Introduction to Data Acquisition

ISOTDAQ 2015: 6th International School of Trigger and Data Acquisition

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Acknowledgment

- Lecture inherited from **Wainer Vandelli**
  - Material and ideas have been taken from:
    - CERN Summer Student lectures,
      N.Neufeld and **C.Gaspar**
    - the “Physics data acquisition and analysis” lessons given by **R.Ferrari** at the University of Parma, Italy
- Errors and flaws are mine

Outline

- Introduction
  - What is DAQ?
  - Overall framework
- Basic DAQ concepts
  - Digitization, Latency
  - Deadtime, De-randomization
- Scaling up
  - Readout and Event Building
  - Buses vs Network
- Do it yourself

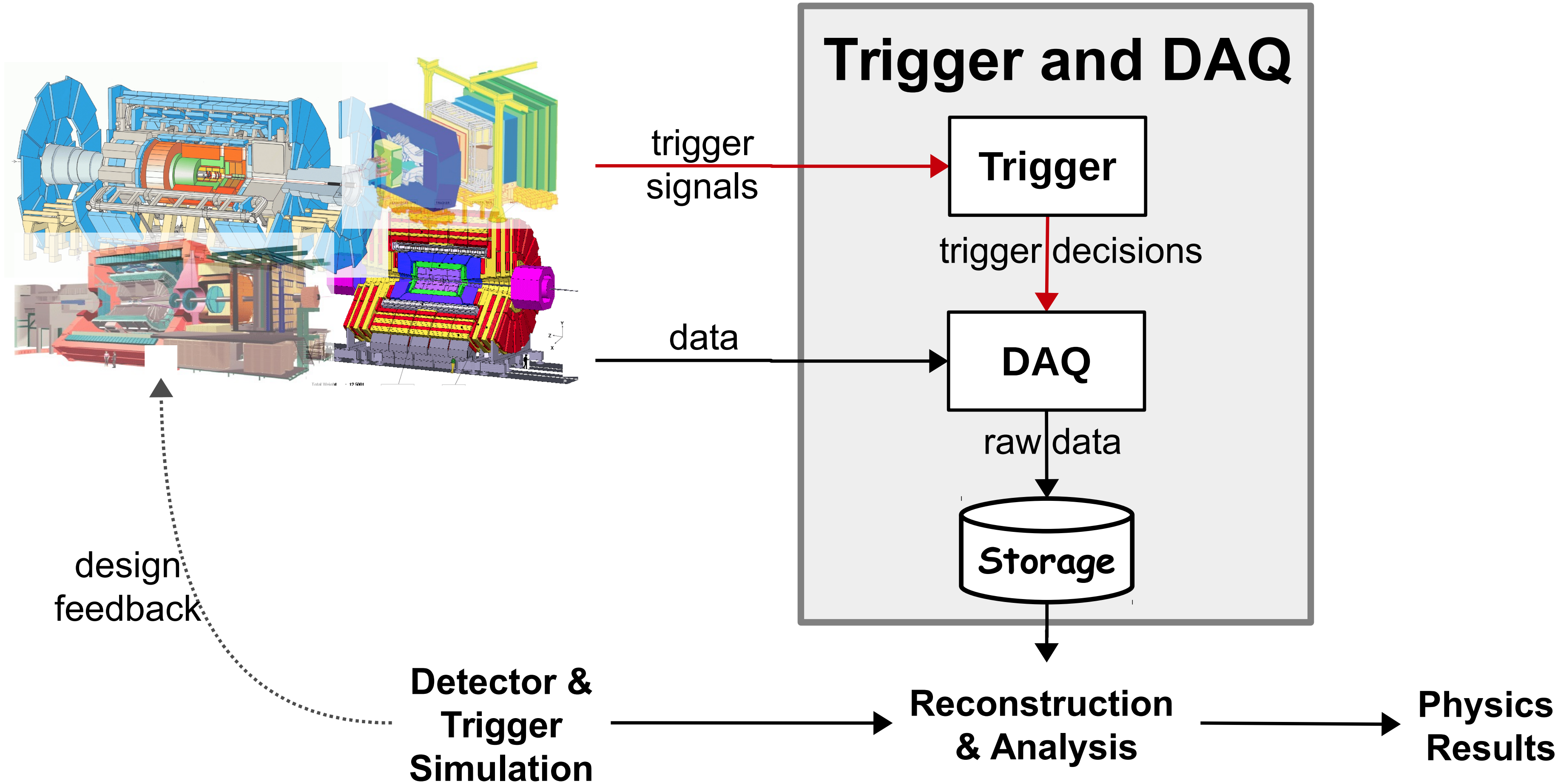
Introduction

- Data AcQuisition is not an exact science
- DAQ is an alchemy of physics, electronics, networking, hacking and experience
  - …, money and manpower matter as well
- Aim of this lesson is to introduce the basic DAQ concept avoiding as many technological details as possible
  - The following lectures will cover these aspects

- I'll mostly refer to DAQ in High-Energy Physics

Overview

- Overall the main role of T & DAQ is to process the signals generated in a detector and saving the interesting information on a permanent storage



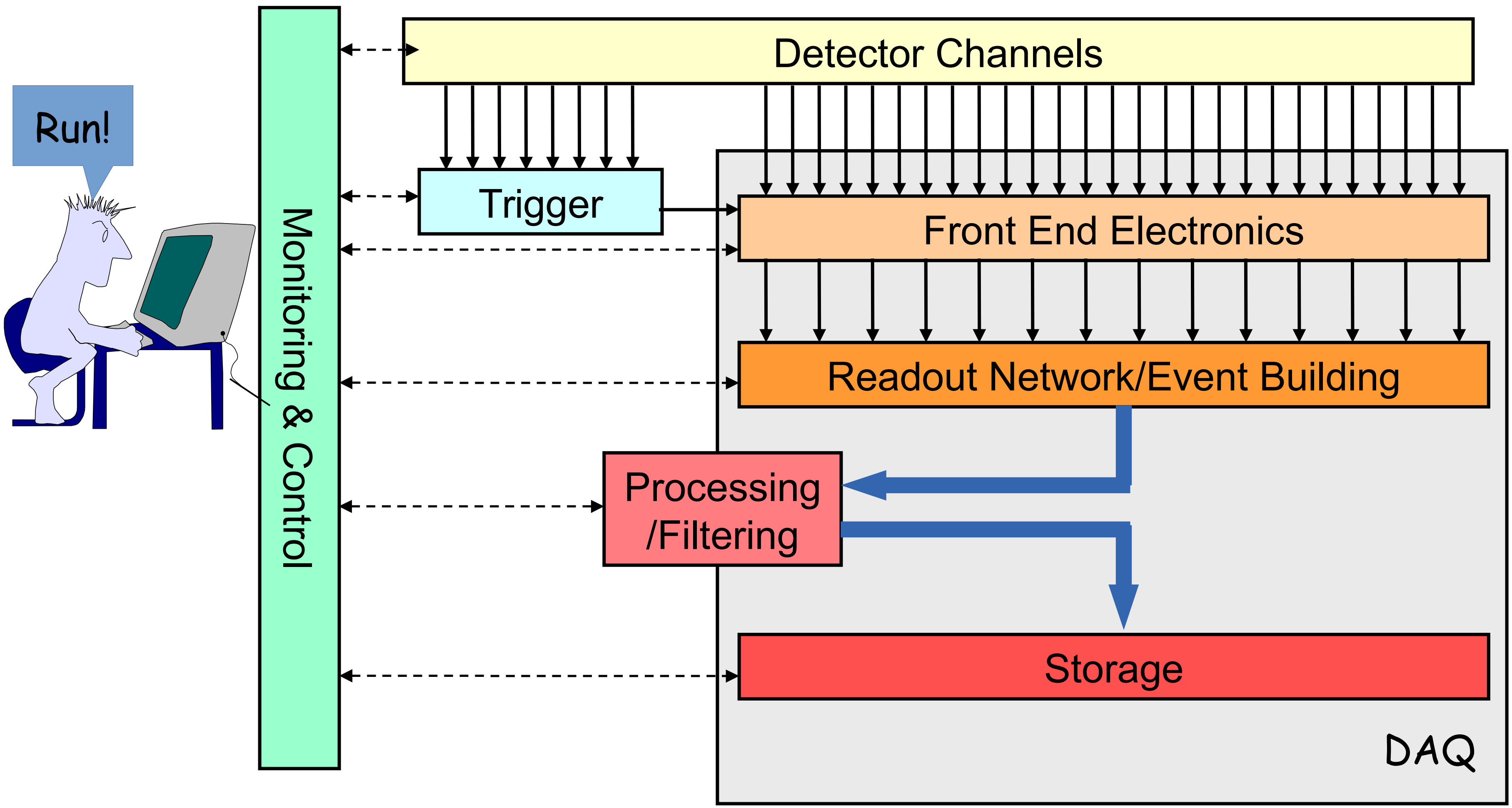
Trigger & DAQ

- Trigger
  - Either selects interesting events or rejects boring ones, in real time
  - i.e. with minimal *controlled* **latency**
    - time it takes to form and distribute its decision

- DAQ
  - Gathers data produced by detectors: **Readout**
  - Possibly feeds several trigger levels
  - Forms complete events: **Event Building**
  - Stores event data: **Data Logging**
  - Provides **Run Control**, **Configuration** and **Monitoring** facilities

(Possibly feeds several trigger levels / Forms complete events / Stores event data: **Data Flow**)

Trigger, DAQ and Controls



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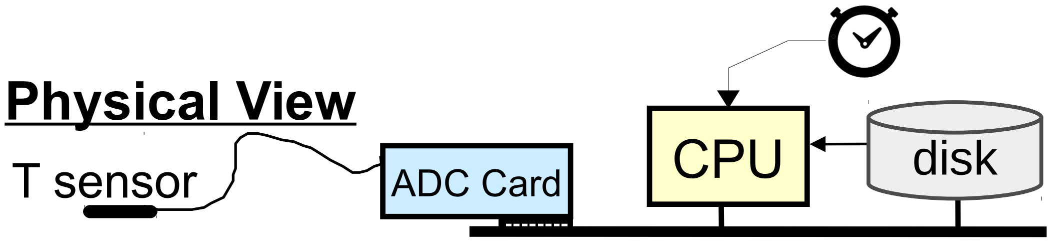
Basic DAQ: periodic trigger

- Es: measure temperature at a fixed frequency
  - ADC performs analog to digital conversion, digitization (our front-end electronics)
  - CPU does readout and processing
- System clearly limited by the time τ to process an "event"
  - ADC conversion + CPU processing + Storage
- The DAQ maximum sustainable rate is simply the inverse of τ, e.g.:
  - $\tau = 1$ ms $\rightarrow R = 1/\tau = 1$ kHz



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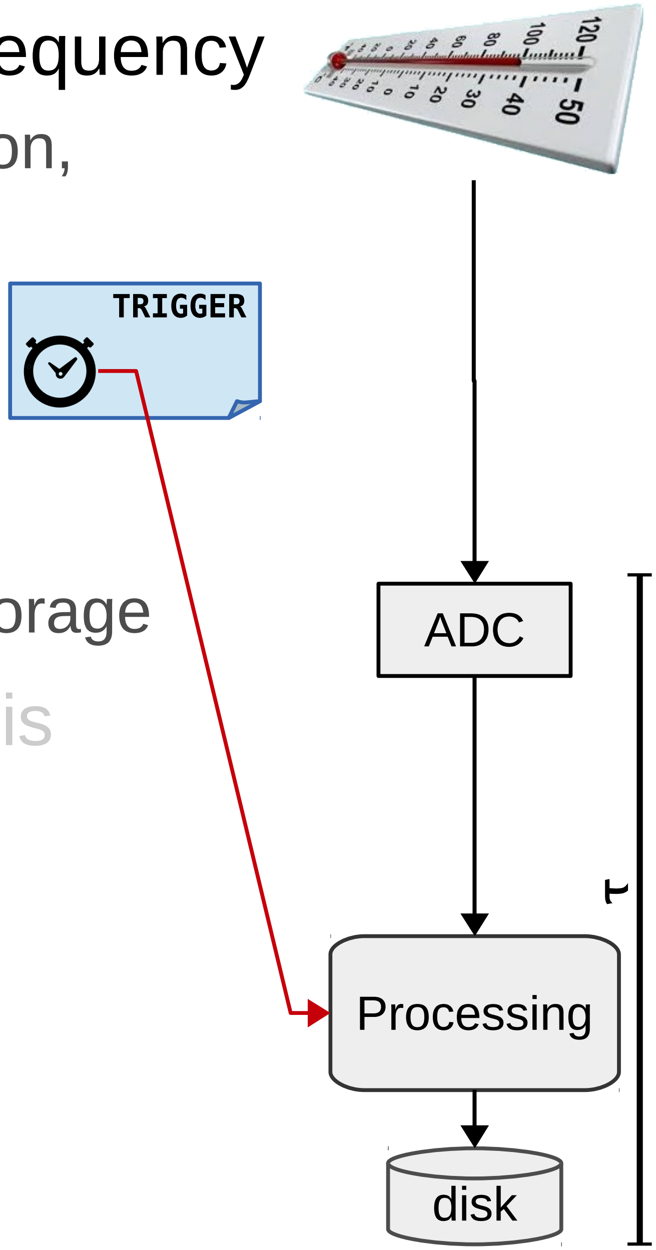
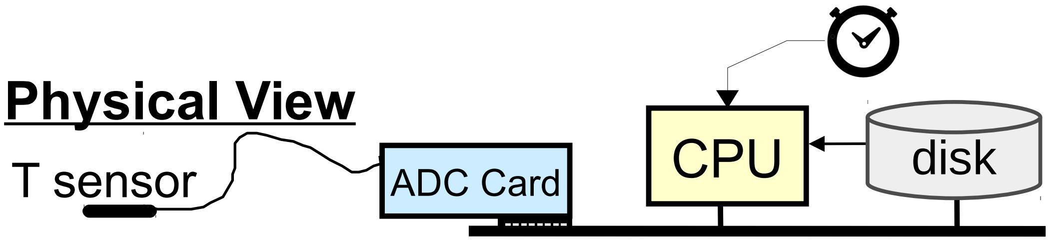


Physical View



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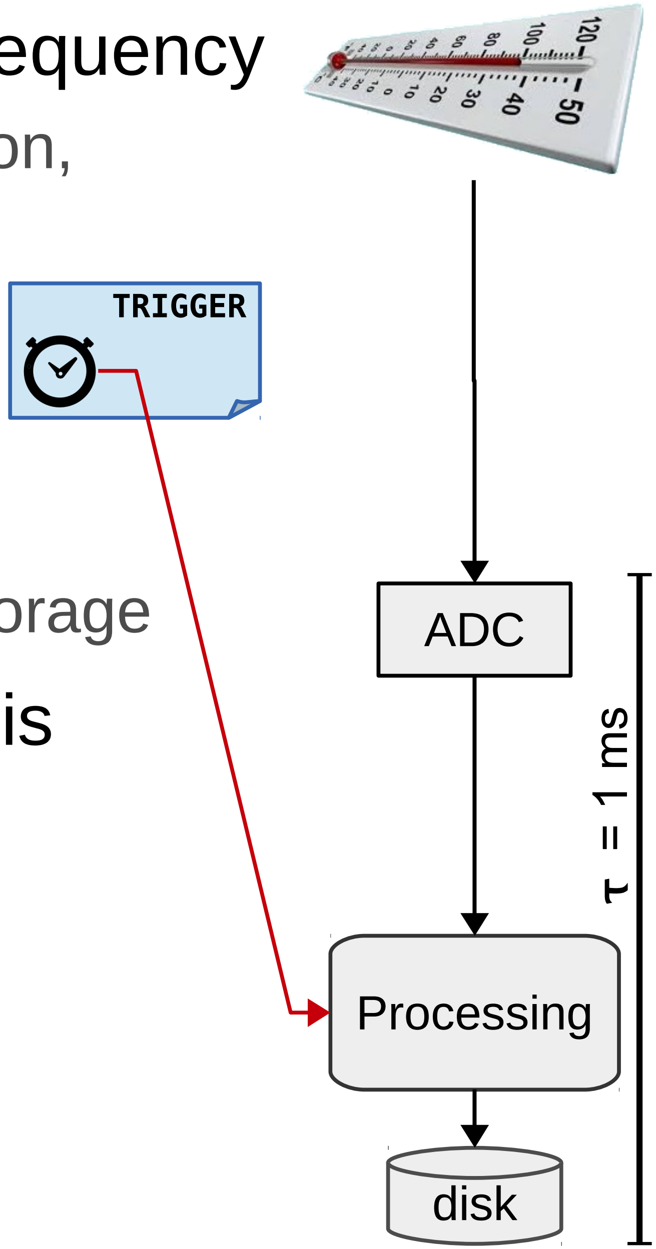
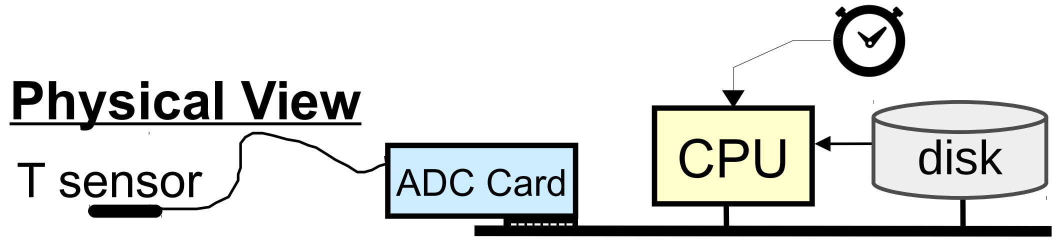
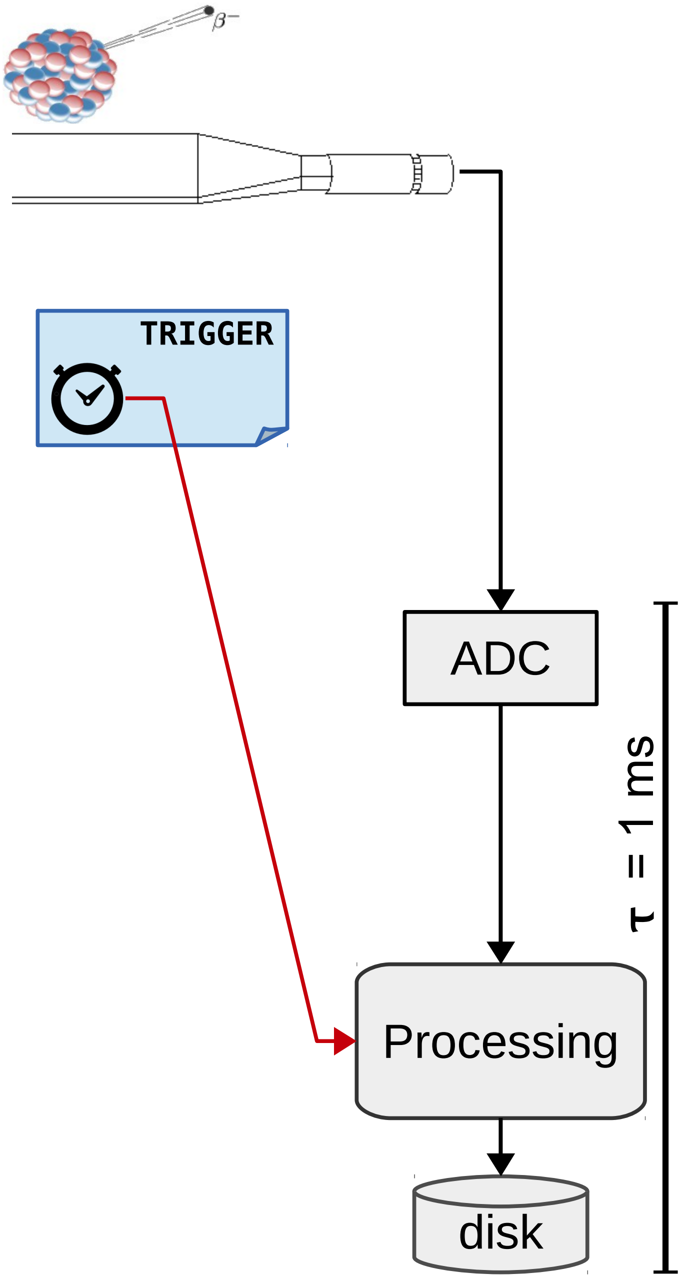




Basic DAQ: “real” trigger

- Events asynchronous and unpredictable
  - E.g.: beta decay studies
- A physics trigger is needed
  - delay compensate for **trigger latency**
  - **Discriminator**: generate an output signal only if amplitude of input pulse is grater than a certain threshold



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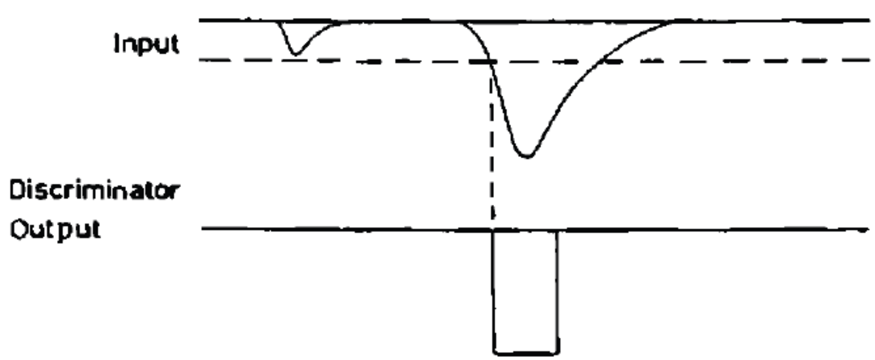

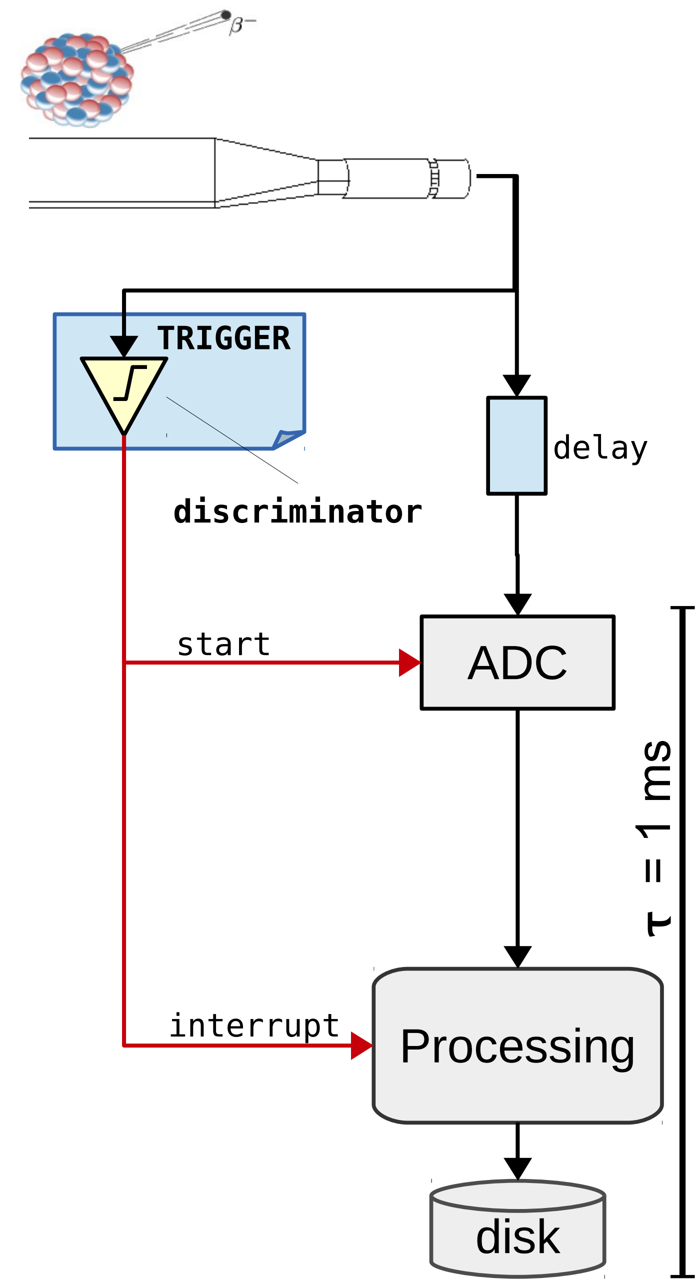

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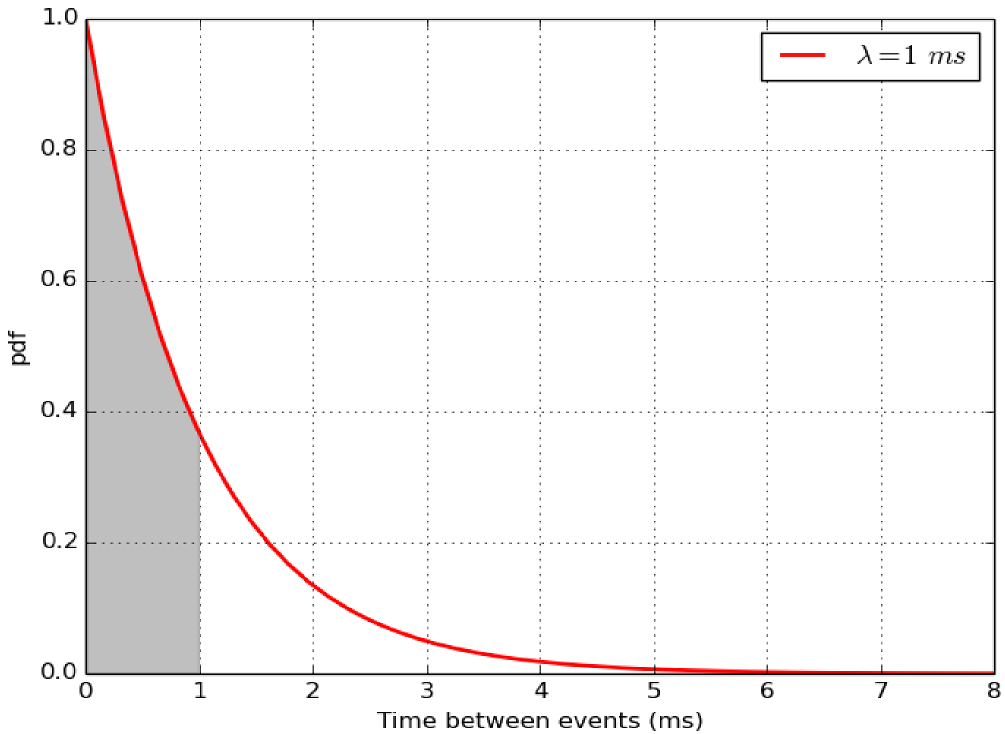
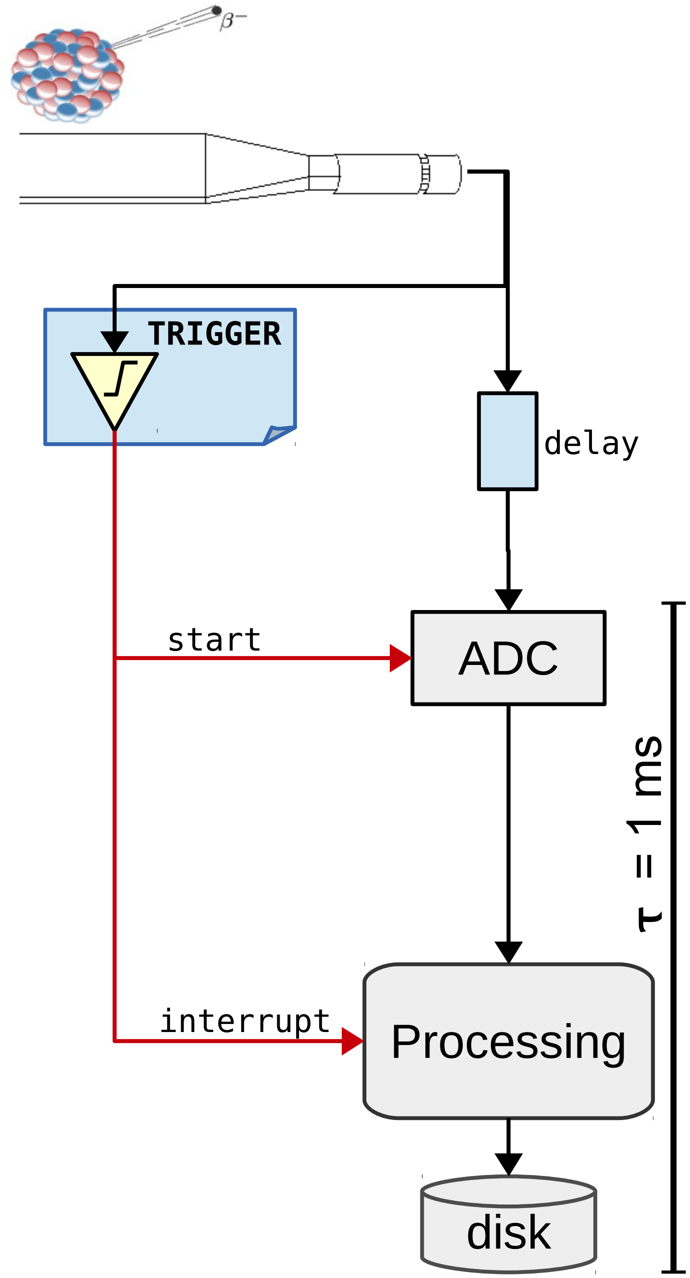
- Stochastic process
  - Fluctuations in time between events
- Let's assume for example
  - a process rate f = 1 kHz, i.e. λ = 1 ms
  - and, as before, τ = 1 ms





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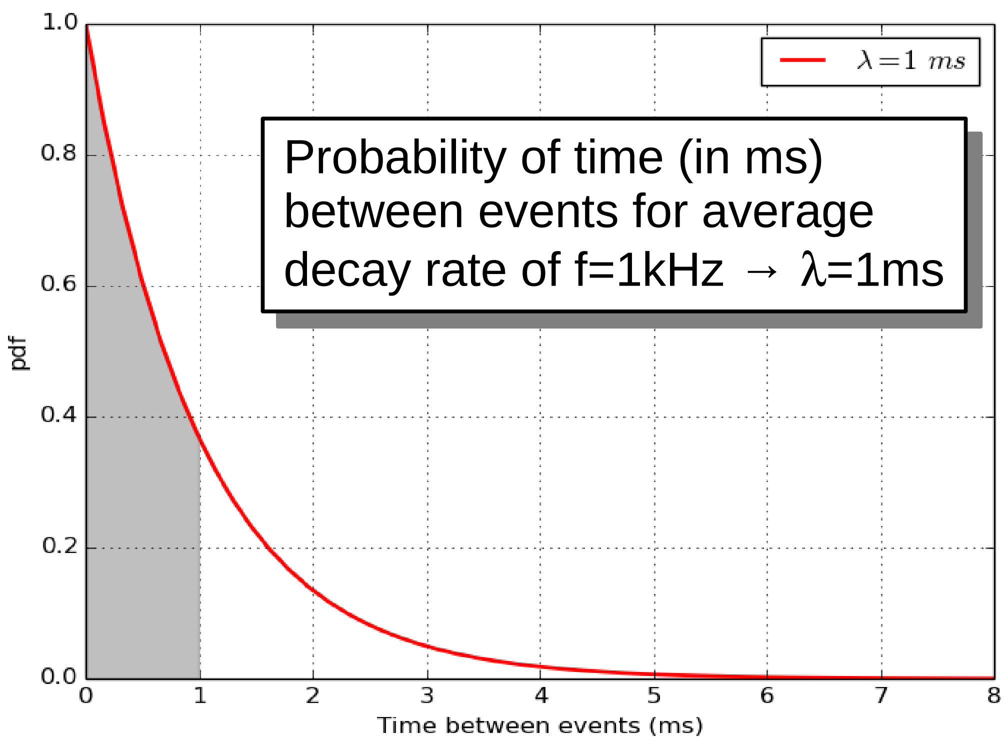

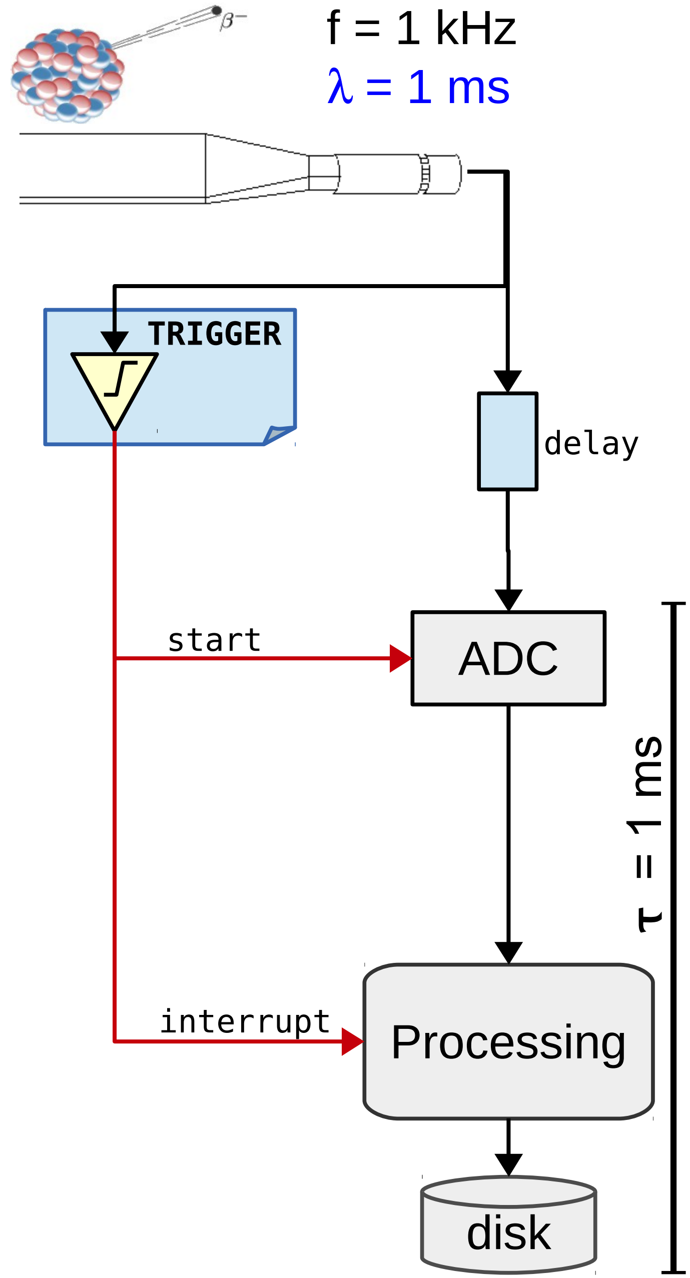

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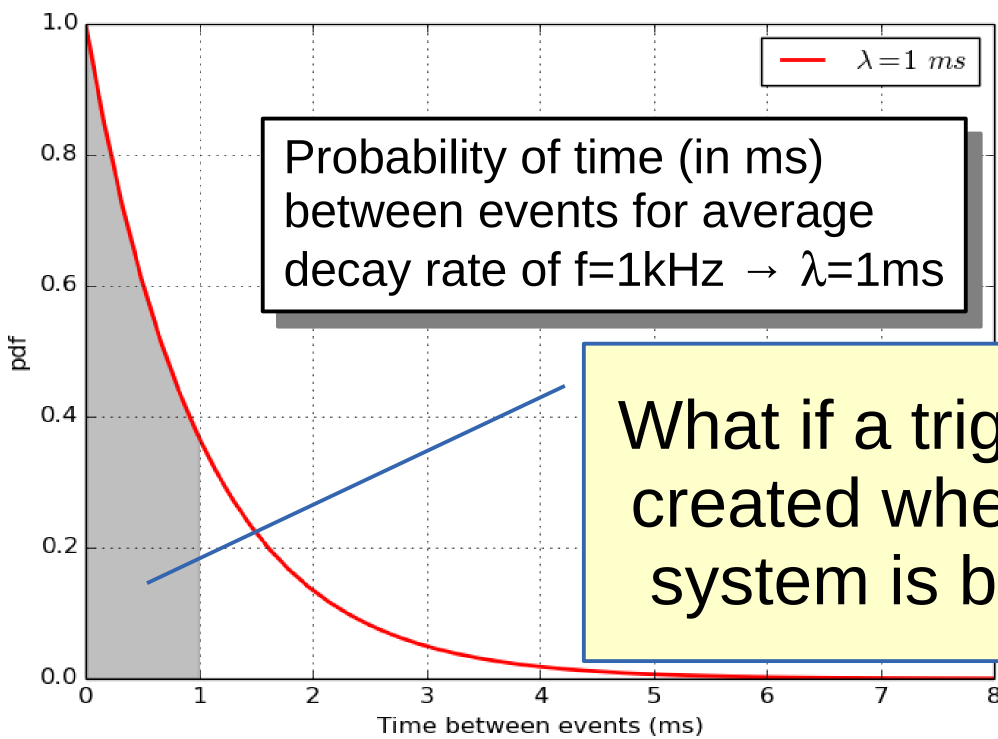
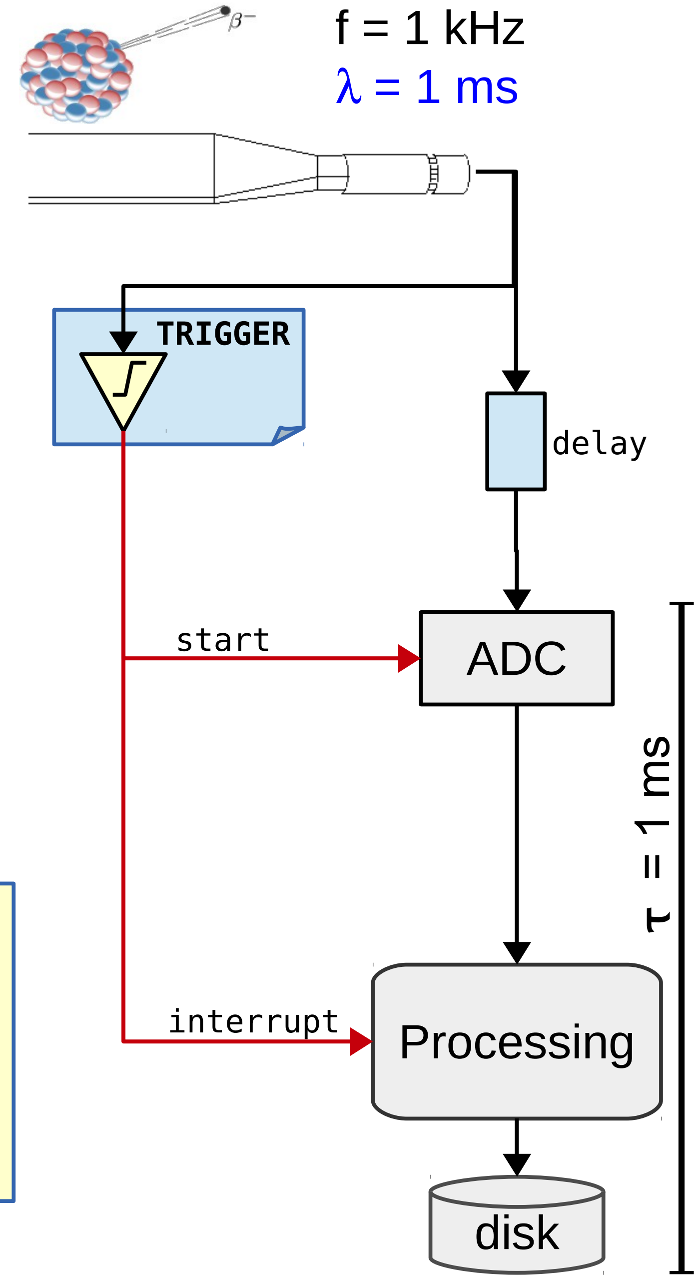


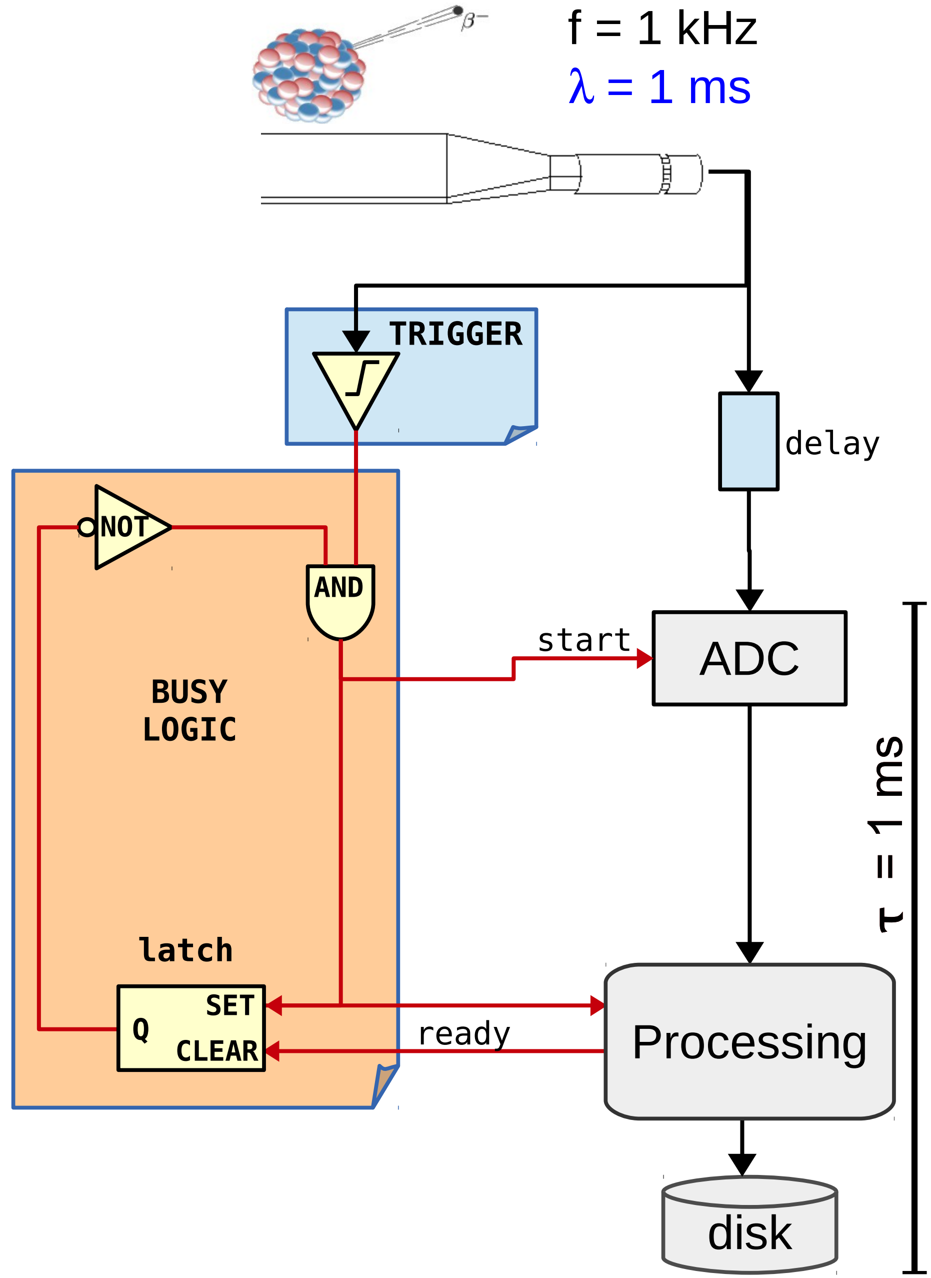
Probability of time (in ms) between events for average decay rate of f=1kHz → λ=1ms

What if a trigger is created when the system is busy?



Basic DAQ: “real” trigger

- **Busy logic** avoids triggers while the system is busy in processing
  - E.g.: using an AND port and a latch (flip-flop)
    - a bistable circuit that changes state (Q) by signals applied to the control inputs (SET, CLEAR)
- Which (average) DAQ rate can we achieve now?
  - Reminder: with a clock trigger and τ = 1 ms the limit is 1 kHz



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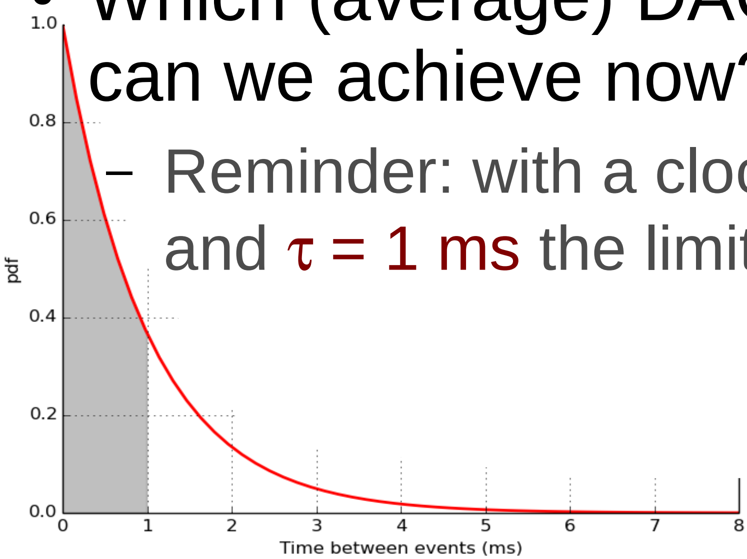

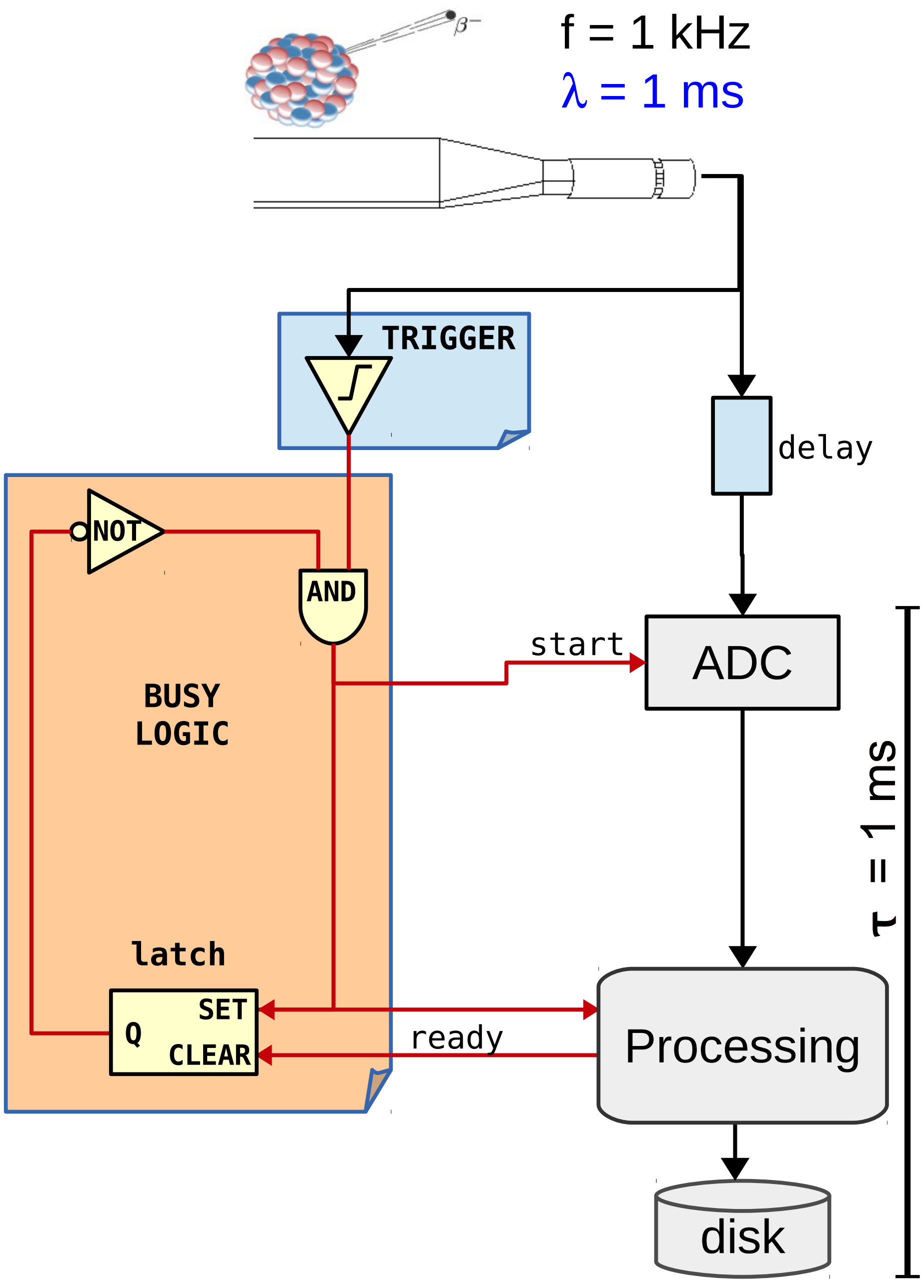

Deadtime and efficiency

- Definitions
  - **f** average rate of physics phenomenon (input)
  - **ν** average rates of DAQ (output)
  - **τ: deadtime**, the time the system requires to process an event, without being able to handle other triggers
  - the probability that DAQ is busy   P[busy] = ν τ
  - the probability that DAQ is free   P[free] = 1 - ν τ
- Therefore:

$$\nu = f P[free] \Rightarrow \nu = f(1-\nu\tau) \Rightarrow \nu = \frac{f}{1+f\tau} < f$$

$$\epsilon = \frac{N_{saved}}{N_{tot}} = \frac{1}{1+f\tau} < 100\%$$

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Deadtime and efficiency

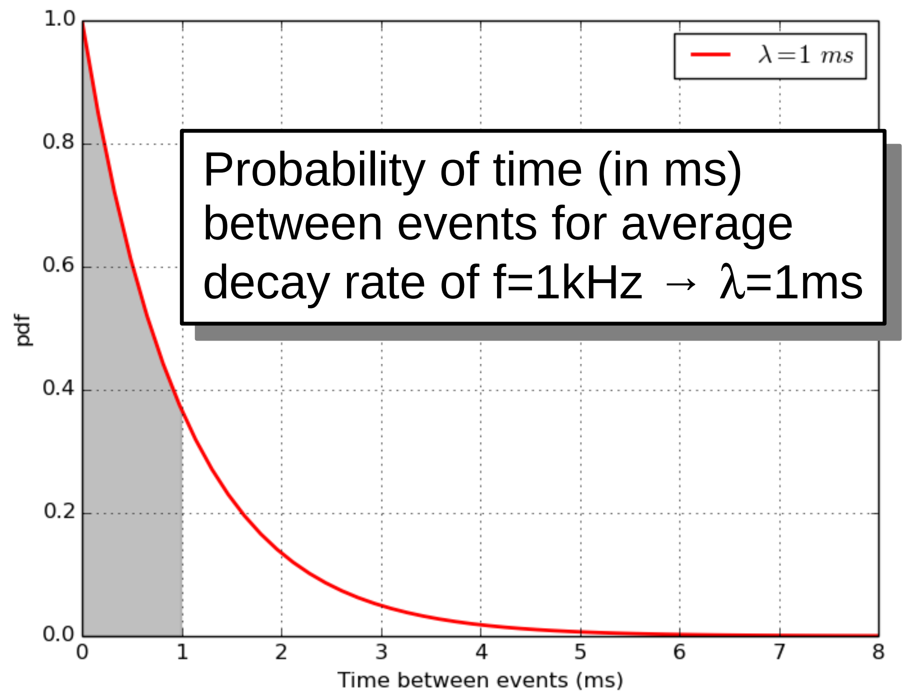
- Due to stochastic fluctuations
  - DAQ rate always < physics rate
  - Efficiency always < 100%

$$\nu = \frac{f}{1+f\tau} < f$$

$$\epsilon = \frac{1}{1+f\tau} < 100\%$$

- So, in our specific example

$$\left| \begin{array}{l} f = 1\,kHz \\ \tau = 1\,ms \end{array} \right. \rightarrow \left| \begin{array}{l} \nu = 500\,Hz \\ \epsilon = 50\% \end{array} \right.$$



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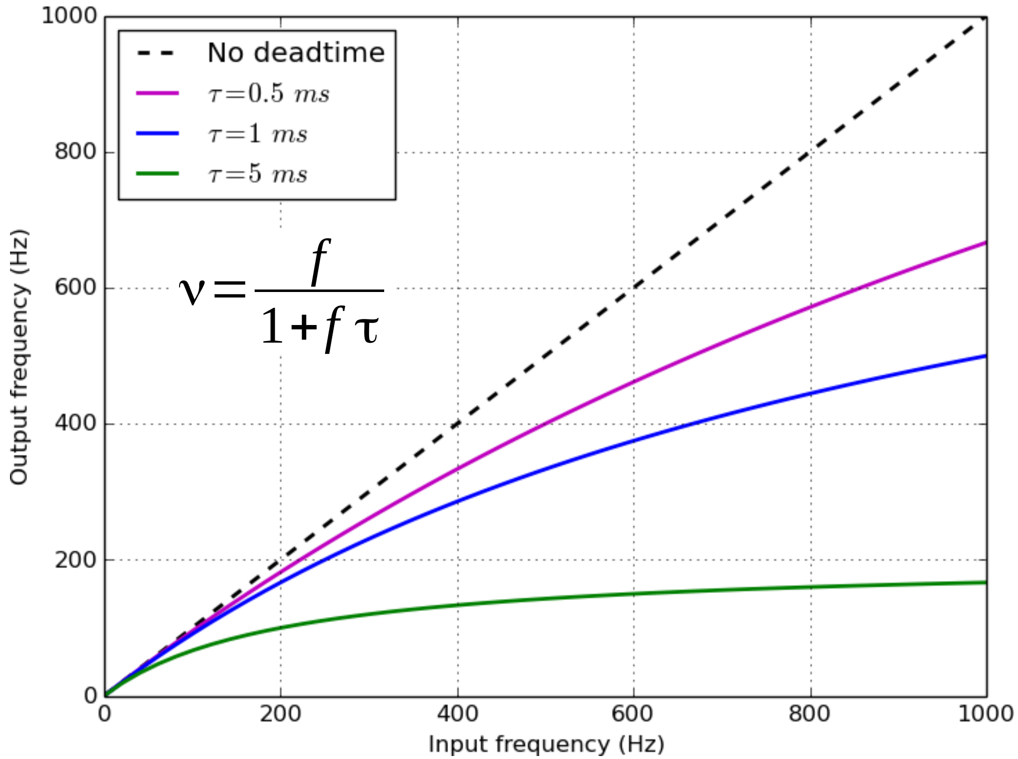
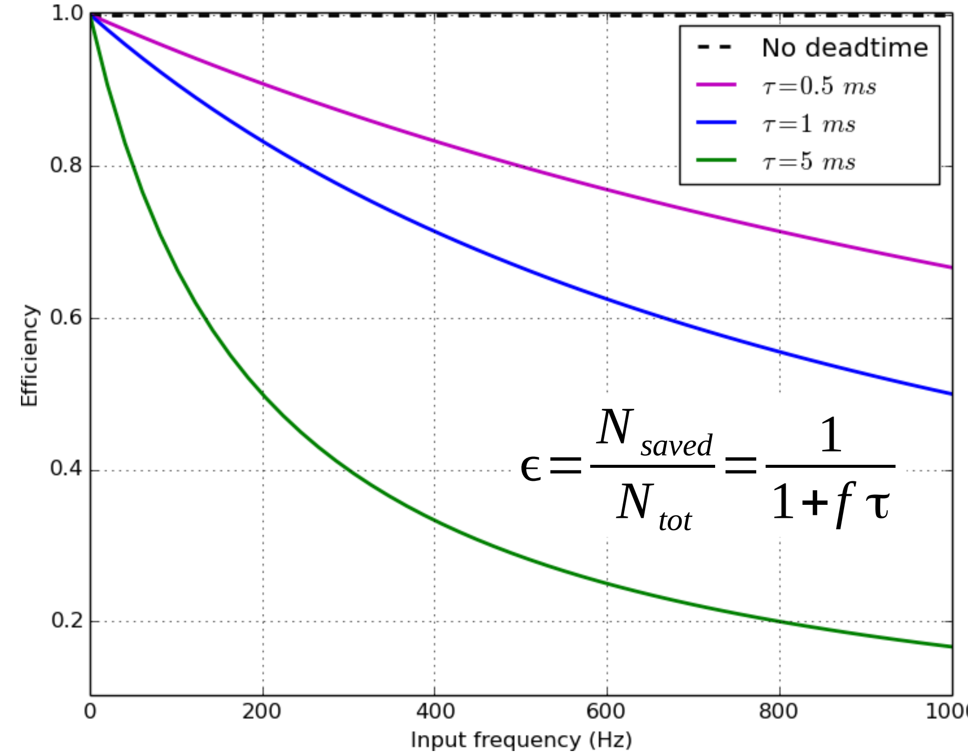
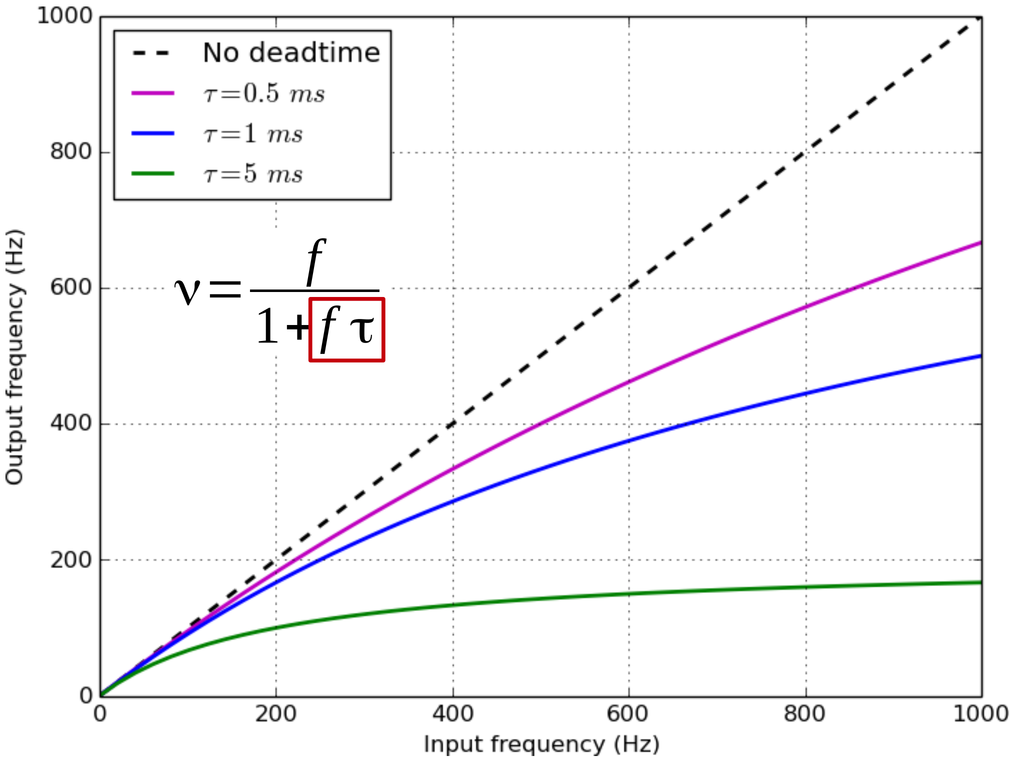
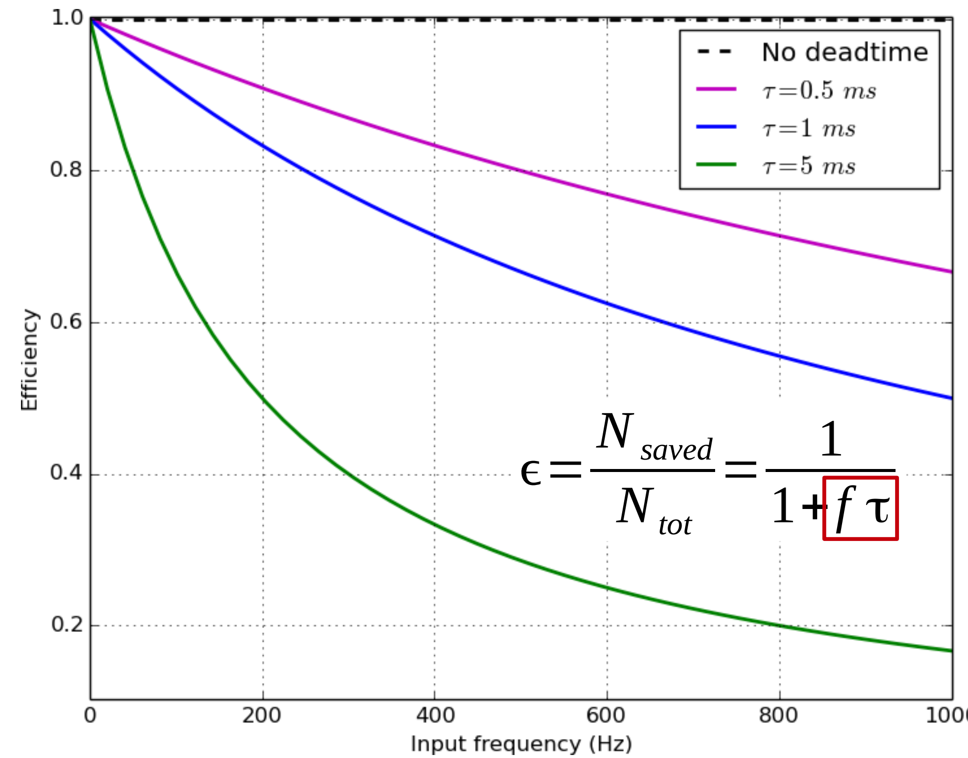




- In order to obtain $\varepsilon \sim 100\%$ (i.e.: $\nu \sim f$) $\rightarrow f\tau << 1 \rightarrow \tau << \lambda$
  - E.g.: $\varepsilon \sim 99\%$ for f = 1 kHz $\rightarrow$ $\tau < 0.1$ ms $\rightarrow 1/\tau > 100$ kHz
  - To cope with the input signal fluctuations, we have to **over-design** our DAQ system by a factor 10.
- How can we mitigate this effect?

Deadtime and efficiency





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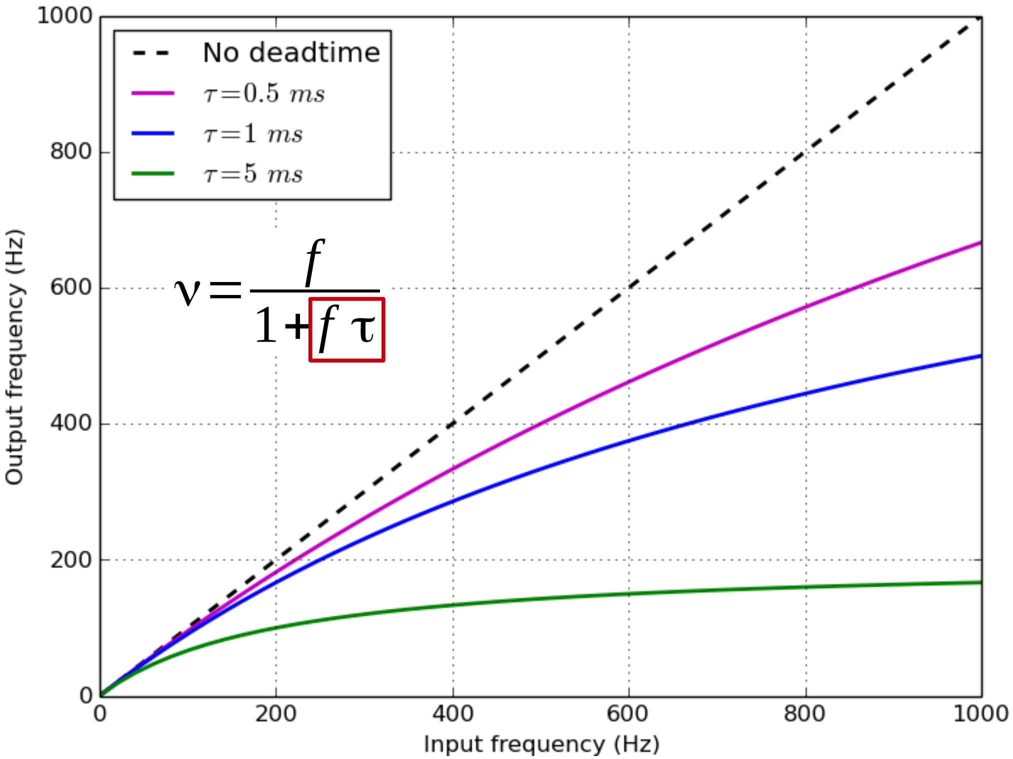

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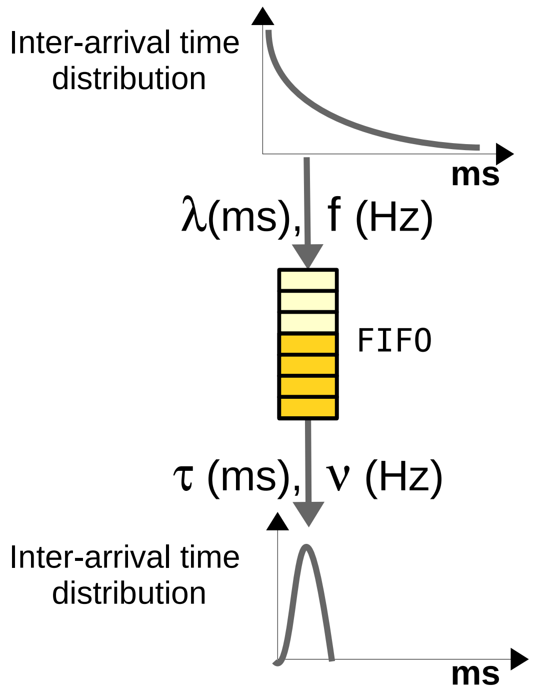
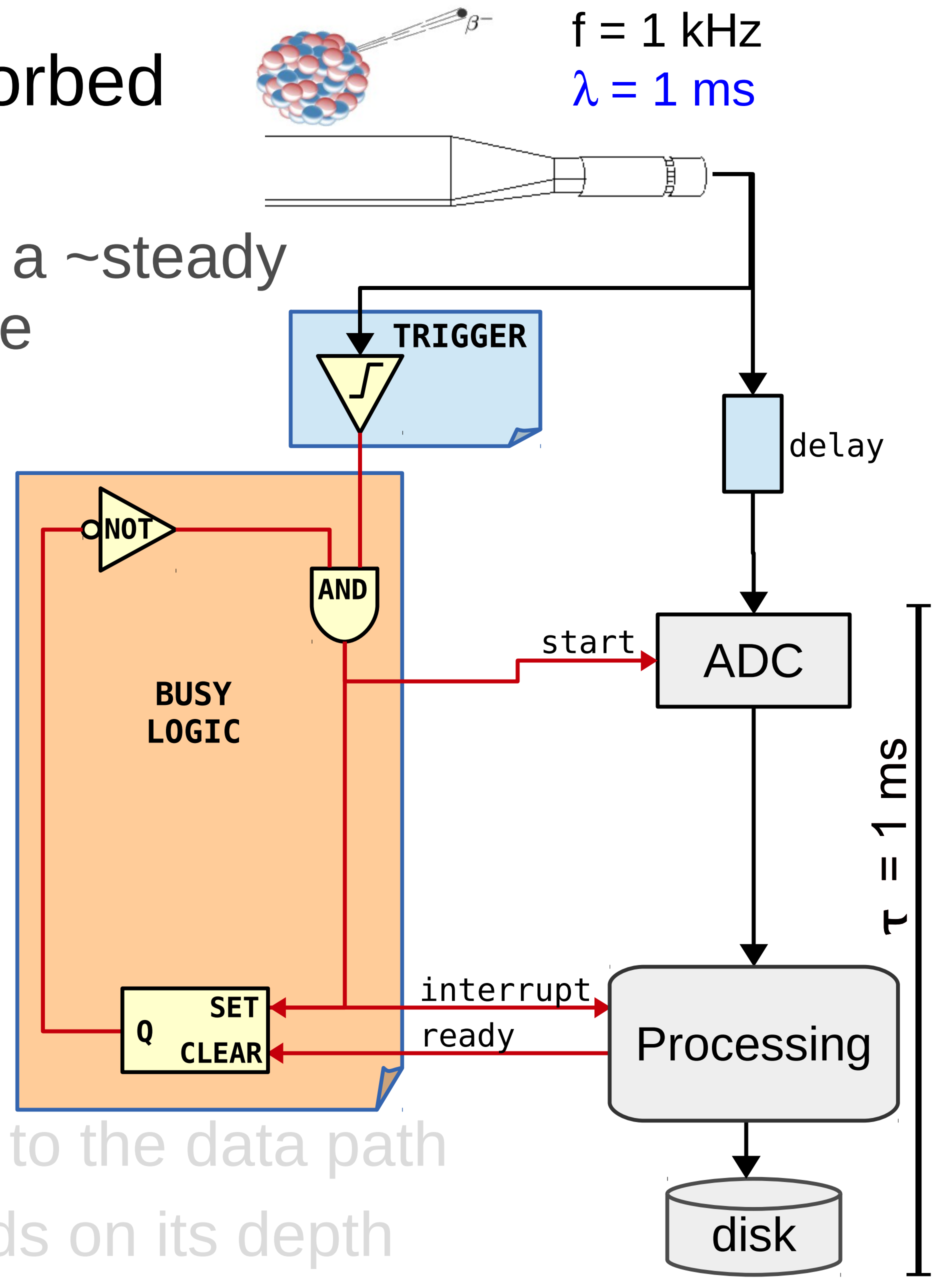
De-randomization

- Input fluctuations can be absorbed and smoothed by a queue
  - A First In First Out can provide a ~steady and **de-randomized** output rate





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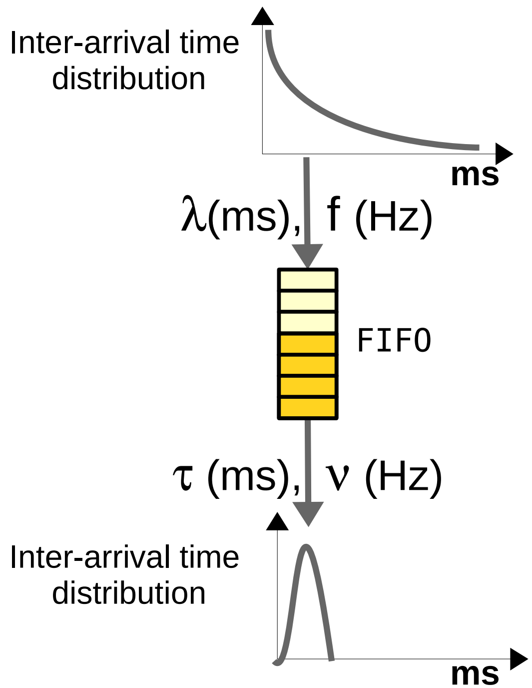

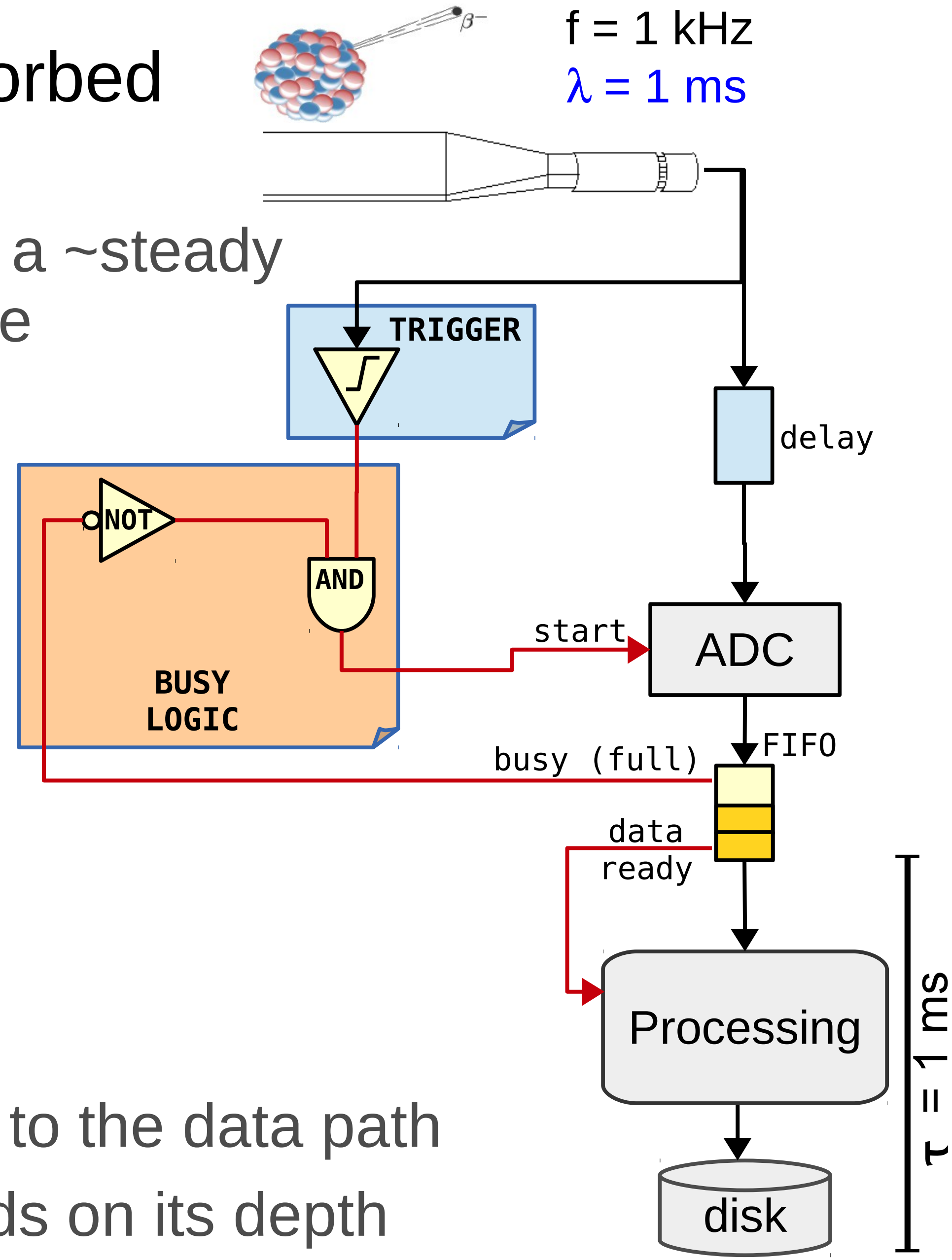

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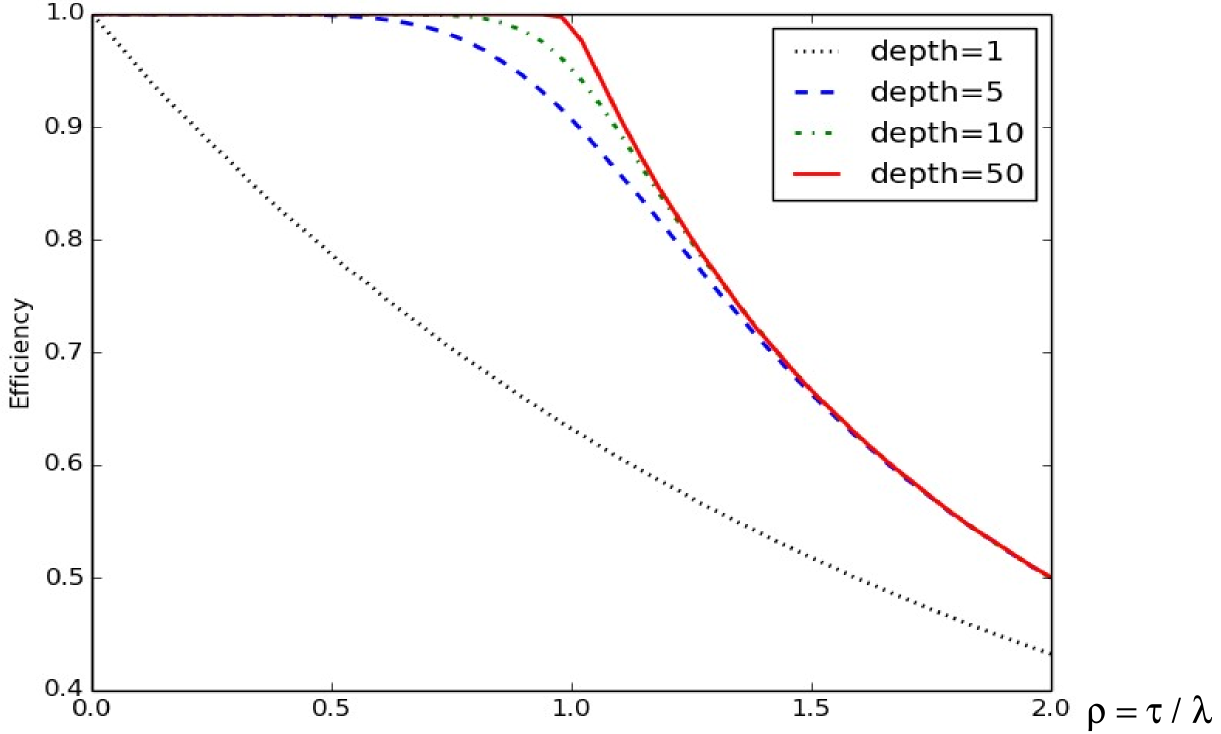
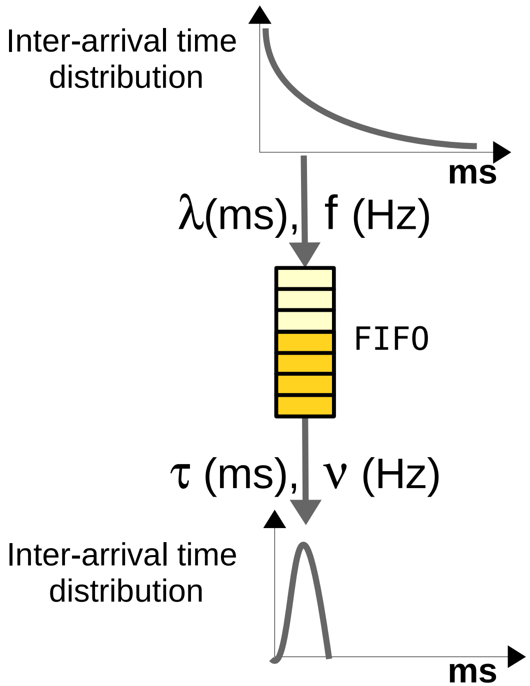
Queuing theory

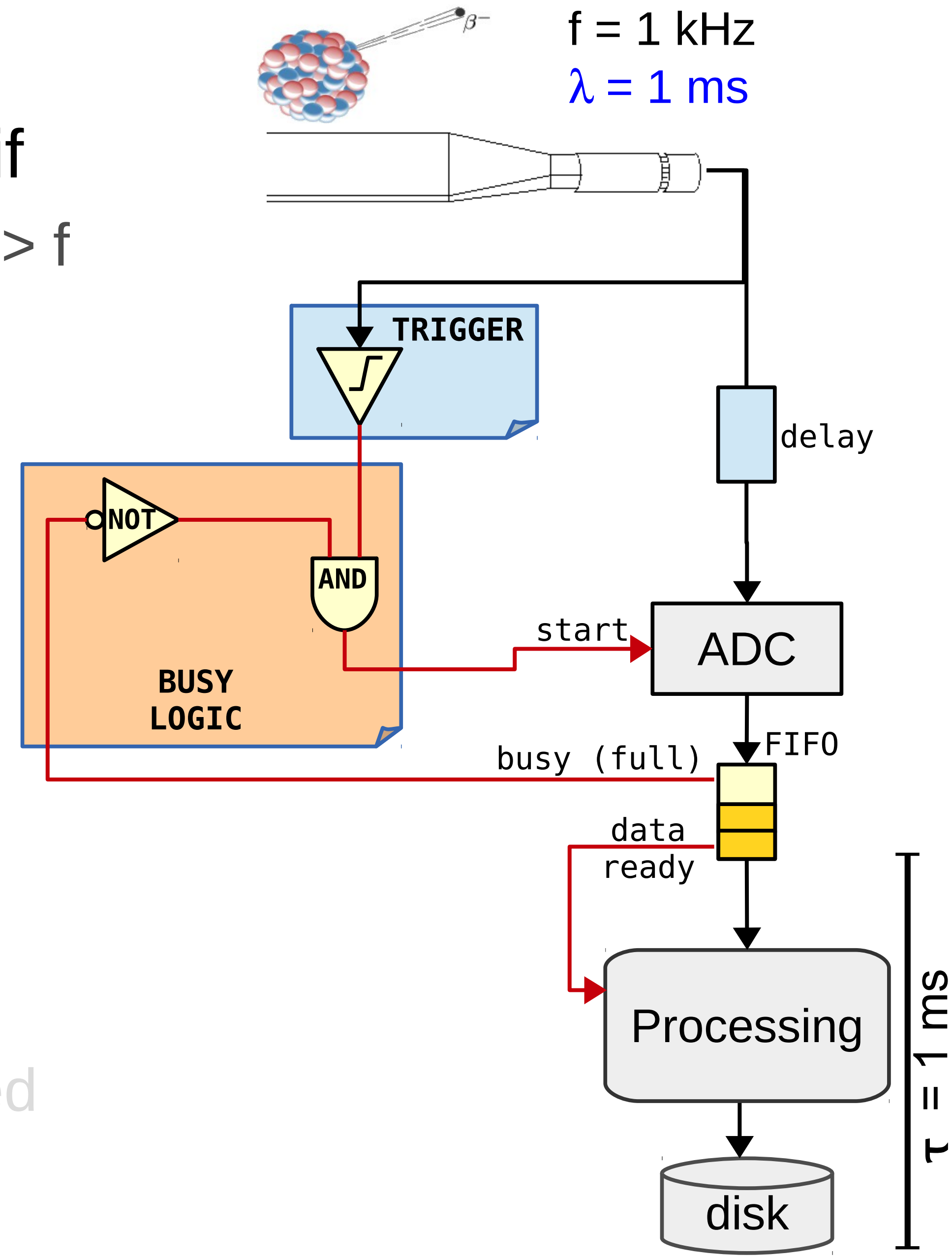




- Efficiency vs traffic intensity ($\rho = \tau / \lambda$) for different queue depths
  - $\rho > 1$, the system is overloaded
  - $\rho << 1$, the output is over-designed
  - $\rho \sim 1$, using a queue, high efficiency can be obtained even w/ moderate depth
- Analytic calculation possible for very simple systems only
  - Otherwise MonteCarlo simulation is required

De-randomization summary

- Almost 100% efficiency with minimal deadtime achievable if
  - ADC is able to operate at rate >> f
  - Data processing and storing operate at a rate ~ f
- The FIFO decouples the low latency front-end from the data processing
  - Minimize the amount of “unnecessary” fast components
- Could the delay be replaced with a “FIFO”?
  - Analog pipelines → Heavily used in LHC DAQs



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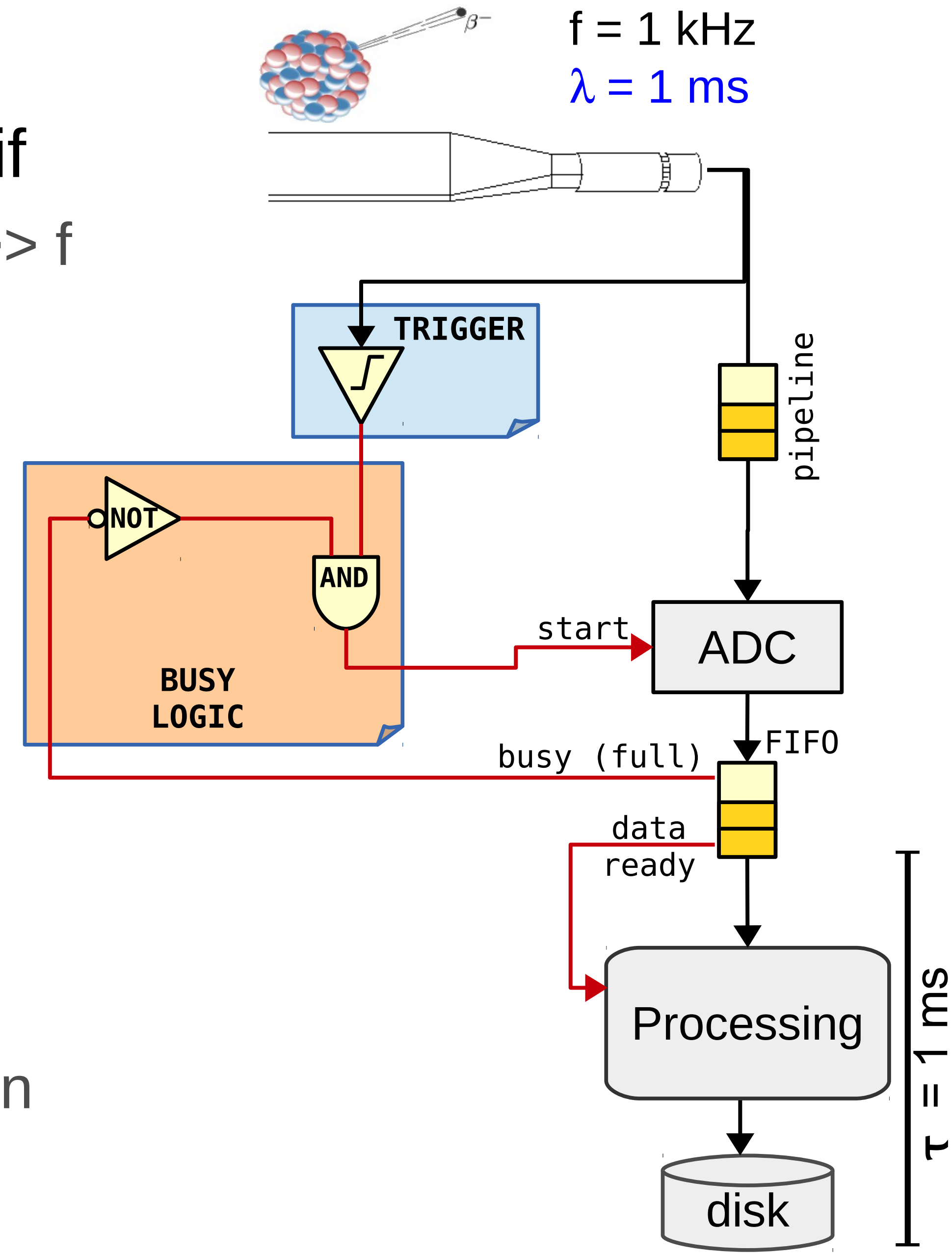
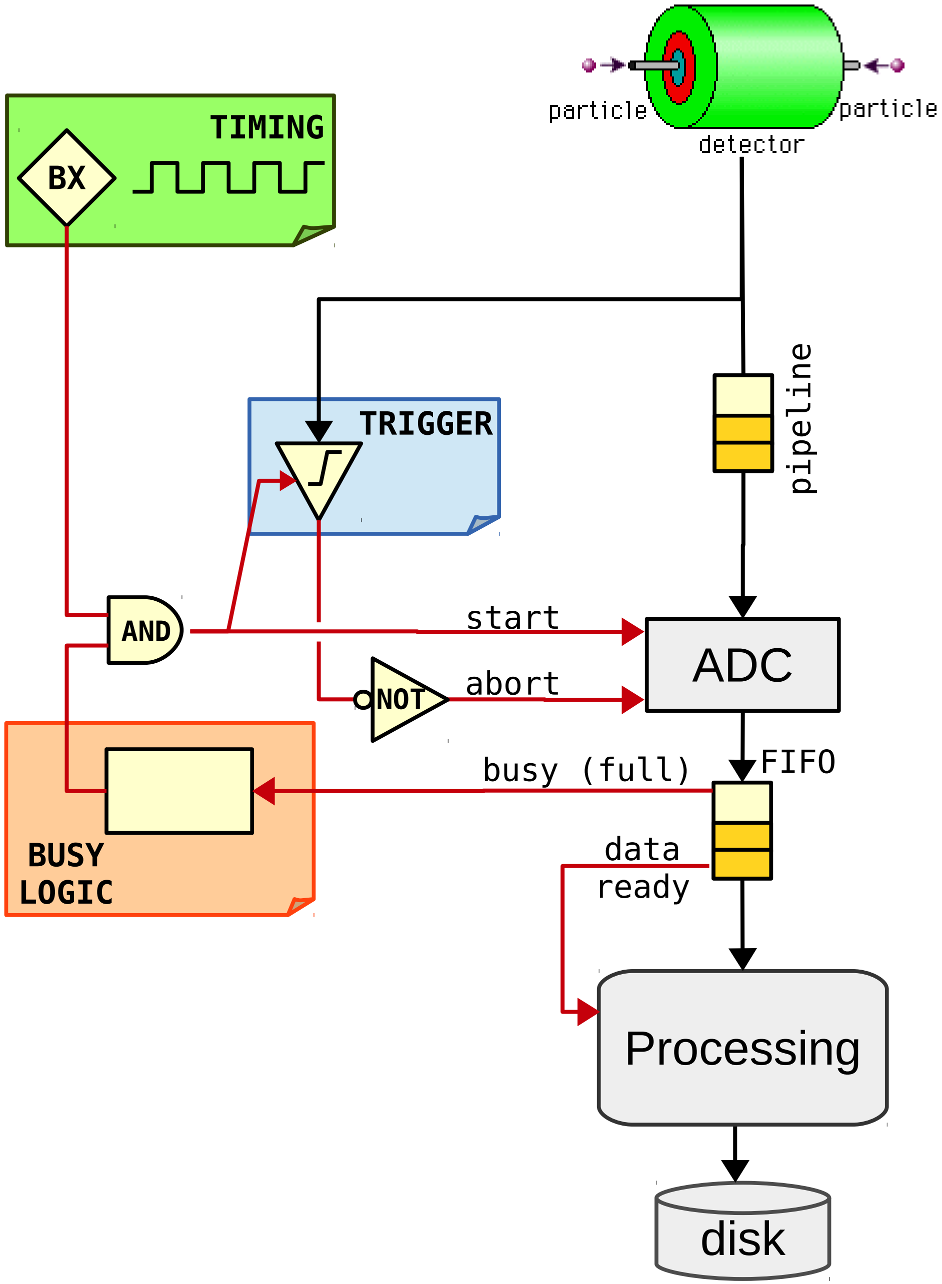


Collider setup

- Particle collisions are synchronous
  - So, do we still need de-randomization buffers?
- Trigger rejects uninteresting events
  - Good events are unpredictable
- Even if collisions are synchronous, the time distribution of triggers is random
  - De-randomization is still needed



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Adding more channels

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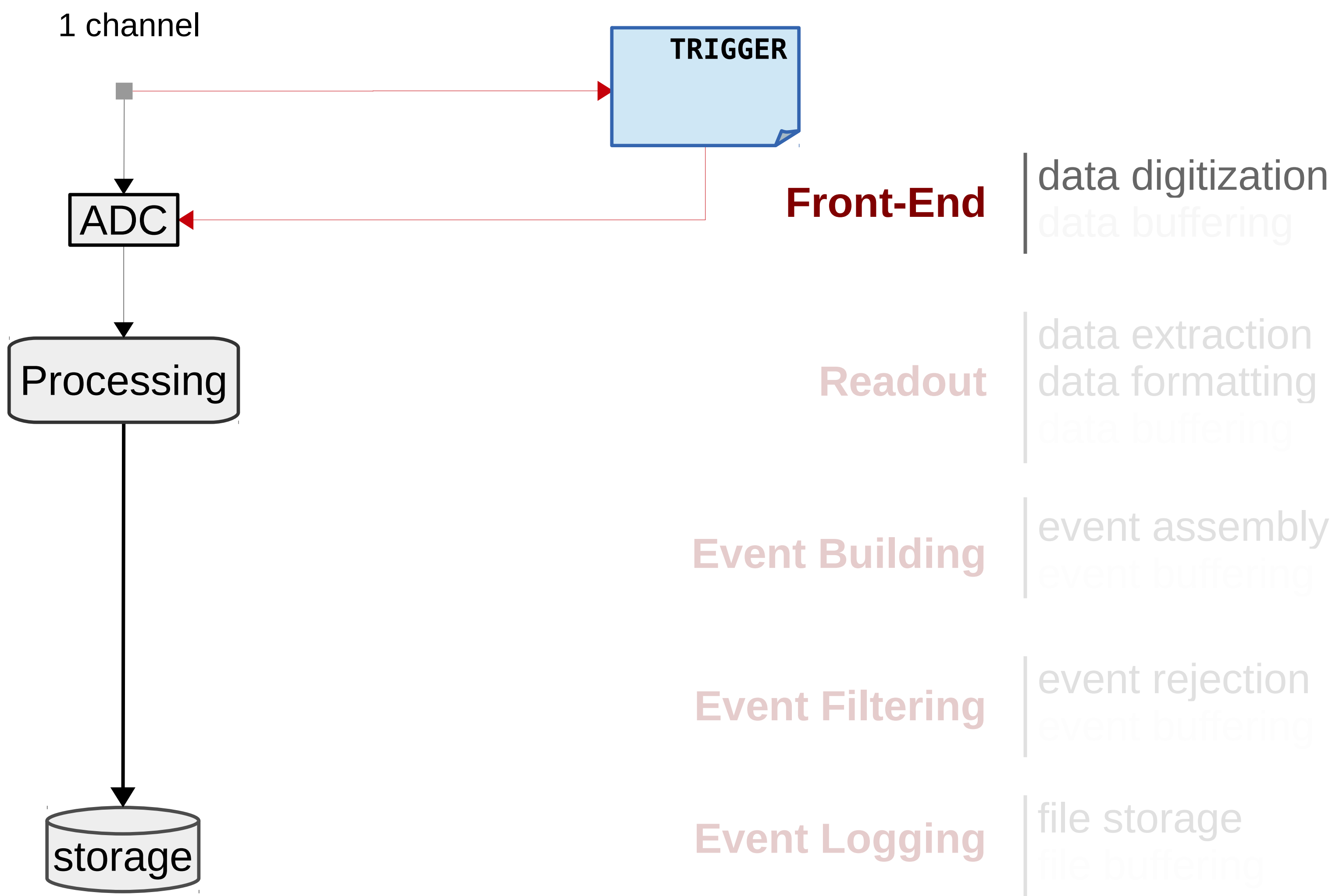

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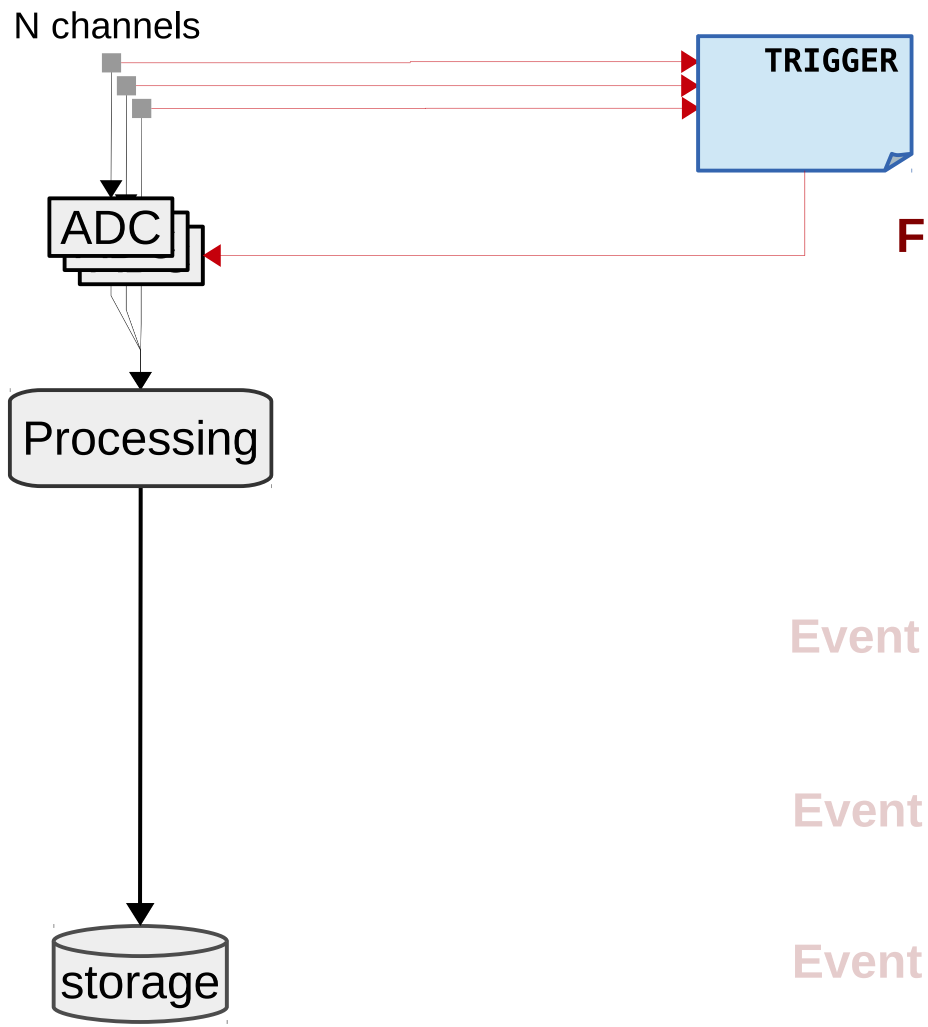

Front-End
data digitization
data buffering

Readout
data extraction
data formatting
data buffering

Event Building
event assembly
event buffering

Event Filtering
event rejection
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Event Logging
file storage
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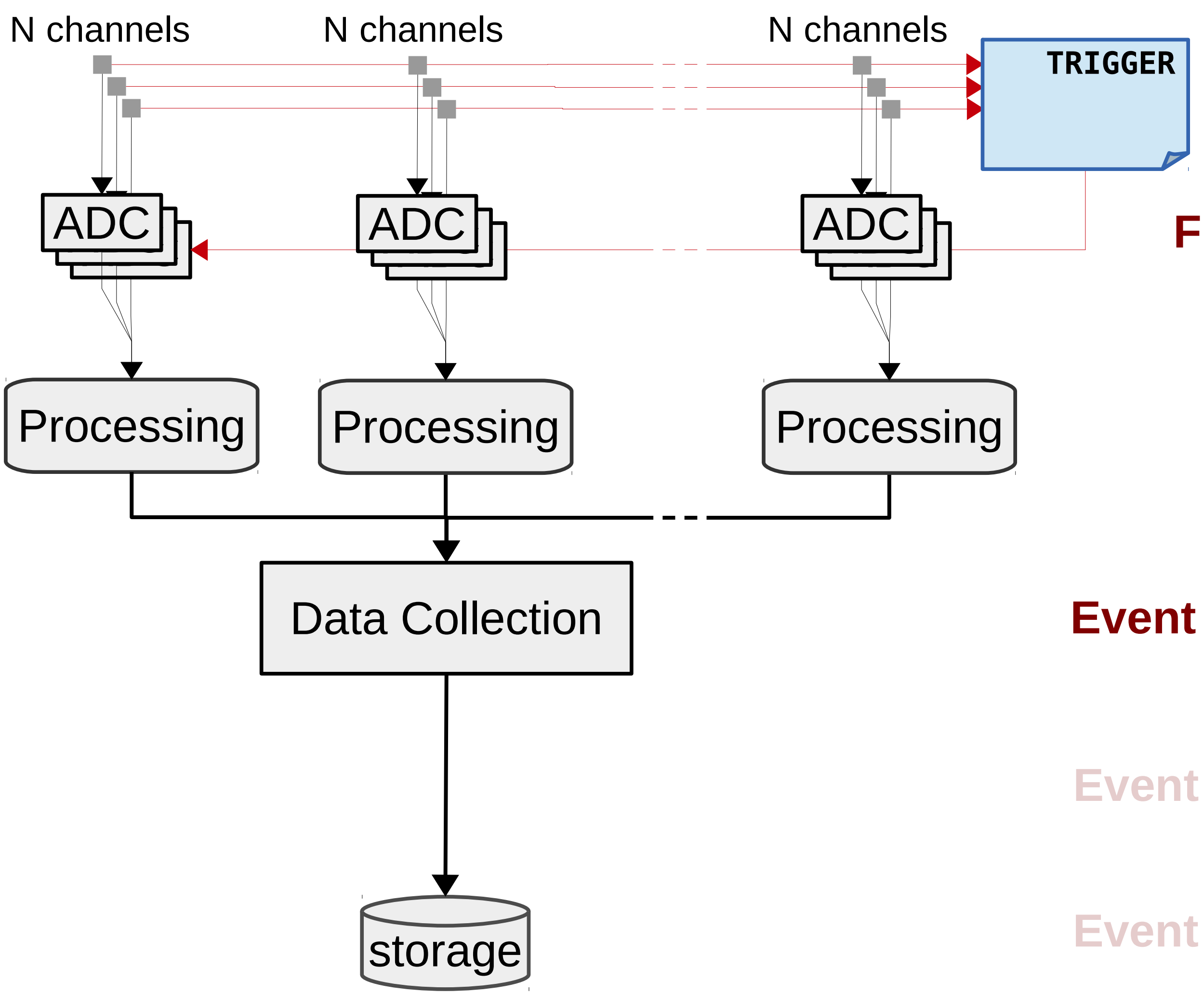

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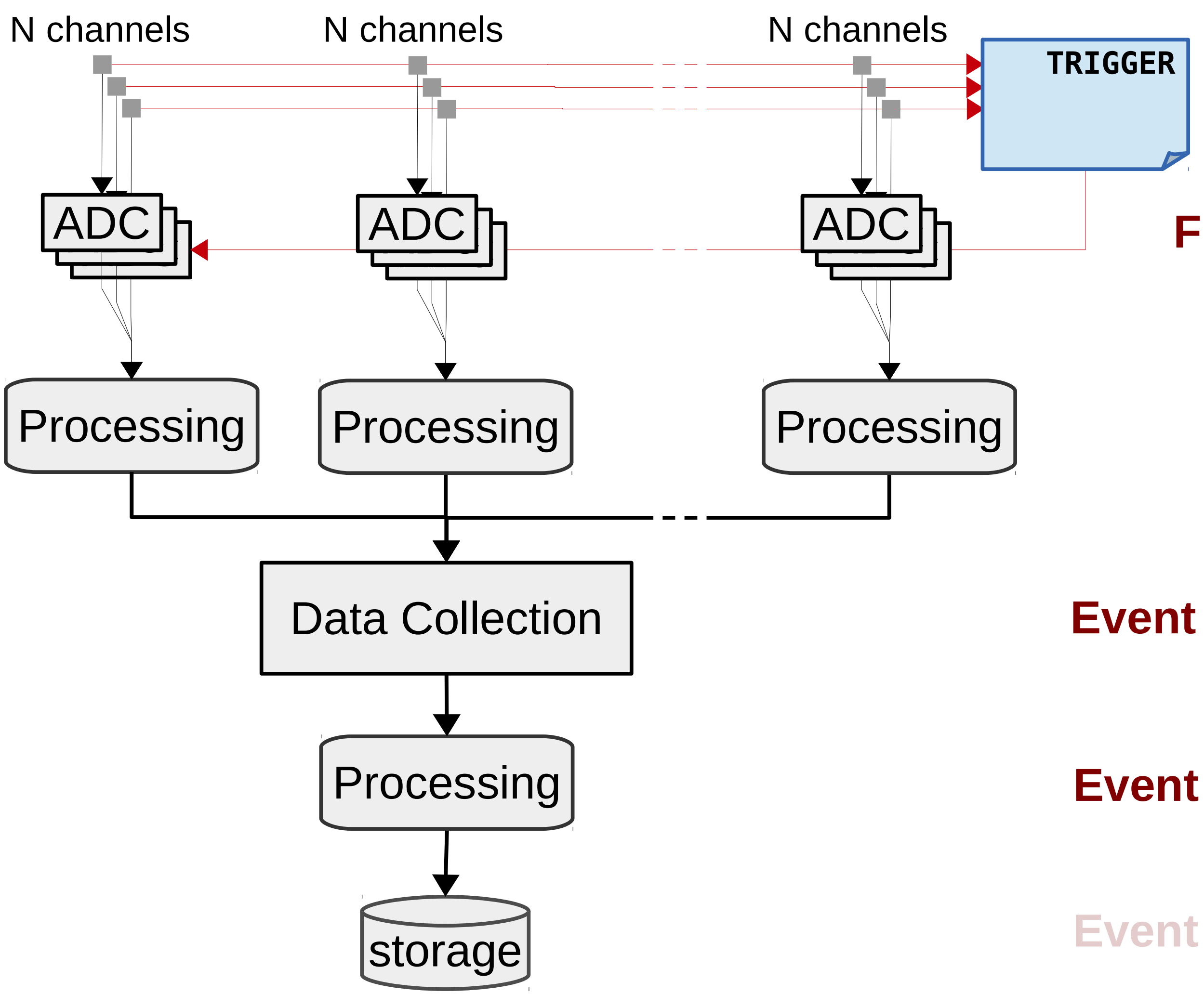

Front-End | data digitization, data buffering

Readout | data extraction, data formatting, data buffering

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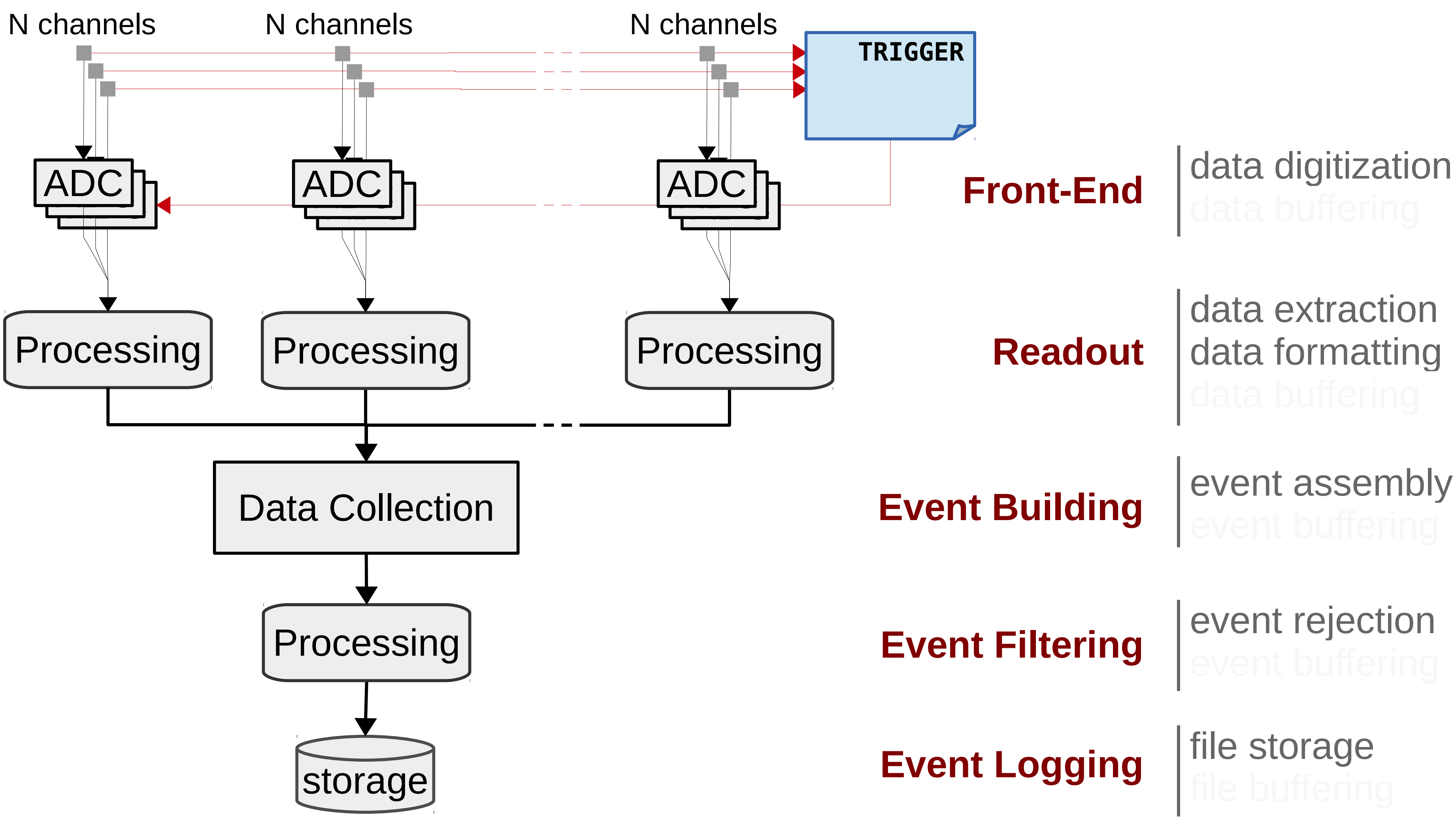
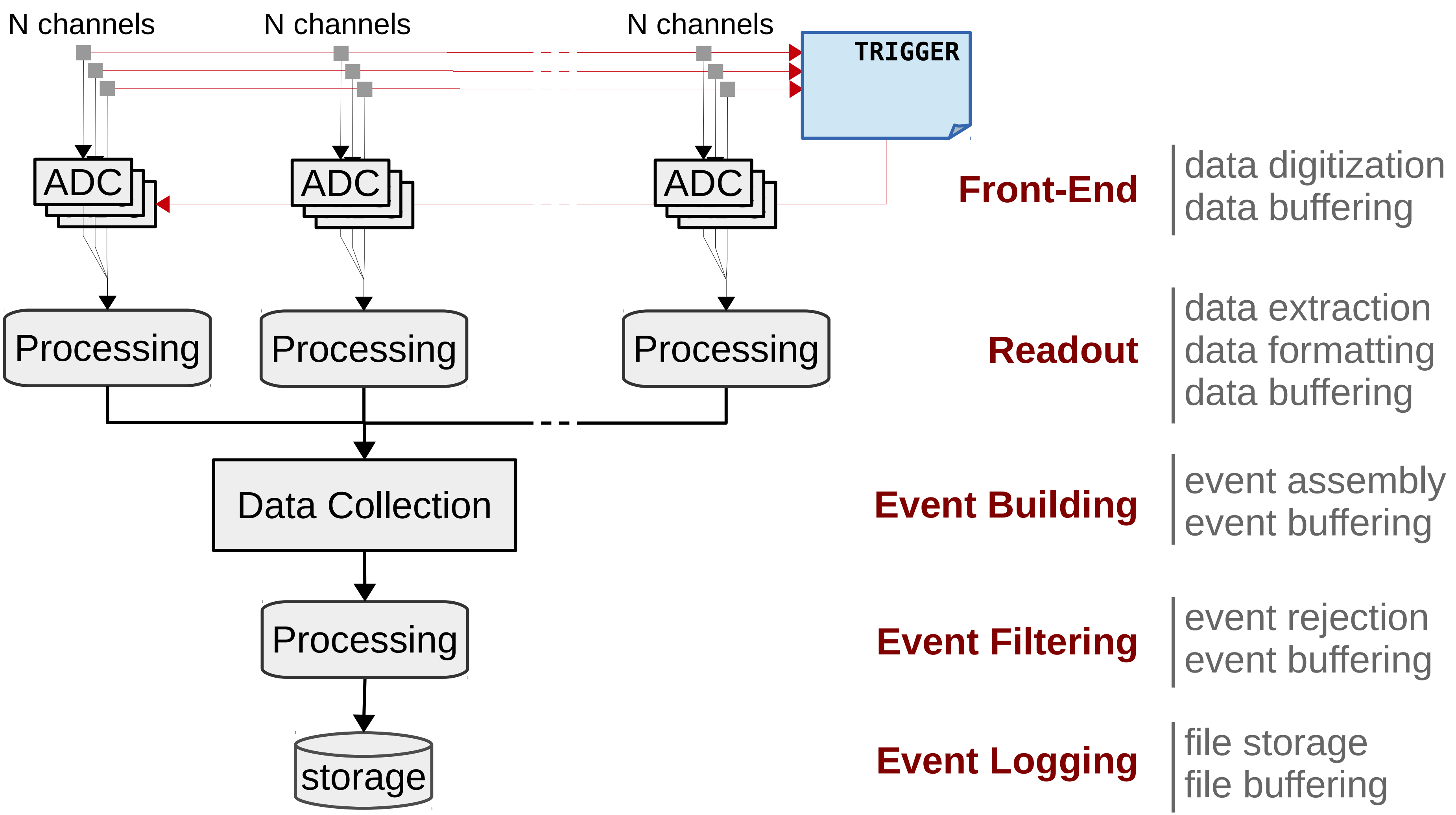


Adding more channels

- Buffering usually needed at every level



Readout Topology

- Reading out data or building events out of many channels requires many components
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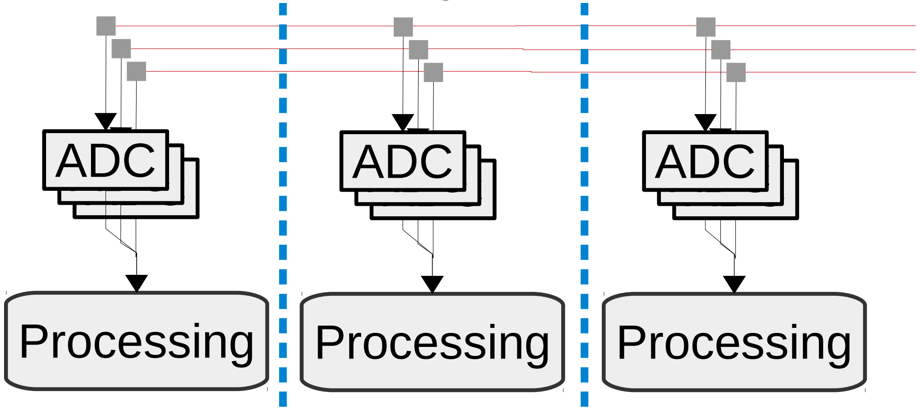
  - Eg: readout crates, event building nodes, daq slices ...



- How to organize the interconnections inside the building blocks and between building blocks?
  - Two main classes: **bus** or **network**
    - Warning: buses and network are generic concepts that can be easily confused with their most common implementations

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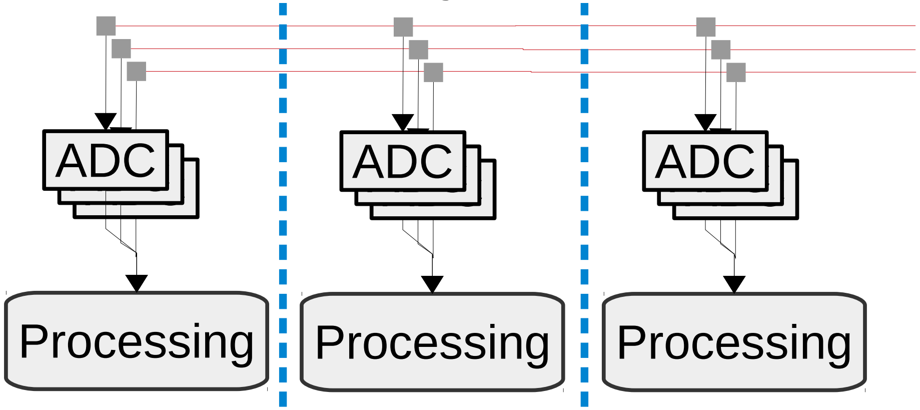

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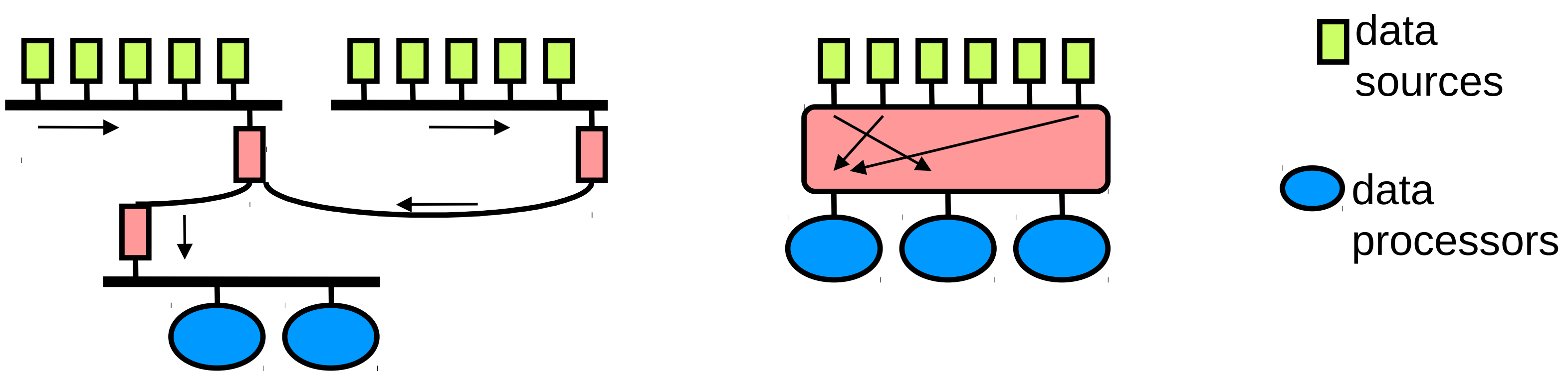
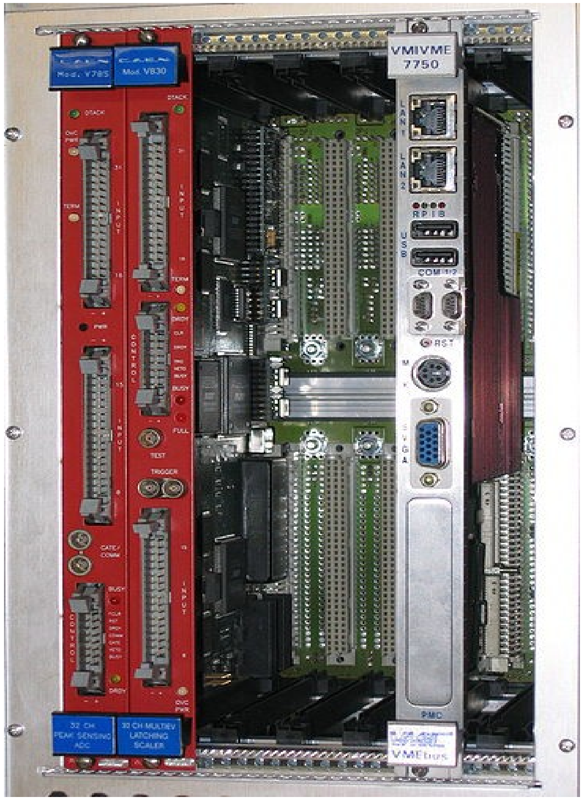
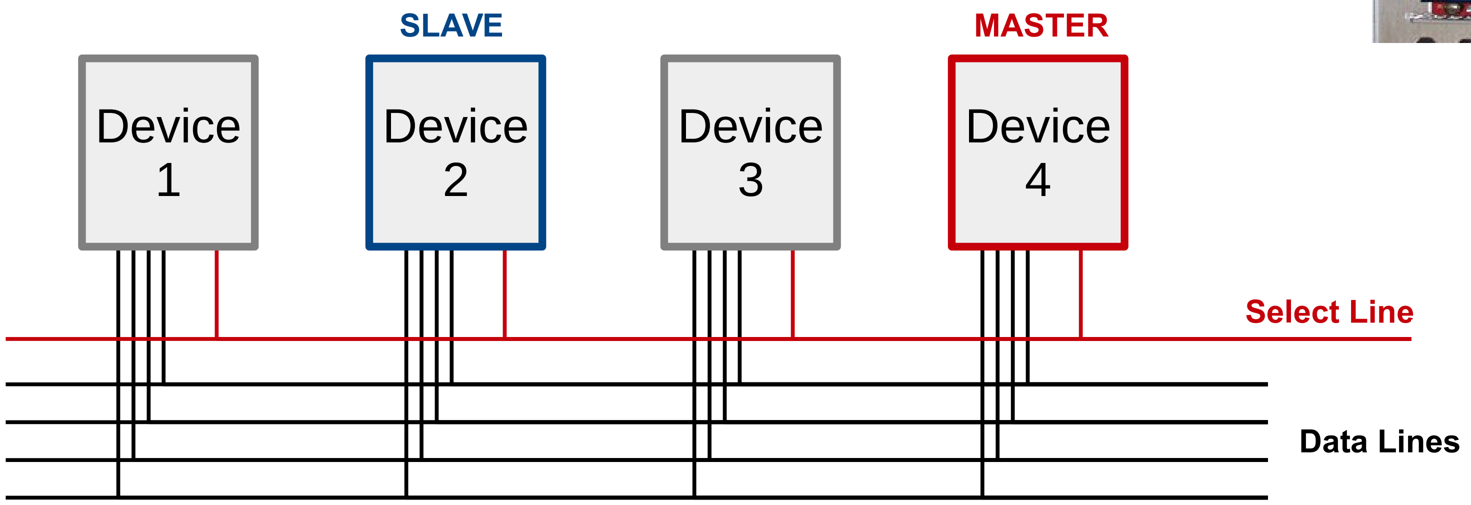
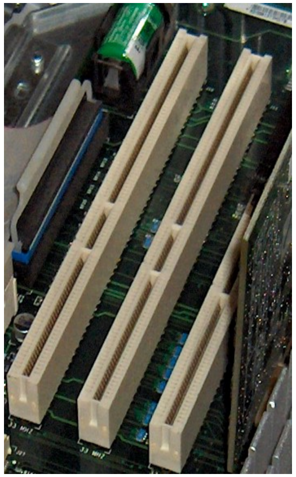


Buses

- Examples: VME, PCI, SCSI, Parallel ATA, …
  - local, external, crate, long distance, ...
- Devices connected via a **shared bus**
  - Bus → group of electrical lines
- Sharing implies **arbitration**
  - Devices can be **master** or **slave**
  - Devices can be addresses (uniquely identified) on the bus



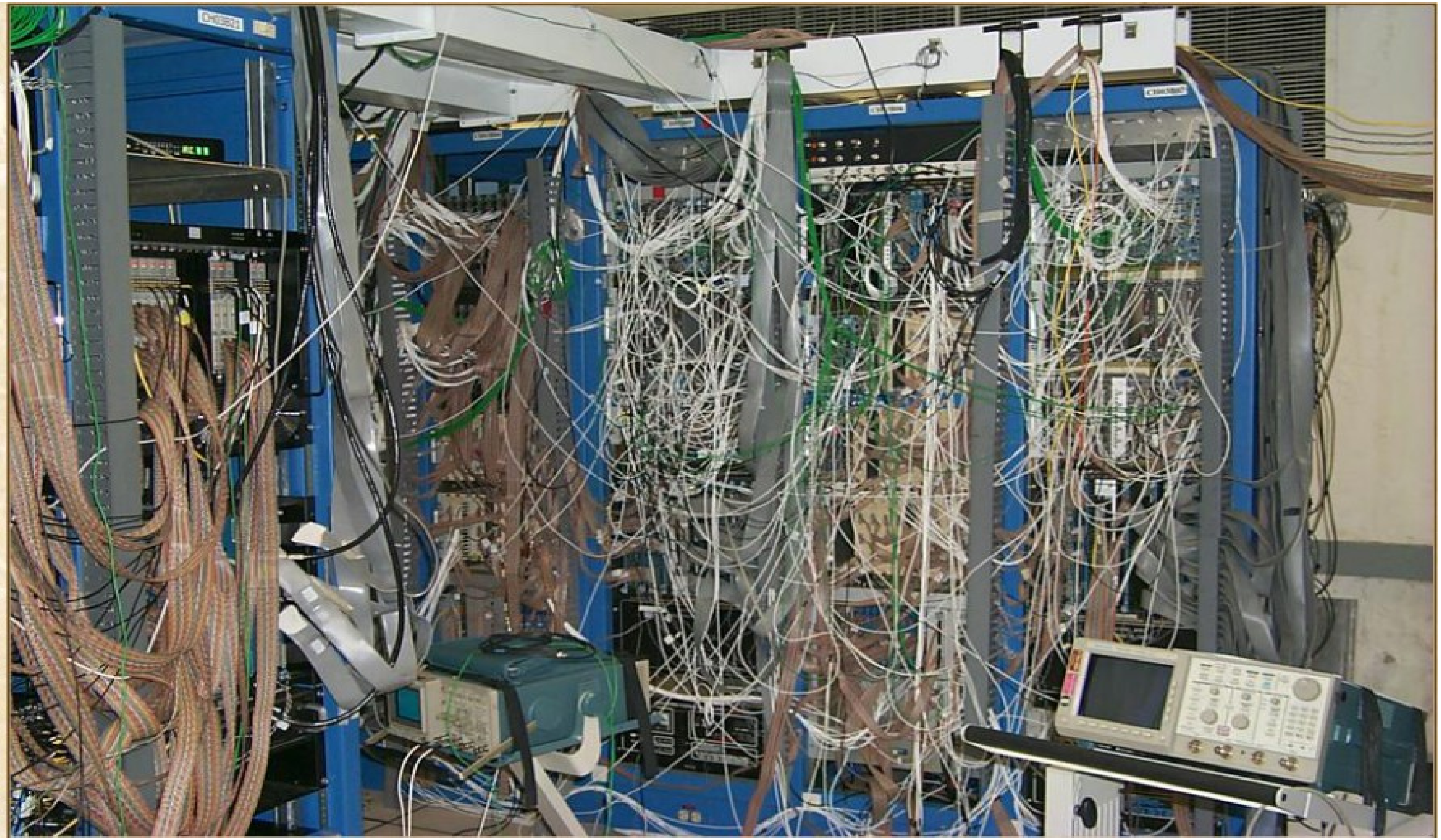




Bus facts

- Simple :-)
  - Fixed number of lines (bus-width)
  - Devices have to follow well defined interfaces
    - Mechanical, electrical, communication, ...
- **Scalability** issues :-(
  - Bus bandwidth is shared among all the devices
  - Maximum bus width is limited
  - Maximum bus frequency is inversely proportional to the bus length
  - Maximum number of devices depends on bus length
  - On the long term, other “effects” might limit the scalability of your system

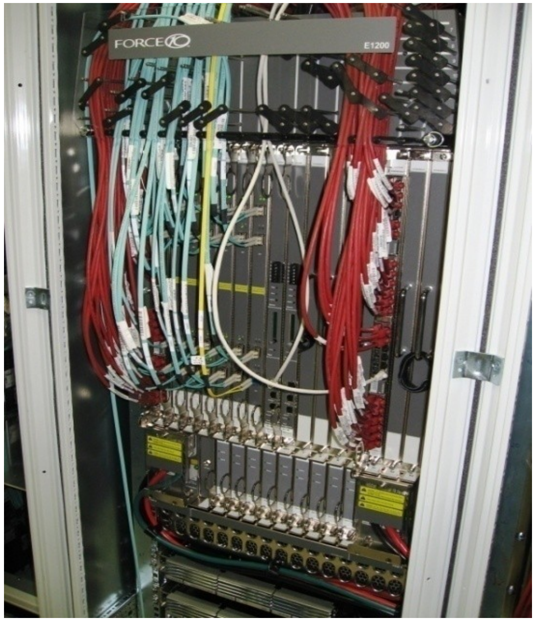
Bus facts

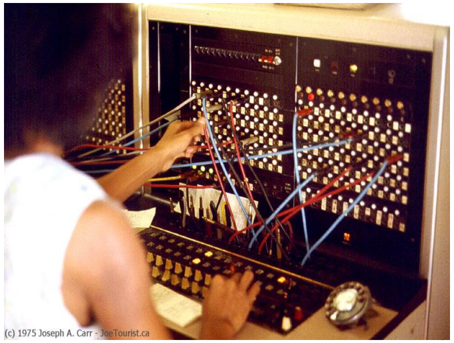


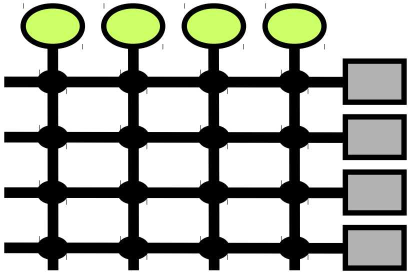
– On the long term, other “effects” might limit the scalability of your system

Network

- Examples:
  - Telephone, Ethernet, Infiniband, …
- All devices are **equal**
  - Devices <u>communicate directly</u> with each other sending messages
  - No arbitration, simultaneous communications
- In switched networks, **switches** move messages between sources and destinations
  - Find the right path
  - Handle **congestions** (two messages with the same destination at the same time)
    - The key is .... buffering

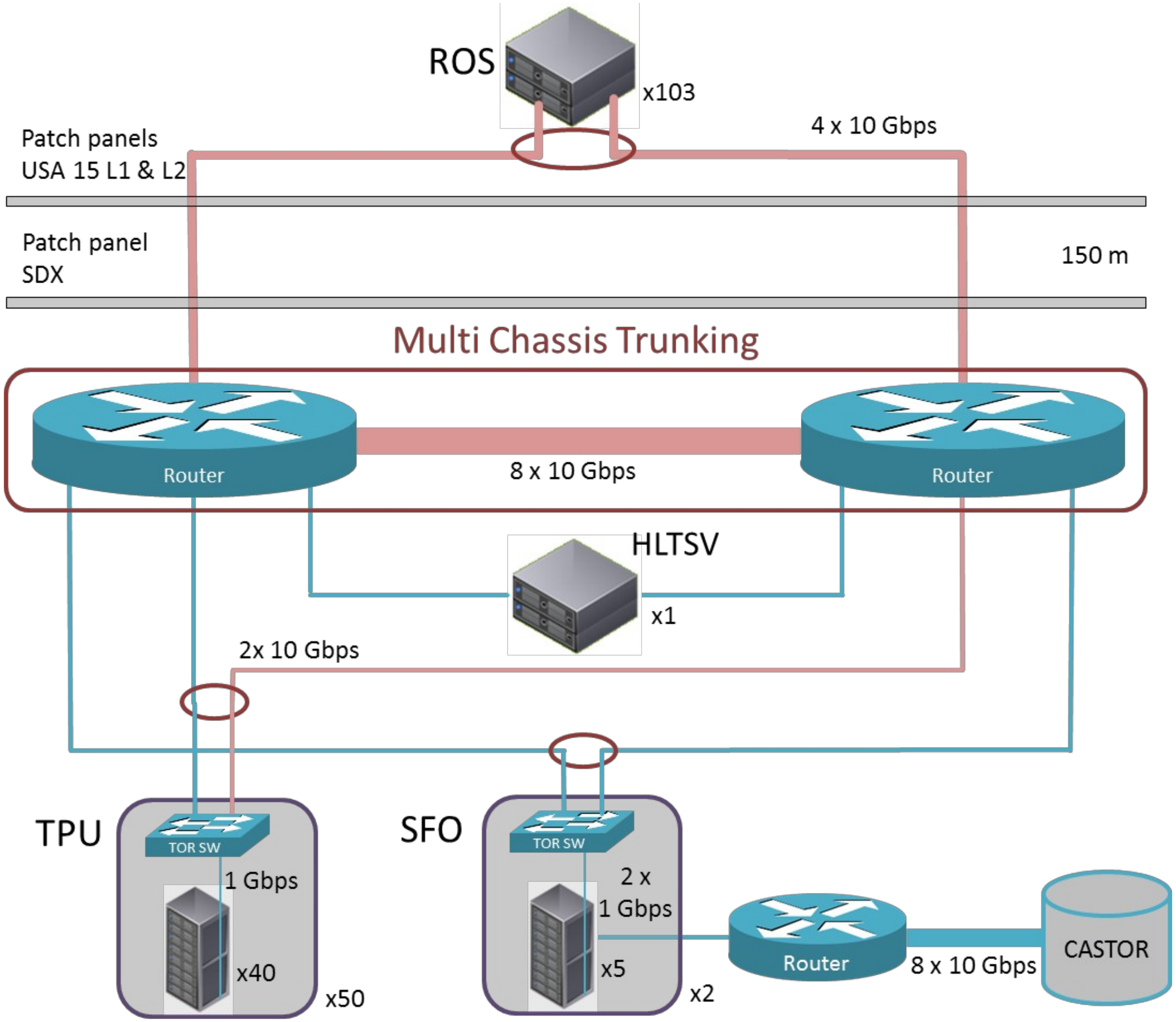






Network

- Networks scale well
  - They are the backbones of LHC DAQ systems

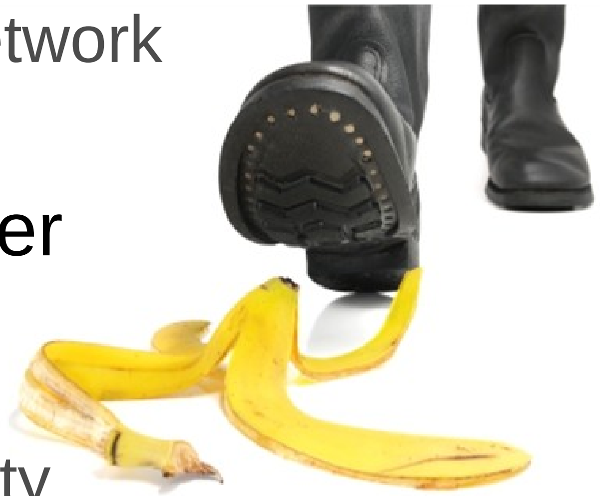


Outline

- Introduction
  - What is DAQ?
  - Overall framework
- Basic DAQ concepts
  - Digitization, Latency
  - Deadtime, De-randomization
- Scaling up
  - Readout and Event Building
  - Buses vs Network
- Do it yourself

DAQ Mentoring

- Study the trigger properties
  - Periodic or stochastic, continuous or bunched
- Consider the needed efficiency
  - It is good to keep operation margins, but avoid over-sizing
- Identify the fluctuation sources and size adequate buffering mechanisms
  - Watch out: (deterministic) complex systems introduce fluctuations: multi-threaded software, network communications, ...
- An adequate buffer is not a huge buffer
  - Makes your system less stable and responsive, prone to divergences and oscillations. Overall it decreases reliability



DAQ Mentoring

- Keep it simple, keep under control the number of free parameters without losing flexibility
  - Have you ever heard about SUSY phase-space scans? Do you really want something like that for your DAQ system?
- Problems require perseverance
  - Be careful, a rare little glitch in your DAQ might be the symptom of a major issue with your data
- In any case, ...

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