The Mu2e Trigger system

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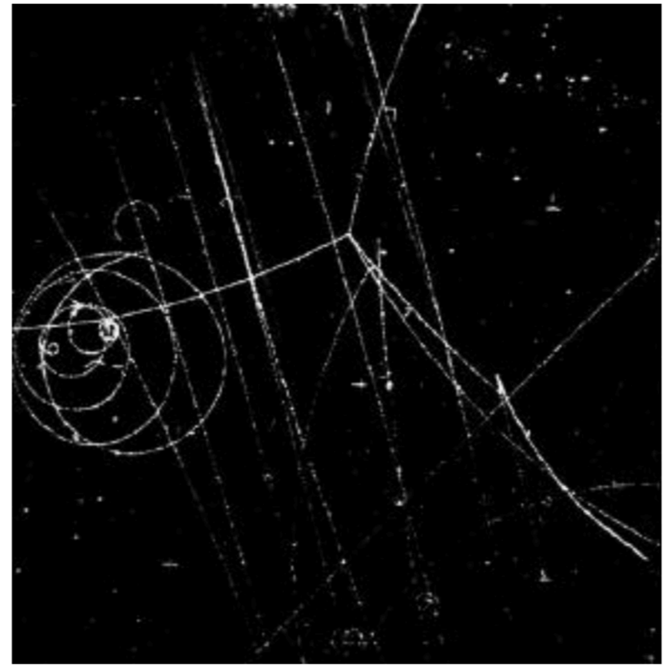
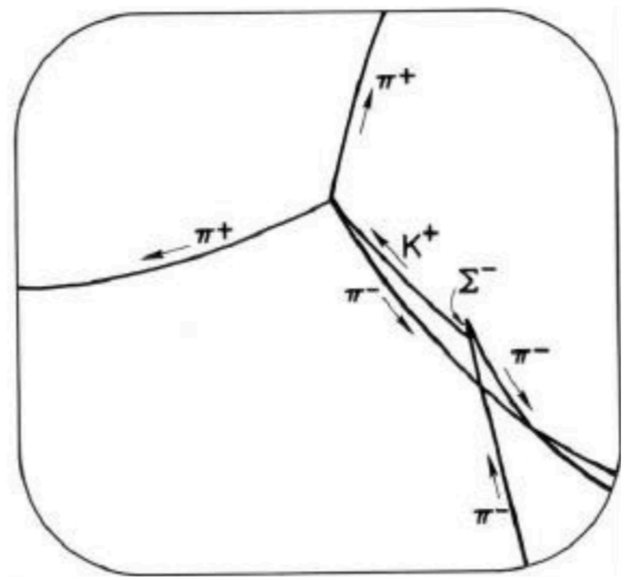
Why do we need a trigger?

- select the interesting events of interests for further analysis
- rate of data accumulated in the experiment is too high to practically record directly to mass media
- effort for storing and filtering the large volume of data is time consuming and expensive

Early accelerator expts: Bubble chambers

- Bubble chamber, Cloud chambers…
  - ❖DAQ was a stereo photograph!
  - ❖actually no trigger
    - ➡each expansion was photographed based on accelerator cycle
    - ➡High level trigger was human
  - ❖slow repetition rate
    - ➡only most common processes were observed
- Emulsions still used in some neutrino experiments
  - ➡events selected with electronically readout detectors





Early fixed target experiments

- 1964 Cronin & Fitch: CP violation experiment
  - ❖ K_2^0 mesons produced from 30 GeV protons on Be target
  - ❖ two arm spectrometer with spark chambers, Cherenkov counters and scintillators for triggering
  - ❖ Spark chambers require fast (~20 ns) HV pulse to develop spark, followed triggering cameras to photograph tracks
  - ❖ Trigger on coincidence scintillators and water Cherenkov counters
  - ❖ Only one trigger level
  - ❖ Dead time incurred while film advances

Detector Layout of $K_2^0 \rightarrow \pi\pi$ Experiment of Cronin and Fitch (1964)

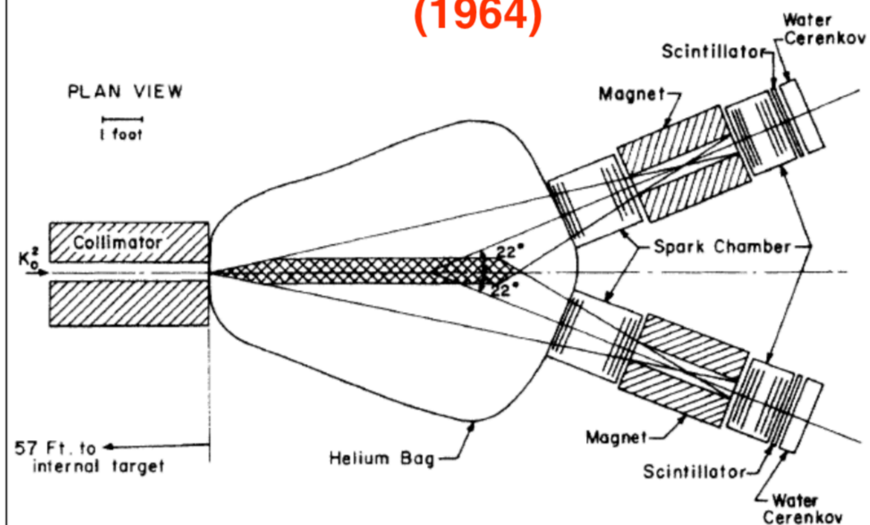


FIG. 1. Plan view of the detector arrangement.

Christenson, Cronin, Fitch and Turlay **PRL 13**, 138 (1964)

Efficiency and dead time

- Goal of the Trigger and DAQ is to maximize data for desired process to storage for analysis with minimal cost

$$\epsilon = \epsilon_{\text{operations}} \cdot \epsilon_{\text{tirgger}} \cdot (1 - \textit{deadtime})$$

- Relevant efficiency is for events that will be useful in the analysis:

$$\epsilon_{\text{trigger}} = \mathrm{N}_{\text{good}}(\text{accepted})/\mathrm{N}_{\text{good}}(\text{produced})$$

- Deadtime incurred due to fluctuations when rate into a stage of trigger (or readout) approaches the rate in can handle. Case of no buffering:

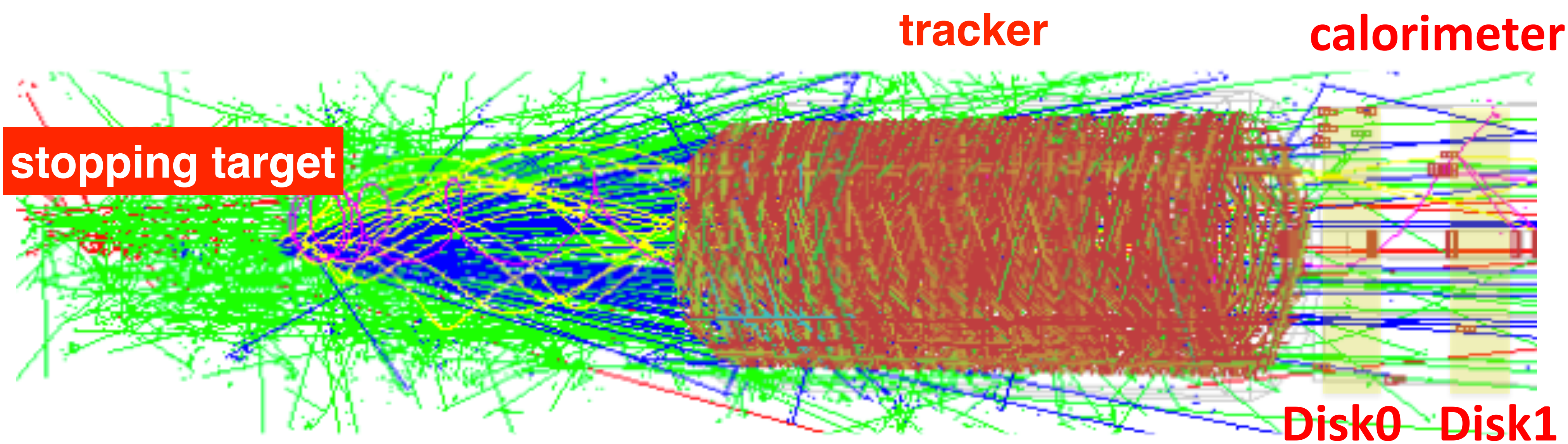
$$\text{deadtime} = \text{Rate\_in} \cdot \text{Execution\_time}$$

- Buffering incoming data reduces deadtime

➡if **Incoming_rate > 1/Execution_time**, dead no matter what

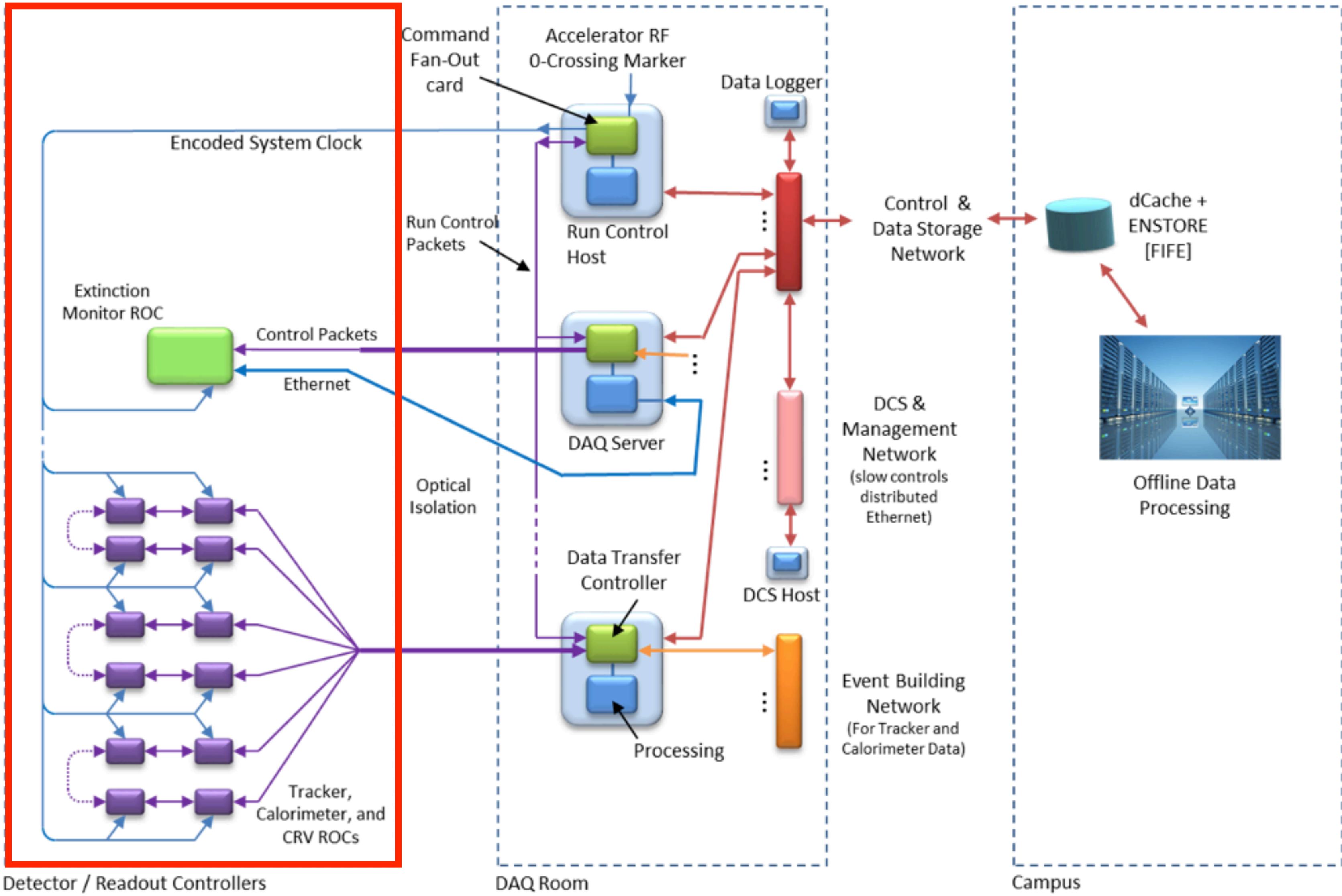
Experimental constrains

- Trigger specs are driven by the operating environment:
  - ➡ timing structure of the beam
  - ➡ production rate of the physics signal of interest
  - ➡ production rate of background processes
  - ➡ resources available (aka 💵 💵 💵)



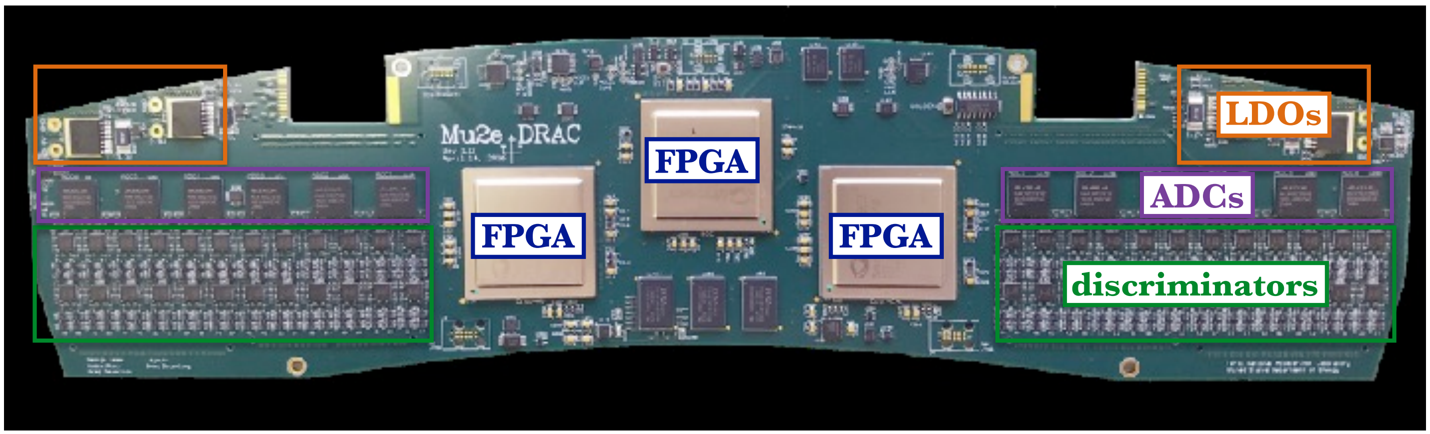
TDAQ architecture

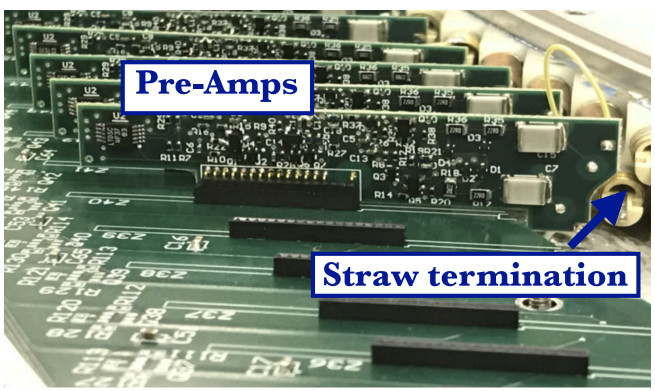
- DAQ servers handle data readout, event building and processing

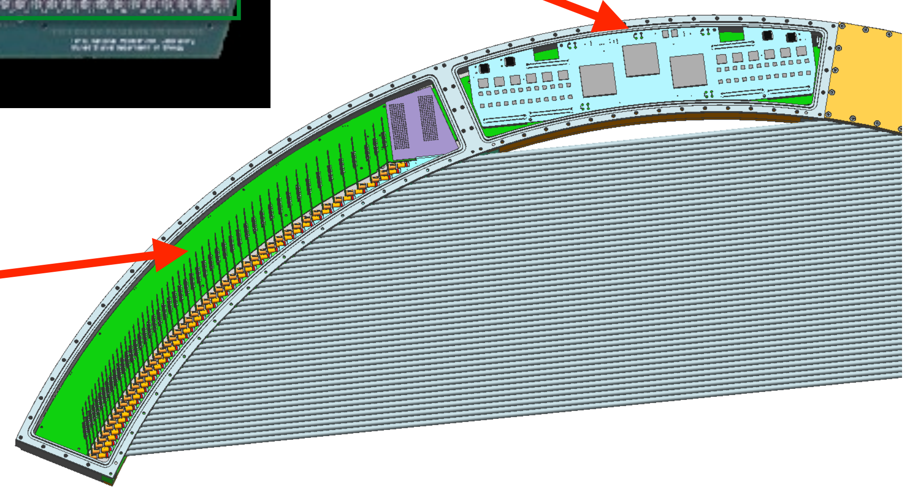


Digitization - Tracker

- Outer part of the panel houses the FEE and Digitizer Readout & Assembler Controller (DRAC)
- High hit rate sustainability: 15 kHz/cm^2

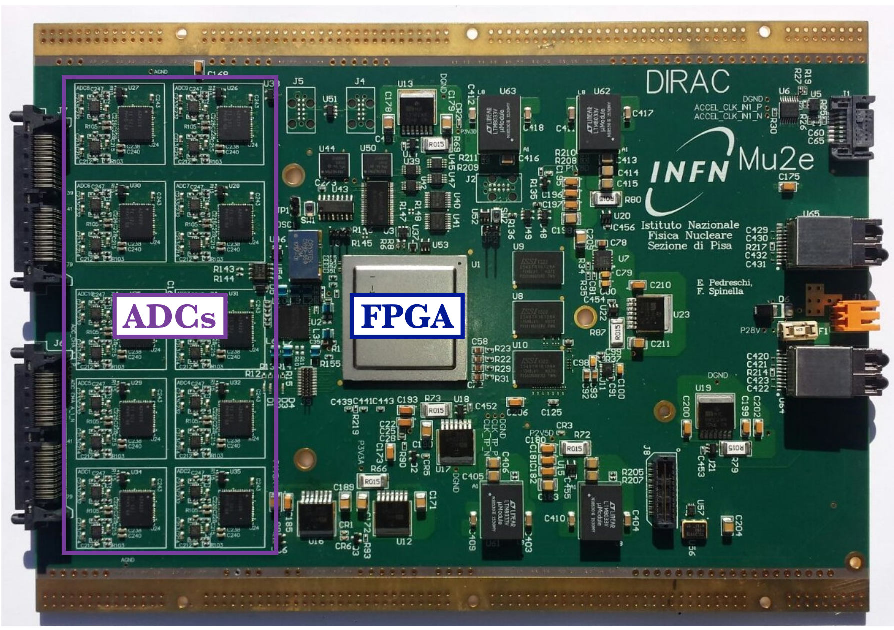




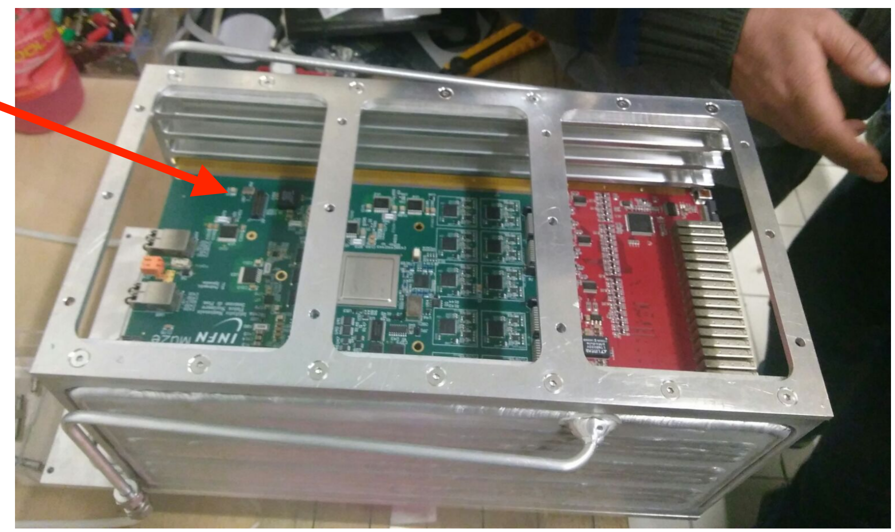


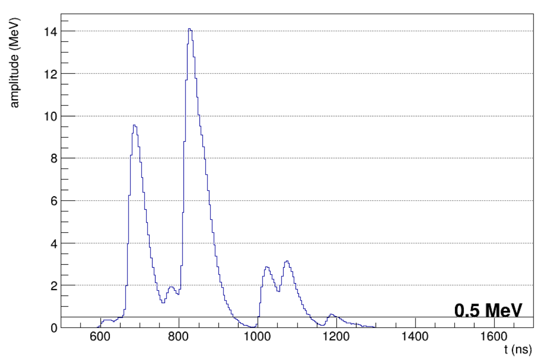
Digitization - Calorimeter

- Crates on the out outer part of the calorimeter house the Digitizer Readout & Assembler Controller (DIRAC)
- Pulses are digitized with 12 bit flash ADC @ 200 MHz



calorimeter crate - prototype

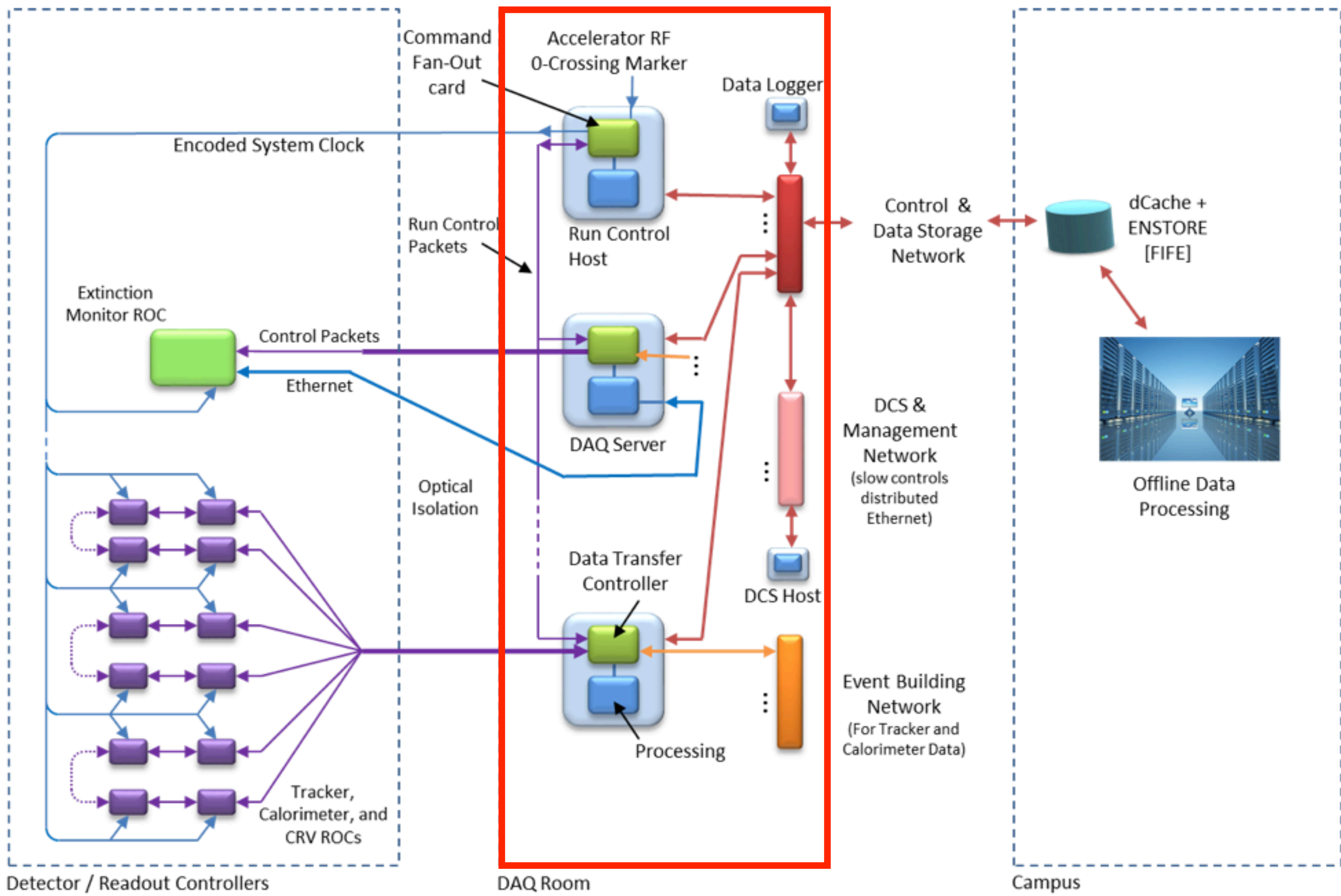




- digitized pulse from background particles

TDAQ architecture

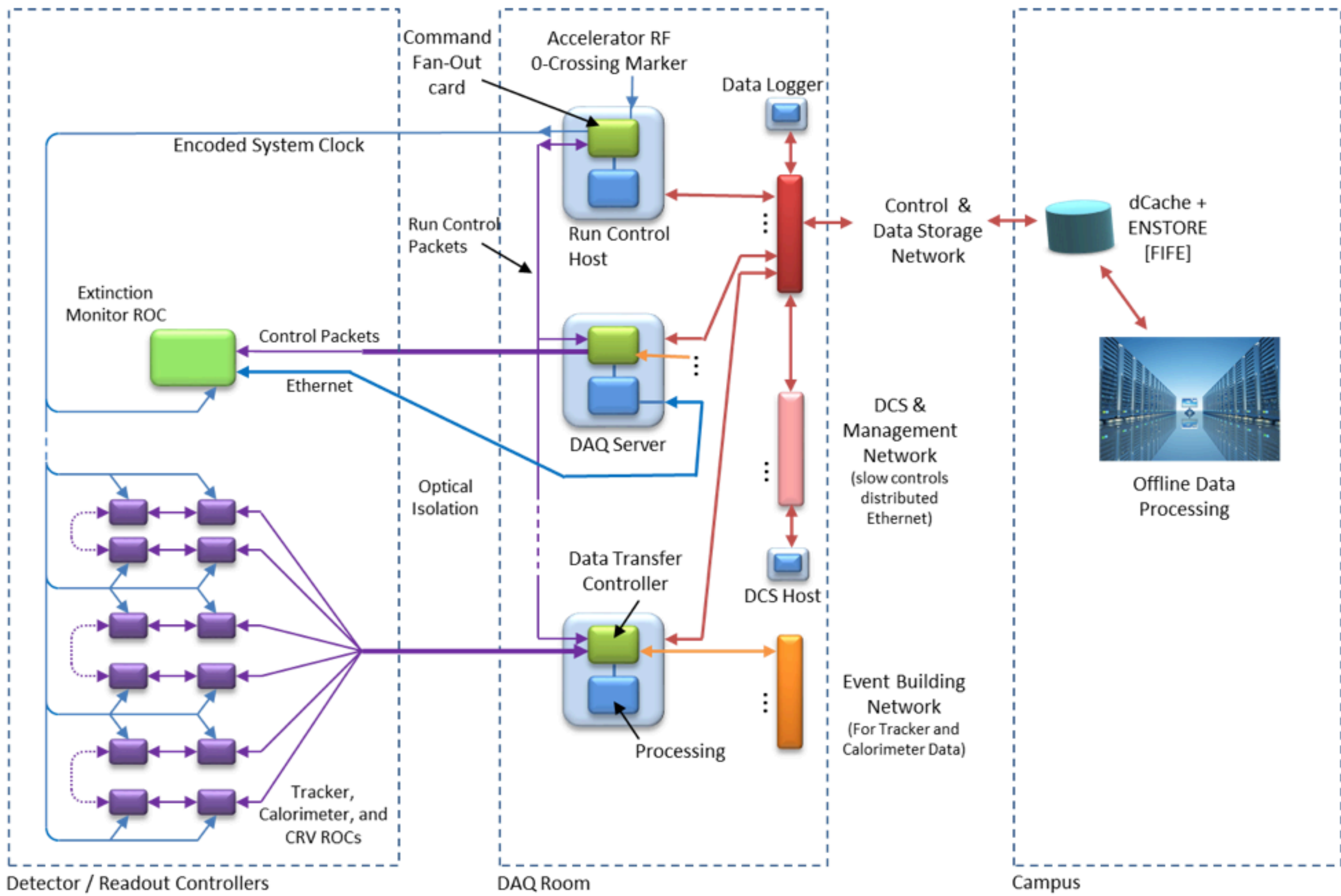
- DAQ servers handle data readout, event building and processing



Mu2e DAQ room

TDAQ architecture

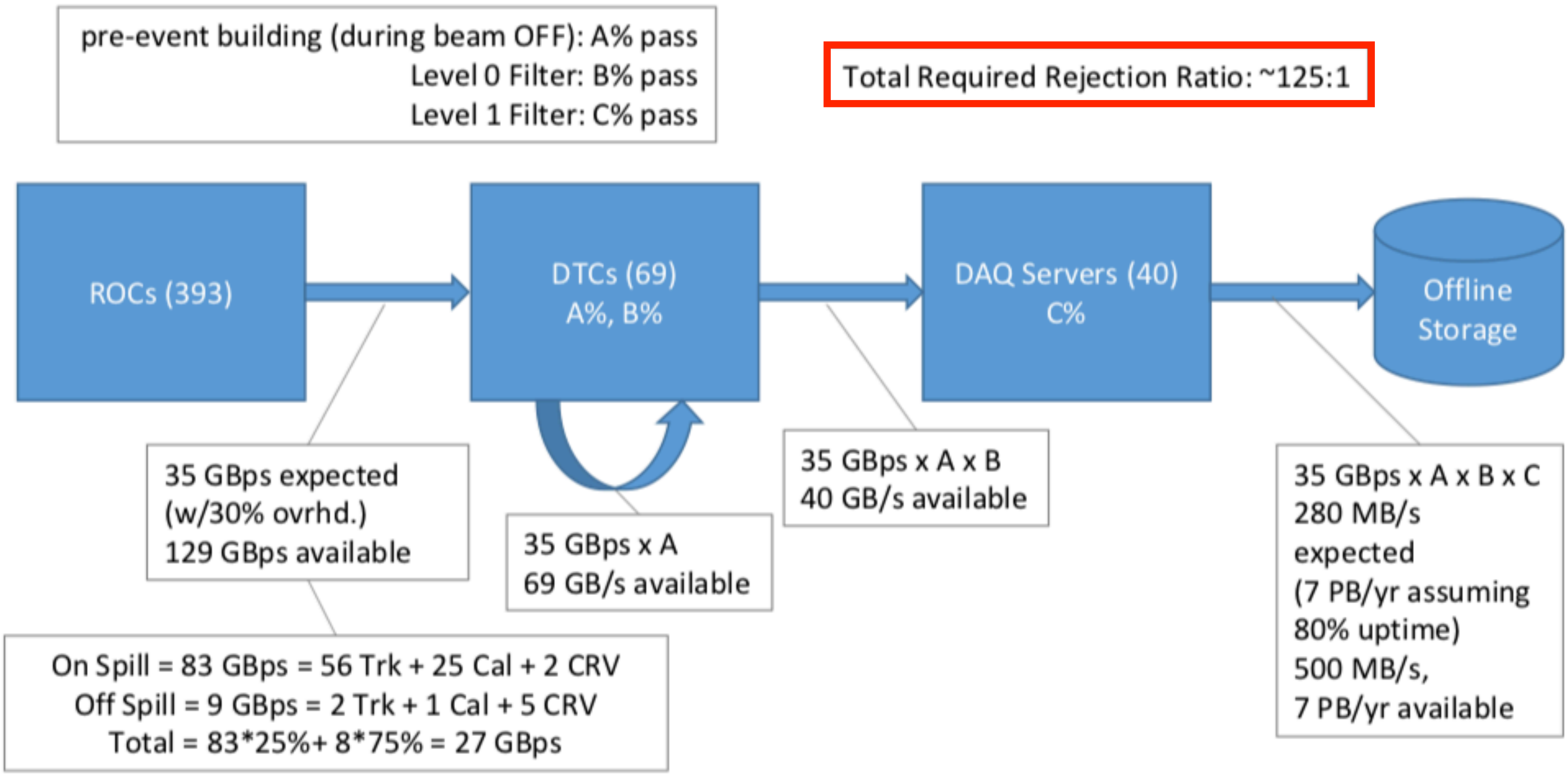
- DAQ servers handle data readout, event building and processing



Data rates

- Data rates limited by the amount of disk space available:

➡ ~7 PB/year



Processing time

- The Trigger decision is made on the DAQ servers
- Performance of the DAQ servers determines the average time/event available to make the Trigger decision:

$$\left(\frac{1}{200\text{K}}\frac{\text{s}}{\text{Events}}\right)\cdot(40\ \text{nodes})\cdot\left(20\frac{\textit{art Threads}}{\text{Nodes}}\right) = \mathbf{4}\ \frac{\text{ms}}{\frac{\text{Events}}{\textit{art Threads}}}$$

- **That's just a benchmark!**
- CPU performance are affected by various factors, like:
  - ➡ number of cores used
  - ➡ memory usage

Trigger Panel

- Design of the Trigger Strategy is fundamental for the success!
- In general, a Trigger panel is designed to accomodate for:

✓ **physics processes of interest**

✓ **calibrations**

✓ **zero bias**: random trigger on accelerator clock

✓ **lower bias:** triggers accepted with pre-scale

Physics processes

- Need to take into account ALL the physical processes we might need in the data analyses:

  - ✓ μ- + Al → e- + Al conversion
  - ✓ μ- + Al → e+ Na conversion

  CLFV signal

  - ✓ e+/e- from Radiative π-Capture
  - ✓ e+/e- from Radiative μ-Capture
  - ✓ e- from μ-Decay In Orbit
  - ✓ protons from μ Capture

  backgrounds

  μ-capture normalization

- **Today, I discuss the Trigger for $\mu^{-} \rightarrow e^{-}$**

μ^- to e^- Trigger plan

- Want to maximize as much as we can the Trigger efficiency
- Multiple Trigger paths ensure:
  - ➡ maximize the global Trigger efficiency
  - ➡ redundancy of the system
  - ➡ handle to measure/monitor relative trigger efficiency
- We designed 3 different Trigger paths for the μ-to-e- search:
  - ✓ "pure" track Trigger
  - ✓ "Calo seeded" track Trigger
  - ✓ "pure" Calorimeter Trigger

“pure” Track Trigger

- Applies the preliminary part of the offline track reconstruction that uses only info from the Tracker
- Reconstruction is staged in different layers
- Trigger decision is made at each stage

Time Cluster Finder → Helix Finder → 3D Track Fitter

- groups of straw-hits correlated in time

- pattern recognition:
  - ➡X-Y circle fit
  - ➡z-ϕ line fit

- global 3D track fit:
  - ➡no drift time used
  - ➡no Kalman filter

- $\varepsilon_{trigger}$ ~ 100%, Rejection ~ 200

Calo-seeded Track Trigger

- Applies the preliminary part of the offline calorimeter seeded track reconstruction
- Reconstruction is staged in different layers
- Trigger decision is made at each stage

Time Cluster Finder → Helix Finder → 3D Track Fitter

Time Cluster Finder

- groups of straw-hits correlated in time and space with the calorimeter clusters

Helix Finder

- pattern recognition:
  - ➡3D hit search
  - ➡calo-cluster used as “constrain”

3D Track Fitter

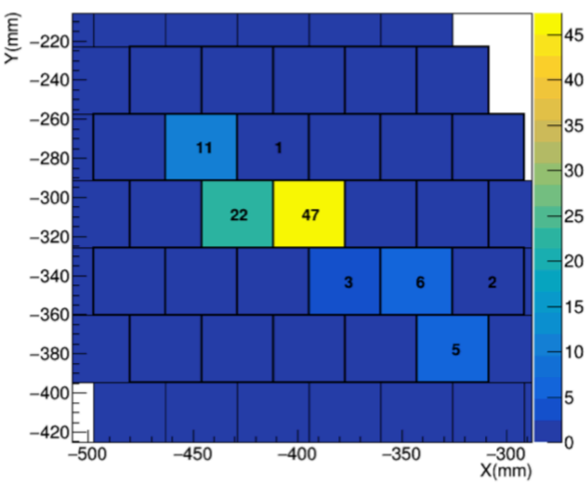
- global 3D track fit:
  - ➡no drift time used
  - ➡no Kalman filter

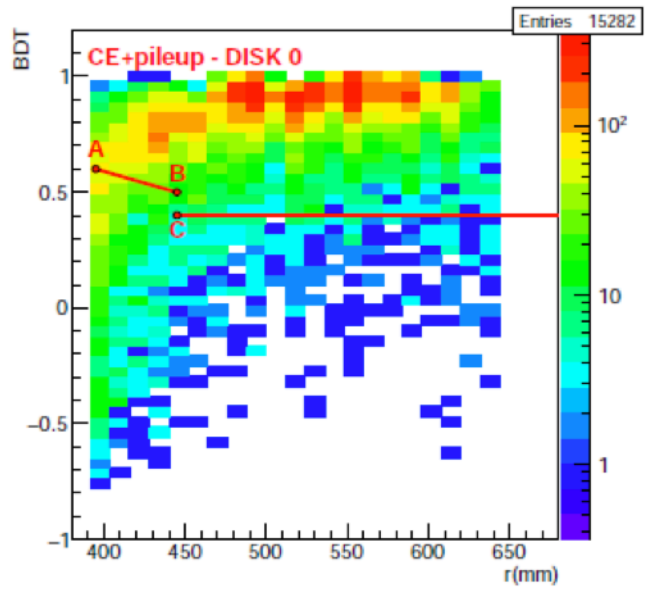
- $\varepsilon_{trigger}$ > 95% (calorimeter acceptance), Rejection > 500

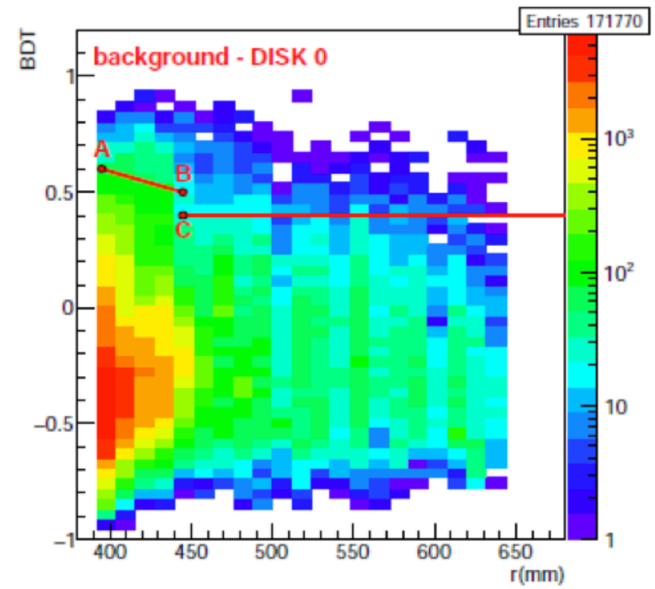
Calorimeter Trigger

- Applies fast-hit reconstruction + clustering in the calorimeter
- uses a specialized **Boost-Decision-Tree** that uses calo-cluster info to make Trigger decision
- fast algorithm!

event display zoom







- $\varepsilon_{trigger}$ ~ 90% (calorimeter acceptance), Rejection ~ 300

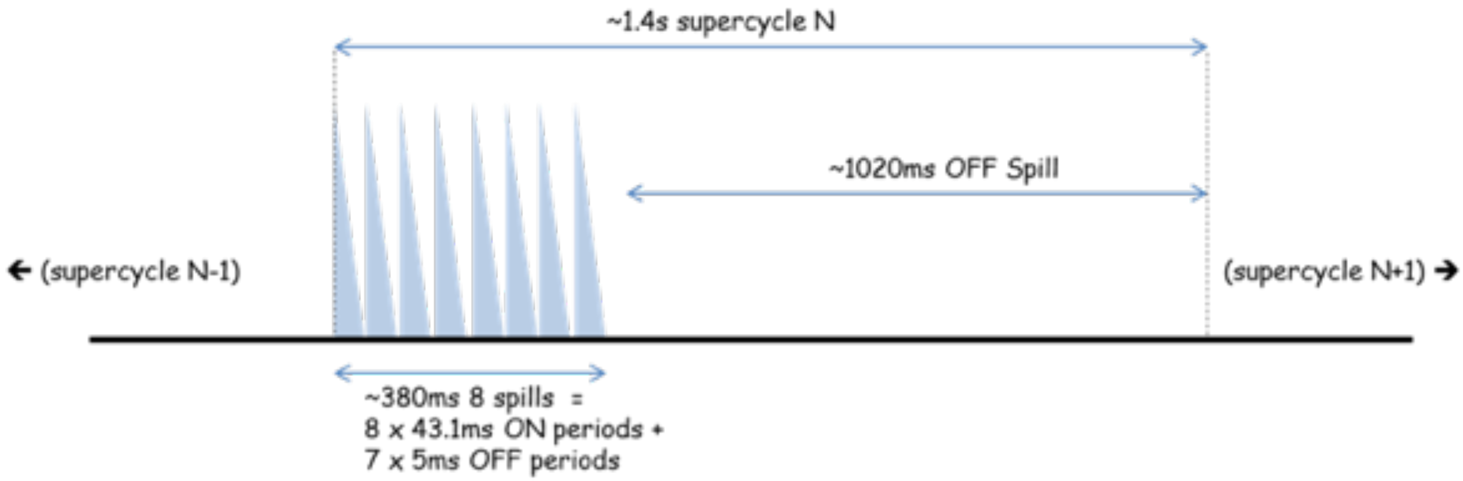
Summary

- One of the Mu2e challenges will be the design of its Trigger
  - ✓ match the 4 ms/event requirement is not so simple
- Current Trigger algorithms use part of the full **offline reco:**
  - ✓ **Track triggers**
  - ✓ **Calorimeter trigger**
- Work is ongoing to improve our expected performance
  - **extremely fun and instructive!**

backup slides

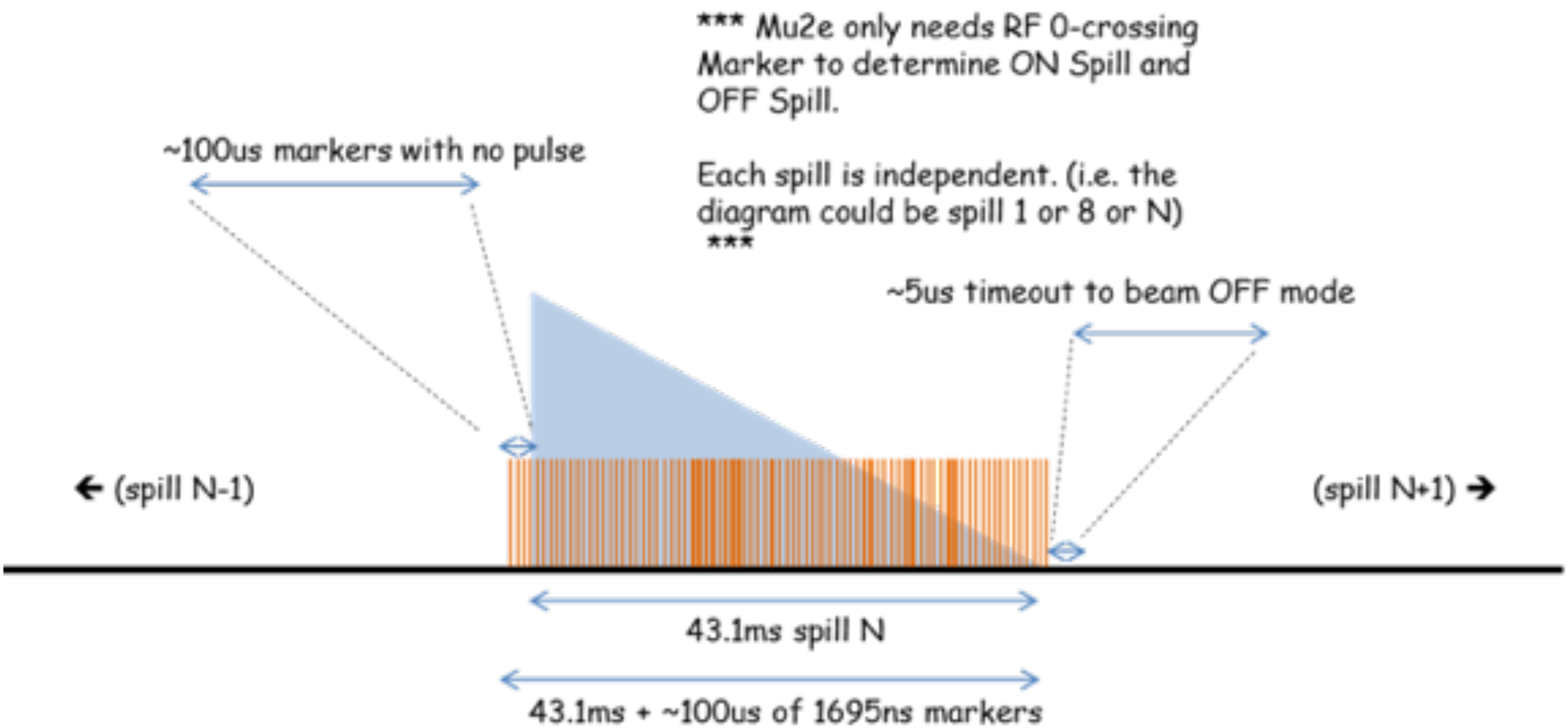
Event rate

- Globally ~200K events per second



- ON Spill event contribution:
  - ➡43.1ms / 1695ns = 25K pulses per spill
  - ➡25K * 8 / 1.4s = 145K ON Spill events per second
- OFF Spill event contribution:
  - ➡1.4s – 43.1ms * 8 = 1s OFF Spill time

Spill structure



Calo-seeded Track Trigger

- Helix finder provides rejection in the range [10,100]
- Track-seed reco uses helix candidates with nhits>= 10
- Track-seed provides rejection at ~ 800
- Signal efficiency > 95 % (calorimeter acceptance)