CONCEPTUAL DESIGN FOR SR MONITOR IN THE FCC BEAM EMITTANCE (SIZE) DIAGNOSTIC

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Abstract

A conceptual design for emittance diagnostics through a beam size measurement using the synchrotron radiation (SR) is studied for the FCC. For the FCC-ee, a X-ray interferometer is propose to measure a nano-radian order vertical beam size. Also conceptual design of SR monitor is studied for FCC-hh. In the FCC-hh, visible SR will emitted from bending magnet in the energy range from the injection (3 TeV) to top energy (50 TeV). Hard X-ray SR will only available in the energy upper than 30TeV. The various instrumentations using the visible SR is usable for all energy range. Around the top energy, the X-ray pinhole camera will convenient for beam diagnostics of emittance through the beam size measurement.

INTODUCTION

The FCC-ee is a proposed circular e_+e_- collider delivering high luminosity to four experiments at centre-of-mass energies ranging from 91 GeV (Z pole) over 160 GeV (*W* threshold) and 240 GeV (*H* production) to 350 GeV (*t* physics) [1]. The FCC-ee design is pursued as part of the global Future Circular Collider (FCC) study, which regards the FCC-ee as a potential intermediate step towards a 100-TeV hadron collider. FCC-hh will provide pp collisions at a centre-of-mass energy of 100 TeV using 16-T Nb3Sn magnets in a tunnel of about 100 km circumference [2]. For diagnose small emittances in FCC-ee and FCC-hh through a beam size measurement using the synchrotron radiation (SR), a conceptual design of SR monitor is studied in this paper.

PARAMETERS AT THE SOURCE POINT IN FCC-ee

The source point for SR is assumed to use a last bending magnet in the arc section. The beam parameters at the source point are listed in Table 1.

Table 1: Parameters at the Source Point in FCC-ee

Bending magnet length	24.585 m
Bending radius	11590.8 m
Magnetic field strength	0.0503 T
Bending angle	2.144 mrad
Beam energy and current	175GeV 6.6 mA 45GeV 1500 mA
emittance	1.3 pmrad
Estimated vertical beam size	σ_y = 5.1 mm / β=20 m = 0.05 μrad at 100 m

The vertical phase space profile of the beam for α=0,1 and 2 is indicated in Fig. 1. The vertical beam size and divergence is about 5 μm and order of 10^{-7} rad, respectively.

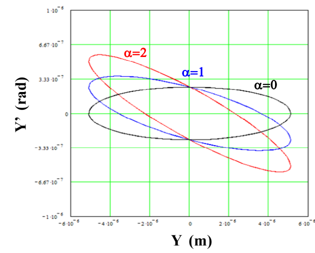

Figure 1: Vertical Phase Space Profile of the Beam for α=0,1 and 2.

SPECTRUM AND ANGULAR DIVERGENCE OF SR IN FCC-ee

The expected spectral brightness at 45 GEV and 175 GeV is indicated in Fig. 2. Due to the long bending radius, the spectrum has no rich component of hard X-ray in 45 GeV, but still we can use 10keV hard X-ray in all energy range of FCC-ee.

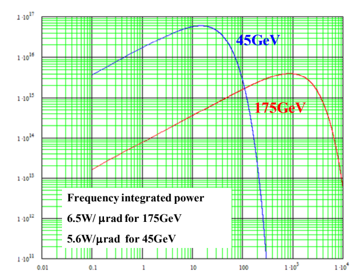

Figure 2: Expected spectral brightness of SR at 45 GeV and 175 GeV form FCC-ee.

The expected angular divergence in vertical at wavelength of 0.1nm is indicated in Fig.3. The beam energy is 175 GeV. Tail to tail opening is about 2 × 10^{-5} rad. Compare with vertical beam divergence, this opening is 100 times larger than vertical beam divergence.

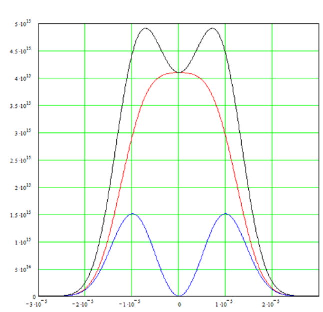

Figure 3: Expected angular divergence of SR at 0.1nm. The beam energy is 175 GeV.

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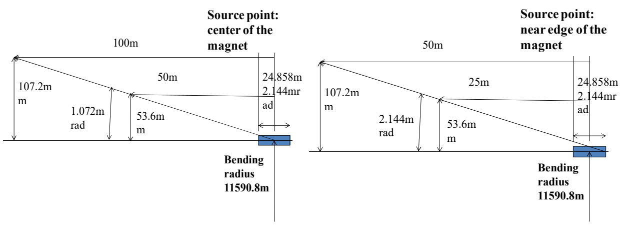
EXTRACTION OF SR

Due to the long bending radius, a long distance form the source point is necessary to extract the SR from the vacuum duct. The horizontal size of the vacuum duct is 50mm in radius. Possible geometrical arrangements for SR extraction are shown in Fig. 4.



(a) (b)

Figure 4: Possible geometrical arrangements for SR extraction. (a) Source point at the near entrance of the bending magnet, and (b) source point at centre of the magnet.

We need about 100 m for the extraction of the SR from the vacuum duct.

SUMMERY FOR POPULER METHEDS FOR BEAM SIZE MEASUREMENT

The popular methods for beam size measurement using SR are summarized in Table 2. For the convenience, apparent angular size of the beam defined by $\theta_s = \sigma/d$ is used in this table. In here, θ_s is apparent angler size, σ rms beam size and d distance between beam and measurement point, respectively. Expected vertical beam size in FCC-ee is 5 mm, and corresponding apparent angular size is 0.05 μrad. Smallest possibility in popular methods seems 0.1μrad and it is not enough to measure the apparent very small beam size in FCC-ee. The X-ray interferometry listed in last line in Table 2 has a good resolution to measure the small beam size of 0.05 μm. The optical property of X-ray is actively investigated around 1920-30 with optical method including interferometry [3]. This method is not applied yet for beam instrumentation in accelerator.

Table 2: Popular Methods for Beam Size Measurement

	wavelength	measurable minimum beam size in angular diameter in μrad
Visible light imaging [4]	500 nm	50
X-ray pinhole [5]	0.1 nm	0. 5
FZP imaging of soft-ray [6]	0.35 nm	0.3
Visible light interferometry [7]	400 nm	0.47
Interferometry with imbalance input [8]	400 nm	0.2
Coded aperture[9]	0.3 nm	0.5 (0.1)
X-ray nterferometry	0.1 nm	0.01

X-RAY INTERFEROMETRY

A simple configuration for Young type double slit interferometer for beam size measurement in FCC-ee is shown in Fig. 5.

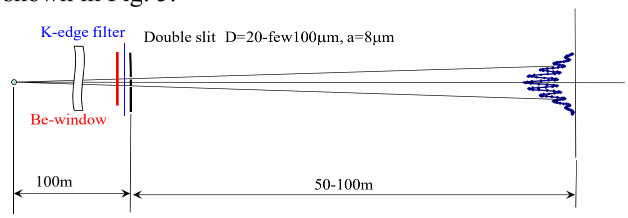


Figure 5: Young type double slit X-ray interferometer.

Double slit in phase space is shown in Fig. 6. Due to rather large opening of SR, double slit will cover whole information of the beam size.

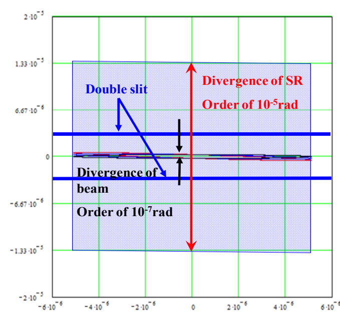


Figure 6: Double slit in phase space with divergence of SR.

An expected spatial coherence as a function of beam size using λ=0.1 nm X-ray is shown in Fig. 7.

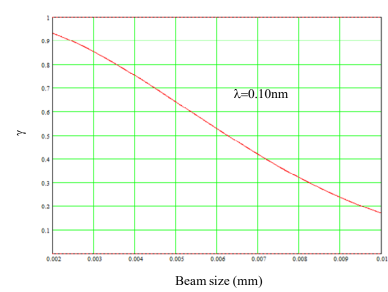


Figure 7: Expected spatial coherence as a function of beam size using λ = 0.1 nm X-ray.

An expected interferogram using λ = 0.1 nm is shown in Fig. 8. A quasi-monochromatic ray (20% bandwidth) filtered by a K-edge filter with Kr gas is assumed as incident ray.

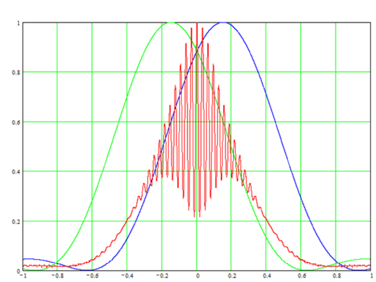


Figure 8: An expected interferogram using a wavelength of 0.1 nm with K-edge filter of Kr gas.

PARAMETERS AT SOURCE POINT IN FCC-hh

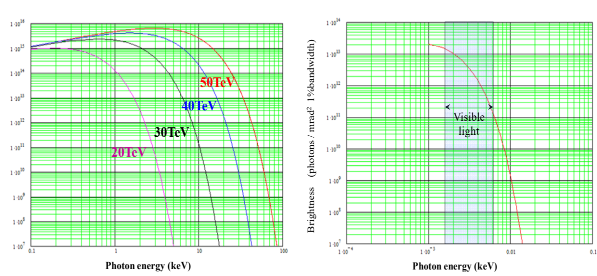
The beam parameters of FCC-hh at the source point are listed in Table 3. Expected vertical beam size at high β-section will be 200 μm.

Table 3: Beam Parameters of FCC-hh at the Source Point

Bending magnet length	14.3 m
Bending radius	10514.7 m
Magnetic field strength	15.85T at 50 TeV 0.951T at 3 TeV
Bending angle	1.36mrad
Beam energy and current	50TeV 500 mA 3TeV injection
emittance	20pmrad
Estimated beam size	σ_y =30 μm / β=60 m σ_y ≈200 μm / high β σ_x =30 μm / β=60 m σ_y ≈200 μm / high β

SPECTRUM AND ANGULAR DIVERGENCE OF SR

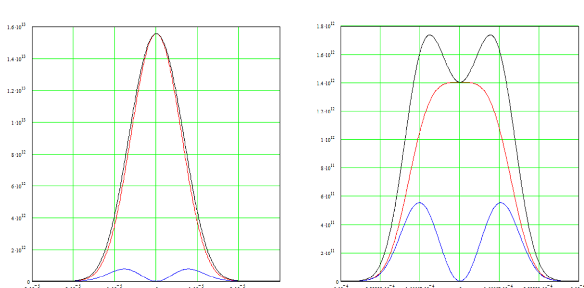
Expected spectral brightness at 30-50 TeV and injection energy 3TeV is shown in Fig. 9. We can use visible light (500 nm) for all energy range from injection (3 TeV) to top energy(50 TeV) from the bending magnet. The hard X-ray (10 keV) will available for higher energy range (>30 TeV).



(a) (b)

Figure 9: Expected spectral brightness of SR from FCC-hh. (a) 20-50 TeV, (b) injection energy 3 TeV.

Expected angular divergence for Hard X-ray (0.1nm) and visible light (500 nm) at 50 TeV is shown in Fig. 10.



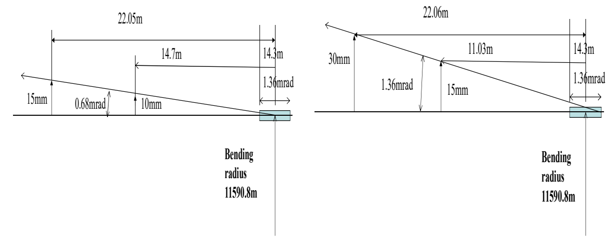
(a) (b)

Figure 10: angular divergence of SR at 50 TeV. (a) 0.1 nm, (b) 500 nm.

EXTRACTION OF SR AT FCC-hh

Possible geometrical arrangements for SR extraction for FCC-hh are shown in Fig.11.

The horizontal size of the vacuum duct is 15 mm in radius.



(a) (b)

Figure 11: Possible geometrical arrangements for SR extraction for FCC-hh. (a) Source point at the near entrance of the bending magnet, and (b) source point at centre of the magnet.

Although the bending magnet has a long bending radius, the SR will come outside of the vacuum duct in 22-23 m downstream from the source point. By this reason, extraction of SR is easier than FCC-ee case. This distance is almost same distance range (around 28 m) as in LHC SR monitor.

INSTRUMENTATION FOR FCC-hh

Since possible geometrical arrangement for SR extraction in FCC-hh and beam size at high β-section are almost same as in the SR monitor in LHC [10], we can use various diagnostic system such as imaging system for beam profile observation, SR interferometer [11] for beam size measurement, coronagraph [12] for beam halo measurement, etc. by using the visible SR in the LHC SR monitor. Different from LHC, we can use a hard X-ray in energy range higher then 30 TeV, so, X-ray pinhole camera will be most convenient method for simple monitoring of beam profile and size in this energy range.

SUMMARY

For the beam size measurement for FCC-ee, a X-ray interferometer has a good resolution for 0.05μrad vertical beam size in FCC e-e with distance of 100m. The system seems very simple and easy to construction.

For FCC H-H, we can use visible SR for all energy range for diagnostics. The hard X-ray is available higher than 30 TeV. Various diagnostics system using visible SR in the LHC will be useable for all Energy range. A simple pinhole camera should be convenient for beam size measurement at 40-50 TeV.

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