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SSC Beam Dynamics Scaled to the Eloisatron[★]

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Introduction

As crossections drop as E^{-2} a desirable target for a 100 TeV the Eloisatron would be to achieve luminosities $\sim 1.10^{35}$cm^2/sec. To understand the impact of such an objective we have compared parameters for the SSC and Eloisatron to differentiate areas which involve considerable extrapolations from current technologies from those which represent more conventional scale-ups. Synchrotron radiation losses per m for the same guide magnetic field associated with such luminosities would be up by $E^2 \times I$ where E is the energy and I is the circulating current. This would result in energy densities of $\sim$ 250 times the nominal SSC values. The SSC is already limited by installed refrigeration power and if the circulating current was to be increased would have to use liners at liquid nitrogen temperatures to intercept the radiation as is proposed for the LHC. This issue was the subject of lively discussion at the workshop and is dealt with elsewhere by other authors. This author believed that the radiation could be intercepted by room temperature catchers spaced every 15-25 m around the ring.

Table 1 presents the author's choice for a consistent set of parameters scaled from the SSC current design. To obtain the requisite luminosities it assumes similar bunch spacing but circulating currents an order of magnitude larger than at the SSC. The SSC already uses a bunch spacing as small as 5 m and further reduction does not appear easy. The justification for the choice of bore for the magnets, emittances and attainable luminosities are discussed below. A further section looks into whether seismic ground disturbances might cause unacceptable emittance growth. The conclusion of this section is that careful use of current design practices should be adequate and that it is unlikely that exotic vibration free mounts will be required.

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Choice of Aperture

Significant costs or savings are associated with the choice of collider aperture. Typically the machine tune, ν, scales as

$$\nu \propto \sqrt{\frac{E}{B_{max}}}$$

where E_{max} is the maximum energy and B_{max} is the maximum magnetic field.

Thus the betatron tune of the Eloisatron could be expected to scale from the current SSC choice of 100 to around 200 and the β values by a comparable factor two.

Invariant brightnesses (particles per bunch/invariant emittance) are largely set at the start of the injector chain though without care degradation can occur during the acceleration cycle. We would propose values $\sim$ 3 times nominal at the SSC. Such values are routinely achieved and used at the Tevatron and SPS. The beam beam induced tune shift parameter is directly proportional to the invariant brightness and higher values are likely to lead to unacceptable high tune shifts using currents 15 times greater than for the SSC and taking into account the adiabatic damping during acceleration gives comparable actual emittances (not normalized emittances) at injection into the SSC and Eloisatron main colliders. Tracking studies made at the SSC show that long term dynamic apertures scale as the magnetic bore to the 1.5 power. Therefore even allowing for less safety margins than presently required for the SSC we can expect magnetic apertures requirements comparable or perhaps slightly less than for the SSC of a 4-5 cm bore for the main Eloisatron collider. Therefore linear costs for the Eloisatron should be comparable to those for the SSC.

Beam Beam Limits to Luminosities

The currently projected colliders are two ring machines with beams crossing at an angle. This crossing angle is required to be such as to separate long distance crossings by the order of 10σ. If the angle is too small the effects of long distance collisions become prohibitive, if too large the geometric overlap of the beams is poor and there is a loss in luminosity. 10σ is an estimate of the expected tradeoff between these factors. The author would expect the use of warm bore dipole bends prior to the first IR quad to provide increased separation of the beams 40 or 50 metres downstream from the IPs. If this is done the same considerations apply to the beam beam limitations at the Eloisatron and at the SSC or LHC. On this basis a total (for all IRs) head-on beam-beam tune shift around the machine in the neighborhood of .01-.02 seems in accord with both current experience and extensive computer modeling for the SSC by the author.

Effects From Ground Motion

These effects have been discussed for the SSC in a number of reports including the early work of Fischer and Morton 1. The author has investigated aspects of this problem via simulations.

The results of the above work can be summarized as follows. Physical movement of quadrupoles results in moving both the equilibrium orbits and causing motion of the beam centroids about the equilibrium orbit. The motion about the equilibrium orbit will decohere in time and result in filamentation or emittance growth. Such movements are best parameterized in terms of a power spectrum in frequency. The power law spectrum below the betatron rotation frequency ($\sim 250KHz$) causes adiabatic translations of the equilibrium orbits but minimal emittance growth. At the betatron frequency (or modulo the rotation frequency)motion is induced about the equilibrium orbit causing stochastic emittance growth. High frequency components of ground motion are heavily attenuated and the power spectrum falls sharply as a function of frequency so that at these frequencies the power spectrum can be relatively low. However in the absence of adequate "policing" cultural or man made disturbances resulting for instance from traffic, construction or vibration from compressors can dominate the power spectrum at high frequencies. However with care such sources can be controlled.

In general therefore there are two regions that can cause problems. The first is motion of the equilibrium orbits causing the countercirculating beams to miss each other. This is a few Hz effect and can be controlled by feed back to ensure beam centering. The favored method to accomplish this is the "Jostlein feed back" which puts a small circular sweep motion on one of the beams. The relative luminosity is measured with a forward calorimetric detector. If the beams are centered there will be no modulation of the luminosity. The hadronic debris from the IPs is in the neighborhood of 100 KWatts and therefore fast luminosity measurements of high precision are quite feasible. If the beams are off center there will be a modulation signal at the sweep frequency that can be used to provide feedback. The synchrotron betatron coupling effects caused by the sweep frequency are small compared to those produced by the beam crossing angle in association with synchronous motion and therefore will cause only minimal further degradation of beam beam limits. This has been confirmed by simulation studies by the author.

The other region of interest is the few hundred Hz region. Provided cultural noise sources are kept small, careful but conventional support isolation should remove any residual problems. One caveat is that if the radius of the machine should be very substantially increased to cut the guide field and hence the associated synchrotron radiation problems the damaging power spectrum components would be moved into the 50-100 Hz region and this could require more exotic isolation techniques.

Conclusions

Over and above the obvious political problems in obtaining funding at a level five times greater than for the SSC and maintaining the requisite level of enthusiasm of physicists attached to such an enormous enterprise the difficulties appear to lie in the engineering domain. The problem of synchrotron radiation power was alluded to in the introduction.

The stored beam energy is up by a factor two hundred from the SSC. Already at the SSC an accidental loss of beam in the accelerator would have catastrophic consequences. Thus the SSC already will require a 100% efficient beam abort system and always provided that this works it should work for the Eloisatron. Of course the engineering of the scrapers, protection collimators and beam dump(s) is certainly not trivial.

The currents required are up by an order of magnitude but the assumed beam-beam limits are those presently observed and coherent instabilities while a function of peak or average circulating currents are also an inverse function of beam energy. This is therefore not a large extrapolation of existing practices.

The required apertures of the magnets will be comparable to those for the SSC.

The tolerances for preventing emittance growth associated with magnet vibrations are more severe for the Eloisatron but do not appear to require exotic technologies, always provided full superconducting guide field are used.

Thus this author concludes that a reasonable luminosity goal for the Eloisatron is indeed in the range of 1.10^{34} cm^2/sec luminosities up to 1.10^{35} cm^2/sec.

Table 1

Eloisatron IR Parameters Compared With SSC

		Ratio to SSC
Energy [Tev]	100.	5.
Circum [Km]	300.	4.
Bunch separation [m]	5.	same
IPs	4.	same
Magnet bore [cm]	6.	same
IP to first IR quad [m]	20.	6.
Chromaticity/ip	100.	2.
β_{max} [m]	40,000	4.
Stored energy	200.	
IP losses [energy]	500.	
Synchrotron power/m	$/sim300$	
Luminosity[1e35],[nom]	1.	100.
Current [1e11/bunch],[nom]	115.	
$\beta*_{ip}$ [cm],[nom]	200.	4.
Emittance [1e-9 cm rad],[nom]	4.	1.
Crossing angle[microrad],[nom]	70.	0.6
σ_{long} [cm],[nom]	12.	2.
Beam overlap [],[nom]	.6	same
Beam size σ_{ip} [microns],[nom]	7.	1.5
$\delta\nu_{ho}$/ip,[nom]	.002	3.
$\delta\nu_{lr}$/ip ,[nom]	.004	2.
Dynamic aperture [σ][nom]	>10.	same

REFERENCES

1. Ground motion tolerances for the SSC. G.E.Fischer, P.L.Morton SLAC,SLAC-PUB-3870, Jan 1986.