MICE STATUS

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Illinois Institute of Technology

NuFact03 - June 7, 2003 - Columbia University, New York

Outline

- Introduction - Why MICE?
- Collaboration
- Experiment
  - Cooling Hardware
  - Measurement Technique
  - Detectors
  - Backgrounds
- Status

INTRODUCTION

Ionization Cooling

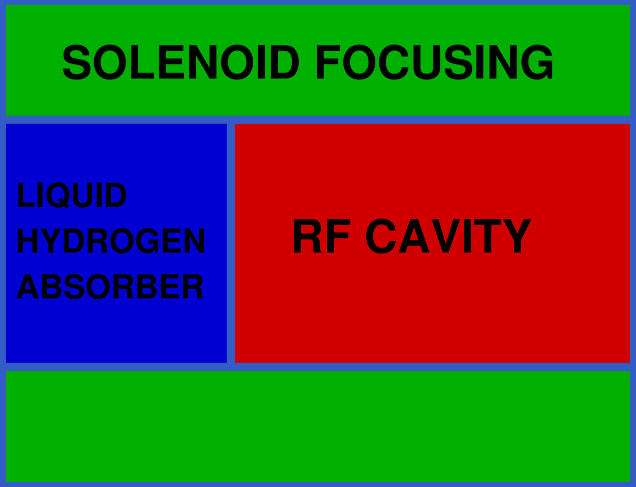
- only practical technique fast enough for cooling muons
- large performance boost for Neutrino Factory
- essential for muon collider

Ionization Cooling

- Evolution of normalized transverse emittance ε along absorber axis in solenoidal field

$$\frac{d\varepsilon}{ds} \simeq -\frac{1}{\beta^2 E}\langle\frac{dE}{ds}\rangle(\varepsilon - \varepsilon_0)\,, \quad \varepsilon_0 \sim \frac{\beta_\perp}{2\beta m\langle\frac{dE}{ds}\rangle X_0}$$

- For minimum equilibrium emittance ε_0, we need
  - strong focusing (small $\beta_\perp$)
  - material with large $\langle\frac{dE}{ds}\rangle X_0$ (hydrogen)
- Need large rf gradient to replace lost energy (30 MeV/m in liquid hydrogen)



Ionization Cooling

Works great on paper, but many technical challenges:

- High-gradient normal-conducting rf cavities in high magnetic field with Be foil (or Al grid) windows
- Liquid hydrogen vessels with thin windows
- Superconducting solenoids
- Very tight packing
- Possibly tricky diagnostics

Need experience with the technology and accurate simulation and test of channel dynamics $\Rightarrow$ experiment

Proposal

MICE-Note 21 - http://www.mice.iit.edu/mnp/MICE0021.pdf

The MICE Collaboration has designed an experiment in which a section of an ionization cooling channel is exposed to a muon beam. This channel includes liquid-hydrogen absorbers providing energy loss and high-gradient rf cavities to re-accelerate the particles, all tightly packed in a solenoidal magnetic channel. It reduces the beam transverse emittance by $>$10% for muon momenta between 140 and 240 MeV/c. Spectrometers placed before and after the cooling section perform the measurements of beam transmission and emittance reduction with an absolute precision of $\pm$0.1%.

Proposal

A Neutrino Factory based on a muon storage ring is the ultimate tool for studies of neutrino oscillations, including possibly the discovery of leptonic CP violation. It is also the first step towards a $\mu^+\mu^-$ collider. Ionization cooling of muons has never been demonstrated in practice but has been shown by end-to-end simulation and design studies to be an important factor for both performance and cost of a Neutrino Factory. This motivates an international program of R&D, including an experimental demonstration. The aims of the International Muon Ionization Cooling Experiment are:

- 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 various modes of operation and beam conditions, thereby investigating the limits and practicality of cooling

History

- Proposal to RAL submitted Jan 10, 03
- Presentations to International Peer Review Panel Feb 17, 03
- Panel response with questions
- Submitted supplemental report with answers mid-April
- Second panel meeting May 2
- Panel report just came out with strong endorsement

COLLABORATION

The MICE Collaboration

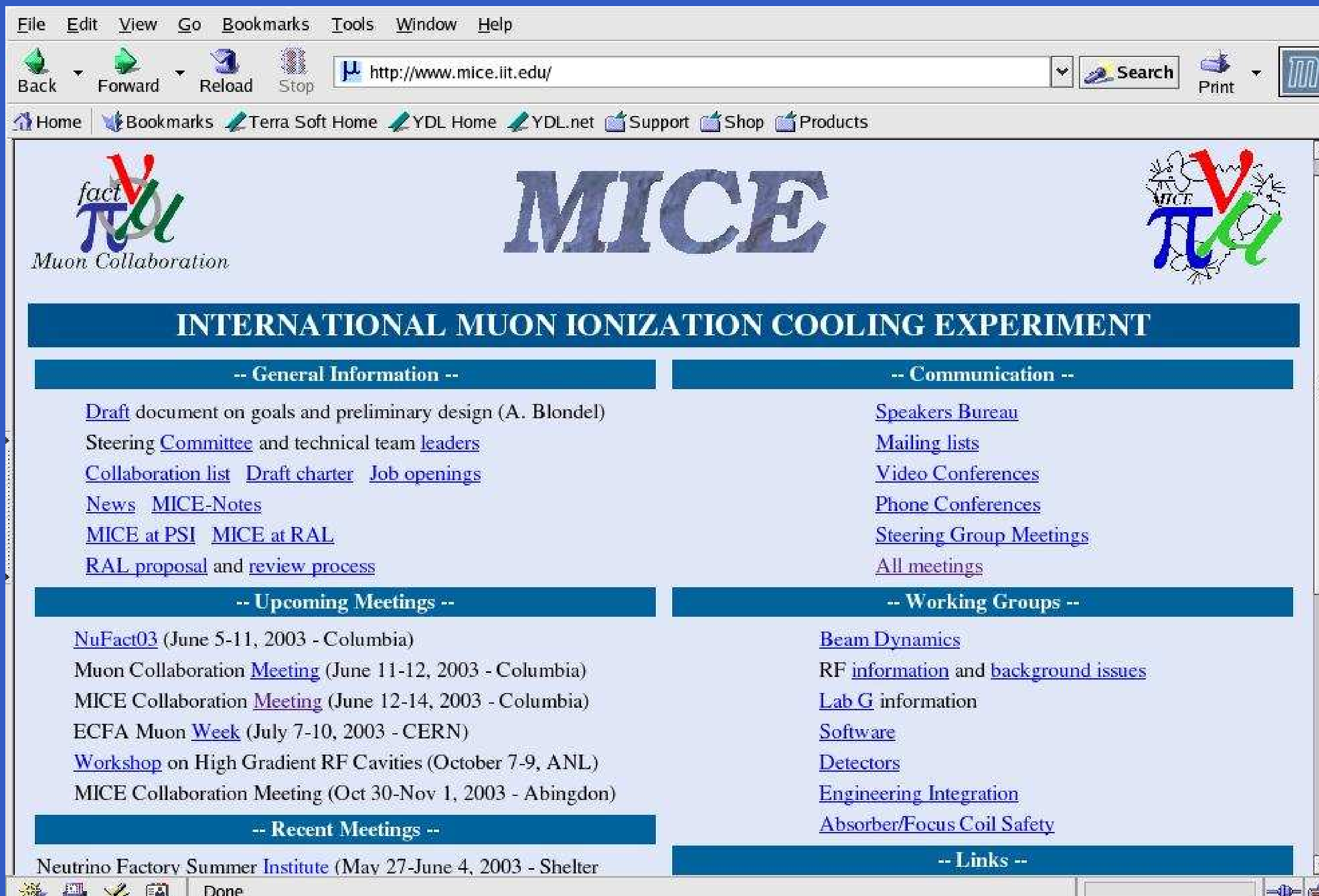
141 physicists and engineers from 40 institutions in 9 countries

- Belgium: UC Louvain
- France: CEA/Saclay
- Italy: INFN Bari, Frascati, Genoa, Legnaro, Milano, Napoli, Padova, Roma III, Trieste
- Japan: KEK, Osaka U
- Netherlands: NIKHEF
- Russian Federation: BINP
- CERN
- Switzerland: U Geneve, ETH-Zurich, PSI
- UK: Brunel, Edinburgh, Glasgow, Liverpool, Imperial, Oxford, RAL, Sheffield
- USA: ANL, BNL, Fairfield, Chicago, Fermilab, IIT, JLab, LBNL, UCLA, Northern Illinois, Iowa, Mississippi, UC Riverside

Organization

- Communication infrastructure in place (website, email lists, MICE-Notes)
- Regular video conferences (biweekly)
- 3 collaboration meetings a year (CERN, UK, US)
- Next (6th) collaboration meeting here June 12-14
- Several Collaboration Board meetings
- Steering committee meets biweekly by phone
- Working group activity
  - 2 software workshops + biweekly phone conf
  - detector meetings during ECFA Muon Weeks
  - absorber/focus coil safety group biweekly phone conf
- Draft charter under review

http://www.mice.iit.edu/



Organization

Steering Committee

- A. Blondel (Geneva), Chair and European Spokesmouse
- P. V. Drumm (RAL)
- R. Edgecock (RAL)
- S. Geer (FNAL)
- H. Haseroth (CERN)
- I. Ivaniouchenkov (RAL)
- D. M. Kaplan (IIT), US Spokesmouse
- Y. Kuno (Osaka)
- K. Long (ICL)
- V. Palladino (INFN Naples)
- Y. Torun (IIT)
- M. S. Zisman (LBNL)

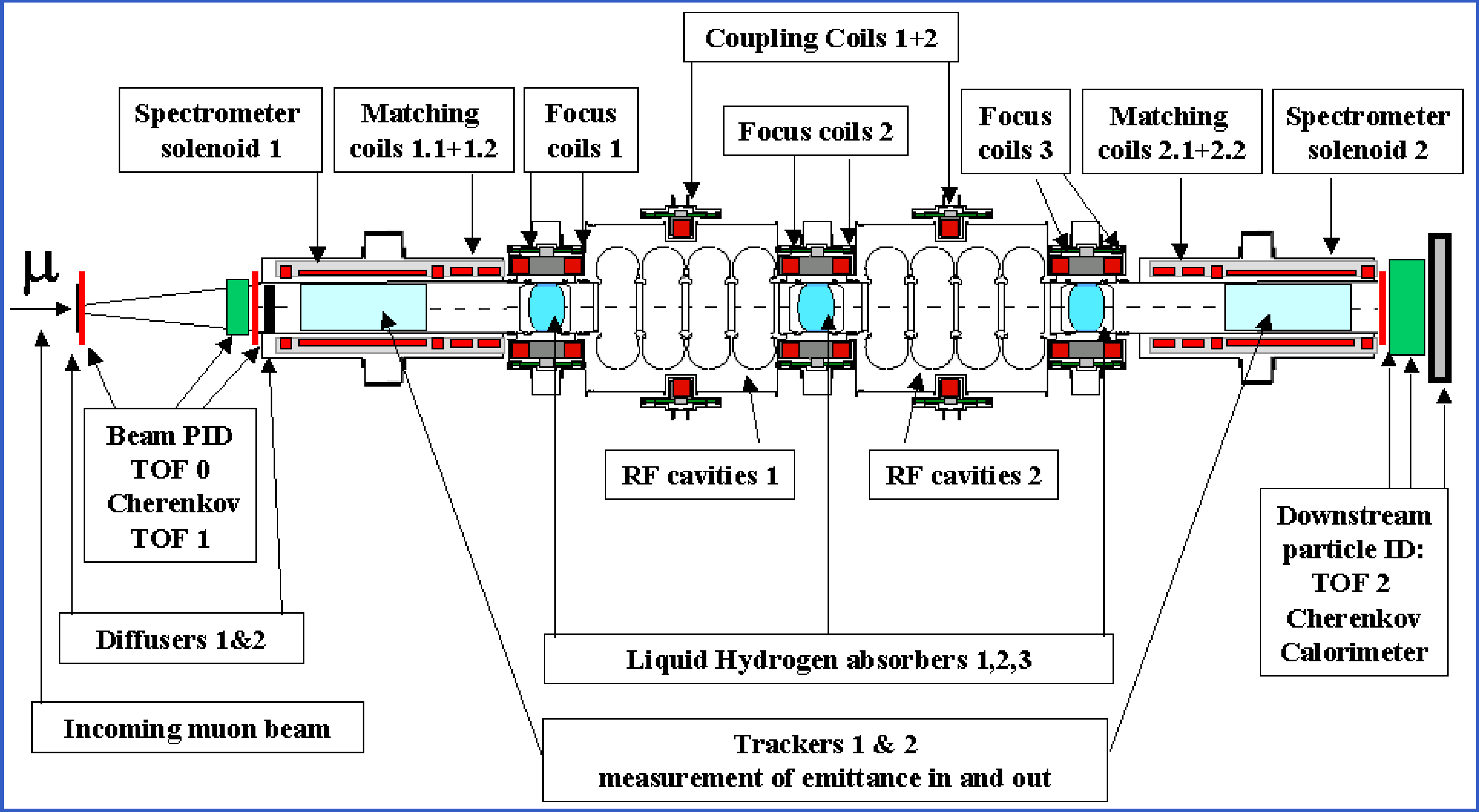
Organization

Working Group Conveners

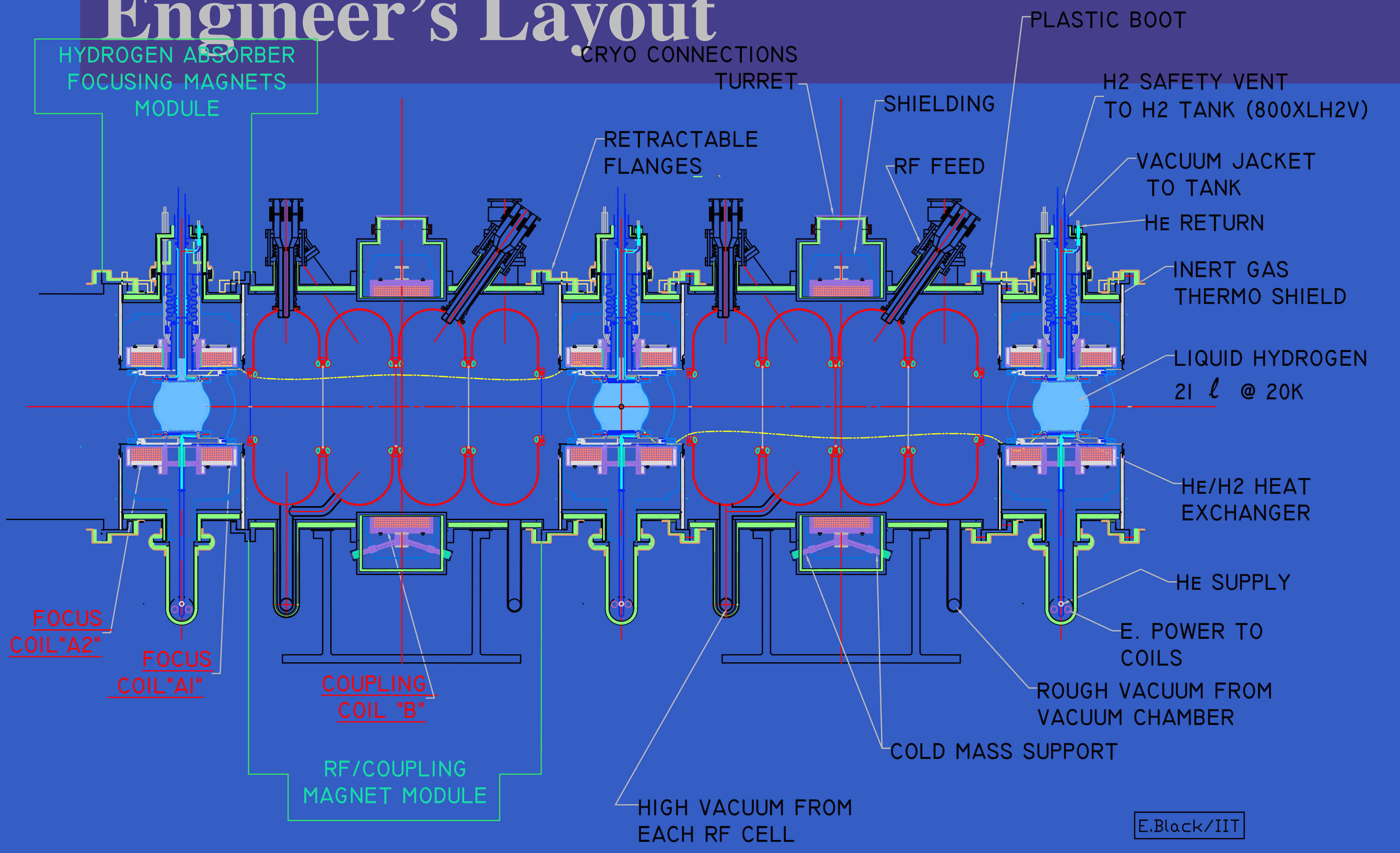
- Concept development: R. Edgecock (RAL), R. B. Palmer (BNL)
- Simulation: M. G. Catanesi (INFN Bari), Y. Torun (IIT)
- Hydrogen absorbers: M. A. Cummings (NIU), S. Ishimoto (KEK)
- RF cavities and power supplies: H. Haseroth (CERN), D. Li (LBNL)
- Magnet systems: M. A. Green (LBNL), J.-M. Rey (Saclay)
- Particle detectors: A. Bross (FNAL), V. Palladino (INFN Napoli)
- Beam line: P. V. Drumm (RAL)
- RF radiation: E. McKigney (ICL), J. Norem (ANL)
- Engineering integration: E. Black (IIT), I. Ivaniouchenkov (RAL)
- Absorber/Focus Coil Safety: M. S. Zisman (LBNL)

EXPERIMENT

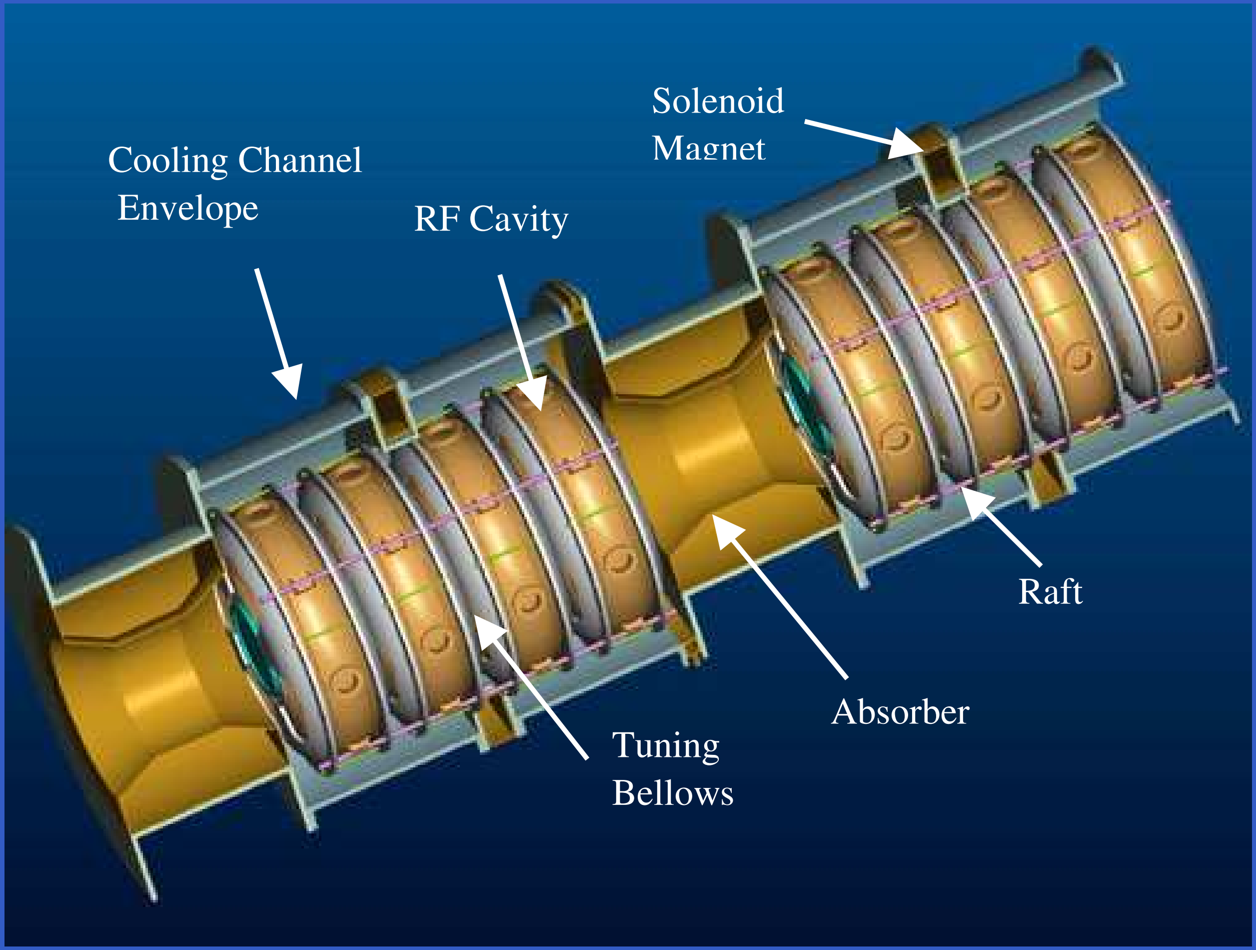
Physicist’s Layout



Engineer's Layout

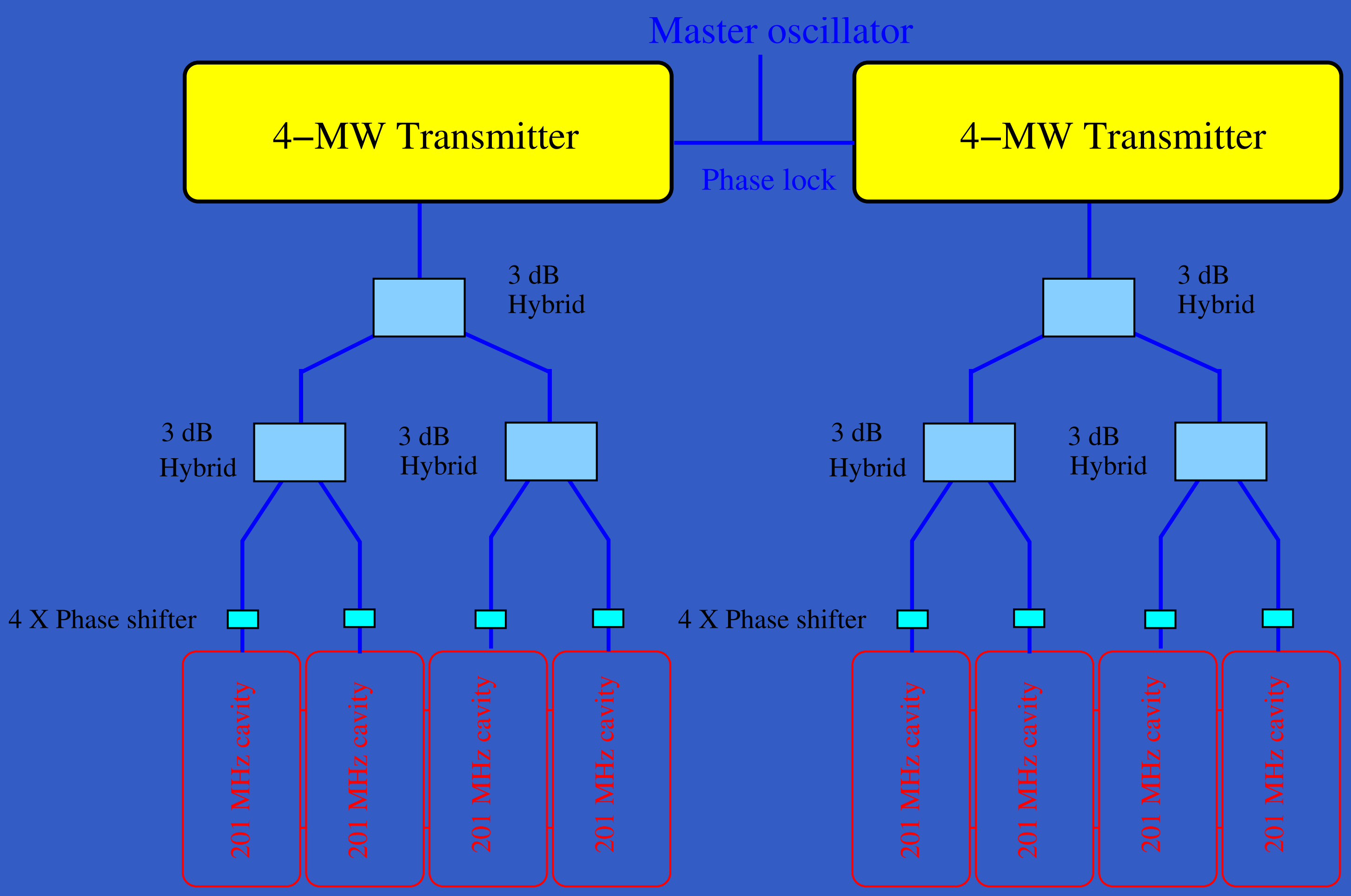


RF Cavities

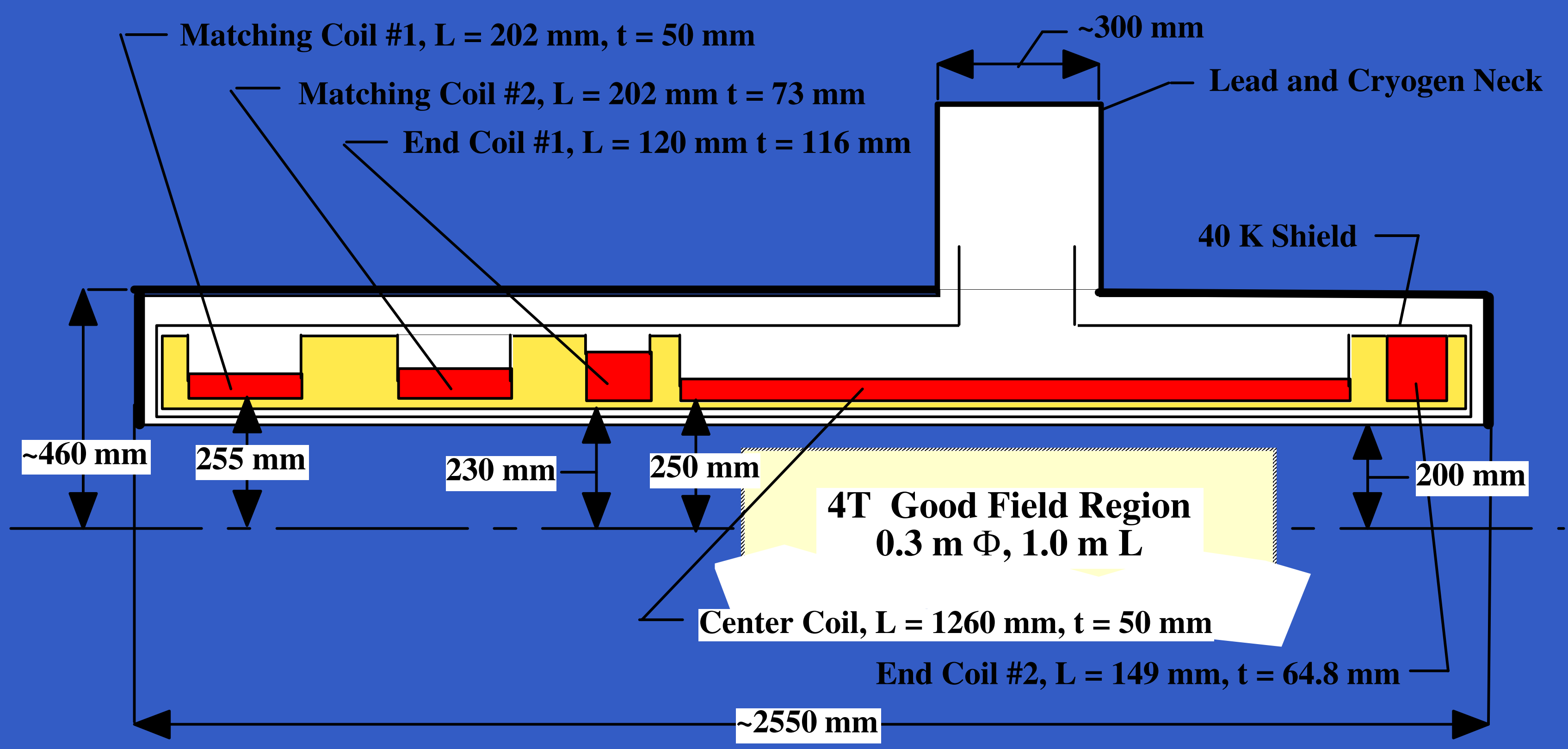


Solenoid
Magnet
Cooling Channel
Envelope
RF Cavity
Raft
Absorber
Tuning
Bellows

RF Power

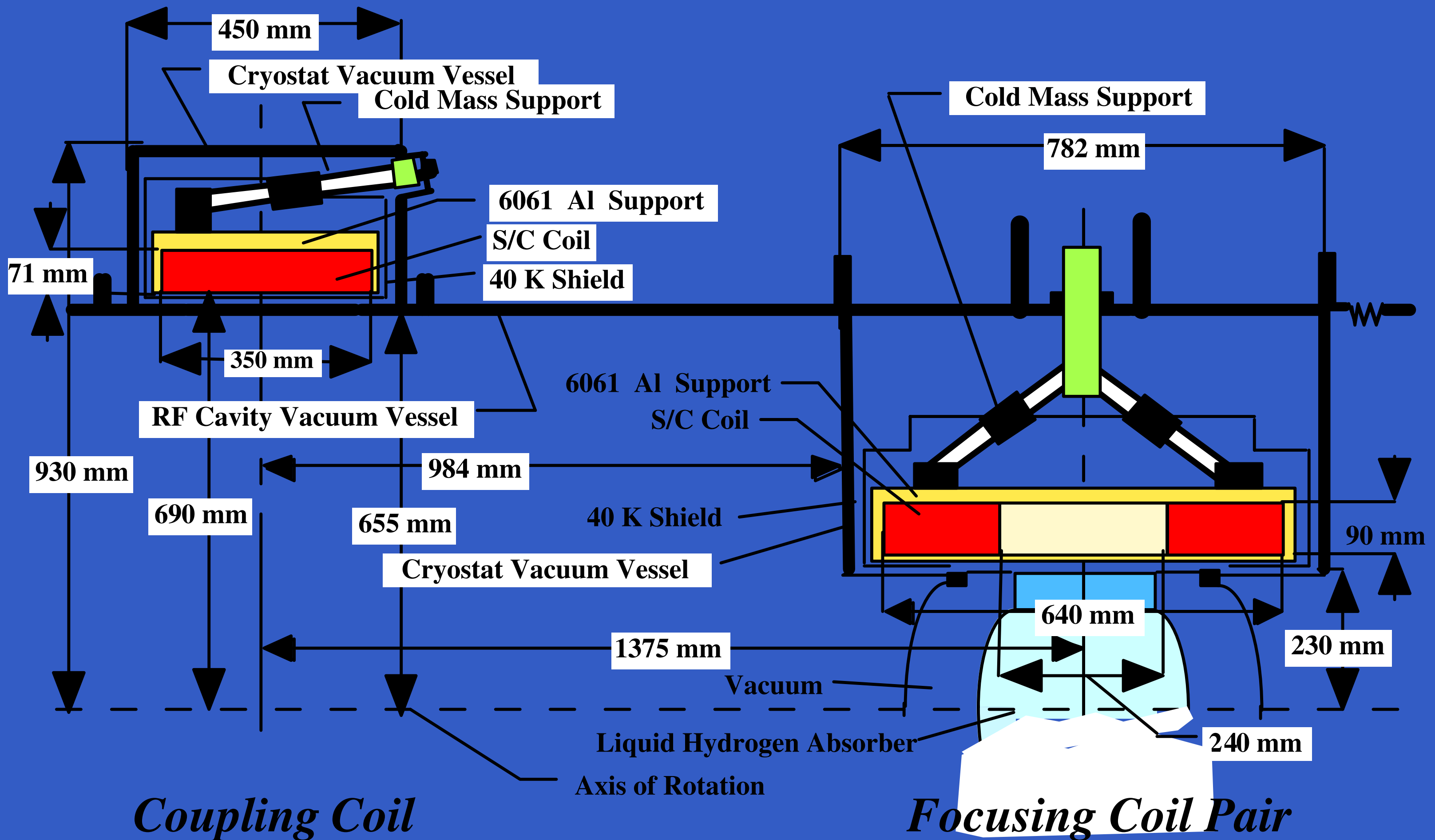

Master oscillator
4–MW Transmitter
Phase lock
4–MW Transmitter
3 dB Hybrid
3 dB Hybrid
3 dB Hybrid
3 dB Hybrid
3 dB Hybrid
3 dB Hybrid
4 X Phase shifter
4 X Phase shifter
201 MHz cavity
201 MHz cavity
201 MHz cavity
201 MHz cavity
201 MHz cavity
201 MHz cavity
201 MHz cavity
201 MHz cavity

Magnets

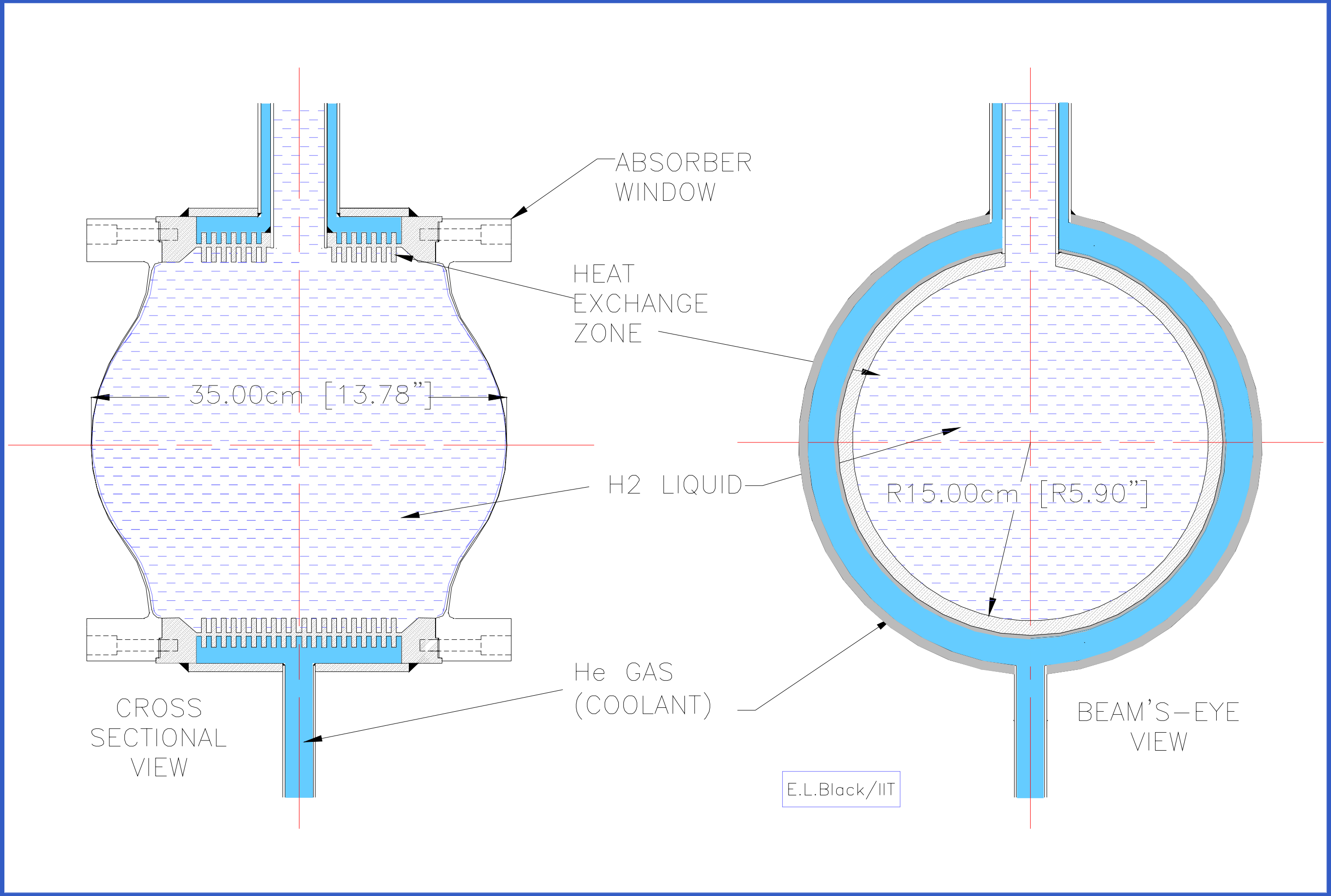


Matching Coil #1, L = 202 mm, t = 50 mm
Matching Coil #2, L = 202 mm t = 73 mm
End Coil #1, L = 120 mm t = 116 mm
~300 mm
Lead and Cryogen Neck
40 K Shield
~460 mm
255 mm
230 mm
250 mm
200 mm
4T Good Field Region
0.3 m Φ, 1.0 m L
Center Coil, L = 1260 mm, t = 50 mm
End Coil #2, L = 149 mm, t = 64.8 mm
~2550 mm

Magnets


450 mm
Cryostat Vacuum Vessel
Cold Mass Support
6061 Al Support
S/C Coil
40 K Shield
71 mm
350 mm
RF Cavity Vacuum Vessel
930 mm
690 mm
655 mm
984 mm
1375 mm
Cold Mass Support
782 mm
6061 Al Support
S/C Coil
40 K Shield
Cryostat Vacuum Vessel
90 mm
640 mm
230 mm
Vacuum
240 mm
Liquid Hydrogen Absorber
Axis of Rotation
Coupling Coil
Focusing Coil Pair

Absorbers



ABSORBER
WINDOW
HEAT
EXCHANGE
ZONE
35.00cm [13.78"]
H2 LIQUID
R15.00cm [R5.90"]
He GAS
(COOLANT)
CROSS
SECTIONAL
VIEW
BEAM'S–EYE
VIEW
E.L.Black/IIT

Measurement Technique

- Traditional beam instrumentation (profile monitors, etc.) gives 10% emittance measurement - we need 0.1%
  $\Rightarrow$ use standard HEP techniques
  - track one muon at a time through the apparatus
  - form “virtual bunches” in offline analysis
- Magnetic spectrometer for momentum measurement (solenoid for easy matching)

Measurement Technique

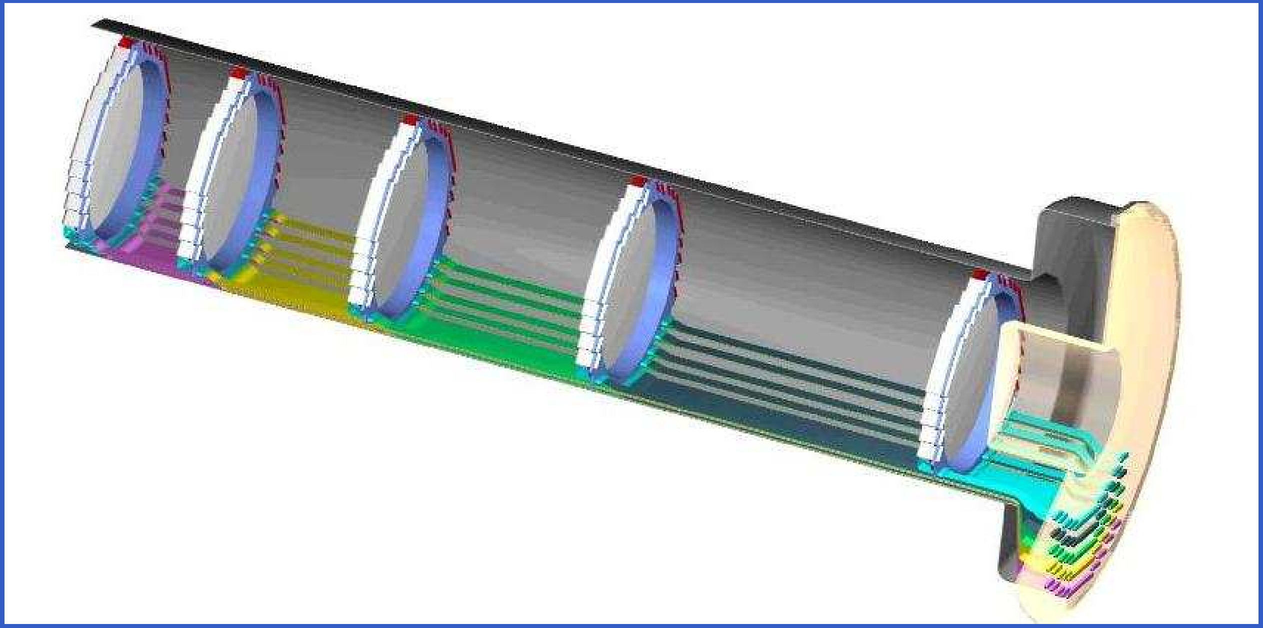
Detectors

MICE detectors have to

- efficiently reject contamination in the beam and muon decays without biasing muon sample
- measure all 6 coordinates of each particle
- with resolution better than 10% of the rms size at equilibrium emittance in each dimension
- tolerate background from rf cavities
- present low mass to the beam

Detectors

Baseline scintillating fiber tracker with 5 stations of 3 doublet planes made of 0.35mm fiber.



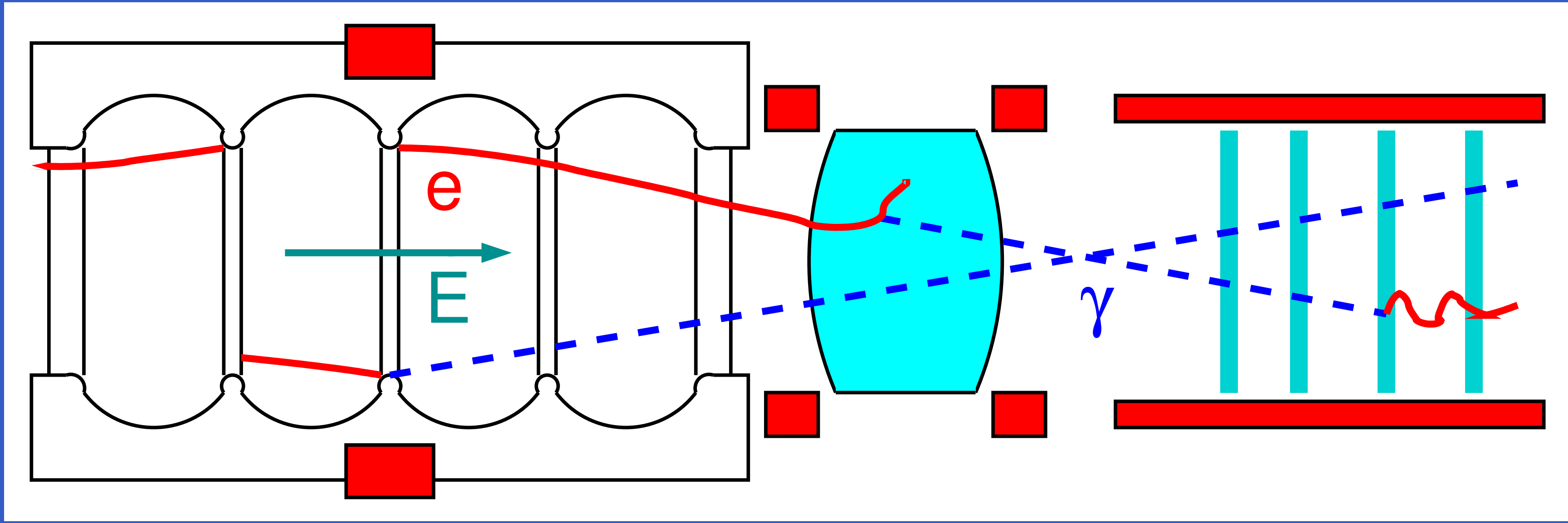
Detectors

For low background levels, significant cost savings possible by

- multiplexing fibers (eg. 7 to 1)
- using a TPC with light gas and GEM readout (TPG)

Prototyping in progress for both tracker options.

Backgrounds



- Electrons stripped from metal surface
- accelerated by cavity field, generate x-rays
- dark current absorbed by liquid hydrogen
- x-rays flood downstream detectors

Field emission

Fowler-Nordheim current density j_{FN} from tunneling through potential barrier (work function ϕ) at metal surface

$$j_{FN}(E) = \frac{A}{\phi}(\beta E)^2 exp\left(-\frac{B\phi^{3/2}}{\beta E}\right)$$

$$n = \frac{E}{j}\frac{dj}{dE} \simeq 2 + \frac{67.4\text{GV/m}}{\beta E}$$

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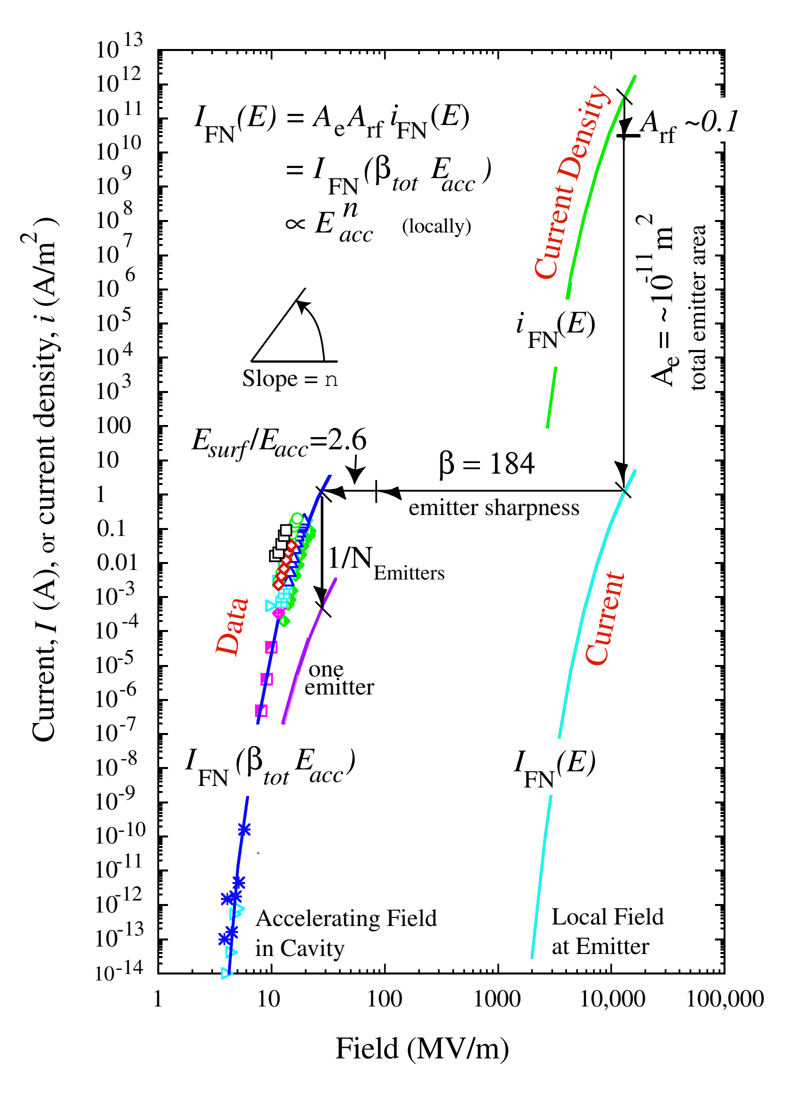


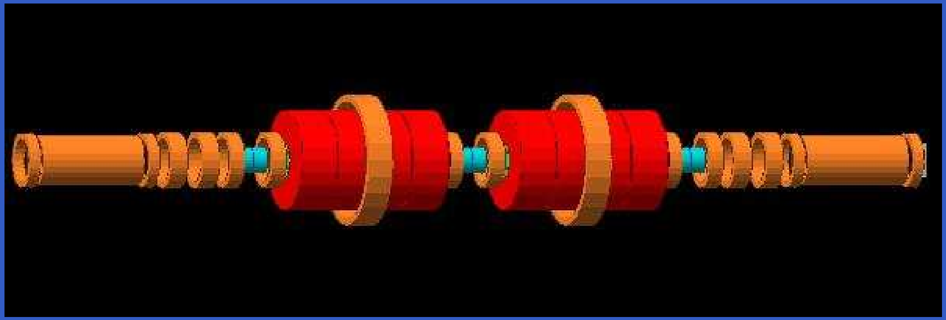
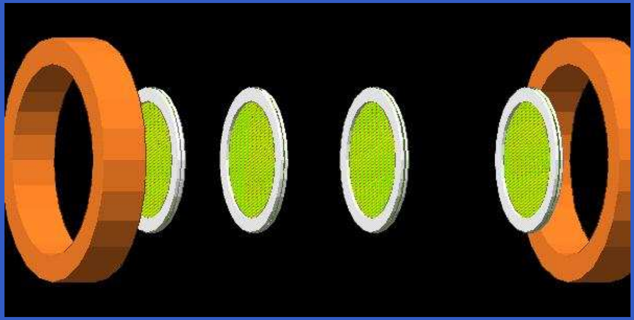
Backgrounds

- Background measurements at Lab-G (Fermilab) with 805MHz prototypes
- Extrapolation to 201MHz implies MICE detectors should work
- Would like to reduce rf radiation to save channel count
- Tested scintillating fiber hit rates in cavity background
- Fibers are robust in rf environment

Software

Set up a GEANT4 based project to handle beam, cooling hardware, detectors and physics within the same framework $\Rightarrow$ G4MICE

- Implemented essentially complete magnetic lattice, detector geometry and response, rf background and full reconstruction
- Working on detector optimization, background sensitivity
- Starting physics analysis

MICE @ RAL

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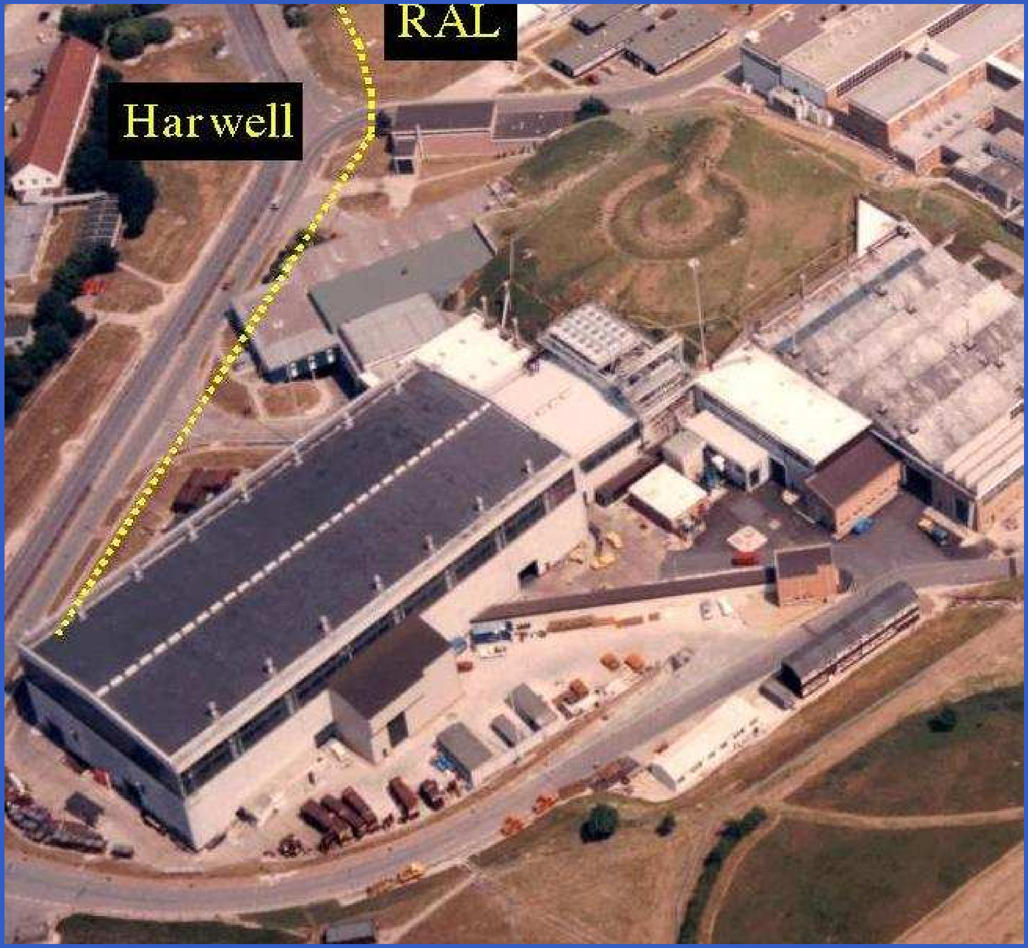
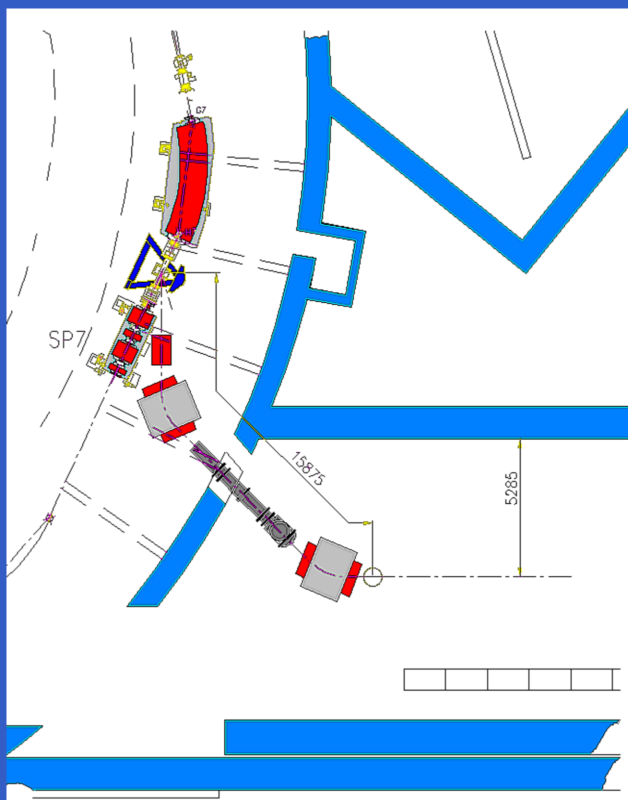
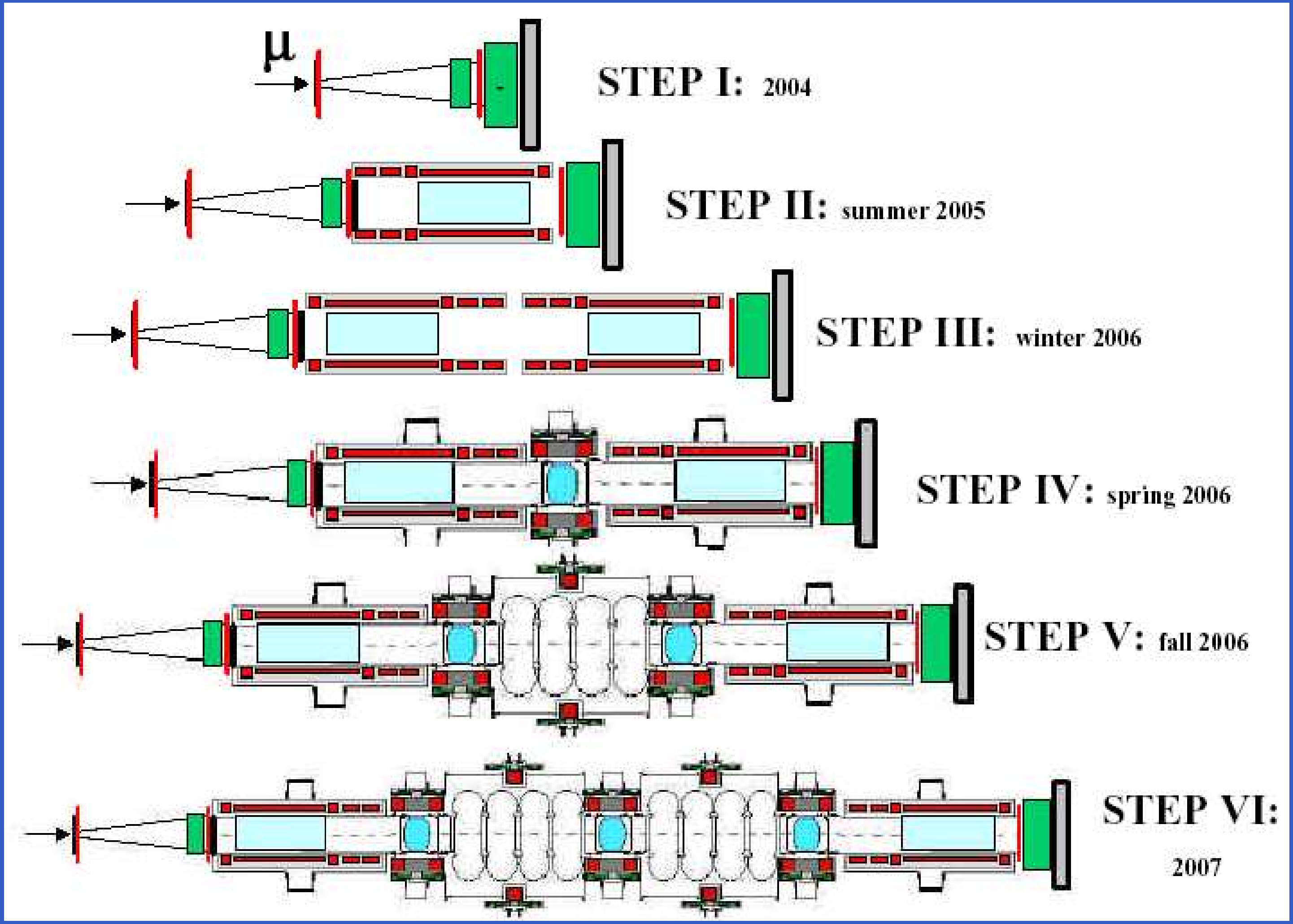


ISIS Beamline



Possible Staging Scenario



Future Possibilities

- Other absorber configurations (solid absorbers, empty one absorber, etc.)
- Different beam momentum and optics ($\beta_\perp$)
- Different focus coil polarity to remove field flips
- Larger rf gradient, different rf phase
- Other cooling hardware (ring cooler components, gaseous hydrogen, etc.)

STATUS

Quotables

MUTAC Report on the Muon Collaboration Review
Fermilab, January 14-15, 2003

The committee is very pleased to see the development of the MICE proposal, as we believe ionization cooling is a fundamental part of the neutrino factory accelerator design that must be demonstrated. The international character of the MICE experiment is also very encouraging.
The committee is pleased to see that the proposal has been submitted to a laboratory (Rutherford Lab, ISIS) that has much of the needed infrastructure and potential for easy beamline modification to supply muons, as well as experience with liquid hydrogen safety. With the recent reemergence of UK interest in accelerator physics, this proposal appears to be a very positive development. We hope for acceptance of the plan by the laboratory in the near future.

Quotables

EMCOG
CERN, Feb 6, 2003

EMCOG was impressed by the quality of the experiment, which has been well studied, is well organized and well structured. The issue of ionization cooling is critical and this justifies the important effort that the experiment represents. EMCOG recommends very strongly a timely realization of MICE.

Quotables

Report from the MICE International Peer Review Panel
Abingdon - May 2-3, 2003

The MICE proposal, which was submitted following the discussion of a Letter of Intent in March 2002, has been reviewed by an International Peer Review Panel .. which strongly recommends approval of the project.
The Panel endorses the scientific case for MICE. It is a timely experiment and will provide a realistic prototype of an ionisation cooling channel for muons. This is an important piece of accelerator physics, and will remove many of the current uncertainties of performance and cost associated with this method of muon accumulation and cooling. The MICE experiment is therefore a crucial prerequisite in understanding the potential use of muons in a future Neutrino Factory or muon collider.

Outlook

- Ionization cooling is a key technology for high-performance Neutrino Factories
- A timely test of the technology is crucial for the future of neutrino physics
- The time to start is NOW if we want the ability to build a Neutrino Factory in the future
- MICE is an experiment in international collaboration for accelerator R&D
- We have scientific approval
- Funding search in progress