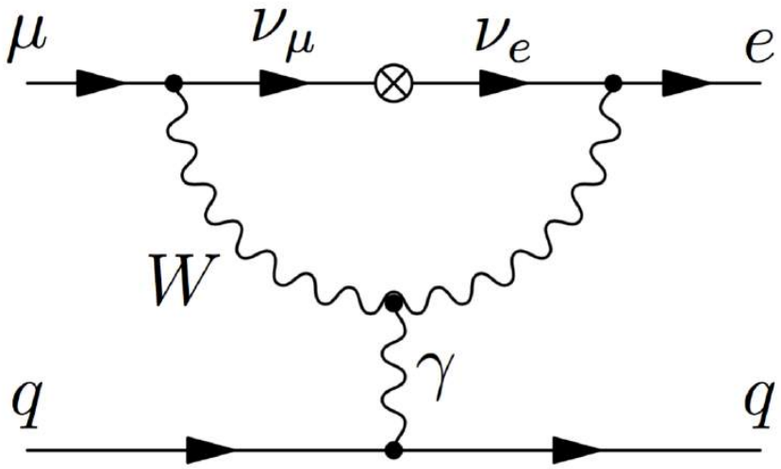
TOWARDS THE CONSTRUCTION OF THE MU2E ELECTROMAGNETIC CALORIMETER AT FERMILAB

ELEONORA DIOCIAIUTI ON BEHALF OF THE MU2E EXPERIMENT

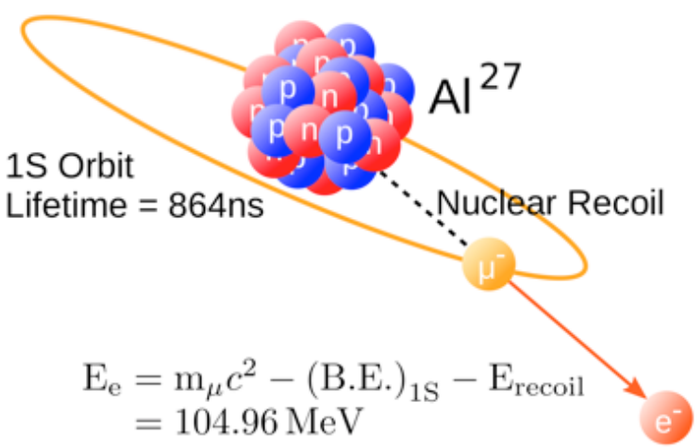
TIPP 2021 International Conference on Technology and Instrumentation in Particle Physics

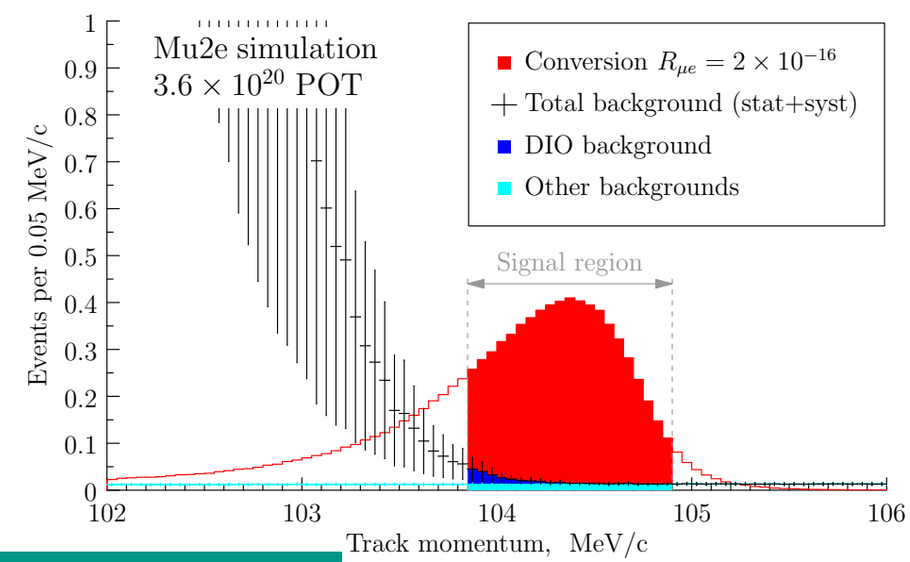
CLFV AND MUON CONVERSION

- μ converts into an electron in presence of a nucleus $\mu^- N \rightarrow e^- N$
  - μ-e conversion is an example of CLFV
- CLFV processes are forbidden in Standard Model
  - Assuming neutrino oscillations, they are allowed BUT negligible with BR $\sim 10^{-52}$
- Any observation will be a clear evidence of New Physics



Mu2e will measure the rate of the μ-e conversion normalised to the μ captures in nuclei < 10^{-17} (@90% CL)





Improve by 4 orders of magnitude the current best limit set by Sindrum-II : $R_{\mu e} < 7 \times 10^{-13}$

THE MU2E EXPERIMENT AT FERMILAB

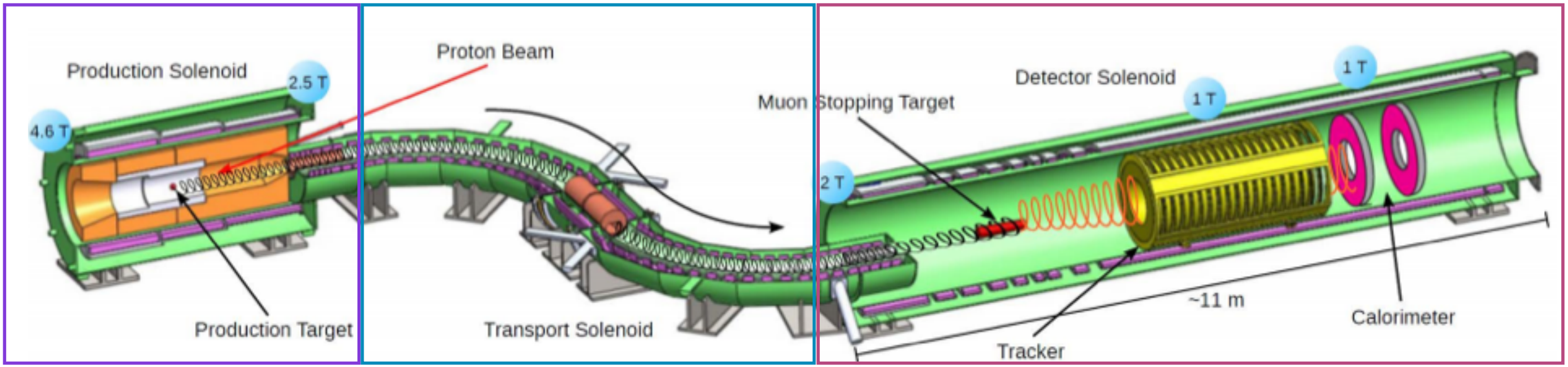
Production Solenoid

- 8 GeV protons hit the target and produce mostly π
- Graded B field reflects slow forward particles

Detector Solenoid

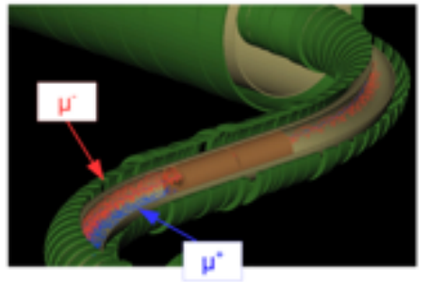
- Capture μ in the Al target
- Momentum measurement in the tracker and energy reconstructed with calorimeter
- CRV to veto cosmic ray events **

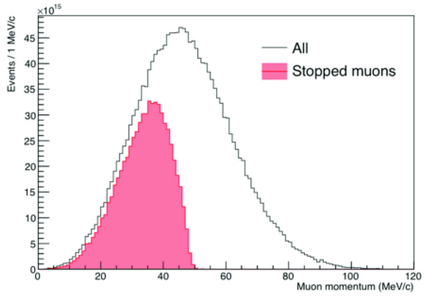
** See E. Dukes talks

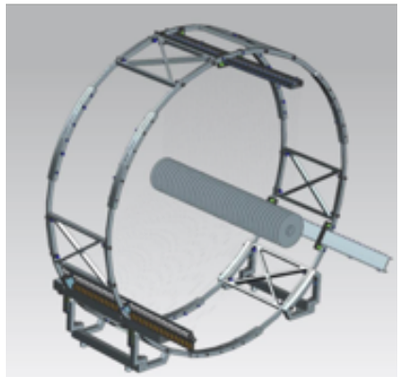


Transport Solenoid

- Selection and transport of low momentum μ-
- Antiproton absorbers in the mid-section





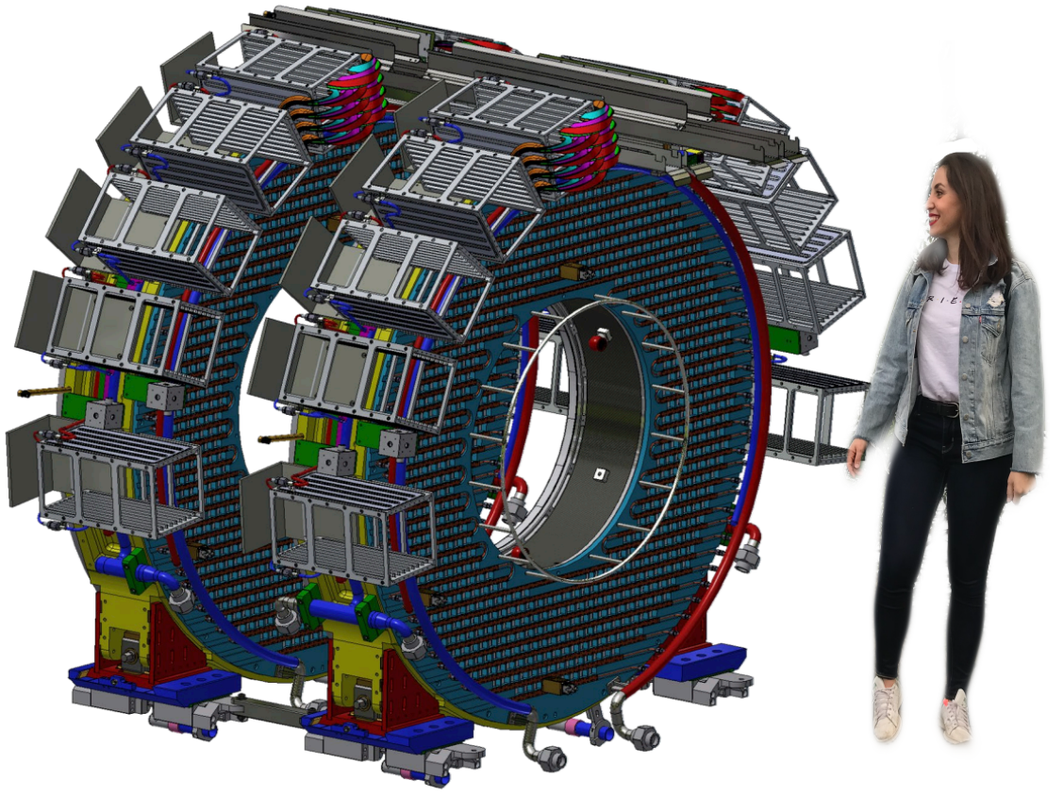


THE ELECTROMAGNETIC CALORIMETER

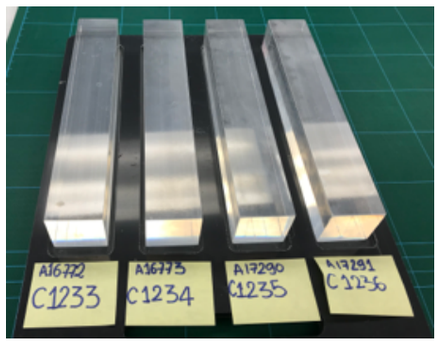
Confirmation for 105 MeV CE, PID (e/μ separation), EMC seeded track finder, standalone trigger

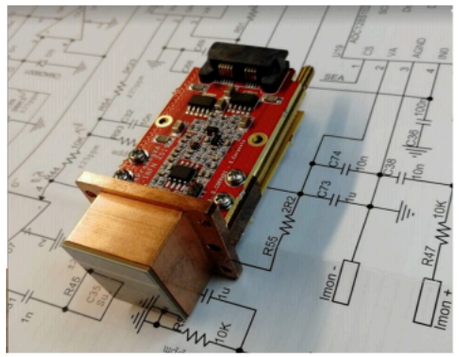
- $\sigma_E/E = \mathcal{O}(10\%)$ for CE
- $\sigma_T < 500$ ps for CE
- $\sigma_{X,Y} \leq 1$cm
- High acceptance

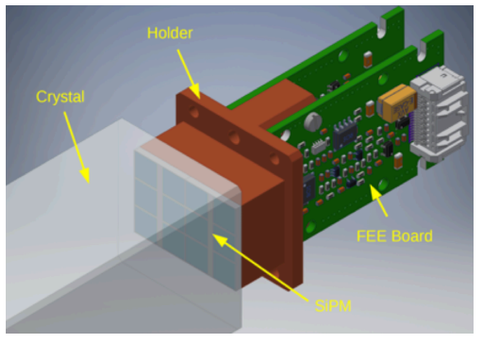
- Fast ($\tau < 40$ ns)
- Operate at 1 T and 10^{-4} Torr
- Redundancy in readout to operate 1 year w/o interruption
- Radiation hard: 90 krad and $3 \times 10^{12} n_{1MeV}/cm^2$



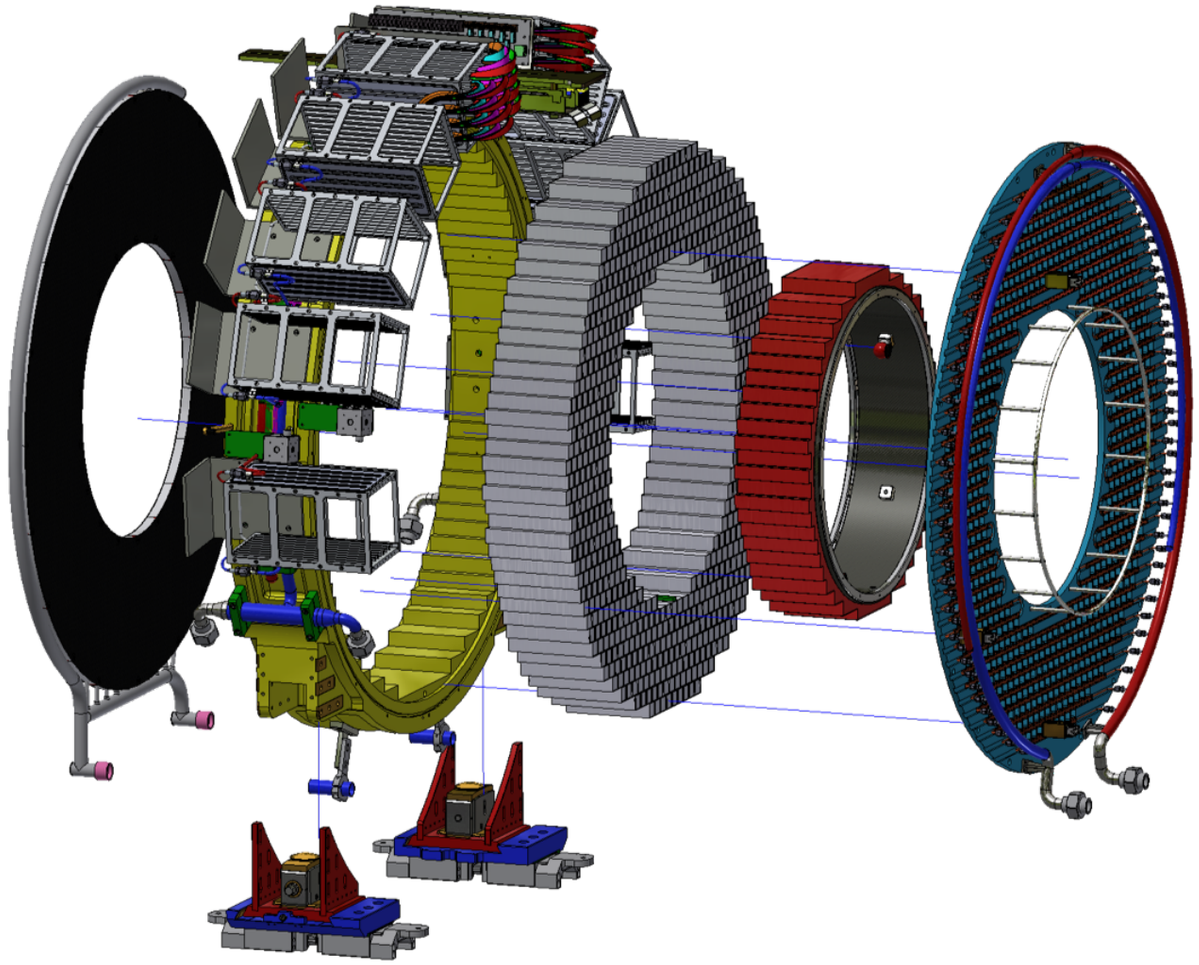
- 2 annular disks filled with 674 pure CSI crystals (34x34x200 mm³) each
- custom array of UV-extended SiPMs, two per crystal
- R_{in}= 35.1 cm, R_{out}= 66 cm
- 1 FEE/SiPM, Digital readout on crates
- Calibration/Monitoring with 6 MeV radioactive source and a laser system







CALORIMETER STRUCTURE BREAKDOWN

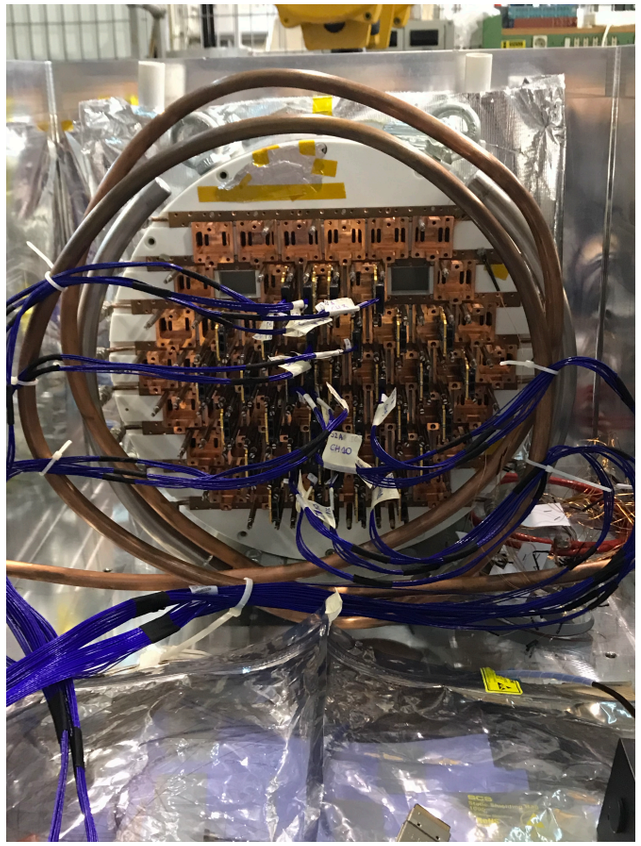


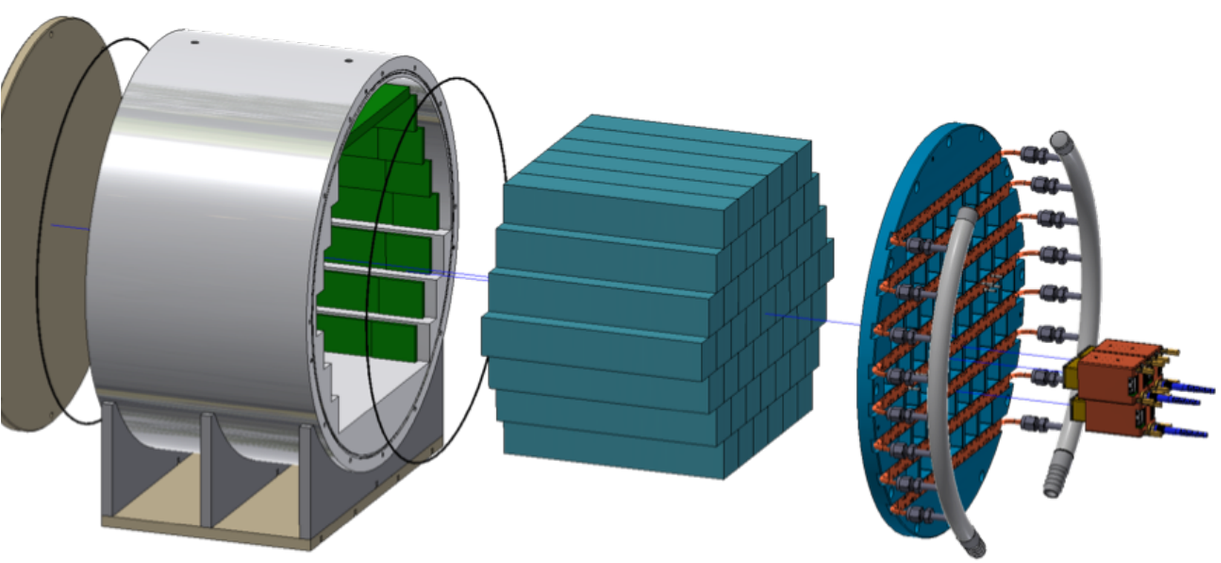
See D. Pasciuto's poster for more info!

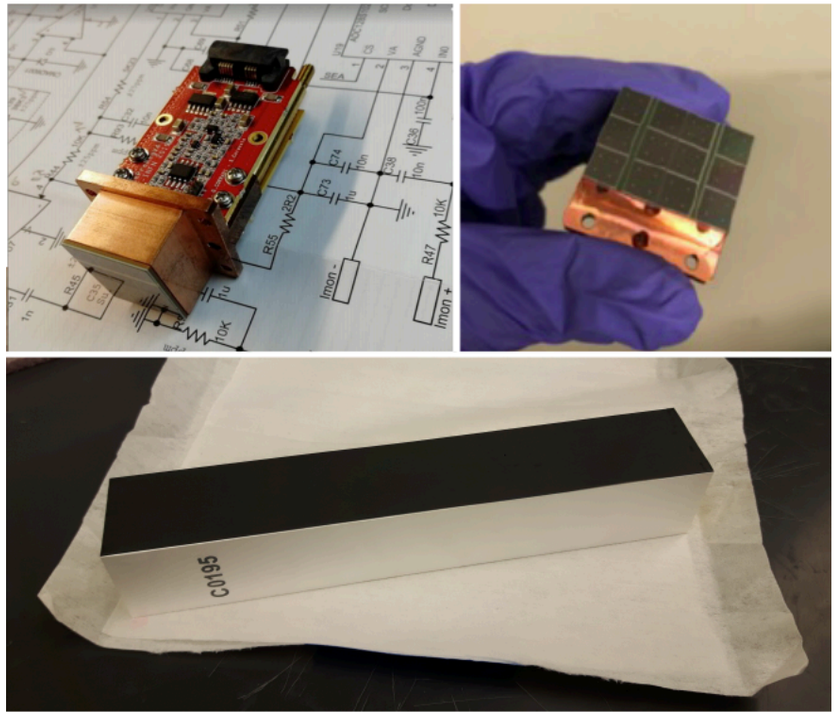
- Crystals stacked inside the external aluminum annular cylinder from the bottom
- Inner cylinder: Carbon Fiber + honeycomb + Al stiffening rings
- Back plate in PEEK for FEE positioning and SiPM cooling
- Front panel Carbon Fiber + honeycomb plate with embedded source pipes
- FEE crates placed outside of the cylinder

MODULE-0: A LARGE SIZE PROTOTYPE

- 51 crystals, 102 SiPMs + FEE boards
- Goals:
  - Test integration and assembly procedure;
  - Measure calorimeter performance @ test beam;
  - Work under vacuum, low temperature;
  - Validate the electronic chain
    - Vertical slice test with cosmic ray events



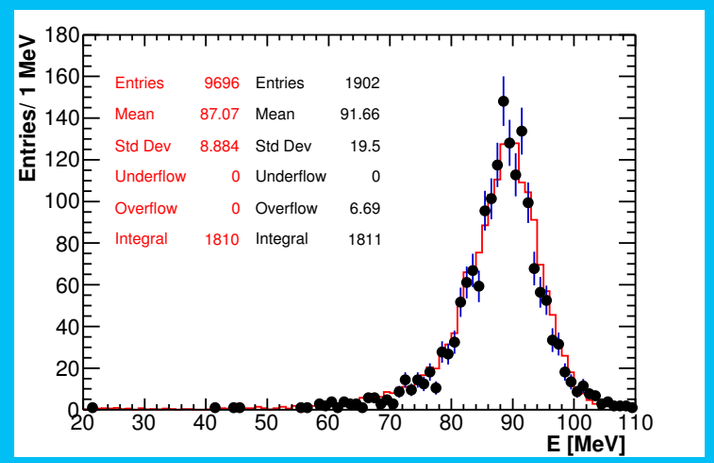


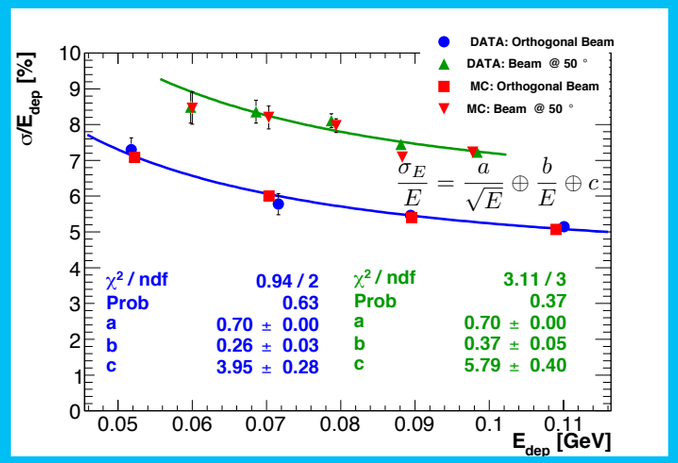


CALORIMETER PERFORMANCE

Test beam at BTF (LNF) in 2017 with e^- with 60<E<120 MeV

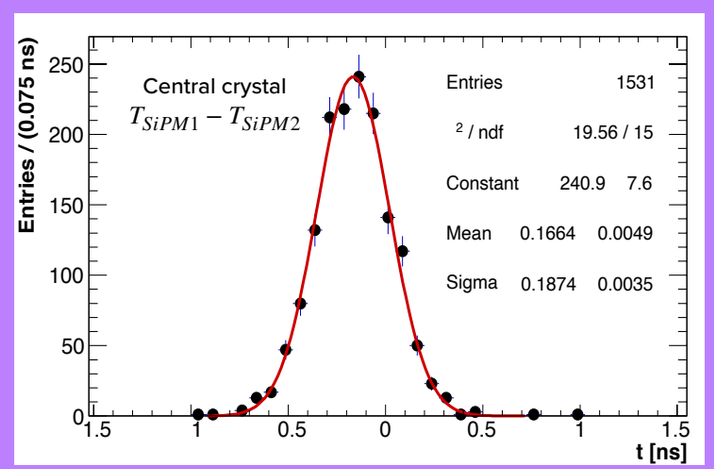
- single particle selection
- MIPs equalization and time scale
- LY/SiPM =30 Npe/MeV
- Excellent Data-MC agreement
- 5.4% (7.3%) resolution @100 MeV for 0° (50°) impact angles

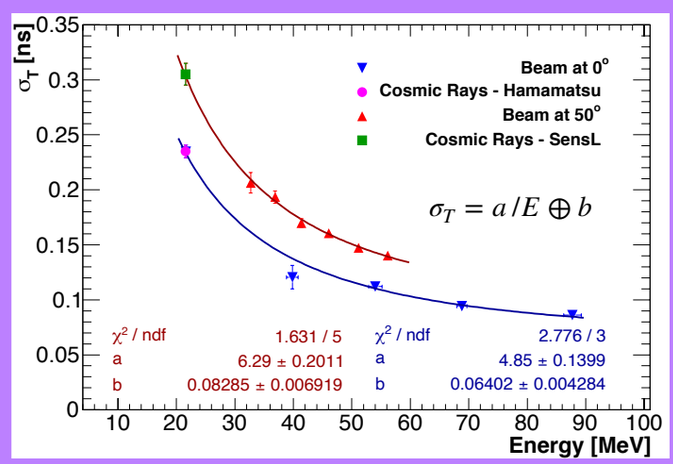




energy

- Log-normal fit on leading edge+ Constant Fraction method @5%
- Timing resolution <150 ps @ 100 MeV

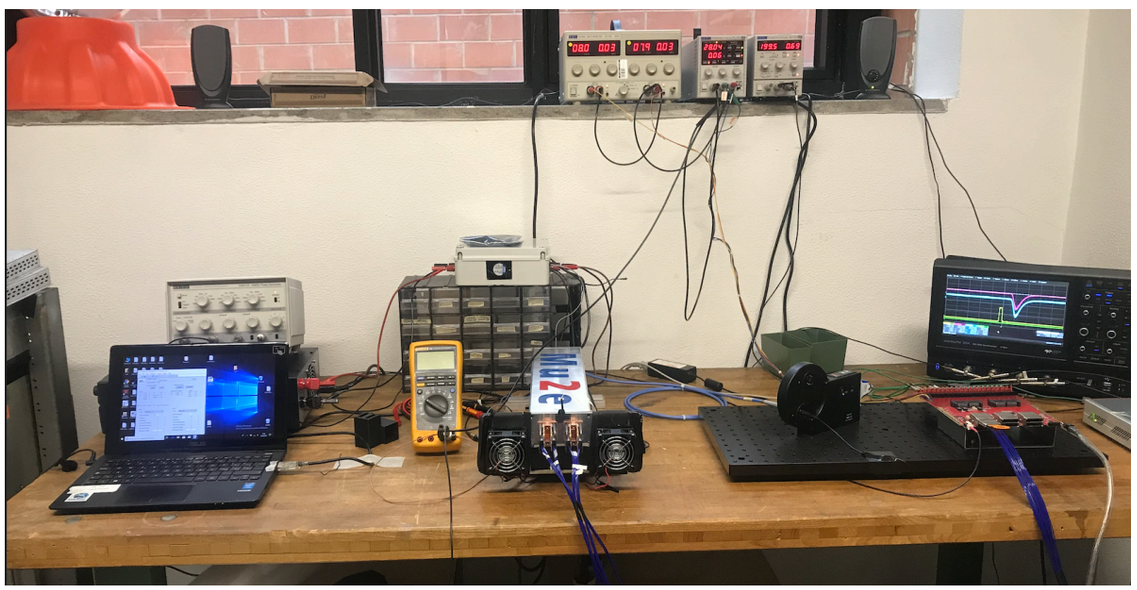


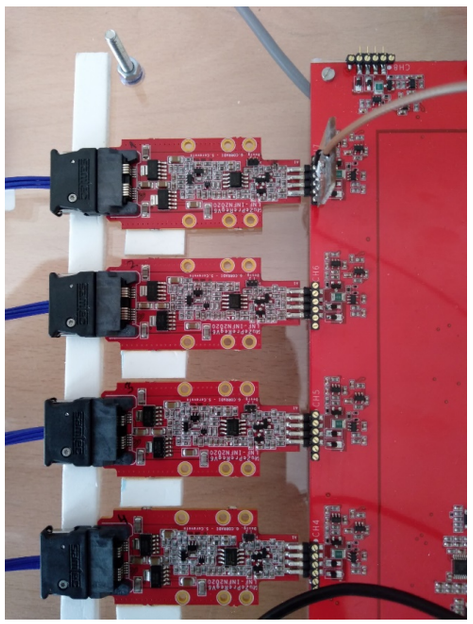


Timing

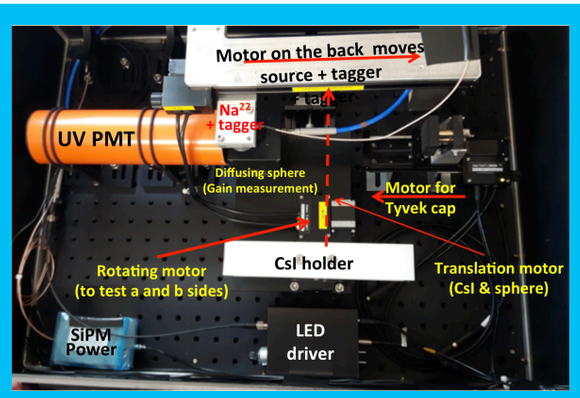
STATUS OF THE CONSTRUCTION

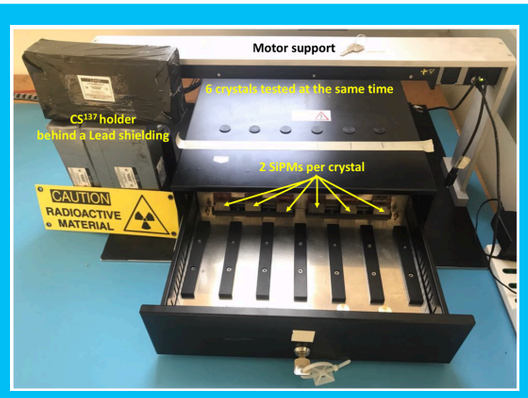
- Crystals production and test completed in 2021
- SiPMs production and test completed in 2019
- Gluing procedure relocated at LNF due to COVID
  - 750/3000 done
- Production of FEE started
  - first 760 PCBs under test these days @ JINR
  - VST with final Mezzanine board + Dirac ongoing
- Cosmic Ray Tagger in construction
- First Aluminum disk installed in our clean room at Fermilab

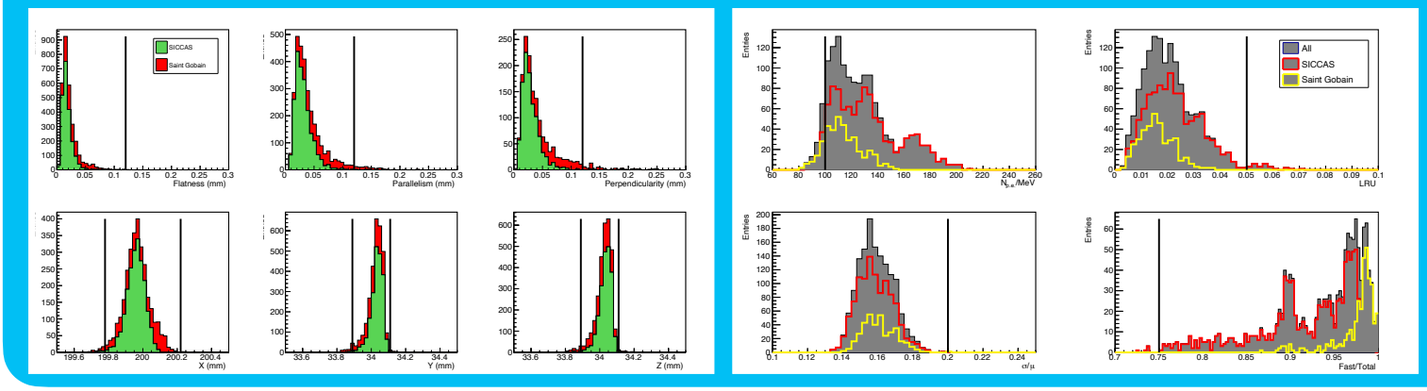




CRYSTALS AND SIPM QC

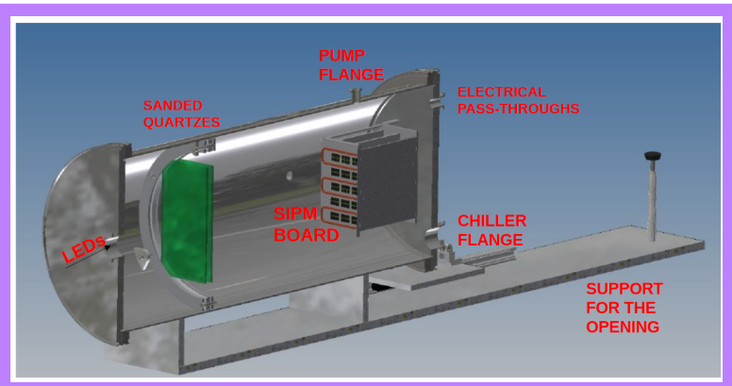


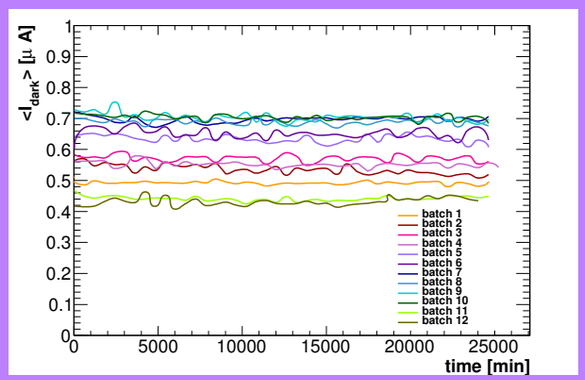


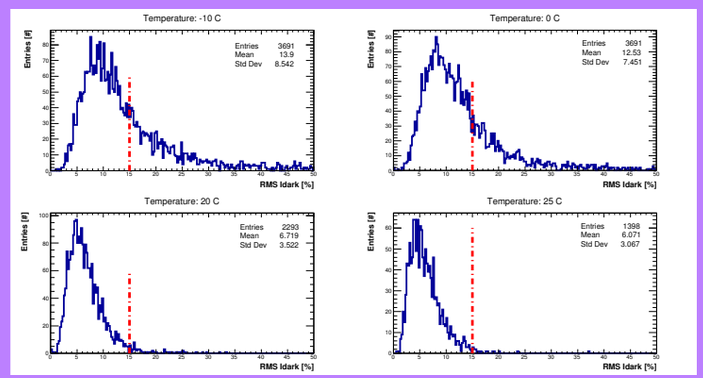


CsI crystals from Siccas and St. Gobain

- 1430/1430 crystals delivered and tested
- Good optical properties (~4% rejection)
- Irradiation test up to 100 krad on random samples





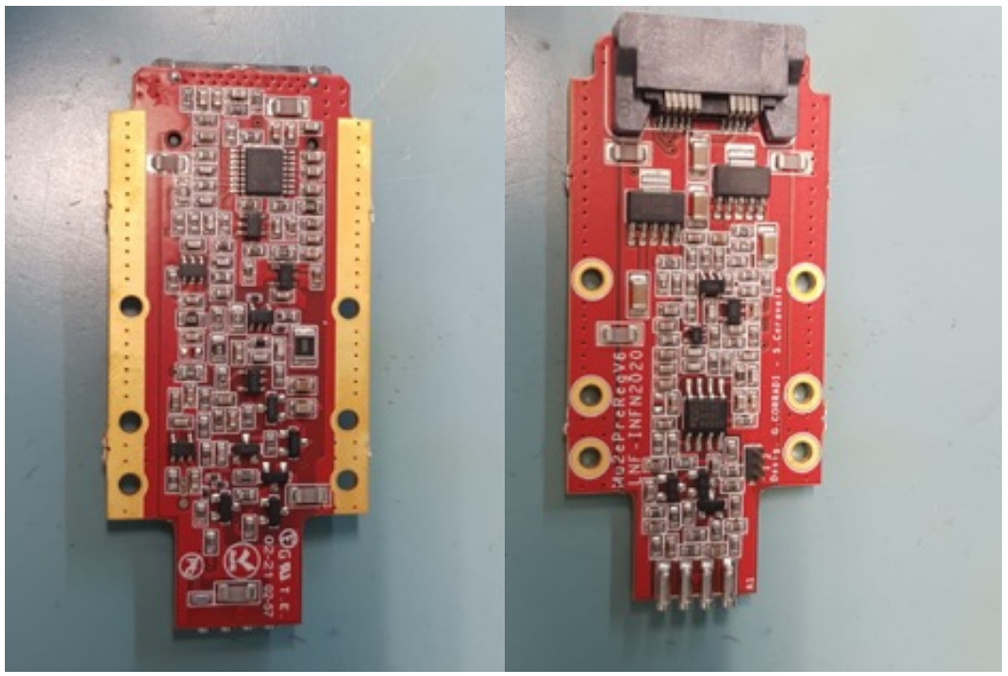


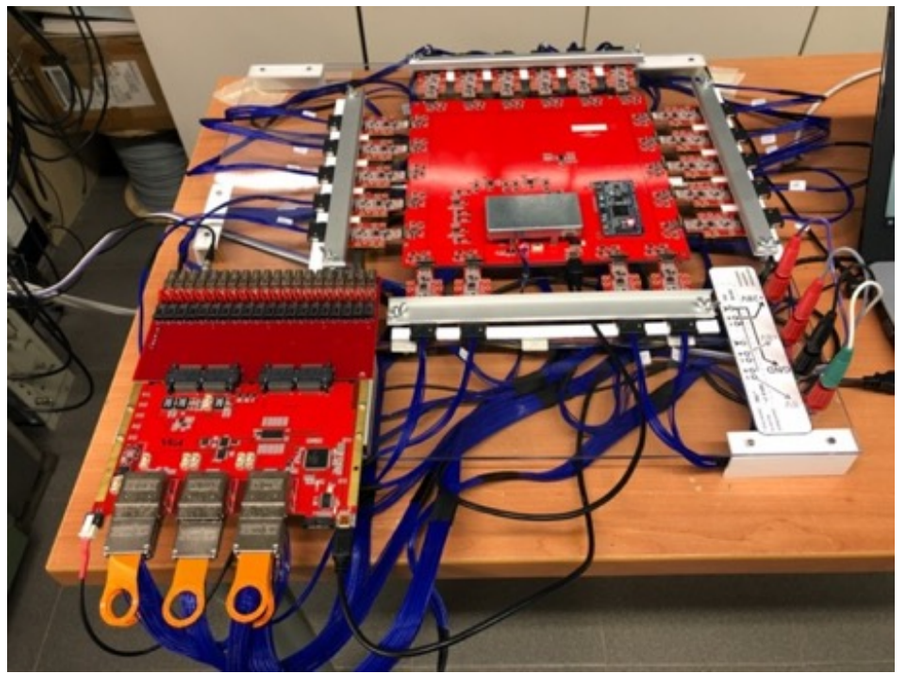
Custom UV-extended SiPM from Hamamatsu

- 4000/4000 delivered and tested
- 1.2% SiPM rejected
- Passive n irradiation @ HZDR + MTTF>10^7 hours

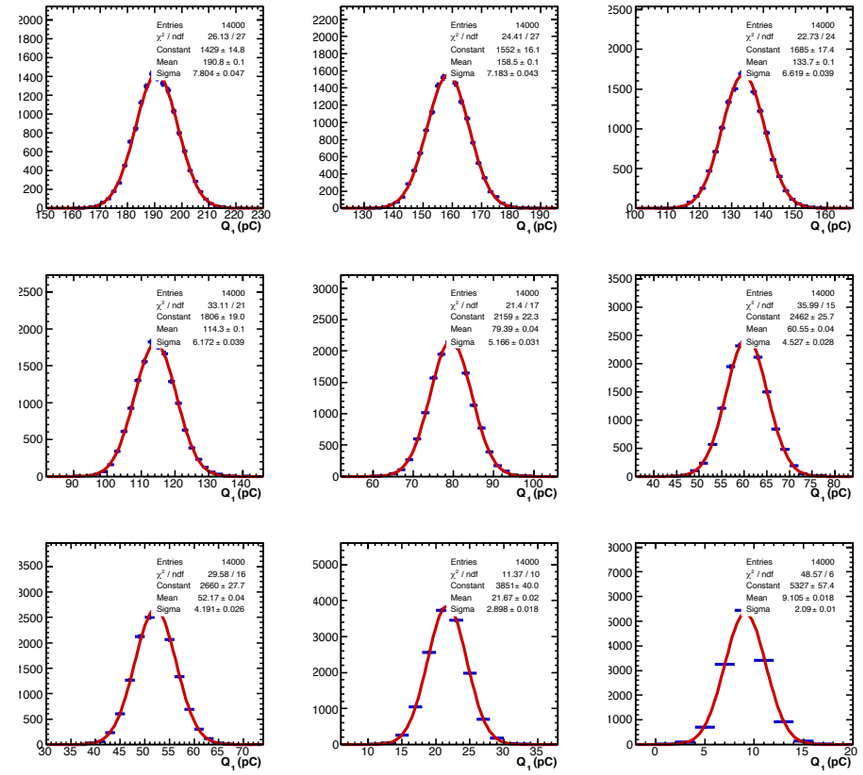
FEE BOARDS

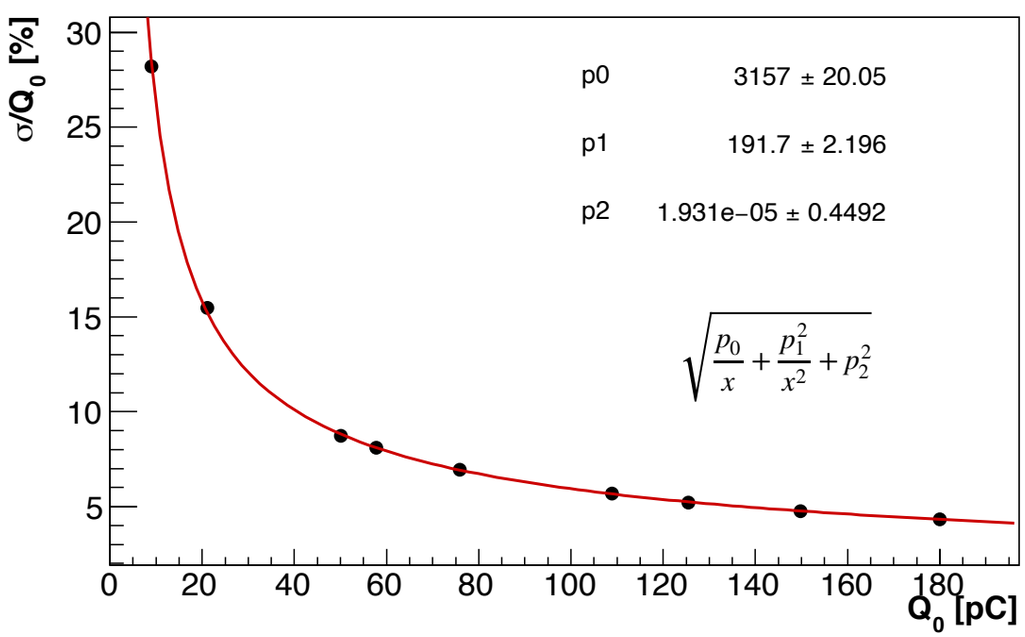
- Several irradiation campaigns carried out @ Calliope(Enea Casaccia) and @FNG (Enea Frascati)
- Failures of single components observed in first prototypes, replaced with rad-hard components
- First 120 PCBs with mounted components as pilot run end 2020
  - 2250 /3500 FEE produced , end of production expected for June
- First 750 Fee sent to JINR for test:
  - 65 °C burn-in for 6 hours —> 1 case of infant mortality
  - Linearity, gain pulse shape tests in progress
    - few minutes per boards





QA STATION FOR SIPM+FEE



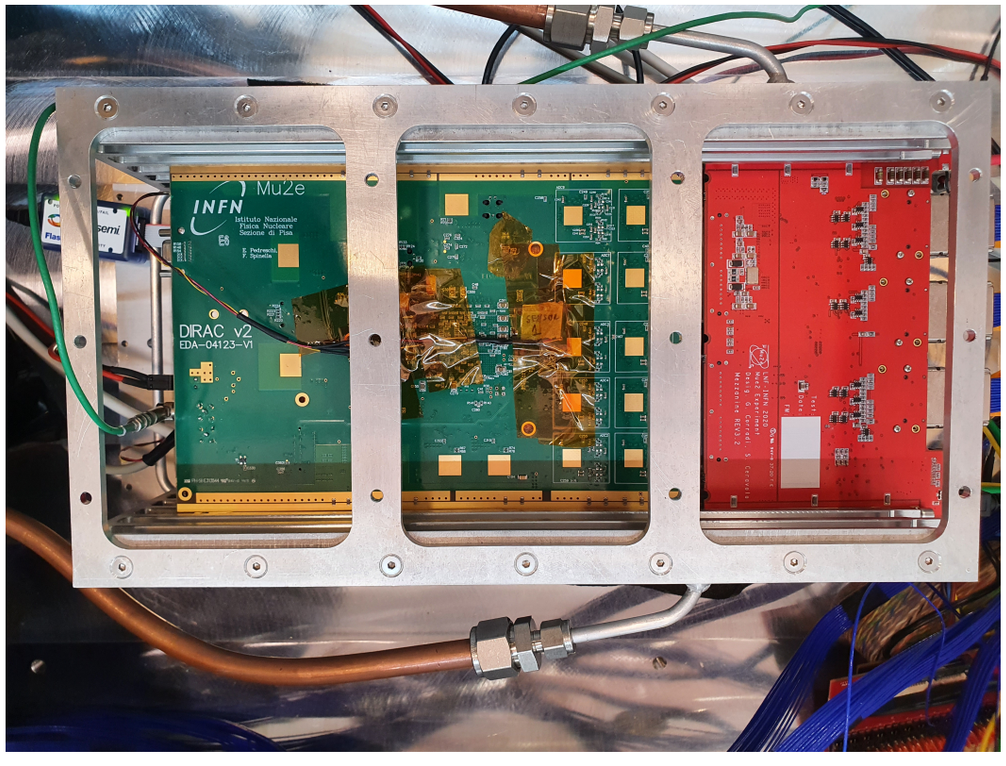


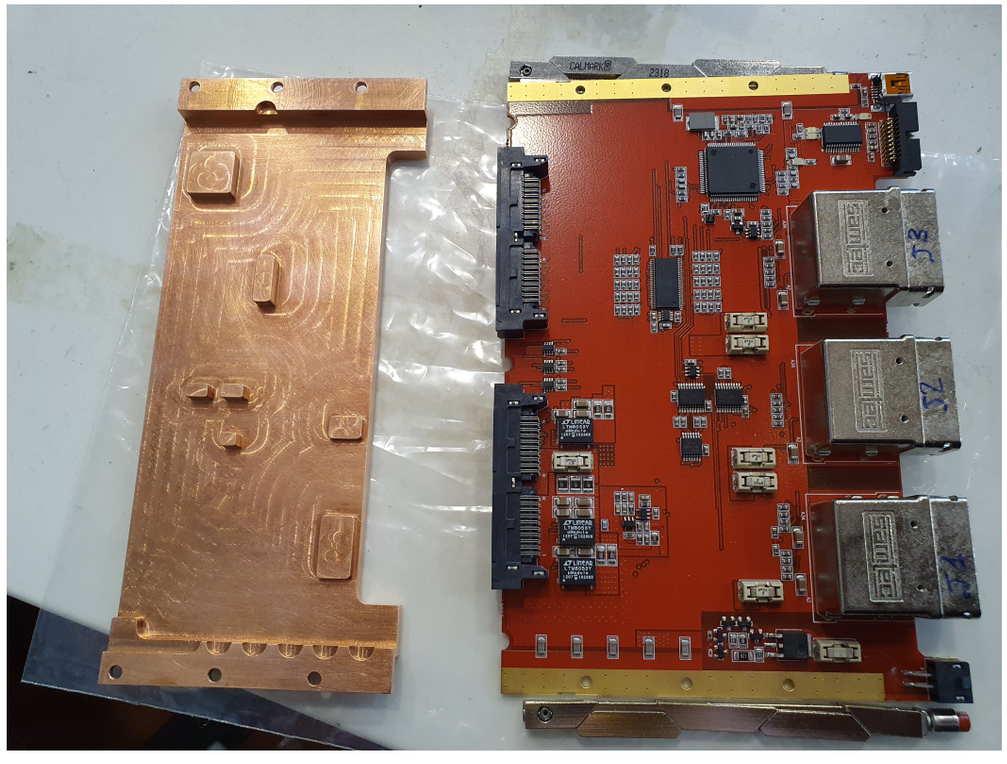
- Box with sanded glass to diffuse the blue LED (420 nm) light @ 1 kHz hosting 2 holders
- Box temperature stabilized at 25 °C with to 2 Peltiers + radiator + fans
- Automatic wheel filter attenuator [9 position acquired]
- GUI for acquisition + analysis
- Pilot run with 36 FEE done

READOUT SYSTEM

10 crates per disk with 6-8 digital boards/crate

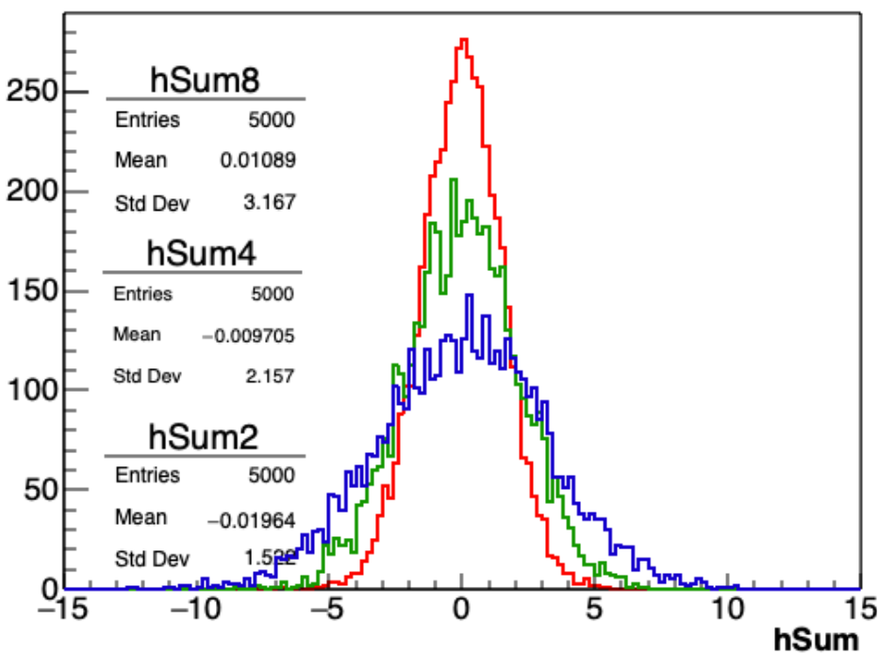
- 20 SiPM+FEE channels/board
- Mezzanine Board: provide SiPM biases, handle HV readout/settings and I, T readout
- DIRAC board provides digitization at 200 Msps, 12 bit ADC
- All components (DC-DC converter, FPGA, ARM) rad-hard tested up to 20 krad @ Calliope
- 5 MB + 5 DIRAC boards produced
- Prototype of copper plate for cooling produced and tested in vacuum



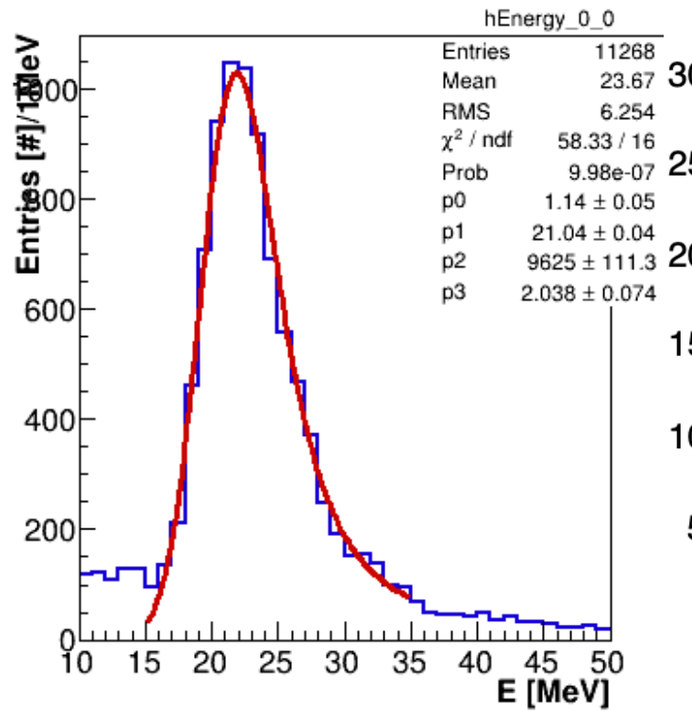


CALIBRATION AND DCS TEST WITH MODULE-0

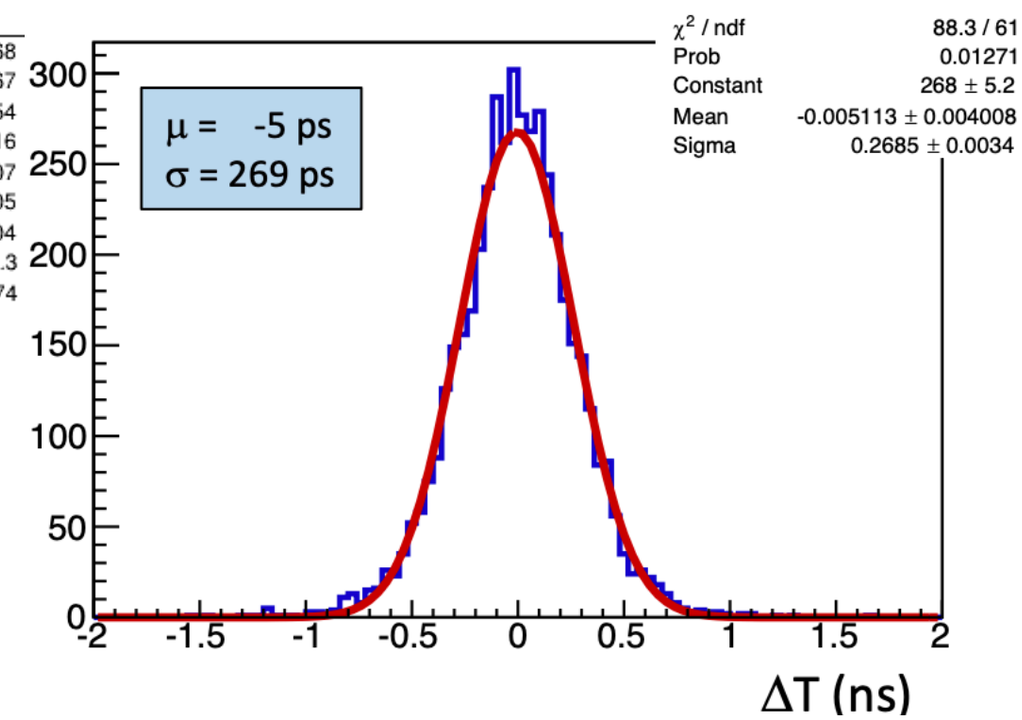
Noise Evalution



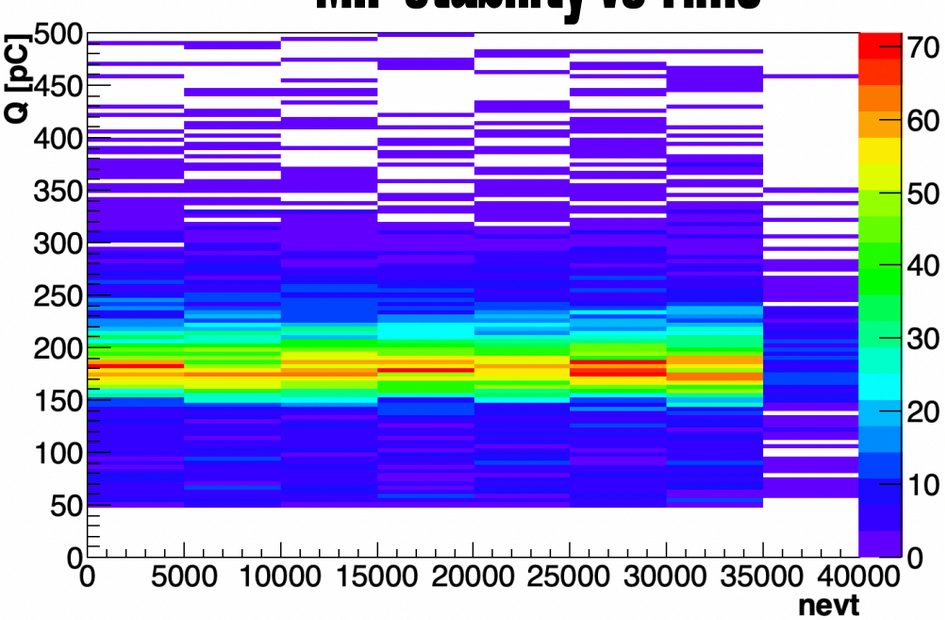
MIP energy



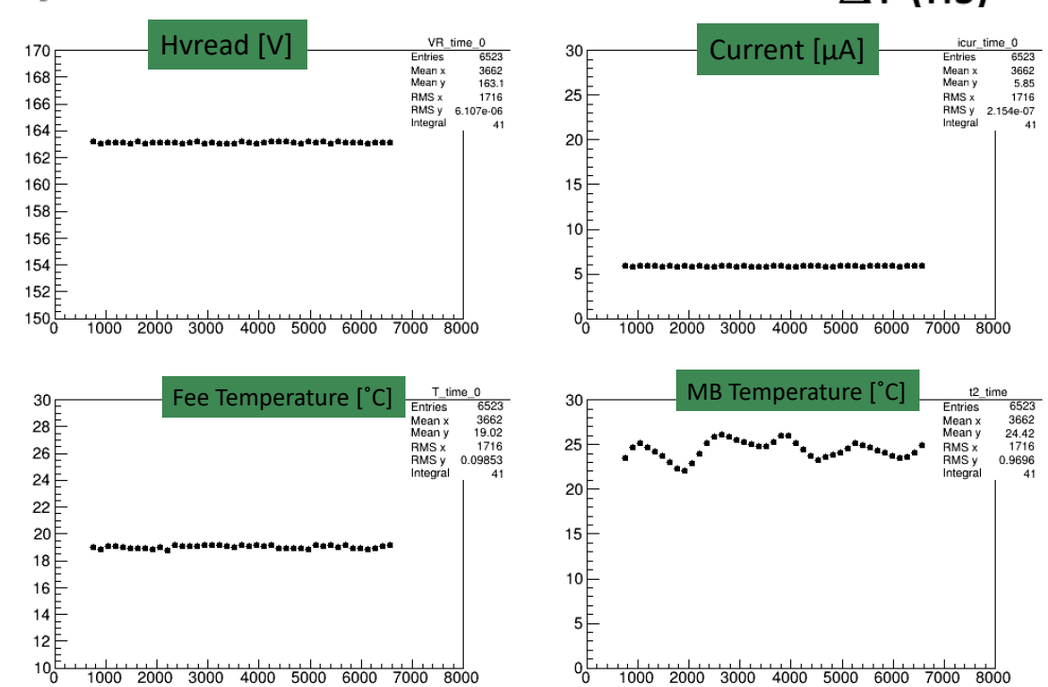
Time resolution



MIP stability vs Time

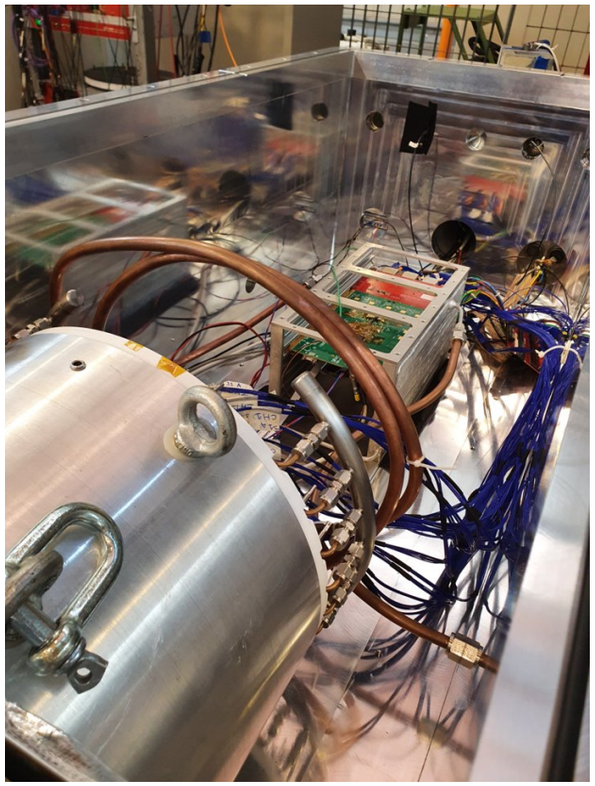


operate for 4 months with a commercial digitiser



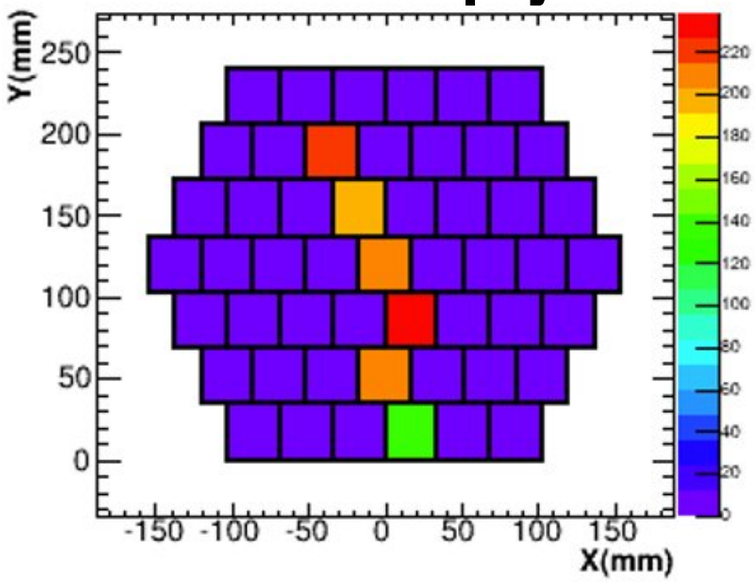
VERTICAL SLICE TEST @ LNF

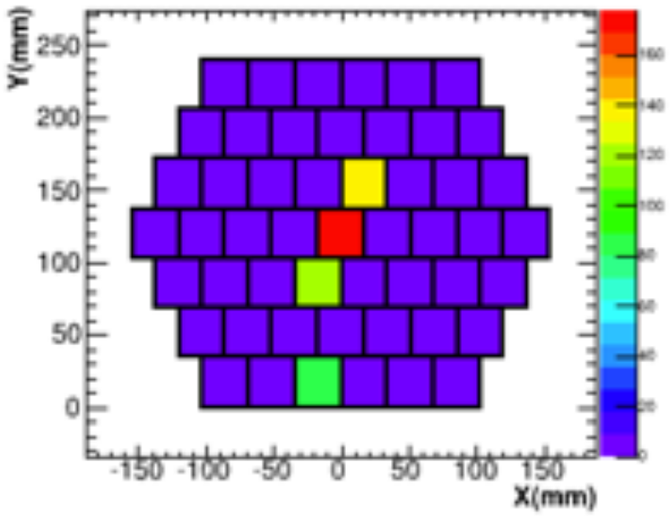
- Vertical Slice Test ongoing!
- 20 channels of the Module-0 with Final Mezzanine Board and Dirac
- Running temperature 0 °C and 0.1 mbar

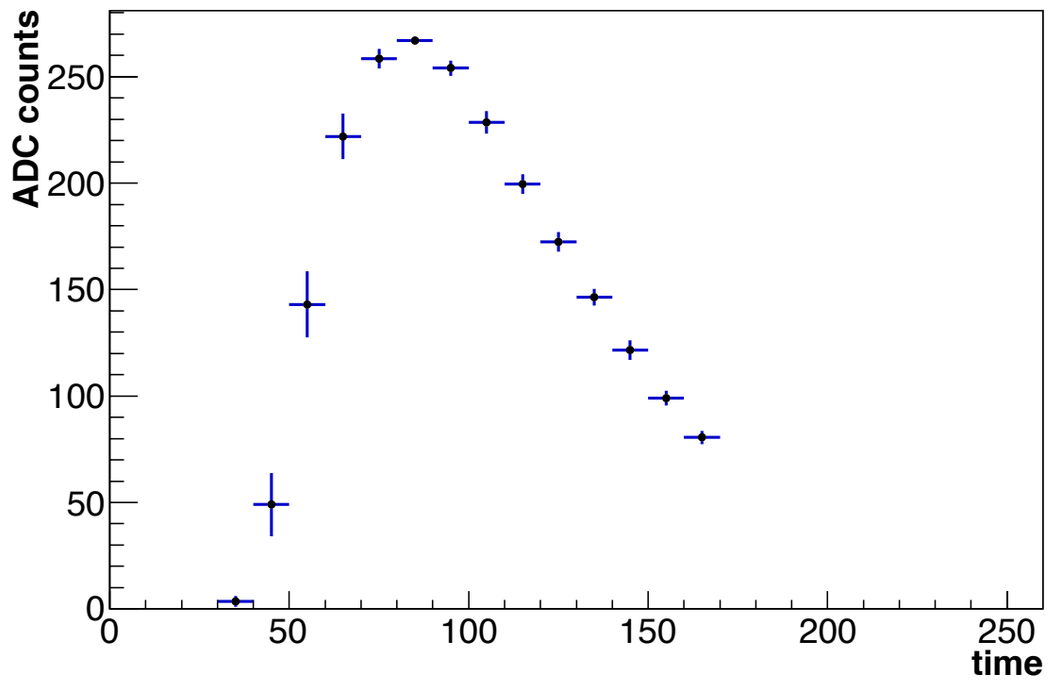


the Setup

Event Display







CONCLUSIONS

- The Mu2e experiment will exploit the world's highest intensity muon beam at the Fermilab Muon Campus to search for CLFV, improving current sensitivity by a factor 10^4
- The calorimeter provides good energy and time resolution for 100 MeV electrons for PID, triggering and track seeding purposes
  - Tests on Module-0 fully meet the requirements
- Despite the delay due to the pandemic, most of the components have been produced (or under production)
- Large mechanical components are being delivered
- Vertical Slice Test with final electronic ongoing —> satisfying results achieved
- Planning to start assembling the first disk during this summer
- Aiming for installation in Mu2e building late 2022

THANK YOU!

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