The International Muon Ionization Cooling Experiment

MICE

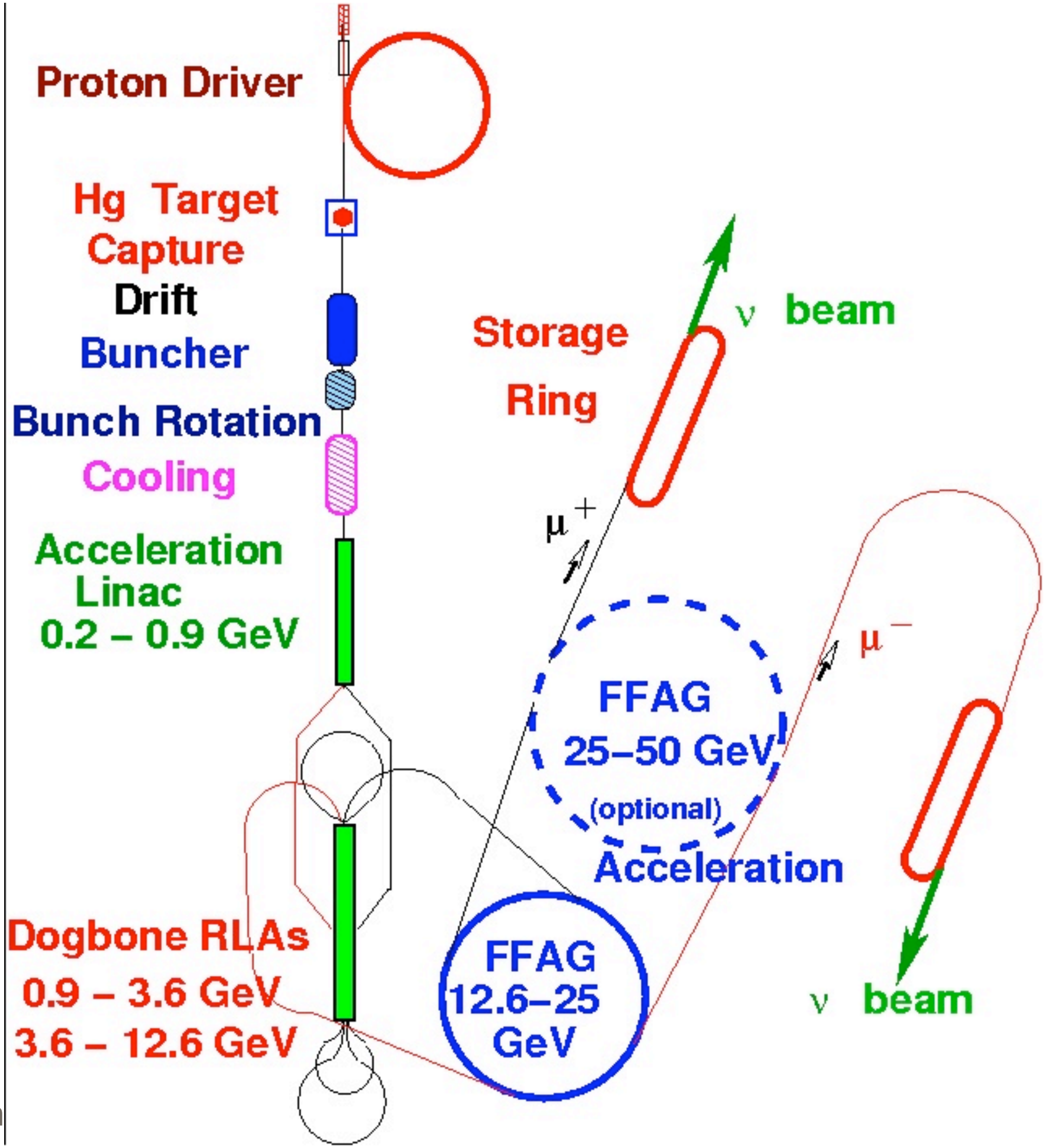
1. Why, what and who?

2. MICE status and schedule

3. Conclusions

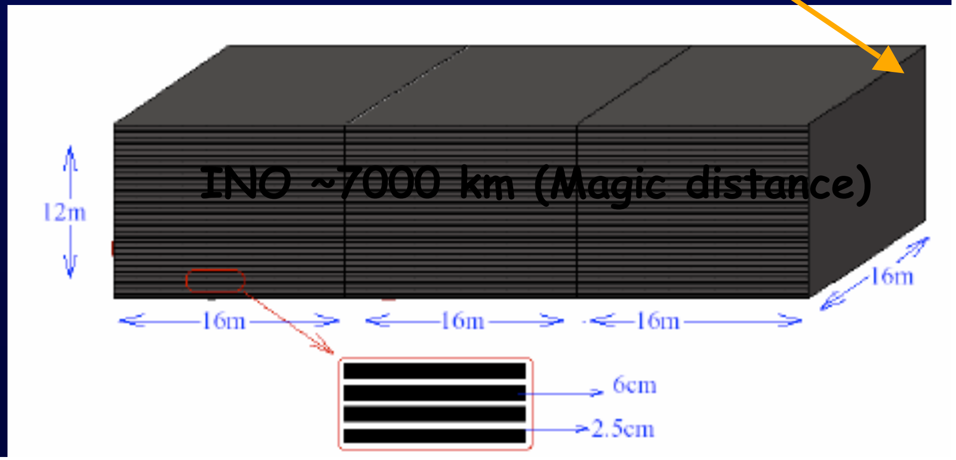
Collaboration life can be explored here:
http://mice.iit.edu

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



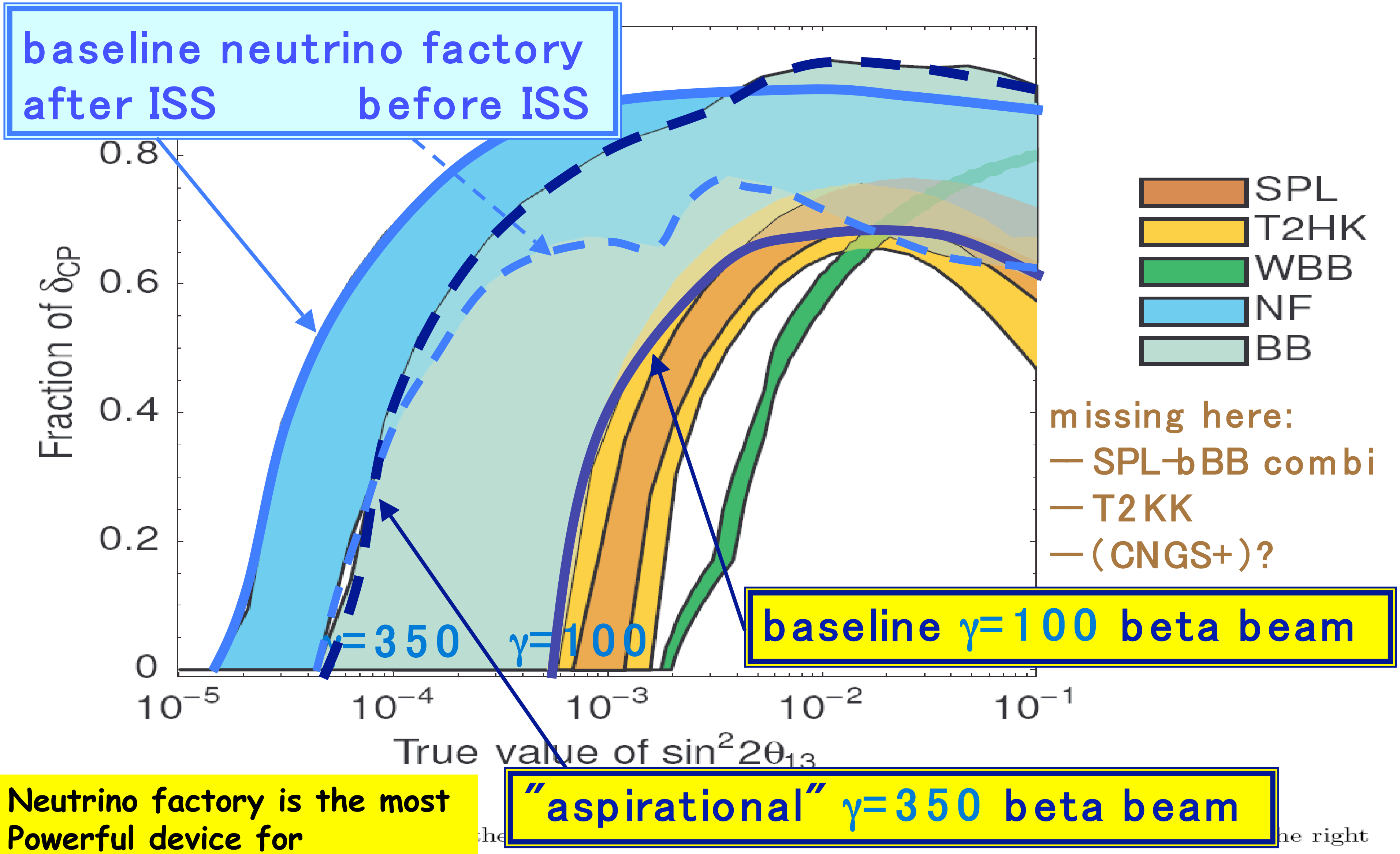
We do MICE because
we want to explore neutrino factory
or muon collider
as an option for the future.
Feasibility, cost

Long baseline detectors: Magnetized Iron, emulsions, liquid argon



INO ~7000 km (Magic distance)

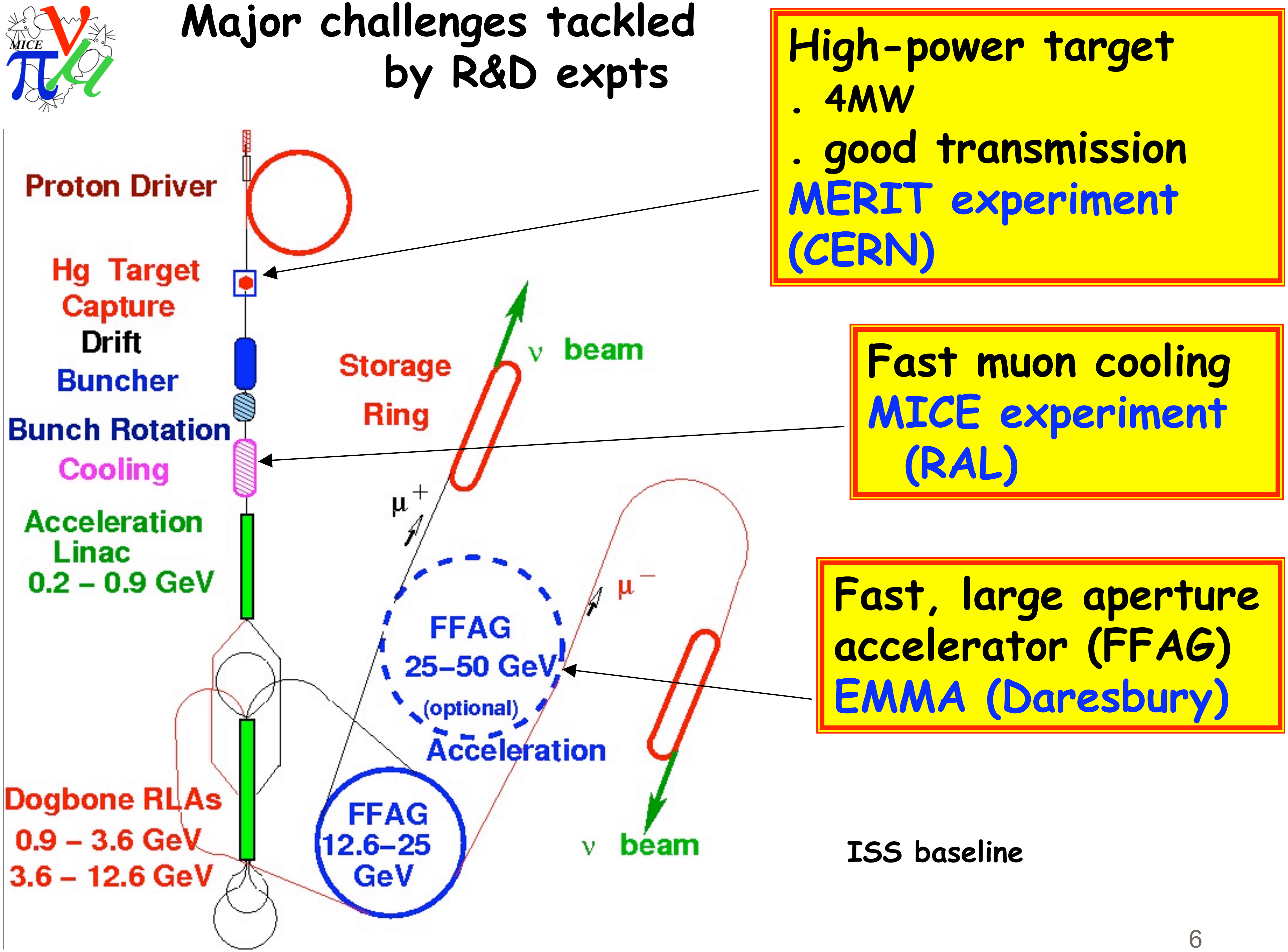
el



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.

Major challenges tackled by R&D expts



ISS baseline

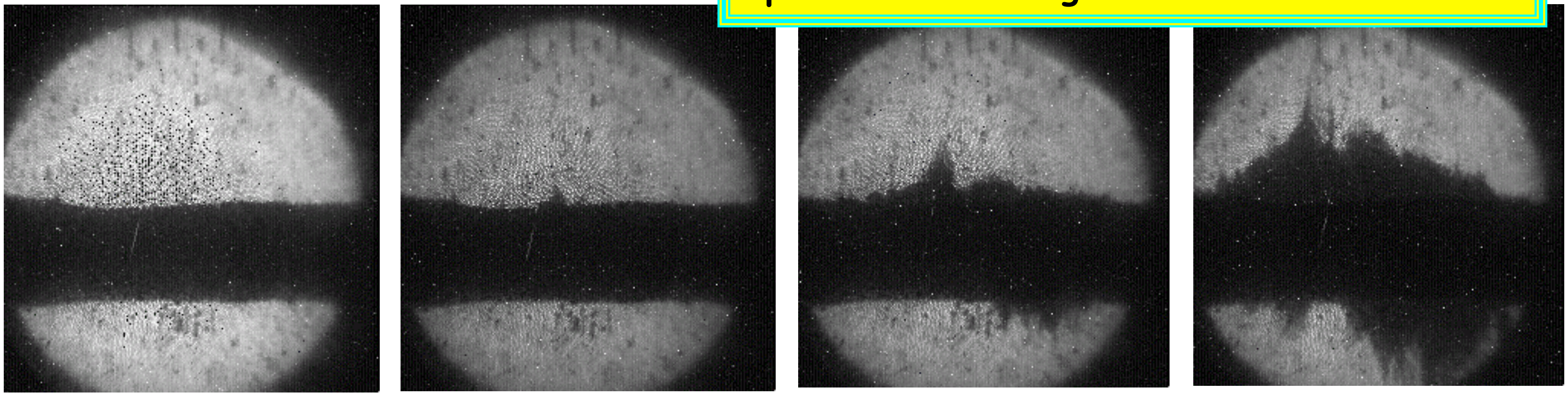
MERIT EXPERIMENT at CERN

BNL, MIT, ORNL, Princeton University CERN, RAL

Splash velocity
– 24 GeV beam

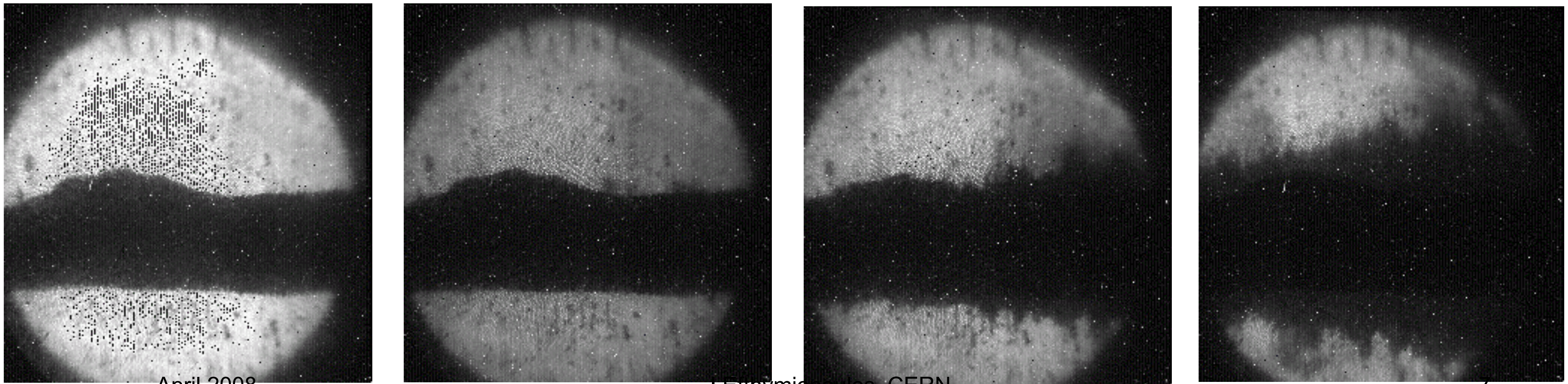
Demonstrated liquid mercury jet technology for neutrino factory and muon collider up to 8MW on target *Oct22-Nov12 2007*

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



t=0 *t=0.075 ms* *t=0.175 ms* *t=0.375 ms*

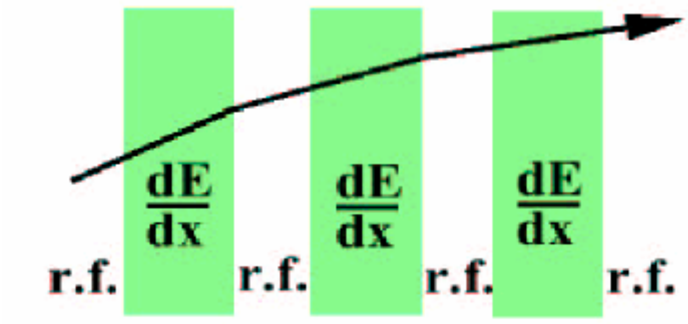
20TP, 15T *V = 65 m/s*



t=0 *t=0.050 ms* *t=0.175 ms* *t=0.375 ms*

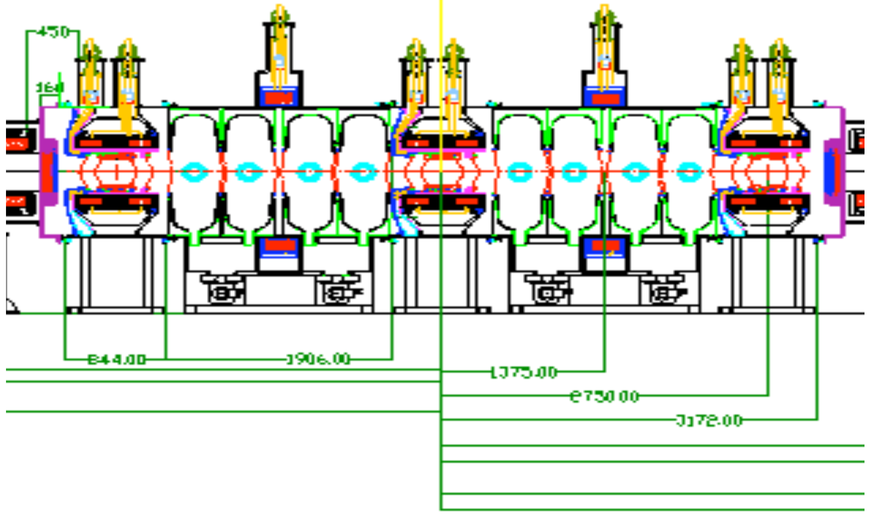
IONIZATION COOLING

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

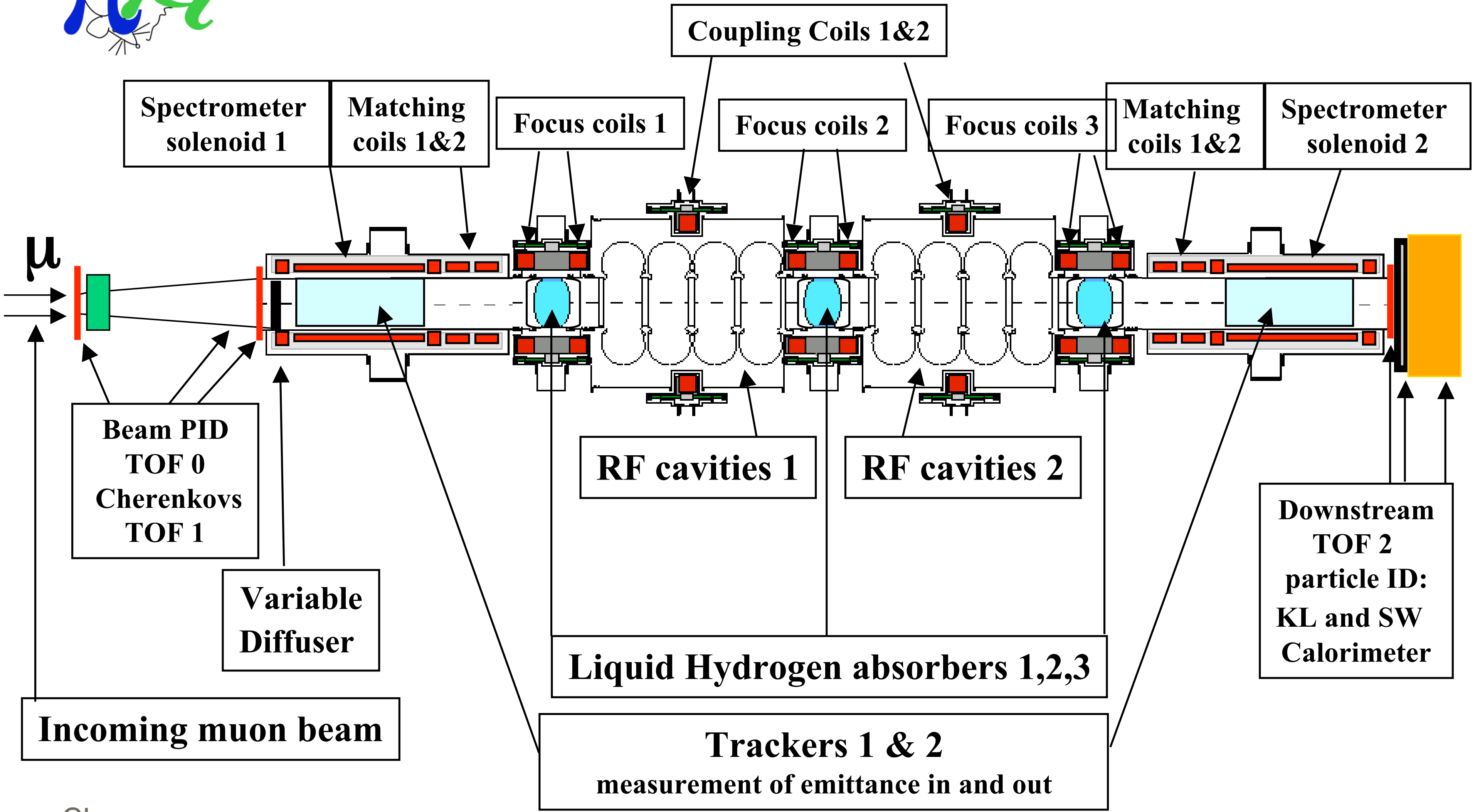
state-of-the-art particle physics instrumentation will test state-of-the-art accelerator technology.

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



Cl

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

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

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

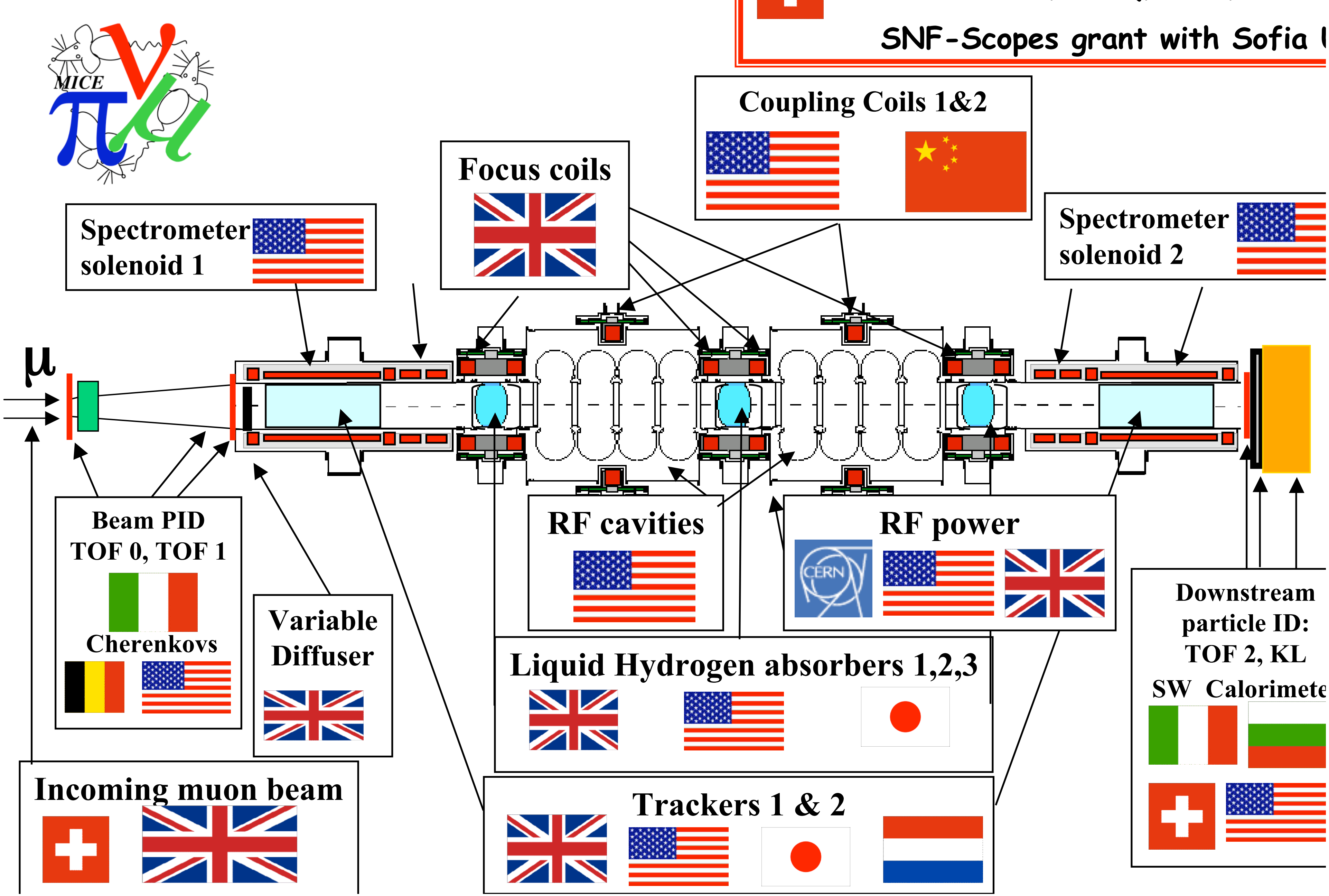
Evaluate emittance with:

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

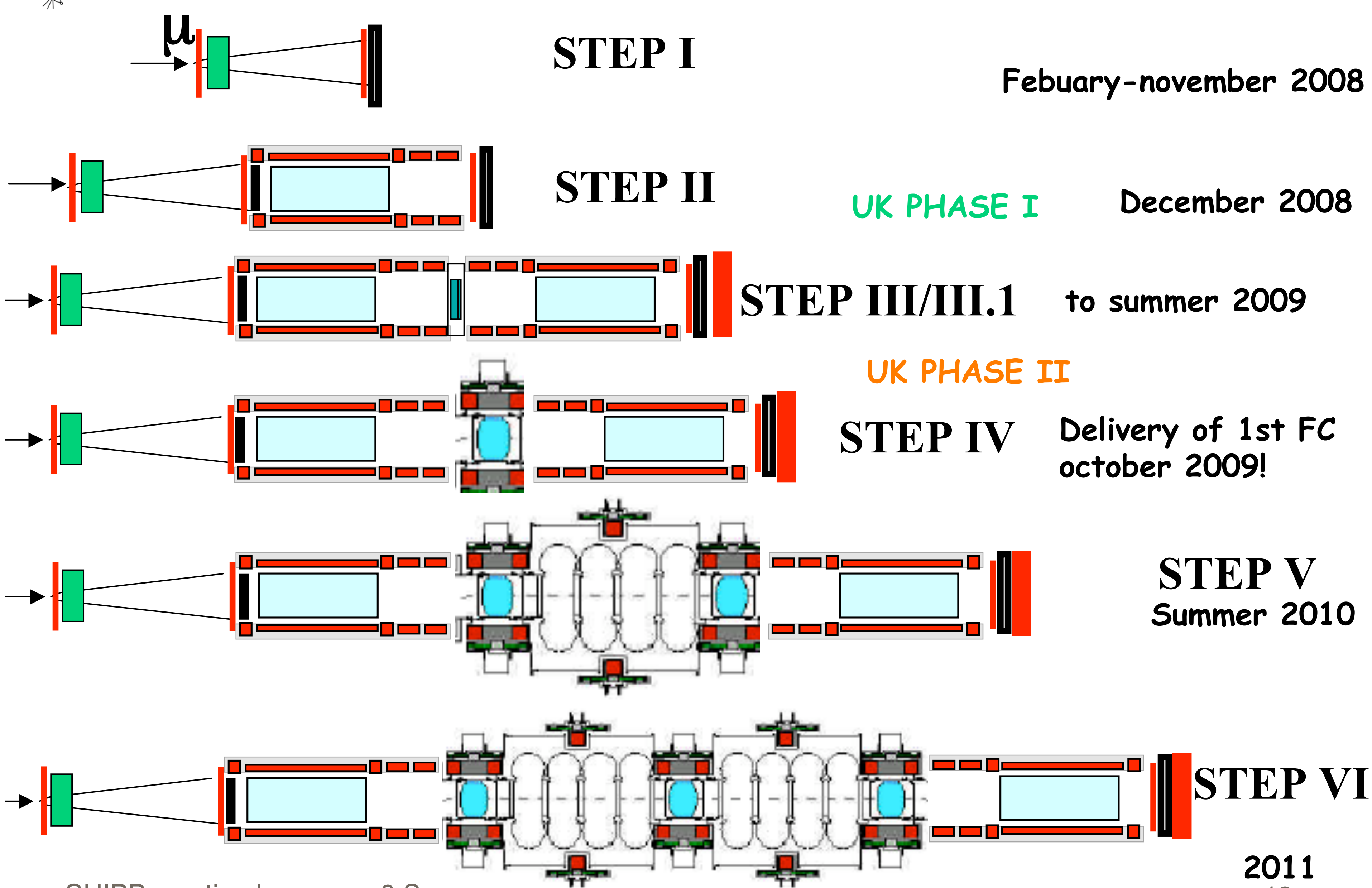
$$\varepsilon^{4D} = \sqrt{\det(M_{xyx'y'})} = \varepsilon_\perp^2$$

Compare ε^{in} with ε^{out}

MICE Collaboration across the planet



Aspirational MICE Schedule



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.

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

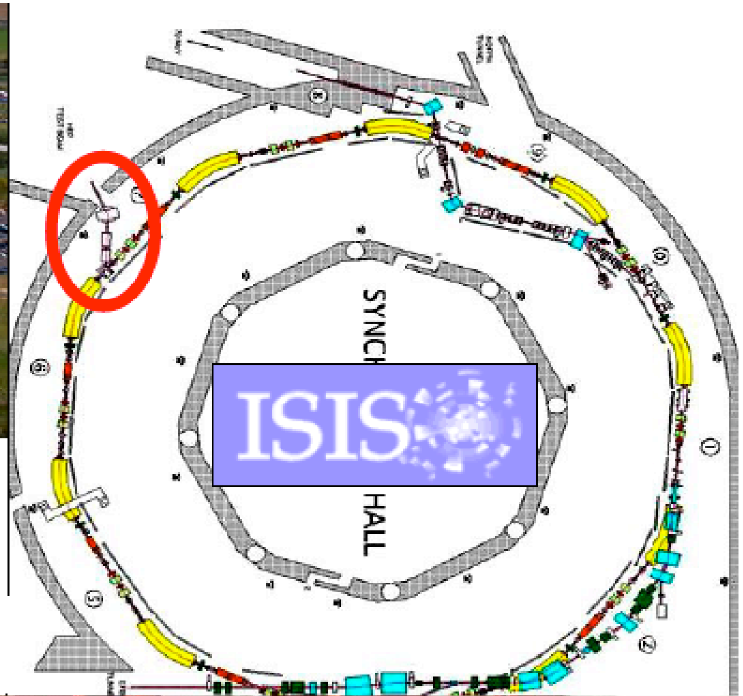
2. Hydrogen safety (substantial amounts of LH_2 in vicinity of RF cavities)

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

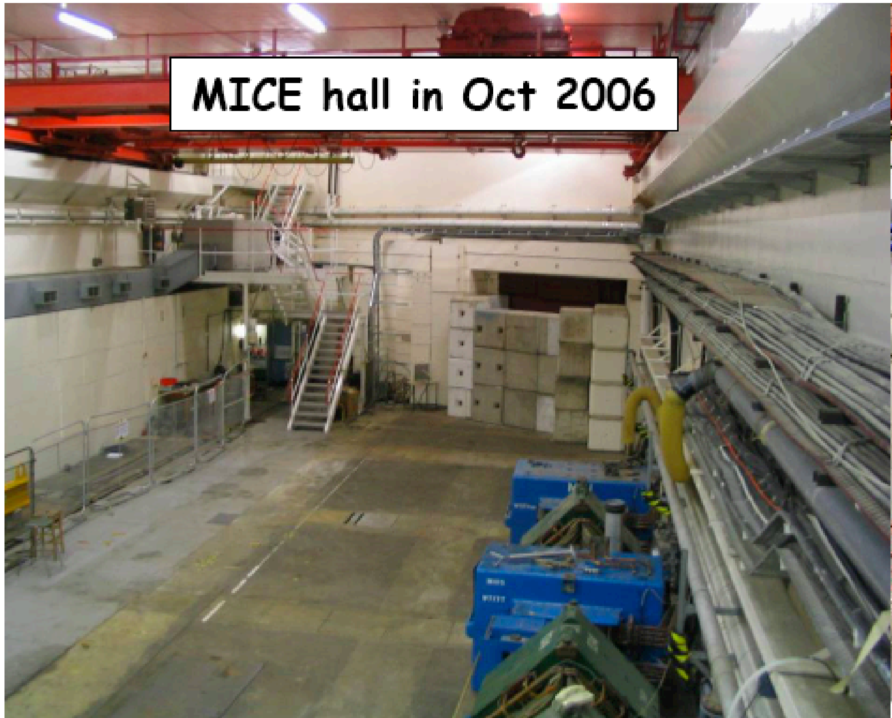
and…

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


ISIS
MICE Hall
R5.2



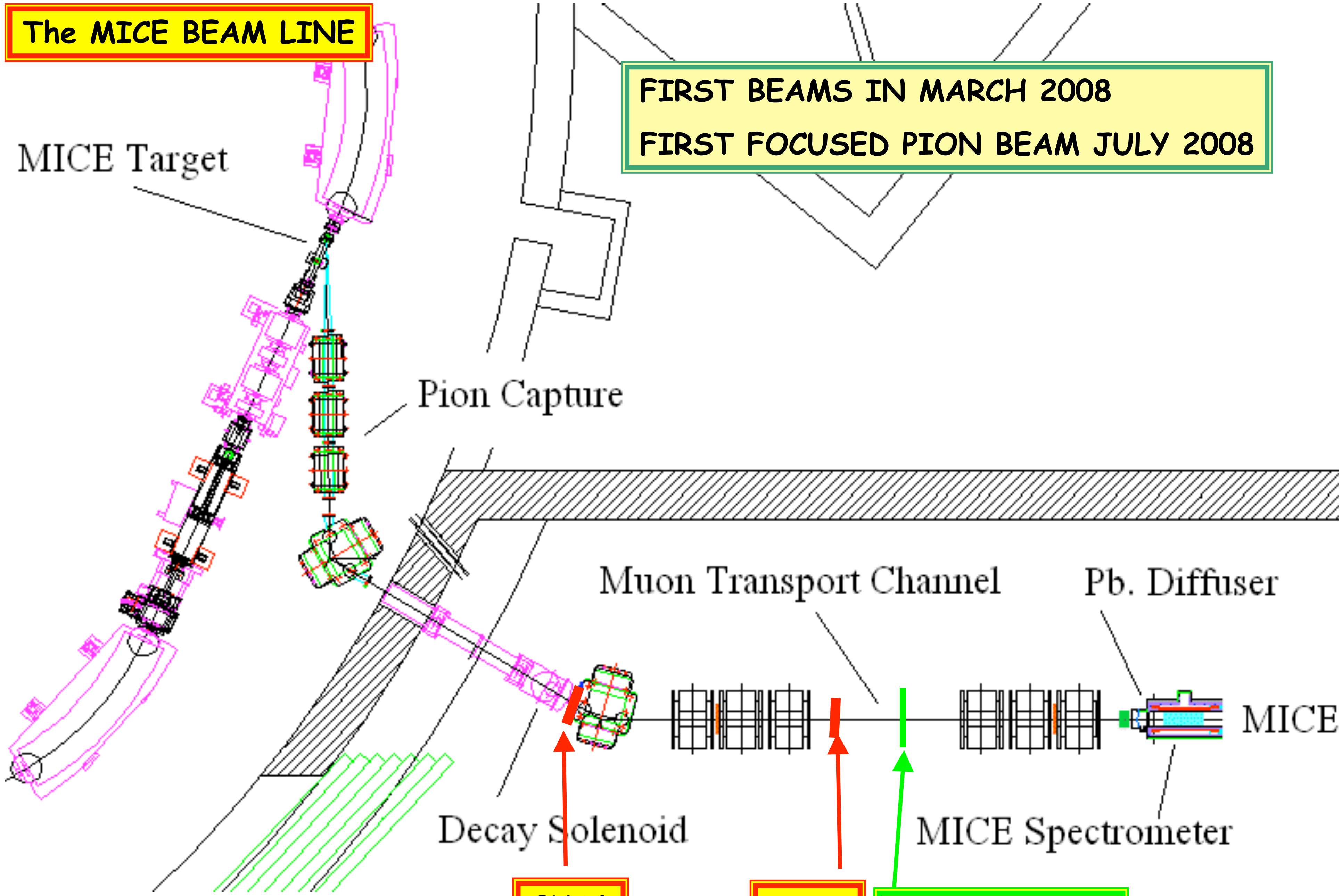
- **MICE is hosted at Rutherford Appleton Laboratory, UK**
  - Brand new muon beam line in construction
  - Built from scratch



The MICE BEAM LINE

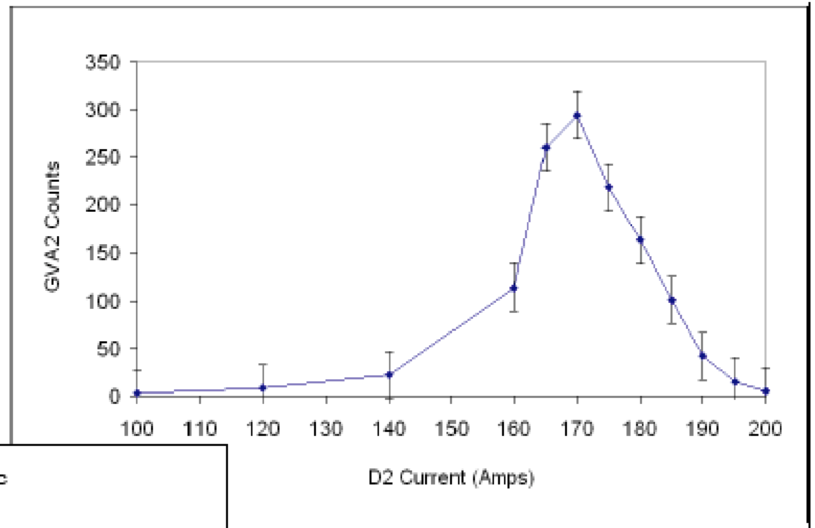
FIRST BEAMS IN MARCH 2008

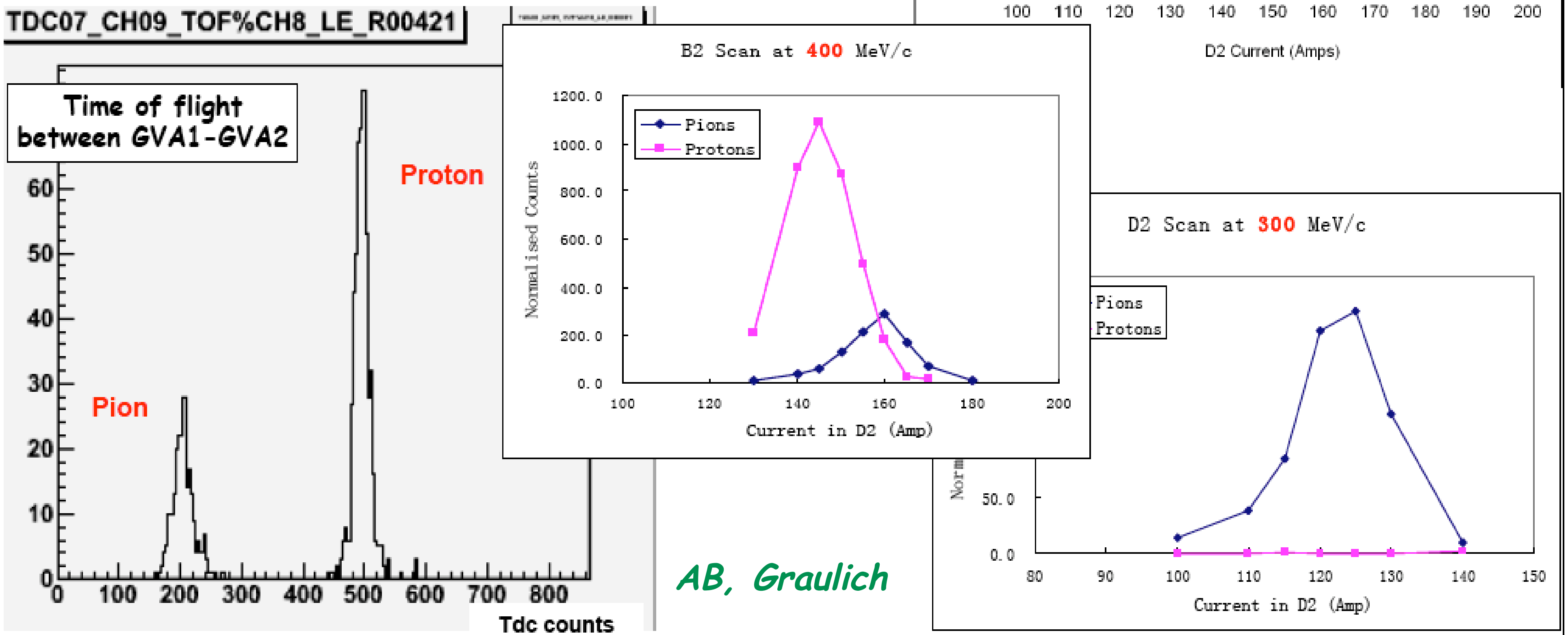
FIRST FOCUSED PION BEAM JULY 2008



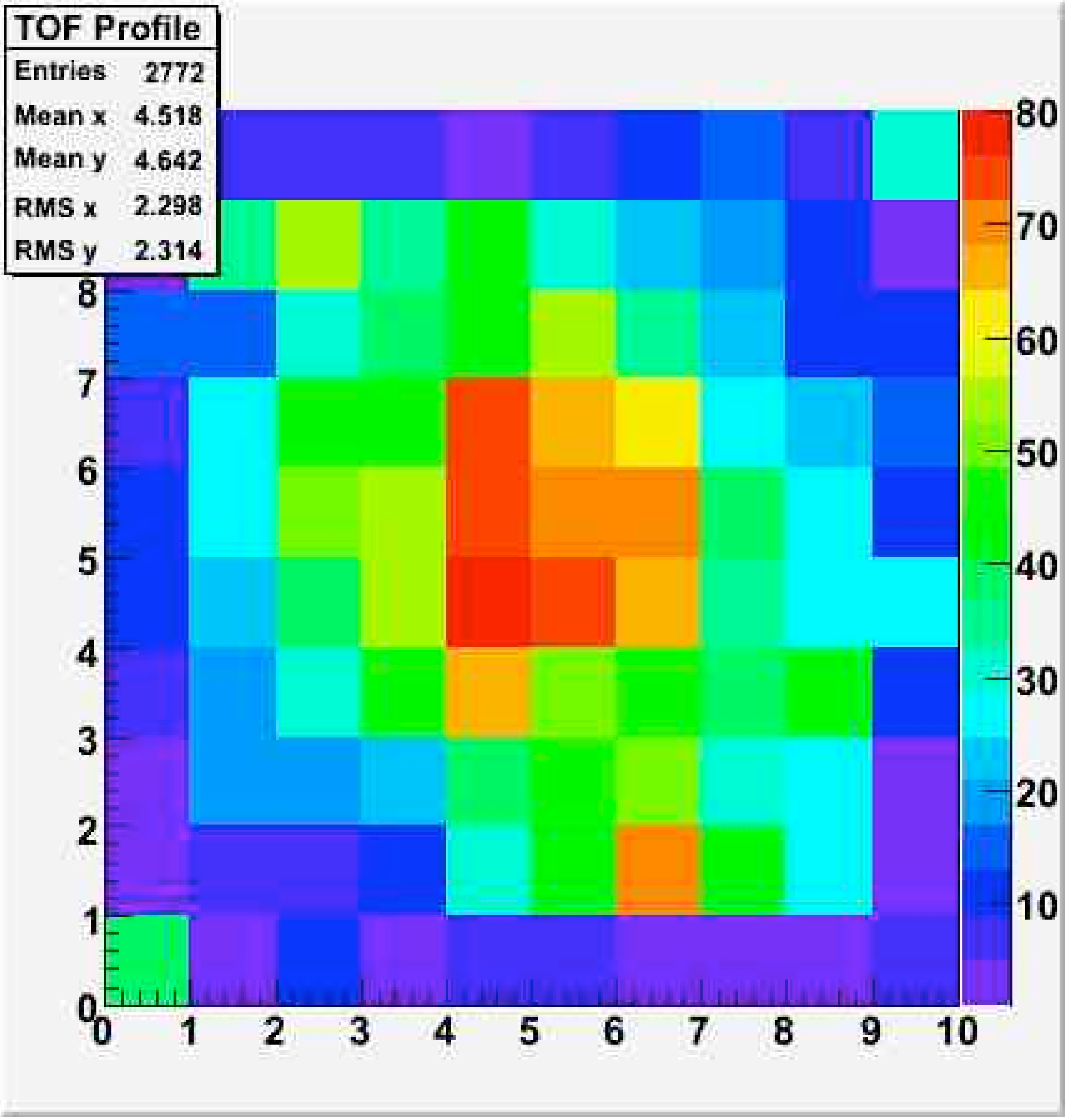
Beam tuning still going on:

- The dipoles behave like expected
- We can separate pions from protons using time of flight between GVA1 and GVA2
- Protons and pions have different momenta when they reach D2
  - Different dE/dX
- Protons at 300 MeV/c are stopped before GVA2





AB, Graulich



Beam after Q6

With all quads on.

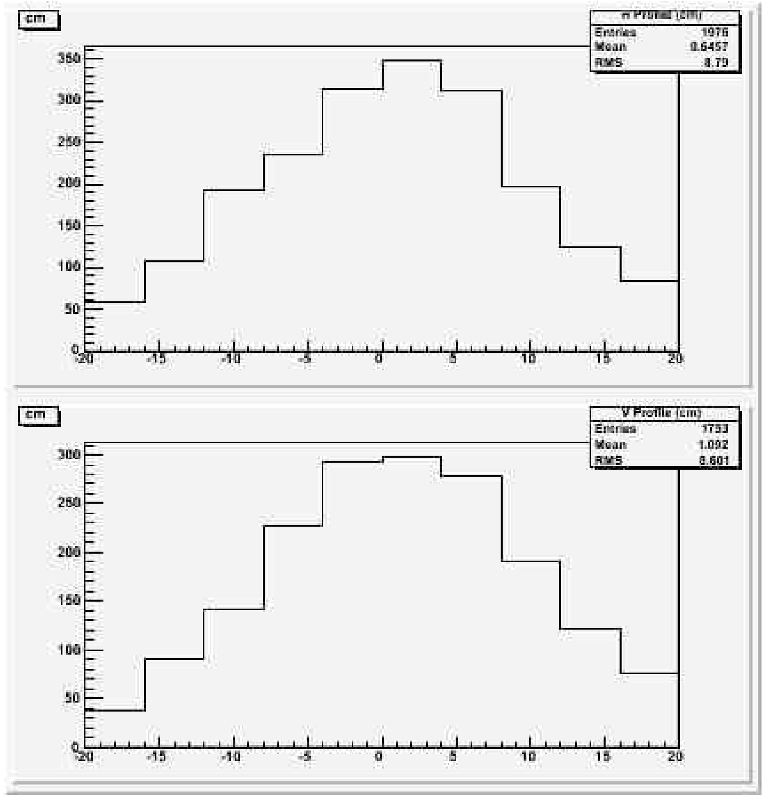
350 MeV/c

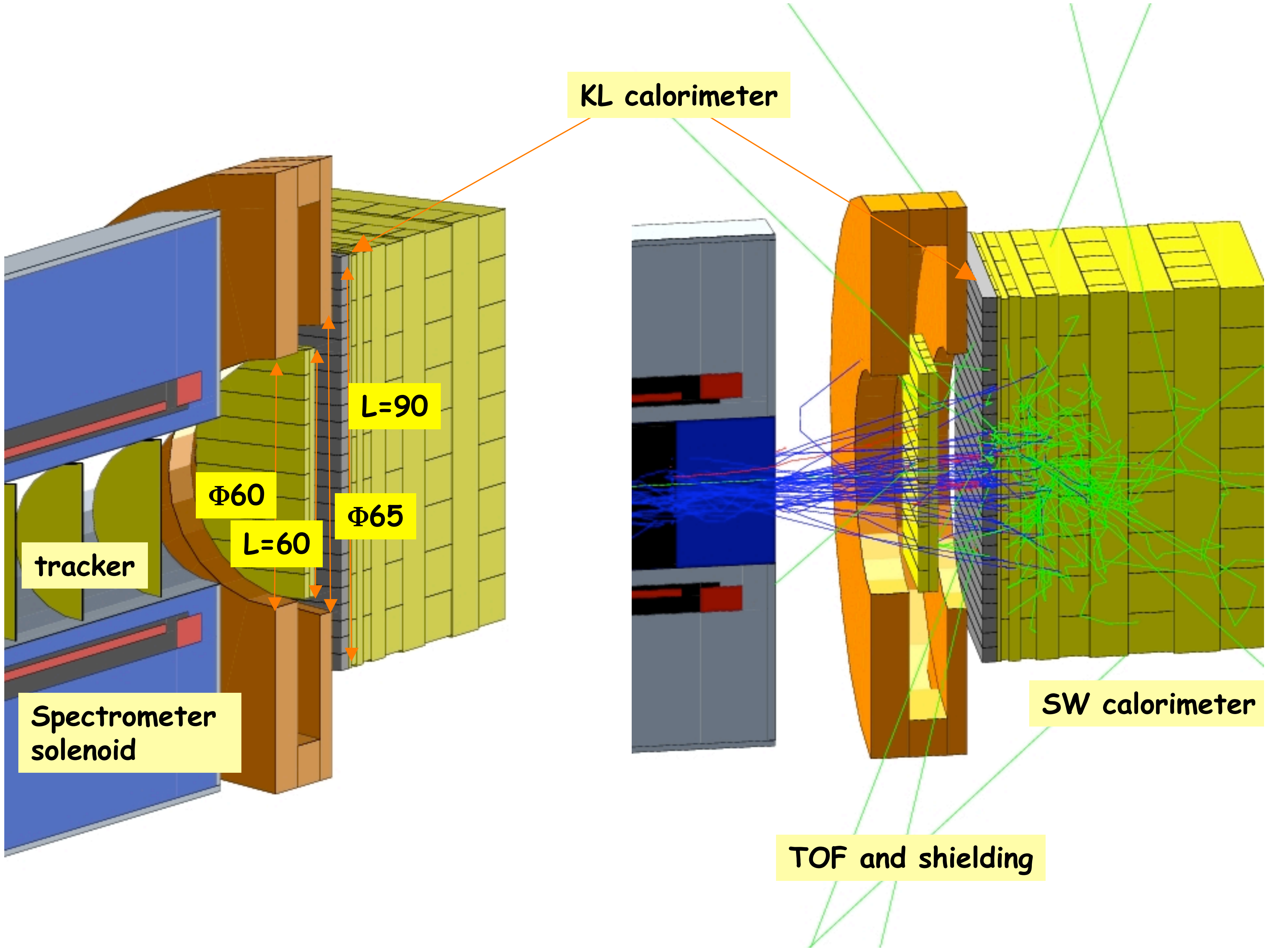
<-- 2D profile

x and y profiles

!

V





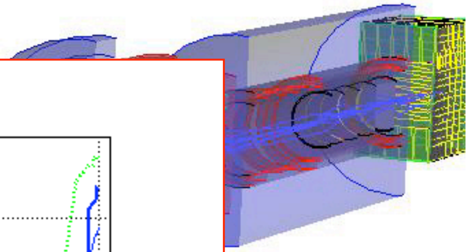
KL calorimeter
L=90
Φ60
Φ65
L=60
tracker
Spectrometer
solenoid
SW calorimeter
TOF and shielding

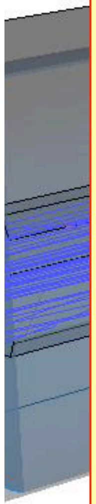
software, analysis & DATA Challenge

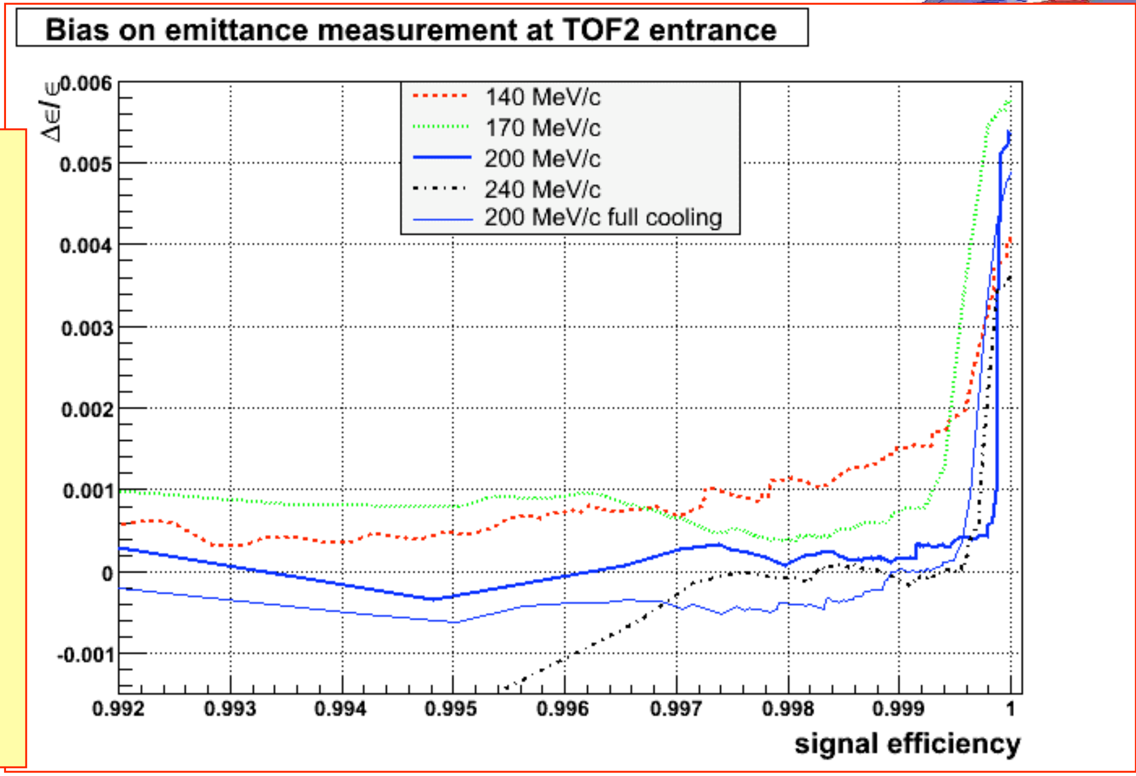
1. Basic simulation and reconstruction of MICE is complete for the various steps
Both G4MICE and MUCOOL are used.

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

R. Sandström







Example →
Bias on emittance
due to muon decays
Would be ~0.5%
(i.e. 5% error
on cooling meast)
Reduced to <<0.1%
by PID+ tracker
This uses
tracker & TOF info
and PID signals
+Neural Network

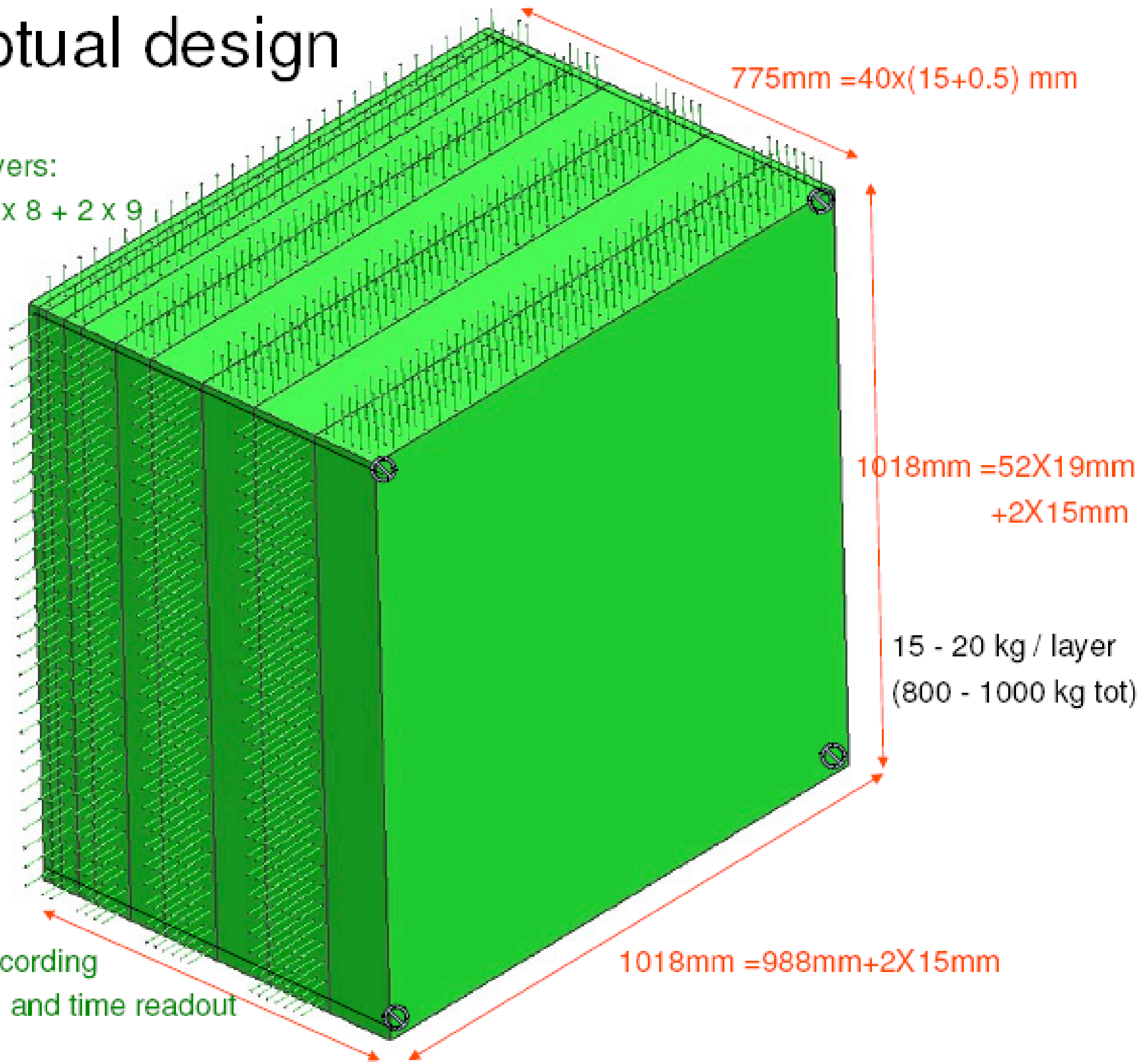
SW calorimeter

Conceptual design

50 planes in
10 variable thickness layers:
2 x 1 + 2 x 2 + 2 x 5 + 2 x 8 + 2 x 9

Lateral segmentation
according to rate!

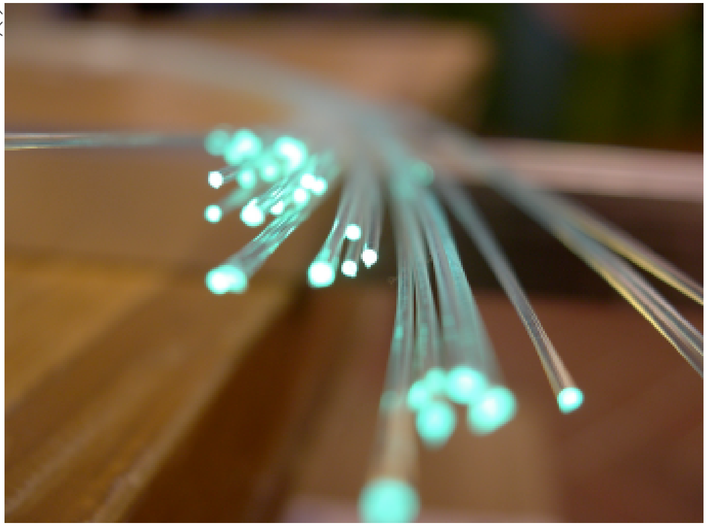
Time measurements
MAY help with
coordinate
reconstruction.

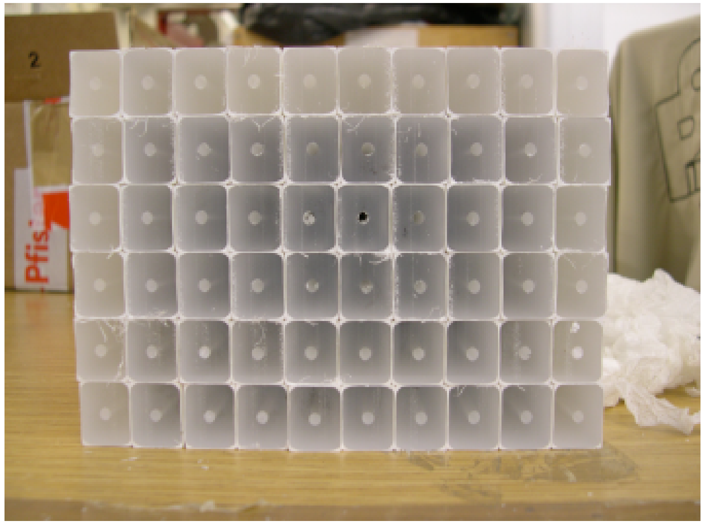


15 - 20 kg / layer
(800 - 1000 kg tot)

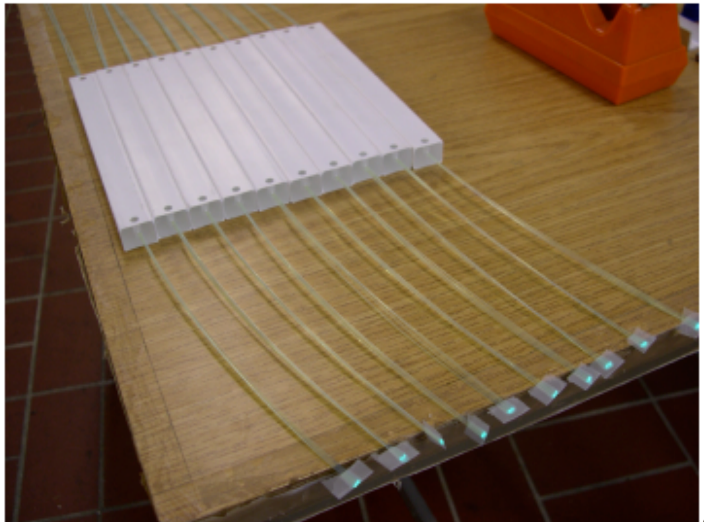
Flexible fiber bundling
Number of channels according
to lateral segmentation and time readout

Graulich, Sandström

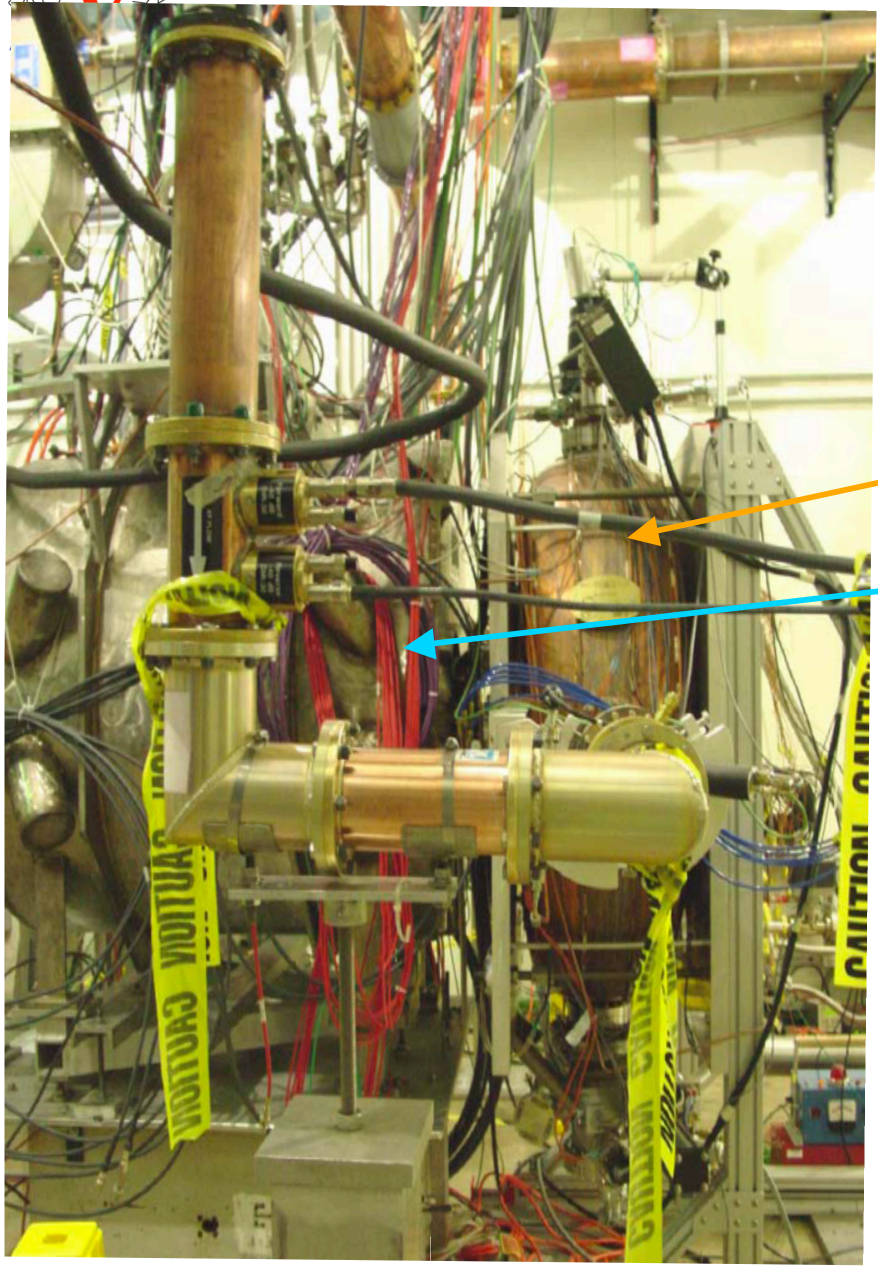




Extrusion provided by Fermilab and mechanical assembly, gluing etc. at INFN Trieste
Electronics and DAQ in Geneva estimated cost 120kCHF



Essential for full precision (10^{-3}) of the experiment over full momentum range



The crucial technological issue:

Field emission by RF cavities in mag. field.

Tests at Fermilab.
Simulations R. Sandstroem GVA

201 MHz RF cavity (MICE prototype)

SC magnet --> 0.5 T at RF cavity

Cavity reaches 19 MV/m at B=0
without break downs

So far no evidence for strong field emission
with 0.5 T.
Next year:
3 T MICE magnet around cavity

CONCLUSIONS

MICE is a collaboration of accelerator and experimental physicists aiming at
demonstration of a new accelerator technique
Ionization cooling
Essential for neutrino factory and muon collider

MICE is now a running experiment! (UNIGE is heavily involved)

STEP I, Beam commissionning and characterization, ongoing (PSI solenoid !)

STEPS II and III, precision (10^{-3}) measurement of emittance in 2009

STEPS IV and V, first cooling measurements, in 2010

STEP VI, the final measurements, in 2011

In time for 2012 and the major decisions for the future of particle physics
After first results from LHC, D-Chooz, T2K….

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:

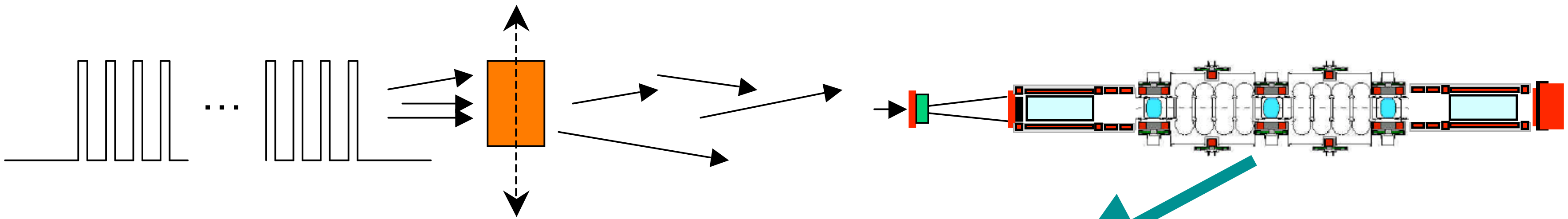
A. with the existing MICE hardware to test optics beyond the neutrino Factory study II:
non flip optics,
low-beta optics (down to 5 cm vs 42 cm nominal)
other absorber materials He, Li, LiH, etc..
LN2 cooled RF cavities

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

MICE DAQ & Trigger

Gva, Sofia, UK, IIT, Osaka

data rate ~1MHz

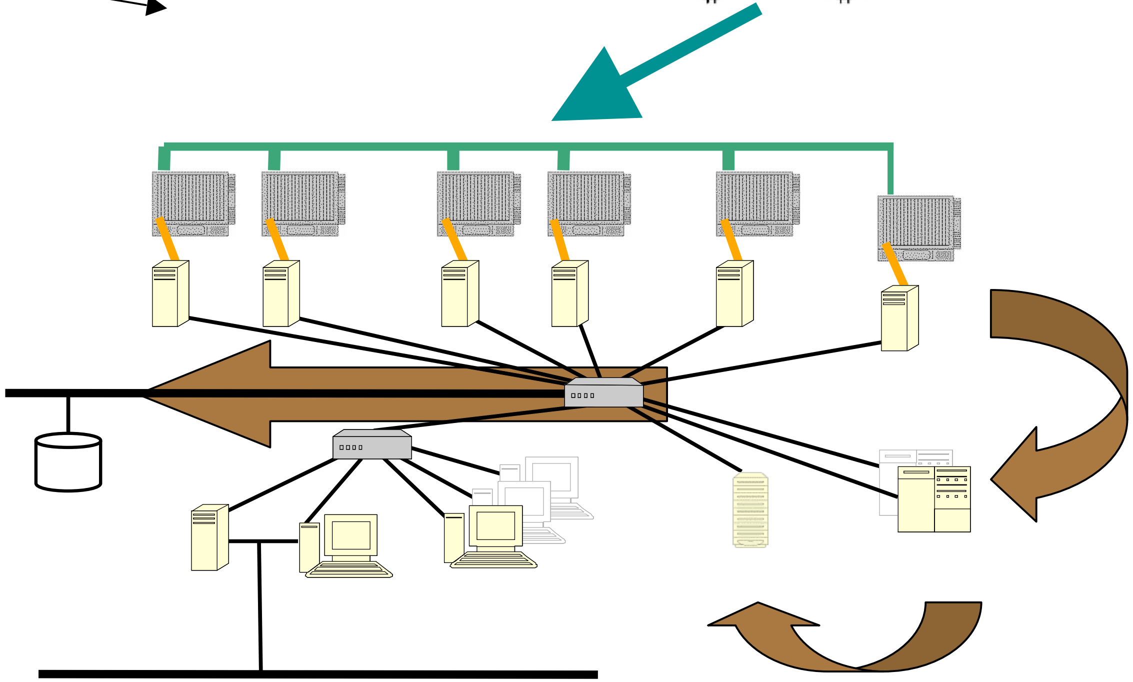


DATE framework (ALICE expt @cern)

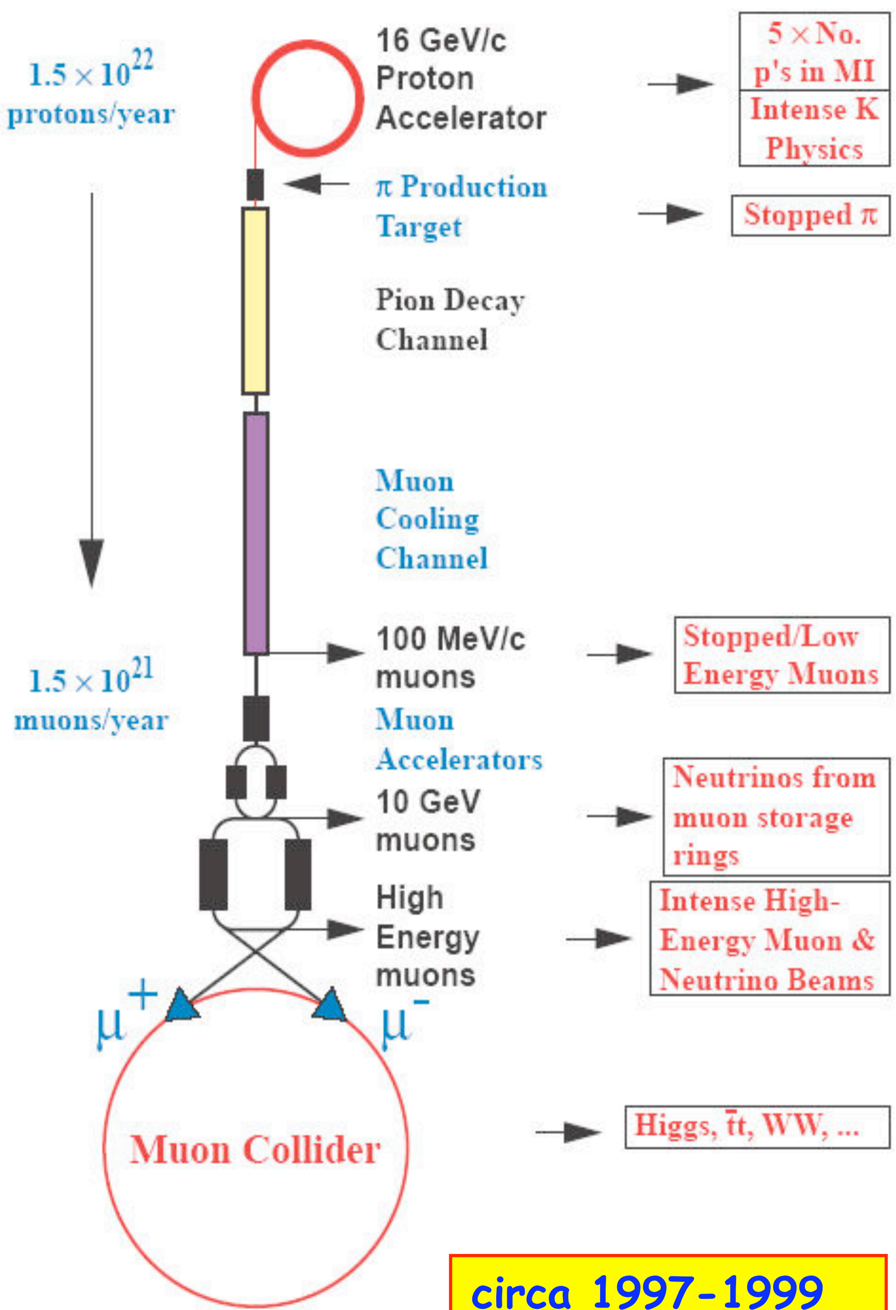
Readout by VME

Trigger signals and run modes established

Control and monitoring established (Daresbury)

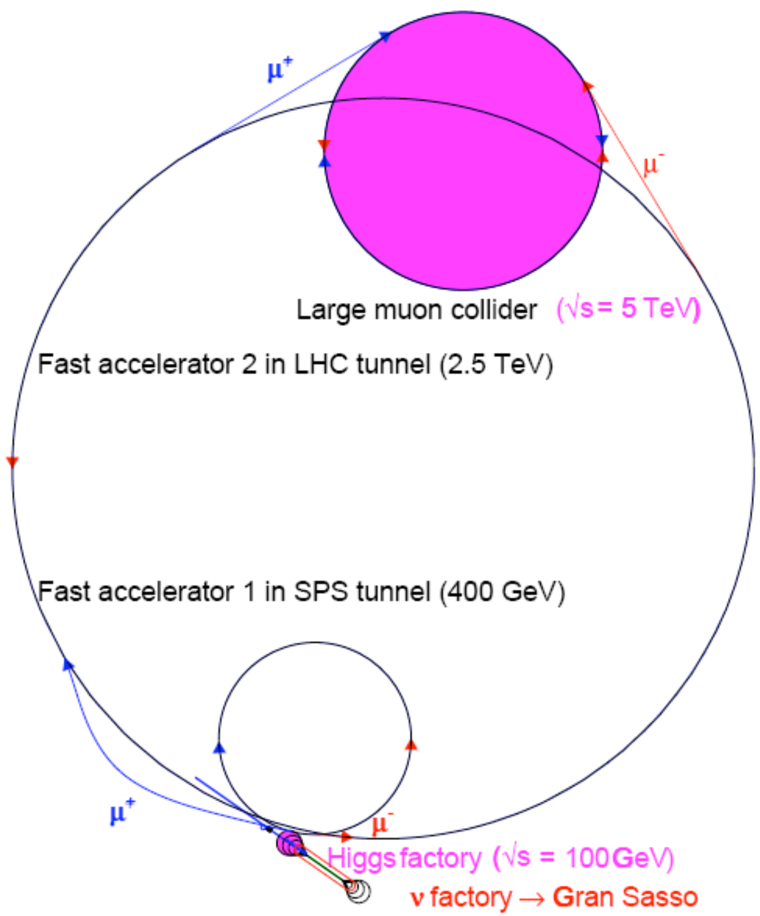


Controls working for beam magnets, March 14 2008
Electronic Logbook, March 15 2008
DAQ working in MICE Stage 1, 4 April 2008



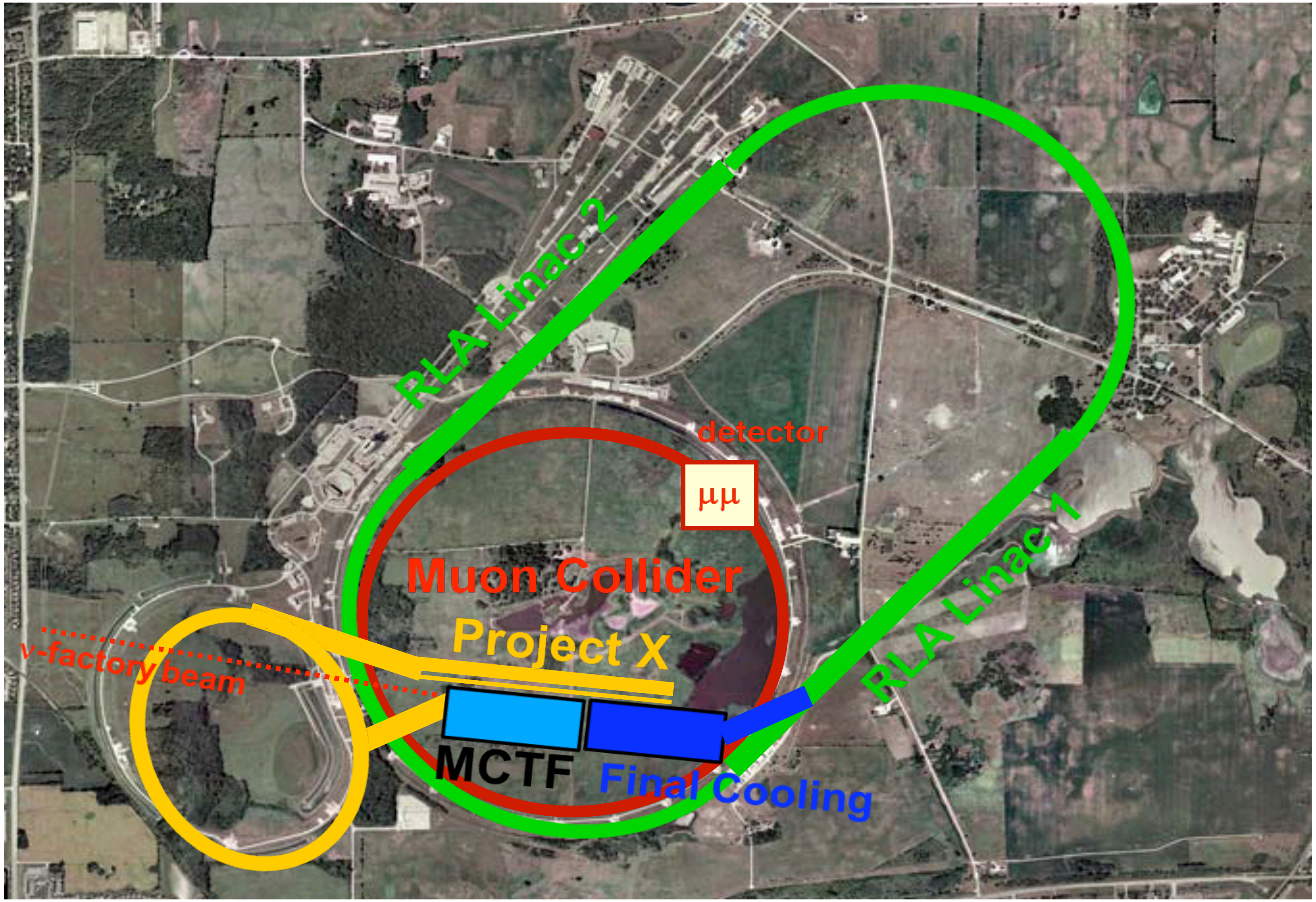
circa 1997-1999
US, Europe, Japan

Intense K physics
Intense Low-E muons
Neutrino Factory
Higgs(es) Factory(ies)
Energy Frontier -> 5 TeV



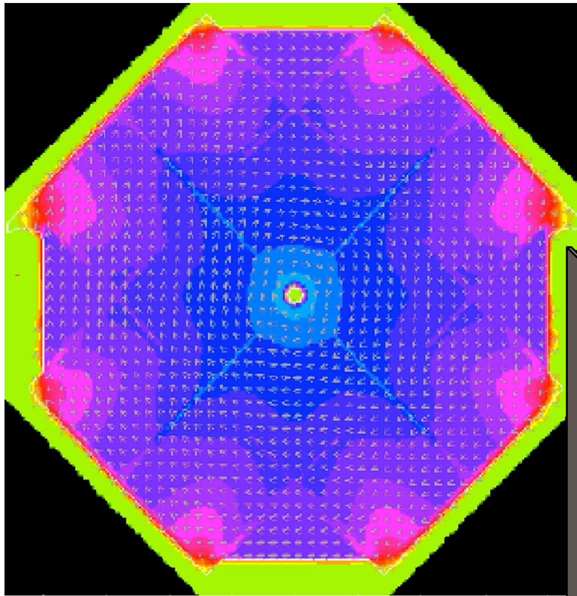
Possible layout of a muon complex on the CERN site.

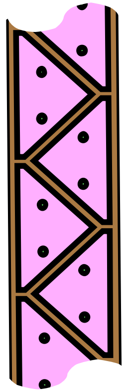
Fermilab Muon Complex - *Vision*

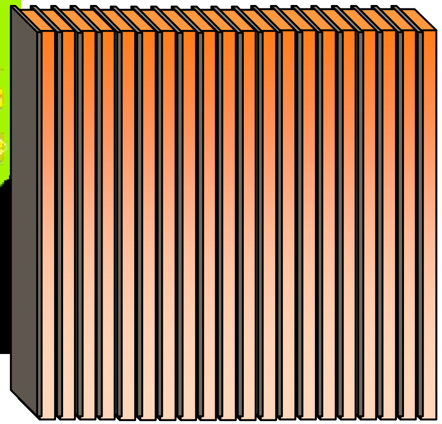


Magnetized Iron calorimeter

(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
very similar to MINOS/NOvA/ND280
ex. detector: sci. fi. detector with multipixel APD readout







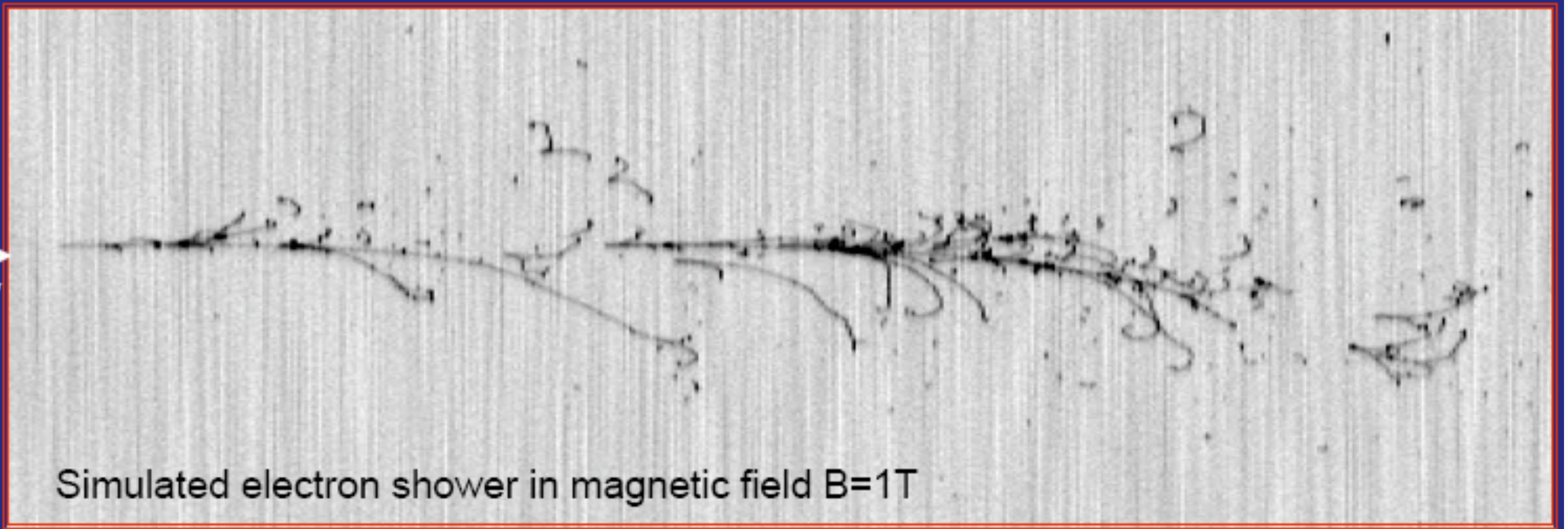
Event rates for 10^{21} muon decays for 50 GeV beam

Baseline	$\bar{\nu}_\mu$ CC	ν_e CC	ν_μ signal ($\sin^2\theta_{13}=0.01$)	
732 Km	10^9	2×10^9	3.4×10^5	(J-PARC I→ SK = 40)
3500 Km	4×10^7	7.5×10^7	3×10^5	

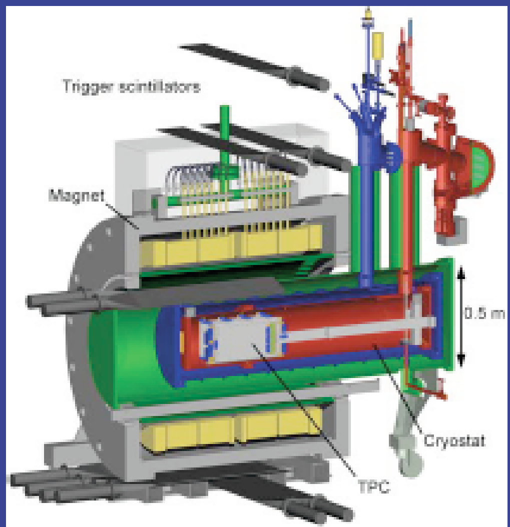
A superconducting magnetized LAr TPC detector

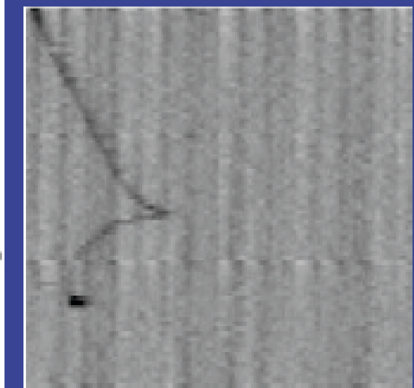
e^-

2.5 GeV



First real events in B-field (B=0.55T):





Required field for 3σ charge discrimination:

x=track length

λ=pitch angle

$$B \geq \frac{0.2\,(Tesla)}{\sqrt{x(m)\,\cos^3\lambda}}$$

x ~ a few X0=14cm….

B > 0.5 T

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

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

MICE is an international effort from the start.

NUFACT00	Re-activated the recognized need for muon cooling expt
2000-2001	Workshops on Cooling Experiment (CERN, Chicago, London)
NUFACT01 7:00 am	Steering group formed
Sept. 2001	Workshop at CERN where final experiment took shape.
November 2001	Letter of Intent (LOI) submitted to PSI and RAL
January 2002	PSI cannot host experiment, will collaborate (beam solenoid)
June 2002	RAL IPRP Review Panel encouraged submission of a proposal
January 2003	Proposal submitted
July 2003	Recommendation by International Peer Review Panel
October 2003	'Scientific approval' letter by RAL CEO John Wood
December 2003	Gateway 1 review
June 2004	Gateway 1 passed on 'amber'
20 December 2004	Gateway 2/3 passed (MICE PHASE I)
March 2005	UK phase I funding approved by PPARC and CCLRC 9.7 M£
April 2005	US NFMCC proposes a 5-year plan to fund MICE
June 2006	Harbin ICST joins MICE collaboration
July 2006	UK phase II bid submitted
February 2008	Muons Inc. Joins MICE
March 2008	First beam in MICE step I

THE MICE COLLABORATION -130 collaborators-

Universite Catholique de Louvain, Belgium

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

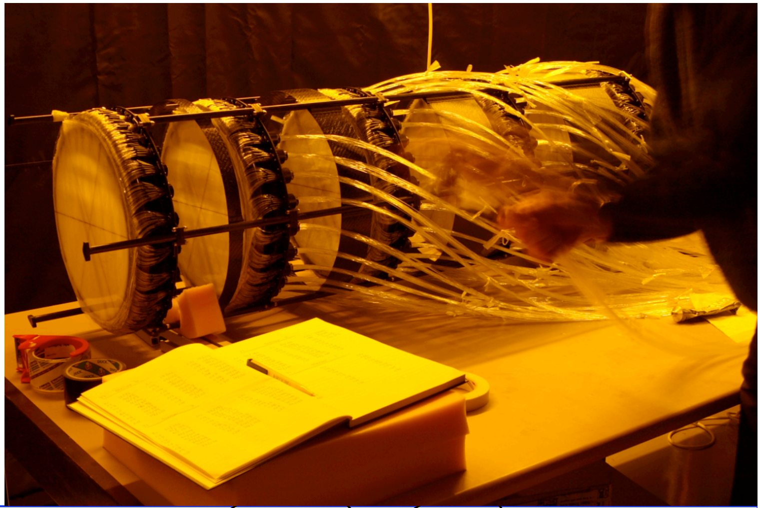
Geneva University, Paul Scherrer Institut Switzerland

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

Tracker

resp: Japan,UK,US

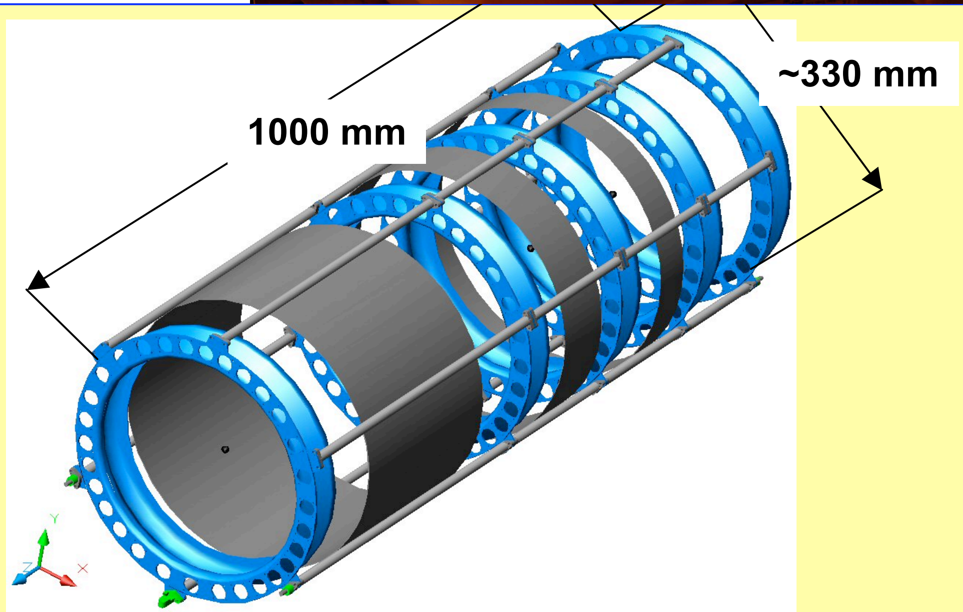


two identical trackers with 5 planes of 3-views,
440 μm point resolution achieved
scintillating fiber detector read-out with VPLCs
(7-fold ganging of 350 μm diameter fibers)

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

<u>Full production of tracker started in January 2007</u>



TRACKER

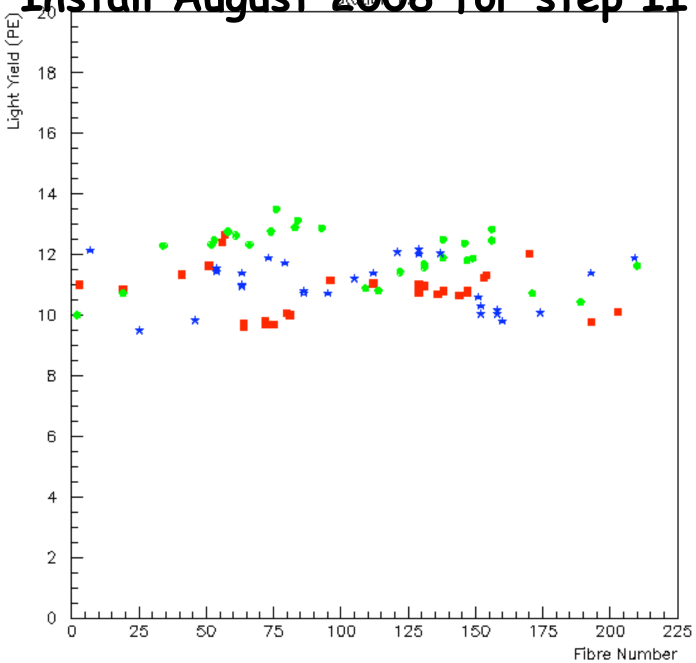
Sci-fi tracker with 5 stations of 3 views of 350 microns diam. fibers

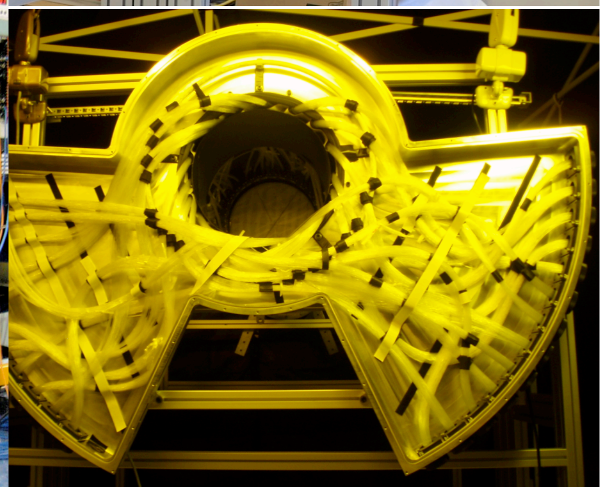
Tracker construction complete

Superb quality of construction (1/5000 channels dead)

Test on cosmics at RAL

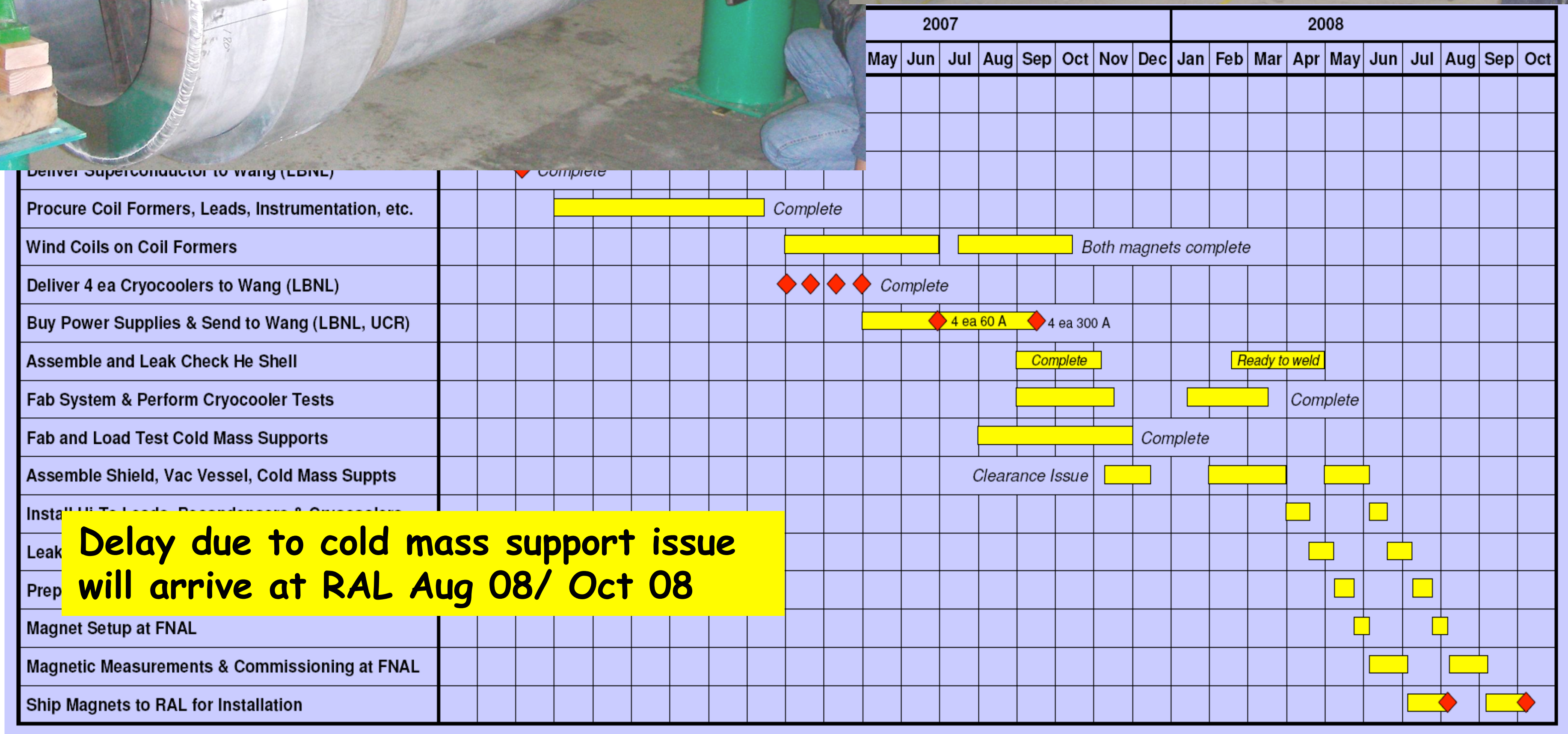
Install August 2008 for step II





Patch panel

Spectrometer solenoids



Delay due to cold mass support issue will arrive at RAL Aug 08/ Oct 08