

Muons, Inc. Status



BNL, FNAL, IIT, Jlab, Muons, Inc.

Rolland Johnson, Feb. 14, 2005

- HP HG GH2 RF
 - Ph II, w IIT, DK
- 6D HCC
 - Ph II, w Jlab, YD
- H2 Cryostat due 4/13/2005
 - Ph I, w FNAL, VY
- MANX due 4/13/2005
 - Ph I, w FNAL, VY
- PIC due 4/13/2005
 - Ph I, w Jlab, YD
- HCC Magnets w BNL RG
- REMEX w Jlab YD
- G4BL w IIT DK
- GH2 Phase rotation w FNAL DN

Thanks to Excellent Collaborators

- JLab; Slava Derbenev, Alex Bogacz, Kevin Beard
- BNL; Ramesh Gupta, Erich Willen, Steve Kahn
- IIT; Dan Kaplan, Katsuya Yonehara
- Fermilab; Victor Yarba, Chuck Ankenbrandt, Emanuela Barzi, Timer Khabiboulline, Al Moretti, Dave Neuffer, Milorad Popovic, Gennady Romanov
- Muons, Inc.; Mohammad Alsharo'a, Pierrick Hanlet, Bob Hartline, Moyses Kuchnir, Kevin Paul, Tom Roberts

HP HV RF Cavities

Ph II, Dan Kaplan, IIT

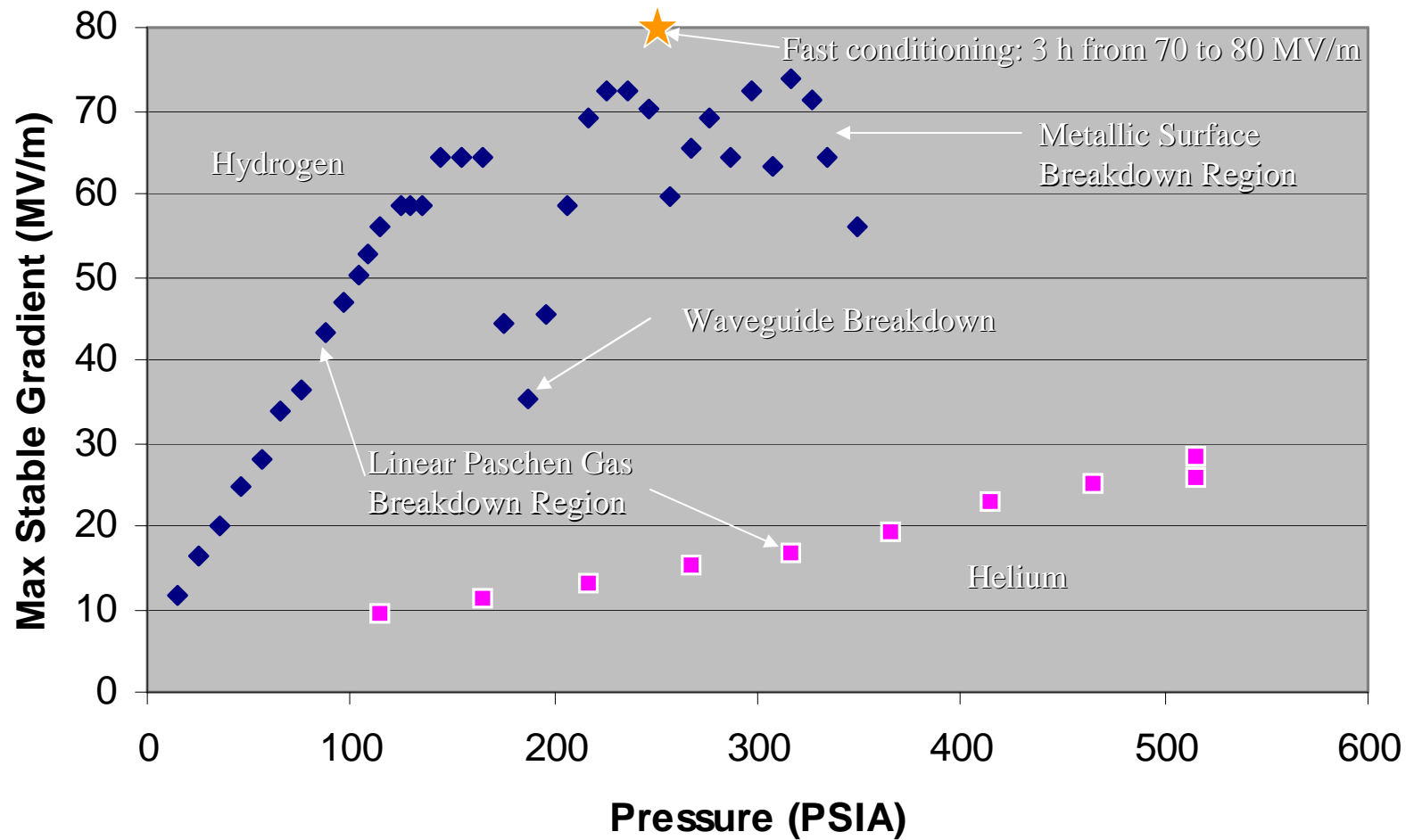
- Dense GH_2 suppresses high-voltage breakdown
 - Small MFP inhibits avalanches (**Paschen's Law**)
- Gas acts as an energy absorber
 - Needed for ionization cooling
- Only works for muons
 - No strong interaction scattering like protons
 - More massive than electrons so no showers

2003 STTR Phase II Project

- To develop RF cavities, pressurized with dense hydrogen or helium gas, that are suitable for use in muon cooling and accelerator applications.
- Measurements of RF parameters (e.g. breakdown voltage, dark current, quality factor) for different temperatures and pressures in magnetic and radiation fields will be made in RF cavities to optimize the design of prototypes for ionization cooling demonstration experiments

11/19/03 Lab G Results, Molybdenum Electrode

H2 vs He RF breakdown at 77K, 800MHz



Hopes for HP GH2 RF

- Higher gradients than with vacuum
- Less dependence on metallic surfaces
 - Dark currents, x-rays diminished
 - Very short conditioning times already seen
- Easier path to closed-cell RF design
 - Hydrogen cooling of Be windows
- Use for 6D cooling and acceleration
 - Homogeneous absorber concept
 - Implies HF for muon acceleration (1.6 GHz)

Present Activities for HP RF Phase II project

- Moving from Lab G to MTA (>1 year delay!)
- Studying RF breakdown with cu, mo, cr, be electrodes 50:85:112:194 (Perry Wilson)
- Planning Test Cell for Operation in the LBL 5 T solenoid at 1600 PSI and 77K
- Working on MTA Beam Line
 - Want radiation test of GH2 RF in 2005

2004 Phase II, w JLab, Derbenev GH2 Emittance Exchange

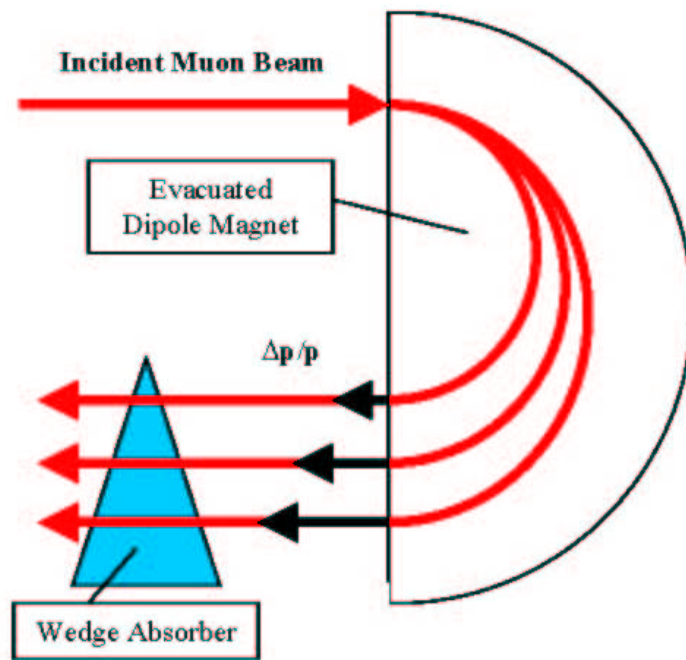


Figure 1. Use of a Wedge Absorber for Emittance Exchange

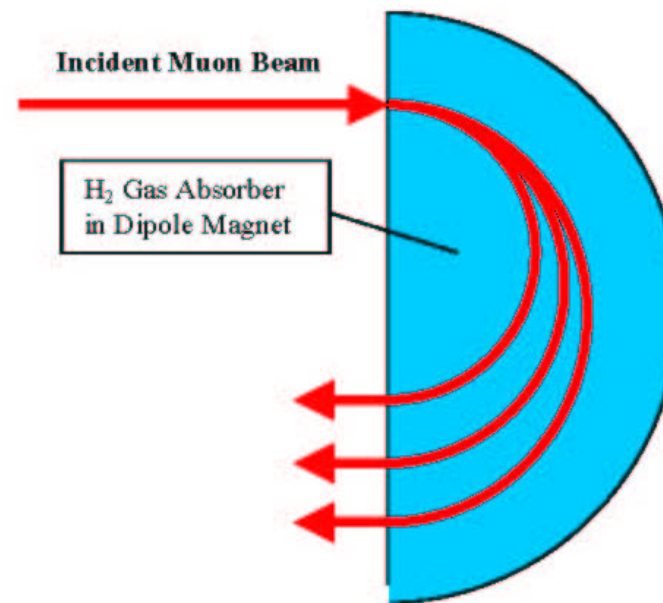


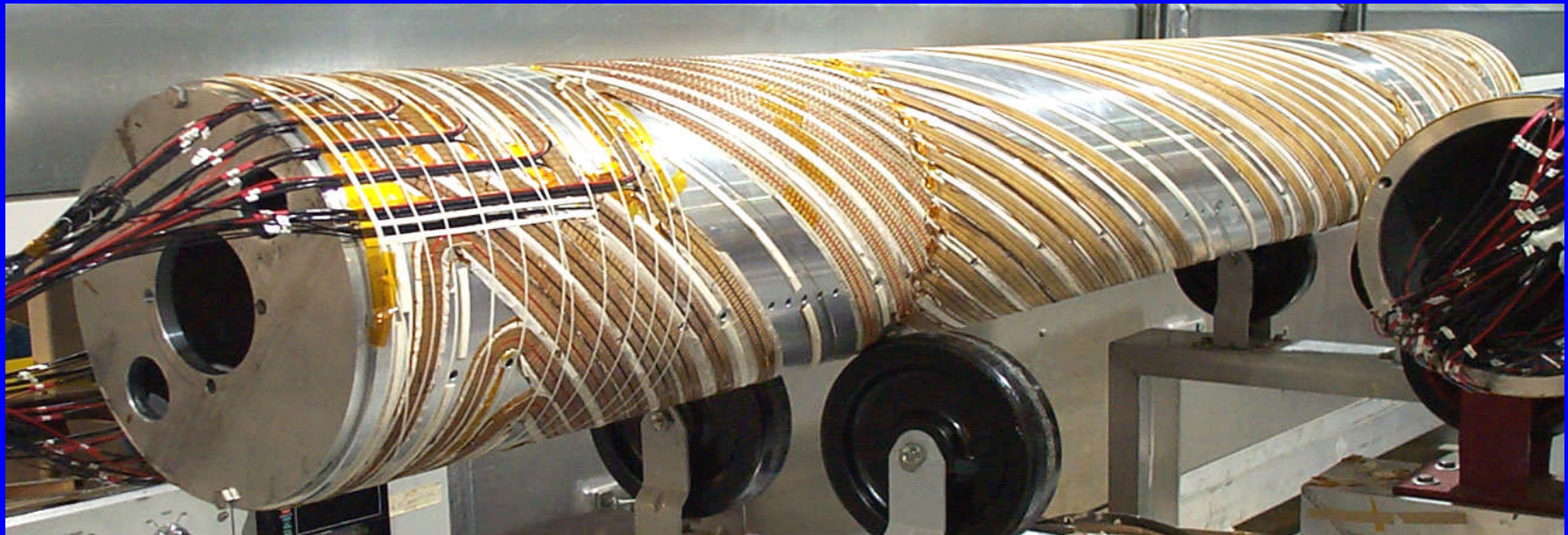
Figure 2. Use of Continuous Gaseous Absorber for Emittance Exchange

This concept of emittance exchange with a homogeneous absorber first appeared in our 2003 SBIR proposal!

6D Cooling with GH2

- Helical cooling channel (HCC)
 - Solenoidal plus transverse helical dipole and quadrupole fields
 - z-independent Hamiltonian
- Avoids ring problems
 - Injection and Extraction
 - Multi-pass Beam loading or Absorber heating
 - Fixed channel parameters as beam cools

Figure 5. Photograph of a helical coil for the AGS Snake.



$$F_{h-dipole} = p_z \times B_{\perp}; \quad b \equiv B_{\perp}$$

$$F_{solenoid} = -p_{\perp} \times B_z; \quad B \equiv B_z$$

$$b = .7T, \quad B = 3.5T$$

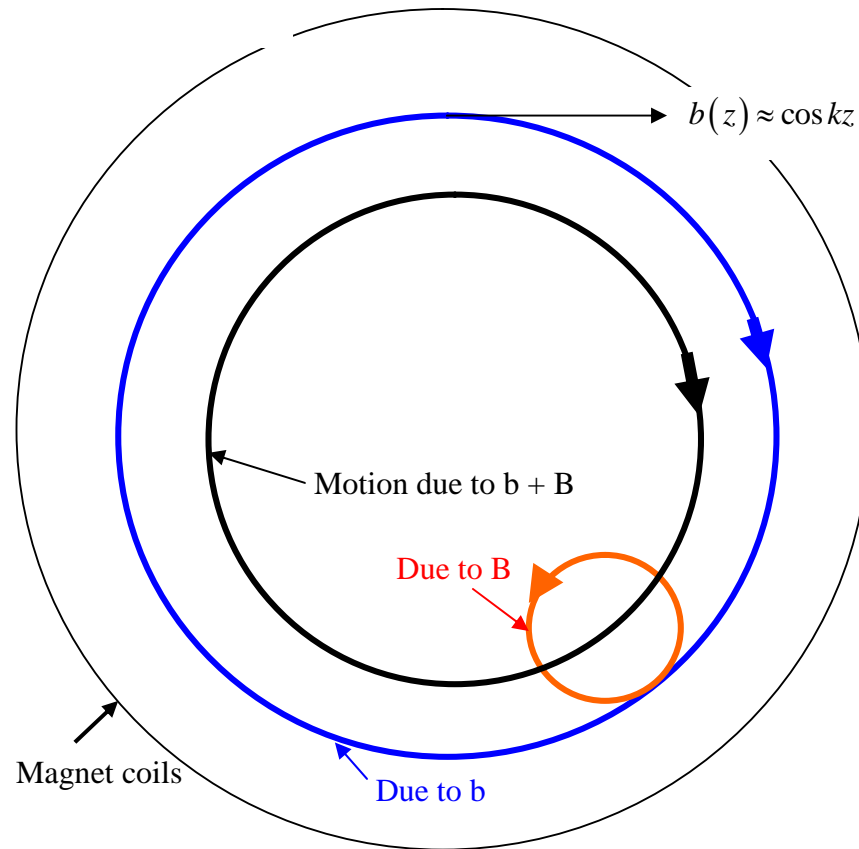
$$p = 100MeV / c$$

$$p_{\perp} / p_z = 1.$$

$$r_{B+b} = 15cm$$

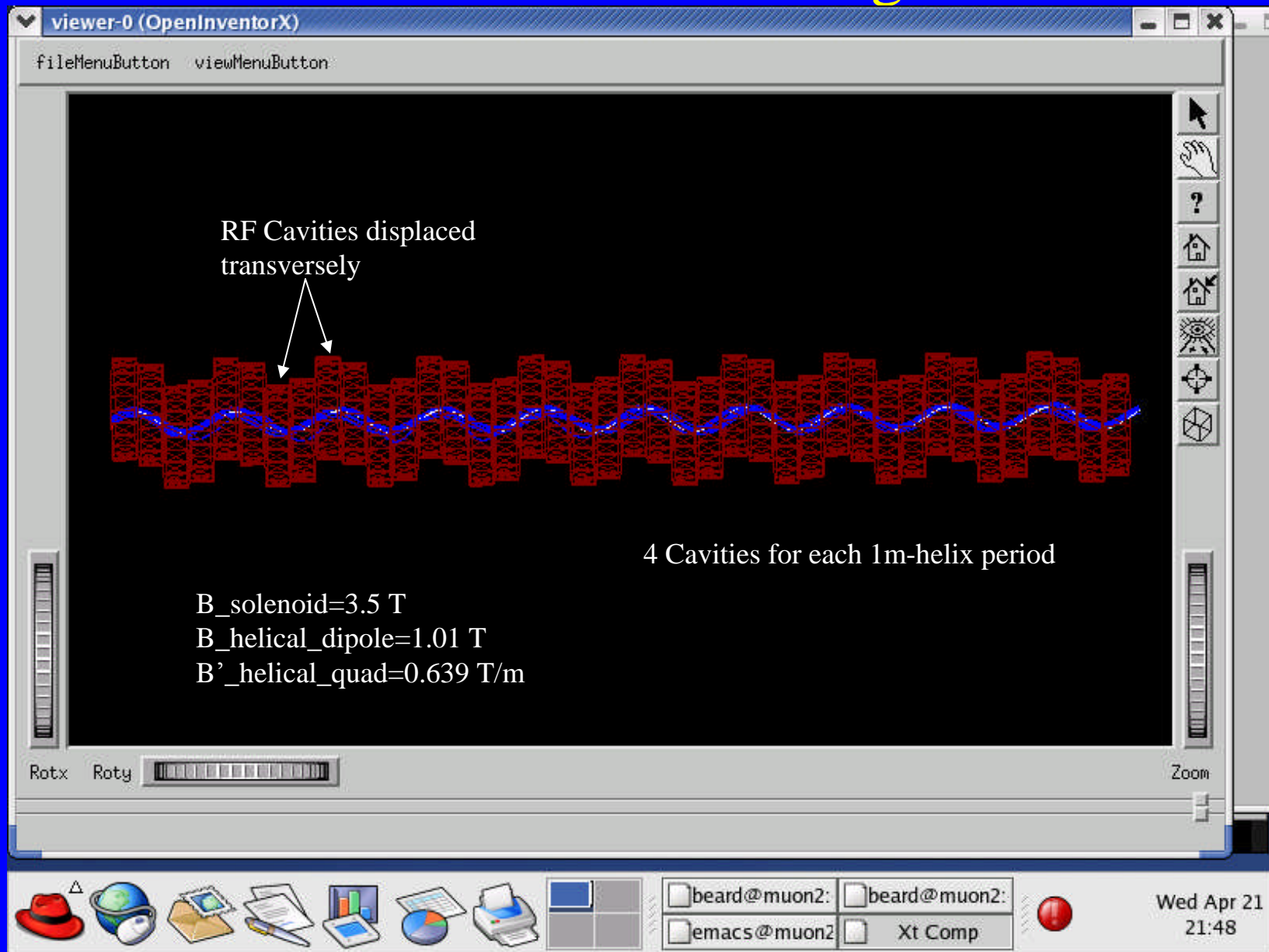
$$\lambda = 2\pi / k = 1m$$

$$r_{coil} = 30cm$$

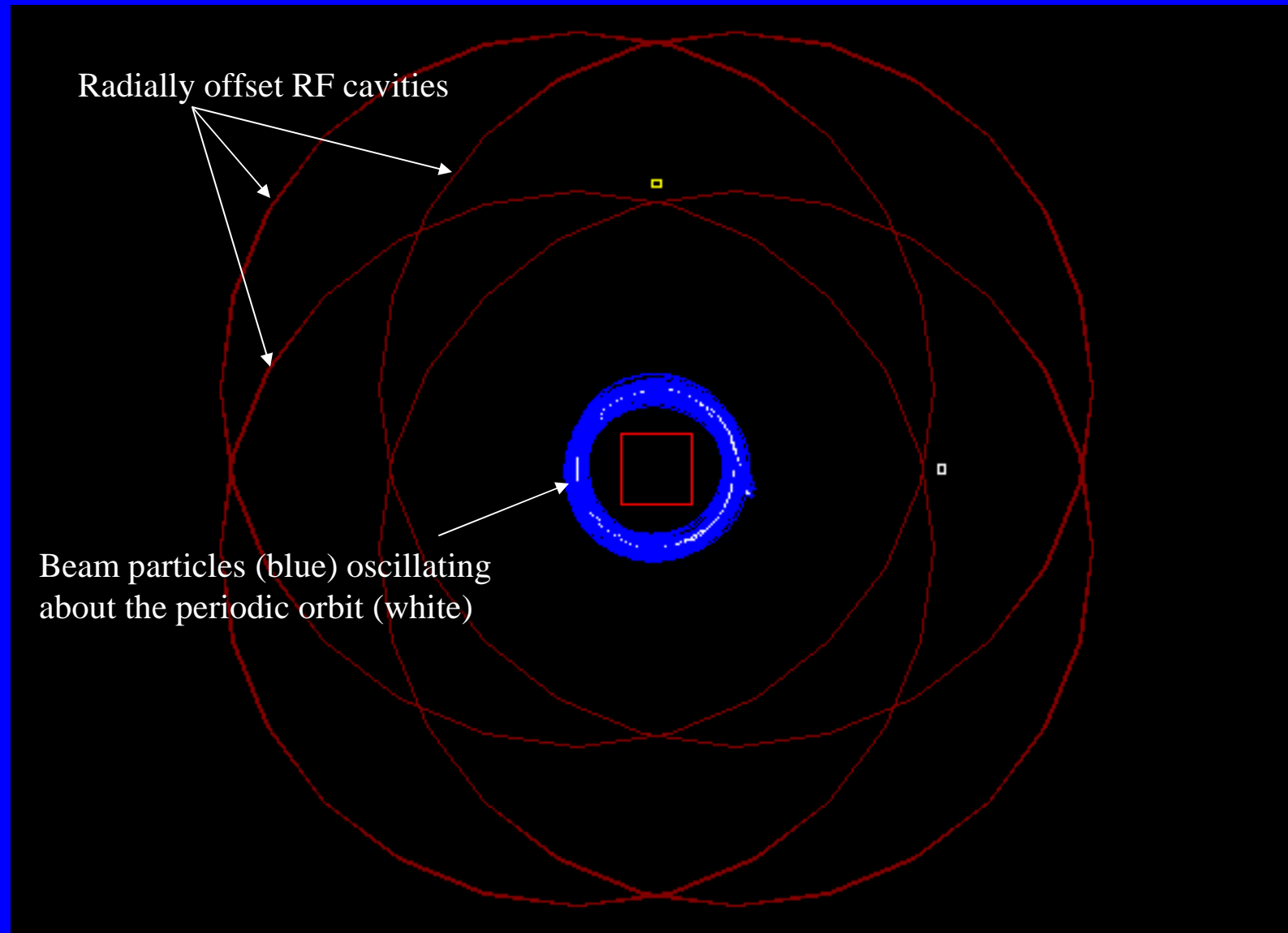


Helical Cooling Channel. Derbenev invention of combination of Solenoidal and helical dipole fields for muon cooling with emittance exchange and large acceptance. Well-suited to continuous absorber. Mucool note 284.

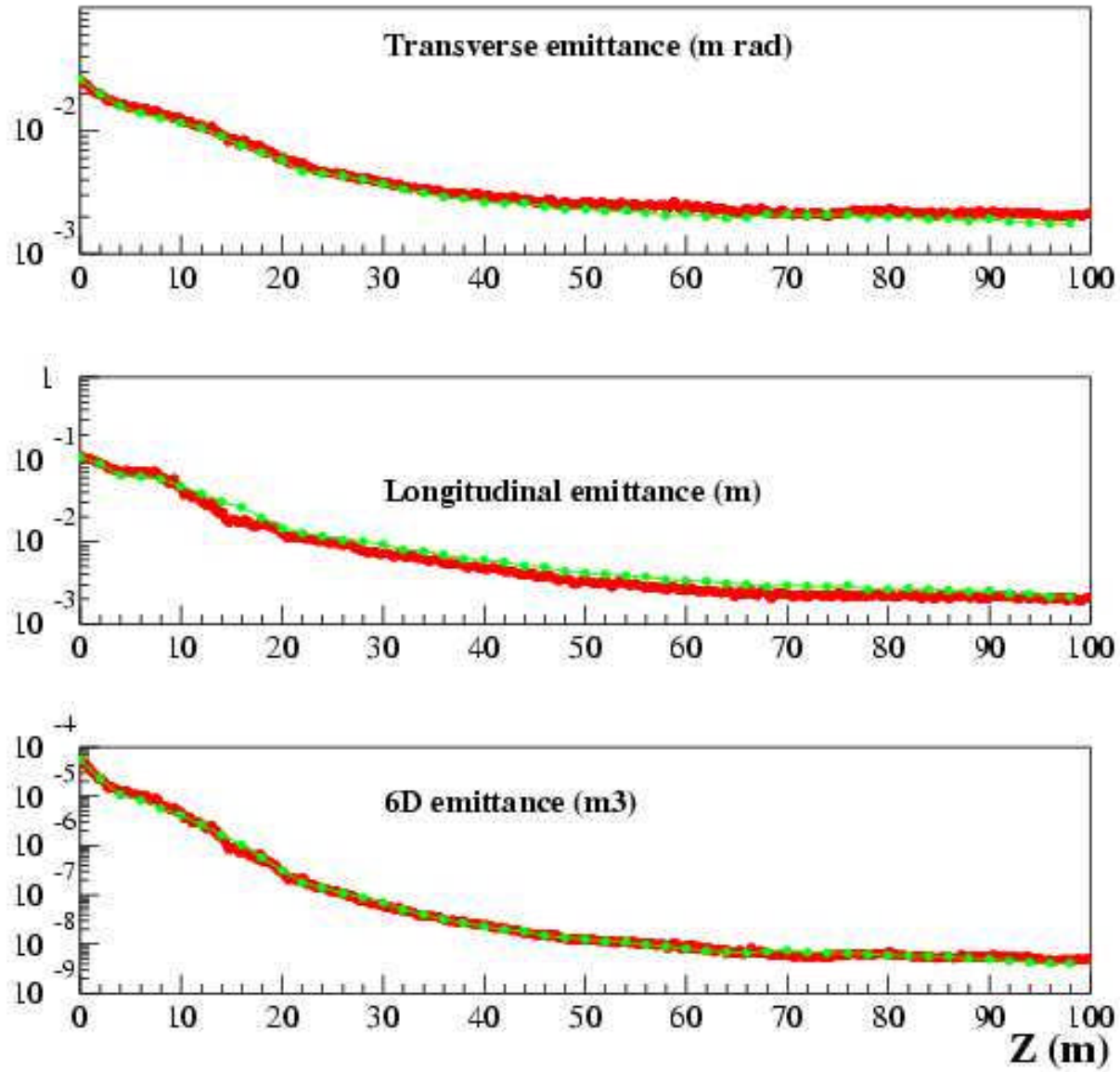
G4BL 10 m helical cooling channel



G4BL End view of 200MeV HCC



Evolution of Beam emittance



See
Katsuya
tomorrow.

Comments on 6D cooling project

- Analytic description essential to guiding simulation effort (see Derbenev et al.)
- Latest simulation results:
- First of 3 or 4 segments (200 MHz), MF5000
 - Study of other segments and matching between them next
 - Addressing RF and SC magnet realism
 - Match to RF capture, precooling sections
 - Can we use higher frequency RF for first HCC section?

New 2004 Project!!

Hydrogen Cryostat

w Victor Yarba, Fermilab

- simultaneously refrigerate
 - 1) HTS magnet coils
 - 2) cold copper (or Be?) RF cavities
 - 3) hydrogen gas heated by the muon beam
- extend use of hydrogen to that of refrigerant
 - besides breakdown suppressant and energy absorber
 - large amount of hydrogen for IC anyway
- relevance for hydrogen economy?
- Dr. Moyses Kuchnir

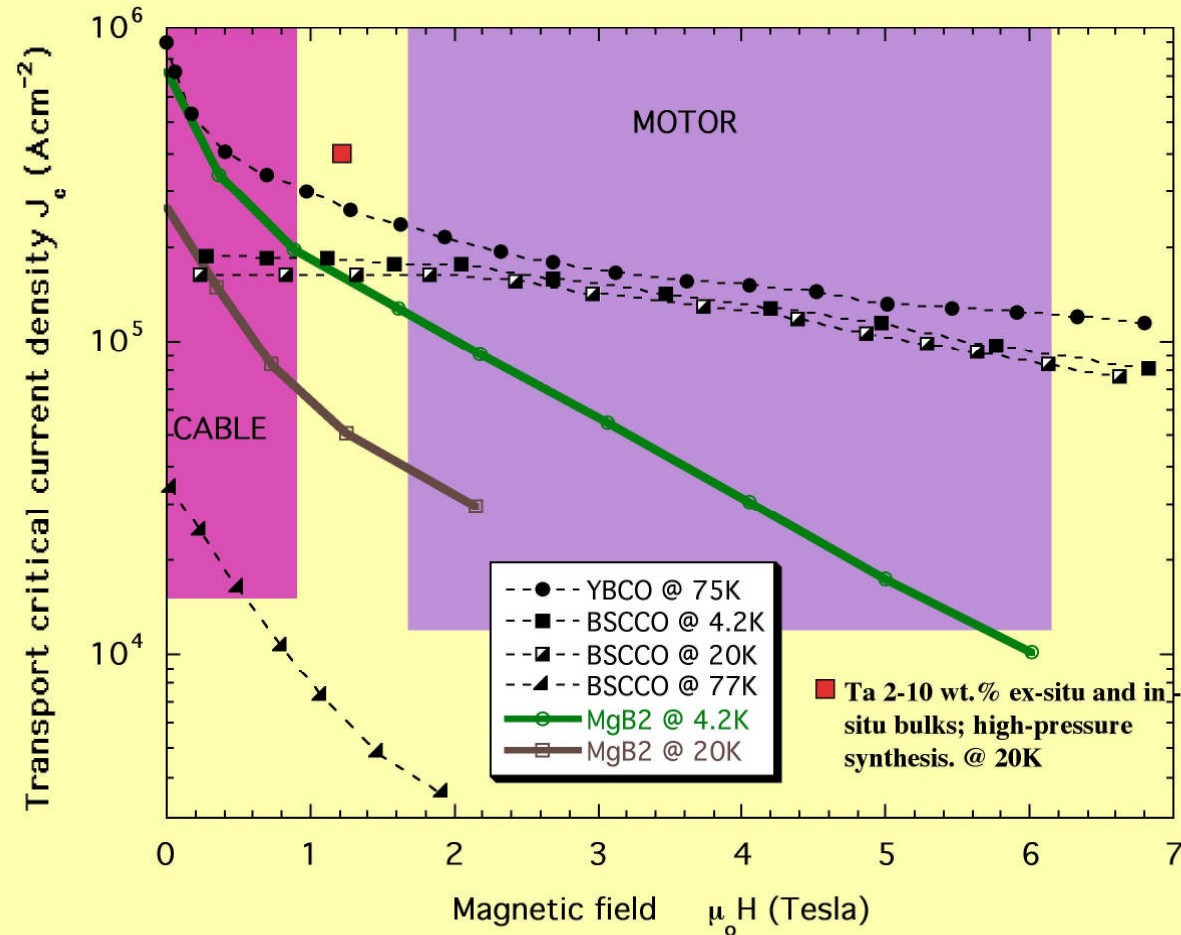
HTSC I, B, T

APPLICATIONS

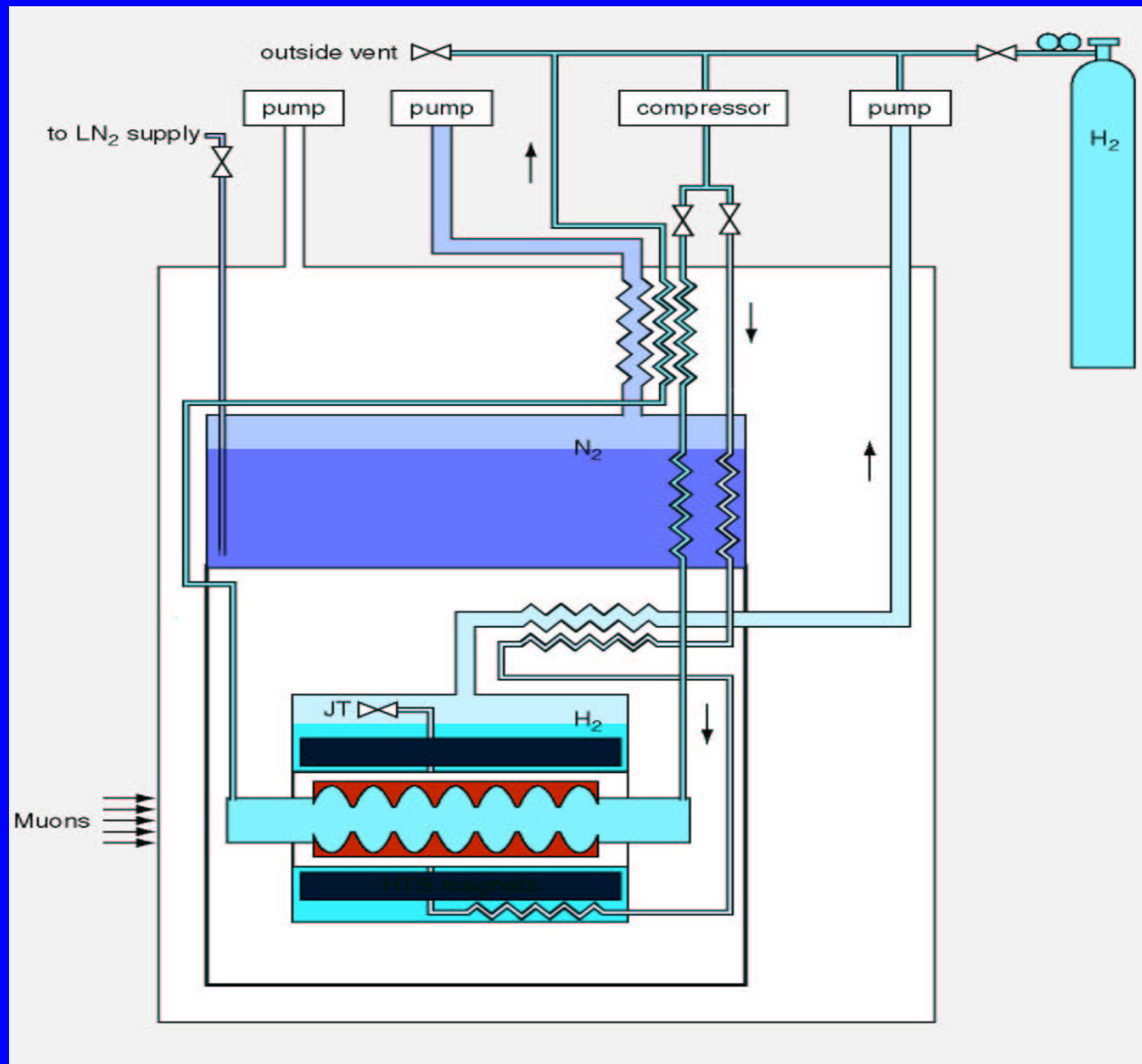


B.A. Glowacki

Applied Superconductivity Research - University of Cambridge



Hydrogen Cryostat w/o HTS



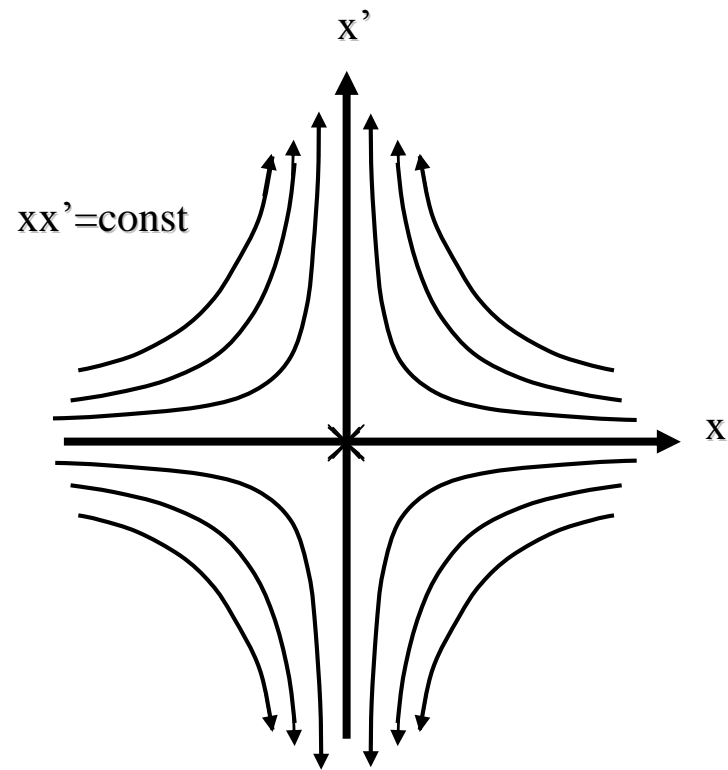
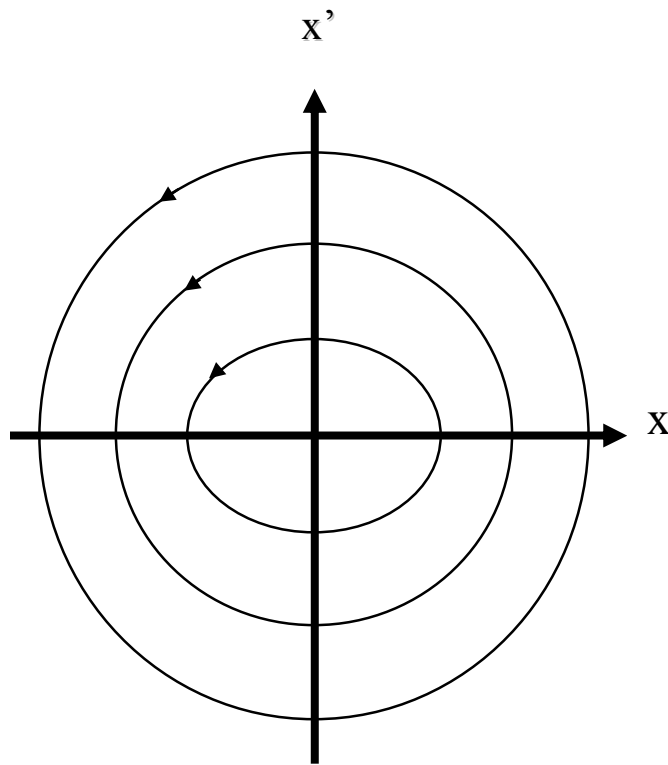
New 2004 Project!!

Phase Ionization Cooling (PIC)

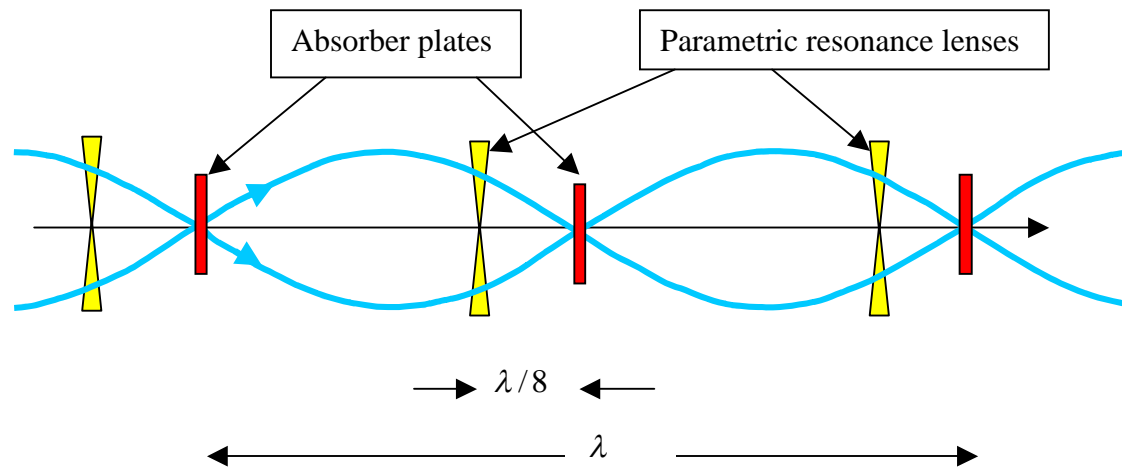
Slava Derbenev, Jlab

- Derbenev: 6D cooling allows new IC technique
- PIC Idea:
 - Excite parametric resonance (in linac or ring)
 - Like vertical rigid pendulum or $1/2$ -integer extraction
 - Use $xx' = \text{const}$ to reduce x , increase x'
 - Use IC to reduce x'
- 1 to 2 orders smaller emittance than usual IC
 - Fewer muons needed for high luminosity MC
 - Easier proton driver and production target
 - Fewer detector backgrounds from decay electrons
 - Less neutrino-induced radiation

Hyperbolic phase space motion



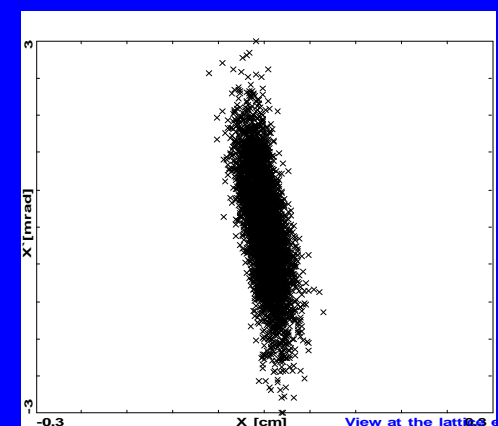
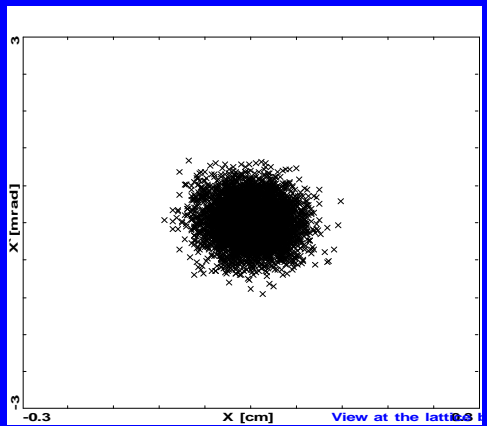
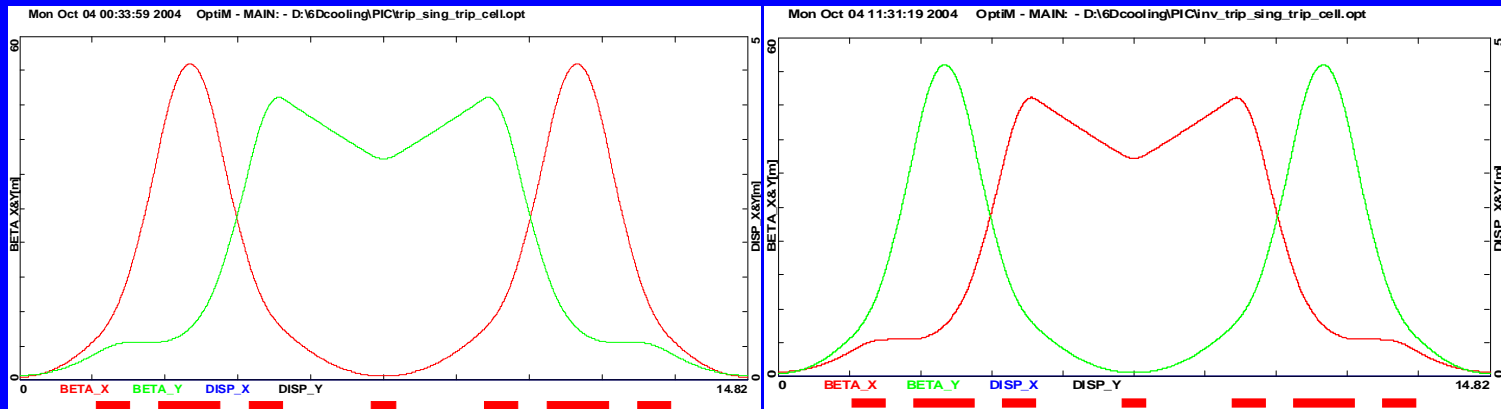
Transverse PIC schematic



Conceptual diagram of a beam cooling channel in which hyperbolic trajectories are generated in transverse phase space by perturbing the beam at the betatron frequency, a parameter of the beam oscillatory behavior. Neither the focusing magnets that generate the betatron oscillations nor the RF cavities that replace the energy lost in the absorbers are shown in the diagram.

The longitudinal scheme is more complex.

Angular 'shearing' of the transverse phase-space (Bogacz & Beard)



New Proposals Submitted 12/13/04

- Muons, Inc. workshop 10/4-5/04 had 14 ideas for new Phase I proposals.
- The 4 submitted were:
 - HCC Magnets with BNL
 - RevEmEx with Jlab
 - G4BL with IIT
 - Muon Precooling, bunching with Fermilab

**REMEX starting point.
Basic 6D Cooling;
Estimated final parameters of a helical 6D cooling
channel**

<i>Parameter</i>	<i>Unit</i>	<i>equilibrium rms value</i>
Beam momentum, p	MeV/c	100
Synchrotron emittance,	μm	300
Relative momentum spread	%	2
Beam width due to dp/p	mm	1.5
Bunch length	mm	11
Transverse emittances,	mm-mr	100/300
Beam widths,	mm	4.5/2.8

Figure 1. Emittance Exchange

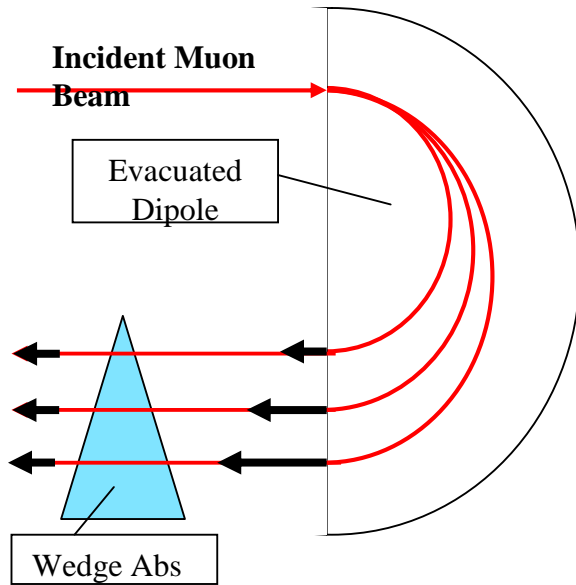


Figure 2. Reverse Emittance Exchange

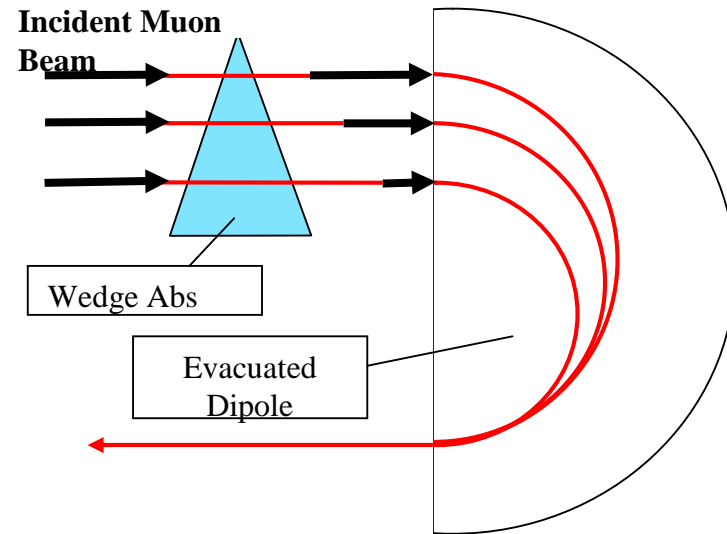


Figure 1. Conceptual diagram of the usual mechanism for reducing the energy spread in a muon beam by emittance exchange. An incident beam with small transverse emittance but large momentum spread (indicated by black arrows) enters a dipole magnetic field. The dispersion of the beam generated by the dipole magnet creates a momentum-position correlation at a wedge-shaped absorber. Higher momentum particles pass through the thicker part of the wedge and suffer greater ionization energy loss. Thus the beam becomes more monoenergetic. The transverse emittance has increased while the longitudinal emittance has diminished.

Figure 2. Conceptual diagram of the new mechanism for reducing the transverse emittance of a muon beam by reverse emittance exchange. An incident beam with large transverse emittance but small momentum spread passes through a wedge absorber creating a momentum-position correlation at the entrance to a dipole field. The trajectories of the particles through the field can then be brought to a parallel focus at the exit of the magnet. Thus the transverse emittance has decreased while the longitudinal emittance has increased.

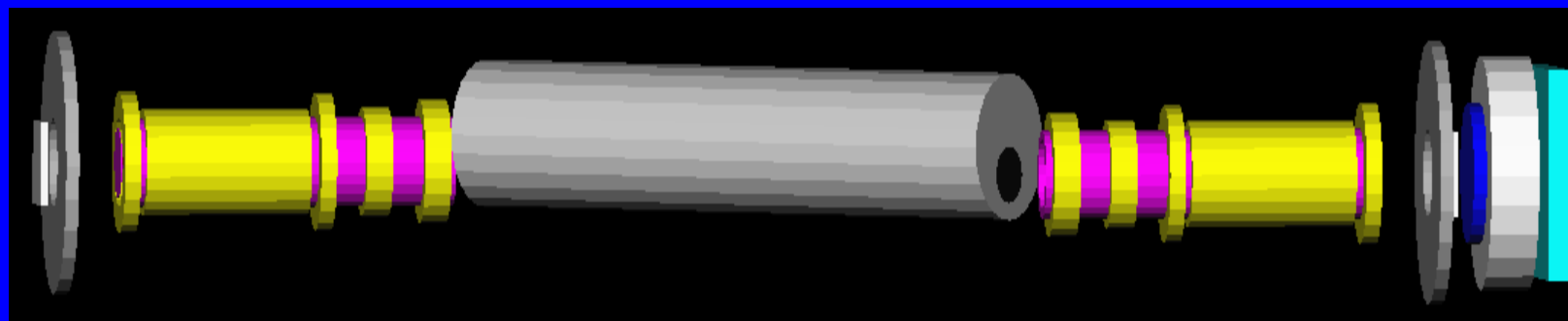
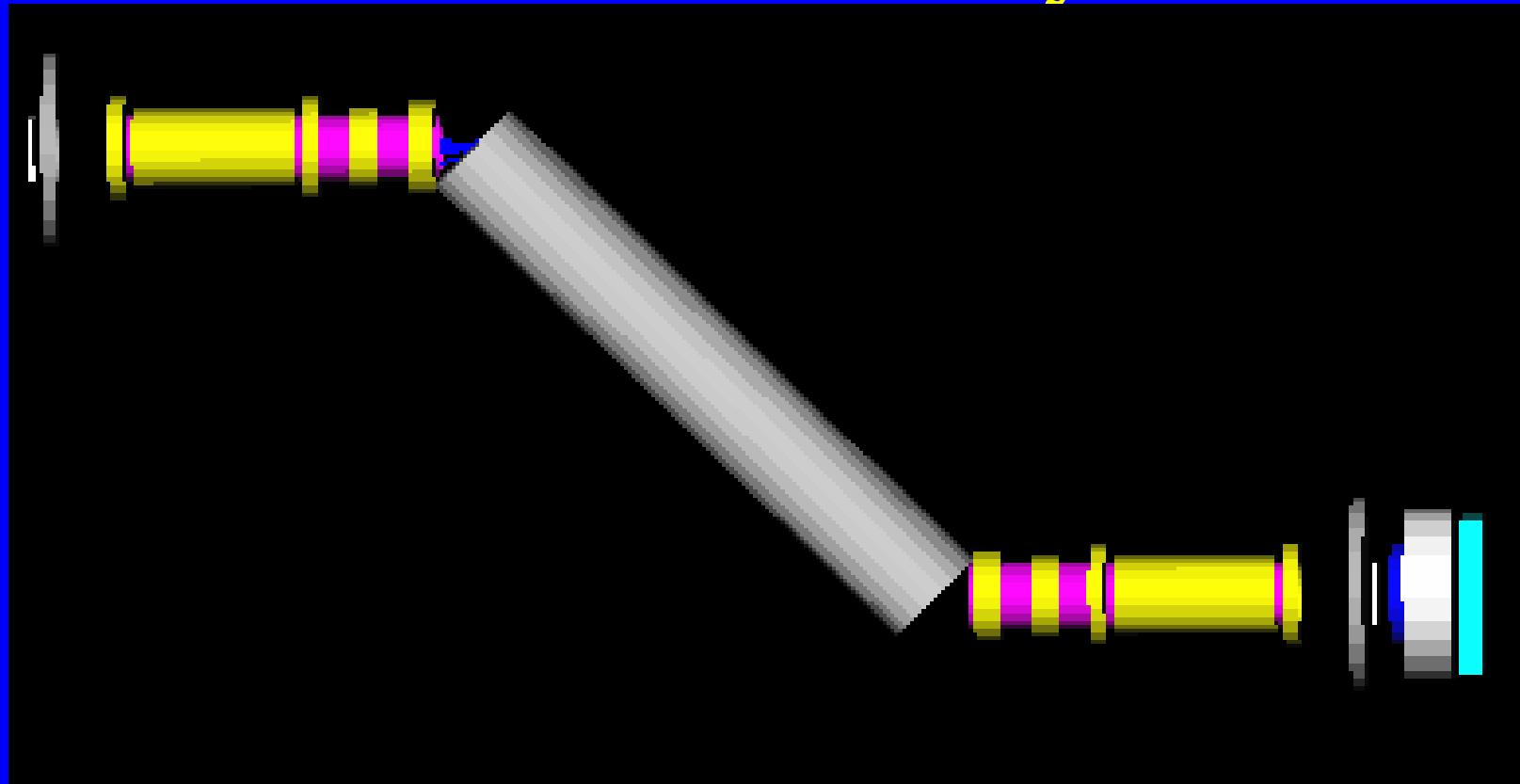
All New 6D MANX

Muon Collider And Neutrino Factory eXperiment
Ph I, w Victor Yarba, Fermilab

- To Demonstrate
 - Longitudinal cooling
 - Helical cooling channel
 - 6D cooling in cont. absorber
 - Prototype precooler
 - New technology (HCC, HTS)
- By using
 - No RF
 - LH2 (or LHe?)
 - MICE detectors



6DMANX Layout



02/14/05

MC LBNL

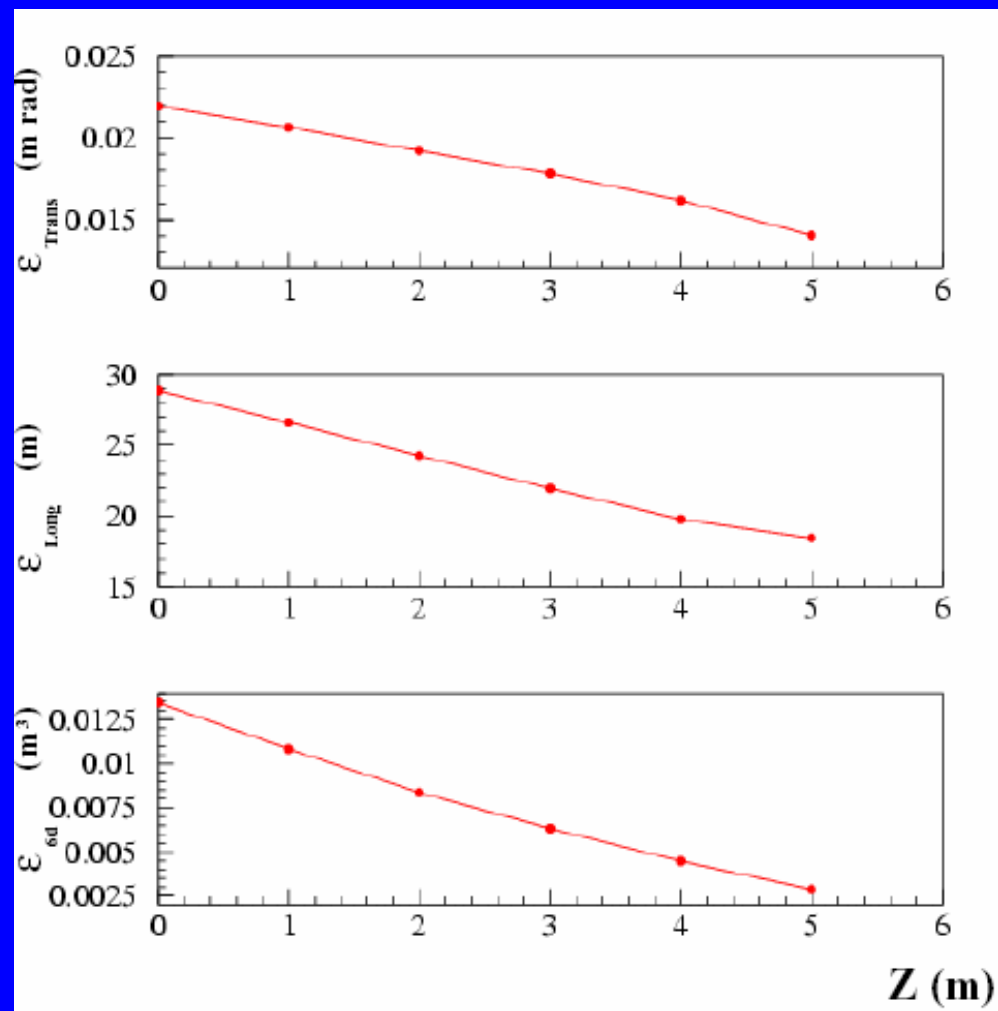
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1st Simulations by Katsuya

Equal decrement case.
~x1.7 in each direction.

Total 6D emittance
reduction ~factor of 5.5

More by Kevin Paul
after some comments
by Slava



Smaller ε_T means fewer μ

$$\mathcal{L} \approx \frac{N_{\mu^+} N_{\mu^-}}{\beta_{\perp} \varepsilon_N}$$

Factor of 100 lower emittance means factor 10 fewer muons needed.

Then, proton driver needs 400kW, not 4MW on target (new Linac * MI)

Neutrino radiation problem reduced.

Detector backgrounds reduced.

Take advantage of $(m_{\mu}/m_e)^2=40,000$ s-channel Higgs production cross-section.

Needs Booster sized ring.

After the Higgs factory, the next step is an energy frontier muon collider using Tesla cavities (perhaps with recirculation) to feed a 2 (or more) TeV ring.

GOAL: Higgs Factory at Fermilab using new muon beam cooling ideas

- μ cooling technique
 - Initial Precooling implies
 - 6D cooling in helix
 - Needs HPRF
 - Parametric resonance
 - Ionization Cooling
 - Reverse emittance exchange (next SBIR proposal)
- ε_N transverse (mm-mr)
 - 10^4
 - 10^2 (usual IC limit)
 - 6D cooling is 10^6
 - 10
 - 1

Summary

- Take advantage of unique properties of muons
 - Pressurized RF Cavities
 - 6D Cooling with homogeneous absorber
 - May make Muon Collider possible
 - Less expensive acceleration for Neutrino Factory
- Once 6D cooling is achieved, use other tricks
 - Parametric Resonance Ionization Cooling
 - Reverse Emittance Exchange
- Is a Higgs Factory an intermediate step to an Energy Frontier Muon Collider?