Triggering in the LHC Environment

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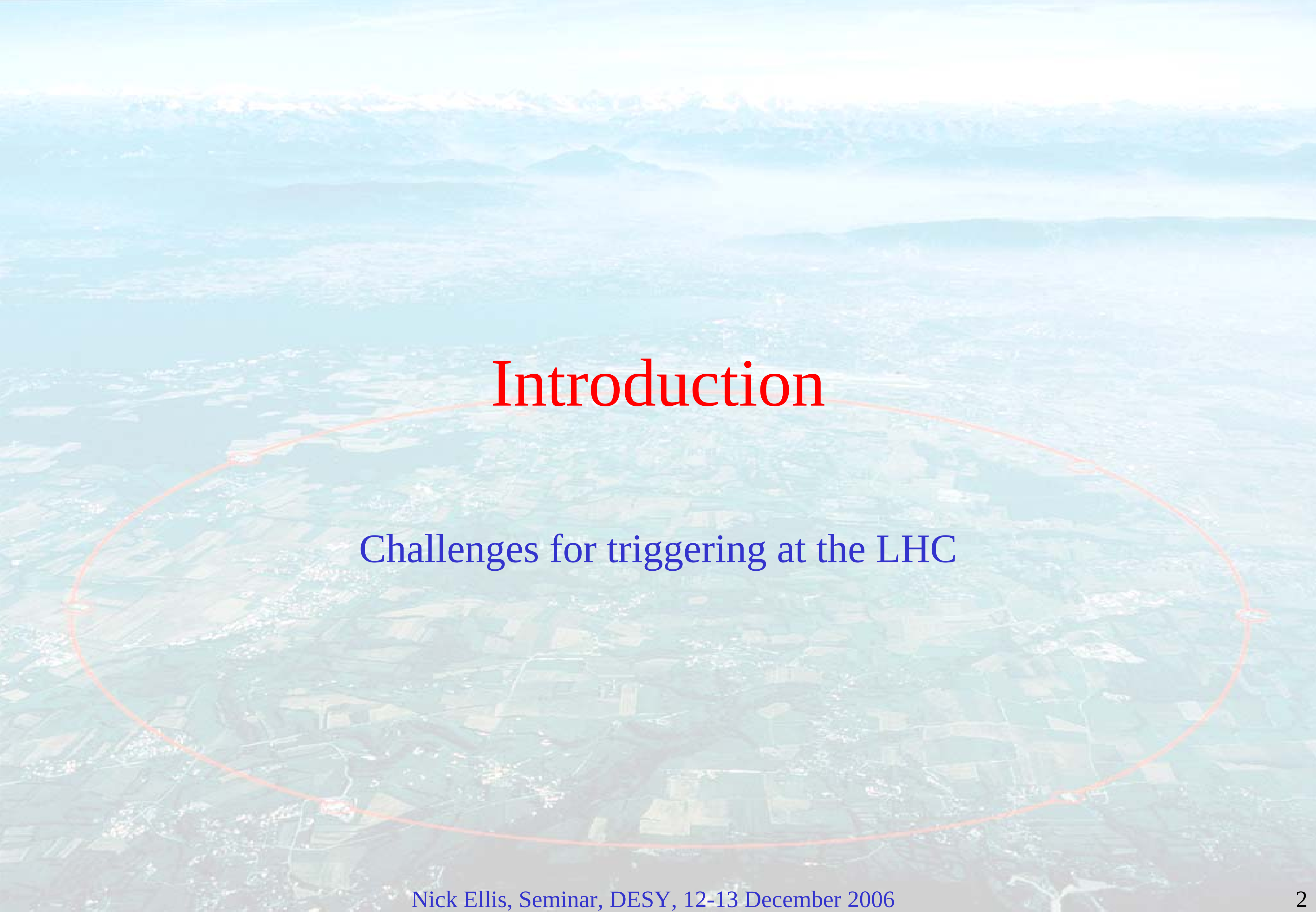
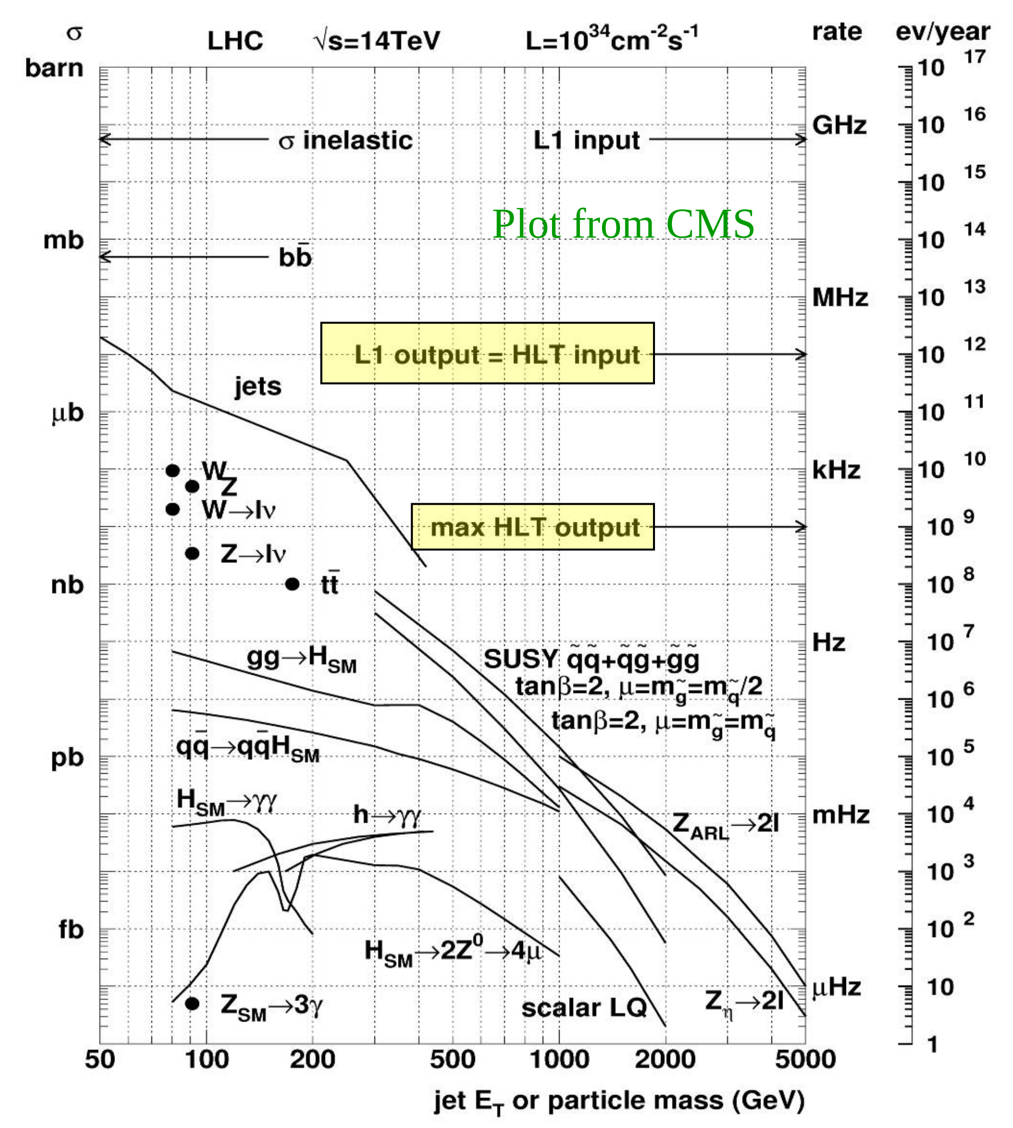


Introduction

Challenges for triggering at the LHC

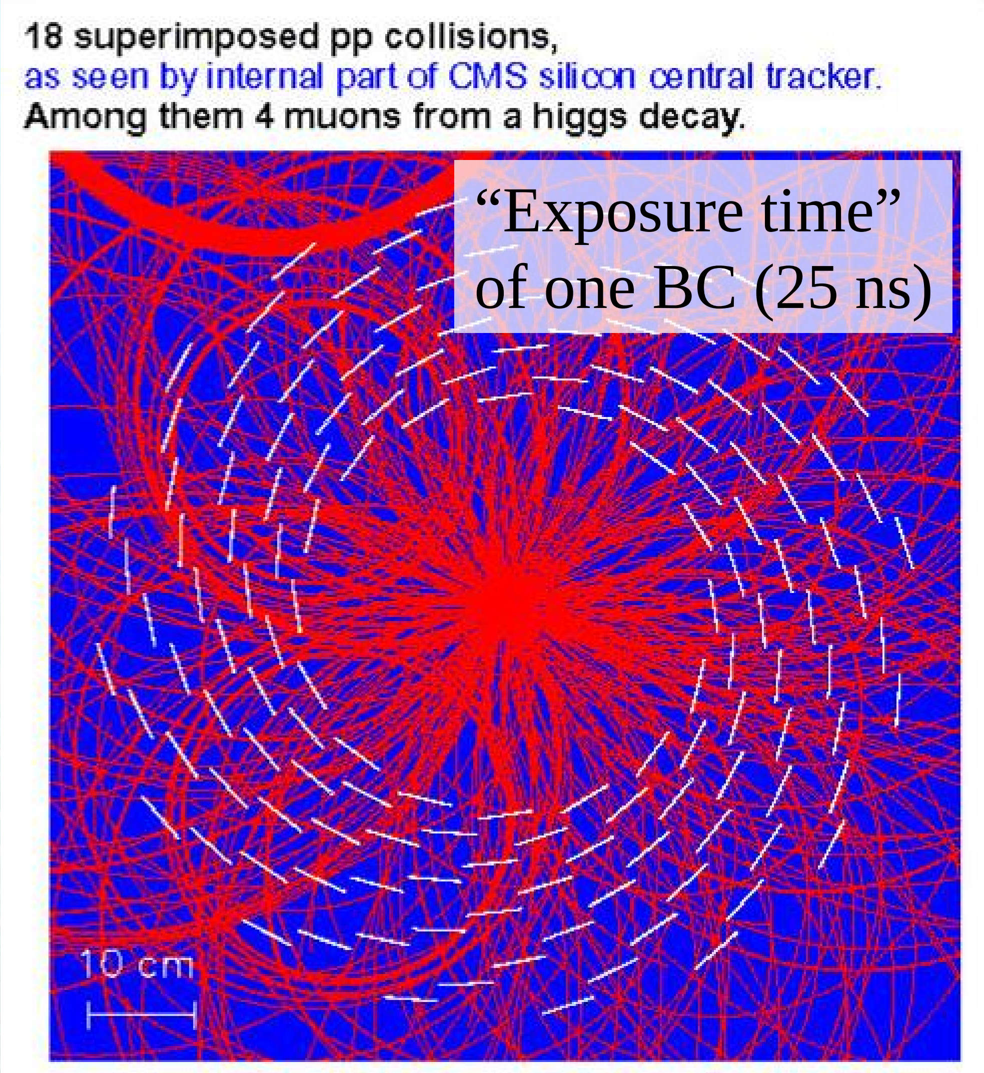
Rare signals; high-rate physics backgrounds

- Huge total rate of pp collisions
  - $O(10^9)$ s^{-1}
- Searching for processes that are predicted to be extremely rare
  - “Discovery physics”
- For cost reasons, first-level trigger output rate is limited to ~75 kHz in ATLAS and CMS
  - Limited bandwidth for readout and processing power in High-Level Trigger (HLT)
- For cost reasons, HLT output rate is limited to $O(100)$ Hz
  - Limited offline computing capacity for storing and processing the data



Plot from CMS

Multiple interactions per BC = “pile-up” Has strong impact on detector designs

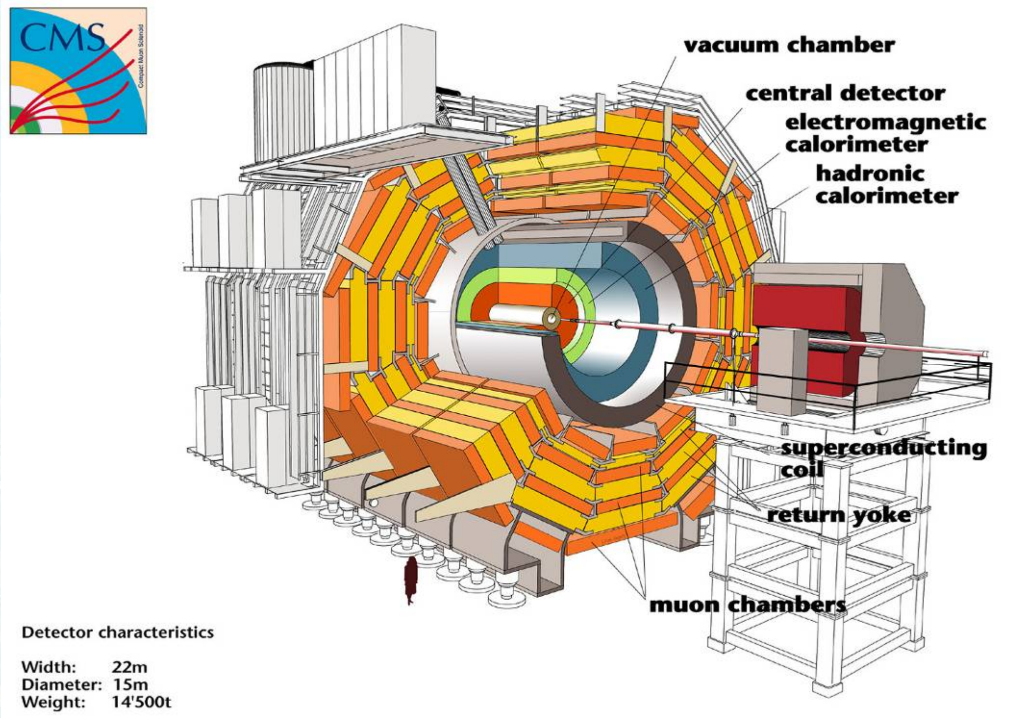


18 superimposed pp collisions,
as seen by internal part of CMS silicon central tracker.
Among them 4 muons from a higgs decay.

“Exposure time” of one BC (25 ns)

- Need detectors with fast time response ~ “exposure time”
  - Pile up in a single bunch crossing already presents a challenge!
  - Except in the case of ALICE where the rate of heavy-ion collisions is much less than the bunch-crossing frequency
- Need fine detector granularity to be able to reconstruct the “event”
  - Minimize the probability of pile-up in the same detector element as an interesting object
    - E.g. probability for energy from the “pile-up” interactions being deposited in the calorimeter cell hit by a photon in an H → $\gamma\gamma$ decay

Huge numbers of sensor channels



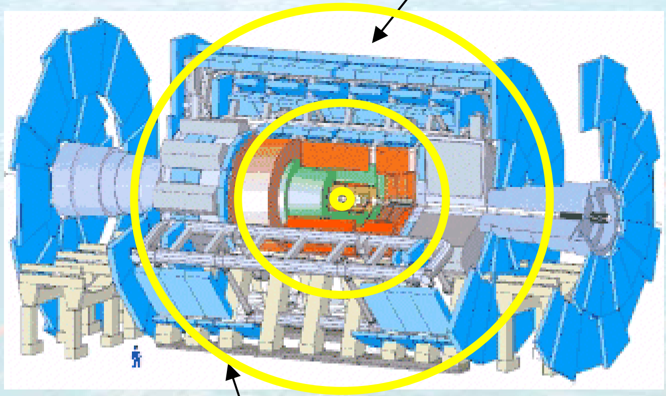
- The general-purpose experiments (ATLAS, CMS) have massive numbers of sensor channels
  - $O(10^7)$ in inner detector
  - $O(10^5)$ in calorimeters
  - $O(10^6)$ in muon detectors

It is not practical to move all the information off the detector at 40 MHz rate

Information from all channels has to be retained in memories, mostly on the detector, until the first-level trigger decision is received

Huge physical size of detectors

$p_T \equiv$ transverse momentum ⊥ beams



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 need a few microseconds)

Requirements and Concepts

Reminder of some basic requirements in triggering

Reminder of some key ingredients in trigger design

Basic requirements

- Need high **efficiency** for selecting processes for physics analysis
  - Efficiency should be precisely known
  - Selection should not have biases that affect physics results
  - Dead-time and event losses must be low (and known)
- Need **large reduction of rate** from unwanted high-rate processes (capabilities of DAQ and also offline!)
  - Instrumental background
  - High-rate physics processes that are not relevant for analysis
- System must be **affordable**
  - e.g algorithms executed at high rate must be fast

- **Not easy to achieve above simultaneously!**

Dead-time and event losses

- Dead-time can arise from a number of sources, with a typical total of up to *O*(10%)
  - Readout and trigger dead-time
  - Operational dead-time (e.g. time to start/stop runs)
  - T/DAQ down-time (e.g. following computer failure)
  - Detector down-time (e.g. following high-voltage trip)
- Events may also be lost at various points in the selection and processing chain, e.g. if event processing fails
- Given the investment in the accelerators and the detectors for a modern HEP experiment, it is clearly very important to keep dead-time and event losses to a minimum!

What is an “event” anyway?

- In high-energy particle colliders (e.g. Tevatron, HERA, LHC), the particles in the counter-rotating beams are bunched
  - Bunches cross at regular intervals
    - Interactions only occur during the bunch-crossings
  - The trigger has the job of selecting the bunch-crossings of interest for physics analysis, i.e. those containing interactions of interest
- I will use the term “**event**” to refer to the record of all the products of a given bunch-crossing (plus any activity from other bunch-crossings that gets recorded along with this)
  - Be aware (beware!): the term “event” is not uniquely defined!
    - Some people use the term “event” for the products of a single interaction between the incident particles
      - People sometimes unwittingly use “event” interchangeably to mean different things!

Trigger menus

- 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
  - 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
  - The menu has to cover the physics channels to be studied, plus additional event samples required to complete the analysis:
    - Measure backgrounds, check the detector calibration and alignment, etc.

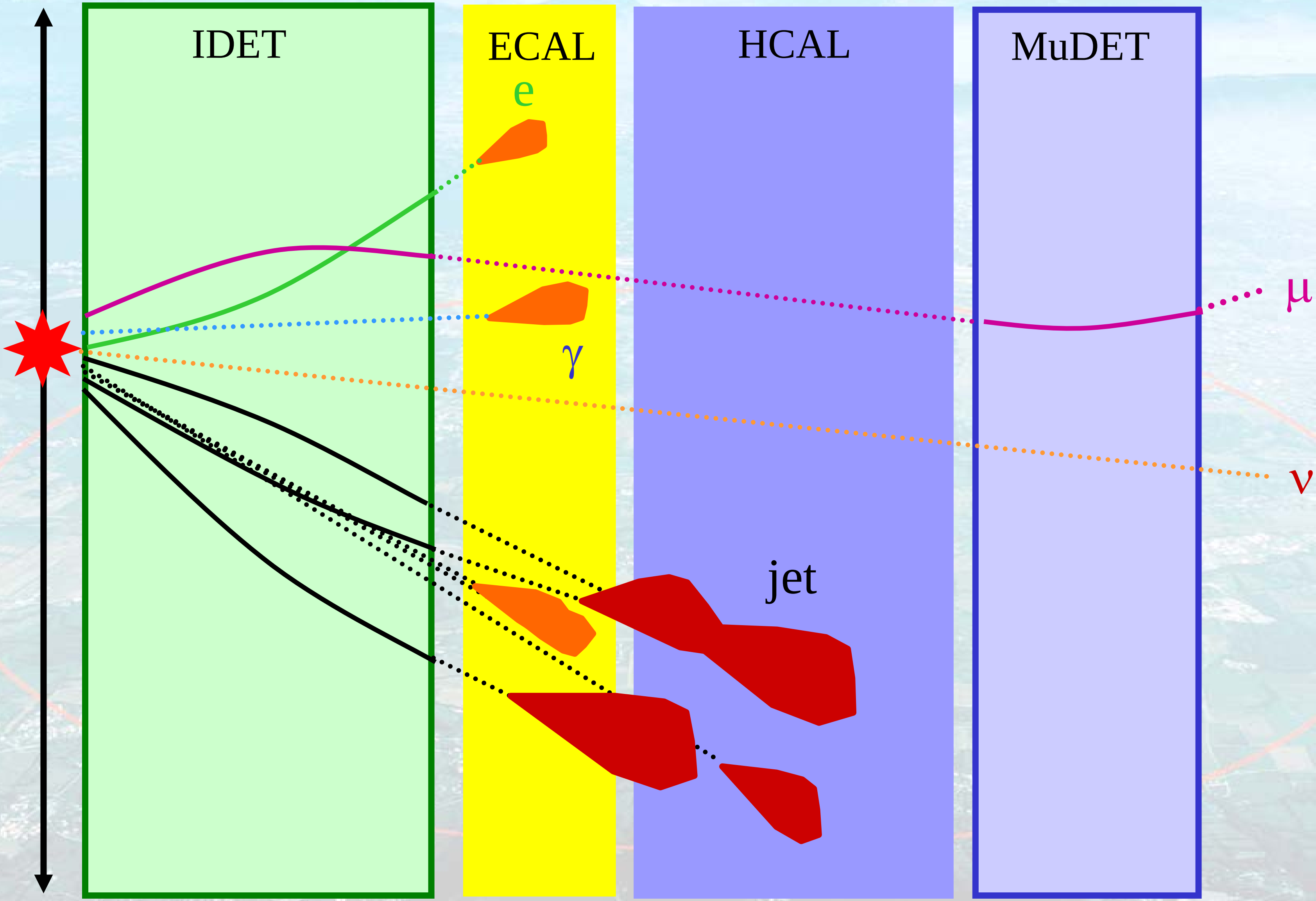
ATLAS/CMS physics requirements

- Triggers in the general-purpose proton–proton experiments, ATLAS and CMS, will have to:
  - Retain as many as possible of the events of interest for the diverse physics programmes of these experiments
    - Higgs searches (Standard Model and beyond)
      - e.g. $H \rightarrow ZZ \rightarrow$ leptons, $H \rightarrow \gamma\gamma$; also $H \rightarrow \tau\tau$, $H \rightarrow bb$
    - SUSY searches
      - With and without R-parity conservation
    - Searches for other new physics
      - Using inclusive triggers that one hopes will be sensitive to any unpredicted new physics
    - Precision physics studies
      - e.g. measurement of W mass
    - B-physics studies (especially in the early phases of these experiments)

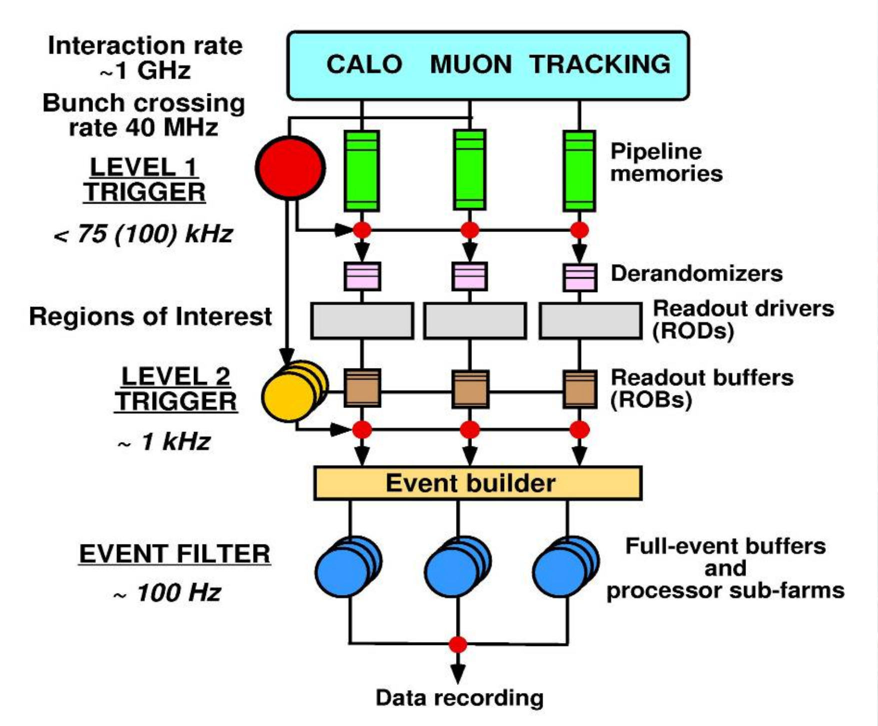
ATLAS/CMS rate requirements

- However, they also need to reduce the event rate to a manageable level for data recording and offline analysis
  - – $L = 10^{34}$ cm^{-2}s^{-1}, and $\sigma \sim 100$ mb $\Rightarrow 10^{9}$ Hz interaction rate
    - Even rate of events containing leptonic W and Z decays is *O*(100 Hz)
  - – The size of the events is very large, *O*(1) MByte
    - Huge number of detector channels, high particle multiplicity per event
  - – Recording and subsequently processing offline, *O*(100) Hz event rate per exp^{t} with *O*(1) MByte event size implies major computing resources!
  - – Hence, only a tiny fraction of proton–proton collisions can be selected
    - Maximum fraction of interactions triggering at full luminosity *O*(10^{-7})
- Have to balance needs of maximising physics coverage and reaching acceptable (i.e. affordable) recording rates

Signatures used for triggers



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
  - 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

Short bunch spacing; high data rates

- It is not practical to make a trigger decision in the time between bunch crossings because of the short BC period
  - We have to introduce the concept of **"pipelined" readout** (and also **pipelined LVL1 trigger processing**)
- The data rates after the LVL1 trigger selection are still very high
  - We have to introduce new ideas also for the High-Level Triggers and DAQ
    - Event building based on data **networks** rather than data buses
    - Use of **region-of-interest** to guide processing (and reduce data movement)
    - **Sequential selection**
    - **Factorization of data-movement** problem

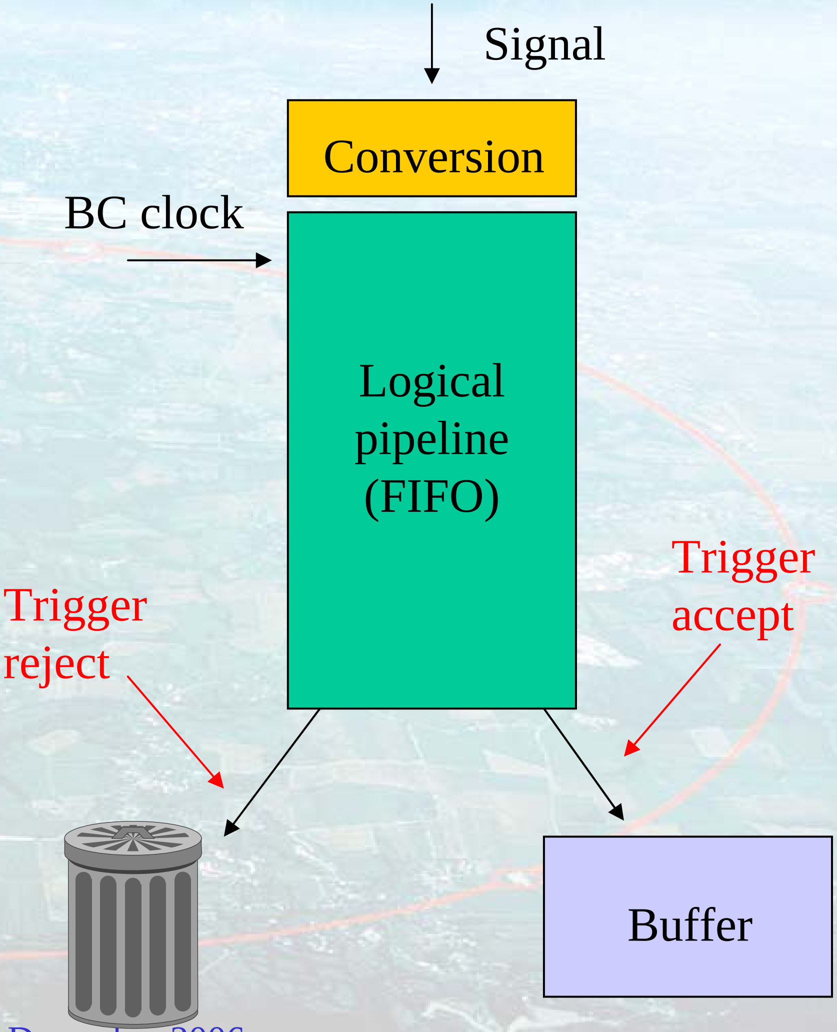
Machine	**BC period**
Tevatron-II	132 ns
HERA	96 ns
LHC	25 ns

First-Level Triggers

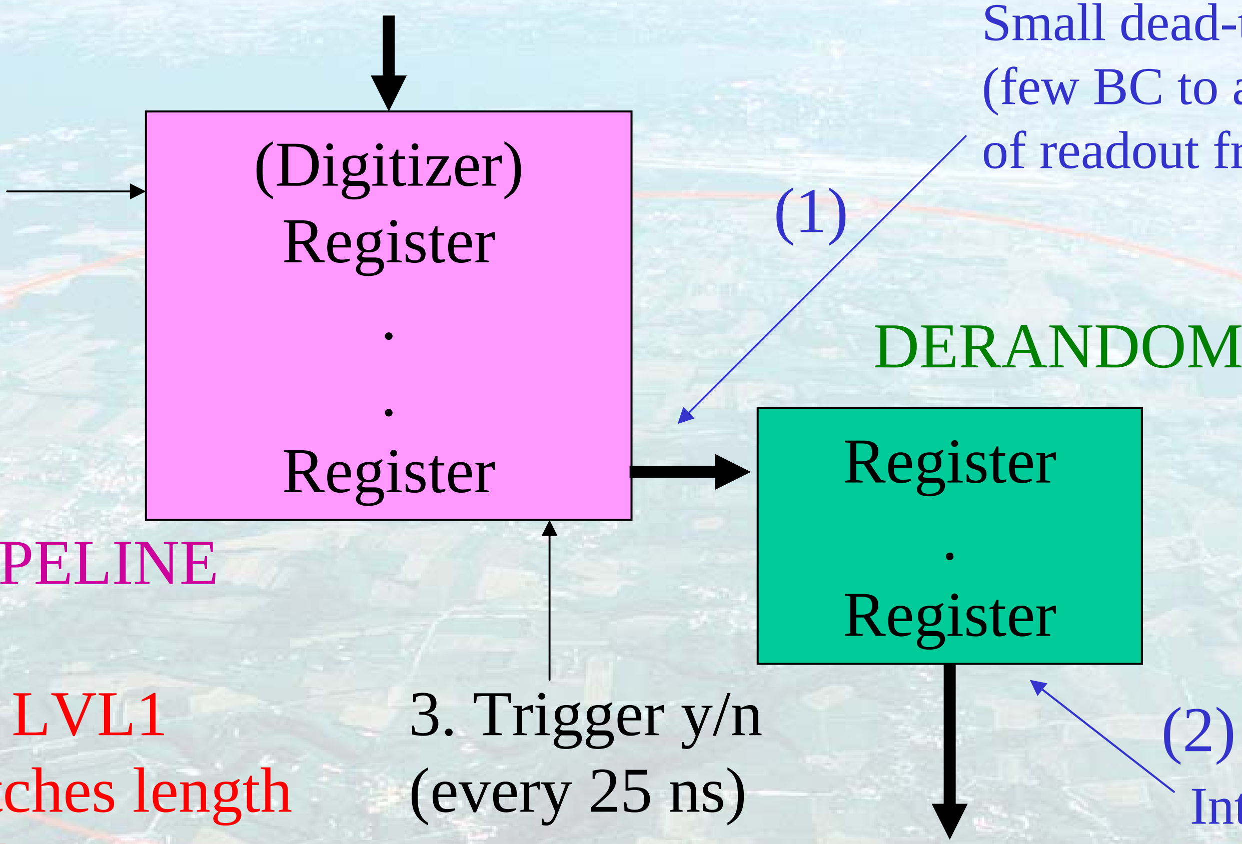
Based on custom electronic processors

Pipelined readout

- In pipelined readout systems, the information from each bunch crossing, for each detector element, is retained during the latency of the LVL1 trigger (several μs)
- The information retained may be in several forms
  - Analogue level (held on capacitor)
  - Digital value (e.g. ADC result)
  - Binary value (i.e. hit / no hit)



Pipelined readout (e.g. LHC)



2. Signals (every 25 ns)

1. BC clock
(every 25 ns)

(Digitizer)
Register
.
.
Register

PIPELINE

Small dead-time here
(few BC to avoid overlap
of readout frames)

(1)

DERANDOMIZER

Register
.
Register

Latency of LVL1
trigger matches length
of the pipeline

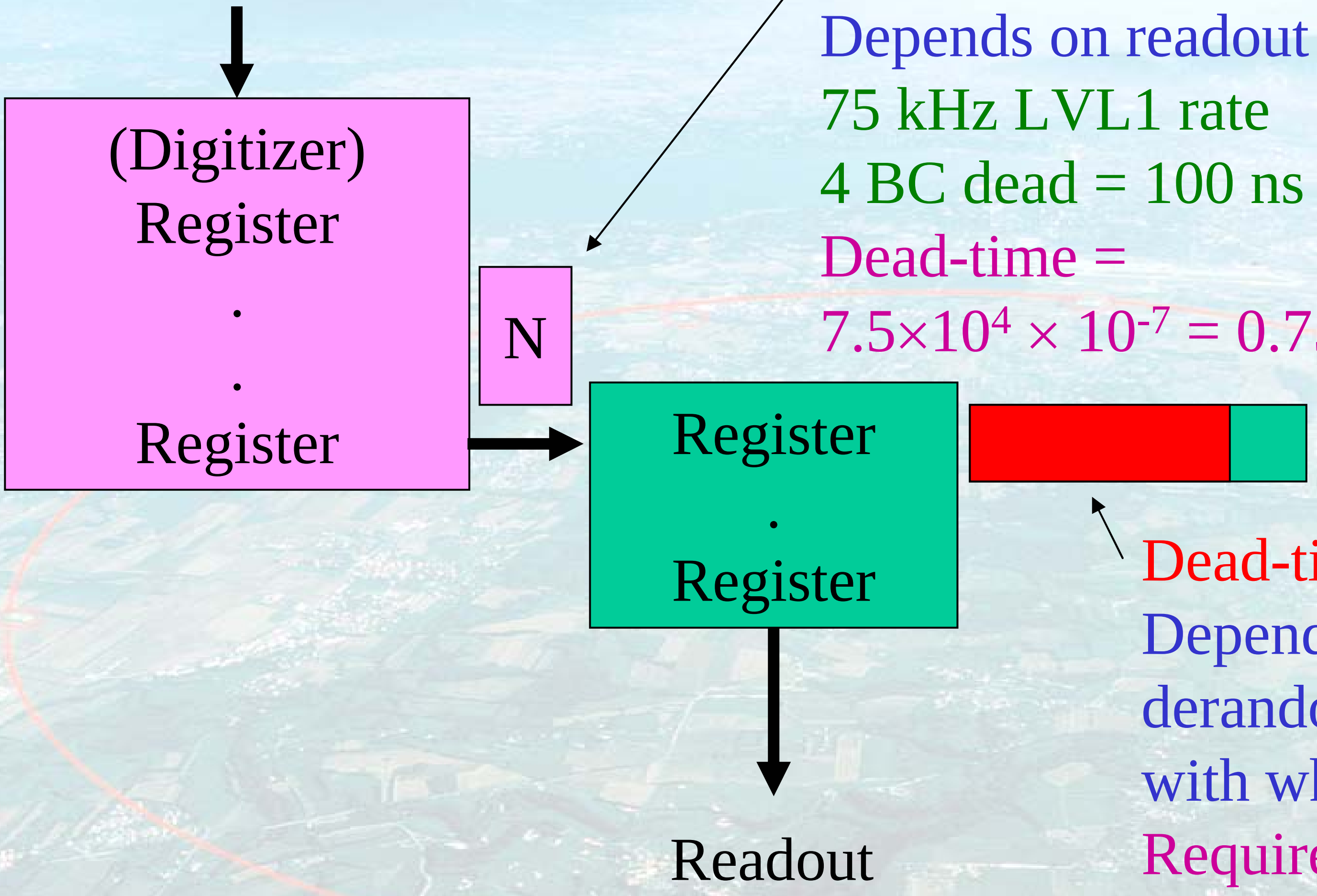
3. Trigger y/n
(every 25 ns)

(2)

Introduce dead-time
here to avoid overflow
of derandomizers

Readout

Example: ATLAS



(Digitizer)
Register
.
.
Register

N

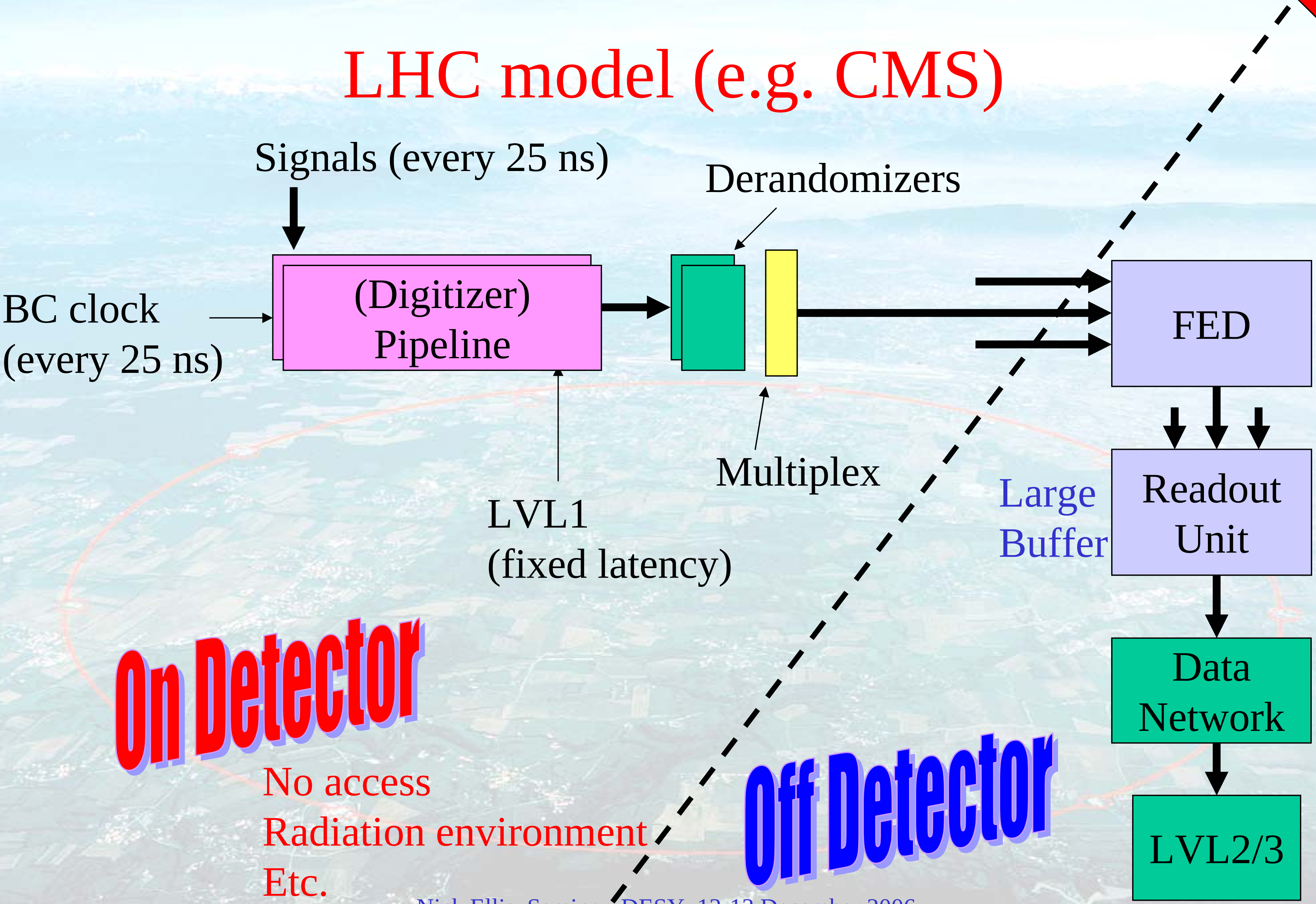
Register
.
Register

Readout

Dead-time (1):
Depends on readout frame size
75 kHz LVL1 rate
4 BC dead = 100 ns
Dead-time =
$7.5\times10^{4} \times 10^{-7} = 0.75\%$

Dead-time (2):
Depends on size of derandomizer and speed with which it is emptied
Require dead-time < 1% @ 75 kHz
(< 6% @ 100 kHz)

LHC model (e.g. CMS)



Signals (every 25 ns)

BC clock
(every 25 ns)

(Digitizer)
Pipeline

Derandomizers

Multiplex

LVL1
(fixed latency)

FED

Large
Buffer

Readout
Unit

Data
Network

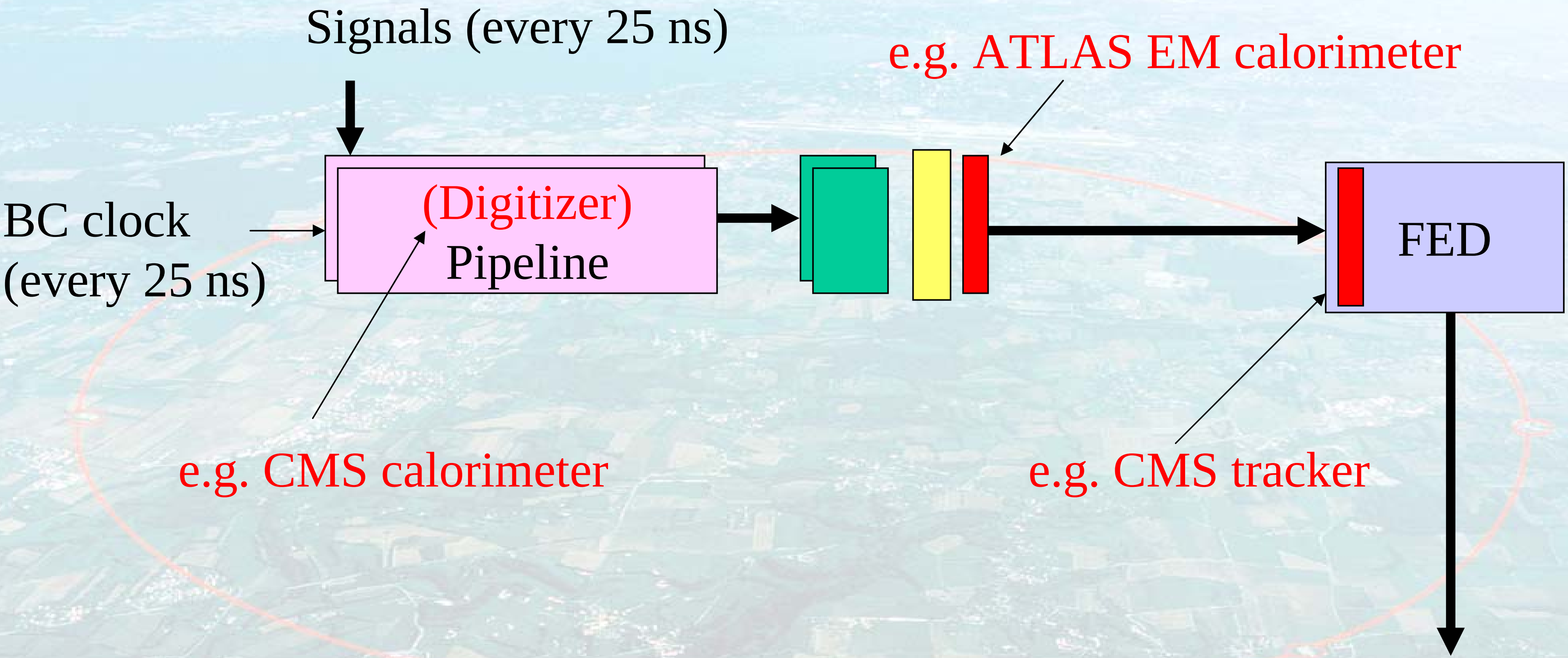
LVL2/3

On Detector

No access
Radiation environment
Etc.

Off Detector

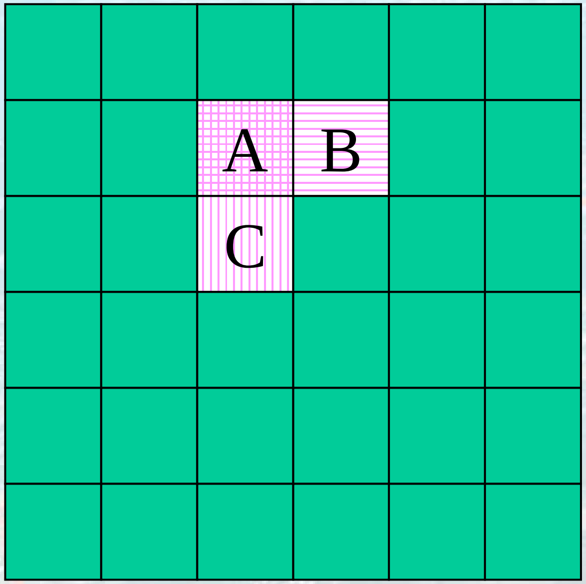
Digitisation options



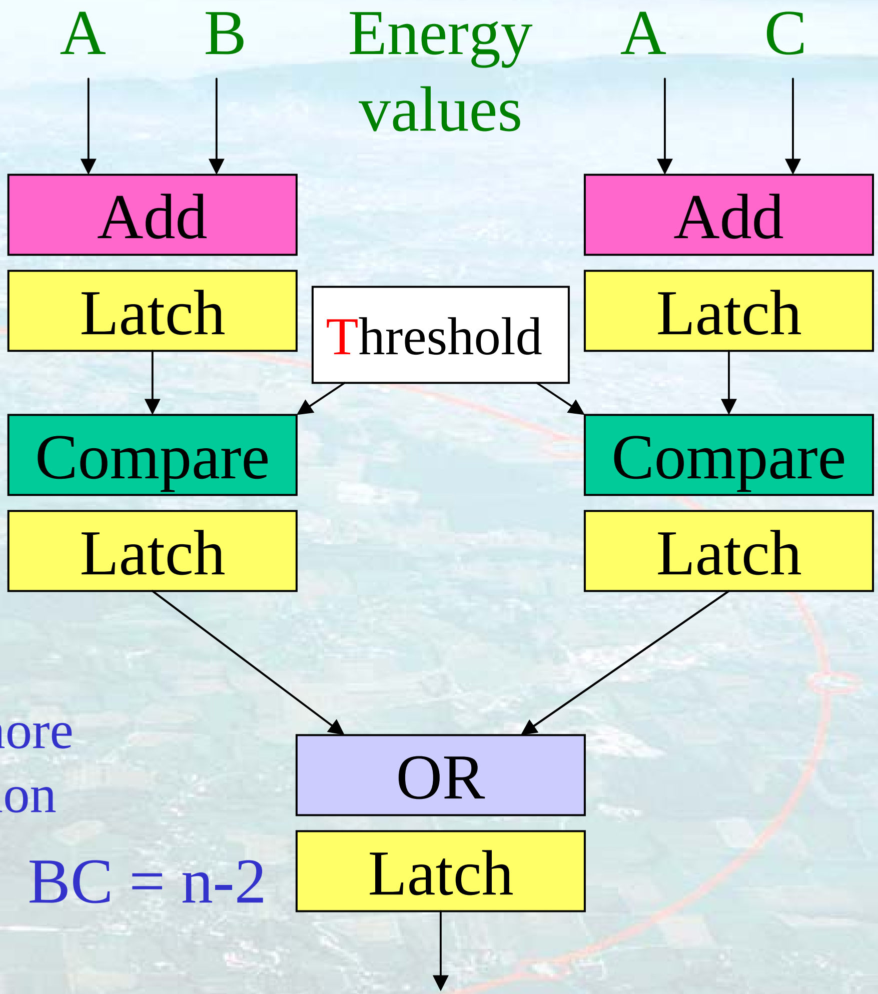
Pipelined LVL1 trigger

- LVL1 trigger has to deliver a new decision every BC, but the trigger latency is much longer than the BC period
  - The LVL1 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

Pipelined LVL1 trigger



EM Calorimeter
(~3500 trigger towers)



A B Energy values A C

Add

Latch

Add

Latch

Threshold

BC = n

Compare

Compare

Latch

Latch

BC = n-1

OR

Latch

BC = n-2

Output

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

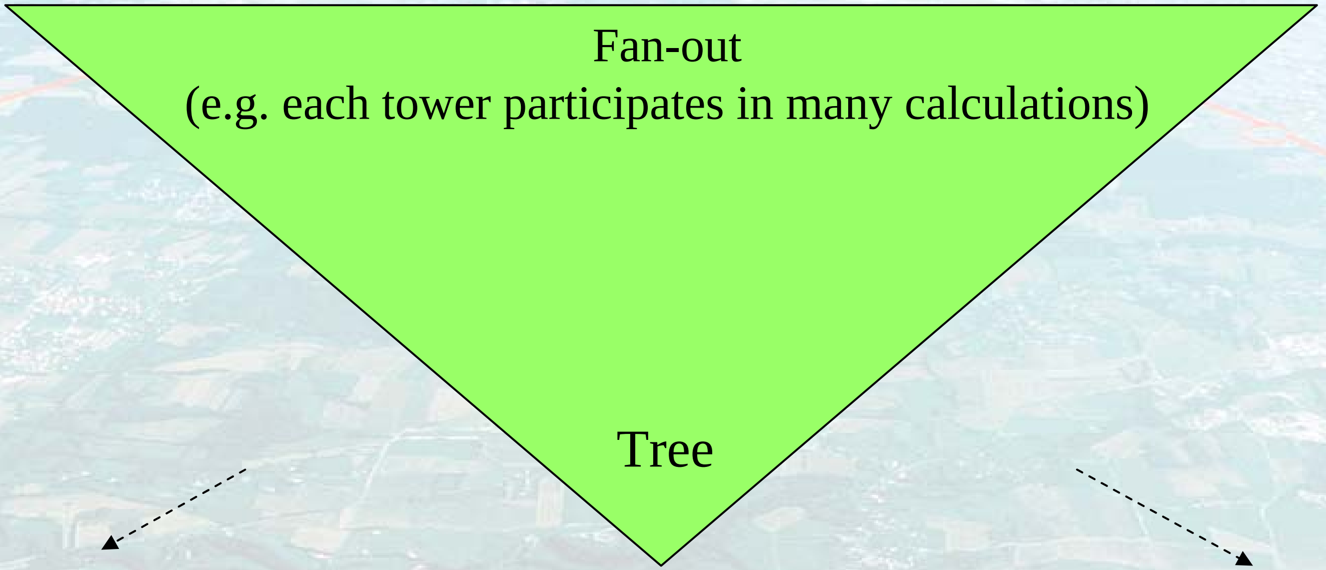
Output = (A+B)>T OR (A+C)>T

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)

LVL1 selection criteria

- Features that distinguish new physics from the bulk of the cross-section for Standard Model processes at hadron colliders are
  - In general, the presence of high-p_T particles (or jets)
    - e.g. these may be the products of the decays of new heavy particles
      - In contrast, most of the particles produced in minimum-bias interactions are soft (p_T ~ 1 GeV or less)
  - More specifically, the presence of high-p_T leptons (e, μ, τ), photons and/or neutrinos
    - e.g. the products (directly or indirectly) of new heavy particles
      - These give a clean signature c.f. low-p_T hadrons in minimum-bias case, especially if they are “isolated” (i.e. not inside jets)
  - The presence of known heavy particles
    - e.g. W and Z bosons may be produced in Higgs particle decays
      - Leptonic W and Z decays give a very clean signature
        - » Also interesting for physics analysis and detector studies

LVL1 signatures and backgrounds

- LVL1 triggers therefore search for
  - High-p_T muons
    - Identified beyond calorimeters; need p_T cut to control rate from $\pi^+ \rightarrow \mu\nu$, $K^+ \rightarrow \mu\nu$, as well as semi-leptonic beauty and charm decays
  - High-p_T photons
    - Identified as narrow EM calorimeter clusters; need cut on E_T; cuts on isolation and hadronic-energy veto reduce strongly rates from high-p_T jets
  - High-p_T electrons
    - Same as photon (matching track in required in subsequent selection)
  - High-p_T taus (decaying to hadrons)
    - Identified as narrow cluster in EM+hadronic calorimeters
  - High-p_T jets
    - Identified as cluster in EM+hadronic calorimeter — need to cut at very high p_T to control rate (jets are dominant high-p_T process)
  - Large missing E_T or total scalar E_T

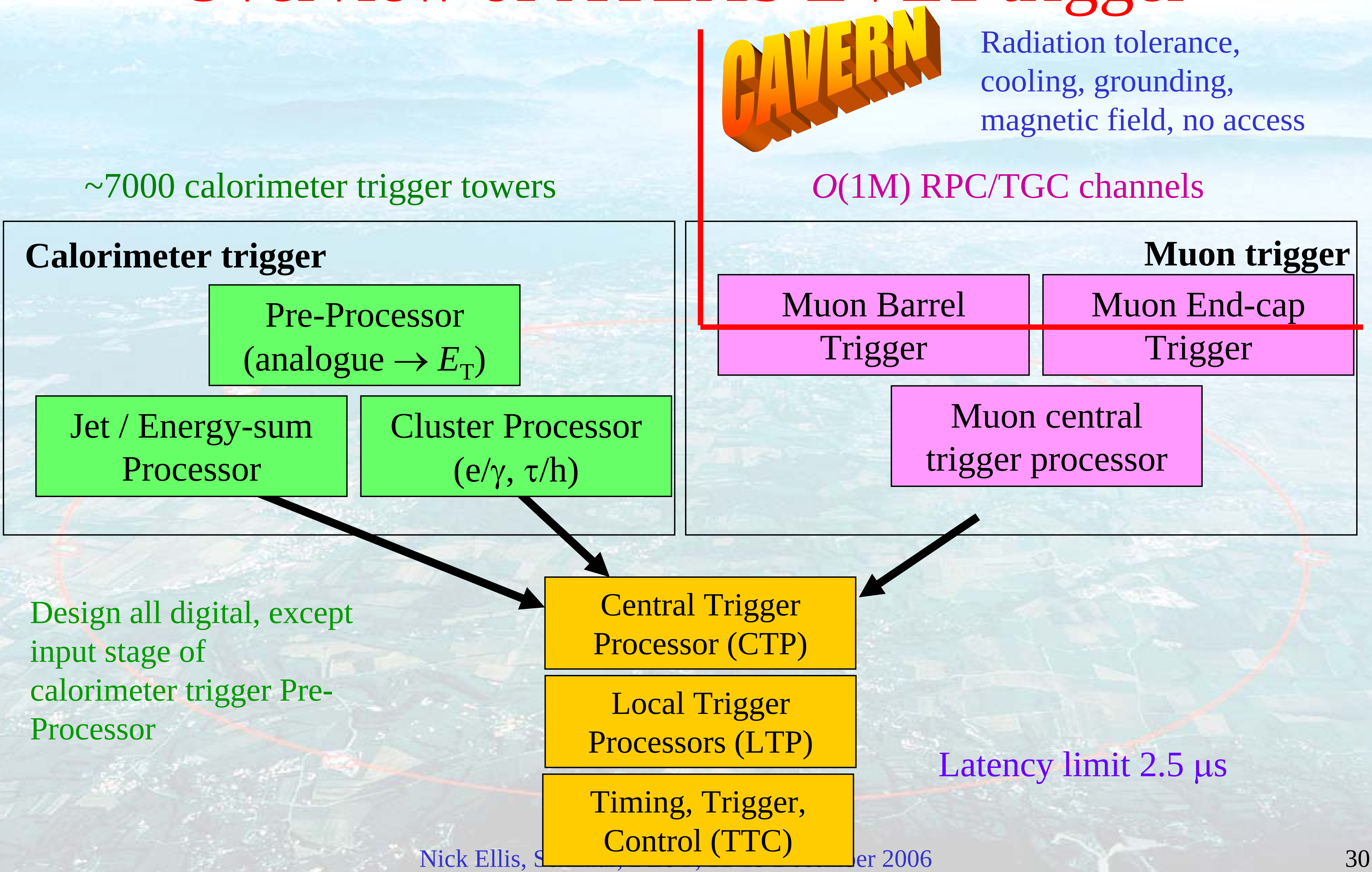
LVL1 trigger menu

- An illustrative menu for LHC at $10^{34}\text{cm}^{-2}\text{s}^{-1}$ luminosity includes:
  - One or more muons with $p_T > 20$ GeV (rate ~ 11 kHz)
  - Two or more muons each with $p_T > 6$ GeV (rate ~ 1 kHz)
  - One or more e/γ with $E_T > 30$ GeV (rate ~ 22 kHz)
  - Two or more e/γ each with $E_T > 20$ GeV (rate ~ 5 kHz)
  - One or more jets with $E_T > 290$ GeV (rate ~ 200 Hz)
  - One or more jets with $E_T > 100$ GeV & $E_T^{miss} > 100$ GeV (rate ~ 500 Hz)
  - Three or more jets with $E_T > 130$ GeV (rate ~ 200 Hz)
  - Four or more jets with $E_T > 90$ GeV (rate ~ 200 Hz)
- Full menu will include many items in addition (~100 items total)
  - Items with τ (or isolated single-hadron) candidates
  - Items with combinations of objects (e.g. muon & electron)
  - Pre-scaled triggers with lower thresholds
  - Triggers for technical studies and to aid understanding of data
    - e.g. trigger on bunch-crossings at random to collect unbiased sample

Some LVL1-trigger design goals

- Need large reduction in physics rate already at the first level (otherwise readout system becomes unaffordable)
  - *O*(10^9) interaction rate → less than 100 kHz in ATLAS and CMS
    - Require complex algorithms to reject background while keeping signal
- An important constraint is to achieve a short latency
  - Information from all detector channels (*O*(10^8) channels!) has to be held in local memory on detector pending the LVL1 decision
    - The pipeline memories are typically implemented in ASICs (Application Specific Integrated Circuits), and memory size contributes to the cost
  - Typical values are a few μs (e.g. less than 2.5 μs ATLAS, 3.2 μs CMS)
- Require flexibility to react to changing conditions (e.g. wide luminosity range) and — hopefully — new physics
  - Algorithms must be programmable (adjustable parameters at least)

Overview of ATLAS LVL1 trigger



CAVERN

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

~7000 calorimeter trigger towers

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)

Local Trigger Processors (LTP)

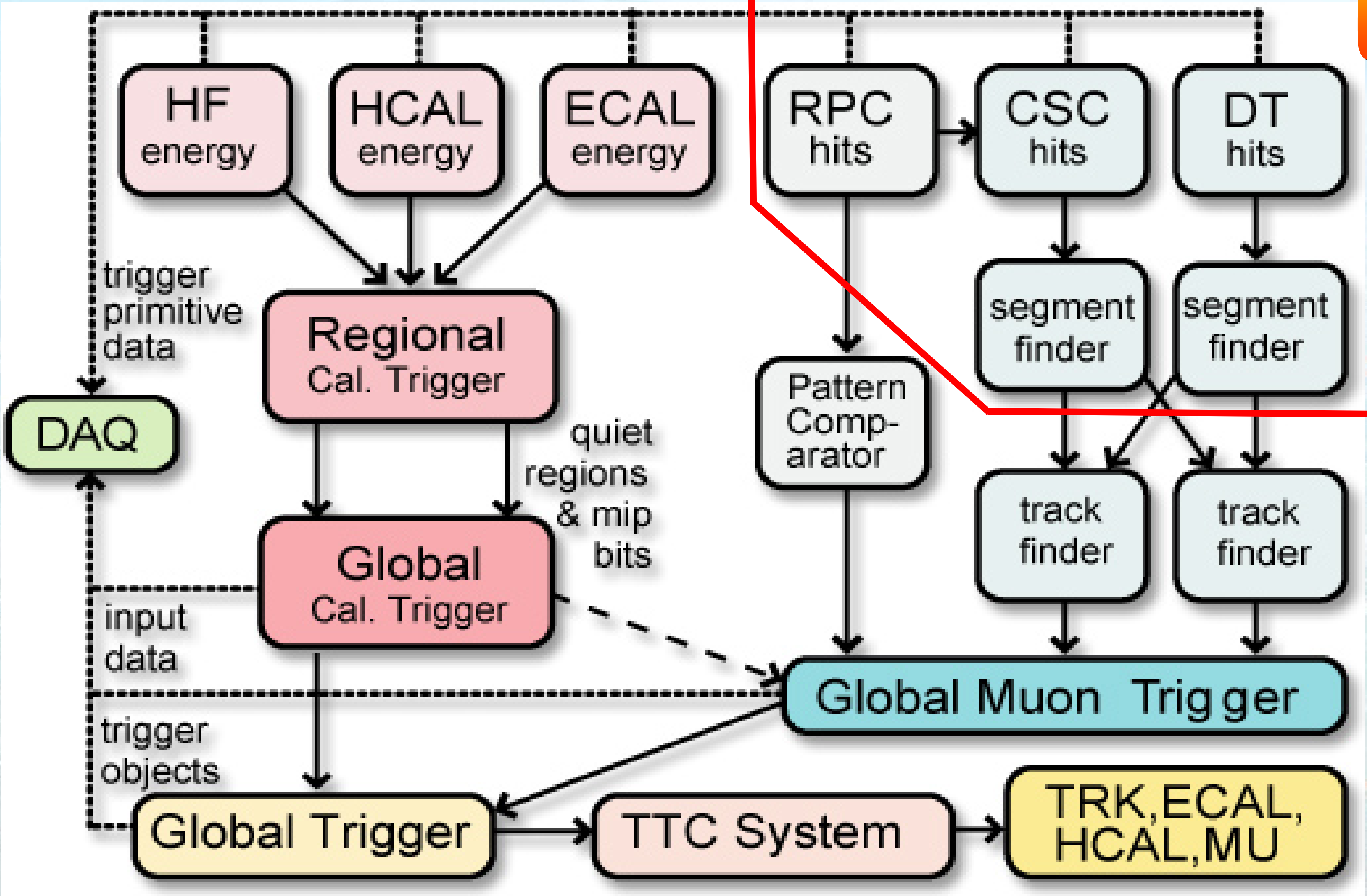
Timing, Trigger, Control (TTC)

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

Latency limit 2.5 μs

Overview of CMS LVL1 trigger

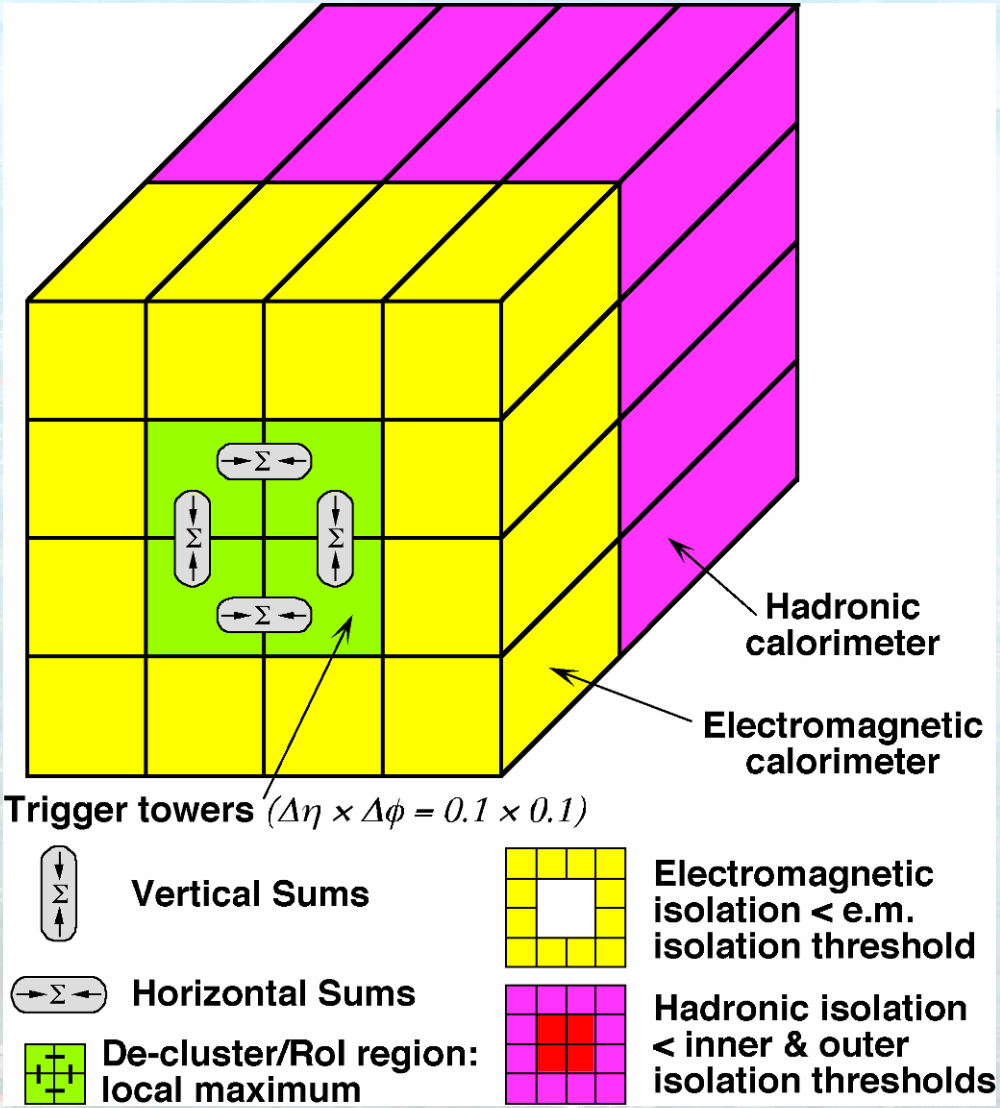
CAVERN



Latency limit 3.2 μs

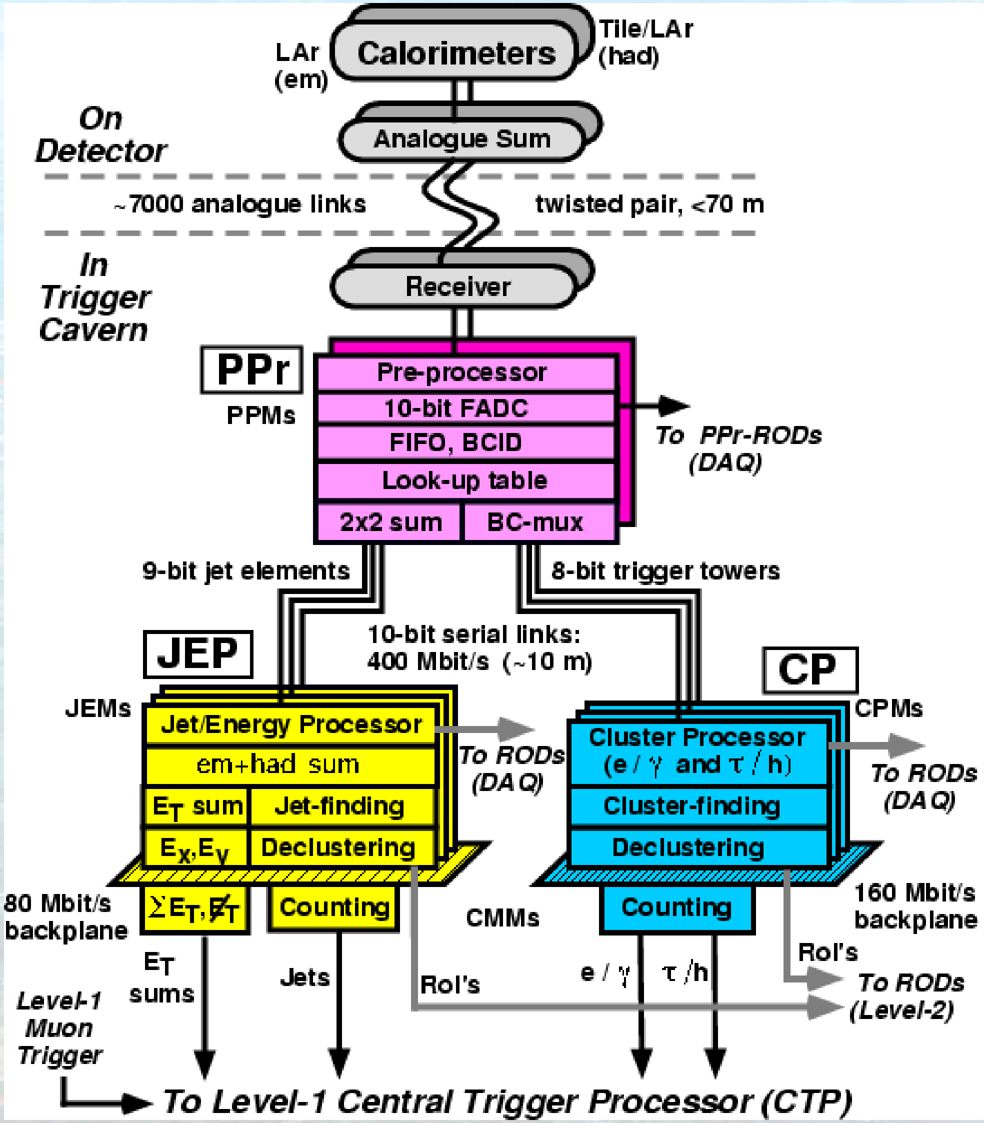
Case study: ATLAS e/γ trigger

- 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



ATLAS LVL1 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 Cluster Processor (only 4 crates in total)
  - Fan out values needed in more than one crate
    - Motivation for very compact design of processor
- Within CP crate, values need to be fanned out between electronic modules, and between processing elements on the modules
- Connectivity and data-movement issues drive the design



On Detector

LAr (em)

Calorimeters

Tile/LAr (had)

Analogue Sum

~7000 analogue links

twisted pair, <70 m

In Trigger Cavern

Receiver

PPr

PPMs

Pre-processor

10-bit FADC

FIFO, BCID

Look-up table

2x2 sum

BC-mux

To PPr-RODs (DAQ)

9-bit jet elements

8-bit trigger towers

10-bit serial links: 400 Mbit/s (~10 m)

JEP

JEMs

Jet/Energy Processor

em+had sum

E_T sum

Jet-finding

E_x,E_y

Declustering

To RODs (DAQ)

CP

CPMs

Cluster Processor (e / γ and τ / h)

Cluster-finding

Declustering

To RODs (DAQ)

80 Mbit/s backplane

ΣE_T,$\not{E}_T$

Counting

CMMs

Counting

160 Mbit/s backplane

E_T sums

Jets

RoI's

e / γ

τ /h

RoI's

To RODs (Level-2)

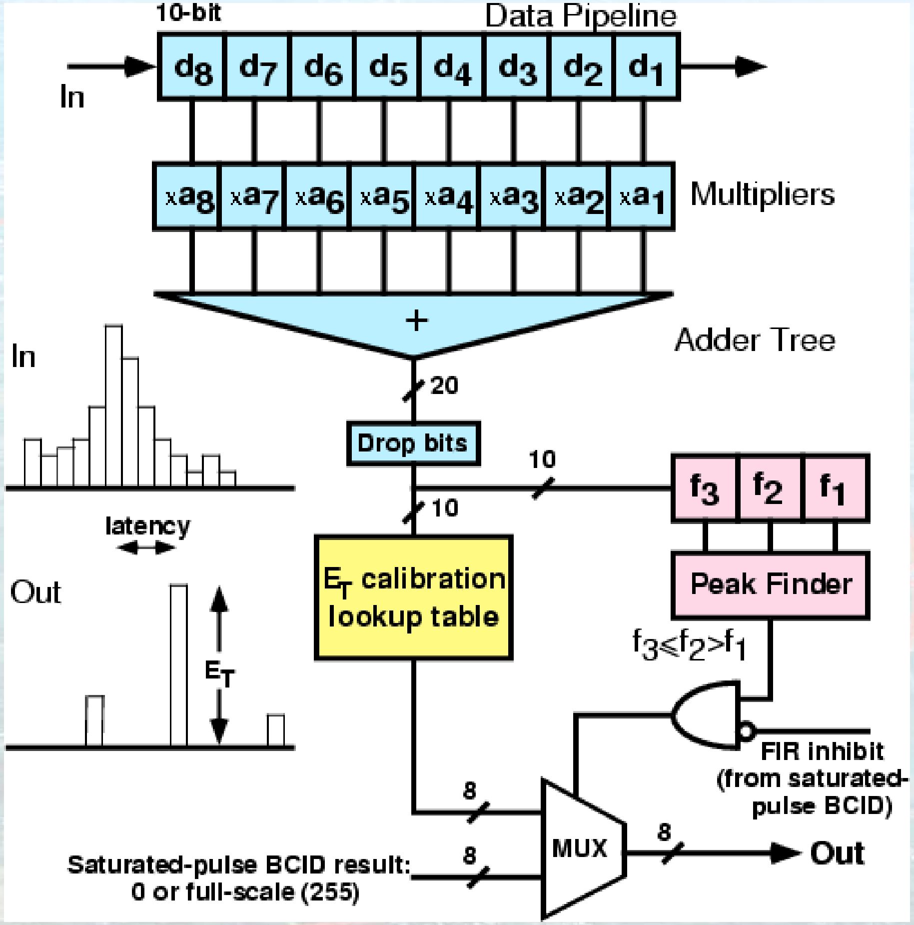
Level-1 Muon Trigger

To Level-1 Central Trigger Processor (CTP)

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 energy was deposited
- Apply Finite Impulse Response filter
  - Result → LUT to convert value 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

e.g. ATLAS



Data transmission and Cluster Processor

(numbers for ATLAS)

- The array of E_T values computed in the previous stage has to be transmitted to the CP
  - Use digital electrical links to Cluster Processor modules
    - ~5000 links @ 400 Mbps
  - 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 † per module
    - On-board fan out is comparatively straightforward
- 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 ($\eta\times\phi\times$\{E/H\})
  - Algorithm is described in a programming language that can be converted into 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

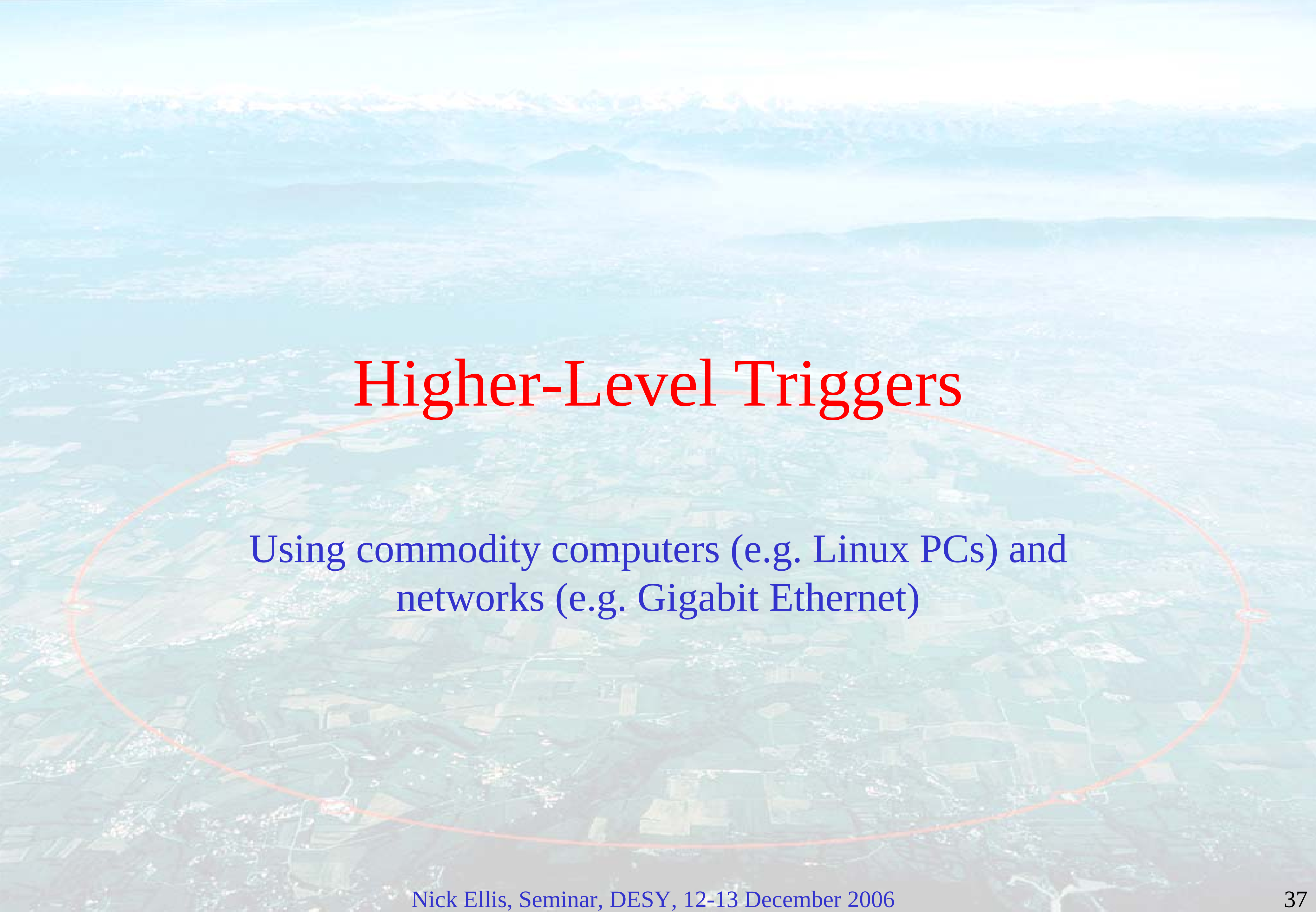
† FPGA = Field Programmable Gate Array
i.e. reprogrammable logic

Just for fun….

- Order of magnitude calculation of input bandwidth for ATLAS calorimeter trigger
  - 4,000 Gbit/s
    - 10,000 channels
    - 10 bits per channel
    - 40 MHz digitisation rate

These data are processed in real time by a compact system (~few 9U crates)

- Compare with bandwidth of a GSM mobile phone *O*(10 kbit/s)
  - Calorimeter trigger bandwidth corresponds to 400M simultaneous phone calls!
    - Don’t assume that telecom industry will have solved all of the problems for us!
- Data movement considerations often drive the design of first-level trigger processors in LHC experiments



Higher-Level Triggers

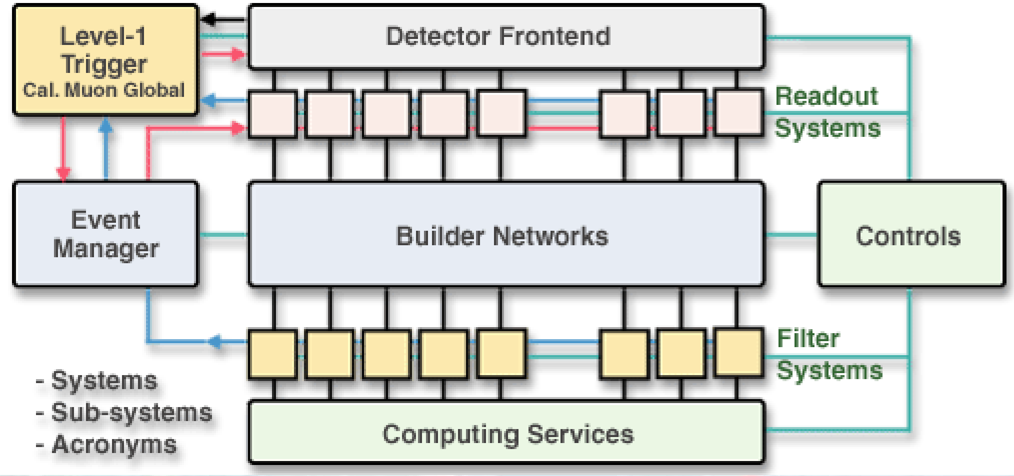
Using commodity computers (e.g. Linux PCs) and networks (e.g. Gigabit Ethernet)

High-Level Triggers and DAQ at LHC

- 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 (i.e ~800 Gbit/s)
- This is far beyond the capacity of the bus-based event building of, e.g., LEP
  - Use network-based event building to avoid bandwidth bottlenecks

e.g. CMS

CMS LVL1 Trigger TDR
CERN-LHCC-2000-038



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

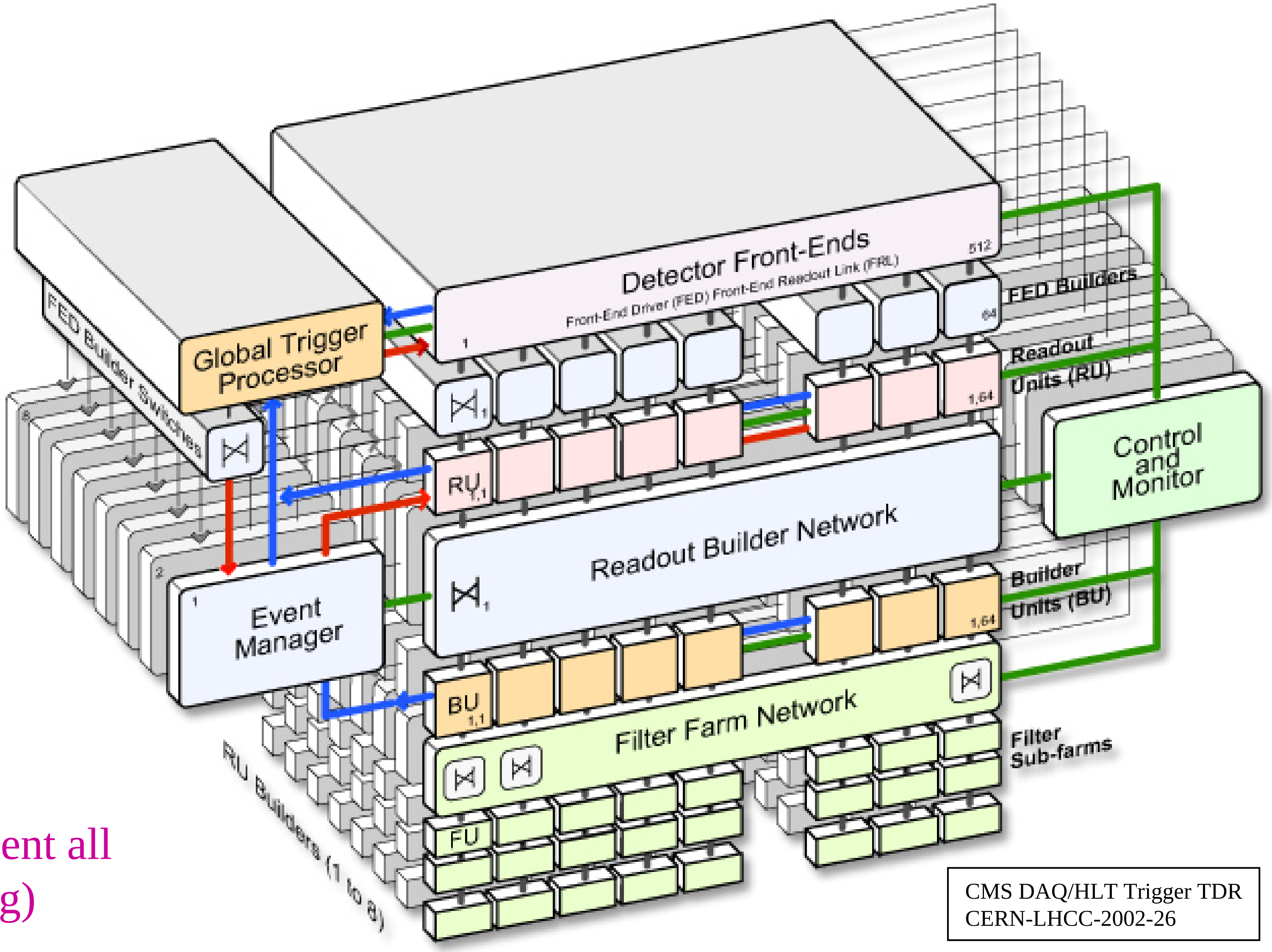
No node in the system sees the full data rate — each Readout System covers only a part of the detector — each Filter System deals with only a fraction of the events

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 with sequential selection to access the data only as required – 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

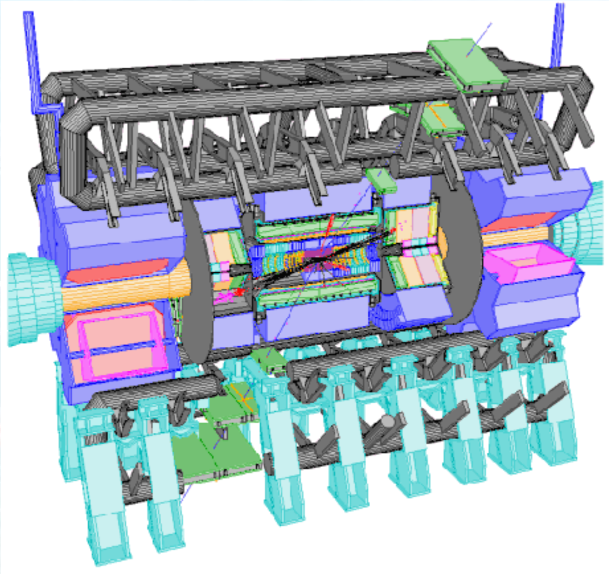


CMS DAQ/HLT Trigger TDR
CERN-LHCC-2002-26

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

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 Readout 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/DAQ at LHC: Implementation

- There are many commonalities in the way the different experiments are implementing their HLT/DAQ systems
  - The computer industry provides the technologies that will be used to build much of the HLT/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)
  - Some custom hardware will be needed in the parts of the system that see the full LVL1 output rate ($O(100)$ kHz in ATLAS/CMS)
    - Readout Systems that receive the detector data following a positive LVL1 decision
    - In ATLAS, the interface to the LVL1 trigger that receives RoI information
    - Of course, this is in addition to the specialized front-end electronics of the detectors

Very large processor farms and computer networks require sophisticated monitoring

```
15:33:32 13-10-2008: LVL2 -SF1 tripping
13:33:33 13-10-2008: EF - SF4 tripping
```

```
15:33:33 13-10-2008: DQM not satisfied, abort
```

e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25mat 30.00 50.00	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	calo25 50.00 21.00	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	CRcl 200.0 10.00	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	L2e25i 500.0 2.00	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	IDsc25 800.0 10.00	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	T2C25hi 900.0 5.00	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0
e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0	e25i 10.00 200.0					

Run: 482535
Run start: 13/10/08 15:34:
Event: 457002
Run stop: 13/10/08 15:34:12
Status: In progress
Date and time: 13/10/08 17:20:09
Mode: Calibration
Luminosity block (s): 60

HLT menu

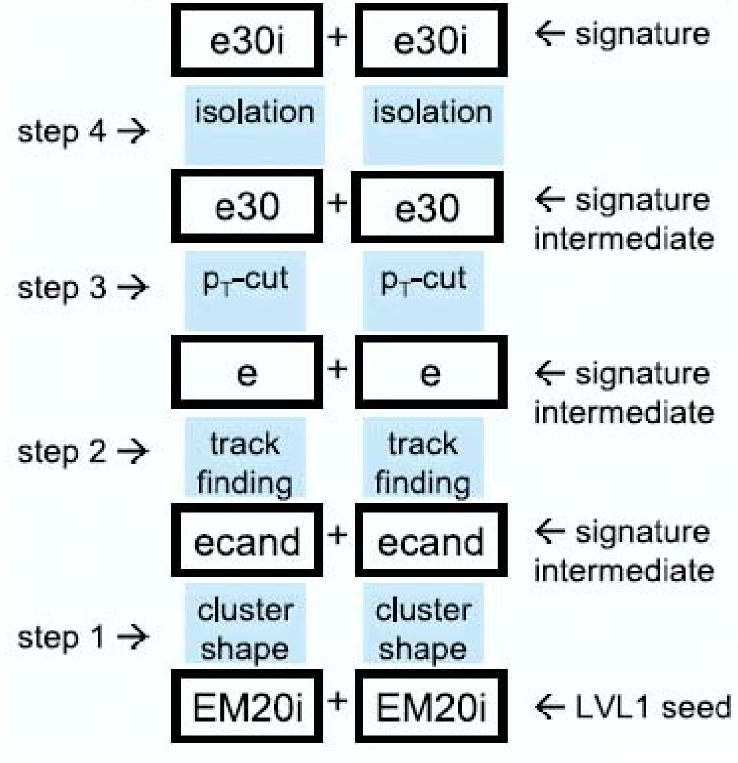
- Illustrative menu for LHC at 2×10^{33} cm^{-2}s^{-1} luminosity (CMS):
  - $p_T^e > 29$ GeV or 2 electrons $p_T^e > 17$ GeV
    - Rate ~ 34 Hz
  - $p_T^\gamma > 80$ GeV or 2 photons $p_T^\gamma > 40, 25$ GeV
    - Rate ~ 9 Hz
  - $p_T^\mu > 19$ GeV or 2 muons $p_T^\mu > 7$ GeV
    - Rate ~ 29 Hz
  - $p_T^\tau > 86$ GeV or 2 taus $p_T^\tau > 59$ GeV
    - Rate ~ 4 Hz
  - $p_T^{jet} > 180$ GeV and missing $E_T > 123$ GeV
    - Rate ~ 5 Hz
  - $p_T^{jet} > 657$ GeV or 3 jets $p_T^{jet} > 247$ GeV or 4 jets $p_T^{jet} > 113$ GeV
    - Rate ~ 9 Hz
  - Others (electron•jet; b-jets, etc.)
    - Rate ~ 7 Hz
  - Total ~ 100 Hz of which a large fraction is “physics” – large uncertainty on rates!
    - Need to balance physics coverage against offline computing cost

Configuration of trigger across trigger levels

(example from ATLAS)

HLT strategy: refinement of TriggerElements (seeded from LVL1) in stepwise processing, perform stepwise decisions

example of step-wise processing:

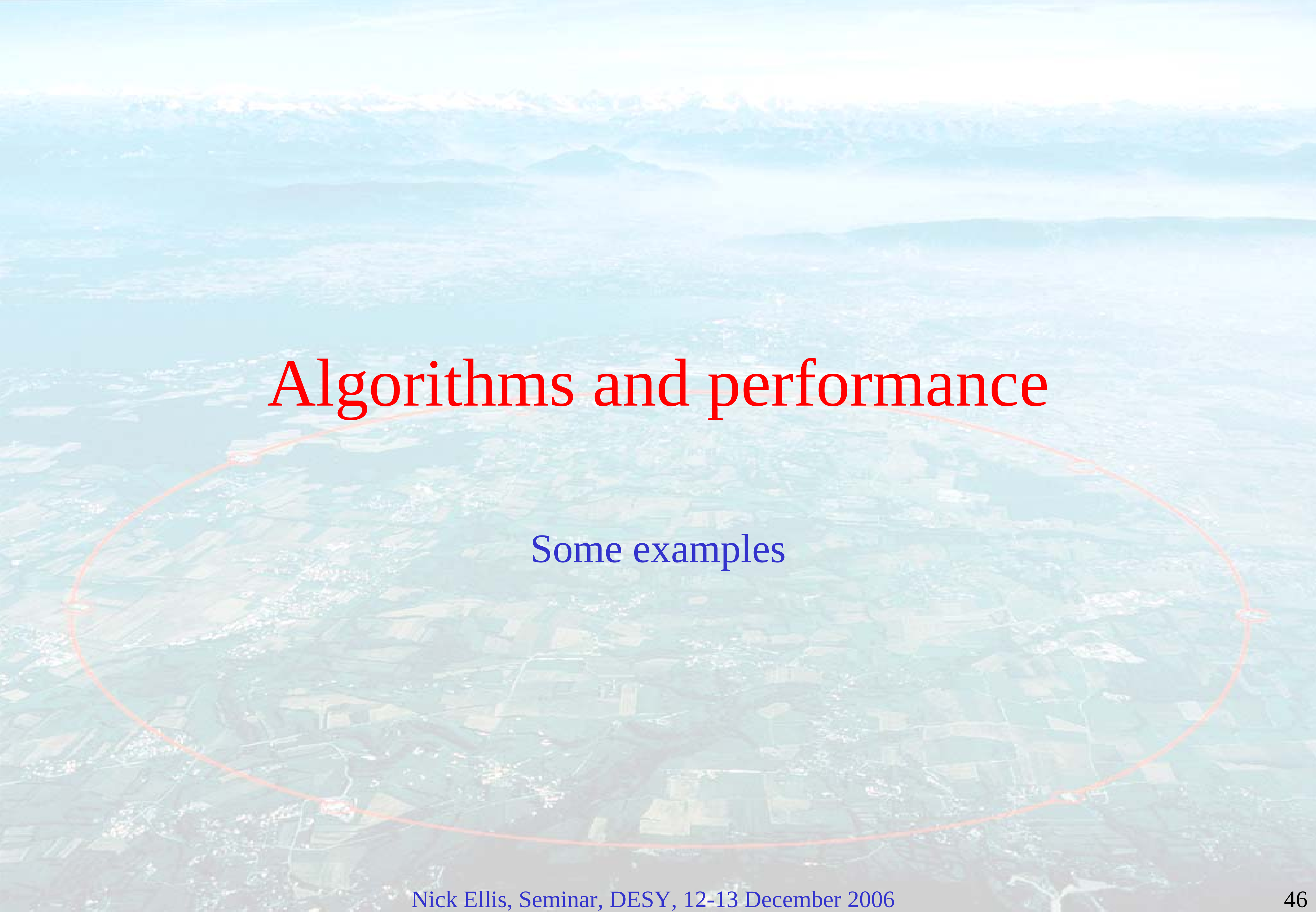


HLT uses the offline reconstruction SW framework ATHENA on ~3000 CPUs

parts to be configured:

1) HLT Menu: determines which algorithms are called at which step and which signatures need to be fulfilled for accepted events
2) all configuration parameters of the algorithms and services, called JobOptions (JO), compatibility with offline important
3) release information

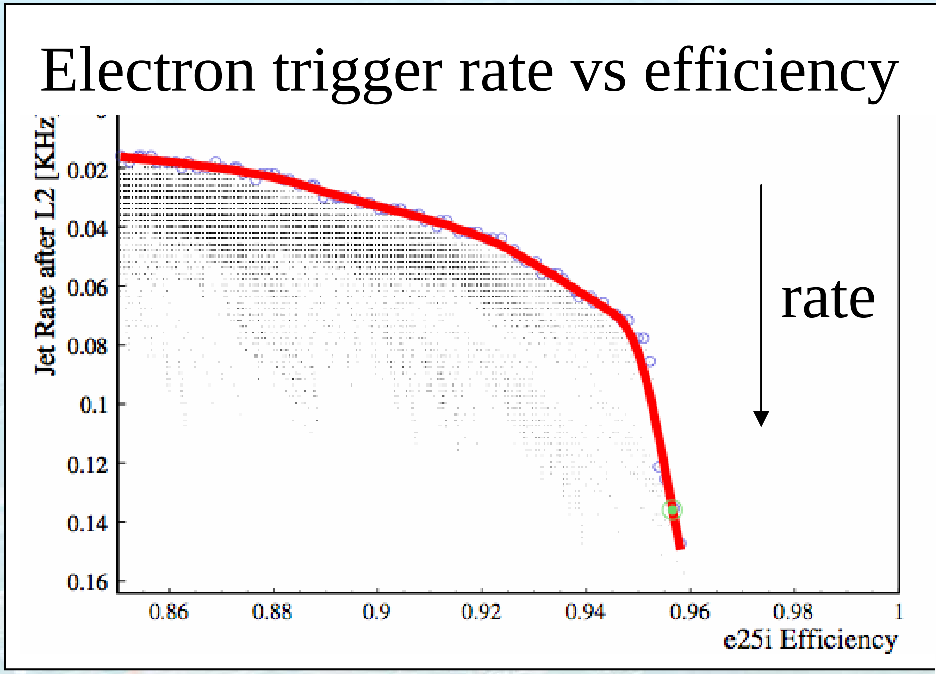
← Consistency (with LVL1) important



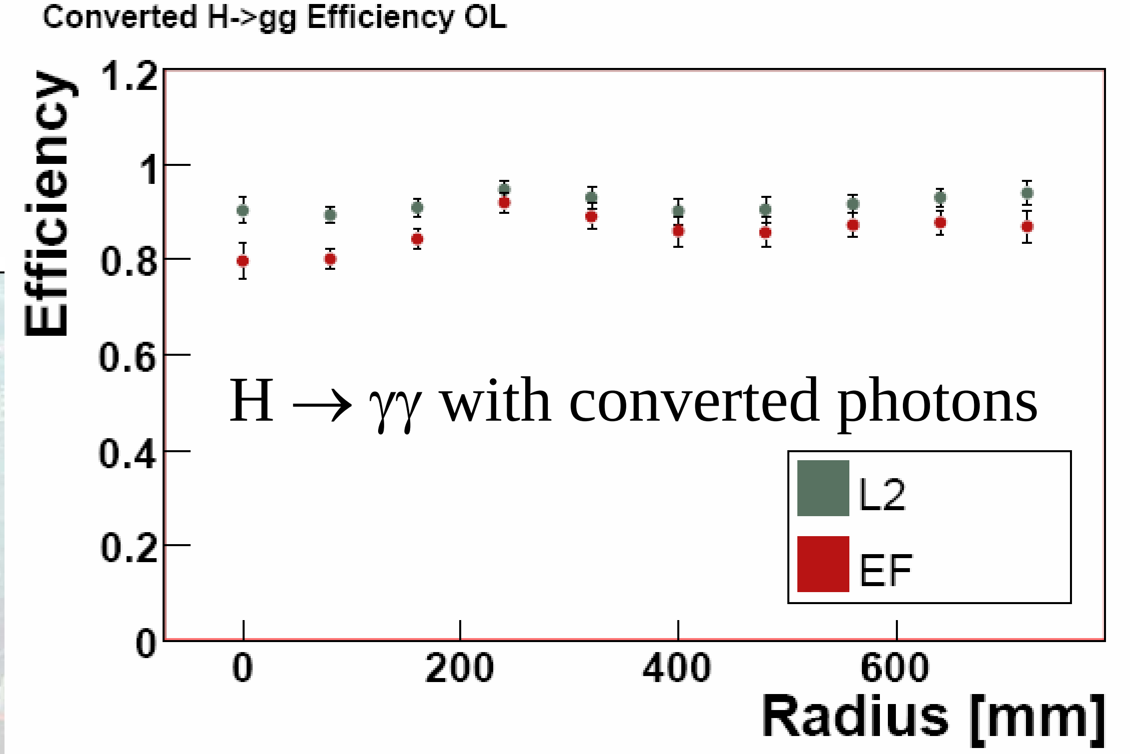
Algorithms and performance

Some examples

Examples of optimization of HLT selection

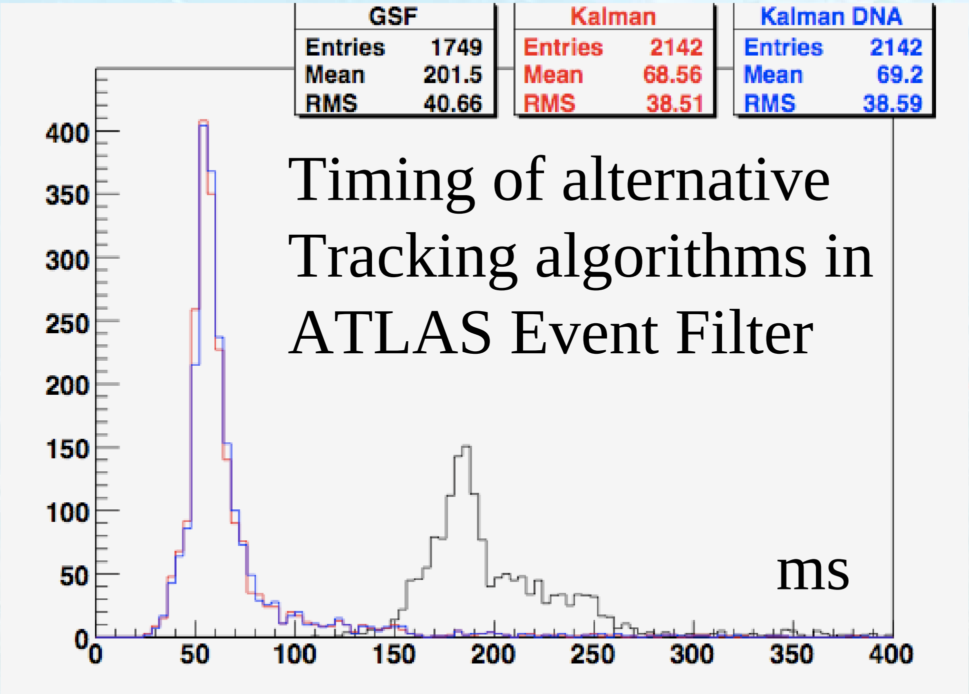

Electron trigger rate vs efficiency

Events pre-selected using detailed simulation of the LVL1 trigger; data in “byte-stream” format


Converted H->gg Efficiency OL

H → γγ with converted photons

Timing and memory usage

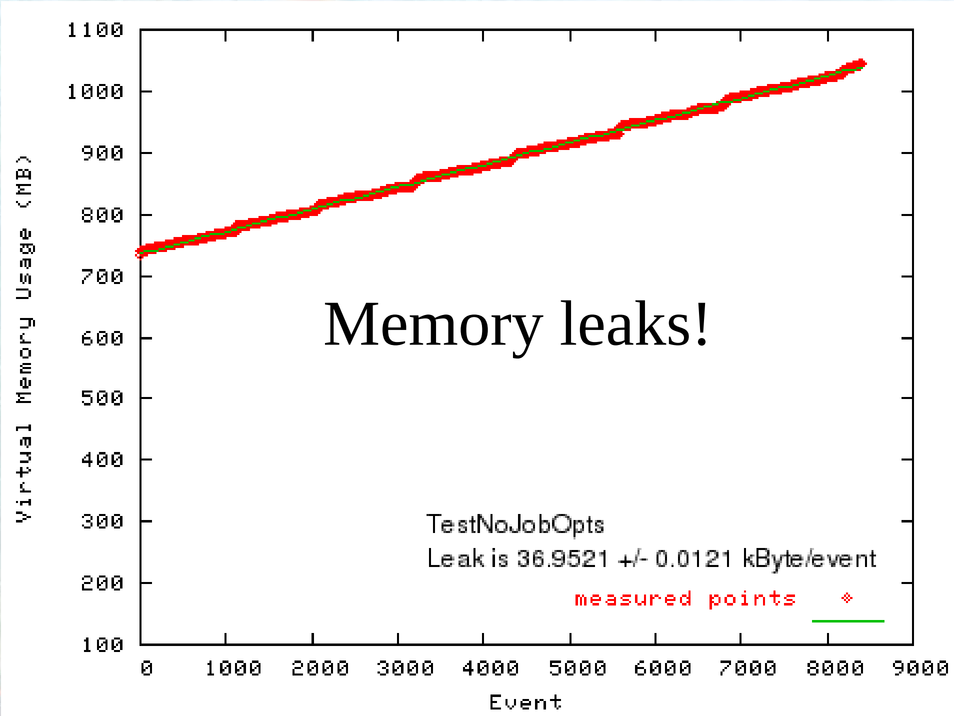


Timing of alternative Tracking algorithms in ATLAS Event Filter

ms

ATLAS time budget
~10 ms LVL2
~1s Event Filter

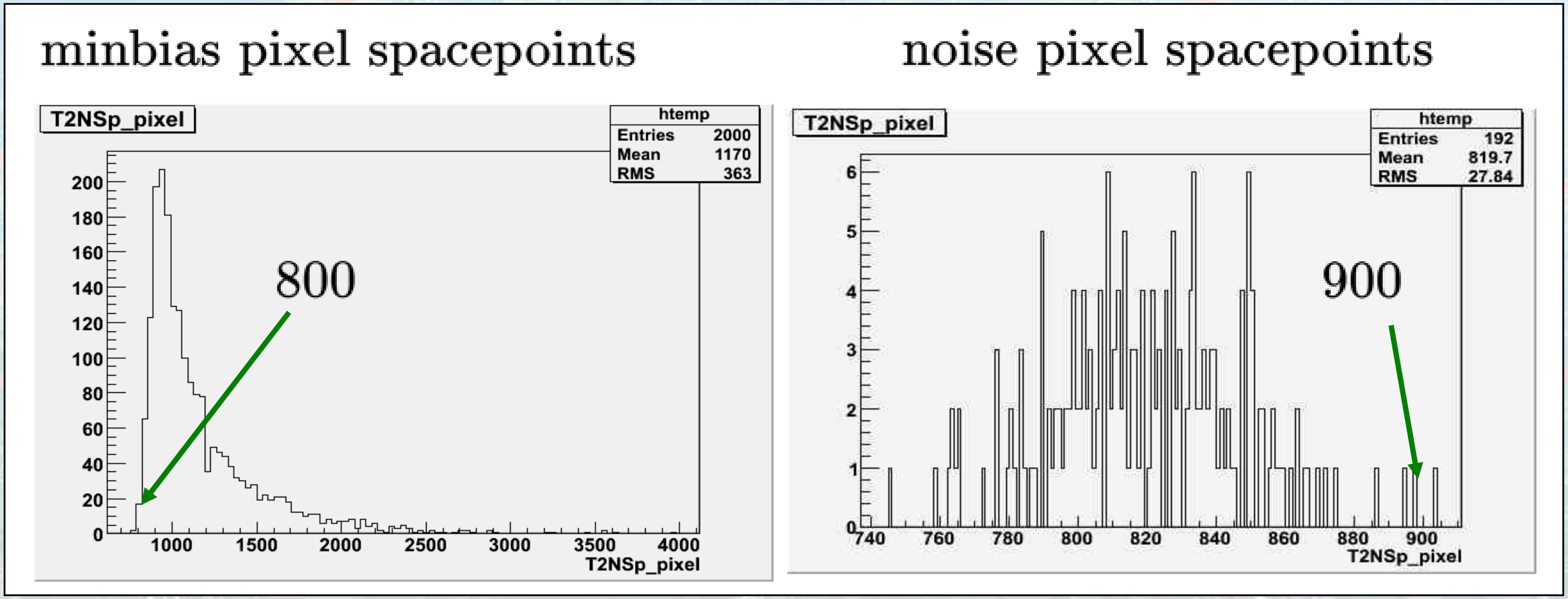
10 kB/event not a big issue offline
LVL2 @ 100 Hz / processor
→ 1 MB/s or 3.6 GB/hour!



Memory leaks!

Minimum-bias selection for early running

- Various possibilities, depending on luminosity
  - Minimum-bias trigger scintillators
  - LVL1 trigger on random bunch crossings, followed by HLT selection to reject empty bunch crossings, e.g. using inner tracking detectors

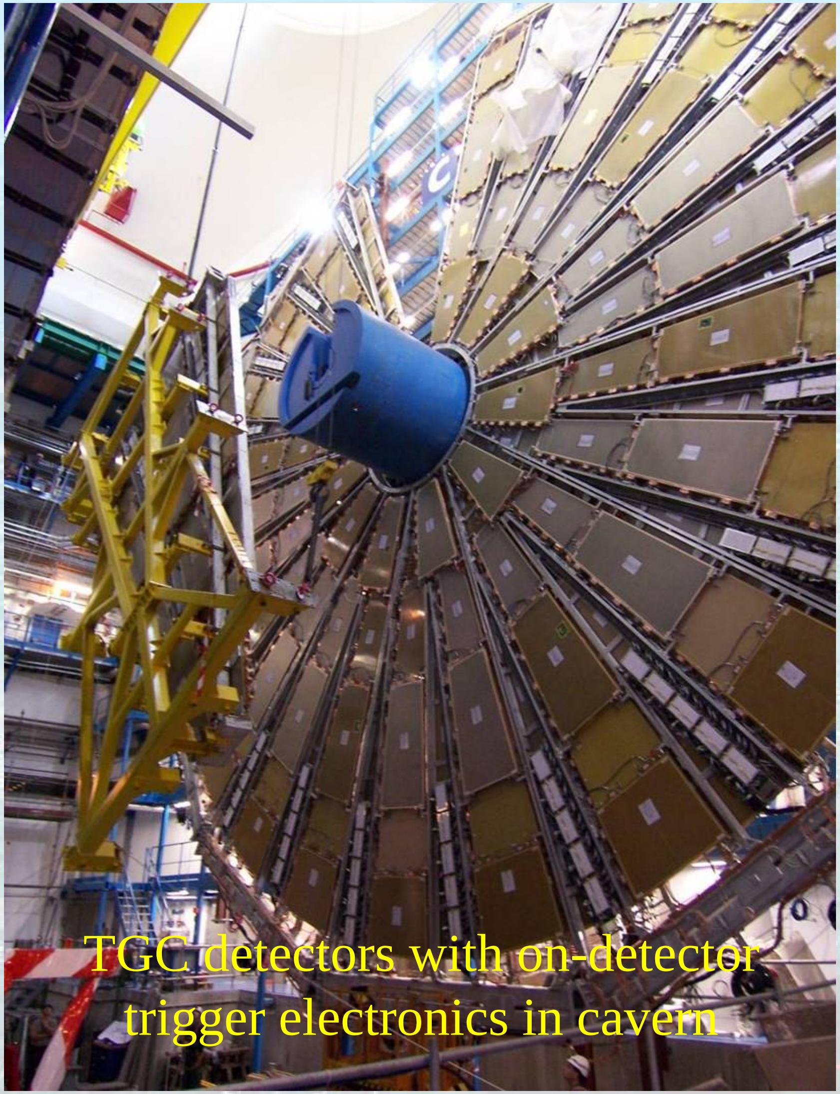


Getting ready for beam

Integration, installation and commissioning

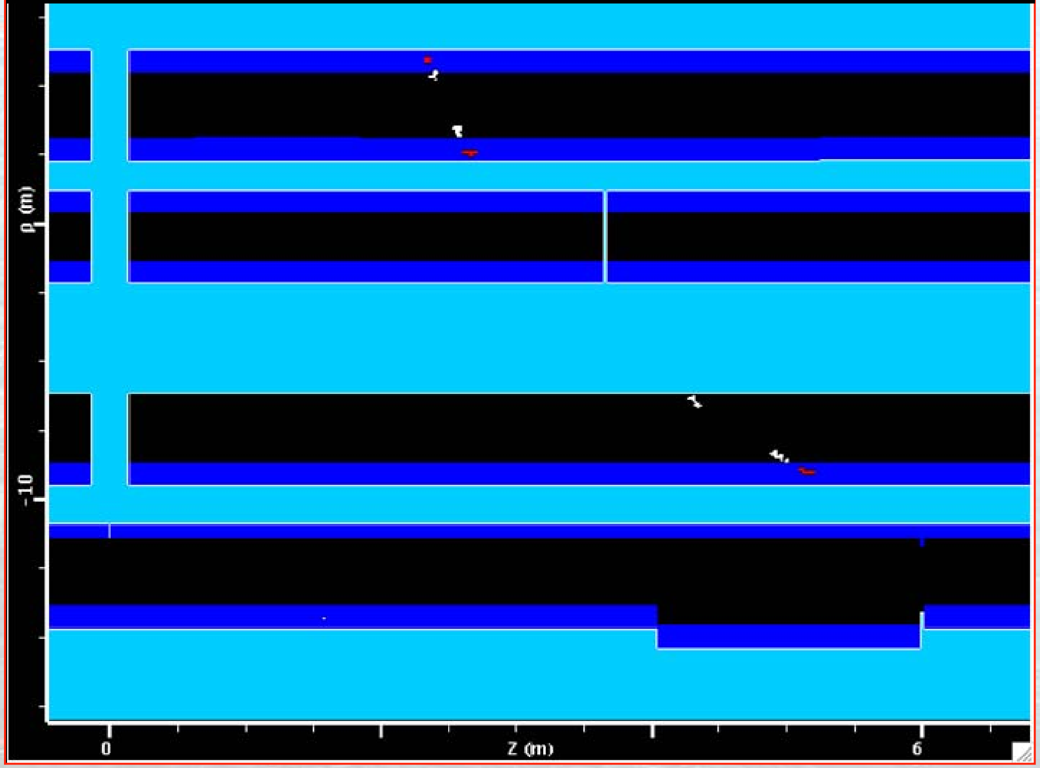
ATLAS LVL1 Muon Trigger Commissioning

(ongoing in ATLAS underground area)



TGC detectors with on-detector trigger electronics in cavern

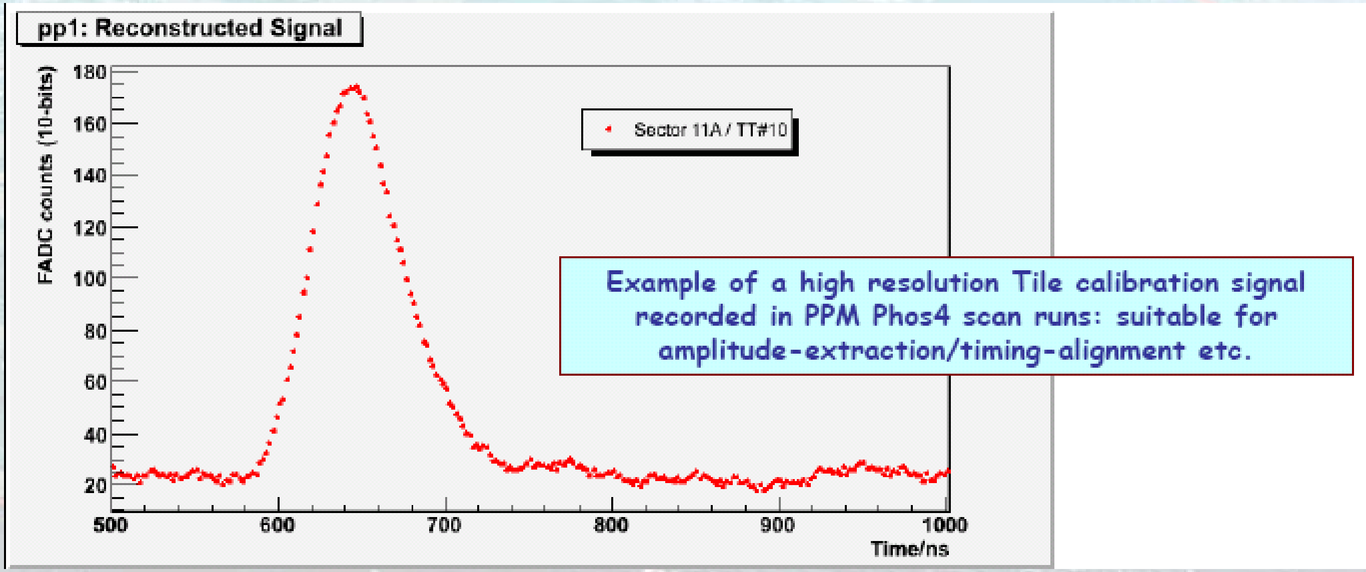
Cosmic ray in barrel muon spectrometer at nominal toroidal field (20 kA) triggered by LVL1 muon trigger



ATLAS LVL1 Calorimeter Trigger Commissioning

(ongoing in ATLAS underground area)

Calorimeter test pulses used to check connectivity, set up timing, and establish calibration procedures

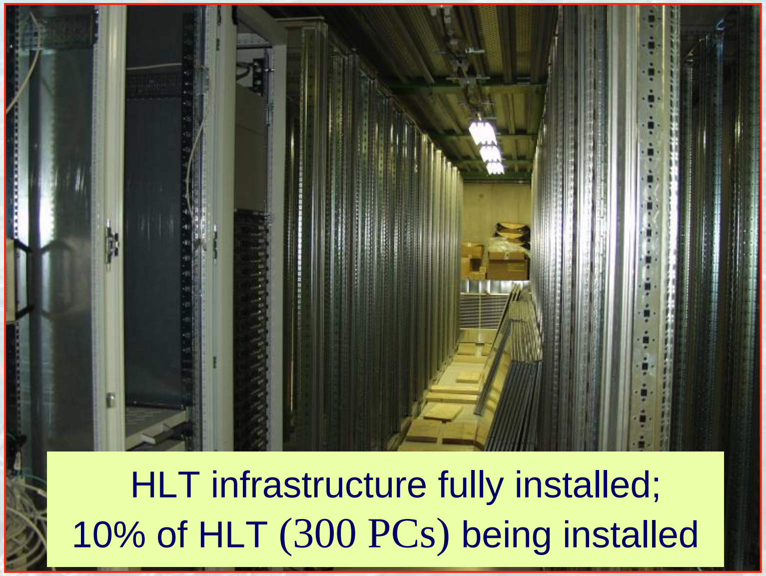


Example of a high resolution Tile calibration signal recorded in PPM Phos4 scan runs: suitable for amplitude-extraction/timing-alignment etc.

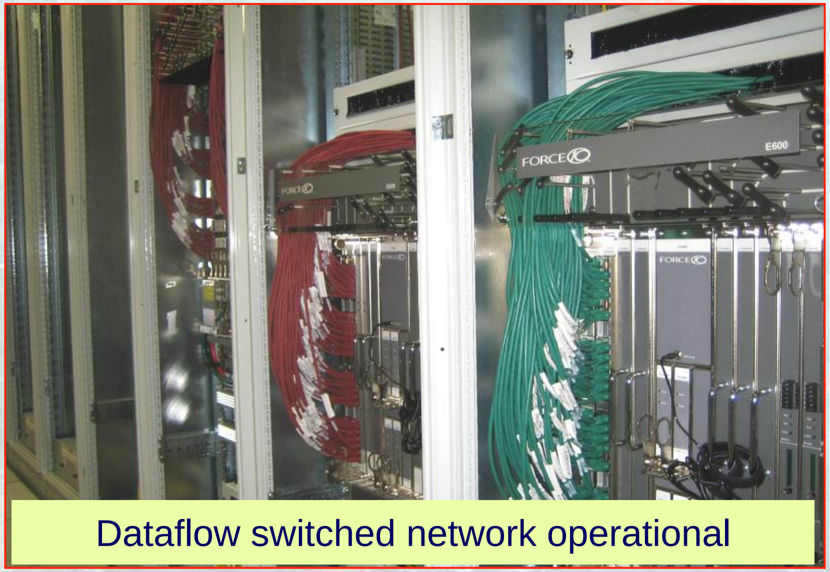
ATLAS DAQ/HLT Commissioning

(ongoing at ATLAS experimental area)

Full read-out system operational



HLT infrastructure fully installed;
10% of HLT (300 PCs) being installed

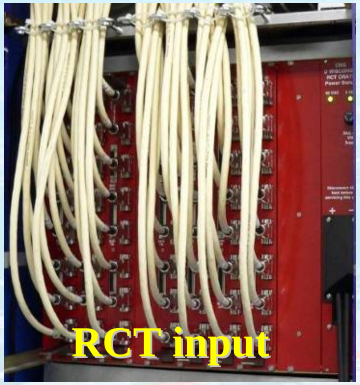


Dataflow switched network operational

CMS Magnet Test and Cosmic Challenge (MTCC)

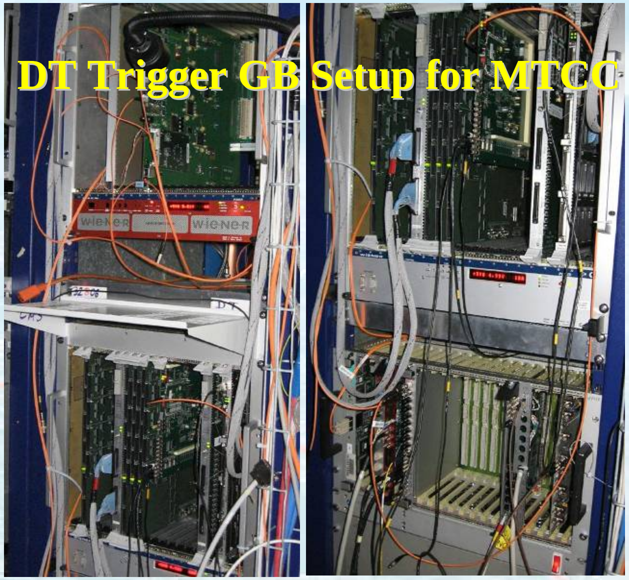
(performed on surface at CMS experimental area)

HCAL to RCT

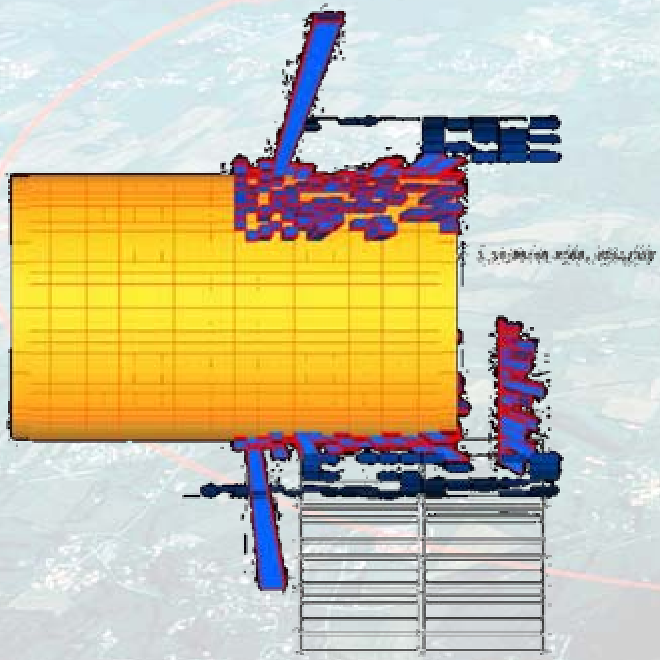


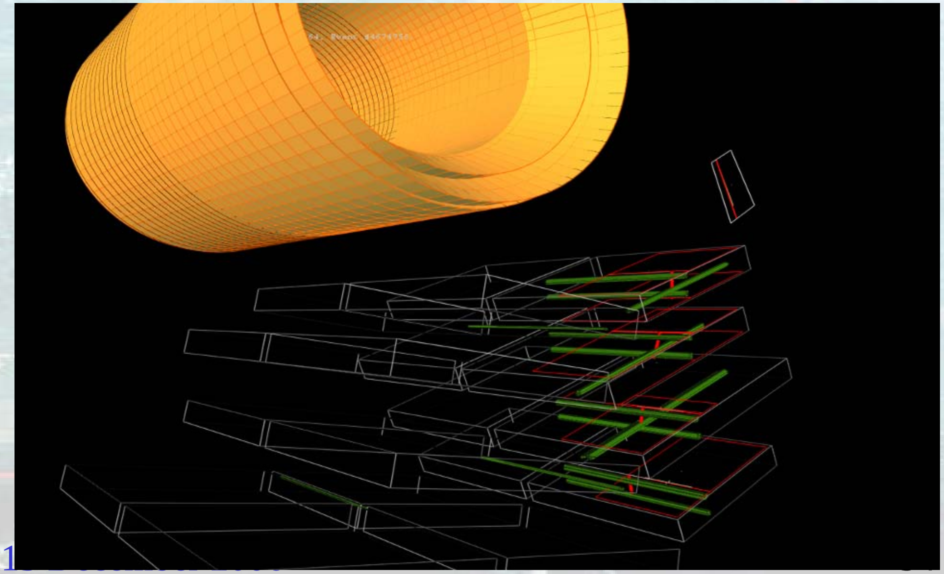
RCT input

RCT output



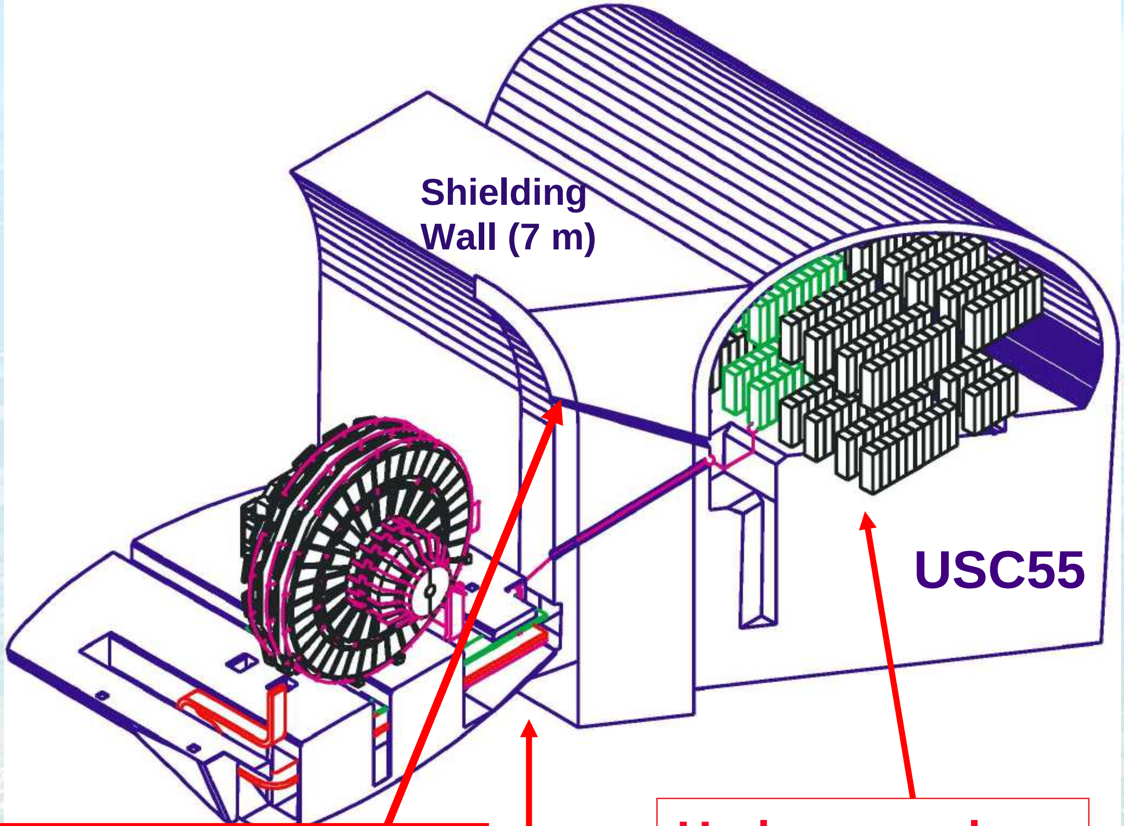
DT Trigger GB Setup for MTCC





CMS LVL1 Calorimeter Trigger Installation

(started in CMS underground area)

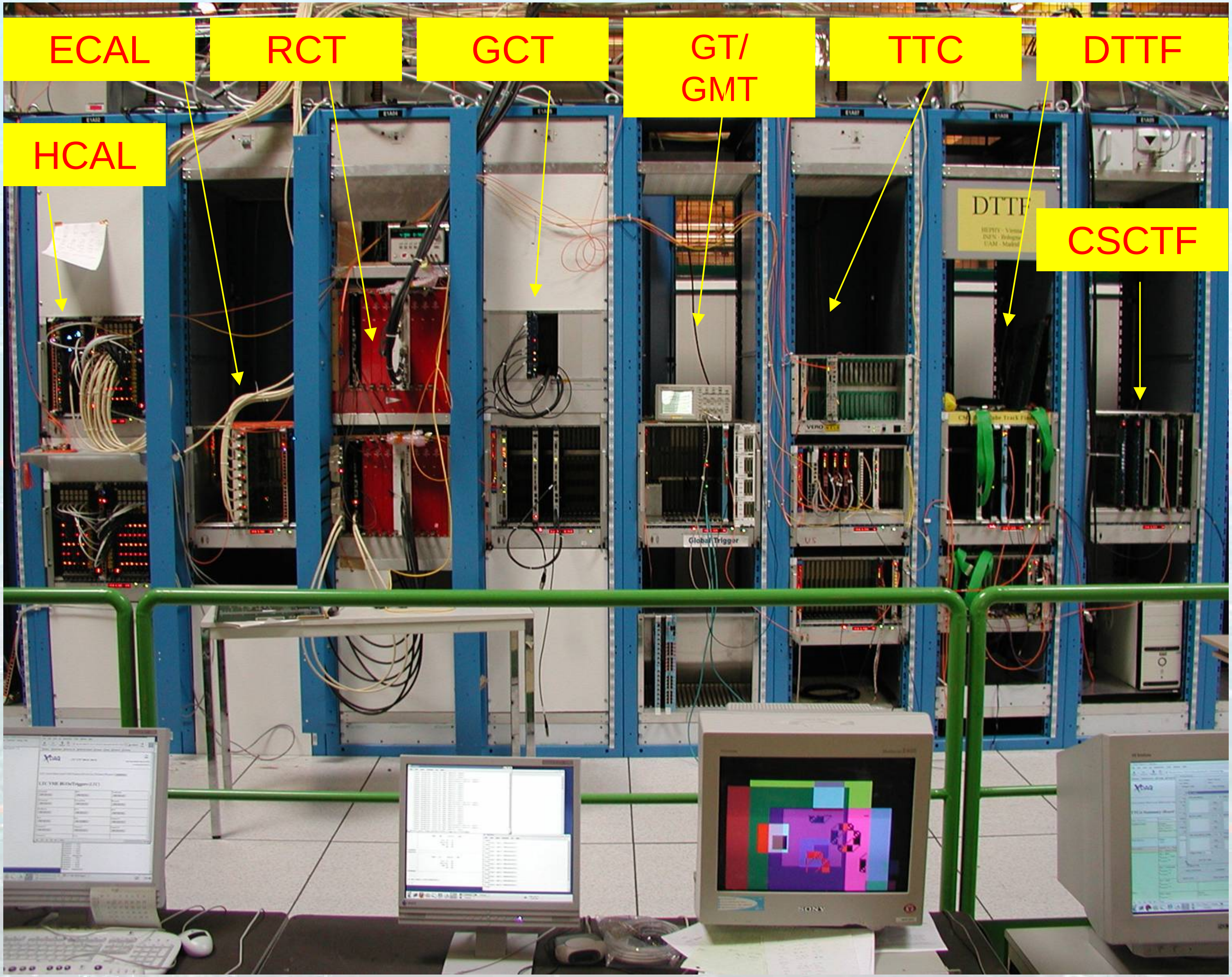


Underground Counting Room

Experimental Hall

CMS LVL1 trigger integration tests

(in electronics integration centre)



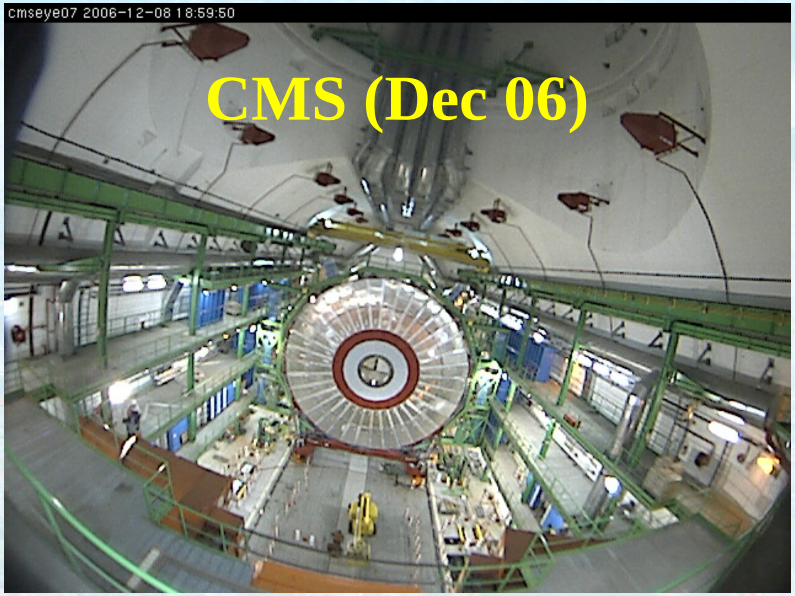
Good progress, but still a lot to do!

- Some ***examples*** of areas where (more) work is needed (ATLAS)
  - Integration of full suite of trigger selection software in online processors, validation in technical runs (play back simulated data) and with cosmic rays
  - Trigger monitoring (and monitoring infrastructure in general)
  - Fault tolerance and error recovery
  - System for coherent configuration of LVL1, LVL2 and EF selection
  - Preparation of trigger menus for start up, including pre-scaled triggers (pre-scale factors adapted to luminosity during coast)
  - Preparation of tools for optimizing trigger as soon as we have real data
  - Additional trigger selection algorithms, e.g. for forward physics, B physics, etc., and refinement/optimization of existing algorithms
- Trigger and Physics
  - There is a very close coupling between the physics and the trigger at LHC
    - Very strong physics selection is made in the trigger
  - “Trigger and Physics weeks” in ATLAS since early this year
    - All physics studies have to be “trigger aware”

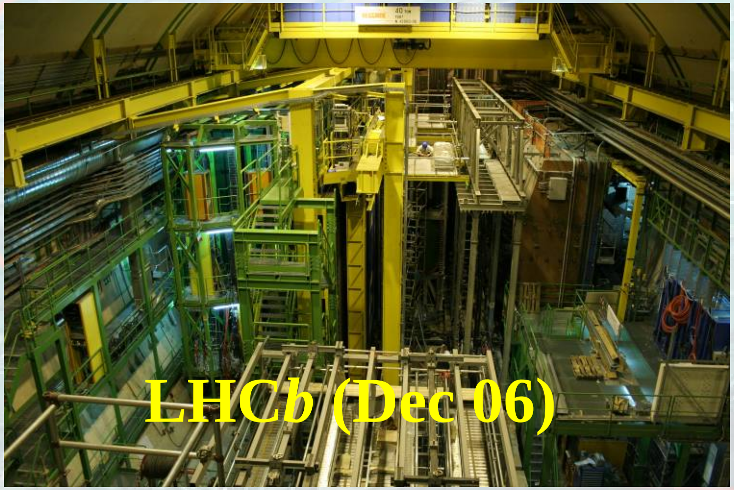
In Conclusion

The LHC experiments are getting ready for collisions in less than a year!

ATLAS (Dec 06)



CMS (Dec 06)



LHC*b* (Dec 06)

ALICE (Dec 06)