Muon Collaboration

International Muon-Cooling Demonstration Experiment Plans

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Outline:

1. Motivations
2. Ionization cooling: background
3. Cooling lattices and simulated performance (US, CERN)
4. Cooling experiment:
   a. Goals
   b. Designs
   c. Possible locations
5. International collaboration
6. Costs

Muon Cooling Demonstration Experiment

(From A. Blondel's summary)

Motivations:

--Ionization cooling is an important ingredient in **performance and cost** of a neutrino factory

--It has never been observed experimentally

--It is a delicate design and engineering problem

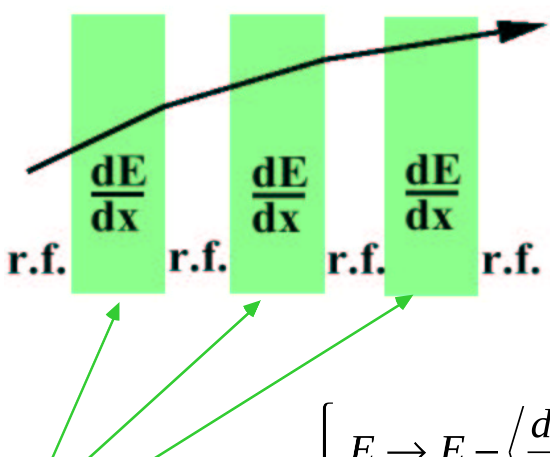
Goal

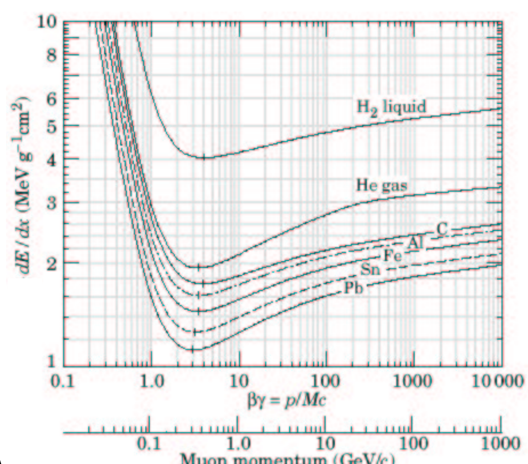
--design, engineer, build a section of cooling channel
  that is part of a high performance neutrino factory design

--put it in a beam and show that it works as expected
  (if not, understand why!) **The beam never lies.**

This is a somewhat larger project that can be afforded by any one of the world's regions => **International collaboration**

Ionization Cooling: Background





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

- 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

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

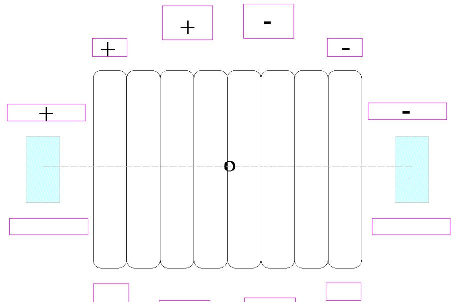
... but in practice it is subtle and complicated so a test is important

Ionization Cooling: Some details

$$\frac{d\epsilon_N}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \text{GeV})^2}{2\beta^3 E_\mu m_\mu L_R};$$

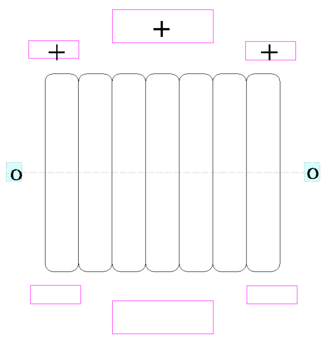
requires strong focusing at low-Z absorber

Several lattice designs have been explored:

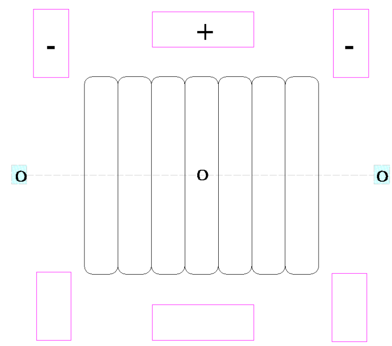


Alternating solenoid

+ RFOFO,
DFOFO,
Single-Flip,
Double-Flip



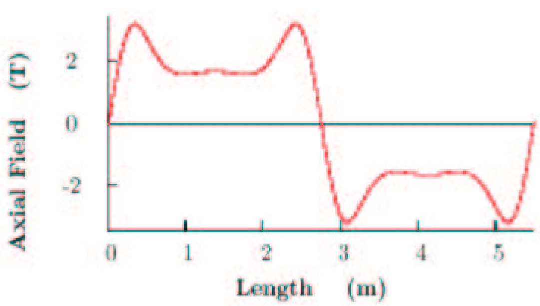
FOFO

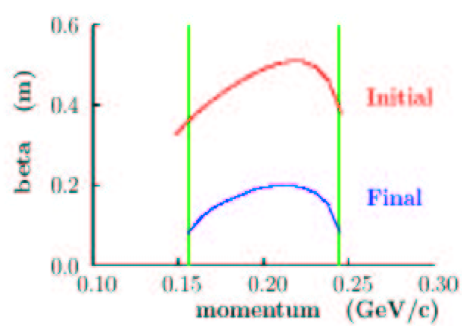


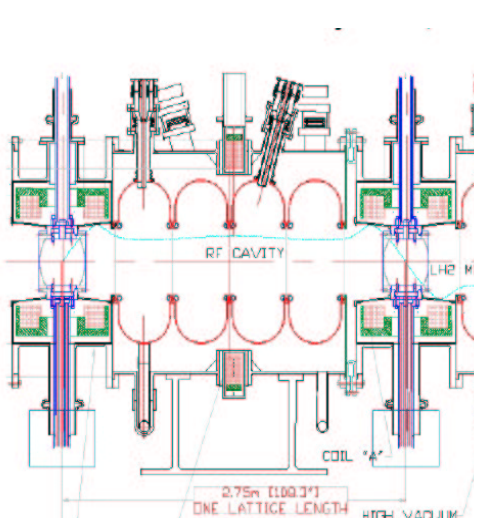
Super-FOFO

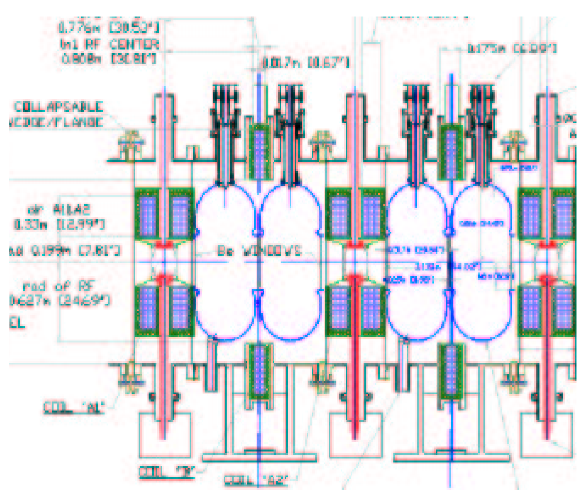
Tapered-SFOFO Cooling Lattice:

(R. Palmer, BNL)

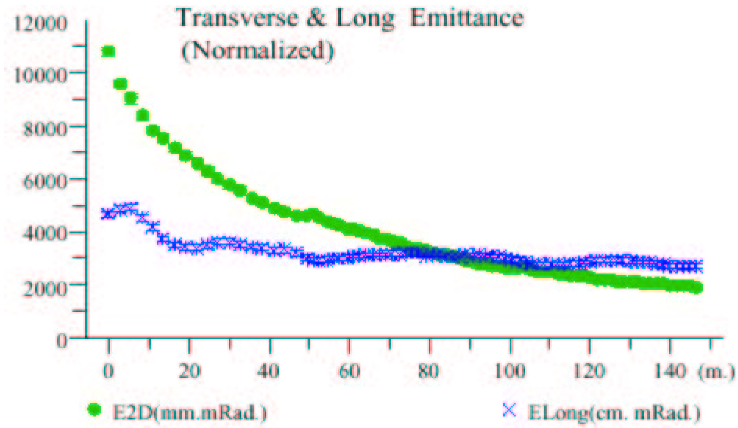


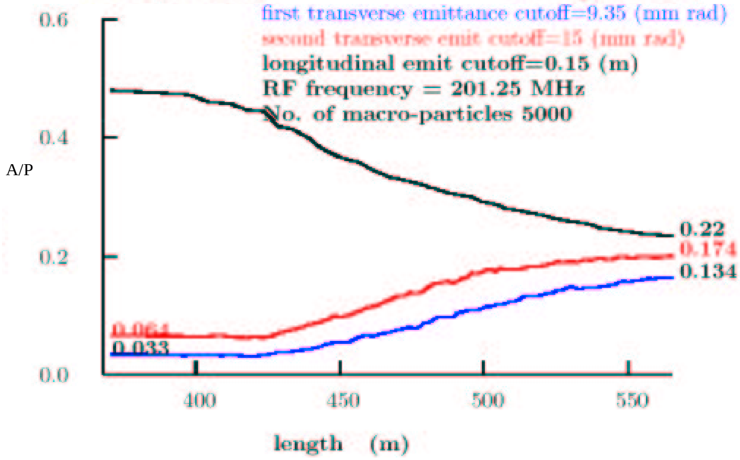






SFOFO Cooling Performance

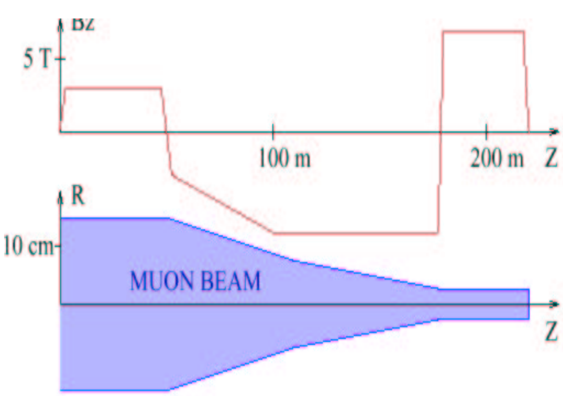


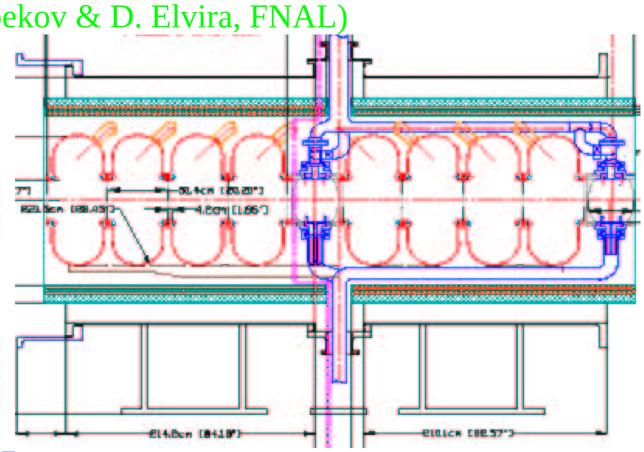


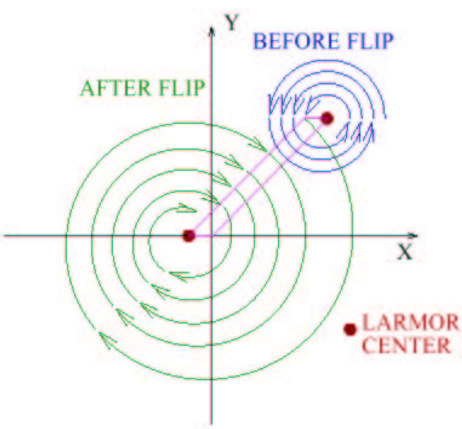
Assuming 15mm trans. acceptance
9.5mm

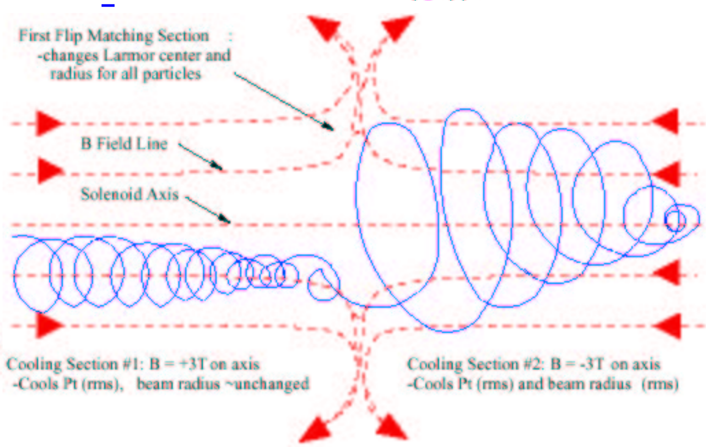
Double-Flip Cooling Channel

(V. Balbekov & D. Elvira, FNAL)

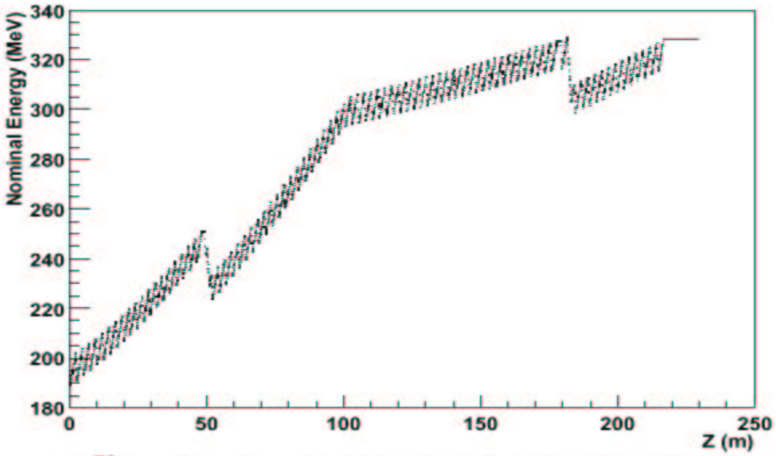


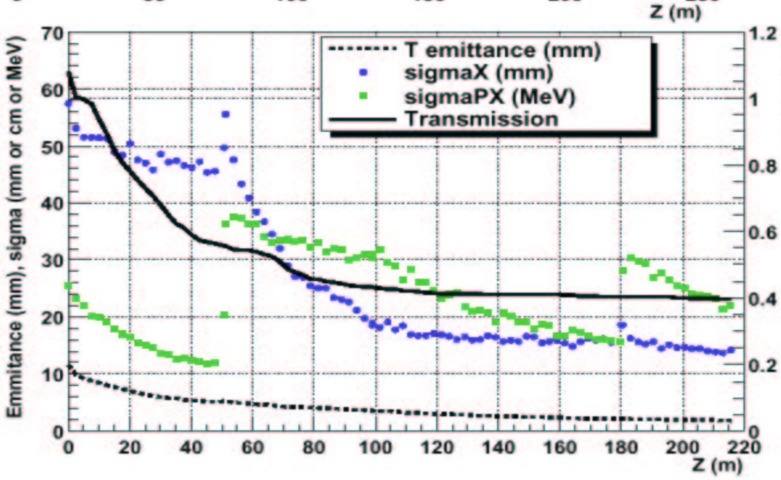






Double-Flip Performance





- Study II Appendix: Performance comparable to SFOFO
- New developments in the works (post-Study II):
- Can improve performance, shorten 7T section, reduce cost

CERN Cooling Channel Design

(A. Lombardi, CERN, Neutrino Factory Note NF-90)

- Details less worked-out than for US designs:
- Uses lower-frequency RF (44/88 MHz)
- Geant sim in progress at Fermilab

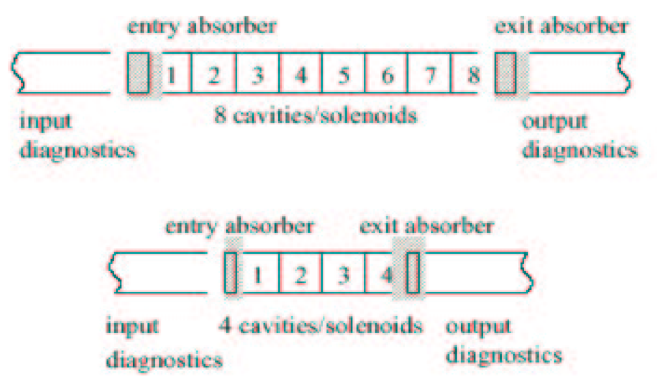
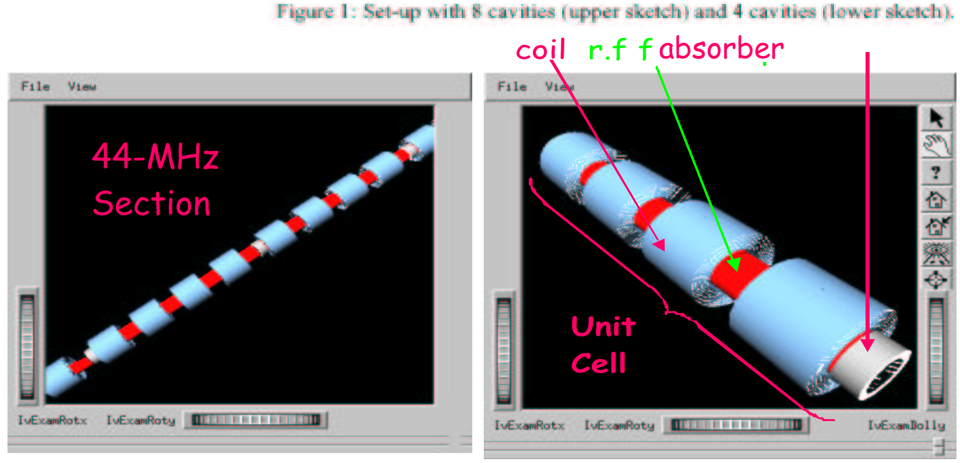


Figure 1: Set-up with 8 cavities (upper sketch) and 4 cavities (lower sketch).



Cooling Experiment

Must demonstrate

1. that hardware of given design can operate in proposed μ-cooling configuration and environment (no beam required)
2. that proposed operating parameters and tolerances can be achieved (no beam required, but could be helpful)
3. that effect on muon beam is in detail as predicted by simulation

- For 2 & 3, helpful to have long enough channel that predicted effects are big
- But in reality we will be constrained by available resources

Note:

70 cm $LH_2 \rightarrow \Delta E \approx 20$ MeV $\Rightarrow (\Delta\varepsilon/\varepsilon)_{2D} \approx 10\%$ (depending on choice of p)

Cooling Experiment – Further considerations

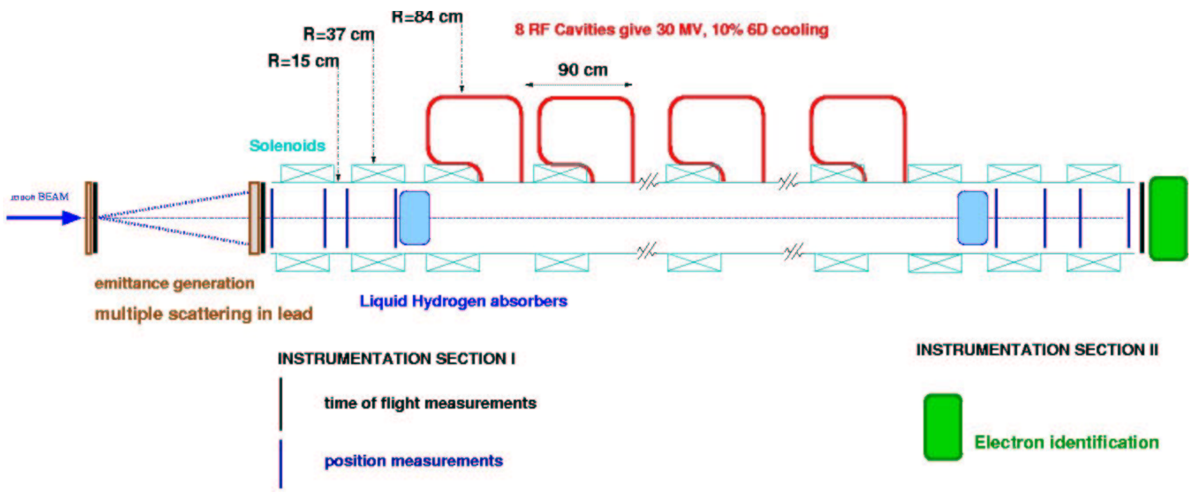
- Should test *realistic* piece of *optimal* νF cooling-channel design
  - insufficient manpower & resources to build & test multiple designs
- Not yet clear which νF design is optimal
  - to reach consensus, need each regional group to simulate & compare multiple designs (in progress)
- Choice may be constrained by
  - which (if any) design cheaper or more convenient to test
  - availability of infrastructure (e.g. 88- vs. 201-MHz RF sources)
- Detectors should
  - operate in strong solenoidal field & intense RF-cavity background
  - contribute negligible emittance degradation

$\Rightarrow$ e.g. scint. fibers or silicon pixel detectors $\rightarrow \Delta\varepsilon_{out}/\varepsilon_{in} \sim 10^{-3}$

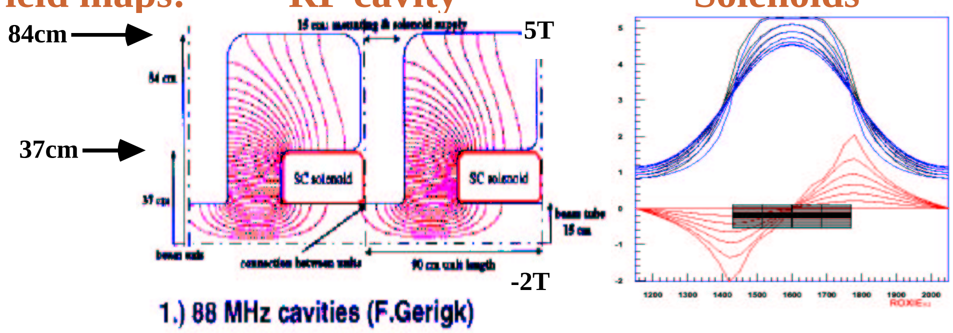
$\rightarrow$ can shield from cavity backgroun d with LH_2 absorbers

Cooling Experiment – CERN design

(A. Blondel, K. Hanke, H. Haseroth, et al.)



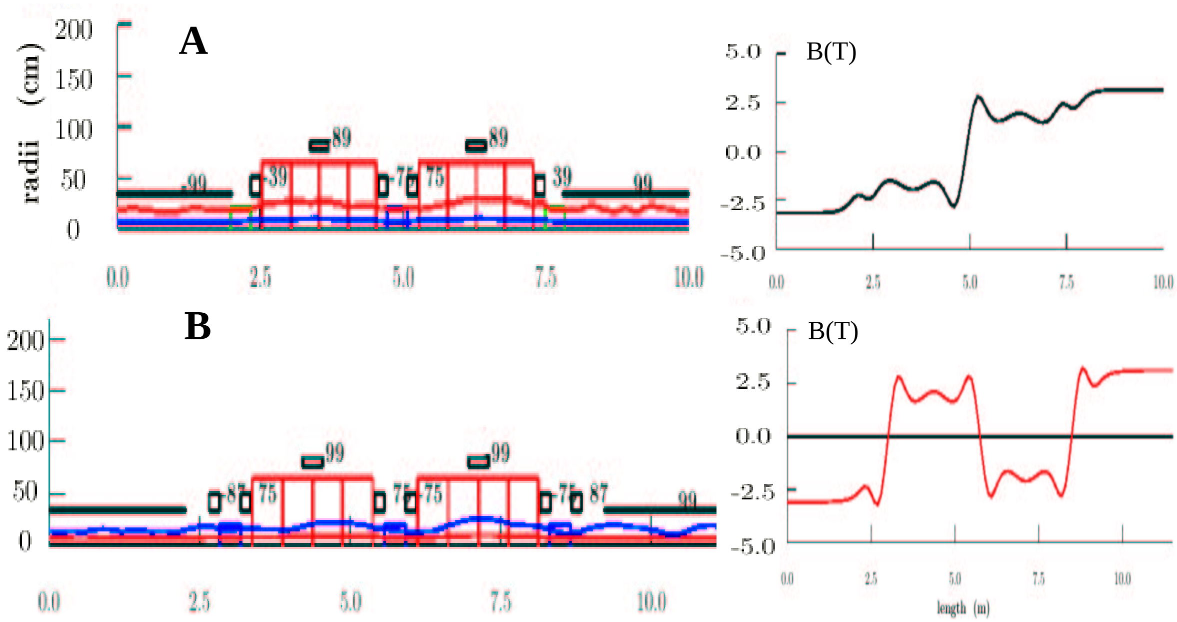
Field maps: RF cavity Solenoids

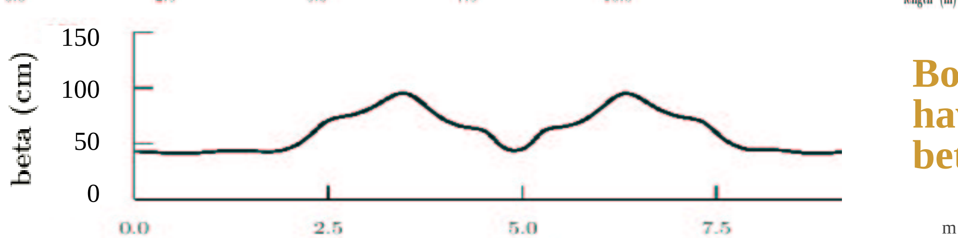


Cooling Experiment – US designs

(R. Palmer & R. Fernow, BNL)

- 201 MHz: 2 geometries considered:

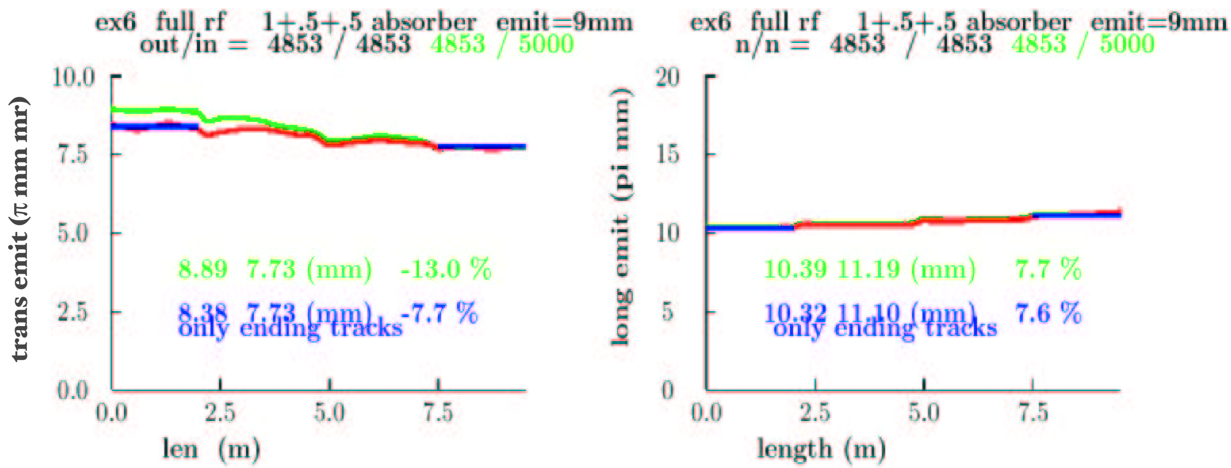




Both options have similar beta functions

Options & Performance

	$E_1 = E_2$?	$n_{absorbers}$	rf grad MV/m	rf phase deg	$\Delta\epsilon_\perp$ %	rf Power MW	simulated
a	yes	1/2+1+1/2	15.5	30	8	32.3	yes
b	no	1+1+1	15.5	30	12	32.3	
c	yes	1/2+1+1/2	8.7	90	2	10.3	yes
d	no	1+1+1	8.7	90	12	10.3	
e	yes	0+1+0	7.7	30	4	8.1	yes
f	no	1+0+1	7.7	30	8	8.1	
g	yes	0+1+0	4.4	90	4	2.6	
h	no	1+0+1	4.4	90	8	2.6	
i	no	0+1+0	0	0	4	0	
j	no	1+1+1	0	0	12	0	

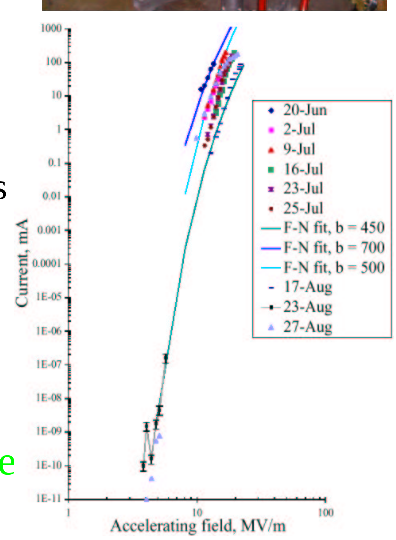


First Look at RF-Cavity Radiation

- 805-MHz open-cell cavity has been tested in Lab G up to ≈13-MW input power (max on-axis gradient 23.5 MV/m, max surf. field 53 MV/m)
  – tested with and without solenoidal field
- Dark current measured with pickup coil – up to ≈700 mA seen
- e^- energy limited to ≈10 MeV ⇒ $P_{e^-} <$ 7 MW
- X-ray rate under study
  – preliminary look ⇒ some orders of magnitude below e^- rate
- Major hurdle to overcome:
  – 2.5-T solenoidal field enhanced & focused discharges
  – coated inside of 5-mil Ti window with copper
  – punched pinhole in Ti window

⇒ Need R&D on reducing discharge rate
  – surface treatment
  – coatings

→ Note closed-cell cavities will have ≈1/2 the surface field for same gradient



Available Beams/Facilities

Comparison between beams

Single particle muon beams:

Beam	Momentum (MeV/c)	ΔP Δ(%)	Muon Intensity (during 1 s)	Area (m^2)	Exists
BNL D2	100 - 250	10	50,000 / 5 ms	5 x 3	~~Yes~~
CERN – TT1	200 - 450	?	720 / 0.1 ms	> 30 x 4	No
CERN – East Hall	200 - 450	?	1,000 / 0.5 ms	30 x 5	No
PSI – μE1	85 - 310	1 (?)	> 50,000 / 5 ms	30 x 5	Yes
RAL - ISIS	100 - 500	~ 2	20,000 / 5 ms	30 x 5	Yes
TRIUMF – M20	20 - 180	5	5,000 / 5 ms	12 x 4	Yes

Kirk McDonald
Monday, 28th May 2001

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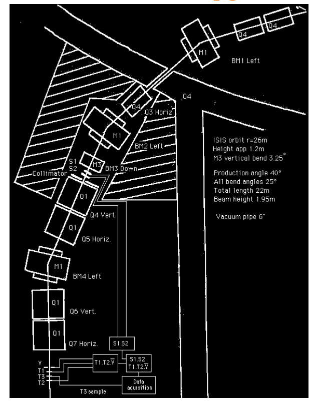
RAL-ISIS Upgrade



PSI-μE1

- We plan proposals to PSI & RAL – both labs interested
- Host lab should provide beamline & infrastructure
- Natural opportunity for important European contribution

Organization of International Collaboration

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

Alain Blondel (Chair), U. Geneva
Rob Edgecock, Rutherford
Steve Geer, Fermilab
Helmut Haseroth, CERN
Daniel M. Kaplan, 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 3 video meetings so far
Workshop upcoming at CERN Oct. 25–27
(see http://muonstoragerings.cern.ch/October01WS/oct01ws.html)

Schedule (Goals & Milestones):

Summer–Fall '01:	Explore & simulate alternative designs
Sept. 14 '01:	RAL S.o.I. for ISIS beamline upgrade
Oct. 25–27 '01:	CERN Workshop – 1st cut at design parameters
Nov. '01:	Key design parameters settled
Nov. 16 '01:	Deadline for preliminary proposal to PSI
Spring '02:	Detailed technical proposal
2004:	Experiment operational

Cooling Experiment – Preliminary cost estimate

- A possible scenario (Palmer-Fernow option "a"):

item	unit cost ($)	#	NRE	total cost ($)
4-cell 201-MHz cavity	0.5M	2	0.3M	1.3M
5-MW tetrode RF power source	1.2M	8	1M	9.6M
Lattice solenoids:				
Focus coil pair	1M	3	1M	4M
Coupling coil	1M	2	1M	3M
Detector solenoids	1M	2		2M
Absorber	0.1M	3	0.5M	0.8M
Absorber cryo & safety		--	1–3M	1-3M
Detectors	0.1M	10		1M
Infrastructure (non-beam)	≈5M	--		≈5M
TOTAL				**≈$30–40M**

- This is too expensive for existing R&D budgets

⇒ New international proposal under development

- Likely U.S. contributions: absorbers, cavities, some detectors

Summary

- Scope of the Muon Cooling Demonstration Experiment defined
- Well on the way to specifying the experimental details
- International collaboration formed and leadership structure in place
- Need to line up necessary resources
- Strong endorsement from MUTAC will be crucial to doing so