Swiss Institute of Particle Physics

2010 CHIPP Annual Plenary Meeting

23/24 August 2010 – Paradieshotel Rotschuo Gersau

MICE and the Neutrino Factory

Jean-Sebastien Graulich, Geneva

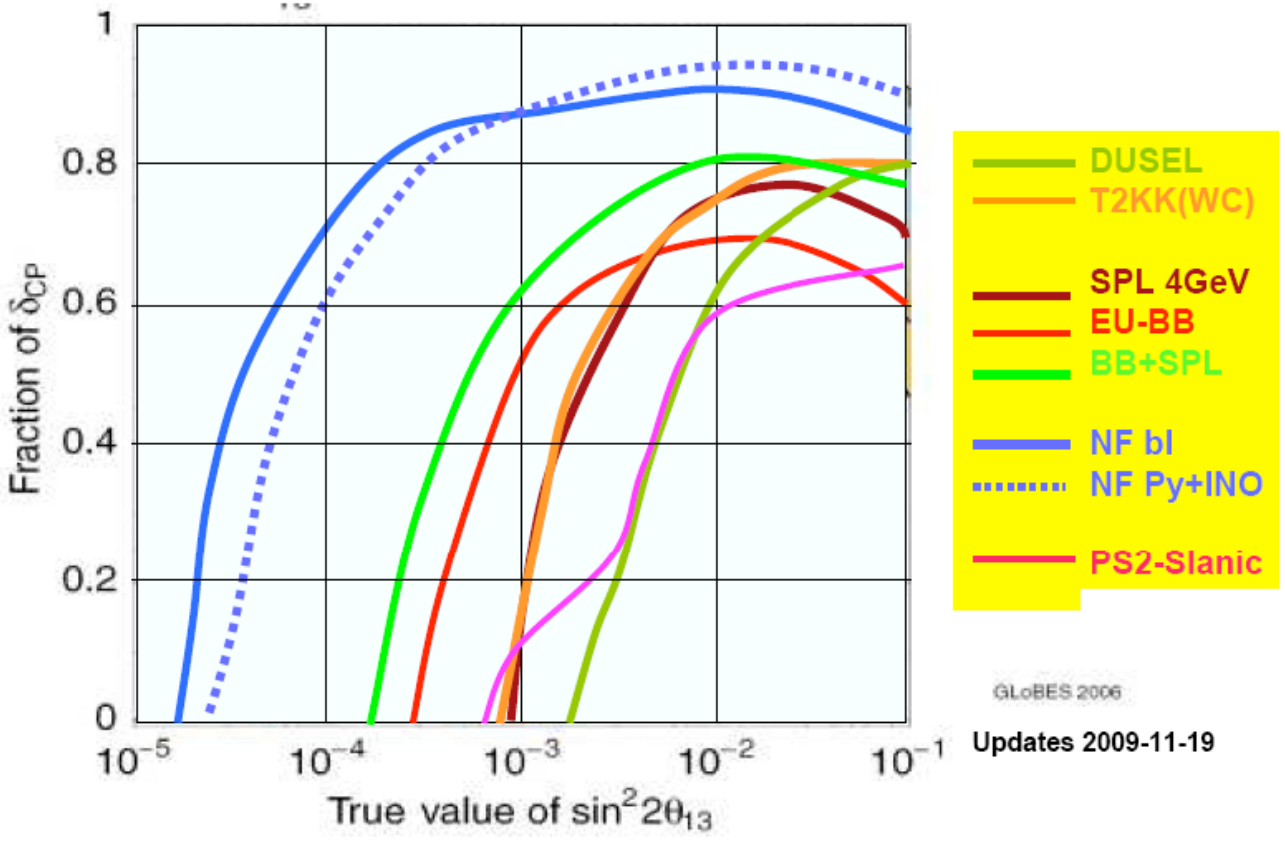
Neutrino Physics

- **Neutrino Oscillation is established**
  - The Standard Model is incomplete !
- **Phenological Model**
  - Neutrinos have masses
  - Flavor states are mixed
    - Same as for quarks BUT… completely different !
- ***A full bunch of fundamental questions***
  - Is lepton number conserved ?
  - Is the ν its own anti-particle ? Majorana masses ?
  - Does the oscillations violate CP ?
  - Why ν masses are so small ?
- ***A strong need for precision measurements***
  - Mixing angles
  - Mass differences and Mass hierarchy
  - CP violation parameter

Options for the future

- **Improve Current Technology**
  - High Power Super Beam
- **Radioactive Ions Storage ring**
  - Beta-Beam
- **Muon Storage Ring**
  - Neutrino Factory
- **How to choose ?**
  - Performances
  - Strategy (or risk management), flexibility
- **Advantages of NF**
  - High energy, High intensity neutrino beam
  - Very well defined beam content (ν_μ , $\overline{\nu_e}$) or ($\overline{\nu_\mu}$, ν_e)

Sensitivity: δ_{CP}

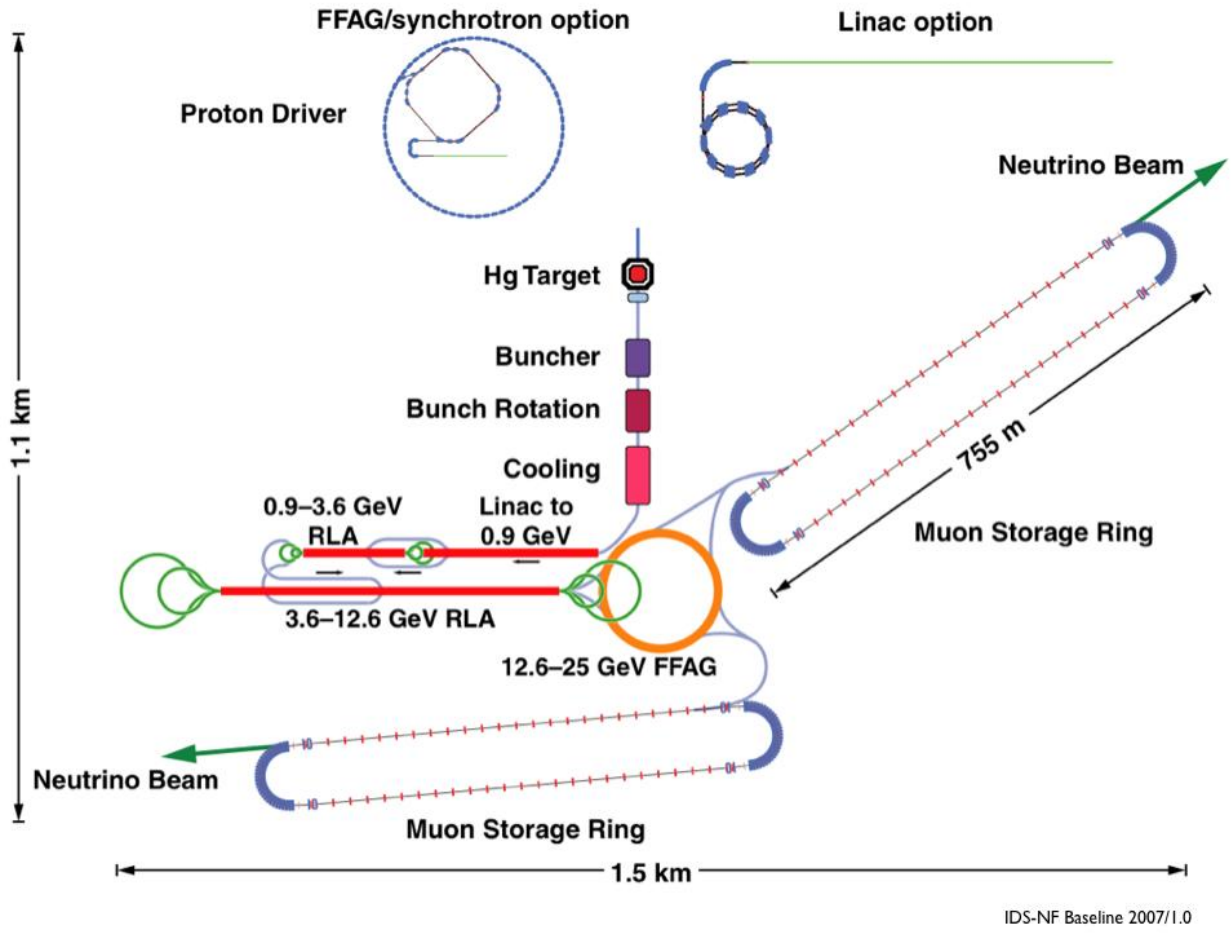


From the report of the CERN Scientific Policy Committee, March 2010

The Ultimate

- The most sensitive also for
  - Mass Hierarchy
  - $\sin^2 2\theta_{13}$ (down to 2.10^{-5})
- Neutrino factory is outstanding
- Can we do it ?
  - How ? -> Some R&D needed
  - Where ?
  - What Detector ?
  - When ?
  - (How much it costs ?)

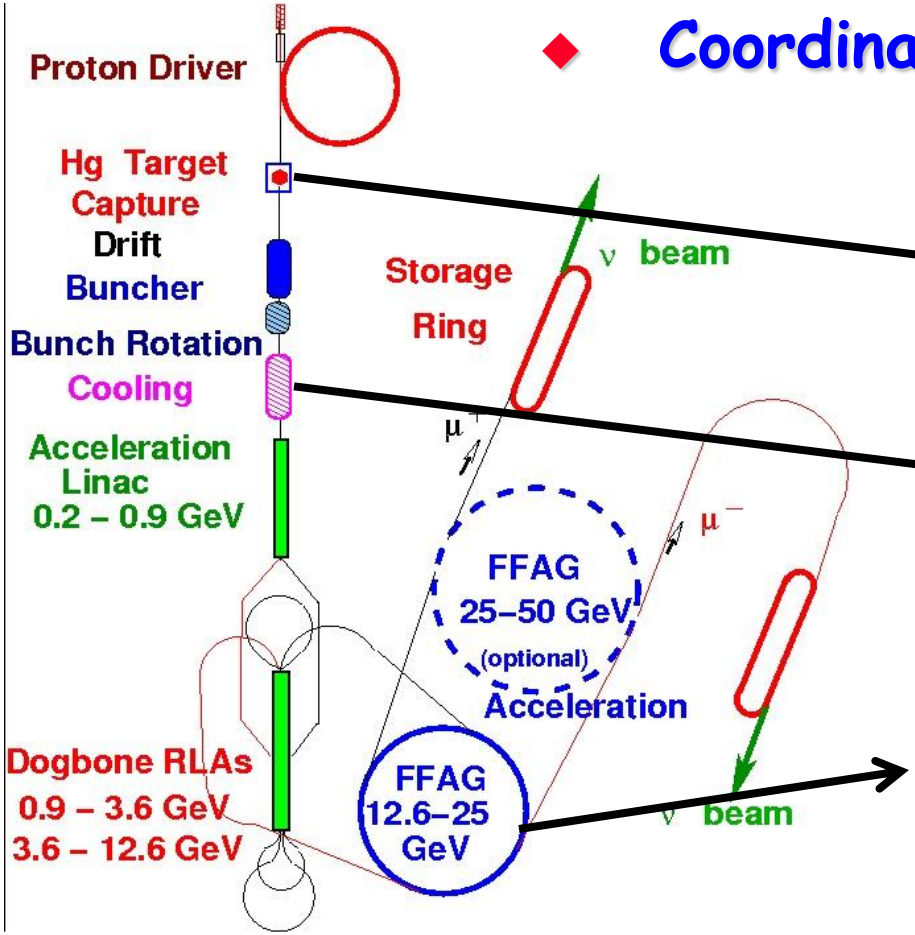
Neutrino Factory



IDS-NF-002: https://www.ids-nf.org/wiki/FrontPage/Documentation?action=AttachFile&do=view&target=IDS-NF-002-v1.1.pdf

R&D for ν-Factory

- Coordinated International Effort



MERIT (CERN)
High Power Target

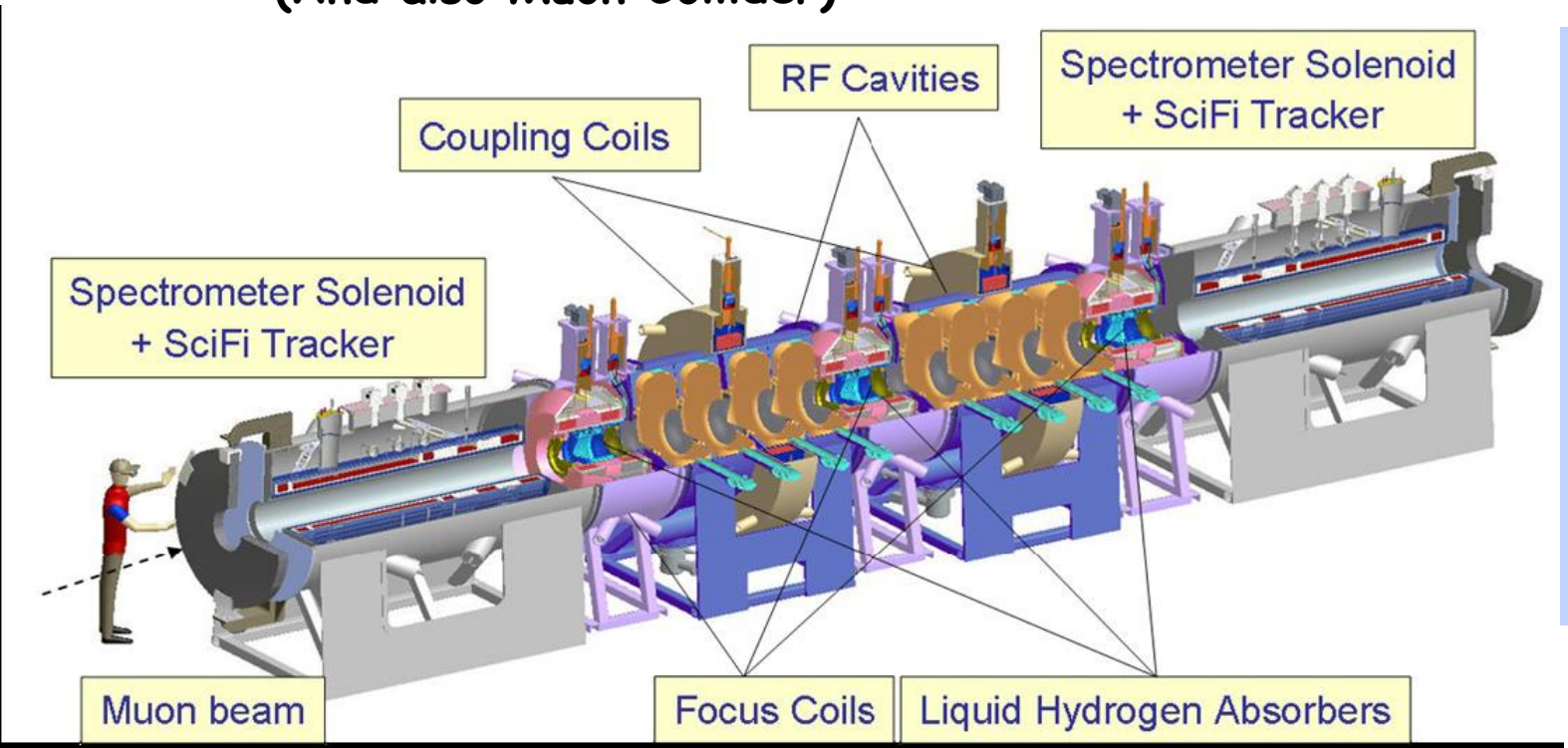
MICE (RAL, UK)
Muon Cooling

EMMA (UK)
Large Acceptance
Fast Accelerator (FFAG)

MICE

- **Muon Ionisation Cooling Experiment**
  - Design, build and operate a realistic section of cooling channel
  - Measure its performance (in different modes)
- **=> Optimize Neutrino Factory designs**

  (And also Muon Collider)

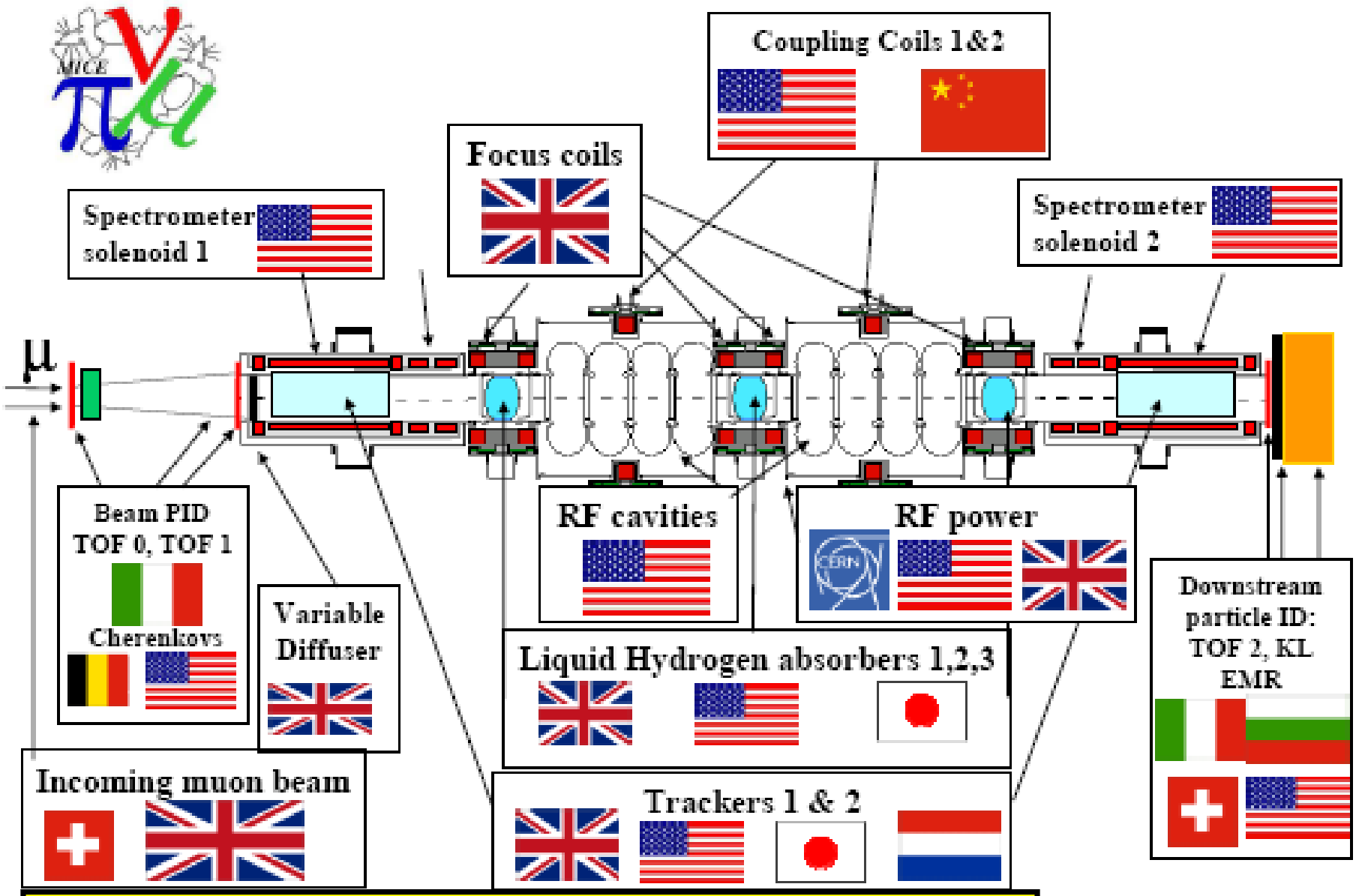


Super-conducting channel

High gradient RF in Magnetic Field

Liquid H2

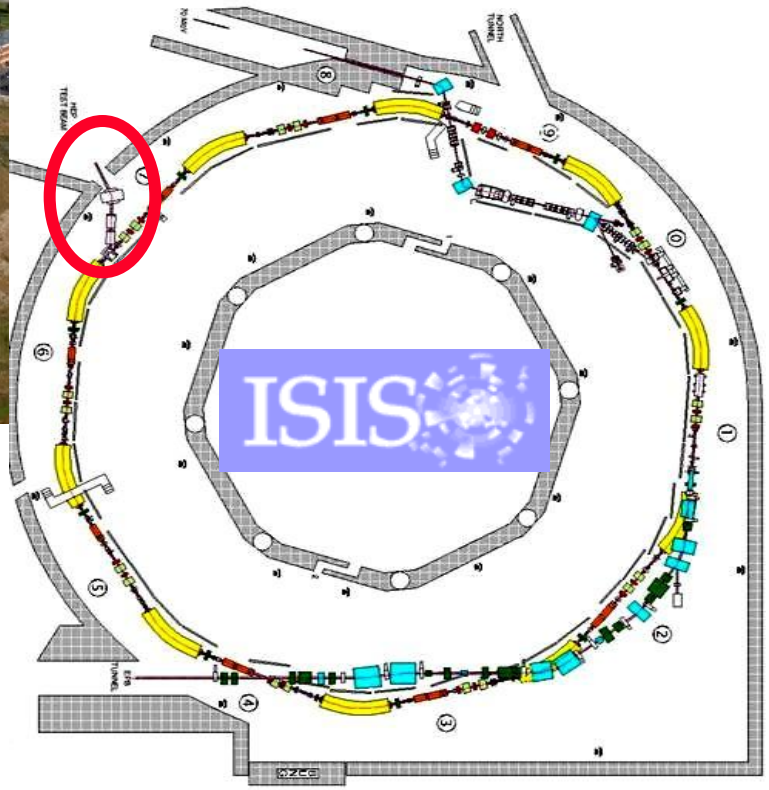
MICE Collaboration across the planet



Spokesperson: Alain Blondel (Geneva, Switzerland)

MICE @ RAL

Science & Technology Facilities Council



- **Rutherford Appleton Laboratory, UK**
  - Brand new muon beam line
  - Built from scratch
- **ISIS proton Synchrotron**
  - 800 MeV
  - 200 μAmp

MICE Step By Step

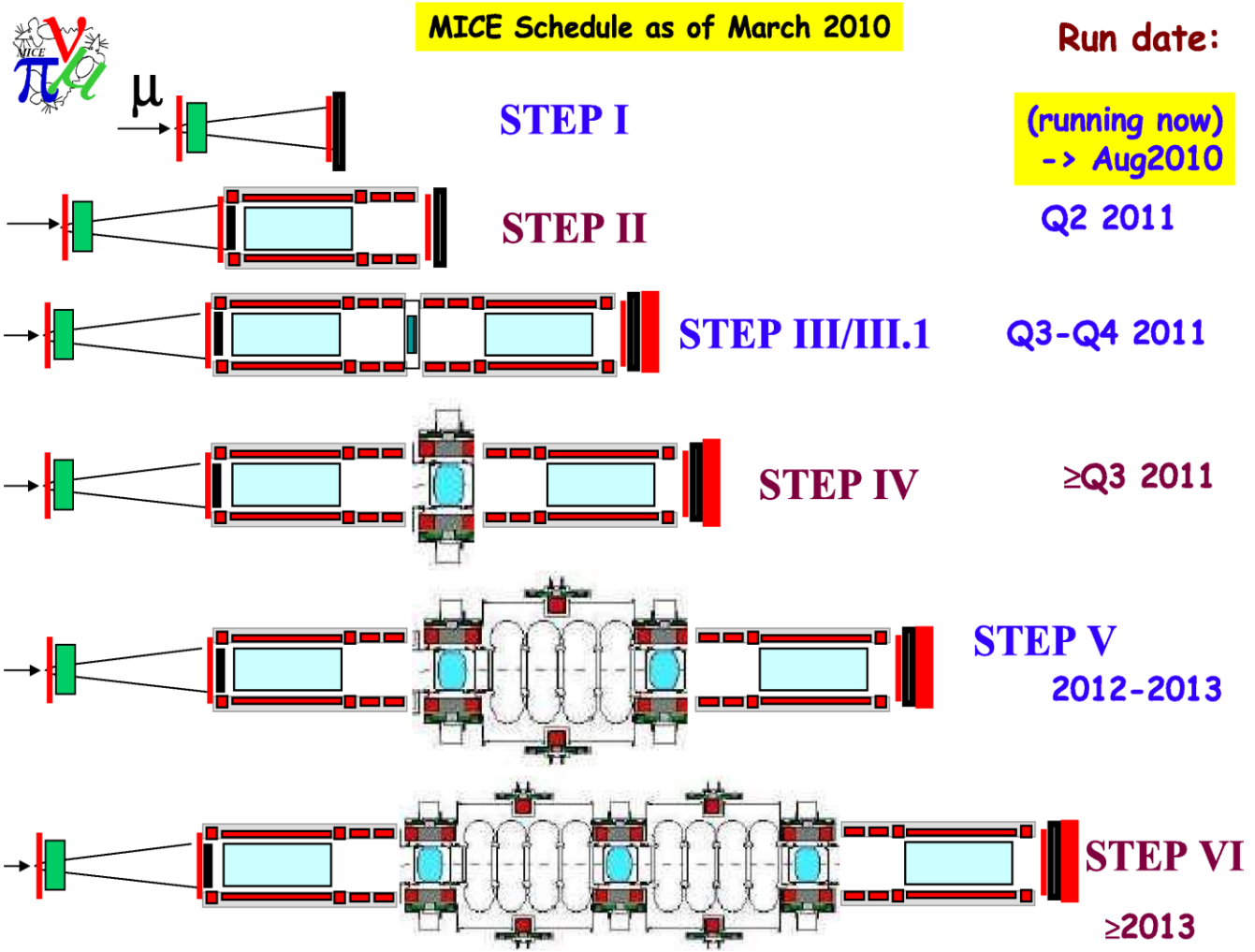
Commission beam line & detectors

Precisely measure incoming emittance & compare trackers

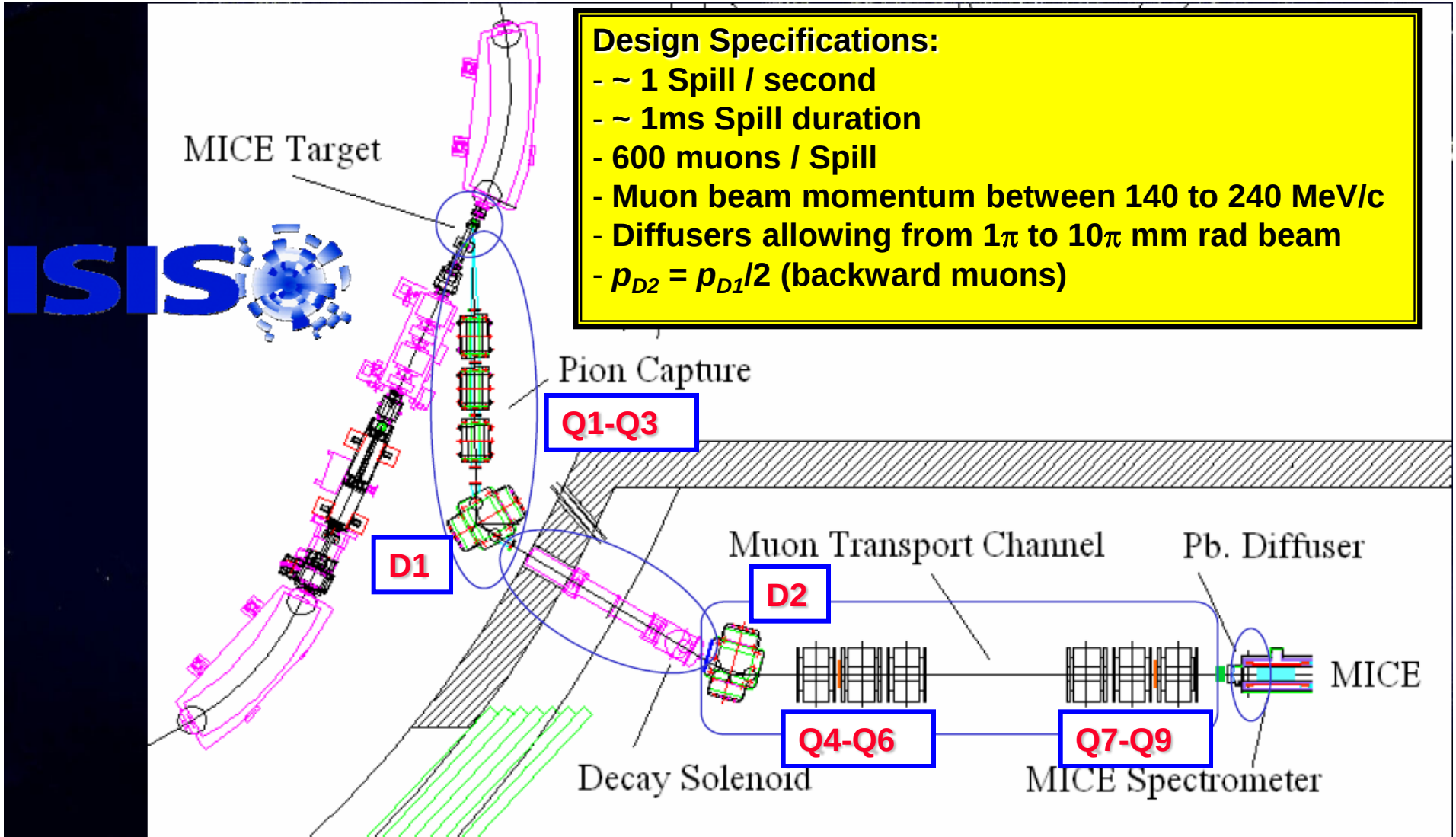
Precisely measure muon cooling

Test sustainable cooling

Ultimate MICE goal: operate full cooling channel



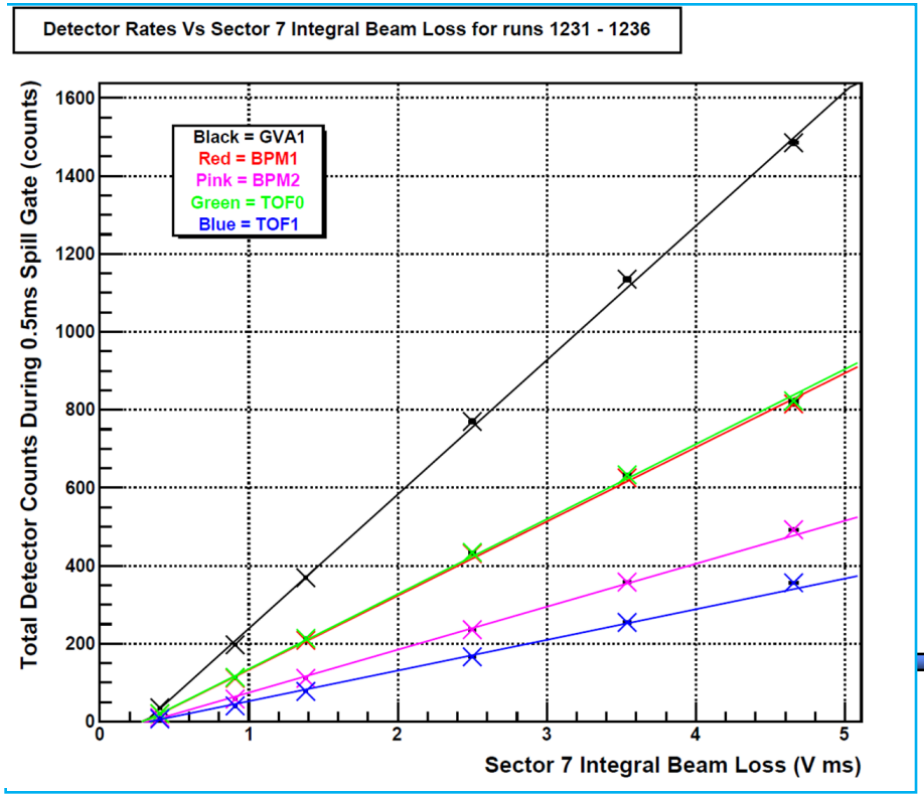
MICE Beam Line

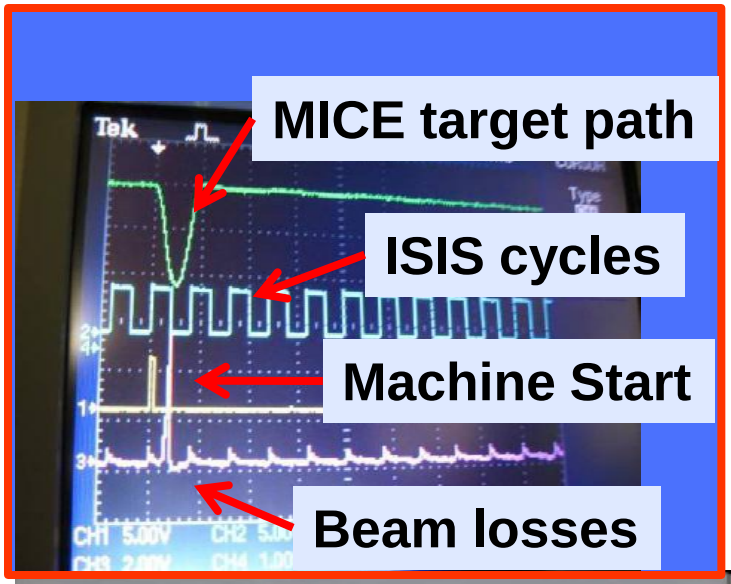


MICE Target

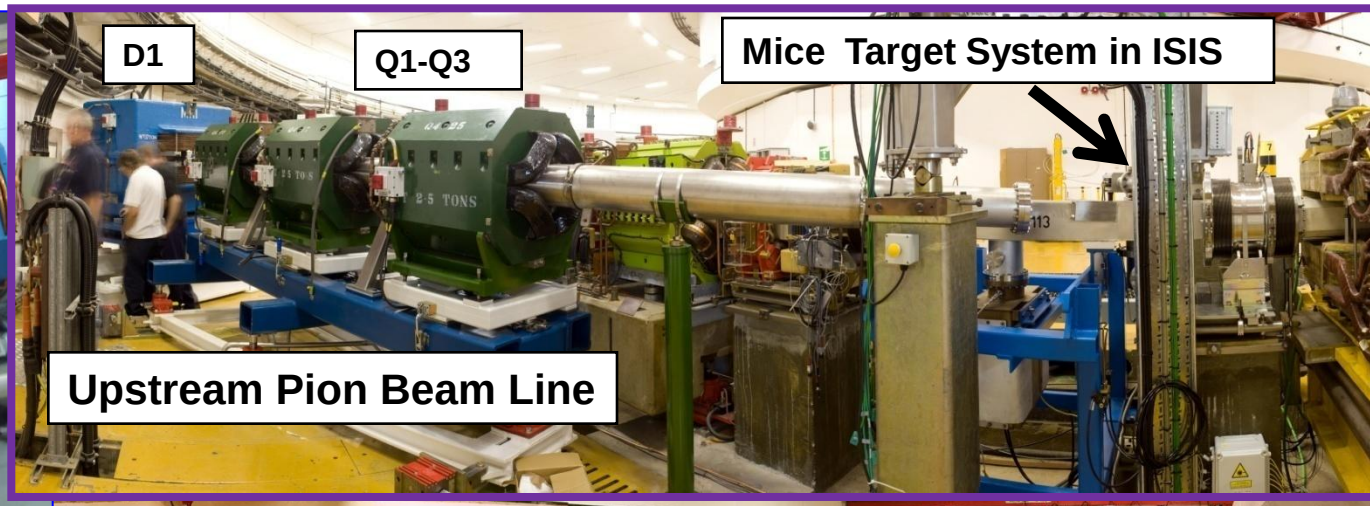
- New Target installed in 2009
- Running at 0.4 Hz
- Stable over 570,000 dips

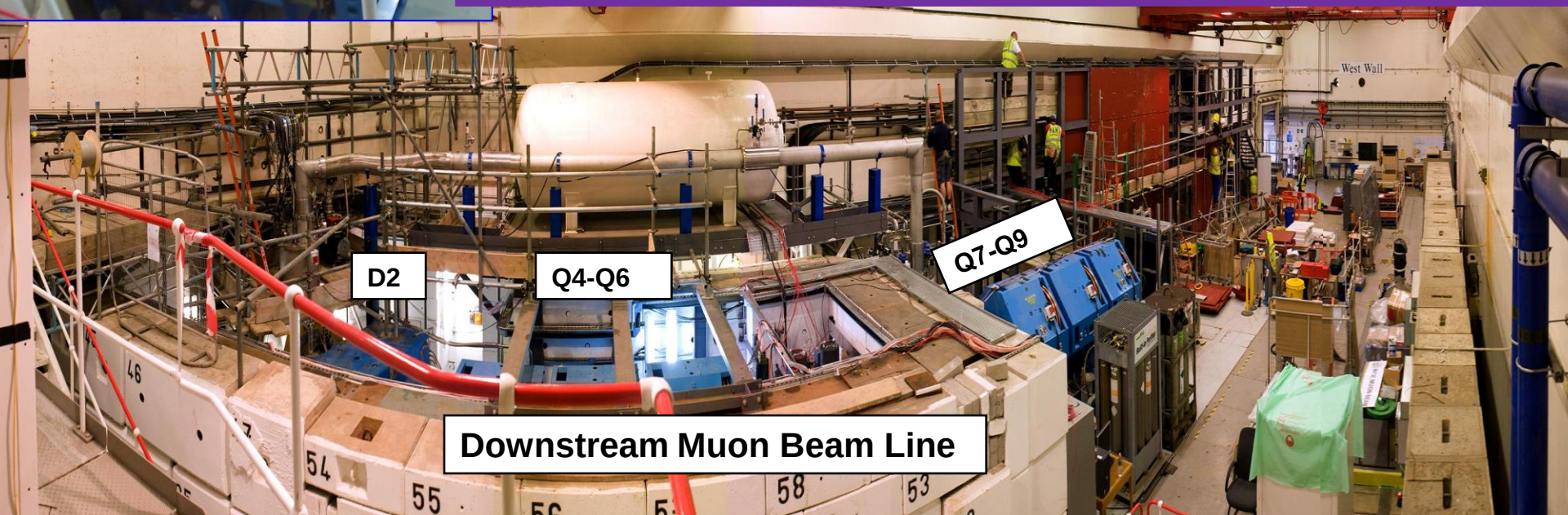
Rates VS Beam Losses in ISIS





The Beamline is Operational





PID Detectors

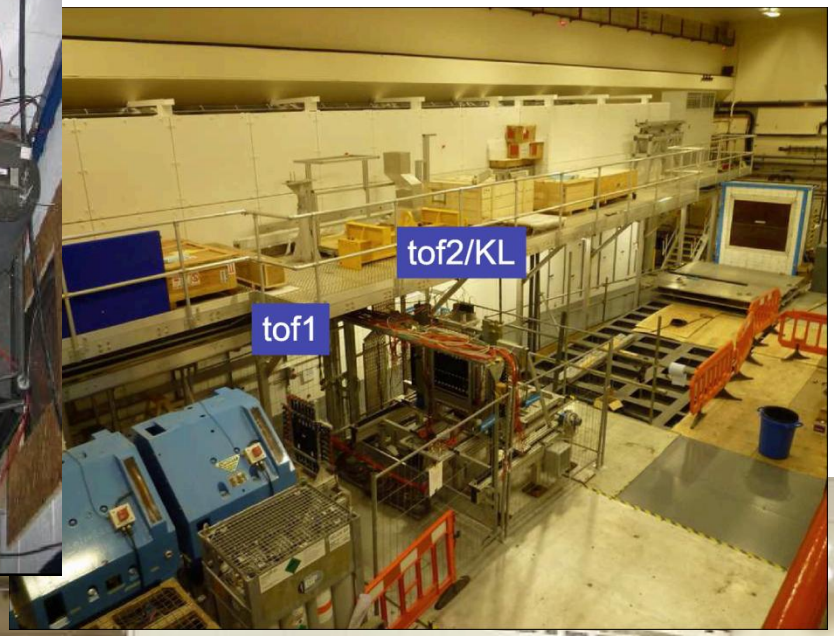
Three Time of Flight Stations

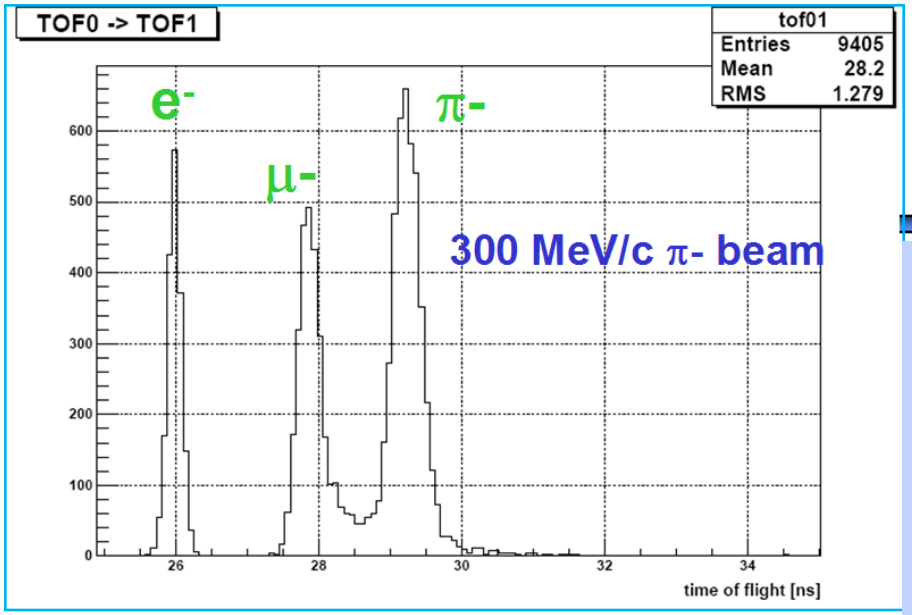
55 ps resolution

PID + Phase Space

Cherenkov Counters

EM-Cal (preshower)

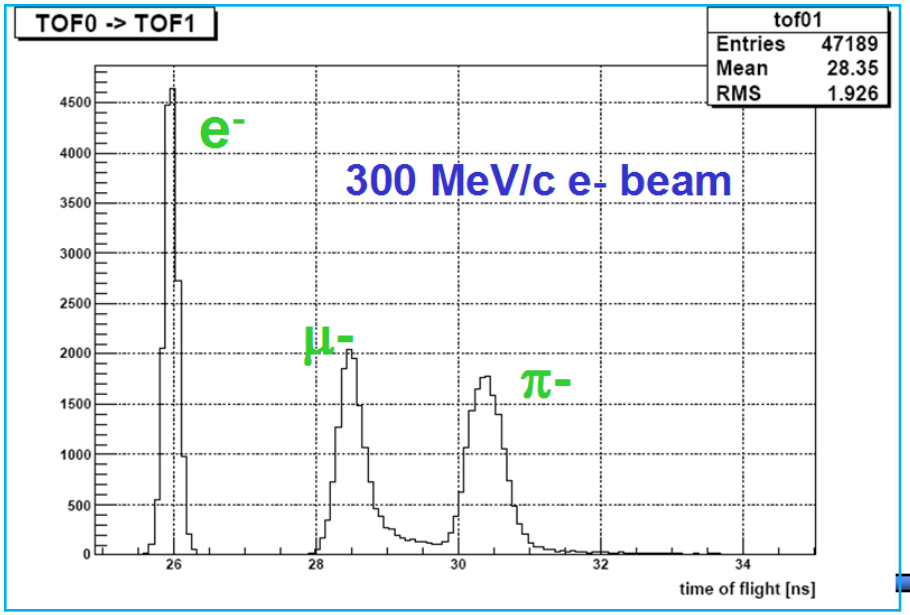


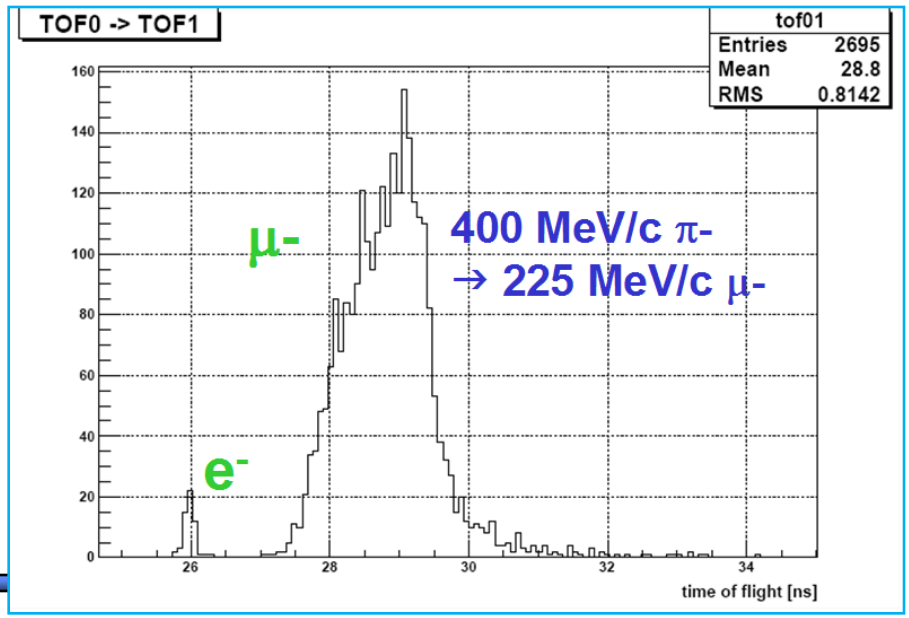


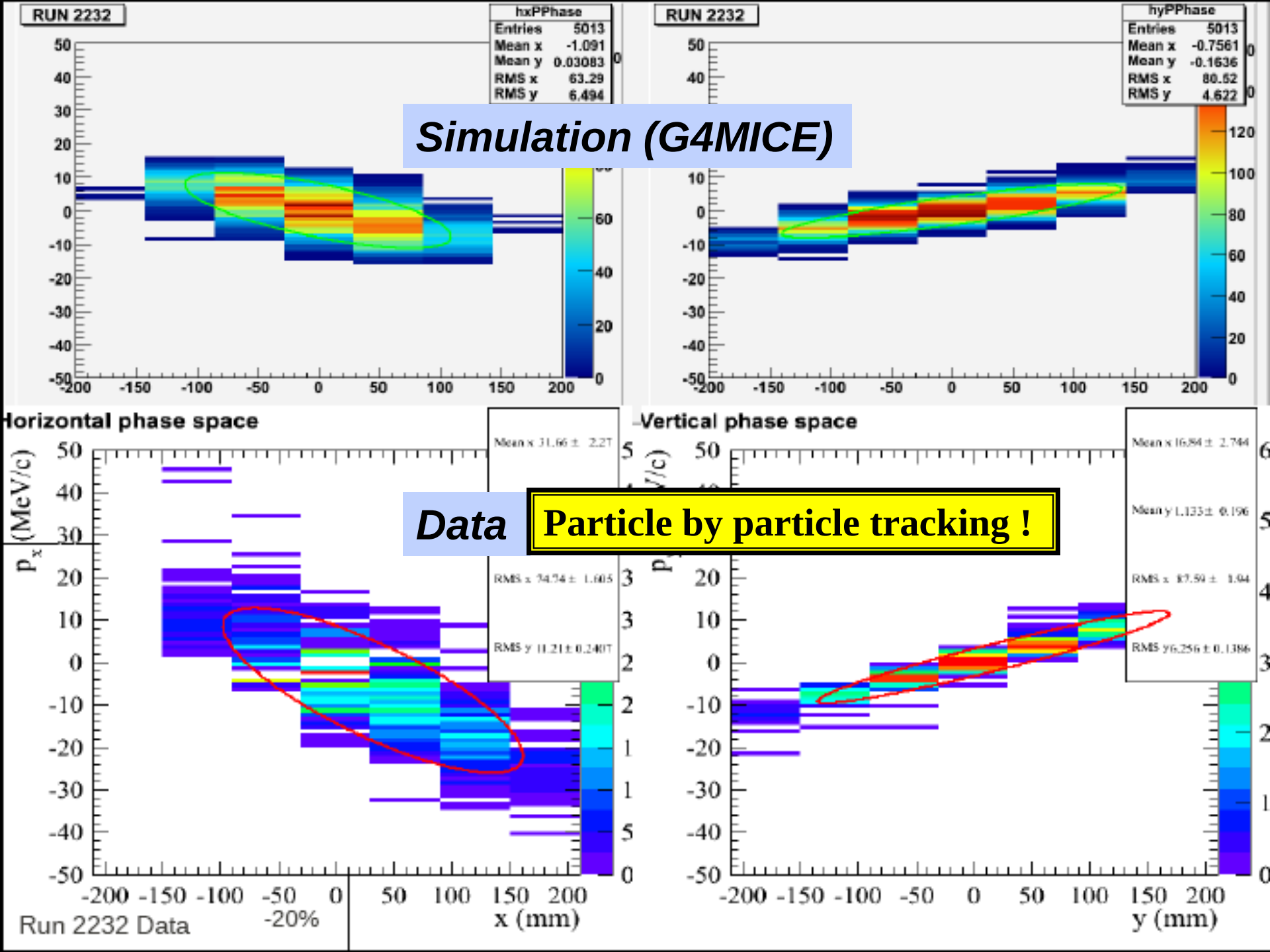
MICE has a Muon Beam !

Beam Studies in progress

All data on tape

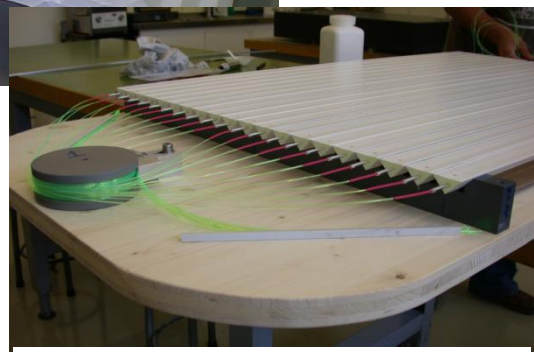


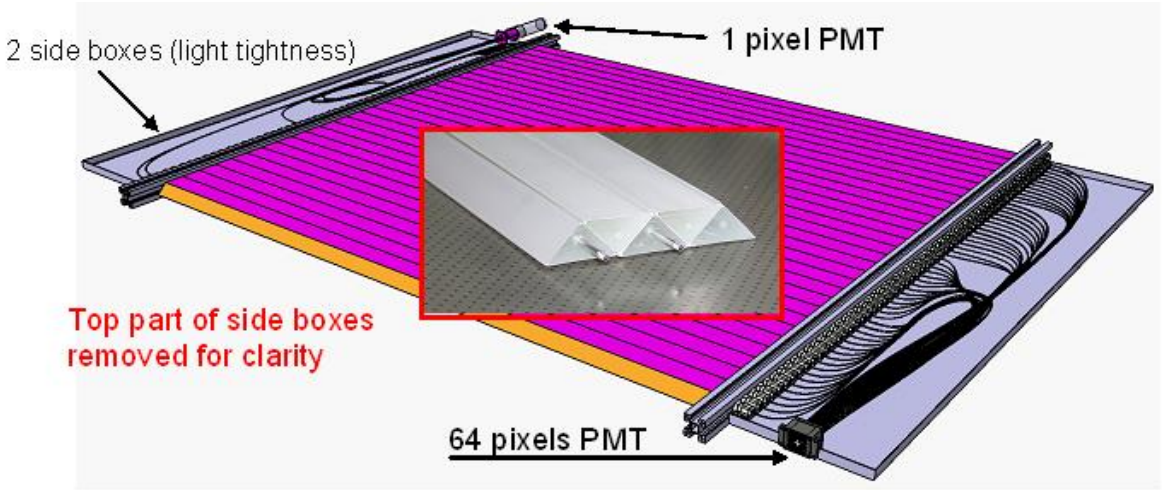



RUN 2232
hxPPhase
Entries 5013
Mean x -1.091
Mean y 0.03083
RMS x 63.29
RMS y 6.494
RUN 2232
hyPPhase
Entries 5013
Mean x -0.7561
Mean y -0.1636
RMS x 80.52
RMS y 4.622
Simulation (G4MICE)
Horizontal phase space
Vertical phase space
Data
Particle by particle tracking !
p_x (MeV/c)
x (mm)
y (mm)
Run 2232 Data
-20%

Electron Muon Ranger

- In construction in Geneva
- Conceptual Idea, Simulation, Design, Electronics and Construction
- In Collaboration with Como/Trieste for the front-end and readout electronics
- 3000 digital channels read out by Multi-Anode PMTs
- 48 layers with one common charge readout each
- Small scale Model of TASD



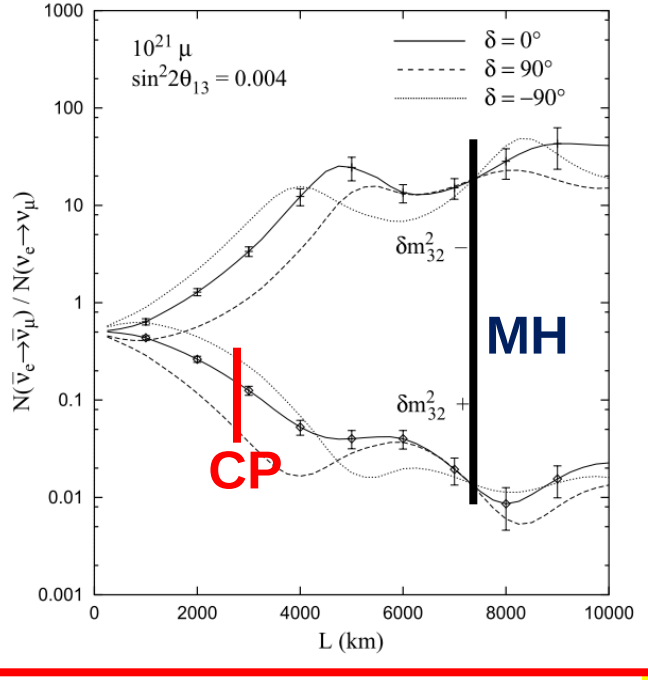


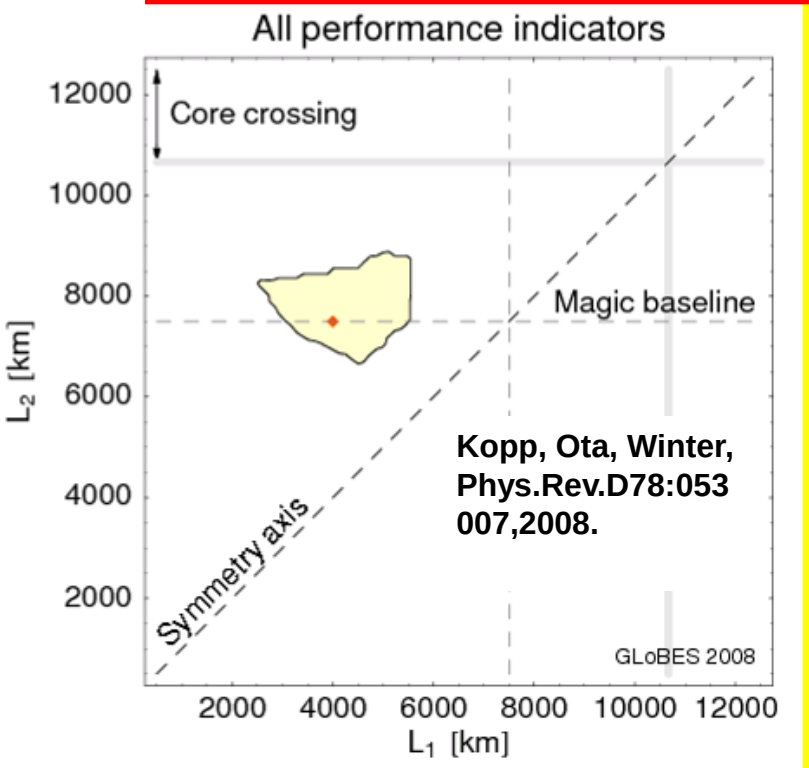
IDS-NF

- International Design Study for the Neutrino Factory (the IDS-NF) collaboration and the EUROnu collaboration
- Final Report due for 2012

NF-Detectors

- **Two detectors !**
  - At different baselines
  - Better than 1 larger detector at a single BL
- **Preferred combination !**
  - 2000—5000 km; good sensitivity to CP violation
  - 7000—8000 km; mass hierarchy, θ_{13}, degeneracy resolution





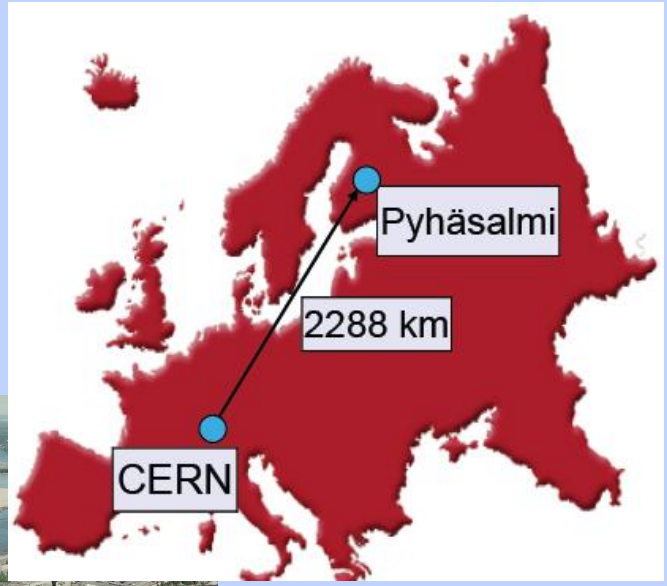
Possible Sites

- Let's assume the NF is built at CERN
- Possible sites

CERN – Phyasalmi, Finland

2285 km

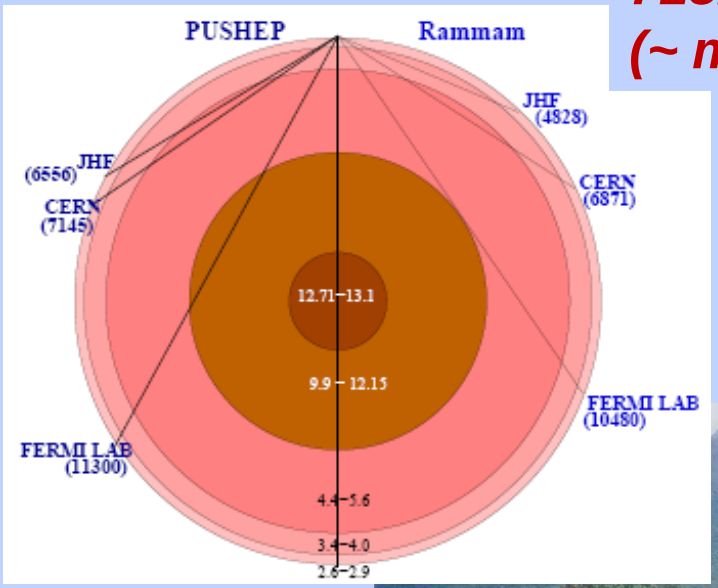
Studied under LAGUNA



Deep copper mine

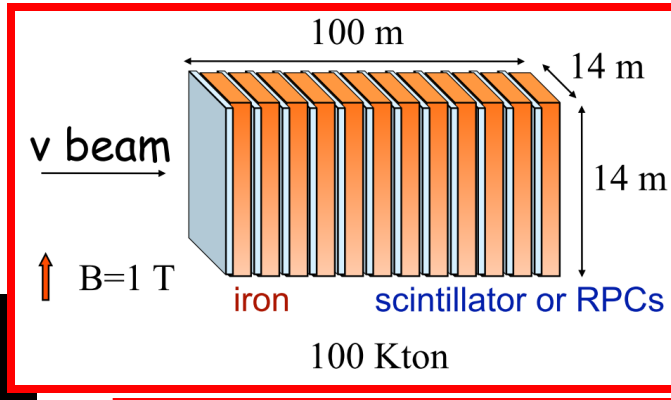
CERN – INO, India

7152 km (~ magic)

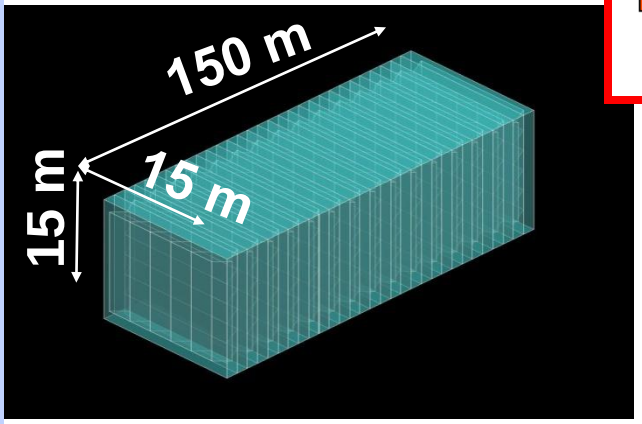


Possible Detectors

- **Detectors must be magnetised**
  - Best signature is « Wrong Sign Muon »



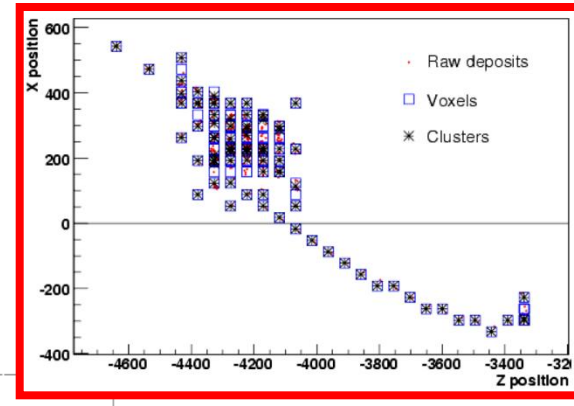
Magnetised Iron Detector (MIND)



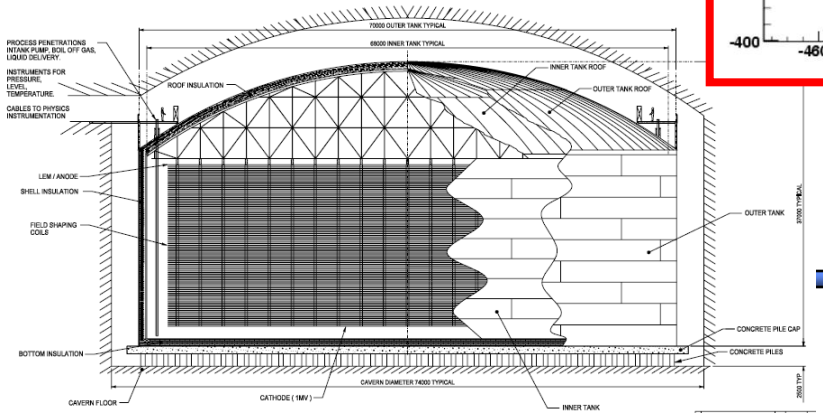
Active Scintillator Detector (TASD)

Similar to NOvA and …

… MICE Electron Muon Ranger

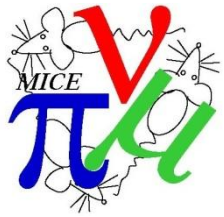


Magnetised Liquid Argon Detector



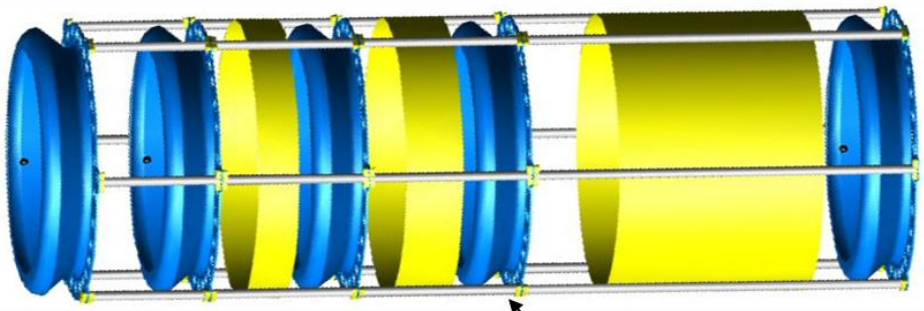
Summary

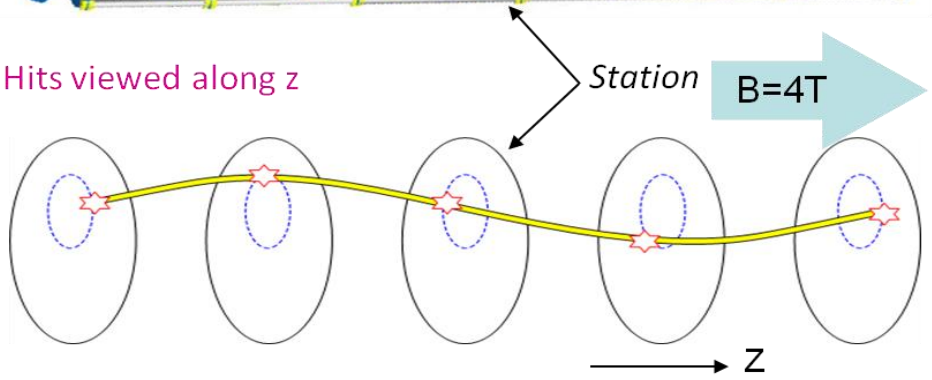
- The Neutrino Factory is the most powerful tool for precision neutrino physics
- MICE is a key R&D Step toward NF
- MICE has completed its first step
  - Detectors and Beamline Commissioning
- There is an IDS-NF in preparation
- CERN-Phyasalmi and CERN-INO combination looks attractive


MICE

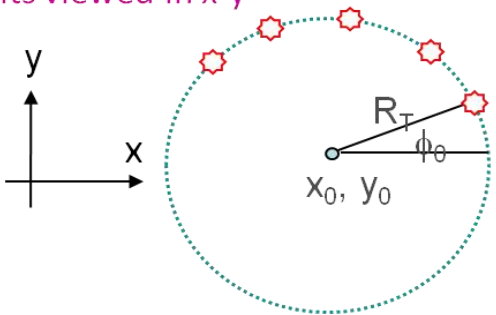
Next Step: Spectrometer

SciFi Tracker (w/o light-guides)





Hits viewed in x-y



$$x_i = x_0 + R_T \cos[z_i/R_L + \phi_0]$$
$$y_i = y_0 + R_T \sin[z_i/R_L + \phi_0]$$
$$R_T = p_T/(0.3B)$$
$$R_L = p_L/(0.3B)$$

Construction problems with the superconduction solenoids

Tracker Ready, tested with cosmics

Installation delayed to spring 2011

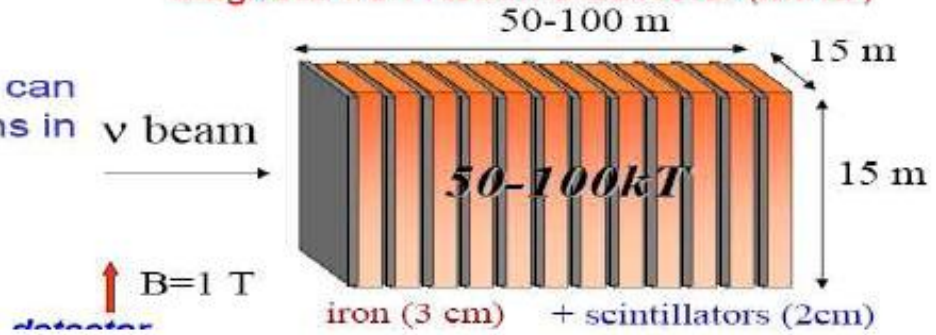
R&D for Neutrino Factory Baseline Detector

Magnetic Solid Sci Detectors for **wrong sign μ**

Magnetised Iron Neutrino Detector (MIND)

- Golden channel signature: "wrong-sign" muons in magnetised calorimeter
  (Cervera et al. 2000)
- Far detector (2000-7600 km) can search for "wrong-sign" muons in appearance mode

Magnetic Iron Neutrino Detector (MIND)

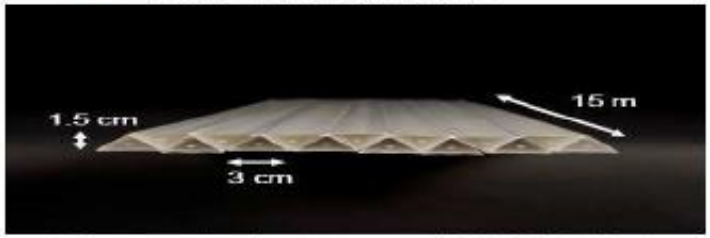


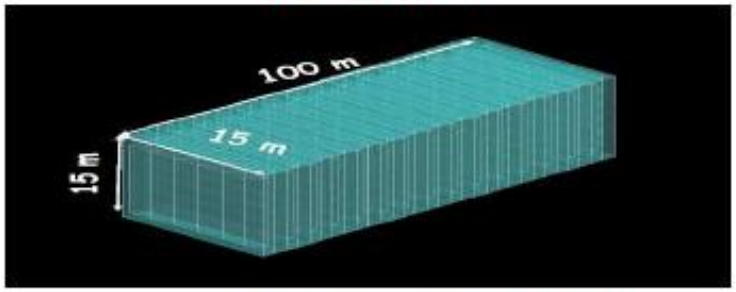
Totally Active Scintillating Detectors (TASD)

Possible improvement: Totally Active Scintillating Detector (TASD) using Nova and Minerva concepts

- 3333 Modules (X and Y plane)
- Each plane contains 1000 slabs
- Total: 6.7M channels

Ellis, Bross





- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

Reduction threshold: access second oscillation maximum and electron identification

15