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LUMINOSITY DEPLETION IN A COLLIDER FOR HEAVY IONS BEYOND RHIC ENERGIES

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Recently there has been some question on the feasibility of a heavy–ion collider at energies larger than RHIC, for instance in either the LHC or SSC.

The issue that has been raised deals with very large cross–section effects peculiar to heavy–ion colliding beams like for instance electron–pair production. These cross–sections have been estimated to approach the 100 barn values and cause some concern on the luminosity depletion in the collider. Both the luminosity requirements and the cross–section values could increase with the energy and cause a shortening of the luminosity lifetime.

A closer examination of the problem, nevertheless, shows that the problem does not exist. In a collider like the SSC the beams can be configured easily to cause the least of the luminosity depletion.

Let us assume the case of bunched beams colliding head–on. In the limit of short bunches the luminosity is

$$L = \frac{N^2 f_{rev} \gamma M}{4\pi \epsilon_N \beta^*} \tag{1}$$

where

N = number of ions per bunch
f_{rev} = revolution frequency
M = number of bunches per beam
ϵ_N = normalized rms emittance $\equiv \sigma^2/\beta^*$
β^* = amplitude lattice function at the crossing point
γ = relativistic energy factor

We shall assume in the following only one (high luminosity) crossing in the collider.

Let σ_0 denote the cross–section of the event under consideration which causes most of the luminosity depletion. The average number of interactions per bunch crossing is

$$< n >= \frac{L\sigma_0}{M f_{rev}} \tag{2}$$

Another important parameter is the beam–beam tune–shift

$$\Delta\nu_{BB} = \frac{r_0 N Q^2}{4\pi\epsilon_N A} \tag{3}$$

where

Q = charge state

A = atomic mass number

$r_0 = 1.535 \times 10^{-18}$ m

Finally the luminosity lifetime (with only one crossing) is given by

$$\tau^{-1} = -\frac{1}{L}\frac{dL}{dt} \;=\; 2\,\frac{\sigma_0 L}{NM} \tag{4}$$

where obviously NM is the total number of ions in one beam.

Procedure

For a given collider and energy, we shall require a luminosity L and lifetime τ. The cross–section σ_0 is also assumed to be known; it might carry an energy dependence. From (4) then we estimate the total number of ions in one beam

$$NM = 2\sigma_0 L\tau \tag{5}$$

We use eq. (1) for the luminosity to derive the ratio β^*/N required to achieve the proposed luminosity. After some cancellation we obtain

$$\frac{\beta^*}{N} = \frac{\gamma f_{rev}\sigma_0\tau}{2\pi\epsilon_N} \tag{6}$$

which does not depend on the luminosity. Moreover the size of the collider increases roughly with the beam energy, so that γf_{rev} is about constant and the ratio β^*/N does not depend on the energy either, (except for the dependence of σ_0 on E).

For large energies, intrabeam scattering is less important. In this case ϵ_N is an invariant emittance which depends solely on the performance of the source. From RHIC studies

$$\epsilon_N = 1.7 mm \cdot mrad$$

One then estimates the number of ions per bunch N from the ratio β^*/N assuming a reasonable value of $\beta^* \geq 0.5$ m. From the product NM, one then derives the number of bunches M per beam.

Finally the average number of interactions $< n >$ and the beam–beam tune–shift $\Delta\nu_{BB}$ are calculated using eqs. (2) and (3).

The procedure outlined above has been applied twice: once for RHIC and then for the SSC.

The case for RHIC has been recovered according to the CDR with a lifetime of 70 hours.

For the case of the SSC we have assumed a larger cross–section σ_0 and a large luminosity. We made an estimate for a 20 hour lifetime. The solution we found is quite feasible. The beam intensity in the SSC ought to be 25 times that of RHIC. With the same source this requires a filling time of 25 minutes per ring consistent with the proton mode of injection. Also the bunch spacing is 5.8 meter consistent with the SSC RF design.

Observe that because of the much larger energy and the lower intensity per bunch, intrabeam scattering should not be existing at all.

	RHIC	SSC
Energy	100 GeV/A	8 TeV/A
γ	108	8530
f_{rev}	78.3 KHz	3.61 KHz
ϵ_N	1.7 mm·mrad	1.7 mm·mrad
σ_0	100 barn	1000 barn
L	1.0×10^{27}cm^{-2}s^{-1}	1.0×10^{28}cm^{-2}s^{-1}
τ	70 hours	20 hours
β^*/N	2×10^{-9}	2×10^{-8} m
β^*	2 m	2 m
N	1.0×10^9	1.0×10^8
NM	5.7×10^{10}	1.44×10^{12}
M	57	14,400
$\Delta\nu$	0.0023	0.00023
$< n >$	0.025	0.19