Mu2e calorimeter readout system

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mu2e.fnal.gov

1. Mu2e: Search for $\mu + N \rightarrow e + N$

Mu2e will search for the coherent, neutrinoless muon-to-electron conversion in the field of a nucleus. **This charged lepton flavor-violating process allows to probe energy scales up to thousands TeV**, far above the existing colliders. If no conversion events are observed in 3 years of running, Mu2e will set a limit on the ratio between the muon conversion and the muon capture rate: $R_{\mu e} < 6 \times 10^{-17}$ **(@ 90% C.L.).**

Production Solenoid (PS)

An **8 GeV proton beam** hits a tungsten target
A graded magnetic field reflects muons to the TS

Cosmic Ray Veto (CRV)

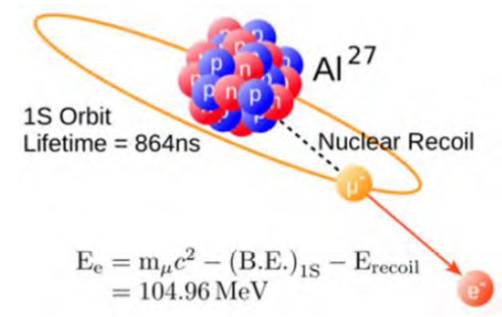
4 layers of plastic scintillator bars
Covers the entire DS and half of the TS

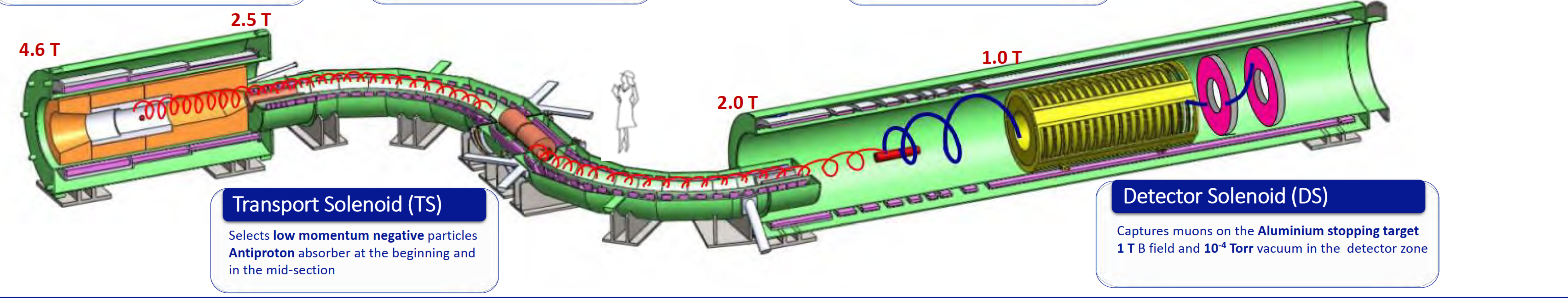
Straw Tracker (TRK)

20,000 low mass straw drift tubes
Momentum resolution **180 keV/c @100MeV/c**

Electromagnetic Calorimeter (ECAL)

1348 undoped CsI crystals
Energy, Time and Position measurements





Experimental Technique

Stop muons in Aluminium target
Muons quickly get to 1S orbit
Lifetime of muonic atom is 864 ns
Look for the 105 MeV conversion electron

Transport Solenoid (TS)

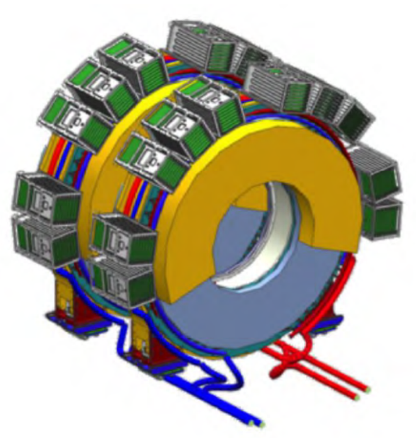
Selects **low momentum negative** particles
Antiproton absorber at the beginning and in the mid-section

Detector Solenoid (DS)

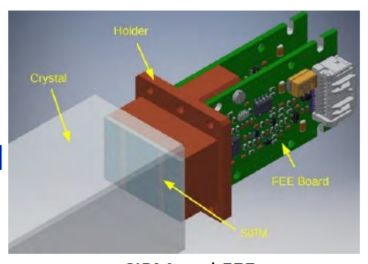
Captures muons on the **Aluminium stopping target**
1 T B field and **10^{-4} Torr** vacuum in the detector zone

2. The Electromagnetic Calorimeter

High granularity crystal calorimeter made of 1348 **undoped CsI crystals** (3.4x3.4x20 cm^3).
Crystals arranged in **two disks** (inner/outer radius 37.4 cm / 66 cm, separation between disks 75 cm).


Calorimeter disks

1 crystal coupled to 2 **large** (14x20 mm^2) **area UV-extended SiPM** (total of **2696 electronic channels**).
SiPM packed in a parallel arrangement of 2 groups of 3 cells biased in series.

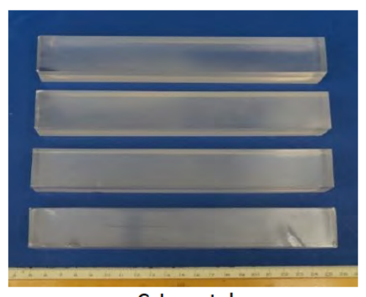

SiPM and FEE

Calorimeter Provides:

- Particle identification μ/e
- Seed for track pattern recognition
- Independent trigger

⇛ **ΔE/E < 10% and Δt < 500 ps**

⇛ **Position resolution of O(1 cm)**

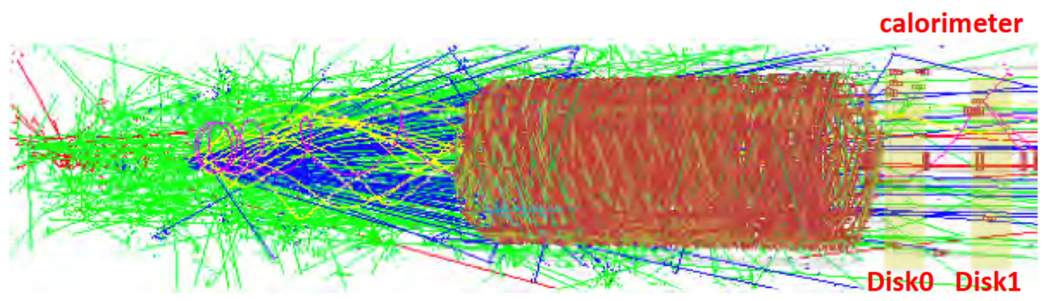

CsI crystals

DAQ crates located inside the cryostat to limit the number of pass-through connectors.

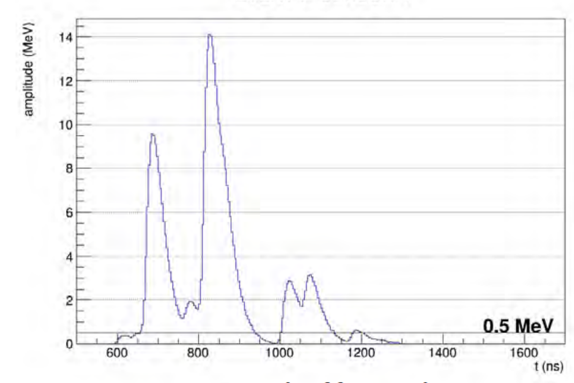
3. Why a digitizer ? Which requirements ?

Requirements:

- Very intense particle flux expected in the calorimeter → high sampling rate digitizer crucial to resolve pile-up
- Sample SiPM signal at the frequency of **200 Msamples** with **12 bits** ADC
- System located inside the cryostat → harsh environment:
  - **Magnetic field of 1 T and 10^{-4} Torr vacuum**
  - **Total Ionizing Dose (TID) 0.5 krad/yr (from simulation)**
  - **Neutron flux 5×10^{10} 1 MeV (Si)/yr (from simulation)**
- **Mechanical constraints:**
  - Limited space: 20 ADC channels/board
  - Limited access for maintenance: highly reliable design mandatory

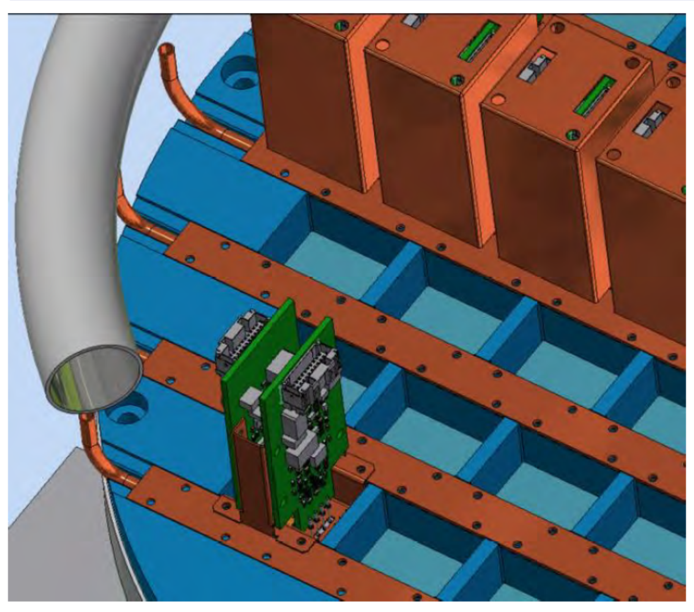


Typical 1.7 µs Mu2e event



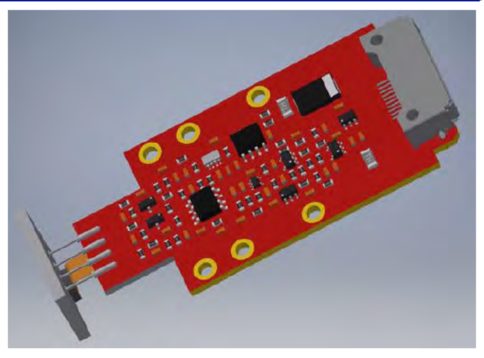
Example of front end output

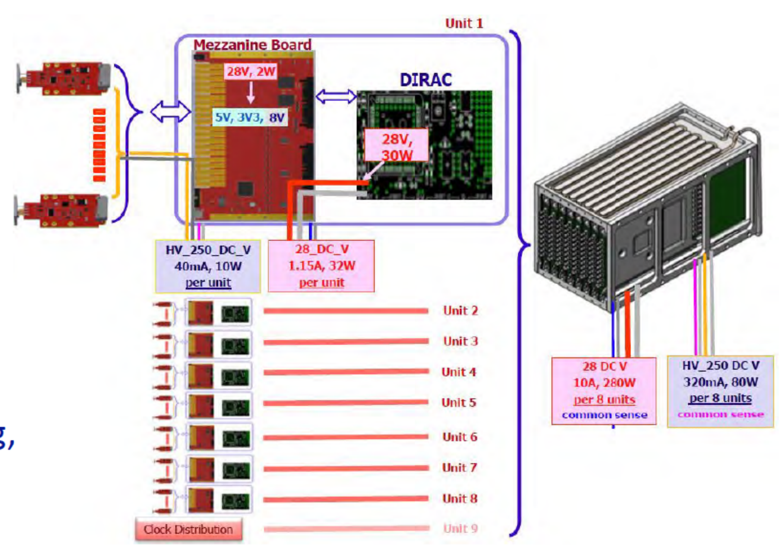
4. Front End Electronics



FE boards connected to SiPM to provide:

- Amplification
- Local linear regulation of the bias voltage
- Monitoring of current and temperature
- Test pulse

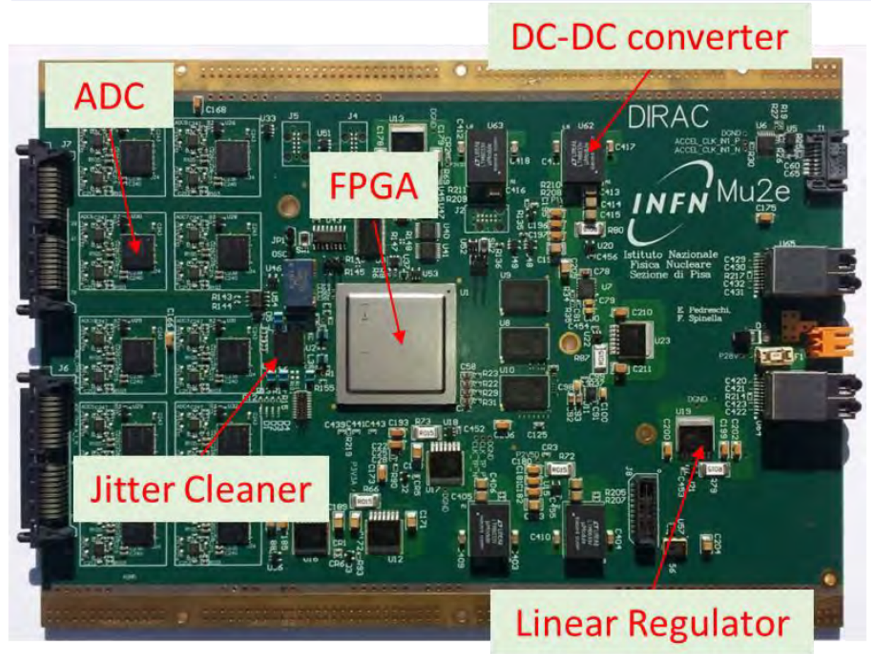




20 FE boards controlled by 1 mezzanine board in the DAQ crate: SiPM LV and HV distributed by an ARM controller.

Data from 20 FE boards (differential signals) sent to 1 digitizer for sampling, processing and transmission to the Mu2e DAQ.

5. Digitizer design



The working environment of the digitizer and the sampling rate (200 Msamples) put severe limitations on the components choice. Also the cost is an important parameter (~3,000 digitized channels).

After an intense campaign of tests, our choice:

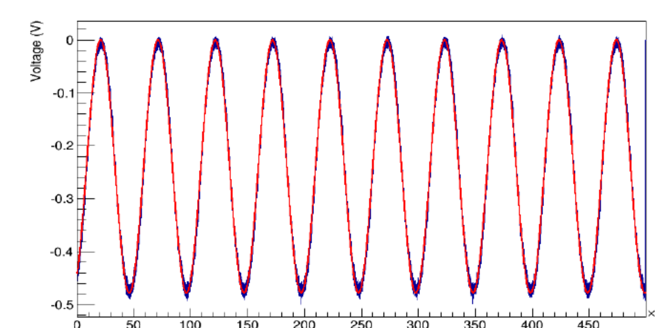
- ADC : Texas instruments ADS4229
- DCDC converter: Linear Technologies LTM8033
- FPGA (SoC): Microsemi SmartFusion 2 SM2150T
- Fiber transceiver: Cotsworks RJ-5G-SX

- All components must be qualified for radiation tolerance and the DCDC converter must also be tested for operation in 1 T magnetic field.
- Microsemi SmartFusion2 already qualified for radiation by the producer, but the ADC is read out through a DDR bus, so it must be operated at 400 MHz, which is near the maximum allowed for the device. Compatibility between the SoC and the ADC must be tested.

6. ADC & DCDC radiation tolerance

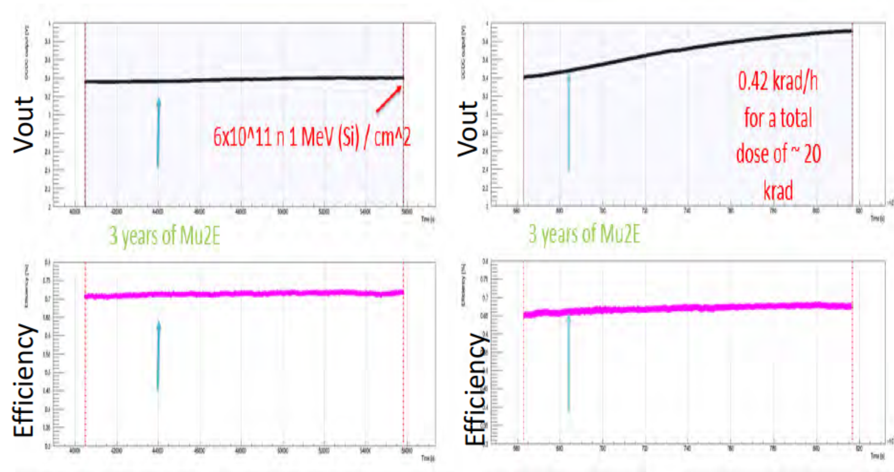
- ADC and DCDC converter tested with neutrons and gamma rays.
- Neutron irradiation performed at the ENEA Frascati Neutron Generator (fluence ~ 10^{11} neutrons 1 MeV eq (Si)/cm^2)
- Gamma irradiation performed at the ENEA Calliope facility (Co^{60}, TID 20 krad).

- ADC test: digitize 200 kHz sinusoidal signal and convert it back to analog (automatic comparison between input/output signal with a scope)



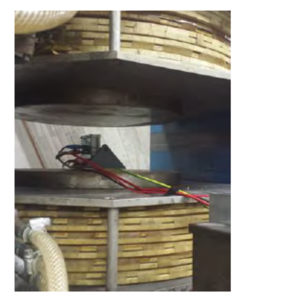
Analyzed more than 300 GB of data from neutron and TID tests, no evidence of bit flips or waveforms shape variation.

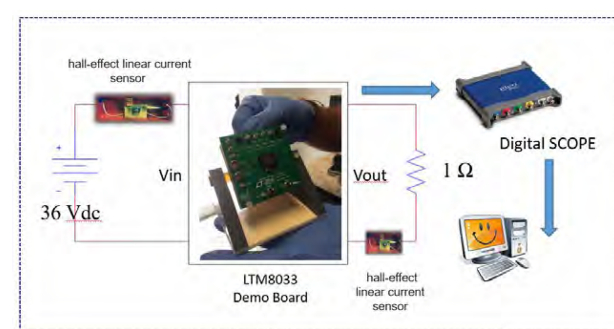
- DCDC test: measure input/output voltages and currents, monitor conversion efficiency and output voltage



7. DCDC magnetic field compatibility

- DCDC converter tested in a magnetic field up to 1.5 T at the INFN Lasa laboratory
- Used the same setup developed for radiation tests to monitor conversion efficiency and output voltage in all the 3 axes (no significant difference between axes)





8. Conclusions

- Mu2e waveform digitizer conceptually defined and designed
- All relevant components chosen and tested individually both under radiation and magnetic field, with good results
- Compatibility between Microsemi SoC and ADC (ADS4229) demonstrated
- First digitizer prototype constructed: tests progressing smoothly
- New prototype radiation tolerance tests planned at Helmholtz Zentrum Dresden Rossendorf in June 2018

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