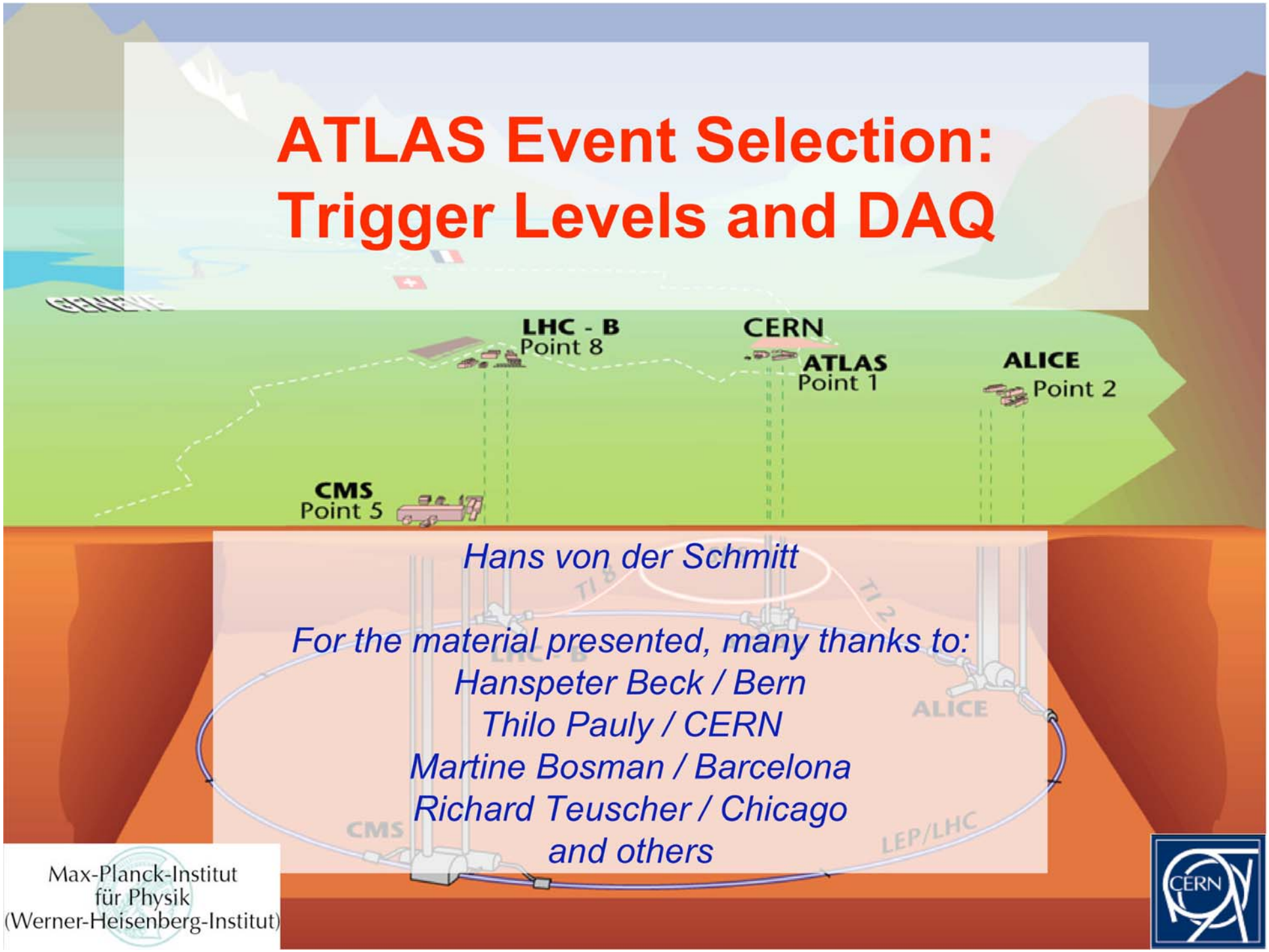
ATLAS Event Selection: Trigger Levels and DAQ



Hans von der Schmitt

For the material presented, many thanks to:
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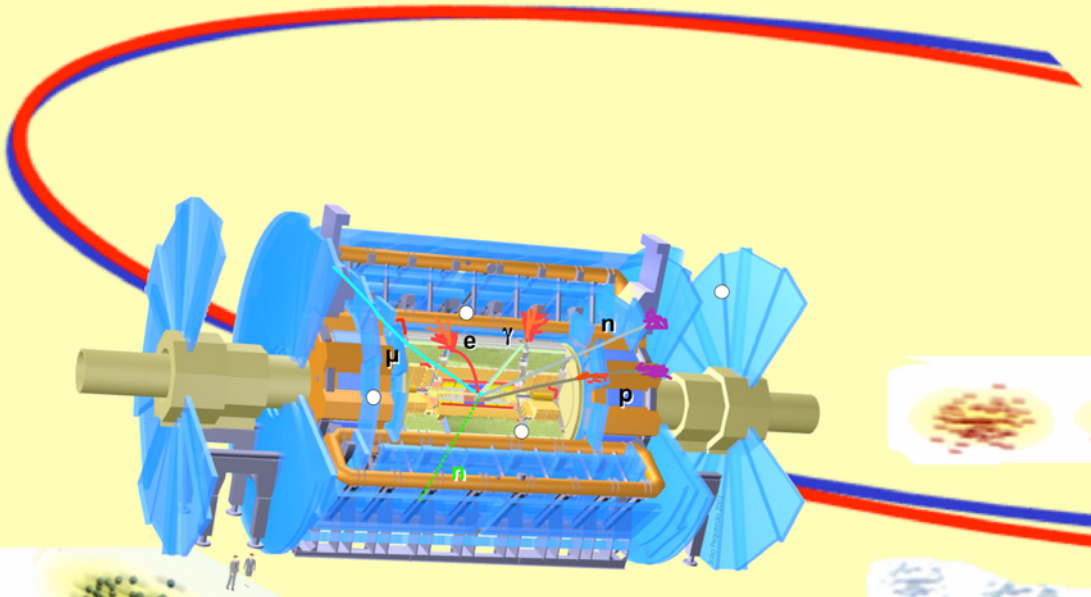
Thilo Pauly / CERN
Martine Bosman / Barcelona
Richard Teuscher / Chicago
and others

Max-Planck-Institut
für Physik
(Werner-Heisenberg-Institut)

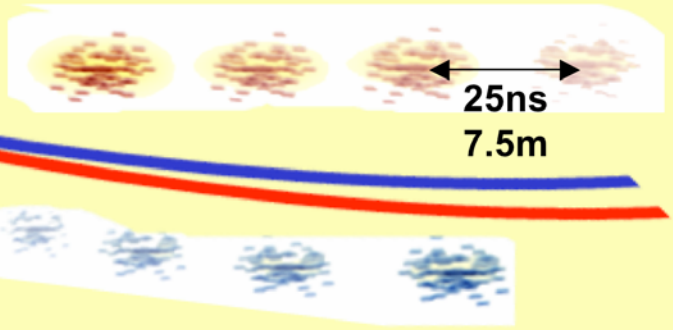
Proton-Proton Collisions at the LHC



Nominal LHC Parameters:

7 TeV	Proton Energy
$10^{34}cm^{-2}s^{-1}$	Luminosity
2808	Bunches per Beam
10^{11}	Protons per Bunch

(full specification here)



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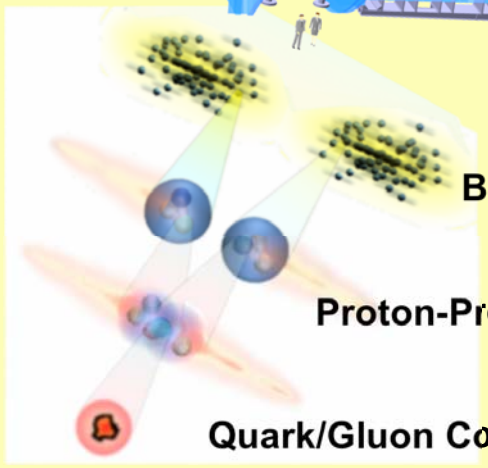
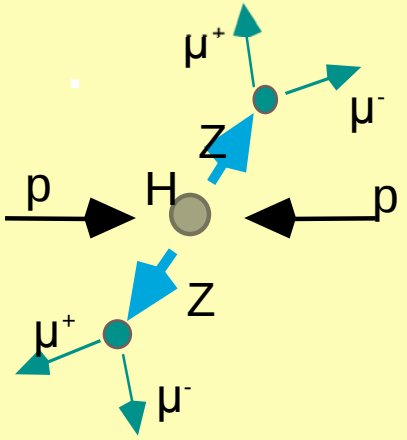
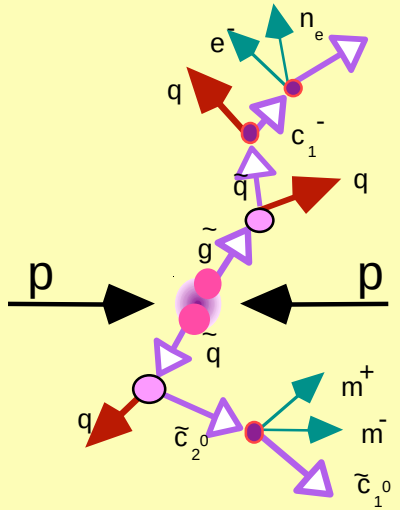


Bunch Crossings 4x10⁷ Hz

Proton-Proton Collisions 10⁹ Hz

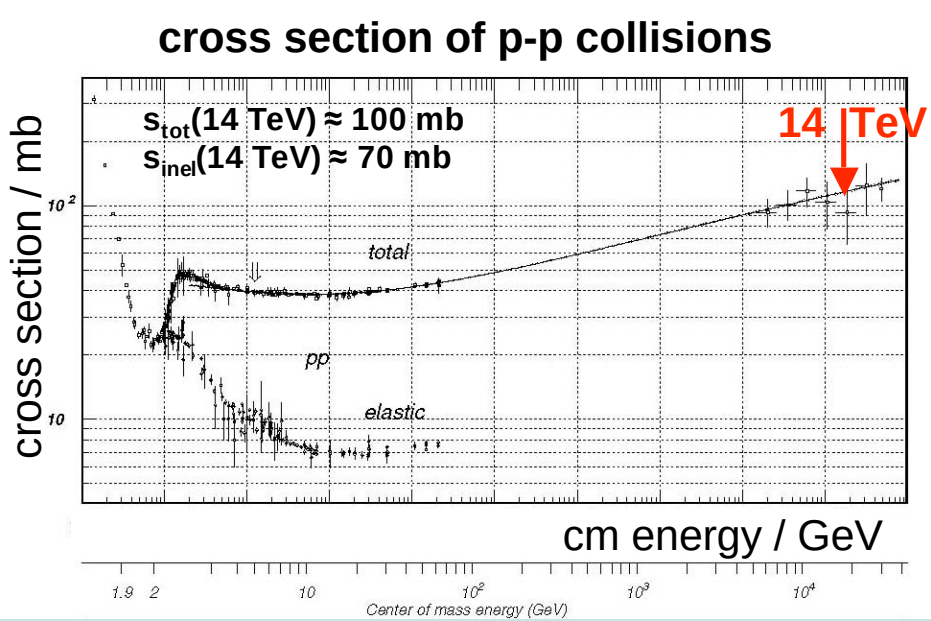
Quark/Gluon Collisions





Heavy particle production $10^{+3...-7}$ Hz
(W, Z, t, Higgs, SUSY,…)

Event Rates and Multiplicities



R = event rate
L = luminosity = 10^{34} cm^{-2} s^{-1}
σ_{inel} = inelastic cross section = 70 mb
N = interactions / bunch crossing
Dt = bunch crossing interval = 25 ns

$R = L \times \sigma_{inel} = 10^{34}\ cm^{-2}\ s^{-1} \times 70mb = 7 \cdot 10^{8}$ Hz

$N = R / Dt$
$= 7 \cdot 10^{8}\ s^{-1} \times 25 \cdot 10^{-9}\ s = 17.5$
$= 17.5 \times 3564 / 2808$ (not all bunches filled)
= 23 interactions / bunch crossing (pileup)

With every bunchcrossing

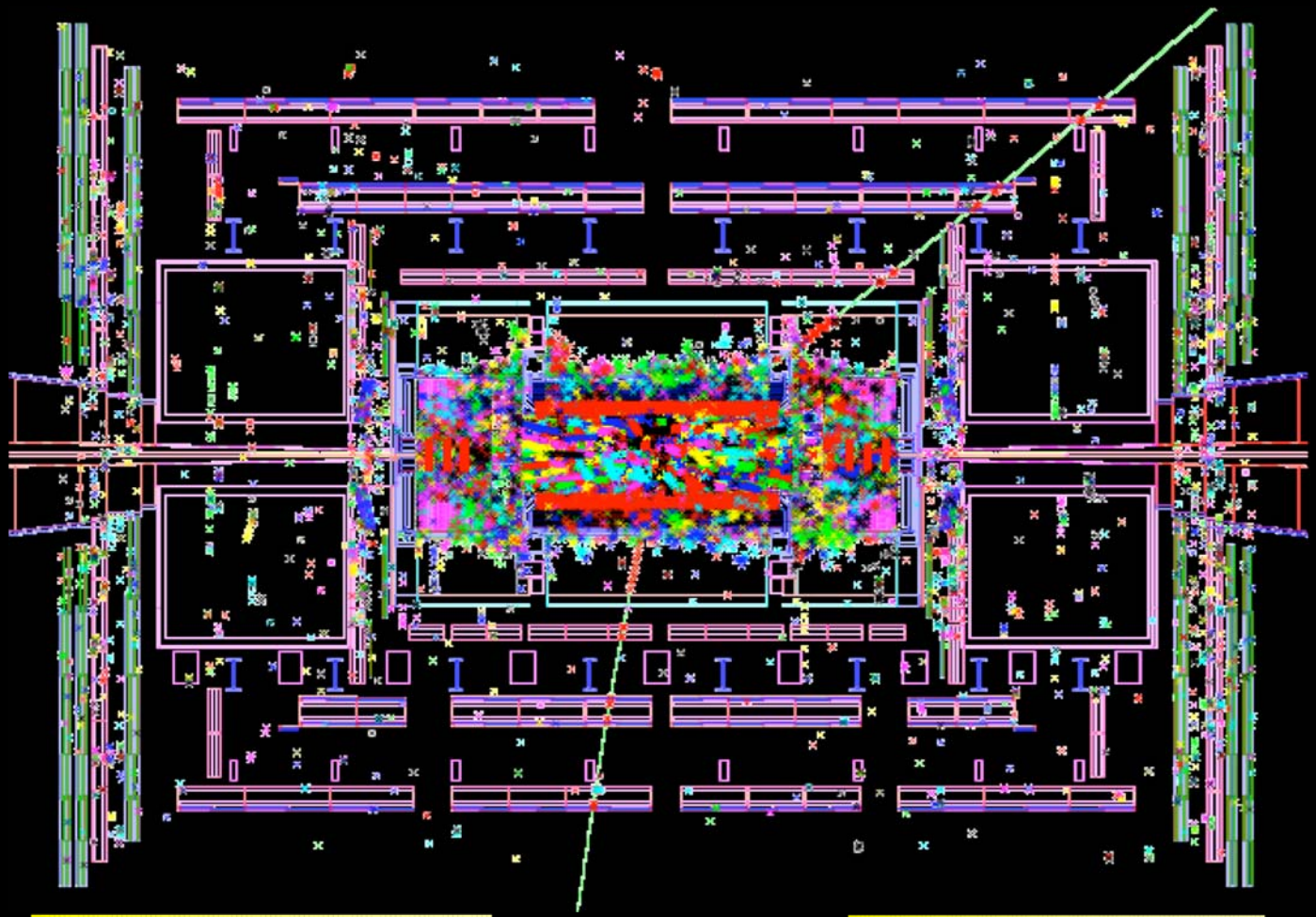
23 Minimum Bias events

with ~1725 particles produced

n_{ch} = charged particles / interaction
N_{ch} = charged particles / BC
N_{tot} = all particles / BunchCrossing

$n_{ch} \approx 50$
$N_{ch} = n_{ch} \times 23 = \sim 1150$
$N_{tot} = N_{ch} \times 1.5 = \sim 1725$

Looking for Interesting Events



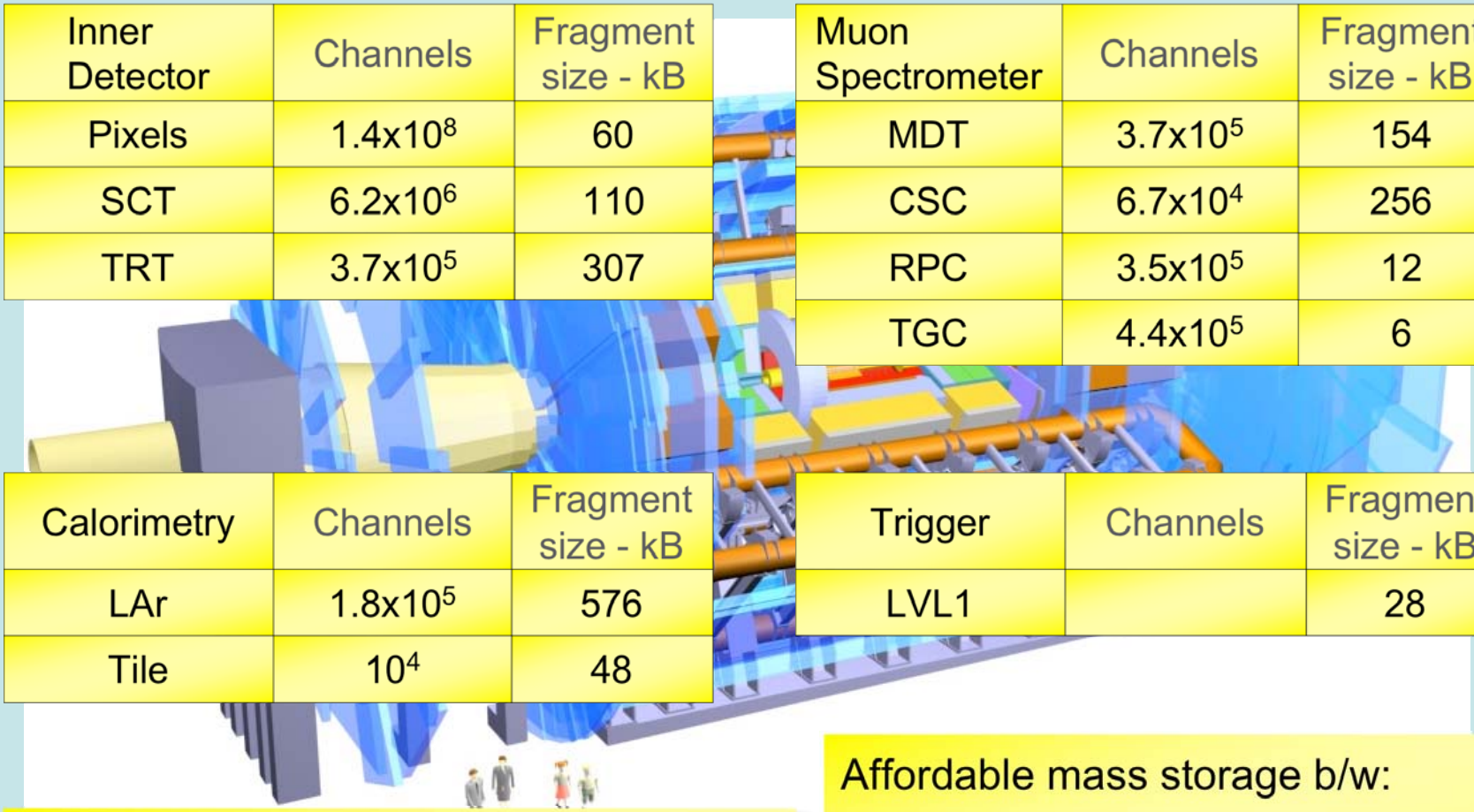
Higgs → ZZ → 2e+2μ

23 min bias events

ATLAS Event Sizes

Inner Detector	Channels	Fragment size - kB
Pixels	1.4×10^8	60
SCT	6.2×10^6	110
TRT	3.7×10^5	307

Muon Spectrometer	Channels	Fragment size - kB
MDT	3.7×10^5	154
CSC	6.7×10^4	256
RPC	3.5×10^5	12
TGC	4.4×10^5	6



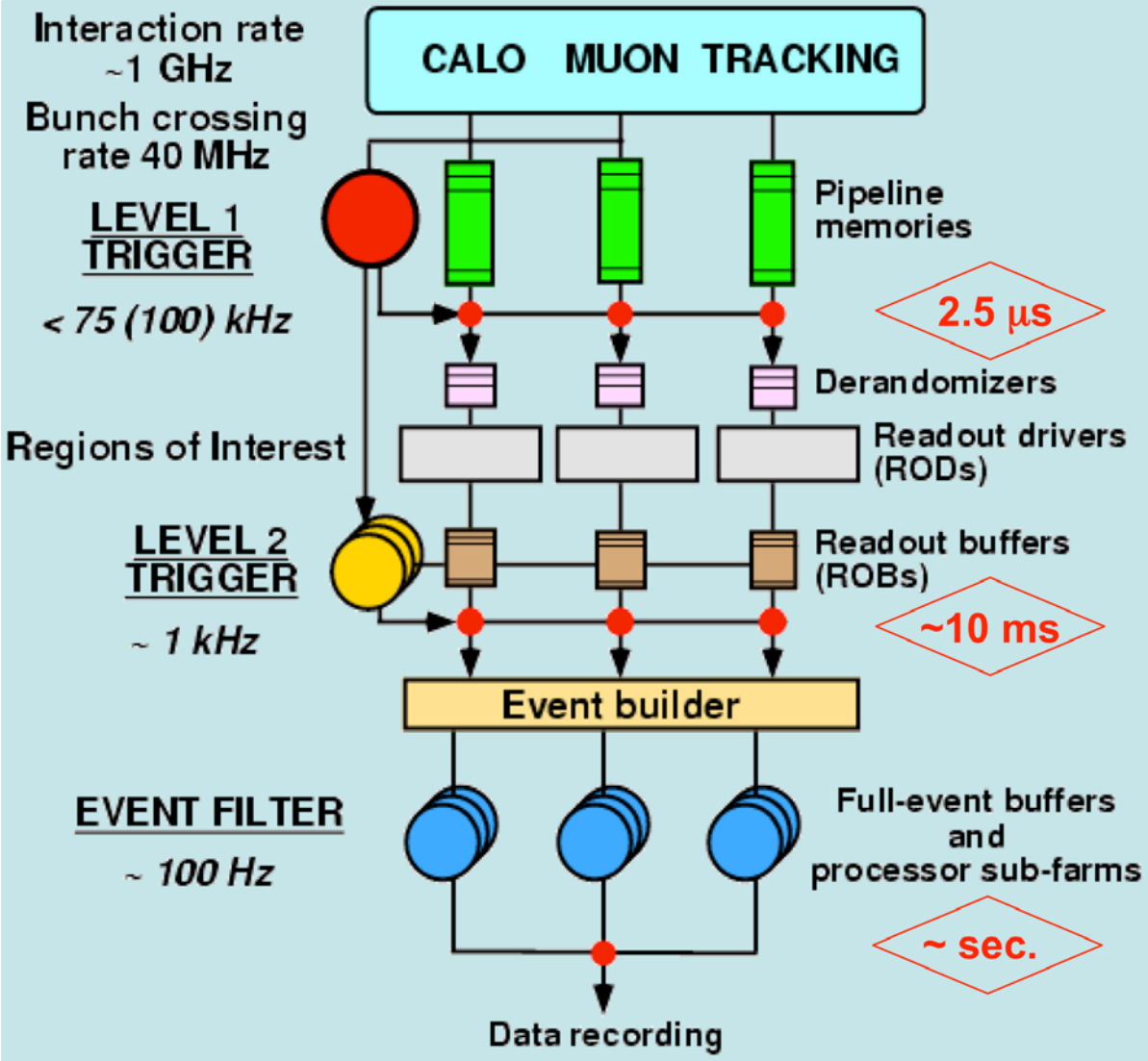
Calorimetry	Channels	Fragment size - kB
LAr	1.8×10^5	576
Tile	10^4	48

Trigger	Channels	Fragment size - kB
LVL1		28

Atlas event size: 1.5 MBytes
140 million channels
organized into ~1600 Readout Links

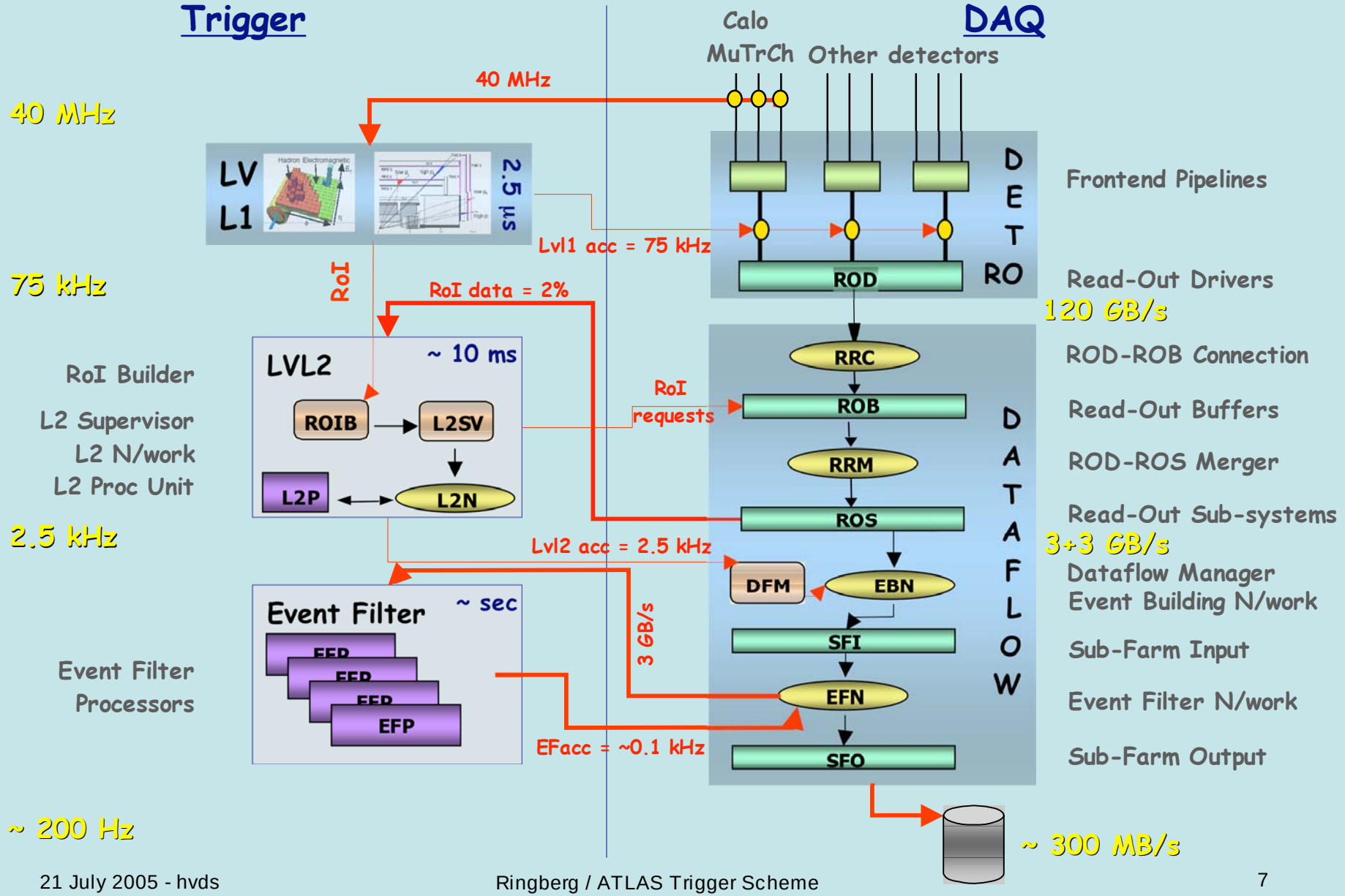
Affordable mass storage b/w:
300 MB/sec
☛ 3 PB/year
for offline analysis

ATLAS Three-Level Trigger Architecture

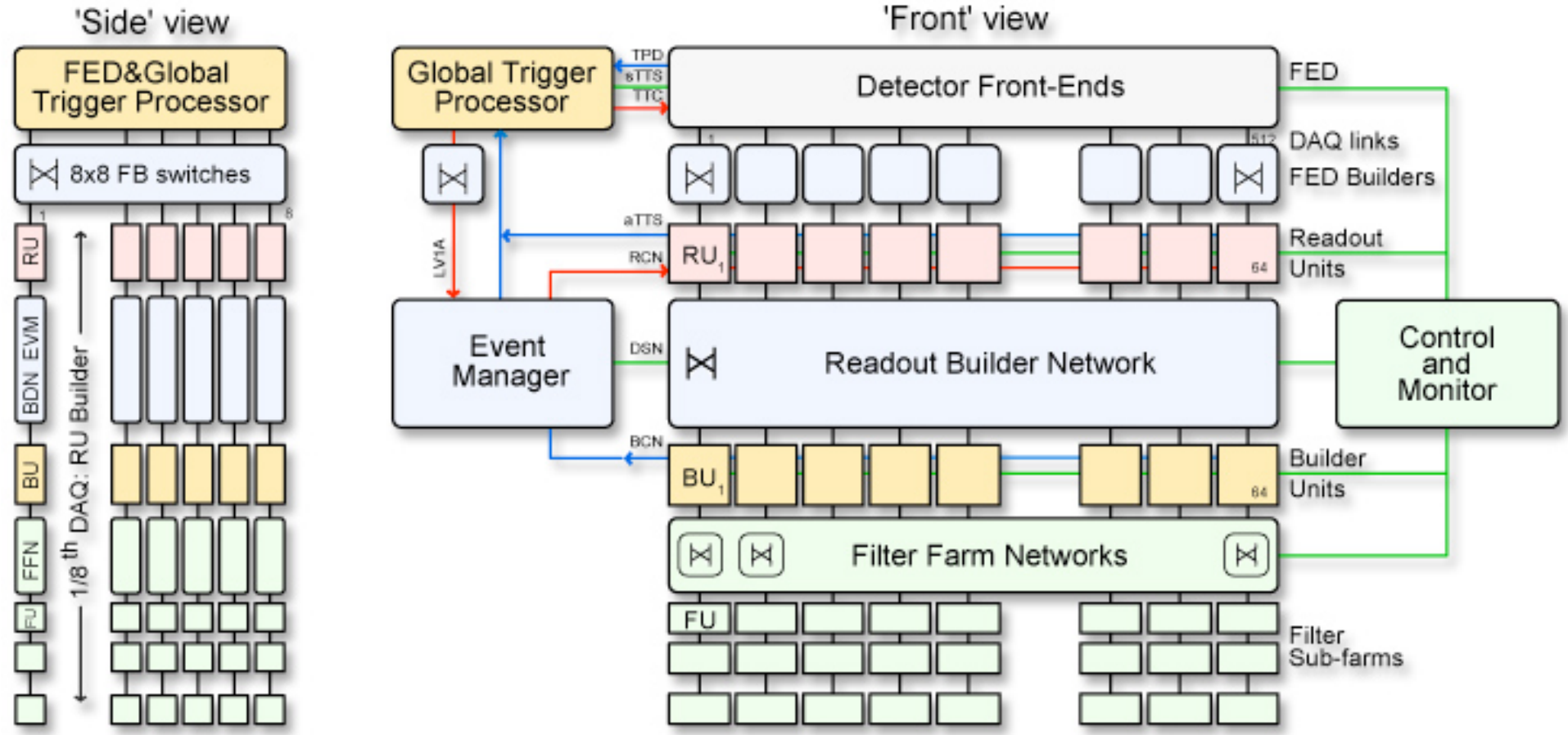


- LVL1 decision made in hardware with calorimeter data with coarse granularity and muon trigger chambers data.
  - Buffering on detector
- LVL2 uses Region of Interest data (ca. 2%) with full granularity and combines information from all detectors; performs fast rejection.
  - Buffering in ROBs
- EventFilter refines the selection, can perform event reconstruction at full granularity using latest alignment and calibration data.
  - Buffering in EB & EF

Trigger + Data Acquisition (TDAQ) in more detail...



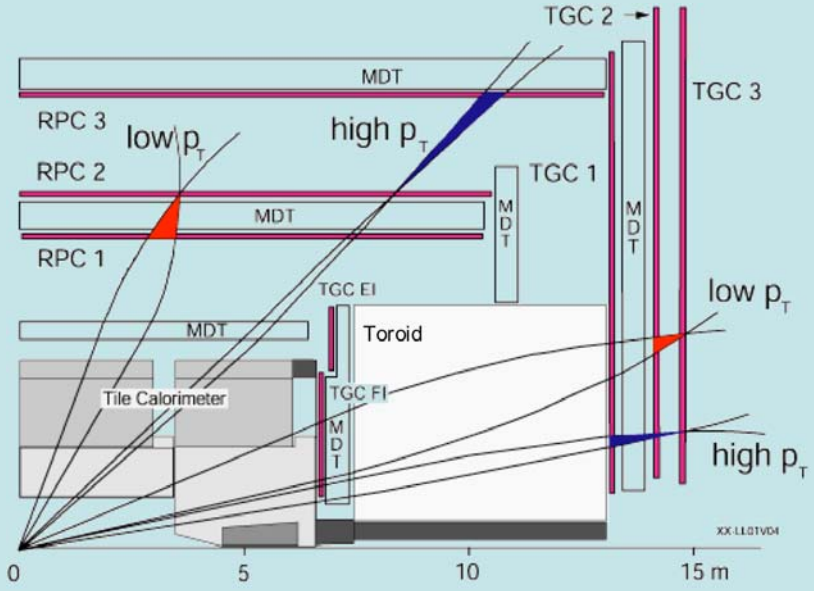
Quick Comparision - CMS TriDAS Chain



- Level 1 trigger in hardware - as usual
- All higher level triggering in one set of Filter Units (FU)
- Two levels of event building:
  - Frontend builders, also average out data size fluctuations among detectors
  - Readout builder +Farms for full events - can be procured in 1/8 increments

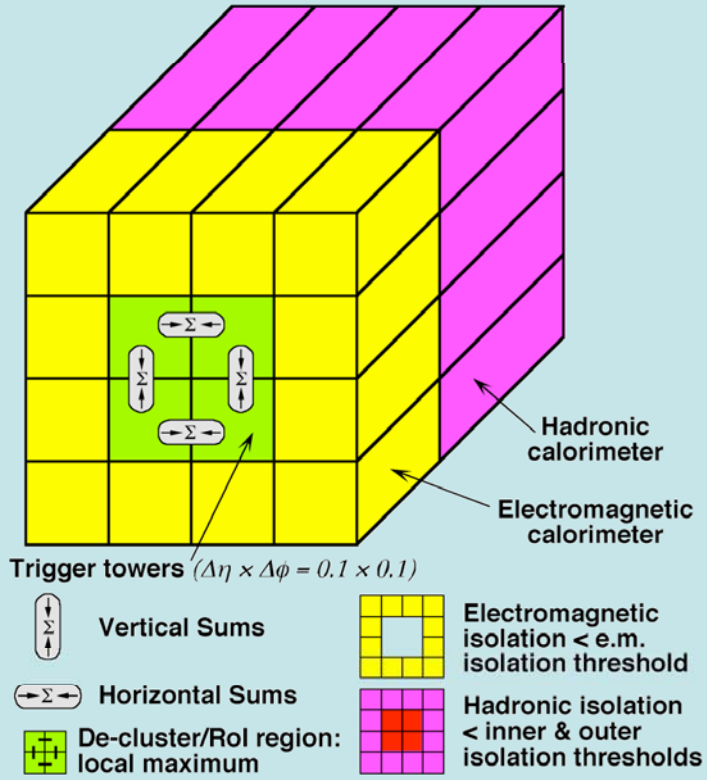
Mechanisms used for Triggering in ATLAS

ATLAS Trigger Level 1 (LVL1) - Muons and Colorimetry



Muon Trigger looking for coincidences in muon trigger chambers
2 out of 3 (low-p_T; >6 GeV) and
3 out of 3 (high-p_T; > 20 GeV)

Trigger efficiency 99% (low-p_T) and 98% (high-p_T)



Calorimetry Trigger looking for e/γ/τ + jets

- **Various combinations of cluster sums and isolation criteria**
- **$\Sigma E_T^{em,had}$, E_T^{miss}**

Region of Interest (RoI) Mechanism

LVL1 triggers on high pT objects

- Calorimeter cells and muon chambers to find e/γ/τ-jet-μ candidates above thresholds

LVL2 uses Regions of Interest as identified by Level-1

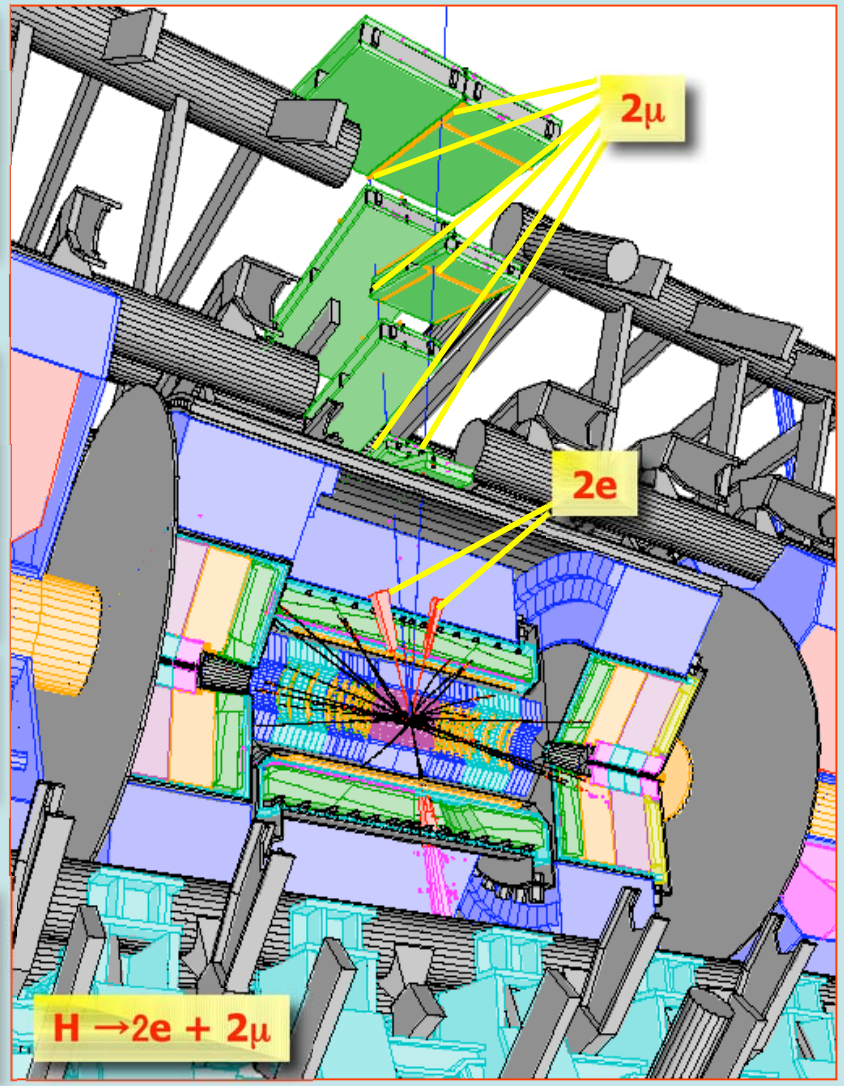
- Local data reconstruction, analysis, and sub-detector matching of RoI data

The total amount of RoI data is minimal

- ~2% of the Level-1 throughput but it has to be extracted from the rest at 75 kHz

EF can use full event data

- And also the results obtained by LVL2



Event Selection Strategy

- ATLAS has an inclusive trigger strategy
  - LVL1 Trigger on individual signatures
    - EM / Had Cluster
    - Total Energy
    - Missing Energy
    - Muon track
  - LVL2 confirms & refines LVL1 signature
    - requires seeding of LVL2 with LVL1 result – i.e. RoI
  - EventFilter confirms & refines LVL2 signature
    - seeding of EventFilter with LVL2 result
    - tags accepted events according to physics selection
- Reject events early
  - Save resources
    - minimize data transfer
    - minimize required CPU power
  - Look at signatures one by one
    - i.e. do not try to reconstruct full event upfront
    - if no signatures left, reject event

LVL1 Trigger Thresholds + Rates

Selection		Rates (Hz) $2x10^{33}$ $cm^{-2}s^{-1}$	Rates (Hz) 10^{34} $cm^{-2}s^{-1}$
MU20	20	800	4000
2MU6		200	1000
EM25I	30	12000	22000
2EM15I	20	4000	5000
J200	290	200	200
3J90	130	200	200
4J65	90	200	200
J60+xE60	100+100	400	500
TAU25+xE30	60+60	2000	1000
MU10+EM15I		100	400
Others (prescales,calibration)		5000	5000
Total		~25000	~40000

LVL1 rate is dominated by electromagnetic clusters: 78% of physics triggers

Inclusive Higher Level Trigger (HLT) Event Selection

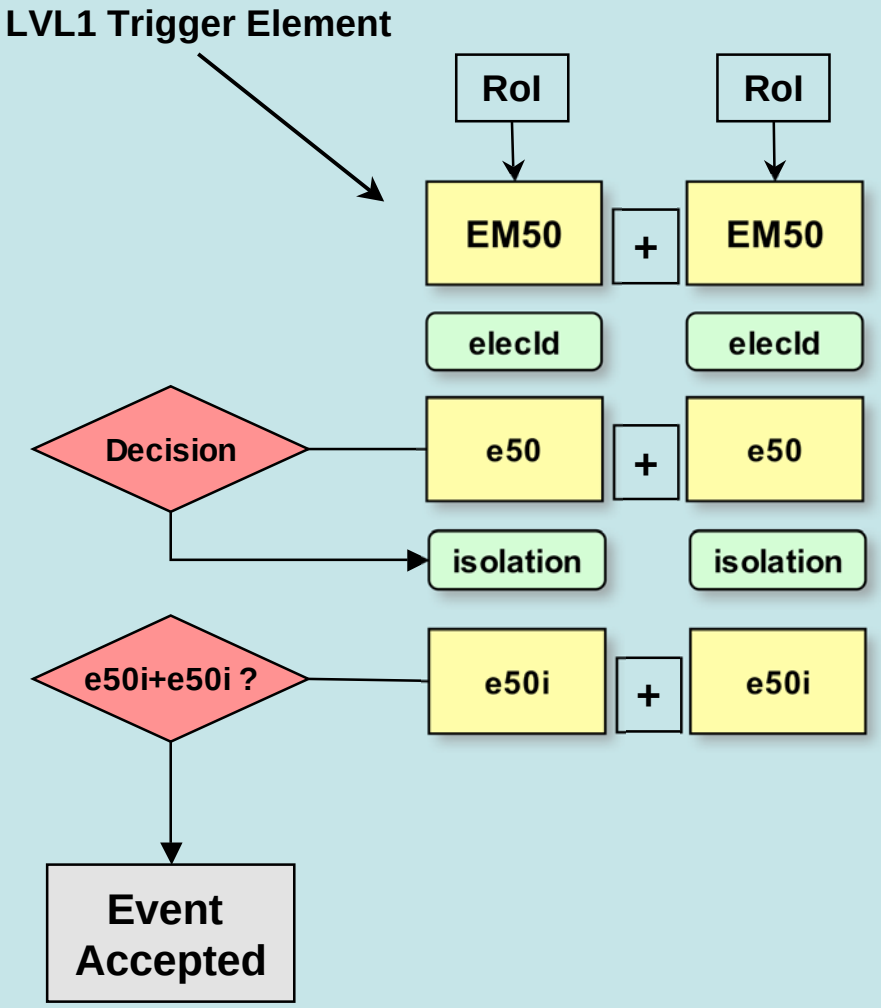
Selection	$2x10^{33}$ $cm^{-2}s^{-1}$	Rates (Hz)
Electron	e25i, 2e15i	~40
Photon	γ60i, 2γ20i	~40
Muon	μ20i, 2μ10	~40
Jets	j400, 3j165, 4j110	~25
Jet & E_T^{miss}	j70 + xE70	~20
tau & E_T^{miss}	τ35 + xE45	~5
B-physics	2μ6 with m_B /$m_{J/\psi}$	~10
Others	pre-scales, calibration, …	~20
Total		~200

HLT rate reduces by e/γ a lot: 45% of physics triggers

Stepwise Event Selection in LVL2

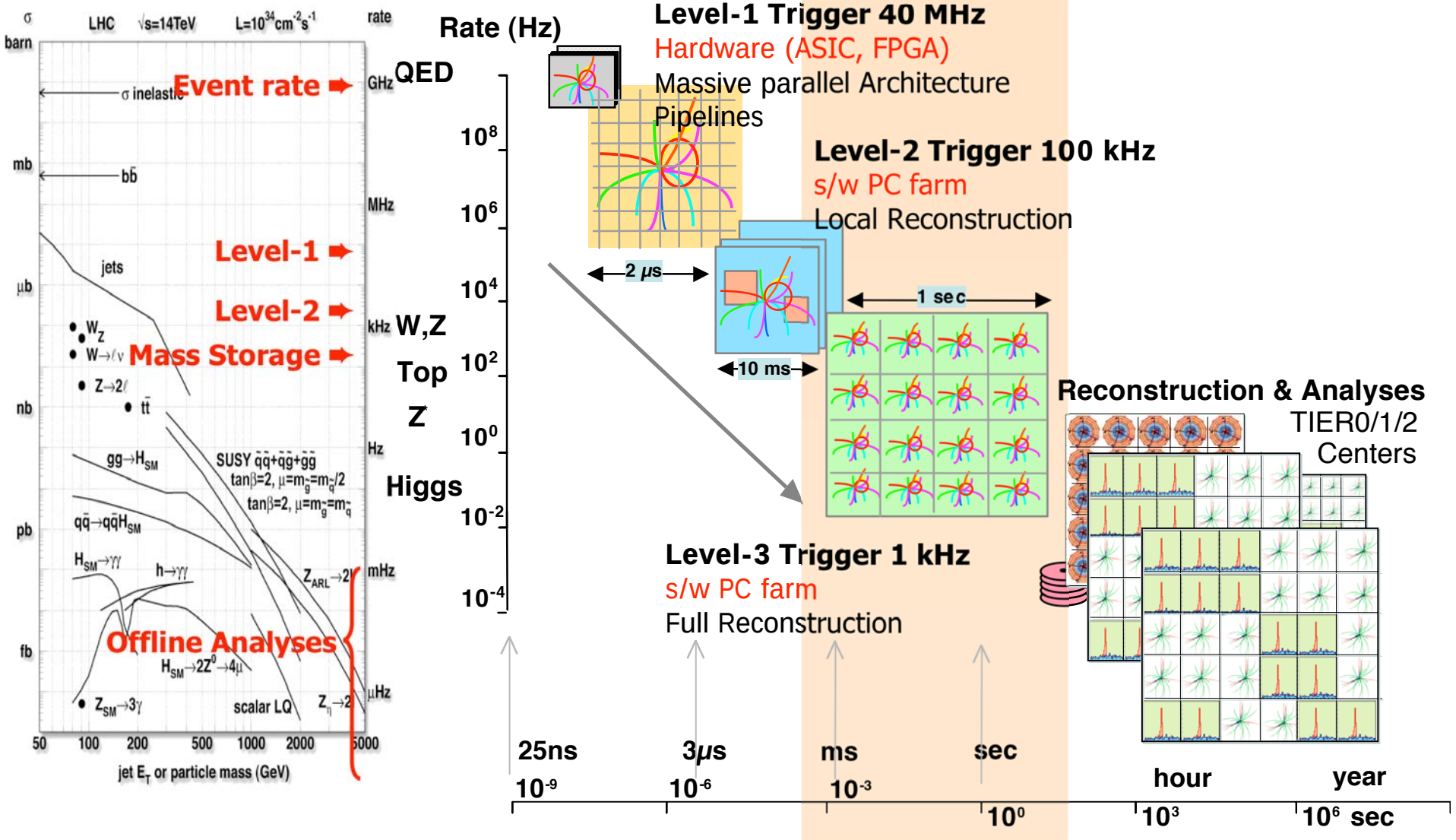
- Selection takes place in steps
- Rejection can happen at every step

- The initial seeds for the L2 steps are the L1 Regions of Interest
- Trigger Decision and Data Navigation is based on Trigger Elements
- Algorithms use the result from previous steps (Seeding) using the Data Navigation and the Trigger Elements



Software used in the Higher Level Triggers

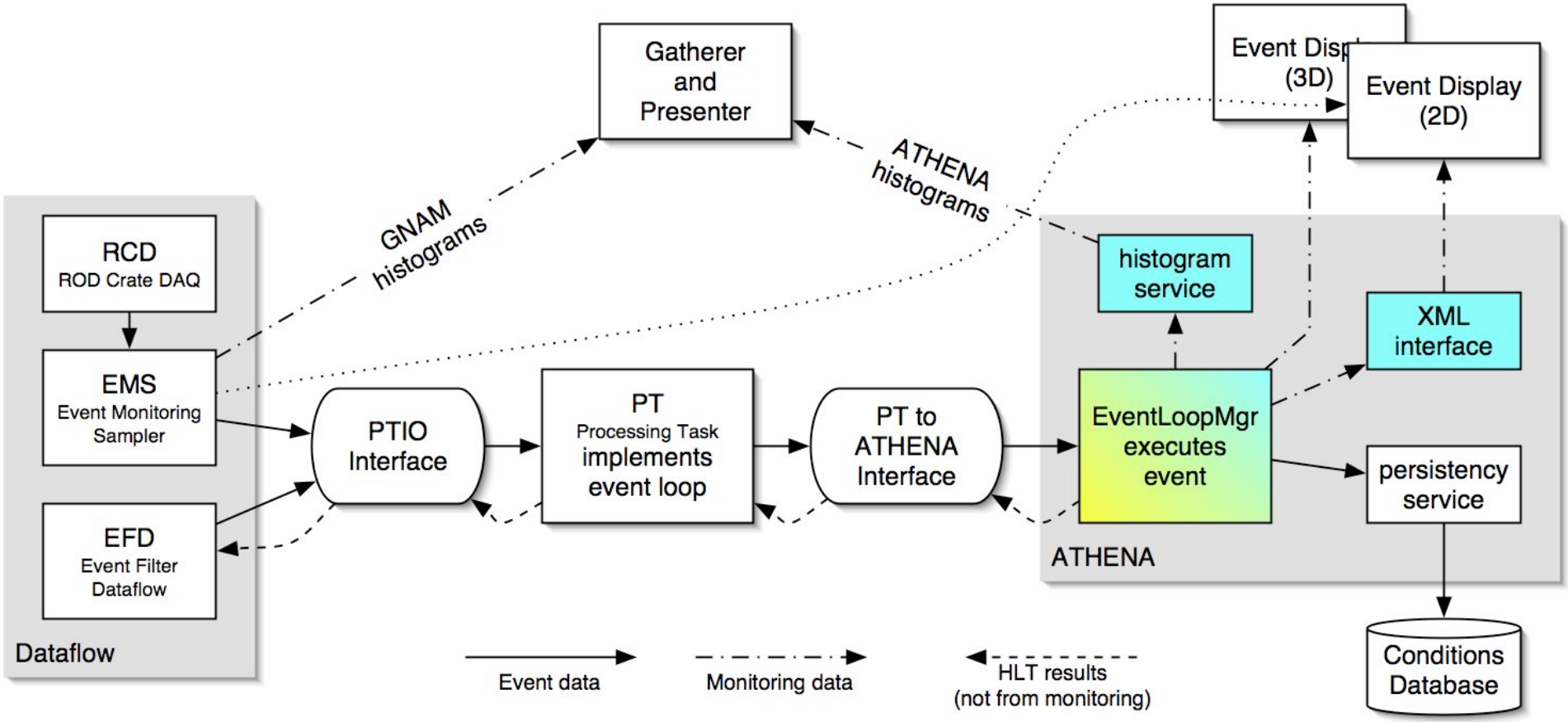
From Bunch Crossings to Physics Analyses



HLT Challenges

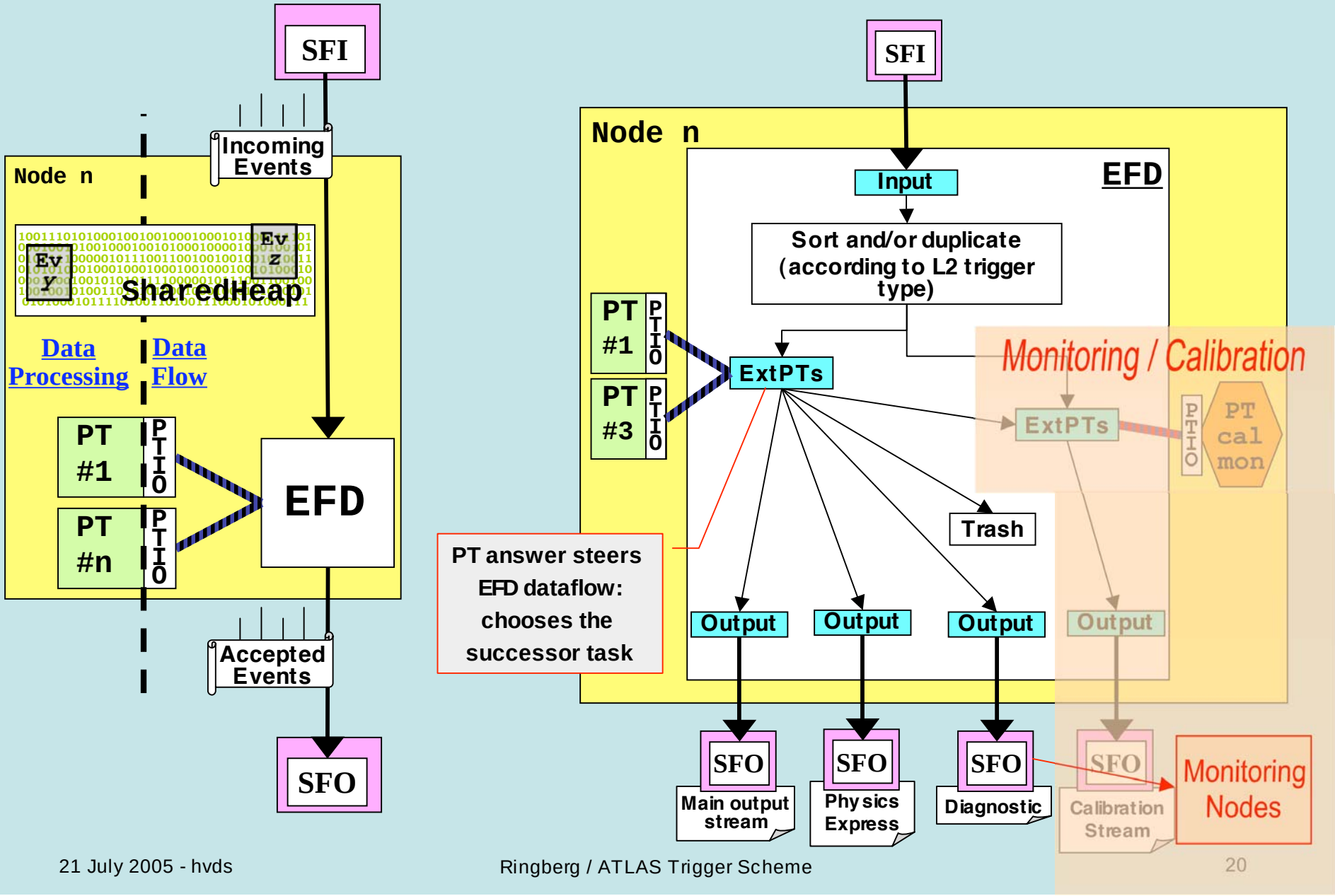
- HLT is based on large farms of PCs running Linux
  - LVL2: 500 dual-CPU PCs (multicore to come)
  - EF: >1600 dual-CPU PCs
- Many problems need attention - how to organize O(2000) PCs
  - racks, space, weight, heat & cooling, cabling
  - data I/O & networking
  - operating – booting, s/w installation, operational monitoring
- How to get performance right
  - I/O latency and CPU overhead
  - Local/Full (seeded) reconstruction from a raw bytestream & selection algorithms
- How to configure all trigger levels consistently and reproducibly
  - Including the software of course
- How to write reliable, robust, maintainable and fast code that is built from many frameworks and that needs to execute in a realtime environment
  - “online”, “offline” and “HLT” releases
  - Immunity agains corrupted bytestream data
- Re-use of offline software in HLT
  - Benefit from flexible framework, shared services and algorithms
  - But introduces tight coupling with many software components

The athenaPT Interface between online/offline

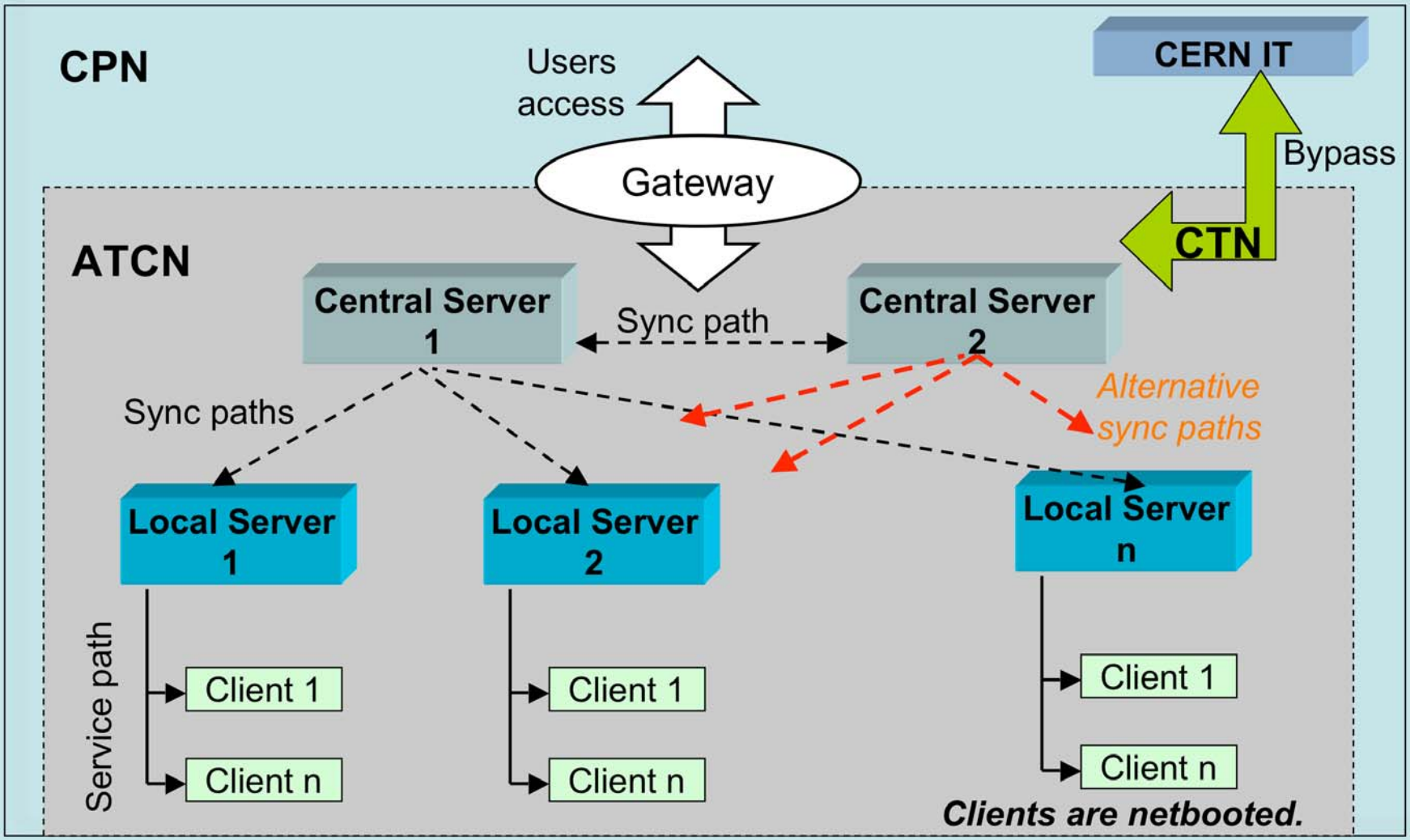


- Dataflow: online
- Athena: offline SW running online
- Used for event selection in the Event Filter
- ... as well as for online monitoring

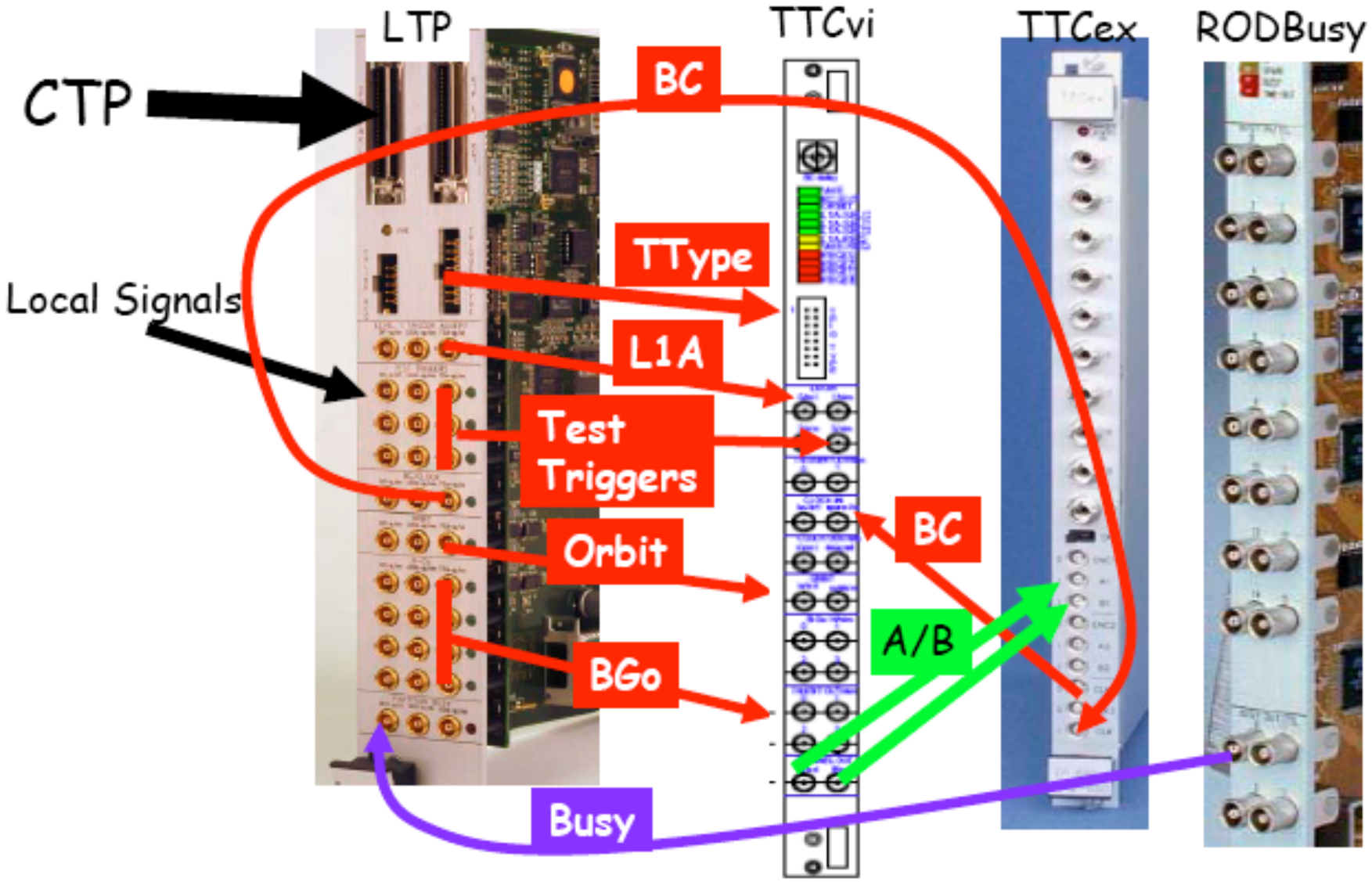
Filtering, Calibration, and Monitoring in the EF



Computer and network architecture at Point1



ATypical TTC Crate



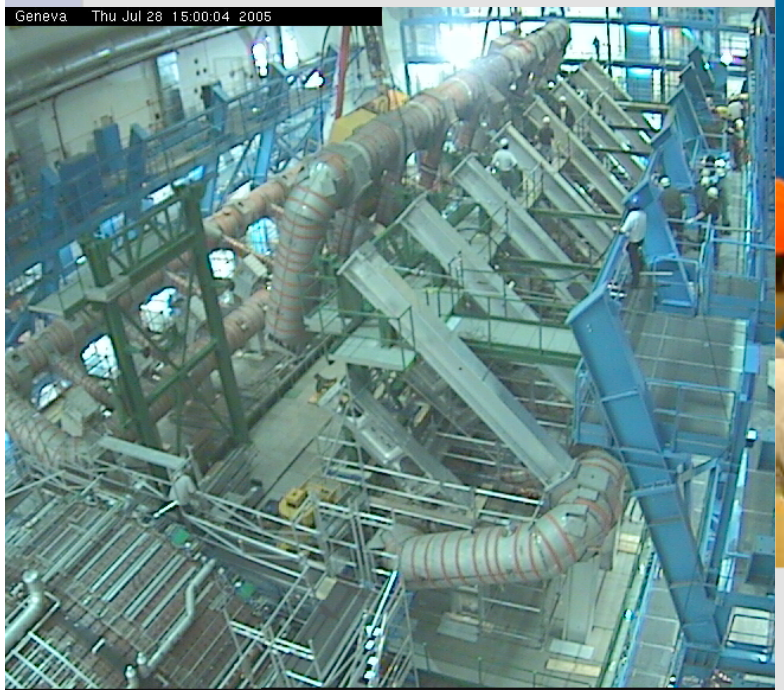
What's going on at the moment -

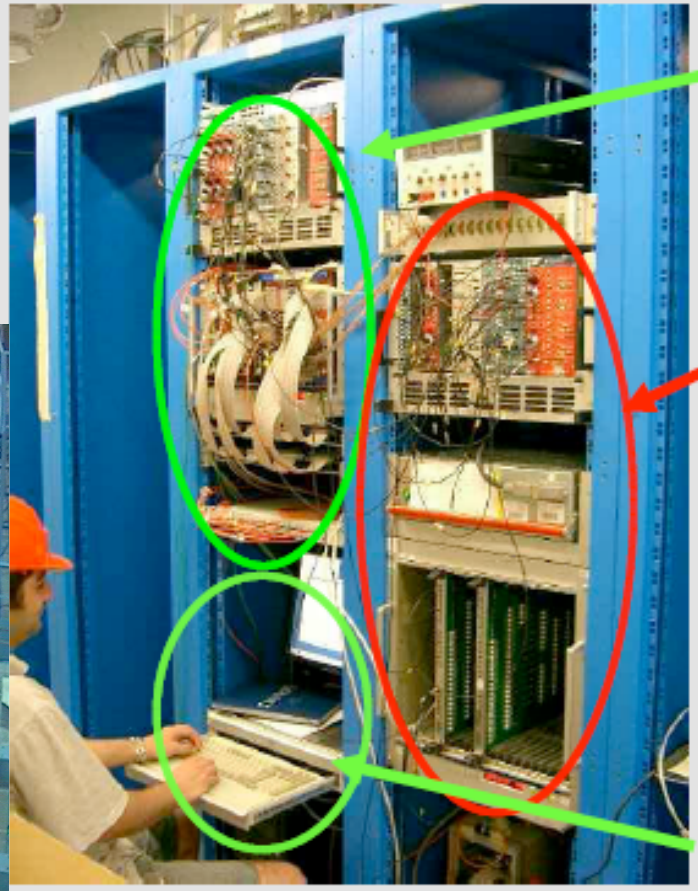
Commissioning with Cosmics

Status at MobiDAQ commissioning

Tiles calorimeter cosmics datataking at the Pit

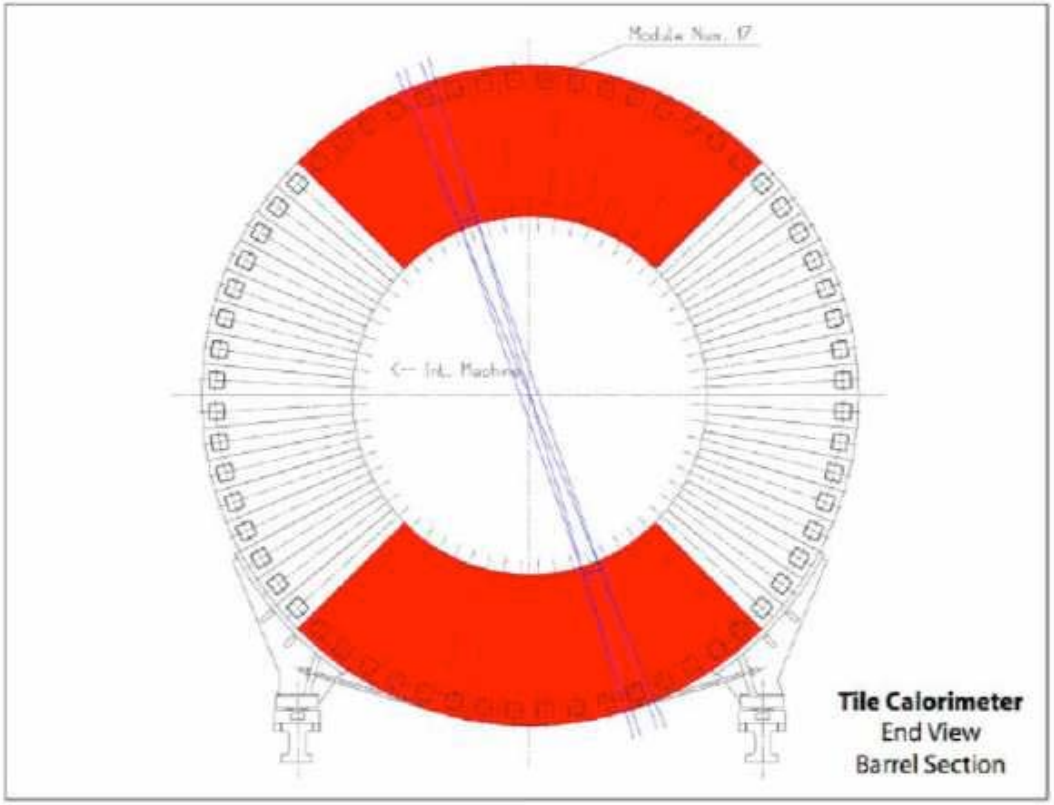
- MobiDAQ (Mobile DAQ): read out of 8 drawers in the pit with temporary RODemu but real TDAQ (tdaq-01-02-00), tests of electronics, cosmic muons runs

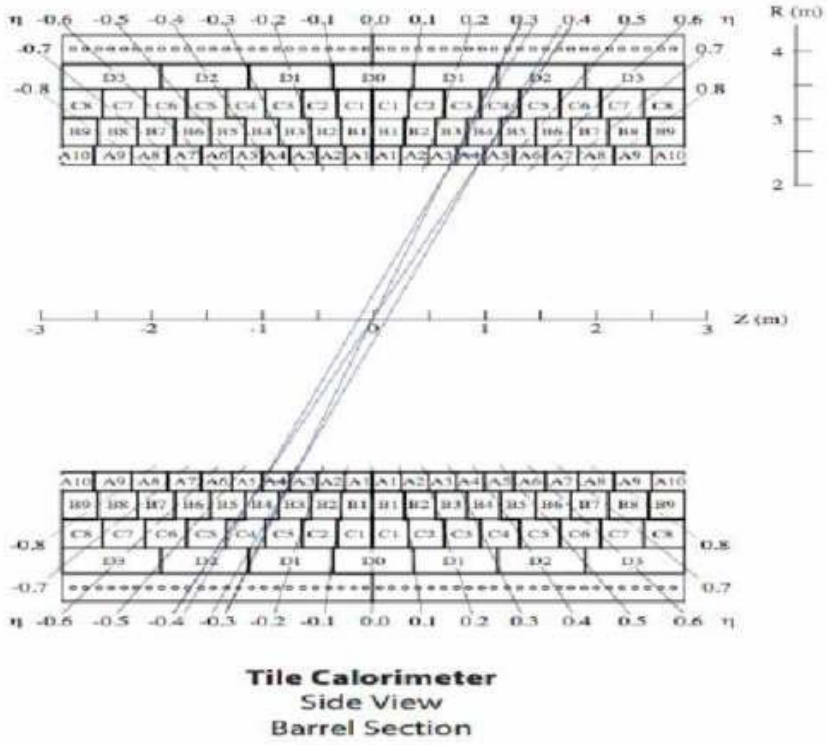




Cosmics triggering

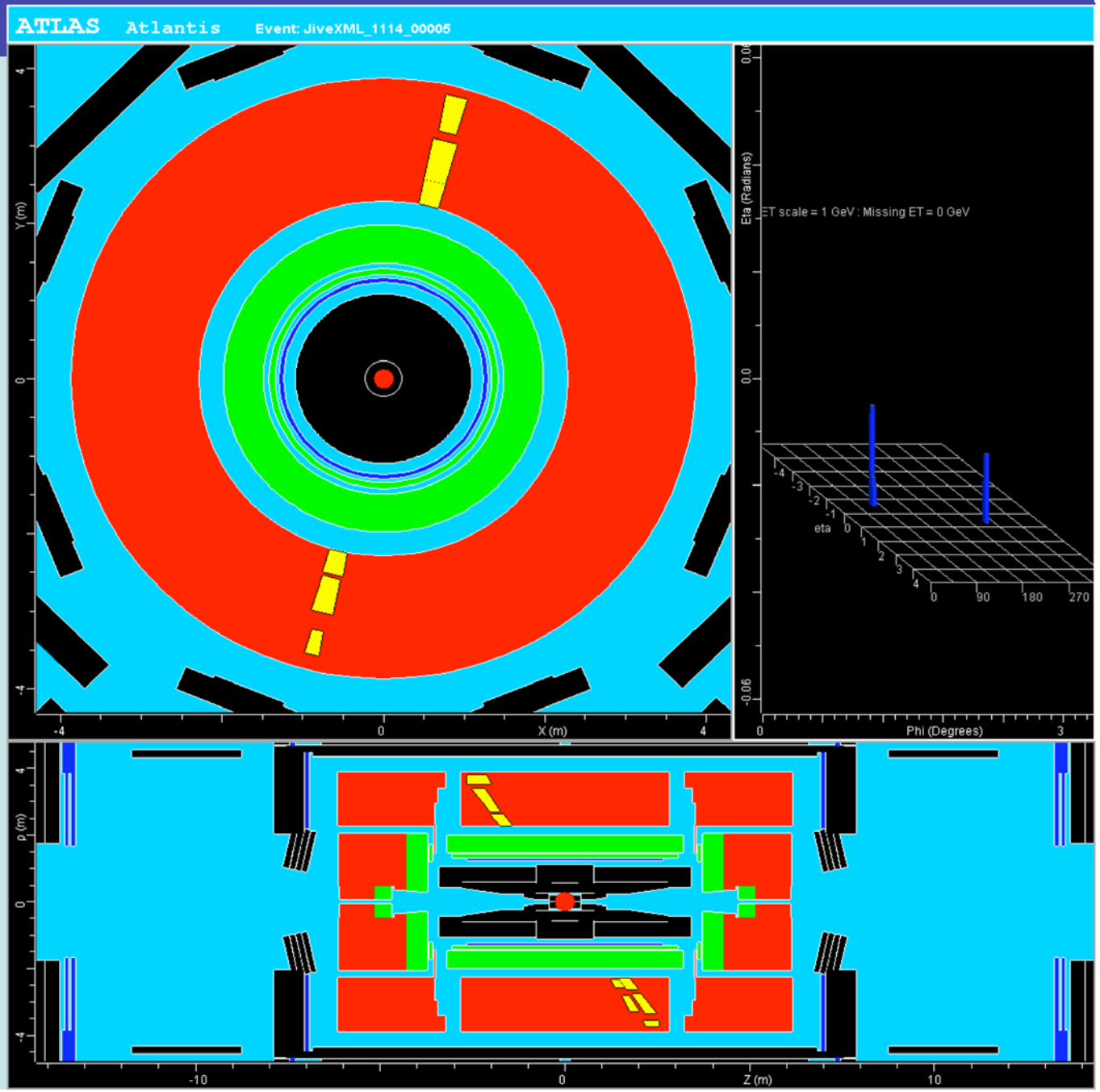
- Back-to-back trigger towers - rates estimate: ~ 150 per hour (incl. shafts)
- Each tower covers $\eta * \phi = 0.1 * 0.1$
- These are the most useful triggers
  - Muon fully traverses single Tile towers
  - Single-tower triggers also available and used
- Dedicated trigger logic designed at Chicago - now taking data in the pit

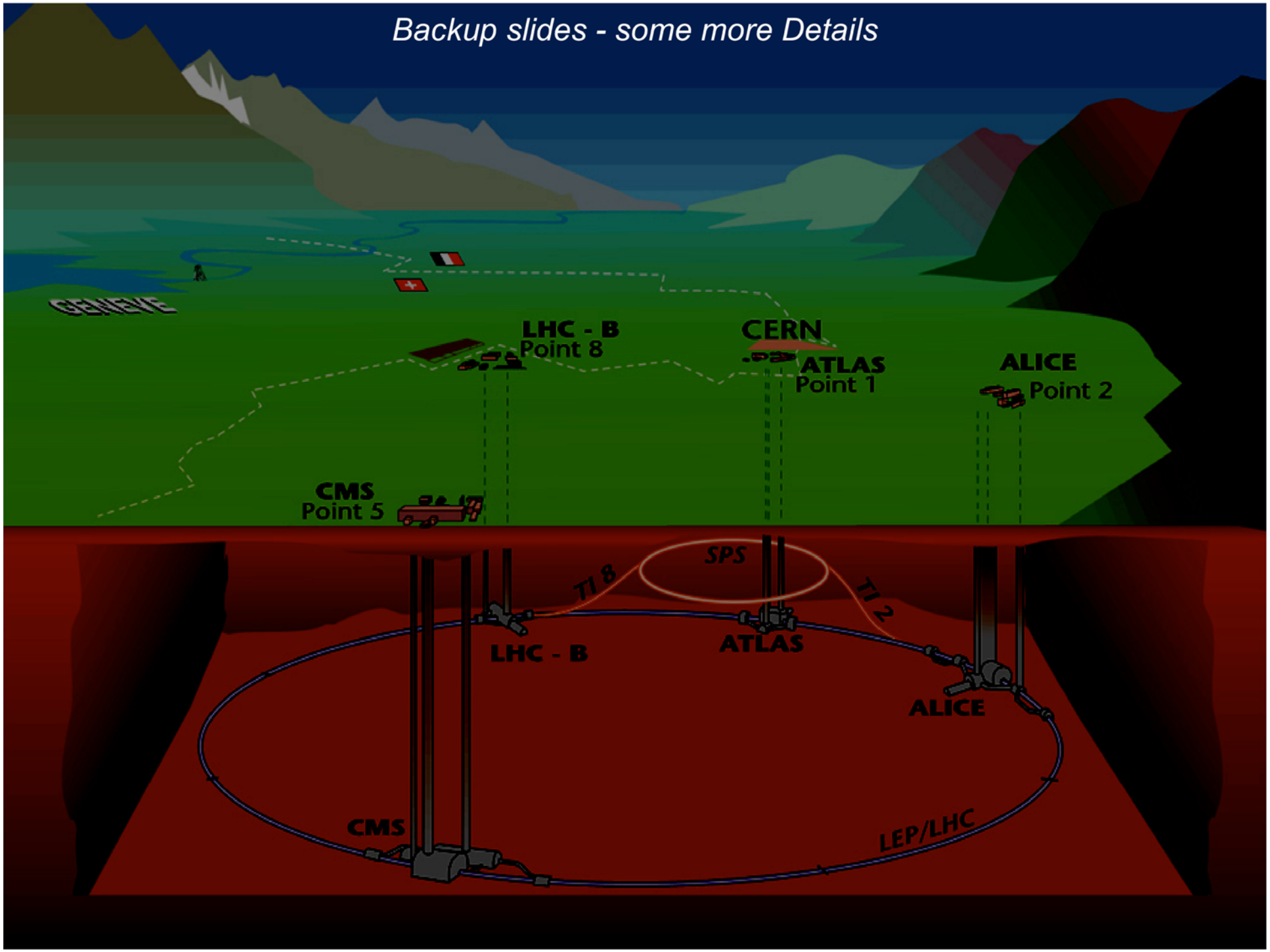




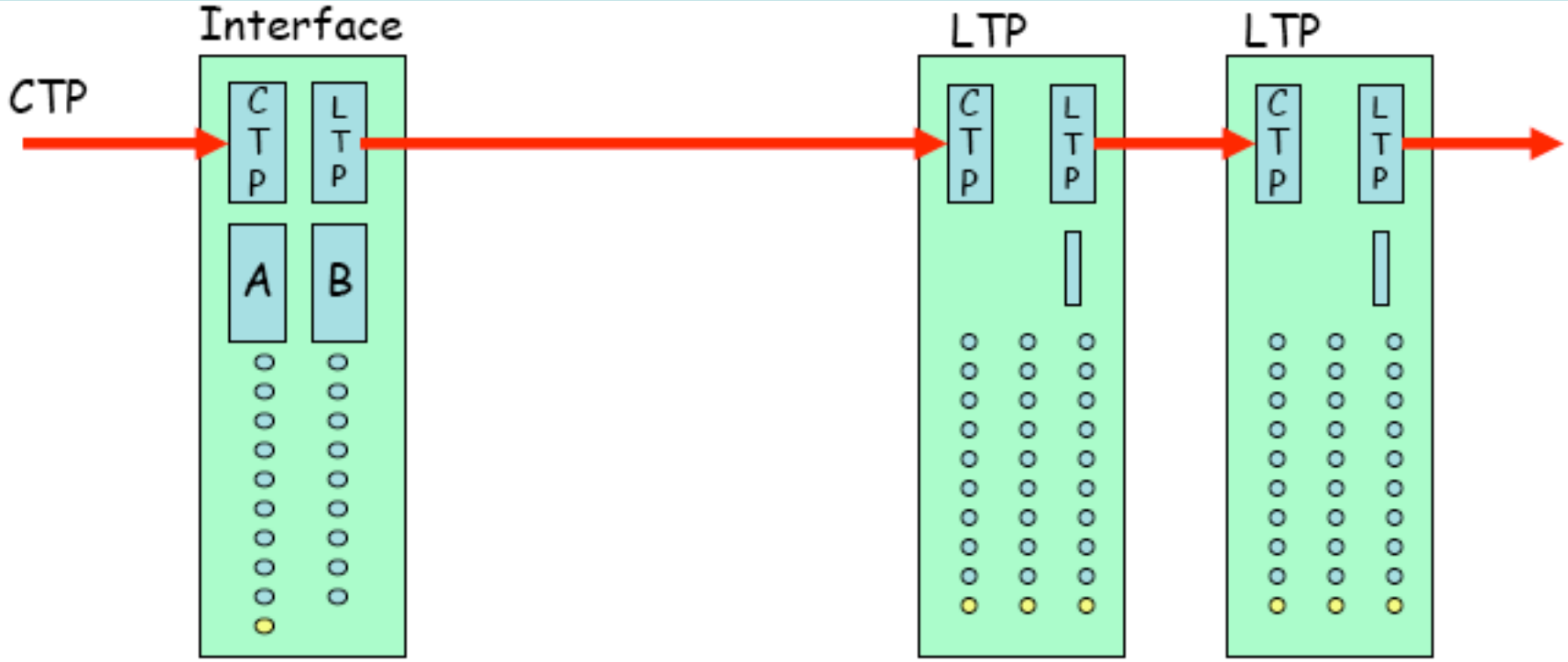
Cosmics triggering

First Tiles Events from the Pit...




GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC

Interface Module connecting CTP to LTP



Interface module in transparent mode: Additional 10-15ns delay

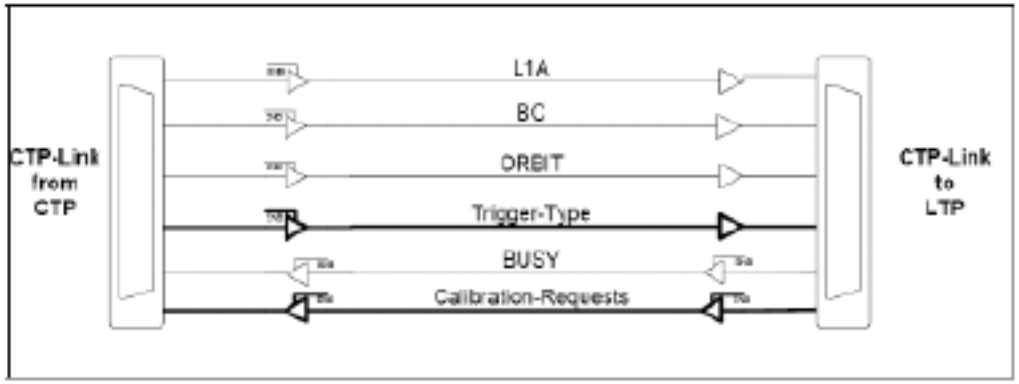
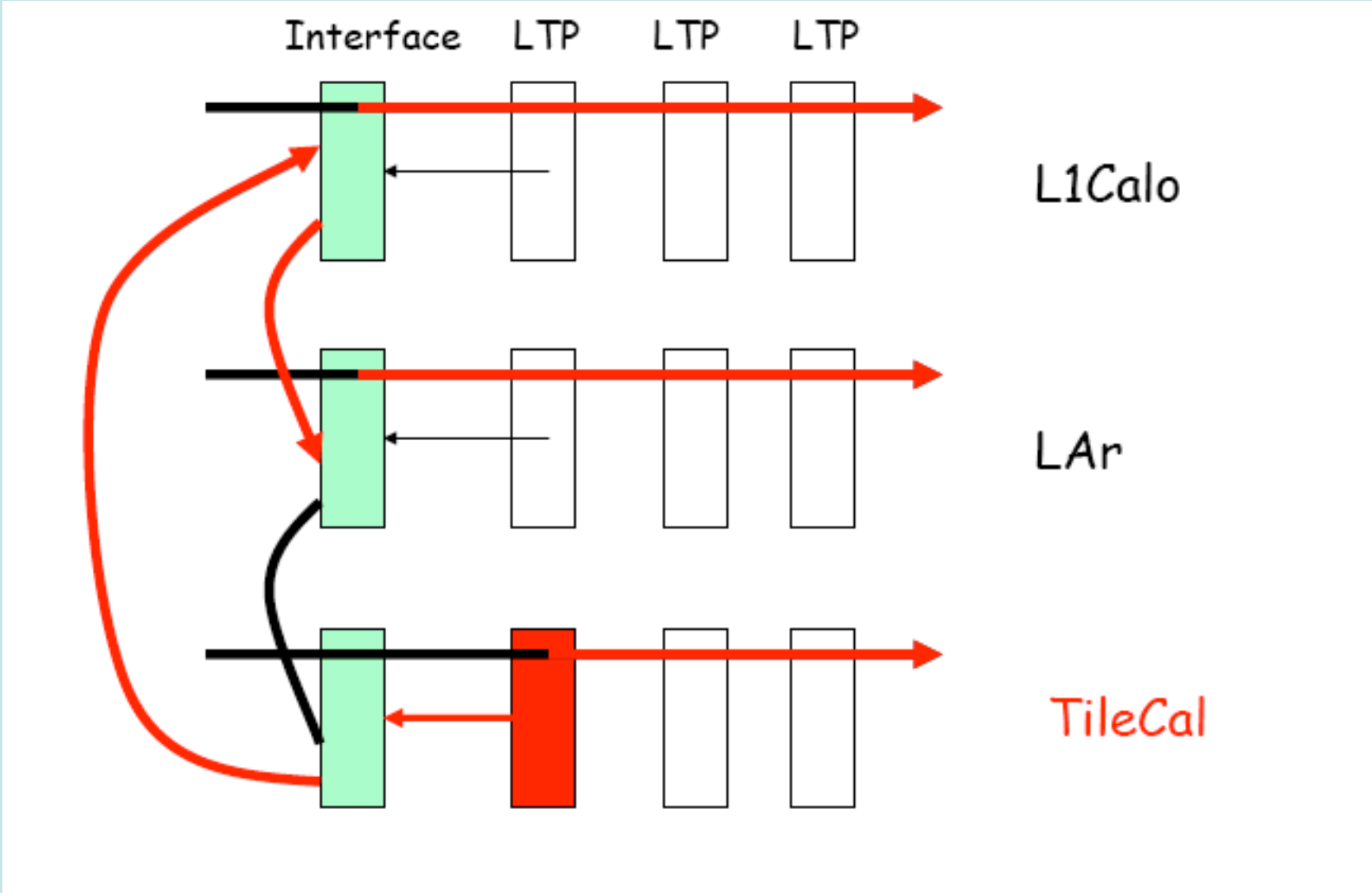
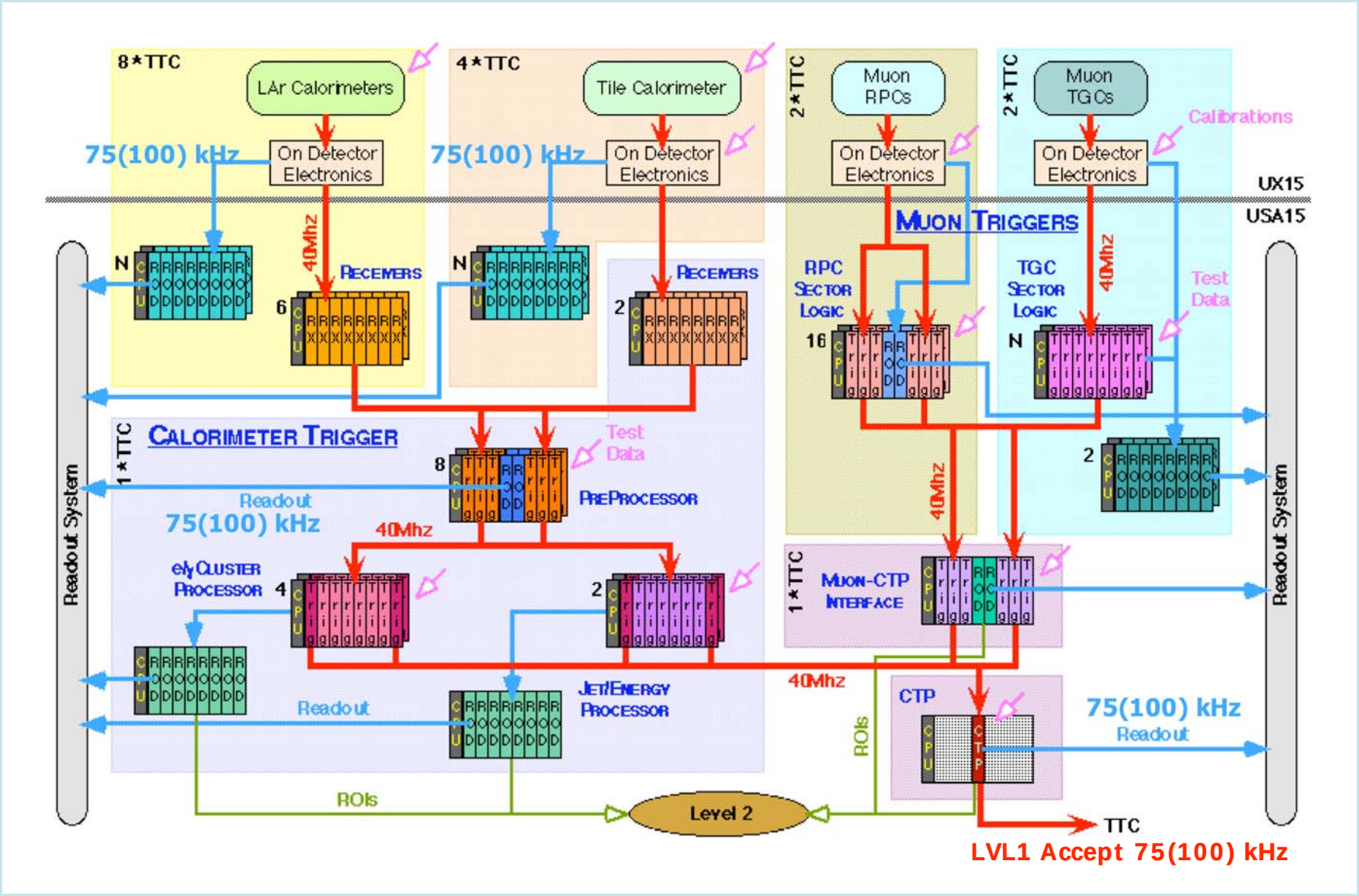


Figure 4. Interface module in transparent mode

Using Interface Module - e.g. Tiles as Master



LVL1 Trigger



Places where Athena is used Online