Electron-Muon Ranger: Performance in the MICE beam

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1. Introduction

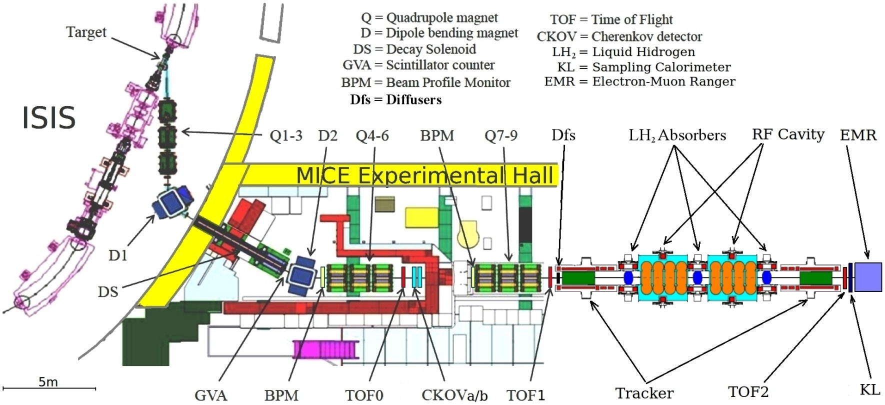
Muon Ionization Cooling Experiment (MICE), an R&D project established to demonstrate the cooling of muons critical to future ν experiments

1. Ionization cooling principle

$$\frac{d\varepsilon_n}{ds} = -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\varepsilon_n}{E_\mu} + \frac{1}{\beta^3}\frac{\beta_\perp(0.014)^2}{2E_\mu m_\mu X_0} \tag{1}$$

2. Muon Ionization Cooling Experiment
   - Description of its complete cooling channel (AFC, RFCC, Trackers)
3. MICE beamline
   - Description of the target, DS, diffuser, quadrupoles and dipoles
4. Beam instrumentation
   - Description of the PID system (TOFs, CKOVs, KL, **EMR**)

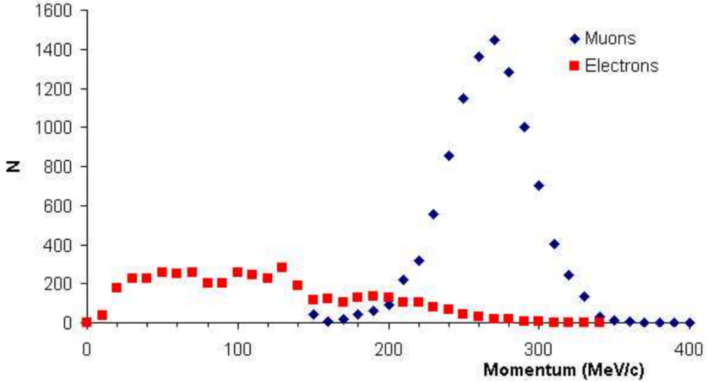
MICE beamline and cooling channel



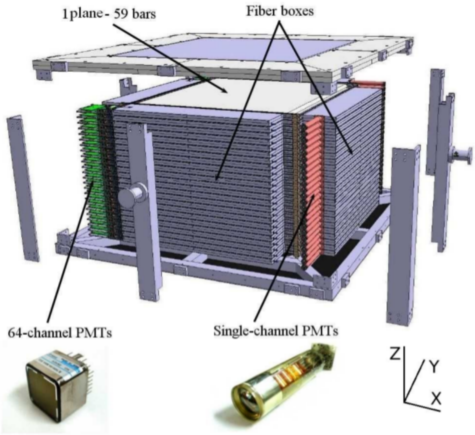
2. Electron-Muon Ranger

The EMR is fully active scintillator tracker calorimeter

- Pupose of the EMR in the MICE beam
  - measure the range of muons, rejecting the muons that decayed inside the cooling channel and their decay products
  - Keep the contamination downstream the CC below 1%



Overall detector design

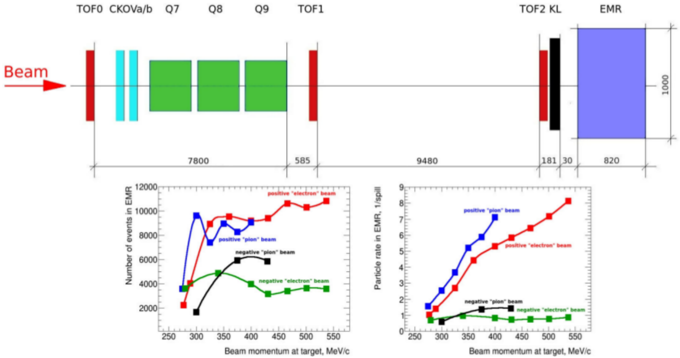


A Fully active scintillator tracker-calorimeter located at the very end of the cooling channel. It stops electrons / muons / pions with momentum below 150 / 300 / 350 MeV/c, records muon/pion decays and give very distinct particle identification signatures.

- 1 m^3 of active volume
- 48 planes made of 59 triangular scintillator bars with glued 1.2 mm wavelength shifting fibers
- light is collected by single-anode PMT on one side of a plane and by 64-channel PMTs - on the other: 3120 channels in total

- the granularity of the detector allows for the individual track reconstruction
- muons/pion decay products can be reconstructed as well
- the detector help to reach high precision of the emittance measurements

3. EMR Performance in the MICE beam



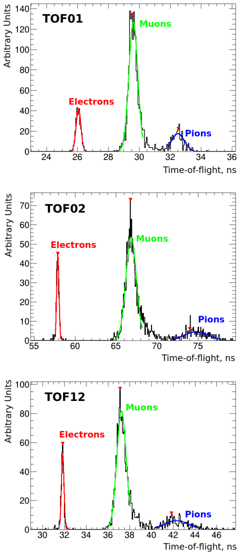
- during one month the detector was exposed to the MICE beam
- the beam was composed of e, μ, π with momenta from 250 to 550 MeV/c
- spill period is 1 sec. and there are from 1 to 8 particles per spill
- particle type and momentum is identified by TOF detectors
- for each particle the following is measured in the EMR:
  1. range of primary (muon/pion) and secondary (electron) tracks
  2. total charge

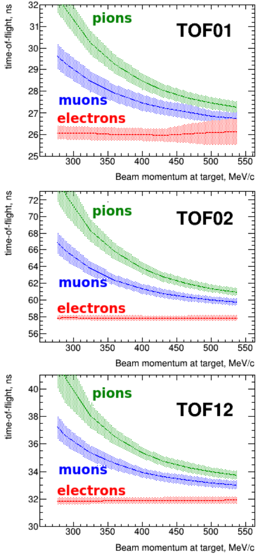
TOF selection system

- Only the tracks with one TOF spacepoint are selected
- The TOF measurement between station 1 and 2 is used to tag the particle ID and momentum at the entrance of the EMR

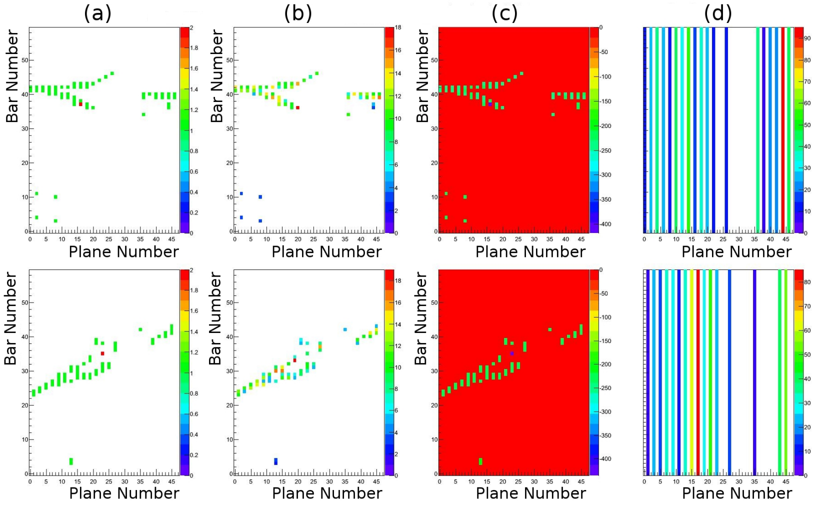
left TOF measurements

right TOF measurement as a function of the momentum at target



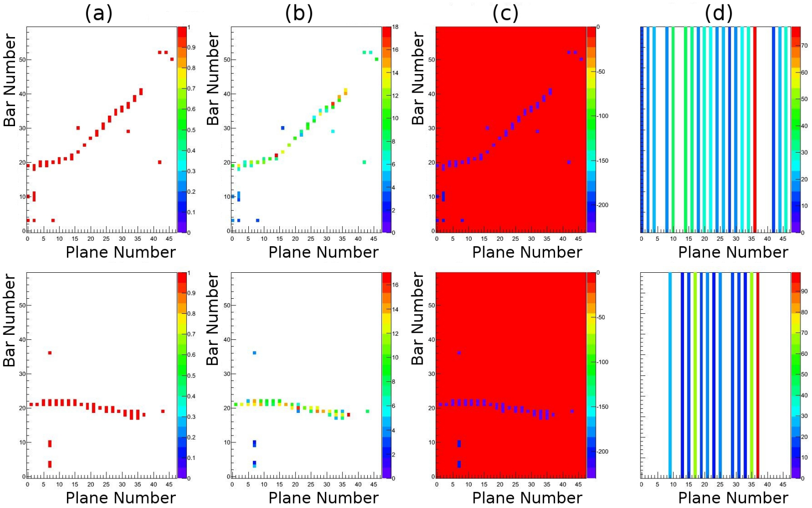


Event display of an electron shower in the EMR



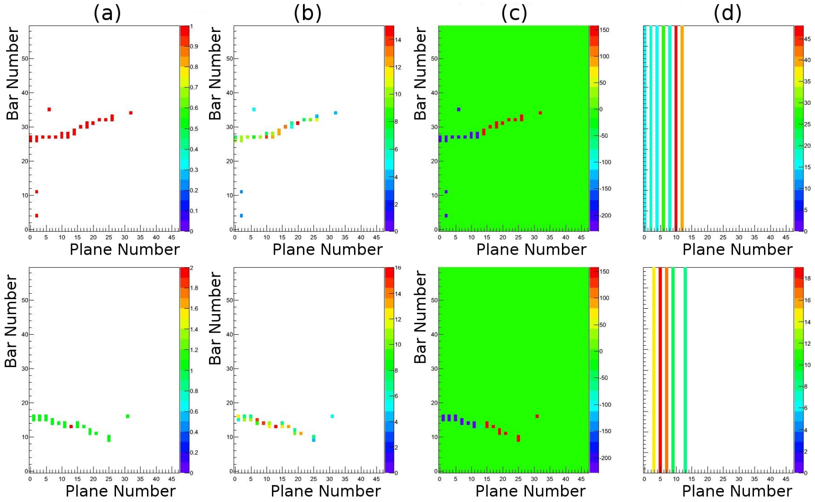
(a) Hit count, (b) Time over Threshold, (c) Δt, (d) Plane charge

Event display of a negative pion capture in the EMR



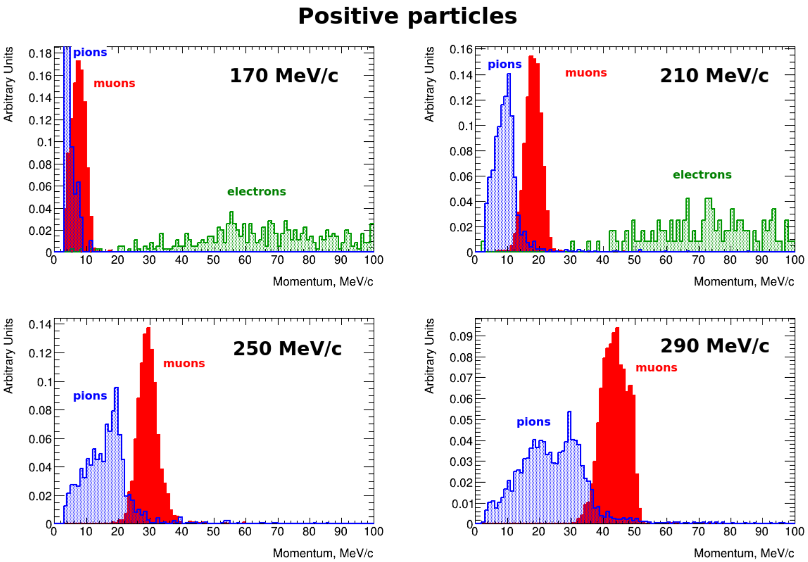
(a) Hit count, (b) Time over Threshold, (c) Δt, (d) Plane charge

Event display of a positive pion decay in the EMR

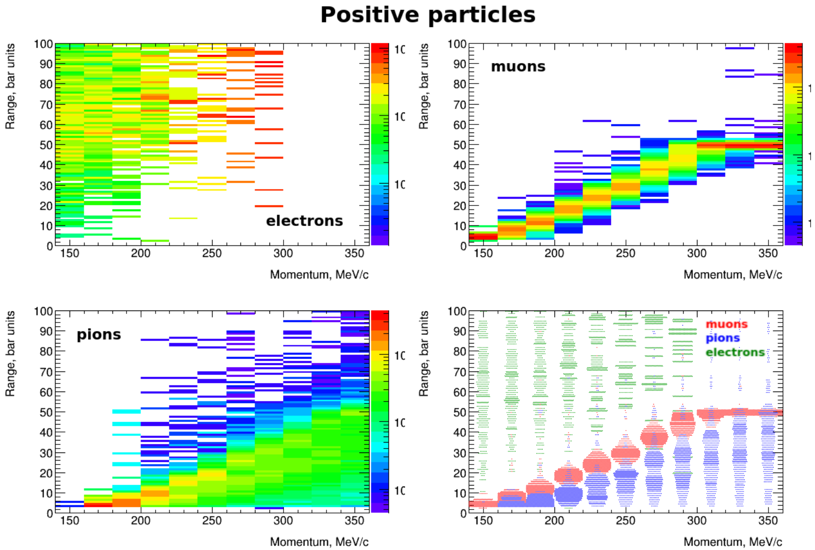


(a) Hit count, (b) Time over Threshold, (c) Δt, (d) Plane charge

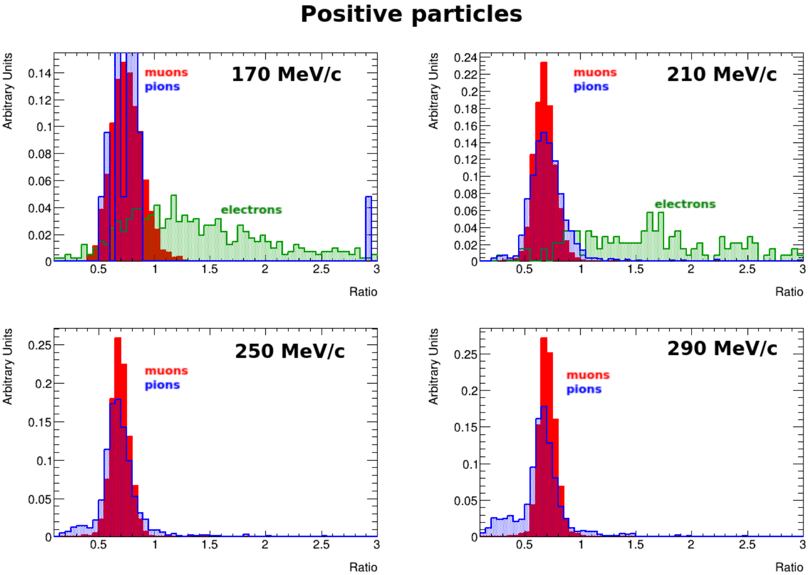
Distribution of primary range



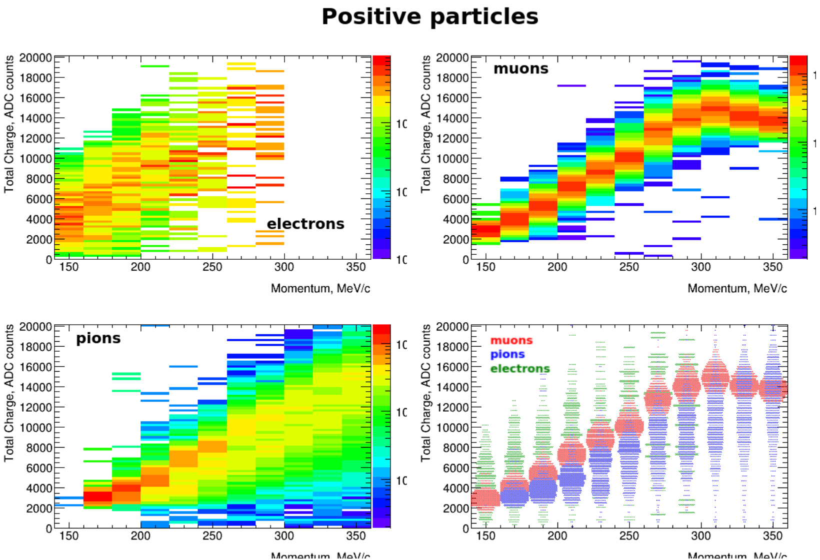
Distribution of primary range as a function of momentum



Distribution of charge

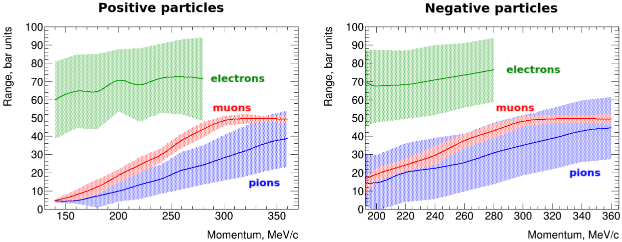


Distribution of charge as a function of momentum

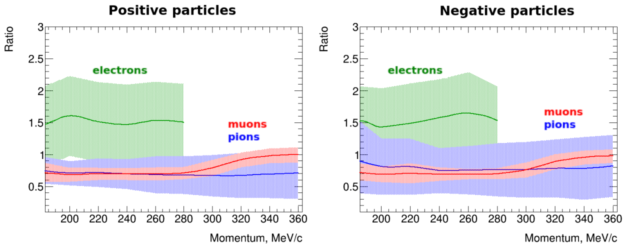


Ultimate plot (RMS)

Reconstructed primary range



Reconstructed total charge

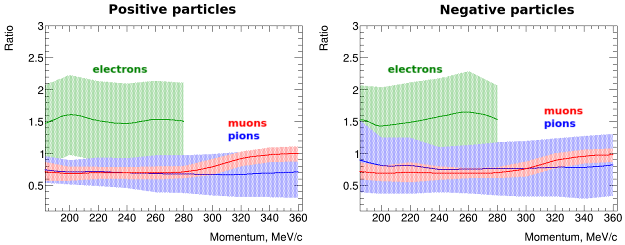


Average plane charge ratio

Muons and pions energy deposition patterns exhibit a Bragg peak at the end of the track that can be used to tag them

- The charge ratio is defined as the average plane charge ratio of the first four fifth of the track over the last fifth, i.e.

$$R_Q = \frac{\sum_{i=0}^{n_1-1} Q_{pl}^i/(n_1-1)}{\sum_{i=n_1}^{n_2} Q_{pl}^i/(n_2-n_1)} \quad (2)$$



4. Conclusions

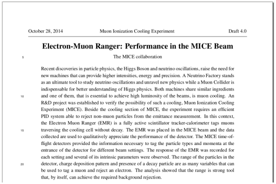
The main objective of the beam tests was to commission the detector and to verify its functionality, i.e its ability to measure the range of particles and clearly separate electrons from muons

- e, μ and π have significantly different range
  $\rightarrow$ their separation can be achieved efficiently
- The detector was not tuned nor optimised, these results could even be improved:
  - The ASIC configuration could be optimized
  - The PMTs need to be subjected a high voltage scan
  - Reconstruction software update
- Tracks can be reconstructed and identified in the EMR:
  - Muon and pion decays can be reconstructed and matched
  - The presence of a secondary particle rejects electrons
  - The presence of a Bragg peak at the end of the track as well
- This analysis was **qualitative** and not quantitative

Paper production status

Drafts production history:

- 1st draft on the 21st August
- 2nd and 3rd draft at the end of October (important size reduction and corrections)
- 4th version coming out this week



October 28, 2014 Muon Ionization Cooling Experiment Draft 4.0

Electron-Muon Ranger: Performance in the MICE Beam

The MICE collaboration

Recent discoveries in particle physics, the Higgs Boson and neutrino oscillations, raise the need for new machines that can provide higher intensities, energy and precision. A Neutrino Factory stands as an ultimate tool to study neutrino oscillations and unravel new physics while a Muon Collider is indispensable for better understanding of Higgs physics. Both machines share similar ingredients and one of them, that is essential to achieve high luminosity of the beams, is muon cooling. An R&D project was established to verify the possibility of such a cooling, Muon Ionization Cooling Experiment (MICE). Beside the cooling section of MICE, the experiment requires an efficient PID system able to reject non-muon particles from the emittance measurement. In this context, the Electron Muon Ranger (EMR) is a fully active scintillator tracker-calorimeter tags muons traversing the cooling cell without decay. The EMR was placed in the MICE beam and the data collected are used to qualitatively appreciate the performance of the detector. The MICE time-of-flight detectors provided the information necessary to tag the particle types and momenta at the entrance of the detector for different beam settings. The response of the EMR was recorded for each setting and several of its intrinsic parameters were observed. The range of the particles in the detector, charge deposition pattern and presence of a decay particle are as many variables that can be used to tag a muon and reject an electron. The analysis showed that the range is strong tool that, by itself, can achieve the required background rejection.

Please check out the latest Draft at
`http://micewww.pp.rl.ac.uk/issues/1472`
→ **The 4th Draft is ready for the next step**