Estimated Inner Triplet Quadrupole Length and Aperture for Really Large Hadron Colliders of $E_{\text{beam}} = 30, 60$ and 100 TeV

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ABSTRACT

Inner triplet quadrupole length and aperture are estimated for Really Large Hadron Colliders (RLHC) of energies 30, 60 and 100 TeV. For a 300 T/m quadrupole, the length grows from 13 m (for $E_{\text{beam}} = 30$ TeV) to 28 m (for $E_{\text{beam}} = 100$ TeV). The required quadrupoles coil diameter is estimated to be 60-70 mm for all energies.

I. Introduction

This brief note presents a rough estimate of the lengths and apertures of inner triplet quadrupoles required for Really Large Hadron Colliders (RLHC) with beam energies of 30, 60 and 100 TeV. The estimates are made by scaling from the LHC insertion [1]. The LHC inner triplet is made of 4 identical 5.5 m long quadrupoles (Q1 and Q3 focusing and Q2a and Q2b defocusing) which are powered in series and operate at a gradient of 225 T/m. Two independently powered “trim” quadrupoles are located behind Q1 and Q3. They allow tuning of the triplet and provide the additional strength required of the two outer elements. They operate at 80 T/m (Q01) and 100 T/m (Q02). Our model of inner triplets only estimates the average strength, so we lump the trim quads with their corresponding main quads and compute an average magnetic length for the 4 units (Q1, Q2a, Q2b, Q3) of 5.8 m.

II. The model

To scale to other machines, we assume that the integrated focusing strength is proportional to the beam energy and inversely proportional to the focal length, which we take to be the distance from the IP to the center of the triplet (between Q2a and Q2b):

$$l_R G_R \frac{(L^* + 2l_R + a_R)}{E_R} = l_L G_L \frac{(L^* + 2l_L + a_L)}{E_L}$$

where the subscripts $L$ and $R$ refer to the LHC and RLHC respectively, $l$ is the quadrupole length, $G$ is the field gradient, $L^*$ is the distance from the IP to the front of Q1, and $a$ is additional length corresponding to magnet interconnections, correction coils, etc. Table I gives the values of the parameters used in this study.

A somewhat higher gradient than that planned for the LHC has been assumed, based on the expectation that the aperture required for the RLHC will be similar to that for the LHC and that there will be modest technical advances before the RLHC is built. The experimental free space has been lengthened slightly to allow more forward detectors or more absorbers between the IP and the triplet. The same amount of “fluff” (parameter $a$) is assumed for the RLHC as for the LHC, although it may tend to grow with $E$. However, the results are not very sensitive to this parameter.

We estimate $\beta_{\text{mae}} = b E^7_f / \beta^*$, where $L_f = L^* + 2l + a$, and $b$ is a fudge factor to make the answer come out right for known cases. For the LHC $\beta^* = 0.5$ m and $\beta_{\text{mae}} = 4400$ m, yielding $b = 1.65$.

The good field aperture must be large enough to contain about 10 beam $\sigma$. In addition, since both beams will pass through the single aperture of the quadrupoles with a small crossing angle, space for the beam separation must be included in the aperture estimate. To estimate the required aperture, we compute the maximum beam size assuming an rms transverse emittance of $3.75 \pi \mu\text{m-rad}$ (22.5 $\pi \mu\text{m-rad}$ in Fermilab 95% emittance units), the value assumed for the LHC and similar to that achieved in the Tevatron. The required good field radius is taken to be $13\sigma$, $3\sigma$ for the half beam - beam separation (the value used at LHC) and $10\sigma$ for a good dynamic aperture.

III. Results

Table II summerizes the results. With increasing beam energy, the quadrupole length grows from 13 to 28 m, but the required good field region decreases from 14 to 12 mm radius.

Several cross-checks have been made against more detailed calculations to verify this simple scaling computation. An explicit IR lattice for a 30 TeV RLHC has been computed in [2]. They take $L^* = 20$ m, $G = 300$ T/m and use an average $l = 14$ m. For these conditions we compute $l = 13.8$ m, in reasonable agreement. For $\beta^* = 0.1$ m in [2], $\beta_{\text{mae}} \approx 41$ km (average between the two planes); we compute $\beta_{\text{mae}} = 42$ km. For the LHC we compute $r_{GR} = 20$ mm in reasonable agreement.

*Fermilab is operated by Universities Research Association, Inc. under contract with the United States Department of Energy.
with more detailed calculations [3] [4].

The actual $r_{GF}$ should be several mm larger than it is given in Table II due to tolerances, orbit errors, etc. [1]. The physical aperture needs to be about twice the $r_{GF}$ to ensure the field quality, and it must be at least 8 to 10 mm larger than $r_{GF}$ to allow adequate internal absorbers to limit beam energy deposition in the coils[5]. Thus quadrupoles with coil diameters of 60-70 mm seem appropriate, which is consistent with our assumed $G = 300$ T/m.

REFERENCES


