# THE CALORIMETERS OF MU2E AND MEG EXPERIMENTS

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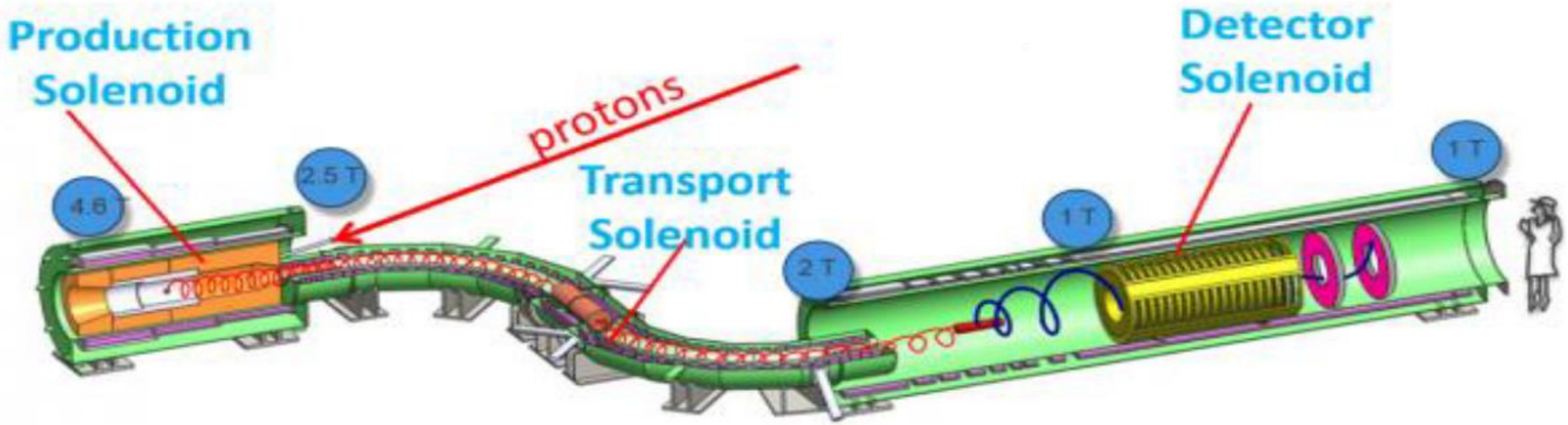
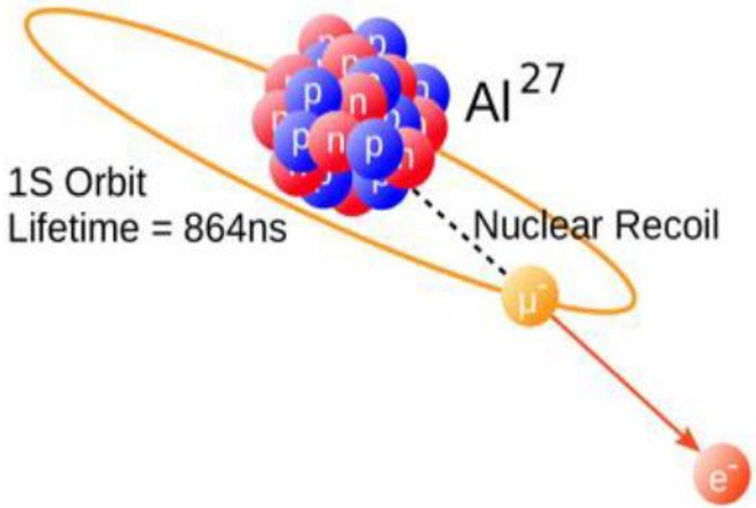
Bari – INFN Future Detectors 2022 – 17/19 October 2022

# THE MU2E EXPERIMENT

- In construction at Fermilab, Mu2e will search for $\mu^- \rightarrow e^-$ conversions in muonic atoms. This process:
  - happens in a coherent nuclear interaction, with the emission of an $e^-$ with $E_e \sim 105$ MeV = $m_\mu$
  - is a Charged Lepton Flavor Violation (CLFV), unobservable in the Standard Model, so any observation is a New Physics evidence
- Mu2e will measure $R_{\mu e}$ = #conversions / #nuclear captures. The single-event sensitivity is $2.2 \times 10^{-17}$ , i.e. a $\times 10^4$ improvement
- Over $10^{10}$ $\mu^-$/s stopped in an aluminium target for three years, with a magnetic transportation and selection system
- 1.7 us pulsed beam to reject prompt backgrounds + hermetic veto with scintillators to reject cosmic-ray backgrounds by a factor $10^4$
- Conversion electrons observed by a very precise straw-tube tracker and a fast calorimeter

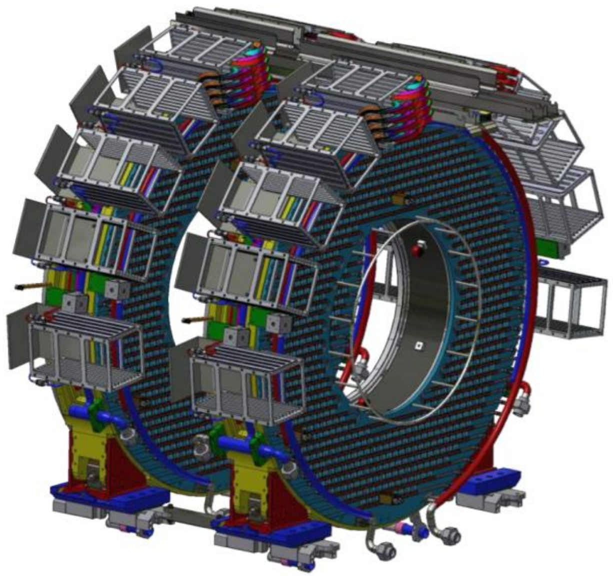


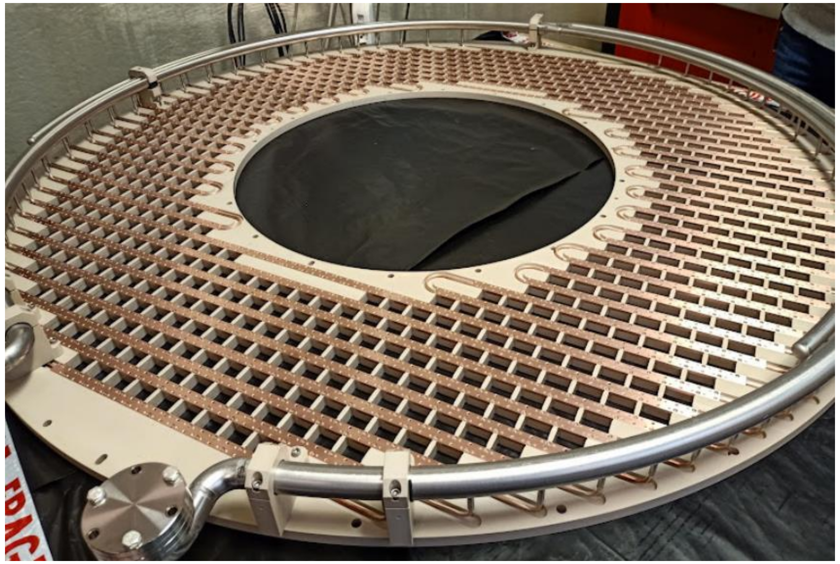



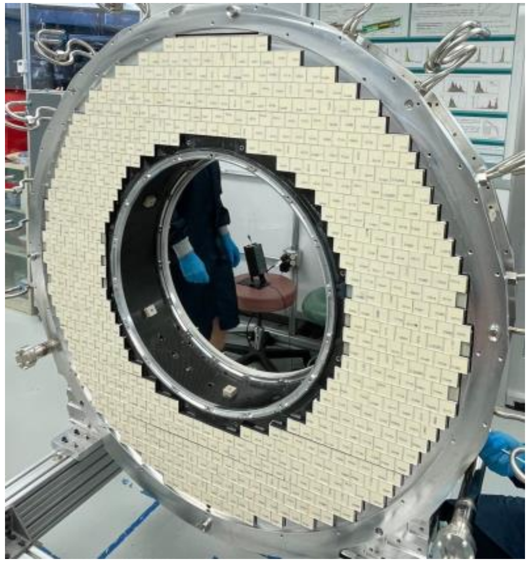
# MU2E CALORIMETER OVERVIEW

- Very precise Mu2e tracker ($\sigma_p$<200 keV/c) not sufficient for Mu2e aims → Calorimeter needed to provide:
  - Stand-alone trigger — Track-seeding — Electron/muon separation for cosmic-rays rejection

- Physics requirements: $\sigma_E$ /E <10% , $\sigma_t$ < 500 ps and good pileup handling → Granular calorimeter with fast pure CsI crystals
- High particle fluxes (20 kHz/cm$^2$) in a very harsh environment (50 krad total ionizing dose):
  - 1T magnetic field → Silicon sensors
  - 320 nm CsI light → Custom UV-extended SiPMs
  - Intense low-p beam background → Two annular disks
  - High neutron fluence ($3 \times 10^{12}$ $n_{1MeV}$ /cm$^2$) → SiPM operated at -10°C
  - $10^{-4}$ Torr vacuum → Low outgassing components and powerful cooling system
  - Detector accessible once in 6 months → Redundant readout with 2 SiPM arrays

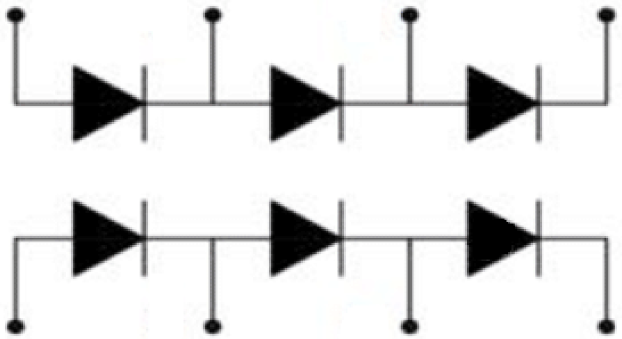


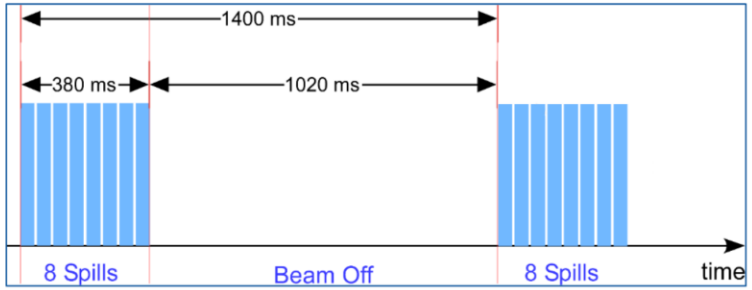


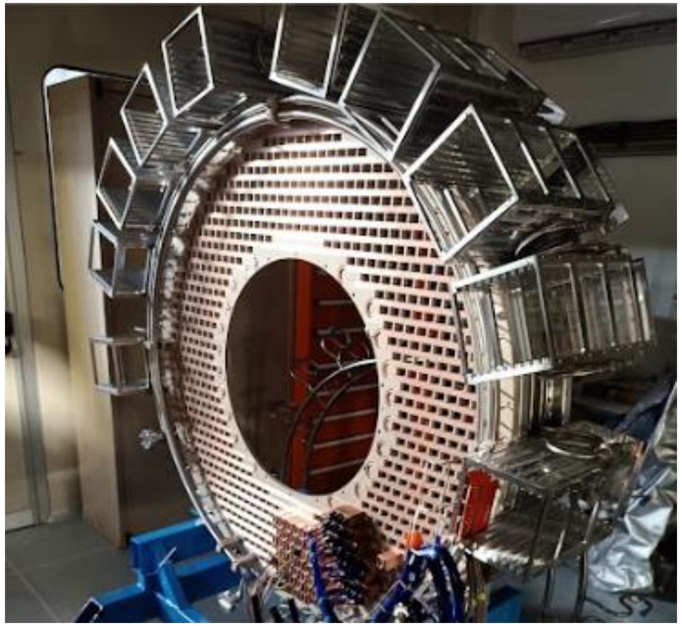


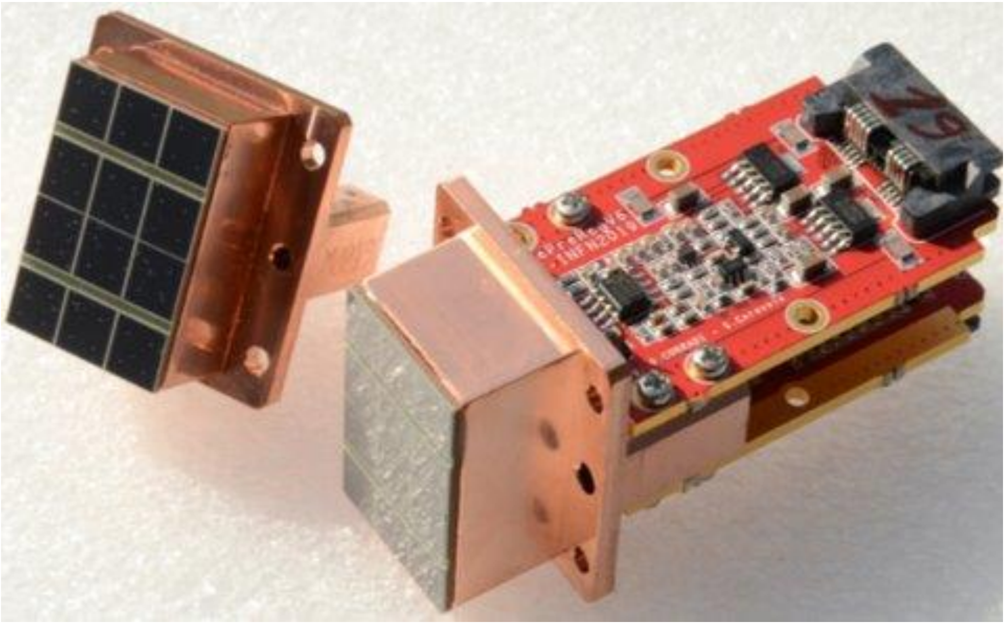
# MU2E CALORIMETER DAQ

- Good pile-up handling needed → Scintillation τ<30 ns — Two series of 3 SiPMs to reduce capacitance — Fast preamps in front-end electronic boards
- 2700 channels with 200 MHz 12 bit digitizers in **D**I**gital** **R**e**A**dout **C**ontrollers
  - 140 DIRAC boards (20 ch. each) with FPGAs for zero-suppression, pile-up handling and throughput reduction, housed in electronics crates
- 8GB/s calorimeter DAQ output, with Mu2e maximum storage limit of 0.7GB/s
  - Online trigger based on PC servers and exploiting beam-off periods

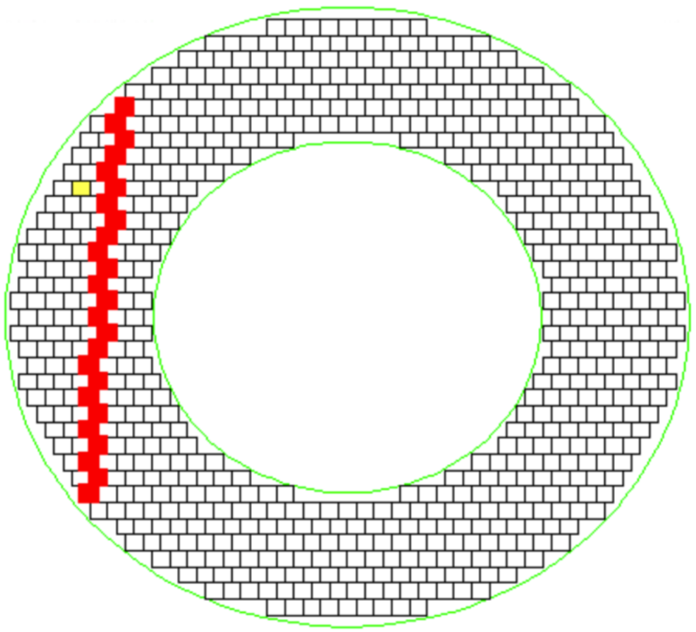


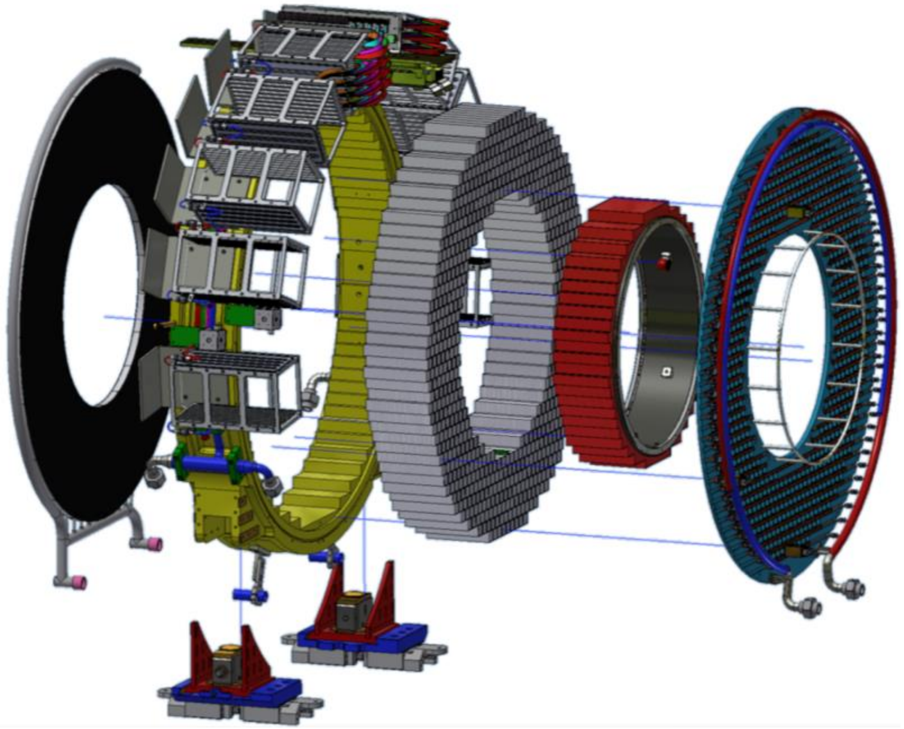



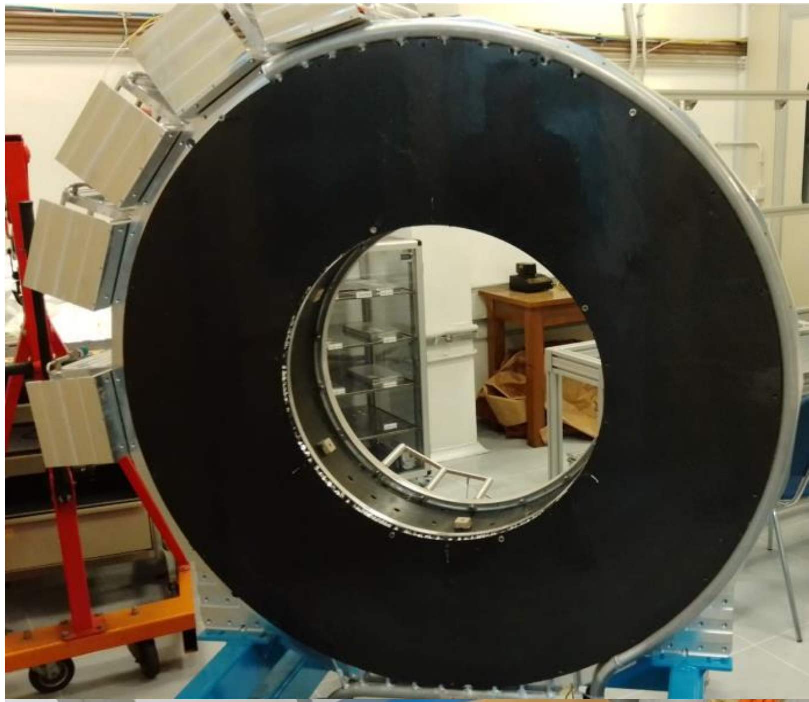


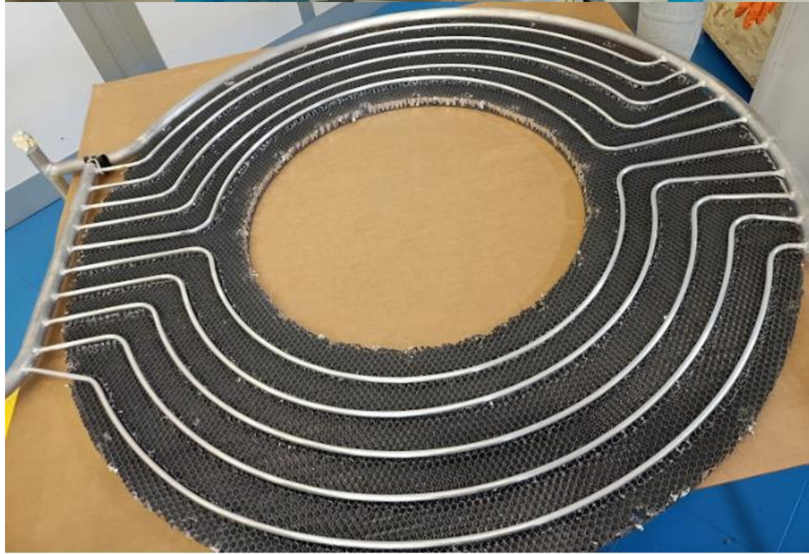
# MU2E CALORIMETER CALIBRATION

- High stability required at run time → Multiple calibration methods available:
  - SiPM+FEE Gain monitor using a green laser light transported with optical fibers
  - Cosmic rays calibration, for energy equalization and time-offset alignments
  - Low energy 6 MeV gamma rays from fluorine-containing liquid activated with a neutron DT generator
    - Low material-budget carbon-fiber/aluminium honeycomb front plate with integrated pipes



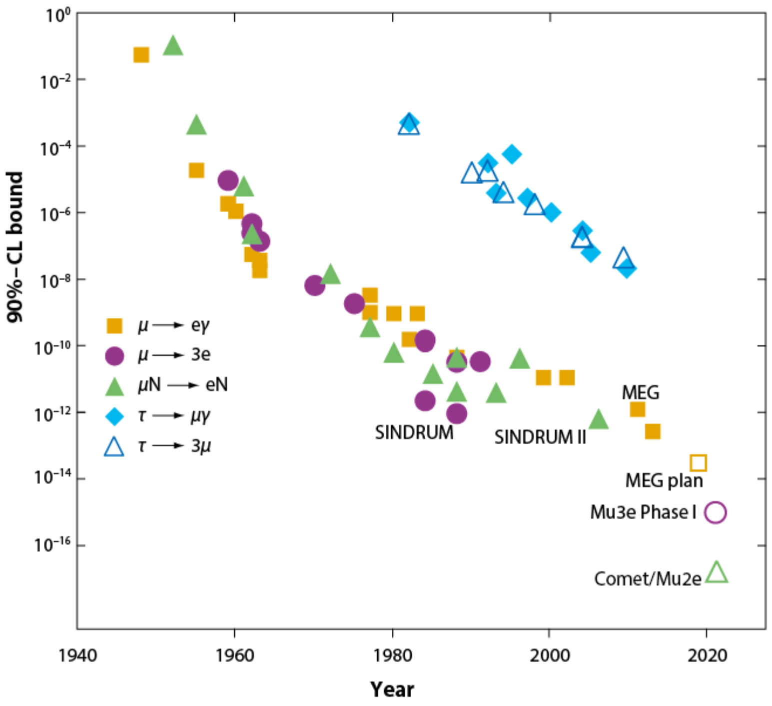


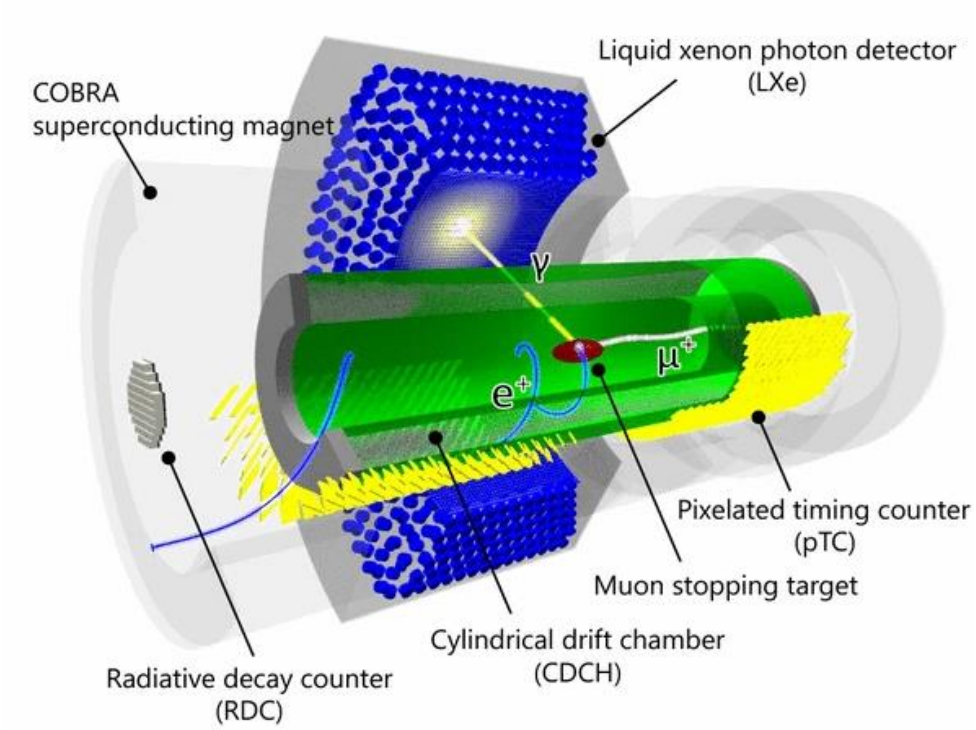




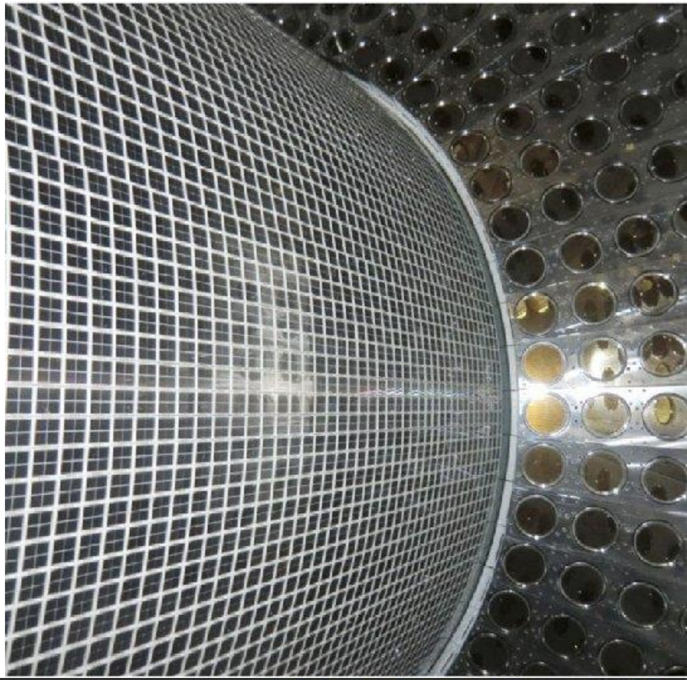
# COMPARISON WITH MEG/MEG-II

- Muon to Electron Gamma CLFV search at PSI, looking for the $\mu^+ \rightarrow e^+ \gamma$ decay
- MEG published a limit on the branching ratio at a level of $10^{-13}$, MEG-II (in commissioning) will improve by a factor 10
- MEG-II observes a signal → Mu2e also should see a bump, but converse not true
- Over $7\times10^7$ $\mu^+$/s stopped in a plastic target (no muonic atoms), to fix the kinematics
- ~53 MeV conversion positrons and photons observed with Drift Chamber + Pixelated Timing Counter + Gamma Detector



# MEG-II CALORIMETER OVERVIEW



- High energy resolution (~1%) needed at ~53 MeV → Homogeneous calorimeter
- Photons-only detector → No energy loss in the walls → Scintillating liquid calorimeter suitable
- High rates → Liquid Xenon (fastest scintillating noble gas with ~180 nm light emission, 2.2 ns singlet lifetime and 27 ns triplet lifetime)
- Non-uniform response reduction → Substitution of MEG PMTs in the inner region with custom VUV-extended SiPMs