NOW 2012

Progress of MICE , the International Muon Ionization Cooling Experiment

MICE Collaboration

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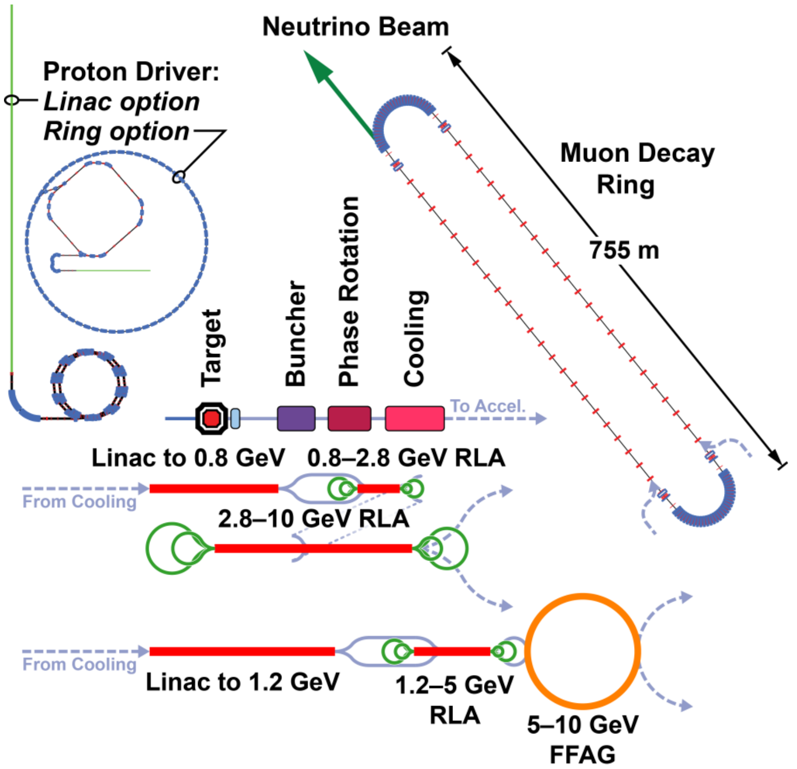
Neutrino Factory

International Scoping Study baseline



S.Choubey et al., Design Study, IDS-NF-20 (arXiv:1112.2853) and updates

neutrino factory:
accelerate muons and
store to produce neutrinos

$$\mu^+ \to e^+ \nu_e \overline{\nu}_\mu$$

Or opposite charges (and anti-)

-- flux known to <±1%

-- high energy electron neutrinos

Golden channel:

long baseline oscillation manifests itself by wrong sign muons:

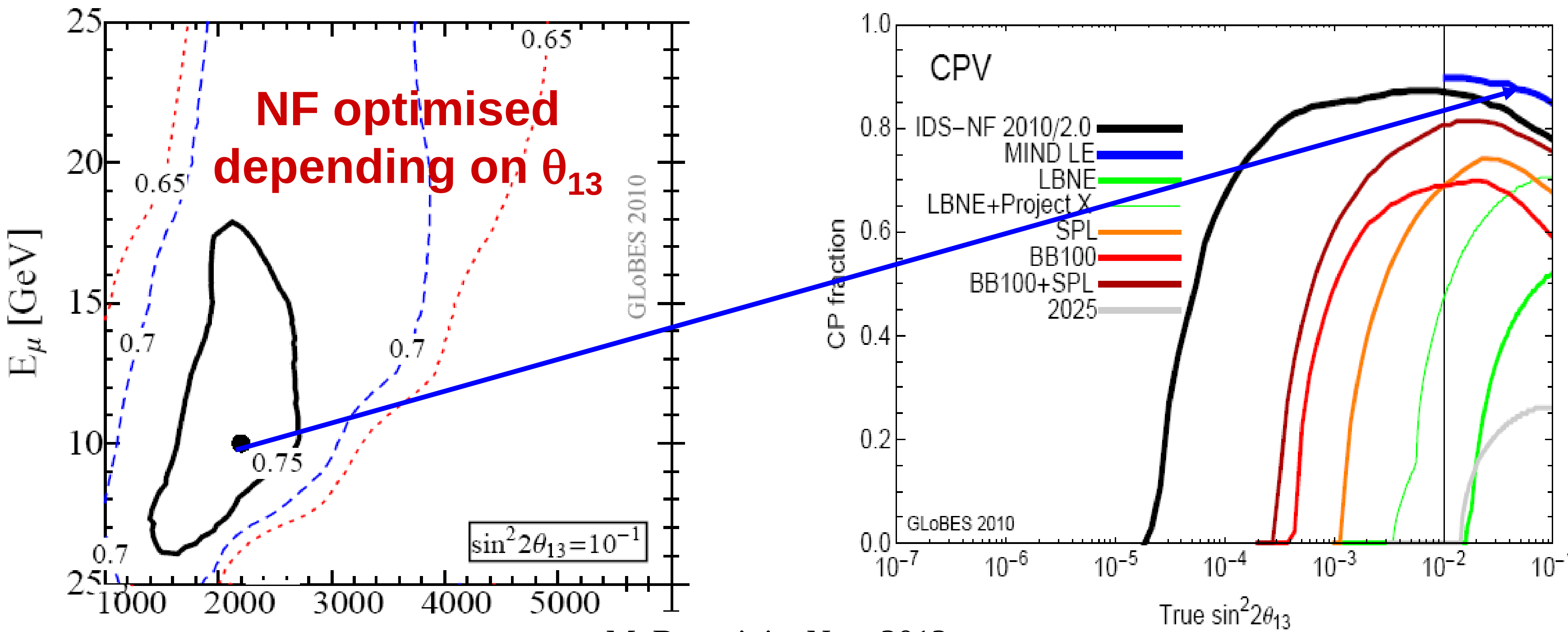
$$\nu_e \to \nu_\mu ; \quad \nu_\mu + N \to \mu^- + X$$

LARGE (100kton)
magnetized iron detector

+ unique ability to test $\nu_e \to \nu_\tau$

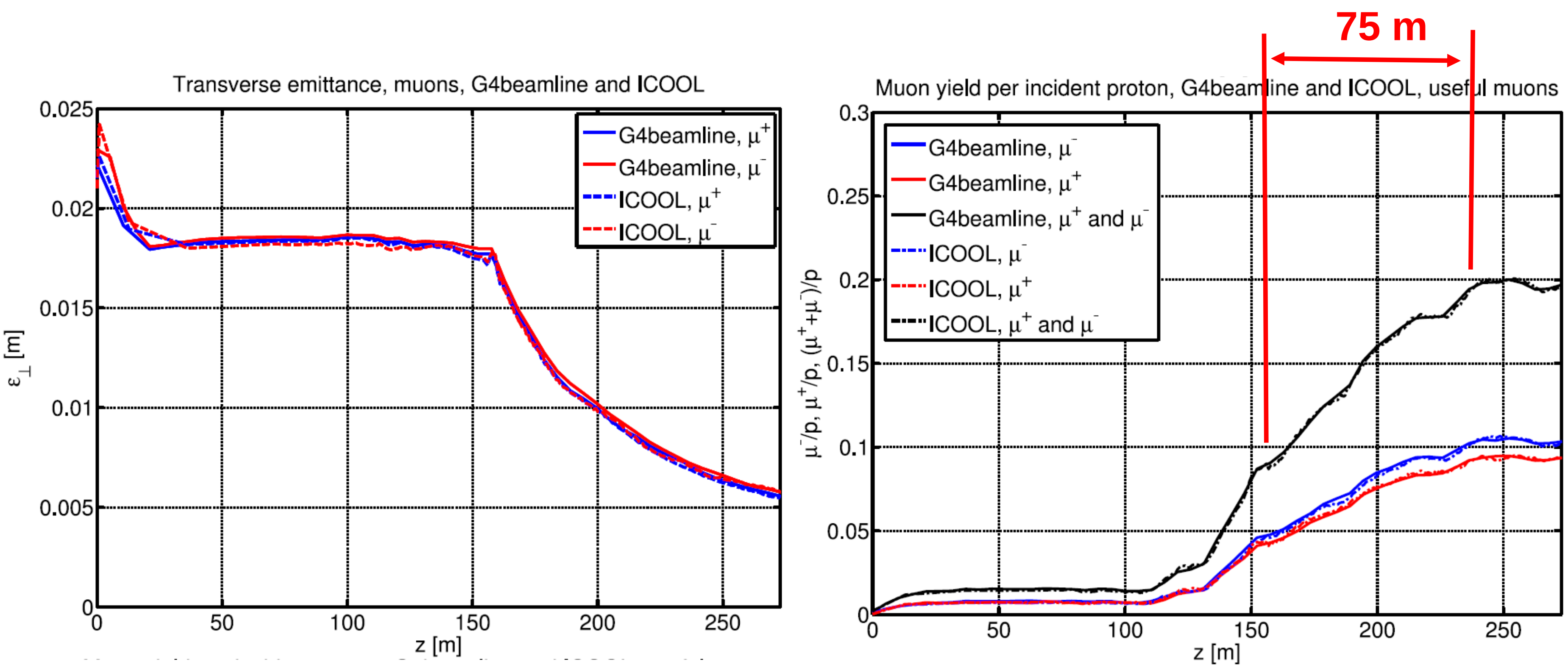
Neutrino Factory optimisation

- Neutrino Factory optimisation depends on value of θ_{13}
- At $\sin^2 2\theta_{13} \sim 0.1$ optimum is ~10 GeV NF with ~2000 km baseline
- Neutrino Factory offers best sensitivity and smallest $\Delta\delta_{CP}$ ~ 5^o out of all future facilities



Neutrino Factory: cooling reqs.

- Cooling essential to deliver Neutrino Factory performance

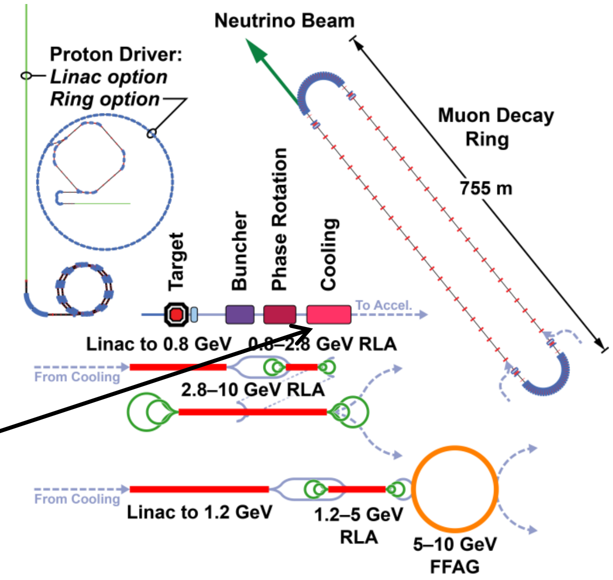


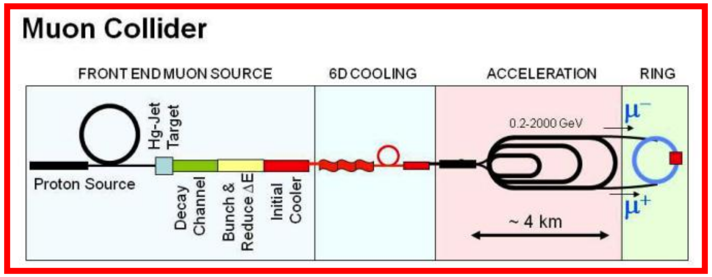
Emittance: 18 mm rad→7.5 mm rad Muon yield: 0.08 μ/p.o.t.→0.19 μ/p.o.t.

Increase in performance: 2.4

Neutrino Factory R&D [and μ-collider]

- R&D on many items:
  - High power (~4 MW) proton driver (~8 GeV)
  - Target and collection (HARP/MERIT)
    - Maximize π^+ and π^- production
    - Sustain high power (MW driver)
    - Optimize pion capture
  - Muon cooling (MICE)
    - Reduce μ+/μ- phase space to capture as many muons as possible in an accelerator channel [mu-flux increase by a factor 2-10]. It is an essential item for μ-colliders [6D cooling, needed cooling factor ~10^6]
  - Muon acceleration (EMMA) [~10 GeV]
    - Has to be fast, because muons are short-lived ! (RLA, FFAG, …)



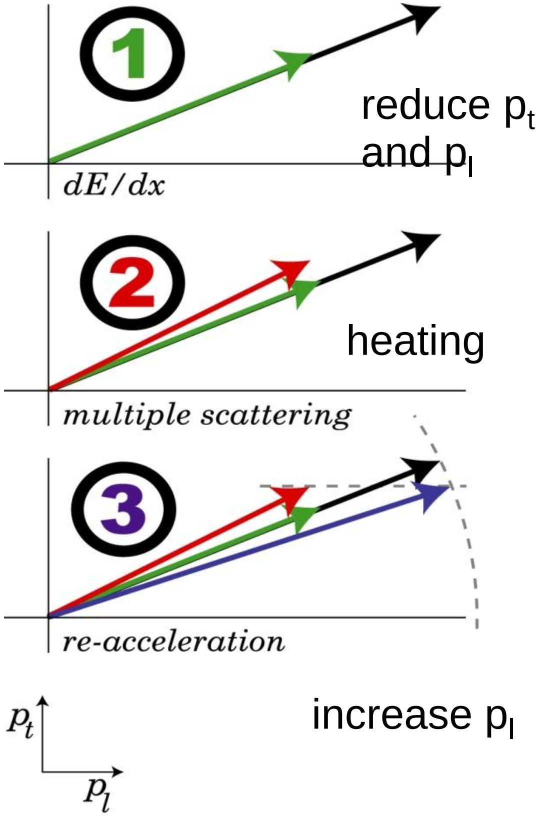


- Negligible synchrotron radiation (and beamstrahlung)
- Precise det of E_{beam} (0.003%)
- Strong coupling to the Higgs

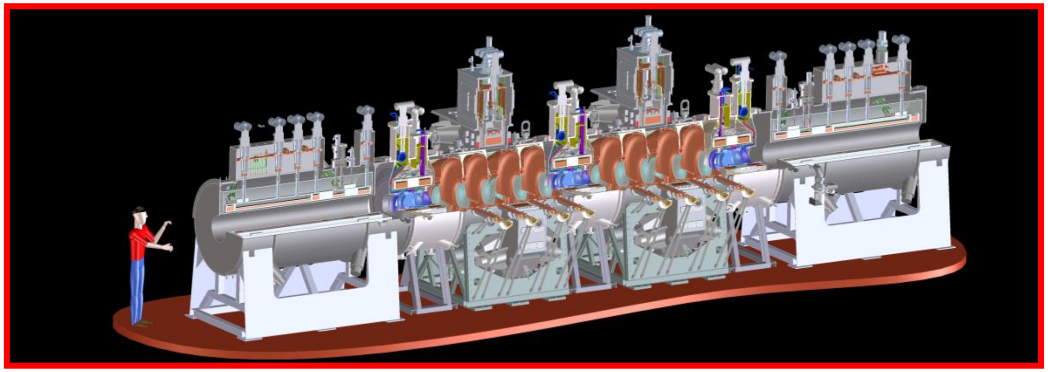
Muon ionization cooling

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

principle



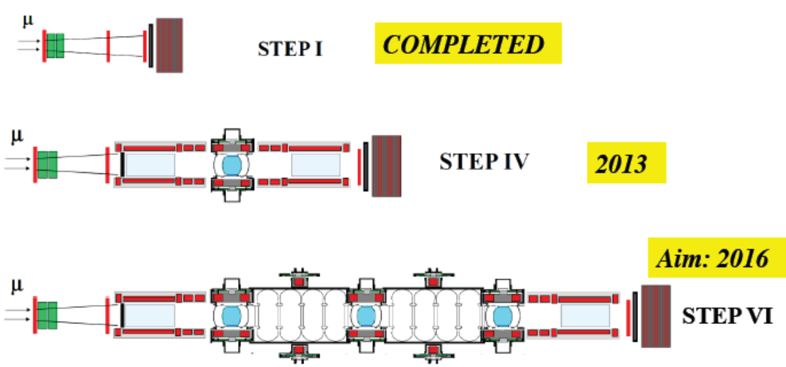
reality including beam diagnostics(simplified)

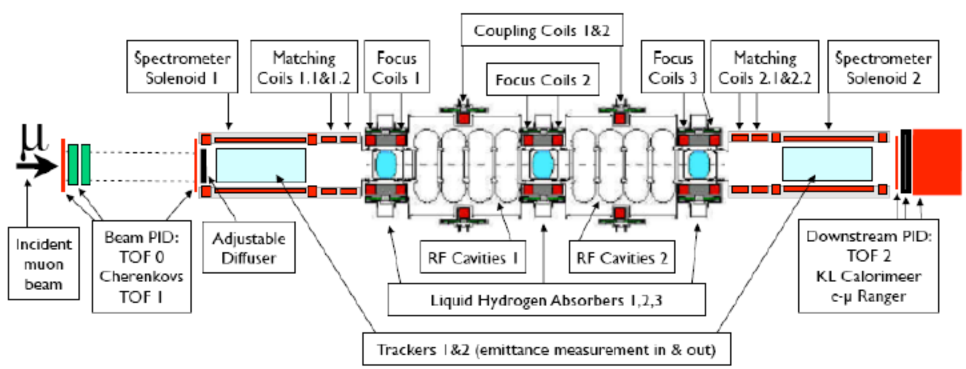


- Build a section of cooling channel long enough to provide measurable cooling (10%) and short enough to be affordable and flexible
- Wish to measure this change to 1%
- Requires measurement of emittance of beams into and out of cooling channel to 0.1% !
- Cannot be done with conventional beam monitoring 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

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

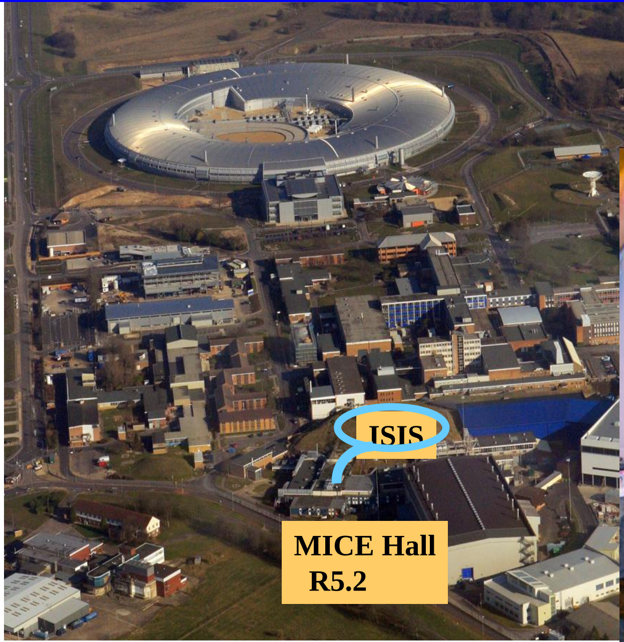


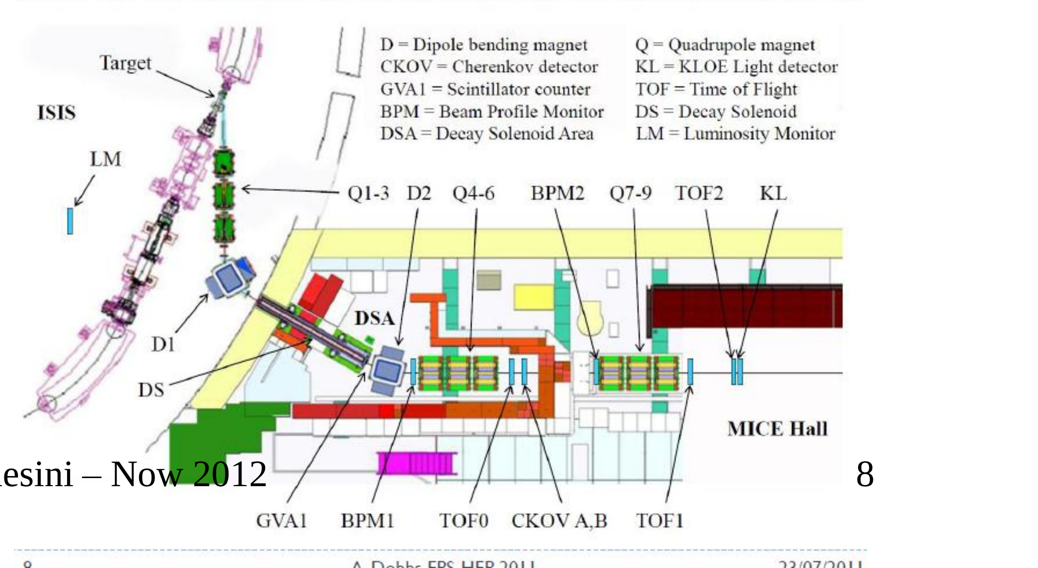


MICE in STEPS

STEP I: 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**
  important to insure high μ purity for muon cooling measurement.
  - Upstream:
    - Time of Flight TOF0 + TOF1 x/y hodoscopes
    - 2 Aerogel Cherenkov detectors (n=1.07 and 1.12)

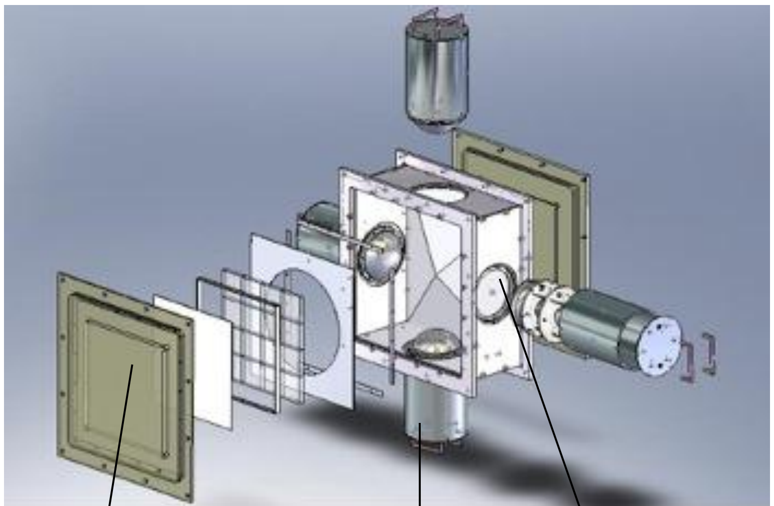
    ➔ π/μ separation up to 360 MeV/c

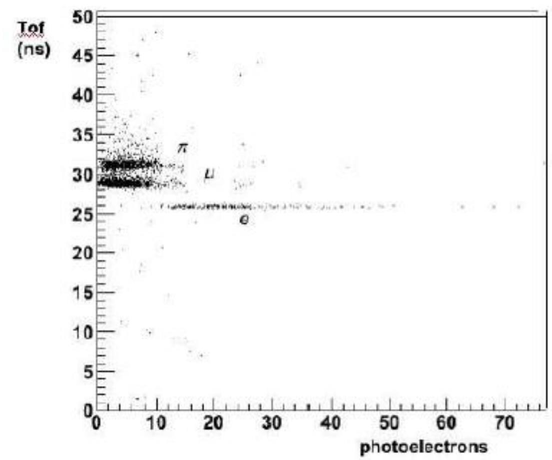
    ➔ Beam purity better than 99.9%
  - Downstream:

    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
      - Kloe-like (KL) Lead-scintillating fiber sandwich layer
      - Electron-Muon Ranger (EMR) (in construction)
        - » $1m^3$ block extruded scintillator bars
        - » Also measure muon momentum
- Particle tracking
  - Scintillating Fiber trackers
  - Measure position and reconstruct momentum

Upstream : CKOVa/CKOVb

Aereogel Cherenkov detector blowup



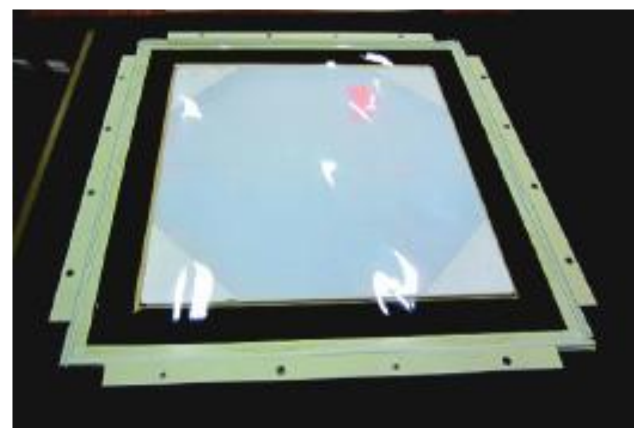


Ckov vs TOF measurement

radiator

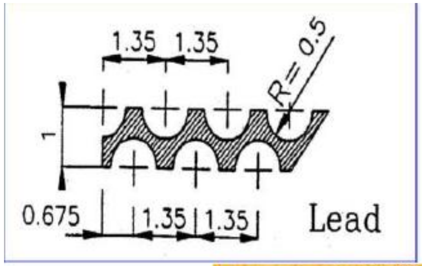
Reflector Panels

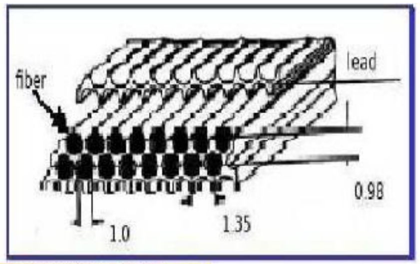
8" PMT port

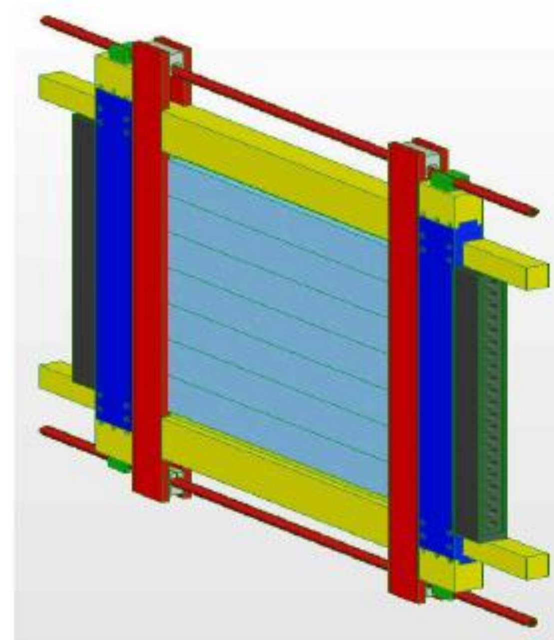


Aerogel

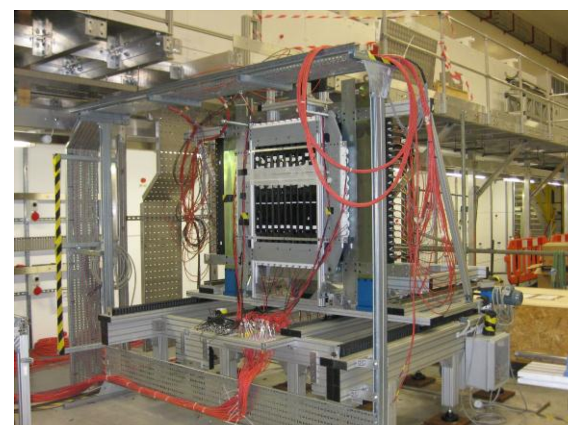
KL calorimeter





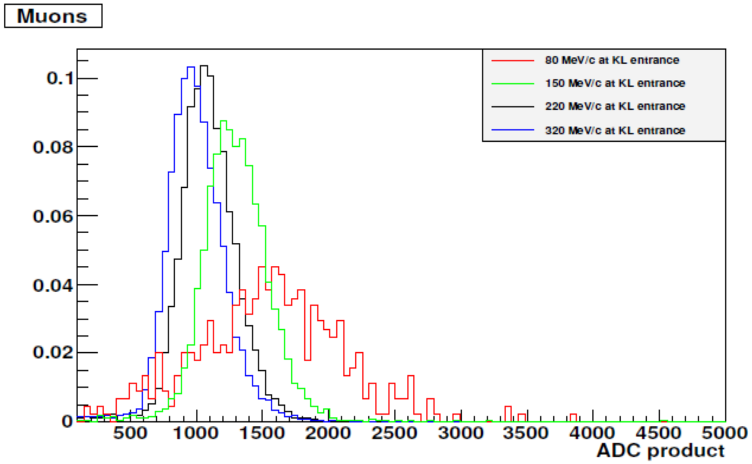


Schematic layout of KL extruded fibers and lead

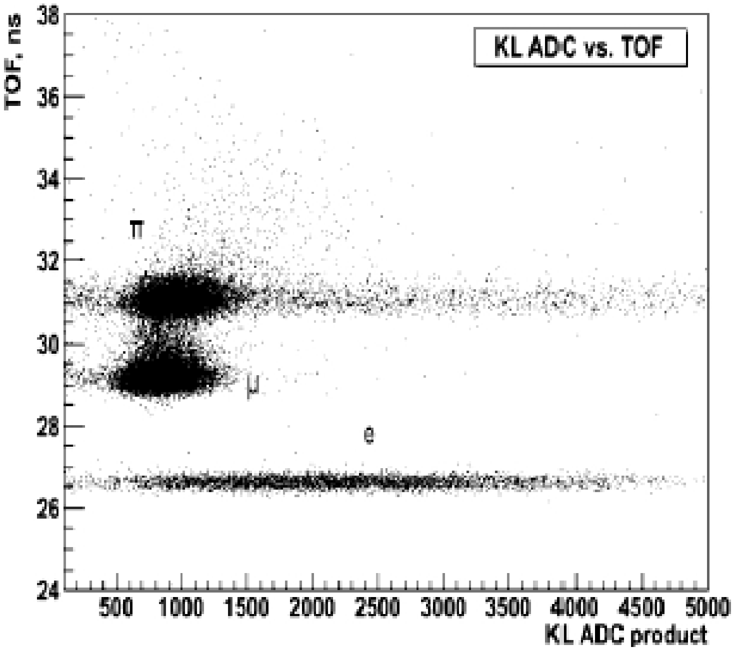


Installation in temporary position after Q9 at RAL

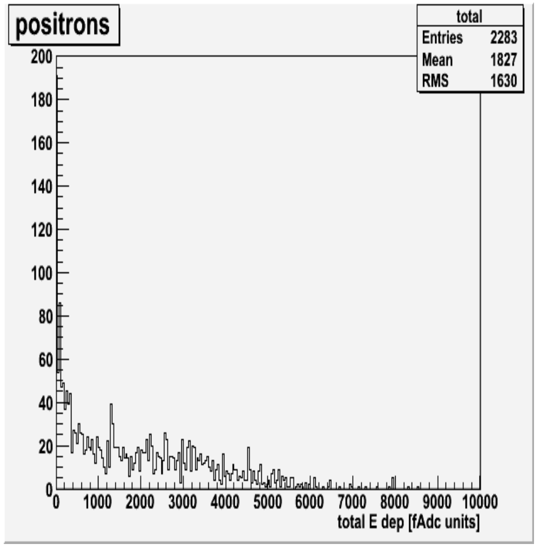
KL performances in beam



KL response to muons



Performance KL vs TOF



KL response to 100MeV e^+ beam

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:

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

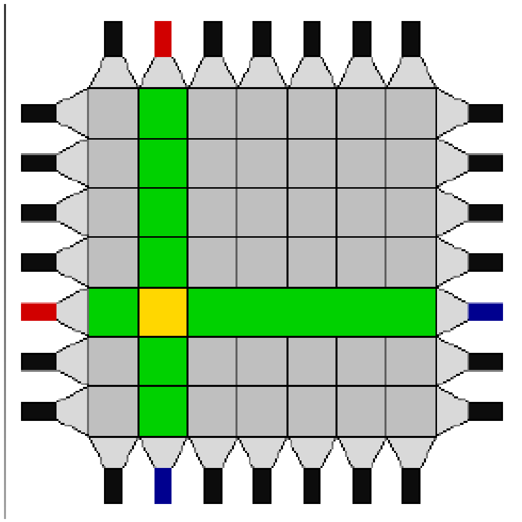
with good timing performances (σ_t~50 ps) → **Some points to look at to have high resolution TOFs**

- 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)**

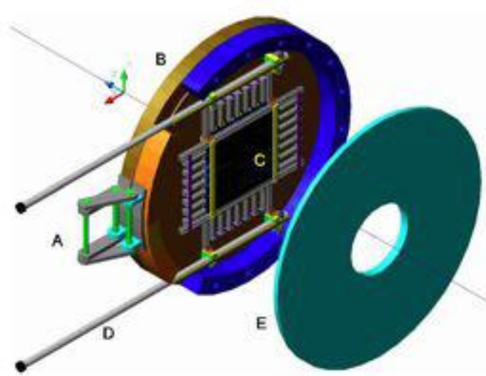
+

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

TOF design



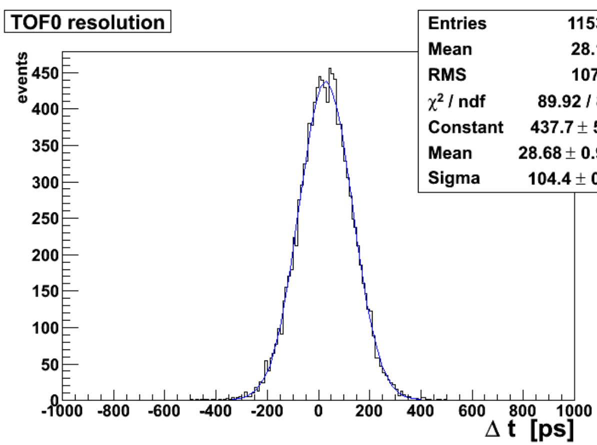
- "conventional" X/Y scintillator structure with readout at both ends, to provide redundancy & intercalibration with inc. μ
- CAEN V1724 FADC + CAEN V1290 TDC readout
- problems: high incident particle rate (1 MHz) and solenoid fringe field: $B_{\parallel} \sim 200-300\, G$, $B_{\perp} \sim 1\, kG$

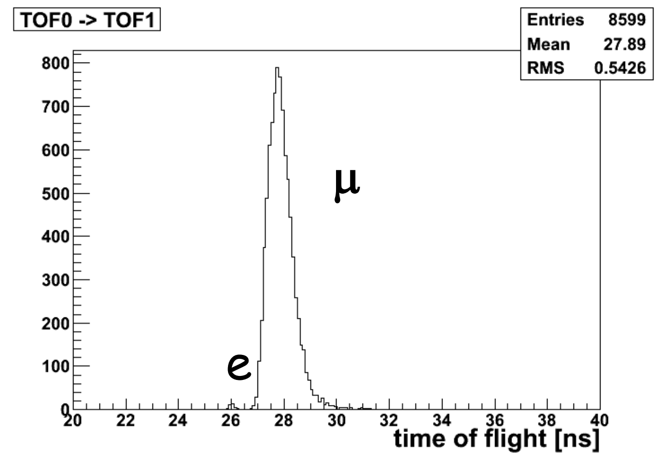


External B-field cage TOF1

Magnetic ARMCO Shielding TOF2

TOF performances

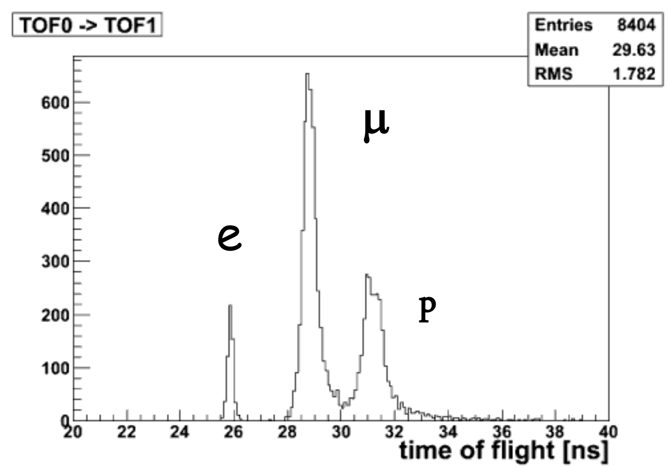




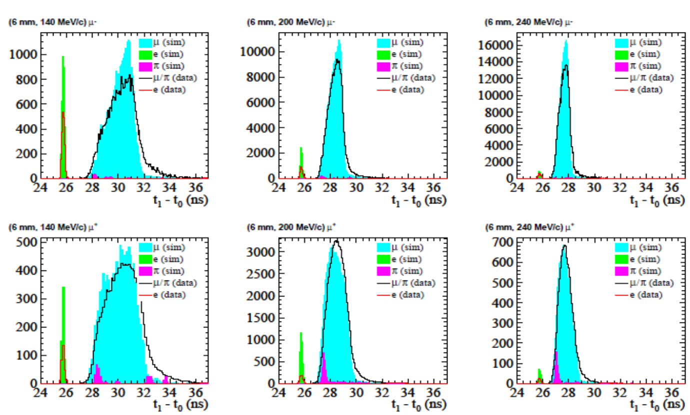
- Time resolution after calibration:

TOF0 – 51ps; TOF1 – 53ps; TOF2 – 52ps.

TOF for μ beam, calibration beam

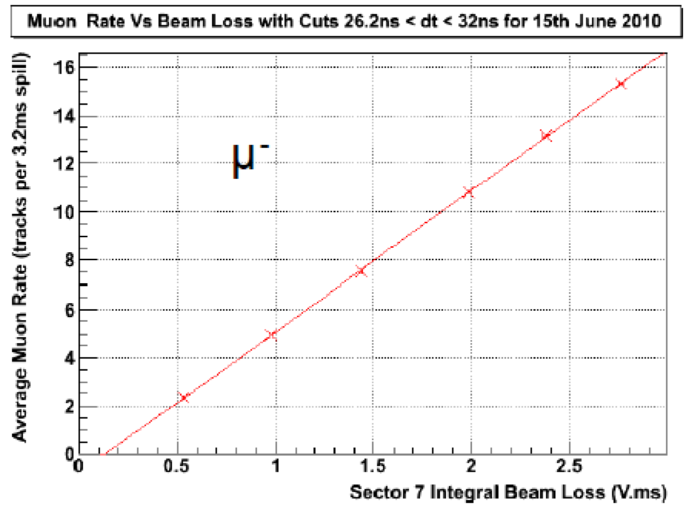


Comparison data-MC



Beamline Commissioning

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



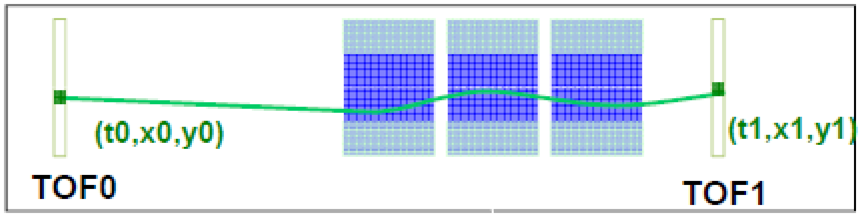
μ rate related to ISIS beam losses

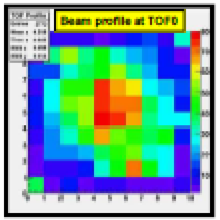
Momentum (MeV/c)

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



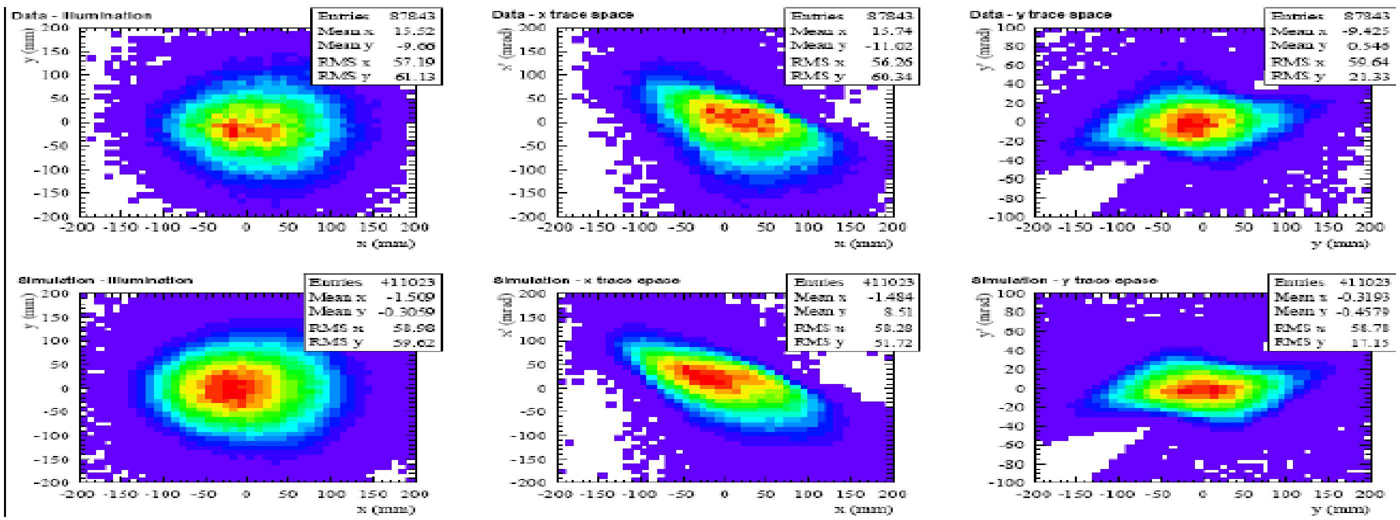


Momentum-dependent matrix relates: $(t_0,x_0,y_0,t_1,x_1,y_1)$ -> $(t_1,p,x_1,x'_1,y_1,y'_1)$ solved by iteration

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

data

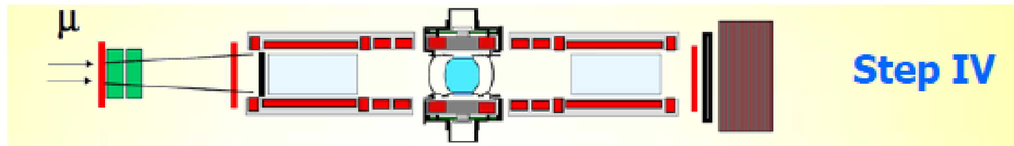
MC



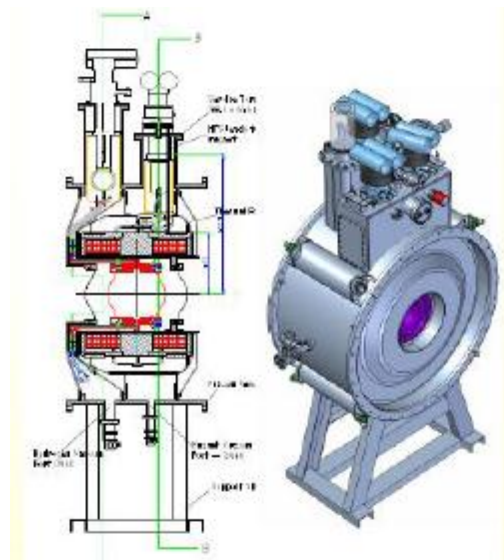
y(mm) vs x(mm) **x' (mrad) vs x (mm)** **y'(mrad) vs y (mm)**

STEP IV overview

The addition of the SC spectrometer solenoids (US) and the first absorber module later this year will enable first emittance reduction measurement using fully MICE in 2013. Detector instrumentation will be completed with trackers and EMR.



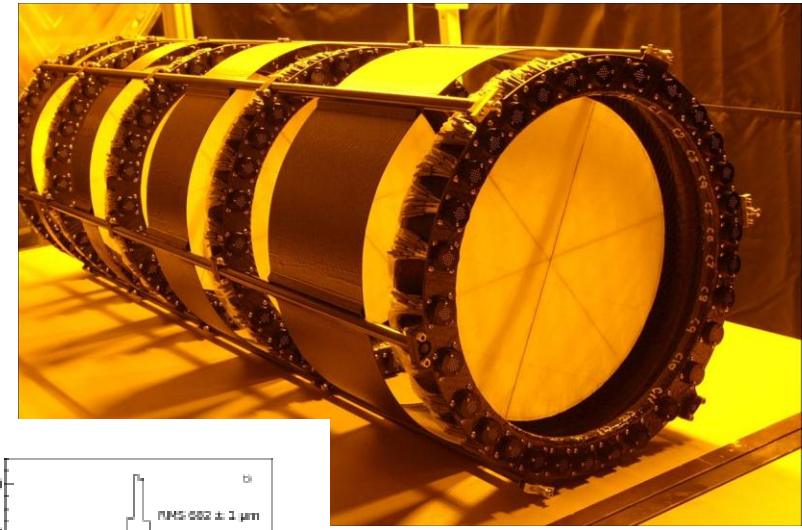
4T SC solenoids. Trackers inside.



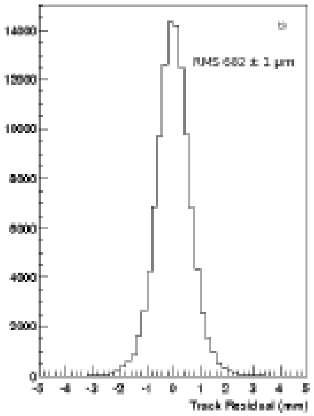
Absorber-Focus-Coil modules

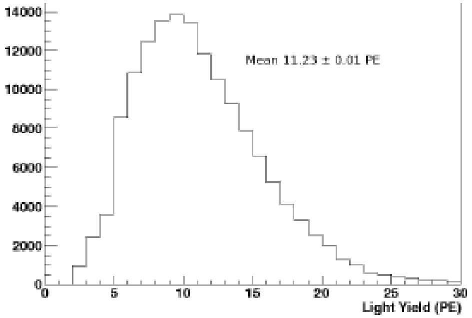
STEP IV : MICE Trackers installation

- **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%)

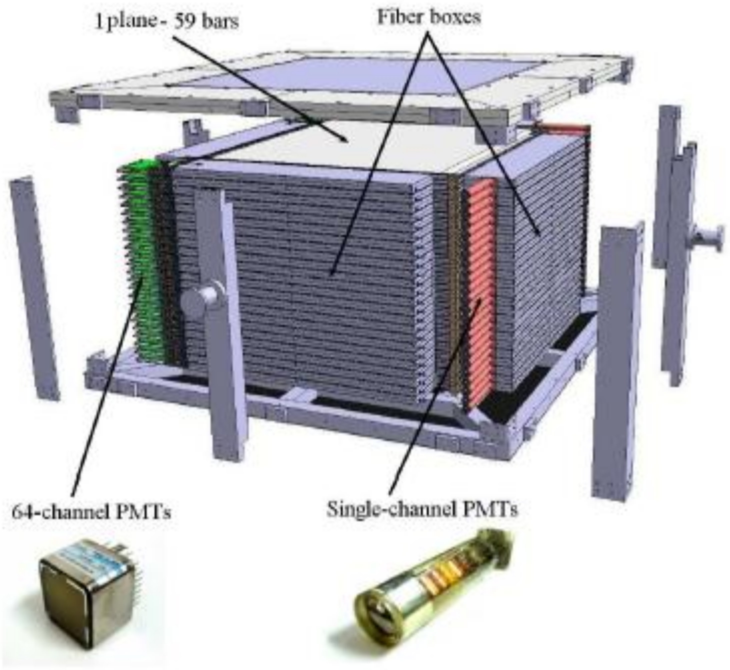




Performances with cosmics:

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

STEP IV: EMR installation (PID upgrade)



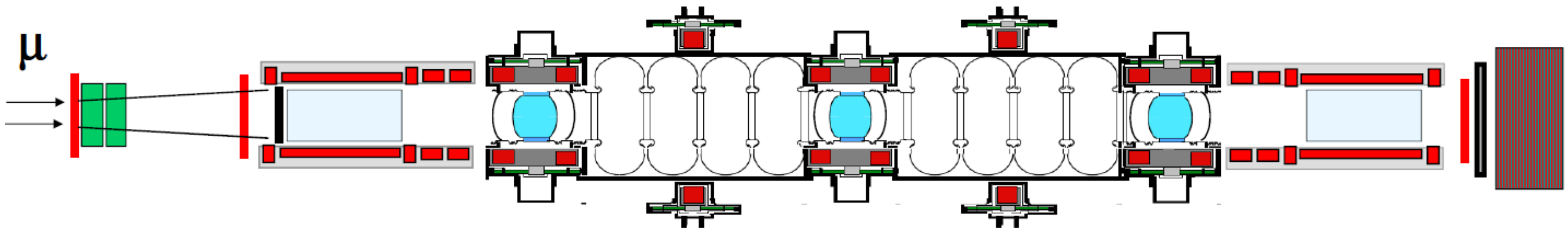
- 24 modules (X-Y planes)
- 48 planes
- 59 bars per plane
- 2832 bars
- 3m WLS fibers per bar
- 8.5 km WLS fibers
- single and 64-channel PMTs per plane
- 3072 + 48 channels

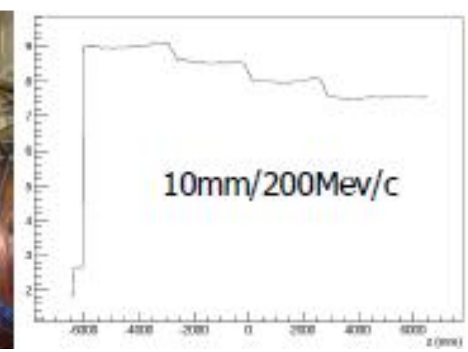
- **Discriminate muons from electrons.**
  1. **Track Properties:**
     - **Muons show tracks;**
     - **Electrons converted in EM showers in KL show scattered hits**
  2. **dE/dx along Z**
     - **Muons have constant dE/dX up to the Bragg peak**
     - **Electrons have large fluctuations in Energy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

… and to completion: STEP VI

The addition of RF cavities (built) and absorber modules will permit an emittance reduction of ~10% to be measured to an absolute accuracy of 0.1%

STEP VI





201-MHZ RF cavities RF amplifier RF power coupler

Conclusions

- The MICE experiment is an essential R&D milestone towards a Neutrino Factory and a μ-Collider
- MICE beamline in place and commissioned: over 13×10^6 triggers collected in STEPI
- PID detectors (upstream: TOF0,TOF1,CKoV, downstream: TOF2,KL) installed and working well
- Preliminary emittance measurement with TOF only
- STEP IV in preparation and ready to take data (2013) with addition of trackers+EMR to instr.
- Components for STEP VI under construction