Trigger and Data Acquisition

Summer Student Lectures
15, 16 & 18 July 2002

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Contents of the Lectures

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- **Front-end essentials**
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  - Signal processing
- **Trigger algorithms and implementations** ← Break
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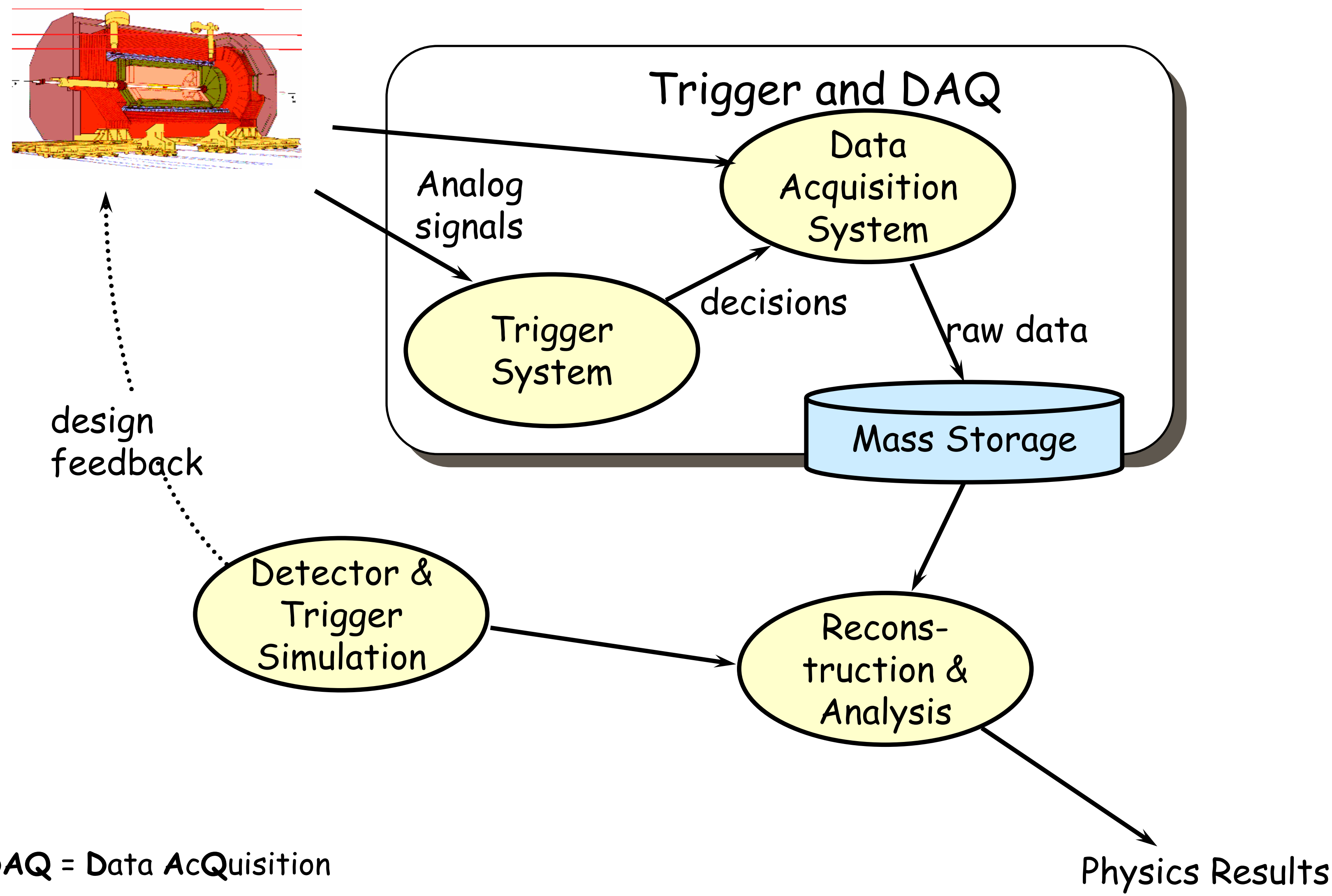
  - Fast hardware trigger (Level-1)
  - Software triggers (Level-2, Level-3, etc.)
- **Data Acquisition**
  - Readout networks (buses, switches, etc.)
  - Event building and event filters ← Break
  - Data storage
- **Configuration, Control and Monitoring**
  - Operating modes
  - Run Control
  - Data monitoring and quality control

Foreword

- This course presents the experience acquired by **the work of many people** and many teams which have been developing and building trigger and data acquisition systems for high energy physics experiments for many years.
- The subject of this course is **not an exact science**. The trigger and data acquisition system of each experiment is somehow unique (different experiments have different requirements and even similar requirements may be fulfilled with different solutions).
- This is not a review of existing systems. The reference to existing or proposed systems are used as examples.
- To prepare this course I have taken material and presentation ideas from my predecessors in previous years:
  P. Mato and Ph. Charpentier.

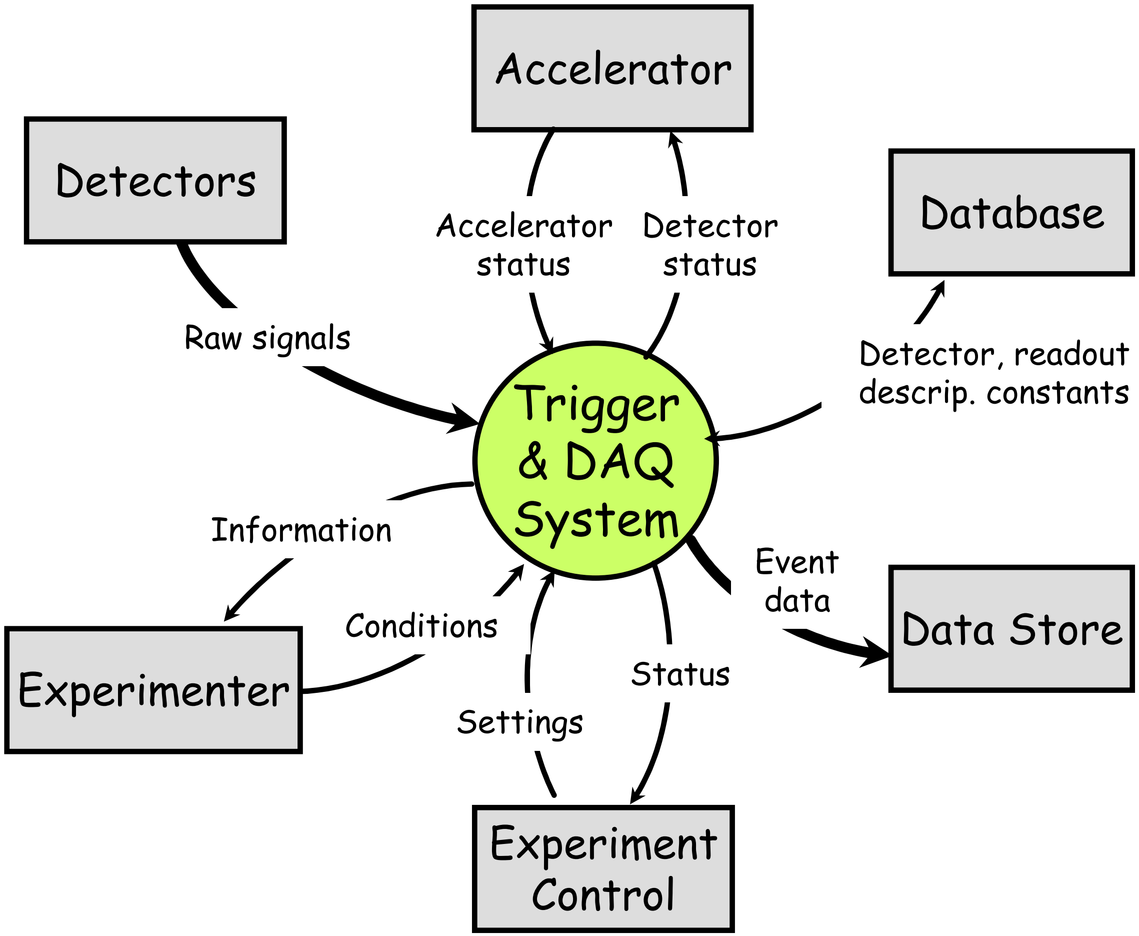
General Framework



DAQ = **D**ata **A**c**Q**uisition

Context Diagram

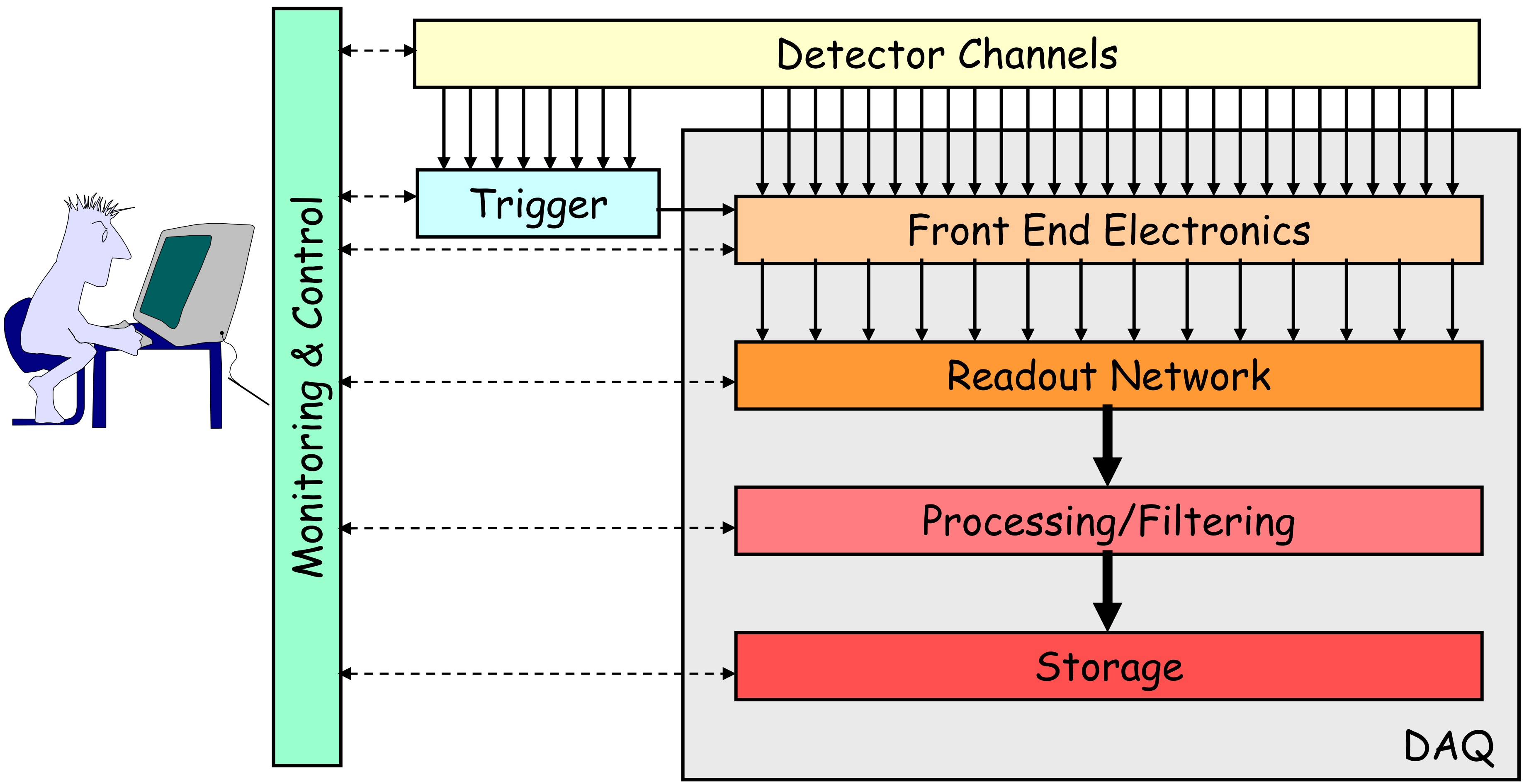
⌘ The main role of T & DAQ is to process the signals generated in the detector and write the information onto data storage, but:



Trigger & DAQ

- **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)
    - Front End Electronics:
      - Receive detector, trigger and timing signals and produce digitized information
    - Readout Network
      - Reads front end data and forms complete events (sometimes in stages) - Event building
    - Central DAQ
      - Stores event data, can do data processing or filtering
      - Overall Configuration Control and Monitoring

Trigger, DAQ & Control

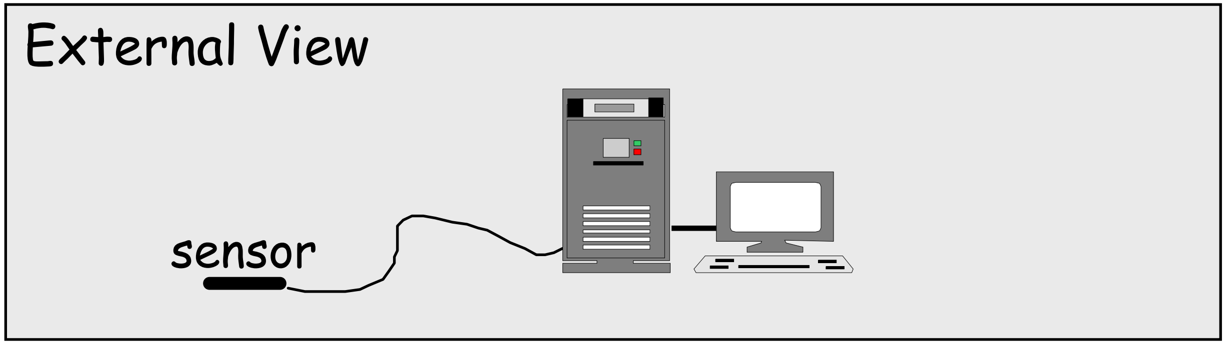


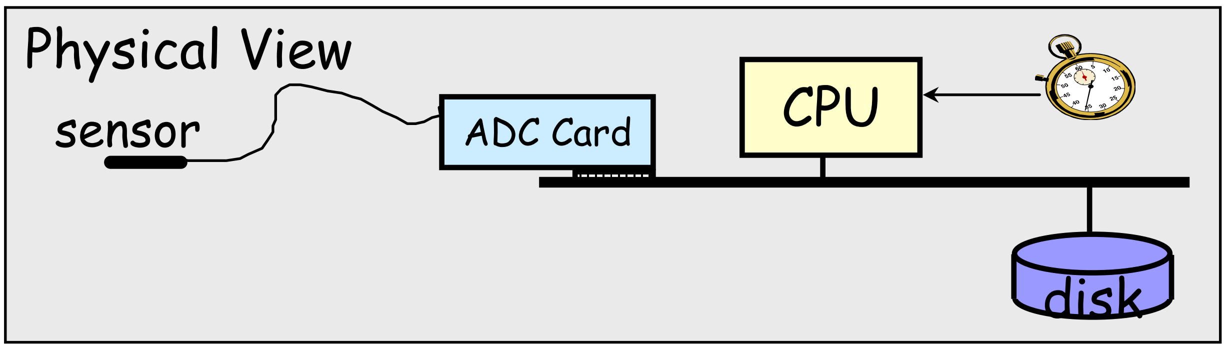
LEP & LHC in Numbers

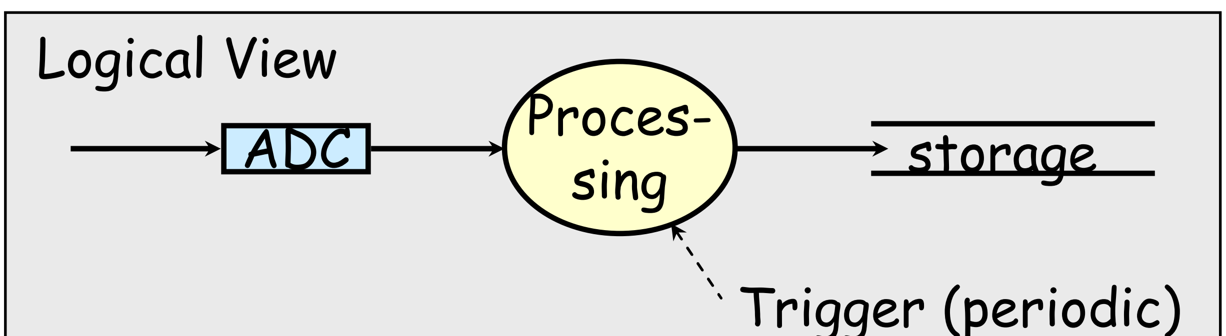
	LEP (1989/2000)	LHC (2007)	Factor
Nr. Electronic Channels	≈ 100 000	≈ 10 000 000	x 10^2
Raw data rate	≈ 100 GB/s	≈ 1 000 TB/s	x 10^4
Data rate on Tape	≈ 1 MB/s	≈ 100 MB/s	x 10^2
Event size	≈ 100 KB	≈ 1 MB	x 10
Bunch Separation	22 μs	25 ns	x 10^3
Bunch Crossing Rate	45 KHz	40 MHz	x 10^3
Rate on Tape	10 Hz	100 Hz	x 10
Analysis	0.1 Hz (Z_0, W)	10^{-6} Hz (Higgs)	x 10^5

Basic Concepts

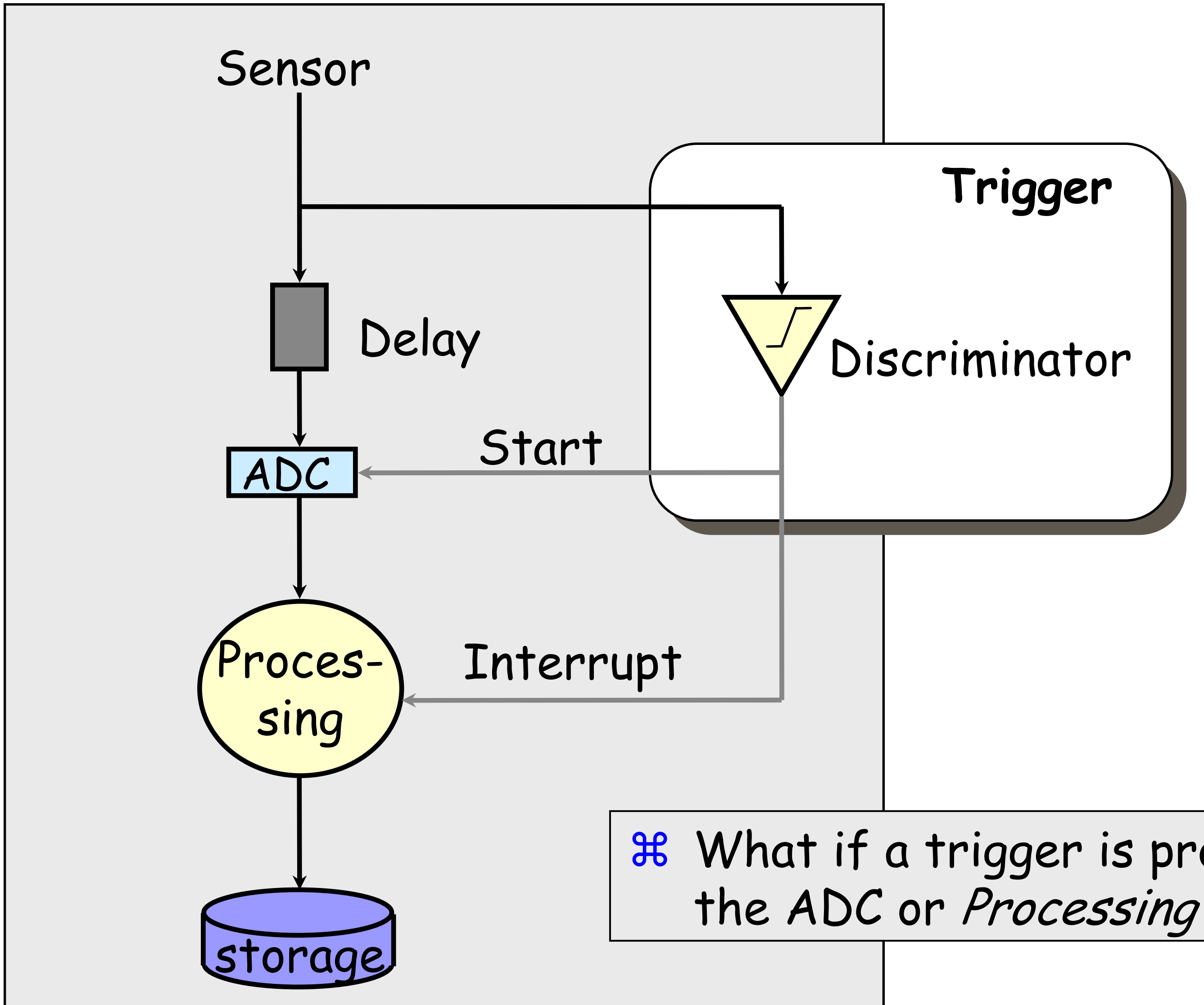
Trivial DAQ


External View
sensor


Physical View
sensor
ADC Card
CPU
disk

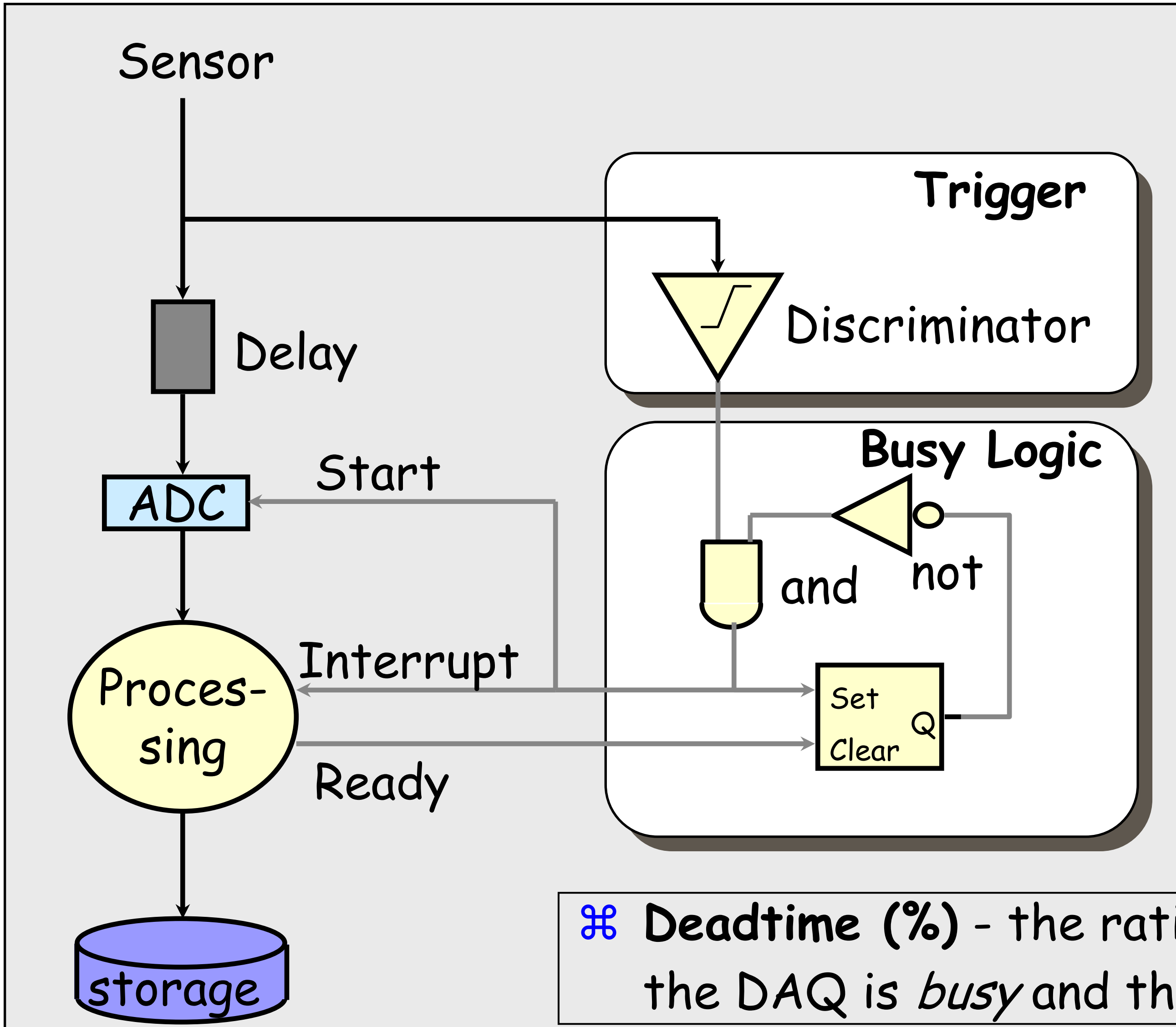

Logical View
ADC
Proces-
sing
storage
Trigger (periodic)

Trivial DAQ with a real trigger



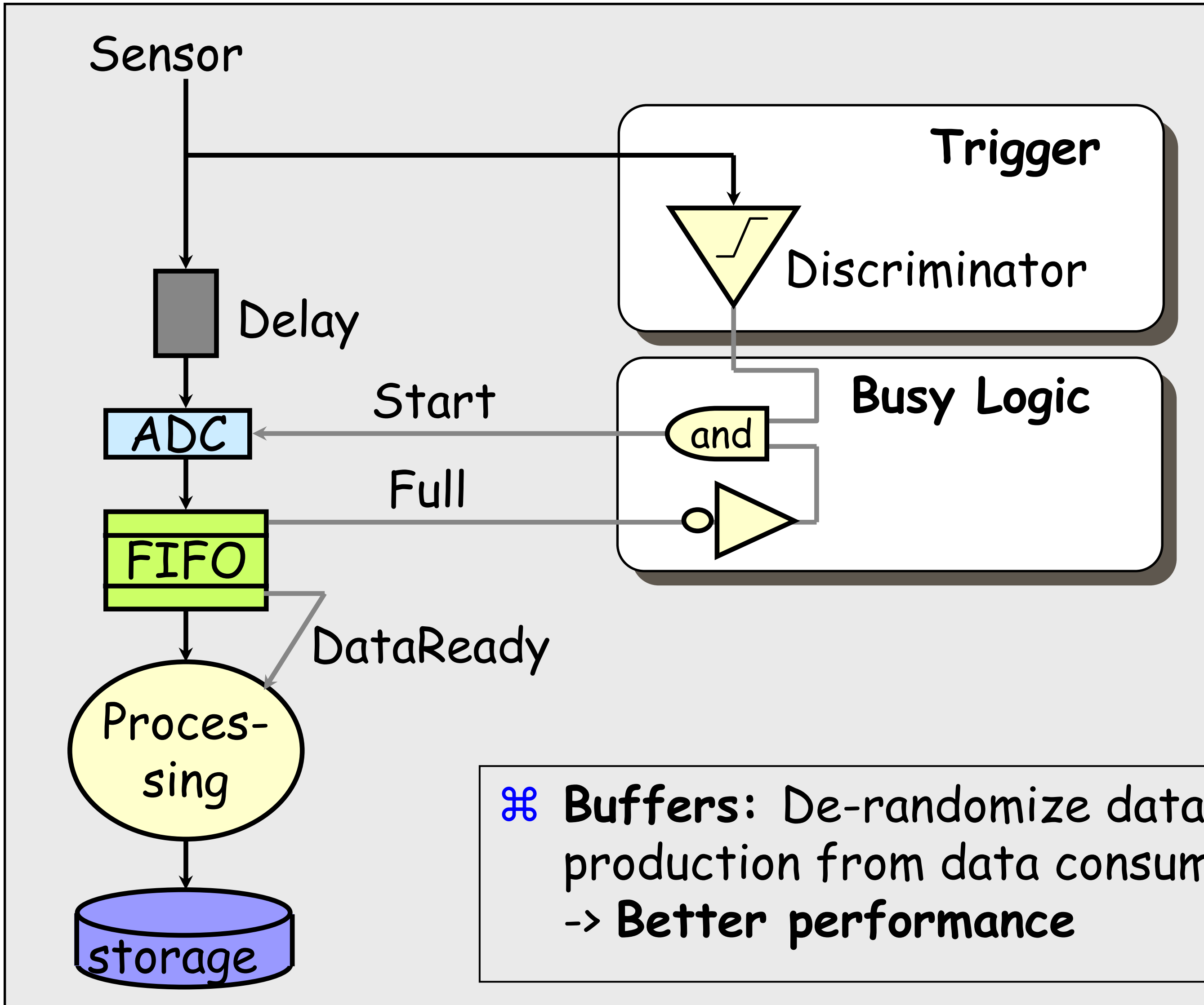
- What if a trigger is produced when the ADC or *Processing* is busy ?

Trivial DAQ with a real trigger (2)



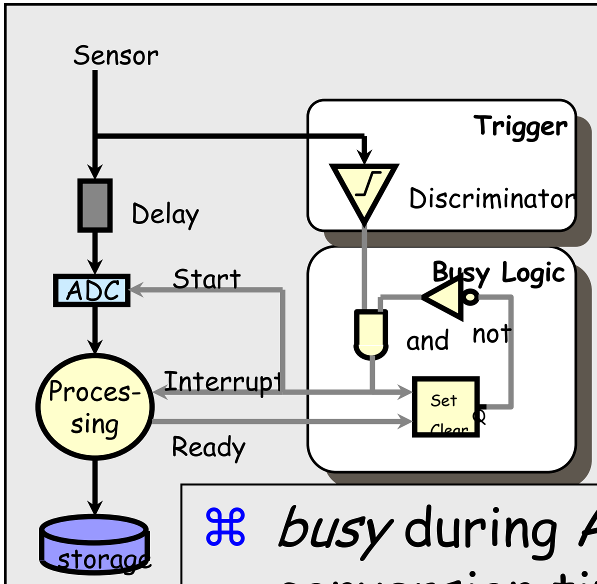
- **Deadtime (%)** - the ratio between the time the DAQ is *busy* and the total time

Trivial DAQ with a real trigger (3)

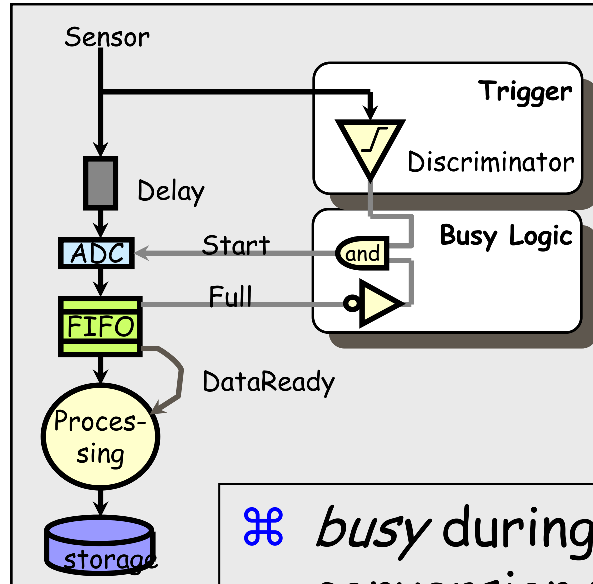


- **Buffers:** De-randomize data -> decouple data production from data consumption -> **Better performance**

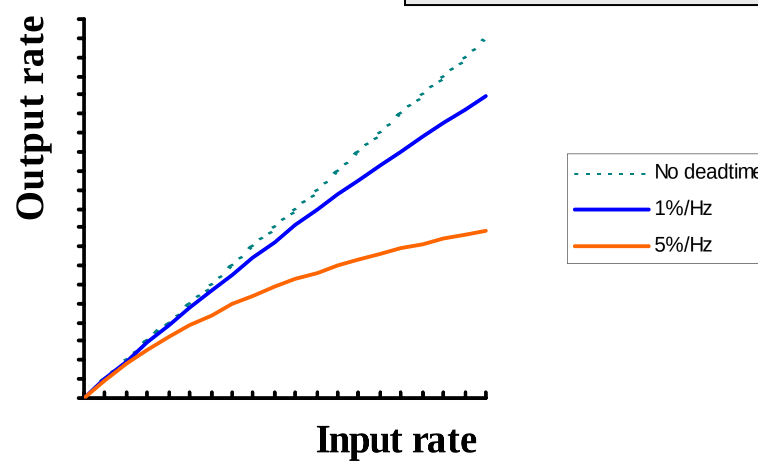
Derandomizer buffers (queues)



- *busy* during ADC conversion time + processing time

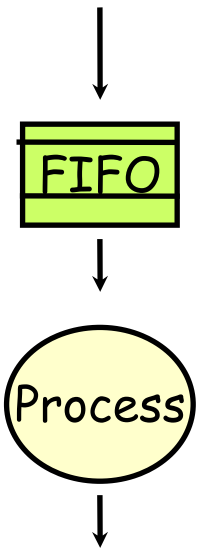


- *busy* during ADC conversion time if FIFO not full



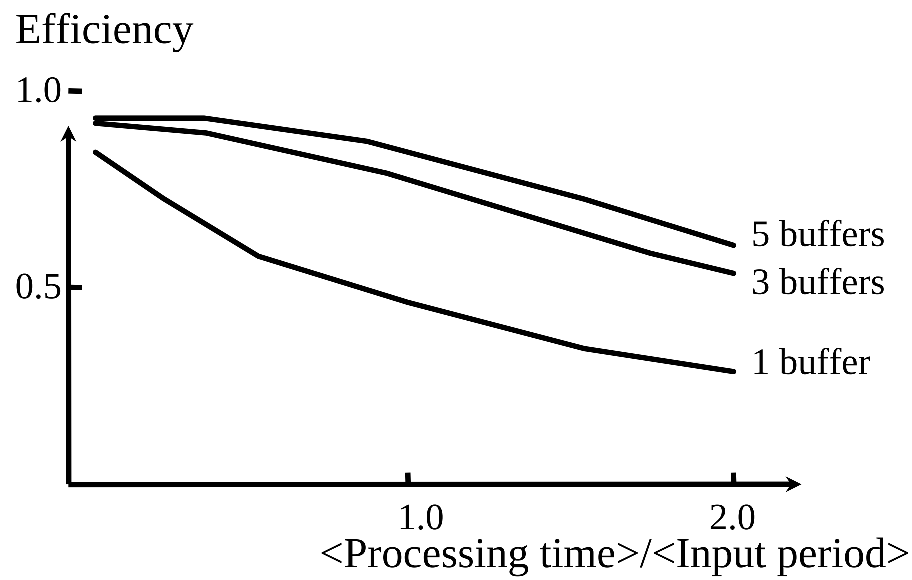
Queue Theory

Arrival time following
exponential distribution (Poisson process)



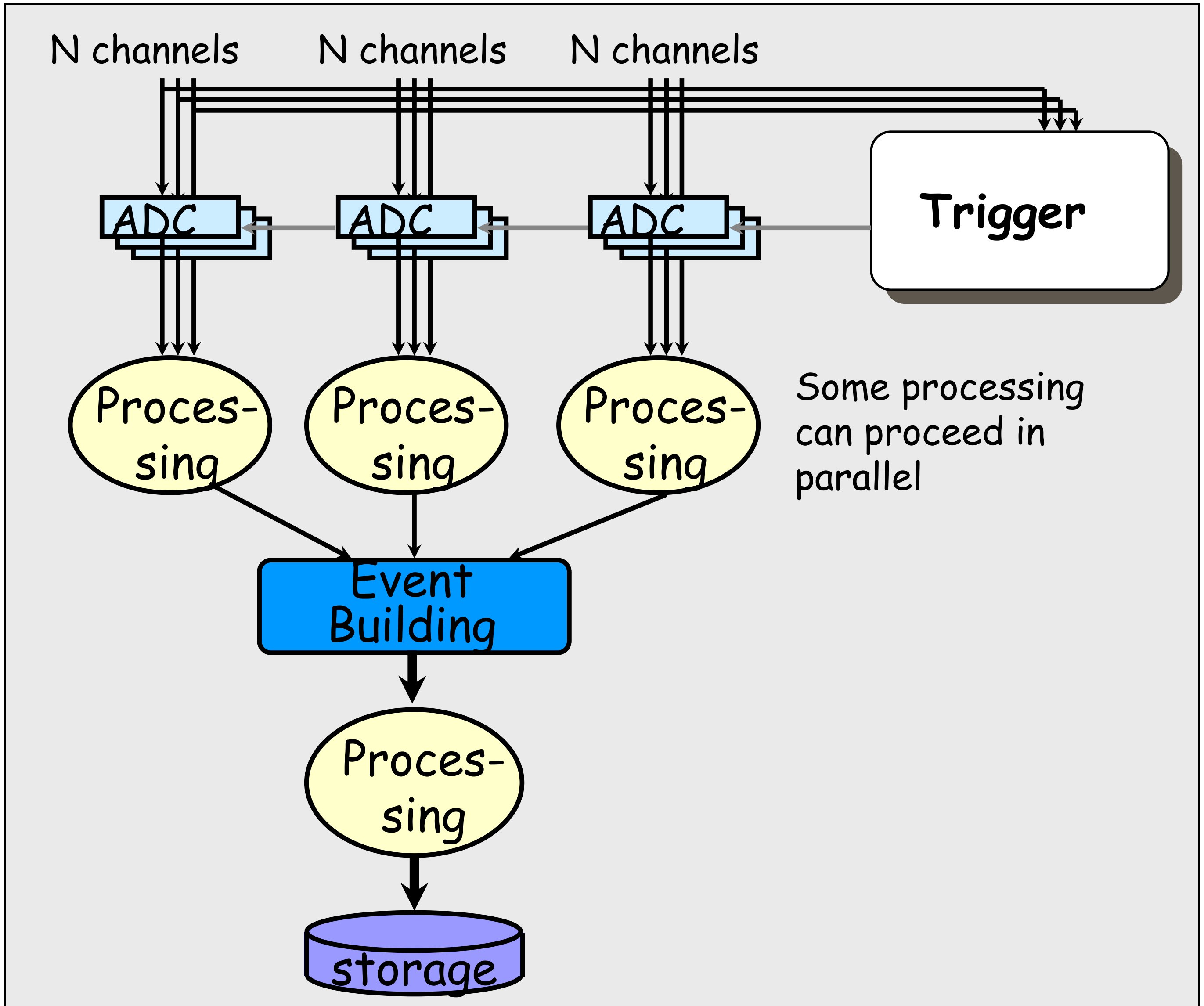
Depth 1, 3, 5

Processing time following
gaussian distribution

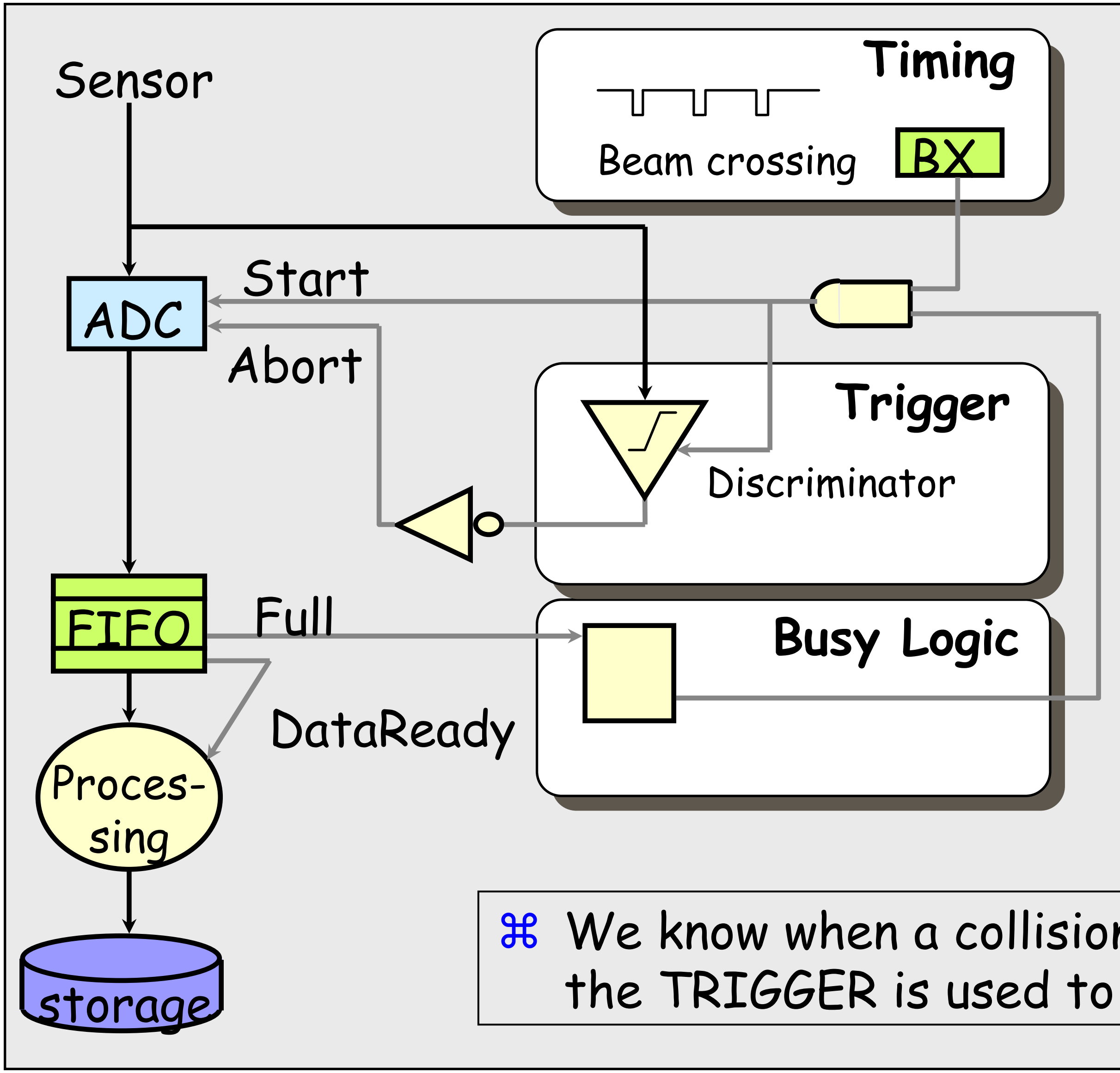


⌘ **For simple cases, the behavior of the system can be calculated analytically using *queue theory*. Soon you have to use simulation techniques.**

Less trivial DAQ



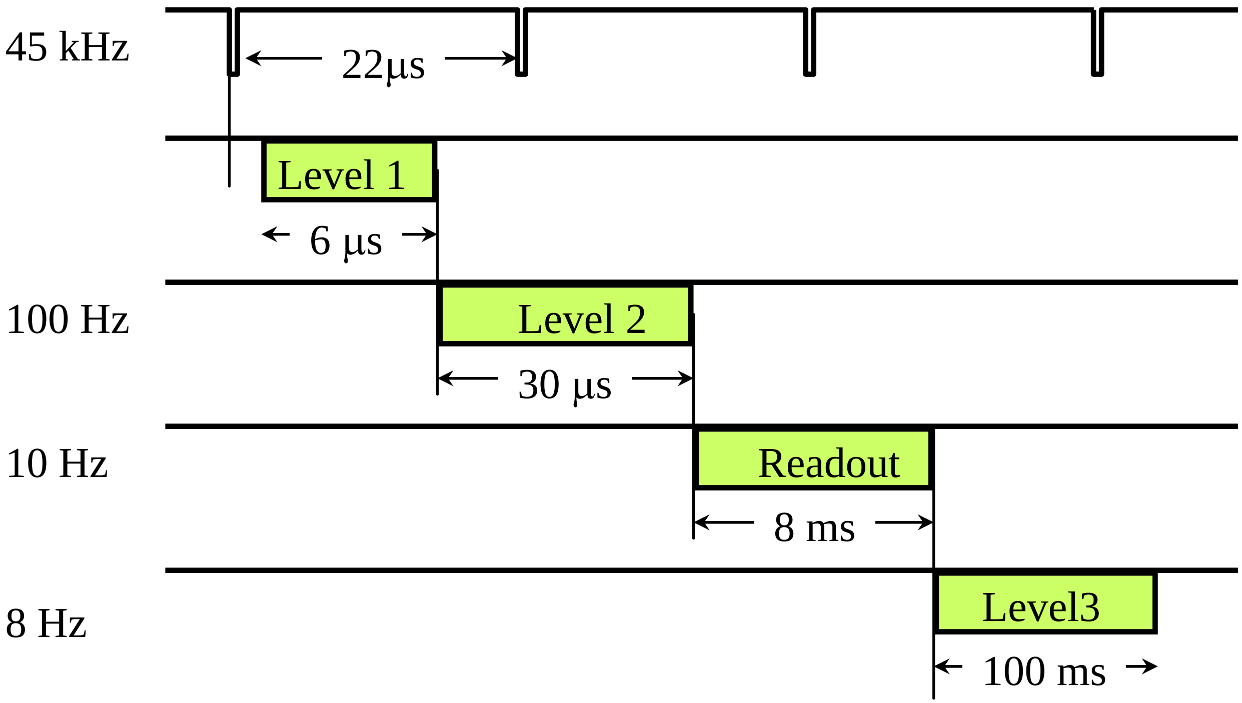
Trivial DAQ in collider mode



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

LEP collider timing

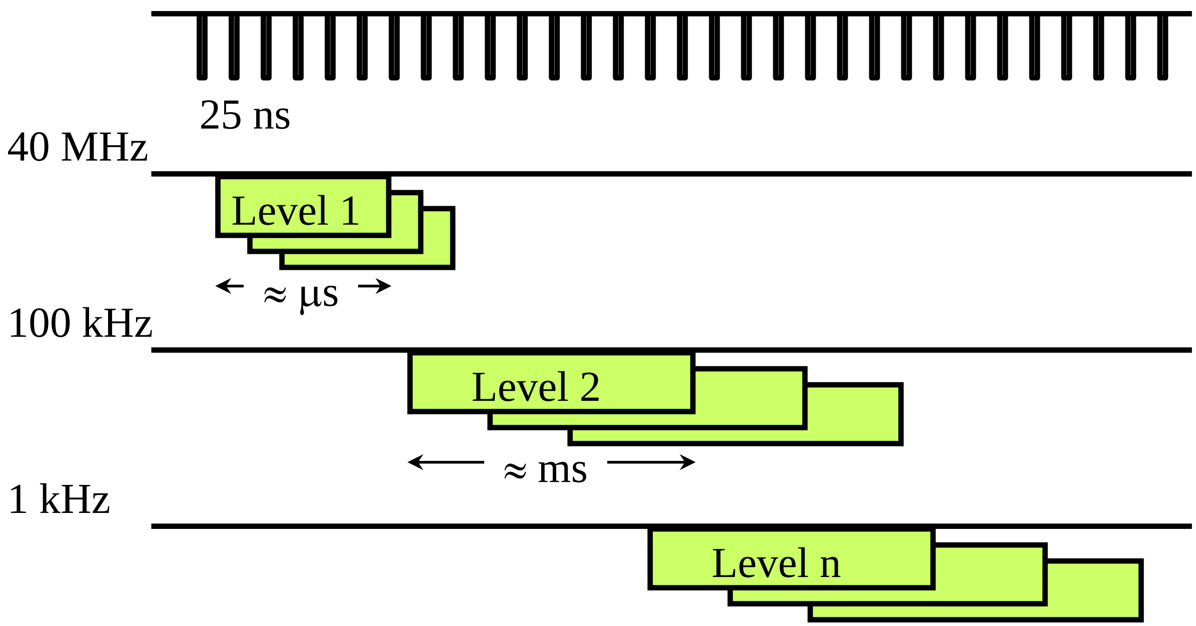
e^+e^- Crossing rate 45 kHz (4 bunches)



- Level 1 trigger latency < inter bunch crossings –> No deadtime
- No event overlapping
- Most of the electronics outside the detector

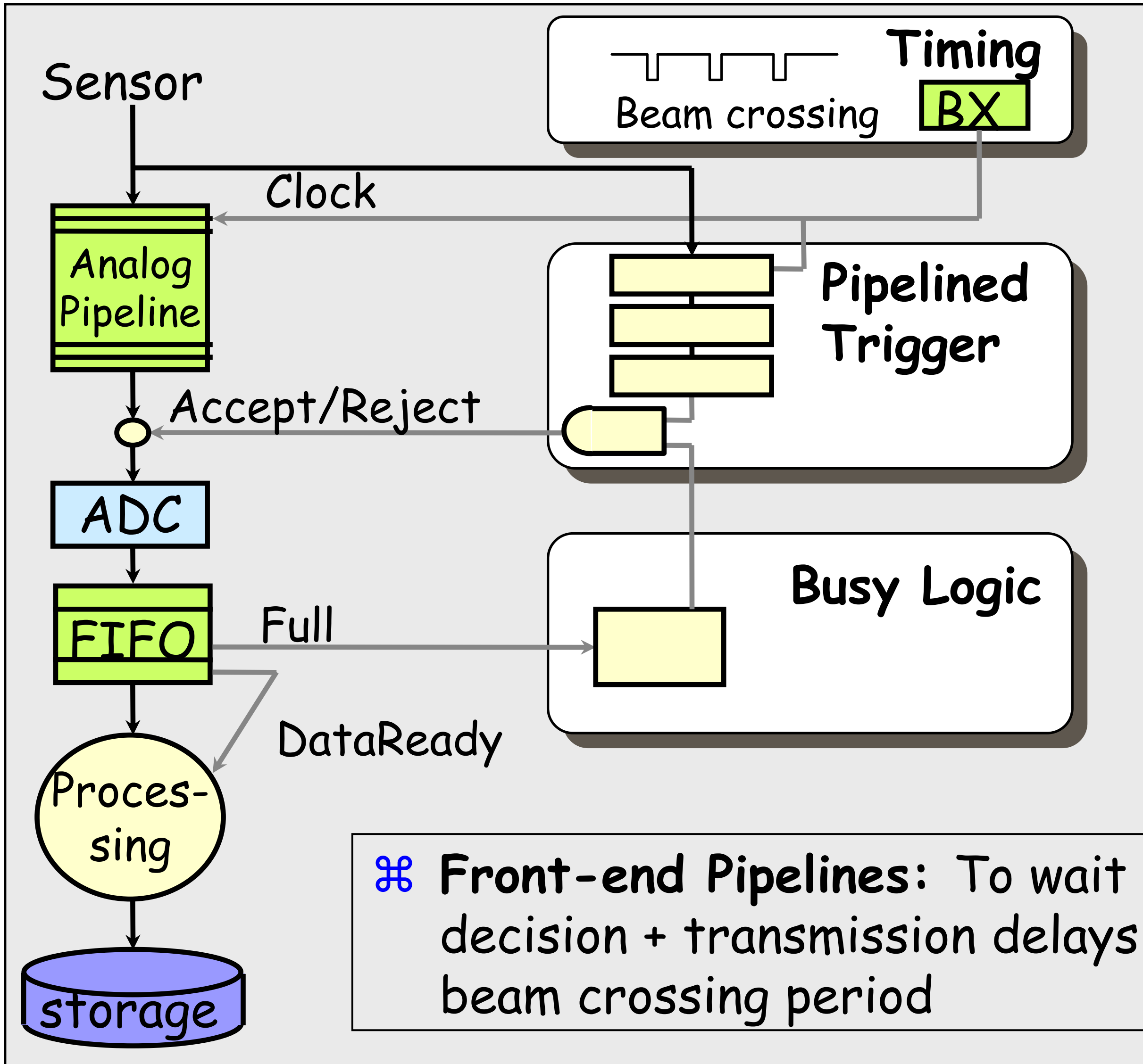
LHC timing

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



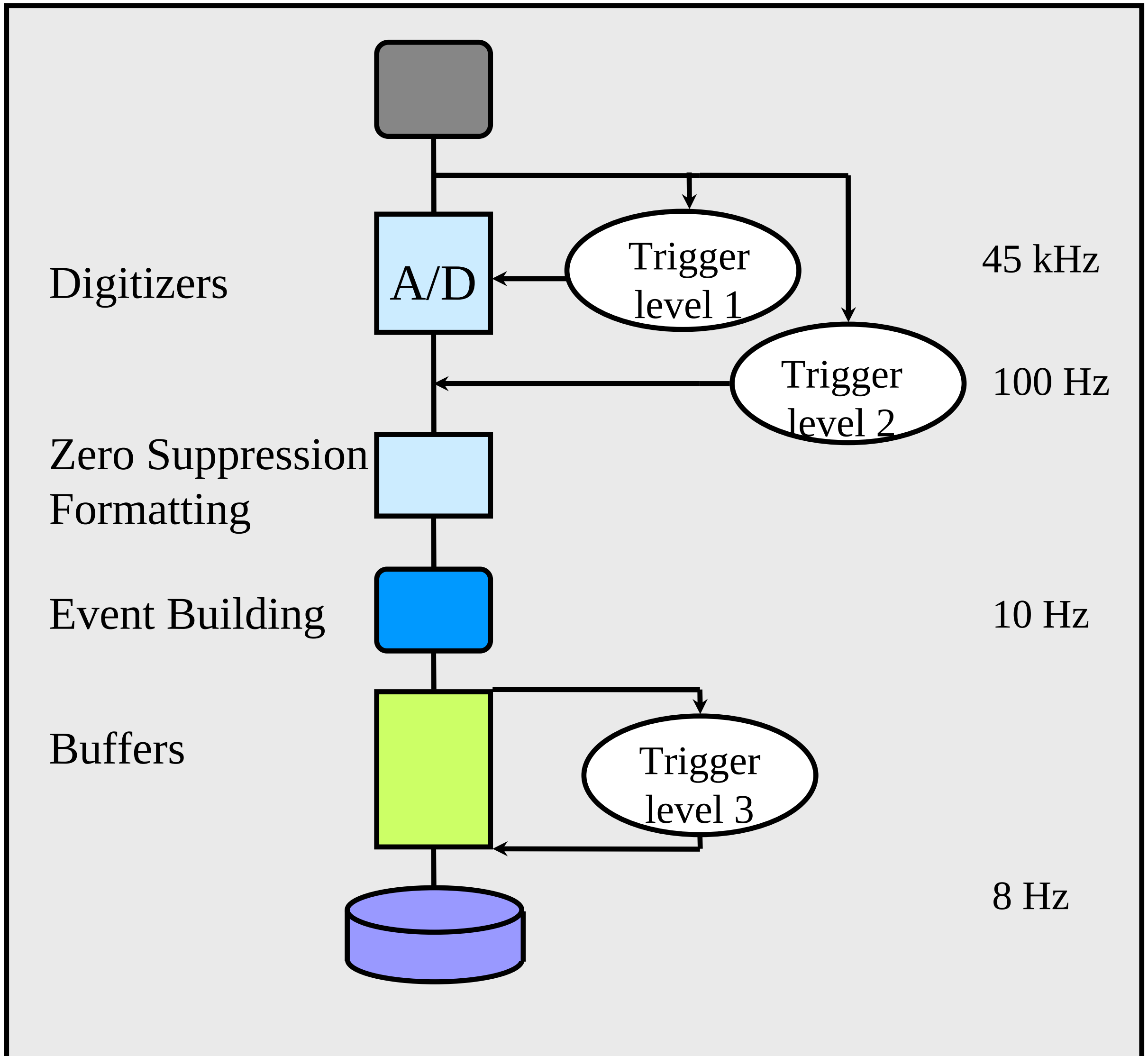
- Level 1 trigger time exceeds bunch interval
- Event overlap & signal pileup (multiple crossings since the detector cell memory greater than 25 ns)
- Very high number of channels

Trivial DAQ in LHC

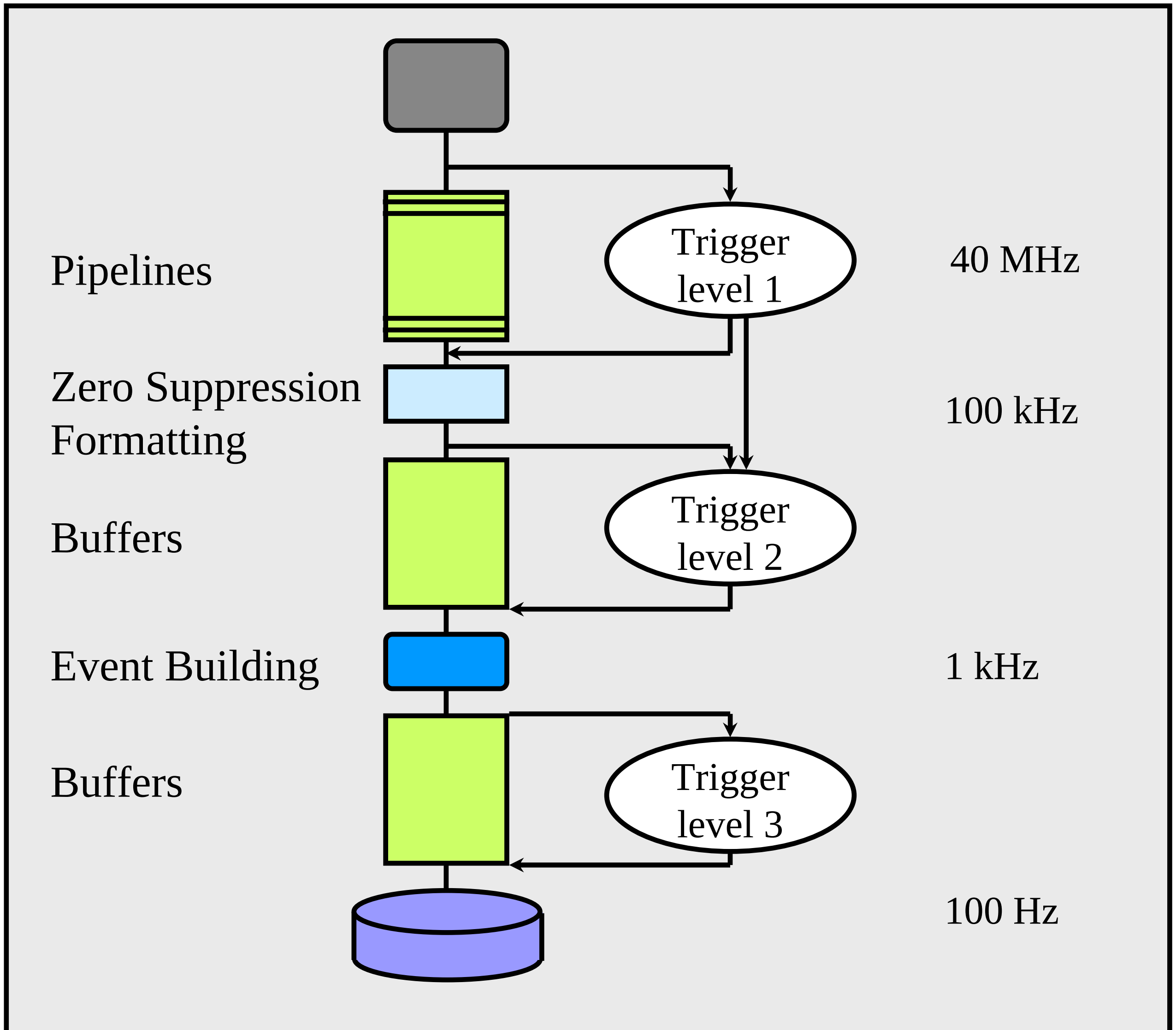


⌘ **Front-end Pipelines:** To wait for the trigger decision + transmission delays are longer than beam crossing period

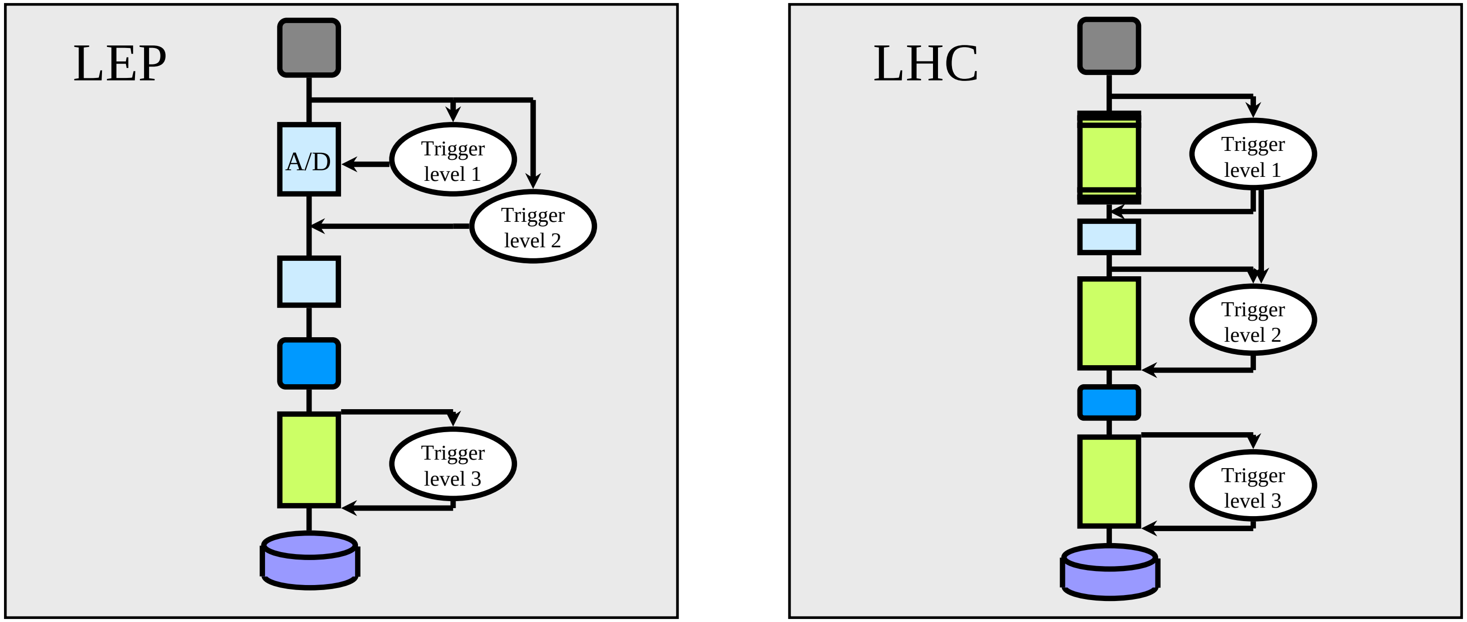
LEP readout structure



LHC readout structure



Readout structures differences



- Rates are very different.
- At LEP the readout of the digitizers is only done after Level-2 accept (few 10 μs).
- At LEP the trigger data for Level-2 comes from detector.
- At LHC you need data pipelines and data buffers to store the events during Level-1 and Level-2 processing

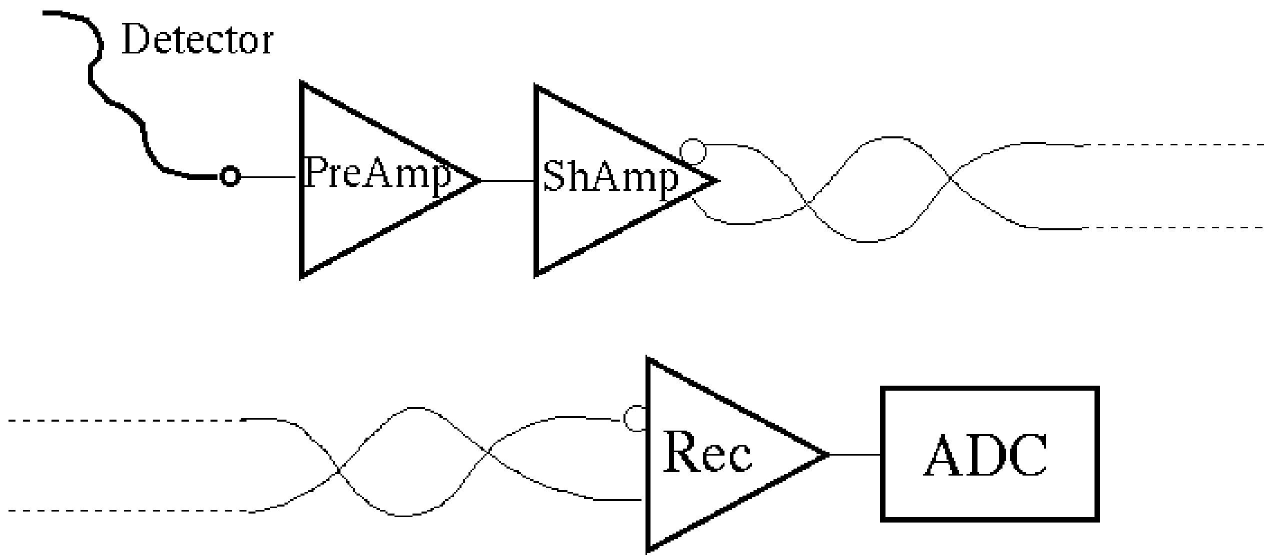
Front-end essentials

Front-Ends

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

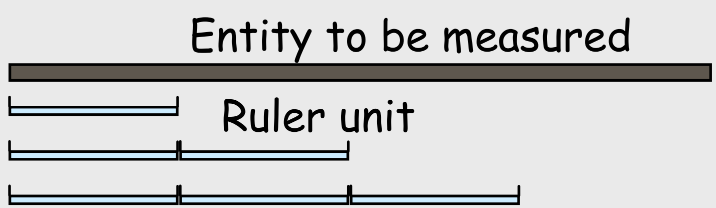
Front-Ends (2)

- Example: Charged particle creates ionization ⟶ e^- drifted by electric field

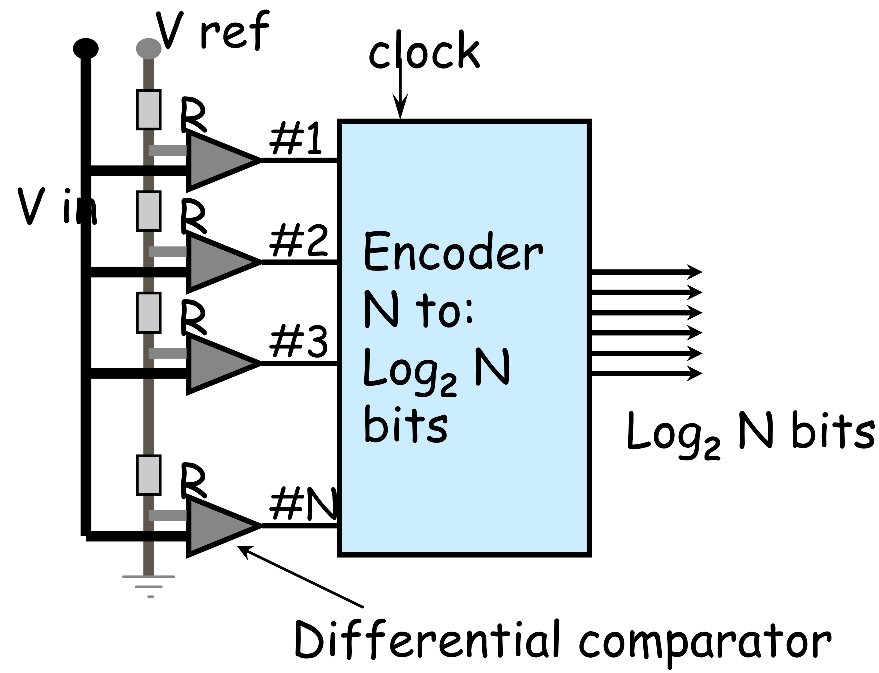


Analog to digital conversion

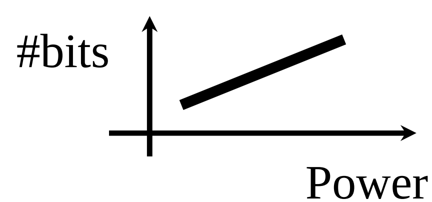
- Digitizing means measuring something (charge, amplitude, time, ...) comparing it with a reference unit.
- Ex: Flash ADC



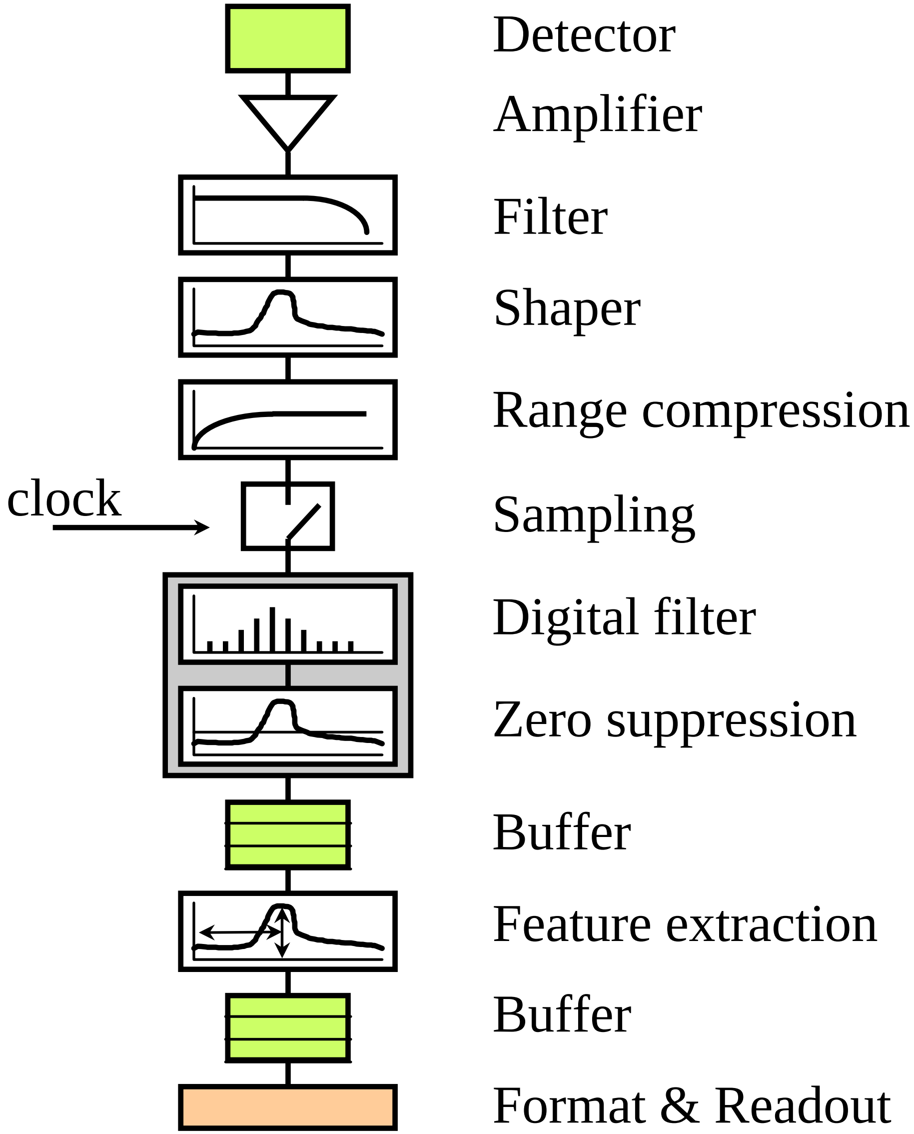
Compare entity with a series of rulers in sequence (standard ADC, counting) or in parallel (flash ADC)



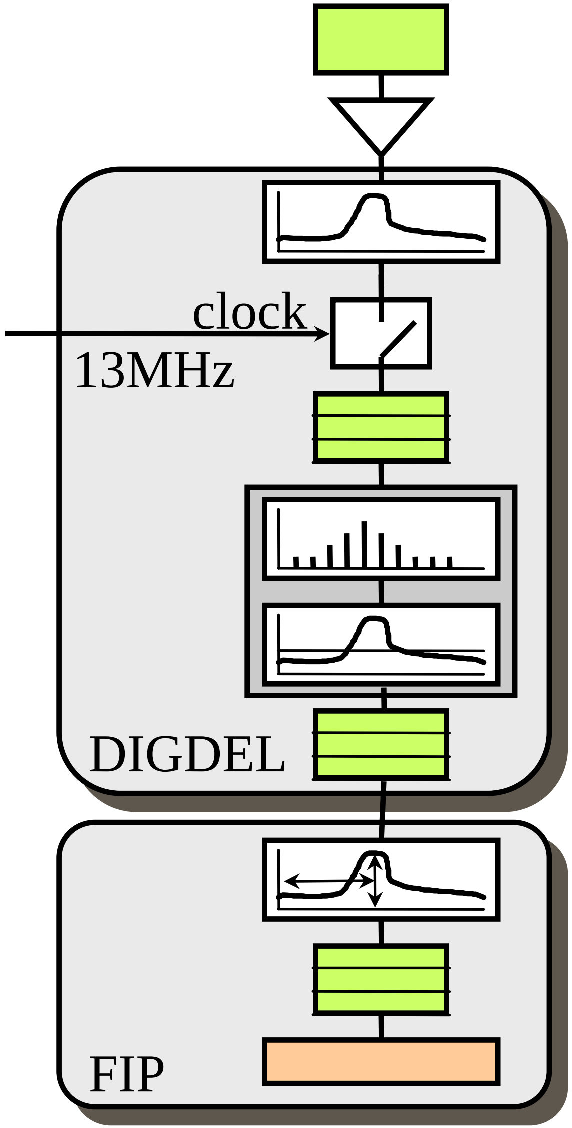
- The fastest method
- Prohibitive for > 10 bits



Front-end structure



Front-end example: DELPHI TPC



Detector

Amplifier

Shaper

Sampling

4 raw data banks.

Digital filter

Zero suppression

Buffer

Feature extraction

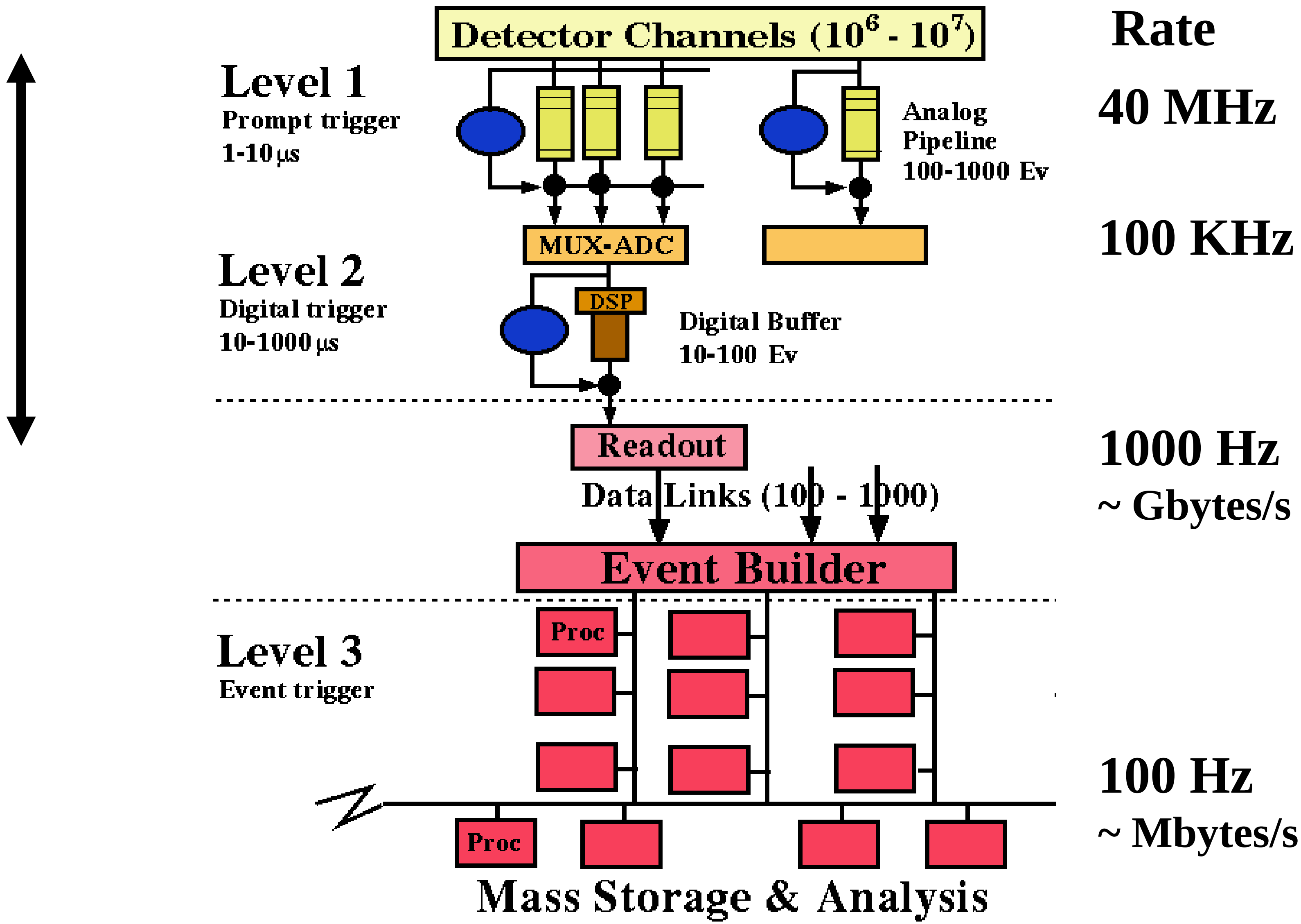
Buffer

Format & Readout

F.E. at LHC (challenges):

- **Small bunch interval**
  - Pipeline buffering (analog) to keep events until trigger decision (2μs - 100 col.)
  - Very Fast A/D conversion
  - Very precise timing distribution (order of sub-ns)
- **Large Nr. of channels**
  - High Integration (Custom VLSI chips)
- **Piled-up Events**
  - Digital Signal Processors (DSP) to sort them out
- **Large amount of data**
  - Data Compressors (instead of zero skipping)
- **Power Consumption**
- **Radiation Levels**

Front-end at LHC

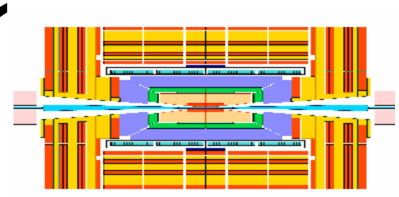


Trigger

Trigger System

The trigger system is the system which triggers the recording of the data in an experiment.

The trigger is a function of:

T() ➡

REJECTED

ACCEPTED

Event data & Apparatus

Physical channels & Parameters

Since the detector data are not promptly available and the function is highly complex, T(...) is evaluated by successive approximations called:

TRIGGER LEVELS

Trigger Goals

- **Leptonic Collisions (e+e- colliders)**
  - **Cross Section** - probability of interaction (unit = barn = 10^{-24} cm^{-2})
    - σ tot = 30 - 40 nb (30-40 $*10^{-33}$ cm^{-2})
  - **Luminosity** - density of crossing beams (~ nb. of particles per section)
    - L = 10^{31} cm^{-2}s^{-1} (LEP)
    - ➔ **Event rate (L $*$ σ) 0.1 - 1 events/s**
  - σ interesting $\approx$ σ tot (All interactions are interesting)
    - ➔ **No physics rejection needed**
  - But background rejection is crucial to perform precision measurements:
    - Cosmics, Beam-gas, Off-momentum e+-, Detector noise

Trigger Goals (2)

- **Hadronic collisions** (fixed target or pp)
  - **Cross Section**
    - σ tot = 30 - 40 mb (30-40 $*10^{-27}$ cm^{-2})
  - **Luminosity**
    - L = 10^{30} $cm^{-2}s^{-1}$ (SPS), 10^{34} $cm^{-2}s^{-1}$ (fixed target), 10^{34} $cm^{2}s^{-1}$ (LHC)
    - ➔ **Event rate 10^5 - 10^9 events/s**
  - σ interesting $\approx$ nb $\rightarrow$ pb
    - ➔ **Rejection needed of $10^6 \rightarrow 10^{13}$ (LHC)**

Trigger Design (Physics Aims)

- **Leptonic interactions**
  - High rejection of background
  - Criteria:
    - Very good efficiency for selected channel $\approx 100\%$
    - Good rejection background. Depends on physics/background ratio, i.e. on machine conditions. ≈ 10
    - Good monitoring of efficiency $\pm 0.1\%$
- **For High precision measurements:**
  - "A 60% well known efficiency is much better than a 90% uncertain efficiency"

Trigger Design (Physics Aims)

- **Hadronic Interactions**
  - High rejection of physics events
  - Criteria:
    - Good efficiency for selected channel $\geq$ 50%
    - Good rejection of uninteresting events $\approx 10^6$
    - Good monitoring of efficiency $\pm 0.1\%$

- **Similar criteria, but in totally different ranges of values**

Trigger Design (2)

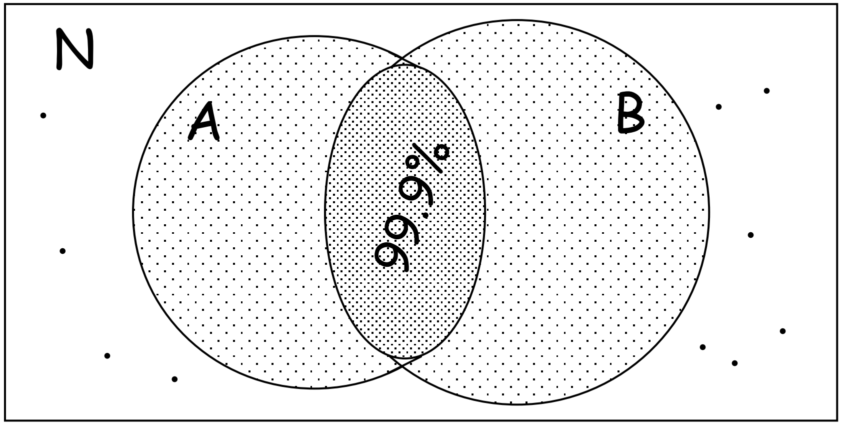
- Simulation studies
  - It is essential to build into the experiment's simulation the trigger simulation.
  - For detector/machine background rejection
    - Try to include detector noise simulation
    - Include machine background (not easy).
    - For example at LEP the trigger rate estimates were about 50-100 times too high.
  - For physics background rejection, the simulation must include the generation of these backgrounds

Trigger Performance

- Efficiency monitoring
  - Key point: REDUNDANCY
  - Each event should fire at least two independent sub-triggers (the global trigger is a logic OR of all sub-triggers)
    - Use the simulation (or common sense!) to evaluate for different sub-triggers how redundant they are.
    - Use DATA (after reconstruction) to compute efficiency.
- Ex: Electrons Efficiency

A = TPC (tracking)
B = Calorimeter

$$\varepsilon_A = \frac{N(A \cap B)}{N(B)}$$

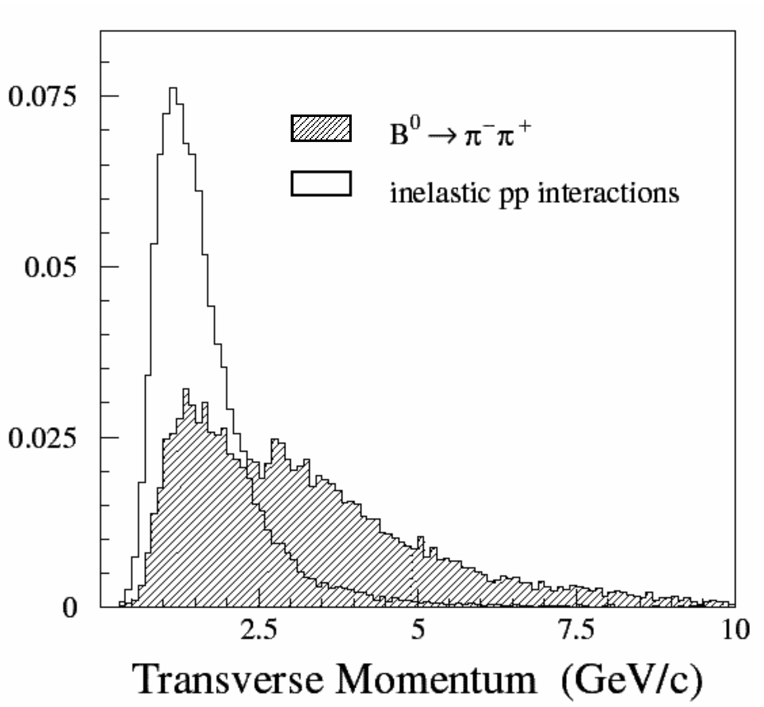


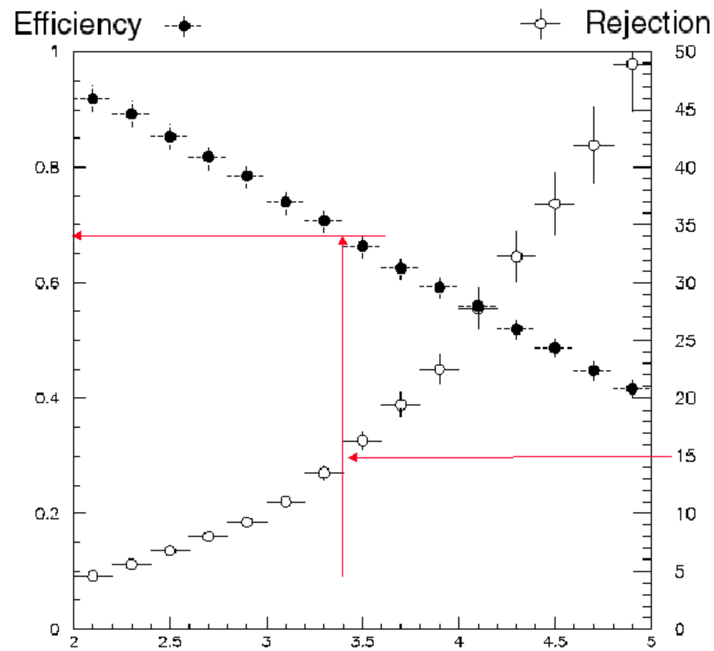
Trigger Levels

- Since the detector data is not promptly available and the trigger function is highly complex, it is evaluated by **successive approximations**.
- We need to optimize the amount of data needed and the time it takes to provide a decision.
- Trigger levels
  - Hardware trigger: *Fast* trigger which uses crude data from few detectors and has normally a limited time budget and is usually implemented using hardwired logic.
    $\Rightarrow$ **Level-1** sometimes **Level-2**
  - Software triggers: Several trigger levels which refines the crude decisions of the hardware trigger by using more detailed data and more complex algorithms. It is usually implemented using processors running a program.
    $\Rightarrow$ **Level-2, Level-3, Level-4, ...**

Example:B meson trigger in LHCb

⌘ Discriminating variable: **Transverse momentum (P_T)**

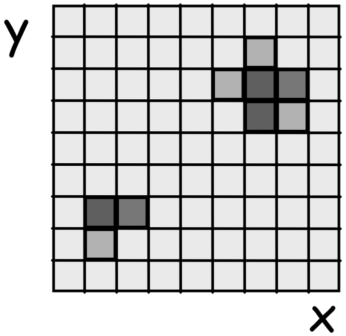




⌘ Efficiency versus background rejection

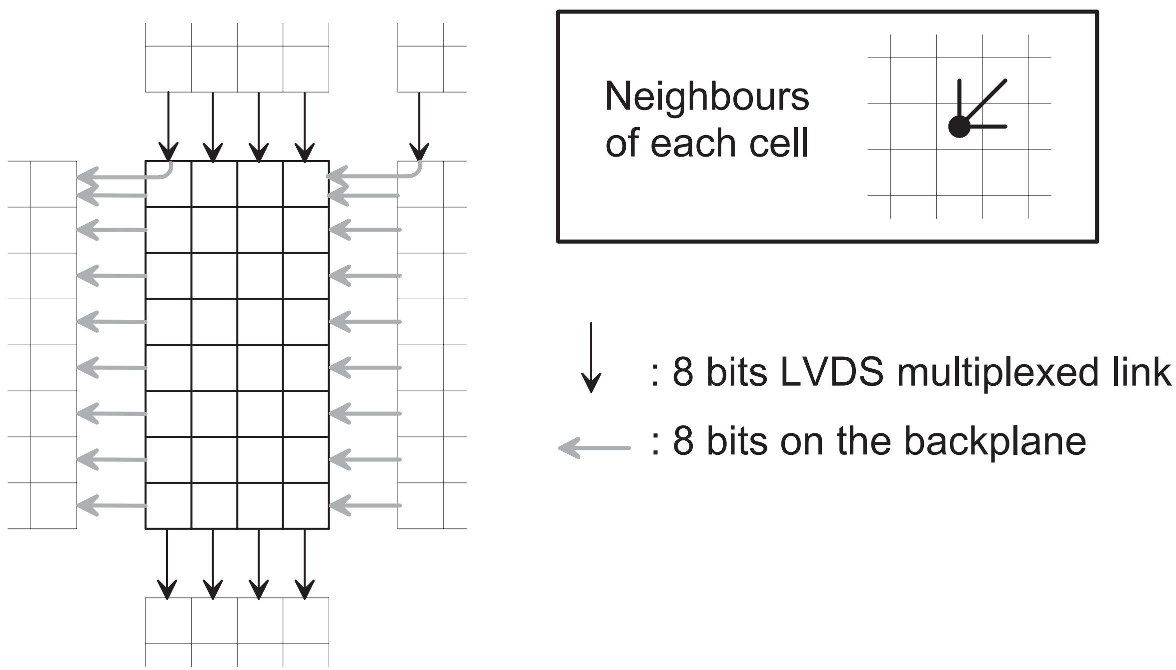
LHCb L0 Calorimeter Trigger

- **Select the particles with the highest P_T**
  - For the Level 0 decision, we need only the particle with the highest P_T
  - Check if above threshold
- **Identify hot spots**
  - Detect a high energy in a 'small' surface
  - Use a square of 2 x 2 cells area
    - 8 x 8 cm2 in the central region of ECAL
    - more than 50 x 50 cm2 in the outer region of HCAL



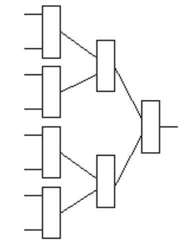
LHCb L0 Calorimeter Trigger (2)

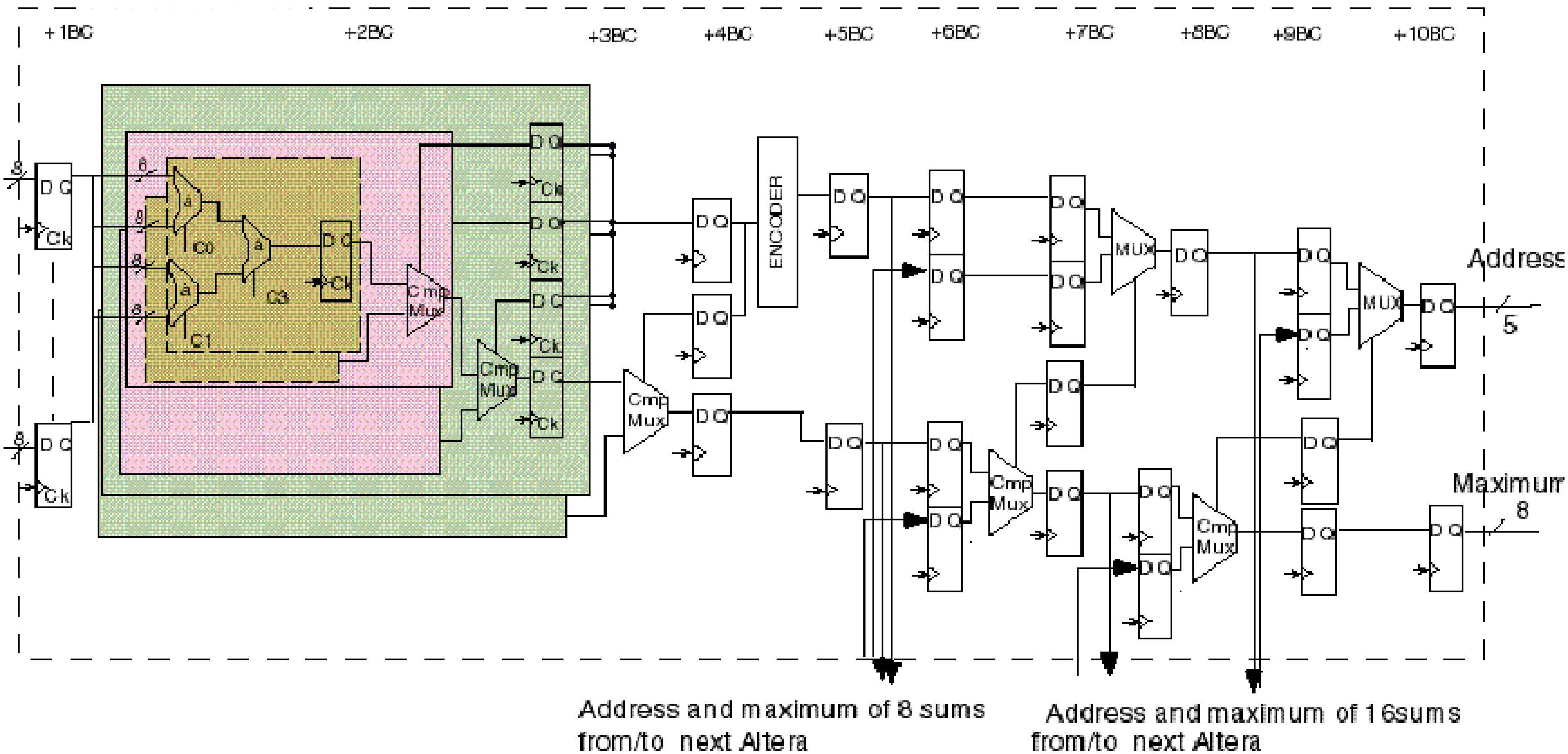
- **Build the 2x2 sums**
  - Work inside a 32 channels (8x4) front-end card
    - To obtain the 32 2x2 sums, one needs to get the 8 + 1 + 4 neighbours
    - Via the backplane (bus) or dedicated point-to-point cables



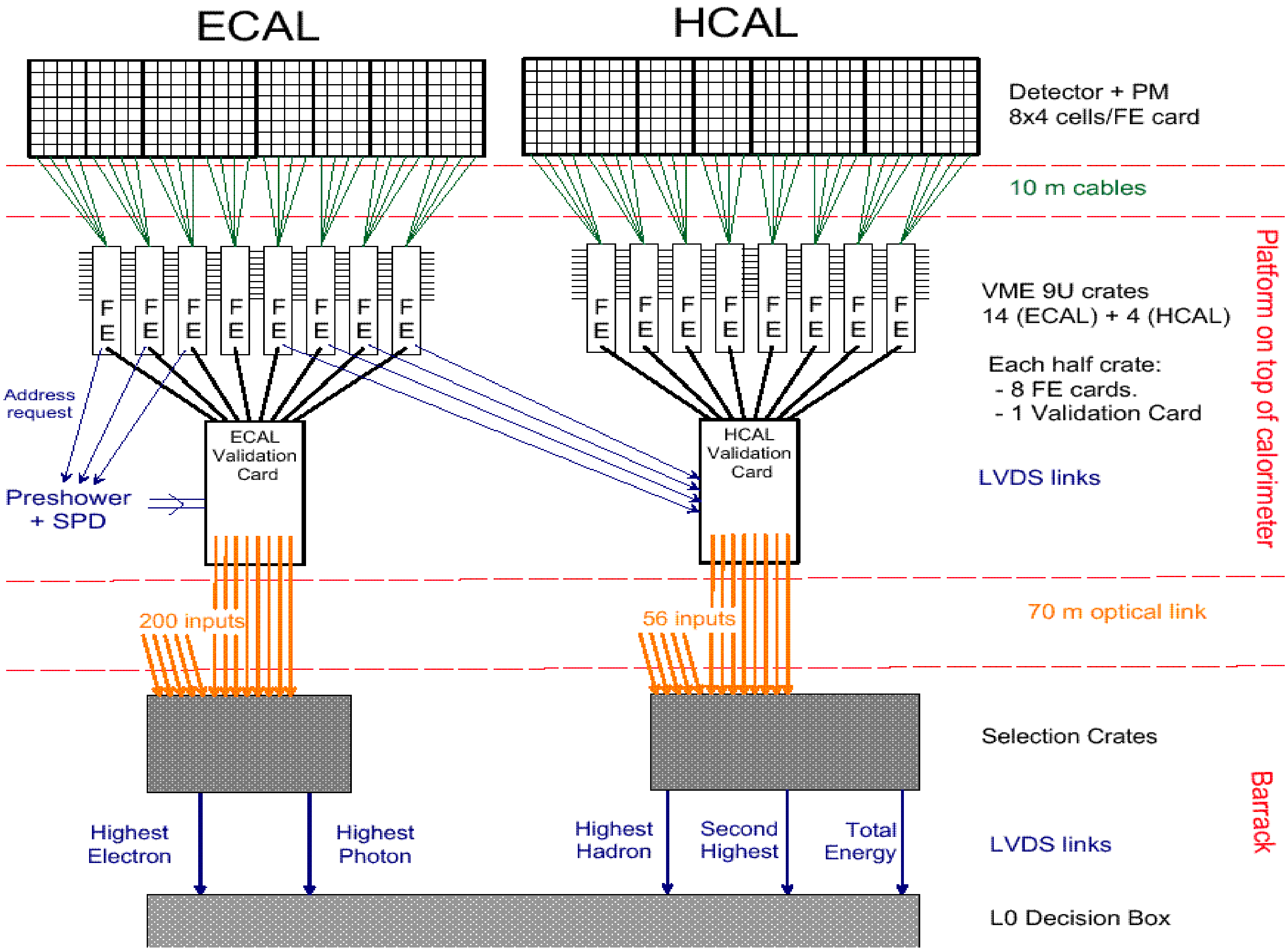
LHCb L0 Calorimeter Trigger (3)

- **Select the local maximum in the card**
  - Simple comparison of the summed E_T.
  - Currently implemented in 4 ALTERA FPGA's





LHCb L0 Calorimeter Trigger (4)



Central Decision Logic

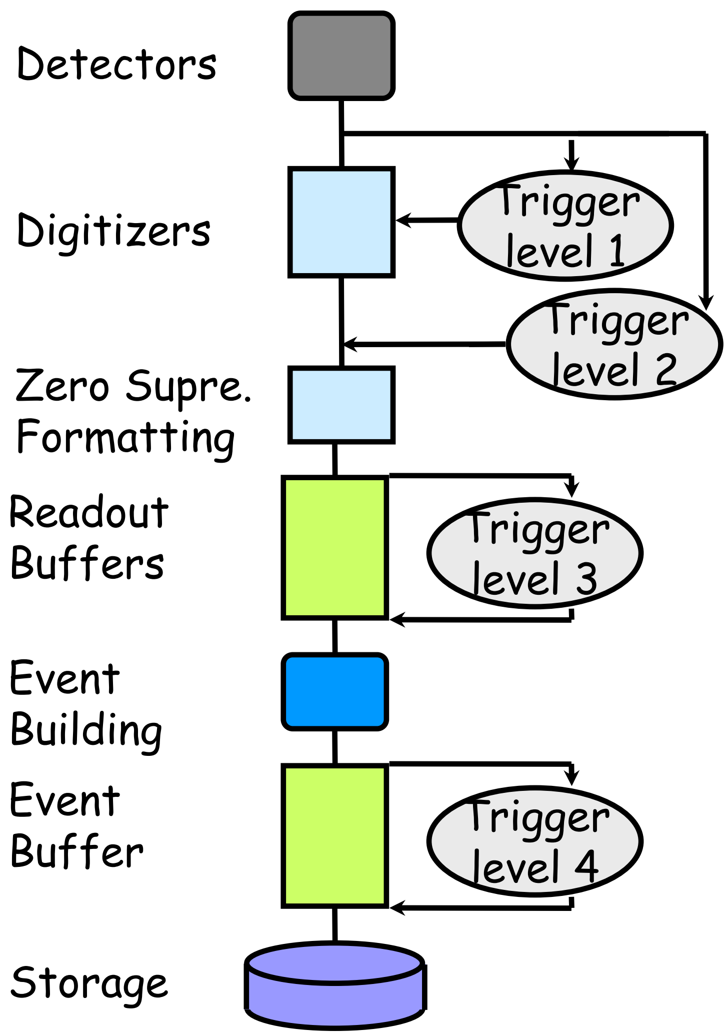
- **Look Up Tables**
  - Use N Boolean informations to make a single decision: YES / NO
  - Use a RAM of 2^N bits
  - Example: N=3

RAM Address

EM	μ	TR	RAM	
0	0	0		No track, no EM
0	0	1		Track, no μ
0	1	0		μ, track inefficient
0	1	1		μ, track
1	0	0		EM, no track
1	0	1		EM, track, no μ
1	1	0		EM, μ, track ineffic.
1	1	1		EM, μ, track

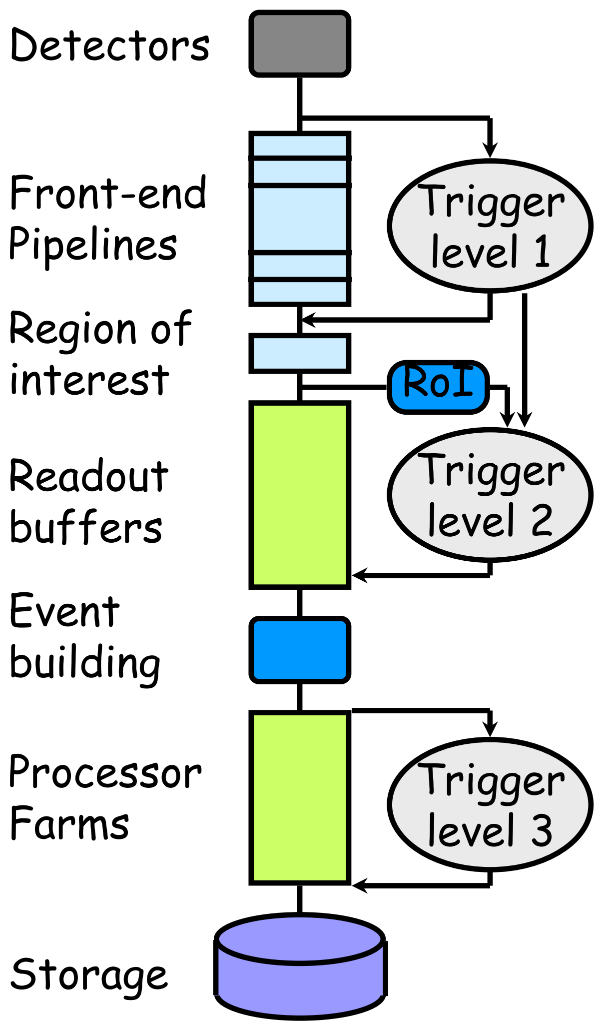
- **To Trigger On:**
  - "Single Photons"
  - → 0,0,0,0,1,0,0,0
  - "At least one μ"
  - → 0,0,1,1,0,0,1,1

Trigger Levels in DELPHI (LEP)



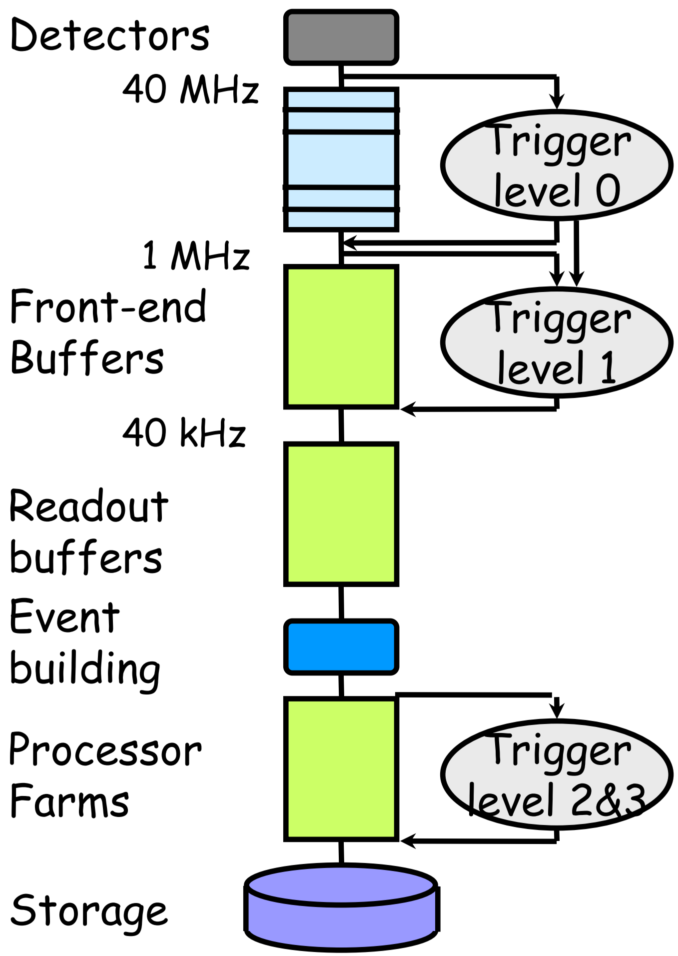
- Level-1 (3 μs) (hardware proc.)
  - Single detector Information:
    - Energy: calorimeter (EM and Had.)
    - Tracks: counting, coincidences
    - Muons: Had. Cal. and Muon Chambers
    - Luminosity: analog sums
- Level-2 (36 μs) (hardware proc.)
  - Detector Coincidences:
    - Accept only tracks coming from the IP.
    - Beam-gas rejection. Uses the TPC
- Level-3 (≈ms) (In parallel for each sub-detector: OS9 processors)
  - Verifies L2 triggers with digitized data
- Level-4 (≈ms) (a small farm: 3 alpha CPU)
  - Reconstructs the event using all data
  - Rejects Empty Events
  - Tagging of interesting physics channels

Trigger Levels in ATLAS (LHC)



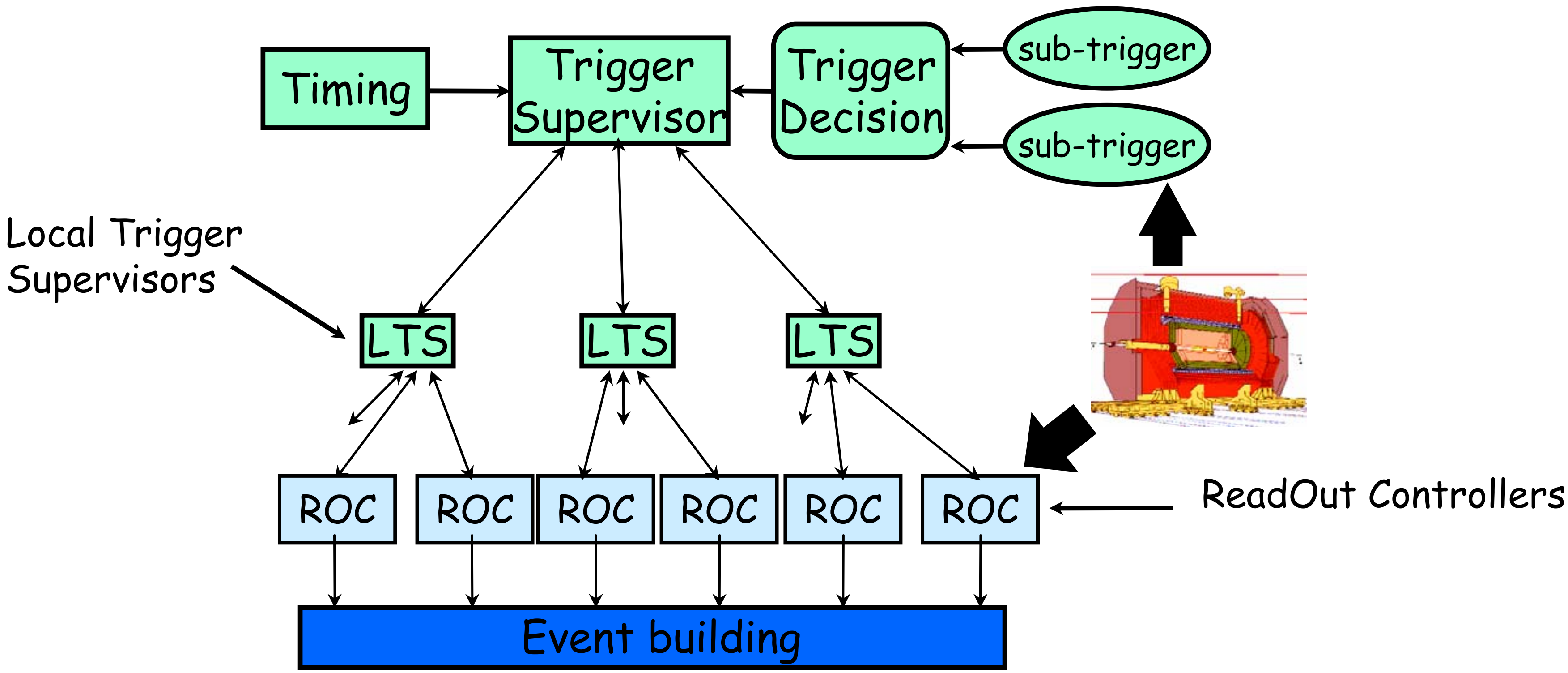
- Level-1 (3.5 μs) (custom processors)
  - Energy clusters in calorimeters
  - Muon trigger: tracking coincidence matrix.
- Level-2 (100 μs) (specialized processors)
  - Few Regions Of Interest relevant to trigger decisions
  - Selected information (ROI) by routers and switches
  - Feature extractors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

Trigger Levels in LHCb (LHC)



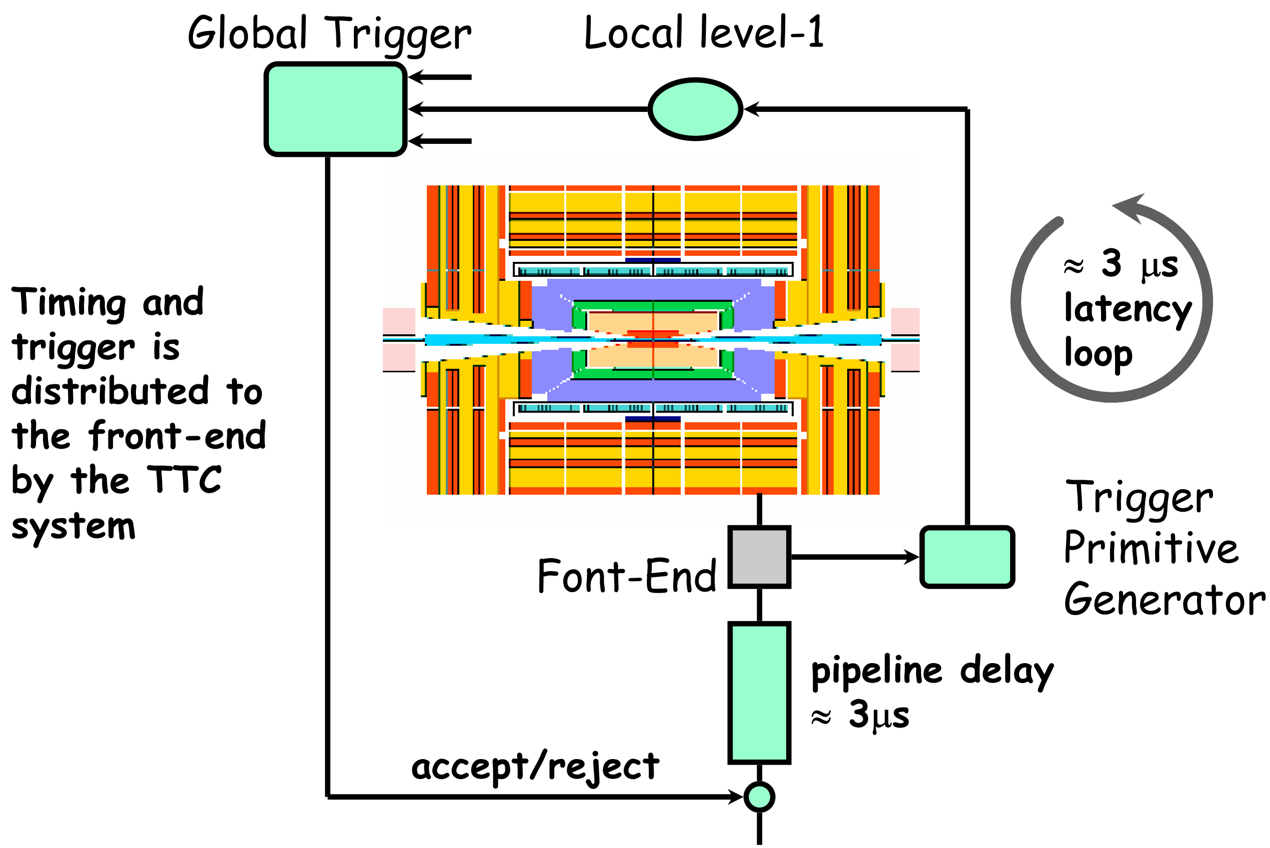
- Level-0 (4 μs) (custom processors)
  - High p_T for electrons, muons, hadrons
  - Pile-up veto.
- Level-1 (1000 μs) (specialized procs)
  - Vertex topology (primary & secondary vertices)
  - Tracking (connecting calorimeter clusters with tracks)
- Level-2 (≈ms) (commercial processors)
  - Refinement of the Level-1. Background rejection.
- Level-3 (≈ms) (commercial processors)
  - Event reconstruction. Select physics channels.

LEP: Trigger Distribution



- Trigger decision logic: look up tables
- Trigger protocol (Busy, L1yes, Abort, etc.)
- Trigger identifier can be delivered to each ROC.
- Programmable TS and LTS to distribute trigger signals and collect them from subsets of ROCs.

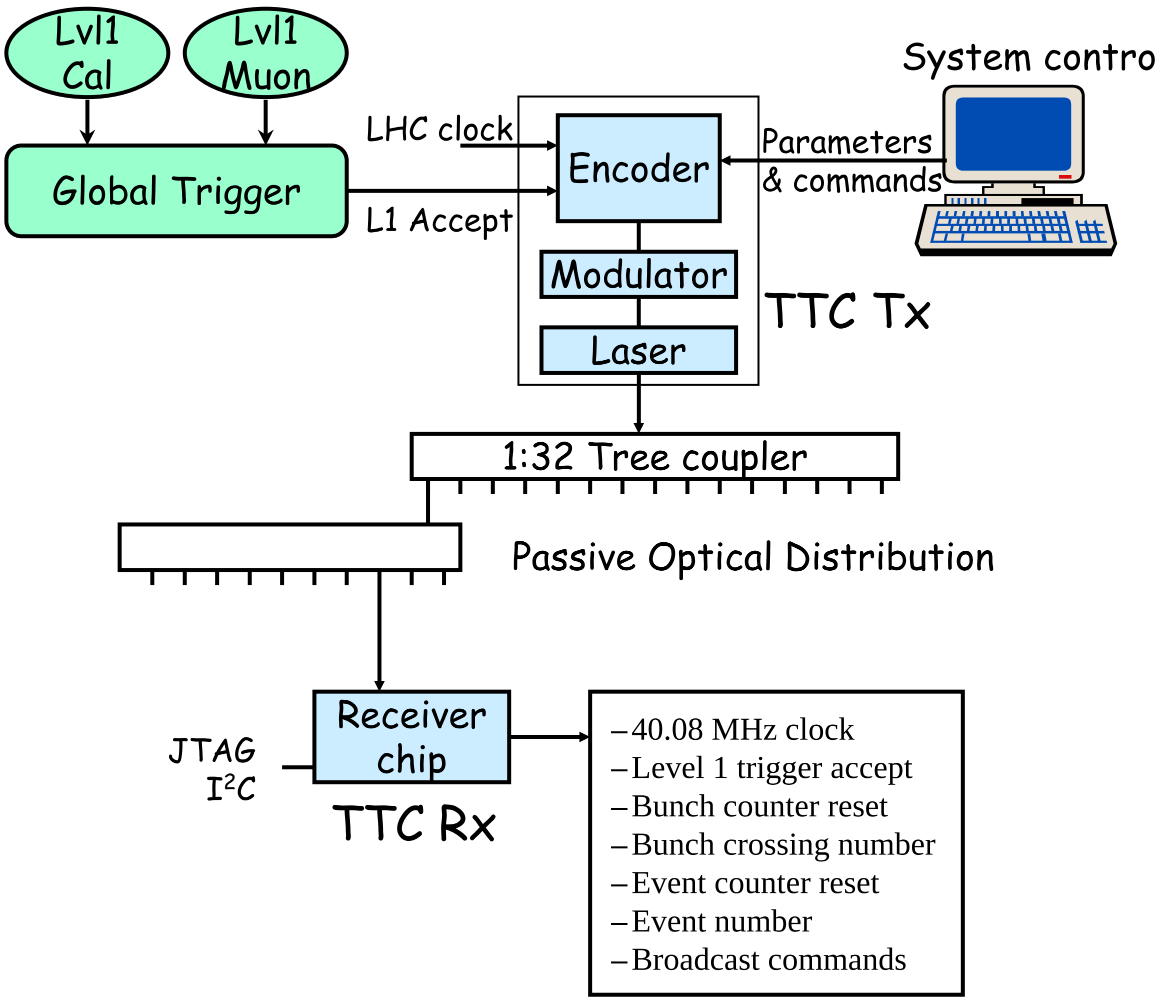
LHC: Trigger communication loop



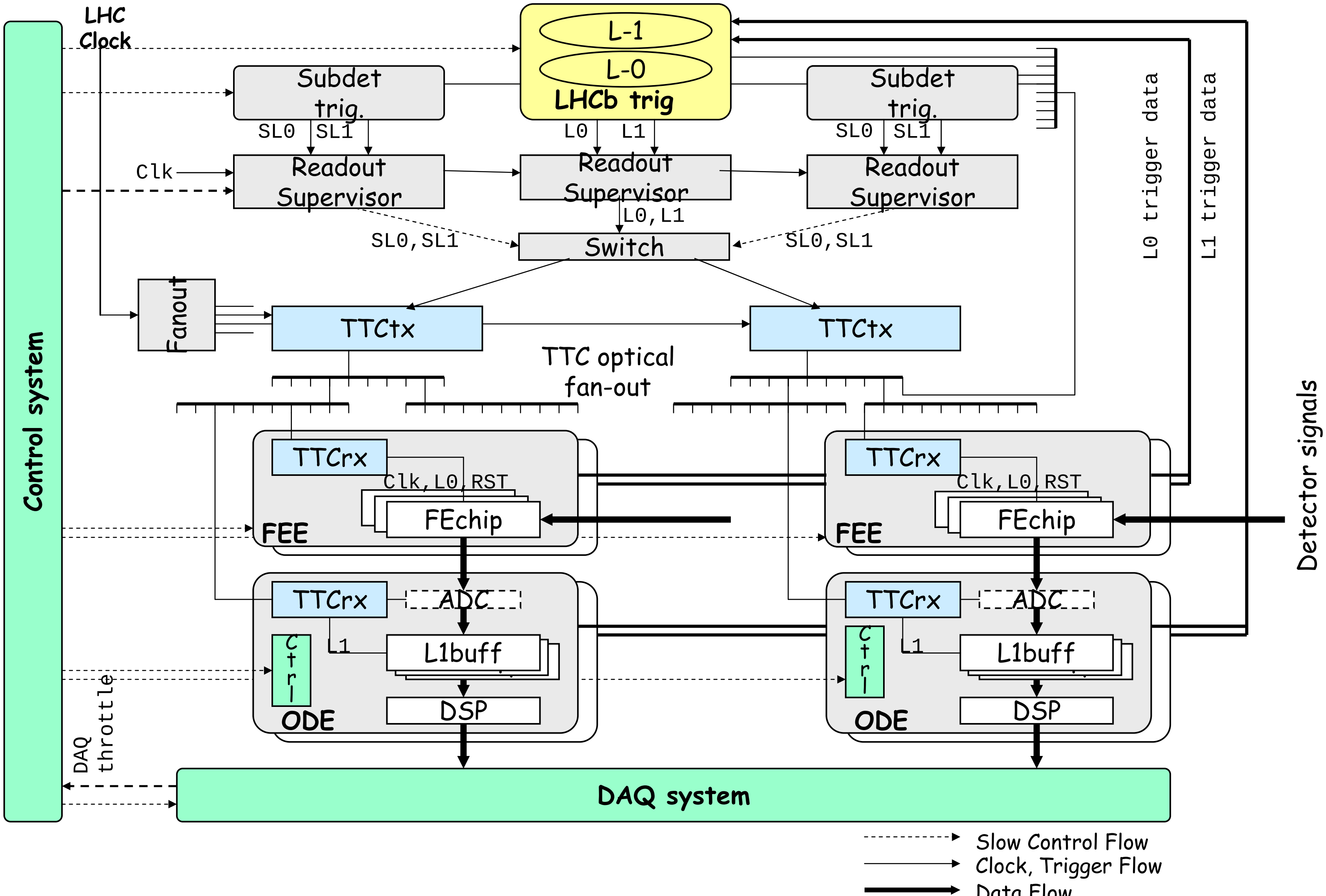
- 40 MHz synchronous digital system
- Synchronization at the exit of the pipeline non trivial.
  ⇒ Timing calibration

LHC: Timing & Trigger distribution

⌘ The TTC system



LHCb: Timing & Fast Control

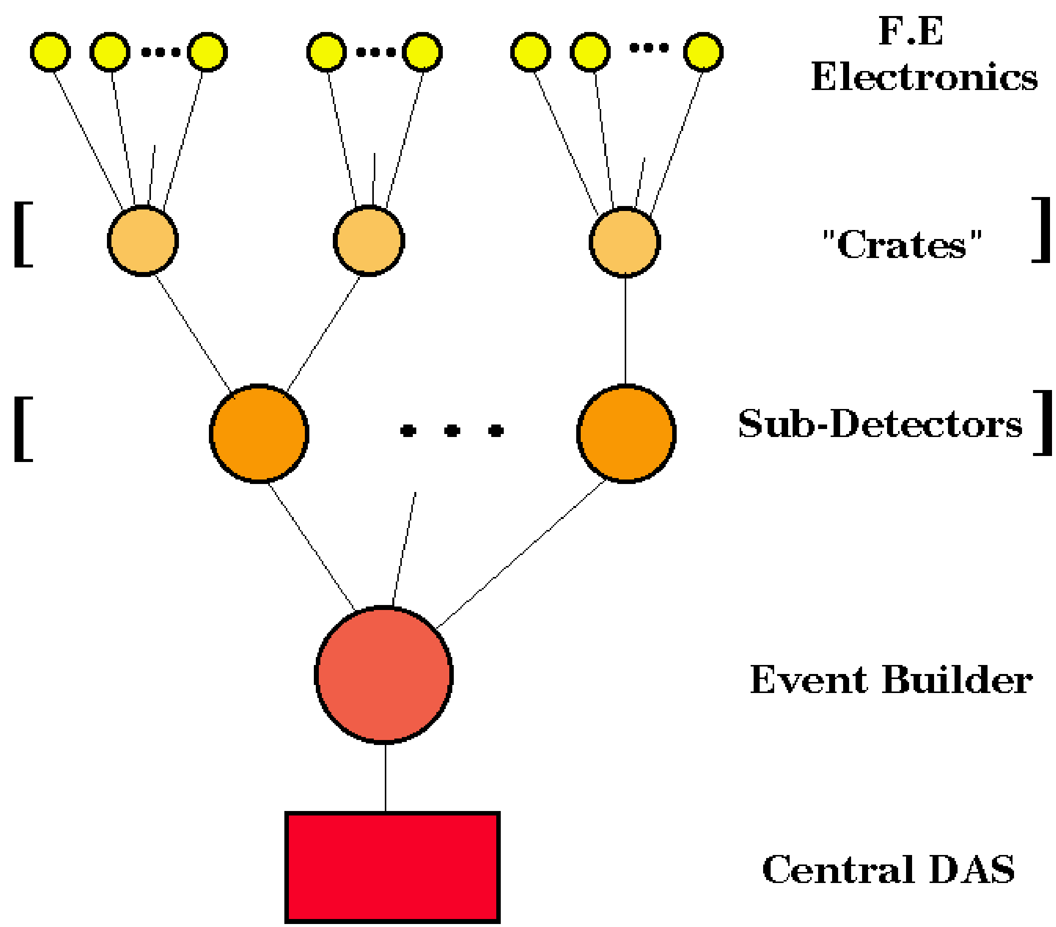


Data Acquisition

DAQ Readout

- **Reading data from FE buffers to form a full "event" on tape:**
  - (Sub-event building)
  - Event Building
  - (Processing)
  - Storage
- **Asynchronous with beam crossing**
- **HW (and SW) can be common to all sub-detectors**

LEP Readout Architecture



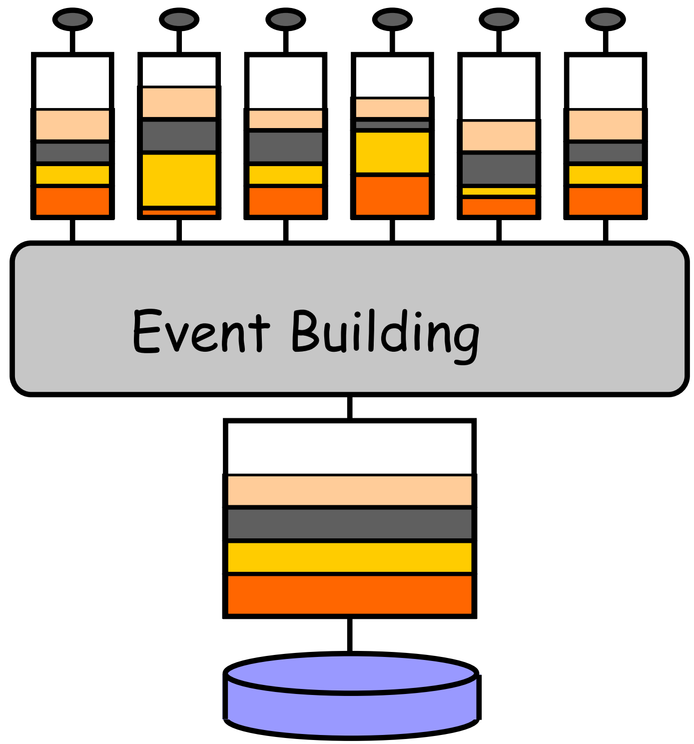
Event Building

Data sources

Event Fragments

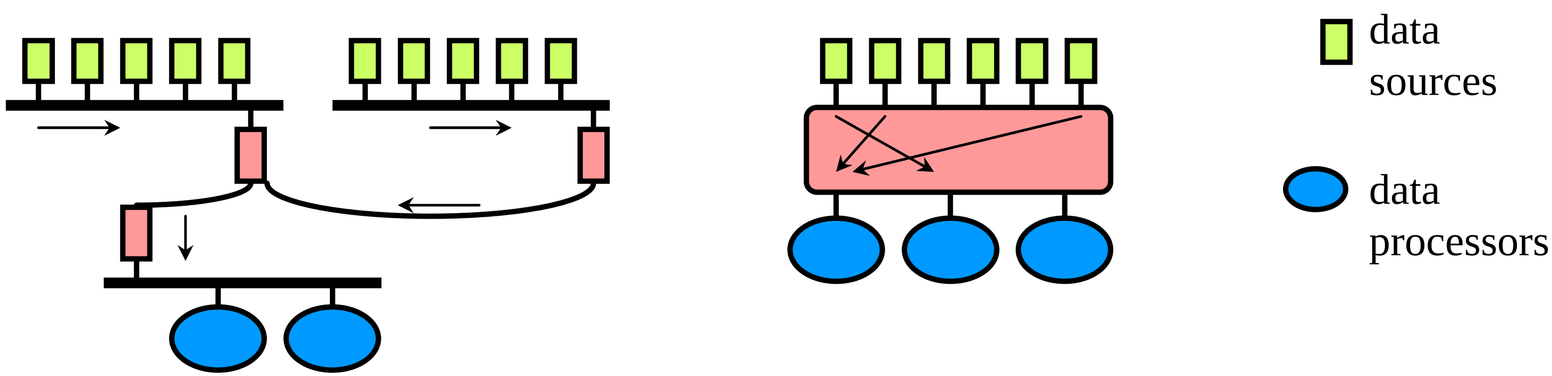
Full Events

Data storage



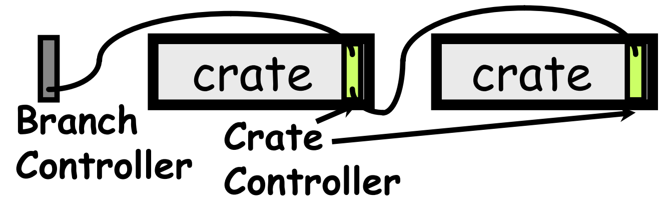
Readout Networks

- Since the early 70's there have been a need for a standard for building big readout systems with many hundred thousands of electronics channels.
- Basic components needed:
  - FE boards (digitizers, etc), Readout controllers, Crates, Crate interconnects
- With these components you can build networks using buses or switches.

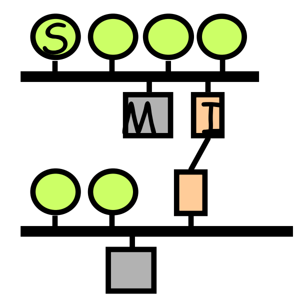


Buses used at LEP

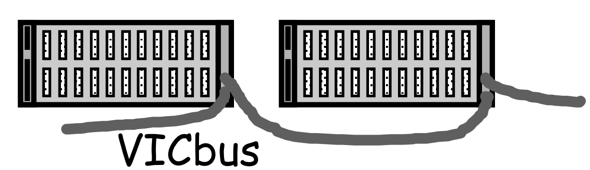
- **Camac**
  - Very robust system still used by small/medium size experiments
  - Large variety of front-end modules
  - Low readout speed (0.5-2 Mbytes/s)



- **Fastbus**
  - Fast Data Transfers (Crate: 40Mbyte/s, cable: 4 Mbyte/s)
  - Large Board Surface (50-100 electronic channels)
  - Few commercial modules (mostly interconnects)



- **VME**
  - Large availability of modules
    - CPU boards (68k, PowerPC, Intel), Memories, I/O interfaces (Ethernet, Disk, …), Interfaces to other buses (Camac, Fastbus,…), Front-end boards.
  - Small Board Size and no standard crate interconnection
    - But VICBus provides Crate Interconnects
    - 9U Crates provide large board space

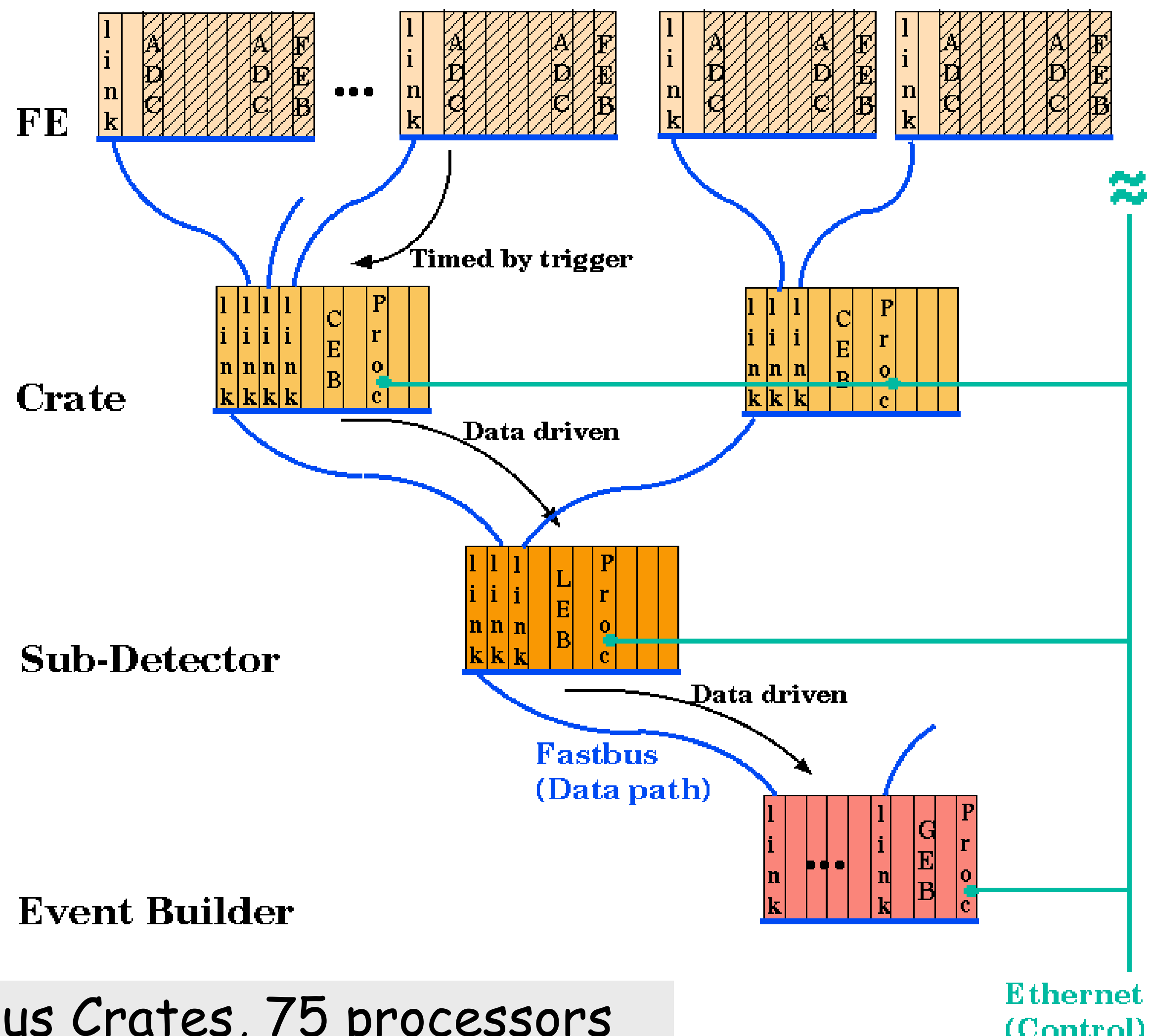


Choice of the bus standard

- LEP experiments had to choose a standard bus.
  - How to choose:
    - There is no truth
    - There are fashions and preferences.
  - Hybrid solutions are possible.
  - Choices taken:
    - OPAL Camac, Fastbus, VME for Front-end, VME for Readout
    - ALEPH Fastbus for Front-end, VME for Readout
    - L3 Fastbus
    - DELPHI Fastbus + few Camac for Front-end
- For LHC, standard buses will not be used to readout the data (performance limitations). VME may be used for configuration and control.

Readout in Delphi

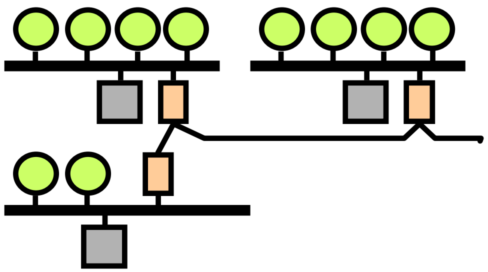
- FE data
- Full Event

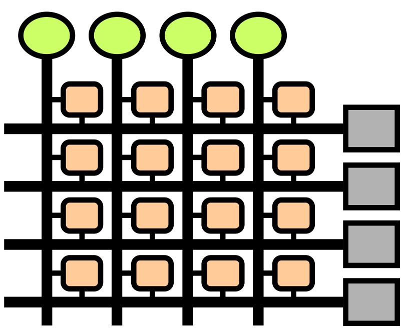


- In Total: 200 Fastbus Crates, 75 processors

Event builder techniques

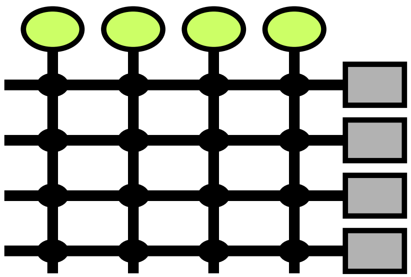
Data source
Data destination





- Time-shared Bus
  - Most common at LEP (VME, Fastbus)
  - Bi-directional
  - Limited to the maximum throughput
  - Staged event building by independent buses in parallel (trees). No real gain, but reduces overhead.
- Dual-port memory
  - Event fragments are written in parallel and read sequentially by the destination processor.
  - Easy to implement. Commercially available. ex. D0, OPAL (VME/VSB)

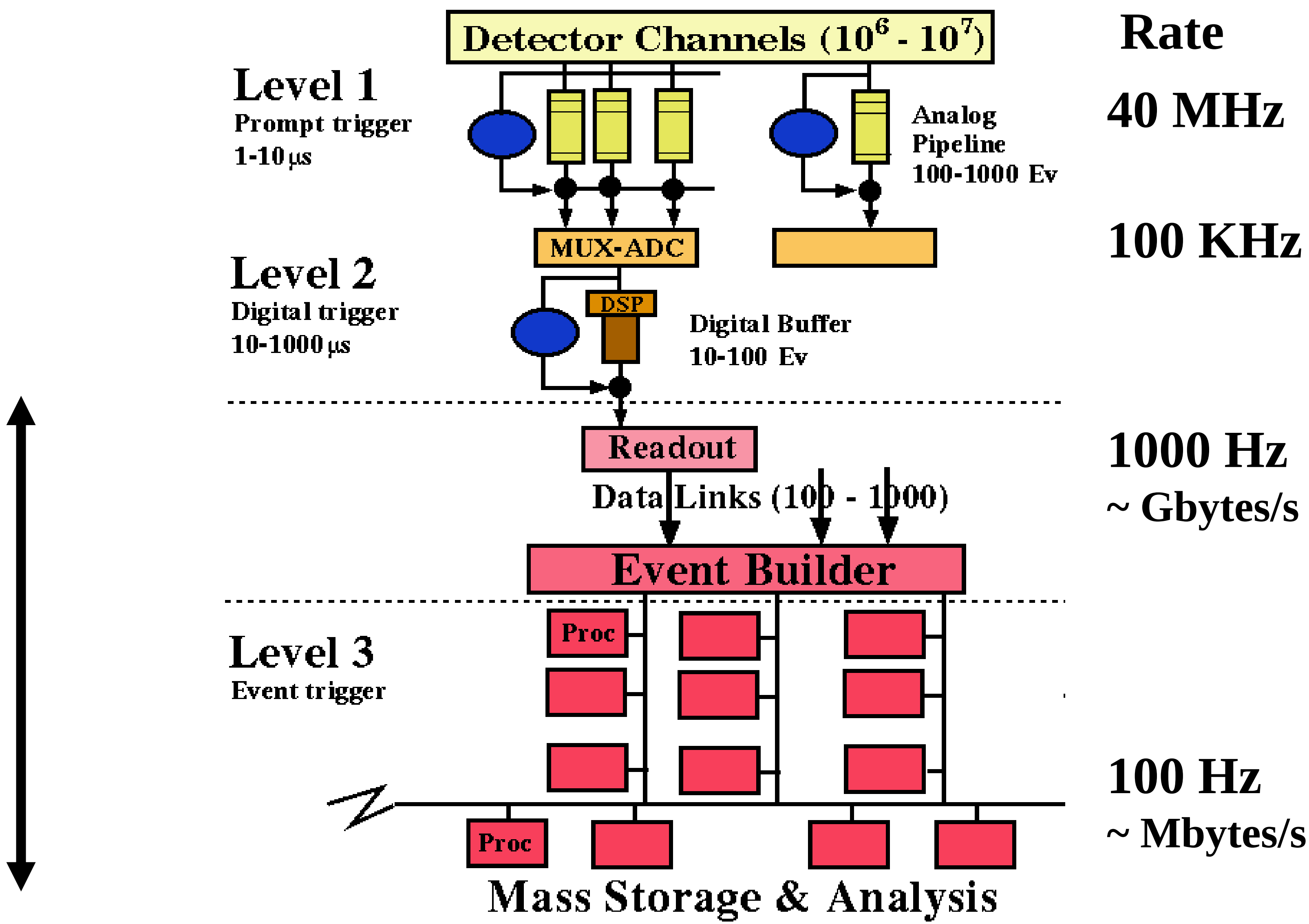
Event builder techniques(2)



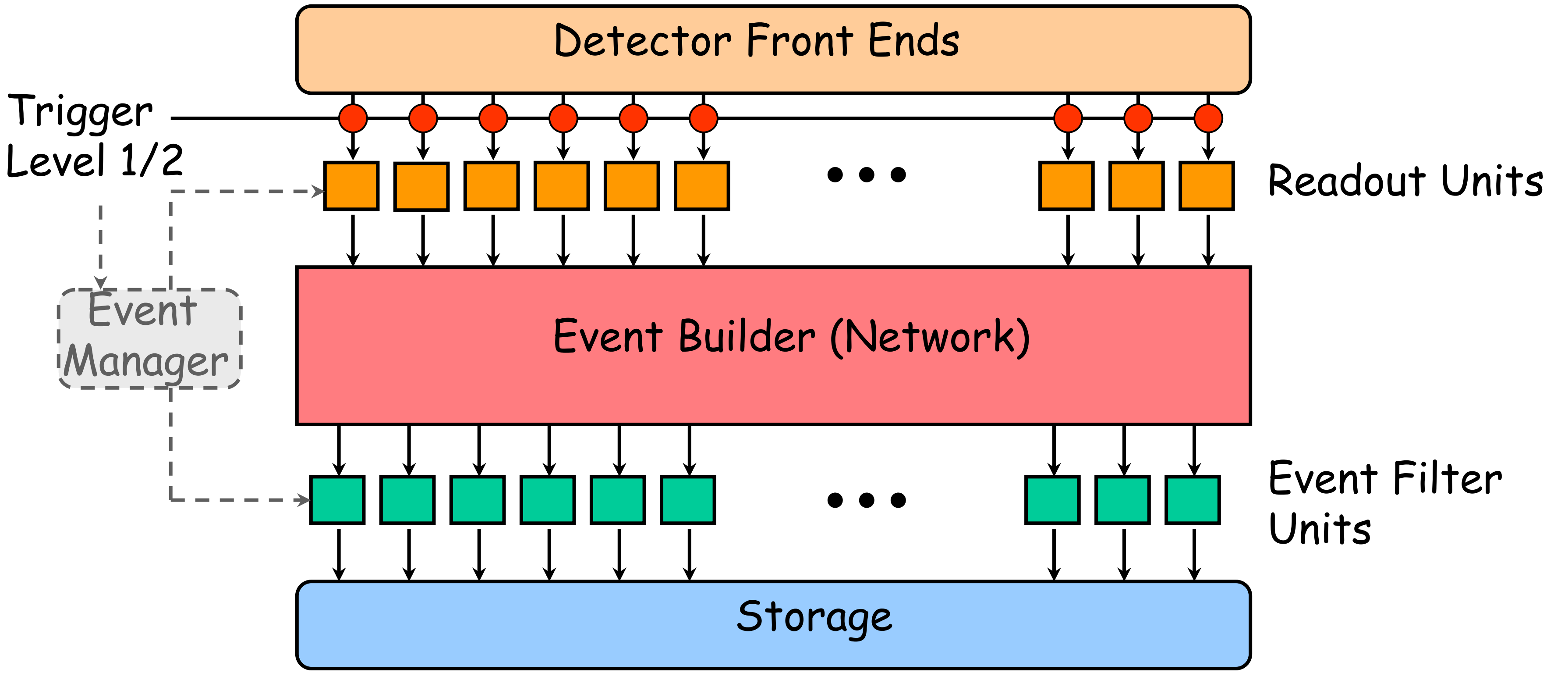
- Cross bar switch
  - Complete, non blocking interconnection all inputs/all outputs.
  - Ideal bandwidth efficiency.
  - N^2 crosspoints.
  - Control of the path routing:
    - External control (barrel shifter).
    - Auto-routing (by data). Data frame protocols.

- **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


Detector Channels (10^6 - 10^7)
Rate
Level 1
Prompt trigger
1-10 μs
Analog
Pipeline
100-1000 Ev
40 MHz
MUX-ADC
100 KHz
Level 2
Digital trigger
10-1000 μs
DSP
Digital Buffer
10-100 Ev
Readout
1000 Hz
~ Gbytes/s
Data Links (100 - 1000)
Event Builder
Level 3
Event trigger
Proc
100 Hz
~ Mbytes/s
Proc
Mass Storage & Analysis

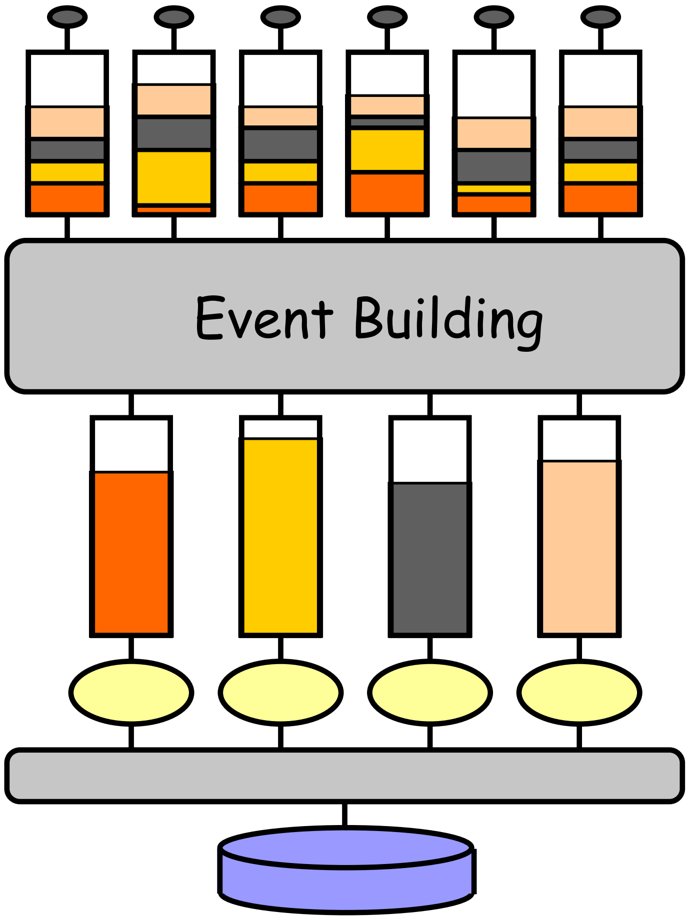
LHC Readout Architecture



Event Building to a CPU farm

Data sources

Event Fragments



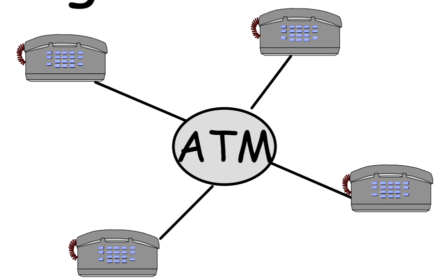
Full Events

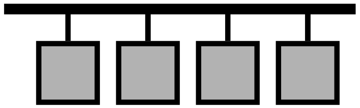
Event filter CPUs

Data storage

⌘ Industrial Digital Switching Technology

- From Telecommunications and Computing Industries
- Some Possibilities:
  - ATM (speeds up to 9.6 Gb/s)
    - 53 byte cells, expensive
  - Fiber Channel (1 Gb/s)
    - Connection oriented -> more overhead
  - Myrinet (2.5 Gb/s)
    - Unlimited message size, cheap switches
    - No buffer in the switch -> less scalable
  - SCI - Scalable Coherent Interface (4 Gb/s)
    - Memory mapped IO, 64 byte messages
  - Gigabit Ethernet (specification for 10 Gb/s)
    - Cheaper, ethernet protocol

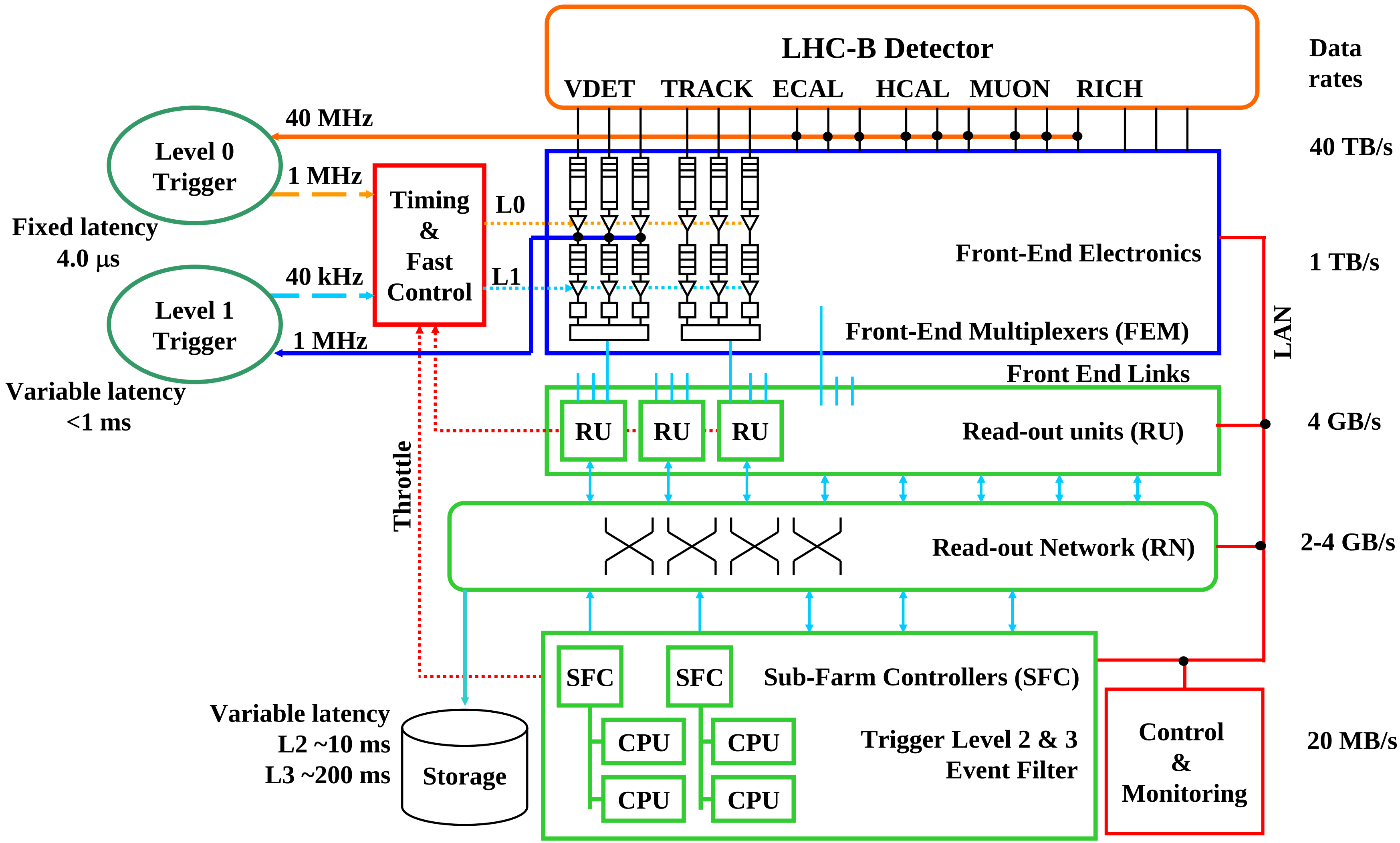




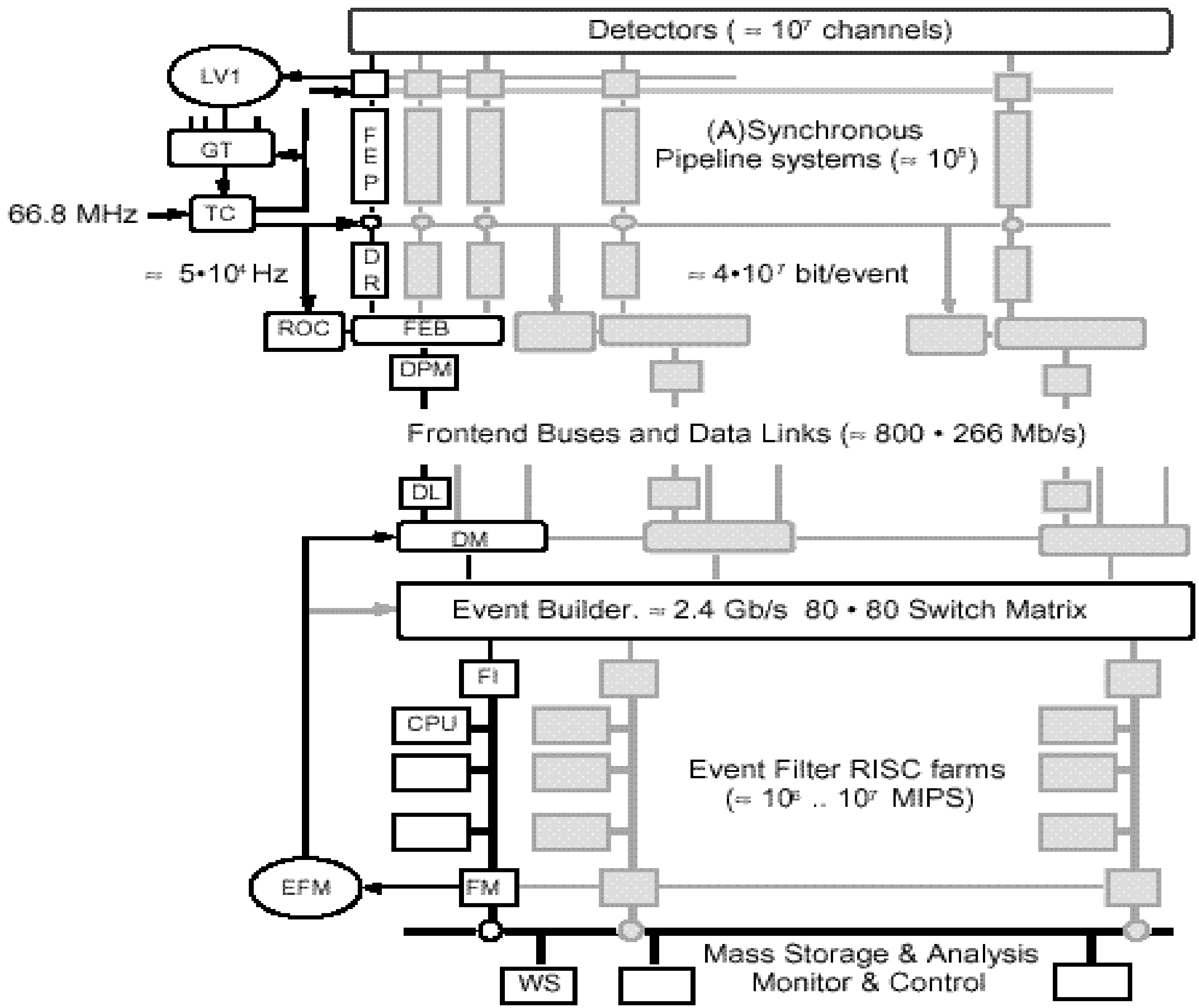
Event Building protocol

- **Push protocol**
  - The data is pushed to the destinations by the sources.
  - The source needs to know the destination address.
  - It is assumed that there is sufficient data buffer at the destination.
  - There is no possibility of re-transmitting a fragment of event.
  - The protocol is simple.
- **Pull protocol**
  - The data in the sources is pulled from the destinations.
  - Only buses can implement a pure pull protocol.
  - Sources need in any case indicate to the destinations when data is ready (interrupt??).
  - Destinations can re-read the event fragment.
  - Destinations need to indicate when the transfer is finished to free memory in the source.
  - The protocol is heavier.

LHCb DAQ (Push Protocol)

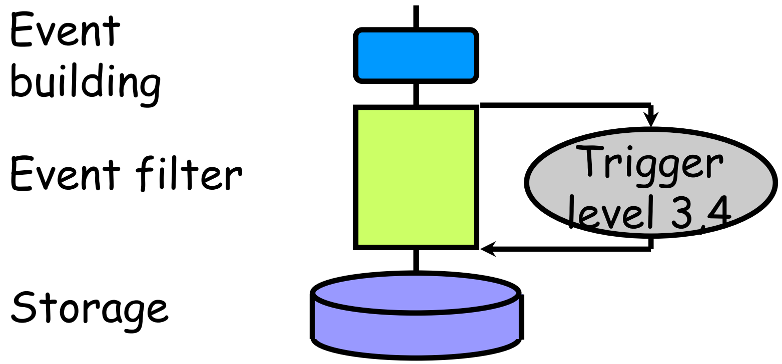


CMS DAQ (Pull Protocol)



Event Filters

⌘ **Higher level triggers (3, 4, …)**



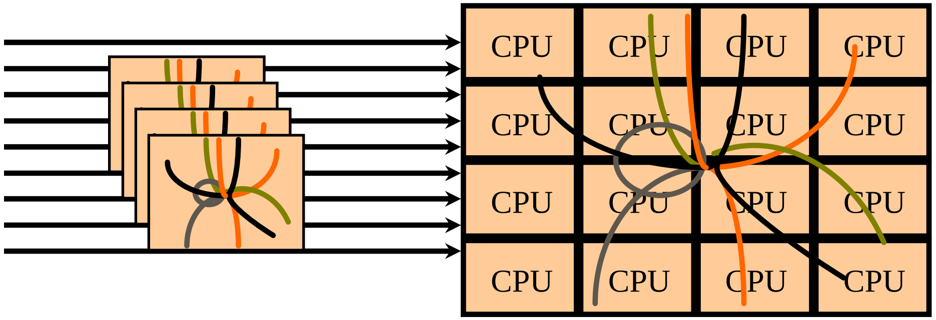
- LHC experiments can not afford to write all acquired data into mass-storage. -> Only useful events should be written to the storage
- The event filter function selects events that will be used in the data analysis. Selected physics channels.
- The algorithms are usually high level (dealing with physics quantities) therefore implying a full or partial event reconstruction.

Parallel versus Farm processing

- A single CPU can not provide the required processing power (especially in LHC)

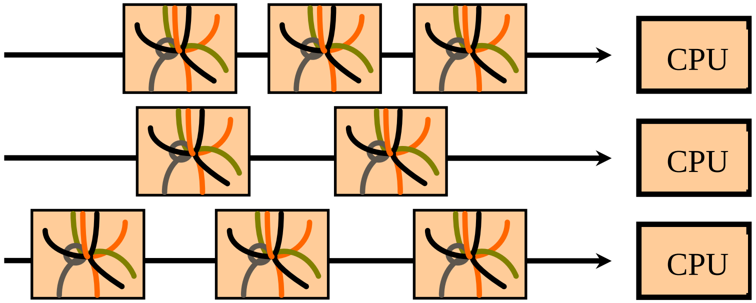
Parallel

Massive parallel processing



- Low latency, complex, expensive.

Farm



- Larger latency, simple, scalable.
- Exploits the fact that each event is independent of the next one.
- Use of commercially (commodity items) available processors

Data Storage

- **Data logging needs:**
  - LEP experiments:
    - Storage bandwidth < 1 MB/s
    - Data is stored on disk and then copied to magnetic tape.
    - Data set: 500 GB/year
  - LHC experiments:
    - Storage bandwidth: » 100 MB/s (general purpose)
    - Expected data set: » 100 TB/year
- **Hierarchical Storage System (HSS)**
  - File system where files are migrated to the mass storage system (tape robot) automatically when not in use and retrieved automatically when needed.
  - Cache system at the level of files.

Data Storage (2)

- **How the data is organized in the storage**
  - The LEP experiments organized the data in events and banks within the events written sequentially.
  - Studying the data access patterns on the analysis programs (which data are more often used and which are hardly ever accessed) should give us an idea on how to store the data.
  - Data is written once and read many times. Therefore the optimization should go into the read access.
- **Organizing the event data store as a huge distributed database**
  - We could profit from the database technology to have fast access to specific data. Sophisticated data queries to do event selection.
  - Problems: How to populate the database at the required throughput? Database backup? Schema evolution? ...

Configuration, Control and Monitoring

Clara Gaspar CERN/EP-LBC

System Performance

$$\text{Total Efficiency} = \frac{\text{\# of interesting events on tape}}{\text{\# of interesting events produced}}$$

= Trigger efficiency * Deadtime *
DAQ efficiency * Operation efficiency

DAQ system not running

Detector problems: background, data quality

weighted by the Luminosity

- All the factors have equal importance. Therefore all of them need to be optimized.
- The performance needs to be monitored in order to detect problems and point where there is a need for improvement.

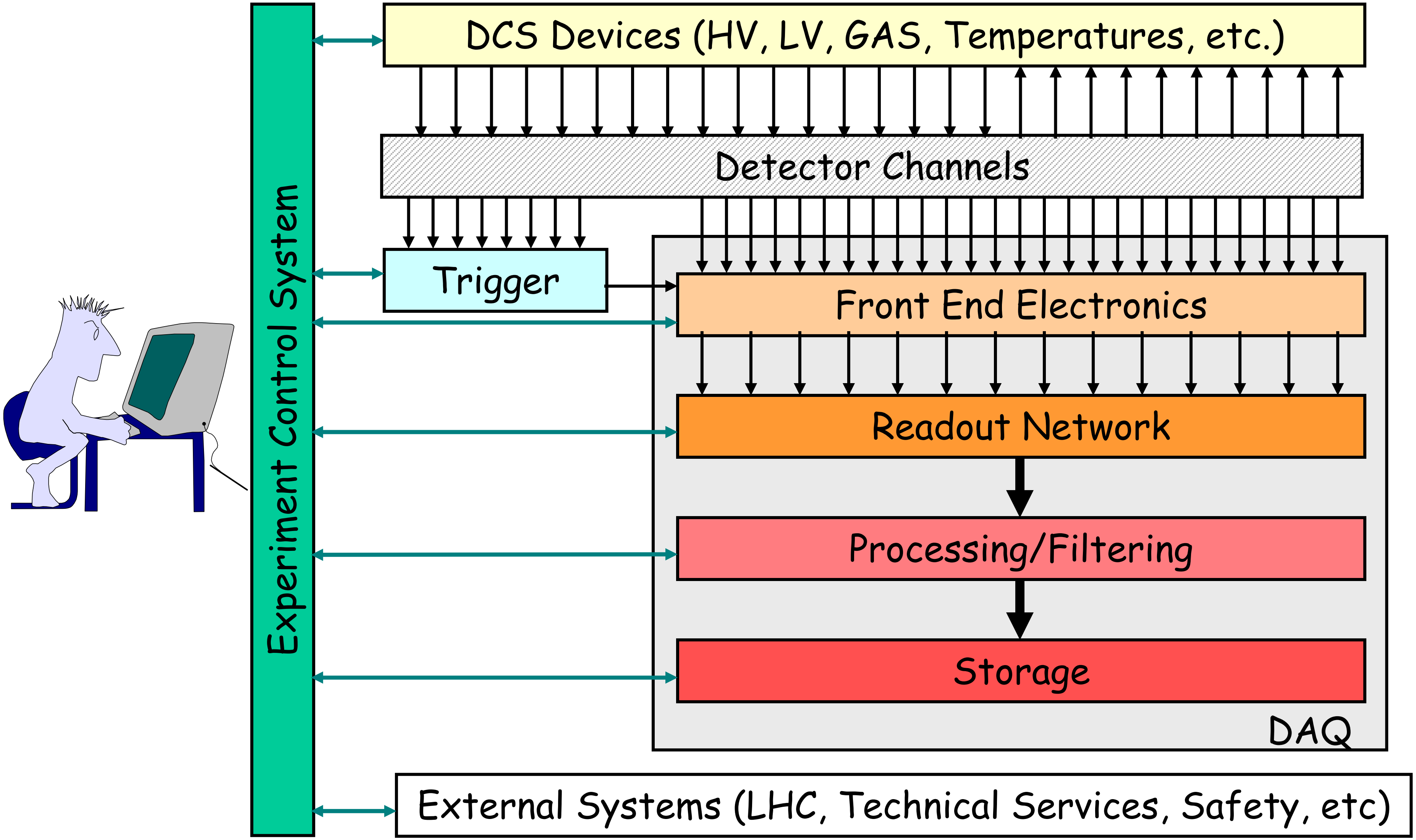
Trigger & DAQ Control

- **Run Control**
  - Configuration
    - Type of RUN, loading of parameters, enabling/disabling parts of the experiment
  - Partitioning
    - Ability to run parts of the experiment in stand-alone mode simultaneously
  - Error Reporting & Recovery
  - Monitoring
  - User Interfacing

Experiment Control (ECS)

- **In charge of the Control and Monitoring of:**
  - Data Acquisition and Trigger (Run Control)
    - FE Electronics, Event building, EFF, etc.
  - Detector Control (Slow Control)
    - Gas, HV, LV, temperatures, ...
  - Experimental Infrastructures
    - Cooling, ventilation, electricity distribution, ...
  - Interaction with the outside world
    - Magnet, accelerator system, safety system, etc.

ECS Scope


DCS Devices (HV, LV, GAS, Temperatures, etc.)
Detector Channels
Trigger
Front End Electronics
Readout Network
Processing/Filtering
Storage
DAQ
Experiment Control System
External Systems (LHC, Technical Services, Safety, etc)

ECS Requirements

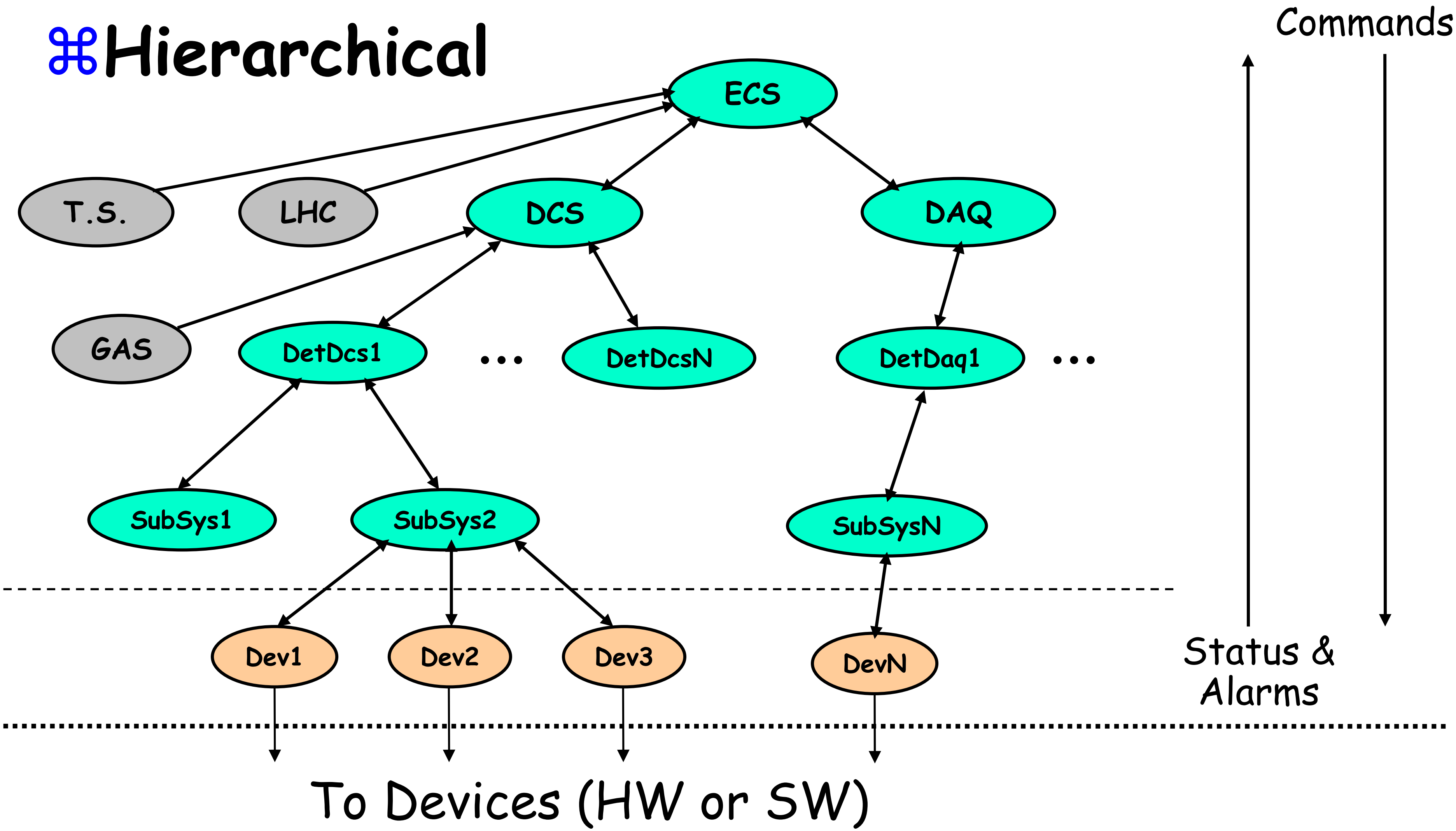
- **Integrate the different activities**
  - Such that rules can be defined (ex: Stop DAQ when SC in Error)
- **Allow Stand-alone control of sub-systems**
  - For independent development and concurrent usage.
- **Automation**
  - Avoids human mistakes and speeds up standard procedures
- **Easy to operate**
  - Two to three operators (non-experts) should be able to run the experiment.
- **Scalable & Flexible**
  - Allow for the integration of new detectors
- **Maintainable**
  - Experiments run for many years

Experiment Control

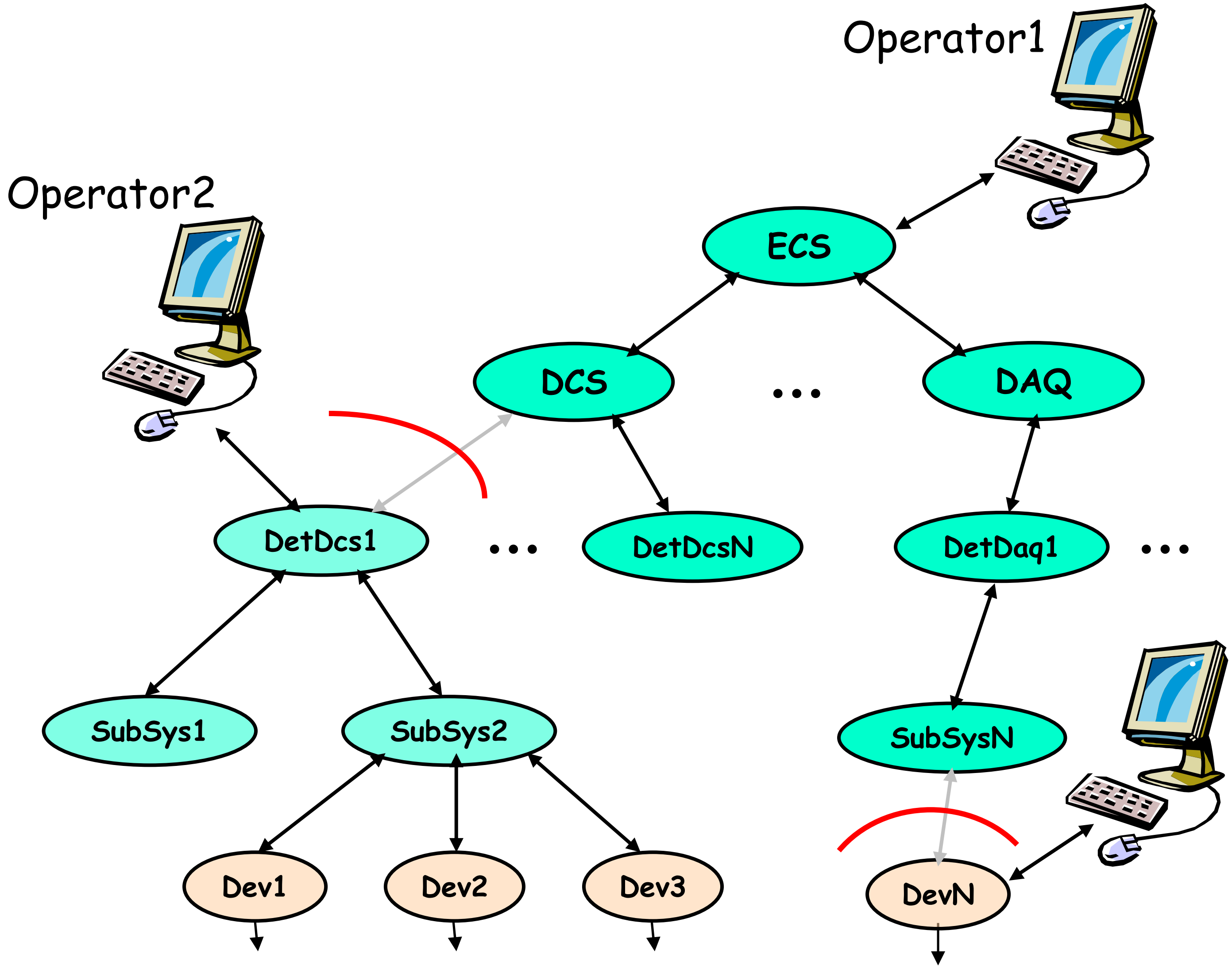
- **Keyword: Homogeneity**
  - A Common Approach in the design and implementation of all parts of the system:
    - Facilitates inter-domain integration
    - Makes it easier to use:
      - Standard features throughout the system (ex: partitioning rules)
      - Uniform Look and Feel
    - Allows an easier upgrade and maintenance
    - Needs less manpower

Control System Architecture

⌘Hierarchical



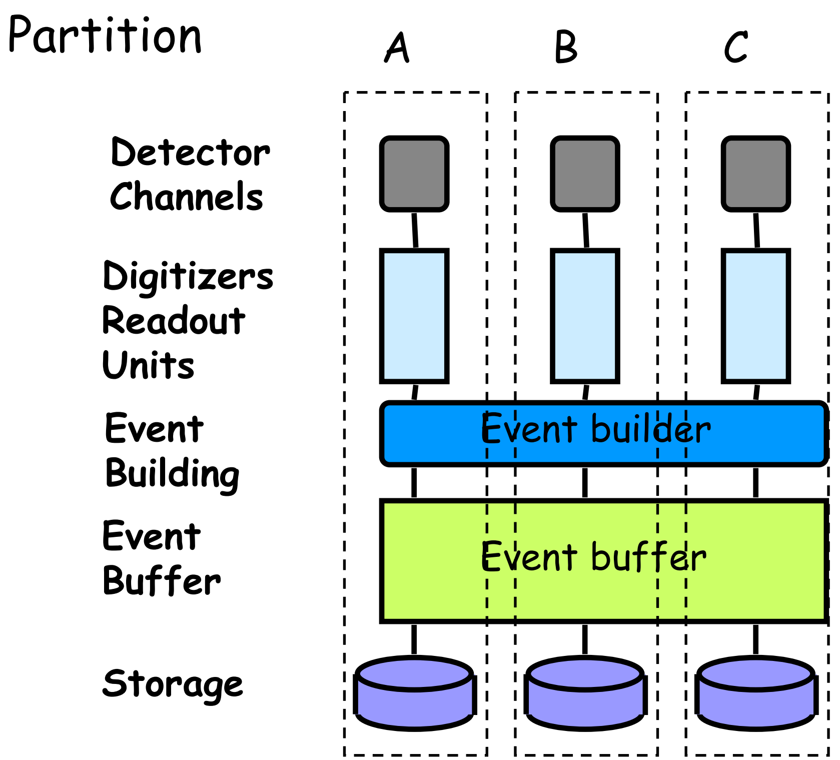
Partitioning



To Devices (HW or SW)

Partitioning (2)

- Partitioning the DAQ imposes strong constraints in the software and hardware. Some resources are shareable and some not



- A trigger source (local trigger or trigger supervisor)
- A set of readout units (data sources) attached to the detector parts which we want to use.
- Some bandwidth on the event building.
- Processing resources.
- Data storage.

System Configuration

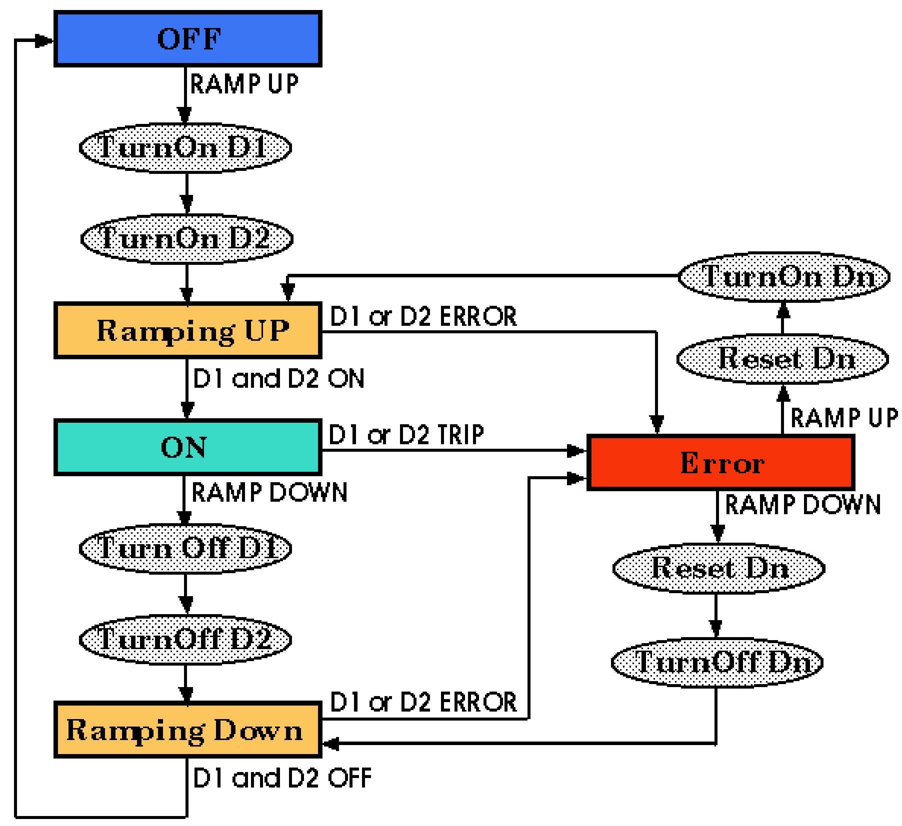
- **All the components of the system need to be configured before they can perform their function.**
  - Detector channels: thresholds, calibration constants need to be downloaded.
  - Processing elements: programs and parameters.
  - Readout elements: destination and source addresses. Topology configuration.
  - Trigger elements: Programs, thresholds, parameters.
- **Configuration needs to be performed in a given sequence.**

System Configuration (2)

- **Databases**
  - The data to configure the hardware and software is retrieved from a **database system**. No data should be hardwired on the code (addresses, names, parameters, etc.).
- **Data Driven Code**
  - Generic software should be used wherever possible (it is the data that changes)
  - In Delphi all sub-detectors run the same DAQ & DAQ control software

System Configuration (3)

- Finite State Machine methodology
  - Intuitive way of modeling behaviour, provide:
    - Sequencing
    - Synchronization
  - Some FSM tools allow:
    - Parallelism
    - Hierarchical control
    - Distribution
    - Rule based behaviour

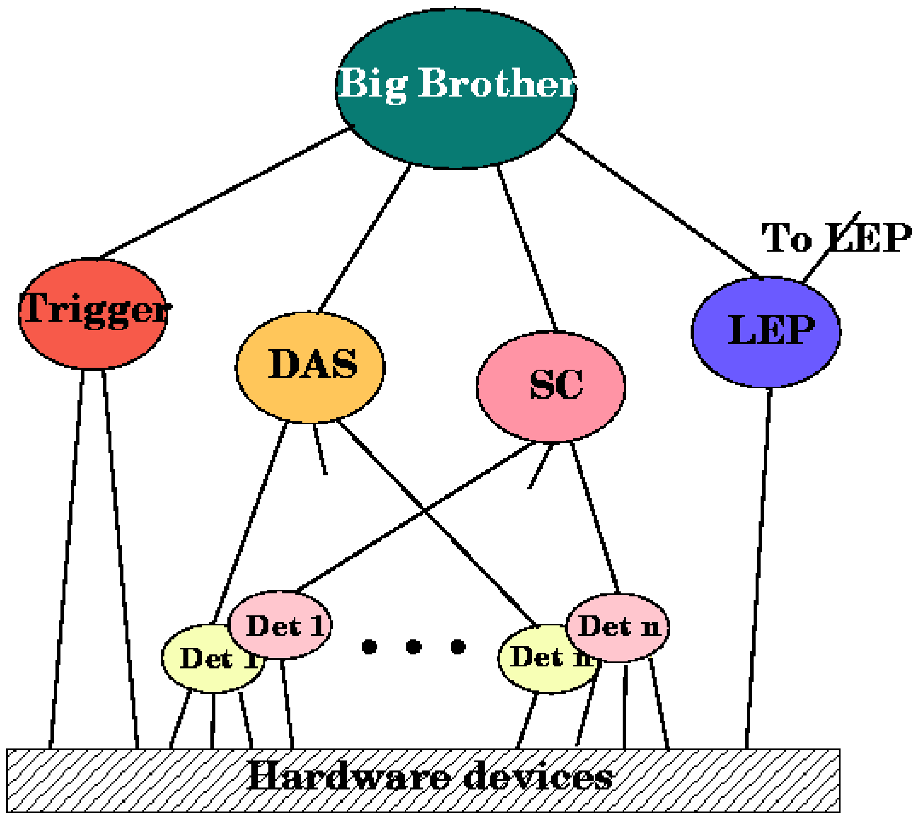


Automation

- **What can be automated**
  - Standard Procedures:
    - Start of fill, End of fill
  - Detection and Recovery from (known) error situations
- **How**
  - Expert System (Aleph)
  - Finite State Machines (Delphi)

Delphi Control System

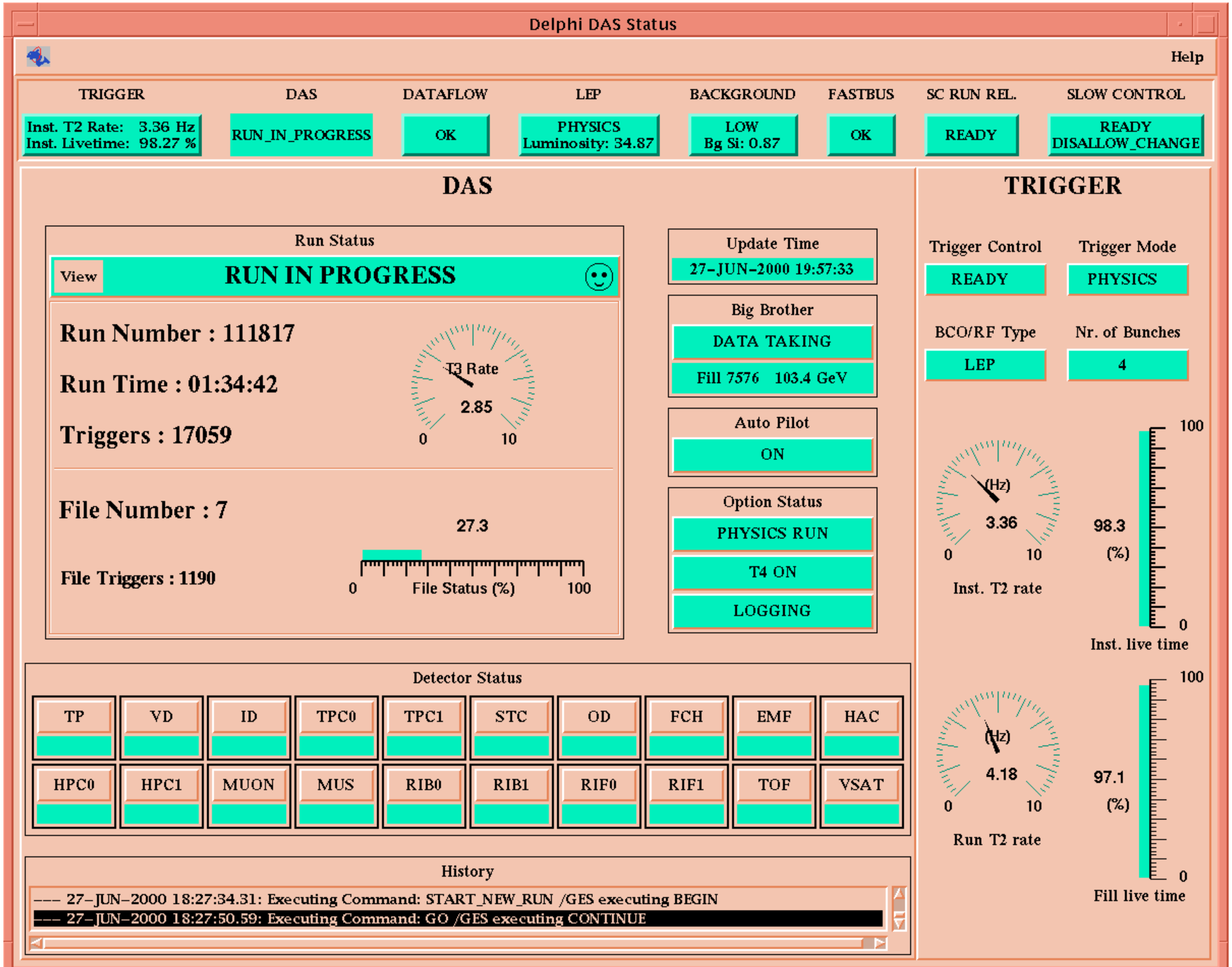
- Hierarchical
- Fully Automated
- Homogeneous
  - One single control mechanism
  - One single communication system
  - One user interface tool



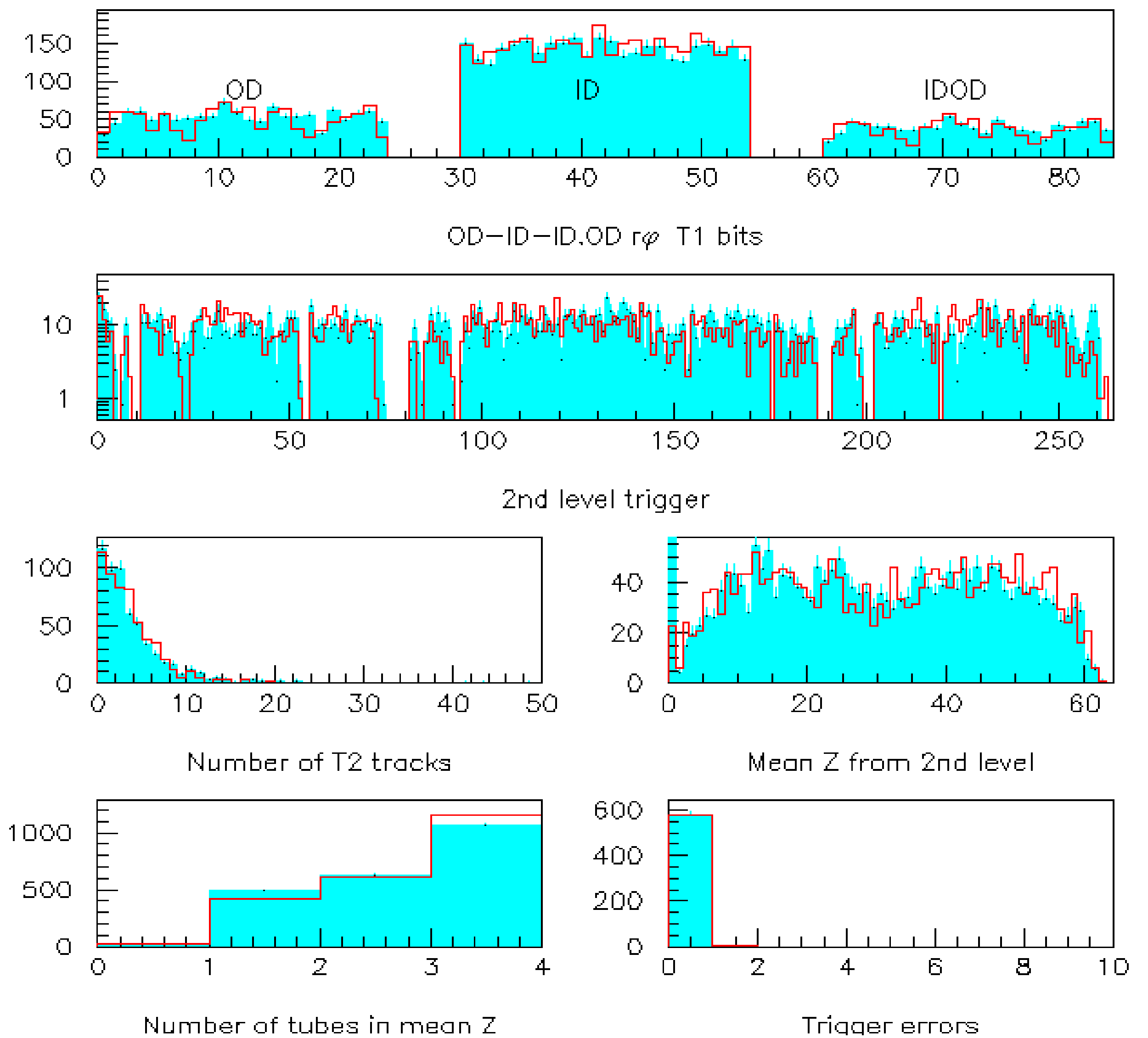
Monitoring

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

Run Control U.I.



Histogram Presenter



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

Concluding Remarks

- Trigger and Data Acquisition systems are becoming increasingly complex as the scale of the experiments increases. Fortunately the advances being made and expected in the technology are just about sufficient for our requirements.
- Requirements of telecommunications and computing in general have strongly contributed to the development of standard technologies and mass production by industry.
  - Hardware: Flash ADC, Analog memory, PC, Helical scan recording, Data compression, Image processing, Cheap MIPS, ...
  - Software: Distributed computing, Integration technology, Software development environment, ...
- With all these off-the-shelf components and technologies we can architect a big fraction of the new DAQ systems for the LHC experiments. 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.