The International **Muon** **Ionization** **Cooling** **Experiment**

MICE

1. Why, what and who?

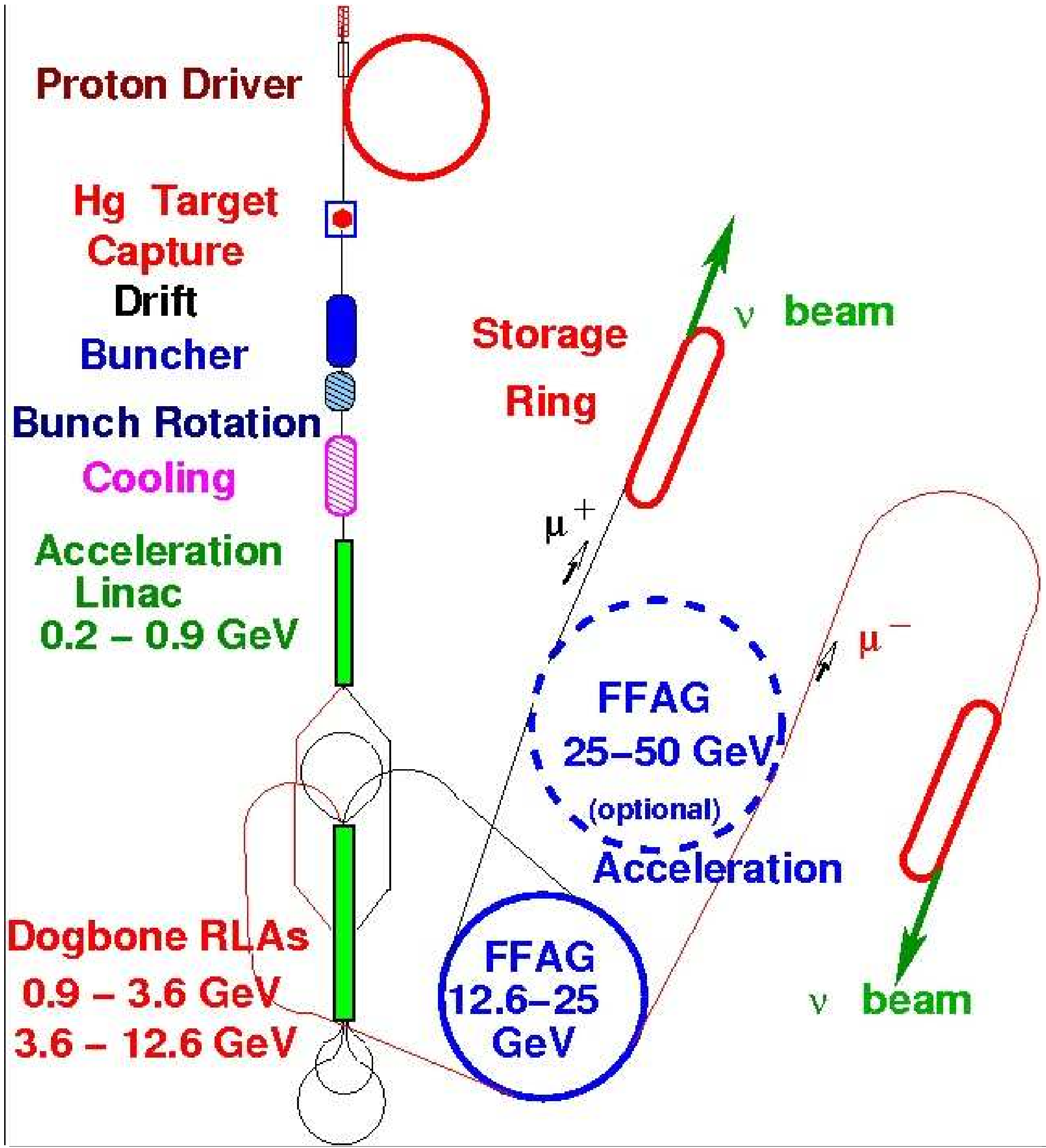
2. The MICE experiment principles and main challenges

3. status and schedule

4. Conclusions

Collaboration life can be explored here:
http://mice.iit.edu

We do MICE because we want to investigate the feasibility of neutrino factory and muon collider



neutrino factory:

accelerate muons and

store to produce neutrinos

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

high energy electron neutrinos
Unique to future facilities

Golden /silver channel:

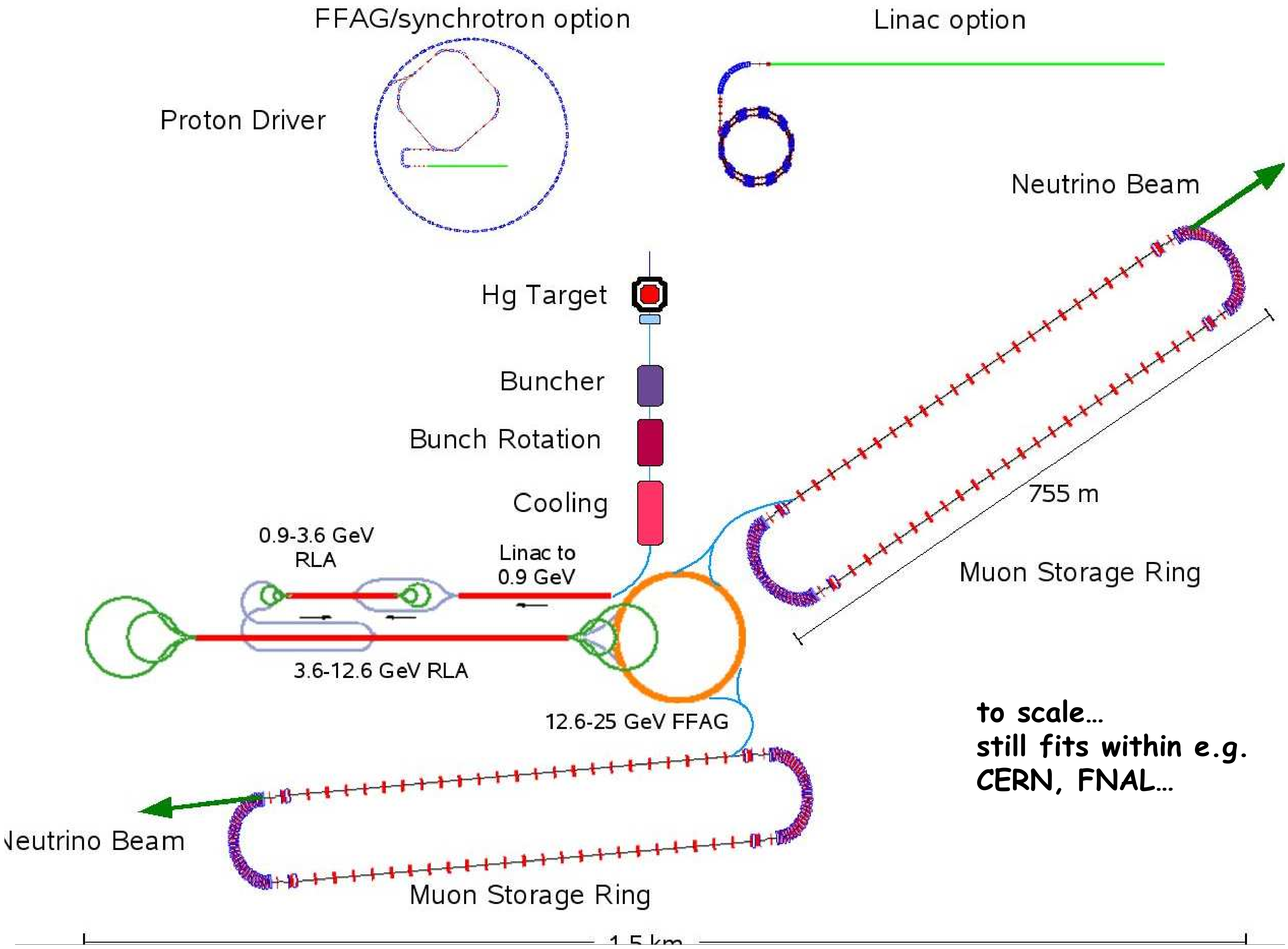
long baseline oscillation manifests itself by wrong sign muons/taus

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

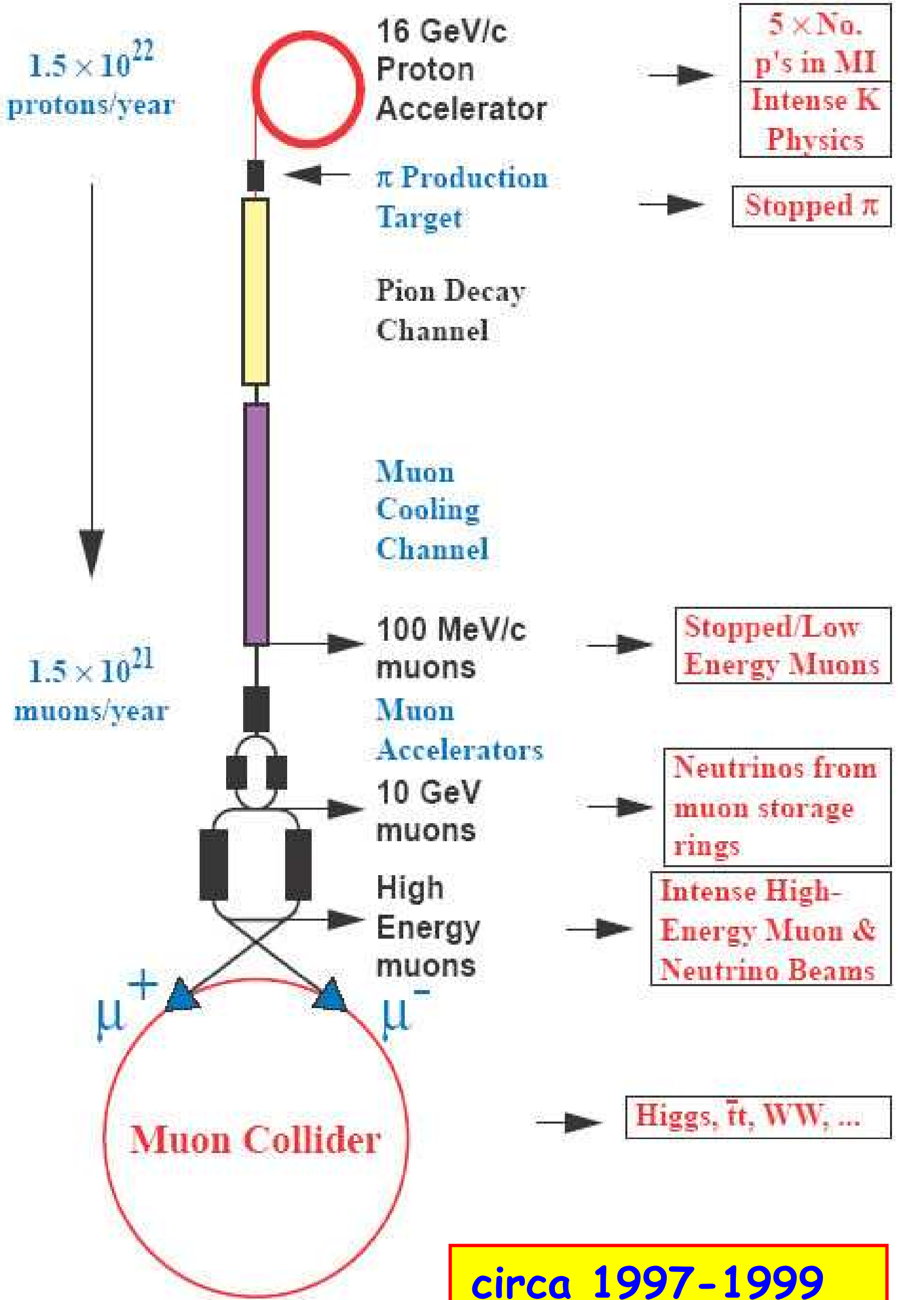
(100kton)magnetized iron detector

Platinium channel:

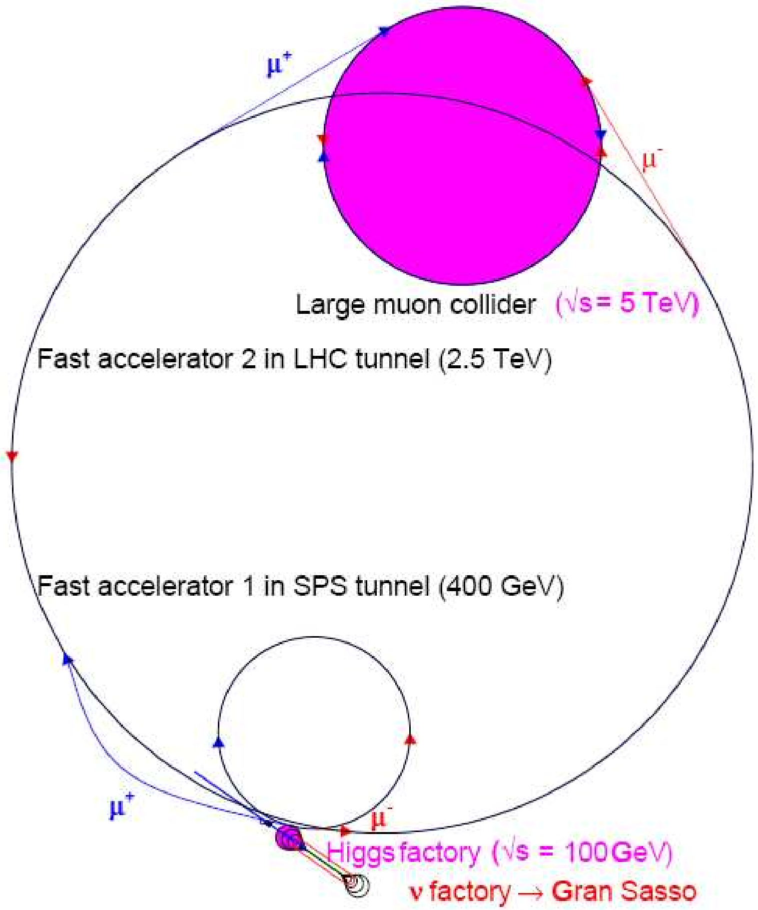
$$\overline{\nu}_\mu \rightarrow \overline{\nu}_e ; \quad \overline{\nu}_e + N \rightarrow e^+ + X$$


FFAG/synchrotron option
Linac option
Proton Driver
Neutrino Beam
Hg Target
Buncher
Bunch Rotation
Cooling
755 m
0.9-3.6 GeV
RLA
Linac to
0.9 GeV
Muon Storage Ring
3.6-12.6 GeV RLA
12.6-25 GeV FFAG
to scale…
still fits within e.g.
CERN, FNAL…
Neutrino Beam
Muon Storage Ring

Intense nucl. and hadr. physics
Intense Low-E muons
Neutrino Factory
Higgs(es) Factory(ies)
Energy Frontier -> 5 TeV

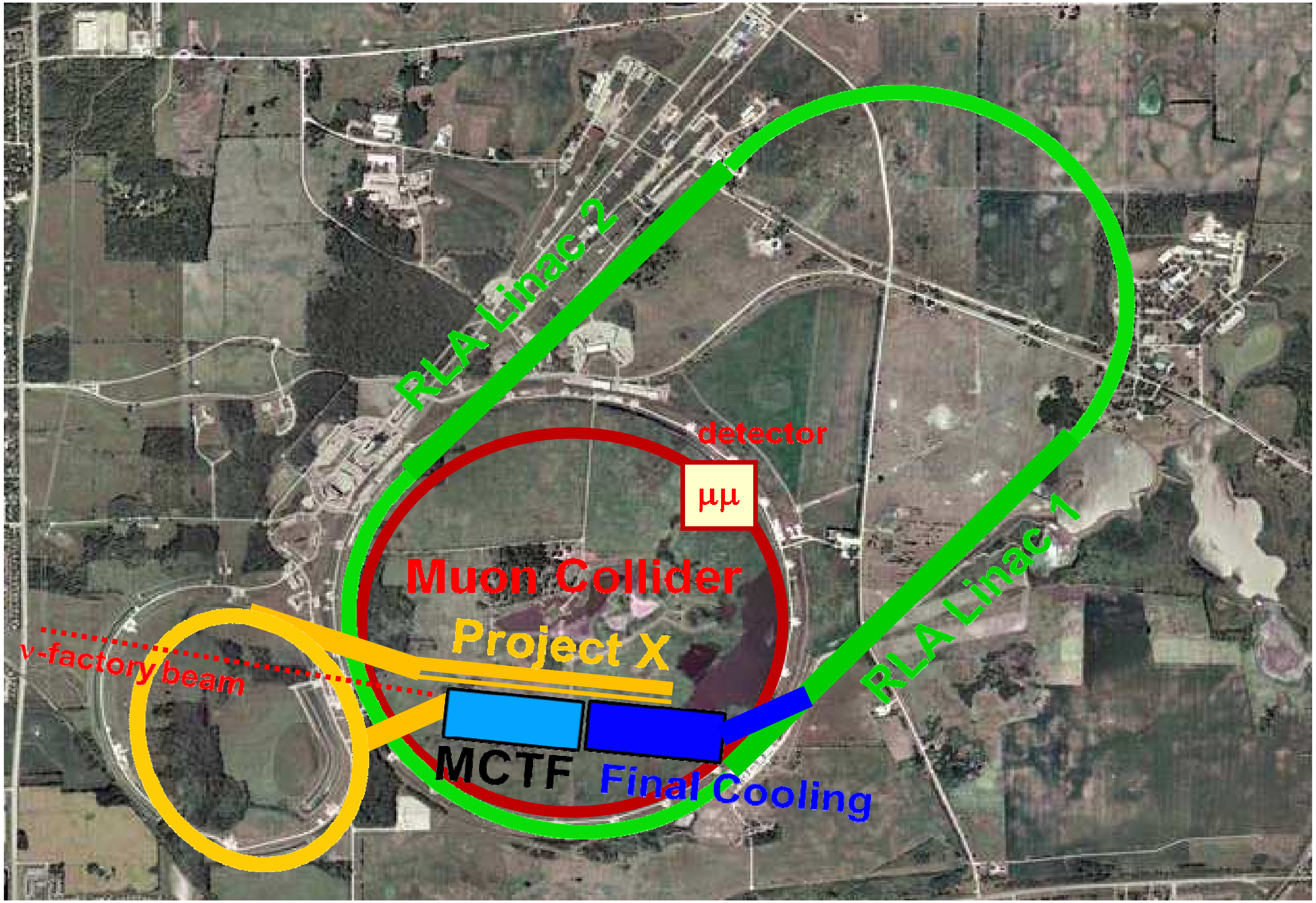


circa 1997-1999
US, Europe, Japan



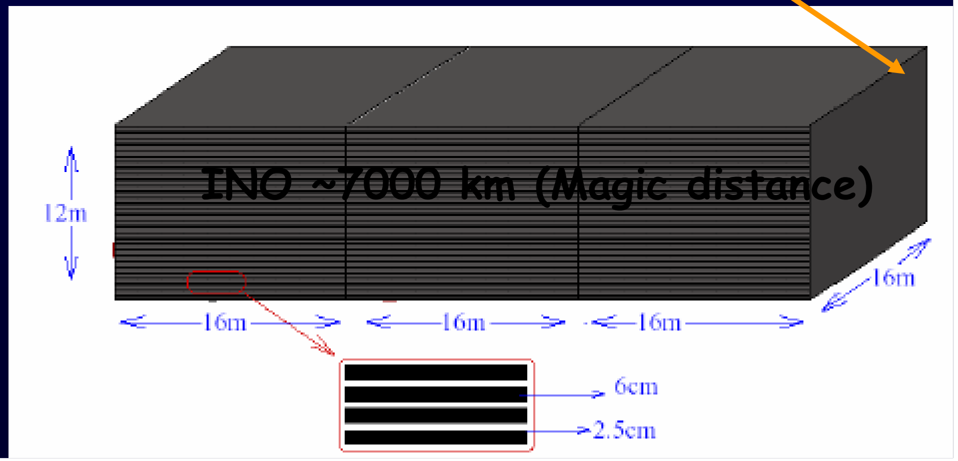
Possible layout of a muon complex on the CERN site.

Fermilab Muon Complex - *Vision*



We do MICE because
we want to explore neutrino factory
or muon collider
as an option for the future.
Feasibility, cost

Long baseline detectors: Magnetized Iron, emulsions, liquid argon



Magnetized Iron calorimeter

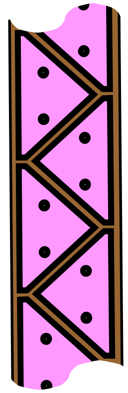
(baseline detector, Cervera, Nelson)

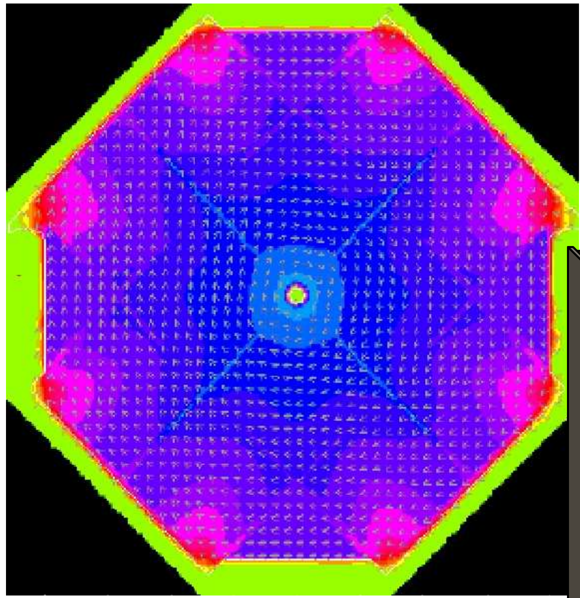
B = 1 T Φ = 15 m, L = 25 m

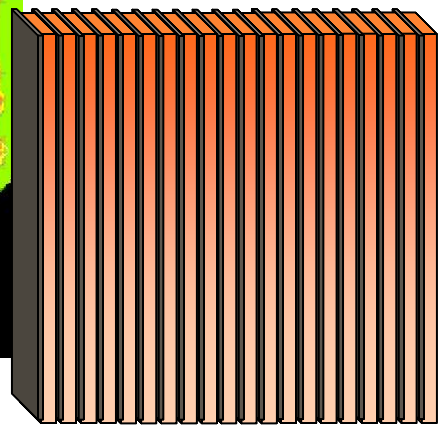
t(iron) =4cm, t(sc)=1cm

Fiducial mass = 100 kT

Charge discrimination down to 1 GeV



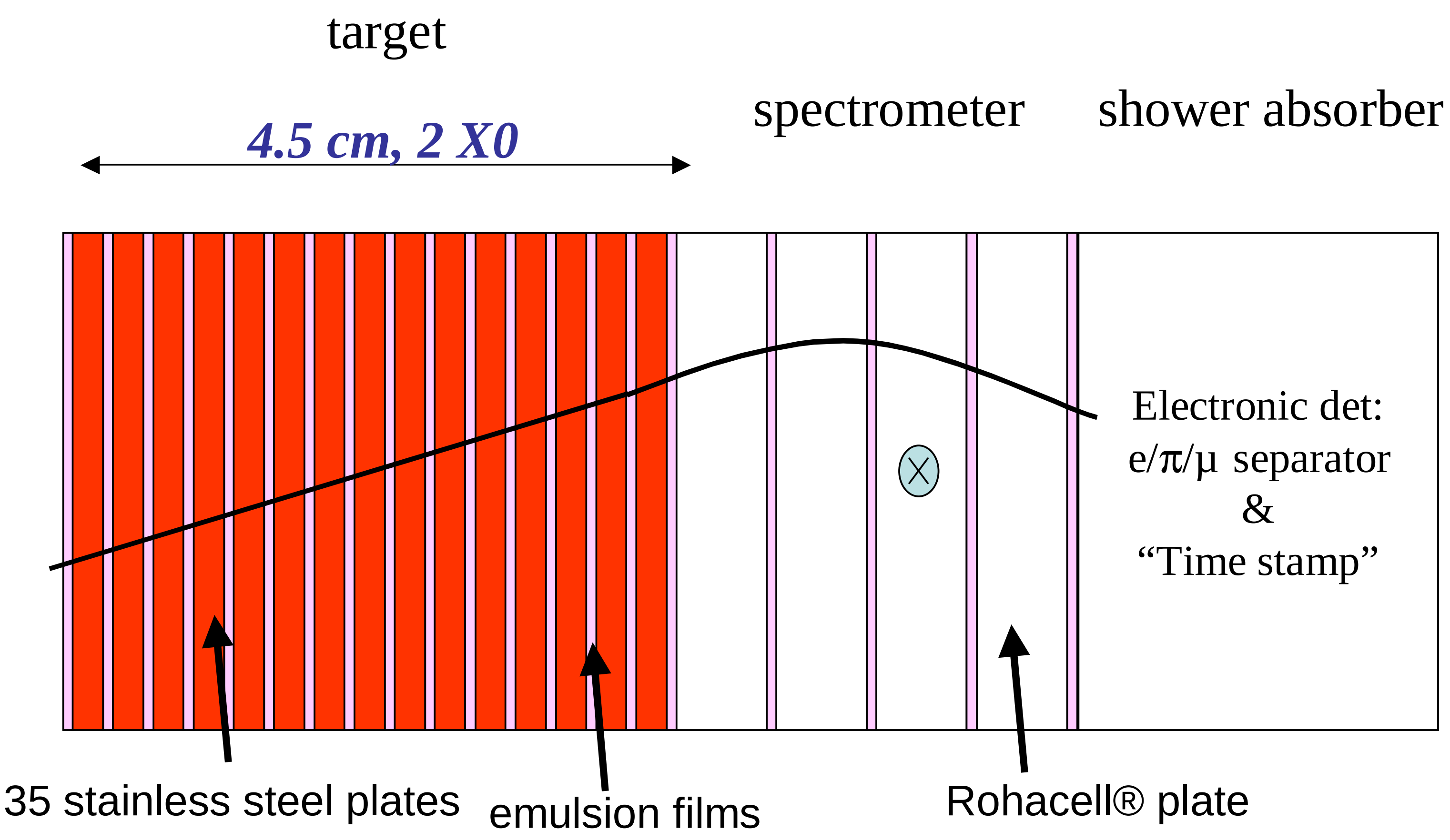




Event rates for 10^{20} muon decays (<~1 year)

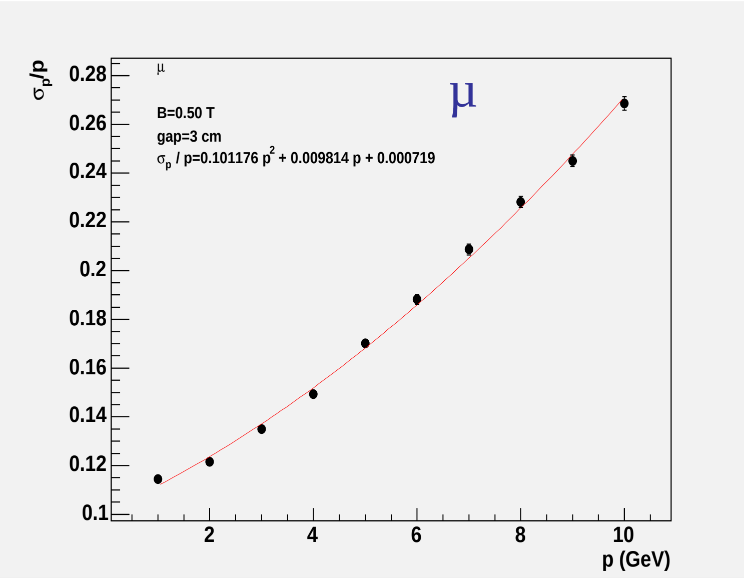
Baseline	$\bar{\nu}_\mu$ CC	ν_e CC	ν_μ signal (sin$^2\theta_{13}$=0.01)	
732 Km	10^8	2×10^8	3.4×10^5	(J-PARC I→ SK = 40)
3500 Km	4×10^6	7.5×10^6	3×10^5	

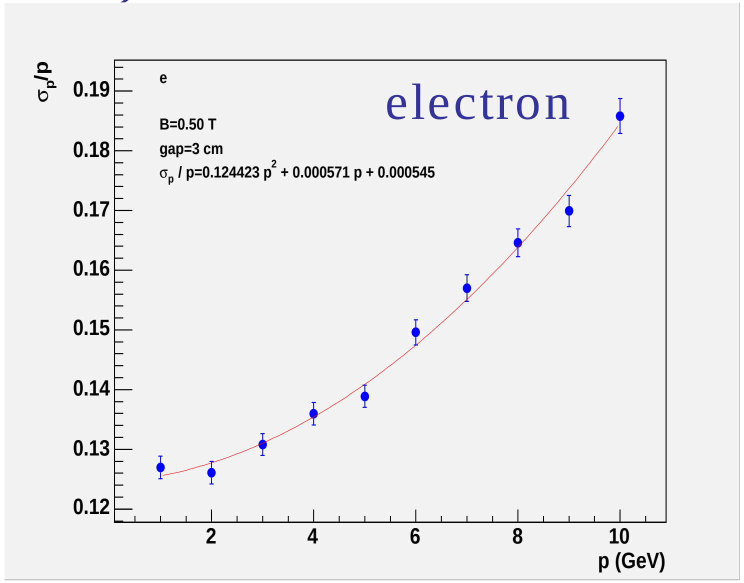
Magnetized ECC structure



We have focused on the "target + spectrometer" optimization

μ end electron momentum resolution: 3 gaps (3cm thick) and 0.5 T

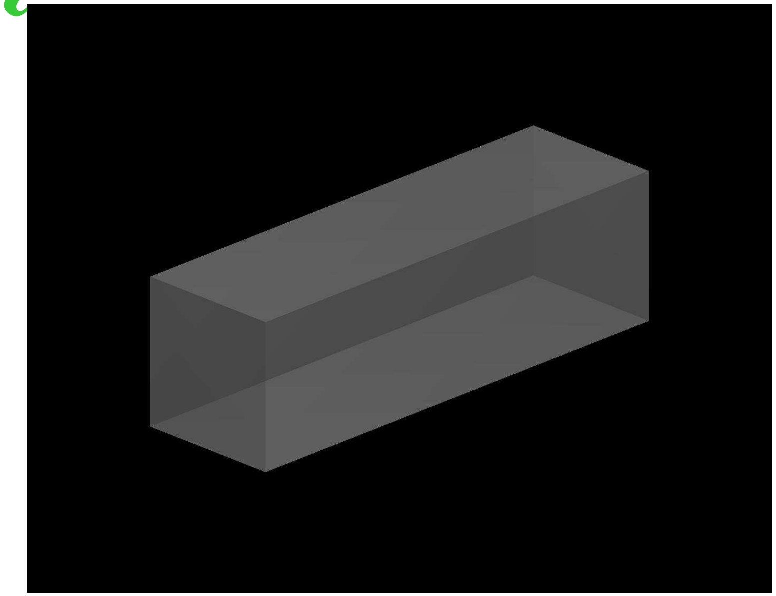


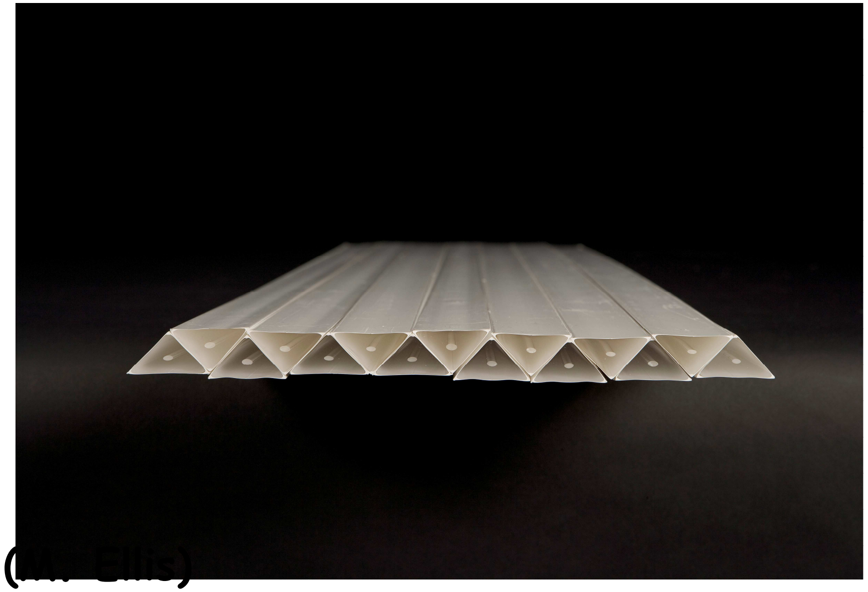


For the electron only hits associated to the primary electrons used in the parabolic fit (Kalman not used)
Given the non negligible energy loss in the target, the electron energy is taken downstream for the comparison of true against reconstructed

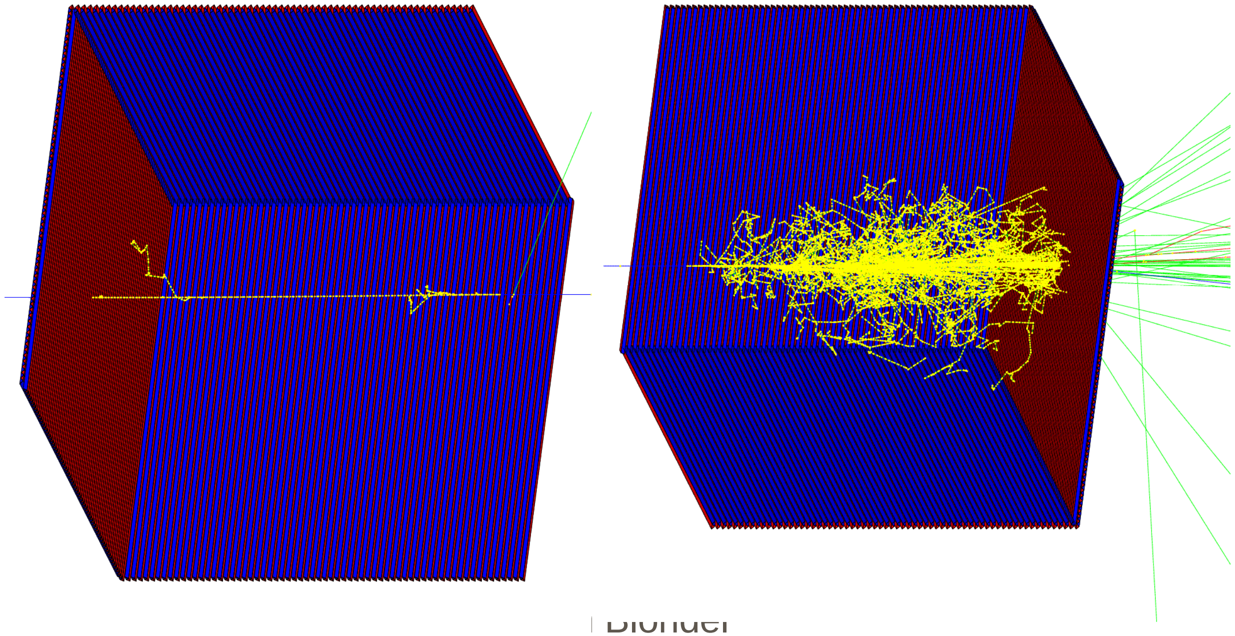
FIRST CONVINCING DEMONSTRATION THAT THE PLATINUM CHANNEL COULD BE USED!

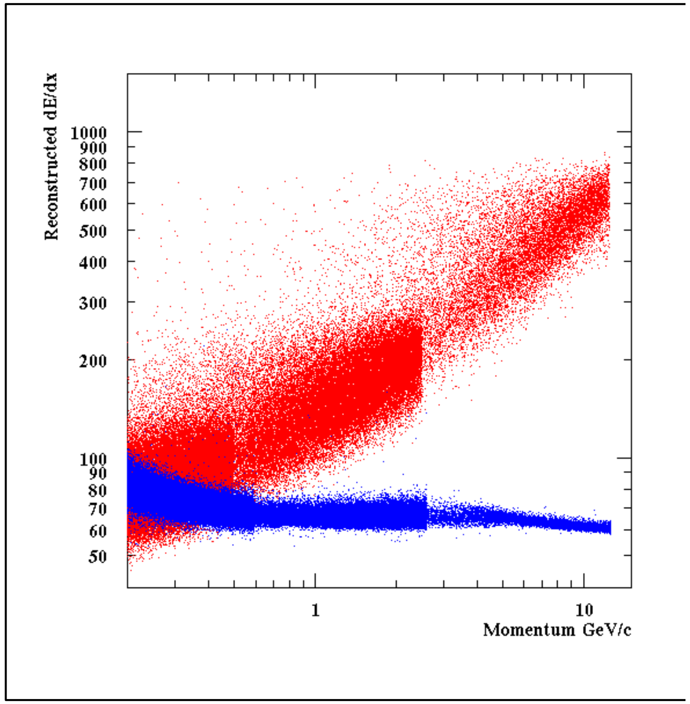
Magnetized fully active detector

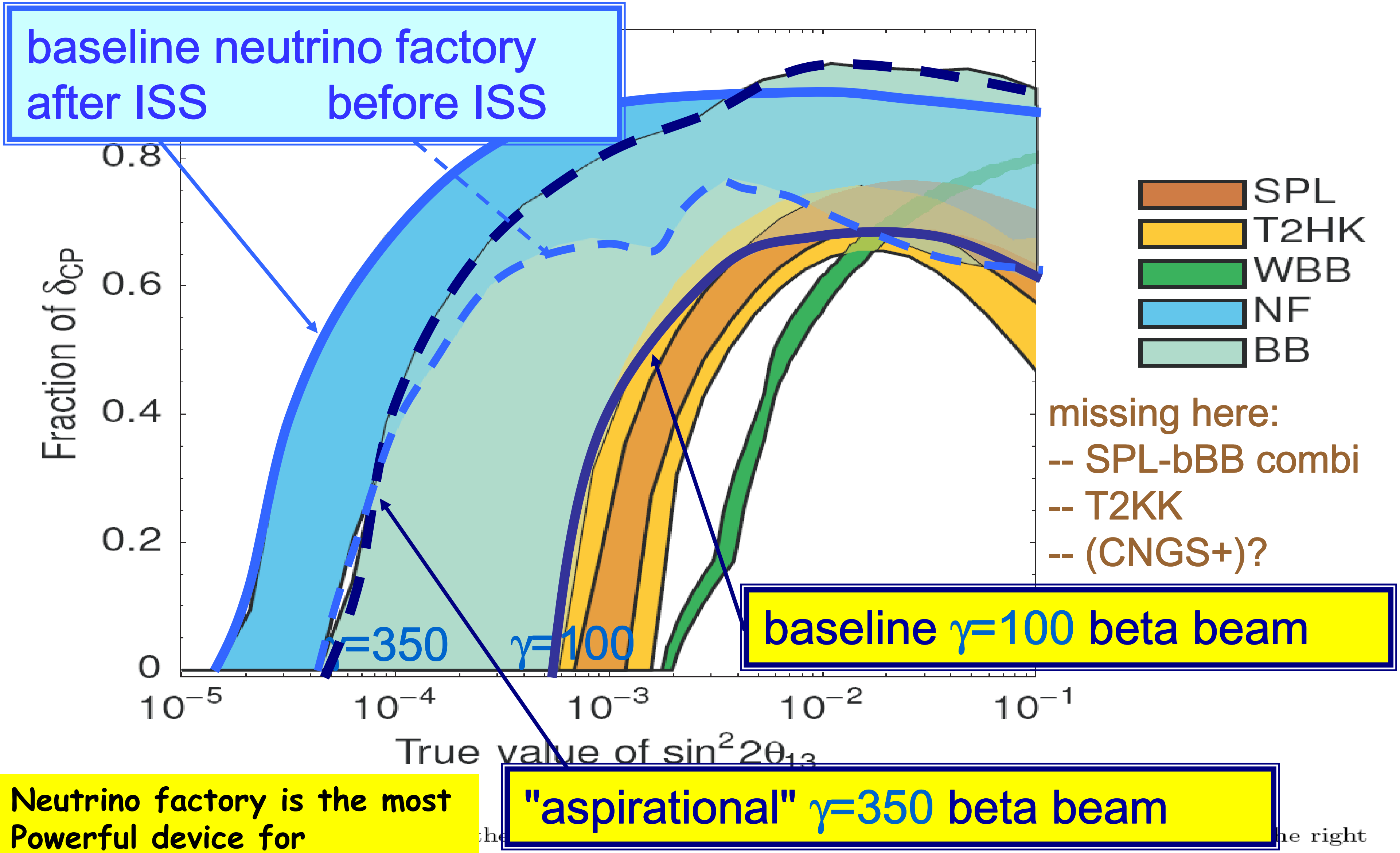




studies (





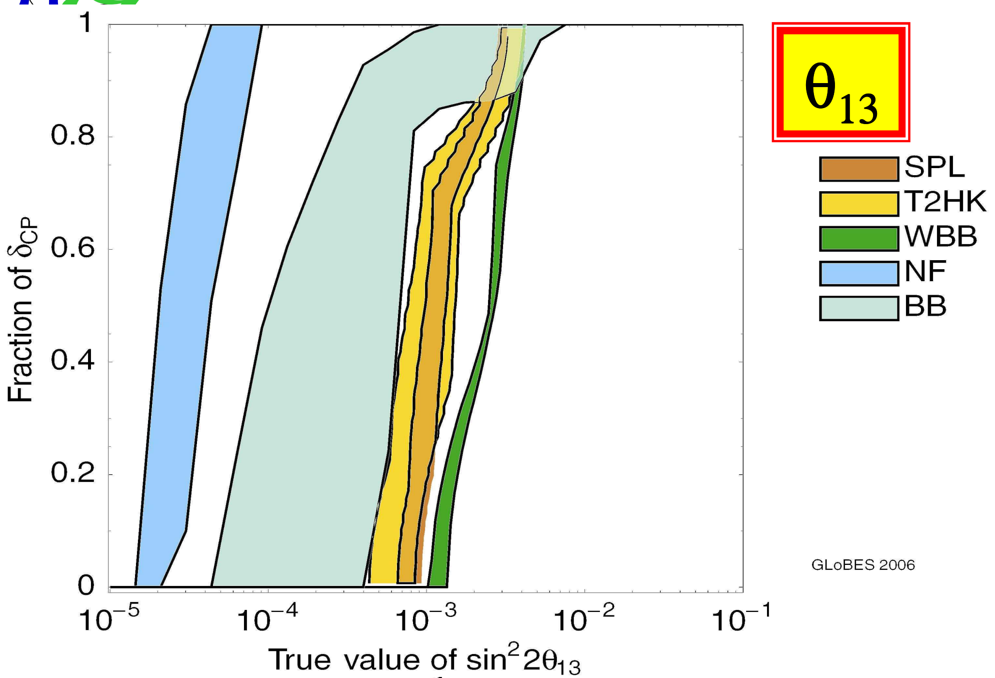


Neutrino factory is the most Powerful device for neutrino CP violation, matter effects, universality, precise measurements of Neutrino mixing parameters

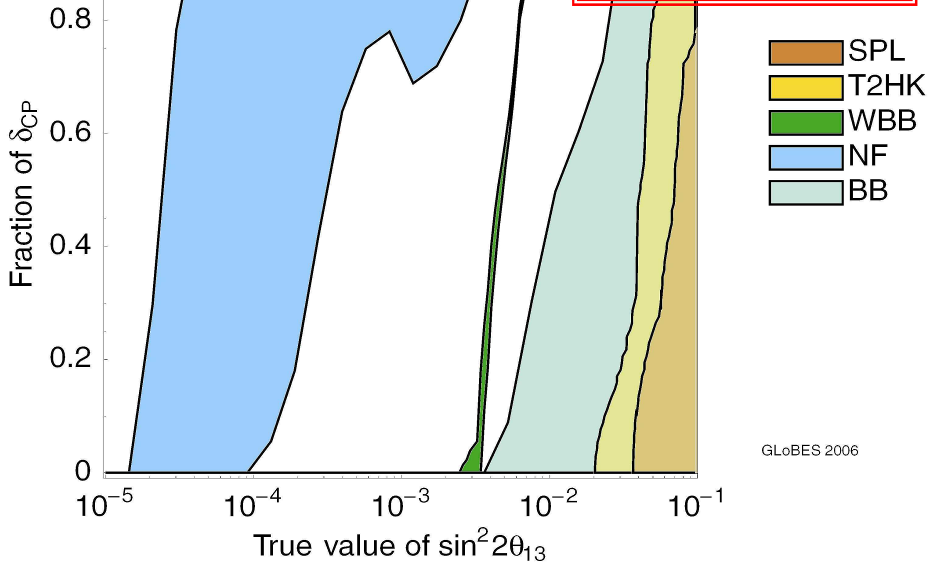
...he ... he right
... excluded at the 3σ confidence level. The discovery limits are shown as a
... values of the true value of the CP phase δ ('Fraction of δ_{CP}') and the true
...ges of the bands correspond to the conservative set-ups while the left-hand
...-ups, as described in the text. The discovery reach of the SPL super-beam
... T2HK as the yellow band, and that of the wide-band beam experiment as
...f the beta-beam is shown as the light green band and the Neutrino Factory
...band.

Overall comparisons from ISS

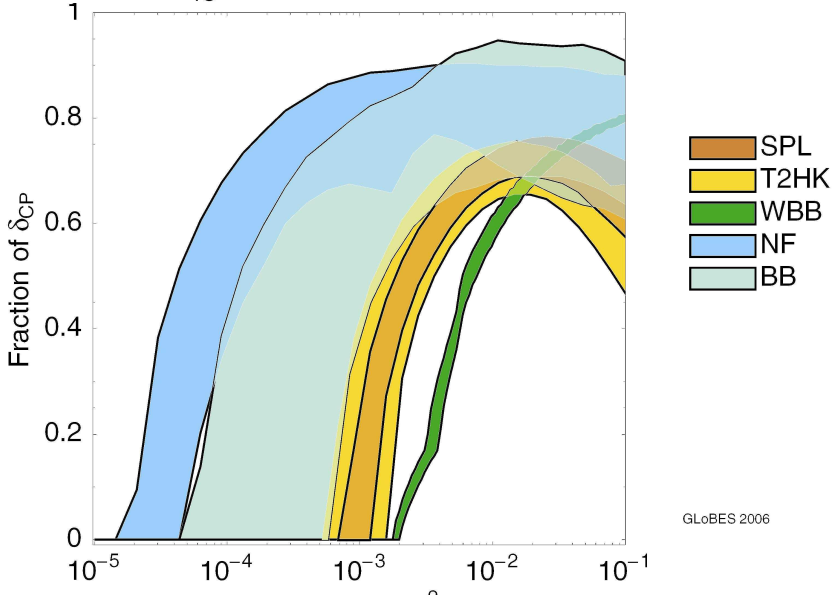
θ_{13}



sign Δm^2_{13}

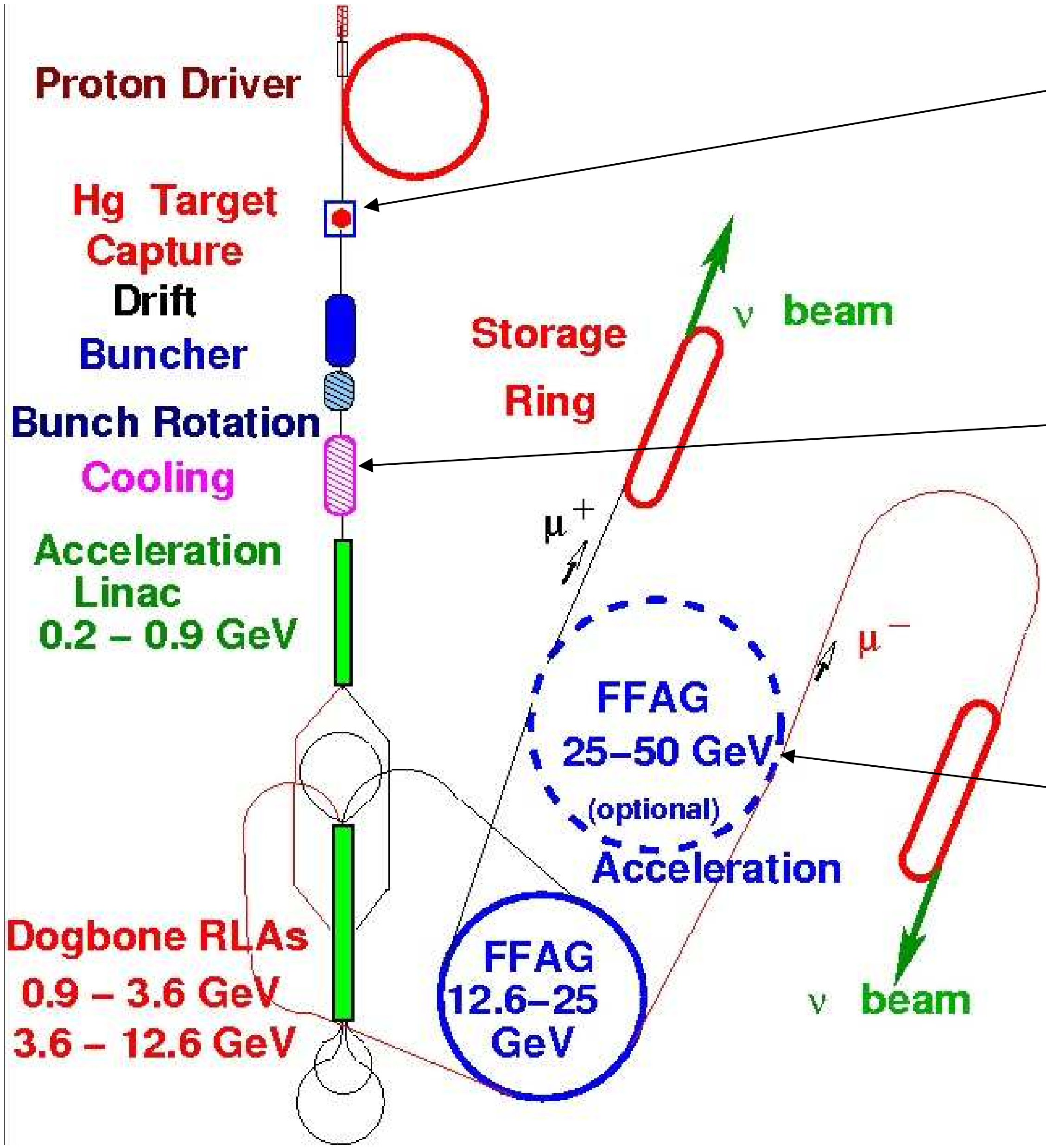


CP phase δ



NuFACT does it all…
(+ univ. test etc…)
but <u>when</u> can it do it
and <u>at what cost</u>?

Major challenges tackled by R&D expts



High-power target
. 4MW
. good transmission
MERIT experiment (CERN)

Fast muon cooling
MICE experiment (RAL)

Fast, large aperture accelerator (FFAG)
EMMA (Daresbury)

ISS baseline

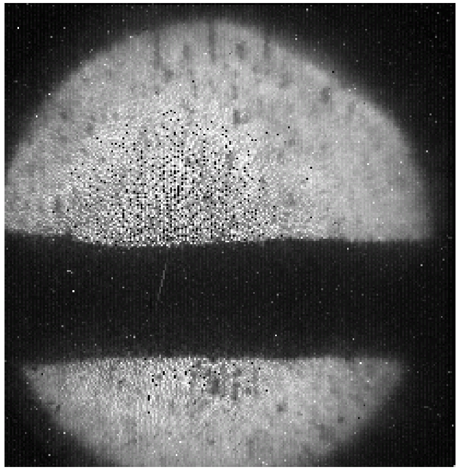
MERIT EXPERIMENT at CERN

BNL, MIT, ORNL, Princeton University CERN, RAL

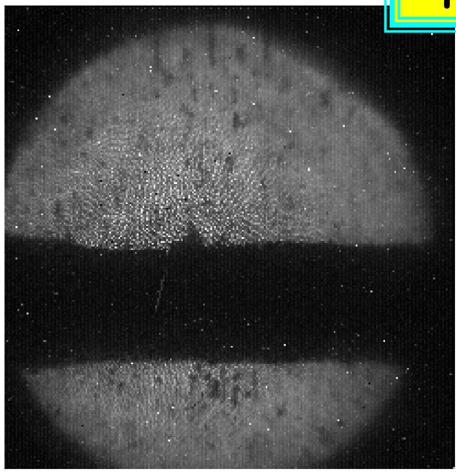
Splash velocity – 24 GeV beam

Demonstrated liquid mercury jet technology for neutrino factory and muon collider up to 8MW on target *Oct22-Nov12 2007*

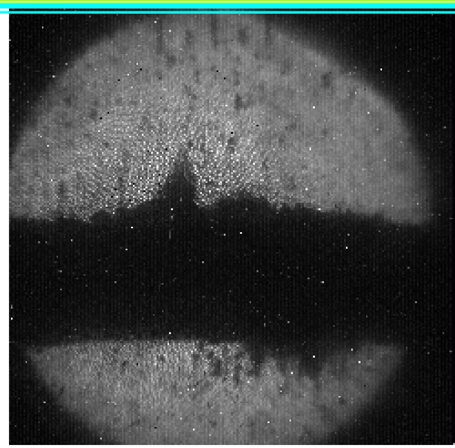
10TP, 10T ***V = 54 m/s***



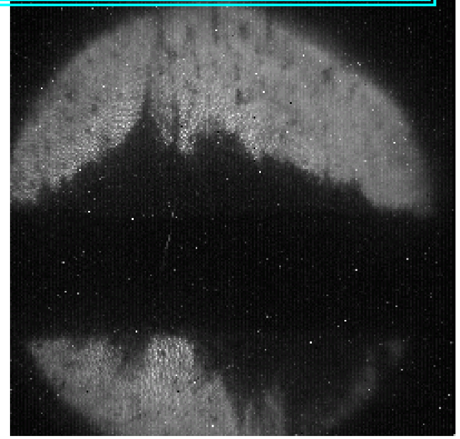
t=0



t=0.075 ms

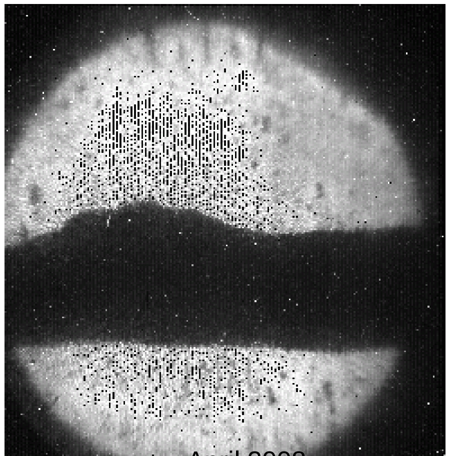


t=0.175 ms

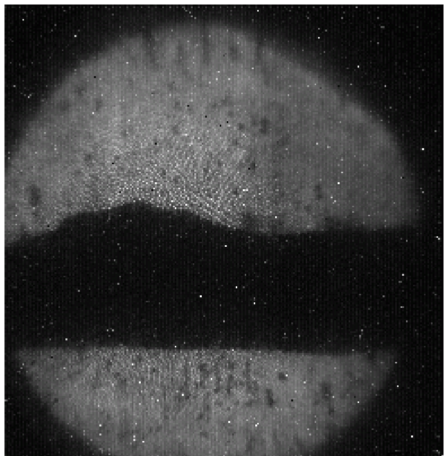


t=0.375 ms

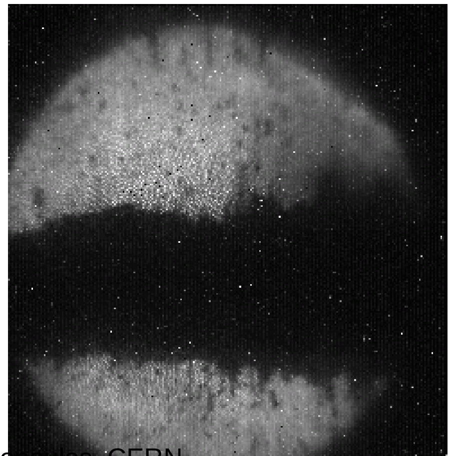
20TP, 15T ***V = 65 m/s***



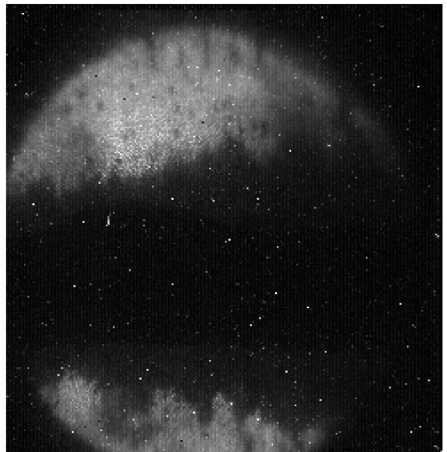
t=0



t=0.050 ms



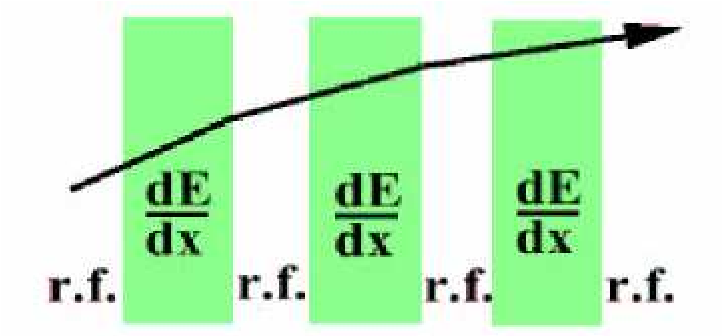
t=0.175 ms



t=0.375 ms

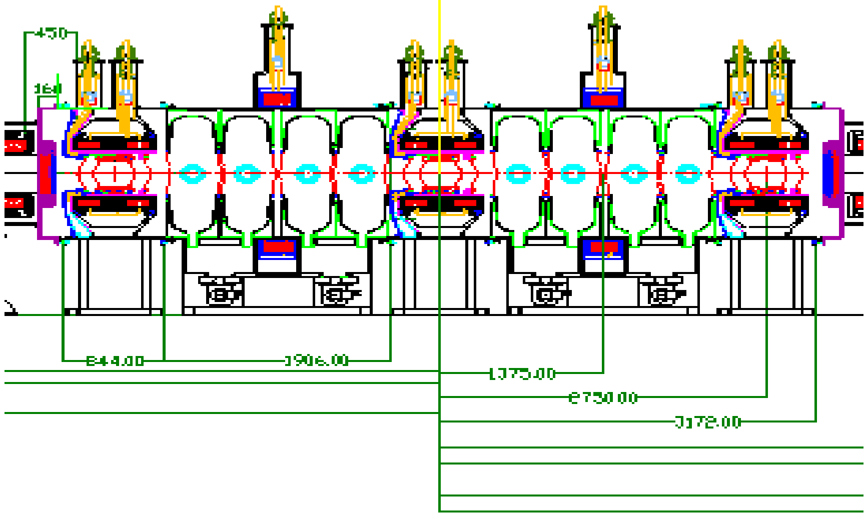
IONIZATION COOLING

principle:



this will surely work..!

reality (simplified)



Front elevation of the Cooling Channel

….maybe…

Cooling is necessary for Neutrino Factory and crucial for Muon Collider.
Delicate technology and integration problem
Need to build a realistic prototype and verify that it works (i.e. cools a beam)

Can it be built? Operate reliably? What performance can one get?
Difficulty: affordable prototype of cooling section only cools beam by 10%, while standard emittance measurements barely achieve this precision.
Solution: measure the beam particle-by-particle

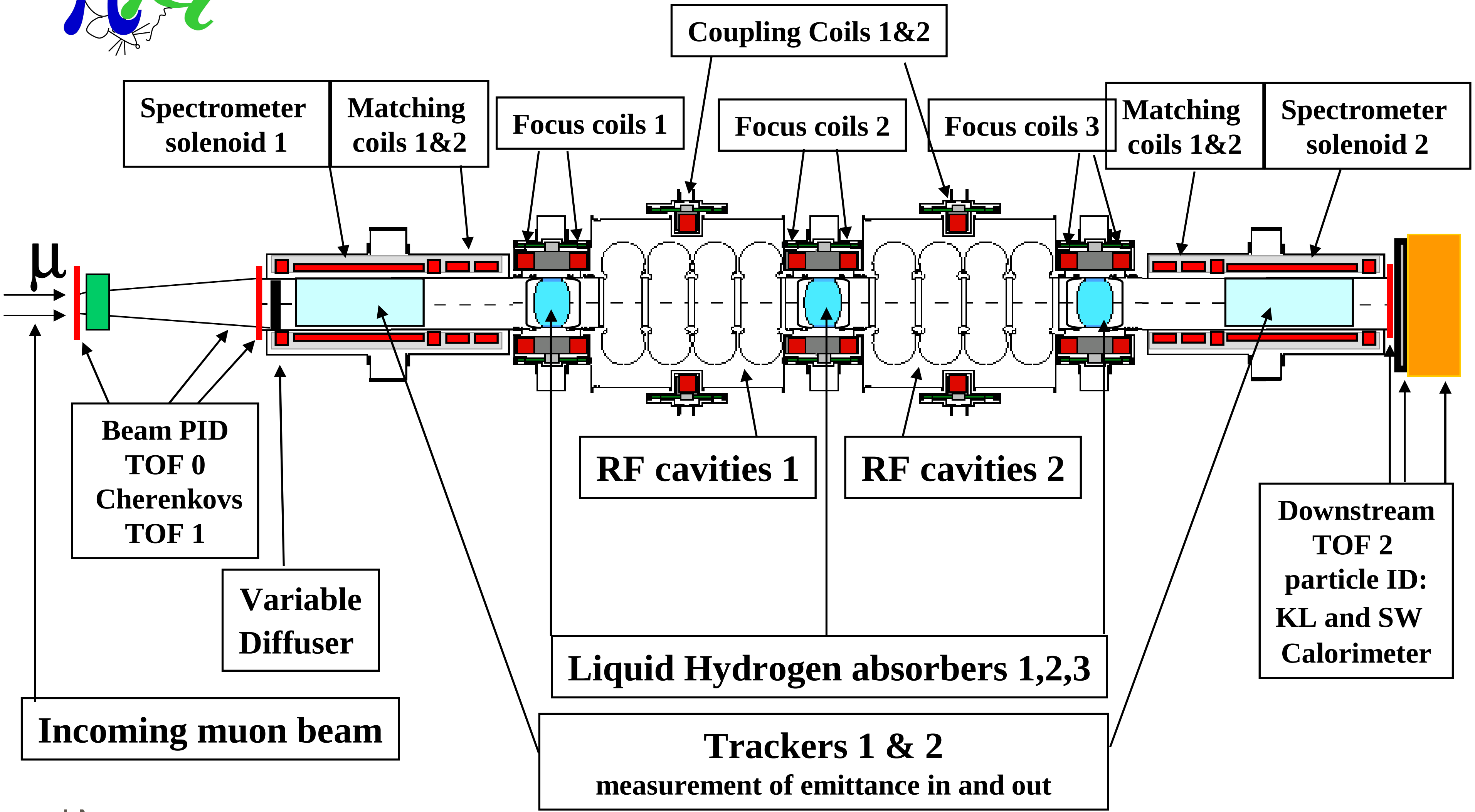
state-of-the-art particle physics instrumentation will test state-of-the-art accelerator technology.

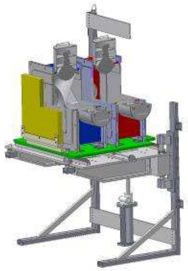
10% cooling of 200 MeV/c muons requires ~ 20 MV of RF

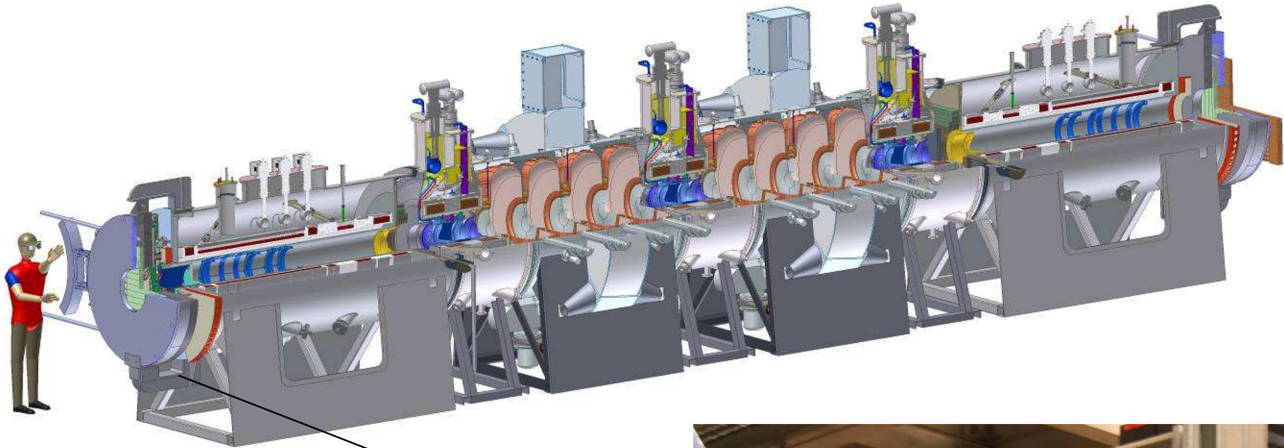
single particle measurements =>

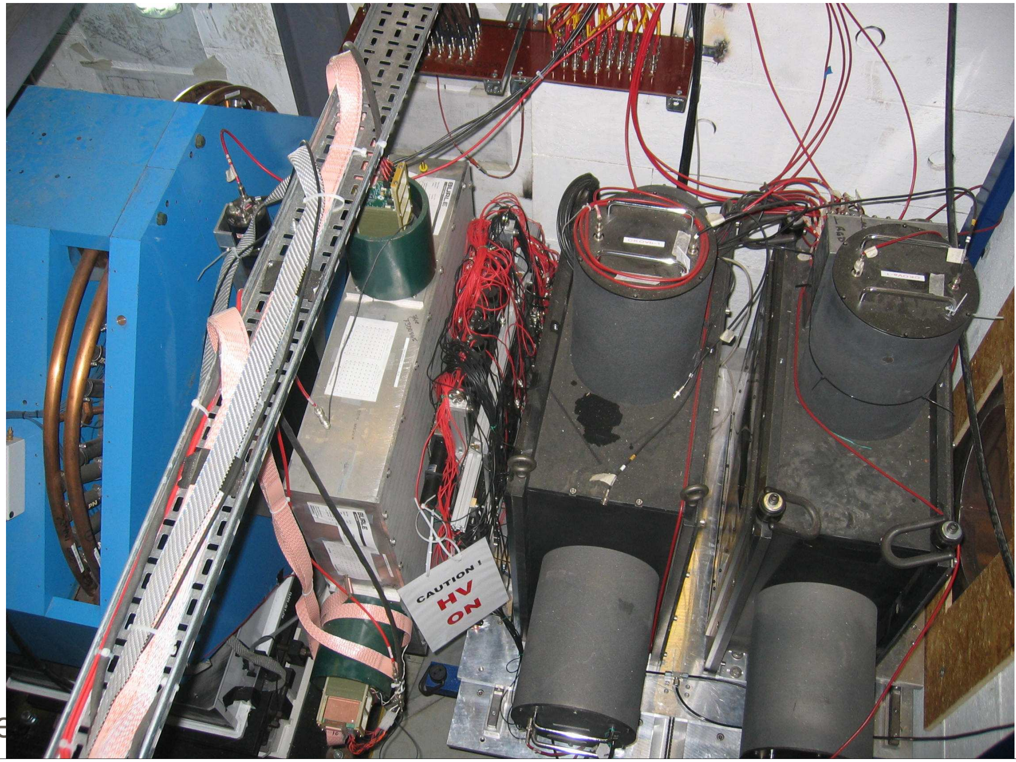
measurement precision can be as good as $\Delta(\varepsilon_{out}/\varepsilon_{in}) = 10^{-3}$

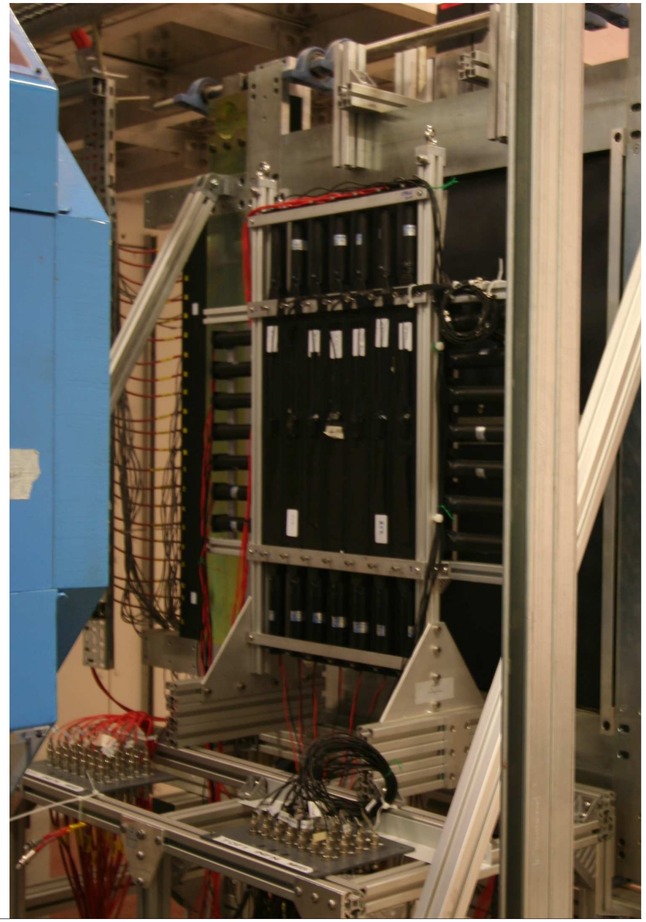
never done before

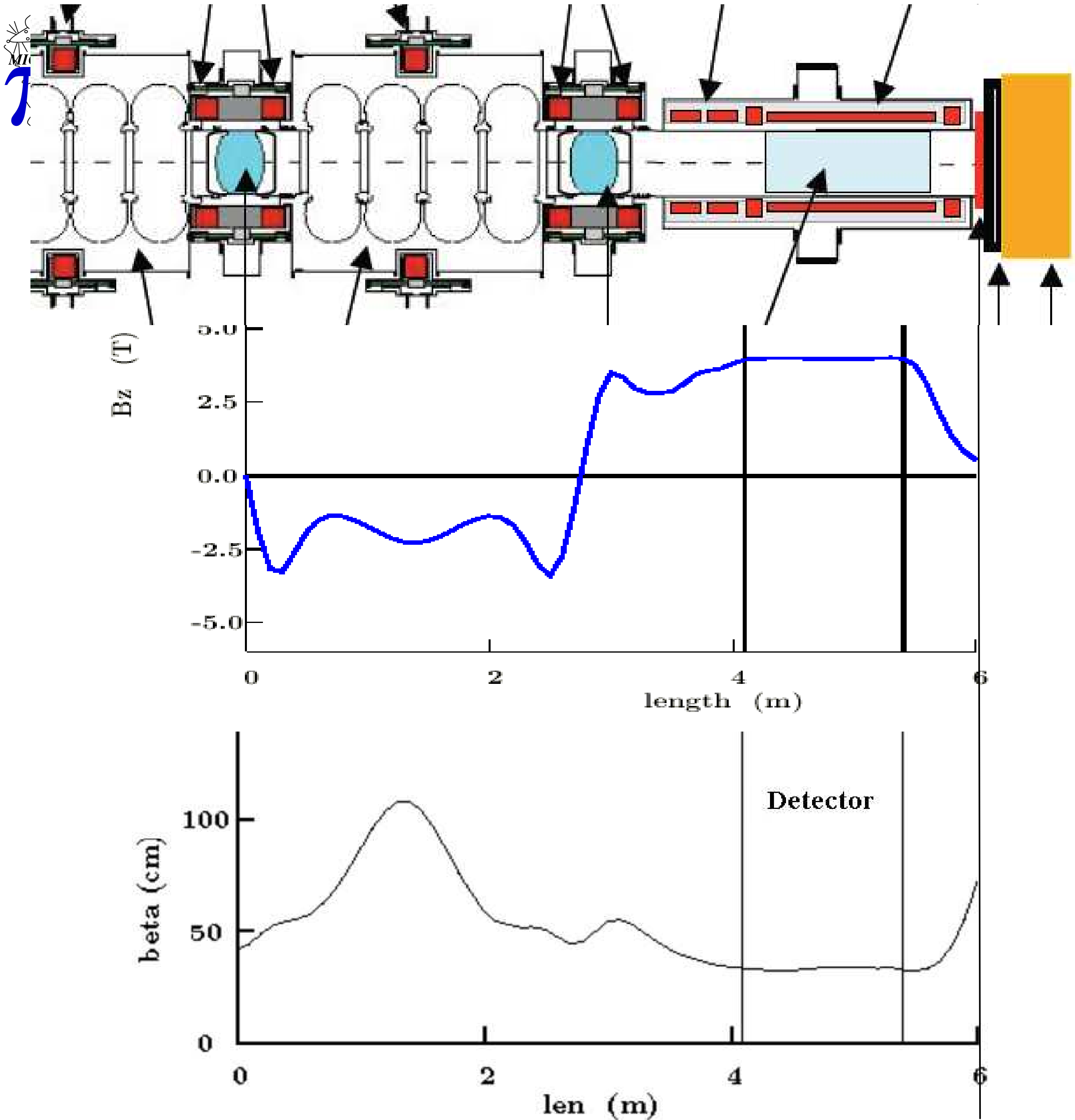







CAUTION !
HV
ON





Magnetic field

beta functions

MICE optics
nominal 200 MeV/c

Emittance measurement

Each spectrometer measures 6 parameters per particle

$x \quad y \quad t$

$x' = dx/dz = P_x/P_z \quad y' = dy/dz = P_y/P_z \quad t' = dt/dz = E/P_z$

Determines, for an ensemble (sample) of N particles, the moments:

Averages $\langle x \rangle$ $\langle y \rangle$ etc…

Second moments: variance(x) $\sigma_x^2 = \langle x^2 - \langle x \rangle^2 \rangle$ etc…

covariance(x) $\sigma_{xy} = \langle x.y - \langle x \rangle \langle y \rangle \rangle$

Covariance matrix

$$M = \begin{pmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xt} & \sigma_{xx'} & \sigma_{xy'} & \sigma_{xt'} \\ \cdots & \sigma_y^2 & \cdots & \cdots & \cdots & \sigma_{yt'} \\ \cdots & \cdots & \sigma_t^2 & \cdots & \cdots & \sigma_{tt'} \\ \cdots & \cdots & \cdots & \sigma_{x'}^2 & \cdots & \sigma_{x't'} \\ \cdots & \cdots & \cdots & \cdots & \sigma_{y'}^2 & \sigma_{y't'} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \sigma_{t'}^2 \end{pmatrix}$$

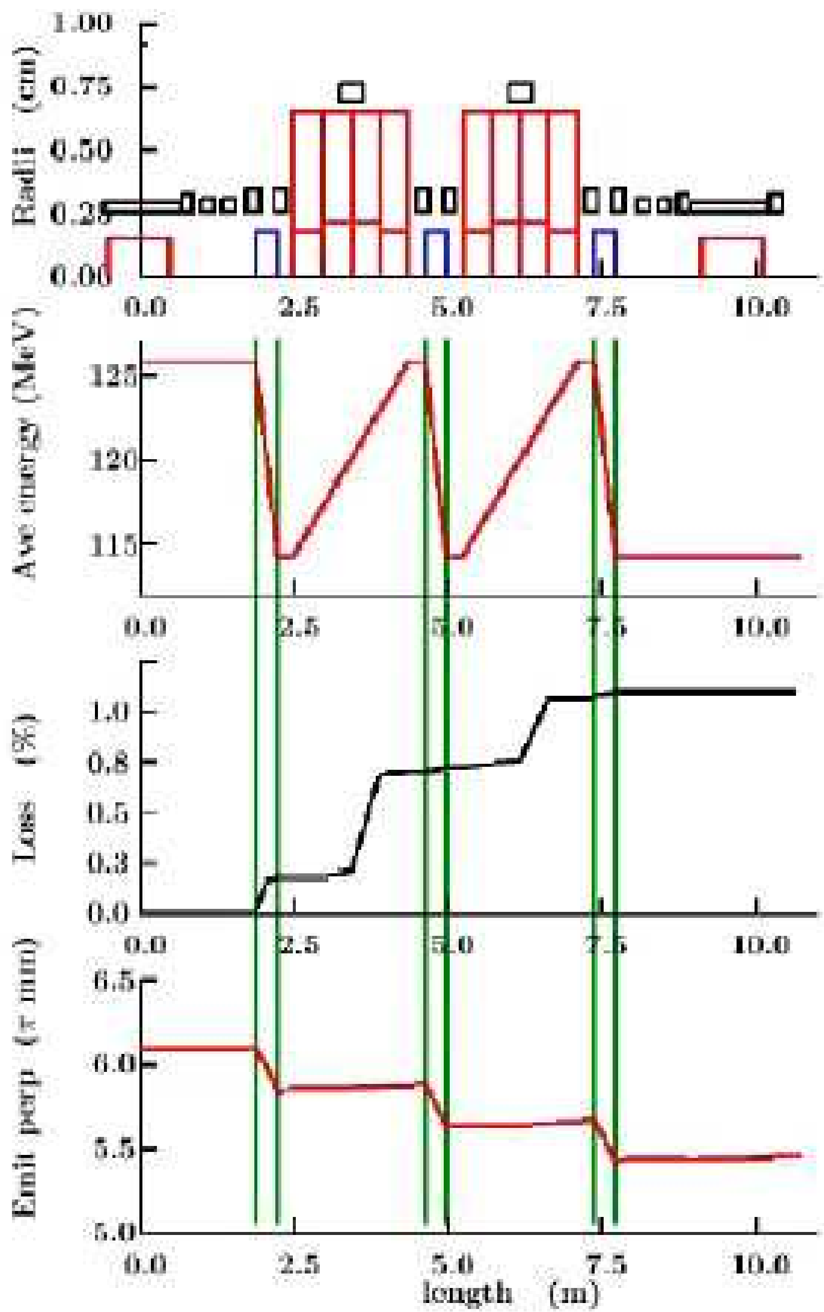
Getting at e.g. $\sigma_{x't'}$ is essentially impossible with multiparticle bunch measurements

Evaluate emittance with:

$$\varepsilon^{6D} = \sqrt{\det(M_{xytx'y't'})}$$

$$\varepsilon^{4D} = \sqrt{\det(M_{xyx'y'})} = \varepsilon_\perp^2$$

Compare ε^{in} with ε^{out}

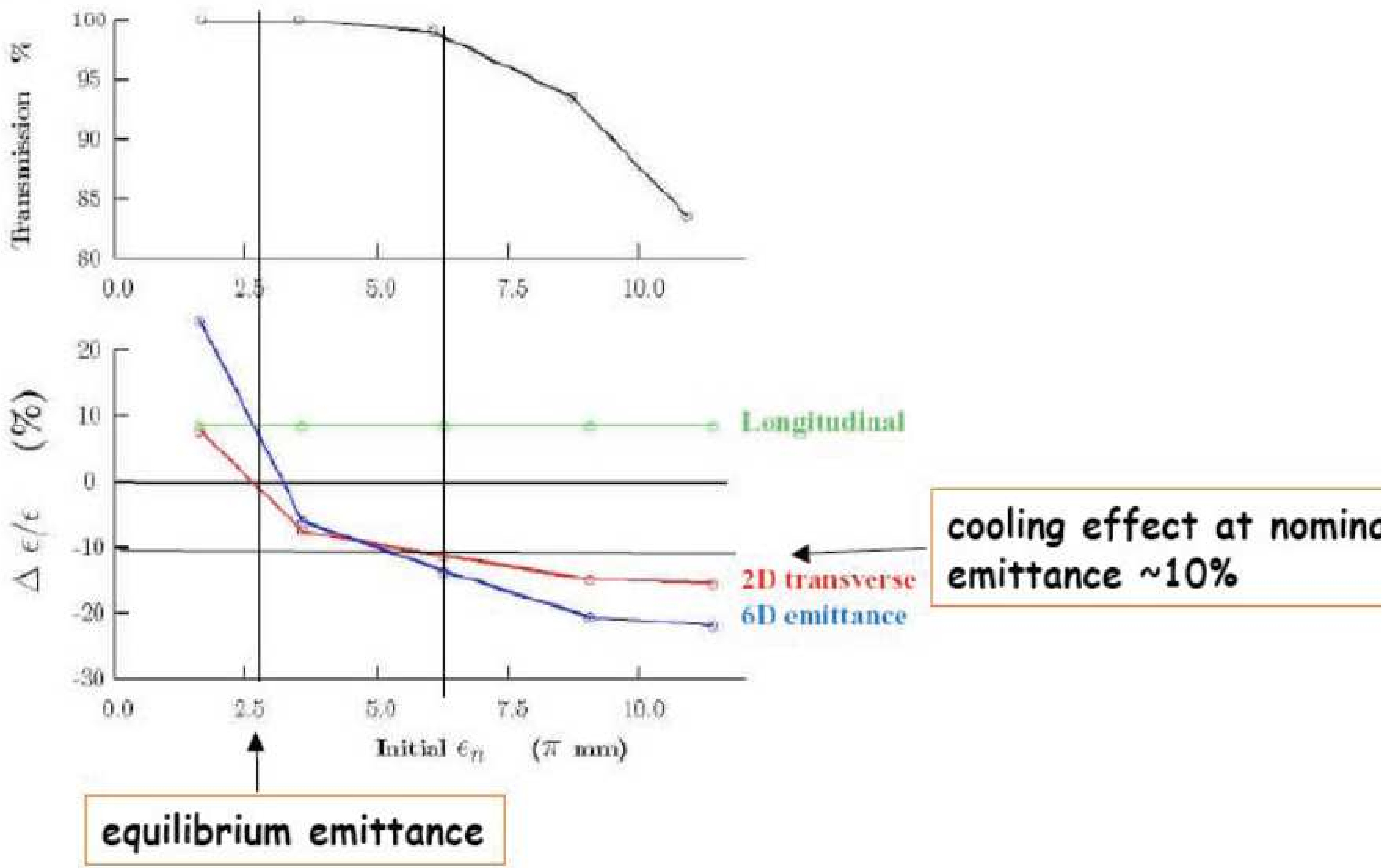


Energy variation

Particle loss

2D ε reduction

Quantities to be measured in a cooling experiment



curves for 23 MV, 3 full absorbers, particles on crest

Requirements on detectors for MICE:

1. Must be sure to work on muons
   1.a use a pion/muon decay channel with 5T, 5m long decay solenoid
   1.b reject incoming pions and electrons
   TOF over 6m with 70 ps resolution+ threshold Cherenkov
   1.c reject decays in flight of muons
   downstream PID (TOF2 + calorimeter set up)

2. Measure all 6 parameters of the muons x,y,t, x', y', β_z=E/Pz
   tracker in magnetic field, TOF, EMR

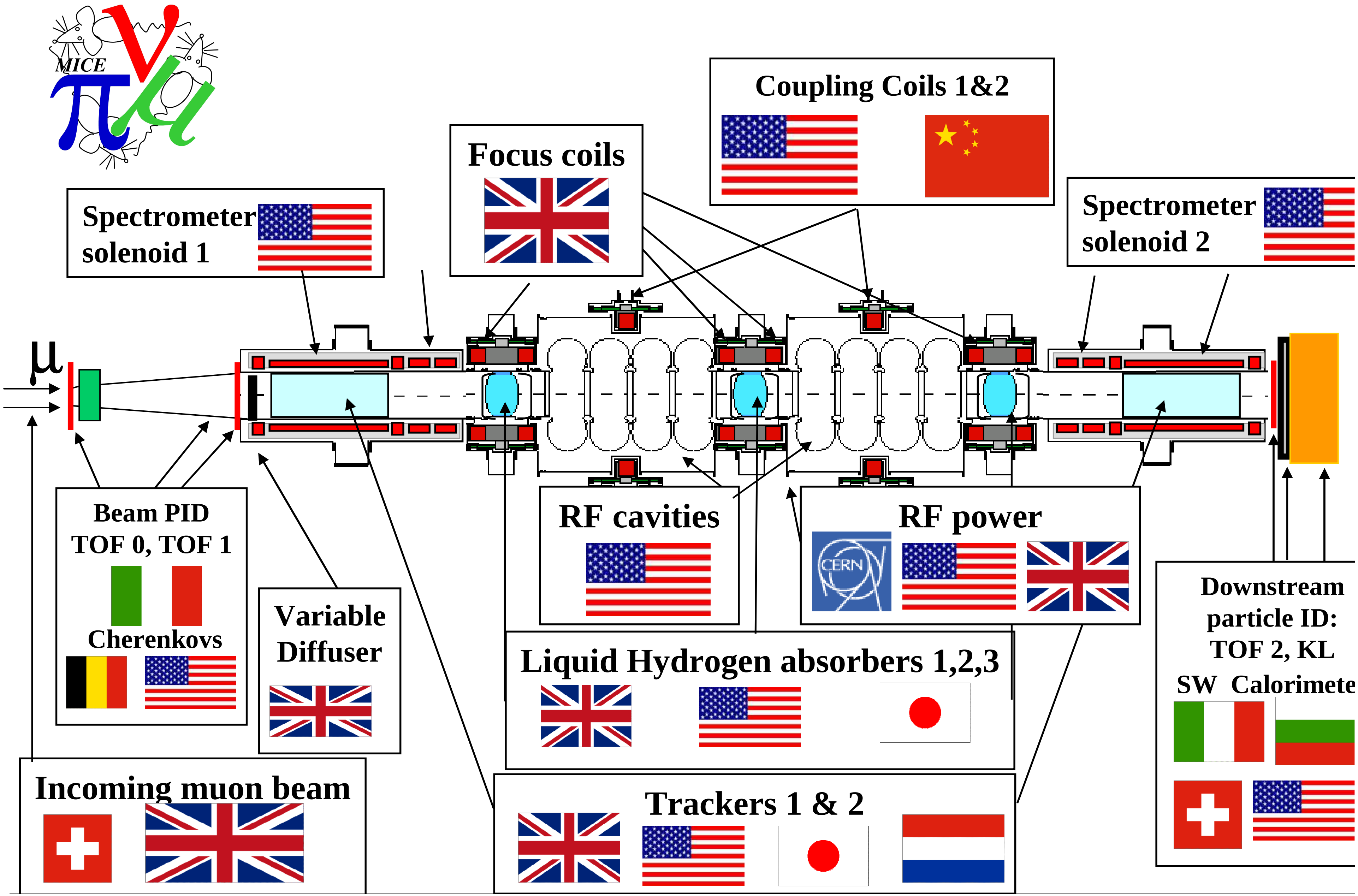
3. Resolution on above quantities must be better than 10% of rms of beam at equilibrium emittance to ensure correction is less than 1%.
   + resolution must be measured

4. Detectors must be robust against RF radiation and field emission

Design of MICE detectors and beam test results have satisfied the above requirements

NB: Although MICE does not perform longitudinal cooling, the MICE detectors are designed to measure 6D emittance

MICE Collaboration across the planet



THE MICE COLLABORATION -128 collaborators-

Some new since last year

University of Sofia, Bulgaria

The Harbin Institute for Super Conducting Technologies PR China

INFN Milano, INFN Napoli, INFN Pavia, INFN Roma III, INFN Trieste, Italy

KEK, Kyoto University, Osaka University, Japan

NIKHEF, The Netherlands

CERN

Geneva University, Paul Scherrer Institut Switzerland

Brunel, Cockcroft/Lancaster, Glasgow, Liverpool, ICL London, Oxford, Darsbury, RAL, Sheffield, Warwick UK

Argonne National Laboratory, Brookhaven National Laboratory, Fairfield University,
University of Chicago, Enrico Fermi Institute, Fermilab, Illinois Institute of Technology,
Jefferson Lab, Lawrence Berkeley National Laboratory, UCLA, Northern Illinois University,
University of Iowa, University of Mississippi, UC Riverside,
University of Illinois at Urbana-Champaign, Muons Inc. USA

Challenges of MICE:

(these things have never been done before)

1. Operate RF cavities of relatively low frequency (201 MHz) at high gradient (nominal 8MV/m in MICE, 16 MV/m with 8 MW and LN2 cooled RF cavities) in highly inhomogeneous magnetic fields (1-3 T)
   dark currents (can heat up LH_2), breakdowns

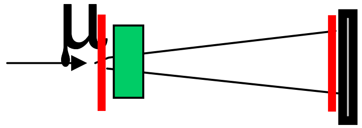
2. Hydrogen safety (substantial amounts of LH_2 in vicinity of RF cavities)

3. Emittance measurement to relative precision of 10^{-3} in environment of RF bkg requires
   low mass (low multiple scattering) and precise tracker
   fast and redundant to fight dark-current-induced background
   precision Time-of-Flight for particle phase determination ($\pm 3.6^0$ = 50 ps)
   complete set of PID detectors to eliminate beam pions and decay electrons

and…

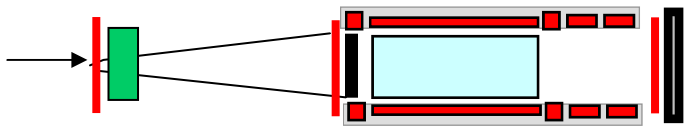
4. Obtaining (substantial) funding for R&D towards a facility that is not (yet) in the plans of a major lab

MICE Schedule April 2009



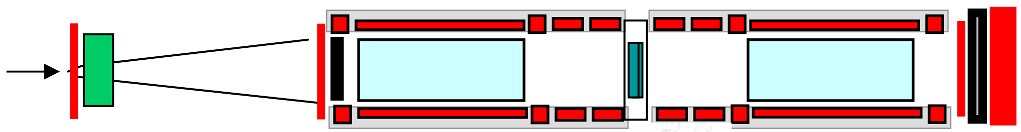
STEP I

fix DS + new target
Run: Sep09



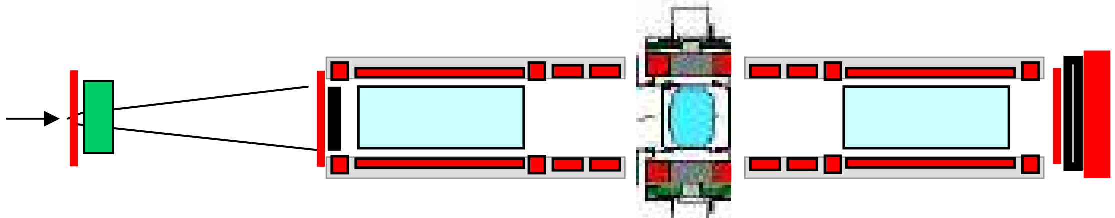
STEP II

Deliv SS-1 Jun09
Run: Q4 2009



STEP III/III.1

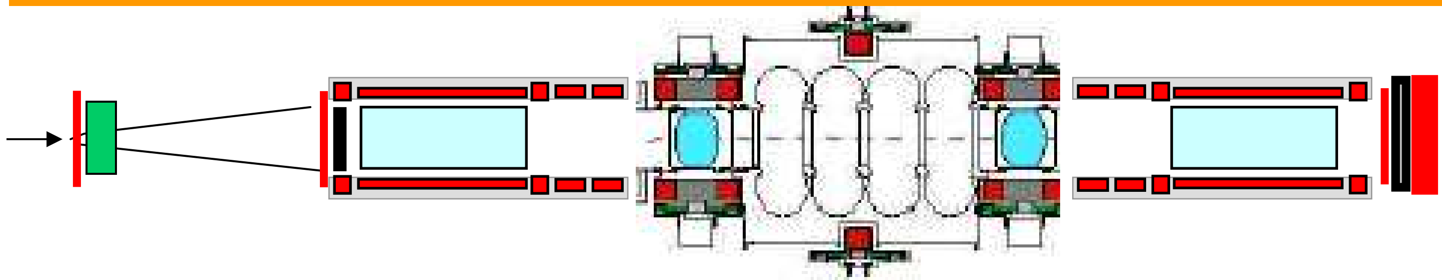
Deliv SS-2 Sep09
Run: Q1 2010



STEP IV

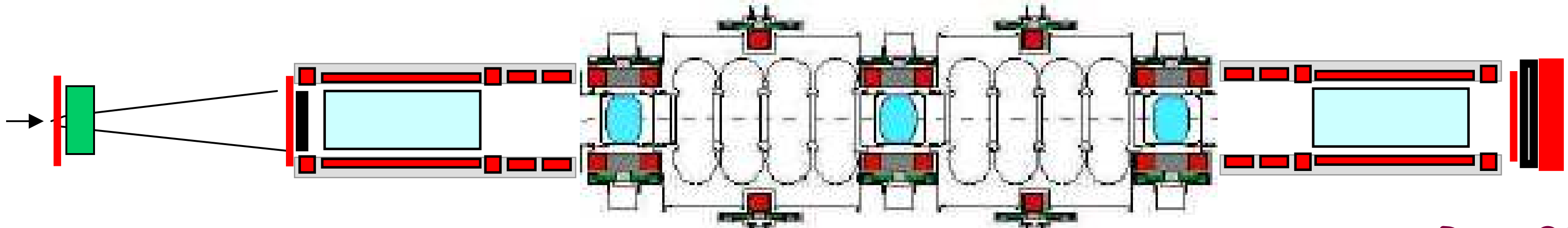
Deliv FC-1 Feb10
Run: Q2 2010

----------- ISIS shut-down (provisional) Aug 2010-Apr 2011 -----------



STEP V

Run: 2011



STEP VI

Run 2011-2012

Towards a high-intensity neutrino programme

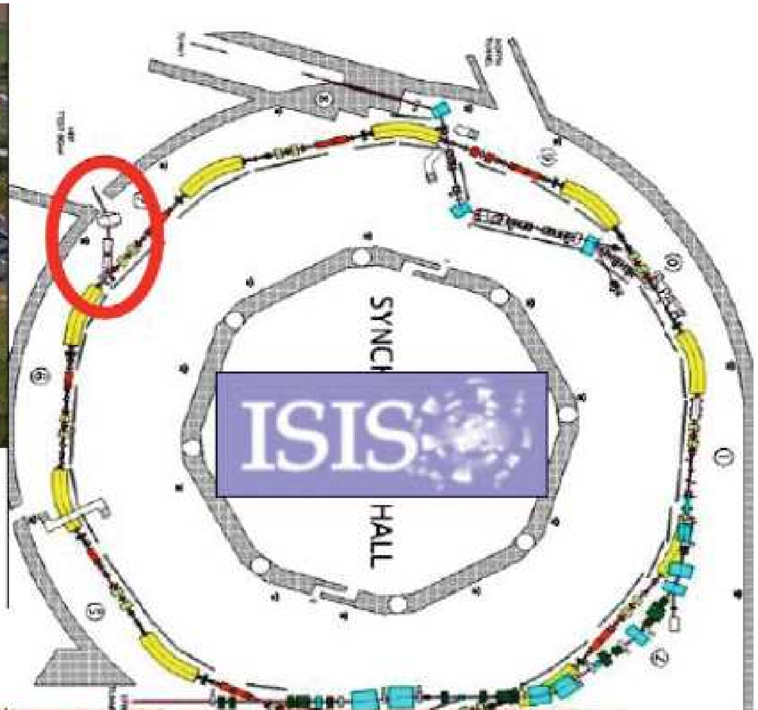
EP2010:

« pursue an internationally coordinated, staged program in neutrino physics »

CERN-SG:

Studies of the scientific case for future neutrino facilities
and the R&D into associated technologies are required to
be in a position to define the optimal neutrino programme
based on the information available in around **2012;**
Council will play an active role in promoting a coordinated European participation in a global neutrino programme.

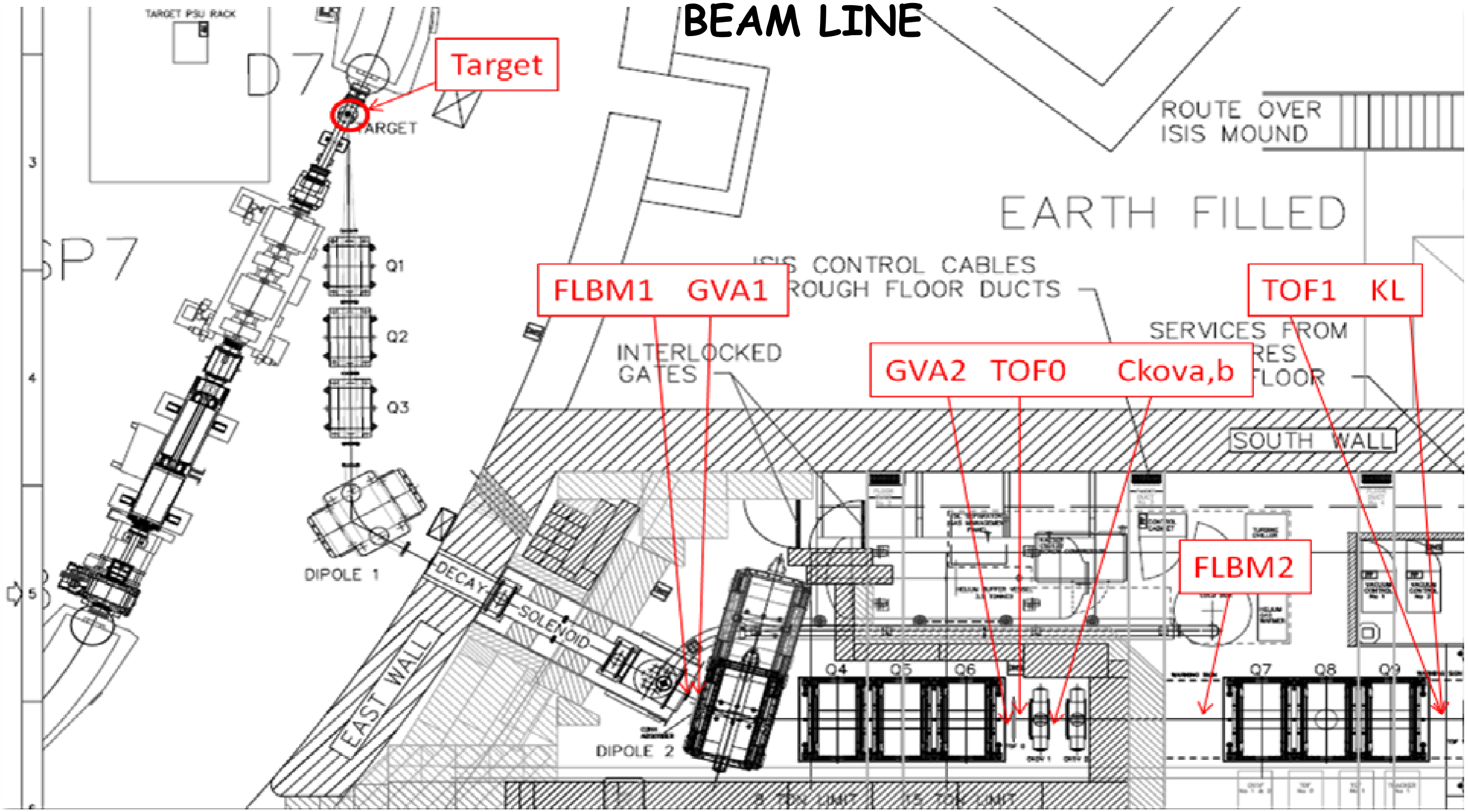

ISIS
MICE Hall
R5.2

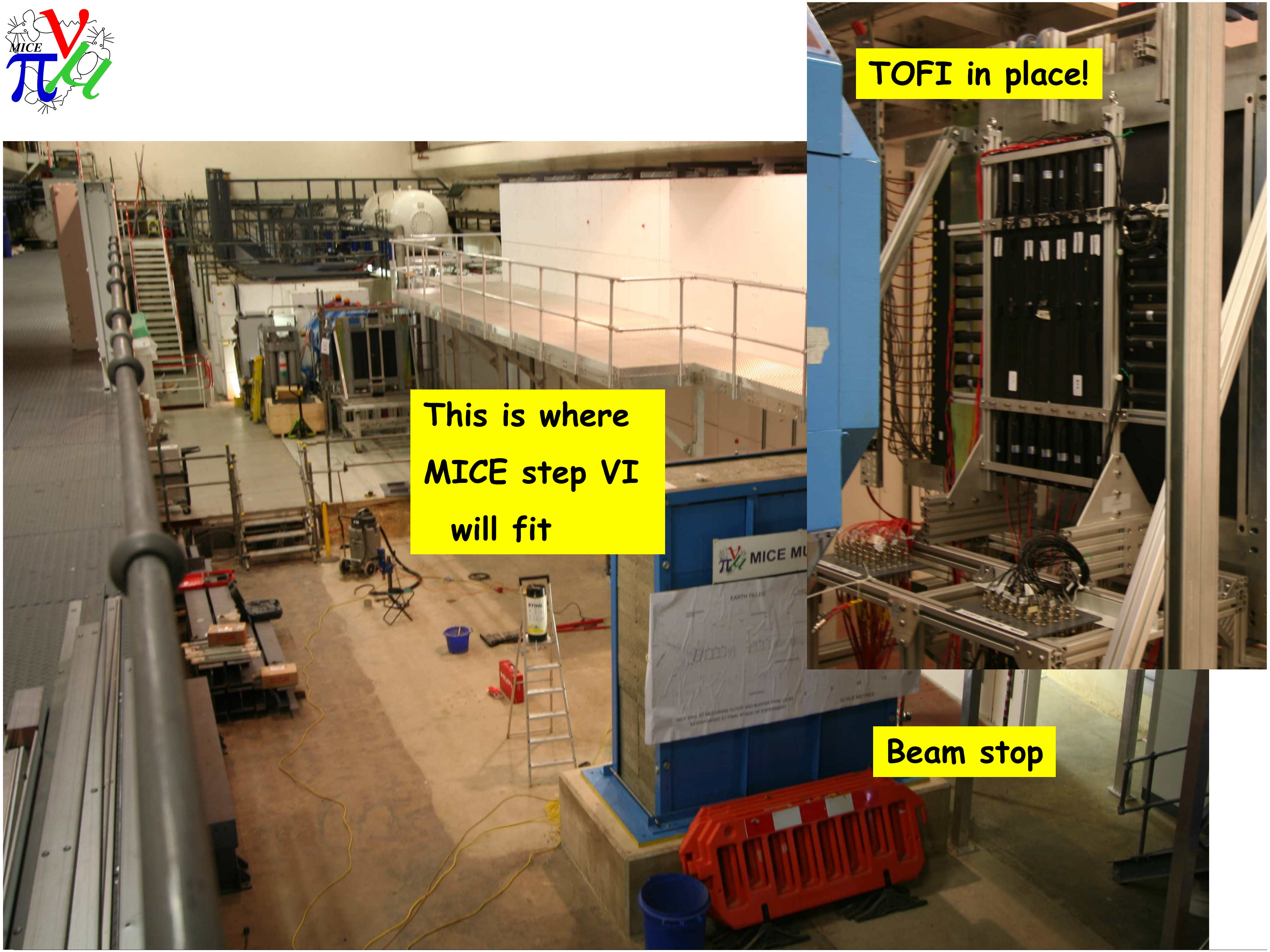


- **MICE is hosted at Rutherford Appleton Laboratory, UK**
  - Brand new muon beam line in construction
  - Built from scratch


West Wall
54
55
56
58
59
53

BEAM LINE


TARGET PSU RACK
D7
Target
TARGET
SP7
Q1
Q2
Q3
DIPOLE 1
DECAY SOLENOID
DIPOLE 2
EAST WALL
ROUTE OVER
ISIS MOUND
EARTH FILLED
FLBM1 GVA1
INTERLOCKED
GATES
GVA2 TOF0 Ckova,b
TOF1 KL
SOUTH WALL
FLBM2
Q4
Q5
Q6
Q7
Q8
Q9


TOFI in place!
This is where
MICE step VI
will fit
Beam stop

The MICE BEAM LINE

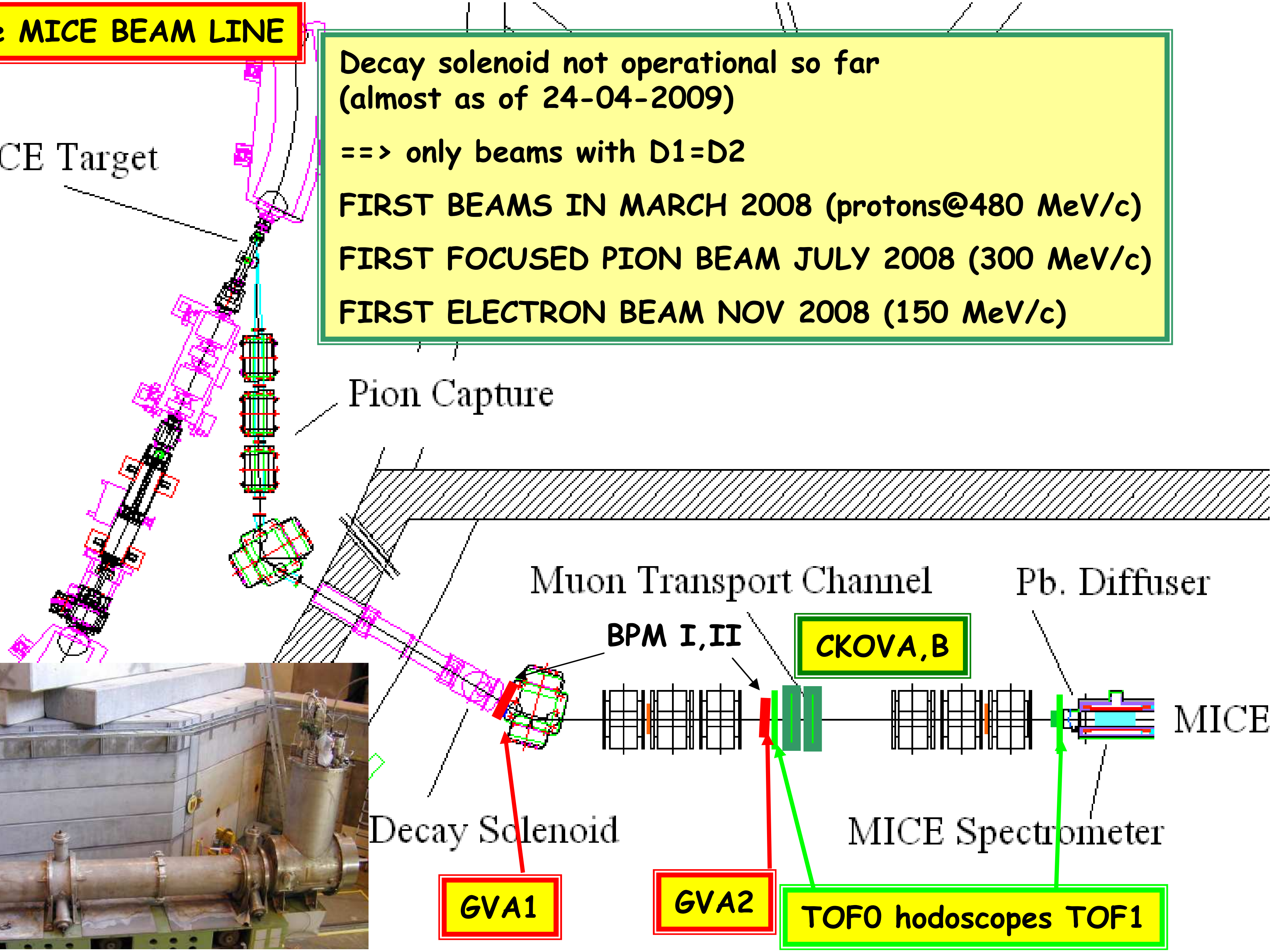
Decay solenoid not operational so far
(almost as of 24-04-2009)

==> only beams with D1=D2

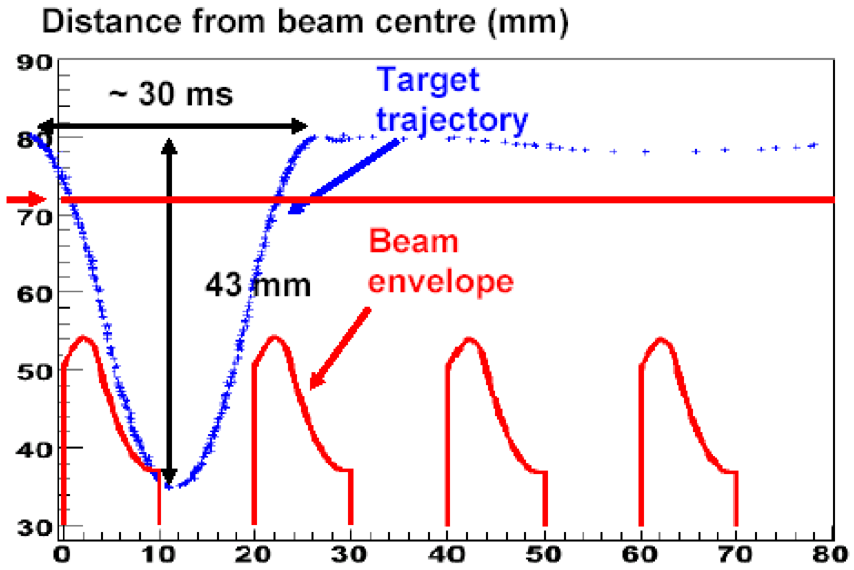
FIRST BEAMS IN MARCH 2008 (protons@480 MeV/c)

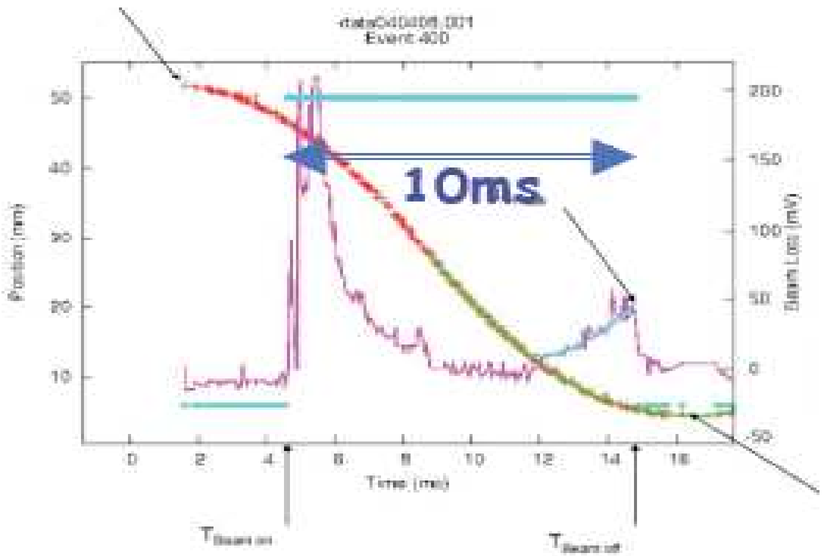
FIRST FOCUSED PION BEAM JULY 2008 (300 MeV/c)

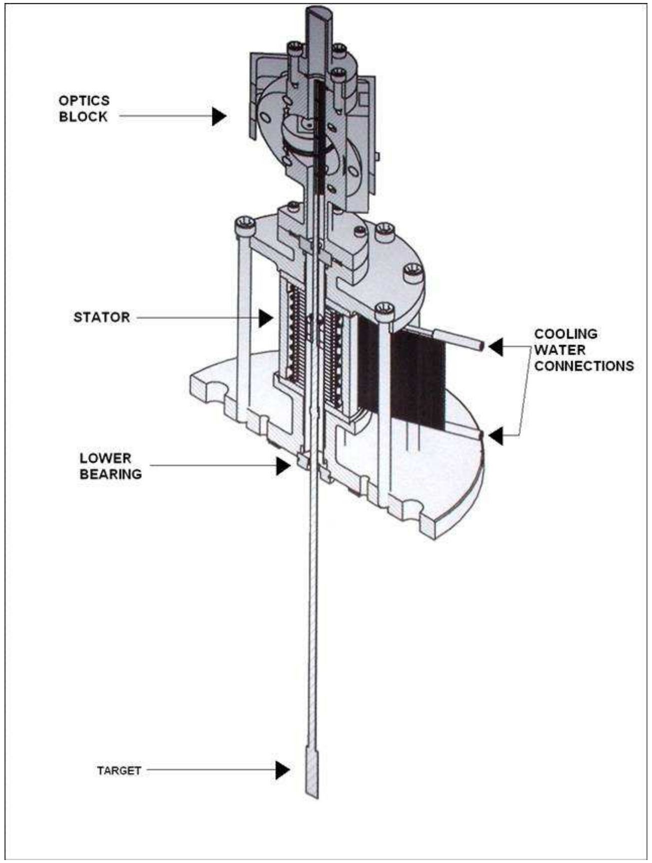
FIRST ELECTRON BEAM NOV 2008 (150 MeV/c)

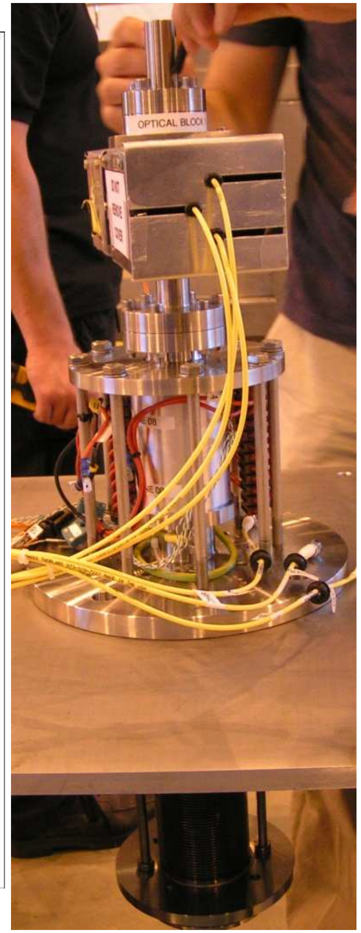


Target (Sheffield/RAL)









Linear motor sends target in beam at >80g into beam and back in less than 30ms.

Optical measurement of position;
Record of ISIS beamloss monitors

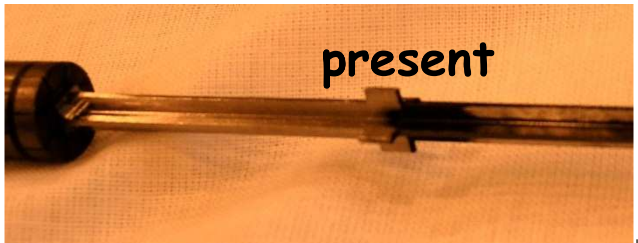
2008 target

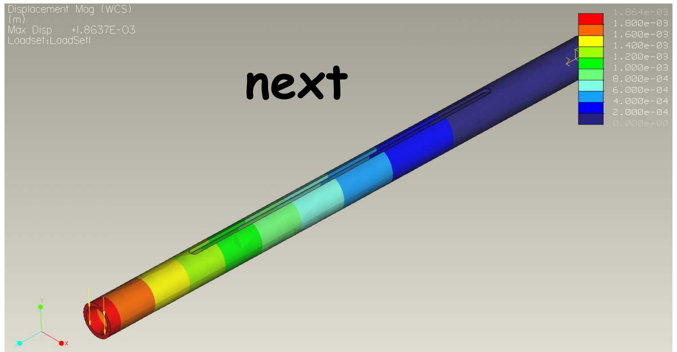
allowed us to do a lot!

15Mar08: parasitic operation in ISIS
30Mar08: first beam to Q6
Jul08: protons and pions
Oct08: electron beam on KL, CKOV
Nov-Dec08: TOF0-TOF1
Was accidentally "parked" in beam and tip melted in Nov08.
Still operated until it broke 19dec09

Had to be changed -- spare failed after 350k pulses in July08.
new one with round shaft in production for Jul09.

Beam back in MICE Sept09.





MICE beam intensity

MICE Goal: 600 muons per spill gate (1ms) at ~1Hz.

Target dip in the beam is limited by resulting beam loss in ISIS. Early limit was set to 50mV on beam loss monitor situated in Section 7-8 where MICE is.

Particle production at 50mV	2-3 10^{9} protons on target per dip
MICE proposal performance	1.7 10^{12} protons on target per dip
Total number	2 10^{13} protons in ISIS

Factor 500 to gain! Goal for Phase I: gain factor 50
Goal for Phase II: gain factor 500

Old HEP target ran at 200mV at 50 Hz, MICE runs at 50mV at 0.4 Hz
Factor 500 is simply there. But instantaneous rate is VERY different

-- excellent runs on 18-19 Oct08 & 8 Nov08 to investigate beam loss issues
Ran up to 0.5 V on BLM for 16 hours with no noticeable increase of radiation

-- ISIS beam loss monitors now recorded in MICE target DAQ
-- Simulations of beam losses in ISIS ongoing (A. Dobbs) to understand:
> Possible effect on losses of target shape and material
> Distribution of losses around the ring
EXCELLENT COLLABORATION WITH ISIS (Dean Adams, David Findlay, DO's)

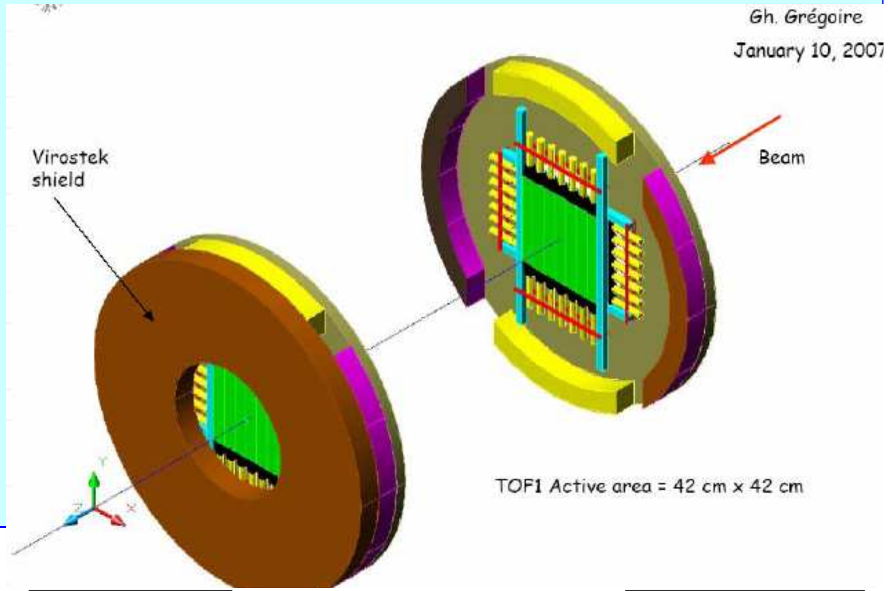
TOF0, TOF1, TOF2

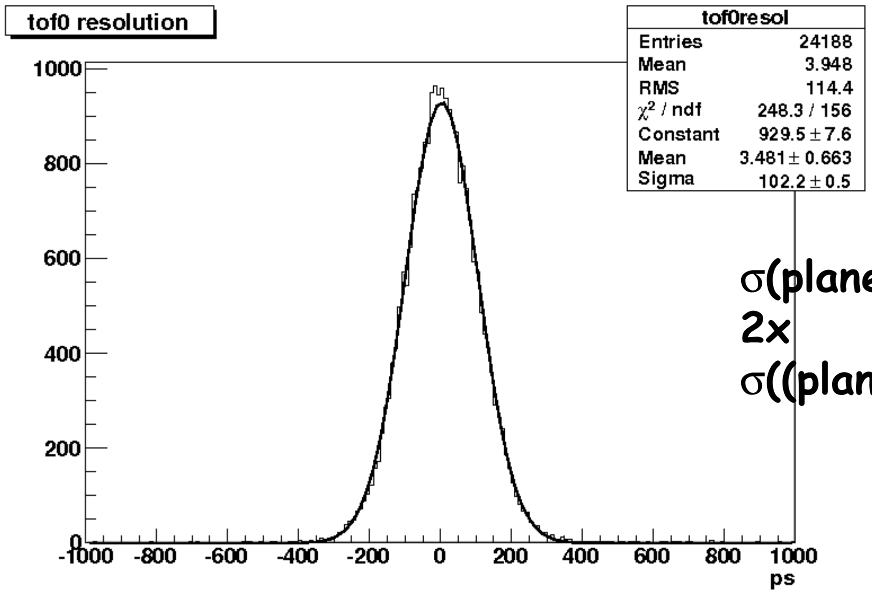
TOF M. Bonesini et al (INFN Milano, Pavia, Roma + Gva & Sofia)

Technically:
Two layers (x and y)
of 4 (resp.6) cm wide hodoscopes

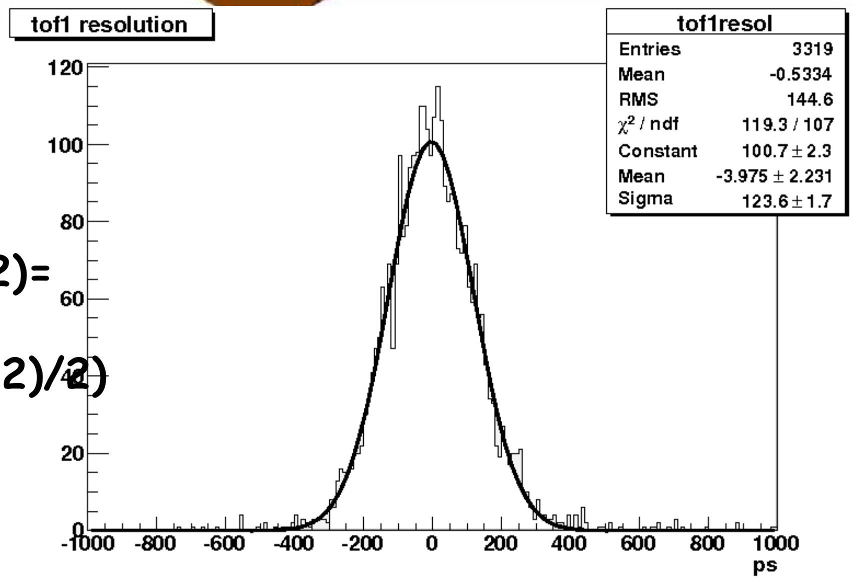
TOF0 and TOF1 installed and running.
51ps (TOF0) and 62ps (TOFI)
resolutions MEASURED

TOFII under construction ==> Jun09





σ(planeI-plane2)=
2x
σ((planeI+plane2)/2)



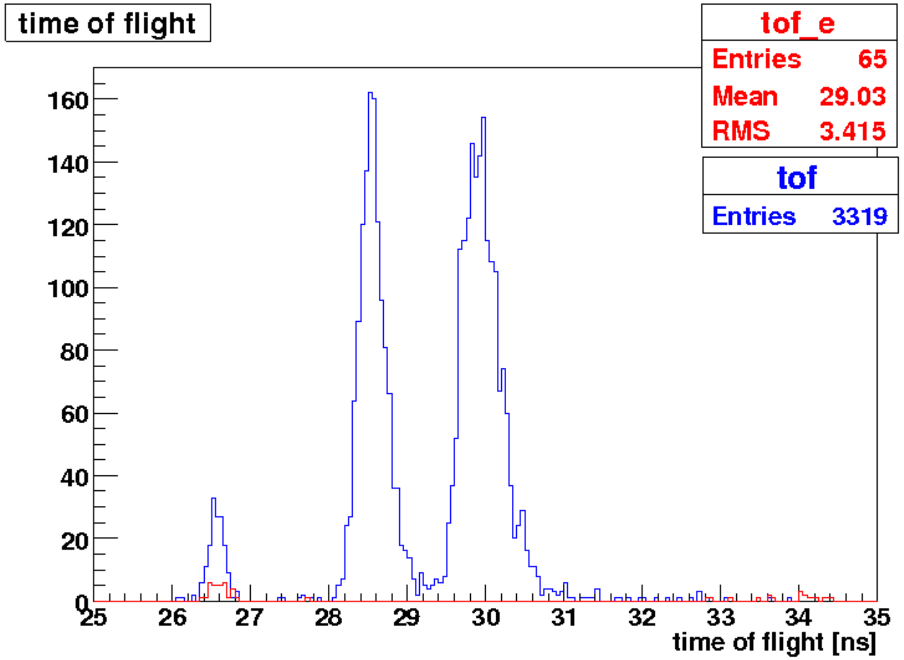
we have a few muons…

electron beam at 150 MeV/c

used for calibration of TOFs

==> 'pion' beam at 300 MeV/c

reveals presence of … muons!

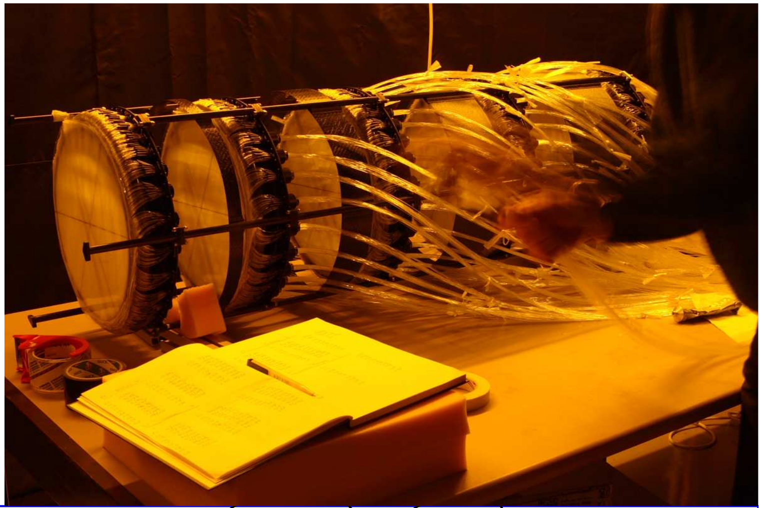


these data took > hour to accumulate. With decay solenoid, and D2≠D1, we should have many more muons, and only muons (to ~<%)

Tracker

resp: Japan,UK,US

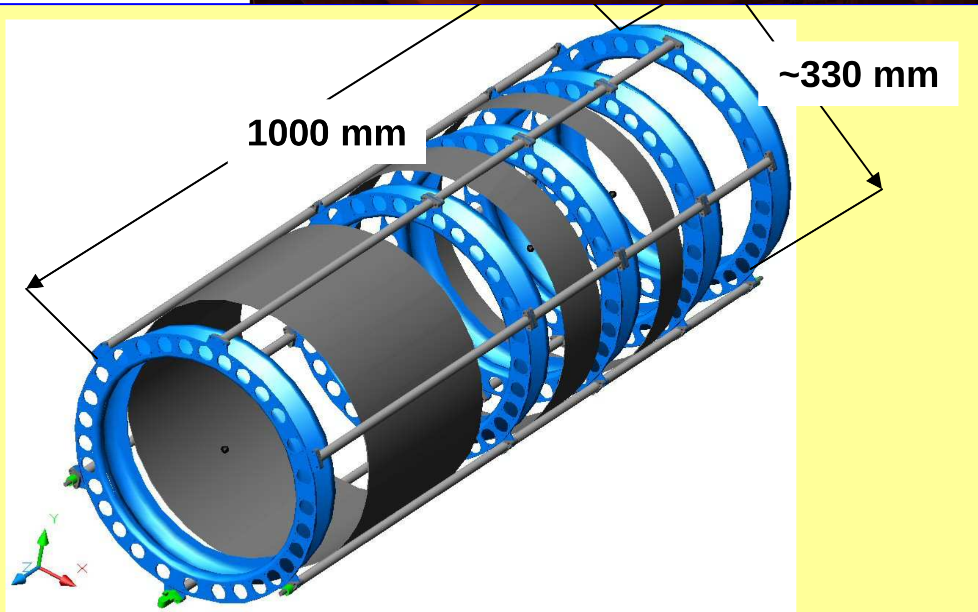
two identical trackers with 5 planes of 3-views,
440 μm point resolution achieved
scintillating fiber detector read-out with VPLCs
(7-fold ganging of 350 μm diameter fibers)



Prototypes with 3, 4 triple-planes were built and tested on cosmics and test beam at KEK (in 1 T mag field)
==> curvature measurement OK.

Improved QA procedures for final production

Full production of tracker complete



MICE Tracker Requirements

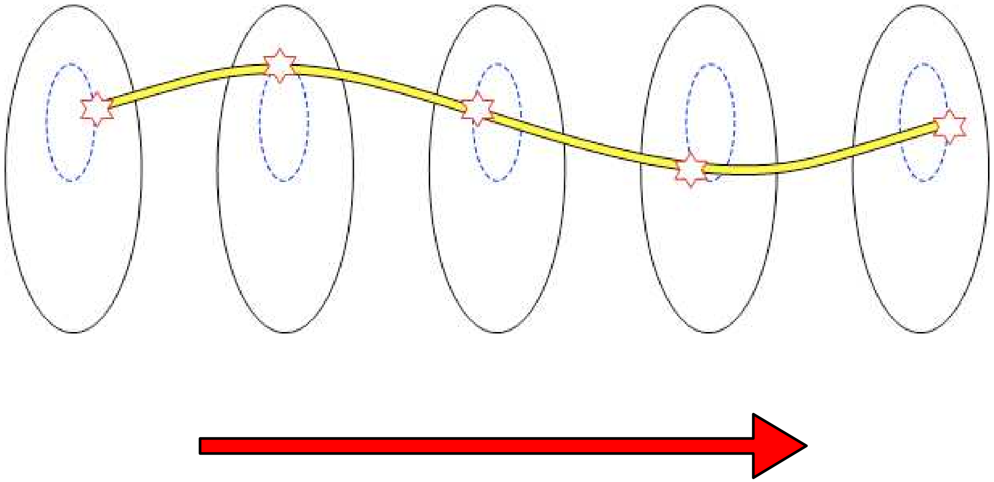
High rate capability :
600 muons in 1 millisecond

Small amount of material :
“no beam heating”

Operation in the backgrounds generated by the RF.

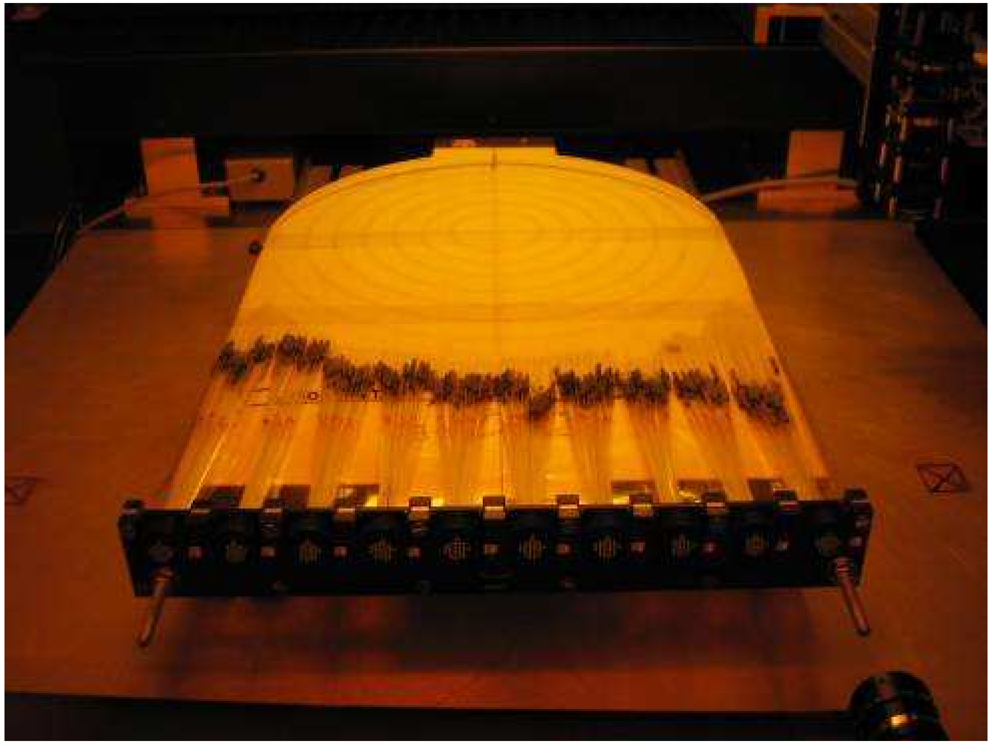
High efficiency / low background

Passive detector system – nothing to pick-up RF noise



4 Tesla field (measure momentum)

Tracker Construction: Stations



TRACKER

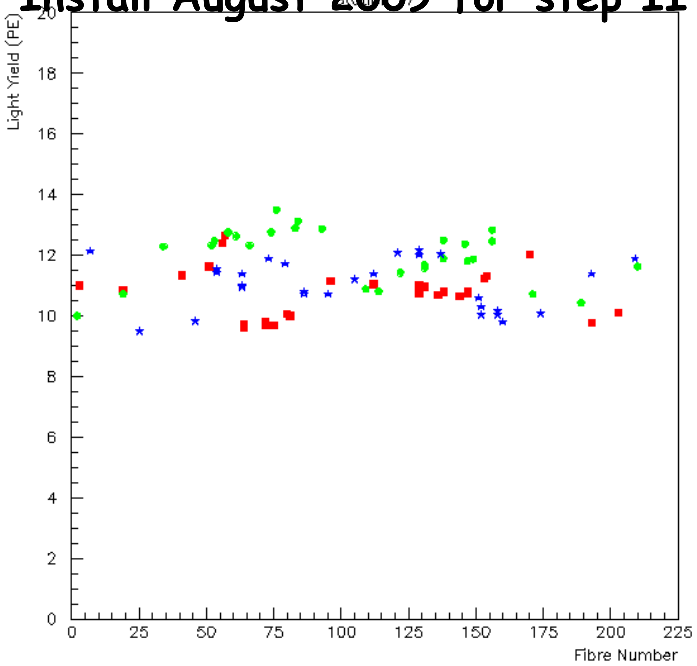
Sci-fi tracker with 5 stations of 3 views of 350 microns diam. fibers

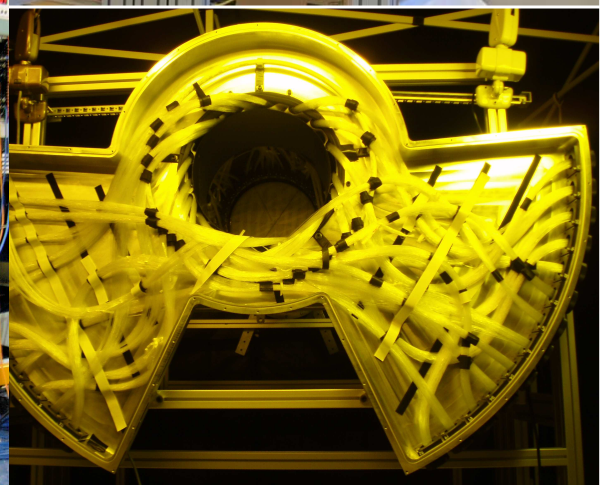
Tracker construction complete

Superb quality of construction (1/5000 channels dead)

Test on cosmics at RAL

Install August 2009 for step II





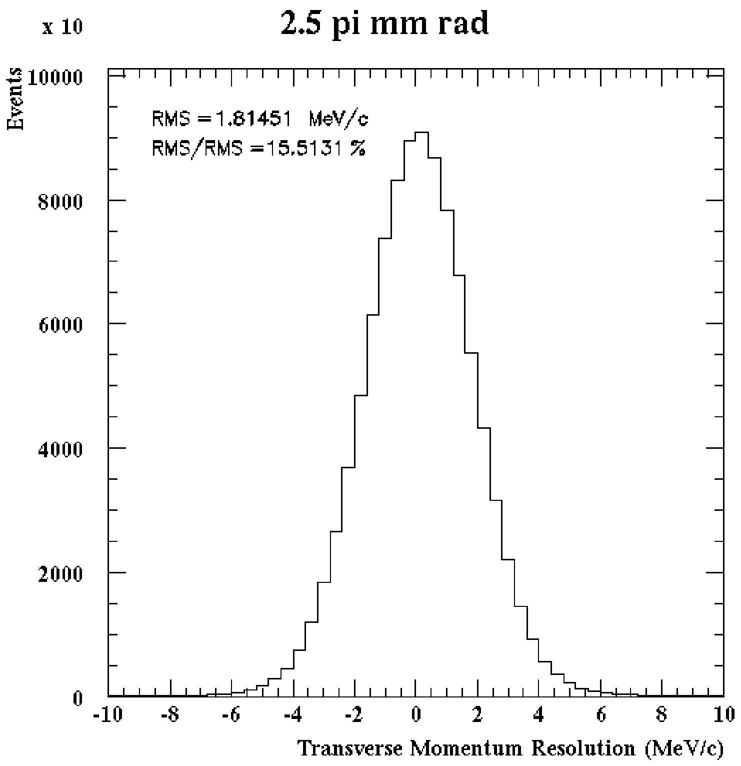
Patch panel

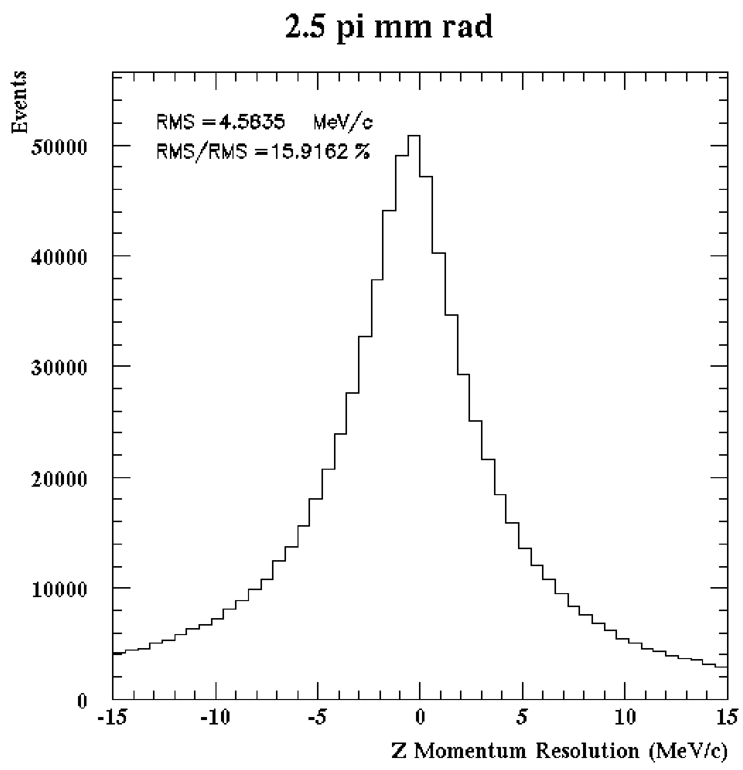
Tracker performance on a beam of 200 MeV/c muons

at equilibrium emittance

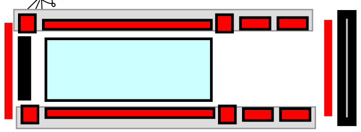
resolution matches requirement of ~10% of beam rms in P_T and P_z

non-gaussian Pz resolution: $\sigma(P_z)/P_z = \sigma(P_T)/P_T$ diverges at small P_T

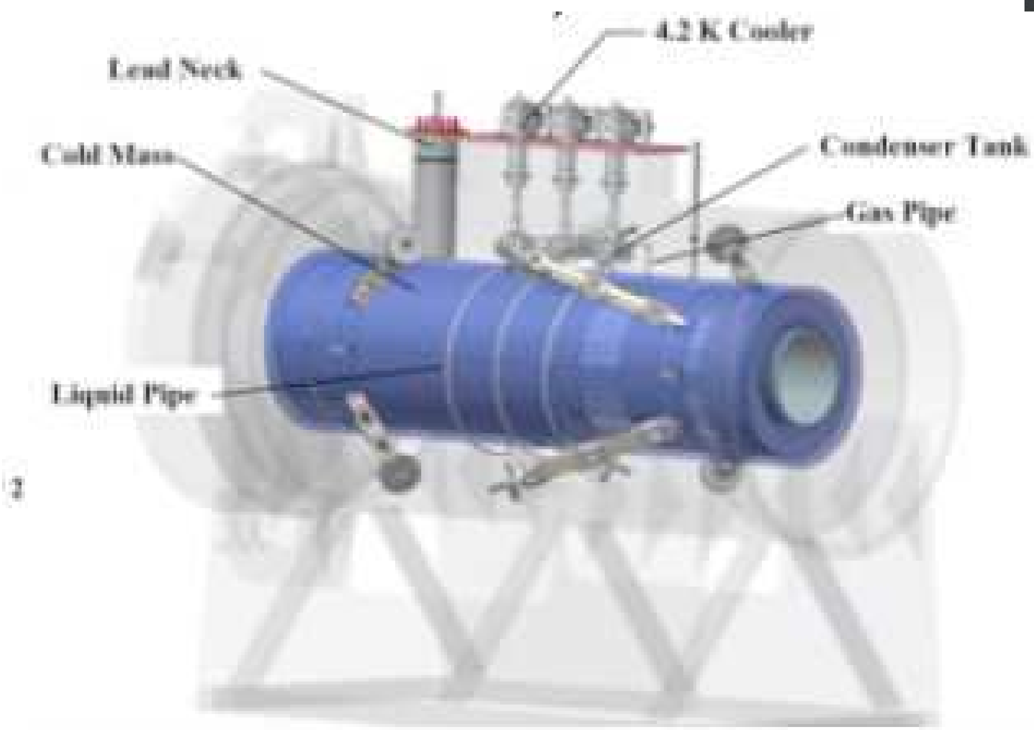




Spectrometer solenoids



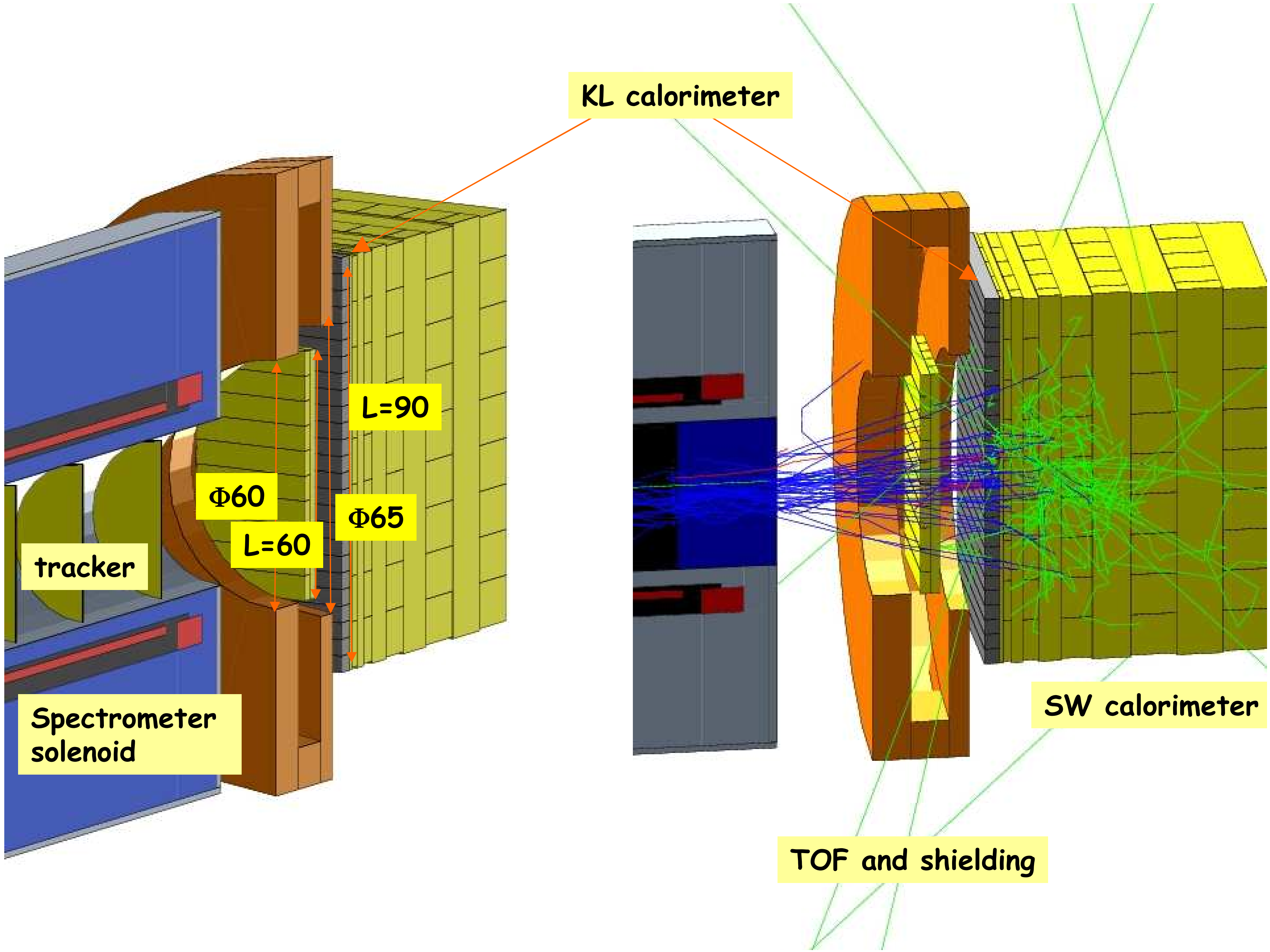
5 coils.
provides 4T uniform field
+ matching to MICE optics
+ support for diffuser,
  tracker, TOFI or TOFII



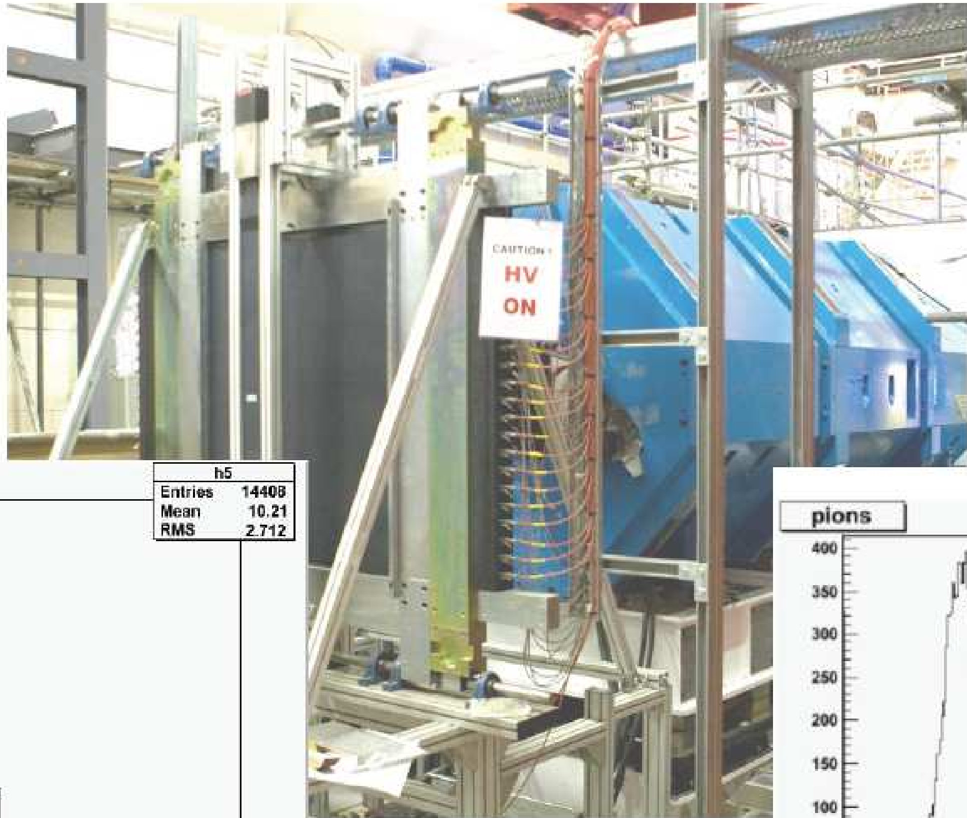
<== Completed magnet I

Magnetic measurement gear at Fermilab (Zip track) ==>

SS-I expected at RAL end Jun09

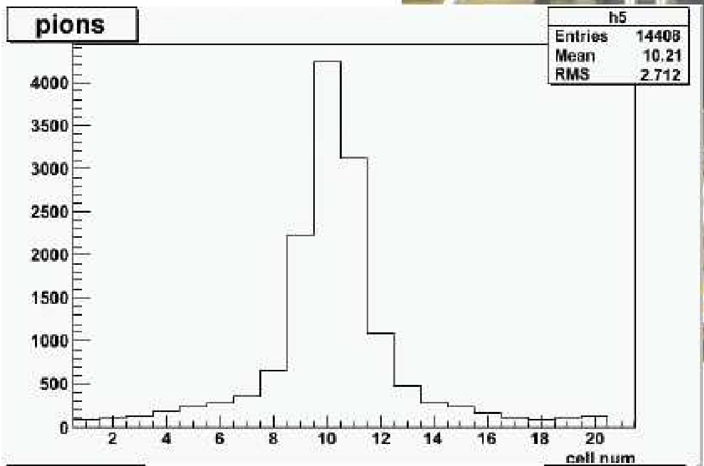

KL calorimeter
L=90
Φ60
Φ65
L=60
tracker
Spectrometer
solenoid
SW calorimeter
TOF and shielding

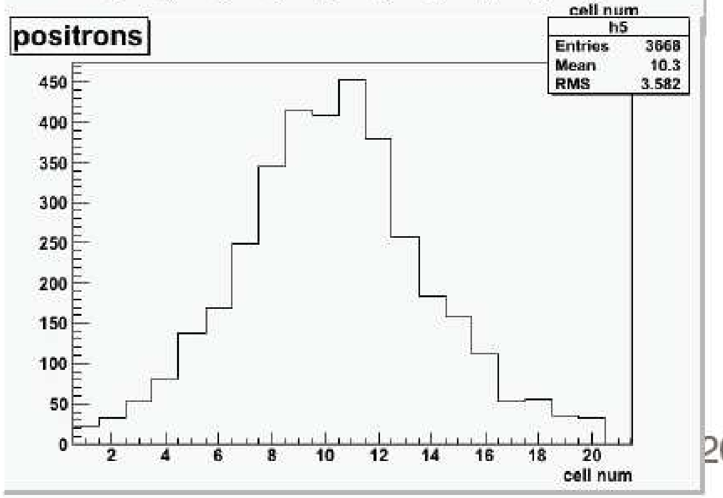
KL calorimeter

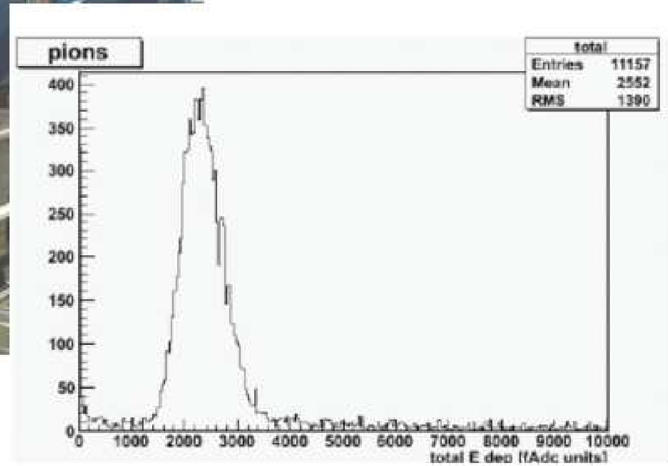


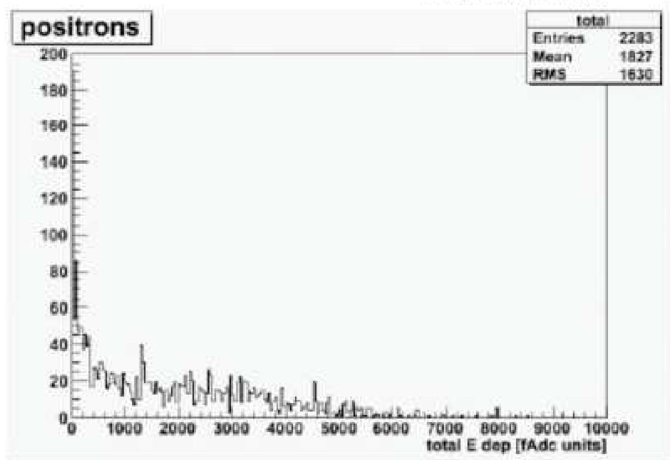
= KLOE-LIGHT
Lead-sci-fi
Similar to KLOE
EM calorimeter
(rel less lead)

On beam Jul08!

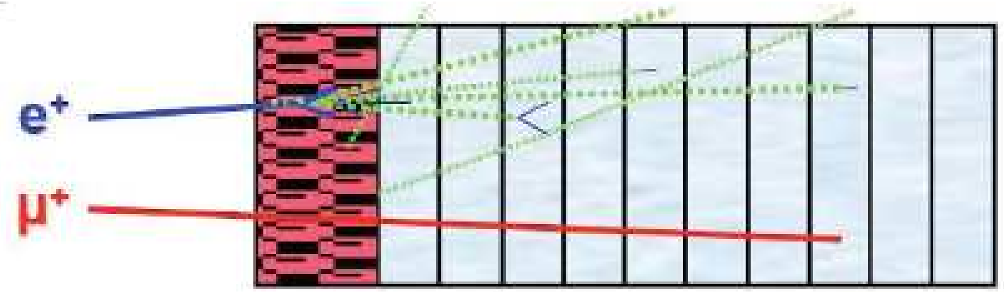


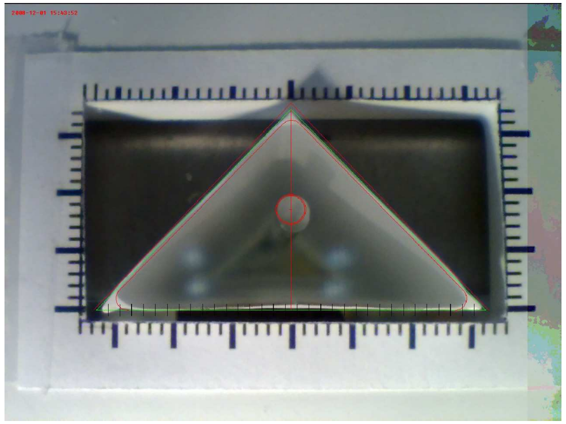


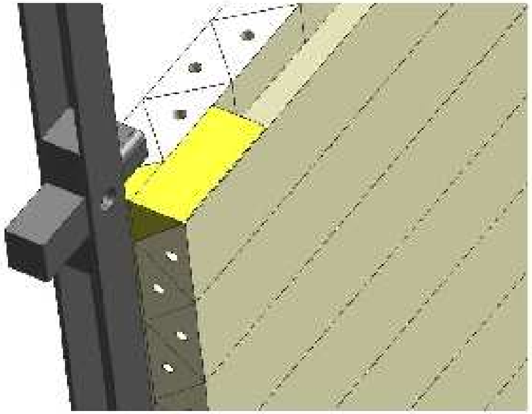


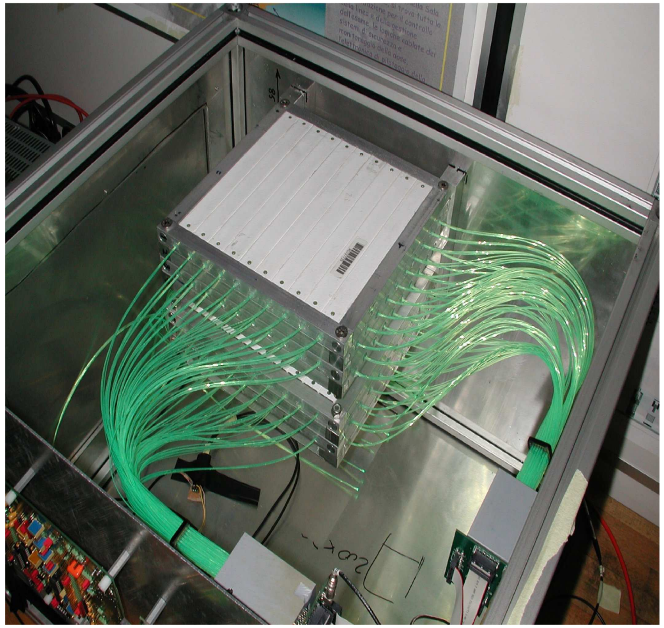


Electron Muon Ranger Trieste + Geneva+ Fermilab









Prototype test successful in 2007.
Design complete: readout on 2sides MAPM/PM
150 scintillator bars arrived 2Apr09 from Fermilab to Geneva
Electronics in order at Geneva
Test of small prototype with final electronics in Jun09 at CERN.
Test of full size double plane in Oct09 at GVA

aim for full detector in Mar10;
final date known when first double plane is built. Funding OK

The 4.2 MeV/c Pz resolution of EMR completes that of the tracker for low P_T

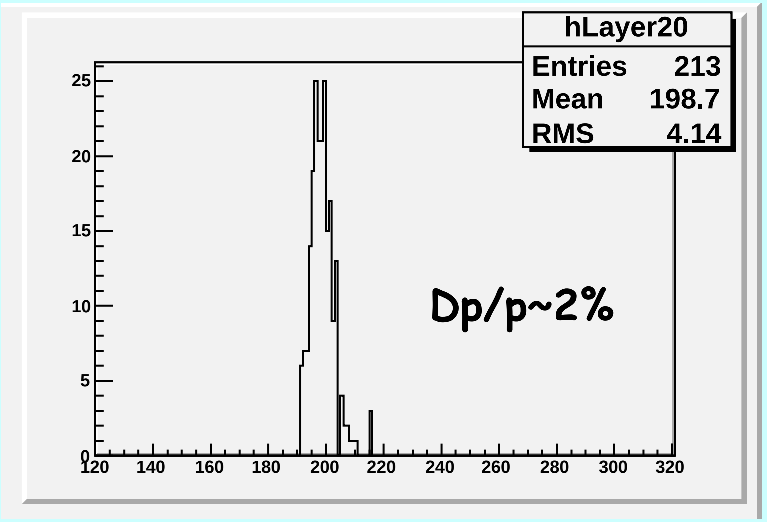
Some work to do to integrate in reconstruction

EMR:

simulation of 200 MeV/c muons stopping in layer 20

hLayer15
Entries 201
Mean 176.2
RMS 3.945

260 280 300 320



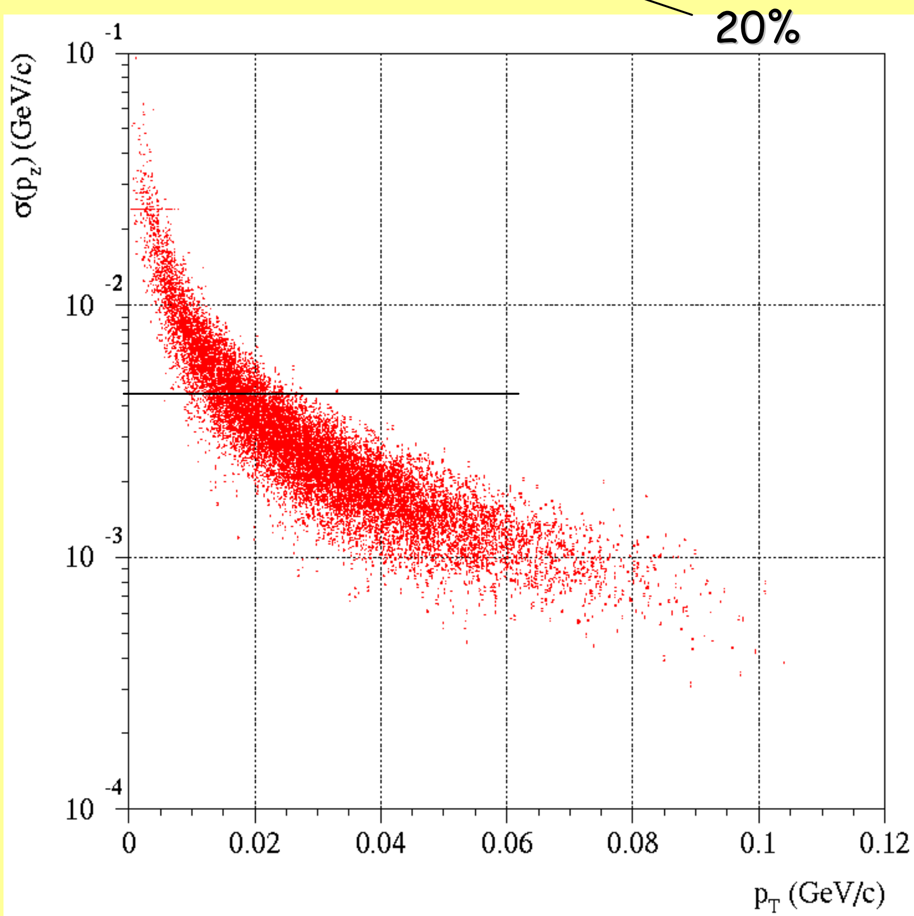
hLayer25
Entries 231
Mean 220.3
RMS 4.618

25
20
15

hLayer30
Entries 197
Mean 239.9
RMS 4.506

Tracker:

Resolution on p_Z:
- Strong dependence on p_T;
- Varies from 1 to 30 MeV/c.

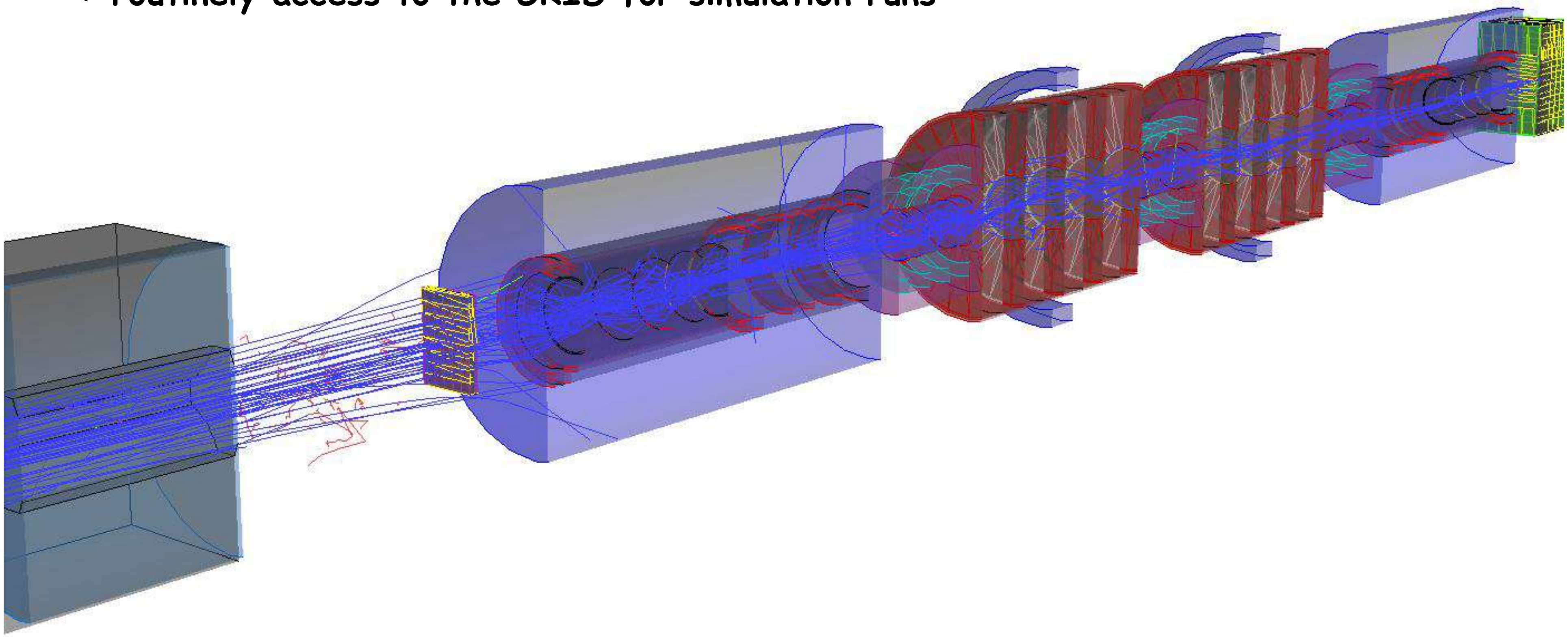


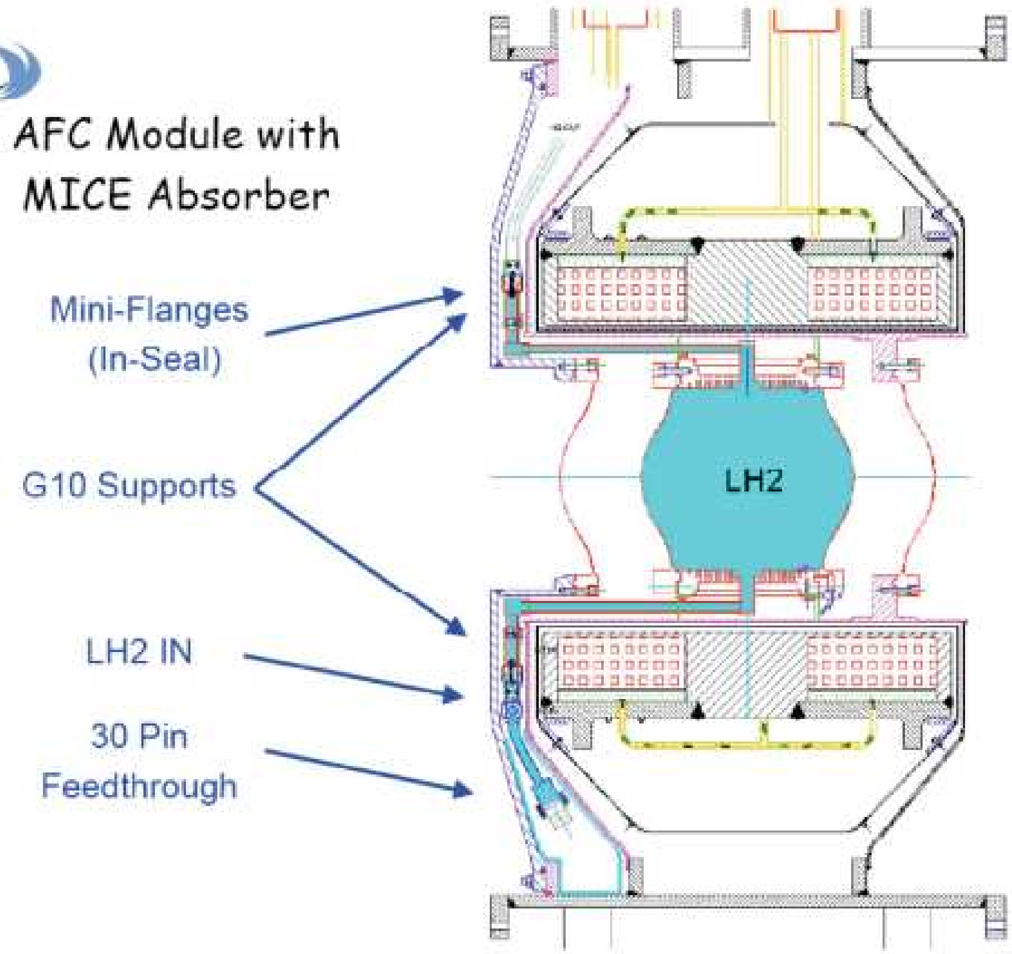
software, analysis & DATA handling

1. Basic simulation and reconstruction of MICE is complete for the various steps
Both G4MICE and MUCOOL are used.

2. Putting it all together to do analysis (particle reconstruction, particle ID algorithms
Single particle amplitude and emittance calculations, etc…)

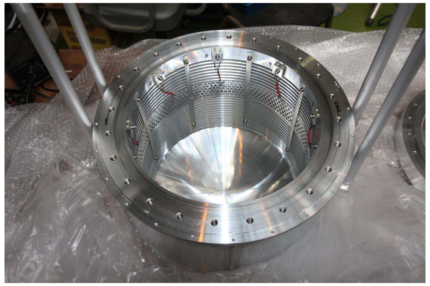
3. Online computer farm with storage worth a few days of data
+ fast link to ATLAS center at RAL
+ routinely access to the GRID for simulation runs





Focus coils: contract with Tesla signed 18Jun08 -- Thanks STFC!
Expected delivery of first magnet Feb10
Second six month later.
Third in option -- pending stepVI funding by STFC.

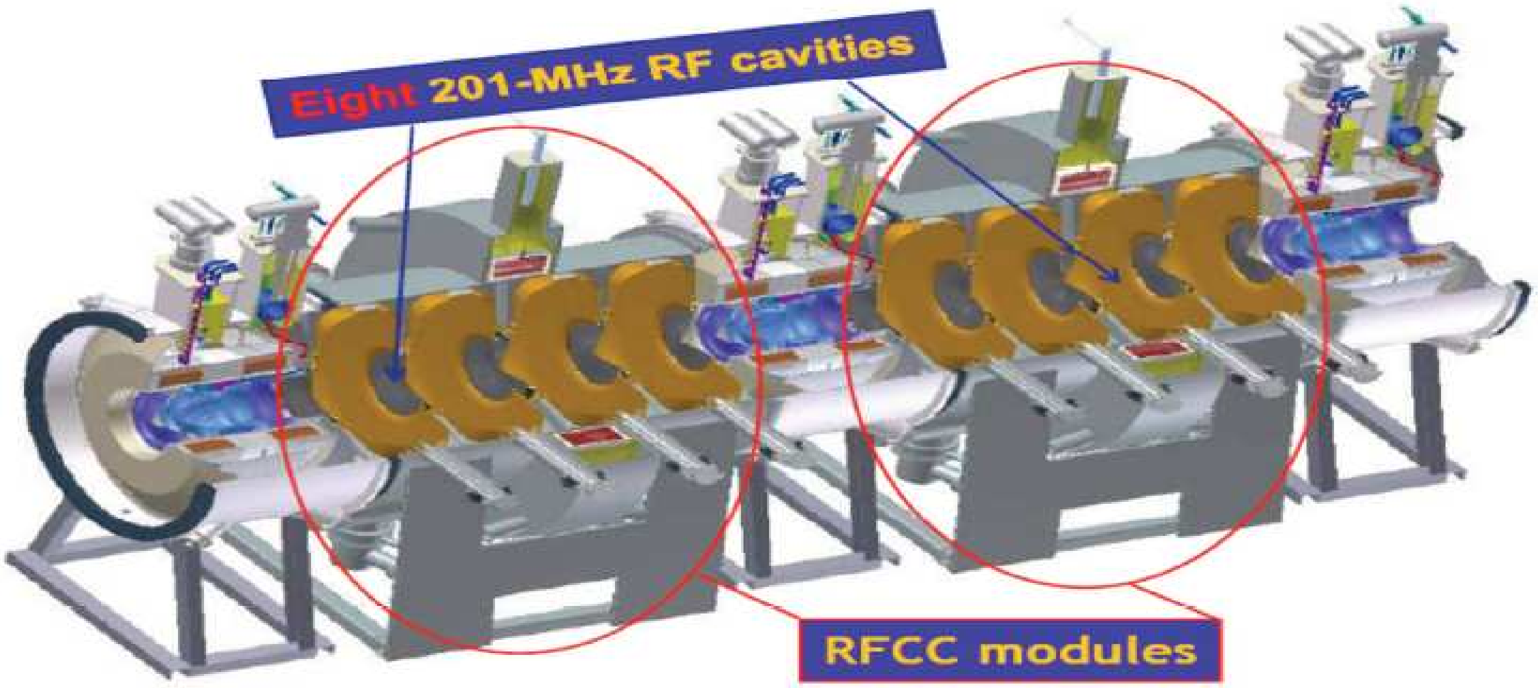
Absorbers (Ishimoto, KEK) and windows (Mississipi)

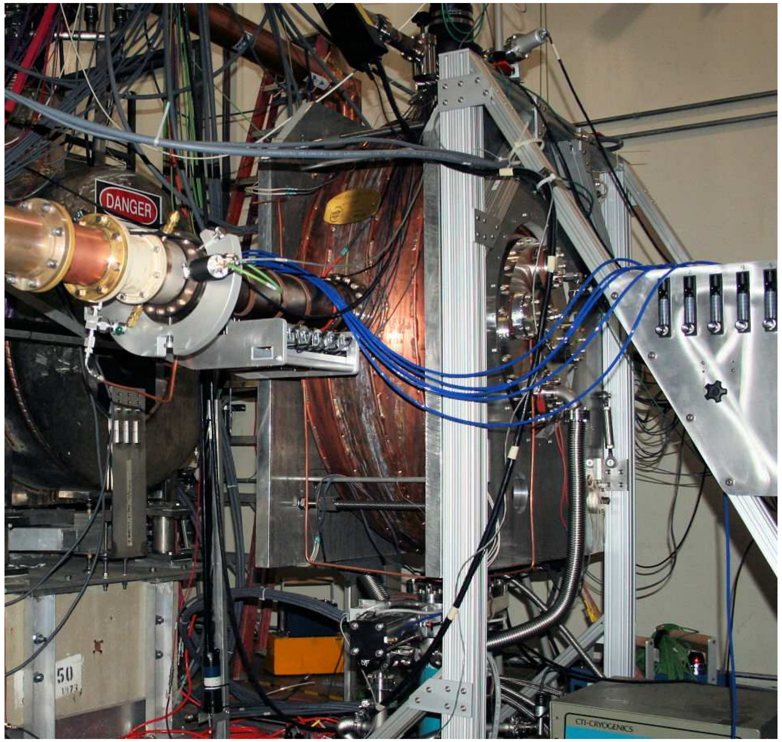


First absorber body completed 18-04-2009

Design and construction by MIRAPRO company.
Windows fabricated at Mississippi.
they have made many for tests -->

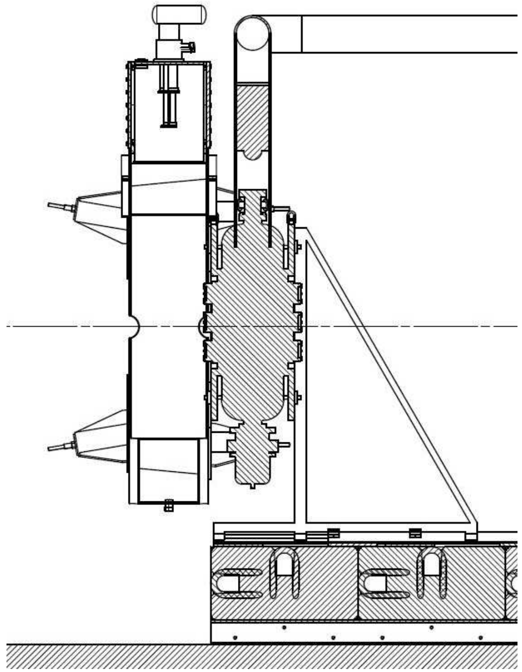
RFCC module



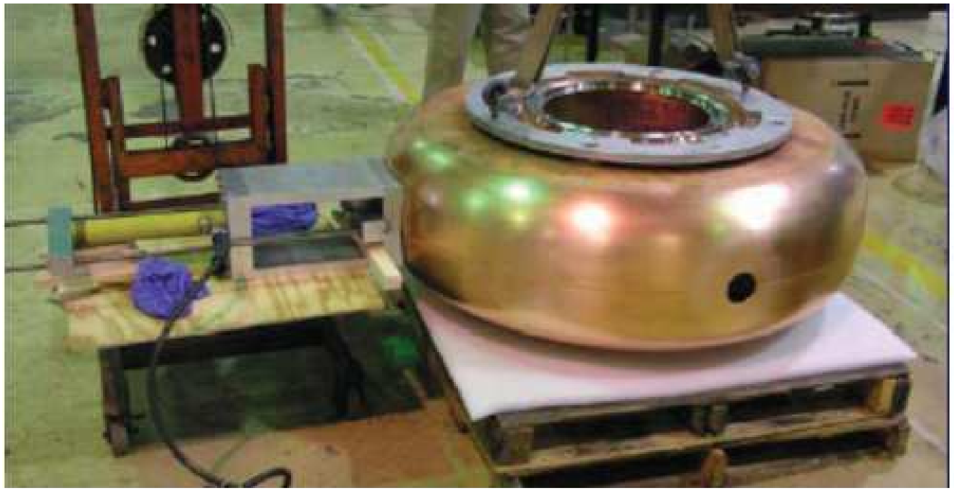


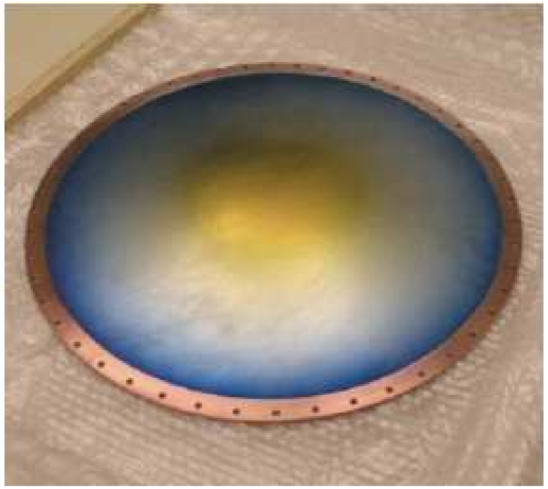
The test cavity at Fermilab will be tested with coupling coil in 2009

RF cavity construction



Procurement for cavities and windows has begun in industry
Spinning / welding / electro-polishing





RF in magnetic field

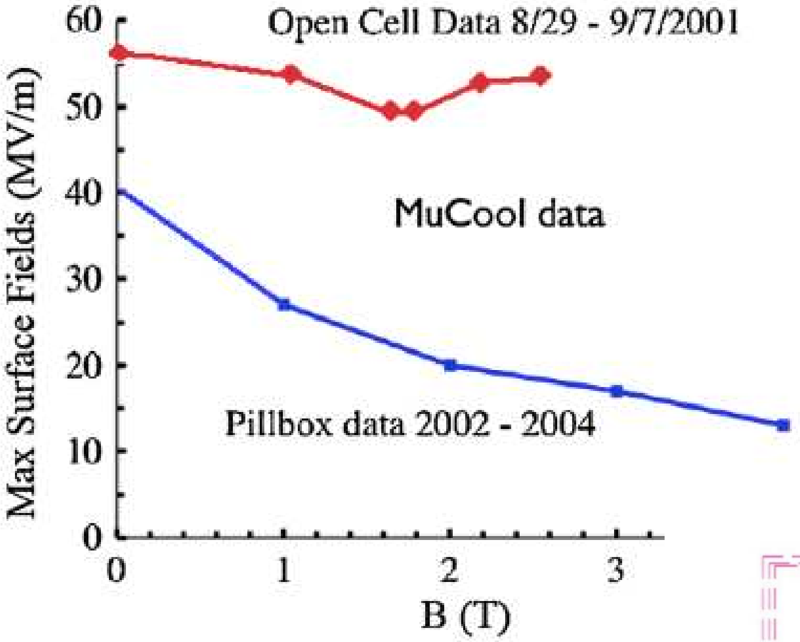
1. Emission of electrons dammages cavity and limits Accel. Gradient. Magnetic field effect is not too well understodd but could enhance effect and focus electrons. Effect goes like E^{13}!
2. In MICE, the electrons could generate huge background in the tracker -- directly or indirectly by emitting photons in material.

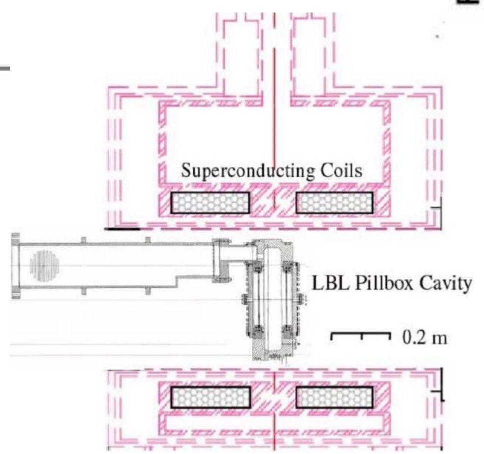
Based on experience with 800 MHz cavities and measurements of rates with scintillators it was evaluated that the gradient MICE could stand with cavities embedded in 2-3 T field was about half the maximal gradient i.e. 8MV/m or 23 MV total acceleration (on crest) with 8 cavities. There is a large uncertainty on the rates – but not so much on the gradient.

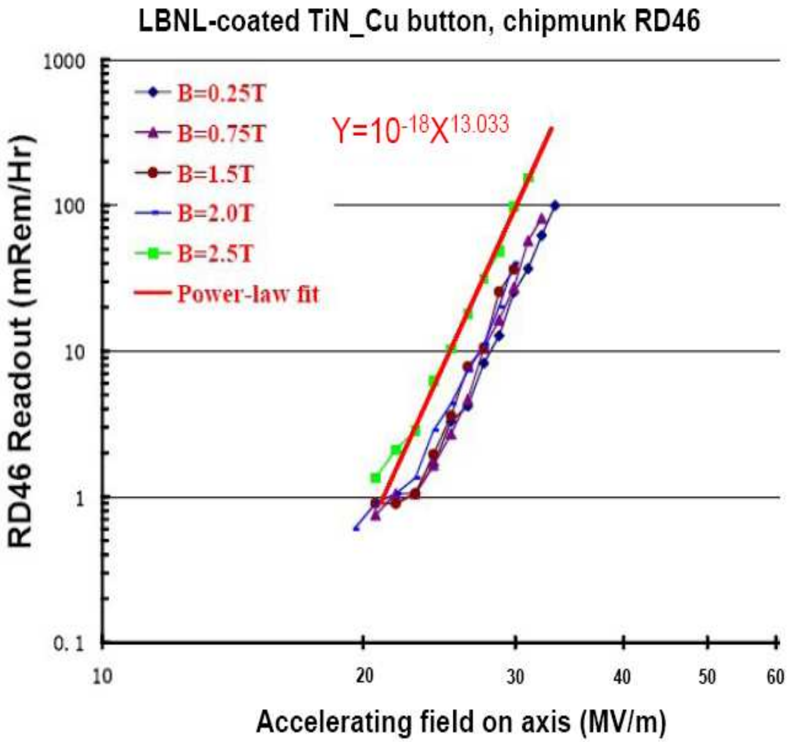
Possibilities of investigations in MICE:
With 8MW RF power 8 MICE RF cavities can reach 8MV/m at room temperature or 12 MV/m if all power is applied on only 4 cavities.
At LiN2 temperature a gradient of 12 MV/m could be achieved on all 8 cavities or 16 MV/m on 4 cavities only.

Effect of Magnetic Field on accelerating cavities.

The RF cavities in a Neutrino Factory or Muon Collider work within a large magnetic field (~>2T).
Magnetic field degrades the M.S.O.G. (maximal stable operating gradient) rapidly. The effect can be described by universal curves. Tests were done on 800 MHz pill box and open cells cavities with reproducible results

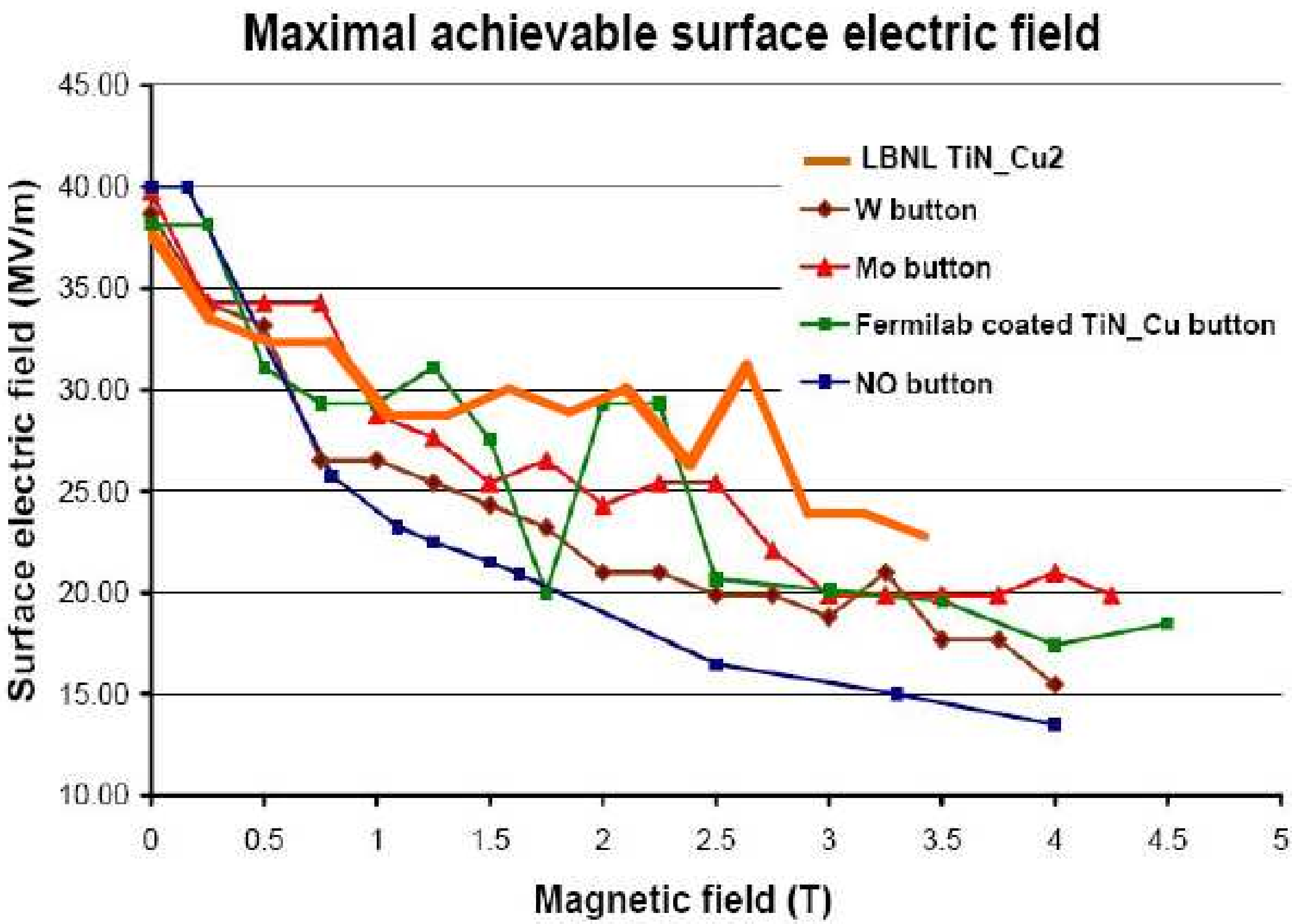




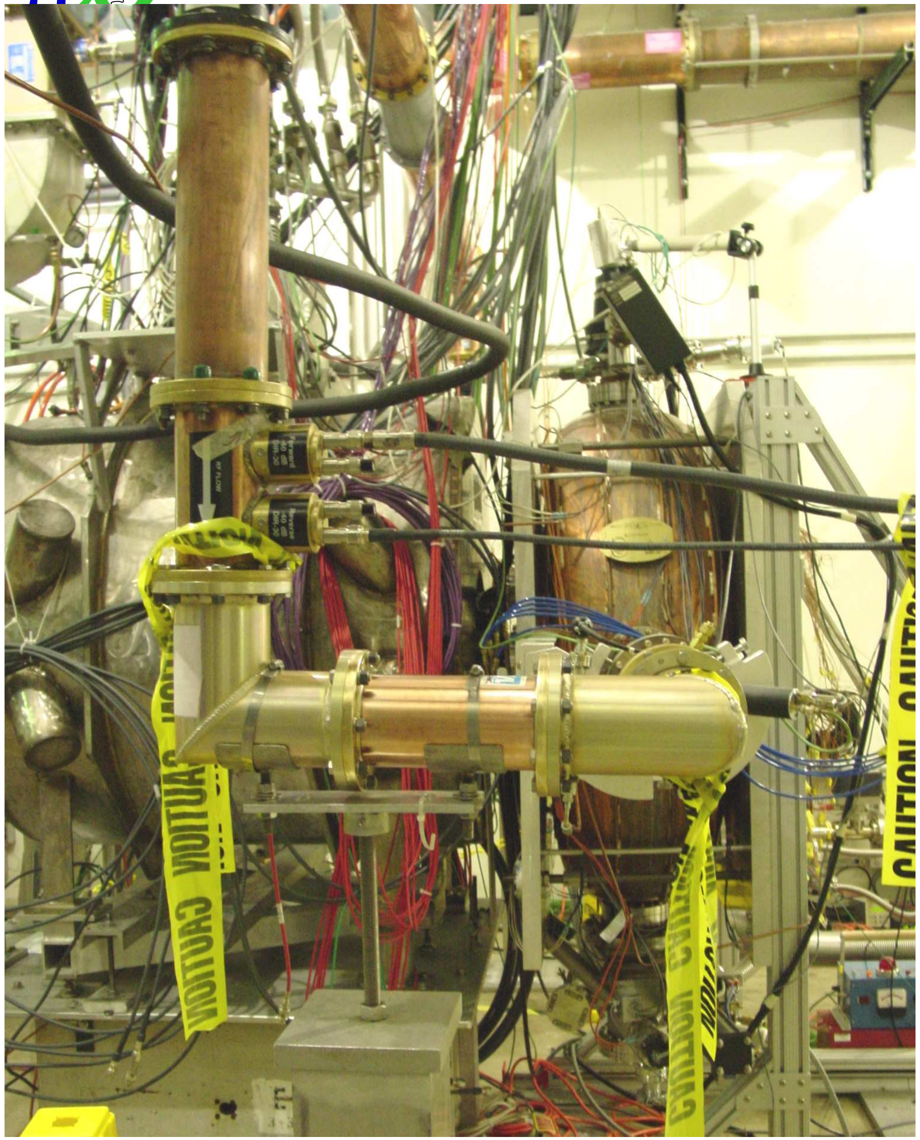


Such data available in 2002 were used to calculate the gradient sustainable by the tracker operation.

The MUCOOL collaboration has a test area available at FNAL.

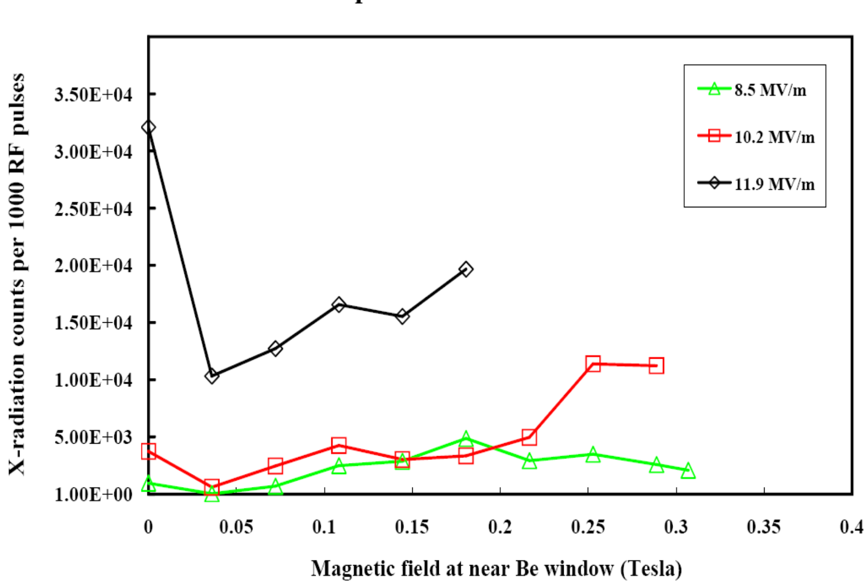


The effect of mag field is to degrade seriously performance of closed cavities. Surface treatment can provide improvement, as tested on buttons inserted in the 800MHz cavity



First 200MHz cavity was produced already 18Mo ago.
Reached 19MV/m
Tested in fringe field of magnet
X-ray rates measured
Progress awaits Coupling Coil Q409

Scintillator paddle counts in 201 MHz test



Refurbishment of power amplifiers from LBNL (at DL)

200 MHz equipment refurbished at CERN now arrived at DL

Test stand at DL operational first half 2009

Will start with CERN stuff -- tests in 2009

Ship and install in 2010. Lots of RF piping etc…

Beyond PHASEII -- Ideas for « Phase III »

ONCE PHASEII will be completed, having equipped the MICE hall with
-- spectrometers, TOF and PID able to measure emittance to 10^{-3}
-- 8 MW of 201MHz RF power
-- 23 MV of RF acceleration
-- Liquid Hydrogen infrastructure and safety

MICE can become a **facility to test new cooling ideas.**

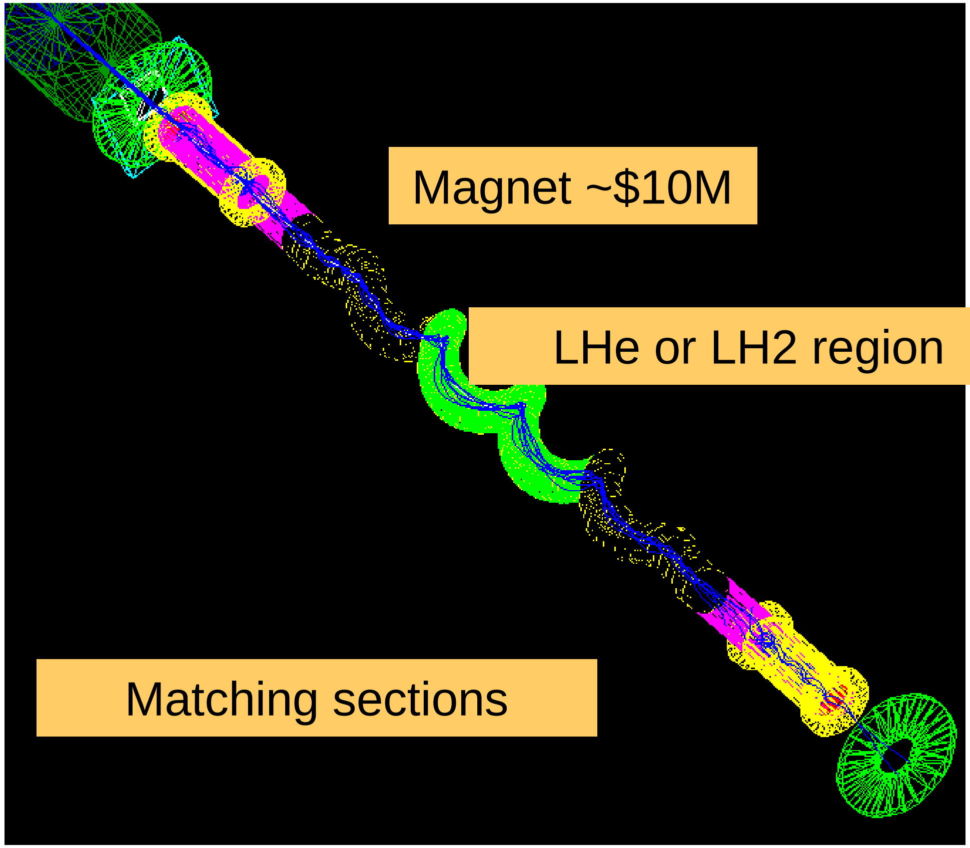
Such ideas were proposed:

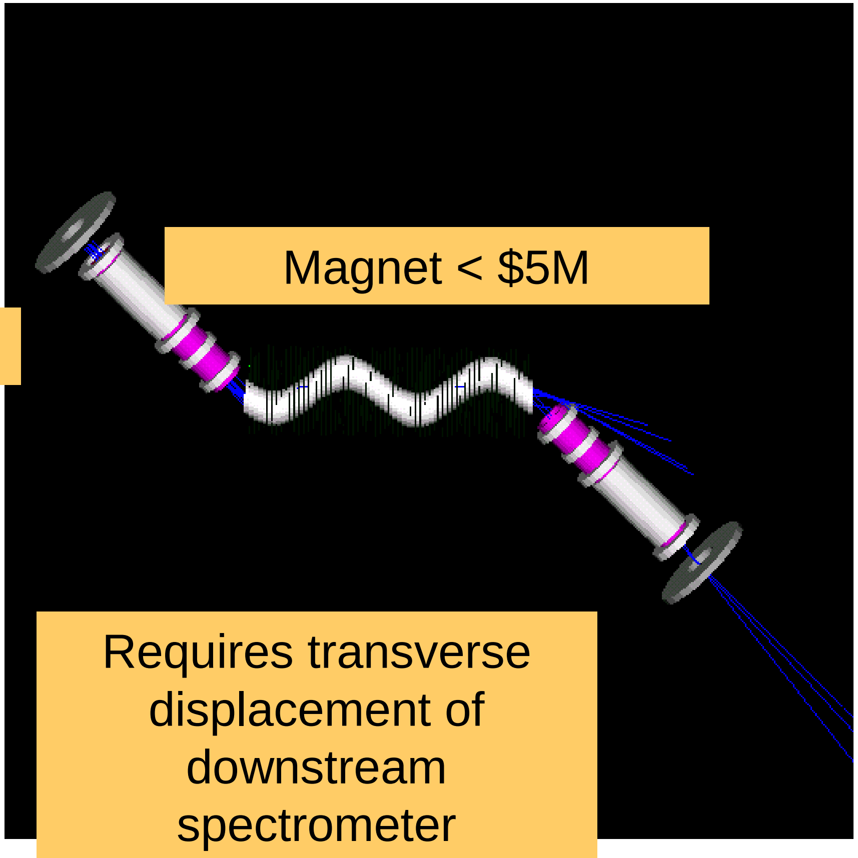
A. with the existing MICE hardware to test optics beyond the neutrino Factory study II:
non flip optics,
low-beta optics (down to 5 cm vs 42 cm nominal)
other absorber materials He, Li, LiH, etc..
LN2 cooled RF cavities

B. with additional hardware:
-- A. Skrinsky to test a lithium lense available at Novosibirsk
-- Muons Inc. to test a section of helicoidal channel (MANX)
-- B. Palmer proposed a poor man's concept of 6D cooling

PHASE III?

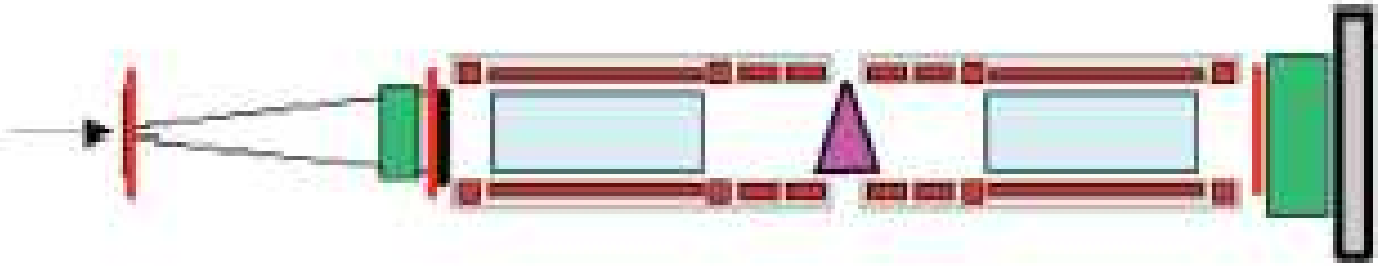
We had presentations by Rol Johnson and Robert Sah (Muons Inc.) on MANX, a possible6D cooling experiment using an helicoidal solenoid





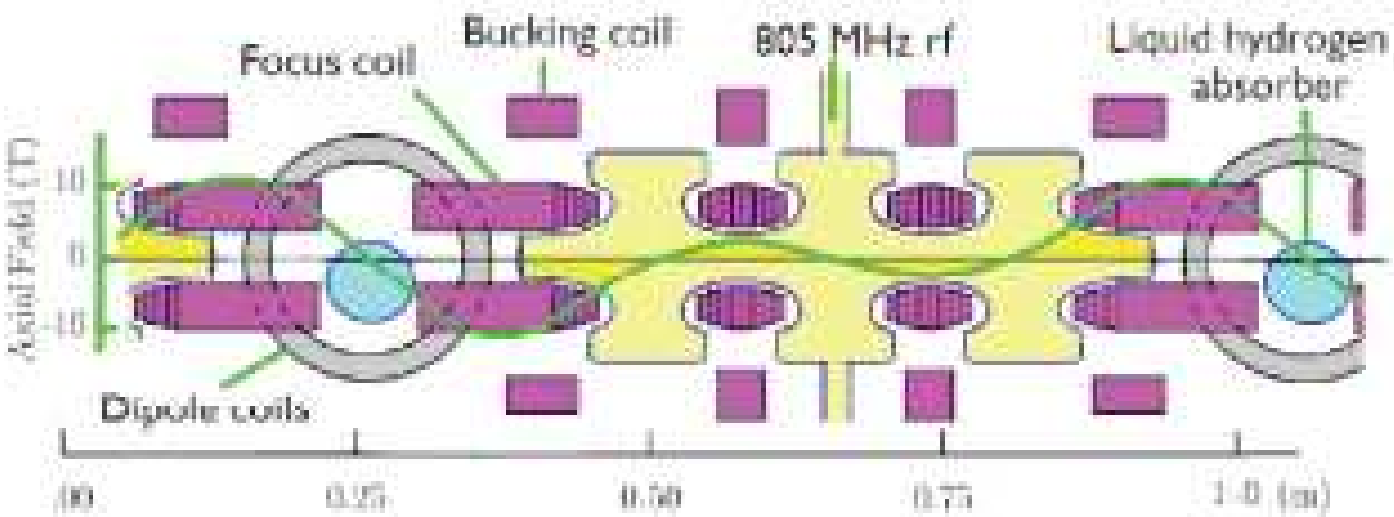
Very interesting … but still a lot of work to do!

B. Palmer's ideas



"Poor mice" cooling channel -- a step III.2?

Pavel Snopok (UCR) volunteered to work on this.



A MICE coouling section with dispersion and small coils allowing containment of electron radiation

Conclusions

MICE is part of a world wide program to establish feasibility and cost of neutrino factory and muon collider

Neutrino Factory is a very powerful tool to produce high energy electron neutrinos and study the Golden Channel
→ $\sin^2 2\theta_{13}$, CP violation, mass hierarchy and unitarity

MICE experiment at RAL is underway:
MICE beam line comissioning, MICE hall infrastructure
Construction of detectors nearly complete
Precision emittance measurements within one year
All cooling equipment components are under construction (to step V)

Cooling measurements by 2012 are of strategic importance

A beautiful suite of devices for many exciting possibilities!