

Beam momentum smearing effects in tagged and exclusive measurements at EIC

T. Ullrich, C. Weiss, Introduction to discussion

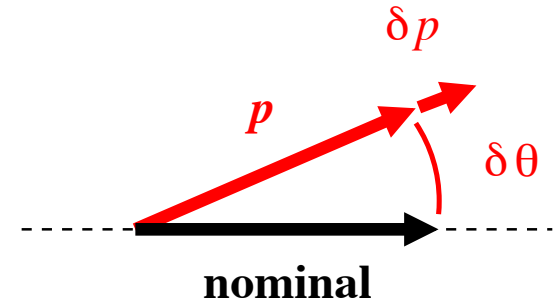
- Basic concepts
- Beam divergence causes and mitigation
- Beam divergence in present EIC IR design
- Effect on tagged and exclusive measurements

Aim: Enable discussion by nuclear physicists

Technical details: See talks by A. Jentsch, H. Witte, F. Willeke

- Particle momenta in e/p/A beam deviate from nominal momentum
- Momentum spread $\delta p/p$

EIC e beam $\delta p/p \sim 7e-4$, Au beam $\sim 8e-4$



- Angular divergence $\delta\theta_x = (\epsilon_x/\beta_x^*)^{1/2}$ (also y)

ϵ_x emittance, β_x^* amplitude function at IP (explained in following)

Divergence is different in x, y directions; beam has elliptical profile

Example: EIC Au beam: $\delta\theta_x = 109 \mu\text{rad}$, $\delta\theta_y = 38 \mu\text{rad}$

Angular divergence causes transverse momentum spread $p_T = \delta\theta p$, typically $p_T \sim 10\text{-}20 \text{ MeV}/u$

ϵ emittance [length*angle]

Measures beam quality; proportional to phase space volume = combined volume in momentum and position space, conserved during free motion

Low emittance: beam particles have almost parallel momenta, small distance

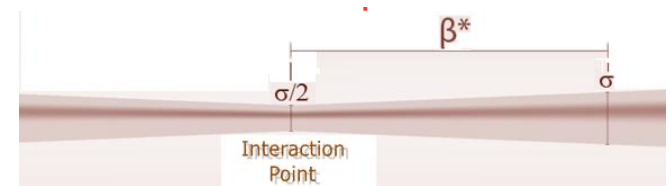
Determined by beam source, cooling (ions)

β^* amplitude function at IP [length]

Measures degree of focusing of beam

Low β^* : beam squeezed & divergent. High β^* : beam wide & parallel.

Determined by accelerator optics



- High luminosity requires small ϵ and small β^*
- Angular divergence $\delta\theta = (\epsilon/\beta^*)^{1/2}$ can be reduced in accelerator configuration with larger β^* at lower luminosity

Configurations with different β^*

[\[see talk by A. Jentsch\]](#)

High-divergence config: $\beta^*_{x/y} = 90/4$ cm, $L = 10e33$ cm⁻²s⁻¹

High-acceptance config: $\beta^*_{x/y} = 227/4$ cm, $L = 6.4e33$ cm⁻²s⁻¹

[for 275 GeV p on 10 GeV e; other examples in tables below]

Acceptance

Scattering with momentum transfer smaller than momentum spread does not get particle out of ion beam

Limits detection of coherent scattering on ions at small x , small p_T

Resolution

Momentum smearing $p_T(\text{measured}) \neq p_T(\text{vertex})$:
e.g. spectator tagging, coherent recoil

Different methods of event reconstruction can lead to different results,
e.g. DVCS Δ_T from $e'\gamma'$ and $e'p'$

[Discussion]

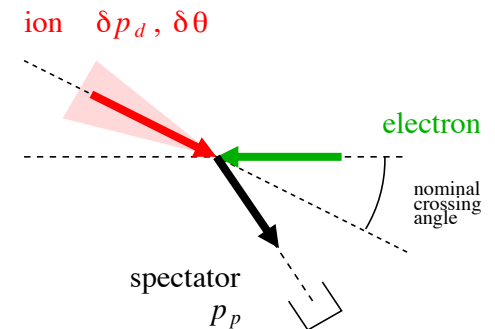


Table 3.3: eRHIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High divergence configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	20.5	6.2	6.9	17.2	6.9	17.2	4.7	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.74	0.227	1	2.5	1	2.5	0.68	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	4.6/0.75	845/72	2.8/0.45	391/24	4.0/0.22	391/25	2.7/0.27	196/20	1.9/0.45	196/34
RMS emittance, h/v [nm]	16/2.6	24/2.0	9.6/1.5	20/1.2	37/2.1	20/1.3	25/2.6	20/2.0	44/10	20/3.5
β^* , h/v [cm]	90/4.0	59/5.0	90/4.0	43/5.0	90/4.0	167/6.4	90/4.0	113/5.0	90/7.1	196/21.0
IP RMS beam size, h/v [μm]	119/10		93/7.8		183/9.1		150/10		198/27	
K_x	11.8		11.9		20.0		14.9		7.3	
RMS $\Delta\theta$, h/v [μrad]	132/253	202/202	103/195	215/156	203/227	109/143	167/253	133/202	220/380	101/129
BB parameter, h/v [10^{-3}]	3/2	100/100	14/7	73/100	10/9	75/57	15/10	100/66	15/9	53/42
RMS long. emittance [10^{-3} , eV·sec]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	2	7	2	7	2	7.5	2
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.006	neglig.	0.003	neglig.	0.028	neglig.	0.019	neglig.	0.05	neglig.
Piwiński angle [rad]	5.6	0.8	7.1	2.4	4.2	1.2	5.1	1.5	4.2	1.1
Long. IBS time [h]	2.1		3.4		2		2.6		3.8	
Transv. IBS time [h]	2		2		2.3/2.4		2/4.8		3.4/2.1	
Hourglass factor H	0.86		0.86		0.85		0.83		0.93	
Luminosity [$10^{33}\text{cm}^{-2}\text{sec}^{-1}$]	1.65		10.05		4.35		3.16		0.44	

Table 3.4: eRHIC beam parameters for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling. High acceptance configuration.

Species	proton	electron	proton	electron	proton	electron	proton	electron	proton	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
CM energy [GeV]	140.7		104.9		63.2		44.7		28.6	
Bunch intensity [10^{10}]	19.53	6.248	6.9	17.2	6.9	17.2	4.7	17.2	2.6	13.3
No. of bunches	290		1160		1160		1160		1160	
Beam current [A]	0.71	0.227	1	2.5	1	2.5	0.68	2.5	0.38	1.93
RMS norm. emit., h/v [μm]	4.9/0.62	845/42.3	2.8/0.45	391/22	3.5/0.25	391/27	2.7/0.27	196/20	1.9/0.45	196/34
RMS emittance, h/v [nm]	16.7/2.1	24.0/1.2	9.6/1.5	20/1.1	33/2.4	20/1.4	25/2.6	20/2.0	44/10	20/3.5
β^* , h/v [cm]]	395/4.0	274/7.0	227/4.0	109/5.5	102/4.0	169/6.8	90/4.0	113/5.0	90/7.1	196/21
IP RMS beam size, h/v [μm]	256/9.2		148/7.8		184/9.7		150/10		198/27	
K_x	0.036		18.9		18.9		14.9		7.3	
RMS $\Delta\theta$, h/v [μrad]	65/229	94/131	65/196	135/143	180/243	109/143	167/253	133/202	220/380	101/129
BB parameter, h/v [10^{-3}]	3/1	100/71	14/5	75/71	11/8	75/57	15/10	100/66	15/9	53/42
RMS long. emittance [10^{-3} , eV·sec]	36		36		21		21		11	
RMS bunch length [cm]	6	0.9	6	2	7	2	7	2	7.5	2
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9	6.8	5.8	9.7	5.8	9.7	6.8	10.3	6.8
Max. space charge	0.006	neglig.	0.003	neglig.	0.027	neglig.	0.019	neglig.	0.05	neglig.
Piwinski angle [rad]	2.6	0.4	4.5	1.5	4.2	1.2	5.1	1.5	4.2	1.1
Long. IBS time [h]	2		3.4		2		2.6		3.8	
Transv. IBS time [h]	2		2		2.0/3.0		2/4.8		3.4/2.1	
Hourglass factor H	0.88		0.87		0.85		0.83		0.93	
Luminosity [$10^{33}\text{cm}^{-2}\text{sec}^{-1}$]	0.83		6.4		4.07		3.16		0.44	

Table 3.5: eRHIC beam parameters for e-Au operation for different center-of-mass energies $\sqrt{s}$, with strong hadron cooling.

Species	Au ion	electron	Au ion	electron	Au ion	electron	Au ion	electron
Energy [GeV]	110	18	110	10	110	5	41	5
CM energy [GeV]	89.0		66.3		46.9		28.6	
Bunch intensity [10^{10}]	0.08	7.29	0.05	17.2	0.05	17.2	0.036	17.2
No. of bunches	290		1160		1160		1160	
Beam current [A]	0.23	0.26	0.57	2.50	0.57	2.50	0.41	2.50
RMS norm. emit., h/v [μm]	5.1/0.7	705/20	5.0/0.4	391/20	5.0/0.4	196/20	3.0/0.3	196/20
RMS emittance, h/v [nm]	43.2/5.8	20.0/0.6	42.3/3.0	20.0/1.0	42.3/3.0	20.0/2.0	68.1/5.7	20.0/2.0
β^* , h/v [cm]]	91/4	196/41	91/4	193/12	91/4	193/6	90/4	307/11
IP RMS beam size, h/v [μm]	198/15		196/11		197/11		248/15	
K_x	0.077		0.057		0.056		0.061	
RMS $\Delta\theta$, h/v [μrad]	218/379	101/37	216/274	102/92	215/275	102/185	275/377	81/136
BB parameter, h/v [10^{-3}]	1/1	37/100	3/3	43/47	3/2	86/47	5/4	61/37
RMS long. emittance [10^{-3} , eV·sec]	16		16		16		16	
RMS bunch length [cm]	7	0.9	7	2	7	2	11.6	2
RMS $\Delta p/p$ [10^{-4}]	6.2	10.9	6.2	5.8	6.2	6.8	10	6.8
Max. space charge	0.007	neglig.	0.008	neglig.	0.008	neglig.	0.038	neglig.
Piwinski angle [rad]	4.4	1.1	4.5	1.2	4.5	1.5	5.8	1.2
Long. IBS time [h]	0.33		0.36		0.36		0.85	
Transv. IBS time [h]	0.81		0.89		0.89		0.16	
Hourglass factor H	0.85		0.85		0.85		0.71	
Luminosity [$10^{33}\text{cm}^{-2}\text{sec}^{-1}$]	0.59		4.76		4.77		1.67	

Table 3.6: eRHIC beam parameters for e-Au operation for different center-of-mass energies $\sqrt{s}$, with stochastic cooling.

Species	Au ion	electron	Au ion	electron	Au ion	electron	Au ion	electron
Energy [GeV]	110	18	110	10	110	5	41	5
CM energy [GeV]	89.0		66.3		46.9		28.6	
Bunch intensity [10^{10}]	0.10	7.29	0.10	30	0.08	30	0.09	30
No. of bunches	290		580		580		580	
Beam current [A]	0.29	0.26	0.57	2.18	0.44	2.18	0.50	2.18
RMS norm. emit., h/v [μm]	2.0/2.0	845/60	2.0/2.0	391/102	2.0/2.0	196/63	2.0/2.0	196/113
RMS emittance, h/v [nm]	16.9/16.9	24.0/1.7	16.9/16.9	20.0/5.2	16.9/16.9	20.0/6.4	45.4/45.4	20.0/11.5
β^* , h/v [cm]]	288/12	203/116	91/12	77/39	146/12	113/31	149/50	339/196
IP RMS beam size, h/v [μm]	221/45		124/45		157/45		261/150	
K_x	0.202		0.363		0.284		0.577	
RMS $\Delta\theta$, h/v [μrad]	77/380	109/38	136/376	161/116	108/380	127/144	174/302	77/77
BB parameter, h/v [10^{-3}]	3/1	35/100	11/4	66/93	11/3	100/96	9/5	100/100
RMS long. emittance [10^{-3} , eV·sec]	64		64		64		64	
RMS bunch length [cm]	15	0.9	18	2	18	2	18	2
RMS $\Delta p/p$ [10^{-4}]	10	10.9	10	5.8	10	6.8	13	6.8
Max. space charge	0.001	neglig.	0.001	neglig.	0.001	neglig.	0.007	neglig.
Piwinski angle [rad]	8.5	0.5	18.1	2.0	14.3	1.6	8.6	1.0
Long. IBS time [h]	2.65		2.65		3.39		2.02	
Transv. IBS time [h]	1.02		0.80		1.32		0.93	
Hourglass factor H	0.54		0.54		0.54		0.65	
Luminosity [$10^{33}\text{cm}^{-2}\text{sec}^{-1}$]	0.14		2.06		1.27		0.31	