

International Muon Ionization Cooling Experiment

Experiment Details

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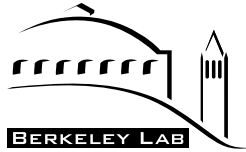
PPRP Review—RAL
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Outline



- Introduction
- Required Components
- Simulation Results
- Host Laboratory Requirements
- Schedule
- Costs
- Organization
- Summary



Introduction



- Motivation for **MICE**
 - we require ionization cooling to build a high-performance Neutrino Factory ($\approx 4 \times 10^{20}$ ν_e aimed at far detector per 10^7 s year)
 - Muon Collider places even higher performance demands on cooling
 - straightforward physics, but not experimentally demonstrated
 - facility will be expensive ($\mathcal{O}(\$1B)$)
 - prudence dictates a demonstration of the key principle
 - a color TV is “just Maxwell's equations”
- Cooling demonstration implies:
 - development and testing individual components with challenging operating specifications (done “outside” of **MICE**)
 - showing these components can function properly in close proximity
 - showing that a realistic system can reduce the emittance of muons



Introduction



- Other requirements
 - show that our design tools (simulation codes) are in agreement with experimental observations
 - important to gain confidence in our ability to optimize the design of an actual facility
 - we test section of “a” cooling channel, not “the” cooling channel
 - ◊ simulations are the means to connect the two
- Why must we move forward expeditiously?
 - experiment forces us to deal with operational and cost issues early
 - cooling demonstration is on the critical path to eventually building a Neutrino Factory
 - particle and accelerator physics communities are unlikely to get behind such a project without this



Introduction



- Challenges of **MICE**
 - for cost reasons, we must measure emittance reduction from only one or a few cells of a cooling channel
 - ⇒ emittance reduction will be small in absolute terms ($\mathcal{O}(10\%)$)
 - need detectors capable of measuring emittance reduction at level of 10^{-3}
 - need simulations to be as close to reality as possible
 - incorporate full engineering details of solenoids, rf cavities, absorbers, detectors

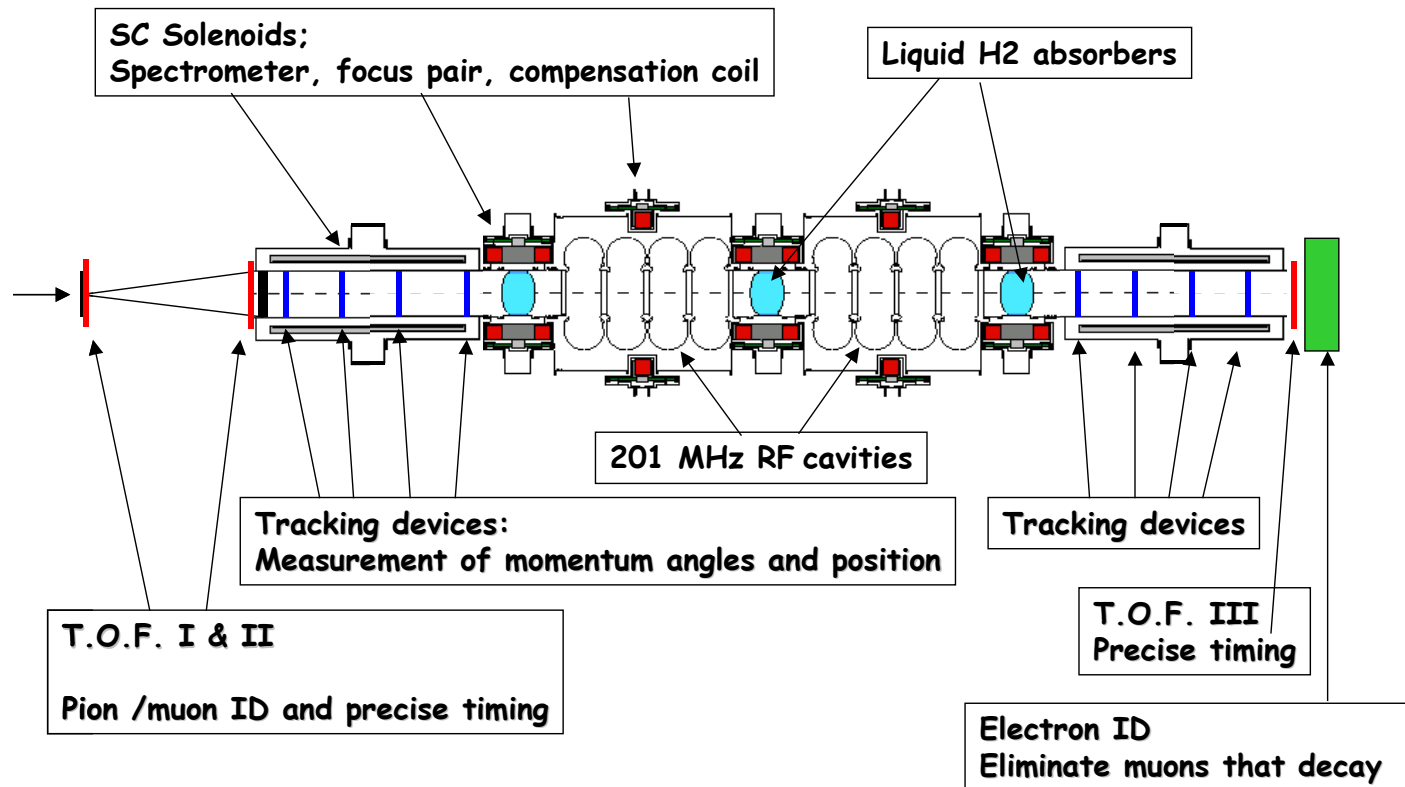


Introduction

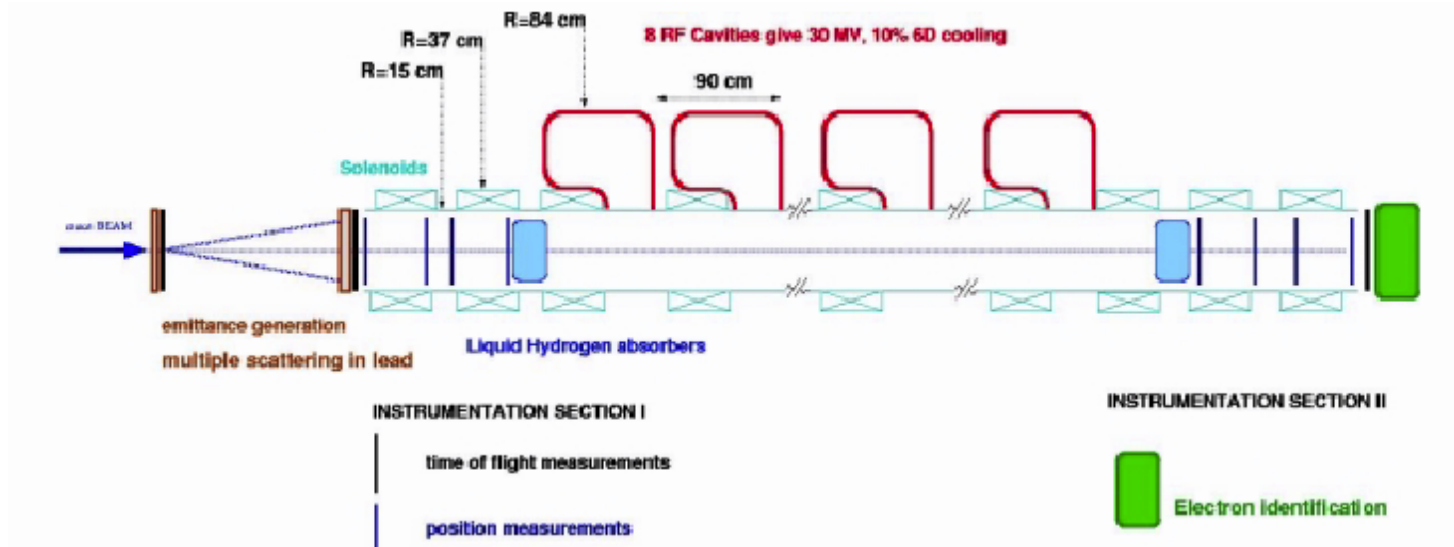


- **Basic ingredients** of a cooling channel are:
 - **absorbers** to give energy loss (LH₂ capable of handling 100–300 W)
 - **rf cavities** to restore energy lost in absorbers (17 MV/m gradient at 201 MHz; 4 MV/m at 88 MHz)
 - **solenoid magnets** to contain the muons as they traverse the channel (up to 5 T)
- For **MICE**, we add
 - **diffuser** to create large emittance sample
 - **upstream diagnostics section** to define initial emittance
 - **downstream diagnostics section** to determine final emittance and particle ID
- **Already at the prototyping stage** for many of these components
- **Simulations** of both systems are **in progress**

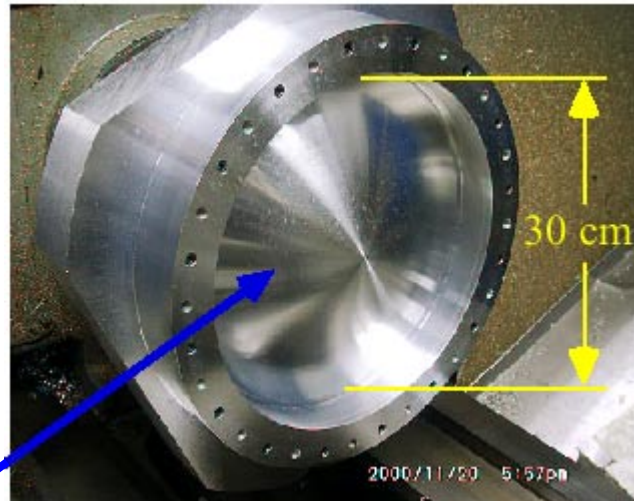
- Baseline option for **MICE** uses 201 MHz



- Alternative design based on 88 MHz rf also studied



- Absorbers (**Kaplan, Cummings, Ishimoto, Summers**)
 - design based on LH₂ system, either externally cooled or with internal convection cooling
 - requires large diameter, very thin (but strong!) Al windows

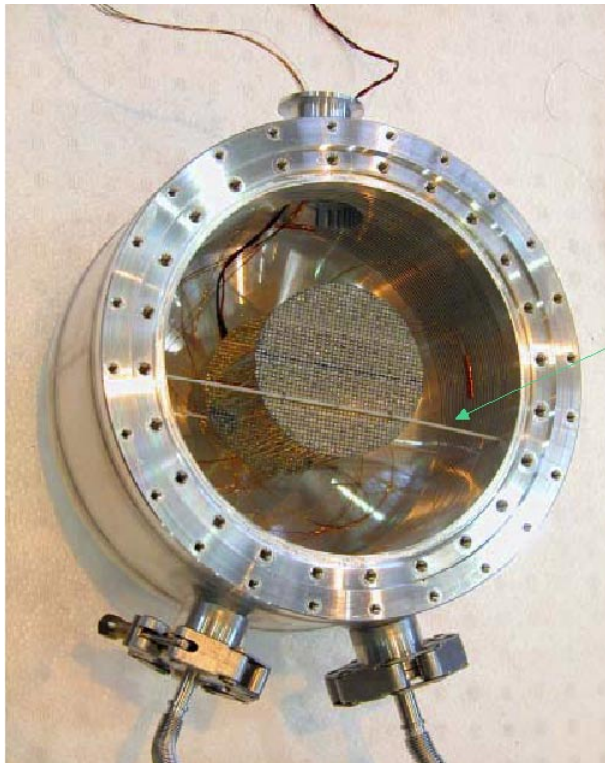


330 μ m tapered window

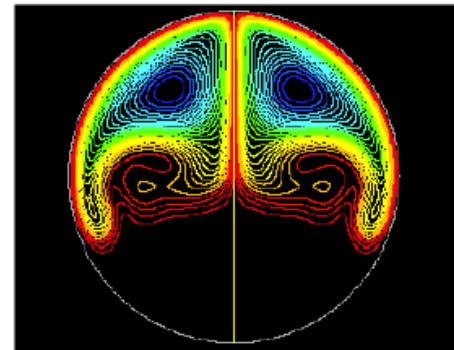
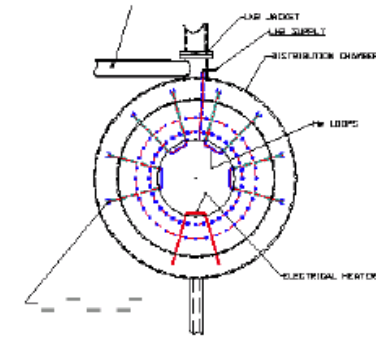
- U-Miss can machine such windows from a solid piece of Al

Required Components

- Convection cooled absorber designed and fabricated at KEK
 - cryogenic tests with LNe have begun
 - thermal simulations under way at IIT

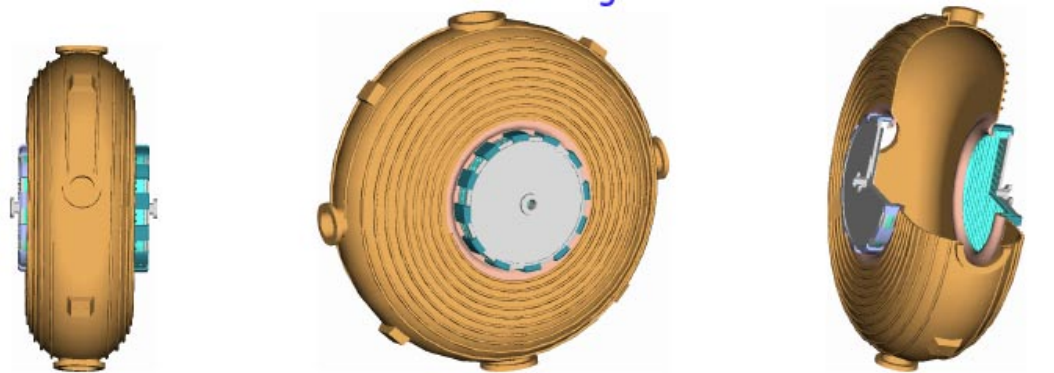


→ Internal heat exchange:

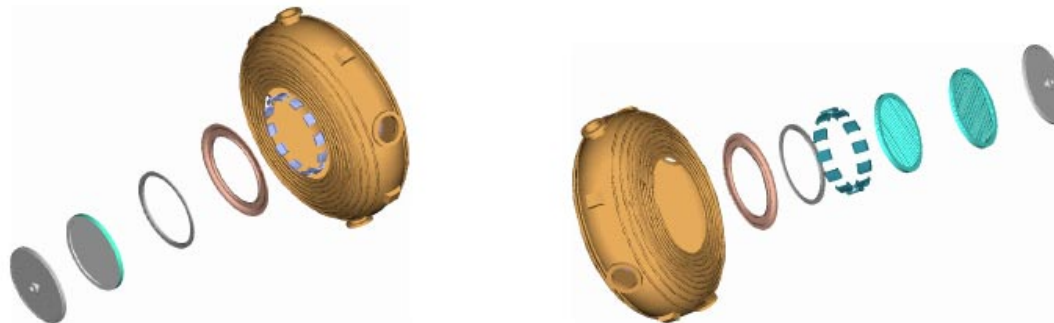


Required Components

- 201 MHz rf cavity design is well along (**Rimmer, Ladran**)



201.25 MHz cavity conceptual design

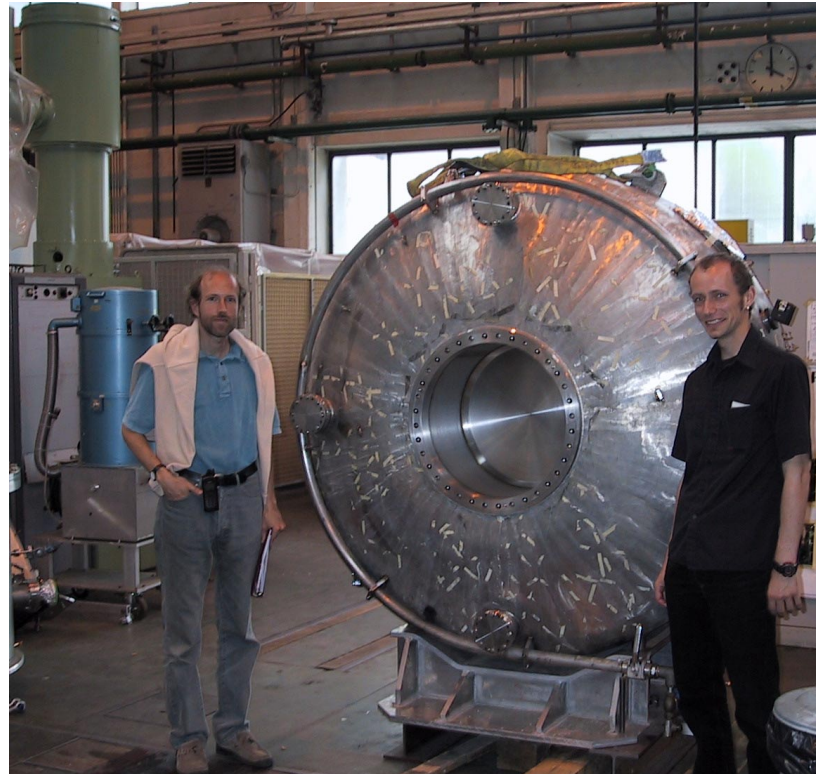


Exploded views showing foil and grid mounting hardware

- options for both stepped Be windows and grids are available

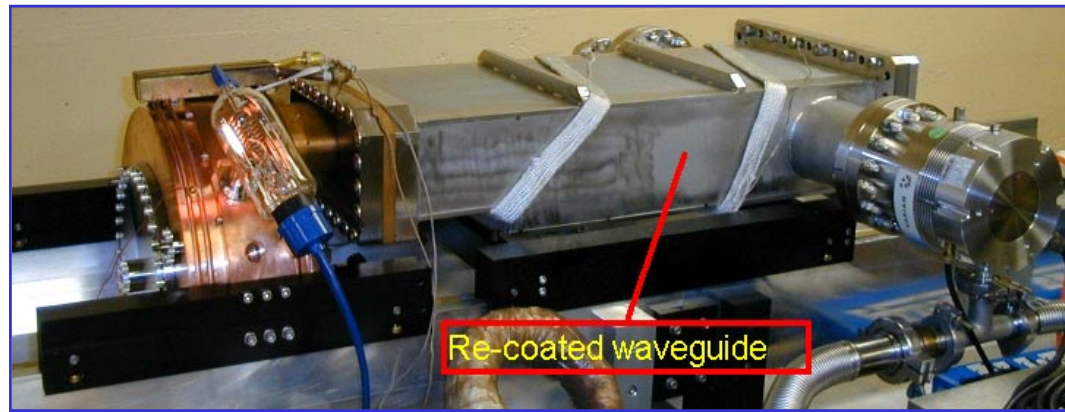
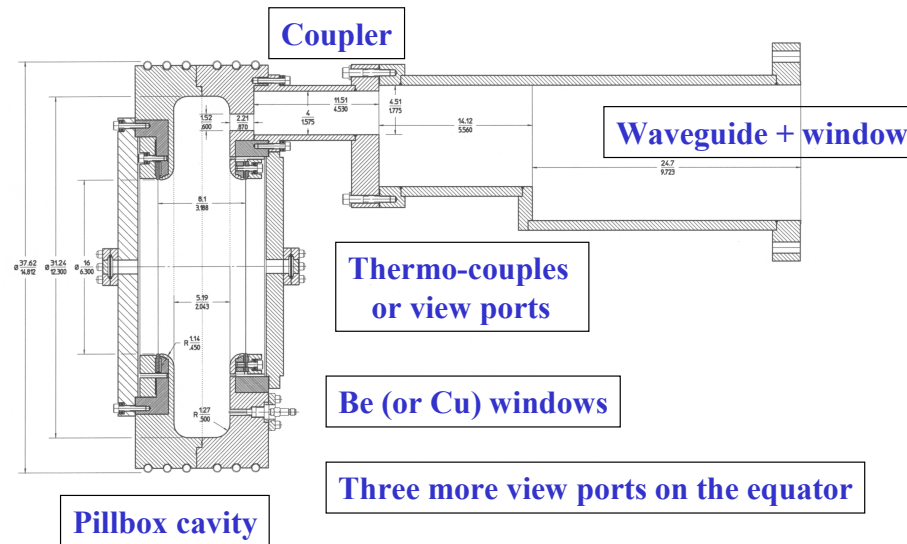
Required Components

- Prototype of 88 MHz cavity also being readied for testing at CERN
(Garoby, Vretenar, Gerigk, Schulz, Rossi)



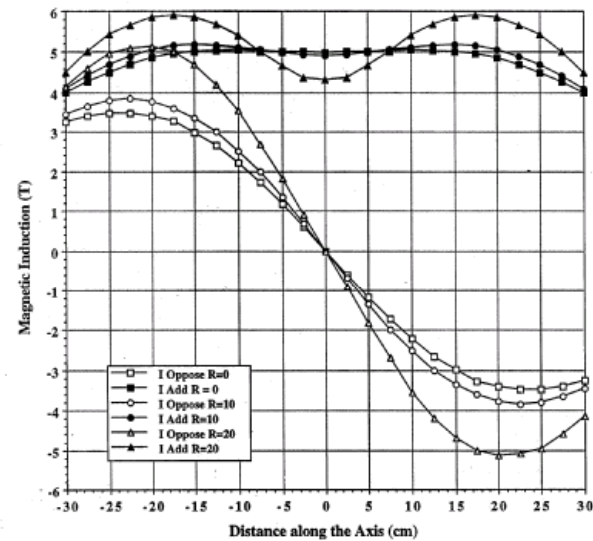
Required Components

- 805 MHz cavity with foils is about to be tested at Fermilab (Li, Rimmer)



Required Components

- Test solenoid, representative of that needed for cooling channel has been built and tested (**Green**)



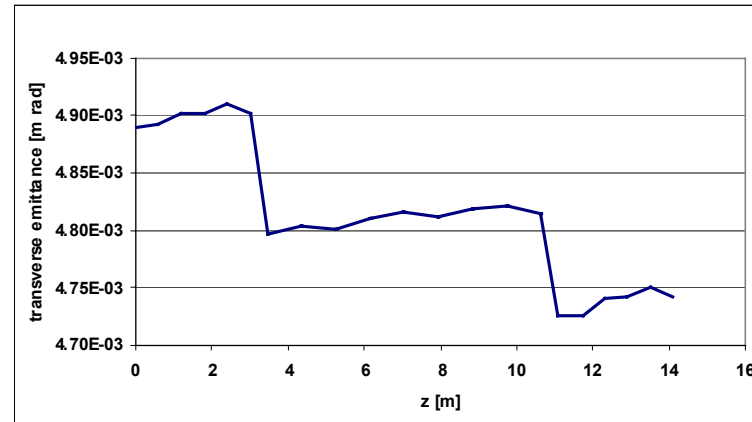


Simulation Results

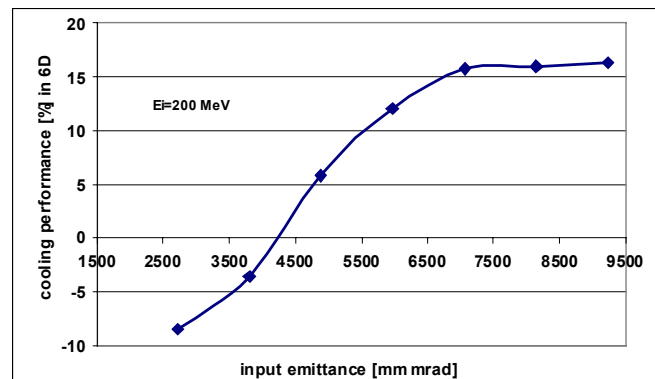


- Simulations of both 201 MHz (Palmer, Fernow, Spentzouris, Elvira, Torun) and 88 MHz (Hanke, Lombardi) experiment are under way
 - several tools developed/adapted for cooling simulations
 - ICOOL, PATH, Geant4
 - codes have been cross checked and (now) give consistent results
 - final simulations with all details will be done with Geant
- Typical parameters (88 MHz case)
 - beam
 - kinetic energy: 200 MeV (variable)
 - energy spread: ± 15 MeV
 - channel
 - solenoid field: ≈ 3 T
 - β_{\perp} : 1 m
 - cavity phase: 90° (on crest)

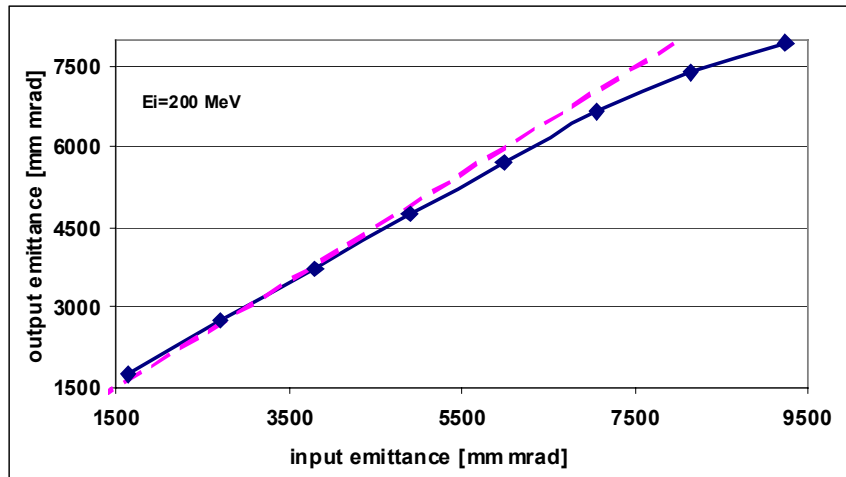
- PATH simulation of the 88 MHz experiment (**Hanke**) using 50,000 particles shows transverse emittance reduction of 3.7%



- increase in particles within $\varepsilon_{\perp, \text{norm}}$ of 15 mm-rad and longitudinal emittance of 0.1 eV-s (our "figure of merit") reaches 15%

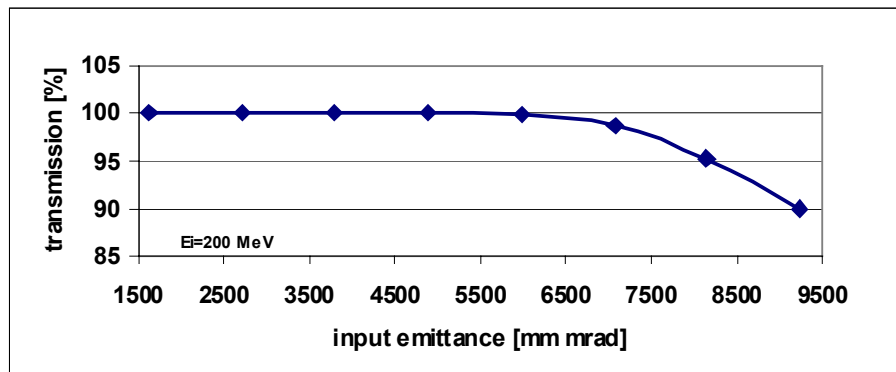


- virtual “scan” over input emittance locates the equilibrium emittance



$$\mathcal{E}_{x,N,equil.} = \frac{\beta_{\perp} (0.014 \text{ GeV})^2}{2\beta m_{\mu} L_R \left| \frac{dE}{ds} \right|}$$

- transmission is 100% for input emittance below 6 mm-rad

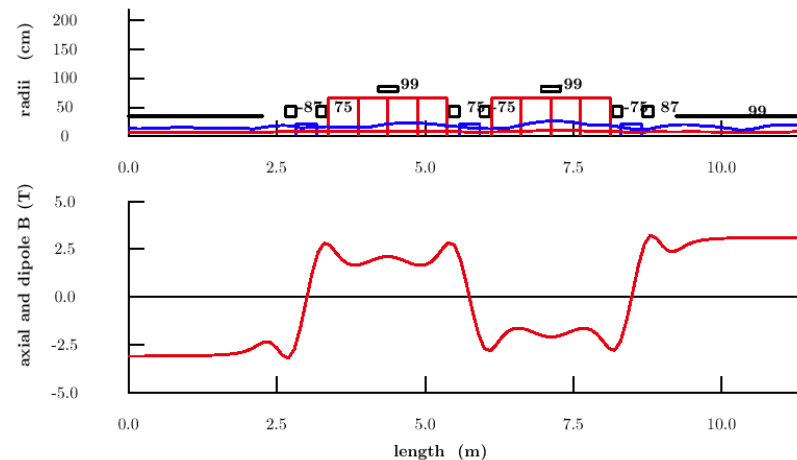


- Corresponding ICOOL simulations being performed (**Palmer, Fernow**) for 201 MHz version of the experiment, with similar results

— input parameters

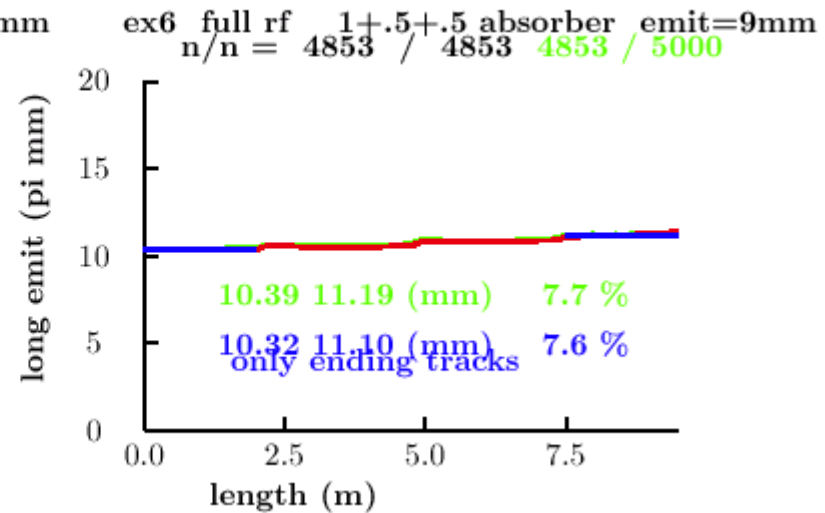
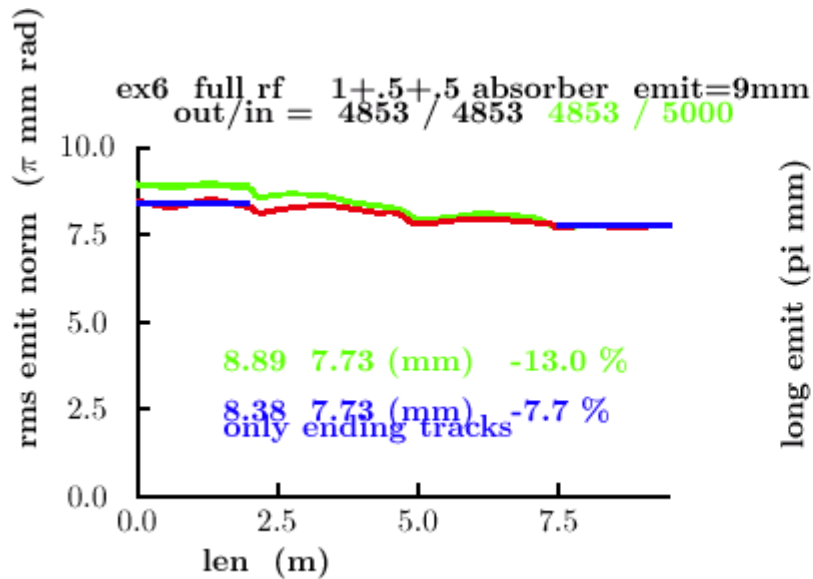
No. of particles	5000
Initial momentum (MeV/c)	200
Initial transverse emittance (mm-rad)	9
Initial longitudinal emittance (mm)	11
Momentum spread	0.07
Bunch length (mm)	90

— layout



— results (Case a)

	<u>All tracks</u>	<u>Ending tracks</u>
Transverse emittance change (%)	-13.0	-7.7
Longitudinal emittance change (%)	+7.7	+7.6
6D emittance change (%)	-18.9	-8.9





Host Laboratory Requirements



- To carry out **MICE**, the following muon beam parameters are desirable:

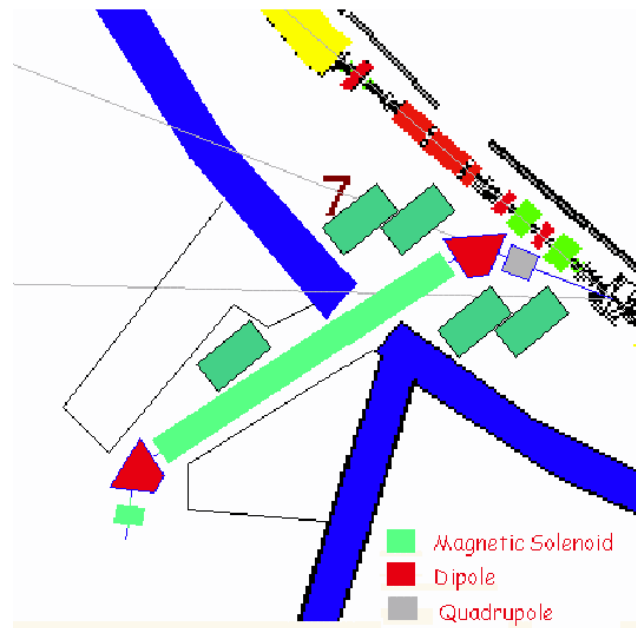
Kinetic energy (MeV):	100-300
Energy spread:	$\pm 10\%$
$\sigma_{x,y}$ (mm):	50
Norm. emittance (mm-rad):	≤ 10
Purity:	$\pi\mu < 1\%$

— other infrastructure needs:

10 m path for emittance preparation
Floor area 15 x 5 m, plus shielding
Provision for cryogenics, LCW, LH₂ (\Rightarrow safety implications)
Electrical power <100 kW (initially)

- **We are assured that all these can be obtained at RAL** after suitable upgrades of an existing beamline

- Proposed new beamline (**Drumm**) would capture at 20°
 - assumes 10 m long, 20 cm aperture, 5 T decay solenoid
 - simulated performance for 10^7 incident p/bunch at 800 MeV
- 50 μ^+ per bunch per turn ($\approx 15,000$ during rf pulse); π^+ few-% level
(we need $\approx 1-2$ muon/bunch)
- PSI offers solenoid** giving similar muon intensity (factor of 2 less)





Schedule



- **Schedule quoted in LOI**

November '01:	LOI to PSI and RAL
2002:	Develop detailed technical proposal; fundraising
2002-2004:	Spectrometer construction
2004:	Spectrometer commissioning with muon beam
2005-2006:	Assembly and commissioning of first cooling cell
2006-2007:	Assembly and commissioning of second cooling cell

- **recent funding situation (both Europe and US) will undoubtedly slow progress**
- **but, an expression by the UK (CLRC) of its willingness to proceed if funding is forthcoming would be a big step forward**

- **Developing detailed schedule will be part of preparing **MICE** Technical Proposal**

- We have taken an **initial look at costs**, using US Feasibility Study-II as the cost basis for cooling channel components
 - if we need new power supplies, **rf power becomes major cost driver**
 - **integrating absorber with focusing coil likely to reduce these costs**

			1 cavity 4 MW	1 cavity 8 MW	2 cavities 4 MW	2 cavities 8 MW
cooling DE (On crest)			11.5MV	16 MV	16 MV	23 MV
Approx. $\Delta\epsilon/\epsilon$ (%)			5%	7%	7%	10%
Cost estimate in US\$, US accounting	Fixed cost	Unit cost				
COOLING CELLS						
RF Cavities						
4 cell cavity 200 MHz	0.3	0.5	0.8	0.8	1.3	1.3
RF Power						
CERN-refurbish		0.2	0.2	0.2	0.2	0.2
FNAL-refurbish (?)		0.2	0	0.2		0.2
Magnets						
Focus pair	1	1	3	3	4	4
Coupling coil	1	1	2	2	3	3
Liquid H2 absorbers						
	0.5	0.1	0.7	0.7	0.8	0.8
H2 safety	2		2	2	2	2
Total for cooling cell US \$ (US costing)			8.7	8.9	11.3	11.5
SPECTROMETERS						
Solenoids		1	2	2	2	2
Detectors		2	2	2	2	2
Total spectrometers			4	4	4	4
Subtotal	4		12.7	12.9	15.3	15.5
Infrastr., extras(20%)						
TOTAL	4.8		14.6	14.9	17.5	17.8



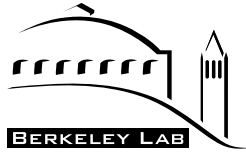
Organization



• Participating institutions:

Louvain La Neuve
NESTOR Institute
Hellenic Open University
INFN LNF Frascati
INFN Milano
INFN Napoli
INFN Roma II
INFN Trieste
Paul Scherrer Institute
University of Zurich
Rutherford Appleton Laboratory
Birmingham University
Osaka University
Brookhaven National Laboratory
Fairfield University
Illinois Institute of Technology
Michigan State University
Princeton University
University of California, Riverside
University of Chicago
University of Iowa

CERN
University of Athens
INFN Bari
INFN Legnaro
INFN Padova
INFN Roma I
INFN Roma III
ETH Zurich
University of Geneva
Imperial College London
Oxford University
KEK
Argonne National Laboratory
Columbia University
Fermi National Accelerator Laboratory
Lawrence Berkeley National Laboratory
Northern Illinois University
University of California, Los Angeles
Indiana University
University of Illinois, Urbana-Champaign
University of Mississippi



Organization



- **Muon Cooling Demonstration Experiment Steering Committee**

Alain Blondel ^a , Convener	U. Geneva
Rob Edgecock	RAL
Stephen Geer	Fermilab
Helmut Haseroth	CERN
Daniel Kaplan ^b	IIT
Yoshitaka Kuno	Osaka U.
Michael Zisman	LBNL

^aEuropean spokesperson

^bUS spokesperson

- **Technical team leaders**

Simulations: **A. Lombardi** (CERN); **R. Palmer** (BNL); **P. Spentzouris** (FNAL)

Absorbers: **S. Ishimoto** (KEK); **M. A. Cummings** (NIU)

RF cavities and power source: **R. Garoby** (CERN); **R. Rimmer** (LBNL)

Magnets: **M. A. Green** (LBNL), **J.-M. Rey** (CEA Saclay)

Particle detectors: **A. Bross** (FNAL); **V. Palladino** (INFN, Napoli)

Beamlines: **R. Edgecock** (RAL); **C. Petitjean** (PSI)

RF radiation: **E. McKigney** (IC-London); **J. Norem** (ANL)

- **We meet via regular video conferences and workshops (next at RAL)**



Summary



- **MICE** is **necessary next step** toward a proposal for a Neutrino Factory
 - **MICE** is **international** from the outset; we **welcome new members**
- We have **developed a practical concept to measure muon cooling**
- **Component R&D is already in an advanced state**
- Finding needed resources benefits enormously from **backing of host lab**
- We seek:
 - **encouragement to proceed with MICE Technical Proposal to RAL**
 - **support to plan beamline and infrastructure details**
 - **participation in Fermilab LH₂ absorber safety review process to ensure conformance with RAL requirements (discussions started)**
- **RAL would be an ideal site for MICE**
 - besides the beam, RAL offers a critical ingredient for success
 - ...*the support and enthusiasm of the local physicists!*