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FIRST OPTICS DESIGN FOR A TRANSVERSE MONOCHROMATIC SCHEME FOR THE DIRECT S-CHANNEL HIGGS PRODUCTION AT FCC-ee COLLIDER

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Abstract

The FCC-ee collider baseline foresees four different energy operation modes: Z, WW, H(ZH) and ttbar. An optional fifth mode, called s-channel Higgs production mode, could allow the measurement of the electron Yukawa coupling, in dedicated runs at 125 GeV centre-of-mass energy, provided that the centre-of-mass energy spread, can be reduced by at least an order of magnitude (5-10 MeV). The use of a special collision technique known as monochromatization scheme (mono-scheme) is one way to accomplish it. There are several methods to implement a monochromatization scheme. One method, named transverse monochromatization scheme, consists of introducing a dispersion function different from zero but of opposite sign for the two colliding beams at the Interaction Point (IP); Another one, named longitudinal monochromatization scheme, would make use of the correlation between the particle's longitudinal position and energy by means of RF cavities on each side of the IP. In this paper we will report about the first attempt to design a new optics to implement a transverse monochromatic scheme for the FCC-ee Higgs production totally compatible with the standard mode of operation without dispersion at the IP.

INTRODUCTION

The transverse monochromatization is a proposed way to reduce the centre-of-mass (CM) energy spread of FCC-ee [1] and then to increase the resolution in the CM energy with the natural energy spread, due to the synchrotron radiation (SR). For achieving the monochromatization schemes condition, opposite correlations between transverse position and energy have to be introduced. This requires a non-zero and opposite sign of dispersion function for the two beams, at the interaction point (IP). Monochromatization has been studied for 50 years [2-9], but has never used in any collider.

The FCC-ee collider consists of two horizontally separated rings for electrons and positrons, colliding with a crossing angle (30 mrad), so the horizontal dispersion at the IP can be generated independently with opposite signs. The non-zero dispersion functions are generated by changing the dipole configuration but keeping the crossing angle in the interaction region (IR).

In the following we will show first some analytical and parametric studies, second a first new design of the FCC-ee IR optics with a monochromatization scheme and finally a discussion of the issues to be solved in a future work.

THE PRINCIPLES OF MONOCHROMATIZATION

The standard collision scheme of a collider in comparison with the monochromatization colliding one is shown for comparison in Figure 1.

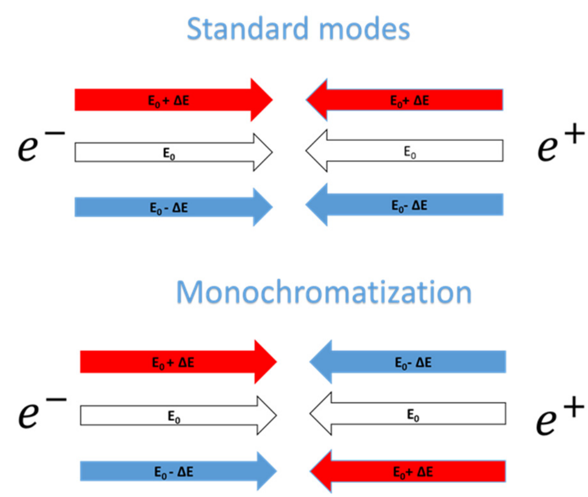

Figure 1: Schematic diagram of standard (Top) and monochromatization (Bottom) collision modes.

In the standard collision mode, the electron and positron beams have the same energy E_0 and energy spread ΔE (top part of Figure 1). In such a case the CM energy spread is given by:

$$\left(\frac{\delta w}{w}\right)_{standard} = \frac{\Delta E}{\sqrt{2}} \quad (1)$$

In the monochromatization collision mode, an IP dispersion of opposite sign for the two beams is introduced, so particles with energy ($E_0 + \Delta E$) will collide on average with particles of energy ($E_0 - \Delta E$) shown in the bottom part of Figure 1. In this configuration, the CM energy spread is reduced by the monochromatization (m.c.) factor λ, defined as [9]:

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$$\left(\frac{\delta w}{w}\right)_{m.c.} = \frac{\Delta E}{\sqrt{2}}\frac{1}{\lambda} \quad (2)$$

If the IP dispersion function is introduced in the horizontal plane ($D_x^* \neq 0$), the monochromatization factor is given by:

$$\lambda = \sqrt{1 + \frac{D_x^{*2}\sigma_\varepsilon^2}{\epsilon_x \beta_x^*}} \ . \quad (3)$$

THE OPTIMIZED PARAMETERS FOR THE FCC-ee MONO-SCHEMES

The mono-schemes increases the CM resolution energy but have some detrimental effects as the reduction of the luminosity and the growth of the emittances, due to the beamstrahlung [10]. Preliminary parametric studies have been made [8,10,11] to evaluate the emittance growth and the trade-off between luminosity and the CM energy spread for FCC-ee. For this work we consider the parameters summarized in Table 1 from [11], with a dispersion function in the IP of 0.105 m with crab cavities and taking the beamstrahlung effect into account. The monochromatize factor in these conditions is 5 and CM energy spread is reduced from 65MeV to 13MeV.

Table 1: Parameters for FCC-ee Monochromatization Scheme [11]

Parameters	value	Unit
CM energy (W)	125	GeV
RMS emittances ($\varepsilon_{x,y}$)	2.5/0.002	nm rad
RMS momentum deviation	0.052	%
RMS bunch length	3.3	mm
Horizontal dispersion at IP (D_x^*)	0.105	m
IP beta function ($\beta_{x,y}^*$)	90/1	mm
RMS beam size at IP ($\sigma_{x,y}^*$)	55/0.045	µm
Full crossing angle	30	mrad
Luminosity per IP	2.6 x10^{35}	$cm^{-2}s^{-1}$
RMS CM energy spread	13	MeV

PRELIMINARY FCC-ee IR OPTICS FOR TRANSVERSE MONO-SCHEME

The Standard FCC-ee IR Optics

Being the IR of a collider one of the most complicated insertions, the design of a new FCC-ee IR optics for the mono-schemes is challenging and presents a lots of constrains. The baseline standard IR optics ($D_x^* = 0$) for FCC-ee is shown in Figure 2. We could observe from Figure 2 the asymmetric IR design in order to limit the SR.

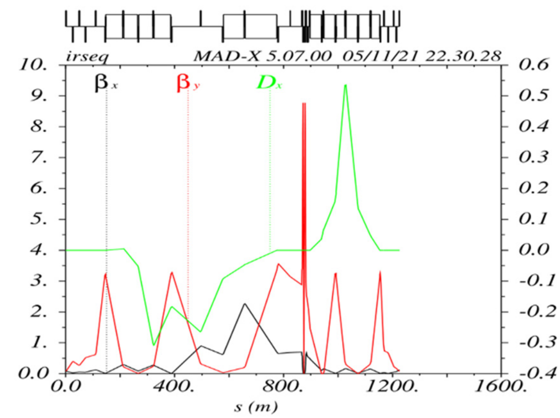

Figure 2: The standard FCC-ee IR optics.

In the following and to facilitate the optics matching, the IR lattice optics will be divided in two parts taking the IP as starting point: the IR-left and the IR-right.

Some Constraints for the New Mono-scheme FCC-ee IR Optics

The new mono-scheme IR FCC-ee optics must be designed taking in to account the following constrains:

- The beam size has to fit in the same beampipe that the standard one, then the beta and the dispersion functions will be limited.
- The new IR optics will be able to provide with the same magnet configuration than in the standard case a dispersion value of D^*_x = 0.105m for positrons, D^*_x = -0.105 m for electron and D'^*_x = 0 for both.
- Each of the IR-left and IR-right end has to be match to the arc standard cells.
- The crossing angle will be the same, then if a change is introduced in the dipole configuration the total angle has to be unchanged.
- As in the standard case the SR is limited 100keV photons.

Taking into account these constraints, a new mono-scheme FCC-ee IR optics has been designed and described in the following.

The IR-left Mono-scheme FCC-ee Optics

For the IR-left mono-scheme optics, we have modified the lattice to produce the needed dispersion at the IP without changing the crossing angle. A new dipole configuration has been introduced, keeping the crossing angle and the beta function at the IP and giving the aforementioned dispersion functions at the IP. The optics functions with $\beta_{x,y}^* = 90/1\ mm$, D^*_x= 0.1 m and D'^*_x= 0, calculated with MADX are shown in Figure 3 for the positrons.

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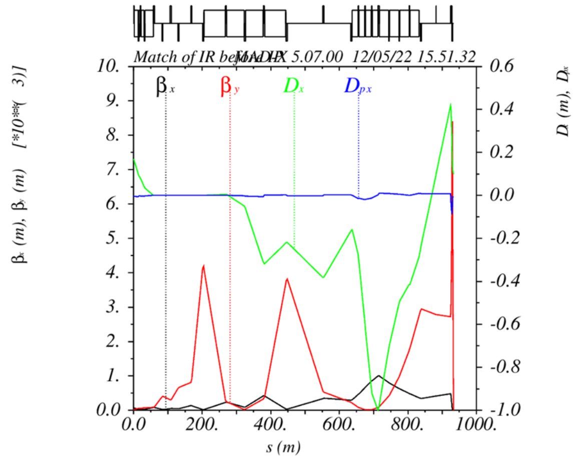

Figure 3: The new optics for the FCC-ee mono-scheme IR-left.

The IR-right Mono-scheme FCC-ee Optics

In the case of the IR-right optics, the lattice has been modified to match the horizontal dispersion to the zero at the dispersion-free region, the beta functions with the rest of the ring and keeping the crossing angle. The resulting optics functions calculated with MADX are shown in Figure 4 for the positrons.

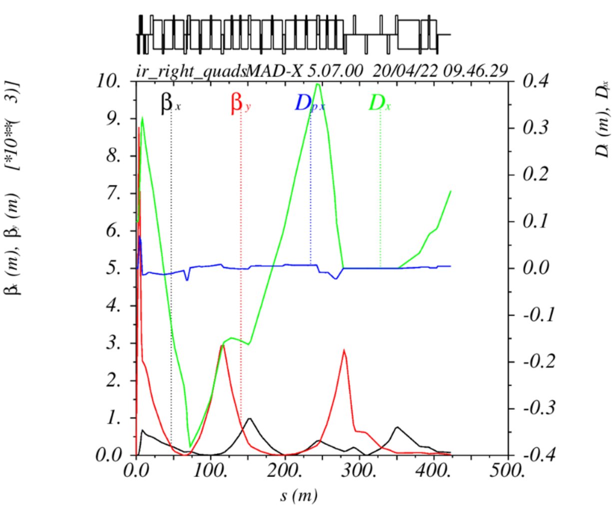

Figure 4: The new optics for the FCC-ee mono-scheme IR-right.

THE MONO-SCHEMES ISSUES

The mono-scheme is reducing the CM energy spread but some issues has to be solved in order to optimize the overall performances of such a scheme. Some of the issues identified are:

- Beamstrahlung: If the dispersion function at the collision point is not zero, beamstrahlung will also increase the transverse emittances.
- Luminosity loss: a trade-off between the luminosity and the energy spread has to be found. The introduction of crabs cavities to recuperate the head-on collision could be explored.
- Large chromaticity: the new mono-scheme optics induce large chromaticity, new sextupole configuration in the Local Chromaticity Correction (LCC) should be implemented.
- Other issues: optimization of the overall beam dynamic aperture (DA) and beam-beam effects.

CONCLUSION

A first preliminary monochromatization scheme for FCC-ee has been implemented. The new positron IR mono-scheme optics is able to provide a monochromatization factor of 5. The new optics features the same crossing angle and meet the main constrains imposed by the standard FCC-ee IR optics. A number of issues have been identified and will be solve in the next future. The next step of this work will be the implementation of the mono-scheme for the electron beam.

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