The Mu2e Experiment @LNF

F. Happacher on behalf of the Mu2e LNF Group – Consiglio di Laboratorio LNF –July 2021

- Brief overview of the Mu2e experiment and status
- Calorimeter details
- LNF group activities
- Resumed work @FNAL
- 2020 Achievements: Because of Covid - In spite of Covid
- Next year plans and support requests

Mu2e group composition for Year 2022

Ricercatori/Tecnologi LNF (6,5/9)

S. Bini (0,4) Ric
C. Bloise (0,8) Dir. Ric
F. Colao (Ass. Enea) (0,5)
M. Cordelli (Ass. senior) (0)
F. Fontana (0,5) (Ass. UniMarconi),
S. Giovannella (0,7) I Ric, L3+L2
F. Happacher (0,9) Ric, L3, Res. Locale
M. Martini (0,3) (Ass. UniMarconi) L3
S. Miscetti (0,8) Dir. Ric. (Res. Nazionale) + L2
D. Rinaldi (Ass. Ancona) (1,0)
I. Sarra (0,7) Art. 36 L3

Tot FTE (Ric+Tecnologi+PHD) => 9.6/15= 0,7

Non strutturati (4 FTE/4)

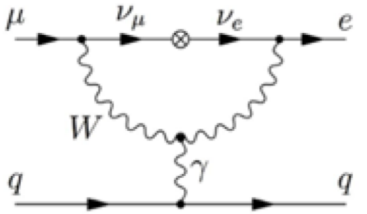
M. Ricci (1,0) Dottorando UniMarconi
E. Diociaiuti (1,0) AR
L. Montalto (Ass. Ancona) (1,0), associazione in progress
D.Paesani (1,0) Dottorando UniTov, associazione in progress

DR: G.Pileggi(0,2), A.Saputi(0,3) L3 , E.Capitolo (0,2), A. Russo (0,5), D. Pierluigi (0,5)
SEA (6 MU) G.Corradi (0,5) L3, S.Ceravolo (0,5), B.Ponzio(0,2)
Servizio Vuoto: V. Lollo
Allineamento: M. Paris, F. Putino
SPCM: 6 MU

Mu2e Experiment

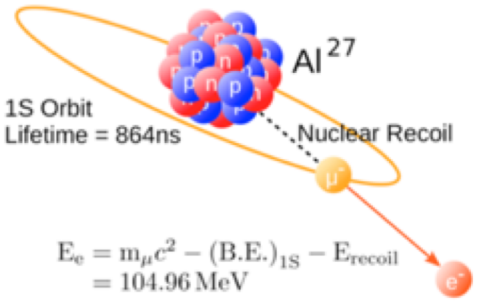
- μ converts into an electron in presence of a nucleus $\mu^- N \rightarrow e^- N$
  - μ-e conversion is an example of CLFV
- CLFV processes are forbidden in the Standard Model

  Assuming neutrino oscillation, they are allowed BUT negligible with BR $\sim 10^{-52}$
- **Any observation will be a clear evidence of New Physics**

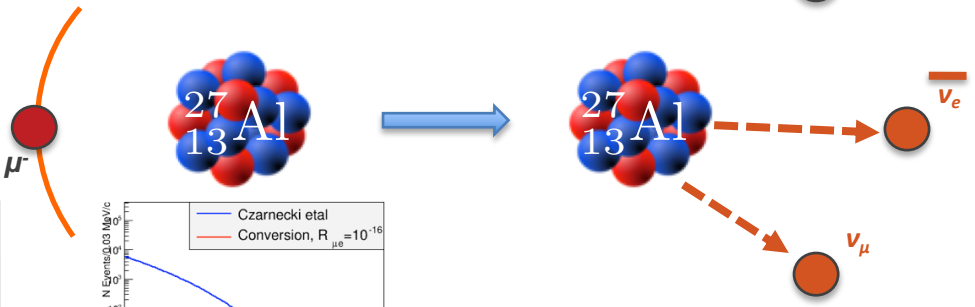


Mu2e will measure the rate of the μ-e conversion normalised to the μ captures in nuclei.
Improve by 4 orders of magnitude the current best limit set by Sindrum-II : $R_{\mu e} < 7 \times 10^{-13}$

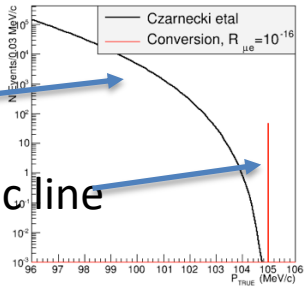
$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z) \rightarrow e^- + N(A,Z))}{\Gamma(\mu^- + N(A,Z) \rightarrow \nu_\mu + N(A,Z-1))} \leq 8 \times 10^{-17} (@\ 90\%\mathrm{CL})$$

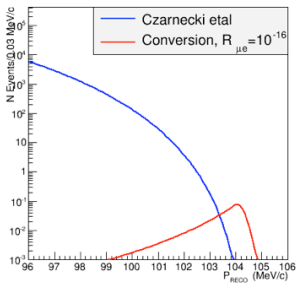


$$[\mu^- + A(N,Z)]^{1S}_{bound} \rightarrow A(N,Z) + e^- + \bar{\nu}_e + \nu_\mu$$



-Michel spectrum
-Converison *e* monochromatic line

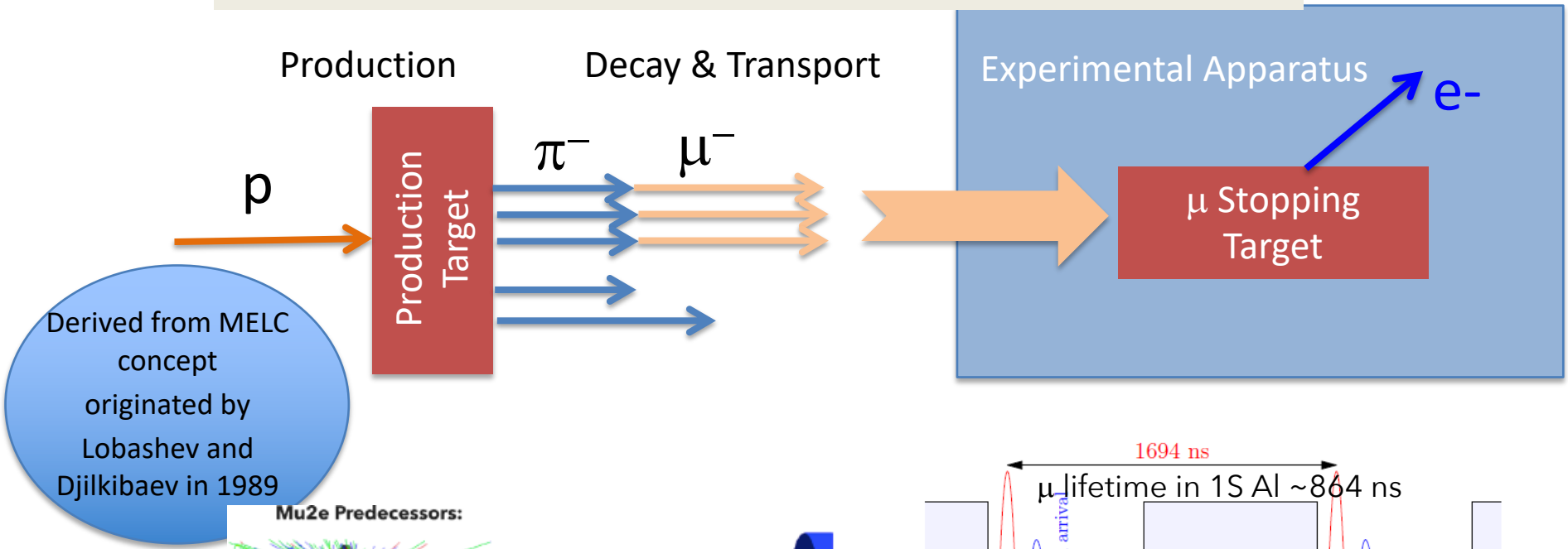


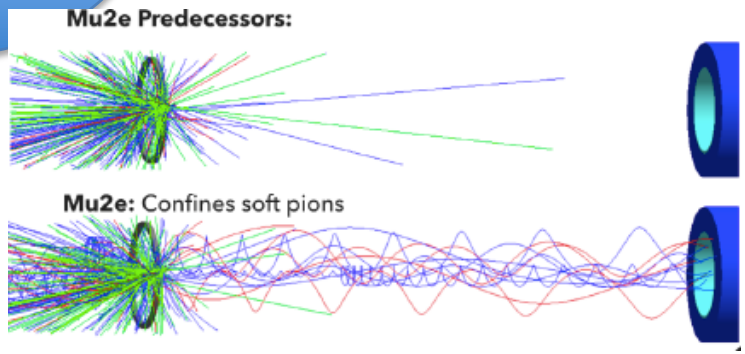


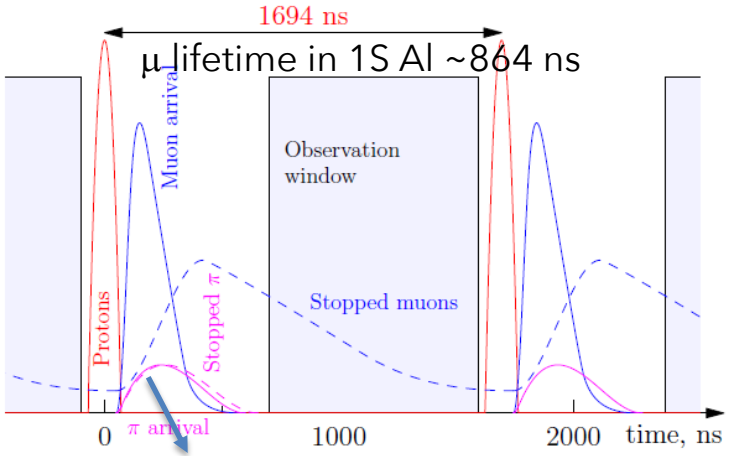
Resolution effects drive the detectors requirements

Mu2e Concept in a sketch

1. High intensity Muon Beams (> x 100 w.r.t. existing facility up to 10^{10} mu/sec)
2. Pulsed beam to eliminate prompt background
3. High proton extinction between pulses
4. High precision spectrometer and calorimeter



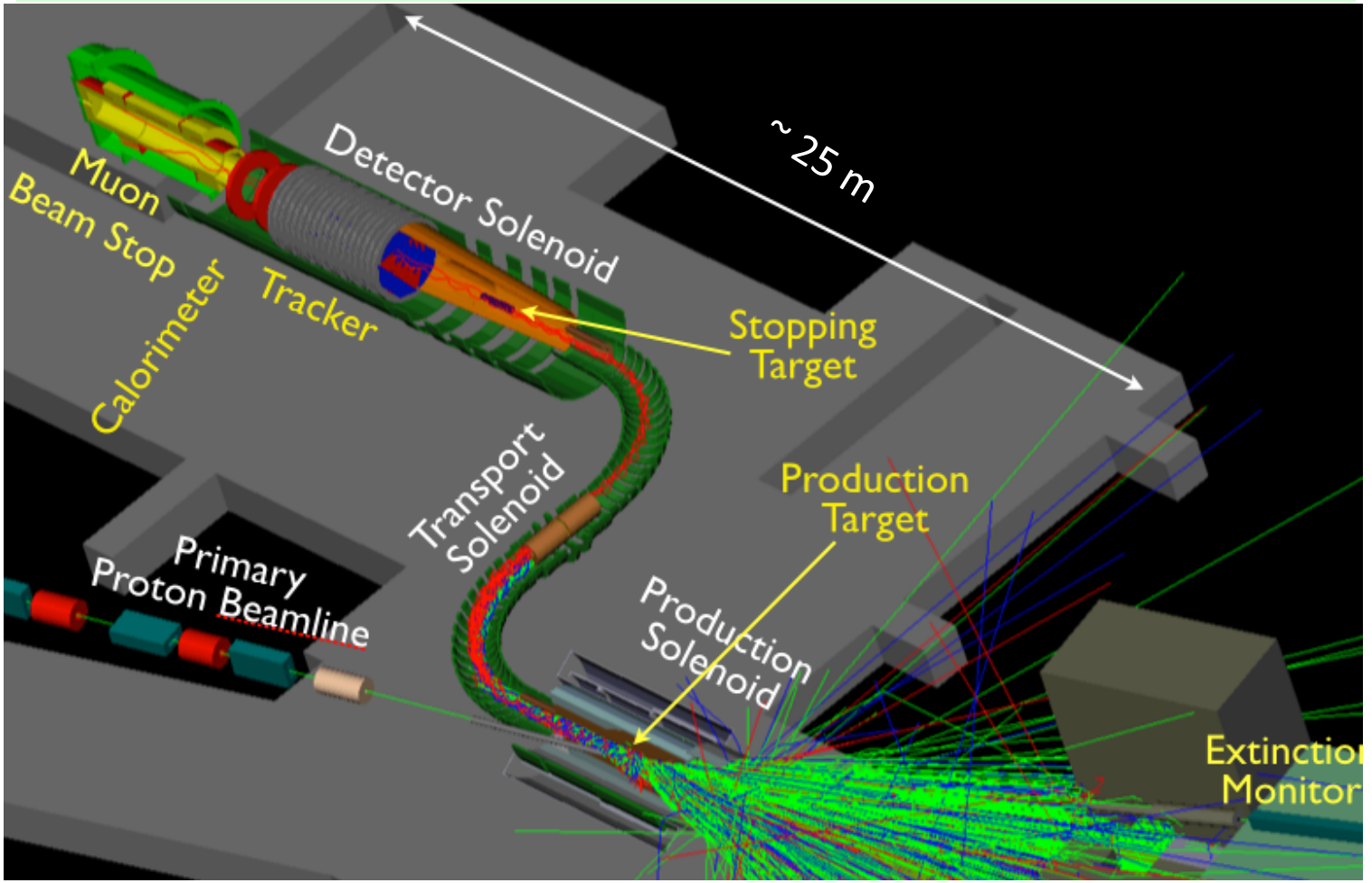




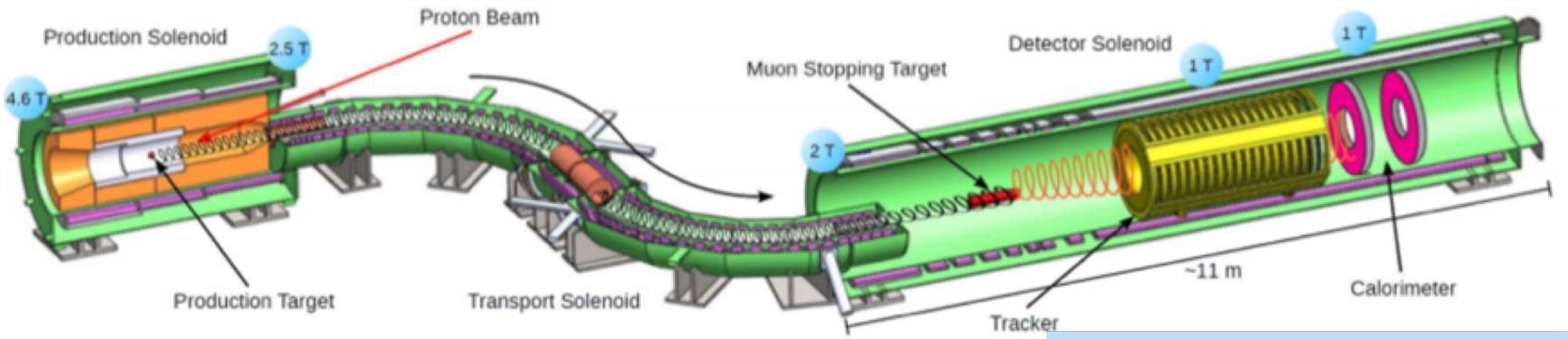
RPC background cut out

Mu2e Experimental Apparatus

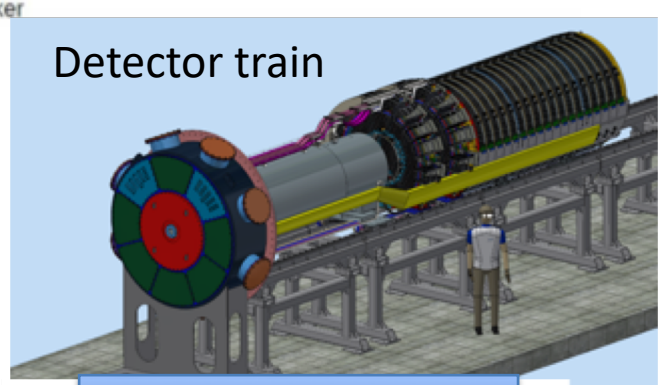
From the cartoons …. To real tough life

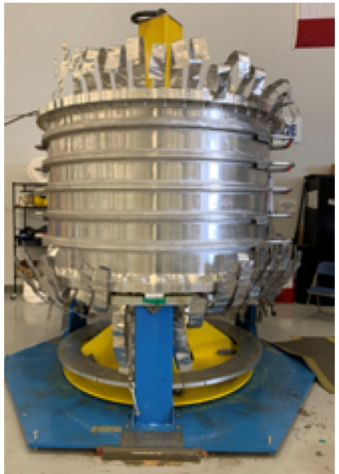


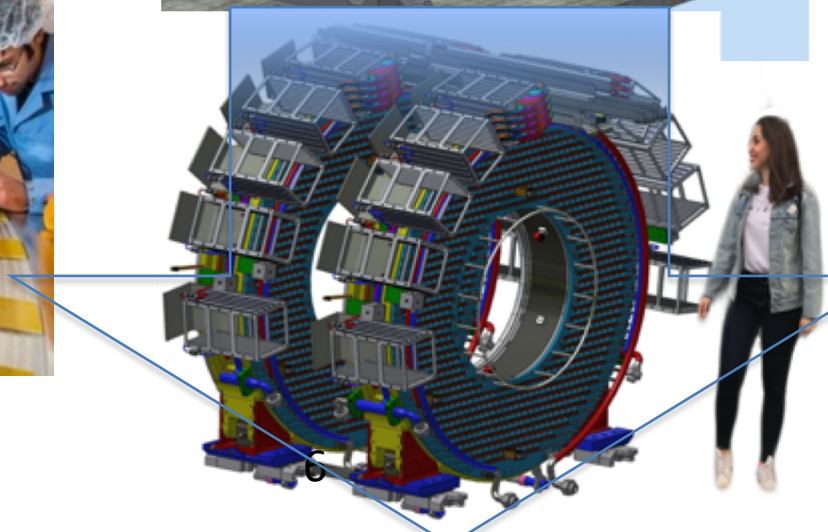
Mu2e experimental setup



Detector train







Mu2e Calorimeter

- mainly INFN with contributions from Caltech and FNAL

LNF responsible for calorimeter construction: S. Miscetti - L2 Calorimeter; - S. Giovannella - L2 Operations and L3 Crystals; M. Martini L3 photosensors ; F. Happacher and A. Saputi- L3 Mechanics and Installation ; G. Corradi - L3 FEE

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Requirements

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

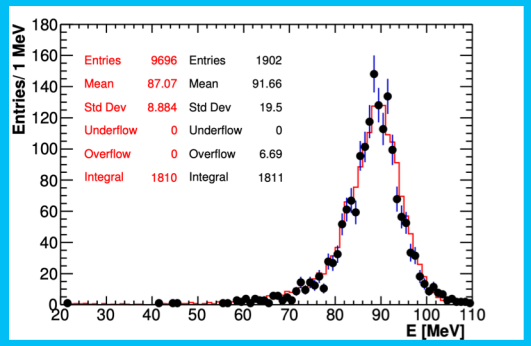
- Fast ($\tau < 40$ ns)
- Operate at 1 T and 10^{-4} Torr
- Redundancy in readout to operate 1 year w/o interruption
- Radiation hard: 90 krad and $3\times10^{12} n_{1MeV}/cm^2$

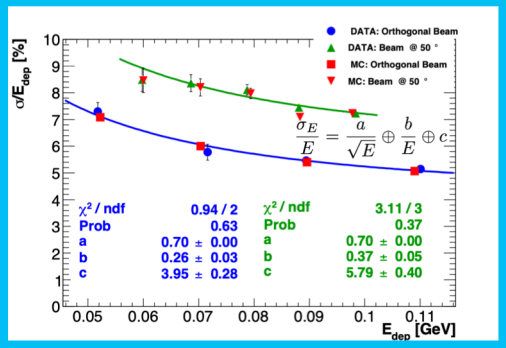
- 2 annular disks filled with 674 pure CSI crystal (34x34x200 mm^3) each
- 2 custom array of UV-extended SiPM per crystal
- R_{in}= 35.1 cm, R_{out}= 66 cm
- 1 FEE/SiPM, Digital readout on crates
- Calibration/Monitoring with 6 MeV radioactive source and a laser system
- Cooling system

Calorimeter Performances from Module-0

energy

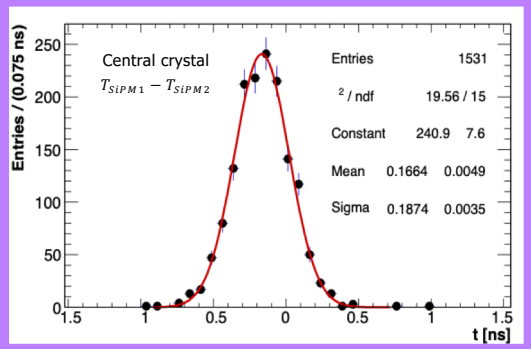
- single particle selection
- Mips equalization and time scale
- LY/SiPM =30 Npe/MeV
- Excellent Data-Mc agreement
- 5.4% (7.3%) resolution @100 MeV for 0° (50°) impact angles

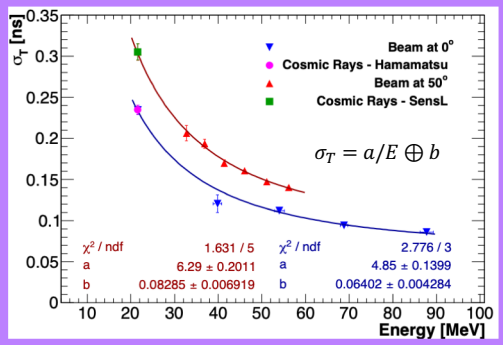




Timing

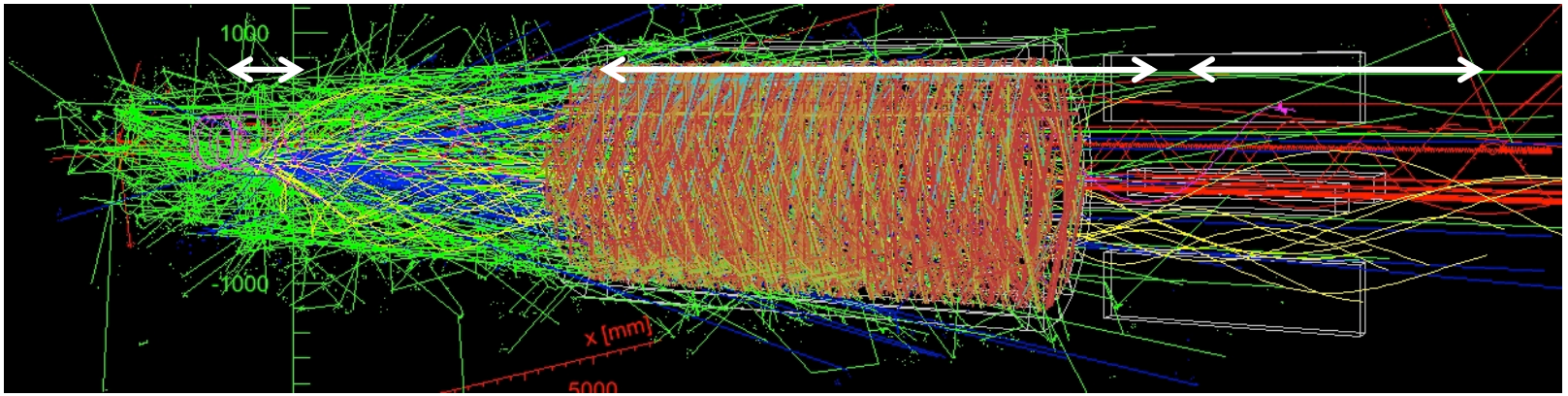
- Log-normal fit on leading edge+ Constant Fraction method @5%
- Timing resolution <150 ps @ 100 MeV



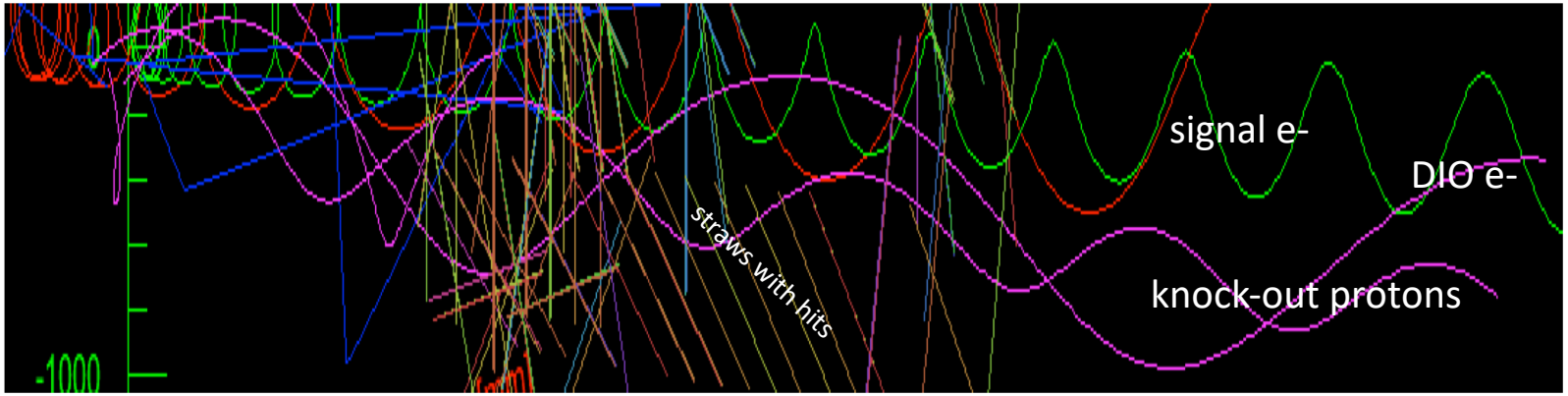


Mu2e Pattern Recognition

Stopping Target Straw Tracker Crystal Calorimeter

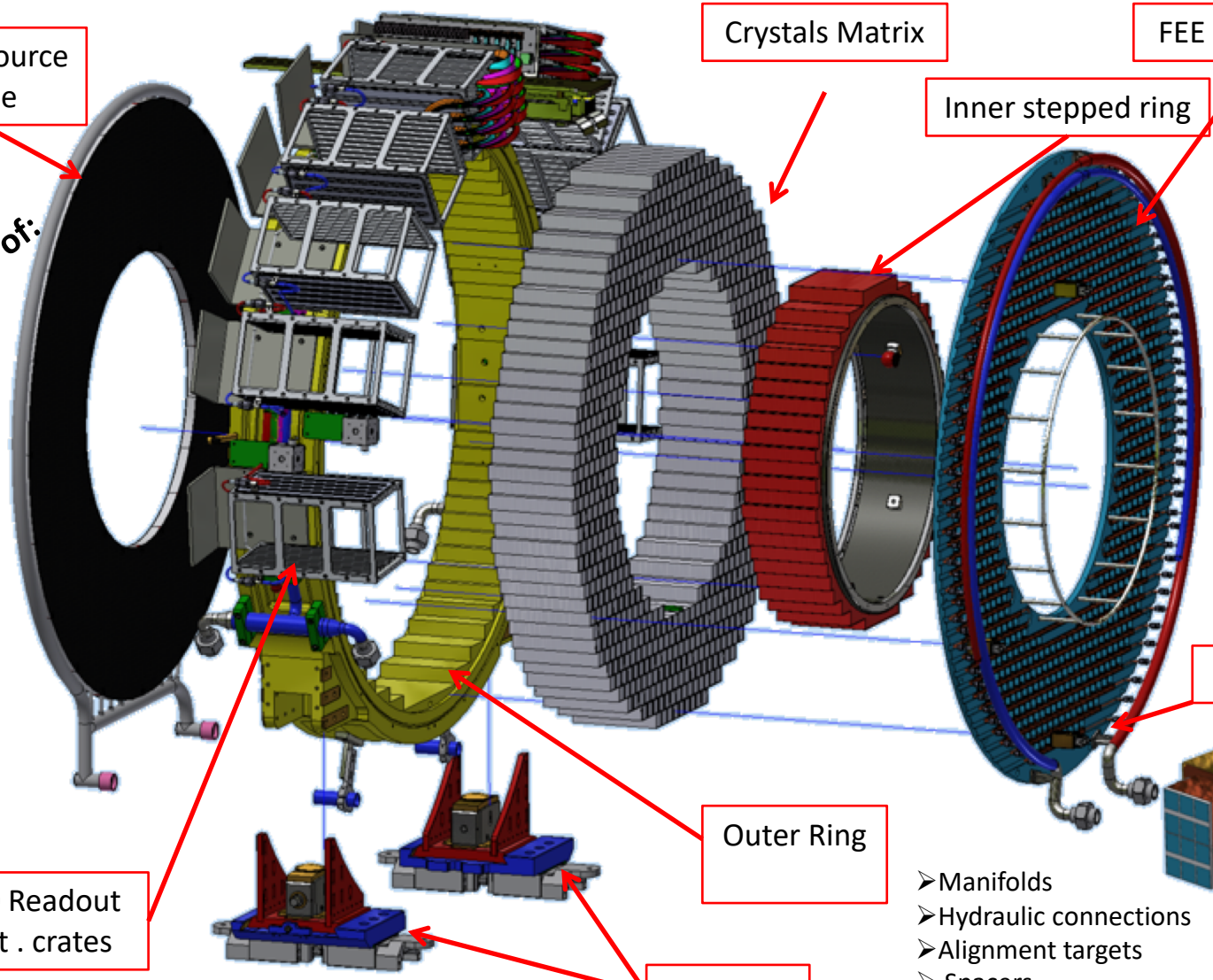


A signal electron, together with all the other interactions

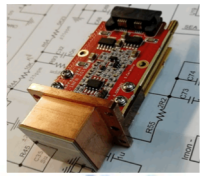


particles with hits within +/-50 ns of signal electron t_{mean}

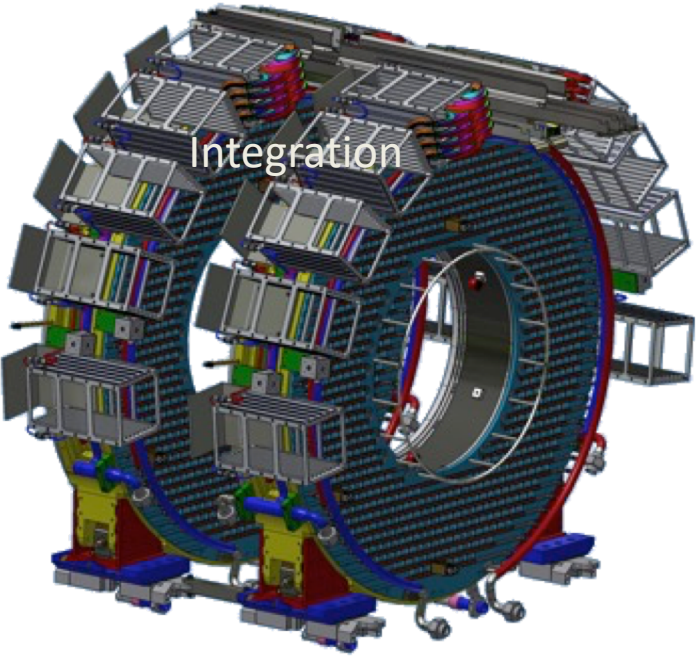
Calorimeter exploded view



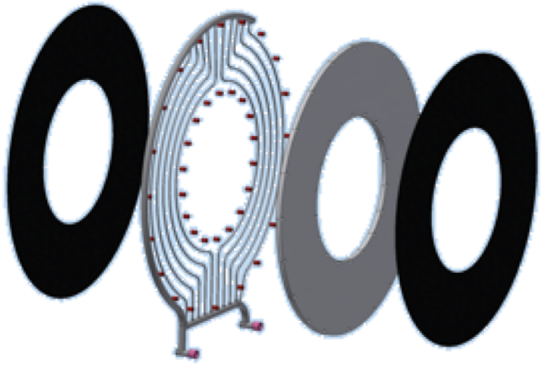
- Manifolds
- Hydraulic connections
- Alignment targets
- Spacers
- calibration

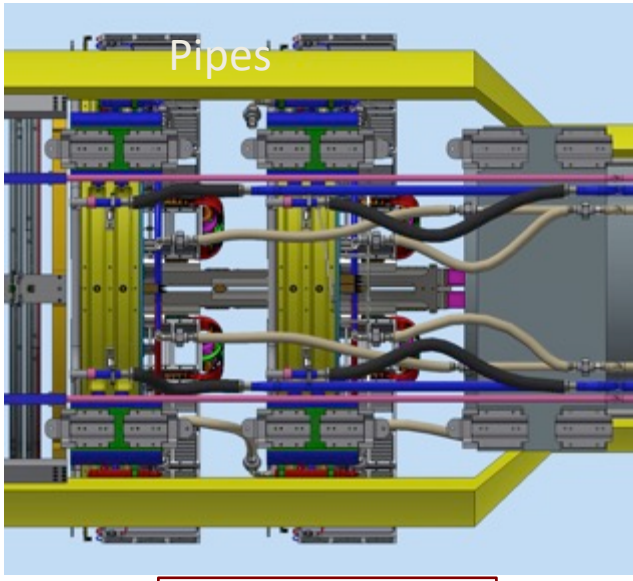


Mechanics and integration where we are: CAD

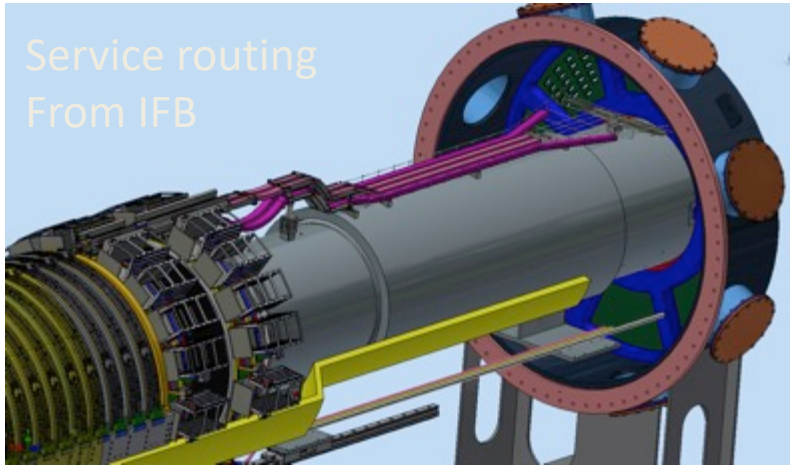


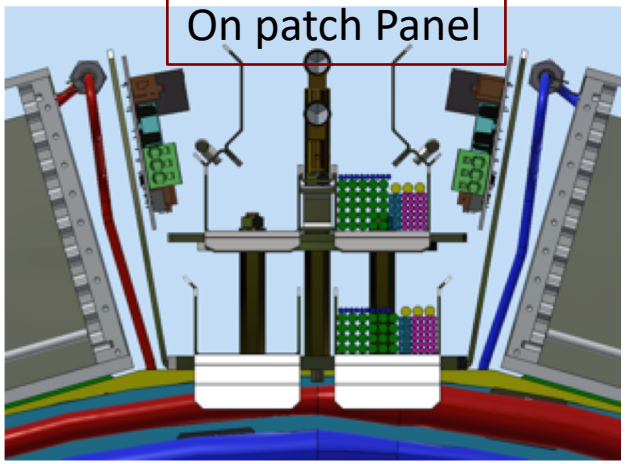
Front Panel CF with embedded source





Cable routing
On patch Panel





LNF group Activities

Mechanics:

- Completed the design, integration of the calorimeter components within our envelope and addressed all interferences with the Detector Solenoid components
- Outer Rings construction - done
- Feet construction – in progress
- Following the manufacturing of Carbon Fiber parts at CETMA
- SiPM Holder and Faraday cages
- SiPM gluing - Activity supposed to be carried out at FNAL -> moved to LNF
  - Shipment of SiPMs – gluing tools at LNF – Shifts ongoing
- Resumed activity at FNAL – Calo assembly tools preparation
- Dry Run of the Mechanical components in Astra clean room

Crystals

- All ready and tested (**PRODUCTION 100% COMPLETED**).

Electronics

- FEE design, construction and testing
- FEE **production 100% completed**, QC in progress
- Integration of SiPM+FEE+Holder+FaradayCage case

Prototyping and Module-0 /slice test@LNF

- Integration of the state-of-the-art technology in the Module-0
  - Mechanics, cooling and full chain of electronic read-out

- CR Tagger construction

Outer cylinders

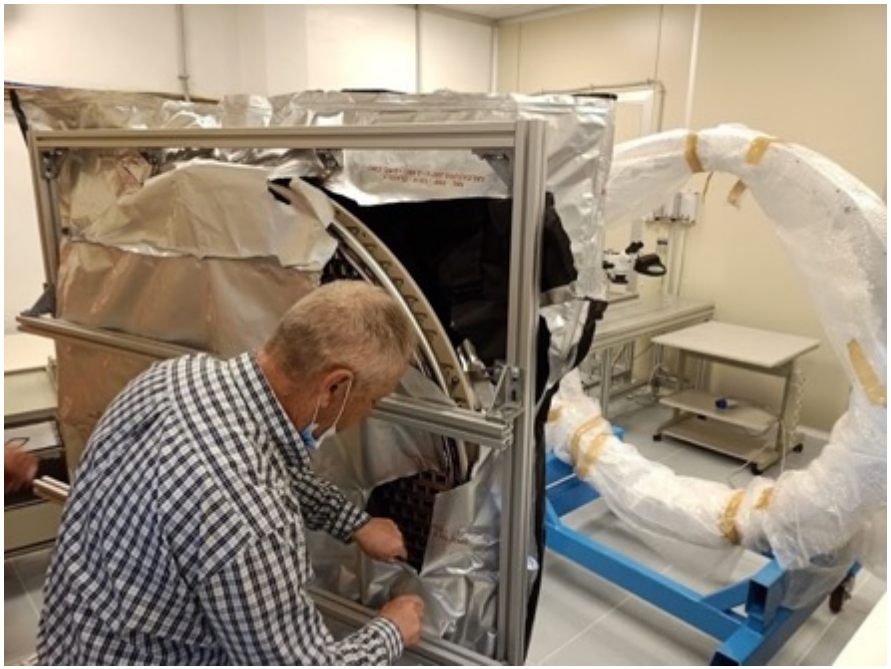
- Both ready, one is at FNAL on its stand. 2nd stand assembled

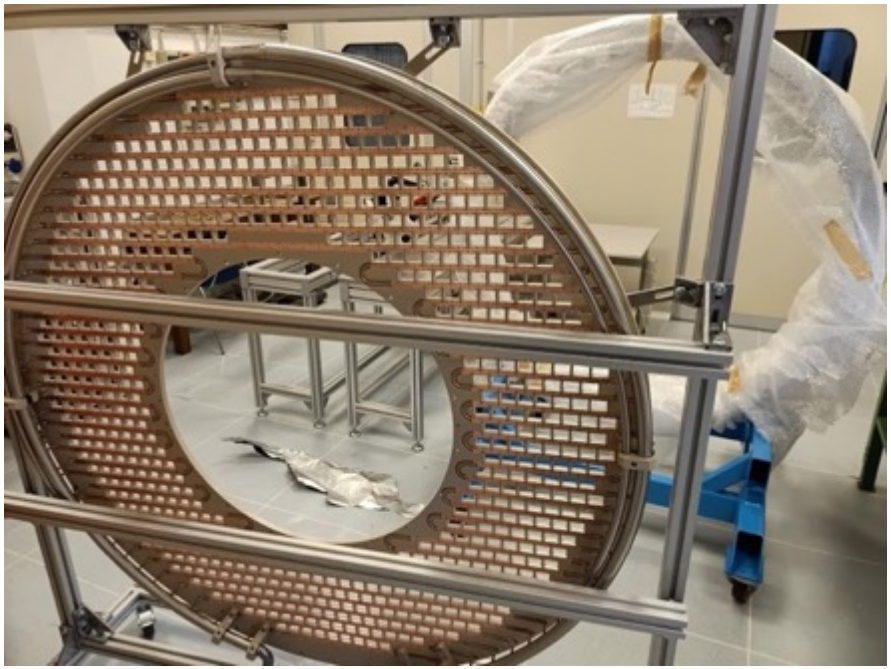
The second one is @LNF in a clean room washed and ready for dry run

Apr 2021

Dry Mechanical Run at LNF

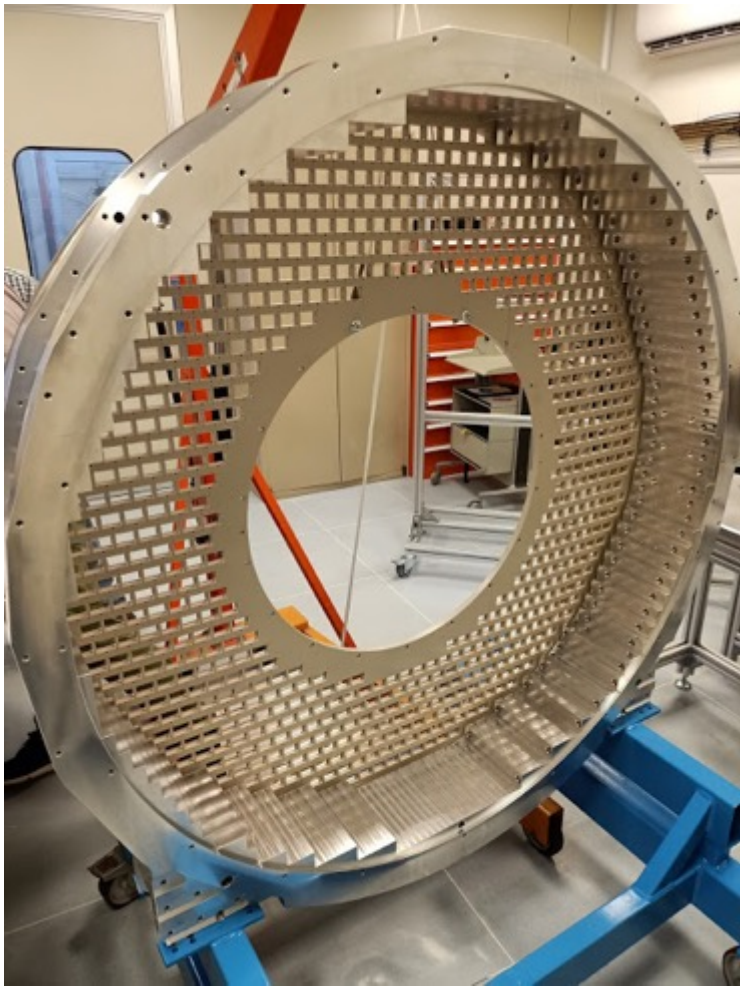
- After the dimensional and hydraulic QA we have shipped the 2 FEE Al Plates from Pisa to LNF
- Together with F. Raffaelli we have installed one FEE plate on the Outer cylinder in the LNF clean room using a dedicated stand





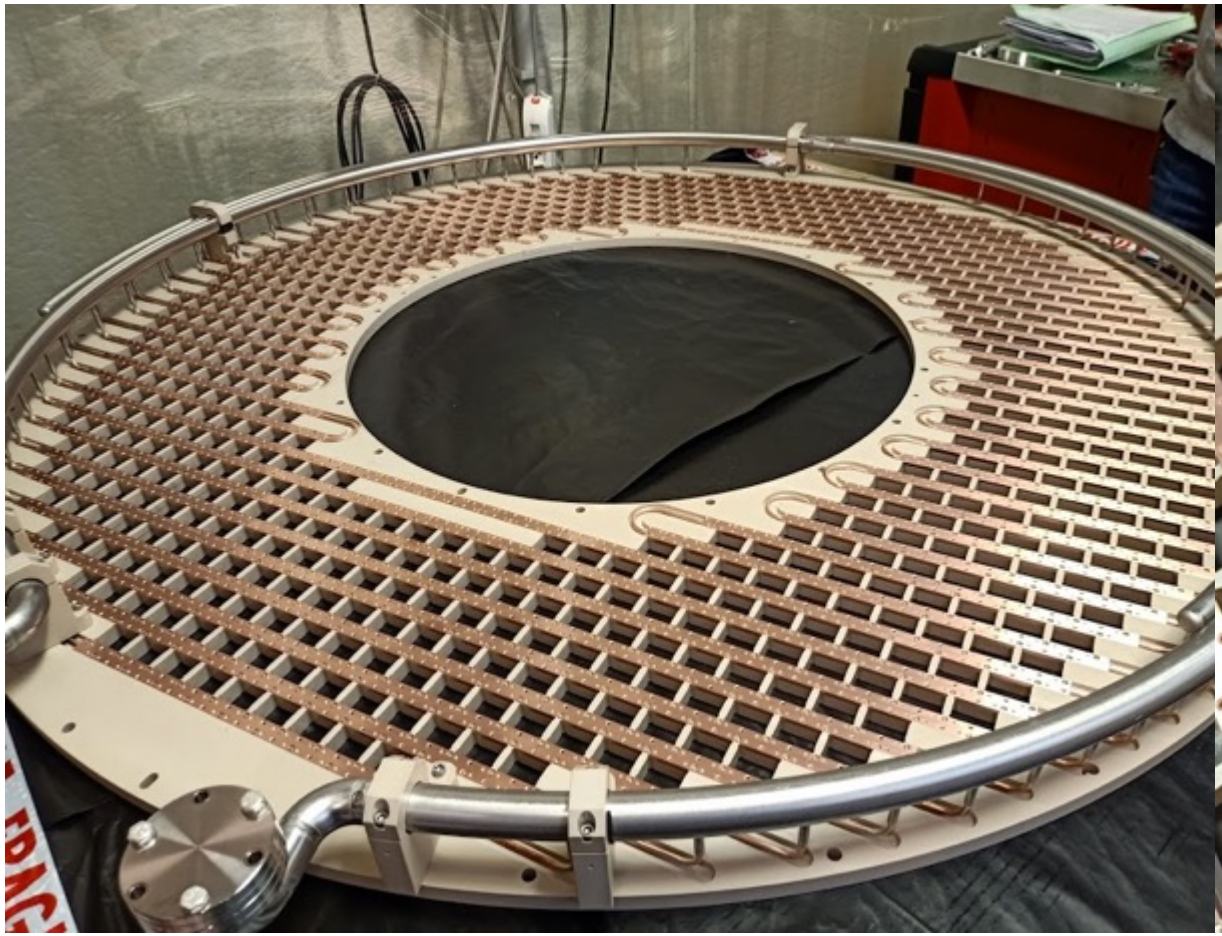
Outer Cylinder + FEE plate

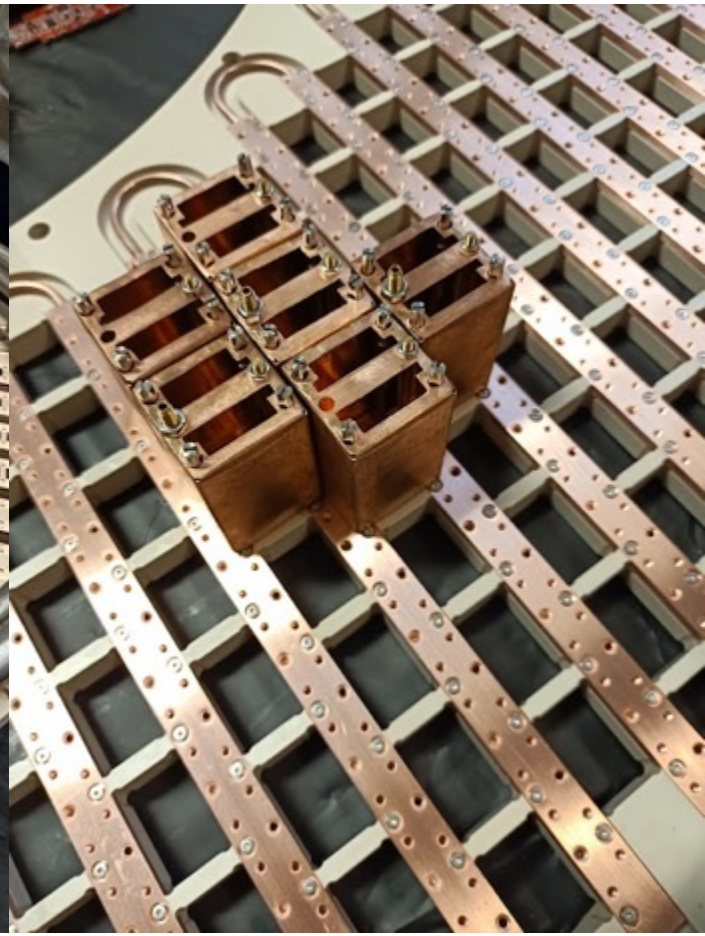
- Perfect match and easy assembly procedure
- LNF Metrology and Alignment squad performed a survey to cross check the geometry of the ring with the geometry of the plate
- Waiting for the company manufacturing crates and cooling manifold to come to LNF and check if everything is fitting
- A delicate test will be the shaping and laying down over the Outer ring groove of the cooling manifolds and the crates
- We will learn the exact position of all the connections of the IN/OUT cooling pipes of the crates and the manifolds



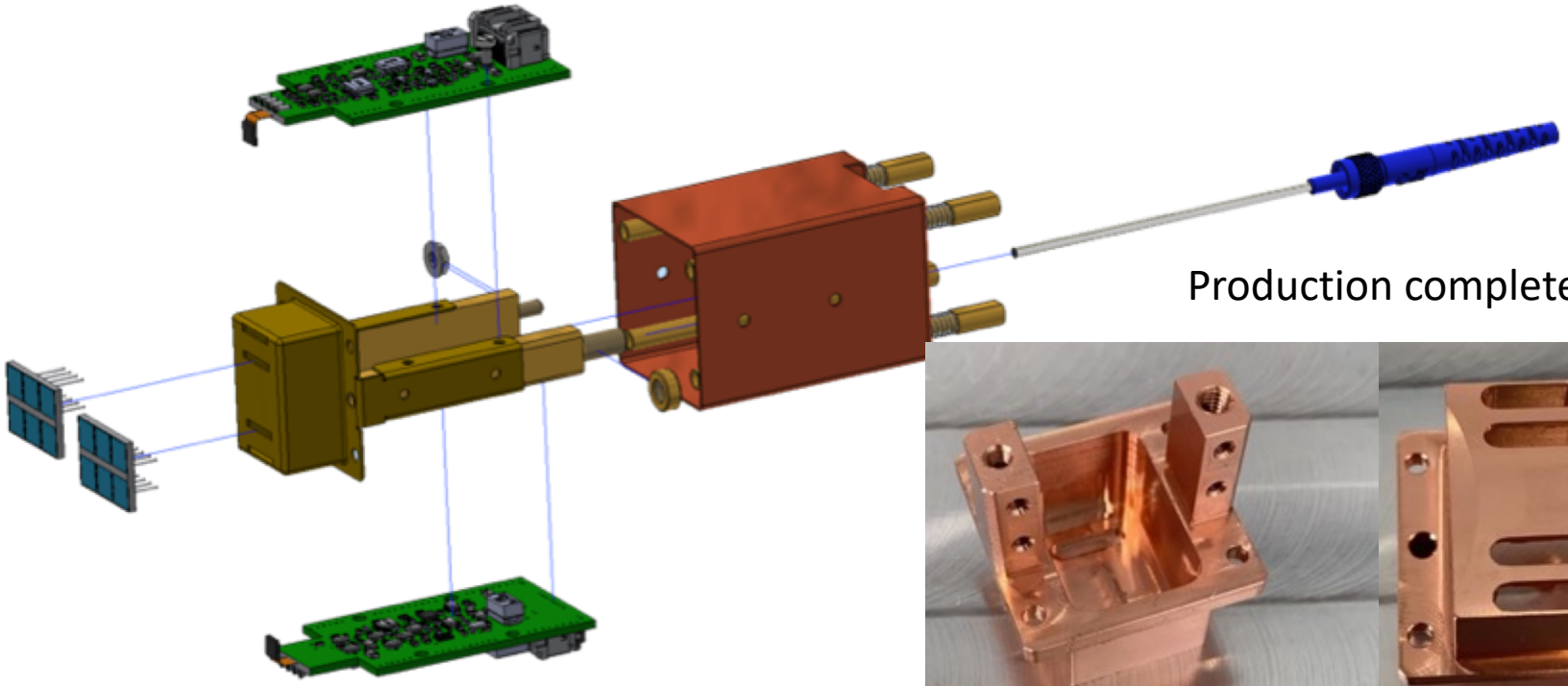
FEE plates

- Very nice component, houses the SiPM+FEE, Power dissipation and temperature control for SiPM's





SiPM+FEE holder – design and prod.

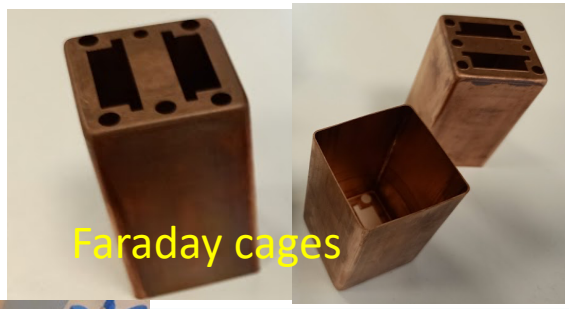


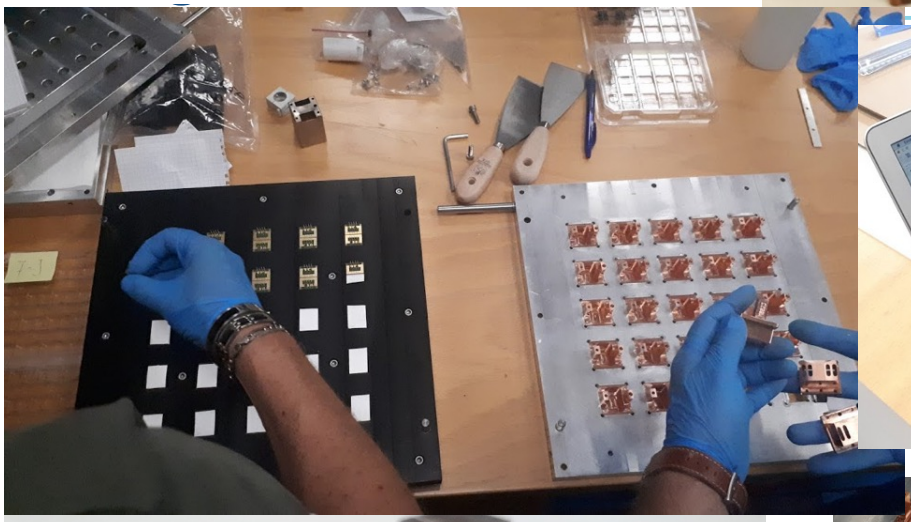
Production completed

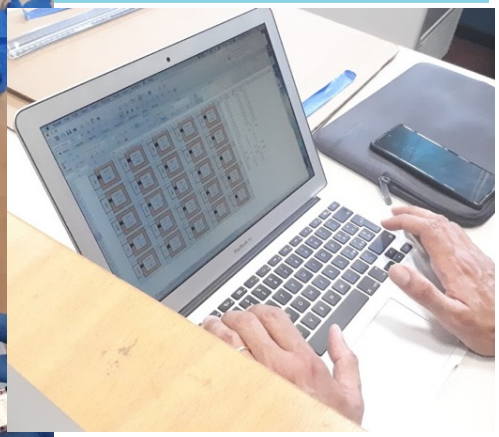
Production in progress

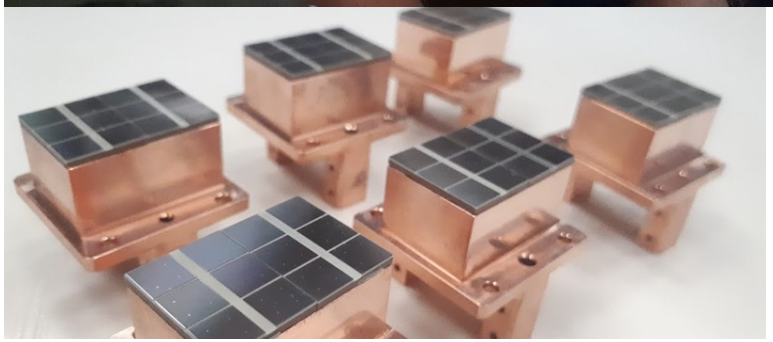
SiPM gluing on SiPM/FEE holders

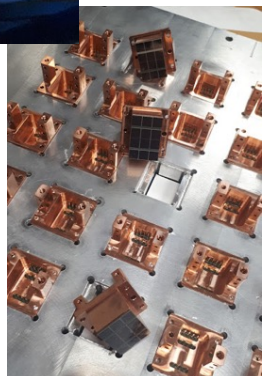
- ❑ All SiPM holders produced (1500 pieces)
- ❑ First 500 got an ultrasound bath + marked with HW numbering
  - → 37 glued with SiPMs and tested in Module-0
  - → 750 SiPMs + 380 holders glued @ LNF in April
  - → Other 750 imported end of May. **Gluing has started this week**
- ❑ **production of Faraday Cages is also under way**

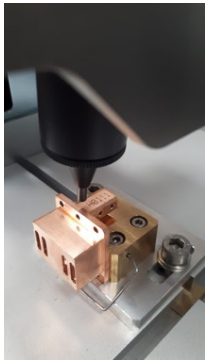




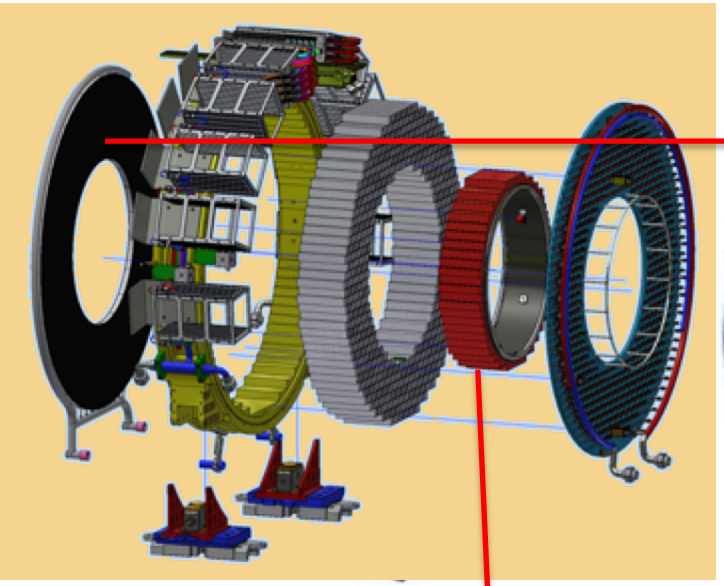




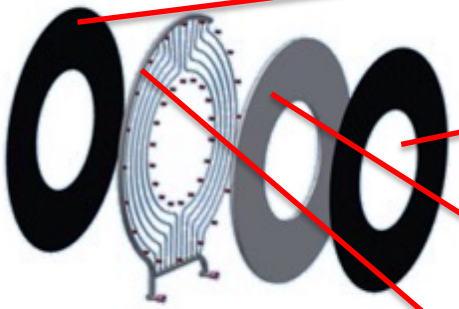


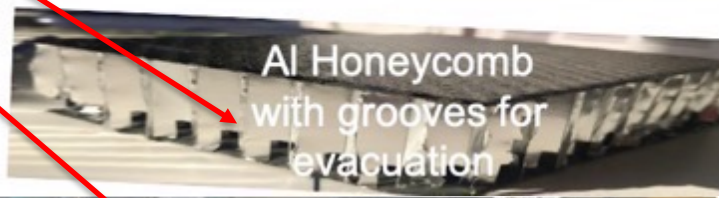


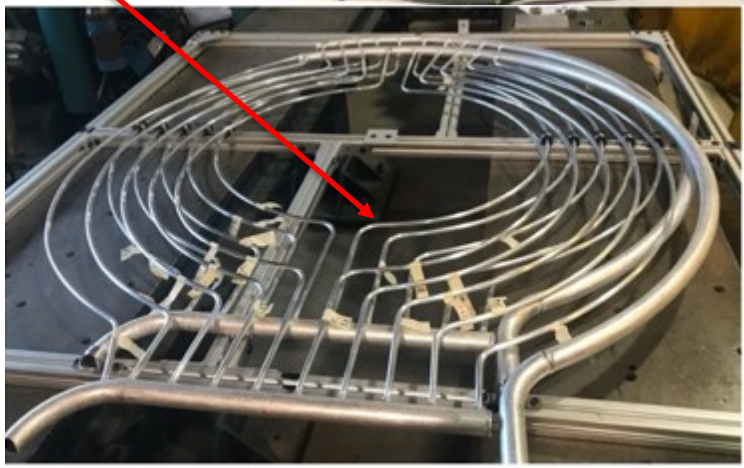
CF parts – Source plate



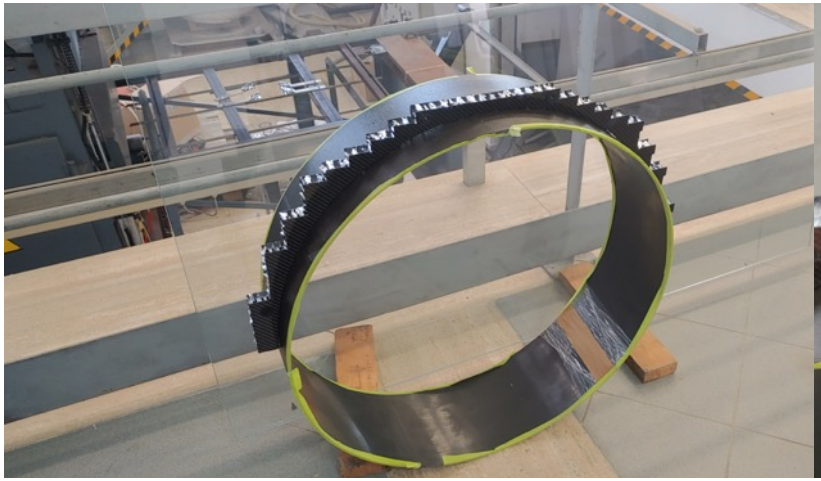
Front Panel CF with embedded source

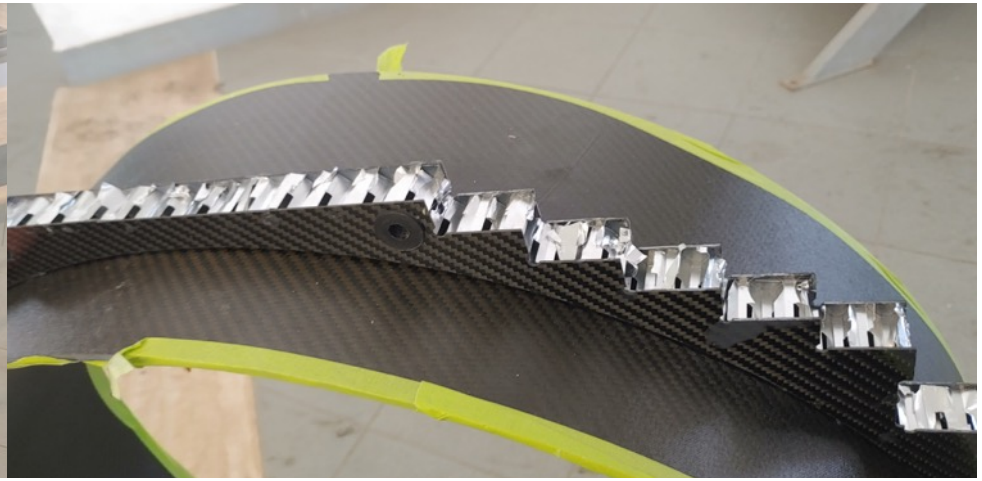


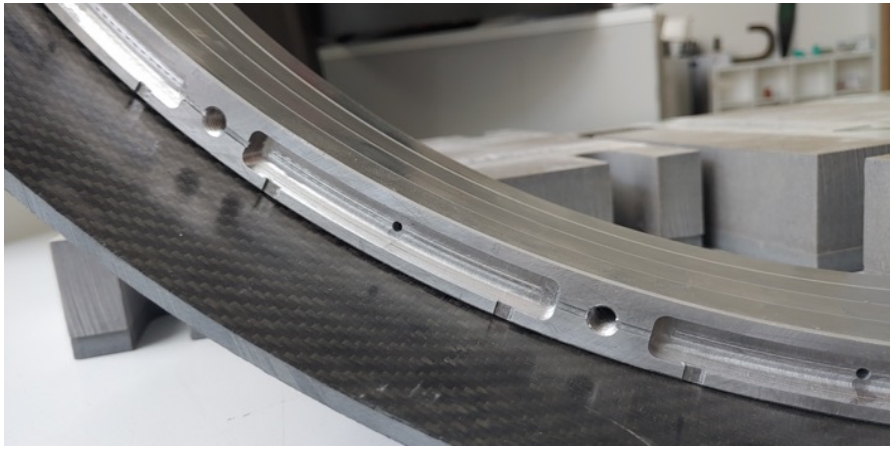




CF parts - Inner Ring



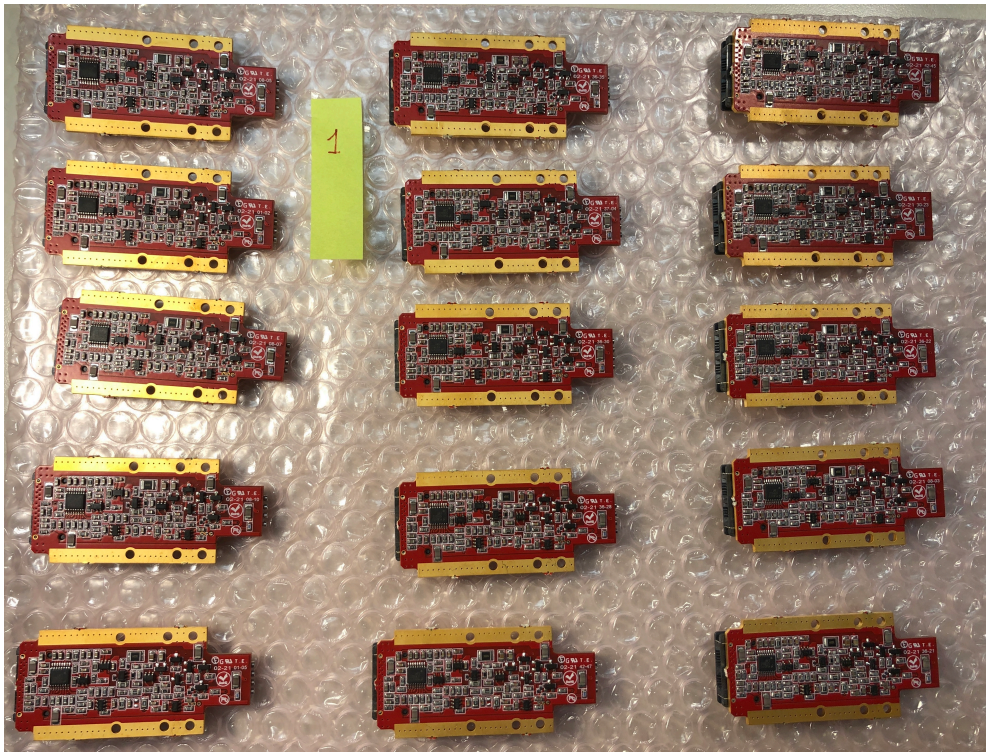


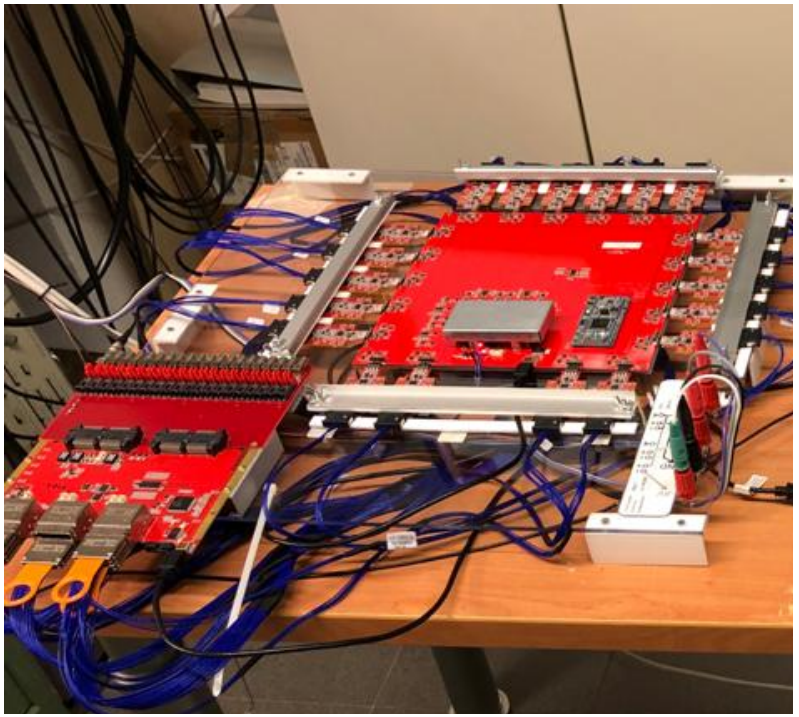


- All pieces available at CETMA for completing the InnerRing
- Expected to have it completed for early September

Rad-Hard FEE production status

3510 PCBs with mounted components produced
+ 10 used for irradiation tests
+ 80 for module-0 production and gain setting
Production pilot run in February: → 80 standard gain , 40 high gain for the PIN diodes
→ All the rest produced with largest batches (500-750 each)
→ All received or shipped from ARTEL to LNF , shifts for QC in progress

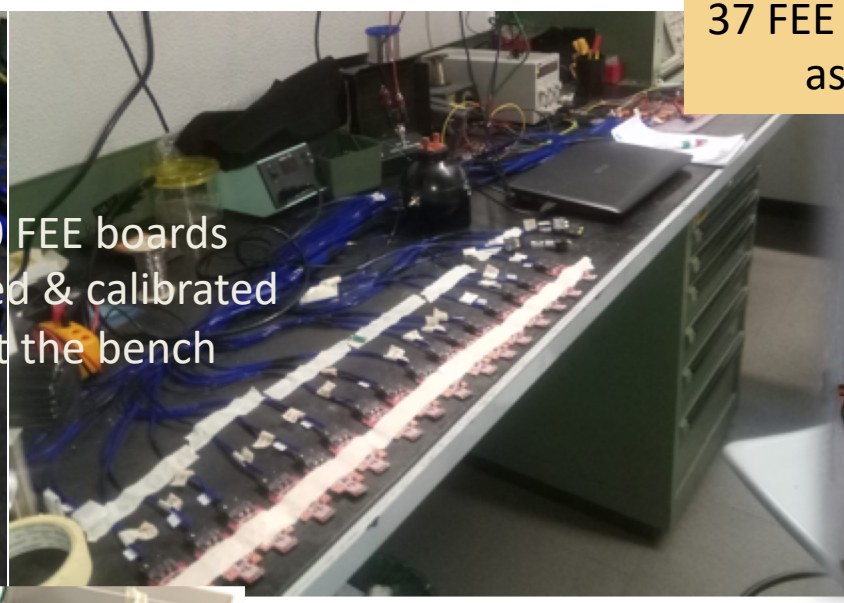




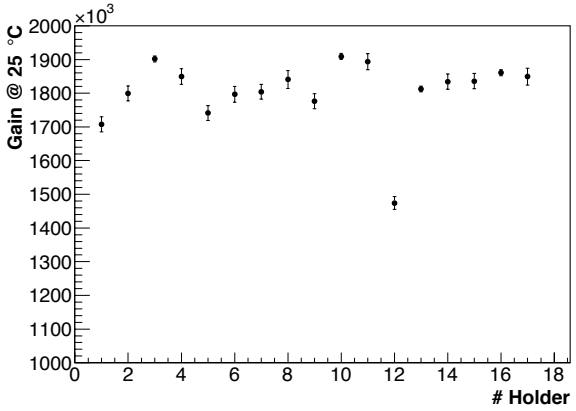
SiPM-FEE Assembly & QC test station @ LNF

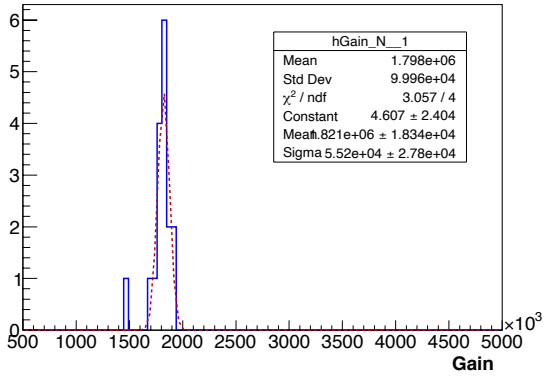
37 FEE holders with SIPMs glued + assembled with final FEE

80 FEE boards
Tested & calibrated
At the bench



QC of SiPM+FEE assembly with pulsed LED, filter wheel & integrating sphere

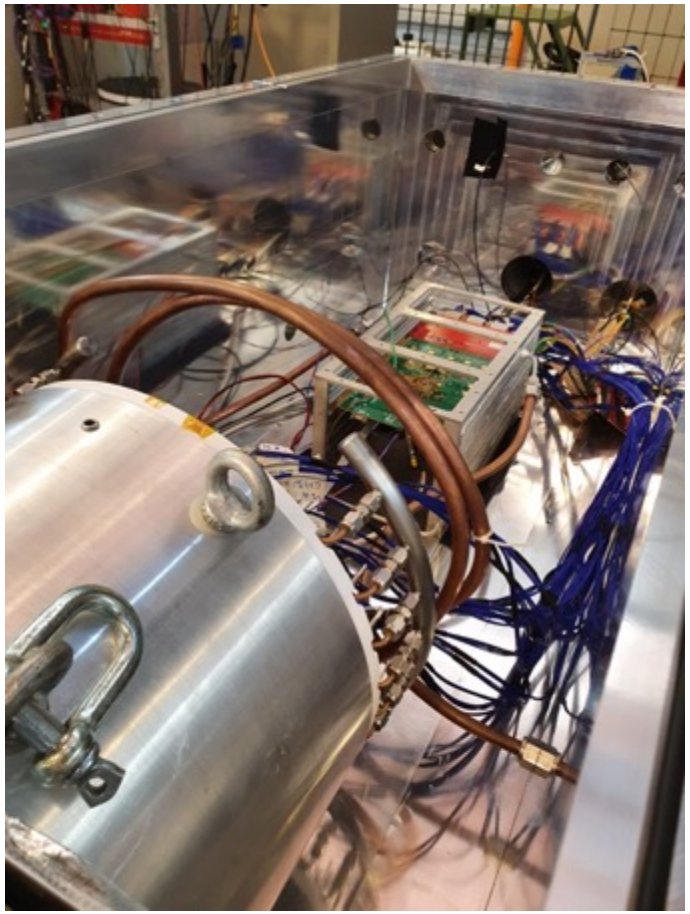


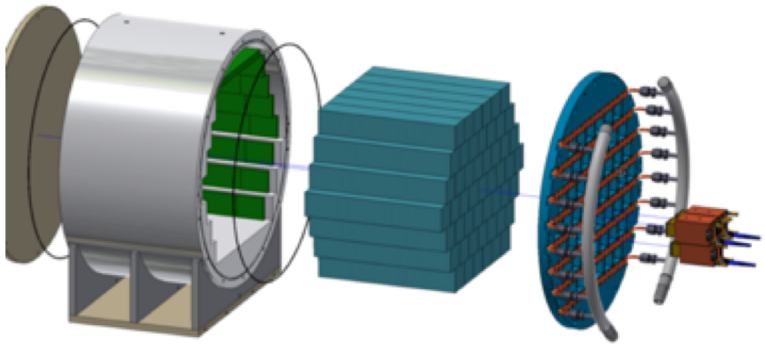


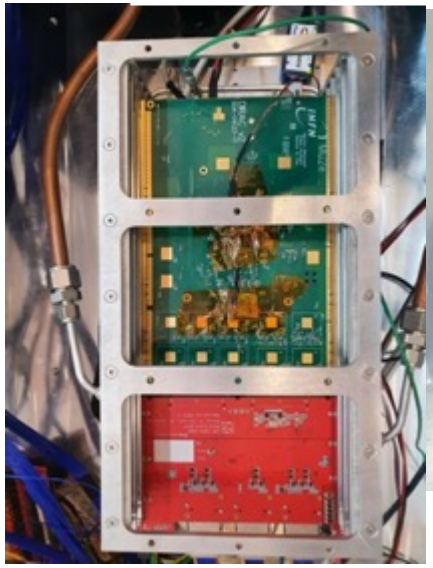
Calibrated Gain-RMS spread of O(3%)

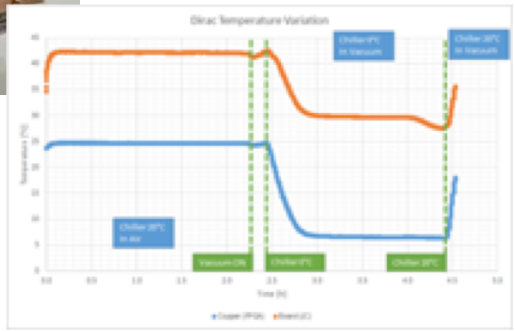
From CAEN to DIRAC (DIgitizer ReAout Controller)

- **Dirac Succesfully installed on May 11**, Temperature OK in vacuum
- (when chiller at 0 ℃, serial line from Module-0 to crate → MB+DIRAC 5-6 ℃)







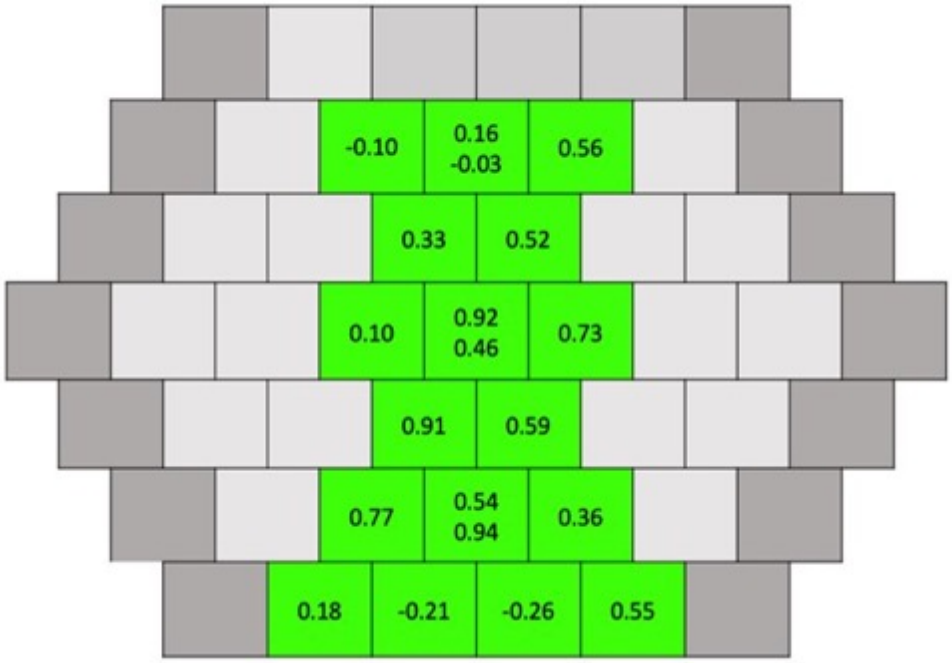


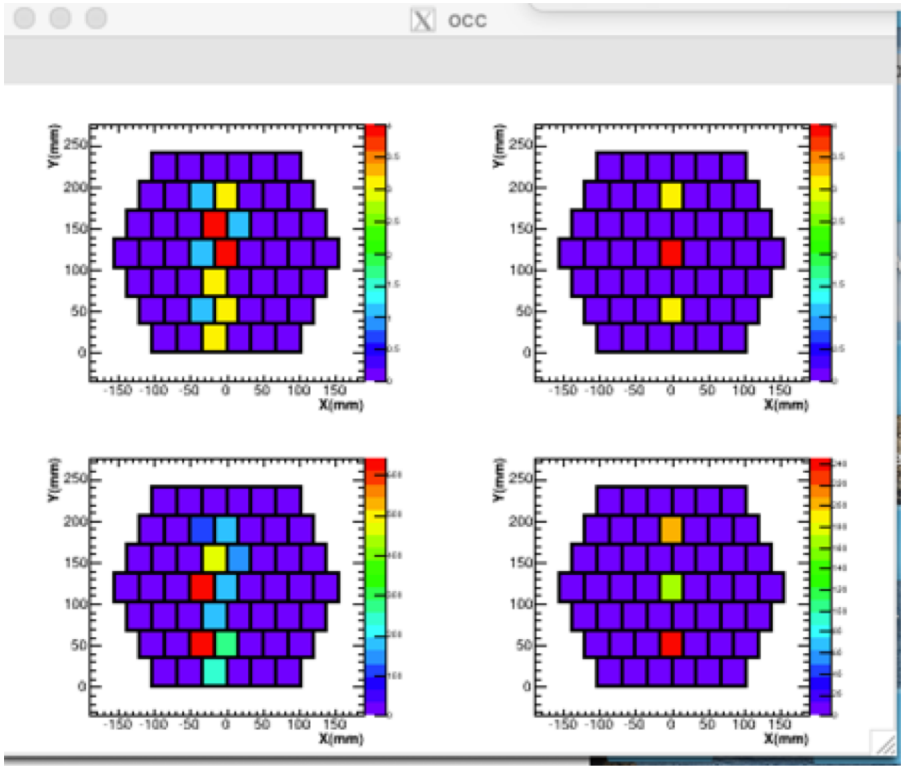
Pictures for the Module-0+DIRAC integration

Thanks to the entire team for this great success

Successful data taking and analysis with DIRAC

We have used 20 chs from a DIRAC to read 17 crystals + 3 with double readout



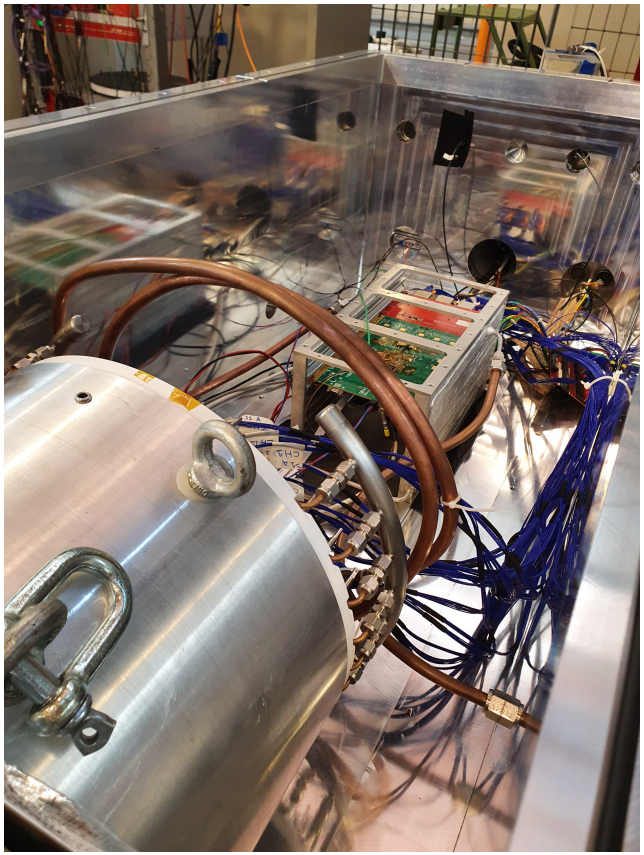


Next step for digital readout :

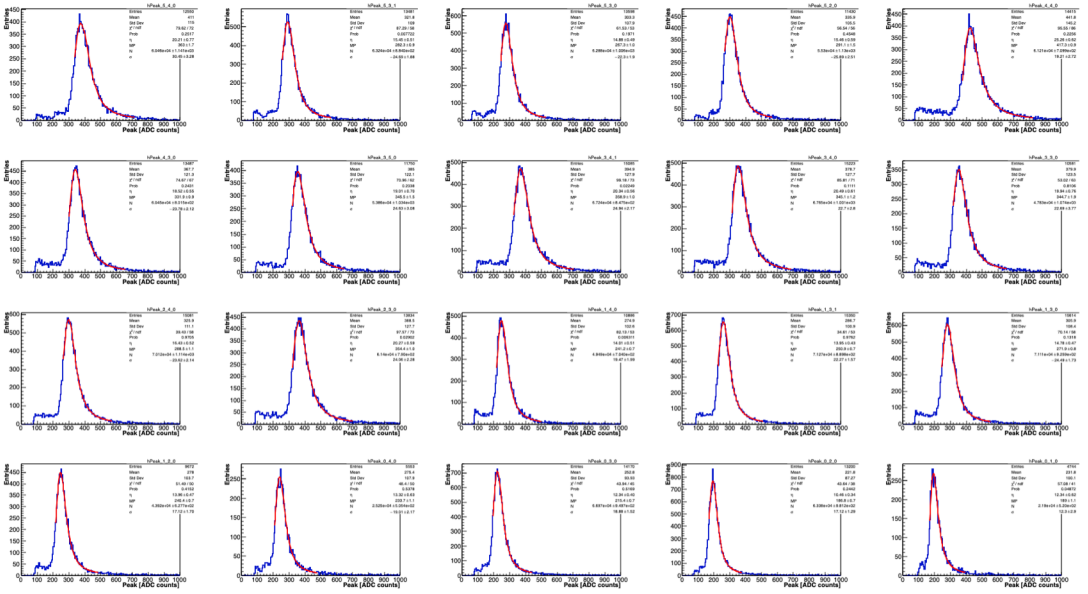
→ Move to DIRAC V3 + Complete TDAQ-fiber readout,

→ Understand the problems related to the VTRX transceiver

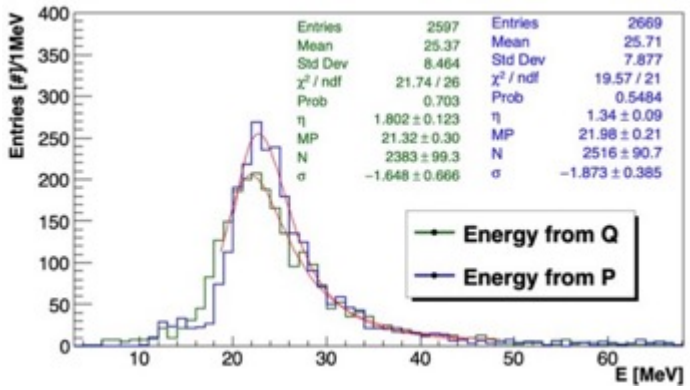
Vertical Slice Test

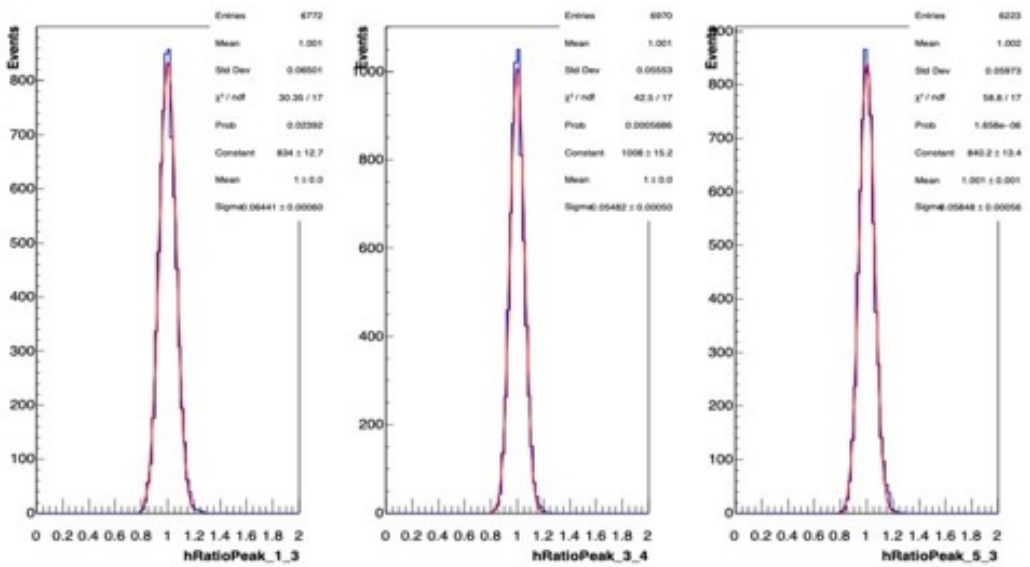


- First test with final DIRAC and Mezzanine boards
- 20 channels acquired, 3 crystals with double readout
- Similar configuration to the run condition in the experiment (temperature, vacuum, cabling)



Response, Light Yield and Timing

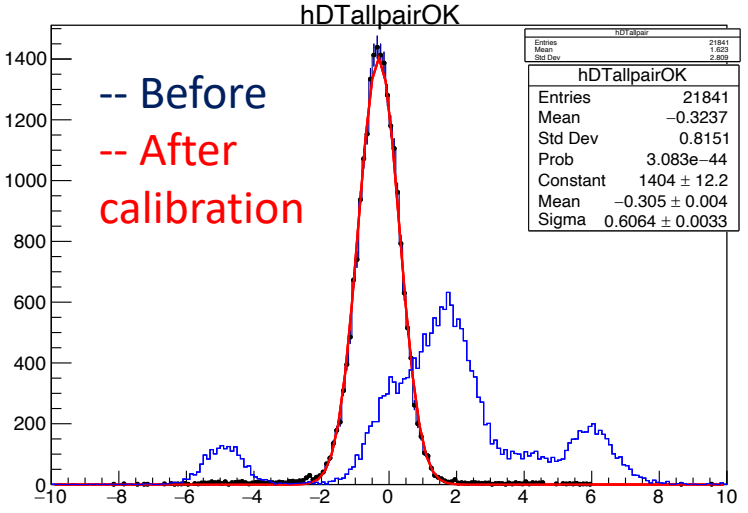




- Q reconstruction not yet completed due to the threshold
- P is a good response estimate
- DP/DHV being determined
- NPE estimated with L/R methods indicated LY in excess of 20 pe/MeV

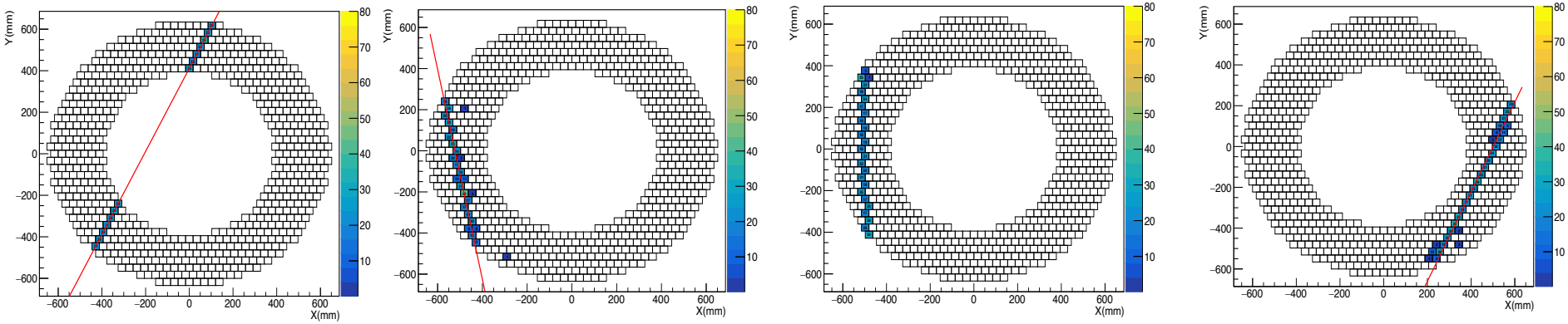
➔ Dependence on HV is small as expected by PDE behaviour

➔ Timing resolution excellent (better than 300 ps/MiP)



CR + Lumi + RMC photon spectrum

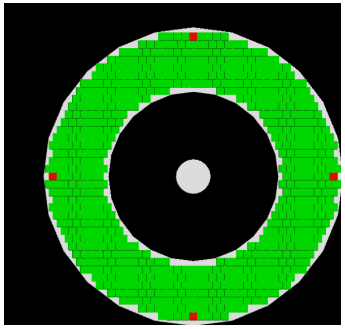
IN-OUT/OUT-IN **OUT-OUT** **Vertical -- Diagonal**

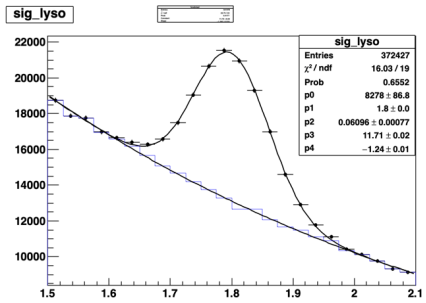


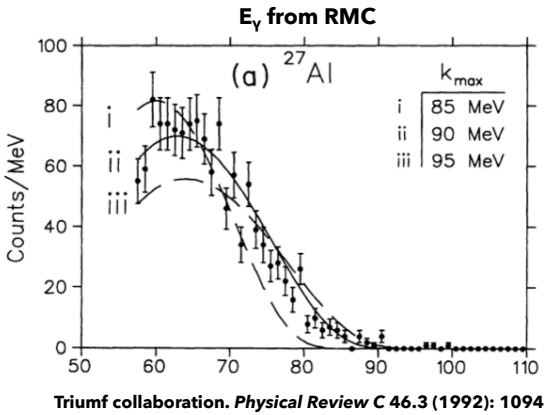
Calibration trigger for commissioning, 20Hz, clean MIP selection

1. Participation to the Lumi DS group with
   Caphri (LYSO crystals)+ PBI monitors
2. Proposal of a RMC photon trigger (15 Hz)
3. 1 thesis on fit to the RMC spectrum

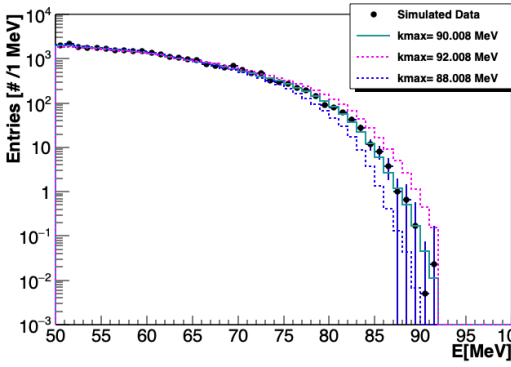
Ground state cascade golden emission line:



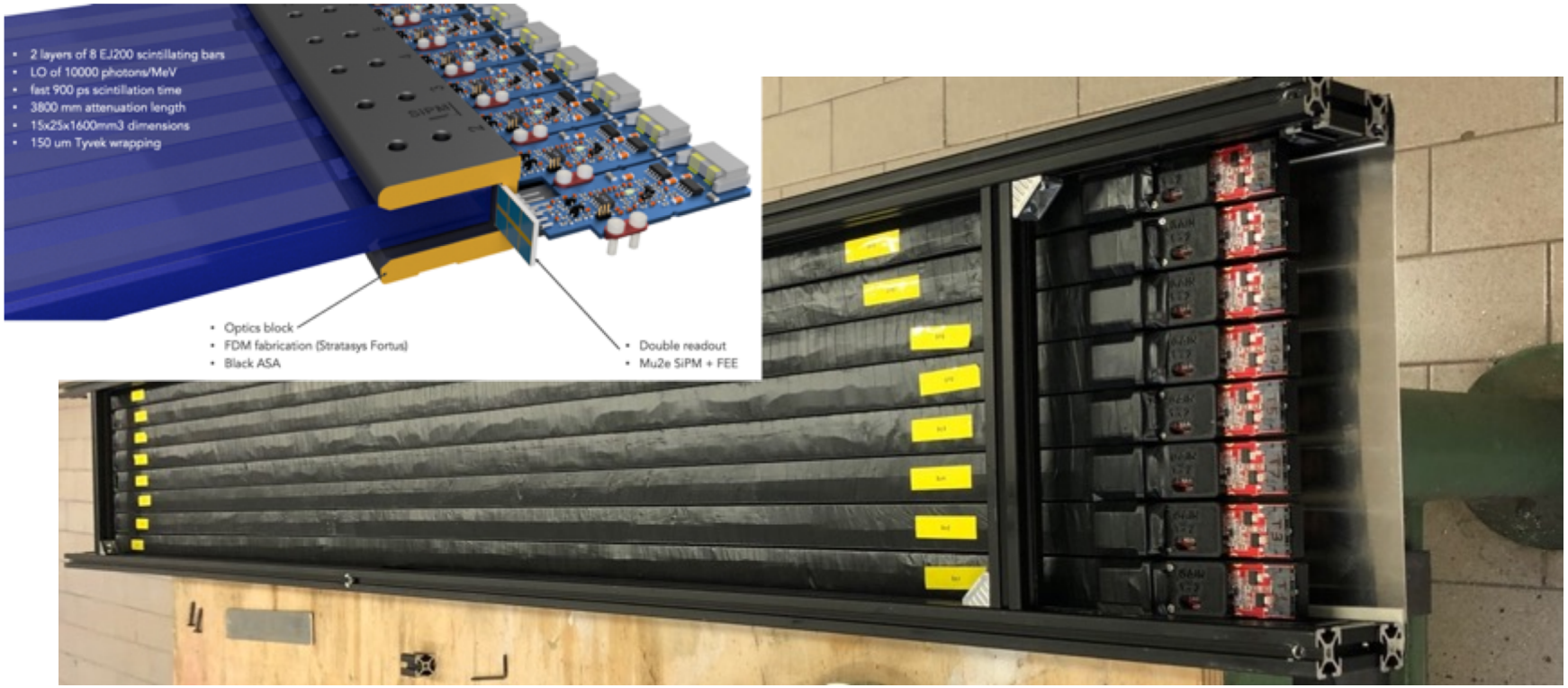




Triumf collaboration. *Physical Review C* 46.3 (1992): 1094

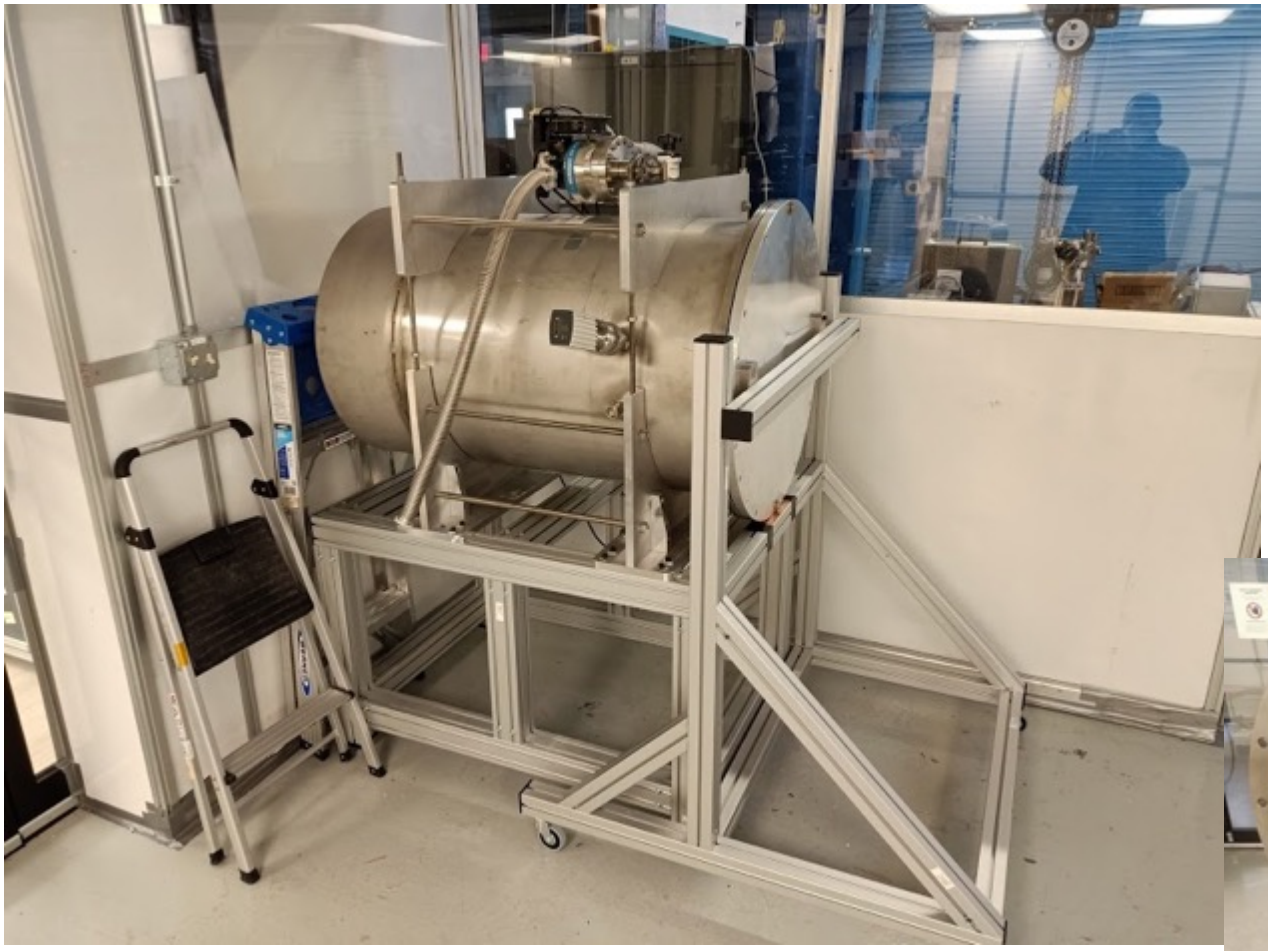


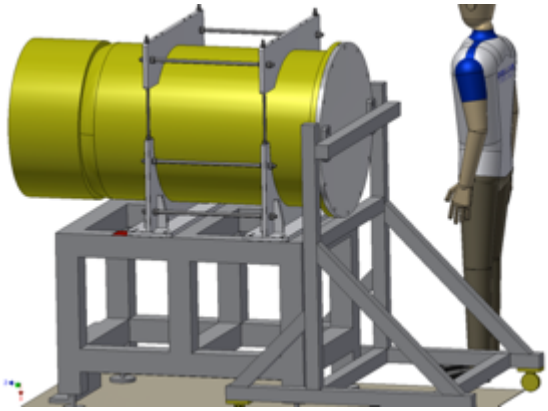
2 CRT

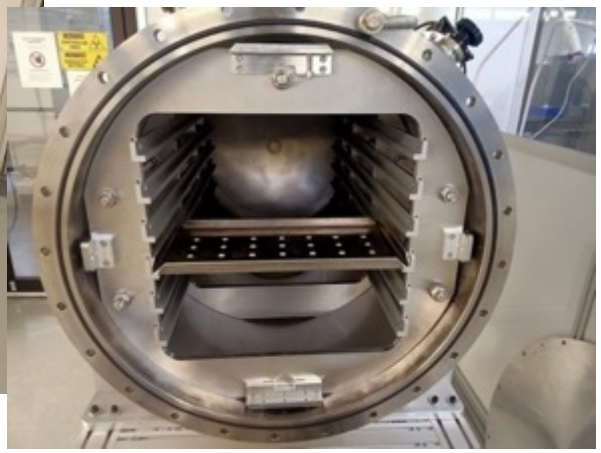


- First set of 8 (1.6 m long) Scint Counters with SiPM readouts ready and integrate with FEE readout and mechanical support
- They will allow to test the depedence of response and resolution along the crystal axis in Module-0 and at SIDET during calo assembly

Outgassing equipment @FNAL

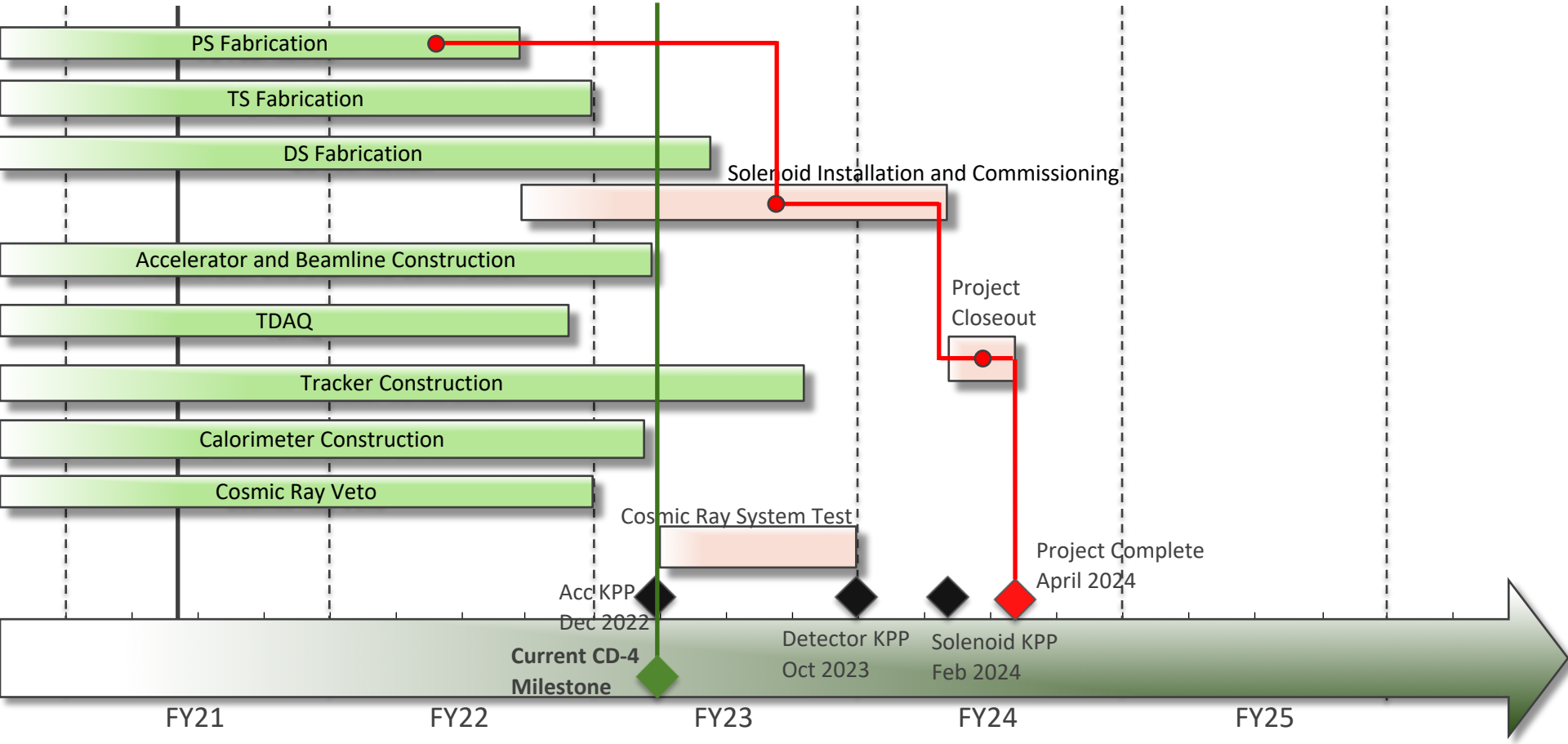






Fully Assembled. Need ORC and to start operating

Schedule With COVID impact



Calorimeter system assembly should start from Sept -2021 to be installed in fall 2022. First detector in Mu2e detector hall!

PMu2e: Richieste 2022

Missioni	Metabolismo	7,0 kE	
Interne	Gettone RN	3 kE	**17 KE**
	Missioni Marconi-LNF	6,5	
Missioni Estere	Responsabilita` Project Leader+5 L3	71,5 kE	**145 kE**
	Calo Assembly	40 kE	
	Missioni per personale tecnico	33 kE	
	Supporto addizionale assemblaggio e installazione In sala (F. Hppacher – A. Saputi –I. Sarra)	33 kE	**33 kE**
Trasporti	Trasporto	10 kE	
Consumi	Metabolismi	13 kE	**23 kE**
C.A	Cooling Station _ Laser head da restituzioni 2020 (80+12)	92	
	Feet manufacturing – extra cost	10	
C.A	Spare mechanics	10	**139 kE**
C.A	Cable supports	3	
C.A	shimmings	4	
C.A	FEE-Dboards+Interlock	10	
Consumi	Consumi for CRT operations + TB	10	**20 kE**
Consumi	Dry air assembly tent	10	
R&D	Cristalli LABR 7 + BaF2 9	16	**26kE**
	SiPMs + FEE 5+5	10	

Plan for late 2021 and 2022

- Resume traveling to FNAL starting from September
- Complete the Mechanics Dry run by September and ship all the parts to FNAL
- Complete FEE+SiPM assembly and test and have at FNAL the components to assemble one calorimeter by the end of 2021, early 2022
- Assembly of both calorimeters
- Commissioning of both calorimeters
- Construction of Handling tools
- Construction of Cable trays
- Construction of Displacement tools
- Move to Mu2e Building