PARAMETERS FOR eRHIC *

R. B. Palmer, C.Montag, BNL, Upton, Long Island, New York, USA

Abstract

Requirements for the proposed BNL eRHIC Ring-Ring Electron Ion Collider (EIC) are discussed, together with the dependence of luminosity with the beam divergence and forward proton acceptance.

Parameters are given for four cases. The first two use no cooling and could represent a first phase of operation. The next two use strong cooling and increased beam currents. In each case parameters are given that 1) meets the requirement for forward proton acceptance, and 2) has somewhat higher divergences giving somewhat higher luminosity.

INTRODUCTION

The primary requirements for eRHIC are a center of mass energy range from 32 to 140 GeV, and a Luminosity of up to 10^{34} cm^{-2}s^{-1}. Much physics could initially be done with lower luminosity, but it is the experience of almost all nuclear high energy physics, that after early running at lower luminosity, a need for increases appears.

For the important study of Deeply Virtual Compton Scattering (DVCS) there is a requirement that the horizontal proton divergence, multiplied by the proton momentum, be less than 200 MeV/c. Meeting this requirement lowers the luminosity or requires larger vertical divergences. But both for this study, and others, vertical divergence and higher luminosity may be more important. All divergences should be low so that the initial states are known with as small error as possible.

Divergences are related to the beam emittances and IR focusing strengths, both of which effect spot size and luminosity. Momentum spreads are related to longitudinal emittance and bunch length, both of which depend on rf and effect Intra-Beam Scattering (IBS). IBS time constants set the run times without cooling, or the cooling strength needed to restrain emittance growth during a run.

Table 1: Constraints

I_p	A	1.35
I_e	A	2.8
$P_p\ \sigma'_{x,p}$	MeV/c	200
ξ_p		0.015
ξ_e		0.1
ΔQ Space charge		0.08
$\sigma'_{y,p}$	(mrad)	0.4
$\sigma'_{x,e}$	(mrad)	0.12
$\sigma'_{y,e}$	(mrad)	0.23
Synch Power	(MW)	10

* Work supported by US Department of Energy under contract DE-AC02-98CH10886

LUMINOSITY

The luminosity of a collider is:

$$\mathcal{L} = f\,\frac{N_p N_e}{4\pi\sigma_x\sigma_y} \tag{1}$$

where the σ_x and σ_y beam dimensions at the IP are the same for both protons and electrons and depend on their geometric emittances $\epsilon_{x,y}$ and $\beta^*_{x,y}$s.

The beam Powers are:

$$P_{p,e} = f\ N_{\rm bunch}\ N_{p,e}\ \gamma_{p,e}\ m_{p,e} \tag{2}$$

$$\sigma_{p,e,x,y} = \sqrt{\epsilon_{p,e,x,y}\beta_{p,e,x,y}} \tag{3}$$

The beam divergences are given by

$$\sigma'_{p,e,x,y} = \sqrt{\frac{\epsilon_{p,e,x,y}}{\beta_{p,e,x,y}}} \tag{4}$$

Limits on the beam powers come from synchrotron radiation and other practical considerations. For this study, the maximum proton current is limited to 1.35 Amps, and that of the electrons to 2.8 Amps, based on the PEP II achievement of 3.0 Amps in their LE ring.

The numbers of particles per bunch $N_{p,e}$ are constrained by the beam-beam tune shifts $\xi_{x,y,e,p}$ (also known as beam-beam parameters) induced by each beam on the other. Their strength is given by:

$$\xi_{p,e,x,y} = \frac{r_{p,e}}{2\pi}\,\frac{N_{e,p}}{\epsilon_{p,e}\gamma_{p,e}}\,\frac{1}{1+\sigma_{y,x}/\sigma_{x,y}} \tag{5}$$

From eq. 1, 3, and 2:

$$\mathcal{L}\ \propto\ \sqrt{(1+K)(1+1/K)}\ \frac{\gamma_{p,e}I_{p,e}\,\xi_{p,e,x,y}}{\beta^*_{p,e,x,y}} \tag{6}$$

where $K = \sigma_x/\sigma_y$. $\gamma_{p,e}$ are the geometric means of the p and e relativistic velocities, $I_{p,e}$ are the geometric mean p and e currents, $\xi, \beta*$ are the geometric averages over permutations of the subscripts: p and e, x and y. .

The ξ_ps for the protons are bounded by beam stability considerations at $\approx$ 0.015. In a ring-ring EIC the ξ_es are bounded by stability at $\approx$ 0.1. This is higher than for protons because of the electron synchrotron damping. In a linac-ring EIC the ξ_es of the electrons can be much higher because the electrons will soon be discarded and can suffer significant emittance growth. But this advantage is offset by practical limits on the electron current ($\approx$ 50 mA), while an electron ring, like PEP II low energy ring, can store and collide currents of 3 A. These and other constraints are listed in Table 1.

From eq. 6, for fixed $I, \gamma, \xi, \beta*$, luminosity can be increased with K $\gg$ 1, giving $\mathcal{L}\ \propto \sqrt{K}$.

Table 2: Table of Parameters

		MLHA		MLHD		HLHA		HLHD	
		p	e	p	e	p	e	p	e
E	GeV	275	10	275	10	275	10	275	10
N	10^{10}	10.9	30.1	11.1	30.5	5.6	15.2	5.6	15.2
$N_{bunches}$		330	330	330	330	1320	1320	1320	1320
ϵ_x	nm	16.5	24.5	16.1	24.2	9.3	12.7	9.3	12.7
(ϵ_{Nx})	μm	4.8	479	4.7	474	2.7	249	2.7	249
ϵ_y	nm	6.1	3.95	6.1	3.47	.4	.24	.4	.24
(ϵ_{Ny})	μm	1.8	77	1.8	68	.1	5	.1	5
(ϵ_z)	eVsec	0.92		0.92		0.46		0.46	
β_x	cm	593.5	399.5	94.4	62.5	283	208	141.5	104
β_y	cm	4.2	6.5	4.2	7.4	2.1	3.7	1	1.9
σ_x	μm	313	313	123	123	162	163	115	115
σ_y	μm	16	16	16	16	2.9	3	2	2.1
σ'_x	μrad	53	78	131	197	57	78	81	111
σ'_y	μrad	381	247	381	217	138	81	195	114
ξ_x		.014	.097	.014	.093	.013	.099	.013	.099
ξ_y		.002	.031	.005	.084	.006	.094	.006	.094
ΔQ		.002	0	.002	0	.026	0	.035	0
σ_z	cm	8	.8	8	1	4	.8	4	.8
I	A	.45	1.24	.46	1.26	.93	2.51	.93	2.51
SR	MW		4.7		4.8		9.6		9.6
Luminosity	$10^{33}\ cm^{-2}s^{-1}$	1.1		2.7		12.7		20.8	

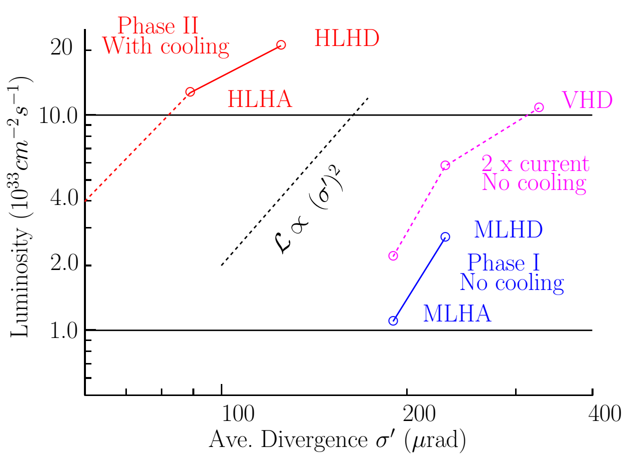

Figure 1: Luminosity vs. Average Divergences.

PARAMETERS

Parameters for the four cases are given in Table 2 and 3.

Luminosity vs. Divergence

Combining equations 1, 3, and 4:

$$\mathcal{L} = f\frac{N_p N_e}{4\pi}\ \frac{\sigma'_x\ \sigma'_y}{\epsilon_x\ \epsilon_y} \tag{7}$$

For fixed emittances, the luminosity is proportional to the horizontal divergence σ' that must be small for good forward track acceptance, or proportional to the average divergences squared. Since the required cooling at the high energy of 275 GeV is challenging, it may thus proposed to operate first without cooling, upgrading later using Coherent electron Cooling (CeC) or strong magnetic electron cooling.

With and without cooling, luminosities are plotted against the average divergences of the four cases in Fig. 1.

Phase I without Cooling

From Fig. 1, without cooling, with large enough divergences, one could have a luminosity of 10^{34} cm^{-2}s^{-1}. Such a case has excessive divergences and is not compatible with the current IR design. While such parameters might be useful for some experiments, the acceptance for DVCS would be very poor and the divergences excessive. Instead, we define parameters with two different choices of x divergence (see Table 2). We refer to these two as ”Medium Luminosity High Acceptance” (MLHA) which meets the DVCS requirement, and ”Medium Luminosity High Divergence” (MLHD”) which does not meet it, but has nearly three times the luminosity. Since the cross sections are high at the low transverse momenta, where the acceptance is needed, but low at higher pt where it is not, it will probably be best to split time between runs of the two cases.

ISBN 978-3-95450-182-3

Table 3: Table of Parameters

		HA		HD		HLHA		HLHD	
		p	e	p	e	p	e	p	e
σ_z	cm	8	.8	8	1	4	.8	4	.8
dp/p	106−4	6.5	6.5	6.5	6.5				
rf freq.	MHz	394	394	788	788				
rf Voltage	MV	15.2	15.2	30.8	30.8				
$\tau_{IBS\parallel}$	hr.	11.6		11.2		1.7		1.7	
$\tau_{IBS\perp}$	hr.	12.5		12.0		0.3		0.3	
HG	%	82		82		85		85	
Luminosity	10^{33} $cm^{-2}s^{-1}$	1.1		2.7		12.7		20.8	

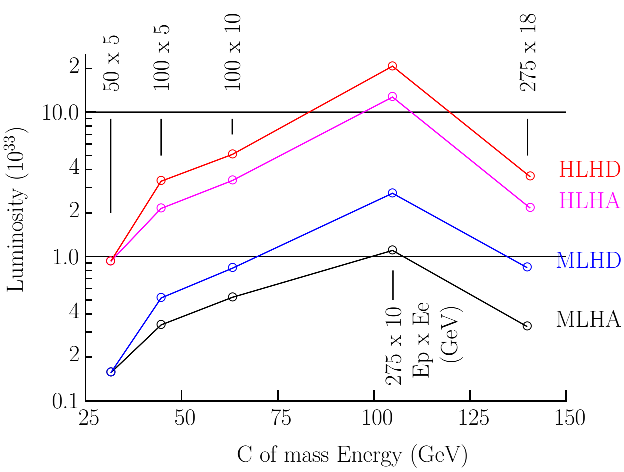

Figure 2: Luminosity vs. Center of mass energy for 4 cases.

Phase II Upgraded with Cooling

To get higher luminosities and reduced divergences, an upgrade would: 1) increase the number of bunches by four; 2) half the charge per bunch; 3) half the vertical $\beta*$ for both hadrons and electrons; 4) half the hadron bunch lengths using rf with double the frequency; and 5) apply cooling to lower the proton normalized y emittance from 1.8 to 0.1 μm.

Again, two cases are given in Table 2 and 3: A High Luminosity High Acceptance (HLHA) with luminosity 1.2 10^{34} cm^{-2}s^{-1} and a High Luminosity High Divergence (HLHD) case with luminosity 2.1 10^{34} cm^{-2}s^{-1}.

Despite the power of simulation, we do not certainly know if the cooling will perform as proposed, or that the now higher beam currents, closer bunch spacing, or beam-beam parameters will be achievable. It is partly with this in mind that the HLHD parameters are defined to give so high a luminosity.

From Fig. 1 one can deduce that, with less cooling lower currents, or lower beam-beam parameters one would still be able to achieve the required energies and luminosities, but with smaller, and less desirable divergences.

Luminosities vs. Energy

Using the same criteria given in table 1, parameters for each of the four cases have been defined for different proton and electron energies. These are plotted on Fig. 2. Luminosities at higher energies fall because the electron bunch charge must be reduced to keep the synchrotron radiation below that specified in Table 1. At lower energies it falls as indicated in equation 6.

IBS and rf

The IBS times in table 3 were given by the approximate formulae:

$$\tau_\parallel \approx 4.78 \times 10^{25} \frac{\gamma^{2.65}\epsilon^{1.15}\sigma_z\delta^{2.5}}{N_p} (\text{minutes})$$

$$\tau_\perp \approx 4.60 \times 10^{27} \frac{\gamma^{2.65}\epsilon^{2.2}\sigma_z\delta^{0.5}}{N_p} (\text{minutes})$$

The ϵs and σ_zs are in m. It is the strong dependence on δ that keeps us from much lowering it. Without cooling, the IBS times are above 12 hours allowing efficient run durations. In the upgraded case, the IBS times are very short and active continuous cooling is required.

CONCLUSION

Luminosities are strongly coupled to the beam divergences, suggesting that for different experiments different choices may be appropriate. Parameters are thus given for two cases each; first without cooling, and then with both strong cooling and higher beam currents. The target luminosity of 10^{34} cm^{-2}s^{-1} can be achieved even without cooling, but with excessive divergences. Only with strong cooling can the divergences be kept low enough to both give good acceptance to forward protons and keep divergences low enough to minimize uncertainty in the initial beam's directions.