LER & Transfer Line Lattice Design

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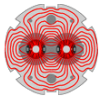
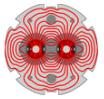


Introduction

- The Low Energy Ring (LER) is proposed as an alternative to rebuilding the SPS. Installed as a 2nd ring in the LHC tunnel during LHC downtime, the LER would accept 450 GeV protons from the SPS & accelerate them to 1.5 TeV for LHC injection.

- To avoid major civil construction the LER & LHC must share common beampipes at *least* through the IR1 & IR5 high luminosity detectors.



The LER Injector in the LHC Complex

- Proton injection from the SPS would continue to occur at IR's 2 & 8, with immediate transfer of the beams to the LER for acceleration to 1.5 TeV.

- The LER will have it’s own dedicated RF system at IR4 with high voltage (~20 MV) for slip-stacking manipulations.

- LHC momentum & betatron scraping at IR's 3 & 7 can not be used by the LER because primary collimators are located at the ends of the straights.

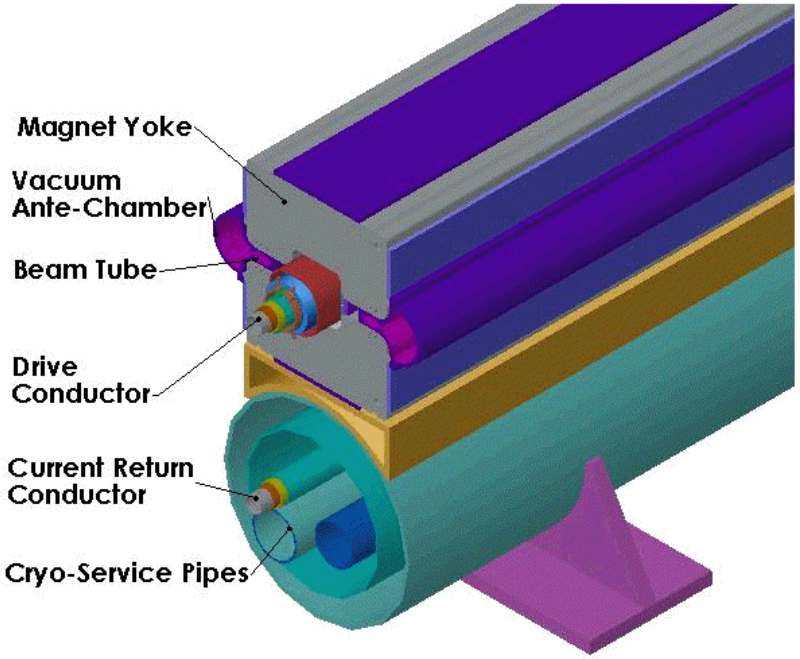
- It is not yet clear whether the LHC’s dump (IR6) can be accessed by the LER.

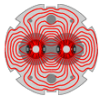
LARP

Arc & Dispersion Suppressor Cells

Magnets

- VLHC gradient magnets are proposed for the arcs & dispersion suppressors.
- Small (24 x 24 cm) physical cross-section, with 40 mm (H) x 28 mm (V) aperture.
- 1.60 T field at 71.0 kA.





Arc & Dispersion Suppressor Cells

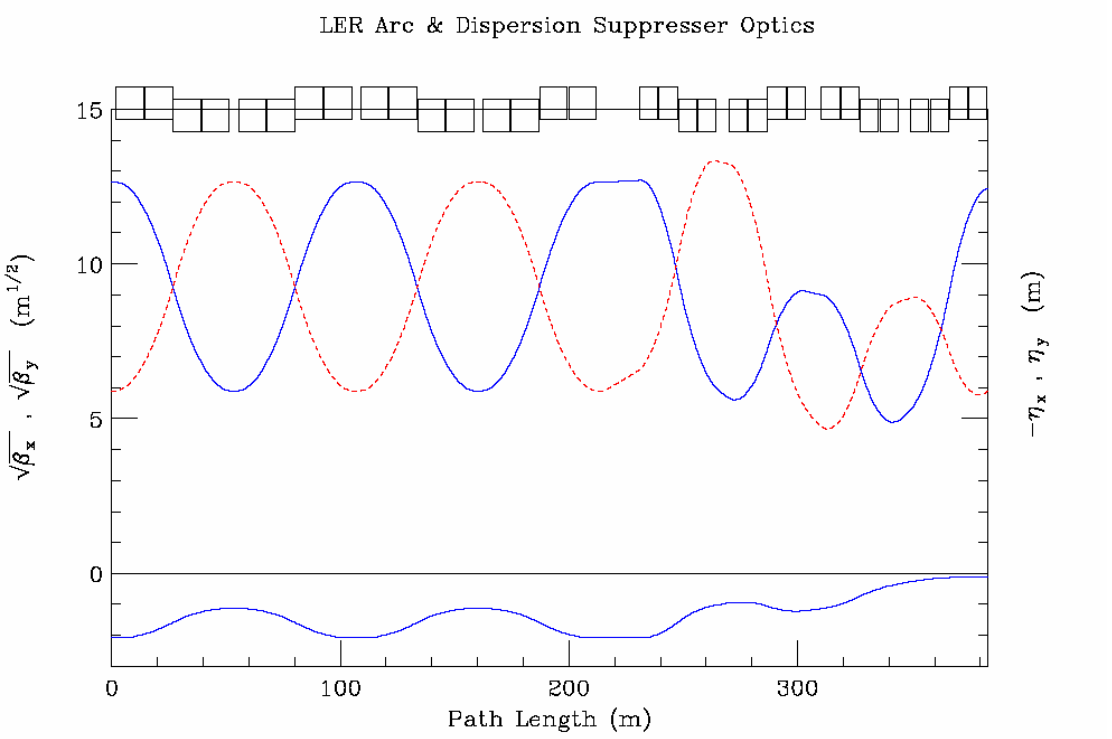
Lattice & Optics

Cell	L_{cell} (m)	L_{mag} (m)	# / cell	B (T)	B' (T/m)
Arc	106.9	12.0	8	1.595	±4.969
D.S.	80.2	8.0	8	1.595	±10.11

Magnet parameters at 1.5 TeV in the standard arc and DS cells.

- The LER arc optics are designed to replicate the LHC optics. With 90° of phase advance per cell, β(max) = 160 m (slightly less than LHC), and η(max) = 2.09 m.
- The LHC & LER dispersion suppressor units are *approximately* based on the $^{3}/_{4}$ arc length plus $^{2}/_{3}$ arc bend scheme.

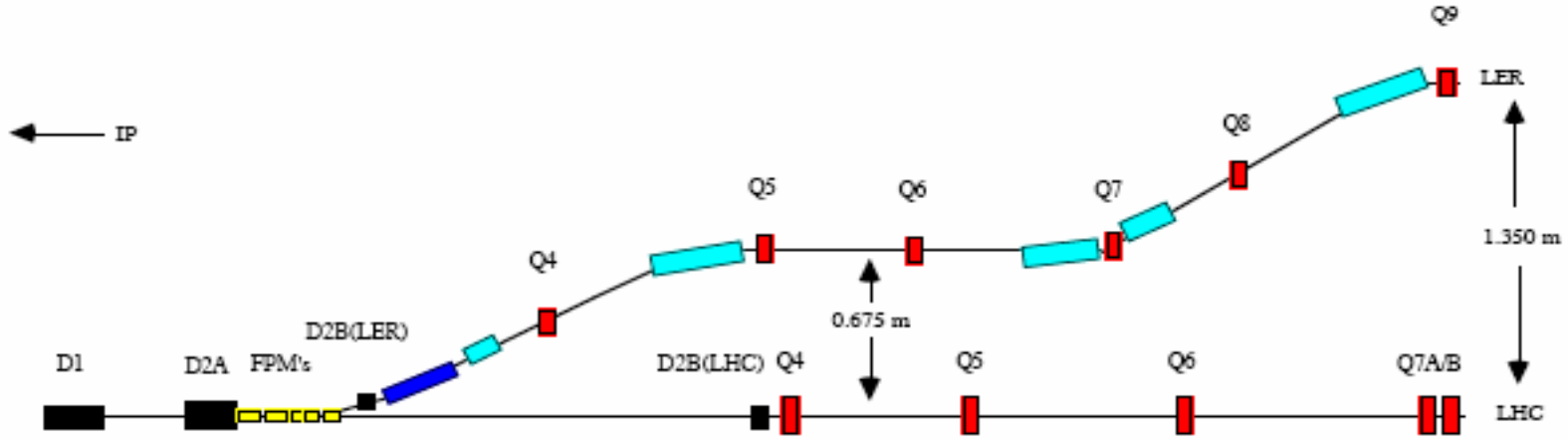
Arc & Dispersion Suppressor Cells



- In duplicating the LHC footprint the gradient magnet focusing centers align with the bend centers. This creates an imperfect β match across the dispersion suppressors.

IR1 & IR5 Insertions

Schematic of the Transfer Concept

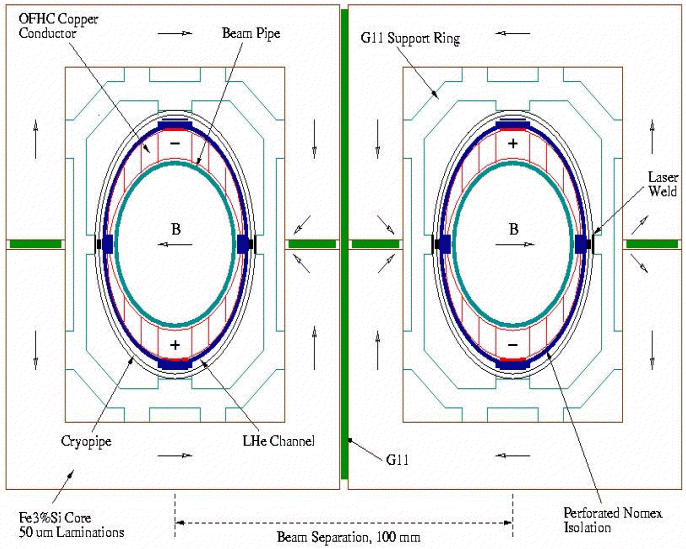


Right side of the IP from D1 to end of the straight, illustrating locations of vertical bends & quads in the LER transfer line relative to LHC elements.

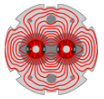
IR1 & IR5 Insertions

Fast Transfer Magnets

- Vertical transfer of beams from the LER to LHC requires pulsed magnets able to turn off in 3 μsec (head-tail gap in the bunch train).
- Optics modeling assumes single conductor magnets with B < 2 T @ 90kA.



Beams must be separated by ~110-120 mm horizontally before vertical bending can begin.



IR1 & IR5 Insertions

Vertical Beam Separation

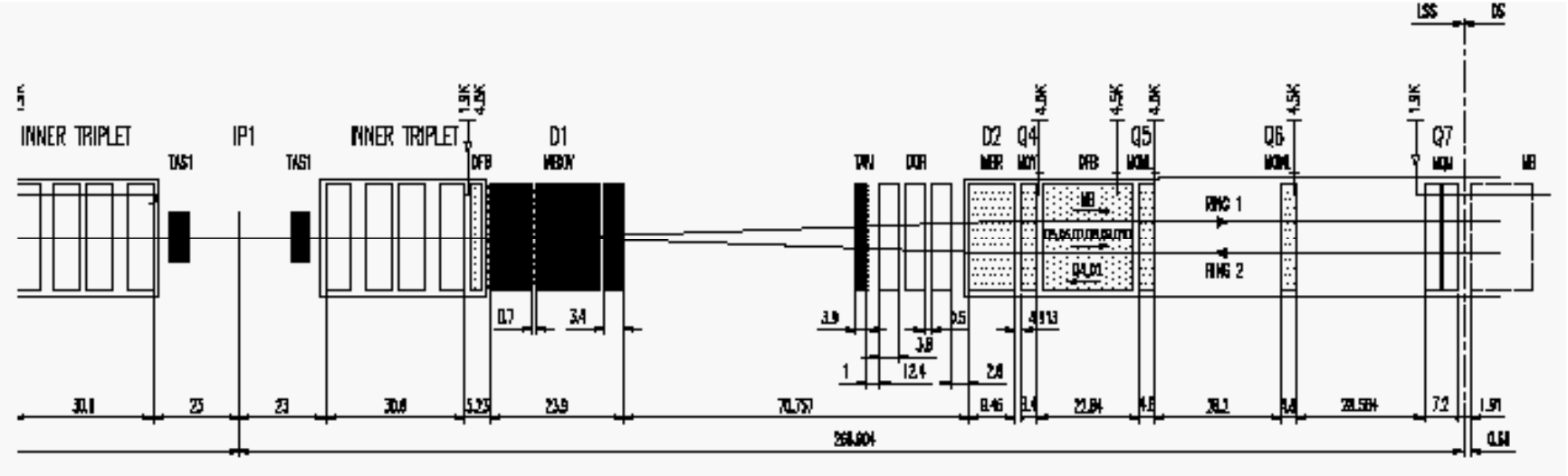
- To simplify optical matching of the vertical dispersion at the IP, elevation changes are accomplished in 2 steps — first to 0.675 m above the LHC to clear D2 & the LHC quads, and then another rise to flatten out at 1.35 m by the end of the straight section.

Type	#	L_{mag}(m)	B (T)	w (mm)	h (mm)
Fast Pulsed Dipoles					
V1	5	1.10	1.667	40	40
V2	4	1.00	1.503	40	50
V3	3	1.00	1.370	40	60
V4	2	1.00	1.255	40	70
V5	2	0.95	1.158	40	80
Normal Conducting					
D2B	1	1.00	2.14	30	30
V6	6	2.00	2.00	30	30
Superconducting					
V7	3	1.50	±8.00	30	30

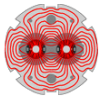
Parameters of the 1st set of vertical separation bends

IR1 & IR5 Insertions

Current LHC Horizontal Beam Separation



- In the baseline LHC design beams exiting the separation/ recombination D1 dipoles diverge at 2.22 mm/m. LER vertical separation magnets could not be installed farther away from the face of D2 than 37.6 m.



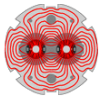
IR1 & IR5 Insertions

Horizontal Separation of the LER/LHC Beams

- The D1/D2 configuration needs to be re-designed to allow vertical bends to be installed close enough to D1 that the beams clear D2 & the downstream LHC quads.

Type	L_{mag} (m)	B (T)	S (m)	Alt. (mm)	Sep'n (mm)
LER & LHC Common Dipoles					
D1	8.96	1.70	8.96	0	27
D2A	7.70	1.70	29.13	0	130
LER Only					
$D2B_{LER}$	1.00	2.14	52.63	75	150
LHC Only					
$D2B_{LHC}$	1.26	1.70	104.10	0	194

A *concept* for horizontal separation-recombination of the LER & LHC beams at 1.5 TeV.



IR1 & IR5 Insertions

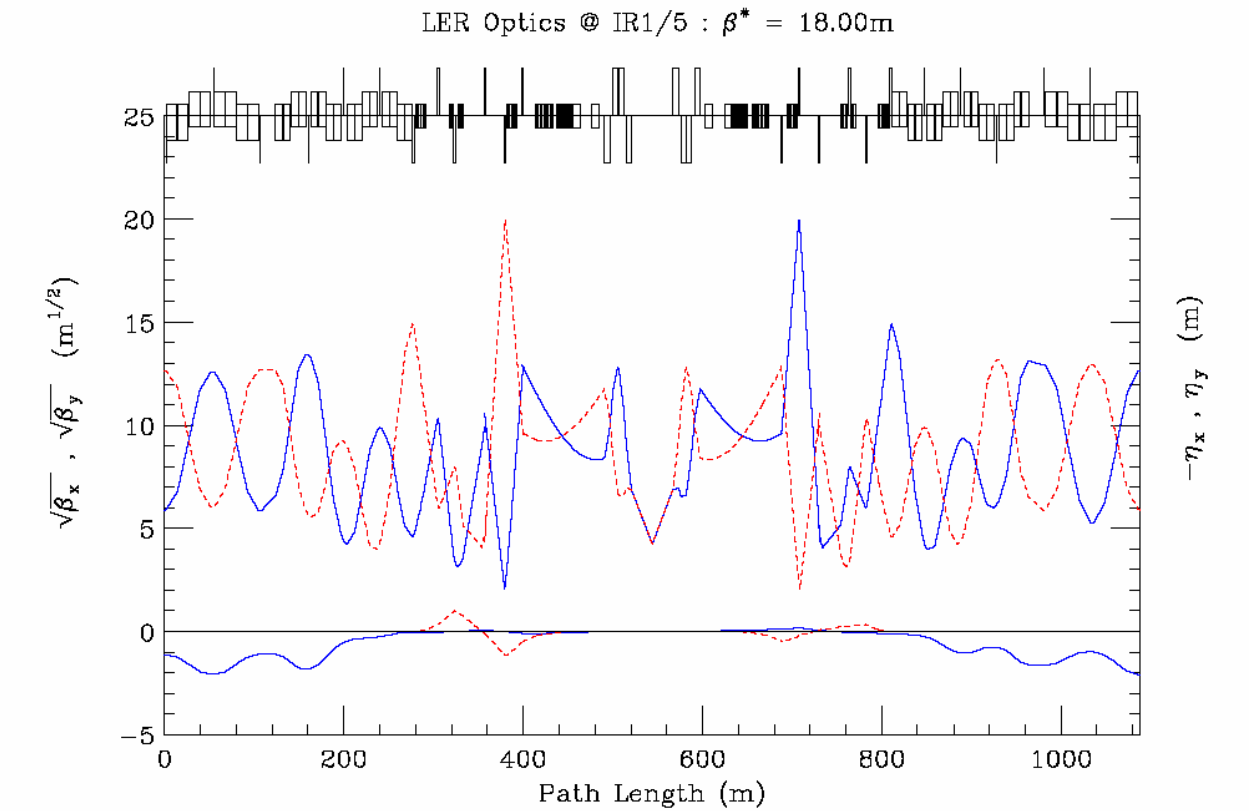
Lattice & Optics

- Optics of the LER are matched to the LHC injection β*'s of 18 m at the IP, with β(max) = 400 m in the straight.
- The LER straights have 2 more quads each side of the IP than the LHC to correct for vertical dispersion.

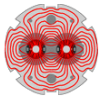
Straight Section Quads			
Quad #	L_{mag} (m)	B' (T/m)	
		u/s	d/s
1	6.30	-40.847	40.847
2a &2b	5.50	40.847	-40.847
3	6.30	-40.847	40.847
4	2.0	131.09	-131.09
5	2.0	-157.03	157.03
6	2.0	198.65	-198.65
7	2.0	-143.52	143.52
8	2.0	159.34	-159.34
9	2.0	-66.78	66.74

Straight section quadrupole parameters in LER insertions IR1 & IR5 at 1.5 TeV

IR1 & IR5 Insertions



Vertical bending is performed achromatically.
η* & η'* are ≡ 0 at the IP.



Summary

- A preliminary design of a 1.5 TeV LHC injector has been constructed that employs proven transmission-line gradient magnets from the VLHC study for the arc & dispersion suppressor lattice construction.

- A preliminary LER solution for IR1 & IR5 that matches LHC injection optics has also been found. This solution involves reconfiguration of the LHC horizontal separation/recombination scheme, and requires new pulsed dipoles to achieve vertical separation between the LER and LHC — both of which are currently under study with encouraging progress.

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