Study 2a Costing

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Subjects I will discuss

1. Methods used for scaling from FS2 to S2b
2. Green Magnet cost formulae
3. Palmer/Berg magnet cost algorithm
4. Other costing used for FFAG costs
5. Table of S2b costs
6. Conclusion

A magnet cost formula is no substitute to designing and costing a needed magnet, but there is still use for a formula for optimizing machine designs prior to this stage. For this purpose, it is important that the dependences on field, length and aperture be as reasonable as possible.

Method

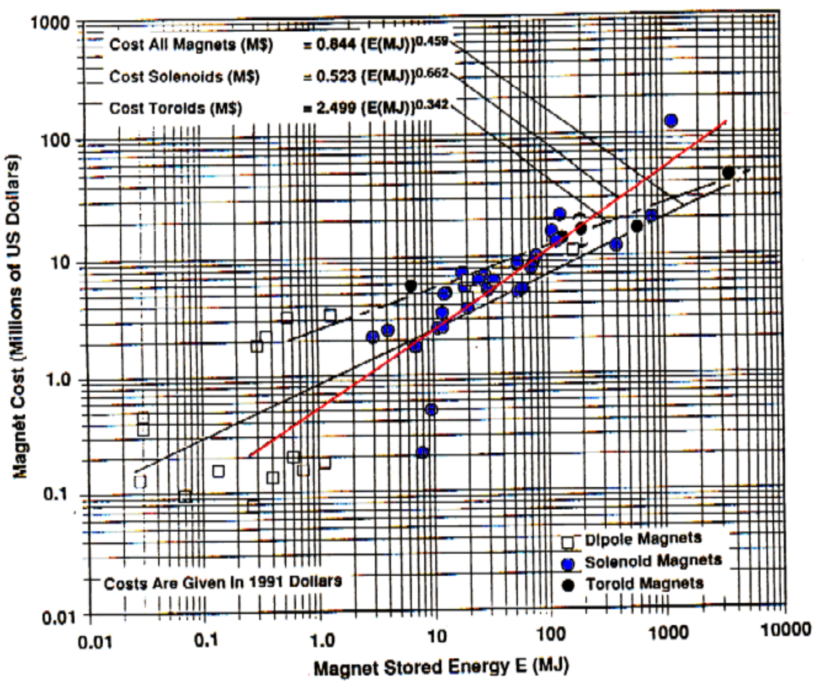
Conventional Construction Vacuum Diagnostics	$\propto$ Length $\propto$ Length $\propto$ Length
RF Cavities RF Power	units: $\propto V/\mathcal{E}$ Watts: $\propto V\ \mathcal{E}$
Simple Transports (Drift, Bunch, Rotate) Complex Lattices (cooling)	Green 1st model: $\propto (B\ R^2)^{.577}$ Green 2nd model: $\propto U^{.662}$
FFAG's	Palmer/Berg Algorithm

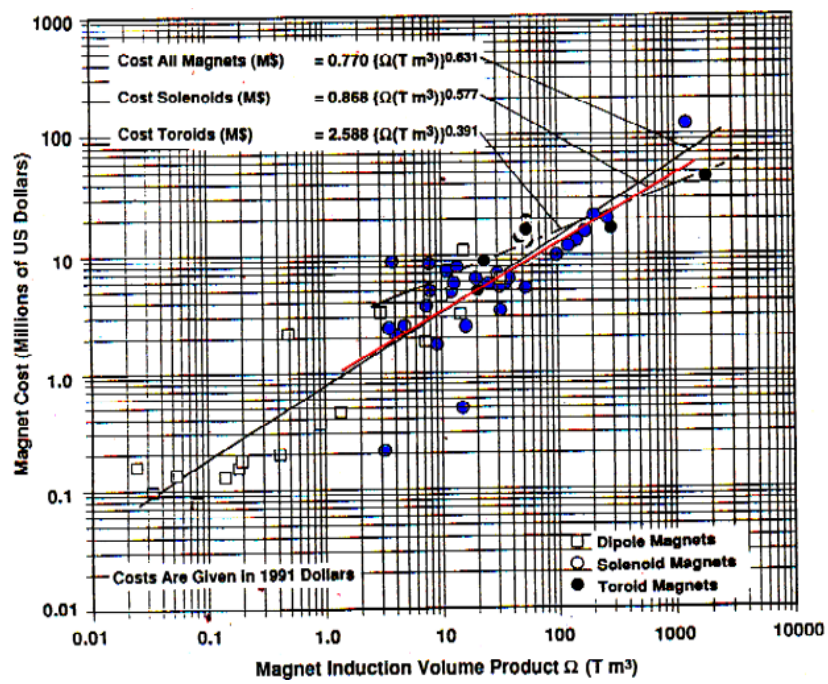
Green Solenoid Cost Algorithms

including factor of 1.34 for 12 years inflation at 2.5%

$$\text{Green1Solenoid (M\$)} \quad = \; 1.34 \times 0.52 \; (B^2 \; \pi R^2 \; L\;)^{.662}$$

$$\text{Green2 Solenoid (M\$)} \quad = \; 1.34 \times 0.87 \; (B \; \pi R^2 \; L)^{.577}$$





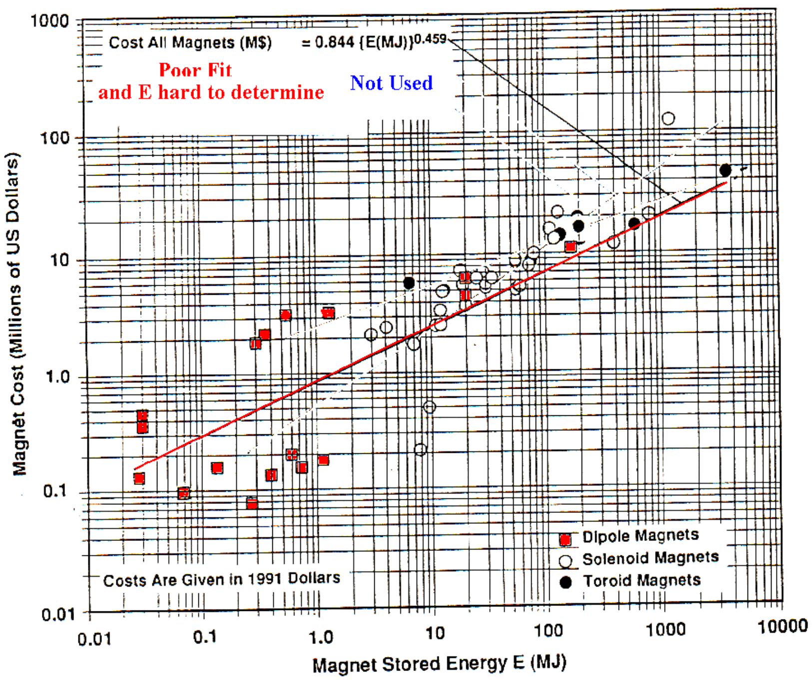
Advances in Cryo Eng. 37, Feb 1992

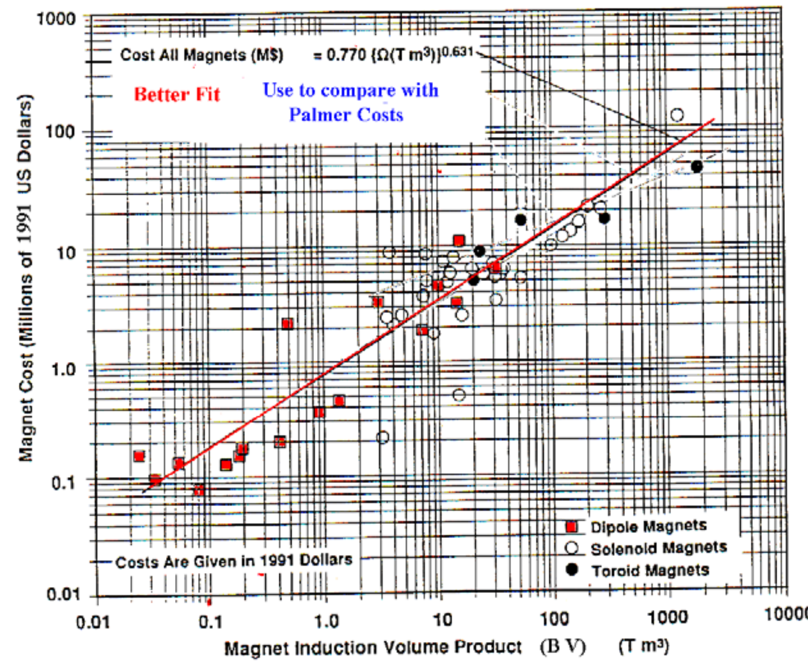
Green Dipole Cost Algorithms

including factor of 1.34 for 12 years inflation at 2.5%

$$\text{Green1Dipole (M\$)} = 1.34 \times 0.84\ (B^2\ \pi R^2\ L\ )^{.459}$$

$$\text{Green2 Dipole (M\$)} = 1.34 \times 0.77\ (B\ \pi R^2\ L)^{.631}$$





- The fit for Green2 is better, so I will only use only #2
- Fits are for all magnets, but looks reasonable for Dipoles only

Reduction of Cost with Quantity

- The Green formula ($\$ \propto L^{.63}$) might imply a cost reduction for quantity:

$$\$ \propto n \ \times \ (n)^{-.37}$$

- Similar Cost reductions with quantity are well documented
- Comparing RHIC cost for 30 magnets to the cost for 300 gives a similar value

I use:

$$\$ \propto \ n \ \times \ (n)^{-1/3}$$

Compare LHC and RHIC Costs to Green Formula

Since Green's table was fitting mostly small numbers of magnets
(I take an average of 3), I correct them for a comparison with RHIC and LHC:

	n	L m	R m	B T	Cost k$	Green k$	Green/cost
LHC	300	2×15.00	0.028	8.30	708.0	247	0.35
RHIC	300	10.00	0.040	5.30	143.0	128	0.89

- Agreement is reasonable for RHIC but low for the higher B LHC
- We need a formula with
  - Similar dependence to Green for moderate B (2-5)
  - Steeper dependence at higher B, and
  - Costs that remain finite as $B \rightarrow 0$
  - Reflects known finite "unit" or "end" costs for zero length magnets, and
  - Costs that go to a finite limit as their radius goes to zero

Palmer/Berg Algorithm for Dipole and Quadrupole Magnet Costs

$$M\$_{\mathrm{Palmer}} \;=\; (100 + 17\ B^{1.5})\ (R + 0.002B)\ (L + 45R)$$

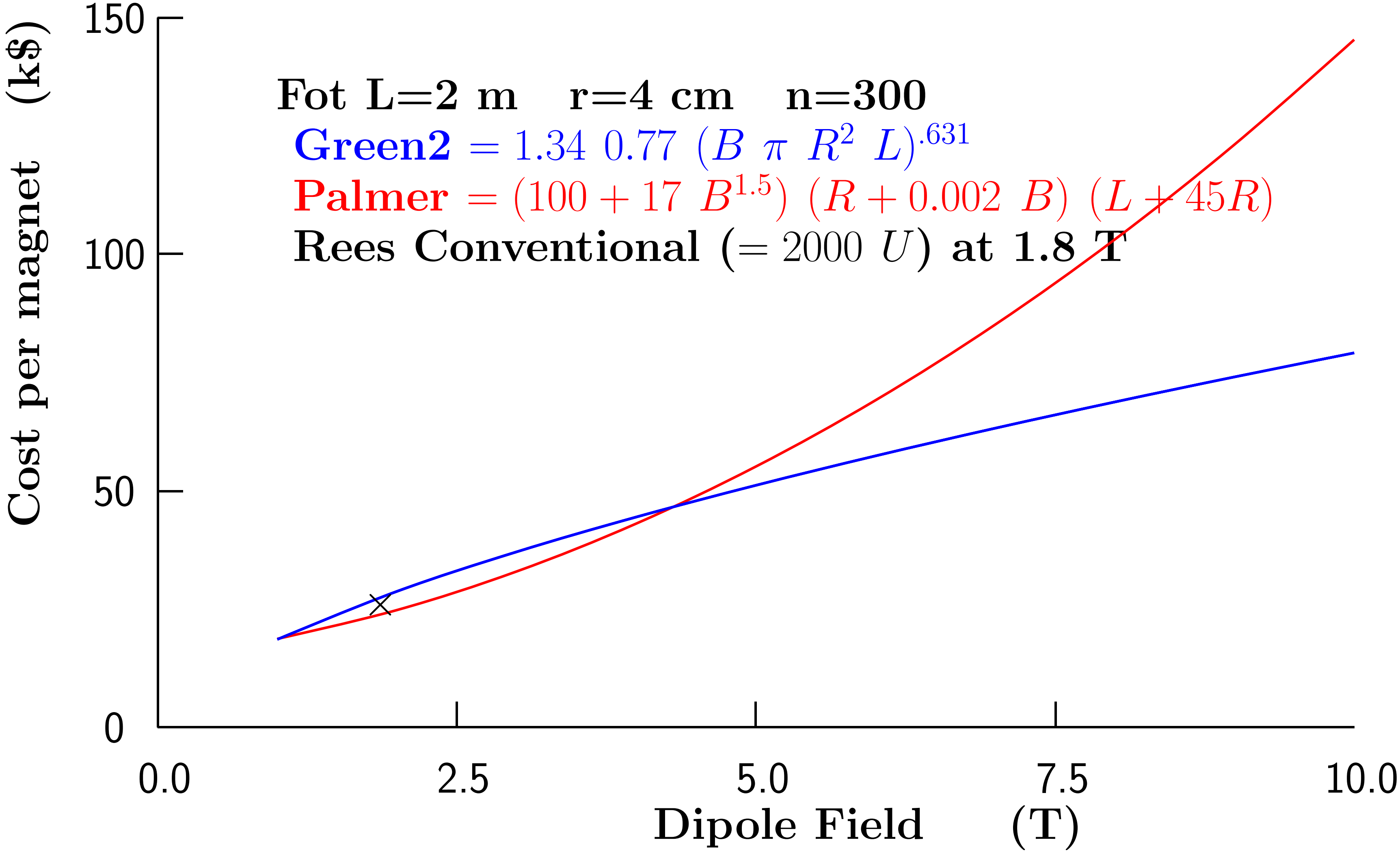
For quads: $B = (R + 0.002|GR|)\ |G|$

- The zero field floor is reasonable and allows low field agreement with Green
- The factor $0.002\ B$ reflects a finite cost even as $R \rightarrow 0$
- The factor 45 R reflects known "unit" (or "end") magnet costs
- Constants obtined by an approximate fit to four "known" magnet costs
- "Willen" is a minimum cost design costed using RHIC experience

	n	L	R	B	cost[1]	Palmer	Palmer/cost
		m	m	T	k$	k$	
RHIC Q	300	1.10	0.040	$(4.30)^2$	36.0	35	0.98
LHC	300	$2\times^3$15.0	0.028	8.30	708.0	706	1.00
RHIC	300	10.00	0.040	4.30	143.0	144	1.01
Willen	300	18	0.02	5.6	193.0	191	0.99

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

Cost vs field for one dimension of magnet



Combined Function magnets

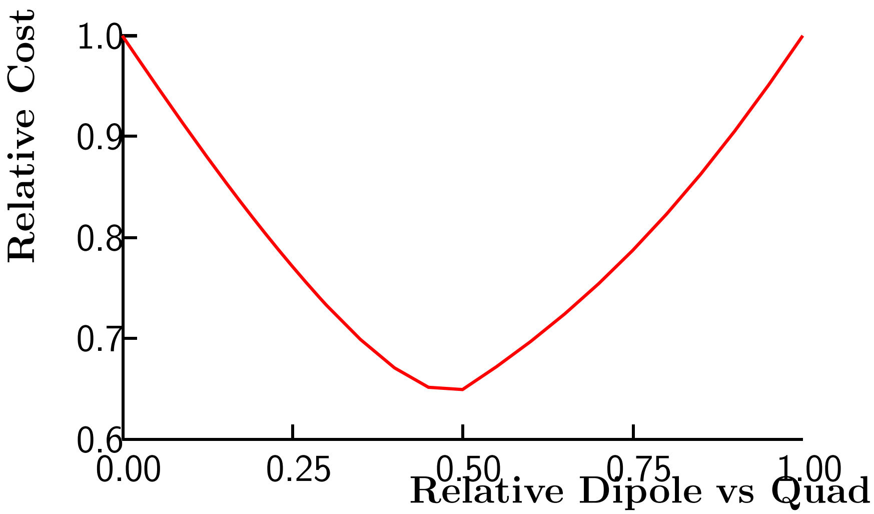
- Assume the use of Japan style assymetric combined function magnets
- Thicness of conductor determined by maximum field
- Amount of conductor is reduced for moderate gradients

Define relative Dipole D and Quadrupole Q charachters $(D + Q = 1)$

$$D = \frac{|Bmax + Bmin|}{2|Bmax|} \qquad Q = \frac{|Bmax - Bmin|}{2|Bmax|}$$

Cost taken to be proportional to relative amount of conductor

$$\frac{\text{Cost}}{\text{Dipole Cost}} = \frac{\int (D \ \cos\theta \ + \ Q \ \cos 2\theta) \ d\theta}{\int (\cos\theta) \ d\theta}$$



Other costs used for FFAG costing
1) 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

2) SC Cavities

SC	cost M$/GeV
Cavities	$30\times16/G$
Power	$89.16/4.375= 20.4\times g/16$
Cryo	$28/4.375=6.4\times g/16$
Total at 16 GV/m	**56.8**

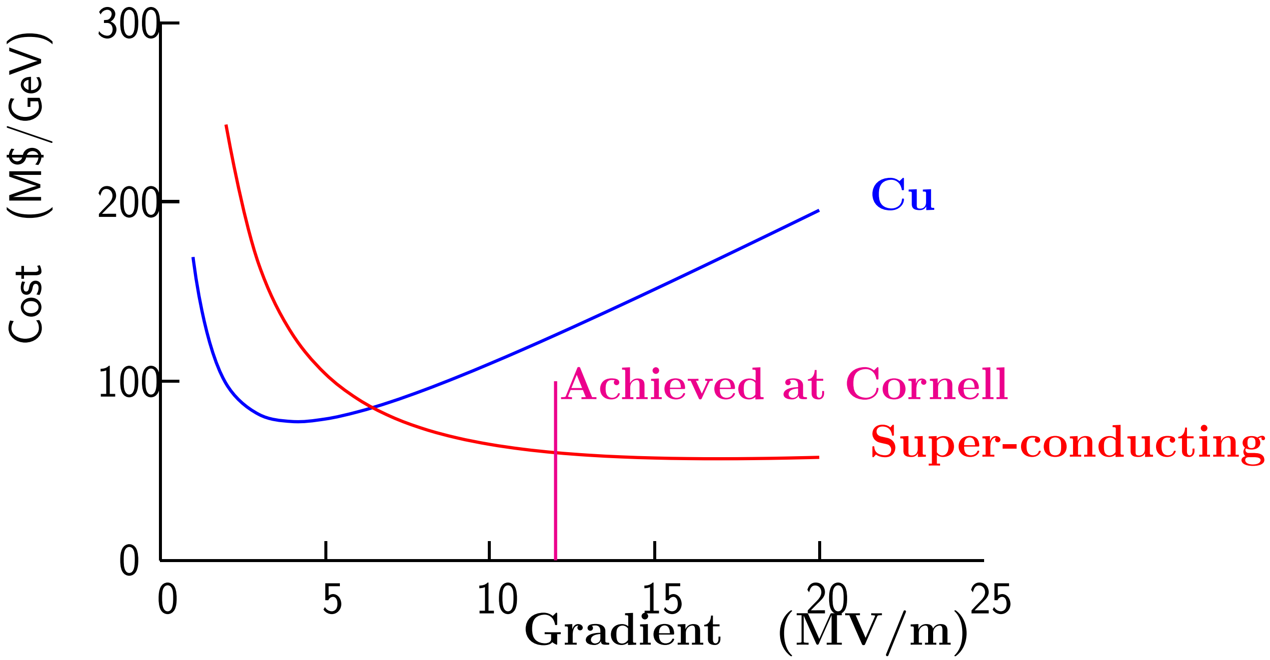
- RF power and cryogenics same as Study-2
- SC cavities 2 × Study-2 after discussion with Padamsee

3) Cu Cavities

Cu	cost M$/GeV
Cavities	$\approx\ 10\times16/G$
Power	$\approx\ 150\times G/16$
Total at 16 MV/m	**160**
Total at 3 MV/m	**81**

- assuming 125 k$/ 75 cm cavity for open cavity, about half of study-2 with foils
- RF 25% more than study-2 allowing for less Shunt Impedance than foil cavities

RF cost vs Gradient



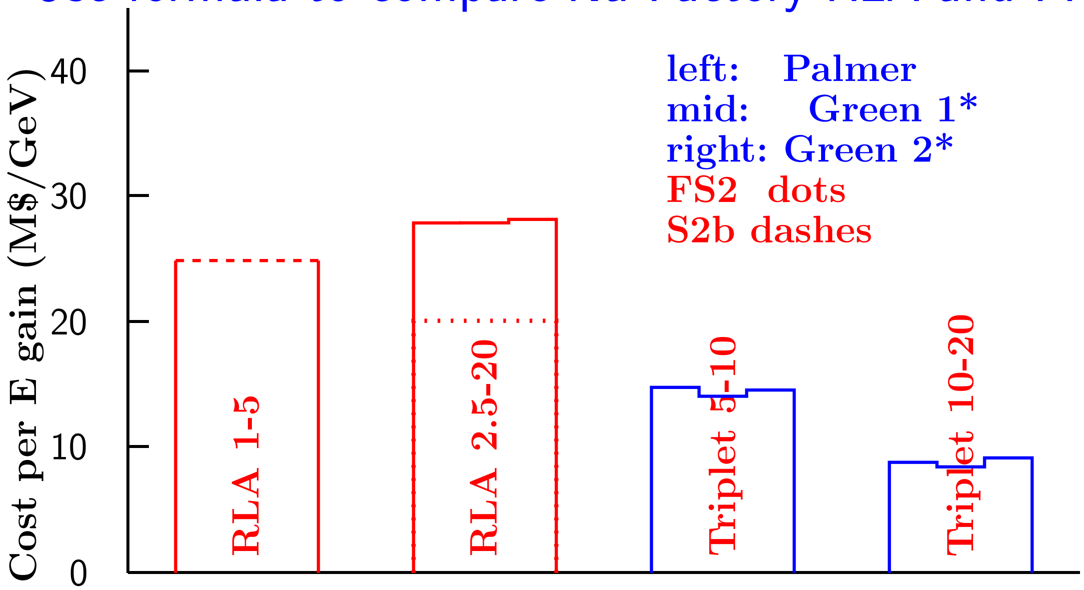
- SC cost min at 17 MV/m $\approx$ 55 M$/GeV
- Cu Cost min at 4 MV/m $\approx$ 75 M$/GeV (1.4 $\times$ SC)

But Loading will require gradients $\geq$ 12 MV/m, where

- Cu is 130 M$/m (2.4 $\times$ SC)
- But, to keep B low, SC requires an approximately 2 m straight for a single 75 cm cavity

RLA & FFAG Costs

Use formula to compare Nu Factory RLA and FFAG accelerators



- Little differences between Green 1, Green 2, and Palmer/Berg
- But differences in cost vs B are effecting opptimization
- In any case, for E>5 GeV, FFAG's are cheaper than RLAs
- The FFAG cost per GeV falls steeply with Energy

  Note significance for E>20 GeV
- Difference in FS2 RLA estimates need reconciliation

  A possible expalantion is the use of differents magnets for each arc, thus reducing quantity discount, where FS2 may have used one or only a few different types

Study 2a Costs

System		M$	M$/GeV		M$	M$/GeV	%
Target, capture, 18 m drift		97.3			96.1		99
	Target	91.5		Target	89.7		
	18 m Drift	5.8		18 m Drift	6.4		
Bunch and Phase Rotate		393.6			148.6		38
	Rotator	306.7	889	82 m Drift	19.3		
	Mini-Cool	11.3		Buncher	44.8		
	Buncher	75.6		Rotator	84.5	180	
cool		310.2			185.1		60
	cool	310.2	349		185.1	215	
Acceleration		544.2			421.4		77
	Match	56.7		Match	23.1		
	Pre-Acc	136.8	28.5	Pre-Acc	98.5	77.5	
	RLA	350.9	23.4	RLA	99.6	28.5	
				FFAG 1	91.1	18.2	
				FFAG 2	109.1	10.9	
Ring		82.5			82.5		100
Total		1427			934		65

Conclusion

- This Study 2b cost is about 65% of FS2.
- This cost, for the same performance, should come down, because systems, other than the FFAGs, have not been cost opptimized:
  - Linac apertures and cell lengths
  - RLA number of turns and linac lattice
  - Amount of cooling vs. acceleration aperture
  - Phase Rotation parameters

- We need to apply an extended version of the algorithm to all S2b systems
- We need to apply a further extended version of the algorithm to other designs
  This must be done judiciously, it will not be easy, but we must try