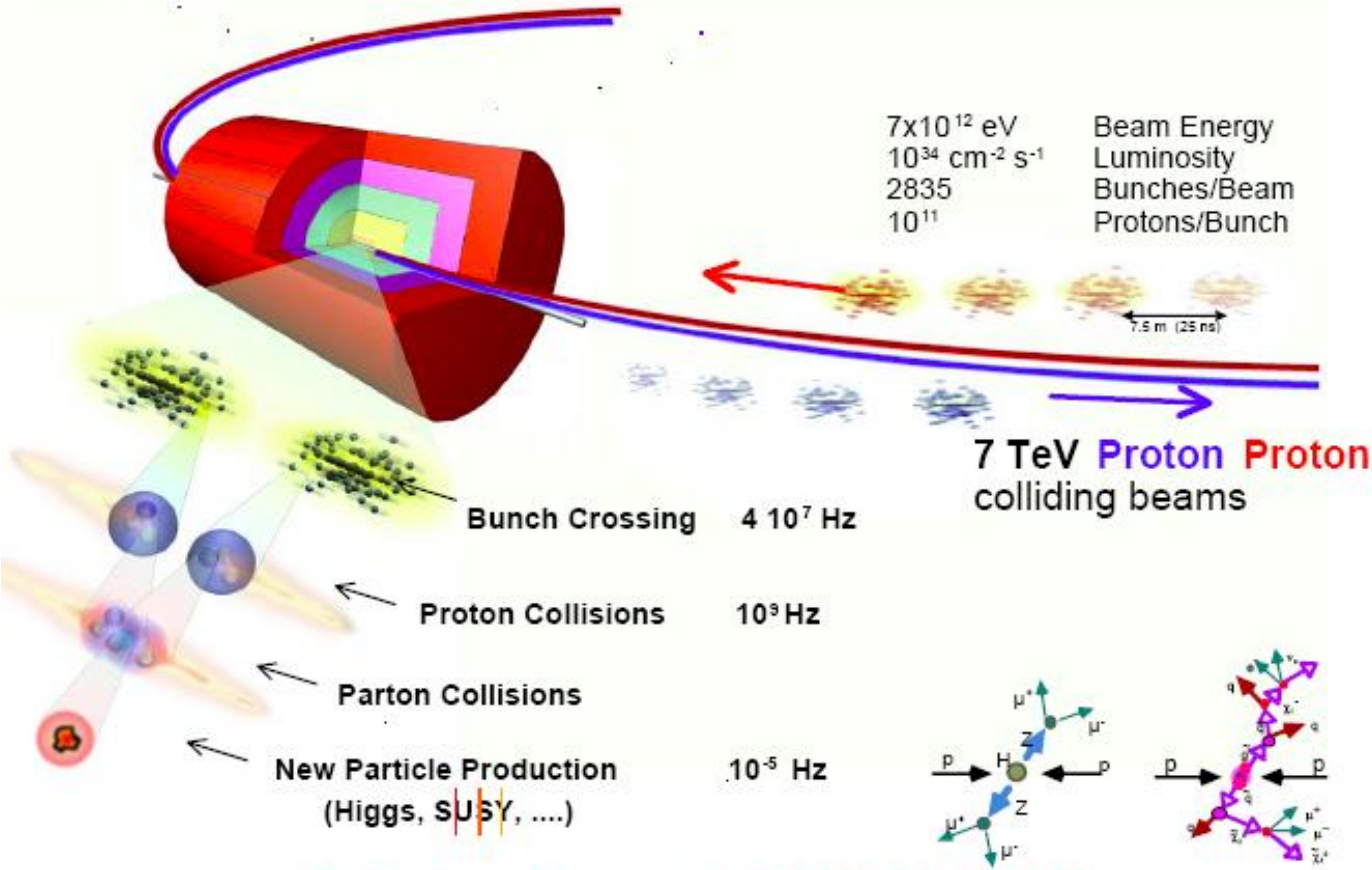
Lecture 4

Computing for HEP experiments

Trigger and DAQ System

Based on lectures given by P. Sphicas
CERN Summer Students Lectures
July 2005

Collisions at the LHC: summary



Selection of 1 event in 10,000,000,000,000

Trigger and Data Acquisition System

- **Mandate:**

  "Look at (almost) all bunch crossings, select the most interesting ones, collect all detector information for them and store it for off-line analysis"

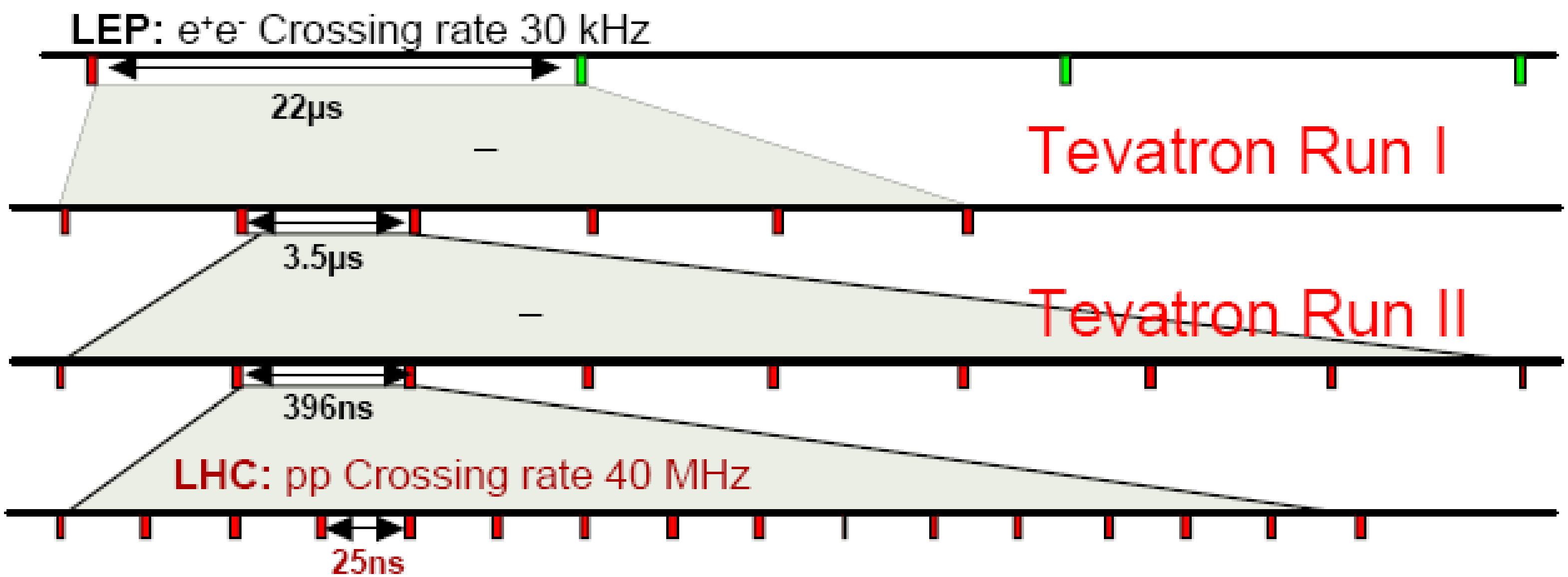
  - P.S. For a reasonable number of CHF

- **The photographer analogy:**
  - Trigger: the photographer/camera push-button combination
  - DAQ: burning the film, rolling out the picture, storing film
  - Quality of shot: number of pictures/second, number of pixels
    - And of course the photographer
  - Cost of shot: the camera (one-time); film (recurring); the shot itself (cannot take another picture for a short time after we push on the camera button)

- **Trigger/DAQ: the HEP experiment photographer. All physics analysis runs off of the film (s)he produces**

Beam crossings: LEP, Tevatron & LHC

- **LHC will have ~3600 bunches**
  - And same length as LEP (27 km)
  - Distance between bunches: 27km/3600=7.5m
  - Distance between bunches in time: 7.5m/c=25ns



Impact on detector design

- **LHC detectors must have fast response**
  - Avoid integrating over many bunch crossings ("pile-up")
  - Typical response time : 20-50 ns

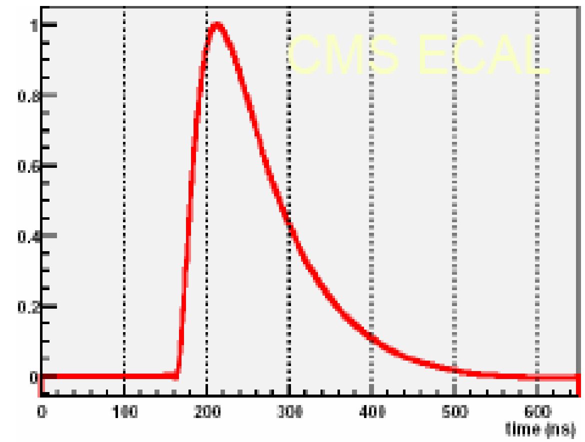
    → integrate over 1-2 bunch crossings → pile-up of 25-50 min-bias events → very challenging readout electronics
- **LHC detectors must be highly granular**
  - Minimize probability that pile-up particles be in the same detector element as interesting object (e.g. γ from $H \to \gamma\gamma$ decays)

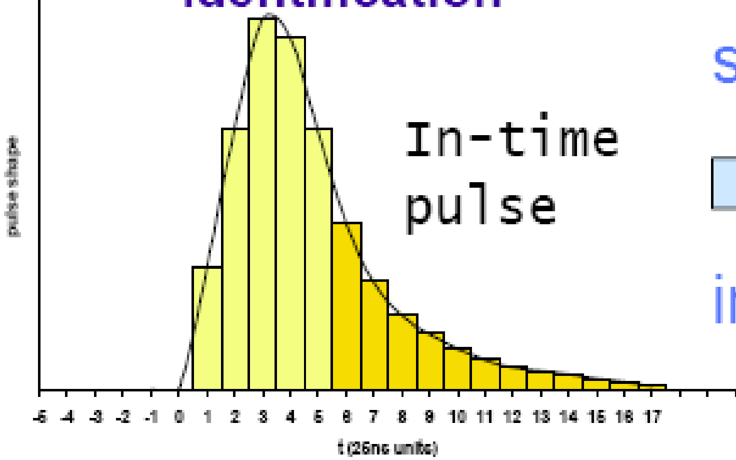
    → large number of electronic channels
- **LHC detectors must be radiation resistant:**
  - high flux of particles from pp collisions → high radiation environment e.g. in forward calorimeters:
    - up to 10^{17} n/cm^2 in 10 years of LHC operation
    - up to 10^7 Gy (1 Gy = unit of absorbed energy = 1 Joule/Kg)

Pile-up

- “In-time” pile-up: particles from the same crossing but from a different pp interaction

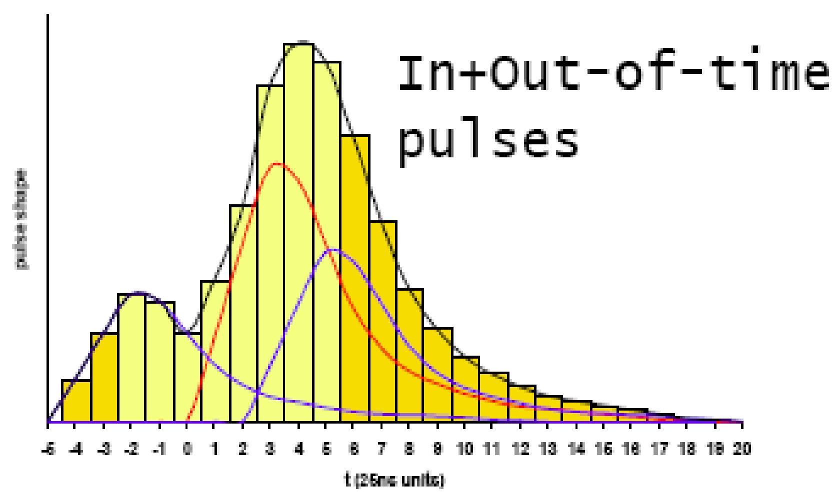
- Long detector response/pulse shapes:
  - “Out-of-time” pile-up: left-over signals from interactions in previous crossings
  - Need “bunch-crossing identification”





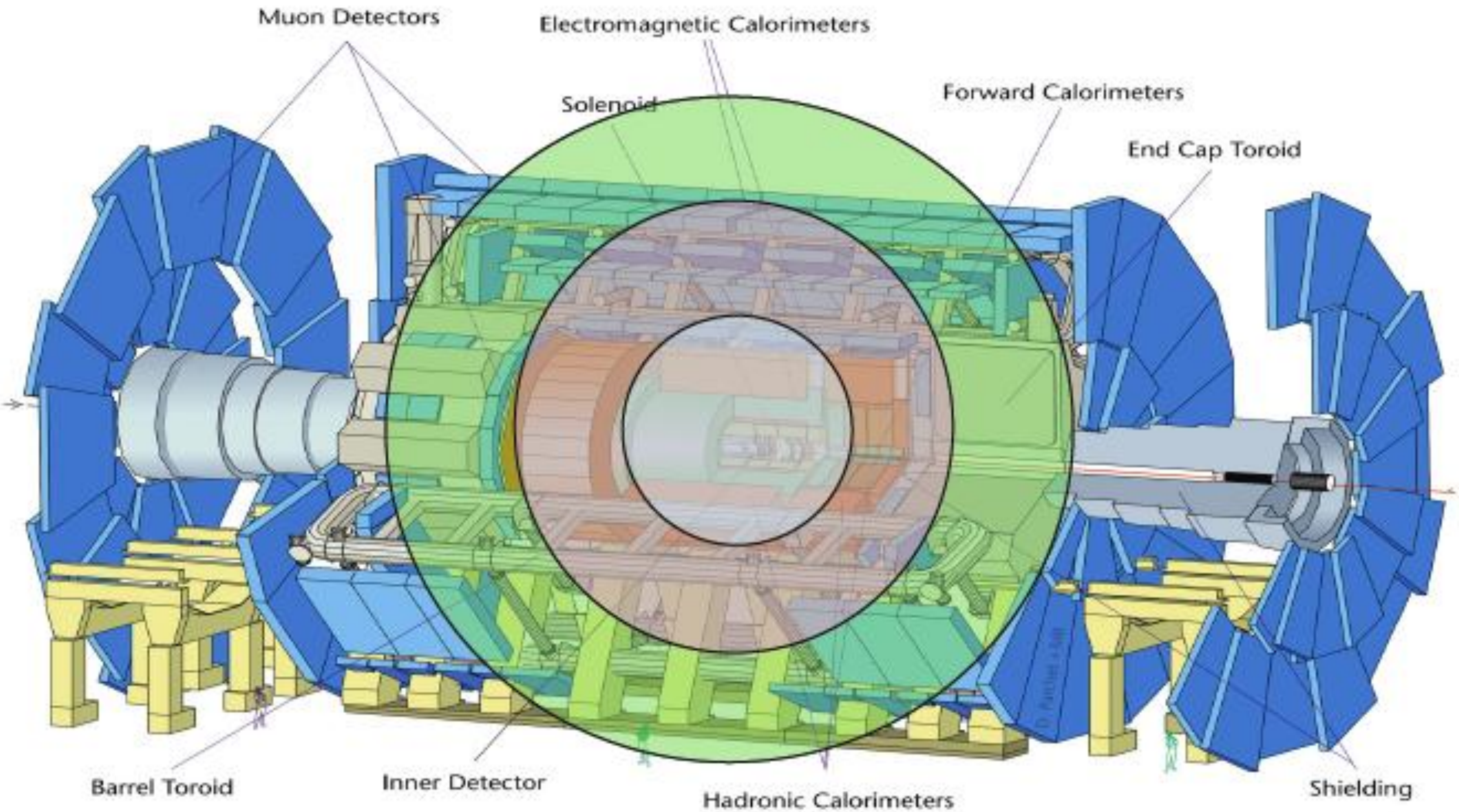
super–

impose

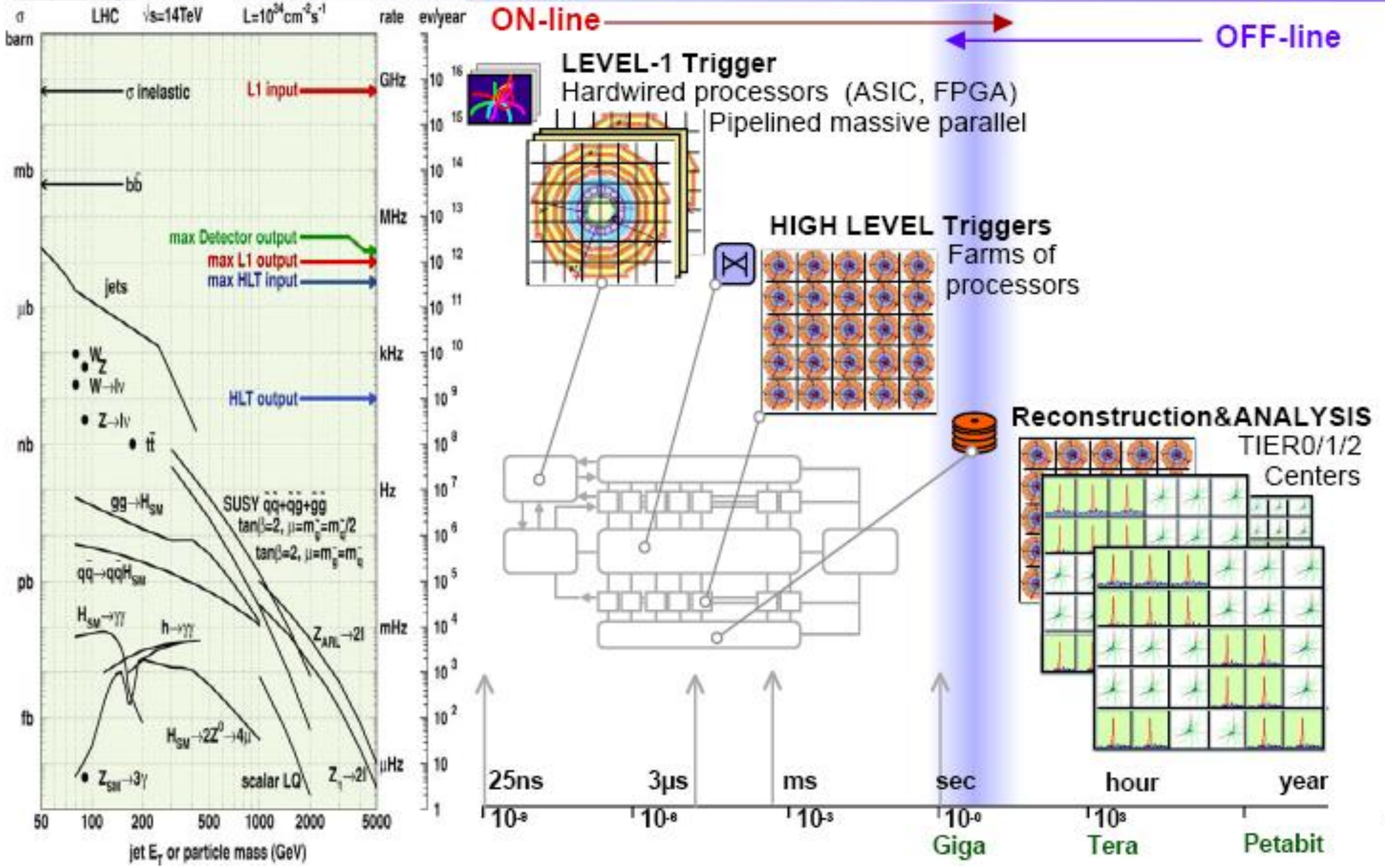


Time of Flight

c=30cm/ns; in 25ns, s=7.5m



Physics selection at the LHC



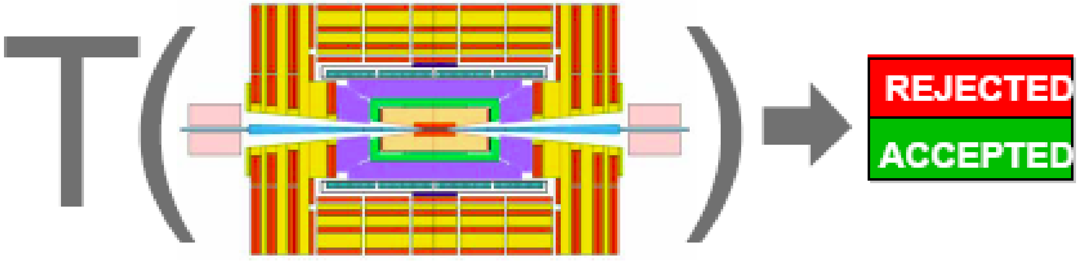
Trigger/DAQ requirements/challenges

- N (channels) ~ O(10^7); ≈20 interactions every 25 ns
  - need huge number of connections
  - need information super-highway
- Calorimeter information should correspond to tracker info
  - need to synchronize detector elements to (better than) 25 ns
- In some cases: detector signal/time of flight > 25 ns
  - integrate more than one bunch crossing's worth of information
  - need to identify bunch crossing...
- Can store data at ≈ 10^2 Hz
  - need to reject most interactions
- It's On-Line (cannot go back and recover events)
  - need to monitor selection

Triggering

- **Task: inspect detector information and provide a first decision on whether to keep the event or throw it out**

The trigger is a function of :



Event data & Apparatus
Physics channels & Parameters

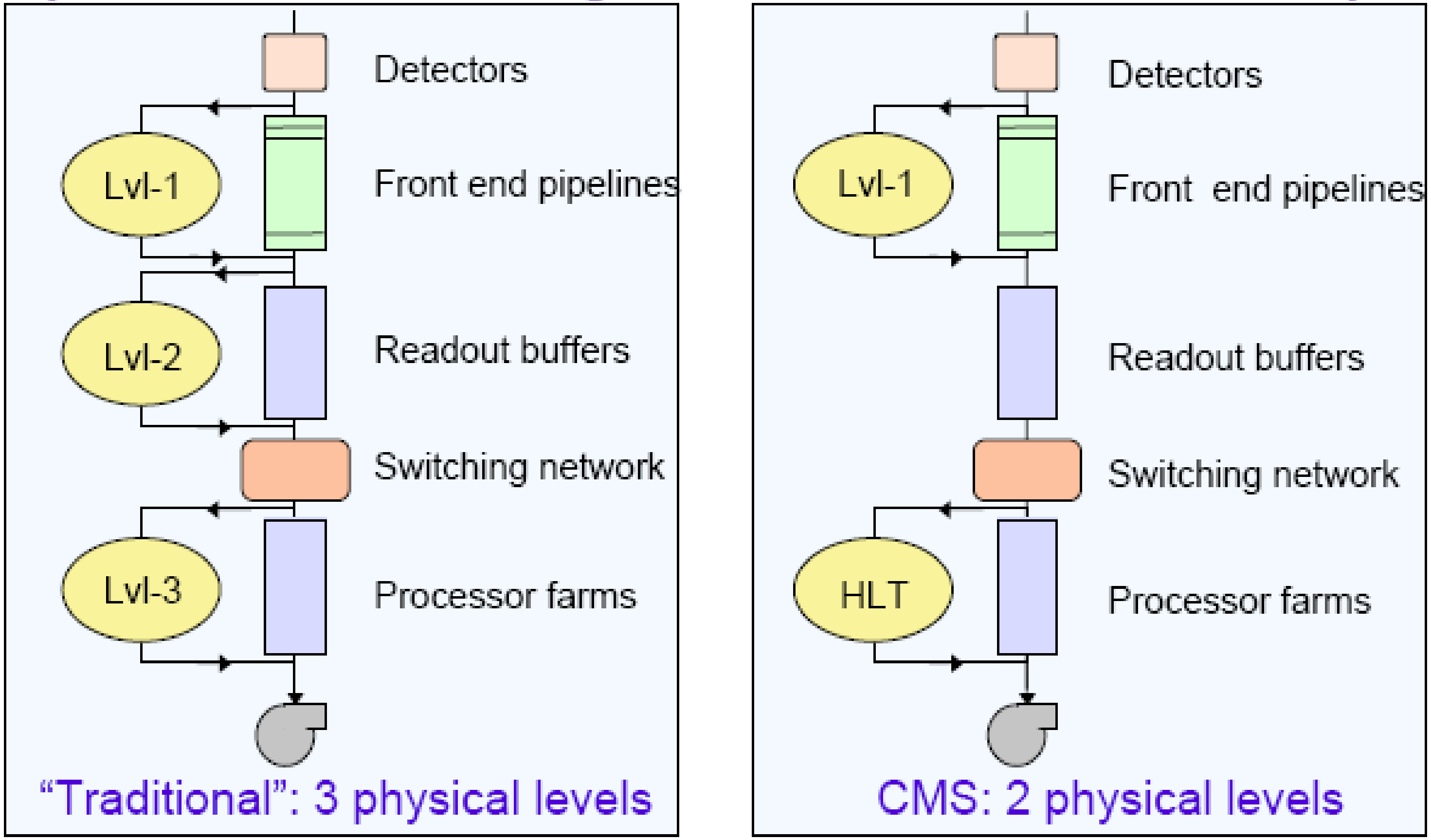
- **Detector data not (all) promptly available**
- **Selection function highly complex**

⇒T(...) is evaluated by successive approximations, the TRIGGER LEVELS

(possibly with zero dead time)

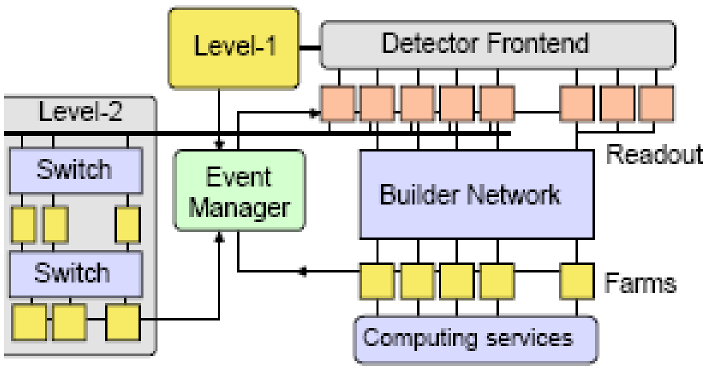
Online Selection Flow in pp

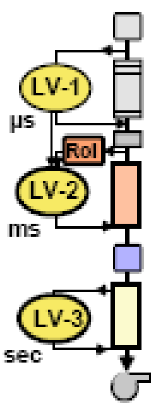
- **Level-1 trigger: reduce 40 MHz to 10^5 Hz**
  - This step is always there
  - Upstream: still need to get to 10^2 Hz; in 1 or 2 extra steps



Three physical entities

- **Additional processing in LV-2: reduce network bandwidth requirements**





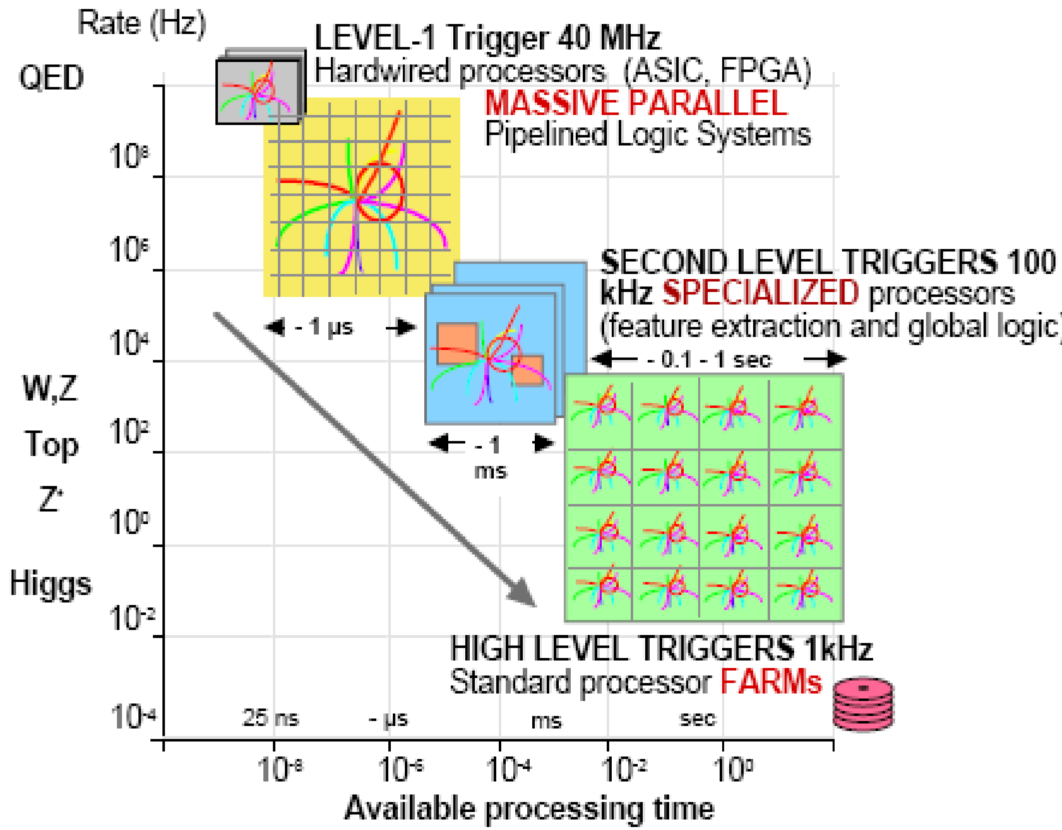
40 MHz

10^5 Hz

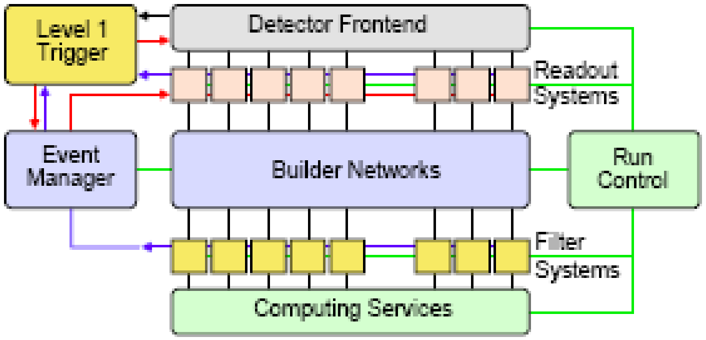
10^3 Hz

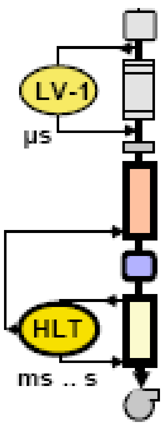
10 Gb/s

10^2 Hz



Two physical entities



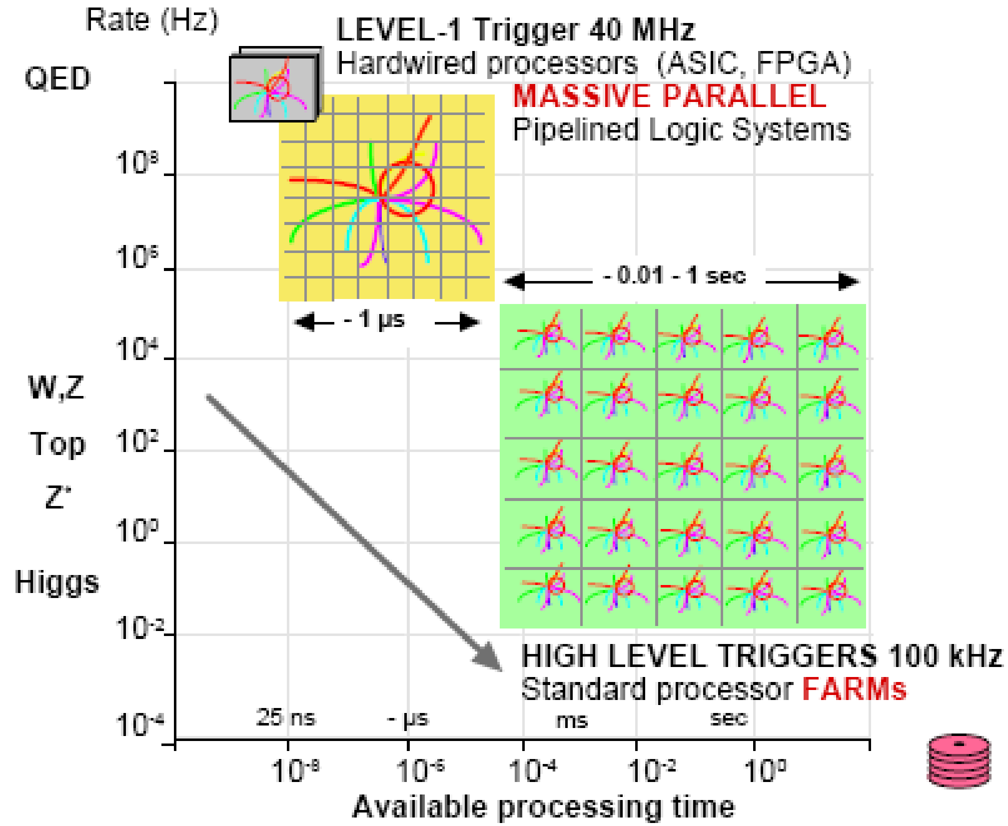


40 MHz

10^5 Hz

1000 Gb/s

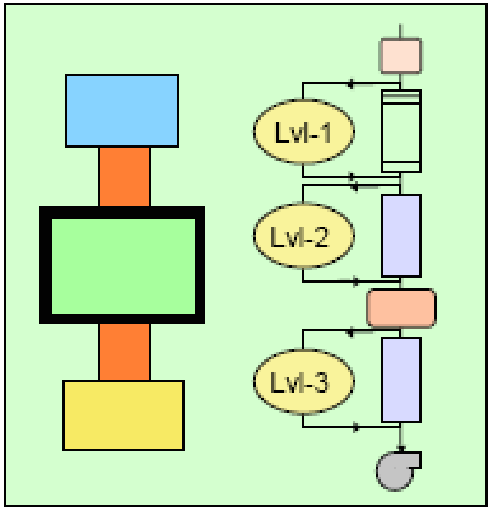
10^2 Hz



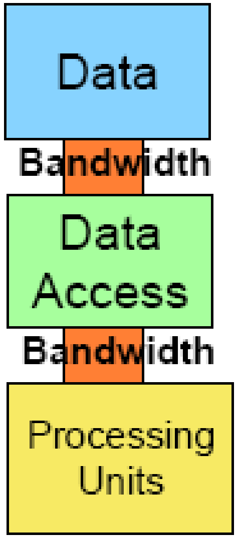
- Reduce number of building blocks
- Rely on commercial components (especially processing and communications)

Comparison of 2 vs 3 physical levels

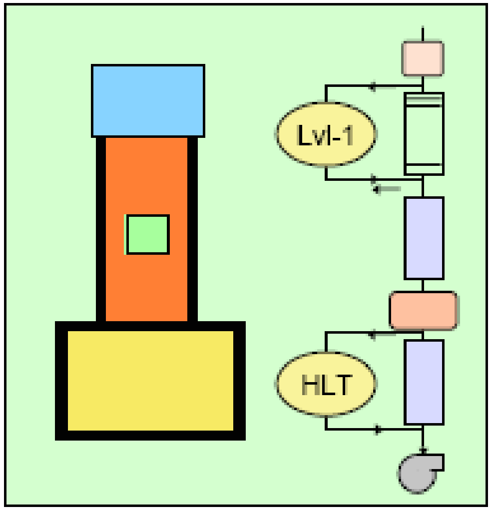
- **Three Physical Levels**
  - Investment in:
    - Control Logic
    - Specialized processors



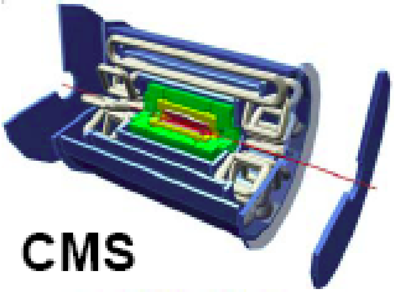
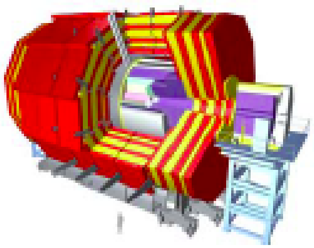
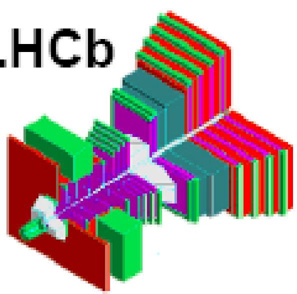
Model



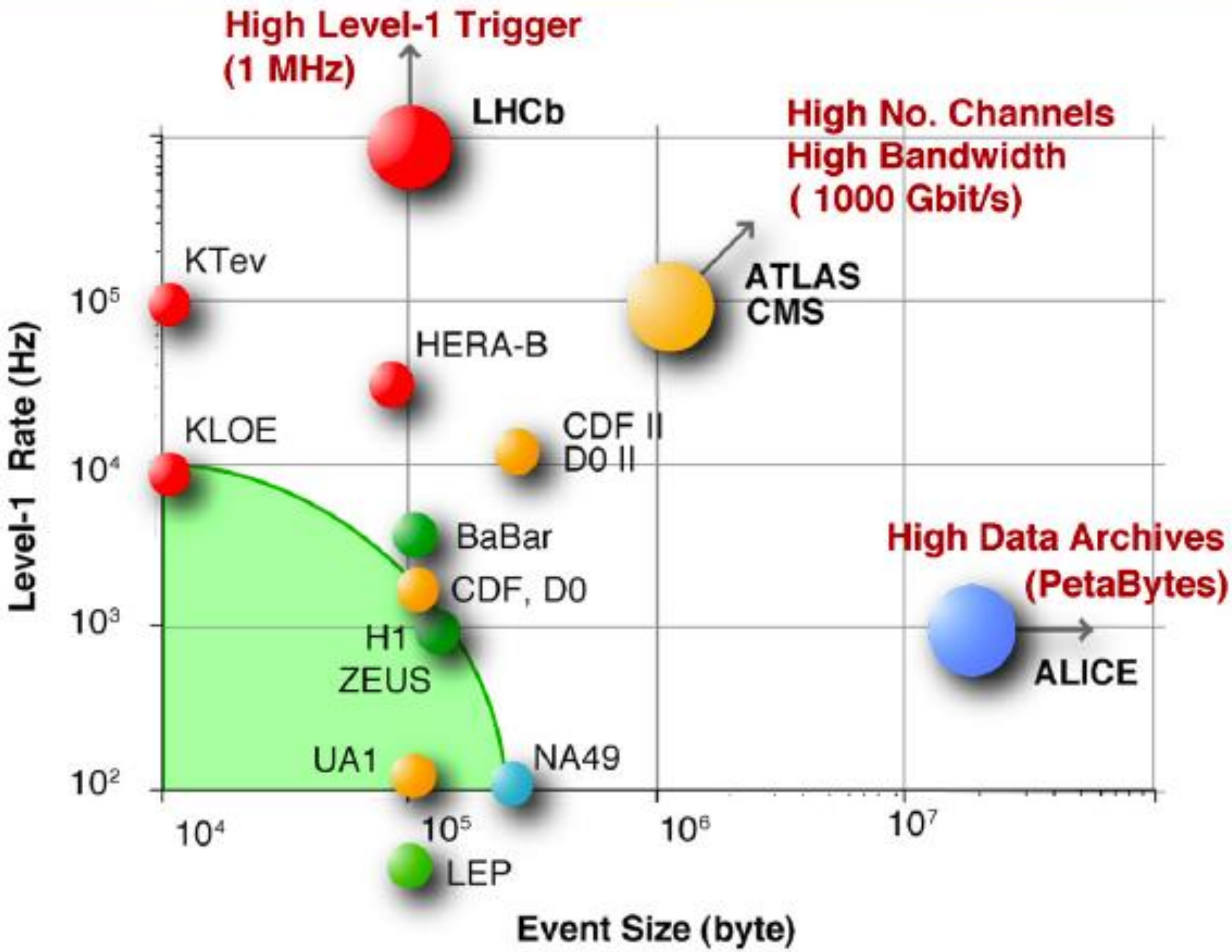
- **Two Physical Levels**
  - Investment in:
    - Bandwidth
    - Commercial Processors



Trigger/DAQ parameters: summary

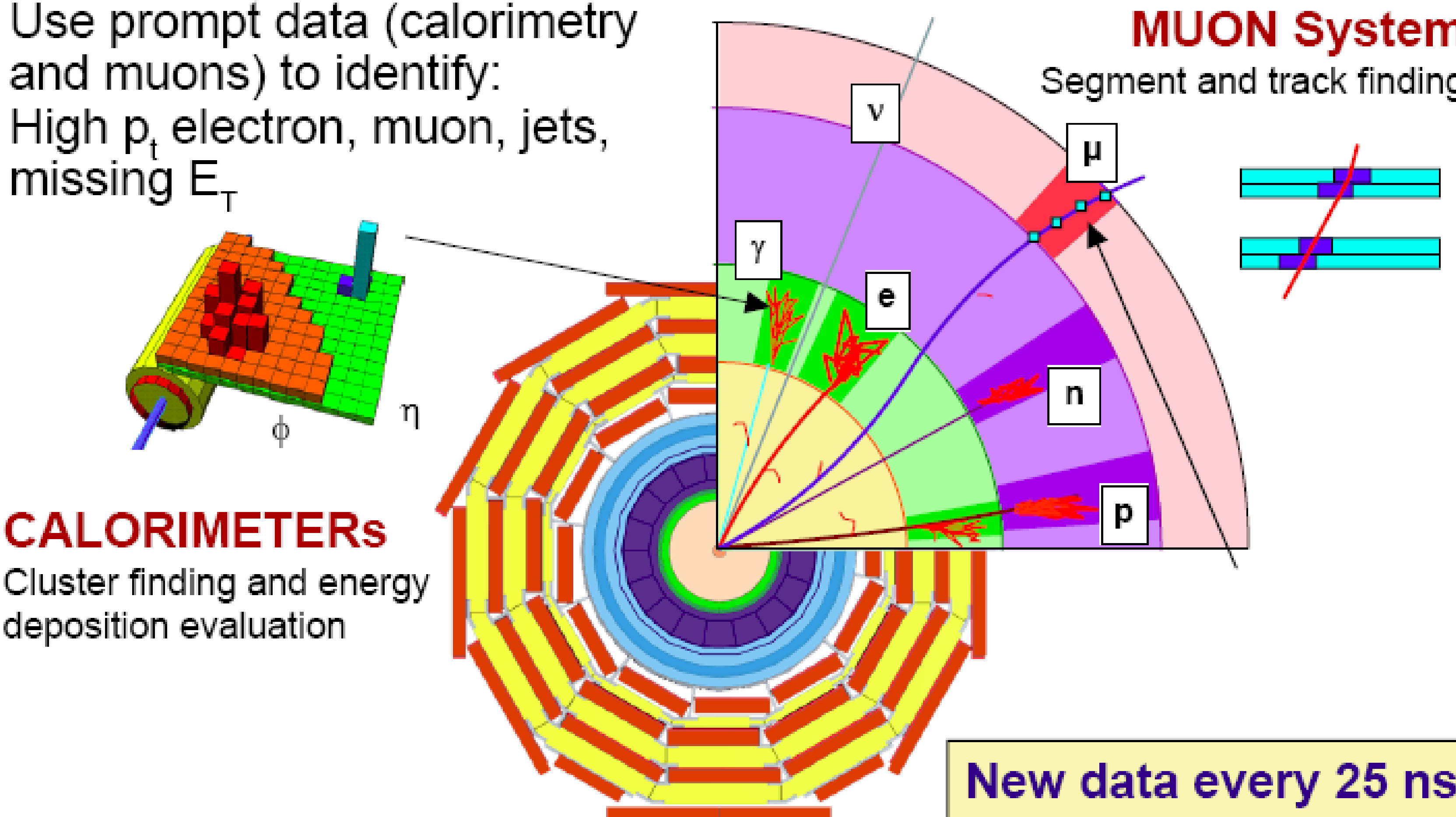
	No.Levels Trigger	Level-1 Rate (Hz)	Event Size (Byte)	Readout Bandw.(GB/s)	Filter Out MB/s (Event/s)
ATLAS 	3	10^5 LV-2 10^3	10^6	10	100 (10^2)
CMS 	2	10^5	10^6	100	100 (10^2)
LHCb 	3	LV-0 10^6 LV-1 $4\ 10^4$	$2x10^5$	4	40 ($2x10^2$)
ALICE 	4	Pp-Pp 500 p-p 10^3	$5x10^7$ $2x10^6$	5	1250 (10^2) 200 (10^2)

Trigger/DAQ systems: present & future



Particle signatures in the detector(s)

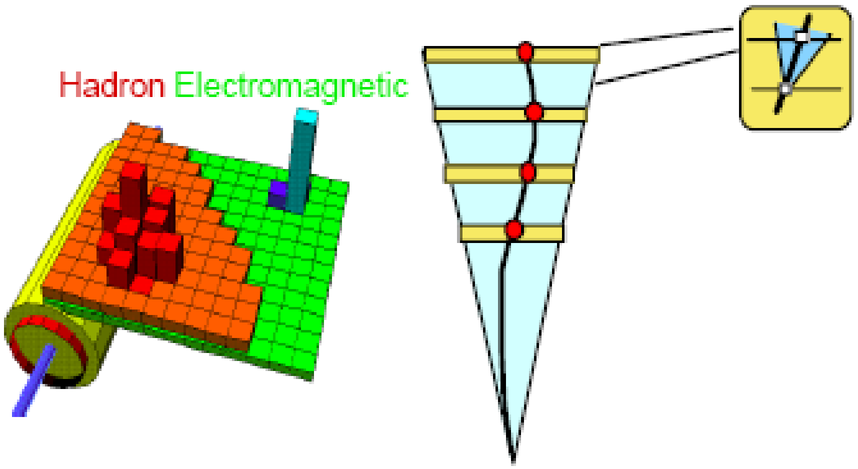
Use prompt data (calorimetry and muons) to identify:
High p_t electron, muon, jets, missing E_T



New data every 25 ns
Decision latency ~ μs

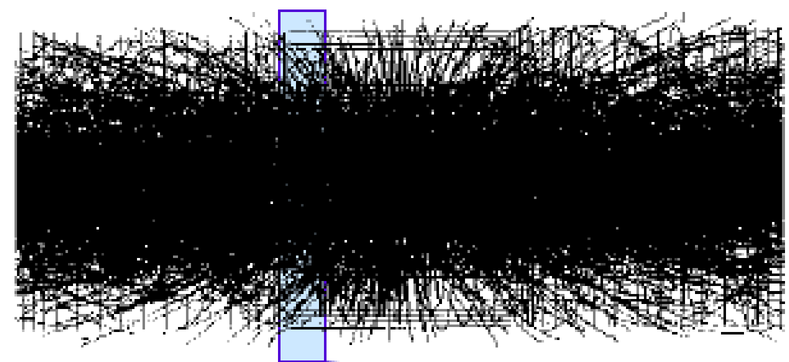
At Level-1: only calo and muon info

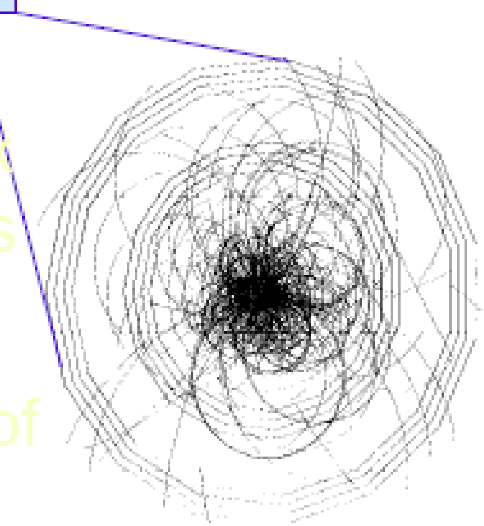
- **Pattern recognition much faster/easier**



- ➢Simple algorithms
- ➢Small amount of data
- ➢Local decisions

- **Compare to tracker info**

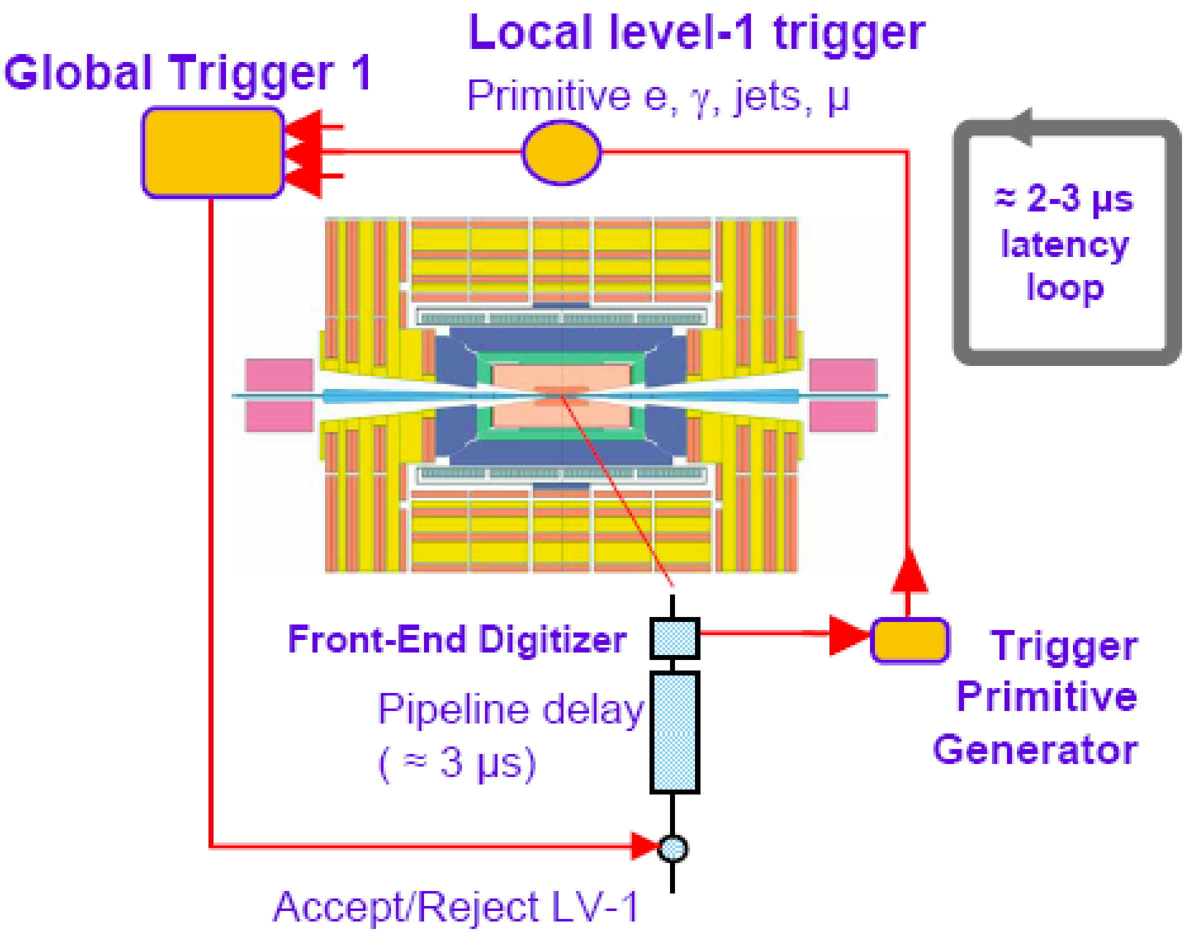




- ➢Complex algorithms
- ➢Huge ammount of data
- ➢Need to link subdetectors

Level-1 Trigger: decision loop

- **Synchronous 40 MHz digital system**
  - Typical: 160 MHz internal pipeline
  - Latencies:
    - Readout + processing: < 1μs
    - Signal collection & distribution: ≈ 2μs
- **At Lvl-1: process only calo+μ info**



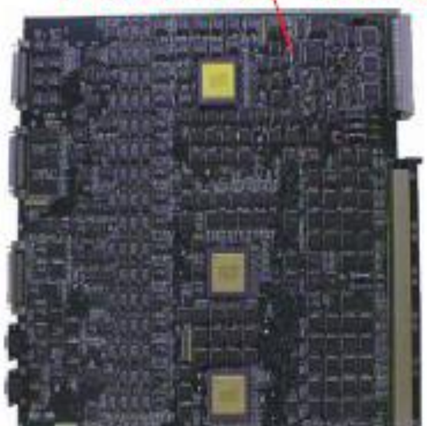
Lvl-1 Calo Trigger: prototypes

Trigger Crate
(160 MHz backplane)

Back

Front

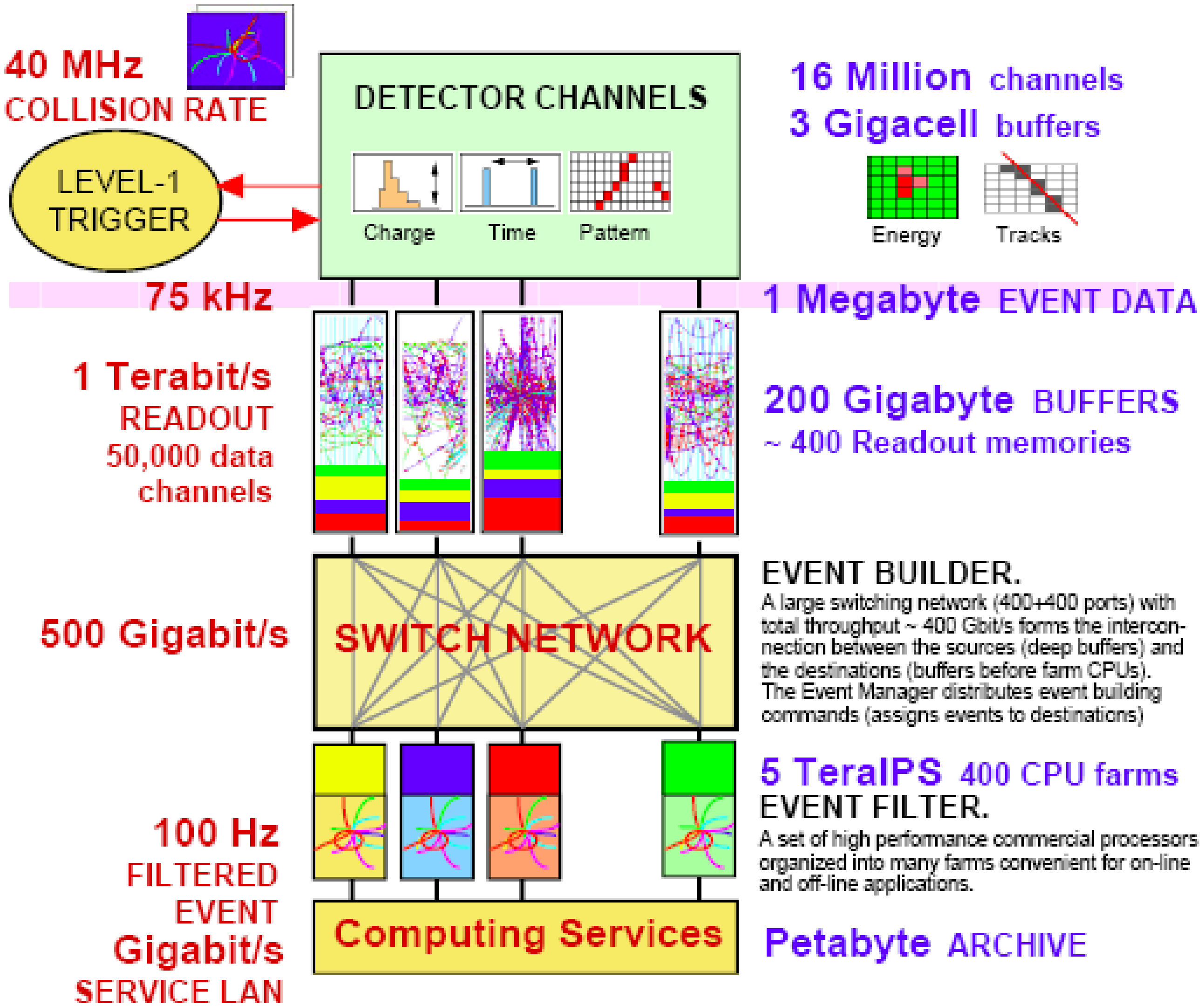
Receiver Card



Links

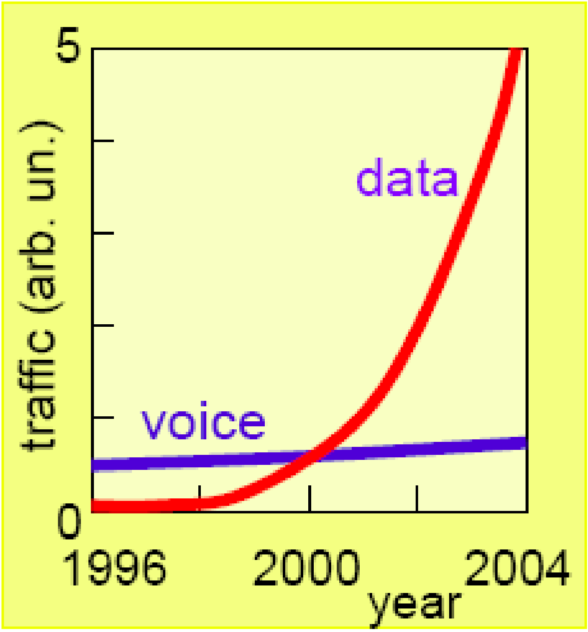
Electron
(isolation)
Card

Online Selection Flow in pp



Internet Growth (a reminder)

- 100 million new users online in 2001
- Internet traffic doubled every 100 days
- 5000 domain names added every day
- Commerce in 2001: >$200M
- 1999: last year of the voice
- Prices(basic units) dropping
- Need more bandwidth
- Conclusion:
  - It'll go on; can count on it.



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Processor Engine (II)

- **PC+Linux: the new supercomputer for scientific applications**

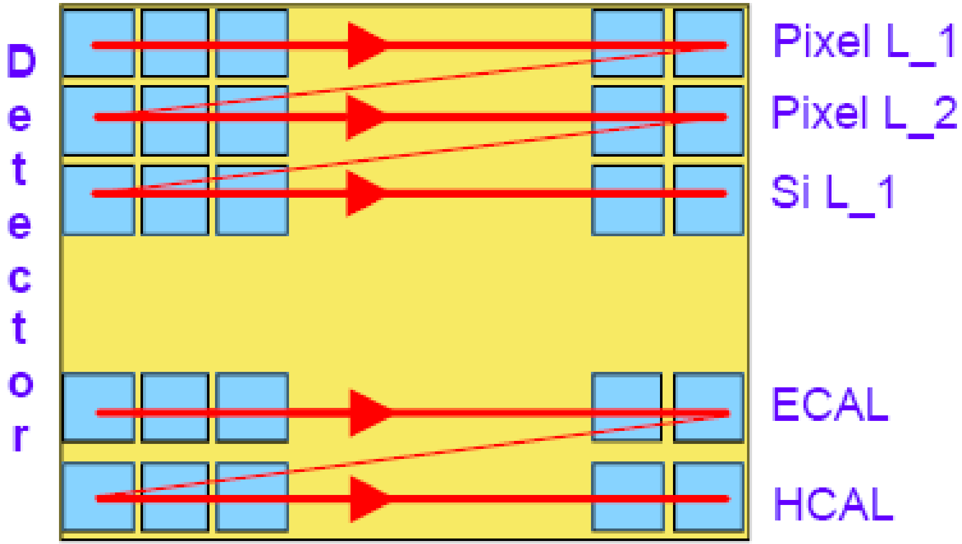
obswww.unige.ch/~pfennige/gravitor/gravitor_e.html

www.cs.sandia.gov/cplant/

HLT requirements and operation

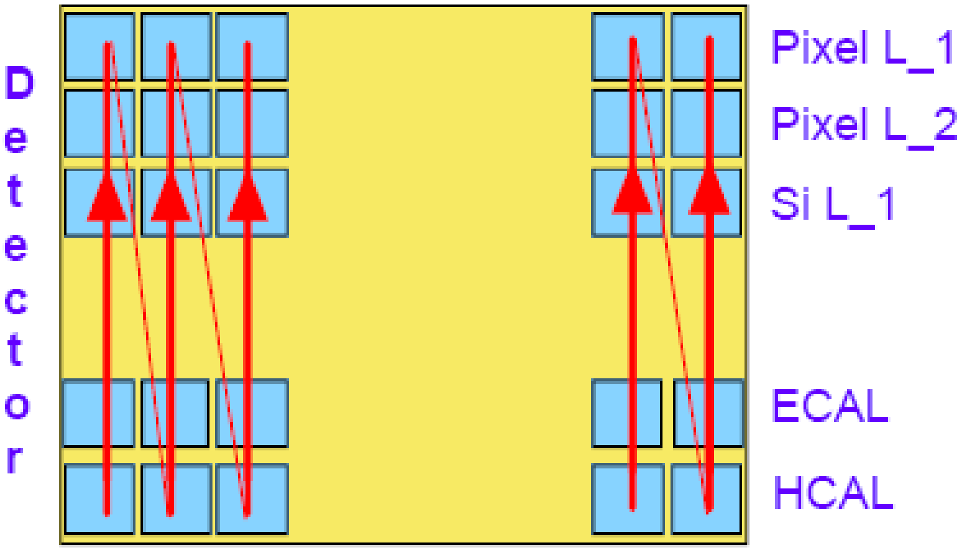
- Strategy/design guidelines
  - Use offline software as much as possible
    - Ease of maintenance, but also understanding of the detector
- Boundary conditions:
  - Code runs in a single processor, which analyzes one event at a time
  - HLT (or Level-3) has access to full event data (full granularity and resolution)
  - Only limitations:
    - CPU time
    - Output selection rate (~10^2 Hz)
    - Precision of calibration constants
- Main requirements:
  - Satisfy physics program (see later): high efficiency
  - Selection must be inclusive (to discover the unpredicted as well)
  - Must not require precise knowledge of calibration/run conditions
  - Efficiency must be measurable from data alone
  - All algorithms/processors must be monitored closely

HLT (regional) reconstruction (I)



Global

- process (e.g. DIGI to RHITs) each detector fully
- then link detectors
- then make physics objects

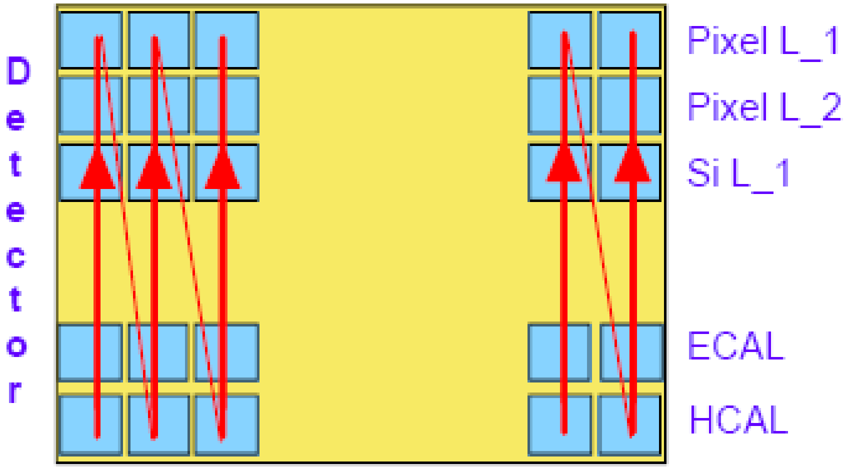


Regional

- process (e.g. DIGI to RHITs) each detector on a "need" basis
- link detectors as one goes along
- physics objects: same

HLT (regional) reconstruction (II)

- **For this to work:**
  - Need to know where to start reconstruction (seed)
- **For this to be useful:**
  - Slices must be narrow
  - Slices must be few
- **Seeds from Lvl-1:**
  - e/γ triggers: ECAL
  - μ triggers: μ sys
  - Jet triggers: E/H-CAL



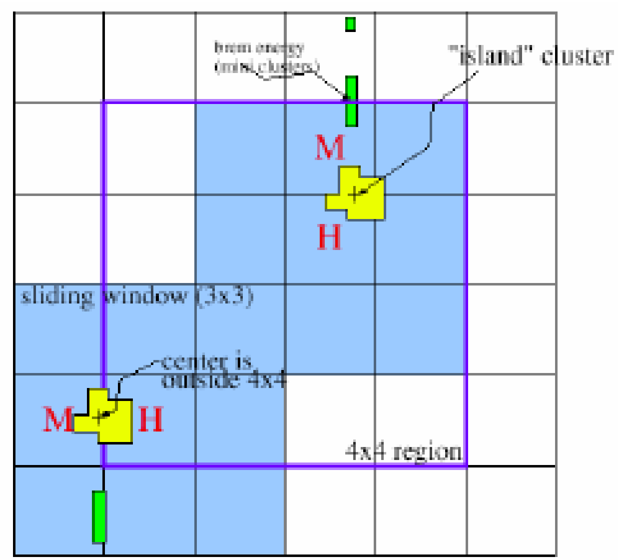
- **Seeds ≈ absent:**
  - Other side of lepton
  - Global tracking
  - Global objects (Sum E_T, Missing E_T)

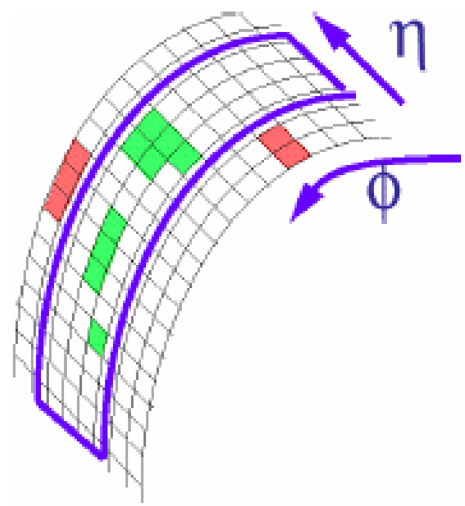
Example: electron selection (I)

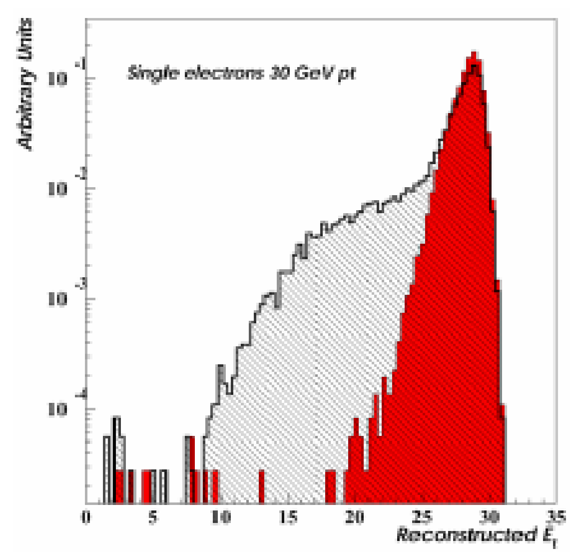
- **“Level-2” electron:**
  - 1-tower margin around 4x4 area found by Lvl-1 trigger
  - Apply “clustering”
  - Accept clusters if H/EM < 0.05
  - Select highest E_T cluster
- **Brem recovery:**
  - Seed cluster with $E_T > E_T^{min}$
  - Road in ϕ around seed
  - Collect all clusters in road

  → “supercluster”

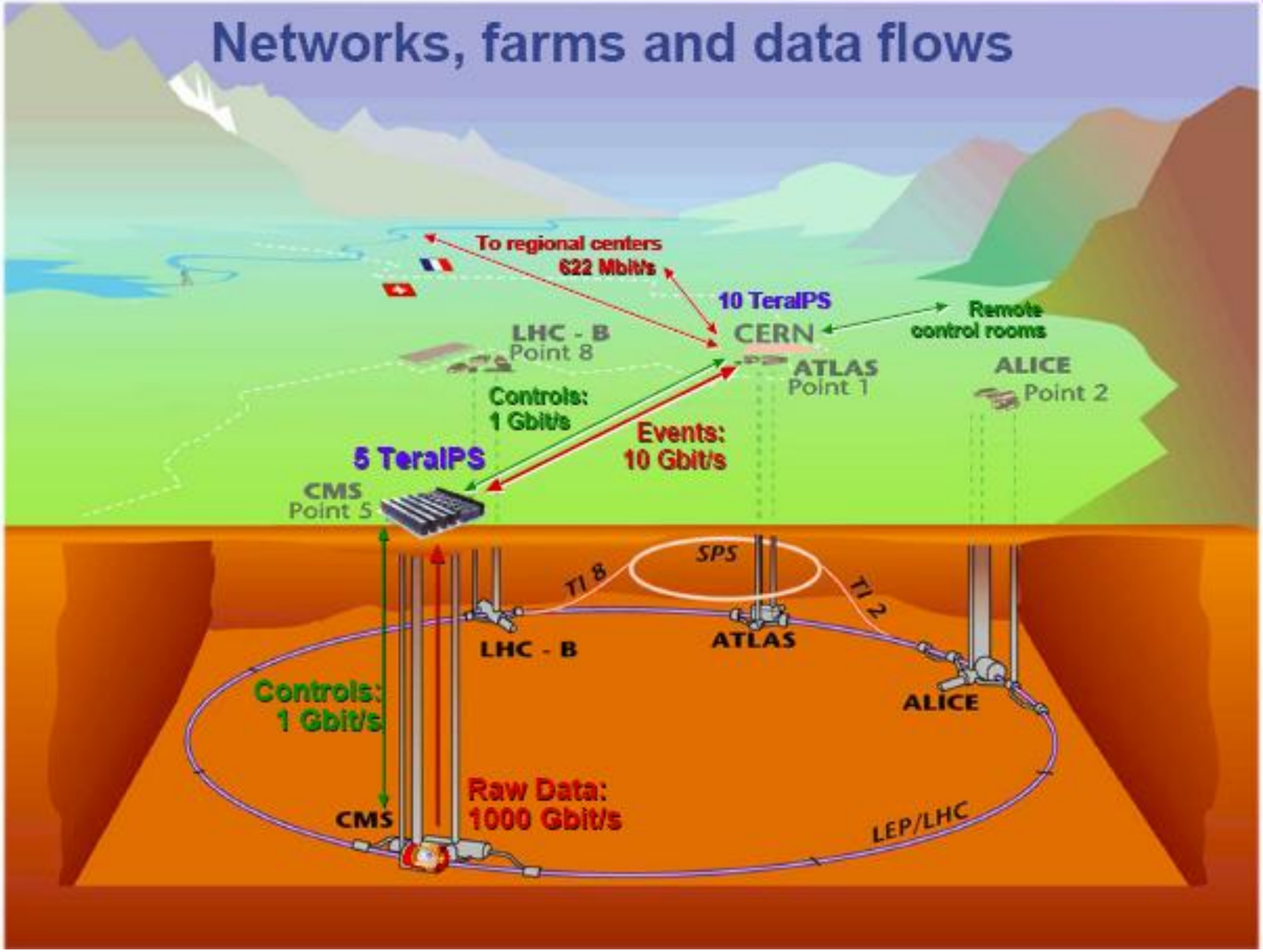
  and add all energy in road:



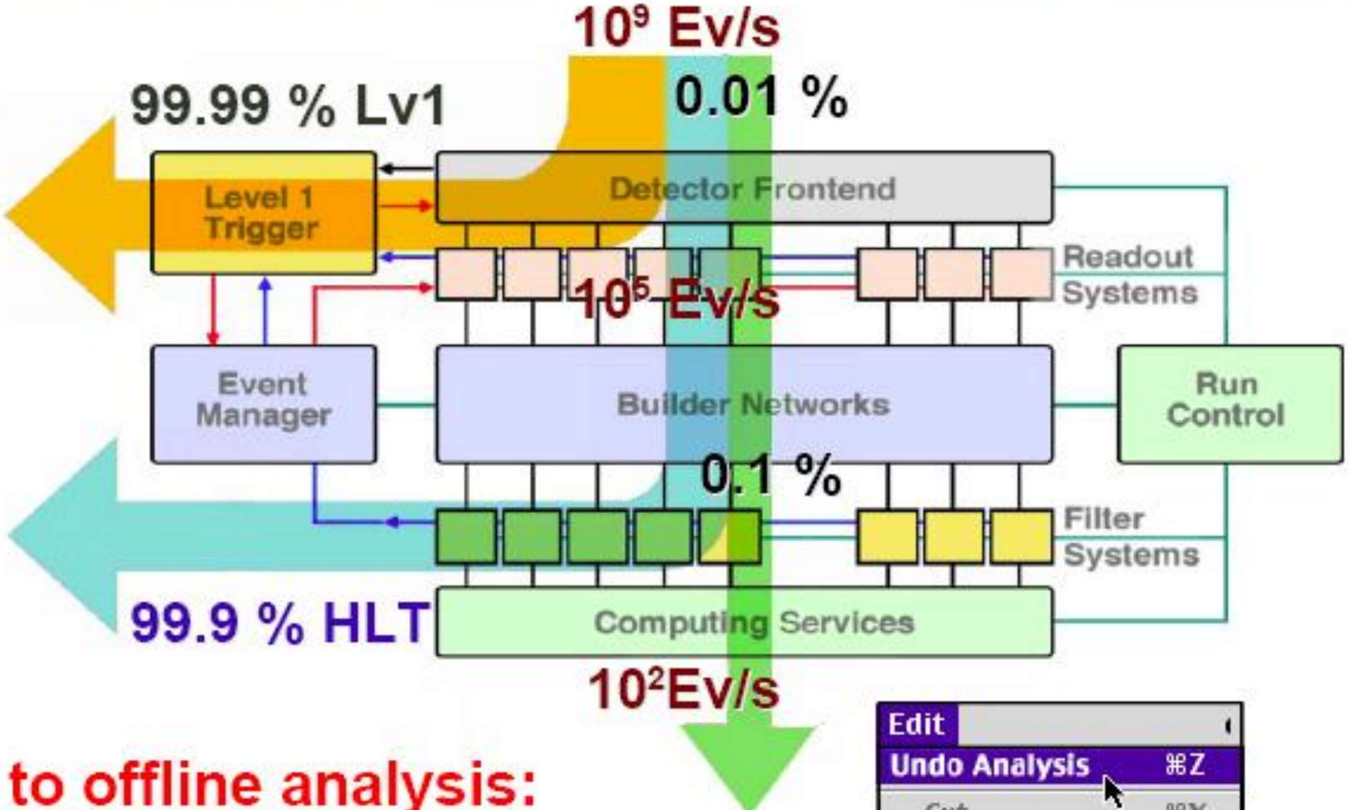




After the Trigger and the DAQ/HLT



A parting thought



With respect to offline analysis:

Same hardware (Filter Subfarms)

Same software

But different <u>situations</u>

(Grand) Summary

- The Level-1 trigger takes the LHC experiments from the 25 ns timescale to the 10-25 μs timescale
  - Custom hardware, huge fanin/out problem, fast algorithms on coarse-grained, low-resolution data
- Depending on the experiment, the next filter is carried out in one or two (or three) steps
  - Commercial hardware, large networks, Gb/s links.
  - If Level-2 present: low throughput needed (but need Level-2)
  - If no Level-2: three-dimensional composite system
- High-Level trigger: to run software/algorithms that as close to the offline world as possible
  - Solution is straightforward: large processor farm of PCs
  - Monitoring this is a different issue
- All of this must be understood, for it's done online.