Design and Simulation

R B Palmer
DOE 12/5/02

- History
- Organization
- Target
- Cost Reduction
  1. Phase Rotation
  2. Cooling
  3. Acceleration
- Conclusion

Recent US Studies

- **Study I of Neutrino Factory**
  - **Emphasized Feasibility**
  - **Sponsored by Fermi (finished March 00)**
  - **"Entry Level" (≈ 0.2 10^{20} $\mu/10^7$sec at 1 MW)**
- **Study II of Neutrino Factory**
  - **Emphasized Performance with Feasibility**
  - **Sponsored by BNL (finished April 01)**
  - **"Higher Flux" (≈ 1.2 10^{20} $\mu/10^7$sec at 1 MW)**
- **Current Work**
  - **Lower Cost**
  - **Improve Performance**
  - **Cooling for Colliders**
- **Future: An International Study 3 (In about 2 Years)**
  - **Emphasize Cost, with Performance and Feasibility**
  - **International Executive Group established**
  - **Site specific part could be RAL or KEK**
- **Collider Study (later)**

Organization

Simulation Committee (chair Raja)

Workshops, Phone & Video conferences, Priorities, Post-Docs

Sub-groups:

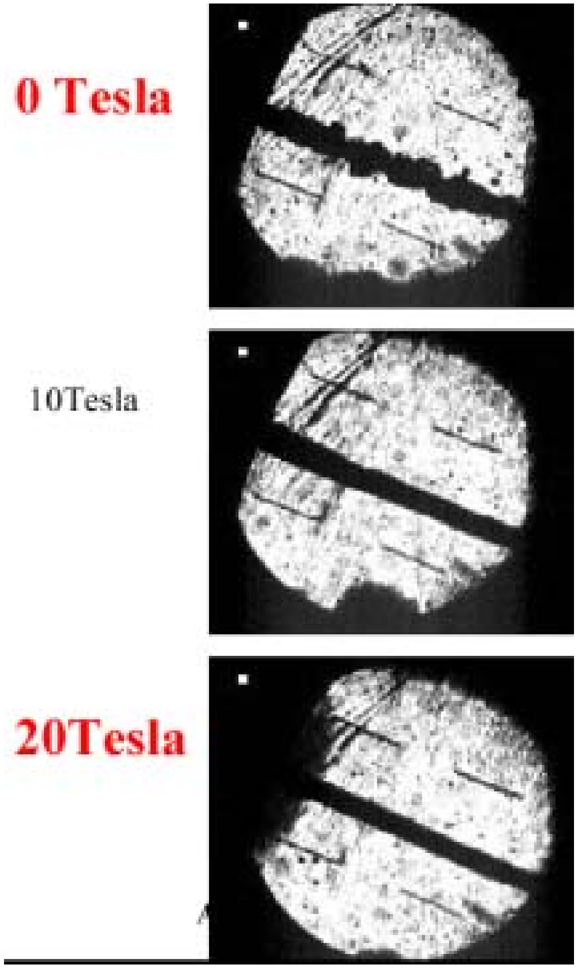
- **Targets (Kirk)**
- **Phase Rotation (Fernow)**
- **Cooling (Raja)**
- **Acceleration (Johnstone)**
- **Theory (Sessler)**

Workshops in 03

- **FFAG KEK July 14 (1 week)**
- **Cooling Rings FNAL Aug 25 (1 week)**
- **Target (+ Exp) BNL Sept 8 (1 week)**
- **FFAG BNL Oct 13 (1 week)**

Target Simulation

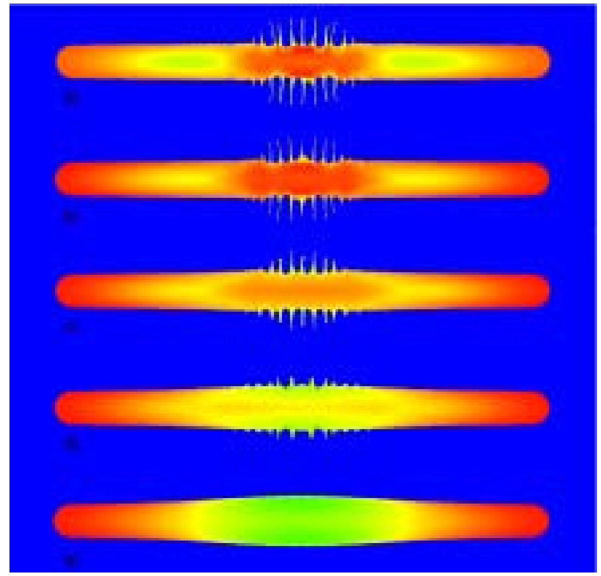
Stabilization From Magnetic Field



Cern Observation

R. Samulyak

Stabilizing of the mercury jet by the longitudinal magnetic field



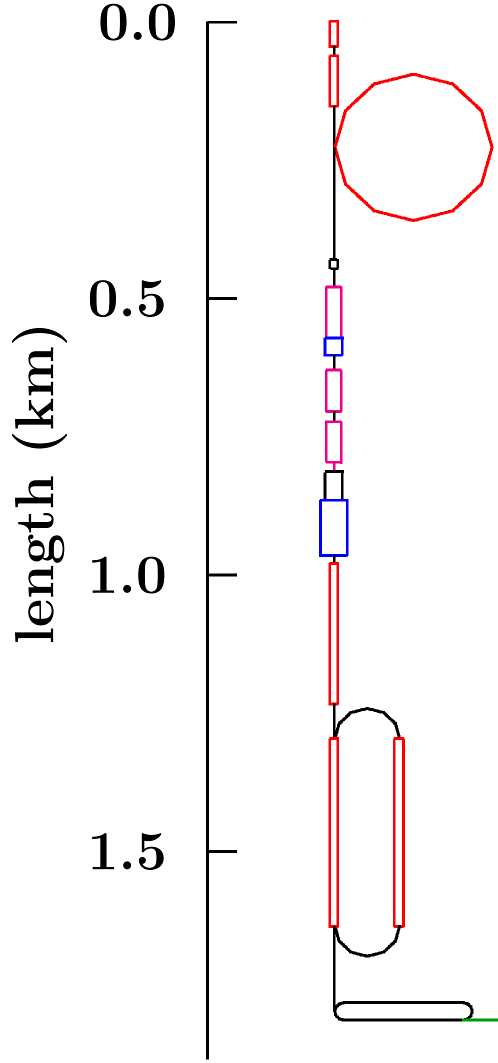
a) B = 0 ; b) B = 2T

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

- **Experiment with Magnet needed to test**

Study 2 Schematic & Cost Fractions

*** Cost Reduction now being Studied



p Driver

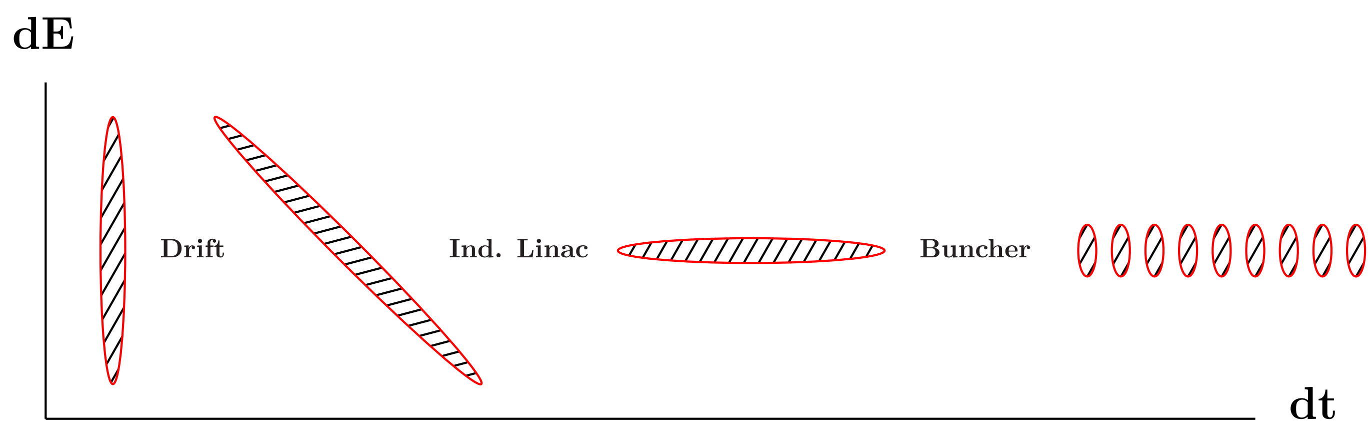
Hg Target

	% of Cost (without driver or target)	
Phase Rotation	(29 %)	***
Cooling	(23 %)	***
Pre-Acceleration	(14 %)	Next
RLA Acceleration	(26 %)	***
Storage Ring	(8 %)	

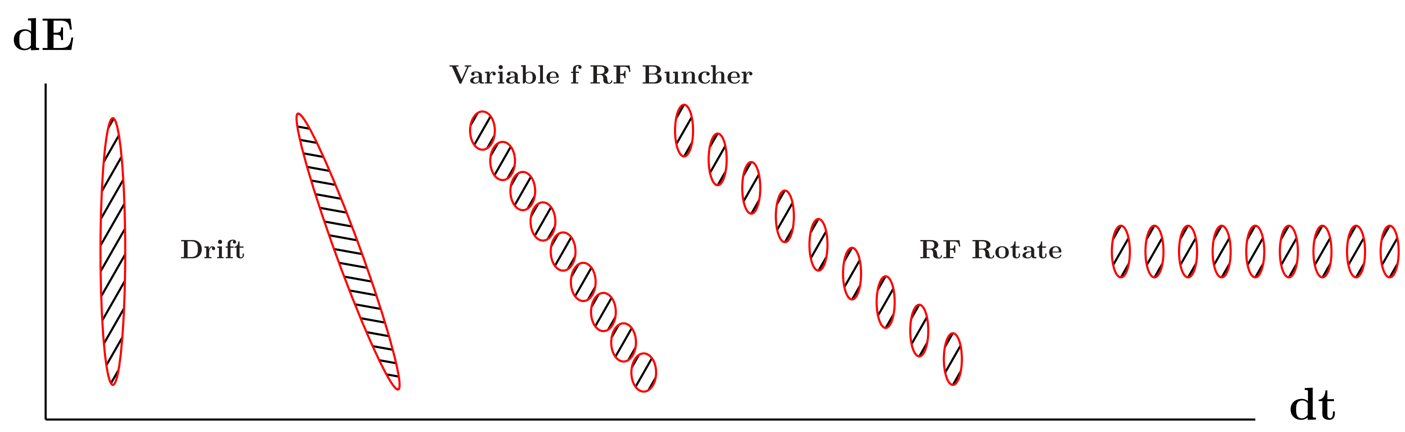
Neutrino Beam

I PHASE ROTATION (Used to reduce dp/p prior to Cooling)

Study 2 with Induction Linacs

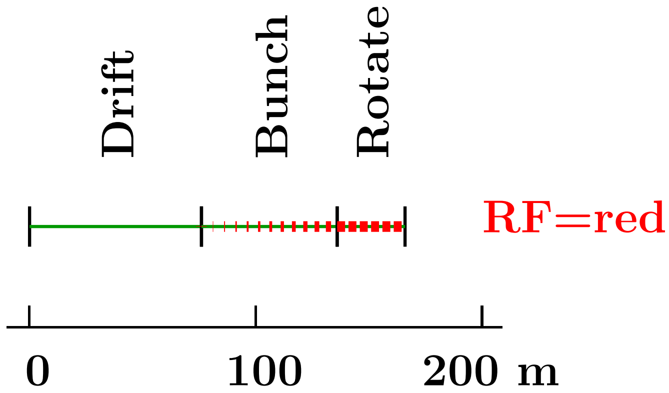


Bunched Beam Rotation with 200 MHz RF (Neuffer)

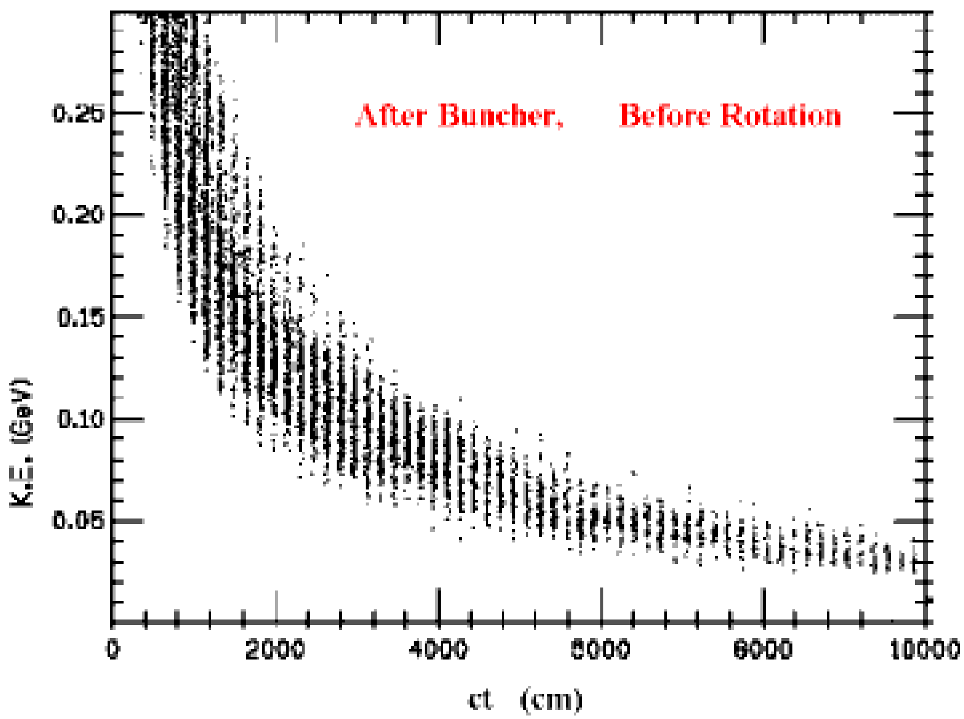


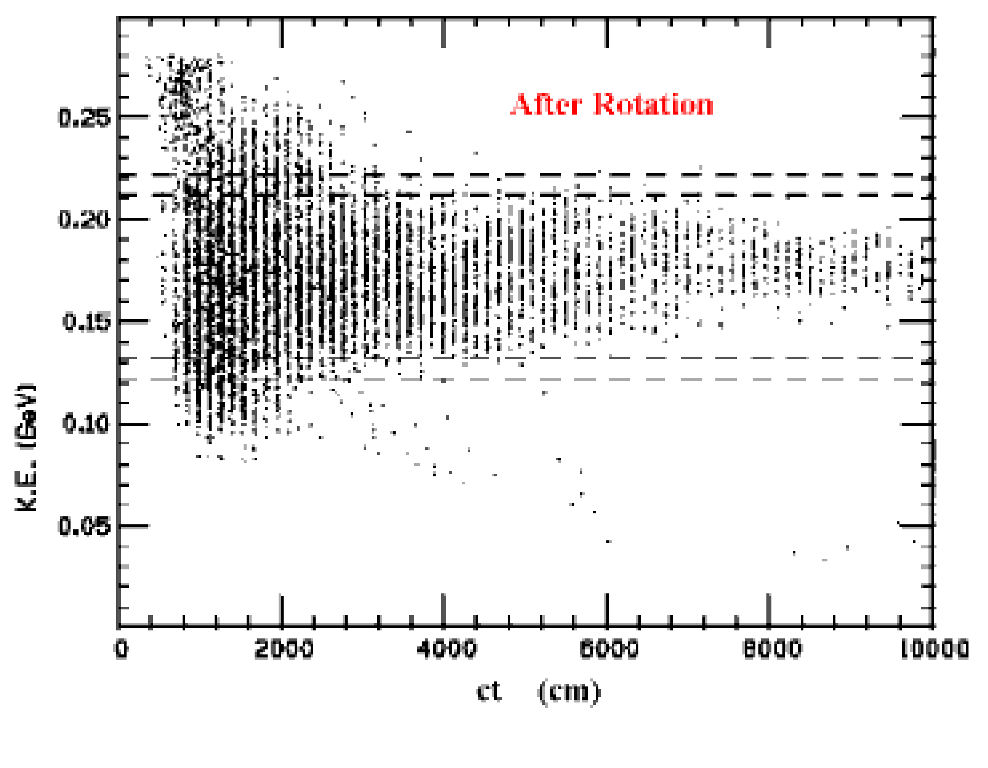
- 200 MHz RF is cheaper than Induction Linacs
- But RF frequency must vary along bunching channel
  (high mom. bunches move faster than low)

Simulation (Several Programs, Inc. ICOOL)



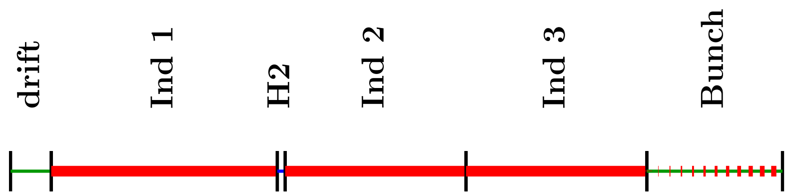
- Similar efficiency to Study 2
- But captures both charges



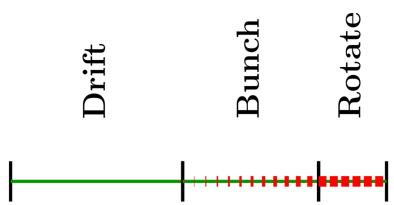


Compare with Study 2

- Study 2



- e.g. Bunch Beam Rotation



	Study 2	Now	Factor
Tot Length (m)	328[1]	166	51 %
Acc Length (m)	269[2]	35	13 %
Acc Type	Induction[3]	Warm RF	

1. 18+100+3.5+80+80+47=328
2. 100+80+80+9=269
3. 260 m induction + 9 m RF

- Expect Substantial Savings

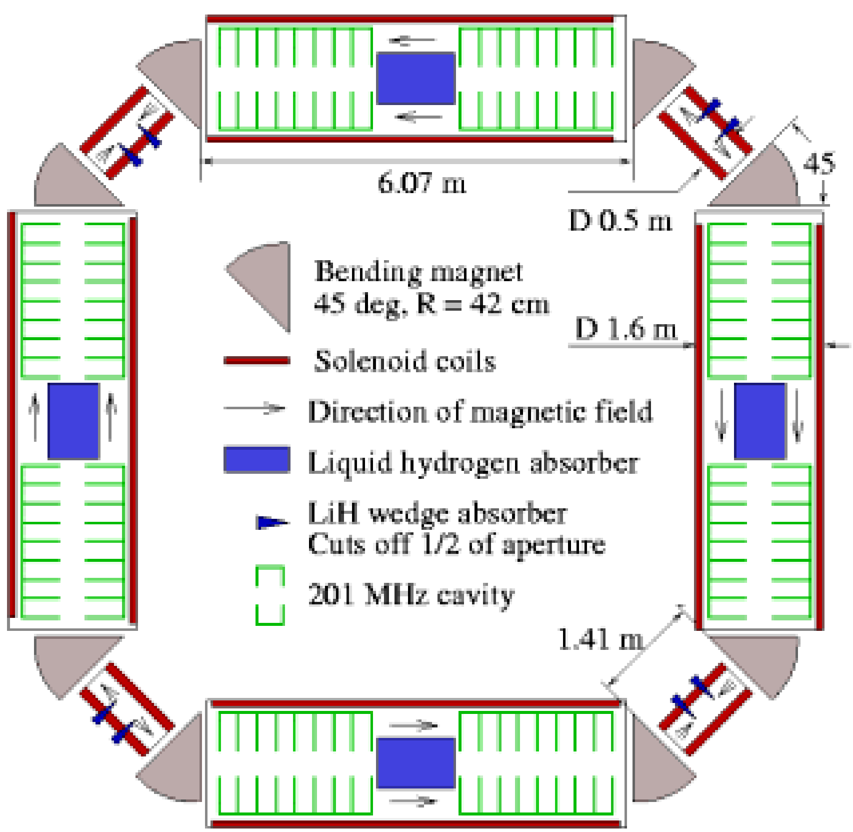
BUT

- Not yet matched into cooling
- Not Engineered

II COOLING RINGS (3 Main Efforts)

1) Balbekov et al

Alternate transverse cooling with H2 with emittance exchange in Li wedge



Circumference	37 m
Energy	250 MeV
Max B_z	5.2 T
Gradient	15 MV/m

- Good cooling in all dimensions
- FIRST
- 6D Density increased by 94
  c.f. Study-2: 15
  Both simulated without windows

BUT

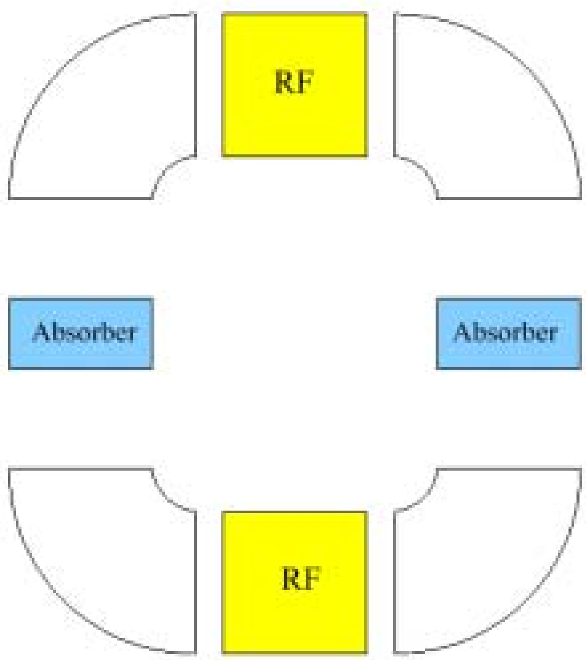
- Calculated without Maxwellian fields
- Design of bends proving hard
- Injection and extraction hard

2) Quadrupole & Bend-only Rings

Garren, Kirk, Fukui et al

- Motivation
  - Easier to design lattice (dispersion suppression, etc.)
  - More experience than with solenoids
- Thick wedge: both cooling and longitudinal/transverse coupling

e.g.



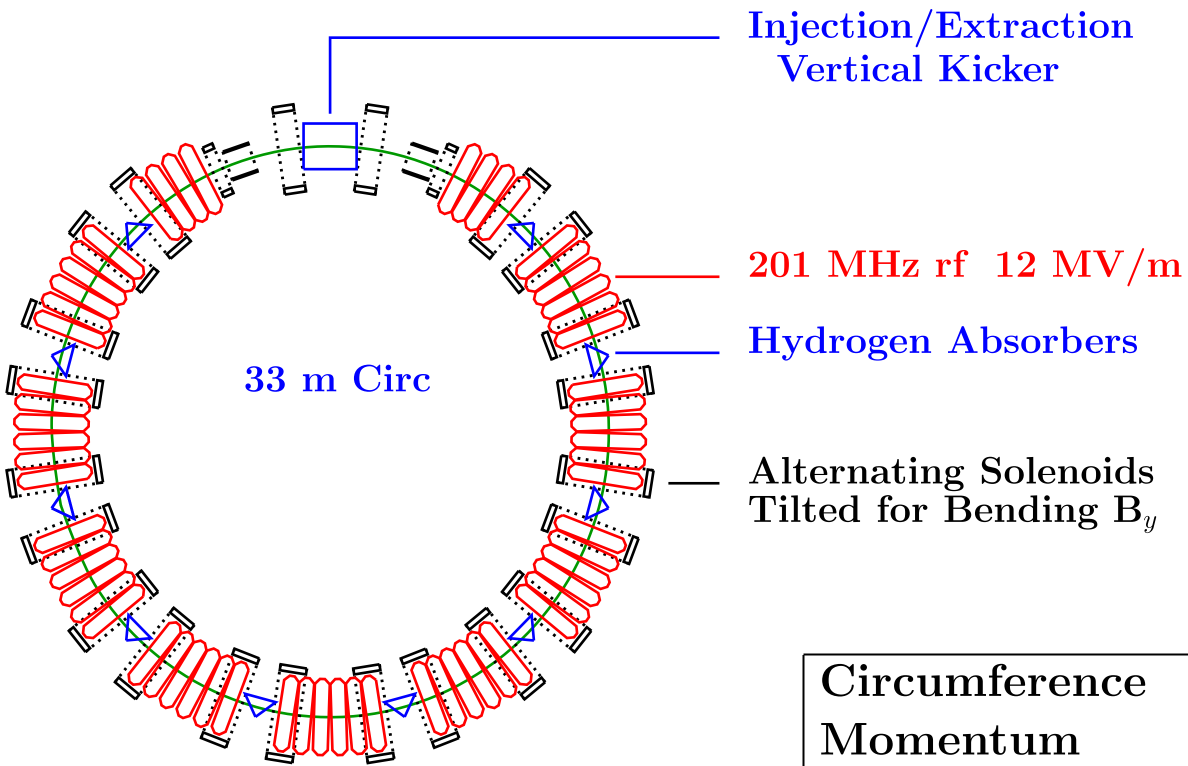
Circumference	m	3.4
Momentum	MeV/c	250
Bend Field	T	3
RF Grad.	MV/m	16

- Good Acceptance with Ideal Fields
- Poor Acceptance with Real Fields
- More Work Needed

3) RFOFO Ring Cooler

V. Balbekov, J.S. Berg, R. Fernow, J. Gallardo, W. Lau, R.B. Palmer, L. Reginato, D. Summers Y. Zhao

Simulated with realistic Maxwellian Fields

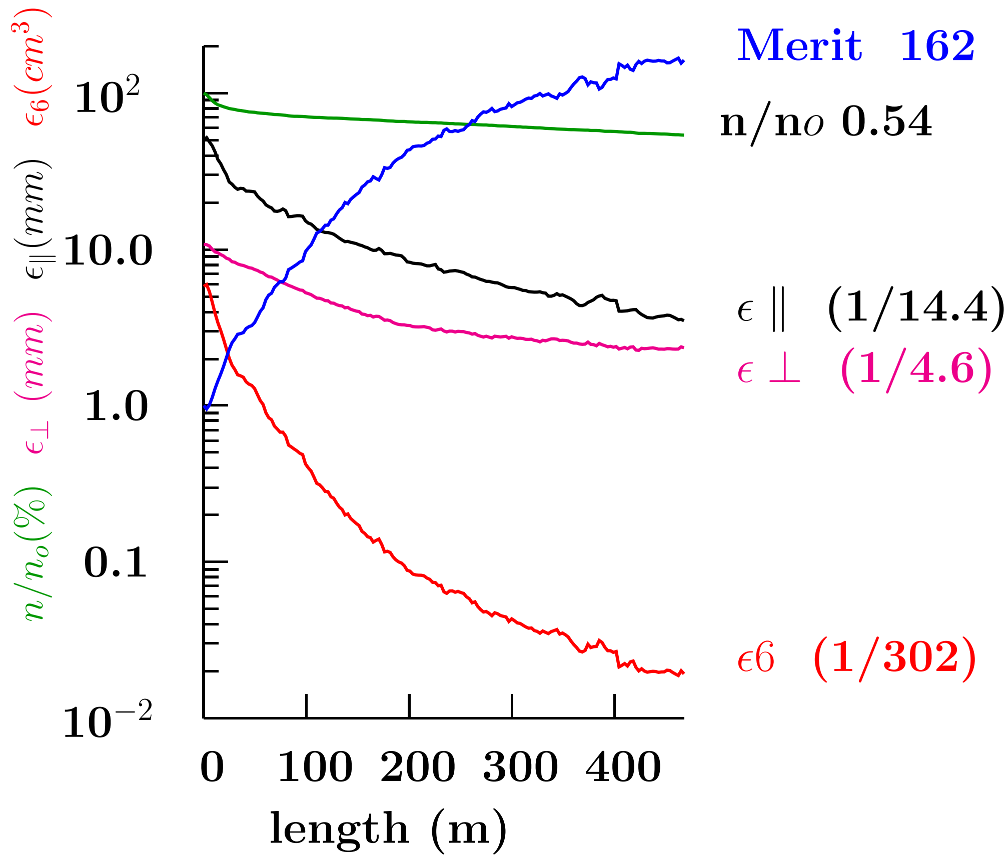


Circumference	m	33
Momentum	MeV/c	200
Maximum axial field	T	3
Ave. bending field	T	0.125
Hydrogen wedge thickness	cm	30
Wedge Angle	deg	100
RF Grad.	MV/m	12

Performance

- ICOOL (& Balbekov) Simulation
- No Windows
- No Injection/Extraction Gap

	initial	final	ratio
Transmission inc.decay	1	.54	54 %
Trans. emittance (π mm)	10.7	2.3	1/4.6
Long. emittance (π mm)	50.1	3.5	1/14.1
6D emittance $(\pi \text{ cm})^3$	5.8	0.019	1/302



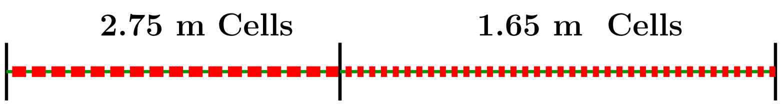
- Good cooling (Density up to 160 $\times$)
  (without windows or injection/extraction)
- Injection/Extraction seems OK

BUT

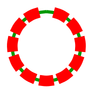
- Injection channel not designed

Compare with Study 2

- Study 2 Cooling



- e.g. RFOFO Cooling Ring



	Study 2	Now	Factor
6D Cooling	15[1]	160[1]	10 ×
Tot Length (m)	108	33	30 %
Acc Length (m)	54	16	30 %
Acc Grad	16 MV/m	12 MV/m	66 %

1. Without windows or injection/extraction

- Expect Substantial Savings

  BUT for any ring cooler

- Absorber heating needs study
- Very thin windows required
- Induction kicker needs development
- Shorter train from Phase Rotation
  will reduce performance

III ACCELERATION (4 main Efforts)

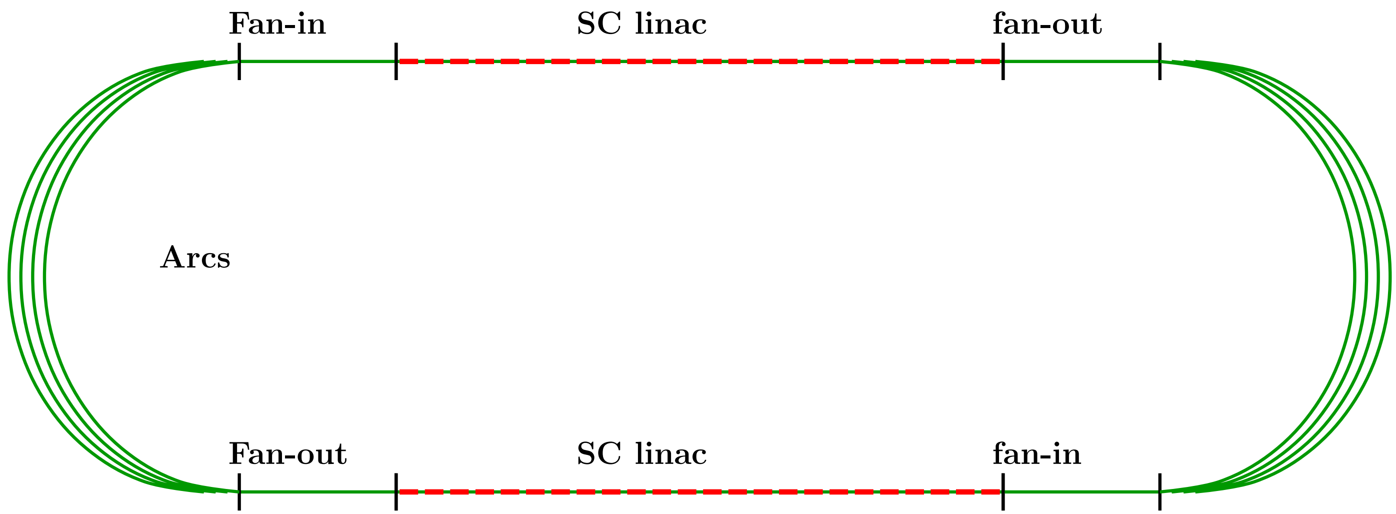
1. **Recirculating Linear Accelerator** (as in Study 2)
   As in Study-2, only 4 turns: high RF cost
2. **Pulsed Synchrotron** (Summers et al)
   Lower Fields: large ring, Smaller acceptance
3. **Scaling FFAG** (Japanese Effort)
   Non-Isochronous: Requires Frequency Modulation or Very Low Frequency
4. **Non-Scaling Linear FFAG** (Johnstone, Trbojevic)
   Isochronous and More compact than Scaling***

GLOSSARY

- Pulsed Synchrotron: Conventional synchrotron but driven from capacitor storage with circa. 50 μs cycle
- FFAG: Fixed Field Alternating Gradient accelerator. Magnets are not ramped. Momentum acceptance over factor of 2 or more. A spiral focused cyclotron is an FFAG.
- Scaling: As in the cyclotron, different momentum orbits have same shape but different scales: higher momenta usually with larger radii. Solutions usually have reverse bends.
- Non-scaling: Really just a very strongly focused conventional lattice with large momentum aperture. Different momenta have quite different shapes.

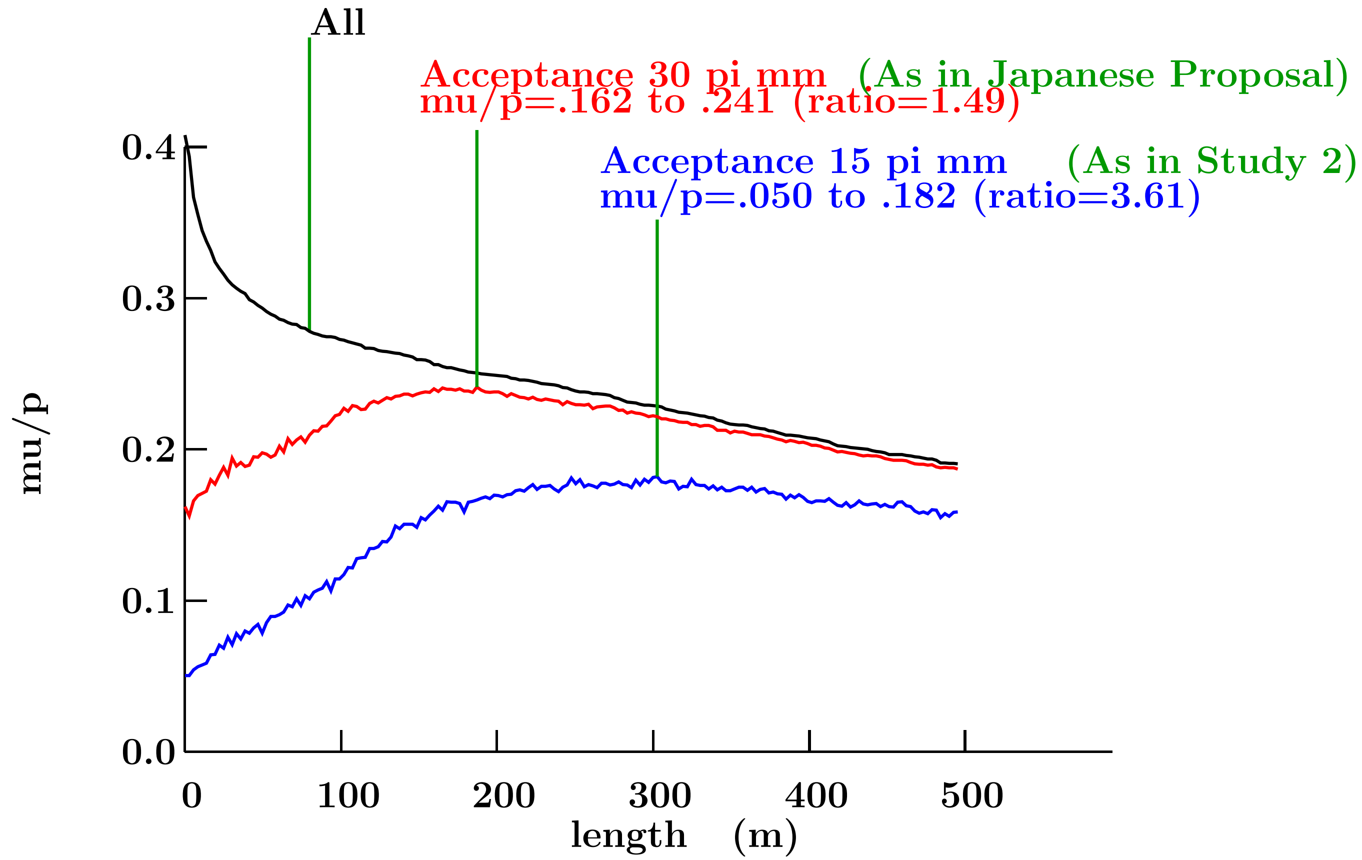
Recirculating Linear Accelerator

as in Study 2



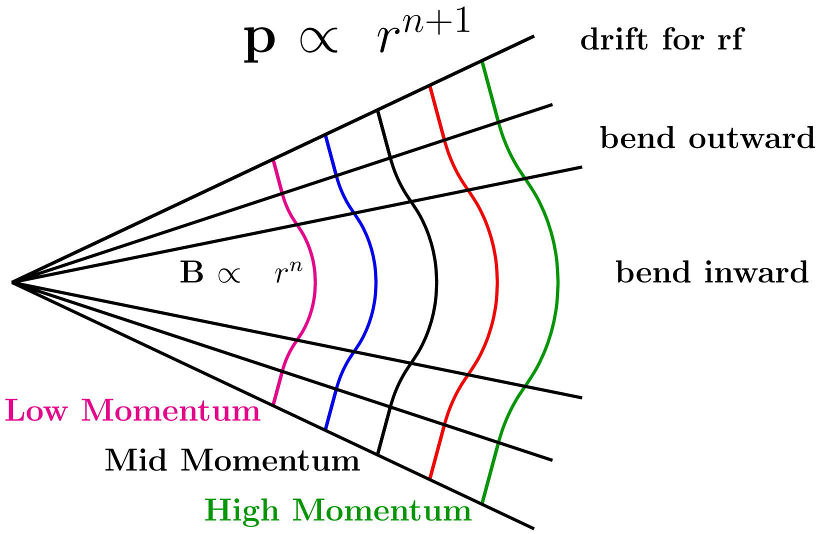
- only 4 turns: much SC Acceleration needed
- Many arcs: 4 km of beam-line
- Recent Work (Bogacz) has raised acceptance from 15 to 30 pi mm

Performance vs Accelerator Acceptance



- 30 pi mm & no cooling $\approx$ 15 pi mm & study-2 (or RFOFO Ring) cooling
- Japanese (Mori) have long claimed large aperture does not require cooling
- Question: Which is cheaper ?
- Performance with 30 pi mm & pre-cooling → even better performance, but needs a system with greater acceptance than Study-2 or RFOFO Ring

Scaling FFAG (proposed by Mori, Japan, for muons)



POP FFAG at KEK

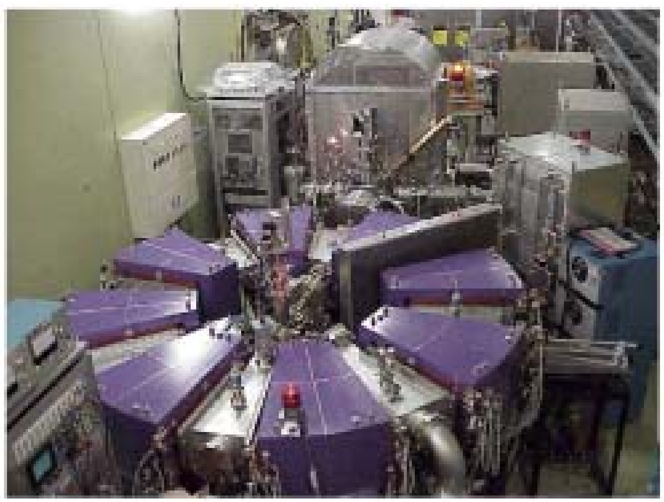


Figure C.2: Top-view of the POP FFAG

- Δp limited only by aperture
- eg 10 to 20 GeV (Japan)

Energy	GeV	10-20
Circumference	m	1257
Max aperture	cm	40
Max Field	T	6.4
Max[1] RF freq.	MHz	25

1. From non-isochronicity unless freq. is modulated

BUT

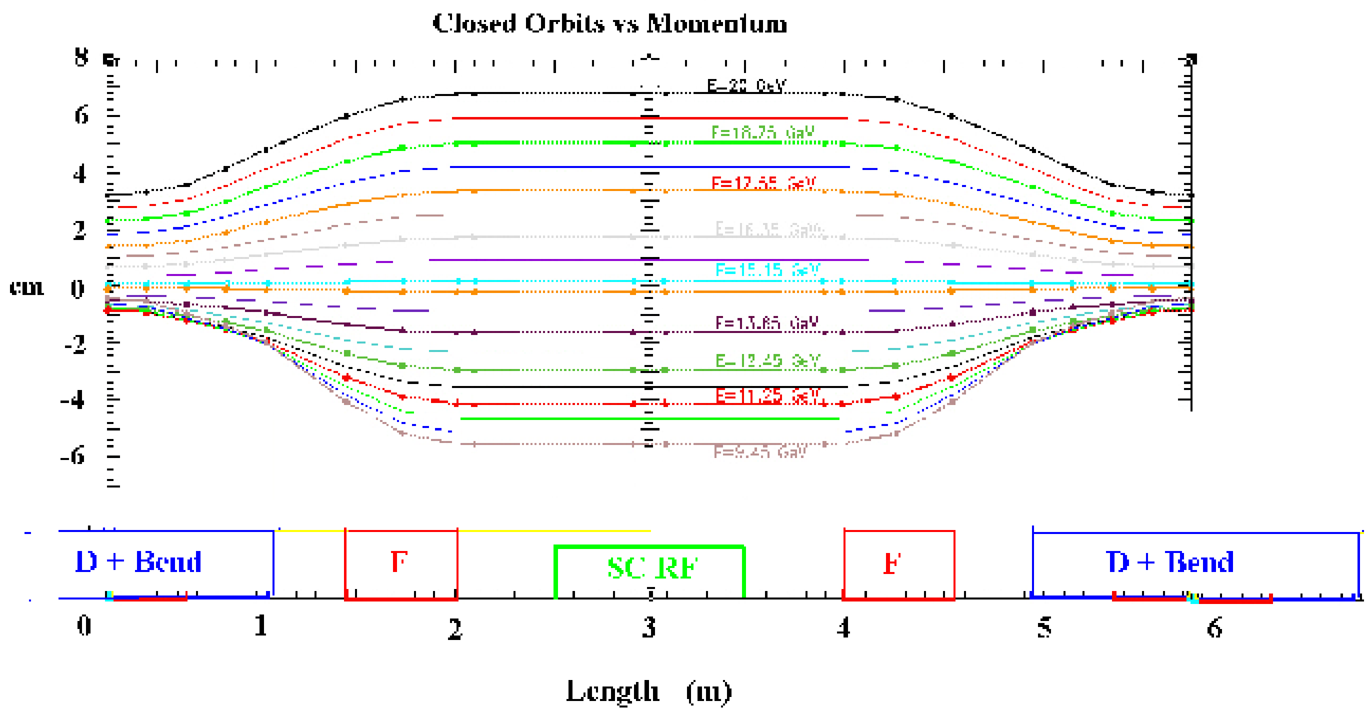
- Non-isochronous
- Low Frequency RF
- Large magnet apertures
- Large circumference
- Non-superconducting RF

Non-Scaling FFAG's (Carol Johnstone)

- Smaller circumference than scaling
- Smaller apertures than scaling
- Semi-isochronous: allows superconducting 200 MHz
- US-Japan Collaboration for protons to be proposed

e.g. Triplet (Dejan Trbojevic)

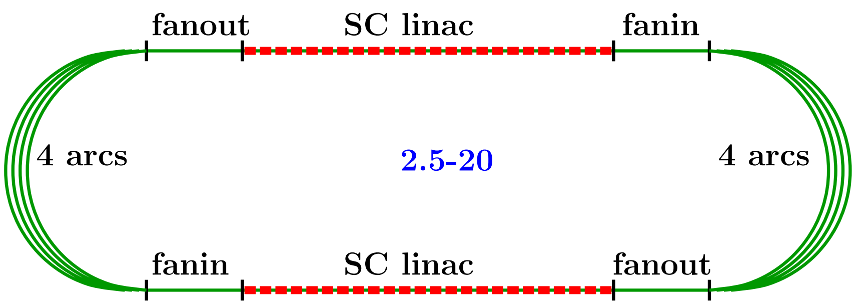
Energy	GeV	10 to 20
Circ	m	320
Max ap	cm	18



- Transverse motion tracked including end fields
- Longitudinal motion tracked, but without trans. motion

Compare with Study 2

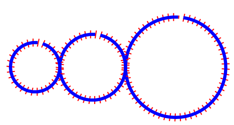
Study 2 RLA



Triplet FFAG Candidates

(Preliminary)

2.5-5 + 5-10 + 10-20



	Study 2	Now	Factor
Vac Length[1]	3261	730	22 %
Tun Length[2]	1494	730	49 %
Acc Length[3]	288	102	35 %
Acc Grad.	16	12	75 %

1. 2 linacs + 4 switch-yards + 7 arcs
2. 2 linacs + 4 switch-yards + 2 arcs
3. $2 \times 24 \times 4 \times 1.5$ m

- Expect Substantial Savings

  BUT

- Only 10-20 GeV tracked
- 30 pi mm pre-acc. not designed
- Inject/extract not designed
- Other Options under study

Conclusions

- **Much Progress**
- **Working towards Study 3**
- **Hope for Lower Cost**
- **Maintaining, or improving, performance**

  BUT

- **Still Much Work to be Done on ν Factory**
  - **Phase Rotation match to Cooling Rings**
  - **Use of both signs**
  - **Kicker for Cooling Ring**
  - **Injection/Extraction lattices for cooling**
  - **Pre-cooling, to match 30 pi mm**
  - **Linac Pre-Acceleration with 30 pi mm**
  - **Lower energy FFAG lattice designs**
  - **Storage ring with 30 pi mm acceptance**
- **Work on Collider** **(Still a possible root to Multi TeV)**