Outstanding Issues in Cost Reduction

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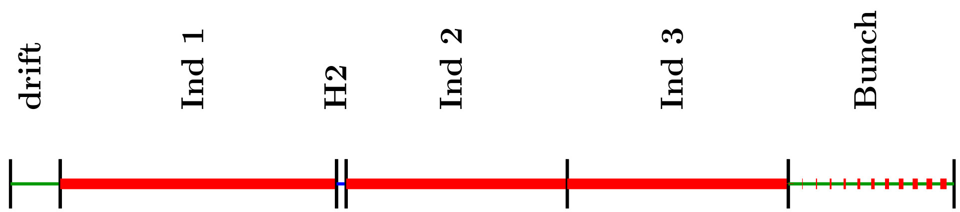
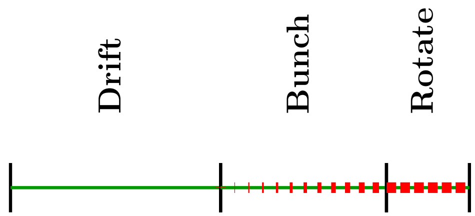
1. **Phase Rotation**
2. **Cooling**
3. **Acceleration**
   a) **Costing Assumptions for Optimization**
   b) **FFAG Injection/Extraction**
   c) **Mention of FFAG Electron Model**
4. **Conclusion**

1) Compare IIa Phase Rotation with Study 2

- Study 2



- e.g. Bunch Beam Rotation

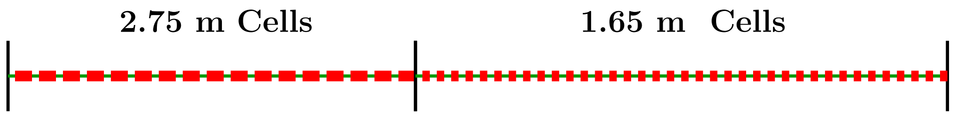


	Study 2	Now	Factor
Beam Line (m)	328	166	51 %
Acceleration (m)	269	35	13 %
Acc Type	Induction	Warm RF	

- SUBSTANTIAL SAVINGS
- Similar performance to Study 2
- But Captures Both Signs

2) Compare IIa Cooling with Study 2

- 108 m Study 2 Cooling



- 50 m New Cooling Lattice

- **42 % of Length**
- **No Liquid Hydrogen**
- **Smaller coils**
- **SUBSTANTIAL SAVINGS**
- **Similar Performance to Study 2 for each of 2 signs**

  BUT
- **Depends on Larger Acceleration Acceptance**

Homework: Relative Cooling Material Merits

From Minimum of beta to maximum of beta e.g center of absorber to center of RF

Study II

	mat	L mm	β/β_o	dE/dx MeV/m	Xo m
absorber	H2	175	1.03	28.7	8.65
absorber window	Al	0.36.132	1.08	436	.089
rf window 1	Be	.20	1.7	295	.353
rf window 2	Be	.70	2	295	.353
1/2 window 3	Be	.350	2	295	.353

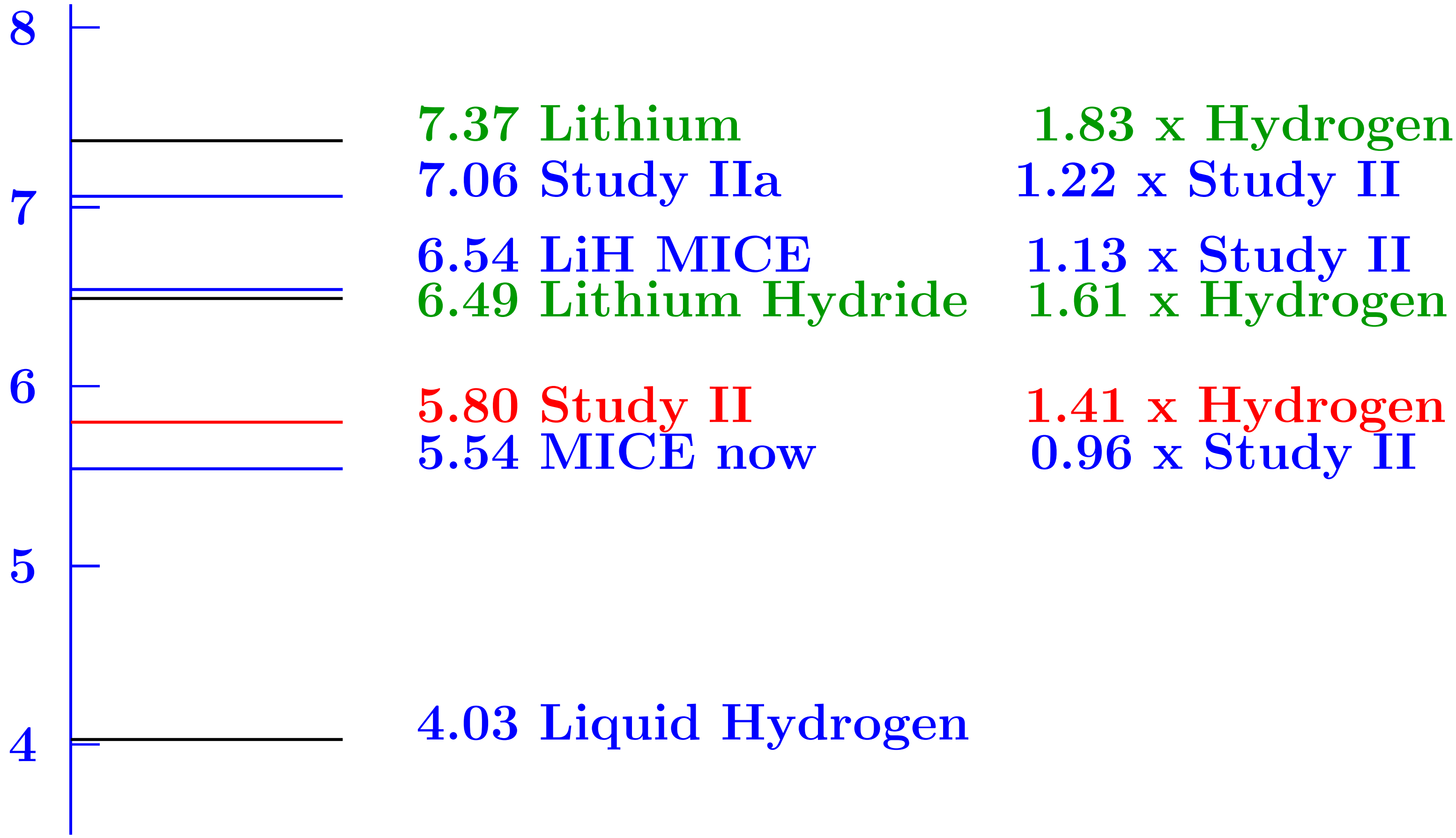
MICE

	mat	L mm	β/β_o	dE/dx MeV/m	Xo m
absorber	H2	175	1.03	28.7	8.65
absorber window 1	Al	.132	1.08	436	.089
absorber window 2	Al	.132	1.4	436	.089
cavity 1 window 1	Be	.250	1.7	295	.353
cavity 1 window 2	Be	.250	2	295	.353
cavity 2 window 1	Be	.250	2	295	.353
cavity 2 window 2	Be	.250	2	295	.353

Study IIa

	mat	L mm	β/β_o	dE/dx MeV/m	Xo m
window 1	Al	.025	1.05	436	.089
absorber	LiH	10	1.05	159	0.971
window 1	Al	.025	1.05	436	.089

$$\text{Merit} = \frac{\int \frac{1}{X_o} \frac{\beta_\perp}{\beta_o}\, ds}{\int \frac{dE}{dx}\, ds} \propto \text{Equilibium Emittance}$$



3) Acceleration

3a) Costing for Acceleration Optimization

Not a substitute for a Feasibility Study
Needed for optimization

Linear Costs

	source	Cost/length K$/m
Vacuum$\propto$ beam pipe	Use	4.6
Diagnostics$\propto$ beam pipe	”	1.2
Other $\propto$ beam pipe	”	4.2
Civil$\propto$ tunnel	”	15
Total		25

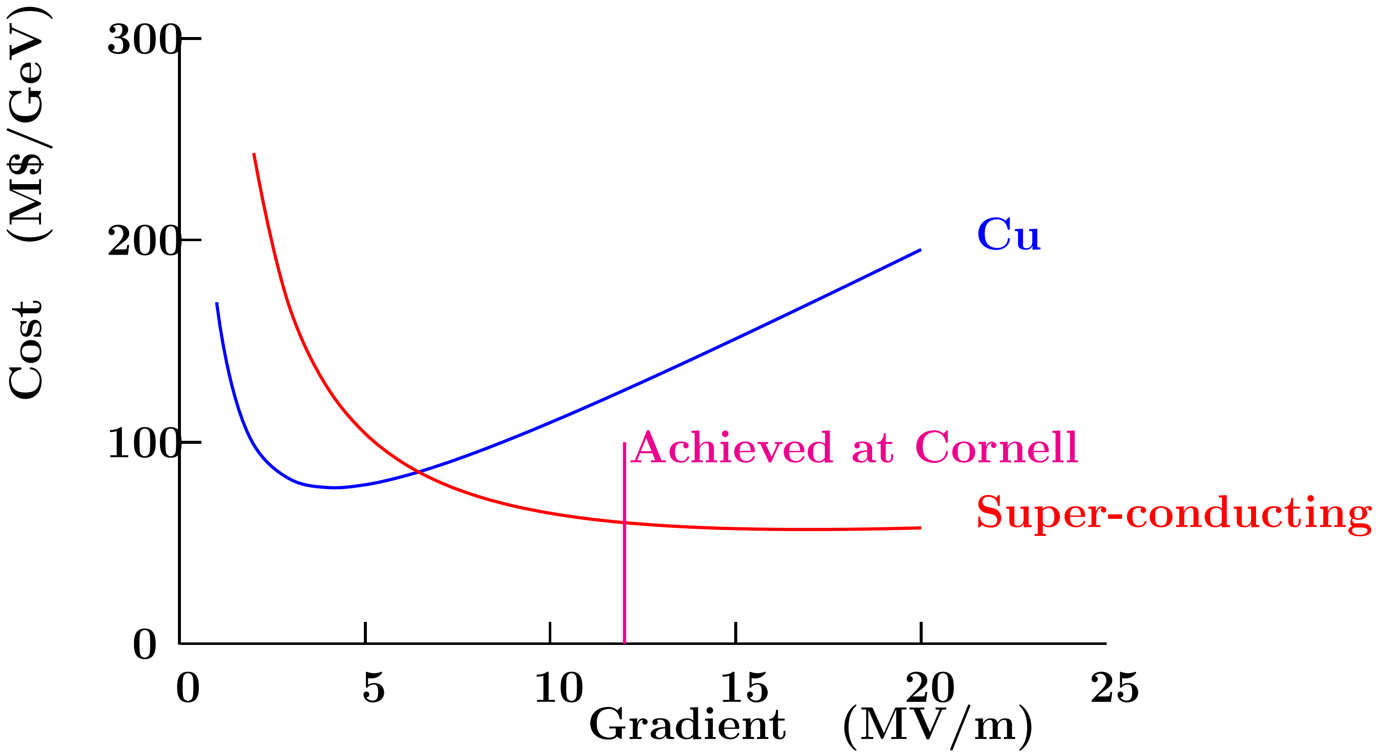
- Vacuum and diagnostics taken from Study-2
- ”Other” taken from Loew's study of SLAC (agreed with SSC) includes survey stands cable trays moving equipment etc
- ”Civil” taken from Loew's study (= 20% above Study-2)

Superconducting 200 MHz Acceleration

	unit cost k$	cost/GeV M$/GeV
Cavities	360	$30\times16/G$
Power	245 (at 16 MV/m)	$20.4\times g/16$
Cryo	77	$6.4\times g/16$
Total at 16 GV/m	682 (at 16 MV/m)	56.8

- RF power and cryogenics same as Study-2
- SC cavities 2 $\times$ Study-2 after discussion with Padamsee

RF cost vs Gradient



- **SC cost min at 17 MV/m $\approx$ 55 M$/GeV**
- **Cu Cost min at 4 MV/m $\approx$ 75 M$/GeV (1.4 $\times$ SC)**

But Loading will require gradients $\geq$ 11 MV/m, when

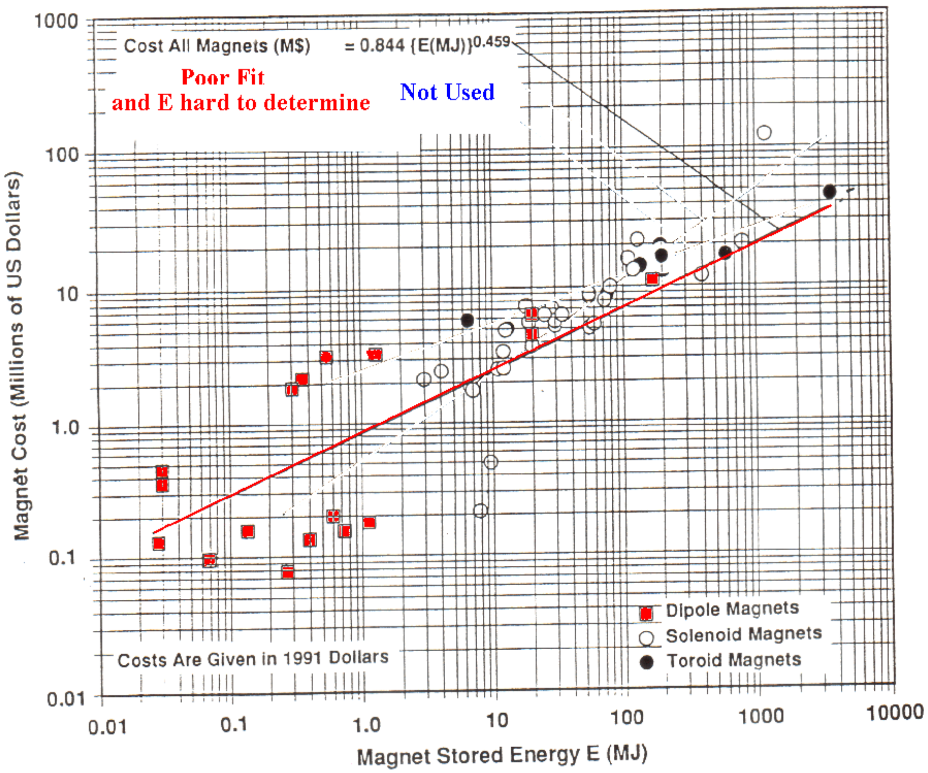
- **Cu is 130 M$/m (2.4 $\times$ SC)**

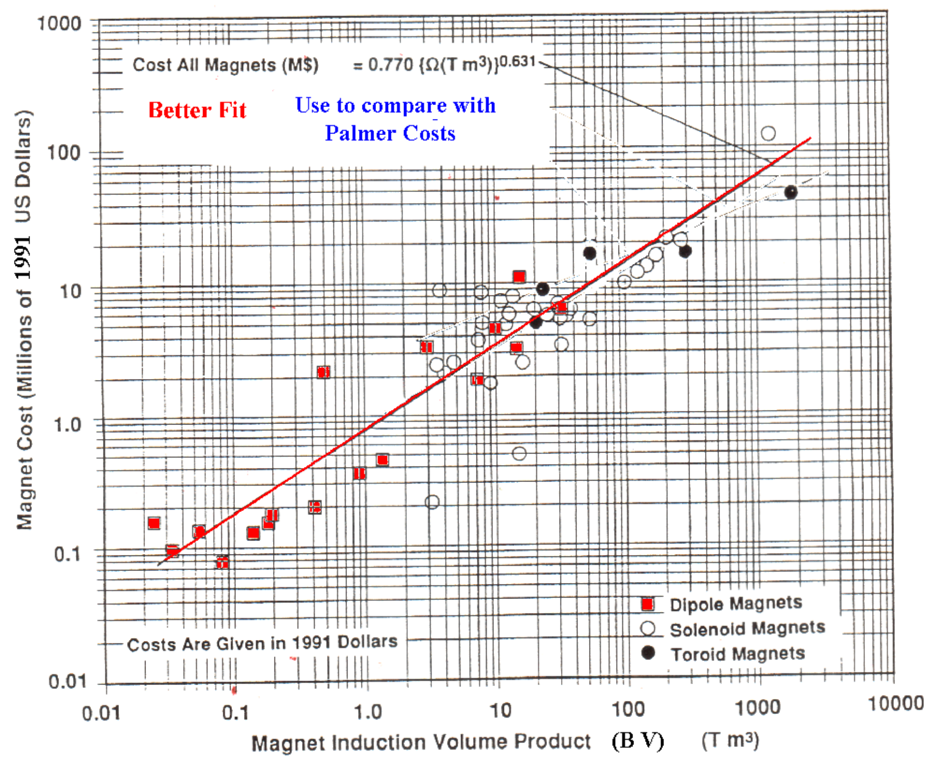
Mike Green[1]Estimates of SC Magnet Costs

$$\text{Green(1) (M\$)} = 1.34^{\times}0.55\ (B^2\ \pi R^2\ L\ )^{.459}$$

$$\text{Green (2) (M\$)} = 1.34^{\times}0.77\ (B\ \pi R^2\ L)^{.631}$$

Both mostly of single magnets **#2 has better fit**





[1] Avd. in Cryo Eng. 37, Feb 1992, including factor of 1.34 for 12 years inflation at 2.5%

Palmer Formula

But cost $\propto B^{.63}$ not true for long accelerator dipoles.
Generate new formula Normalize on LHC and RHIC Magnets

$$\text{Palmer Est (M\$)} = 22.5\ \text{B}^{1.5}\ \text{R}'\ (\text{L} + 20\ \text{R}')$$

2nd term is for unit, or "end" costs

$$\times 1.5\ \text{(if quad)}, \qquad \times \left(\frac{\text{n}}{300}\right)^{-1/3}\ \text{(quantity)},$$

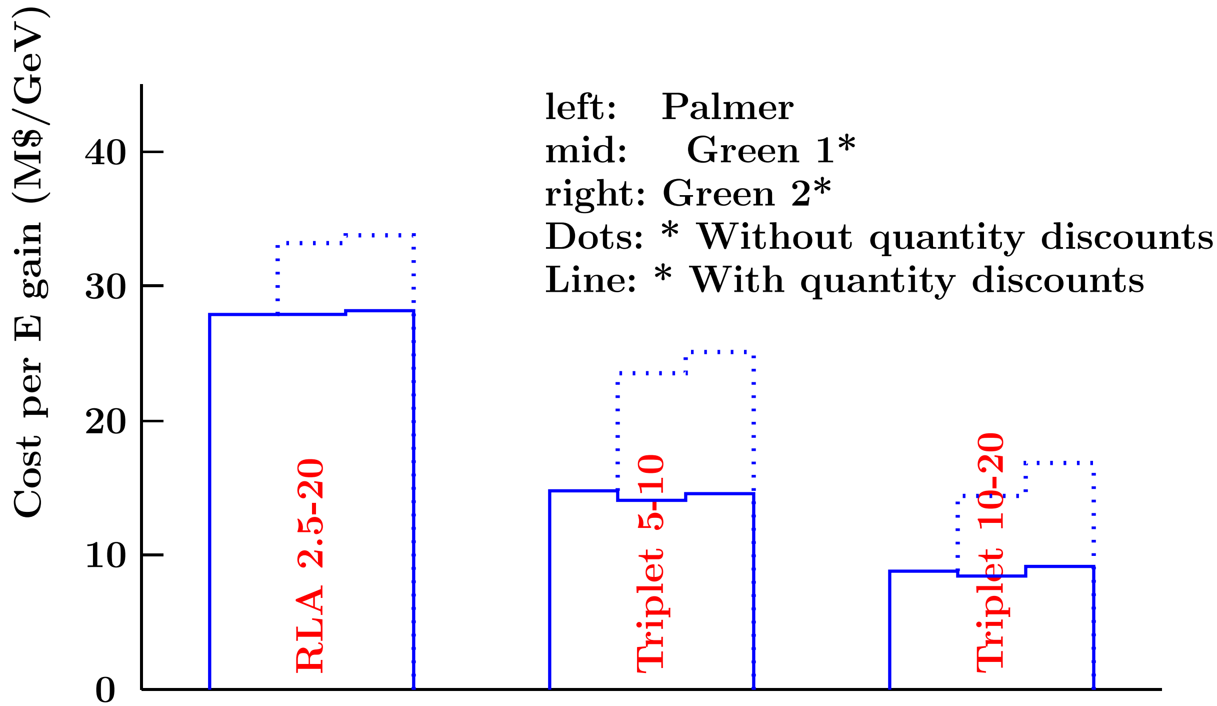
$$R' = R + 0.003\,B,\quad \text{B} = <|\text{B}|>\ \text{at coil IR (T)},\quad \text{R} = \text{IR (m)},\quad \text{L} = \text{len (m)}$$

	n	L m	R m	B T	cost* k$	Green 2 k$	/cost	Palmer k$	/cost
RHIC Q	300	1.10	0.040	4.30	29.0	98.8	3.41	27.8	0.96
LHC	300	30.00	0.028	8.30	708.0	765.2	1.08	733.3	1.04
RHIC	300	10.00	0.040	5.30	149.0	452.5	3.04	150.0	1.01

* Costs corrected for inflation of 2.5% for 11 years = 1.31

Compare RLA & Non-Scaling FFAG Costs

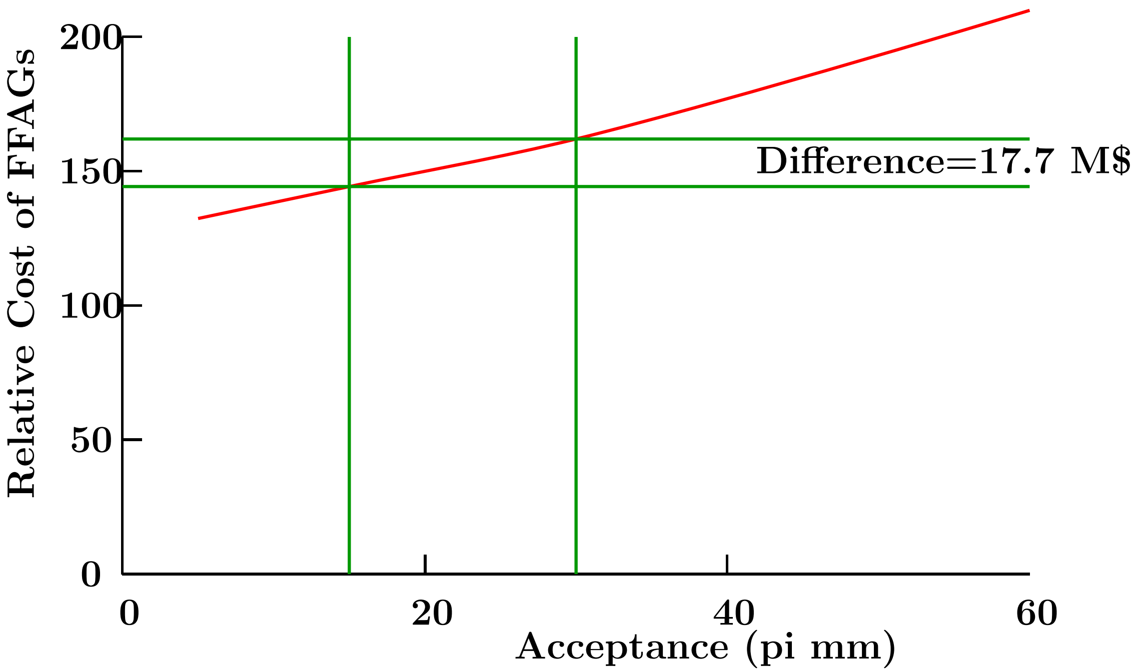
Using 10 MV/m (as achieved) (17 MV/m in Study 2)
Injection/Extraction and Transfer Lines Not Included



- Conclusions ≈ independent of Magnet Cost Model
- **10-20 GeV FFAG cost/GeV is 31% of RLA**
- **5-10 GeV FFAG cost/GeV is 53% of RLA**

FFAG Cost vs Acceptance

The use of the cost model will allow study of relative cost of cooling vs. larger accelerator acceptance

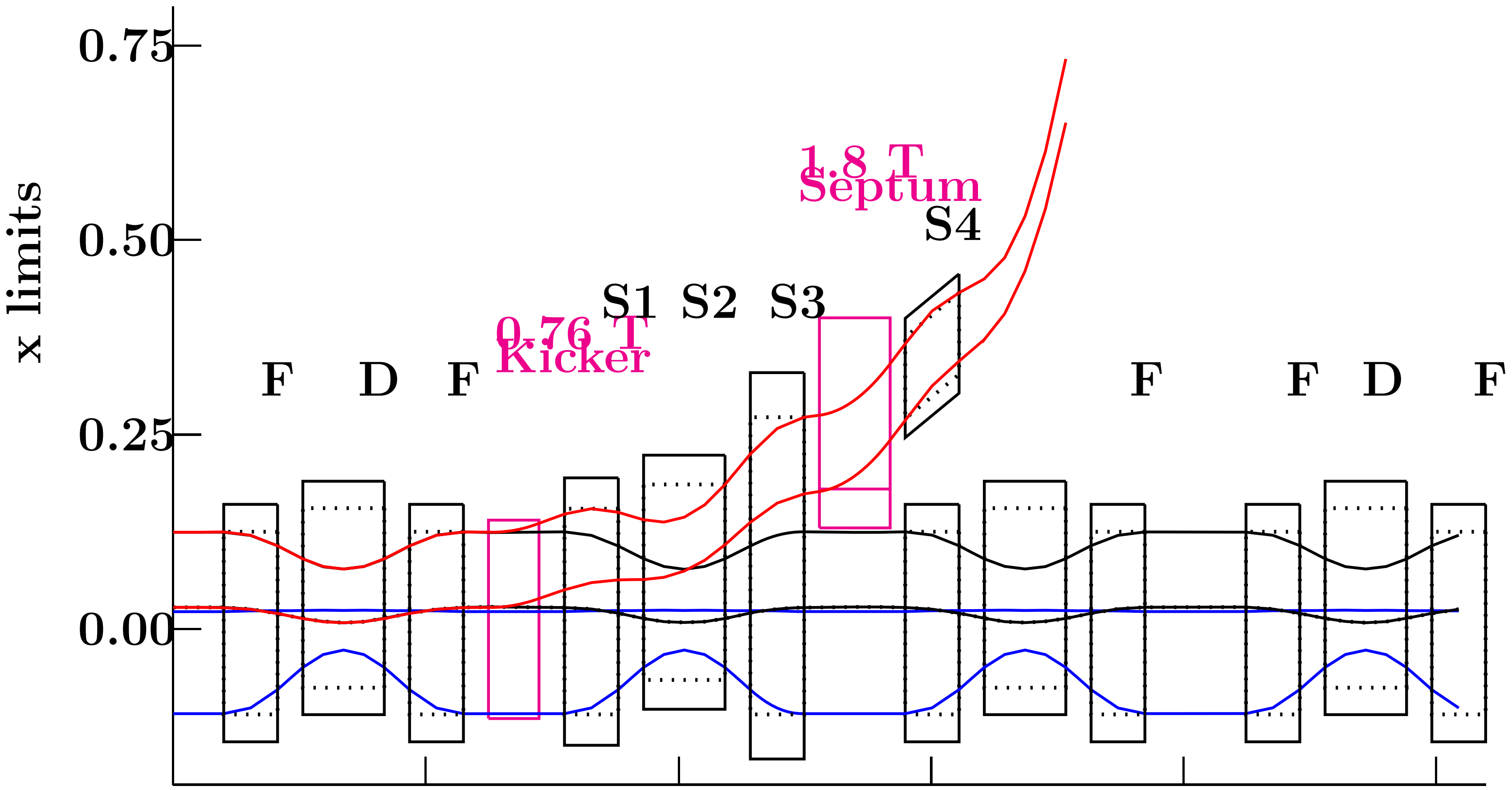


To this must be added an increase for the Pre-Acceleration

But it seems likely that, even wiht thise included, the increase in acceleration cost is small compared with savings in cooling that must be $\geq$ half the Study 2 Cooling of $\approx$ 400 M$ = 200 M$

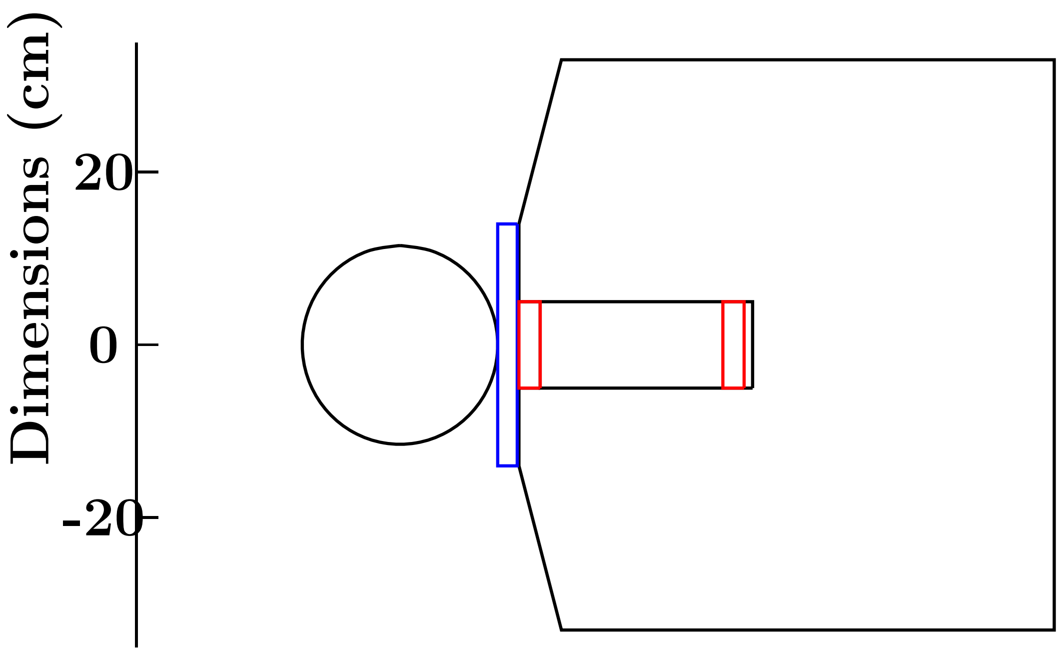
3b) FFAG Injection/Extraction

e.g. Scott Triplet Lattice, Extraction from 5-10 GeV:
Using kicker in one straight and septum in the next:

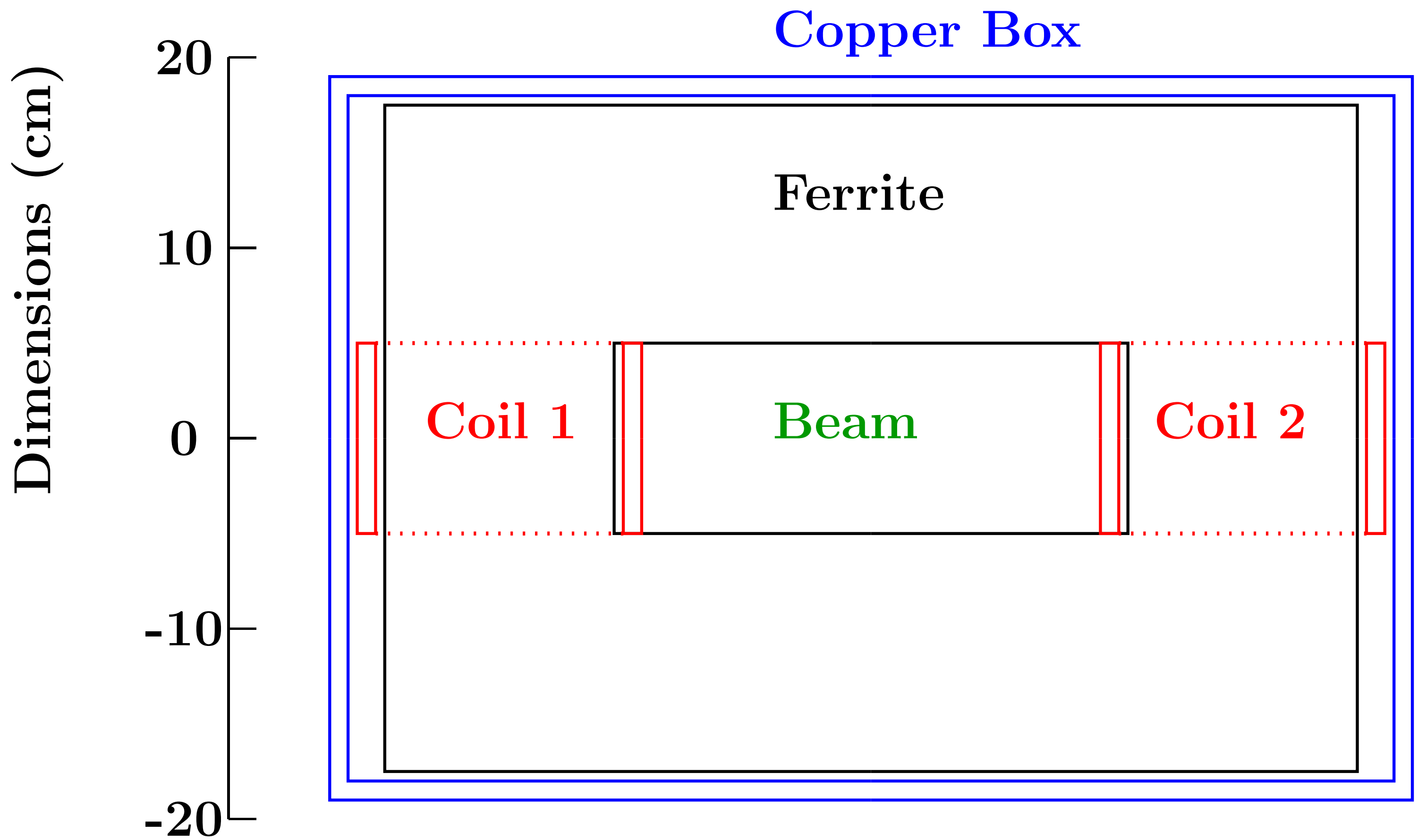


Septa

length	m	1.4
Field	T	1.8
Height	cm	10
Width	cm	23
septum	cm	5



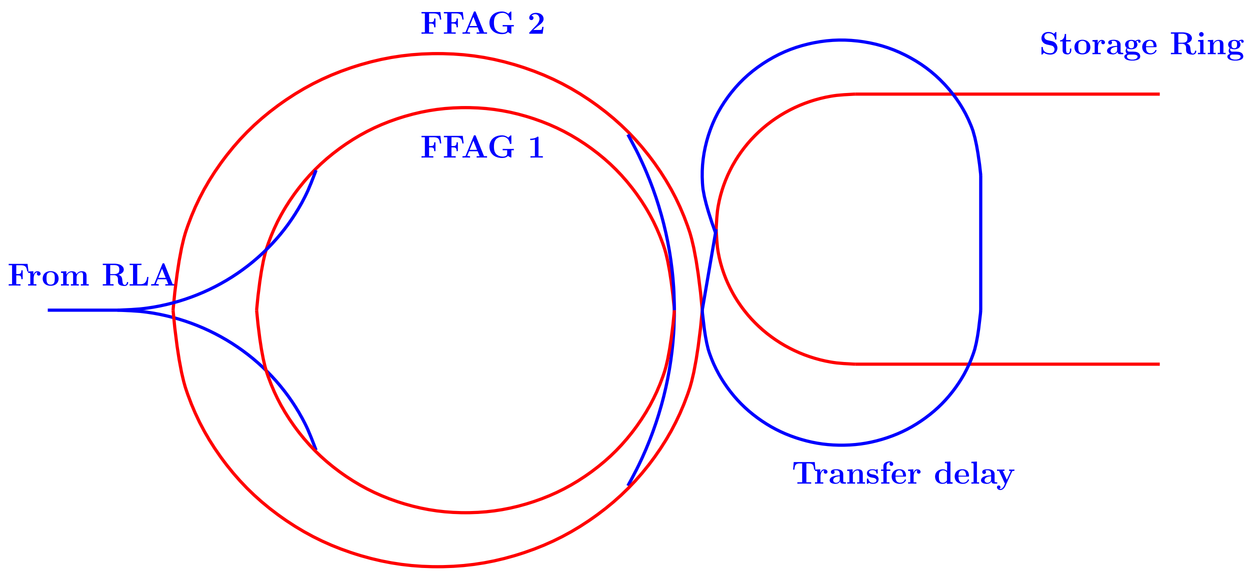
Kickers


Copper Box
Dimensions (cm)
20
10
0
-10
-20
Ferrite
Coil 1
Beam
Coil 2

Layout

- Inject from insides because easier kicker
- Share ejection of two signs (ejection kicker is more difficult)
- But use separate injectors to reduce transfer line lengths

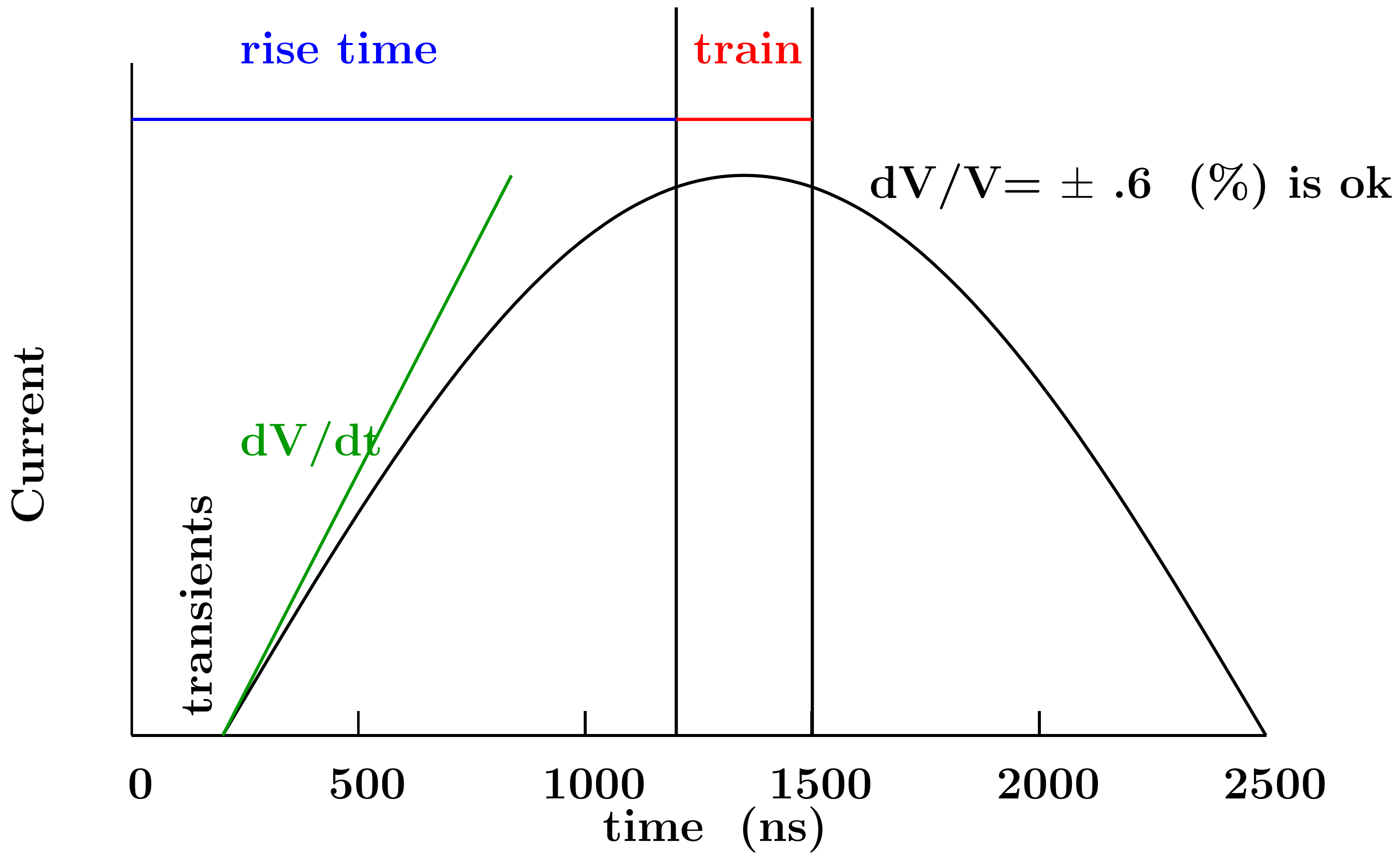
Schematic Layout



Required Rise time

Assume: Injection at +/- 45 degrees, Extraction at 0 degrees

e.g. for injection into 5-10 GeV ring



Kicker Parameters

		Inj 5-10	Ext 5-10	Inj 10-20	Ext 10-20	RFOFO	$\bar{p}$	Ind
Length [2]	m	1.5	1.5	1.5	1.5	1.0	≈5	1.0
Y	m	.1	.1	.076	.076	.42	.08	
X	m	.25	.25	.195	.195	.63	.25	
B $[2]_o$	T	.37	0.51	.58	.78	.42	≈0.018	0.6
I	kA	29	40	35	47	105	3.6	
U [2]	J	850	1620	1260	2280	8200	≈13	1600
t_{fall}	ns	640	950	875	1270	50	90	40
$t_{pulse\ length}$	ns	300	300	300	300	100	500	100
$V_{1\ turn}$	kV	230	240	208	193	5,700	800	1000
V_{supply}	kV	±58	± 60	± 52	± 48	190	80	190

- Simple circuit
- Stored Energy similar to Induction Linac
- Rise time Much slower
- Voltage moderate
- Should not be very difficult or expensive - but needs study

3c) Possible Non scaling FFAG Model

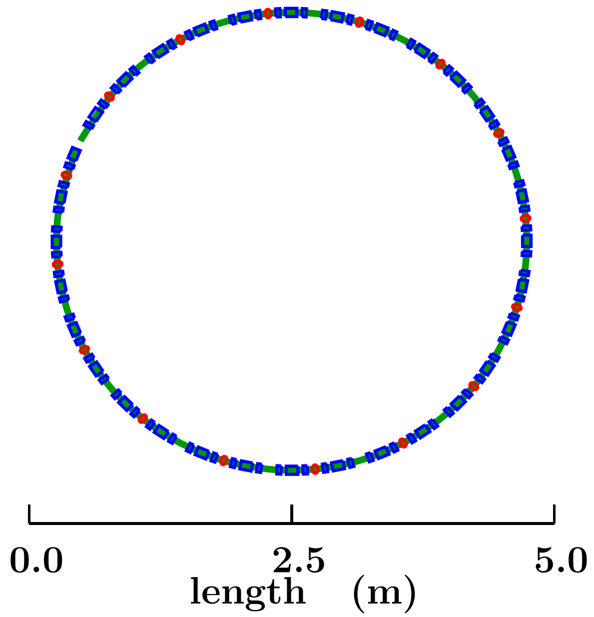
Remember

- **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 on Cost Models

- **Cost Models are not comparable with Engineering Studies (such as Feasibility Studies 1 and 2)**
- **But Models needed:**
  - **for optimization**
  - **to give estimate of savings prior to an Engineering Study**

- **Cost Model developed for RLA and FFAG acceleration**
- **It can be extended to**
  - **Transfer lines**
  - **Pre-acceleration**
  - **Cooling channel**
  - **Phase Rotation**
- **But an Engineering Study 3 will be essential to establish believable numbers**
- **We will try to do such a study within the "World Study" organization**

Conclusion on Non-Scaling FFAG Studies

- **Without Injection/Extraction or transfer lines:**
  - **10-20 GeV FFAG about 1/3 cost per GeV of RLA**
  - **5-10 GeV FFAG about 1/2 cost per GeV of RLA**
  - **2.5-5 GeV FFAG probably not worth it**

- **Injection/Extraction looks ok,**
  Probably not expensive compared with above savings,
  But needs more Study

- **An electon model may be desirable and not too expensive**