Muon Collider & Neutrino Factory Studies

R B Palmer LBNL

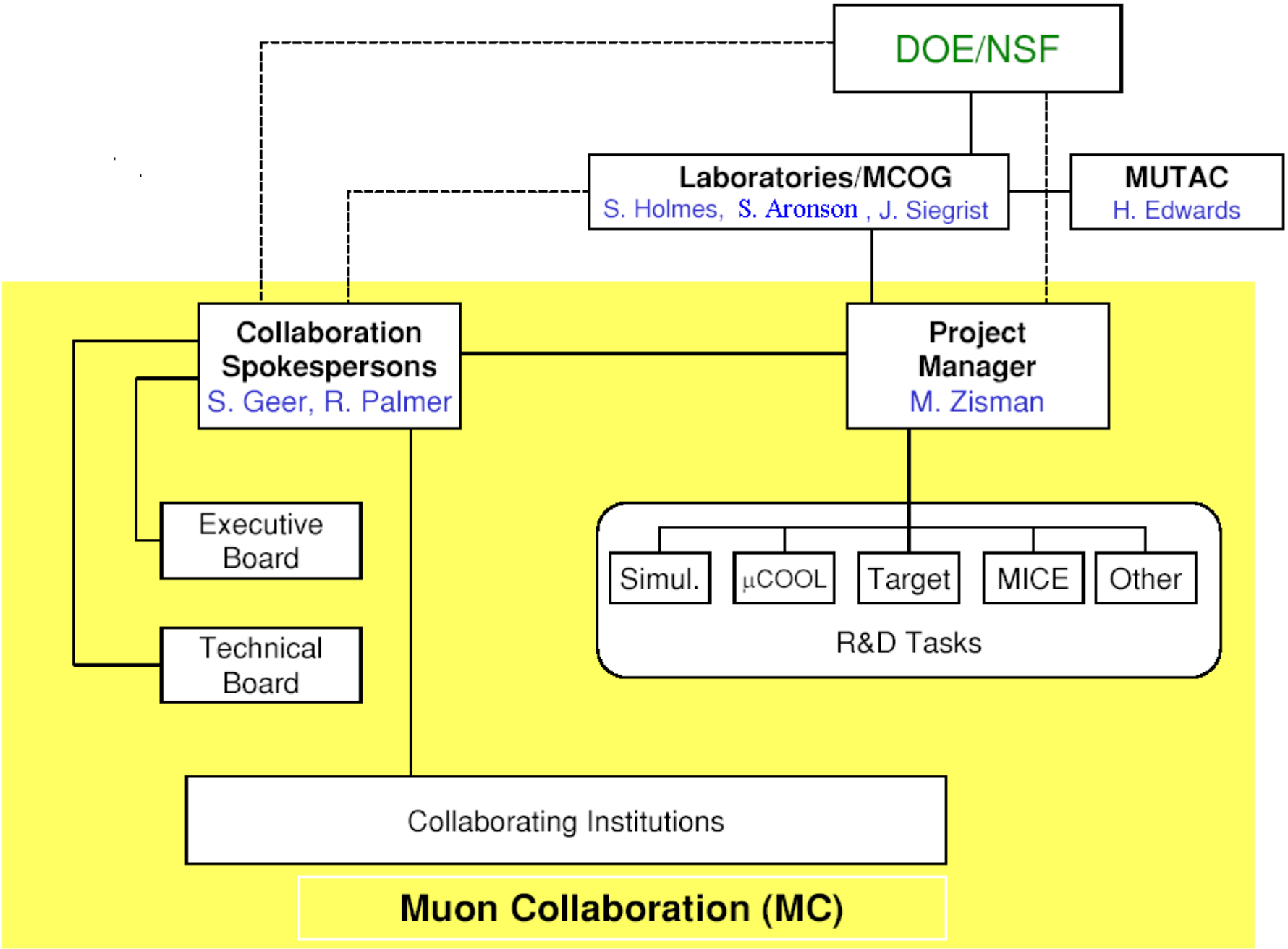
Muon Collaboration (MC) Goals

MC Charter* that defines its goals and organization

The goal of this organization (referred to hereinafter as the Muon Collaboration) is to study and develop the theoretical tools, the software simulation tools, and to carry out R&D on the hardware that is unique to the design of neutrino factories and muon colliders. An important part of the program will be an extensive experimental program to verify the theoretical and simulation predictions and to gather the necessary data for a future facility.

* http://www.cap.bnl.gov/mumu/info/MC_Charter_Final_020903.pdf

National Organization



Members

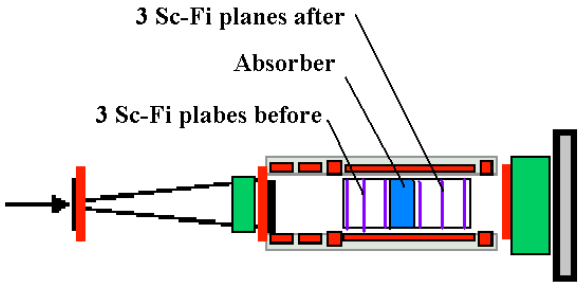
- 135 Scientists and Engineers
- 6 US Labs
- 17 US Universities
- 14 Foreign Institutions

in Collaboration with

- European Groups
  CERN, RAL (UK), INFN (Italy), Universities
- Japanese Groups
  KEK, Osaka, other Universities
- Russia
  BINP (including Skrinski, who started all this)
- Annual NuFact International Workshops
  (Rotating: Europe, US, Japan)

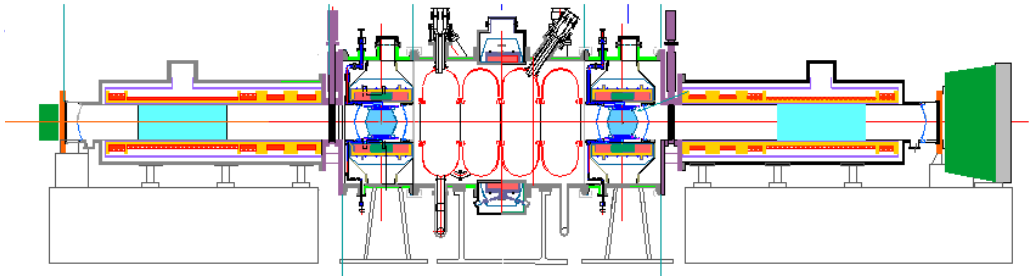
Technical Milestones Since Last year

- **First Experiment in Muon Test Area at Fermilab (MTA)**
  Liquid Hydrogen Absorber Filled
  Near completion of
  first 200 MHz RF Cavity

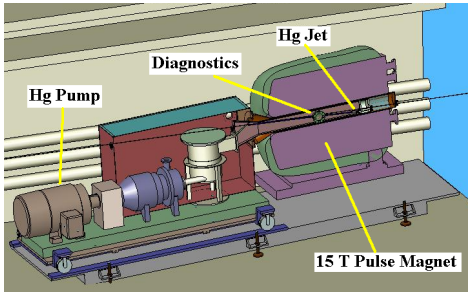


- **UK Funding approval for Phase One of Muon Ionization Cooling Experiment (MICE)**

  US plan for funding to 'Stage V



- **CERN approval of Mercury Target Experiment (NTOF 11)**
  & Near completion of Pulsed 15 T Magnet



5 Year Plan from the Project manager

- "baseline" (flat-flat, $3.6M/yr) and "incremental" ($4M/yr)
- base program funds: BNL ($1.0M); FNAL ($0.6M); LBNL ($0.3M)
  - "threat" to BNL base program adds uncertainty to plan
- then, MC funds of $1.7M available each year in baseline case

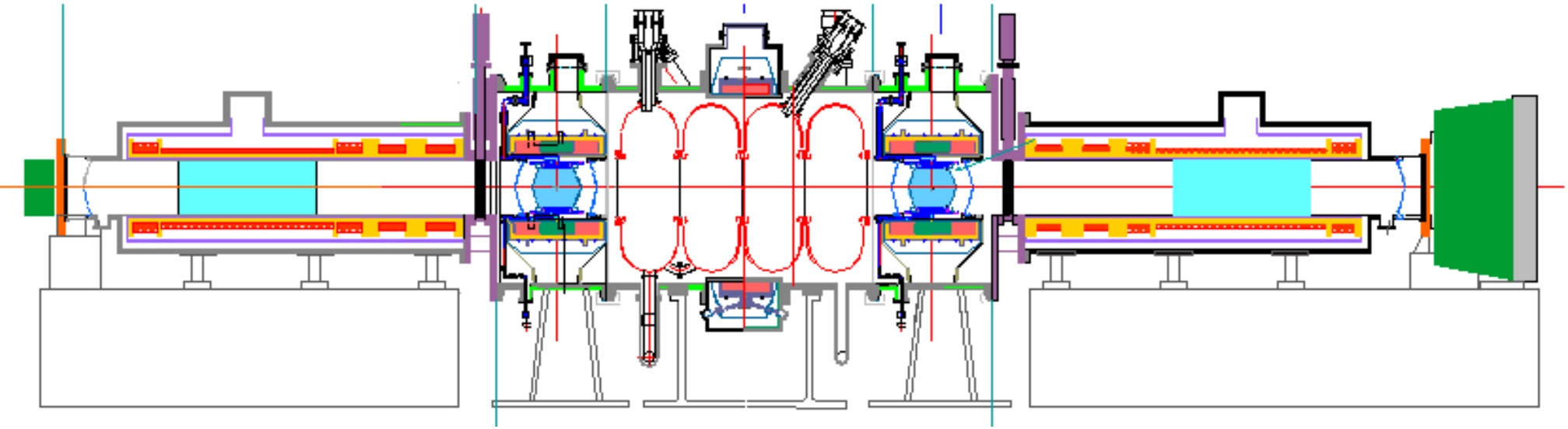
• Summary of baseline case is

Activity	FY05	FY06	FY07	FY08	FY09	FY10
Cooling	492	245	345	705	615	225
Targetry	713	640	625	100	100	100
System Studies	195	195	195	295	295	195
MICE	300	620	535	600	690	1180
TOTAL	1700	1700	1700	1700	1700	1700

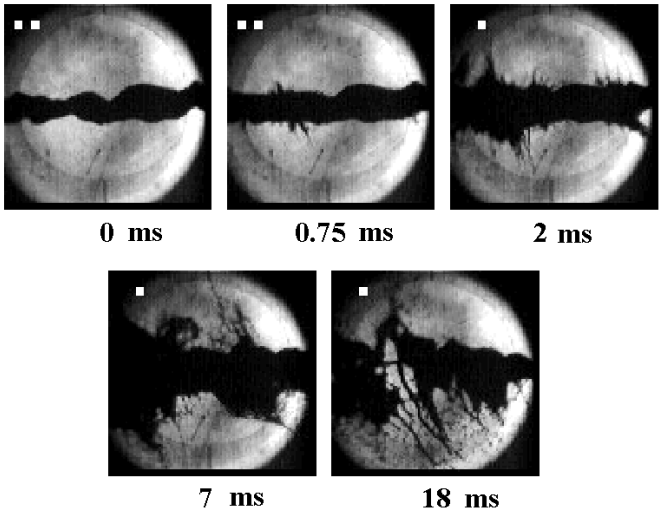
- amounts for Targetry and System Studies are assigned first
- remaining funds available for MUCOOL + MICE

Muon Ionization Cooling Experiment (MICE)

- Design based on Study-2 channel
- International Collaboration: (US, Europe, Japan)
- Proposal has Scientific Approval at RAL
- UK Funding ($\approx$ 18 M$) approved for phase 1
- US Funding 5 year Plan (flat-flat) for stage V



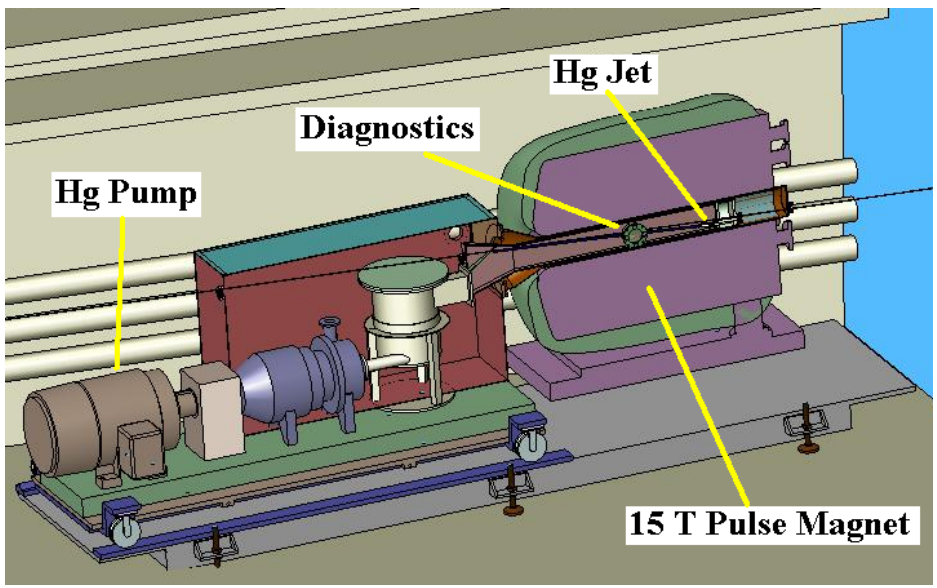
c.f. BNL Target Experiment E951

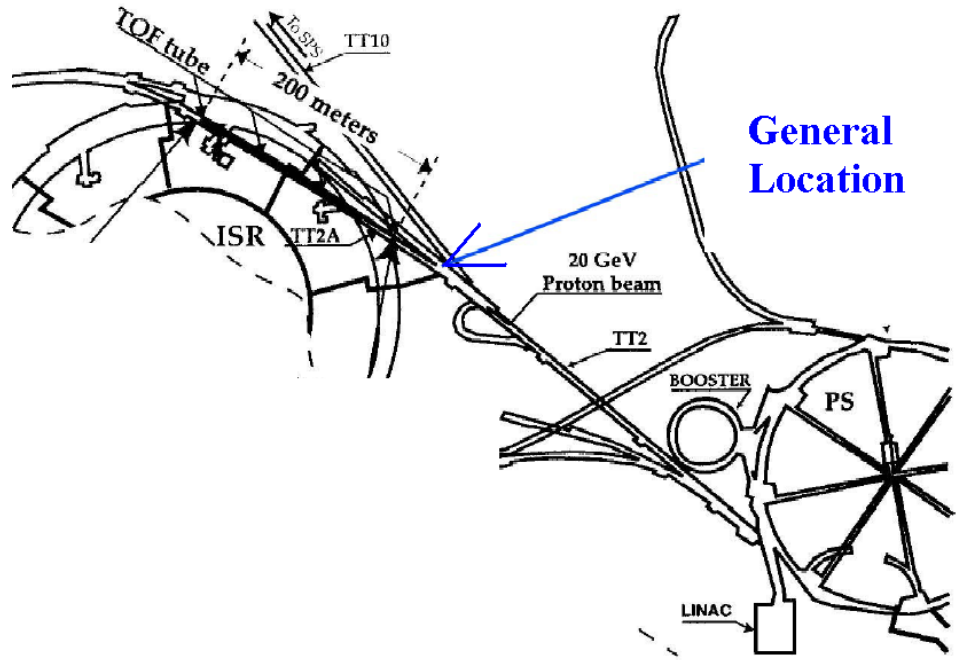


- Single pulse $\boxed{\text{4 Tp}}$
  But density equiv to 1 MW
- Non-Explosive Dispersion good
- But 4 MW Nu-Factory requires:
  32 Tp/bunch

CERN Approved Experiment (NTOF 11)

- More intensity $\boxed{\text{32 Tp}}$ as required for 4 MW
- 15 T pulsed Magnet near completion





Theory and Simulation Studies

- History
  - Study I, sponsored by FNAL, Feasibility
  - Study II, Sponsored by BNL, Performance $\times$ 6

Theory and Simulation Milestones since last Year

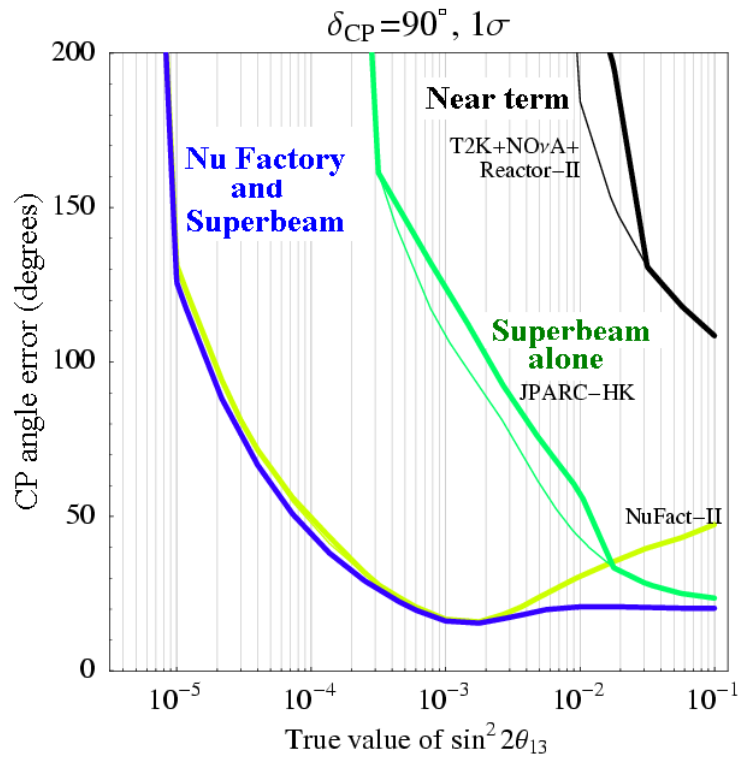
- Study IIa, APS Study Less Cost and both signs ($\approx \times 12$)
- Start of negotiations with Japan and Europe on a 'World Design Study' Sponsored by RAL
- Progress in FFAG optimization
- Design of Electron FFAG Model (with Japan & UK)
- New ideas for 6 dimensional Cooling
  Hydrogen Gas in Helical Magnet
  'Desk Top Ring'
  Inverse Cyclotron

APS Study of Neutrino Physics

"A high-intensity neutrino factory or a beta beam facility is the ultimate tool in neutrino physics for the long term, and may be the only facility capable of definitively addressing some of the physics issues."

e.g. Search for CP violation with Leptons

- Conventional/Super-Beams
  using $\nu_\mu \longrightarrow \nu_e$
  have backgrounds of order 1%
- Neutrino Factories
  using $\nu_e \longrightarrow \nu_\mu$
  have backgrounds of order 0.01%
- If $\sin^2(2\theta_{13}) < 0.01$
  then only Neutrino Factory
  can study it



"The neutrino factory R&D program needs increased levels of support if the facility is to be realized in the long term."

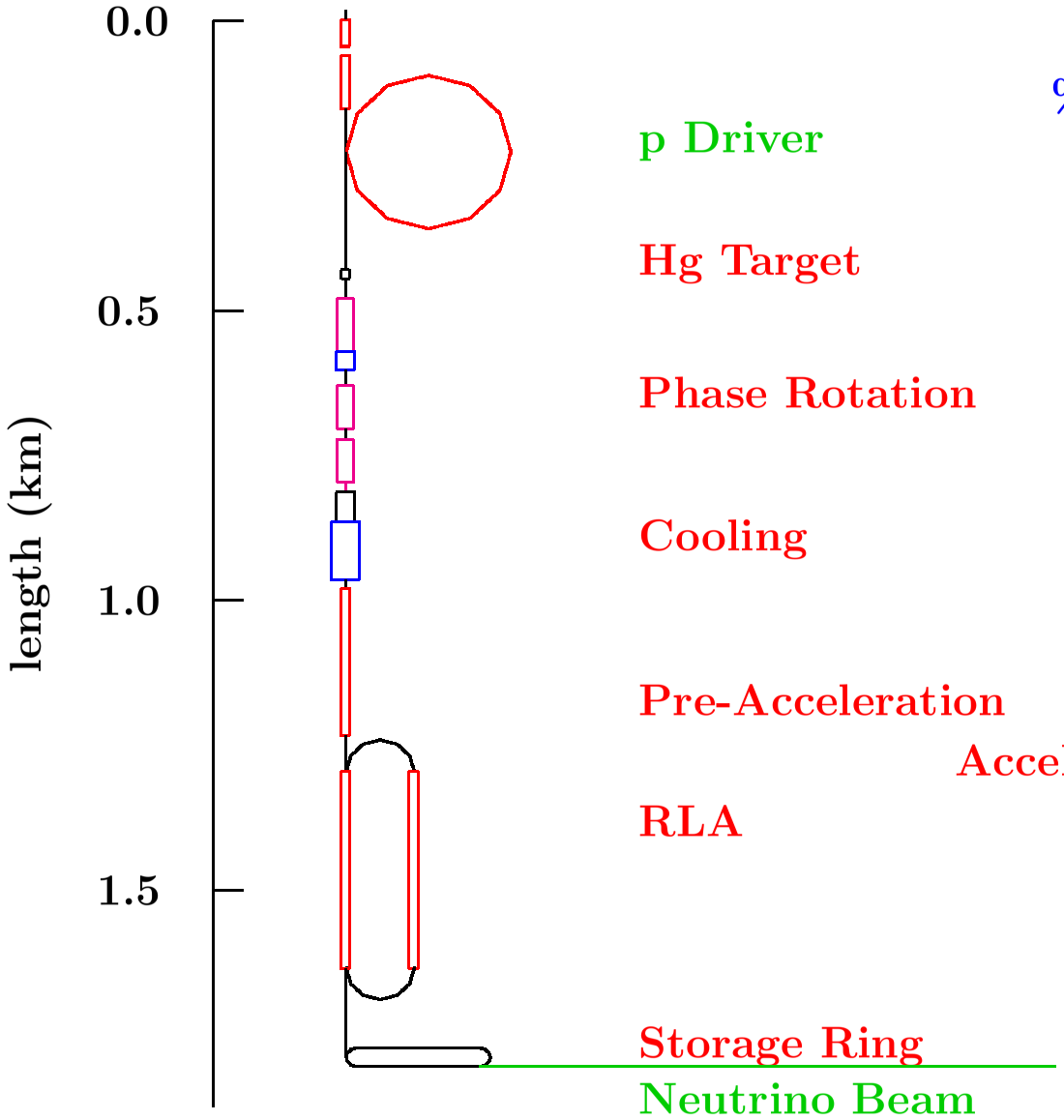
Study 2a

- Maintained performance per muon of given sign
- Allows use of both signs
- 40 % Lower cost
- Main Innovations
  1. Bunching before RF Phase Rotation
  2. Less Cooling
  3. Larger Acceptance Acceleration including FFAG's
- Work Continuing (Study 2b)

World Design Study (Study 3)

- Lead by RAL (UK)
- Europe, US,Japan
- Study choices of frequency, amount of cooling, energy etc.

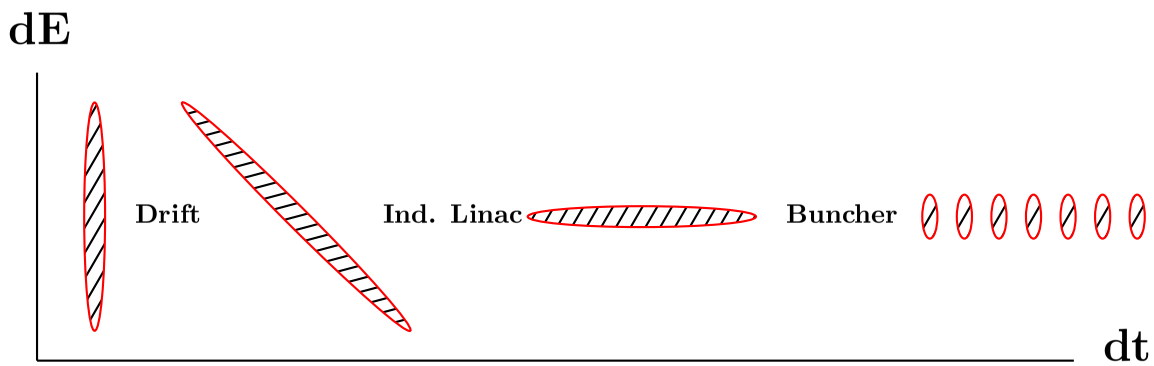
Study 2a Schematic



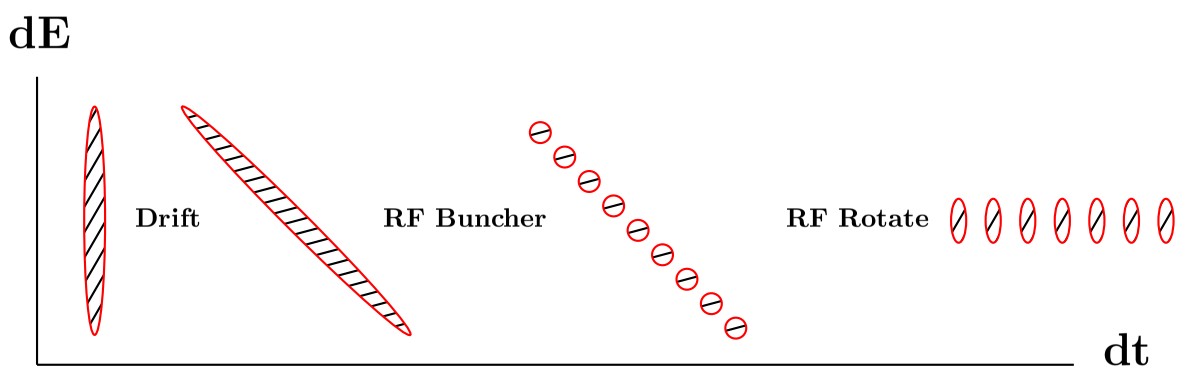
	% of 1.0 B$ Cost (no EDIA etc) without driver
Hg Target	(10 %)
Phase Rotation	(17 %)
Cooling	(21 %)
Pre-Acceleration, Acceleration, RLA	(42 %)
Storage Ring	(8 %)

1) Phase Rotation (Reduce dp/p prior to Cooling)

Bunching before RF Rotation (Neuffer) vs. Induction Linac Rotation First

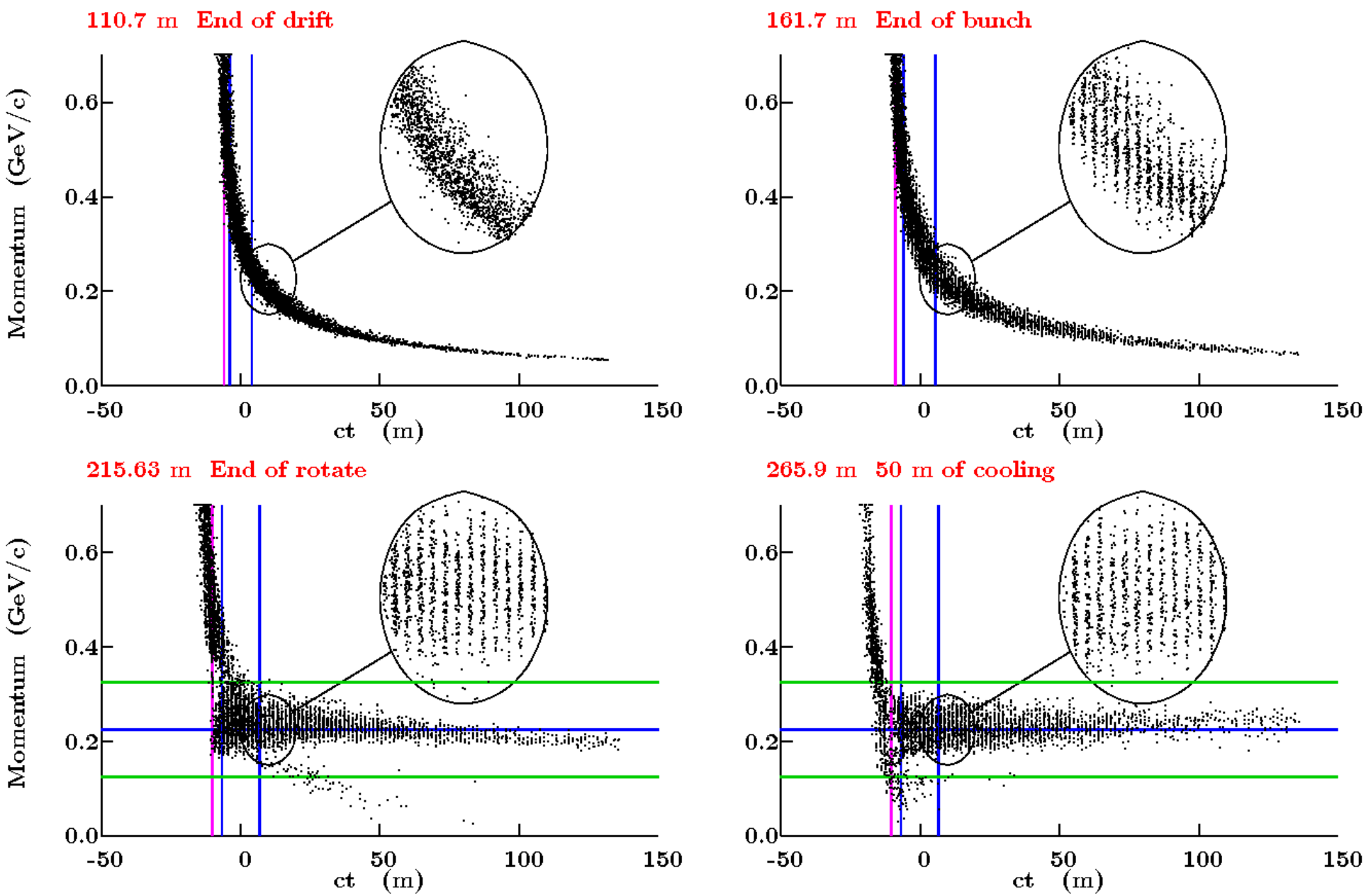


Neuffer's Bunched Beam Rotation with 200 MHz RF



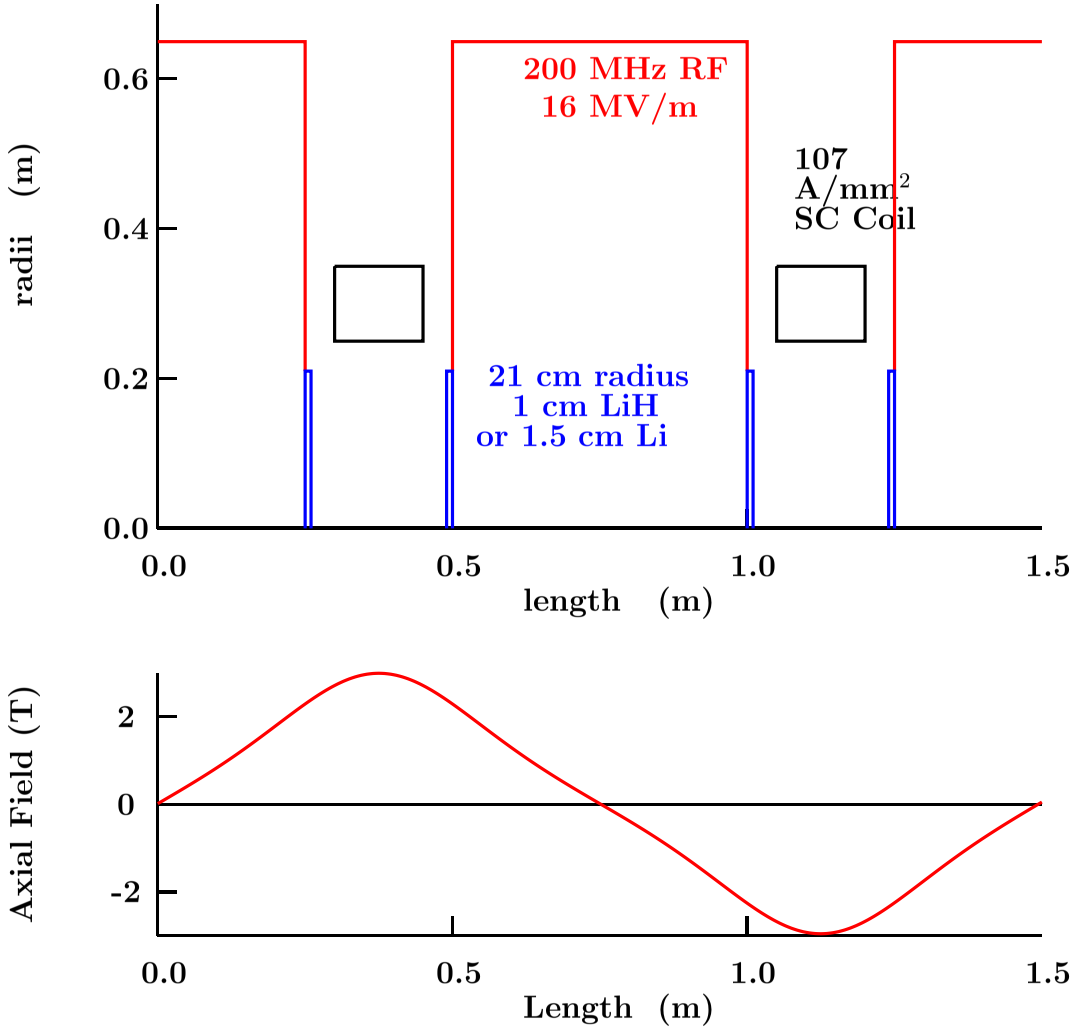
- 200 MHz RF is cheaper than Induction Linacs
- But RF frequency must vary along bunching channel (high mom. bunches move faster than low)

Phase Rotation Simulation

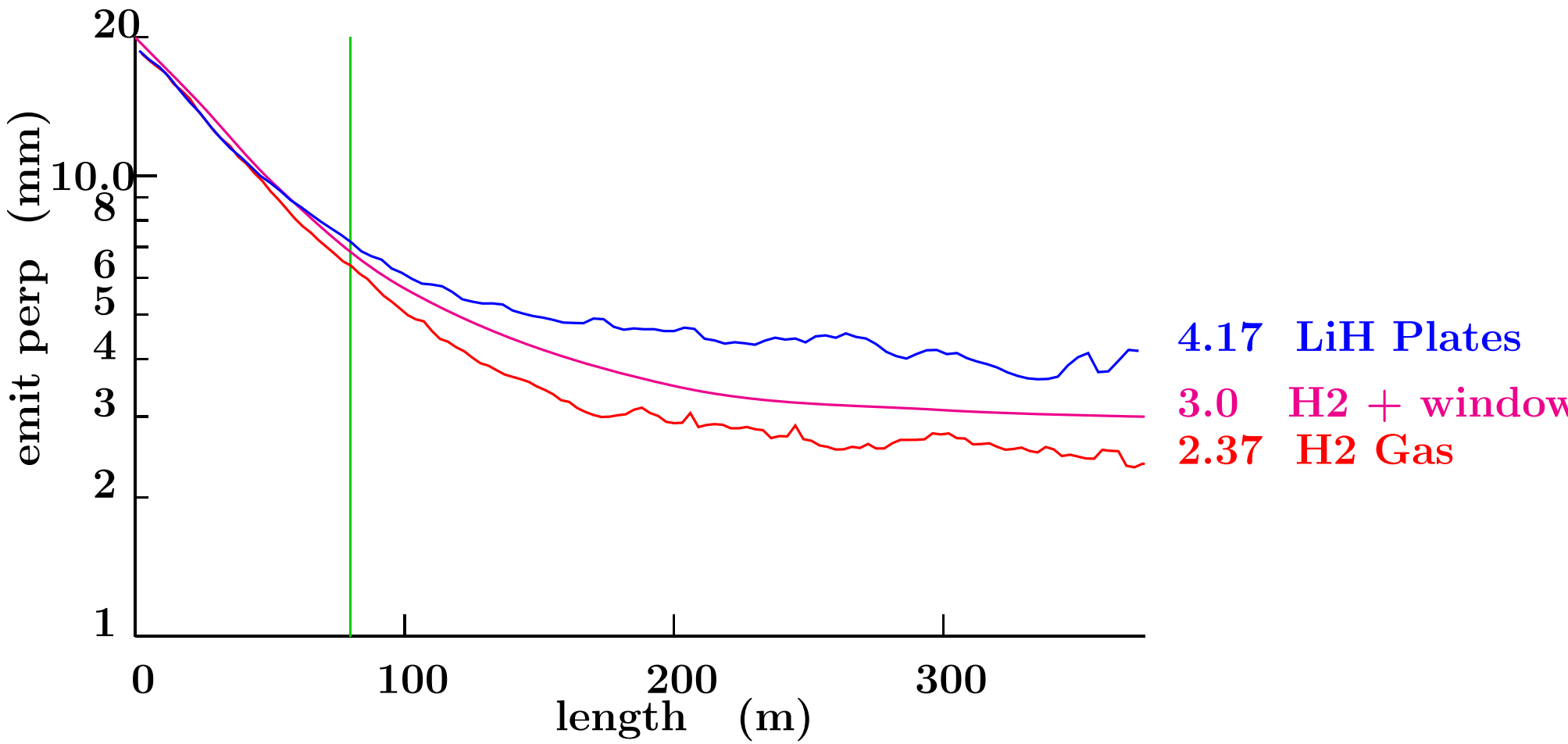


2) Cooling

- Use Larger Acceptance in Acceleration (c.f. Japan)
- Simpler Lattice than Study 2
- LiH instead of Liquid Hydrogen

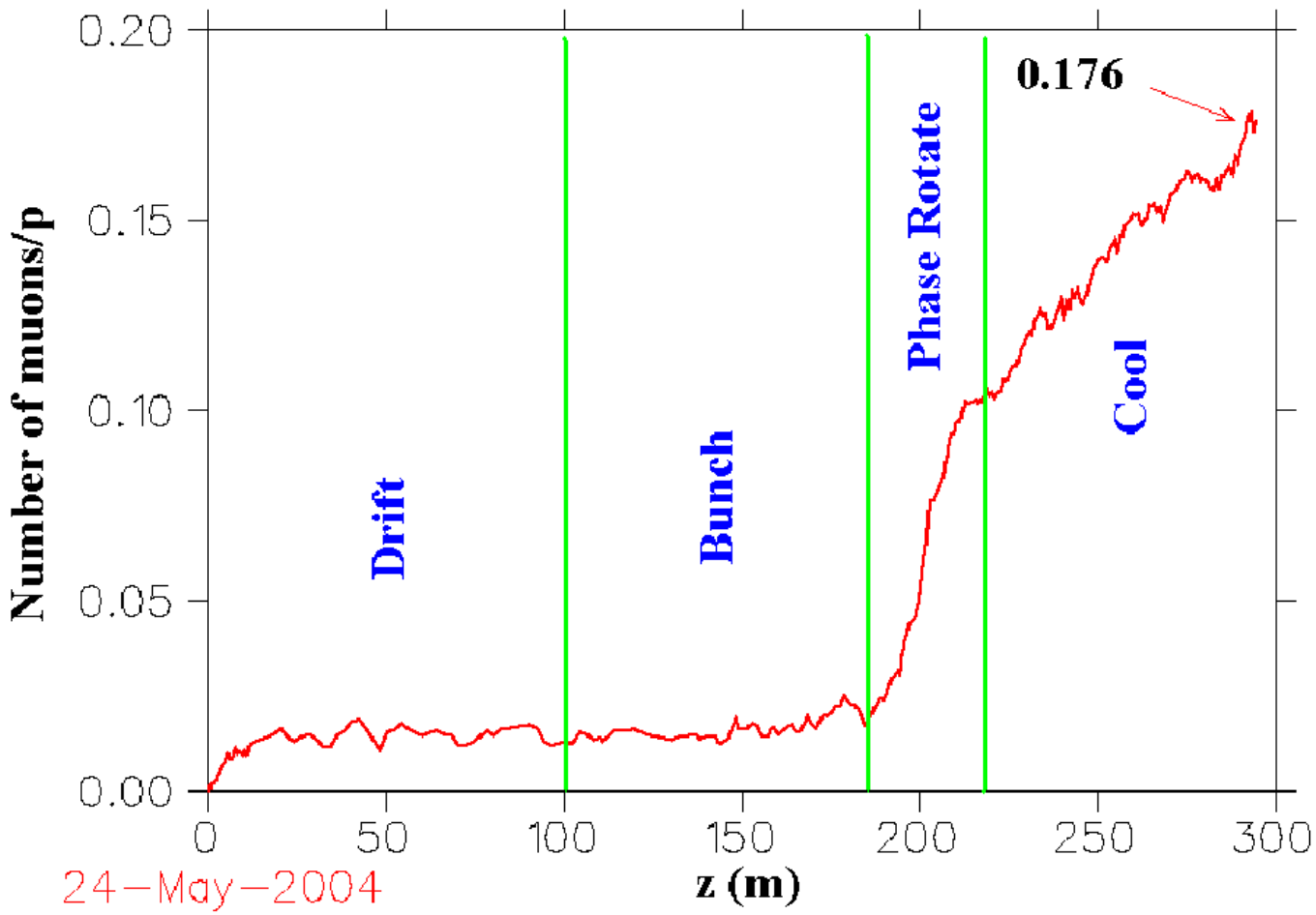


Cooling from Gaussian Input



- Little difference between LiH and H2 before 80 m

Cooling Performance

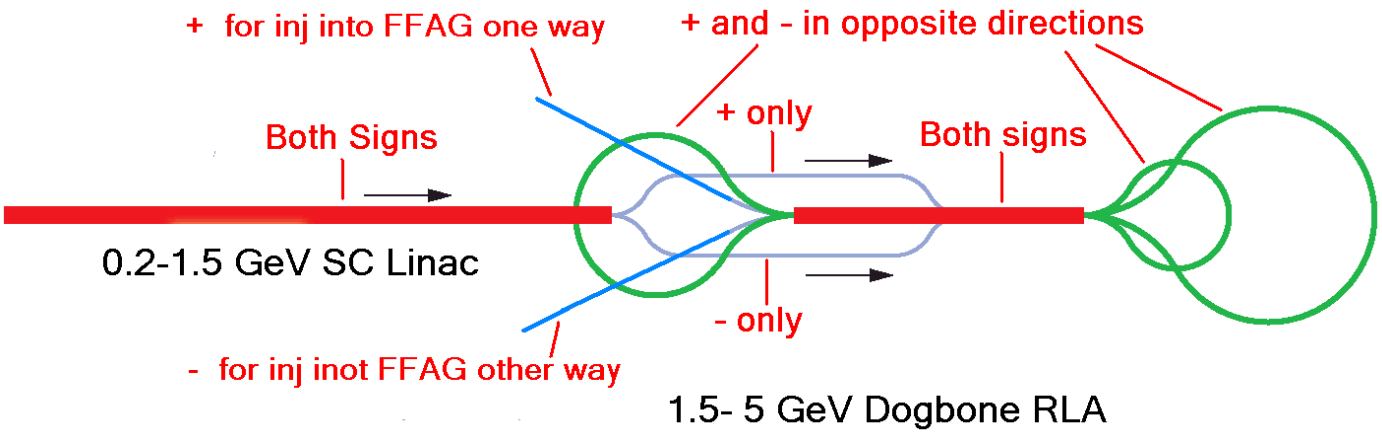


cf Study 2
0.17

- Same Muons per proton as Study 2
- But both signs

3) Acceleration

Linac and RLA‘(0.2 TO 5 GeV)



- 30 pi mm Acceptance (c.f. 15 pi mm in Study 2)
- Both signs are accelerated
- Switchyards are easier in Dog Bone RLA

Non-Scaling FFAG (5 to 20 GeV)

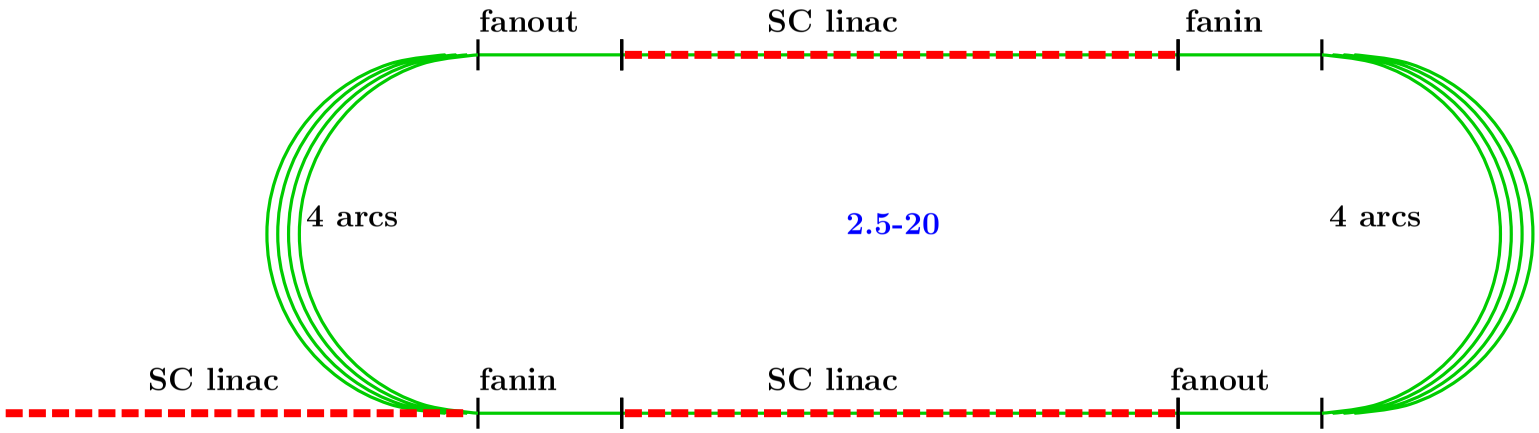
(Proposed by Carol Johnstone & Dejan Trbojevic)

- Orbits are not similar, as in scaling
- They are closer together than in scaling
  $\longrightarrow$ smaller apertures
  $\longrightarrow$ more isochronous

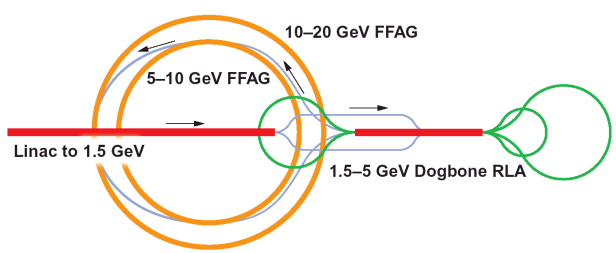
e.g. Compare IIa Acceleration with Study II

Use of Fixed Field Alternating Gradient (FFAG) Acceleration

Study II Linac + RLA



Study IIa Linac + RLA + 2 FFAG's



- **FFAG also under study as high intensity p Source**

Summary of Cost Reductions

	Study 2 M$	study 2a M$	2a/2 %
Target and Capture	97	97	100
Rotation	394	144	37
Cooling	310	182	59
Acceleration	544	363	67
Storage Ring	82	82	100
	1427	868	61

- Costs of technical items and conventional construction
- Without controls, missing items, Escalation or EDIA
- Mostly by scaling from Study 2
- Not a Bottoms up costing

Ideas for 6 D Ionization Cooling

- Energy loss in light medium in strong focusing → Transverse Cooling
- Two methods to exchange longitudinal and transverse to get 6D cooling:
- Needed for a Muon Collider

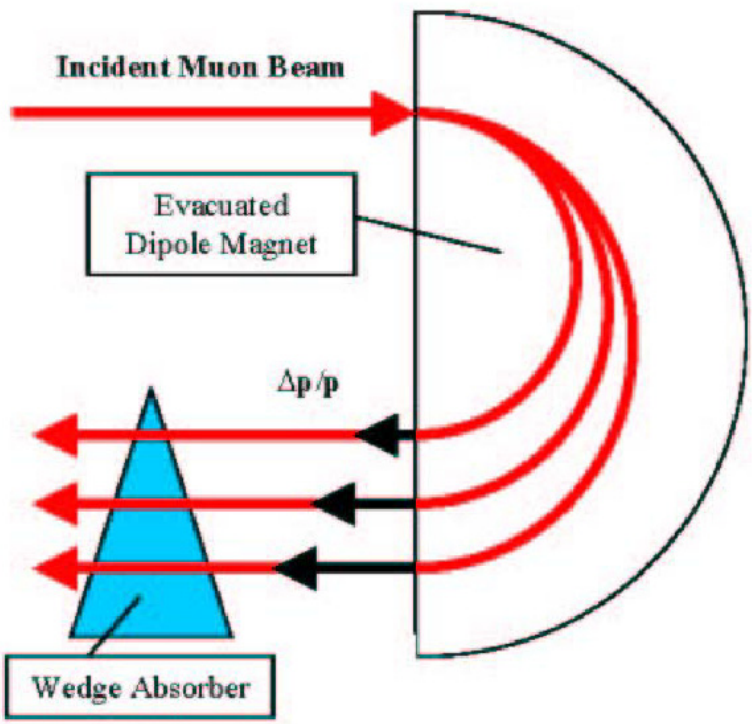


Figure 1. Use of a Wedge Absorber for Emittance Exchange

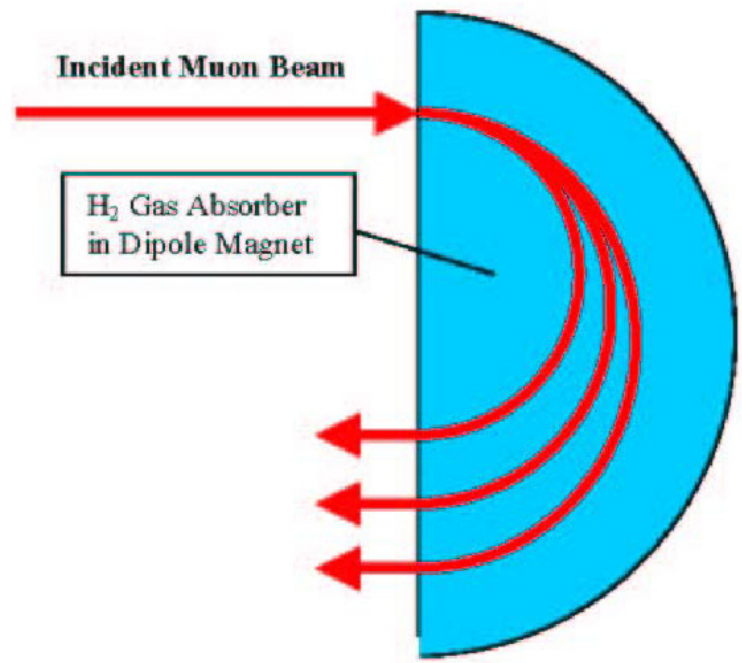
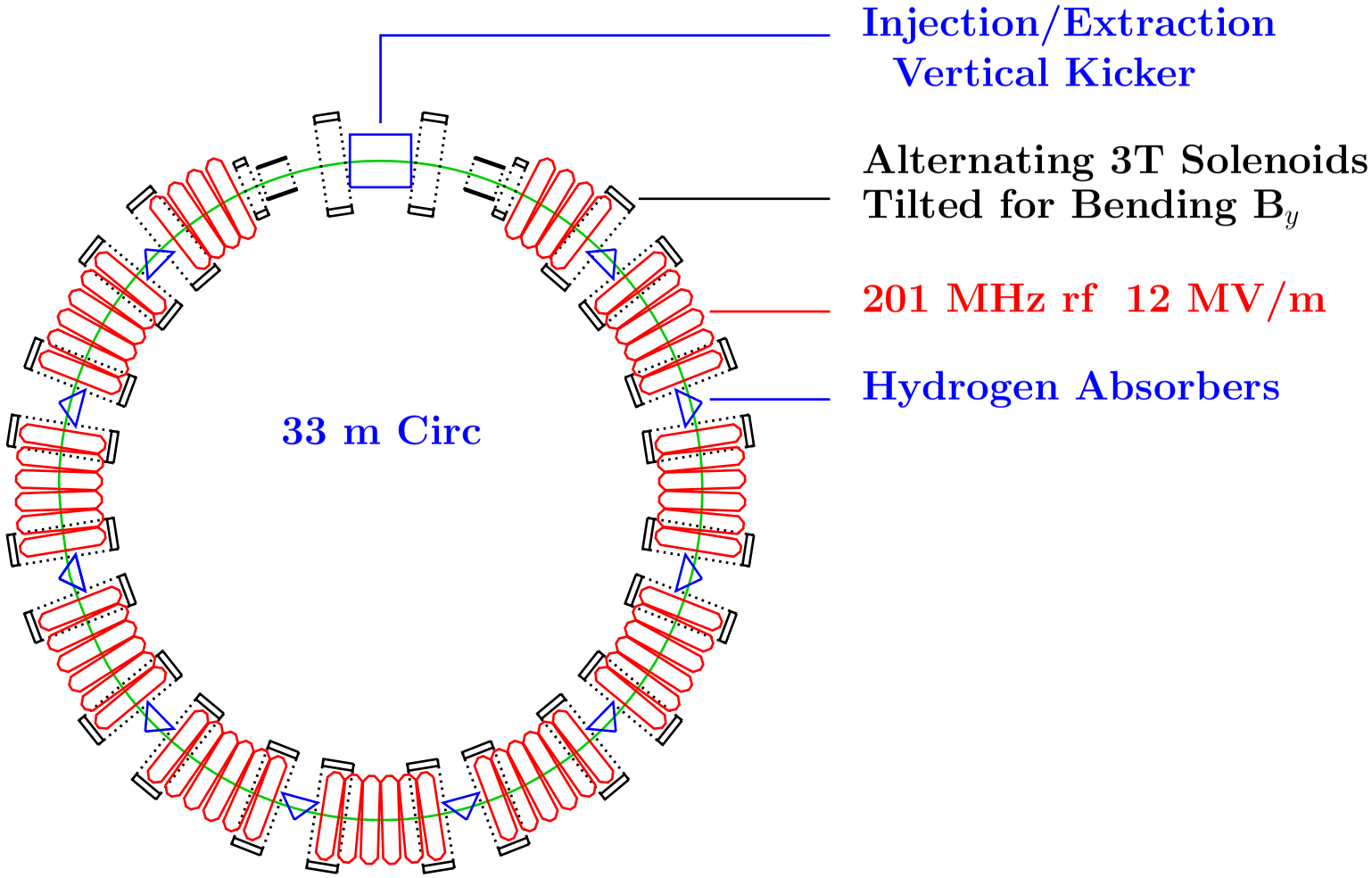


Figure 2. Use of Continuous Gaseous Absorber for Emittance Exchange

e.g. With wedges

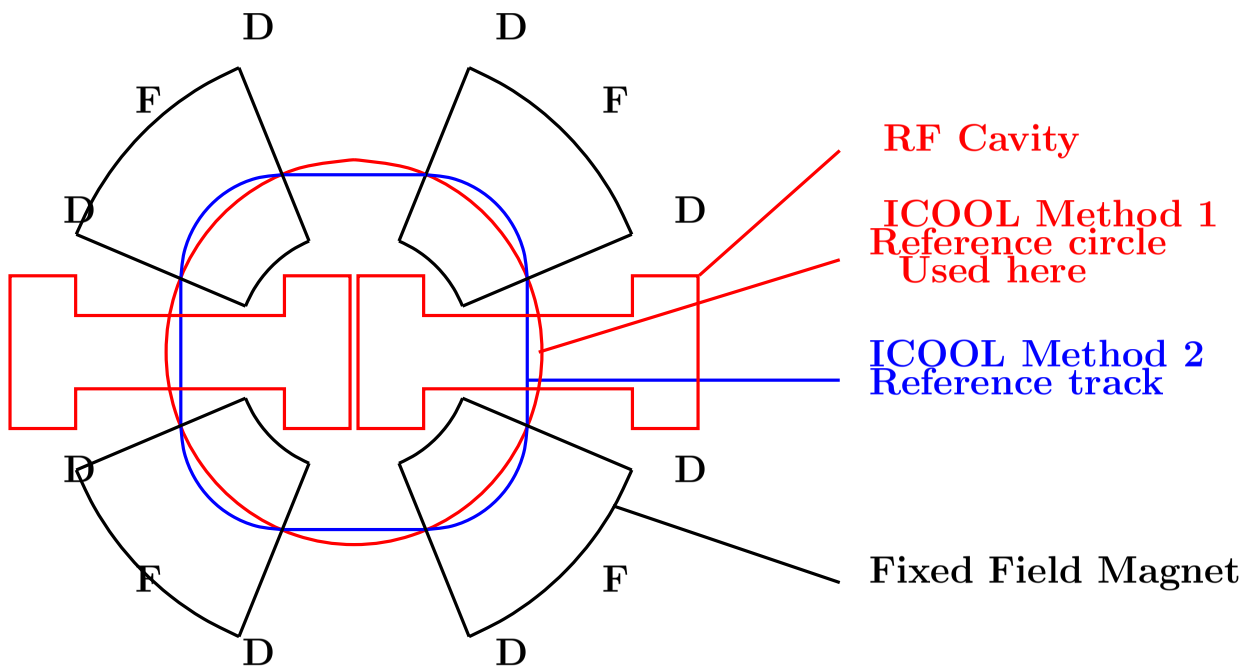
- Many turns in Ring gives more cooling at lower cost
- e.g RFOFO Ring Fully simulated



6D emittance down by 300 (cf 1000,000 req for Collider)

e.g. With Gas in a Ring

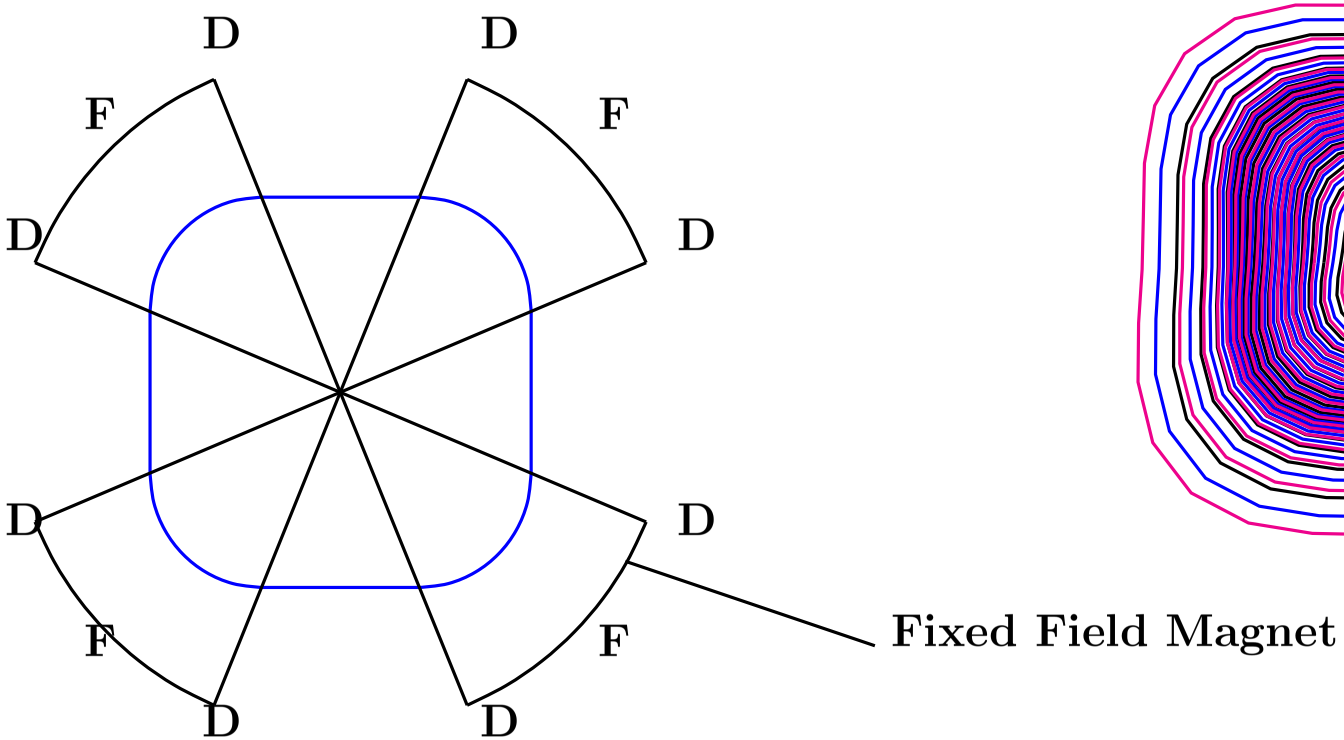
A. Garren, H Kirk

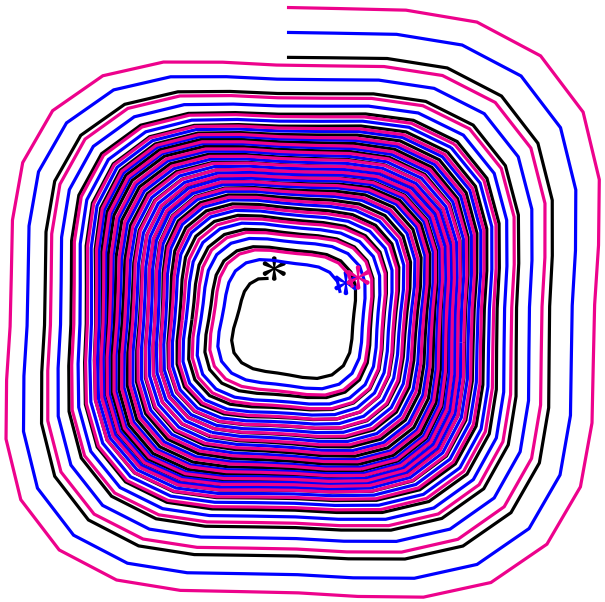


- 2 T fields
- 6 D cooling simulated
- Small: diam= 2 m
- Injection/Extraction hard
- Demonstration Experiment ?

e.g. With Gas and Wedges: Inverse Cyclotron

D Summers, A Garren, H Kirk





- Pole angles ≡ D focus
- fine wedges and gas give graded density with radius
- 6D cooling could be of order 1000,000
- Work In progress

Problem with future of BNL Muon Group

- **Problems in funding for BNL Physics Groups**

  Leading to

- **Probable loss of one member of Muon Group now**
- **Intent to eliminate group in 6 months time**
- **Requests to DOE to reprogram accelerator funds**

Consequences

- **A reduction by more than 50% of the DOE "base" support**
- **Probable cancelation of the approved and funded CERN Target Experiment**
- **Effective loss of the program ICOOL, resulting in:**
  - **Serious Damage to Simulations Studies, including the potential "World Design Study"**
  - **Risk to MICE design effort**

Conclusion: Exciting Program

- **Simulation and Design Studies**
  - **Cost Reductions**
  - **Performance improvements**
  - **"World Design Study"**
  - **New ideas**

- **Ionization Cooling R&D**
  - **MTA starting**
  - **200 MHz RF near**
  - **H2 Target under test**
  - **Muon Ionization Cooling Experiment (MICE) Funded**

- **Liquid Mercury Target**
  - **Run approved Target Experiment at CERN (NTOF 11)**
  - **15 T Pulsed Magnet near**

- **Threat to Base Program with Grave Consequences**