LAUREN TOMPKINS

HEPCAT SUMMER SCHOOL 2024

BASICS OF TRIGGER AND DATA ACQUISITION SYSTEMS

Stanford University

GENERAL OUTLINE OF THE LECTURE

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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?

GENERAL OUTLINE OF THE LECTURE

- 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

HELLO!

HELLO!


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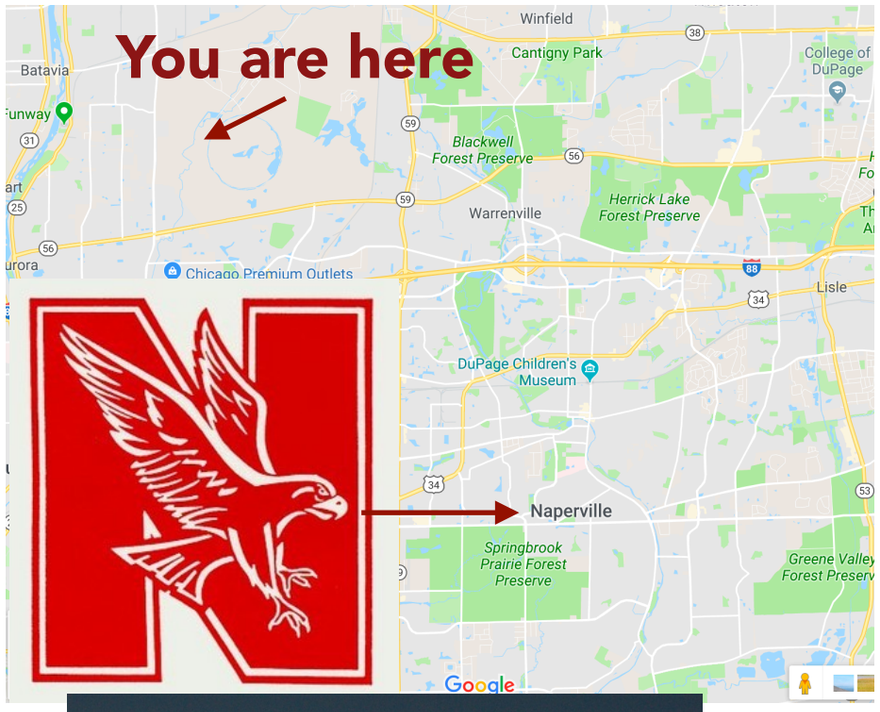
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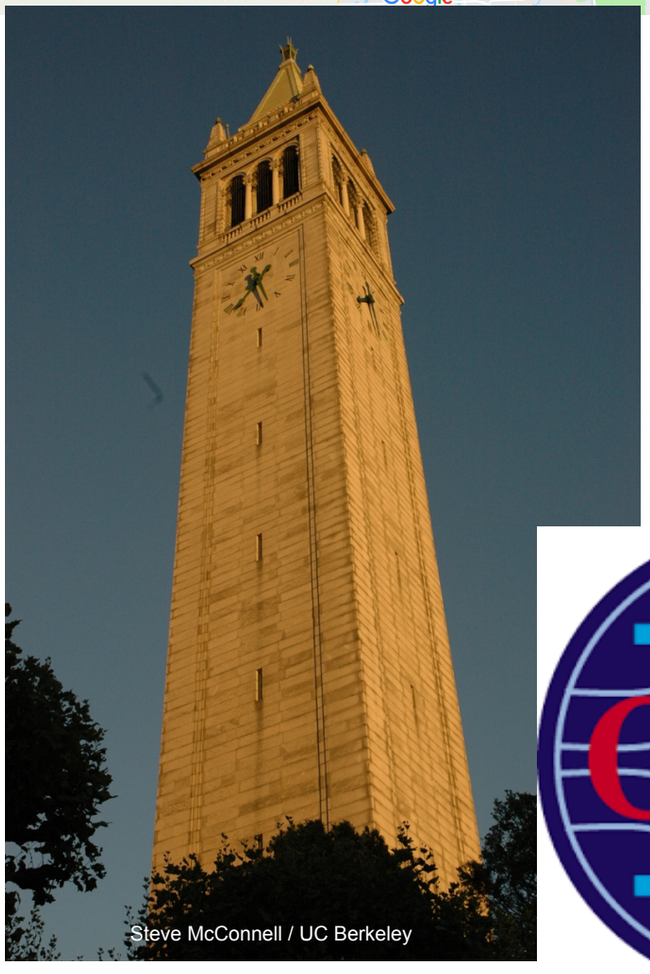
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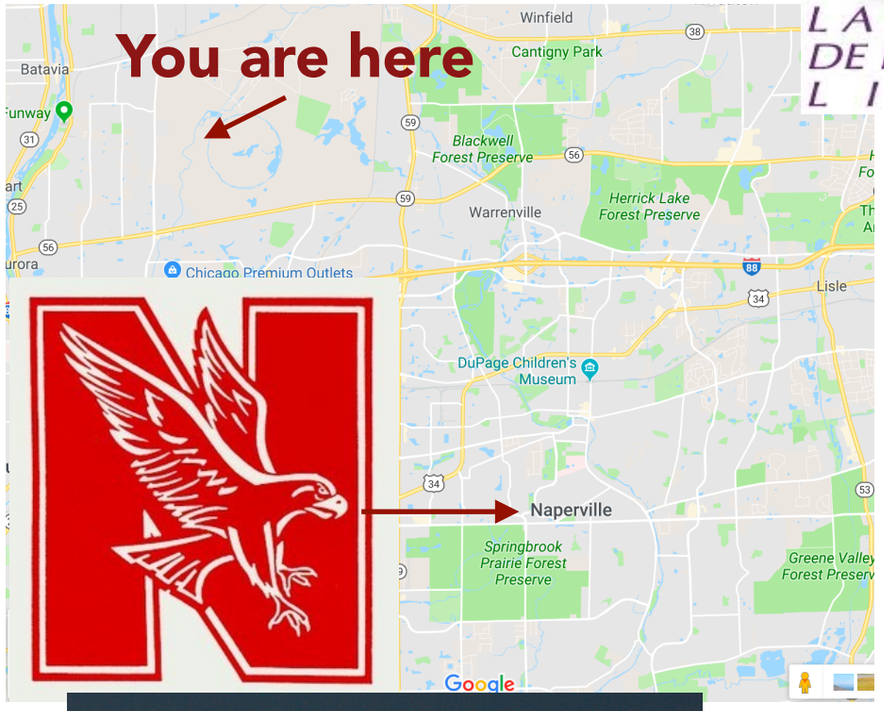
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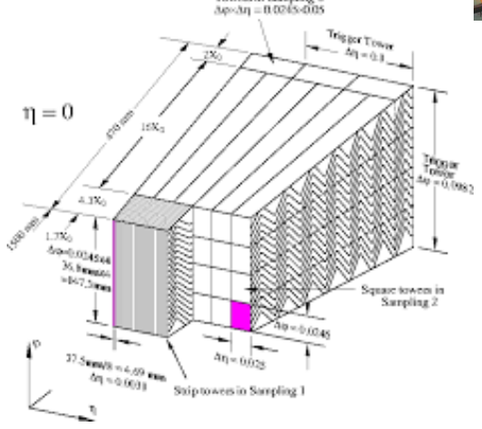
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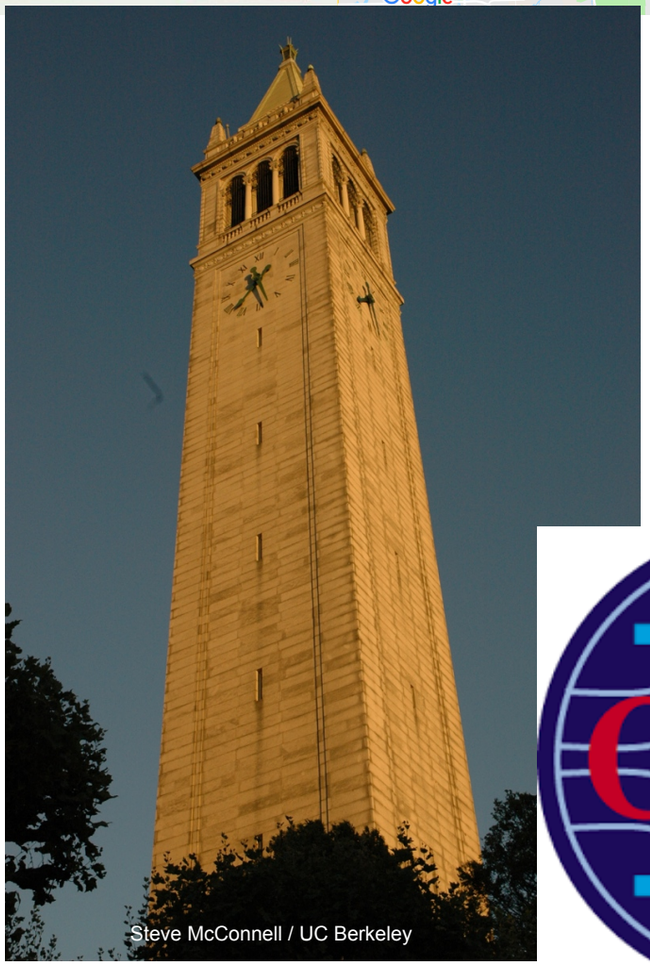
Trigger Tower
Square towers in Sampling 2
Strip towers in Sampling 1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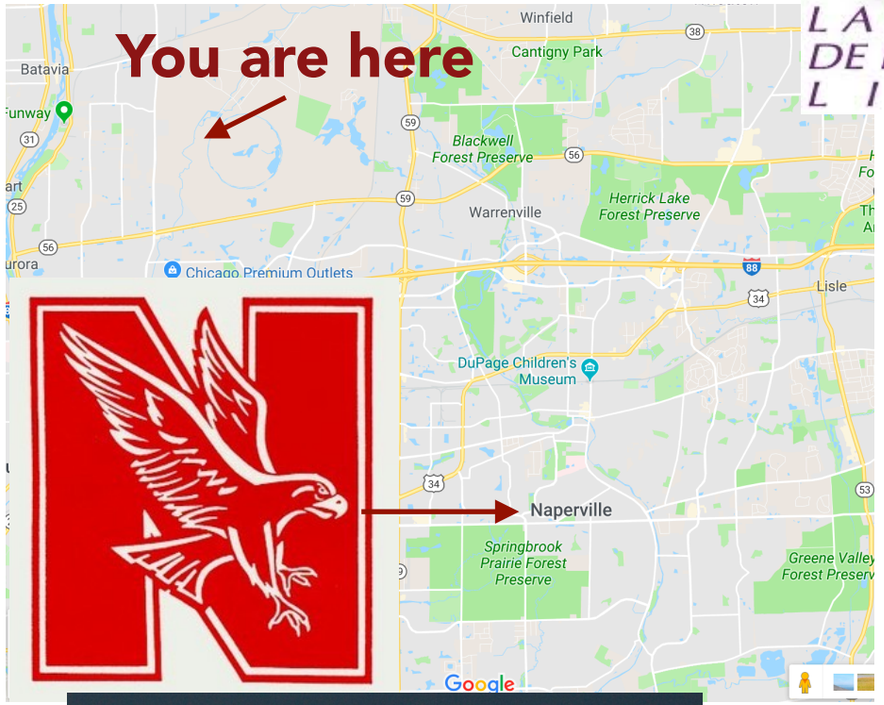
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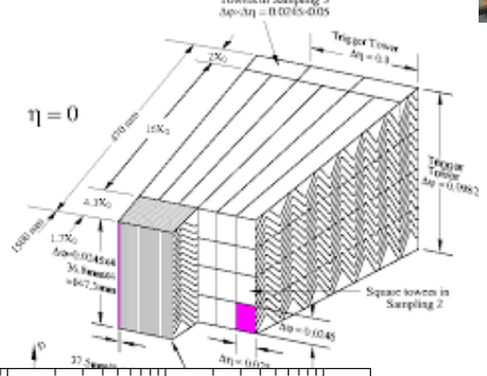
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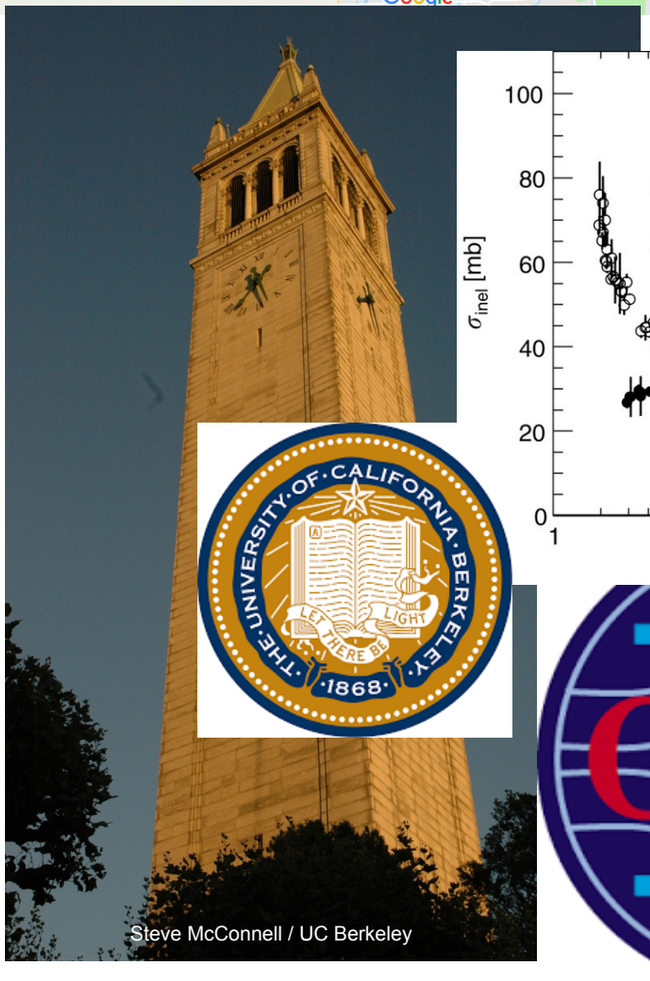
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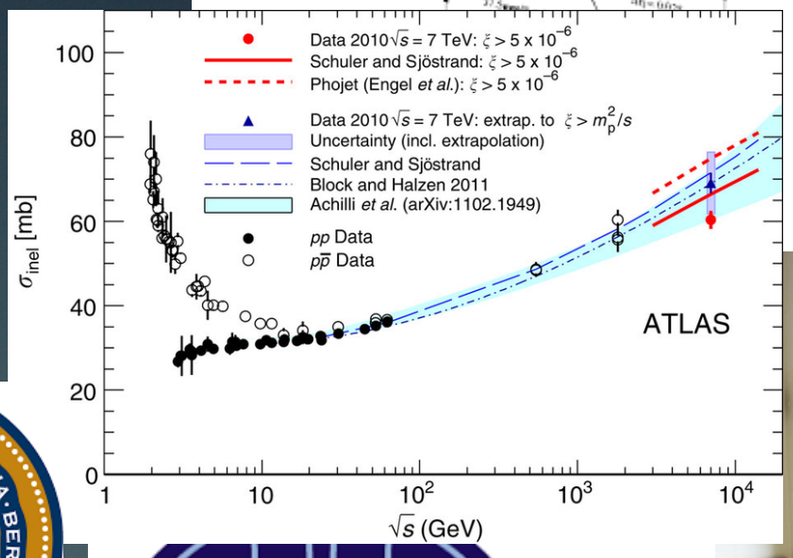
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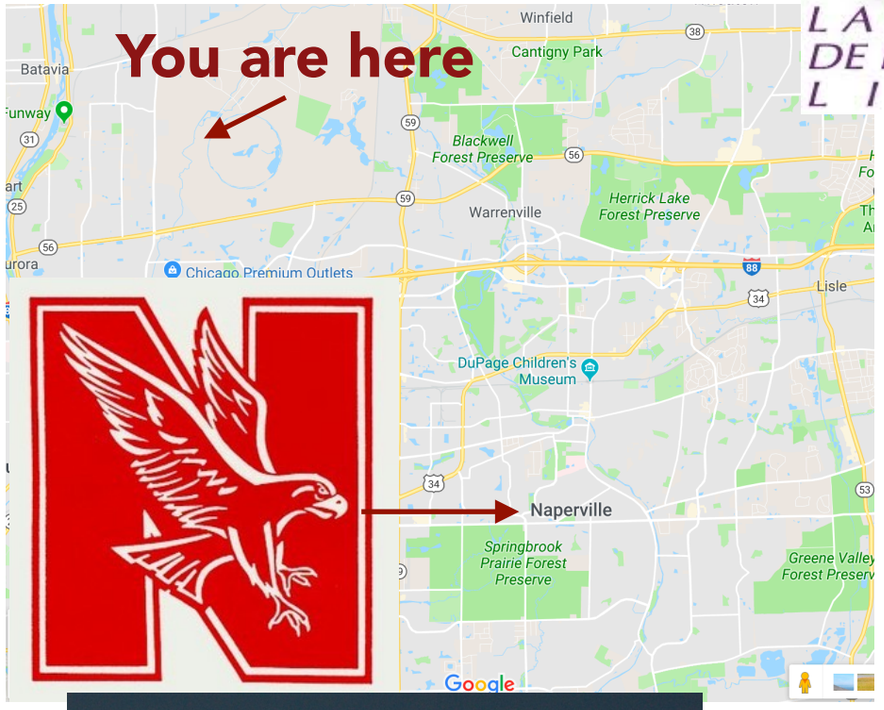
Schuler and Sjöstrand
Block and Halzen 2011
Achilli *et al.* (arXiv:1102.1949)
pp Data
$p\bar{p}$ Data
ATLAS
σ_{inel} [mb]
$\sqrt{s}$ (GeV)


Collision Event at 7 TeV
Mar. 30, 2010

HELLO!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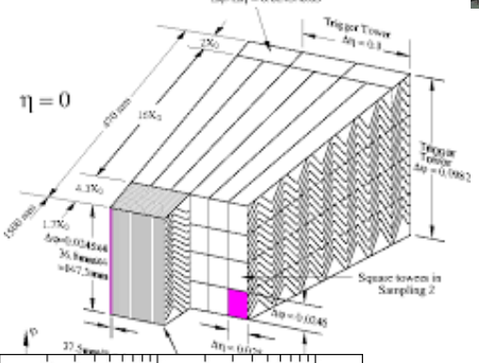
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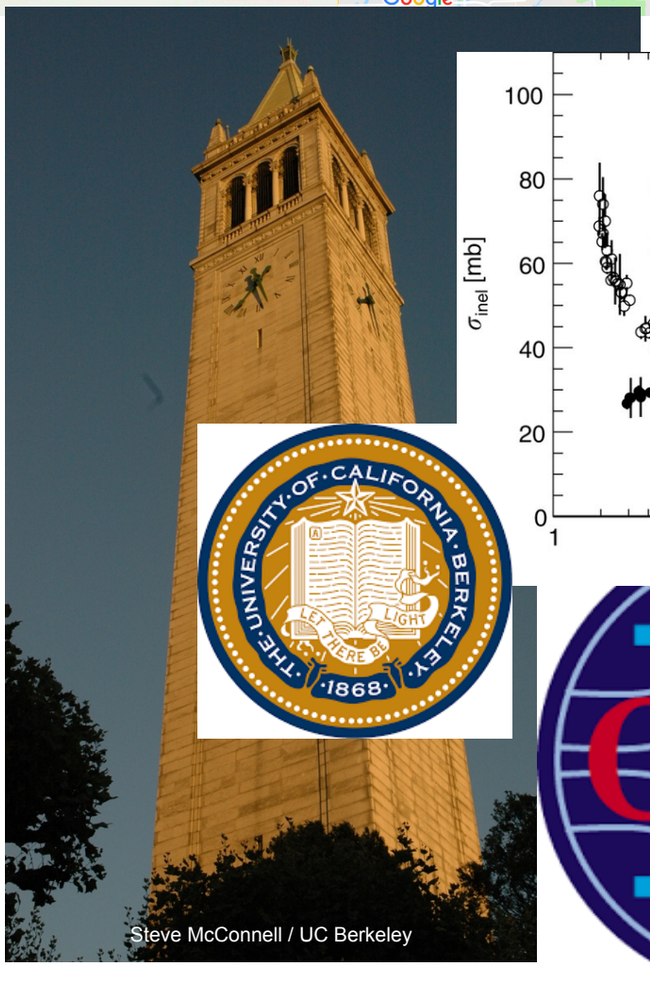
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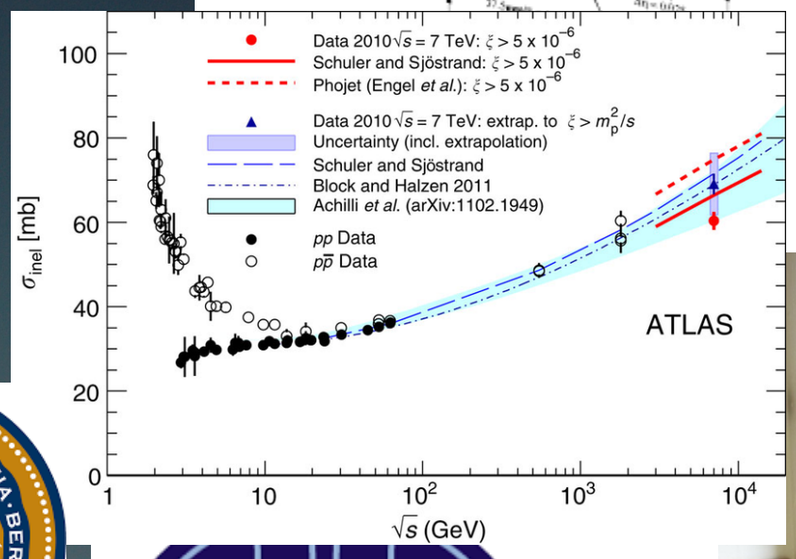
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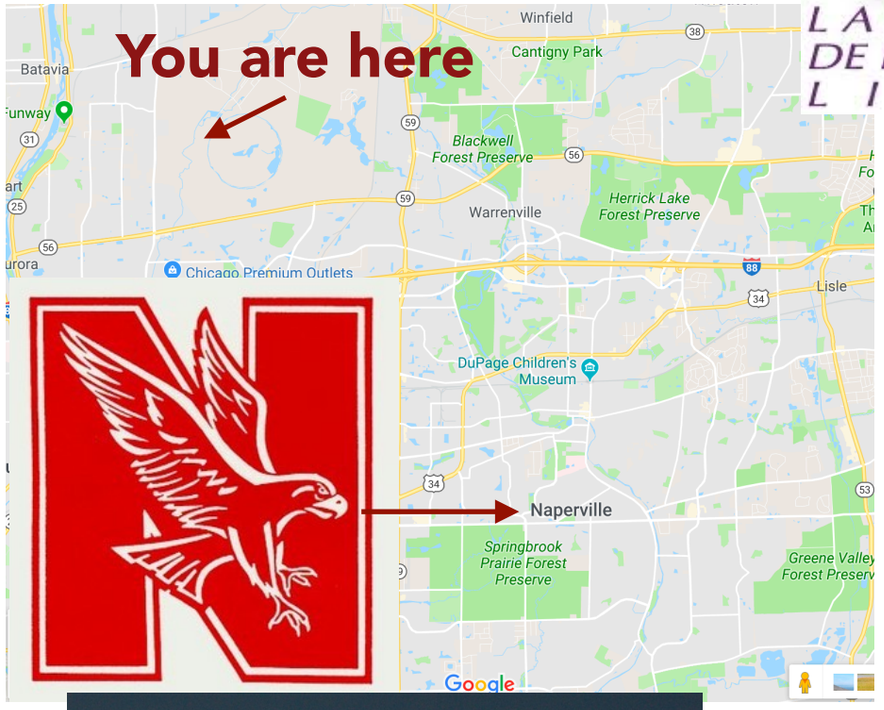
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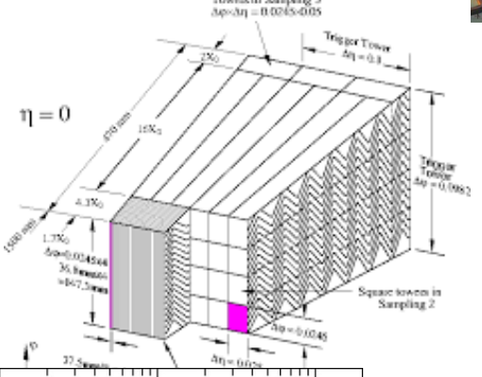
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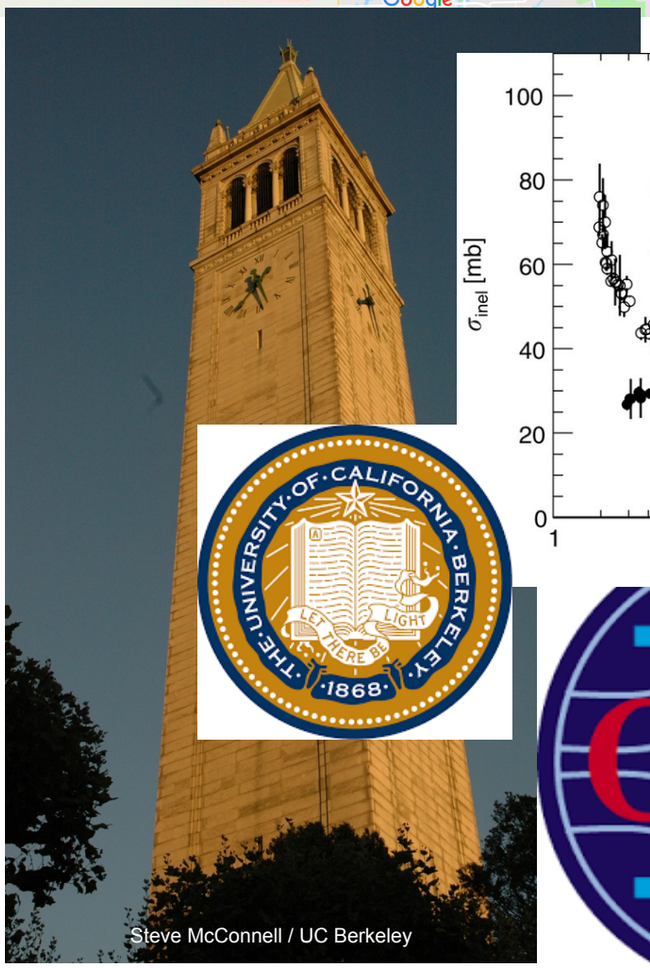
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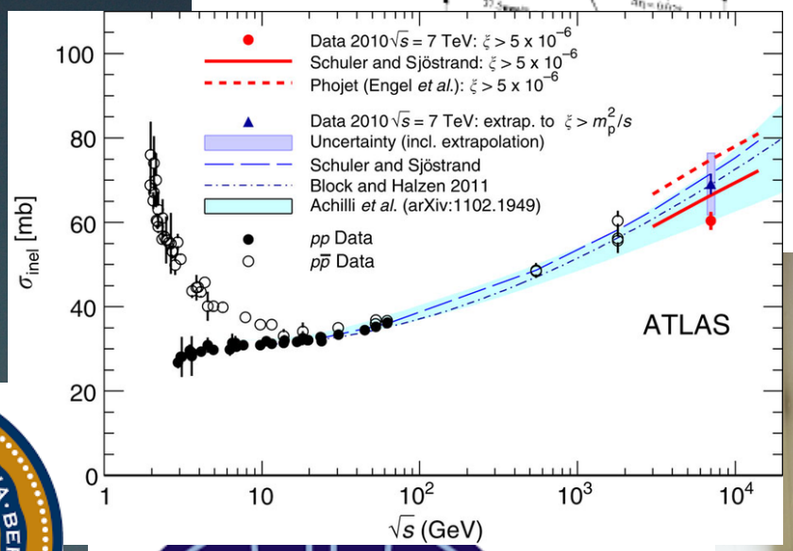
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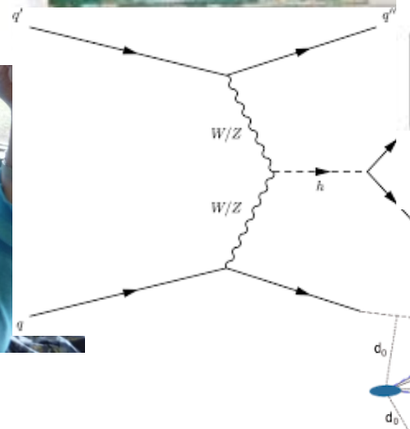
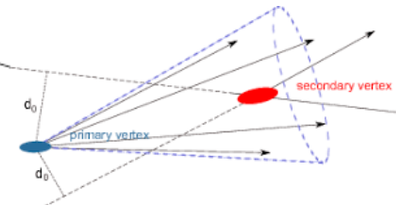
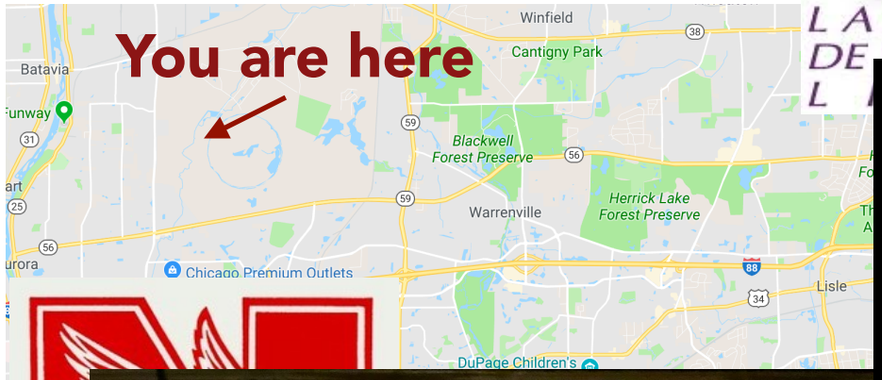

W/Z
W/Z
h
b


secondary vertex
primary vertex
d_0
d_0

HELLO!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LCLS II
Super Conducting
SOFT SXR
LCLS II
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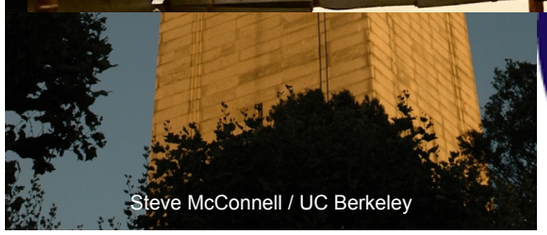
DUMP
DASEL
S30XL
LCLS II
Super Conducting
HARD HXR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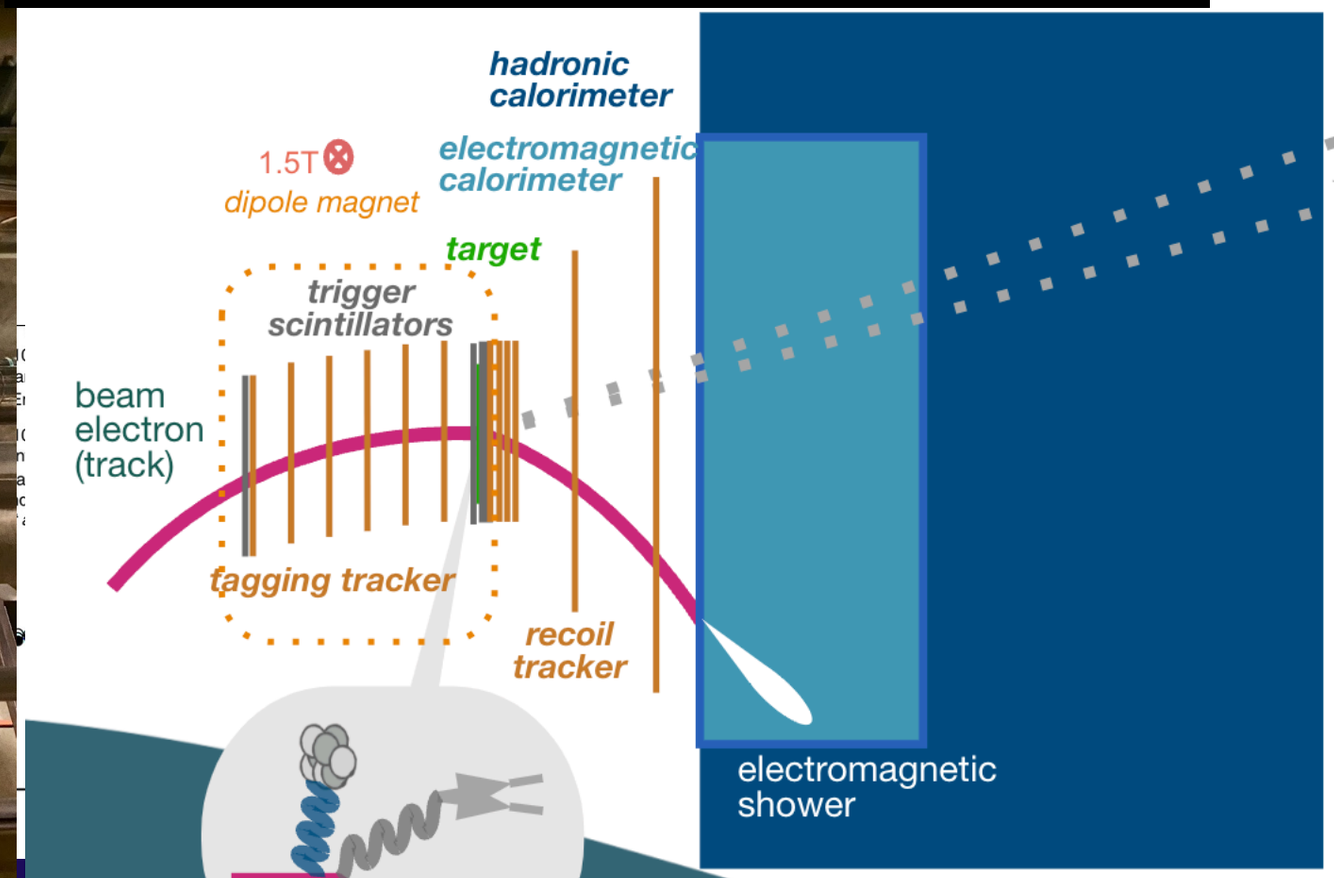

hadronic calorimeter
1.5T
dipole magnet
electromagnetic calorimeter
target
trigger scintillators
beam electron (track)
tagging tracker
recoil tracker
electromagnetic shower

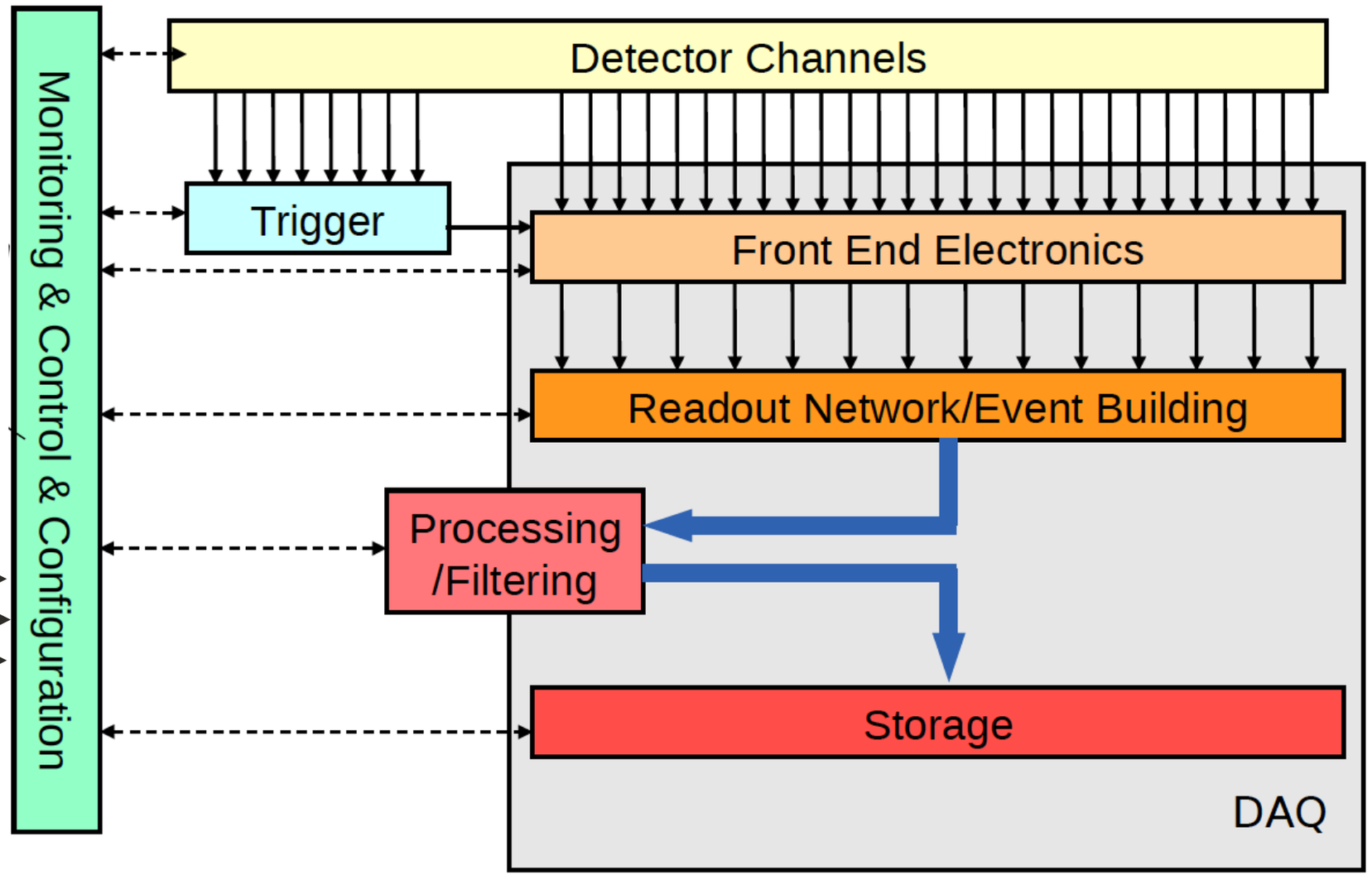

Mar. 30, 2010

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.
- These are accelerator-heavy, but the concepts apply somewhat 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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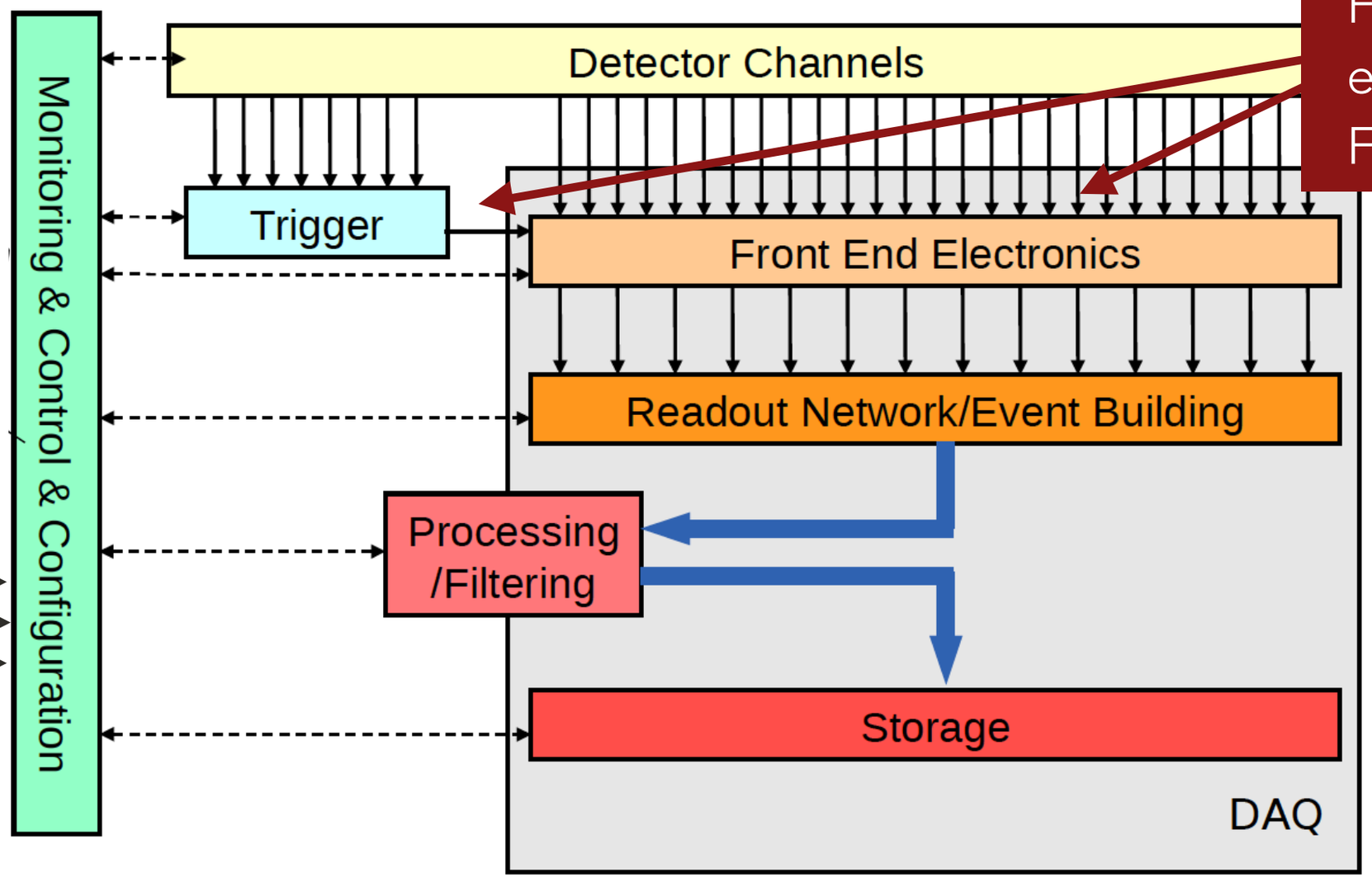

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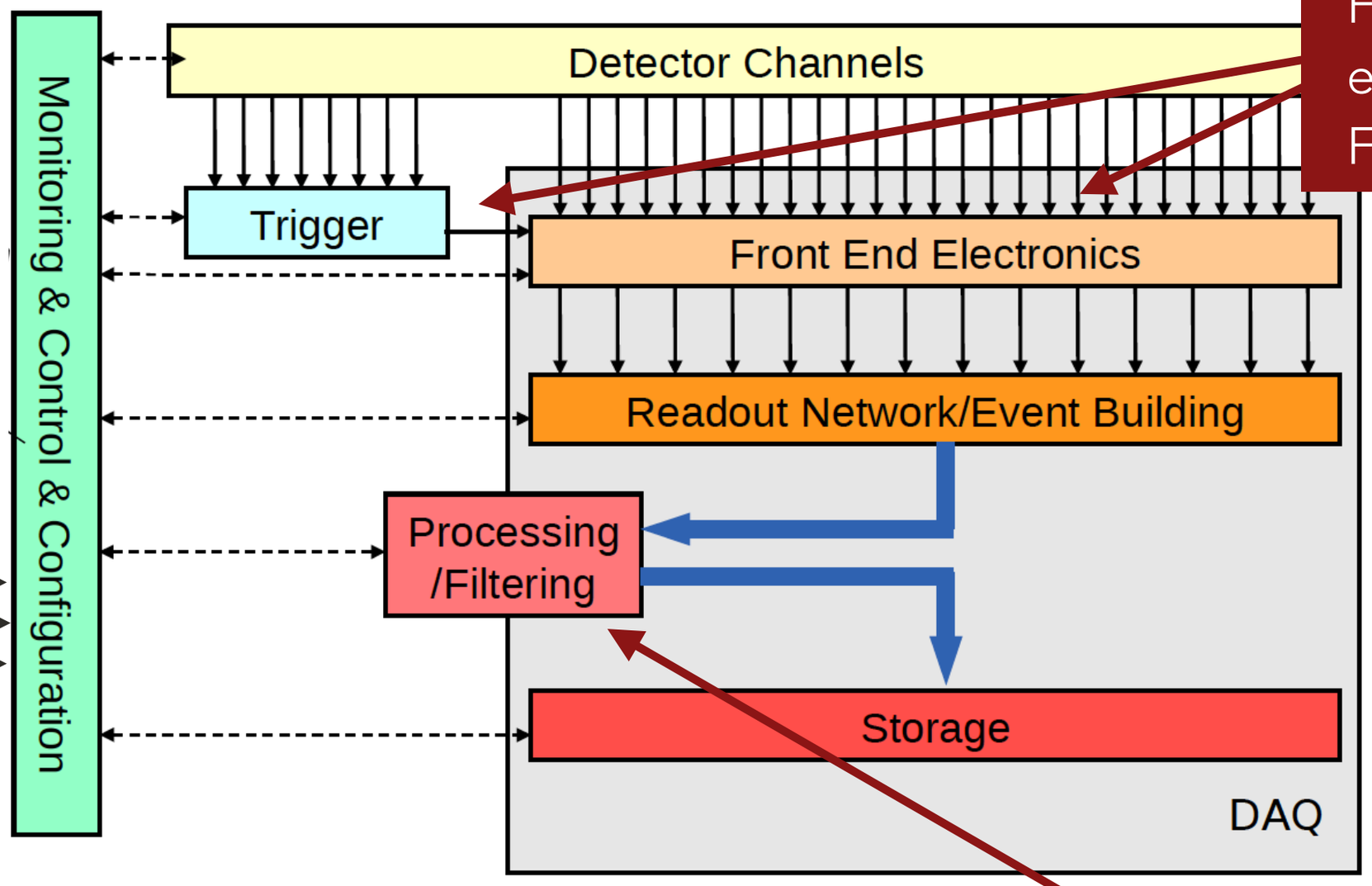

Fast, custom electronics: FPGAs, ASICs

Computing power: CPUs/ GPUs

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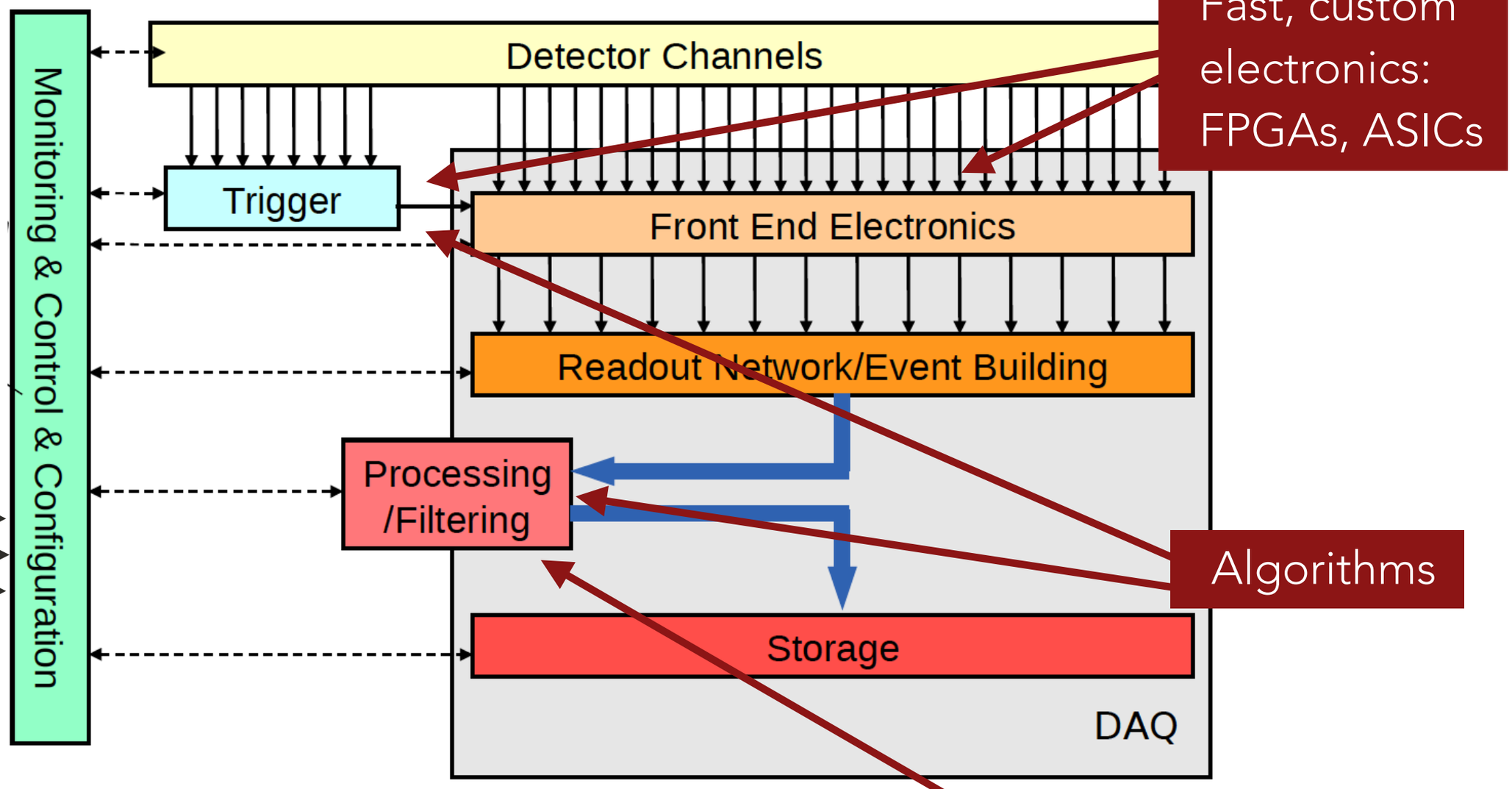

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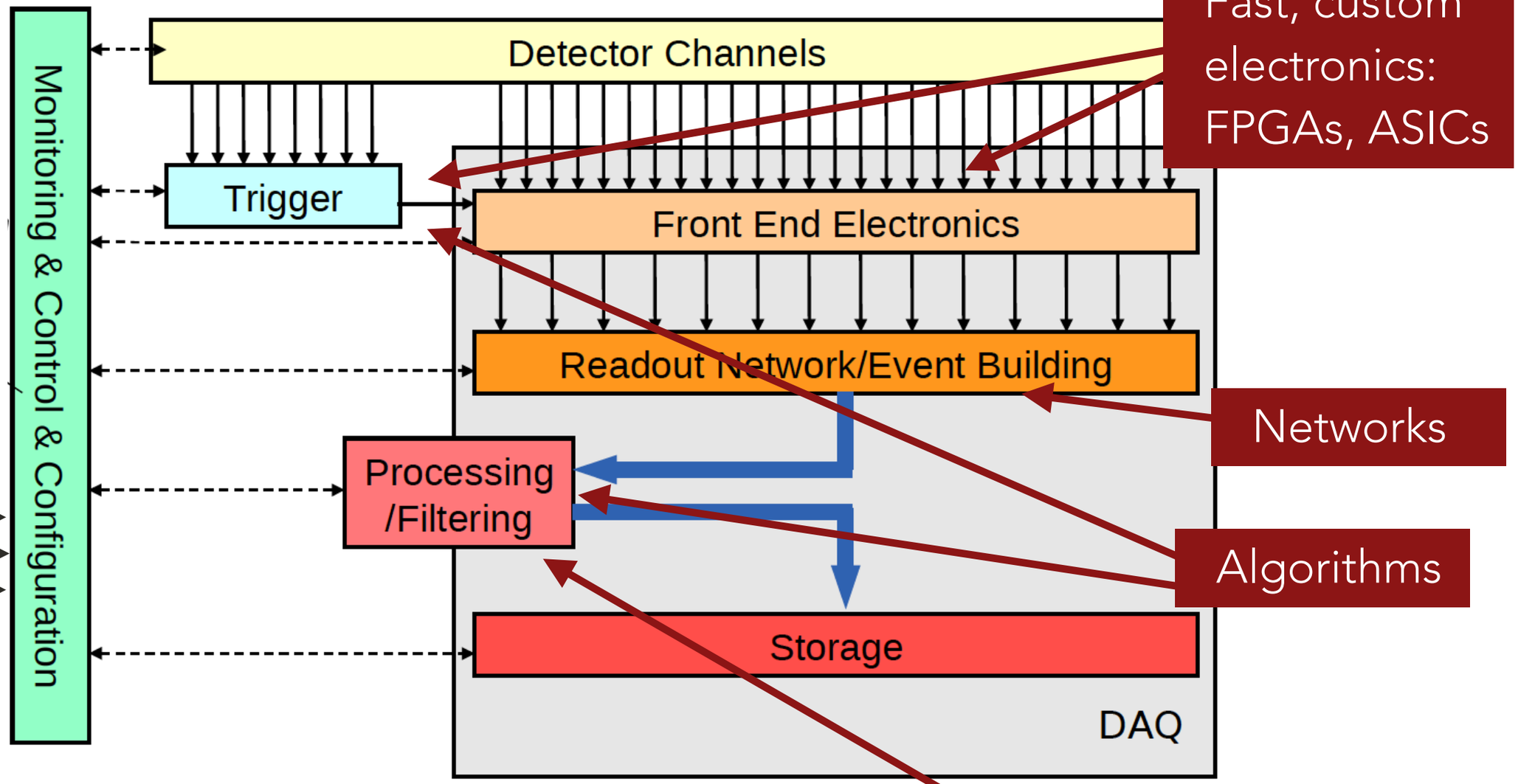

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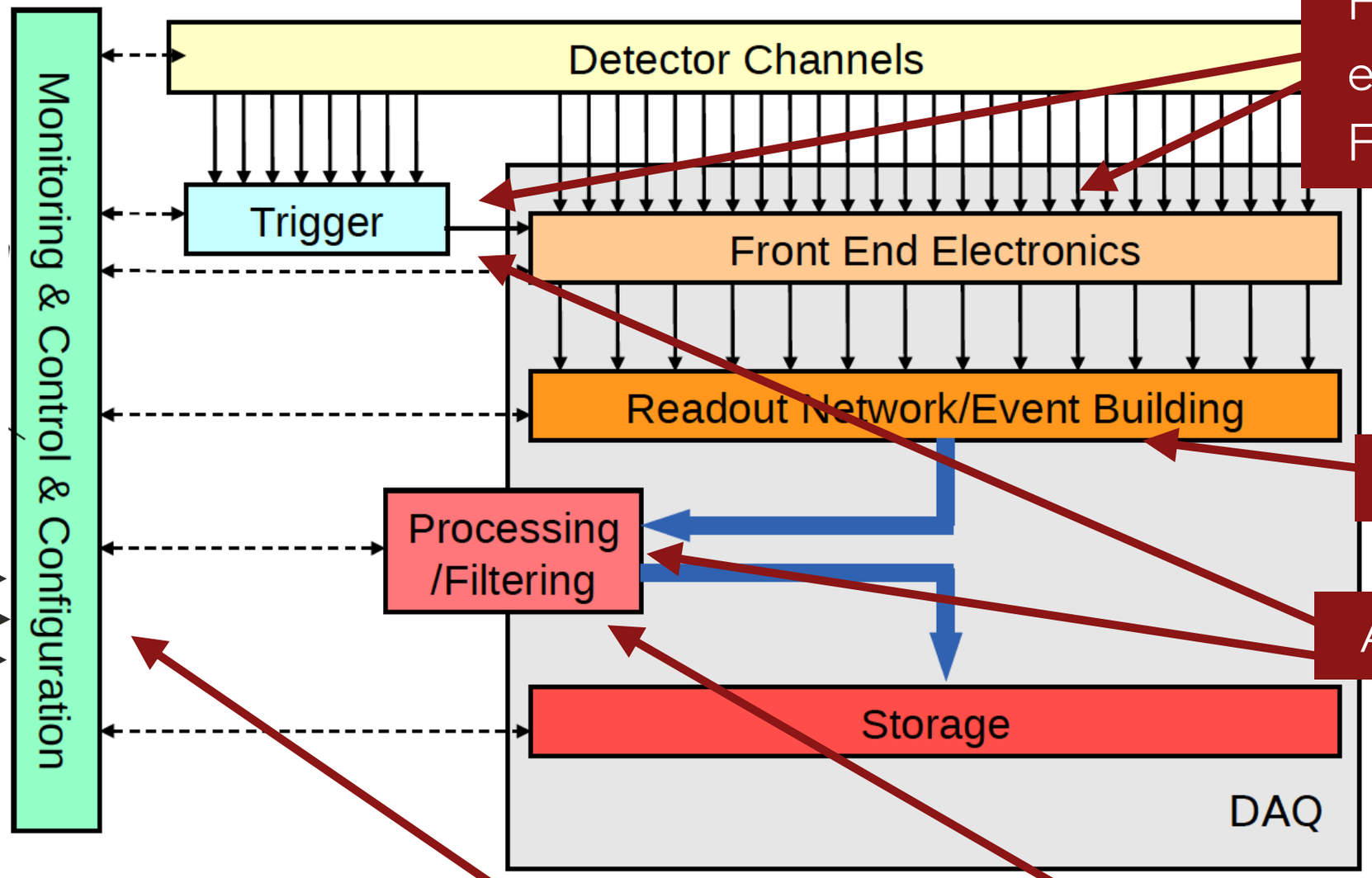

Fast, custom electronics: FPGAs, ASICs

Networks

Algorithms

Computing power: CPUs/ GPUs

Software & hardware; dynamic control

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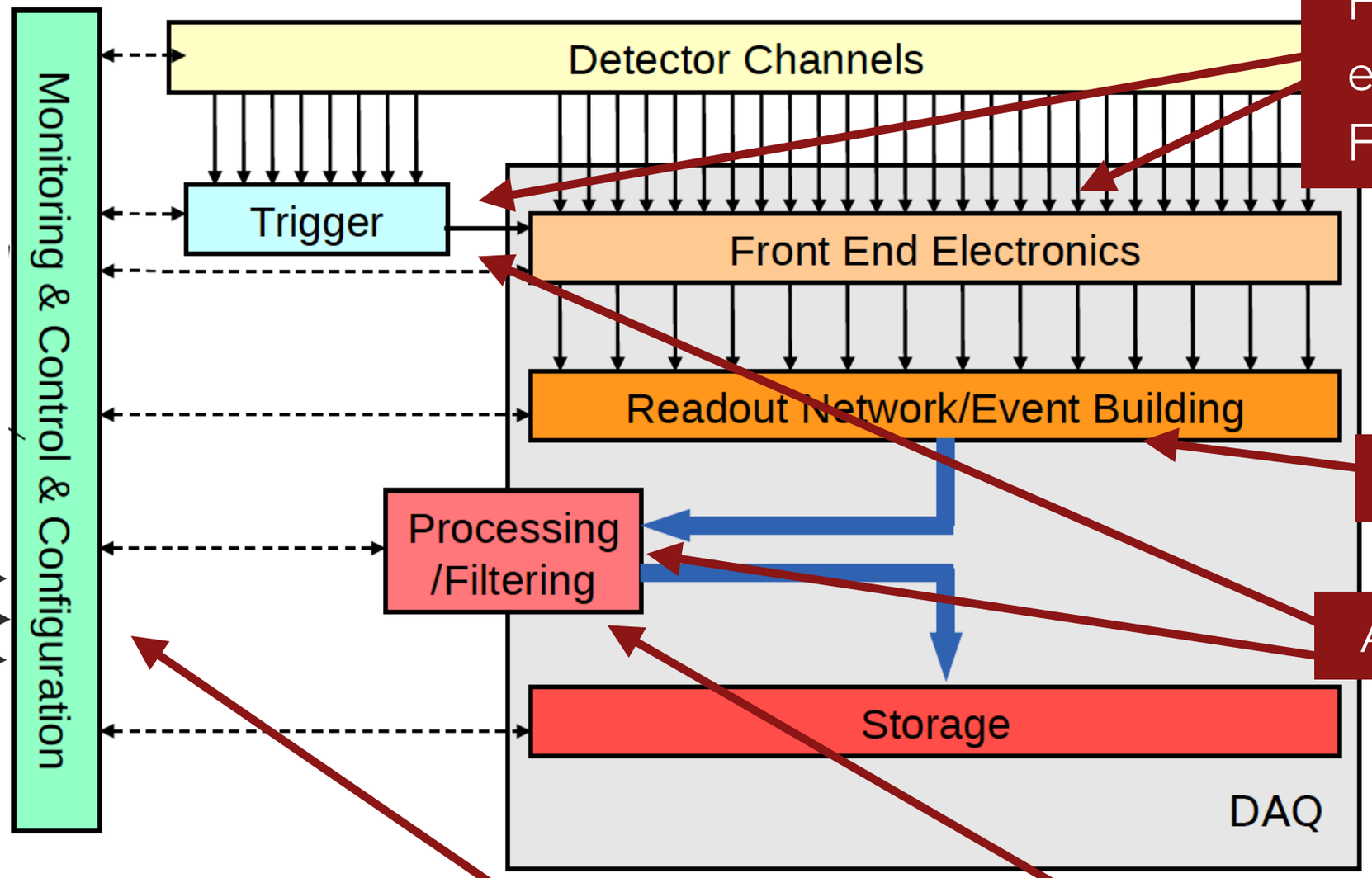

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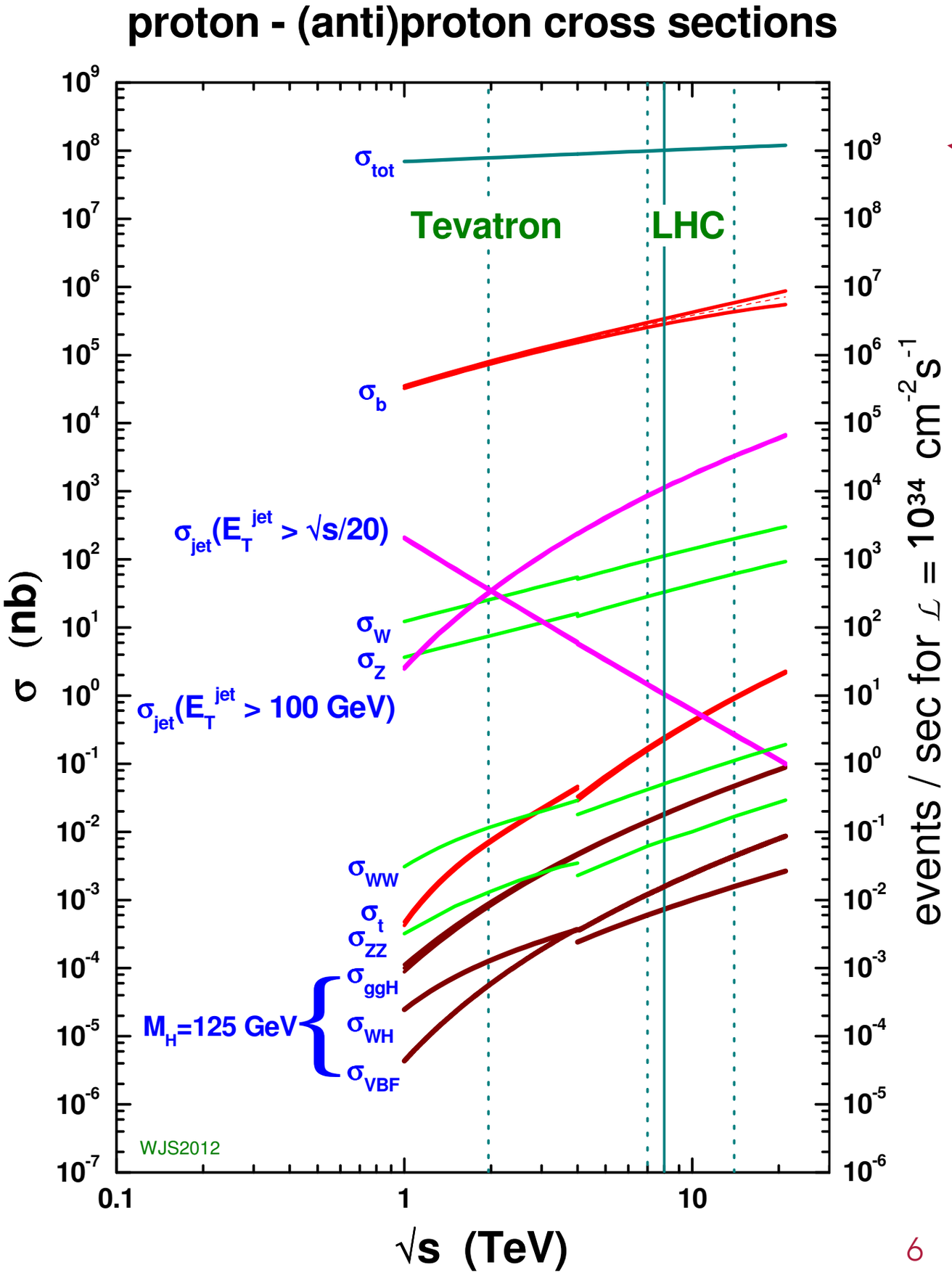
People!

Software & hardware; dynamic control

Computing power: CPUs/ GPUs

THE CHALLENGE : PART 1



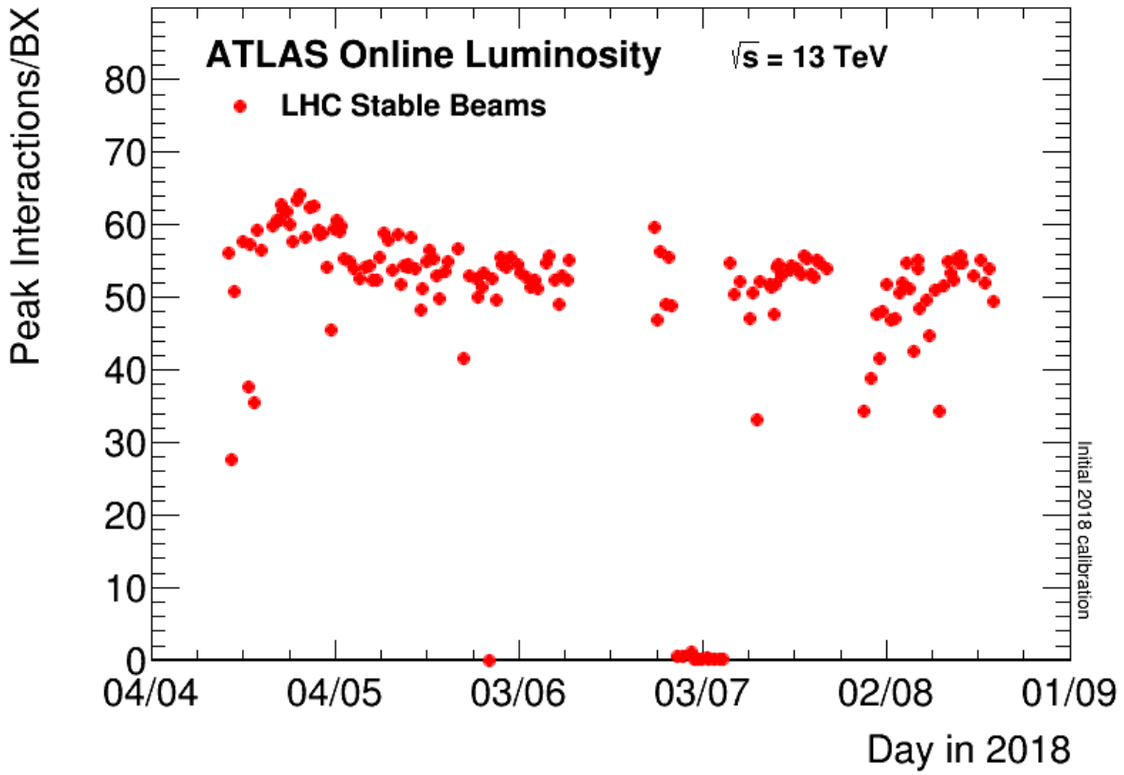
~Total Event rate

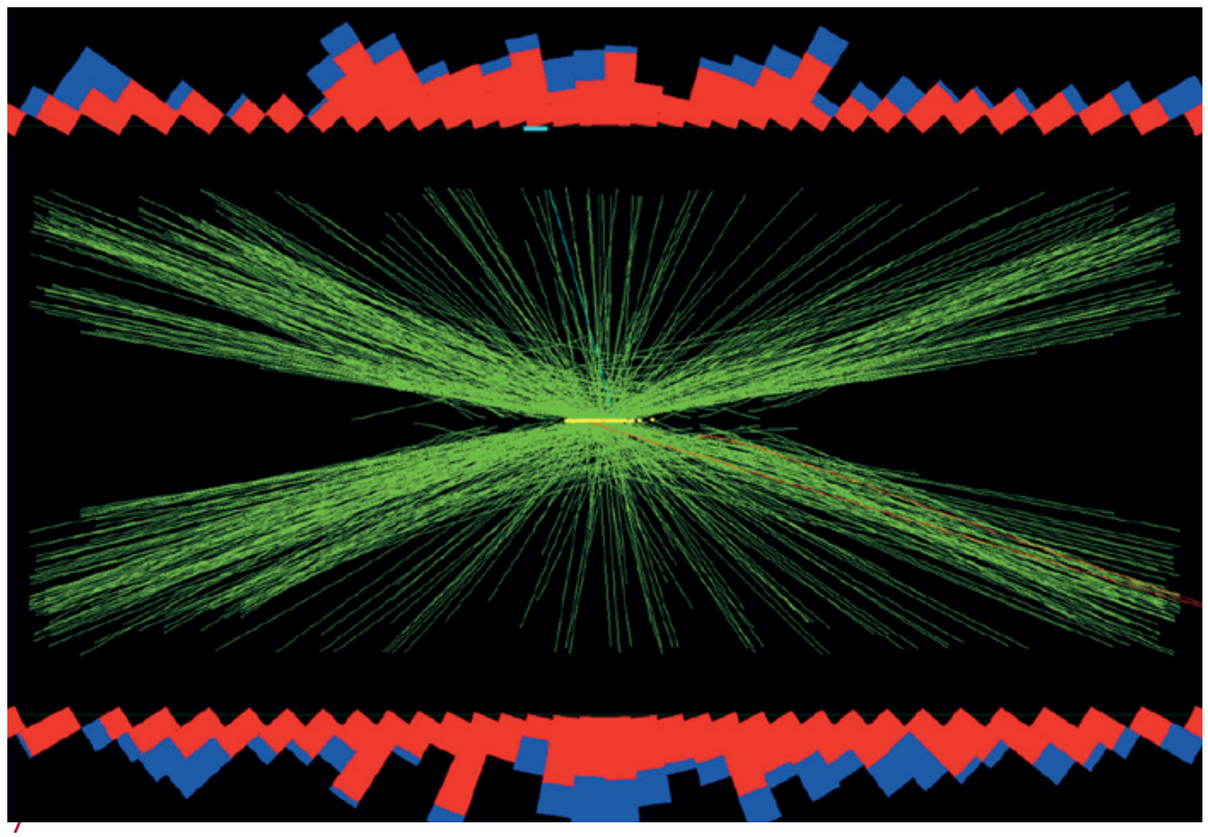
W & Zs (!!)

What you are probably interested in

THE CHALLENGE : PART 2

- A lot of things are going on at the same time!
  - ~50 simultaneous pp collisions in LHC Runs 2 & 3 (LHC design was 23)
- Collisions every ~25ns
  - Come in bunches and trains





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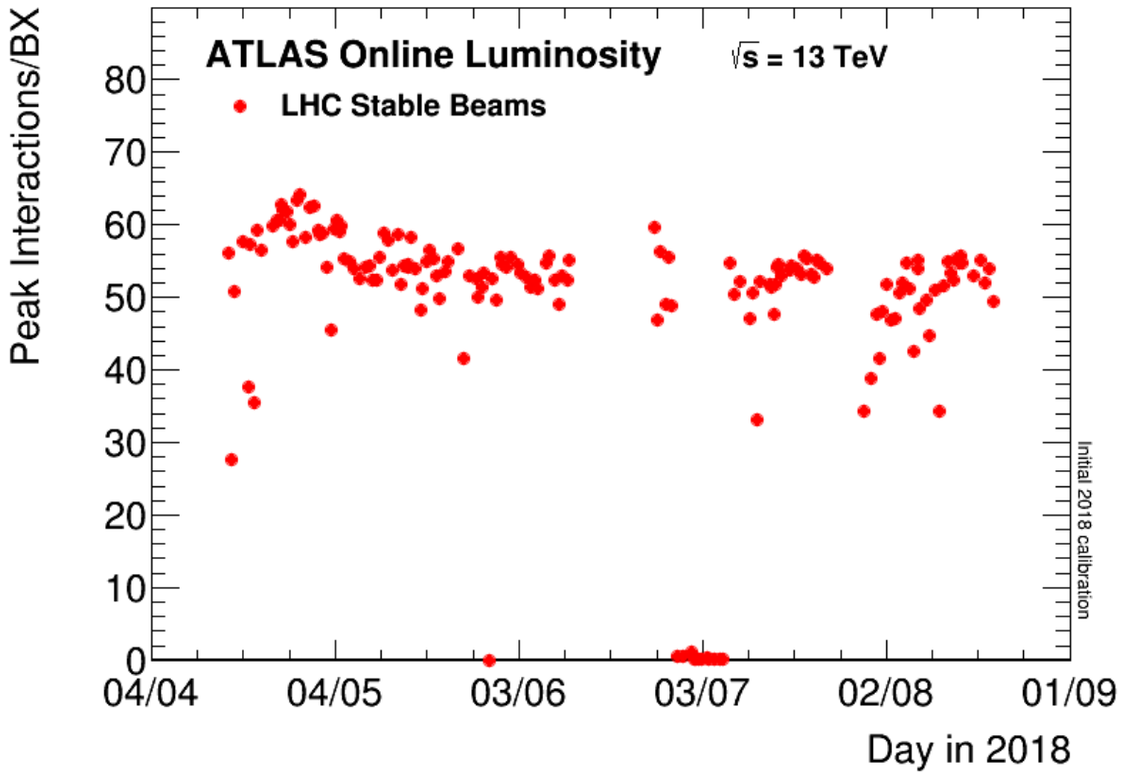

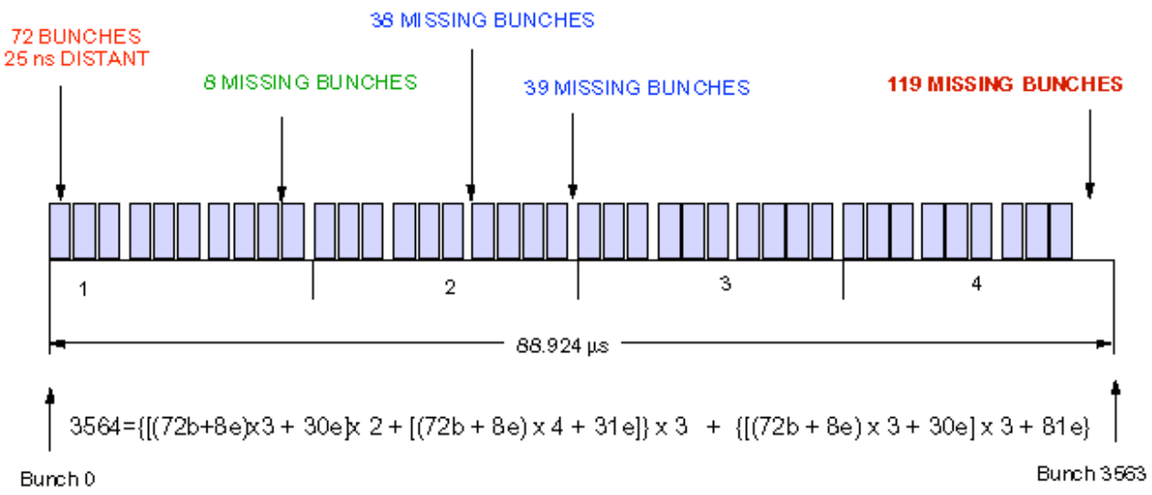

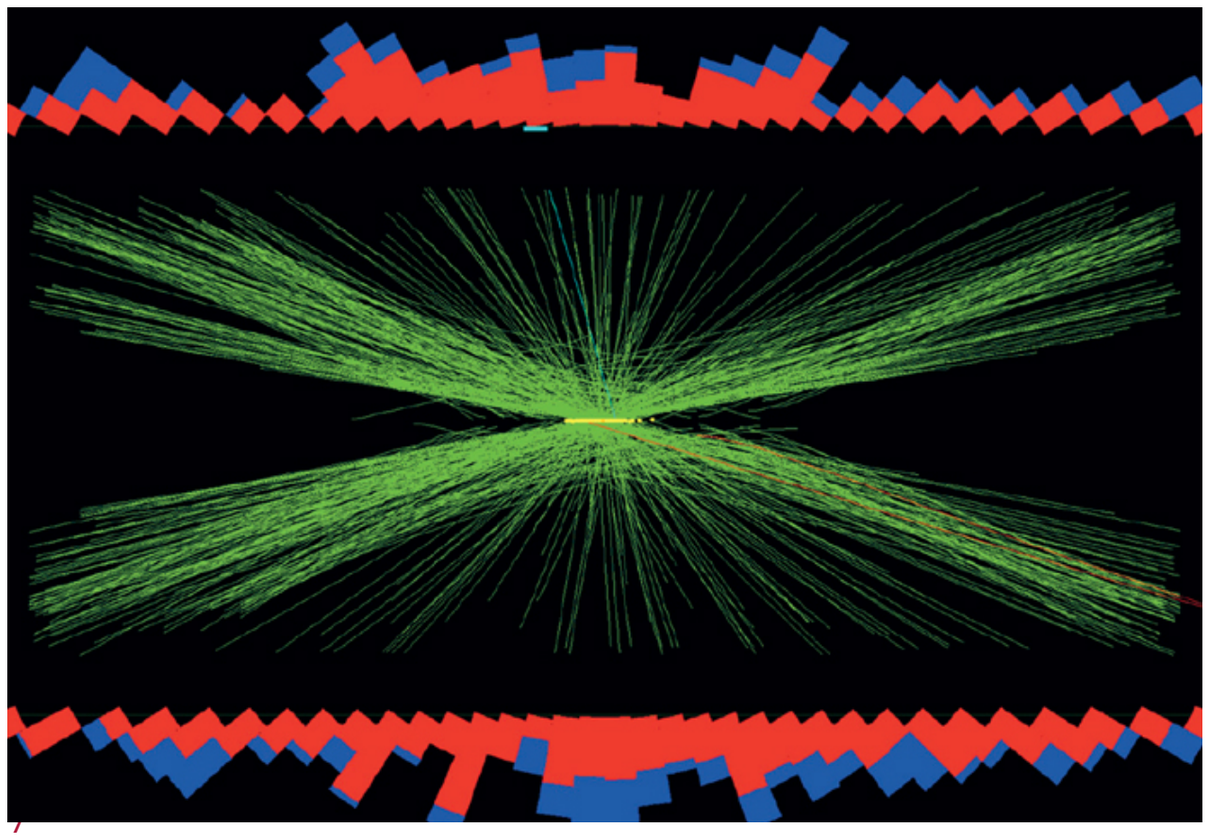

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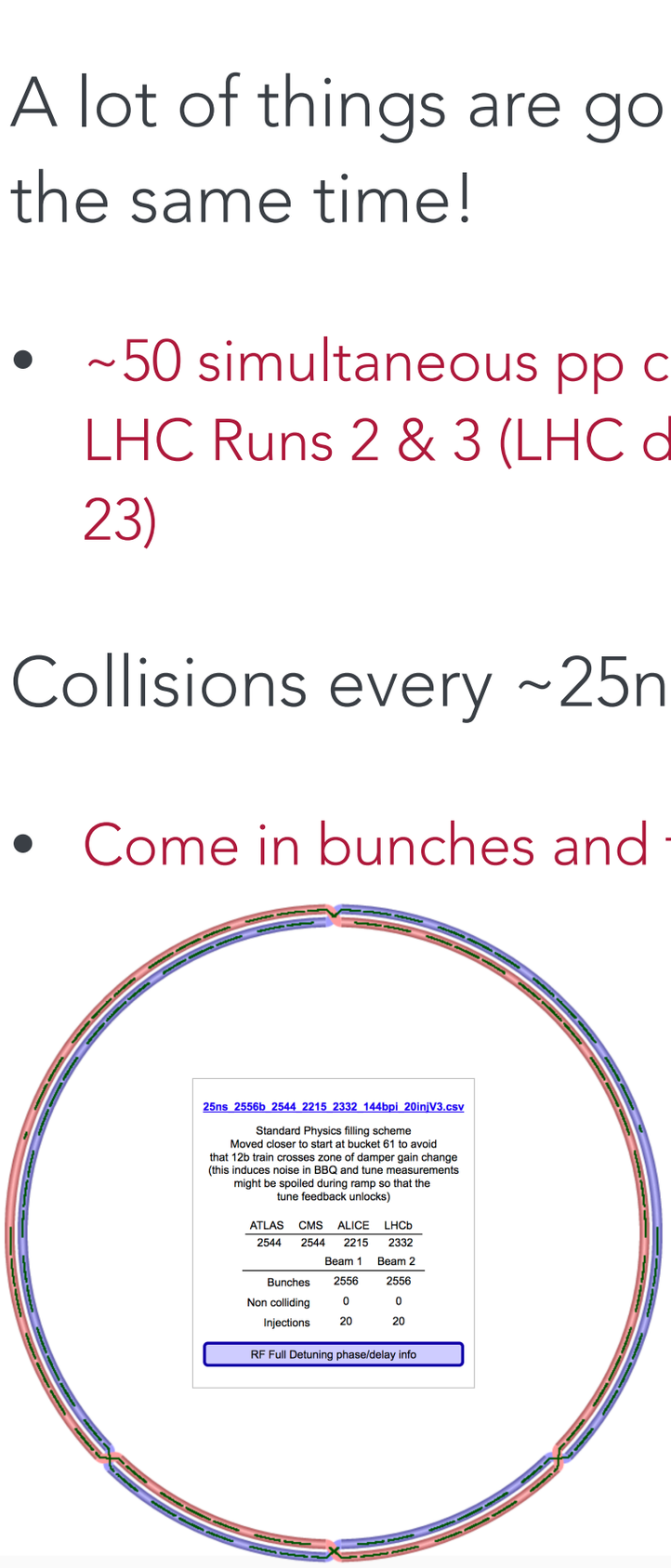

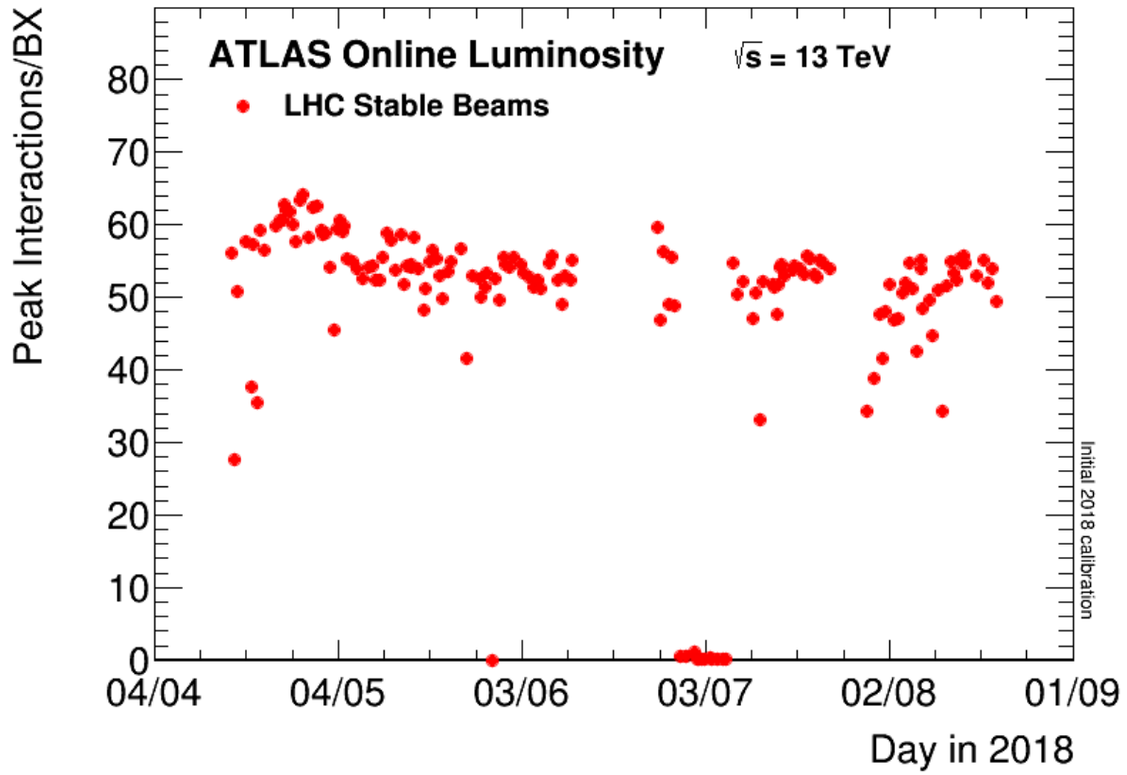

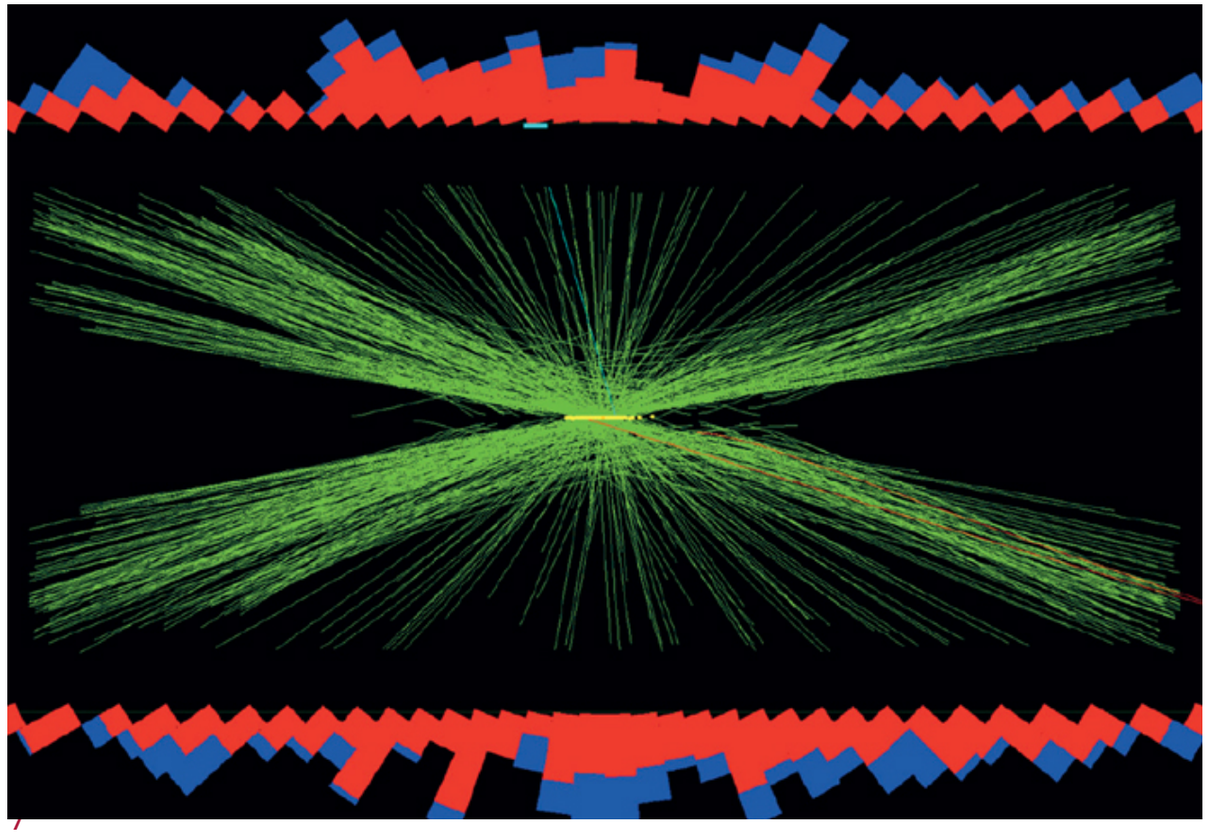

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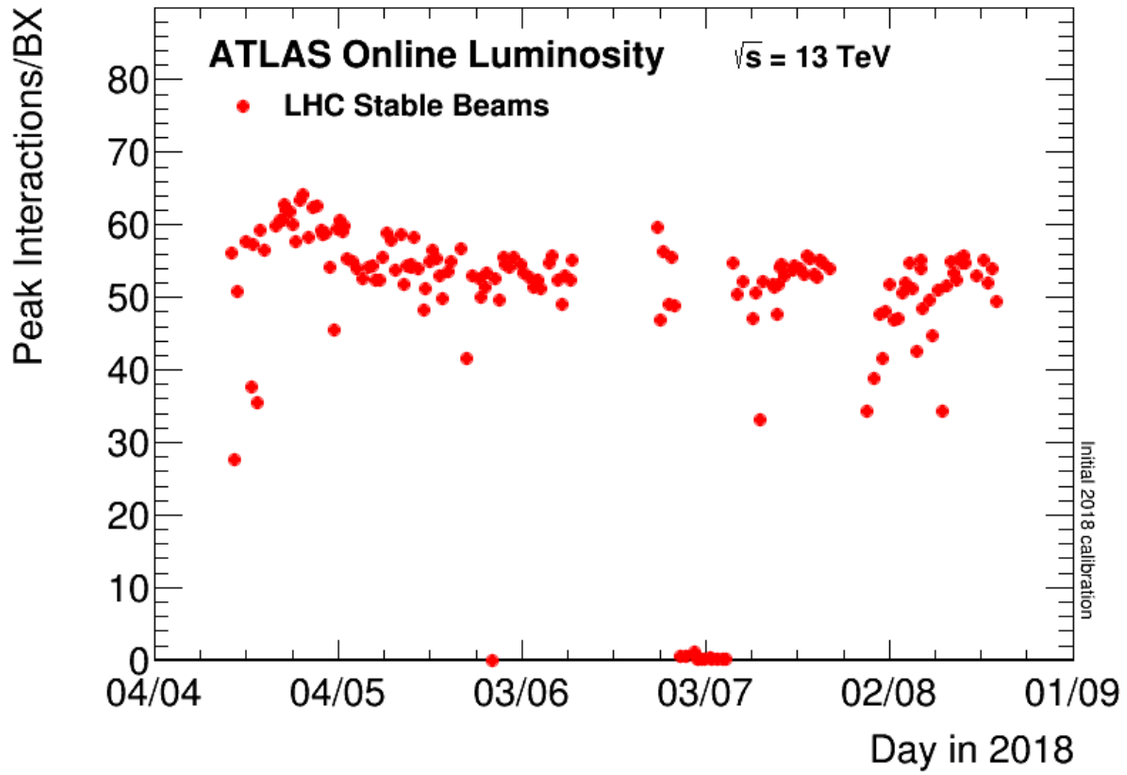

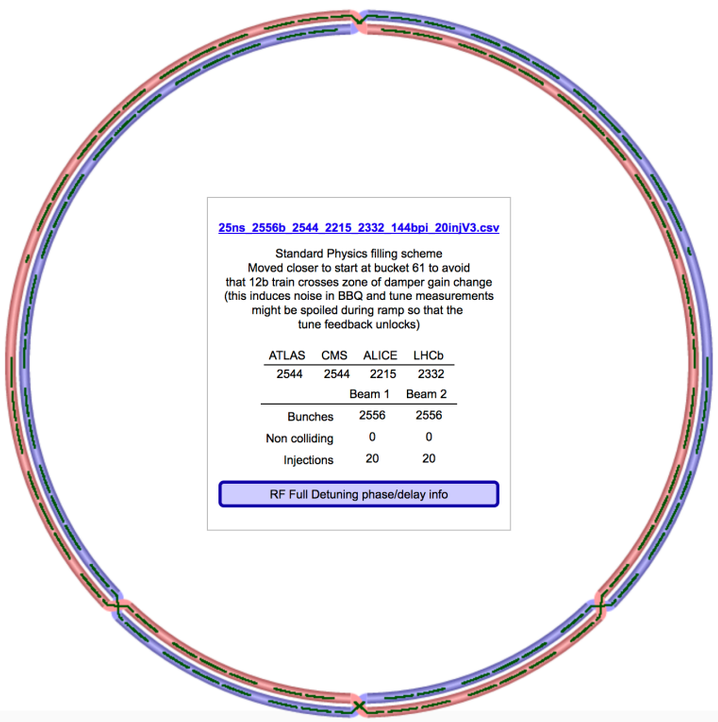

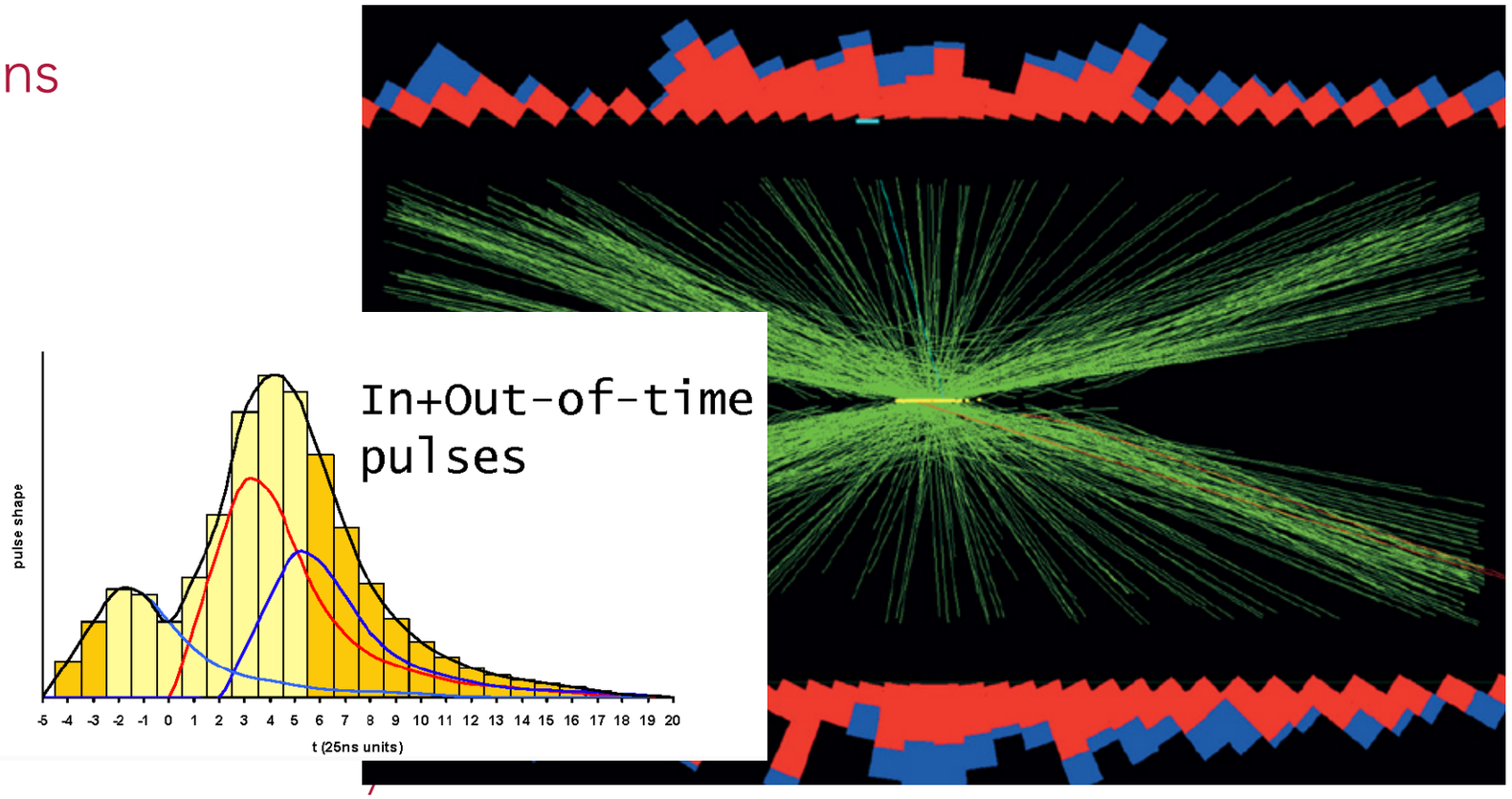

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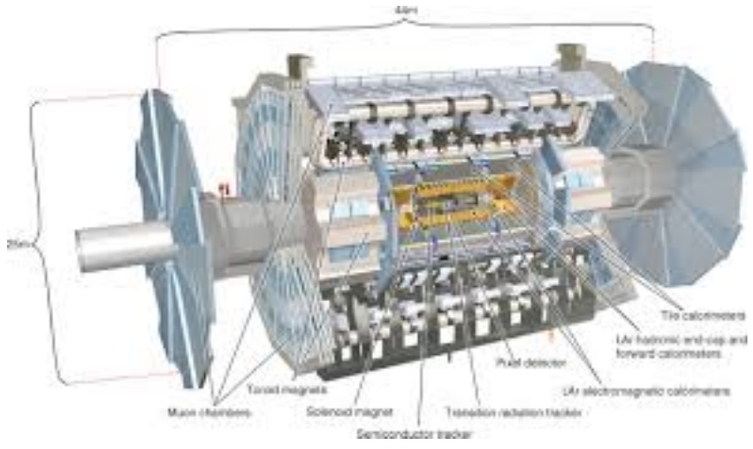

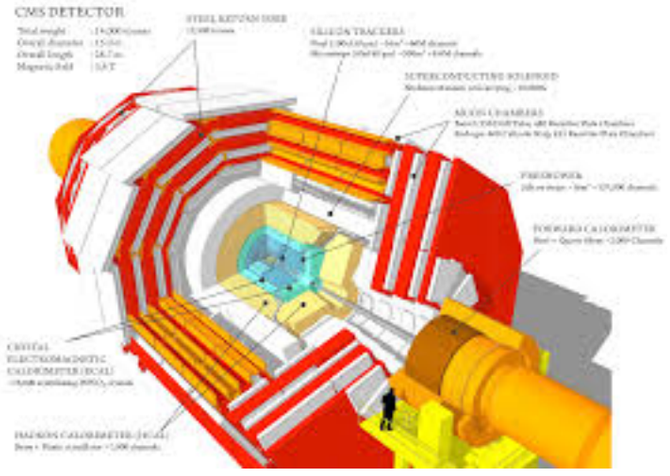

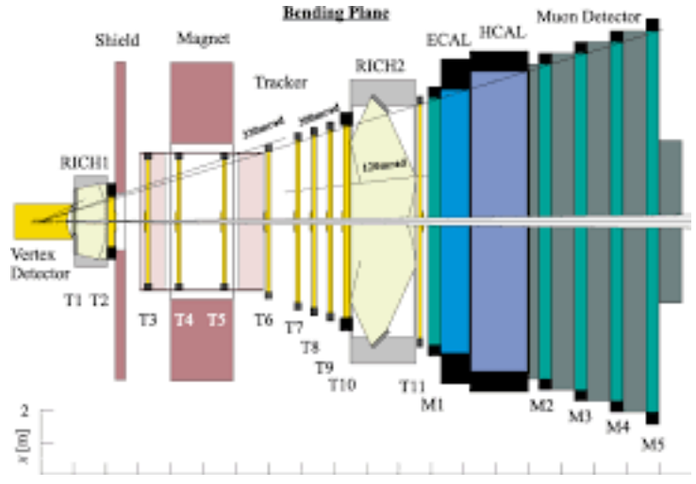

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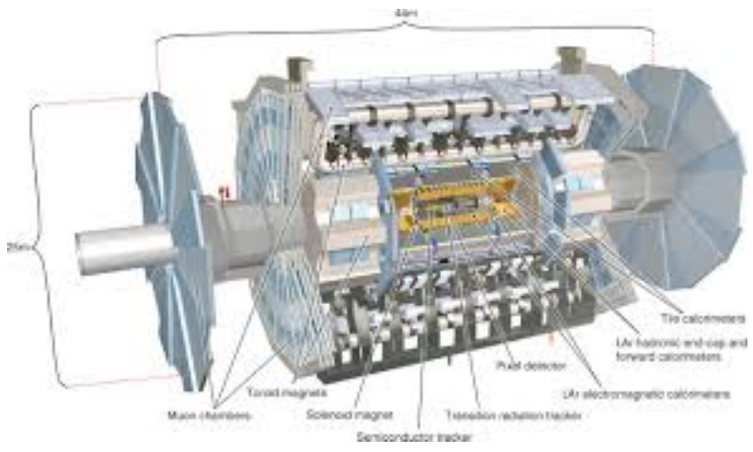

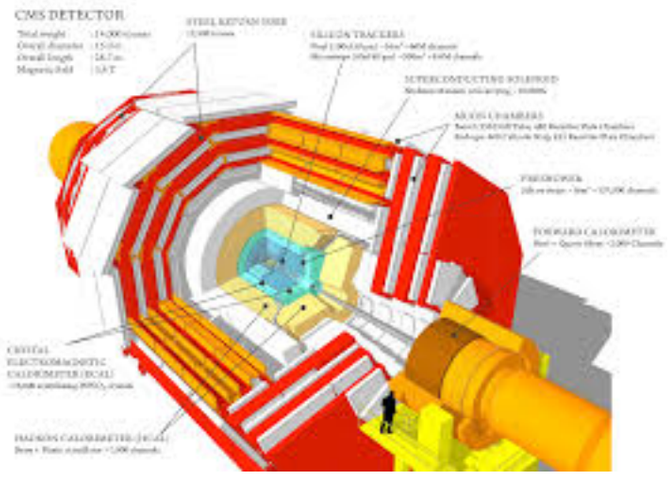

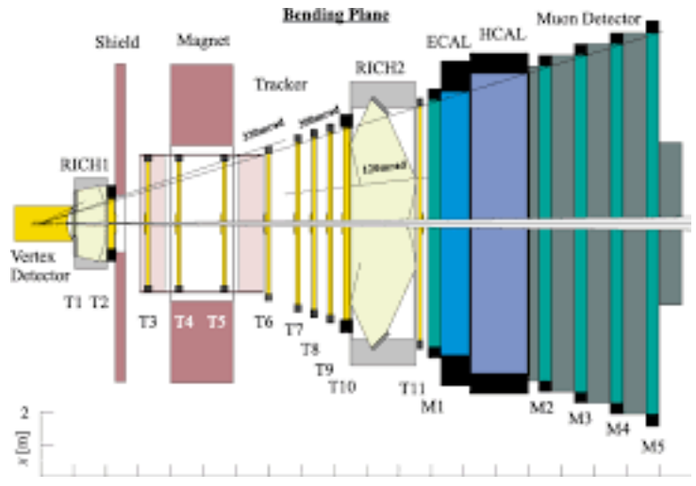

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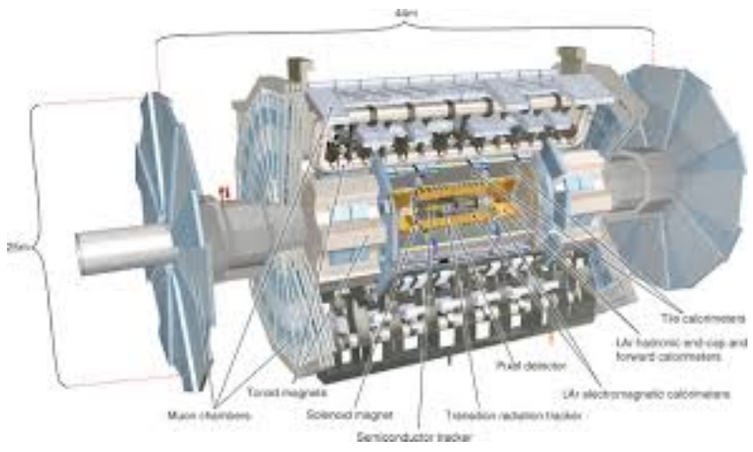

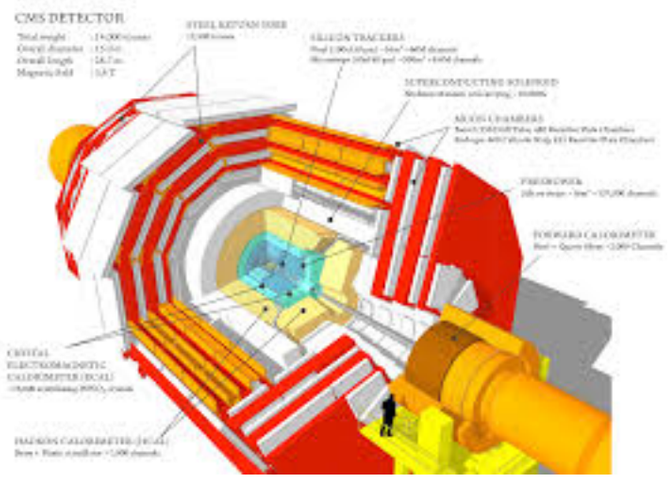

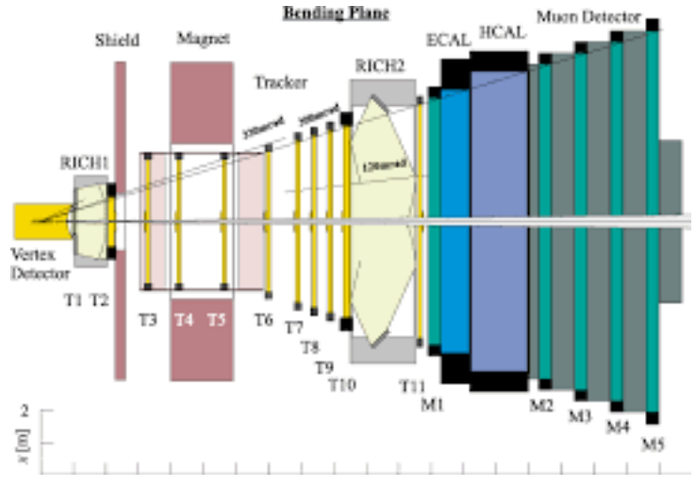

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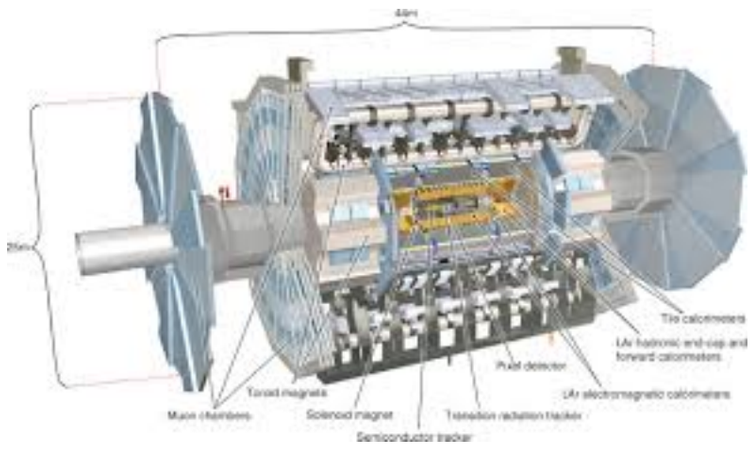

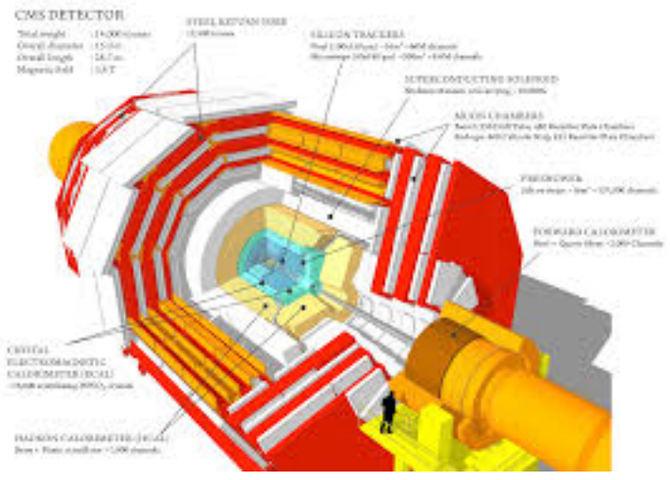

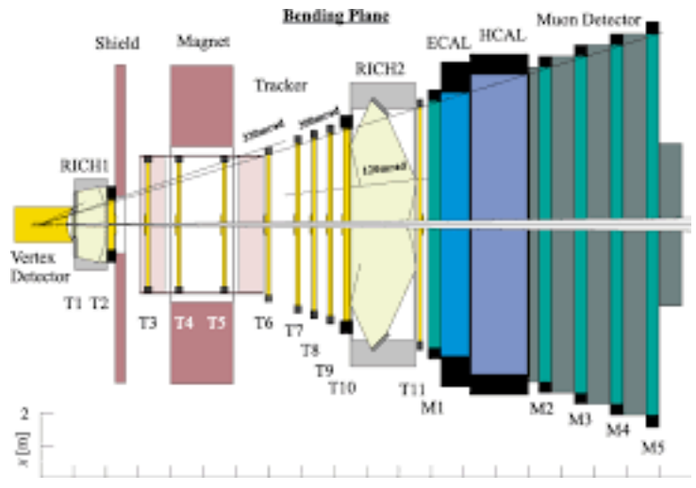

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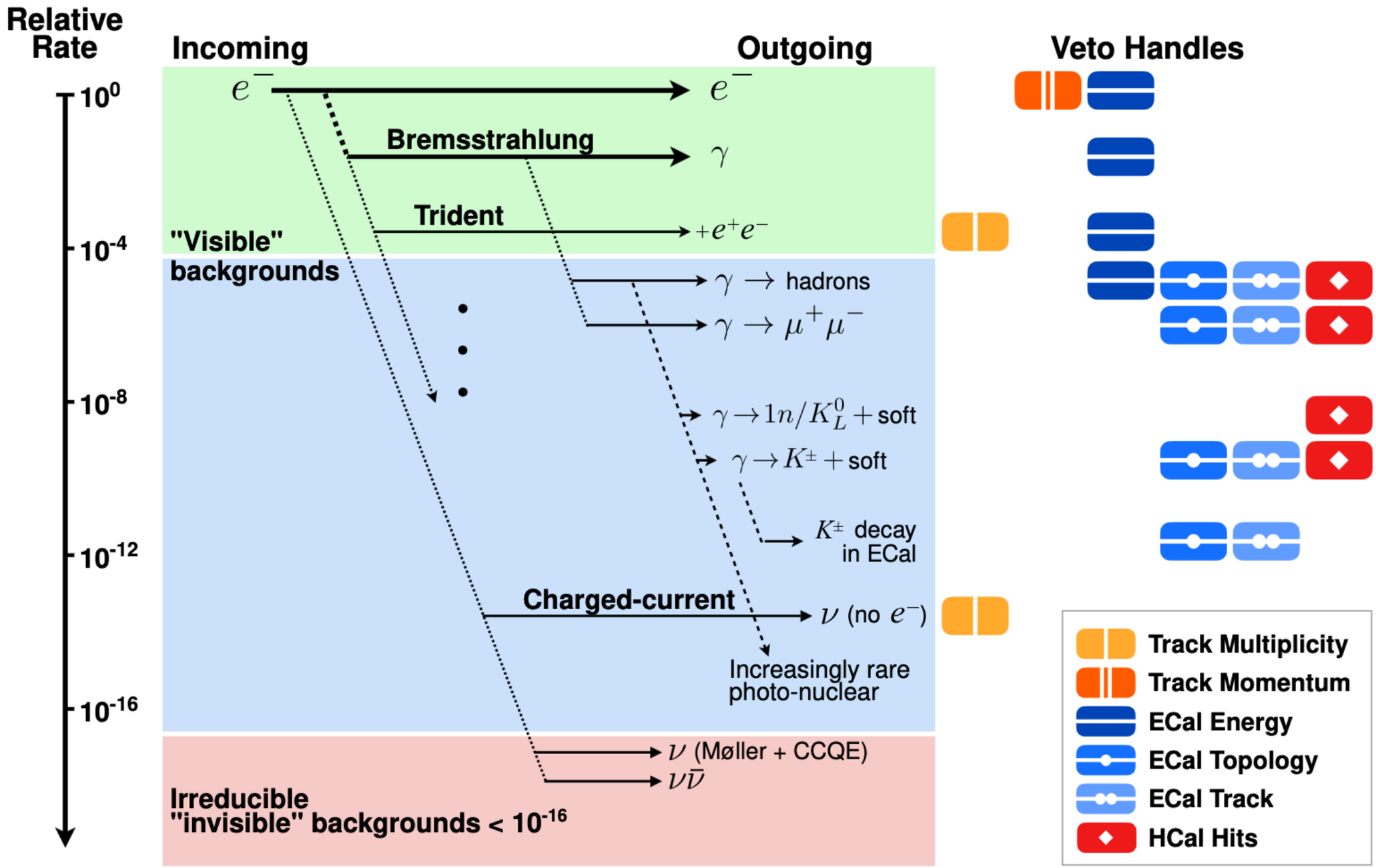
  - Can’t write all of it — 150000 PB/year!
- There are a number of bottlenecks to contend with:
  - Local, on detector data storage — how much data can I store on my detector before shipping it out?
  - How fast can I get data off my detector — what are my readout bandwidth limitations?
  - How much data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

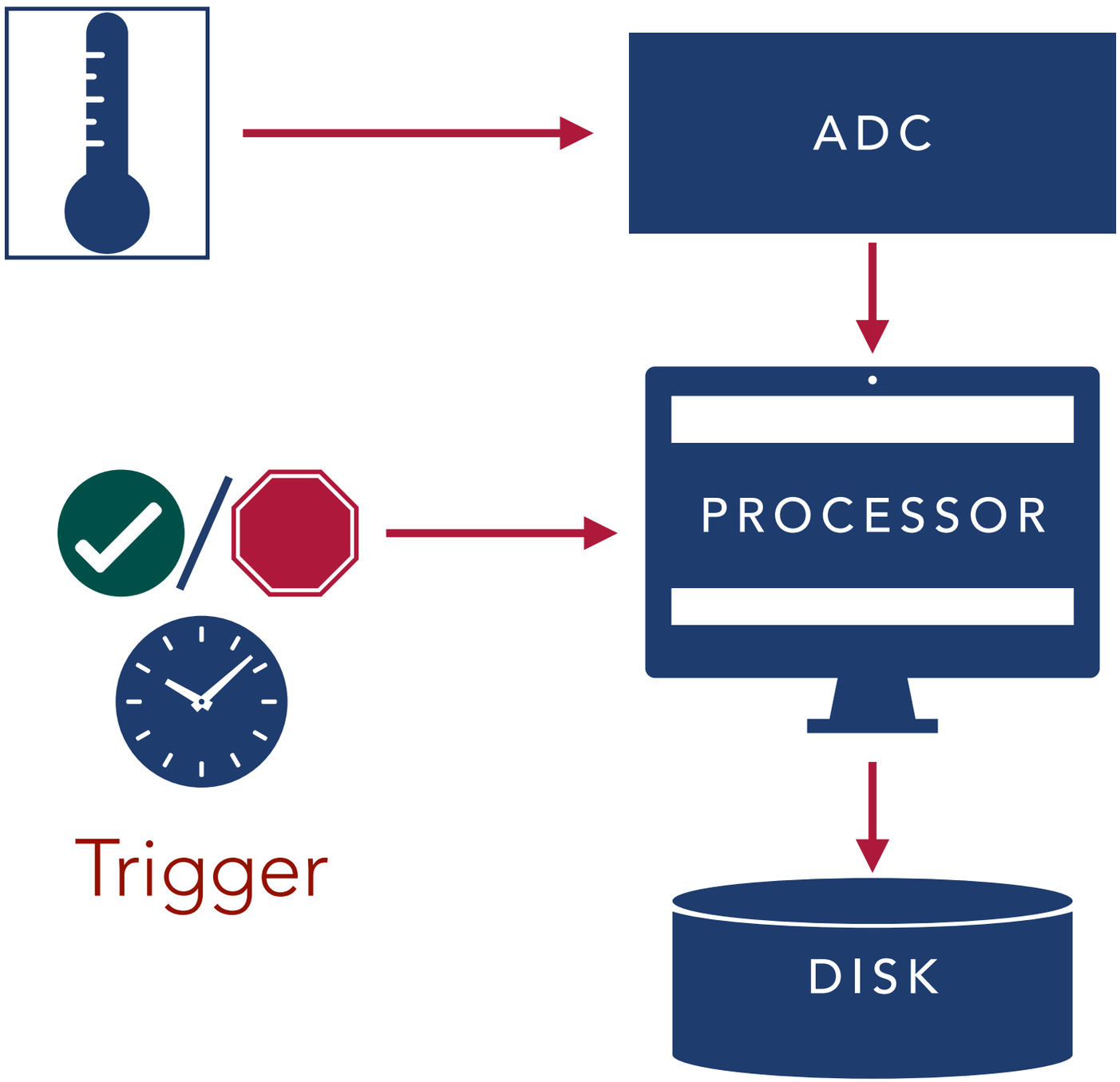
THE CHALLENGE: LMDX



THE BASICS: A TOY EXAMPLE

DRAWS HEAVILY FROM EXAMPLE BY ANDREA NEGRI

FIXED FREQUENCY PROCESSING



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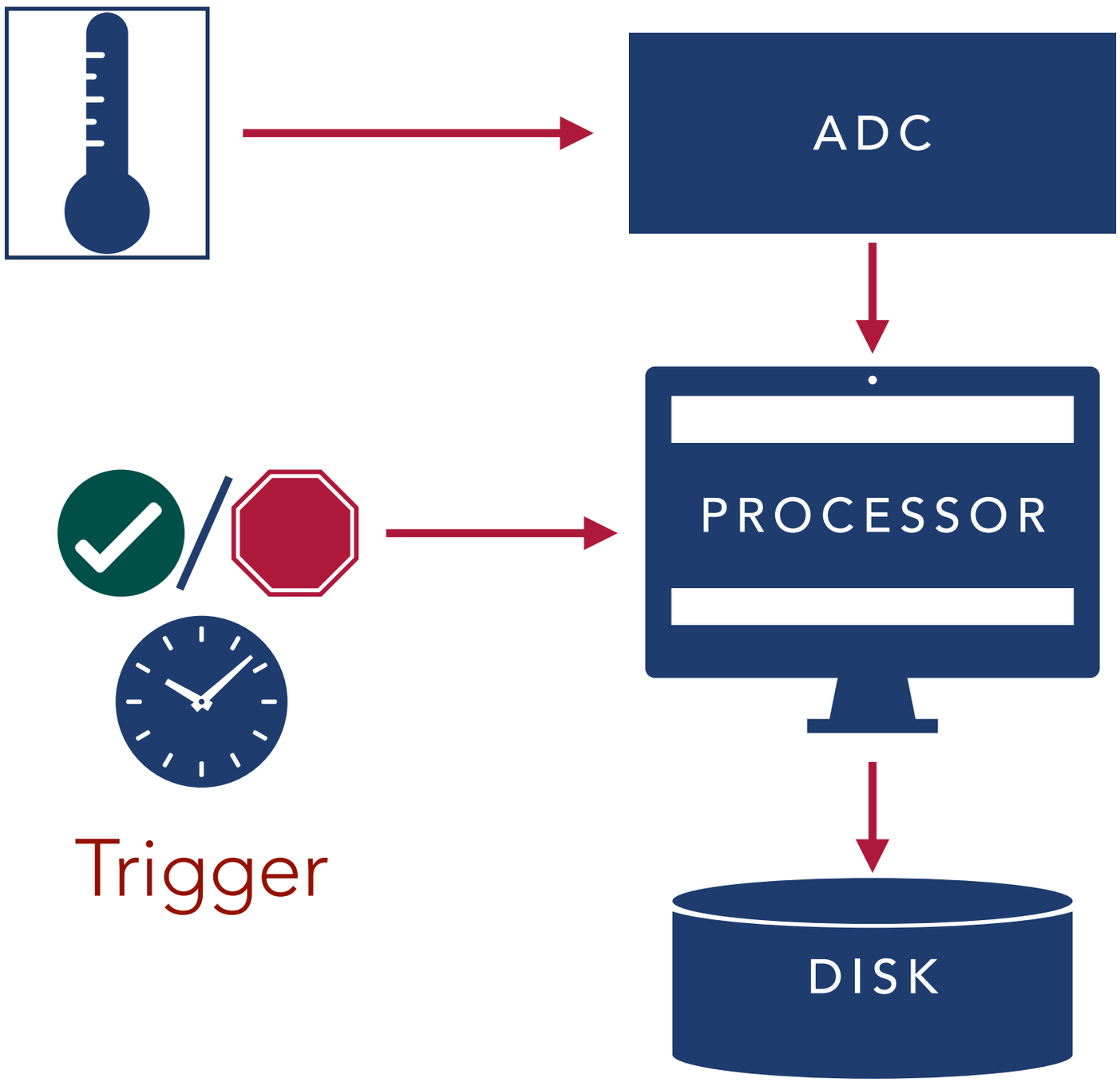

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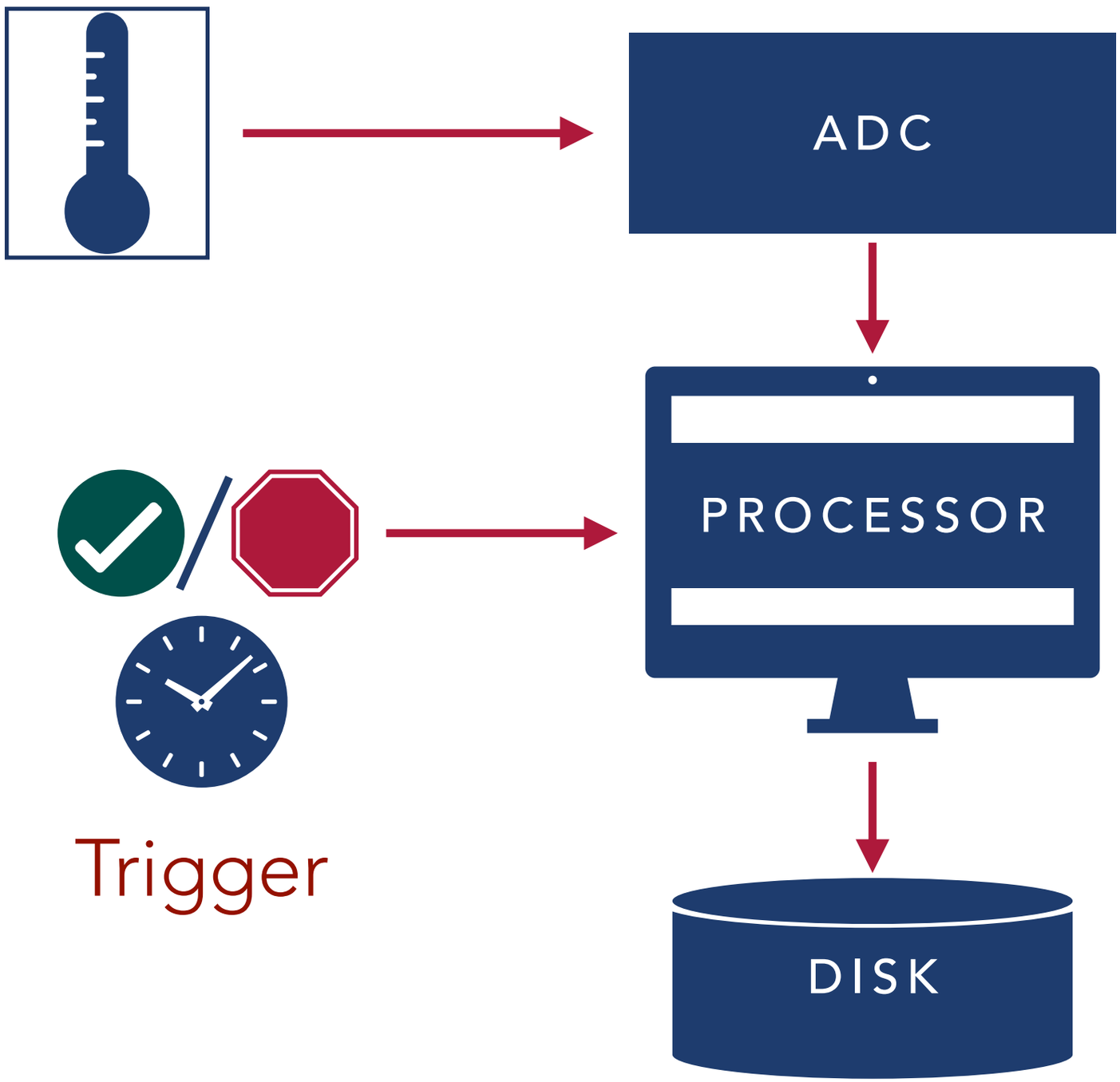

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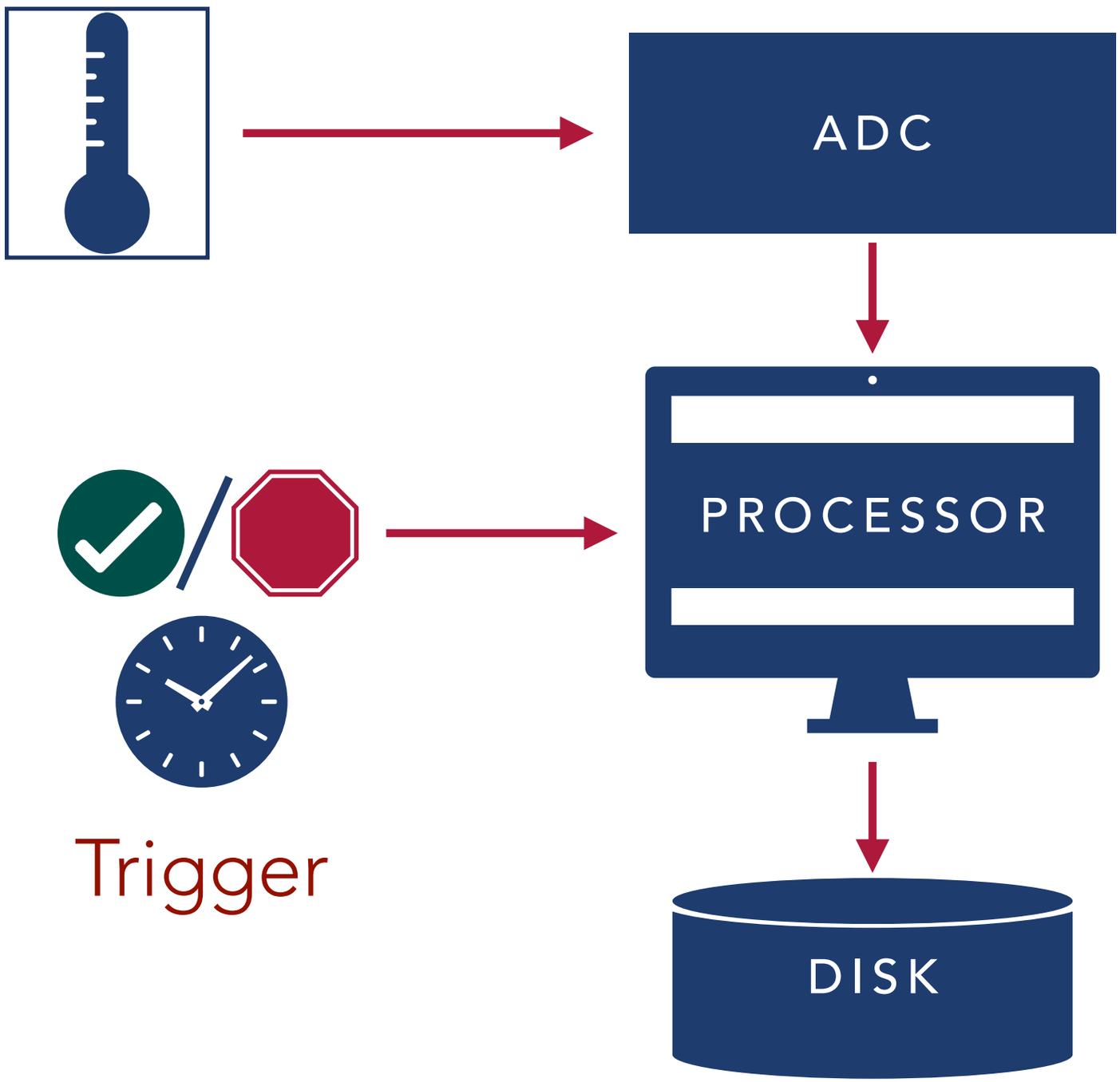

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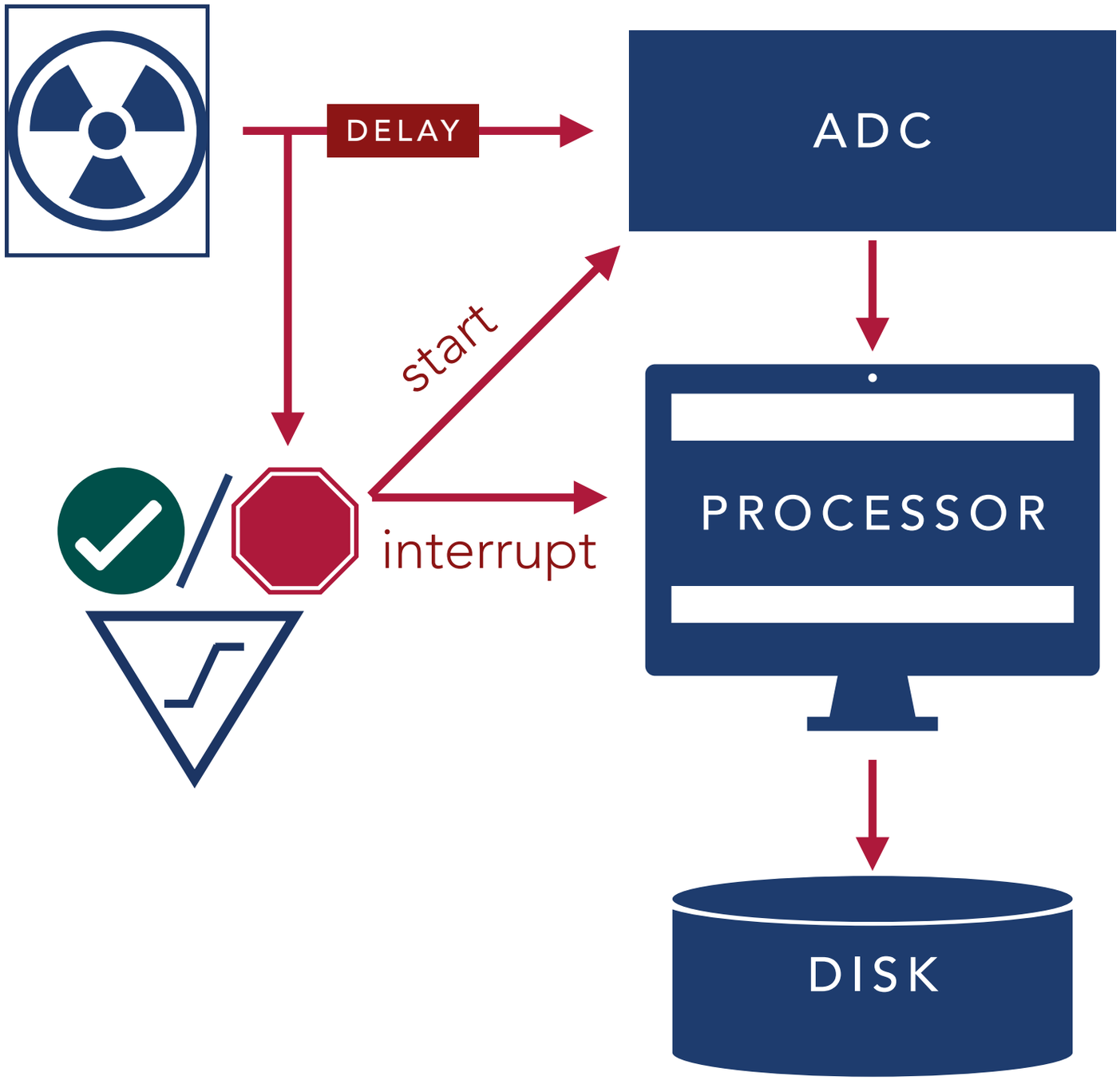
  - $R = 1/\tau$
  - If τ = 1ms ; R = 1kHz

STOCHASTIC PROCESSING



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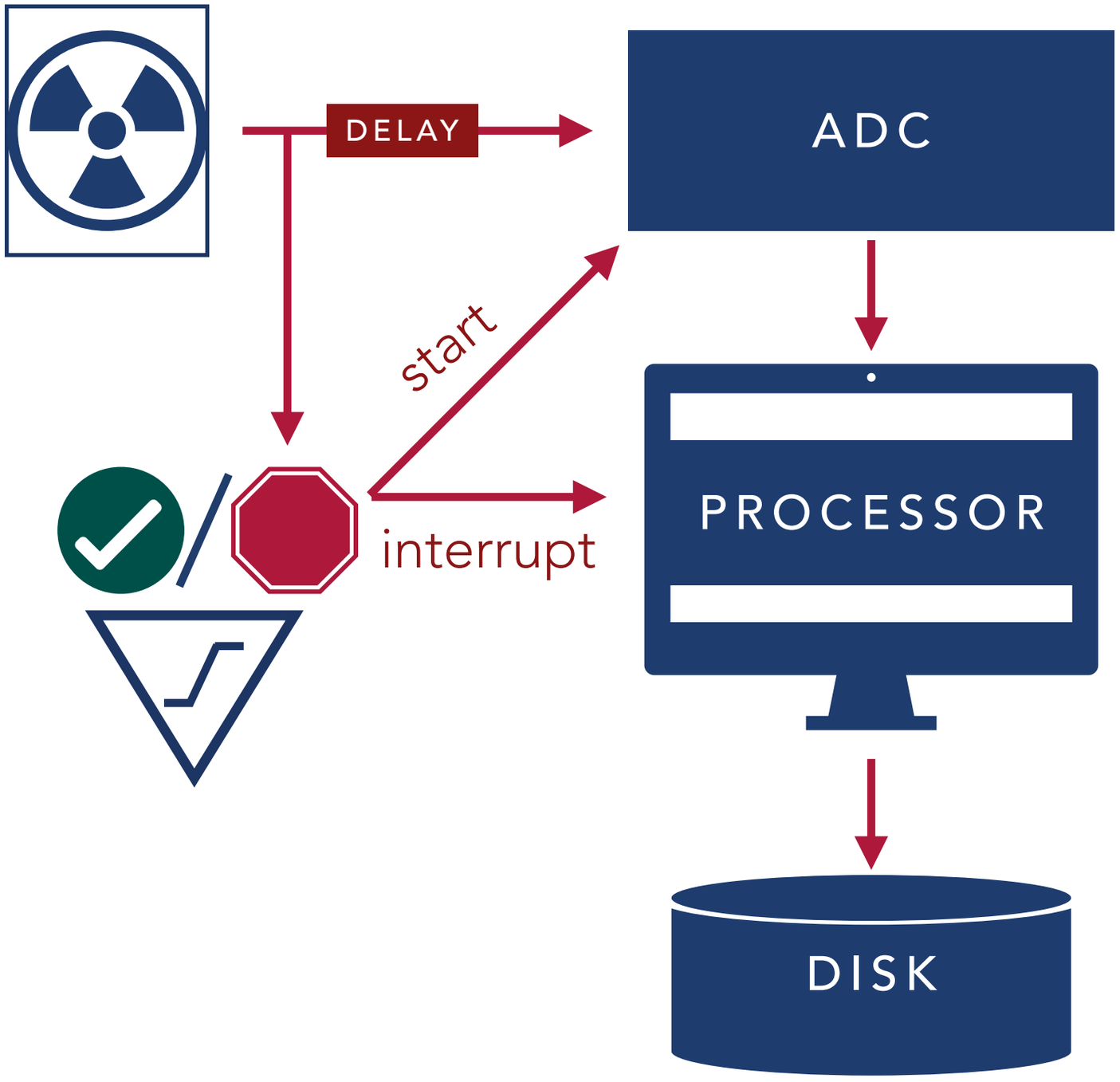

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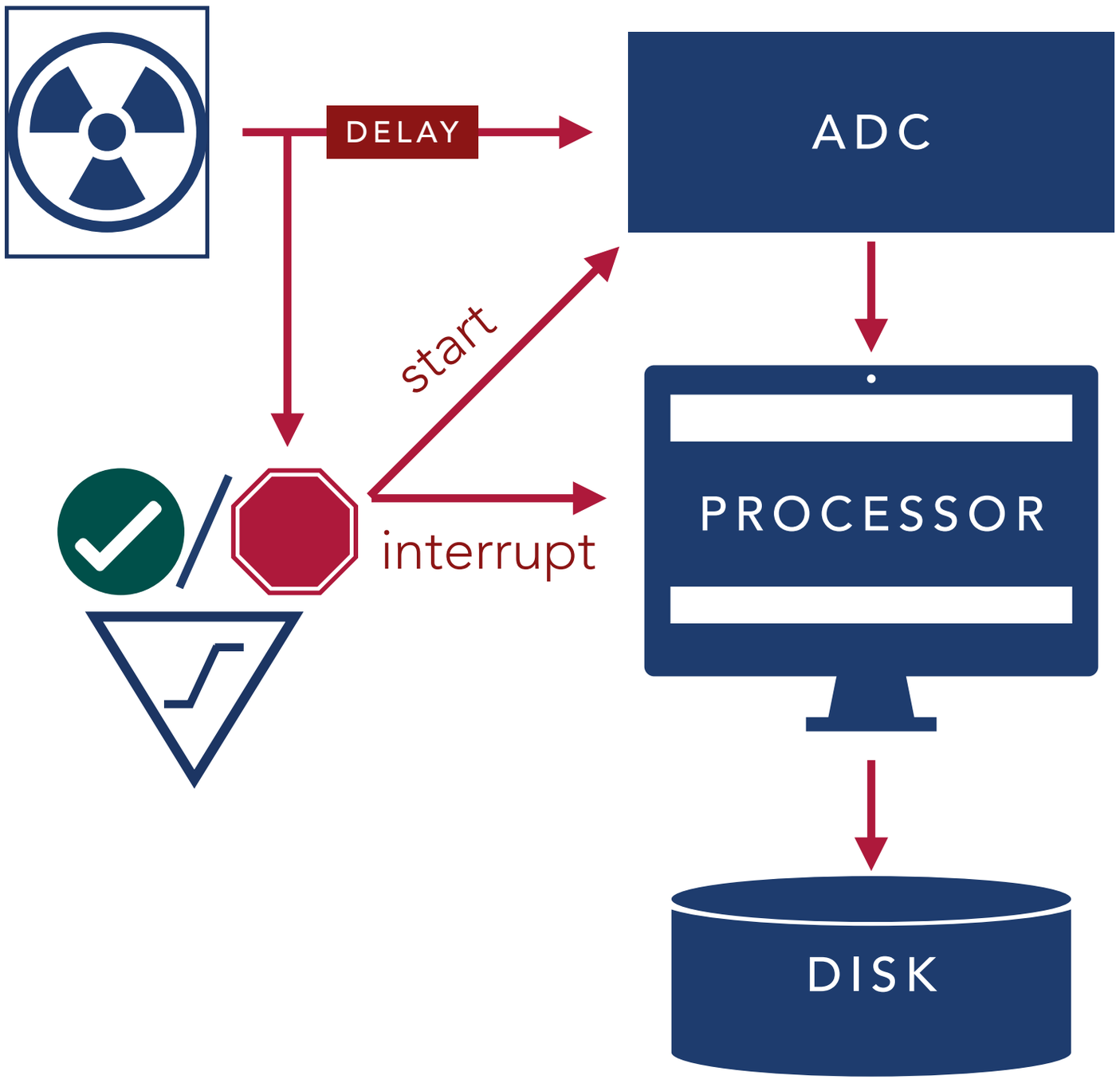

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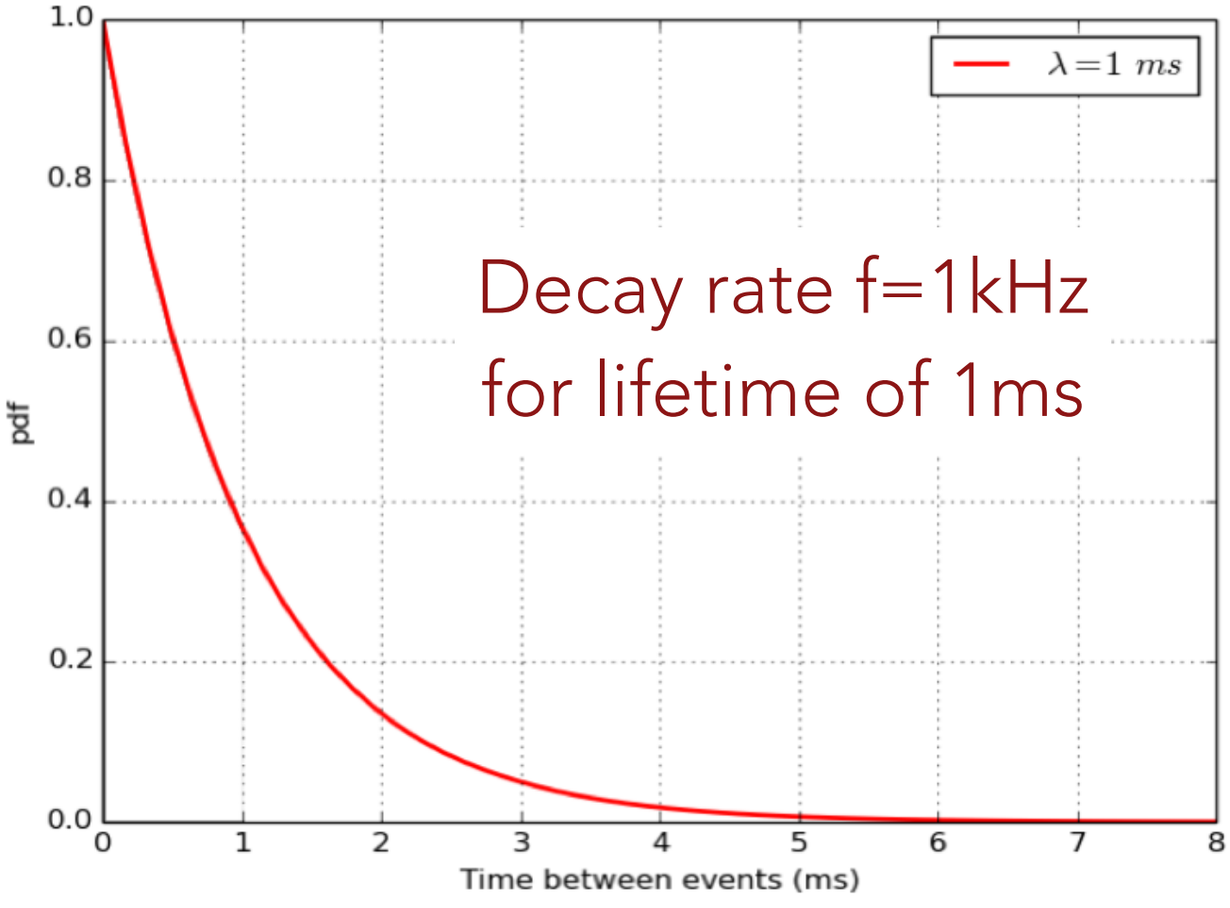
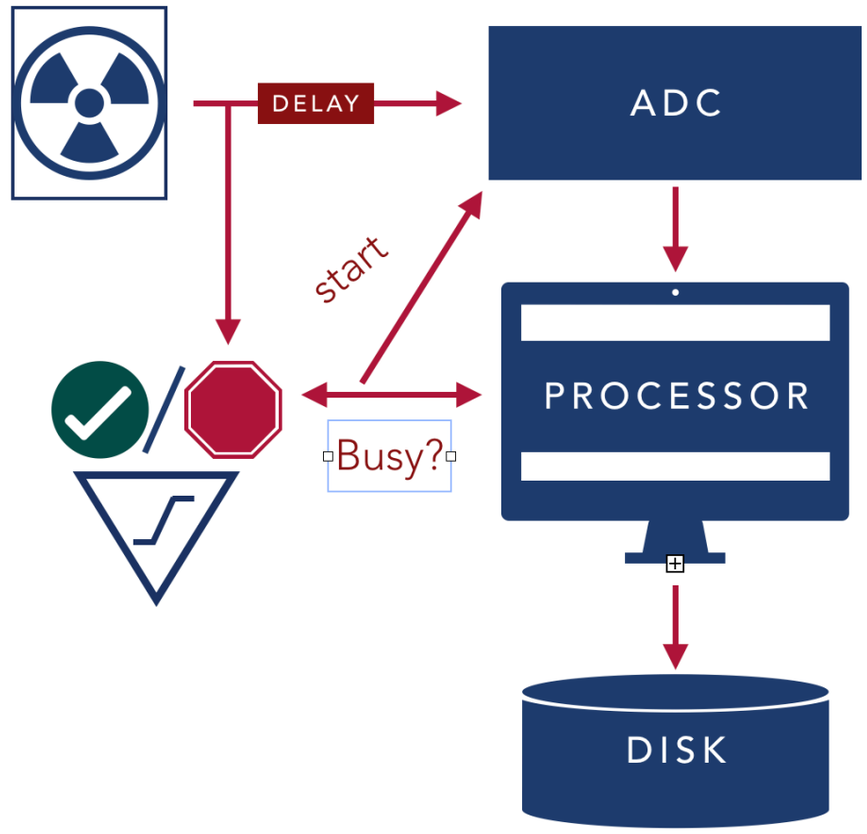
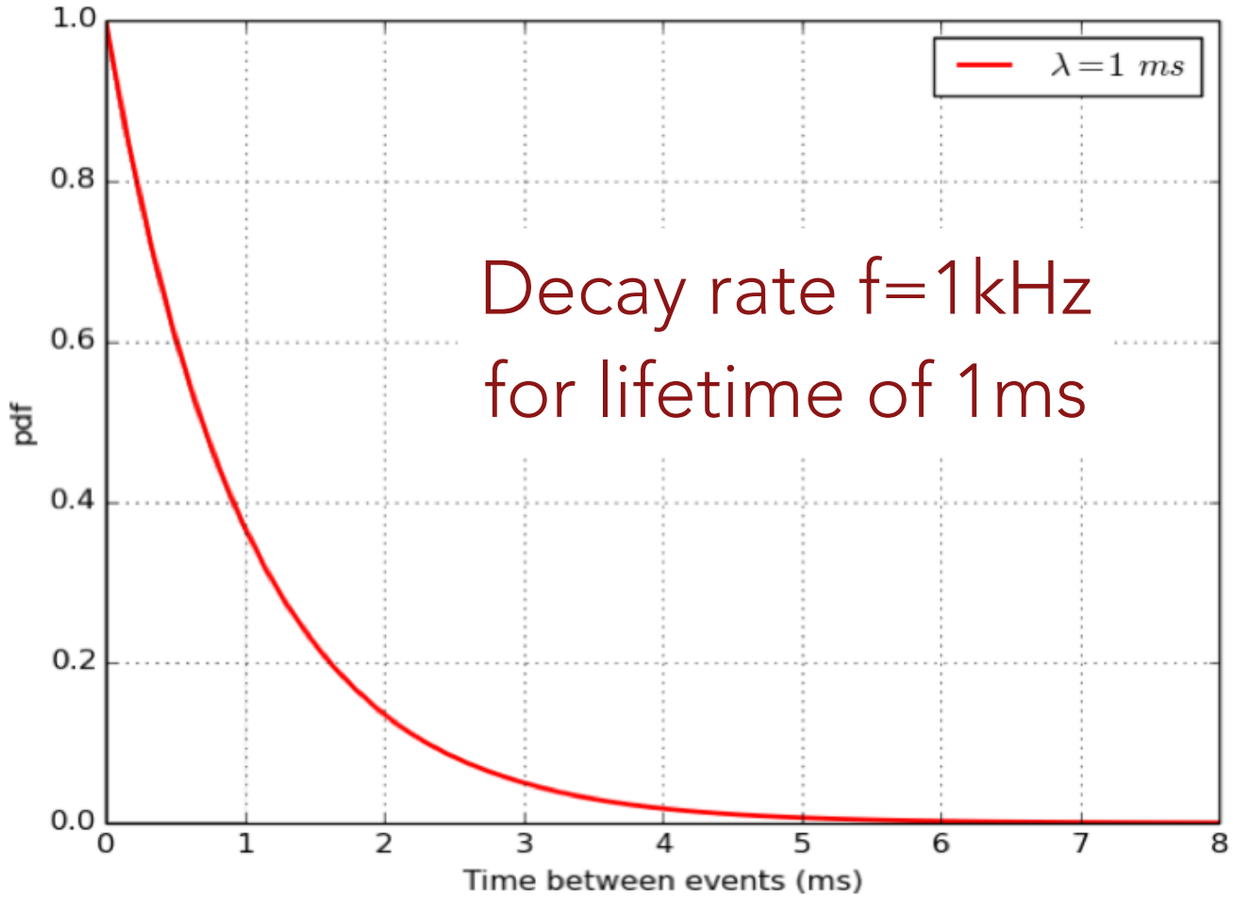


Decay rate f=1kHz
for lifetime of 1ms





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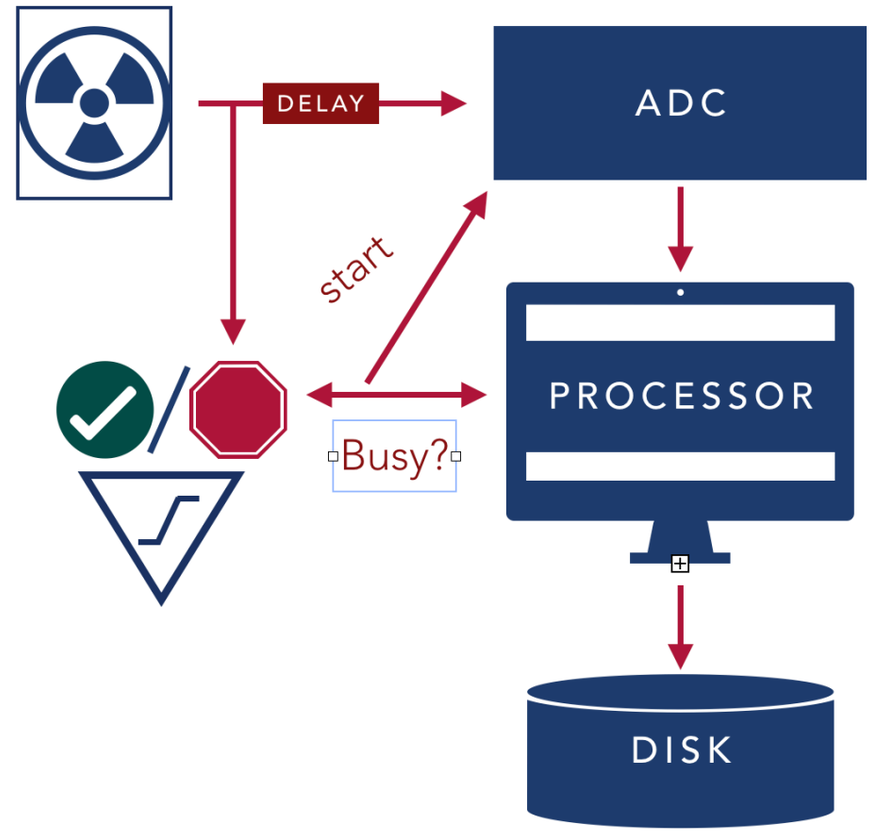

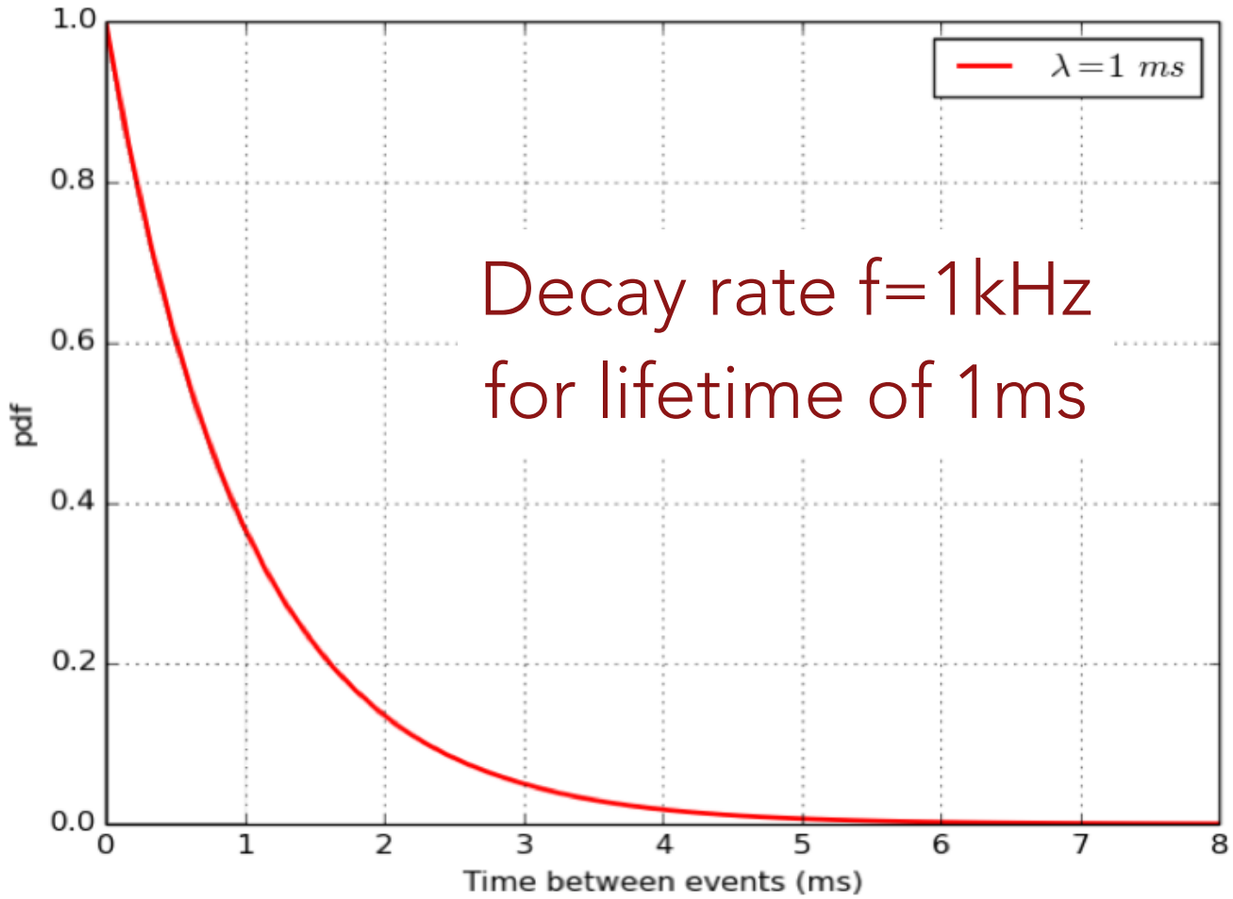

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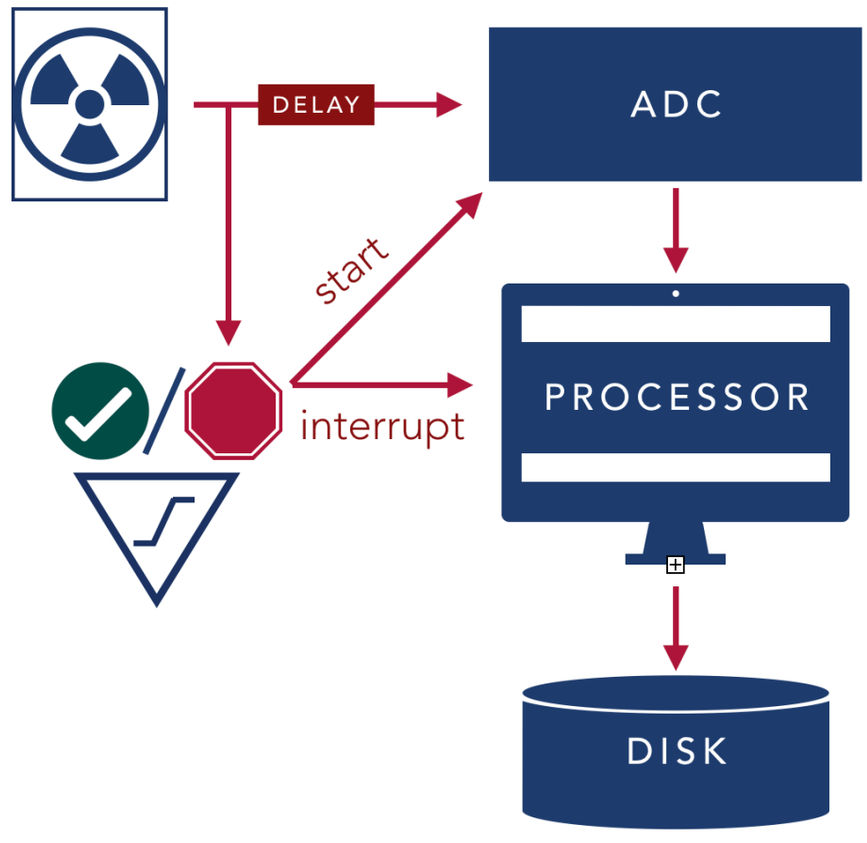

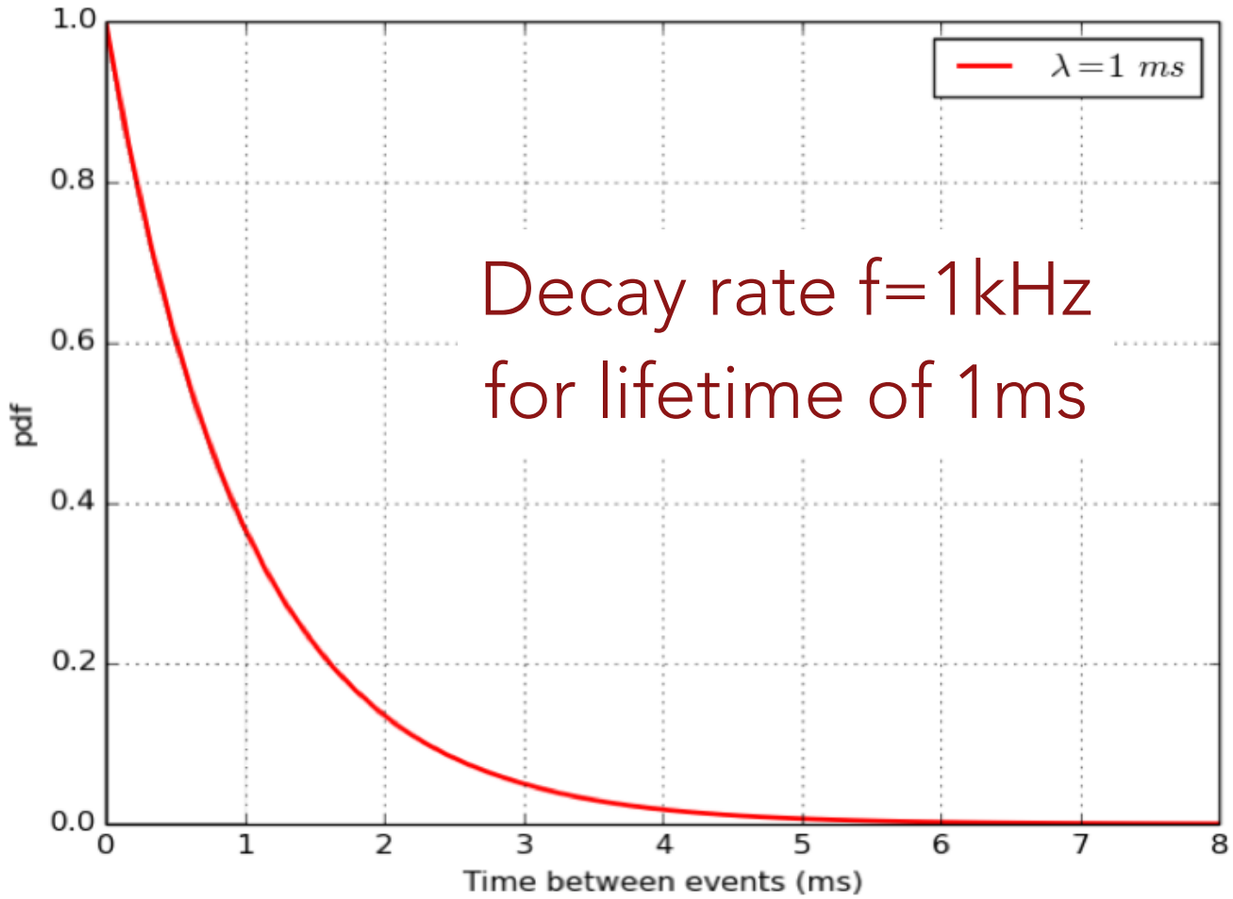

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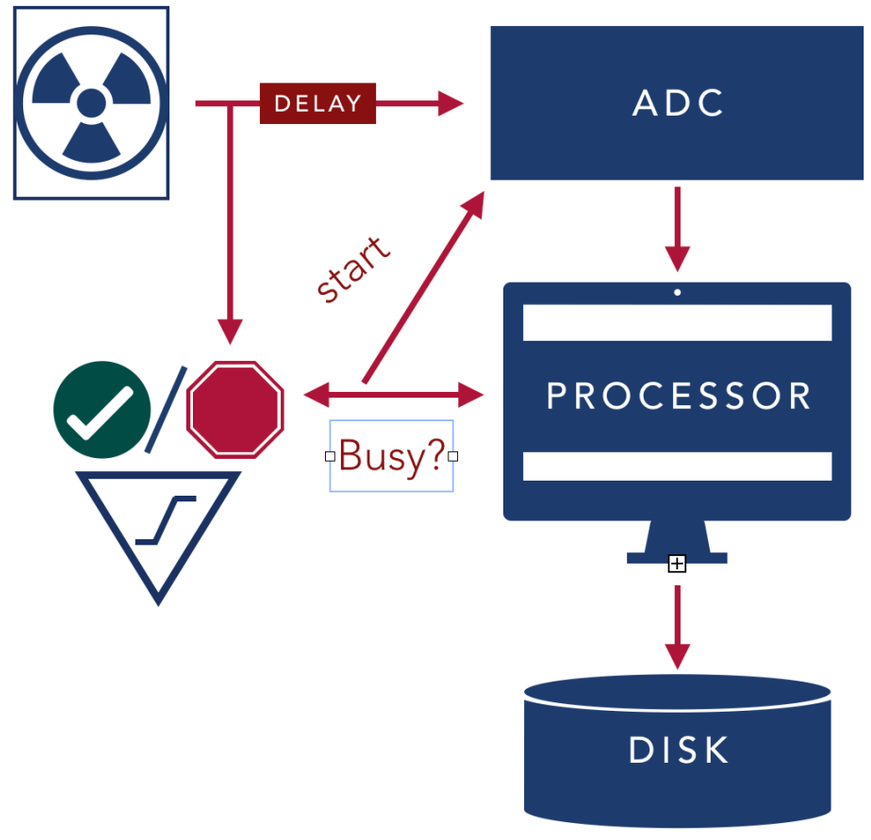

BRIEF PAUSE TO REGROUP

- 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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- Therefore, our DAQ rate is ν = f P[free] = f (1 - τν) ; ν = f/(1+fτ)

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?

- So if $f = 1/\tau = 1$ kHz ; then $\nu =$ 500 Hz ; $\varepsilon = 50\%$

- How can we maximize our efficiency?

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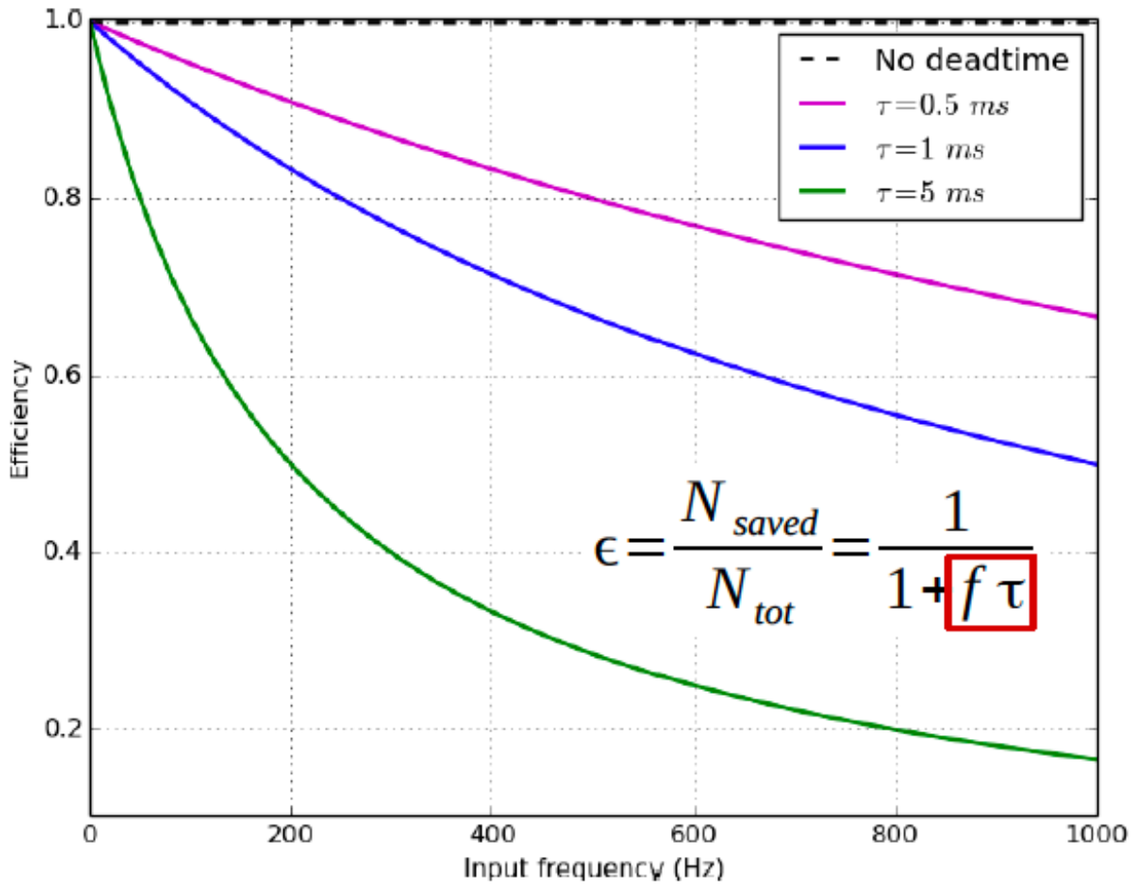

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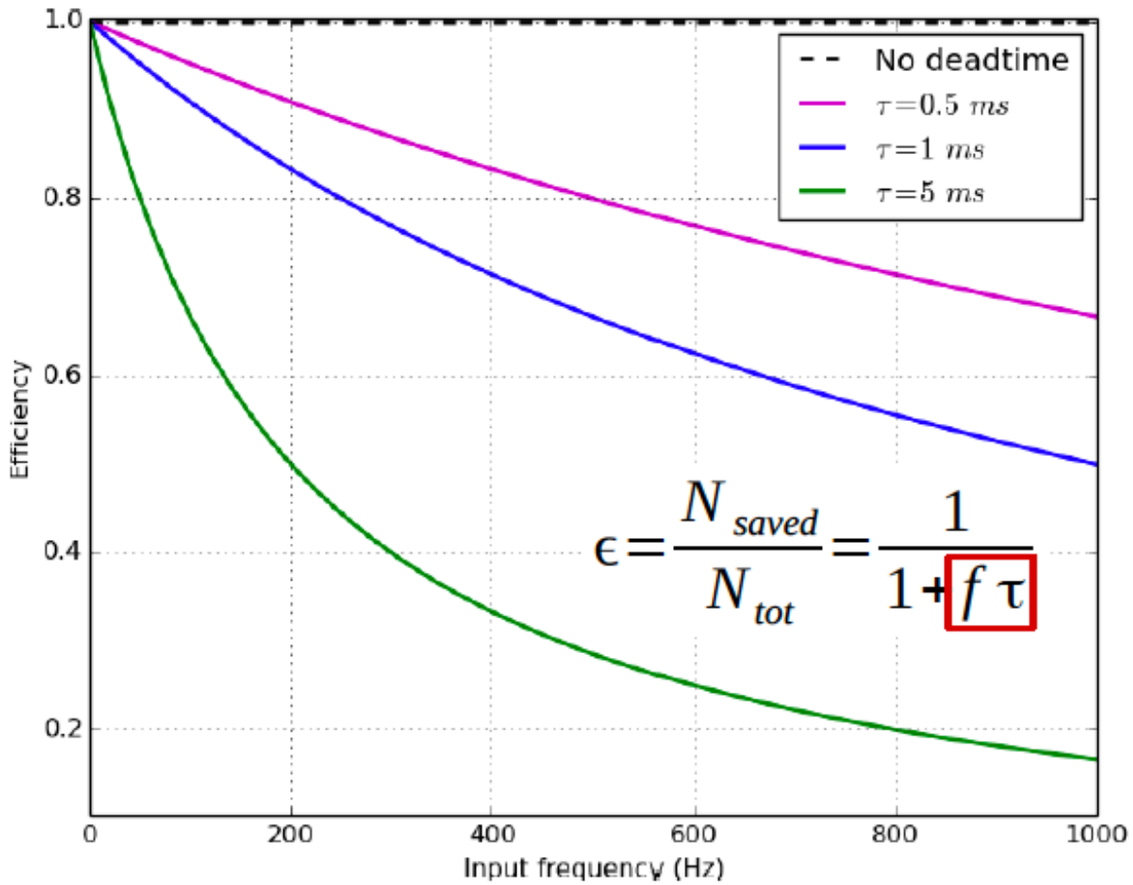
  - We need $f\tau << 1$
  - For $\varepsilon = 99\%$ and $f = 1$ kHz we need $\tau = 0.01$ ms!



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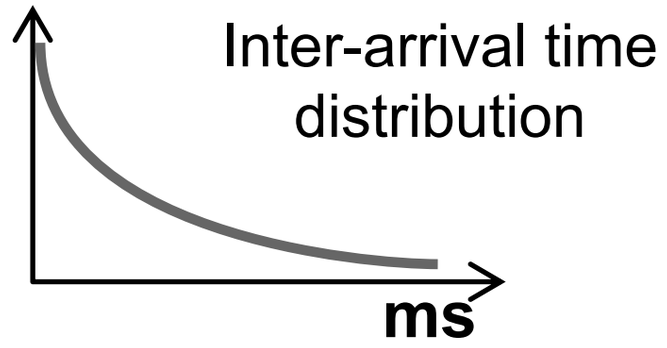

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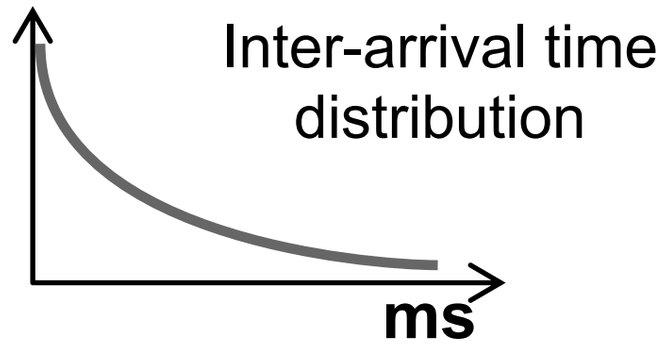

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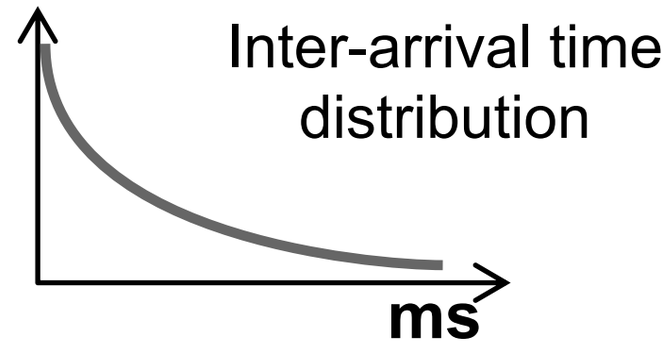

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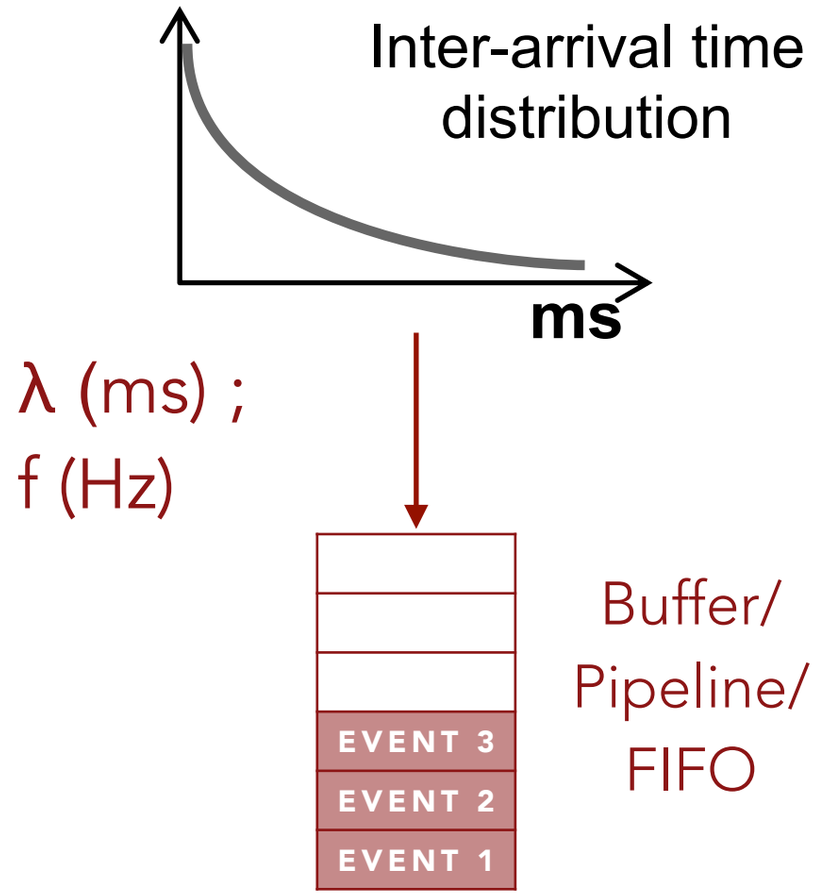

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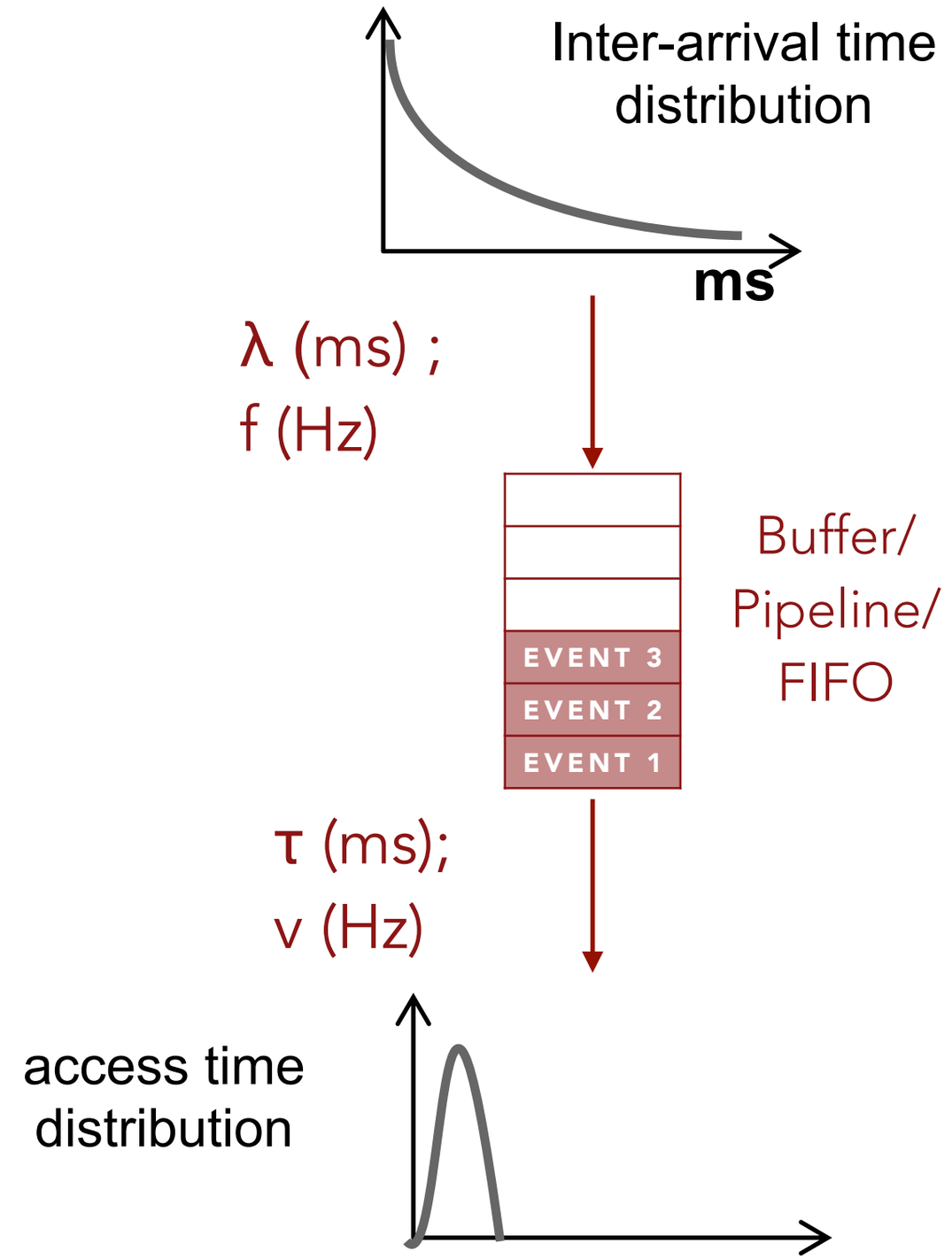
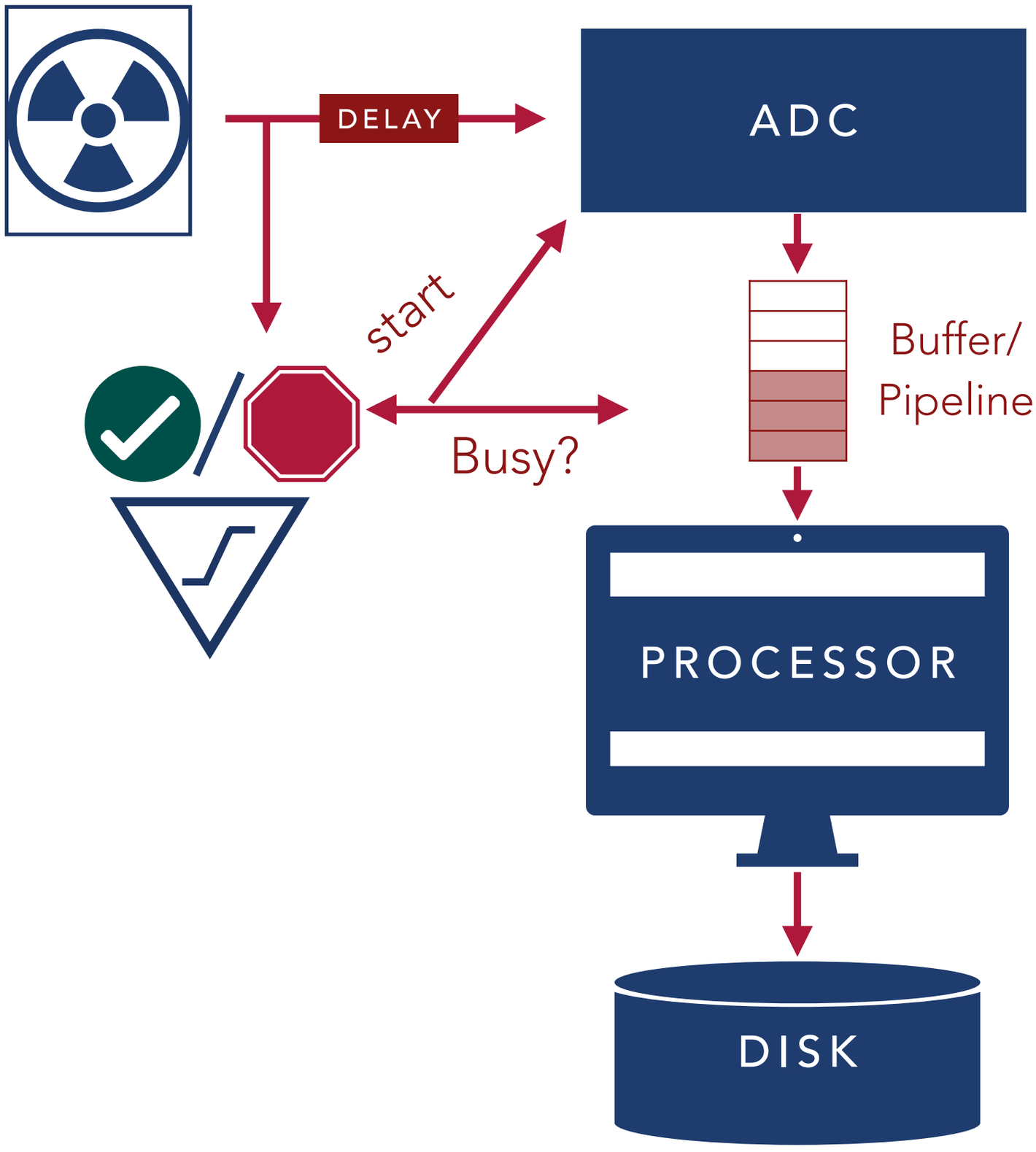
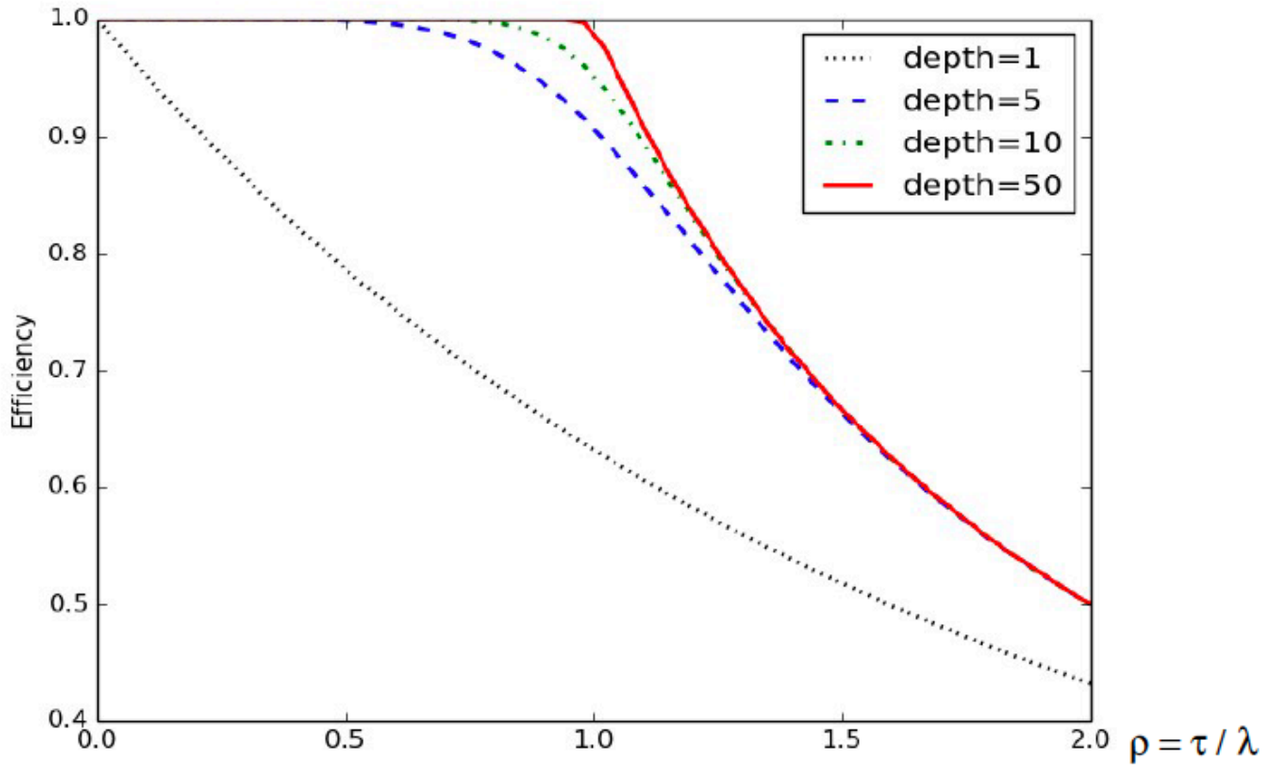


DE-RANDOMIZING



- 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:
  - $\rho > 1$:
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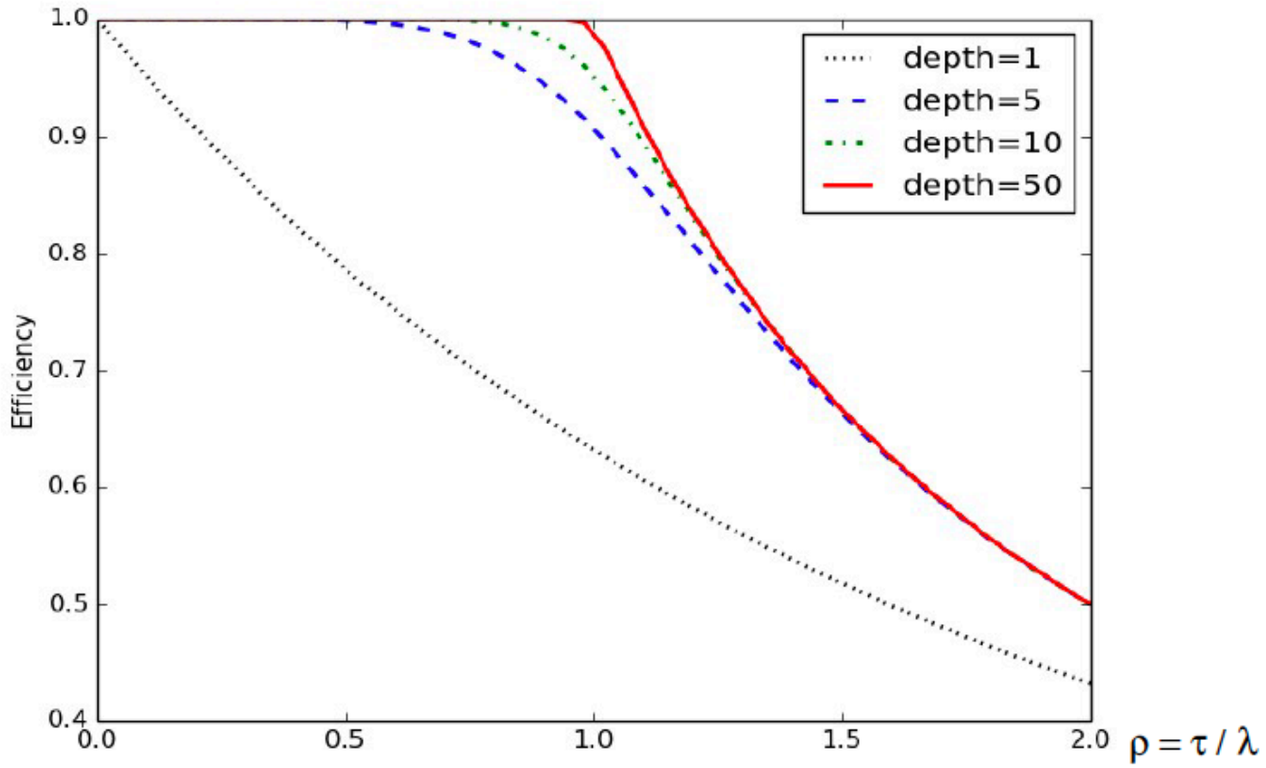

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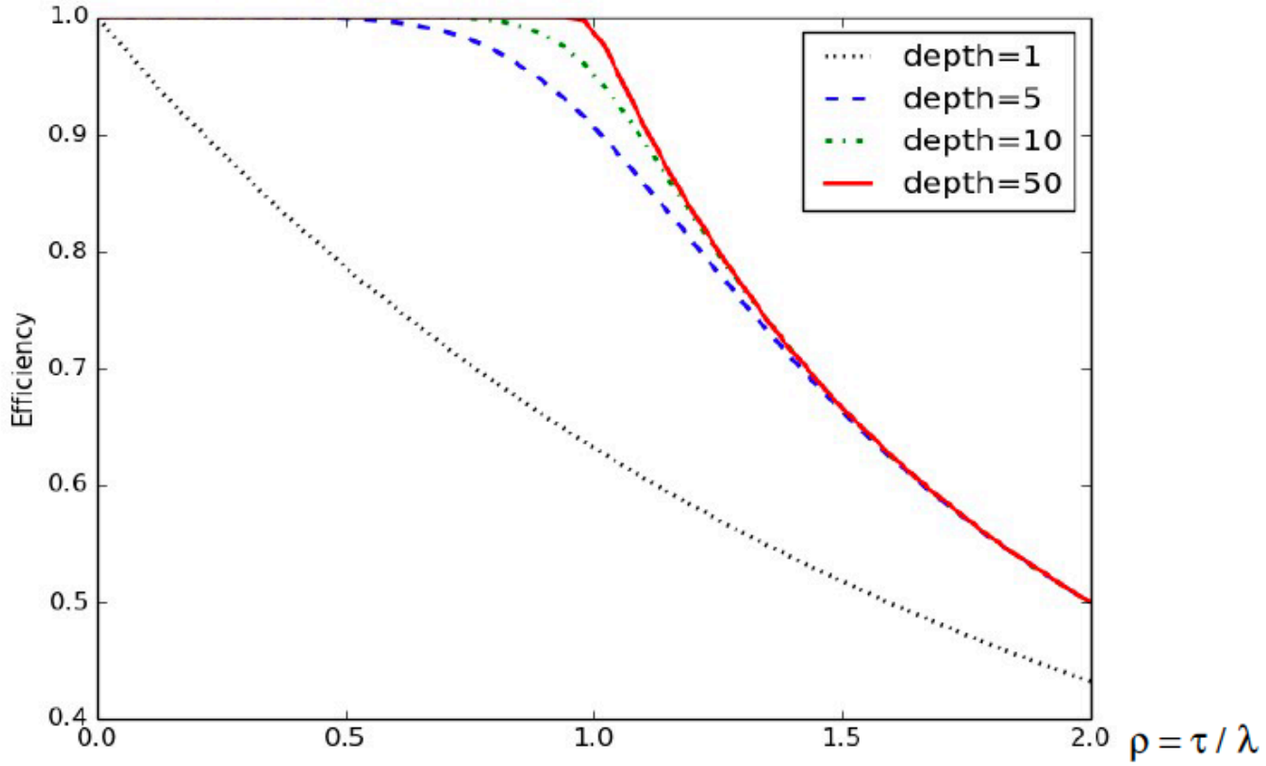

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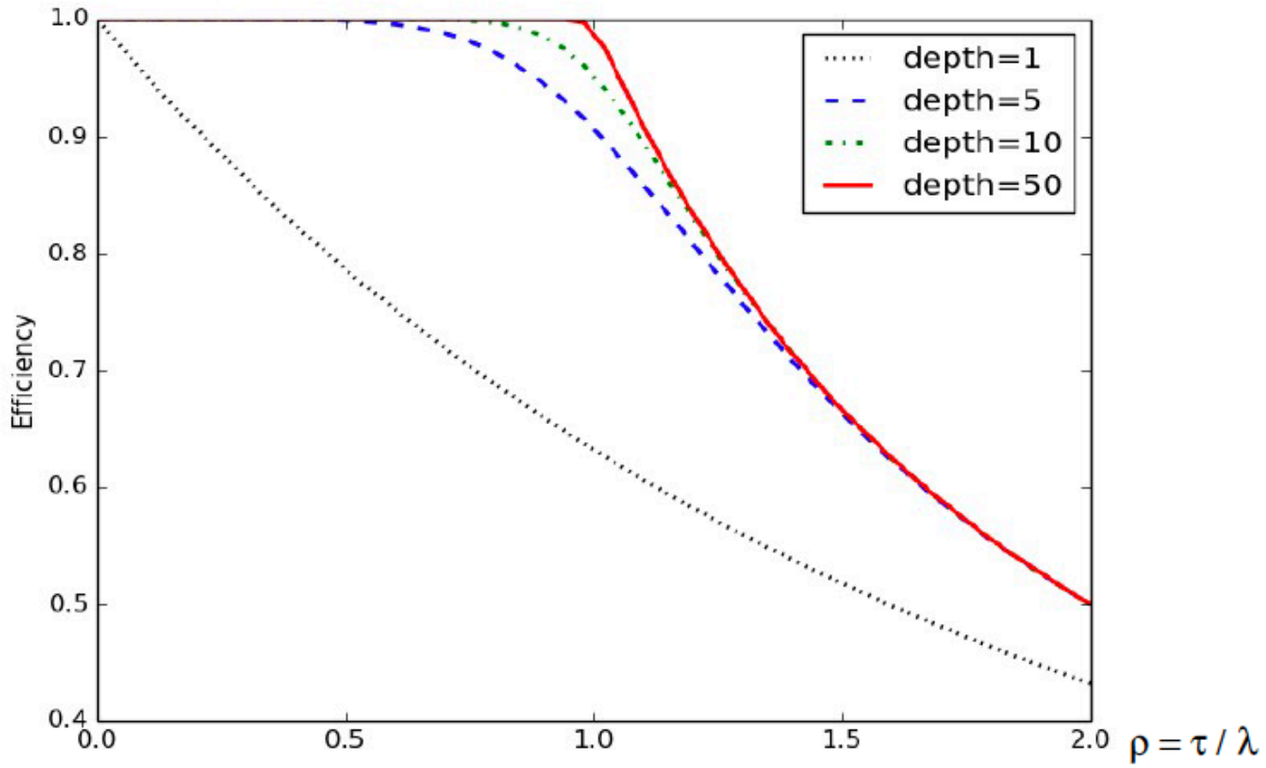

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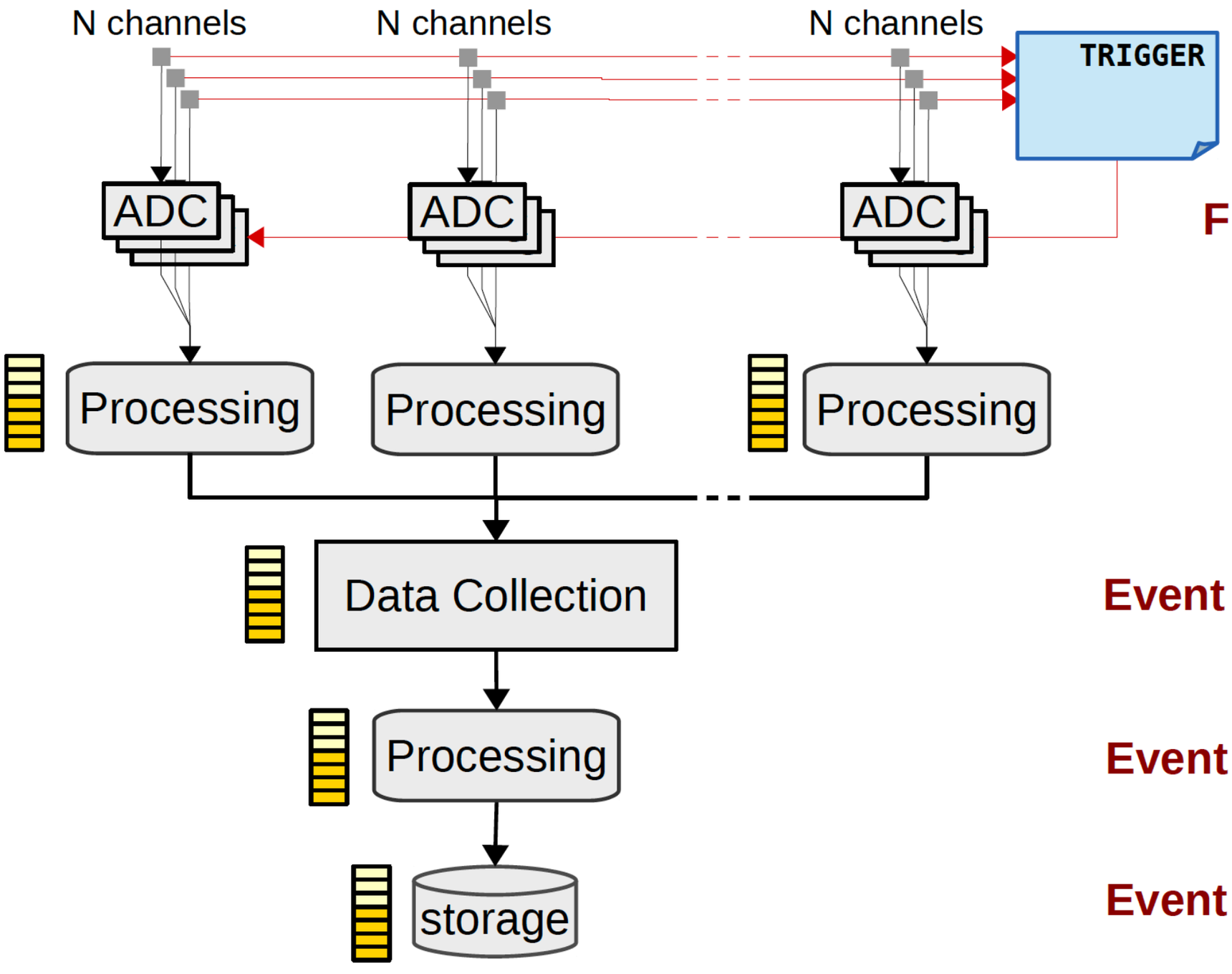
GENERALIZING TO MULTI-CHANNEL SYSTEM



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

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- 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

ATLAS RUN II TDAQ SYSTEM

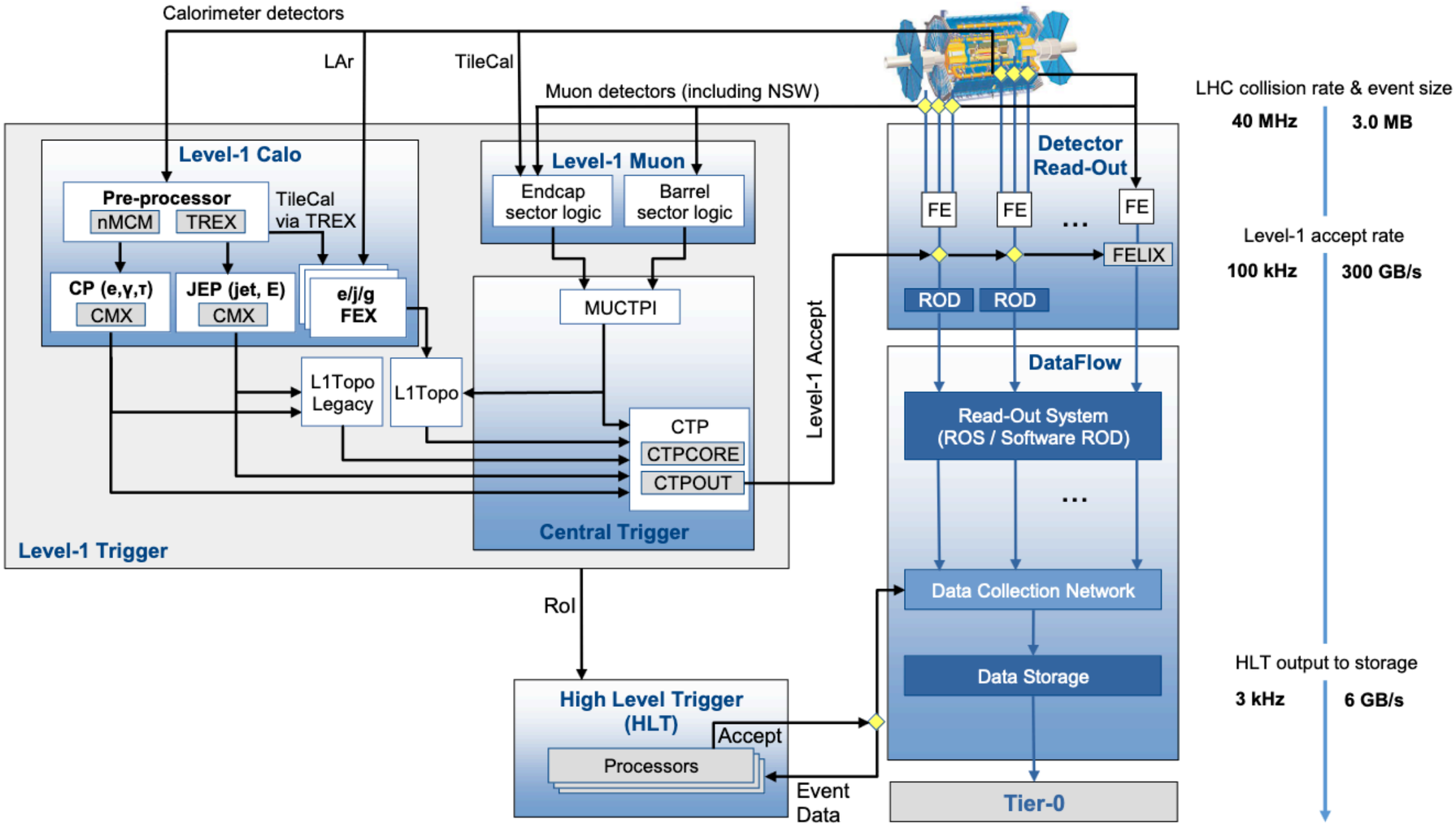
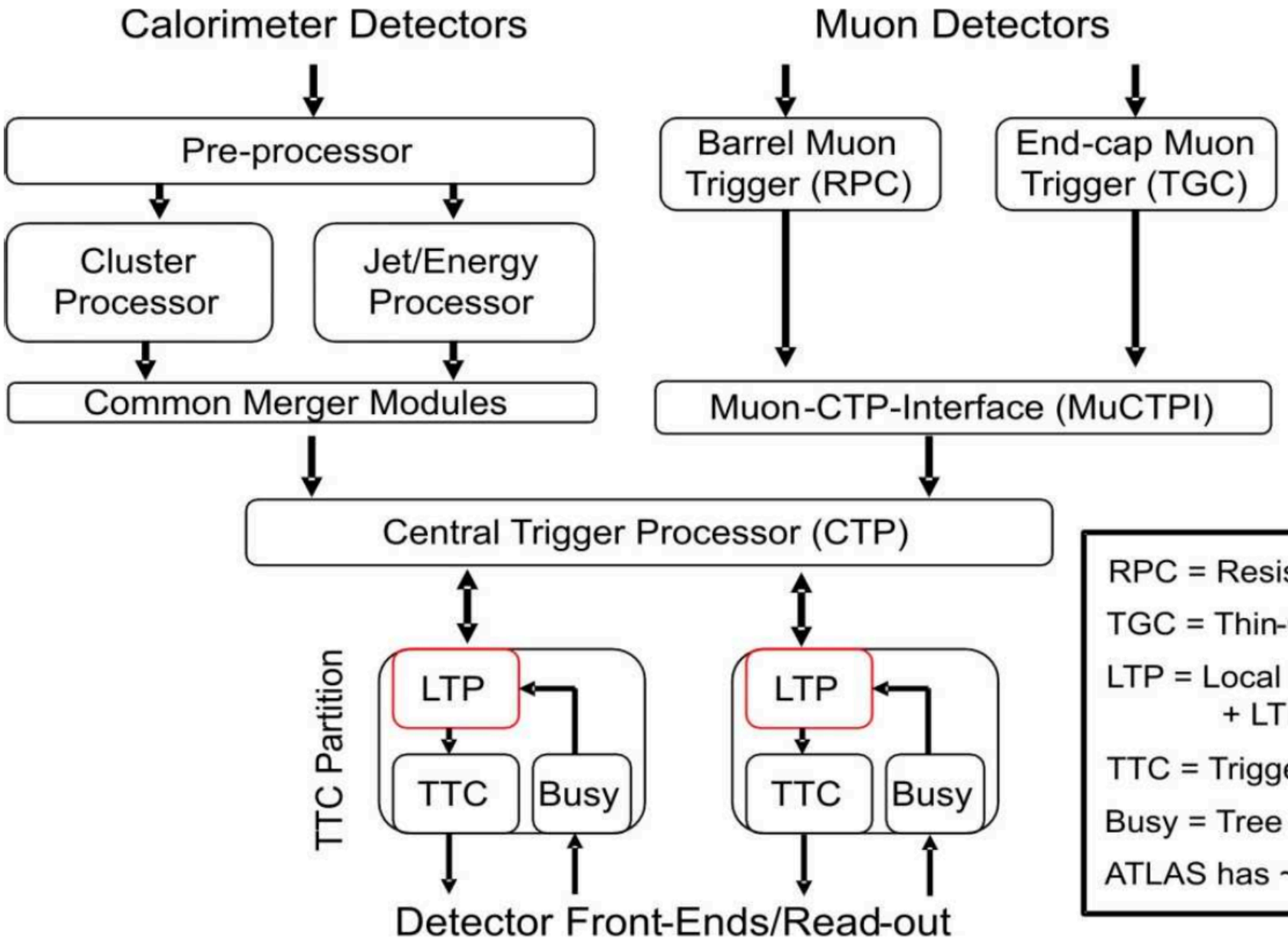


Fig. Ref

ATLAS LEVEL 1 TRIGGER SYSTEM



RPC = Resistive-Plate Chamber

TGC = Thin-Gap Plate Chamber

LTP = Local Trigger Processor + LTP interface

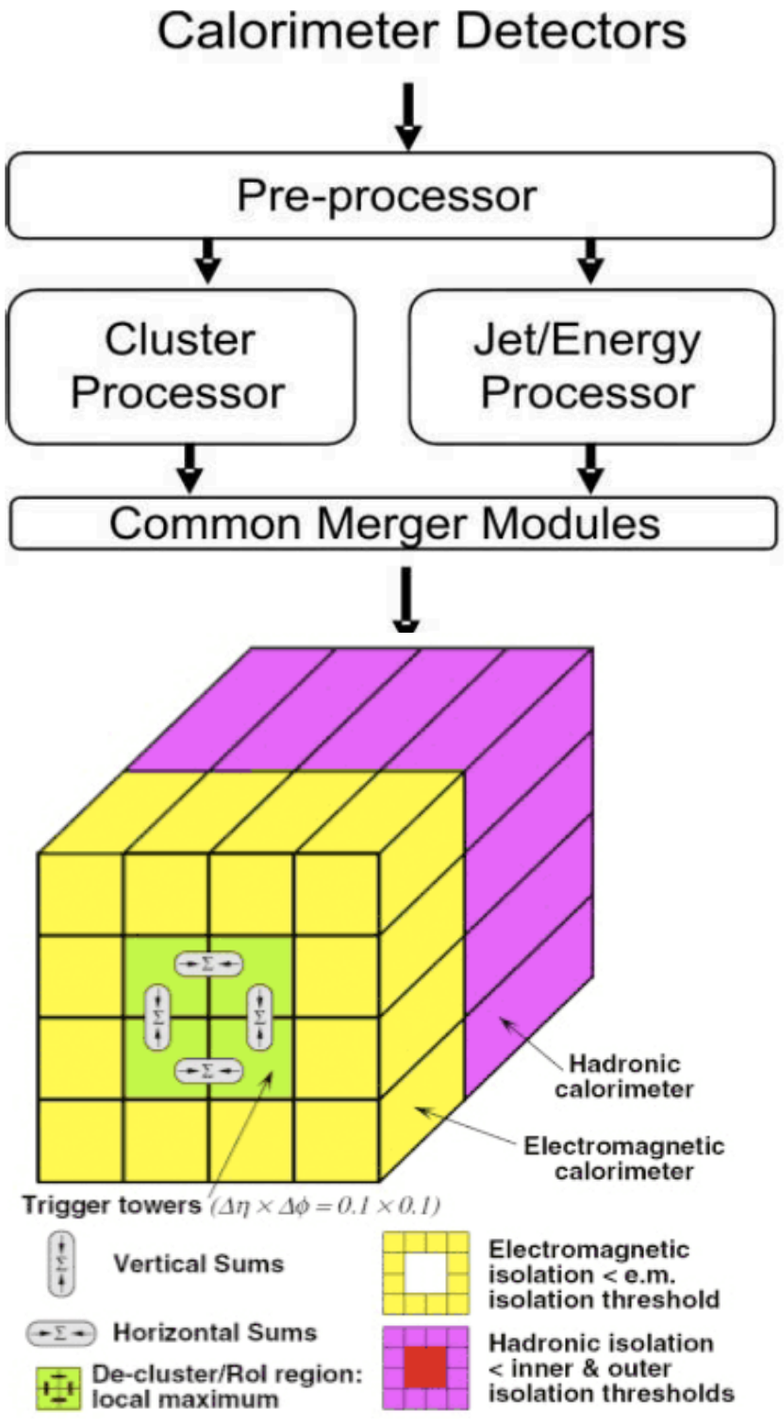
TTC = Trigger Timing & Control

Busy = Tree of ROD_Busy modules

ATLAS has ~40 TTC partitions

Fig. Ref

ATLAS LEVEL 1 TRIGGER SYSTEM



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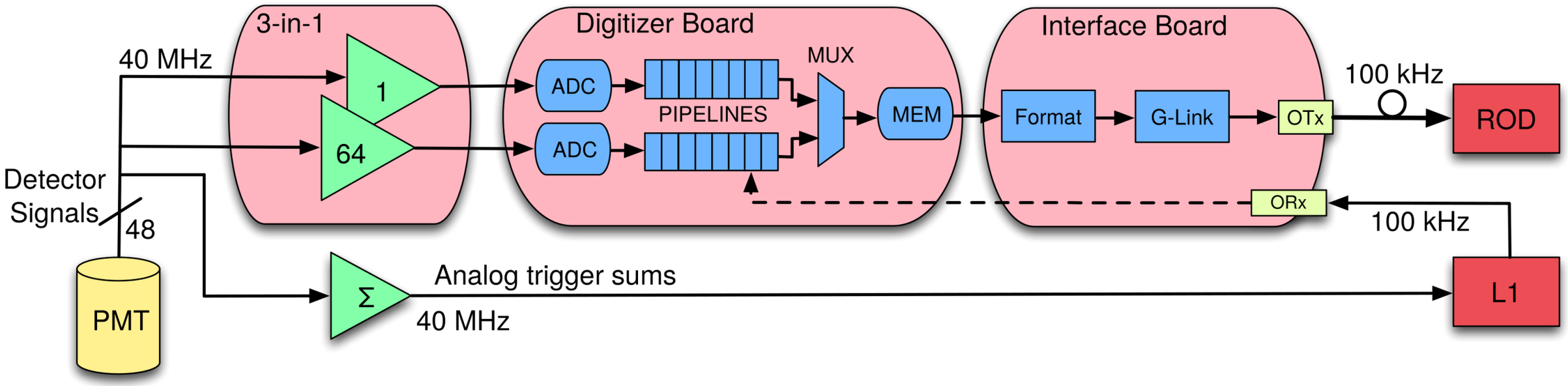


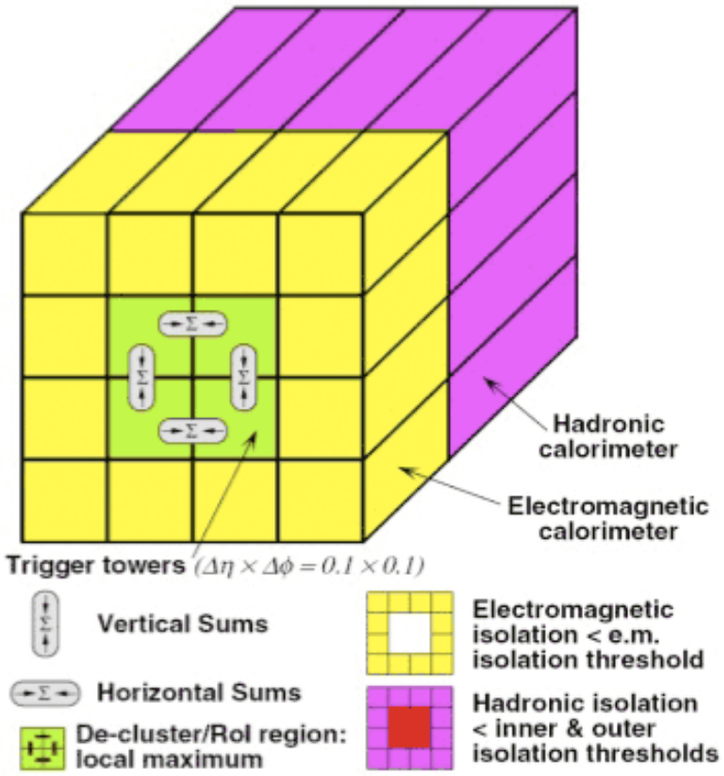
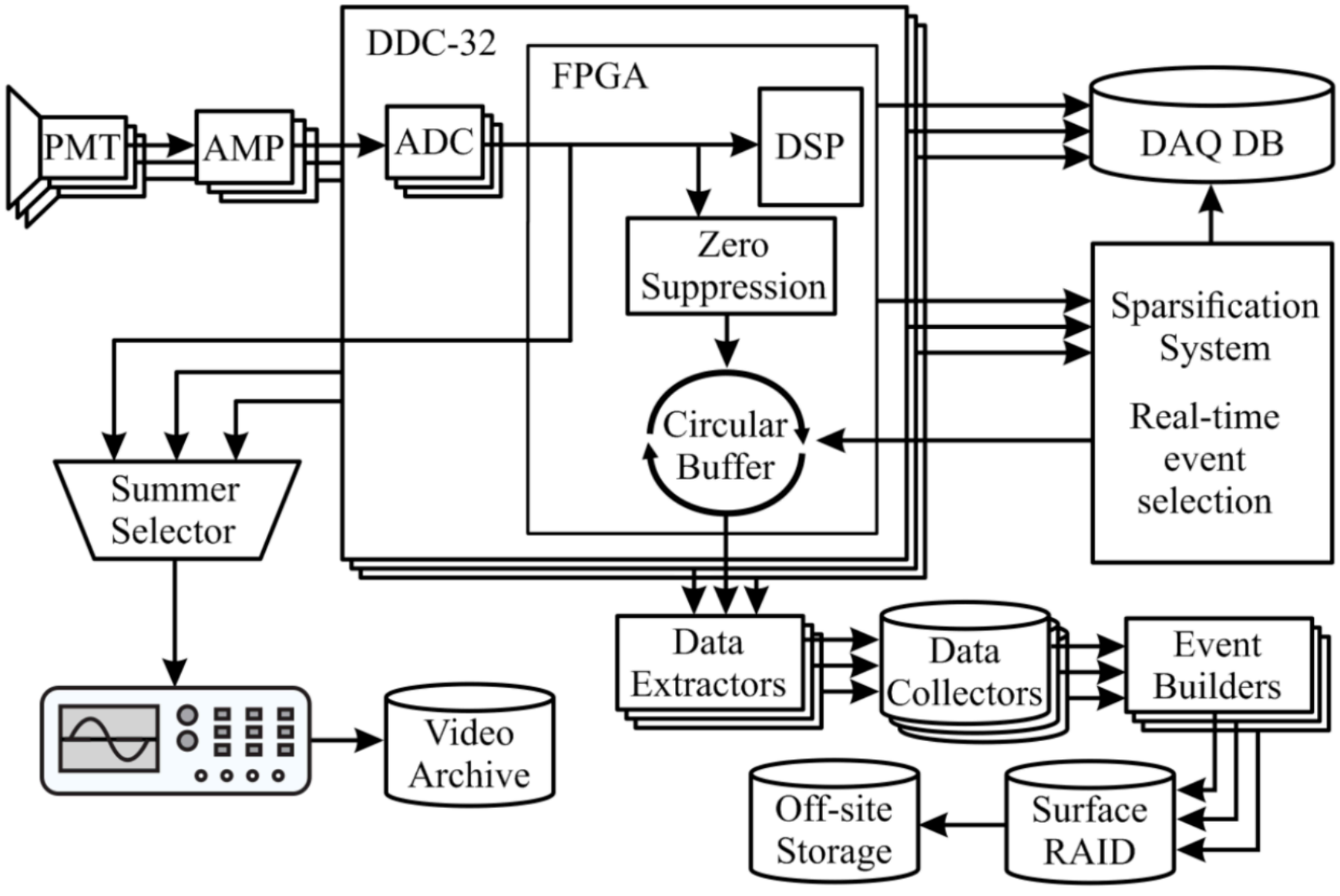


Fig. Ref

LZ TDAQ SYSTEM



QUESTIONS?

CENTRAL TRIGGER PROCESSOR & TIMING TRIGGER AND CONTROL SYSTEM

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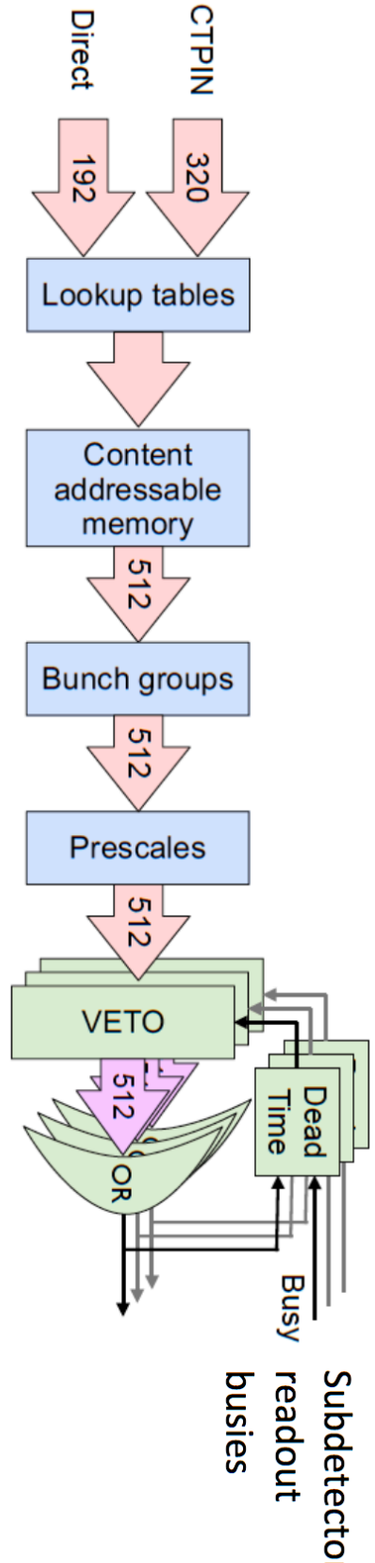
- Central Trigger Processor (CTP) and the Trigger Timing and Control (TTC) form the brains of the Level-1 Trigger:



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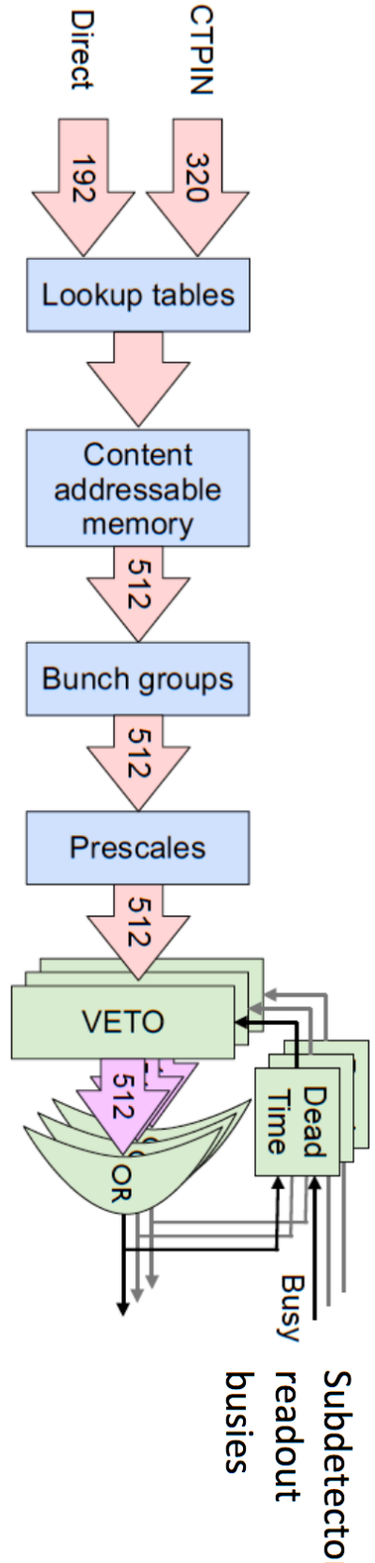

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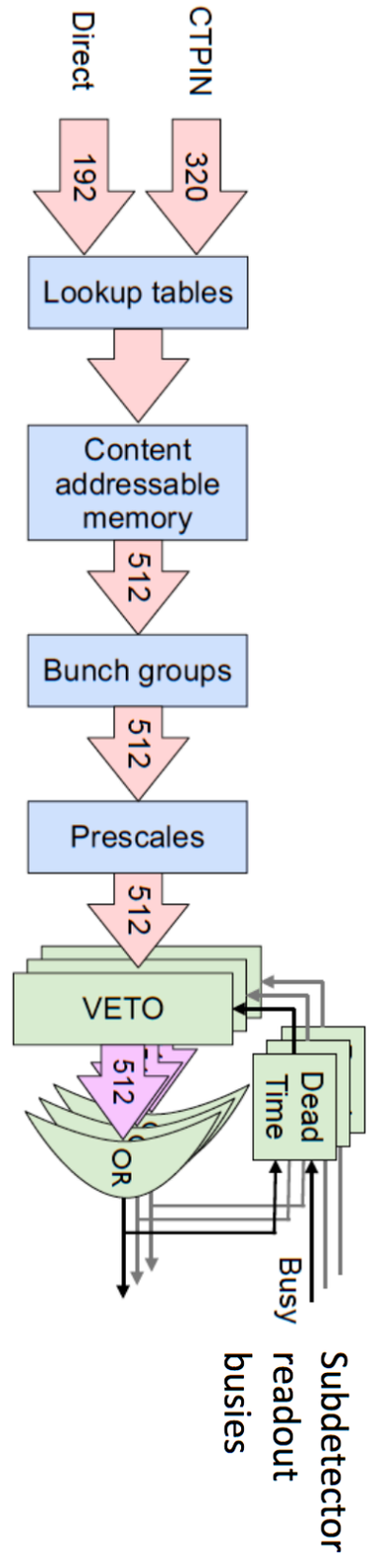

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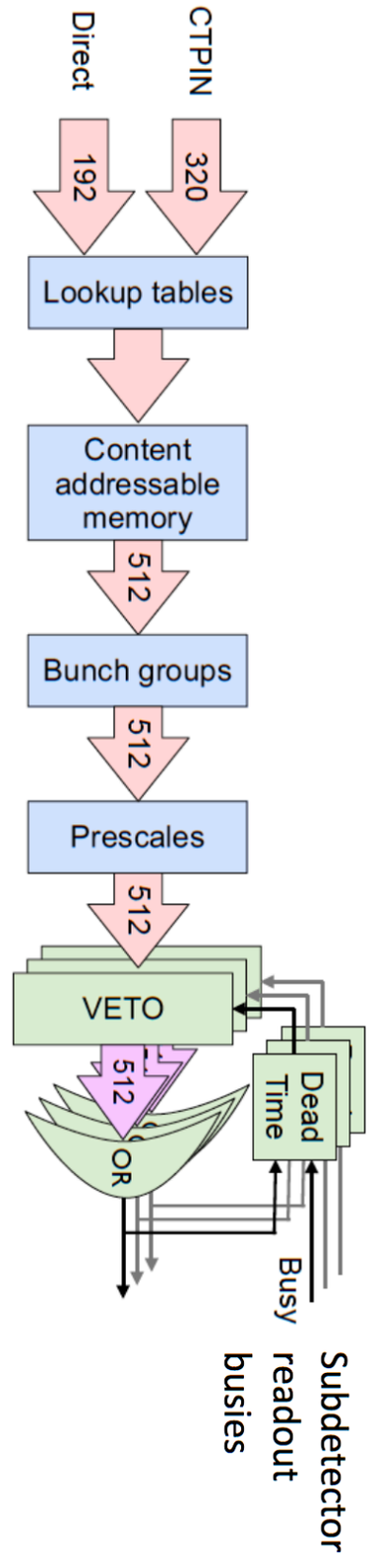

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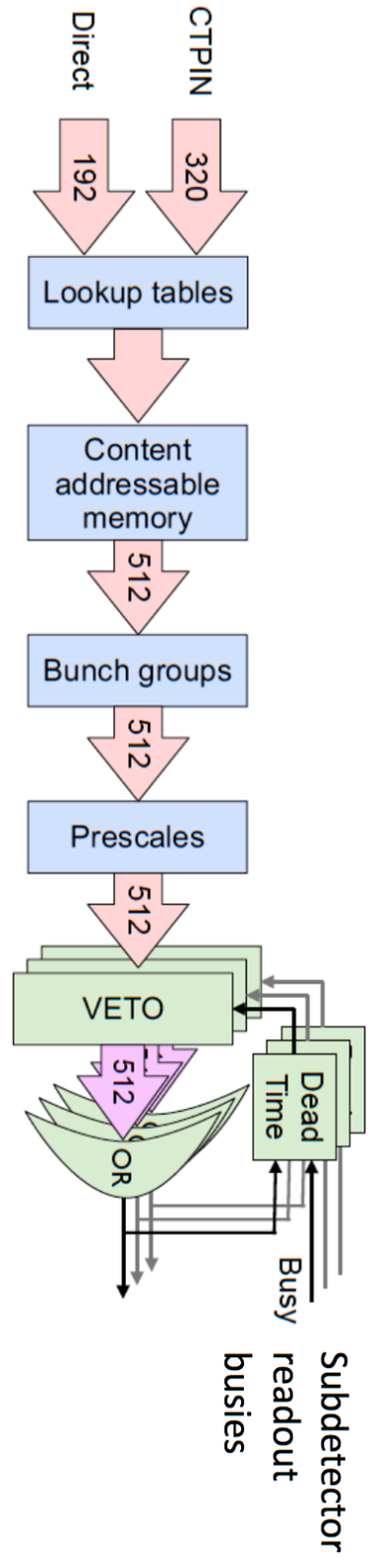
  - Controls detector BUSY



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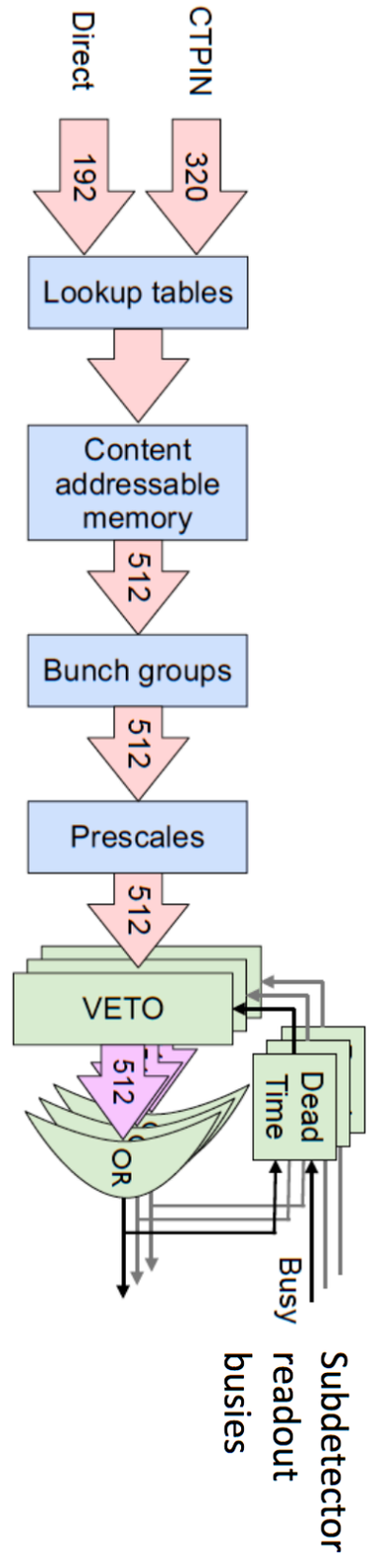
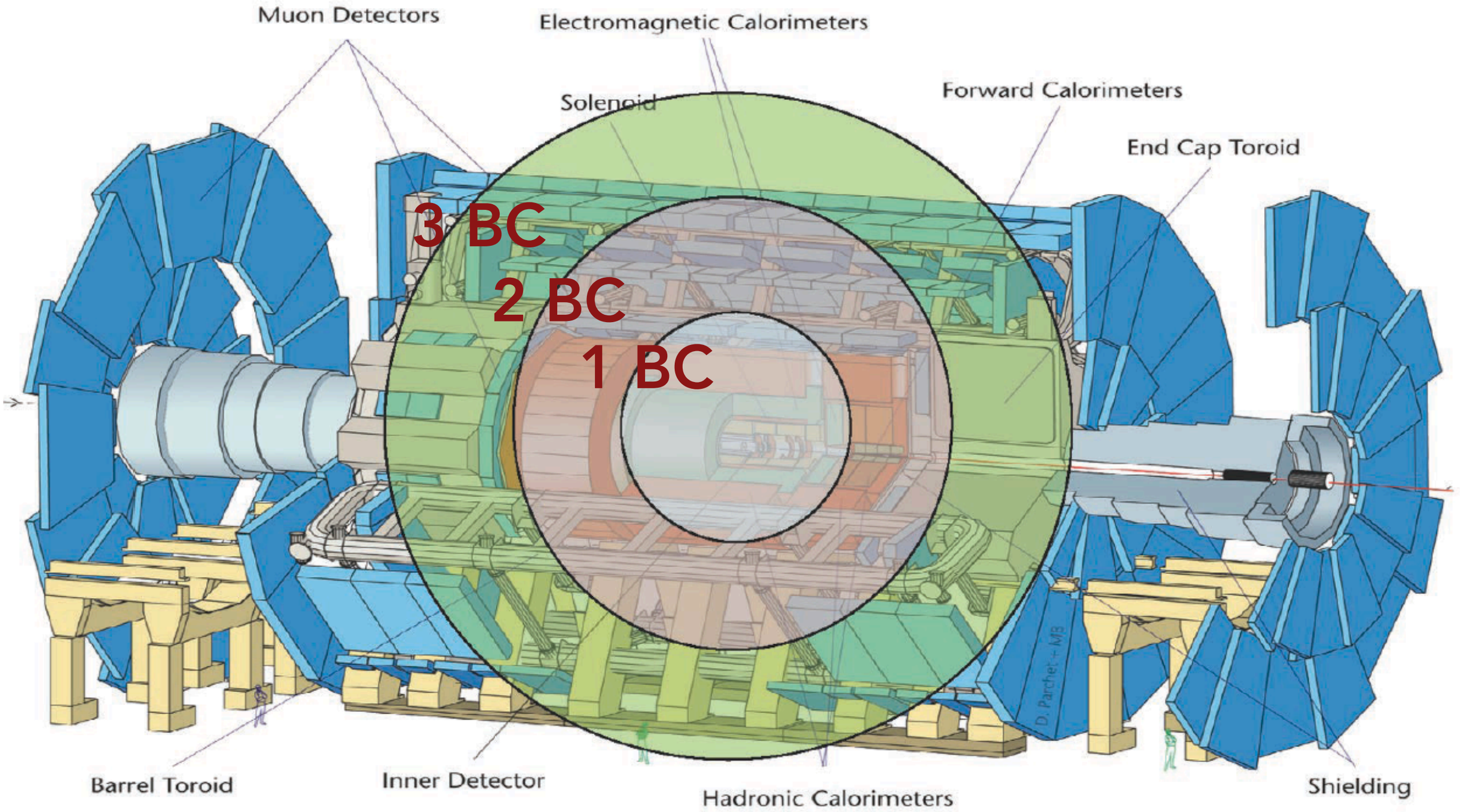
  - Controls detector BUSY
  - ***All within 100ns***

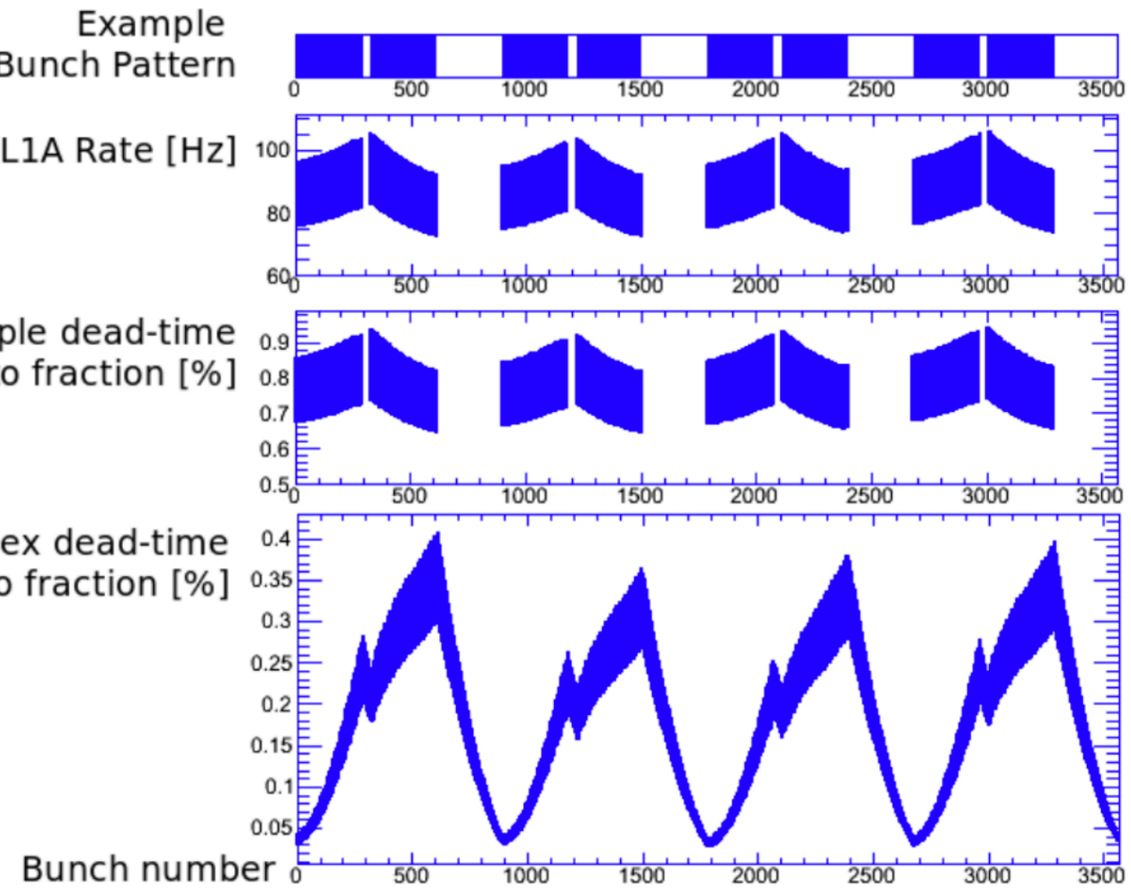


TIMING IS EVERYTHING



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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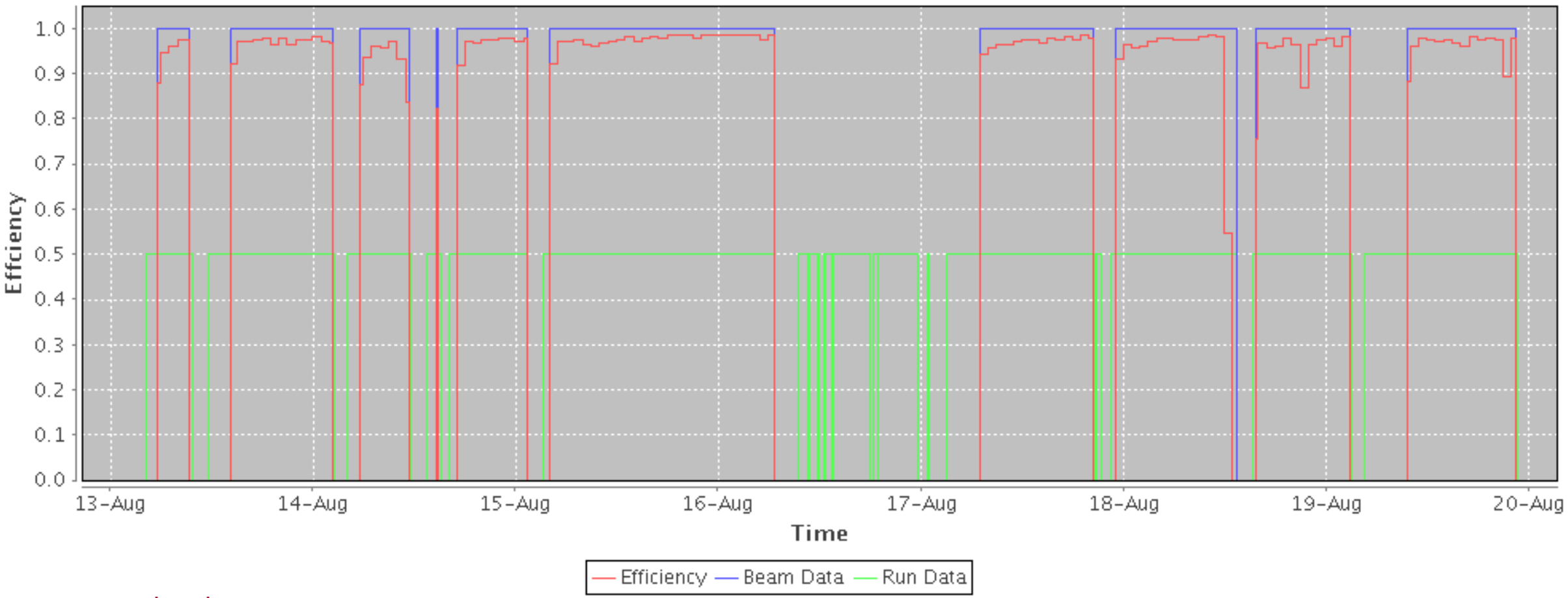
- 

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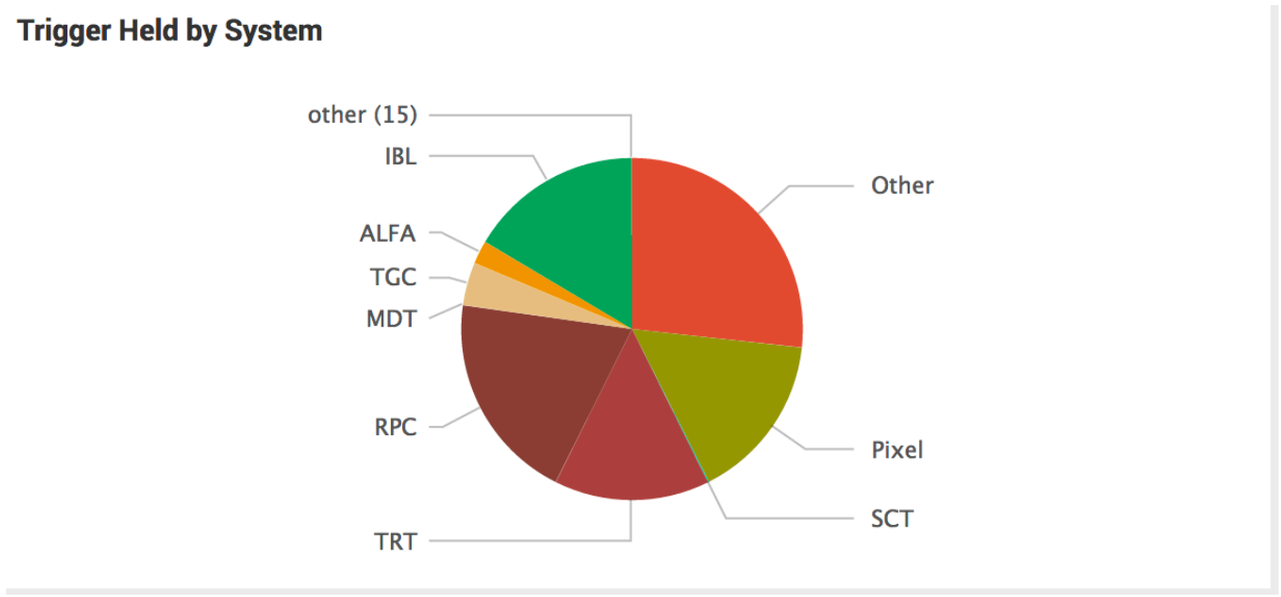

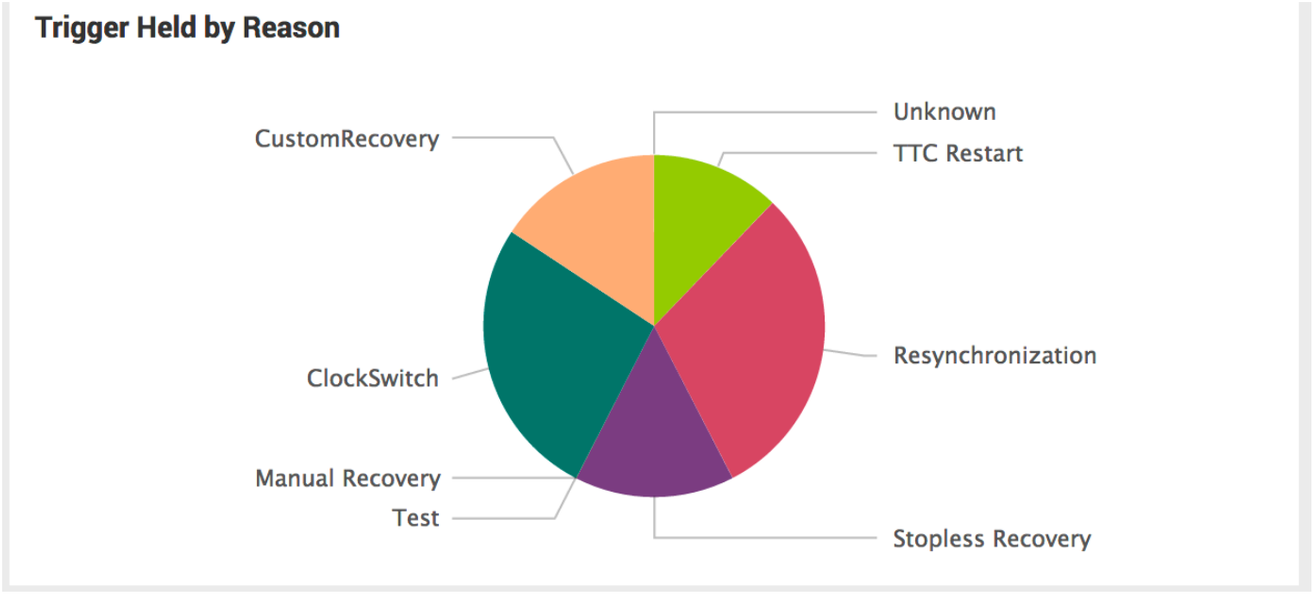

SUMMARY

- 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!