Development of the Trigger system for the Mu2e Experiment at Fermilab

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The Mu2e Experiment

Mu2e will search for coherent $\mu^{-}\mathrm{Al} \to e^{-}\mathrm{Al}$ at a sensitivity level of few parts by 10^{-17}, an improvement by 10^{4} over the existing limit.

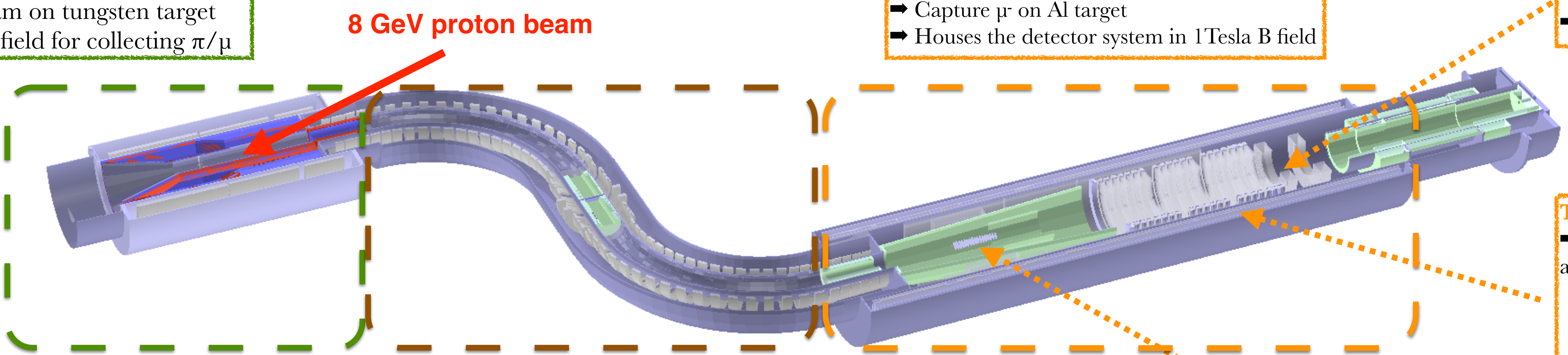
Search for muon conversion explores new physics sector and probes physics scales up to ~ 10^{4} TeV, beyond the reach of present or planned high energy colliders.

The experimental expected sensitivity is $R_{\mu e} = \frac{\Gamma\left(\mu^{-} + (A,Z) \to e^{-} + (A,Z)\right)}{\Gamma\left(\mu^{-} + (A,Z) \to \text{ capture}\right)} \leq 6 \times 10^{-17}$ @ 90% CL

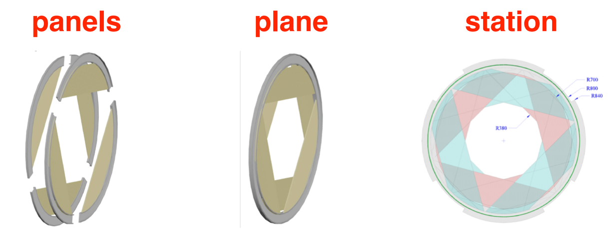
Production Solenoid
- ➡ 8 GeV proton beam on tungsten target
- ➡ Graded magnetic field for collecting π/μ

Detector Solenoid
- ➡ Capture μ on Al target
- ➡ Houses the detector system in 1Tesla B field

Calorimeter
- ➡ 2 disks of **~ 1860 CsI (pure) crystals**
- ➡ σ_t **< 500 ps @ 100 MeV**
- ➡ σ_E/E **< 10% @ 100 MeV**



Tracker
- ➡ **~ 22000 straw tubes** filled with Ar/CO_2 arranged in planes on 18 stations



- ➡ $\Delta p/p$ **~ 2‰ @ 100 MeV/c**

Transport Solenoid
- ➡ Select low momentum μ^{-}
- ➡ Antiproton absorber in the mid-section

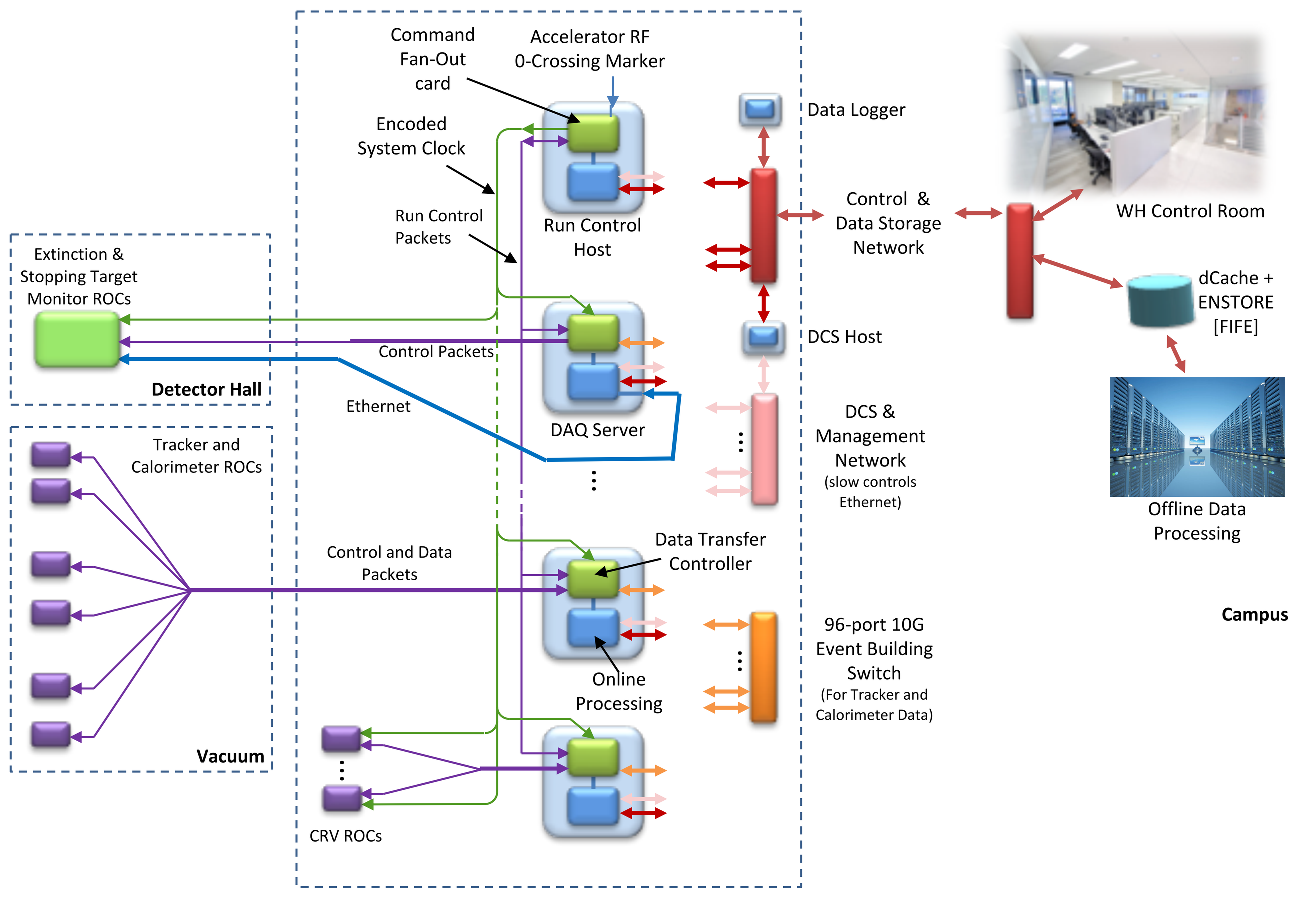
Stopping target
- ➡ 17 Al foils; μ lifetime in the Al meso-atom is 864 ns

Trigger architecture

1) Helix search

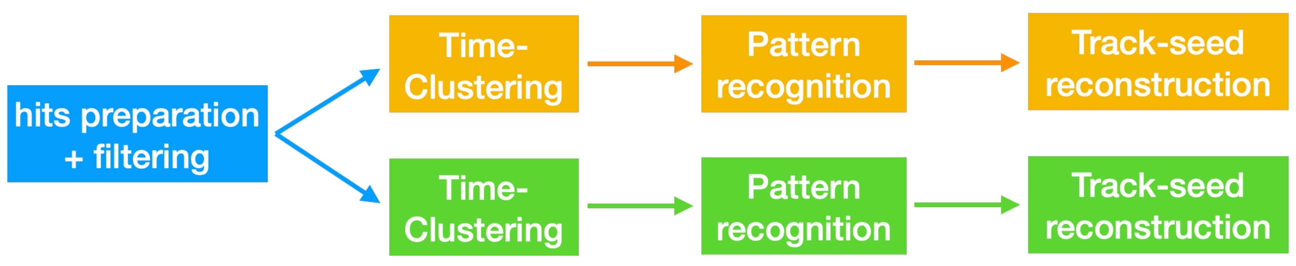
- The detector Read Out Controllers (ROC) stream out continuously the data from the Tracker and Calo to the Data Transfer Controller units (DTC).
- We then group the data of a given event in a single server using a 10G switch
- Than, we start the Online reconstruction of the event and make a trigger decision
- Trigger accept causes readout of the CRV data
- Event data from all detectors are aggregated at Data Logger

Requirements:
- trigger rate of a few kHz - equivalent to ~7 Pb/year
- processing time < 5 ms/event



2) Track trigger structure

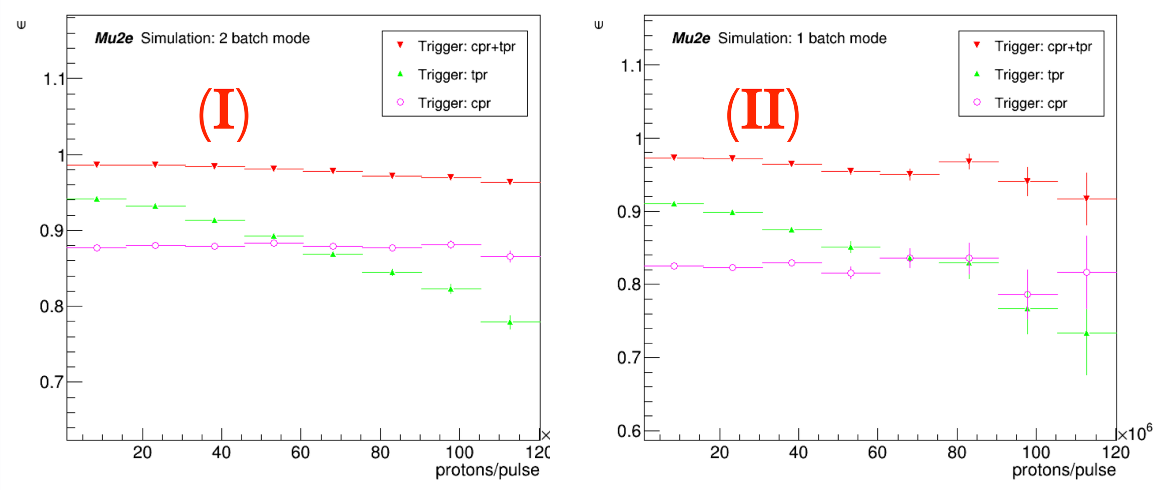
- **Online reconstruction** to perform a selection using tracks
  - i) Hits preparation + filtering
  - ii) Hits Time-Clustering: we group the hits correlated in time
  - iii) Pattern recognition: to identify full helicoidal trajectories
  - iv) Track-seed reconstruction:
    - Kalman-based fit w/o left-right ambiguity
- We apply a dedicated filter after each reconstruction stage
- We run multiple track trigger lines with different setting of the filters thresholds w/o running the reco modules multiple times



- Two **track-search methods** are used to improve the signal efficiency:
  - i) A calorimeter-seeded algorithm (**cpr**)
  - ii) A tracker-seeded algorithm (**tpr**)

3) Efficiency & Rejection

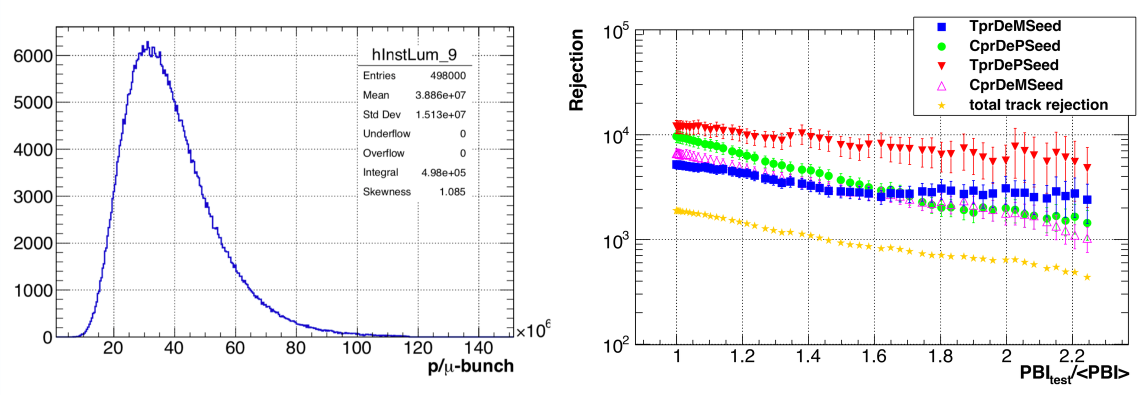
Efficiency evaluated simulating the **CE** (I) and **CPos** (II) + background:
- ✓ **ϵ > 95%** for both cases and stable w.r.t. the beam intensity
- ✓ The **OR** of the two algorithms provide a visible benefit



Rejection @ high intensity

The trigger rejection was tested also in harsher conditions:
- ✓ The total expected rate is < 1 kHz
  - ✓ Non-signal trig can be prescaled
- ✓ Rejection of ~700 @ x2 intensity

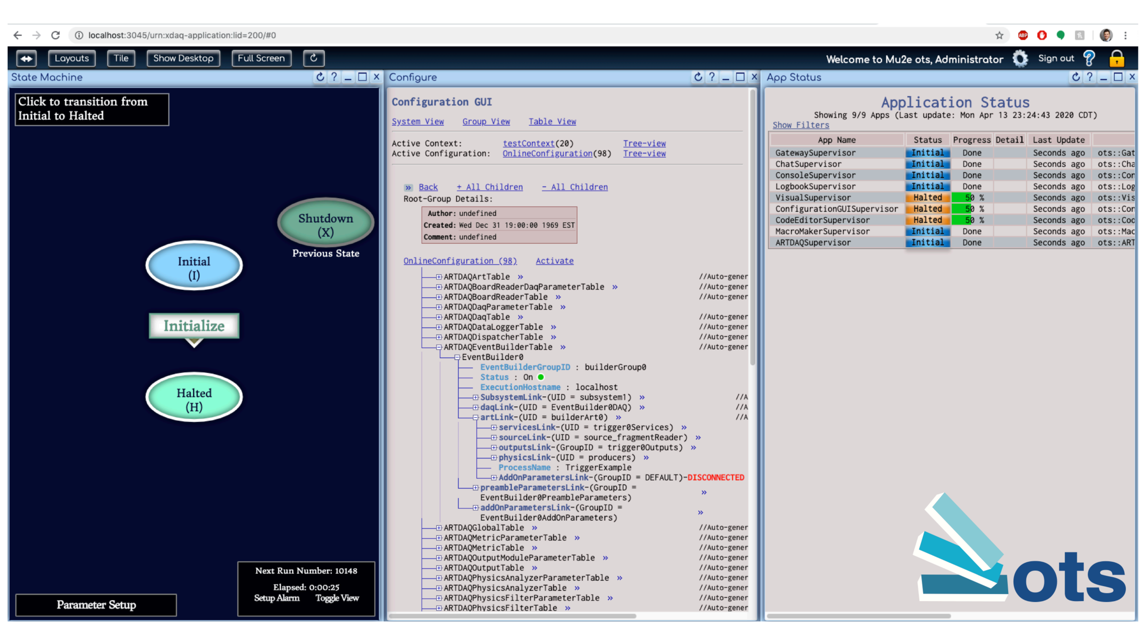
	Instantaneous rate [Hz]
Signal triggers (high-P DIO e- and mis-repo events)	<60
DIO e- from the Stopping Target (calibration and monitoring)	~700
Total	**< 800**



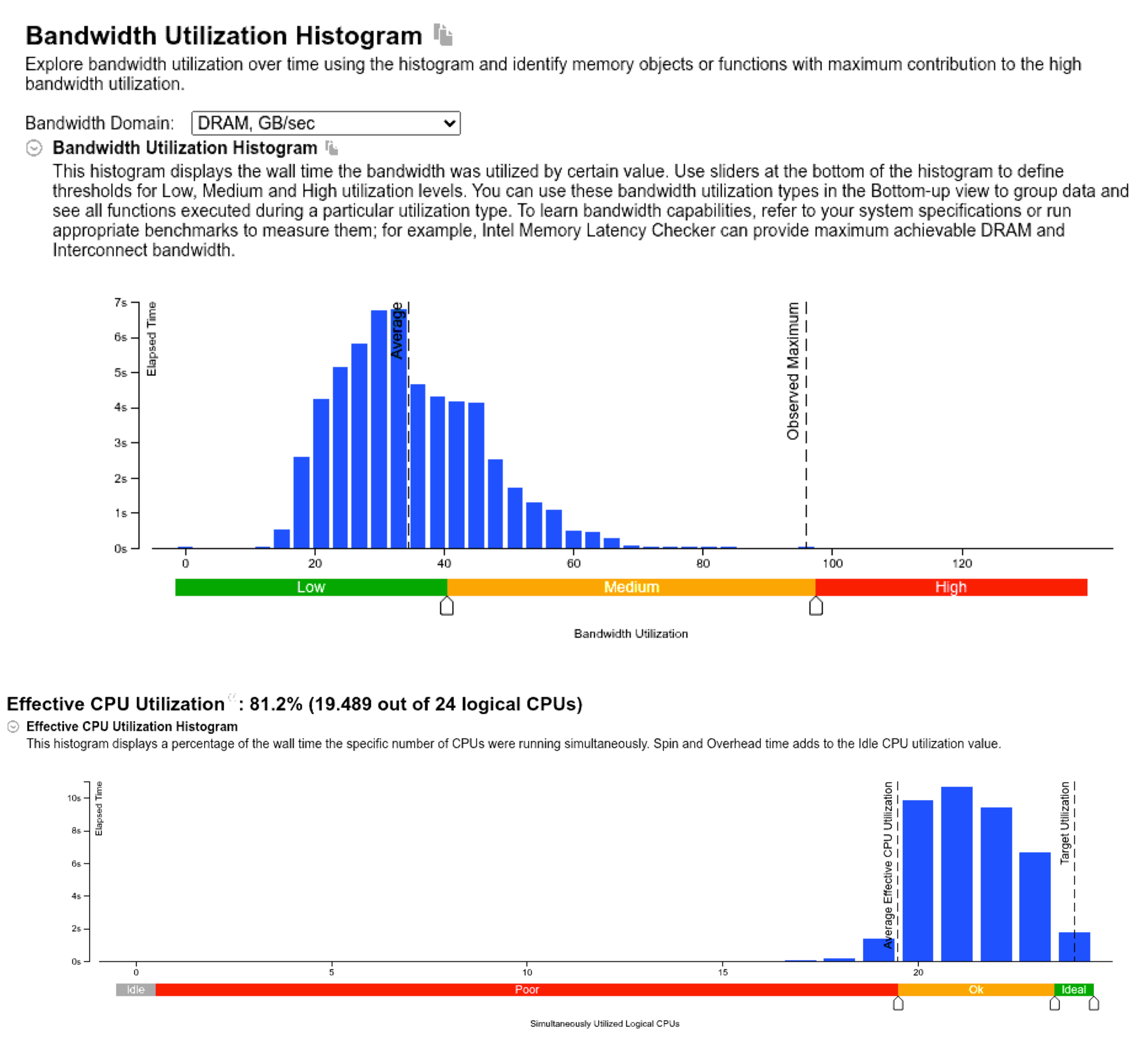
TDAQ prototype performance

TDAQ prototype

- Large-scale prototype that provides advanced testing capabilities
  - It consists of 20 detector-transfer-control units in 10 servers
- Web-based GUI powered by "Off-The-Shelves" software
  - OTS: https://otsdaq.fnal.gov
- The TDAQ software is being used by the various sub-systems



Profiling the system with VTune



Timing performance

- The timing performance are tested by injecting sim data in the DTC
  - The data includes fluctuations in the beam intensity
- Full chain (event-building+data-logger+DQM) run on the servers
- Detailed module-by-module analysis to spot the sources of inefficiency

Results:
- The resulting average time is ~3.5 ms/event
  - Well below our 5 ms/event constraint