Trigger and data acquisition in high energy physics large experiments

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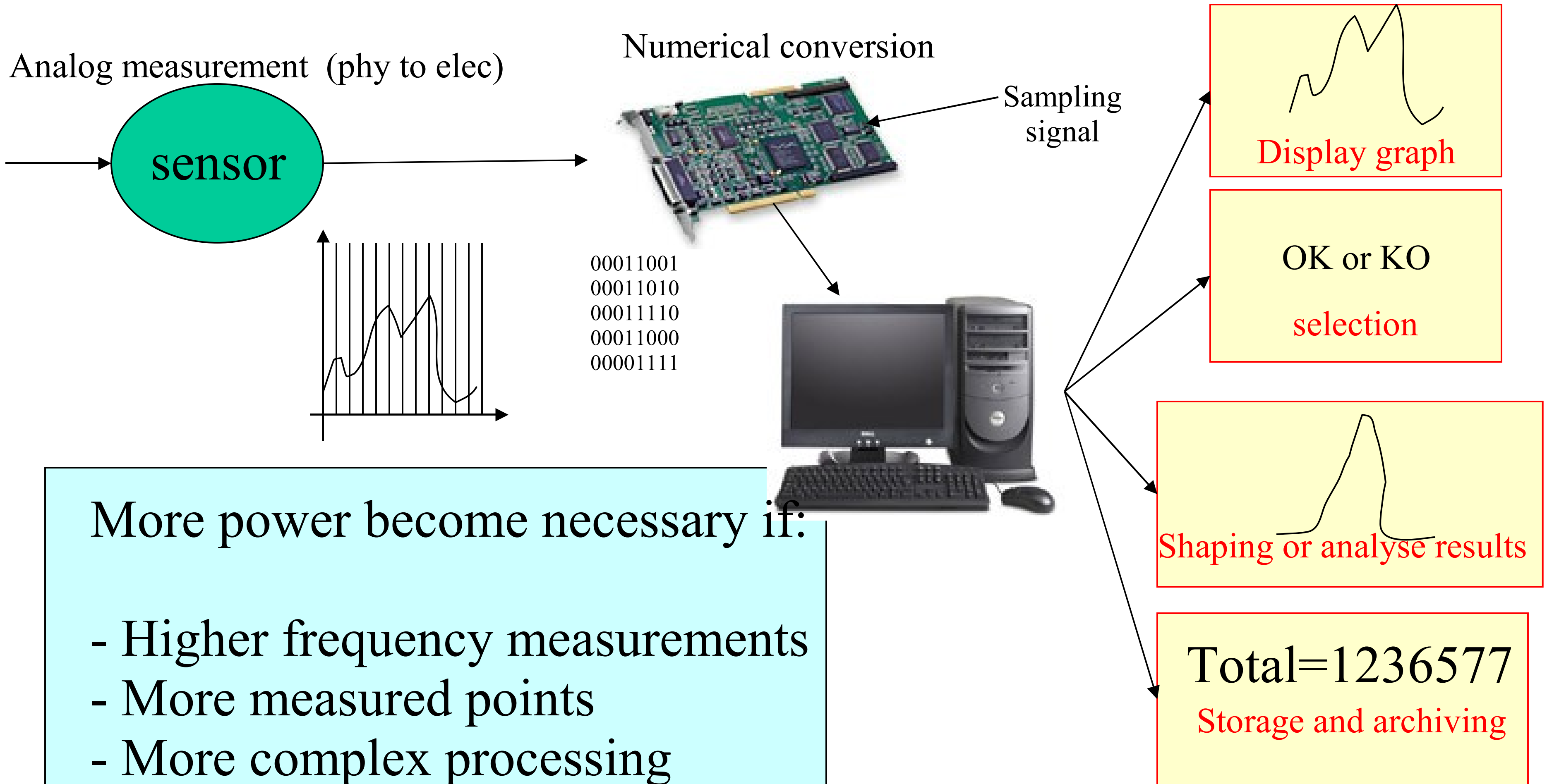
Overview

Data acquisition systems (DAQ) and Trigger systems

An example of a trigger and DAQ system in high energy physics

Data acquisition basics



More power become necessary if:

- Higher frequency measurements
- More measured points
- More complex processing

Definitions

Event

The set of measurement values collected during a physical phenomenon that occurs at an identifiable point in time.

A subset of an event is an event fragment

Examples:

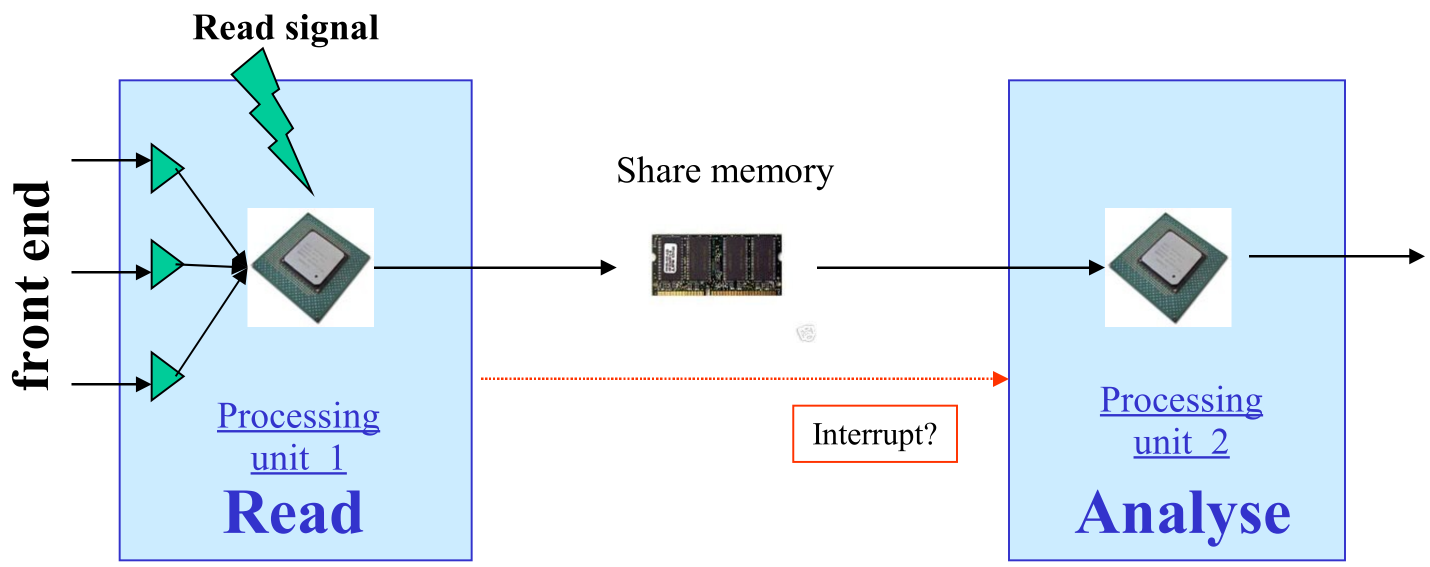
Accelerator : data associated to a collision

Astroparticles: data associated to a shower, muon path

Dead time

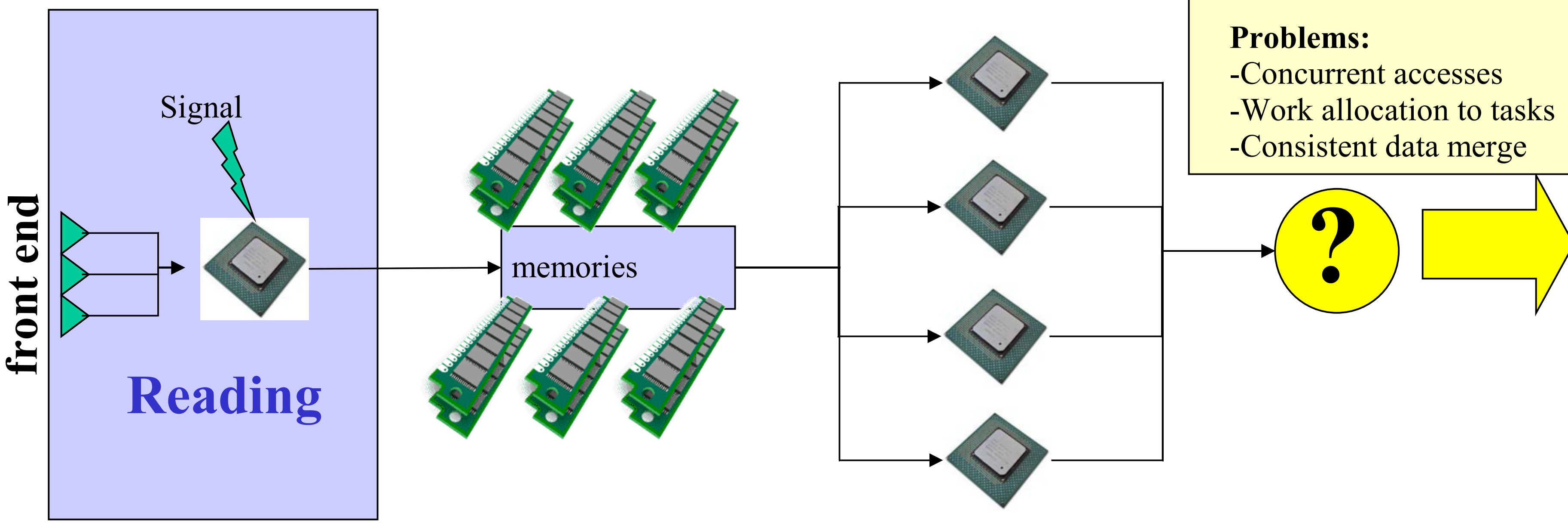
Fraction of time during which event data are dropped/lost because the TDAQ system is busy.

DAQ chain functional blocks



Scheduling type:
- -Interrupt driven
- -Temporized polling
- -Pure polling (time driven)

Larger DAQ chain functional blocks

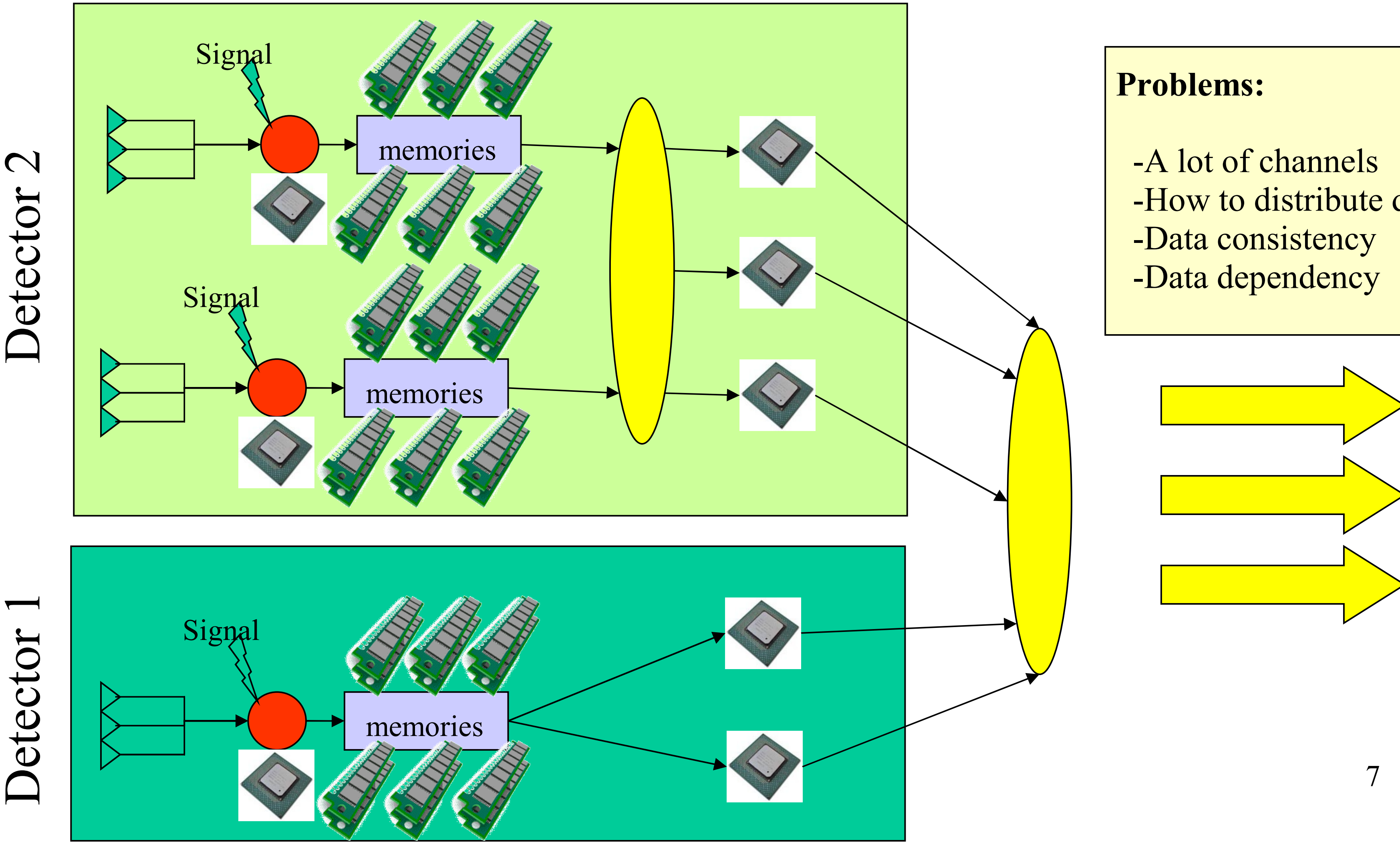


Problems:
-Concurrent accesses
-Work allocation to tasks
-Consistent data merge

If stable input flow And limited by processing time Then
add more processing units to work in parallel
(example read DMA engine, use multiprocessor or multicore for analysing tasks)

If irregular bursty input flow Then
increase the buffers depth to absorb bursts

Still larger DAQ chain functional blocks



Problems:

- -A lot of channels
- -How to distribute data?
- -Data consistency
- -Data dependency

Event builder

Problems arise when we have several channels to assemble:

- geographically distributed
- parallel processing lines/chains with different processing delay

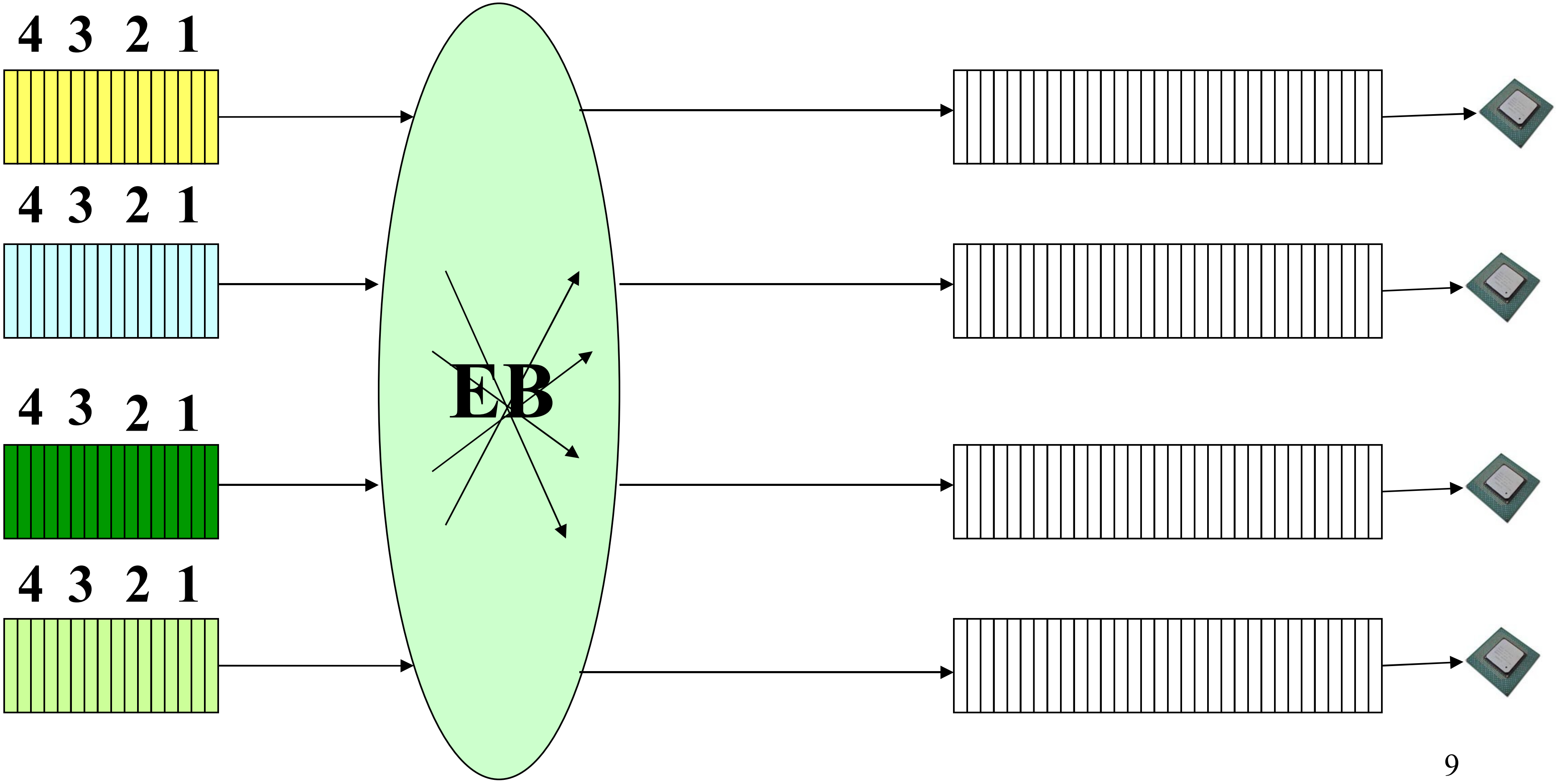
then the necessary time to get the different events fragments is very different from one channel to another.. (time of flight, sensor latencies, intermediate processing...)

The event builder collects and assembles the various fragments coming out of different channels into a larger consistent block of data belonging to the same event.

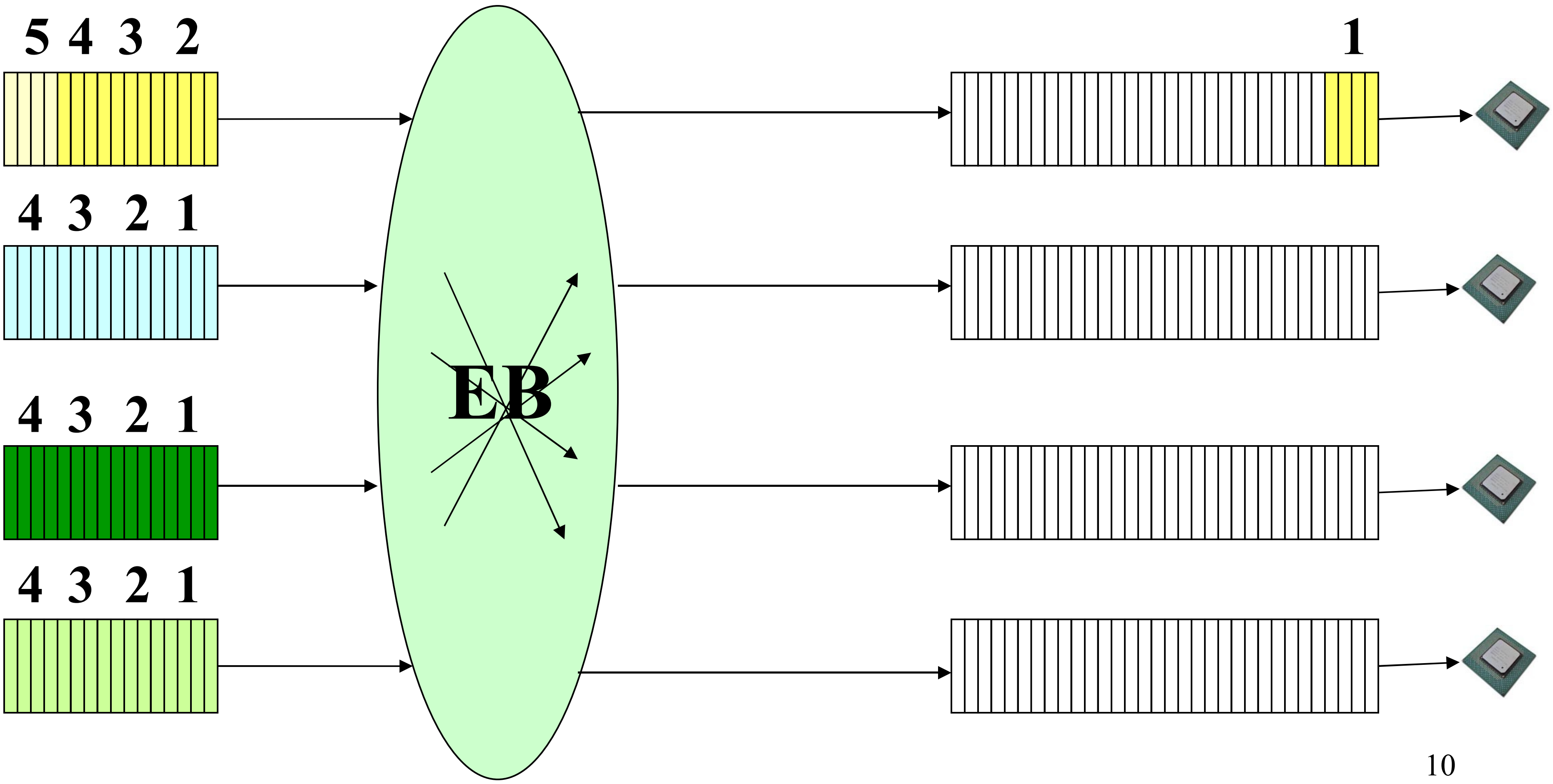
The last event builder in the acquisition chain assemble the complete event.

Its two functions are:
- assembling
- routing of the data to several down flow parallel processing units

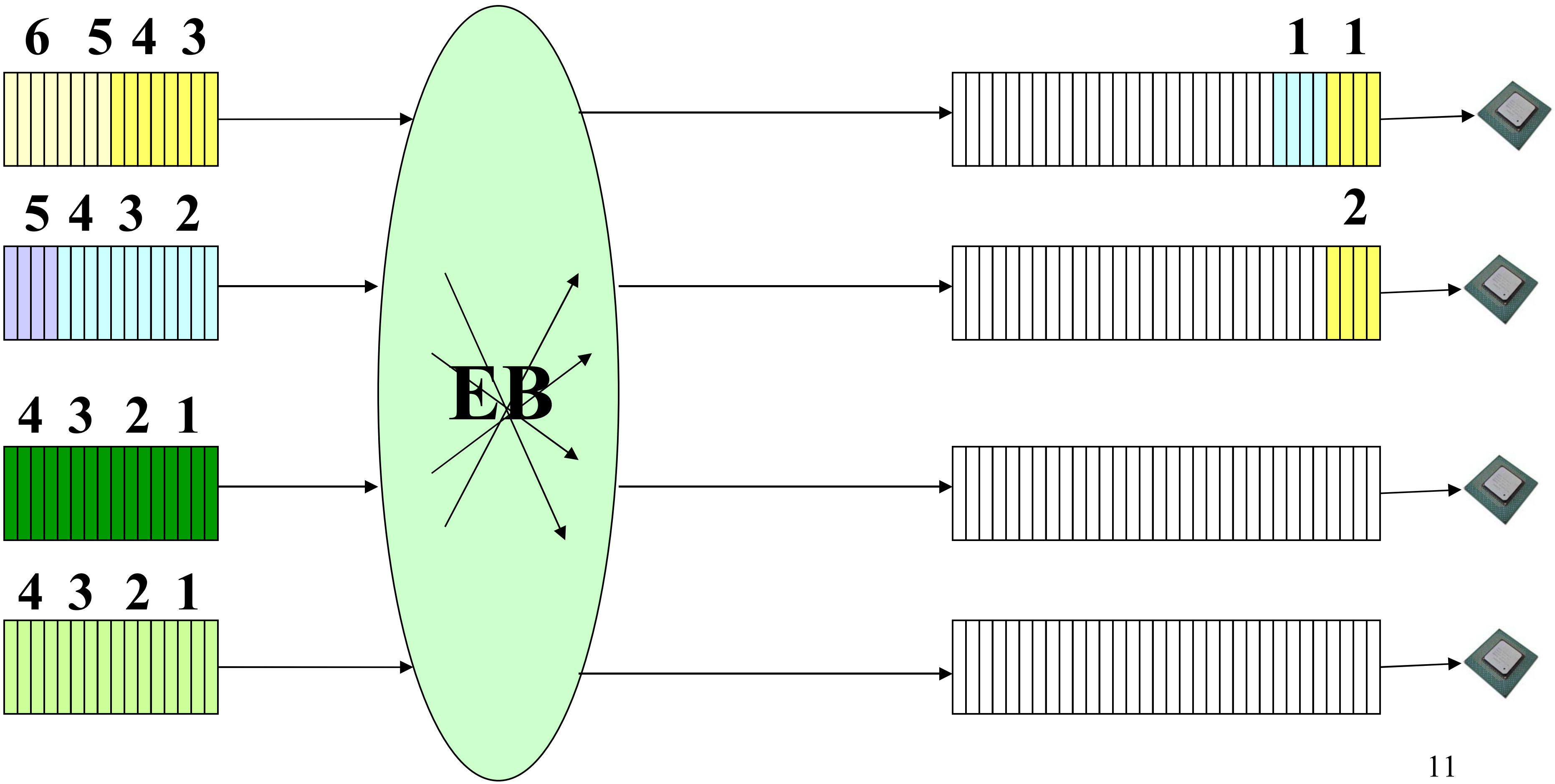
Event builder



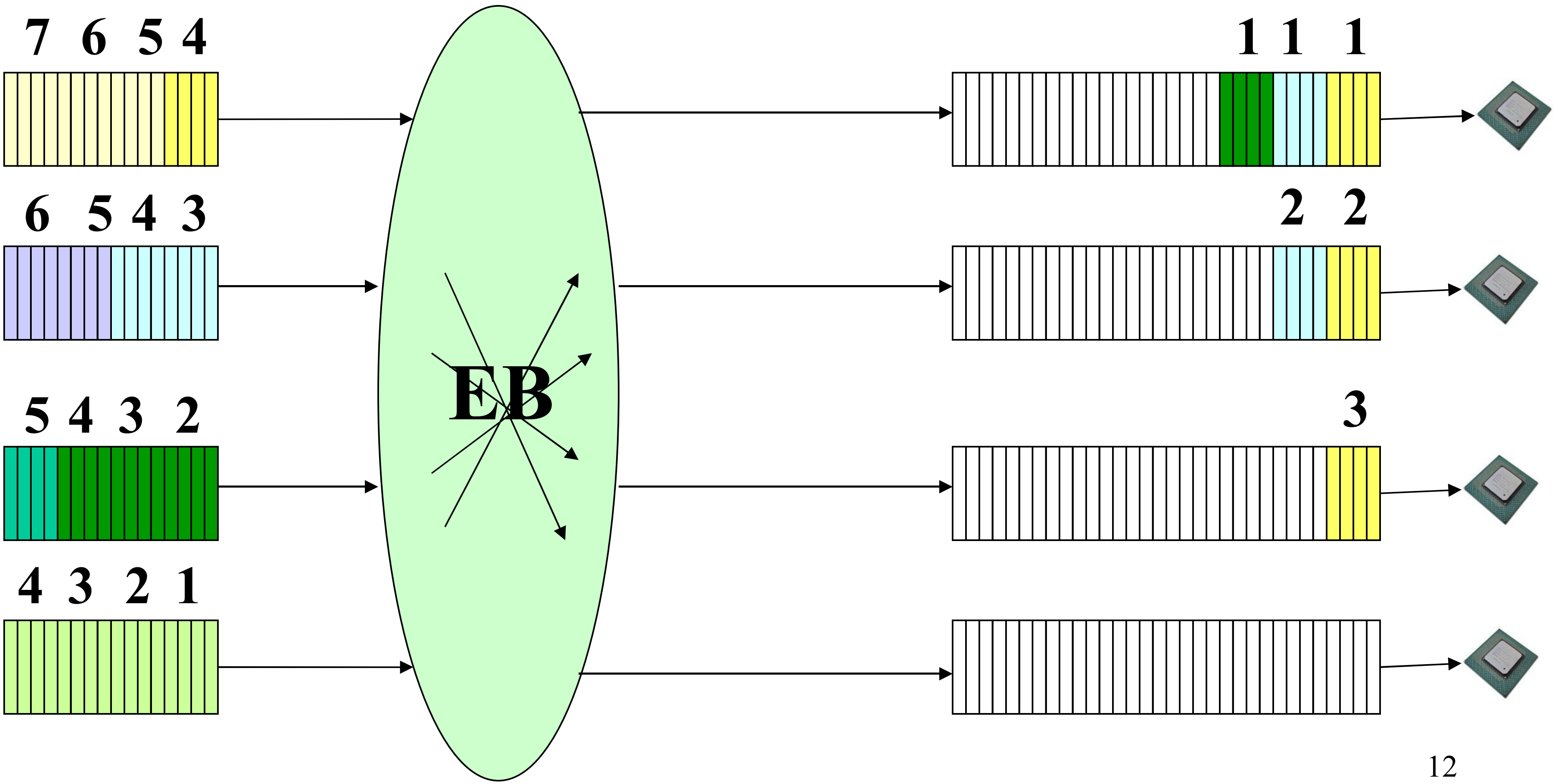
Event builder



Event builder



Event builder



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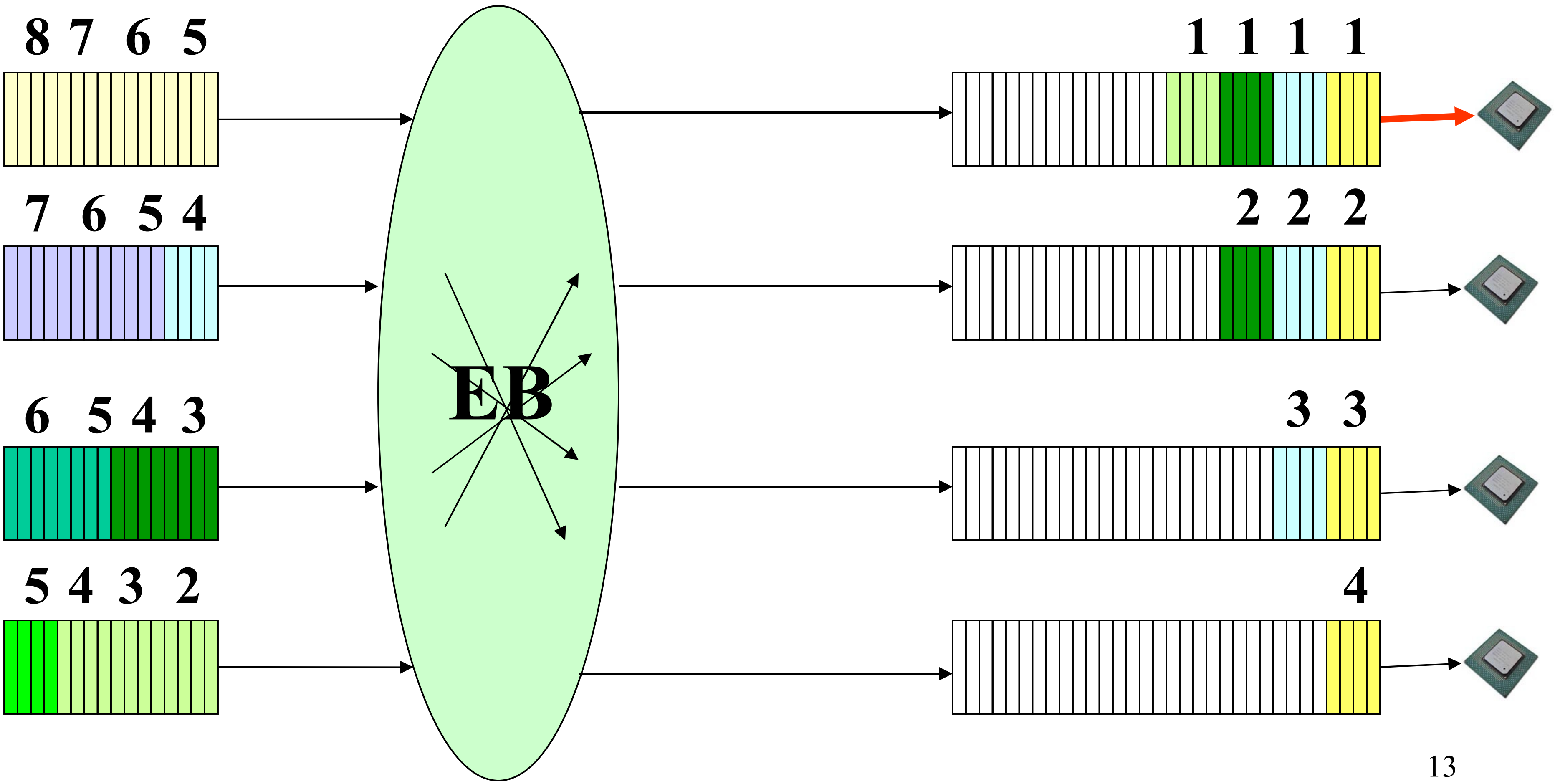
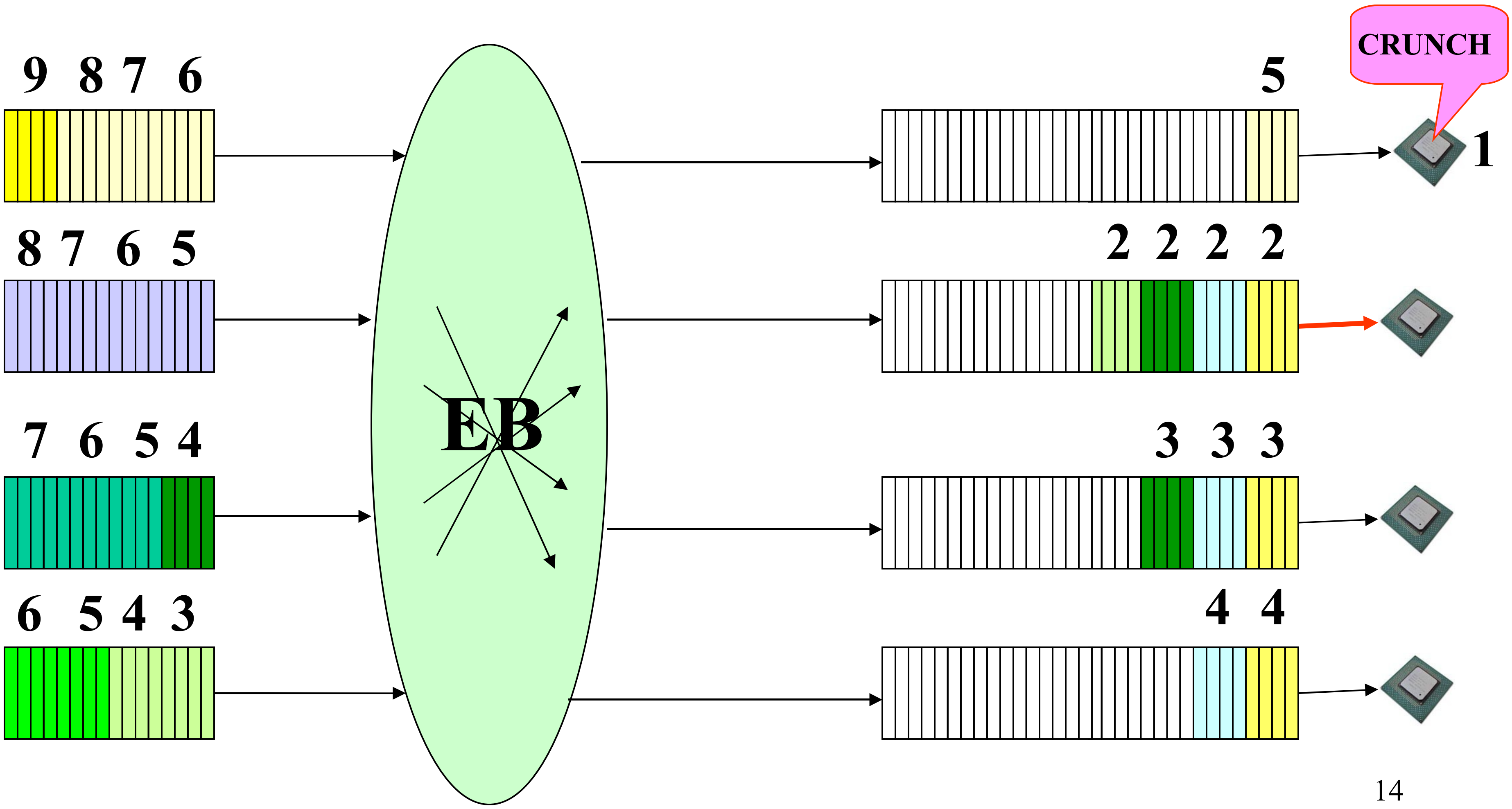
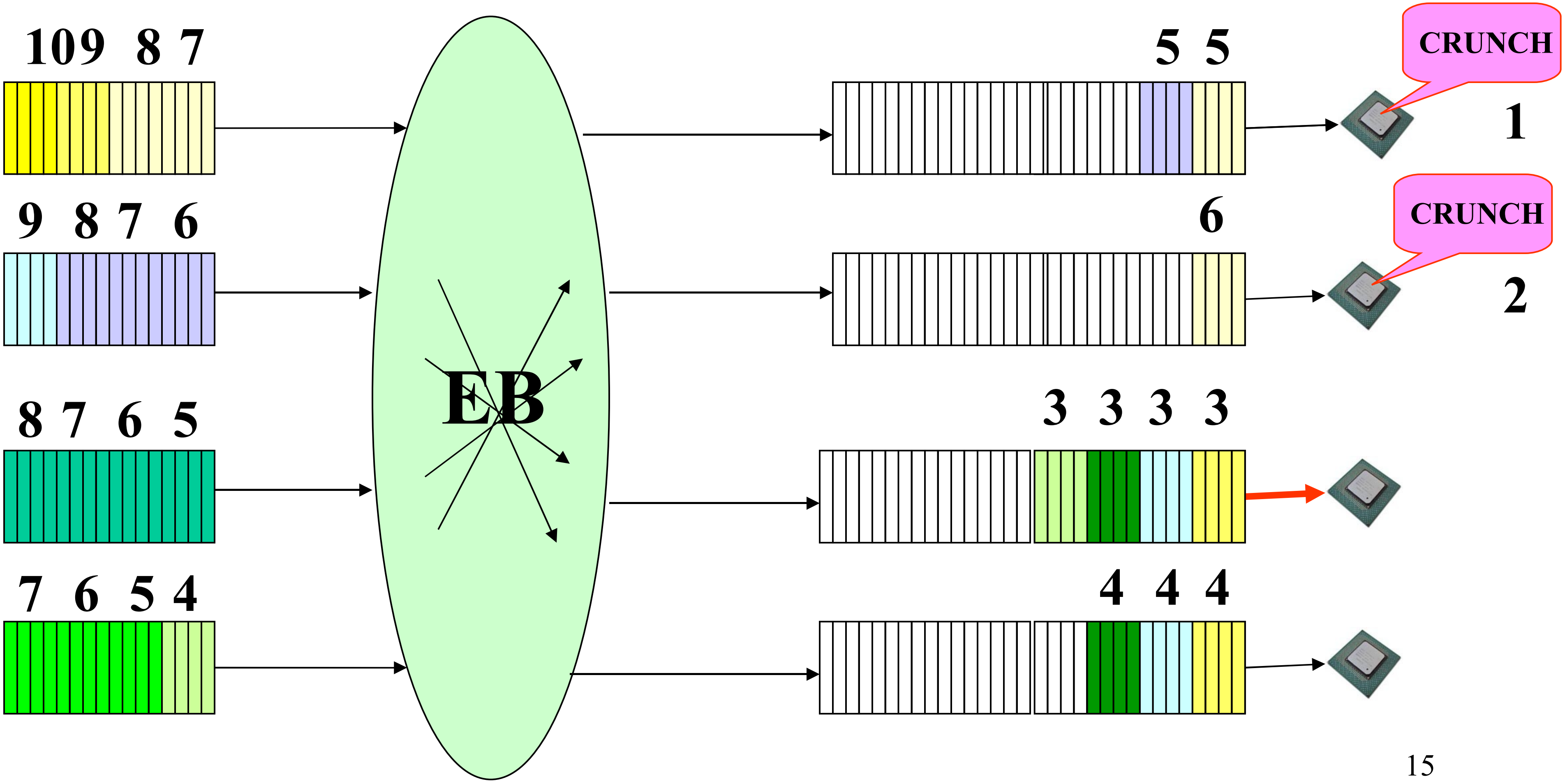


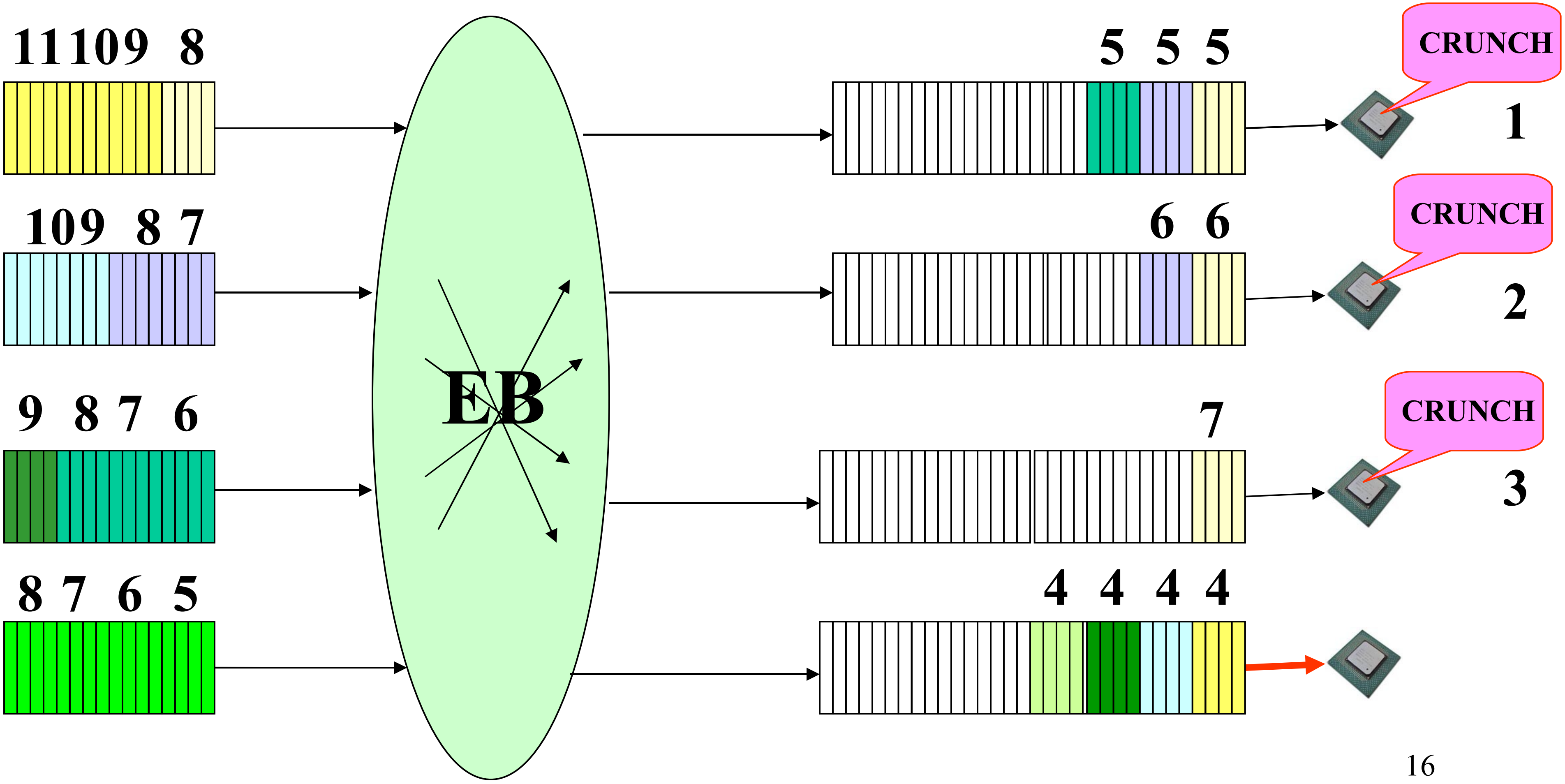
Event builder



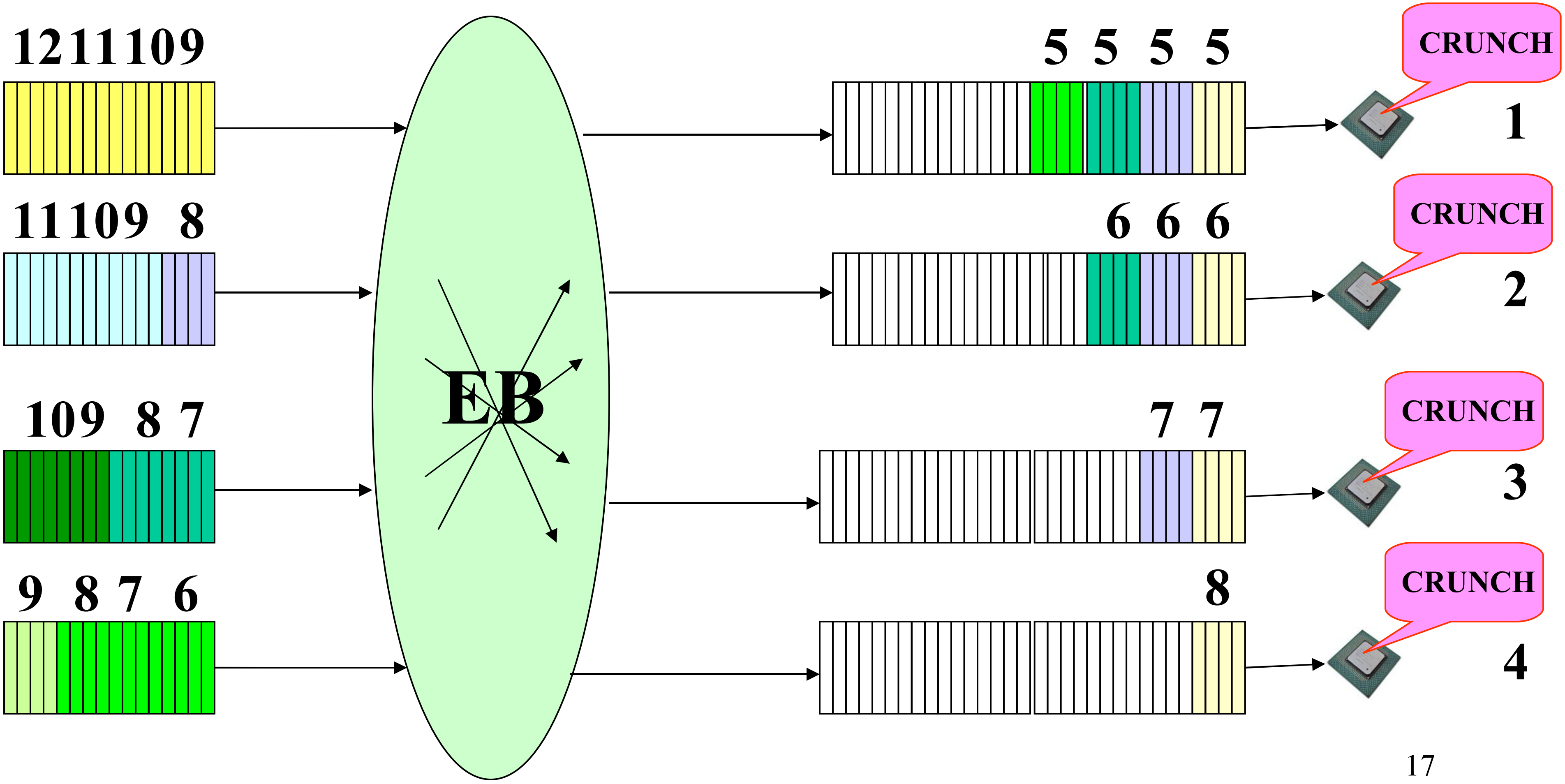
Event builder



Event builder

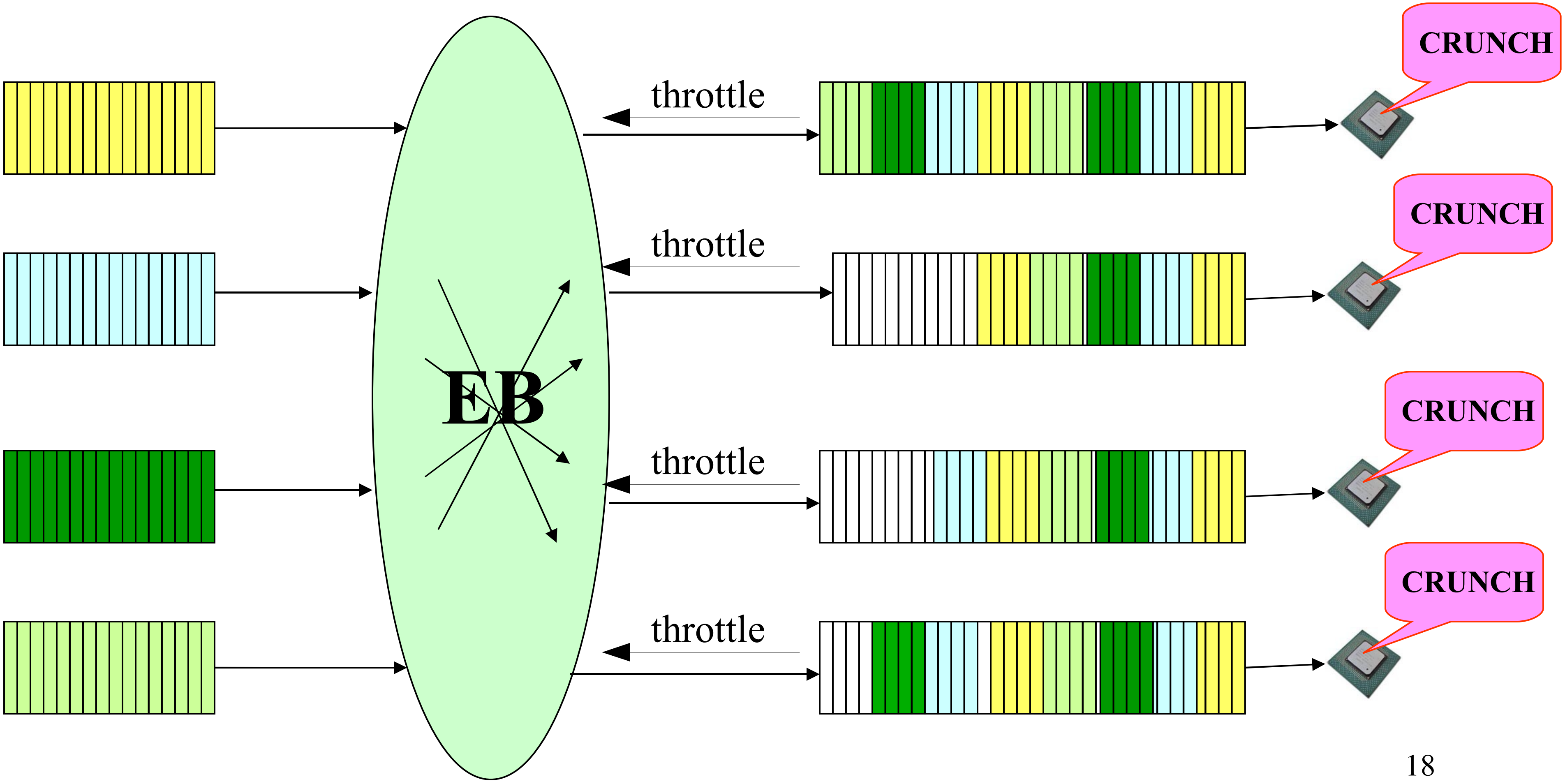


Event builder



Event builder

A better policy to allocate destination can be implemented in order to provide load balancing between data crunchers



Trigger

A trigger is a data processing unit that

selects data on the fly

data that match some rules based upon:

- geographic or time correlations
- threshold detection
- signal shape

It provides:

- a selection signal towards the data buffers
- some data tagging to facilitate later data use and checking

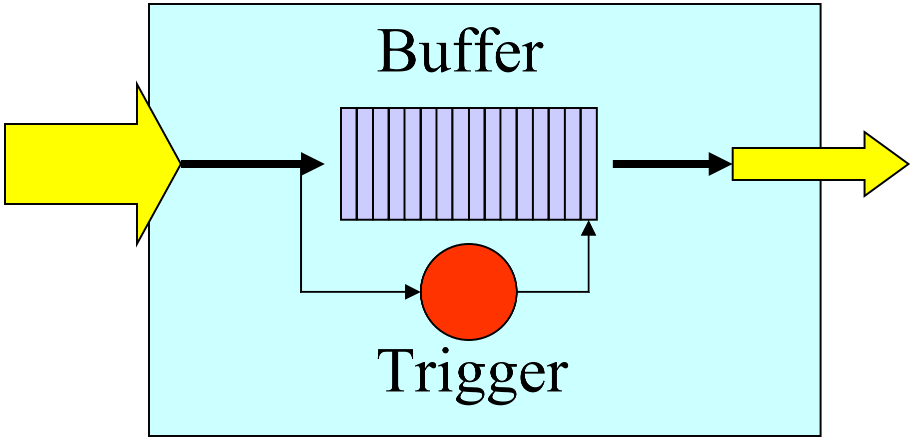
The aim is to keep only those data that are potentially interesting for some kind of physics (energy range, special trajectory, number of particles ...)

A trigger system can be implemented in hardware or software (delay/complexity)

Trigger functional block

Functional block for the specification of a trigger level in a large DAQ:

The buffer depth depends on the processing latency



Performances:
Reduction rate:
flow IN/flow OUT
Processing latency

Synchronous or asynchronous:

Synchronous: Input data stream regular and processing done with a fixed number of instructions both sequenced by a clock (pure numerical electronics) (output flow is always asynchronous)

Asynchronous: Input flow is irregular and trigger processing delay depends on the data to analyse (software tasks)

Data identification
time stamping

Why:

- Need to identify event fragments belonging to the same event (process/assemble)

Two possibilities:

- Sequence numbers (match a collision number on the accelerator)
- Time stamp (based upon a synchronised distributed common clock)

Big issue:

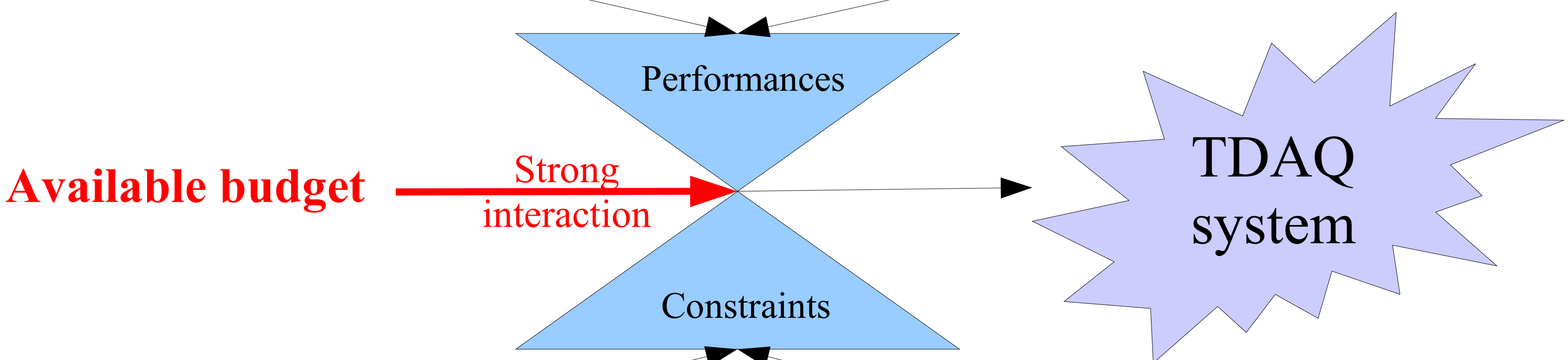
It is technically very difficult to precisely distribute on a large scale a precise clock signal (ns).

Most of the time a dedicated system associated to the synchronous broadcast of short messages is implemented (clock is just one particular kind of short message). Example of such message is a global synchronous "reset" to thousands of front end boards.

Specifications topics summary

Data:
-Number of input channels
-Input flow volume and speed
-Input law (periodic, non periodic (arrival law))

Processing
-Accepted loss rate (dead time)
-Processing complexity (statistic, stability)

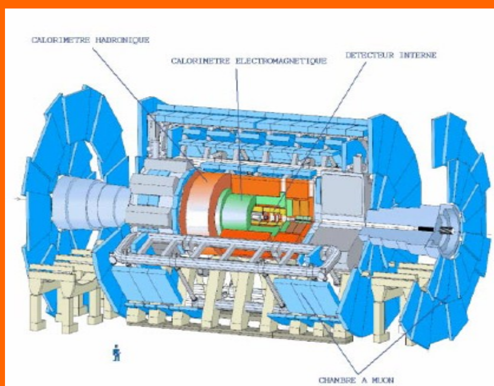


Usage constraints:
-Environment constraints (hostile or regular : radiations, space, under see …)
-Exploitation constraints (continue, seasonal)

Technical/Design constraints:
-Planned evolution/upgrade (scalability)
-Constraints to use available or standardized components

Large experiment architecture (ATLAS figures)

LHC=40MHz



Front end electronics
Analog electronics
and digital conversion

L1

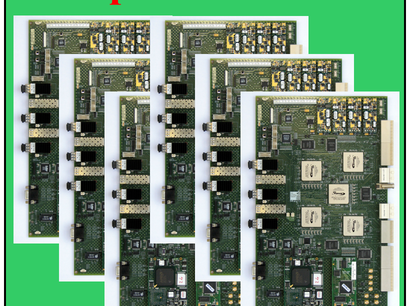
2.5μs

100Gbs

75kHz

First level selection

Dedicated electronic processors



L2

~ ms

Simple processing on <u>local</u> data

1 Gbs

2kHz

Second level selection

L3

~ sec

Global processing full event reconstruction

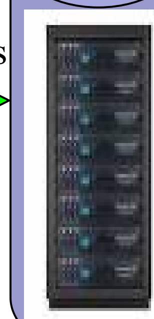
100Mbs

200Hz

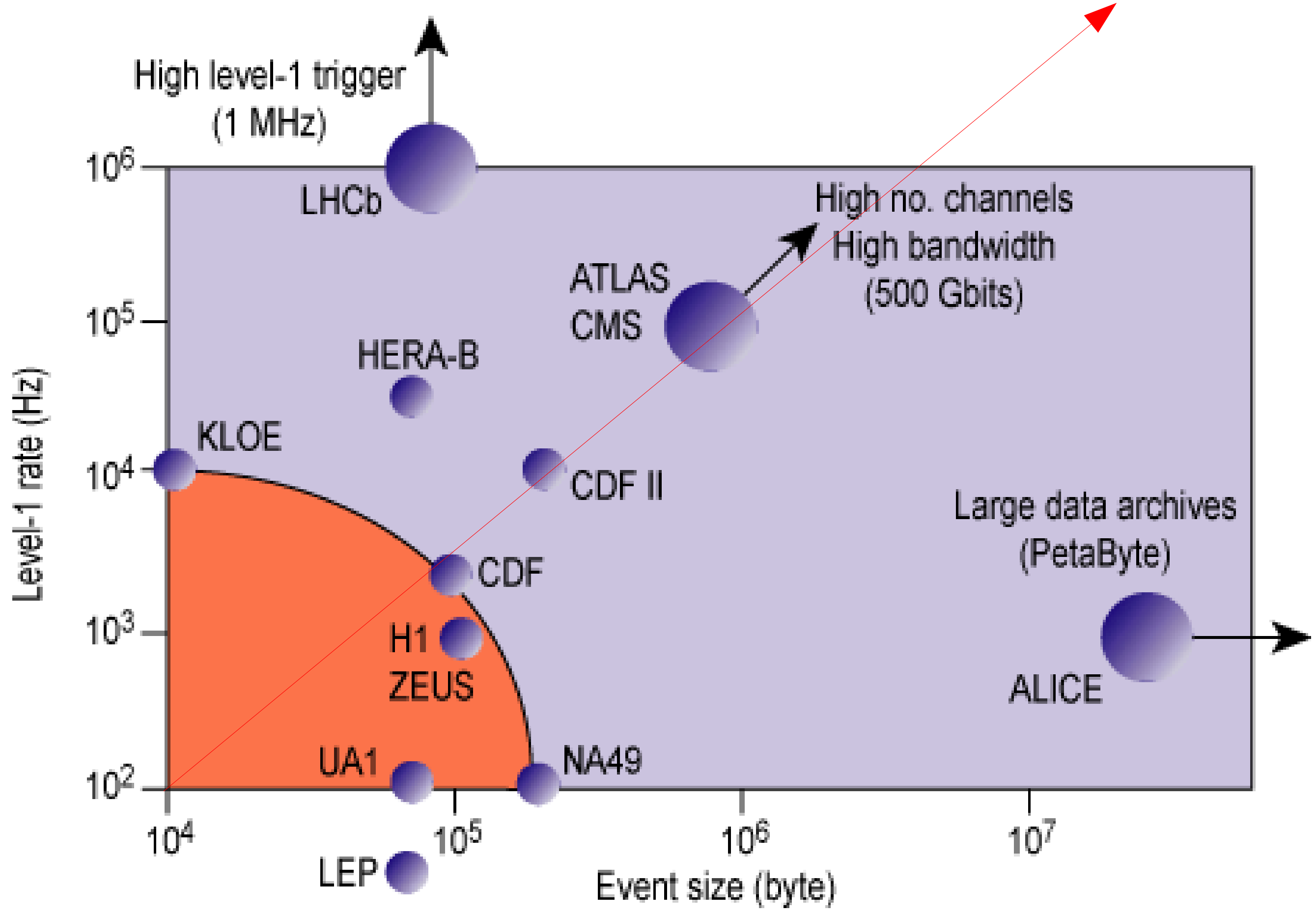
High level selection

Network of computers

Recording

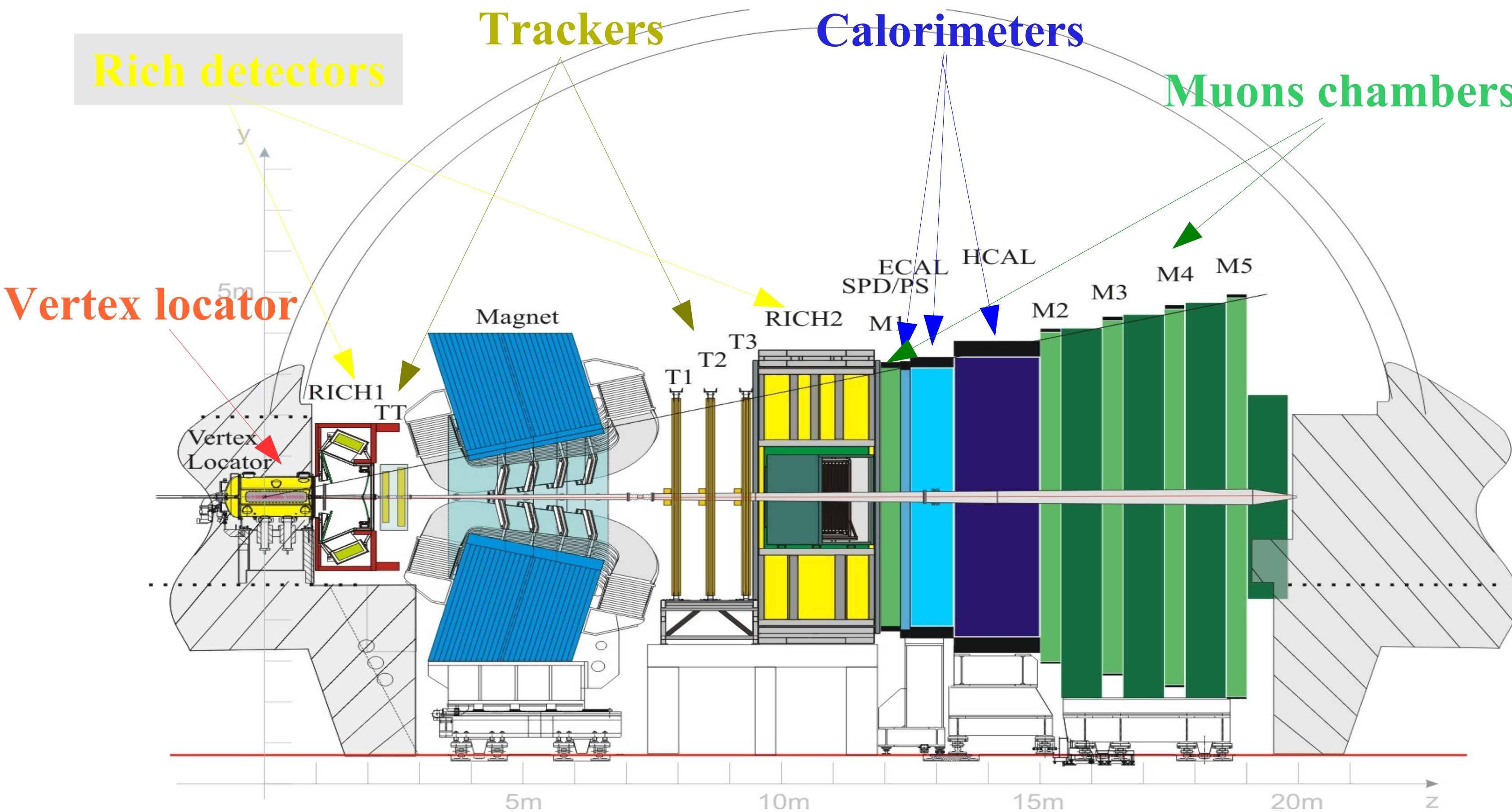


Large experiment performances

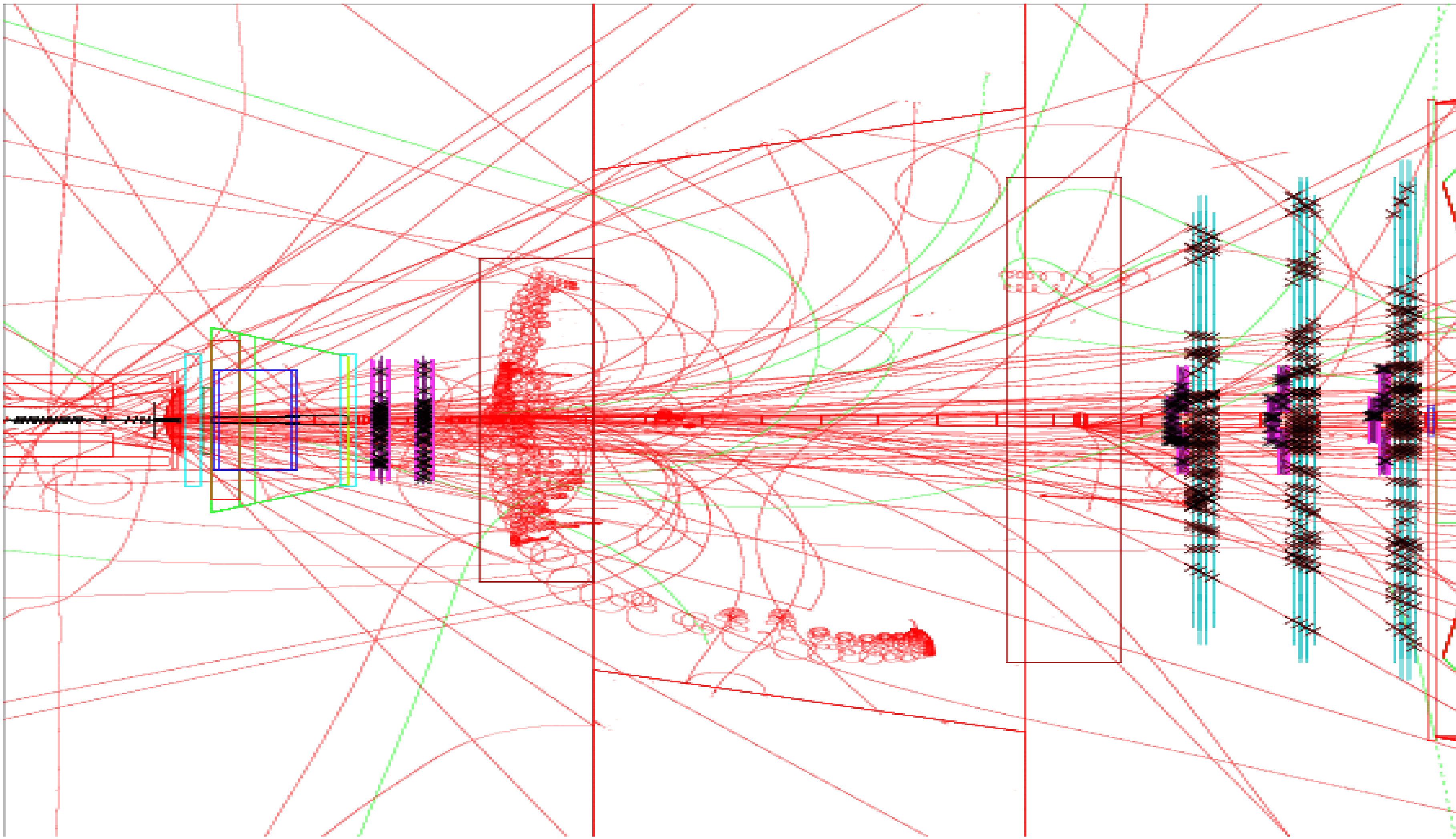


Example: the LHCb experiment

Study CP violation in beauty quark system

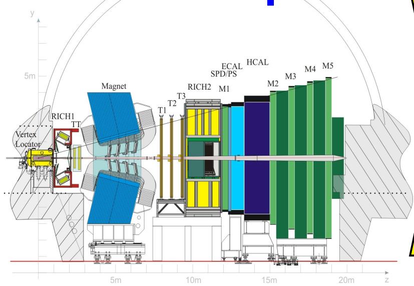


What is useful there inside ?



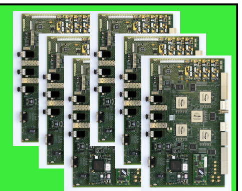
Trigger overview

visible collisions
12 MHz
100kHz bb pairs



1.2 million channels

L0+L1



2.5μs

Trigger L0 and data compression

detector readout 1 MHz

~50Gbs

HLT(L2+L3)

~ ms

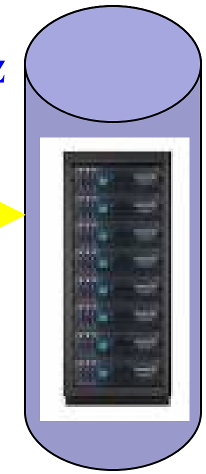
Simple processing on <u>local</u> data

~ sec

Global processing full event reconstruction

2kHz

Recording



Event building

<u>Hardware Trigger (L0)</u>

“high pt” calorimeter & muon objects

rejects busy events

<u>Software Trigger (**H**igh **L**evel **T**rigger)</u>

HLT first level: trigger on B decay products

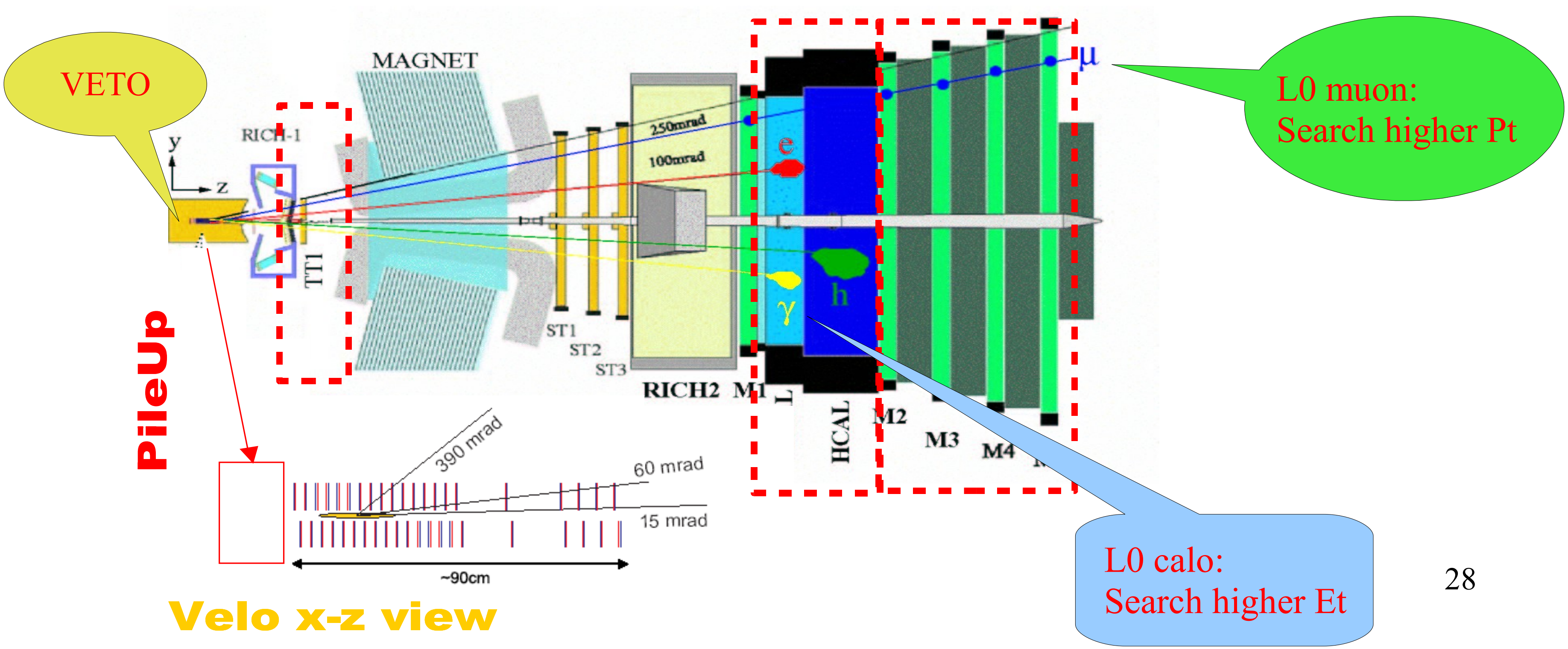
HLT second level: trigger fully reconstructed B decays

L0 global selection

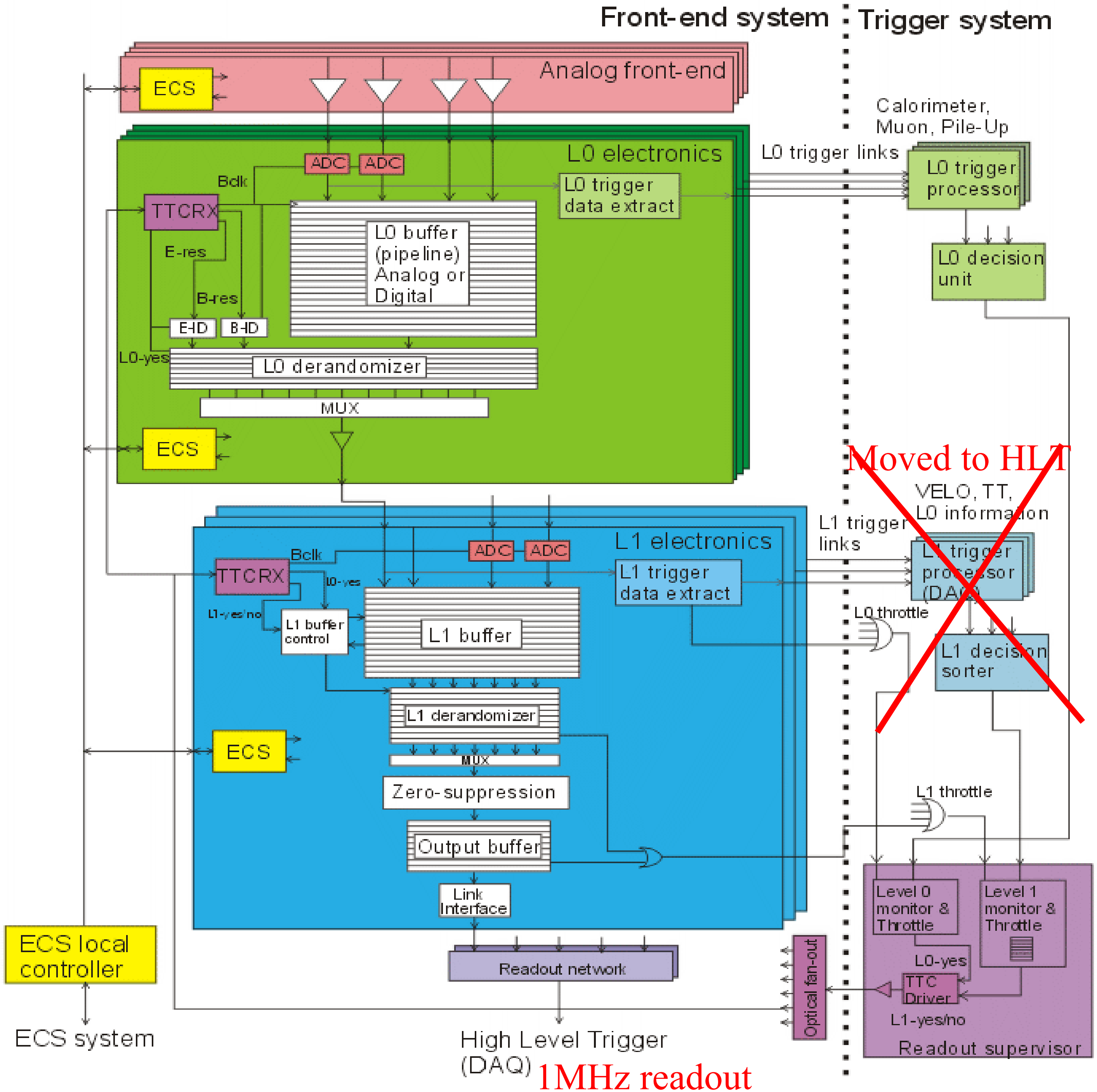
Data from 3 detectors with 3 L0 local triggers: calorimeters, muons and pile-up veto

Decision in a L0 decision Unit:

IF (candidates with E_T OR P_T > level) AND (only one BB interaction)
THEN select event

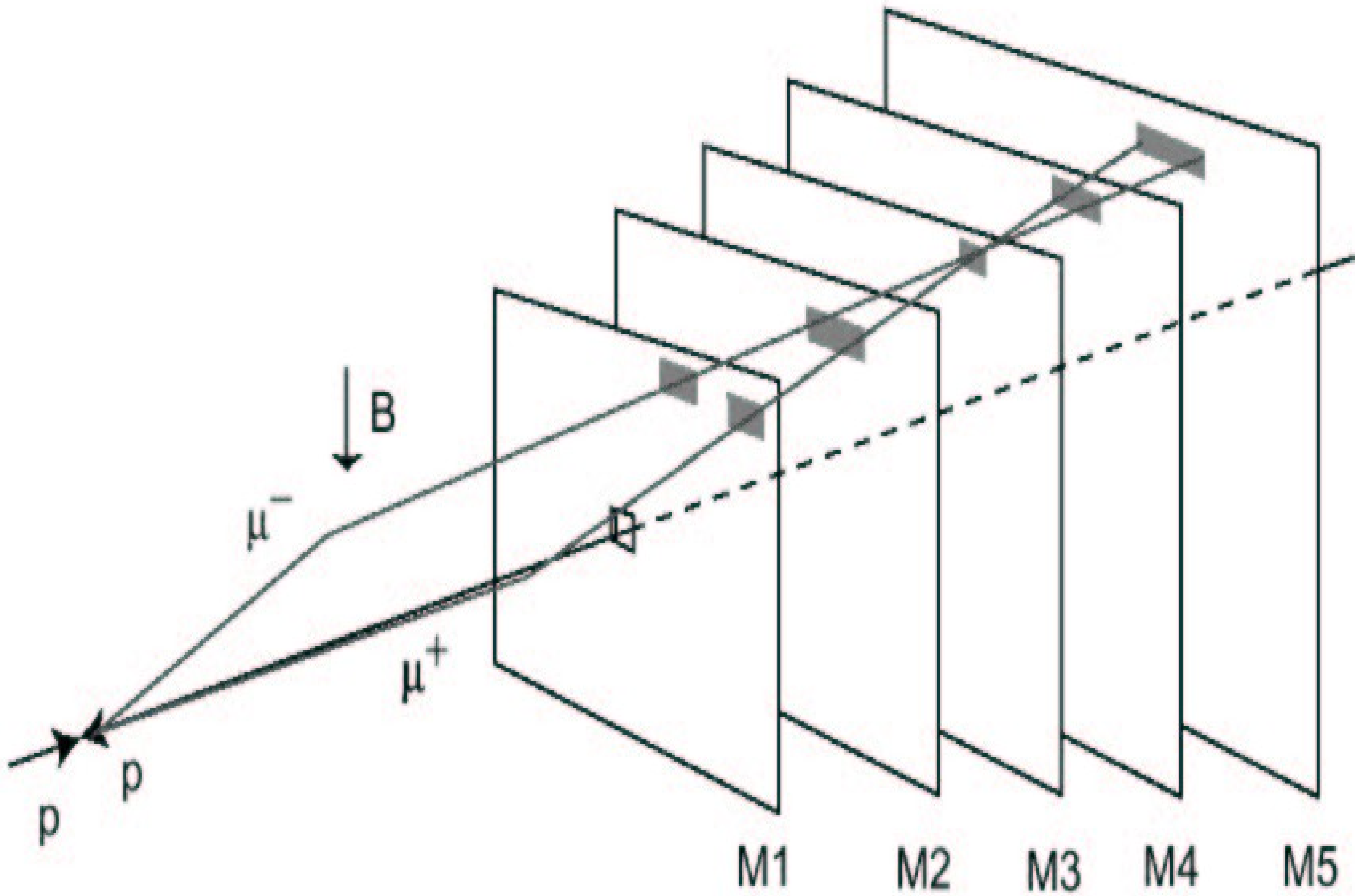


L0+L1 architecture



L0 muons trigger

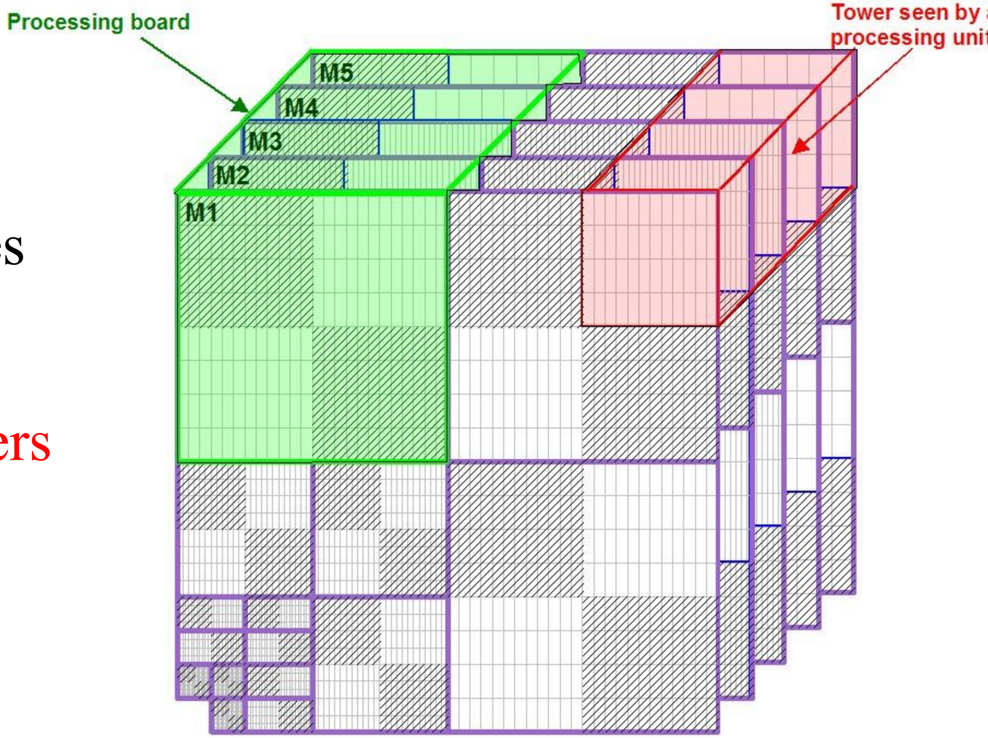
Uses pads and strips hits data to compute the 2 highest Pt trajectories in the quarter



L0 muons trigger selection

Selection algorithm by tower:

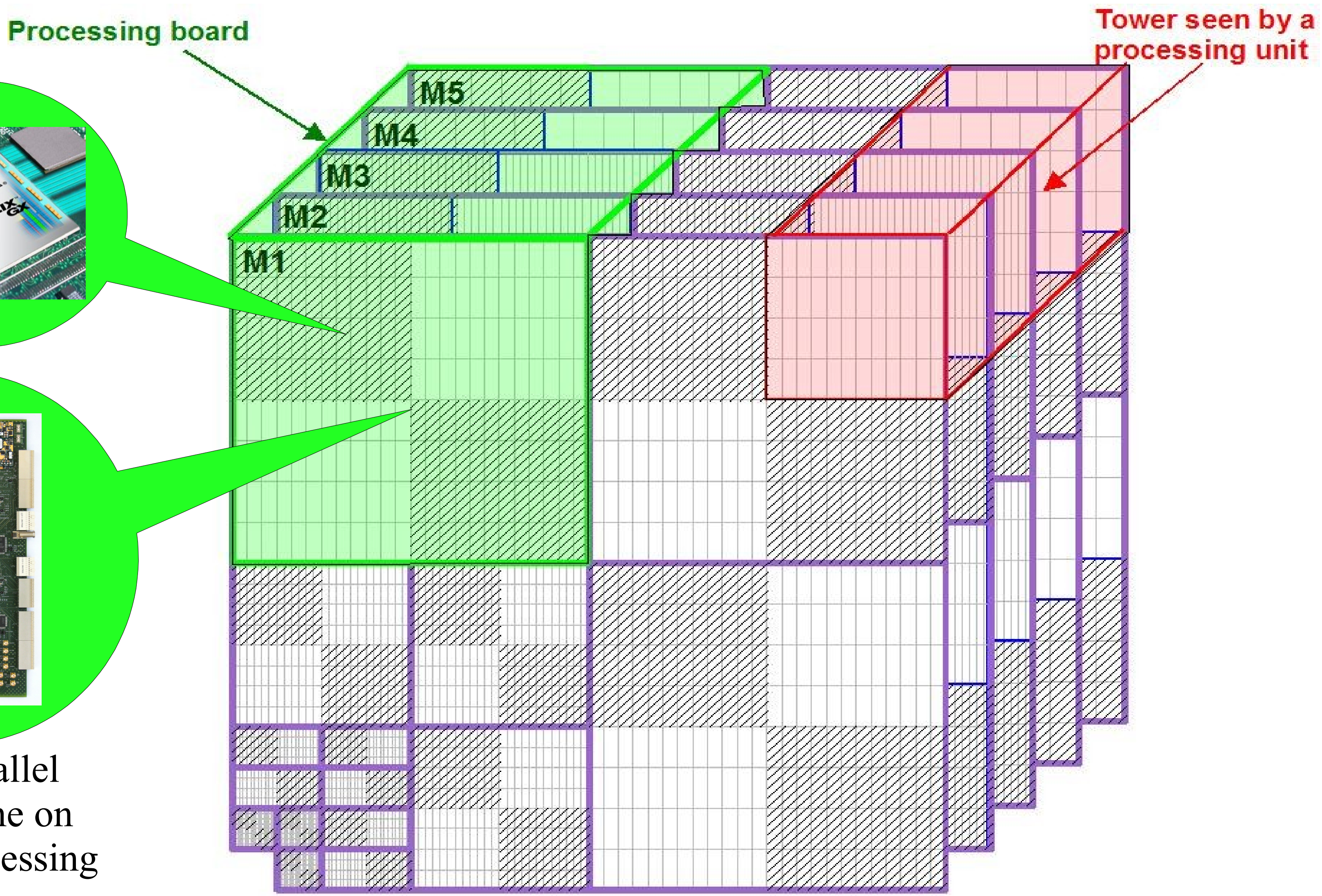
- all towers analysed in parallel
- search correlated hits in 4 stations
- compute candidate trajectories angles
- select the two best

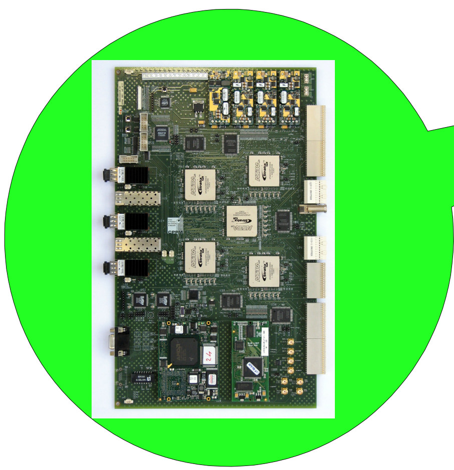


Can analyse trajectories crossing towers borders by data exchanges between neighbouring processing units

All towers contain the same quantities of data to analyse but cover a smaller area near the beam axis because the higher density of pads.

L0 muon trigger hardware allocation





Massively parallel processing done on dedicated processing boards.

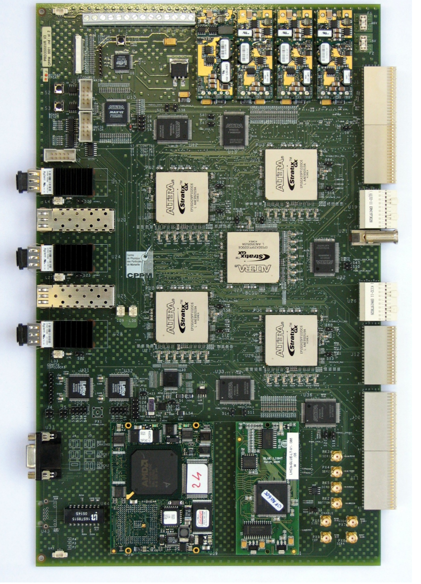
L0 technology

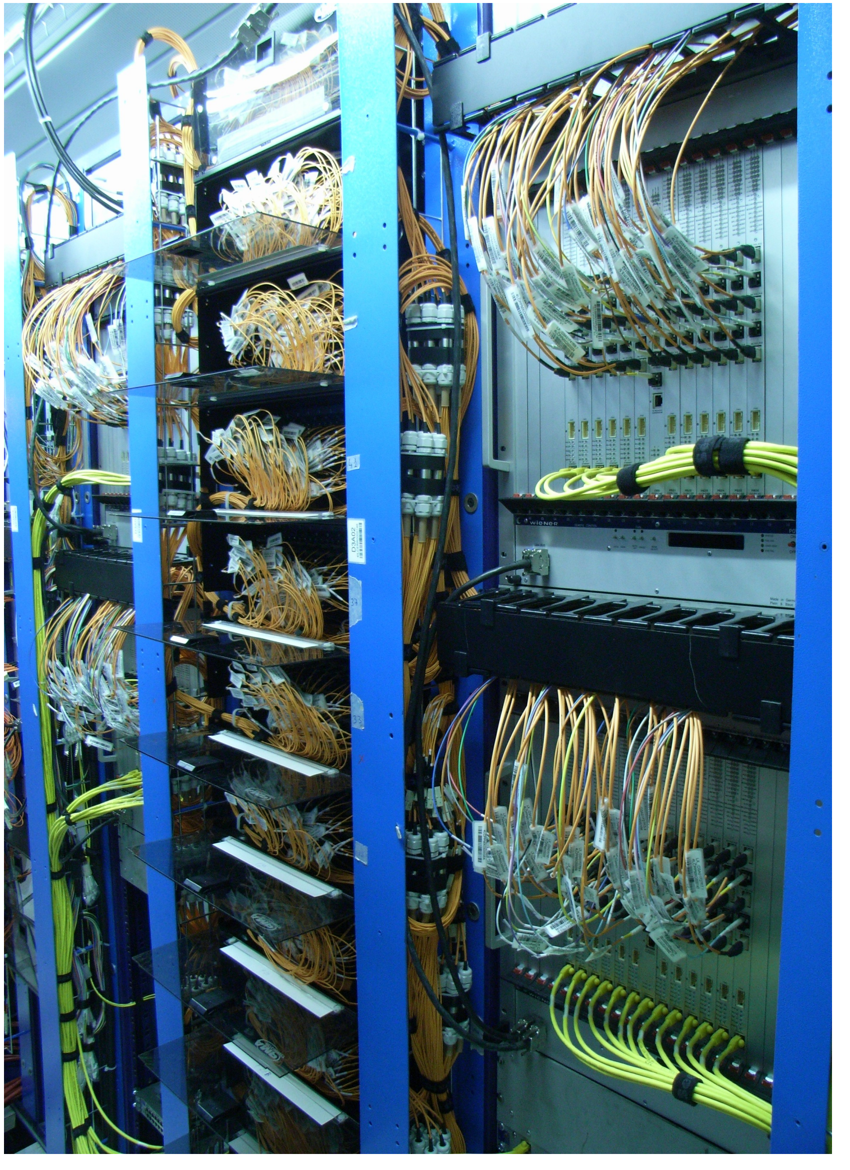
Synchronous, massively parallel and pipelined selection done in large FPGA processing units.

Latency 1.2μs

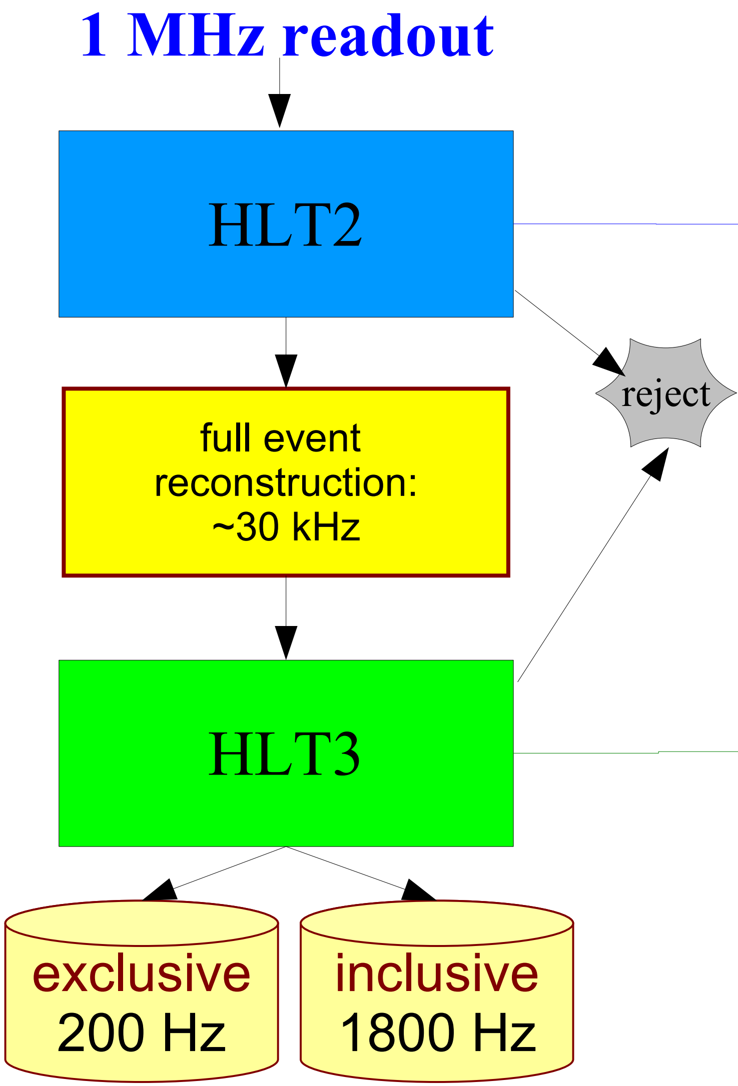
Input via 1248 optical fibers@1.6Gbs

52 processing boards





HLT (high level trigger) selection



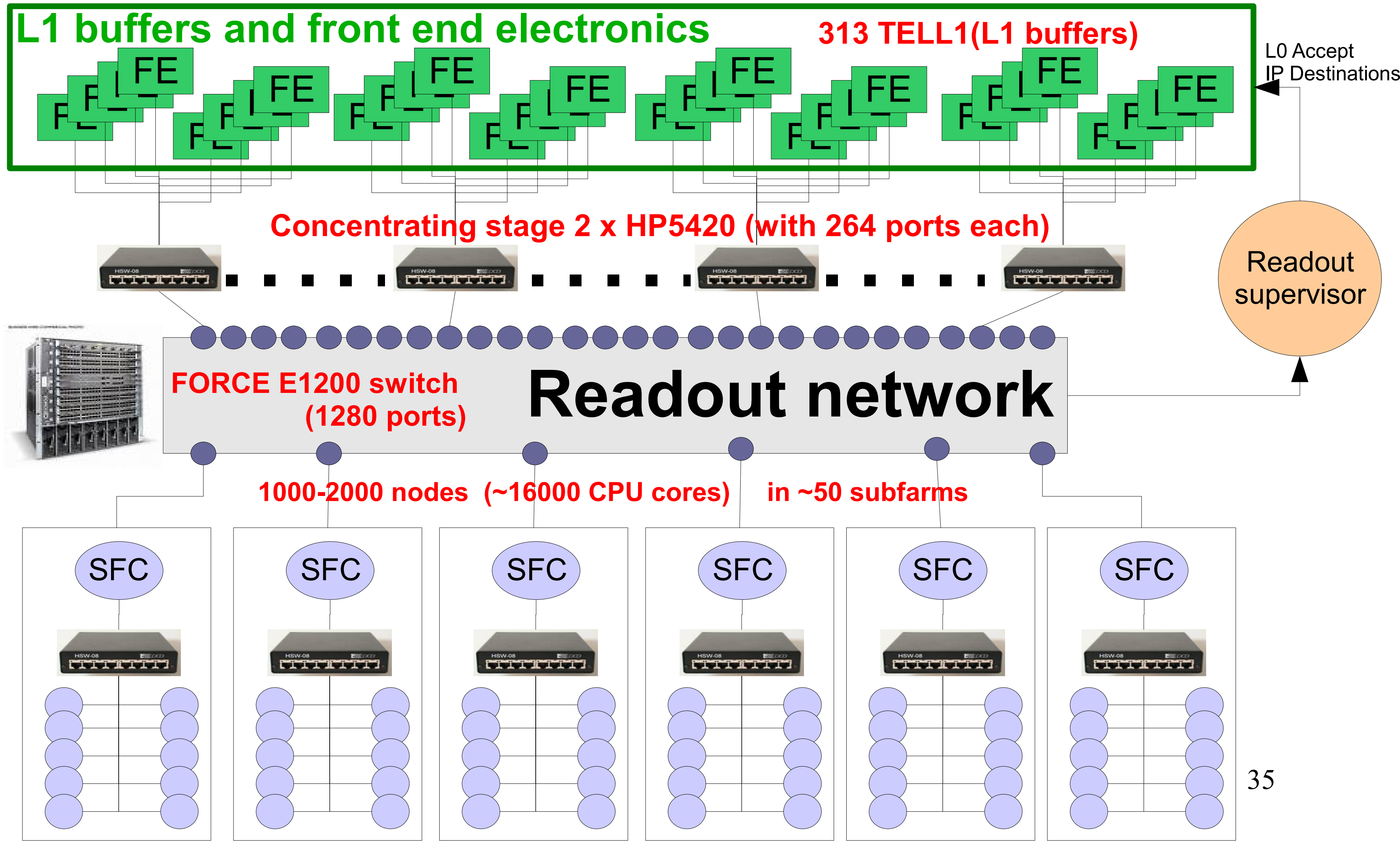
– **HLT first step (L2 selection):**
  - confirms L0 decision using tracking system
  - does reconstruction in region of interest
  - triggers on simple signatures (pt, IP, ..)

    → increase fraction of bbar

– **HLT second level (L3 selection):**
  - **exclusive signal selections**
    – full B analysis (relaxed offline cuts)
  - **inclusive streams**
    – trigger on clear signatures
    – gives unbiased B sample

    → selection of interesting B-decays

LHCb: DAQ overview



Conclusions

Trigger and DAQ system of large experiments are very complex because of:

- the high number of data that must be dramatically reduced to be stored and processed
- the high data flow that must be analysed and selected online
- the great number of channels that must be merged and kept synchronised
- the technology limits that implies a lot of components to share the work in parallel

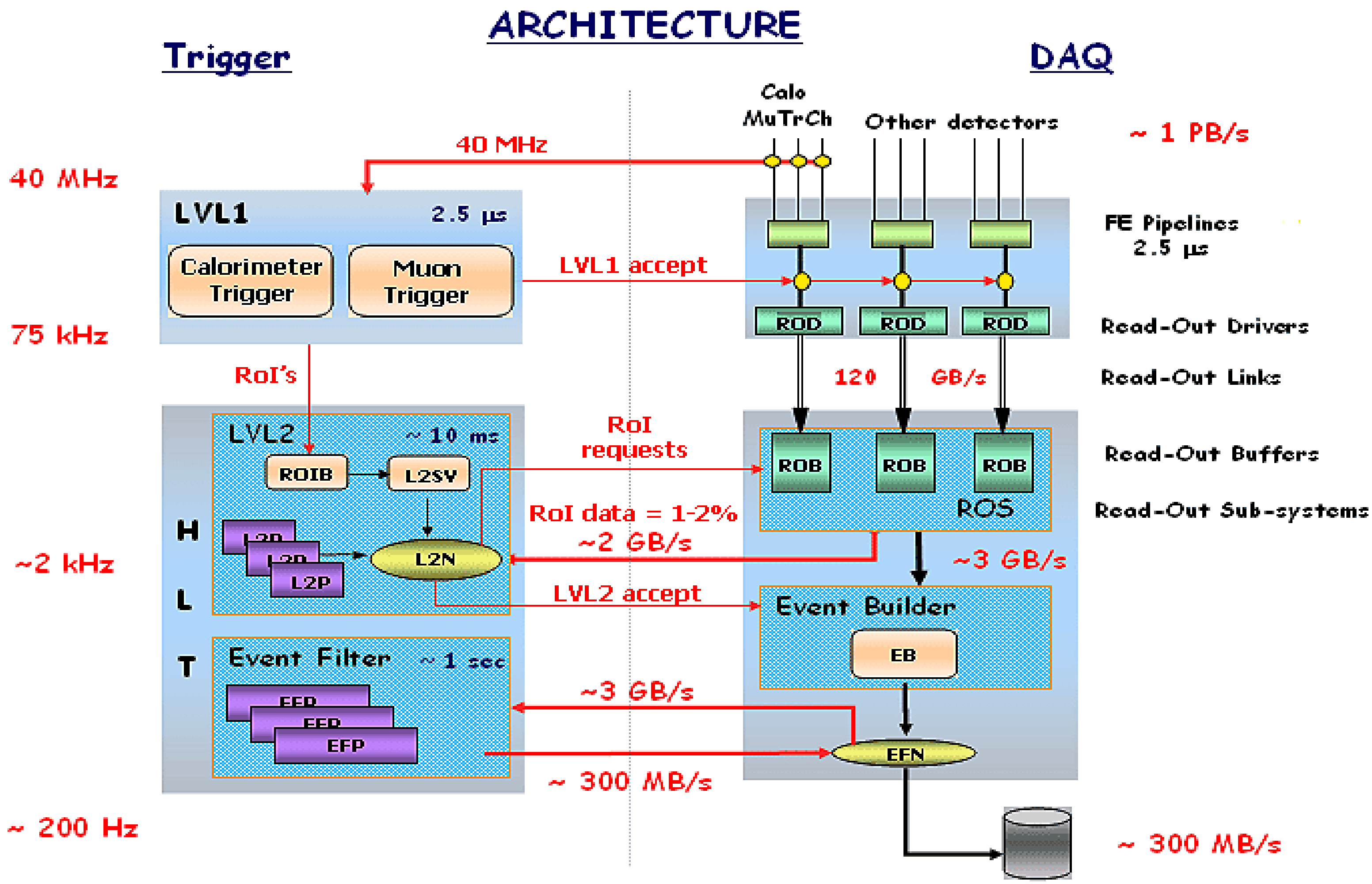
With the technological progress in electronics they are becoming simpler, cheaper and easier to implement and maintain due to the wide availability of standardised, high performance components on the market:

- Powerful PCs and widespread OS
- High bandwidth communication systems and standards (IP and ETHERNET)
- FPGA (reprogrammable hardware blocks)

The need for intermediate triggering by dedicated components between the front end and a versatile trigger farm is decreasing with time.

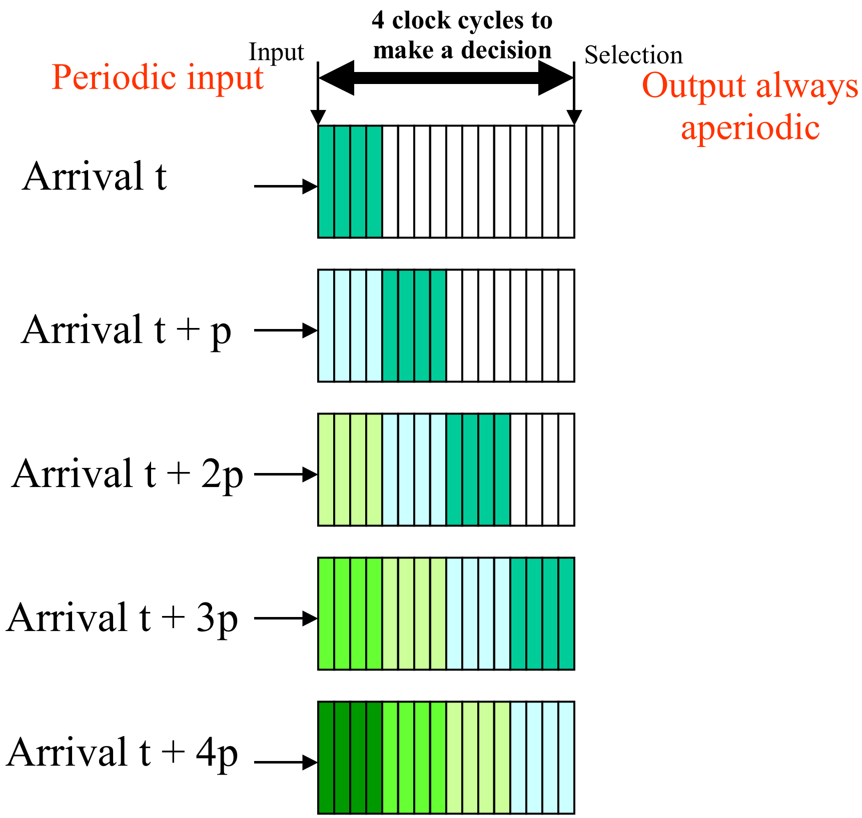
ATLAS: Trigger DAQ overview

Need to reduce the flow in the event building: only transfer useful data from ROI at L2



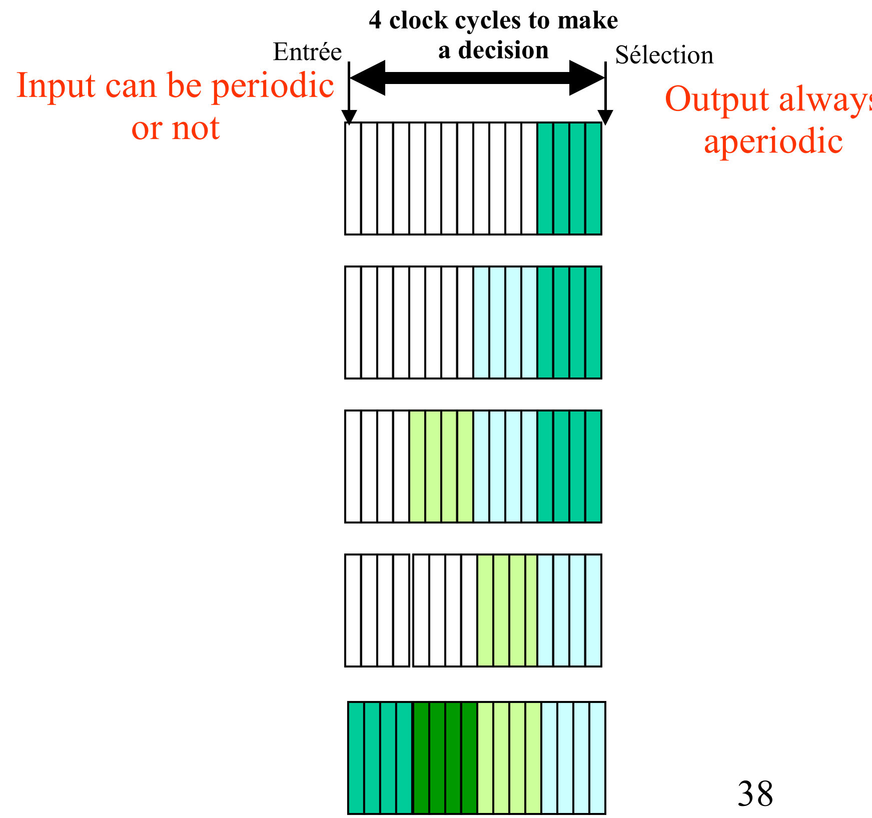
Trigger

Synchronous buffer



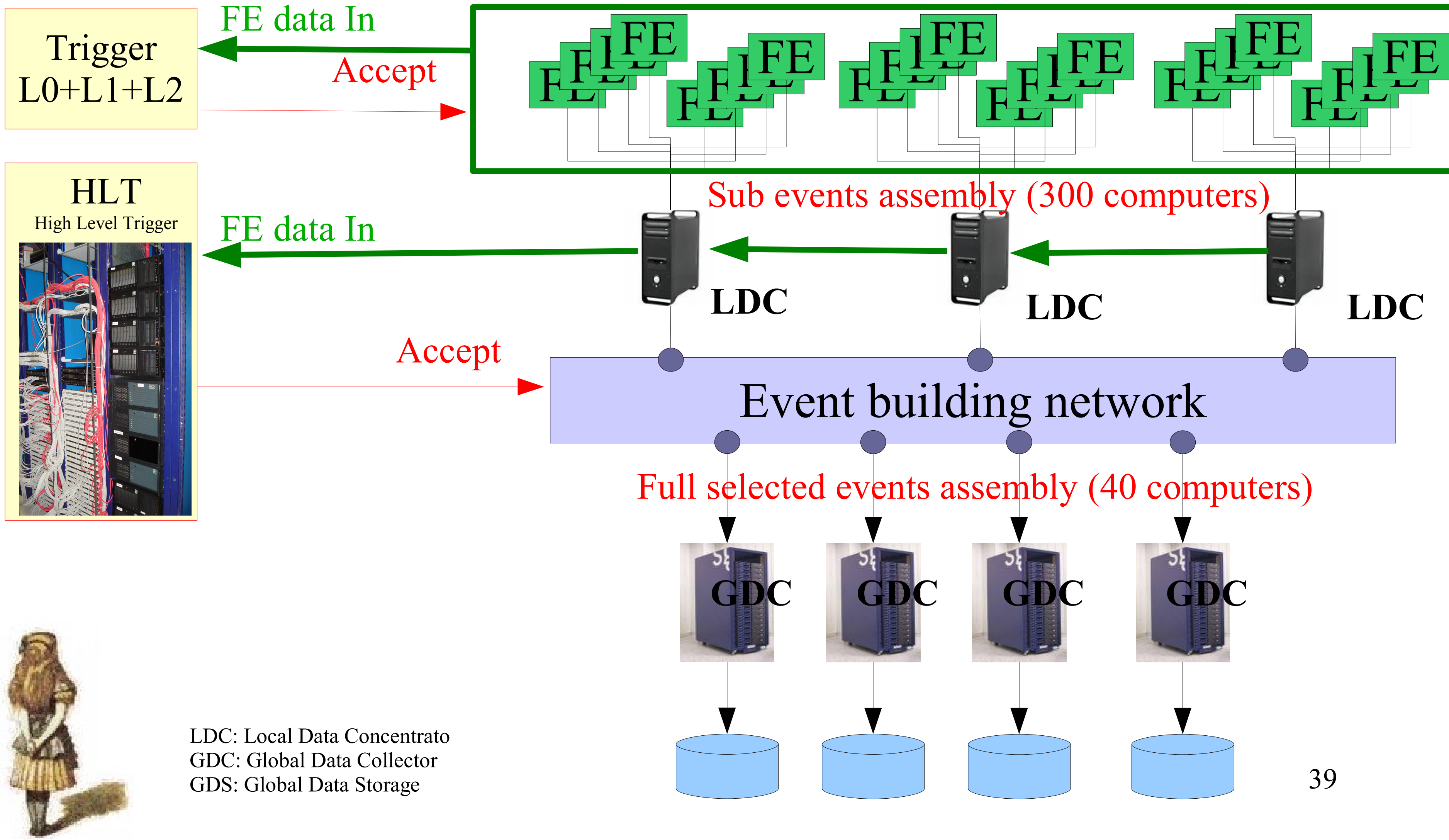
No data loss can be caused by the buffer

Asynchronous buffer

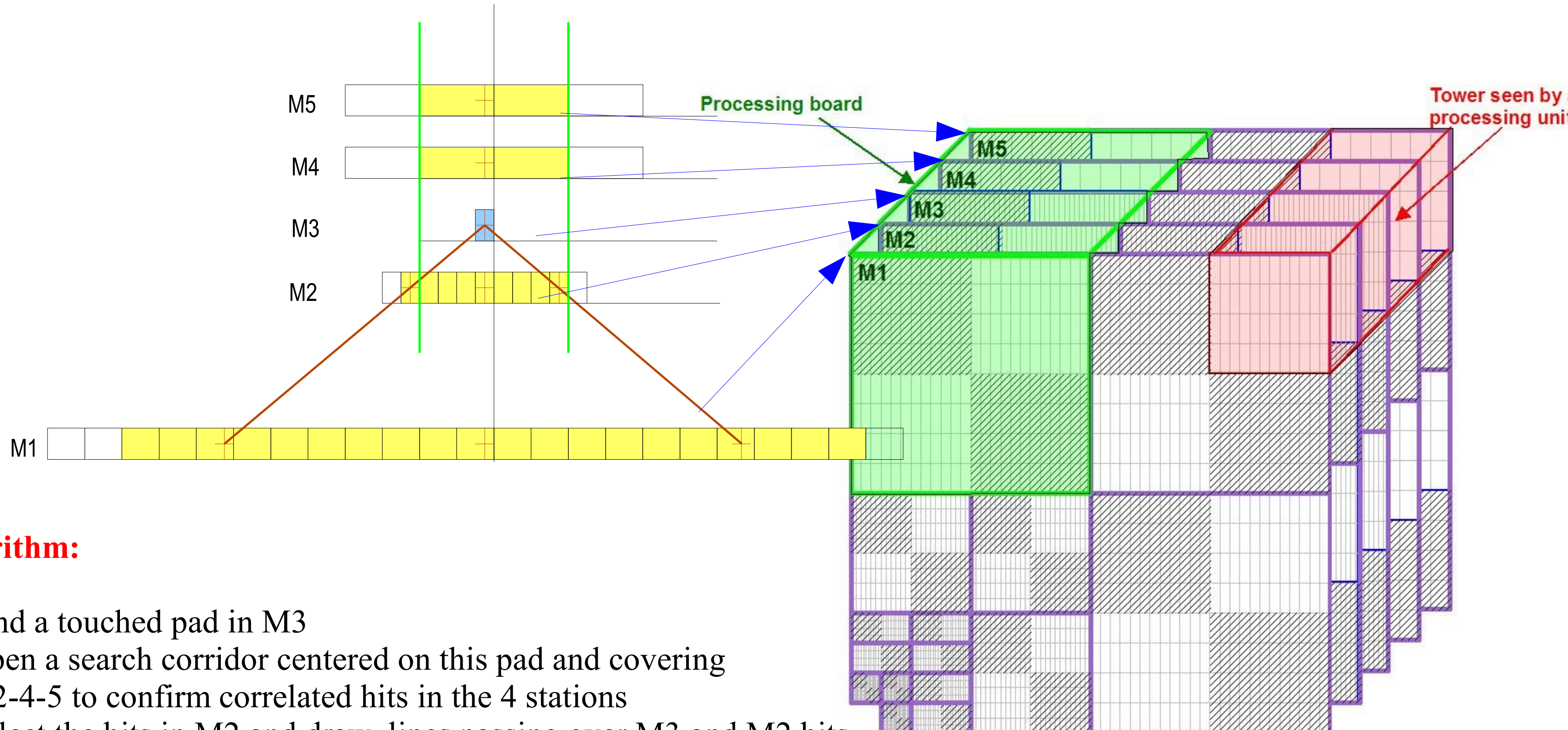


Buffer full => data loss

ALICE: Trigger DAQ overview



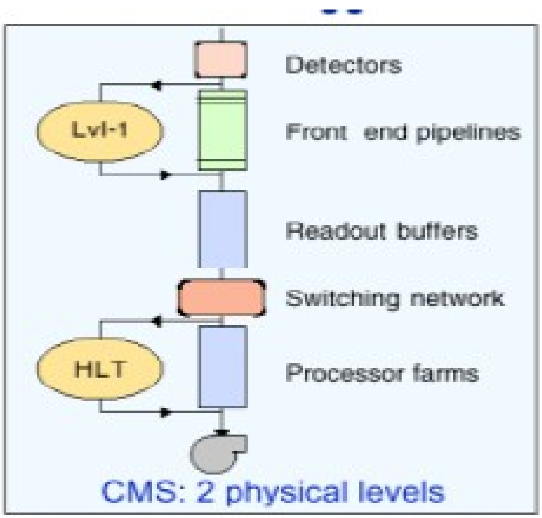
L0 muons trigger selection

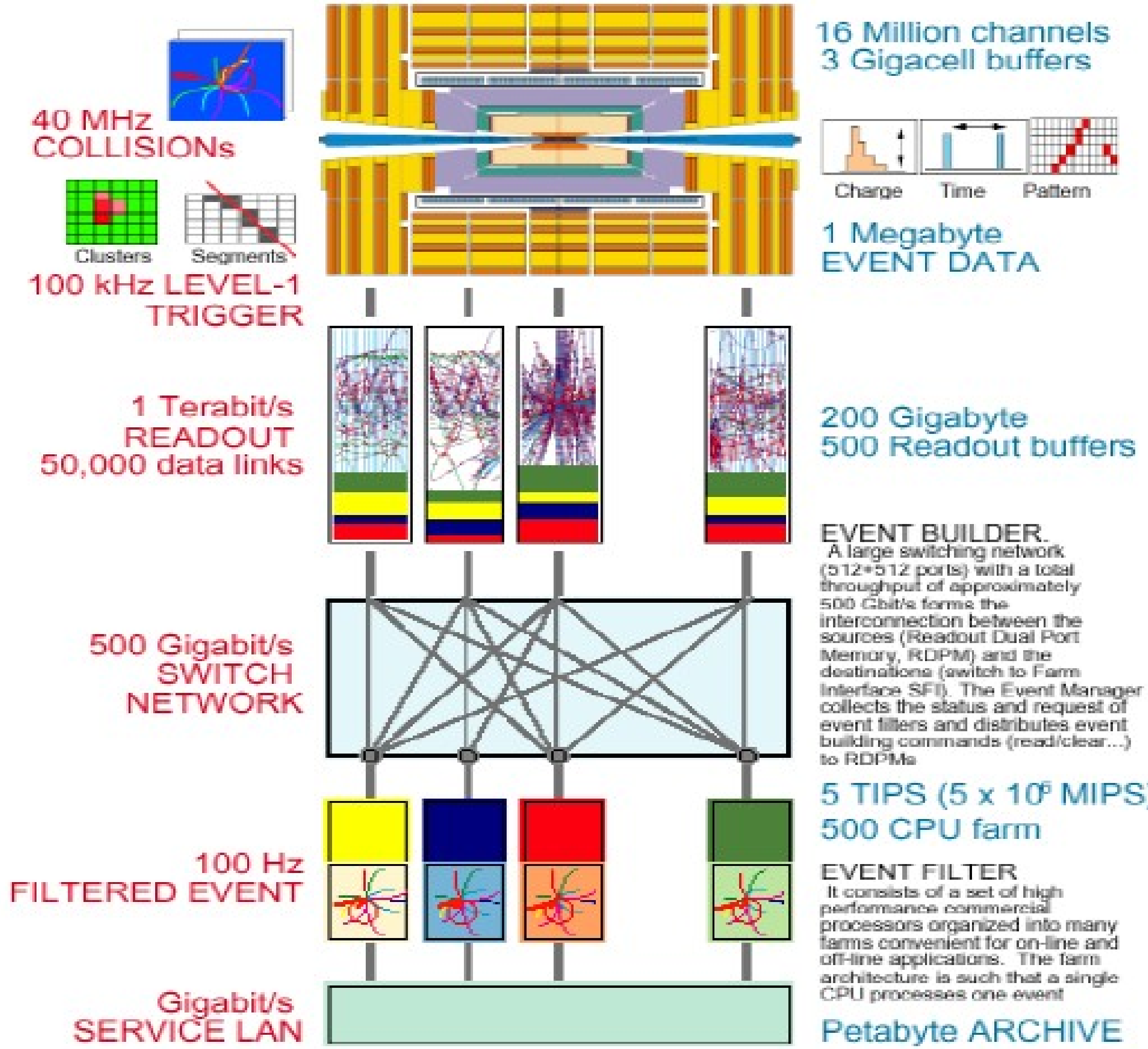


algorithm:

1- Find a touched pad in M3
2- Open a search corridor centered on this pad and covering M2-4-5 to confirm correlated hits in the 4 stations
3- Select the hits in M2 and draw lines passing over M3 and M2 hits
4- Project those lines to M1 and search hits in M1 close to those lines for a new confirmation
5- Pt are given by the angle of the lines passing by M3 and M1 and the beam axis.

CMS: Trigger DAQ overview



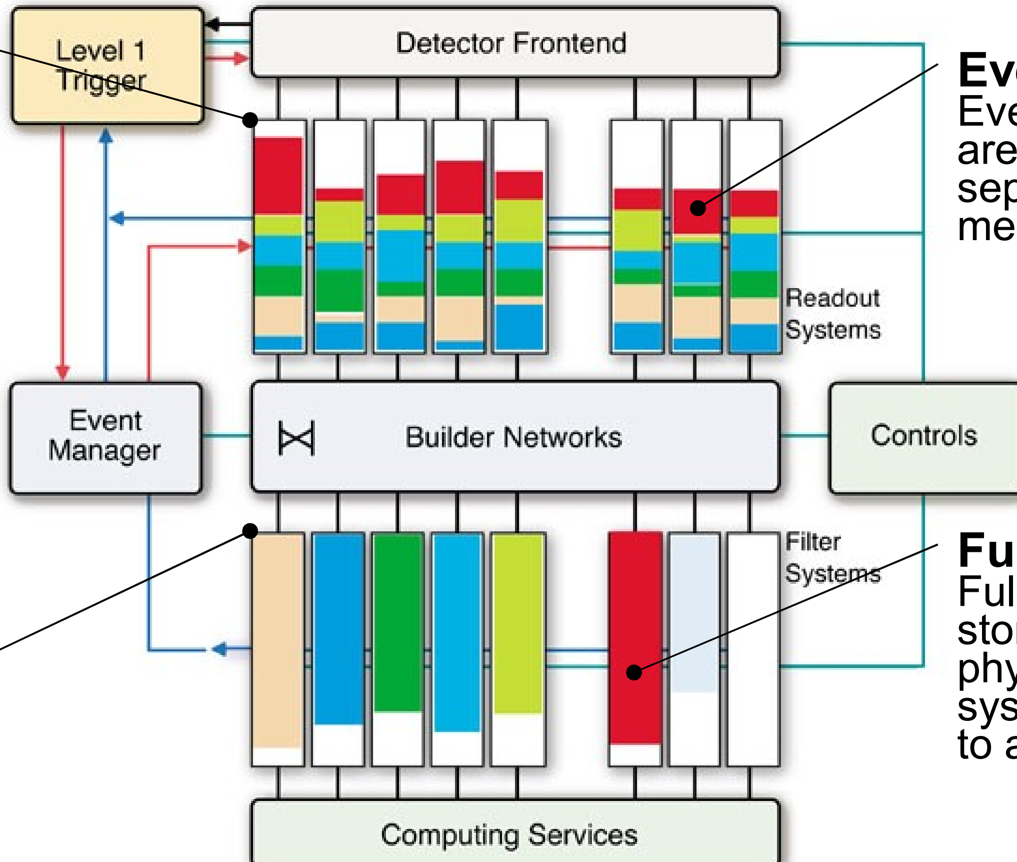


Distributed Event Builder

Readout Units
Buffer event fragments

Event Manager
Interfaces between RU, BU and trigger

Builder Units
Assemble event fragments



Event fragments:
Event data fragments are stored in separated physical memory systems

Full events:
Full event data are stored in a single physical memory system associated to a processing unit

Requirements:
L1 trigger: 100 kHz (@2KB), ev-size 1MB,
200 MB/s in AND out per RU, 200 MB/s in AND 66 MB/s out per BU

Event fragments:
Event data fragments are stored in separated physical memory systems

Readout Units
Buffer event fragments

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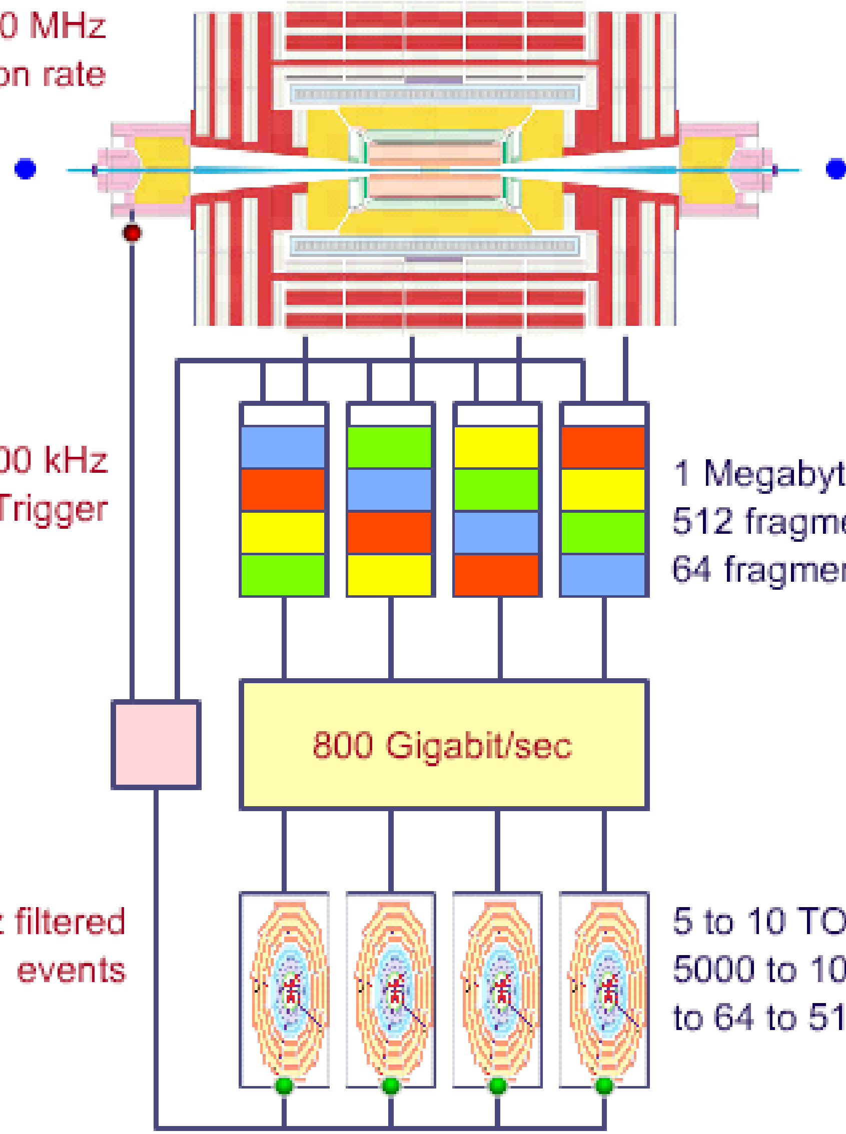
Assemble event fragments



Distribution des signaux et horloges

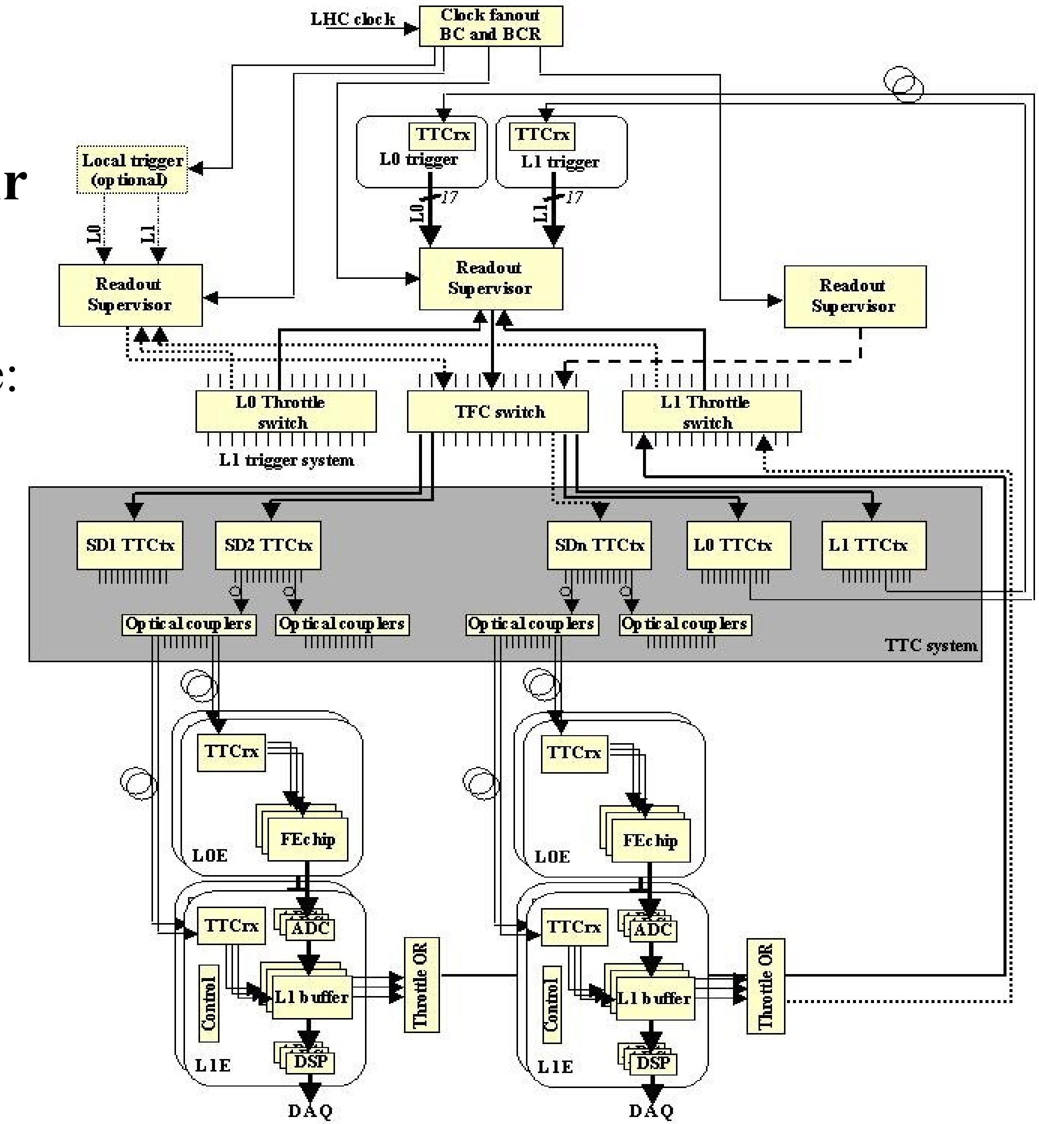
Utilisation du système TTC pour les expériences LHC

Réseau de diffusion sur fibre optique:

- horloge
- message diffusés
    - no évènement, bunch
    - reset compteurs
    - etc ...
- messages adressés

3 composants:

- TTCtx
- TTCRx (ASIC)
- Etoiles optiques de diffusion



Specifications topics summary

Input channels number
Input flow volume and speed
Input law (periodic, non periodic (arrival law))
Accepted loss rate (dead time)
Processing complexity (statistic, stability)
Planned evolution and upgrade possibilities (scalability)
Environment constraints (hostile or regular : radiations, space, under see …)
Exploitation constraints (continue, seasonal)
Constraints to use available or standardized components
Available budget
On-line and off-line storage capacity
Safety and reliability