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Preliminary design consideration for CEPC fast luminosity feedback system

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Introduction

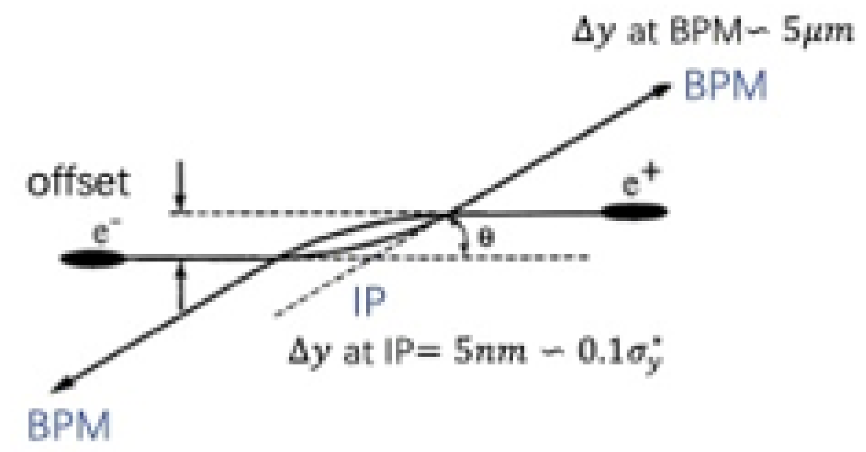
With very small beam sizes at IP (several tens of nanometers in the vertical direction) and the presence of strong FFS quadrupoles in the CEPC, the luminosity is very sensitive to the mechanical vibrations, requiring excellent control over the two colliding beams to ensure an optimum geometrical overlap between them and thereby maximize the luminosity. Fast luminosity measurements and an IP orbit feedback system are therefore essential. In this paper, we will show the preliminary design consideration for a fast luminosity feedback system at CEPC.

Orbit feedback methods

There are two methods for the IP orbit feedback system at CEPC[1,2,3]:

- **Beam-beam deflection driven method [vertical]**

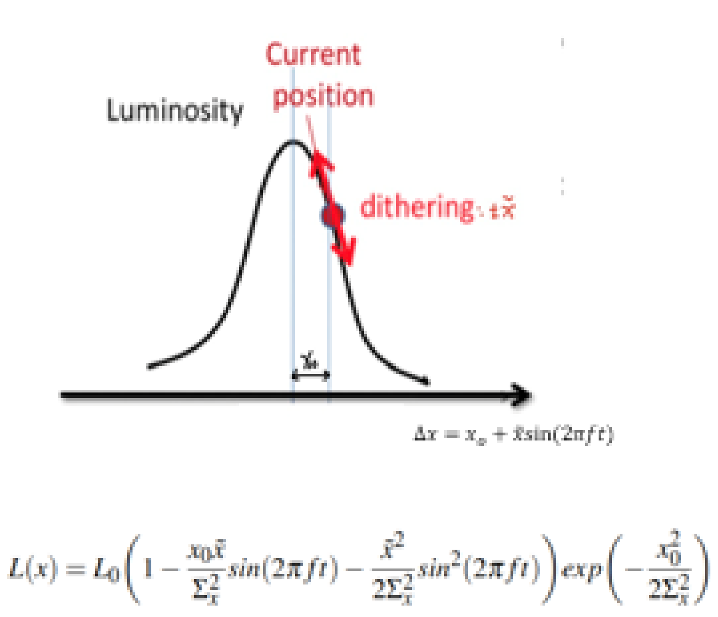
The offset at the IP is too small to be accurately measured, but due to the beam-beam effect, which can introduce an deflect angle, and then transfer to a larger offset, by measuring this beam orbit with BPMs upstream and downstream of the IP , we can estimate the offset at the IP and the sign.

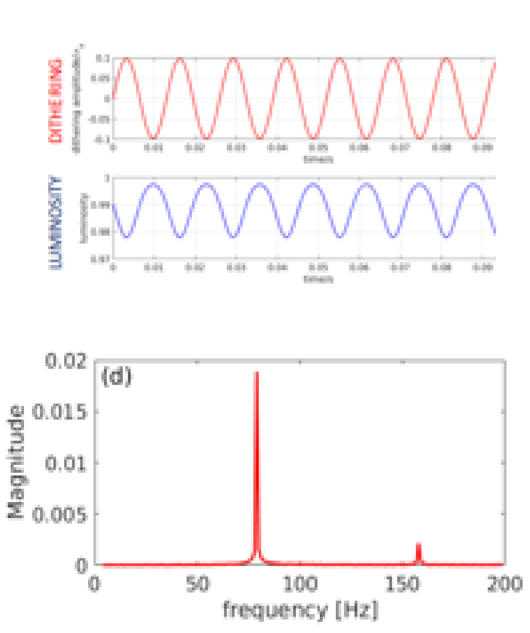


$$\Delta y'_{\pm} = -\frac{r_e N_{\mp}}{\gamma_{\pm}\sigma^*_{y\mp}(\tilde{\sigma}^*_{x\mp}+\sigma^*_{y\mp})}\Delta y_{IP} \qquad \Delta y_{BPM} = \sqrt{\beta^*\beta_{BPM}}\Delta y'$$

- **Luminosity driven system [horizontal]**

Based on the measurement of the luminosity, we can know the offset between two beams, but cannot easily know its sign. And many other effects may also cause luminosity changes at relatively low frequency, should introduce a dithering with certain frequency.



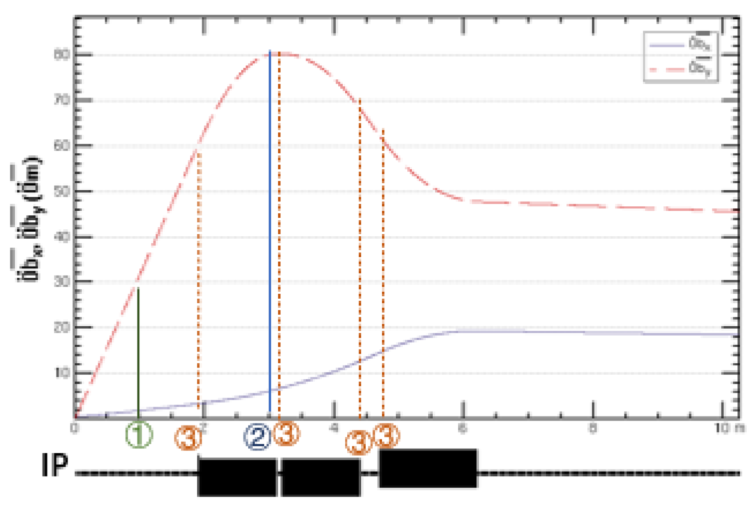


Vertical—Beam-beam deflection driven method

Our preliminary scheme is to place 4 sets of BPMs on both sides of the IP for each ring, which located near the maximum betay. In this way, the current resolution of BPMs is good enough for vertical IP orbit feedback.

CEPC	N_{bunch} $[10^{11}]$	β^*_x/β^*_y $[m/mm]$	σ^*_x/σ^*_y $[\mu m]$	ξ^*_x/ξ^*_y	$\Delta x_{IP}/\Delta y_{IP}$ 0.1σ $[\mu m/nm]$	$\Delta x'/\Delta y'$ $[\mu rad]$	$l_{IP\to BPM}$ $[m]$	BPM resolution
Higgs	1.3	0.3/1	14/0.036	0.015/0.11	1.4/3.6	-0.44/-2.49	0.85	0.3um@10Hz
Z	1.4	0.13/0.9	6/0.035	0.004/0.127	0.6/3.5	-0.12/-3.1		
W	1.35	0.21/1	13/0.042	0.012/0.113	1.3/4.2	-0.47/-2.98		
tt	2.0	1.04/2.7	39/0.113	0.071/0.1	3.9/11.3	-4.85/-2.63		

f[Hz]		GM	Correct	Measure	BPM resolution
HEPS	H	<1	10	100	1um@100Hz
	V	5	50	500	2um@500Hz
BEPC	H	0.02	0.2	2	0.1um@2Hz
	V	50	500	5000	7um@5kHz
KEK	H	0.1	1	10	0.3um@10Hz
	V	50	500	5000	7um@5kHz



① The location of the current designed BPM → *not good enough for both direction*

$$\Delta y_{BPM} = \sqrt{\beta^*\beta_{BPM}}\Delta y' \approx s * \Delta y' = 2.2um \approx 1res@500Hz$$
$$\Delta x_{BPM} = \sqrt{\beta^*\beta_{BPM}}\Delta x' \approx s * \Delta x' = 0.4um \approx 0.4res@100Hz$$

② If place BPM at or near β_{ymax}-location → *get a larger offset at BPM*

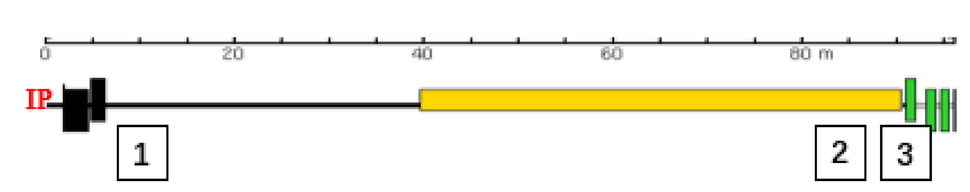
$$\Delta y_{BPM} = \sqrt{\beta^*\beta_{BPM}}\Delta y' = -6.3\mu m \approx 3res@500Hz$$

③ If use multiple BPMs → *can reduce the requirement for BPM resolution*

$$\Delta y_{BPM}(n_{BPM}) \approx (\sqrt{n} * 3)\ res@500Hz$$

Horizontal—Fast Luminosity Monitor

The fast luminosity monitor based on radiative Bhabha at zero degree, which has a very large cross section ($\approx 150mbarn$). Find 3 possible detector positions where the loss rate is large enough and radiative Bhabha at zero degree process dominates over the sum of other particles loss processes.



	Position1→ $10m$	Position2→ $84m$	Position3→ $90.5m$
Average Number detected/BX	~3.4(Two sides)	~3(One Side)	~3.2(One Side)
Average Bhabha Number /1ms	~2830	~2500	~2670
Expected measurement accuracy	1.9%@1kHz	2%@1kHz	1.95%@1kHz
Average Energy of Pris	~24 GeV	~70 GeV	~75.3 GeV
Average Hitting Angel	~1.7E-4 rad	~7E-4 rad	~7E-4 rad
T_{max} in mm	88.32	103.85	104.91
Detector Size assumed	5*20 cm^2	3*15 cm^2	3*15 cm^2
Backgrounds	SR Photons in 1 Side	-	-
Pros	Measurement affected by beam-beam deflection angle, two detectors	signals only on one side, measurement quite independent of beam-beam deflection angle	
Detector technology	LGAD; SiC; Diamond		

Conclusion

- **Fast Luminosity Tuning System, including fast BPMs and fast luminosity monitor, would be necessary for CEPC.We already have some candidate positions and potential detector solutions.The detailed design of the detectors is get started.**
- **More detailed simulations needs to be done to study more, including determine the detailed location and quantity of BPMs and the design of detectors and feedback.**

[1] Y. Funakoshi et al., “Interaction point orbit feedback system at SuperKEKB”, in Proc. 6th Int. Particle Accelerator Conf. (IPAC’15), Richmond, VA, USA, May 2015.
[2] D. El Khechen, “Fast Luminosity Monitoring Using Diamond Sensors for SuperKEKB”, PhD thesis, Université Paris-Sud, Orsay, France, 2016.
[3] C. G. Pang et al., "A fast luminosity monitor based on diamond detectors for the SuperKEKB collider", Nucl.Instrum.Meth. A931 (2019) 225-235.