Pressurized GH2 RF Cavities for Muon Beam Cooling

R. P. Johnson, R. E. Hartline
Muons, Inc., Batavia, IL 60510

C. M. Ankenbrandt, M. Kuchnir, A. Moretti, M. Popovic
Fermi National Accelerator Lab., Batavia, IL 60510

M. Alsharo'a, E. L. Black, D. M. Kaplan,
Illinois Institute of Technology, Chicago, IL 60616

Muons, Inc.

- Formed in 2002
- High Pressure RF Cavities Funded for $100k
  - DOE Grant phase 1 for 9 months.
  - Small Business Technology Transfer Research(STTR)
  - MUCOOL note 247 is the proposal.
  - Phase 2 proposal submitted 4/23/2003.

Need for Cooled Muon Beams

- Muon Colliders (Energy Frontier Machine)
  - Not limited by synchrotron radiation like e+e-
  - 1/10 energy and footprint of Proton Colliders
- Neutrino Factories (Muon Storage Ring)
  - Exciting New Physics
- Intense Sources of Muons
  - e.g. Muon Spin Resonance

1^{st} Goal: HP HV RF Cavities

- 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

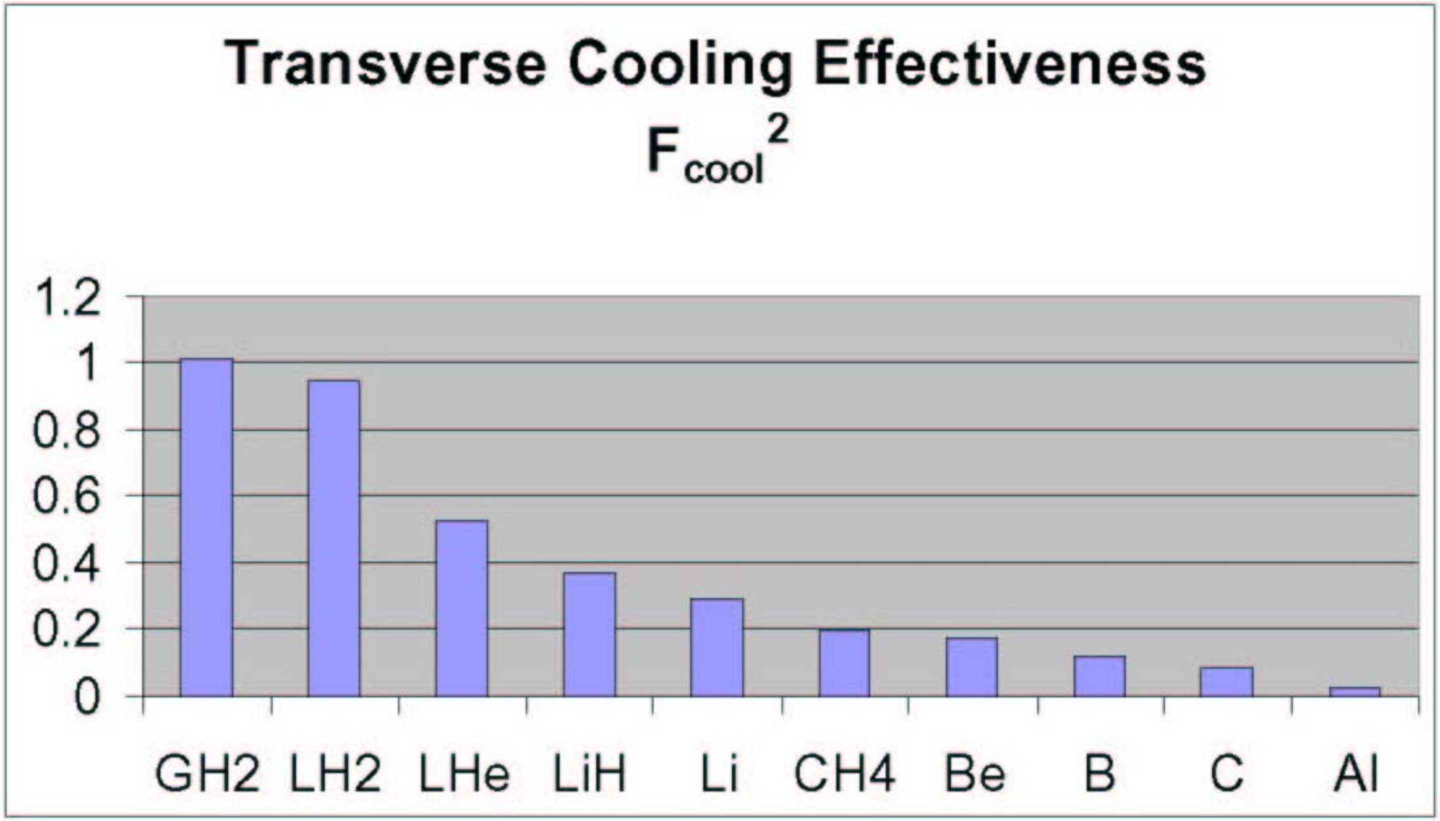
Muon Ionization Cooling

- Muons lose energy by dE/dx in 3 directions
- Longitudinal energy replaced by RF
- Focused by 5 Tesla solenoidal field
  - No Superconducting RF
- Cools to limit of multiple scattering

Hydrogen Gas Virtues/Problems

- Best ionization-cooling material
  - $(X_0 * dE/dx)^2$ is figure of merit
- Good breakdown suppression
- High heat capacity
  - Cools Beryllium RF windows
- Scares people
  - But much like CH_4

Comparison of Absorber Materials



Regions of Interest for High Pressure Gaseous Hydrogen Cooling Channels

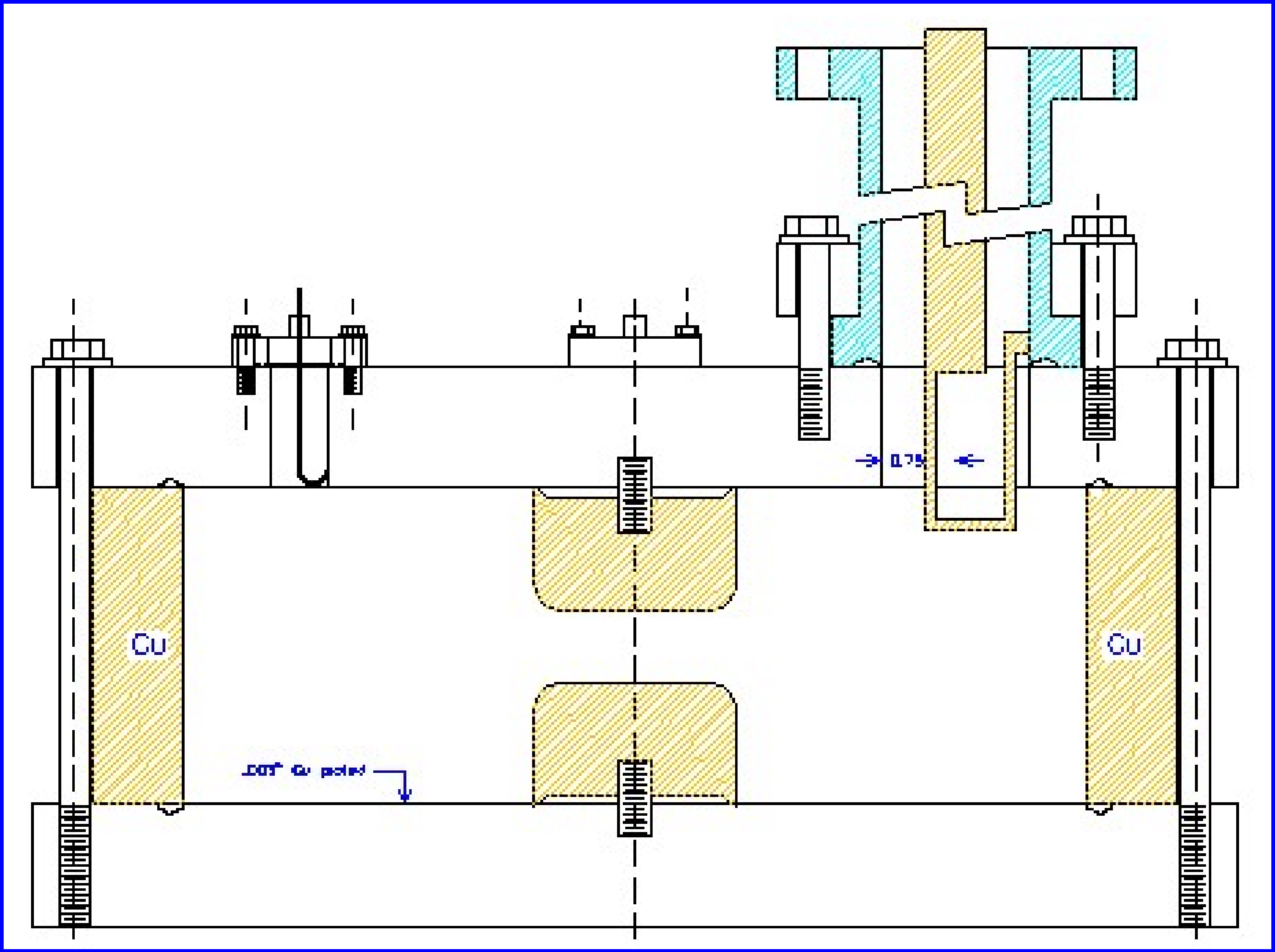
	Pressure	Temperature	rho/rhoLH	dE/dx	L/200MeV	Vs	Rs/Rs293	Rs/Rs293
	Atm	K		MeV/m	m	MV/m	(@ 200MHz)	(@ 800MHz)
Gaseous H2								
at STP	1	293	0.001	0.04	5304	4	1.00	
Felici [1948]	**23**	293	0.027	0.87	231	**28**	1.00	
Lab G achieved	12	77	0.054	1.72	116	50		
Lab G goal	**100**	**77**	**0.450**	**14.35**	**14**	**435**	**0.35**	**0.35**
Liquid H2								
Averages Double Flip	1	293	0.125	3.98	50	50	1.00	1.00

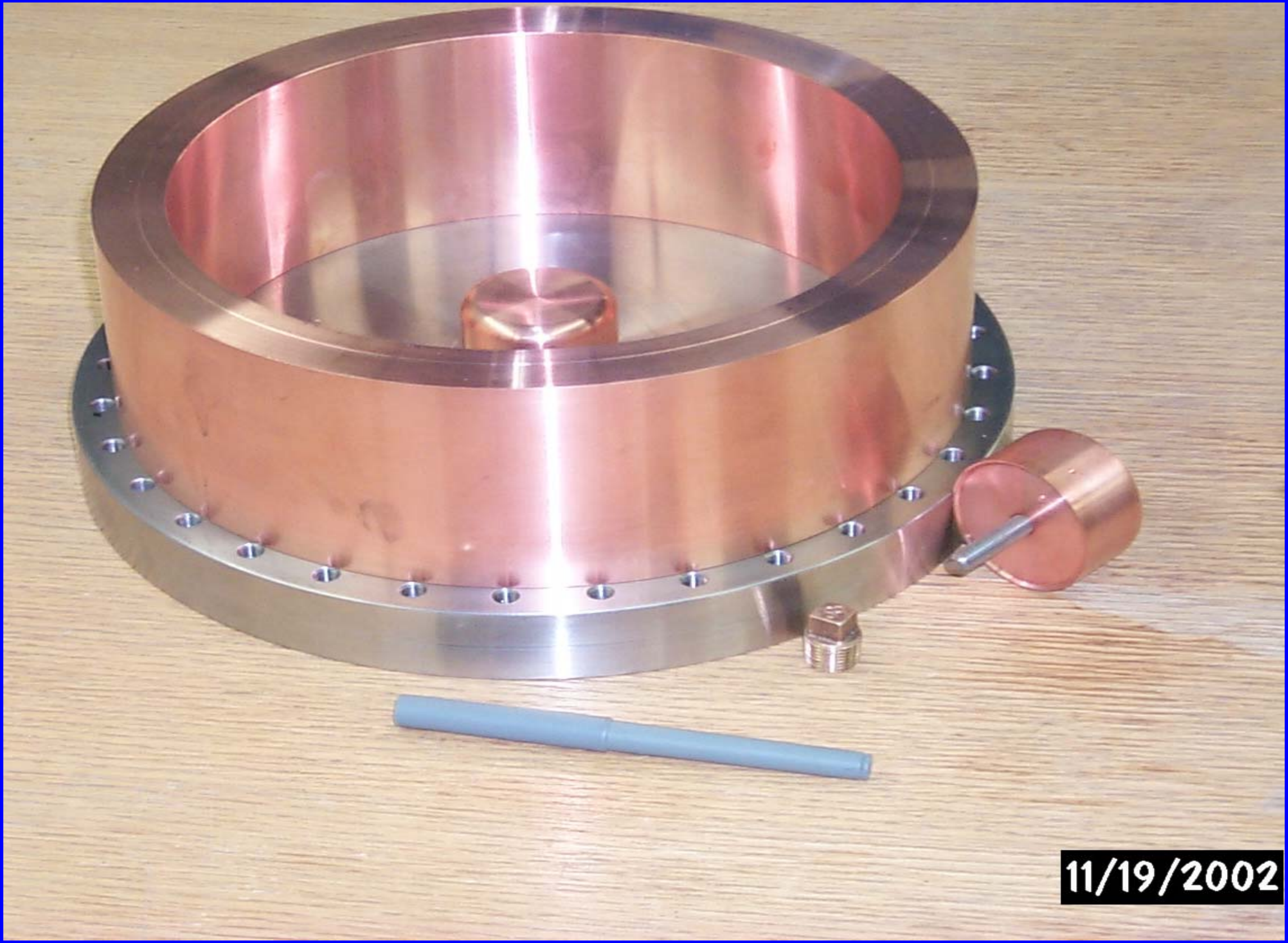
STTR Phase I Goal

To build an RF test cell for testing breakdown characteristics of gases for ionization cooling.

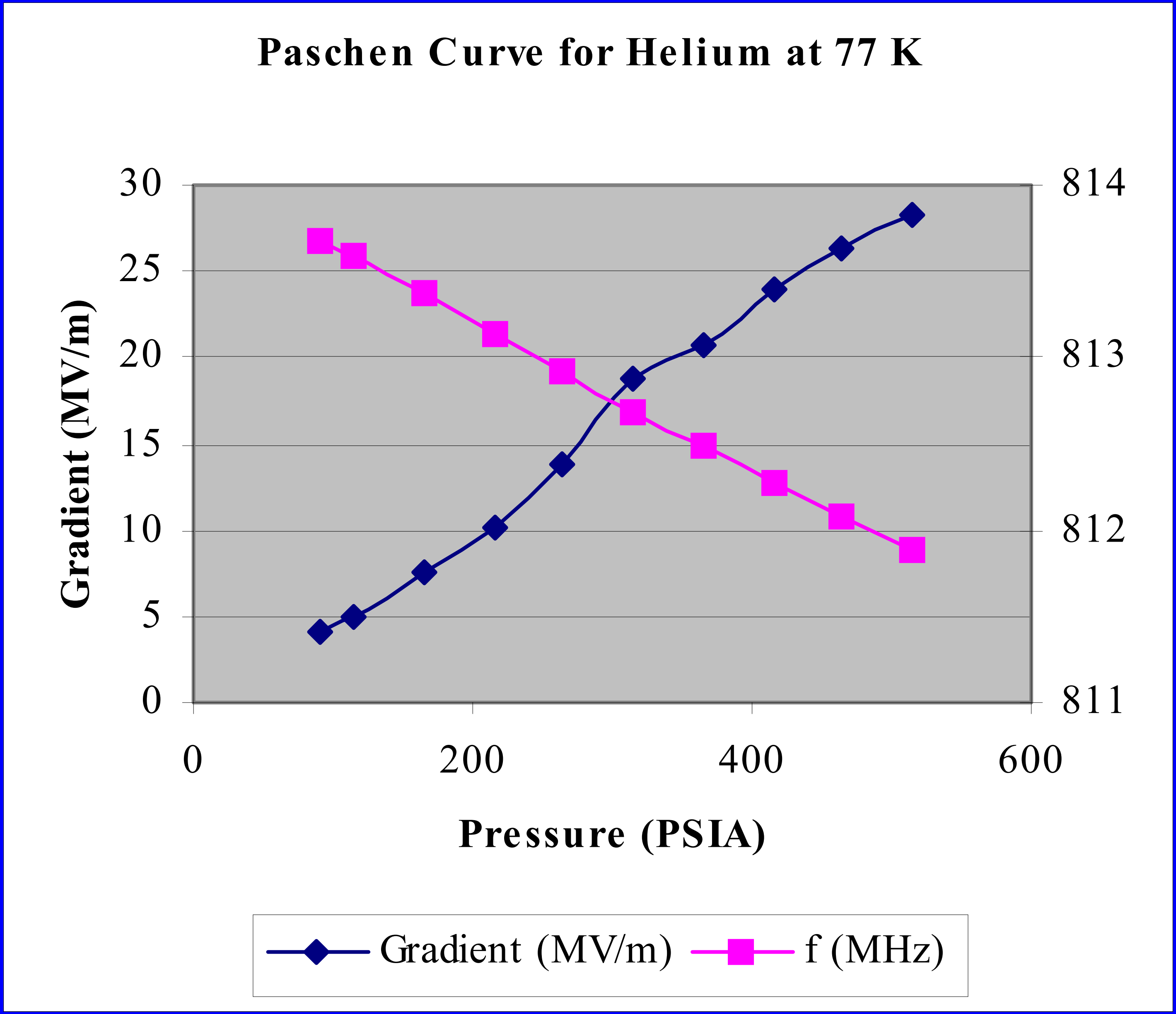
The test cell will allow the exploration of Paschen's Law, relating breakdown voltages to gas density, over a range of temperatures, pressures, external magnetic fields, and ionizing particle radiation at Lab G and the Linac Test Area.

805 MHz RF test cell schematic

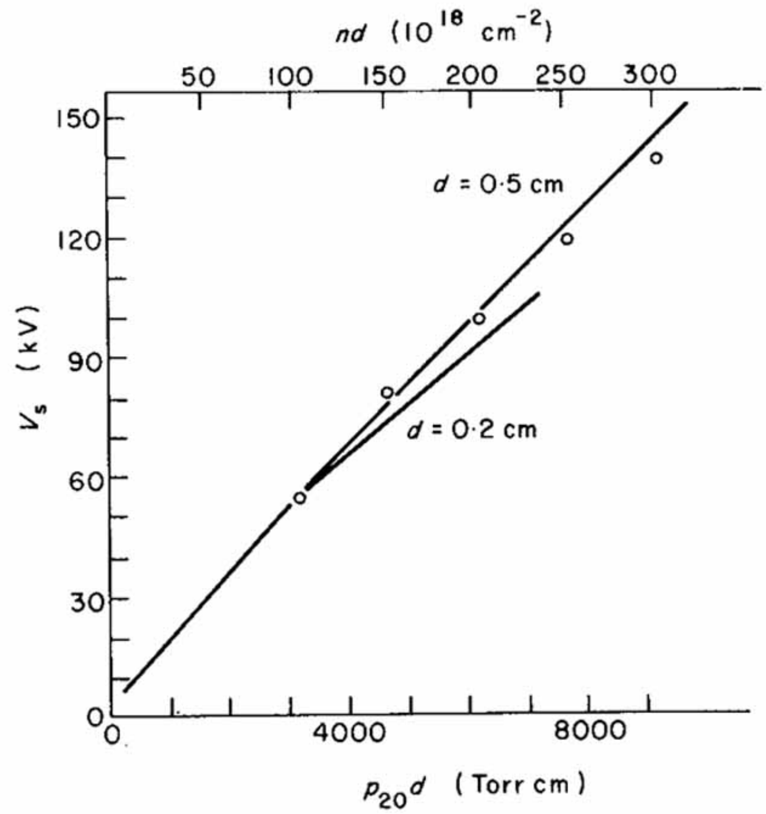



11/19/2002


4/9/2003


Paschen Curve for Helium at 77 K
Gradient (MV/m)
30
25
20
15
10
5
0
814
813
812
811
0
200
400
600
Pressure (PSIA)
Gradient (MV/m)
f (MHz)

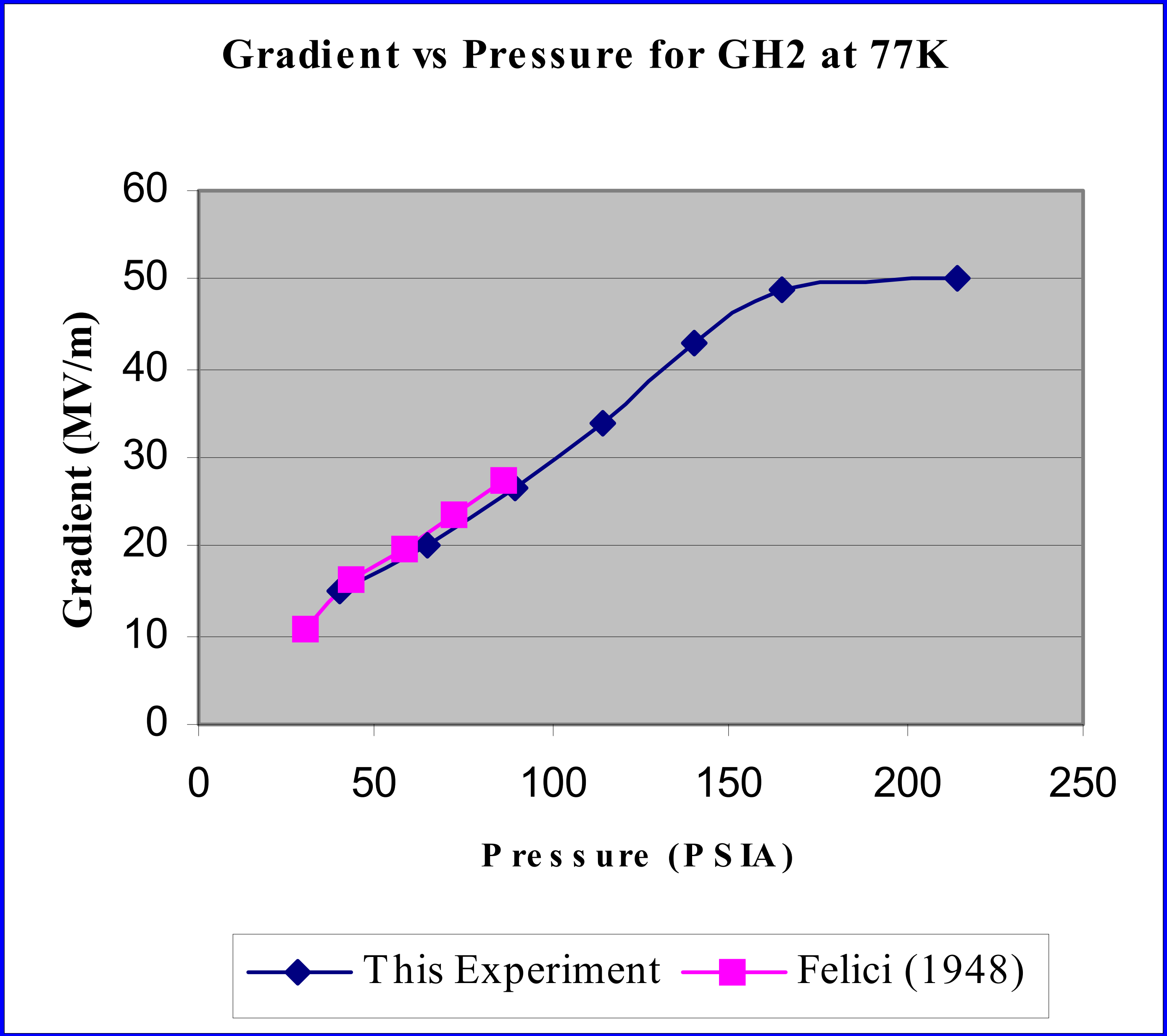
H2 DC Paschen Data existed up to P=25 Atm,V=28 MV/m



Breakdown voltages in hydrogen (Müller, 1966. Reproduced by permission of Springer–Verlag)

—— Müller (1966)

○ Félici and Marchal (1948)



Gradient vs Pressure for GH2 at 77K
60
50
40
30
20
10
0
Gradient (MV/m)
0
50
100
150
200
250
Pressure (PSIA)
This Experiment
Felici (1948)


HOT
9/4/2002


10/11/2002


HANDLE WITH CARE
DELICATE INSTRUMENTS
FRAGILE
10/13/2002

STTR Phase I & II Status

- Measured helium Paschen curve
  - Built RF test Cell
  - Achieved Phase I goal
- Measured hydrogen Paschen curve
  - Satisfied FNAL safety requirements
  - 50 MV/m at 77 K and 12 Atmospheres!
- Phase II proposal submitted 4/23/03
  - Study Hydrogen breakdown (B and radiation)
  - Develop cavity designs (800 & 200 MHz)

Hopes for HP GH2 RF

- Higher gradients than with vacuum
- Less dependence on metallic surfaces
  - Dark currents, x-rays diminished
- Easier path to closed-cell design
  - Hydrogen cooling of Be windows
- Use for 6D cooling and acceleration
  - Homogeneous absorber concept

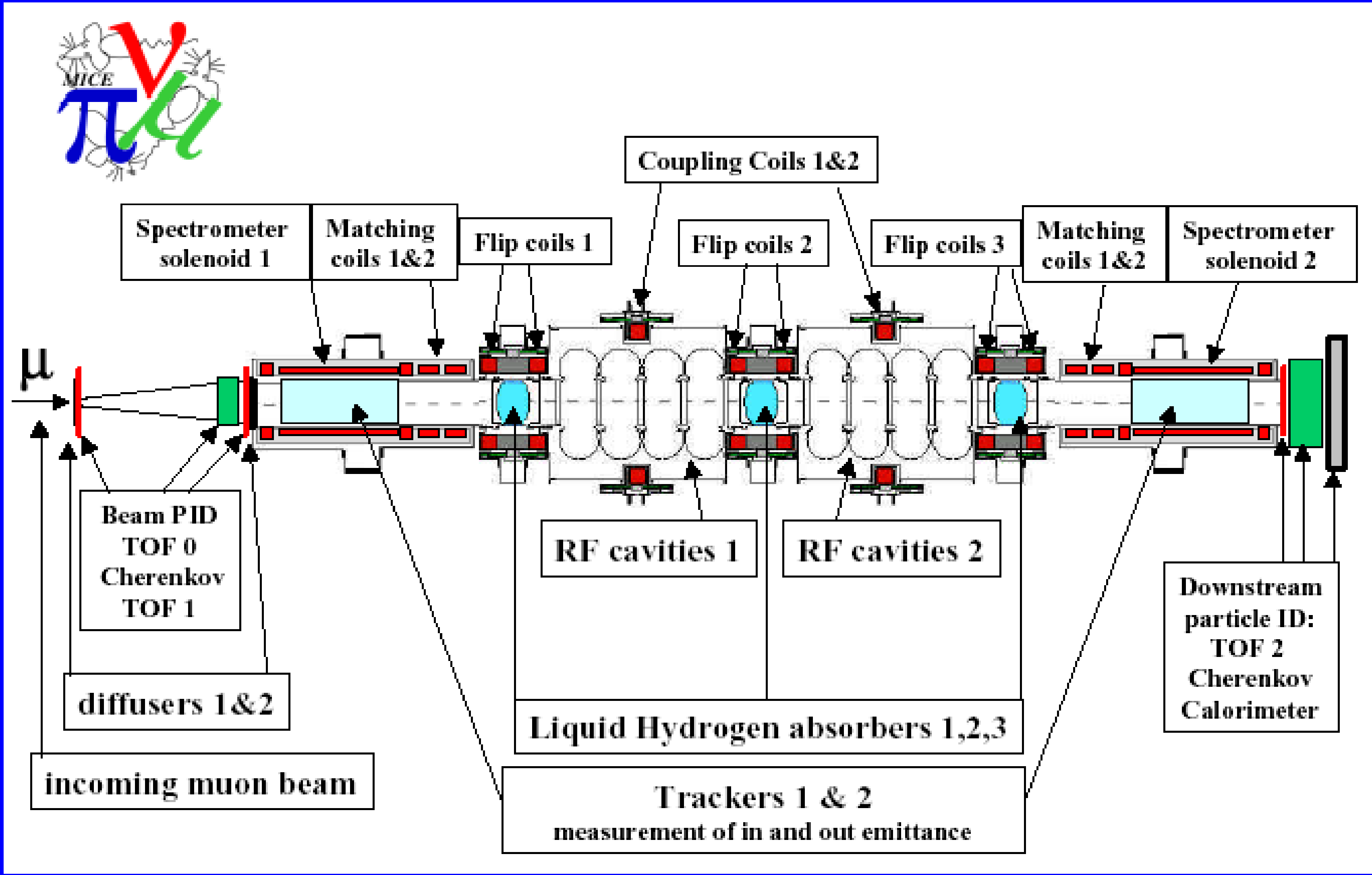
New Muons Inc. Ph I Proposals:

- Transverse Ionization Cooling (w/ FNAL)
  - MANX ion-cooling demonstration rejected
- RF power sources (w/ FNAL) approved
  - Cryogenic pulse compressors; MTA facility
- 6D Cooling (w/ TJNAF) approved
  - Homogeneous absorber (No wedges)
  - helical dipole channel

Muon Collider And Neutrino Factory eXperiment

- MANX follows MICE
- Hi-Pressure GH2
- Continuous Absorber
- Continuous low-β
  - Single-flip Solenoids
- Internal Scifi detectors
  - Minimal scattering

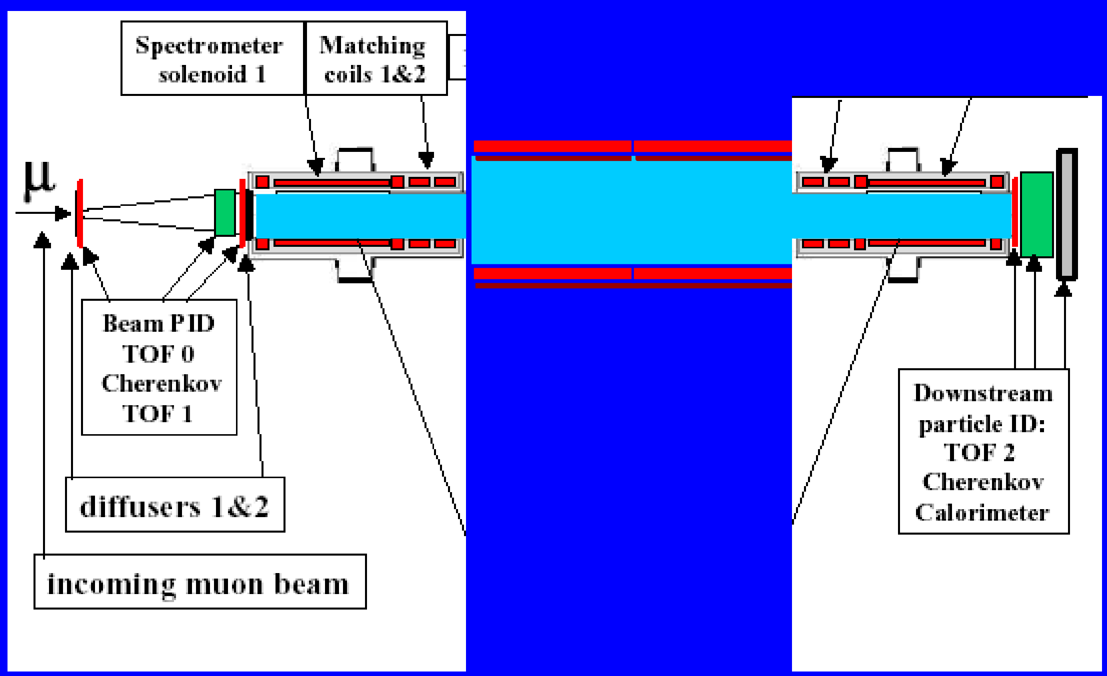
MICE



MICE
Coupling Coils 1&2
Spectrometer solenoid 1
Matching coils 1&2
Flip coils 1
Flip coils 2
Flip coils 3
Matching coils 1&2
Spectrometer solenoid 2
μ
Beam PID
TOF 0
Cherenkov
TOF 1
RF cavities 1
RF cavities 2
Downstream particle ID:
TOF 2
Cherenkov
Calorimeter
diffusers 1&2
Liquid Hydrogen absorbers 1,2,3
incoming muon beam
Trackers 1 & 2
measurement of in and out emittance

MANX is GH2 version of MICE

MANX



MICE changes into MANX

- Continuous GH2 replaces LH2 flasks
  - High density from P and/or T
- Opposing solenoids
  - Simple picture of “single-flip” lattice
  - Needs blackboard
- Detectors (scifi) in gas
  - No pressure windows to obscure cooling

6-dimensional cooling

- Essential for Muon Collider, useful for NF
- Still IC, but dE/dx depends on μ Energy
- Ring Cooler studies in fashion
  - Generates dispersion as in a synchrotron
  - Economical:15 turns means reused RF and absorbers
  - Problems with injection/extraction, absorber heating, RF beam loading

Emittance Exchange With GH2

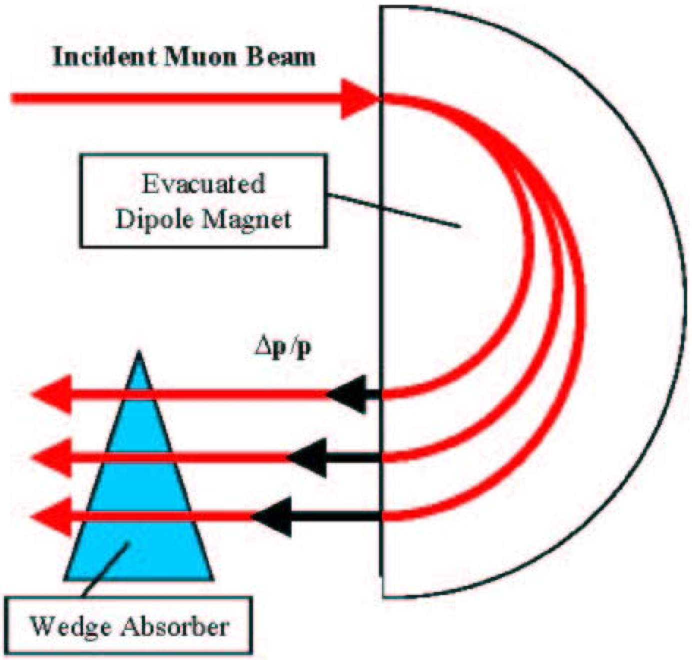


Figure 1. Use of a Wedge Absorber for Emittance Exchange

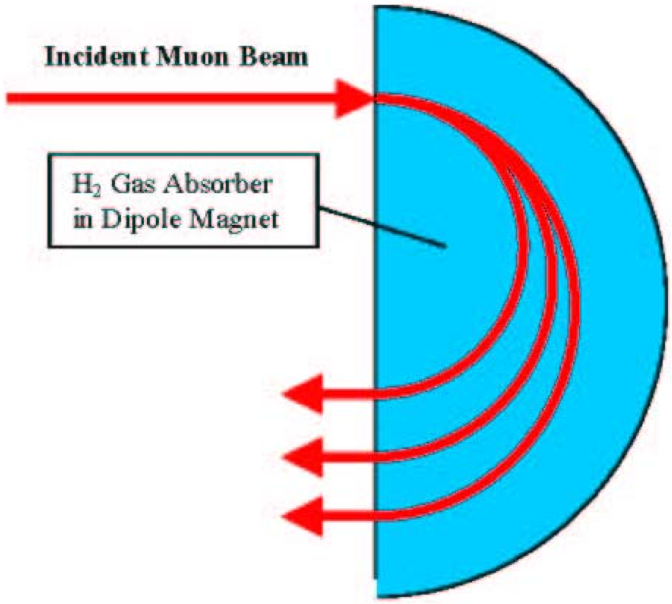


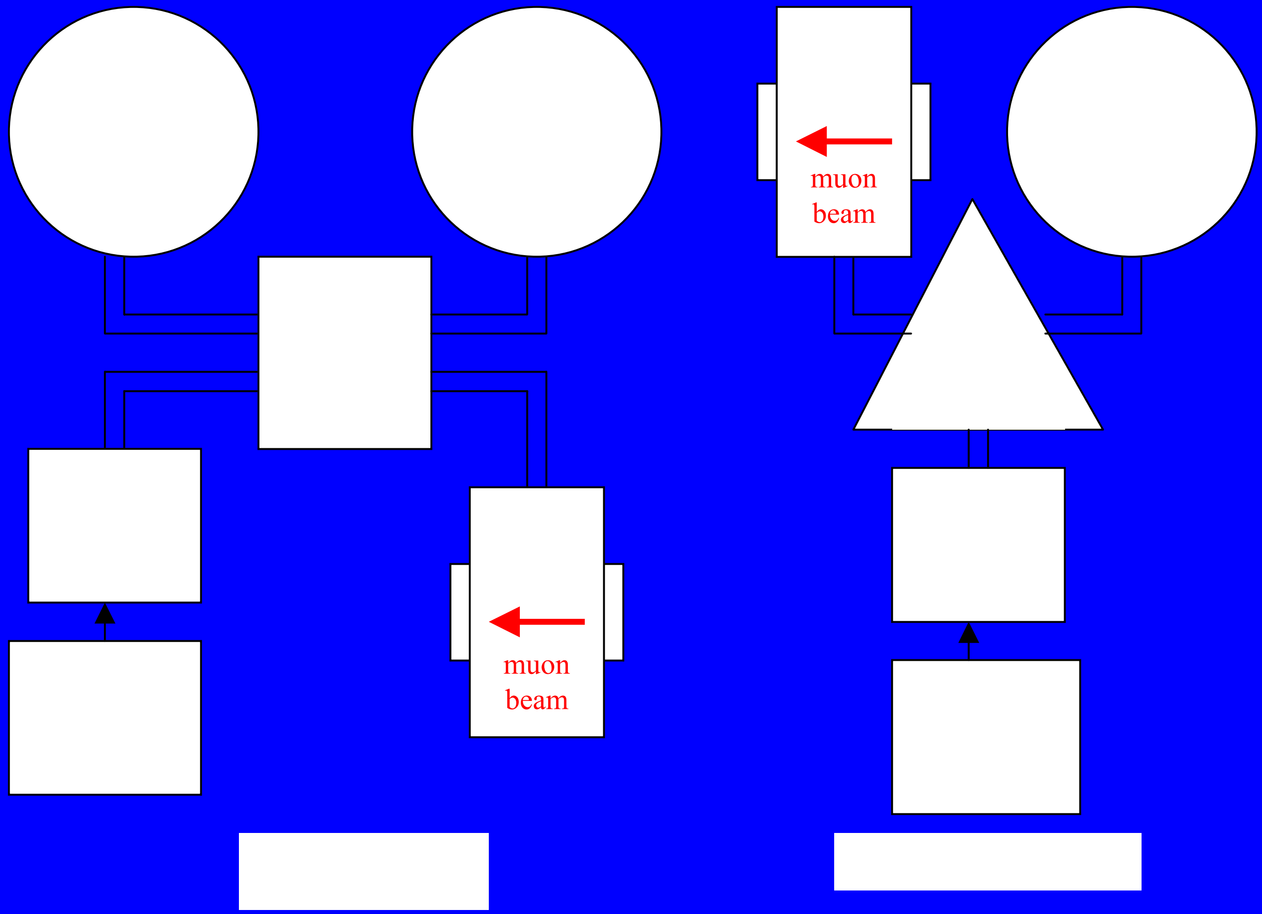
Figure 2. Use of Continuous Gaseous Absorber for Emittance Exchange

6-d Cooling with GH2

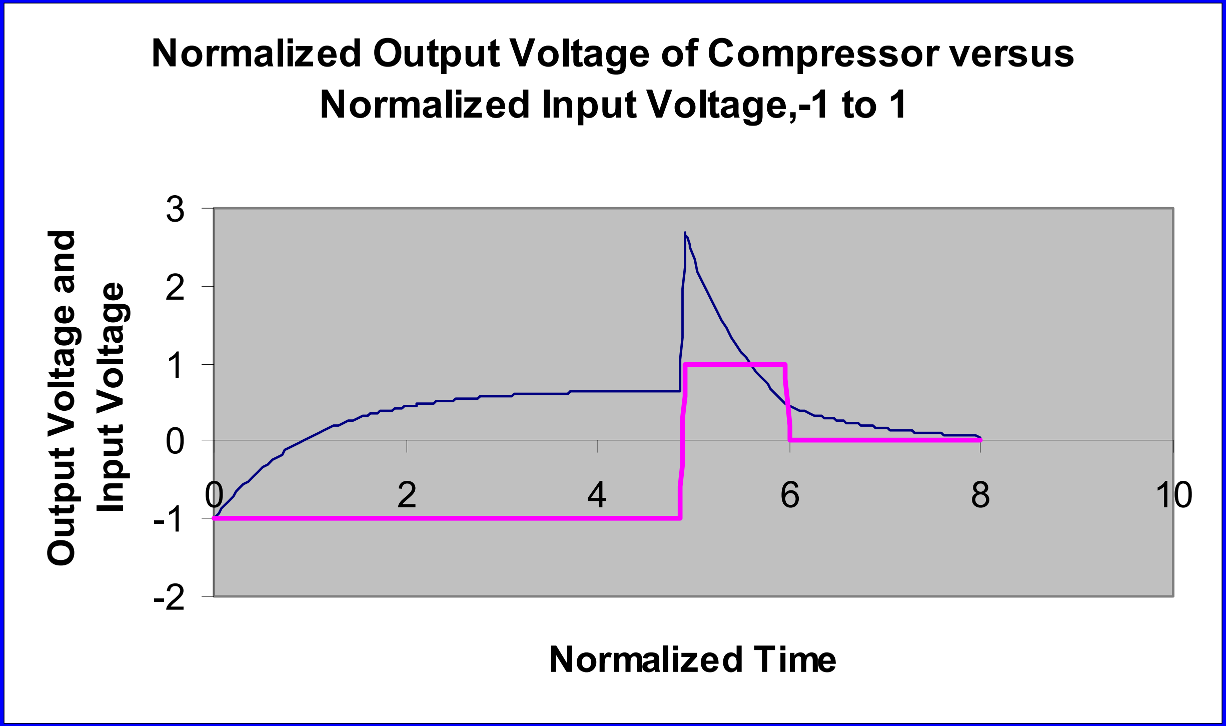
- Derbenev channel: Solenoid plus transverse helical dipole fields
- Analytically see equal cooling decrements and 10^6 phase space reduction in ~150 m channel
- Avoids ring problems
  - Injection and Extraction simpler
  - No Multi-pass Beam loading or Absorber heating
  - Can adjust channel parameters as beam cools

Cryogenic Pulse Compressors;

A comparison of the SLED and Circulator designs.



Input and output voltage of a compressor as a function of time.



Conclusions

- GH2 an enabling technology for μ machines
  - New possibilities for gas-filled RF cavities
  - Continuous energy absorber has virtues
- SBIR/STTR funding new for basic research
  - Explicit in last solicitation
  - Depending on grants, will need to hire physicist(s) and engineers(s). CVs to roljohn@aol.com