LAUREN TOMPKINS

HCPSS 2018

TRIGGER AND DATA ACQUISITION

Stanford
University

GENERAL OUTLINE OF THE LECTURES

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- Introduction to me, this talk, and TDAQ

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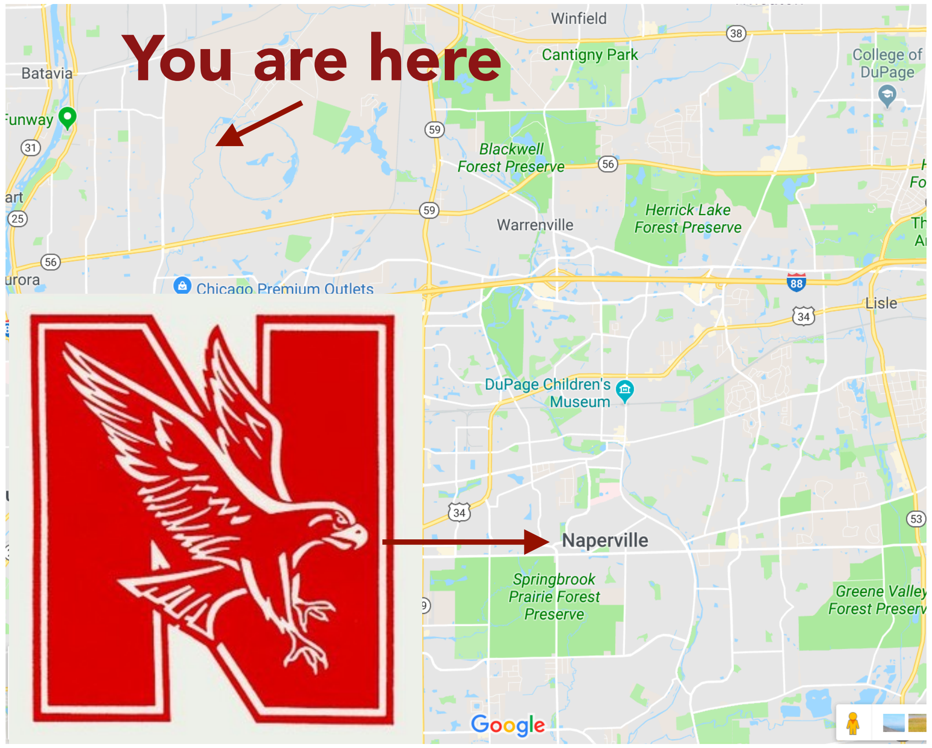
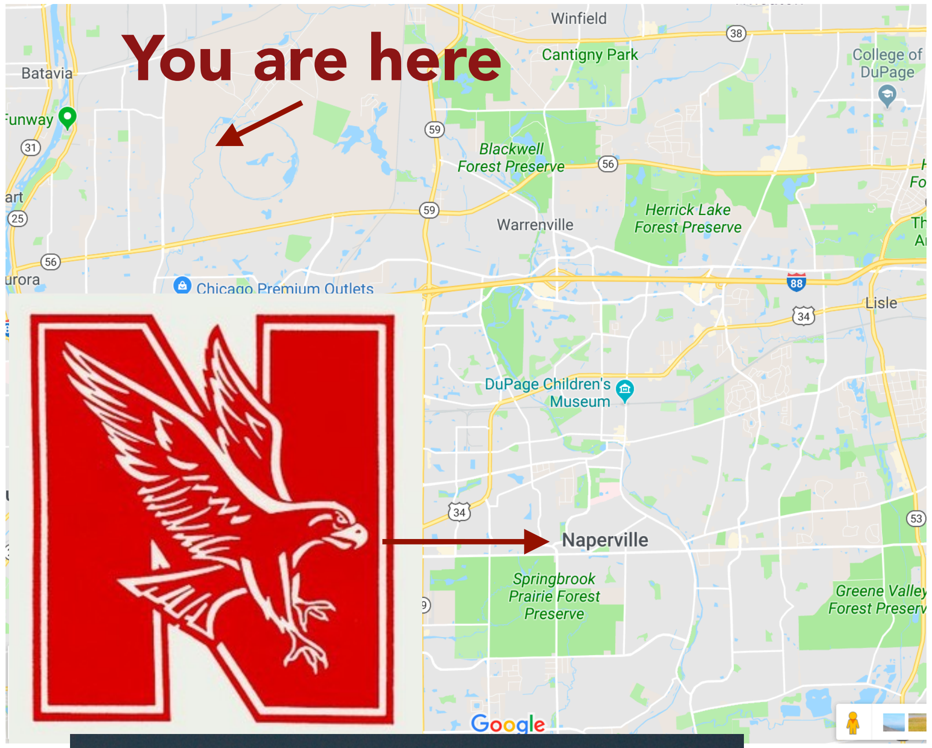
- Introduction to me, this talk, and TDAQ
- Start off with some context: what is the trigger & data acquisition challenge?
- Spend some time with a toy example
- Translate that example into the LHC ecosystem
- Look to the future

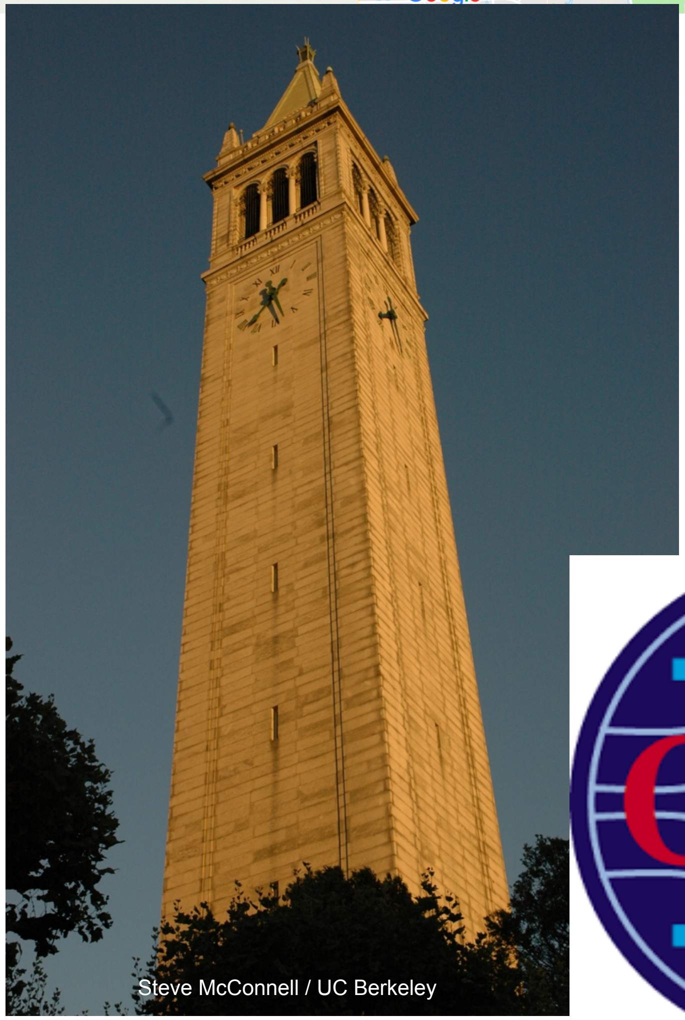
HELLO!

HELLO!


You are here
Winfield
Batavia
Cantigny Park
College of DuPage
Blackwell Forest Preserve
Herrick Lake Forest Preserve
Warrenville
Chicago Premium Outlets
Lisle
DuPage Children's Museum
Naperville
Springbrook Prairie Forest Preserve
Greene Valley
Google

HELLO!





Steve McConnell / UC Berkeley

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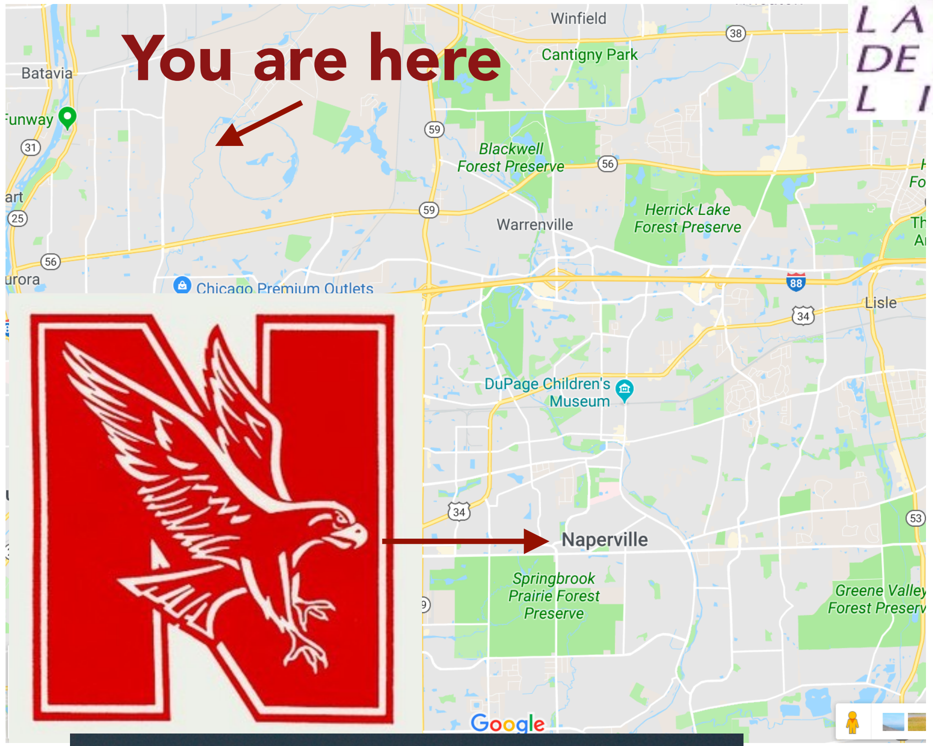

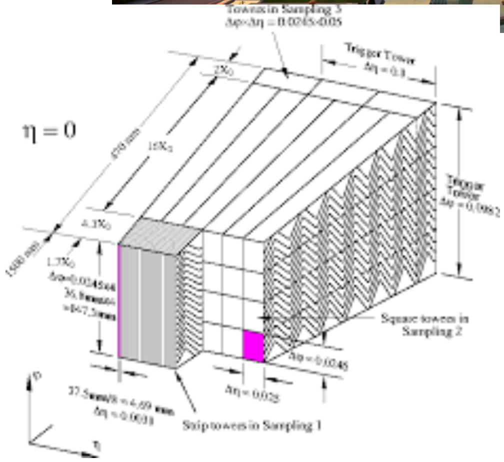

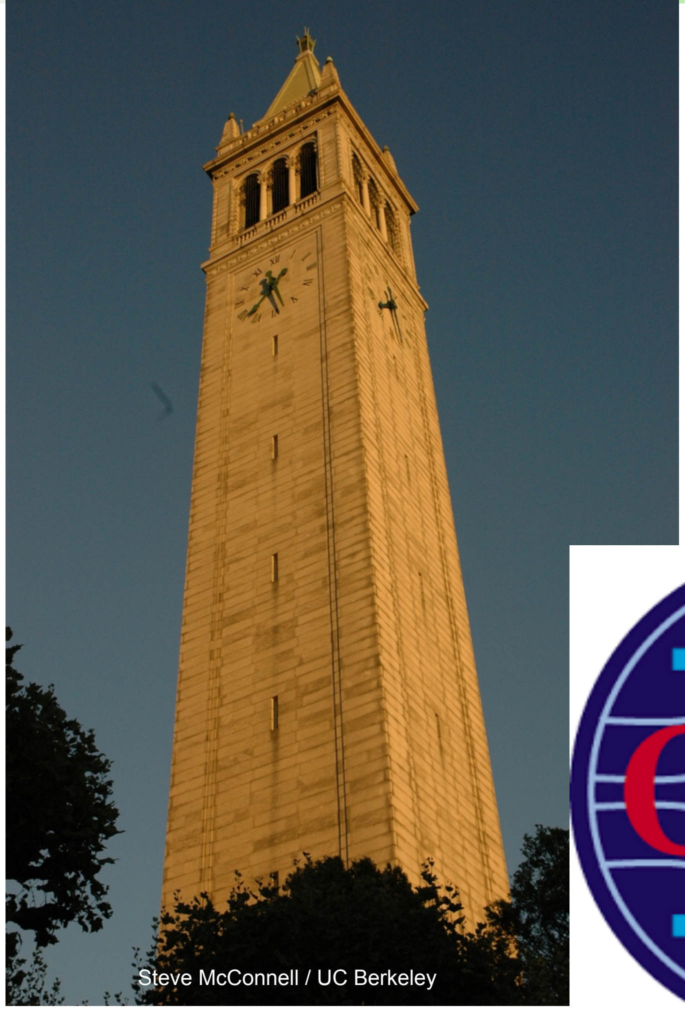

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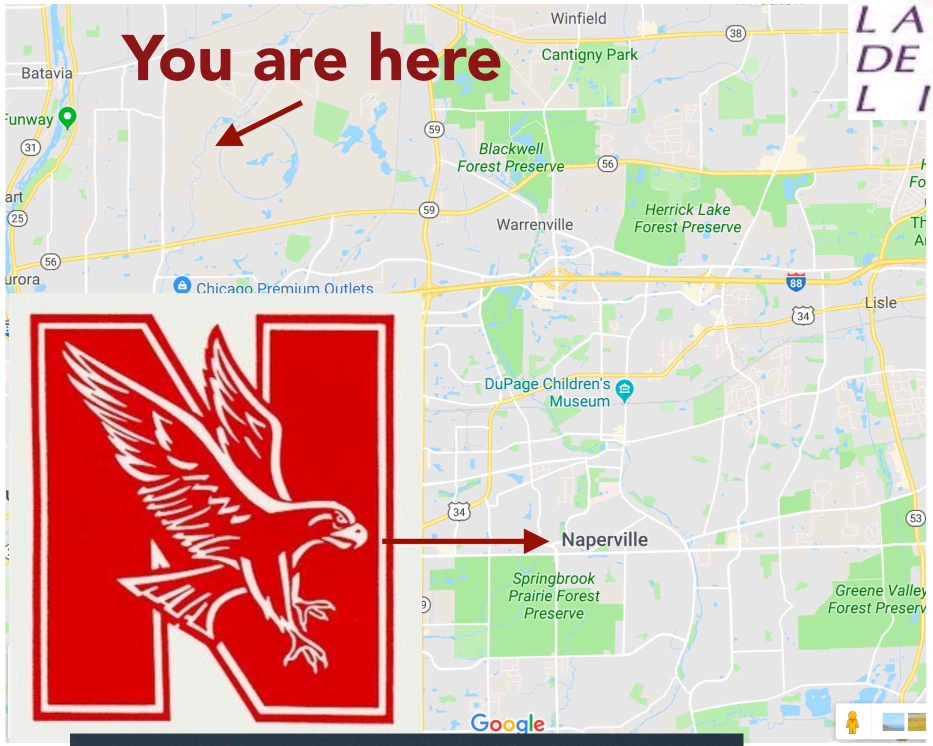
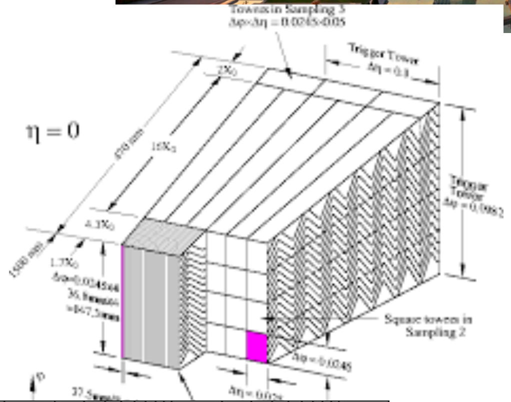
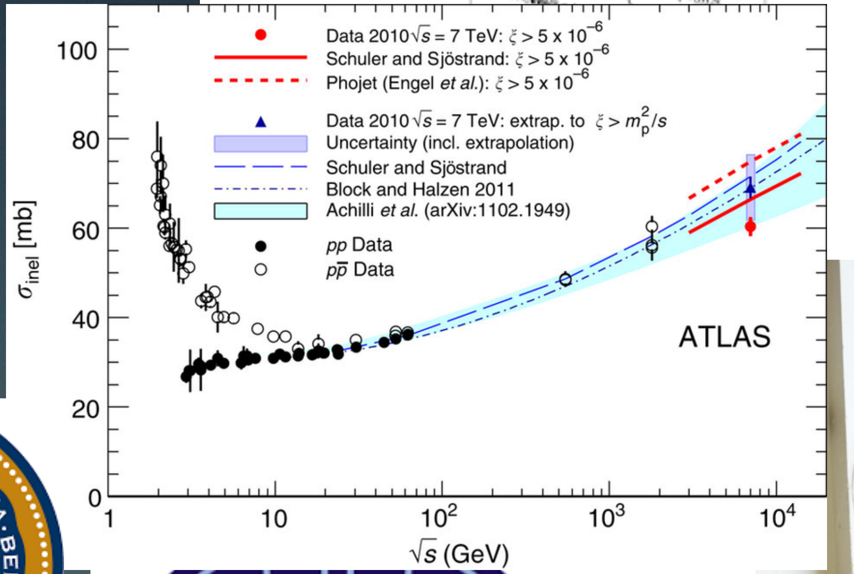
HELLO!

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

ATLAS EXPERIMENT





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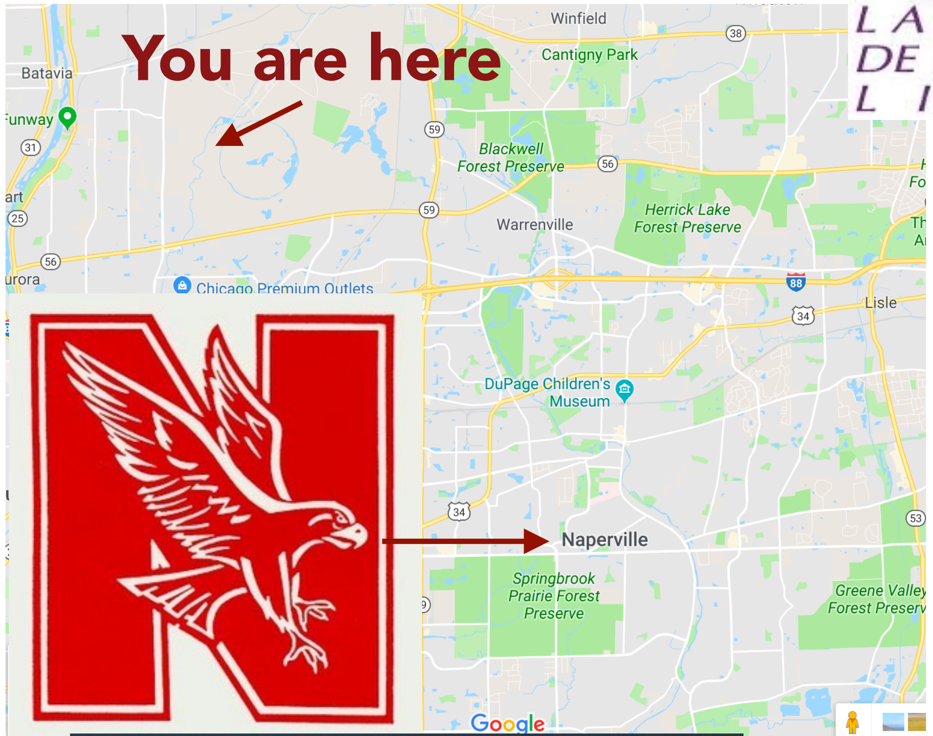
Mar. 30, 2010

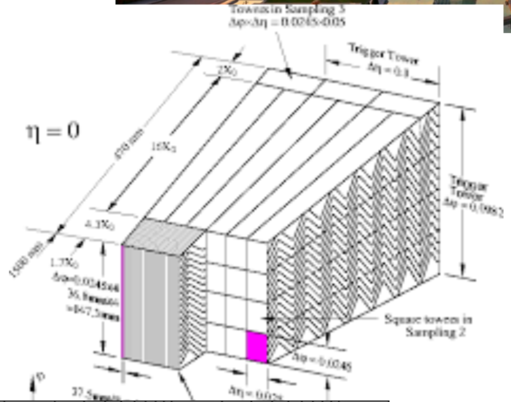
HELLO!



LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

ATLAS EXPERIMENT

LELAND STANFORD JUNIOR UNIVERSITY 1891



THE UNIVERSITY OF CHICAGO 1890

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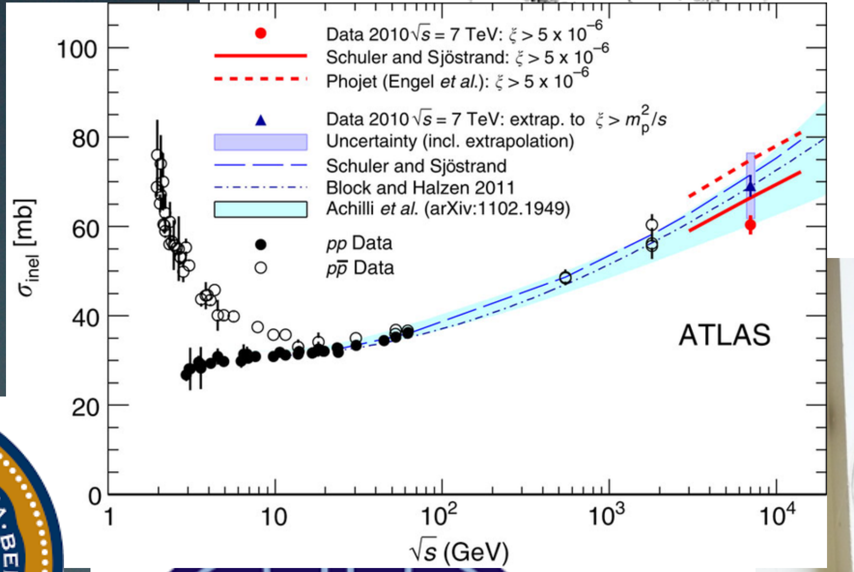
THE UNIVERSITY OF CALIFORNIA BERKELEY 1868



CDF II

Mar. 30, 2010

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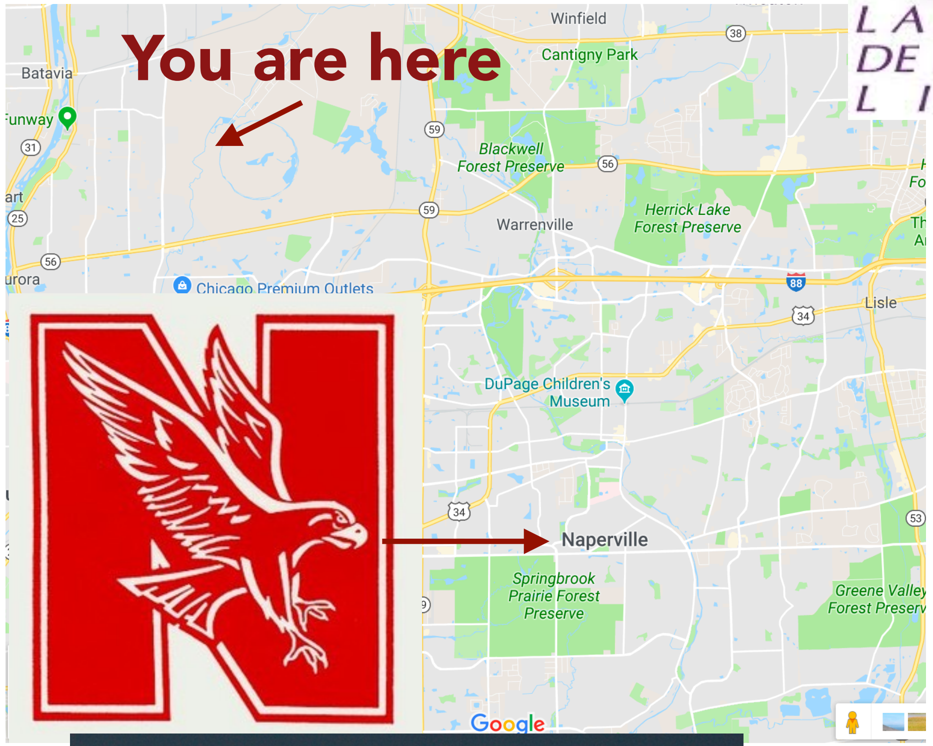

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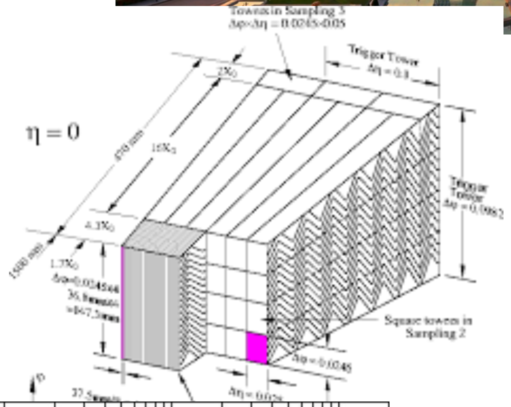

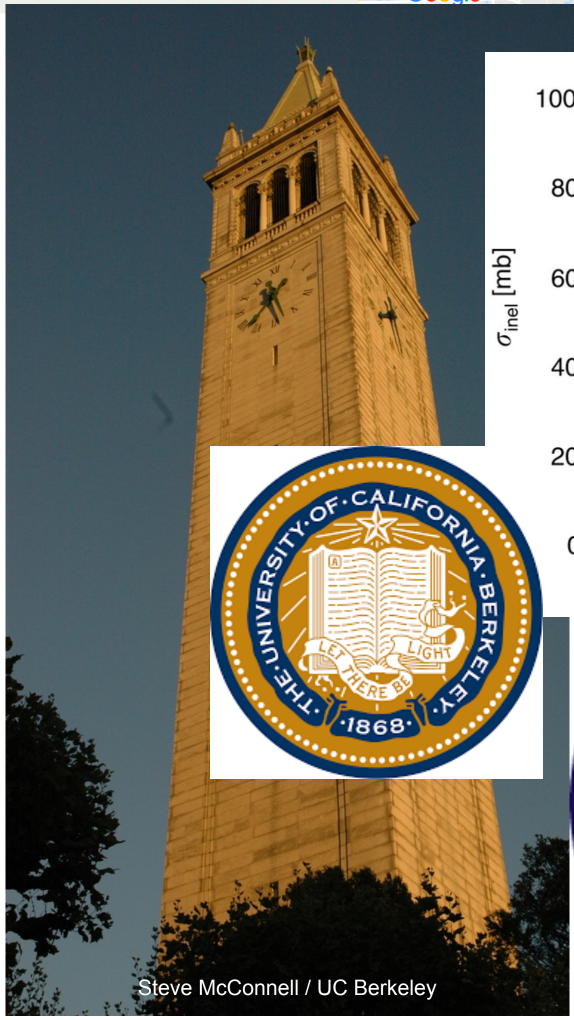

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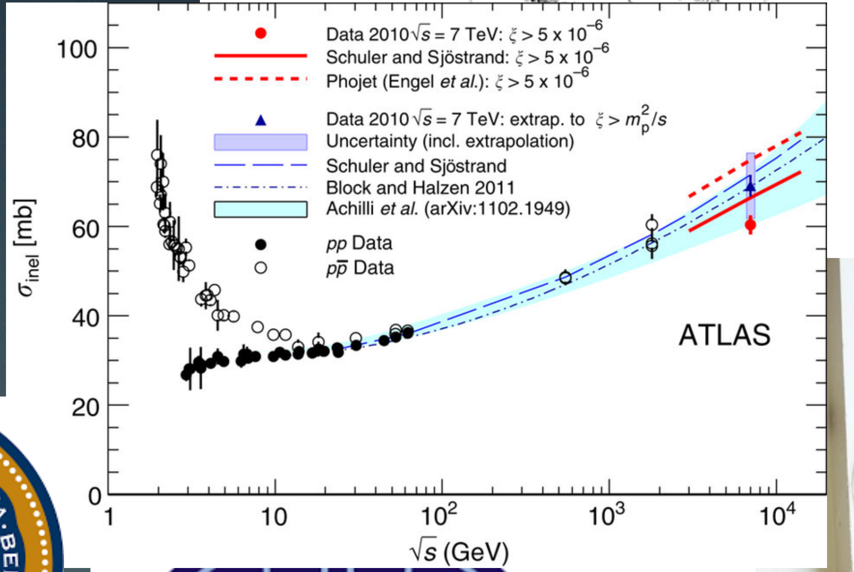

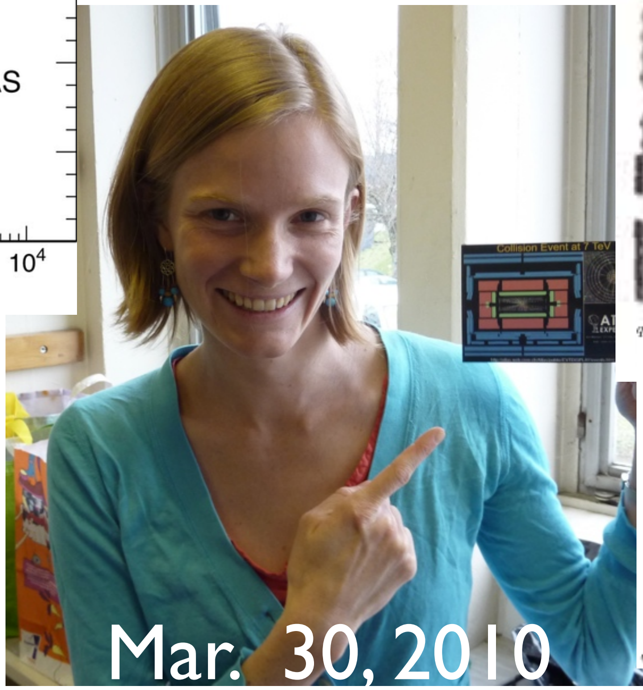

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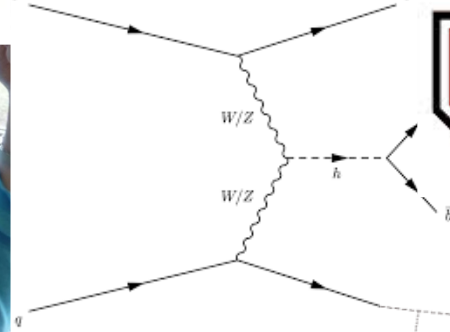
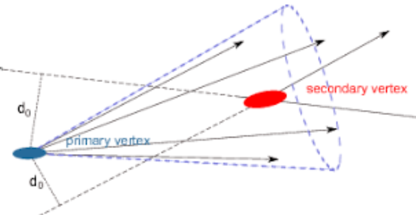


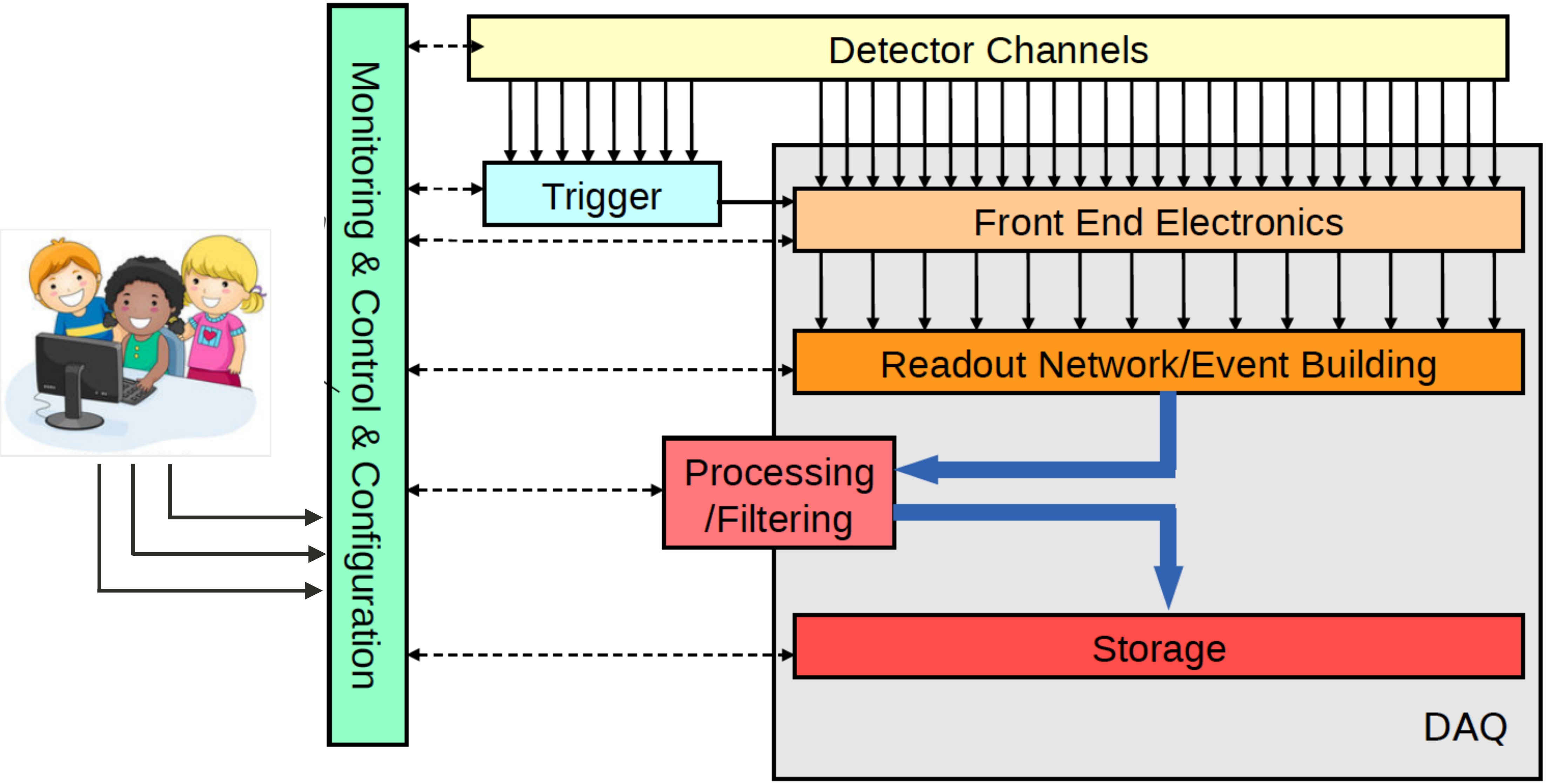


BEFORE WE GET STARTED

- Will I learn how (insert experiment here) specifically triggers on (insert physics process here)?
  - No, my goal is to give you enough of a framework for understanding TDAQ generally such that you can apply your knowledge to specific situations
- Will I learn basic electronics?
  - Not really. We'll cover a few important concepts, but take a class at your institution or attend the ISOTDAQ or EDIT schools for more information
- These lectures are inspired by Andrea Negri, Wainer Vandelli, and Roberto Ferrari's lectures at ISOTDAQ and CERN as well as Wesley Smith's previous HCPSS lectures.
- These are a little ATLAS-heavy, but the concepts apply generally so please forgive me!

TDAQ COMPONENTS

- Trigger & Data Acquisition comprise the systems for deciding which data to record (Trigger) and getting it off the detectors to storage for analysis (DAQ)



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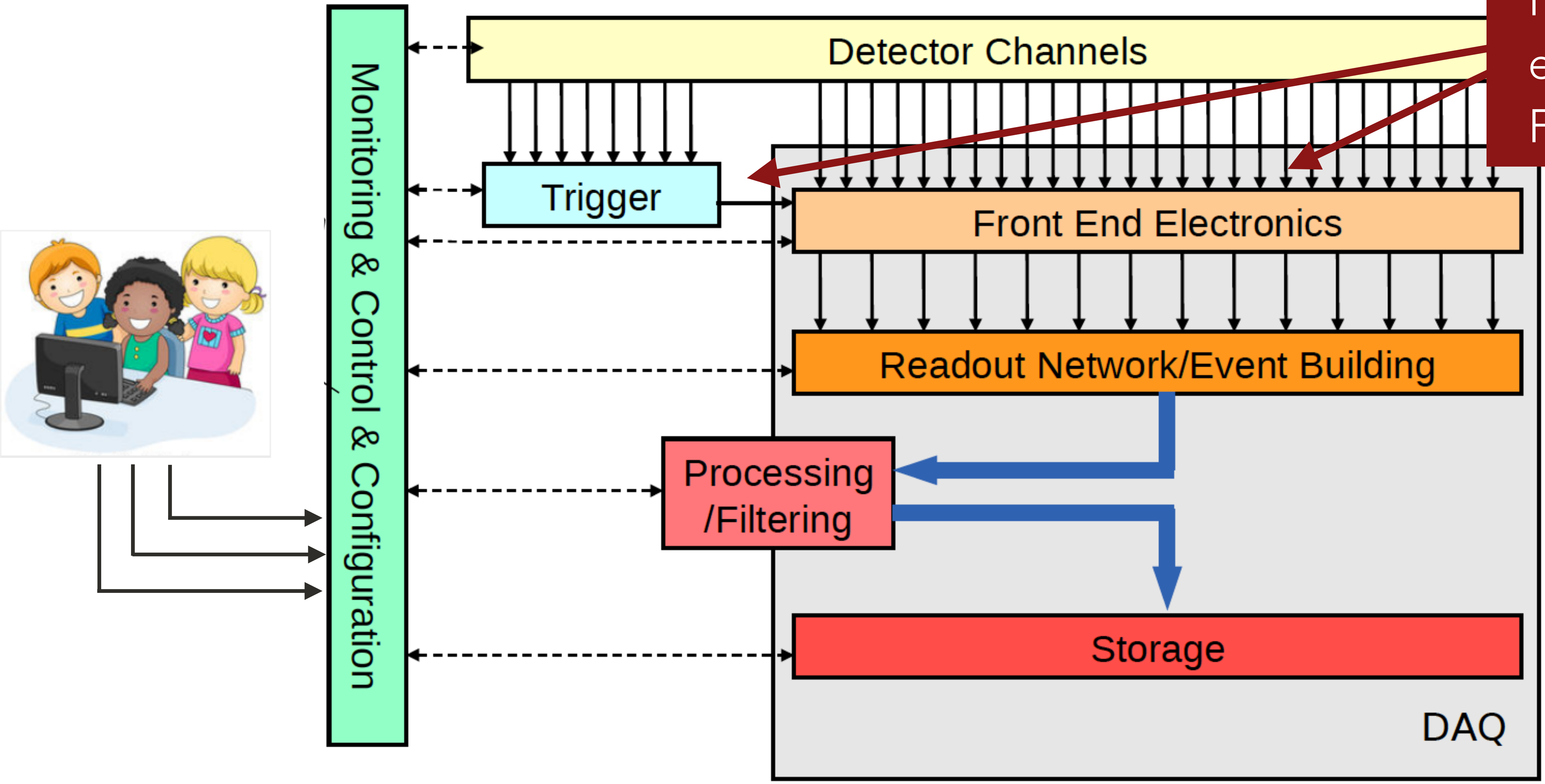

Fast, custom electronics: FPGAs, ASICs

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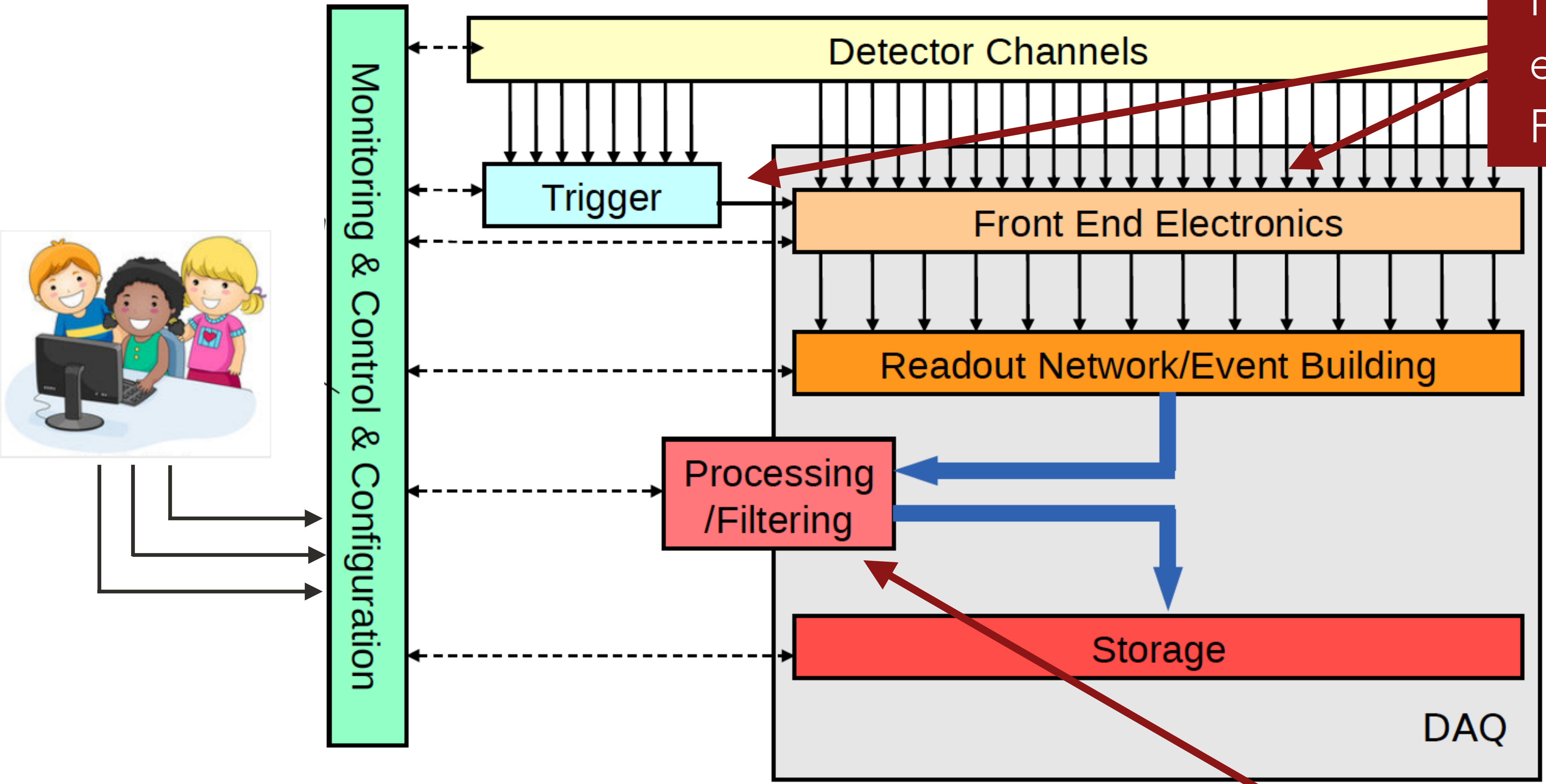

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Computing power: CPUs/ GPUs

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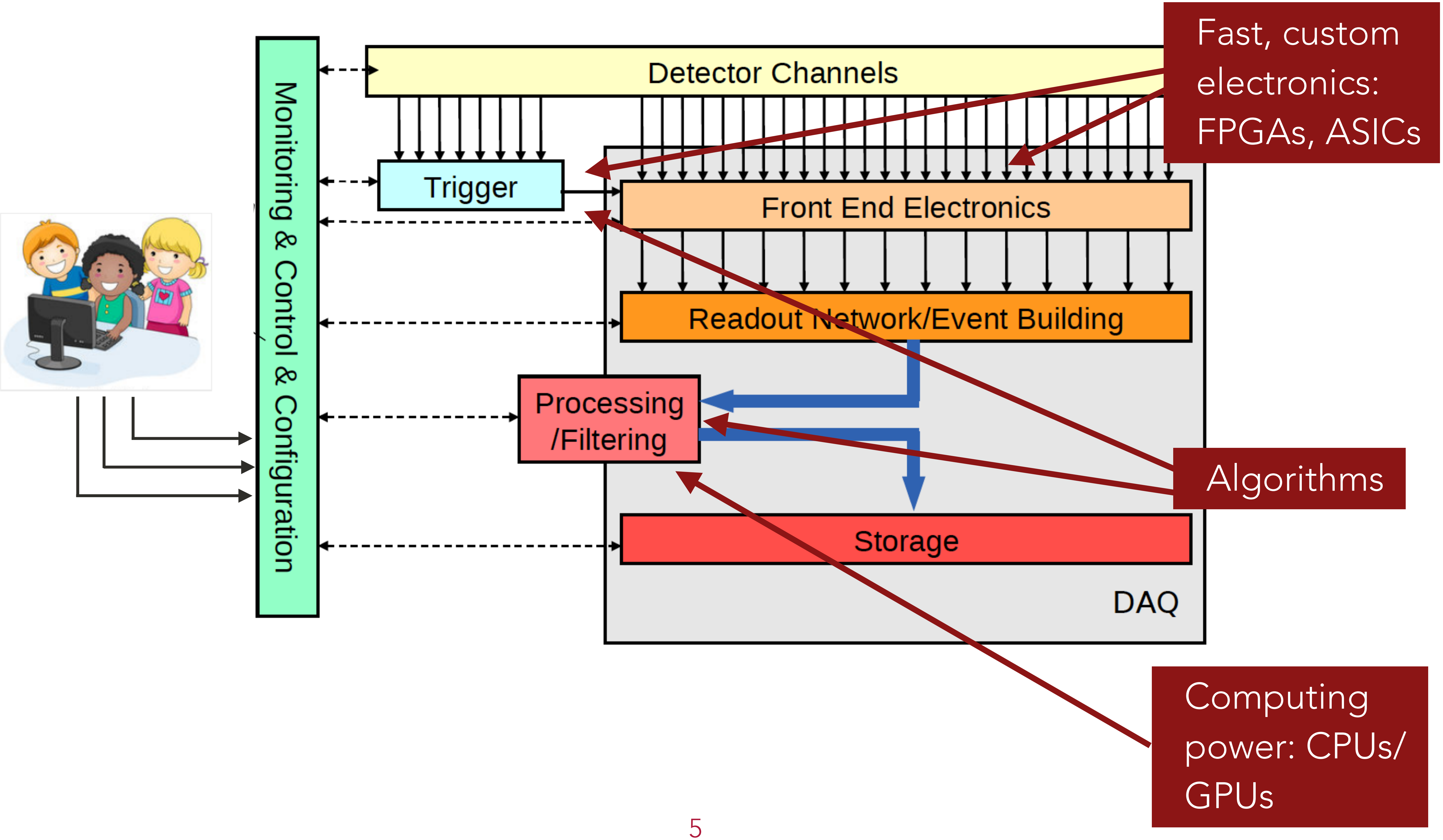

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Algorithms

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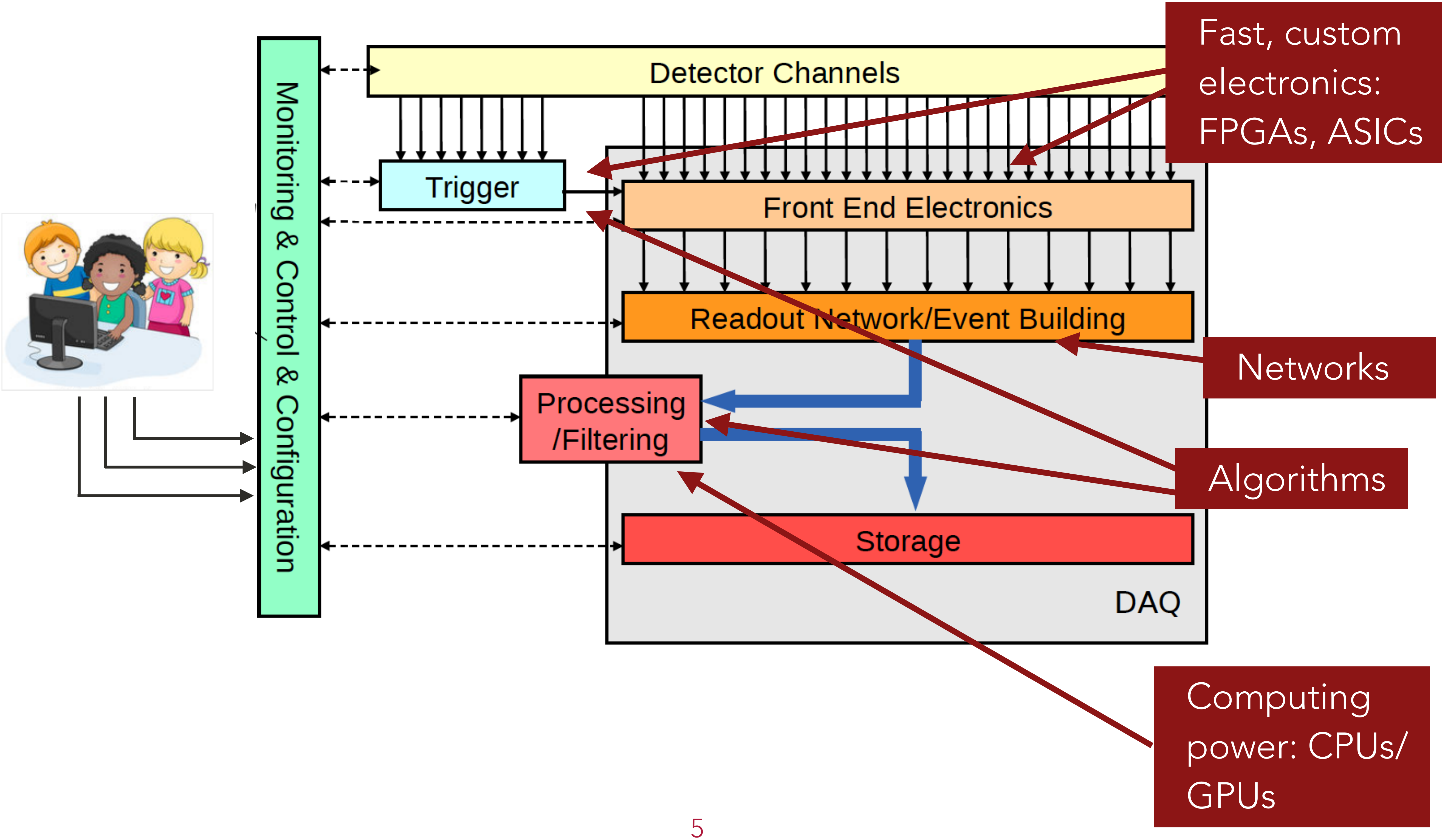

Monitoring & Control & Configuration

Detector Channels

Trigger

Front End Electronics

Readout Network/Event Building

Processing /Filtering

Storage

DAQ

Fast, custom electronics: FPGAs, ASICs

Networks

Algorithms

Computing power: CPUs/ GPUs

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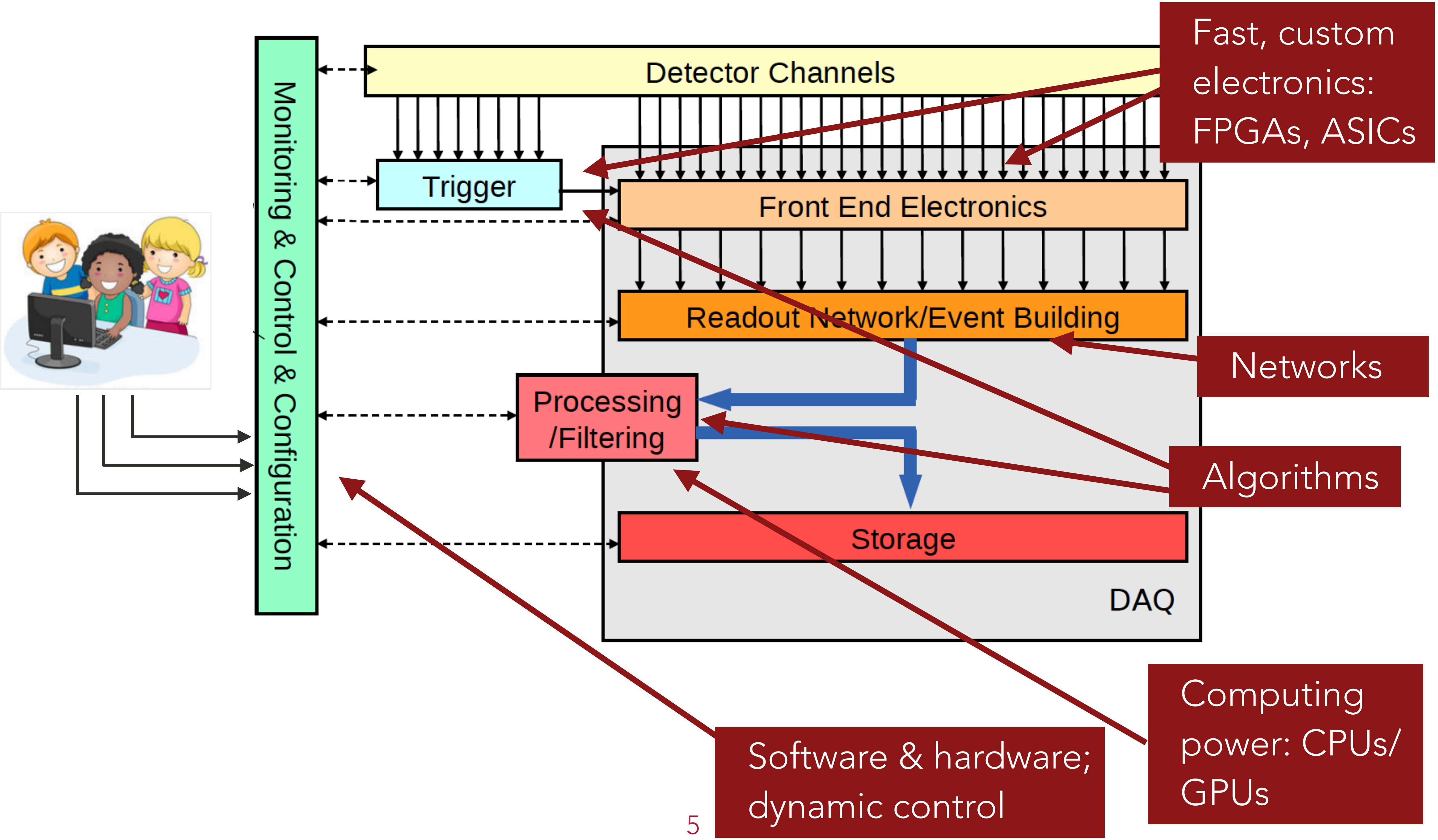

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Computing power: CPUs/ GPUs

Software & hardware; dynamic control

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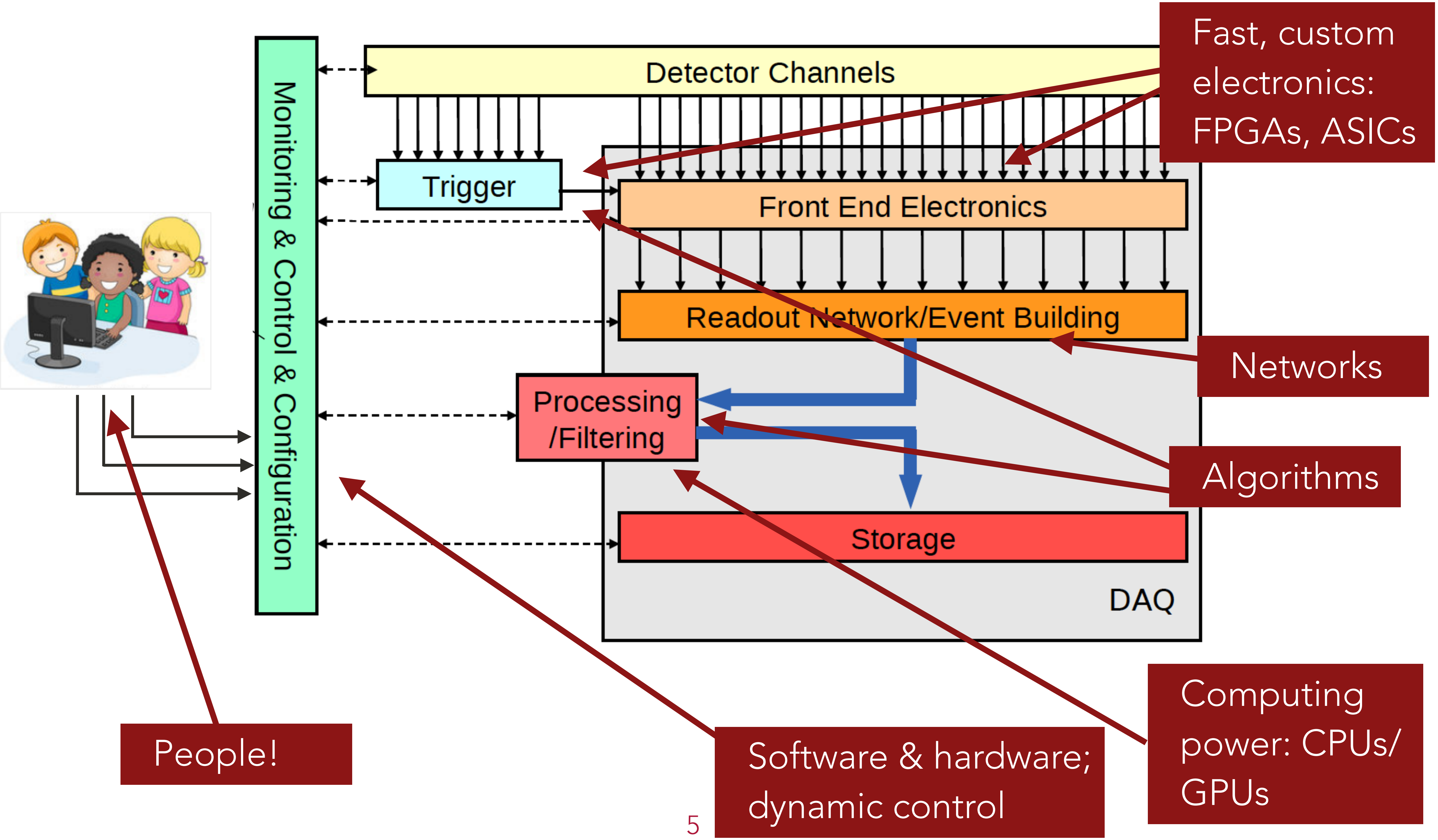


Fast, custom electronics: FPGAs, ASICs

Networks

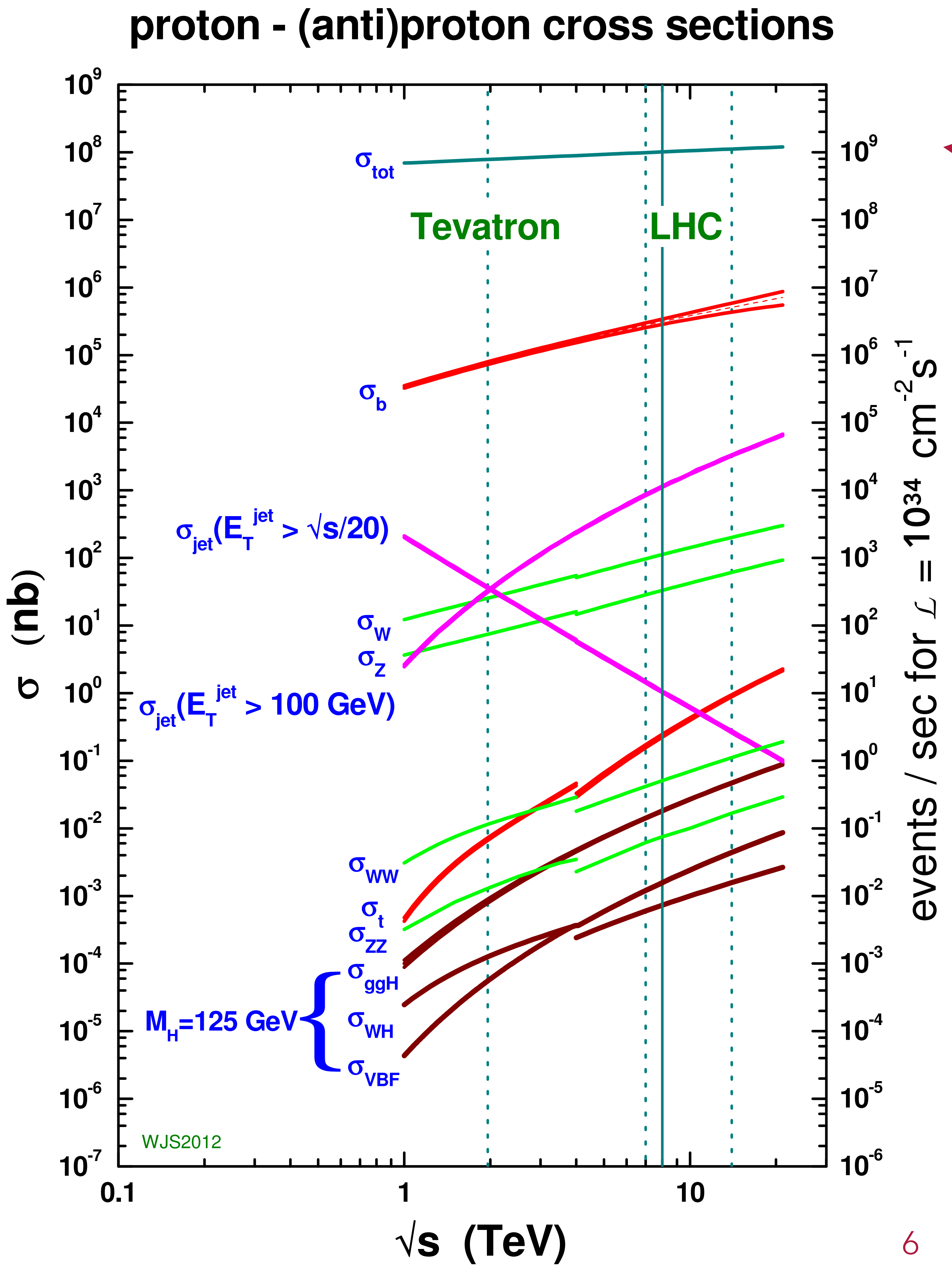
Algorithms

People!

Software & hardware; dynamic control

Computing power: CPUs/ GPUs

THE CHALLENGE : PART 1



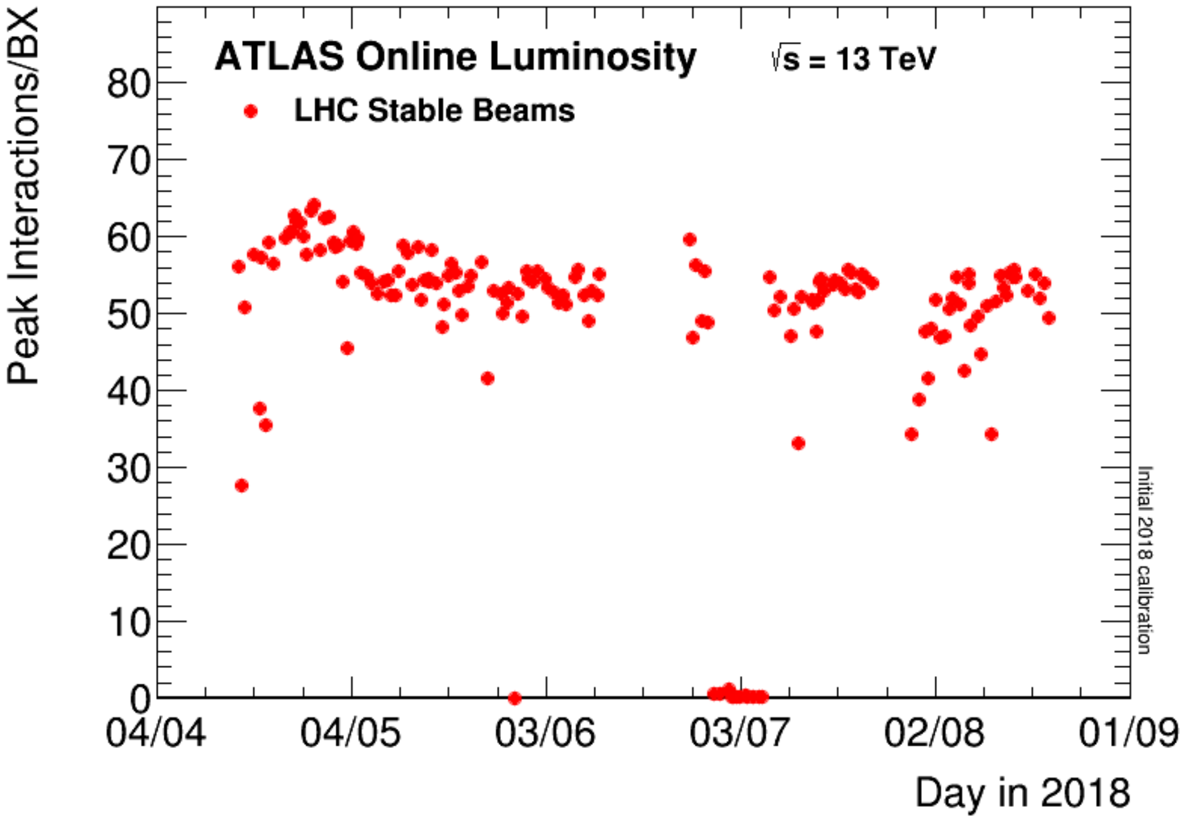
~Total Event rate

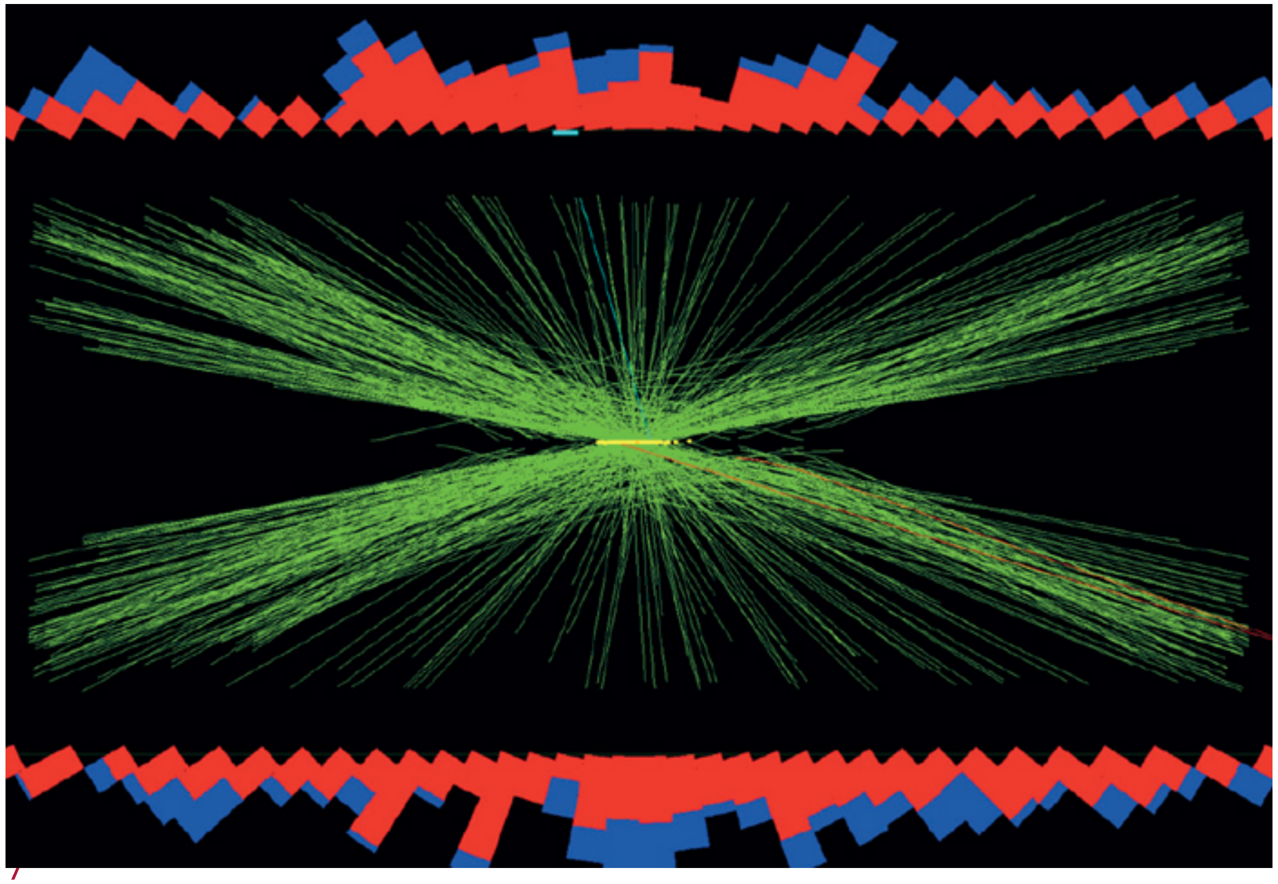
W & Zs (!!)

What you are probably interested in

THE CHALLENGE : PART 2

- A lot of things are going on at the same time!
  - Average 55 simultaneous pp collisions in 2018 (LHC design was 23)
- Collisions every ~25ns
  - Come in bunches and trains





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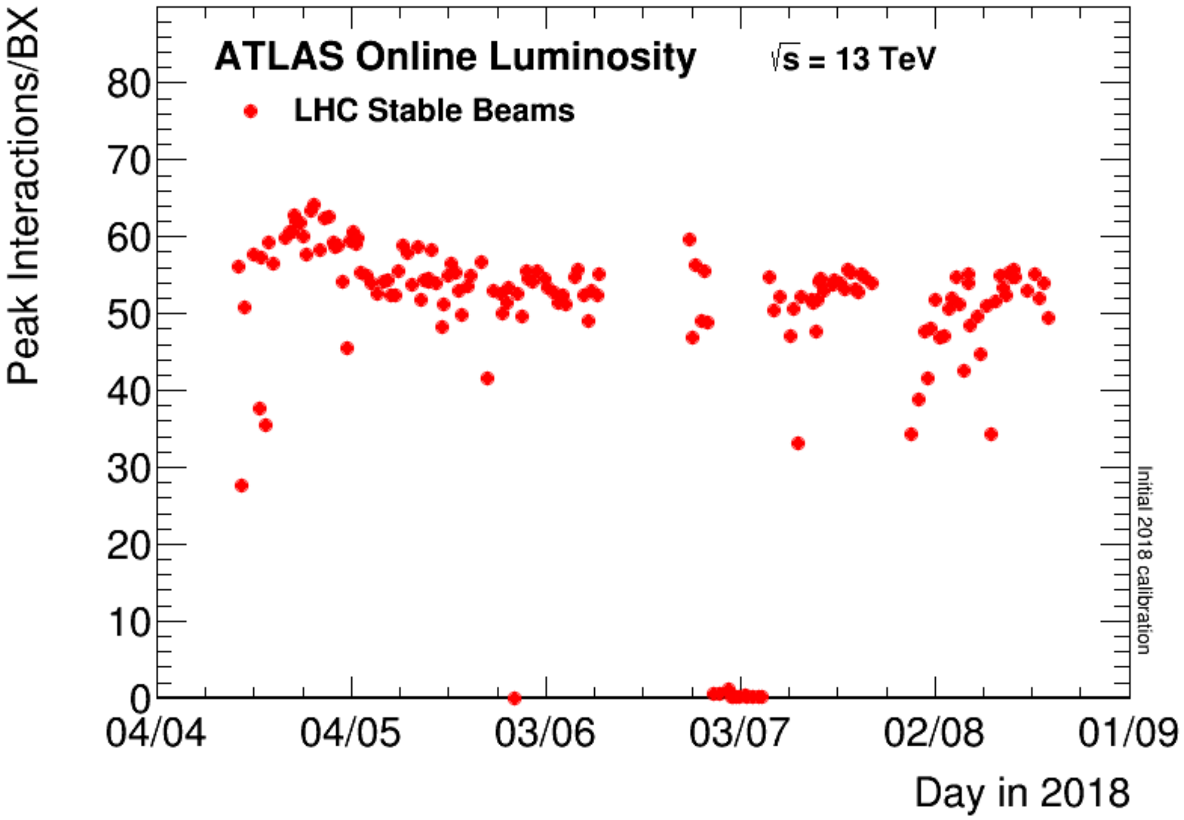
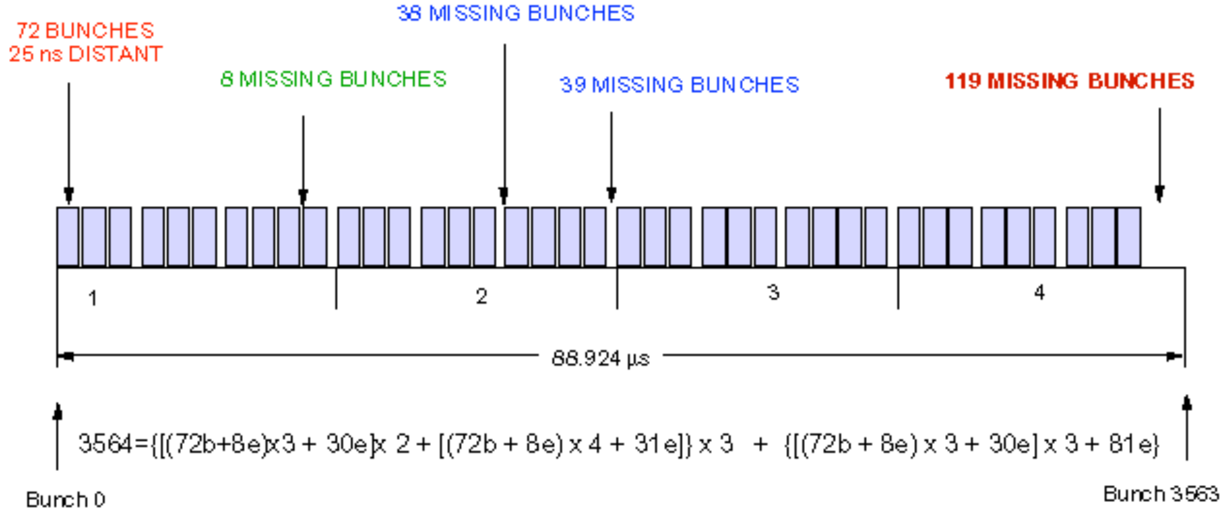
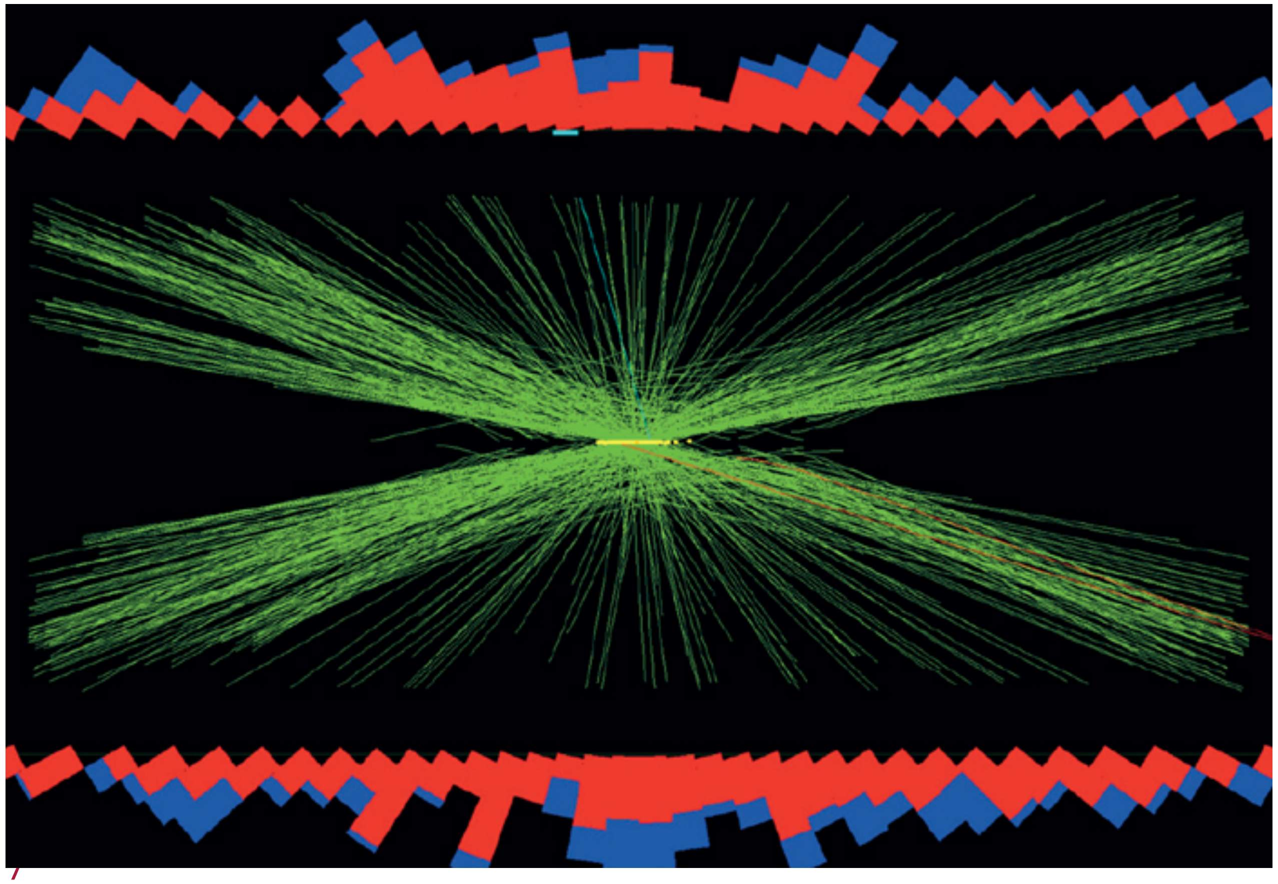




3564={[(72b+8e)x3 + 30e]x 2 + [(72b + 8e) x 4 + 31e]} x 3 + {[(72b + 8e) x 3 + 30e] x 3 + 81e}



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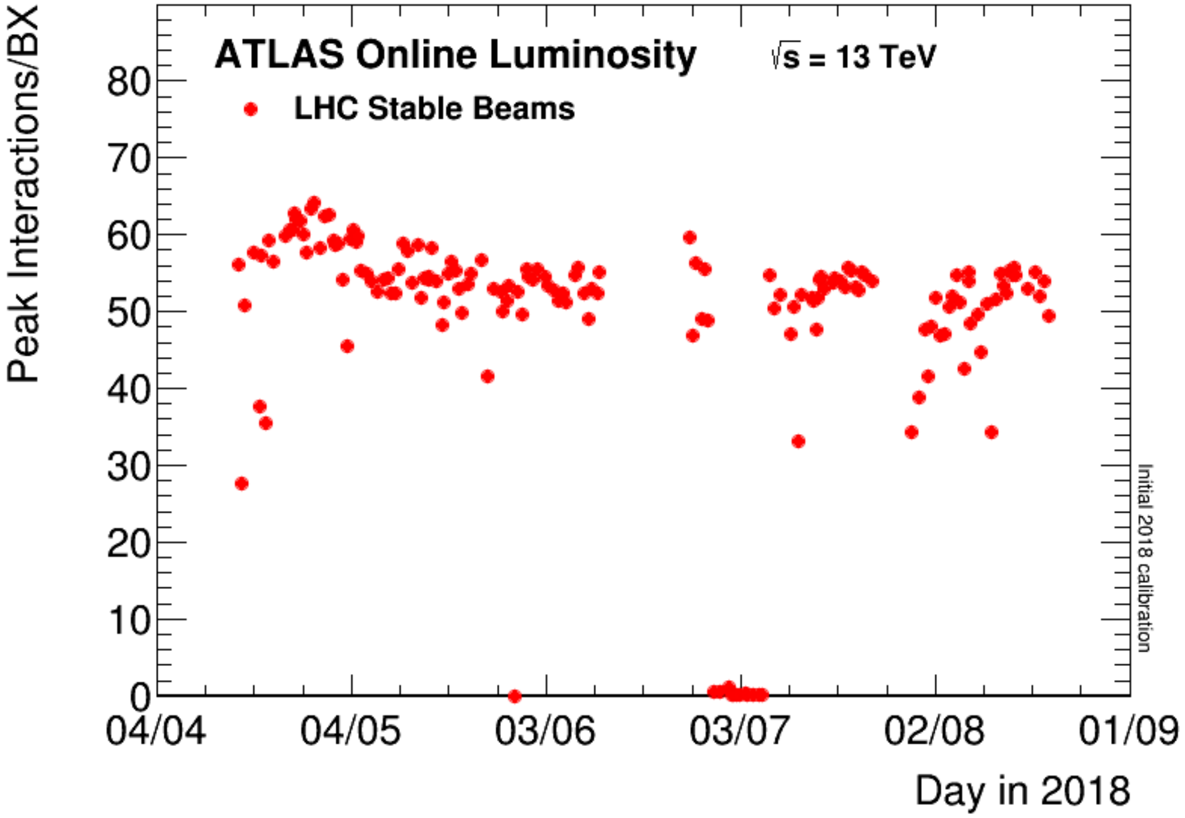

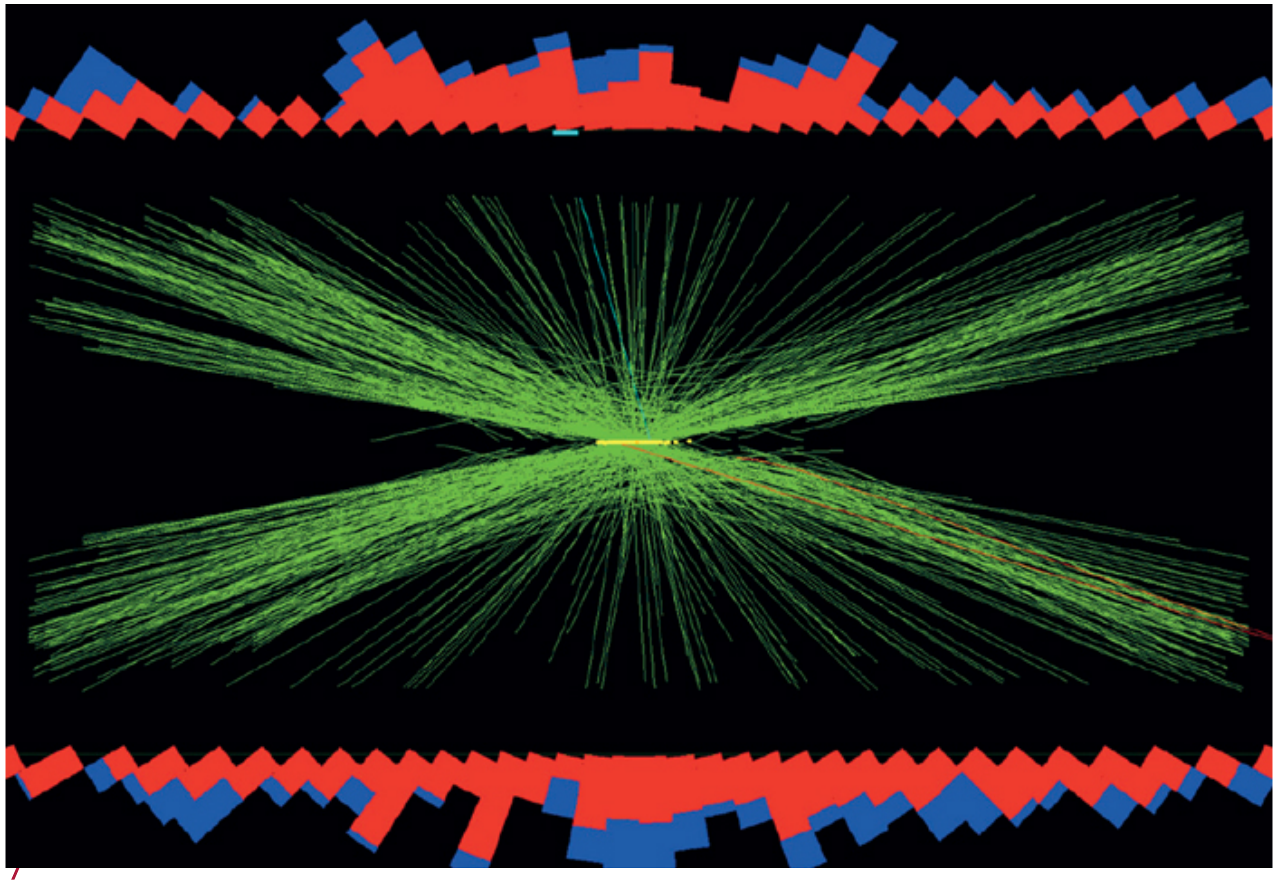

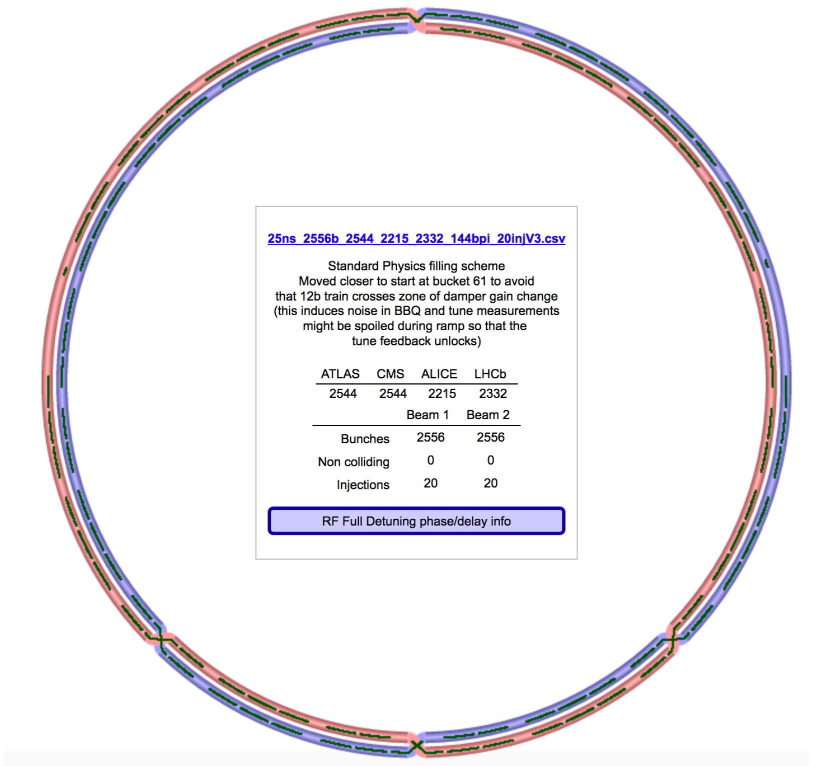

25ns_2556b_2544_2215_2332_144bpi_20injV3.csv

Standard Physics filling scheme
Moved closer to start at bucket 61 to avoid
that 12b train crosses zone of damper gain change
(this induces noise in BBQ and tune measurements
might be spoiled during ramp so that the
tune feedback unlocks)

ATLAS	CMS	ALICE	LHCb
2544	2544	2215	2332

	Beam 1	Beam 2
Bunches	2556	2556
Non colliding	0	0
Injections	20	20

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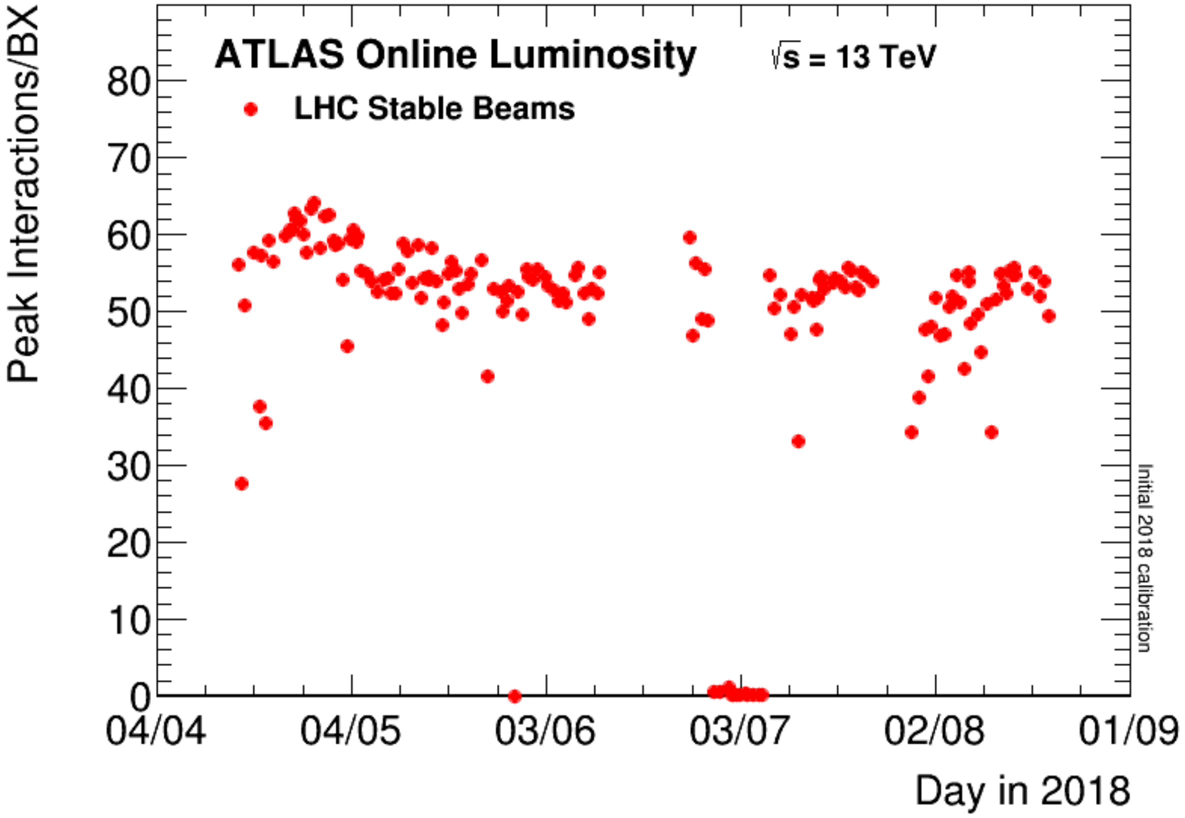

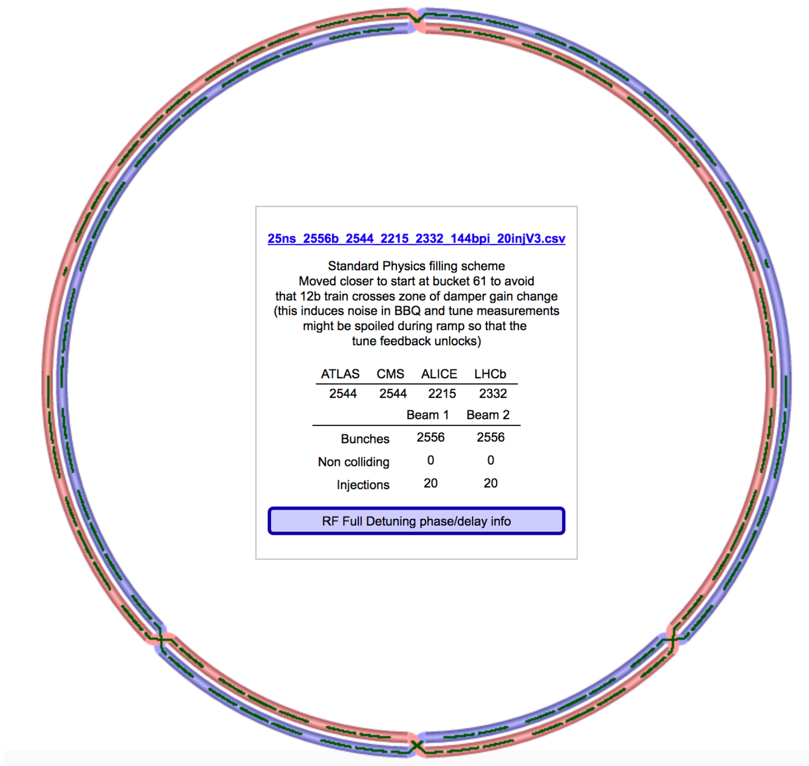

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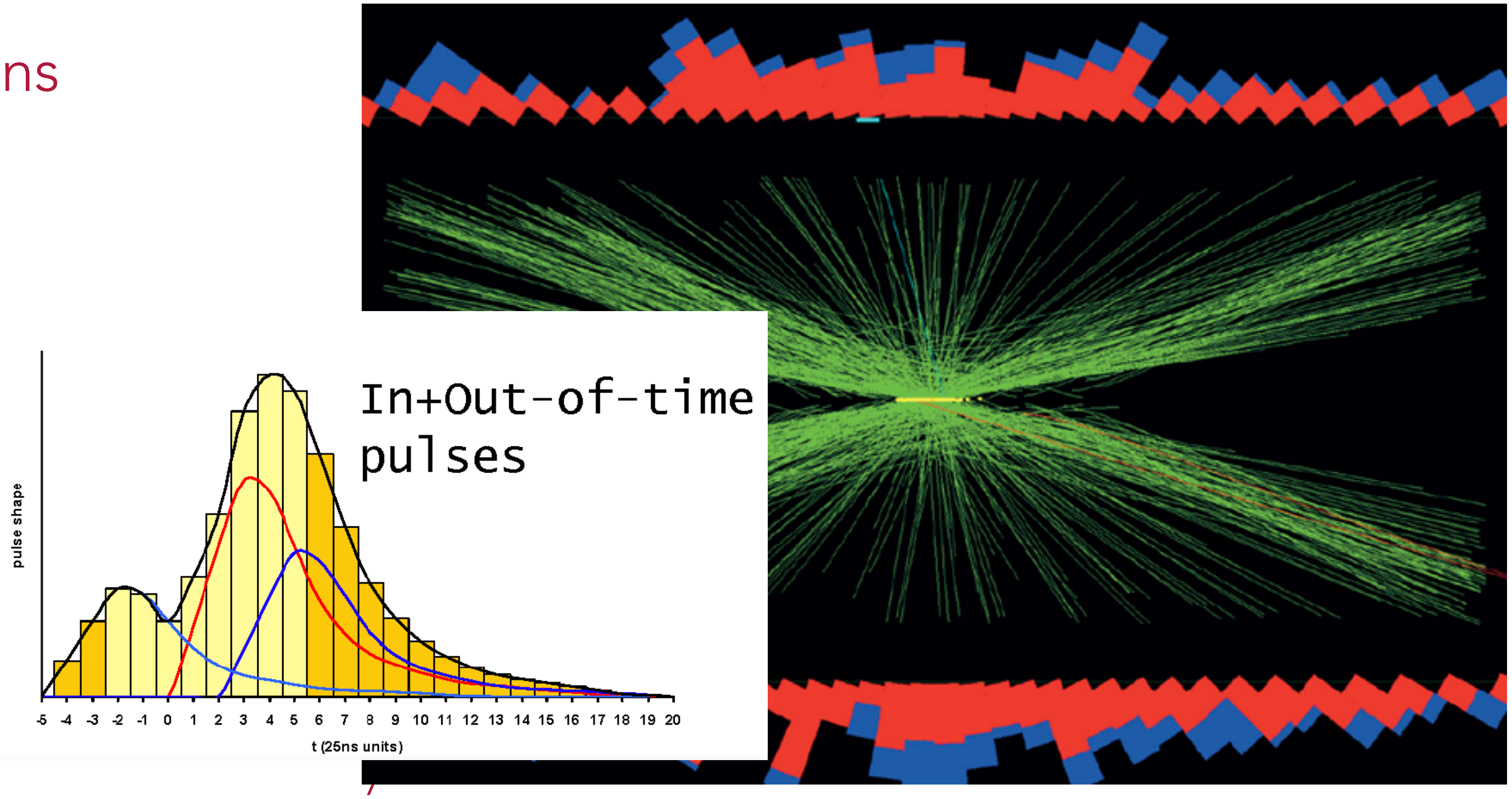
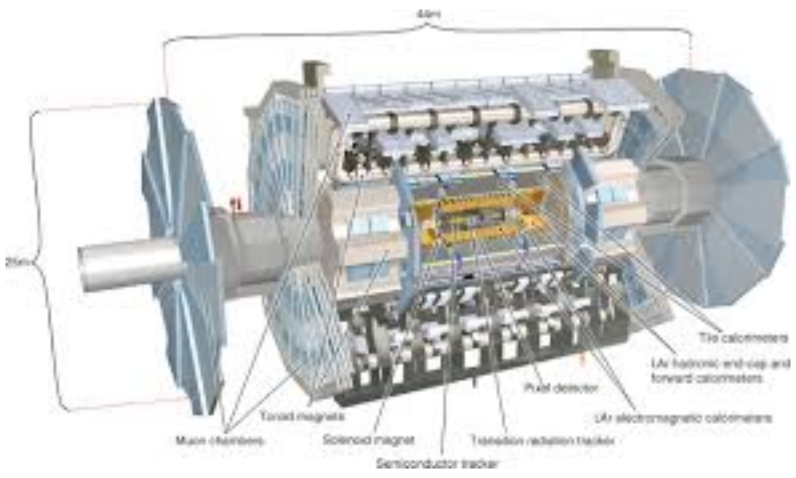
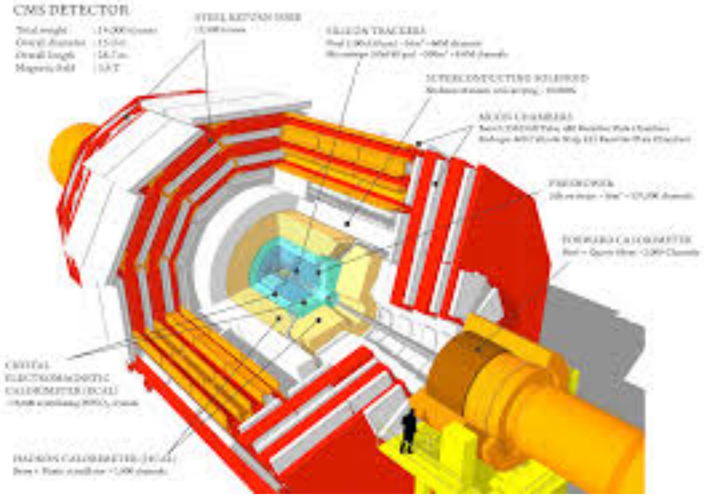
RF Full Detuning phase/delay info

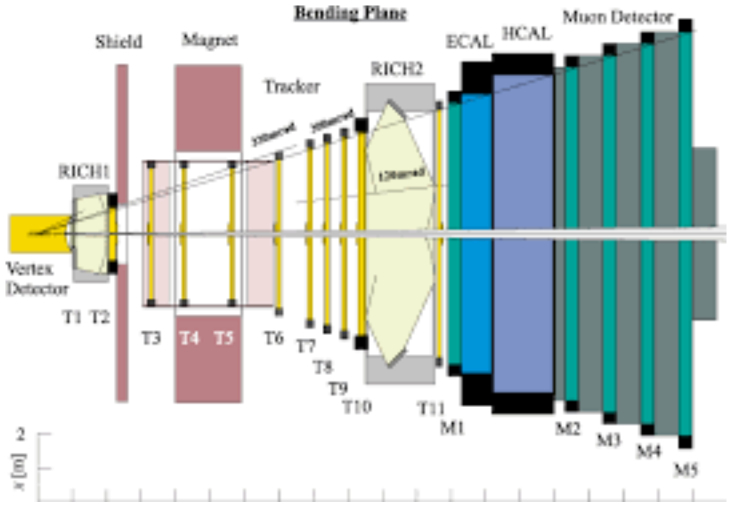


In+Out-of-time pulses

THE CHALLENGE: PART 3







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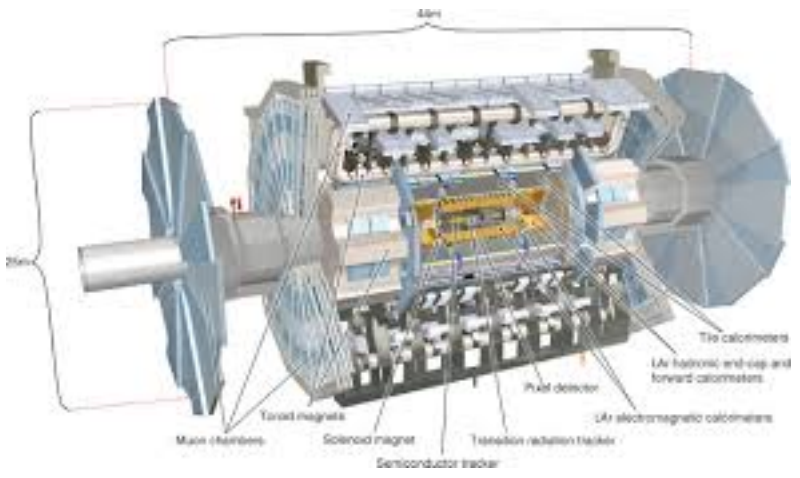

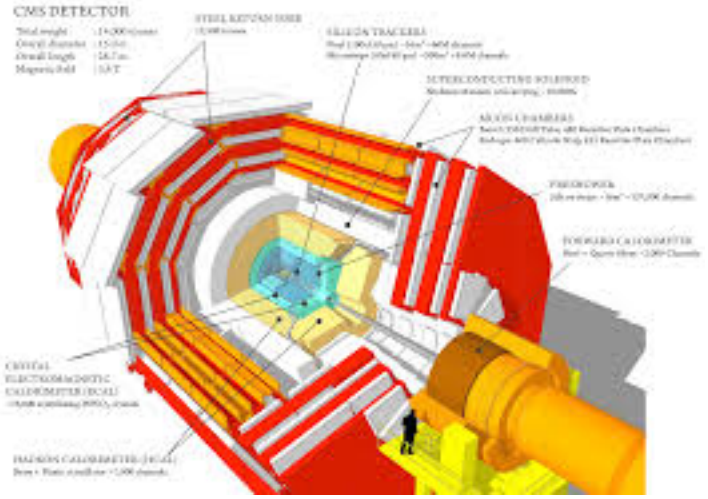

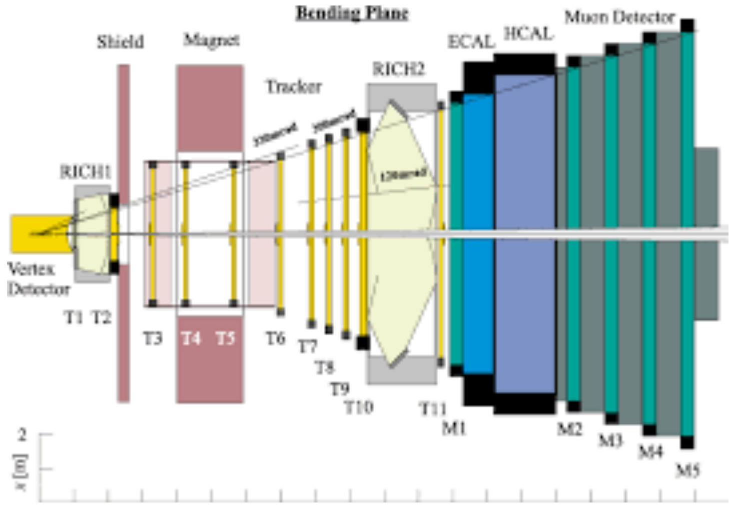

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  - Number of channels: ~100M (ATLAS/CMS); (1M LHCb)
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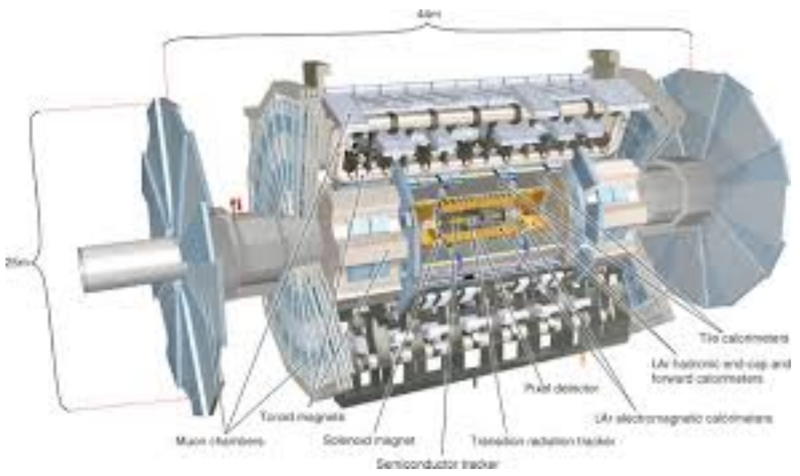

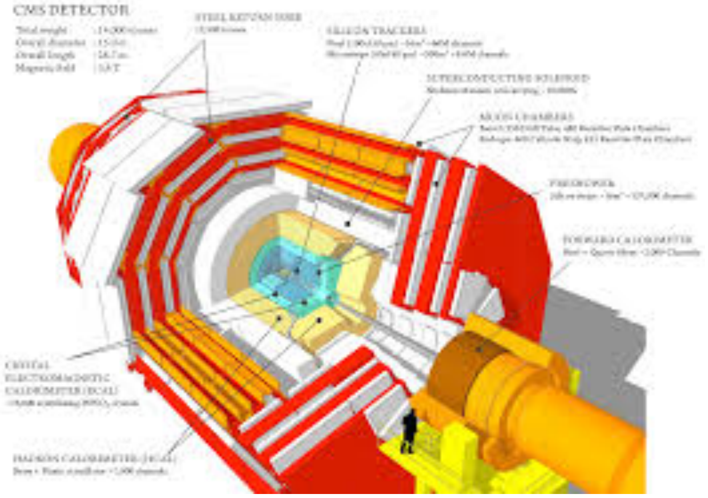

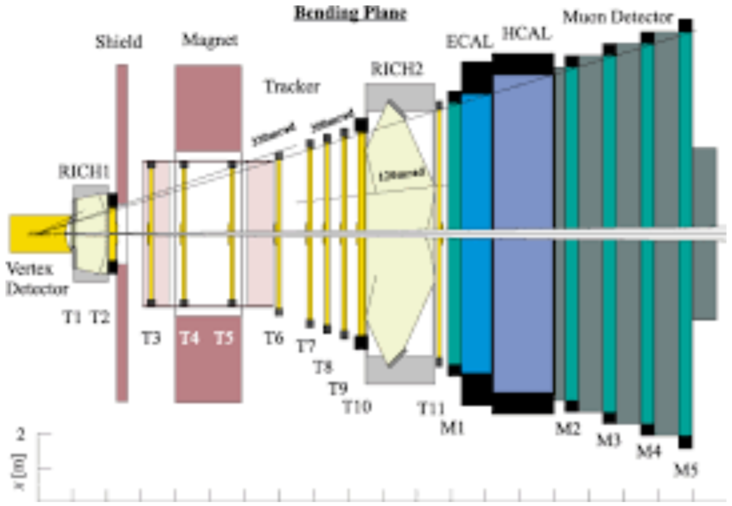

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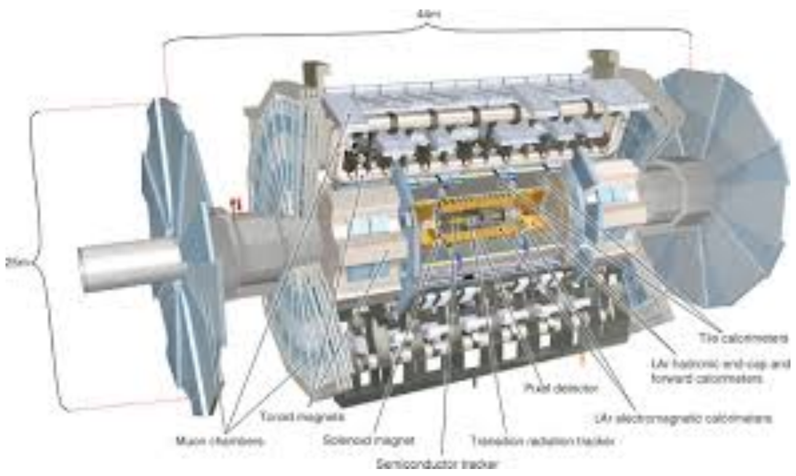

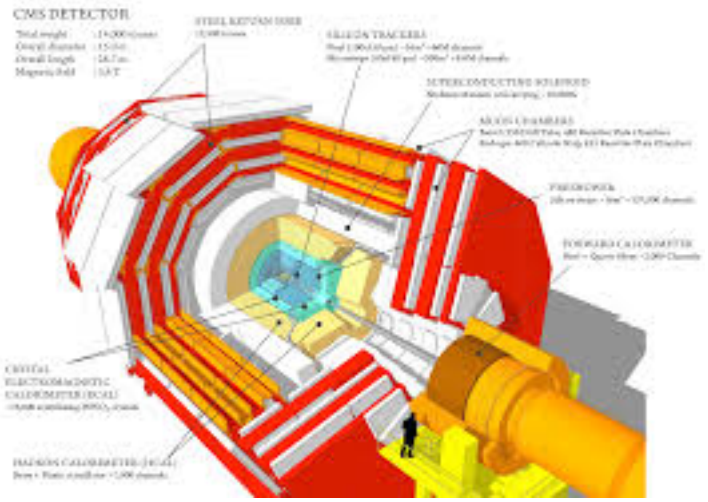

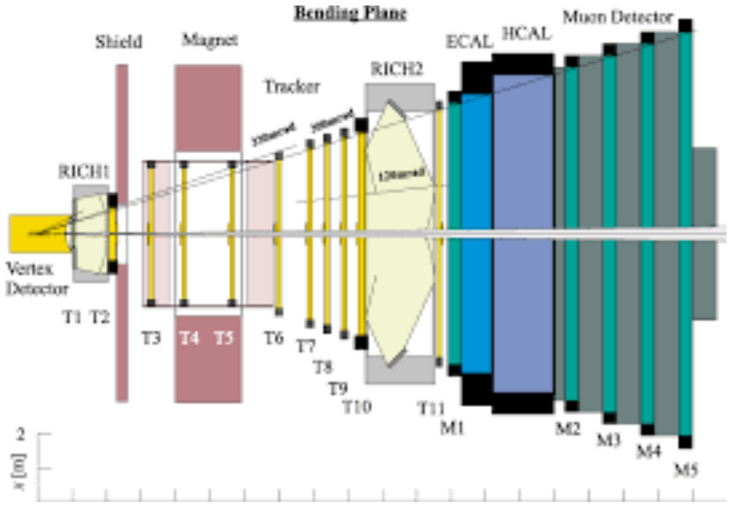

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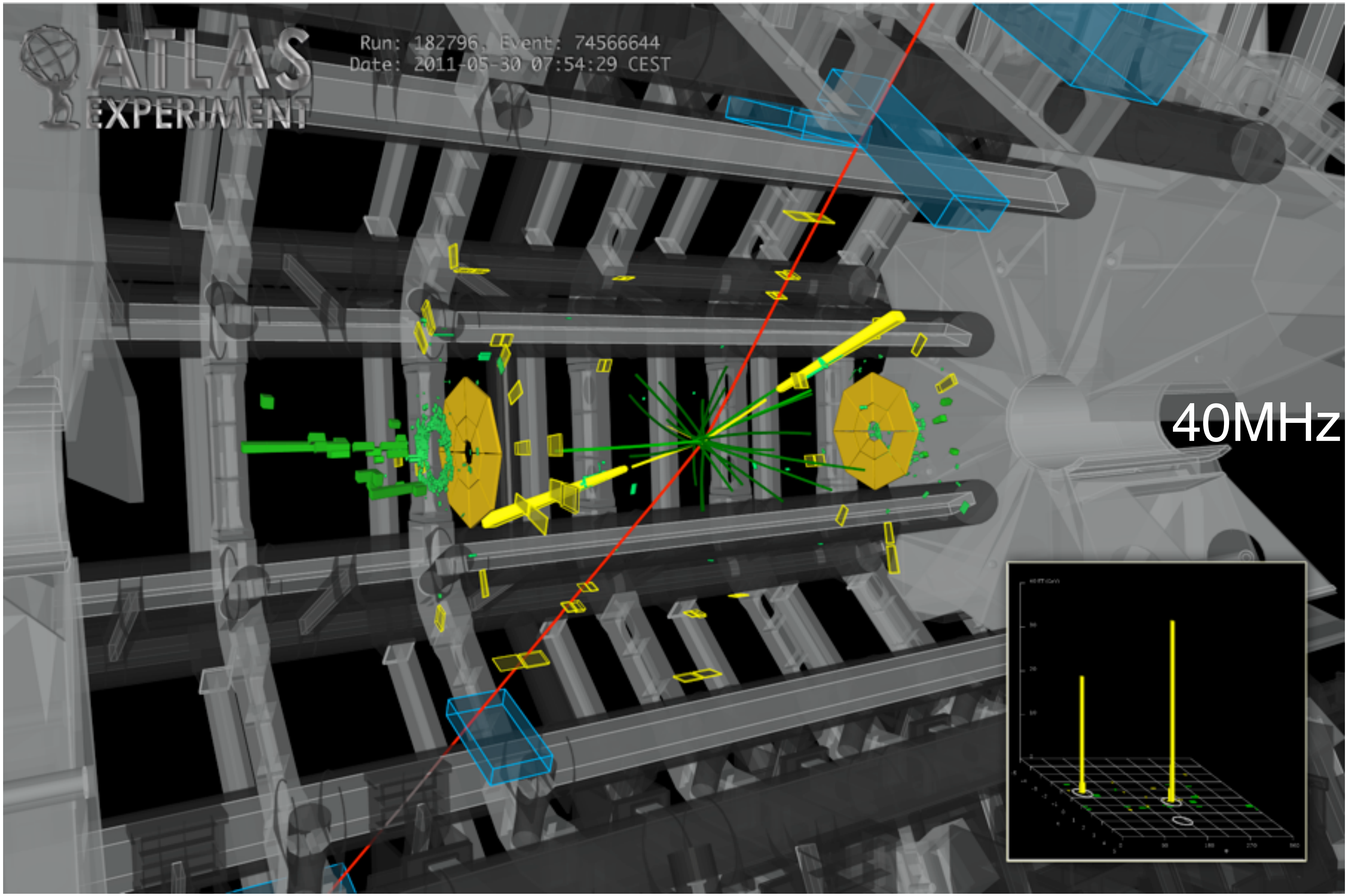
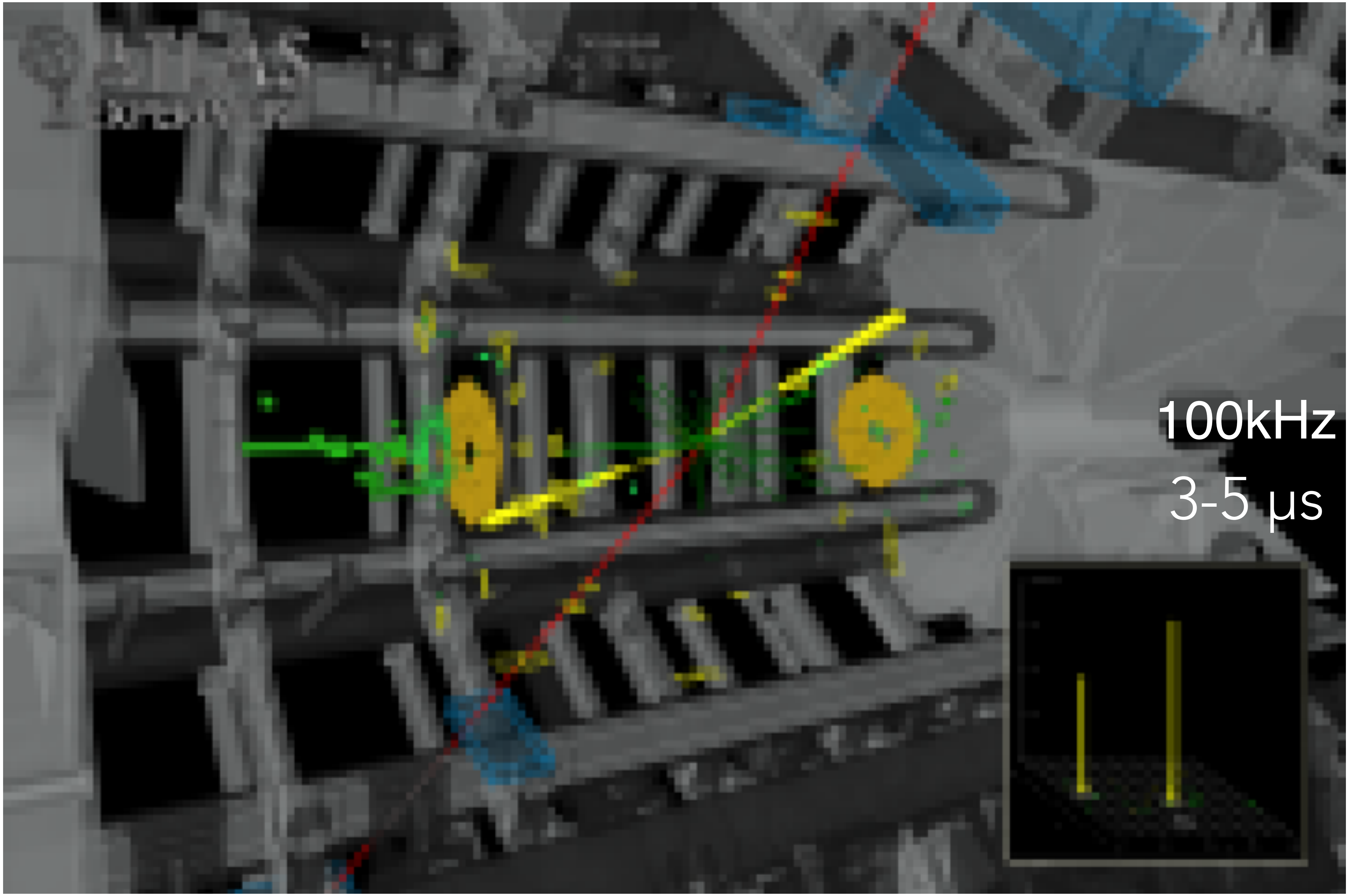
  - Can't write all of it — 150000 PB/year!
- There are a number of bottlenecks to contend with:
  - Local, on detector data storage — how much data can I store on my detector before shipping it out?
  - How fast can I get data off my detector — what are my readout bandwidth limitations?
  - How much data can I write to storage — can my output bandwidth, disk space and computing resources cope?

RECORDING THE DATA: MULTI-STEP APPROACH



40MHz

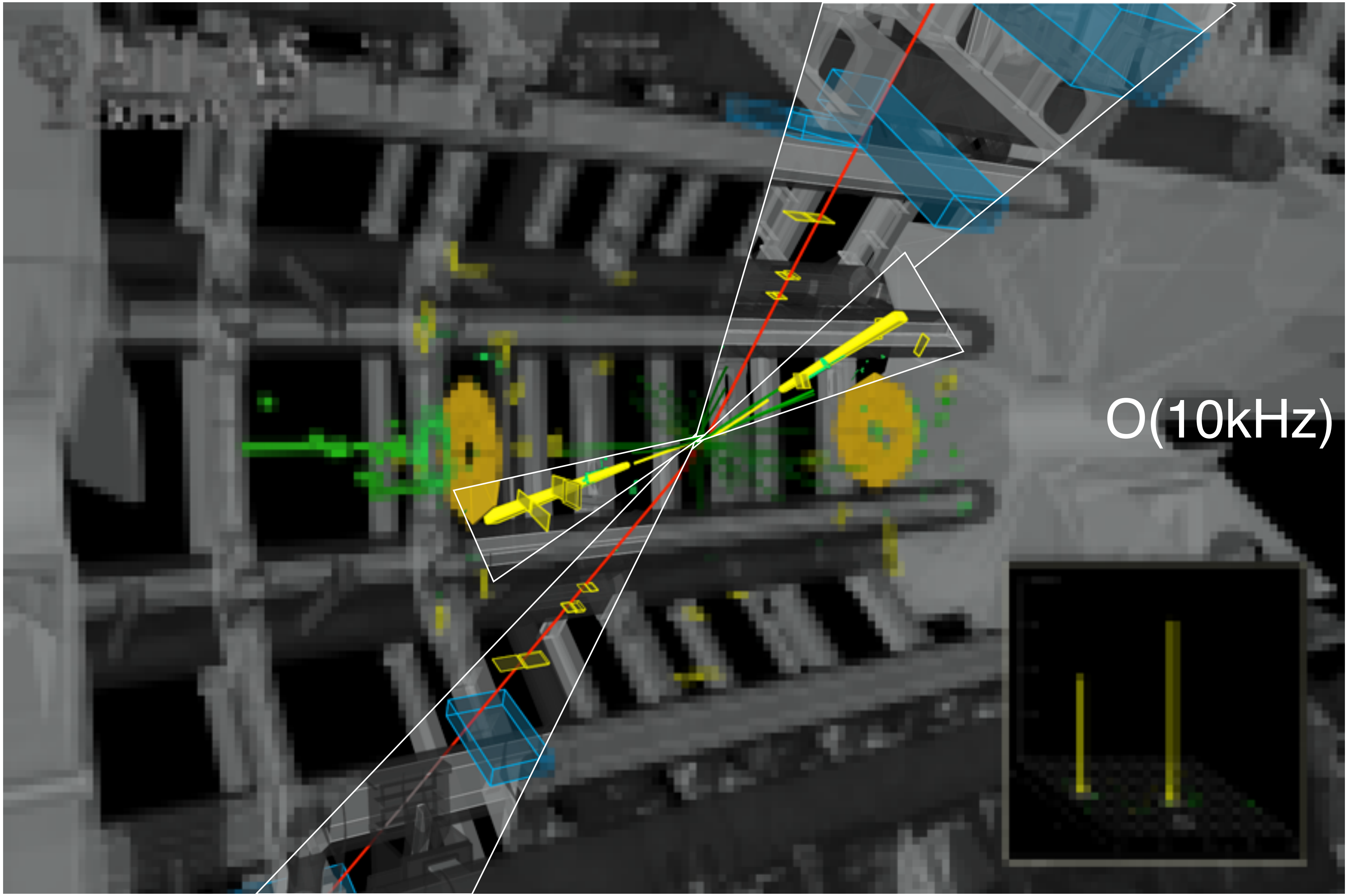
STEP 1: QUICK AND DIRTY



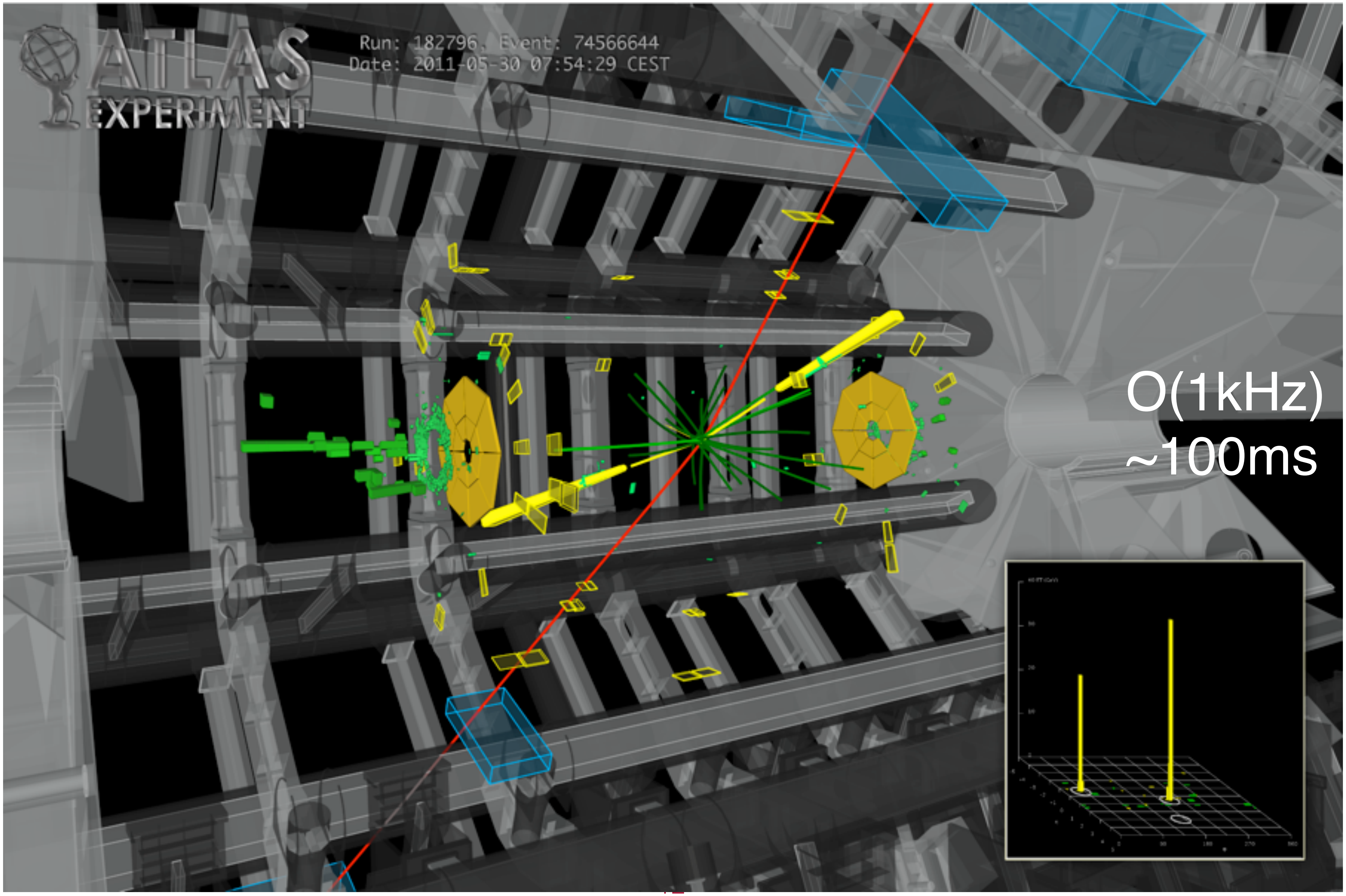
100kHz

3-5 μs

STEP 2: SELECTIVE SIGHT



STEP 3: THE FULL PICTURE (ALMOST)



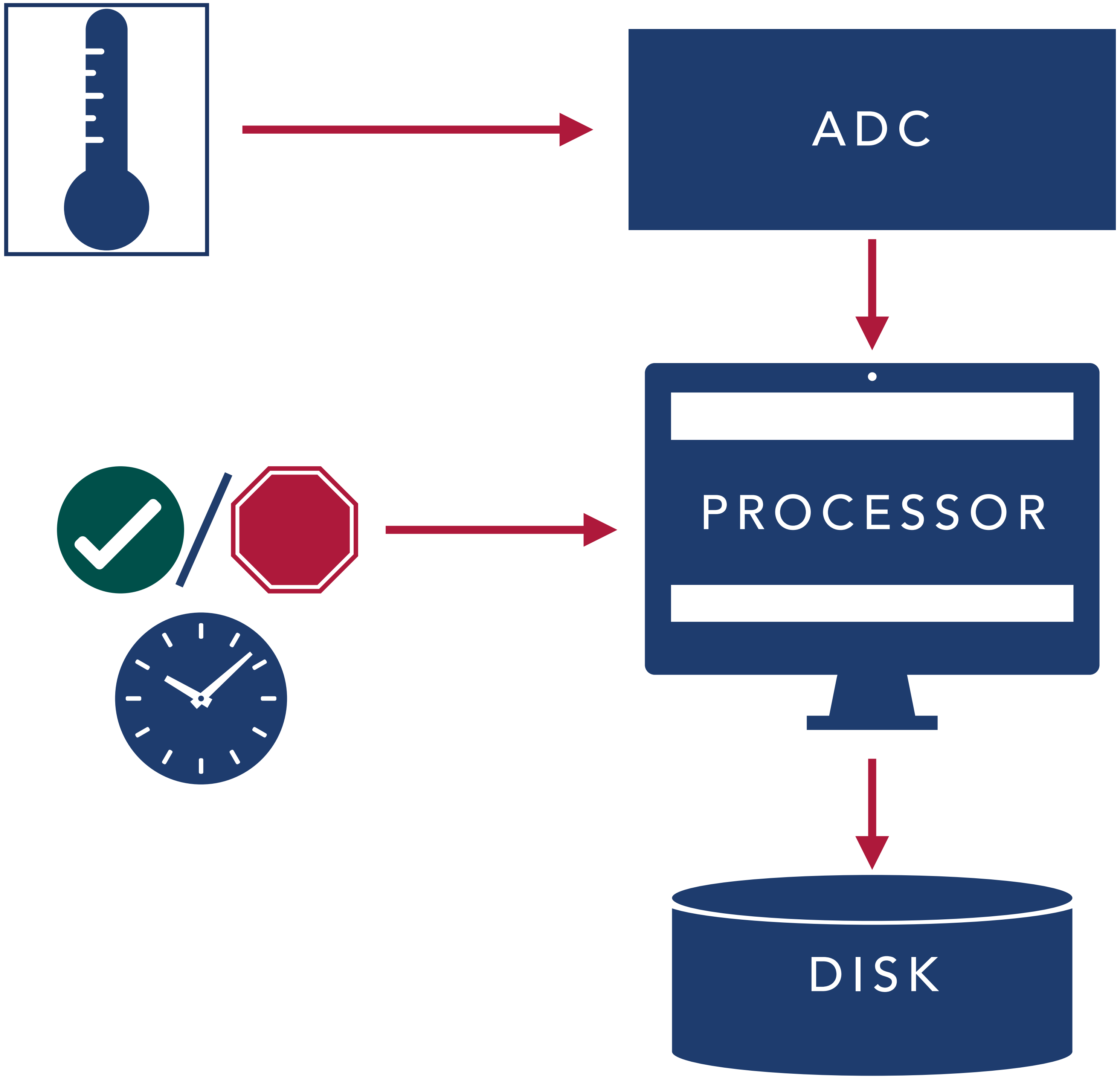
O(1kHz)

~100ms

LET'S START WITH AN EXAMPLE

DRAWS HEAVILY FROM EXAMPLE BY ANDREA NEGRI

FIXED FREQUENCY PROCESSING



- How is an event defined?
- What is the processing time per event?
- What is the maximum sustainable readout rate?

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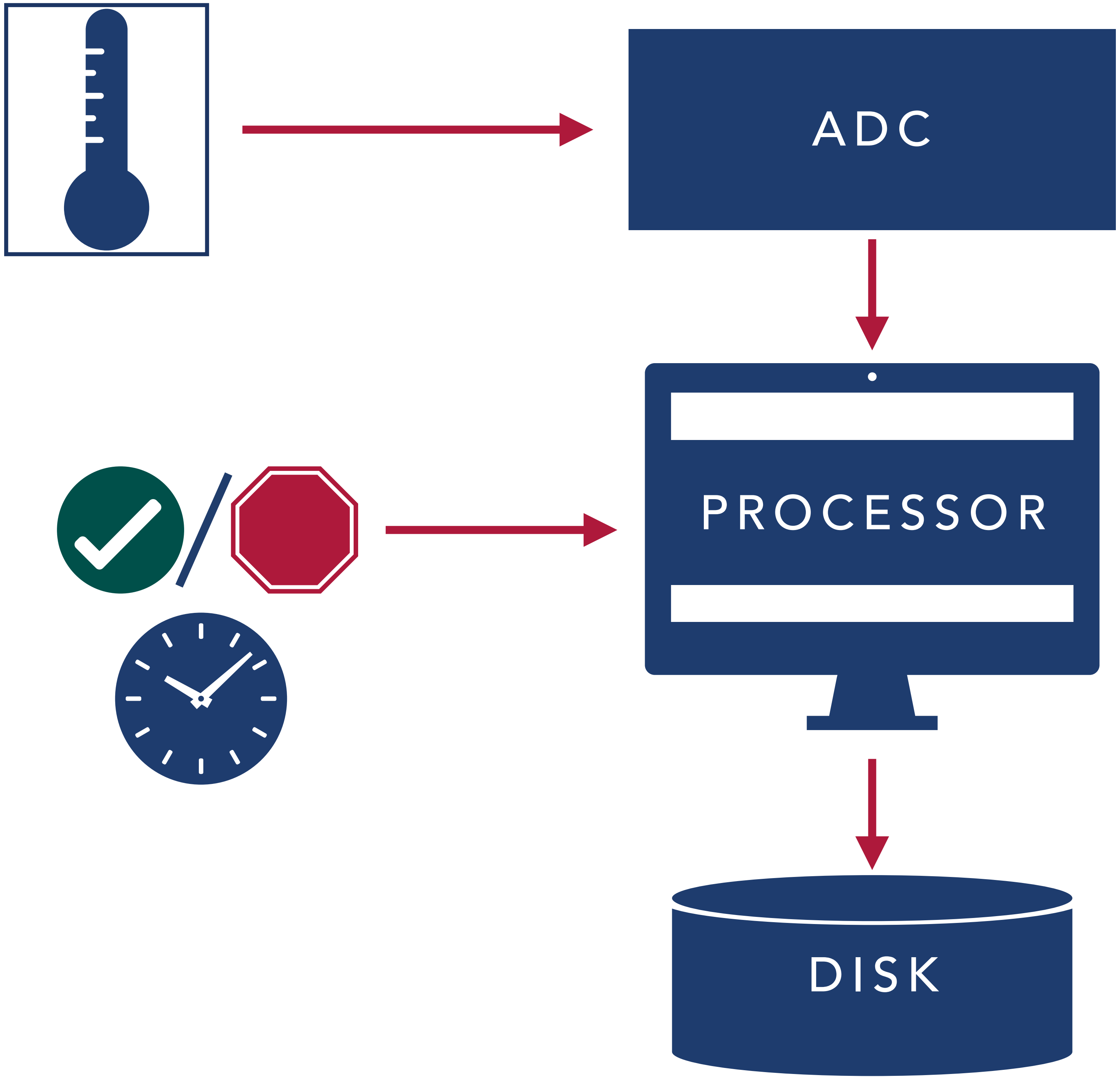

ADC

PROCESSOR

DISK

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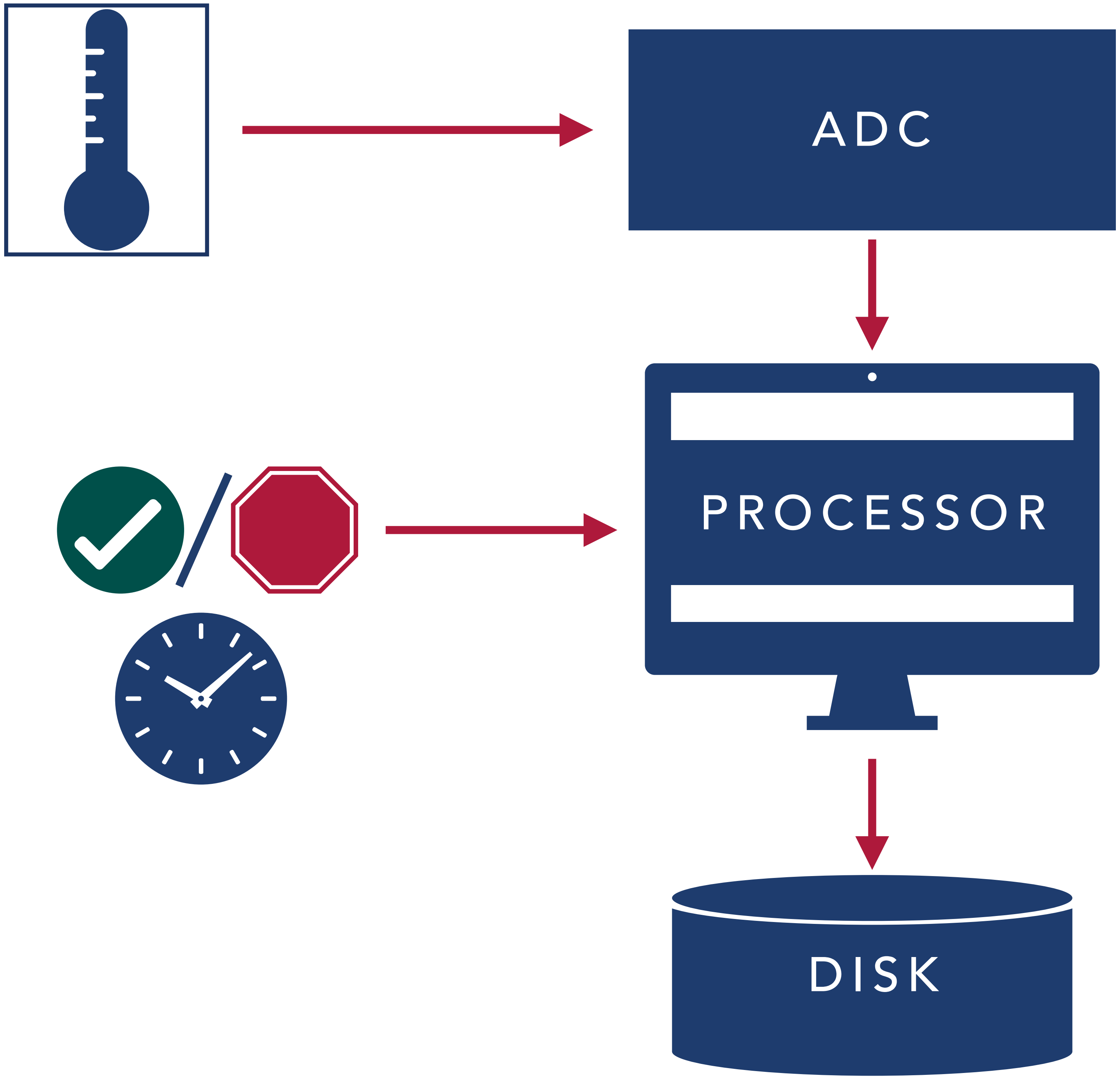

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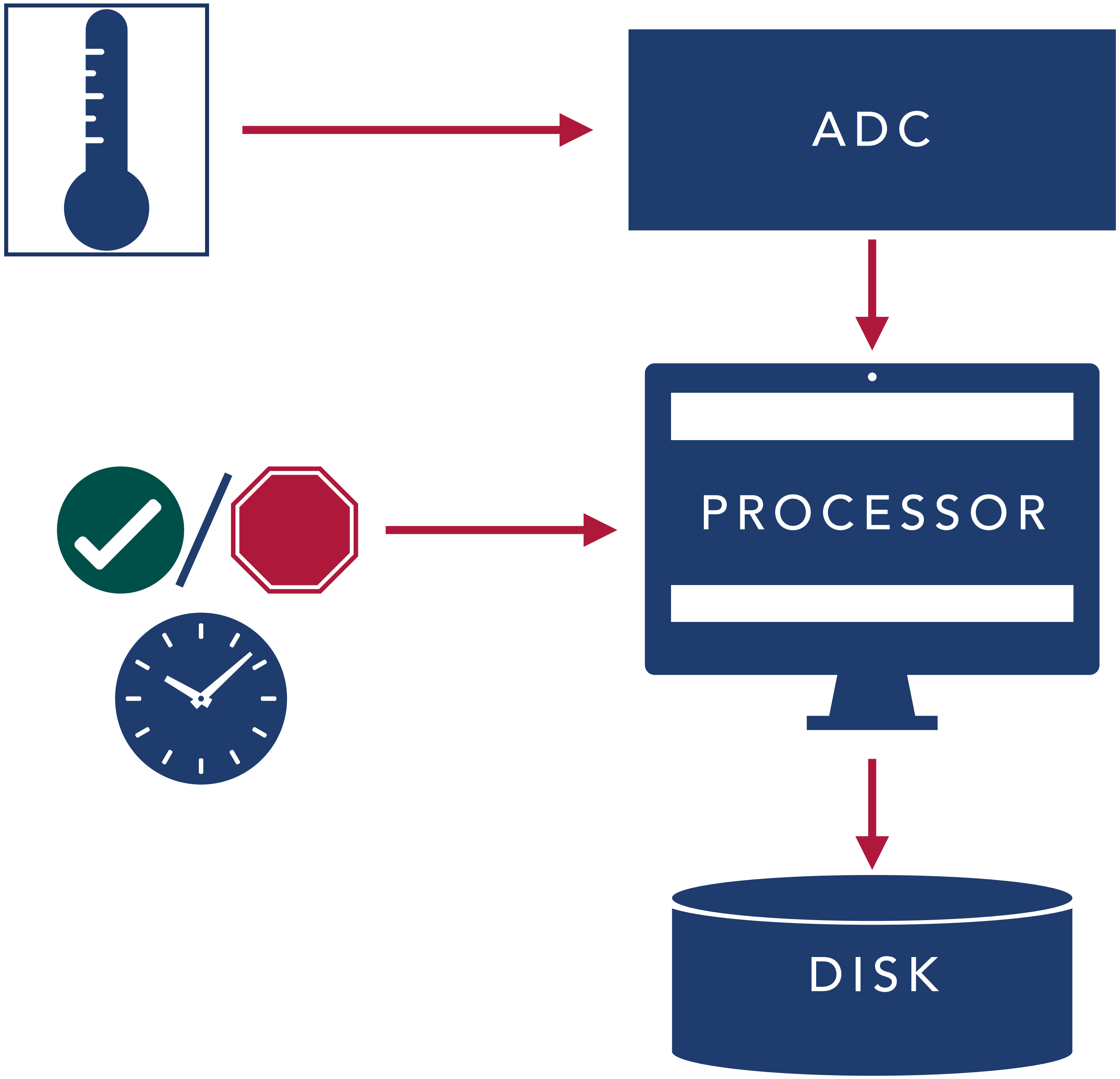

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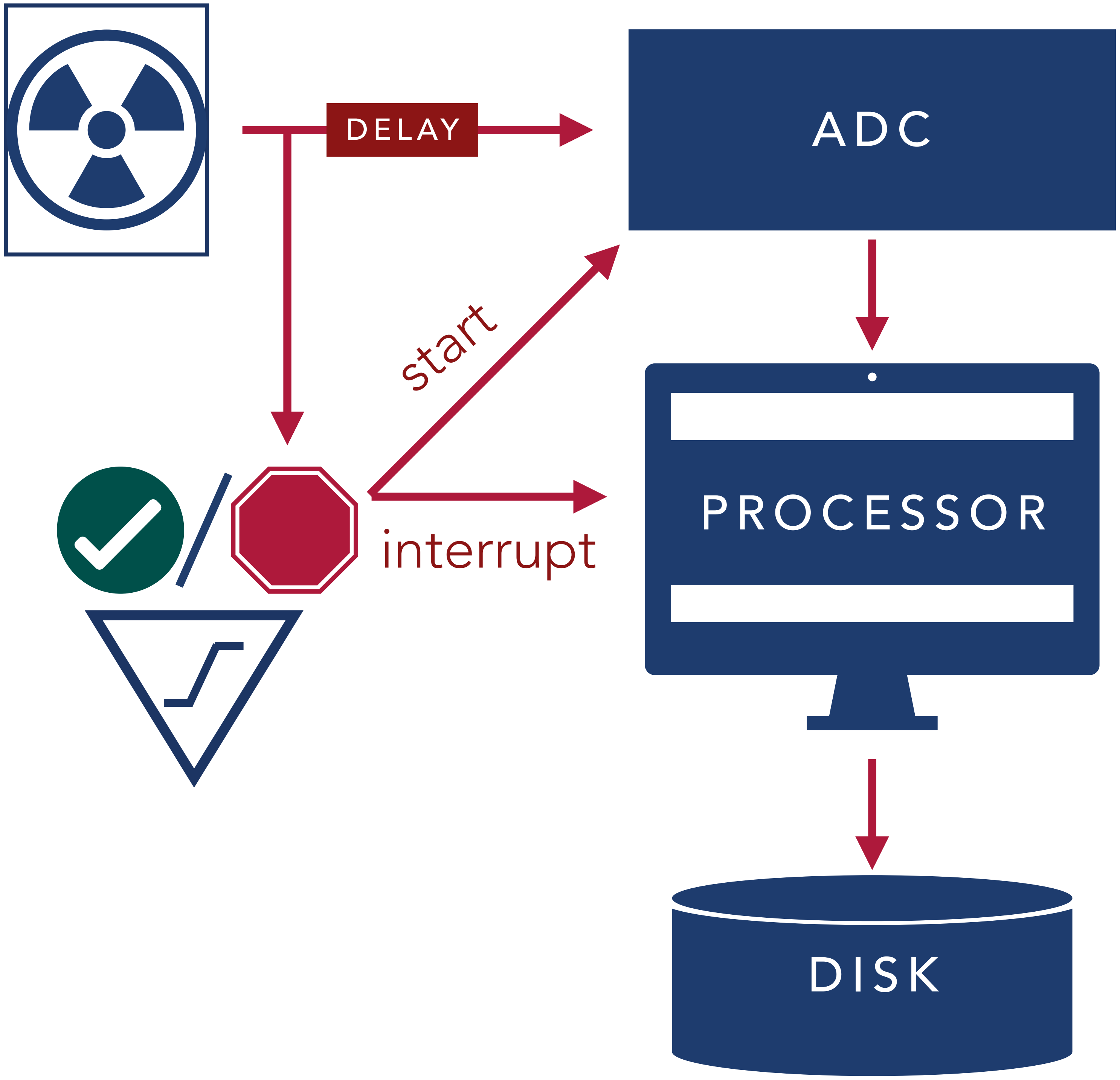
  - $R = 1/\tau$
  - If τ = 1ms ; R = 1kHz

STOCHASTIC PROCESSING



DELAY

ADC

start

interrupt

PROCESSOR

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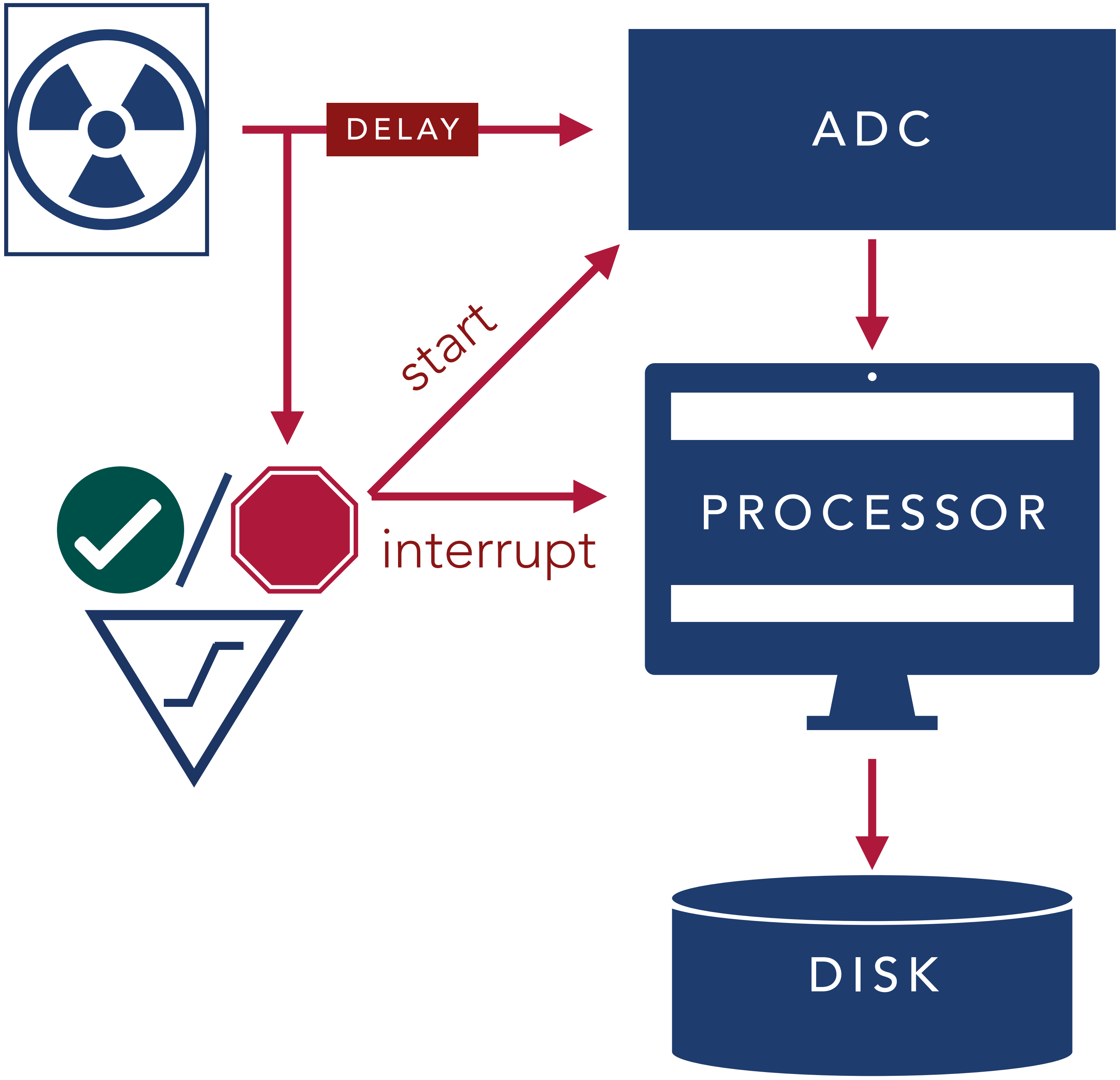

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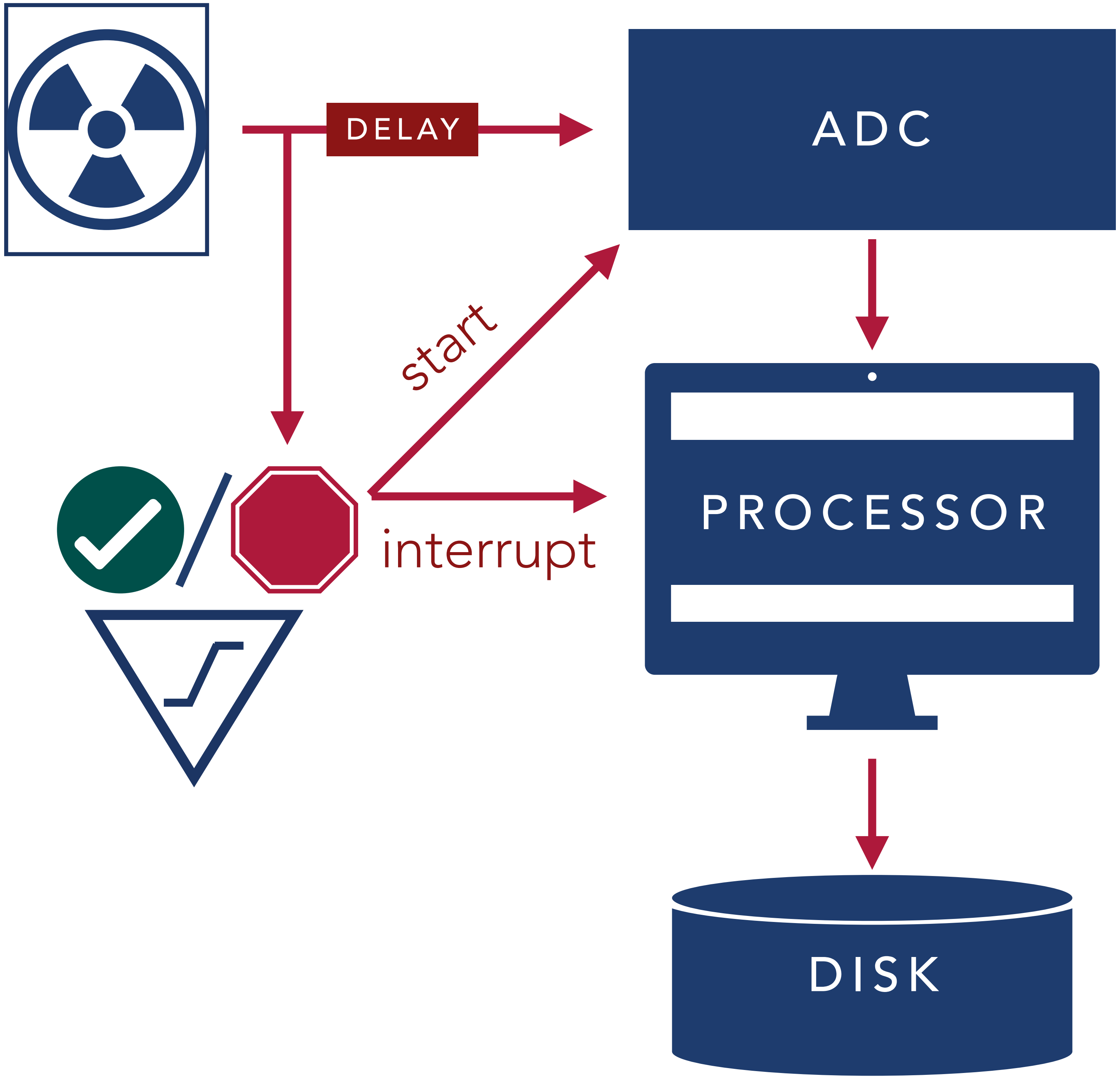

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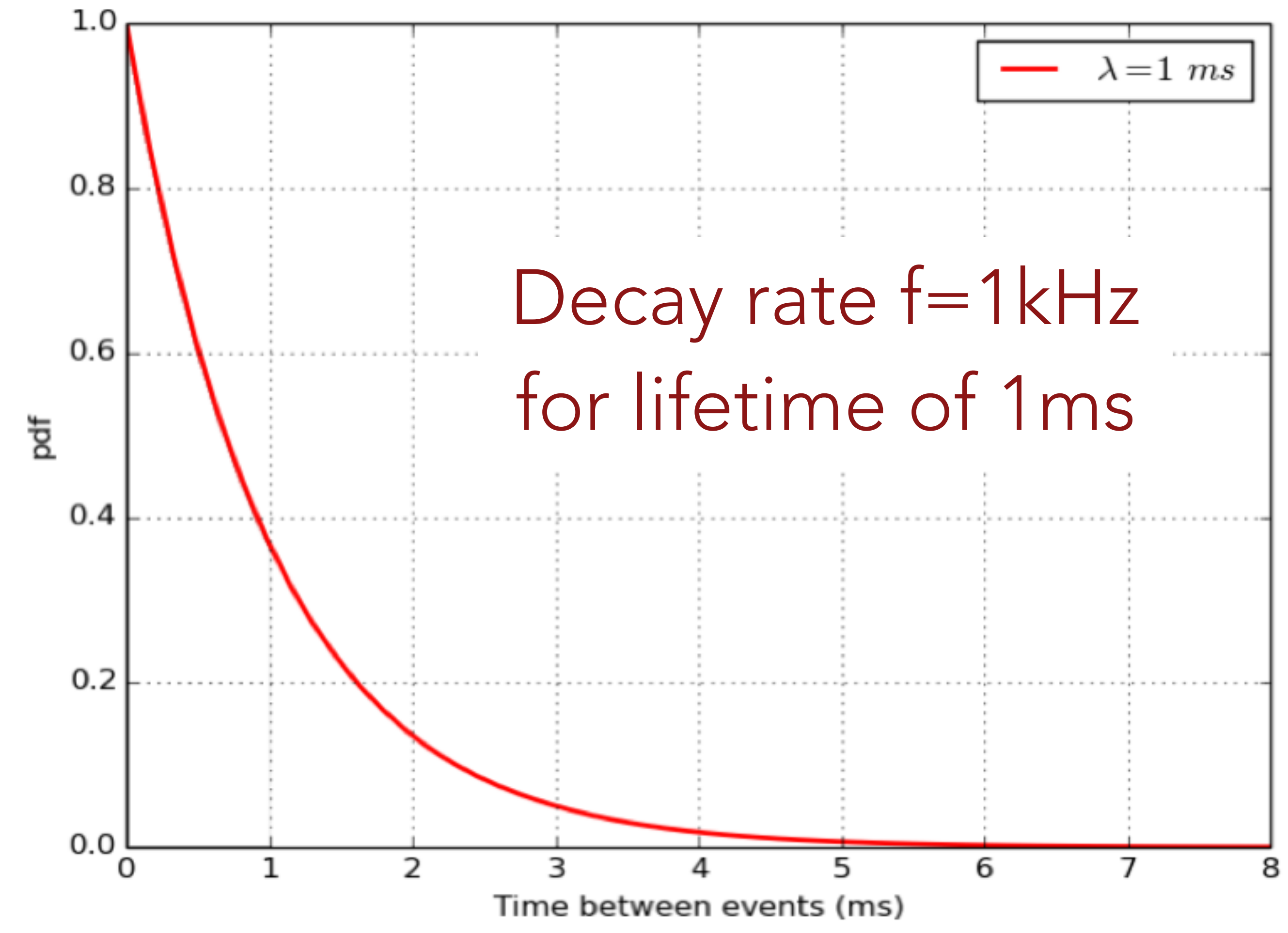
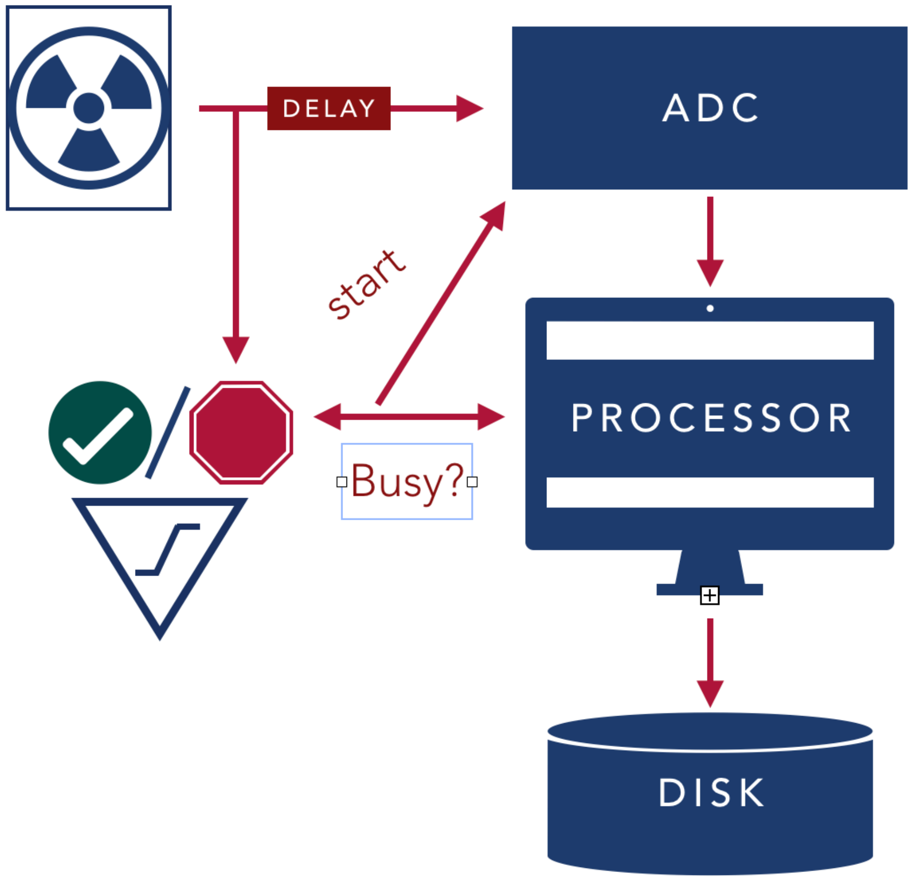
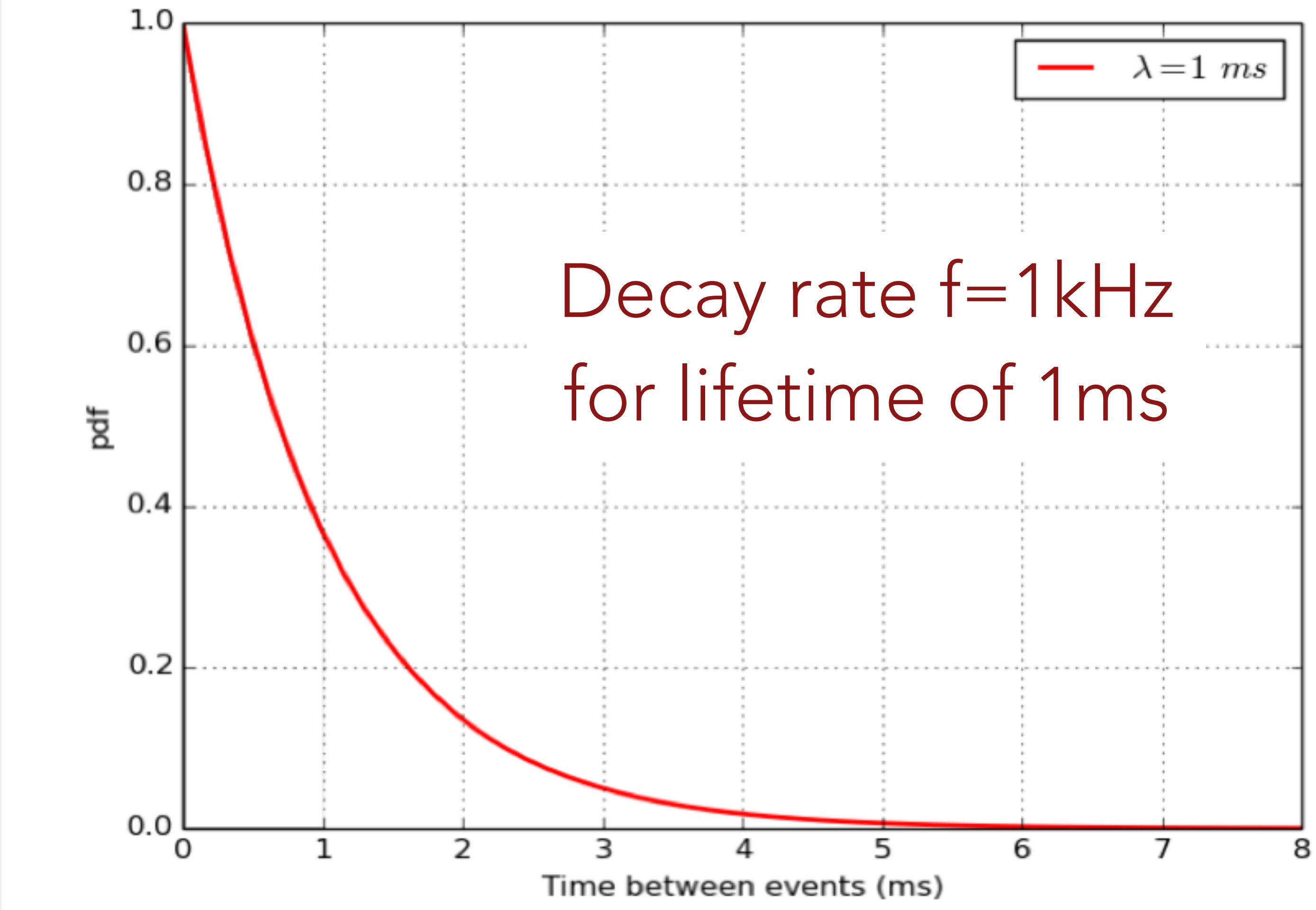


Decay rate f=1kHz
for lifetime of 1ms





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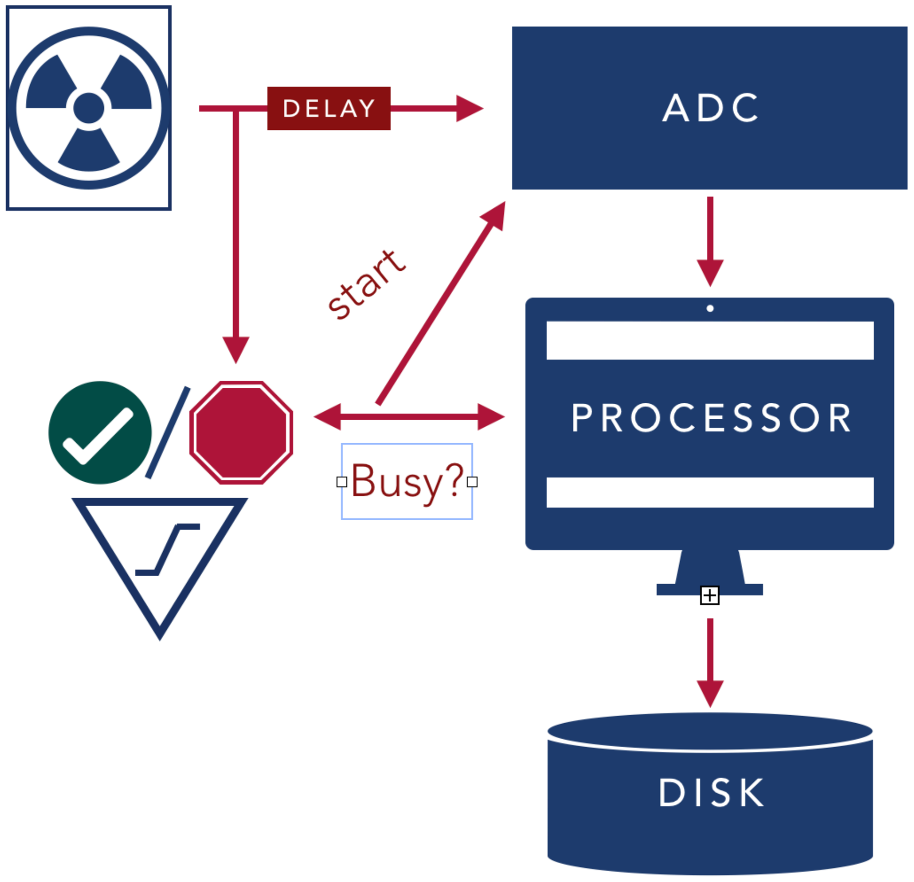

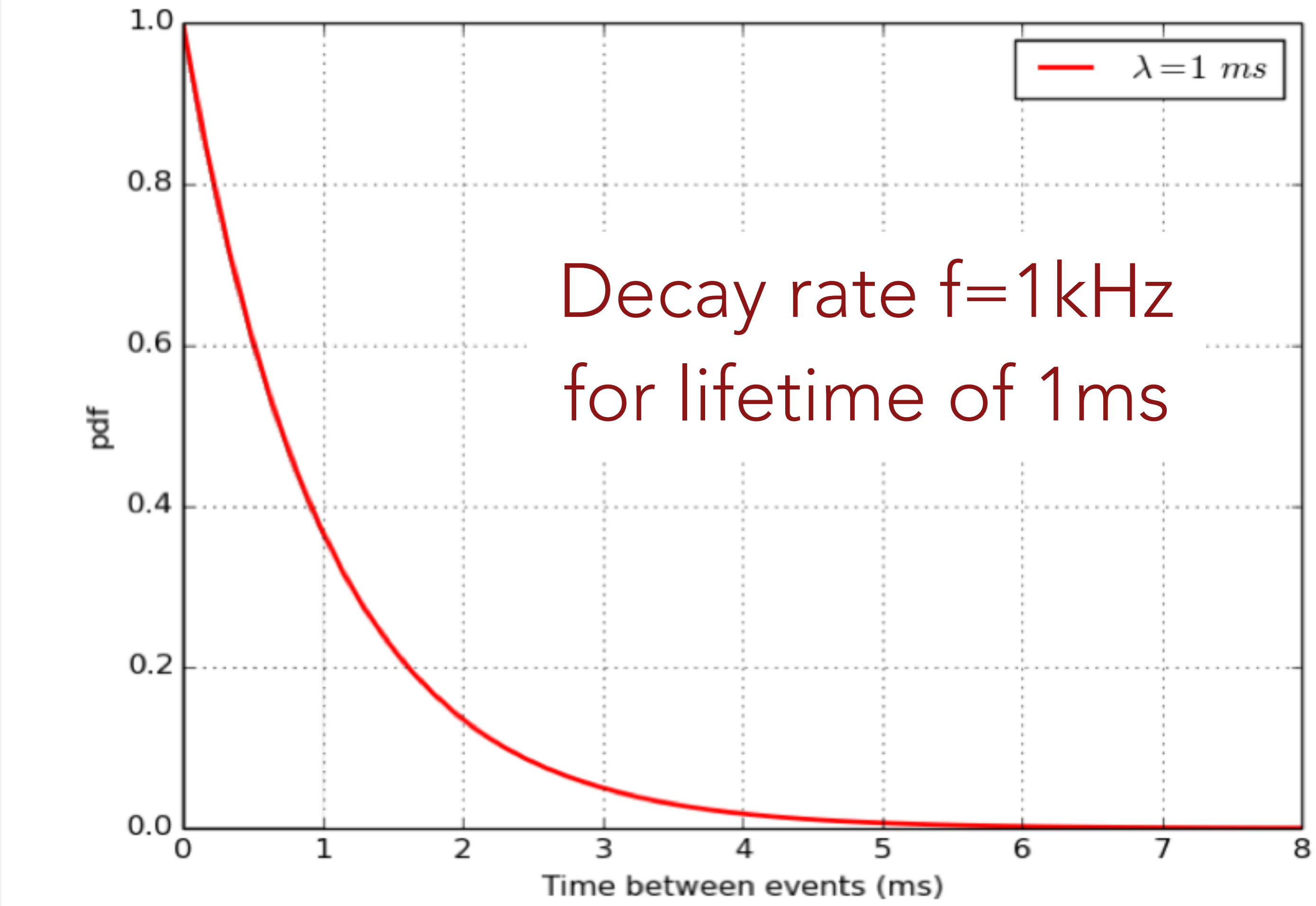

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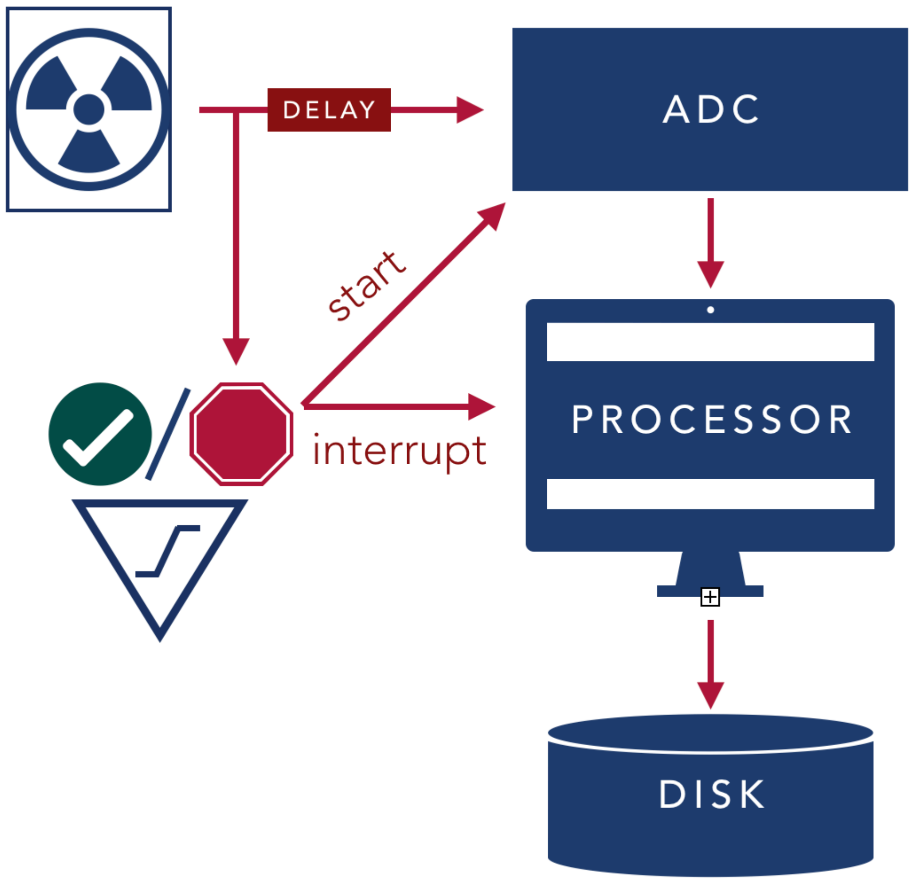

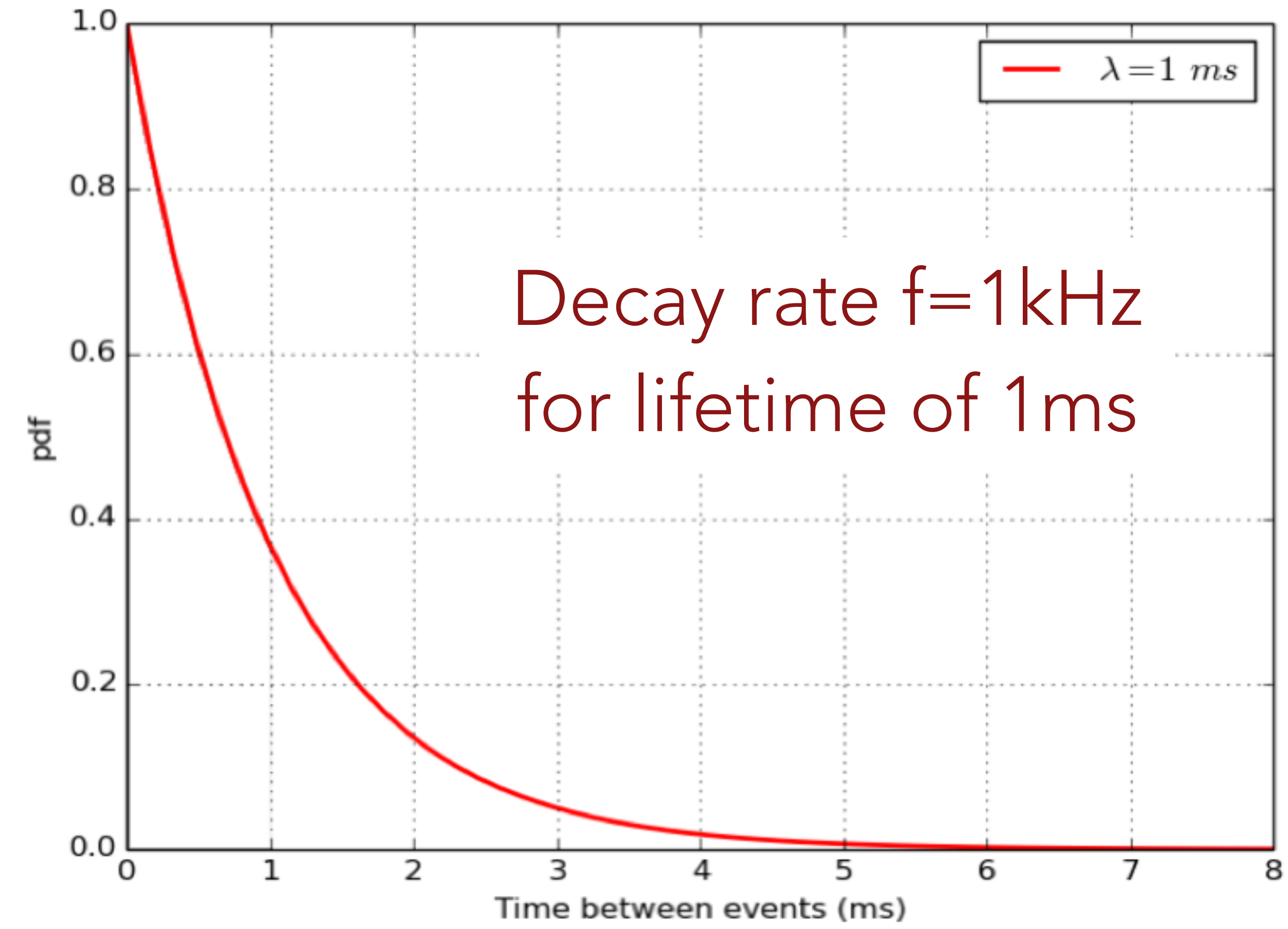

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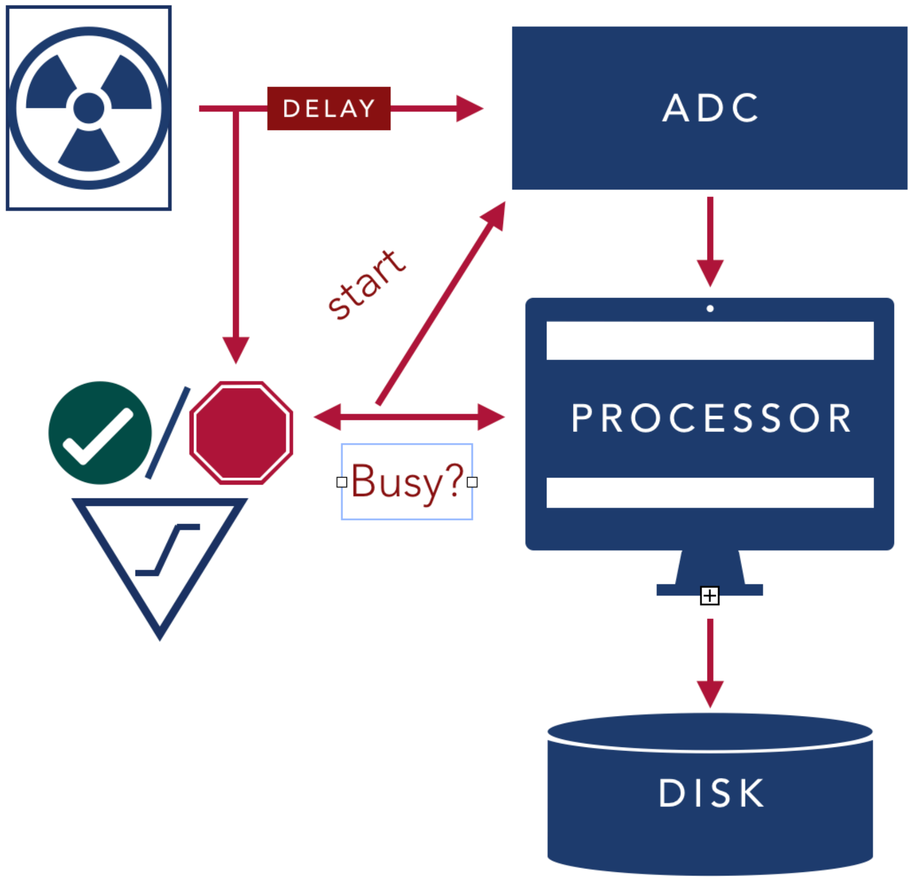

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BRIEF PAUSE TO REGROUP

- For stochastic processes, our system needs to be able to:
    - Determine if there is an “event” (trigger)
    - Process and store the data from the event (acquisition)
    - Have a ***feedback*** mechanism so that the trigger knows if the data processing pipeline is free to process a new event

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  - $P[\text{busy}] = \tau\nu$; $P[\text{free}] = 1 - \tau\nu$
- Therefore, our DAQ rate is $\nu = f\,P[\text{free}] = f\,(1 - \tau\nu)$; $\nu = f/(1+f\tau)$

RATES AND EFFICIENCIES

- What can we say about our DAQ rate relative to our physics process rate?

- What can we say about our efficiency to record events?

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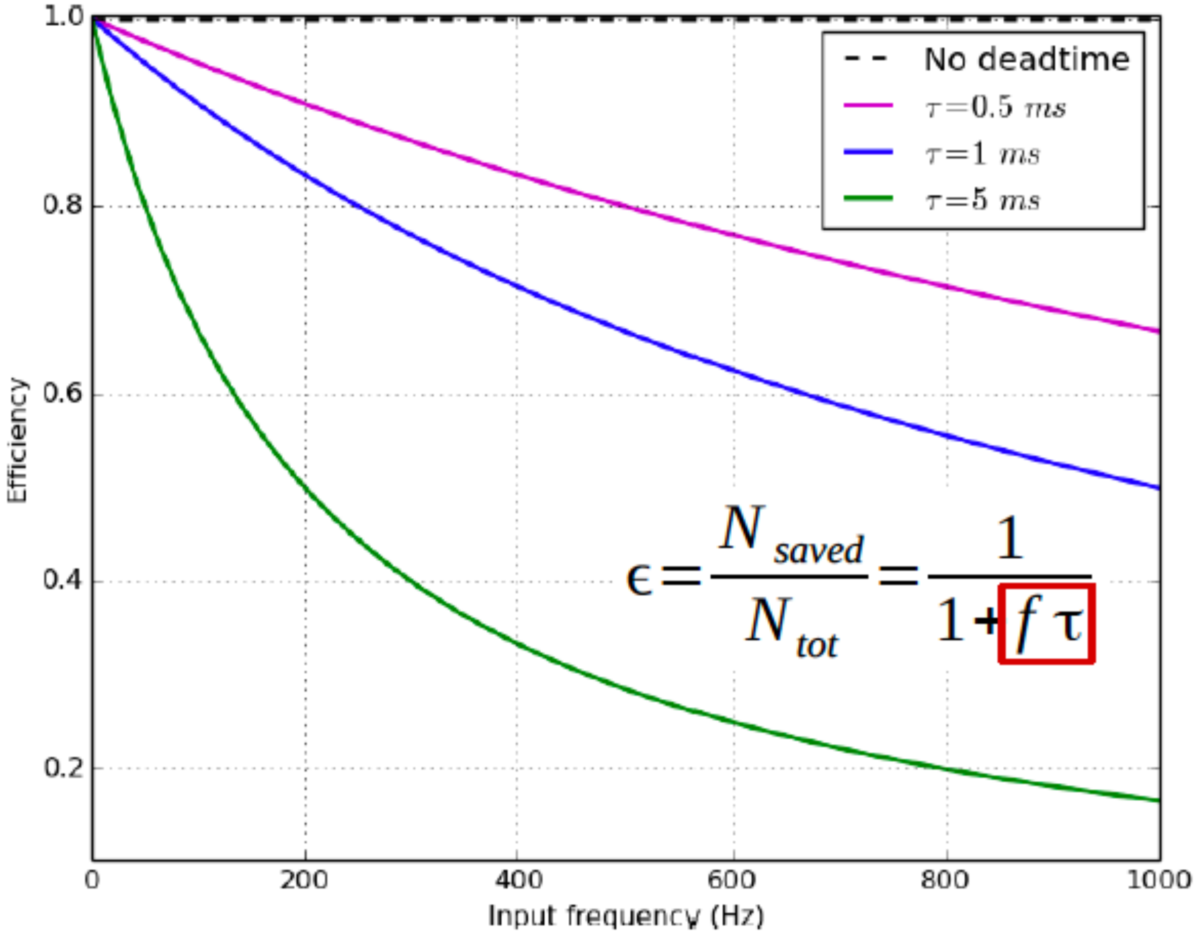

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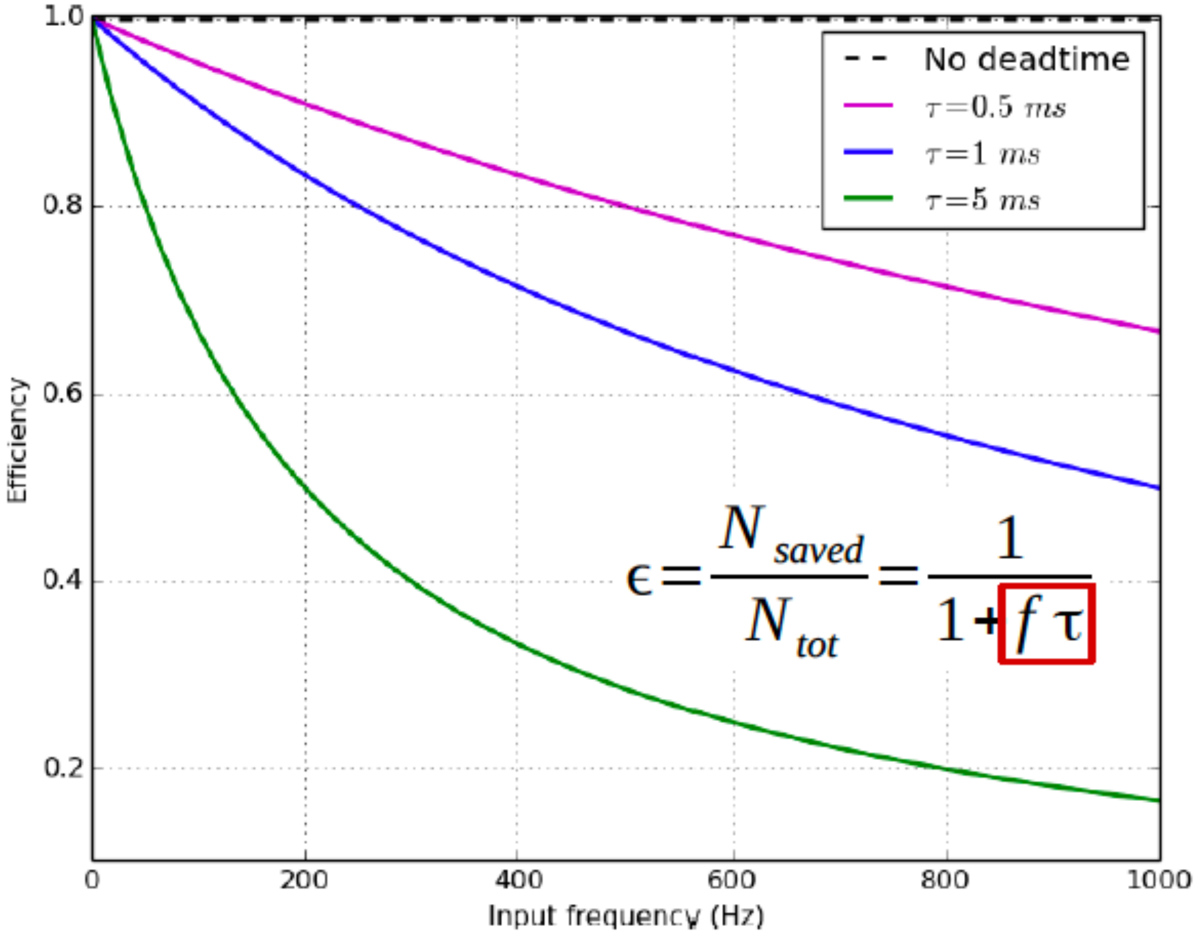
    - We need $f\tau \ll 1$
    - For $\varepsilon = 99\%$ and $f = 1$ kHz we need $\tau = 0.01$ ms!



$$\epsilon = \frac{N_{saved}}{N_{tot}} = \frac{1}{1+\boxed{f\,\tau}}$$

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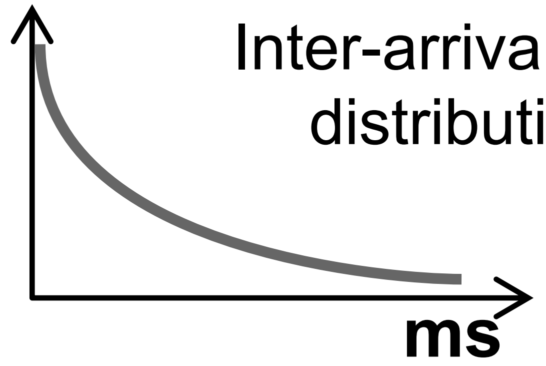

λ (ms) ;
f (Hz)

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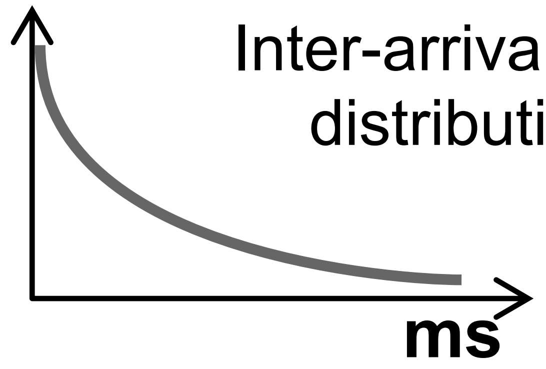

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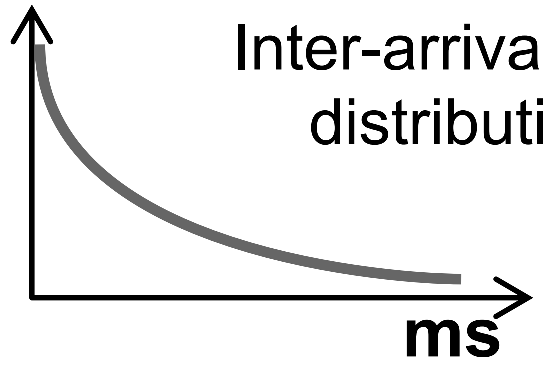

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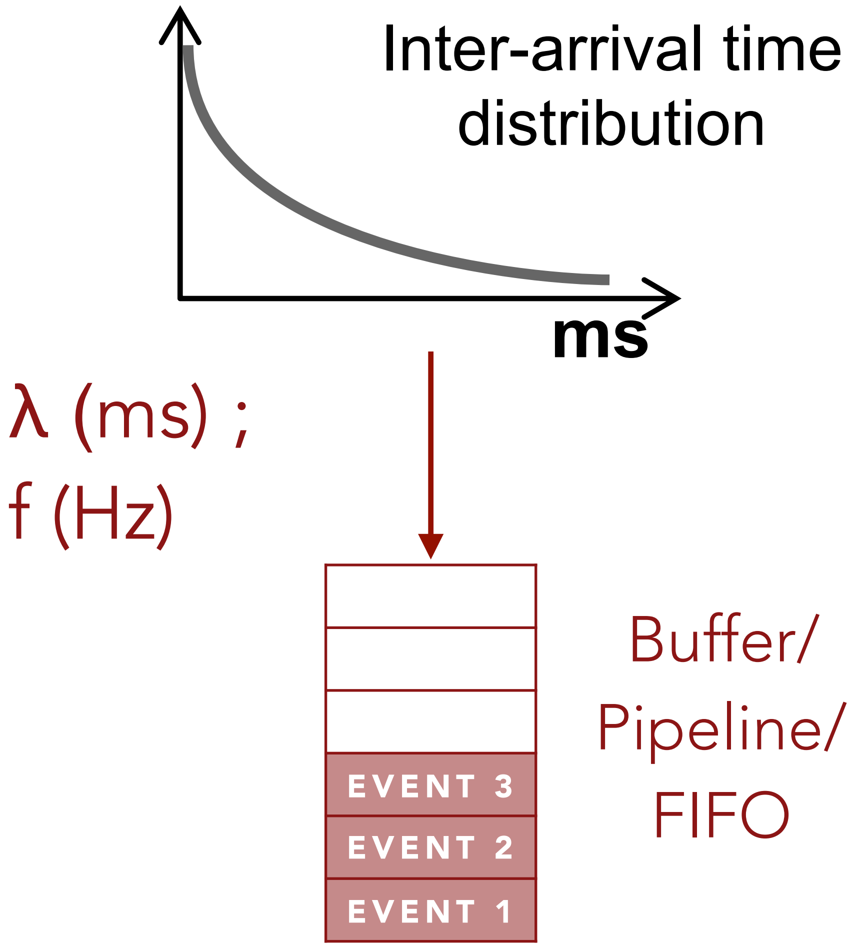

λ (ms) ;
f (Hz)

EVENT 3
EVENT 2
EVENT 1

Buffer/
Pipeline/
FIFO

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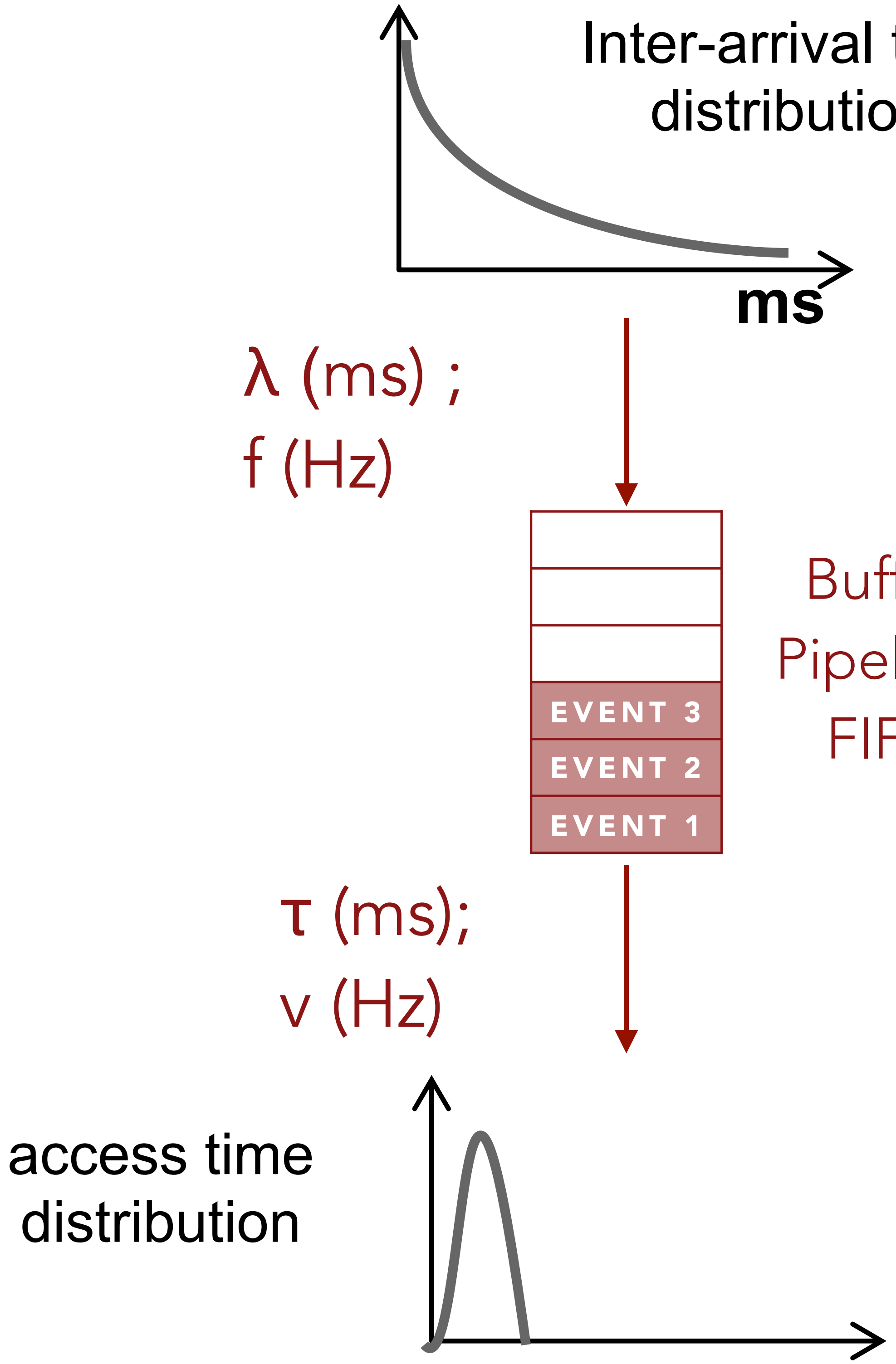


Inter-arrival time distribution

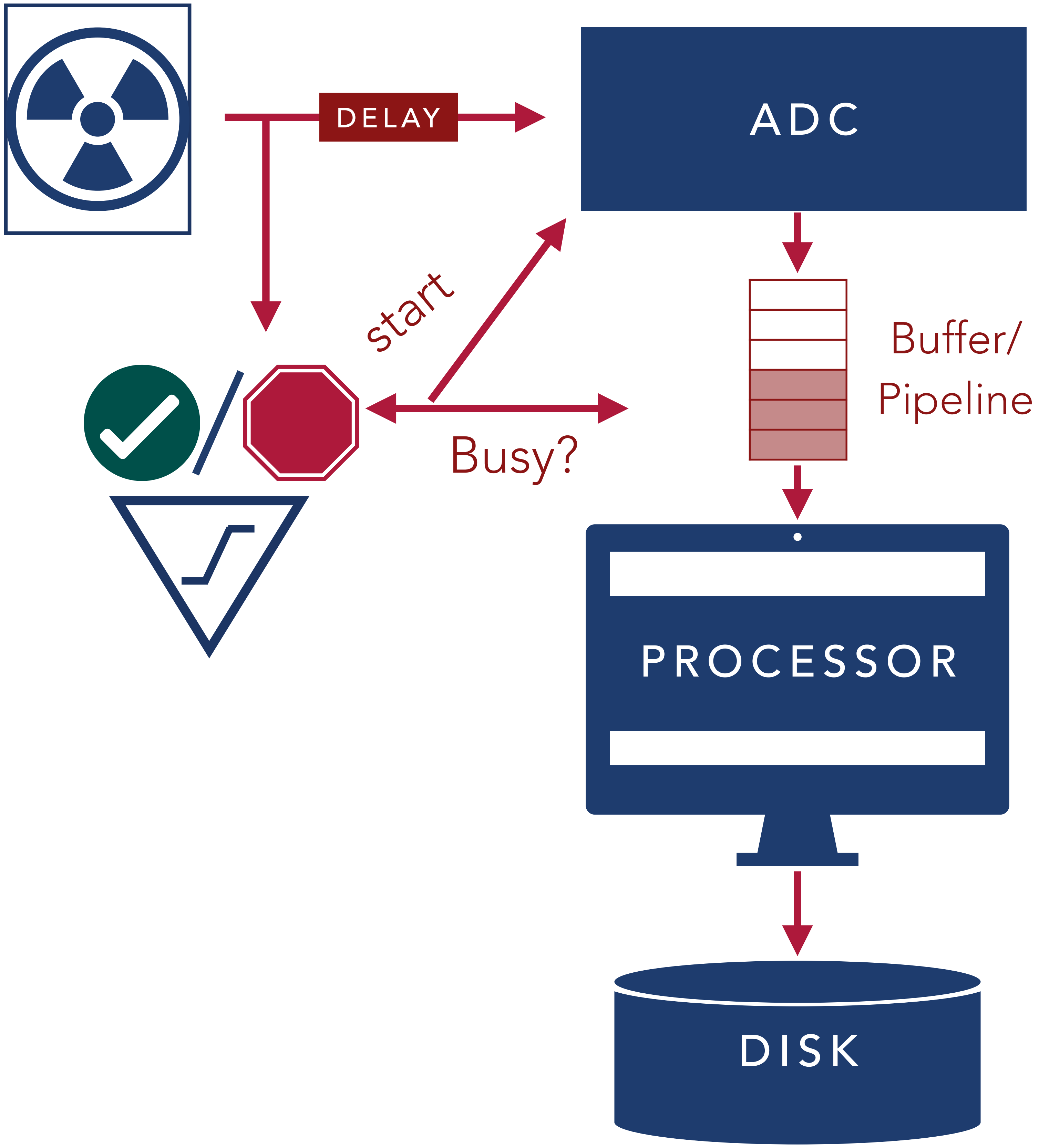
λ (ms) ;
f (Hz)

Buffer/
Pipeline/
FIFO

τ (ms);
v (Hz)

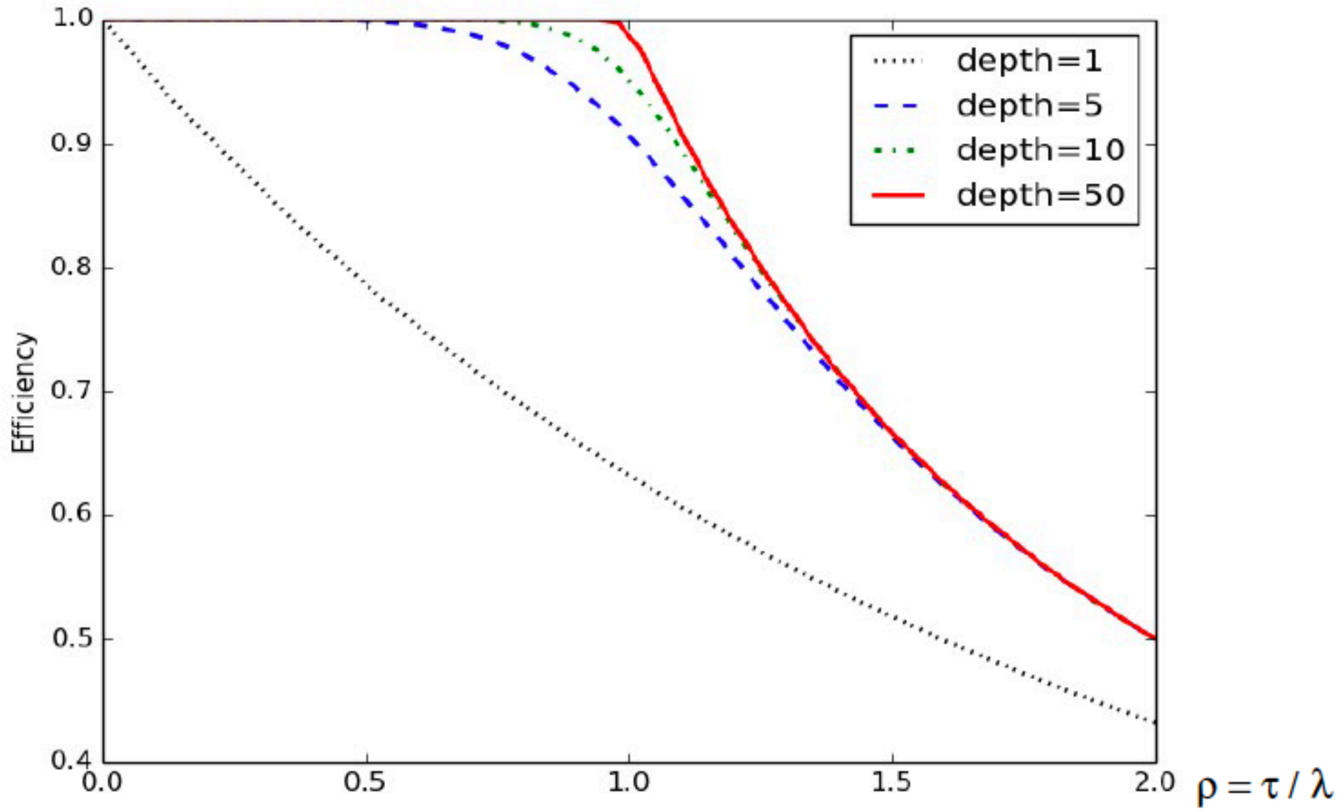
access time distribution

DE-RANDOMIZING



- Busy is now defined by if the buffer is full or not.
- Processor pulls data from the buffer at fixed rate, separating the event receiving and data processing steps

QUEUEING THEORY



- Efficiency as a function of the ratio of the event processing time (τ) to average event arrival time (λ)

- Qualitatively describe the system for:
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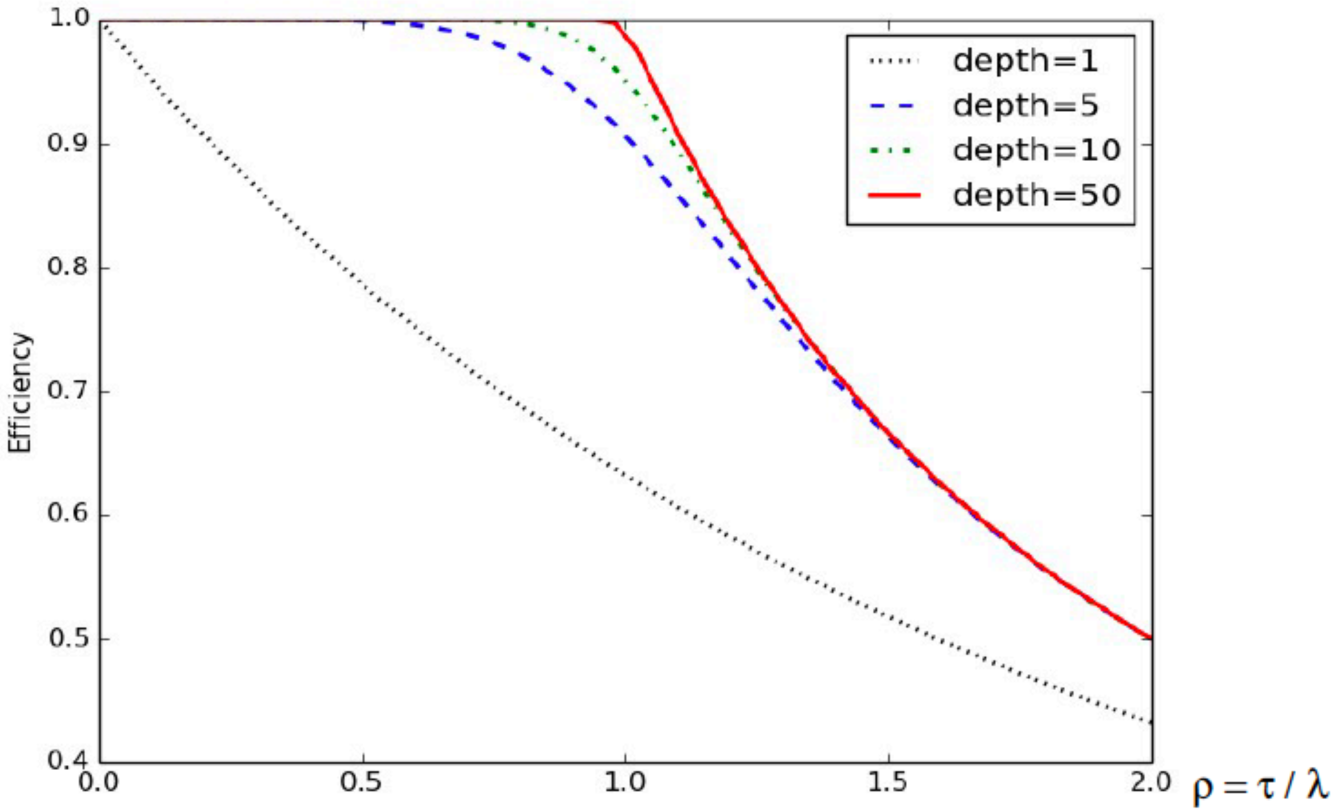

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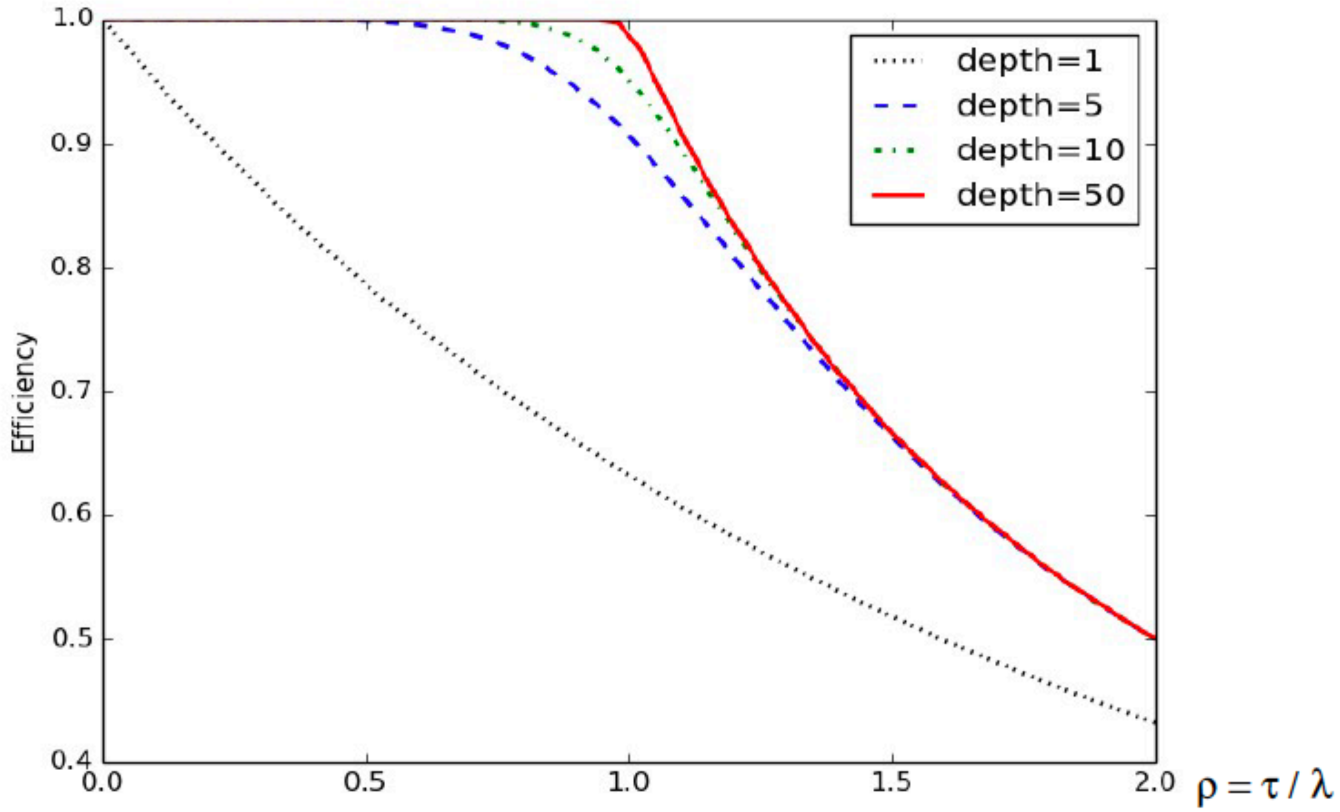

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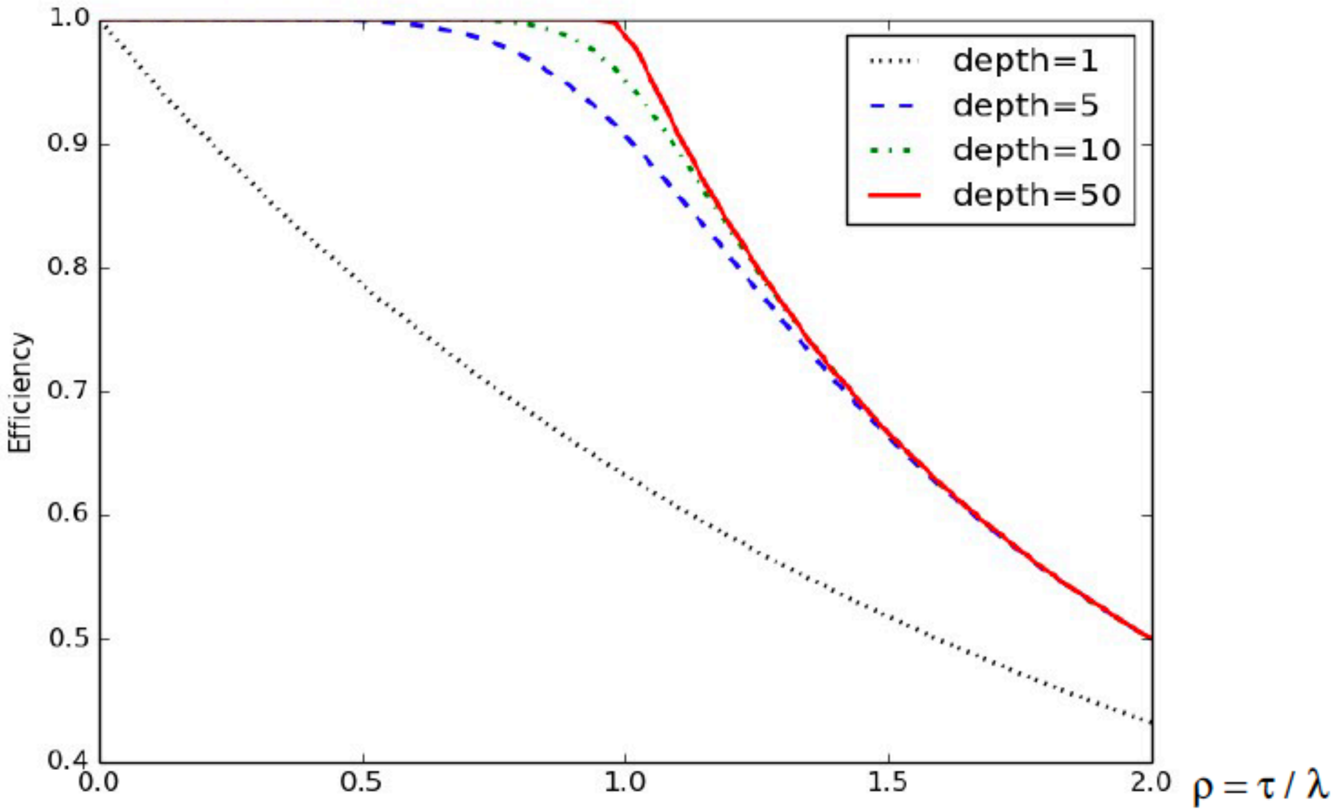

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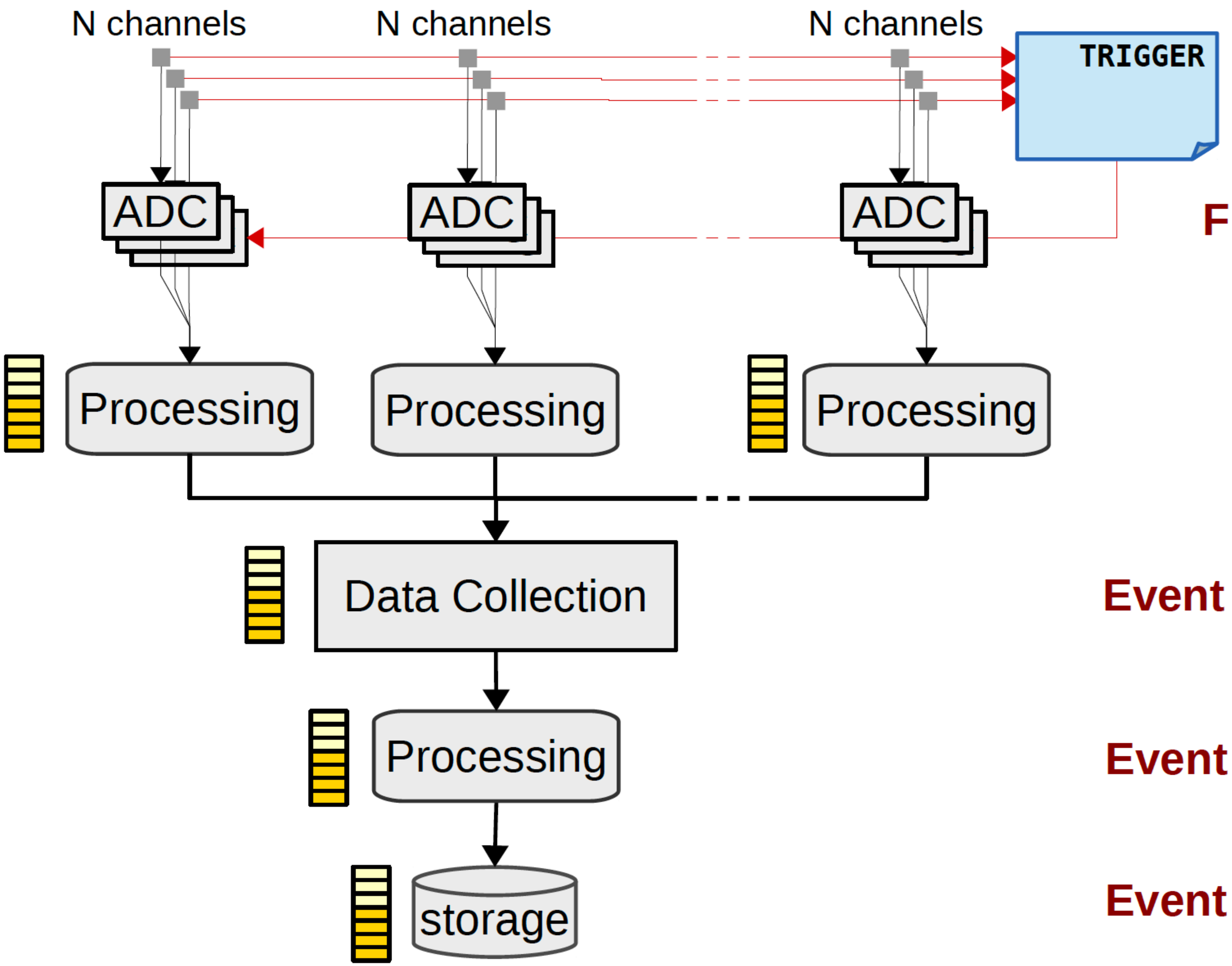
GENERALIZING TO MULTI-CHANNEL SYSTEM



Front-End	data digitization data buffering
Readout	data extraction data formatting data buffering
Event Building	event assembly event buffering
Event Filtering	event rejection event buffering
Event Logging	file storage file buffering

Andrea Negri

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- What are the similarities & differences?
  - Fixed frequency of LHC collisions means you don't need to have continuous readout
  - But events are still random —> de-randomization is needed!
- Remainder of today and tomorrow's lectures are going to explain how these basic concepts are applied to the LHC trigger & data acquisition problem now and in the the future

THE REST OF THE LECTURES

- Overview of the current ATLAS & CMS TDAQ architecture
  - ATLAS Level 1 Trigger & DAQ

Today

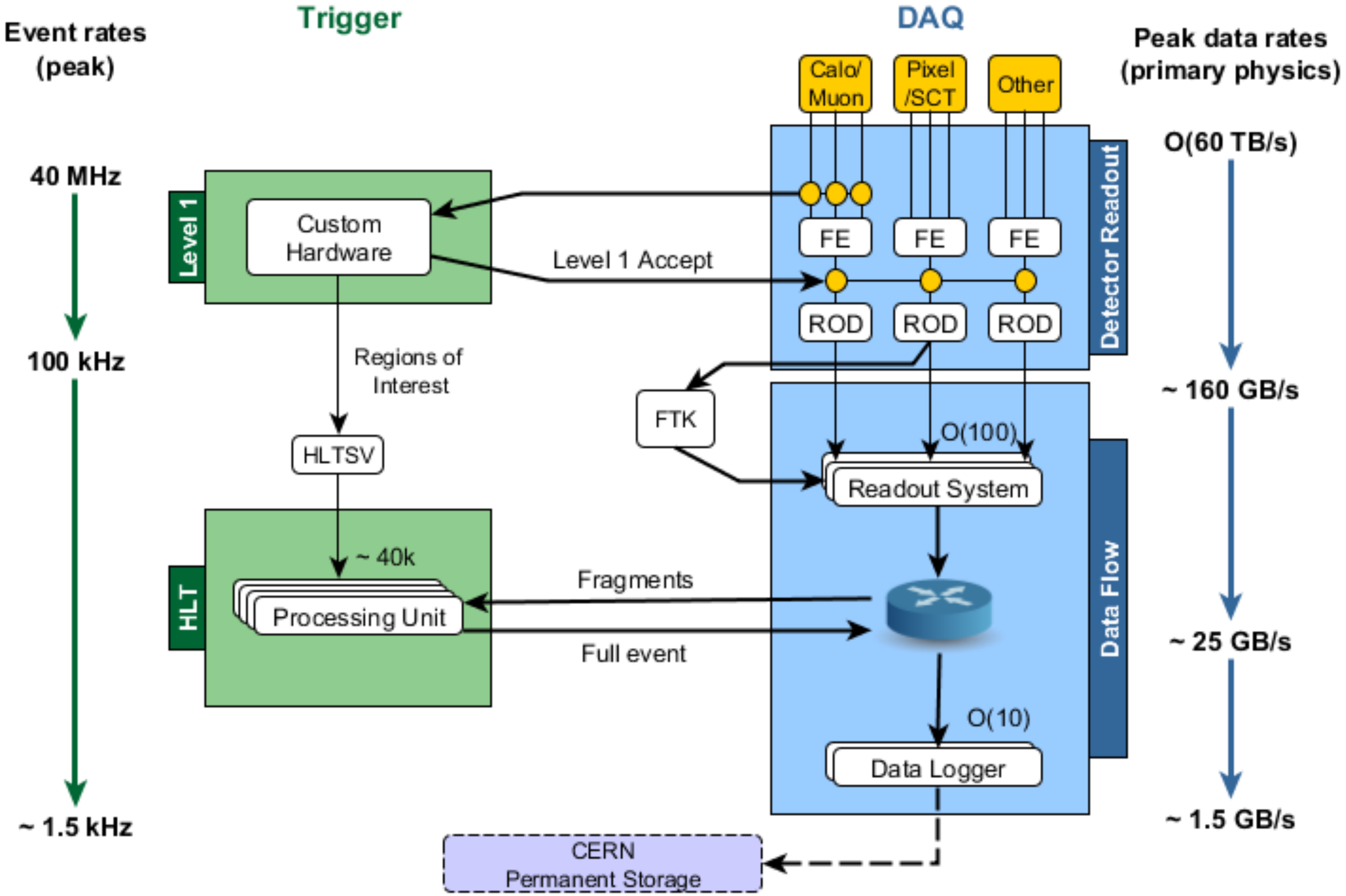
  - CMS High Level Trigger & DAQ

Tomorrow

- How triggers are constructed for the LHC environment
  - The art of menu building
  - Creative solutions to challenging conditions
- Looking forward to the upgrades
  - LHCb: The trigger-less future?
  - Contending with 200 simultaneous collisions

TDAQ: CMS & ATLAS STYLE

ATLAS RUN II TDAQ SYSTEM



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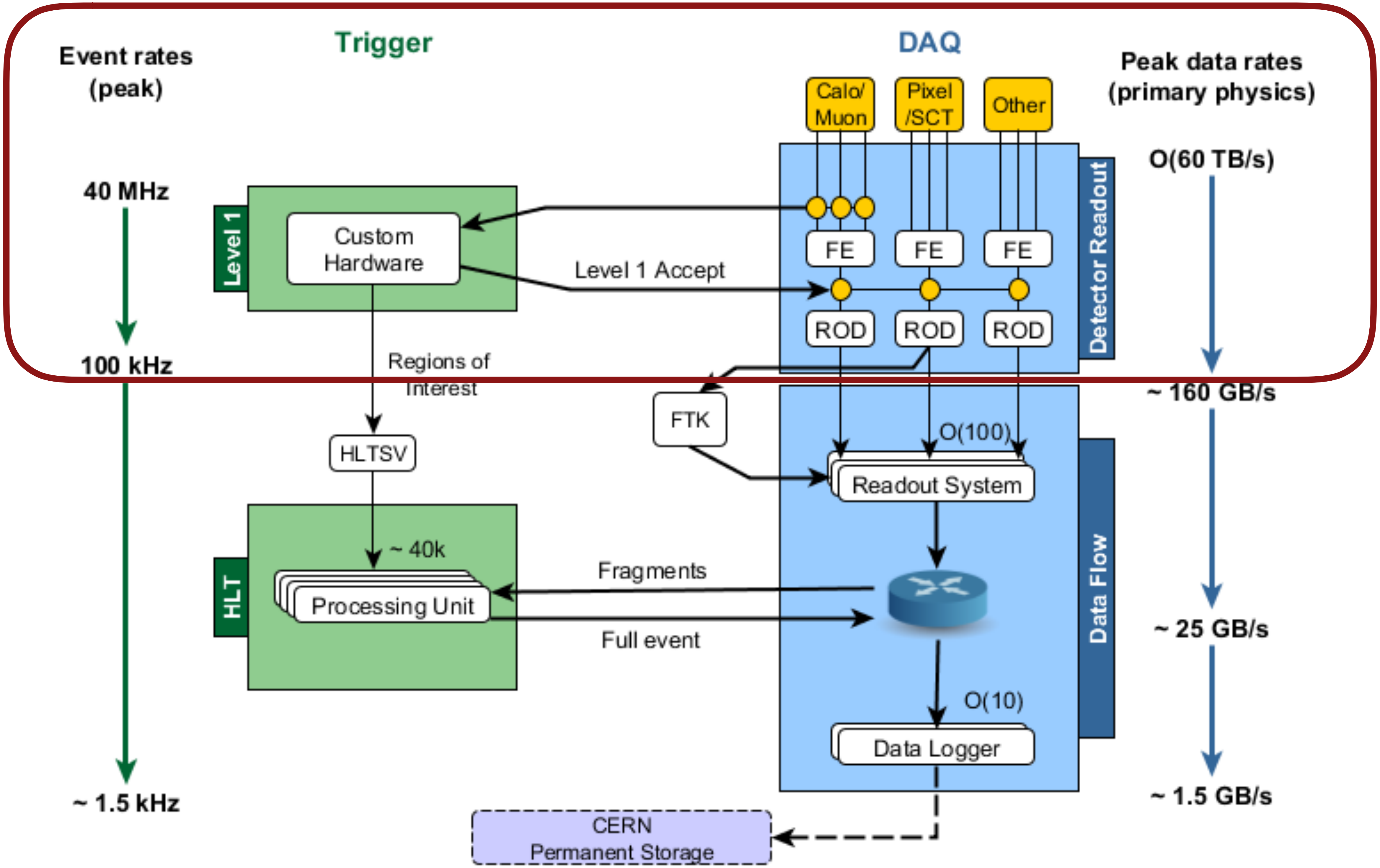

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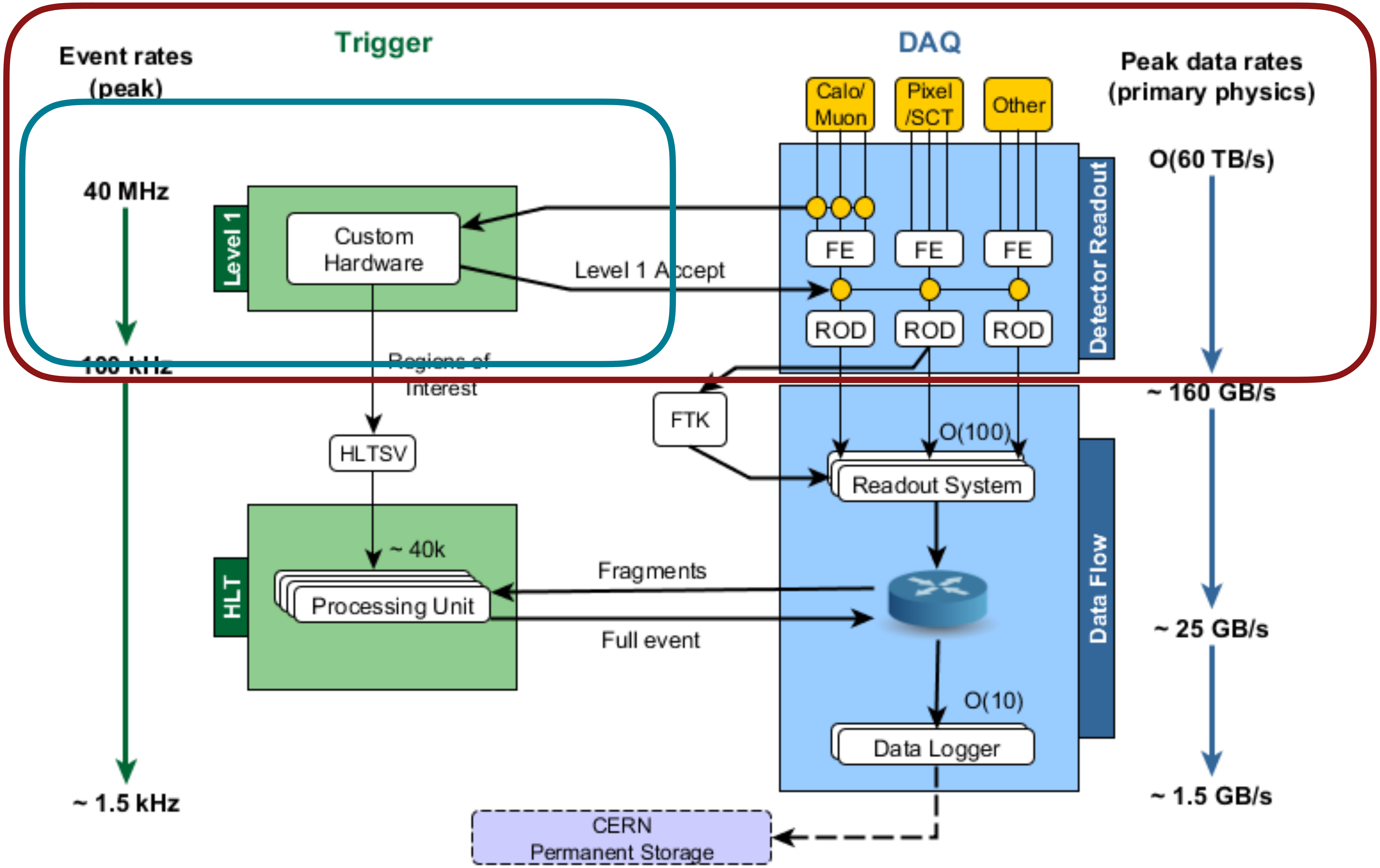
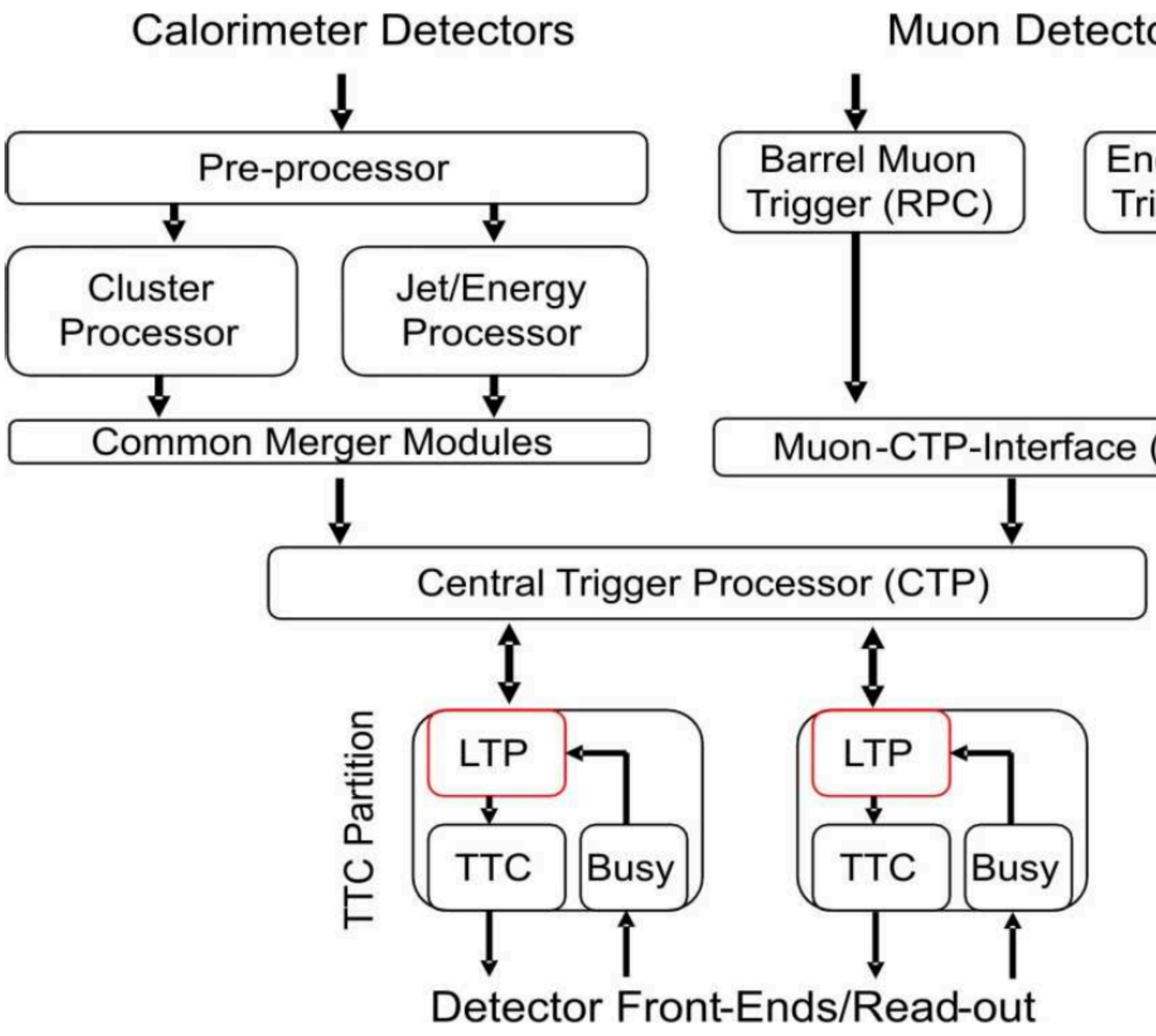


Fig. Ref

ATLAS LEVEL 1 TRIGGER SYSTEM



Calorimeter Detectors

Muon Detectors

Pre-processor

Barrel Muon Trigger (RPC)

End-cap Muon Trigger (TGC)

Cluster Processor

Jet/Energy Processor

Common Merger Modules

Muon-CTP-Interface (MuCTPI)

Central Trigger Processor (CTP)

TTC Partition

LTP

TTC

Busy

LTP

TTC

Busy

Detector Front-Ends/Read-out

RPC = Resistive-Plate Chamber

TGC = Thin-Gap Plate Chamber

LTP = Local Trigger Processor
+ LTP interface

TTC = Trigger Timing & Control

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ATLAS has ~40 TTC partitions

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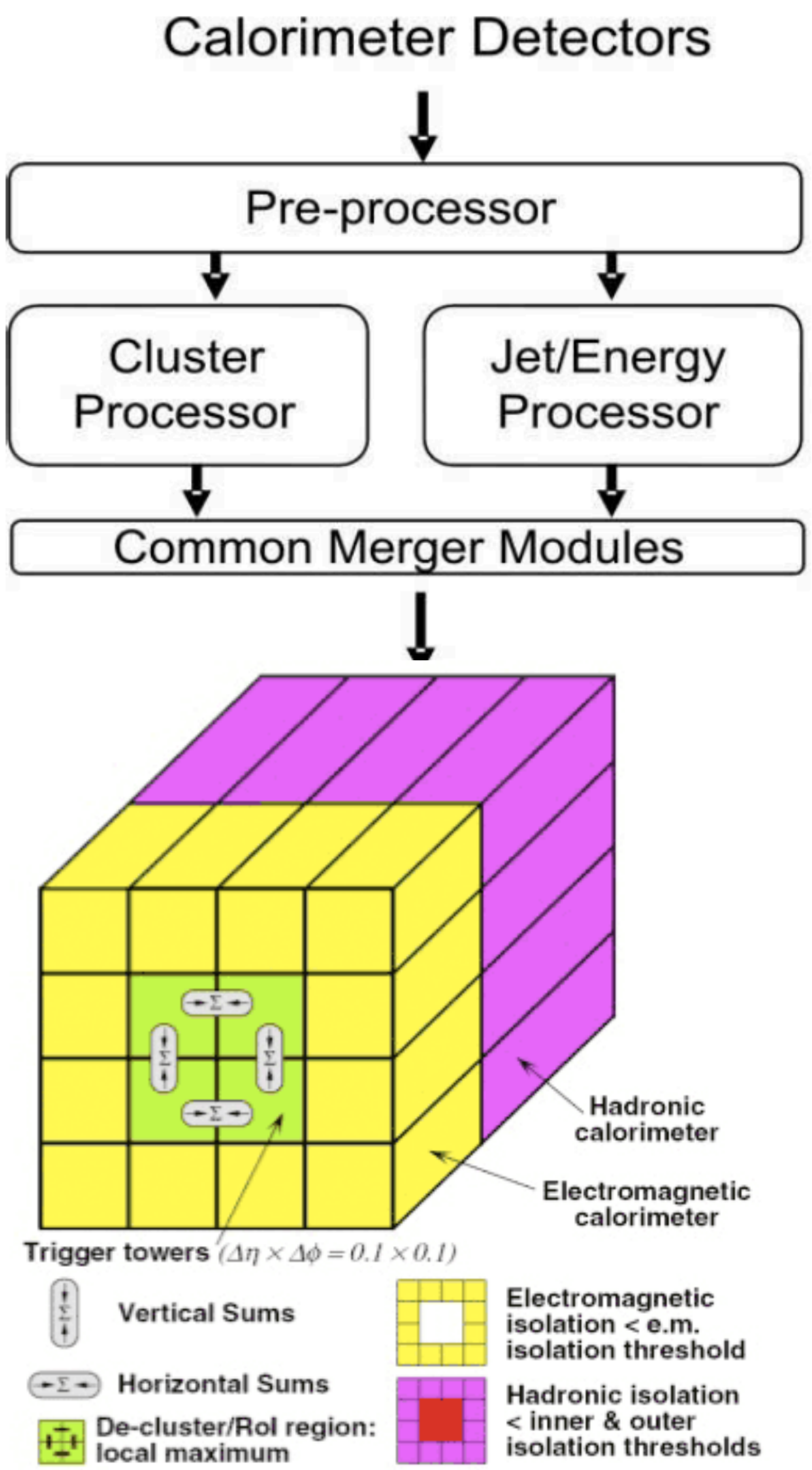

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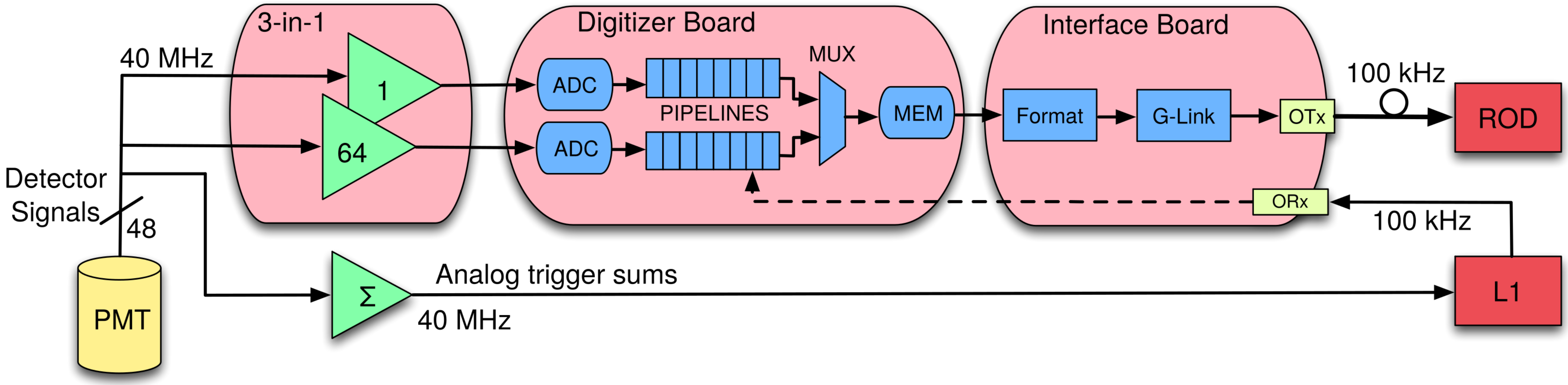

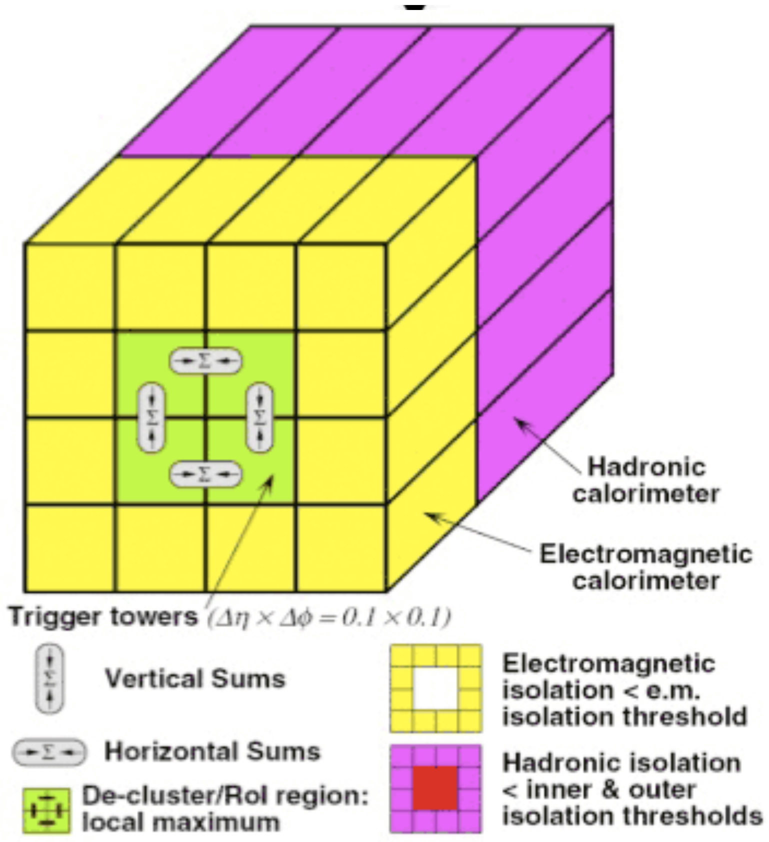

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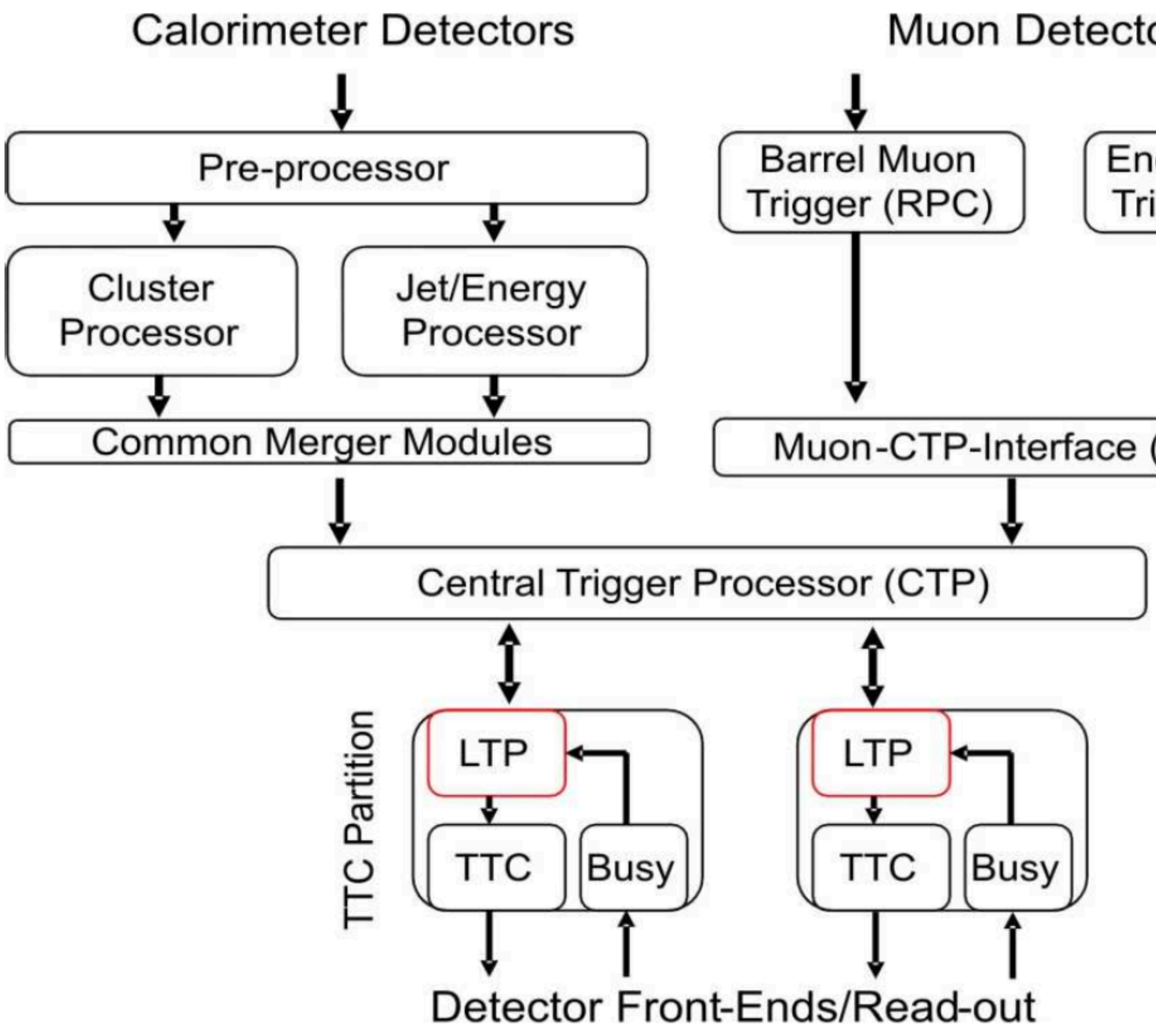

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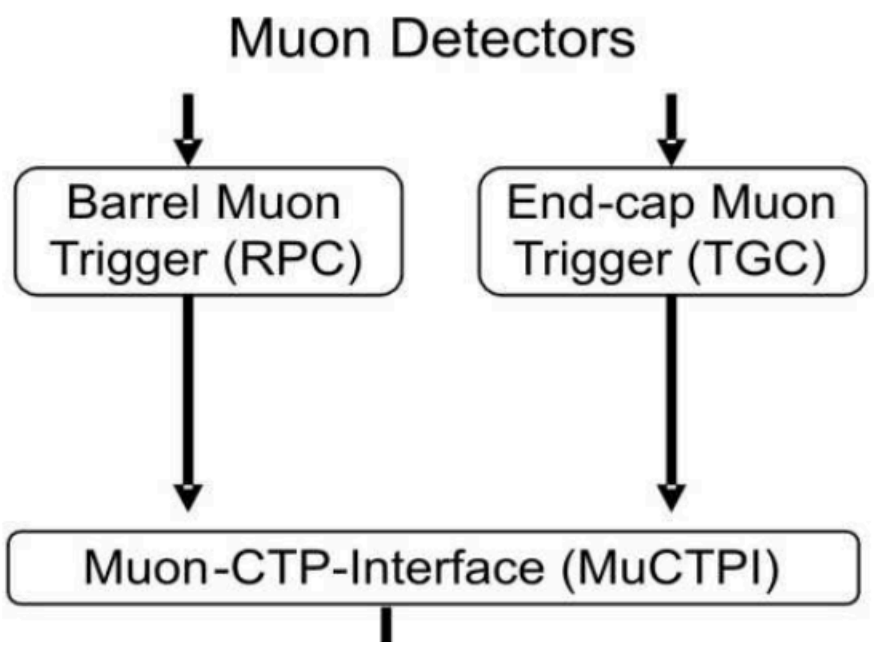

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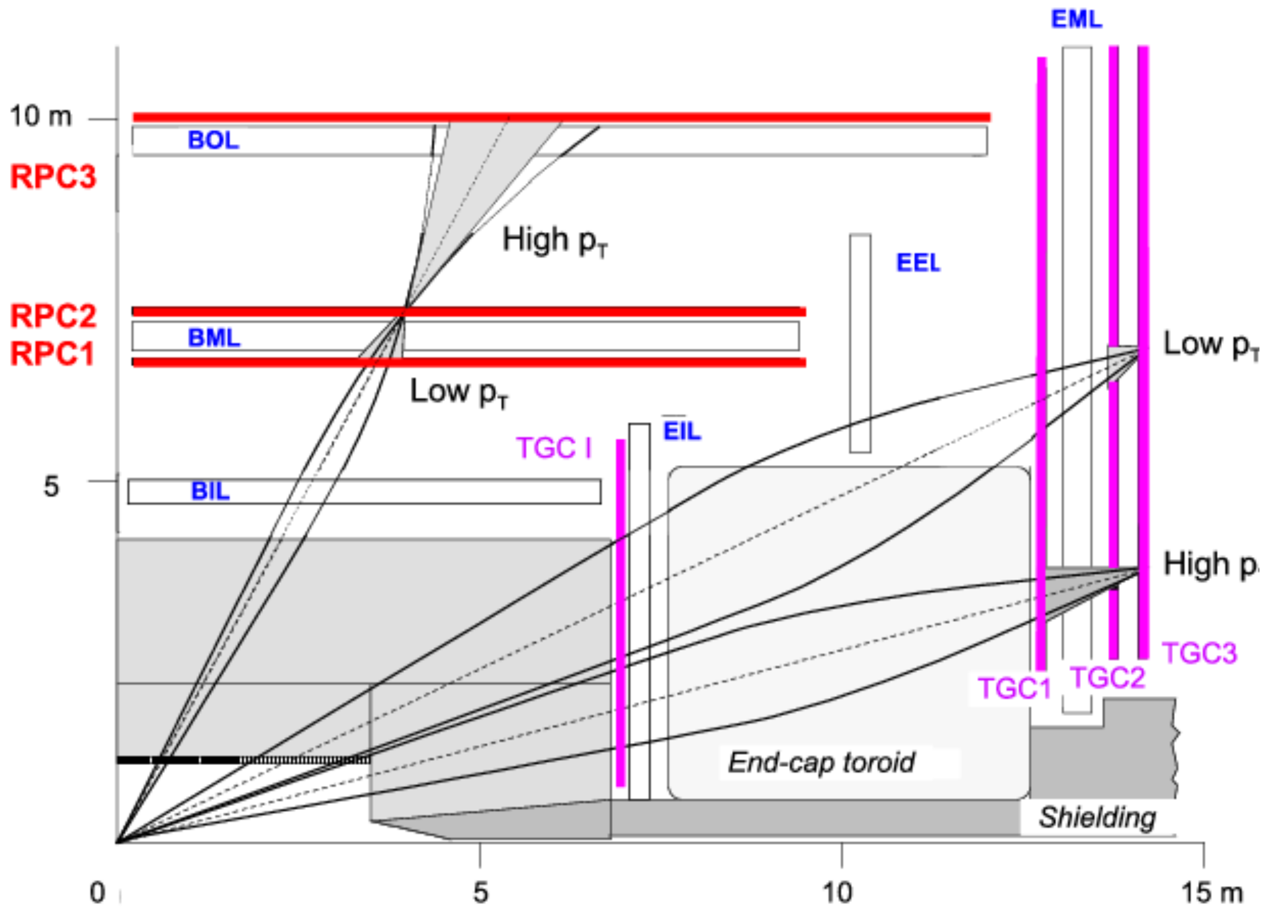
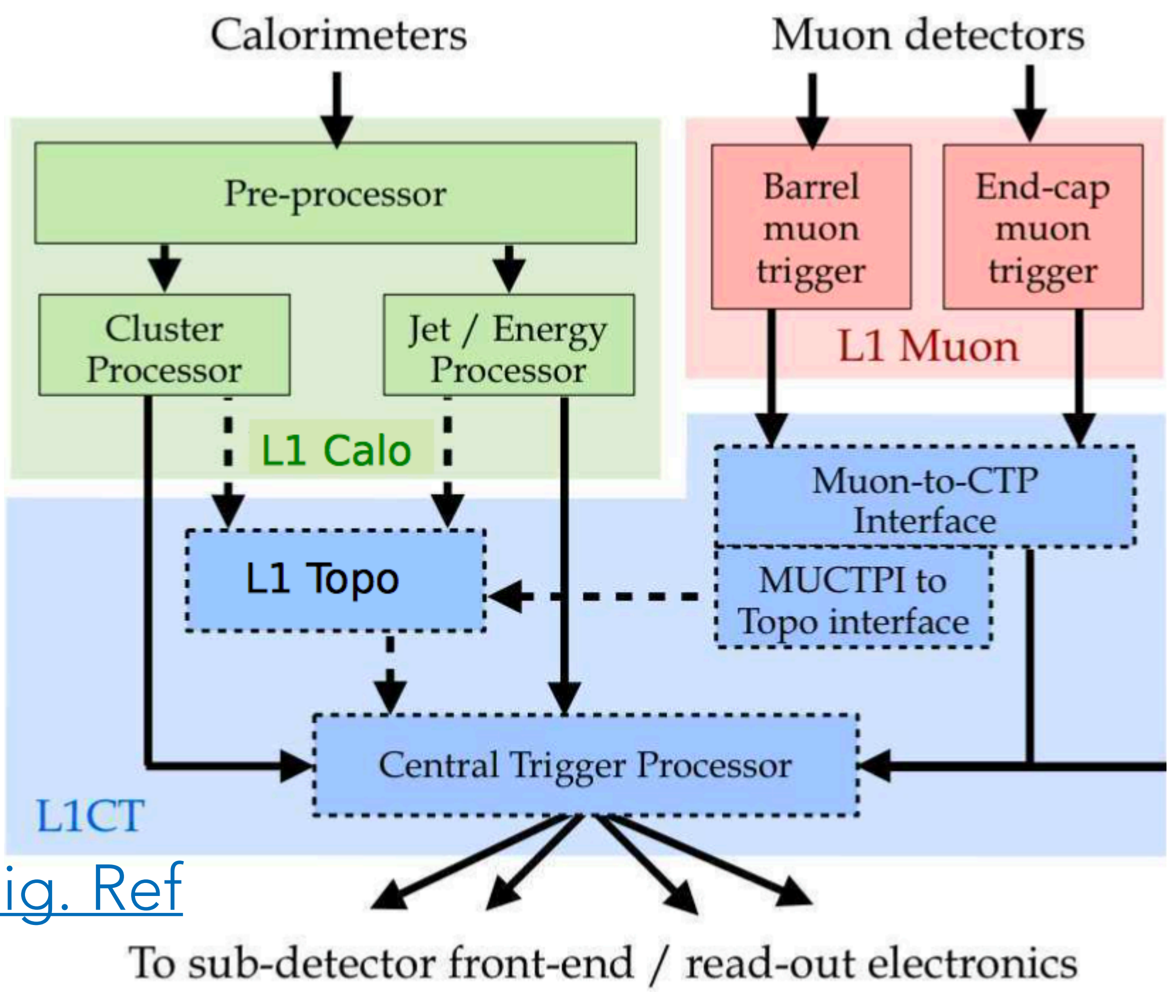


Fig. Ref

TOPOLOGICAL TRIGGERS



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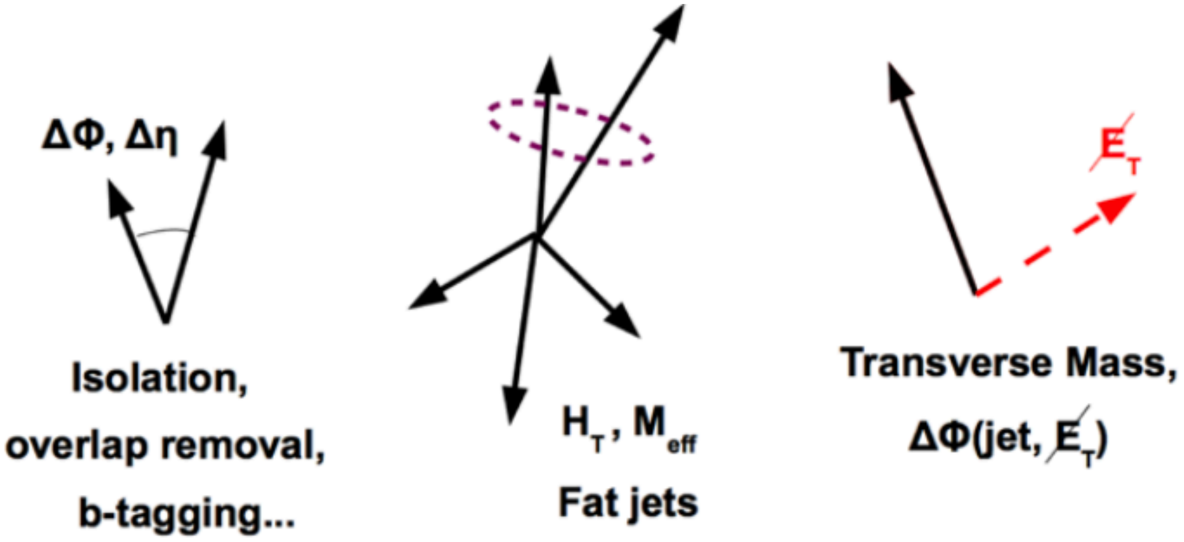


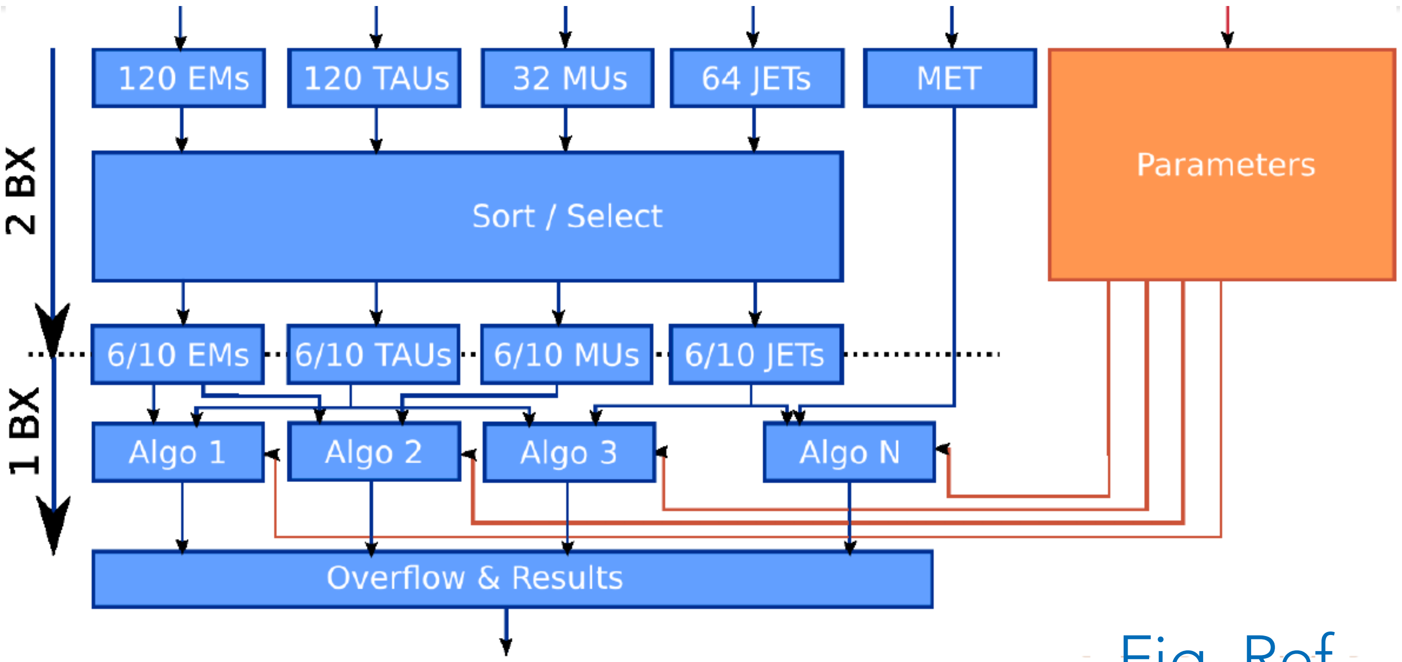
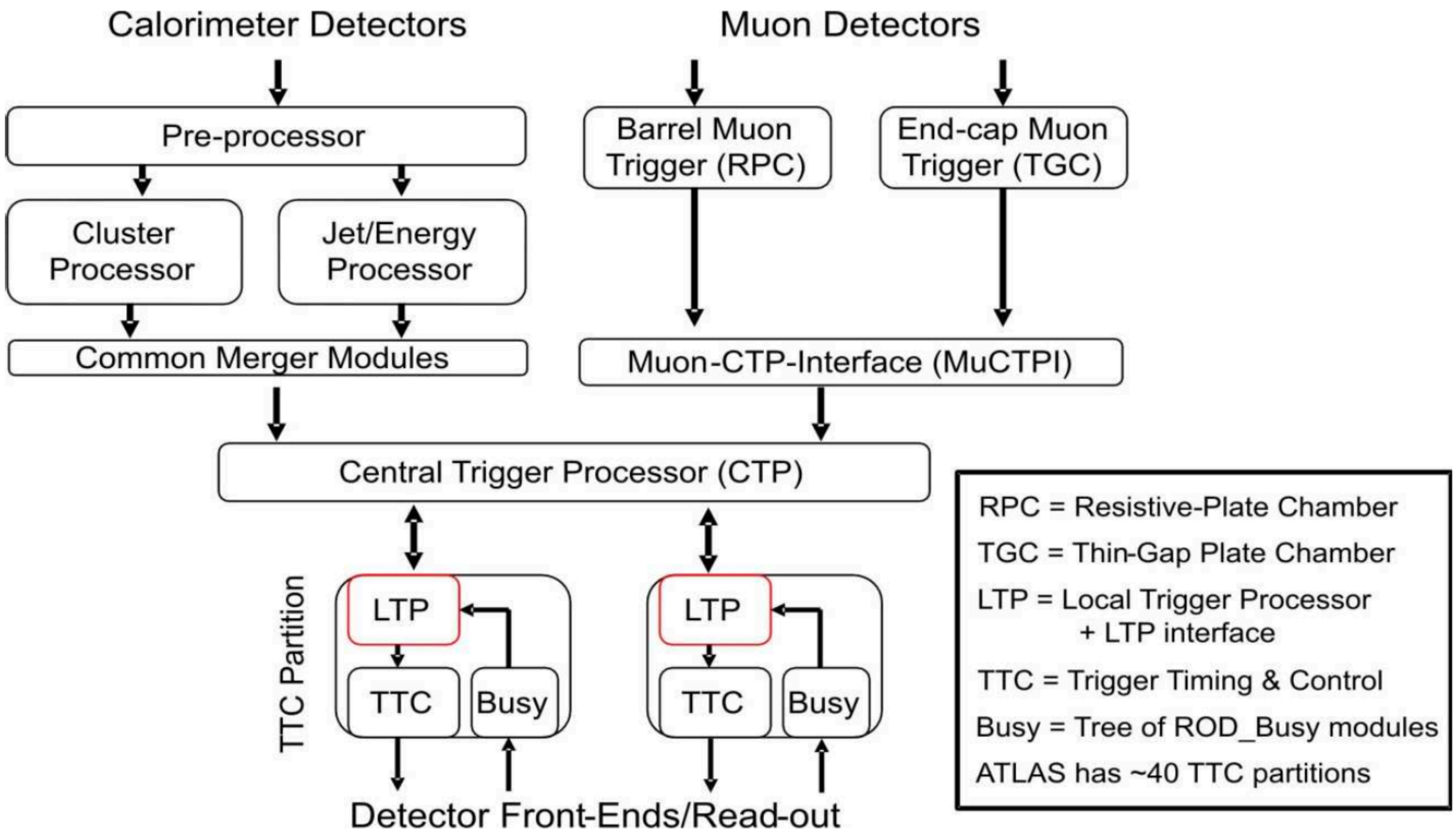


Fig. Ref

ATLAS LEVEL 1 TRIGGER SYSTEM



Calorimeter Detectors

Muon Detectors

Pre-processor

Barrel Muon Trigger (RPC)

End-cap Muon Trigger (TGC)

Cluster Processor

Jet/Energy Processor

Common Merger Modules

Muon-CTP-Interface (MuCTPI)

Central Trigger Processor (CTP)

TTC Partition

LTP

TTC

Busy

LTP

TTC

Busy

Detector Front-Ends/Read-out

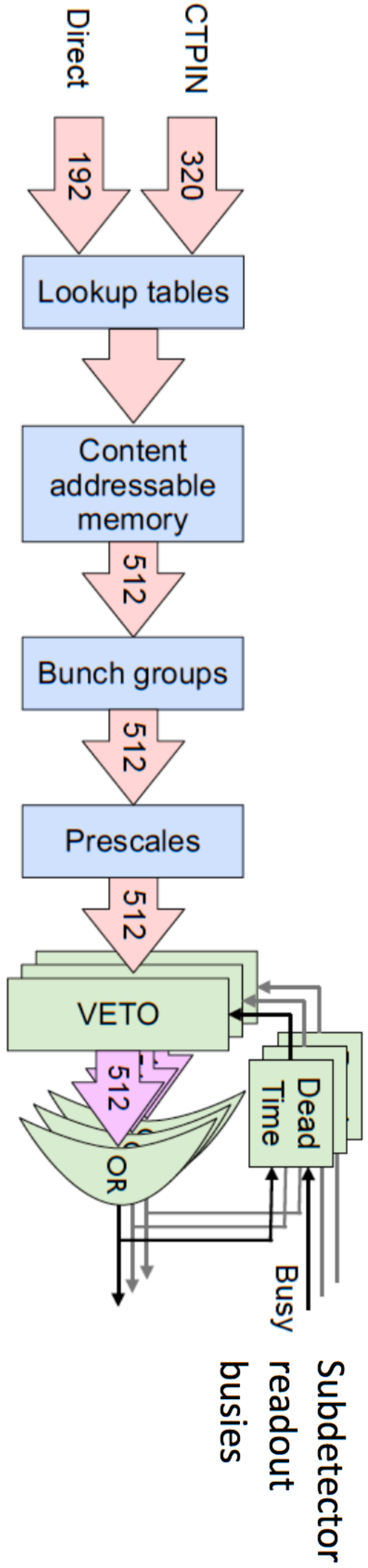
RPC = Resistive-Plate Chamber
TGC = Thin-Gap Plate Chamber
LTP = Local Trigger Processor + LTP interface
TTC = Trigger Timing & Control
Busy = Tree of ROD_Busy modules
ATLAS has ~40 TTC partitions

Fig. Ref

CENTRAL TRIGGER PROCESSOR & TIMING TRIGGER AND CONTROL SYSTEM

CENTRAL TRIGGER PROCESSOR & TIMING TRIGGER AND CONTROL SYSTEM

- Central Trigger Processor (CTP) and the Trigger Timing and Control (TTC) form the brains of the Level-1 Trigger:



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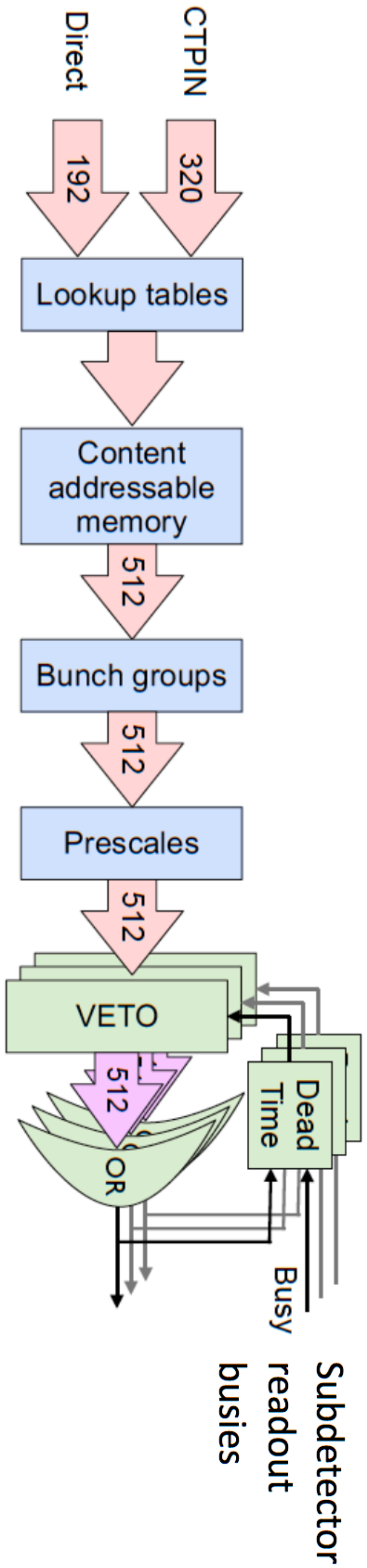

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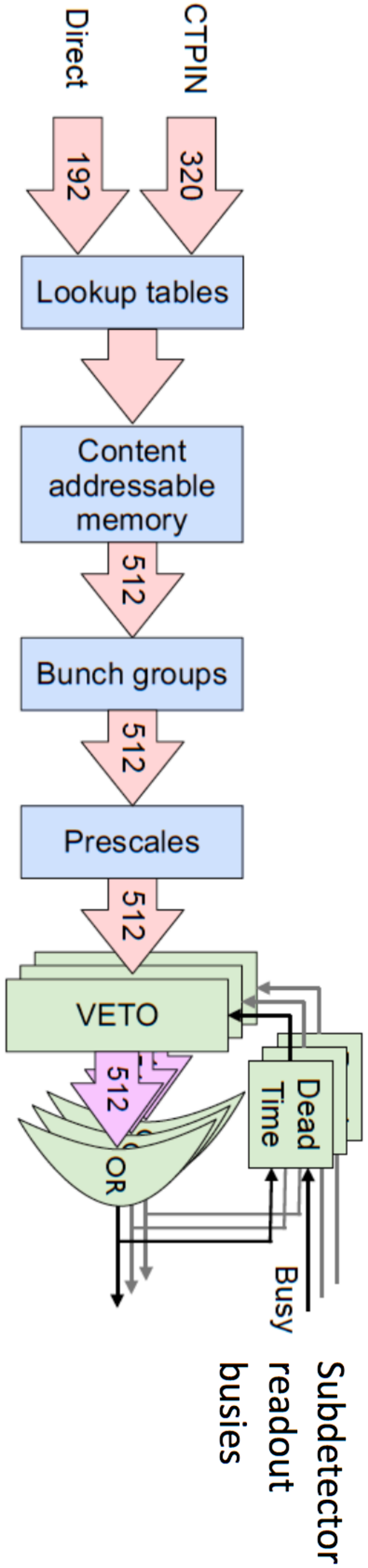

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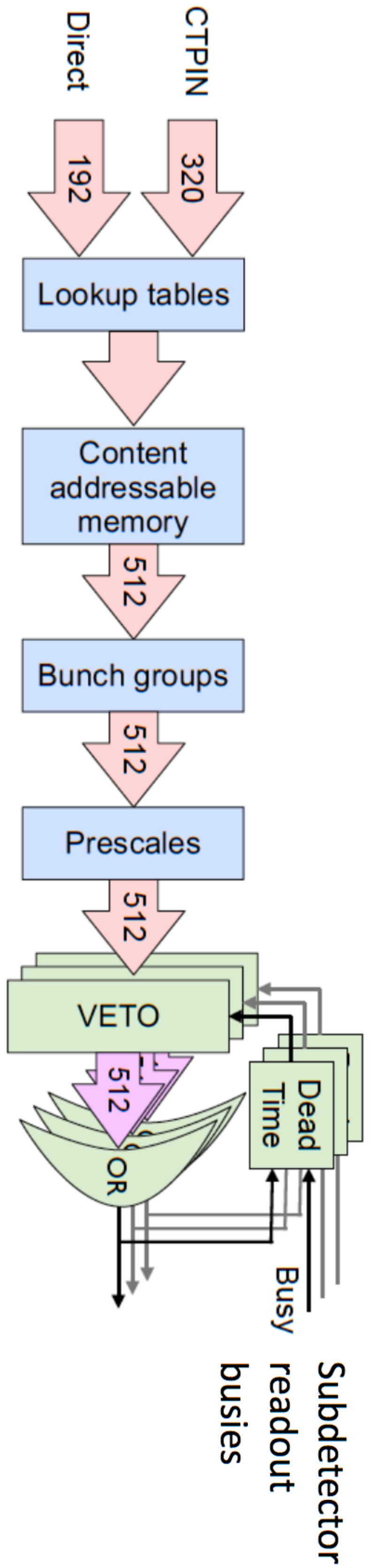

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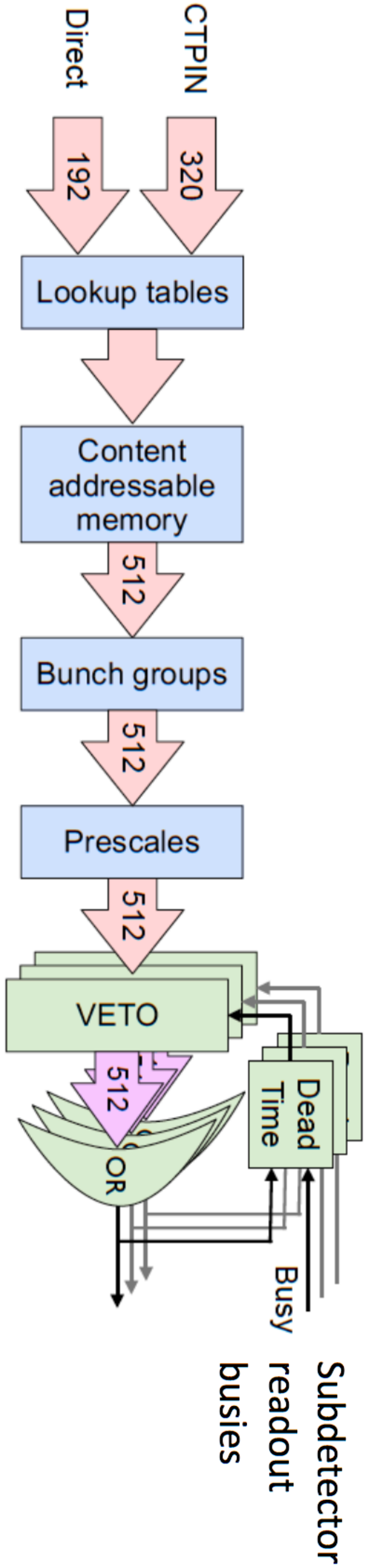
  - Controls detector BUSY



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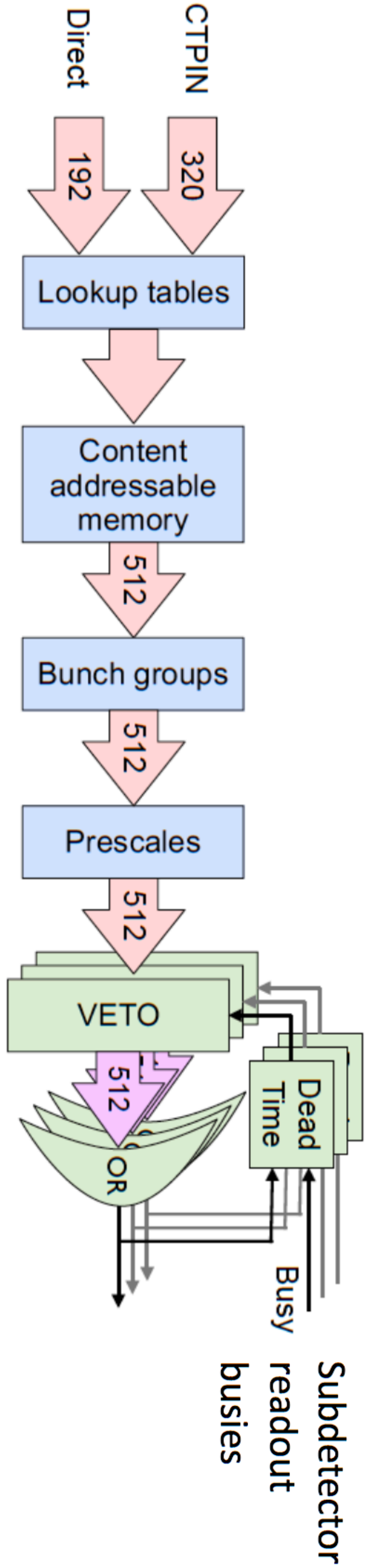
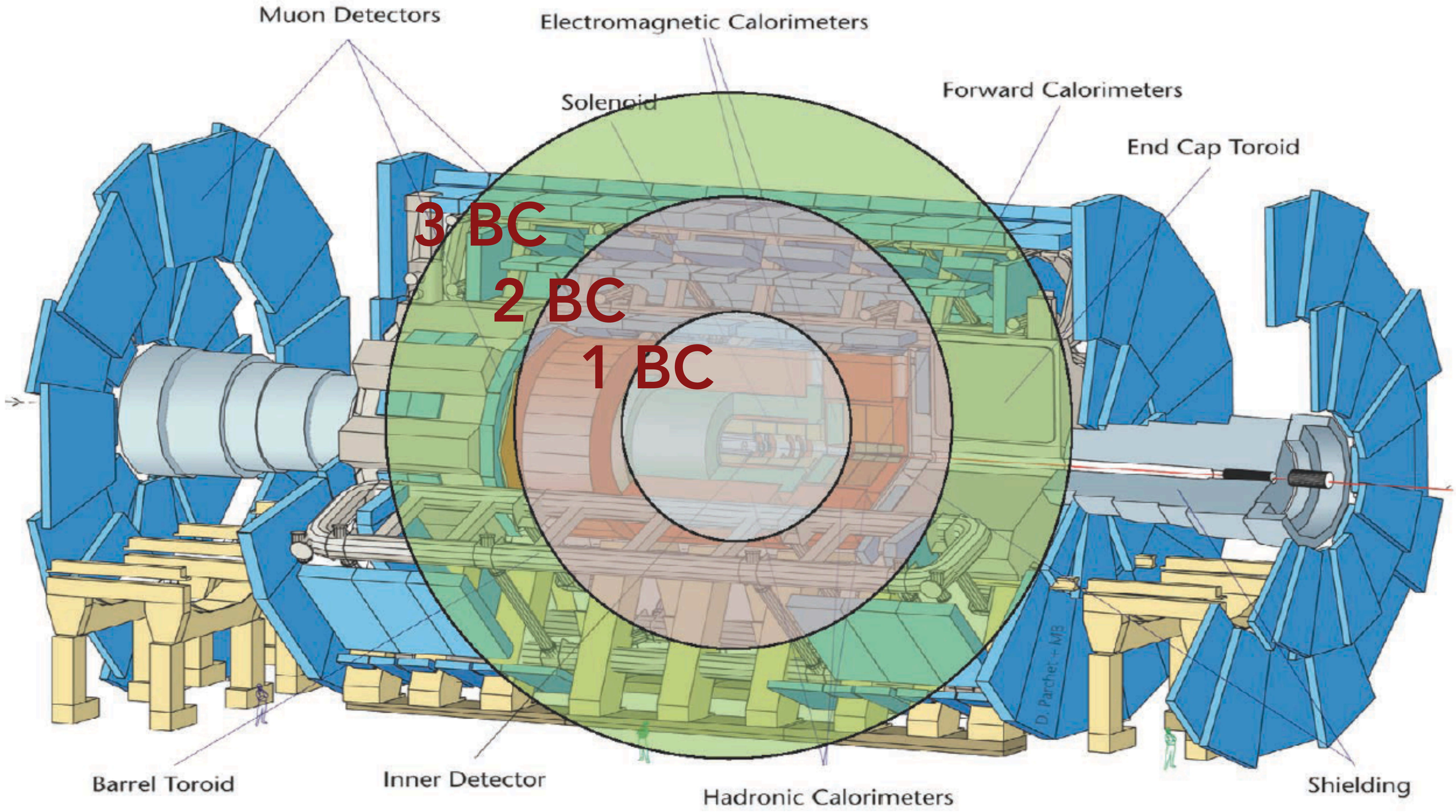
  - Controls detector BUSY
  - ***All within 100ns***

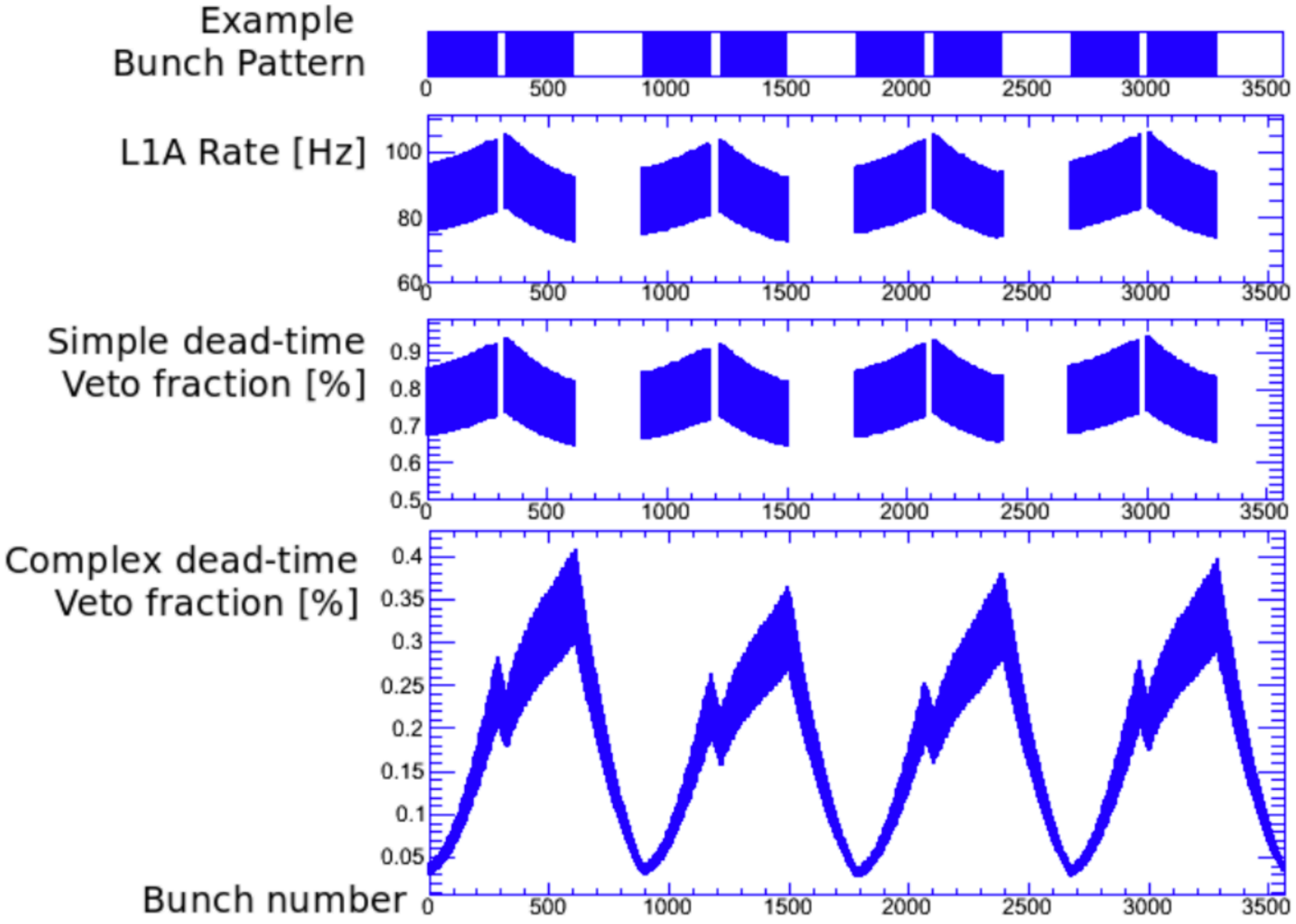


TIMING IS EVERYTHING



ATLAS DEADTIME

- Simple dead-time veto:
  - No new L1A after fixed number of BC
- Leaky-bucket Deadtime Algorithm:
  - Bucket leaks at rate R
  - Contents increase by X at each L1A until full, then BUSY is asserted
- Allows system to maintain high efficiency for data taking



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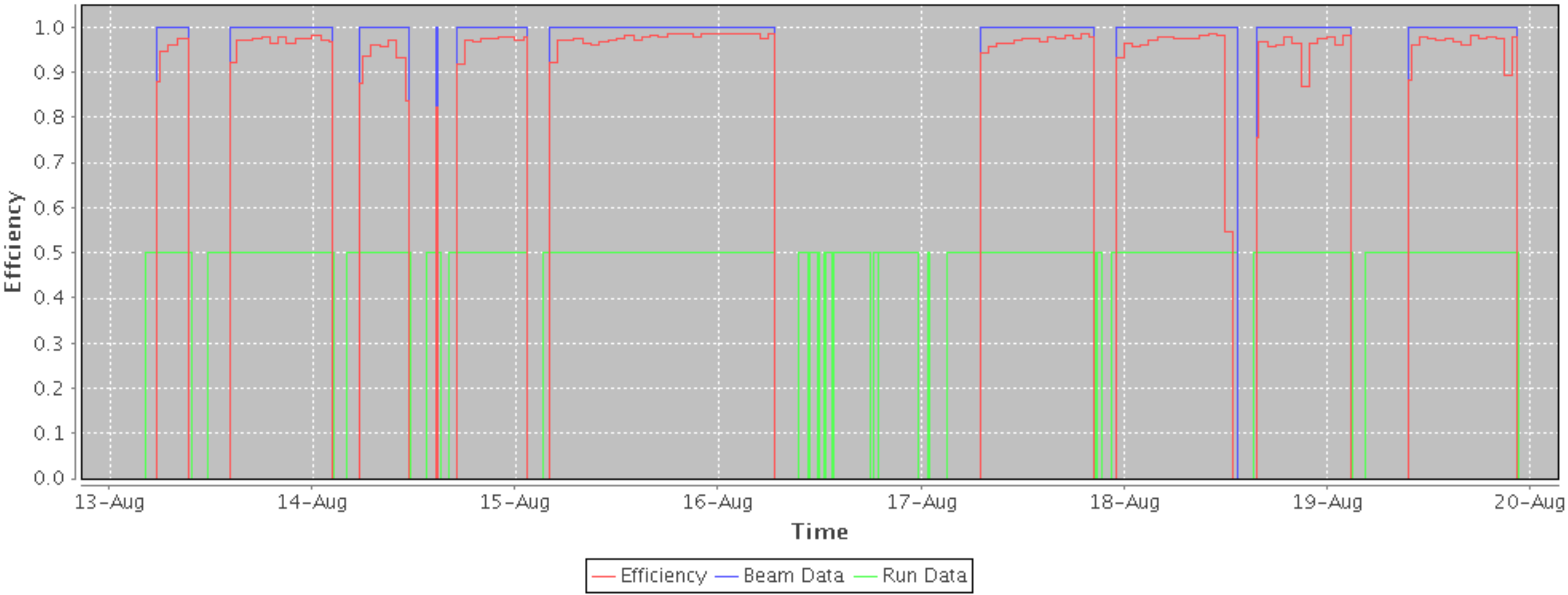

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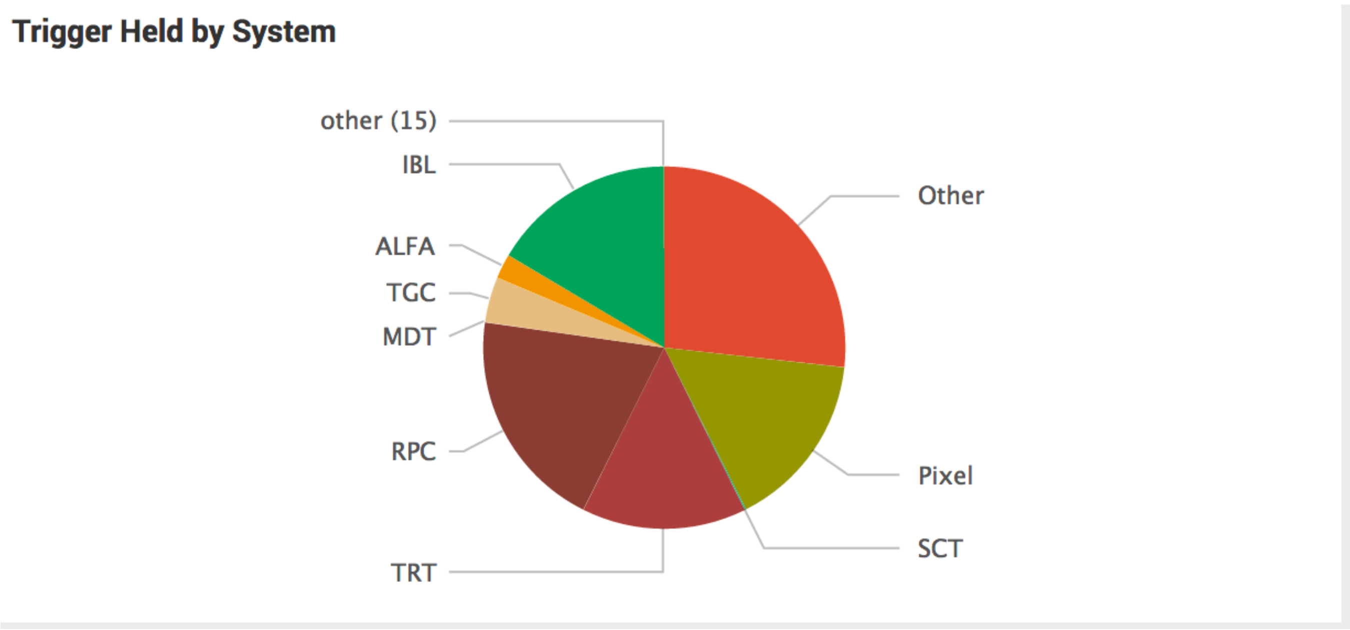
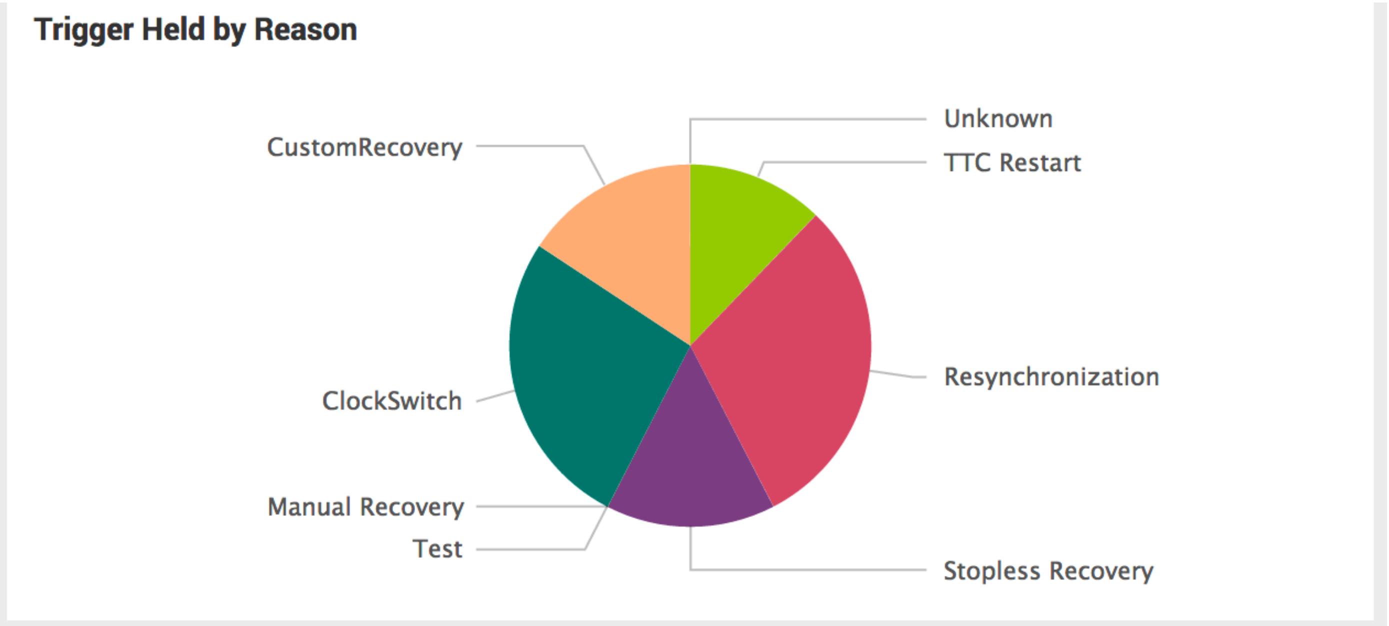

Trigger Held by System


Trigger Held by Reason

SUMMARY

- TDAQ is the system which allows us to take data off our detectors for analysis
- Efficiency of data taking is controlled through stochastic input rate, DAQ processing rate, and ability to buffer events to process
- We'll learn more about how these are implemented and what people are thinking about the future tomorrow!