WEPIK050

PARAMETERS FOR eRHIC

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Requirements for the proposed BNL eRHIC Ring-Ring Electron Ion Collider (EIC) are discussed, together with the dependence of luminosity on 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) have somewhat higher divergences giving higher luminosity.

Requirements

Primary:

- Centre of mass Energy from 32 to 140 GeV
- Luminosity from $10^{33}\ cm^{-2}s^{-1}$ to $10^{34}\ cm^{-2}s^{-1}$

Secondary: for analysis of the physics

- Low divergences at IP
  Limits random changes in the initial conditions of an interaction
- Horizontal proton divergence $\times$ proton energy $<$ 140 MeV/c
  For acceptance of forward protons in Deeply Virtual Compton Scattering (DVCS)
- Low dp/p
  To define initial conditions

Divergences related to Luminosity

dp/p related to IBS

Constraints

Parameters selected to maximize luminosity, consistent with these constraints

I_p	Current	A	1.35
I_e	Current	A	2.8
$P_p\ \sigma'_{x,p}$	Acceptance	MeV/c	150
ξ_p	Beam-beam		0.015
ξ_e	Beam-beam		0.1
ΔQ_p	Space charge		0.08
$\sigma'_{x,p}$	Divergence	(mrad)	0.35
$\sigma'_{y,p}$	Divergence	(mrad)	0.4
$\sigma'_{x,e}$	Divergence	(mrad)	0.2
$\sigma'_{y,e}$	Divergence	(mrad)	0.25
P_{SC}	Synch Power	(MW)	10
ϵ_{Nyp}	no cooling	μm	1.8
ϵ_{Nyp}	with cooling	μm	0.1

Luminosity

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

$$\sigma_{p,e,x,y} = \sqrt{\epsilon_{p,e,x,y} \; \beta_{p,e,x,y}} \tag{2}$$

$$\xi_{p,e,x,y} = \frac{r_{p,e}}{2\pi} \frac{N_{e,p}}{\epsilon_{p,e} \gamma_{p,e}} \; \frac{1}{1 + \sigma_{y,x}/\sigma_{x,y}} \tag{3}$$

$$\mathcal{L} \; \propto \; \sqrt{(1+K)(1+1/K)} \; \frac{\gamma_{p,e} I_{p,e} \; \xi_{p,e,x,y}}{\beta^*_{p,e,x,y}} \tag{4}$$

$K = \sigma_x/\sigma_y$. I, γ, ξ, β^* are geometric means

For K $\gg 1 \;\; \rightarrow \;\; \mathcal{L} \; \propto \sqrt{K}$.

Luminosity is higher with flat beams

Cases

- Since the required cooling at the high energy of 275 GeV is challenging, it is proposed to operate
  - First without cooling: "Medium Luminosity"
  - Later using Coherent electron Cooling (CeC) or strong magnetic electron cooling: "High Luminosity"
- In each of the above we consider two cases:
  1. With a high β_x^* giving a low enough horizontal divergence σ' for DVCS acceptance: "High Acceptance"
  2. With a lower β_x^* for a higher divergence, and a higher luminosity: "High Divergence"
- Four cases:
  1. Medium Luminosity High Acceptance (MLHA)
  2. Medium Luminosity High Divergence (MLHD)
  3. High Luminosity High Acceptance (HLHA)
  4. High Luminosity High Divergence (HLHD)

Parameters I

		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

Parameters II

		HA		HD		HLHA		HLHD	
		p	e	p	e	p	e	p	e
I	A	.45	1.24	.46	1.26	.93	2.51	.93	2.51
SR	MW		4.7		4.8		9.6		9.6
σ_z	cm	8	.8	8	1	4	.8	4	.8
dp/p	10^{-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	

Additional possible cases

Cases not covered in the above tables

- Two intermediate cases, the same as the Medium Luminosity examples, but with twice the number of bunches, giving twice the luminosities, and the same currents as in the High Luminosity cases.
- Another case, also without cooling and double the bunches, but with even greater horizontal divergence: Very High Divergence (VHD).
- Two additional cases, like the High Luminosity cases, but with greater vertical emittances. Such cases would give luminosities intermediate between the Medium and High Luminosity performances, would have intermediate divergences, and more moderate IBS rates and cooling requirements.

Phase I: Without cooling

Case	σ'_{xp} μrad	$< \sigma_p >$ μrad	Luminosity $10^{33} 10^{-2} s^{-1}$	
MLHA	53	189	1.1	High Accptance
MLHD	78	231	2.7	High Divergence
VHD	197	328	10.8	Very High Divergence*

Note *: Not compatible with current IR design

- Medium Luminosity High Acceptance meets acceptance criterion needed for forward protons. Luminosity less important because cross sections are large.
- Medium Luminosity High Divergence needed for low cross section higher pt tracks.
- Split time between the two probably best.
- Both have large average divergences giving unpleasant uncertainty in knowing the initial states

Phase II with strong cooling

1. Increase the number of bunches by four
2. Half the charge per bunch: 2 times currents
3. Half the vertical β^* for both hadrons and electrons
4. Half the hadron bunch lengths using rf with double the frequency
5. Cooling to lower proton normalized y emittance: 1.8 $\rightarrow$ 0.1 μm

Case	σ'_{xp} μrad	$<\sigma_p>$ μrad	Luminosity 10^{33} $10^{-2}s^{-1}$	
HLHA	57	89	12.7	High Acceptance
HLHD	81	125	20.8	High Divergence

- Much better average divergences
- High Luminosity
- Could meet 10^{33} requirements even with less current, less cooling, or requirements of lower beam-beam parameters

Luminosity vs. Divergences

$$\sigma'_{p,e,x,y} = \sqrt{\frac{\epsilon_{p,e,x,y}}{\beta_{p,e,x,y}}} \tag{5}$$

Combining equations 1, 2, and 5:

$$\mathcal{L} = f \frac{N_p N_e}{4\pi} \; \frac{\sigma'_x \; \sigma'_y}{\epsilon_x \; \epsilon_y} \tag{6}$$

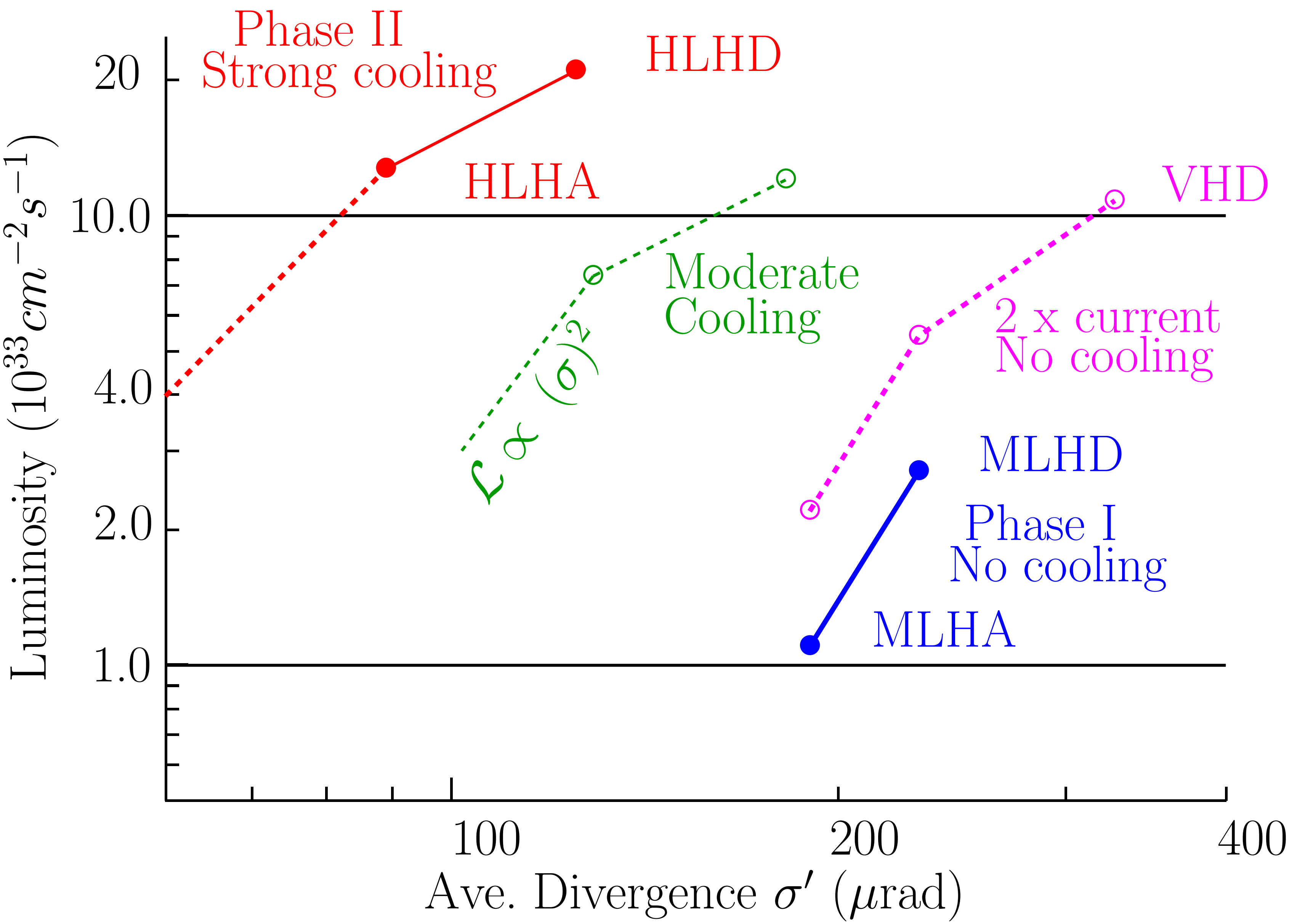
For fixed emittances,

$\mathcal{L} \; \propto \sigma'_x$ for forward track acceptance,

$\mathcal{L} \; \propto < \sigma' >^2$. for initial conditions

Until β^* gets too short and hour-glass effect slows the gain

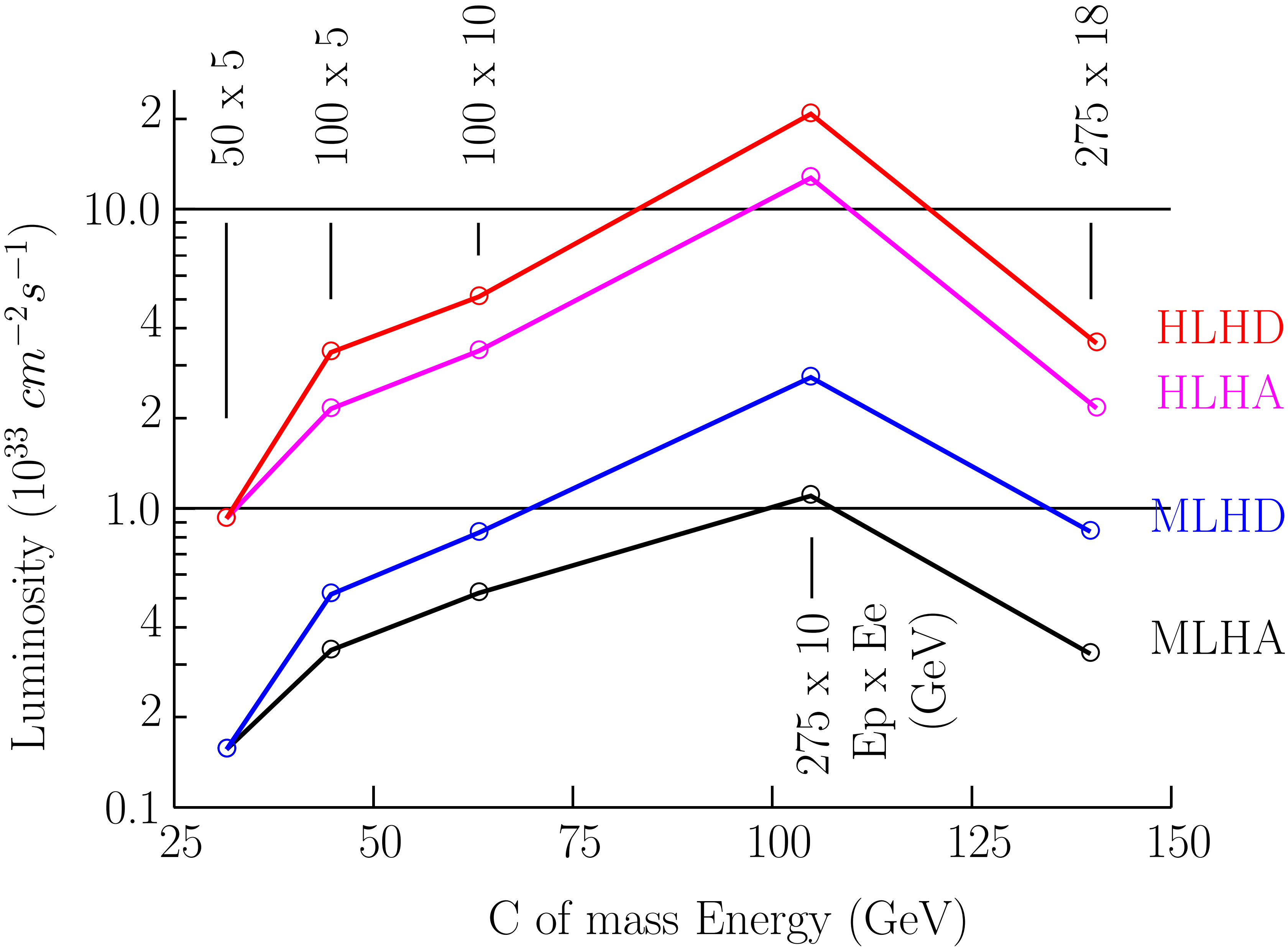
Luminosity vs. Divergences II



Luminosities vs. energy I

Using the same criteria given in slide 2, for each of the four cases, parameters defined for five different proton and electron energies. These are plotted below. Luminosities at higher energies fall because the electron bunch charge must be reduced to keep the synchrotron radiation below the 10 MW constraint. At lower energies luminosity falls as indicated in equation 4 on slide 4.

Luminosities vs. energy II



IBS and rf

Approximate formulae for Intra-Beam Scattering time:

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

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

The ϵs and σ_zs are in m.

The strong dependence on δ keeps it at 6.5 10^{-4}.

- Without cooling, the IBS times are above 11 hours allowing efficient run durations.
- In the High Luminosity cases , the IBS times are very short and active continuous cooling is required.

IBS incl. Moderate Cooling

Not in paper

Cooling	case	δ	ϵ_{Nyp}	$\tau_{\parallel}$	$\tau_{\perp}$	Luminosity
		10^{-4}	μm	hours	hours	$10^{33}\ cm^{-2}s^{-1}$
None	MLHA	6.5	1.8	11.6	12.5	1.1
None	MLHD	6.5	1.8	11.2	12.0	2.7
Moderate	MCHA	6.5	0.4	3.2	1.1	7.3
Moderate	MCHD	6.5	0.4	3.2	1.1	12.0
Strong	HLHA	6.5	0.1	1.7	0.3	12.7
Strong	HLHD	6.5	0.1	1.7	0.3	21.0

CONCLUSION

- Luminosities coupled to forward proton Acceptance
- Luminosities coupled to beam divergences that give initial state uncertainty
- Parameters needed with different criteria
- Allowing different experiments different choices
  e.g. High Acceptance HA, vs. High Divergence HD
- Initial cases without cooling give luminosities:
  HA: $\mathcal{L} = 1.1\ 10^{33}$ cm^{-2}s^{-1} HD: $2.7\ 10^{33}$ cm^{-2}s^{-1}
- Later with strong cooling, more shorter bunches give luminosities:
  HA $\mathcal{L} = 12\ \ 10^{33}$ cm^{-2}s^{-1} HD: $21\ \ 10^{33}$ cm^{-2}s^{-1}
- Intermediate cases using more moderate cooling give intermediate luminosities