MICE: the International Muon Ionization Cooling Experiment

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COOL05
Eagle Ridge, Galena, IL, USA
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Outline:

1. Introduction: Ionization Cooling
2. MICE
3. Current status
4. Summary

Introduction

- Would like to be able to cool muon beams

  – this would enable

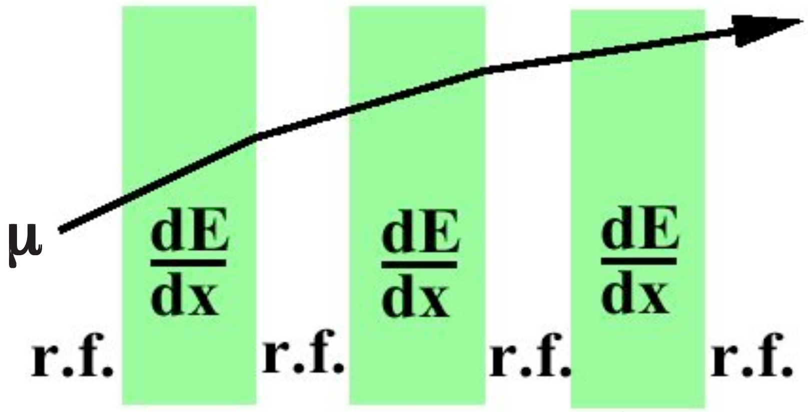
    1. Neutrino Factories – *ultimate tool* for study of ν oscillations

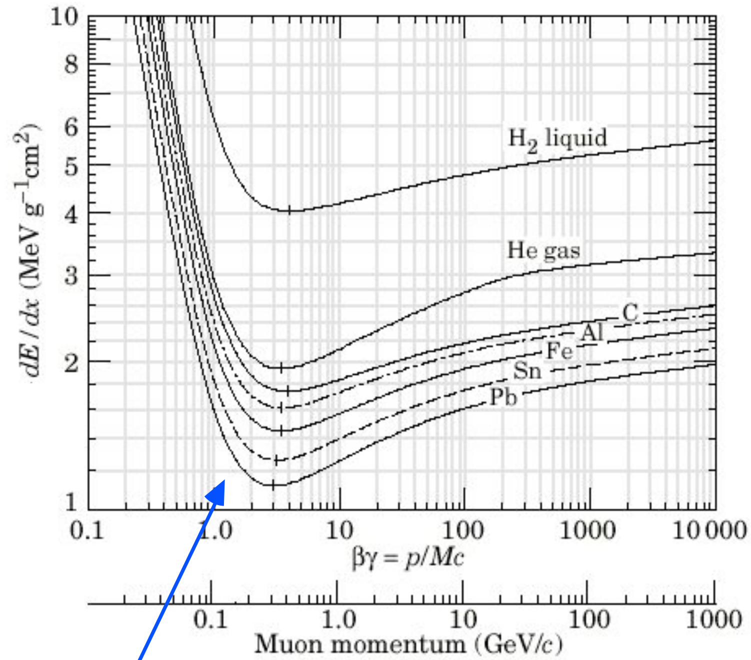
    2. Muon Colliders – route to *multi-TeV* lepton collisions

Introduction

- Muons decay too quickly for stochastic or electron cooling, but can be cooled via. . .

Ionization Cooling





- Absorbers:

$$\begin{cases} E \to E - \left\langle \dfrac{dE}{dx} \right\rangle \Delta s \\ \theta \to \theta + \theta_{space}^{rms} \end{cases}$$

ionization energy loss

multiple Coulomb scattering

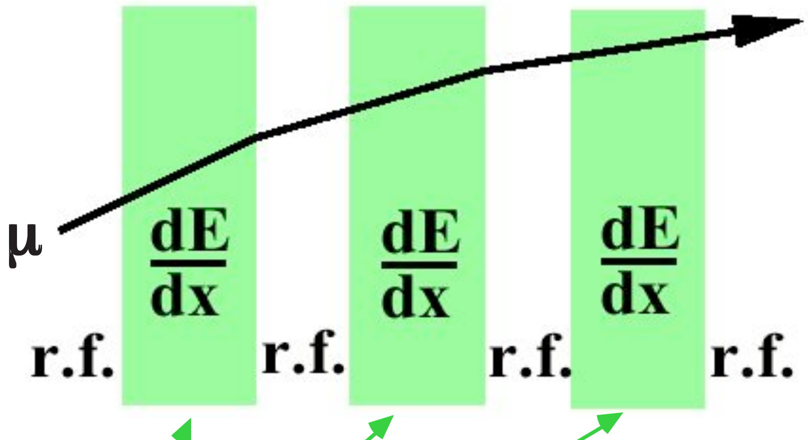
- RF cavities between absorbers replace ΔE
- Net effect: reduction in $p_\perp$ w.r.t. $p_\parallel$, i.e., transverse cooling

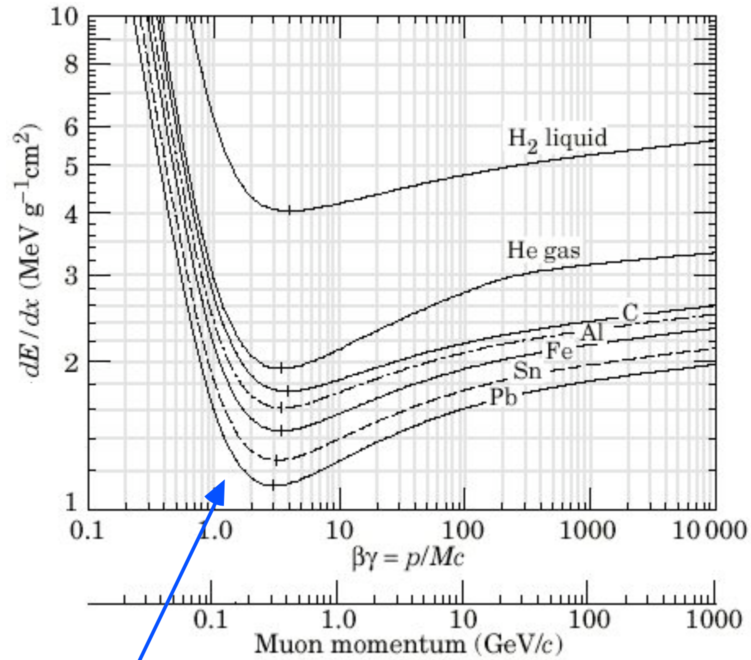
Note: The **physics** is not in doubt

⇒ in principle, ionization cooling **has** to work!

... but in practice it is subtle and complicated...

Ionization Cooling





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... but in practice it is subtle and complicated...

...so a test is essential!

Practical Difficulty:

- Cooling channels are expensive

⇒ affordable channel gives only ≈10% emittance reduction

- But standard beam instrumentation can measure emittance to only ≈10%

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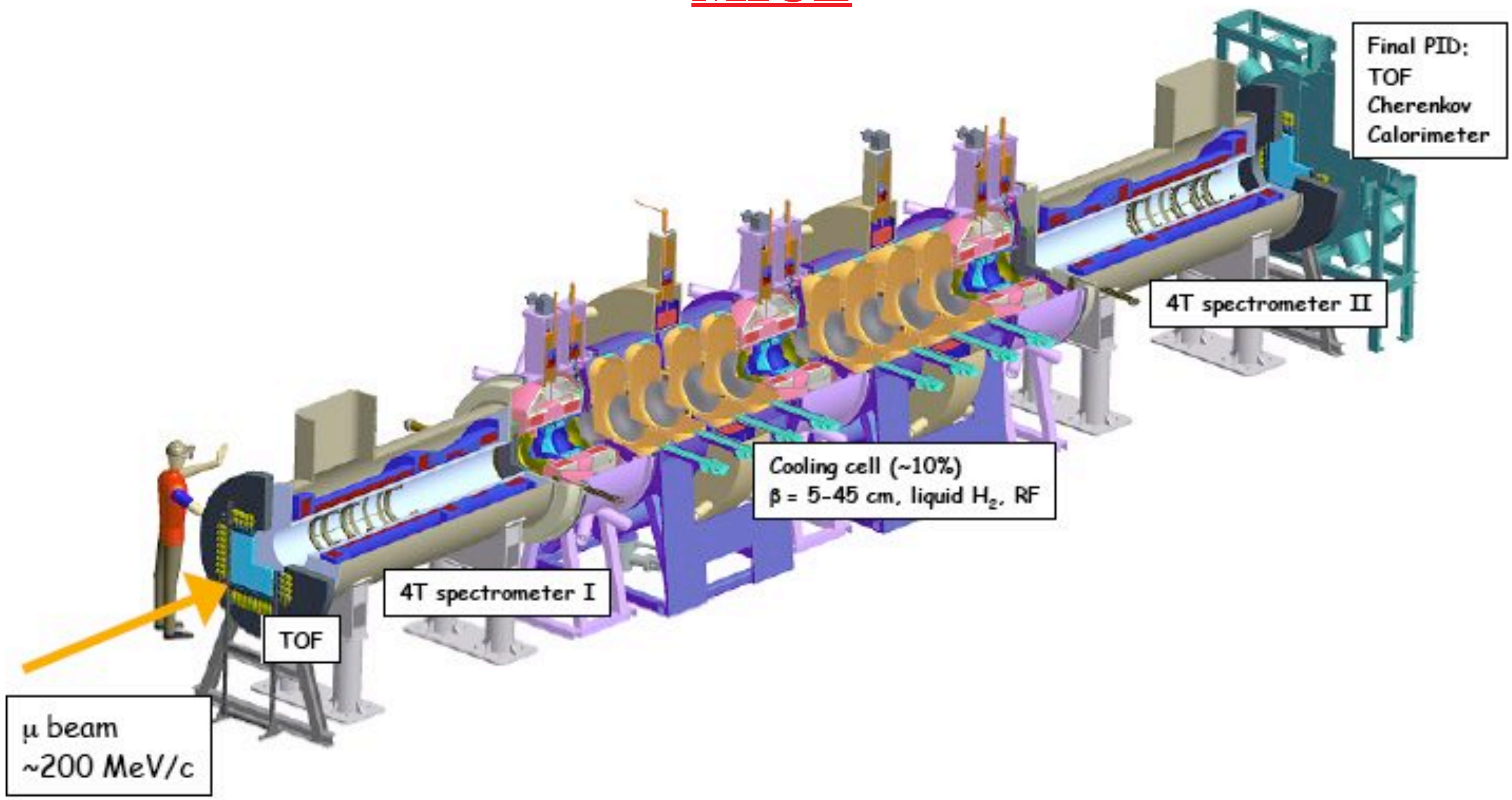
- But standard beam instrumentation can measure emittance to only ≈10%

Solution:

Measure the beam one muon at a time!

MICE



Goals of MICE:

- to show that it is possible to design, engineer and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory;
- to place it in a muon beam and measure its performance in a variety of modes of operation and beam conditions.

MICE Collaboration (>100 collaborators from 36 institutions in 9 countries)

Belgium: Universite Catholique de Louvain (G. Gregoire)

Bulgaria: St. Kliment Ohridski University of Sofia (M. Bogomilov, D. Kolev, A. Marinov, I. Russinov, R. Tsenov)

Italy: INFN Milano (A. Andreoni, D. Batani, M. Bonesini, G. Lucchini, F. Paleari, P. Sala, F. Strati)
INFN Napoli e Università Federico II (V. Palladino)
INFN Roma III and ROMA TRE University (A. Cassatella, D. Orestano, M. Parisi, F. Pastore, A. Tonazzo, L. Tortora)
University of Trieste and INFN, Trieste (M. Apollonio, P. Chimenti, G. Giannini, A. Gregorio, A. Romanino, T. Schwetz)

Japan: KEK (S. Ishimoto, S. Suzuki, K. Yoshimura)
Osaka University (A. Horikoshi, Y. Kuno, H. Sakamoto, A. Sato, M. Yoshida)

Netherlands: NIKHEF, Amsterdam (S. de Jong, F. Filthaut, F. Linde)

Russia: Budker Institute, Novosibirsk (N. Mezentsev, A. N. Skrinsky)

CERN: CERN (H. Haseroth, F. Sauli)

Switzerland: Université de Genève (A. Blondel, A. Cervera, J.-S. Graulich, R. Sandstrom, O. Voloshyn)
Paul Scherrer Institut (C. Petitjean)

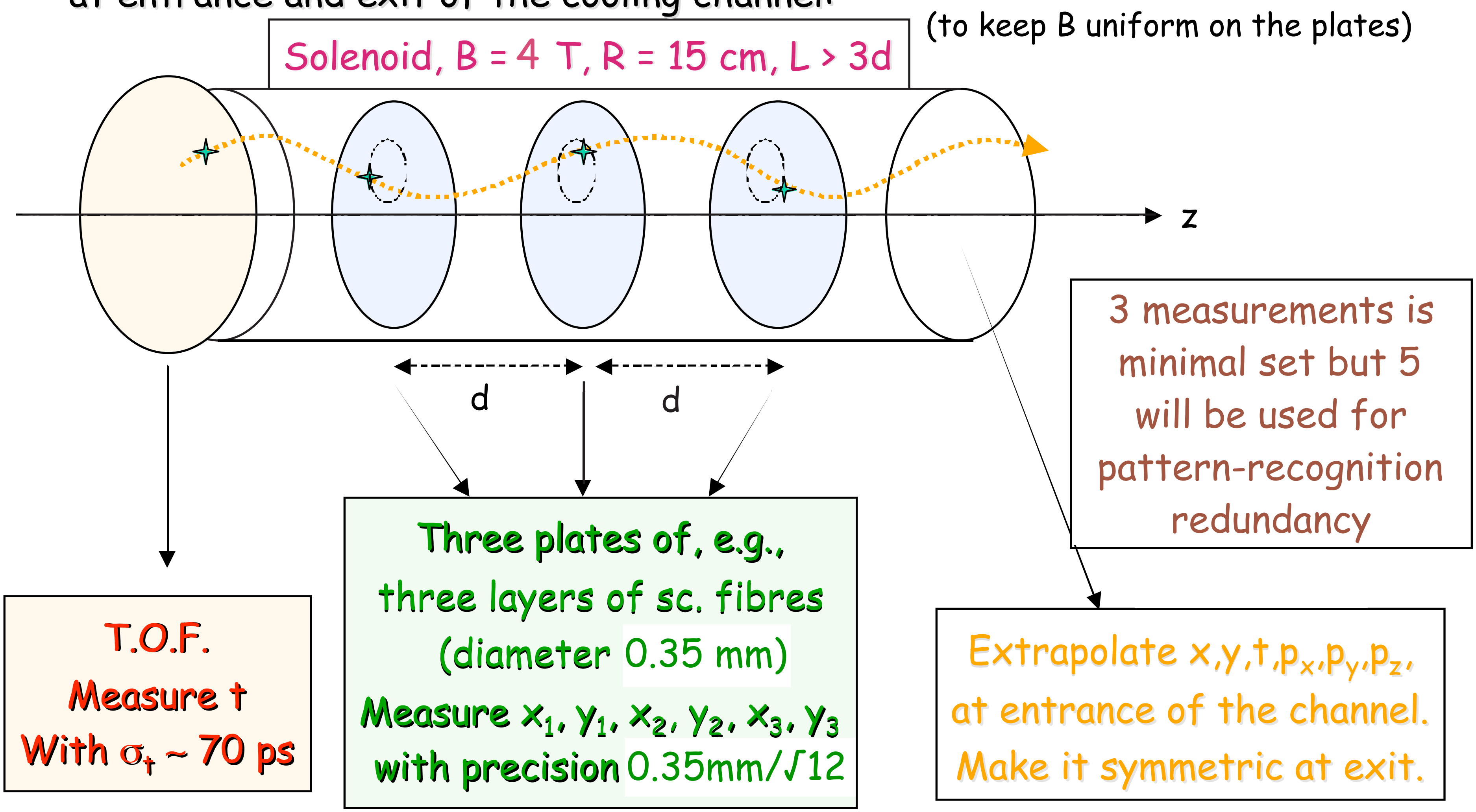
UK: Brunel University (P. Kyberd)
University of Edinburgh (A. Khan, A. Walker)
University of Glasgow (F. J. P. Soler, K. Walaron)
University of Liverpool (P. Cooke, J. B. Dainton, J. R. Fry, R. Gamet, C. Touramanis)
Imperial College London (G. Barber, P. Dornan, M. Ellis, A. Fish, K. Long, D. R. Price, C. Rogers, J. Sedgbeer)
University of Oxford (W. W. M. Allison, G. Barr, U. Bravar, J. Cobb, S. Cooper, S. Holmes, H. Jones, W. Lau, H. Witte, S. Yang)
Daresbury Laboratory (P. Corlett, A. Moss, J. Orrett)
Rutherford Appleton Laboratory:(D. E. Baynham, D. Bellenger, T. W. Bradshaw, R. Church, P. Drumm, R. Edgecock, I. Gardner, Y.M. Ivanyushenkov, A. Jones, H. Jones, R. Mannix, A. Morris, W.J. Murray, P.R. Norton, J.H. Rochford, K. Tilley, A. Weber)
University of Sheffield (C. N. Booth, P. Hodgson, L. Howlett, P. Smith)

USA: Argonne National Laboratory (J. Norem)
Brookhaven National Laboratory (R. B. Palmer, R. Fernow, J. Gallardo, H. Kirk)
Fairfield University (D. R. Winn)
University of Chicago and Enrico Fermi Institute (M. Oreglia)
Fermilab (A. D. Bross, S. Geer, D. Neuffer, A. Moretti, M. Popovic, R. Raja, R. Stefanski, Z. Qian)
Illinois Institute of Technology (D. M. Kaplan, N. Solomey, Y. Torun, K. Yonehara)
Jefferson Lab (R. A. Rimmer)
Lawrence Berkeley National Laboratory (M. A. Green, D. Li, A. M. Sessler, S. Virostek, M. S. Zisman)
UCLA (D. Cline, K. Lee, Y. Fukui, X. Yang)
Northern Illinois University (M. A. C. Cummings, D. Kubik)
University of Iowa (Y. Onel)
University of Mississippi (S. B. Bracker, L. M. Cremaldi, R. Godang, D.J. Summers)
University of California, Riverside (G. G. Hanson, A. Klier)
University of Illinois at Urbana-Champaign (D. Errede)

Single-Particle Emittance Measurement

- **Principle:** Measure each muon precisely before and after cooling cell
  Off-line, form "virtual bunch" and compute emittances in and out

Need to determine, for each muon, x,y,t, and x',y',t' (=p_x/p_z, p_y/p_z, E/p_z) at entrance and exit of the cooling channel:



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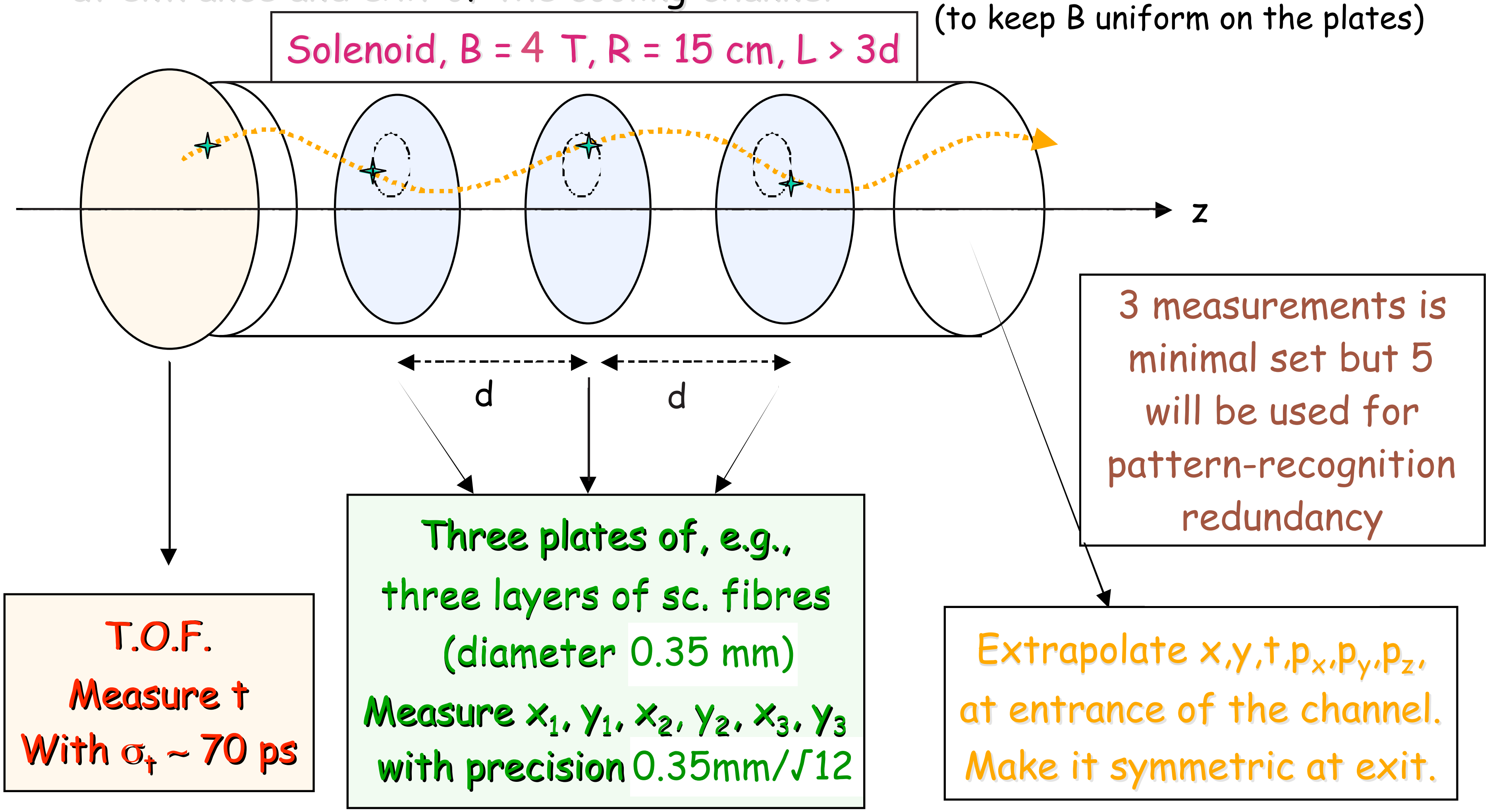
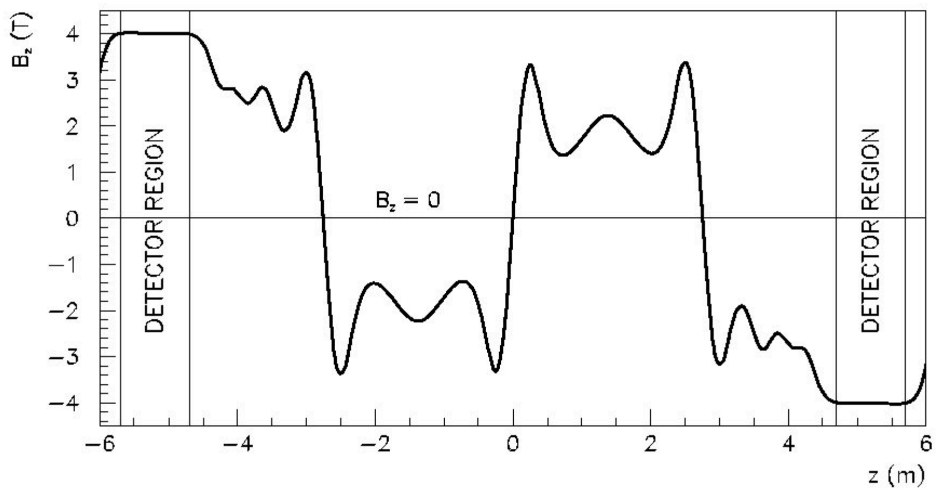


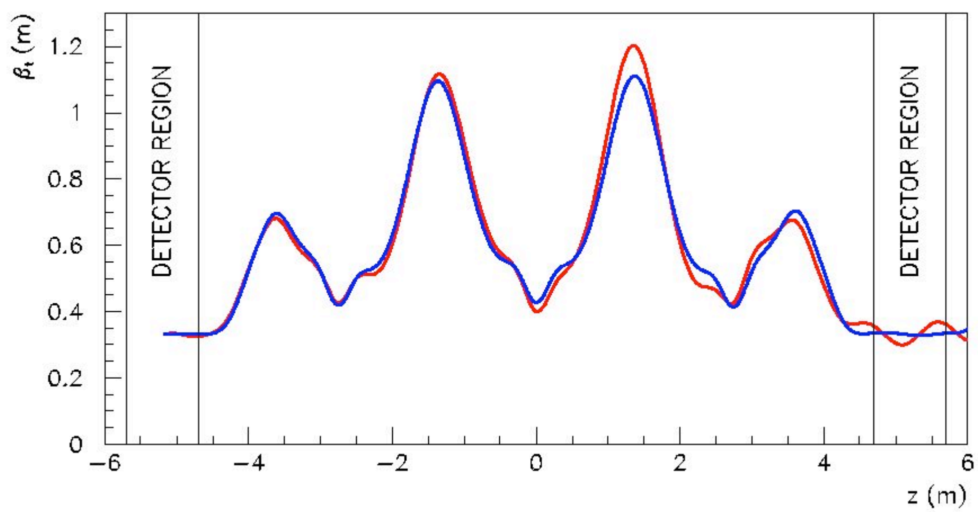
...but mux'ing readout by 7 gives suff. resolution and reduces cost

Nominal (“SFOFO”) Lattice (200 MeV/*c*)

- B_z vs. z:



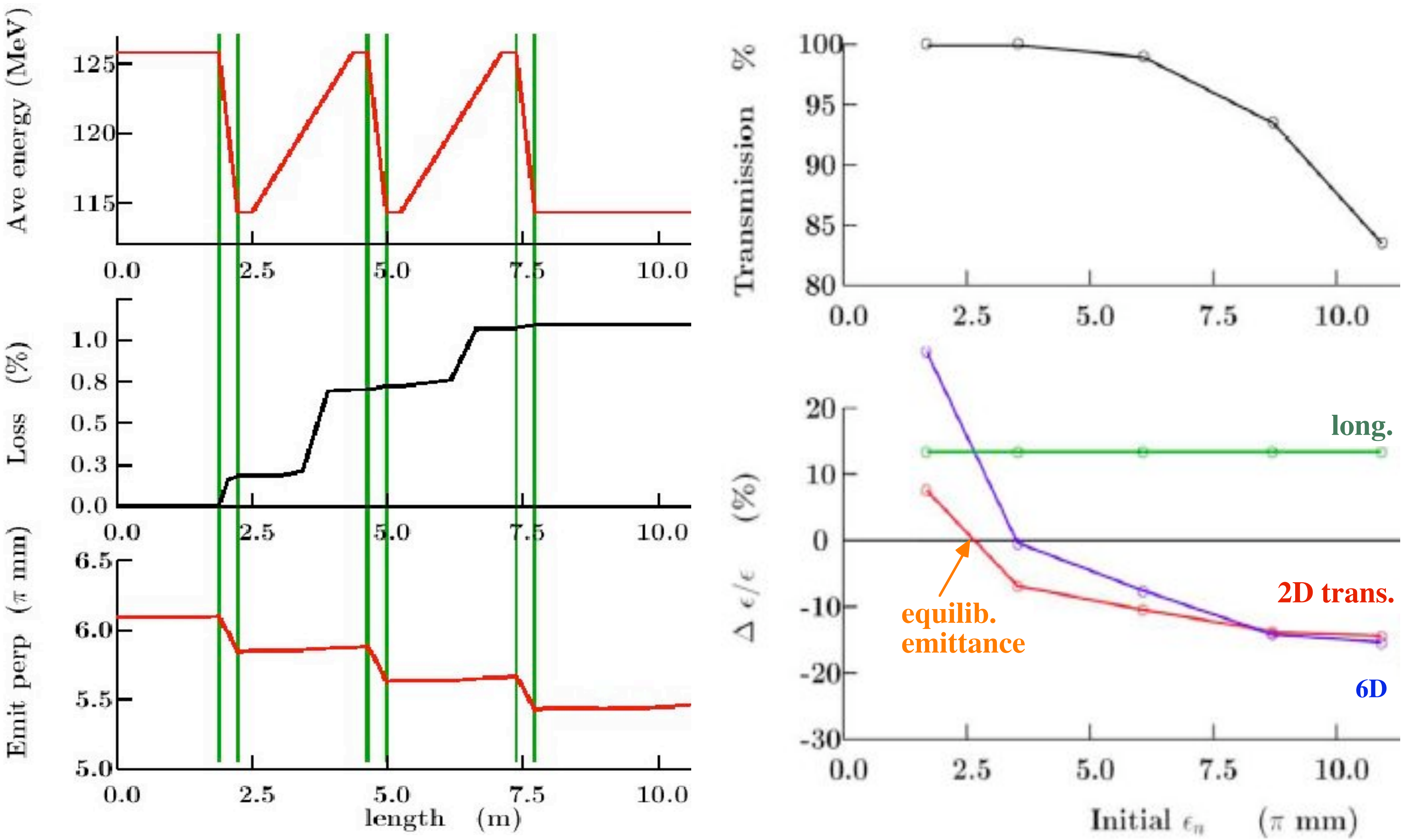
- β_t vs. z:



- ∃ flexibility to explore other settings, momenta, absorber mat’ls...

Performance Simulation (nominal SFOFO mode):

(BNL ICOOL simulation)

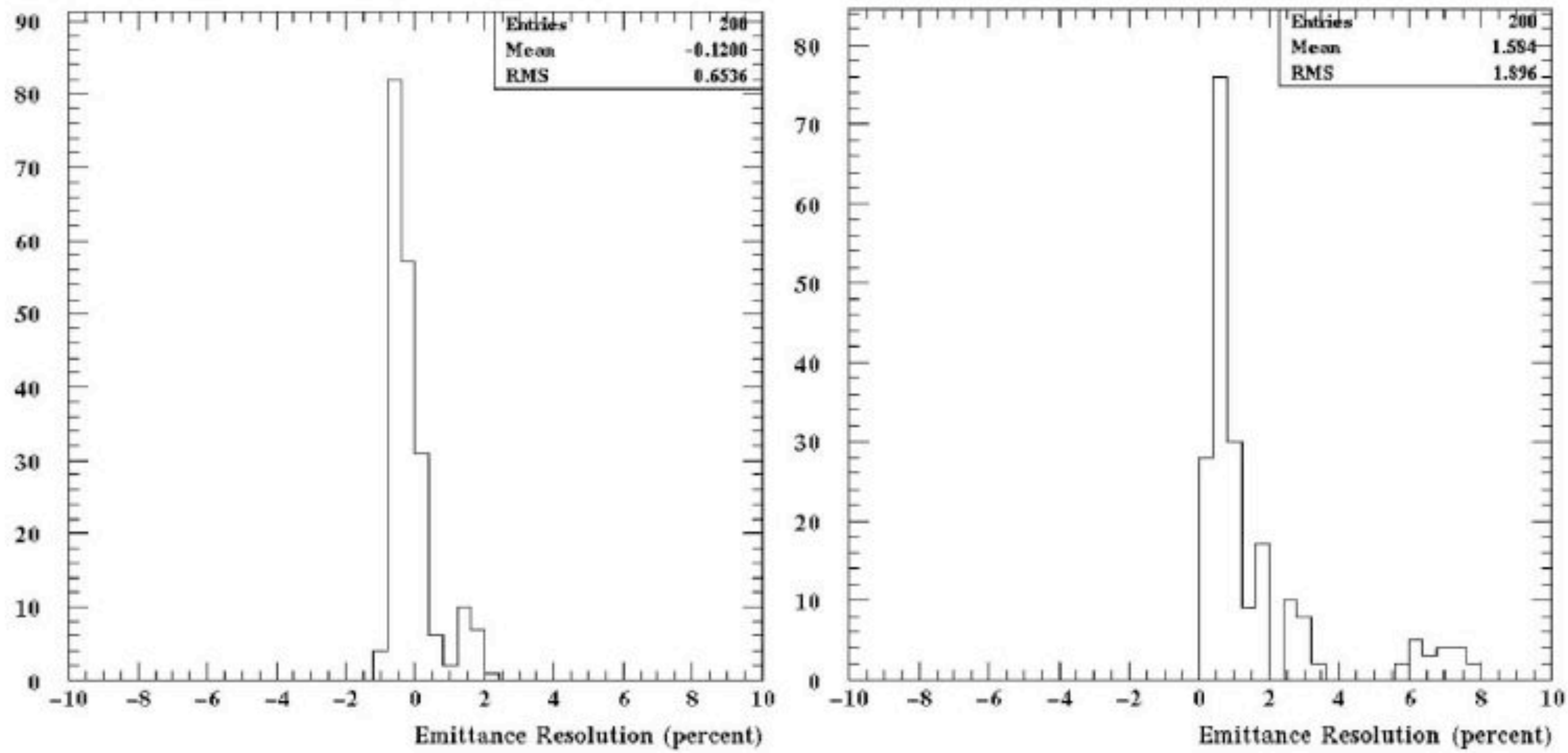


→≈10% transverse emittance reduction, measurable to 0.1% (abs.) given precise spectrometer, clean beam, and efficient, redundant particle ID

Tracker Performance Simulation:

(C. Rogers, ICL G4MICE simulation)

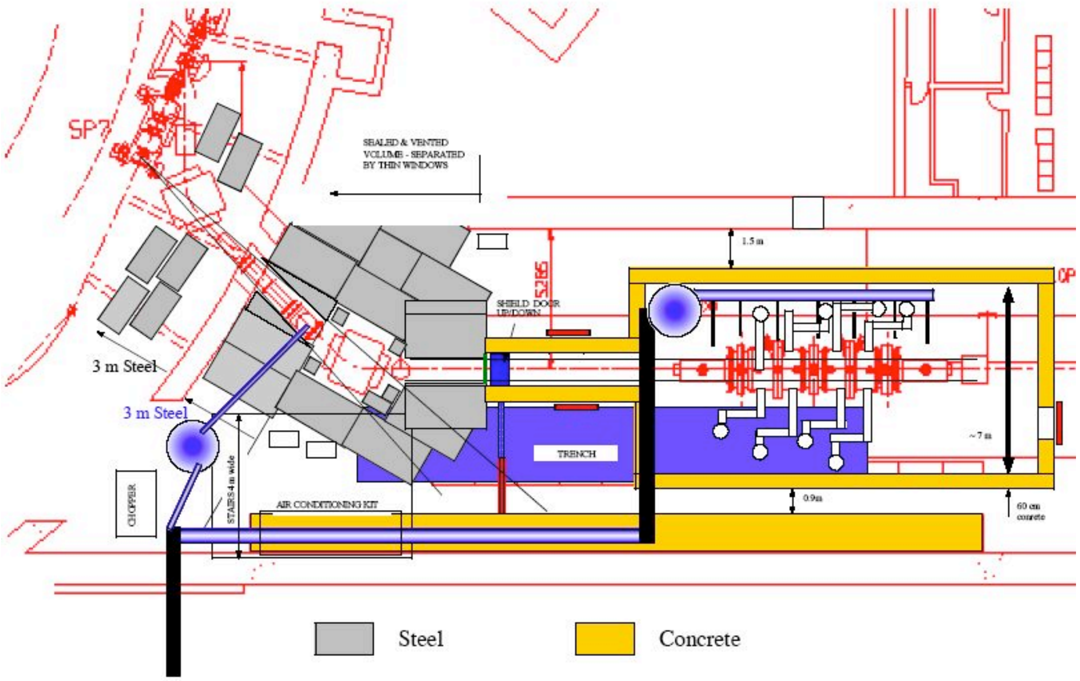
- Correctable ≈1% bias due to scattering in detectors:



- Key physics goal of "MICE Phase 1":
  - demonstrate bias correction to <10% of itself, as needed for 0.1% emittance measurement

Current Status:

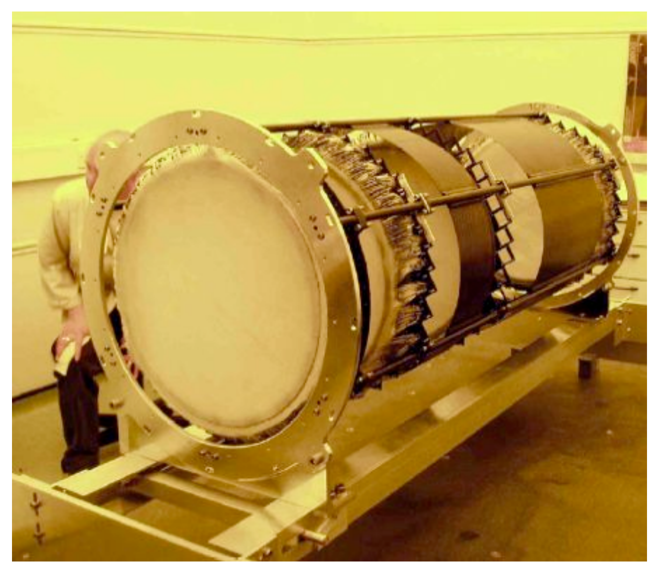
- MICE proposal submitted January 2003
- Proposal approved by CCLRC 10/24/03
- MICE funding (Phase 1) approved in Italy, Japan, Netherlands, Switzerland, UK, US
  - Includes installation of muon beamline on ISIS at RAL:



Beamline includes:

2 bends
3 small-aperture quads
6 large-aperture quads
4T decay solenoid (from PSI)

... as well as MICE spectrometers, e.g.:

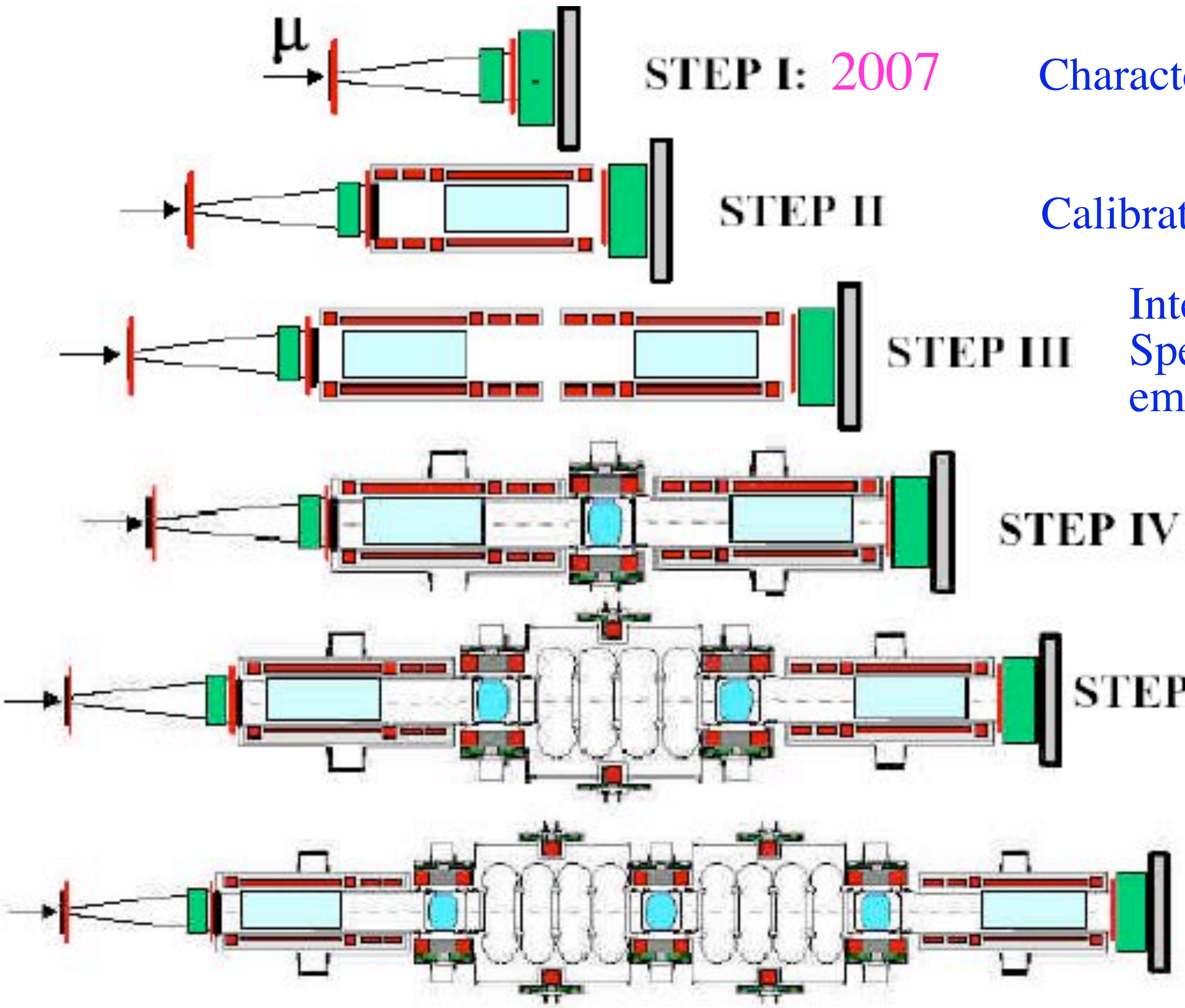


Prototype solenoidal spectrometer:
4 3-view SciFi stations
designed for insertion in 4T SC solenoid

- Plan: 1st MICE beam at RAL 4/07

Avatars of MICE

- Measurement precision relies crucially on precise calibration & thorough study of systematics:



STEP I: 2007 — Characterize beam

STEP II — Calibrate Spect. 1

STEP III — Intercalibrate Spect. 2 w.r.t. Spect. 1; demonstrate 0.1% emittance measurement

STEP IV: 2008? — Study 1st abs./ focus-coil pair, check dE/dx and scattering

STEP V — Cooling study w/ 1/2 lattice cell

STEP VI: 2009? — Cooling study w/ full lattice cell & realistic field flip

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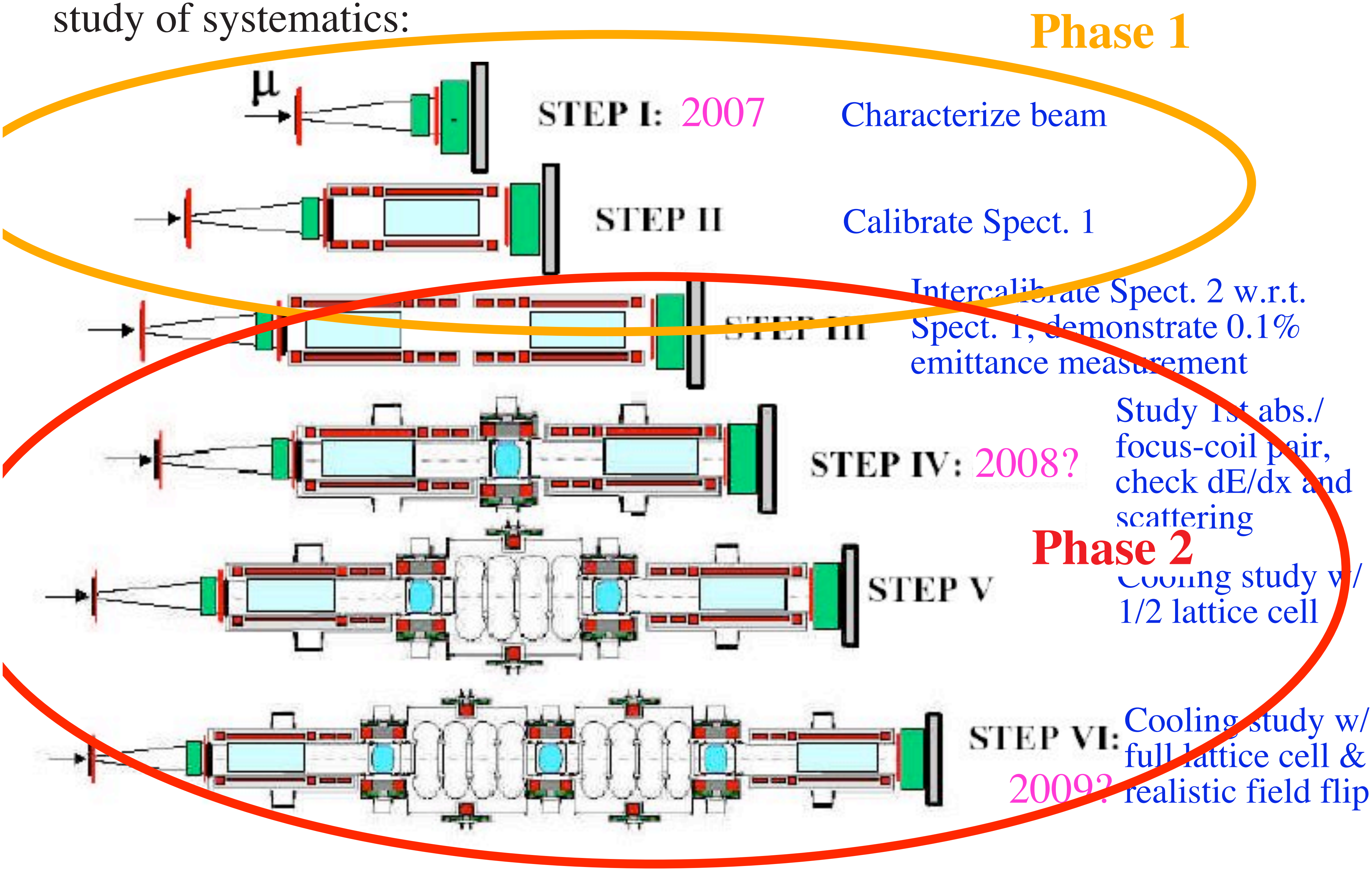
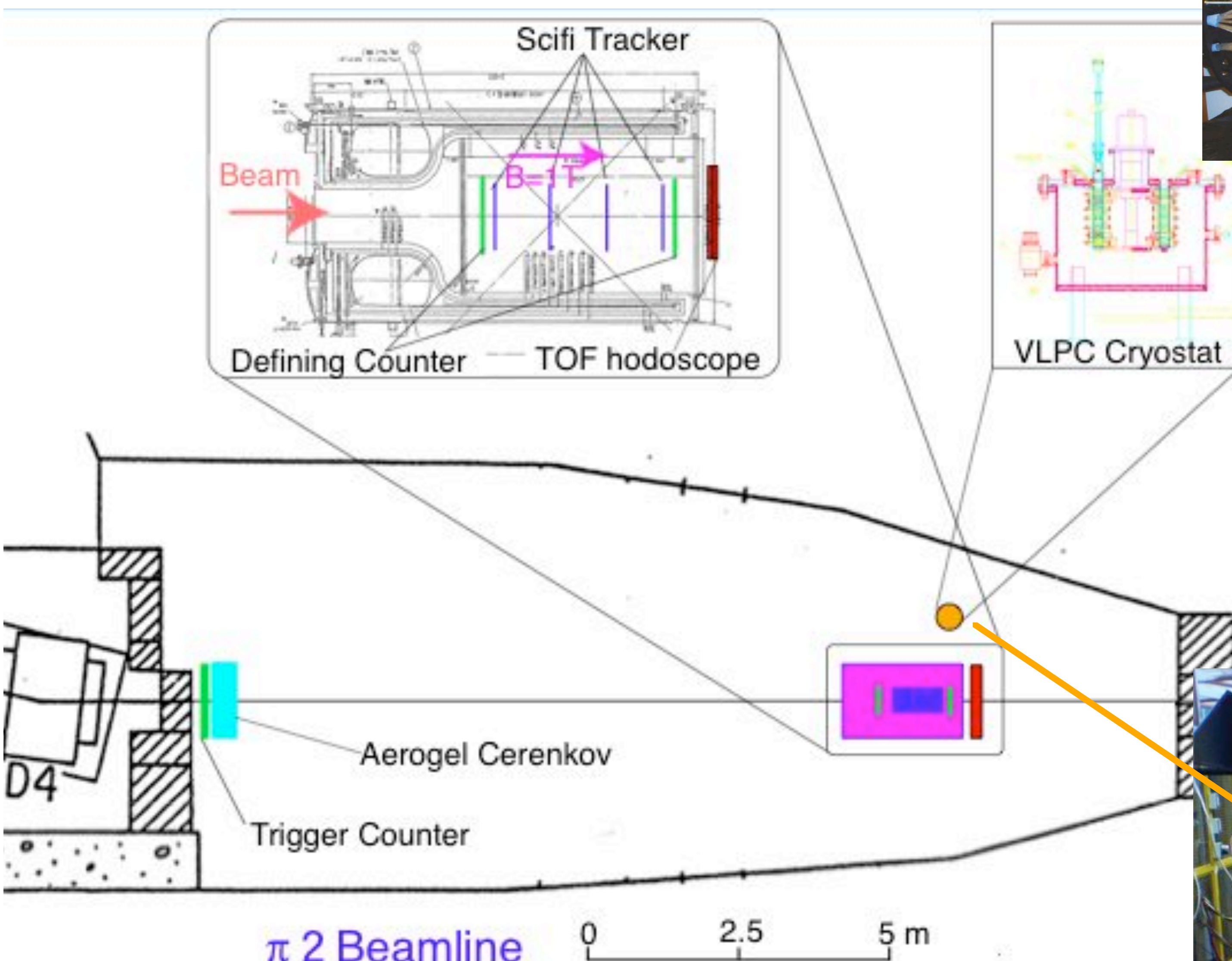


Sampler of Recent Progress: SciFi Tracker Test at KEK

(KEK / Osaka / UK / FNAL / IIT / UCR / UCLA)

- Installing 4-station prototype in 1T SC solenoid:



(already passed cosmic-ray test)

- Test beam scheduled for Sept. 27 – Oct. 7

Tracker prototype

Electronics area

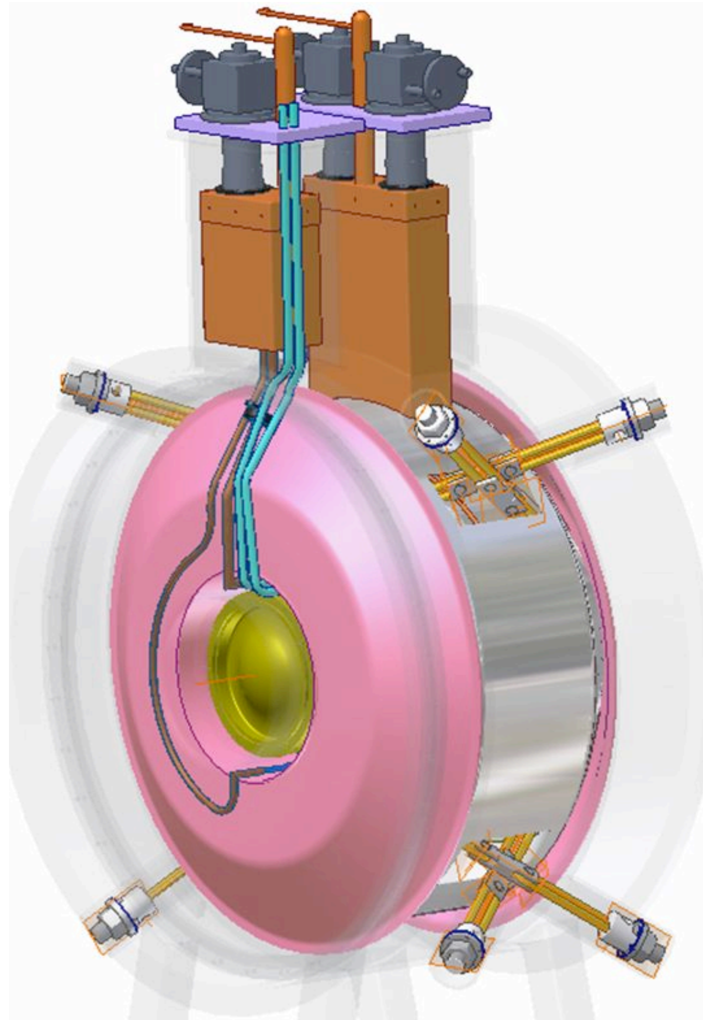
Beam area

Absorber Design

(KEK, Oxford, RAL)

- Need LH_2 absorbers with 0.1–1 kW power-handling capability

Prototype high-power LH_2 absorber (MuCool)

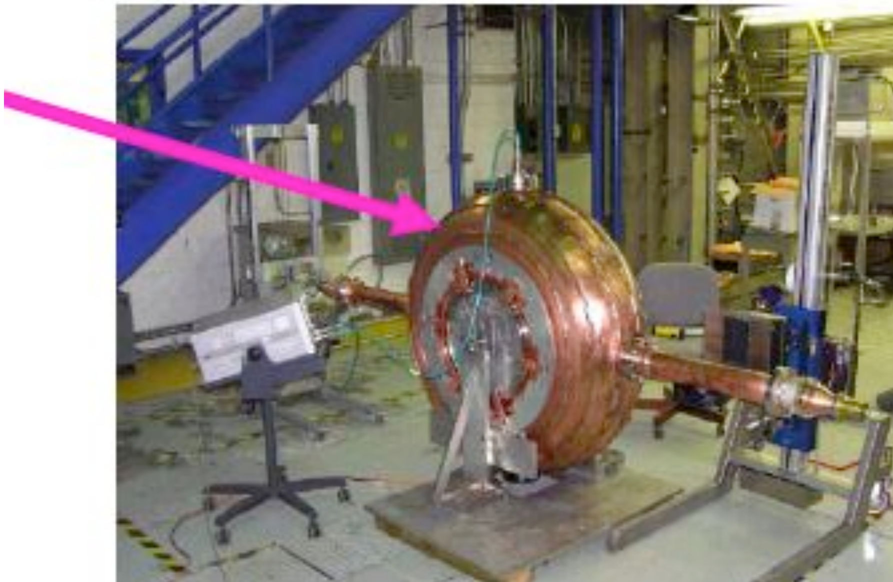


MICE low-power design (cryocooler-cooled)

  – also much work on hydrogen safety

RF Cavities

(LBNL)



- Prototype 201 MHz cavity with thin, curved Be windows

...about to begin high-power testing at Fermilab MTA

RF Power

- Two surplus 4 MW, 201 MHz power amplifiers shipped from LBNL to DL for refurbishing

@ LBNL

@ DL

- Plan to get two more refurbished from CERN

→ 2 MW per cavity in Step V,

1 MW per cavity in Step VI

More...

- Work also proceding on
  - spectrometer solenoids
  - beamline and infrastructure
  - particle-ID detectors
  - DAQ system
  - software...

...but I’m out of time to tell you about it!

Conclusions

- MICE is now approved and Phase 1 is funded
- Progressing well technically
- On track to exploit first beam in 2007
- Complete program requires Phase 2 funding approvals
  - additional collaborators could help
- Aim to finish by 2010