Gaseous Hydrogen in Muon Accelerators

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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 due 4/23/2003.

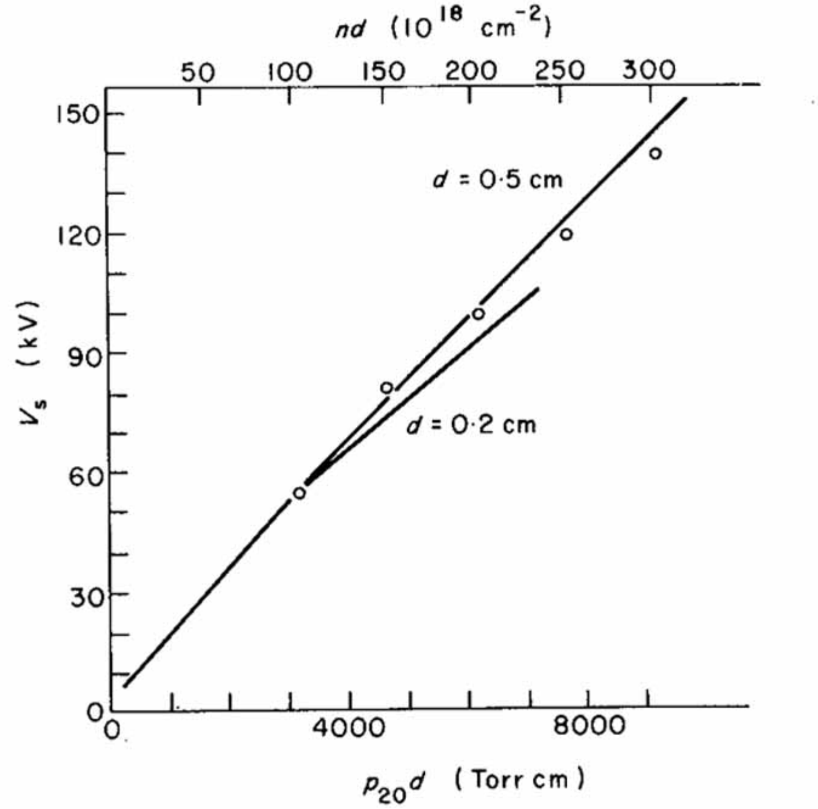
Muon Accelerators

- Muon Colliders (Energy Frontier Machine)
  - Not limited by synchrotron radiation like e+e-
  - 1/10 energy/footprint of Proton Colliders
- Neutrino Factories (Muon Storage Ring)
  - Exciting New Physics
- Intense Source 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

H2 Paschen Data exist 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)

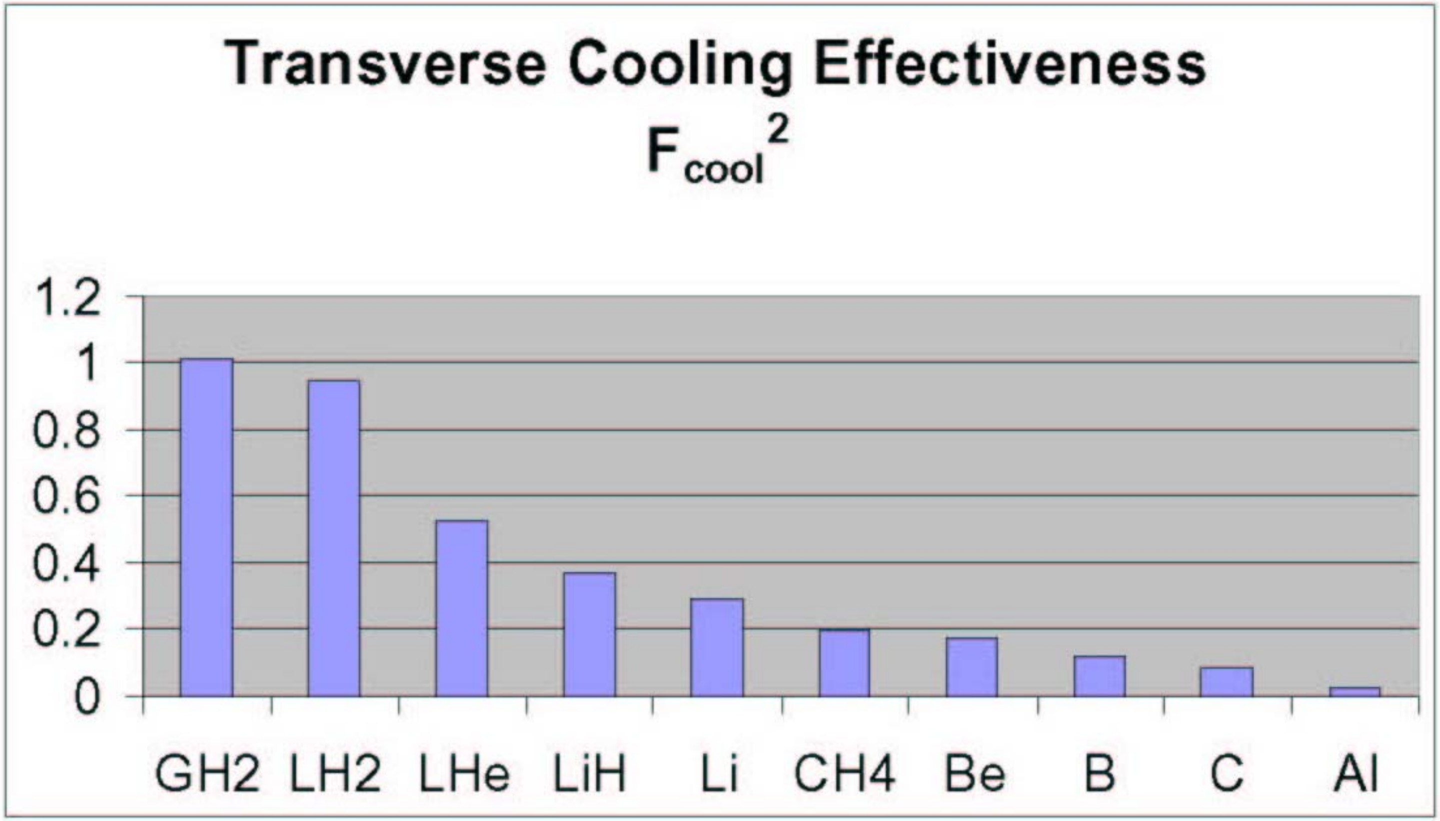
Muon Ionization Cooling

- Muons lose energy by dE/dx in 3 directions
- Longitudinal energy replaced by RF
- Focused by 5 Tesla solenoidal field
  - No SRF
- 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	
	1	30	0.012	0.37	543	15	0.05	0.13
highest Paschen data	**25**	293	0.030	0.94	212	**28**	1.00	
	20	**30**	**0.231**	**7.37**	**27**	**140**	**0.05**	**0.13**
critical T, P	26.3	33.2	0.275	8.75	23	162		
	30	80	0.130	4.14	48	87	0.35	0.35
Lab G goal	**100**	**80**	**0.433**	**13.81**	**14**	**239**	**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.

Measures of Phase 1 Success

- Paschen curve measurements H_2, He
  - 805 MHz breakdown vs. gas density
  - At 300K and 80K (LN2)
  - Pressures up to 100 Atmospheres
  - H_2 at 80K, 100 Atm extrapolates to **239 MV/m**
- This should increase probability for phase 2
  - Also for new phase 1 proposals

Accomplishments so far

- Developed Pb-Sn solder HP, RF Seal
  (after trying knife-edges on Cu conflat gasket)
  6” SS flanges
  - Hydrostatic(HS) to 3400 PSI
  - He to 1800 PSI, 3 cycles to 300K to 80K

  12” SS flanges to 1400 PSI HS
  6” SS-Cu-SS sandwich to 3400 PSI HS
- Developed 1 5/8” coax epoxy feedthrough
  Hydrostatic to 3000 PSI


HOT
9/4/2002

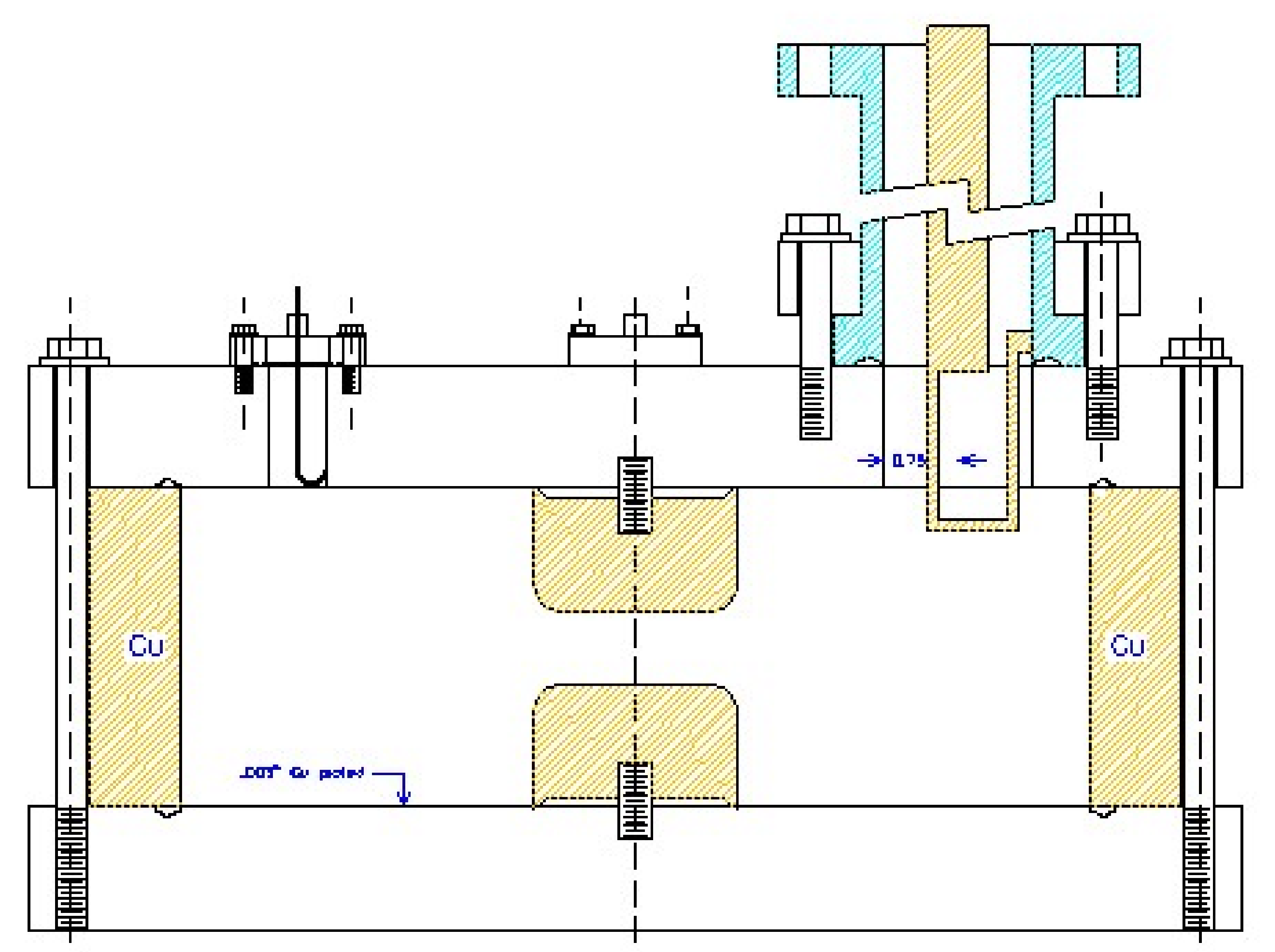

10/11/2002

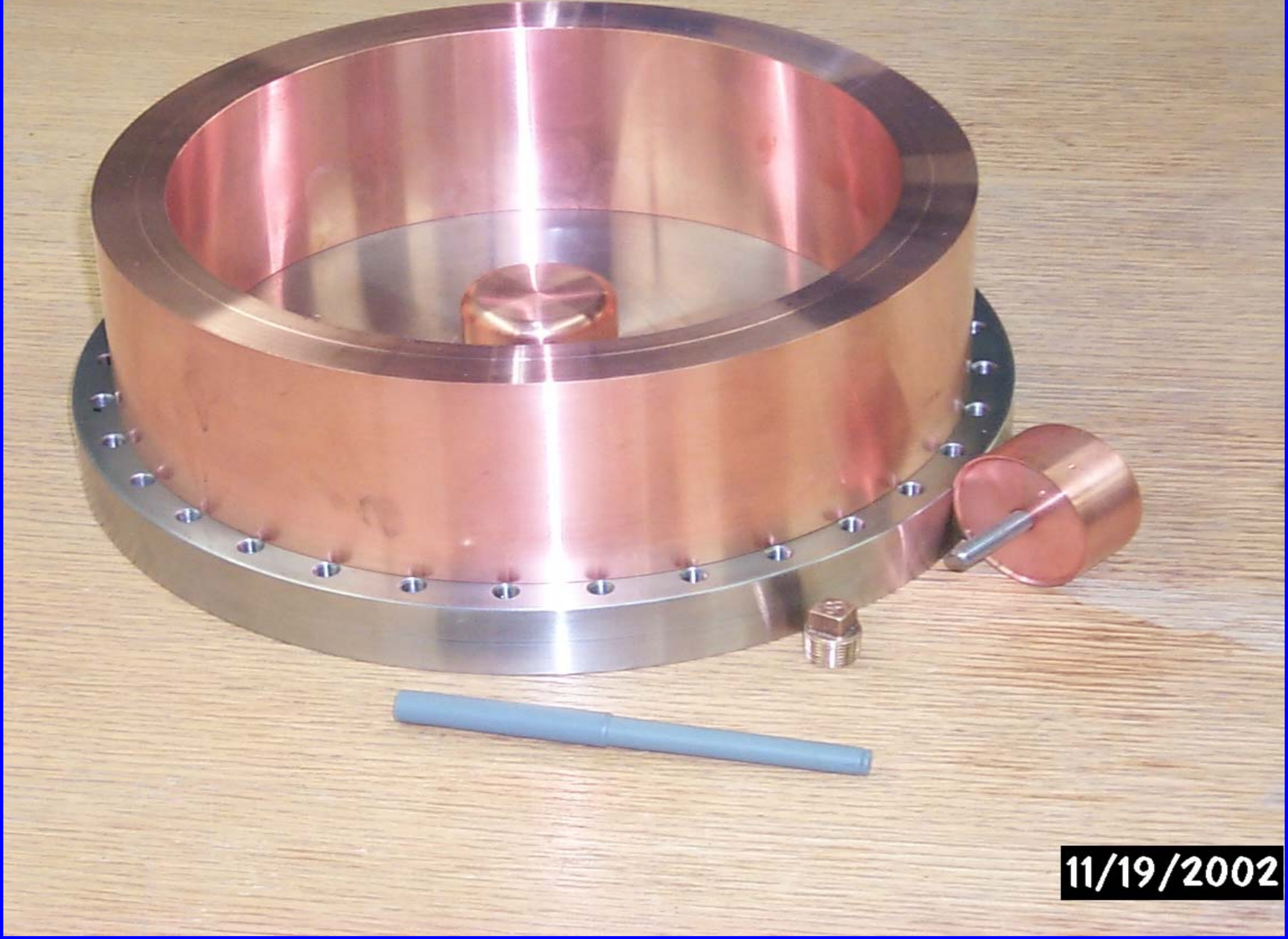

HANDLE WITH CARE
DELICATE INSTRUMENTS
FRAGILE
10/13/2002

Present Activities

- TC design, construction done.
- Safety calculations for He and H_2
  - Test Cell too small to be pressure vessel, BUT still considered one! Eng. note to 34 atm.
  - Class 0 flammable gas hazard, BUT required to pass <u>liquid</u> hydrogen <u>target</u> requirements!
  - ODH analysis requires 20 air changes/h in cave.
  - http://members.aol.com/muonsinc/TC.pdf
- Almost ready for RF tests ~3/8/03

805 MHz RF test cell schematic

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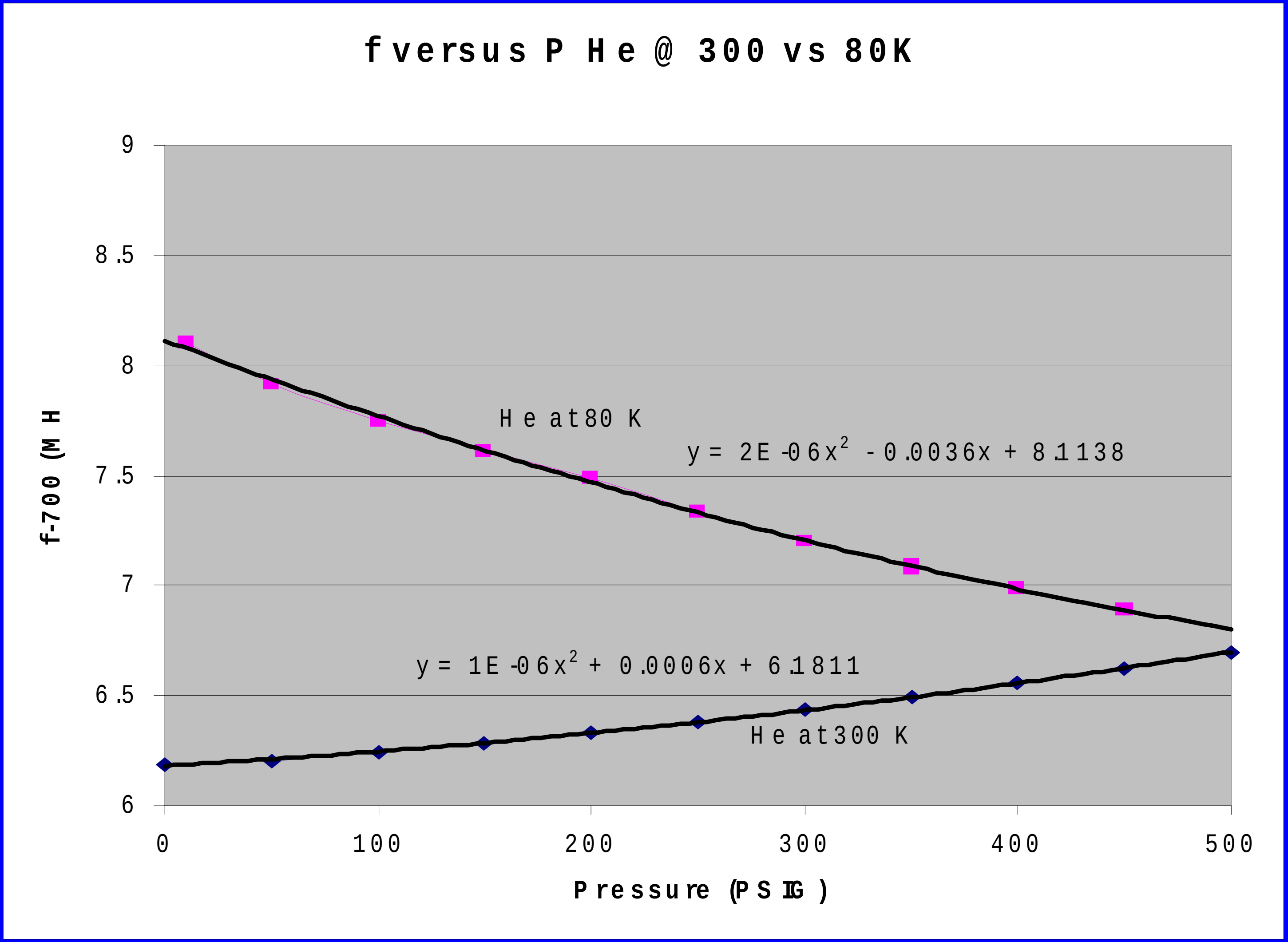
Lab G frequency vs Pressure

Test Cell in LN2 bath

TC f_0 vs P for He at 80 and 300K



STTR Phase I & II Status

- Adjusted f_0 by shaping electrodes
  - Edge radius changed from 0.25” to 0.94”
  - Changed f_0 from ~706 to 806.02 MHz
- Will measure He breakdown versus P & T
  - Next few weeks (Goal of Phase I)
  - Still trying for hydrogen safety okay
- Preparing Phase II proposal (due 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

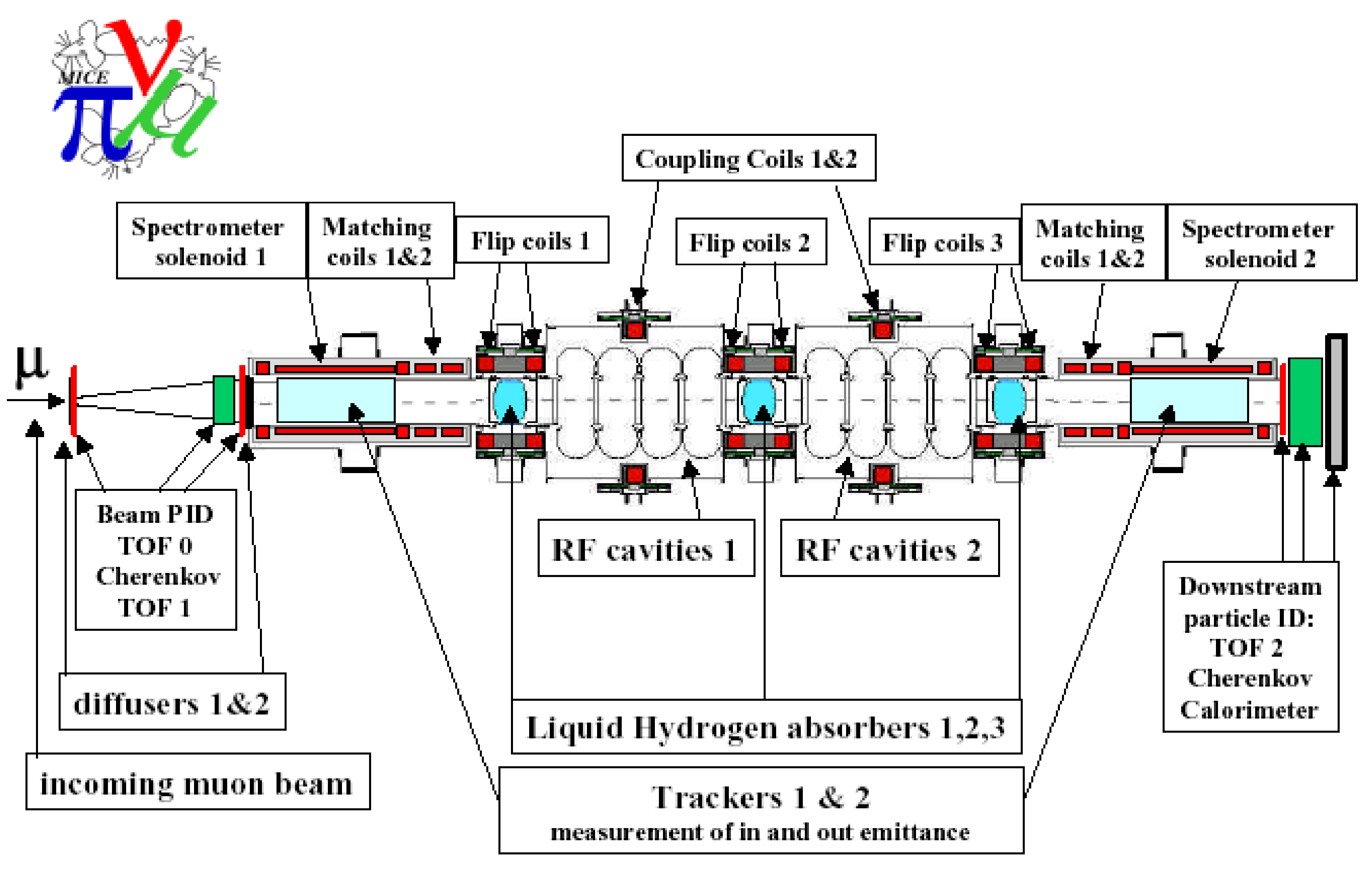
New Muons Inc. Ph I Proposals:

- Transverse Ionization Cooling (w/ FNAL)
  - MANX ion-cooling demonstration
- RF power sources (w/ FNAL)
  - Cryogenic pulse compressors; MTA facility
- 6D Cooling (w/ TJNAF)
  - 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

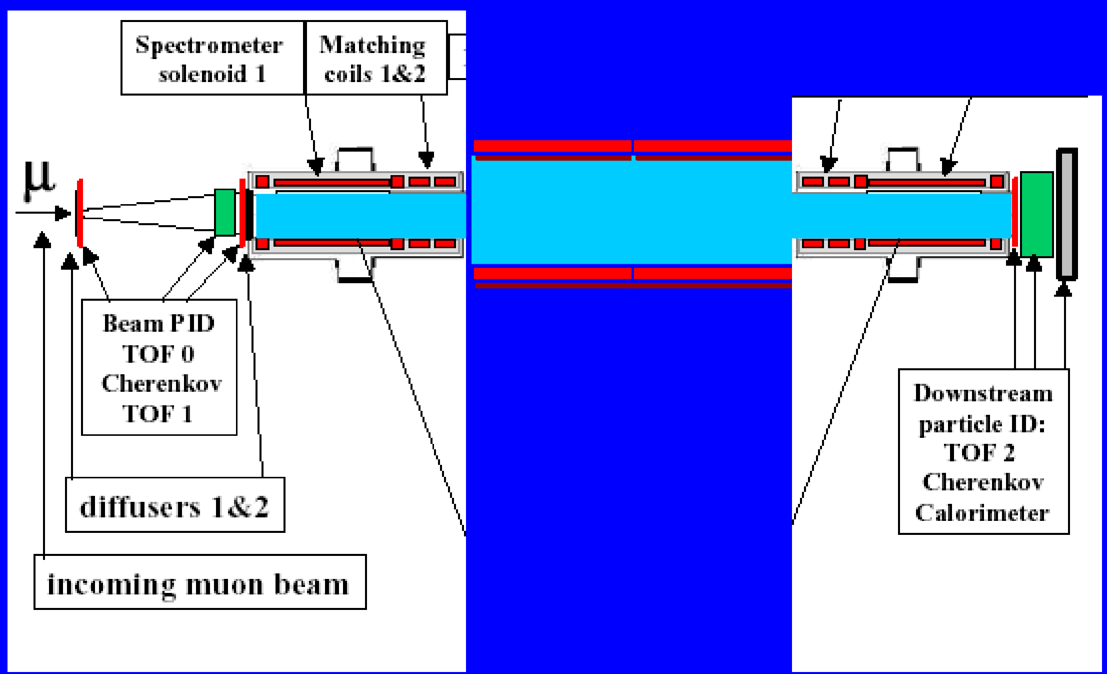
MICE



MICE
μ
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
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



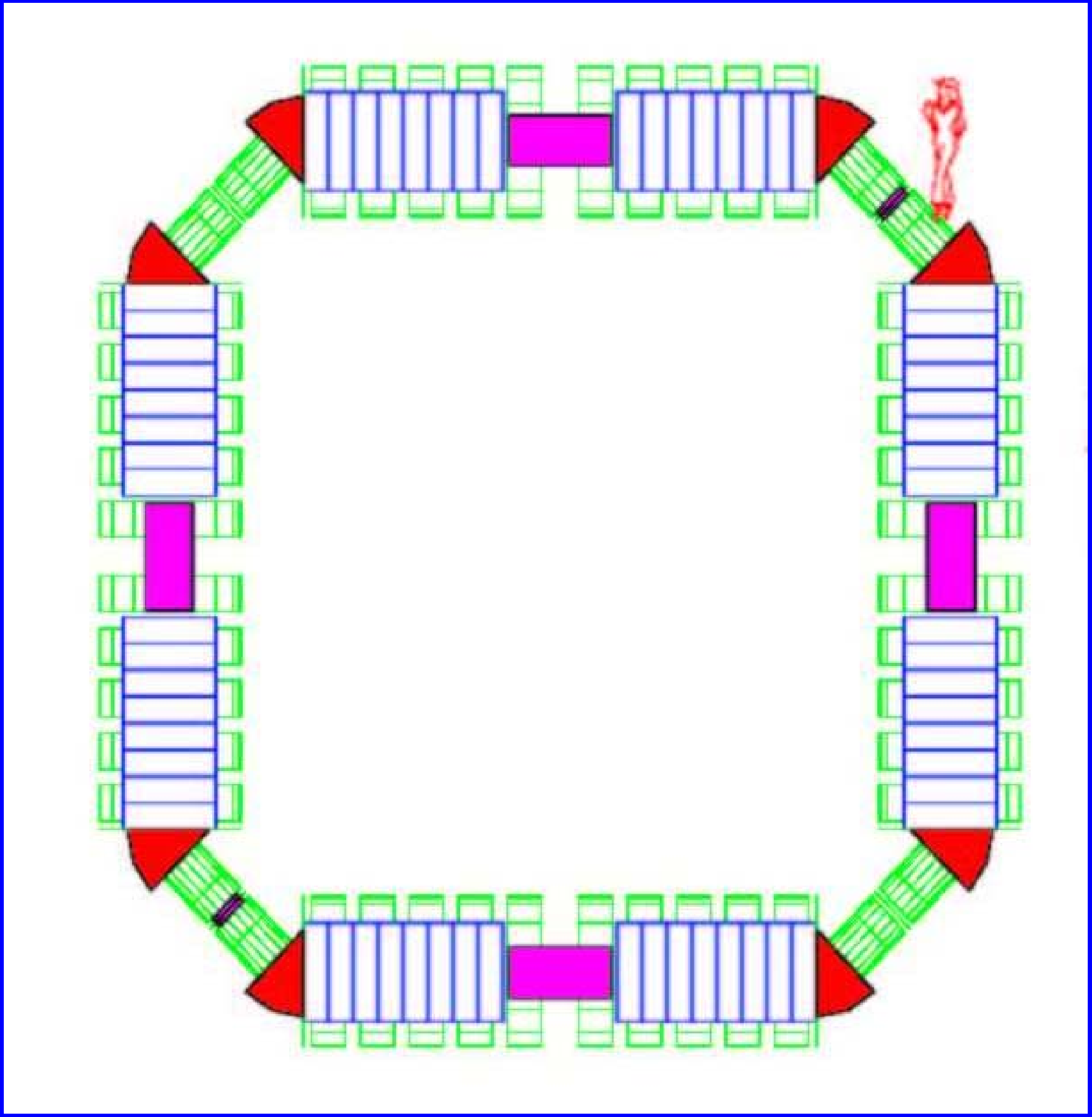
MICE changes into MANX

- 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

Balbekov Muon Ring Cooler



Emittance Exchange With GH2

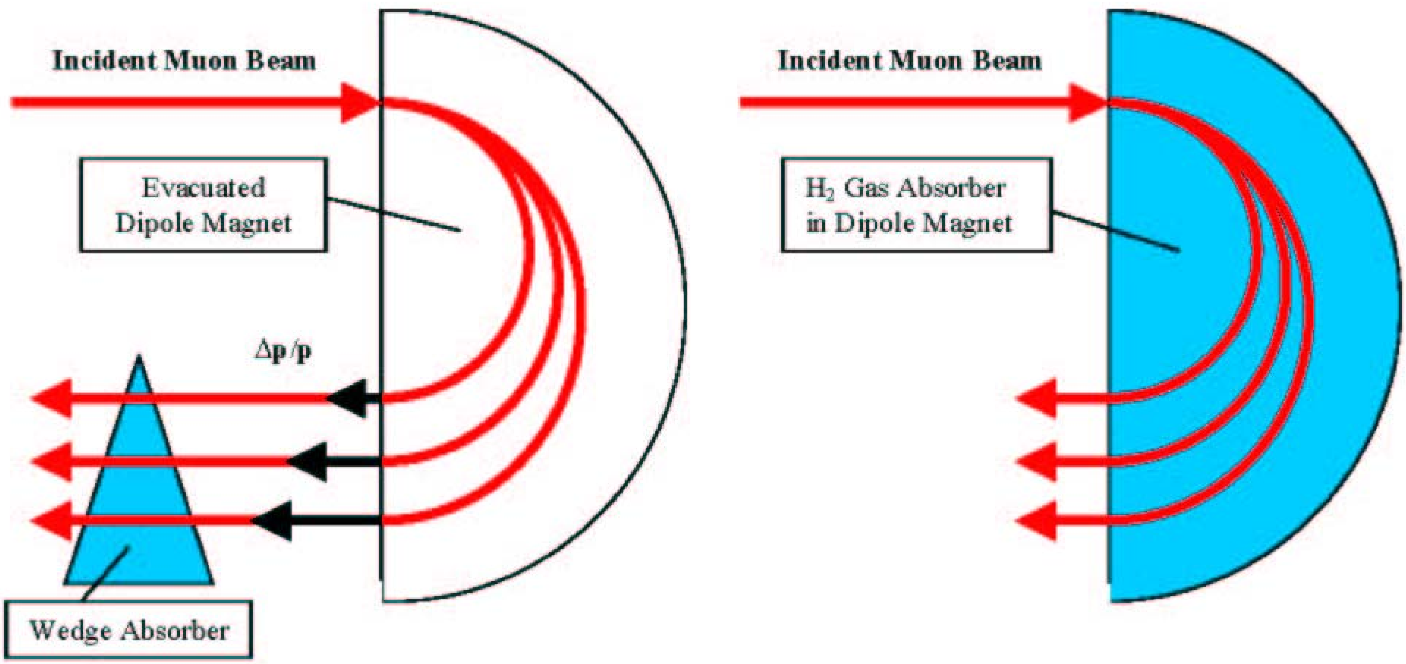


Figure 1. Use of a Wedge Absorber for Emittance Exchange

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

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
  - Muons, Inc. may have a future