Muons, Inc. Status:  
Six SBIR/STTR Muon Projects  
Rolland Johnson, May 17, 2004

- HP HG GH2 RF  
  - Ph II, w IIT, DK
- 6D Cooling on Helix  
  - Ph I, w Jlab, YD
- Pulse Compression  
  - Awarded, not funded
- H2 Cryostat (next year?)  
  - Proposed w FNAL, DF
- MANX NEW Award!  
  - w FNAL, DF
- PIC NEW Award!  
  - w Jlab, YD
Thanks to Excellent Collaborators

- IIT; Dan Kaplan, Tom Roberts, Katsuya Yonehara
- JLab; Slava Derbenev, Alex Bogacz, Kevin Beard
- Fermilab; Chuck Ankenbrandt, Al Moretti, Milorad Popovic
- Muons, Inc.; Bob Hartline, Moyses Kuchnir
Project 1: 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.
High-Pressure RF Test Cell
with Moly Electrodes at Lab G

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Muons, Inc.

C. M. Ankenbrandt, A. Moretti, M. Popovic
Fermilab

D. M. Kaplan, K. Yonehara
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See MuCool Note 285 for paper
Mark II 805 MHz RF test cell
New TC; 2000PSI @ 77K
H2 vs He RF breakdown at 77K, 800MHz

- Fast conditioning: 3 h from 70 to 80 MV/m
- Metallic Surface Breakdown Region
- Waveguide Breakdown
- Linear Paschen Gas Breakdown Region
- Hydrogen
- Helium
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
- 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
Project 2, with JLab, Derbenev
Emittance Exchange With GH2

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

5/17/04
Fermilab Absorber Review
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
Preliminary 6D Simulation
Results Presented in Next Talk

ICOOL and Geant4 Comparison
Discussed by
Katsuya Yonehara, IIT

5/17/04  Fermilab Absorber Review
Status of 6D cooling project

• Interesting Ph I analytic, simulation results
  – PRSTAB paper, MuCool Note 248 is preprint
  – ICOOL and GEANT4 HCC simulations under study; cooling and RF behavior a puzzle
  – Precooling-without-RF study of HCC started

• Phase II proposal submitted (April 22)
Project 3 Cryogenic Pulse Compressors
Ph I, Dave Finley, Fermilab

These are seven foot diameter spheres for 200 MHz

Figure 1. A comparison of the SLED and Circulator designs.
Status of Cryogenic Pulse Compressor Project

• Principles developed for >50 MV/m @200MHz
  – Two compression schemes to get power compression by a factor of 7, or voltage by $\sqrt{7}=2.65$
  – Cold RF increases voltage by $(\text{resistivity ratio})^{1/4}=1.68$
  – Voltage thus increased by $(4.45 \times 15) = 66.7$ MV/m
New 2004 Proposal not approved
Hydrogen Cryostat
with Dave Finley, Fermilab

• simultaneously refrigerate
  – 1) HTS magnet coils
  – 2) cold copper 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
Hydrogen Cryostat
New 2004 Project!!

MANX

Muon Collider And Neutrino Factory eXperiment
Ph I, w Dave Finley, Fermilab

• Hi-Pressure GH2
• Continuous Absorber
• Continuous low-β
  – Single-flip Solenoids
• Internal Scifi detectors
  – Minimal scattering
• MANX follows MICE
  – Engineering proof
MANX comparison to MICE

• Conventional LH2 cooling channel
  – Liquid hydrogen absorbers between RF cavities
  – Placed at low $\beta$ locations, where solenoidal fields change direction

• Proposed GH2 cooling channel
  – Continuous dense hydrogen absorber fills RF cavities
  – Low $\beta$ is continuous along channel
MANX is GH2 version of MICE
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 $\frac{1}{2}$-integer extraction
    • Use $xx'=$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

\[ xx' = \text{const} \]
Fig. 3 Phase space compression. The spread in $x$ diminishes due to the parametric resonance motion while the spread in $x'$ diminishes due to ionization cooling. The area of the occupied phase space ellipse is reduced as the particles are restricted to a narrow range of phase angle, psi.

PIC concept first appears in our 2004 SBIR proposal! First paper EPAC2004, YD,RJ.
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.
Summary

• SBIR/STTR can support a vigorous R&D effort
  – Innovation requirement demands creativity
  – Scientific interests well-served
    • Government---expands project choices with most value
    • Academic---leads to best projects, support of researchers
    • Business---allows small business to take part in big science

• GH2 an enabling technology for $\mu$ machines
  – HG RF for less-expensive, more efficient beam cooling
    • Takes advantage of unique properties of muons
  – Emittance exchange with homogeneous absorber
    • 6D Cooling makes Muon Collider possible, maybe PIC
    • Less expensive acceleration for Neutrino Factory