

MEASUREMENT OF BEAM SIZE IN INTRABEAM SCATTERING DOMINATED BEAMS AT VARIOUS ENERGIES AT CESR TA *

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Abstract

Recent reports from CEsrTA have shown measurement and calculation of beam size versus current in CEsrTA beams at 2.1 GeV. Here, the effect of changing the energy of Intra-beam Scattering-dominated beams is reported. IBS growth rates have roughly a γ^{-3} dependence. Measurements at 1.8, 2.1, 2.3, and 2.5 GeV are shown and compared with predictions from IBS theory.

INTRODUCTION

Intrabeam scattering (IBS) describes the change in beam emittances due to multiple-event scattering among the particles that compose the beam. The scattering events transfer momentum, and therefore emittance, between the different bunch dimensions. Importantly, similar to the process whereby photon emission generates beam emittance, if the scattering events change the particle energy in a region with non-zero $\mathcal{H}_{x,y} = \gamma_{x,y}\eta_{x,y}^2 + 2\alpha_{x,y}\eta_{x,y}\eta'_{x,y} + \beta_{x,y}\eta_{x,y}^{\prime 2}$, then the total emittance of the bunch can increase.

The horizontal dispersion of CEsrTA is rather large, with a rms value of 1 m and peaks at about 3 m. The rms \mathcal{H}_x is 0.11 m and peaks at about 0.37 m. IBS has been measured to blow up the horizontal emittance to 3 times the single-particle emittance. In such beams, IBS, rather than photon emission, is the dominant source of horizontal emittance.

Typical applications of IBS theory give a time rate of change in the beam emittances. In electron storage rings this growth rate competes with radiation damping resulting in new, usually larger, emittances. These larger emittances depend on the beam energy, single-bunch current, and machine optics.

IBS is relevant in new low emittance colliders and storage rings, some now being commissioned and others in early stages of design [1]. Collider luminosity and light source brilliance both depend on beam size. At the few GeV energies targeted by these machines, IBS can dominate the beam size.

THEORY

IBS growth rates have a strong energy dependence of approximately γ^{-3} [2]. Emittance generated by photon emission, however, goes as γ^2 . Increasing the beam energy decreases the emittance contribution from IBS but increases the contribution from photon emission. Figure 1 shows the equilibrium emittance curve which results from these competing effects. Note that CEsrTA is a wiggler-dominated

storage ring, and that the wiggler field is not scaled when the beam energy is changed.

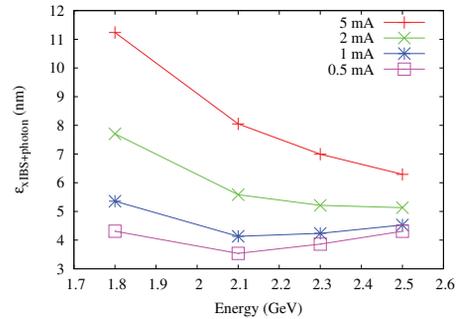


Figure 1: Calculated horizontal emittance versus beam energy for CEsrTA lattices, assuming the same vertical emittance for each energy and current. Emittance generated by photon emission is independent of current, while that by IBS depends on current, pushing the optimum energy higher as current is increased.

The method for calculating IBS beam sizes we use in this paper is that published by Kubo & Oide [3]. We use this formula because it is very general and its integrals are quickly and robustly evaluated with ordinary numerical integration techniques. In addition, it naturally handles vertical dispersion and arbitrary coupling conditions. We find that if machine optics and the Coulomb Logarithm are treated consistently, the beam sizes given by this calculation method agree with those given by Bjorken & Mtingwa's and also Pwinski's [4].

The theory here applies the tail-cut procedure. Without the tail-cut, the IBS theory significantly overestimates the beam size blow up and no agreement between theory and data is found. Details of applying the tail-cut procedure can be found in [4] and [5].

EXPERIMENT

CESR is a 768 m FODO storage ring capable of storing electrons or positrons with energies ranging from 1.8 to 5.3 GeV. It is most often operated as a high-energy photon light source in the CHESS program. About 4 weeks per year, it is funded as CEsrTA for machine studies aimed at understanding the physics of lepton beams of a few GeV energy. It has remarkably flexible optics and can store large currents, allowing for a variety of beam configurations for different experiments.

The IBS experiment procedure at CEsrTA has been documented at [5]. In short, the data is taken by charging a single bunch to more than 10^{11} particles and recording beam sizes

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as it decays naturally due to Touschek scattering. At low current, the lifetime becomes very long and a pulsed bump is used to scrape current out of the beam in 0.25 mA or more increments. Horizontal beam size measurements are taken with a visible synchrotron light interferometer. Vertical beam size measurements are made by imaging x-rays from a hard bend through an optic onto a vertical diode detector array. For high energy and/or high current, a pinhole optic is used. For low energy and/or low current, a coded aperture optic is used [6, 7]. Bunch length measurements are done with a visible light streak camera [8].

DATA

Part of the IBS data measured at 2.1, 2.3, and 2.5 GeV have been published at [9]. Since then, more IBS data were acquired at different beam energies with different machine optics. They showed consistent results.

Measurements at 1.8 GeV were taken April 2014 with electrons in the machine and are shown in Fig. 2. The vertical beam size is not modeled with IBS theory. The data is fitted to a line of the form $a_0 + b_0I + c_0I^2$. The width of the fit is the $\pm 2 \mu\text{m}$ systematic uncertainty in the vertical beam size measurement. We will discuss this issue in the following section.

Vertical Beam Size

The vertical beam size measured at CsrTA is dominated by processes that have not been identified. Difficulties understanding sources of the zero-current emittance and sharp blow-up seen in the vertical beam size above 5 mA have been documented elsewhere [9, 10].

Modelling the vertical dimension in an IBS simulation is not straightforward. The horizontal IBS rate is strongly dependent on the horizontal dispersion, and similarly is the vertical IBS rate dependent on the vertical dispersion. Whereas the horizontal dispersion is dominated by the design optics and can be known fairly accurately, the vertical dispersion is entirely due to machine misalignments, which may not be known so precisely. The vertical dispersion at CsrTA is smaller than the resolution limit of the DC dispersion measurement, though it is known that the rms vertical dispersion is smaller than 12 mm [10].

In IBS studies at 2.1, 2.3, and 2.5 GeV, the growth in the vertical beam size from zero-current up till the onset of the blow-up at high current is relatively flat and can be modeled by assuming approximately 10 mm vertical dispersion. At 1.8 GeV, the vertical beam size growth is larger, and we have been unable to model the growth using an IBS model along with reasonable assumptions about the sources of vertical dispersion and coupling.

A few possible explanations for the anomalous growth at 1.8 GeV are: 1) The IBS simulations we have developed do not accurately model the vertical dimension. This could point to a deficiency in IBS theory. 2) The vertical beam size in CsrTA is dominated by a not yet identified current-dependent process. The horizontal separators and sliding

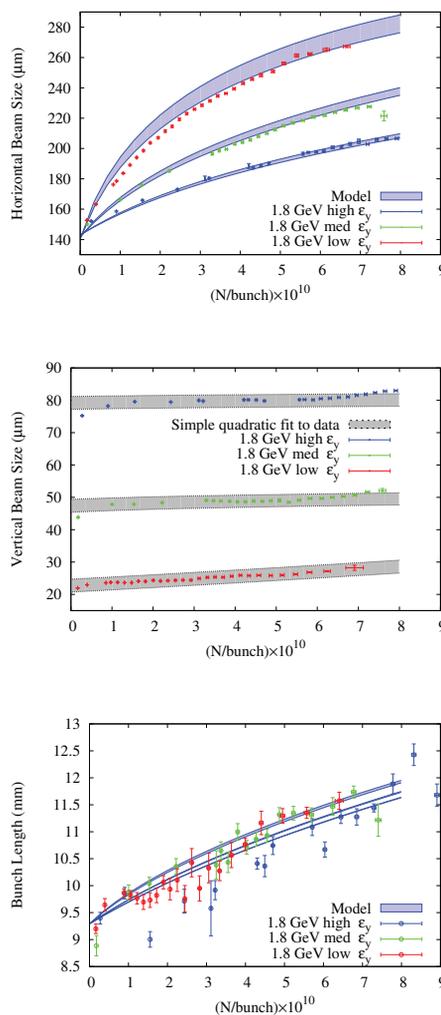


Figure 2: Measured and computed (a) horizontal size, (b) vertical size, and (c) bunch length for a 1.8 GeV bunch of electrons. Points are data, shaded bands are calculated beam sizes reflecting the uncertainty in the zero current vertical emittance. N refers to number of particles. In CsrTA, $1\text{mA} = 2.6nC = 1.6 \times 10^{10}$ particles/bunch.

jointly are significant contributors to an overall very large machine impedance, whose effect on beam size is yet to be understood. 3) There is something missing from our model of the CsrTA optics.

In the present study, the focus is the horizontal beam size, and the vertical beam size is not modeled. The vertical beam size data is fitted to a simple quadratic function which is used by the simulation to determine the vertical beam size at a given current. Because IBS depends on particle density, the horizontal beam size depends on the vertical beam size.

Horizontal Beam Size

Shown in Fig. 3 is a comparison of modeled horizontal beam size versus current, along with the vertical beam size data and ranges of vertical beam sizes used in the model. The

measurements are in lowest vertical emittance conditions, which are different for each of the four lattices.

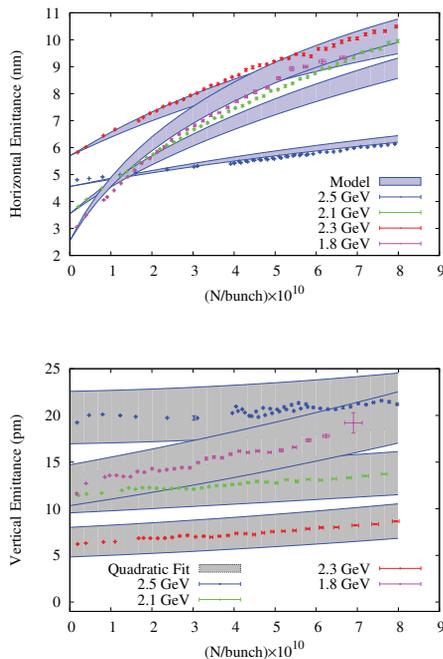


Figure 3: Comparison of emittance versus current for 1.8, 2.1, 2.3, and 2.5 GeV. The bands represent systematic uncertainty in the vertical beam size measurement.

In addition to measurements in lowest emittance conditions, measurements are taken with the vertical emittance blown up by creating a closed coupling and vertical dispersion bump through the damping wigglers. Shown in Tab. 1 is the percent blow up in the horizontal emittance at 4 mA (9.6 nC/bunch or 6.4×10^{10} part./bunch) for each of the four energies in two different case: 1) lowest emittance conditions and 2) vertical beam size approximately $50 \mu\text{m}$. The corresponding emittance versus energy plot is shown in Fig. 4.

Table 1: Comparison of emittance blow up at 4 mA in lowest emittance conditions and conditions where the vertical beam size is approximately $50 \mu\text{m}$.

		1.8 GeV	2.1 GeV	2.3 GeV	2.5 GeV
Data	Low ϵ_y	257%	145%	69%	25%
	$\sigma_y \approx 50 \mu\text{m}$	148%	72%	24%	13%
Sim.	Low ϵ_y	270%	130%	63%	32%
	$\sigma_y \approx 50 \mu\text{m}$	160%	69%	23%	17%

CONCLUSION

Beam size versus current measurements at CEsrTA at 1.8 GeV have been presented. These complement the measurements made at 2.1, 2.3, and 2.5 GeV in earlier studies.

The horizontal beam size versus current data closely matches that predicted by IBS theory. The data at 1.8 GeV

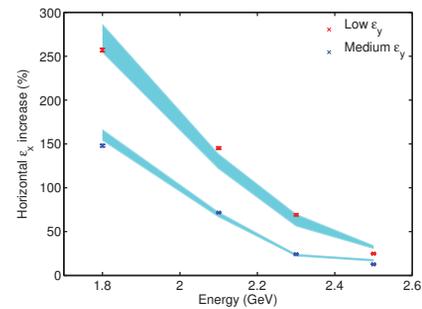


Figure 4: Percent emittance blow-up versus beam energy at 4 mA. Symbols with error bars are data, light blue bands are simulation, taking into account systematic uncertainty in vertical beam size.

is further evidence that, provided the tail-cut procedure is applied, IBS theory is an accurate predictor of the current dependence of the horizontal emittance.

The vertical beam size at 1.8 GeV could not be modeled with IBS theory. It was instead used as an input parameter to the simulation, which then modeled the horizontal beam size and bunch length. This could point to a deficiency in IBS theory. However, there are other unknowns with regards to the vertical beam behavior in CEsrTA which prevent strong conclusions from being drawn at this point.

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