A Cost Optimized Small-Aperture 2-in-1 2-Phase VLHC

R. B. Palmer, B. Parker,
BNL

G. W. Foster, J. Strait
FNAL

S. A. Gourlay
LBNL

Snowmass, 7/17/01

1. This talk: http://pubweb.bnl.gov/people/palmer/magnet/snowvlhc.pdf

Assume

- **1-in-1, 2-in-1 cos(θ), & pipeatron**
- **Design Magnets by approximate formulae**

- **apertures $\propto B^{-1/3}$**
  scaled from 18 mm diameter pipe at 2 T.
  justified by VLHC workshop[2] conclusions
- **magnet costs $\propto$ weights and cold areas**
- **SSC linear costs include magnet ends: 22 k$/m**
- **linear costs for 'long' magnets: 16 k$/m**
- **saving if ring exists: 11 k$/m**
- **details in PJ paper[3]**

- **no contingency, R&D, EDIA, escalation**

- **Calibrations:**
  20 + 20 TeV rings: SSC = Pipeatron = 4 B$

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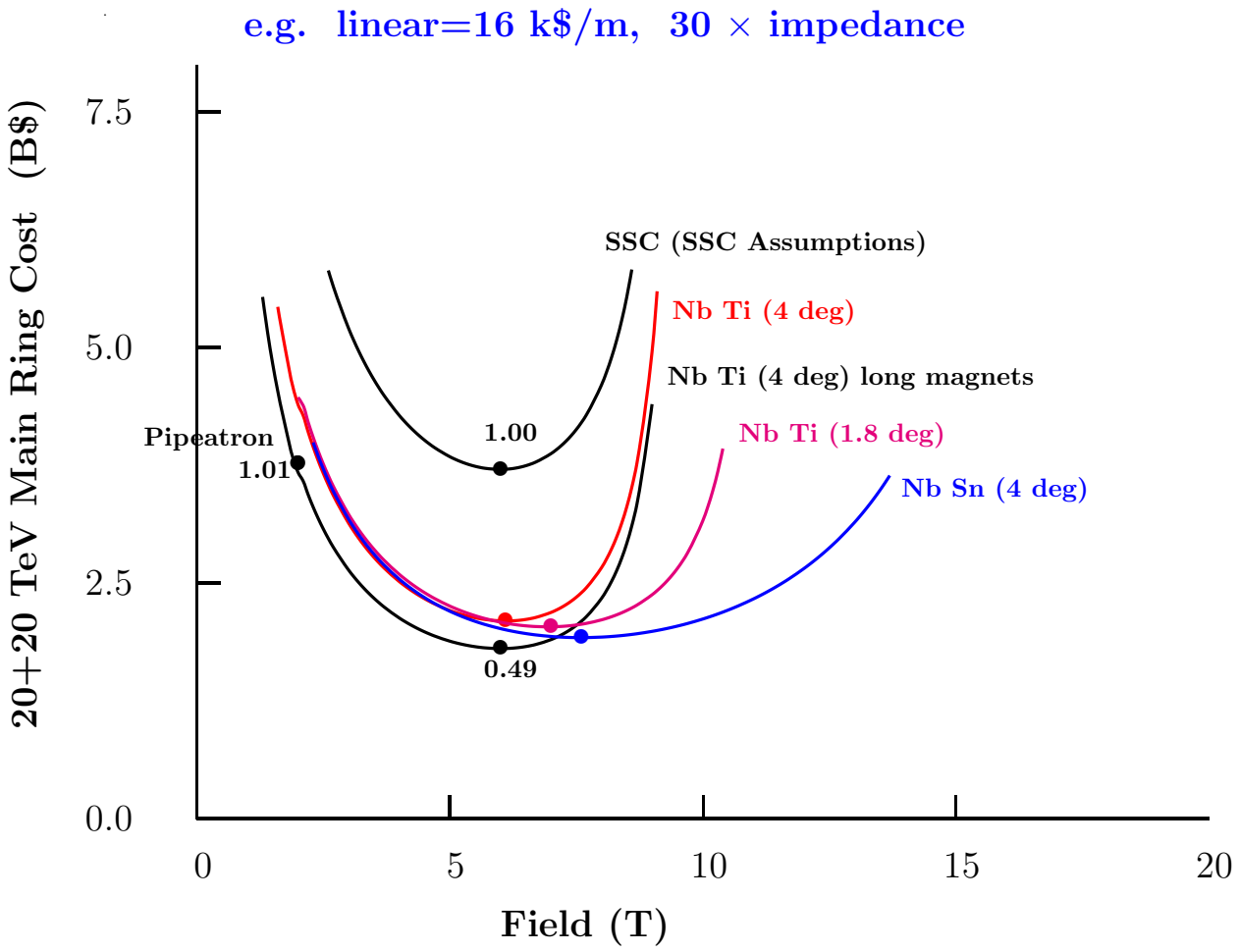
2. PJ paper: http://pubweb.bnl.gov/people/palmer/magnet/pjmagopt.pdf
3. VLHC workshop:http://www.slac.stanford.edu/ achao/VLHCworkshop.html

Costs vs. Fields



Minimum costs relative to SSC

		reg cost	NbTi B	long cost	NbTi B	NbSn cost	B	Pipe cost	B
A	SSC Assumptions	.91	6			.86	7.2	1.7	2
B	SSC linear, 1/30 Impedance	.69	6.4	.59	6.3	.61	8.2	1.3	2
C	'long magnet' linear ,1/30 Impedance	.57	6.1	.49	6.0	.52	7.6	1.0	2

Consider:

1. Pre accelerator at 2.5 TeV

2. Phase I at 25+25=50 TeV

3. Phase II in same Tunnel

Pre-Accelerator

For impedance and field reasons
take E=E(phase 1)/10=2.5 TeV
CERN would avoid this cost

Should it have a new tunnel ?

	circ. km	B T	E TeV	cost B$	loaded B$
NbTi at cost minimum + new Tunnel	8	6	2.5	.25	.5
NbSn + TeVatron Tunnel	4	12.5	2.5	.36	.73

Yes

Phase I Field ?

go a little below best field:
5 T (.5×SSC cost) vs. 6T (.49×SSC cost)
Circumference=93 km is reasonable
Can this be built at CERN?

Phase II Energy ?

	circ. km	B T	E TeV	cost B$	loaded B$
10 T NbSn	93	10	50+50=100	5.0	10
12.5 T NbSn	93	12.5	62.5+62.5=125	8	16
15 T NbSn	93	15	75+75=150	17	34

Pick 100 TeV

Possible 2-Phase Project

	circ. km	B T	E TeV	cost B$	loaded B$
Pre Accelerator	10	6	2.5	.25	.5
Phase I	120	5	25+25	2.6	5.2
Phase II	120	10	50+50	5.0	10
Detector(s)				.8	1.6
Total Phase I only				3.65	**7.3**
Total Phase I & II				8.65	**17.3**

Phase I about the same cost as NLC, but is a frontier machine, and no conflict with TESLA

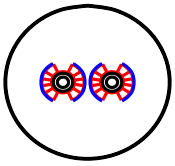
c.f. Fermi Design Study Fermi-TM-2149

	circ. km	B T	E TeV	cost B$	loaded B$
Pre Accelerator	10	6	2.5	.25	.5
Phase I	230	2	20+20	4.1	8.3
Phase II	230	10	100+100	10	20
Detector(s)				.8	1.6
Total Phase I only				5.2	**10.4**
Total Phase I & II				15.2	**30.4**

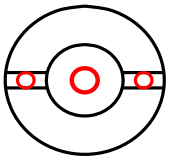
SSC Energy for phase I is unfortiunate, and both phases are too expensive.

Comparative Cross sections

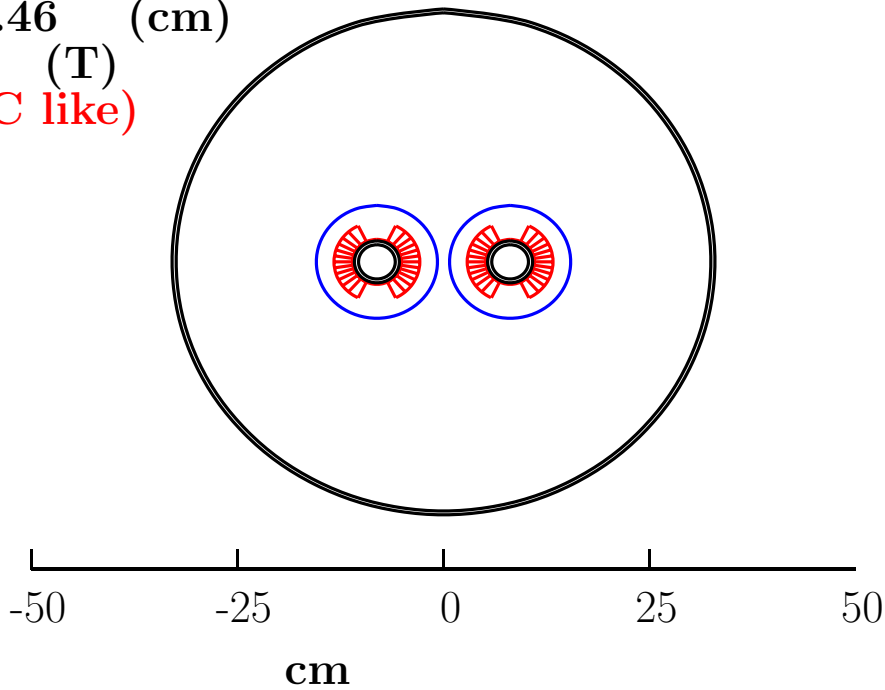
Nb Ti (4 deg)
ap 1.35 (cm)
B 5 (T)
This Proposal



Nb Ti (4 deg)
ap 1.80 (cm)
B 2 (T)
Pipeatron



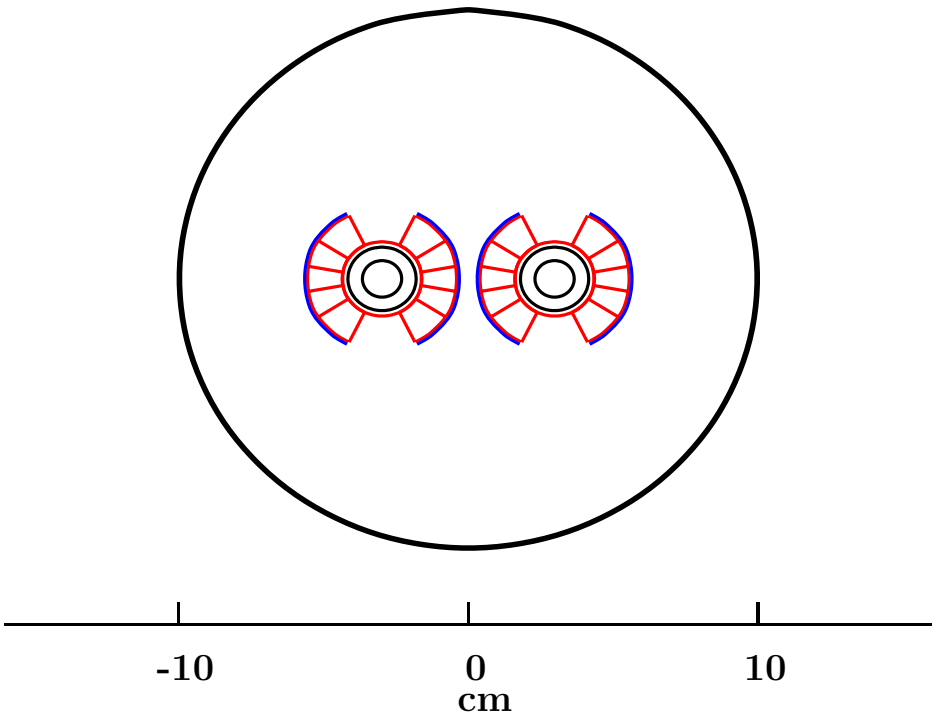
Nb Ti (1.8 deg)
ap 4.46 (cm)
B 8 (T)
(LHC like)



Possible Details

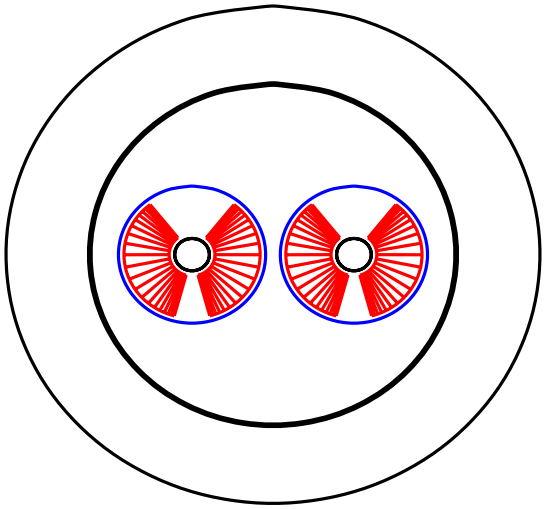
Could be RHIC like conventional separate function lattice with correctors, but the cost should be less if:

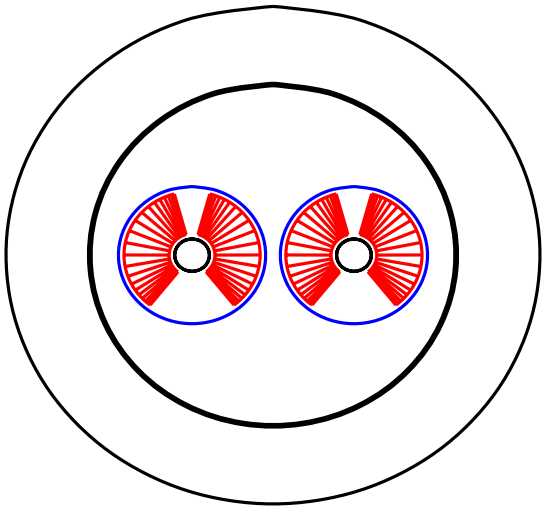
- Continuous five 100 kA busses



- Trim saturation by bus currents
- Local trims by taps & floating supplies

- **Combined skew quads by alternating vert displacement**





Component costs and dimensions

High Field in new tunnel (Normal linear $, 30 × impedance)

Nb Sn (4 deg)

B T	j A/mm^2	j_{SC} A/mm^2	lin k$/m	sc k$/m	Cu k$/m	coll k$/m	fe k$/m	shell k$/m	cryo k$/m	mag k$/m	Tot B$	/SSC
10.0	573	2517	22.0	14.89	1.50	1.03	10.76	0.78	4.65	32.6	2.64	0.65
12.5	511	1773	22.0	32.86	2.33	2.34	25.30	2.32	7.10	69.9	3.40	0.83
15.0	406	1029	22.0	91.92	3.78	6.16	64.90	7.24	11.40	179.2	6.00	1.47

B T	circ km	r_{vac} cm	ir_{coil} cm	r_{sc} cm	r_{Cu+SC} cm	r_{collar} cm	r_{yoke} cm	t_{shell} cm	press MPa	B Fe T	Cu/sc	I.n kA turns	U_{mag} T^2m^2
10.0	56	0.5	1.2	4.0	4.0	6.0	26.4	0.5	116	0.86	2.5	1763	21.8k
12.5	45	0.5	1.2	5.2	5.2	8.4	40.1	1.0	167	0.82	1.8	2990	38.7k
15.0	37	0.5	1.2	7.4	7.4	13.0	64.0	2.0	224	0.75	1.0	5277	79.6k

High field in existing tunnel (1/2 linear $, 30 × impedance)

Nb Sn (4 deg)

B T	j A/mm^2	j_{SC} A/mm^2	lin k$/m	sc k$/m	Cu k$/m	coll k$/m	fe k$/m	shell k$/m	cryo k$/m	mag k$/m	Tot B$	/SSC
10.0	573	2517	11.0	14.89	1.50	1.03	10.76	0.78	4.65	32.6	2.02	0.50
12.5	511	1773	11.0	32.86	2.33	2.34	25.30	2.32	7.10	69.9	2.91	0.71
15.0	406	1029	11.0	91.92	3.78	6.16	64.90	7.24	11.40	179.2	5.59	1.37

'long' low field magnets (3/4 linear $, 30 × impedance)

Nb Ti (4 deg) special

B T	j A/mm^2	j_{SC} A/mm^2	lin k$/m	sc k$/m	Cu k$/m	coll k$/m	fe k$/m	shell k$/m	cryo k$/m	mag k$/m	Tot B$	/SSC
5.0	552	2228	16.5	2.69	0.48	0.00	1.45	0.05	1.73	6.4	2.07	0.51

B T	circ km	r_{vac} cm	ir_{coil} cm	r_{sc} cm	r_{Cu+SC} cm	r_{collar} cm	r_{yoke} cm	t_{shell} cm	press MPa	B Fe T	Cu/sc	I.n kA turns	U_{mag} T^2m^2
5.0	93	0.7	1.4	2.6	2.6	2.7	9.9	0.1	36	1.12	2.2	443	8.0k

Pipeatron

B T	j A/mm^2	j_{SC} A/mm^2	lin k$/m	sc k$/m	Cu k$/m	coll k$/m	fe k$/m	shell k$/m	cryo k$/m	mag k$/m	Tot B$	/SSC
2.0	625	3584	16.5	0.18	0.05	0.00	0.62	0.00	0.57	1.4	4.14	1.01

B T	circ km	r_{vac} cm	gap cm	OR_{He} cm	r_{sc} cm	IR_{yoke} cm	OR_{yoke} cm	spacing cm	MPa	B Fe T	Cu/sc	I/mag kA turns	U_{mag} T^2m^2
2.0	233	0.9	1.0	1.5	1.7	4.7	9.6	38.6	0	2.00	3.6	87	2.8k

Conclusion

- **Do not believe these costs**

But

- **High fields may be expensive**
- **2 T may be too low**
- **Medium Field may be cheaper**
- **If field is low, then small apertures may greatly reduce cost**

- **A 5 T, small aperture design should be studied**

- **50 -100 TeV in $\approx$ 100 km tunnel may be more realistic than $\geq$ 200 TeV in a $\geq$ 200 km tunnel**

- **Need R&D on Field Quality**

- **Need R&D on Feedbacks etc.**