Design and Experimental Studies

R B Palmer

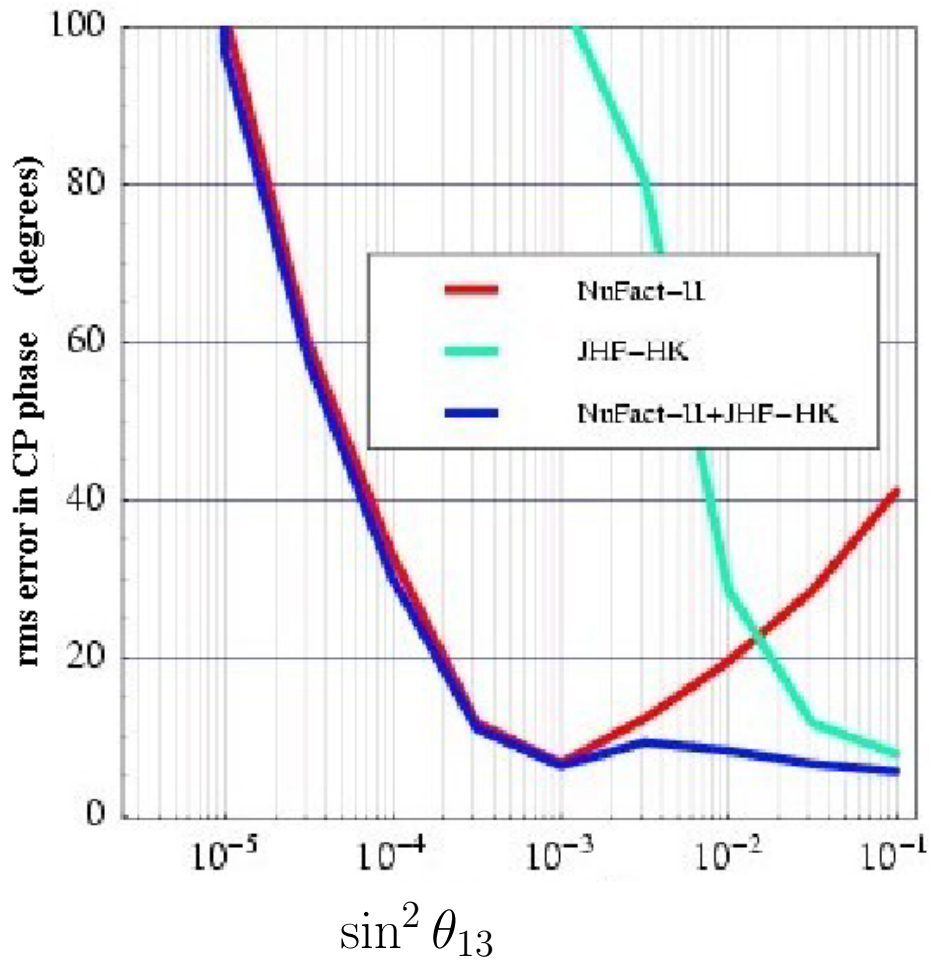
DOE April 2004

- Physics Need
- Design Studies and Cost Reduction
  1. Phase Rotation
  2. Cooling
  3. Acceleration
- Experimental Program
  1. Target
  2. Cooling
  3. Acceleration
- Conclusion

Physics Need e.g. CP Determination

e.g. CERN Report:
Hubner, Lindner & Winter
(HEP-PH/020432)

Assuming
$\delta_{\rm CP} = 90$ degrees
and LMA I



If $\sin^2\theta_{13} < 0.01$ Super beam has a hard time
But if $\sin^2\theta_{13} < 0.0001$ Neutrino Factory can study it
Clearly, a Super beam will preceed a Neutrino Factory and $\sin^2\theta_{13}$ will be known before a factory is built

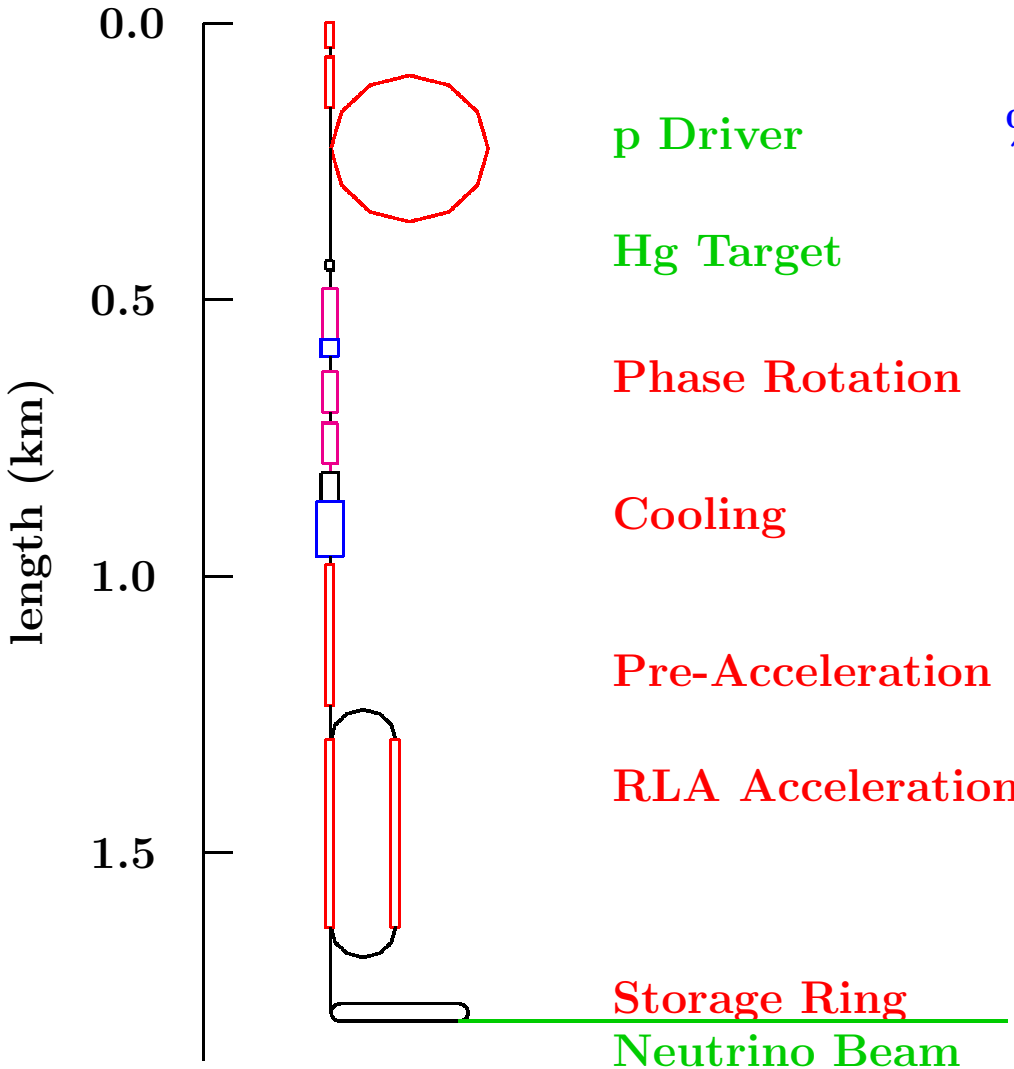
Design Studies in the US

- **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

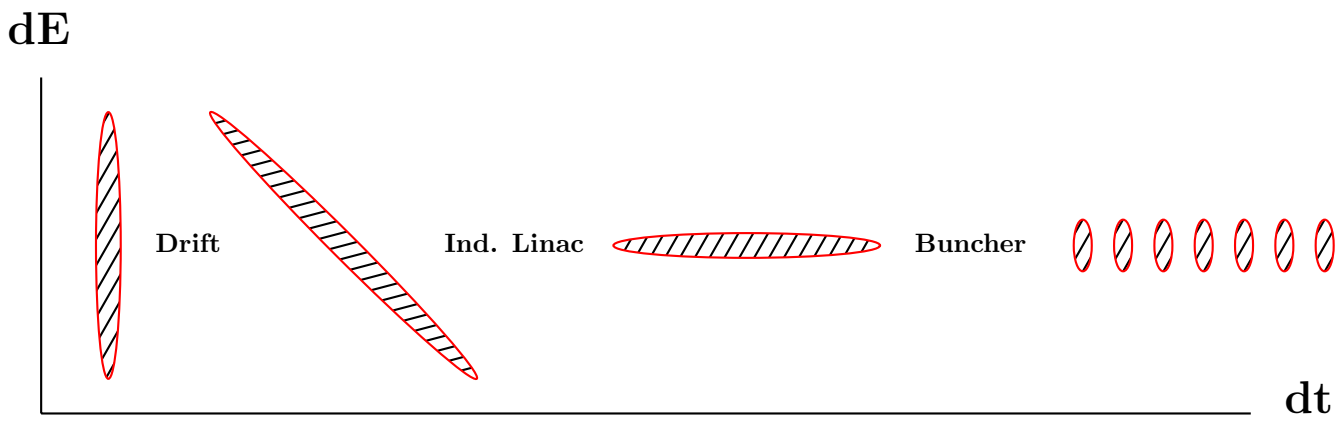


	% of 1.8 B$ Cost (no EDIA etc) without driver or target	
p Driver		
Hg Target		
Phase Rotation	(29 %)	1) ***
Cooling	(23 %)	4) ***
Pre-Acceleration	(14 %)	3) ***
RLA Acceleration	(26 %)	2) ***
Storage Ring	(8 %)	
Neutrino Beam		

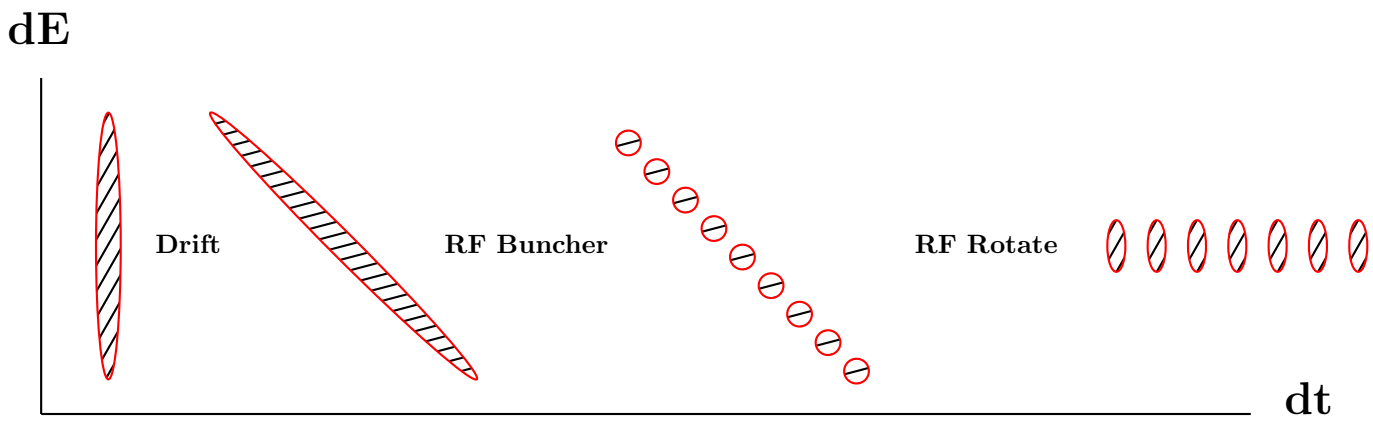
*** Studies of savings on these items will study others later

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

Study 2 with Induction Linacs

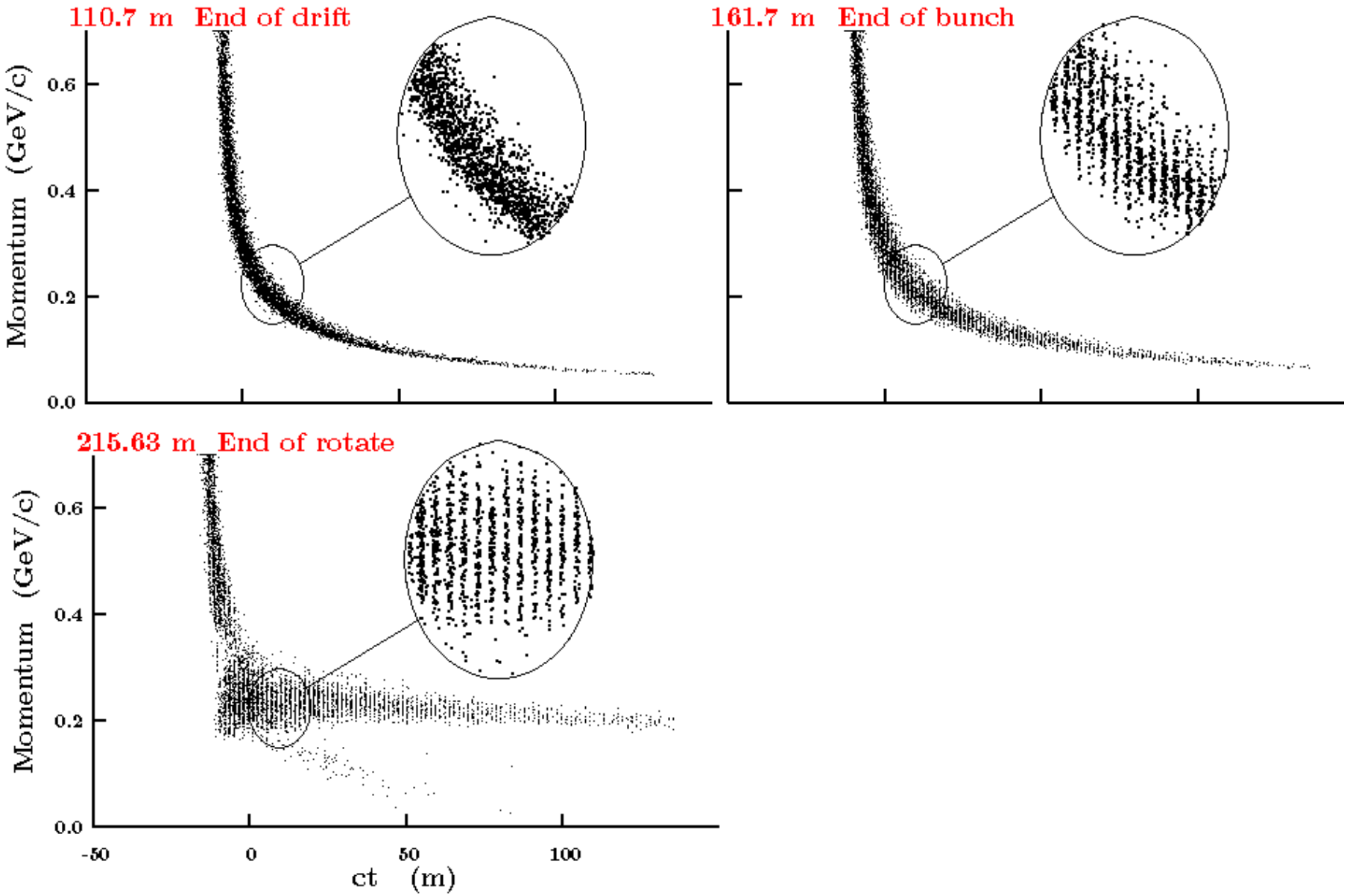


Neuffer's Bunched Beam Rotation with 200 MHz RF



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

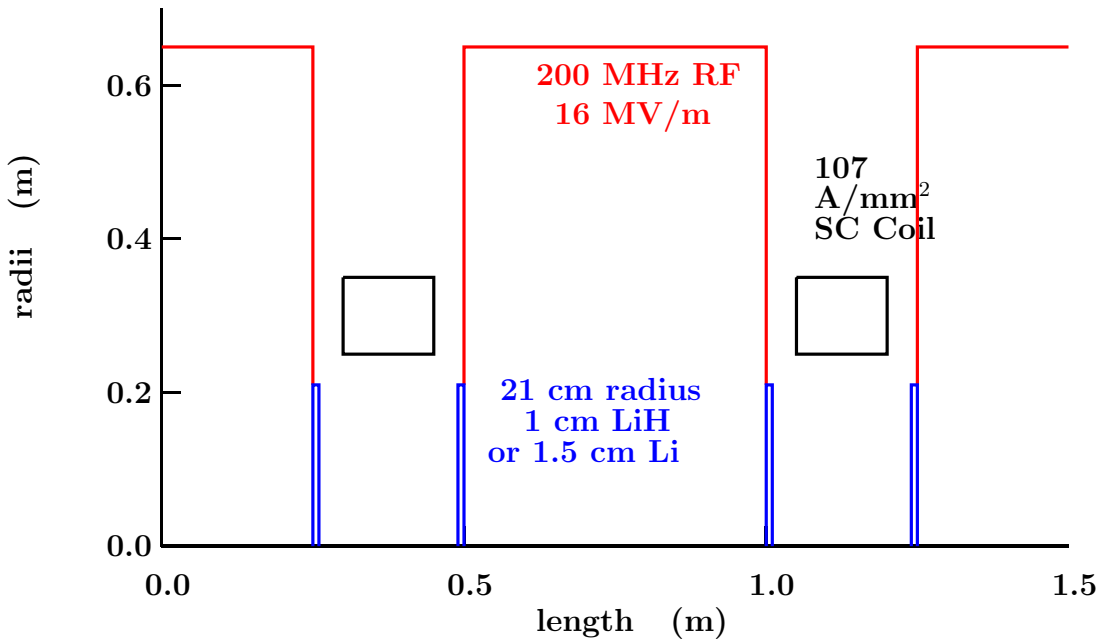
ICOOL Simulation



2) IONIZATION COOLING

Use the Larger Accelerator Acceptance

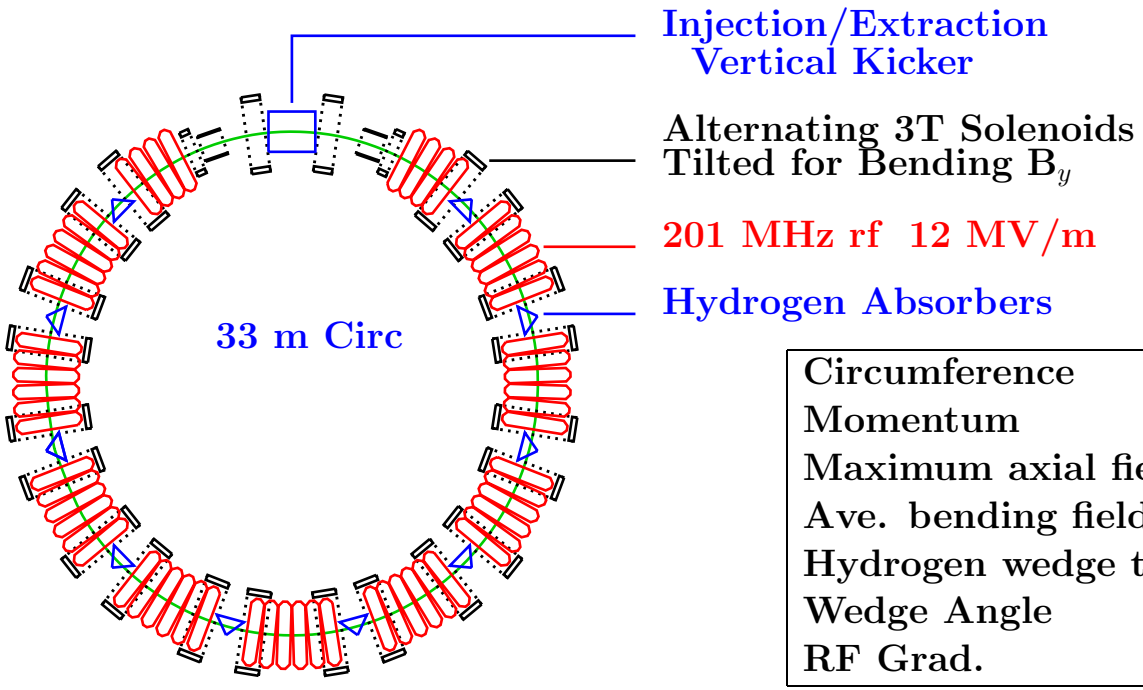
- Less cooling (50 m vs 108 m)
- Weaker focusing: (beta= 70 vs 40 mm)
- No coils outside RF
- No Liquid Hydrogen absorbers



Aside on Cooling Rings

- Bending and wedge absorbers: Cooling also in longitudinal
- Many turns gives more cooling at lower cost
- But not matched to current phase rotation
- Needed for a Muon Collider
- Much Progress Now fully simulated

e.g RFOFO Ring



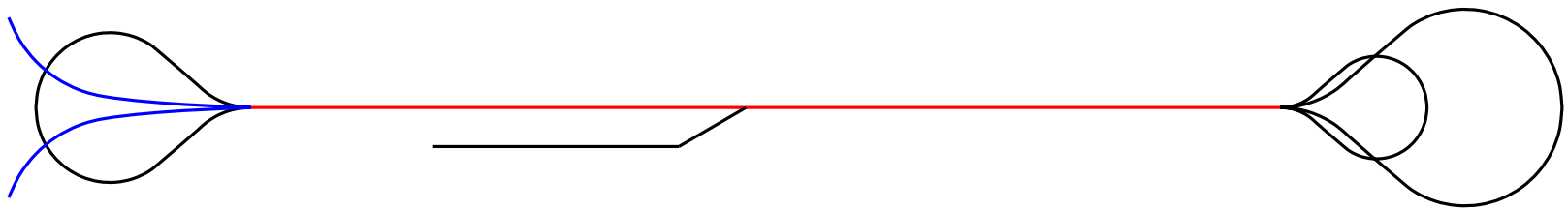
Circumference	m	33
Momentum	MeV/c	200
Maximum axial field	T	3
Ave. bending field	T	0.125
Hydrogen wedge thickness	cm	30
Wedge Angle	deg	100
RF Grad.	MV/m	12

3) ACCELERATION

For the above cooling we require 30 pi mm Acceptance

a) Larger acceptance Pre-Acc Linac (.2 to 1.5 GeV)

b) New Dog-Bone RLA 1.5 to 5 GeV



- Dog bone prefered over racetrack for switch yards
- Shorter linac and more arcs may be cheaper

c) Non-Scaling FFAG's for 5 to 20 GeV

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

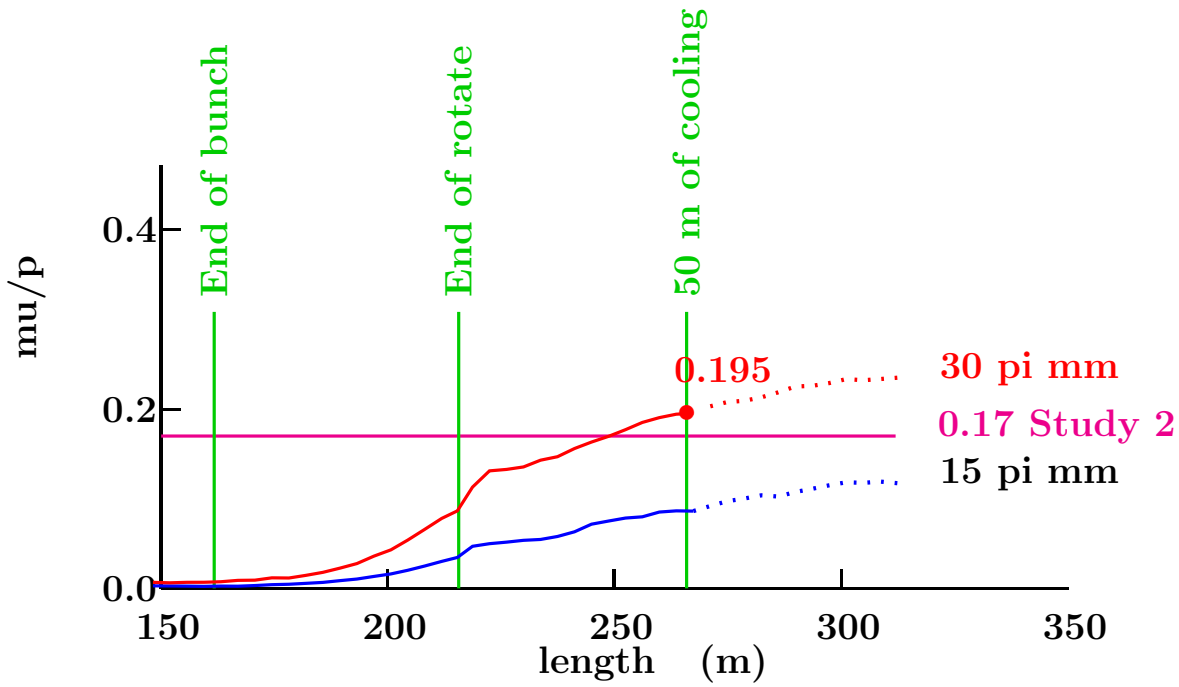
Non-Scaling FFAG's (C. Johnstone & D. Trbojevic)

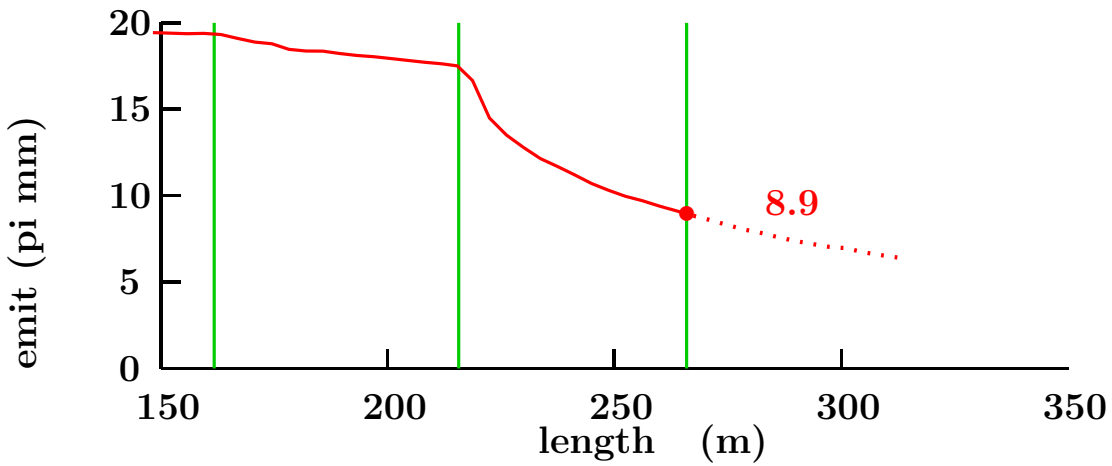
- Smaller circumference (320 vs 1200 m)
- Smaller aperture (18 vs 40 cm)
- Still has 30 pi mm acceptance

Studies in Collaboration with Japan
2-3 Workshops per year

Performance Muons per 24 GeV Proton

Numbers from RBP idealized simulation (later numbers changing & somewhat less)

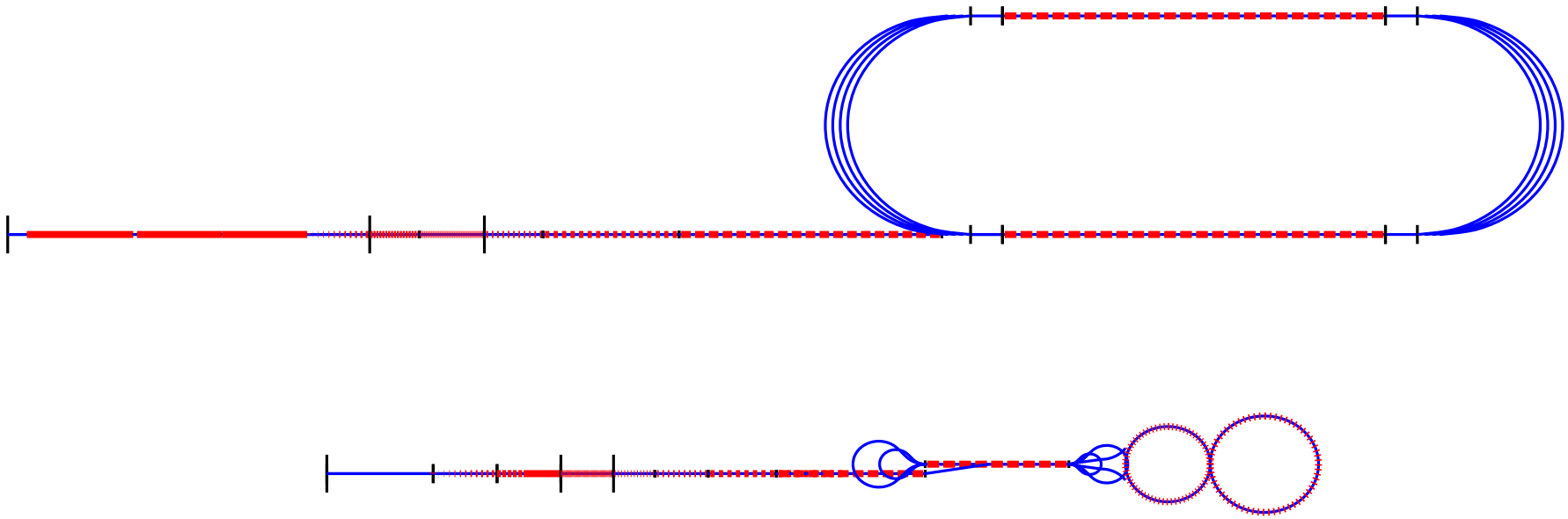




- For one sign
  Muons > Study 2
- But both signs captured
- Effectively
  Muons > 2 times Study 2

Compare All New System with Study 2

Work in progress: list and draw all needed components



Study	Beam line m	Hydrogen m	Acceleration m	B dl T m
2	6891	16.0	802	1649
2a	1950	0.0	360	989
%	28	0	45	60

Note these numbers Use Dejan FFAG's

Target of "half the cost" not unreasonable

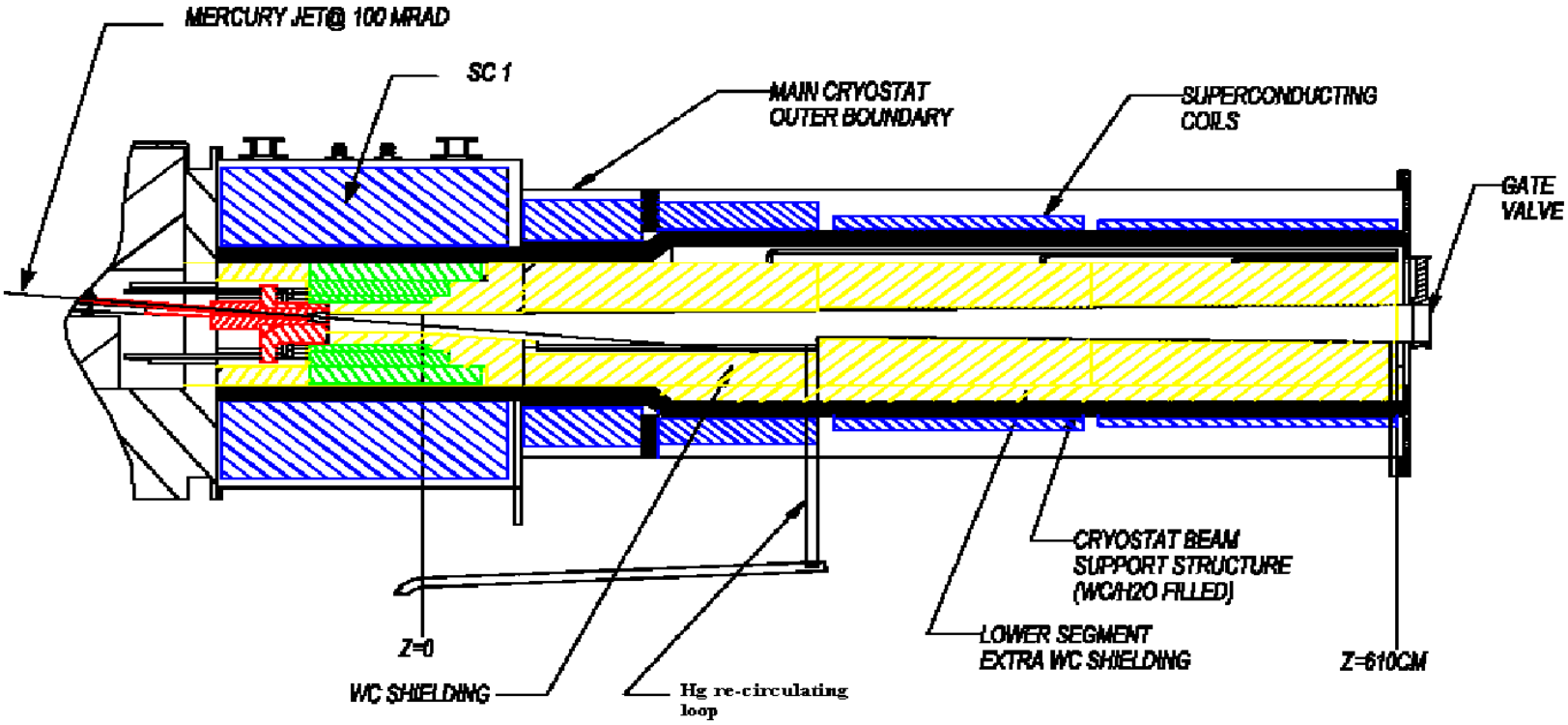
Experimental programs

Technical Challenges

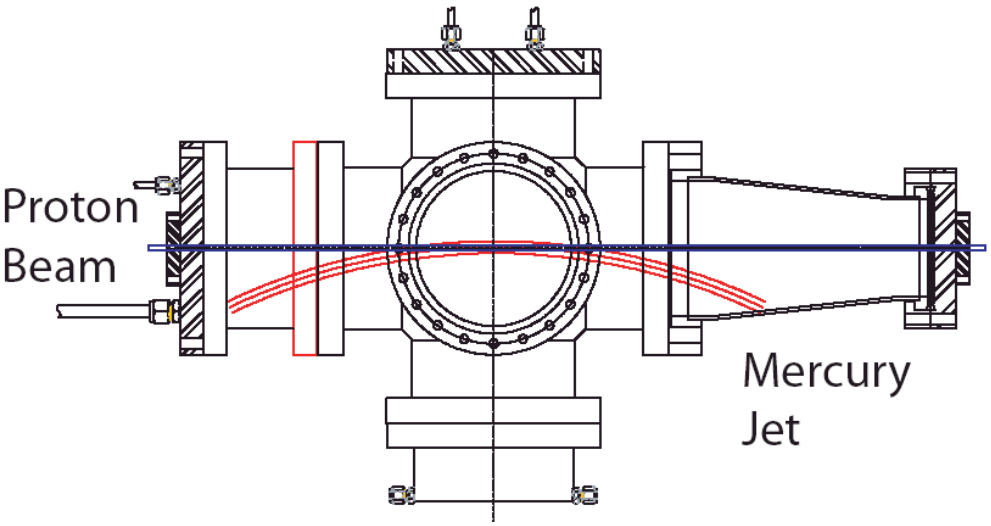
1. Targets
   - High Average power (1-4 MW)
   - High Z material
   - Severe Shocks
2. Cooling
   - High Gradient 200 MHz RF
   - In Solenoid Magnetic Fields
   - Best Absorber is Liquid Hydrogen
3. Muon Acceleration
   - Highest Gradient (to avoid decay)
   - Large Emittance Beam (to avoid need for too much cooling)
   - Needing 200 MHz Superconducting RF (to accept beam) (2 times lower than LEP)

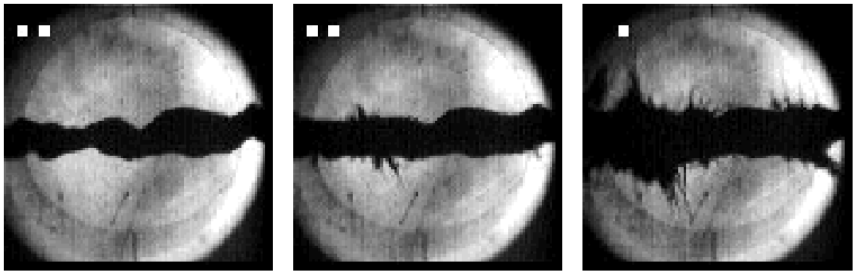
1) TARGET PROGRAM

- 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 proposed in Study 2
- Inside 20 T solenoid to focus pions

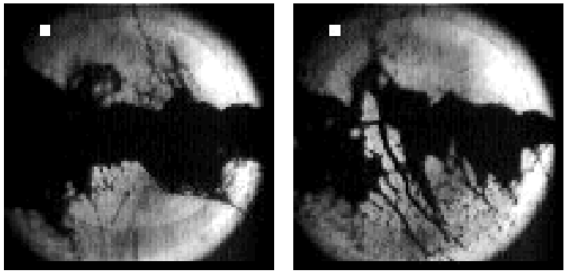


AGS Experiment E951





0 ms 0.75 ms 2 ms



7 ms 18 ms

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

But

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

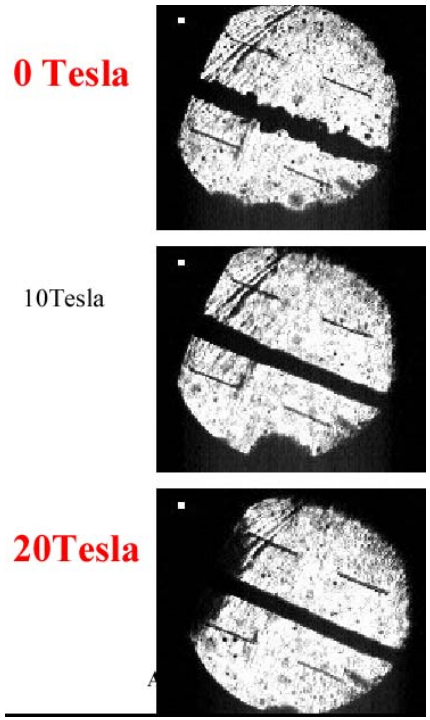
SO

- **Need further Experiment**
  With more intensity

Effects of Magnetic Field

Stabilization From Magnetic Field

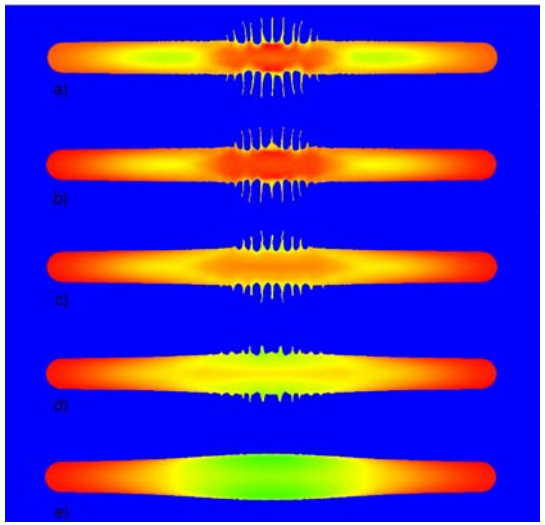
CERN Observation without beam



Simulation with beam

R. Samulyak

Stabilizing of the mercury jet by the longitudinal magnetic field



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

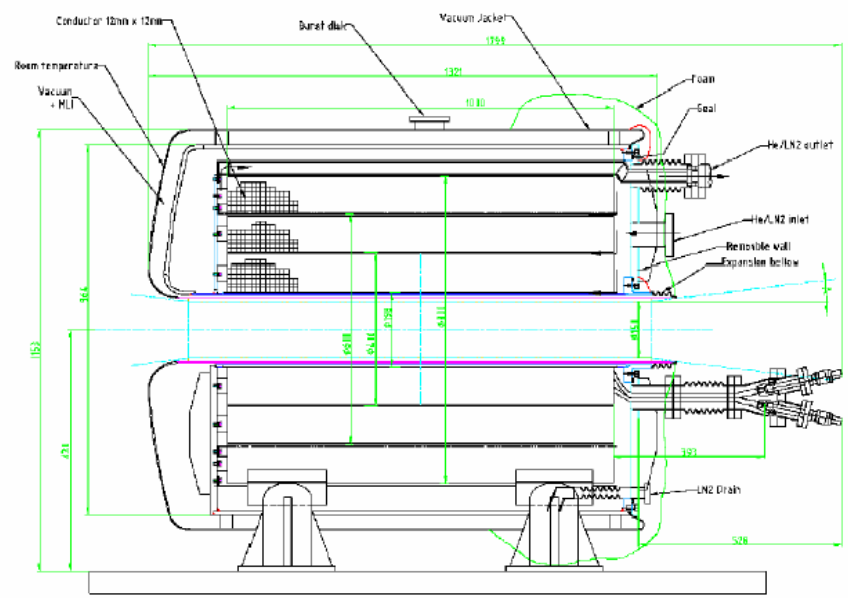
c) B = 4T ; d) B = 6T ; e) B = 10T

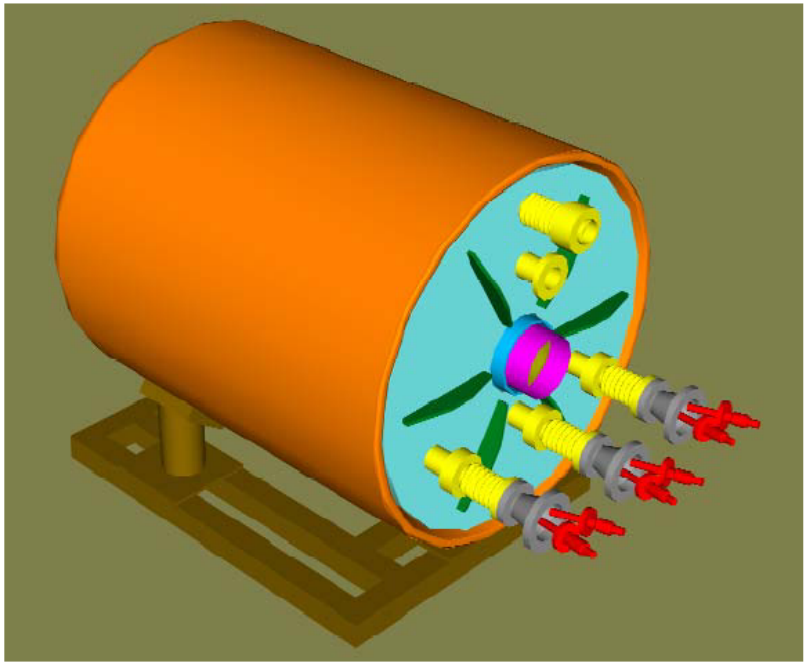
Magnet changes dynamics: suppresses breakup

- **Need experiment with magnet**

Design 15 T Pulsed Magnet (with MIT)

- Very low rep rate acceptable, so:
  - Pre cool with liquid nitrogen
  - Pulse for 10 seconds
- Magnet and cryostat under Construction





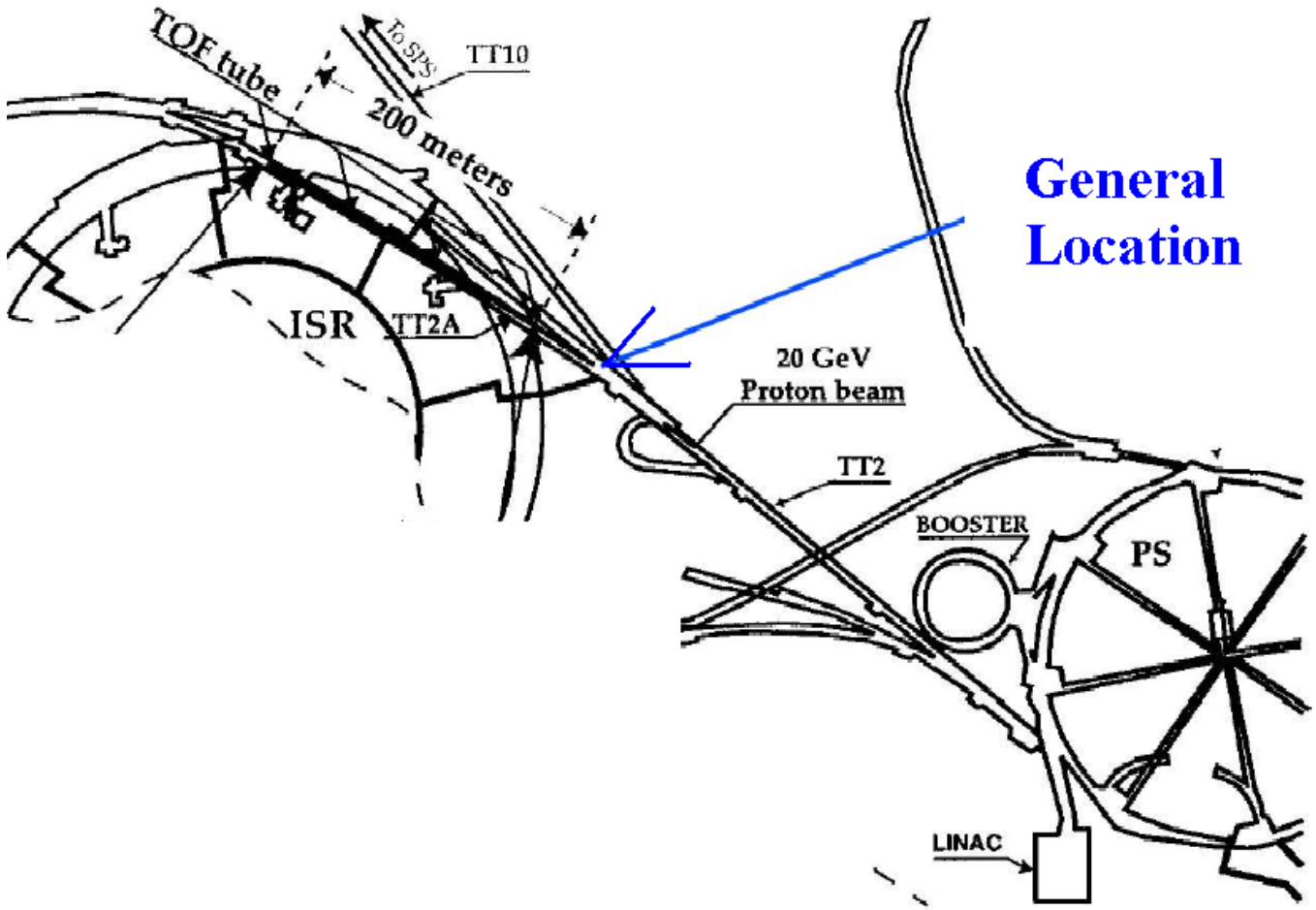
- 70° K Operation
- 15 T with 4.5 MW Pulsed Power
- 15 cm warm bore
- 1 m long beam pipe

Peter Titus, MIT

New Collaboration (BNL, CERN, Japan, Rutherford)

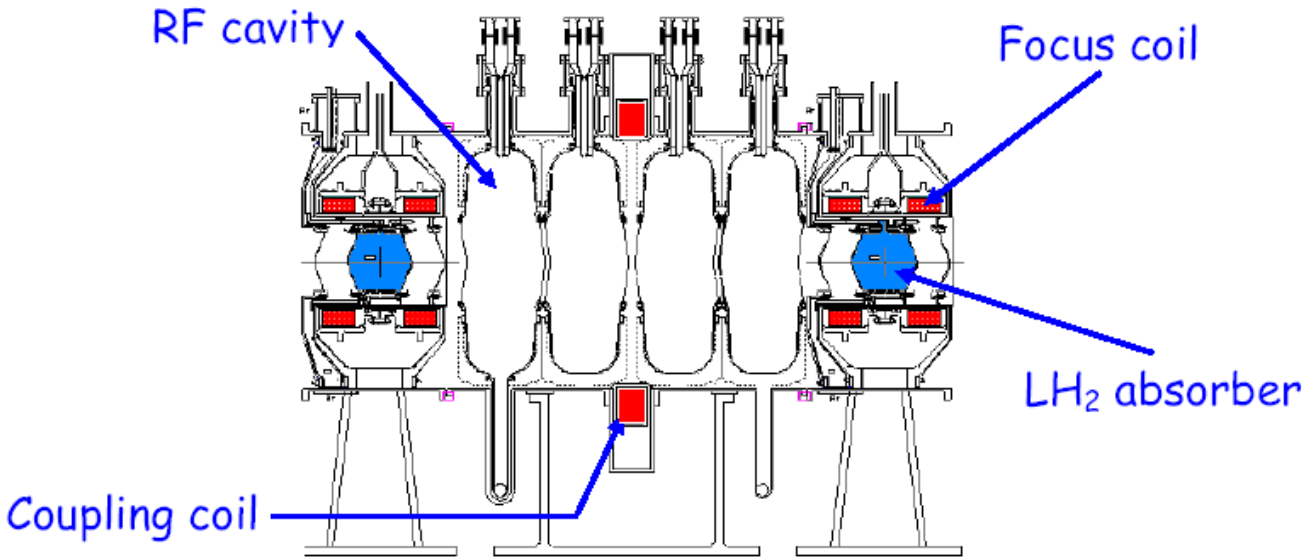
Location for Experiment ? Require 30 Tp for 4 MW Case

- **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
  - Very encouraging response
  - Proposal very soon



2) R&D on Ionization Cooling Components

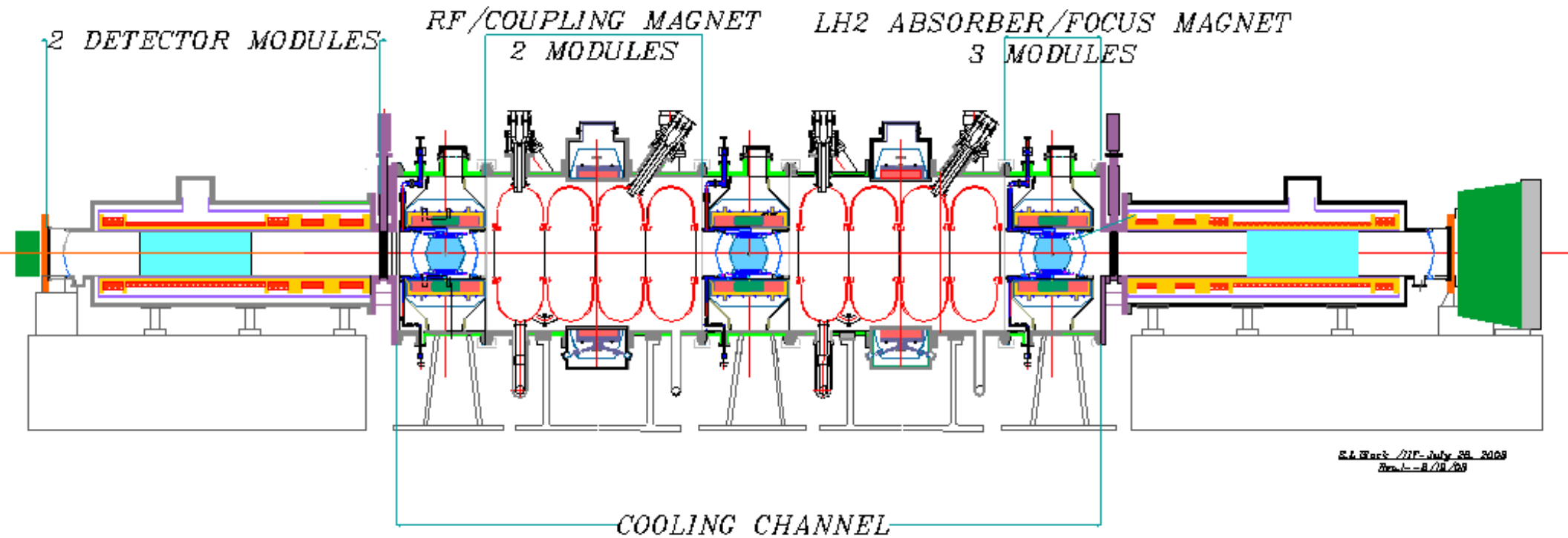
MUCOOL Collab Lead by Fermilab (A. Bross)



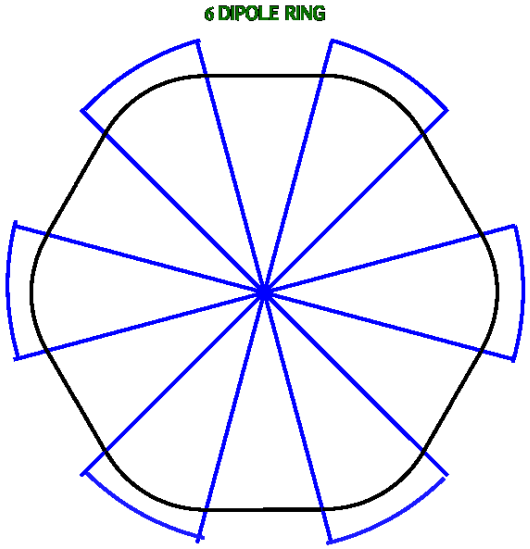
- Design, Build, Absorbers
- Design, Build, and Test Absorber Windows
- High Gradient RF Studies at 805 MHz (Lab G FNAL)
- Design & Start Const. of 201 MHz Cavities
- Experiment with High Pressure Hydrogen STTR
- Test area at FNAL

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, (& in Europe & Japan)**
- **Proposal has Scientific Approval at RAL**



Weak Focused Cooling Ring Experiment ?



- Field $\approx$ 2 T
- Ring is small (circ=4 m)
- Too small for injection Kicker
- But a Cooling demonstration?

Complements MICE

- 6 D rather than 4 D
- A factor $\approx$ 10 cooling, vs, than 10%
- Much cheaper
- But components unlike real cooling system
- May not work (not fully simulated yet)

- Proposal with Mississippi

3) 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

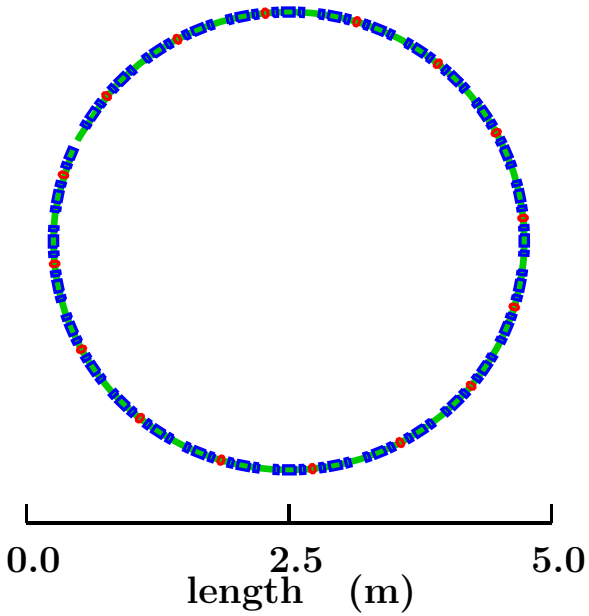
Remember

- **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**

Energy	MeV	10 to 20
Diameter	m	4.5
Peak Mag Fields	T	0.2
Cell length	cm	44
Max Radial Ap	cm	1.7
Freq for mu studies	GHz	3
Freq for p Studies	MHz	21



Discussions in US-Japan collaboration of an electron model

This would be aimed for both muon and proton applications

Conclusion

- **Good Design Progress Since Study 2**
  - **Phase Rotations Without Induction Linacs**
  - **Lower Cost Cooling Solution**
  - **Larger Acceptance Acceleration**
  - **Expect Lower Cost and $\geq 2 \times$ Performance**

- **R&D going well**
  - **Target Experiment Magnet Under Construction**
  - **200 MHz SC Cavity Tested and Being Re-Coated**
  - **Progress on hydrogen and RF windows**
  - **200 MHz Cu RF Under Construction**

- **Proposed Experiments**
  - **CERN Target Experiment**
  - **MICE at Rutherford**
  - **Weak Focus Cooling Ring Demonstration ?**
  - **Non-Scaling FFAG Electron Model ?**

- **But short of funds since DOE 1/2 cut in 2001**