International Europhysics Conference on High Energy Physics
Grenoble, Rhône-Alpes France July 21-27 2011
European Physical Society
HEP 2011

The MICE beamline instrumentation for a precise emittance measurement

MICE Collaboration

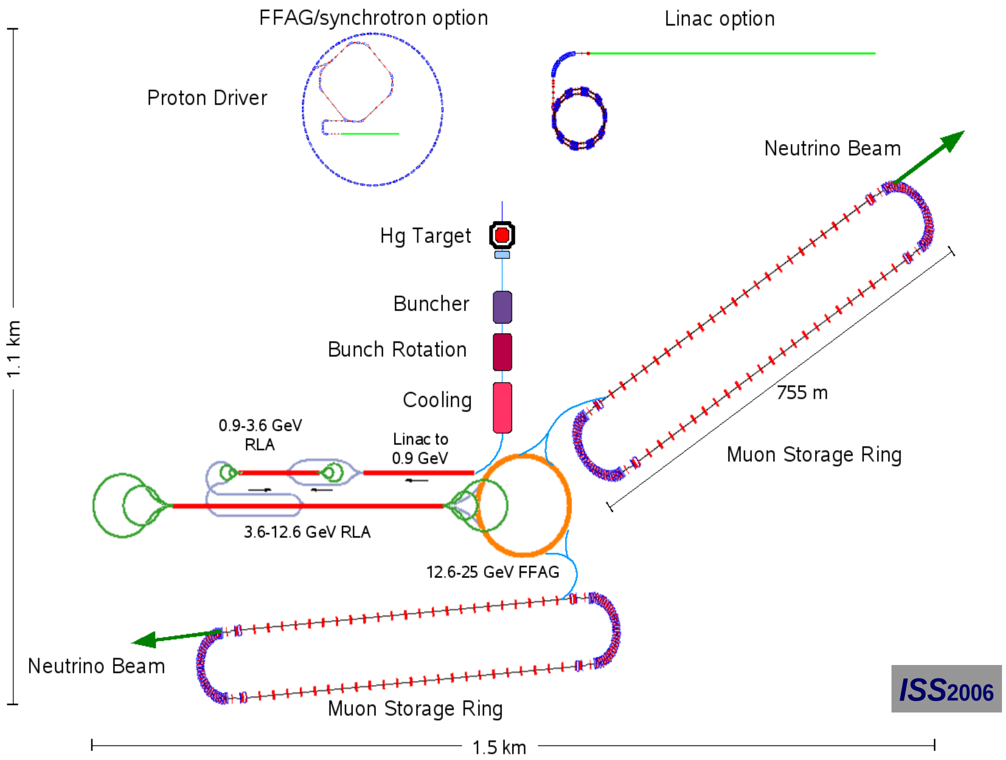
M. Bonesini

INFN, Sezione di Milano Bicocca

Milano Italy

Neutrino Factory

International Scoping Study baseline

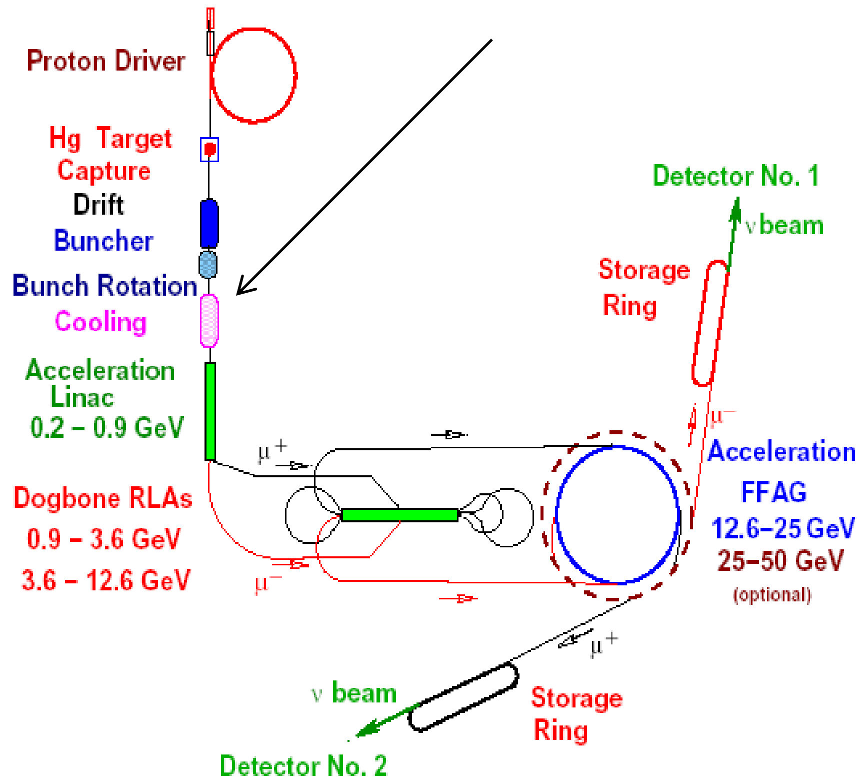


- Proton Drive (4 MW, 2 ns bunch)
- Target, Capture, Drift ($\pi \to \mu$) & Phase Rotation
  - Hg Jet
  - 200 MHz train
- Cooling
  - 30 πmm ($\perp$)
  - 150 πmm (L)
- Acceleration
  - 103 MeV $\to$ 25 GeV
- Decay rings (baseline is race-track design):
  - 7500 km L
  - 4000 km L

S.Choubey et al., Design Study, IDS-NF-20

Neutrino Factory R&D

- High power (MW) proton driver
- Target and collection (HARP/MERIT)
  - Maximize π^+ and π^- production
  - Sustain high power (MW driver)
  - Optimize pion capture
- Muon cooling (MICE)
  - Reduce $\mu+/\mu-$ phase space to capture as many muons as possible in an accelerator
- Muon acceleration
  - Has to be fast, because muons are short-lived ! (RLA, FFAG, …)

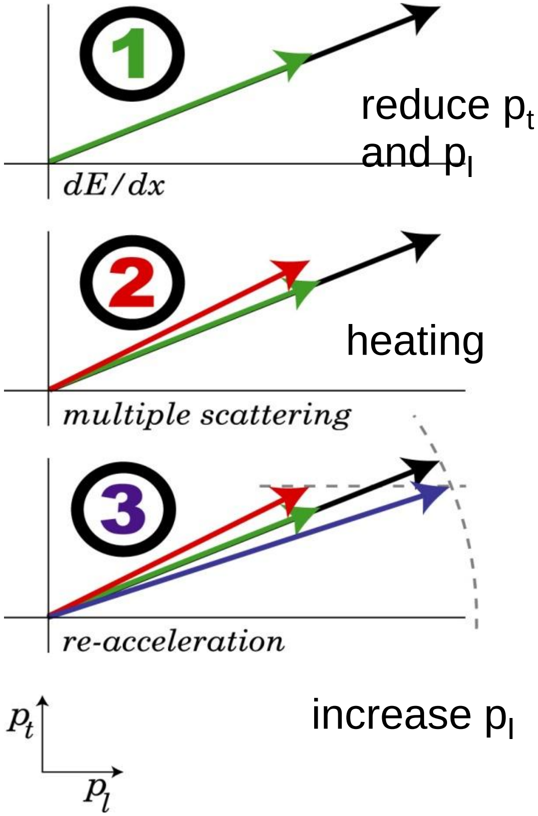


Muon ionization cooling

Stochastic cooling is too slow.

A novel method for μ+ <u>and</u> μ- is needed: **ionization cooling**

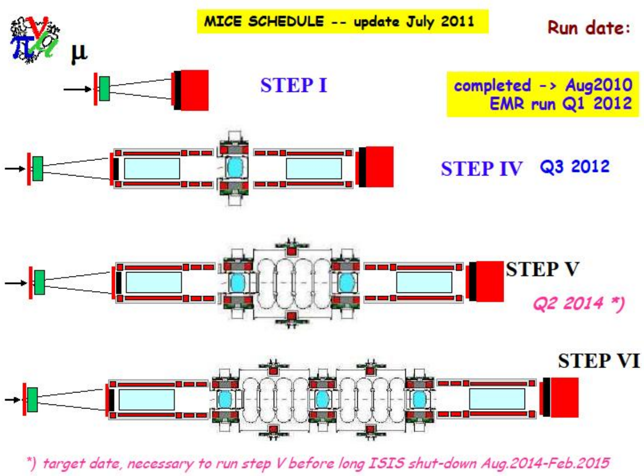
principle



reality including beam diagnostics(simplified)

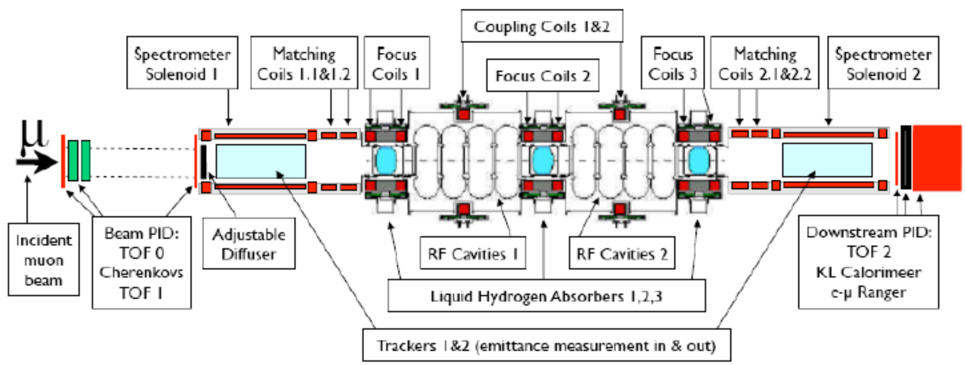
- Build a section of cooling channel long enough to provide measurable cooling (10%) and short enough to be affordable and flexible
- Wish to measure this change to 1%
- Requires measurement of emittance of beams into and out of cooling channel to 0.1% !
- Cannot be done with conventional beam monitoring device
- Instead perform a single particle experiment:
  - High precision measurement of each track (x,y,z,px,py,pz,t,E)
  - Build up a virtual bunch offline
  - Analyse effect of cooling channel on many different bunches
  - Study cooling channels parameters over a range of initial beam momenta and emittances

MICE installation status (2011)



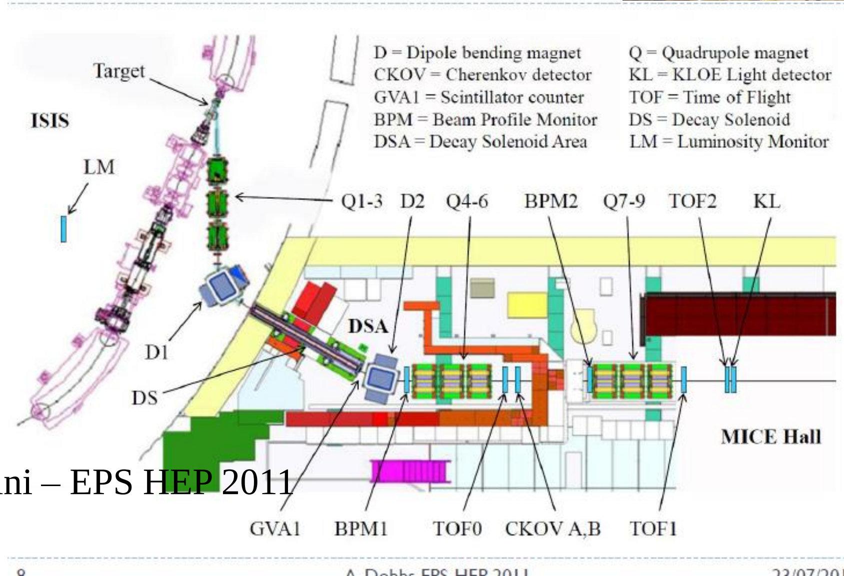
MICE in STEPS

- **Target**
- **Beamline**
- **PID detectors** (CKOV, TOF,KL, EMR)



MICE Beamline

- ISIS 800 MeV proton synchrotron at RAL
- Titanium target, grazing ISIS beam
- π captured by quad triplet and momentum selected by dipole (D1)
- Followed by 5T decay superconducting solenoid (5 m long): contain π and decay μ
- Second dipole momentum select muons (D2)
  - $p_{D1} \sim 2 \times p_{D2}$ μ beam
  - $p_{D1} \sim p_{D2}$ e/π calib beam



MICE beam detectors

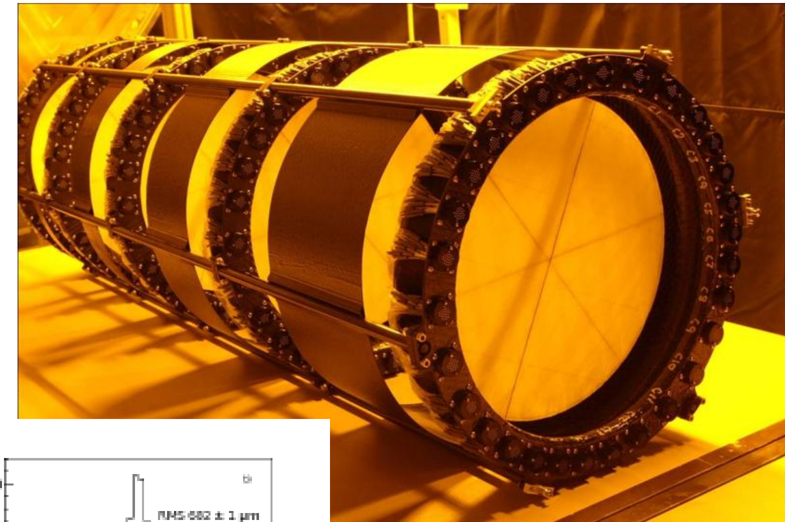
- Particle identification: TOF, CKOV, Calorimeter
  - Upstream
    - Time of Flight TOF0 + TOF1
    - 2 Aerogel threshold Cherenkov detectors

    ➔ π/μ separation up to 360 MeV/c

    ➔ Beam purity better than 99.9%
  - Downstream
    - TOF2
    - EMC Calorimeter
      - Kloe-like (KL) Lead-scintillating fiber sandwich layer
      - Electron-Muon Ranger (EMR) (in construction)
        - » $1 m^3$ block extruded scintillator bars
        - » Also measure muon momentum

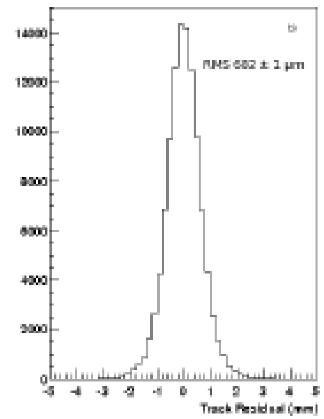
    ➔ μ/e separation
- Particle tracking
  - Scintillating Fiber trackers
  - Measure position and reconstruct momentum

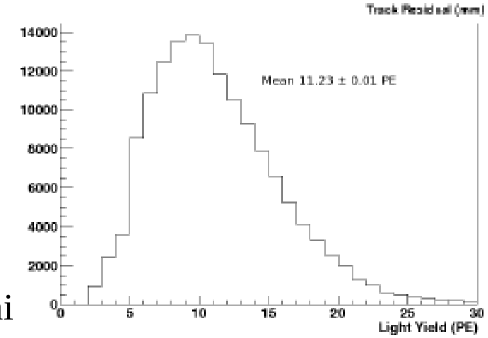
MICE Tracker: will be installed in STEP IV



- **Scintillating fiber trackers**
  - Determine x,x',y,y' and momentum
  - High resolution on order of 1 fiber needed
- **Design**
  - 350 μm scintillating fiber doublet layers
  - Active area has diameter of 30 cm
  - 5 measurement stations with 3 planes for each tracker
  - In 4T superconducting solenoids with cryocoolers

  - Readout via VPLC (low band-gap avalanche devices, QE~80%)





Performances with cosmics:

- **RMS of residual distribution 682+-1 μm**
- **MEAN number of P.E. 11.23+-0.01**

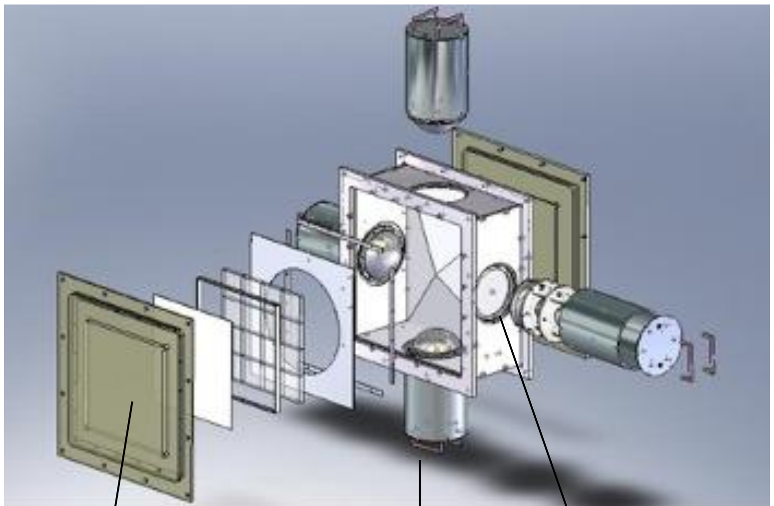
PID system: overview

MICE Particle ID important to insure high muon purity for muon cooling measurement.

- Upstream :
  - TOF0,1 X/Y hodoscope with 10m path, 70 ps resolution
  - 2 Aereogel threshold Cherenkov detectors (n=1.07 and n=1.12)
  - $\pi/\mu/e$ separation at better than 1% at 230 MeV/c
- Downstream :
  - 0.5% of μ s decay in flight: need electron rejection at 10^{-3} to avoid bias on emittance reduction measurement
  - TOF2 X/Y hodoscope
  - EMC Calorimeter for MIP vs E.M. Shower (KL (built) + EMR (in construction, first layers installed in June 2011))

Upstream : CKOVa/CKOVb

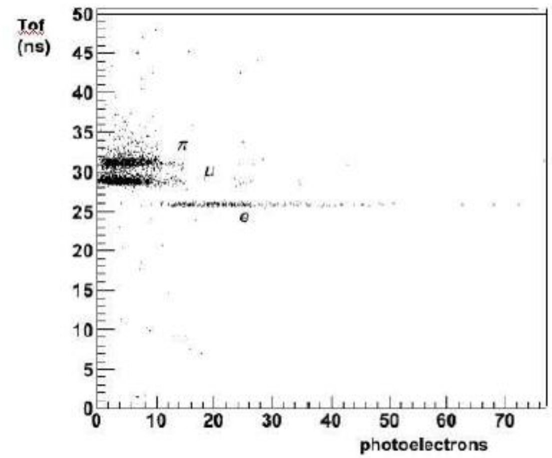
Cherenkov detector blowup



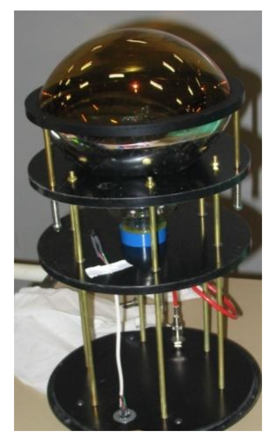
radiator

Reflector Panels

8" PMT port



Ckov vs TOF measurement

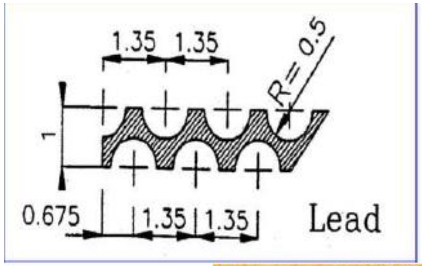


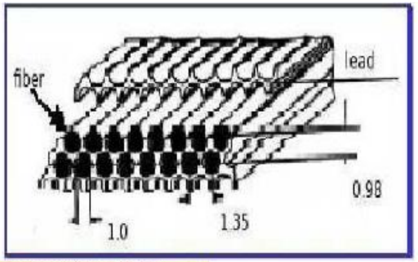
CKOV PMTs
(from CHOOZ)

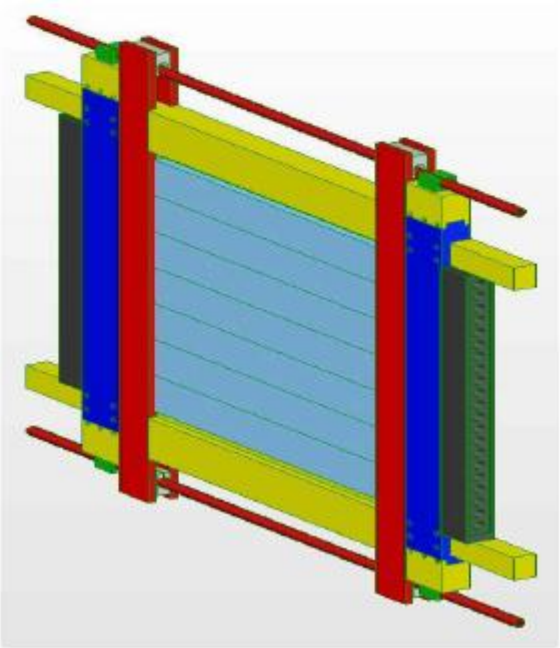
The downstream calorimetry electron-muon calorimeter (EMC)

- EMC is not primarily intended for energy measurements
- It's main role is to provide e/μ separation
- In MICE proposal this was provided by a CKOV counter + an em calorimeter (KL)
- Now it will be provided by KL + a fully active calorimeter (EMR in construction)
- KL (KLOE-light) is a fiber spaghetti calorimeter with a design similar to the KLOE one

KL calorimeter

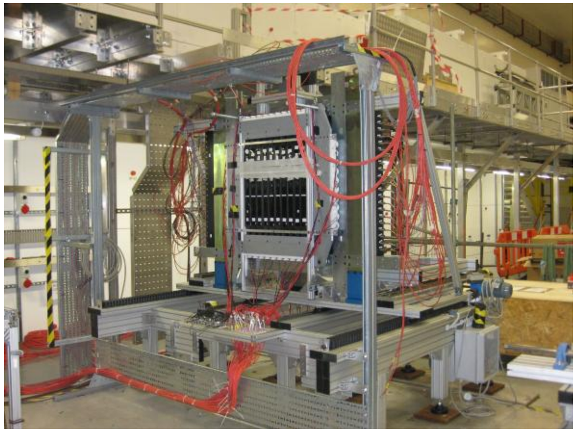




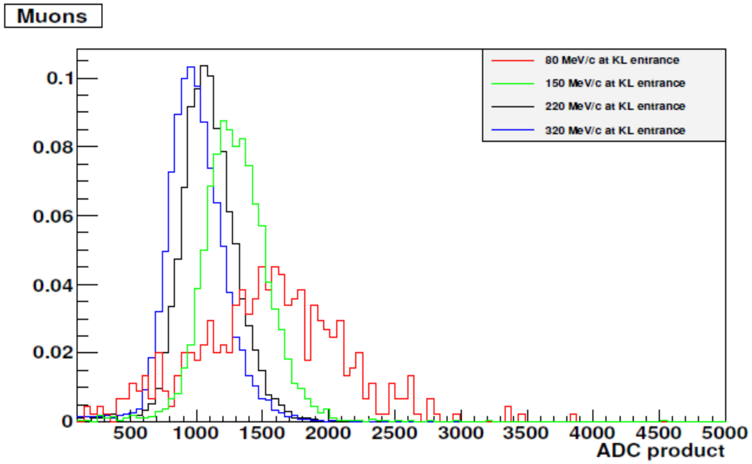


Schematic layout of KL extruded fibers and lead

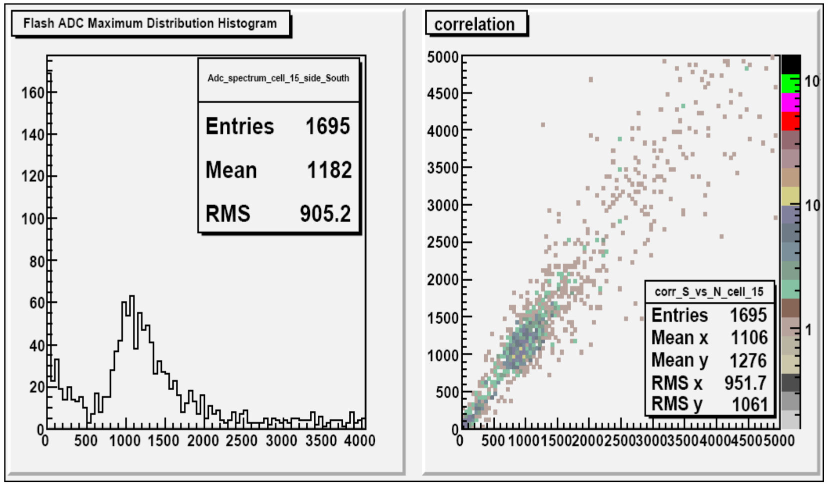
Installation in temporary position after Q9 at RAL



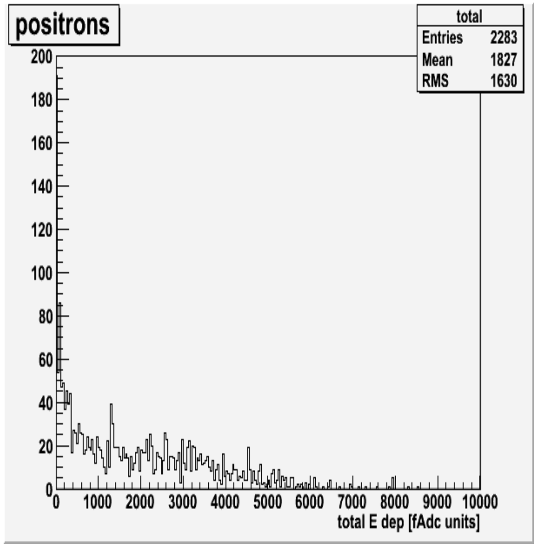
KL performances in beam



KL response to muons

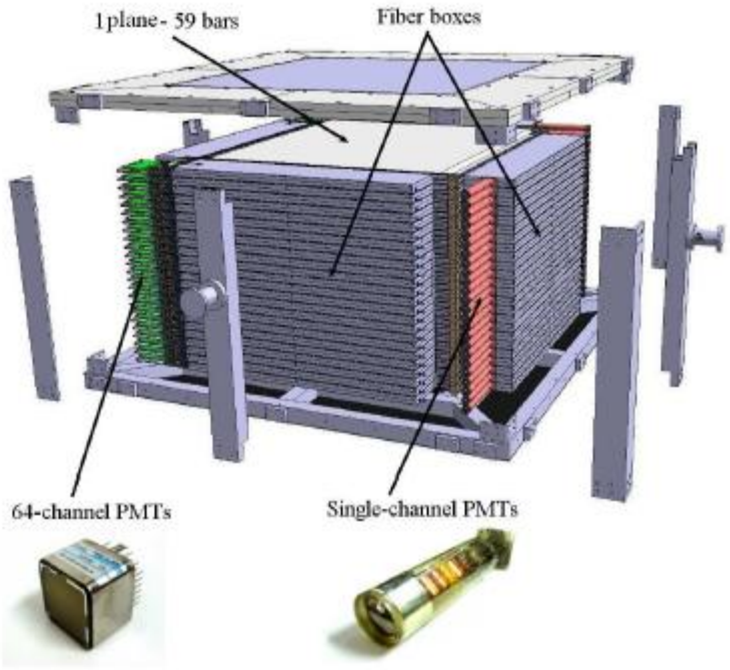


The typical MIP distribution and the correlation left-right of the photomultiplier signals with cosmics.



KL response to 100MeV e^+ beam

PID upgrade: EMR



- 24 modules (X-Y planes)
- 48 planes
- 59 bars per plane
- 2832 bars
- 3m WLS fibers per bar
- 8.5 km WLS fibers
- single and 64-channel PMTs per plane
- 3072 + 48 channels

- **Track Properties:**
  - **Muons show tracks;**
  - **Electrons converted in EM showers in KL show scattered hits**
- **dE/dx along Z**
  - **Muons have constant dE/dX up to the Bragg peak**
  - **Electrons have large fluctuations in Energy loss which tends to decrease with Z**

TOF system requirements

- Exp trigger, upstream/downstream PID and measure of t vs RF
- Work in a harsh environment (high incoming particle rate, high fringe fields from solenoids, X rays from converted e^-)

Tof resolution can be expressed as:

$$\sigma_t = \sqrt{\frac{\sigma^2_{scint} + \sigma^2_{PMT} + \sigma^2_{pl}}{N_{pe}} + \sigma^2_{elec}}$$

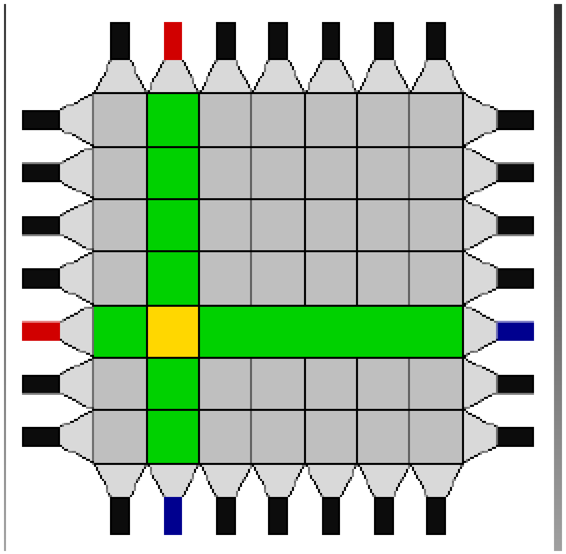
with good timing performances (σ_t~50 ps) → **Some points to look at to have high resolution TOFs**

- σ_{pl} **dominated by geometrical dimensions ~√(L/Npe)**
- σ_{scint} ~ **50-60 ps (mainly connected with produced number of γ's fast and scintillator characteristics, such as risetime)**
- σ_{PMT} **PMT TTS (typically 150-300 ps)**

+

- **HARSH Environment (shielding from B, RF noise, high particle rate)**

TOF design



- "conventional" X/Y scintillator structure with readout at both ends, to provide redundancy & intercalibration with inc. μ
- FADC (CAEN V1724) + TDC (CAEN V1290) readout
- problem: choice of PMTs for high incident particle rate (1 MHz) and solenoid B fringe field ($B_{//}$ ~ 200-300 G, B_{perp} ~ 1K G)

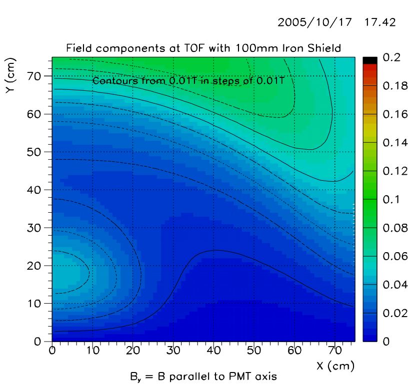


Figure 4: $B_{\parallel}$ at the position of TOF2 with the 100 mm iron shield.

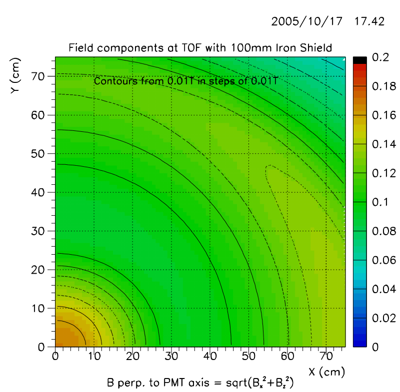
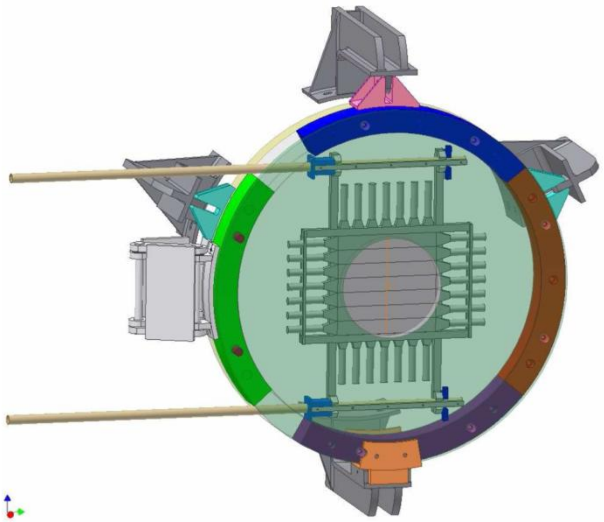
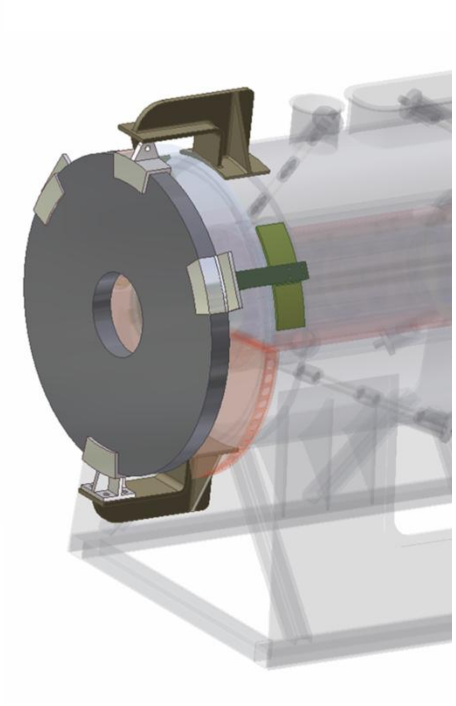
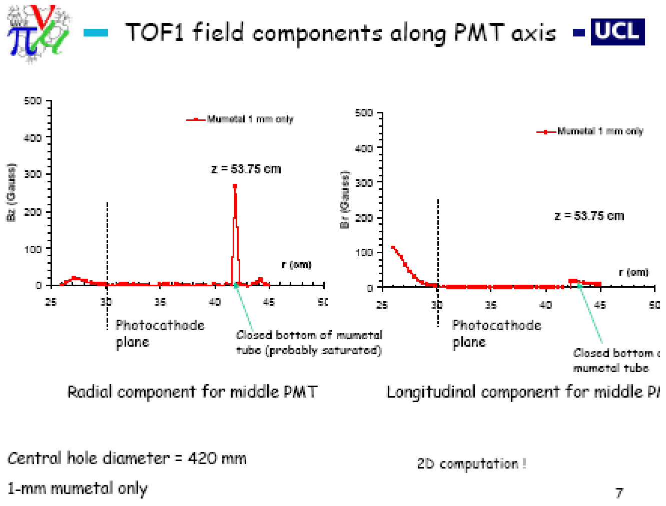


Figure 5: $B_{\perp}$ at the position of TOF2 with the 100 mm iron shield.

Magnetic field shielding

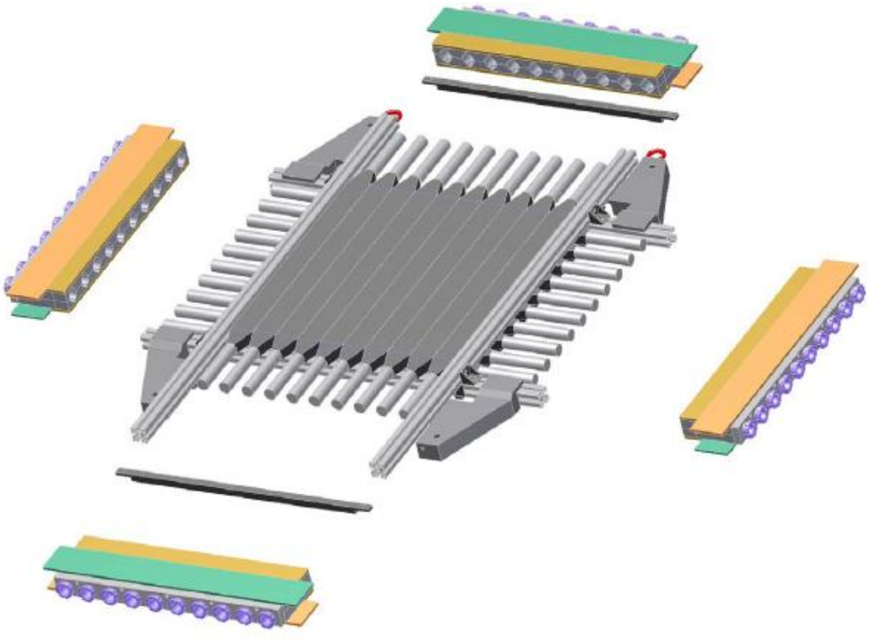


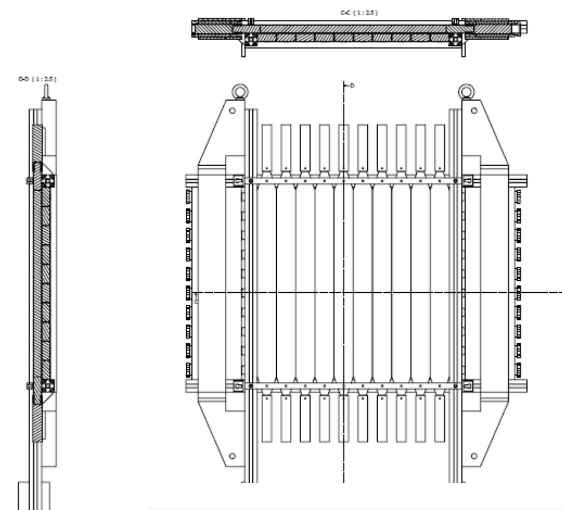


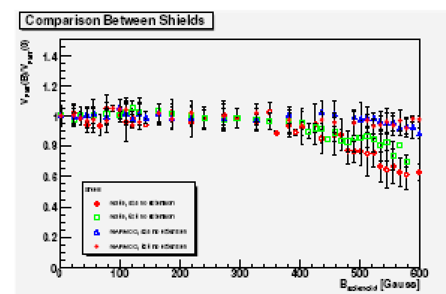


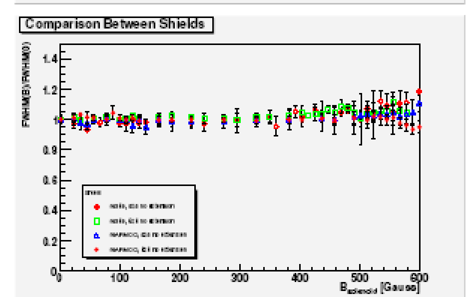
With an external cage B field is reduced to tolerable levels for conventional R4198 PMTs (solution adopted for TOF1)

TOF2 Local Shielding



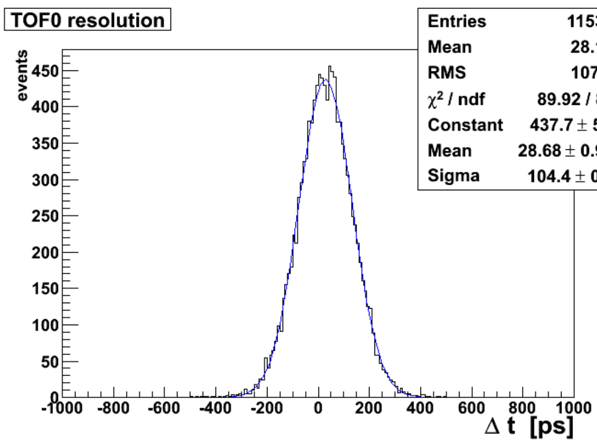


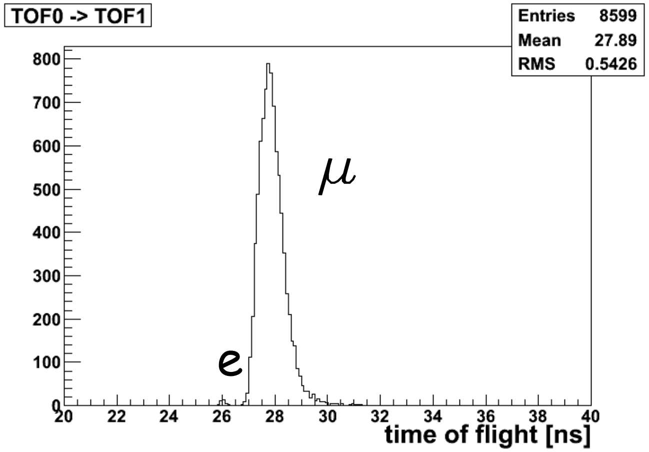




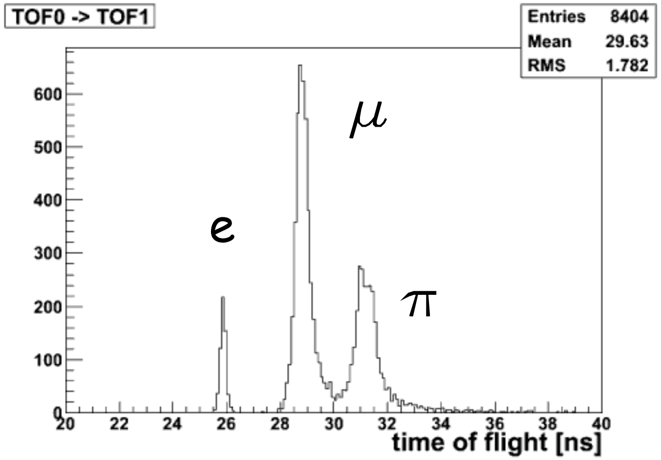
- for TOF2 **massive box ARMCO local shielding (D0-like)** solution
- PMT studies show solution is adequate..

TOF performances in 2010 run



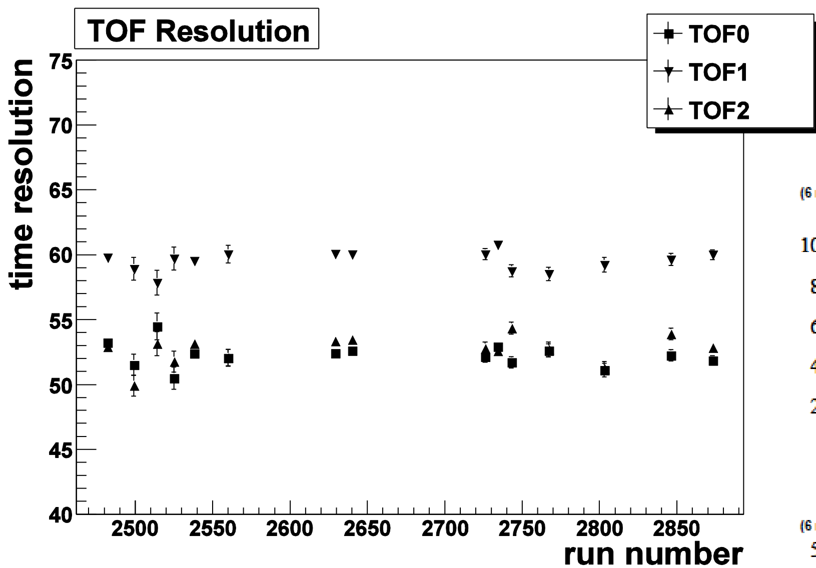


TOF for μ beam, calibration beam



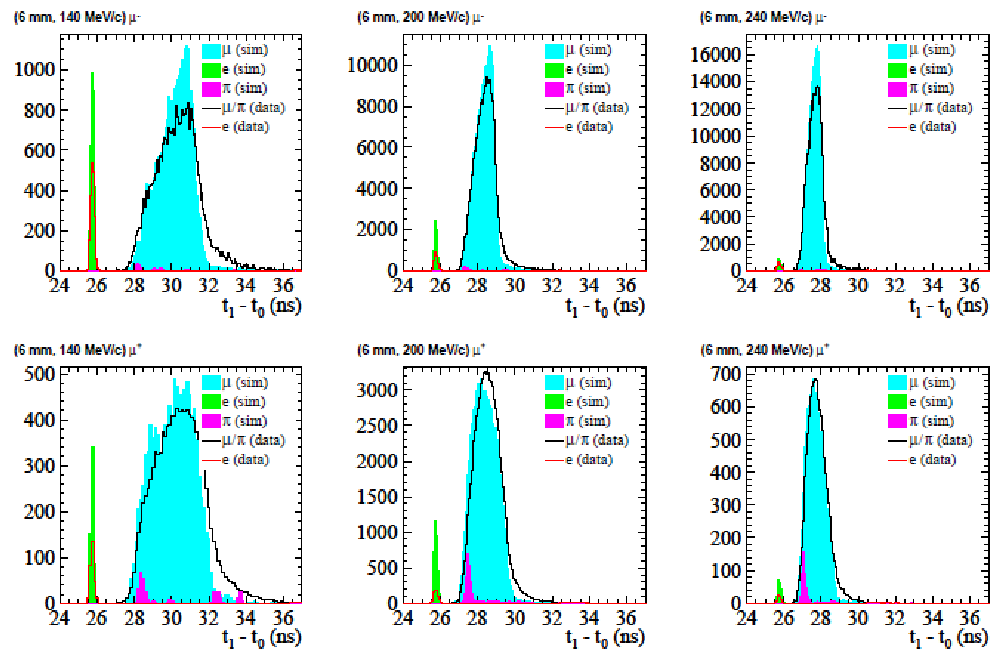
- Time resolution after calibration:
- TOF0 – 51ps;
- TOF1 – 58ps;
- TOF2 – 52ps.

More on TOF detectors



1 month data taking

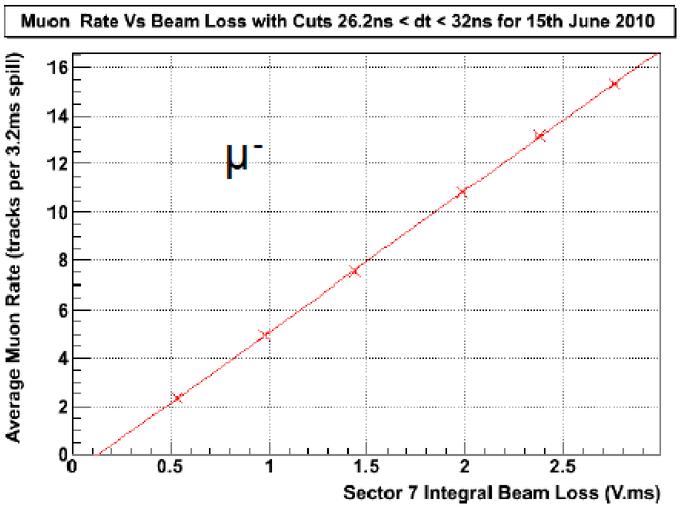
- Stability of TOF stations resolution



Comparison data-MC

Beamline Commissioning

- The beamline has been operated over a range of momenta, producing positrons, π and μ
- TOF detectors used for PID and record beam profiles
- TOF have been used for a preliminary measure of emittance



μ rate related to ISIS beam losses

Momentum (MeV/c)

emittance	140		200		240	
3	39	80	58	171	57	237
6	98	207	112	527	85	198
10	95	183	78	200	89	174

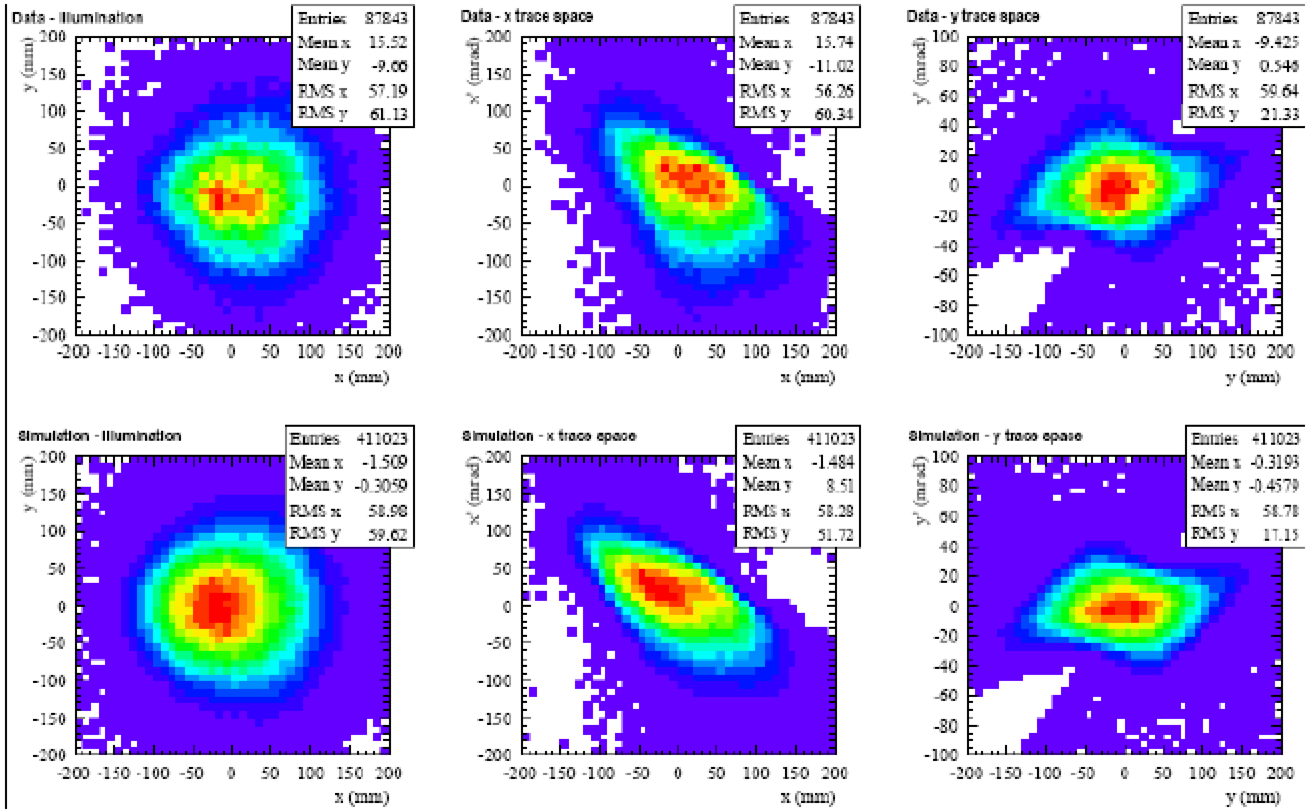
Data collected in STEP I (in 1kevt) (+ve in black)

Emittance measurement with TOF

Reconstructed transverse phase space of the baseline MICE beam (6-200) at TOF1

data

MC



y(mm) vs x(mm) **x' (mrad) vs x (mm)** **y'(mrad) vs y (mm)**

For more details see A. Dobbs talk (Acc. session)

Conclusions

- MICE beamline in place and commissioned: over 13×10^6 triggers collected
- PID detectors (TOF0,TOF1,CKoV, TOF2,KL) installed and working well
- Detectors for next STEP (STEP IV): trackers + EMR calorimeter ready
- Preliminary emittance measurement with TOF only