Intro to Triggering

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Cambridge Dictionary

trigger

noun · UK /ˈtrɪɡ.əʳ/ US /ˈtrɪɡ.ɚ/

trigger *noun* (GUN PART)

[C] **a part of a gun that causes the gun to fire when pressed:**

*It's not clear who actually **pulled** the trigger.*

+ Thesaurus: synonyms and related words

trigger *noun* (START)

[C usually singular] **an event or situation, etc. that causes something to start:**

*There are fears that the incident may be a trigger **for** more violence in the capital.*

SPECIALIZED psychology [C usually singular] **something that causes someone to feel upset and frightened because they are made to remember something bad that has happened in the past:**

A trigger is something that sets off a flashback, transporting the person back to the traumatic event.

Trigger in HEP

trigger

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trigger *noun* **(GUN PART)**

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trigger *noun* **(START)**

[C usually singular] **an event or situation, etc. that causes something to start:**

In particle physics, a trigger is a system that uses criteria to rapidly decide which events in a particle detector to keep (i.e. to start storing the event data) when only a small fraction of the total can be recorded.

traumatic event.

Particle Physics Experiments

Different experiments have very different trigger requirements:

- Fixed target
  - No trigger : Geiger, photo-emulsions, cloud/bubble chambers
  - Trigger: electronic detectors
- Colliders
  - Electronic detectors
- Cosmic

Lectures

- ~ 4 lectures
  - Introduction
    - Generic detector
    - NA57 example
  - Collider: LHC – ALICE example
  - Fixed target experiment:
    - NA62

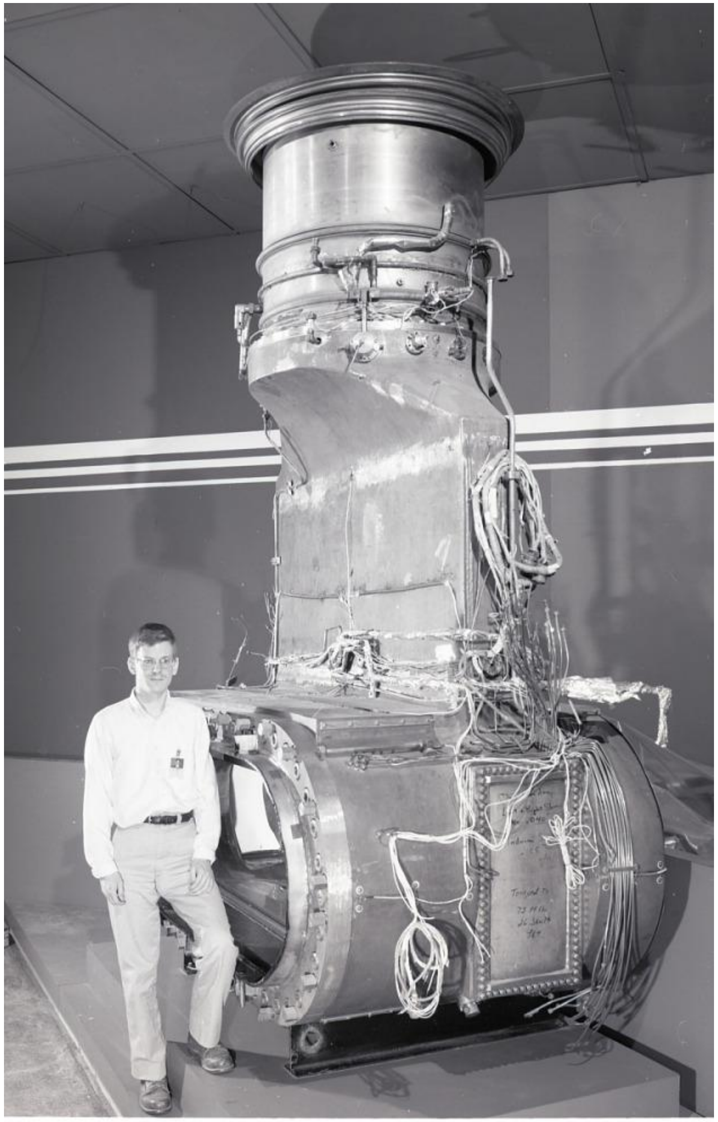
Lectures:
http://epweb2.ph.bham.ac.uk/user/lietava/triggerlectures/index.html

Content

- Particle experiments
- Why we need trigger
  - Bubble chamber
  - Interaction rate (LHC)
  - How much data ?
- What to trigger on ?
- How to trigger ?
- Comparison
  - Atlas/CMS/LHCb/Alice

Why Trigger et all ?

- Bubble chambers operated for many years and generated several Nobel Prizes, yet are not suitable for triggers at all
- How did they do it?



Brookhaven 80" Hydrogen Bubble Chamber (Courtesy of National Museum of American History)

Discovery of Omega (1964)

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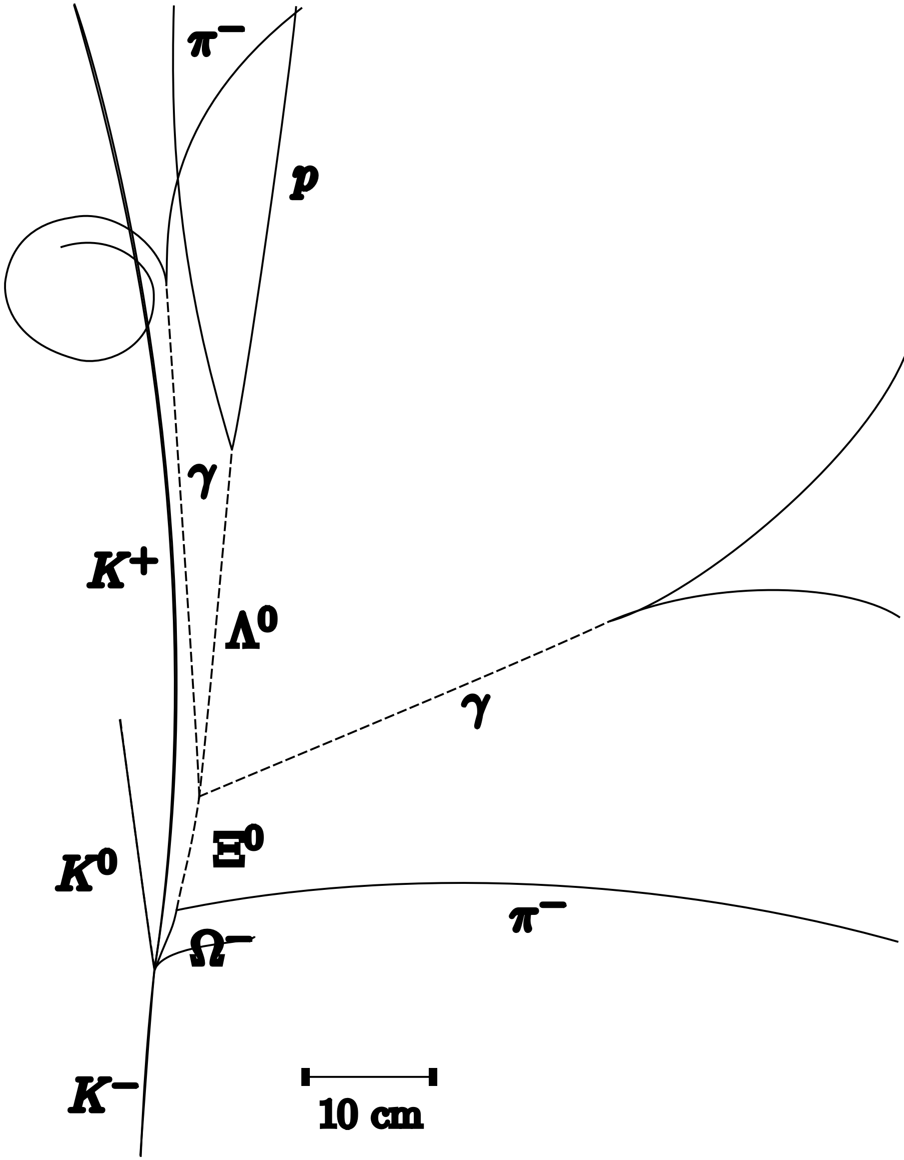
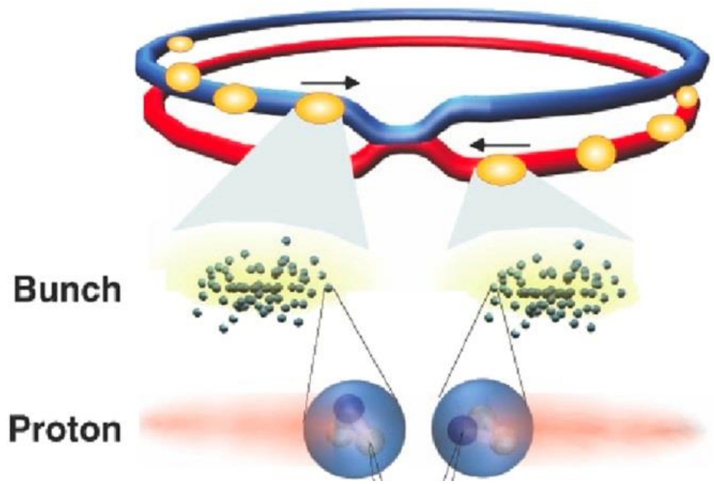


Taking photographs !

Outcome

- Without any triggering (except in the sense of cycling the chamber in a way which synchronizes with the beam extraction) a bubble chamber gives you, on average, about 1 interaction per second.
- Assuming 50% down time (a bit pessimistic) gives about 300k events per week.
- Satisfactory for minimum bias ("total cross section") studies
  - Higher interaction and readout rates needed => electronic experiments

LHC Interaction Rate: Machine x Physics



Proton-Proton	2835 bunch/beam
Protons/bunch	10^{11}
Beam energy	7 TeV (7×10^{12} eV)
Luminosity	10^{34} cm^{-2} s^{-1}
Crossing rate	40 MHz
Collisions ≈	10^7 - 10^9 Hz

$$Interaction\ rate\ R = L \times \sigma$$

$$Luminosity\ L = 10^{34} cm^{-2} s^{-1}$$

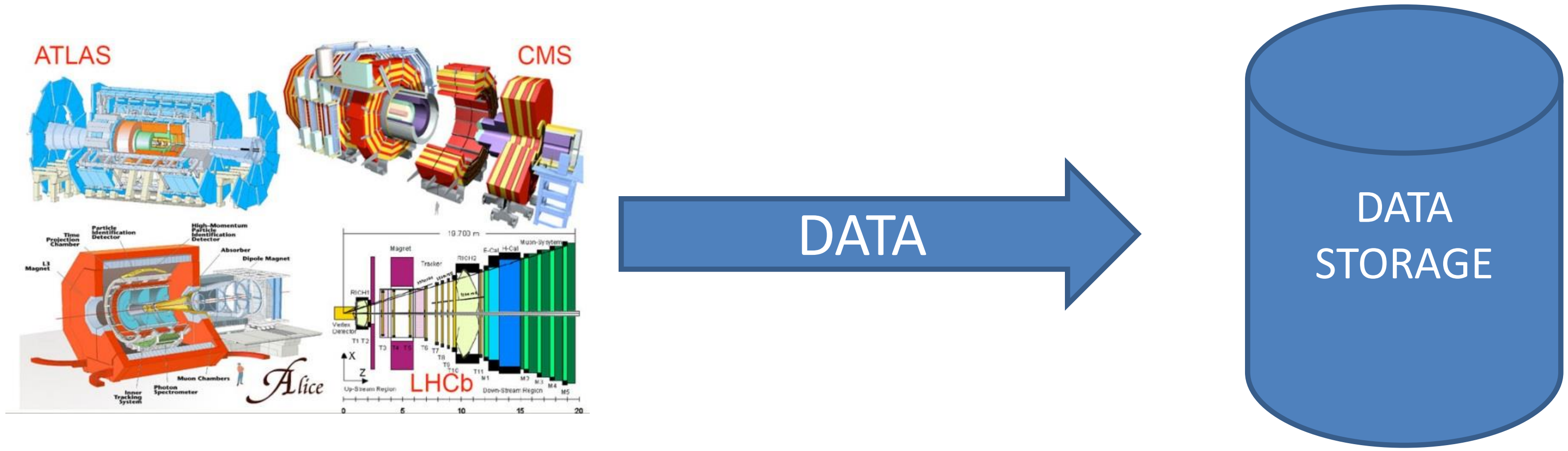
$$Inelastic\ cross\ section\ \sigma = 100mb$$

$$\boldsymbol{R = 1GHz}$$

$$L \sim \frac{f \times n \times N^2}{S}$$

f – revolution frequency
n – number of bunches
N – number of protons in bunch
S – bunch transverse cross section

Why trigger: how much data ?



$$Data\ per\ year\ V = R \times v \times T \times n$$

$$Event\ size\ v \sim 2MB$$

$$Time\ (10\ months) T = 2.6 \times 10^6 s$$

$$Number\ of\ experiments\ n = 4$$

$$V = 10^{23} Bytes/year$$

Why trigger: how much money?

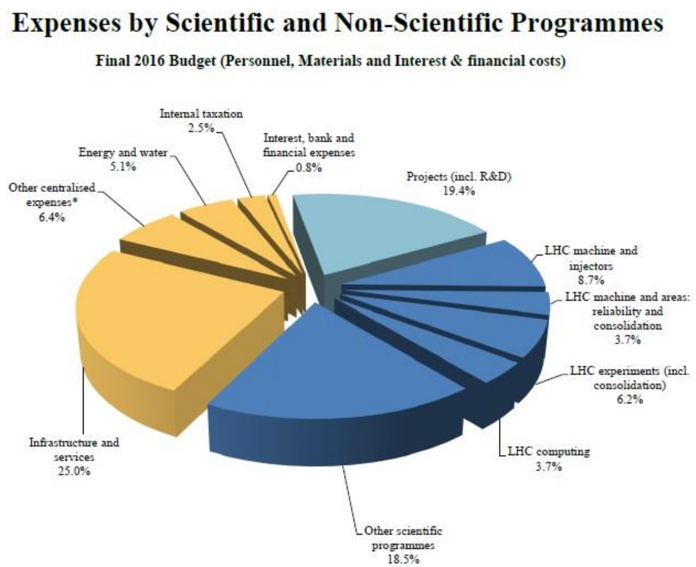
$Data\ per\ year\ V = R \times v \times T \times n$

$V = 10^{23} Bytes/year$ ~ world data storage

$Google\ cost\ c = 4GBP/\ 1TB/month$

$Cost\ per\ year\ C = V \times c \times 12 = 5 * 10^{12} GBP$

$CERN\ budget\!:\ 10^{9} CHF$



2023 numbers

Why trigger: how much data can we effort?

LHC data/year = $10^{23}B$

280 PetaBytes (2019)

= $2 \times 10^{17}B \Rightarrow$

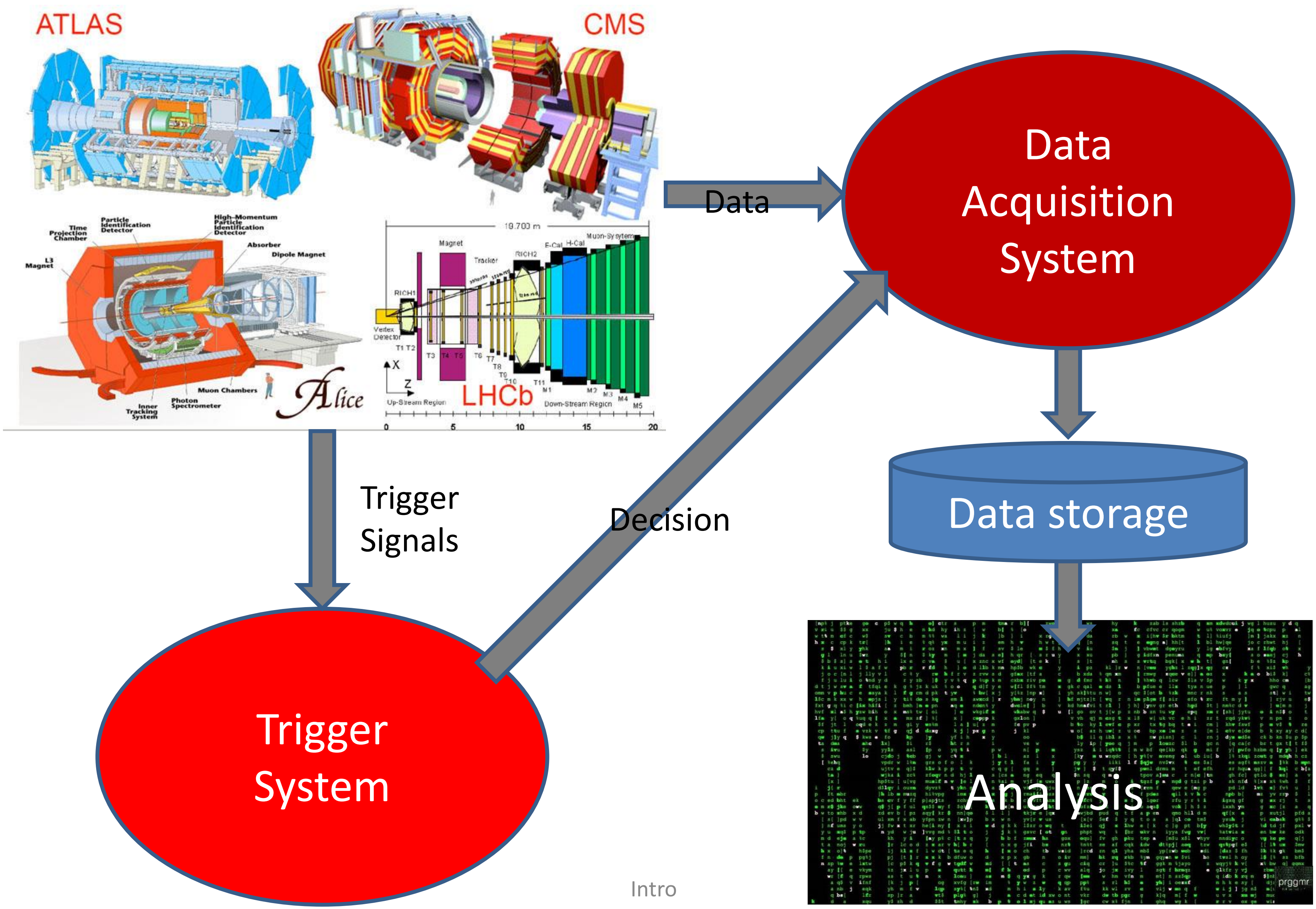
reduction factor $\sim 10^{6} \Rightarrow$

TRIGGER

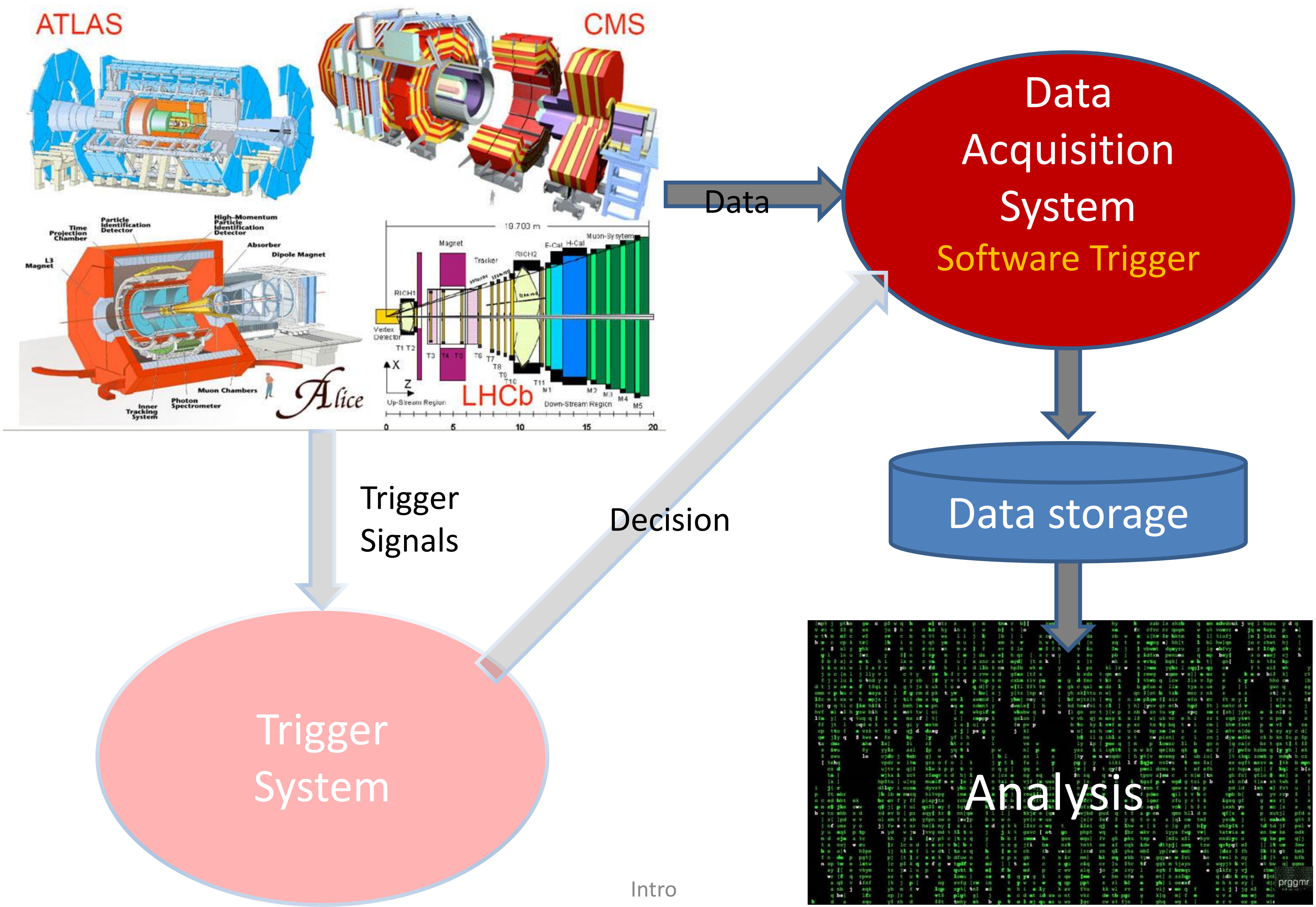
CERN's Data Centre (Image: Robert Hradil, Monika Majer/ProStudio22.ch)

On 29 June 2017, the CERN DC passed the milestone of 200 petabytes of data permanently archived in its tape libraries. Where do these data come from? Particles

General schema

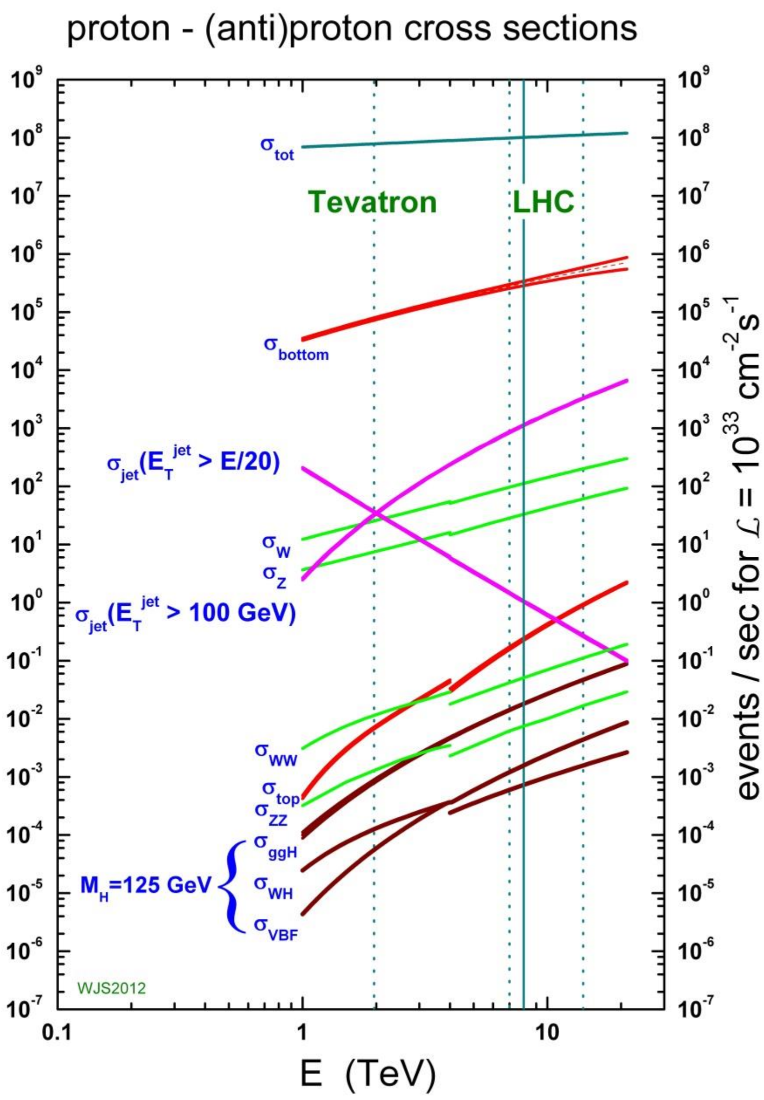


General schema



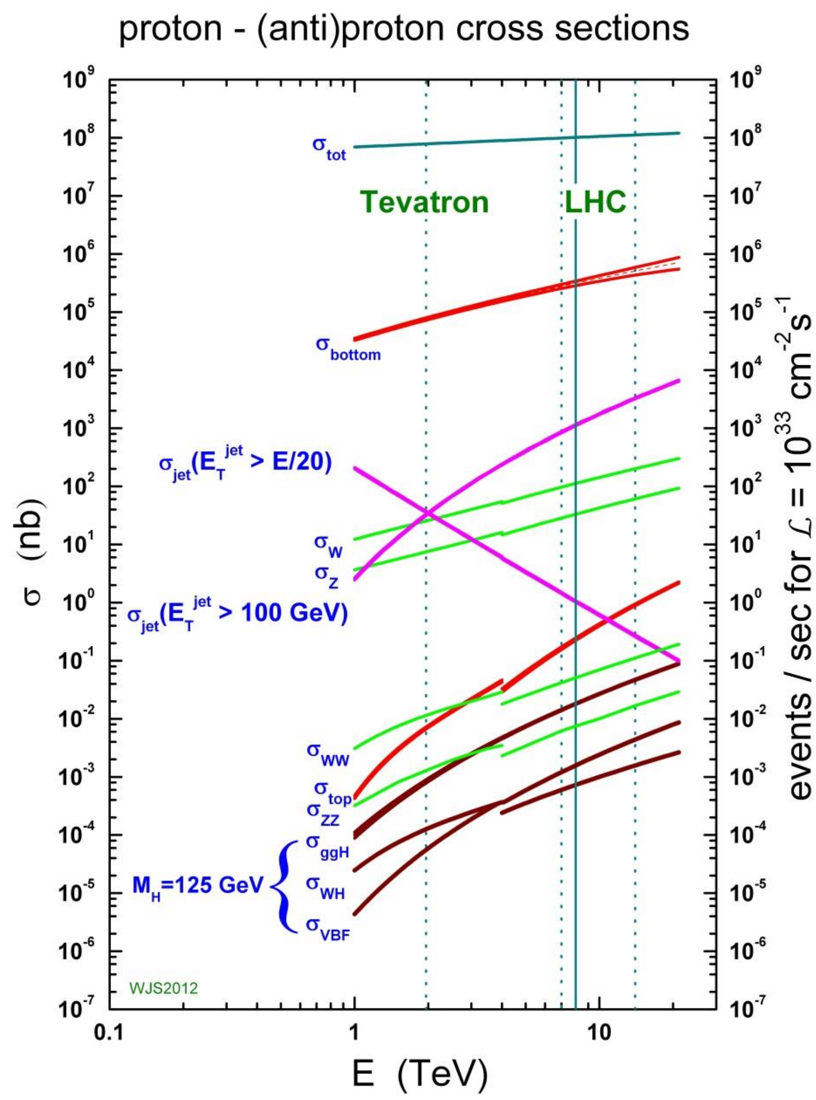
What to choose ?

Process	Production Rate $10^{34}\ cm^{-2}s^{-1}$
inelastic	~1 GHz
bbbar	5 MHz
W →lν	150 Hz
Z →lν	15 Hz
ttbar	10 Hz
Z'	0.5 Hz
H(125) SM	0.4 Hz
$B_s^0 \to \mu^+\mu^-$	10^{-7} Hz



What to choose ?

- ATLAS/CMS
  - Higgs
  - New physics
- LHCb
  - Rare decays
  - CP violation
- ALICE
  - QCD



What to choose ?

- **ATLAS/CMS**
  - **Higgs**
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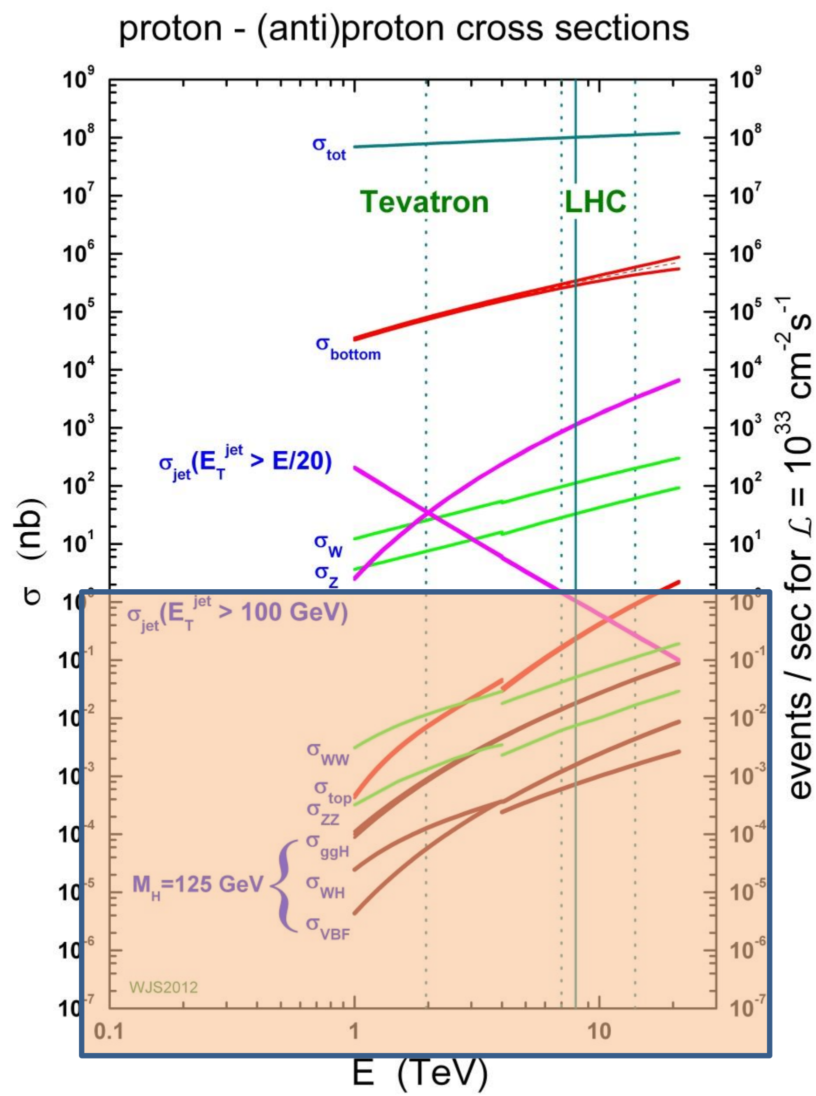
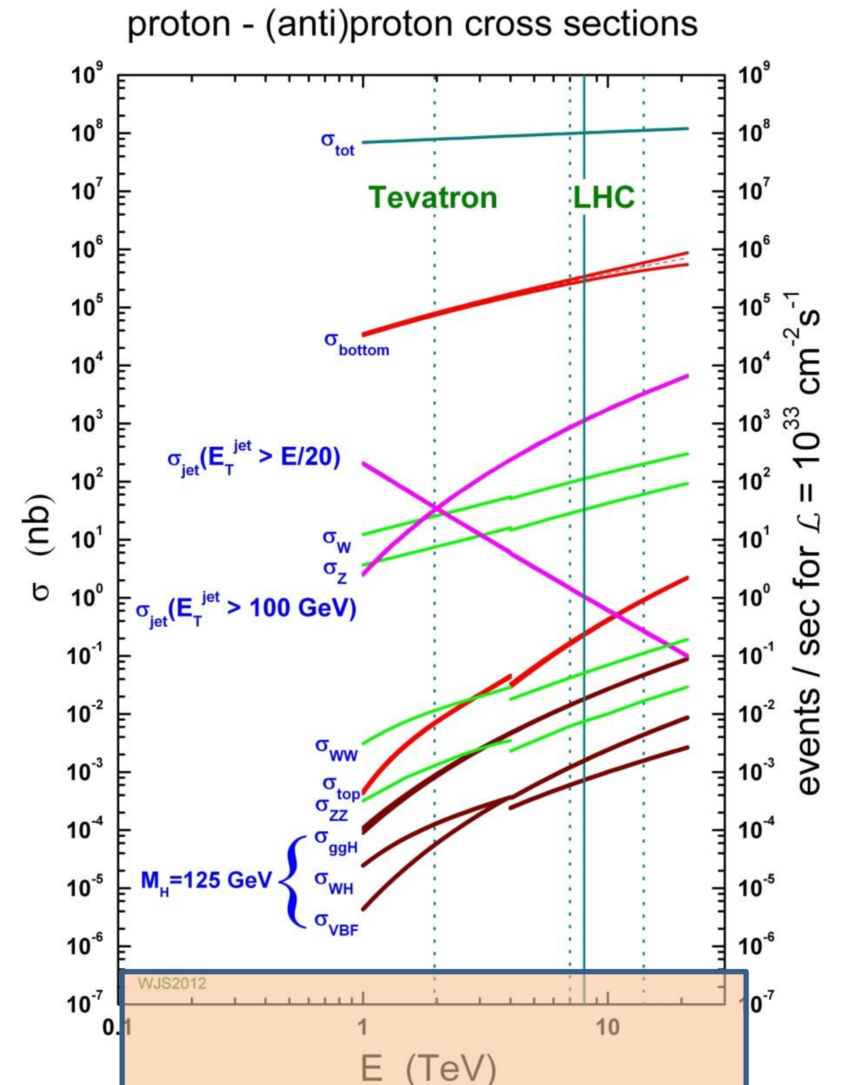


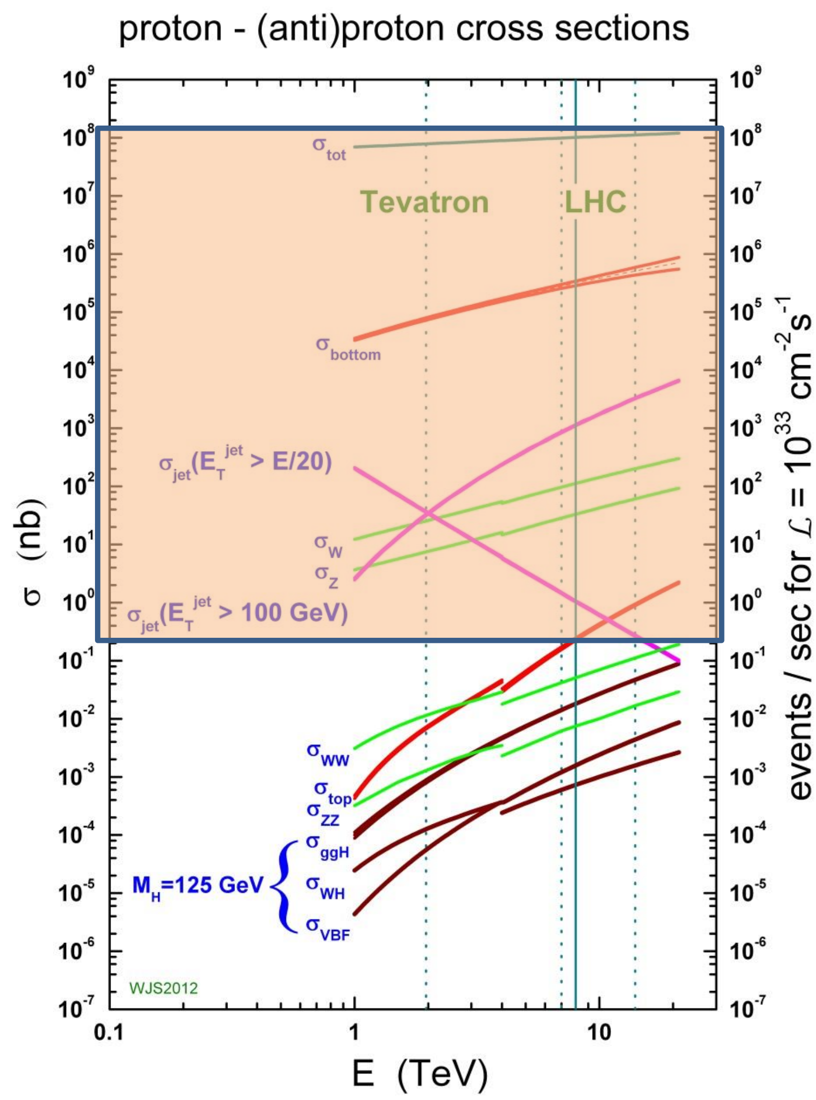
What to choose ?

- ATLAS/CMS
  - Higgs
  - New physics
- **LHCb**
  - **Rare decays (b,c)**
  - **CP violation**
- ALICE
  - QCD

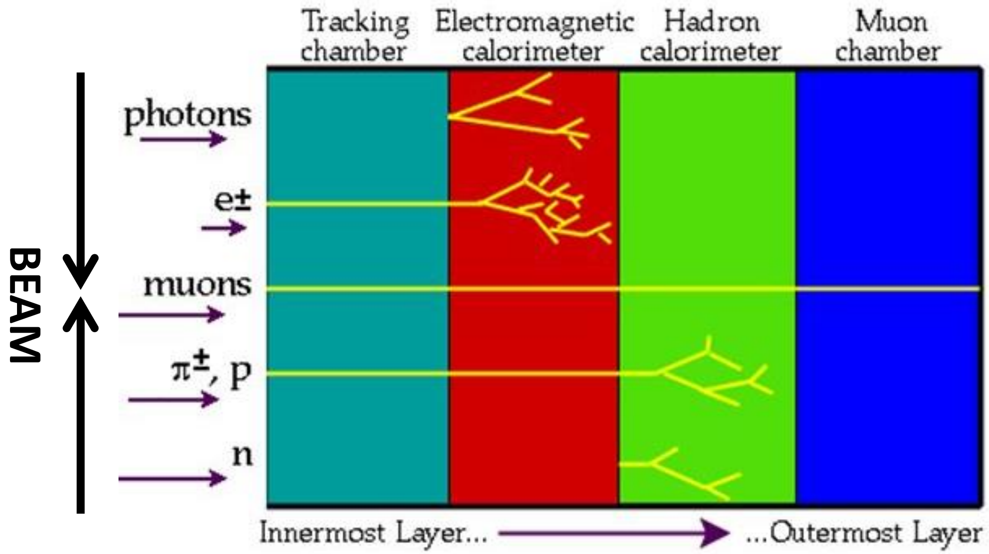


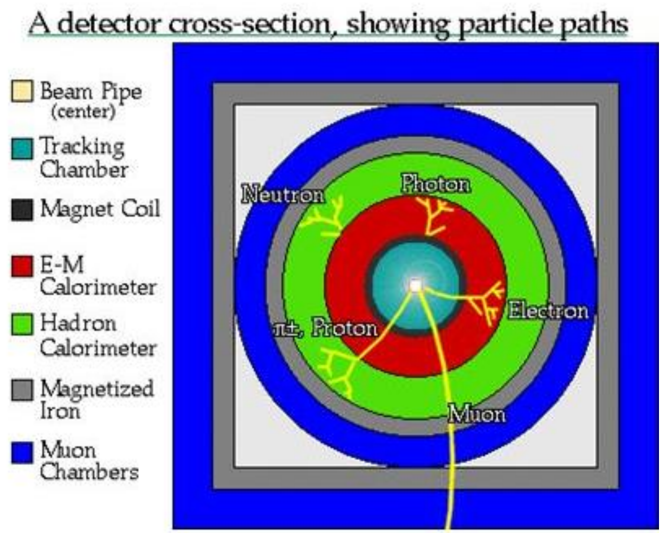
What to choose ?

- ATLAS/CMS
  - Higgs
  - New physics
- LHCb
  - Rare decays (b,c)
  - CP violation
- **ALICE**
  - **QCD/ QGP**



How to choose ?





Identify different particles produced:

- Photons: Electromagnetic calo (ECAL)
- Electrons: Tracker+ECAL
- Hadrons:
  - Charged: tracker+ECAL+Hadron Calo (HCAL)
  - Neutral: HCAL
- Muons: tracker+ECAL+HCAL+muon chambers
- Neutrino: none

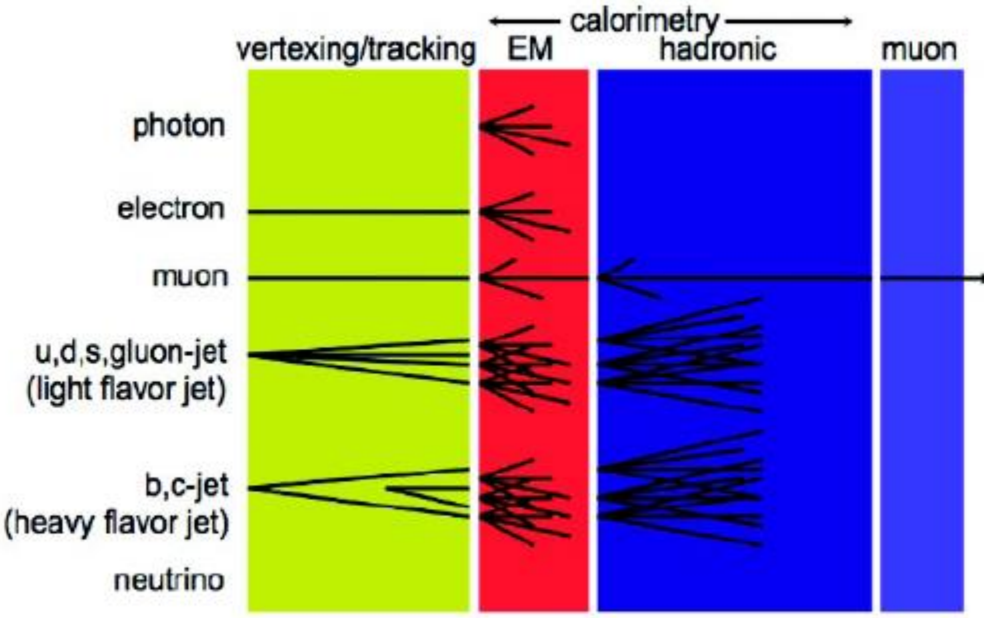
Triggering detectors

- Triggering detectors
  - Fast trigger signals
    - Every triggering detector has full readout also
  - Small amount of data
  - Segmented enough
- Technologies:
  - Calorimeters: ECAL, HCAL
  - Scintillators
  - Gas detectors:
    - Resistive Plate Chambers (RPC)
    - Thin Gap Chambers (MWPC)
    - Drift tubes
    - Cathode strip chambers
    - Gas Electron Multiplier (GEM)

Trigger selection

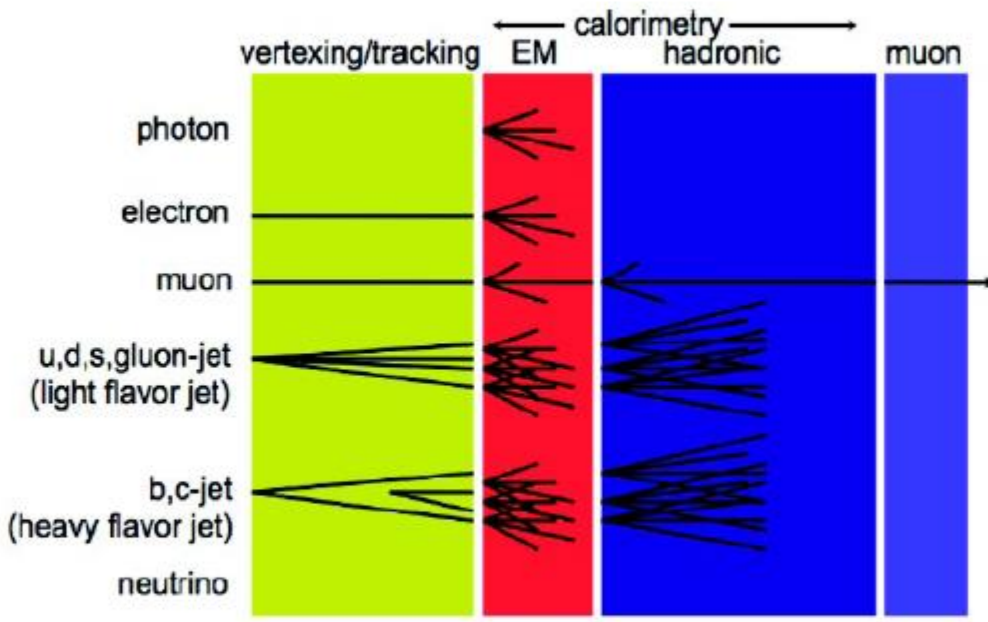
Combining information from detector elements and different detectors:

- Isolated Photon
- Isolated Electron
- Isolated Muon
- Jet
  - τ jet
  - Heavy flavour jet
- Missing energy



Trigger selection

Combining information from detector elements and different detectors:



- Isolated Photon
- Isolated Electron
- Isolated Muon
- Jet
  - τ jet
  - Heavy flavour jet
- Missing energy MET

- Multiplicity
  - 1,2,3,4 jets
  - ....
- Topological trigger
  - 2 photons with Higgs mass
  - ....

Trigger menu

- Physics triggers
  - Most of the bandwidth
- Additional triggers (downscaled)
  - Needed in Analysis
    - Efficiency
    - Background
  - Calibration triggers
  - Monitoring triggers

ALICE Trigger Menu

Trigger menu 2017 for pp 13 TeV

Interaction rate ~150 kHz (V0and), ~190 kHz (inelastic)

Class	Description	Cluster	RO rate
CINT7	0V0A & 0V0C = INT7 (ds ~ 0.2%)	CENT	150 Hz → 100 Hz
CVHMV0M	V0A high multiplicity (~0-0.24% of the INT7 cross section)	CENT	115 Hz
C0TVX	T0 vertex for lumi monitoring (ds ~ 0.2%)	CENT	-
C[E|D]MC7[E|D]G1	E/Dcal L0 >2.5 GeV + L1 gamma > 9 GeV	CENT[NOTRD]	19 Hz
C[E|D]MC7[E|D]J1	E/Dcal L0 >2.5 GeV + L1 jet > 20 GeV	CENT[NOTRD]	
C[E|D]MC7[E|D]G2	E/Dcal L0 >2.5 GeV + L1 gamma > 4 GeV, ds=~12%	CENT	12 Hz
C[E|D]MC7[E|D]J2	E/Dcal L0 >2.5 GeV + L1 jet > 16 GeV, ds=~12%	CENT	
CPHI7	PHOS L0 > 4 GeV	CENT[NOTRD]	11 Hz
CCUP25	Diffractive gap (!V0 & 0STG & TOF)	CENTNOTRD	53 Hz
CCUP13	Diffractive gap (!V0 & 0STG), ds~0.5%	CENTNOTRD	3 Hz
CINTHQU	TRD L1 quarkonia: pt > 2 GeV, PID > 130	CENT	50 Hz (@14 kHz inspection)
CINTHNU	TRD L1 nuclei: PID > 207 - 239		
CINT7HJT	TRD L1 jet: >=3 tracks with pt > 1.5 GeV/c		
CMSL7	Single muon low-pt (0.5 GeV/c), ds~6%	MUFAST	350 Hz
CMSH7	Single muon high-pt (4 GeV/c)	MUFAST	
CMLL7	Dimuon like-sign low-pt (0.5 GeV/c), ds~10%	MUFAST	
CMSL7	Dimuon unlike-sign low-pt (1 GeV/c)	MUFAST	
C[E|D]MC7M[SH|UL]	E/Dcal & dimuon US, E/Dcal & single muon high-pt	ALLNOTRD	8 Hz
C[E|D]MC7MSL	E/Dcal & single muon low-pt, ds ~10%	ALLNOTRD	
CMUP6	Forward UPC	MUFAST	10 Hz

Monitoring

CENT livetime 40%
CENTNOTRD livetime 54%
MUFAST livetime 88%

L1r busy from TRD inspection ~4%

Efficiency

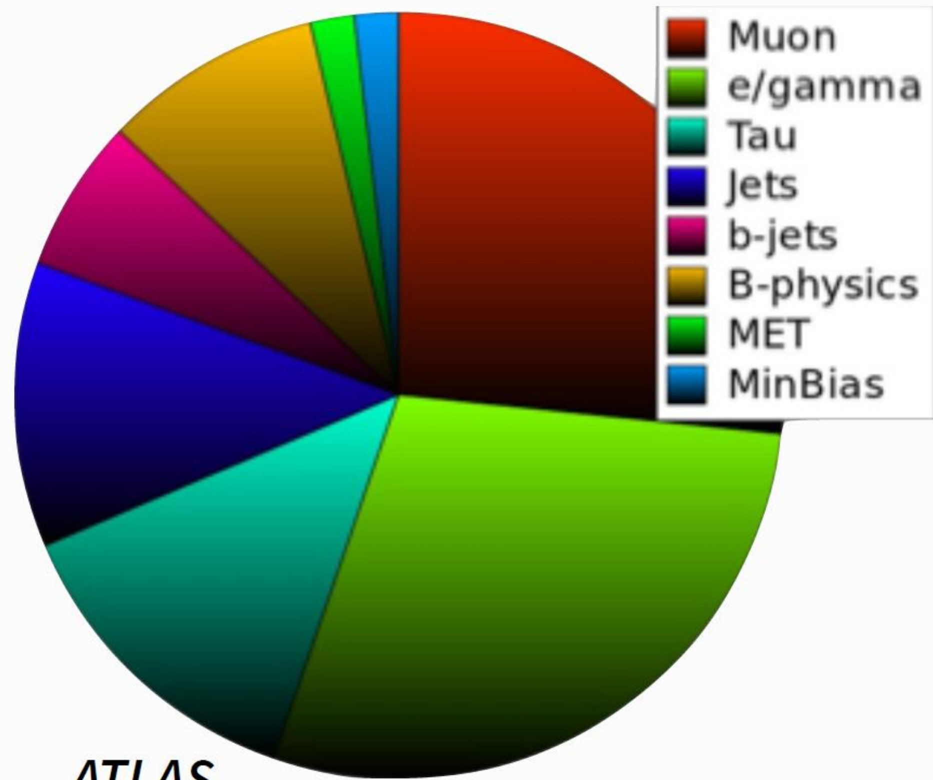
- **Total read-out rate of TPC ~400 Hz**

5

ATLAS Trigger Menu

Priority List for >300 Hz

Chain					
EF_xe60_verytight_noMu	SUSY/Exotics				
EF_j100_a4tc_EFFS_ht400	SUSY				
EF_4j45_a4tc_EFFS	SUSY/SM				
EF_5j30_a4tc_EFFS					
EF_j240_a10tc_EFFS	Exotics/SM				
EF_tau29_loose1_xs45_loose_noMu_3L1J10	Higgs				
EF_b10_medium_4j30_a4tc_EFFS	Top/Higgs				
EF_2mu4_BmumuX	B-physics				
EF_2mu4_Jpsimumu					
EF_mu4mu6_DiMu					
EF_mu4mu6_DiMu_DY20	SM				
EF_2MUL1_l2j30_HV_allMS	Exotics				
EF_mu20i_medium	$5x10^{33}$ prep.				
EF_mu18_MG_medium	Many				
EF_mu18_medium					
EF_e60_loose	(Exotics)				
EF_mu15/18/22_njX?	SUSY/??				
EF_g22_hiptrt?	Exotics				
EF_e15_medium_xe40_noMu	SUSY/Exotics				
EF_j55_a4tc_EFFS_xe55_medium_noMu_dphi2j30xe10					
EF_e10_medium_mu6_topo_medium	Higgs				
EF_tau20_medium_e15_medium	Higgs				
EF_xe60_tight_noMu	SUSY				
EF_e10_medium_mu6	Higgs/SUSY				
EF_l2j30_Trackless_HV_L1MU6	Exotics				
Total extra rate		6500	600	100	Peak at 3×10^{33}



ATLAS

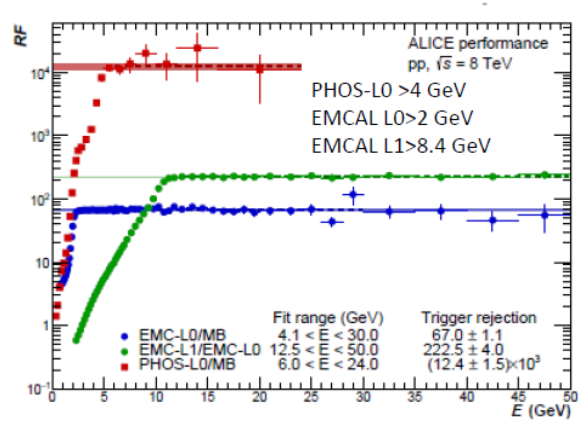
Trigger rates per signature at 10^{33}

Trigger Efficiency

$$Efficiency = \frac{number\ of\ events\ with\ selection}{number\ of\ \ events\ without\ selection}$$

$$Rejection\ Factor = \frac{1}{Efficiency}$$

- Efficiency should be precisely known
- The capability of the selection depends on resolution of quantity we cut on
- Efficiency can evolve with time

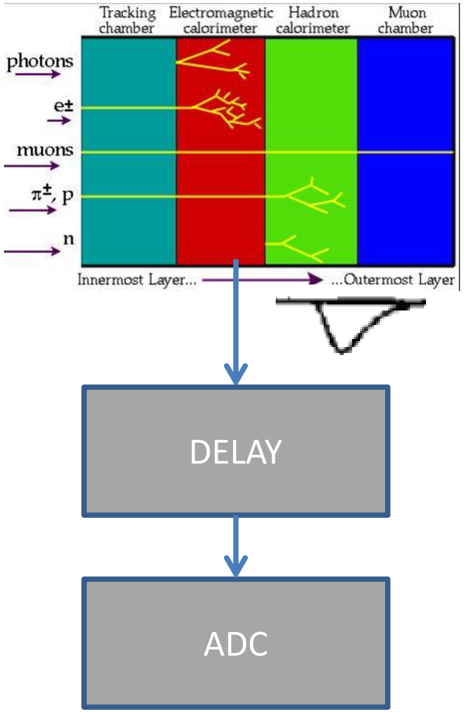


ALICE Emcal Trigger rejection factor RF

How to trigger ?

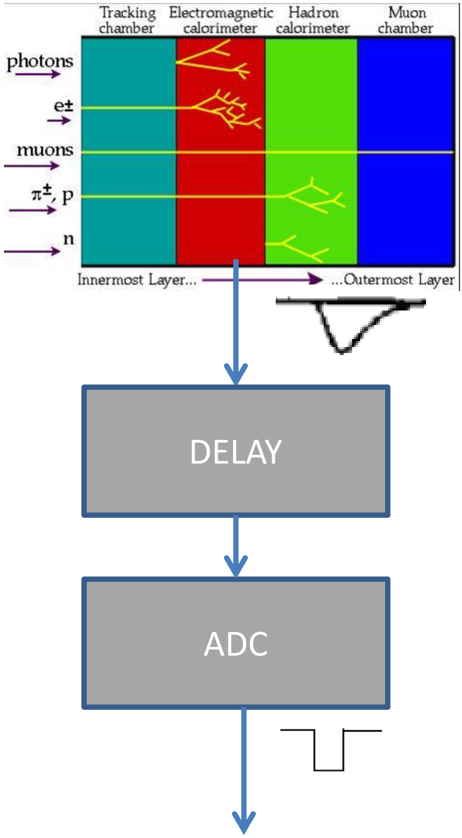
- Trigger system
  - Electronic devices: ADC, Discriminator, FIFO
  - BUSY and Dead time
  - Derandomisation/Pipelines
  - Collider mode
  - Multilevel trigger
  - High Level Trigger (HLT)

Simple Trigger/DAQ example

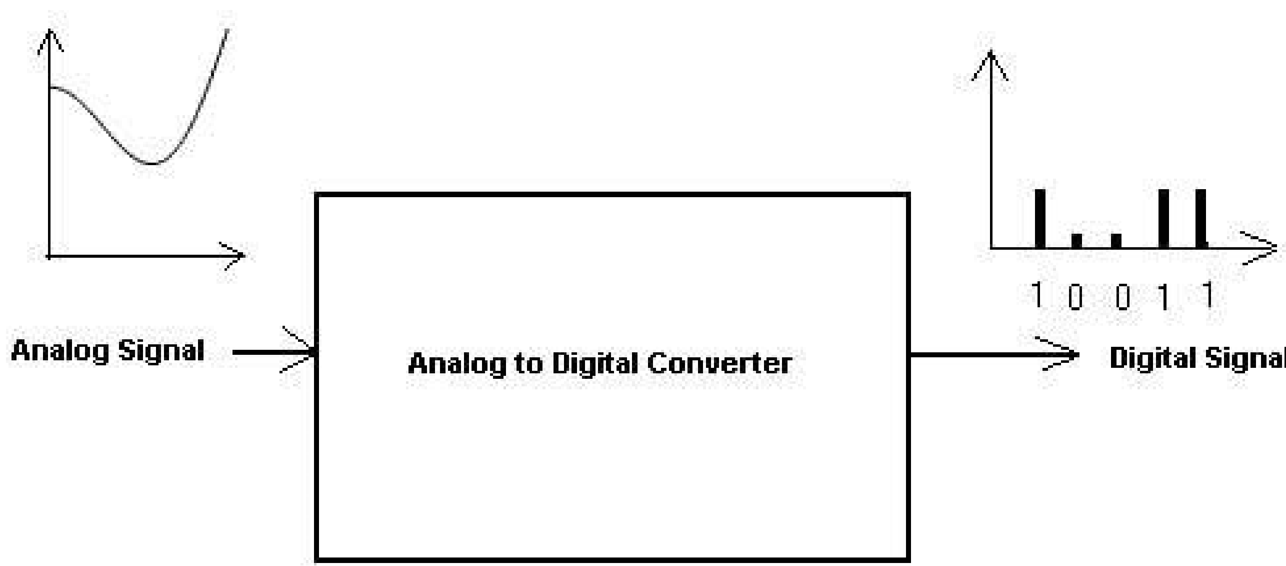


Detector: Calorimeter

Simple Trigger/DAQ example



Detector: Calorimeter



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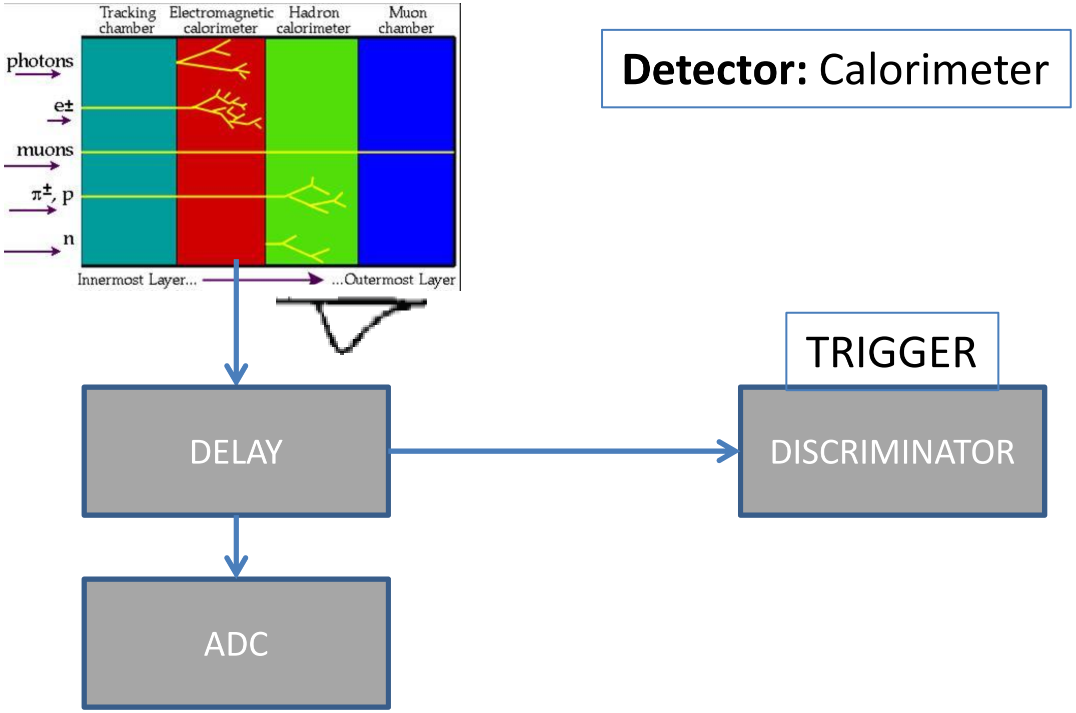

Simple Trigger/DAQ example

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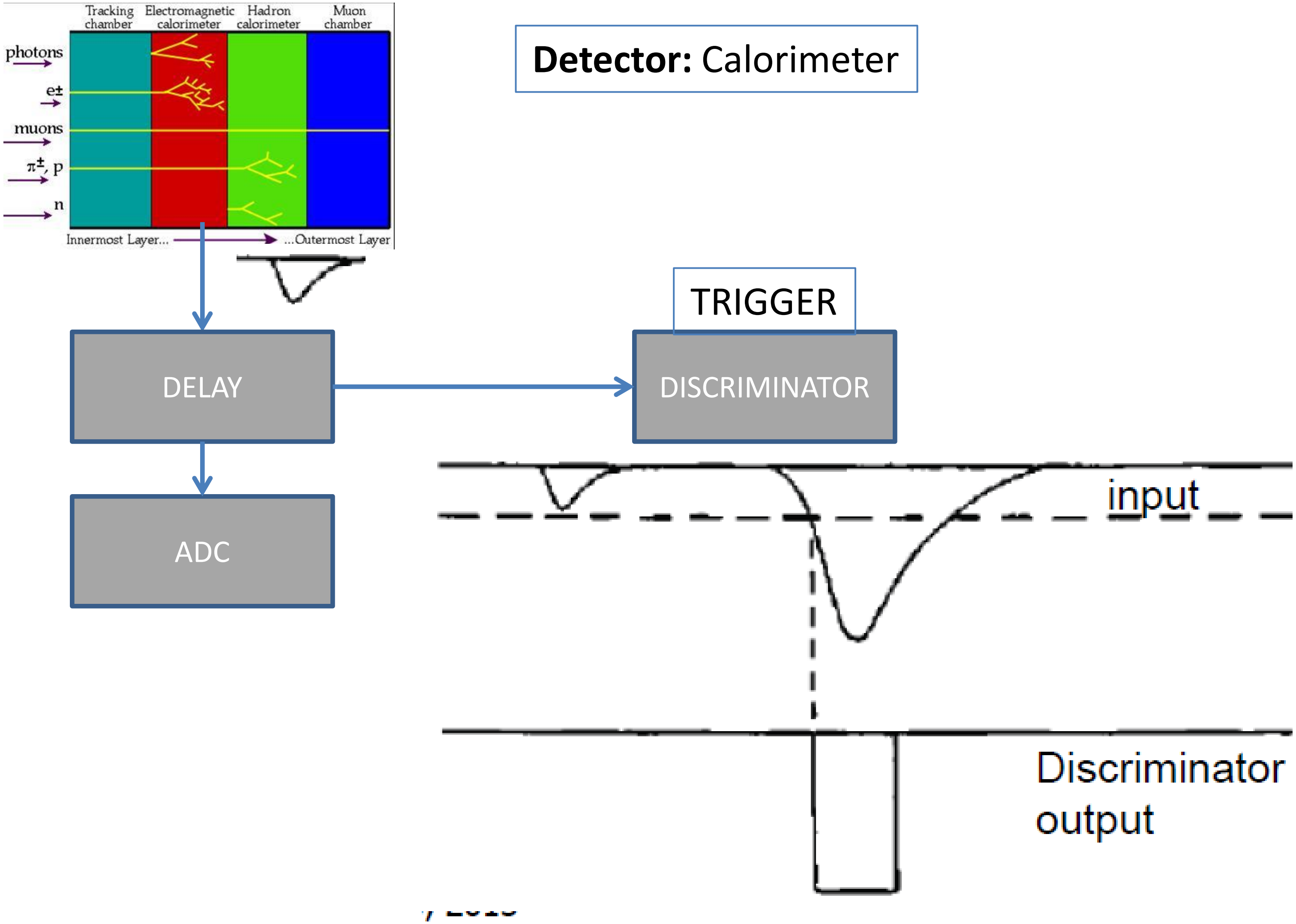
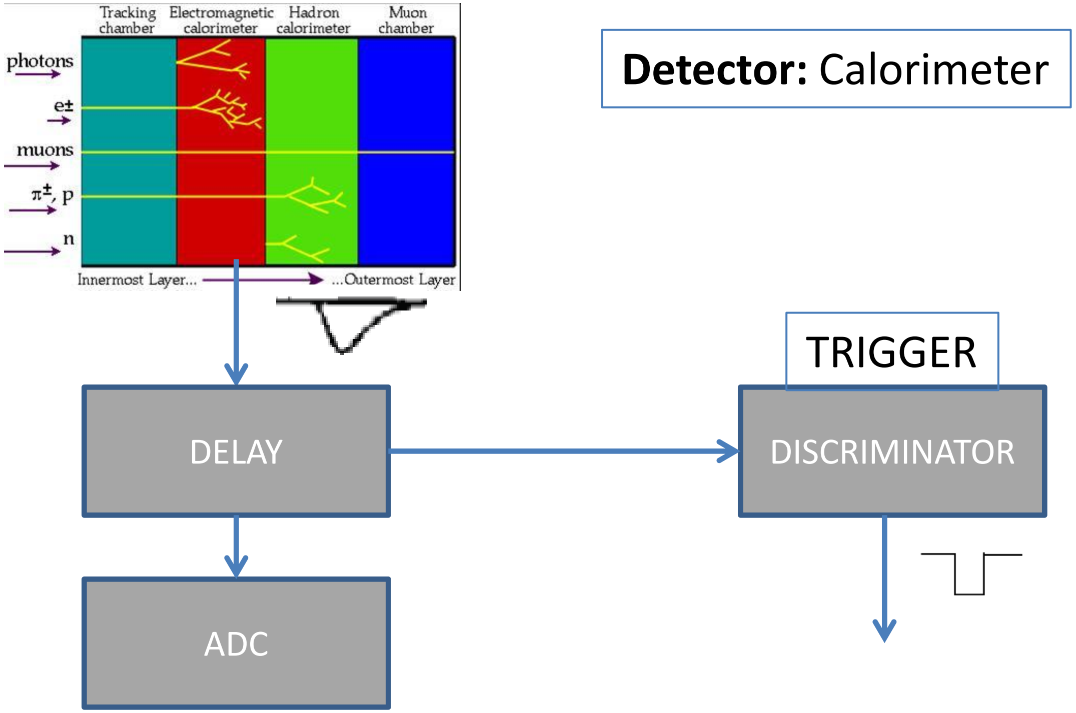


Simple Trigger/DAQ example



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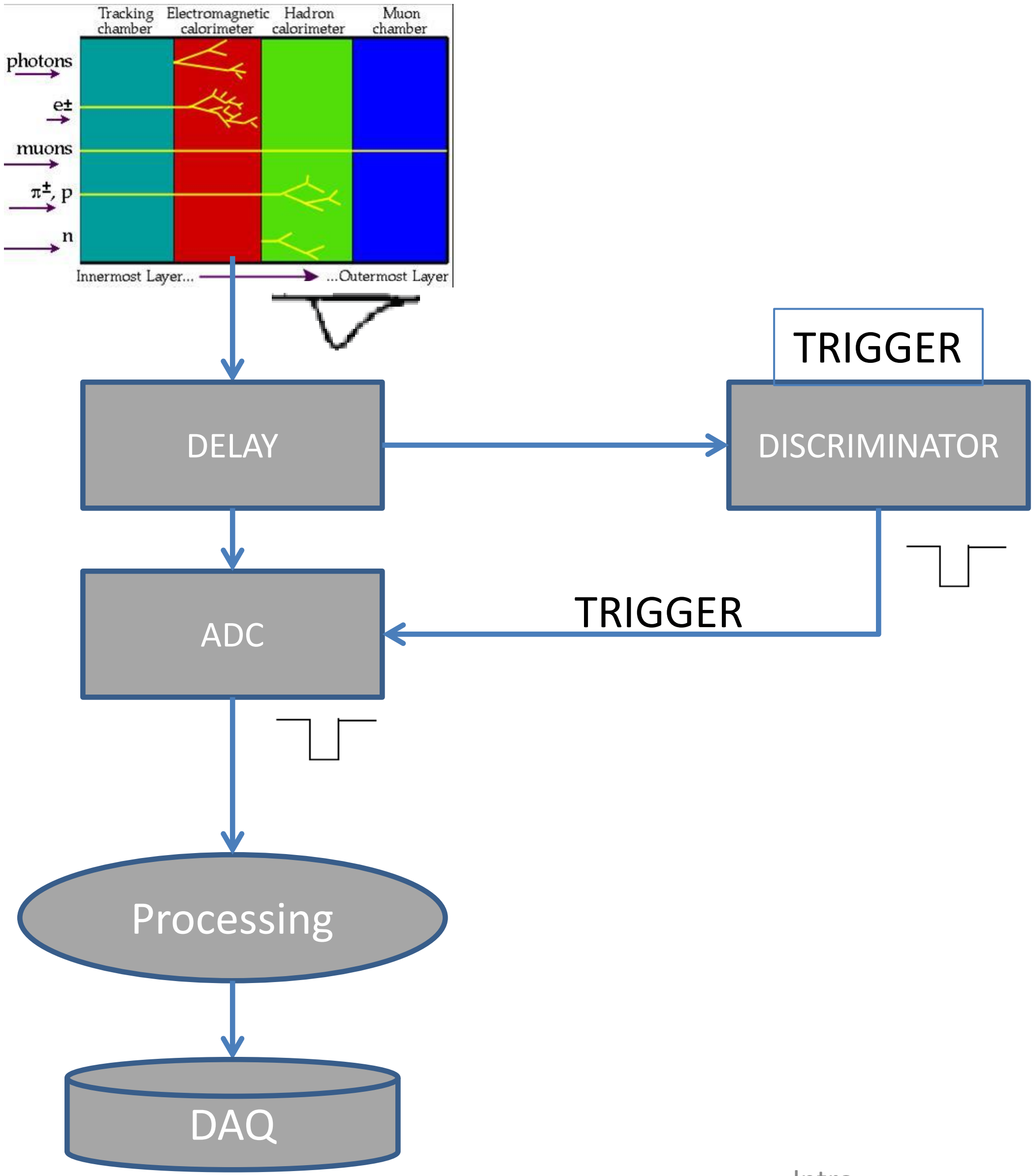

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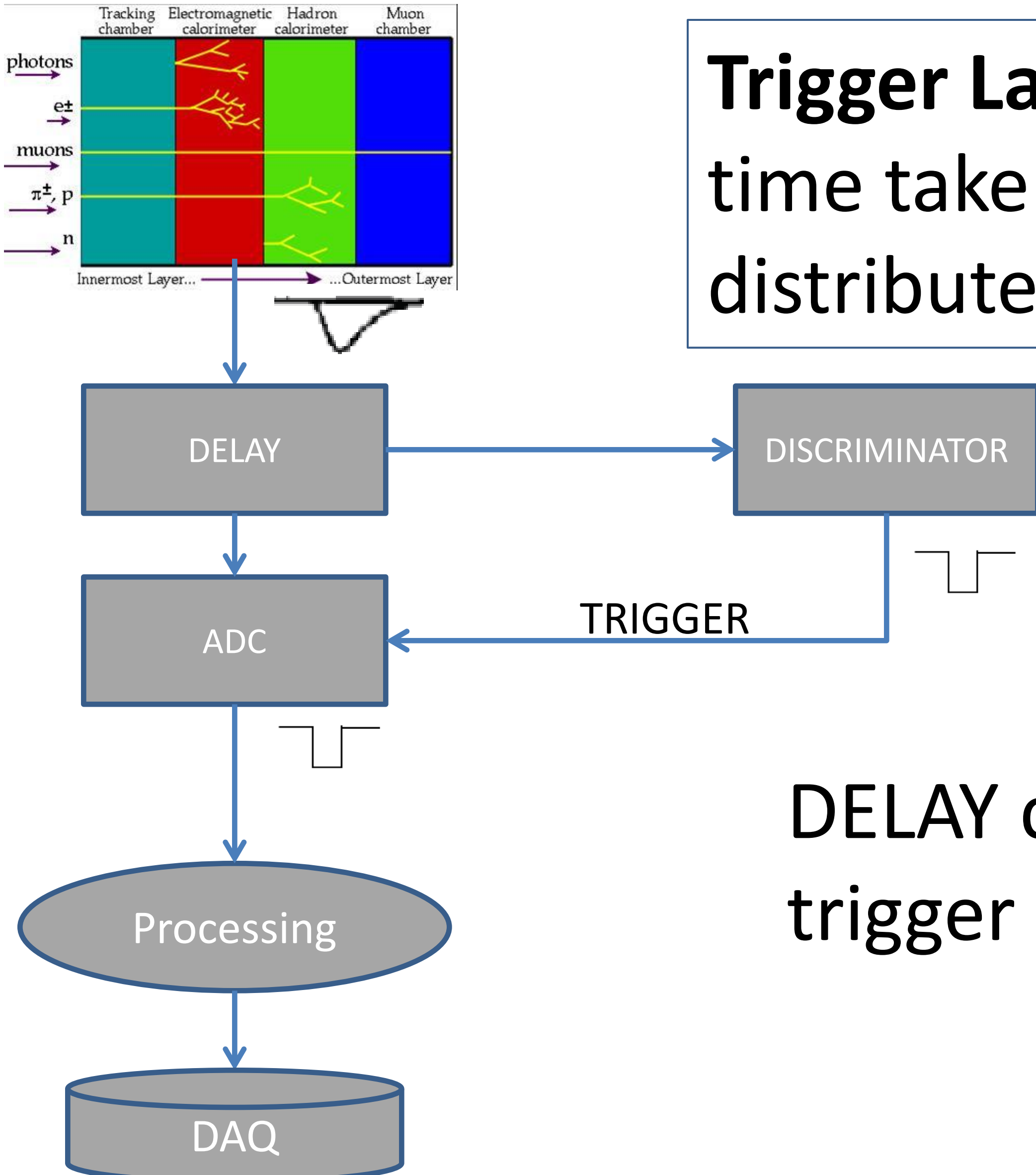
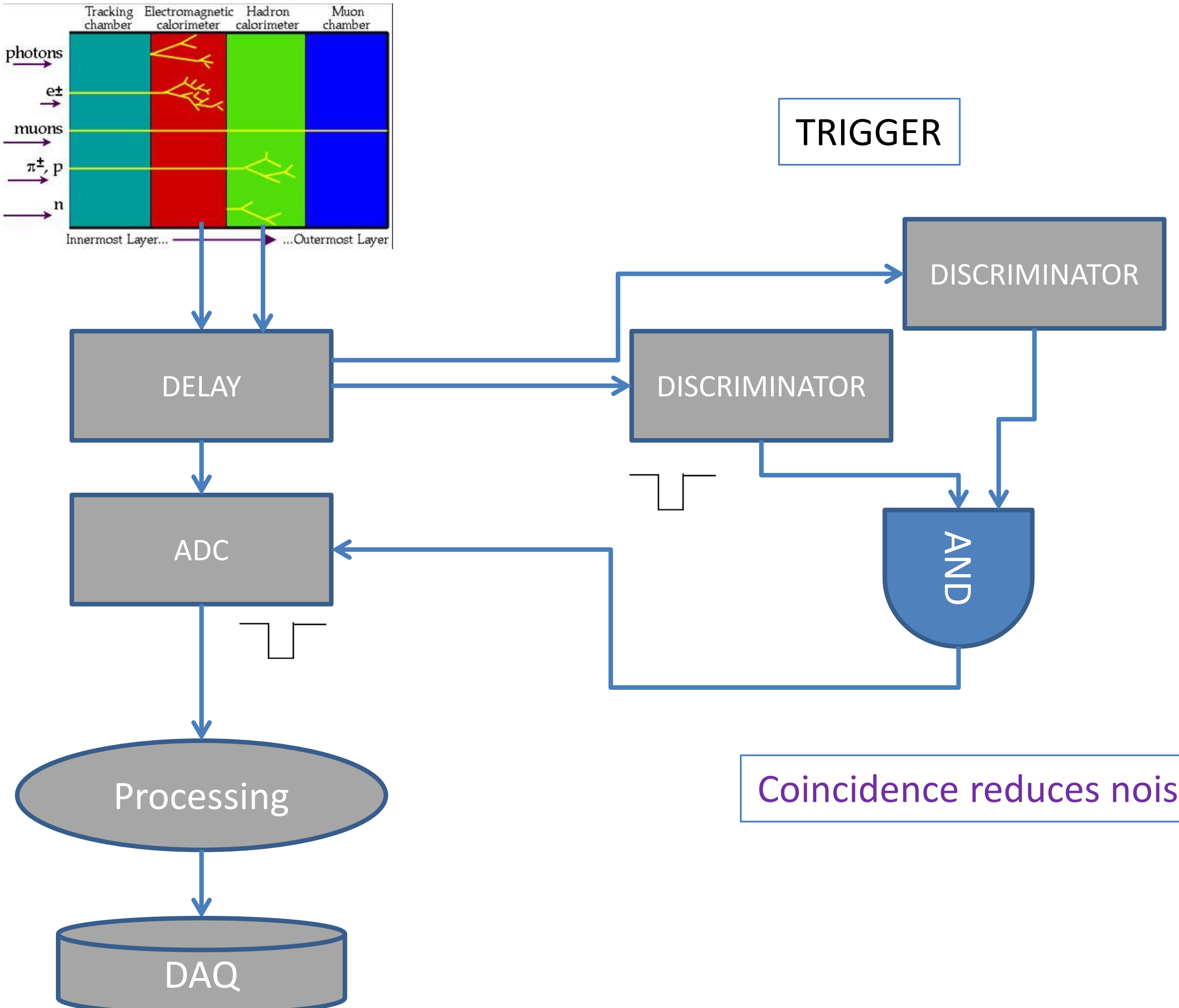


Trigger Latency:
time taken to form and distribute the trigger decision.

DELAY compensates for trigger latency.

Simple Trigger/DAQ example



Coincidence reduces noise

Coincidences

- Given that the pulses we deal with are very short (typically 20-50 ns) the use of coincidences has a dramatic effect on reducing background noise.
- Conversely, the noise from an OR circuit can become very large, and each element has to be monitored carefully.

The accidental coincidence rate for a pair of counters is given by

$$R_{\mathrm{acc}} = 2 R_1 R_2 \tau_{\mathrm{res}}$$

where R_1, R_2 are the rates of the two counters, and τ_{res} is the width of the pulse.

EXAMPLE

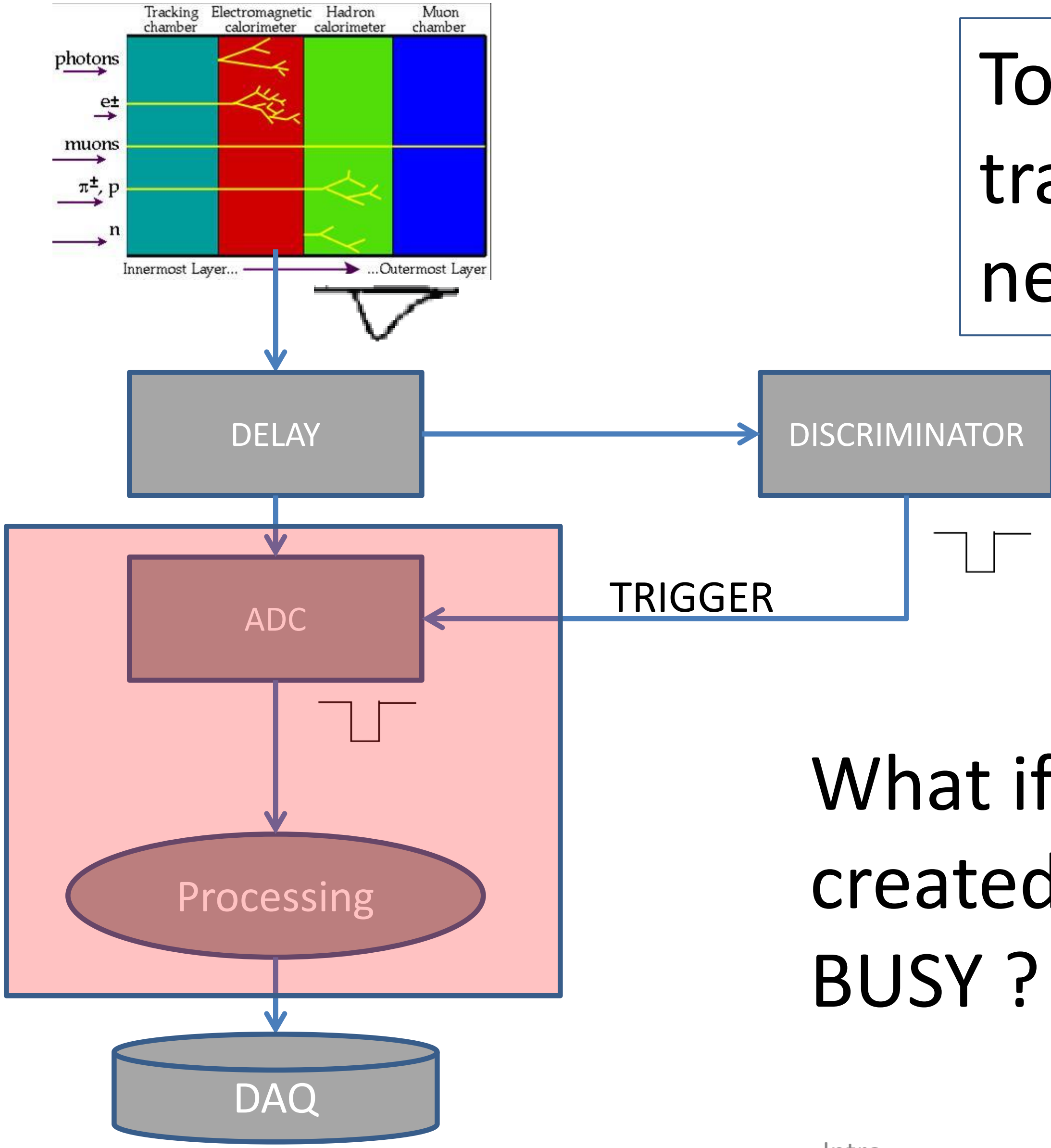
Suppose we have two counters giving 25 ns pulses and with random rates of 1000 Hz and 1500 Hz respectively (quite noisy).

The output of a coincidence would give

$$2 \times 1000 \times 1500 \times 25 \times 10^{-9} = 0.075 \text{ Hz}$$

(note that this calculation assumes the counters can fire in a continuous space. Although the same principle applies, a slightly different calculation is needed when the counters can only fire at fixed times, as for example in a clocked collider experiment.

Simple Trigger/DAQ example

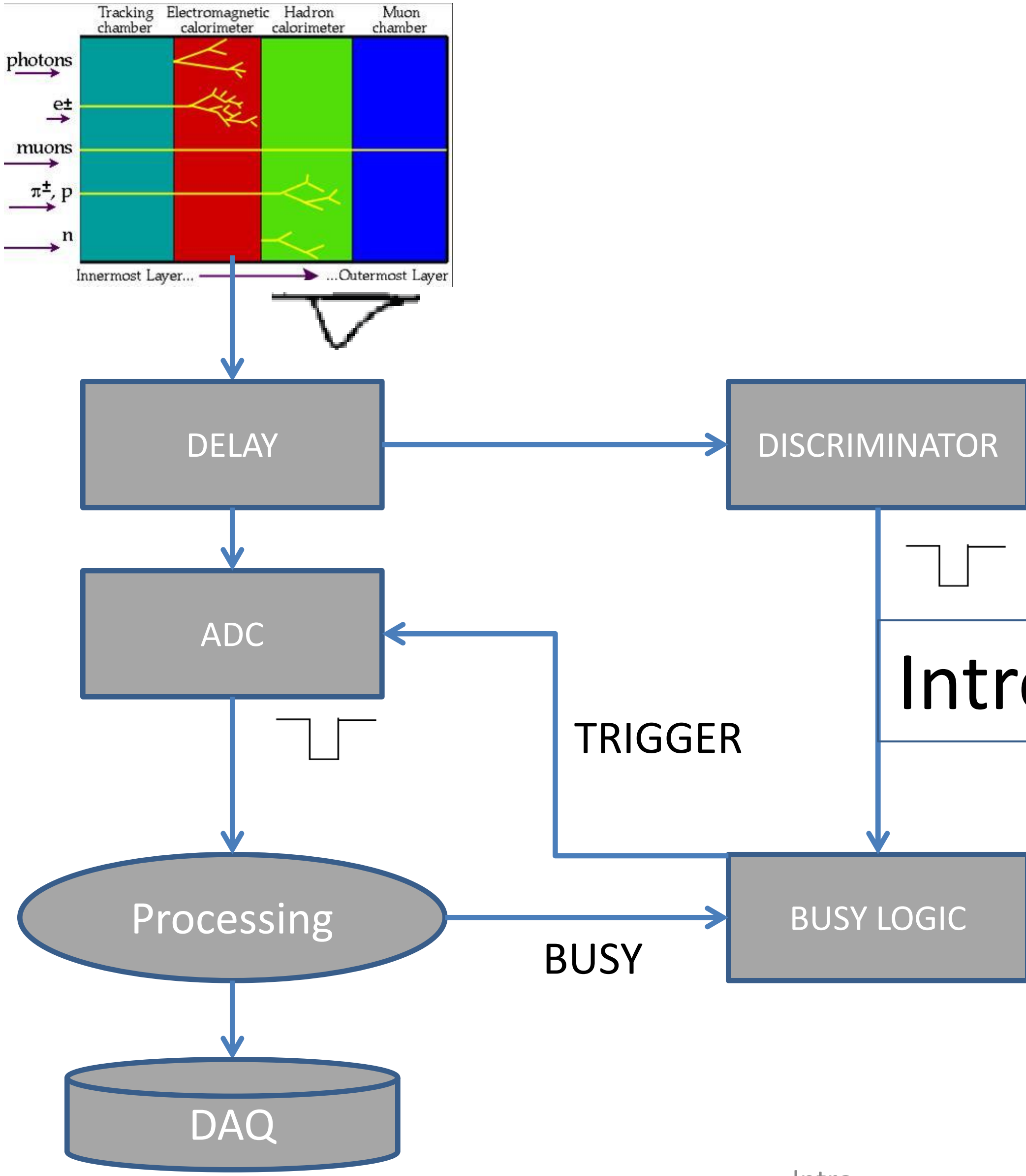


To make ADC and transfer digital data needs some time.

System can NOT process next event: system is **BUSY**

What if trigger is created when system is BUSY ?

Simple Trigger/DAQ example

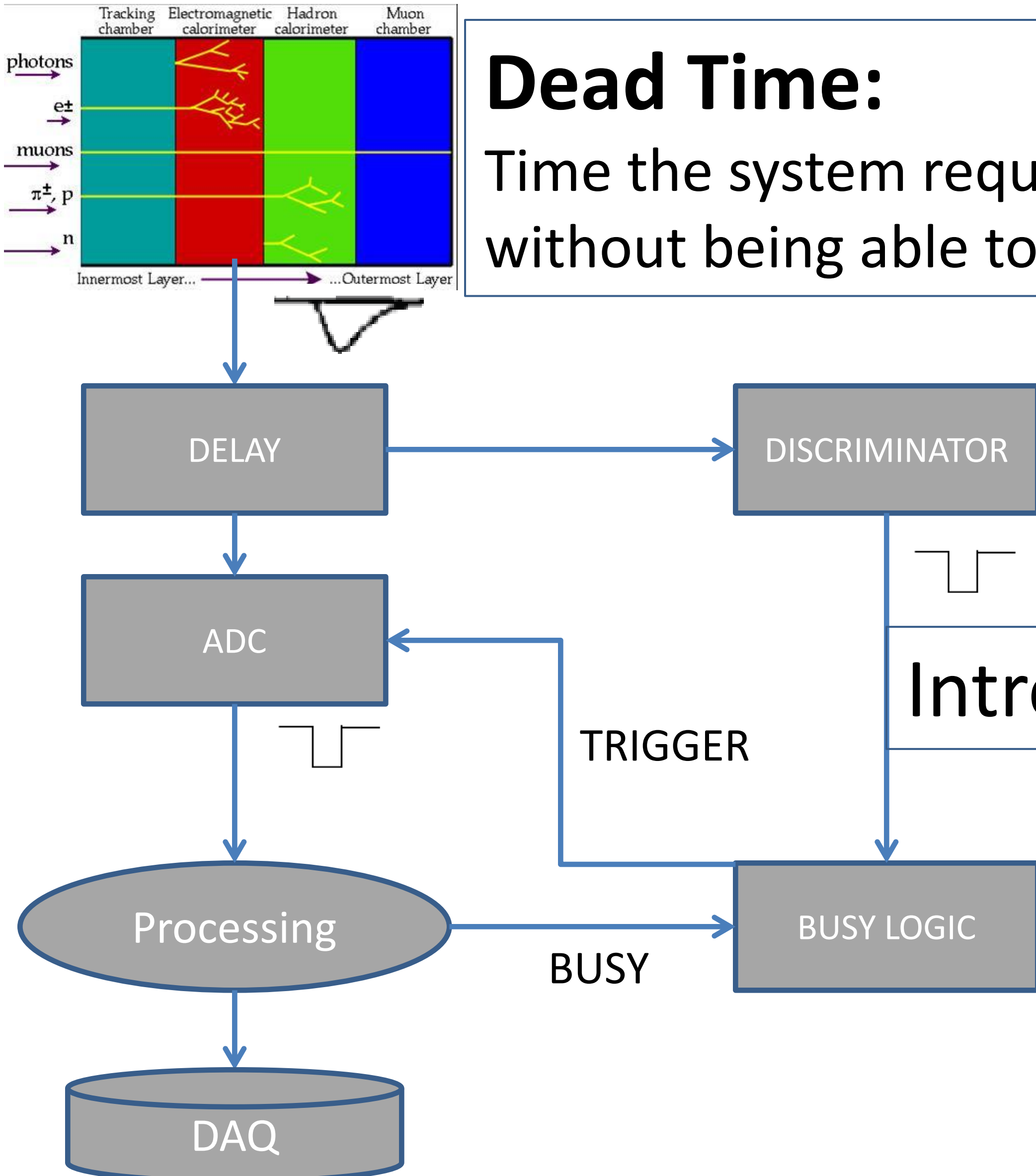


Introduce BUSY logic

Simple Trigger/DAQ example

Dead Time:

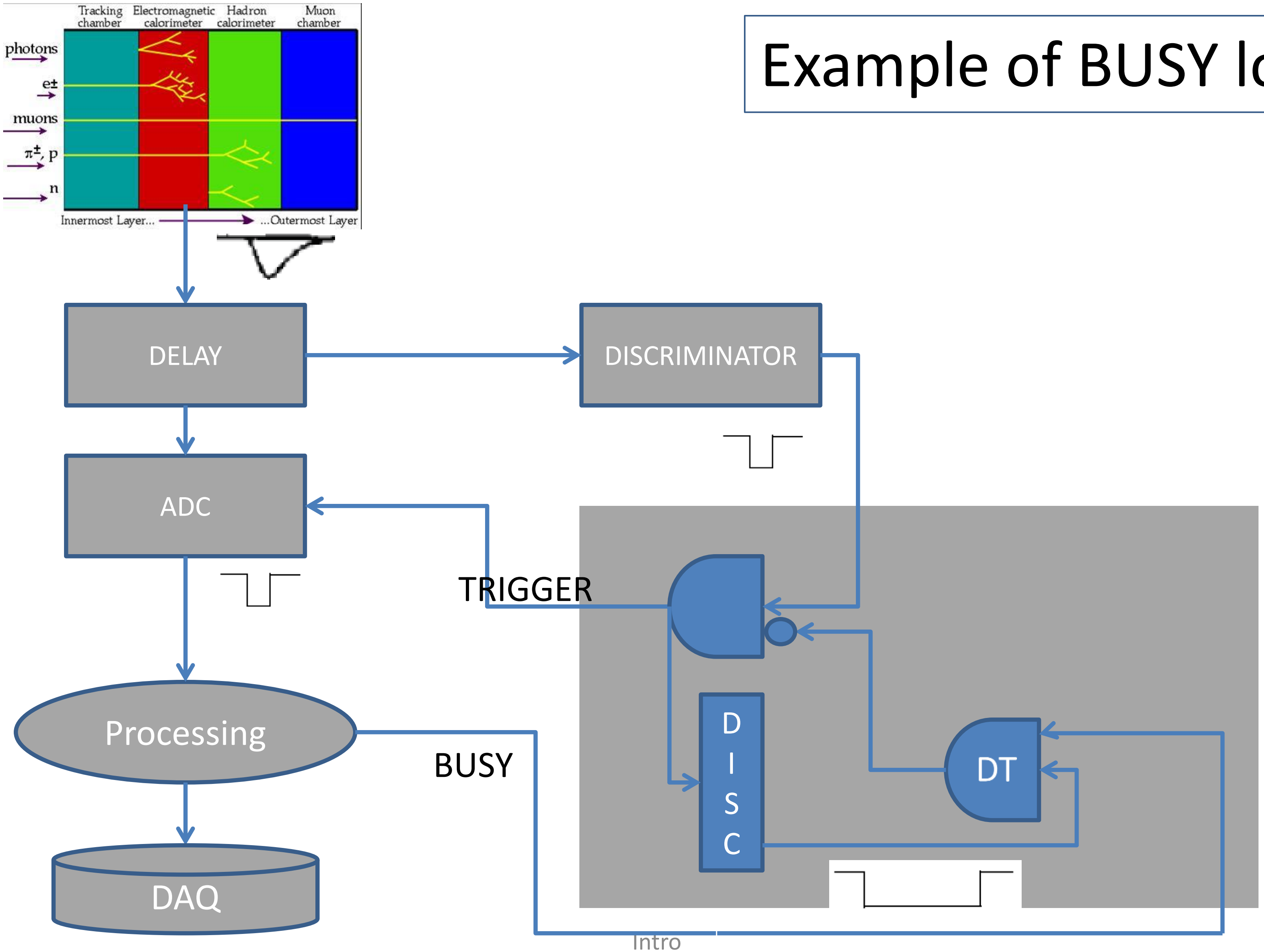
Time the system requires to process an event without being able to handle other triggers



Introduce BUSY logic

Simple Trigger/DAQ example

Example of BUSY logic



Deadtime and Efficiency

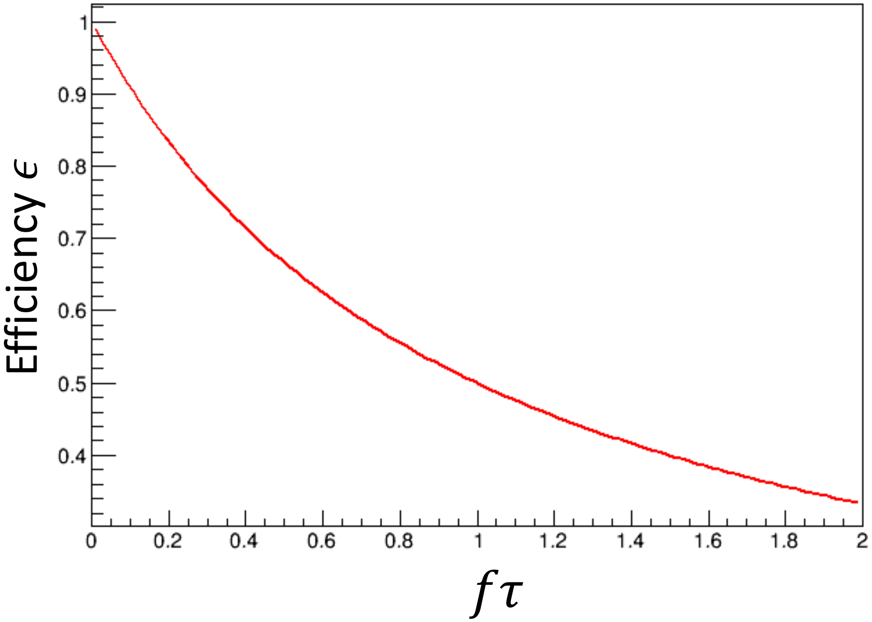
- Definitions:
  - Interaction rate: f
  - Dead time: τ
- Frequency of successful triggers, e.g. DAQ rate f_D:

$$f_D = f(1 - f_D\tau)$$

$$f_D = \frac{f}{1 + f\tau}$$

- Efficiency

$$\varepsilon = \frac{f_D}{f} = \frac{1}{1 + f\tau}$$

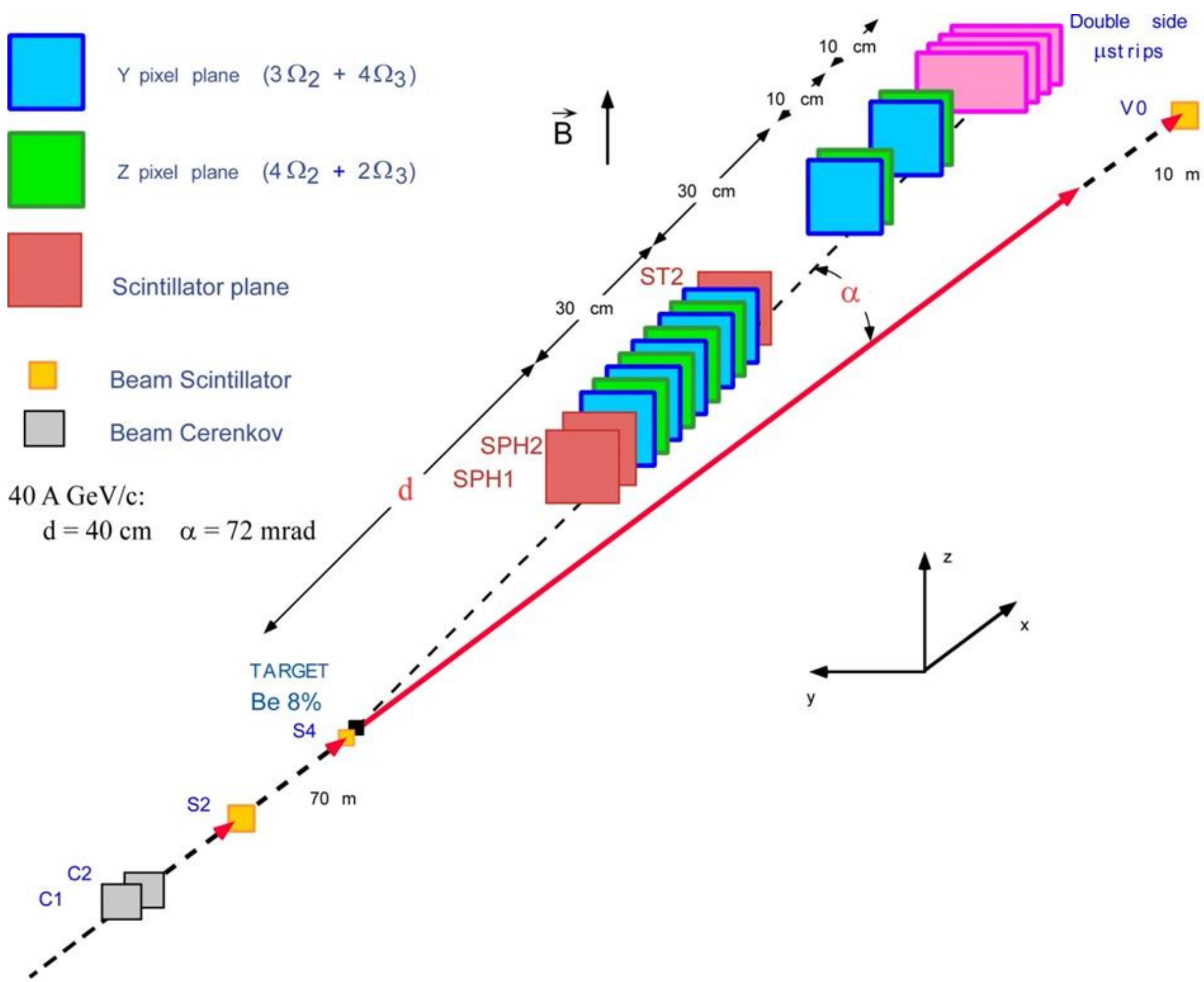


NA57 example

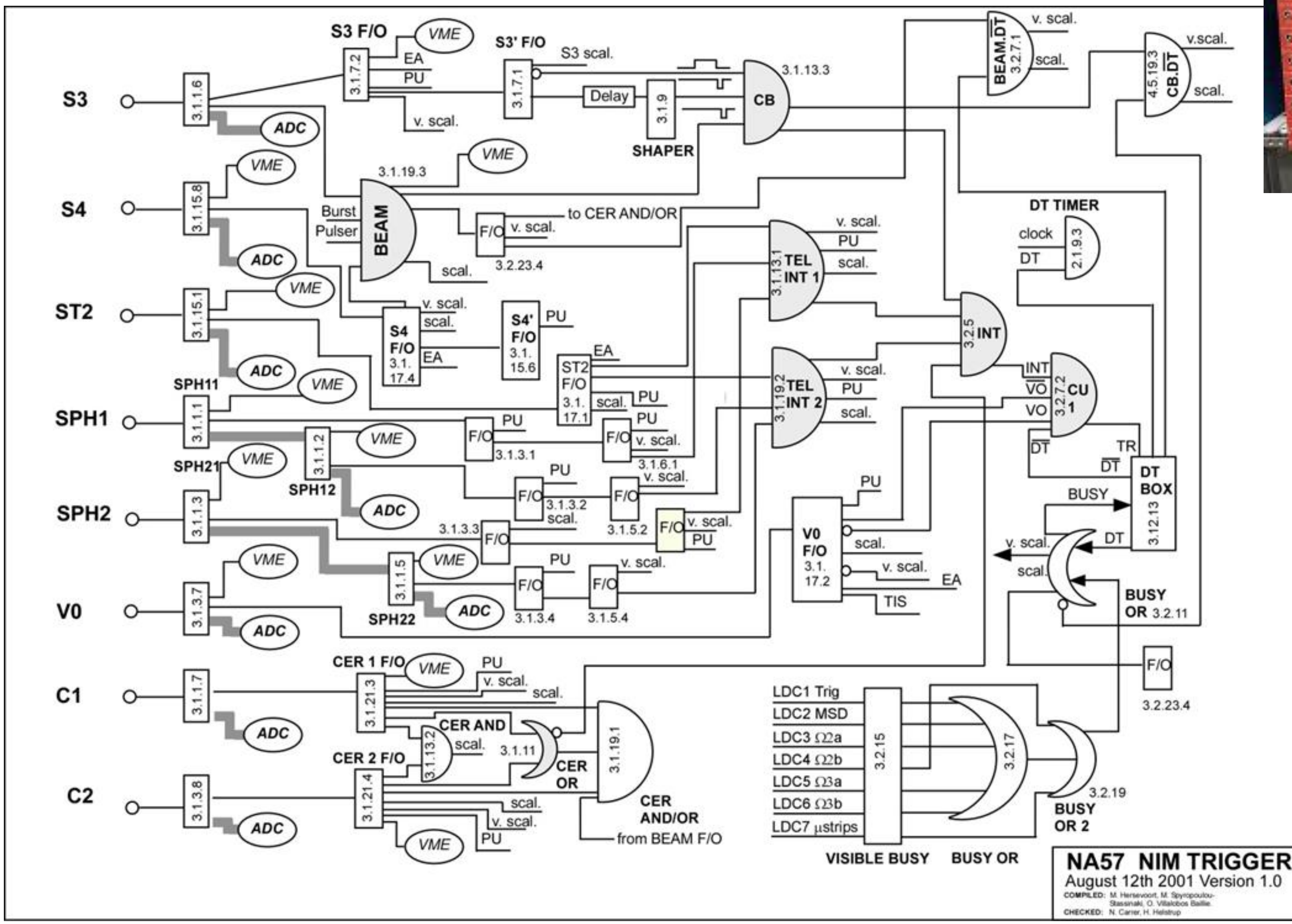
NA57 example

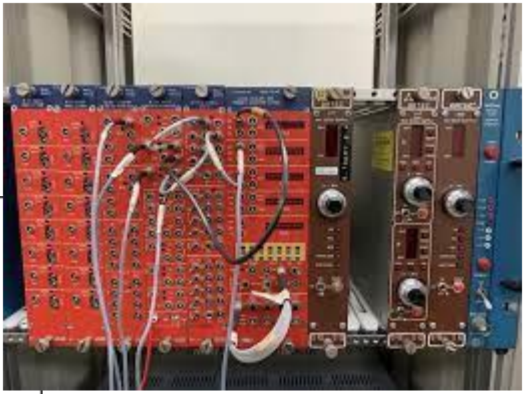
- The NA57 experiment, a heavy ion experiment designed to measure strange particle production in pBe and Pb-Pb collisions, illustrates many of the ideas we have introduced so far.
- The experiment ran from 1998 to 2001. It was used to test many ideas later implemented in the ALICE experiment, and represents a transition from the “old-style” approach with modular NIM based electronics to purpose-built triggers.
- In the pBe mode (shown) the trigger had to select events where at least two tracks entered the Silicon telescope. This was done by looking at pulse heights in two scintillators, and requiring both to be consistent with two tracks. (Requiring this in one only would not be sufficient owing to the long Landau tail in the pulse height distribution.)
- The beam rate was about 10^7 protons per SPS burst, and the trigger rate about 1800 per burst.
- Trigger was implemented in two ways:
  - Nuclear Instrument Module (NIM) based trigger
  - Electronic board

NA57 example

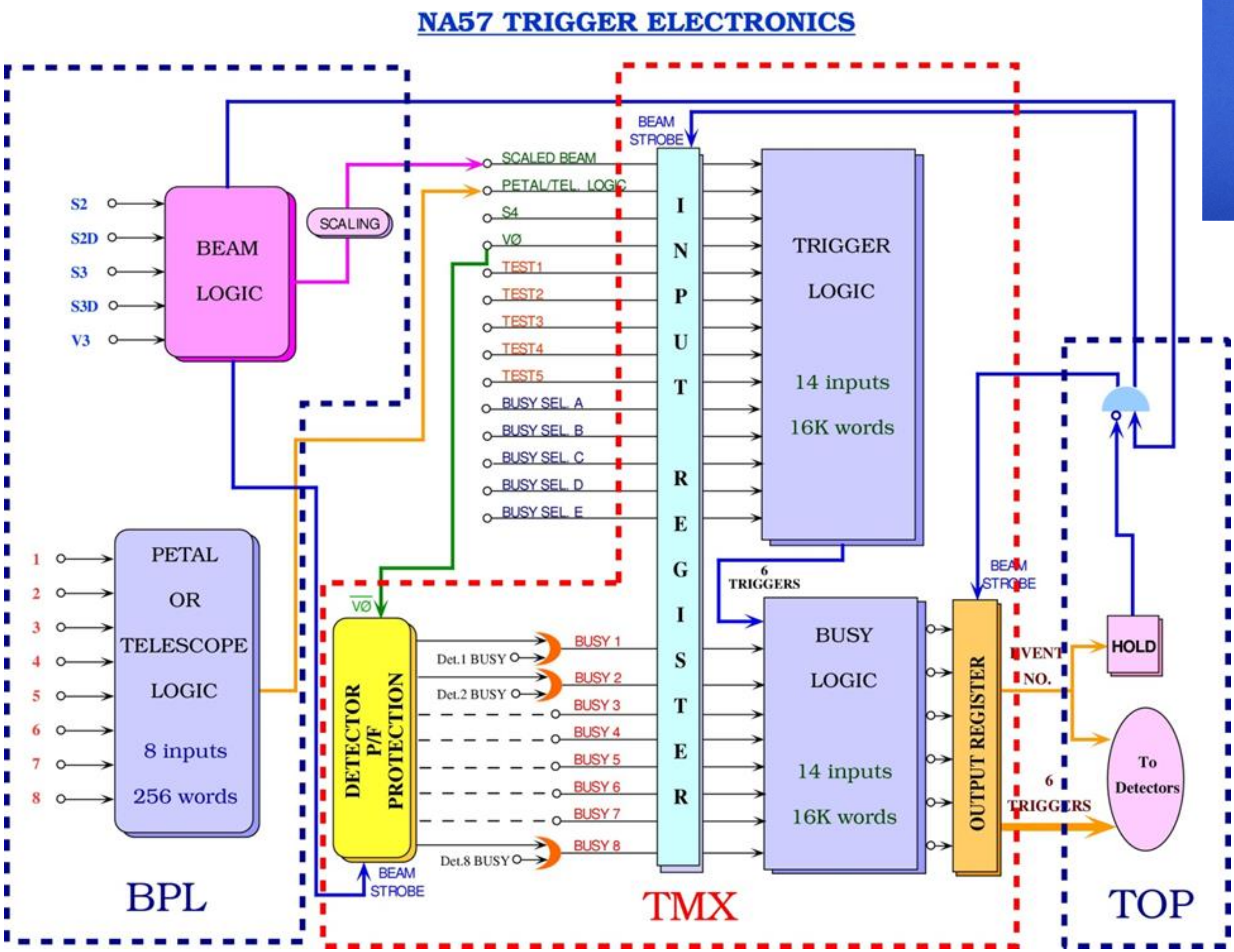


NA57 Trigger Logic NIM



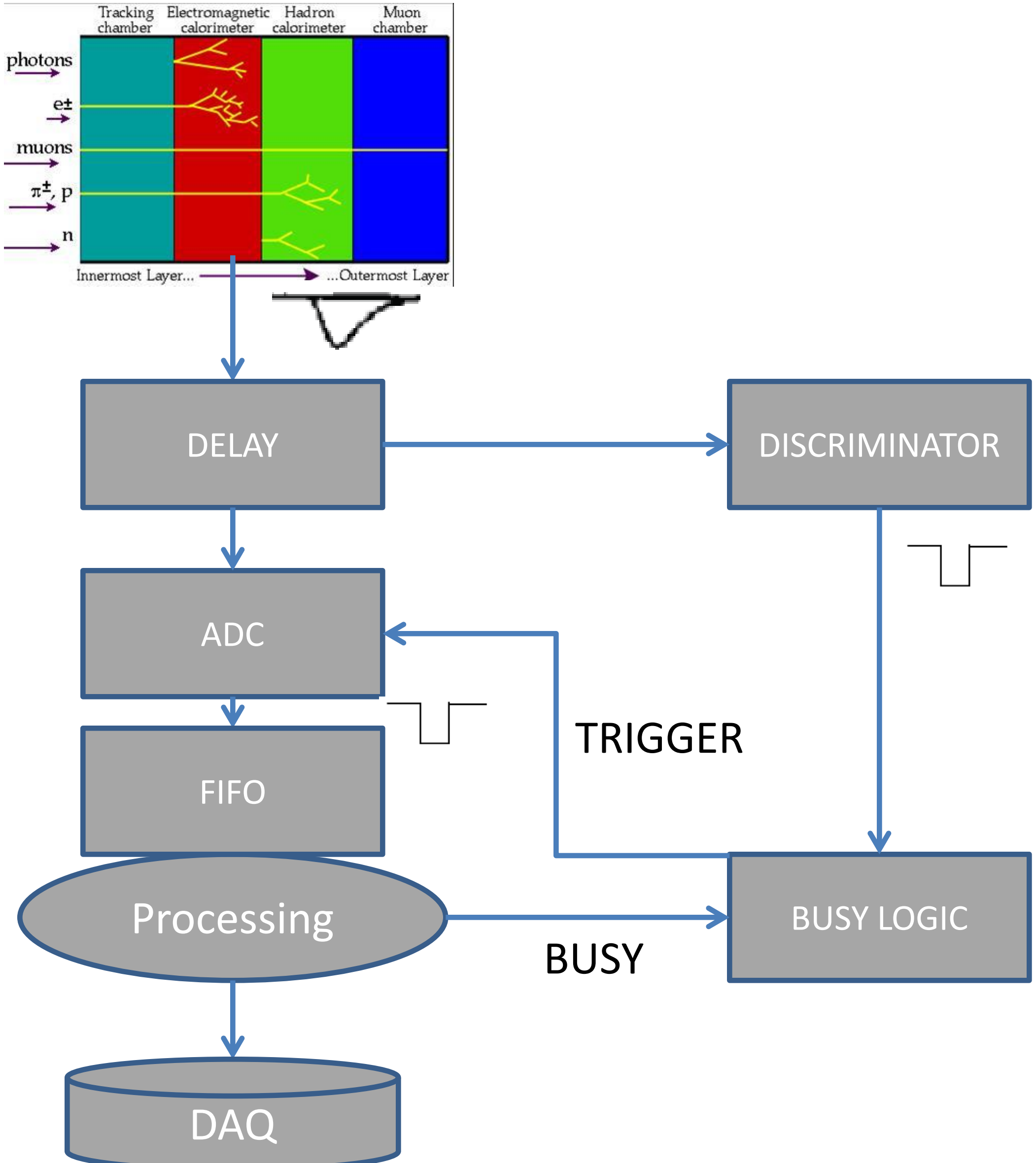


NA57 Trigger Logic VME



VME =
Versa
Module
Europe
= electronic bus standard

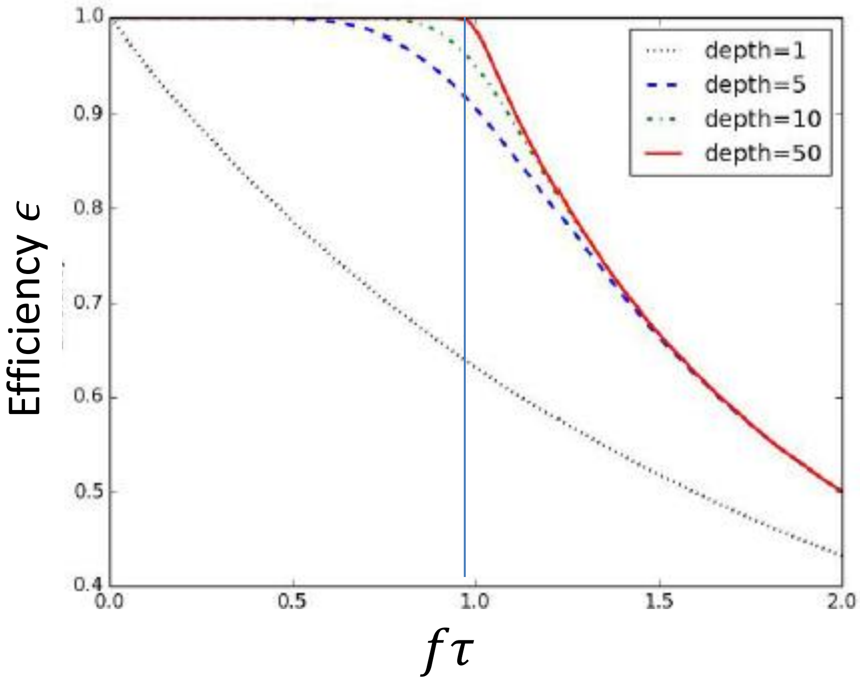
Simple Trigger/DAQ example

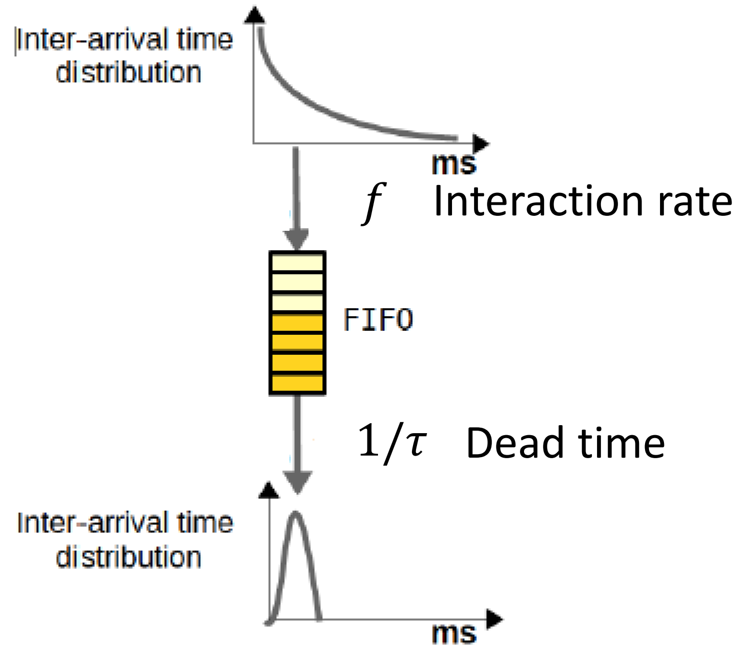


Derandomisation:
Introduce buffers which decouple the data production from the data processing: better performance

FIFO:
First In First Out buffer

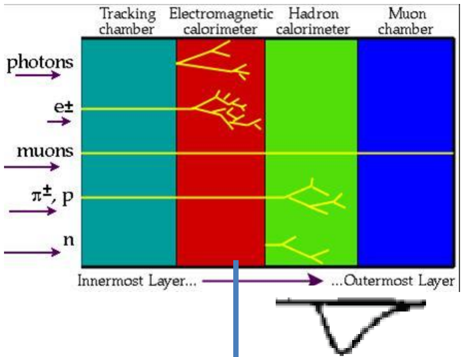
Derandomisation



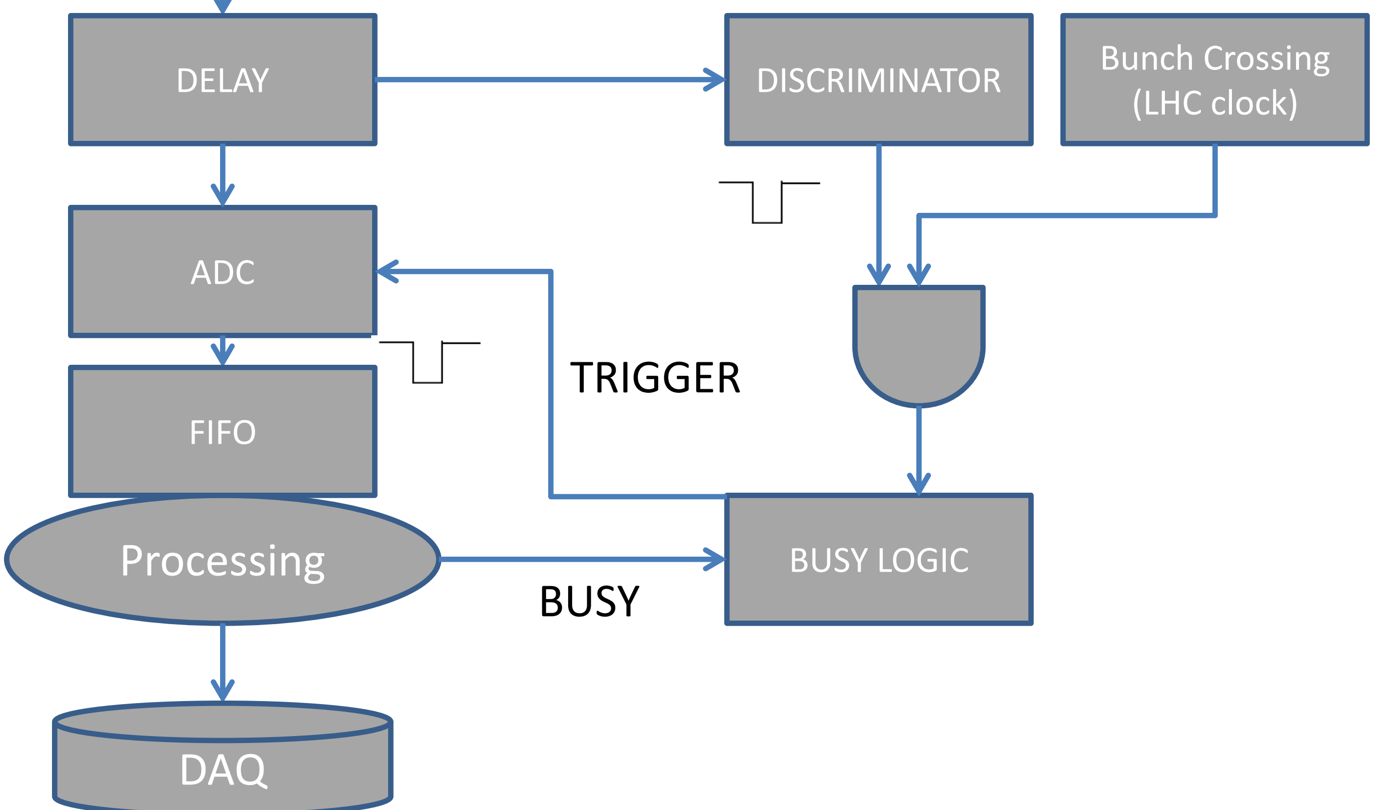


- Efficiency versus ratio of interaction rate to DAQ rate for different FIFO length (depth):
  - $f\tau > 1$:short FIFO
  - $f\tau \ll 1$: too long FIFO (over designed)
  - $f\tau{\sim}1$:optimal FIFO

Simple Trigger/DAQ Collider mode

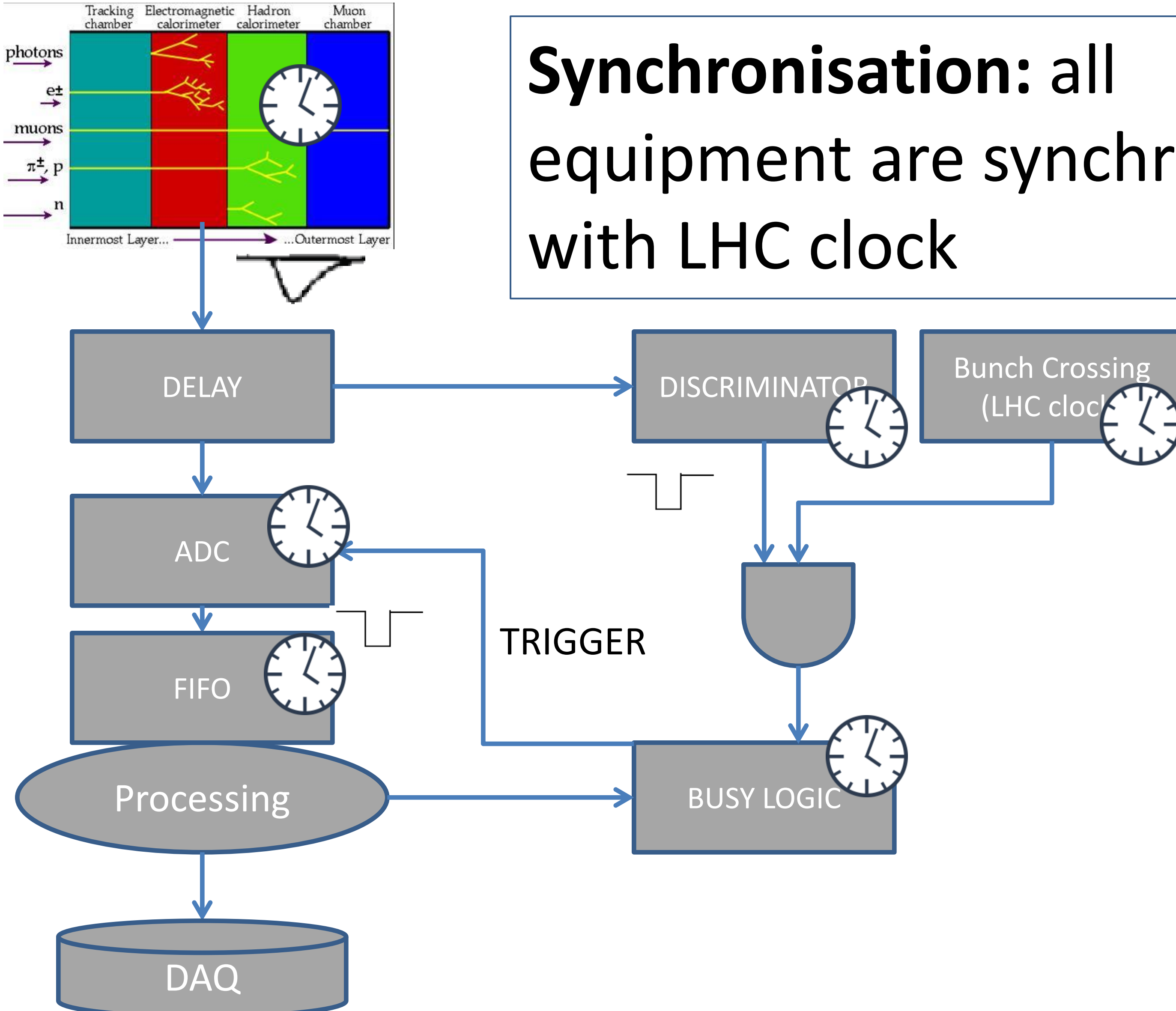


Particle collisions are synchronous. Trigger look only at non empty BCs

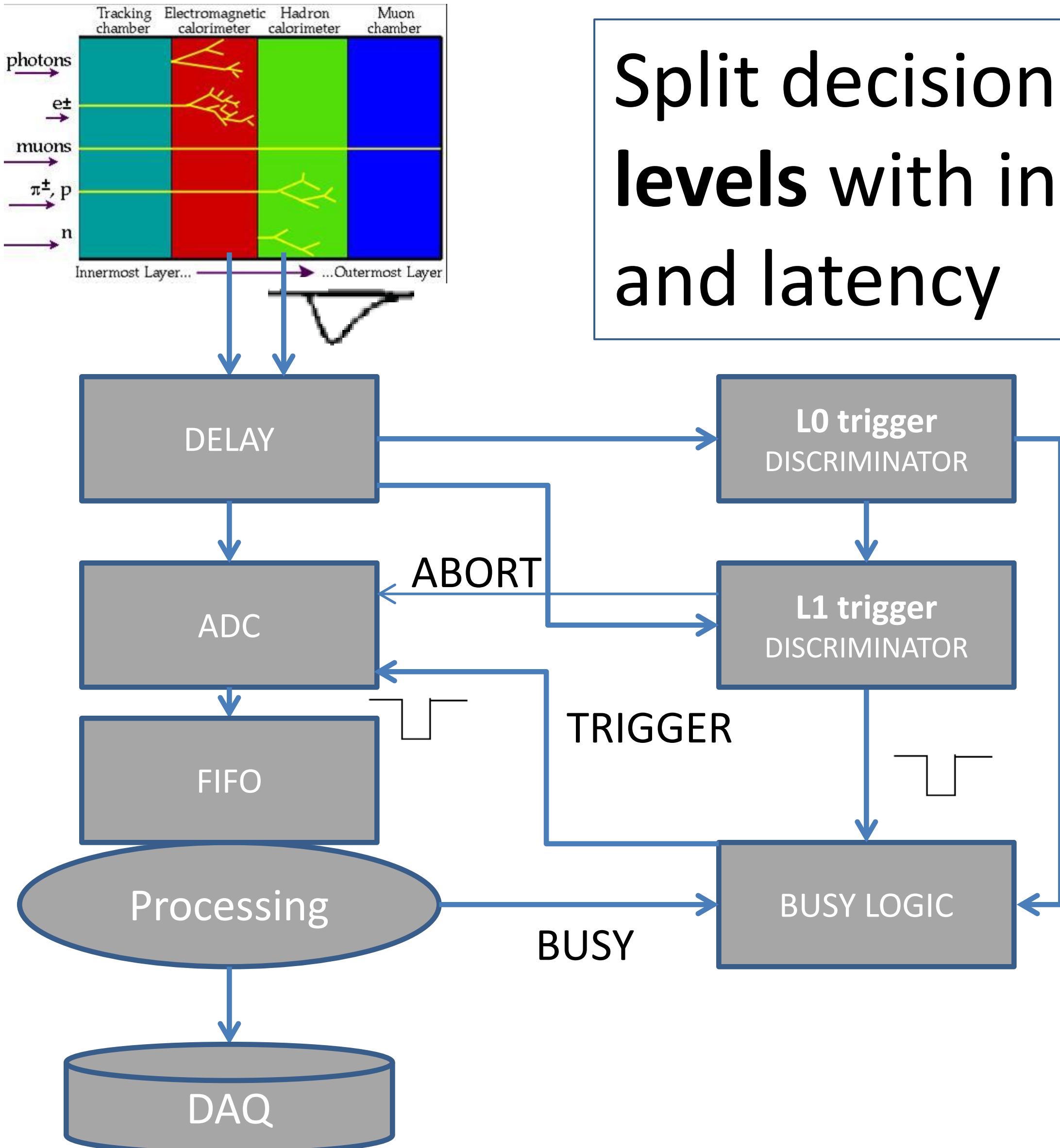


Simple Trigger/DAQ Collider mode

Synchronisation: all equipment are synchronised with LHC clock



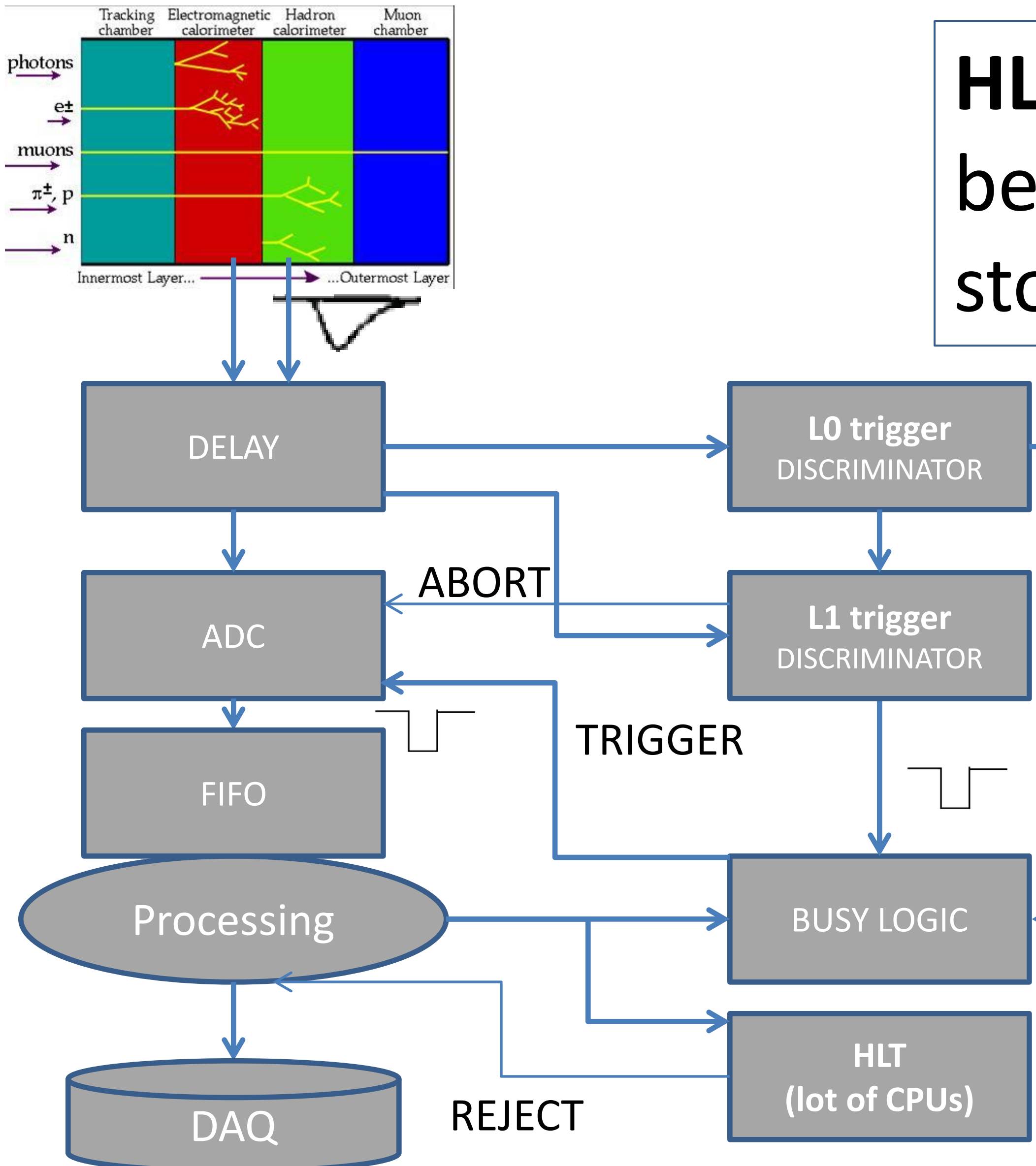
Multilevel trigger



Split decision to several **trigger levels** with increasing complexity and latency

All levels can reject events

High Level Trigger (HLT)

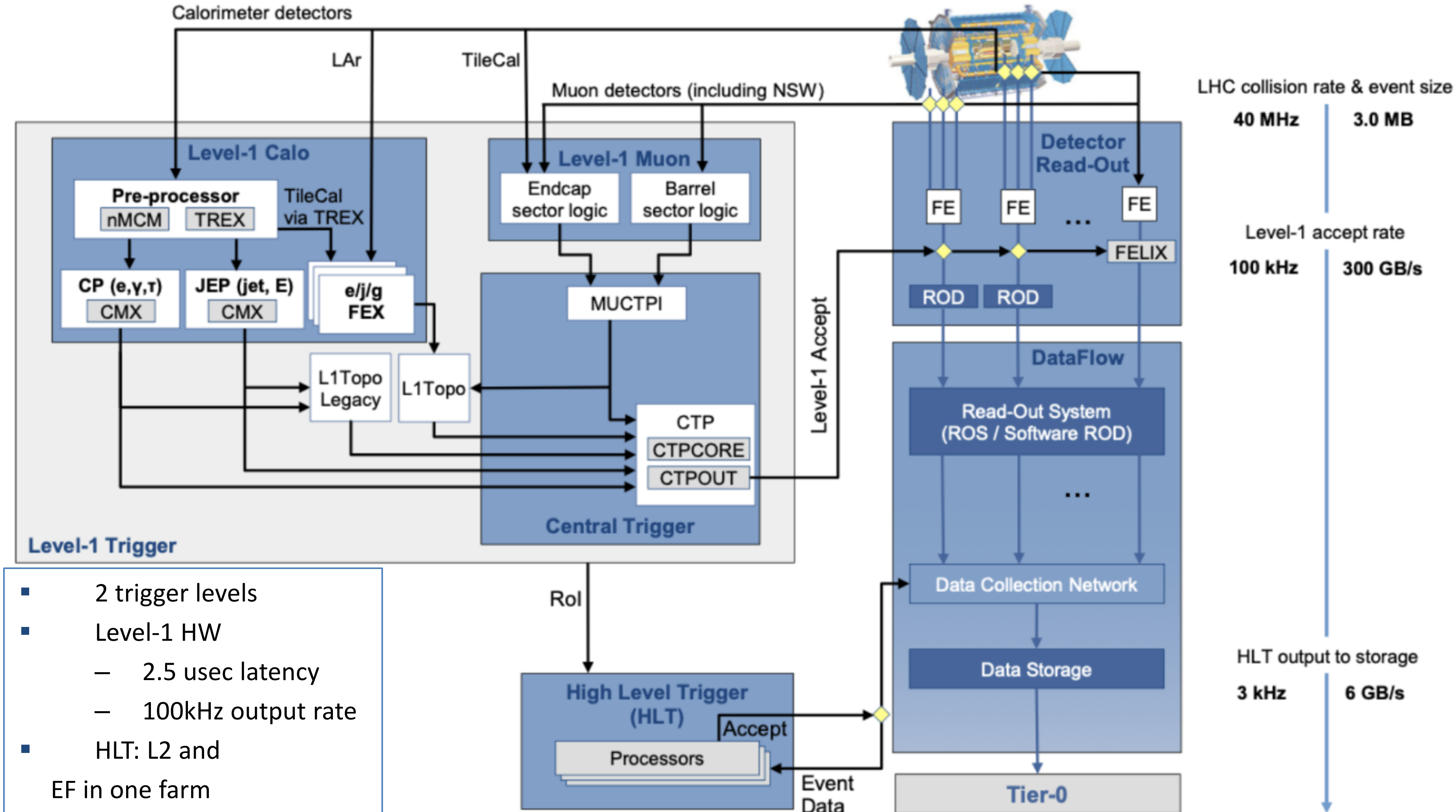


HLT: trigger level between readout and storage.

Fully software (CPU farm) trigger.

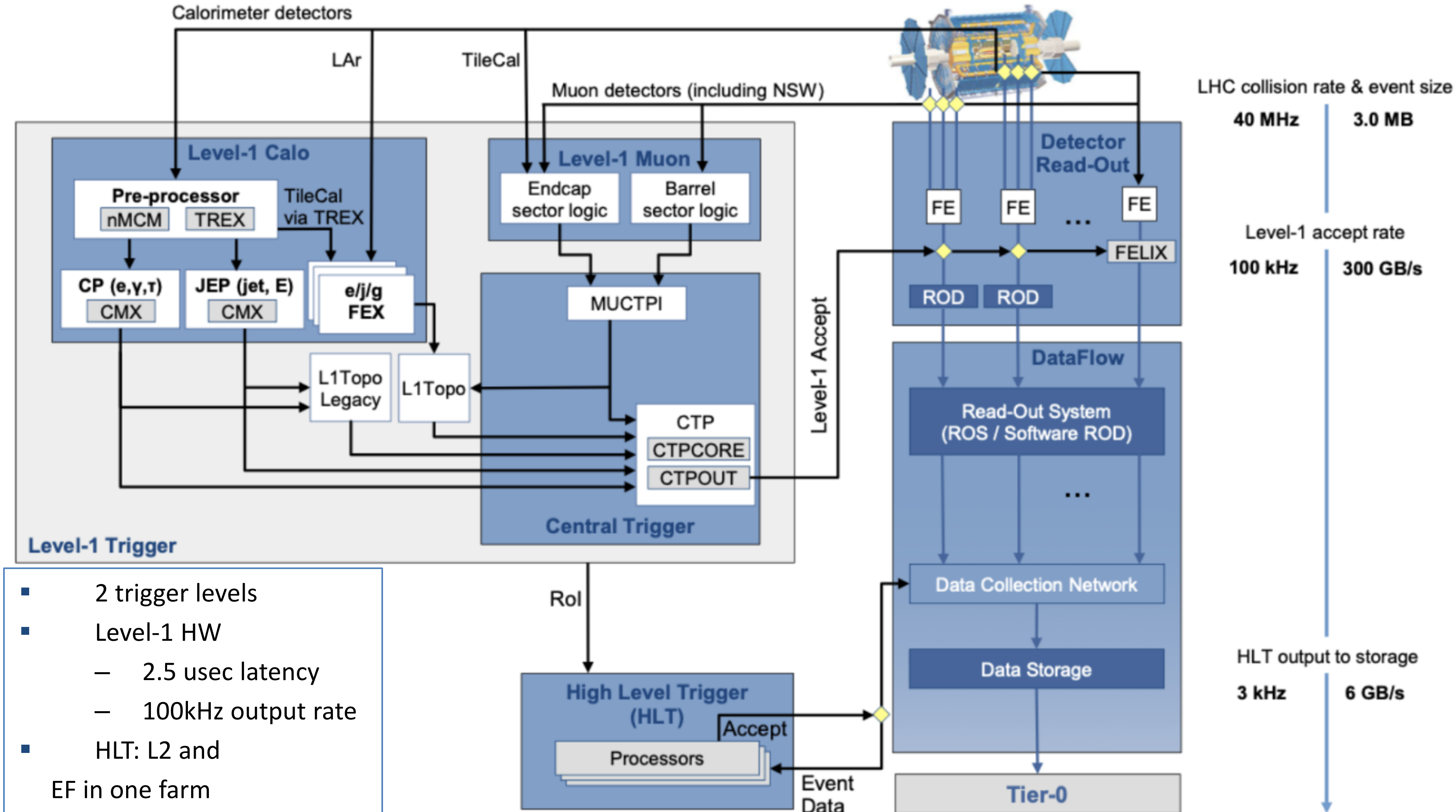
Has access to full event.

ATLAS Trigger/DAQ system



- 2 trigger levels
- Level-1 HW
  - 2.5 usec latency
  - 100kHz output rate
- HLT: L2 and EF in one farm
- Output rate: ~ 1 kHz
- Event size: 1.5-2 MB

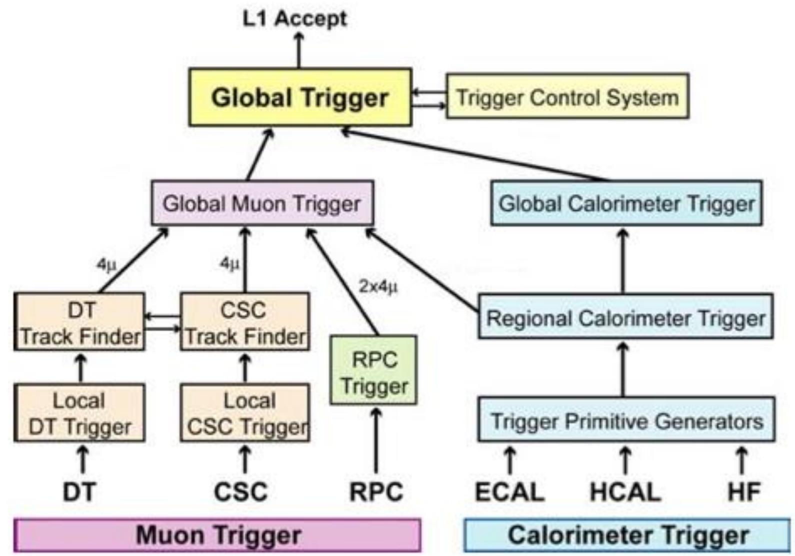
ATLAS Trigger/DAQ system

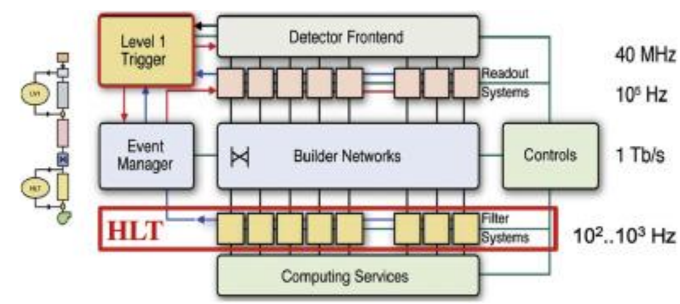


- 2 trigger levels
- Level-1 HW
  - 2.5 usec latency
  - 100kHz output rate
- HLT: L2 and EF in one farm
- Output rate: ~ 1 kHz
- Event size: 1.5-2 MB

CMS Trigger/DAQ system

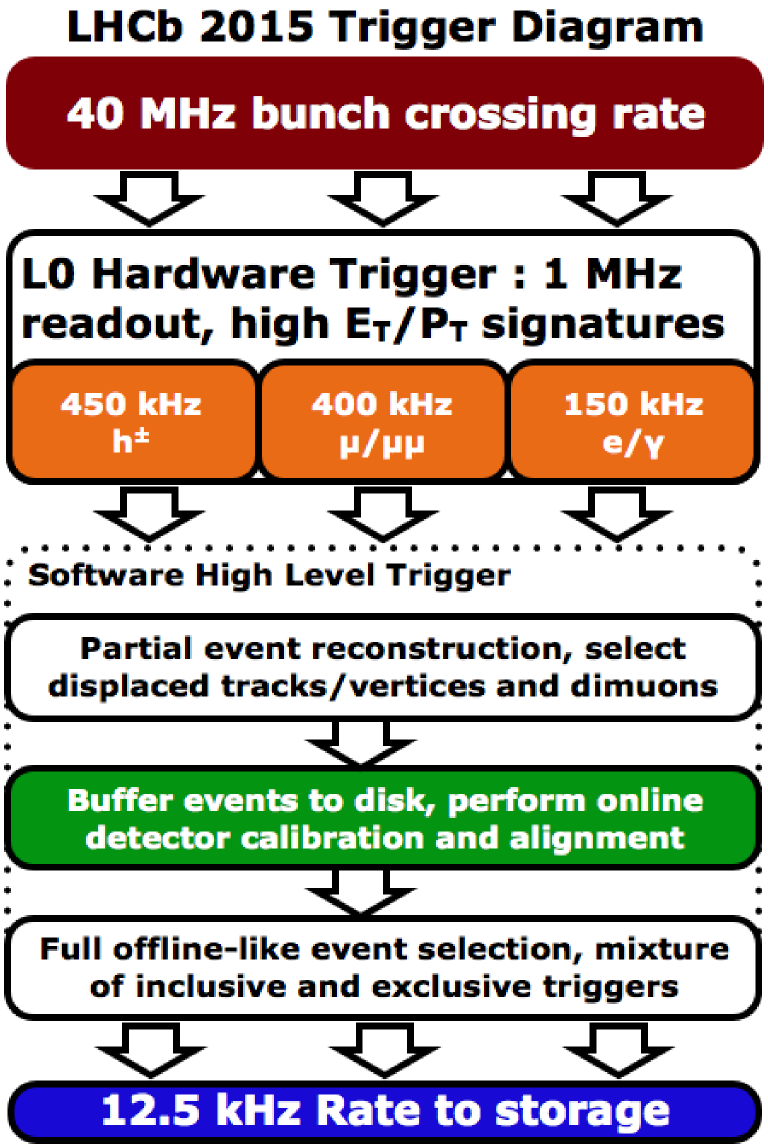
- 2 trigger levels
- Level-1 hardware
  - – 4 μs latency
  - – 100 kHz output rate
- Event building at full L1 rate
- Output rate: average 1 kHz
- Event size:1.5 MB



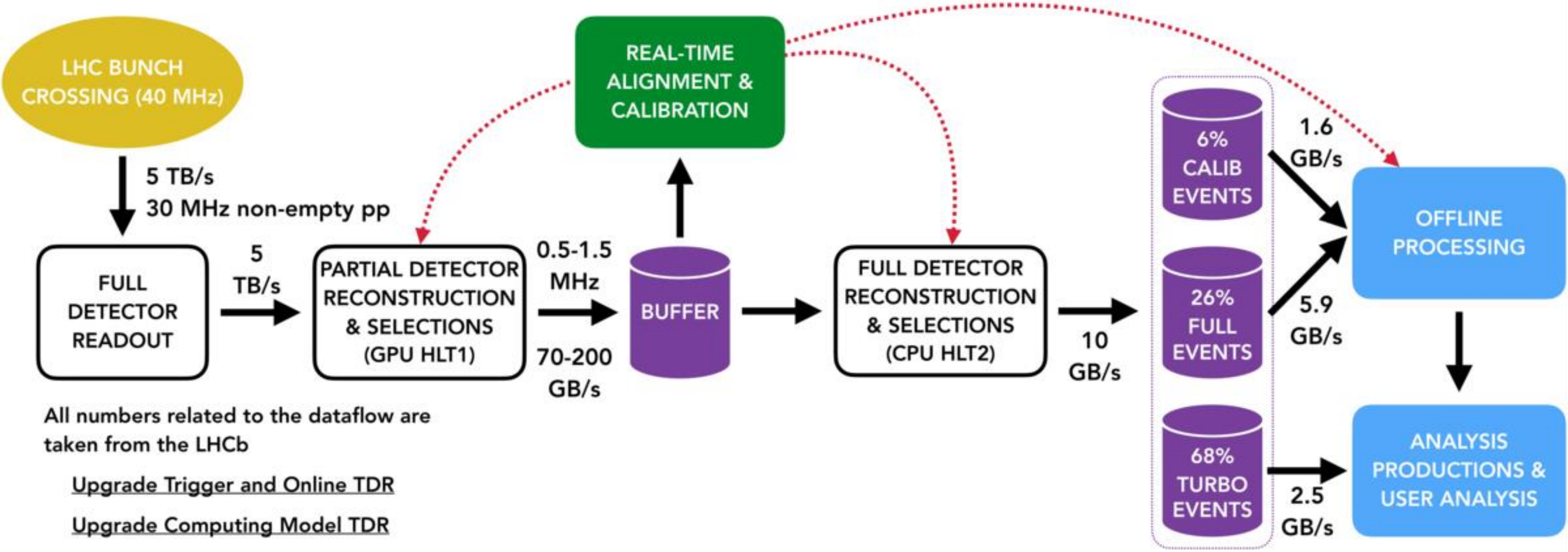


LHCb Trigger/DAQ system (Run2)

- 2 trigger levels
- Level 0:
  - 4 usec latency
  - 1MHz output
  - L1: look at displaced high pt tracks
- HLT full event reconstruction
- Output rate: 12.5 kHz
- Event size: 70 kB



LHCb Trigger/DAQ system (Run3)

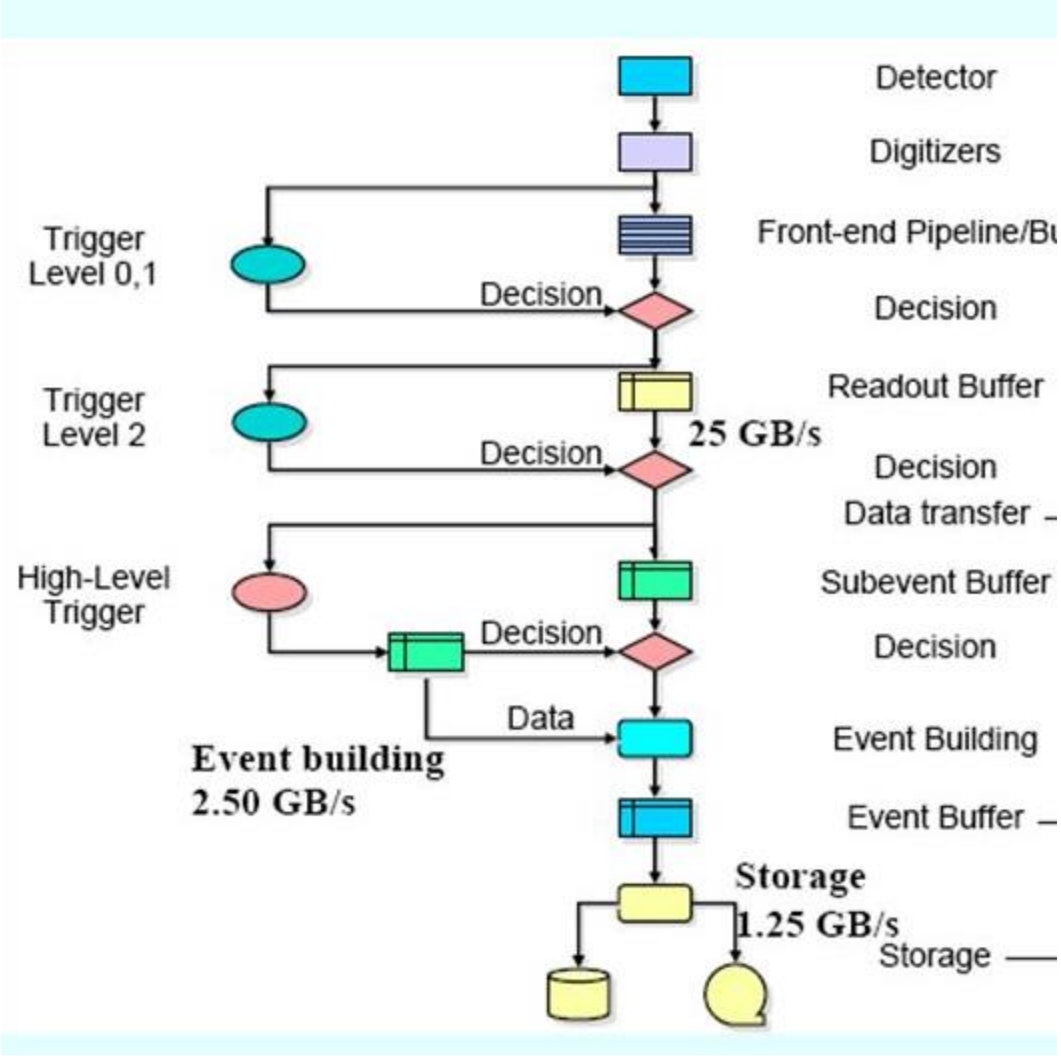


NO Hardware triggers:

- all detectors read-out data at 40 MHz with maximum30MHz interaction rate

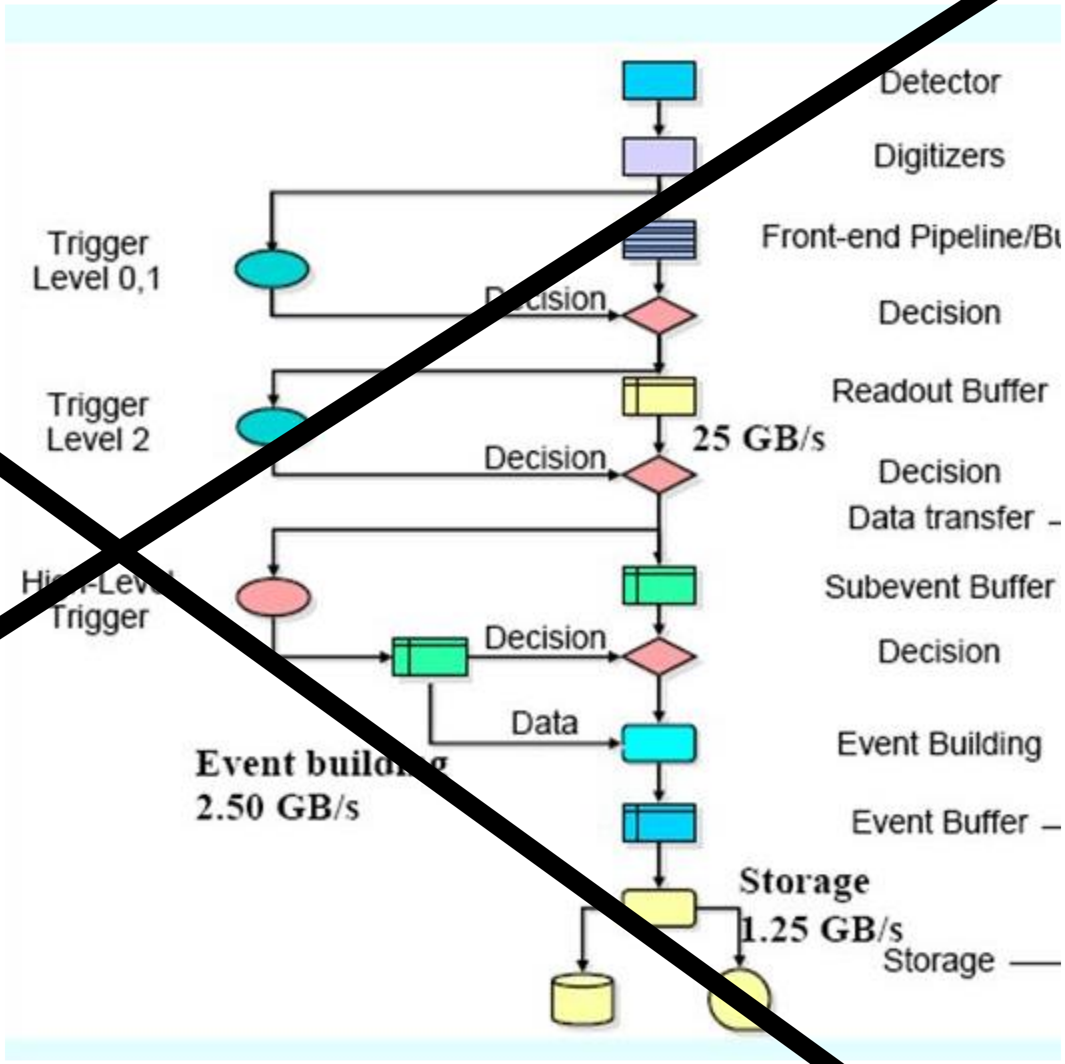
ALICE Trigger/DAQ system (Run2)

- 3 HW trigger levels + HLT
- Latency:
  – L0:1.2μs
  – L1: 6.5 μs
  – L2: 88μs
- Output rate: 500Hz
- Event size:
  7-26MB



ALICE Trigger/DAQ system (Run2)

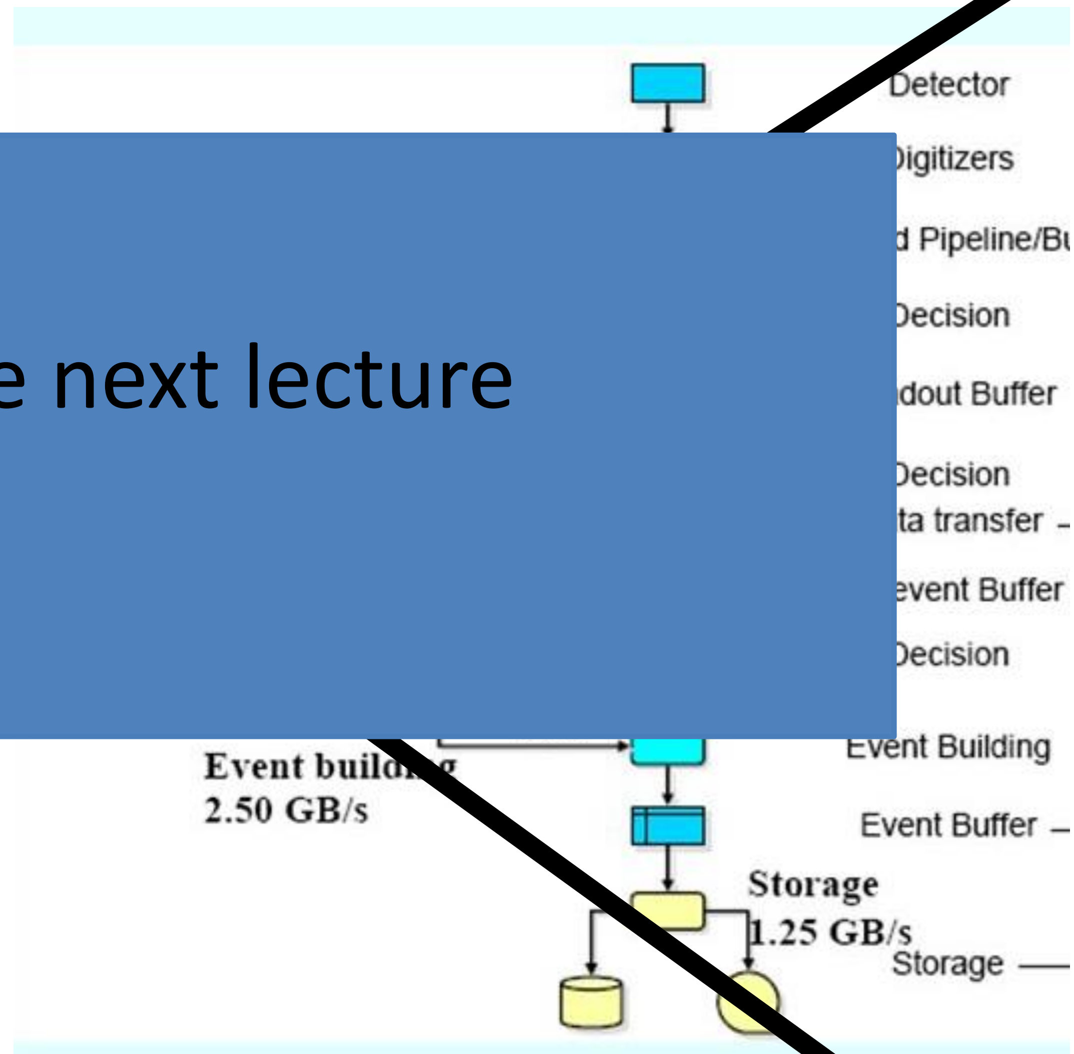
- 3 HW trigger levels + HLT
- Latency:
  – L0:1.2μs
  – L1: 6.5 μs
  – L2: 88μs
- Output rate: 500Hz
- Event size: 7-26MB



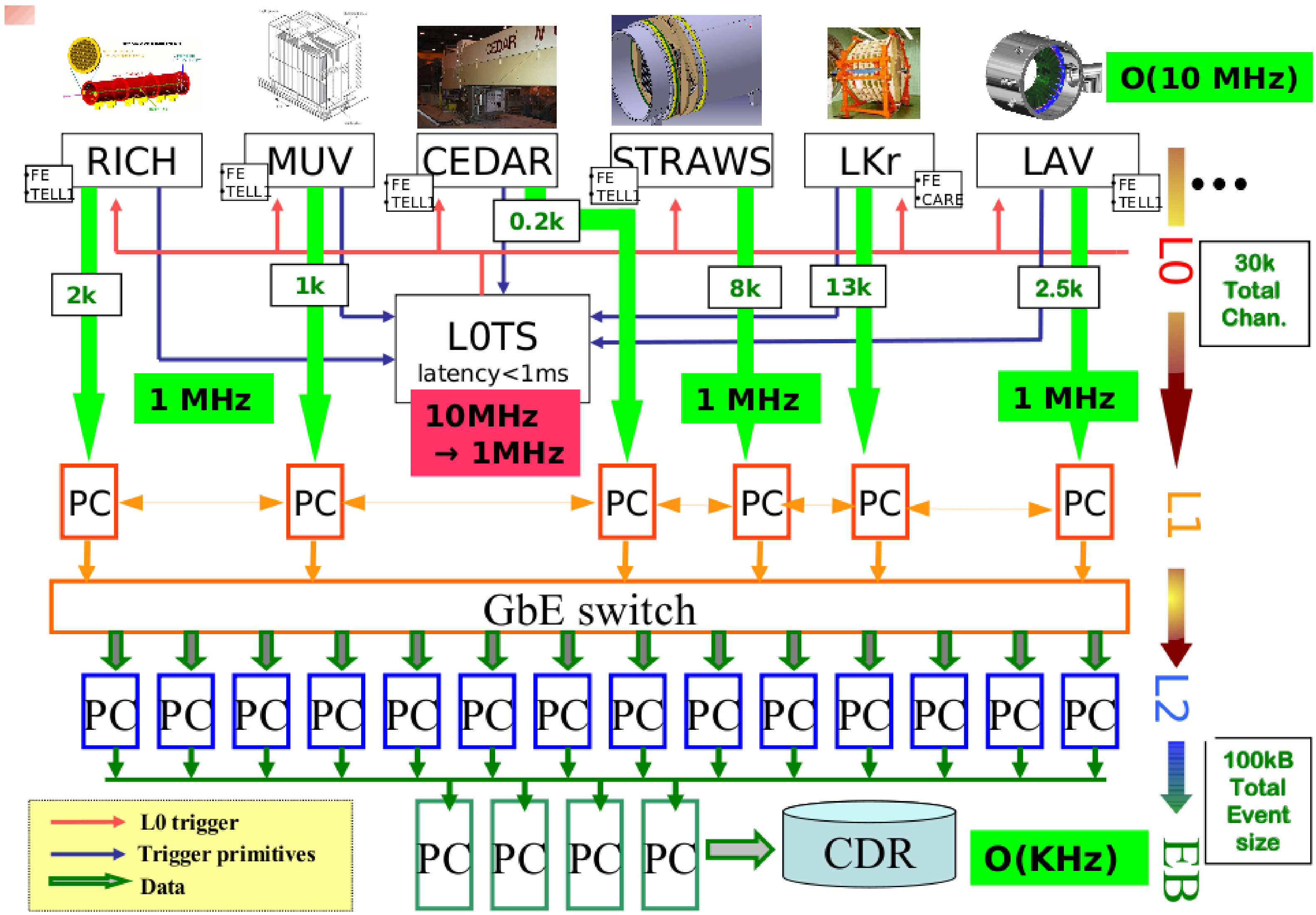
ALICE Trigger/DAQ system (Run3)

- 3 HW trigger levels + HLT
- Late
  - L0:
  - L1:
  - L2:
- Outp
  500H
- Event size:
  7-26MB

See next lecture



NA62 (K+->pi+nu+nu)

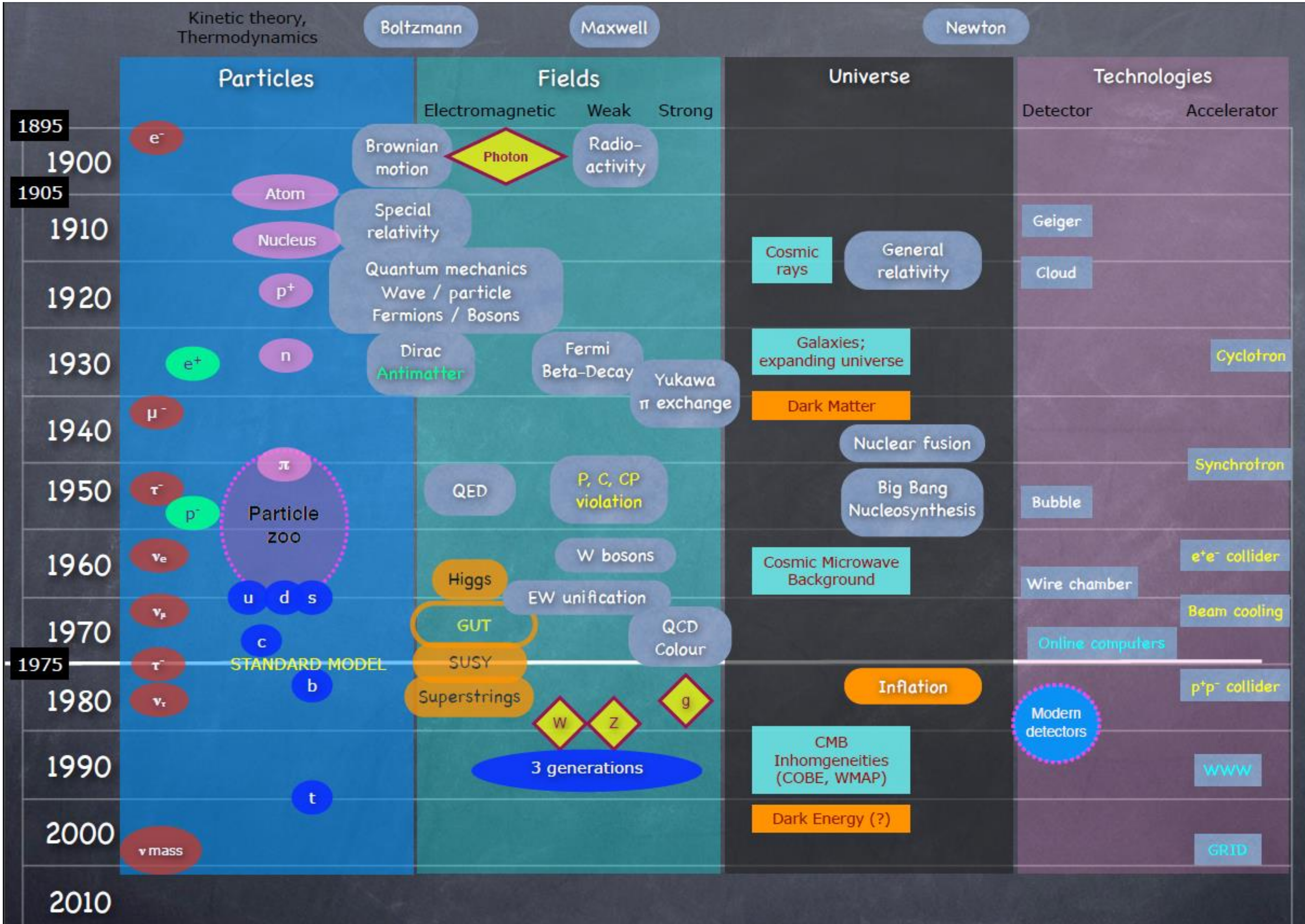


Summary

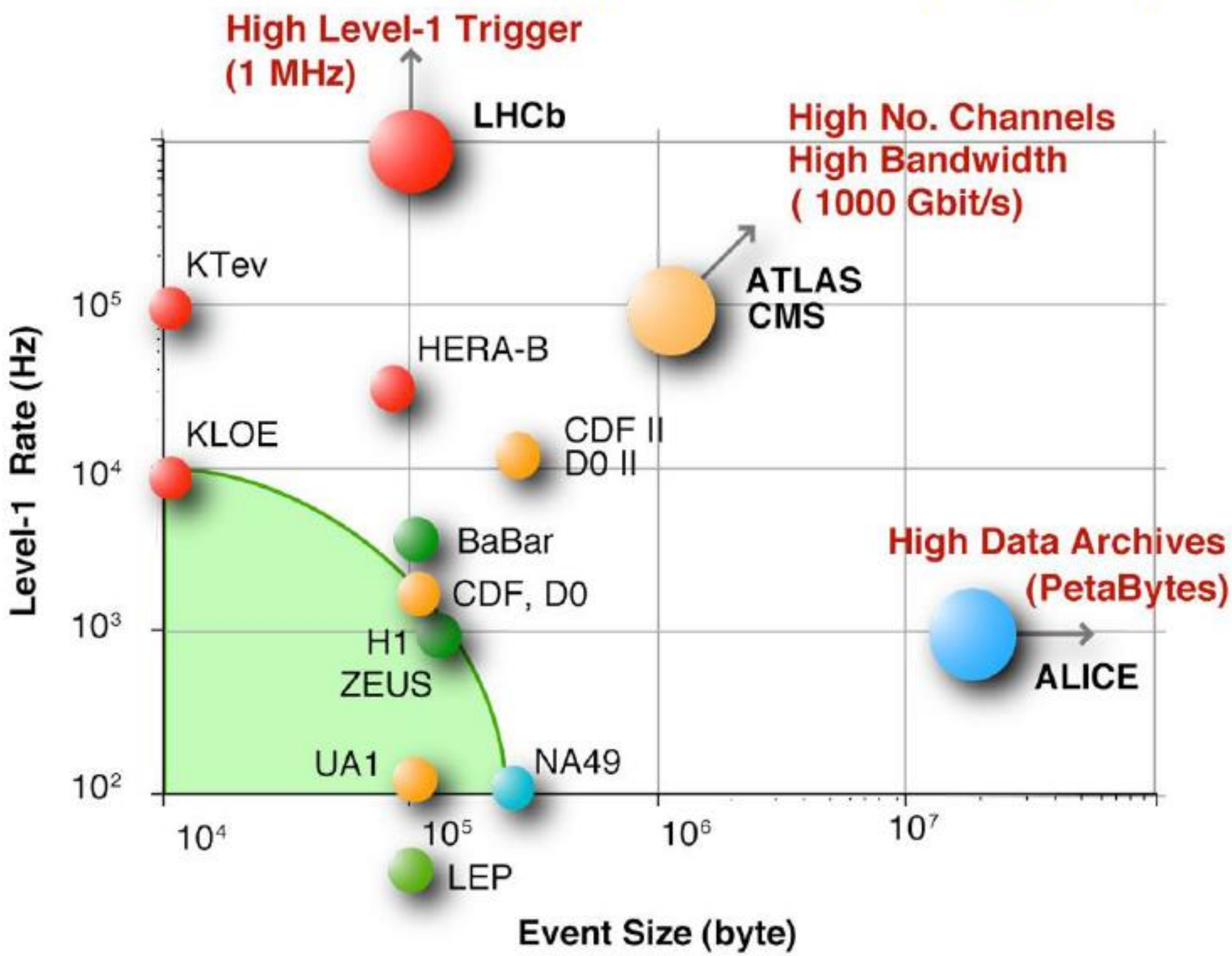
- Basic trigger/DAQ concepts introduced
- Trigger system summary
  - High efficiency
    - No bias on physics results
    - Event losses must be low and measurable
  - Large reduction of rate
  - Affordable
    - Time and money
  - Robust
    - Trigger is mission critical system
  - Flexible
    - Understanding of physics is evolving
    - LHC is improving ..

Lectures

- R.Lietava: http://epweb2.ph.bham.ac.uk/user/lietava/triggerlectures/index.html
- N. Ellis: Proceedings from the 5th CERN-Latin American School of High-Energy Physics, 15 - 28 Mar 2009, Colombia, CERN Report Number CERN-2010-001
- M. Wielers, RAL, Trigger and DAQ lectures, 02/11/2016
- https://warwick.ac.uk/fac/sci/physics/mpags/modules/particle/trigger: to be updated
- F.Pastore, RHUL, An Introduction to trigger systems



Kinetic theory, Thermodynamics
Boltzmann
Maxwell
Newton
Particles
Fields
Electromagnetic
Weak
Strong
Universe
Technologies
Detector
Accelerator
1895
1900
1905
1910
1920
1930
1940
1950
1960
1970
1975
1980
1990
2000
2010
e-
Atom
Nucleus
p+
n
e+
μ-
π
τ-
p-
Particle zoo
νe
u
d
s
νμ
c
STANDARD MODEL
τ-
b
ντ
t
ν mass
Brownian motion
Photon
Radio-activity
Special relativity
Quantum mechanics
Wave / particle
Fermions / Bosons
Dirac
Antimatter
Fermi
Beta-Decay
Yukawa
π exchange
QED
P, C, CP violation
W bosons
Higgs
EW unification
GUT
QCD
Colour
SUSY
Superstrings
g
W
Z
3 generations
Cosmic rays
General relativity
Galaxies; expanding universe
Dark Matter
Nuclear fusion
Big Bang Nucleosynthesis
Cosmic Microwave Background
Inflation
CMB Inhomgeneities (COBE, WMAP)
Dark Energy (?)
Geiger
Cloud
Cyclotron
Synchrotron
Bubble
e+e- collider
Wire chamber
Beam cooling
Online computers
p+p- collider
Modern detectors
WWW
GRID


High Level-1 Trigger
(1 MHz)
LHCb
High No. Channels
High Bandwidth
(1000 Gbit/s)
KTev
ATLAS
CMS
HERA-B
KLOE
CDF II
D0 II
BaBar
CDF, D0
H1
ZEUS
High Data Archives
(PetaBytes)
ALICE
UA1
NA49
LEP
Level-1 Rate (Hz)
Event Size (byte)
10^2
10^3
10^4
10^5
10^6
10^7

ATLAS Trigger/DAQ system

- 2 trigger levels
- Level-1 HW
  - 2.5 usec latency
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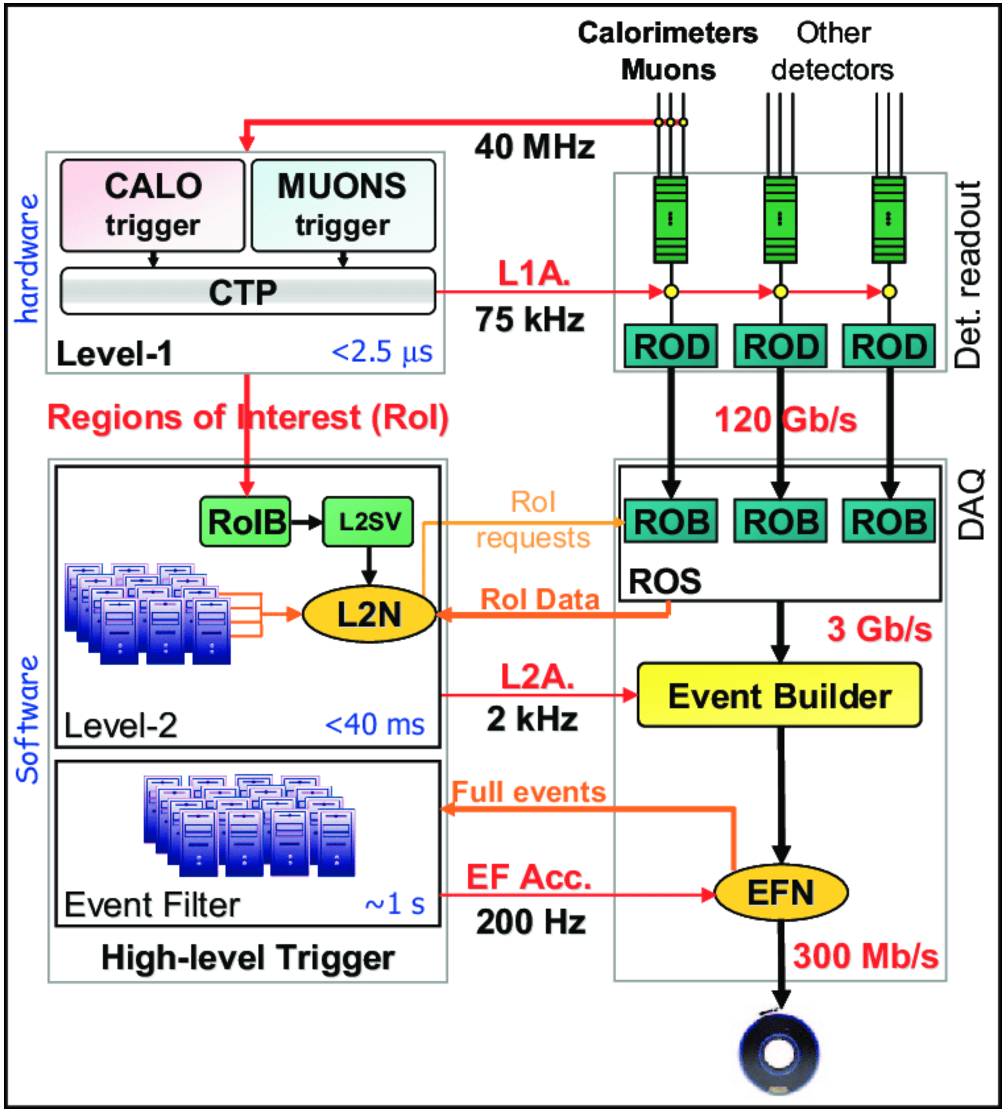
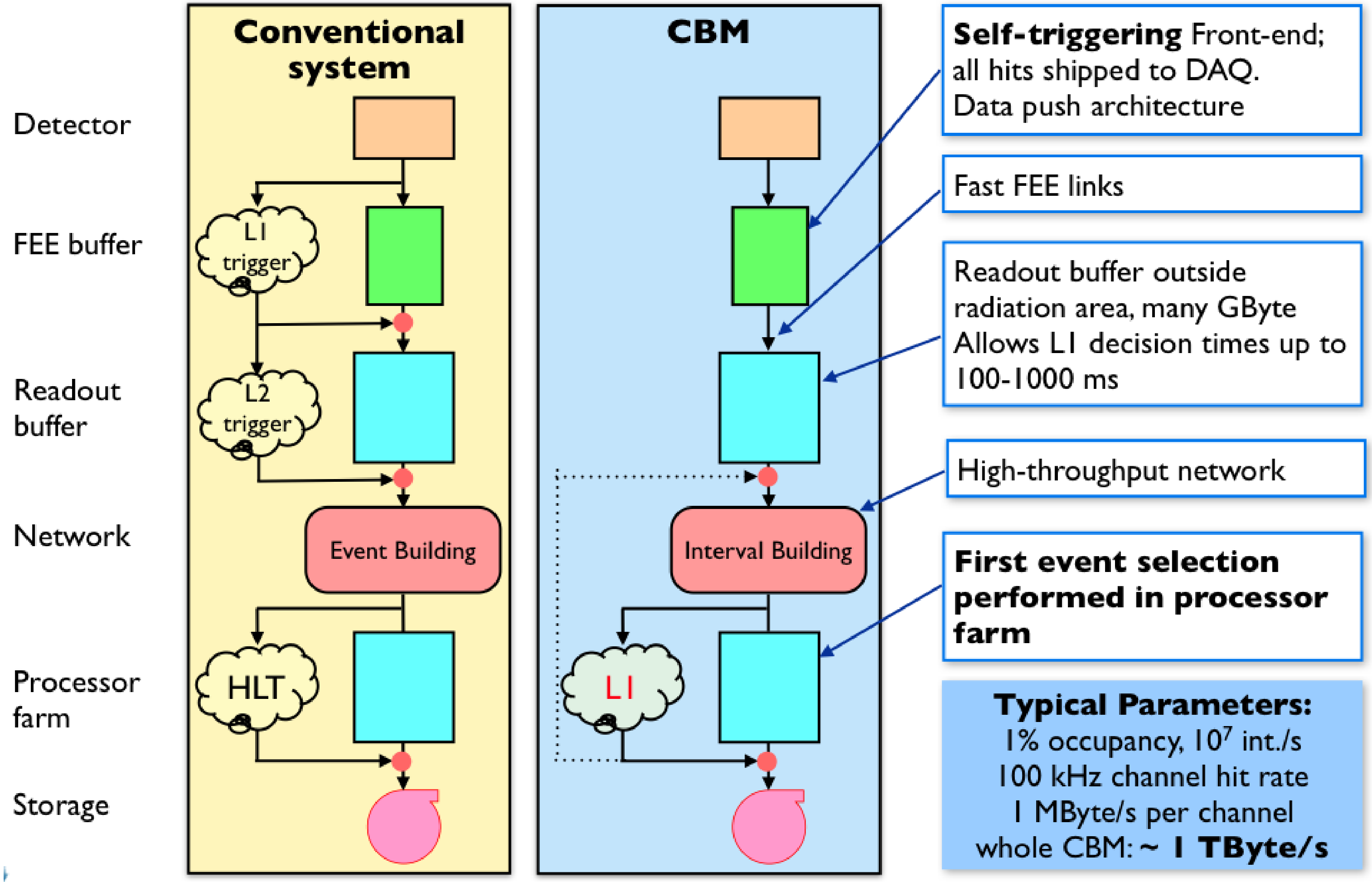


CBM Readout Concept



Finite-size FEE buffer: latency limited

throughput limited