MONOCHROMATIZATION INTERACTION REGION OPTICS DESIGN FOR DIRECT *s*-CHANNEL PRODUCTION AT FCC-ee*

Z. D. Zhang[1,2 †], A. Faus-Golfe, IJCLab, CNRS/IN2P3, Orsay, France
H. P. Jiang, Harbin Institute of Technology, Harbin, China
B. W. Bai, Harbin Institute of Technology, Shenzhen, China
F. Zimmermann, CERN, Geneva, Switzerland
K. Oide[3], University of Geneva, Geneva, Switzerland
[1]also at Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
[2]also University of Chinese Academy of Sciences, Beijing, China
[3]also at KEK, Tsukuba, Japan

Abstract

One of the most fundamental measurements since the Higgs boson discovery, is its Yukawa couplings. Such a measurement is only feasible, if the centre-of-mass (CM) energy spread of the e^+e^- collisions can be reduced from ~50 MeV to a level comparable to the Higgs boson's natural width of ~4 MeV. To reach such desired collision energy spread and improve the CM energy resolution in colliding-beam experiments, the concept of a monochromatic colliding mode has been proposed as a new mode of operation in FCC-ee. This monochromatization mode could be achieved by generating a nonzero dispersion function of opposite signs for the two beams, at the Interaction Point (IP). Several methods to implement a monochromatization colliding scheme are possible, in this paper we report the implementation of such a scheme by means of dipoles. More in detail a new Interaction Region (IR) optics design for FCC-ee at 125 GeV (direct Higgs *s*-channel production) has been designed and the first beam dynamics simulations are in progress.

INTRODUCTION

One of the most fundamental measurements since the Higgs boson discovery, is the measurement of its Yukawa couplings [1-3]. Such a measurement is only feasible, if the centre-of mass (CM) energy spread of e^+e^- collisions can be reduced from ~50 MeV in a conventional collision scheme to a level comparable to the natural width of the Higgs boson ΓH = 4.2 MeV at a future high-energy circular collider such as the proposed FCC-ee at CERN [4]. To reach the desired collision energy spread and improve the CM energy resolution in colliding-beam experiments, the concept of a monochromatic colliding mode has been proposed. The basic idea consists in generating opposite correlations between a spatial position and the energy deviation in the colliding beams, as is illustrated in Figure 1.

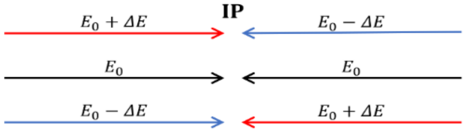

Figure 1: MonochroM scheme for head-on collision

In this configuration we are reducing the CM energies, without necessarily reducing the inherent energy spread of the two individual beams. In beam-optics terms, this can be achieved by generating a nonzero dispersion of opposite signs for the two beams, at the IP. This supposes adding, in the IR of the collider, the necessary devices to create such a dispersion function. Nonzero dispersion function at the IP will contribute to enlarging the IP transverse beam sizes and could also have an impact on the luminosity. If we introduce a monochramatization factor as:

$$\lambda = \sqrt{1 + \sigma_\delta^2 (\frac{D_x^{*2}}{\epsilon_x \beta_x^*} + \frac{D_y^{*2}}{\epsilon_y \beta_y^*})}$$

the spread of CM energy and the luminosity are given then by:

$$\sigma_w = \frac{\Delta E}{\sqrt{2\lambda}}, L_{mc} = \frac{L_{st}}{\lambda}$$

being L_{st} the luminosity in standard conditions without dispersion in the IP and L_{mc} the luminosity in the monochromatization colliding mode. Consequently, the design of a monochromatization scheme has to consider not only the IR beam optics design, but the optimization of the rest of collider parameters to keep luminosity as high as possible.

The essential ideas and the basic theory of monochromatization in e^+e^- colliders were proposed in 1975 by A. Renieri to improve the energy resolution of ADONE [5, 6]. Since then, a variety of monochromatization schemes using different techniques for the generation of the dispersion function at the IP, have been proposed in multiple e^+e^- colliders, mostly at low-energies and in head-on collision configuration: VEPP-4 [7, 8], Tau-Charm factories [9-12], SPEAR [13], B factory or LEP [14-16]. Despite its conceptual simplicity, the monochromatization principle was never investigated to the point of implementation and experimental testing in a collider. Recent studies have revisited and extended the concept of monochromatization for high-energy circular e^+e^- colliders (FCC-ee) in particular for beam collisions with a crossing angle [17-24]. Besides the technical complexity of designing an IR with monochromatization, one of the main difficulties in achieving monochromatization in a high-energy collider such as FCC-ee is the impact of beamstrahlung (BS). In existing low-energy e^+e^- colliders the energy spread of the beams is

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† Corresponding author: zhandong.zhang@ijclab.in2p3.fr

typically below the permille level. It is mainly due to SR emitted in the arc bending magnets. In future high-energy e^+e^- colliders, the BS will become for the first time a significant contributing factor to the increase of the energy spread. As a consequence, the energy spread may become significantly larger than the width of narrow resonances ($\Gamma/m \sim 10^{-5}$). In this context and under the framework of the Future Circular Collider Feasibility Study (FCC FS) [25] a monochromatization scheme has been proposed for the FCC-ee [21, 22, 24].

THE FCC-ee MONOCHROMATIZATION SELF-CONSISTENT PARAMETERS

Taking into account the baseline optics layout and parameters of the FCC-ee [26], featuring a large crossing angle of 30 mrad at the IP, a parametric study of monochromatization for FCC-ee has been made at 125 GeV collision energy. The results calculated with the simulation code Guinea Pig [15] are summarised in Table1. With ~10 cm of horizontal dispersion and taking into account the BS a $\lambda \sim 8$ can be reached [22 ,23, 27].

Table 1: FCC-ee Monochromatization Self-consistent Parameters [27].

Parameters	Unit	Value
CM energy (W)	GeV	125
RMS emittance with BS ($\varepsilon_{x,y}$)	nm rad	2.5/0.002
RMS momentum deviation (σ_δ)	%	0.052
RMS bunch length (σ_b)	mm	3.3
Horizontal dispersion at IP (D_x^*)	m	0.105
IP beta function ($\beta_{x,y}^*$)	mm	90/1
Full crossing angle (θ_c)	mrad	30
Luminosity per IP with BS (L_{mc})	$cm^{-2}s^{-1}$	2.6×10^{35}
RMS CM energy spread (σ_W)	MeV	13

FCC-ee MONOCHROMATIZATION H-D SCHEME IMPLEMENTATION

Standard FCC-ee IR Optics

The FCC-ee IR consists of two horizontal separated rings for electrons and positrons, colliding with a 30 mrad horizontal crossing angle and a local chromaticity correction scheme (LOC), with horizontal dispersion created by horizontal dipole magnets at the two sides of the IP where sextupoles are located. The easiest way to generate the horizontal dispersion in the IP needed for the monochromatization will be by using the horizontal dipoles (HD) already present in the IR. This technique will be used in the following. In order to minimise the impact of SR from IR HD on the detectors, the baseline standard optics of FCC-ee is asymmetric. Figure 2 shows in the top the standard IR optics for positrons. The six LOC-HD in both upstream and downstream of the IR are signalled in red. The dispersion function at the IP (green) is zero around the IP and there are two dispersion-free regions before the arcs. In the bottom part of the figure the IR orbit in the horizontal plane is shown. Magnetic elements are shown in colour (dipoles in red, quadrupoles in blue and sextupoles in yellow). The optics have been calculated with MADX [28].

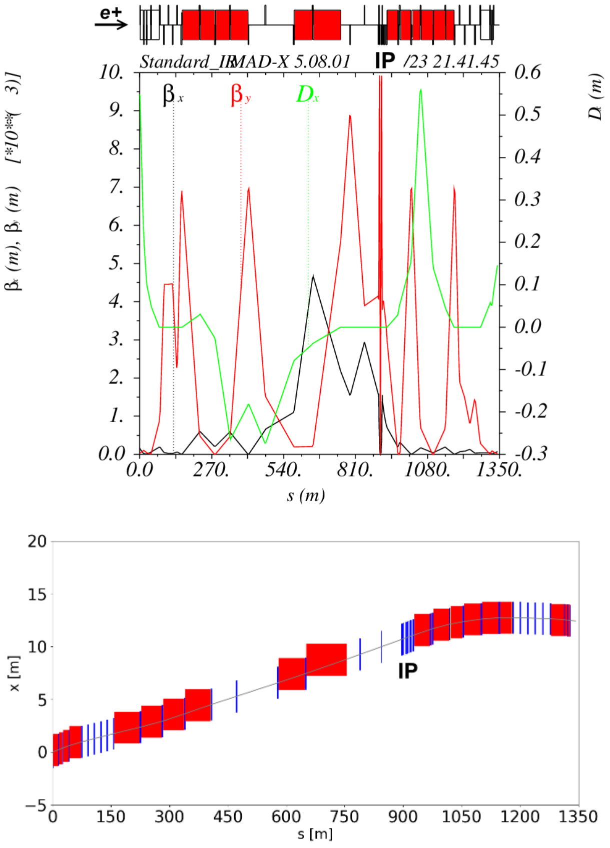

Figure 2: Standard FCC-ee IR optics (top) and orbit in horizontal plane (bottom).

MonochroM LOC-HD FCC-ee IR Optics

There are different ways to generate the necessary dispersion in the IP, in this case we will use the LOC-HD to generate horizontal dispersion (D_x^*). Given the fact that the IR is asymmetric and to gain flexibility to match the optics, we have introduced some extra quadrupoles in the existing LOC-HD and the last long dipole at the two sides of the IP (see green circles in Figure 4 top) has been modified as shown in Figure 3 to match the dispersion. More in detail, Angle 1 is equal to Angle 3, and Angle 2 is equal and opposite sign to the sum of Angle 1 and Angle 3. As a consequence, the orbit of the monochromatization LOC-HD IR is slightly different to the baseline (see green circles in Figure 4 bottom). A re-matching of the baseline IR standard has been made (Figure 5) to get equivalent orbits without/with monochromatization.

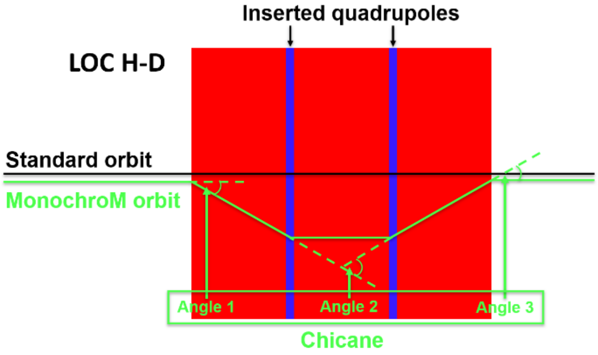

Figure 3: Detail of the FCC-ee MonochroM LOC-HD IR last dipole chicane scheme.

The monochromatization LOC-HD FCC-ee IR optics (top) and the orbit (bottom), calculated with MADX code, are shown in Figure 4. The beam parameters for this optics correspond to the ones of Table 1.

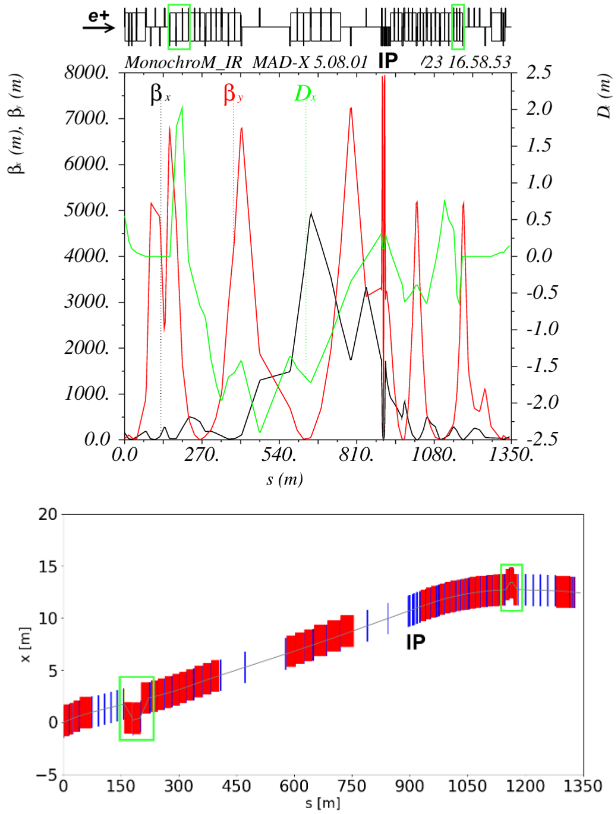

Figure 4: FCC-ee MonochroM LOC-HD IR optics (top) and orbit in horizontal plane (bottom).

Following the same principle, a more simple design optics is in progress.

Standard FCC-ee IR Re-matched Optics with MonochroM LOC-HD Orbit

Due to the introduction of the dispersion matching chicanes in the last dipoles at each side of the IP (Figure 3), the orbit of the MonochroM LOC-HD IR optics (Figure 4 bottom) differs from the Standard IR one (Figure 2 bottom). A rematching of the standard optics using the MonochroM LOC-HD orbit (with chicanes) has been calculated keeping the standard parameters has been performed and it is shown in Figure 5. Notice that bottom part of Figures 4 and 5 are equivalent.

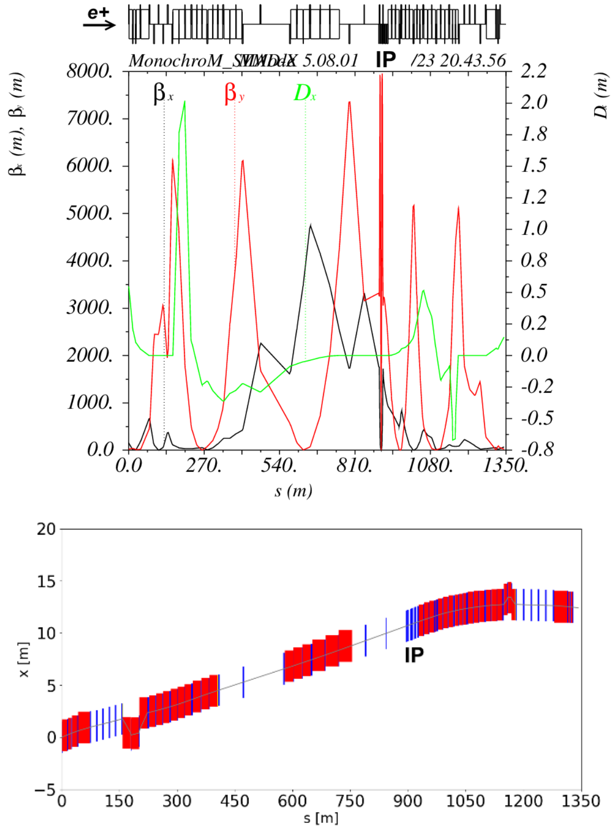

Figure 5: Standard FCC-ee IR re-matched optics (top) with MonochroM LOC-HD orbit (bottom).

CONCLUSION

A first monochromatization IR optics has been designed for FCC-ee. The necessary horizontal dispersion at the IP has been implemented by means of the H-dipoles present in the LOC. Horizontal dispersion of 10 cm at the IP of difference sign for the two beams, is able to reduce the energy spread at the level of 13 MeV. Following a similar approach, more simplified optics design is in progress. Future work involves detailed beam dynamics simulations, including beam-beam, to assess this new mode of operation.

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