



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

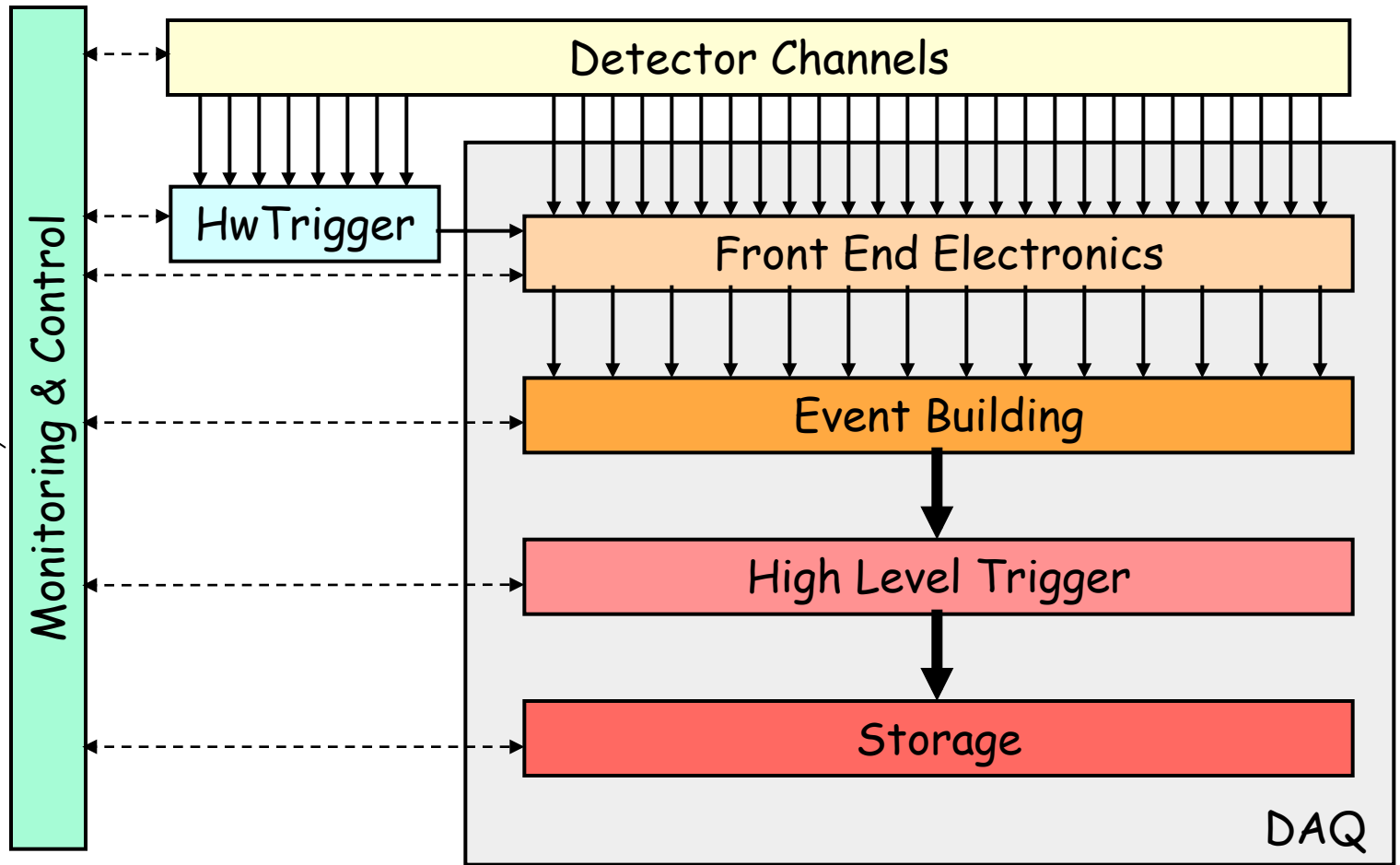
- Gathers the data produced by the detector and stores it (for positive trigger decisions)

■ Control System

- Performs the overall Configuration, Control and Monitoring



Trigger, DAQ & Control





LEP & LHC in Numbers

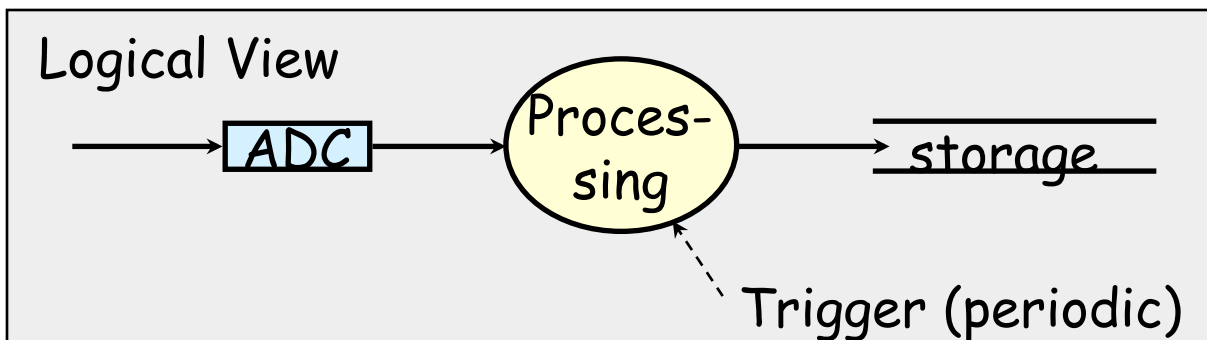
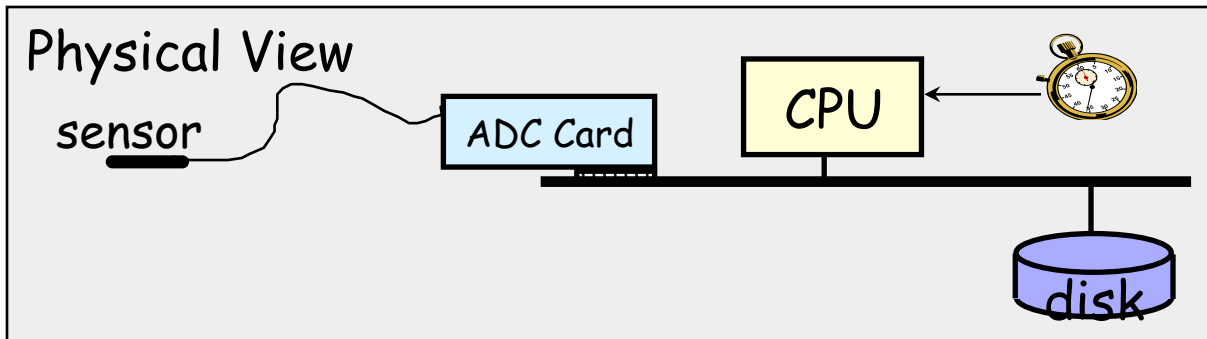
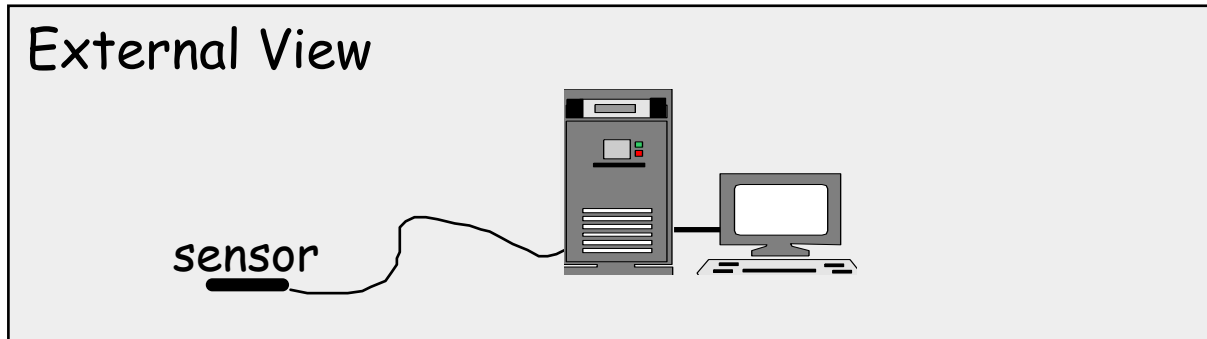
	LEP (1989/2000)	LHC (2009)	Factor
Bunch Crossing Rate	45 KHz	40 MHz	$\times 10^3$
Bunch Separation	22 μ s	25 ns	$\times 10^3$
Nr. Electronic Channels	$\approx 100\ 000$	$\approx 10\ 000\ 000$	$\times 10^2$
Raw data rate	$\approx 100\ \text{GB/s}$	$\approx 1\ 000\ \text{TB/s}$	$\times 10^4$
Data rate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



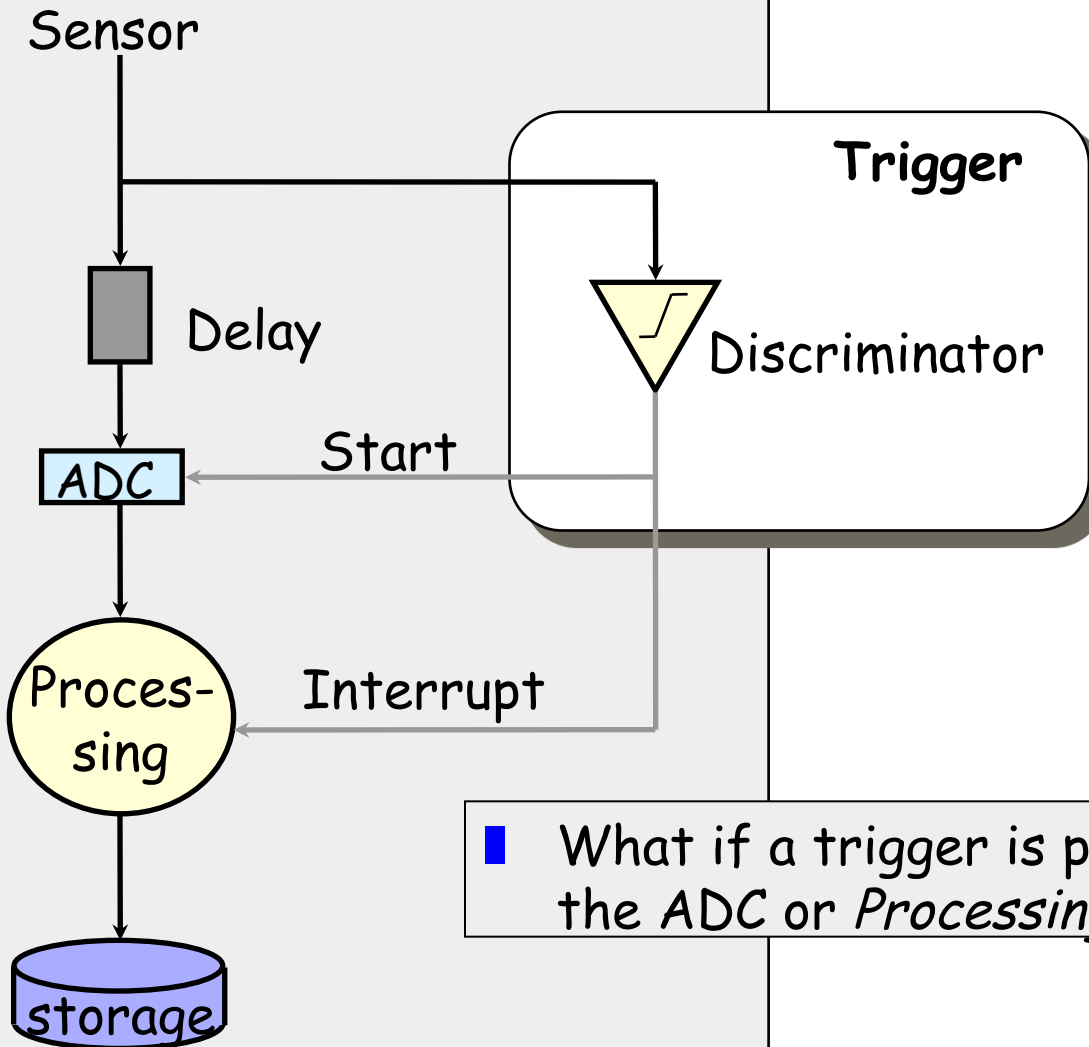
Basic Concepts

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Trivial DAQ

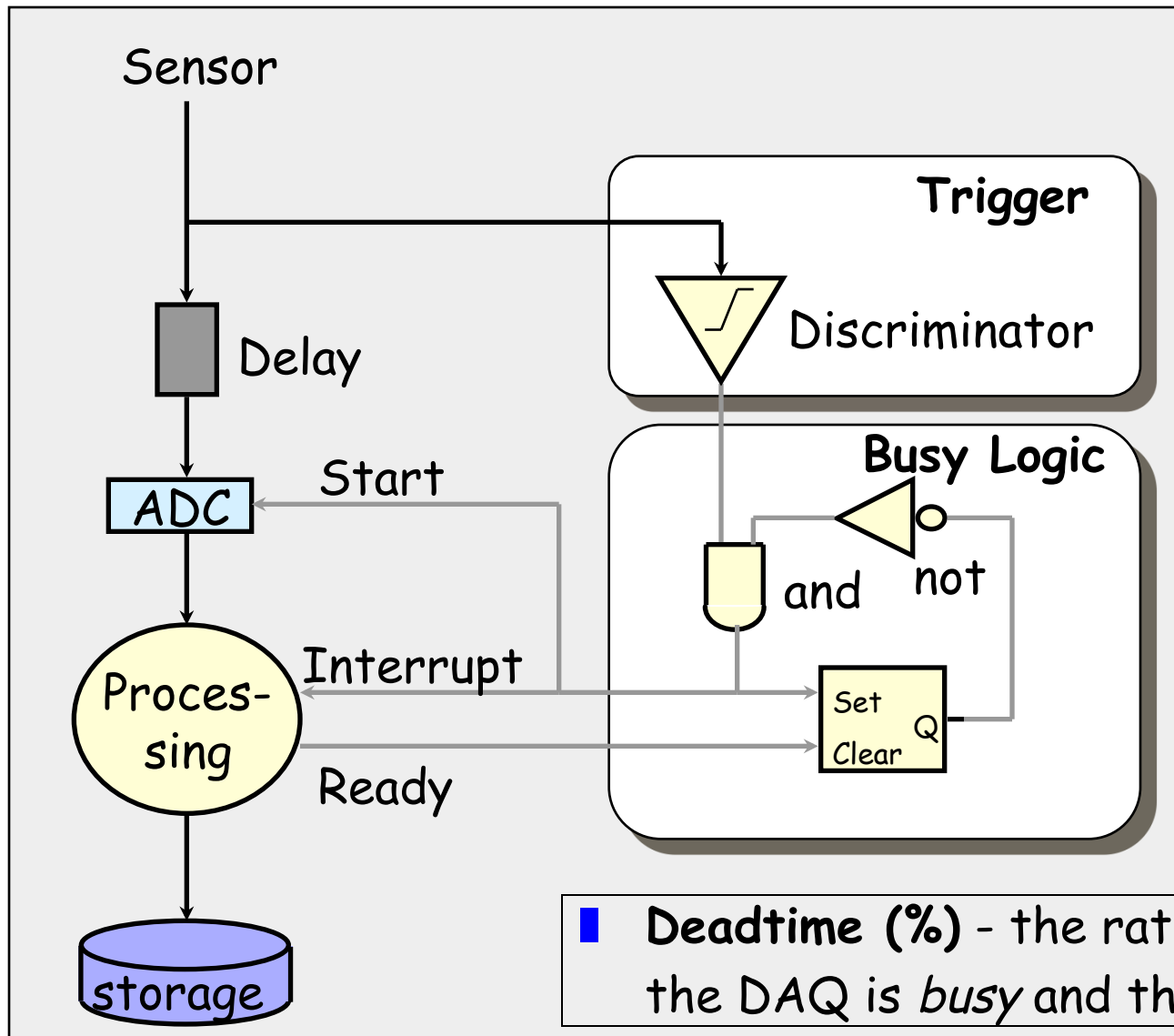


Trivial DAQ with a real trigger



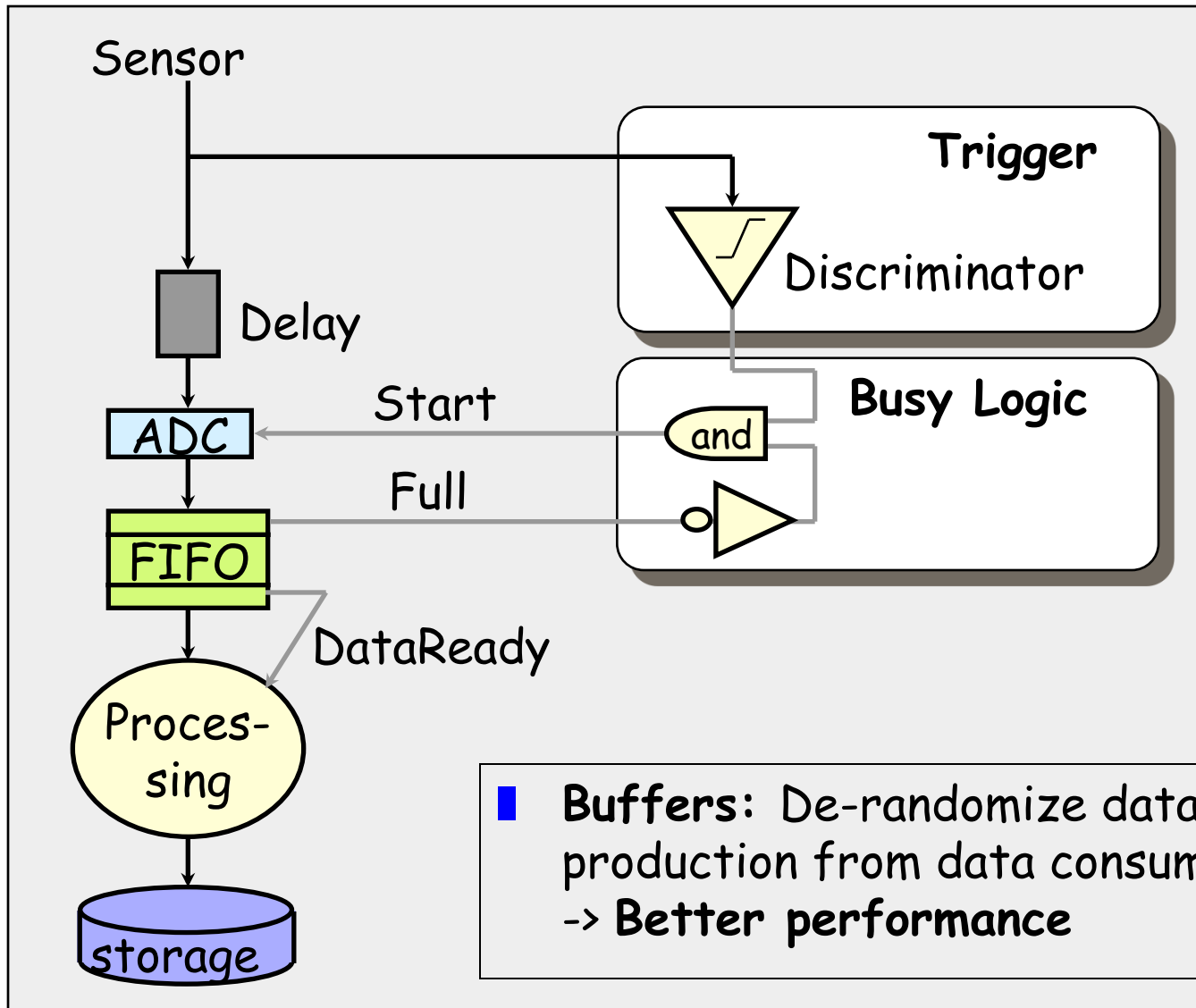
- What if a trigger is produced when the ADC or *Processing* is busy?

Trivial DAQ with a real trigger (2)



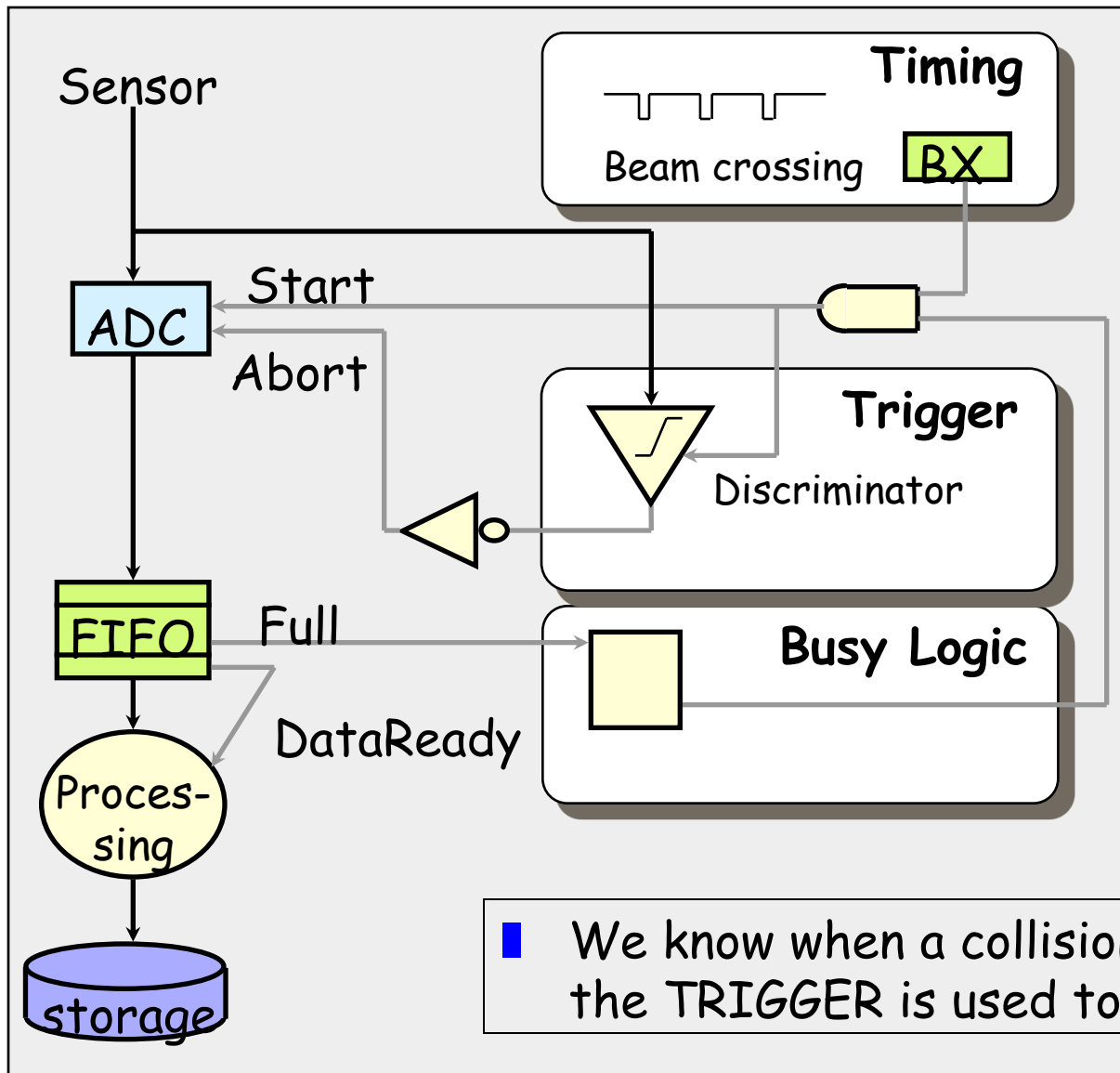
■ **Deadtime (%)** - the ratio between the time the DAQ is *busy* and the total time

Trivial DAQ with a real trigger (3)



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

Trivial DAQ in collider mode

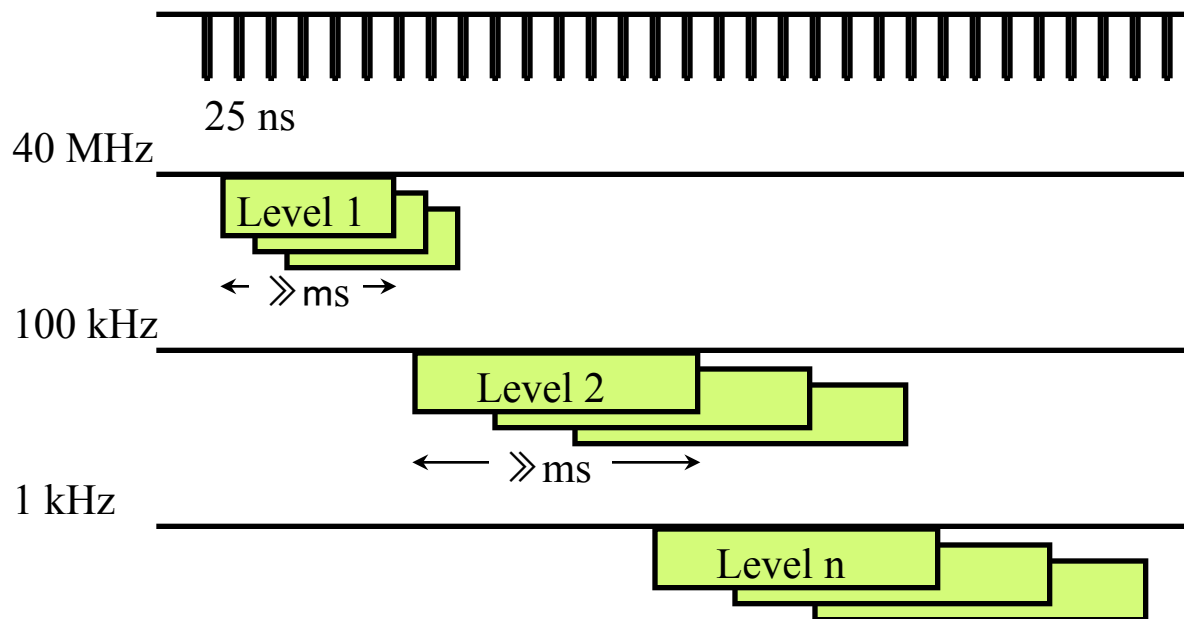


- We know when a collision happens the TRIGGER is used to “reject” the data



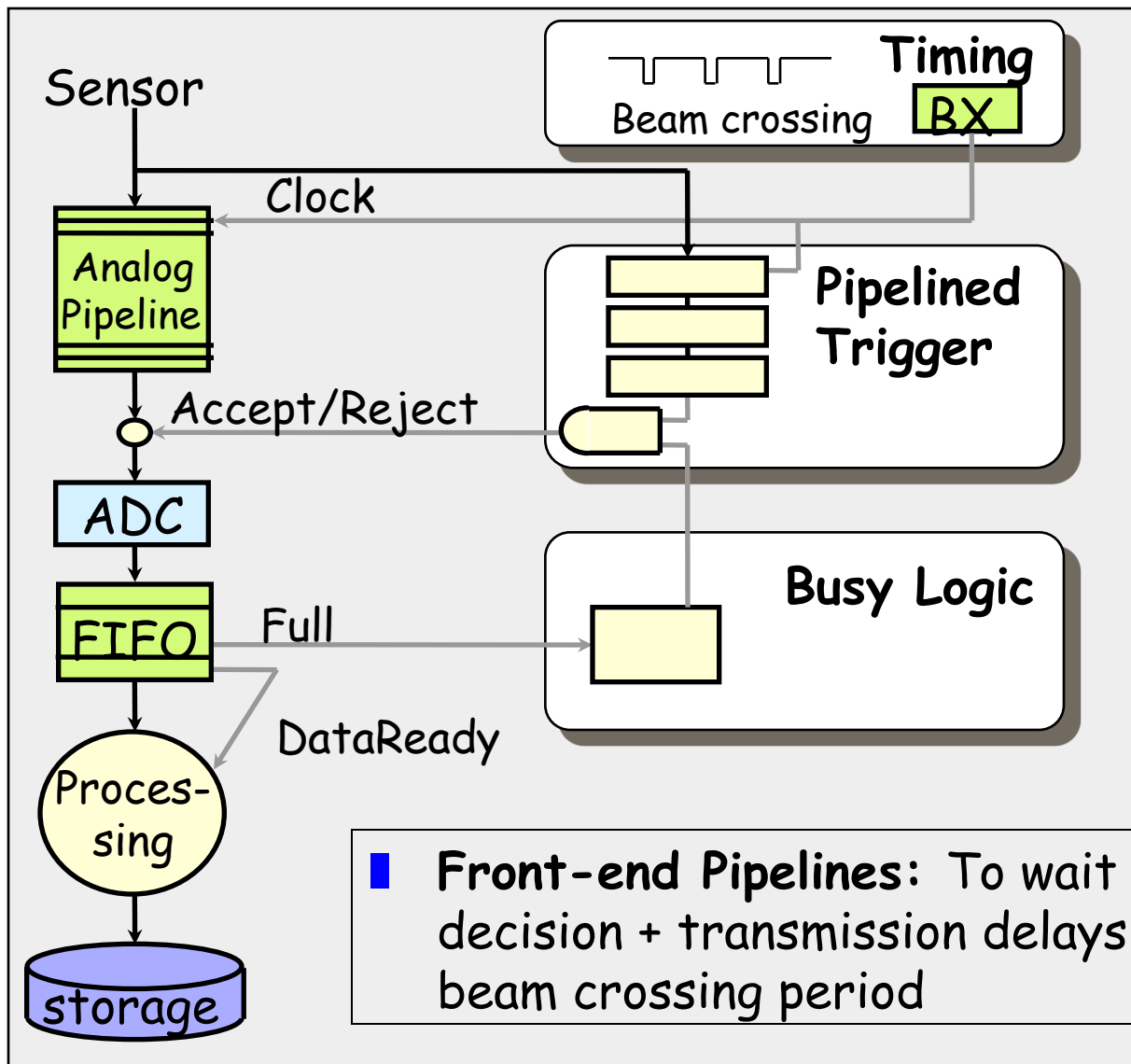
LHC timing

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

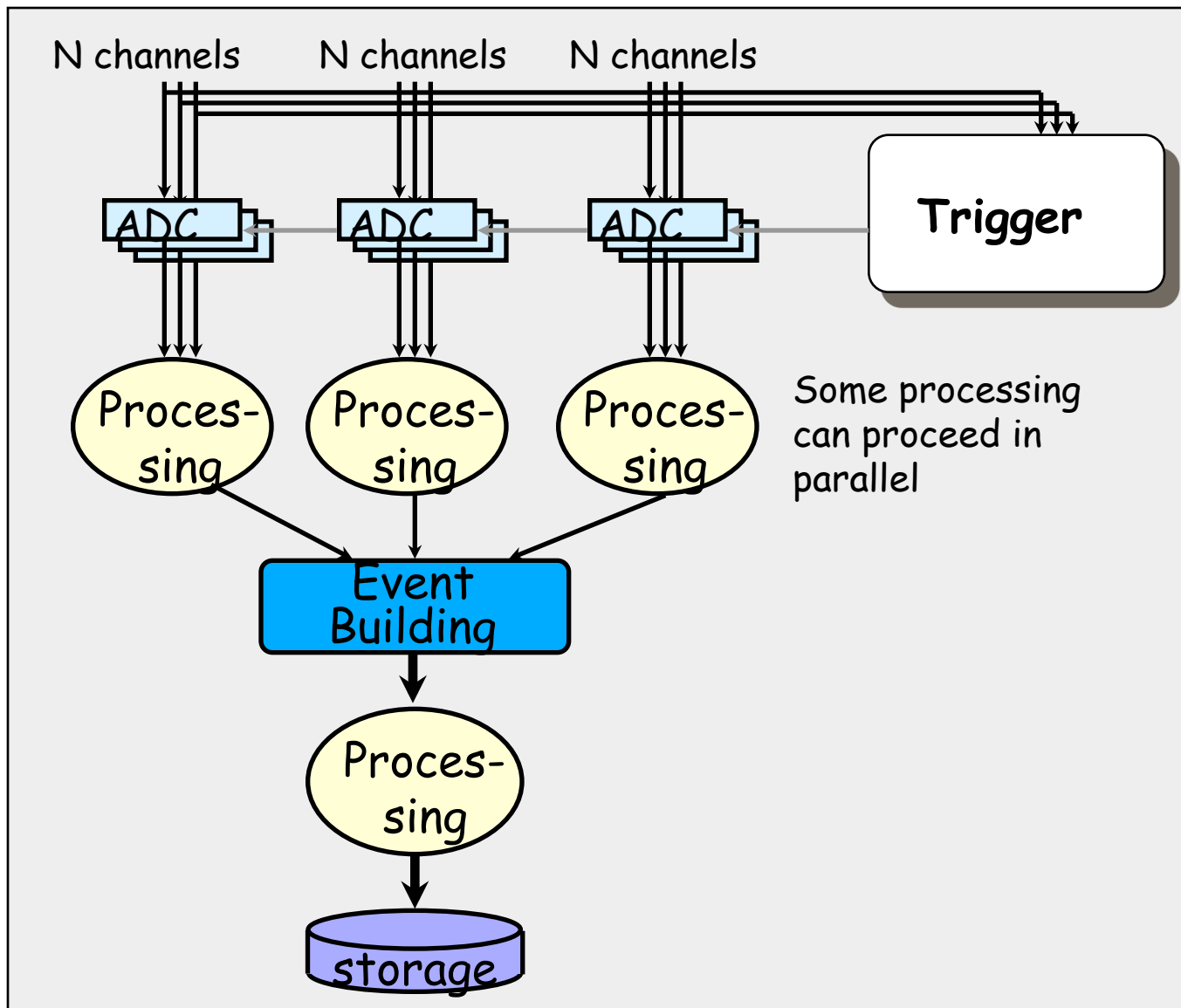


- Level 1 trigger time exceeds bunch interval
- Event overlap & signal pileup (multiple crossings since the detector cell memory greater than 25 ns)
- Very high number of channels

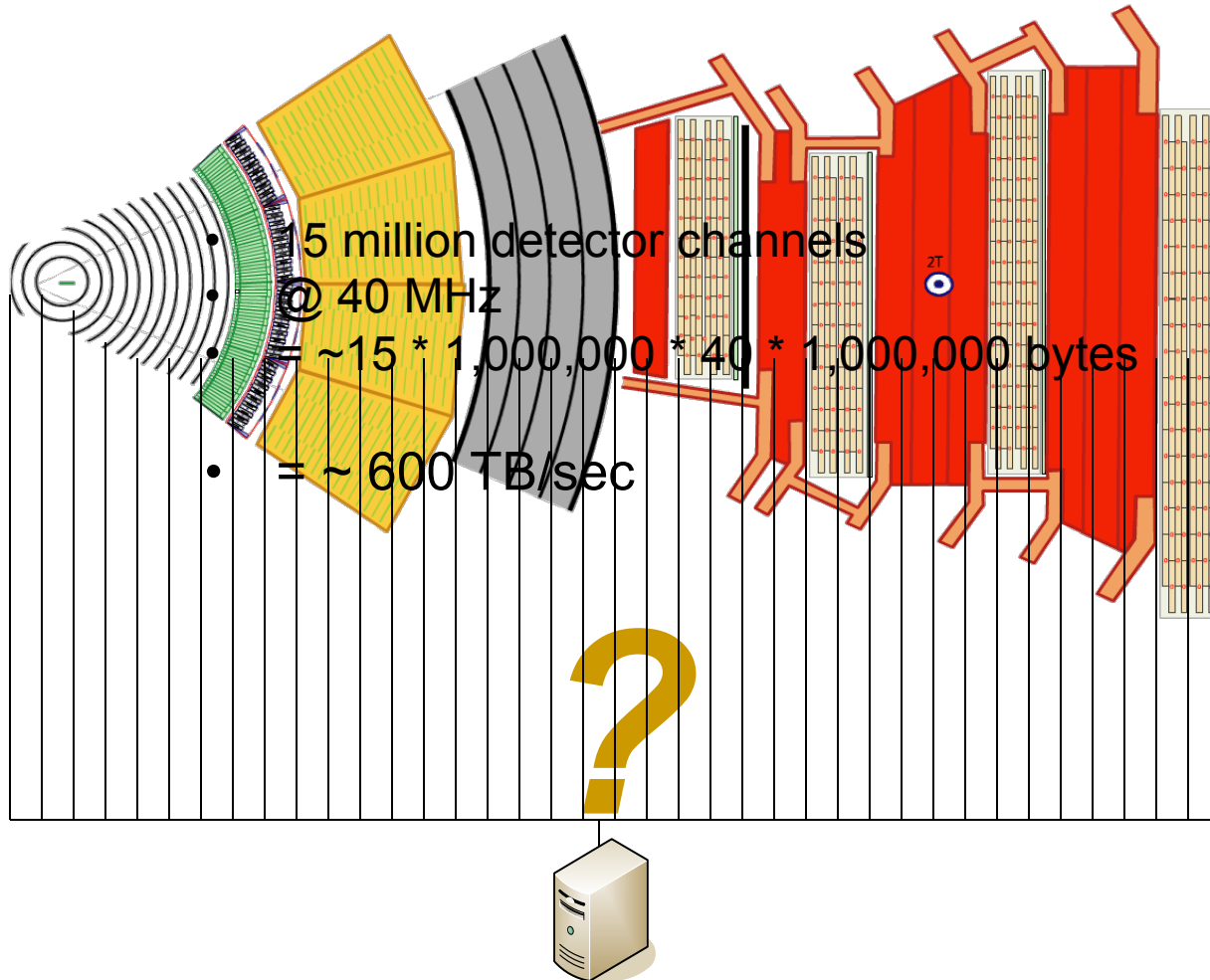
Trivial DAQ in LHC



Less trivial DAQ



The Real Thing



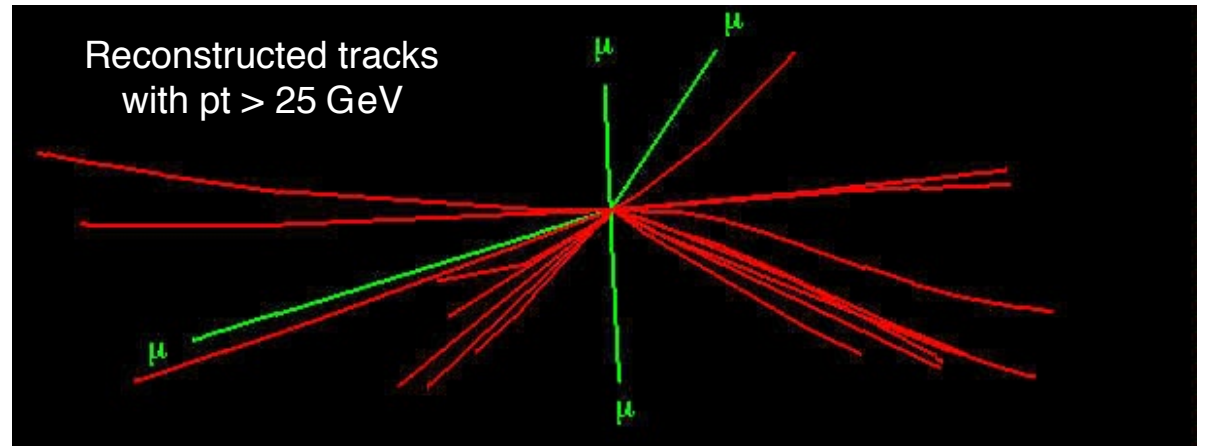
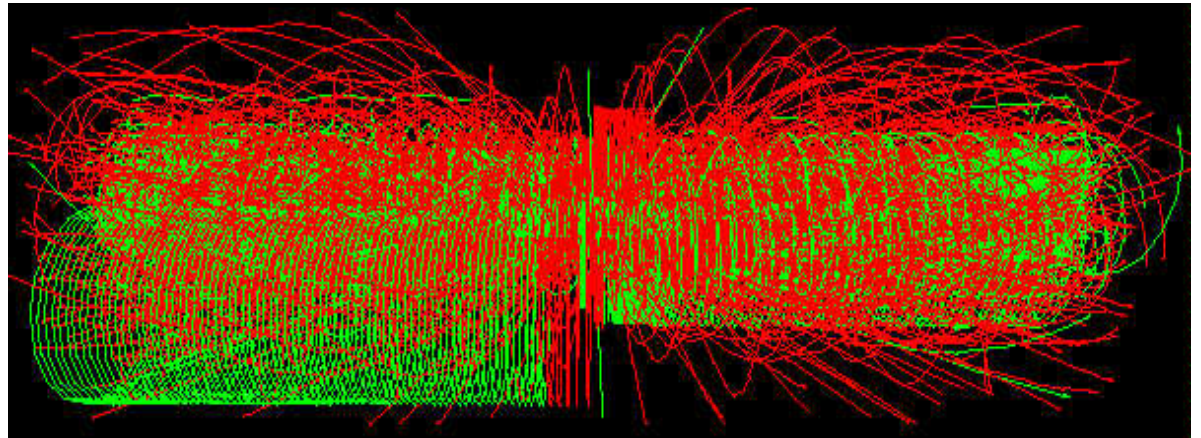


Trigger

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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

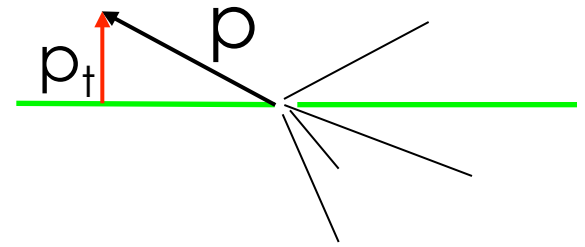


Trigger Levels

- 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_{\perp} " ~ 1 GeV



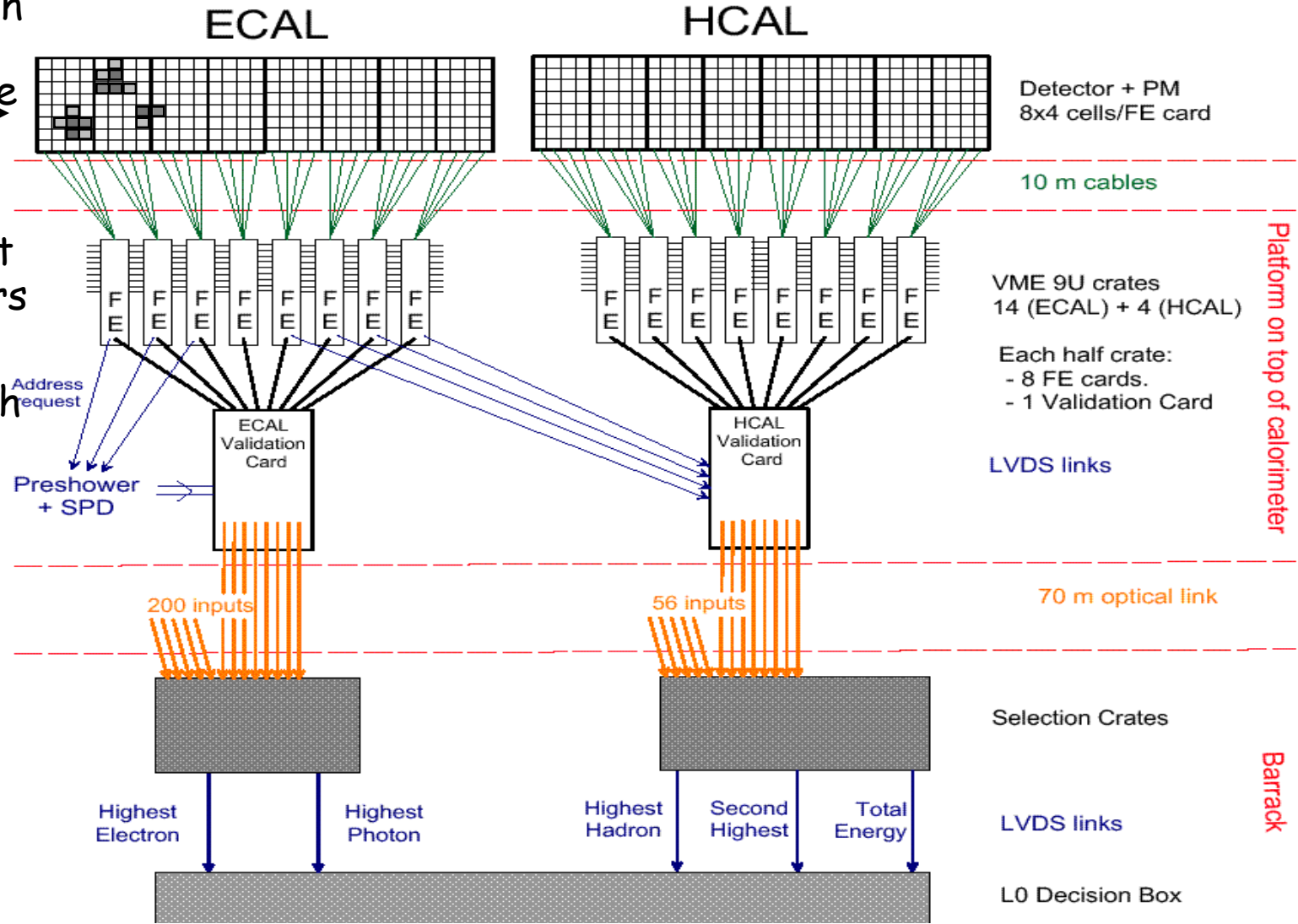
- Interesting physics (old and new) has particles with large p_{\perp}

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

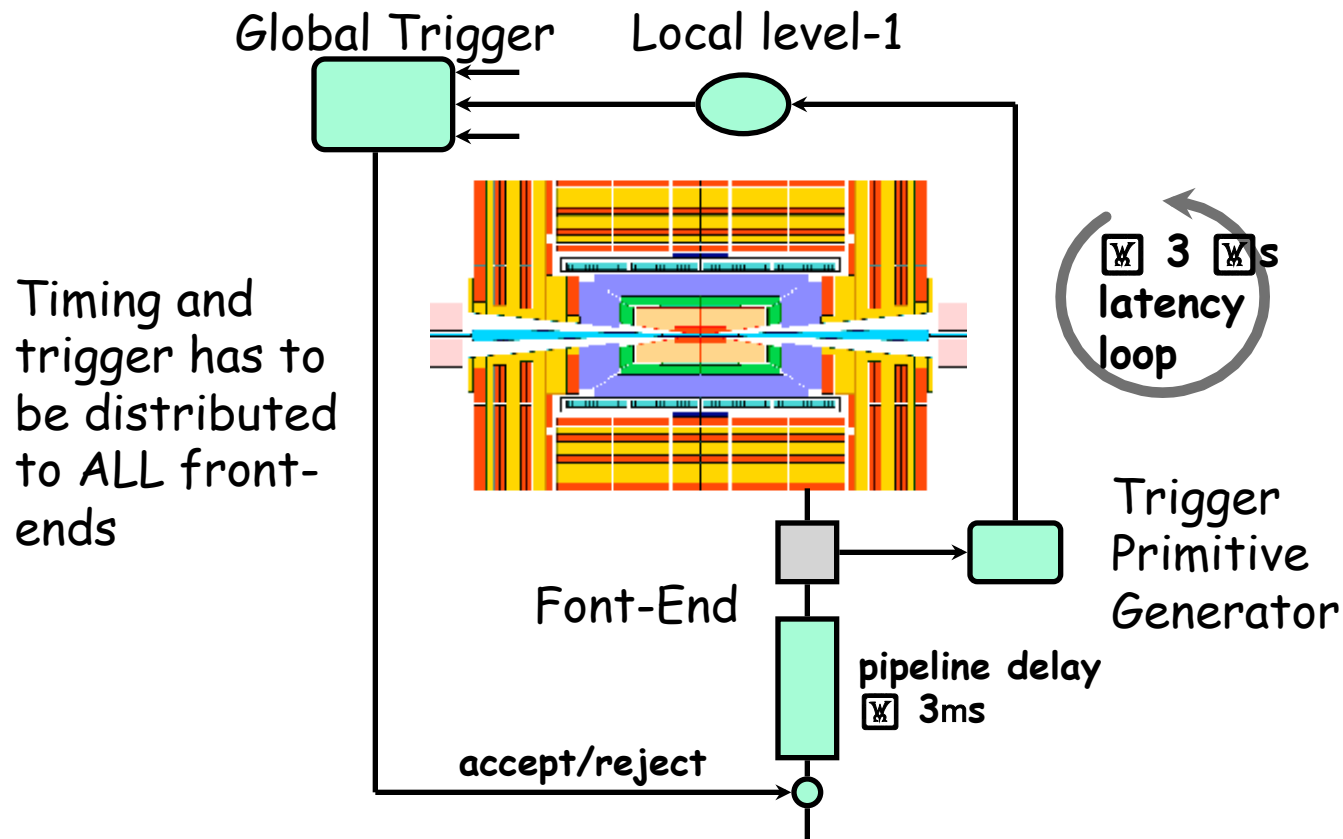


Example: LHCb Calorimeter Trigger

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

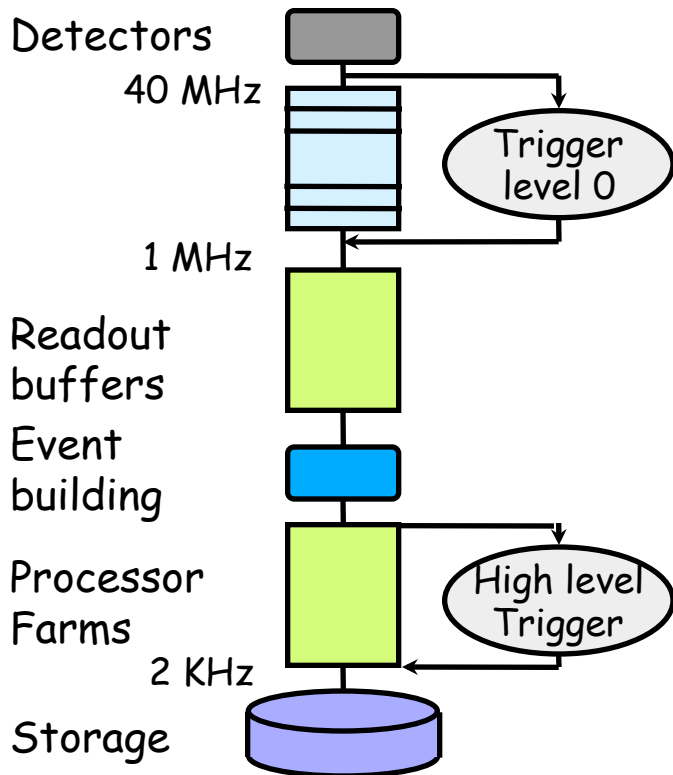


LHC: Trigger communication loop



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

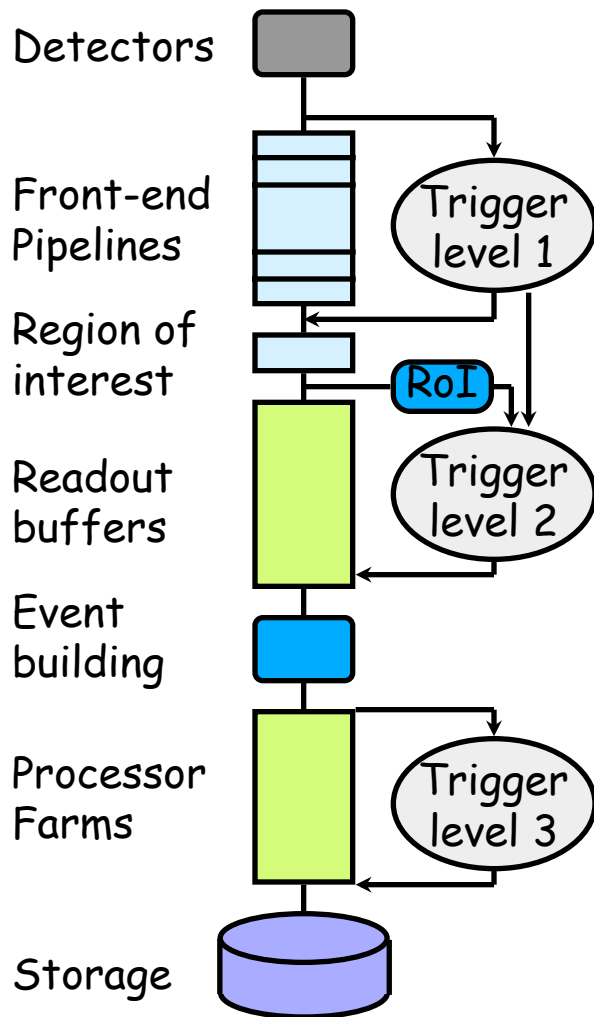
Trigger Levels in LHCb



- Level-0 (4 ms) (custom processors)
 - High p_T for electrons, muons, hadrons
 - Pile-up veto.

- HLT (\gg 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

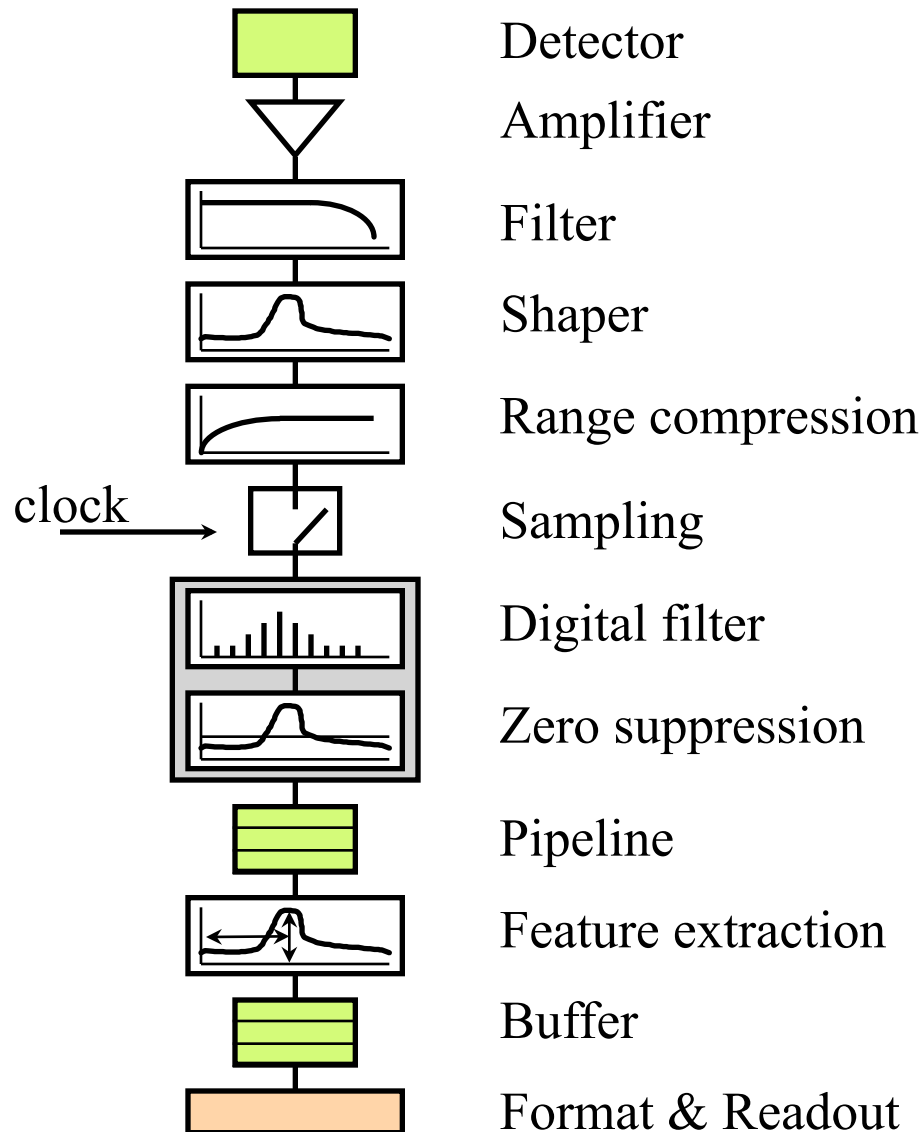
- Gathers the data produced by the detector and stores it (for positive trigger decisions)
 - Front End Electronics:
 - | Receive detector, trigger and timing signals and produce digitized information
 - Readout Network
 - | Reads front end data and forms complete events
 - Event building
 - Processing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



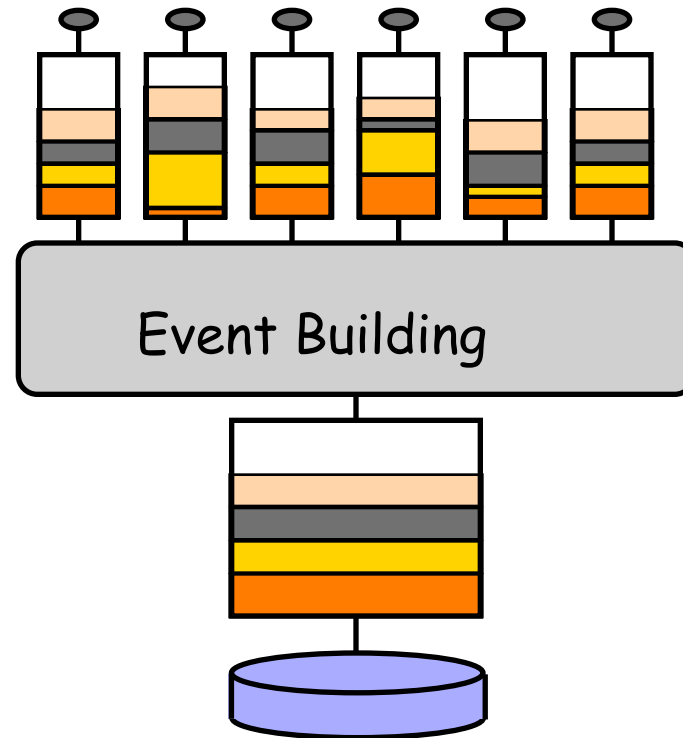
Event Building

Data sources

Event Fragments

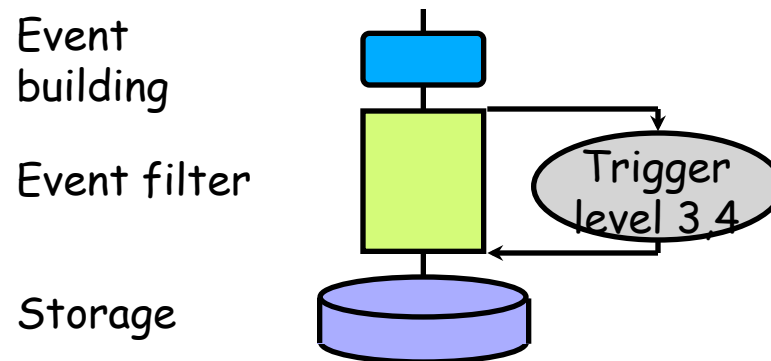
Full Events

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

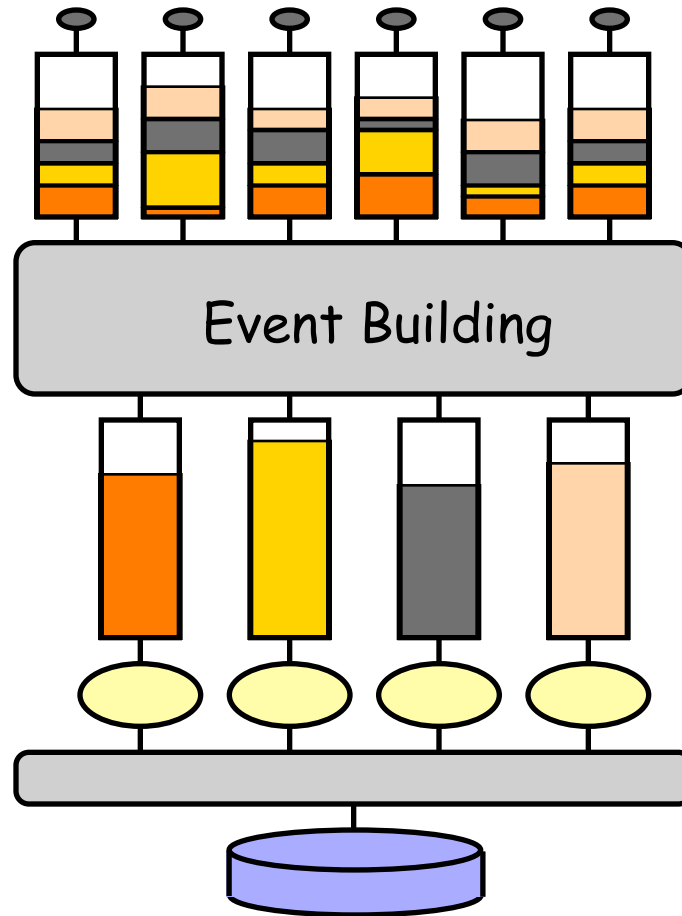
Data sources

Event Fragments

Full Events

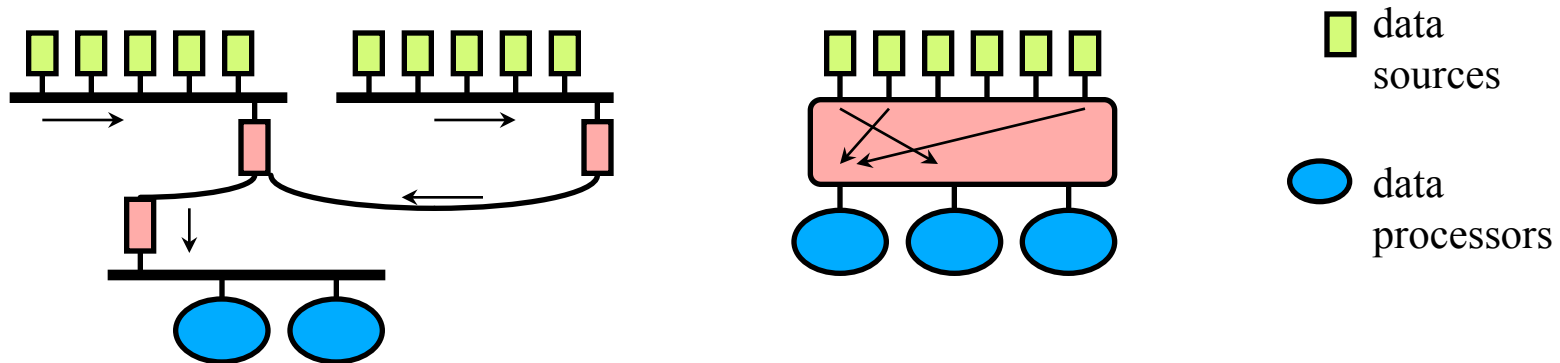
Event filter CPUs

Data storage



Readout Networks

- We can build networks using buses or switches.

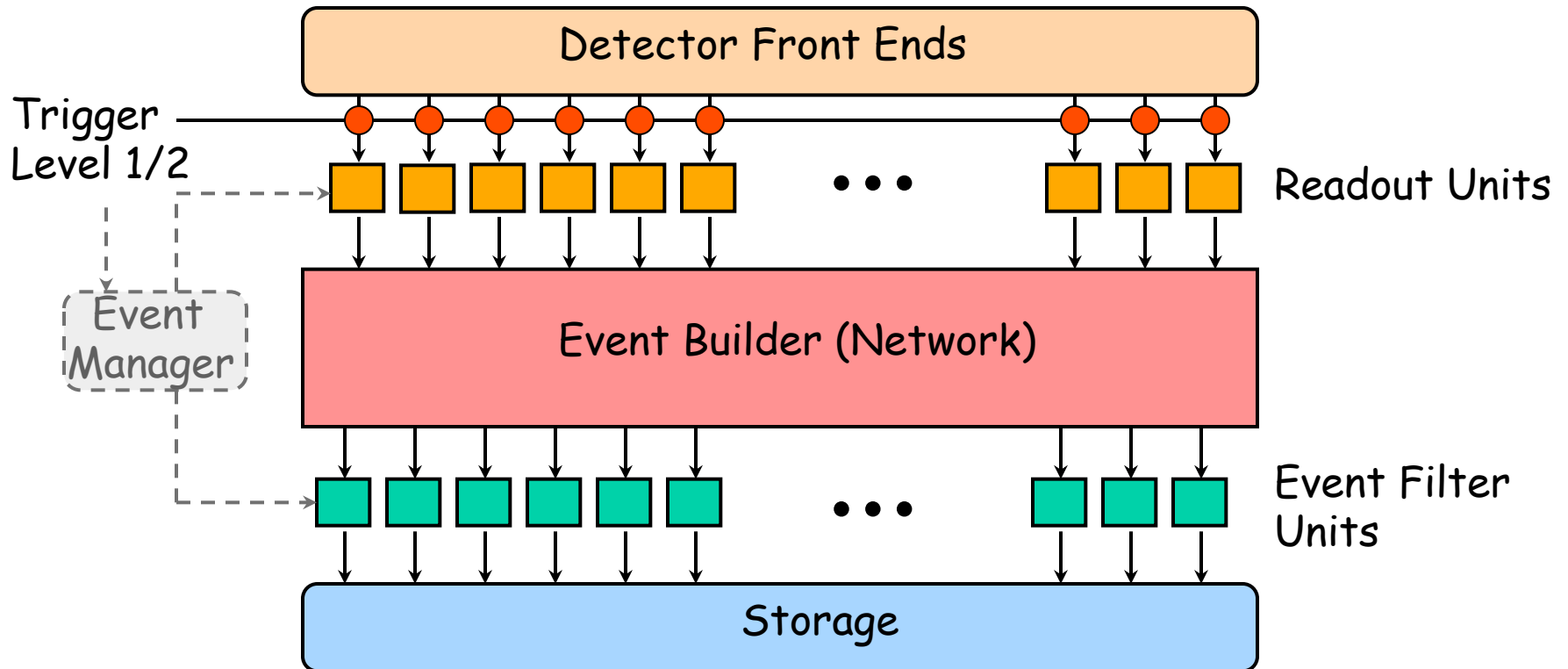


■ Switches vs. Buses

- 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.**

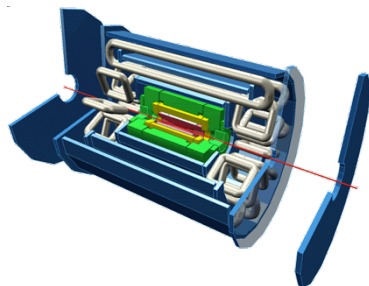


LHC Readout Architecture





LHC Experiments DAQ



ATLAS

Level-1
kHz

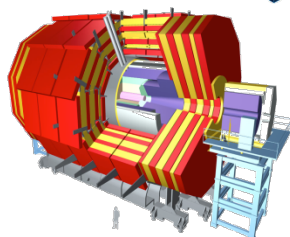
100

Event
MByte

1

Storage
MByte/s

200

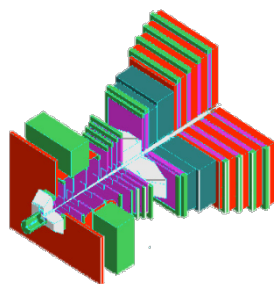


CMS

100

1

200

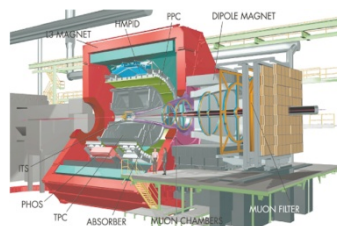


LHCb

1000

0.05

150



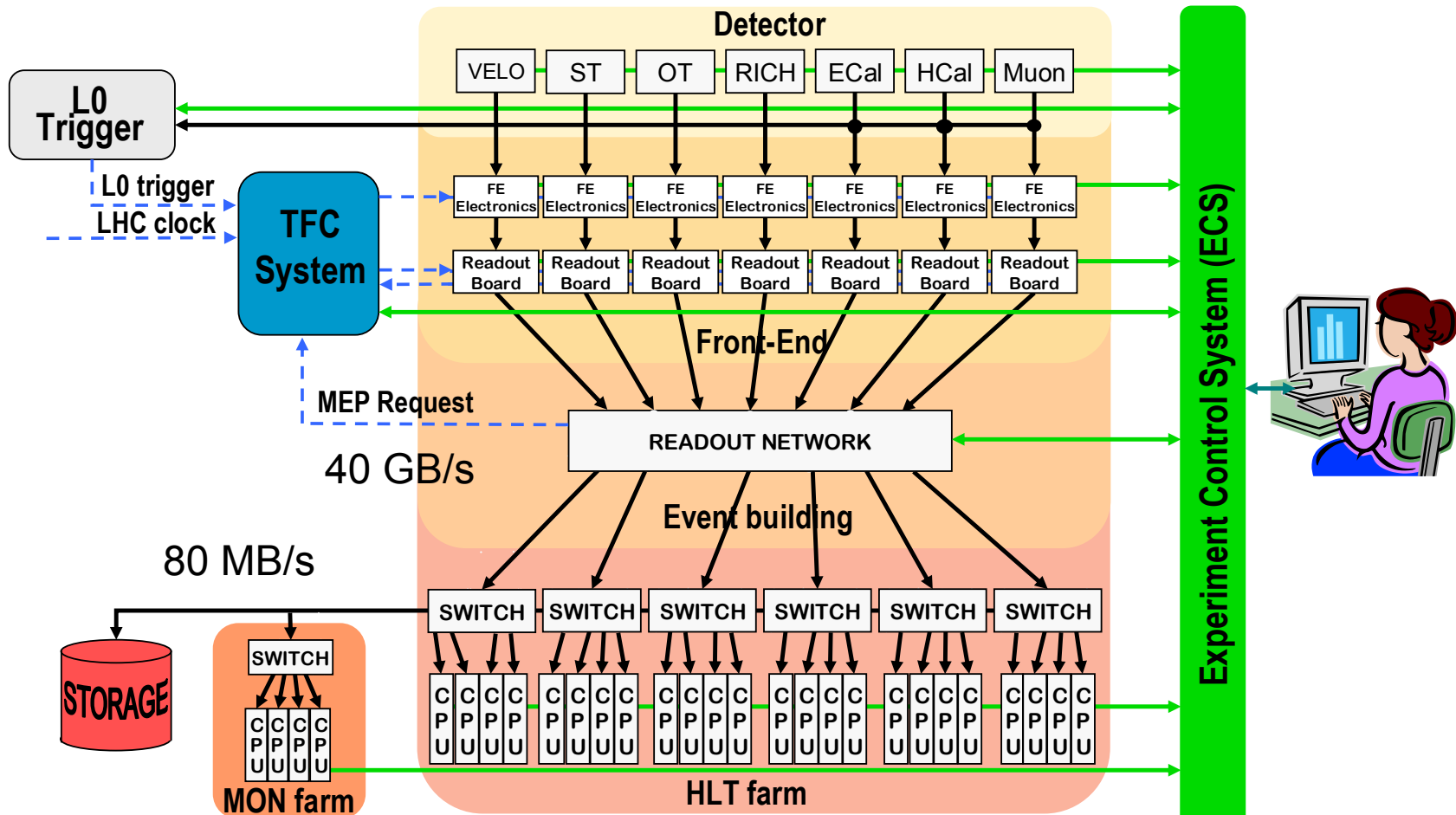
ALICE

1

25

1250

LHCb DAQ



— Event data
 - - - Timing and Fast Control Signals
 — Control and Monitoring data

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

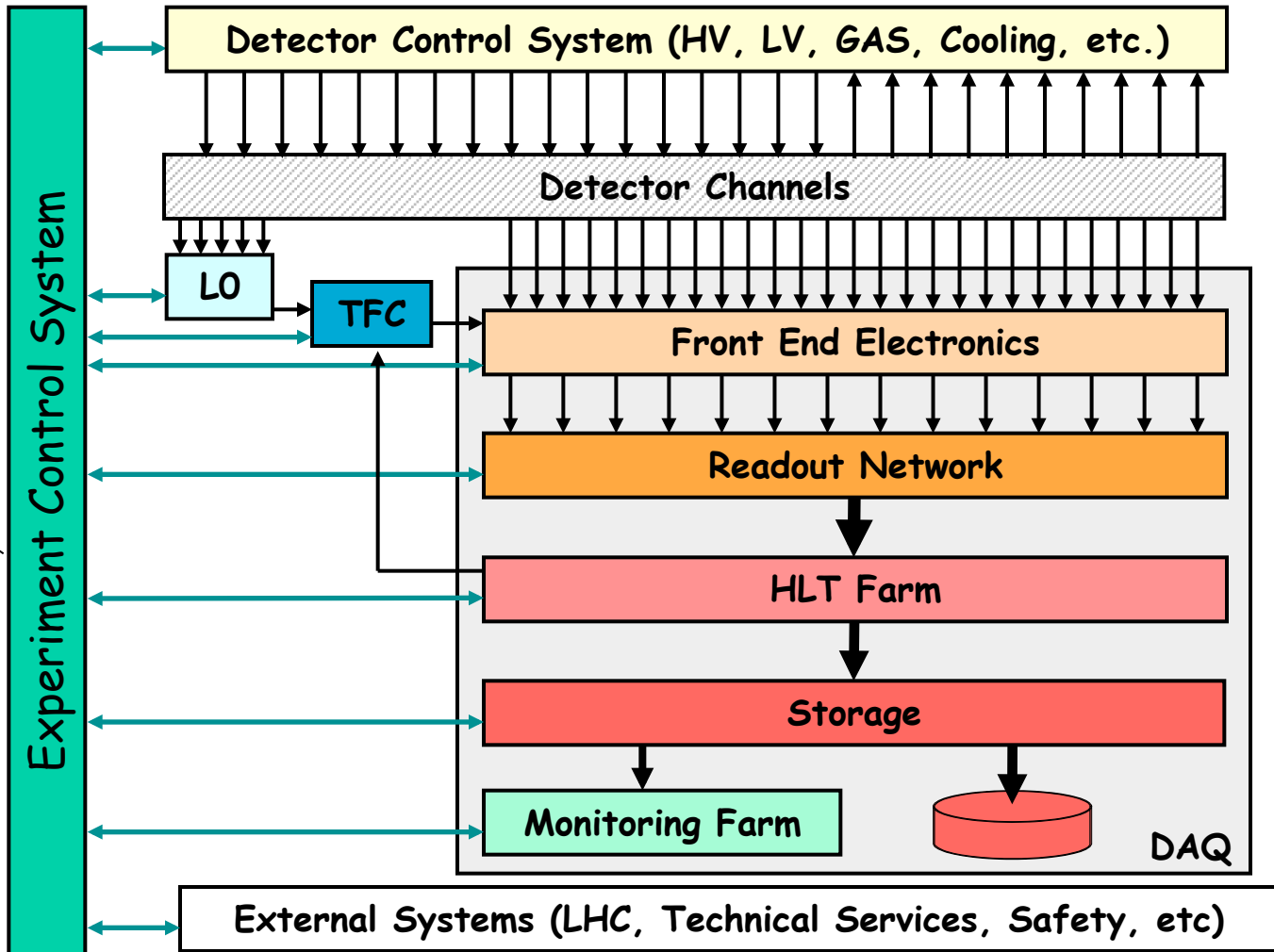
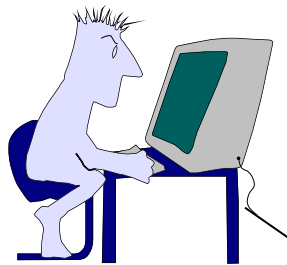


Configuration, Control and Monitoring

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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

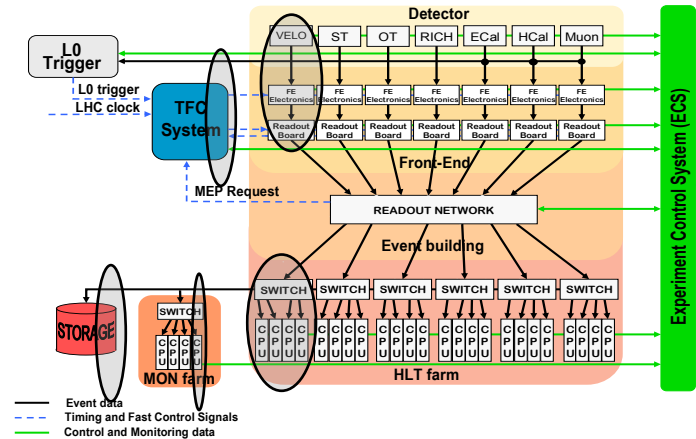
Partitioning

- | 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

LHCb: TOP Tue 20-Sep-2011 15:50:57
root

System: LHCb **State:** RUNNING **Auto Pilot:** ON

Sub-System	State
DCS	READY
DAI	READY
DAQ	RUNNING
RunInfo	RUNNING
TFC	RUNNING
HLT	RUNNING
Storage	RUNNING
Monitoring	RUNNING
Reconstruction	RUNNING
Calibration	RUNNING

Run Parameters:
Run Number: 102088
Run Start Time: 20-Sep-2011 15:50:22
Run Duration: 000:00:32
Nr. Events: 22518863
Step Nr: 0 To Go: 0

Activity: COLLISION
Trigger Configuration: Physics
Time Alignment: TAE half window L0 Gap
Max Nr. Events: Run limited to 0 Events
Automated Run with Steps: Step Run with 0 Steps Start at: 0

L0 Rate: 812092.82 Hz
HLT Rate: 5365.67 Hz
Dead Time: 5.37 %

Data Destination: Offline **Data Type:** COLLISION11 Automatic
File: /daqarea/lhcb/data/2011/RAW/FULL/LHCb/COLLISION11/102088 **Run DB**

Sub-Detectors:

Sub-Detector	State
TDET	HOT_READY
VELOA	RUNNING
VELOC	RUNNING
TT	RUNNING
IT	RUNNING
OTA	RUNNING
OTC	RUNNING
RICH1	RUNNING
RICH2	RUNNING
PRS	RUNNING

Trigger Components:

Component	State
ECAL	RUNNING
HCAL	RUNNING
MUONA	RUNNING
MUONC	RUNNING
L0DU	RUNNING
TCALO	RUNNING
TMUA	RUNNING
TMUC	RUNNING
TPU	RUNNING

Messages:
20-Sep-2011 15:50:21 - *** INFO - Max Run Time (60 minutes) Reached - Changing RUN...
20-Sep-2011 15:50:22 - LHCb executing action CHANGE_RUN
20-Sep-2011 15:50:22 - LHCb_TFC executing action STOP_TRIGGER
20-Sep-2011 15:50:24 - LHCb_TFC executing action START_TRIGGER
20-Sep-2011 15:50:28 - LHCb in state RUNNING

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



LHCb Big Brother

- DCS
- Overall Control

LHCb_LHC: TOP

LHCb System: Big Brother State: READY

Tue 20-Sep-2011 15:28:55
root

Sub-System	State
LHC	PHYSICS
BCM	READY
Magnet	READY
LHCb Clock	EXTERNAL

PHYSICS

Handshakes

LHC: STANDBY LHCb: VETO

Voltages

System	State	Requested	Settings
LHCb_LHC_HV&LV	OK	PHYSICS	PHYSICS

Sub-Detector	State	Req. HV	%Ok	HV State (A/C)	Settings
VELO_LHC_HV	OK	READY	100.00	READY	READY
TT_LHC_HV	OK	READY	100.00	READY	
IT_LHC_HV	OK	READY	100.00	READY	
OT_LHC_HV	OK	READY	100.00	READY	READY
RICH1_LHC_HV	OK	READY	100.00	READY	
RICH2_LHC_HV	OK	READY	100.00	READY	
PRS_LHC_HV	OK	READY	100.00	READY	
ECAL_LHC_HV	OK	READY	100.00	READY	
HCAL_LHC_HV	OK	READY	100.00	READY	
MUON_LHC_HV	OK	READY	99.54	READY	READY

Sub-Detector	State	Requested LV	LV State (A/C)	Settings
VELO_LHC_LV	OK	READY	READY	READY
TT_LHC_LV	OK	READY	READY	
IT_LHC_LV	OK	READY	READY	
RICH1_LHC_LV	OK	READY	READY	
RICH2_LHC_LV	OK	READY	READY	

LHC

Mode: PROTON PHYSICS Fill Number: 2129 Energy: 3500 GeV

Magnet

Set Current: 5850 A Measured Current: 5850.0 A Polarity: DOWN

DB Interfaces

Run DB Server: Cond DB Server: PVSS Archive:

VELO Closing Manager

Motion: ALLOWED State: CLOSED

Beam Position: X: 0.45 mm Y: -0.02 mm
Motion System Position: XA: 0.45 mm XC: 0.45 mm Y: -0.01 mm

Status: v8.4
20-Sep 13:09:49 - Report: conditions OK
20-Sep 13:09:49 - Current: BPM values frozen.
20-Sep 14:09:54 - Report: conditions OK
20-Sep 14:09:54 - Current: BPM values frozen.
20-Sep 15:09:59 - Report: conditions OK
20-Sep 15:09:59 - Current: BPM values frozen.

Safety

Sub-Detector	State
TT_Safety	READY
IT_Safety	READY
OT_Safety	DEAD
RICH_Safety	READY
MUON_Safety	READY

Messages

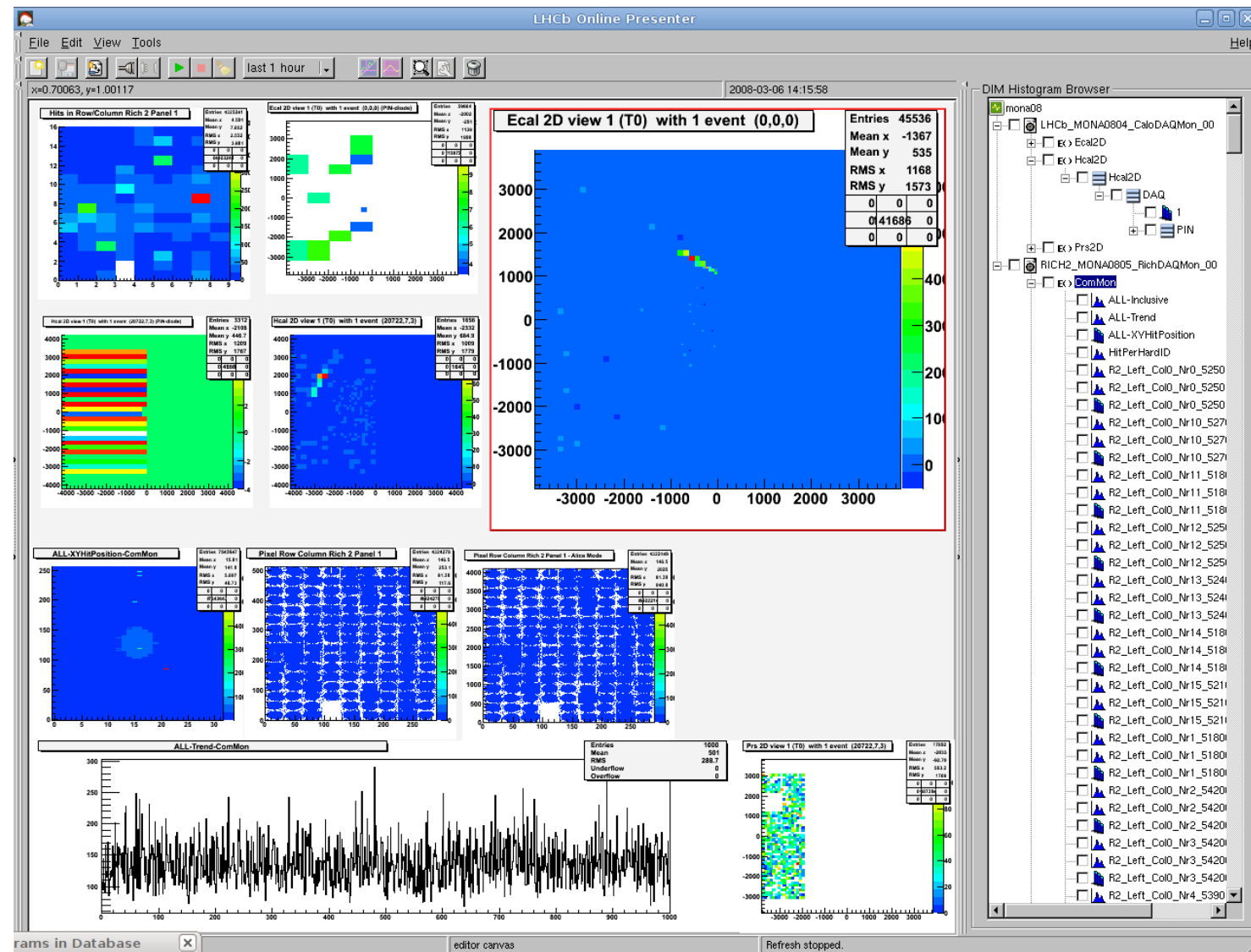
20-Sep-2011 10:05:27 - LHC_STATE in state PHYSICS
20-Sep-2011 10:05:28 - *** INFO - Confirm Prepare PHYSICS
20-Sep-2011 10:05:39 - *** INFO - Action Confirmed

Close



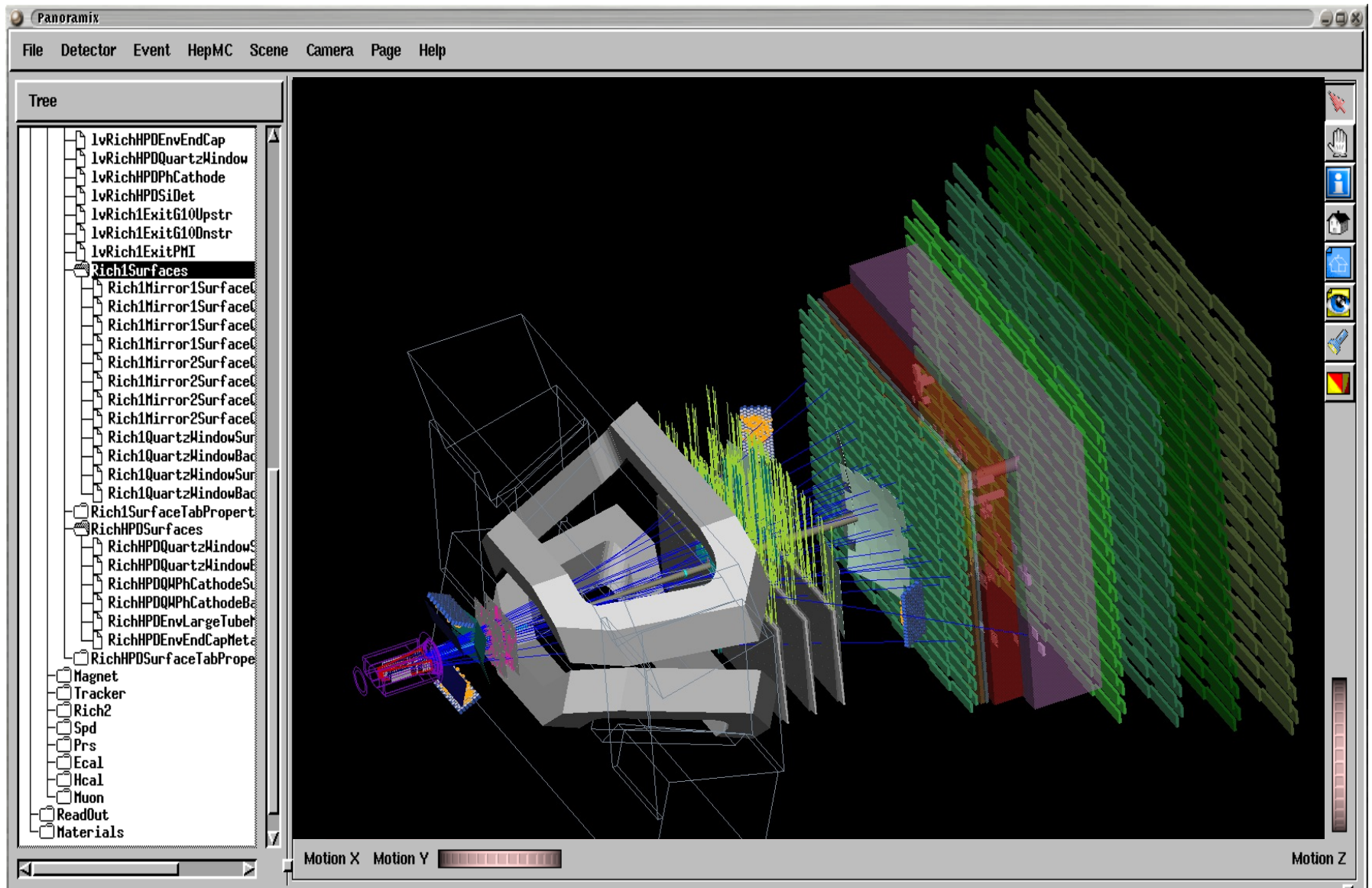
LHCb Histogram Presenter

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





LHCb Online Event Display



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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.