Conceptual design of a robotic arm for the maintenance of the Read-Out Units of the Mu2e electromagnetic calorimeter

mu2e.fnal.gov

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

The **Mu2e Experiment** will search for the neutrino-less coherent conversion of a muon into an electron in the field of an aluminum nucleus**.** Such **Charged Lepton Flavor Violating process allows to probe energy scales up to thousands TeV**, far above the reach of direct searches at the energy frontier colliders. If no conversion events are observed in three years of data taking, Mu2e will set the limit on the ratio between the muon conversion rate and the capture rate **$R_{\mu e}$<3 x 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)

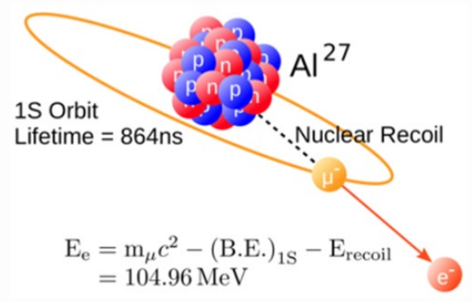
20000 low mass straw drift tubes
Momentum resolution **180 keV/c**

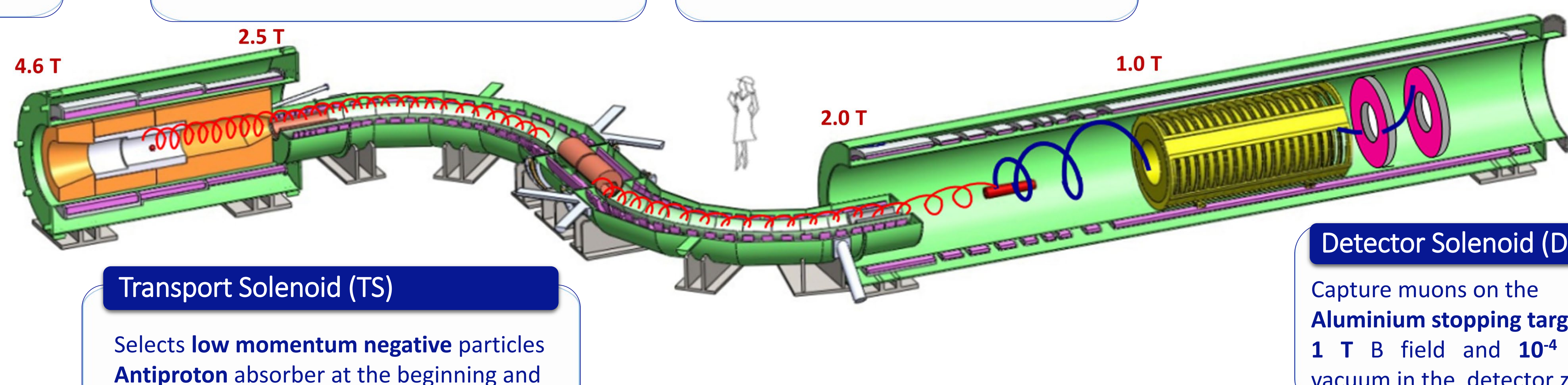
Electromagnetic Calorimeter (ECAL)

Two annular disks
Energy, Time and Position measurements

Experimental Technique

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





Transport Solenoid (TS)

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

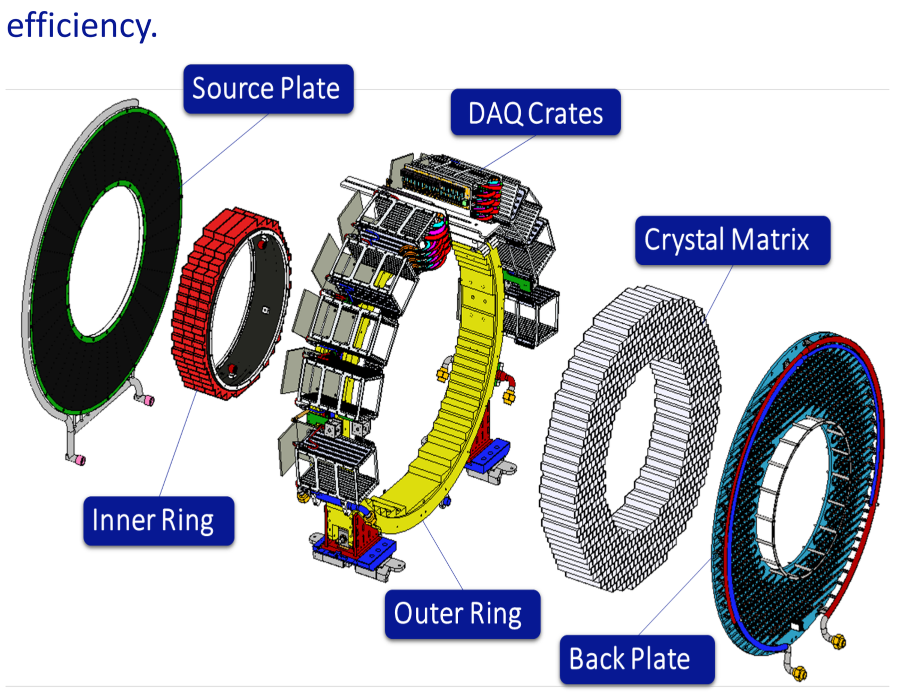
Detector Solenoid (DS)

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

Schematic view of the Mu2e beamline

2. Electromagnetic Calorimeter

The EM calorimeter is composed of a pair of twin annular matrices (disks) of 674 undoped CsI crystals placed downstream of the straw-tracker at a relative distance that maximizes the conversion electrons detection efficiency.



Exploded CAD view of one Mu2e EC disk

The crystal matrix is supported by the aluminum Outer Ring from outside and by the carbon fiber Inner Ring from inside. Ad hoc alignment tools embedded in the Outer/Inner Rings allow to fine tune the crystals positions.

The scintillation light is readout by large area UV-extended SiPMs (two 14x20 mm² SiPMs/crystal to improve operational reliability). The gigantic SiPM + FE Boards matrix is embedded in the Back Plate that also integrates a network of cooling lines to control SiPM and FE electronics temperature. DAQ boards are hosted in a battery of 10 crates/disk placed on the disk lateral surface.

A liquid radioactive source (Fluorinert) is fluxed through a network of pipes housed in the frontal Source Plate to provide an absolute energy scale and the response equalization among the crystals.

Calorimeter Requirements:

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

Calorimeter Performance:

- ΔE/E < 10% and Δt < 500 ps
- Position resolution of O(1 cm)

Operational conditions:

- 1 T B-field
- 10^{-4} torr
- 90 krad, 10^{12} n cm^{-2} year^{-1}
- 25°C

3. Front-End Unit

Copper holders with SiPMs

The whole read-out electronics is embedded into an electromechanical unit made of different components as shown in the image below which fulfills different tasks:

- Cool and thermalize the two SiPMs, glued on the front face of the module;
- Host and cool the two read-out electronics;
- Host and position the laser fiber for the SiPMs calibration;
- Shield electromagnetic noise;
- Easiness to test, mount and replace.

The module has been designed to be a standalone unit that can be easily tested and qualified once assembled. It means that the 1348 units are being preassembled and tested and will be mounted once the calorimeter crystal matrix, the structure and the cooling components have been mounted and tested.

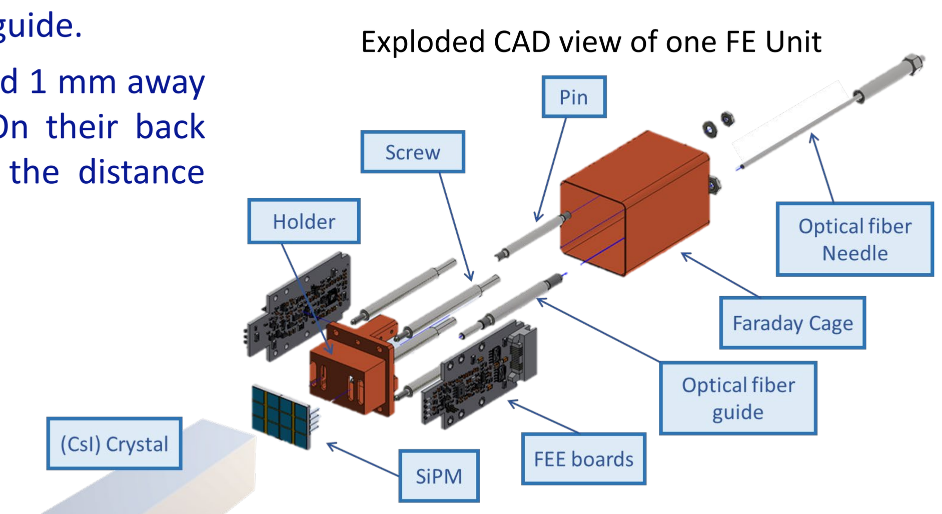
The FE Unit has few connections with the other components:

- four custom-shaped screws fasten the module to the Backplane, granting positioning and thermal contact;
- two SAMTEC PCB-based connectors for powering and signal transmission;
- one optical fiber needle screwed in a dedicated guide.

The modules are 34x34x74 mm³ and they are packed 1 mm away on their sides once fastened on the Backplane. On their back cables and fibers reduce their access. Moreover, the distance between the calorimeter disks is 350 mm.

The tight space, the impossibility to increase the accessibility and the reduced amount of time scheduled for programmed maintenance suggested to develop a robotic system to replace these units in case of failure after the calorimeter has been mounted on the detector train rails.

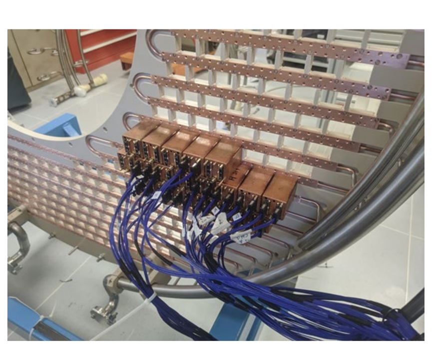
Exploded CAD view of one FE Unit



4. FEE cables routing

The main accessibility constraint to the FE Units is the cables and fibers occupancy, which create a barrier to the FE Unit manipulation. A great effort has been dedicated to the FEE cables and optical fibers routing, to grant enough space to fit all the required mounting-dismounting FE Unit tools.

Several constraints have been considered for the routing, including SiPMs distribution to the different Digitizing boards, cable lengths and fiber bending radius

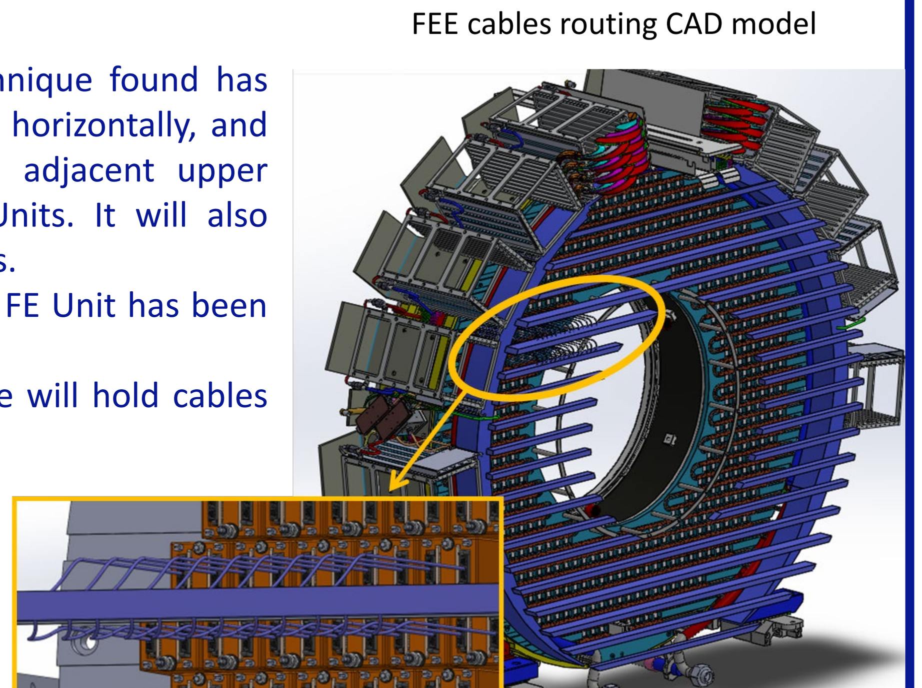


FEE cable routing test at LNF

The optimal routing technique found has been to distribute cables horizontally, and each bundle supply the adjacent upper and lower rows of FE Units. It will also apply for the optical fibers.

- Cable length for each FE Unit has been calculated
- A guidance steel cable will hold cables weight and position.

FEE cables routing CAD model



- A mockup of the solution has been made for cables and fibers on the Calorimeter disk at LNF
- Other tests will be realized after the robot realization

5. The Robot design

The task the robot must fulfill is the replacement of a FE Unit once the calorimeter has taken lace in the detector train. The suboperations the robot must perform can be summarized as the followings:

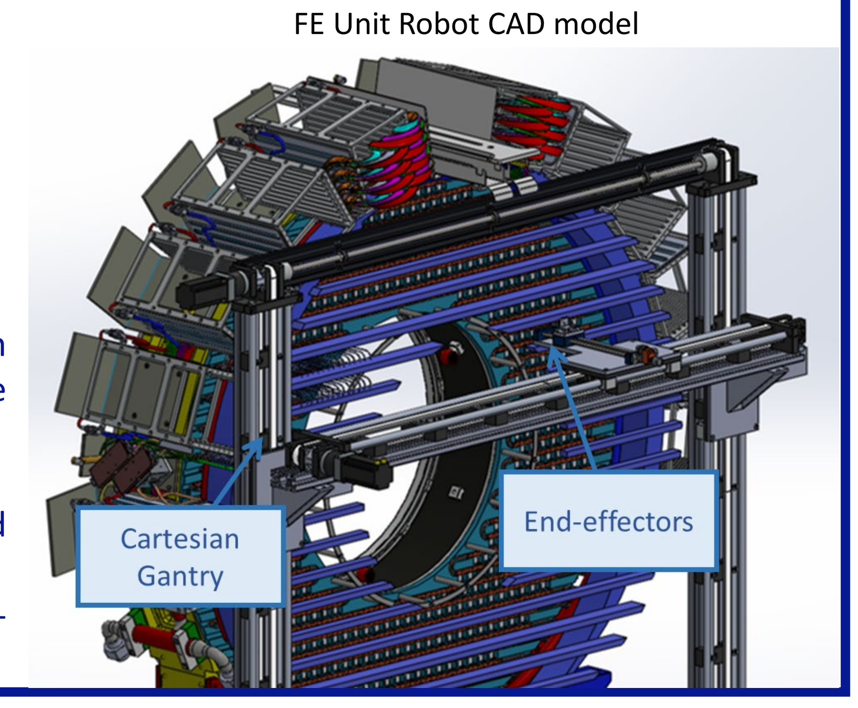
- Disconnect and hold the two FEE connectors;
- Disconnect and hold the optical fiber;
- Unscrew the 4 hex head screws;
- Remove the damaged FE Unit;
- Mount the new unit;
- Tighten the four screws;
- Re-connect the optical fiber;
- Re-connect the two FEE connectors.

The design of robot foresees:

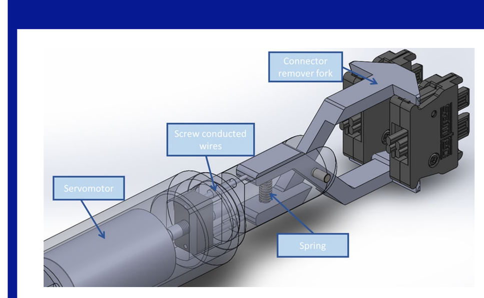
- A gantry structure to fasten to the calorimeter aluminum ring, to have a relative precise positioning respect to the detector;
- A stepper motor actuation system for an easy control;
- A belt-pulley movement system to have embedded compliance;
- A multipurpose 'head' with four different dedicated end-effectors

Additional features of the robot include: the adequate precision of the positioning of a module and the compliance to avoid any damage to itself and to the module in case of misalignment.

FE Unit Robot CAD model

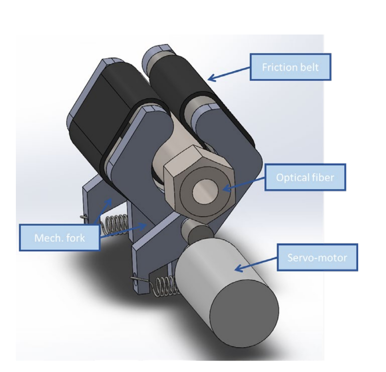


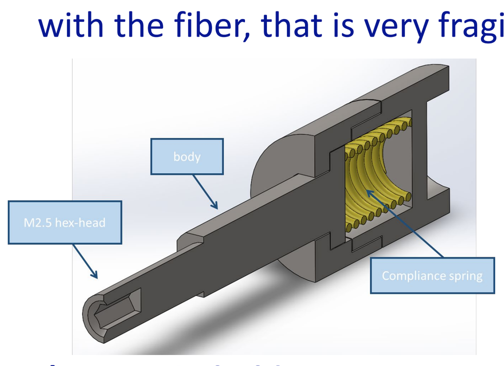
6. End-effectors



1) **Connector remover:** It dismounts the two connectors at the same time, pushing the two lateral clips that tighten the connector to the FE board. It has a spring mechanism to ensure grip also in case of lack of power supply and to calibrate di amount of pressure used. A screw-nut mechanism control the plies displacement.

2) **Optical fiber remover:** it is made of two fingers with a belt pulley to envelop the fiber needle collet and two springs to adjust the amount of pressure used. A motor actuates the belt and with friction will unscrew the fiber needle. With this mechanism it is possible to approach the collet from its side and avoid to interfere with the fiber, that is very fragile





3) **Screwdriver:** It allows to unscrew the 4 screws. The screws will be locked inside the FE Unit, because of design and the amount of torque (0.083 Nm) is set by the motor current. An axial spring assures compliance during the approach movement, while the transversal positioning is made easier with a countersunk hollow on the screwdriver tip

4) **FE Unit holder:** A square shaped plie that embed the decupled unit to transfer it on the side of the calorimeter.

The third and fourth end effectors will be united, while the first two end effectors will be completely independent, in this way fiber and cables can be held in position during the FE Unit substitution

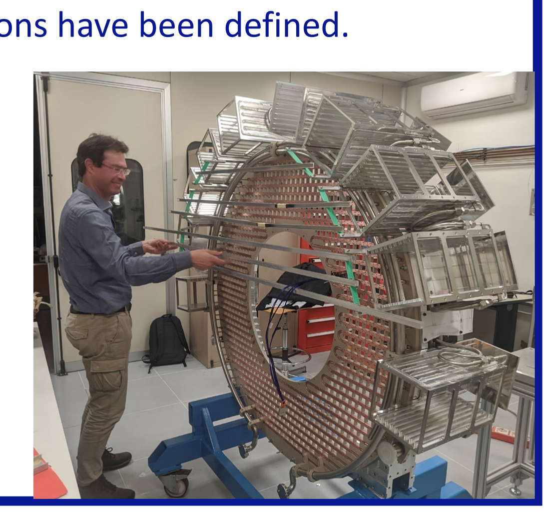
7. Conclusions

What we did:

- A cable and fiber routing has been designed and tested and it will be helpful for calorimeter assembly and maintenance procedures
- A conceptual design of a maintenance robot for the Front-End Units has been developed: tasks have been identified and schematized, a design solution has been achieved and operations have been defined.

Next to be done:

- Mount all the FE Units on the calorimeter disks at Fermilab in the next months, including cables and fibers
- Realize an executive design for a prototype of the robot which we can make at INFN for preliminary tests
- Develop electronics for robot controlling, based on Arduino
- Test the robot on the fully assembled calorimeter



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