Design and Experimental Studies

R B Palmer
NSF Jan 2004

- Experimental Program
  1. Target
  2. Acceleration
  3. Cooling Components
  4. Cooling Exp
- Design Studies and Cost Reduction
  1. Phase Rotation
  2. Acceleration
  3. Cooling
  4. Performance
- Conclusion

Experimental programs

Funded by DOE, NSF, Illinois
Plus Base Salaries in Labs and Universities

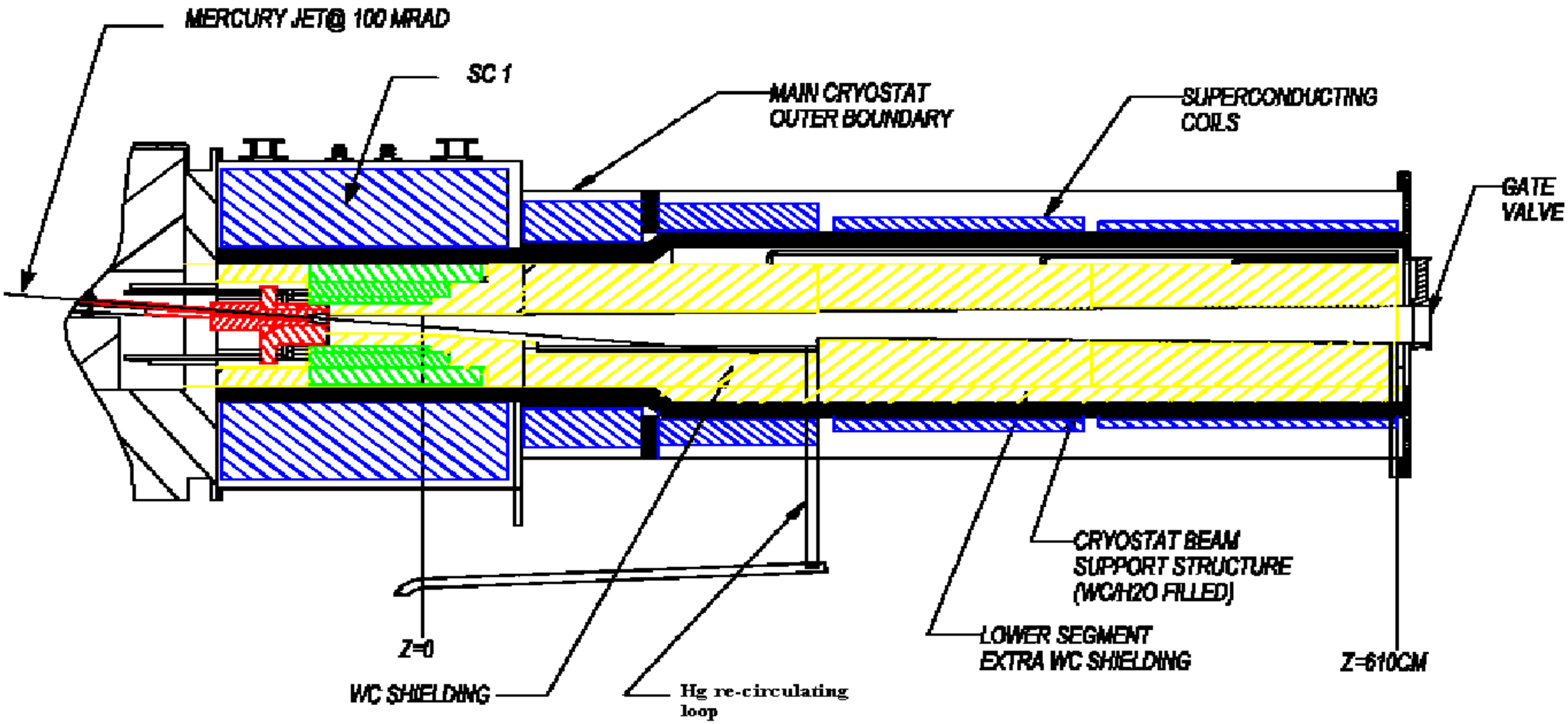
Technical Challenges

Based on Study 2 concepts:

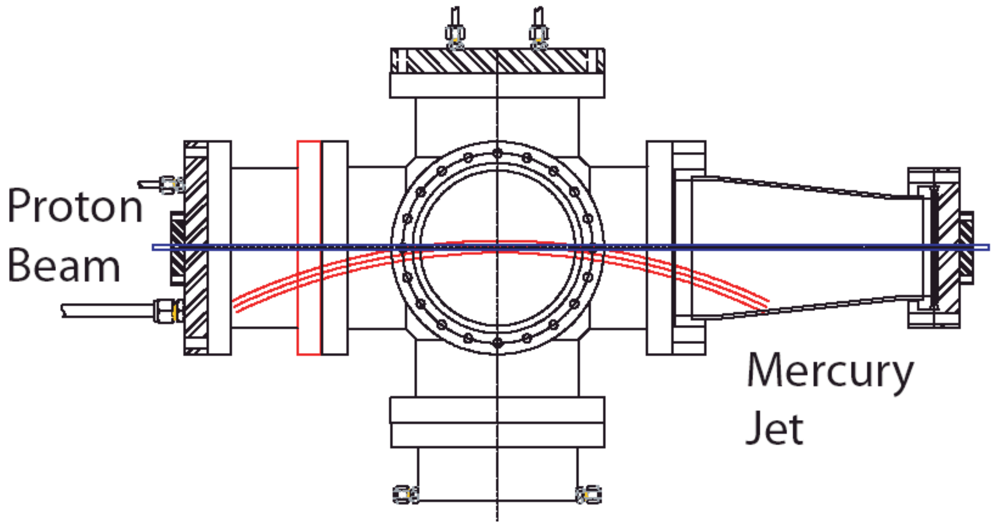
1. Targets
   - High Average power (1-4 MW)
   - High Z material
   - Severe Shocks
2. Muon Acceleration
   - Rapid (to avoid decay) of Large Emittance Beam
   - 200 MHz Superconducting RF (2 Times Lower Than LEP)
   - Highest Possible Gradient
3. Cooling
   - High Gradient 200 MHz RF
   - In Solenoid Magnetic Fields
   - Best Absorber is Liquid Hydrogen

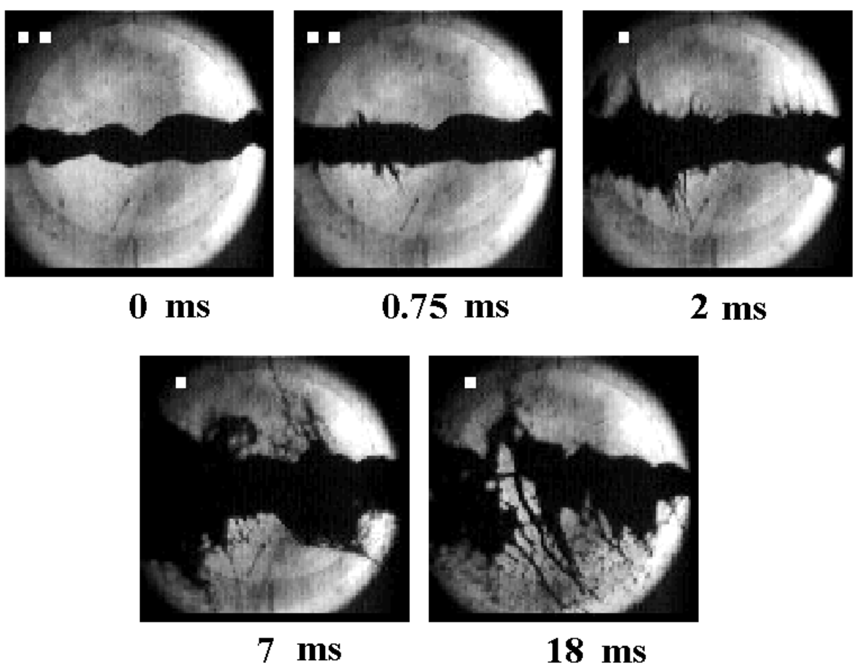
1) TARGET PROGRAM

- 1-4 MW Beam Power
- Greater pion production with high Z target
  Factor of 2 over graphite
- Shock lifetime and cooling problems with solids
  moving chain also considered
- Mercury jet focused by 20 T solenoid proposed in Study 2



AGS Experiment E951





- 4 Tp/bunch $(4\ 10^{12})$
  But density equiv to 1 MW
- Non-Explosive Dispersion
- Good Result

But

1 MW Nu-Factory requires:
16 Tp/bunch $(1.6\ 10^{13})$

4 MW Nu-Factory requires:
32 Tp/bunch $(3.2\ 10^{13})$

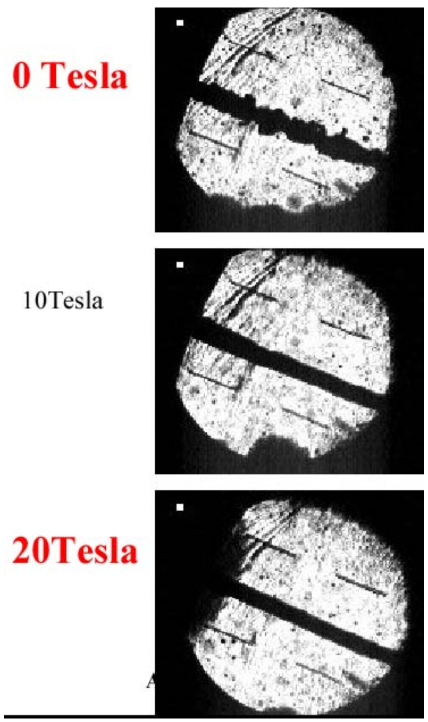
SO

- Need further Experiment
  With more intensity

Effects of Magnetic Field

Stabilization From Magnetic Field

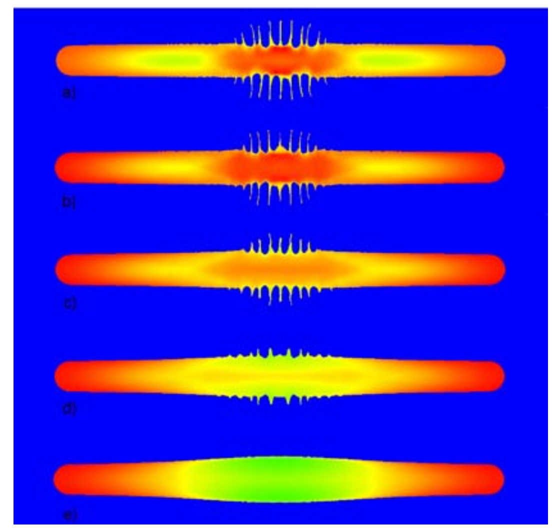
CERN Observation without beam



Simulation with beam

R. Samulyak

Stabilizing of the mercury jet by the longitudinal magnetic field



a) B = 0 ; b) B = 2T

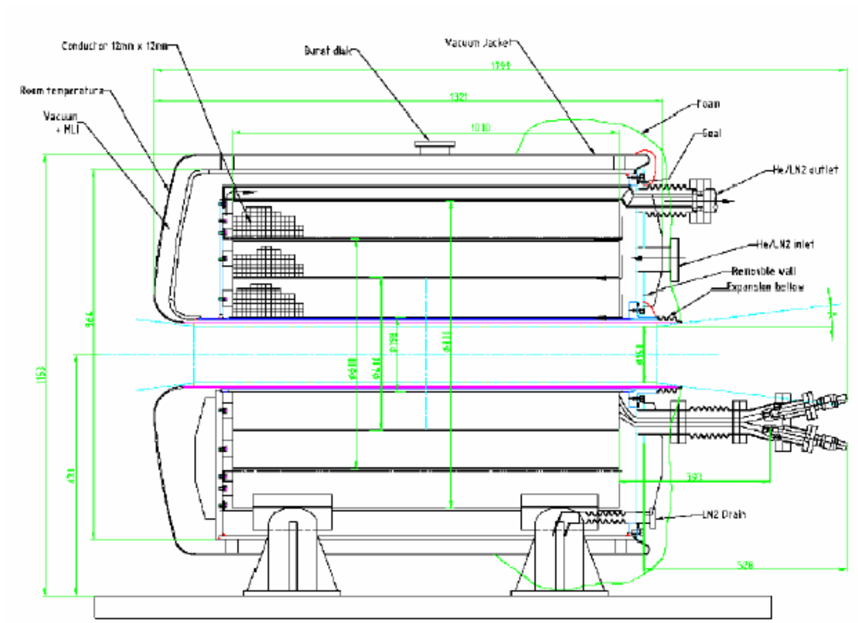
c) B = 4T ; d) B = 6T ; e) B = 10T

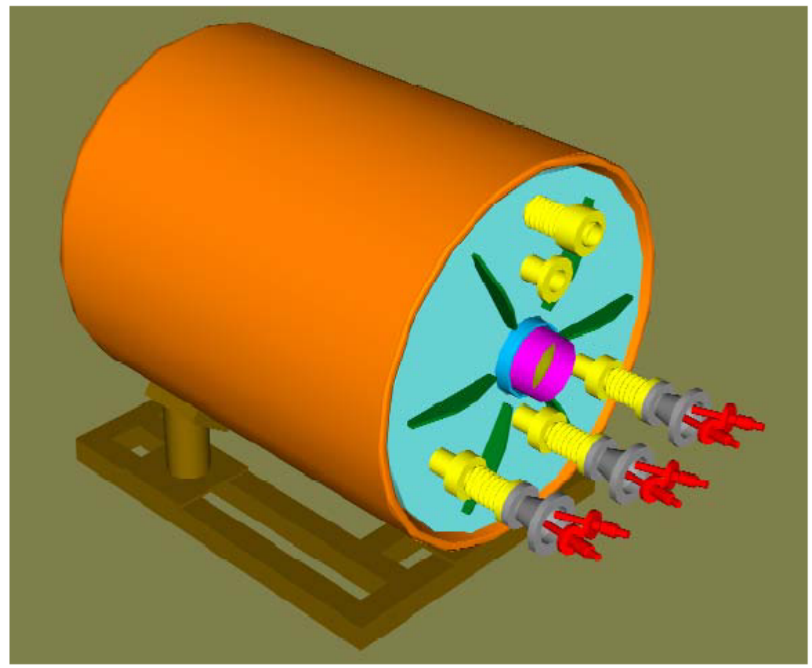
Magnet changes dynamics: suppresses breakup, increases T

- **Need experiment with magnet**

Design 15 T Pulsed Magnet (with MIT)

- Very low rep rate acceptable, so:
  - Pre cool with liquid nitrogen
  - Power from lead batteries (4 MW)
- Magnet and cryostat under Construction





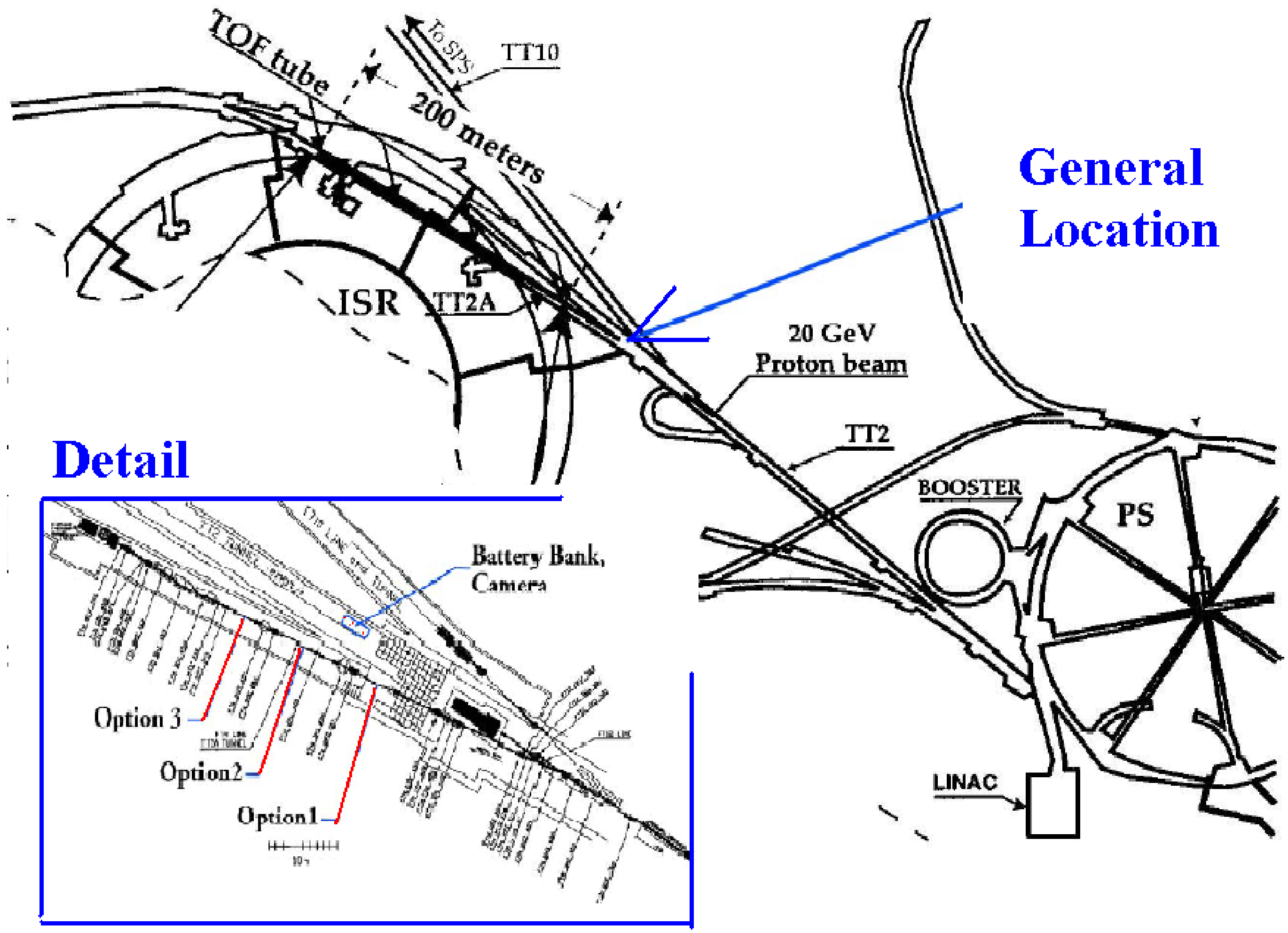
- 70° K Operation
- 15 T with 4.5 MW Pulsed Power
- 15 cm warm bore
- 1 m long beam pipe

Peter Titus, MIT

Location for Test

Require 30 Tp for 4 MW Case

- **BNL : 70 Tp**
  - requires full turn extraction (now $\approx$ 8 Tp)
  - conflict with RSVP
- **JPARC : 300 Tp**
  - not till $>$ 2007
  - but LOI submitted
- **CERN : 30 Tp**
  - Best possibility
  - LOI submitted
  - Proposal soon



2) R&D ON ACCELERATION

SC Cavity work for Acceleration Cornell NSF

- Built new test pit
- Design, build, and test 201 MHz SC cavities
  11 MV/m achieved
  limited by drop in Q c.f. FS2 spec = 16 MV/m
- Cavity returned to CERN for re-coating

Possible Non scaling FFAG Model

(FFAG acceleration will be discussed below under 'Design')

Remember

- **Electron AGS Model at BNL**
- **Electron Scaling FFAG Models at MURA**

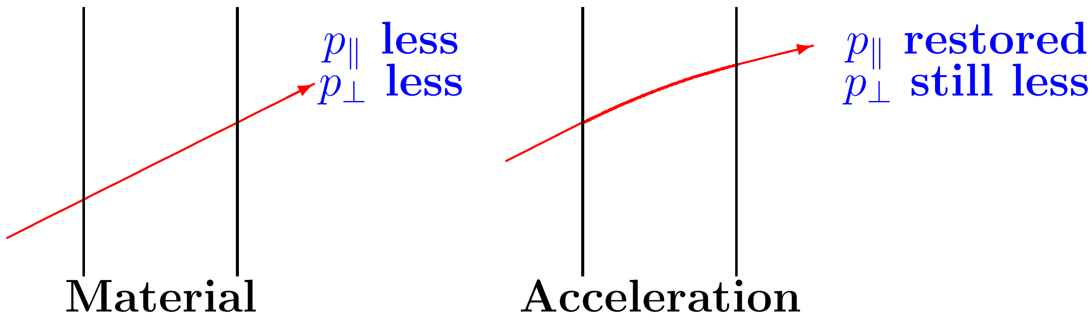
Non-Scaling FFAG Has Two New Dynamics Phenomena:

1. **Rapid acceleration through integer resonances**
2. **Acceleration in RF troughs rather than in buckets**

Both simulated, but may require demonstration

Discussions in US-Japan collaboration of an electron model
This would be aimed for both muon and proton applications

3) IONIZATION COOLING



To reduce heating from Coulomb scattering

- Low Momenta $\approx$ 200 MeV/c
- Low Z material (Hydrogen, LiH, Li ...)
- Strong Solenoid Focusing
- High Gradient Acceleration

The above cools only transverse emittance. With dispersion and wedges, transverse and longitudinal emittance can be exchanged, allowing cooling in all 6 dimensions. This has been well simulated in Cooling Rings as needed for a muon collider, but not used in the current Neutrino Factory Studies.

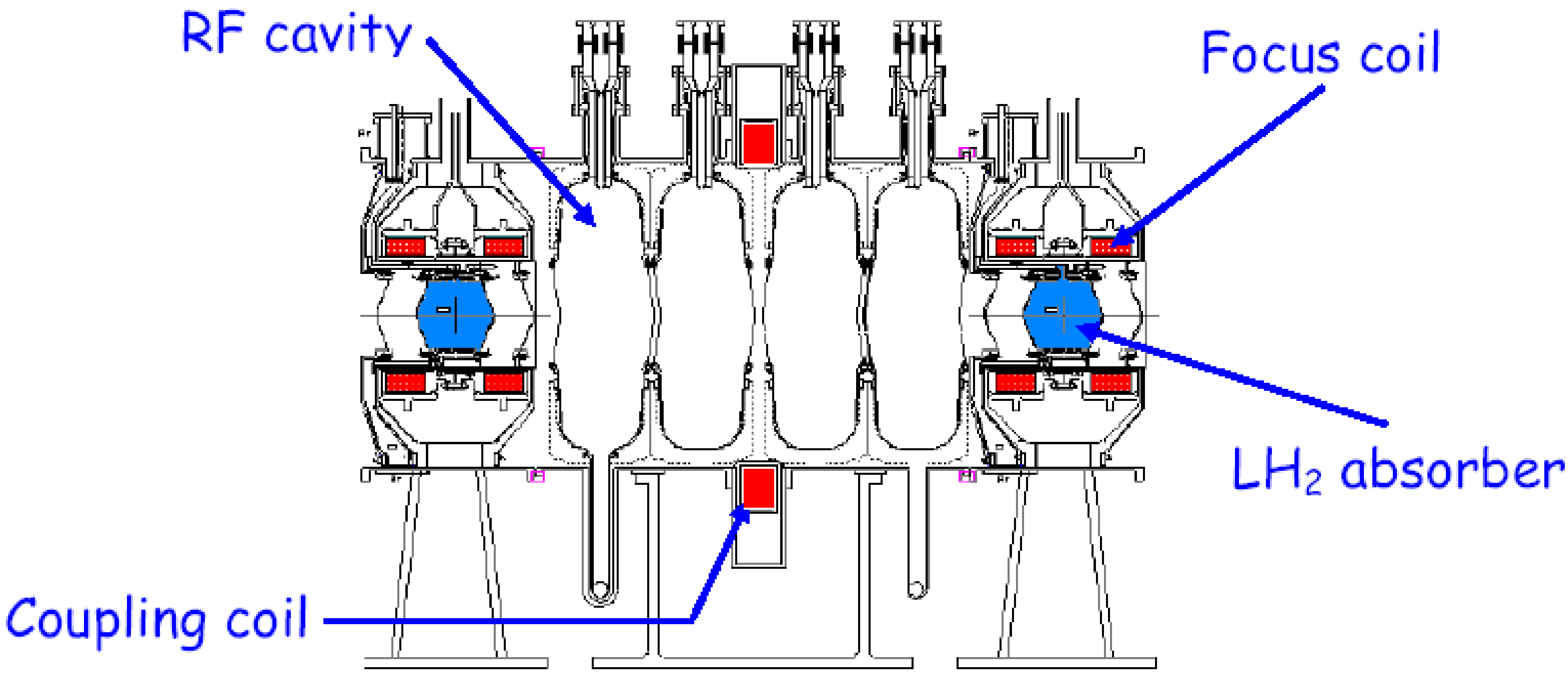
Components are essentially the same for linear and ring cooling:

R&D on Ionization Cooling Components

MUCOOL Collaboration (A Bross)

includes NSF Funding

Cooling as in Study 2 (and cooling experiment MICE)

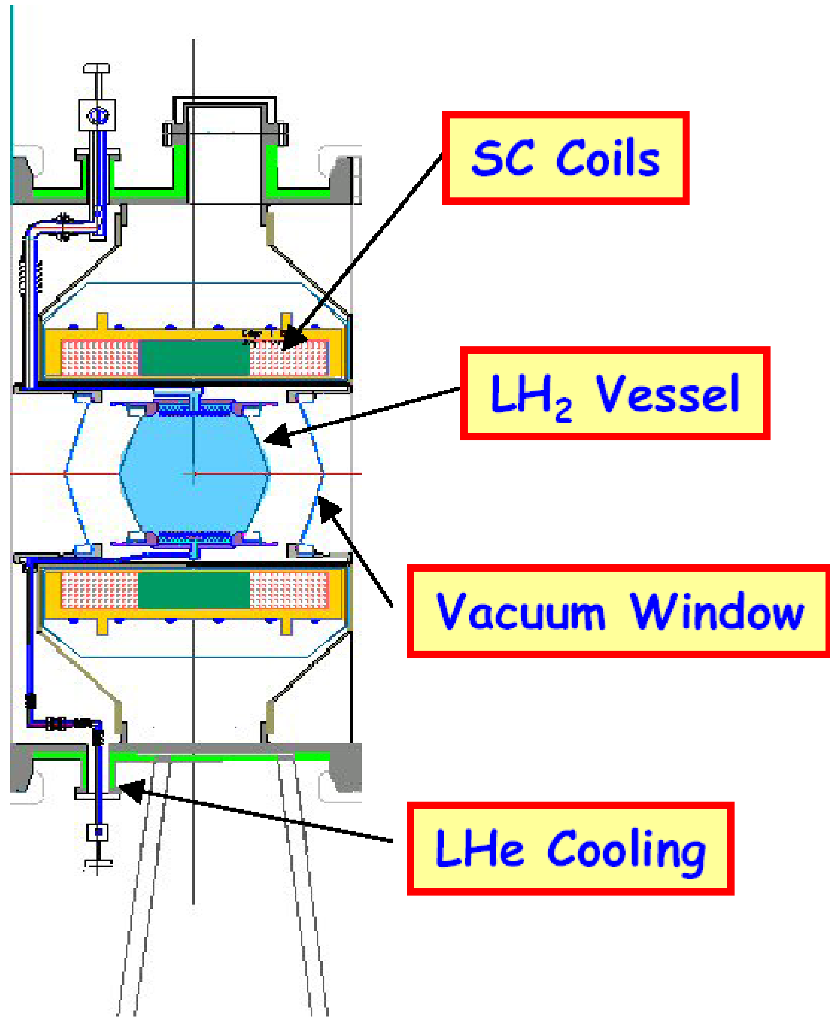


- Superconducting Solenoids
- Hydrogen Absorbers
- Absorber Windows
- High Gradient 200 MHz RF

Design, Build, Absorbers

Design Criteria

- High Power Handling
  - Study II – few 100 W to 1 KW with "upgraded" (4MW) proton driver
  - 10 KW in ring cooler
    - Must remove heat
- Safety issues regarding use of LH_2 (or gaseous H_2)
  - Window design paramount
    - H_2 containment
  - Proximity to RF adds constraints (ignition source)
- Window material must be low Z and relatively thin in order to maintain cooling performance

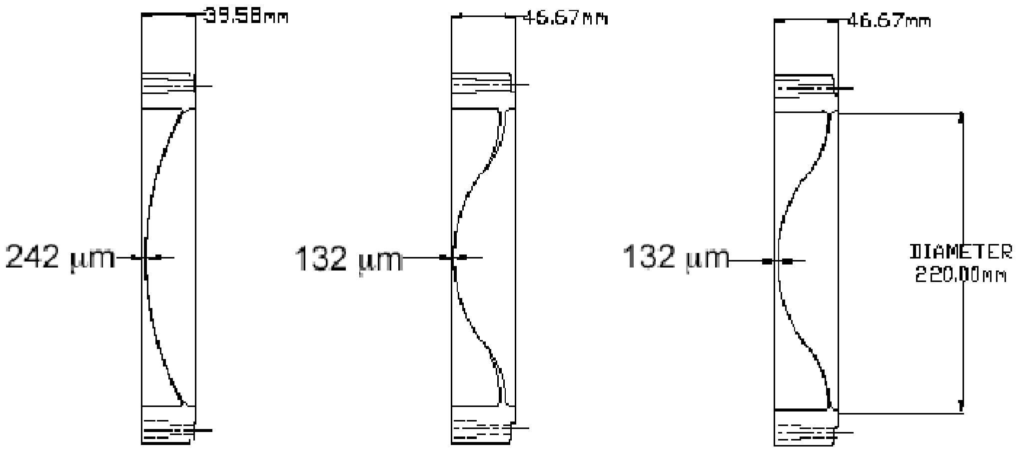


H_2 implies engineering complexity

Design, Build, and Test Absorber Windows

containment windows as thin as possible:

3 iterations of absorber window design:



Windows machined w/ integral flange out of single disk of Al alloy

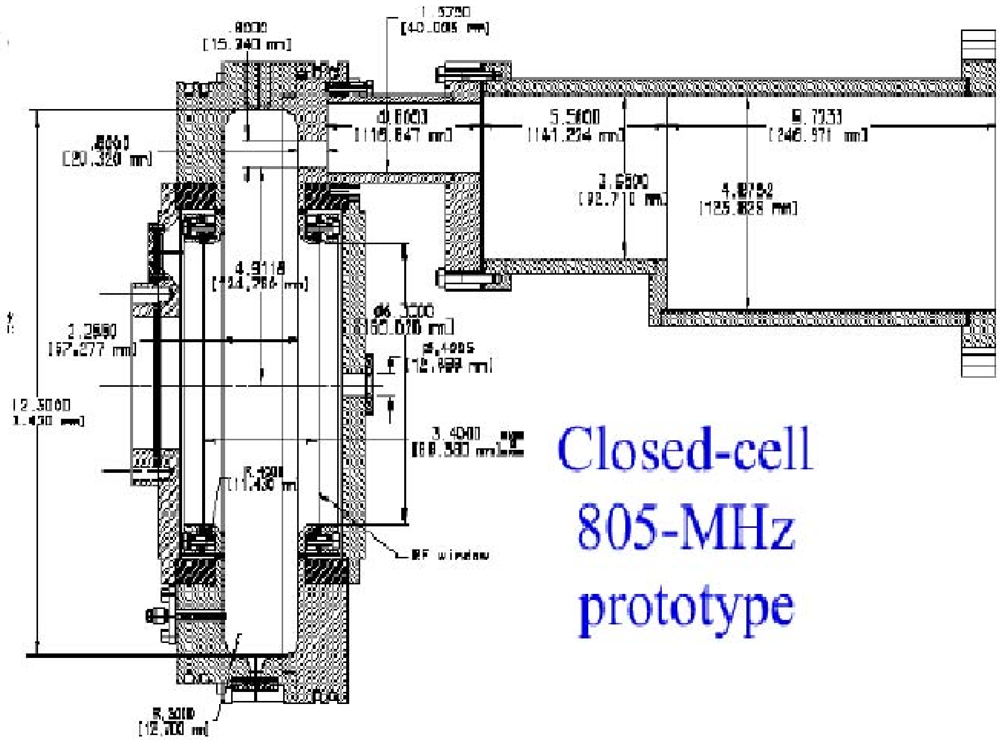
Including Pressure Testing

High Gradient RF Studies (Lab G FNAL)

Initial Studies at 805 MHz

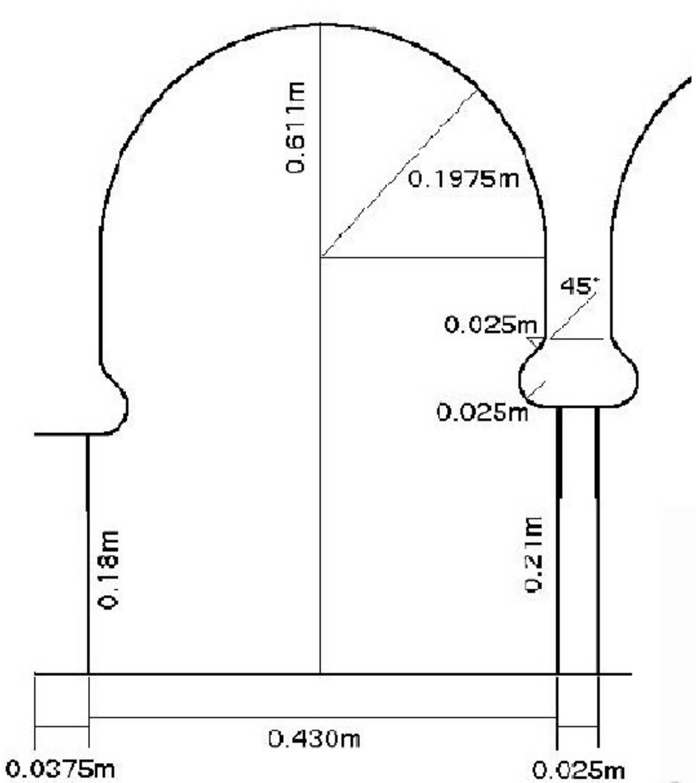
- Construction and radiant heat testing of Be windows for RF
- High gradient testing in a magnetic field
- Measurement of X-rays and dark currents

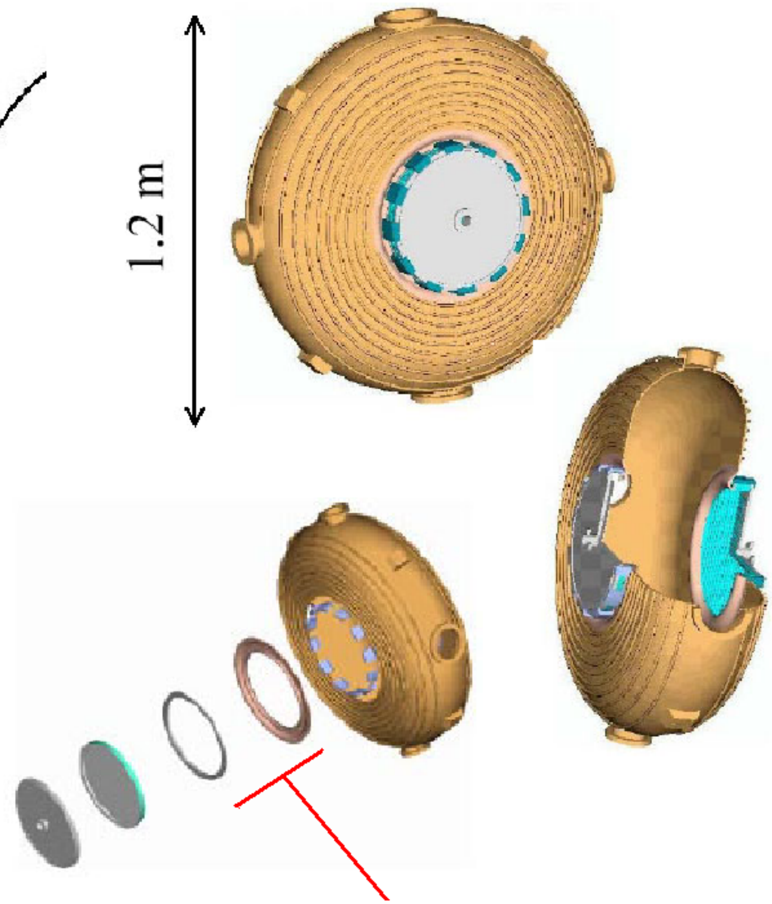
Open-cell 805-MHz prototype under high-power test in Lab G superconducting solenoid



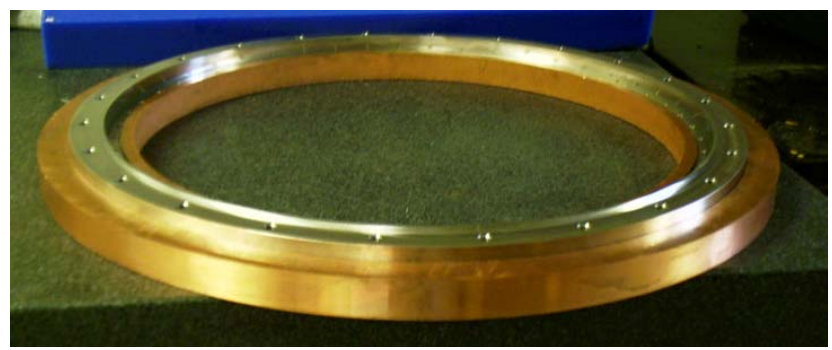
Closed-cell 805-MHz prototype

Design & Start Const. of 201 MHz Cavities





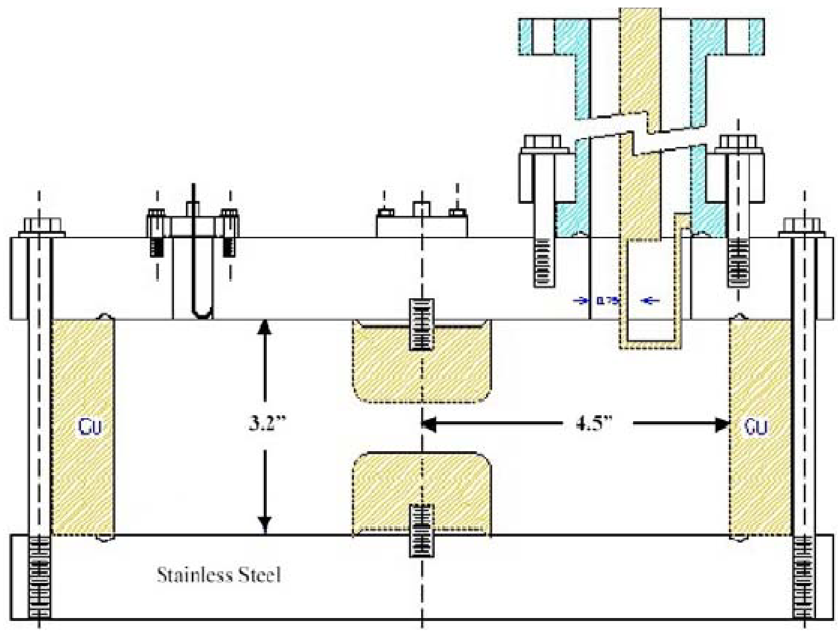
Machining started
at Mississippi

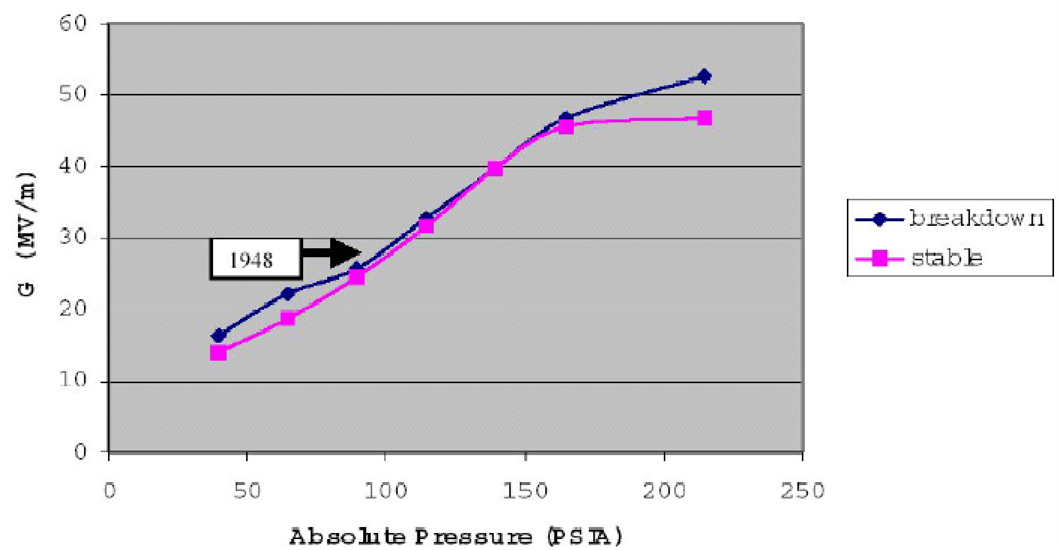


Experiment with High Pressure Hydrogen

As alternative to Liquid Hydrogen as Absorber and Reduce Breakdown in RF

- e.g. 100 atm at 70 degrees
  - Avoid Liquid H2 Windows
  - Allow Higher RF Gradients ?
- STTR funded phase I
- Initial Test
  Confirms Pashen's Law





Test area at FNAL

For RF & Absorber tests

6 months ago

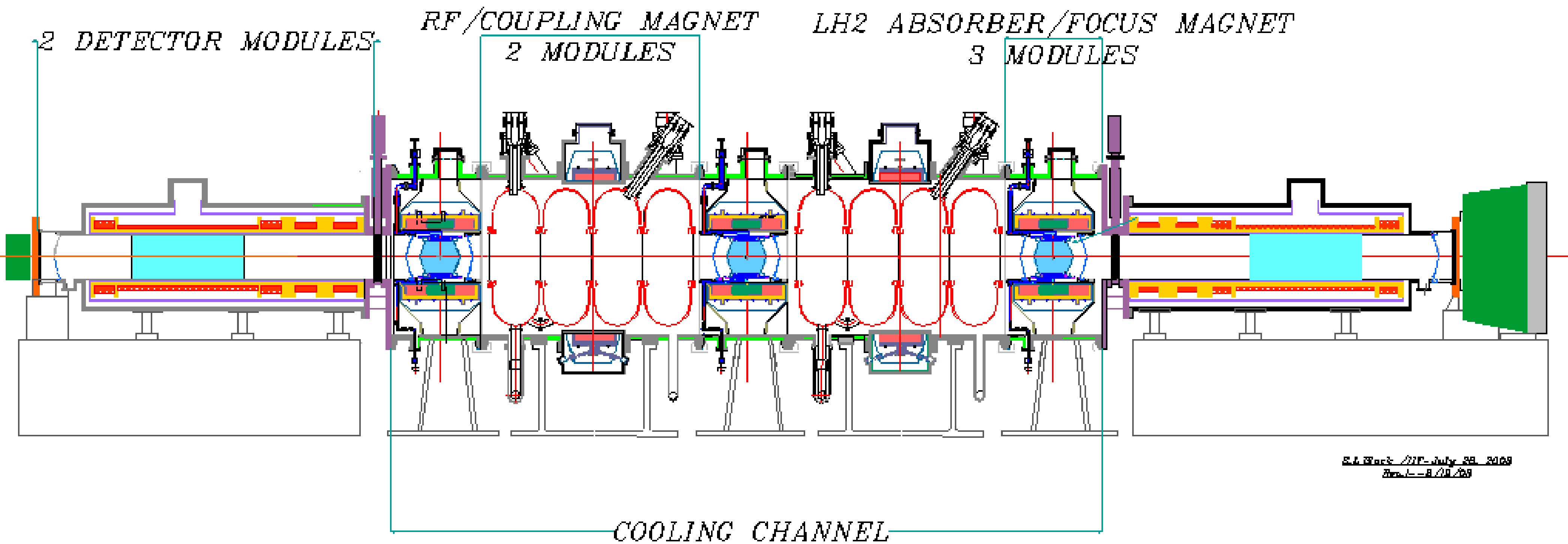
Will have:

- H2 Cryo for absorber
- He Cryo for solenoids
- 200 MHz RF for cavities
- p beam for heating

Now

4) MUON IONIZATION COOLING EXPERIMENT (MICE)

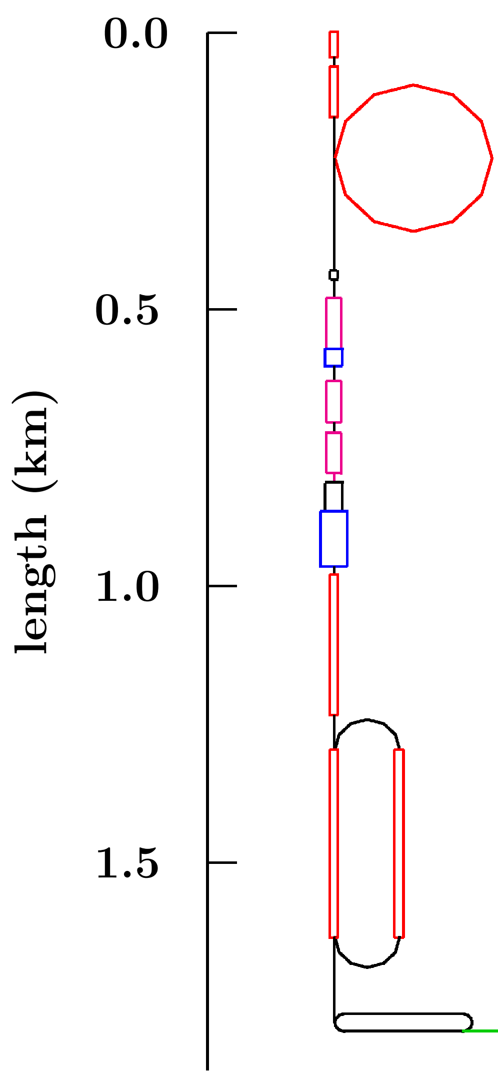
- Solid Design based on Study-2 channel
  (Similar components to RFOFO cooling ring)
- International Collaboration: (US, Europe, Japan)
- Funding proposal sent to NSF, (and similar requests in Europe)
- Proposal has Scientific Approval at RAL



Design Studies in the US

- **Neutrino Factory Study I**
  - **Emphasized Feasibility**
  - **Sponsored by Fermi (finished March 00)**
  - **"Entry Level" ($\approx$ 0.2 10^{20} $\mu/10^{7}$sec at 1 MW)**
- **Neutrino Factory Study II**
  - **Emphasized Performance with Feasibility**
  - **Sponsored by BNL (finished April 01)**
  - **Similar Cost**
  - **"Higher Flux" ($\approx$ 1.2 10^{20} $\mu/10^{7}$sec at 1 MW)**
- **Current Neutrino Factory Work**
  - **Emphasize Lower Cost**
  - **Maintain or improve Performance**
  - **Study 3 (In about 2 Years)**
- **Ongoing Muon Collider Studies**
  - **Cooling Ring Designs**
  - **Conceptual Design**
  - **Feasibility Study (later)**

Study-2 Schematic



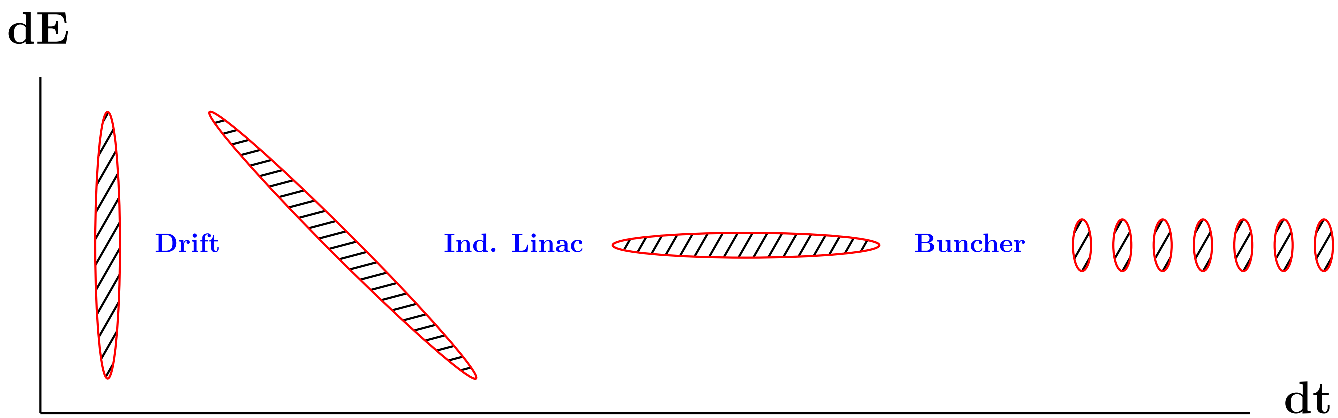
	% of 1.8 B$ Cost (no EDIA etc) without driver or target
p Driver	
Hg Target	
Phase Rotation	(29 %) 1) ***
Cooling	(23 %) 3) ***
Pre-Acceleration	(14 %)
RLA Acceleration	(26 %) 2) ***
Storage Ring	(8 %)
Neutrino Beam	

*** Studies of savings on these items

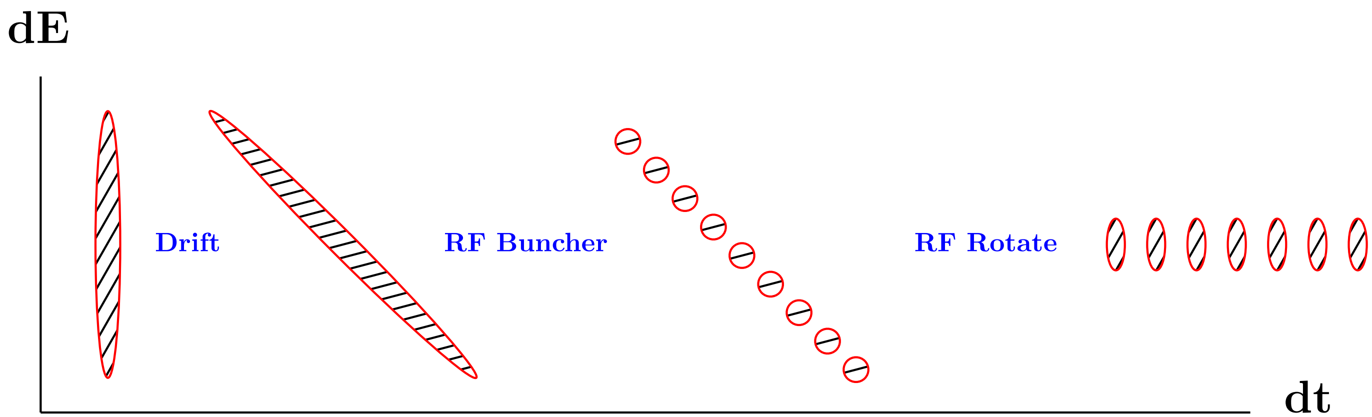
will study others later

1) PHASE ROTATION (Reduce dp/p prior to Cooling)

Study 2 with Induction Linacs



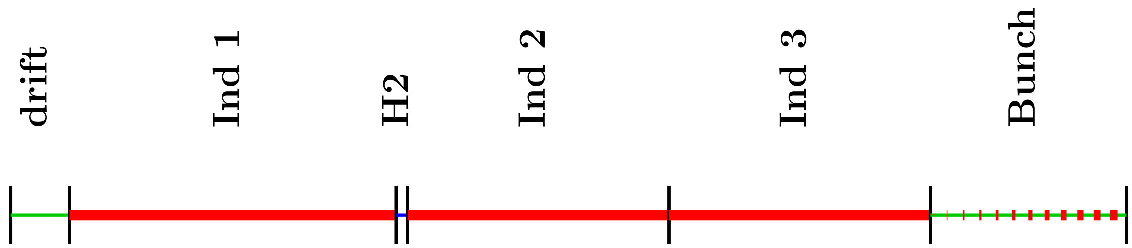
Neuffer's Bunched Beam Rotation with 200 MHz RF



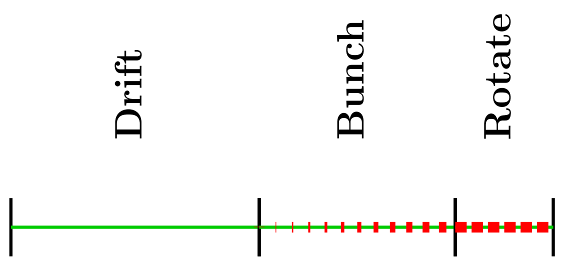
- **200 MHz RF is cheaper than Induction Linacs**
- **But RF frequency must vary along bunching channel (high mom. bunches move faster than low)**

Compare with Study 2

- Study 2



- e.g. Bunch Beam Rotation



- EXPECT SUBSTANTIAL SAVINGS
- And Captures Both Signs

2) ACCELERATION (will consider cooling later)

a)Recirculating Linac Accelerator (RLA)

As in Study 2

- Study 2 design had emittance growth 15 $\rightarrow$ 30 pi mm
- Re-tuning (Bogacz) has reduced this to a few %
- This reduces Cooling Requirement

b) Scaling FFAG (MURA/Japan)

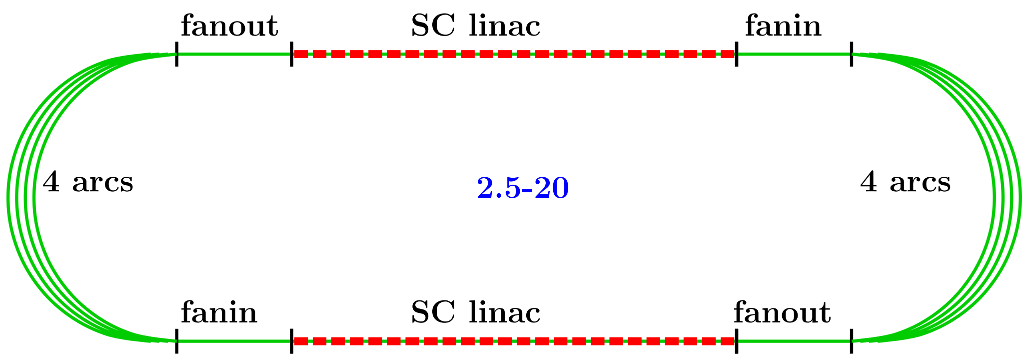
- Fixed Field but huge momentum acceptance (eg 10-20 GeV/c)
- More turns than RLA: requires less RF
- Also has 30 pi mm Acceptance
- But large circumference and apertures

c) Non-Scaling FFAG's (C. Johnstone & D. Trbojevic)

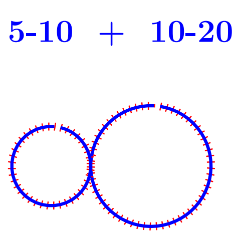
- Smaller circumference (320 vs 1200 m)
- Smaller aperture (18 vs 40 cm)
- Still has 30 pi mm acceptance

Compare FFAGs with Study 2

Study 2 RLA



Triplet FFAG Candidates



- Substantial Savings
- And Still Requires Less Cooling

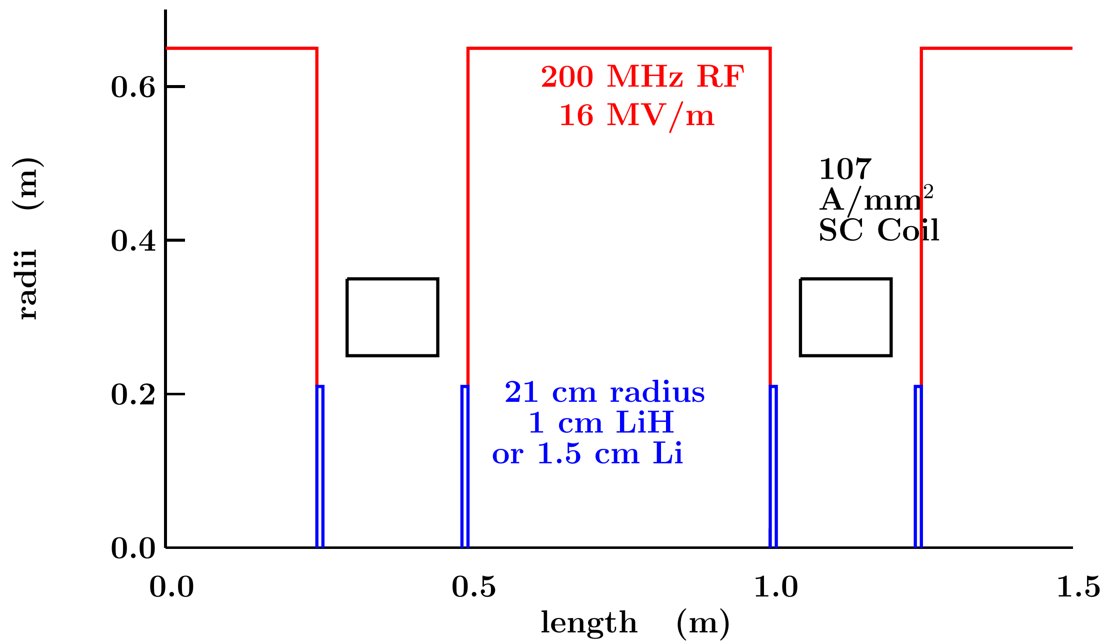
BUT

- Inject/Extract Not Designed
- Other Details Require Study
- Needs Another Method to 5 GeV

3) IONIZATION COOLING

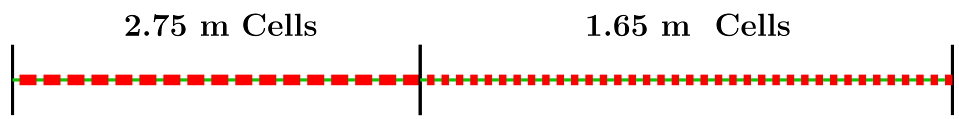
Use the Larger Accelerator Acceptance

- Less cooling (50 m vs 108 m)
- Weaker focusing: (beta= 70 vs 40 mm)
- No coils outside RF
- No Liquid Hydrogen absorbers



Compare New Cooling with Study 2

- 108 m Study 2 Cooling



- 50 m New Cooling Lattice

- **42 % of Length**
- **No Liquid Hydrogen**
- **Smaller coils**
- **Substantial Savings**

BUT

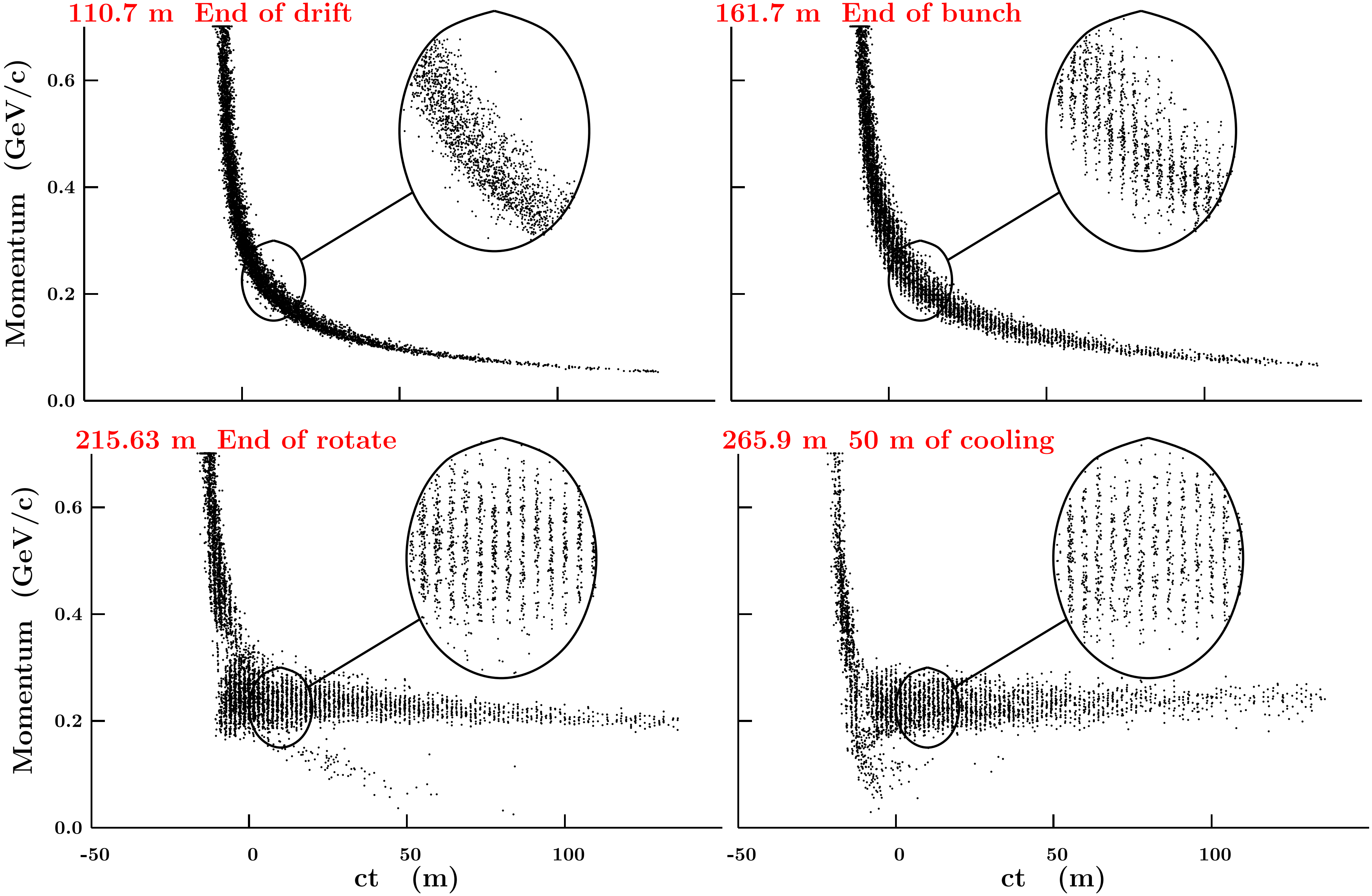
- **Depends on Larger Acceleration Acceptance**

Summary of Cost Reductions on 78% of total

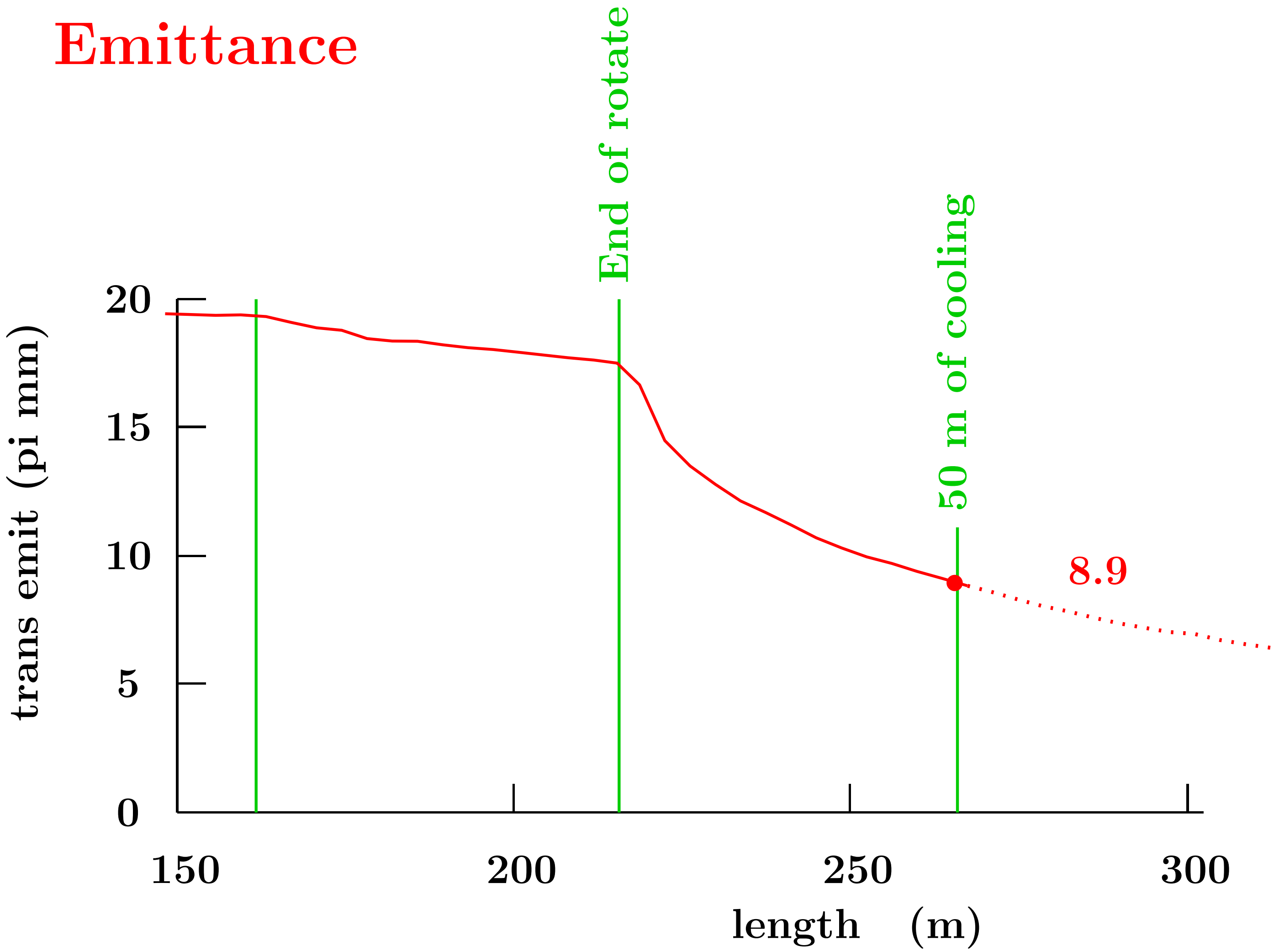
	Study 2	Now	Factor
PHASE ROTATION			
Beam Line (m)	328	166	51 %
Acceleration (m)	269	35	13 %
Acc Type	Induction	Warm RF	
COOLING			
Beam Line (m)	108	51	47 %
Acceleration (m)	74	34	46 %
ACCELERATION			
Beam Line (m)	3261	$\approx$ 700	$\approx$ 21 %
Tun Length	1494	$\approx$ 700	$\approx$ 47 %
Acc Length	288	$\approx$ 130	$\approx$ 45 %

4) ICOOL FRONT-END SIMULATION

Target to end of cooling



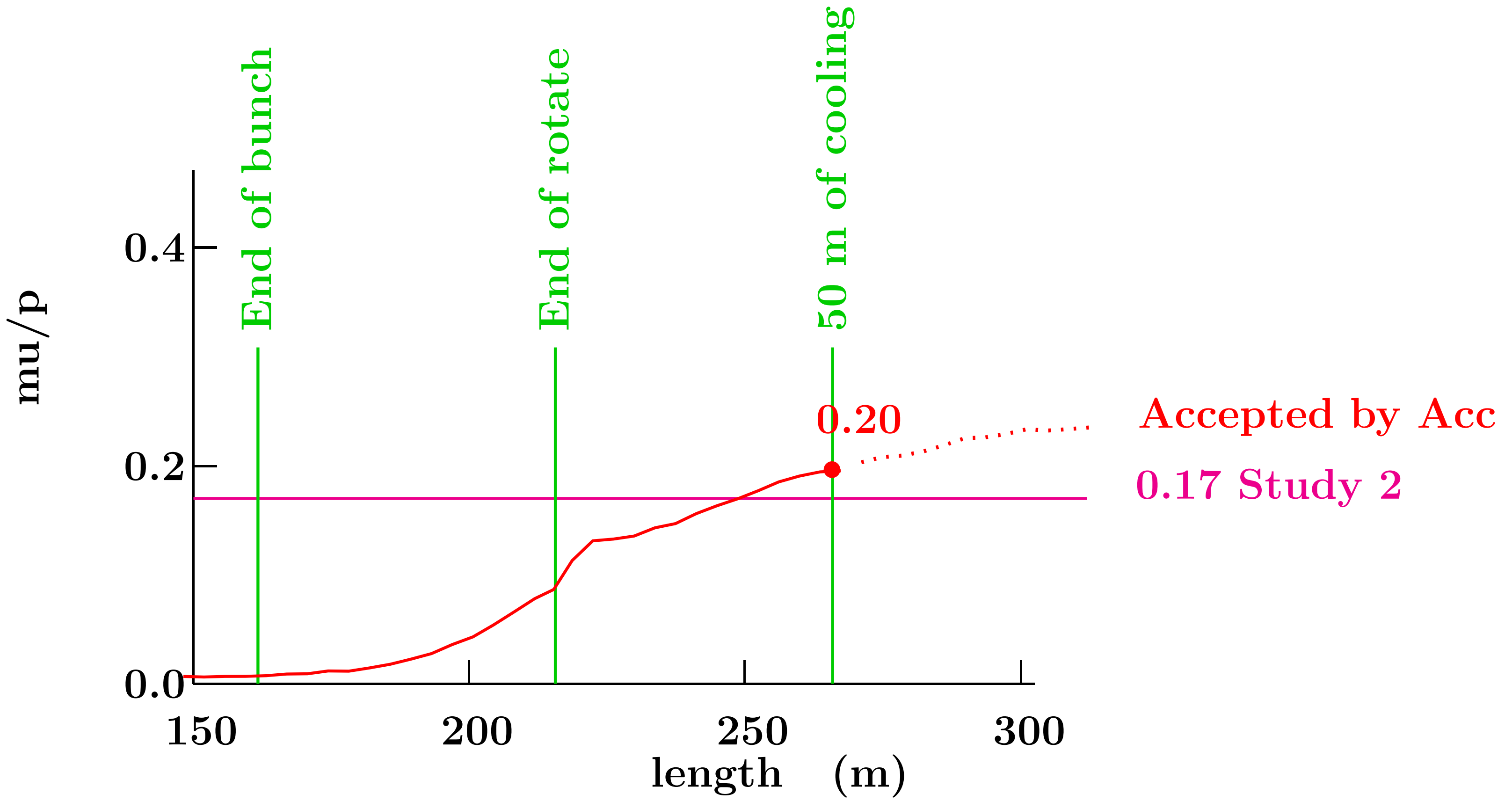
Emittance



- Significant cooling in phase rotation due to Be Windows
- Further cooling possible with Hydrogen and/or Lower beta lattice

Muons per 24 GeV Proton

From ICOOL simulation to end of cooling



- **For one sign Muons/p $\approx$ 1.2 $\times$ Study 2**
- **But both signs captured**
- **Effectively Muons/p $\approx$ 2.4 $\times$ Study 2**

Conclusion

- R&D going well
  - Target Experiment Magnet Under Construction
  - 200 MHz SC Cavity Tested and Being Re-Coated
  - Progress on H2 Absorbers
  - Results from 805 MHz RF in Magnet
  - 200 MHz Cu RF Under Construction
  - MICE has Scientific Approval
- But short of funds from DOE cut in 2001
- Good Design Progress Since Study 2
  - Phase Rotations Without Induction Linacs
  - Larger Acceptance Acceleration
    Including Compact FFAG Acceleration
  - Lower Cost Cooling Solution
- Expect Lower Cost and $\geq$ **2** $\times$ Performance