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A straw man numerology for SSC accelerator circumferences

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Introduction

The circumferences of the SSC accelerators, LEB, MEB, HEB and collider, must all be an integer number times λ_{RF}, the RF wavelength. So, the ratio of circumferences of two neighboring accelerators, C_2:C_1 is a rational fraction. In practice C_1 and C_2 have a range of possible values, typically within a few percent of a nominal value. Without the benefit of constraints, there is a very large number of possible rational fractions for each accelerator pair.

This note first presents three constraints which reduce the number of solutions significantly. Then it goes through the exercise of applying these constraints to arrive at a straw man set of proposed parameters for the four accelerators. Finally, some of the advantages and disadvantages of the constraints and their application are presented. The intention throughout is not to propose parameters, but to propose - for the purposes of discussion - one way of setting them.

Constraints

The same three constraints apply to all four accelerators. They are -

1. The circumference is an integer multiple of 72 S_B, or 360 meters, where $S_B = 5.0$ meters is the nominal bunch spacing. Note that $S_B = 6\,\lambda_{RF}$, as discussed in SSCL-A-1. This allows the nominal bunch spacing to be increased by any factor of $72 = 2^3.3^2$ while still maintaining evenly spaced bunches.

2. The circumference is an integer multiple of $H_{1/2}$, the half cell length. This loosely implies that, as in the collider lattice, each lattice is constructed of modules which themselves are measured in units of half cell lengths.

3. The half cell length is an integer number times $S_B/2$, or 2.5 meters, the nominal length between collisions. Thus the HEB half cell length, for example, which is currently listed as 39.116 meters, would migrate to either 37.5 or 40.0 meters.

One application of the constraints

The general procedure in filling out Table 1 below goes as follows. Take the nominal values for C and $H_{1/2}$, as reported in the 7/19/89 parameter list. Examine four cases, corresponding to two C and two $H_{1/2}$ values just above and just below their nominal values, according to the modular constraints 1 and 3 above. Calculate the number of half cells in one circumference to see if it is an integer - in which case constraint 2 is passed - for each of the four cases. In the case of the collider this procedure is unnecessary, since the values are already satisfactory.

According to this procedure, then, the results in Table 1 show that the circumferences of the colliders are in the ratio 241 : 30 : 11 : 1, where the unit of length is 360 meters. The half cell length of the HEB may be either 37.5 or 40.0 meters, and of the MEB is 22.5 meters. The LEB is a special case, in that there is no reasonably close values of the LEB half cell length which satisfies constraint 3.

Advantages and disadvantages

A direct result of the 241 : 30 ratio of collider to HEB circumferences is that there are 241 possible locations into which a reference bunch may be injected, with a maximum "seek" time of 241 HEB turns, or about 9 milliseconds. In order for the bunch to be placed into any of the possible locations separated by S_B, fine tuning may be performed by using RF cogging. For example, if the average radial displacement in the HEB is $10 / 2\pi$ millimeters, then the reference bunch moves one centimeter per HEB turn, at an equivalent speed of 278 meters per second. It therefore takes 0.65 seconds in order to move $\frac{1}{2.241}$ of the circumference of the collider. By contrast, if the circumference ratio were exactly 8 to 1, it would take 0.3 milliseconds for the coarse adjustment, and 19.4 seconds for the fine cogging adjustment. This argument disfavors a low order rational fraction, especially between the larger machines.

Accelerator	C [m]	C / 360	C / S_B	$H_{1/2}$ [m]	$C / H_{1/2}$	Comment
Collider	86,760	241	$2^3.3^2.241$	90.0	$2^2.241$	nominal
HEB	10,701	****	****	39.1	****	nominal
	10,440	29	$2^3.3^2.29$	37.5	****	FAIL
				40.0	$3^2.29$	$C/H_{1/2}$ is odd
	10,800	30	$2^4.3^3.5$	37.5	$2^5.3^2$	PASS
				40.0	$2.3^3.5$	PASS
MEB	≈3,900	****	****	23.5	****	nominal
	3600	10	$2^4.3^2.5$	22.5	$2^5.5$	far from 3,900
				25.0	$2^4.3^2$	far from 3,900
	3960	11	$2^3.3^2.11$	22.5	$2^4.11$	PASS
				25.0	****	FAIL
LEB	405	****	****	≈3.6	****	nominal
	360	1	$2^3.3^2$	?	?	PASS (?)

Table 1. Circumference parameters before and after application of the constraints.

When a bunch train is injected into an accelerator, there must be an empty gap in order for the injection kickers to rise (and fall). There must also be a somewhat larger gap for the extraction (or abort) kickers to rise. See, for example, figure 2.7 in SSC-164 by L. K. Chen and M. A.Furman. If accurate values of these times are available, then it is possible to dead reckon a circumference ratio which is just larger than an integer, in order that all the injected trains are identical except that there is a larger extraction gap between two of them. For example, if the collider/HEB ratio is 241 / 30 = 8.033.. , then the extra distance between 8 identical trains is 360 meters, or 1.2 microseconds. This is not enough for a 20 TeV abort kicker. However, the rise and fall times are probably not well known, and the modularity of this scheme is uncomfortably large - forcing circumference changes at the 5% level. With the possibility of bunch knockout schemes in an early accelerator, and with the flexibility of transferring a reference bunch into any desired location, it should anyway be possible to carve an appropriately large extraction gap, while at the same time ensuring a maximum filling fraction.

Constraint 3 allows collisions to take place in an accelerator with no further conditions except that the distance between neighboring interaction points should be an integer number of half cell lengths. Collisions are also guaranteed if the bunch spacing is increased by any factor of the number of collision spacings per half cell.

If the modularity of the circumferences is too restrictive at the 360 meter level, it may be reduced to 180 meters, corresponding to 36 nominally spaced bunches. Then the nominal bunch spacing may be increased by any factor of 36, while still maintaining an even distribution of bunches in each accelerator. In this sense constraint 1 takes a variable parameter, unlike the other two constraints.

SSC RF parameters, with 90 meter half cell length

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With the change in half cell length to $H_{1/2} = 90$ meters, it is necessary to adjust the nominal bunch spacing, S_B, and hence the RF wavelength, λ_{RF}, to maintain an integer number of bunch CROSSINGS, N_B, per half cell, so that

$$N_B \frac{S_B}{2} = H_{1/2}$$

We propose $N_B = 36$, so that $S_B = 5.0$ meters, slightly larger than the CDR value of 4.8 meters, and the most recent value of 4.774 meters. This guarantees that the nominal bunch spacing can be increased by factors which divide exactly into $36 = 2^2\, 3^2$, that is, 2,3,4,6,9,12,18 and 36 . Other factors may also be possible, depending on the numbers of half cell lengths between adjacent interaction points - both the short way and the long way, around an arc. These numbers must be integers.

The bunch spacing itself must be an integer number of wavelengths, $S_B = N_{RF}\, \lambda_{RF}$, so that

$$\lambda_{RF} = \frac{2\, H_{1/2}}{N_B\, N_{RF}}$$

Maintaining the old value of $N_{RF} = 6$ leads to a value of $\lambda_{RF} = 0.8333..$ meters, and an RF frequency of approximately 360 MHz (assuming $c = 3\ 10^8$ meters per second). This value, very close to the PEP, LEP and SPEAR values of 353 Mhz, 353MHz, and 358MHz, is somewhat less than the most recent SSC value, 377.1 MHz.