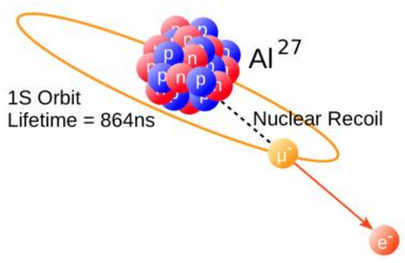
Design, assembly and operation of a scintillator based Cosmic Ray Tagger with SiPM readout

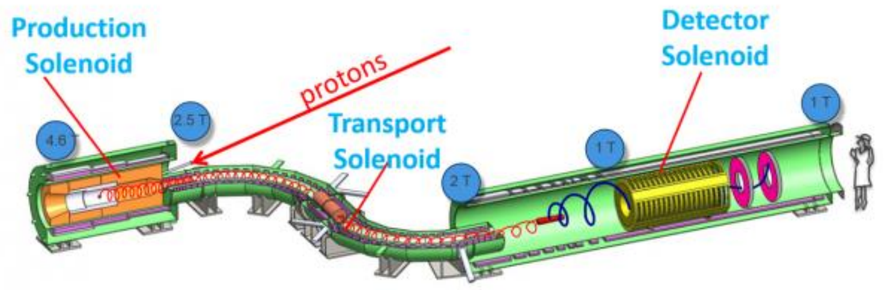
Ruben Gargiulo on behalf of the Mu2e Calorimeter group

The Mu2e experiment



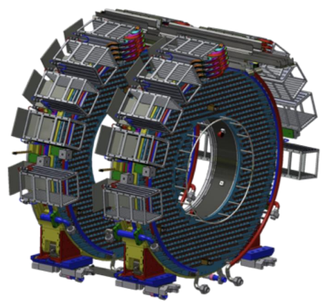
- Mu2e will search for the Charged Lepton Flavour Violating (CLFV) process of coherent μ^- to e^- conversion in the Coulomb field of Al nuclei
- The conversion signature is a 104.96 MeV monoenergetic electron, identified by a straw-tube tracker and an electromagnetic calorimeter
- Mu2e goal is to improve the current limit on conversion by four orders of magnitude, reaching a single-event sensitivity < 3 x 10^{-17}

- An intense pulsed low-momentum μ^- beam is produced and transported to an Al stopping target (~10^{10} μ^- /s)
- The interaction products are measured by the Mu2e detectors:
  - A Straw Tube Tracker, arranged in 36 planes for a length of 3 meters, achieves an excellent momentum resolution (σ_p<200 keV/c), efficiency and reliability, in order to suppress the decay in orbit background
  - A CsI Crystal Calorimeter, guarantees excellent energy and time resolution and complements the tracker information by providing cluster seeding and muon/electron separation



Mu2e Crystal Calorimeter

- The Mu2e calorimeter is composed of two annular disks, consisting in 674 undoped CsI crystals
- It will work in a 10^{-4} Torr vacuum, 1 T B-field, in a harsh radiation environment and provides for 100 MeV e^-:
  - $\sigma_E/E < 10\%$ and $\sigma_t < 500$ ps

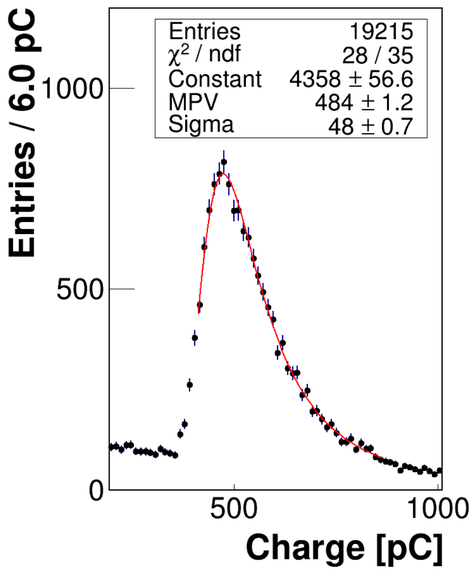


Calorimeter calibration with cosmic rays

- Prior to installation, the calorimeter will be calibrated with minimum ionizing particles (MIP) using cosmic rays, to equalize energy and time response
- 3D MIP tracking will be provided by two Cosmic Ray Tagger (CRT) modules, placed above and below the calorimeter disk under test
- The CRT will also allow to study the dependence of energy and timing response along the crystals z-axis

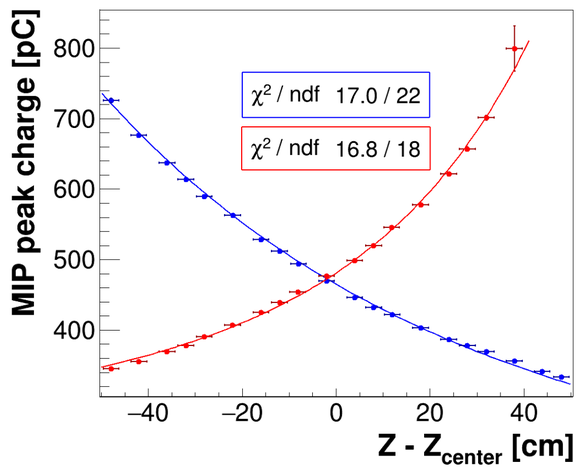
Cosmic Ray Tagger

- The CRT consists of two modules, each one composed of a single layer of 8 parallel (160x1.5x2.5) cm^3 EJ-200 scintillating bars
- Each bar has a dual-side readout based on custom UV-extended large area SiPMs, with the relative front-end electronics board
- The ratio between the bar cross-section and SiPM surface area is 0.58 and the optical coupling is achieved with silicon grease



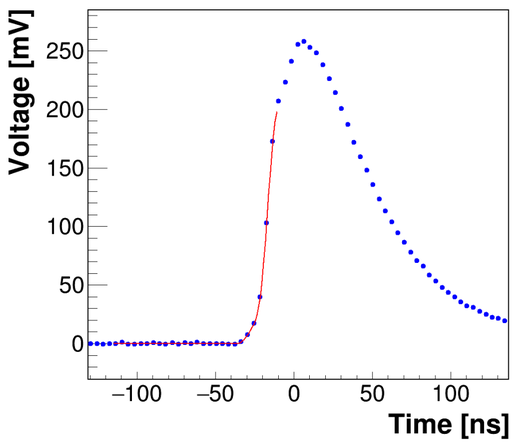
- The EJ-200 scintillator material is a doped polyvinyltoluene (PVT) polymer, showing:
  - High light output (10^4 photons/MeV) peaked at 425 nm
  - A large bulk attenuation length (BAL) of 380 cm
  - A fast rise time (900 ps) and a 80% fast-to-total ratio
- The scintillating bars were wrapped with 150 um Tyvek foil and an outer 500 um Mylar layer and individually darkened with black tape
- The SiPM/bar optical couplers were 3D printed in black Acrylonitrile Styrene Acrylate (ASA)
- An external light-tight PVC box encloses the assembly

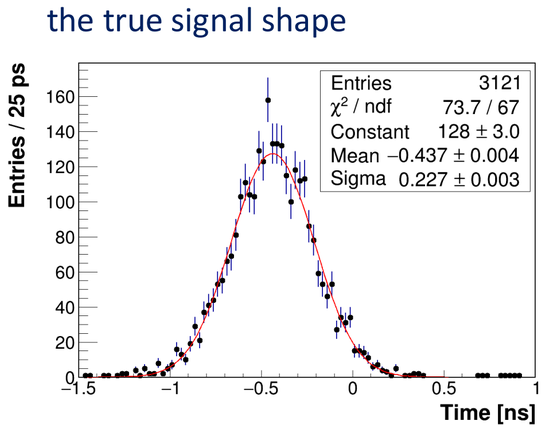
- With a gain of 3.6x10^6, a MIP peak is visible at a ~480 pC charge, for hits at center of the bars
- The light attenuation along the bar axis (Z) is fitted with a double exponential model, in agreement with the nominal BAL and a technical attenuation length (TAL) of O(50 cm)



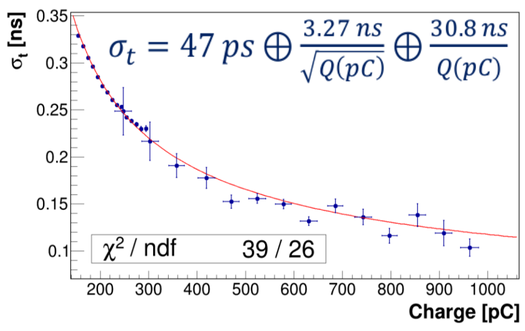
Time reconstruction

- A template fit procedure was developed to reconstruct MIP timing and time-of-arrival hit position (Z)
- During the template generation, 1M waveforms were aligned in time, normalised in amplitude and averaged
- A cubic spline is then created from the resulting wave profile
- The procedure was repeated for 5 different charge slices, to better match the true signal shape





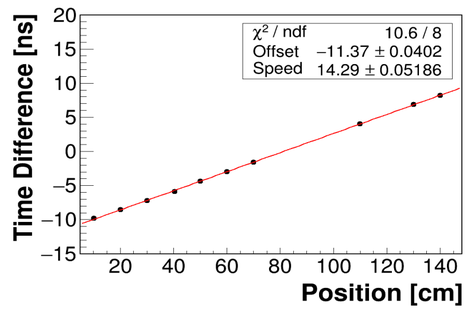
- A ~230 ps RMS on $\Delta T = T_{left} - T_{right}$ was found using two 1cm wide scintillators, placed at the center of a CRT bar, as external triggers for cosmic rays
- The σ_t dependence with respect to charge was studied, using cosmic and β rays, both at the center of one bar

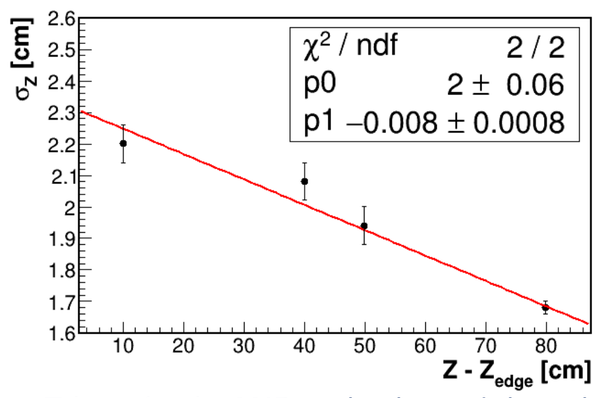


- The time resolution of a single readout side was fitted with a three-term model
- A good agreement between the results with cosmic and β rays is observed
- At the MIP peak, time resolution is ~ 160 ps

MIP tracking

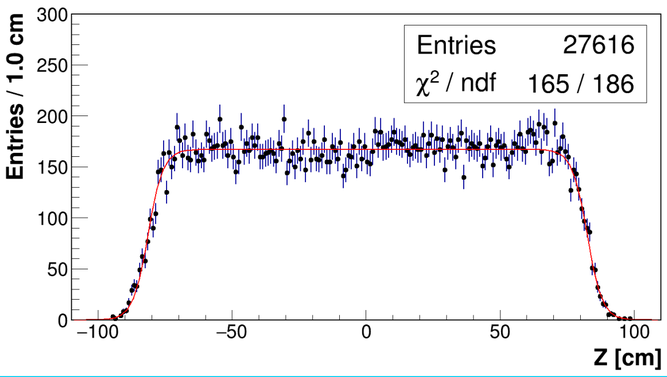
- The Z position is reconstructed from ΔT using the average light speed v_p in the bars
- Scanning a bar with a b source and fitting the ΔT vs. Z graph with a linear regression, a 14.3cm/ns v_p was evaluated

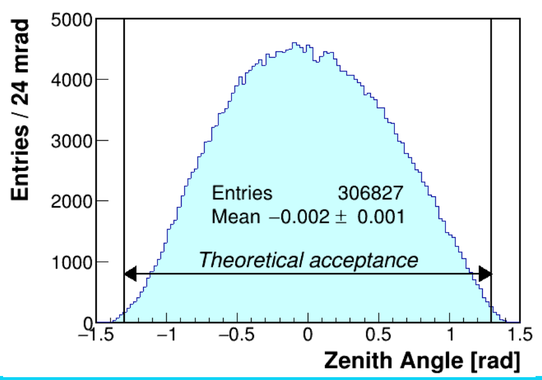




- The Z resolution dependence on Z was studied with MIPs, placing two small scintillators (used as external triggers) in different positions
- A linear fit shows resolutions from 1.6 to 2.3 cm, with a 40% maximum spread along Z

- Triggering in AND on both modules, placed one on top on the other:
  - The hit profile along Z is flat with gaussian tails
  - The reconstructed zenith angles distribution shows good tracking capabilities





R. Gargiulo | ruben.gargiulo@lnf.infn.it
INFN, Laboratori Nazionali di Frascati, Via Enrico Fermi 54, Frascati, Italy