VLHC MAGNET WORKSHOP

Nov. 16-18, 1998
Port Jefferson, NY

CHARGE:

- Guided by the Snowmass '96 parameter sets, explore and develop innovative concepts that will result in significant cost reductions.
- Coordinate parameter sets, infrastructure requirements for the various options, and designs with the other working groups.
- Review progress in magnet R&D (including materials and may include cryogenics, vacuum).
- Develop bases including costs for comparing different magnet designs.
- Monitor, encourage, and coordinate progress in materials development both in academe and industry.

VLHC MAGNET WORKSHOP REVIEW OF SNOWMASS ’96 PARAMETERS

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General Features of the vlhc

Snowmass '96 Machines

Parameter list

Lattice features

Interaction region

Vacuum

Cryogenics

Summary

General Features

of third-generation (E_{CM} = 100 TeV) hadron colliders

1. Physics at the energy frontier: *a discovery machine*

2. Luminosity > 10^{34} cm^{-2} sec^{-1} at two detectors

3. Based on superconducting magnet technology

4. Large scale (circumference >100 km, numbers of magnets >1000)

5. Must be as cost-effective as possible

6. Requires a conservative design approach
that insures reliability at the design goals

7. Will be an internationally supported effort

Snowmass '96 Machines

Motivation: For any vlhc, the magnets are the system cost driver. New approaches are needed since a scale-up of the existing NbTi technology would be prohibitively expensive.

Three examples were considered,
all with E_{CM}=100 TeV,
Peak luminosity=10^{34} cm^{-2}sec^{-1}

Principal distinguishing features:

-the choice of superconducting magnet technology;
-the size of the ring;
-the role of synchrotron radiation damping;

(a) High-field-new technology:

Dipole field >12 T
Circumference 100 km
Synchrotron-radiation damped emittance
1.3 hr emittance damping time
The key is the conductor
>12 T magnet requires either Nb_3Sn @4^oK
or (preferably) the use of high temperature superconductor (HTS)

(b) High-field-current technology:

Dipole field >9-10 T
Circumference 140 km
Synchrotron-radiation damped emittance
2.3 hr emittance damping time

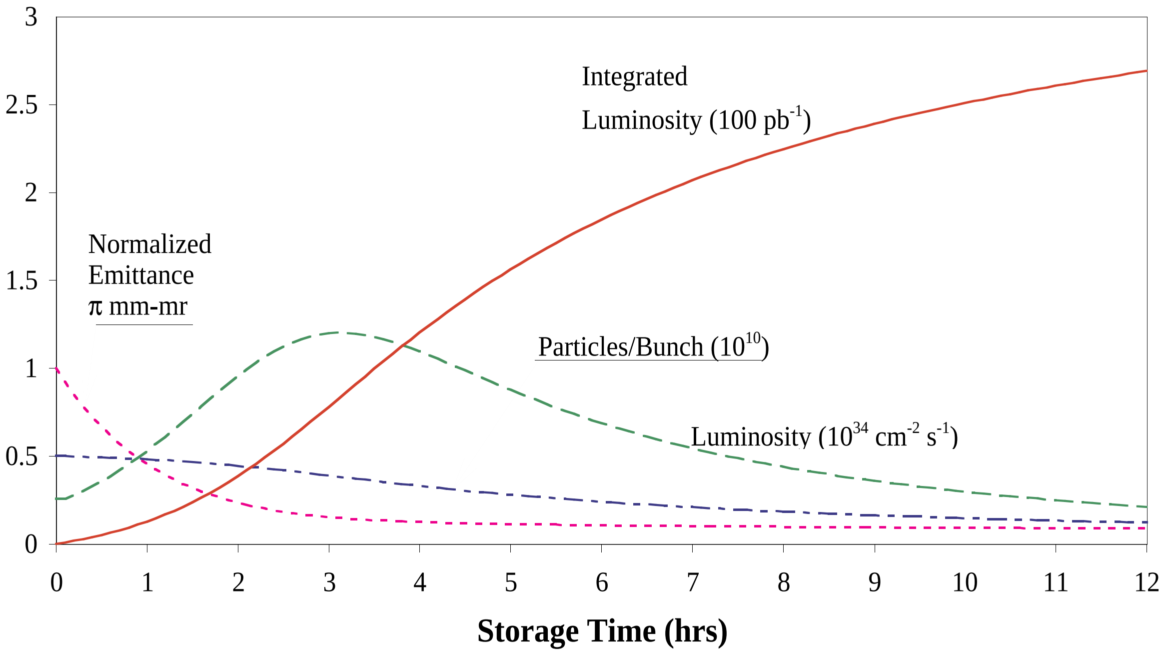
9.5 T magnet could be implemented with NbTi @ 1.8° K.
The engineering challenge is to bring down the cost and complexity of a known technology

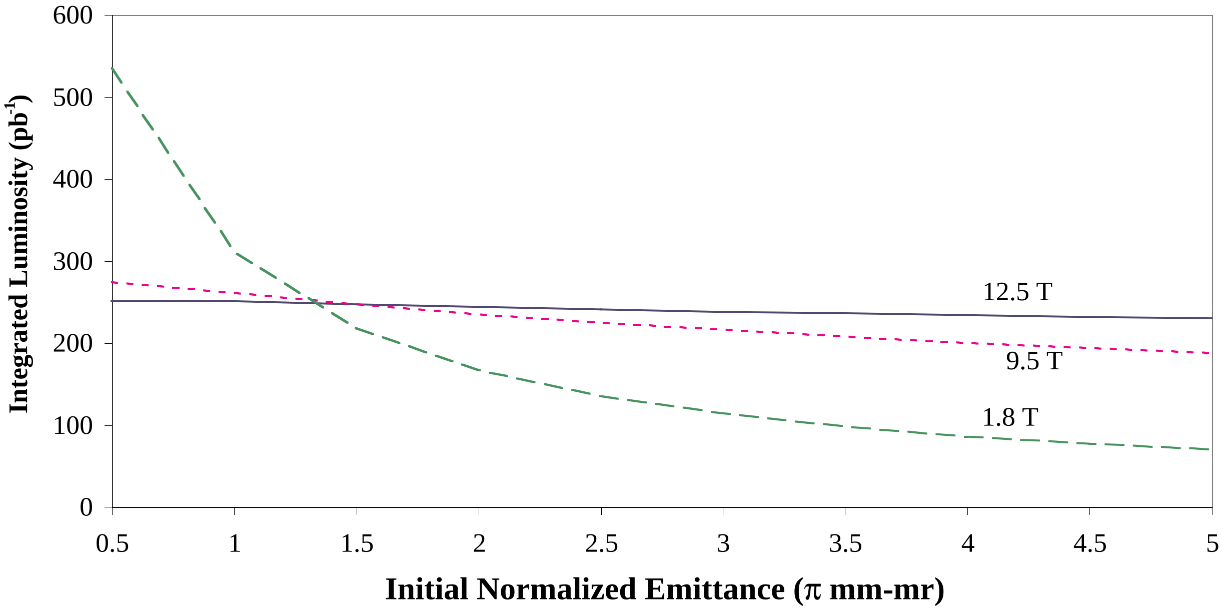
(c) Low field (Pipetron)

Dipole field <2 T
Circumference 650 km
No damping

Simple, low cost superferric (1.8T) combined function "Double-C transmission line" magnet from Fermilab

Goal: 10x lower magnet cost per TeV than conventional SC Magnets


3
2.5
2
1.5
1
0.5
0
Integrated
Luminosity (100 pb^{-1})
Normalized
Emittance
π mm-mr
Particles/Bunch (10^{10})
Luminosity (10^{34} cm^{-2} s^{-1})
0
1
2
3
4
5
6
7
8
9
10
11
12
Storage Time (hrs)


600
500
400
300
200
100
0
Integrated Luminosity (pb^{-1})
12.5 T
9.5 T
1.8 T
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Initial Normalized Emittance (π mm-mr)

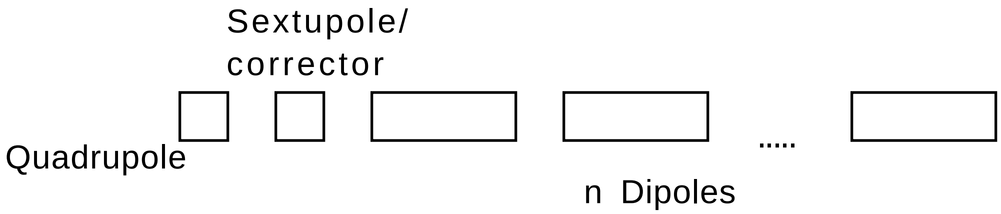
vlhc Machine parameters

Parameter	High field-new technology	Low Field	Units
CM Energy	100	100	TeV
Dipole field	12.6	1.8	T
Circumference	104	646	km
Revolution frequency	2.89	.46	kHz
Injection energy	3	3	TeV
Synchrotron radiation damping time (horizontal amplitude)	2.6	*antidamped*	hr
Equilibrium rms emittance	144.2	---	π nm
Energy loss/turn	3678	526	keV
Synchrotron radiation power/ring	189	48	kW
Initial/peak luminosity	.35/1.2	1./1.	10^{34} cm^{-2}sec^{-1}
Protons/bunch	0.5	0.94	10^{10}
Bunch spacing	16.7	16.7	nsec
Number of bunches	20794	129240	
Total protons/ring	1.1	12.2	10^{14}
Beam stored energy	.89	9.73	GJ
Injected rms normalized emittance	1.	1.	π μm
β^*	20	20	cm
Rms relative energy spread(collision)	15.6 (50)	39.0	10^{-6}
Total current	.05	.09	Amp
Peak current(injection)	3.6	4.2	Amp
$<\beta>$	255	382	m
Tune	65	269	
Half cell length (assumed 90°cells)	200	300	m
Beam pipe radius	1.65	1.0	cm
Beam pipe	Cold, Cu	Warm, Al	

Arc lattice features

Cell parameters:

Phase advance: 90°
Cell length: 400-500 m



e.g, n=10=>40-50 m long dipoles

Number of cells:
Low field ~1300=>13000 dipoles (per ring)
High field ~260=>2600 dipoles (per ring)

Beam pipe physical aperture:
High field: round, 33 mm diameter
Low field: oval, 20 mm diameter (short axis)

Maximum beam size at 3 TeV injection: 1.2 mm (95%)

The cell length/aperture tradeoff:

Cell length L:

$$L \propto \frac{\gamma_I}{\varepsilon_n} r_{GF}^2, \; r_{GF} \propto d_c^2$$

r_{GF}="good-field" radius
d_c=coil diameter
γ_I=injection gamma=3000
ε_n=normalized emittance at injection

Longer cells are cheaper:
fewer correctors, quadrupoles, spools;
larger dispersion, so reduced strength chromatic sextupoles, for increased dynamic aperture

BUT

requires larger r_{GF} =>larger coil diameter, more expensive magnets

Additional constraints:

Low field: smaller apertures run into beam stability problems very rapidly

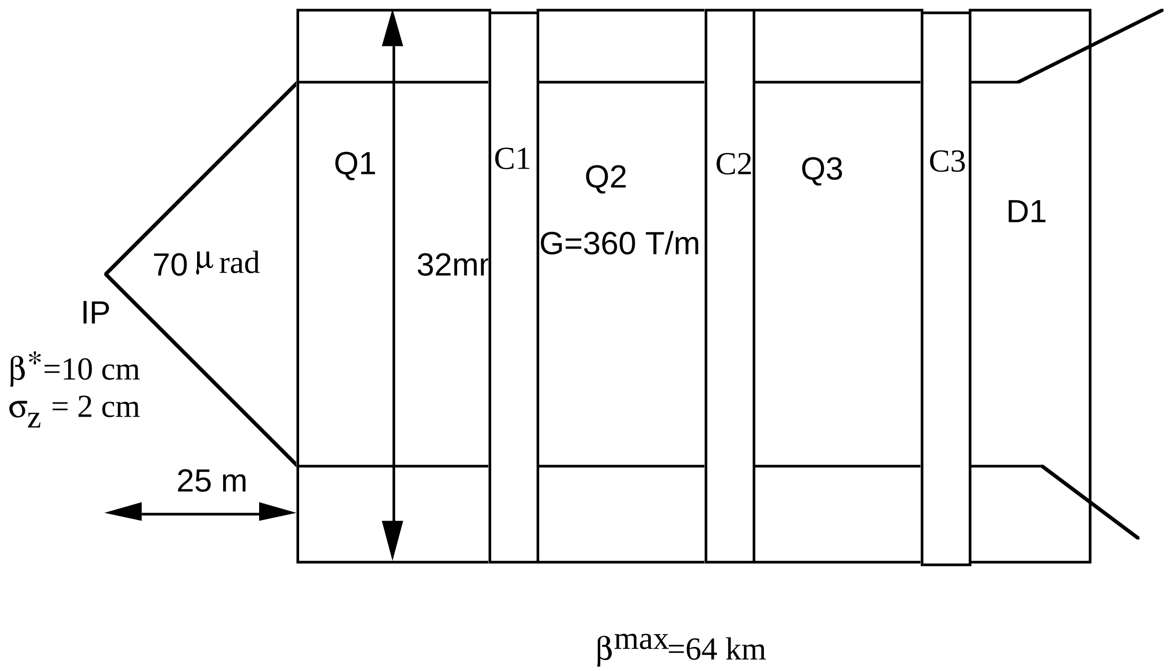
High field: cells longer than about 600 m have equilibrium emittance

$$\varepsilon_x \propto B^3 L^3$$

larger than 1π μm.

Interaction Region

Snowmass example design (Wei, Peggs, Goderre)



Triplet field quality required:
0.5 units of b5 @ 10 mm, without correction, end and body separate
need shimming and/or lumped correctors C1,C2,C3

May need local chromatic correction

Synchrotron radiation power: 100 W
Radiation from the IP: 6 kW

β^* limited by the crossing angle
To go below 10 cm:
Need crab crossing system and local chromatic correction

Interaction Region

FLAT BEAMS

(Peggs, Harrison, Pilat, Syphers)

If the vertical dispersion and the linear coupling are well-controlled in the arcs, the vertical emittance will damp to a value much smaller than the horizontal emittance, resulting *in flat beams* as in an electron storage ring. Such beams have several advantages in IR design over round beams.

The final focus optics can be a doublet, rather than a triplet

The peak beta function is typically x10 smaller, for the same β^*, than with round beam triplet optics=> field quality demands in the final focus quads are relaxed

Long-range tune shifts (mostly vertical) occuring before the beams separate tend to be smaller

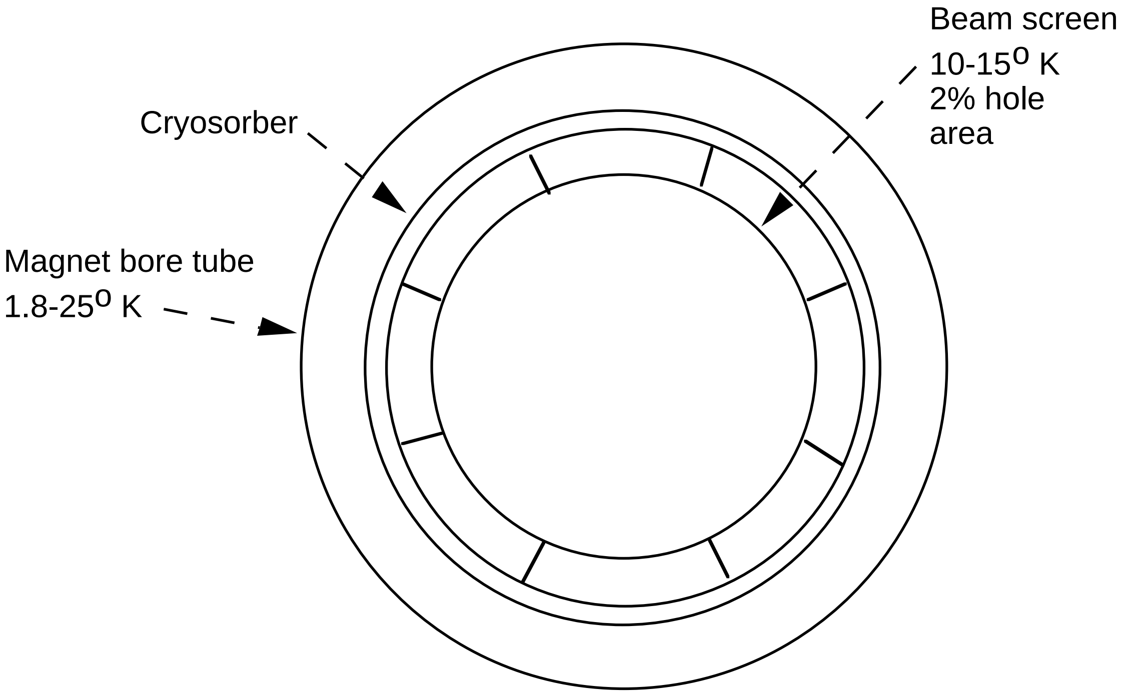
Vacuum

(W. Turner)

High Field

Synchrotron radiation power: 190 kW
Beam lifetime (τ_{pp} = 32 hrs)

Ringwide average vacuum requirement
for **$\tau_{gas} \sim 5\tau_{pp}$: 1.8 nTorr RTE CO**



Needs a liner with distributed cryosorber at 10-15° K to intercept synchrotron radiation and pump photodesorbed gases

Design simplifies if magnets use HTS at ~10-15°K
liner can be integrated to magnet bore tube

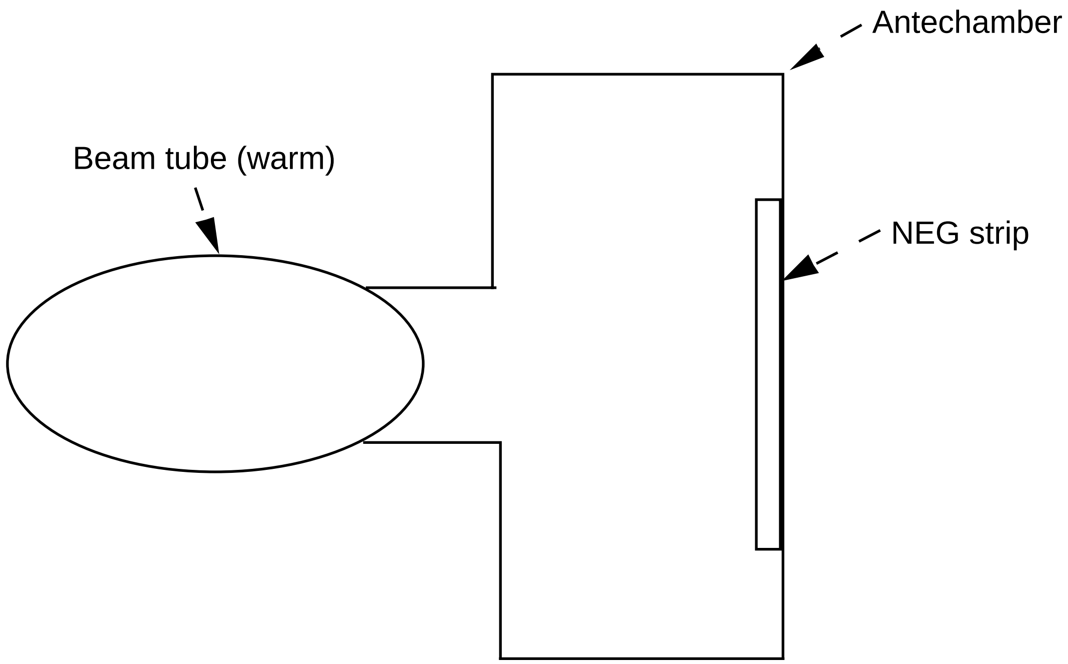
Magnets above~15° K: H_2 is no longer cryosorbed, liner must be cooled separately from the magnet
Magnets at ~1.8° K: no cryosorber needed

Vacuum

Low field
(warm bore)

Synchrotron radiation power: 50 kW
Beam lifetime (τ_{pp} = 130 hrs)

Ringwide average vacuum requirement
for **$\tau_{gas} \sim 5\tau_{pp}$: 0.25 nTorr RTE CO**



Requires the use of a distributed pumping system integrated with the magnets-as in an electron synchrotron.

Lumped pumps
for nonreactive CH_4 also required every 20 m

Cryogenics

(MacAshan, Mazur)

Table III: Comparison of Cryogenic Systems for Different RLHC Magnets

Collider Magnet Operating Temperature	Ring Size	Nº of Station (inc. 1 IR)	Total Heat Load at nominal temperature (kilowatts)					Ideal Pwr	Wall-Plug Power
	km		1.8 K	4.5 K	20 K	50 K	Leads (g/s)	MW	MW
Low Field									
NbTi, 4.5-5.0	646	9	0	247	0	0	200	17.2	66
Nb3Sn, 4.5-6.5	646	9	0	242	0	0	200	12.3	47
HTS, 20-25 K	646	9	0	0	242	0	200	3.7	14
High Field									
NbTi, 1.8 K	138	20	115	413	0	1644	920	45	180
Nb3Sn, 4.5 K	104	18	0	66	420	1080	940	18	72
HTS, 25 K	104	18	0	15	590	1080	940	14	54

Summary

Snowmass vlhc parameters:

100 TeV CM
Peak luminosity>10^{34} cm^{-2}sec^{-1}

High field machine:

~100 km circumference
radiation damped beam dynamics
12.5 T cold bore magnets
190 kW synchrotron radiation power
Flat beam collisions: doublet IR optics

Low field machine:

~650 km circumference
conventional (proton) beam dynamics
2 T warm bore magnets
50 kW synchrotron radiation power
Round beam collisions: triplet IR optics