FCC-ee luminosity reduction from orbit errors

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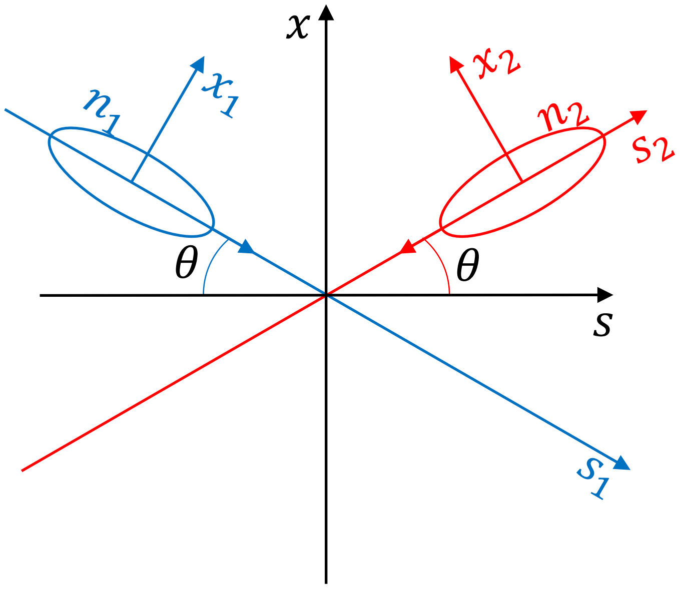
Introduction: luminosity

$$\mathcal{L} = \int dx\, dy\, dz\, dct\, n_1 n_2 \sqrt{\left(1 - \frac{\overrightarrow{v_1}\,\overrightarrow{v_2}}{c^2}\right)^2 - \frac{1}{\gamma_1^2 \gamma_2^2}}$$

$$\approx (1 + \cos 2\theta) \int dx\, dy\, dz\, dct\, n_1 n_2$$

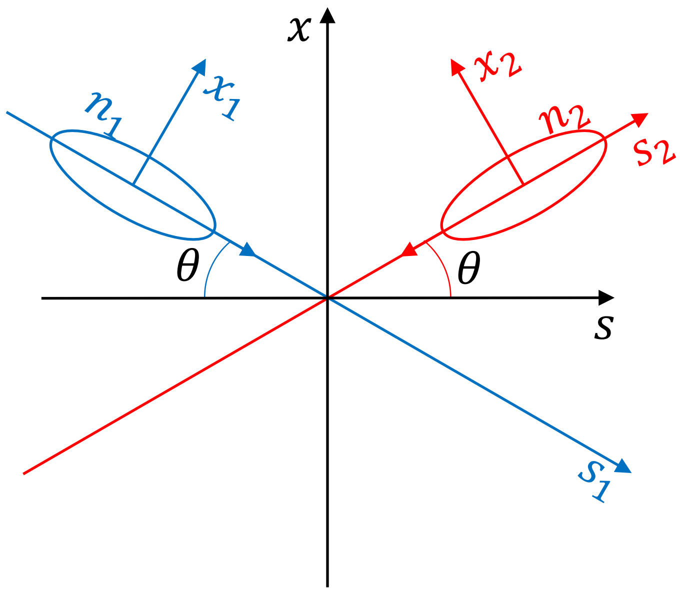
$$\mathcal{L}_0 = \frac{N_1 N_2 f_0}{4\pi \sigma_x \sigma_y \sqrt{1 + \varphi^2}}$$

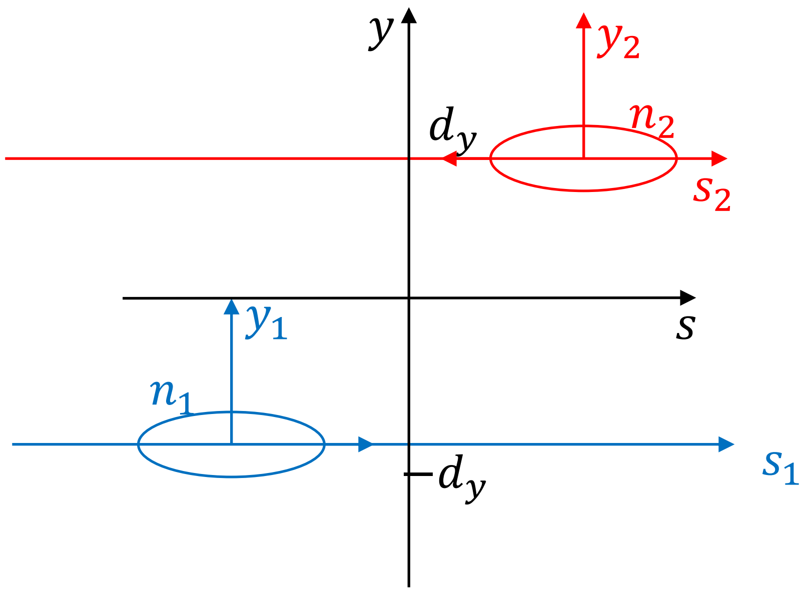
Piwinski angle $\varphi = \frac{\sigma_z}{\sigma_x} \tan\theta$



Vertical separation

$$\mathcal{L} = \mathcal{L}_0 \exp\left(-\frac{d_y^2}{\sigma_y^2}\right)$$





Vertical separation

$$\mathcal{L} = \mathcal{L}_0 \exp\left(-\frac{d_y^2}{\sigma_y^2}\right)$$

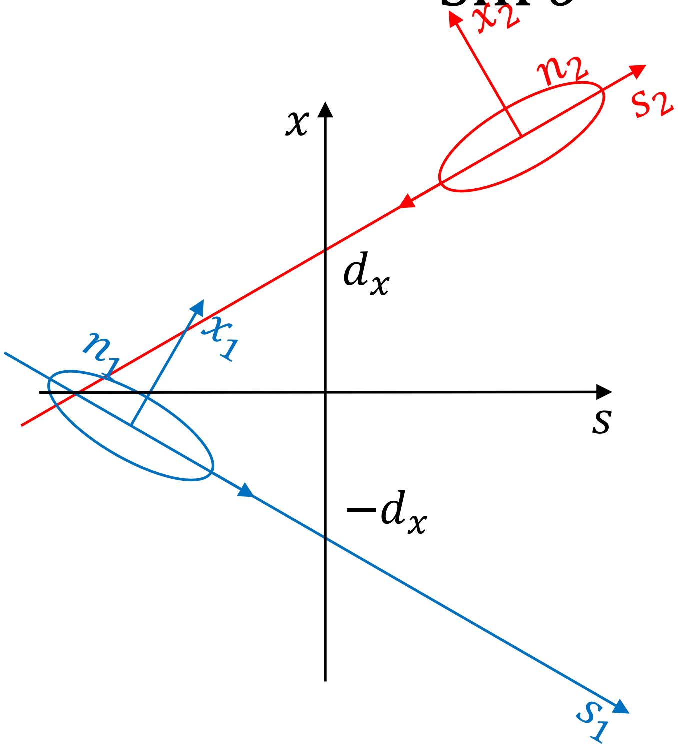
	Z	W	H	tt	ttH
E, GeV	45.6	80	120	175	182.5
$\mathcal{L}_0, 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	230	34	8.5	1.9	1.7
σ_y, nm	28	41	36	76	82
d_y, nm	60	60	60	60	60
$\frac{\Delta\mathcal{L}}{\mathcal{L}_0}$, %	-99	-88	-94	-46	-41

Horizontal separation

$$\mathcal{L} = \mathcal{L}_0 \exp\left(-\frac{d_x^2}{\sigma_x^2 \cos(\theta)^2 (1+\varphi^2)}\right)$$

No hour-glass requires

$$\frac{d_x}{\sin\theta} < l_{int} = \frac{\sigma_z}{\sqrt{1+\varphi^2}} \le \beta_y^*$$



Horizontal separation

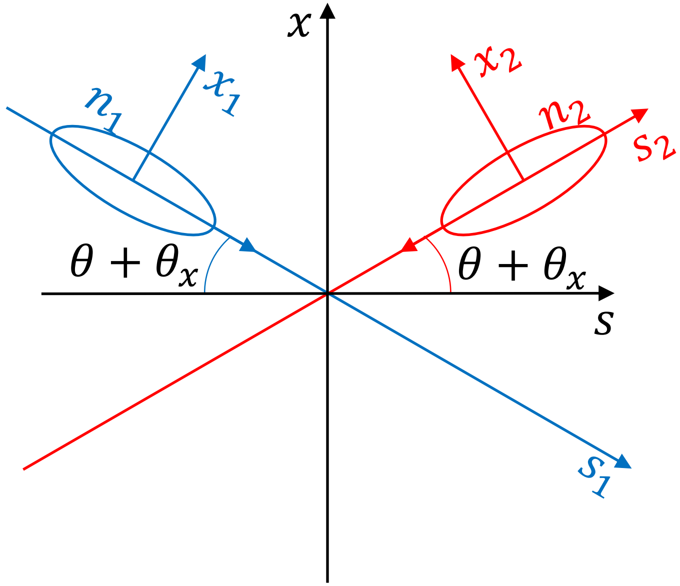
$$\mathcal{L} = \mathcal{L}_0 \exp\left(-\frac{d_x^2}{\sigma_x^2 \cos(\theta)^2 (1+\varphi^2)}\right), \frac{d_x}{\sin\theta} < l_{int} = \frac{\sigma_z}{\sqrt{1+\varphi^2}} \leq \beta_y^*$$

	Z	W	H	tt	ttH
E, GeV	45.6	80	120	175	182.5
$\mathcal{L}_0$, $10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	230	34	8.5	1.9	1.7
l_{int}, μm	420	850	900	2000	2100
d_x, μm	2	2	2	2	2
$d_x/\sin\theta$, μm	130	130	130	130	130
$\sqrt{\sigma_x^2 \cos(\theta)^2 (1+\varphi^2)}$	182	113	79	67	67
$\frac{\Delta\mathcal{L}}{\mathcal{L}_0}$, %	-0.01	-0.03	-0.06	-0.09	-0.09

Horizontal crossing angle: $\theta \rightarrow \theta + \theta_x$

$$\mathcal{L}_0 = \frac{N_1 N_2 f_0}{4\pi\sigma_x\sigma_y\sqrt{1+\varphi^2}}, \qquad \varphi = \frac{\sigma_z}{\sigma_x \tan\theta}$$

$$\mathcal{L} = \mathcal{L}_0 - \mathcal{L}_0 \frac{\varphi^2}{1+\varphi^2}\frac{2\theta_x}{\sin 2\theta}$$



Horizontal crossing angle: $\theta \to \theta + 2\theta_x$

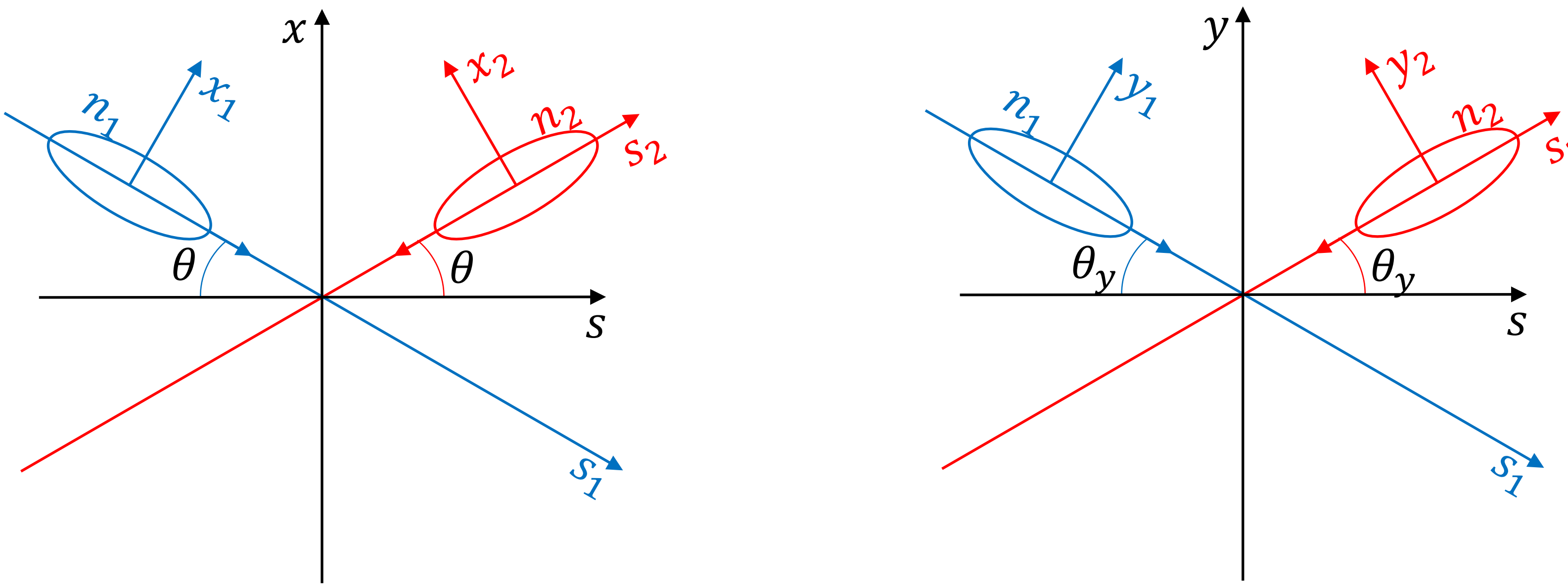
$$\mathcal{L} = \mathcal{L}_0 - \mathcal{L}_0 \frac{\varphi^2}{1+\varphi^2} \frac{2\theta_x}{\sin 2\theta}$$

	Z	W	H	tt	ttH
E, GeV	45.6	80	120	175	182.5
$\mathcal{L}_0, 10^{34}\,\mathrm{cm^{-2}s^{-1}}$	230	34	8.5	1.9	1.7
$\sigma_{px}, \mu\mathrm{rad}$	42	65	46	37	38
$\theta_x, \mu\mathrm{rad}$	100	100	100	100	100
$\frac{\Delta\mathcal{L}}{\mathcal{L}_0}$, %	-0.7	-0.7	-0.6	-0.5	-0.4

Vertical crossing angle

$$\mathcal{L}_0 = \frac{N_1 N_2 f_0}{4\pi\sigma_x\sigma_y\sqrt{1+\varphi^2}}, \qquad \varphi = \frac{\sigma_z}{\sigma_x \tan\theta}$$

$$\mathcal{L} = \mathcal{L}_0 - \mathcal{L}_0 \frac{\sigma_s^2}{8\sigma_y^2(1+\varphi^2)} \frac{3+\cos 4\theta}{(\cos\theta)^4}\ \theta_y^2$$



Vertical crossing angle

$$\mathcal{L} = \mathcal{L}_0 - \mathcal{L}_0 \frac{\sigma_s^2}{8\sigma_y^2(1+\varphi^2)} \frac{3+\cos 4\theta}{(\cos\theta)^4}\, \theta_y^2$$

	Z	W	H	tt	ttH
E, GeV	45.6	80	120	175	182.5
$\mathcal{L}_0$, $10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$	230	34	8.5	1.9	1.7
σ_{py}, μrad	35	41	36	48	51
θ_y, μrad	25	25	25	25	25
$\frac{\Delta\mathcal{L}}{\mathcal{L}_0}$, %	-7	-14	-20	-23	-20