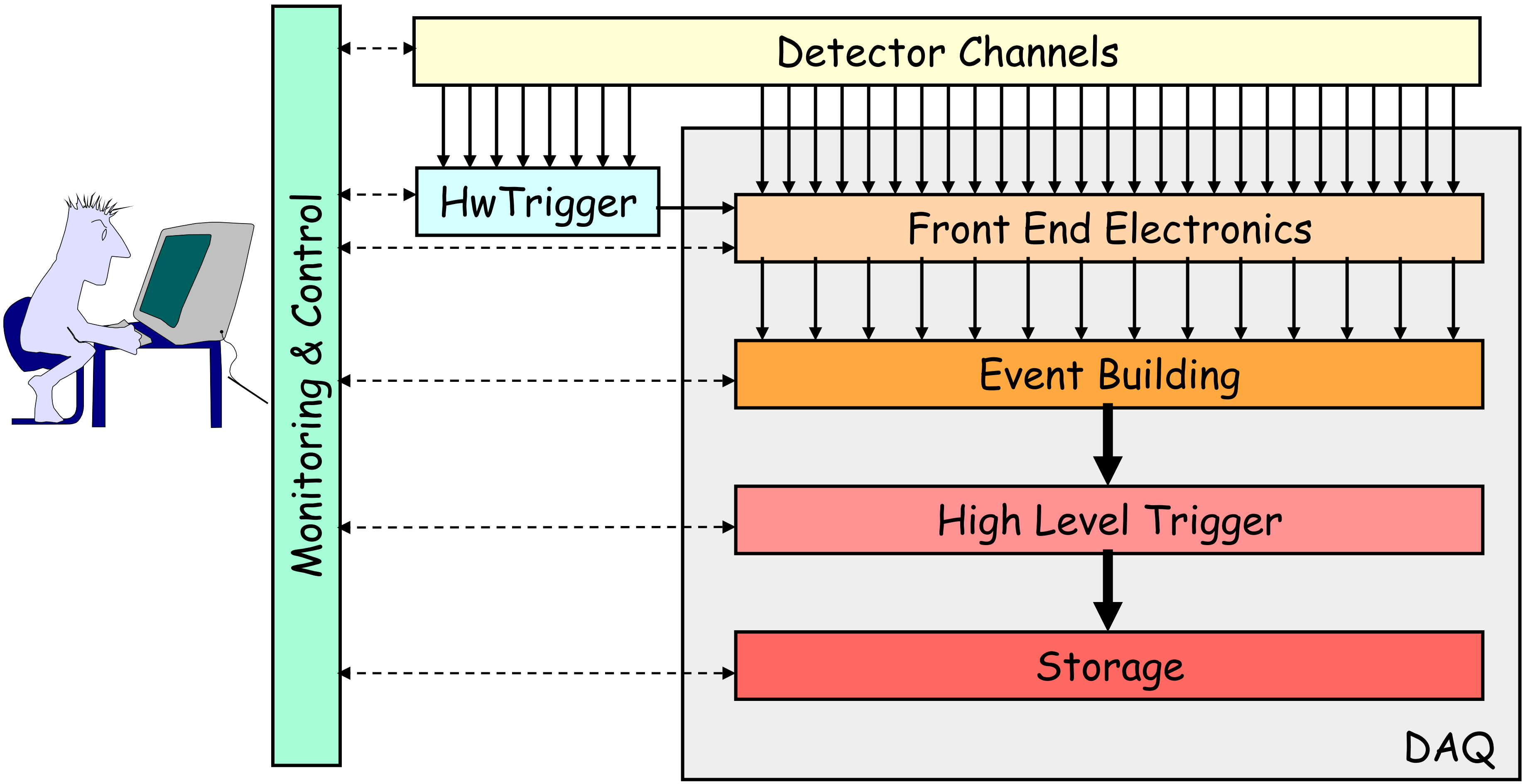
Data Acquisition, Trigger and Control

Clara Gaspar, August 2012

Definitions

- **Trigger System**
  - Selects in Real Time "interesting" events from the bulk of collisions. - Decides if YES or NO the event should be read out of the detector and stored
- **Data Acquisition System**
  - Gathers the data produced by the detector and stores it (for positive trigger decisions)
- **Control System**
  - Performs the overall Configuration, Control and Monitoring

Trigger, DAQ & Control



LEP & LHC in Numbers

	LEP (1989/2000)	LHC (2009)	Factor
Bunch Crossing Rate	45 KHz	40 MHz	x 10^3
Bunch Separation	22 µs	25 ns	x 10^3
Nr. Electronic Channels	≈ 100 000	≈ 10 000 000	x 10^2
Raw data rate	≈ 100 GB/s	≈ 1 000 TB/s	x 10^4
Data rate on Tape	≈ 1 MB/s	≈ 100 MB/s	x 10^2
Event size	≈ 100 KB	≈ 1 MB	x 10
Rate on Tape	10 Hz	100 Hz	x 10
Analysis	0.1 Hz (Z_0, W)	10^{-6} Hz (Higgs)	x 10^5

Basic Concepts

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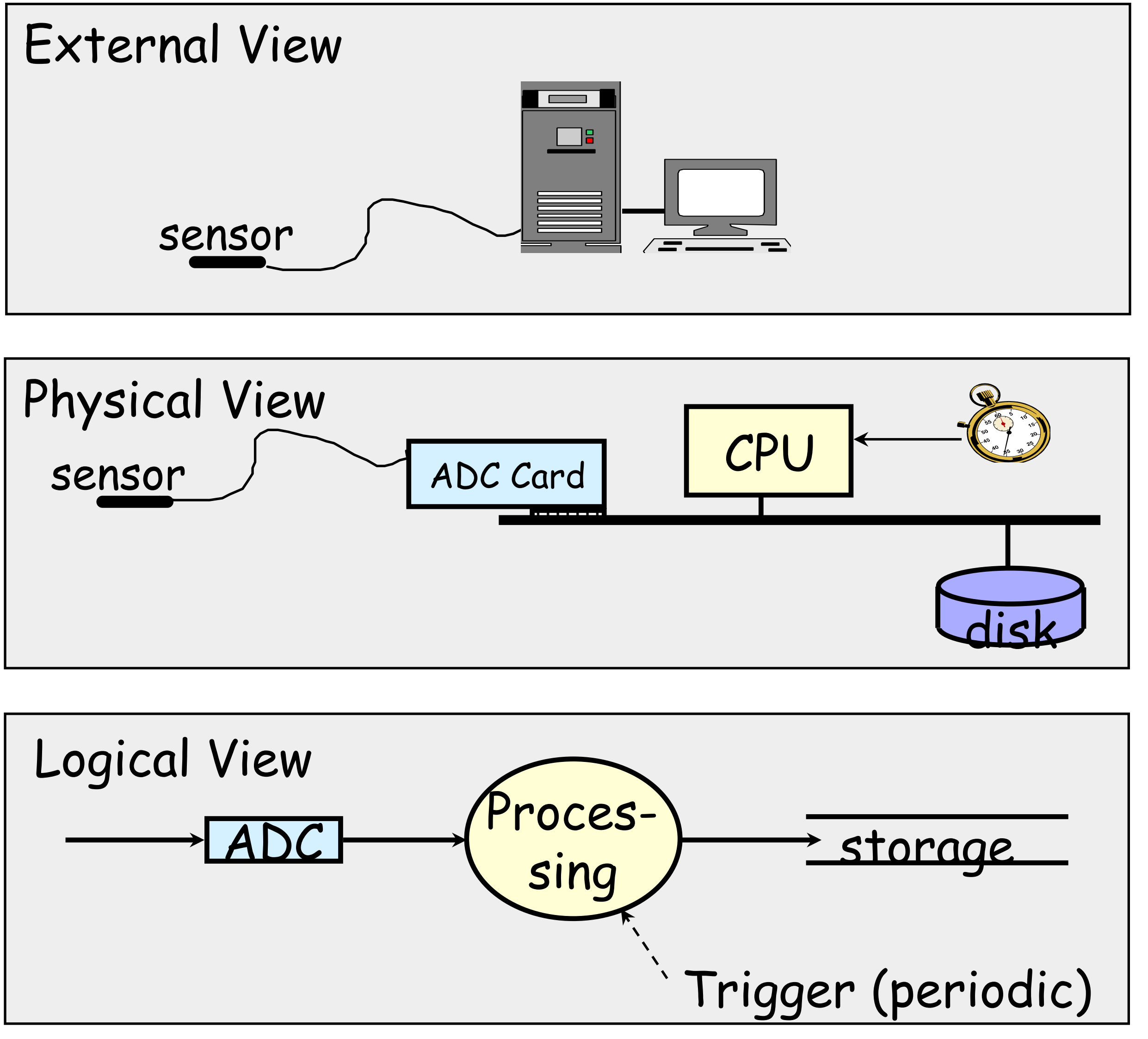
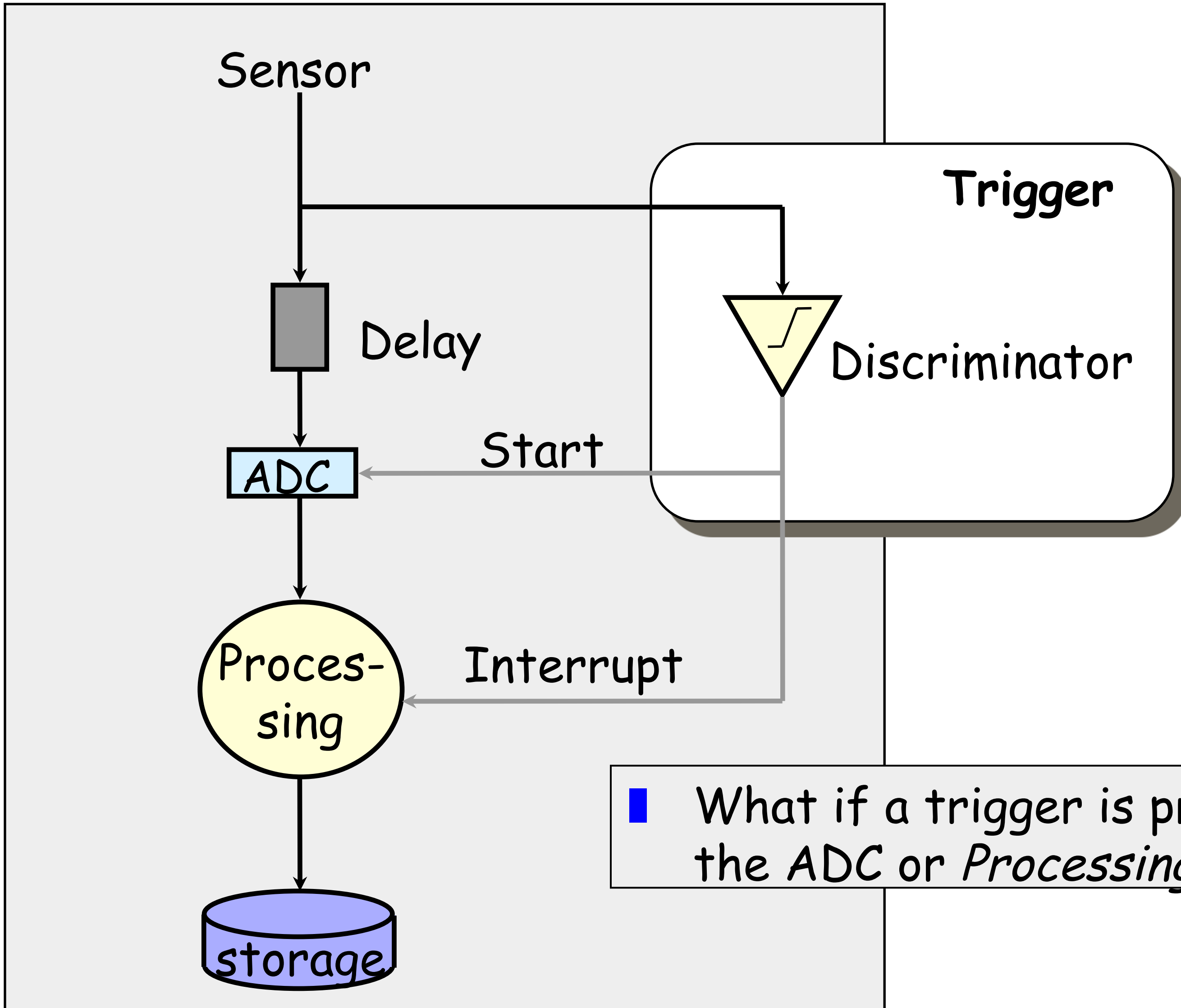
Trivial DAQ



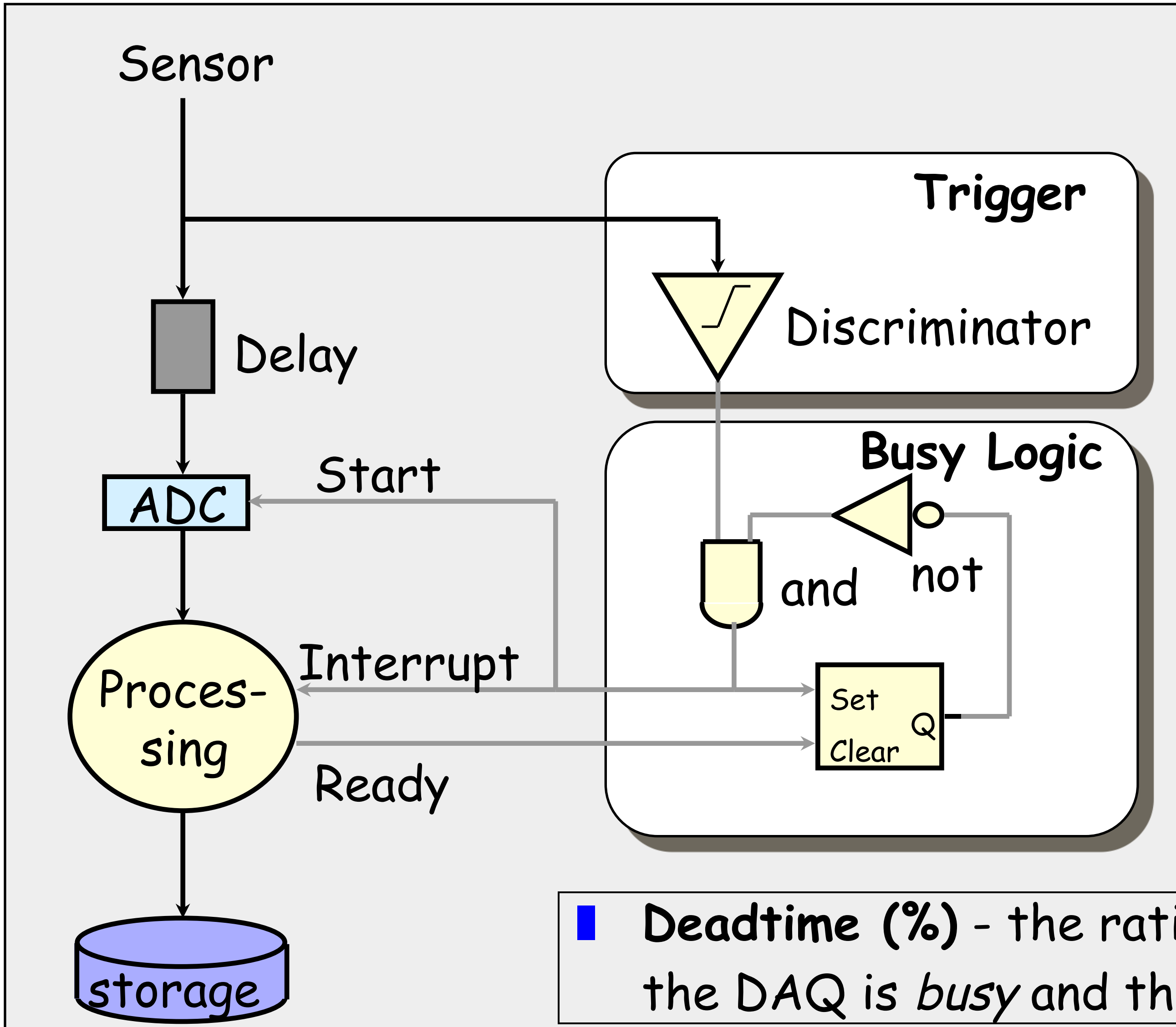
External View
sensor
Physical View
sensor
ADC Card
CPU
disk
Logical View
ADC
Proces-
sing
storage
Trigger (periodic)

Trivial DAQ with a real trigger



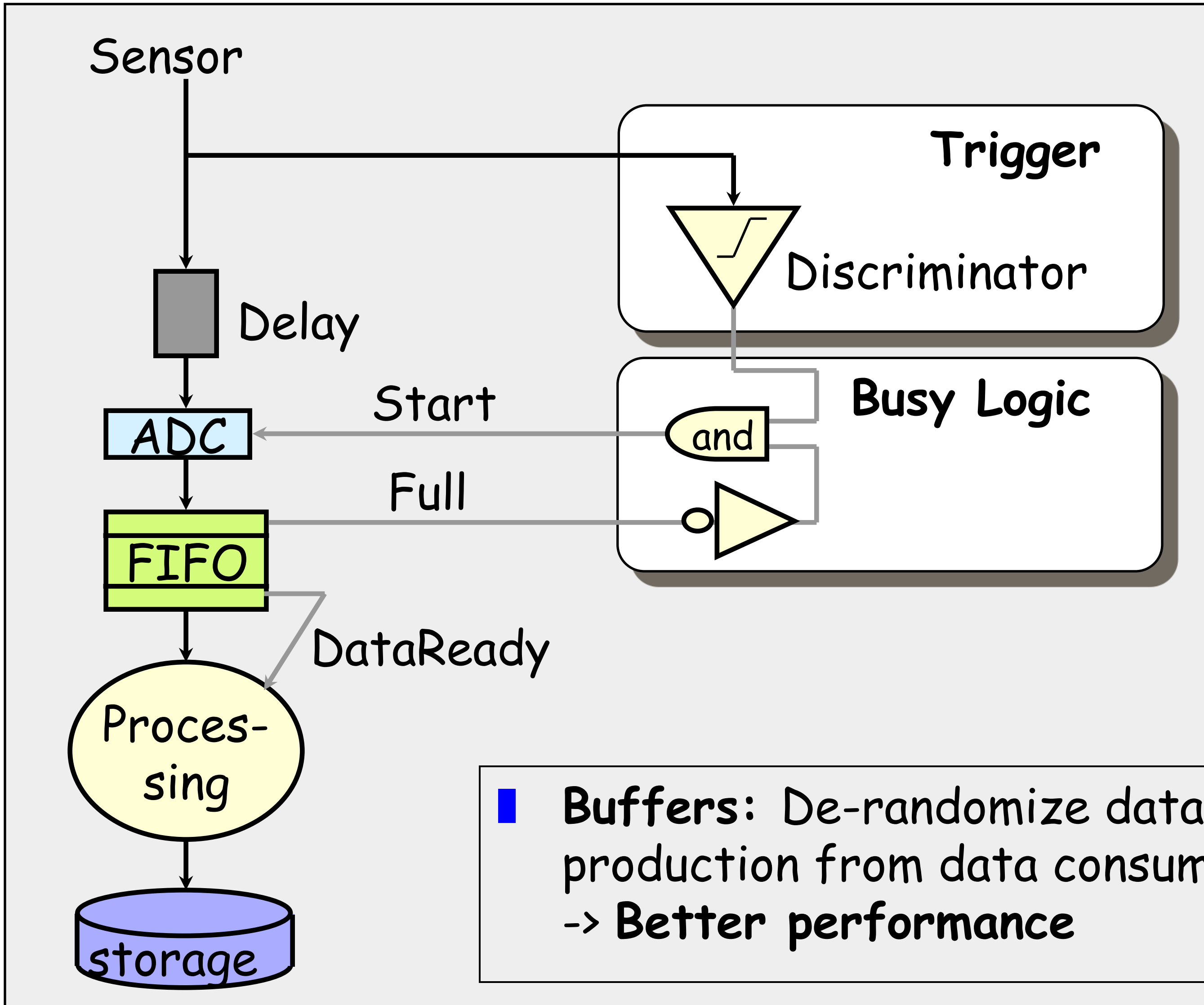
- What if a trigger is produced when the ADC or *Processing* is busy ?

Trivial DAQ with a real trigger (2)



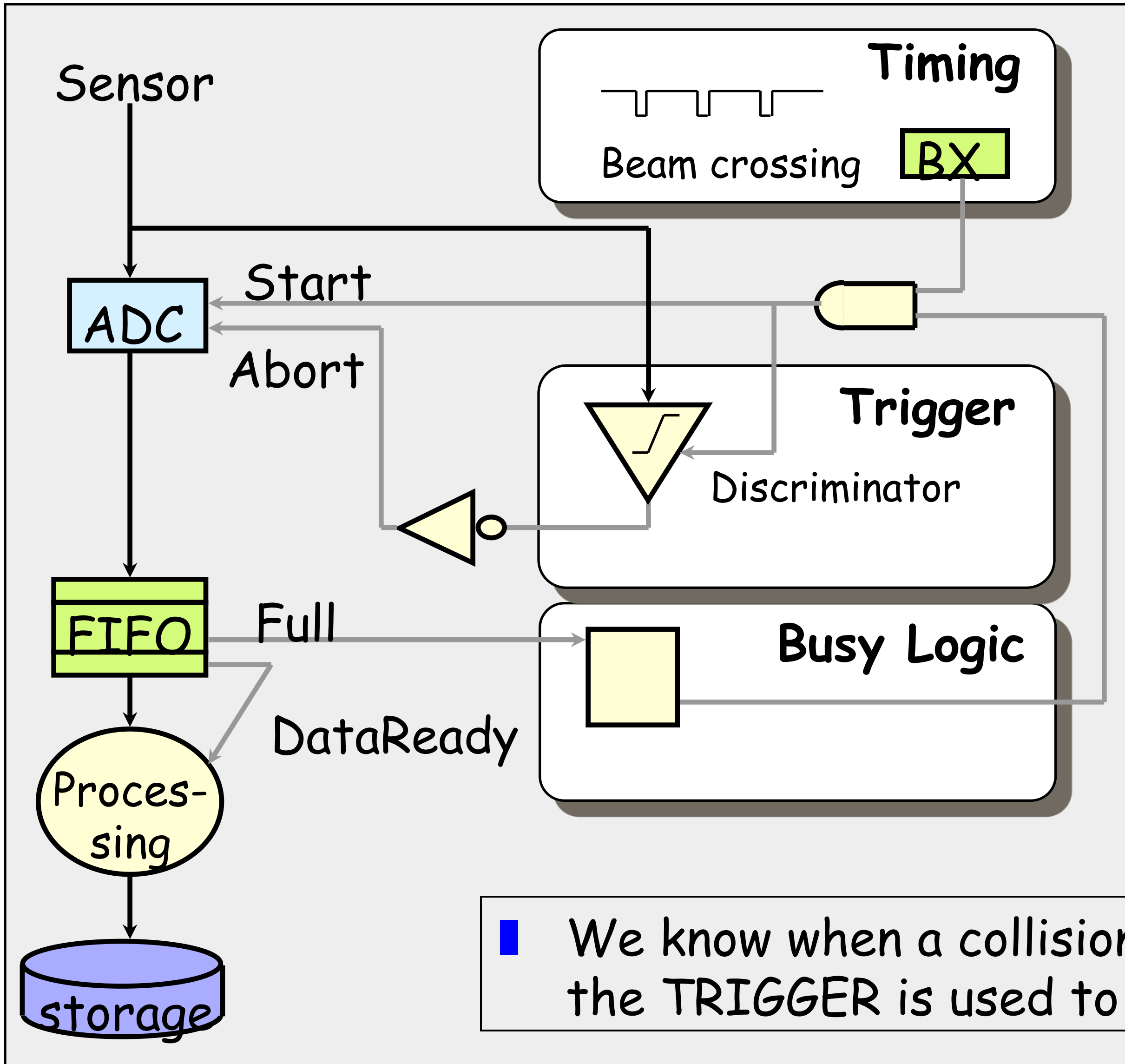
- **Deadtime (%)** - the ratio between the time the DAQ is *busy* and the total time

Trivial DAQ with a real trigger (3)



- **Buffers:** De-randomize data -> decouple data production from data consumption
  -> **Better performance**

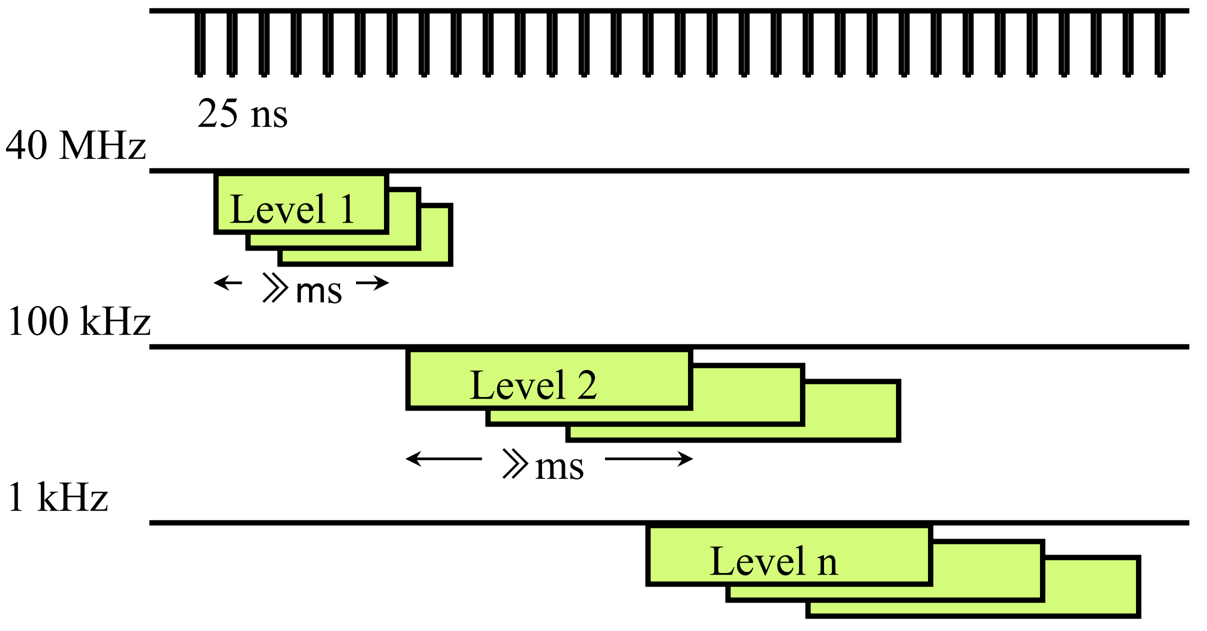
Trivial DAQ in collider mode



- We know when a collision happens
  the TRIGGER is used to "reject" the data

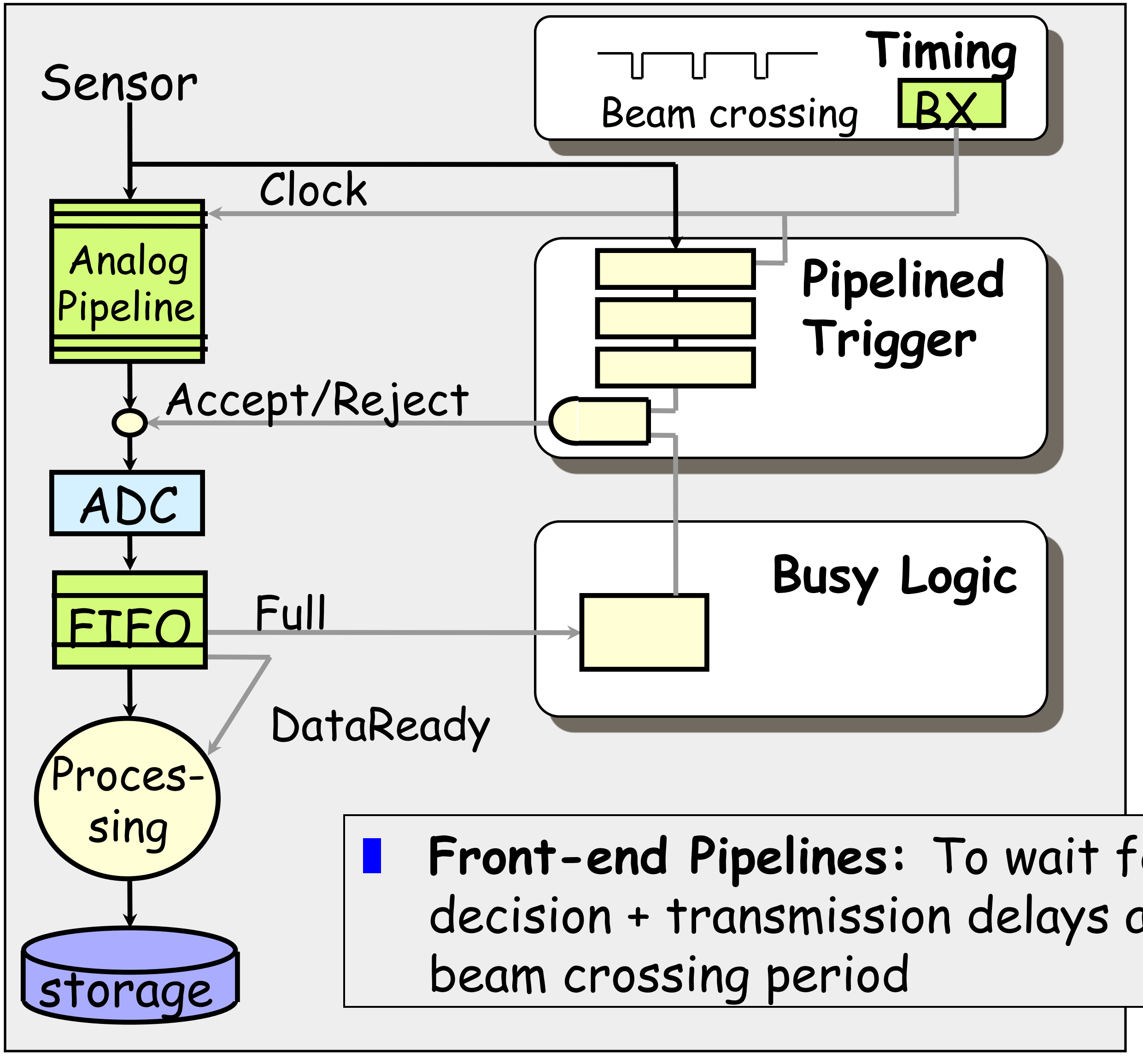
LHC timing

p p crossing rate 40 MHz (L=10^{33}- 4×10^{34}cm^{-2} s^{-1})



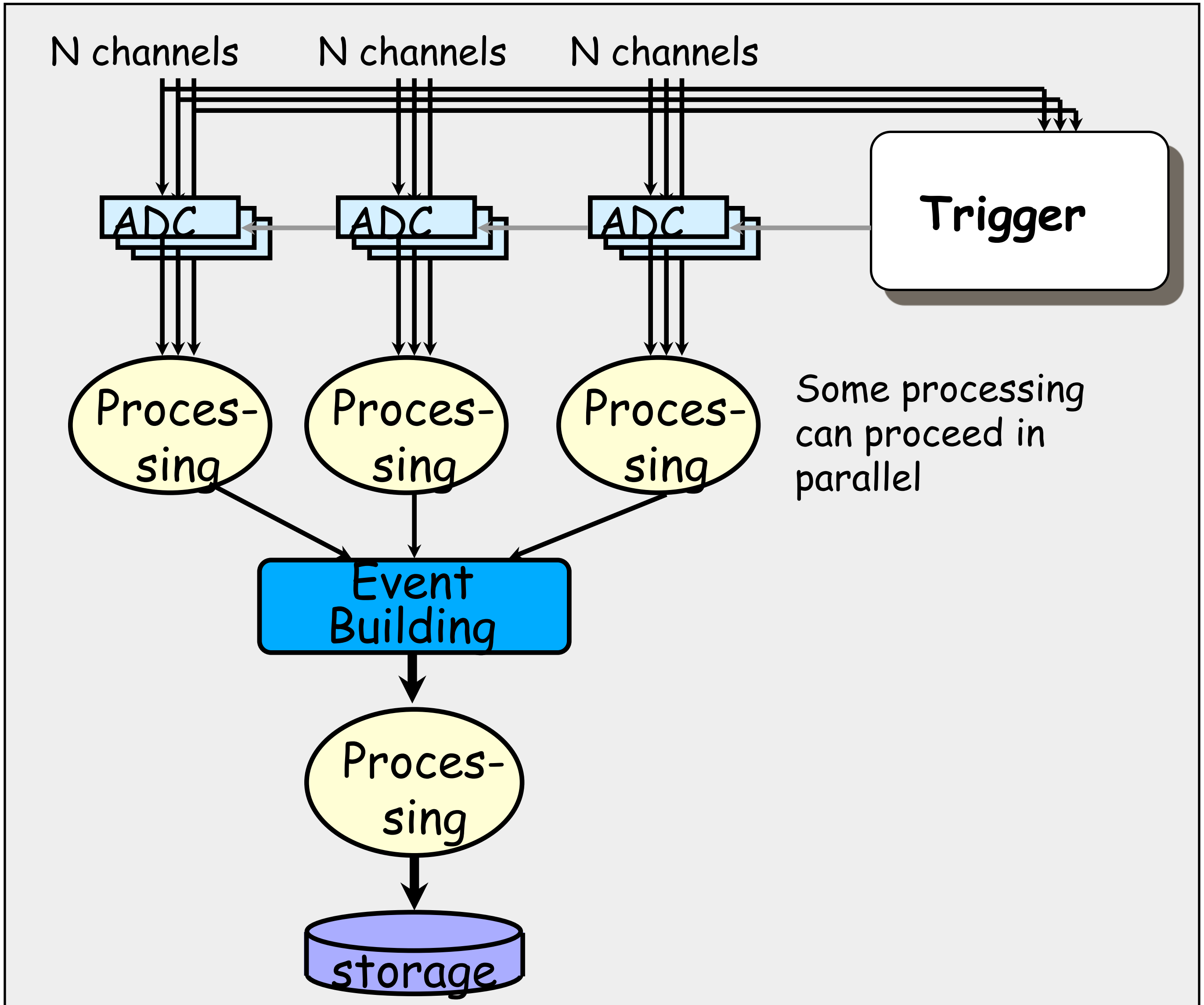
- Level 1 trigger time exceeds bunch interval
- Event overlap & signal pileup (multiple crossings since the detector cell memory greater than 25 ns)
- Very high number of channels

Trivial DAQ in LHC

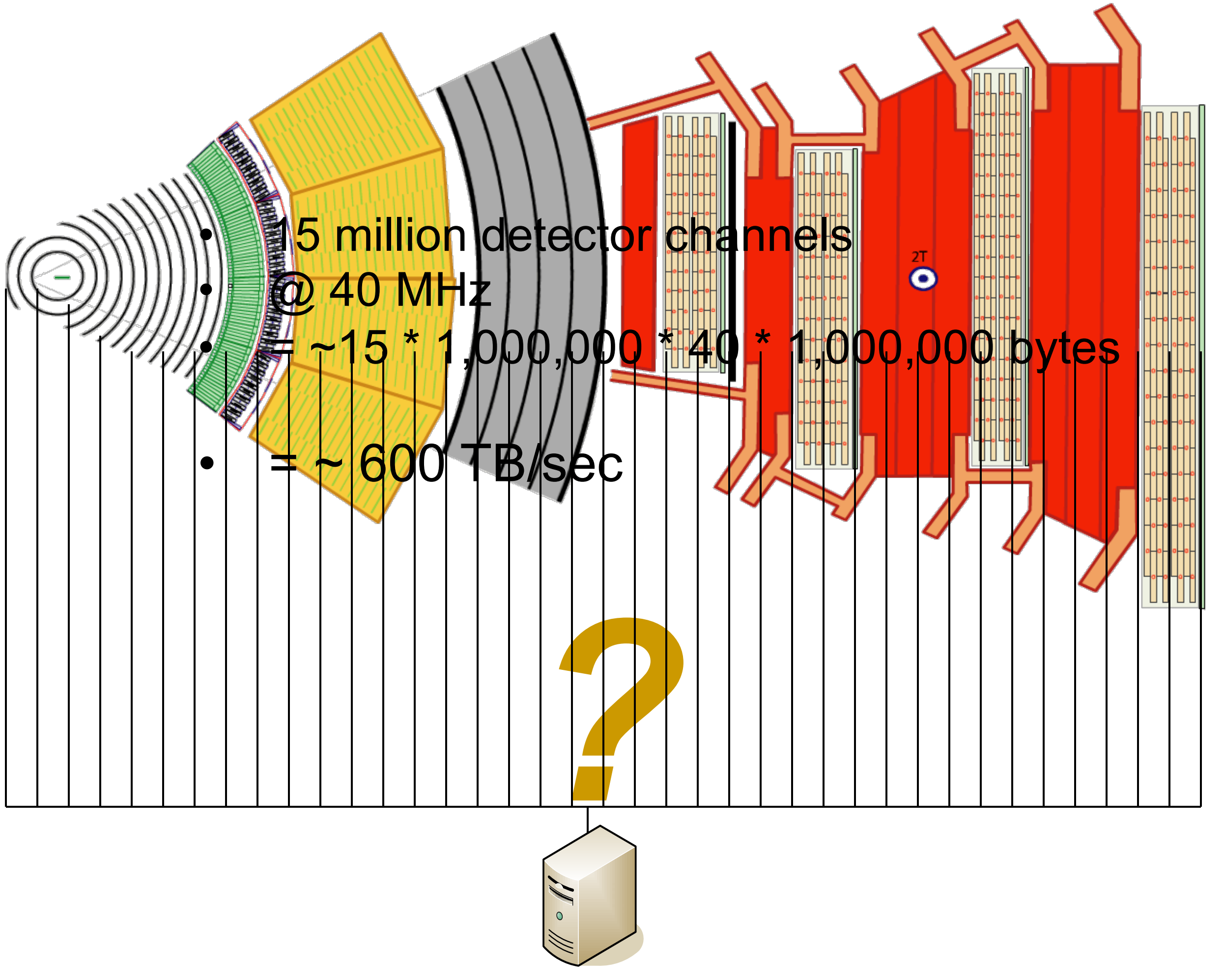


- **Front-end Pipelines:** To wait for the trigger decision + transmission delays are longer than beam crossing period

Less trivial DAQ



The Real Thing



- 15 million detector channels
- @ 40 MHz
- = ~15 * 1,000,000 * 40 * 1,000,000 bytes

- = ~ 600 TB/sec

Trigger

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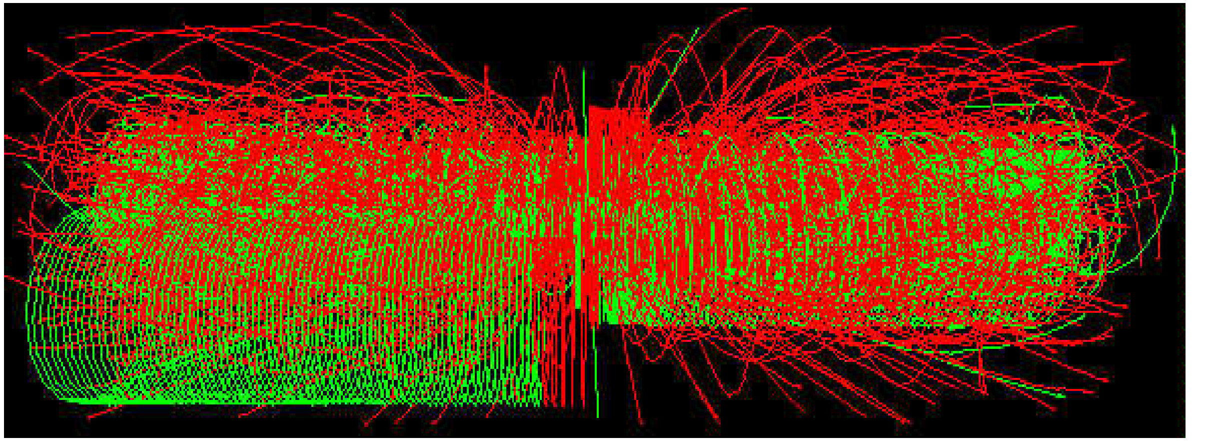
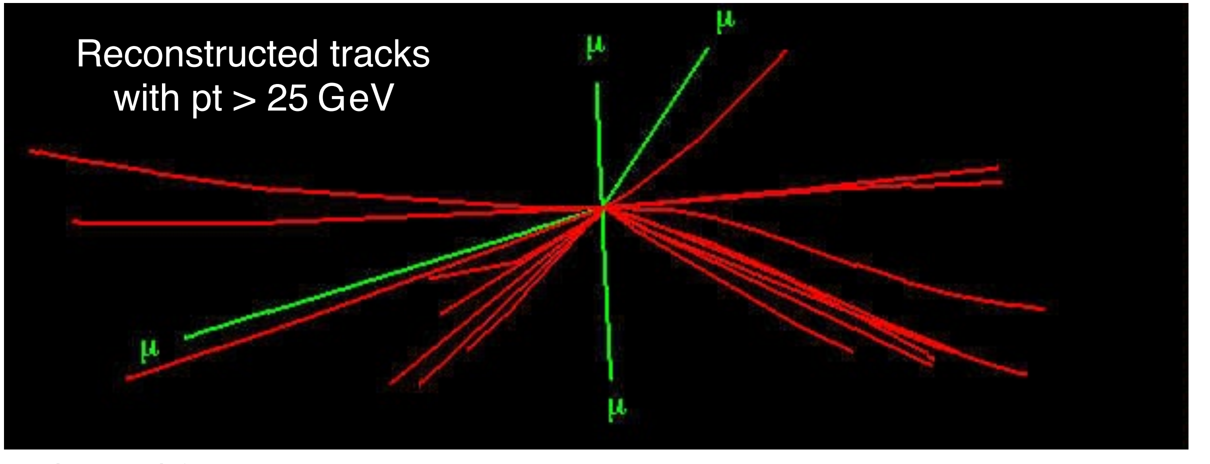
Trigger System

- **The Trigger system** detects whether an event is interesting or not
  - Typical ATLAS and CMS* event
  - 20 collisions may overlap
  - This repeats every 25 ns



  - A Higgs event



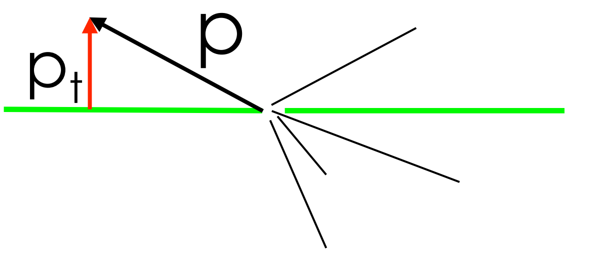
*) LHCb isn't much nicer and in Alice (PbPb) it can be even worse

Trigger Levels

- Since the detector data is not promptly available and the trigger function is highly complex, it is evaluated by successive approximations:
  - Hardware trigger(s):
    - *Fast* trigger, uses data only from few detectors
    - has a limited time budget
    - ➡ Level 1, Sometimes Level 2
  - Software trigger(s):
    - Refines the decisions of the hardware trigger by using more detailed data and more complex algorithms.
    - It is usually implemented using processors running a program.
    - ➡ High Level Triggers (HLT)

Hardware Trigger

- Luckily pp collisions produce mainly particles with transverse momentum "p_t" ~1 GeV

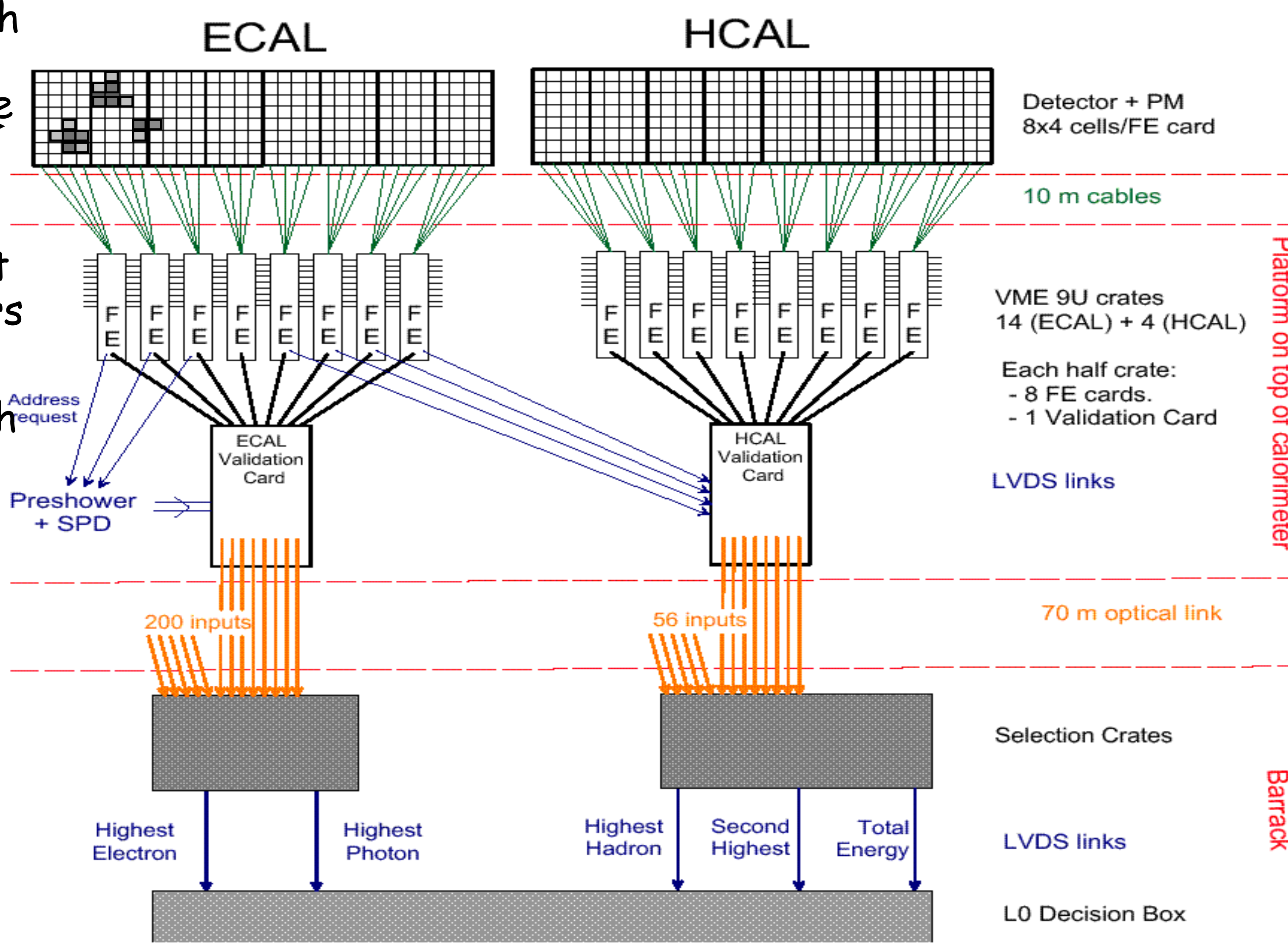


- Interesting physics (old and new) has particles with large p_t

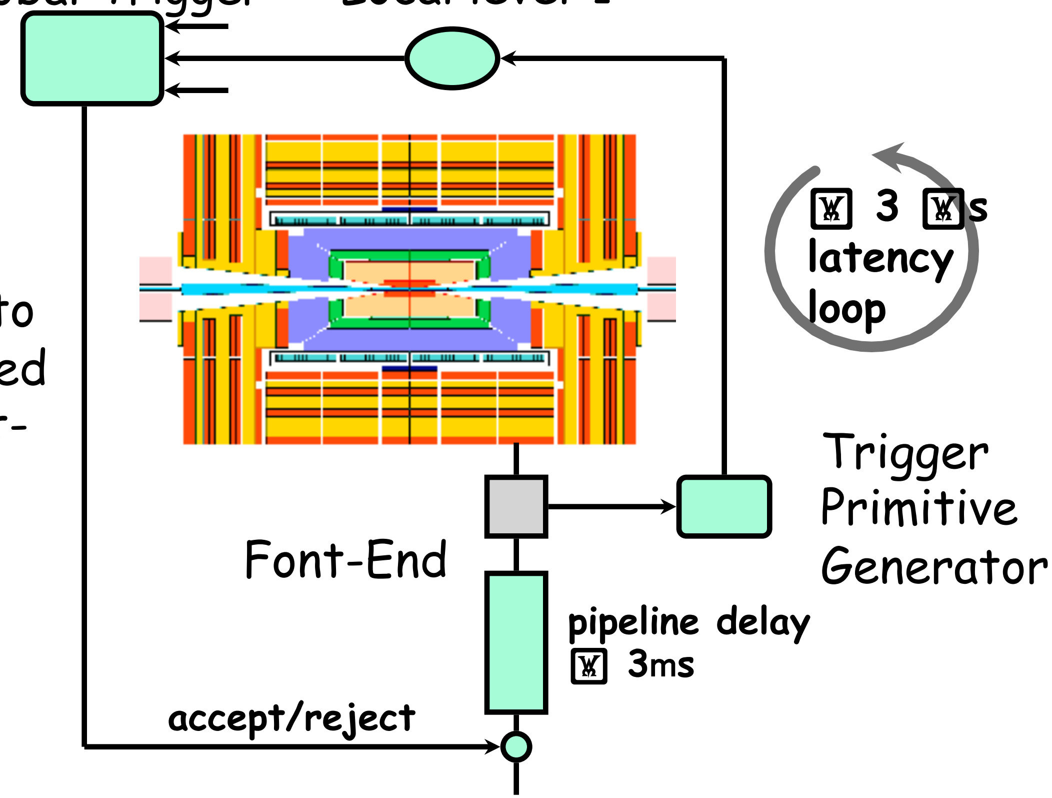
- **Conclusion: in the first trigger level we need to detect high transverse momentum particles**

Example: LHCb Calorimeter Trigger

- Detect a high energy in a small surface
- Don't forget the neighbors
- Compare with threshold



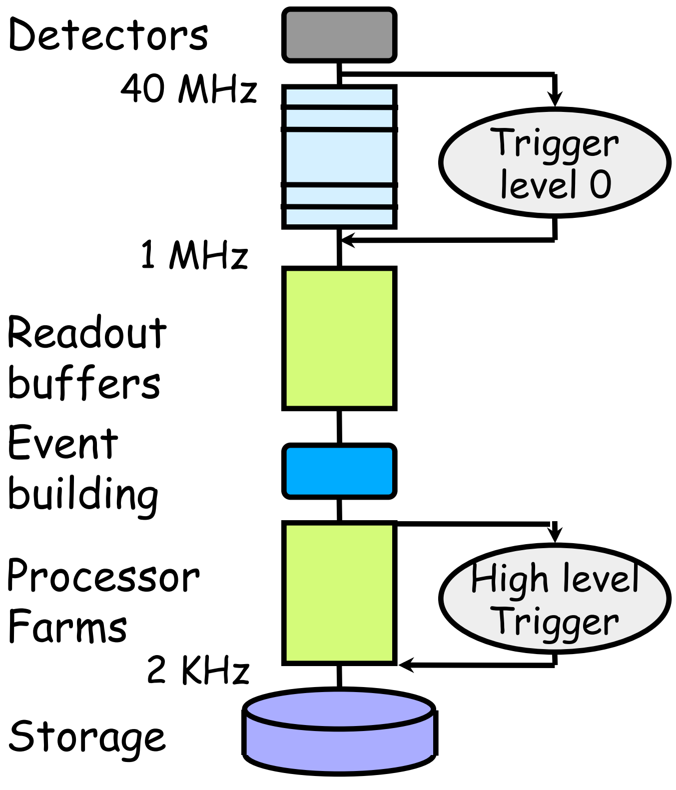
LHC: Trigger communication loop



Timing and trigger has to be distributed to ALL front-ends

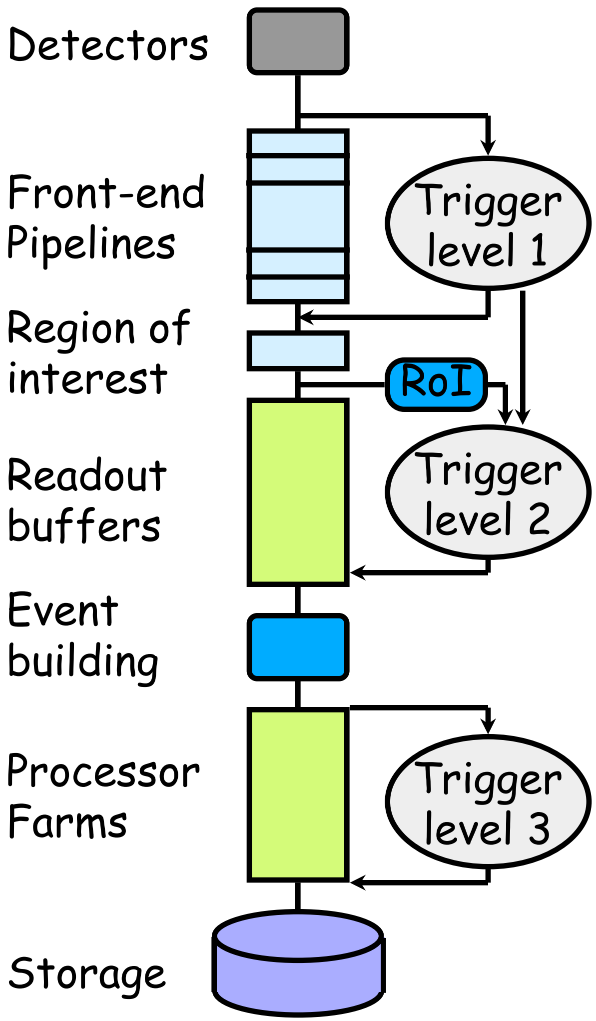
- 40 MHz synchronous digital system
- Synchronization at the exit of the pipeline non trivial. ⊠ Timing calibration

Trigger Levels in LHCb



- Level-0 (4 ms) (custom processors)
  - High p_T for electrons, muons, hadrons
  - Pile-up veto.
- HLT (≫ms) (commercial processors)
  - Refinement of the Level-1. Background rejection.
  - Event reconstruction. Select physics channels.
  - Needs the full event

Trigger Levels in ATLAS



- Level-1 (3.5 ms) (custom processors)
  - Energy clusters in calorimeters
  - Muon trigger: tracking coincidence matrix.
- Level-2 (100 ms) (specialized processors)
  - Few Regions Of Interest relevant to trigger decisions
  - Selected information (ROI) by routers and switches
  - Feature extractors (DSP or specialized)
  - Staged local and global processors
- Level-3 ($\gg$ms) (commercial processors)
  - Reconstructs the event using all data
  - Selection of interesting physics channels

Data Acquisition

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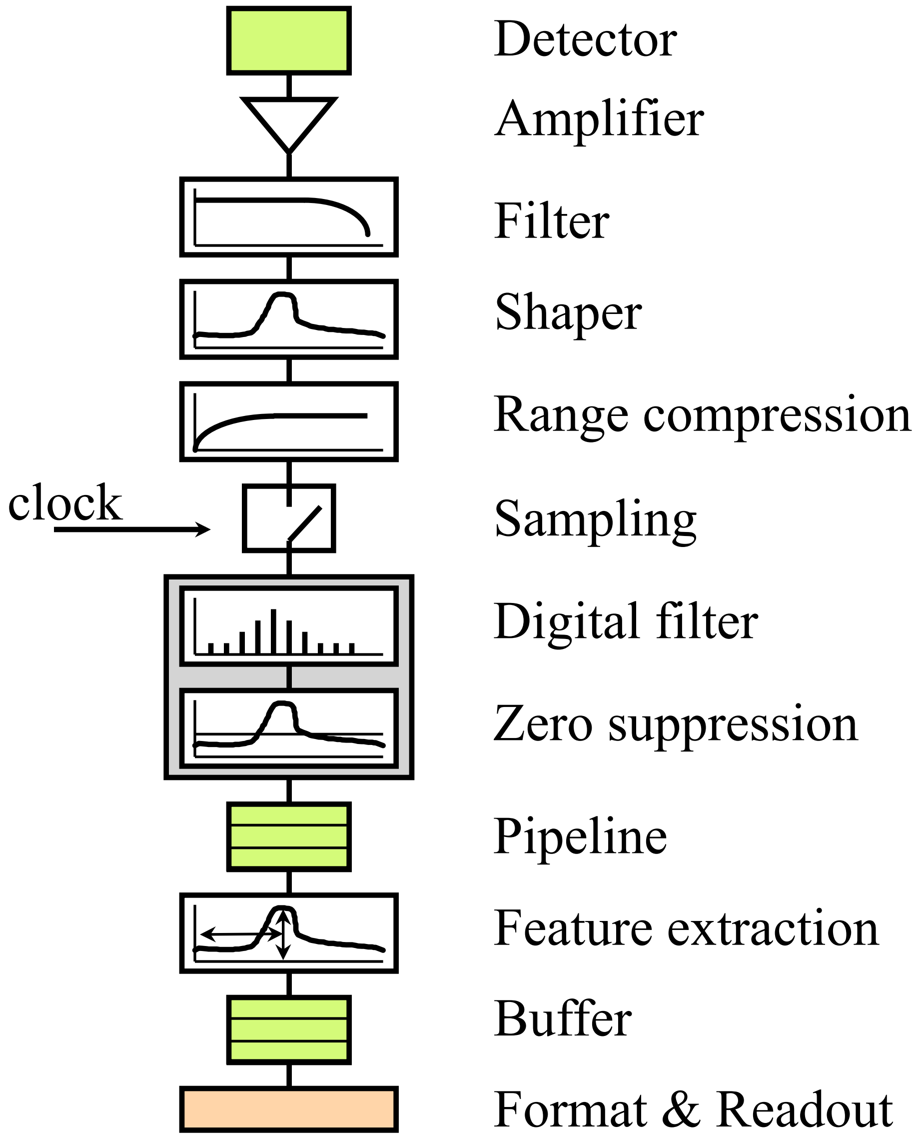
Data Acquisition System

- **Gathers the data produced by the detector and stores it (for positive trigger decisions)**
  - Front End Electronics:
    - Receive detector, trigger and timing signals and produce digitized information
  - Readout Network
    - Reads front end data and forms complete events - Event building
  - Processing & Storage
    - Data processing or filtering
    - Stores event data

Front-Ends

- **Detector dependent (Home made)**
  - On Detector
    - Pre-amplification, Discrimination, Shaping amplification and Multiplexing of a few channels
    - Problems: Radiation levels, power consumption
  - Transmission
    - Long Cables (50-100 m), electrical or fiber-optics
  - In Counting Rooms
    - Hundreds of FE crates :
      Reception, A/D conversion and Buffering

Front-end structure



DAQ Readout

- Event-data are now digitized, pre-processed and tagged with a unique, monotonically increasing number
- But distributed over many *read-out boards* ("sources")
- For the next stage of selection, or even simply to write it to tape we have to get the pieces together:
  Event Building

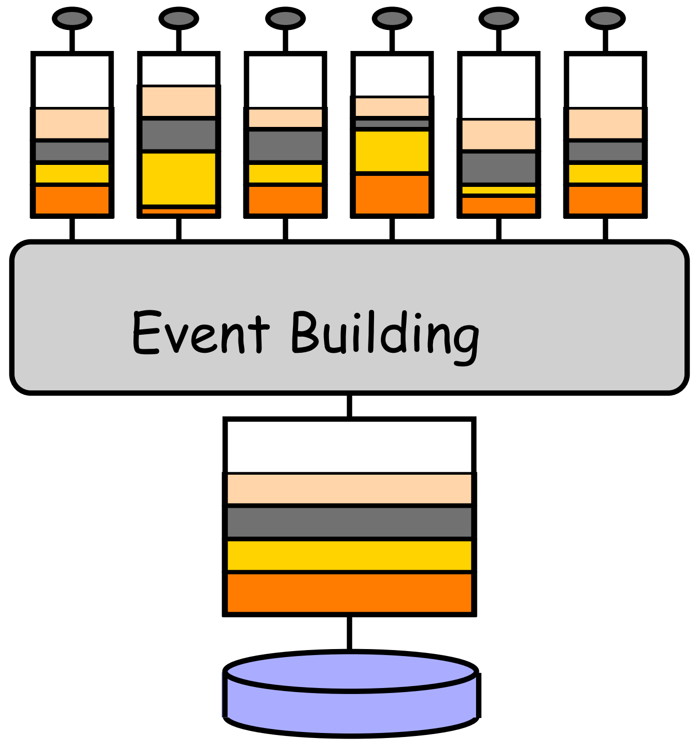
Event Building

Data sources

Event Fragments

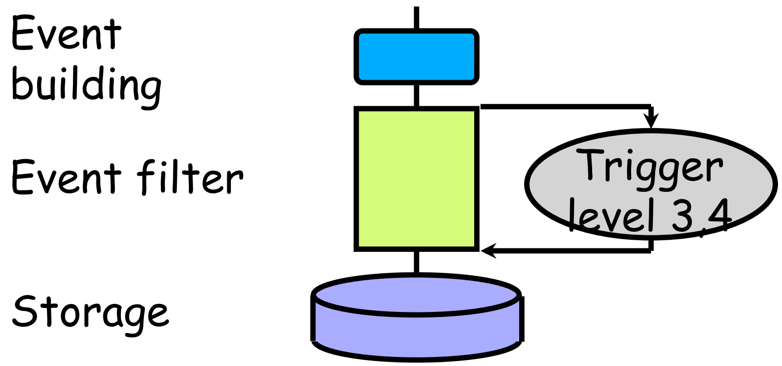
Full Events

Data storage



Event Filters

- **Higher level triggers (3, 4, …)**



- LHC experiments can not afford to write all acquired data into mass-storage. -> Only useful events should be written to the storage
- The event filter function selects events that will be used in the data analysis. Selected physics channels.
- Uses commercially available processors (common PCs) But needs thousands of them running in parallel.

Event Building to a CPU farm

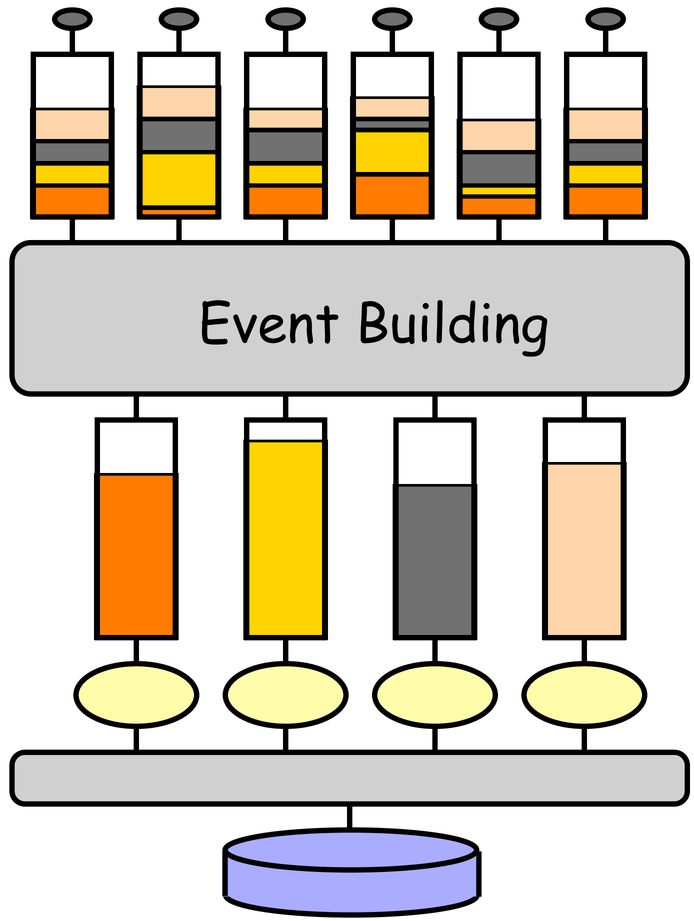
Data sources

Event Fragments

Full Events

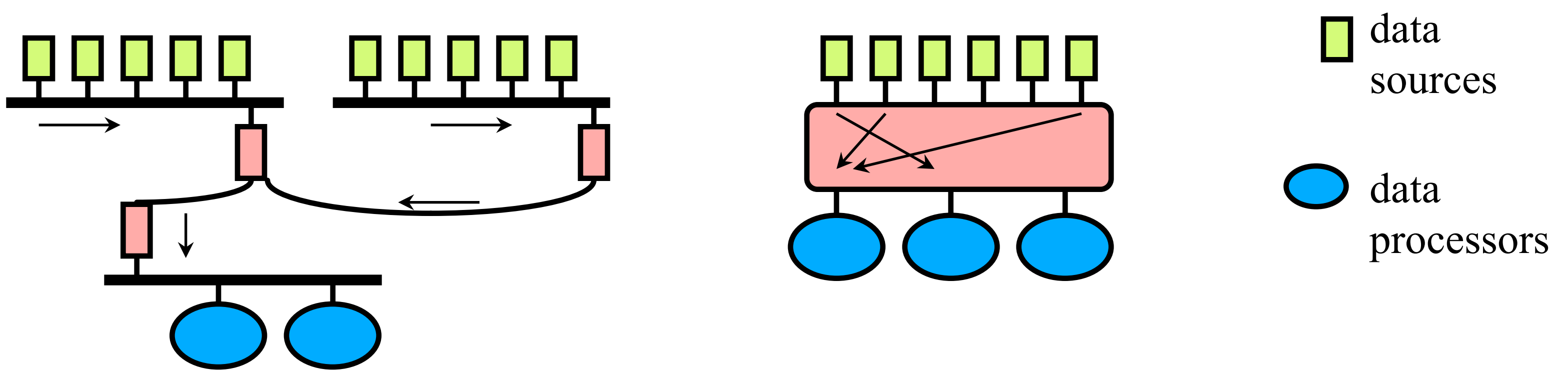
Event filter CPUs

Data storage



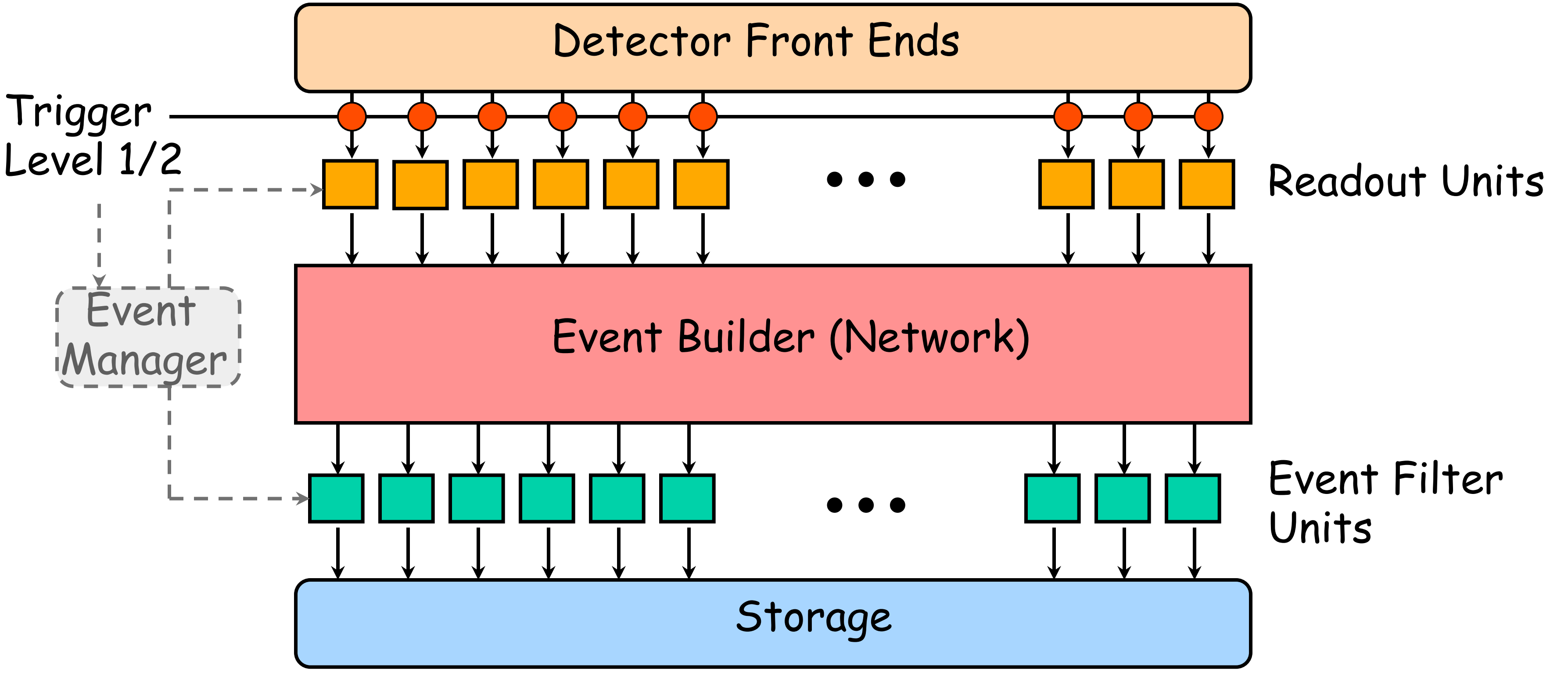
Readout Networks

- **We can build networks using buses or switches.**

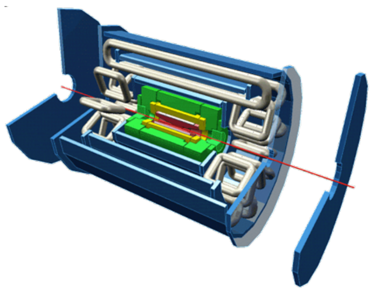
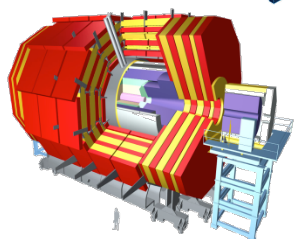
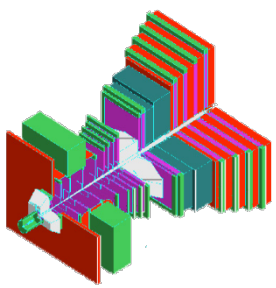
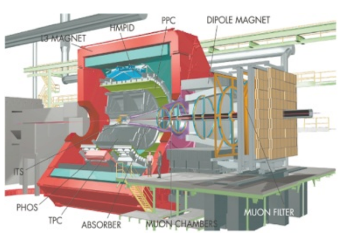


- **Switches vs. Buses**
  - Total bandwidth of a Bus is shared among all the processors. Adding more processors degrades the performance of the others. In general, **Buses do not scale** very well.
  - With switches, N simultaneous transfers can co-exists. Adding more processors does not degrade performance (bigger switch). **Switches are scaleable**.

LHC Readout Architecture

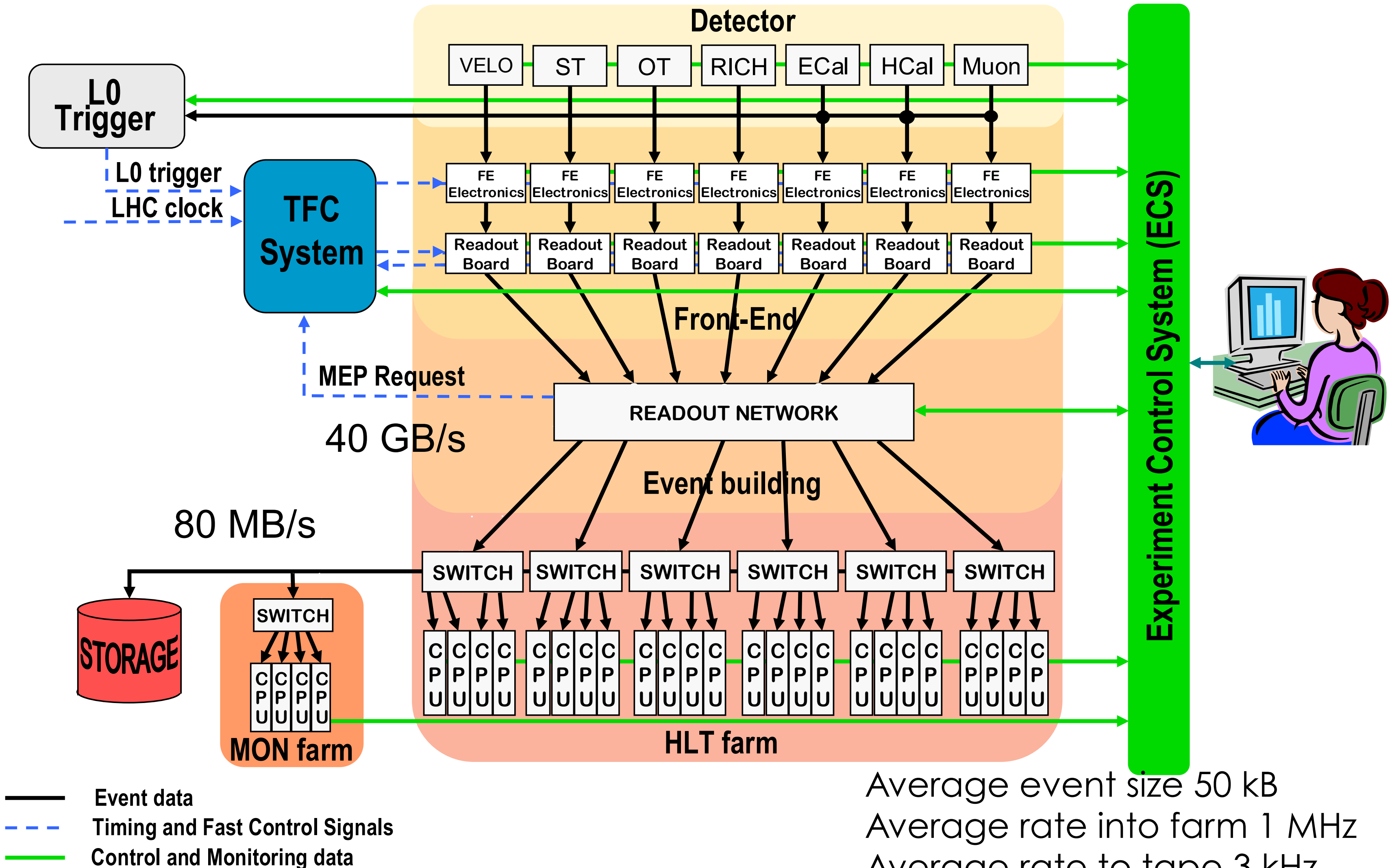


LHC Experiments DAQ

	Level-1 kHz	Event MByte	Storage MByte/s
ATLAS	100	1	200
CMS	100	1	200
LHCb	1000	0.05	150
ALICE	1	25	1250

LHCb DAQ



Average event size 50 kB
Average rate into farm 1 MHz
Average rate to tape 3 kHz

Configuration, Control and Monitoring

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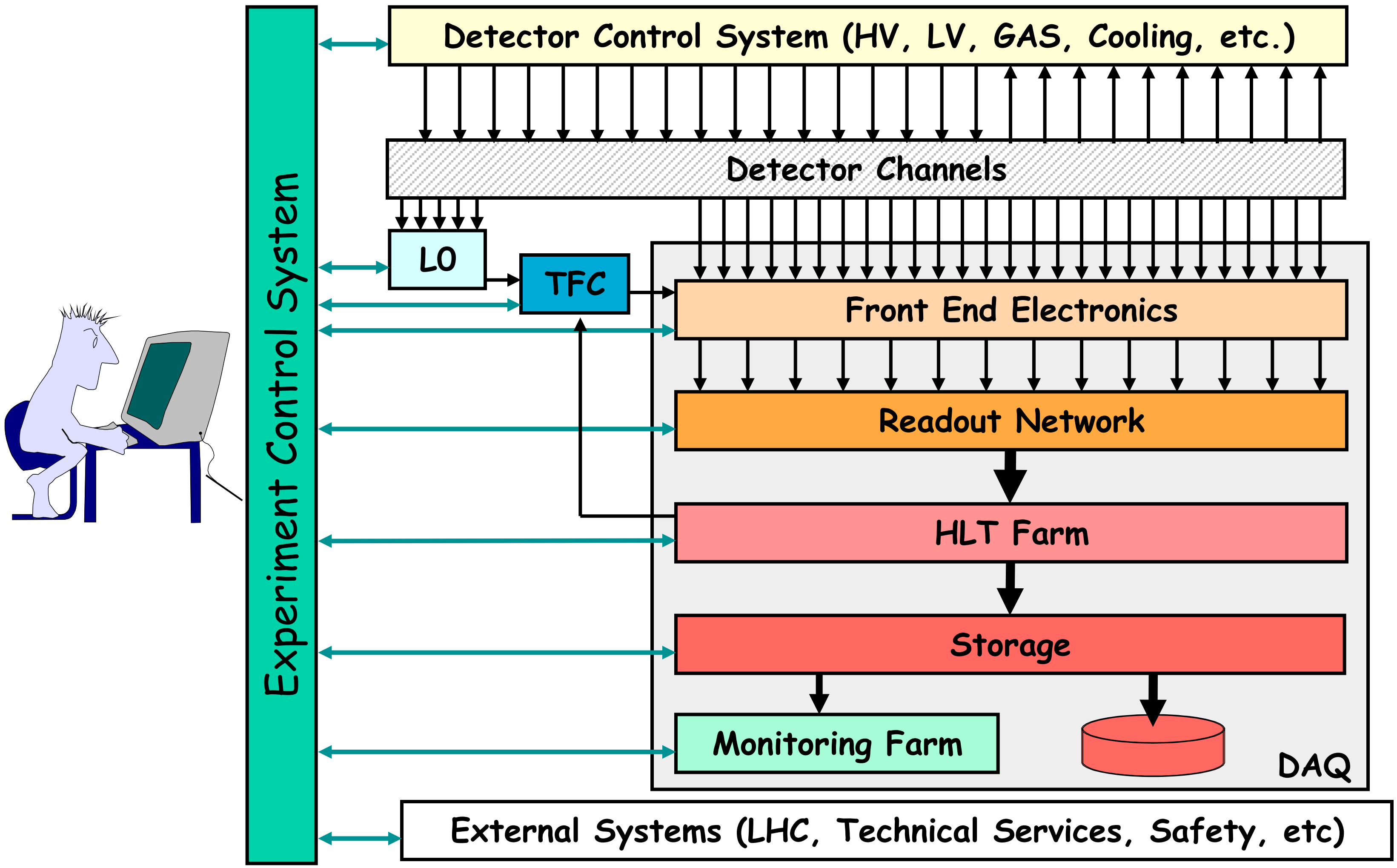
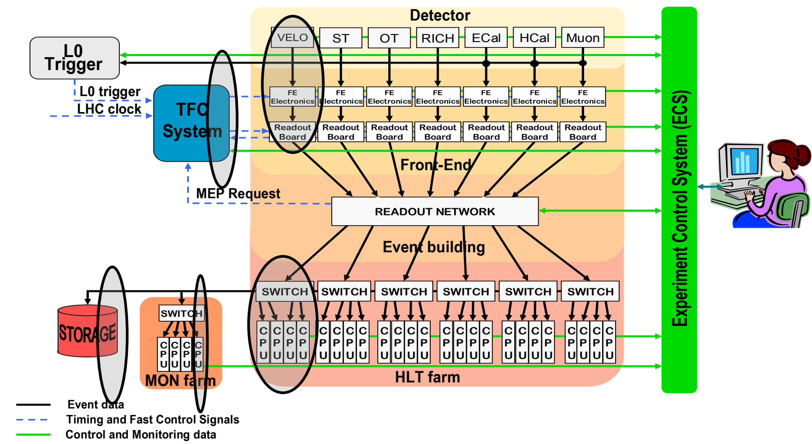
Experiment Control System



Control System

- Control System Tasks
  - Configuration
    - Loading of parameters (according to RUN type)
    - Enabling/disabling parts of the experiment
  - Partitioning
    - Ability to run parts of the experiment in stand-alone mode simultaneously
  - Monitoring, Error Reporting & Recovery
    - Detect and recover problems as fast as possible
  - User Interfacing



LHC Control Systems

- **Based on Commercial SCADA Systems (Supervisory Control and Data Acquisition)**
  - Commonly used for:
    - Industrial Automation
    - Control of Power Plants, etc.
  - Providing:
    - Configuration Database and Tools
    - Run-time and Archiving of Monitoring Data including display and trending Tools.
    - Alarm definition and reporting tools
    - User Interface design tools

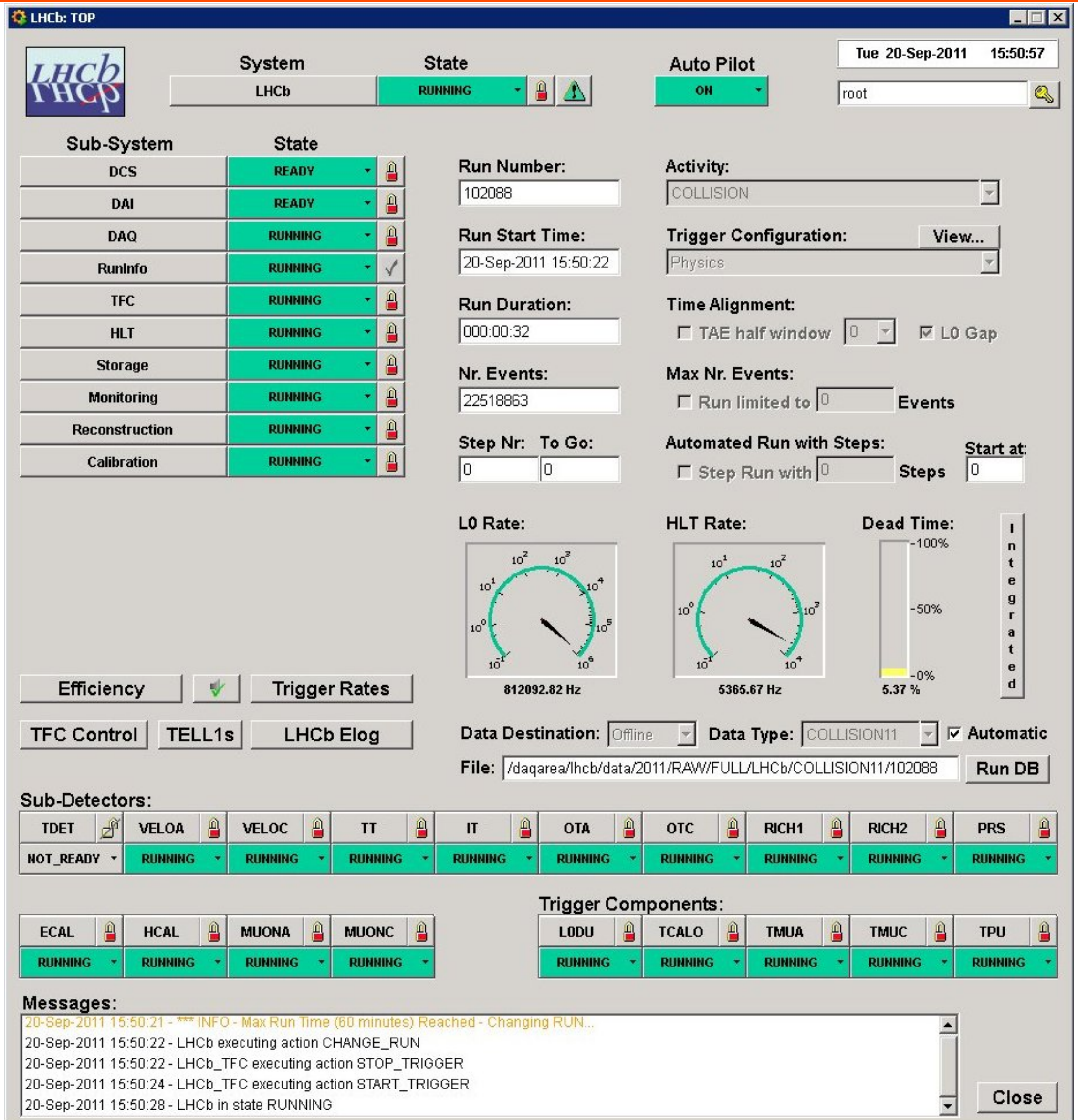
Control Automation

- **Experiment runs 24/24 7/7**
- **Only 2 (non-expert) operators**
- **Automation**
  - Avoids human mistakes and speeds up standard procedures
  - What can be automated
    - Standard Procedures (Start of fill, End of fill)
    - Detection and Recovery from (known) error situations
  - How
    - Finite State Machine tools
    - Expert System Type Tools (automated rules)

Monitoring

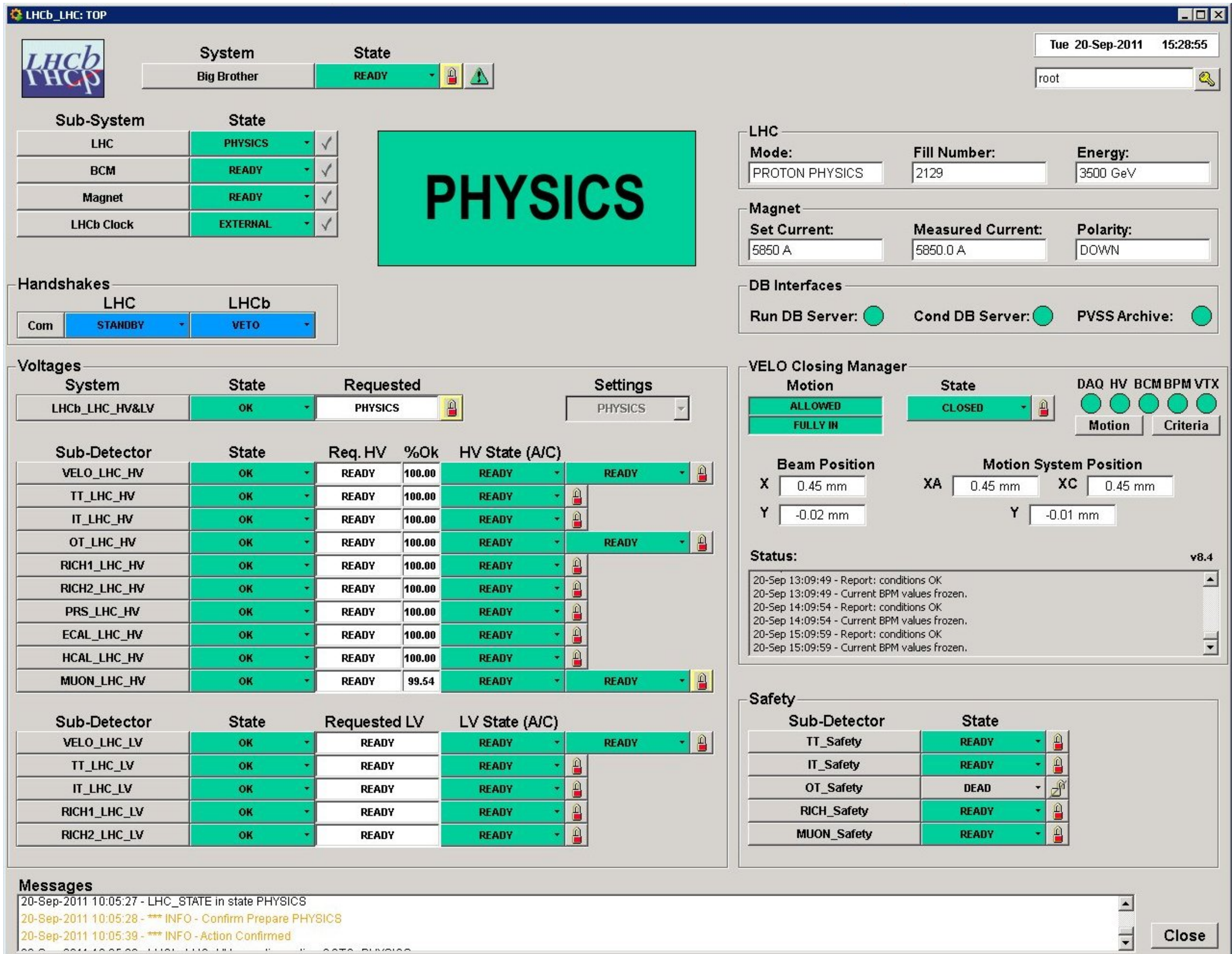
- **Two types of Monitoring**
  - Monitor Experiment's Behaviour
    - Automation tools whenever possible
    - Good (homogeneous) User Interface
  - Monitor the quality of the data
    - Automatic histogram production and analysis
    - User Interfaced histogram analysis
    - Event displays (raw data)

LHCb Run Control



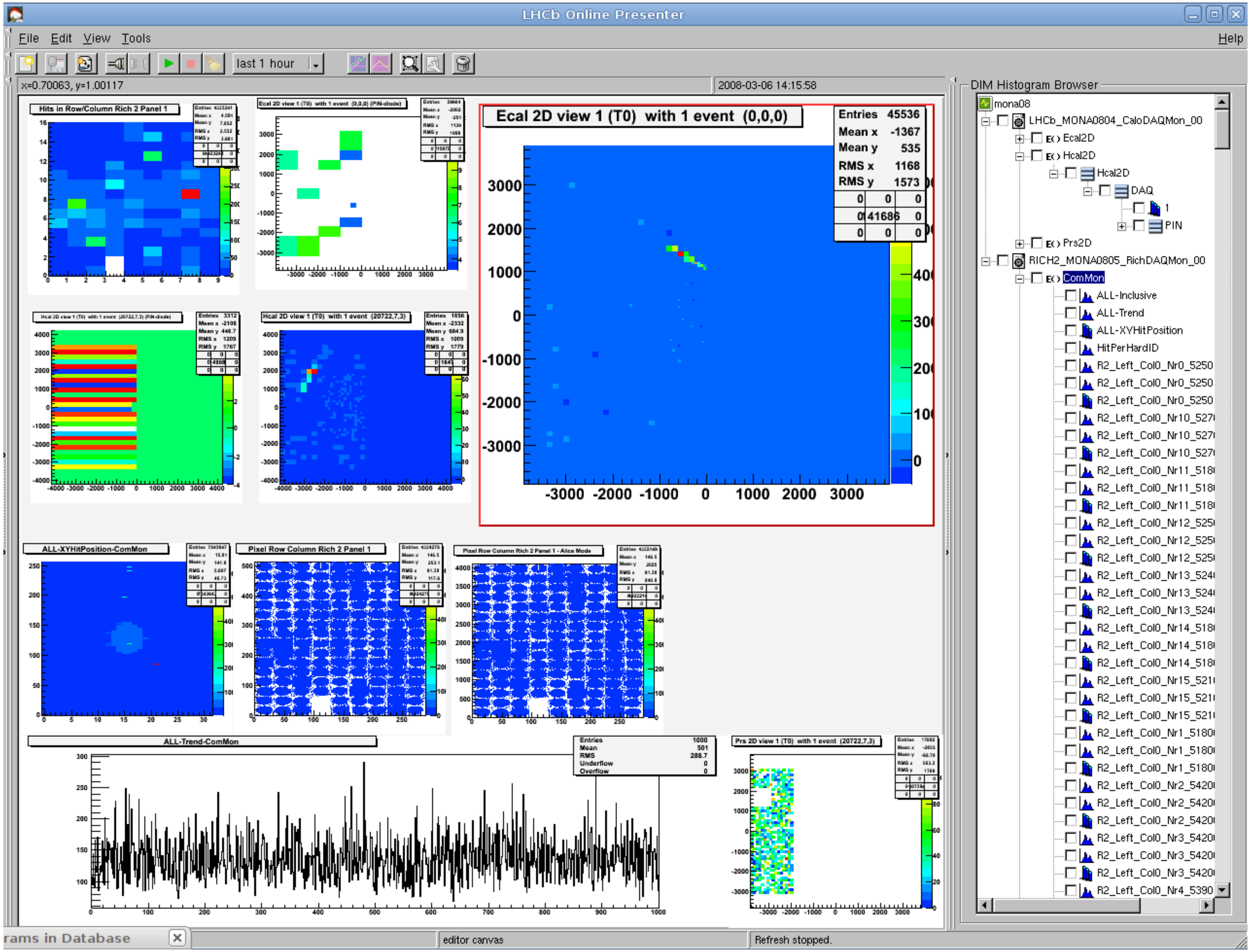
- Homogeneous control of all parts of the experiment
- Stand alone operation (partitioning)
- Full Automation (Auto Pilot)

LHCb Big Brother



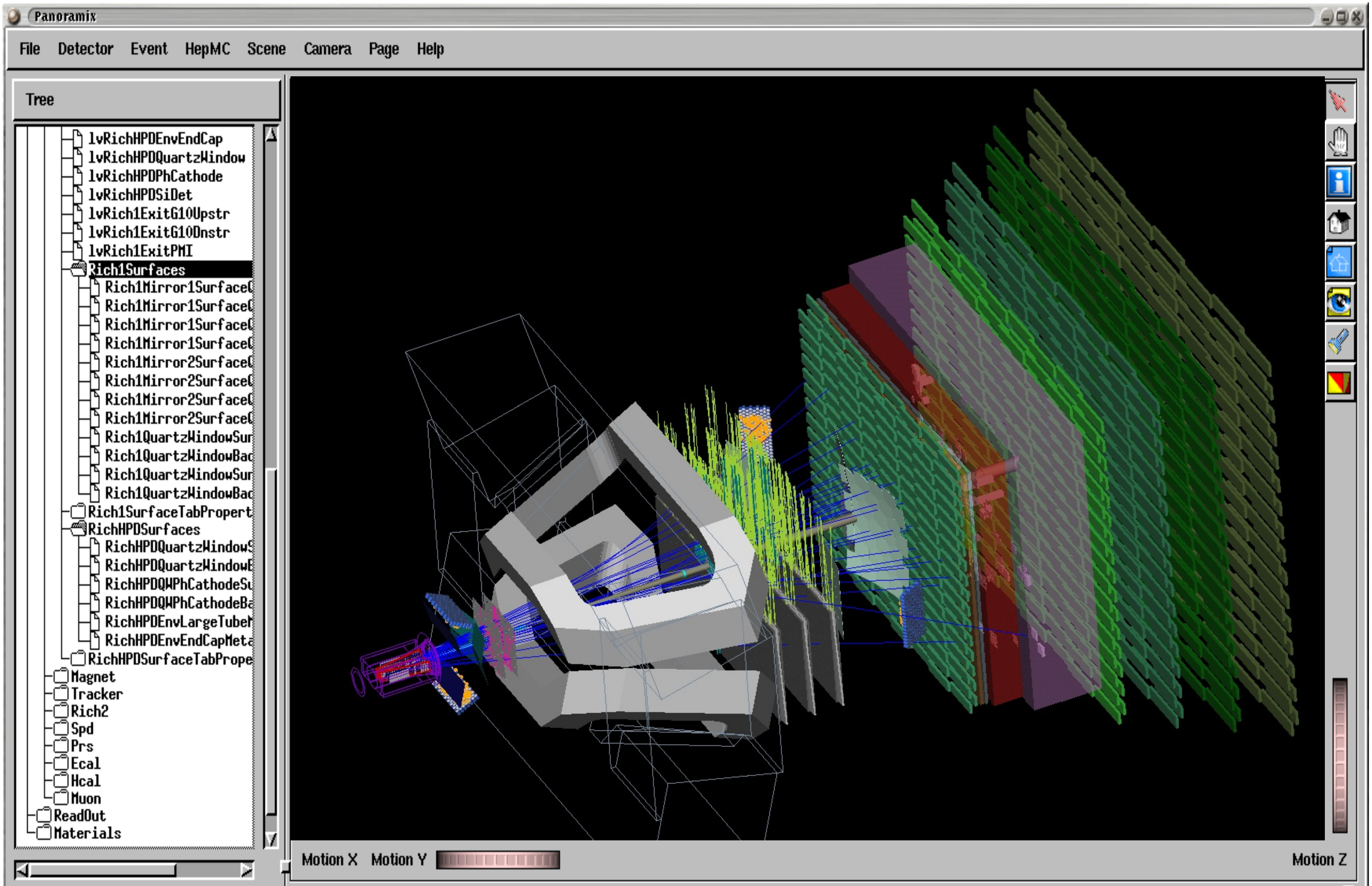
- DCS
- Overall Control

LHCb Histogram Presenter



- Monitor the quality of the data being acquired
- Compare with reference
- Automatic analyses

LHCb Online Event Display



Concluding Remarks

- Trigger and Data Acquisition systems are becoming increasingly complex.
- Luckily the requirements of telecommunications and computing in general have strongly contributed to the development of standard technologies:
  - Hardware: Flash ADCs, Analog memories, PCs, Networks, Helical scan recording, Data compression, Image processing, ...
  - Software: Distributed computing, Software development environments, Supervisory systems, ...
- We can now build a large fraction of our systems using commercial components (customization will still be needed in the front-end).
- It is essential that we keep up-to-date with the progress being made by industry.