International Muon Ionization Cooling Experiment (MICE)

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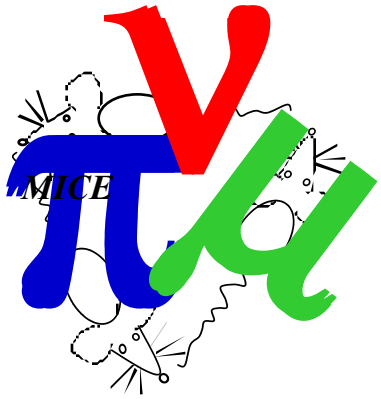


Muon Collaboration Meeting
Shelter Island, NY
5/11/02

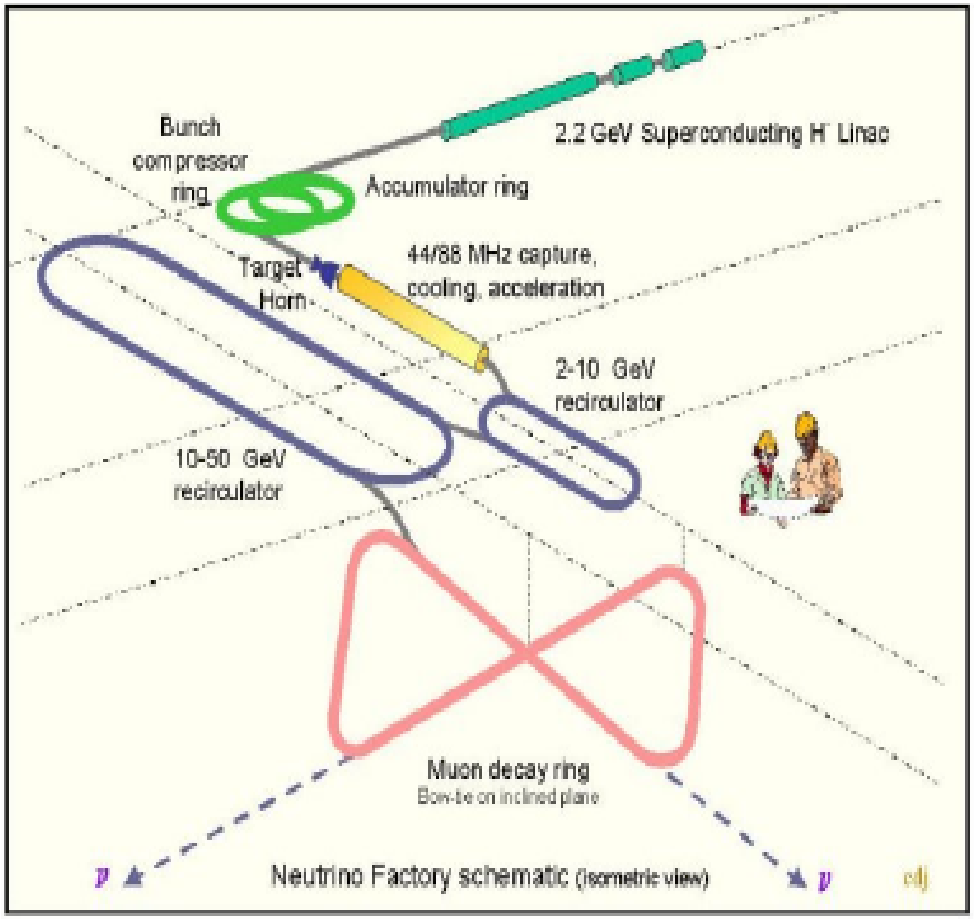
Outline:

1. Need for muon cooling
2. Ionization cooling: background
3. Cooling experiment:
   a. Goals
   b. Schedule
   c. Costs
4. International collaboration
5. Summary

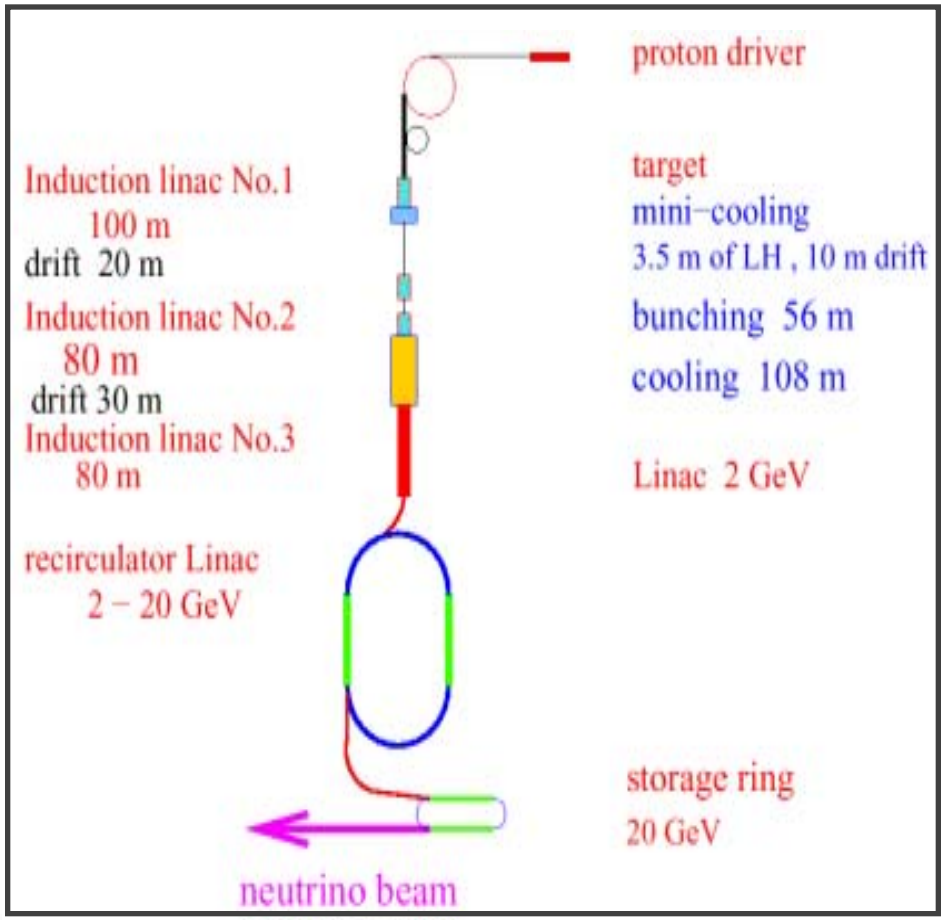
νFac Overview

- Only way to produce intense beam of high-energy electron neutrinos: $\mu^- \rightarrow e^- \nu_\mu \bar{\nu}_e$
- 2 schemes with cooling:

CERN scheme



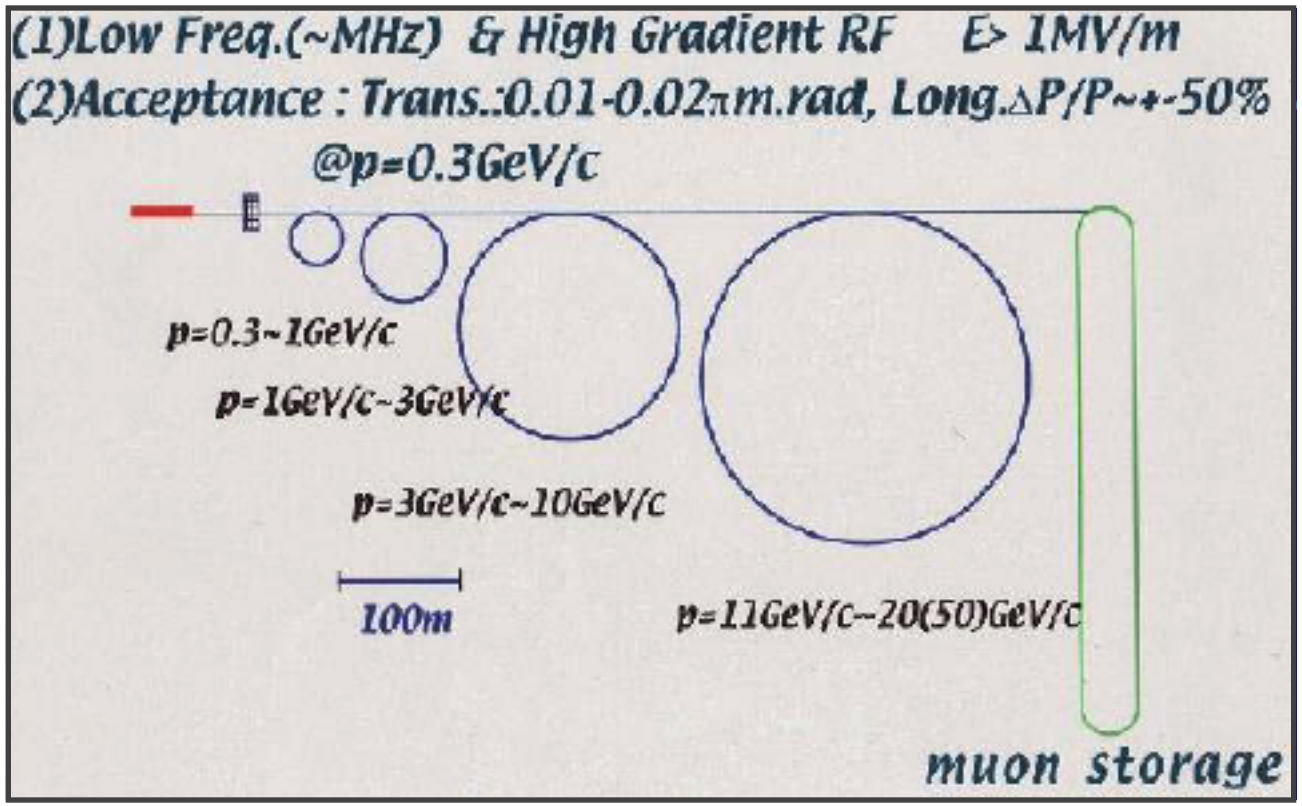
U.S. scheme



- Both designs feature MW proton beams on high-power target, with pion collection & decay in focusing channel
- Decay muons undergo phase-space manipulations, cooling, acceleration, and storage in decay ring

νFac Overview (cont'd)

- 1 scheme without cooling (KEK):



– Based on large-acceptance FFAGs

– No phase rotation or cooling

– Exploring possibility of adding cooling

– R&D Issues: RF, injection/extraction, magnet design, dynamic aperture

→3 world regions cooperatively exploring complementary technical approaches, but all have similar goal:

$>10^{20}$ useful muon decays per year

- Note: KEK working with us on absorber R&D

"Proof of Principle" FFAG tested successfully at KEK in June

Need for Muon Cooling

- νF needs ~0.1 μ/*p*-on-target ⇒ very intense muon beam from pion decay
  ⇒ must accept large (~10π mm·rad r.m.s.) beam emittance around peak p_π

- No acceleration system yet demonstrated with such large acceptance
  ⇒ must cool the muon beam
  - In current studies, cooling → × ~10 in accelerated muon flux

  → μ Collider needs cooling even more

- Only one technique fast enough to cool muons before appreciable fraction decay:

  ⇒ Ionization cooling (at muon $E_{kin} \approx 200$ MeV)

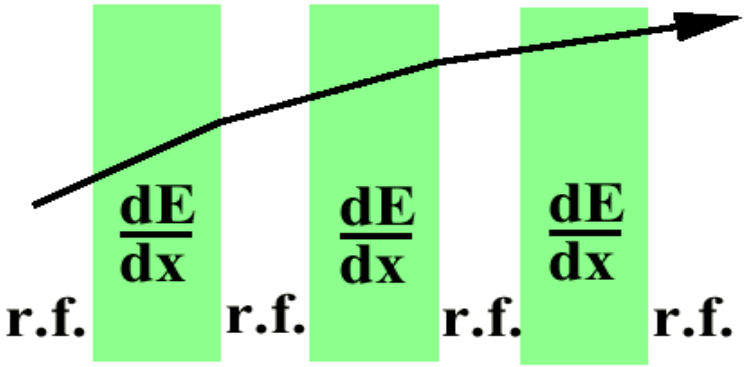
BUT:

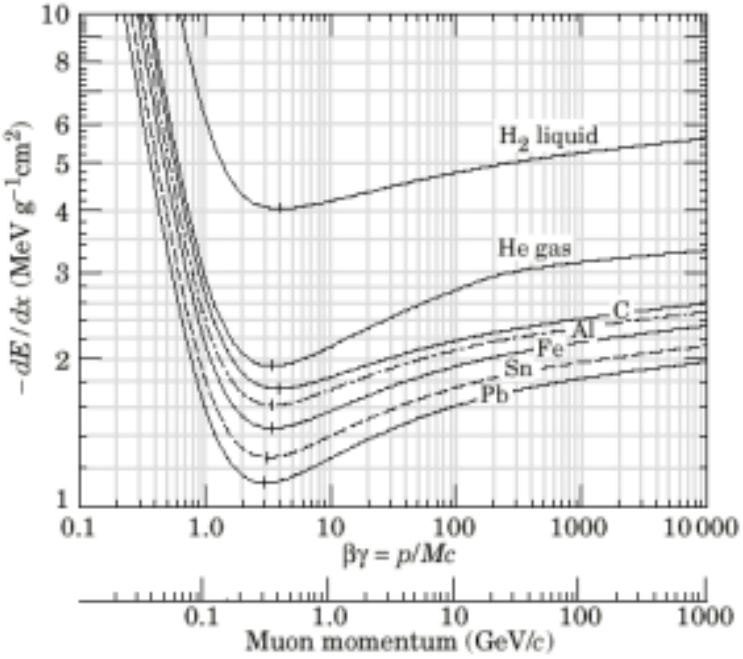
- It has never been observed experimentally
- Studies show it is a delicate design and engineering problem

⇒ Need Muon Ionization Cooling Experimental demonstration!

(Cheapest way to make us go away?)

Ionization Cooling: Background





- Absorbers:

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

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

$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\left\langle \frac{dE_\mu}{ds} \right\rangle \frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \text{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

$\Rightarrow$ want strong focusing, large X_0, and low E_μ

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

$\Rightarrow$ in principle, ionization cooling**has** to work!

...but in practice it is subtle and complicated so a test is important

Cooling Experiment

The aims of the muon ionization cooling experiment are:

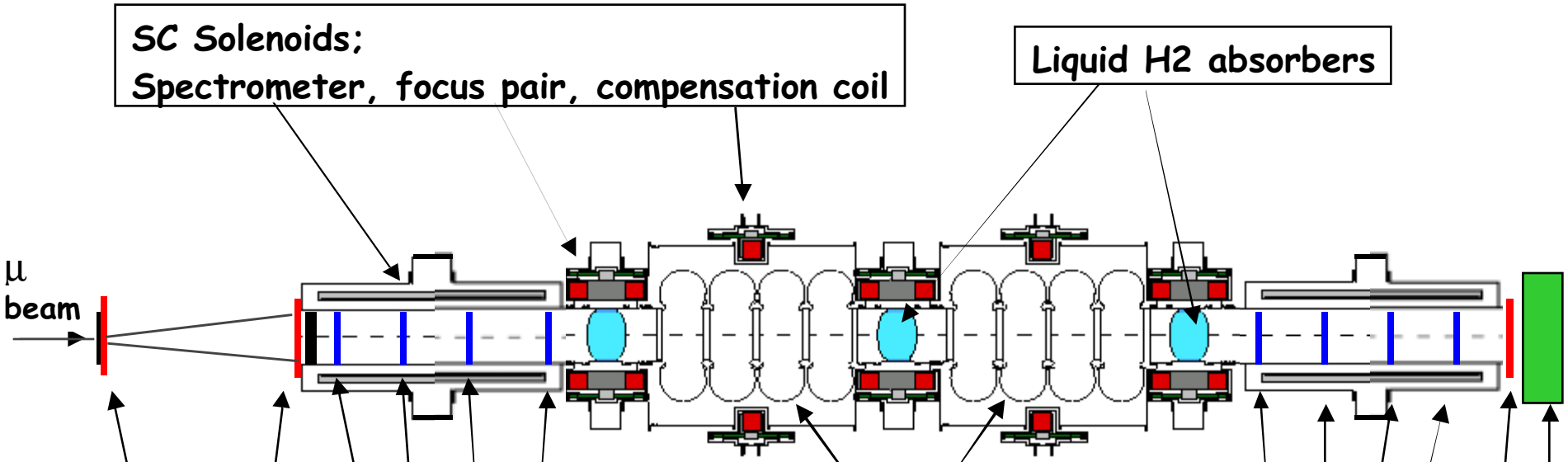
- to show that it is possible to design, engineer and build a section of cooling channel capable of giving the desired performance for a Neutrino Factory;
- to place it in a muon beam and measure its performance in a variety of modes of operation and beam conditions.

As stated in the 2001 review of Muon Collaboration activities by the U.S. Muon Technical Advisory Committee (MUTAC):

⇒ The "cooling demonstration" is the key systems test for the Neutrino Factory.

- Much work over many years has established the components needed for muon cooling: SC solenoids, absorbers, RF cavities
  - This is true whether the cooling channel is linear, square, or circular
  - It is time to assemble a realistic cooling cell and carry out the test

MICE Layout


SC Solenoids;
Spectrometer, focus pair, compensation coil
Liquid H2 absorbers
μ
beam
201 MHz RF cavities
Tracking devices:
Measurement of momentum angles and position
Tracking devices
T.O.F. I & II
Pion /muon ID and precise timing
T.O.F. III
Precise timing
Electron ID
Eliminate muons that decay

Schedule Goals & Milestones:*

Nov. ’01:	Letters of Intent to PSI, RAL
Jan. ’02:	Presentation to PSI
Mar. ’02:	Presentation to RAL → invitation to present full proposal!
2002:	Develop detailed technical proposal; prototyping; fundraising
2003–4:	Spectrometer construction
2004:	Spectrometer shakedown in muon beam
2005–6:	Assembly and shakedown of first cooling cell
2006–7:	Assembly and shakedown of second cooling cell

* This is an aggressive schedule and requires new funding sources to be found

Preliminary Cost Estimate (M$)

			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. Δε/ε (%)			5%	7%	7%	10%
Cost estimate in US$,	Fixed cost	Unit cost				
COOLING CELLS						
RF Cavities						
4 cell cavity 200 MHz	* 0.3	0.5	0.5	0.5	1	1
RF Power						
CERN-refurbish		0.2	0.2	0.2	0.2	0.2
RAL-refurbish (?)		0.2	0	0.2		0.2
Magnets						
Focus pair	* 0.55	0.45	0.9	0.9	1.35	1.35
Coupling coil	*0.4	1	1	1	2	2
Liquid H2 absorbers						
	* 0.5	0.1	0.2	0.2	0.3	0.3
LH2 plant	2		2	2	2	2
Total for cooling cell US $			4.8	5.0	6.85	7.05
SPECTROMETERS						
Solenoids	0.69	0.5	1.69	1.69	1.69	1.69
Detectors		2	2	2	2	2
Total spectrometers			3.69	3.69	3.69	3.69
Subtotal	2.69		8.49	8.69	10.54	10.74
Infrastr., extras(20%)						
TOTAL	3.23		13.4	13.7	15.9	16.1

cost-effective use of existing RF power sources

* development costs borne by MUCOOL

Organization of International Collaboration

- Starting at NuFact'01, we have formed the Muon Cooling Demonstration Experiment Steering Committee (MCDESC):

  Alain Blondel (Chair and European Spokesperson), U. Geneva
  Rob Edgecock, Rutherford
  Steve Geer, Fermilab
  Helmut Haseroth, CERN
  Daniel M. Kaplan (US Spokesperson), IIT
  Yoshitaka Kuno, Osaka U.
  Michael S. Zisman, LBNL

- We have designated the Technical Team Leaders:

  Particle detectors: A. Bross, V. Palladino
  RF radiation (dark current and X-Ray) issues: E. McKigney, J. Norem
  Magnet systems: H. Haseroth (provisional), M. Green
  RF cavities and power supplies: R. Garoby, R. Rimmer
  Hydrogen absorbers: M. A. Cummings, S. Ishimoto
  Concept development and simulations: A. Lombardi, P. Spentzouris
  Beamlines: R. Edgecock, C. Petitjean

- We have held several video meetings, several workshops (CERN, Chicago, London, CERN, Chicago), and a workshop is upcoming at RAL July 8–10

  (see http://muonstoragerings.cern.ch/October01WS/oct01ws.html and http://www.capp.iit.edu/~capp/workshops/mumice02/mumice02.html)

Participating Institutes:

Louvain La Neuve
NESTOR Institute
Hellenic Open University
INFN LNF Frascati
INFN Milano
INFN Napoli
INFN Roma II
INFN Trieste
Osaka University
Paul Scherrer Institute
University of Zurich
Rutherford Appleton Laboratory
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
KEK
ETH Zurich
University of Geneva
Imperial College London
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 at Urbana-Champaign
University of Mississippi

Summary

- The experimental demonstration of muon cooling is a key milestone in the R&D process leading to a Neutrino Factory and Muon Collider, compelling new techniques for particle physics
- The scope of the International Muon Ionization Cooling Experiment has been defined
- We are well on the way to specifying the experimental details
- An international collaboration has been formed and its leadership structure is in place
- We have received a positive signal from a suitable host Lab (RAL)
- We nust now proceed to
  - develop technical proposal in consultation with RAL experts
  - muster needed resources from the world's funding agencies
- Goals:
  - technical proposal submited by end of 2002
  - approval early in 2003
  - operation starting in ≈2006
  - successful cooling demonstration by LHC turn-on!