



Data Acquisition, Trigger and Control (for large Physics Experiments)

Concepts & Principles

Clara Gaspar, July 2023

Acknowledgements:

This presentation is based on the work of many people throughout many years, Thanks!

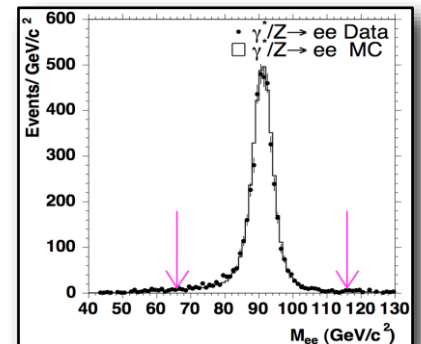
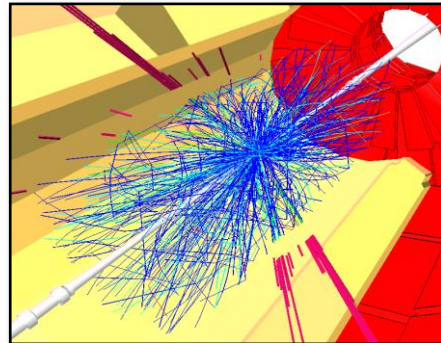
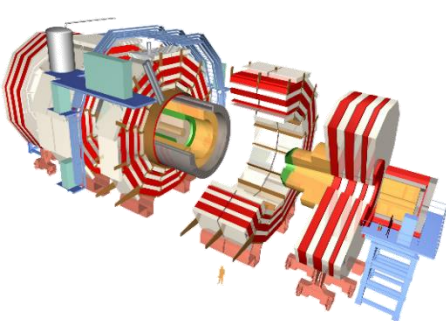


The LHC Experiments

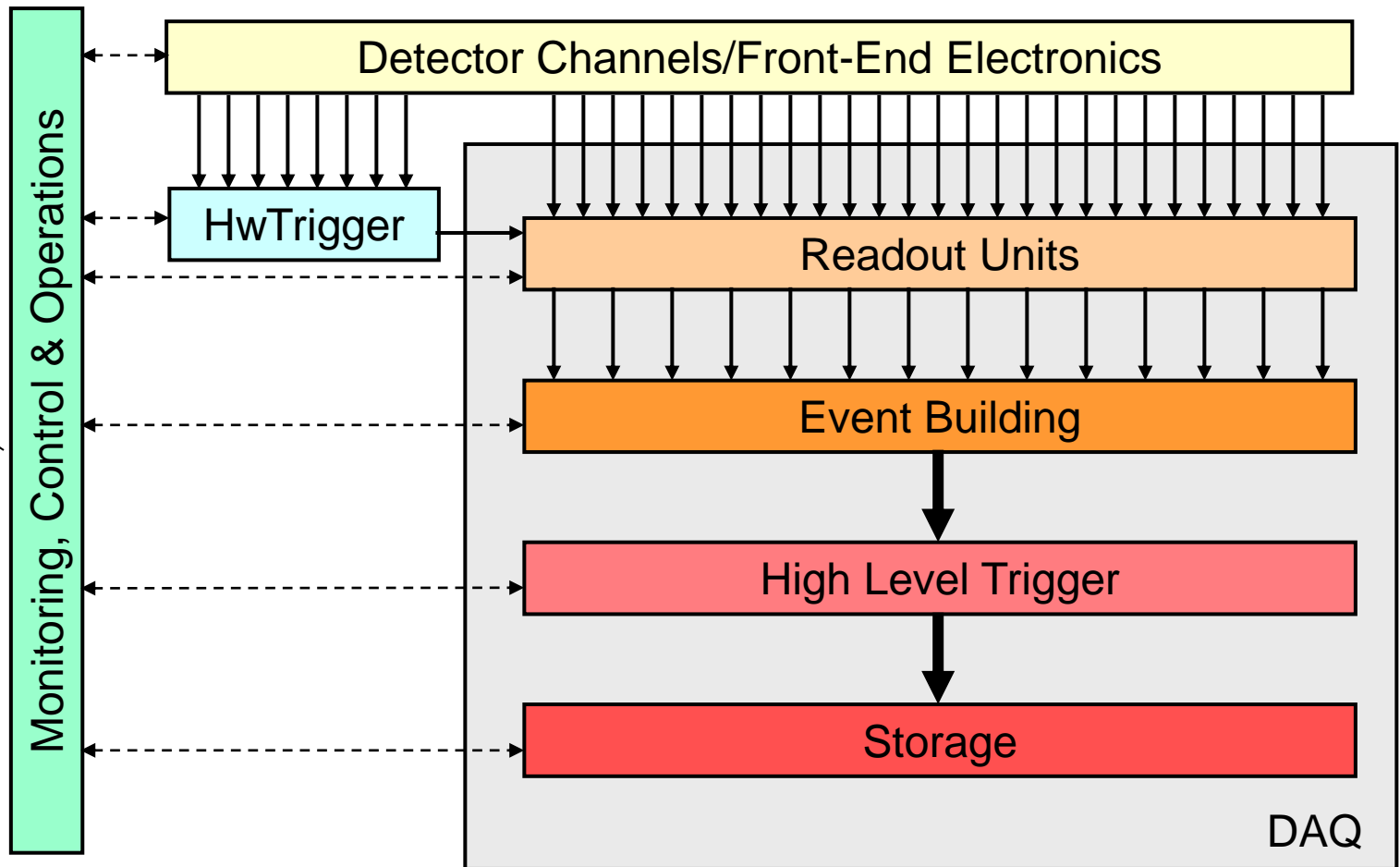


Data Acquisition at the LHC

- Data Acquisition enables physics analyses to be performed on the data produced by the detector. 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
 - Provides the overall Operation, Configuration and Monitoring



Trigger, DAQ & Control



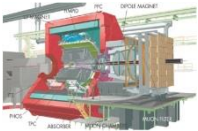
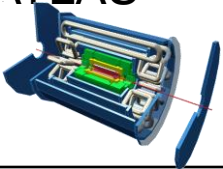
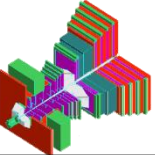


LHC in Numbers

| | LHC (2009) |
|-------------------------|--------------------------------|
| Bunch Crossing Rate | 40 MHz |
| Bunch Separation | 25 ns |
| Nr. Electronic Channels | $\approx 10\,000\,000$ |
| Raw data rate | $\approx 1\,000\text{ TB/s}$ |
| Data rate on Tape | $\approx 100\text{ MB/s}$ |
| Event size | $\approx 1\text{ MB}$ |
| Rate on Tape | 100 Hz |
| Analysis | 10^{-6} Hz (Higgs) |

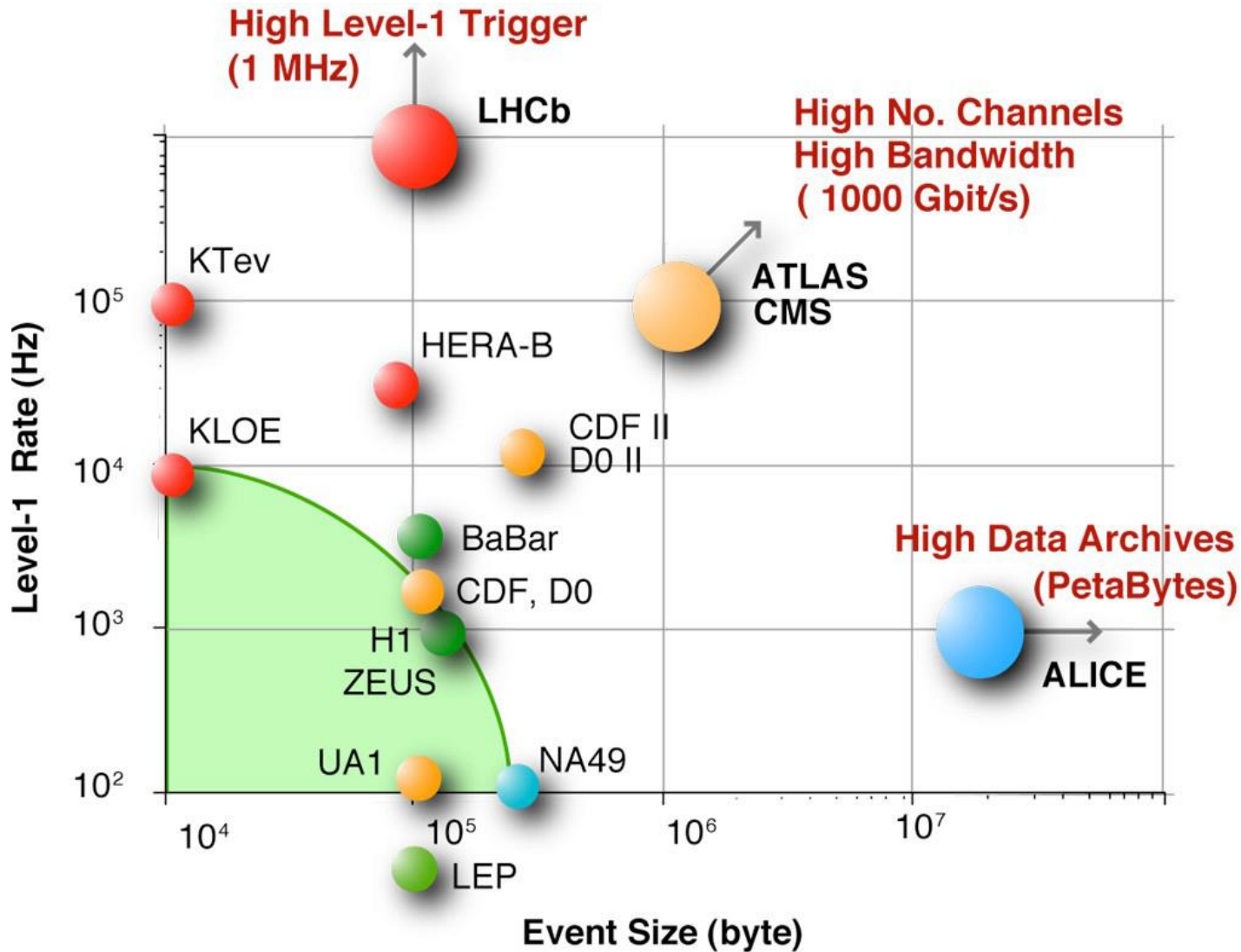


LHC Exp DAQ (until 2020)

| | Event Size (MByte) | L1 Rate (KHz) | Bandwidth (GByte/s) | Storage Rate (KHz) | Storage (GBytes/s) |
|---|-----------------------|------------------|------------------------|-----------------------|-----------------------|
| ALICE  | 25 | 1 | 25 | 0.050 | 1.250 |
| ATLAS  | 1 | 100 | 100 | 0.200 | 0.200 |
| CMS  | 1 | 100 | 100 | 0.200 | 0.200 |
| LHCb  | 0.05 | 1000 | 50 | 5 | 0.250 |



LHC DAQ Phase-space

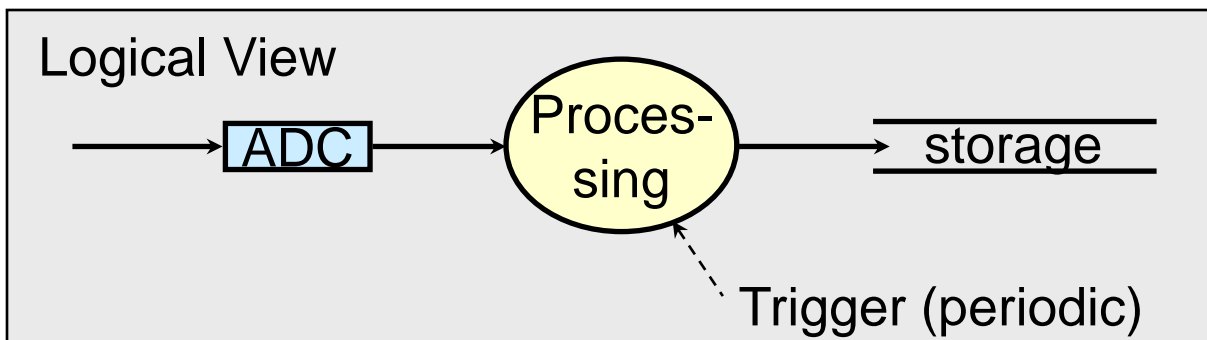
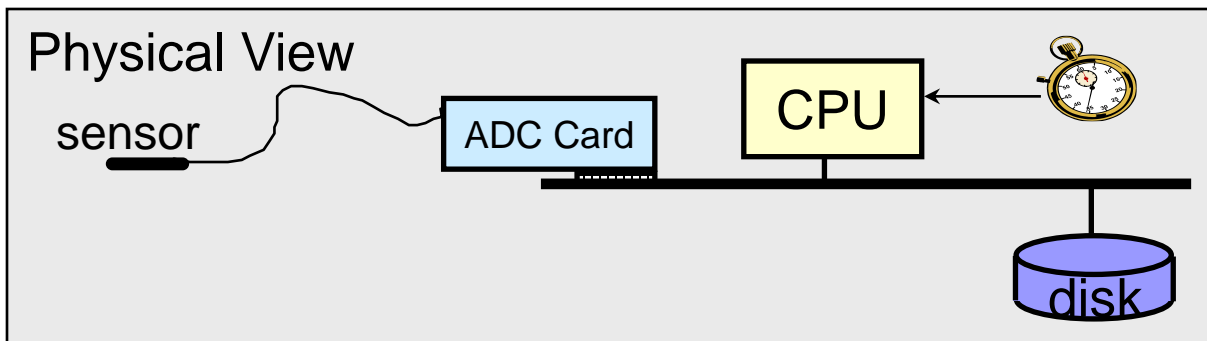
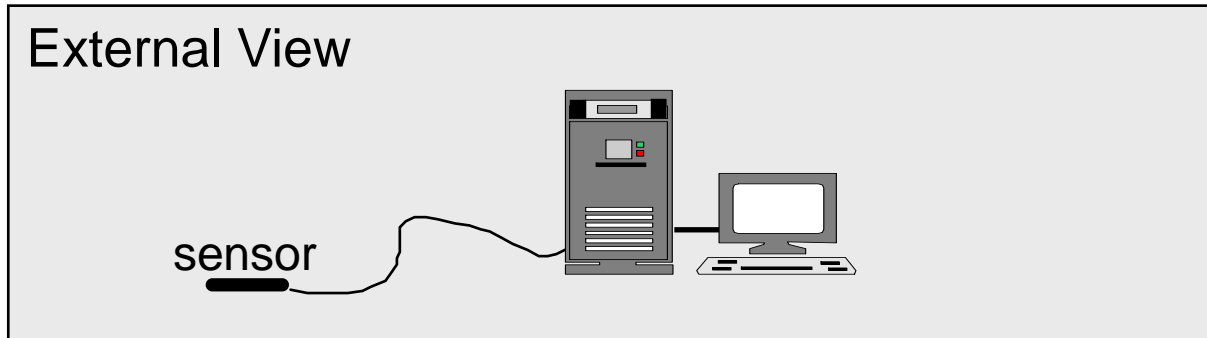




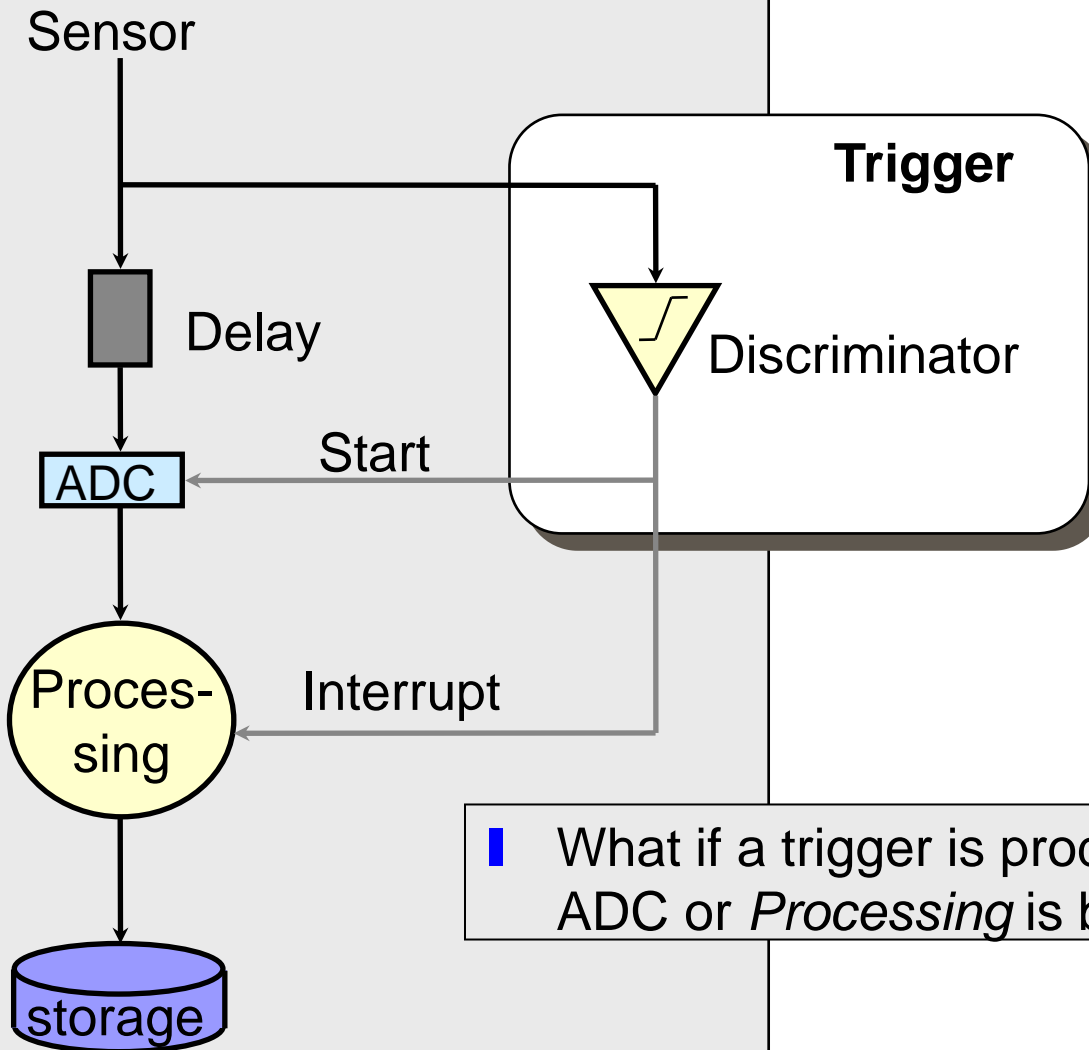
Basic Concepts

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Trivial DAQ

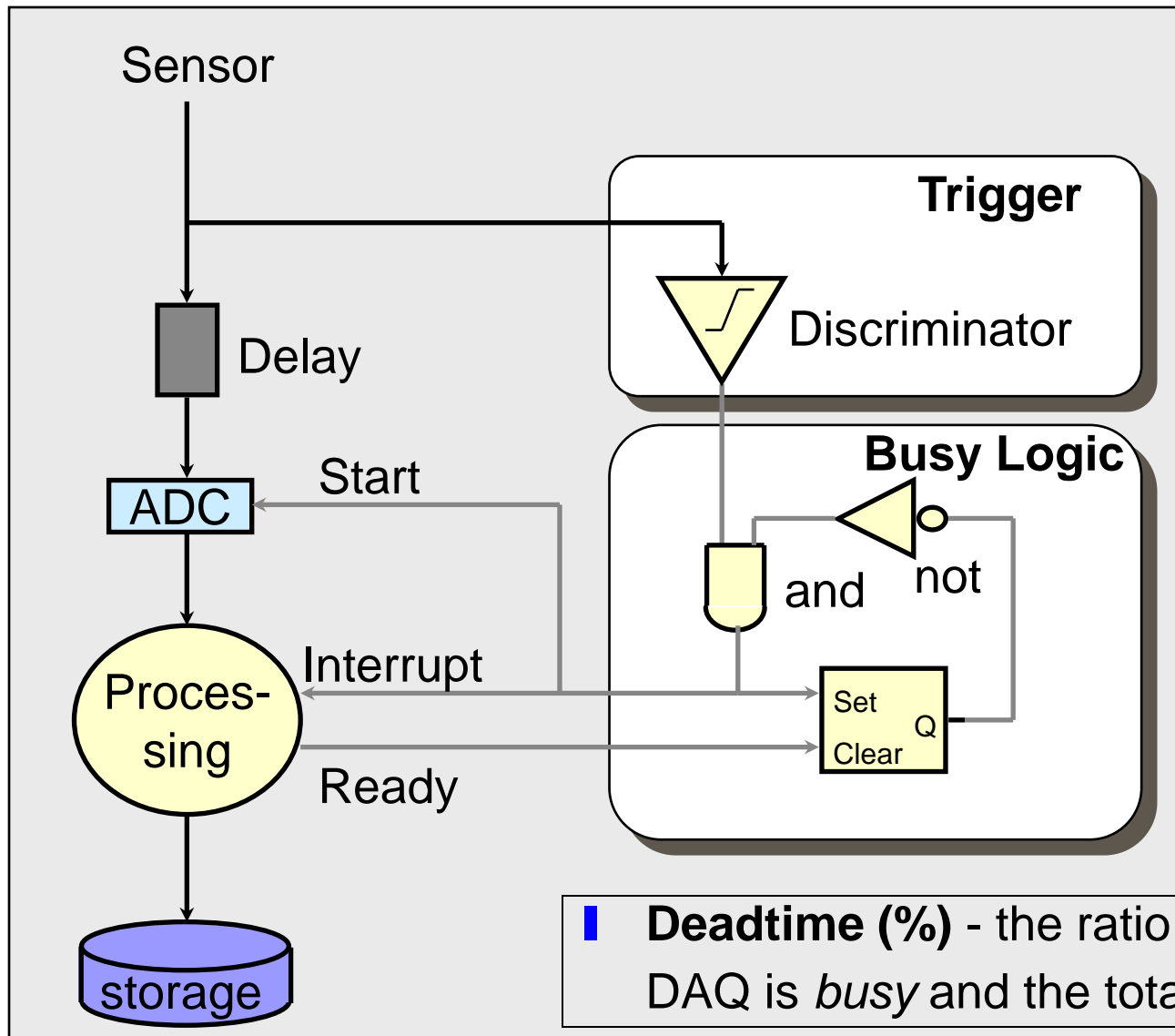


Trivial DAQ with a real trigger



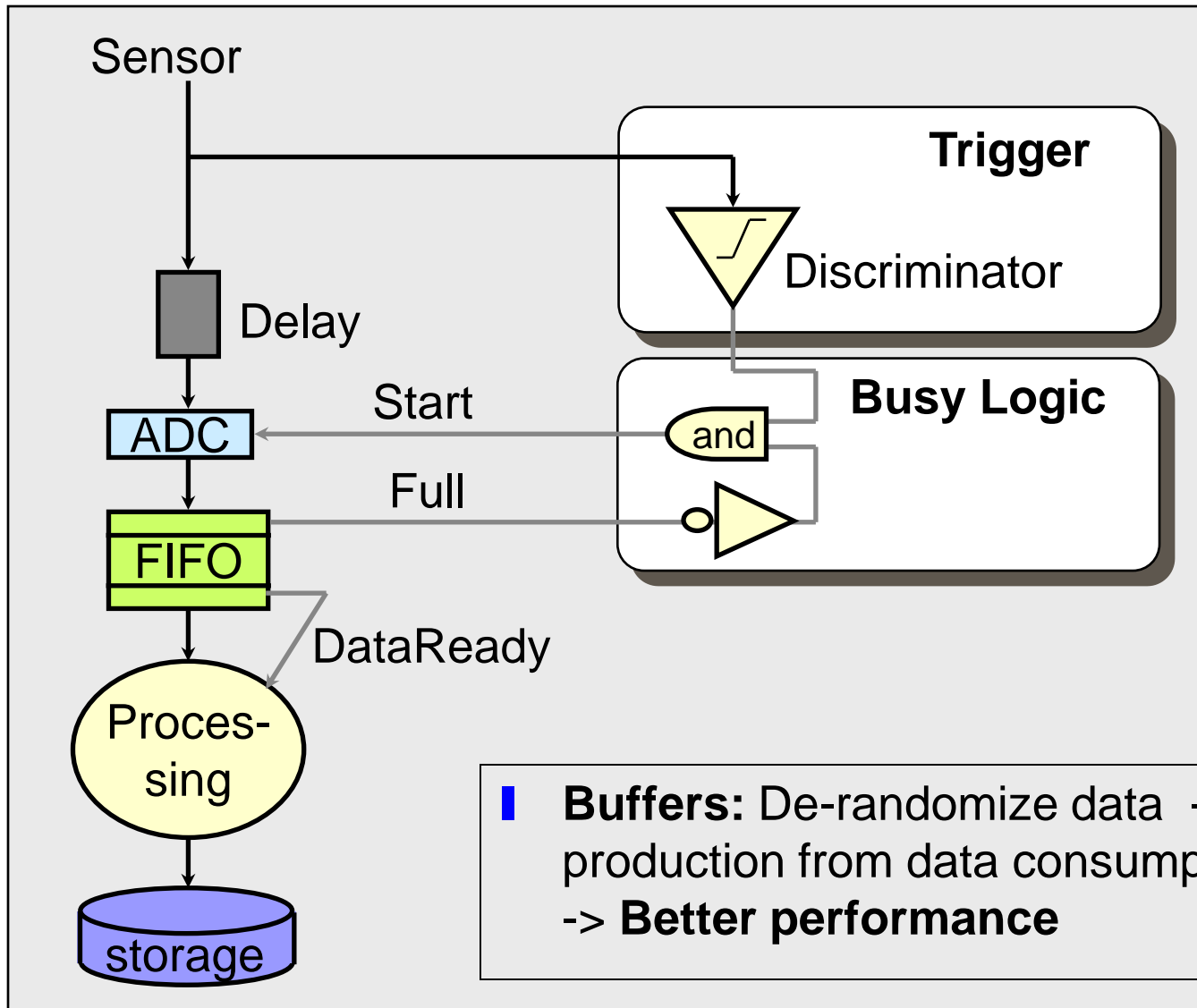
■ What if a trigger is produced when the ADC or *Processing* is busy ?

Trivial DAQ with a real trigger (2)



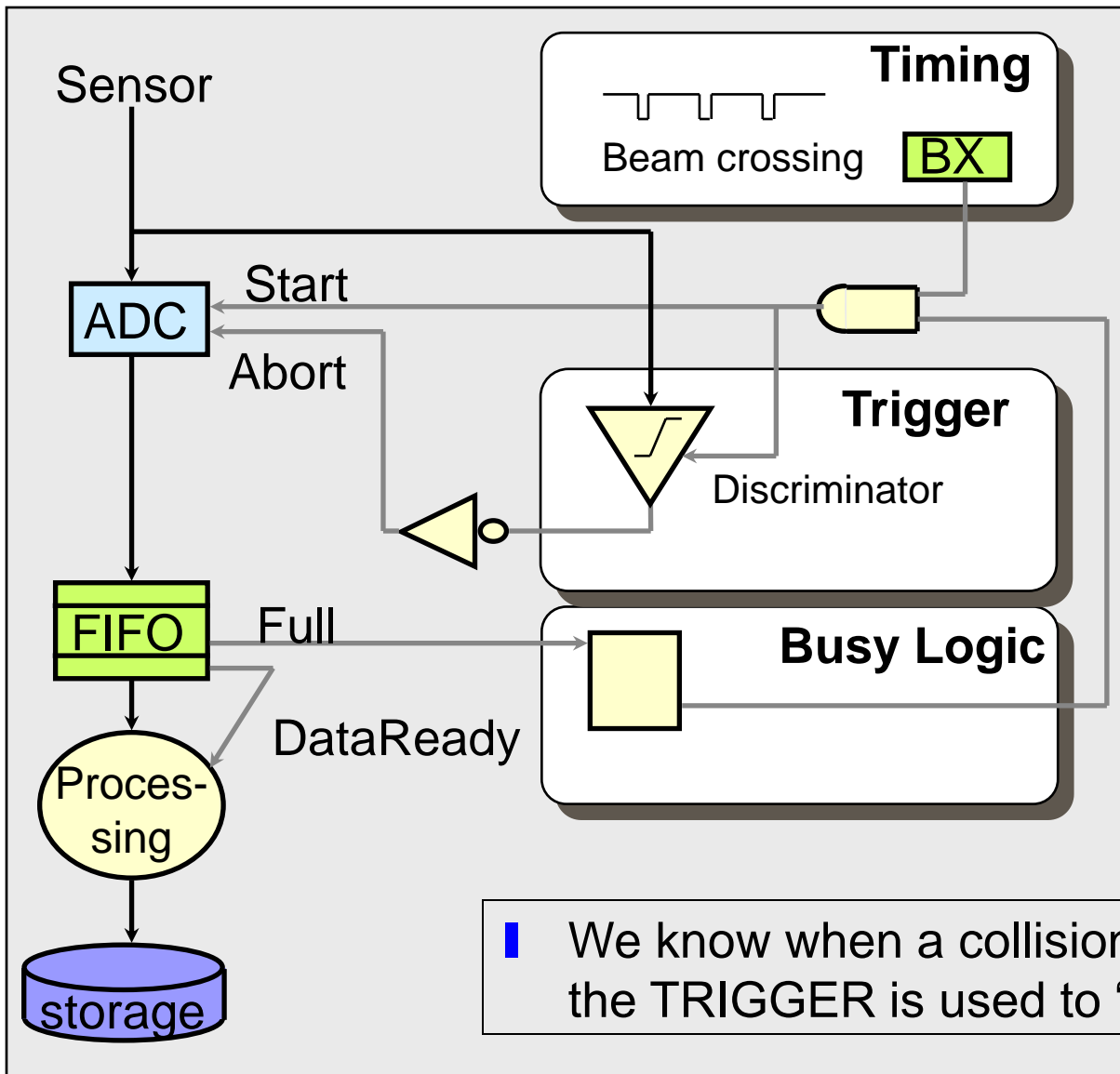
■ **Deadtime (%)** - the ratio between the time the DAQ is *busy* and the total time

Trivial DAQ with a real trigger (3)



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

Trivial DAQ in collider mode

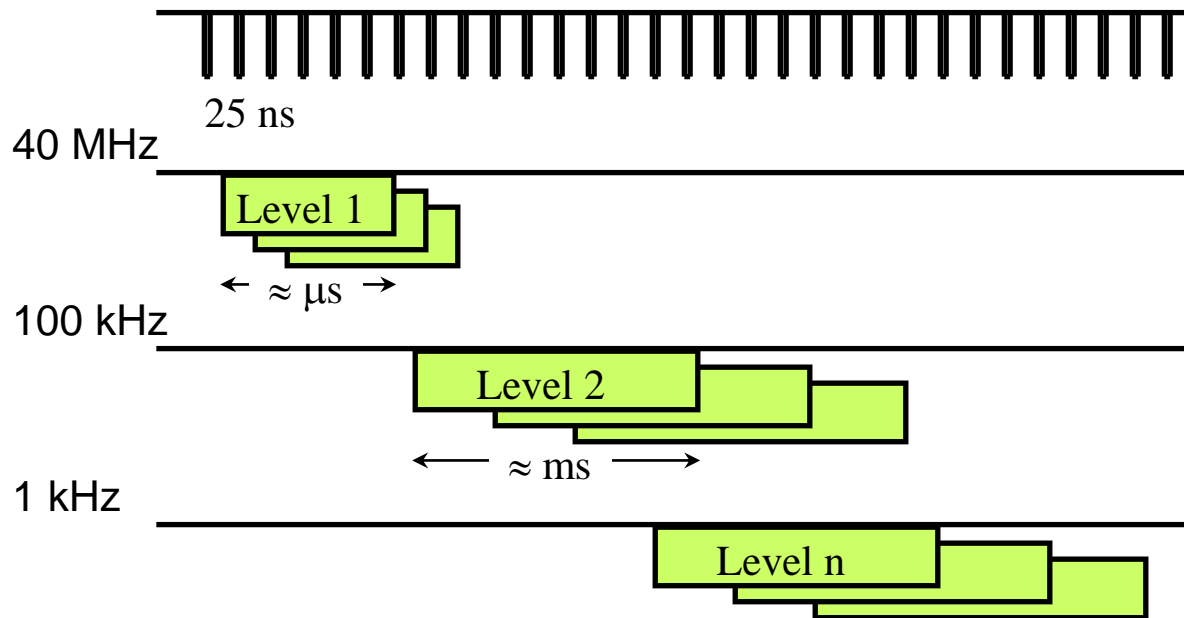


■ We know when a collision happens the TRIGGER is used to “reject” the data



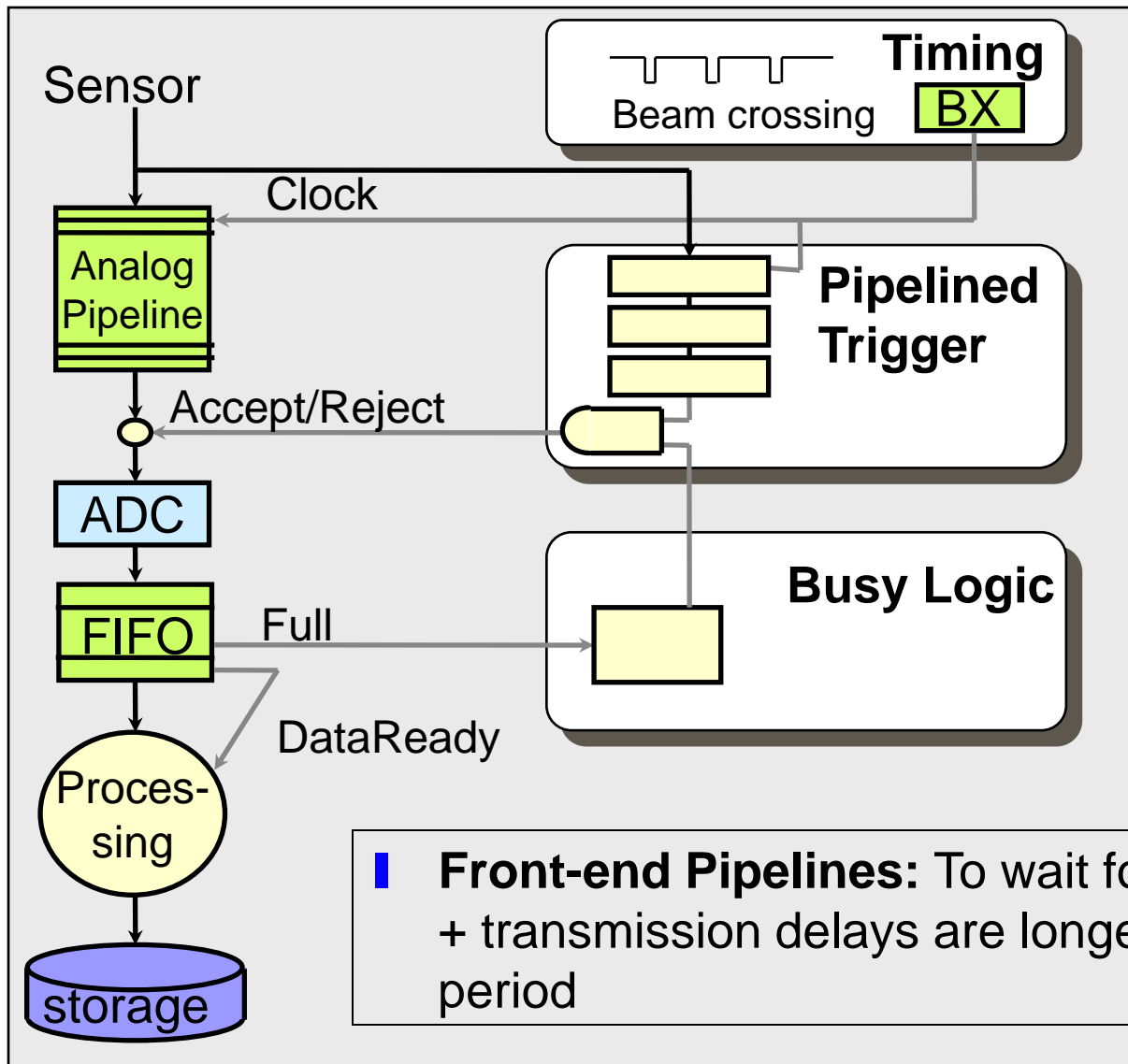
LHC timing

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



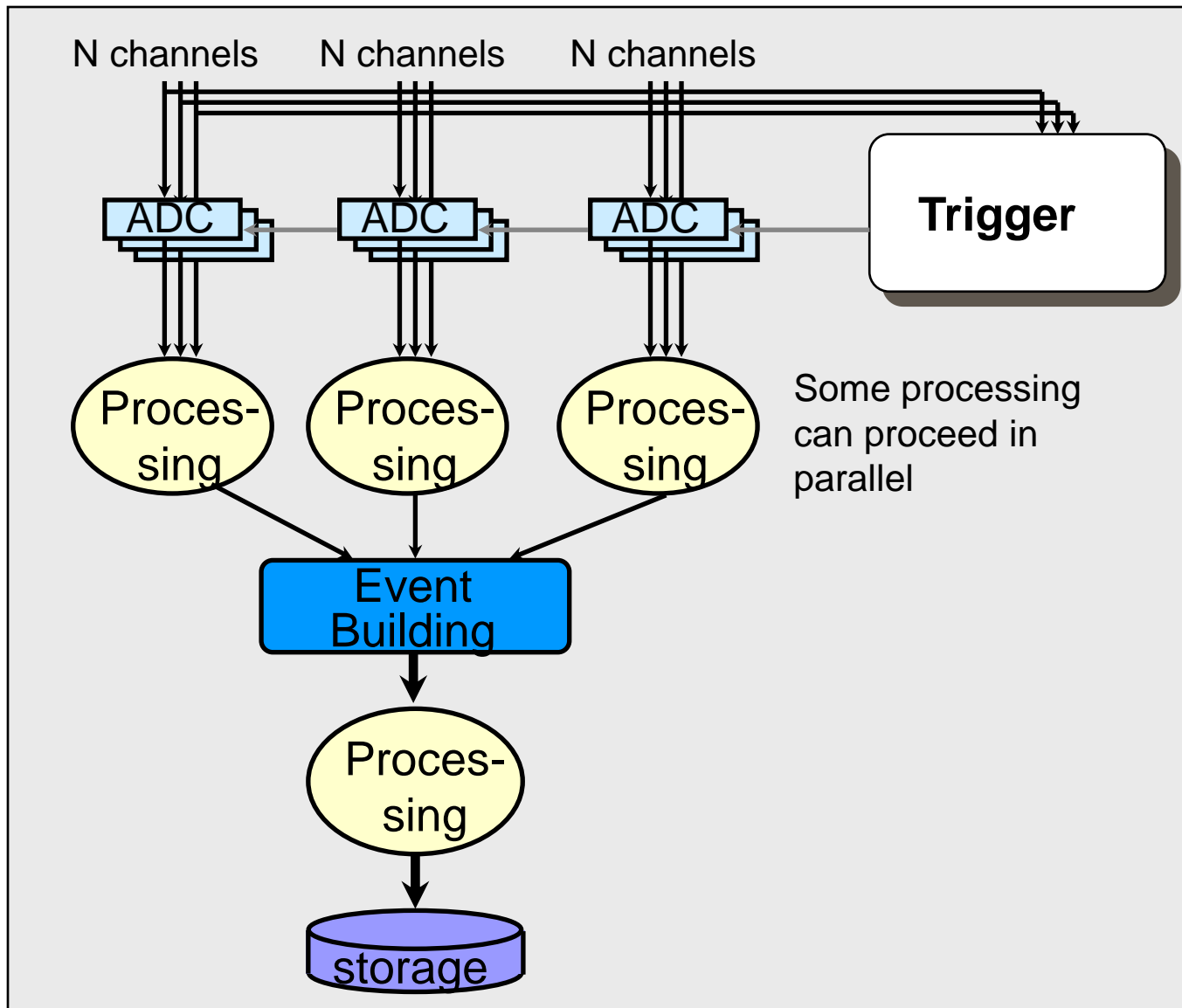
- Level 1 trigger time exceeds bunch interval
- Event overlap & signal pileup (multiple crossings since the detector cell memory greater than 25 ns)
- Very high number of channels

Trivial DAQ in LHC

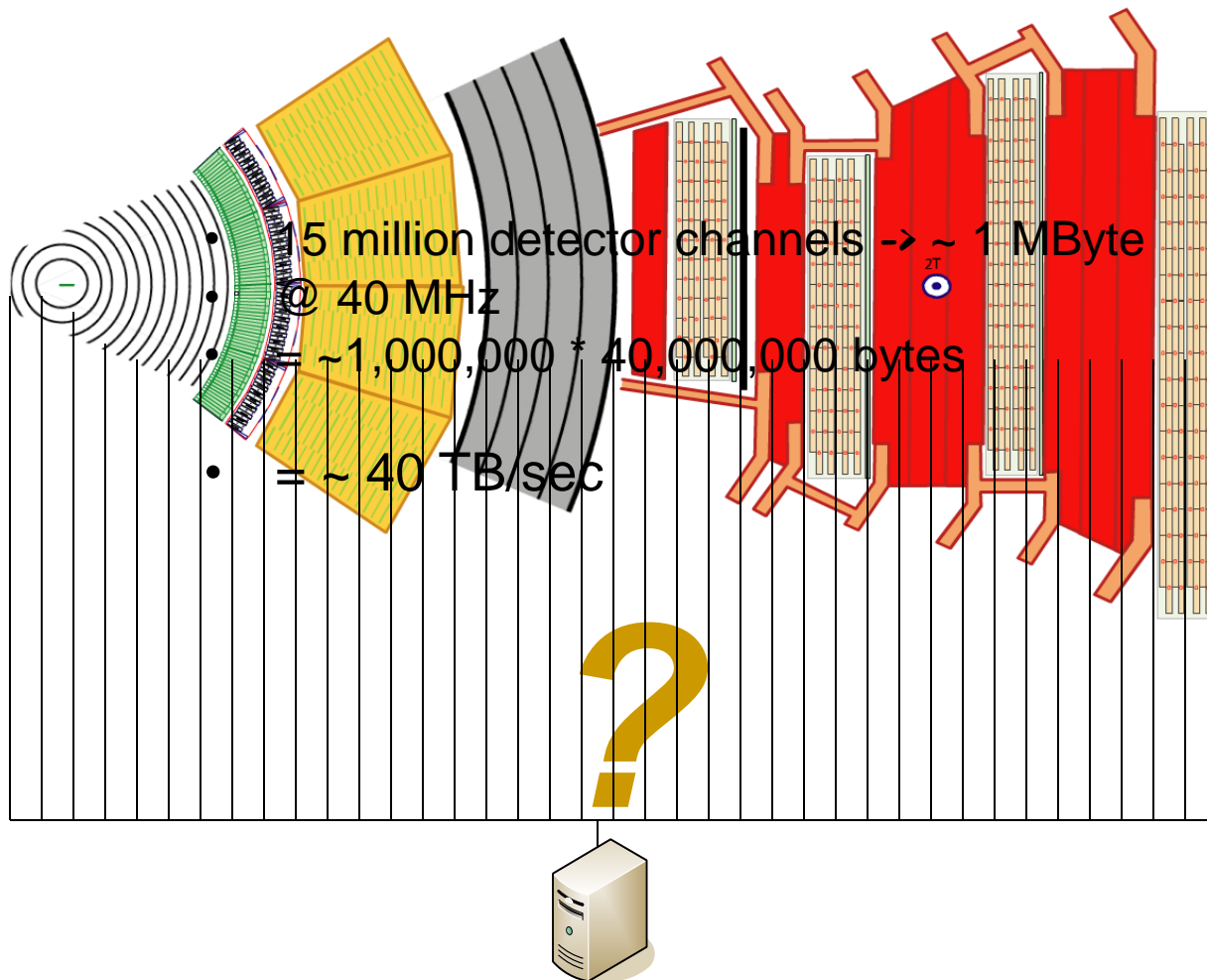


■ **Front-end Pipelines:** To wait for the trigger decision + transmission delays are longer than beam crossing period

Less trivial DAQ



The Real Thing



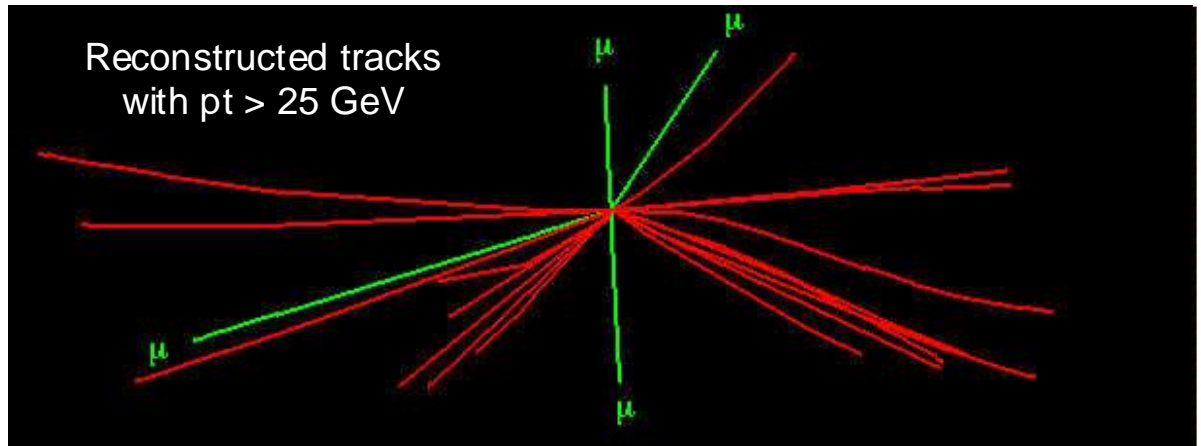
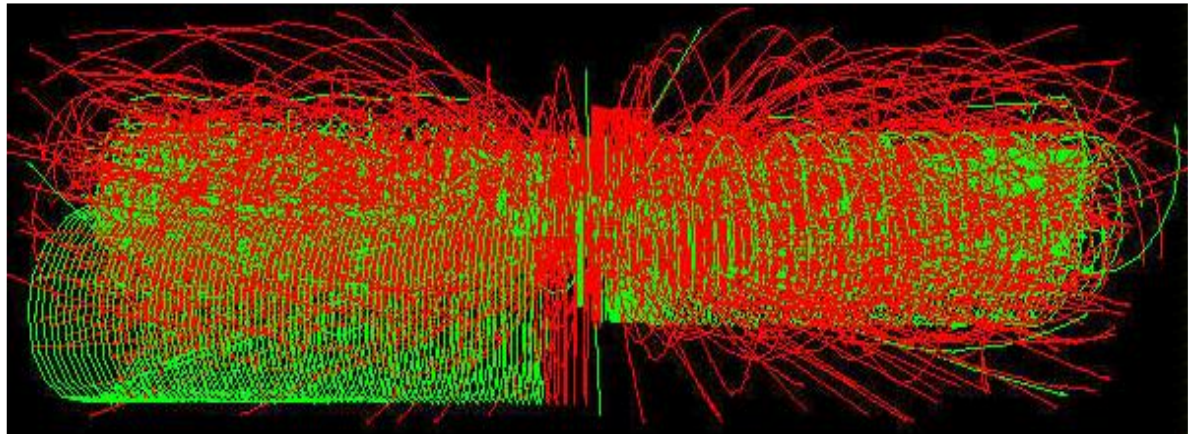


Trigger

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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
 - | Normally implemented using custom electronics
 - ➔ 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)

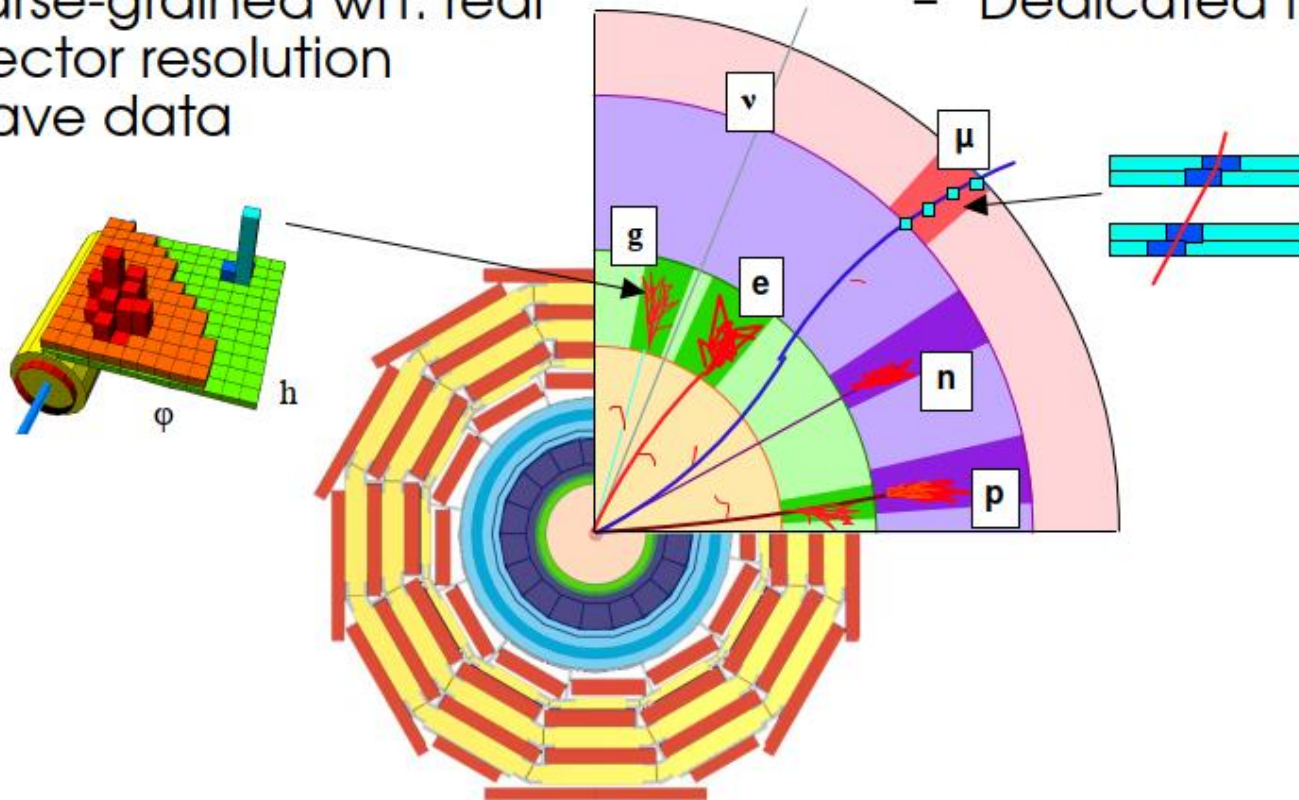
Hardware Trigger

- Calorimeters

- Cluster finding
- Energy deposition evaluation
- Coarse-grained wrt. real detector resolution to save data

- Muon systems

- Track finding
- Momentum evaluation
- Dedicated fast sensors





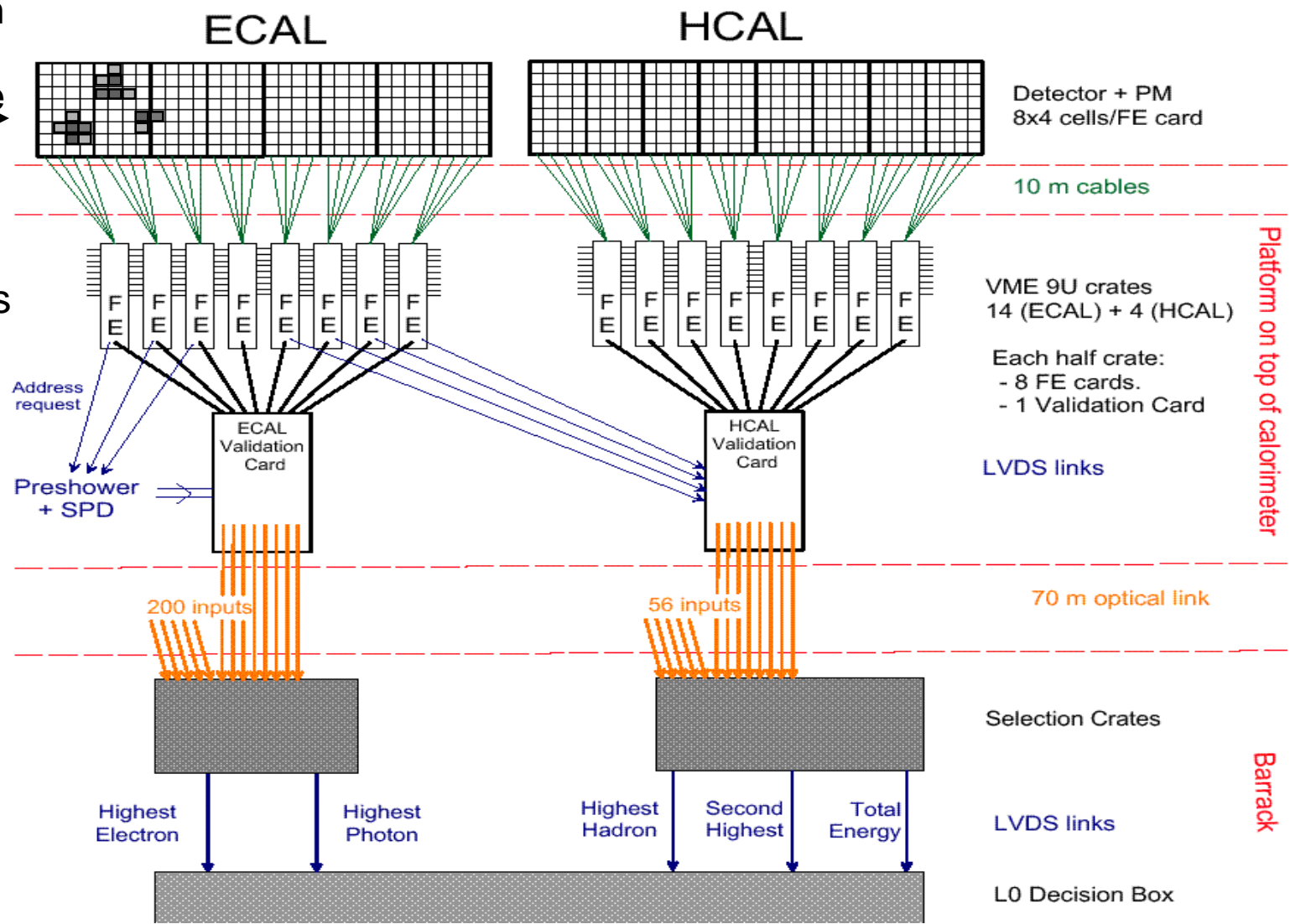
Example: LHCb Calorimeter Trigger

■ Detect a high energy in a small surface

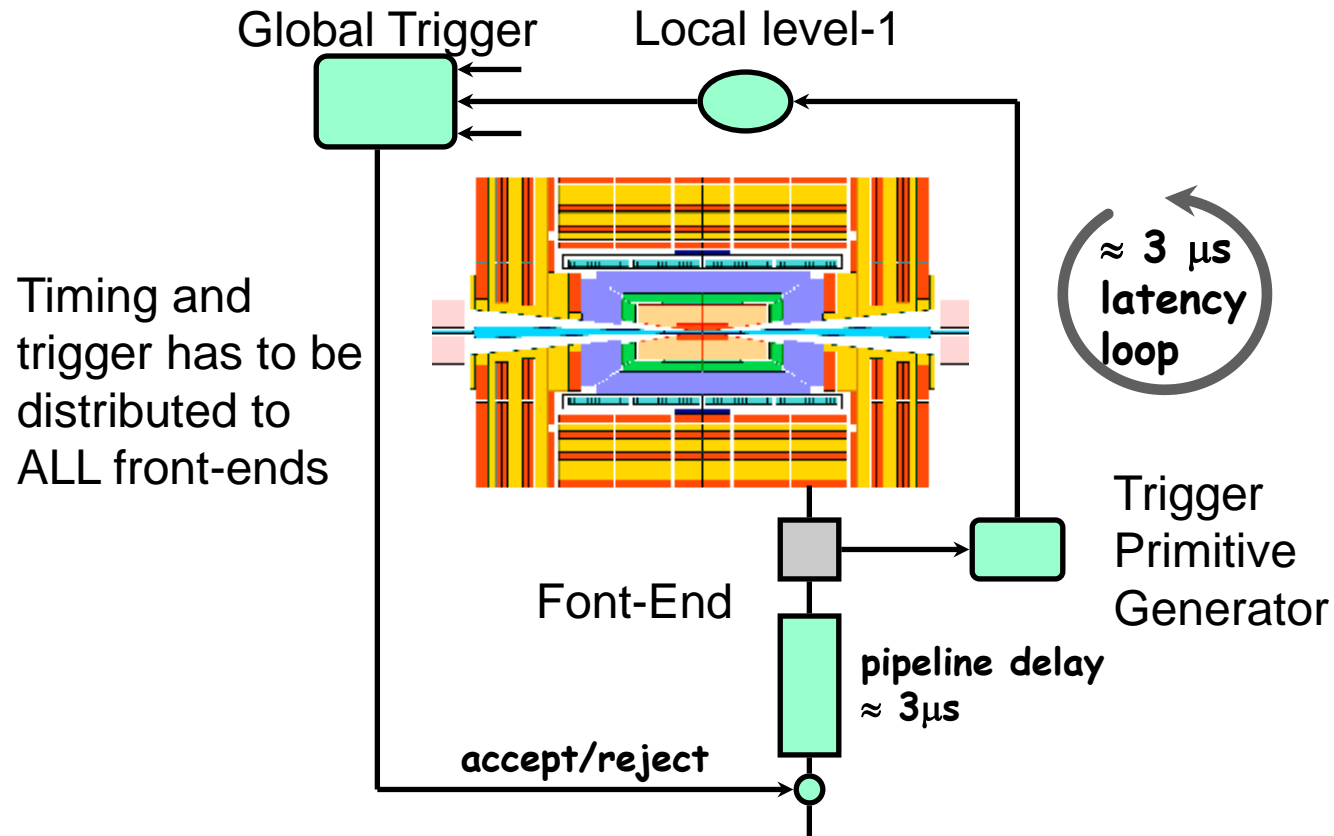
■ Don't forget the neighbors

■ Aggregate information

■ Evaluate decision(s)

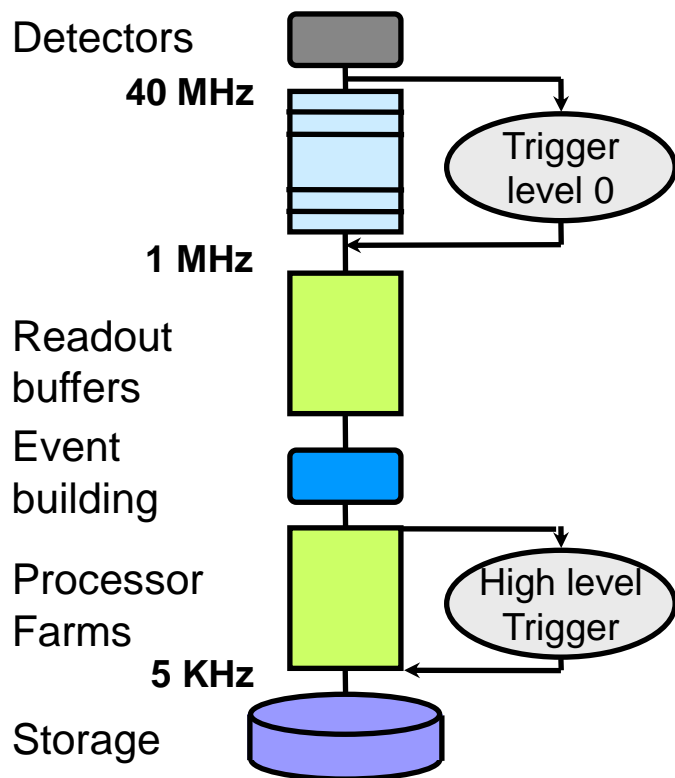


LHC: Trigger communication loop



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

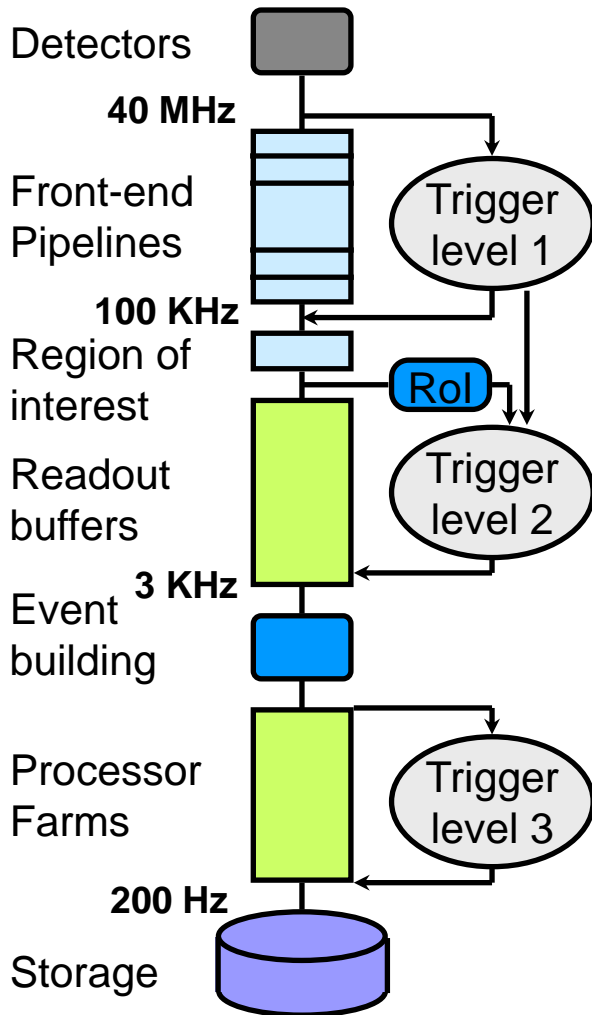
Trigger Levels in LHCb (up to 2020)



- Level-0 ($4 \mu\text{s}$) (custom processors)
 - High p_T for electrons, muons, hadrons
- HLT ($\approx \text{ms}$) (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 μ s) (custom processors)
 - Energy clusters in calorimeters
 - Muon trigger: tracking coincidence matrix.
- Level-2 (\approx ms) (\sim commercial processors)
 - Few Regions Of Interest relevant to trigger decisions
 - Selected information (ROI) by routers and switches
 - More sophisticated algorithms on full-granularity data
- Level-3 (\approx s) (commercial processors)
 - Reconstructs the event using all data
 - Selection of interesting physics channels

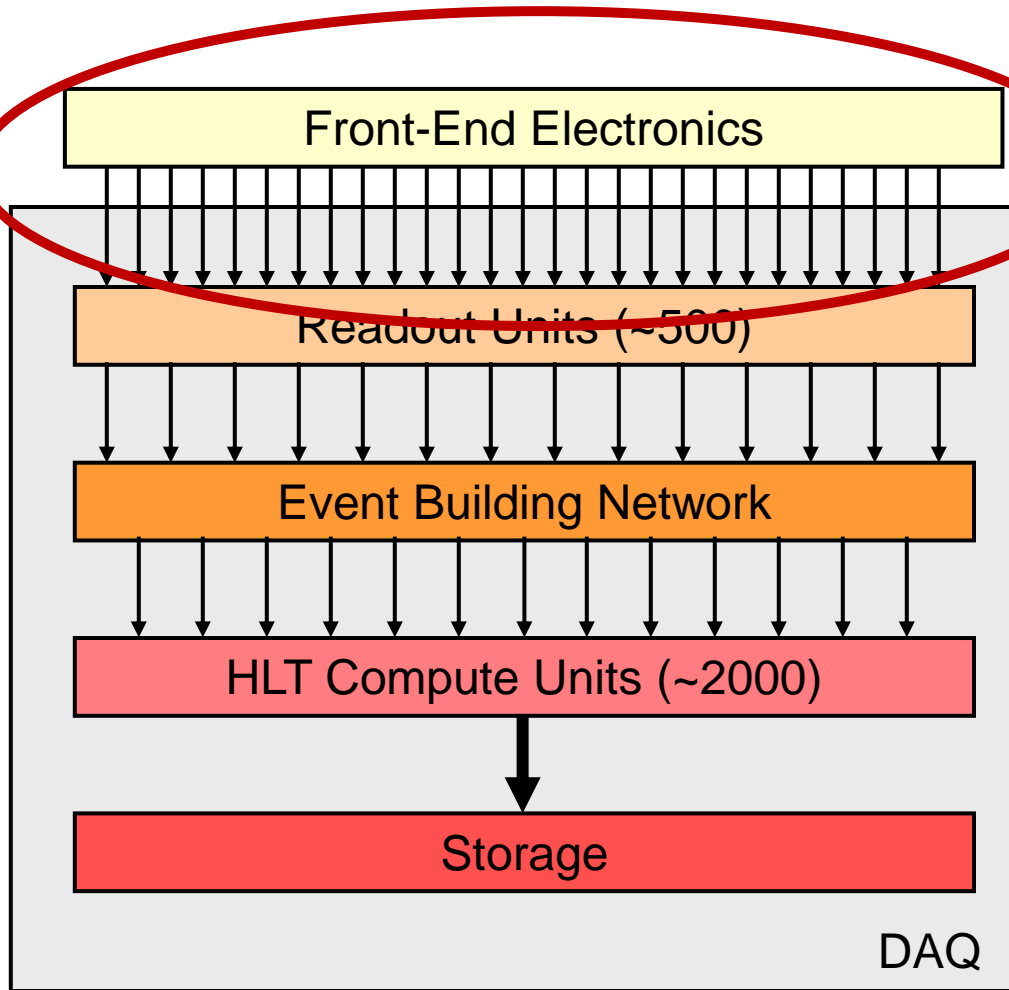


Data Acquisition

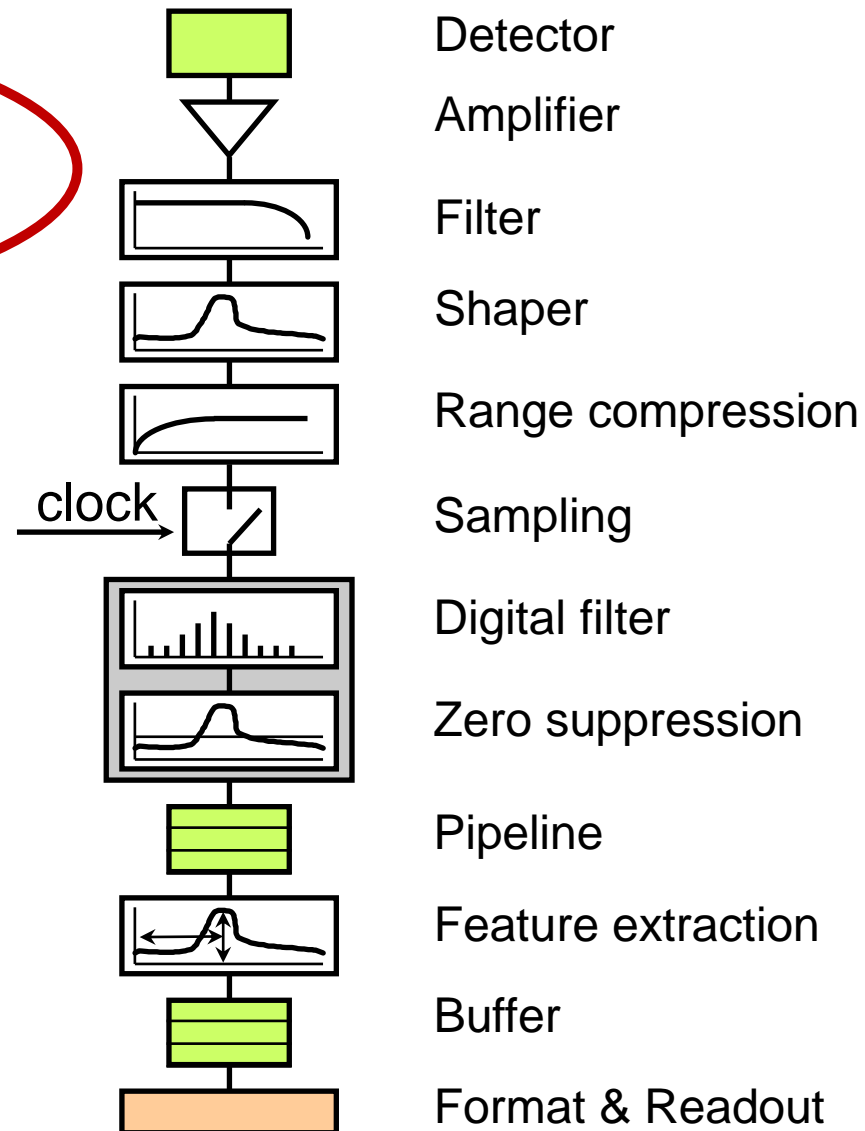
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Front-end electronics



↓ Custom point-to-point radiation-hard links

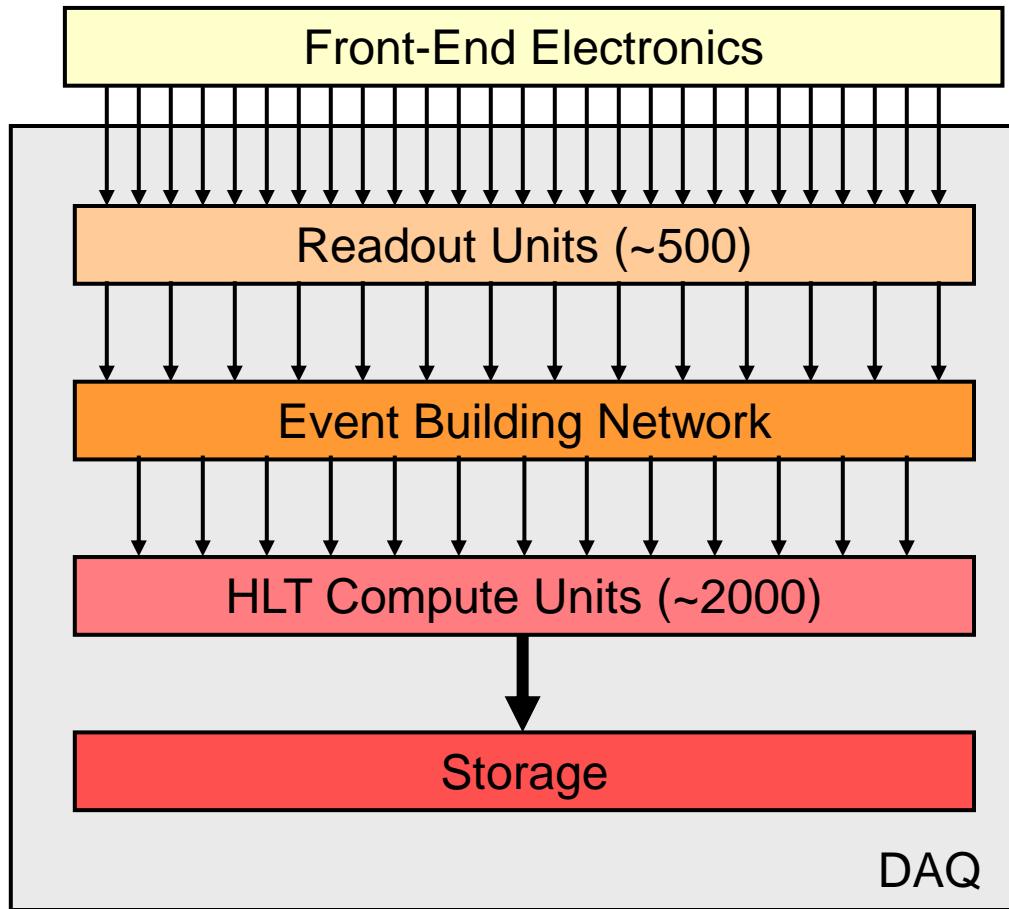




Front-End Electronics

- **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

Data Acquisition proper



- Every Readout Unit has a piece of the collision data tagged with a unique id
- All pieces must be brought together into a single Compute unit
- The Compute Unit runs the software filtering (High Level Trigger)



Event Building to a CPU farm

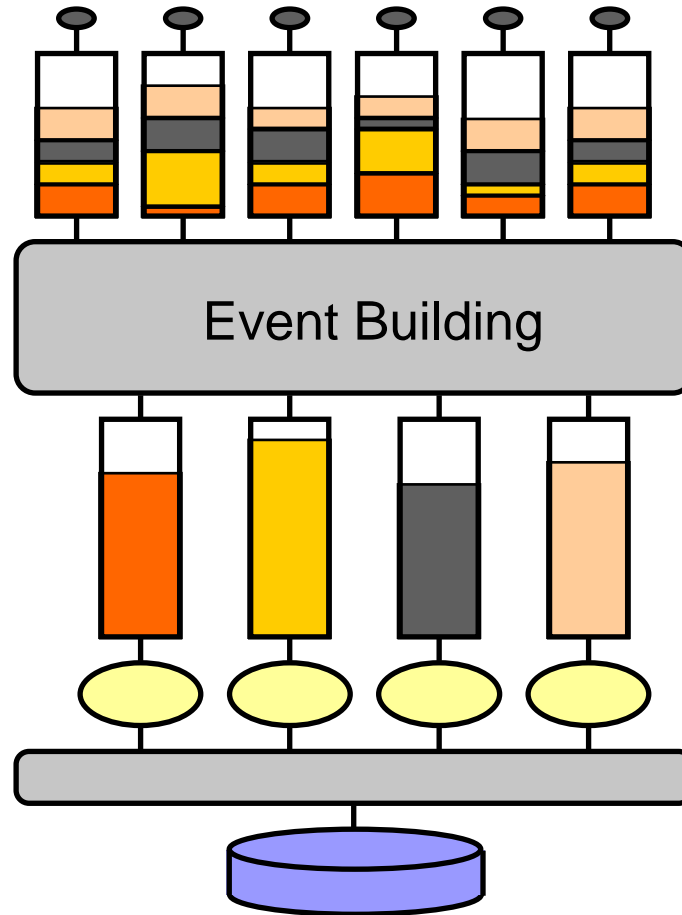
Data sources

Event Fragments

Full Events

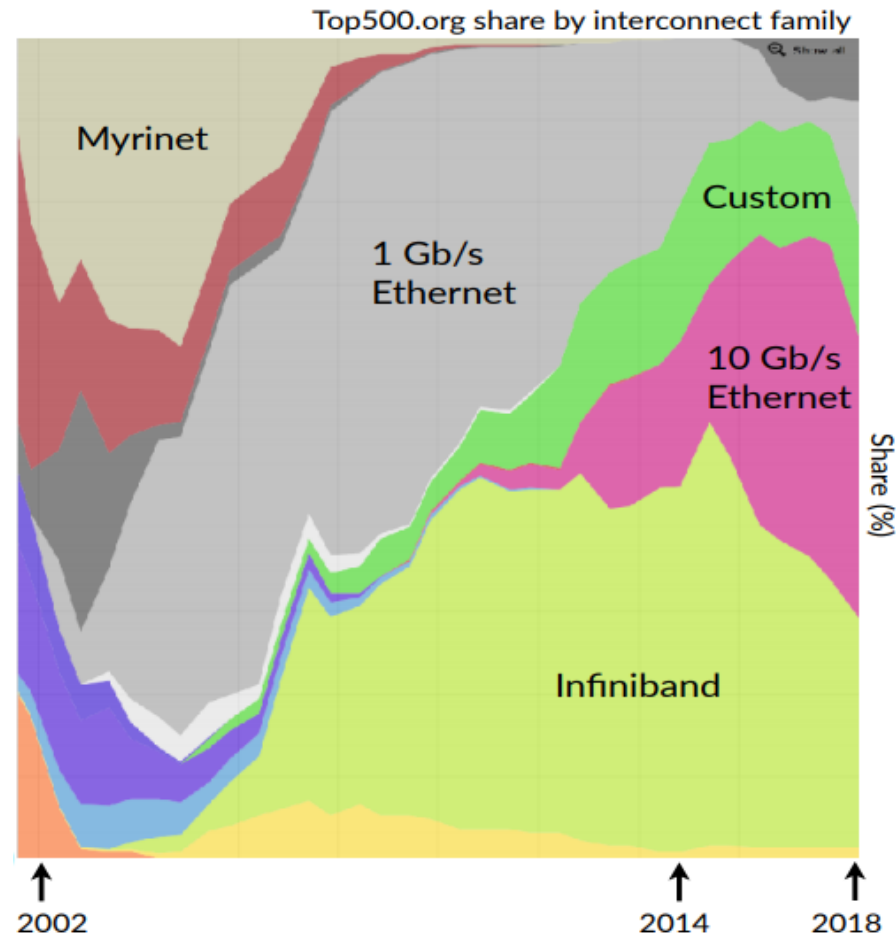
Event filter CPUs

Data storage

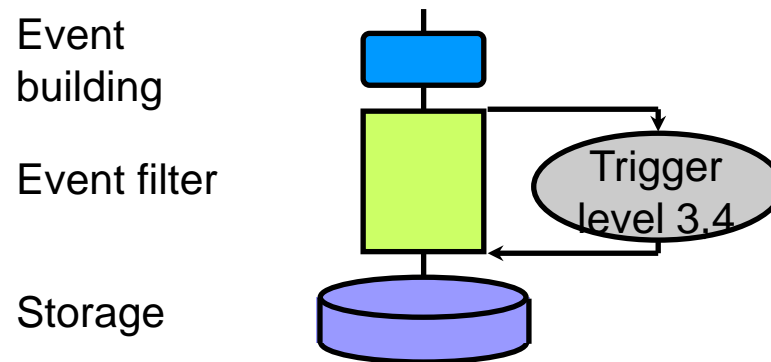


Network Technology

- Need to use what is popular
-> best price
- Myrinet very popular when LHC experiments started being designed
Used by CMS until 2014
- Others could postpone the decision and used Ethernet



Higher level triggers (3, 4, ...)

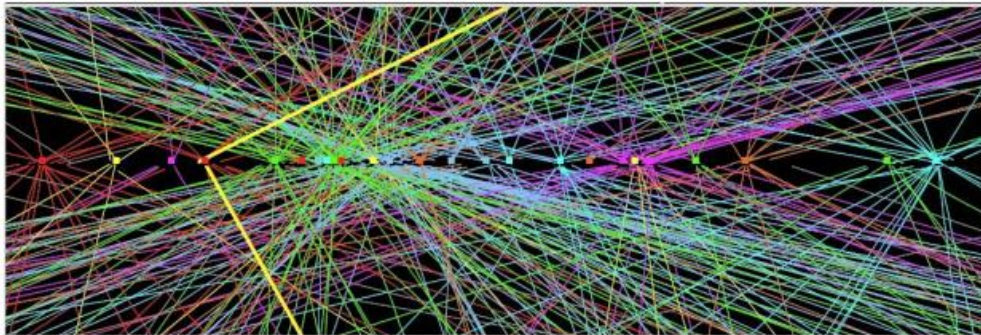


- LHC experiments can not afford to write all acquired data into mass-storage. -> Only useful events should be written to the storage
- The event filter function selects events that will be used in the data analysis. Selected physics channels.
- Uses commercially available processors (common PCs) But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

High Level Trigger

Full Event “Reconstruction”

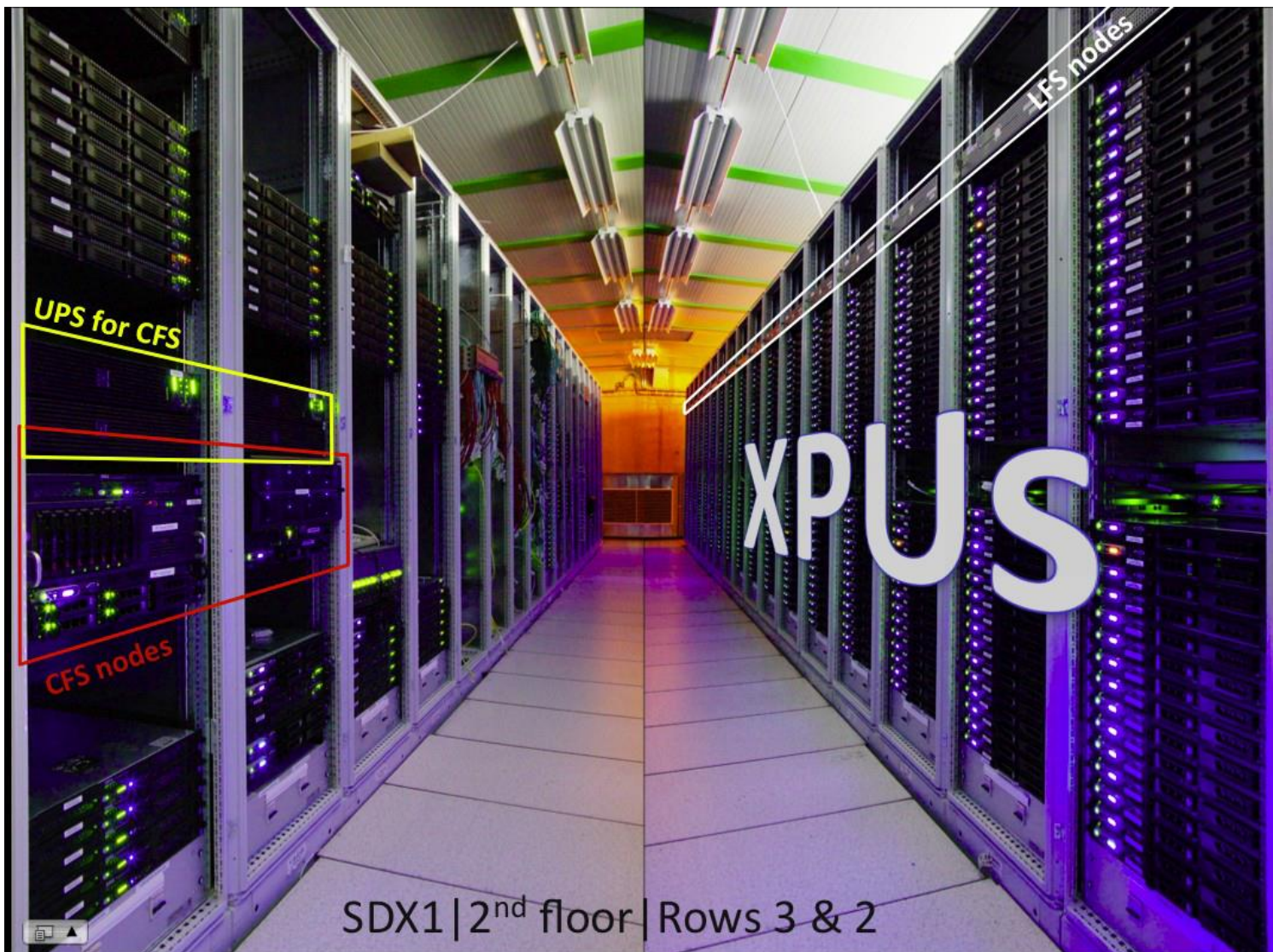
- Reconstruct all charged particle trajectories
 - Find segments, connect them, re-fit to physical trajectory
- Associate the particles with the correct p-p collision
 - Multiple interactions in each crossing



- Measure all the energy depositions in the calorimeters
 - with fine granularity
 - Associate tracks and energy depositions
- ## Decide whether it's interesting



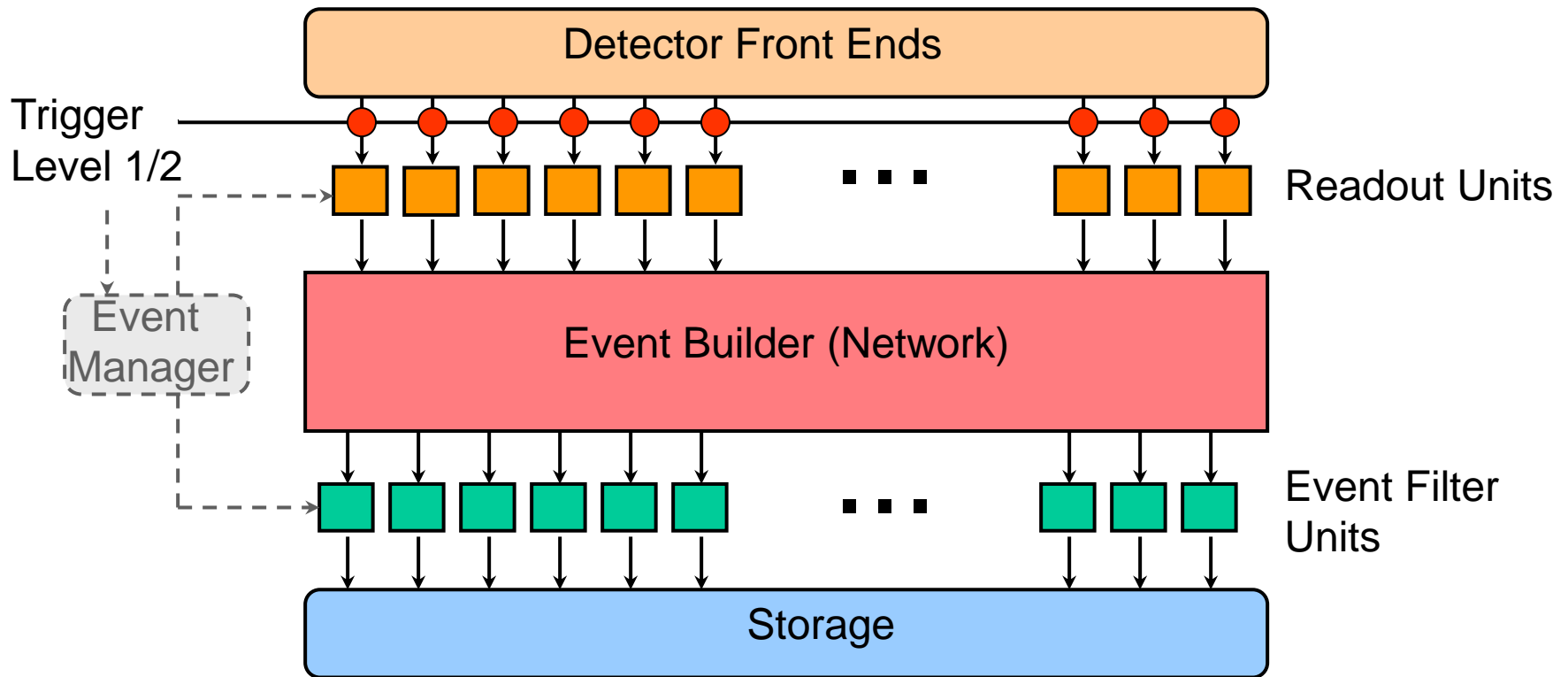
ATLAS HLT Farm



SDX1 | 2nd floor | Rows 3 & 2



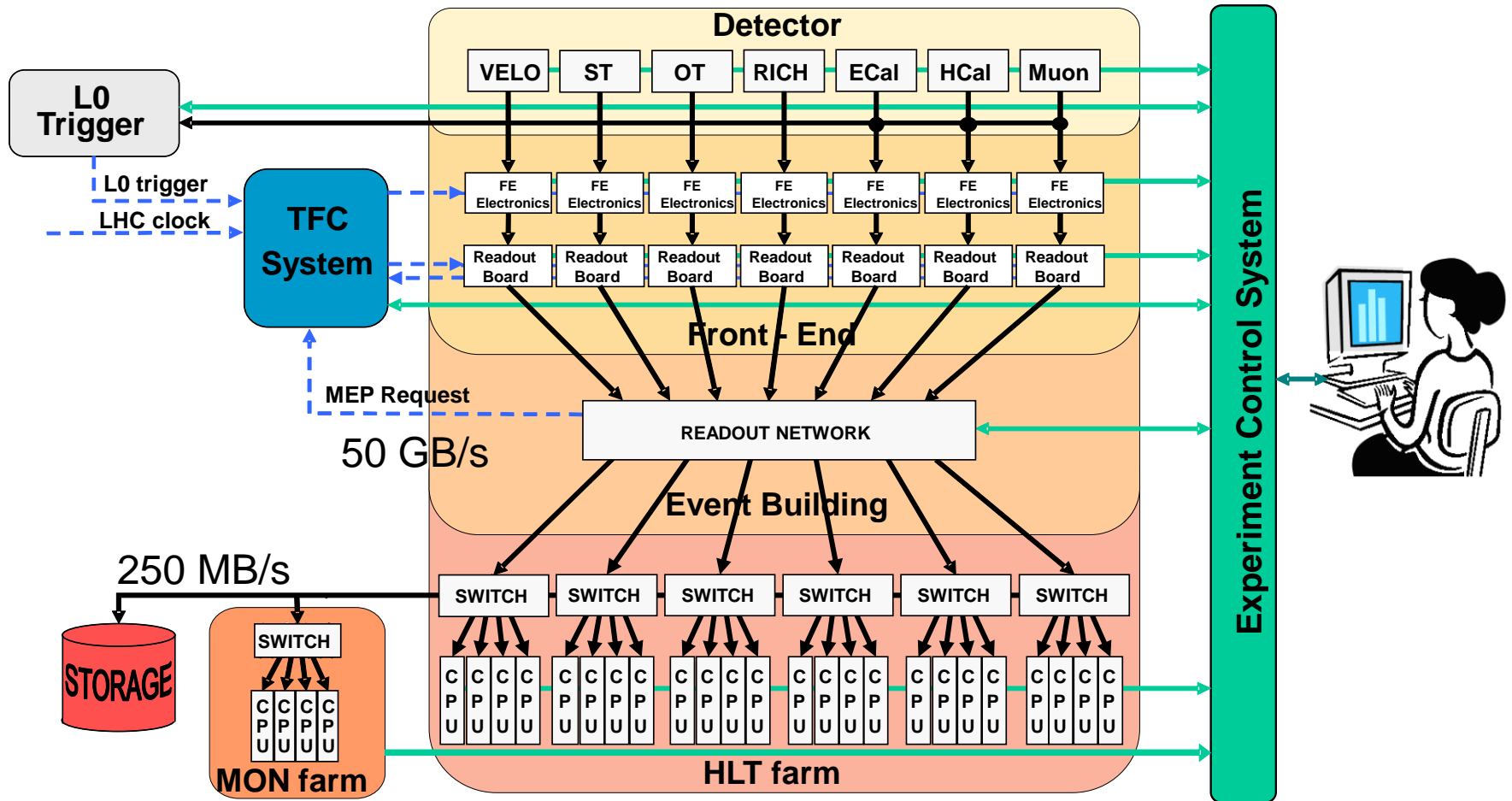
LHC Readout Architecture



- With or Without Event Manager
- Push or Pull Protocols



LHCb DAQ (up to 2020)



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

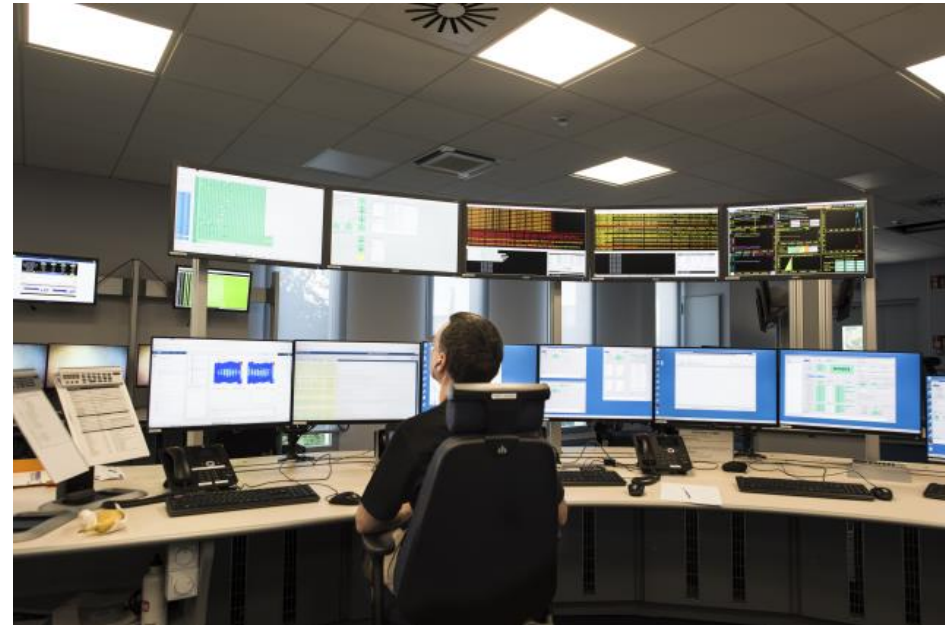
Average event size 50 kB
 Average rate into farm 1 MHz
 Average rate to tape 5 kHz



Operations

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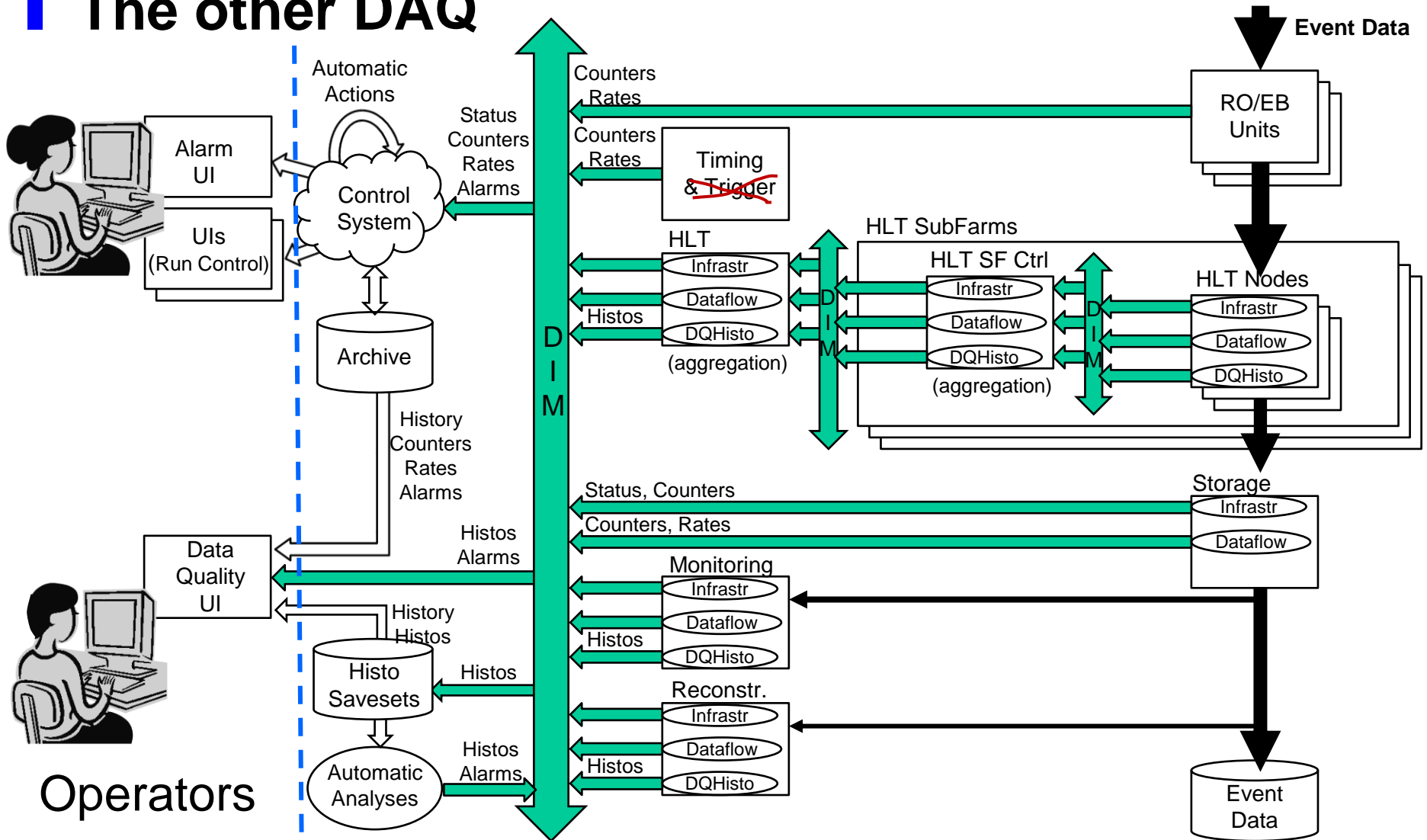
- Experiments run 24/24 7/7
- In LHCb Only 2 (non-expert) operators
- Monitoring
 - Detect any problems as soon as possible
- Configuration
 - Prepare for a particular running mode
- Automation
 - Avoid human mistakes
 - Speed up standard procedures





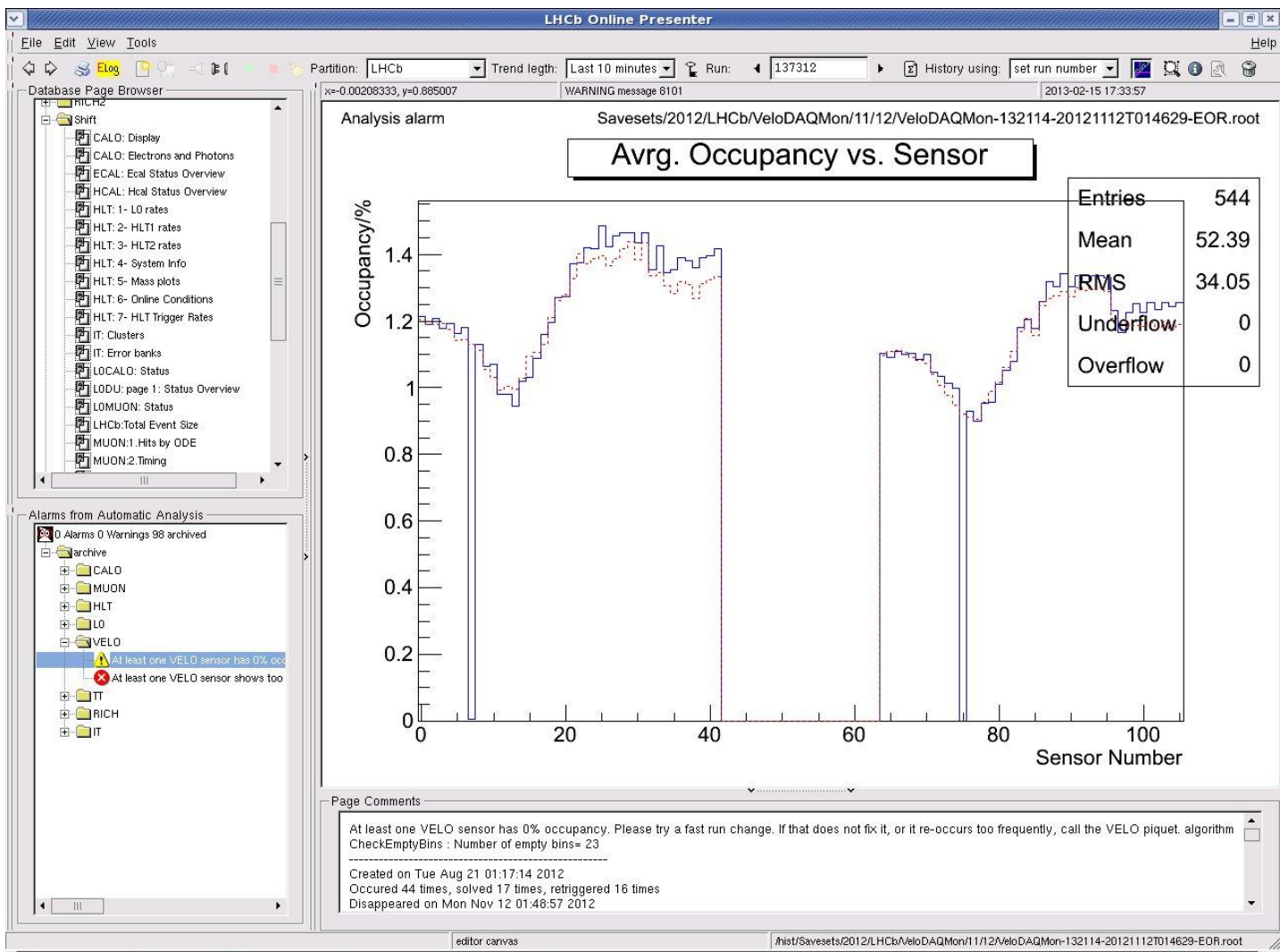
Monitoring Dataflow

The other DAQ





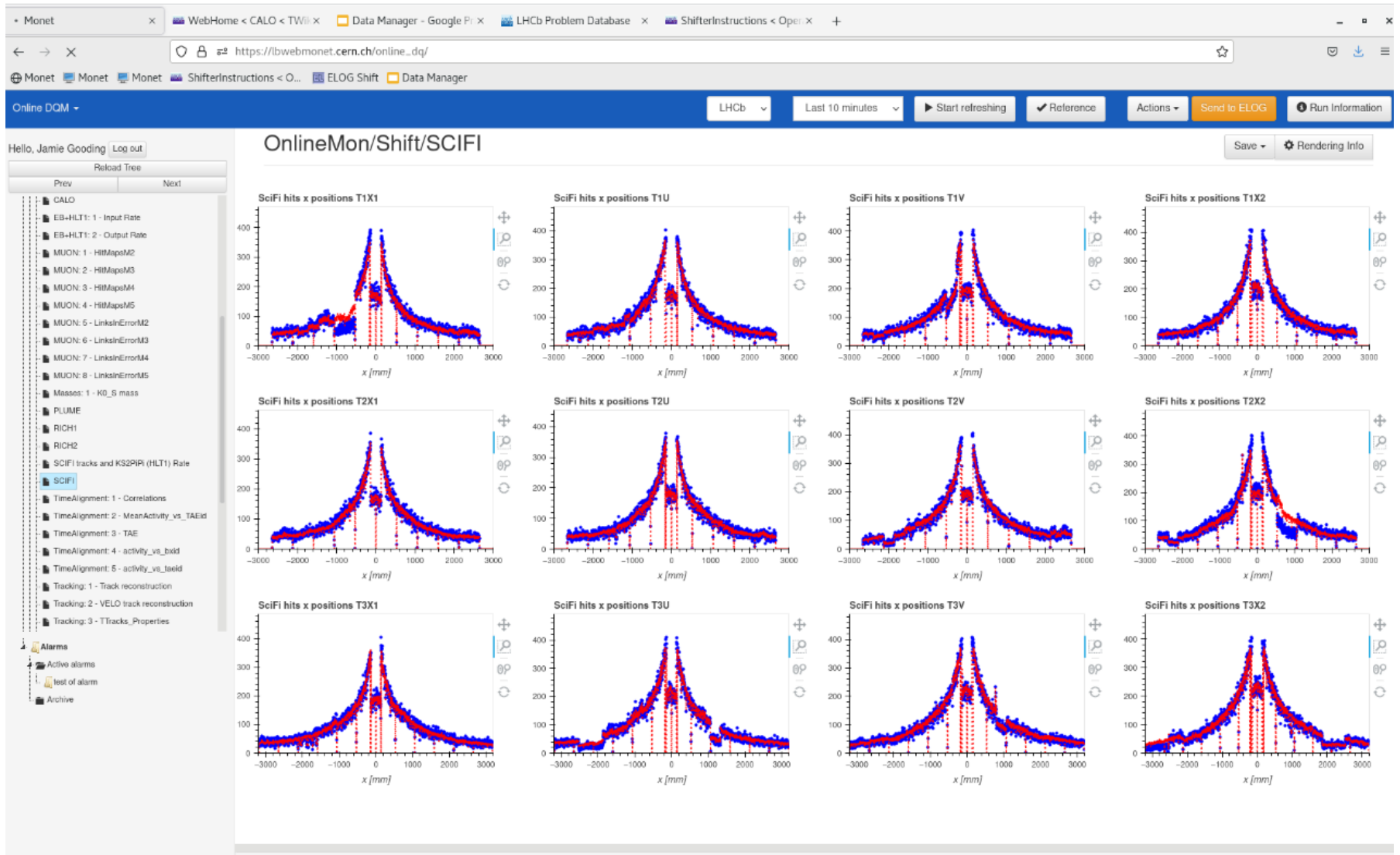
LHCb Data Quality (old)



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



LHCb Data Quality: Monet





LHCb Alarm Screen

Vision_1: vision\fwAlarmScreenNg\fwAlarmScreenNg.xml

NextGen Alarm Screen (Beta)

Source: Live

Filter #1: Exclude X Filter #2: Exclude X +

Filter Type: Include Exclude

Device Name: * Device Description: * Alarm Scope: * Alarm Direction: *
Device Type: * Logical Name: * Acknowledged: *
System: * Alarm Text: *R1DAQ1*,*R2DAQ1* Severity: W E F Filter...

Apply

| Short | Device DP Element | Description | Alarm Text | Dir. | Value | Time |
|-------|---------------------|------------------|---|------|-------|-------------------------|
| W | LBECSINFO:bAlarm... | AutoAnalysisTest | SCIFI: More than 35% different than the reference - Please change Run, drops M0: 23, M1:... | CAME | TRUE | 2023.07.13 18:10:41.915 |
| W | LBECSINFO:bAlarm... | AutoAnalysisTest | VELOalignment: Histogram is empty - Ignore | CAME | TRUE | 2023.07.13 18:10:41.514 |

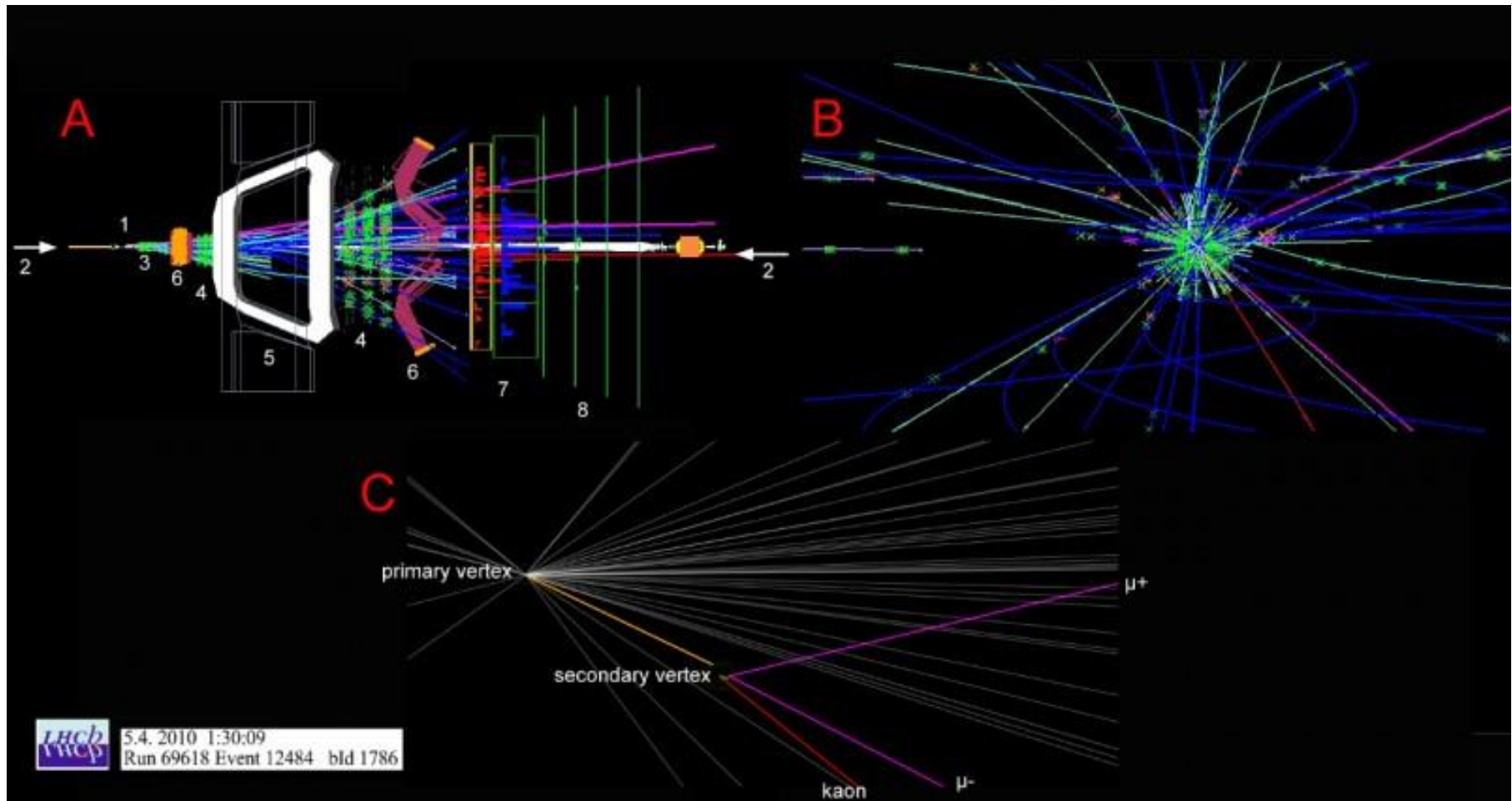
Displaying 2 of 384 alarms

CSV Export... Acknowledge multiple... Settings...

Messages: 5

Connected to 96 systems Systems...

LHCb Online Event Display

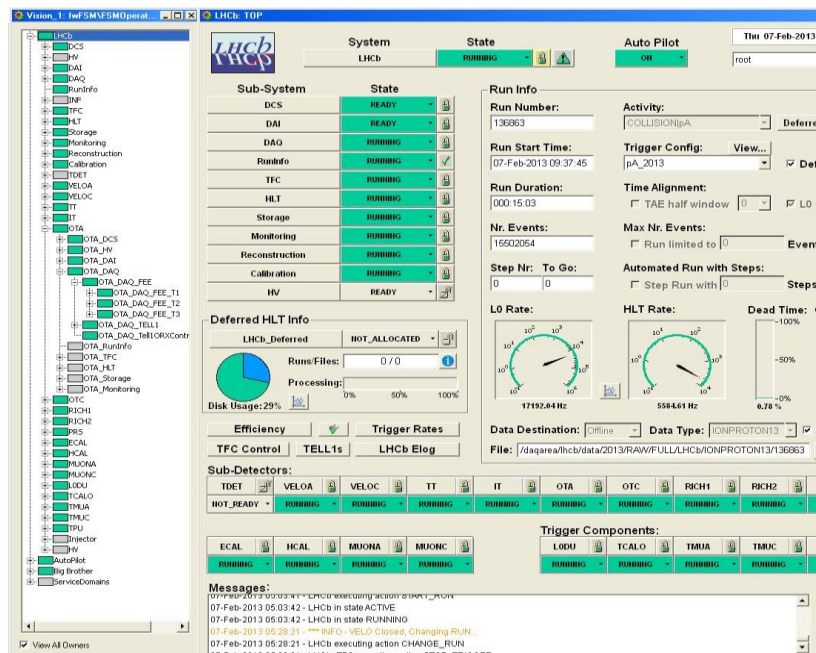
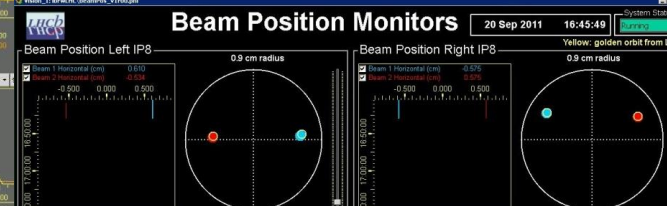
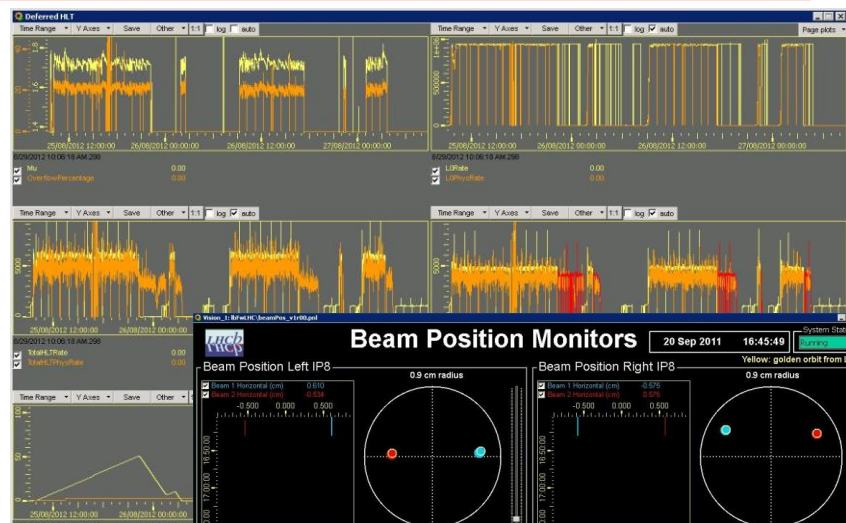




Operator Interfaces

Types of User Interfaces

- Alarm Screens and/or Message Displays
- Monitoring Displays
- Run Control & DCS Control



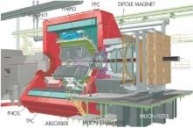
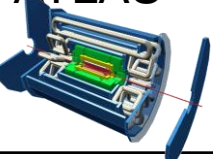
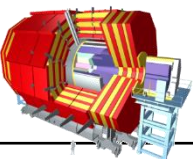
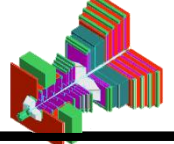


DAQ Upgrades

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LHC DAQ Upgrades

| | Up to Yesterday | | | Upgrade (2022-2026) | | |
|--|-----------------|--------------------|---------------------|---------------------|--------------------|---------------------|
| | L1 Rate (KHz) | Event Size (MByte) | Bandwidth (GByte/s) | L1 Rate (KHz) | Event Size (MByte) | Bandwidth (GByte/s) |
| ALICE  | 1 | 25 | 25 | 50 | 20 | 1000 |
| ATLAS  | 100 | 1 | 100 | 200 | 4 | 800 |
| CMS  | 100 | 1 | 100 | 1000 | 4 | 4000 |
| LHCb  | 1000 | 0.05 | 50 | 40000 | 0.1 | 4000 |



The Upgrades

DAQ network throughput



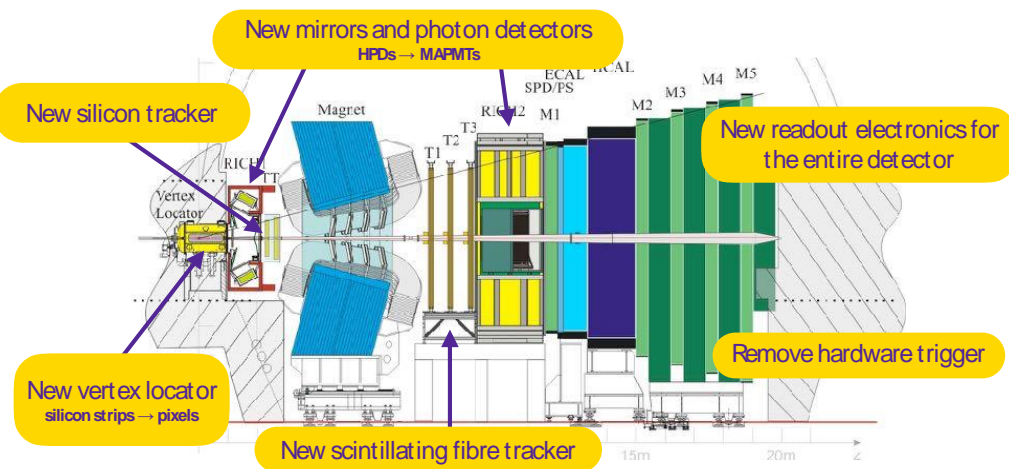


LHC Exp. Upgrades

■ Reasons:

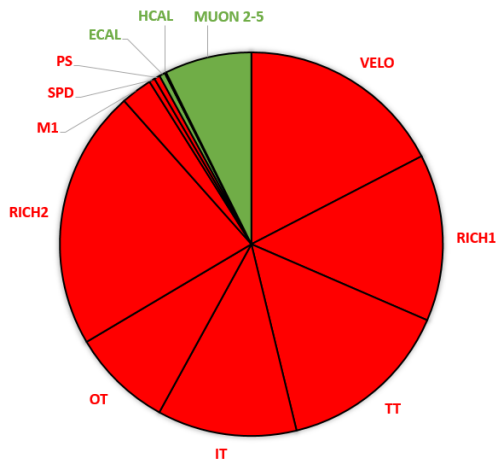
- | More Physics/Faster Physics/Better Physics
- | (Improved Detectors)
- | Reduce impact of Hw Triggers:
 - | Working with partial information and with drastic simplifications has a price:
 - | Potentially interesting and valuable events are lost
 - | Directions:
 - | Eliminate / reduce hardware Level-1 (ALICE, LHCb)
 - | Substantially upgrade Level-1 (ATLAS, CMS)
- | Emphasize Real-Time Alignment and Calibration

LHCb Upgrade

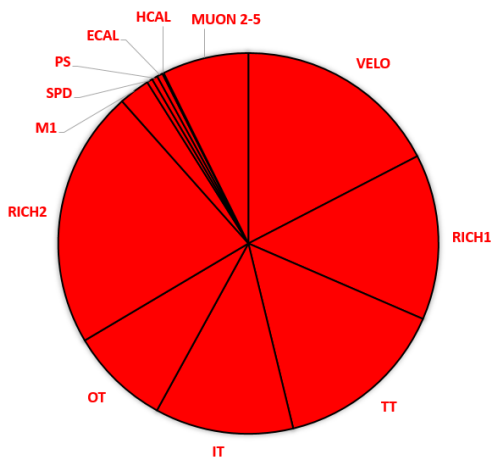


- 40 MHz Trigger-less Readout
- < 10% detector channels kept
- 100% or R/O electronics replaced
- New DAQ system
- New Data Center

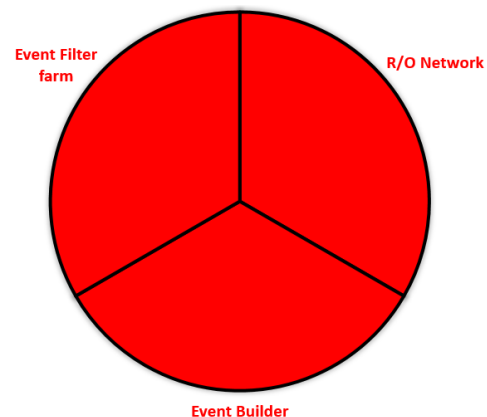
Detector Channels



R/O Electronics

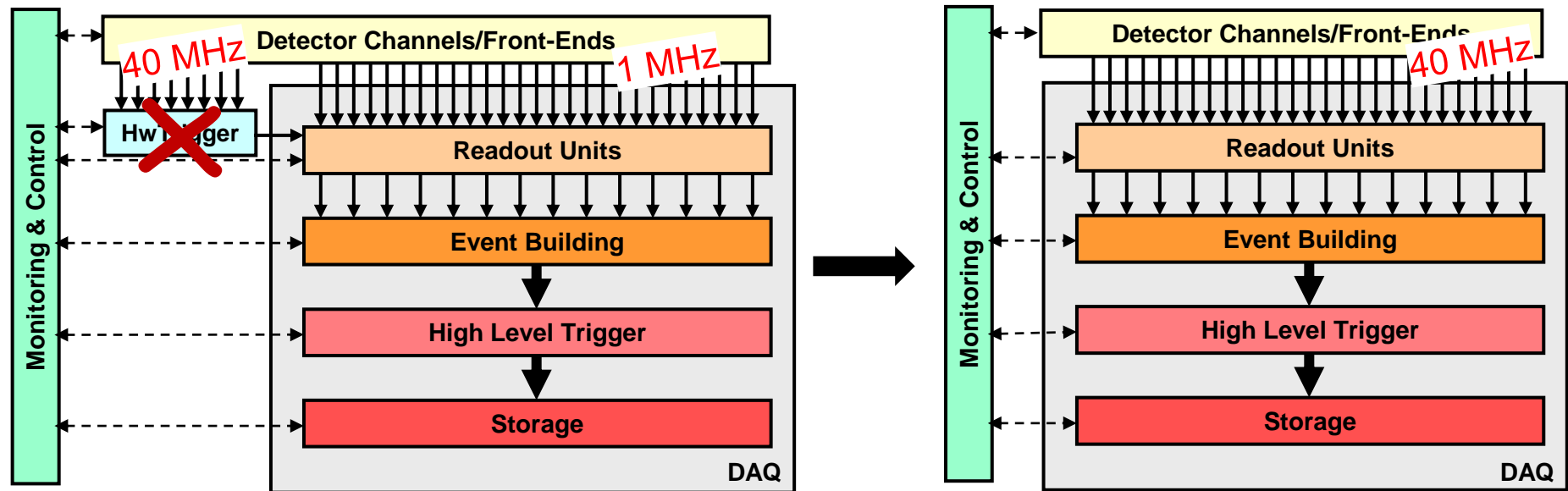


DAQ



The LHCb Example

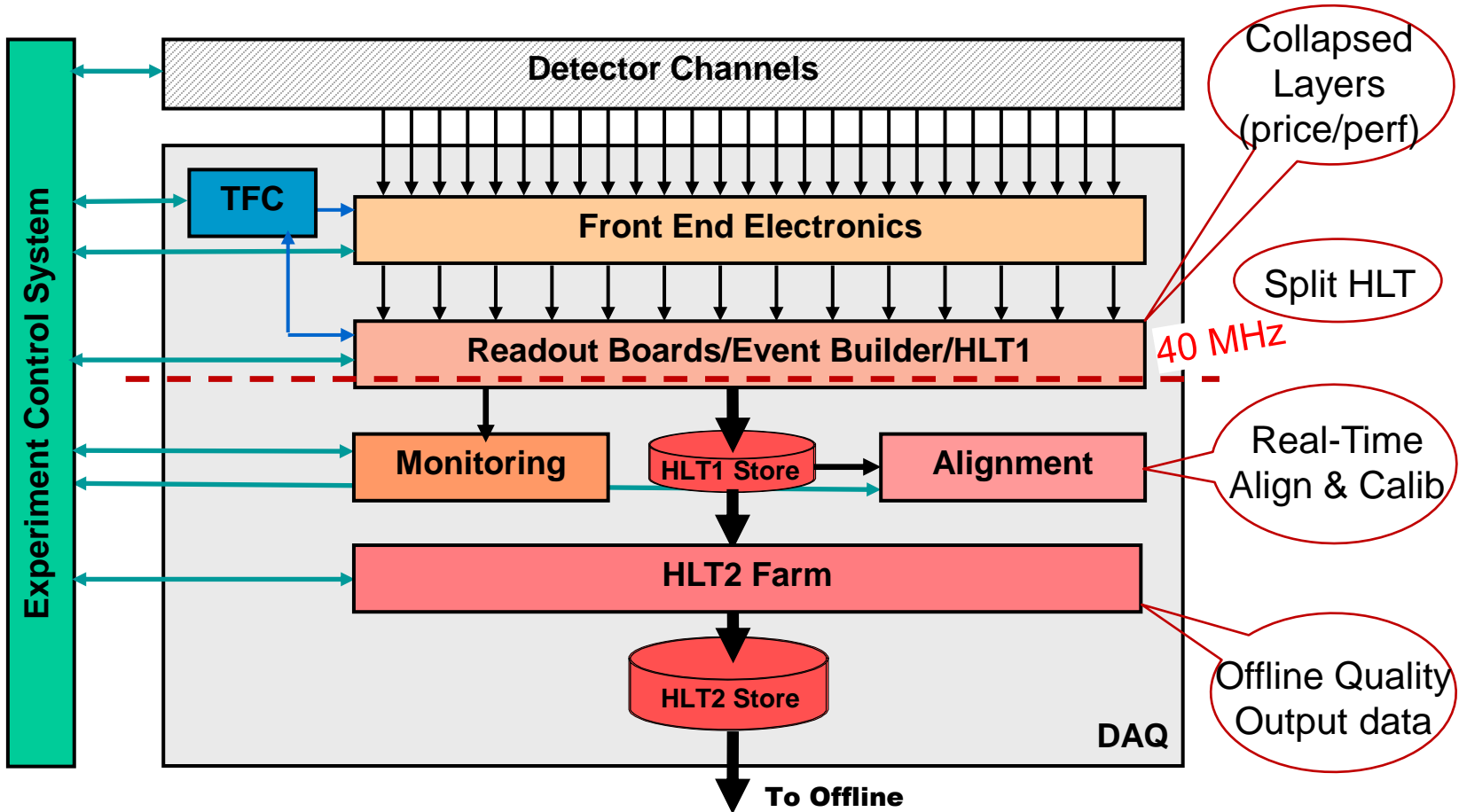
- 1st Large Physics Experiment to completely abolish the Hardware Trigger -> Probably the largest Data Acquisition System in the world today



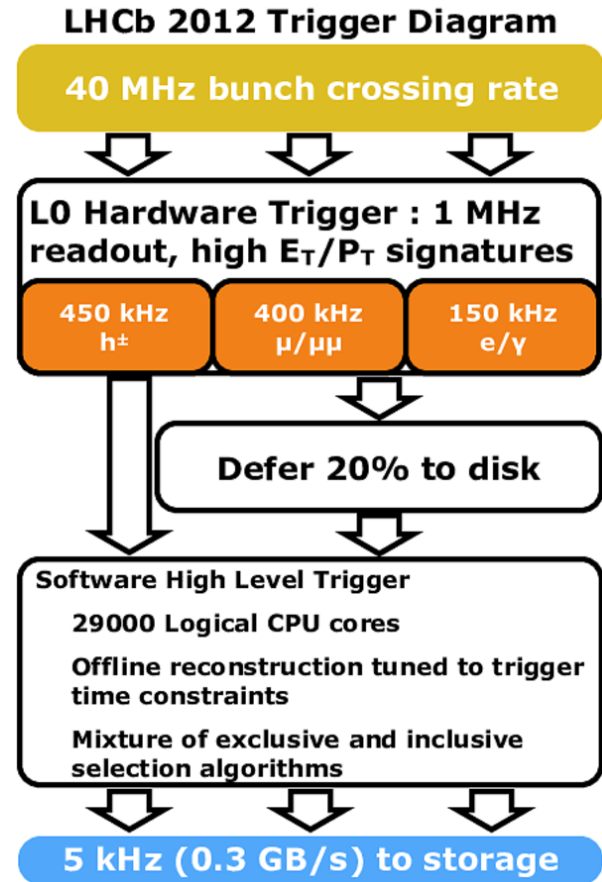
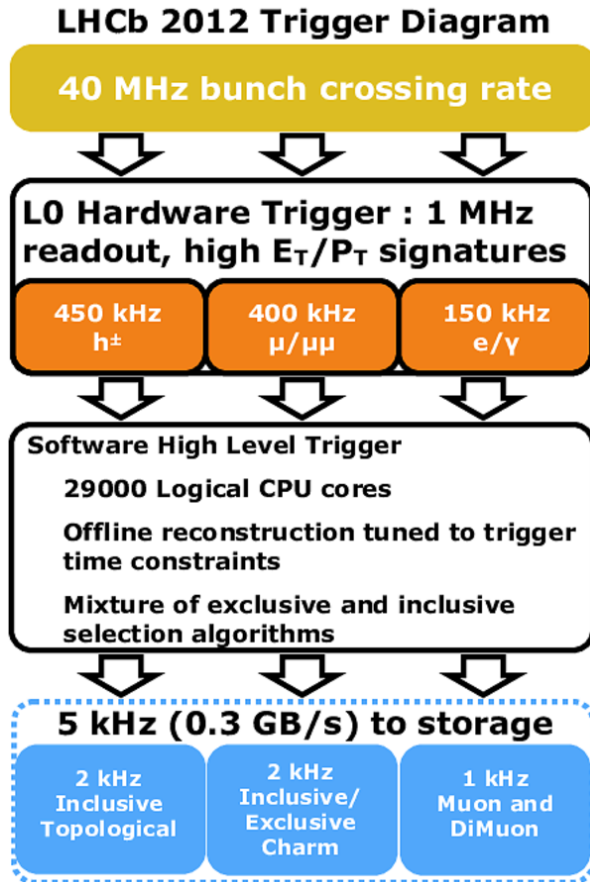
- Spoiler: Commissioned last year -> And it works!!



The New LHCb DAQ



LHCb Dataflow Evolution



I In 2012: More CPU needed for better Trigger

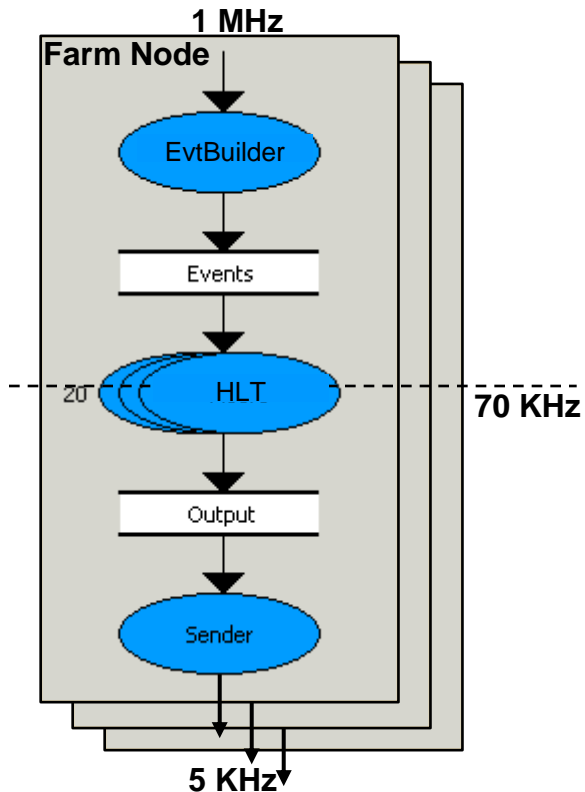
I Since: unused interfill CPU + free disk space

HLT Farm Usage Evolution

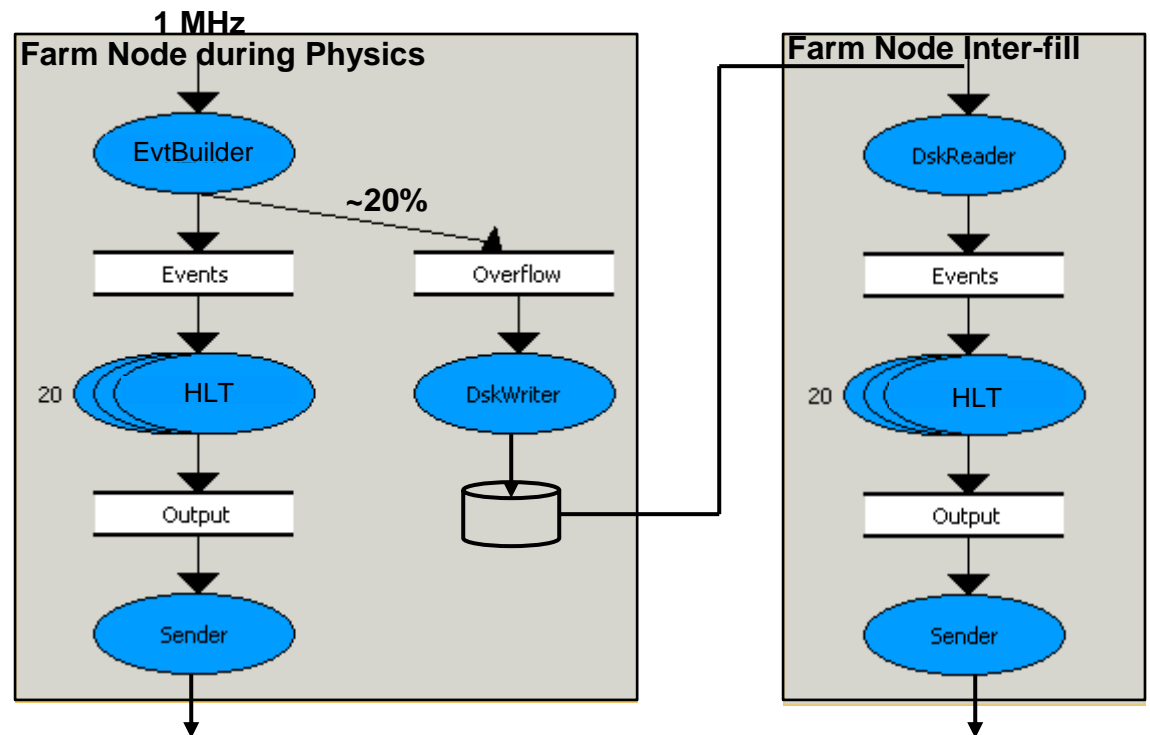
Resource Optimization in 2012 -> Deferred HLT

- Idea: Buffer data to disk when HLT busy / Process in inter-fill gap
- More time for more complex algorithms

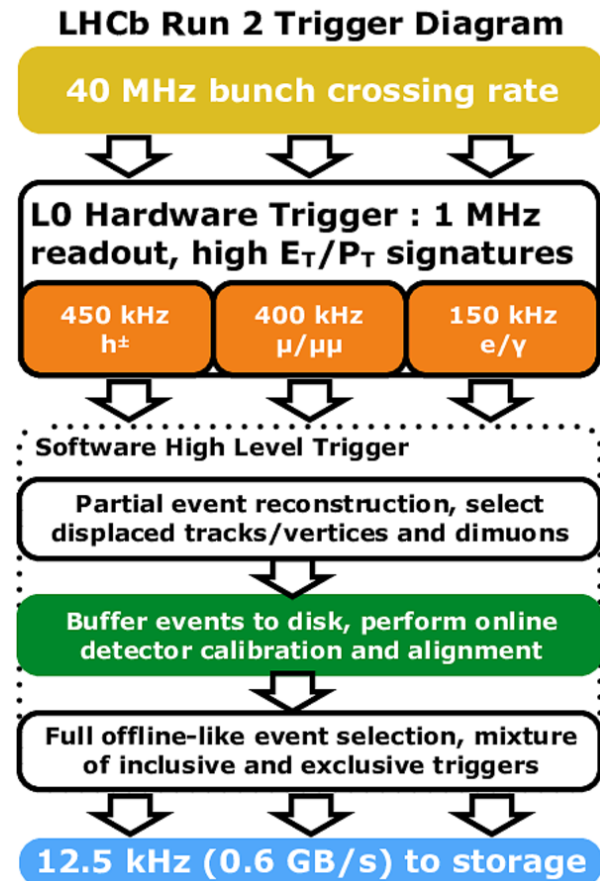
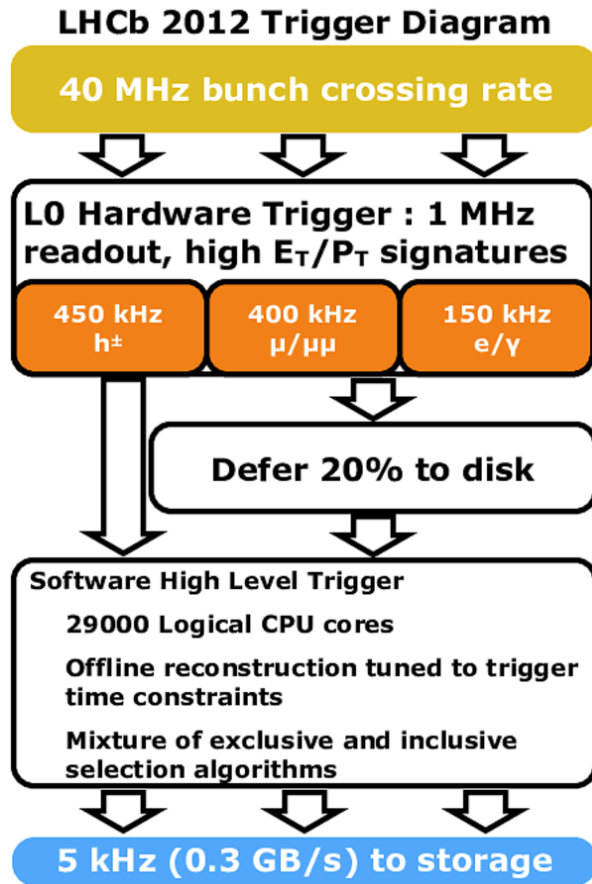
Standard HLT



Deferred HLT



LHCb Dataflow Evolution



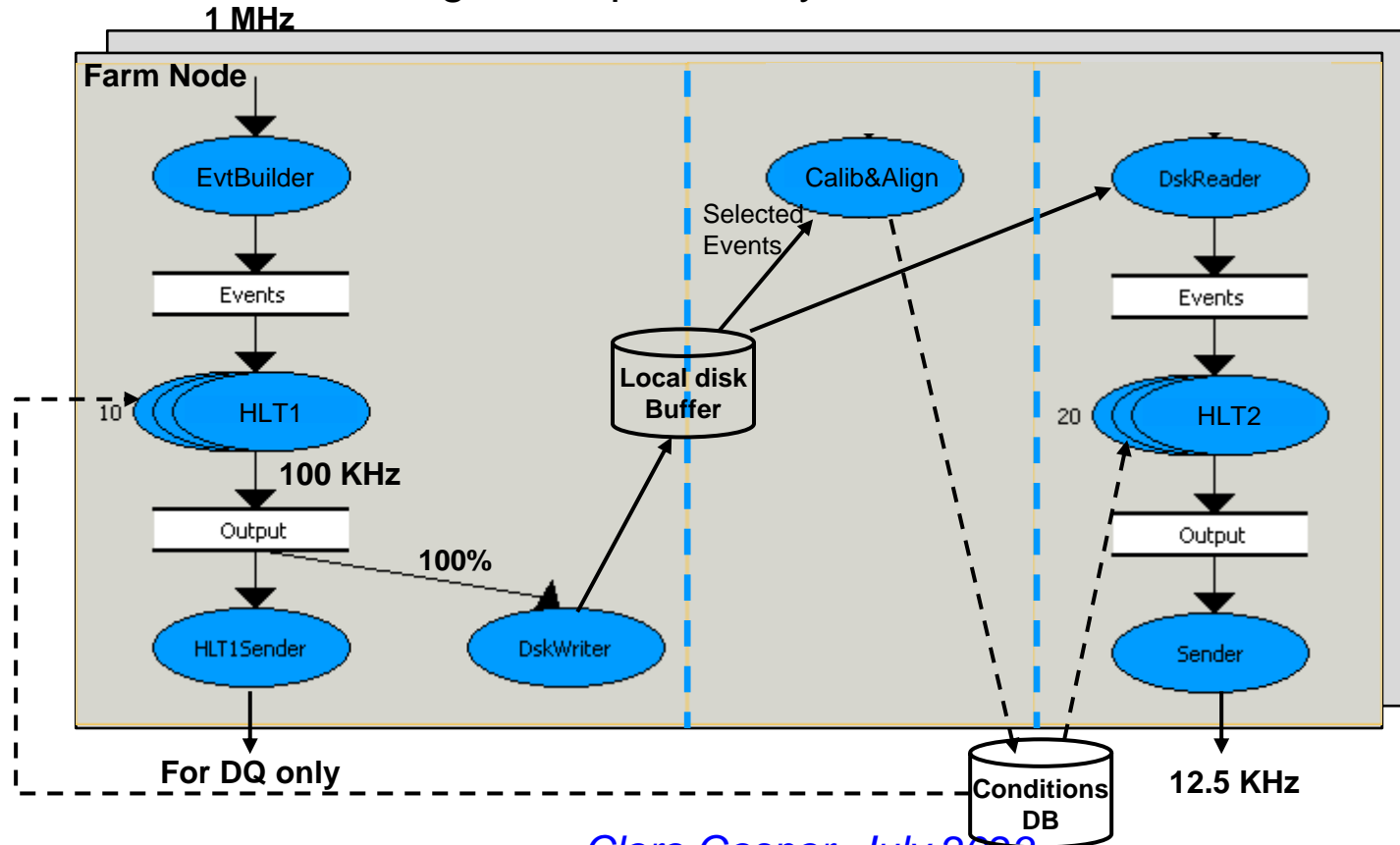
■ In 2015: Better Trigger and Trigger output data

- Since: HLT anyway composed of two steps

HLT Farm Usage Evolution

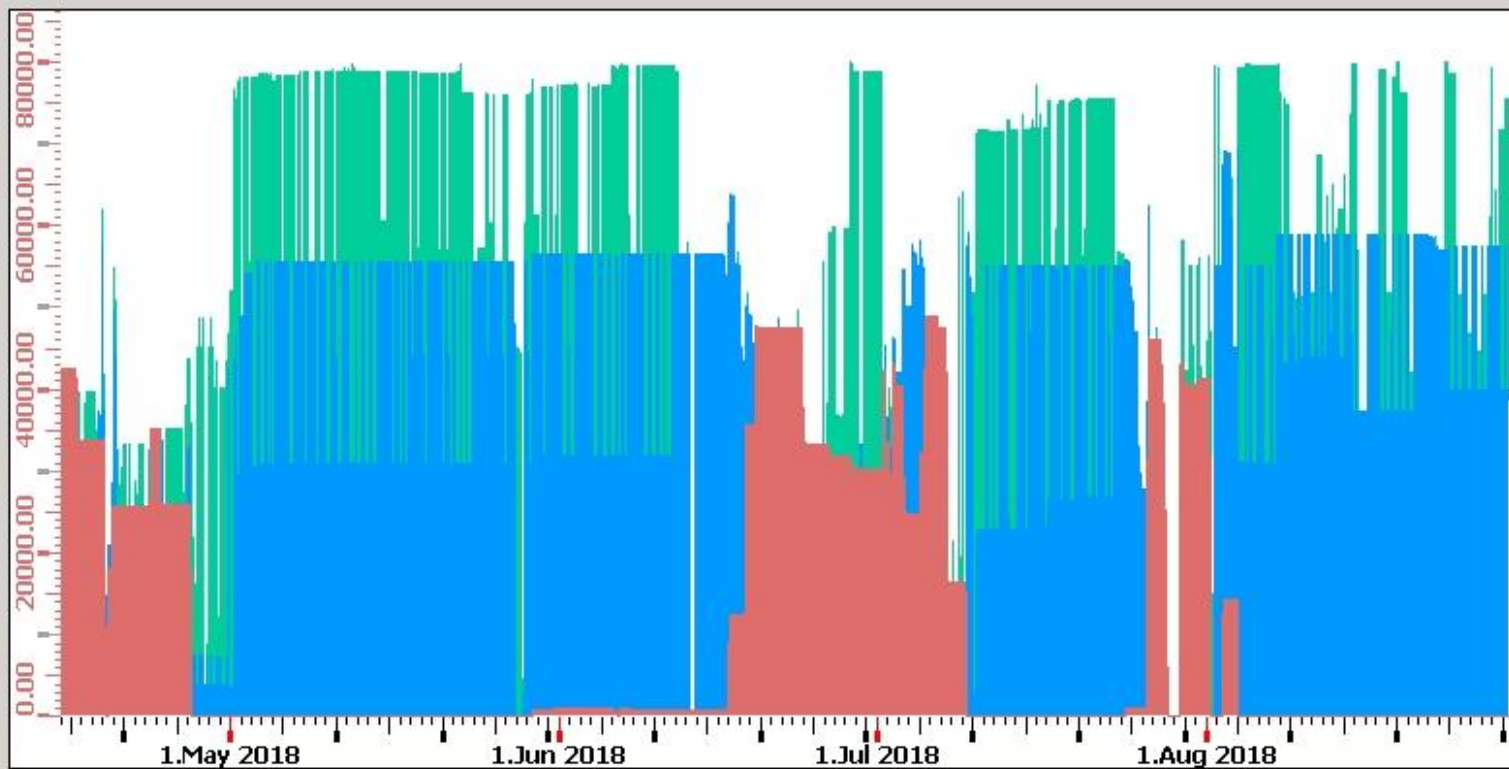
Even better Resource Optimization in 2015 -> Split HLT

- Idea: Buffer ALL data to disk after HLT1 / Perform Calibration & Alignment / Run HLT2 permanently in background
- Calibration and Alignment previously done Offline -> Better data!





Farm Usage in 2018

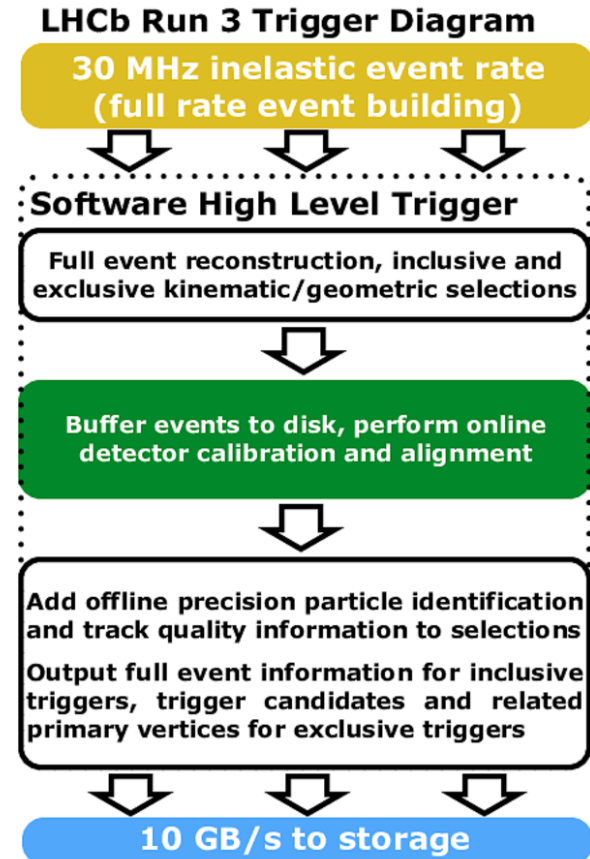
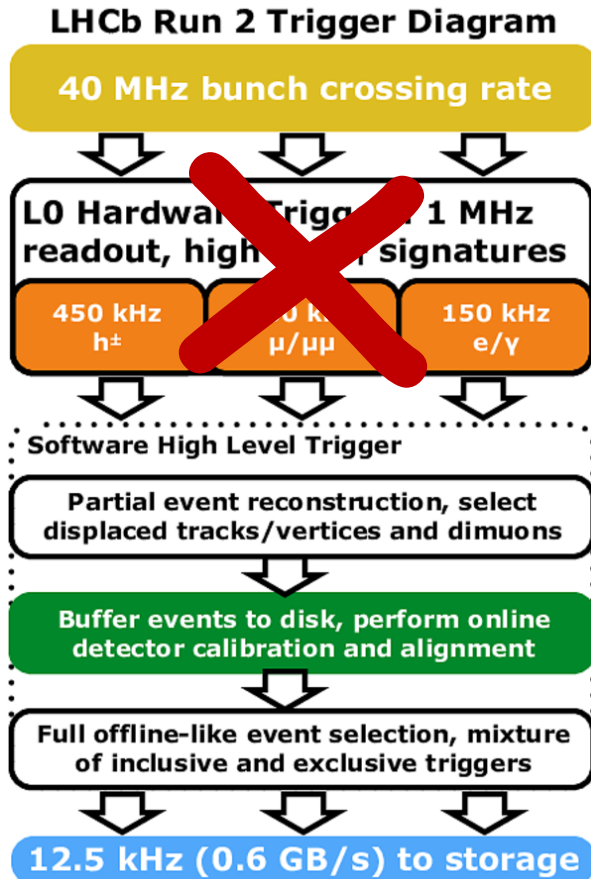


- Keeping farm busy
- Simulation when less physics



- Disk Usage < 25%

LHCb Dataflow Evolution



In 2022: Even better -> No HW Trigger

Since: Better readout and network technology available



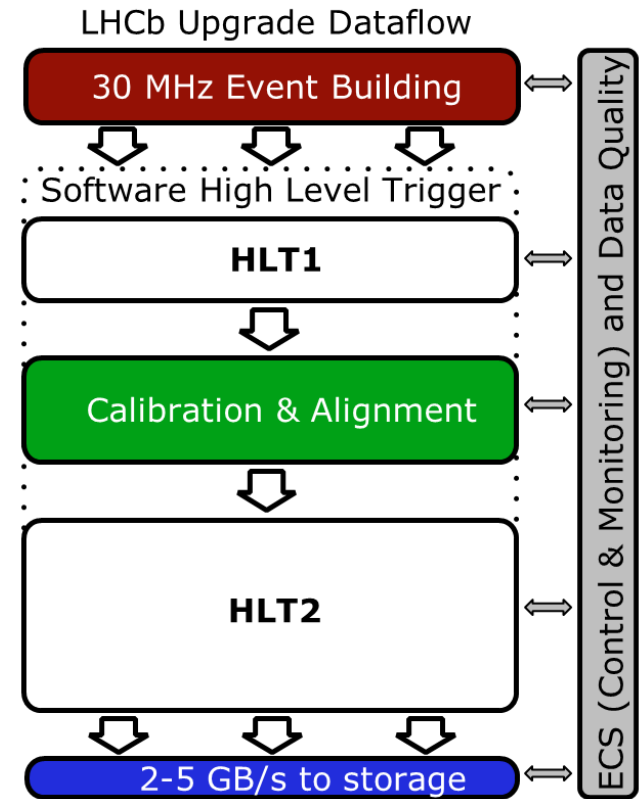
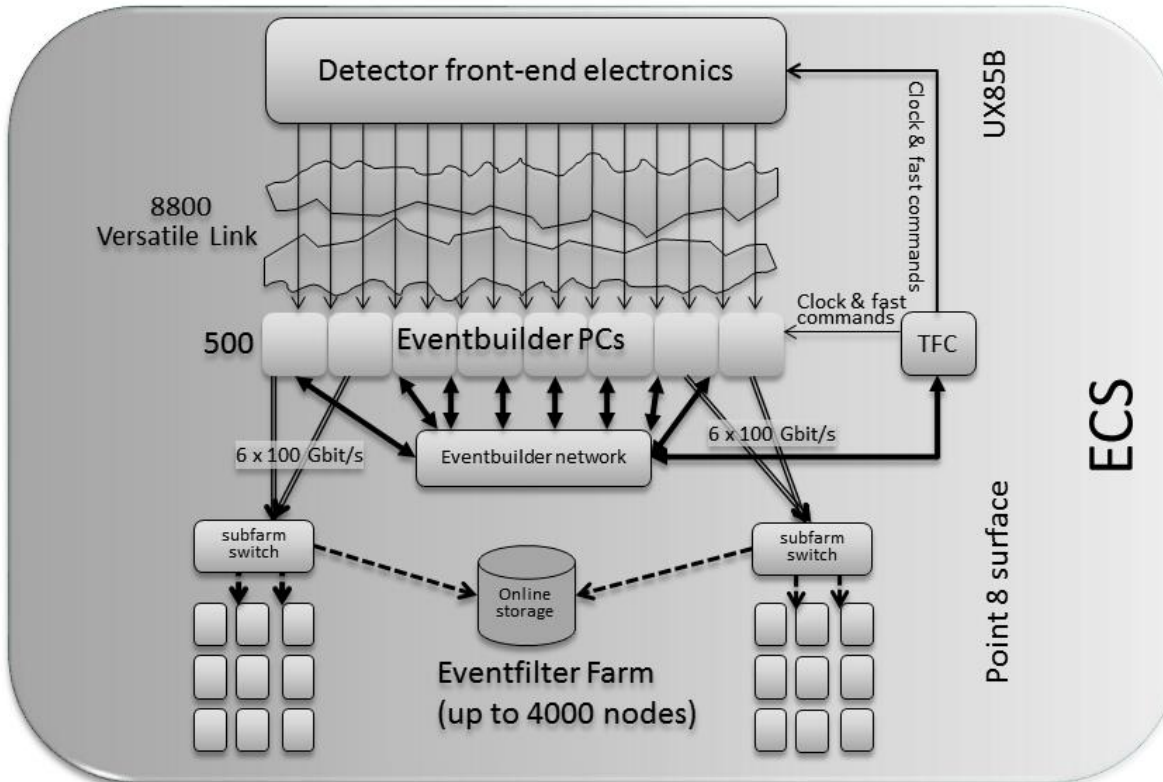
New DAQ Design Principles

■ Selected Concepts:

- | **Simplicity (whenever possible)**
- | **Integration & Homogeneity**
- | **Promote HW Standardization**
 - | Same hardware components for all sub-systems
- | **Promote SW Uniformity**
 - | Guidelines, Framework Components, Templates
- | **Separate Data/Control paths**
 - | From the Front Ends to the High Level Trigger

Online System Upgrade

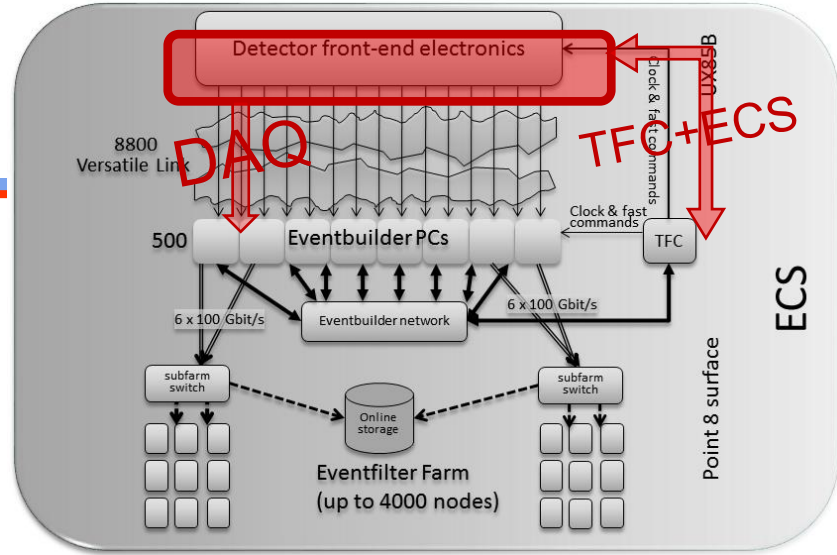
New Data Acquisition Hardware and Dataflow Software



New Infrastructure & Sub-Detector Equipment

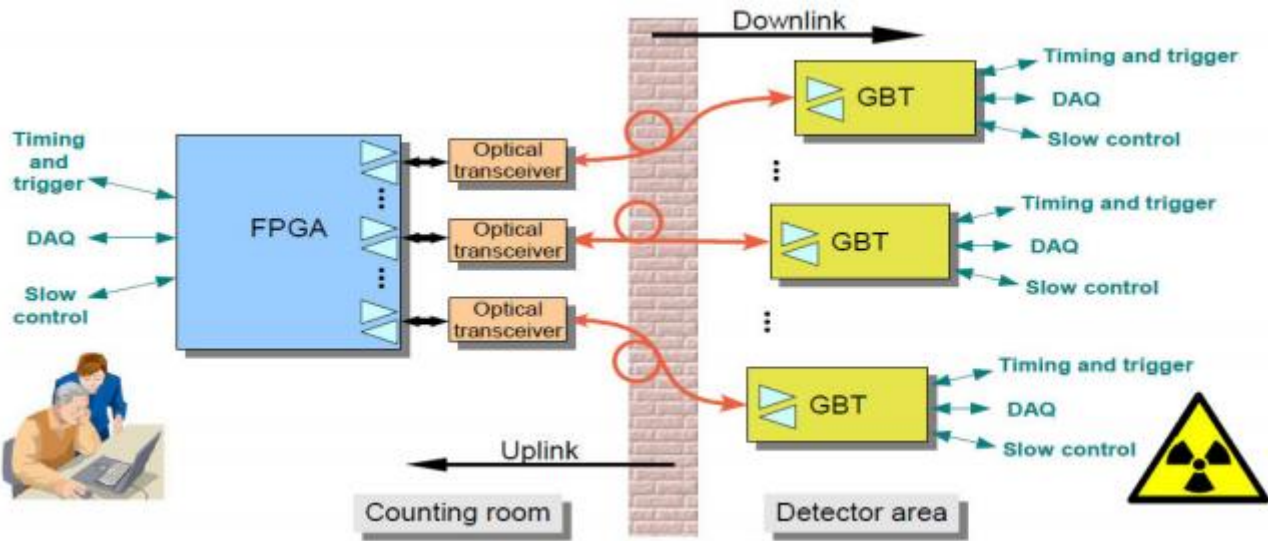


FE Electronics



Front-end electronics

- Use CERN GBT chip (Gigabit Transceiver)
- A radiation hard ASIC (Application Specific Integrated Circuit)

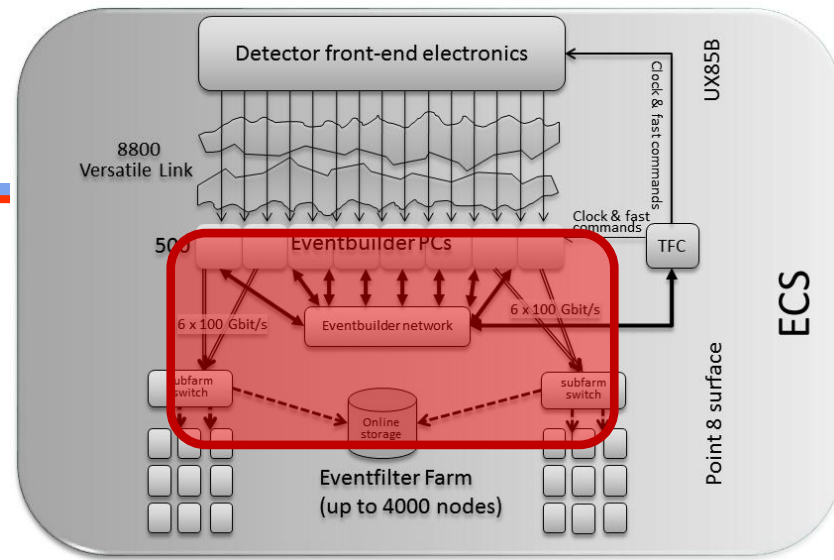


But unlike the drawing: separately for DAQ and for Timing & Control

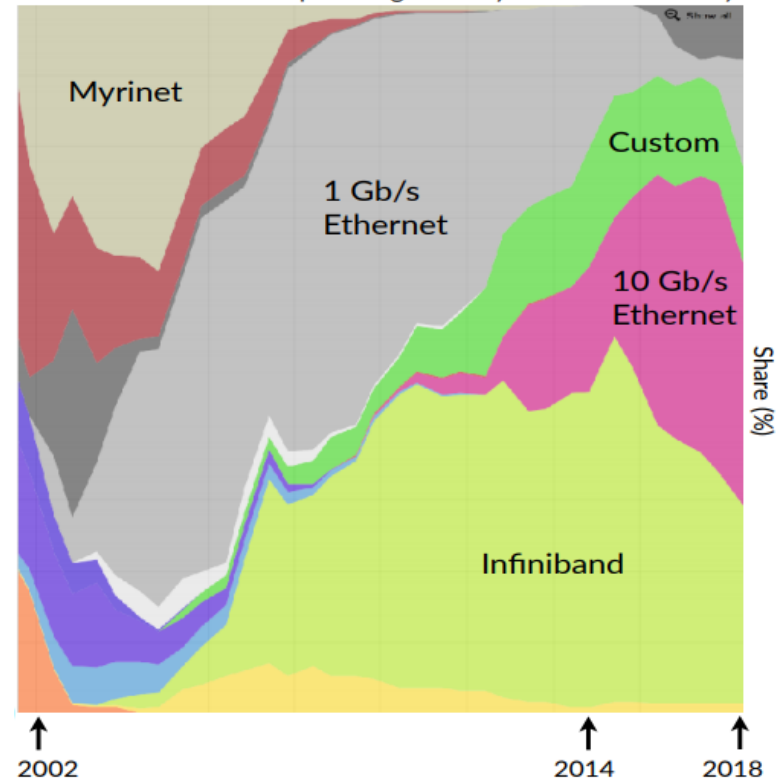


Networking

- Again, use what is popular
-> best price
- Basically the choice was
Infiniband and/or Ethernet



Top500.org share by interconnect family

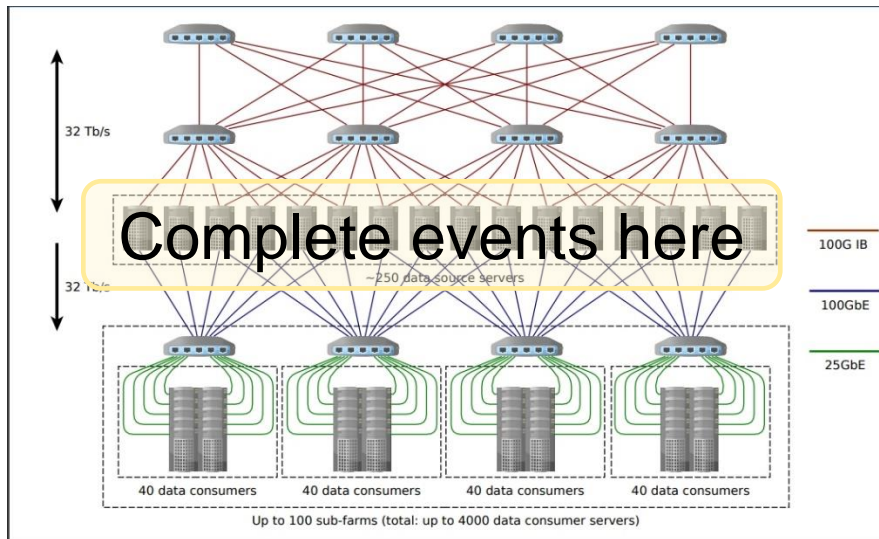
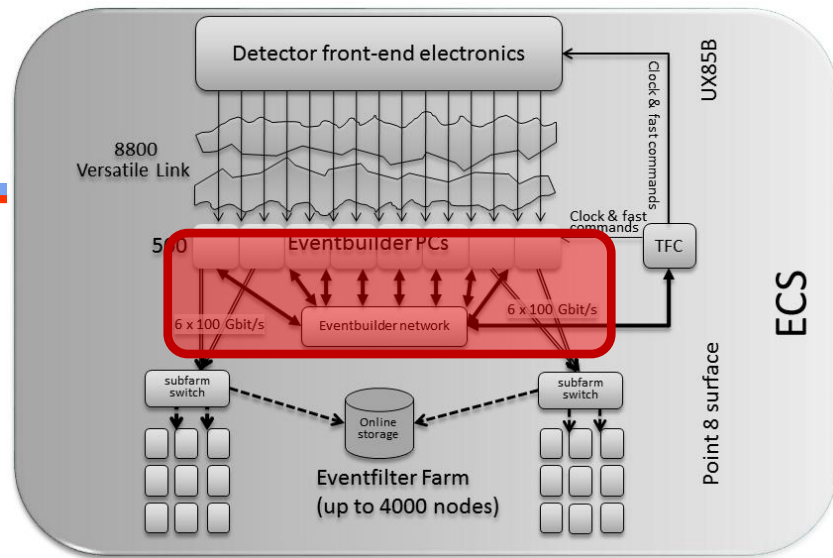




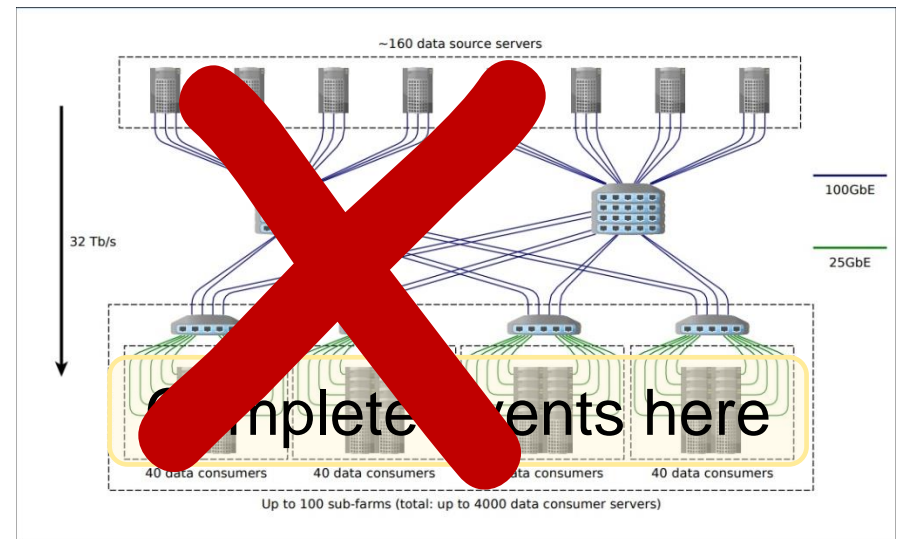
Event Builder

Two options tested

- Only one worked well within our time and budget (traffic pattern: All to One/flow control /switch buffering very expensive)



Technology: **Infiniband**
 + Ethernet for Distribution
Dedicated EB (TDR baseline)

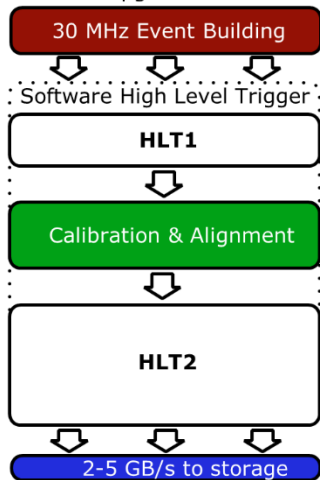


Technology: **Ethernet**
 (Would have been simpler and known)
Distributed EB

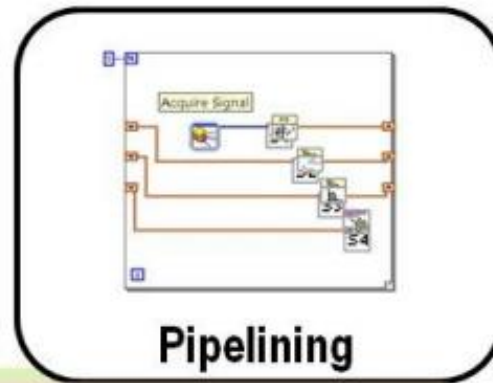
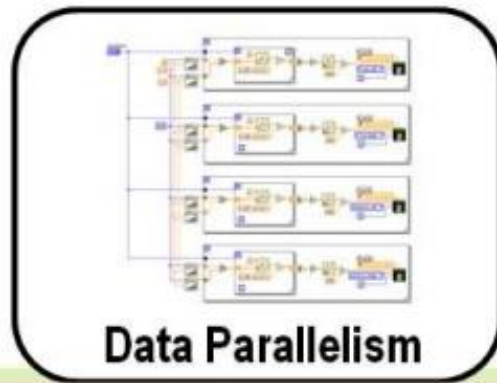
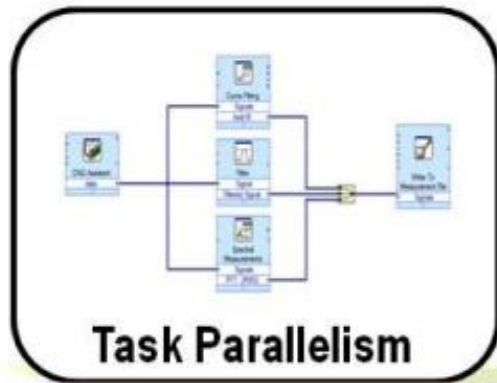


High Level Trigger

LHCb Upgrade Dataflow

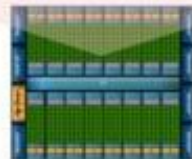


Processing Options (HLT1)



Multicore Processors

Nvidia GPUs:
3.5 B transistors



GPUs*

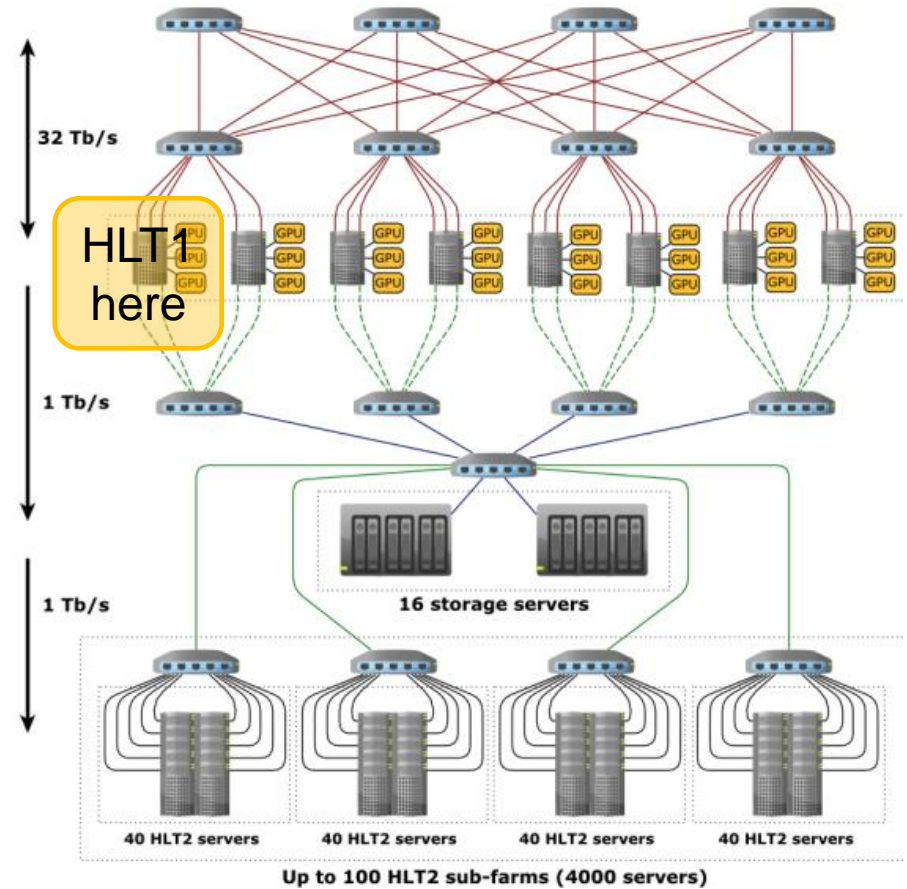
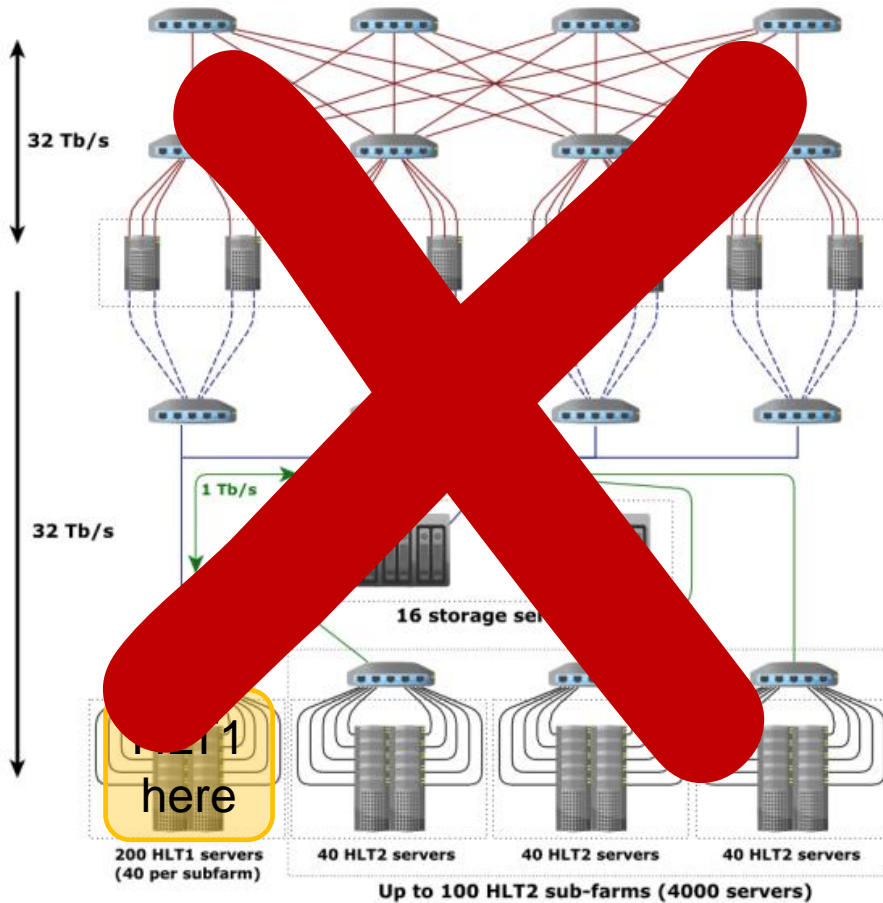
Virtex-7 FPGA:
6.8 B transistors



FPGAs

Several R&D Projects in all these areas

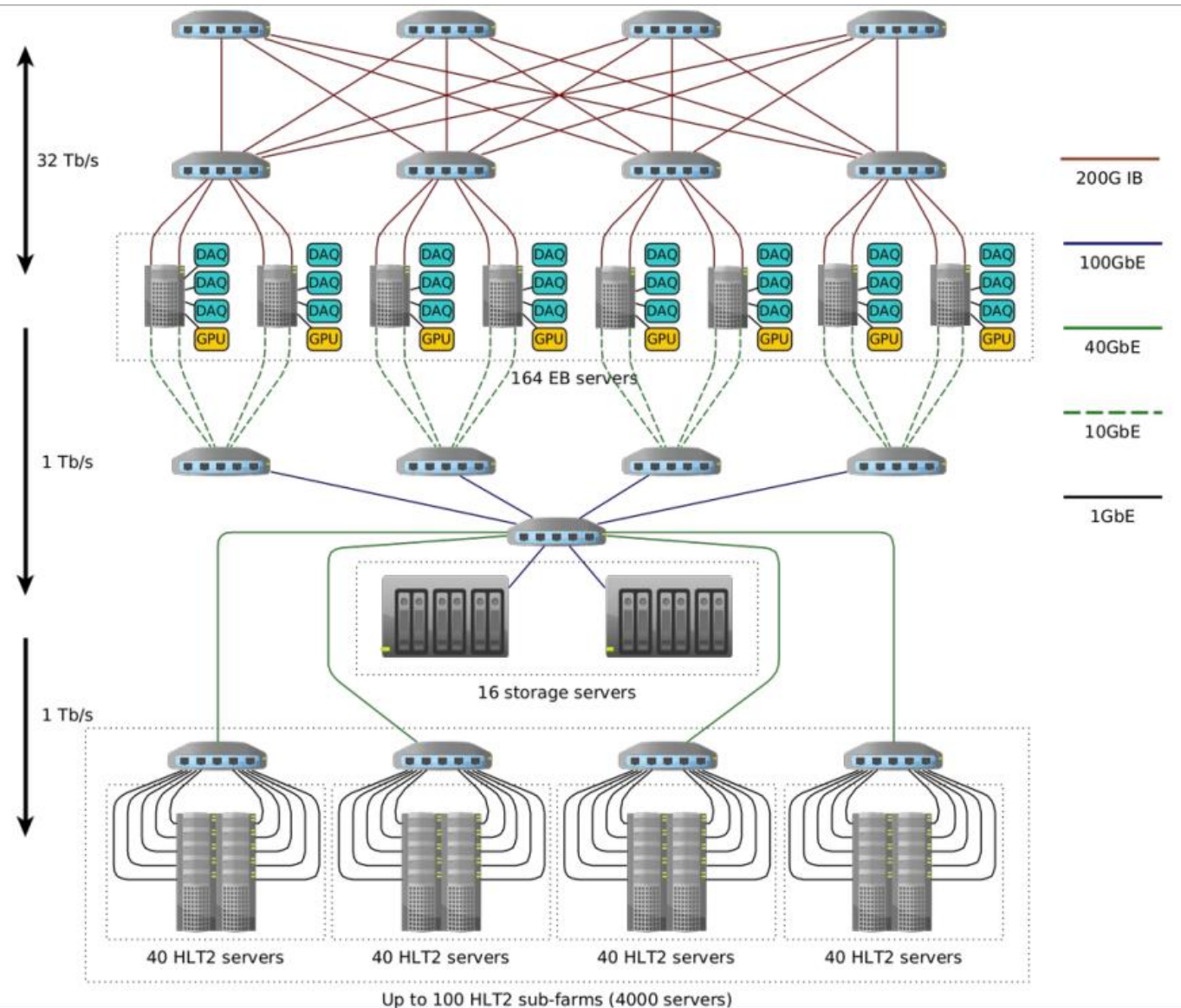
HLT1



Two options: CPU vs GPU

Both worked: Cost (and politics/sociology) made the difference

LHCb Current DAQ Core

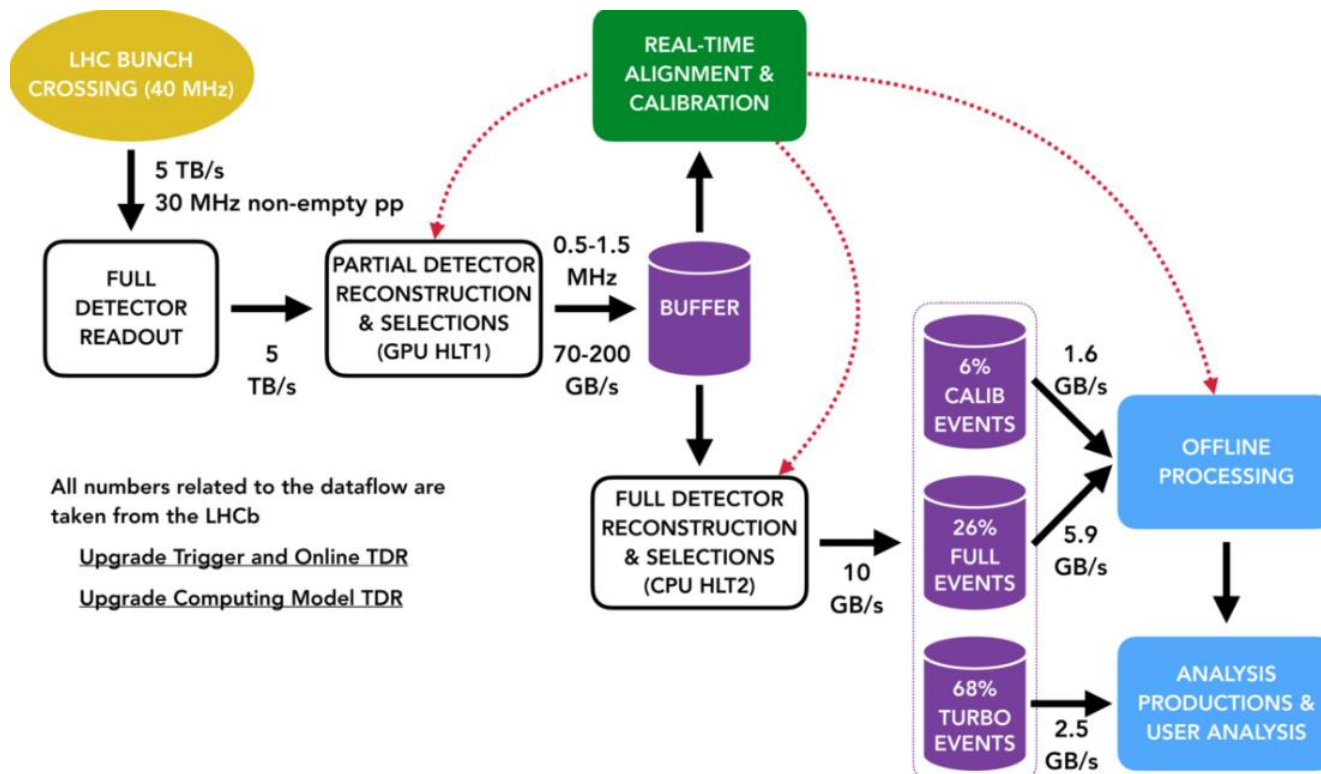


- EB Servers**
 - | ~160
 - | Hosting PCIe cards
- DAQ Readout Units:**
 - | ~500
 - | Powerful FPGA
 - | 48 FE links (1Gb)
- GPU GPUs:**
 - | ~160 -> ~320
 - | Fast HLT1 Pass
- CPU CPUs**
 - | ~4000 (donated)
 - | Thorough HLT2

Data Processing

Improvements all the way to analysis strategy: Turbo stream

- | Since we can automatically perform final alignment and calibration online
- | So we can achieve offline quality alignment and calibration in the trigger
- | Store only part of the event → allows for higher output bandwidth

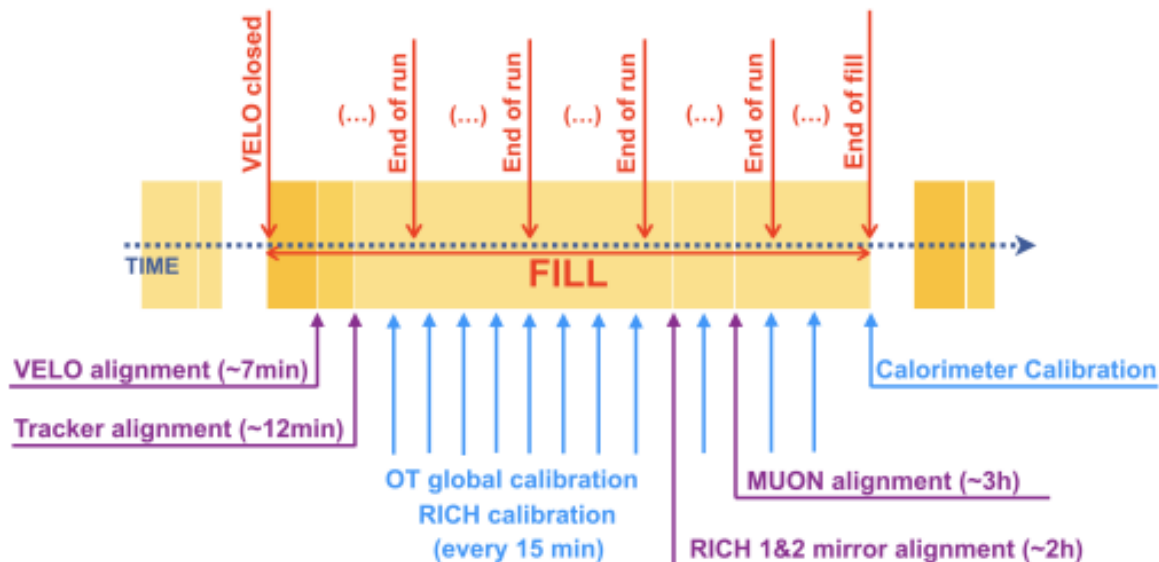


Alignment and Calibration

Why do we need alignment & Calibration?

- | Physical movements, magnetic field, temperature, pressure effects
- | Better mass resolution
- | Better particle identification (PID)
- | Store less background → More bandwidth for physics!

What and when do we align?



((~7min),(~12min),(~3h),(~2h)) - time needed for both data accumulation and running the task

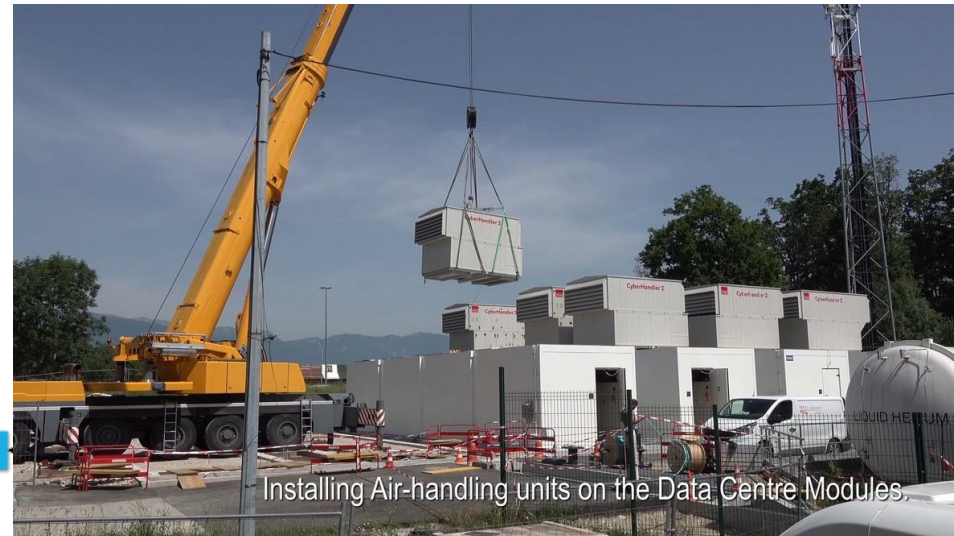
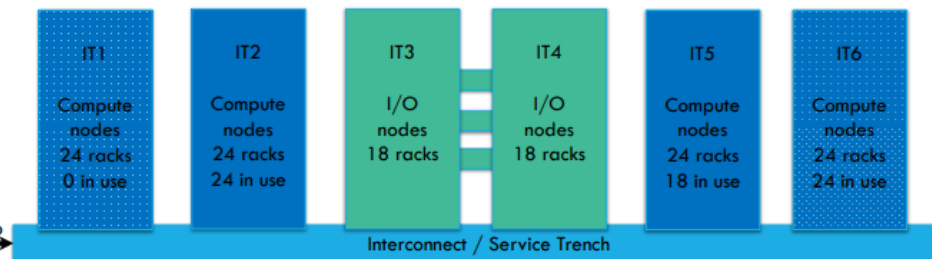
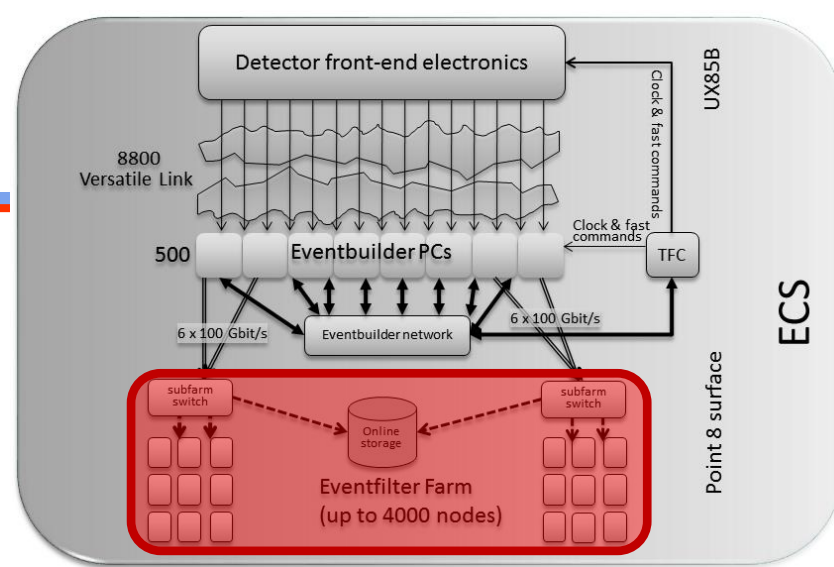


HLT2

A large CPU Farm

- Around 4000 PCs (many inherited for free)
- Also runs Calibration and Alignment tasks

A brand new Computer Center





Configuration, Control and Monitoring

Clara Gaspar, July 2023



Control System Tasks

■ Configuration

- | Selecting which components take part in a certain “Activity”
- | Loading several millions of parameters (according to the “Activity”)

■ Control core

- | Sequencing and Synchronization of operations across the various components

■ Monitoring, Error Reporting & Recovery

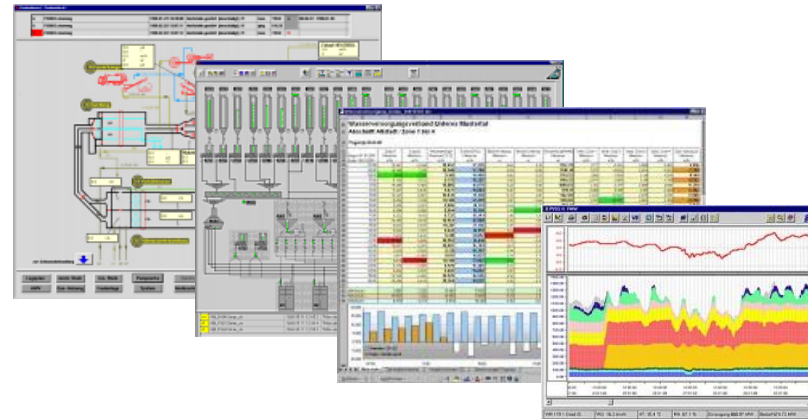
- | Detect and recover problems as fast as possible
- | Automate Standard Operations

■ User Interfacing

- | Allow the operator to visualize and interact with the system

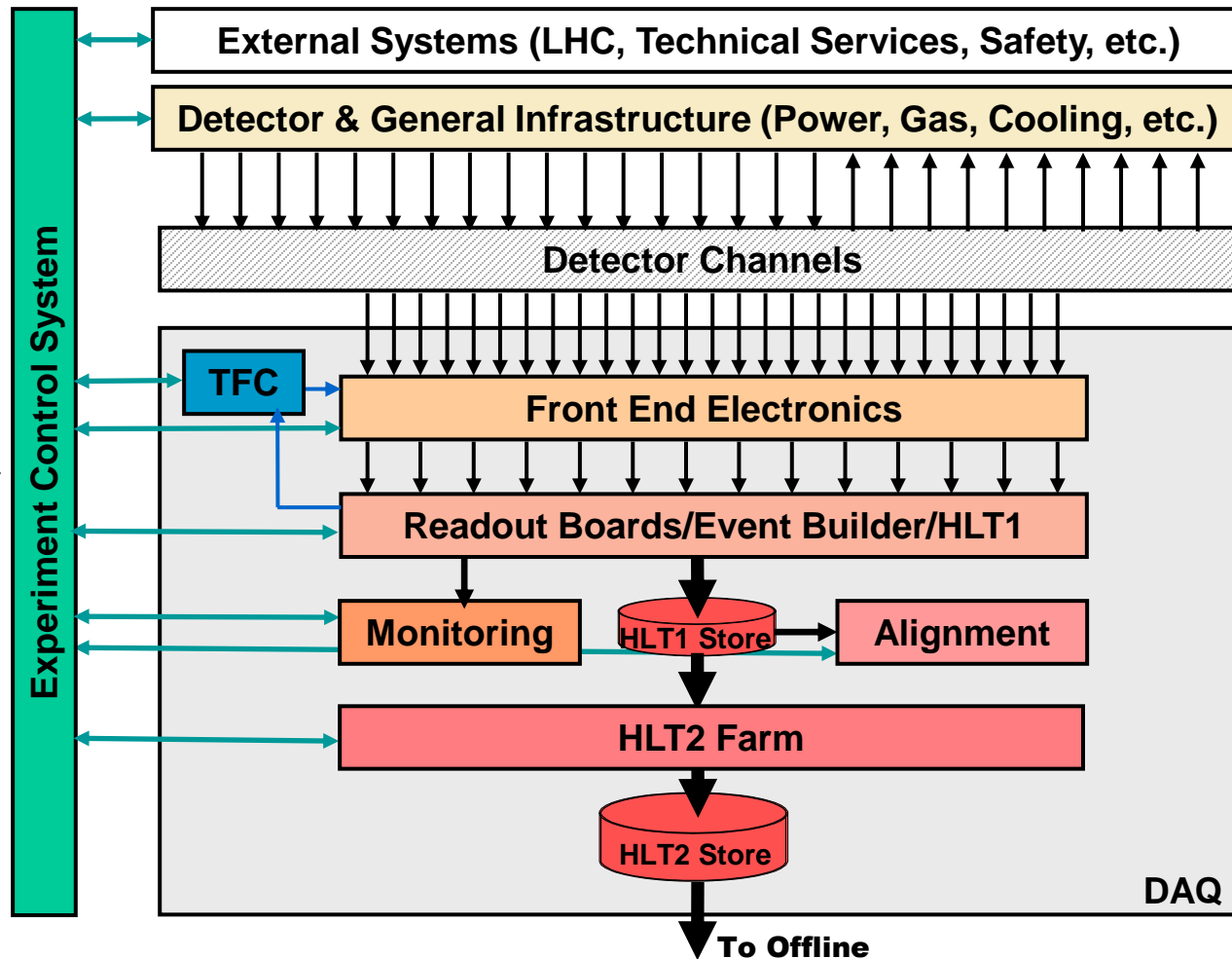
Control Framework

- **Can be based on Commercial SCADA Systems (Supervisory Control and Data Acquisition)**
 - Commonly used for:
 - | Industrial Automation
 - | Control of Power Plants, etc.
 - Providing:
 - | Run-time Database and Tools
 - | Archiving of Monitoring Data including display and trending Tools.
 - | Alarm definition and reporting tools
 - | User Interface design tools
 - Used in LHC experiments DCS and LHCb for everything
- **Or can be home made**



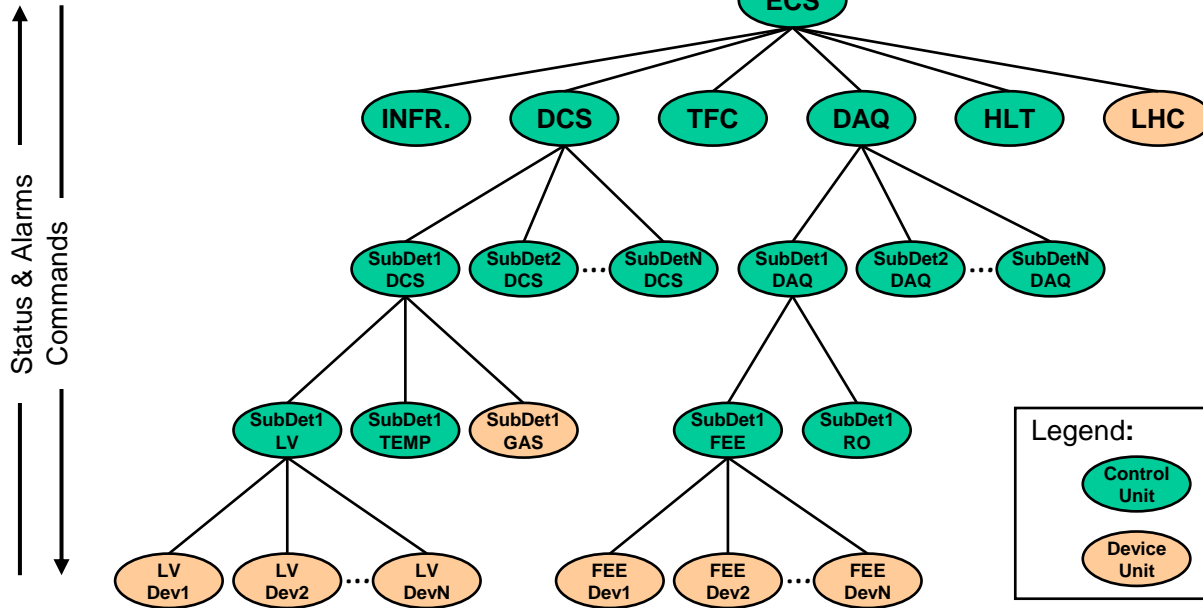


The Control System





Experiment Control System



Implementation: (JCOP project)

- | Framework

Deployment:

- | Runs distributed over >100 PCs (Virtual Machines)

Control Units are logical entities:

- | Behave as a Finite State Machine / Rule Based system:
 - | Capable of Partitioning: Exclude/Include children
 - | Can take local decisions: Sequence & Automate Operations or Recover Errors

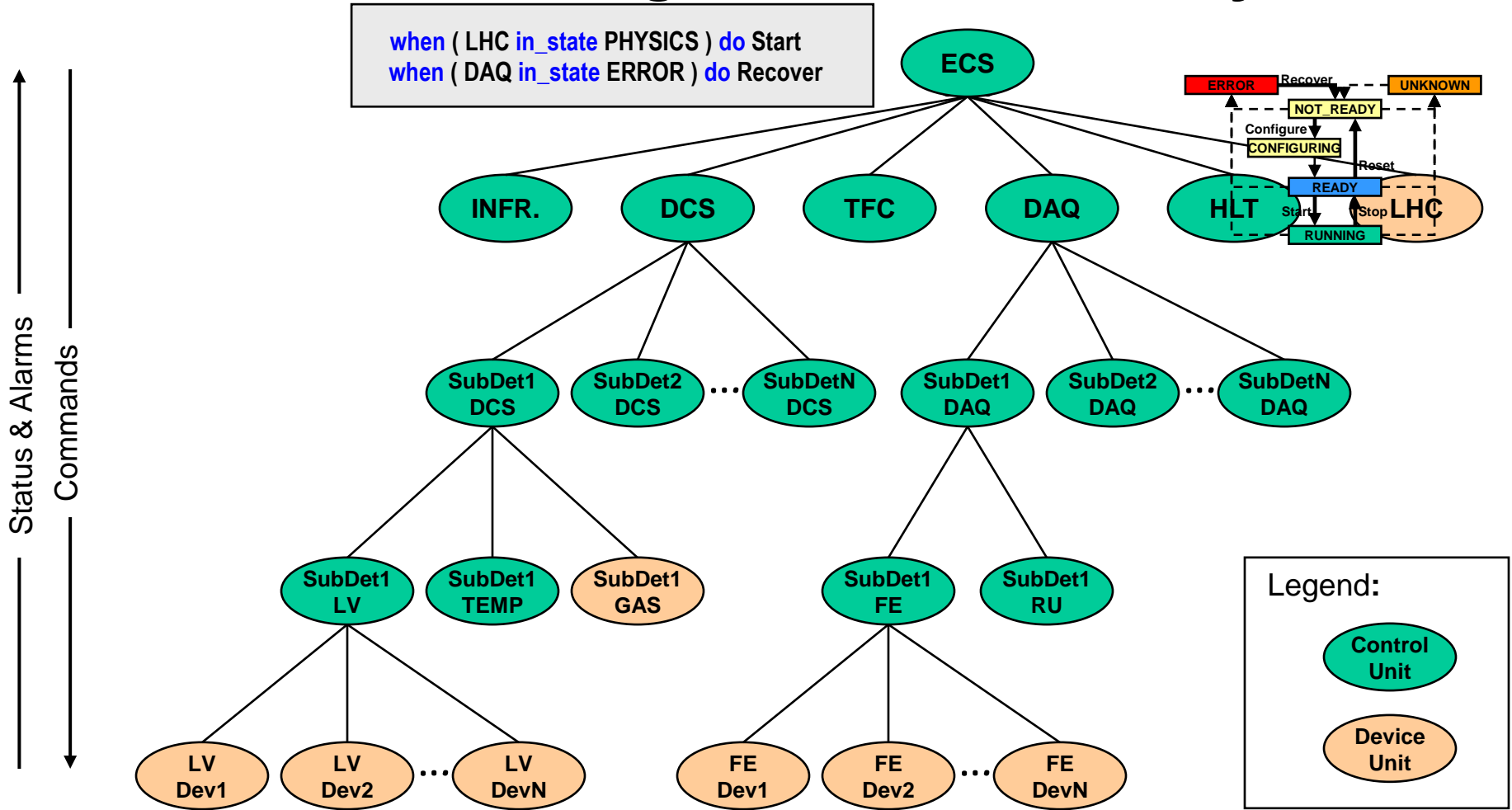
Device Units

- | Provide the interface to the device (hardware or software)

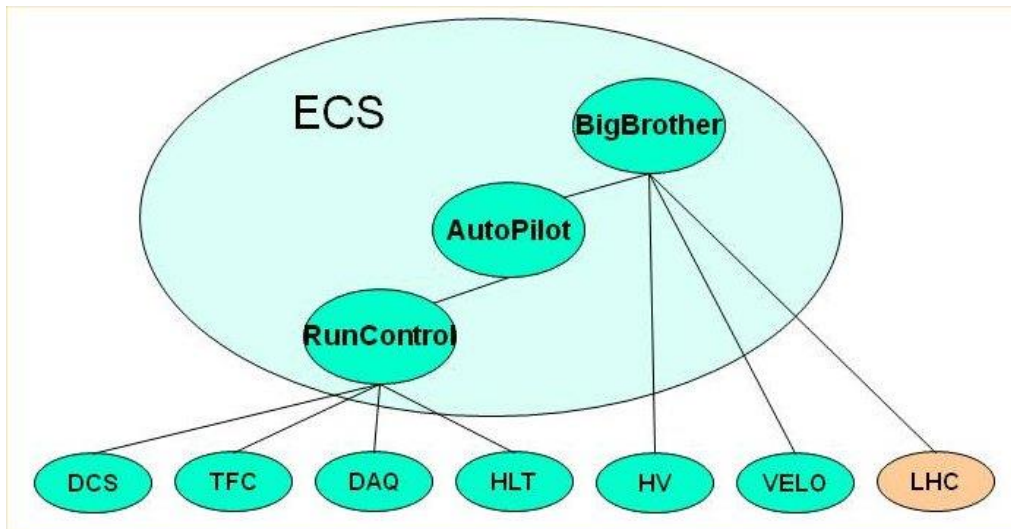


Control System Behaviour

Distributed “Intelligent” Hierarchical System



■ Main Tools:



■ RunControl

- | Handles the DAQ & Dataflow
- | Allows to:
 - | Configure the system
 - | Start & Stop runs

■ AutoPilot

- | Knows how to start and keep a run going from any state.

■ BigBrother

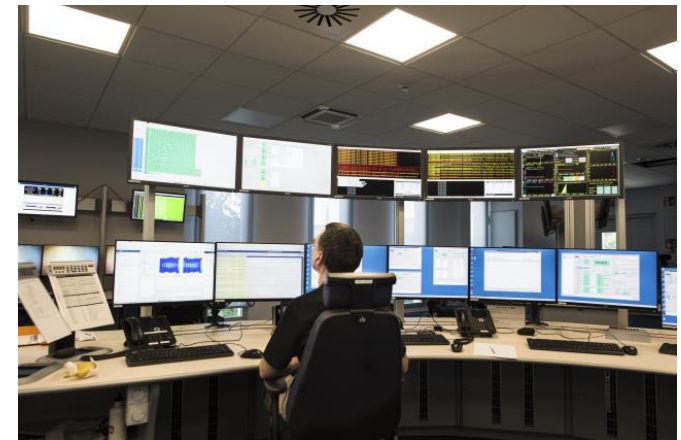
- | Based on the LHC state:
 - | Controls SD Voltages
 - | VELO Closure
 - | RunControl



Run Control

The screenshot displays the LHCb Run Control interface. At the top, the system is labeled 'LHCb: TOP' and the state is 'RUNNING'. The 'Auto Pilot' is set to 'OFF'. The 'System' is 'LHCb' and the user is 'root'. The date and time are 'Fri 02-Jun-2023 20:29:40'. A table of sub-systems shows their states: DCS (READY), DAI (READY), DAQ (RUNNING), RunInfo (RUNNING), TFC (RUNNING), EB+HLT1 (RUNNING), and Monitoring (RUNNING). The 'Run Info' section shows Run Number 265586, Run Start Time 02-Jun-2023 20:27:45, Run Duration 000:01:50, Nr. Events 1'169'789'728, Step Nr. 0, and To Go 0. The 'Input Rate' is 10327.81 kHz and the 'Output Rate' is 225.12 kHz. The 'Dead Time' and 'Incompl. Evs.' are both 0.00%. The 'Data Destination' is 'Offline' and the 'Data Type' is 'MMISSIONING23'. The 'File' is 'hlt1'. The 'Sub-Detectors' section shows the status of various detectors: VELOA (RUNNING), VELOC (RUNNING), UTA (ERROR), UTC (ERROR), SFA (RUNNING), SFC (RUNNING), RICH1 (RUNNING), RICH2 (RUNNING), ECAL (RUNNING), HCAL (RUNNING), MUONA (RUNNING), MUONC (RUNNING), and PLUME (RUNNING). The 'Messages' section shows logs of actions executed by LHCb.

- Run Control & The Autopilot:
 - Configures, Starts and Keeps the RUN going.
 - Configuration Driven by an “Activity”





Run Control

DATEALLPHYSICS_1_DAQ::ALLPHYSICS_1_CONTROL

ALLPHYSICS_1 DAQ - Run Control

HI running on aldaqecs01 with PID 20282
RC running on aldaqecs01 with PID 7601

Disconnected Configuration | Connected Run Parameters | Ready to start | Data Taking

Start processes | Stop | Abort

HLT: mode C
LDC: Local Recording OFF
GDC: NO Recording

RUN NUMBER : 196753 Run Control Status : RUNNING

Trace
Tue 05 10:32:37 (RC) Starting Data Taking for run 196753
Tue 05 10:31:30 (HI) Current RC options loaded from database
Tue 05 10:31:30 (HI) Start processes time : 45 seconds
Tue 05 10:30:45 (RC) GDCs: gdc-DET-ACORDE-0 gdc-DET-ZDC-0 gdc-DET-SD0-0 gdc-DET-PROS
Tue 05 10:30:45 (RC) HLT LDCs: ldc-HLT-0 ldc-HLT-1 ldc-HLT-2 ldc-HLT-3 ldc-HLT-4 ldc-HLT-5
Tue 05 10:30:45 (RC) Detector LDCs: ldc-SPD-01-03-0 ldc-SPD-04-05-0 ldc-SPD-06-08-0 ldc-SPD-09-1
Tue 05 10:30:45 (RC) Run starting with
Tue 05 10:30:45 (RC) Starting processes for run 196753

ALICE:
Tcl/Tk

ATLAS TDAQ SOFTWARE - Partition ATLAS

Run Control Segments & Resources Dataset Tags

RUN CONTROL STATE: RUNNING

Run Control Commands: SHUTDOWN, ROOT, TERMINATE, INITIALIZE, UNCONFIG, CONFIG, STOP, START, HOLD TRG, RESUME TRG

Beam Stable: Warm Start, Warm Stop

Run Information & Settings: Run type: Physics, Run number: 218771, Super Master Key: 1563, LHC Clock Type: BC1, Recording: Enabled, Start time: 04-Feb-2013 16:38:58, Total time: 1 h, 21 m, 31 s

Subscription criteria: WARNING, ERROR, FATAL, INFORMATION, Expression

| TIME | SEVERITY | APPLICATION | NAME | MESSAGE |
|----------|-------------|-------------|----------|---|
| 17:59:59 | INFORMATION | IGUI | INTERNAL | All done! IGUI is going to appear. |
| 17:59:58 | INFORMATION | IGUI | INTERNAL | Waiting for the "Dataset Tags" panel to initialize. |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Waiting for the "Run Control" panel to initialize. |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Creating panel "Igui DSPanel". |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Creating panel "Igui SegmentResourcesPanel". |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Creating panel "Igui RunControlMainPanel". |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Waiting for the "Elog-Dialog" panel to initialize. |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Creating the panel instance of class "Igui ElogDialog". |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Waiting for the "MainCommands" panel to initialize. |
| 17:59:57 | INFORMATION | IGUI | INTERNAL | Creating the panel instance of class "Igui MainPanel". |

ATLAS:
Java
(modular)

Start

Subsystems: PIXEL, TRACKER, ES, ECAL, HCAL, HFILUM, CAITRON, DT, CSC, RPC, TRG, SCAL, DAQ, DDM, DCB

Run Number: 210658

Run History

System State

Sub-System State: DCS (READY), DAQ (RUNNING), RndM (RUNNING), TFC (RUNNING), Storage (RUNNING), Monitoring (RUNNING), Reconstruction (RUNNING), Calibration (RUNNING), HV (READY)

Run Info: Run Number: 136863, Run Start Time: 07-Feb-2013 09:37:45, Run Duration: 00:15:03, Nr. Events: 1550254, Step Nr. To Go: 0

Deferred HLT Info: LHCb_Deferred (NOT ALLOCATED)

Efficiency: Trigger Rates, TFC Control, TELLIs, LHCb Elog

Sub-Detectors: VELOA, VELOC, TT, IT, OTA, OTC, RICH1, RICH2, PPS, TORUS, TPC, TRK, TRK2, TRK3, TRK4, TRK5, TRK6, TRK7, TRK8, TRK9, TRK10, TRK11, TRK12, TRK13, TRK14, TRK15, TRK16, TRK17, TRK18, TRK19, TRK20, TRK21, TRK22, TRK23, TRK24, TRK25, TRK26, TRK27, TRK28, TRK29, TRK30, TRK31, TRK32, TRK33, TRK34, TRK35, TRK36, TRK37, TRK38, TRK39, TRK40, TRK41, TRK42, TRK43, TRK44, TRK45, TRK46, TRK47, TRK48, TRK49, TRK50, TRK51, TRK52, TRK53, TRK54, TRK55, TRK56, TRK57, TRK58, TRK59, TRK60, TRK61, TRK62, TRK63, TRK64, TRK65, TRK66, TRK67, TRK68, TRK69, TRK70, TRK71, TRK72, TRK73, TRK74, TRK75, TRK76, TRK77, TRK78, TRK79, TRK80, TRK81, TRK82, TRK83, TRK84, TRK85, TRK86, TRK87, TRK88, TRK89, TRK90, TRK91, TRK92, TRK93, TRK94, TRK95, TRK96, TRK97, TRK98, TRK99, TRK100

Messages: 07-Feb-2013 05:02:42 - LHCb in state ACTIVE, 07-Feb-2013 05:02:42 - LHCb in state RUNNING, 07-Feb-2013 05:28:21 - LHCb in state CHANGING, 07-Feb-2013 05:28:21 - LHCb executing action CHANGE_RUN

LHCb:
JCOP FW
(UI builder)

CMS: Web Tools (JavaScript+HTML)

Clara Gaspar, July 2023



Big Brother

System State: **READY** Auto Handshake: OFF

Sub-System State

| | | |
|------------|----------|---|
| LHC | PHYSICS | ✓ |
| BCM | READY | ✓ |
| Magnet | READY | ✓ |
| LHCb Clock | EXTERNAL | ✓ |

Handshakes

| | |
|------|---------|
| LHC | STANDBY |
| LHCb | VETO |

Voltages

| System | State | Requested | Settings |
|-------------|-------|-----------|----------|
| LHCb_LHC_HV | OK | PHYSICS | PHYSICS |

| Sub-Detector | State | Req. HV | %Ok | HV State (A/C) | Settings |
|--------------|-------|---------|--------|----------------|----------|
| VELO_LHC_HV | OK | OFF | 92.86 | READY | READY |
| UT_LHC_HV | OK | OFF | 0.00 | NOT_READY | OFF |
| SF_LHC_HV | OK | READY | 100.00 | READY | READY |
| RICH1_LHC_HV | OK | READY | 100.00 | READY | READY |
| RICH2_LHC_HV | OK | READY | 100.00 | READY | READY |
| ECAL_LHC_HV | OK | READY | 100.00 | READY | READY |
| HCAL_LHC_HV | OK | READY | 100.00 | READY | READY |
| MUON_LHC_HV | OK | READY | 99.91 | READY | READY |
| PLUME_LHC_HV | OK | READY | 100.00 | READY | READY |

Big Brother Settings Actions

LHC Mode: PROTON PHYSICS Fill Number: 8863 Energy: 6800 GeV

Magnet Set Current: 5849.9 A Measured Current: 5849.9 A Polarity: DOWN

DB Interfaces Run DB Server: ON Cond DB Server: ON PVSS Archive: ON

VELO Closing Manager Motion State: DEAD

Beam Position Motion System Position

| | | | | | |
|---|---------|----|----------|----|-----------|
| X | unknown | XA | 29.70 mm | XC | -29.70 mm |
| Y | unknown | Y | 0.45 mm | | |

Status: v8.6

Scheduler Activity Scheduler: LHCb

| Start | Activity | Active |
|----------------|-----------|--------|
| At RAMP | COLLISION | ✓ |
| At EOF | IVSCAN | ✓ |
| After Previous | EOFCalib | ✓ |
| At INJECTION | | |
| At RAMP | | |
| At FLATTOP | | |
| At PHYS_ADJUST | | |
| At PHYSICS | | |
| At ADJUST | | |
| At EOF | | |
| After Previous | | |
| Always | | |

Messages

- 02-Jun-2023 20:04:25 - LHCb_LHC_HV in state ERROR
- 02-Jun-2023 20:04:26 - LHCb_LHC_HV in state UNKNOWN
- 02-Jun-2023 20:04:26 - LHCb_LHC_HV in state OK

- Based on LHC state, controls:
 - Voltages
 - VELO Closure
 - Run Control
- Can sequence activities, ex.:
 - End-of-fill Calibration
- Confirmation requests and Information
 - Voice Messages



Detector Control System

Panel for object: HANDSHAKE not found!

Handshake status: NOT READY

Beam Mode: BEAM SETUP

Temperature: 19.8°C, 977.0mm/s

Sub-detectors listed: ALL_DCS, HANDSHAKE, SERVICES, RUN UNIT, ACO_DCS, EMC_DCS, PHAD_DCS, HMP_DCS, MCH_DCS, MTR_DCS, PHS_DCS, PHAD_DCS, SSD_DCS, SPD_DCS, SSO_DCS, T00_DCS, T0F_DCS, TPC_DCS, TRD_DCS, V0_DCS, PTL_DCS, TRT_DCS.

JCOP FW
 ← ALICE
 ATLAS →

NO USER 08-10-2011 13:39:12

Handshake status: READY

ATLAS DETECTOR CONTROL

Sub-detectors listed: PK, SCT, TRT, IDL, LAR, MDT, RPC, TDC, CSC, MUON, CQC, EXT, T0C, LHC, FWD, SAFETY, DCS BE.

Handshake status: READY

Sub-detectors listed: EMC, ECA, BEAR, PLA, PS, GAS, RAC, MAG, COM, ENV, HEL, HER, DIP, CAN, T0H, ELM, BAR, END, EPS.

| System | State | Operator |
|---------|-------------------|------------|
| PHYSICS | READY FOR PHYSICS | D. Sanders |
| STRIPS | READY FOR PHYSICS | D. Sanders |
| ECAL | READY FOR PHYSICS | D. Sanders |
| HCAL | READY FOR PHYSICS | D. Sanders |
| DT | READY FOR PHYSICS | D. Sanders |
| RPC | READY FOR PHYSICS | D. Sanders |
| CSC | READY FOR PHYSICS | D. Sanders |

BEAM MODE DIAGRAM

BEAM DUMP

DCS EVENT LOG

9/14/2012 9:42:29 AM - Beam mode changes to RAMP
 9/14/2012 9:42:29 AM - Beam mode changes to FLAT TOP
 9/14/2012 9:48:29 AM - Beam mode changes to PHYSICS
 9/14/2012 9:48:31 AM - Sending automatic action GO TO PHYSICS to CSC
 9/14/2012 9:48:31 AM - Sending automatic action GO TO PHYSICS to DT
 9/14/2012 10:39:11 AM - Including PDEL in CENTRAL
 9/14/2012 10:40:07 AM - Beam mode changes to LOCAL
 9/14/2012 10:51:07 AM - Setting CSC to LOCAL
 9/14/2012 12:11:00 PM - Including CSC in CENTRAL
 9/14/2012 12:11:00 PM - Beam mode changes to BEAM DUMP

← CMS
 LHCb →

System State: READY

Sub-System State: PHYSICS

Handshakes: LHC, LHCb

Volts: LHC_LHC_JVHVLV

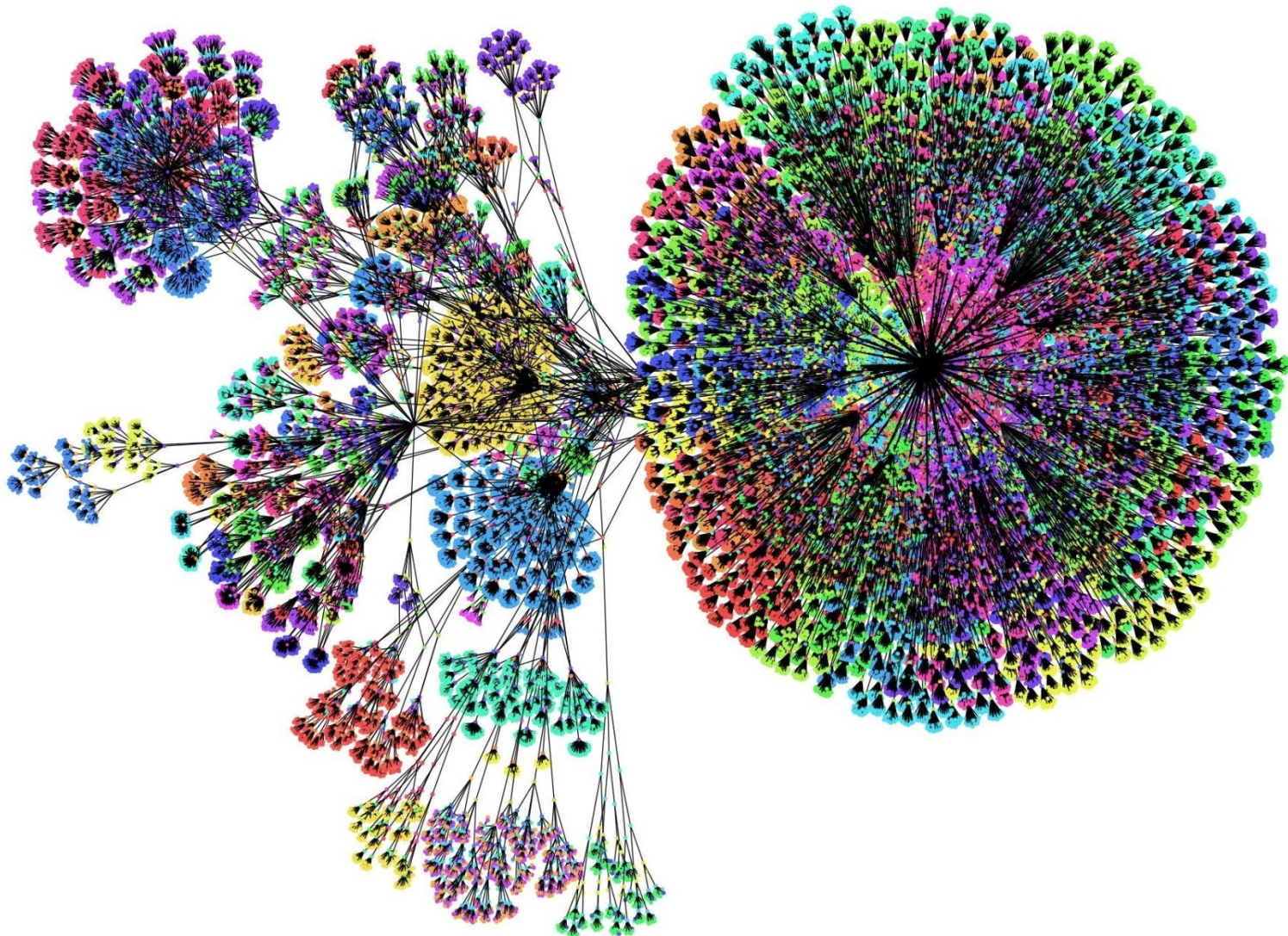
| Sub-Detector | State | Req. HV | %OK | HV State (A/C) |
|--------------|-------|---------|-------|----------------|
| VELO_LHC_JV | OK | READY | 100.0 | READY |
| IT_LHC_JV | OK | READY | 100.0 | READY |
| IT_LHC_LV | OK | READY | 100.0 | READY |
| OT_LHC_JV | OK | READY | 100.0 | READY |
| OT_LHC_LV | OK | READY | 100.0 | READY |
| RPC1_LHC_JV | OK | READY | 100.0 | READY |
| RPC2_LHC_JV | OK | READY | 100.0 | READY |
| PHS_LHC_JV | OK | READY | 100.0 | READY |
| ECAL_LHC_JV | OK | READY | 100.0 | READY |
| HCAL_LHC_JV | OK | READY | 100.0 | READY |
| MUON_LHC_JV | OK | READY | 99.4 | READY |

Beam Position: X 0.69 mm, Y 0.19 mm

Status: 06-Feb-2013 09:22:22 - Now waiting for 2nd update of the BeamPosition...
 06-Feb-2013 09:22:30 - *** INFO - Current HV values (V): V0=0.076
 06-Feb-2013 09:22:30 - Got good update(s), going to next step.
 06-Feb-2013 09:22:30 - End of automatic clearing procedure
 06-Feb-2013 09:22:30 - Current VTX values (mm):
 06-Feb-2013 09:22:30 - Using limits for step: 0

Safety: TT_Safety, IT_Safety, OT_Safety, RICH_Safety, MUON_Safety

LHCb Control System



■ Courtesy of CMS DCS Team (by analyzing our FSM tree)

Clara Gaspar, July 2023

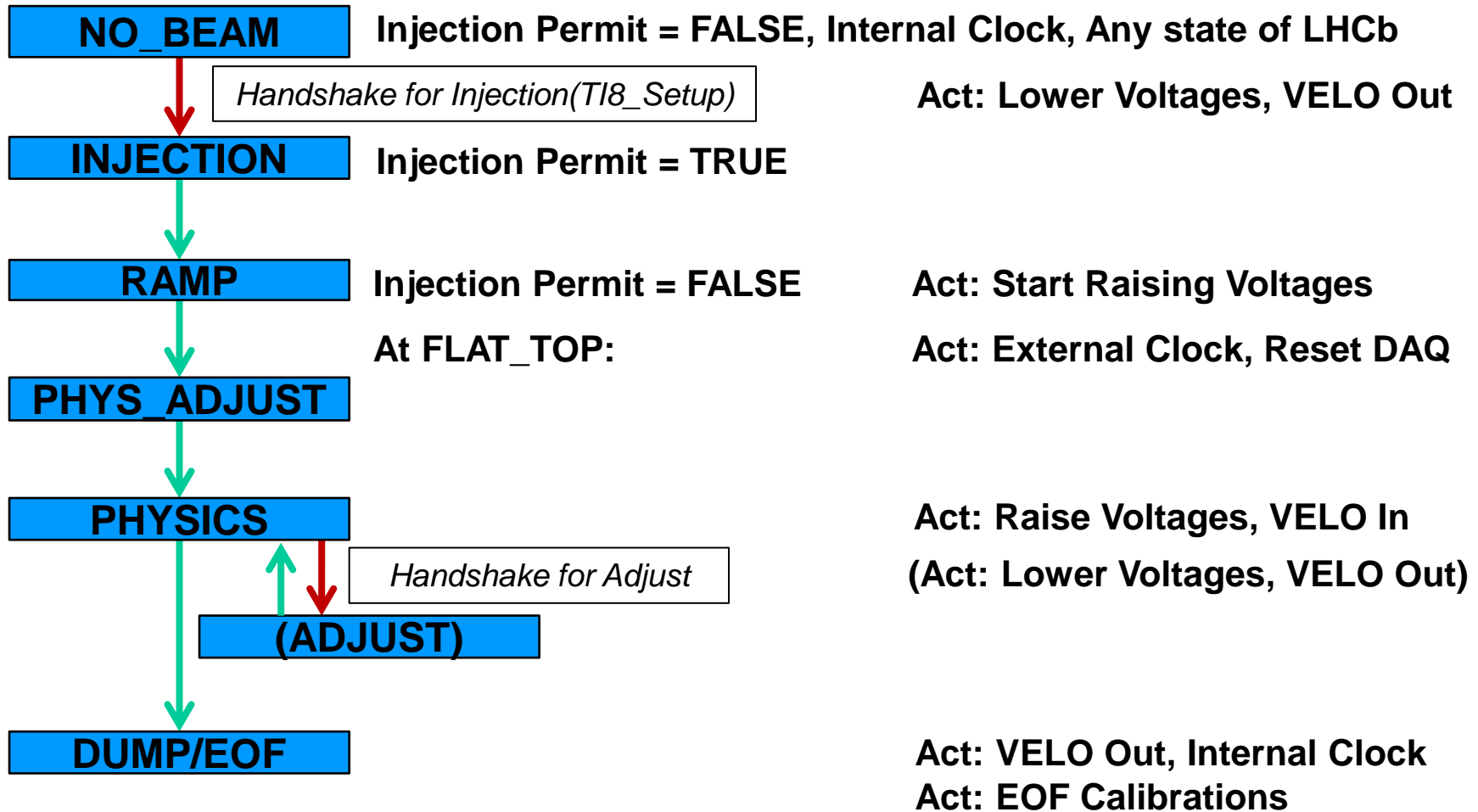


Concluding Remarks

- Trigger and Data Acquisition systems have become increasingly complex.
- Luckily the requirements of telecommunications and computing in general have strongly contributed to the development of standard technologies:
 - Hardware: Fast ADCs, Field-Programmable Gate Arrays, Analog memories, multi-core PCs, Networks, Helical scan recording, Data compression, Image processing (GPUs), ...
 - Software: Distributed computing, Software development environments, Supervisory systems, Artificial Intelligence tools...
- 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.



LHC/LHCb Fill Sequence



↘ Handshake: Confirm Handshake -> Prepare detector -> Confirm Ready

↘ Simple Confirmation



Other Tools & Components

I Main Framework Components:

I Communications

- I Device Access and Message Exchange between processes

I Intelligence: Finite State Machines/Expert System Functionality

- I System Description, Synchronization and Sequencing
- I Error Recovery, Assistance and Automation

I Databases

- I Configuration, Archive, Conditions, etc.

I User Interfaces

- I Visualization and Operation

I Other Services:

- I Process Management (start/stop processes across machines)
- I Resource Management (allocate/de-allocate common resources)
- I Logging, etc.

Communications (example)

■ DIM – Distributed Information Management System

- | Efficient and light weight data exchange across processes (and machines)

- | Available for:

- | C, C++, Java, Python
- | Linux, Windows, etc.

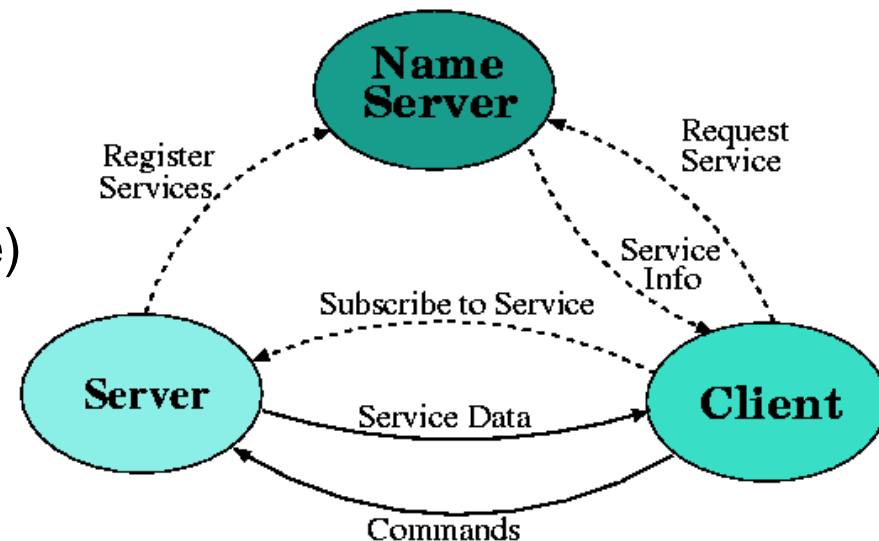
- | Client/Server (Publish/Subscribe)

- | Services

- | Set of data, any type or size
 - | Single items, arrays or structures
- | Free name space
 - | But better use a naming convention
- | Servers publish Services.
- | Clients subscribe to Services.
 - | Once, at regular intervals or on change
- | Clients can also send Commands to Servers

- | Name Server

- | Keeps the coordinates of available Services



Automation (example)

■ SMI++ - State Management Interface

- A Tool for the Automation of large distributed control systems

- Method:

- Classes and Objects

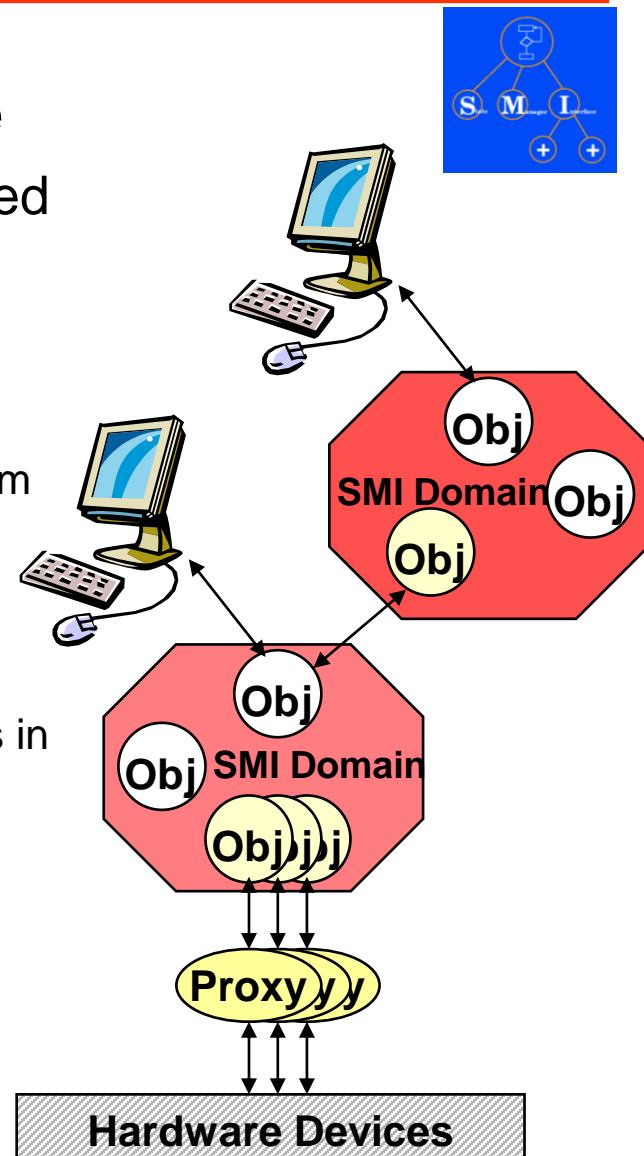
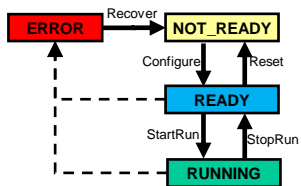
- Allow the decomposition of a complex system into smaller manageable entities

- Finite State Machines

- Allow the modeling of the behavior of each entity and of the interaction between entities in terms of STATES and ACTIONS

- Rule-based reasoning

- React to asynchronous events (allow Automation and Error Recovery)





SMI++ - The Language: SML

I Finite State Logic

- I Objects are described as FSMs their main attribute is a STATE

I Parallelism

- I Actions can be sent in parallel to several objects.

I Synchronization and Sequencing

- I The user can also wait until actions finish before sending the next one.

I Asynchronous Rules

- I Actions can be triggered by logical conditions on the state of other objects.

```
class: EventBuilder /associated
state: UNKNOWN /dead_state
state: NOT_READY
action : Configure
state: READY
action : Start
action : Reset
state: RUNNING
action : Stop
state: ERROR
action : Recover
...
```

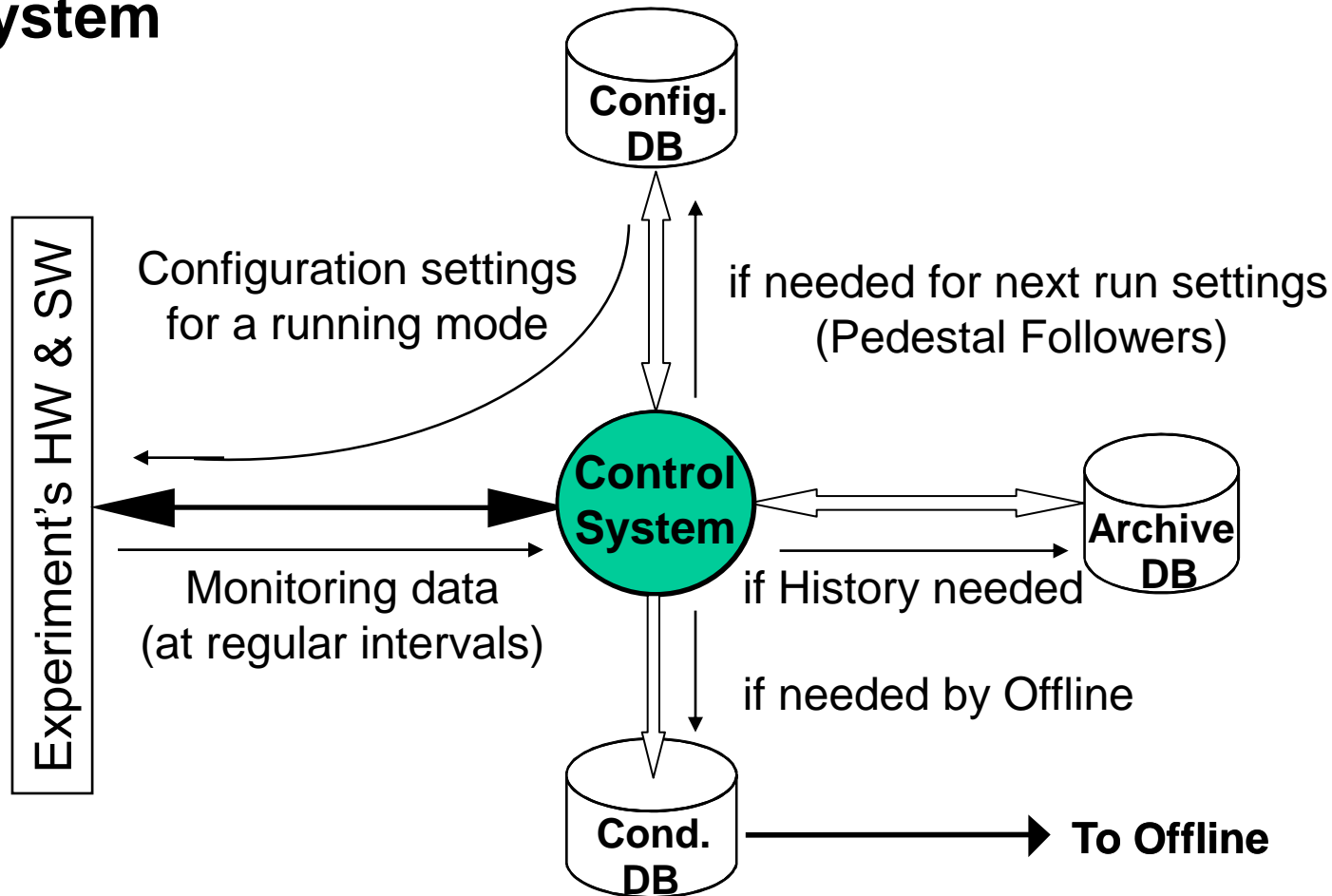
```
object: EB1 is_of_class EventBuilder
object: EB2 is_of_class EventBuilder
object: EB3 is_of_class EventBuilder
...
objectset: EBS {EB1, EB2, EB3, ...}
```

```
class: DAQ
state: NOT_READY /initial_state
action: GET_READY
(do Configure all_in Electronics)
do Configure all_in EBS
if (all_in EBS in_state READY) then
  move_to READY
endif
move_to ERROR
state: READY
when ( any_in EBS in_state ERROR ) do RECOVER
when ( any_in EBS not_in_state READY ) move_to NOT_READY
action: RECOVER
do Recover all_in EBS
...
state: ERROR
...
object: SubDetDAQ is_of_class DAQ
```

```
class: TopControl
state: STANDBY
when ( LHC in_state PHYSICS ) do STARTUP
action: STARTUP
(do GET_READY all_in SubDetDCS)
do GET_READY all_in SubDetDAQ
...
object: BigBrother is_of_class TopControl
```

Online Databases

■ Three main logical Database concepts in the Online System



➔ But naming, grouping and technology can be different in the different experiments...