calorimeter trigger
Pre-Processor

Latency limit 2.5 μs

Overview of CMS first-level trigger



CAVERN

$3<|\eta|<5$ $|\eta|<3$ $|\eta|<3$ $|\eta|<2.1$ $.8<|\eta|<2.4$ $|\eta|<1.2$

HF energy

HCAL energy

ECAL energy

RPC hits

CSC hits

DT hits

trig. primi-tive data

Regional. Cal. Trigger

segment finder

segment finder

DAQ

quiet regions & mip bits

Pattern Comp-arator

track finder

track finder

Global. Cal. Trigger

input data

Global Muon Trigger

trigger objects

Global Trigger

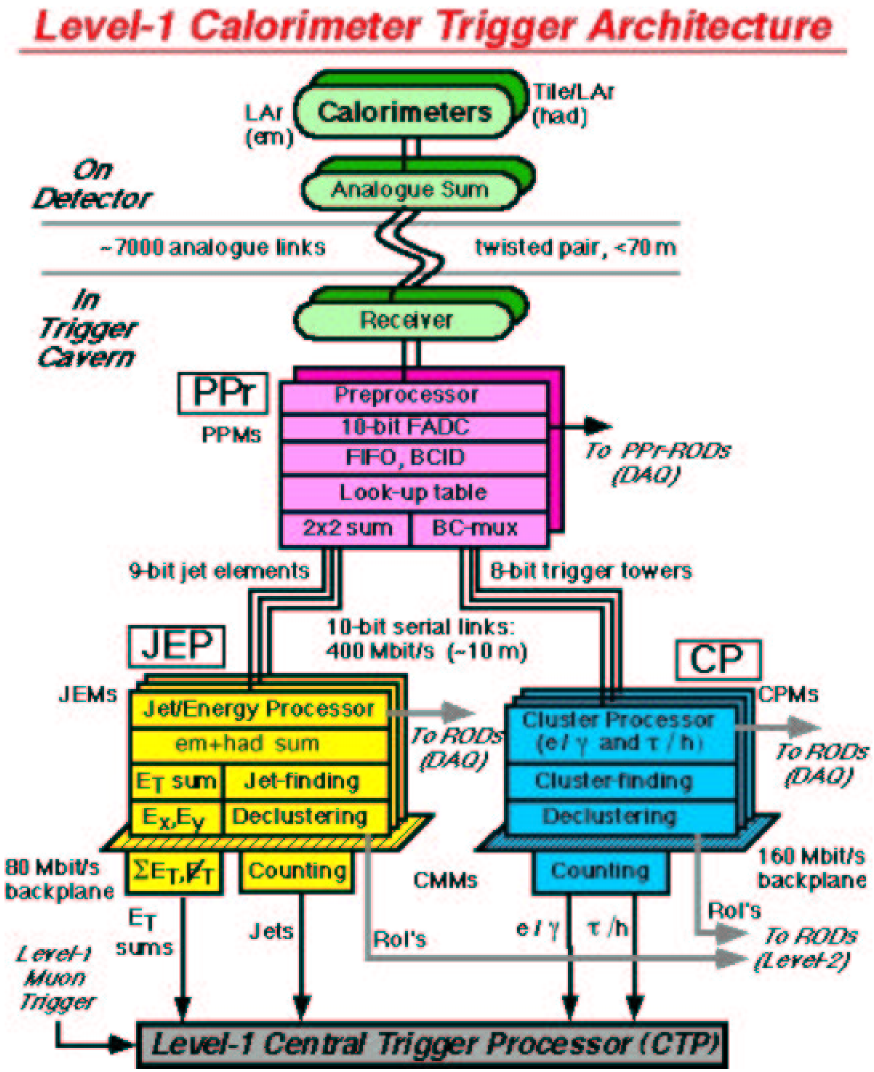
TTC System

TRK,ECAL, HCAL,MU

Latency limit 3.2 µs

Example: ATLAS calorimeter trigger

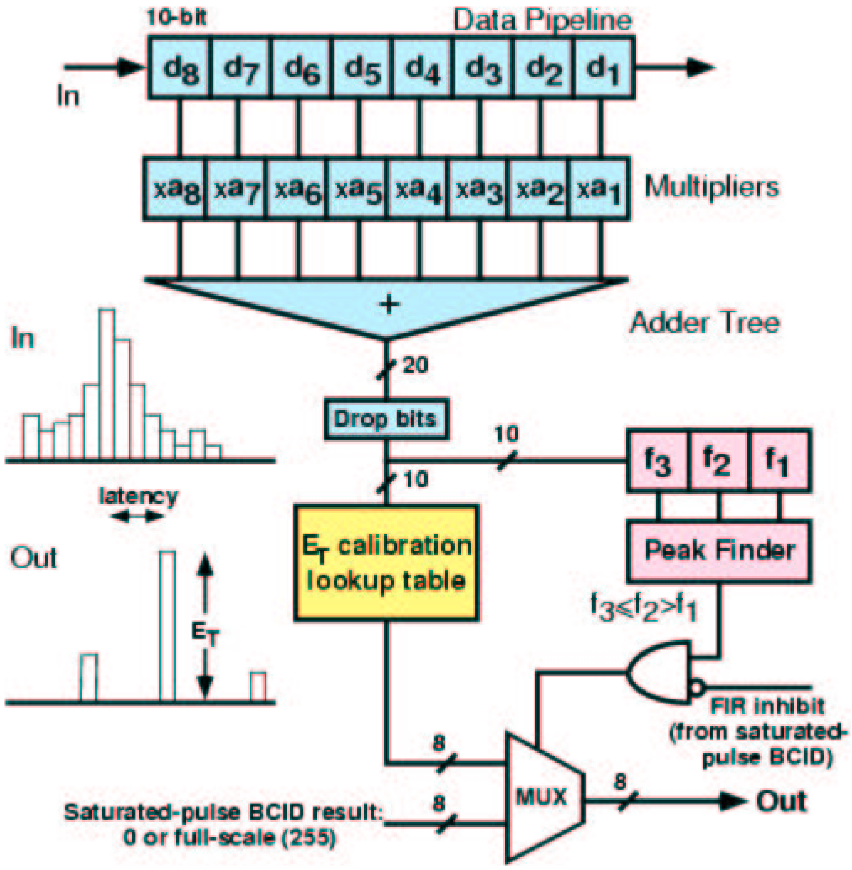
- Analogue electronics on detector sums signals to form trigger towers
- Signals received and digitised
  - Digital data processed to measure E_T per tower for each BC
    - E_T matrix for ECAL and HCAL
- Tower data transmitted to CP (4 crates) and JEP (2 crates)
  - Fan out values needed in more than one crate
    - Motivation for very compact design of processor
- Within CP & JEP crates, values need to be fanned out between electronic modules, and between processing elements on the modules
- Connectivity and data-movement issues drive the design



Bunch-crossing identification

- Calorimeter signals extend over many bunch crossings
  - Need to combine information from a sequence of measurements to estimate the energy and identify the bunch crossing where the energy was deposited
- Apply Finite Impulse Response filter
  - Result → LUT to convert to E_T
  - Result → peak finder to determine BC where energy was deposited
- Need to take care of signal distortion for very large pulses
  - Don’t lose most interesting physics!
- An ASIC incorporates the above
  - Includes data compression on output
    - “BC multiplexing”

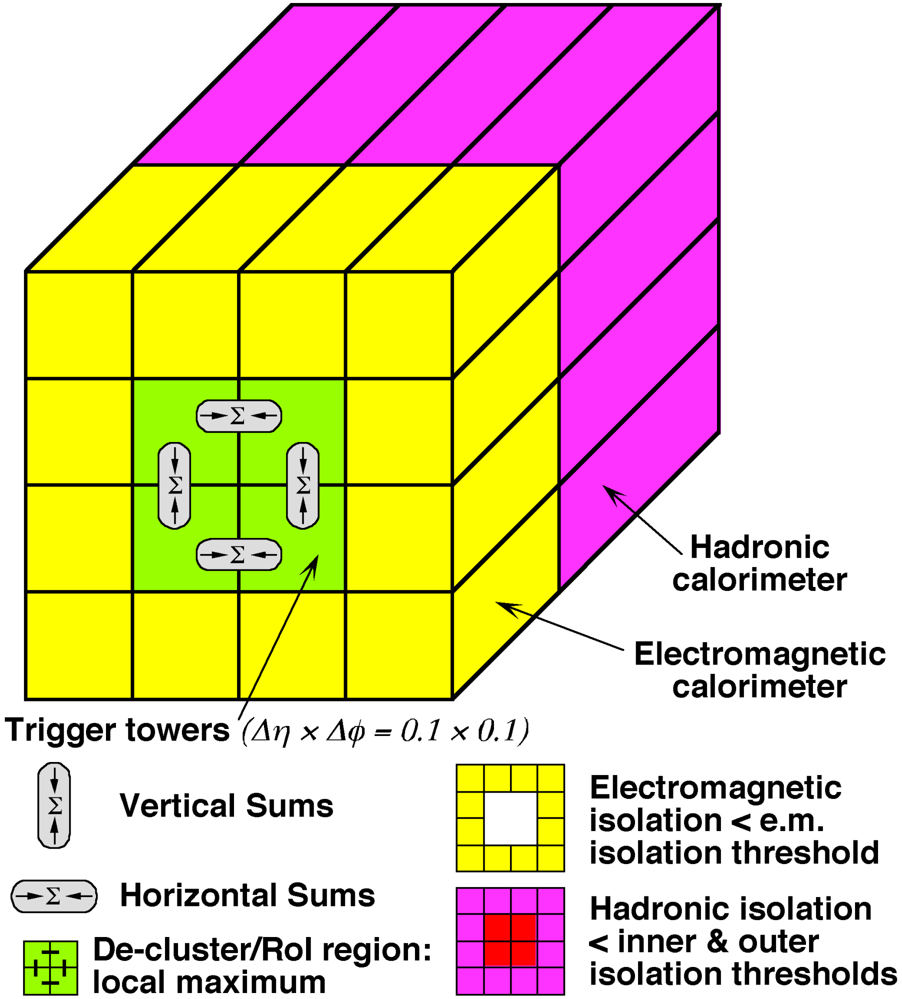
e.g. ATLAS



E_T value assigned to unique BC

ATLAS e/γ trigger (implemented in CP)

- ATLAS e/γ trigger is based on 4×4 “overlapping, sliding windows” of trigger towers
  - Each trigger tower 0.1×0.1 in η×ϕ
    - η pseudo-rapidity, ϕ azimuth
  - ~3500 such towers in each of the EM and hadronic calorimeters
- There are ~3500 such windows
  - Each tower participates in calculations for 16 windows
    - This is a driving factor in the trigger design



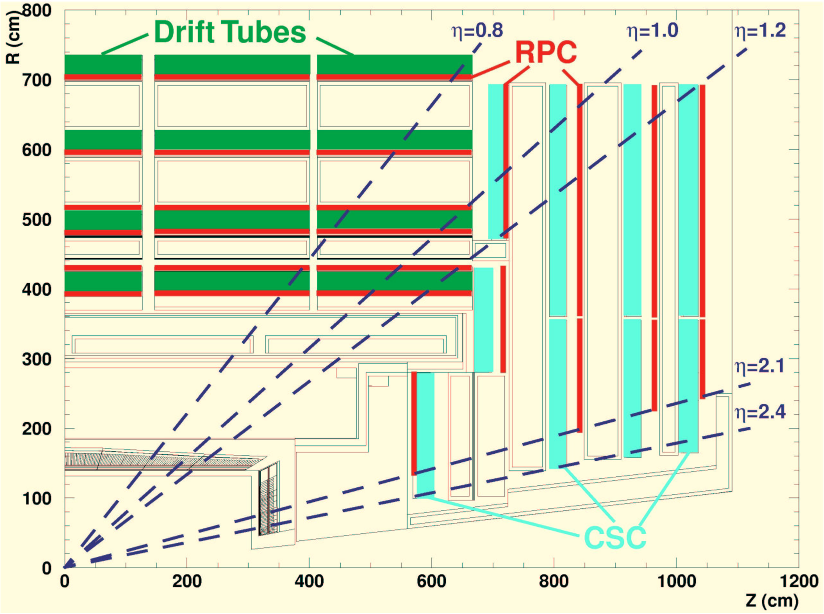
Data transmission and Cluster Processor

- The array of E_T values computed in the Preprocessor has to be transmitted to the CP every 25 ns
  - Use digital electrical links to CP modules (LVDS)
    - **~5000 links @ 400 Mbps**
      - 2000 Gbps total (equiv. *O*(100M) voice calls) after using BC multiplexing compression
    - Convert to 160 Mbps single-ended signals on CP modules
  - Fan out data to neighbouring modules over very high density custom back-plane
    - **~800 pins per slot in 9U crate**
    - **160 Mbps point-to-point**
  - Fan out data to 8 large FPGAs in each CP module
    - Receive data at 160 Mbps in FPGAs that perform algorithms

- The e/γ (together with the τ/h) algorithm is implemented in FPGAs
  - This has only become feasible with recent advances in FPGA technology
    - Require very large and very fast devices
  - Each FPGA handles 4×2 windows
    - Needs data from 7×5×2 towers (η×φ×{E/H})
  - Algorithm is described in a language (VHDL) that can be converted into the FPGA configuration file
    - Flexibility to adapt algorithms in the light of experience
  - Parameters of the algorithms can be changed easily
    - E.g. cluster-E_T thresholds are held in registers that can be programmed without reconfiguring the FPGAs

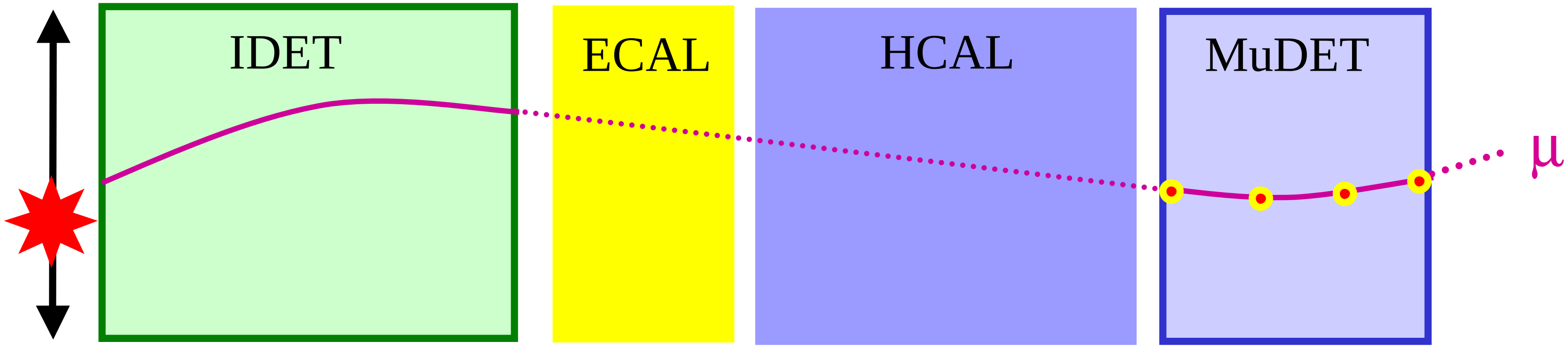
Example: CMS muon trigger

- CMS muon system includes three detector technologies
  - RPC and DT in barrel
  - RPC and CSC in endcaps
- All three detector systems participate in the first-level trigger
  - Specific logic for each system
  - Global logic that combines all the muon information
- I will use RPC-based trigger for illustration in the following
  - Note that RPCs have very good intrinsic time resolution (much better than the BC interval at LHC)



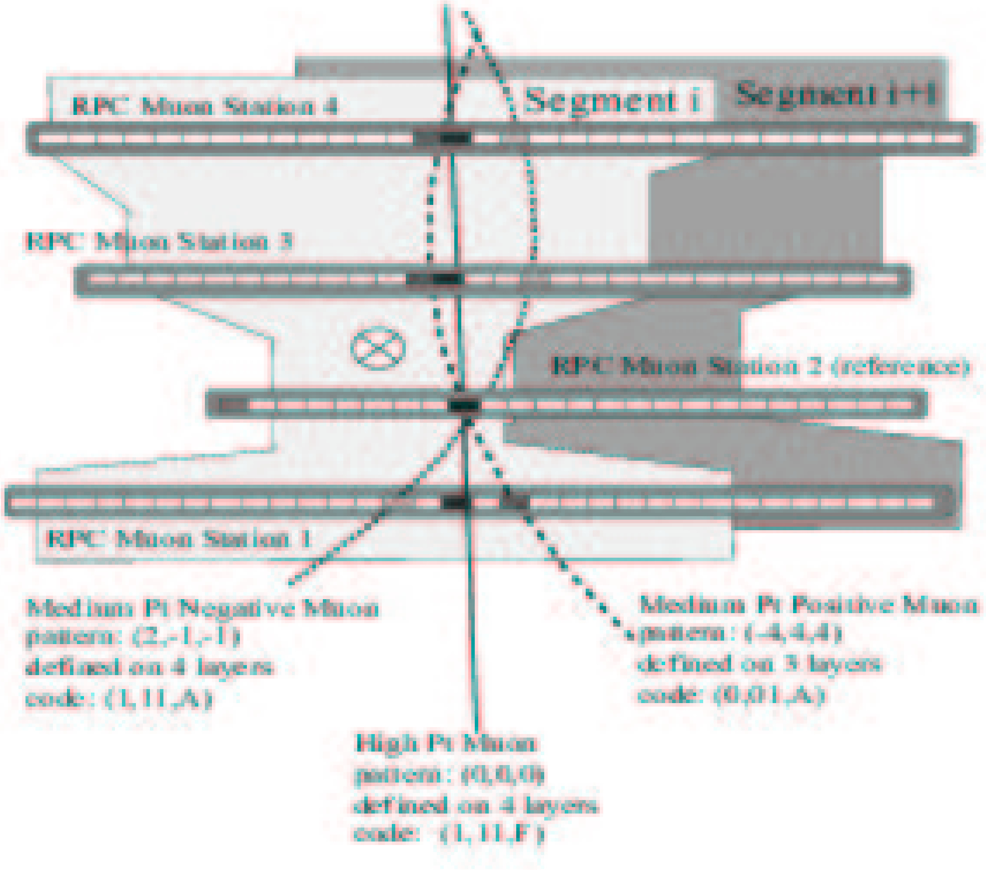
CMS muon trigger - general remarks

- In general, muon triggers look for a pattern of hits in the muon chambers consistent with a high-p_T muon originating from the collision point
  - – The deflection in the magnetic field is inversely proportional to p_T
    - An infinite-momentum muon follows a straight-line trajectory

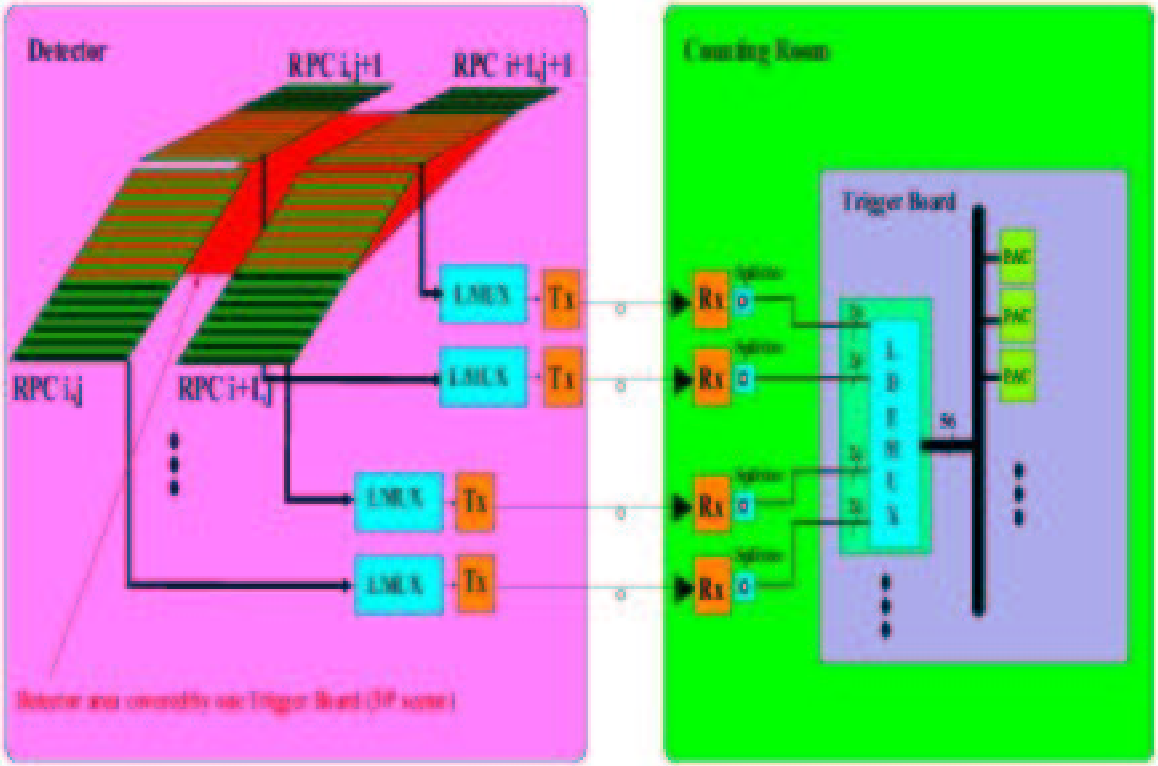


RPC trigger algorithm

- The principle of operation of the CMS RPC-based trigger is to identify patterns of hits in the detectors consistent with high-p_T muons
  - The pattern recognition is implemented in an ASIC ("PAC" = PAttern Comparator)
  - Note that, with the exception of the reference station, strips participate in the logic for several "segments"
    - Need to share information between PACs



RPC trigger - data movement



- On-detector
  - Bunch-crossing identification
  - Data compression
    - Low occupancy allows use of zero-suppression
      - Buffer (latency, possible data loss)
- Off-detector
  - Fan-out
  - Data expansion
  - Pattern matching

FIRST-LEVEL TRIGGER
FOR SUPER-COLLIDER?

Higher luminosity?

- Increased rates for all processes
  - Increased rates for high-p_T processes
    - Compensate by raising p_T thresholds and/or enhancing rate capabilities of DAQ, High-Level Triggers and Offline computing and/or improving algorithms to get more background-rejection power by using more detailed information
  - Increased pile-up (degrades e.g. isolation requirements)
    - Compensate by raising p_T thresholds further
    - Reduce bunch-crossing interval
      - Fewer interactions per BC - i.e. reduce (increase in) pile-up
    - Use finer detector granularity to reduce occupancy at fixed luminosity
  - Increased radiation levels
    - Stronger requirements for shielding and/or radiation tolerance of on-detector trigger electronics
      - Possible implications for personnel access to underground counting rooms in case of SLHC
    - Background hits in muon detectors potentially a problem for muon trigger

Higher energy?

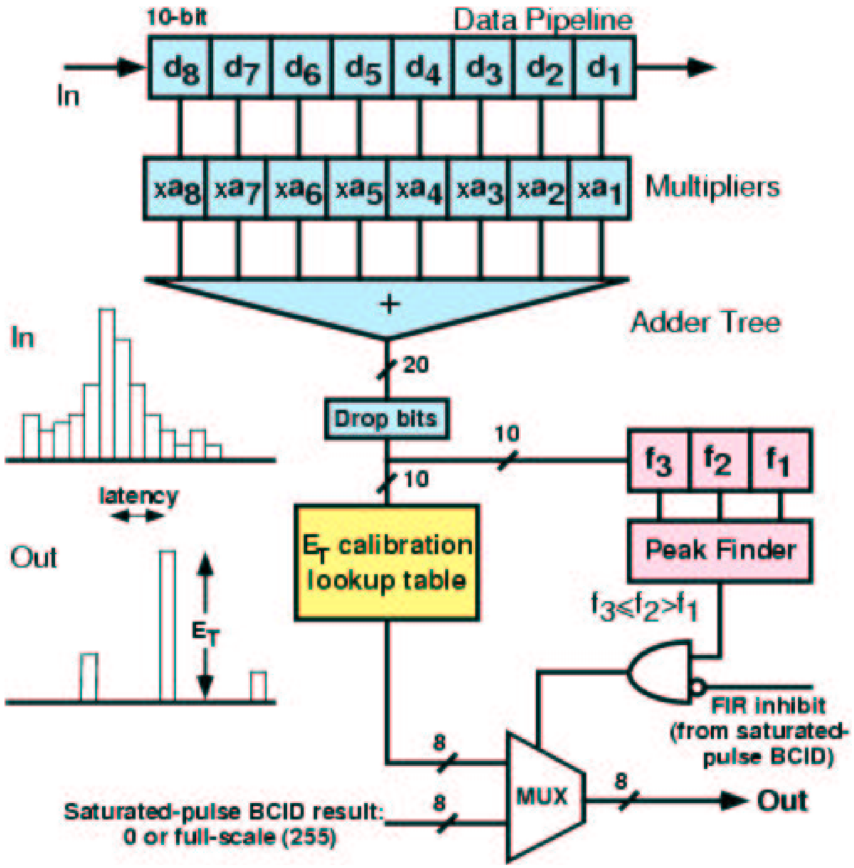
- Less impact on trigger design than increase in luminosity
  - Total cross-section grows slowly with energy
    - Increase in pile-up relatively modest
  - Increase in radiation levels in cavern also comparatively modest
    - Shielding in forward regions important
- Increased rates for high-p_T processes (both signal and background)
  - Compensate by raising p_T thresholds and/or enhancing rate capabilities of DAQ, High-Level Triggers and Offline computing and/or improving algorithms to get more background-rejection power by using more detailed information)

Shorter bunch-crossing interval?

- More data to process per unit time
  - Given continuing advances in microelectronics (e.g. FPGAs), faster trigger processing appears to be feasible
- More data to move per unit time
  - The data-movement aspects of the first-level triggers are already very challenging at LHC, e.g. very high-density and very high-speed backplanes
    - R&D would be required in this area
      - Data movement technologies
      - Data compression techniques
- Issue of "timing-in" the experiment
  - Fine tuning of timing in LHC experiments relies on resolving the bunch structure in trigger and front-end electronics
    - This model may not be viable for BC intervals less than ~ 10 ns.

Calorimeter trigger with 12.5 ns BC period

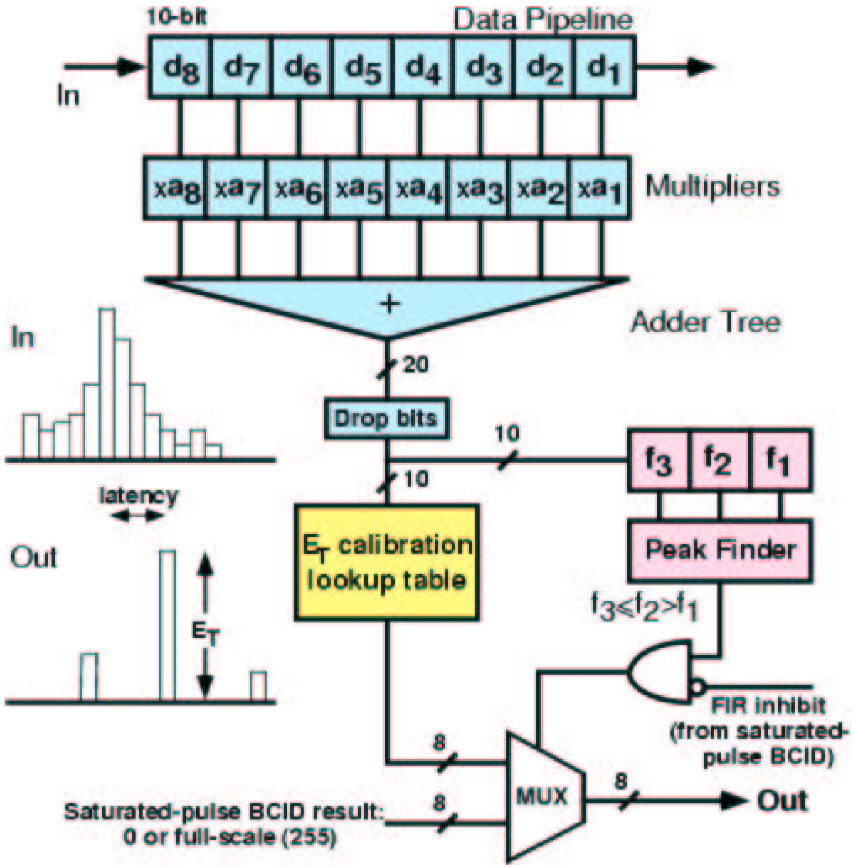
- Digitization ~ OK
  - 80 MHz ADC
- Faster digital processing ~ OK
  - Clock at logic at 80 MHz
    - Note that some logic (e.g. in CMS calorimeter trigger) is clocked at multiples of the machine frequency
- Data movement - need R&D
  - Faster links?
    - LHC trigger designs are quite ambitious (e.g. backplanes)
  - More aggressive data compression?
    - Zero-suppression?
      - Issues of latency and information loss
    - More complex schemes?



Extremely short BC interval

- Important consequences for LVL1 and detector electronics
  - At 25 ns (probably also at 12.5 ns), detectors and LVL1 can resolve the BC that contained the interaction of interest
    - Detector signals digitized (or analogue-buffered) once per BC
    - Time of interaction known at ~1 ns precision from BC time
- Operation with quasi-continuous beam?
  - Clock LVL1 and front-end electronics with frequency less than BC frequency of machine (e.g. BC ÷ N) or free-running
  - Many issues would need to be addressed
    - How to set-up timing of triggers and detectors
    - How to handle timing ambiguities
      - "Event" no longer has clear meaning
        - » Not easy to sort out on timescale of LVL1 trigger
      - E.g. E_T in different towers forming cluster need to be matched in time as well as space (cluster threshold, isolation thresholds, etc)
  - LVL1 trigger (and also detector electronics) for such a machine would require extensive R&D

Calorimeter trigger with continuous beam?



- Modify ideas to work with free-running (e.g. 80 MHz) clock?
  - E_T output must be insensitive particle time of arrival (c.f. clock)
    - Resolution for high E_T c.f. pile-up "noise" for low E_T measurements (important for isolation requirements)
  - Assign E_T to two consecutive clock cycles ("time-bins") in cases of ambiguity
    - Depends on resolution of timing algorithm

Need to use comparatively complex algorithms to extract energy and time

More granular detectors?

- If used in LVL1 trigger
  - Advantage of lower occupancy in presence of pile-up and potentially better background-rejection power
  - In case of muon trigger, would allow more precise p_T measurement for fixed magnet configuration (i.e. better spatial resolution)
  - But more data to move and process
- In any case
  - Increase amount of detector data
    - To be stored during LVL1 latency
      - Motivation to keep latency as short as possible
    - To be moved to higher-level triggers and DAQ
      - Motivation not to enlarge time-frame for readout more than necessary
      - Consider extended use of data compression

LVL1 trigger menu for SLHC

- A very rough assessment has been made [1] of first-level trigger thresholds for SLHC at 10^{35} $cm^{-1}s^{-1}$ luminosity
- Some illustrative examples are:
  - Single muon $p_T > 30$ GeV (rate ~ 25 kHz)
    - Pair of muons each with $p_T > 20$ GeV (rate ~ few kHz?)
  - Single e/γ $p_T > 55$ GeV (rate ~ 20 kHz)
    - Pair of e/γ each with $p_T > 30$ GeV (rate ~ 5 kHz)
  - Single jet $p_T > 350$ GeV (rate ~ 1 kHz)
    - Jet $p_T > 150$ GeV and missing-$p_T > 80$ GeV (rate ~ 1-2 kHz)
- Selection necessarily less inclusive than at LHC
  - Very high thresholds OK for SLHC discovery physics
    - Looking for objects / interactions at very high mass scale
  - Can use more exclusive selections for precision measurements of particles already discovered at LHC

[1] Physics potential and experimental challenges of the LHC luminosity upgrade, hep-ph/0204087

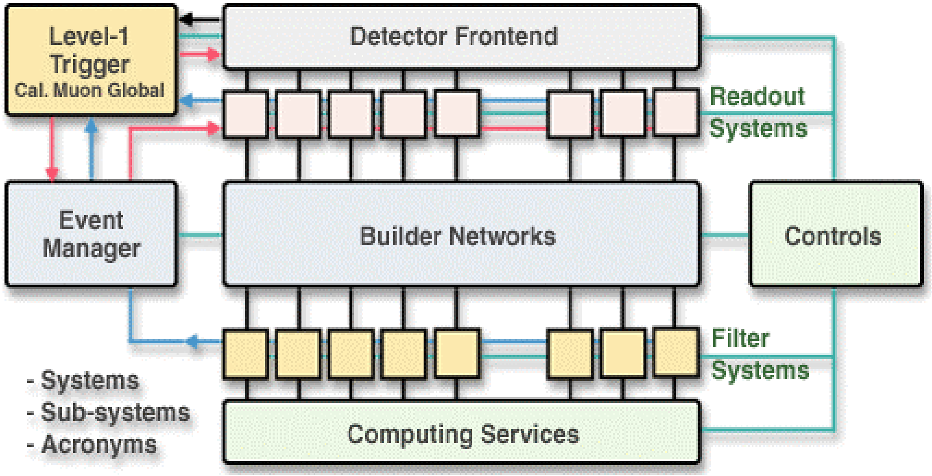
HIGH-LEVEL TRIGGERS

High-Level Triggers (and DAQ) at LHC

e.g. CMS

CMS LVL1 Trigger TDR
CERN-LHCC-2000-038

- In the LHC experiments, data are transferred to large buffer memories after a LVL1 accept
  - In normal operation, the subsequent stages should not introduce further dead-time
- The data rates at the HLT/DAQ input are still massive
  - ~1 MByte event size (after data compression) @ ~100 kHz event rate ⇒ ~ 100 GByte/s data rate
- This is far beyond the capacity of the bus-based event building of LEP
  - Use network-based event building to avoid bandwidth bottlenecks



Data are stored in Read-out Systems until they have been transferred to the Filter Systems (associated with HLT processing), or until the event is rejected

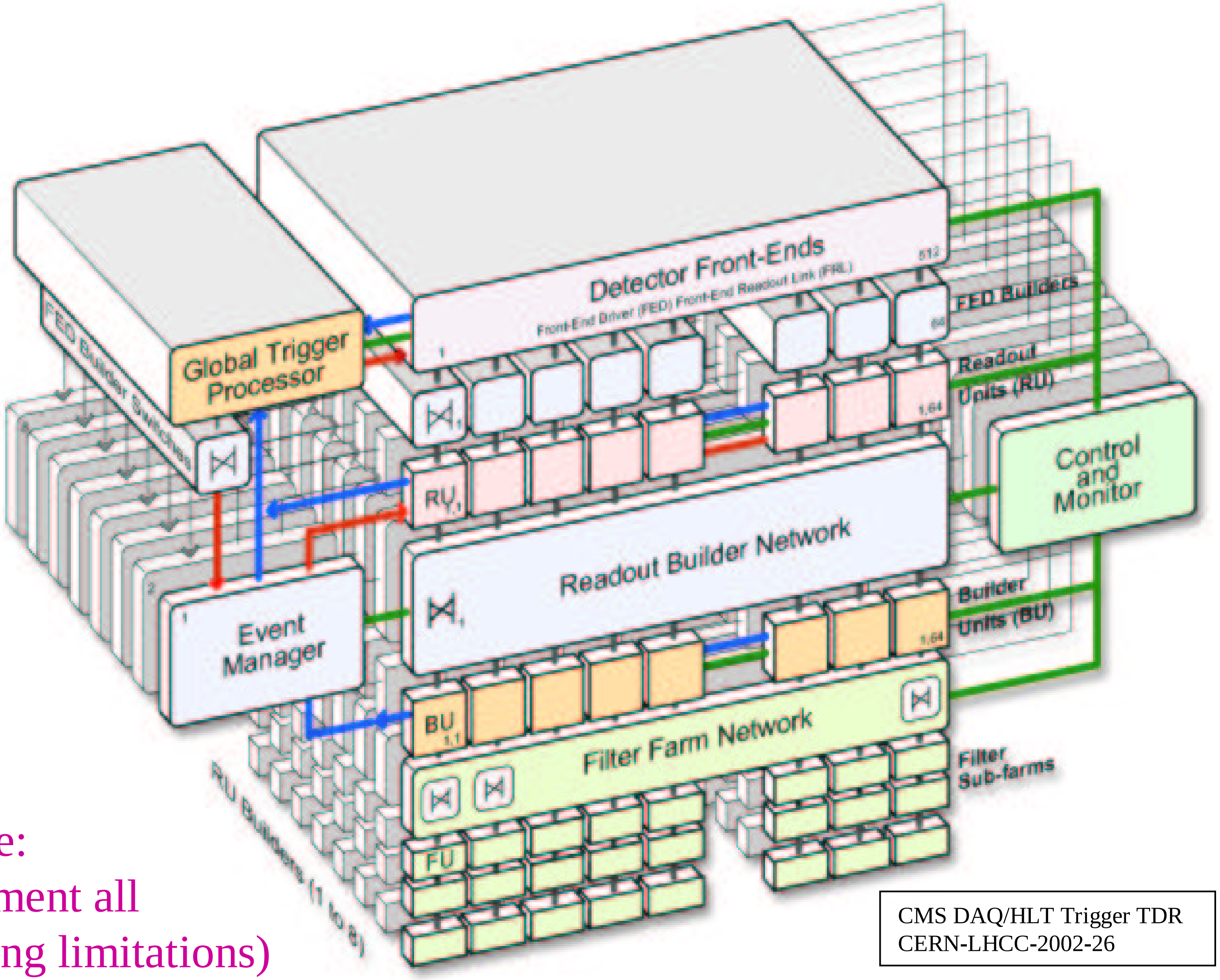
No node in the system sees the full data rate — each Read-out System covers only a part of the detector — each Filter System deals with only a fraction of the events

HLT and DAQ: Concepts

- The massive data rate after LVL1 poses problems even for network-based event building — different solutions are being adopted to address this, for example:
  - In CMS, the event building is factorized into a number of slices each of which sees only a fraction of the rate
    - Requires large total network bandwidth (⇒ cost), but avoids the need for a very large single network switch
  - In ATLAS, the Region-of-Interest (RoI) mechanism is used to access the data selectively — only move data needed for LVL2 processing
    - Reduces by a substantial factor the amount of data that need to be moved from the Readout Systems to the Processors
    - Implies relatively complicated mechanisms to serve the data selectively to the LVL2 trigger processors ⇒ more complex software

CMS: The Slicing concept

Eight slices:
Each slice sees
only 1/8th of
the events

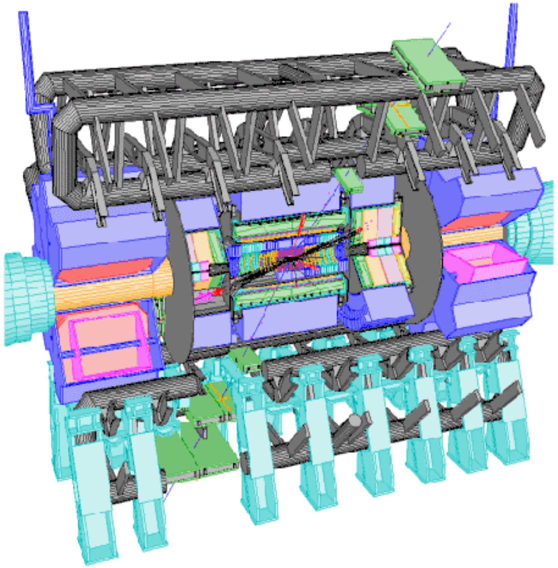


Additional advantage:
Don’t have to implement all
slices initially (funding limitations)

CMS DAQ/HLT Trigger TDR
CERN-LHCC-2002-26

ATLAS: The Region-of-Interest and sequential-selection concepts

Dimuon event in ATLAS



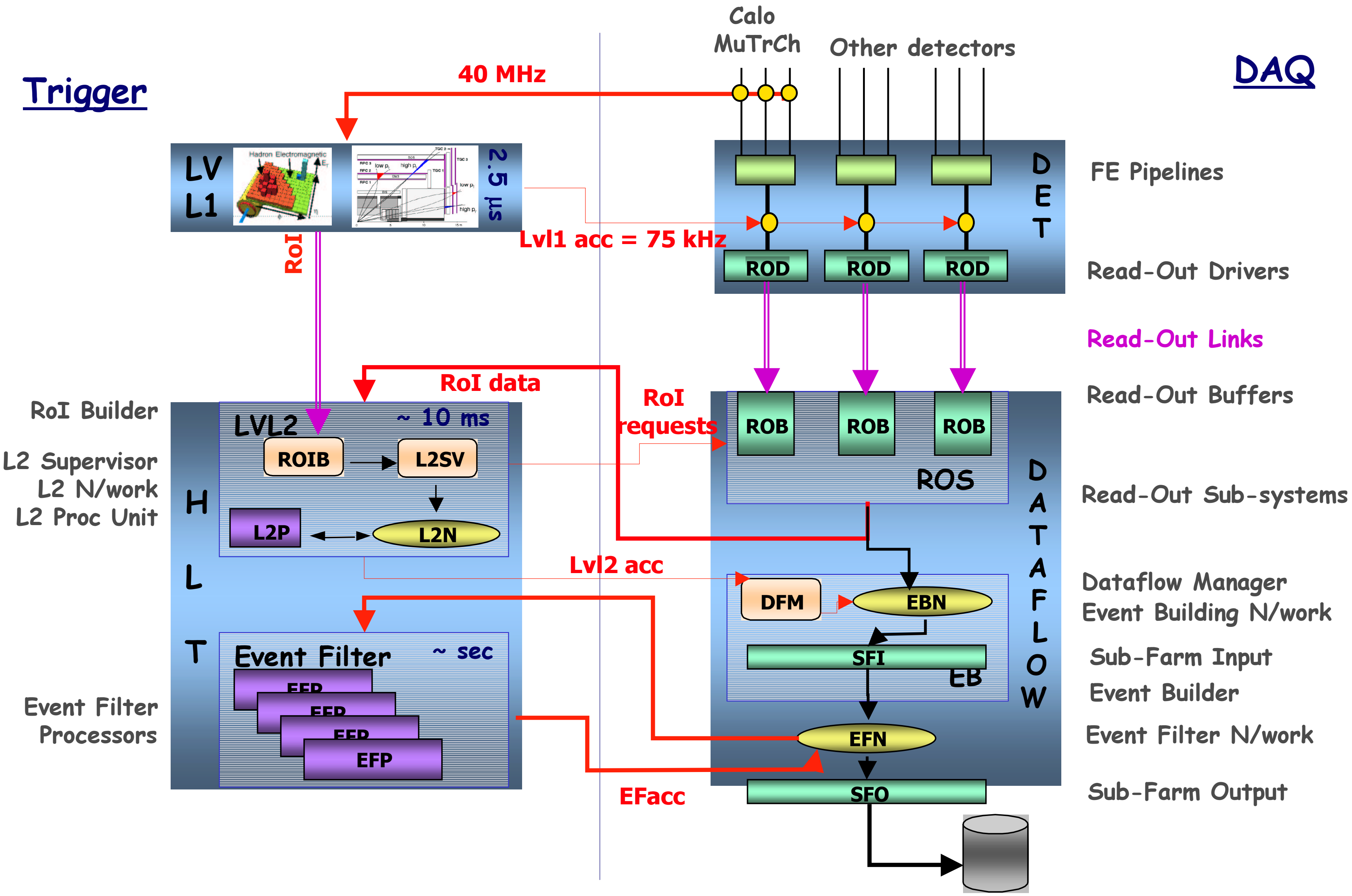
- Muon identification
  - LVL1 identifies RoIs
  - Validate in muon spectrometer
    - Reject?
  - Validate in inner tracker
    - Reject?
  - Isolation in calorimeter
    - Reject?

- Two concepts are used to avoid moving all the data from the Read-out Systems
  - The Region-of-Interest (RoI) concept
    - LVL1 indicates the geographical location of candidate objects
      - E.g. two muon candidates
    - LVL2 only accesses data from RoIs
      - Small fraction of total data
  - The sequential-selection concept
    - Data are accessed by LVL2 initially only from a subset of detectors (e.g. muon spectrometer only)
    - Many events rejected without accessing the other detectors
      - Further reduction in total data transfer

HLT FOR SUPER-COLLIDER?

- The computer industry provides the technologies that will be used to build much of the HLT (and DAQ) systems at LHC
  - Computer networks & switches: high performance at affordable cost
  - PCs: exceptional value for money in processing power
  - High-speed network interfaces: standard items (e.g. Ethernet at 1 Gbit/s)
- Continued improvements in these, driven by mass-market applications, should provide the tools to implement the HLT for experiments at a hadron Super-Collider
  - See talk of Pierre Vande Vyvre
- Concepts used in ATLAS and CMS could be combined:
  - Sliced readout
  - Region-of-interest mechanism
  - Sequential data access, processing and selection

ROI mechanism



Trigger

DAQ

Calo
MuTrCh

Other detectors

40 MHz

LV
L1

2.5 μs

RoI

Lvl1 acc = 75 kHz

DET

FE Pipelines

ROD ROD ROD

Read-Out Drivers

Read-Out Links

RoI data

RoI requests

ROB ROB ROB

ROS

Read-Out Buffers

Read-Out Sub-systems

RoI Builder
L2 Supervisor
L2 N/work
L2 Proc Unit

HLT

LVL2 ~ 10 ms

ROIB

L2SV

L2P

L2N

Lvl2 acc

DATAFLOW

DFM

EBN

SFI

EB

Dataflow Manager
Event Building N/work
Sub-Farm Input
Event Builder

Event Filter ~ sec

EFP EFP EFP EFP

Event Filter
Processors

EFN

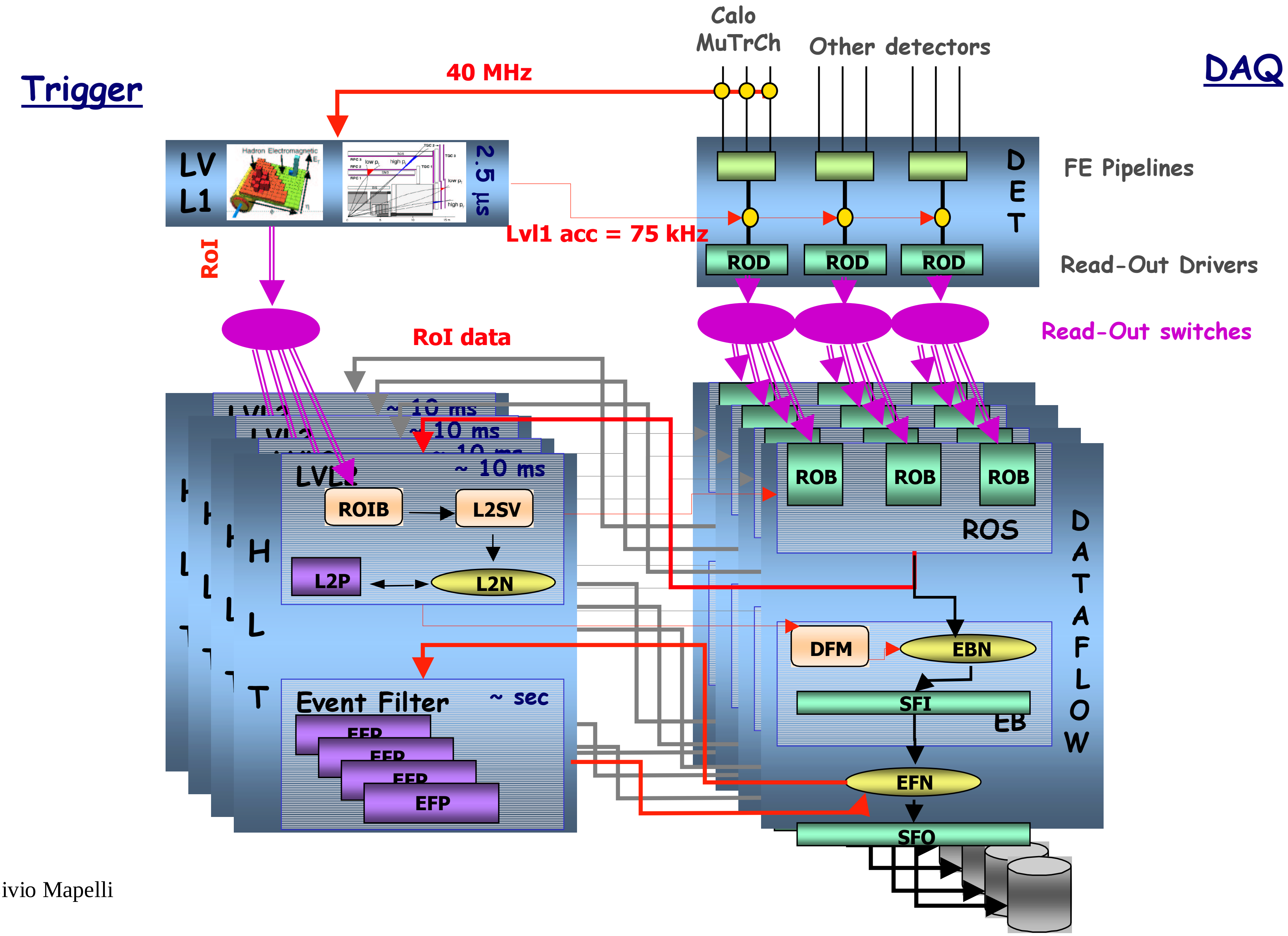
Event Filter N/work

EFacc

SFO

Sub-Farm Output

Slicing with the ROI mechanism

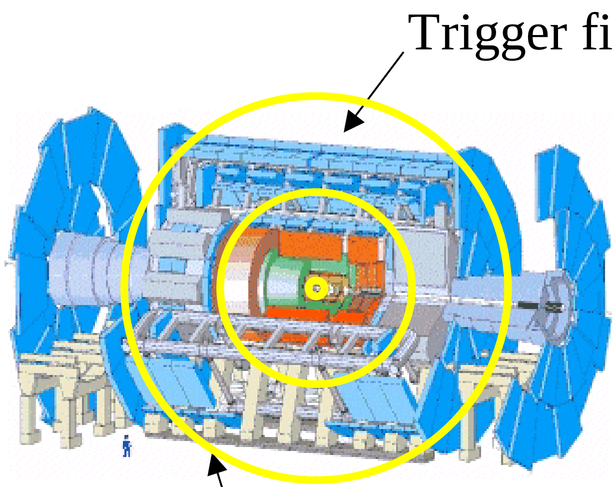


In conclusion....

- Some key issues that would require study for hadron-Super-Colliders are:
  - Improved first-level trigger algorithms and architectures (more complex algorithms, using more information)
    - More rejection power for fixed efficiency (and at affordable cost!)
  - Data movement in the first-level trigger
    - For reduced BC period and/or increased detector granularity
    - Data transfer technologies; data-compression techniques
  - Implications of very short BC intervals
    - Major impact of first-level trigger (and detector electronics) design
  - Improved HLT/DAQ architectures capable of supporting large data bandwidth and processing power
    - To cope with increased LVL1 rate and/or increased event size
    - E.g. combine slicing, ROI and sequential-processing concepts

BACKUP SLIDES

Size of detectors and the speed of light



Trigger finds high-p_T muon here ⇒ select event

Need to read out also here

ATLAS, the biggest of the LHC detectors, is 22 m in diameter and 46 m in length

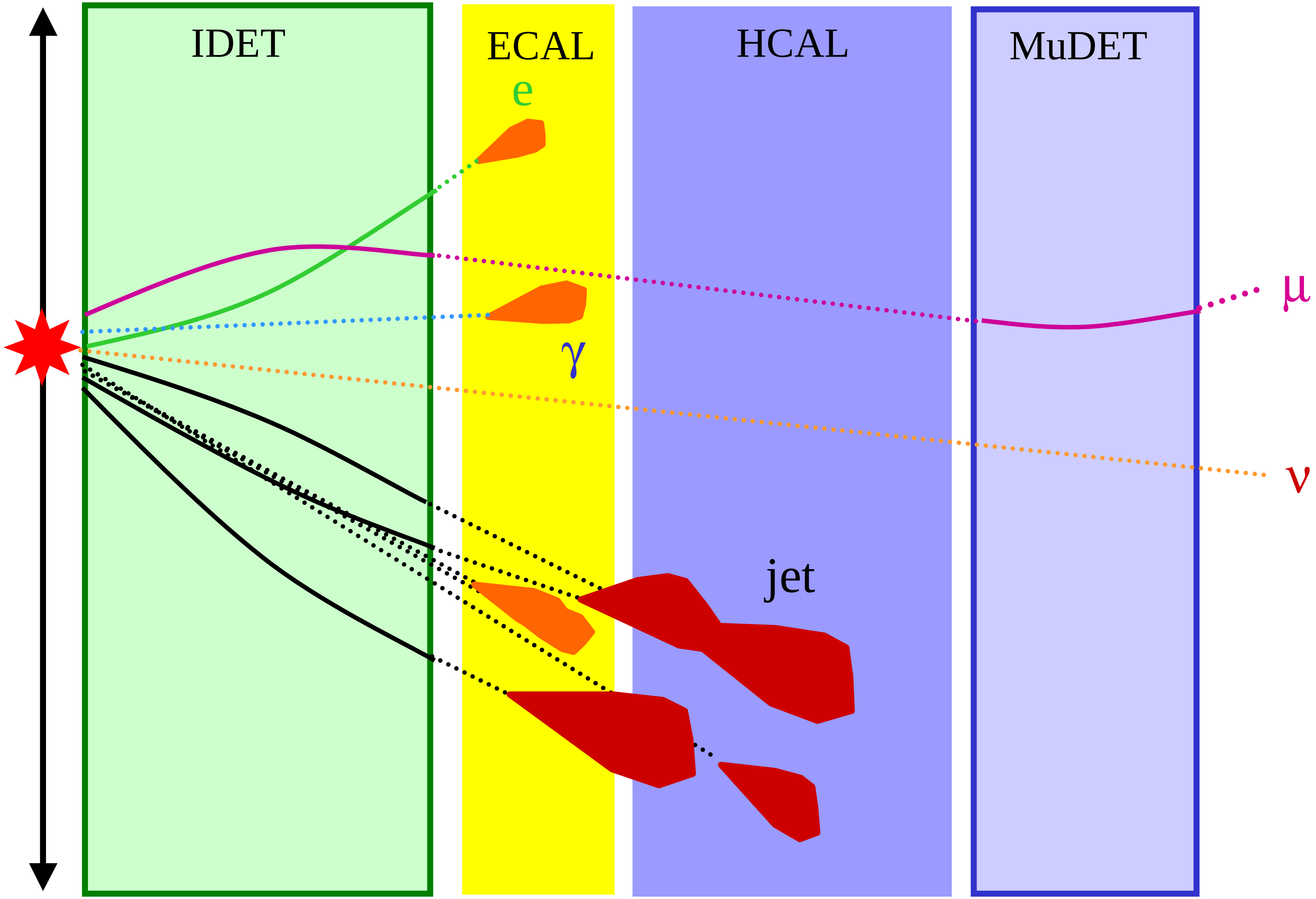
speed of light in air 0.3 m/ns

22 m × 3.3 ns/m = 73 ns
c.f. 25 ns BC period

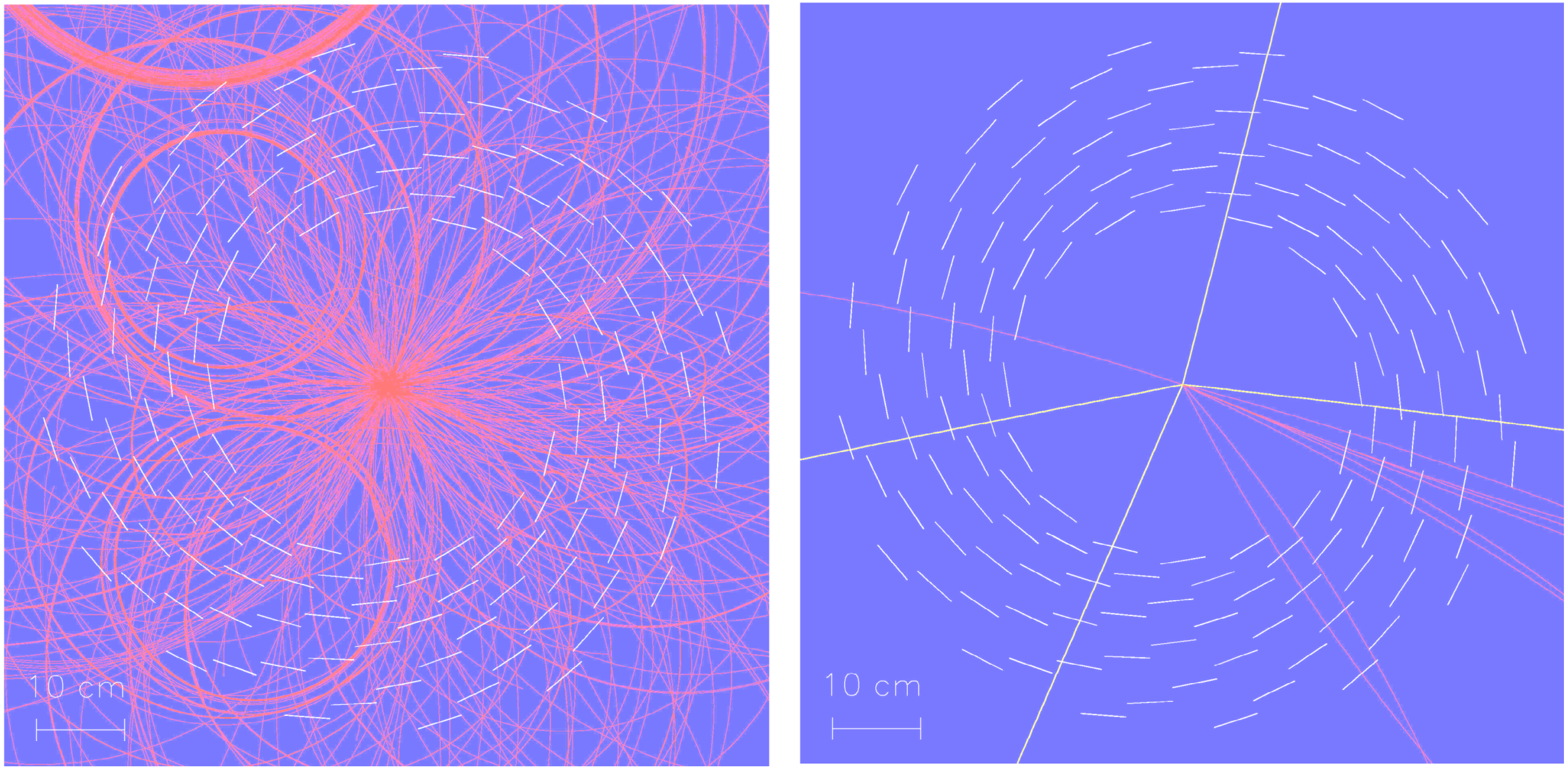
The other LHC detectors are smaller, but similar considerations apply

It is **impossible** to form and distribute a trigger decision within 25 ns
(in practice, latency is at least ~ 2 μs)

What do μ, e, γ, jets, etc “look like”?



Effect of p_T cut in minimum-bias events

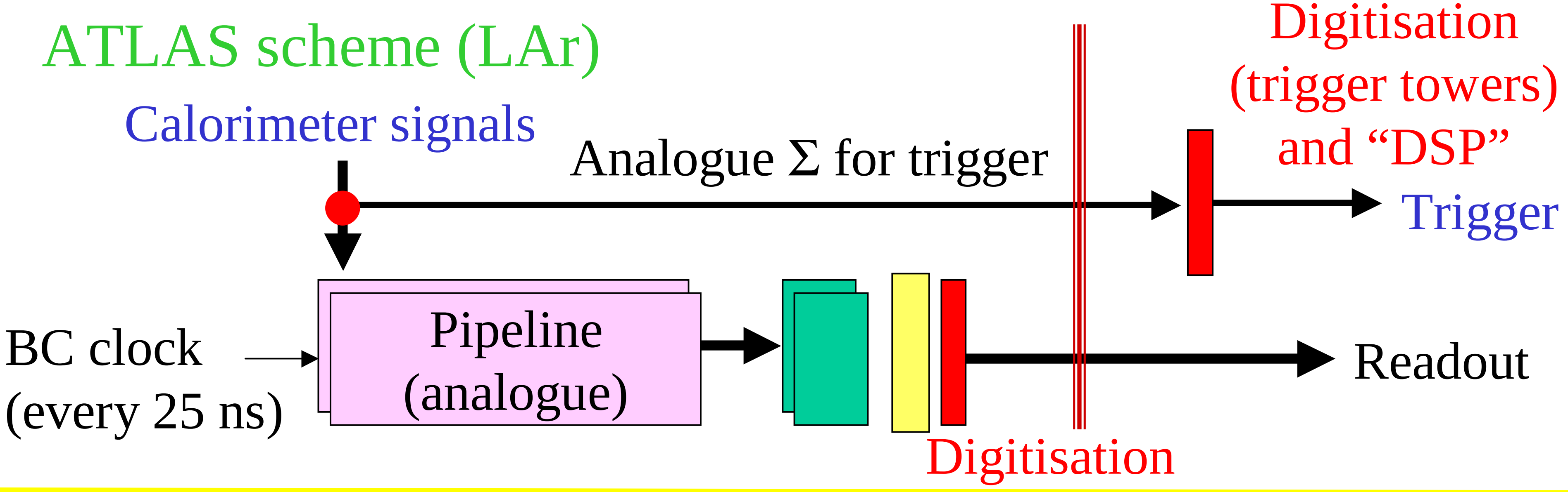


All tracks

$p_T > 2$ GeV

Simulated H→4μ event + 17 minimum-bias events

Digitisation options (ATLAS c.f. CMS)


ATLAS scheme (LAr)

Calorimeter signals

Analogue Σ for trigger

Digitisation (trigger towers) and "DSP"

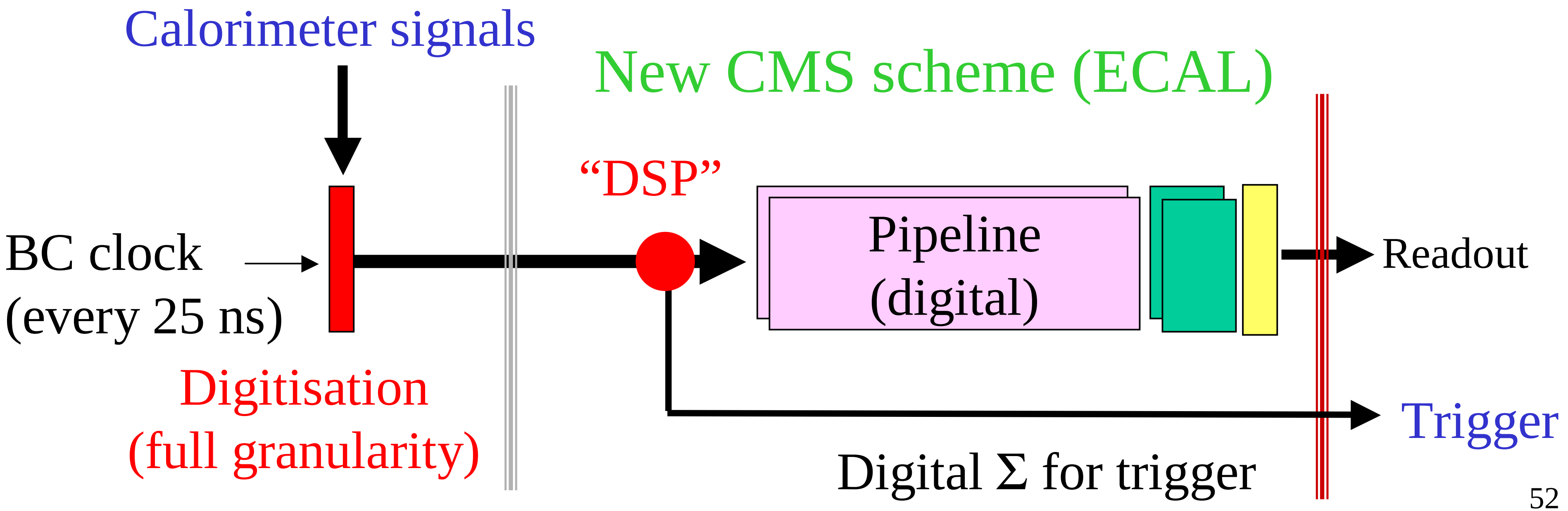
Trigger

BC clock (every 25 ns)

Pipeline (analogue)

Readout

Digitisation


Calorimeter signals

New CMS scheme (ECAL)

"DSP"

BC clock (every 25 ns)

Pipeline (digital)

Readout

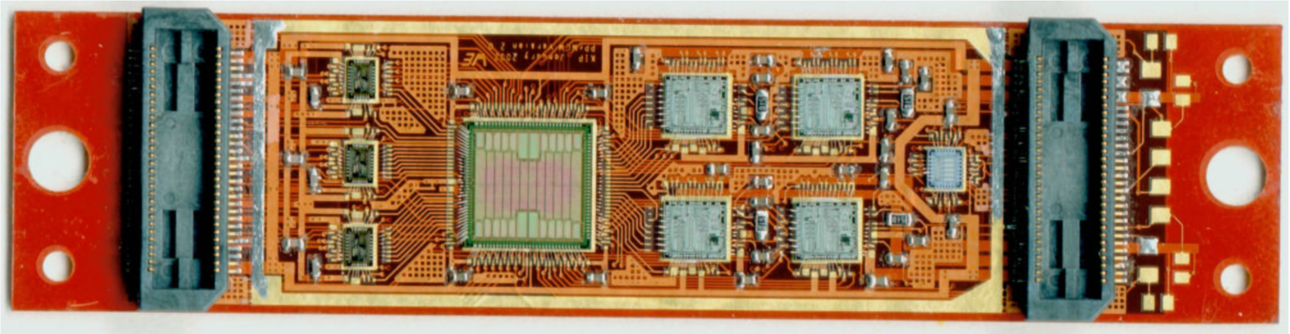
Trigger

Digitisation (full granularity)

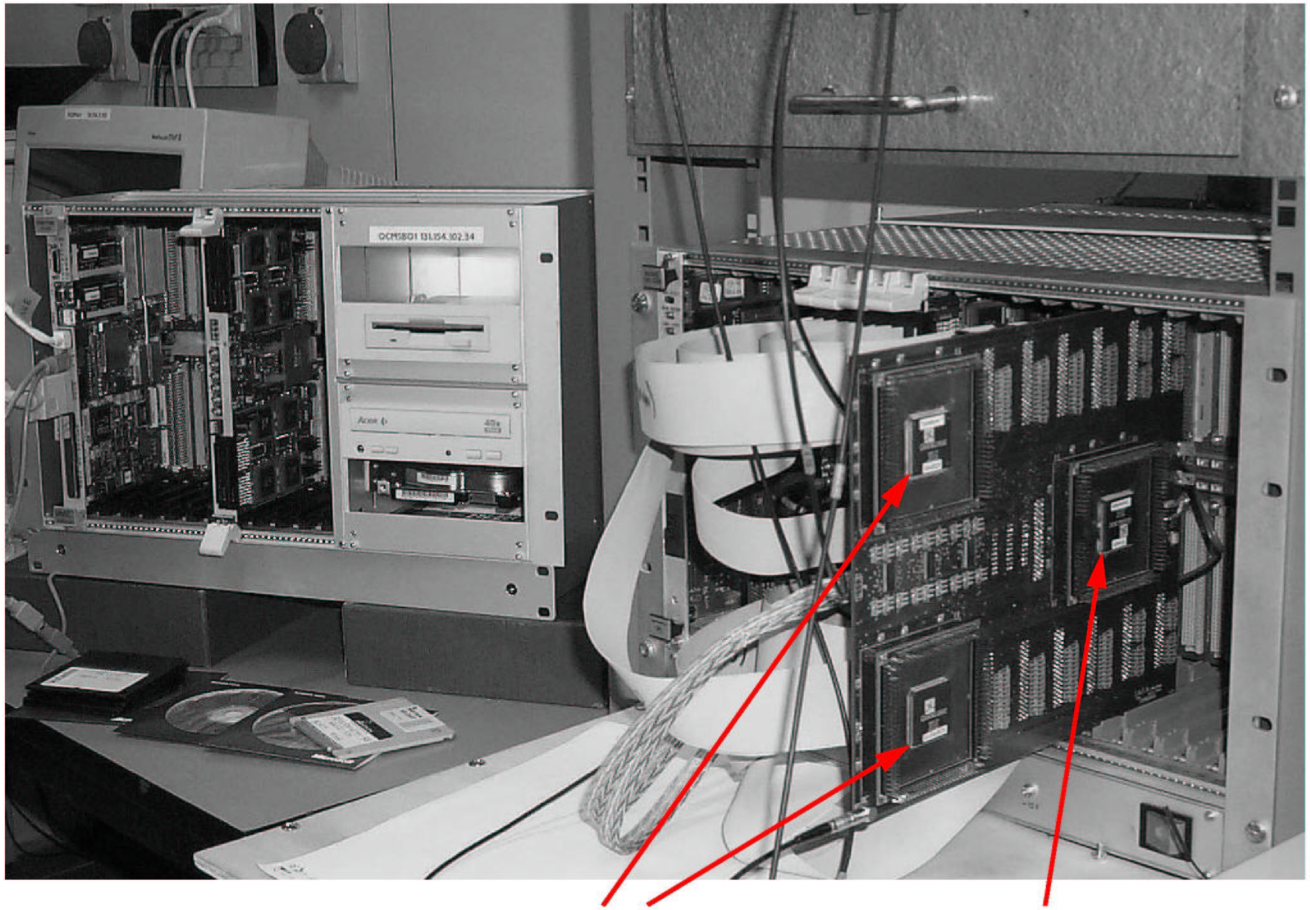
Digital Σ for trigger

ATLAS Pre-Processor MCM and ASIC

- ADC
  - Use commercial 40 MHz ADCs
- ASIC (the only one in the calorimeter trigger)
  - ASIC handles 10-bit inputs from four commercial 40 MHz ADCs
    - Calibration, zero-suppression, BC identification, readout, etc
    - Cost effective solution given quantity needed
- MCM
  - Contains 4 ADCs, PPr ASIC and LVDS drivers
    - Allows high-density, cost-effective implementation



DT trigger - prototype



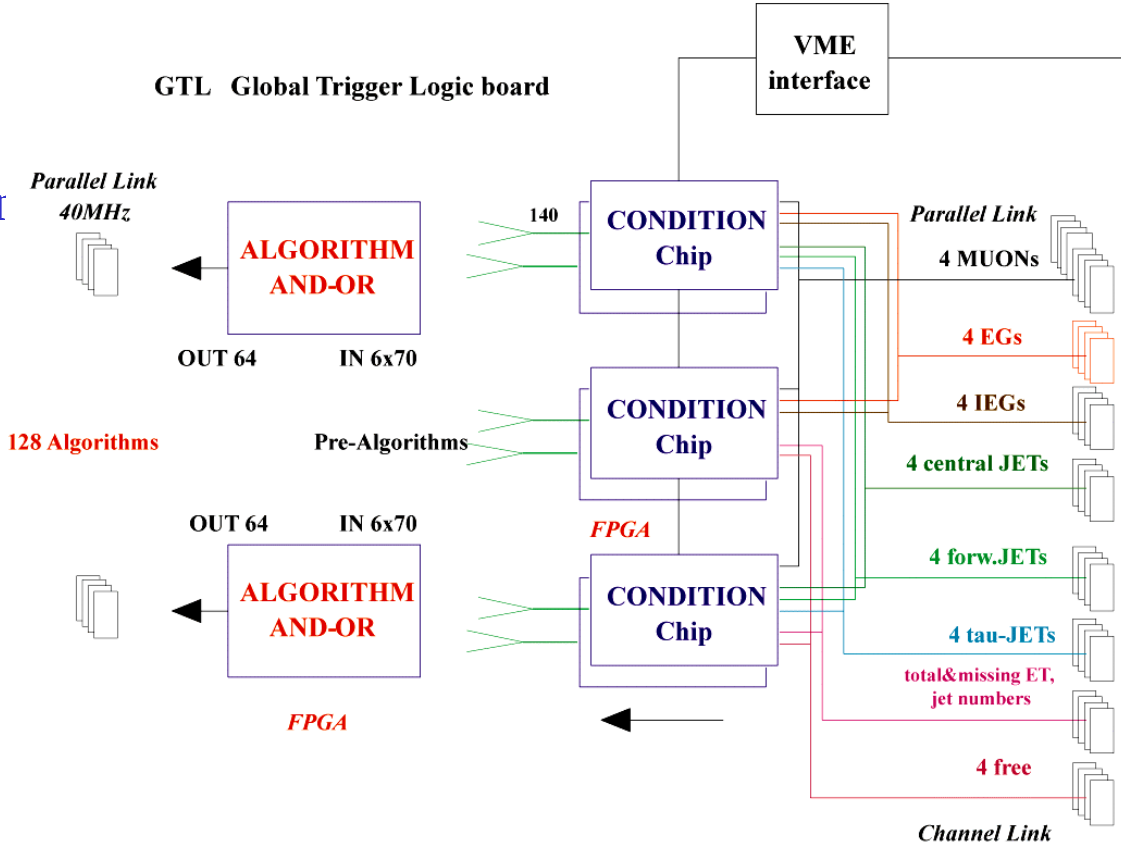
Track Sorter Master (data)

Track Sorter Master (sorting)

Global trigger decision

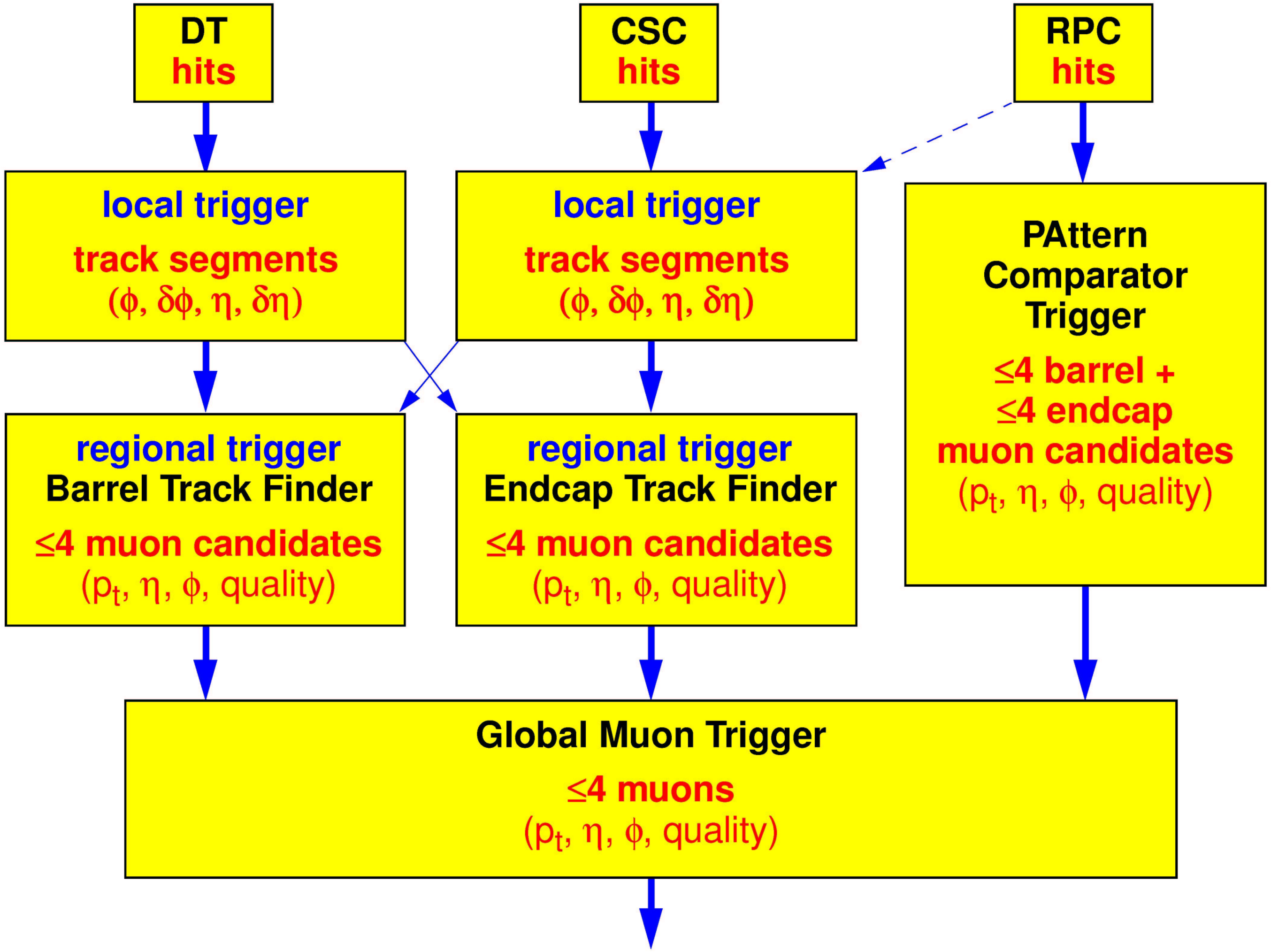
- Global trigger has to combine information from the different parts of the first-level trigger
  - Local objects: μ, e/γ, τ/h, jet
  - Energy sums
- Makes overall decision based on combinations of conditions
  - Inclusive triggers
    - E.g. $p_T(\mu) > 20$ GeV
  - More complex requirements
    - E.g. $p_T(\text{jet}) > 100$ GeV **and** $E_T^{miss} > 100$ GeV
  - Topological conditions (CMS)
    - E.g. $p_T(\mu_1) > 20$ GeV **and** $p_T(\mu_2) > 20$ GeV **and** $170^o < |\phi(1)-\phi(2)| < 190^o$

Example: CMS global trigger



Implemented in FPGAs

CMS muon trigger overview



DT
hits

CSC
hits

RPC
hits

local trigger
track segments
(ϕ, $\delta\phi$, η, $\delta\eta$)

local trigger
track segments
(ϕ, $\delta\phi$, η, $\delta\eta$)

PAttern Comparator Trigger
≤4 barrel +
≤4 endcap
muon candidates
(p_t, η, ϕ, quality)

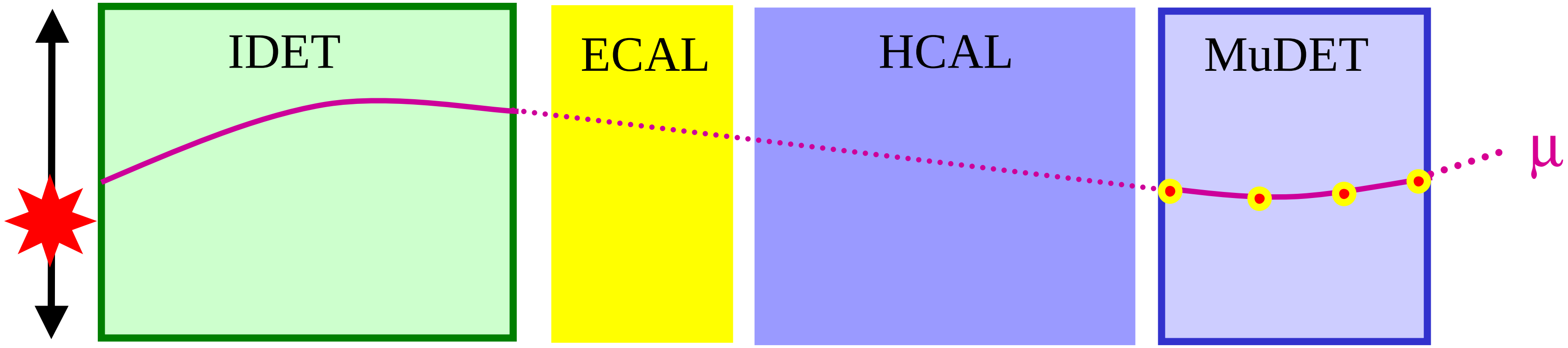
regional trigger
Barrel Track Finder
≤4 muon candidates
(p_t, η, ϕ, quality)

regional trigger
Endcap Track Finder
≤4 muon candidates
(p_t, η, ϕ, quality)

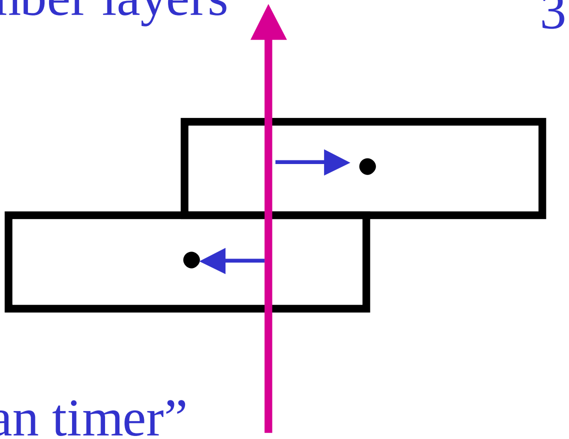
Global Muon Trigger
≤4 muons
(p_t, η, ϕ, quality)

CMS global trigger receives p_T, η, ϕ information for candidate e/γ, μ, etc.
(ATLAS central trigger works with multiplicity information only)

Illustration — principle of DT trigger



2 chamber layers

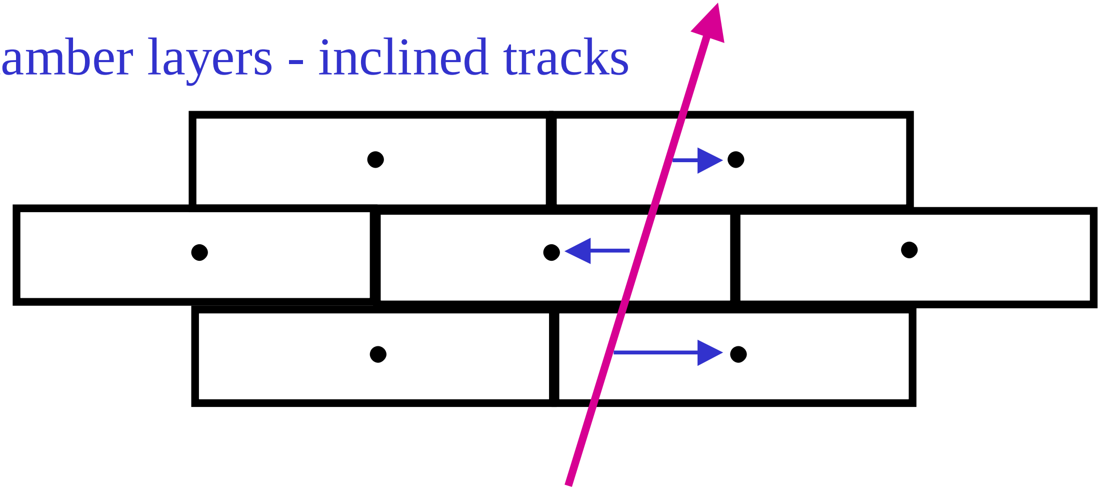


“mean timer”

$T_1+T_2 = T_{max}$

$(T_1-T_2)/2v_d = x$

3 chamber layers - inclined tracks



Extending the scheme to 4 DT layers, can handle inclined tracks even if 1 hit lost due to inefficiency or dead region

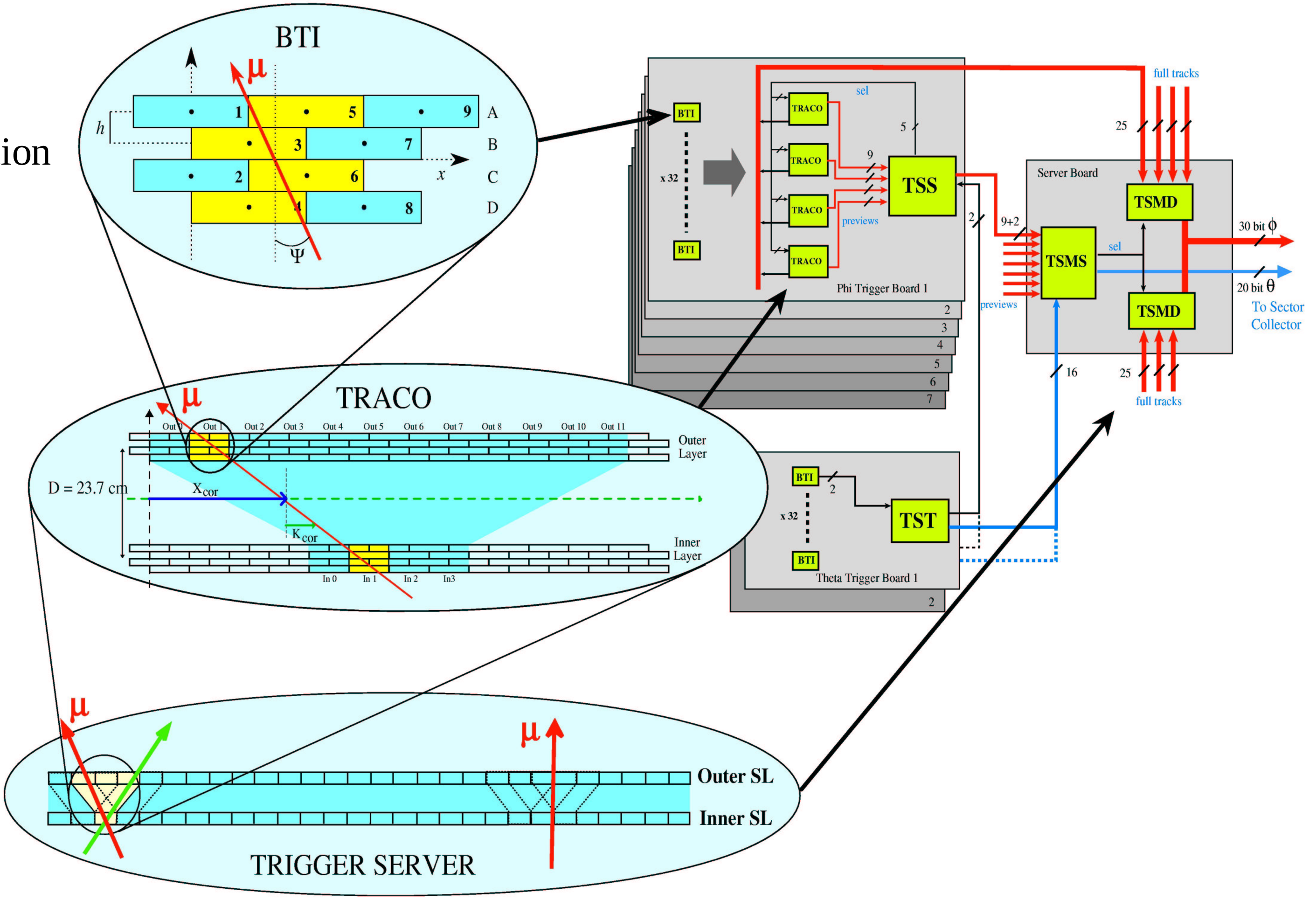
- provides identified BC, position, angle with high efficiency

Maximum DT 380 ns >> 25 ns

CMS local Drift Tube muon trigger

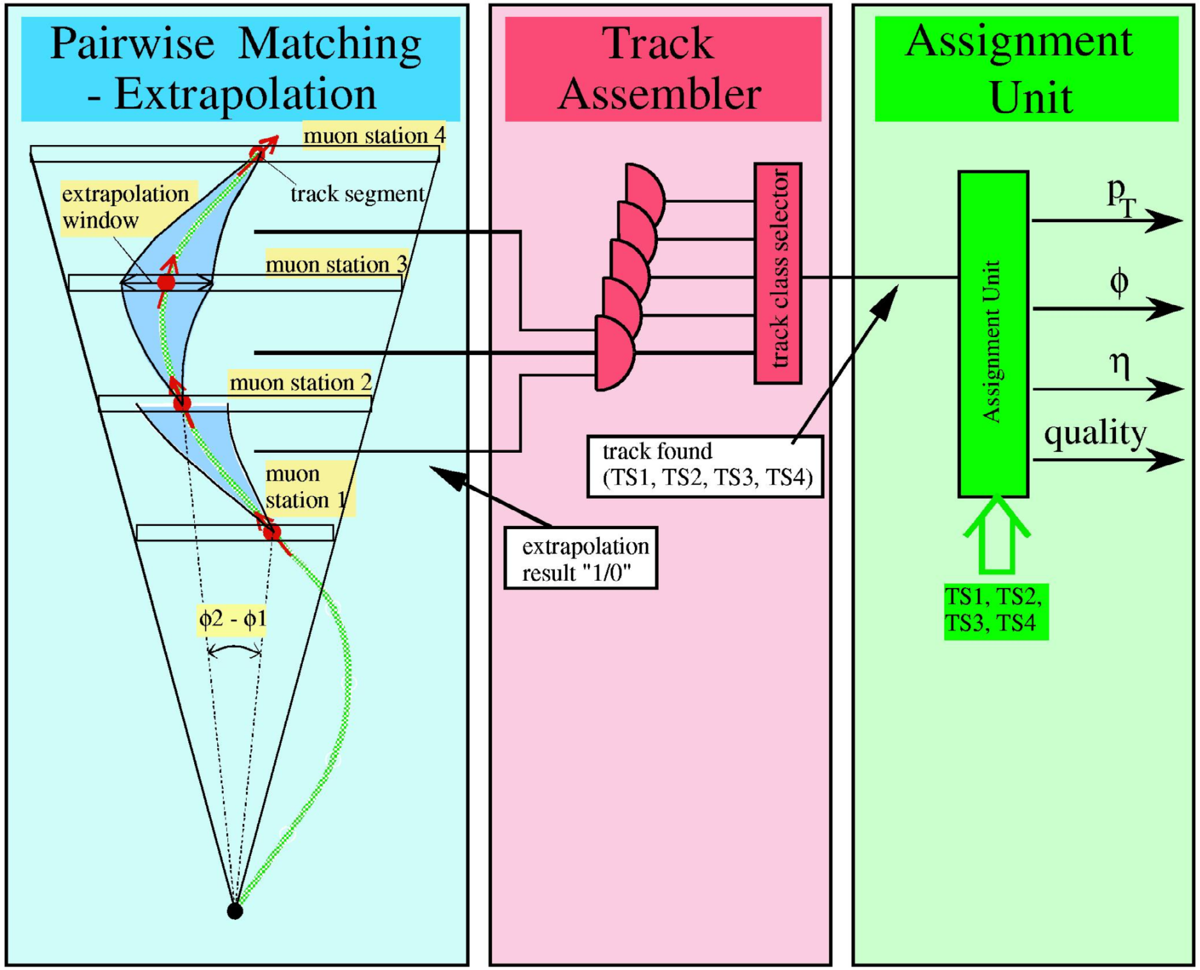
Bunch & **T**ime **I**dentification

TRAck **CO**rrelator



Local trigger electronics associated with each Super Layer is mounted on the detector and implemented using ASICs

CMS DT track finder



Track-finder electronics is mounted off detector and is implemented using FPGAs

- LUTs in FPGAs contain limits of extrapolation windows
- Track segments are combined to find the "best" two tracks within a sector
- The track parameters are then determined from the φ measurements in different stations