Acceleration Costs

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Acceptances

	Trans π mm	Long π mm
After Target	.22/.105*0.08=170	-
After Study-2 Phase Rotation	100	200
After Study 2 Cooling	15	150[1]
After RFOFO Cooling Ring	15	35
After Low Beta Ring	4[2]	35

1. Reduced by scraping
2. Achieved, but with poor transmission

Possible New Acceleration Schemes

Pulsed Synchrotron

1. **Linac: .2 to 1 GeV/c**
2. **RLA : 1 to 4 GeV/c**
3. **Pulsed Synchrotron: 4 to 20 GeV/c**

FFAG

1. **Linac: .2 to .6 GeV/c**
2. **FFAG : .6 to 2 GeV/c**
3. **FFAG : 2 to 6 GeV/c**
4. **FFAG: 6 to 20 GeV/c**

COSTS

SC Cavities

SC		cost M$/GeV
(Study-2)	Cavities	63.36/4.375=14.5×16/G
	Power	89.16/4.375= 20.4×g/16
	Cryo	28/4.375=6.4×g/16
	Total at 16 GV/m	41.3

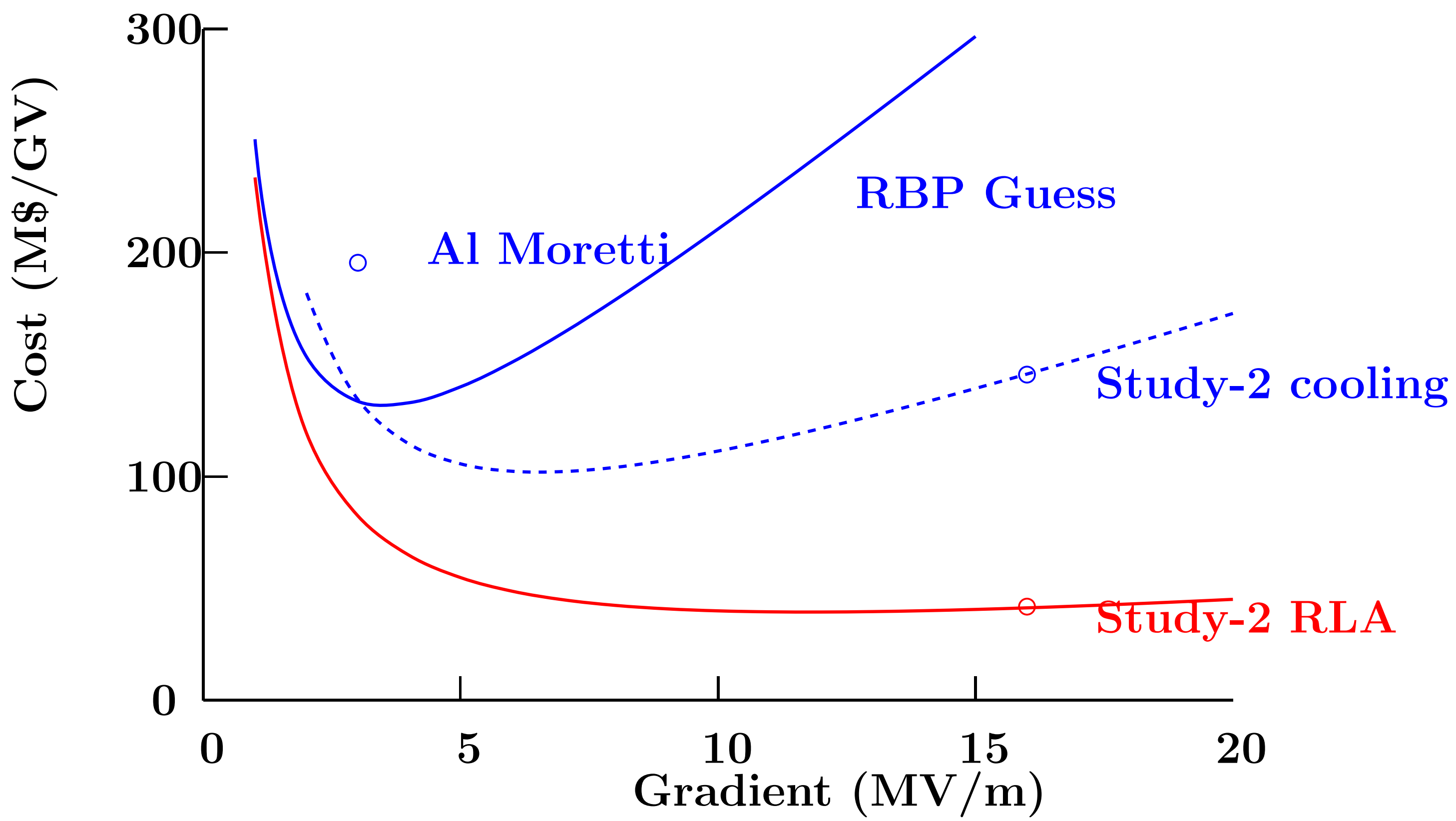
Note: TESLA Cavities + RF

$$\frac{\mathrm{Cost}}{\mathrm{GeV}} \approx \frac{2\ \mathrm{B\$}}{500\ \mathrm{GeV}} = 4\ \mathrm{M\$/GeV}$$

Cu Cavities

Cu		cost M$/GeV
(study-2)	Cavities	125/6=20.8 $\times$ 16/G
+ foils	Power	750/6=125 $\times$ G/16
	Total at 16 MV/m	146
	Total at 6.5 MV/m	103
Open	Cavities	$\approx$ 14.5 $\times$ 16/G
	Power	$\approx$ 250 $\times$ G/16
	Total at 16 MV/m	314
	Total at 3 MV/m	158
	Total at 3 MV/m	133 (AM 195)

- Foil cavites have $\approx$ 2 $\times$ better Shunt Impedance



$$\text{If} \quad \mathcal{E}(\text{Cu}) = \frac{\text{V/turn}}{\Sigma \text{ gaps}} < 3 \text{ (MV/m)} \quad \text{Then fill a fraction to keep } \mathcal{E}(\text{Cu}) = 3$$

$$\text{If} \quad \mathcal{E}(\text{SC}) = \frac{\text{V/turn}}{\Sigma \text{ gaps}} < 6 \text{ (MV/m)} \quad \text{Then fill a fraction to keep } \mathcal{E}(\text{SC}) = 6$$

SC Magnets

$$\mathrm{EST_2(RBP)\ (k\$)} = 27.5\ \mathrm{B}^{1.3}\ \mathrm{R'}\ (\mathrm{L} + 20\ \mathrm{R'})$$

$$\text{where} \quad \mathrm{R'} = \mathrm{R} + 0.003\ \mathrm{B}$$

B **in T,** R **& L in m.**

	L	R	B	G	cost	cost/Est
	m	m	T	T/m	k$	
RHIC Q	1.1	0.04	5.3	91.0	29 *	0.95
LHC	30.0	0.03	8.3	0.0	708	0.95
RHIC	10.0	0.04	5.3	0.0	149 *	0.93
Erich	18.0	0.02	5.6	0.0	178	1.03

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

For Field Quality:

$$\text{Use}\quad \mathrm{R} = \frac{(\text{Max beam width})}{2} \times 1.3$$

Cu Dipole Magnets

Rees 1.93$/J

Main Ring	B	L	W	H	U	cost	cost1
	T	m	m	m	kJ	k$	k$
	1.7	6	.115	.05	40	100	77

Cu Quadrupole Magnets

Rees 5.45$/J

Main Ring	G	L	R	Bmax	U	cost	cost1
	T/m	m	m	T	kJ	k$	k$
	20.2	2.95	.042	0.84	2.29	30	12.5

Linear Costs

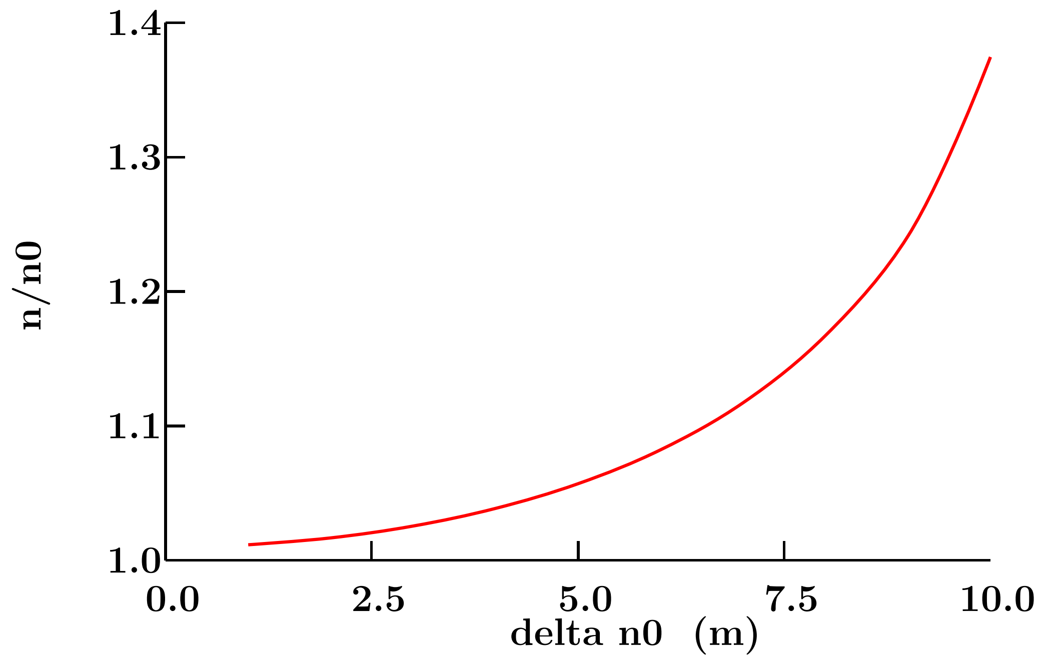
	source	cost	L	Cost/length
		M$	km	K$/m
Vacuum	Study-2	15	3.26	4.6
Diagnostics	”	4	3.26	1.2
Civil	”	19	1.446	13.1
Total				18.9

Phase Slip

Find initial phase for minimum req turns

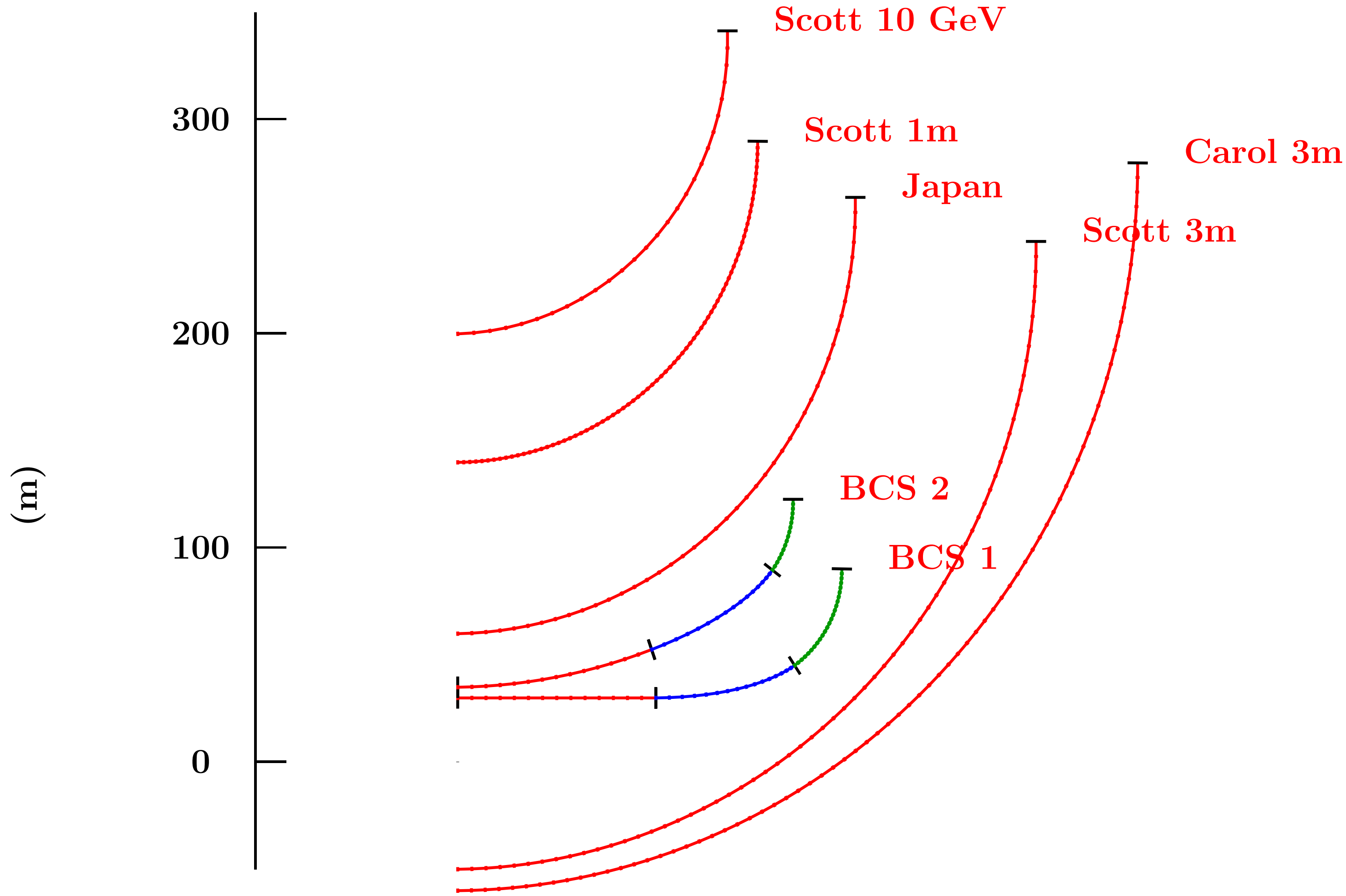
Plot $\frac{\mathrm{Req.Turns}}{\mathrm{Circ/Volts}}$ **vs** $\frac{\Delta \mathrm{E}}{\mathrm{Volts/turn}} \times \mathrm{Circ.}$

Typical **Req Turns/ ideal**



Lattices

1. **Japan: Scaling FFAG for 10-20 GeV**
2. **Scott 10:Carol type n on-scaling FFAG for 10-20 Gev, with 3 m gaps for SC RF**
3. **Carol: Original Carol non-scaling FFAG for 6-20 GeV and 3 m gaps for SC RF**
4. **Scott 3: Modified Carol non-scaling FFAG for 6-20 GeV and 3 m gaps for SC RF**
5. **Scott 1: Modified Carol non-scaling FFAG for 6-20 GeV and 1 m gaps for normal RF**
6. **BCS 1: Bob, Carol, Scott non-scaling FFAG with adiabatic matching rfom arc to straight Linacs**
7. **BCS 2: Bob, Carol, Scott non-scaling FFAG with adiabatic matching rfom arc to curved Linacs**


Scott 10 GeV
Scott 1m
Carol 3m
Japan
Scott 3m
BCS 2
BCS 1
300
200
100
0
(m)

Magnets

	n	cell	L	R	Bmin	Bmax	G	/mag	Tot	delta	circ
		m	m	m	T	T	T/m	k$	M$	m	km
Japan	180	6.99	1.53	0.156	2.5	6.4	9.4	237.9			
10 20	180	6.99	1.96	0.156	2.5	6.4	9.4	256.2	88.9	1.29	1257
Scott 10 GeV	108	8.00	1.00	0.157	-2.1	4.3	15.3	137.7			
10 20	108	8.00	1.00	0.065	2.5	5.2	15.0	40.8	19.3	0.39	864
Carol 3m	314	6.80	0.45	0.169	-4.5	6.5	24.2	279.8			
6 20	314	6.80	0.35	0.086	-2.8	4.6	31.8	47.9	102.9	0.61	2135
Scott 3m	260	7.00	0.50	0.194	-5.0	5.5	20.3	344.2			
6 20	260	7.00	0.50	0.111	-2.4	3.6	20.4	59.4	104.9	0.87	1820
Scott 1m	314	3.00	0.50	0.093	-5.7	7.3	51.4	122.3			
6 20	314	3.00	0.50	0.051	-2.9	4.3	51.5	19.8	44.6	0.31	942
BCS 1	56	7.00	0.50	0.194	-5.0	5.5	20.3	344.2			
str	56	7.00	0.50	0.111	-2.4	3.6	20.4	59.4			
	64	4.60	0.95	0.139	-3.7	6.0	26.2	191.3			
match	64	4.60	0.65	0.079	-1.8	5.6	34.2	48.5			
	96	2.20	1.40	0.084	-0.5	7.3	33.6	84.2			
arc 6 20	96	2.20	0.80	0.047	-1.3	7.9	66.5	34.2	49.3	0.27	730
BCS 2	56	7.00	0.50	0.194	-5.0	5.5	20.3	344.2			
str	56	7.00	0.50	0.111	-2.4	3.6	20.4	59.4			
	64	4.60	0.95	0.139	-3.7	6.0	26.2	191.3			
match	64	4.60	0.65	0.079	-1.8	5.6	34.2	48.5			
	64	2.20	1.40	0.084	-0.5	7.3	33.6	84.2			
arc 6 20	64	2.20	0.80	0.047	-1.3	7.9	66.5	34.2	45.5	0.20	712

RF and Costs

Ave Gradient $= 1$ (MV/m)
gives loss of 17.5% from 6 to 20 GeV with frequency modulation
But not being on crest increases losses

	turns	n/n0	loss %	slip m	V GV	gaps	gap m	SC G MV/m	fill	SC $ M$	RF G MV/m	RF $ M$	lin $ M$	Tot $ M$
10-20 GeV														
Japan	14	1.27	13.1	1.3	1.26	360	1.75	999.0	1.00	999	1.99	185	25	299
Scott	17	1.08	11.3	0.4	0.86	108	3.00	8.0	0.89	37	3.00	107	17	73
6-20 GeV														
Carol 3m	7	1.04	18.1	0.6	2.14	628	3.00	6.0	0.38	104	3.00	265	43	250
Scott 3m	8	1.10	19.1	0.9	1.82	520	3.00	6.0	0.39	89	3.00	226	36	230
Scott 1m	16	1.05	18.3	0.3	0.94	628	1.00	999.0	0.50	999	3.00	117	19	180
BCS 1	20	1.06	18.5	0.3	0.73	112	3.00	6.5	0.72	34	3.00	91	15	98
BCS 2	20	1.04	18.1	0.2	0.71	112	3.00	6.4	0.71	34	3.00	88	14	93

* Frequency modulation required at 200 MHz
† Insuficient space for SC Cavity with field standoff

Conclusion

- **For the same energy increase of 10-20 GeV, The Carol type non scaling FFAG appears significantly cheaper than a scaling design. Its circumference is less, its magnets have smaller apertures and fields, it is sufficiently isochronous as to allow fixed frequency RF and has gaps large probably enough to use Superconducting RF (the required stand off needs study).**
- **Quoted costs do not include injection, extraction and transfer lines. When these are included, there is likely to be a significant advantage in using fewer rings with more energy increas in each ring. Studies were made for 6-20 GeV. It is found that the cost of a Carol type lattice for this larger energy swing is much higher, because of the larger apertures of the magnets.**
- **The magnet apertures and costs are less if the lattice is shortened leaving only 1 m gaps for RF and thus requiring the use of conventional RF. The cost is less in this case, despite a substantial increase in RF power cost.**
- **An better solution (BCS), if it can be designed, is to have a short cell lattice for the arcs and a long cell lattice with 3 m gaps for SC RF, and an adiabatic match between them. Such a match has yet to be successfully designed.**

- **WARNING This analysis has not been very carefully checked, and may contain errors**