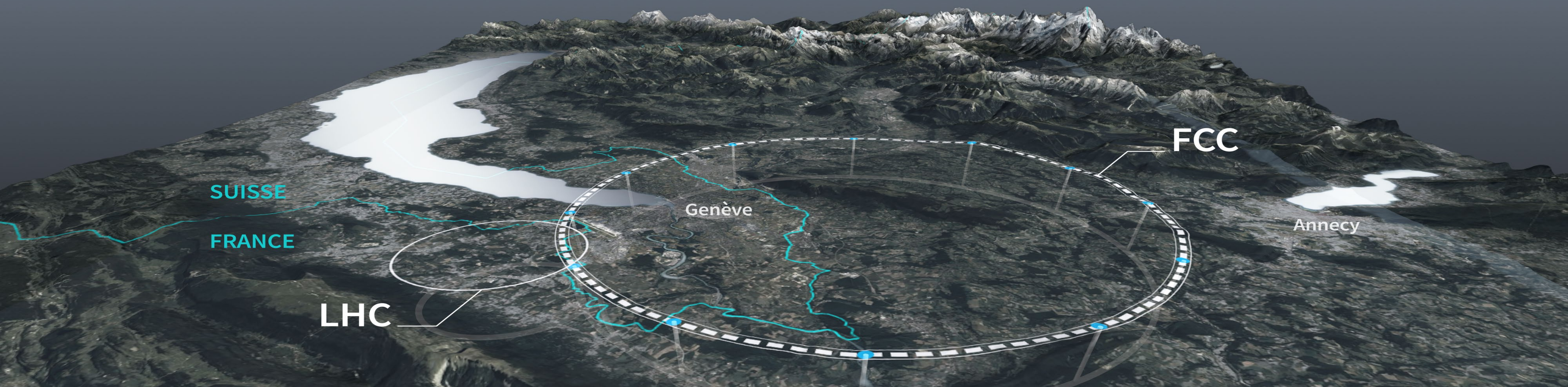

FCC-ee Monochromatization Updates

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FCC-FS EPOL group and FCCIS WP2.5 meeting 21 13 April 2023

Outline

- Transverse Monochromatization Principle
- FCC-ee Monochromatization Schemes
- FCC-ee Monochromatization Optics Design
- Summary and Outlook

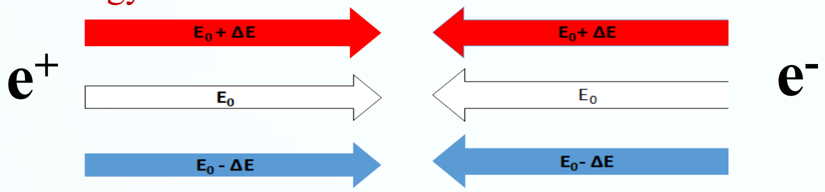
Transverse Monochromatization principle

Standard

D*$_{x,y}$=0

correlation between transverse spatial position and energy deviation

IP



CM energy $w = 2(E_b + \Delta E)$

$$\sigma_w = \sqrt{2}E_b\sigma_\delta$$

Number of bunches

Particles per bunch

Revolution frequency

$$L_0 = \frac{k_b f_r N_+ N_-}{4\pi\sigma^*_{x\beta}\sigma^*_{y\beta}}$$

Luminosity

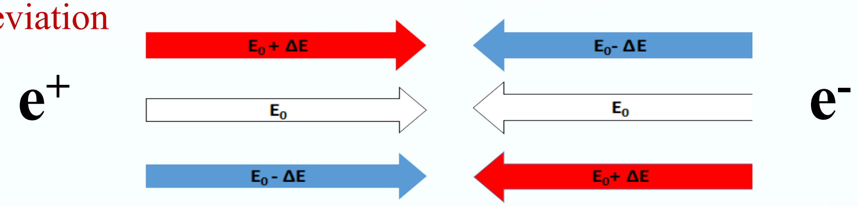
betatronic beam sizes at the IP

Monochromatization

D*$_{x+}$ = - D*$_{x-}$ = D*$_x$
D*$_{y+}$ = - D*$_{y-}$ = D*$_y$

Opposite correlations between transverse spatial position and energy deviation

IP



Dispersion function at the IP created by bending dipoles, when different from zero contribute to the beam size

$$w = 2E_b + O(\Delta E)^2$$

Monochromatization factor $\lambda = \left(1 + \sigma_\delta^2\left(\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}}\right)\right)^{1/2}$

$$\sigma_w = \frac{\sqrt{2}E_b\sigma_\delta}{\lambda}$$

$$L = \frac{L_0}{\lambda}$$

Enhancement of energy resolution, and sometimes increase of the relative frequency of the events at the center of of the distribution but **luminosity loss !!!!**

dispersive beam size at the IP

$$\sigma^*_{x,y} = \sqrt{\beta^*_{x,y}\epsilon_{x,y} + \left(D^*_{x,y}\sigma_\delta\right)^2}$$

Transverse Monochromatization principle

According to the formula of monochromatization factor, we can choose to introduce horizontal dispersion or vertical dispersion to the IP. Because the vertical beam size at the IP is much smaller than horizontal beam size, about ten times smaller vertical dispersion is needed to get the same monochromatization factor compared with the horizontal one.

Parameters	Unit	Horizontal Dispersion	Vertical Dispersion
Beam energy(E)	GeV	62.5	
Horizontal, vertical emittance($\varepsilon_{x,y}$)	nm	0.51, 0.002	
Energy spread(σ_δ)	%	0.052	
Beam length(σ_δ)	mm	3.3	
IP Beta function($\beta^*_{x,y}$)	mm	90, 1	
IP RMS beam size ($\sigma_{x,y}$)	µm	55, 0.045	
Crossing Angle(θ_c)	mrad	30	
Vertical beam-beam parameter(ξ_y)	/	0.106	
Beam current(I_0)	mA	395	
Bunch population(N_b)	10^{11}	0.6	
Bunches per beam(n_b)	/	13420	
IP Dispersion ($D^*_{x,y}$)	m	0.105	0.01
Monochromatization factor (λ)	/	8.1209	11.6705

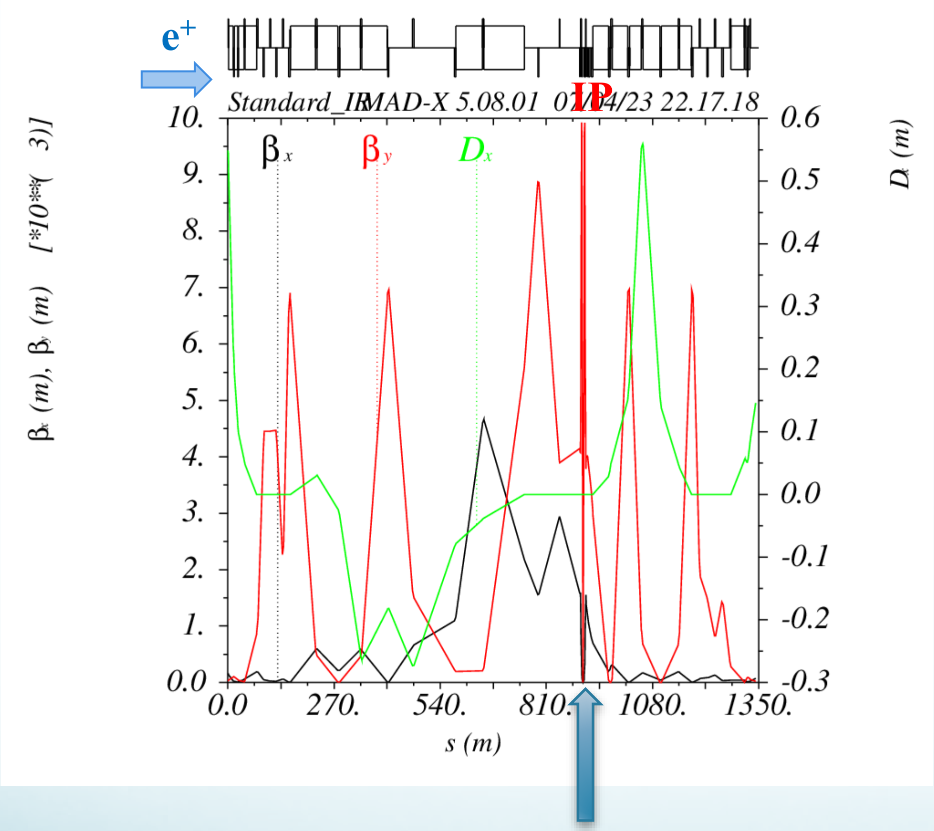
Monochromatization factor

$$\lambda = \left(1 + \sigma_\delta^2 \left(\frac{D_x^{*2}}{\sigma_{x\beta}^{*2}} + \frac{D_y^{*2}}{\sigma_{y\beta}^{*2}}\right)\right)^{1/2}$$

Parameters checked in Mathematica

FCC-ee Monochromatization Scheme Implementation

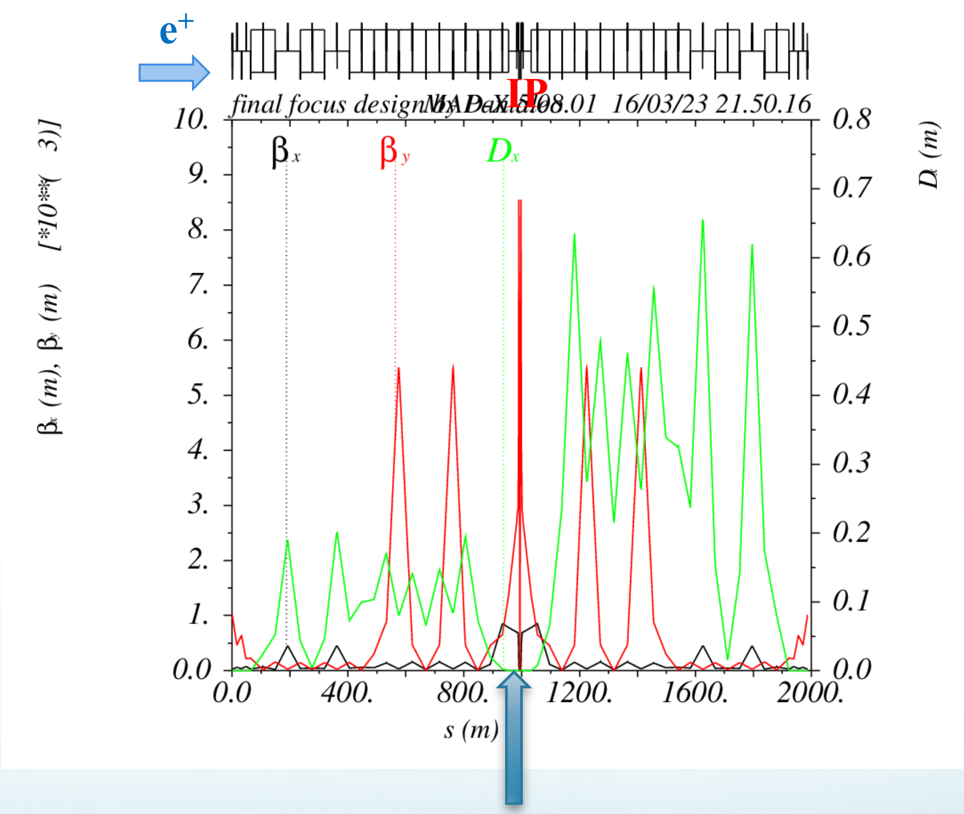
Scheme for Asymmetrical Standard IR Optics



$D^*_x = 0$

Creating horizontal dispersion (D^*_x = 0.105 m)

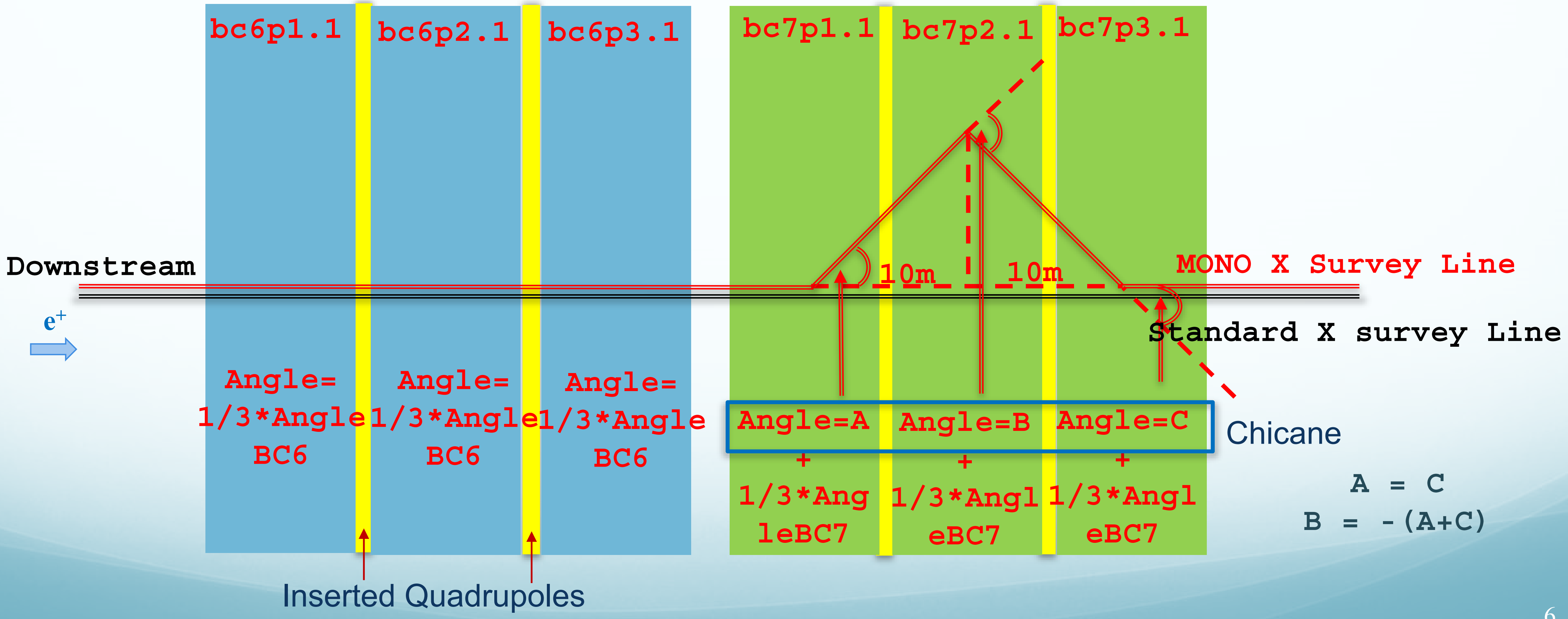
Scheme for Symmetrical Standard IR Optics



Creating vertical dispersion (D^*_y = 0.01m)

Scheme for Asymmetrical Standard IR Optics

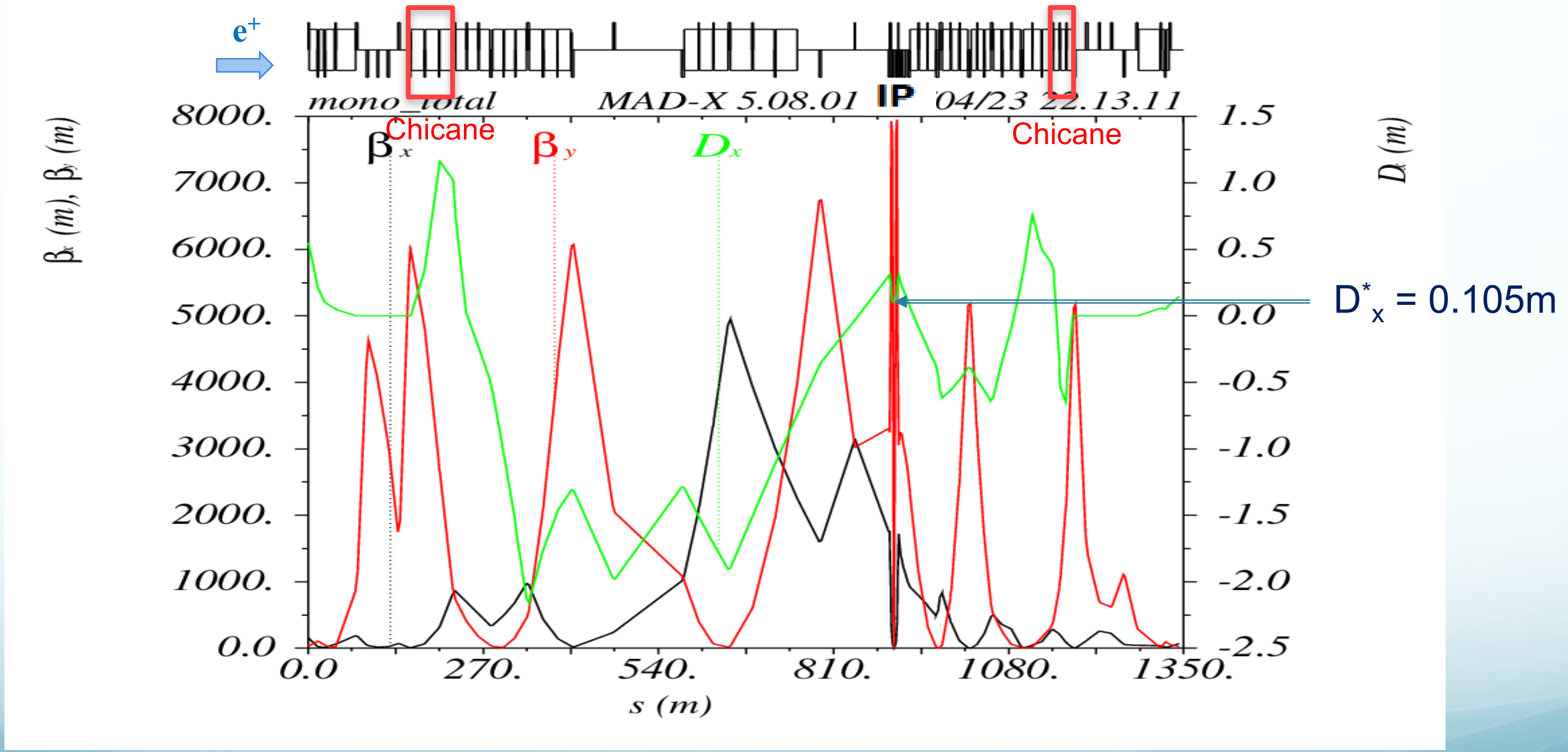
All local vertical chromaticity dipoles in standard IR Optics are cut into three pieces and quadrupoles are inserted between them. One Chicane is implemented in the last dipole in each upstream and downstream to create the dispersion in the IP and to match the dispersion in the arcs while keeping the orbit.



Fcc-ee Monochromatization optics design

Monochromatization optics design base on the asymmetrical standard IR optics

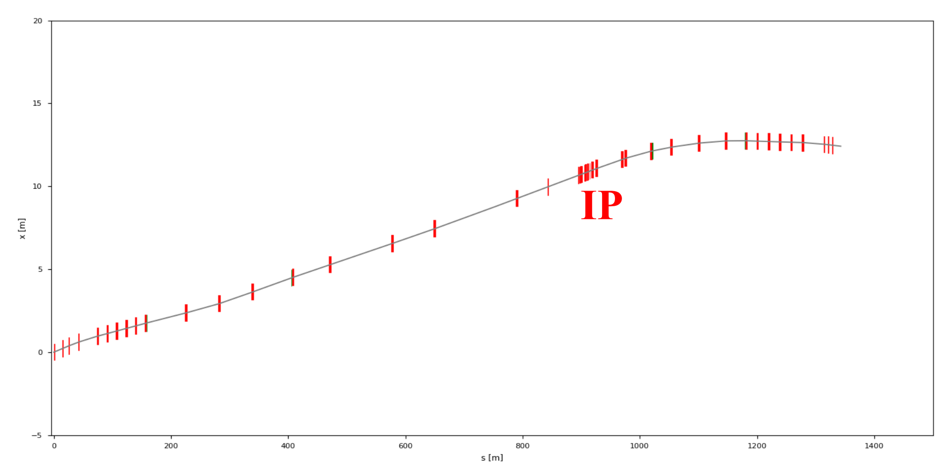
- MonochroM Optics

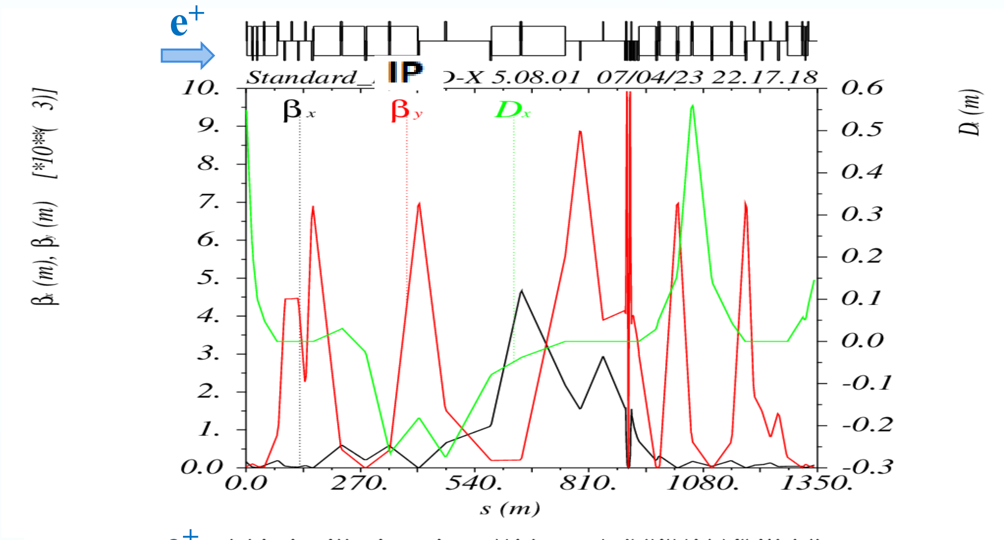


Fcc-ee Monochromatization optic design

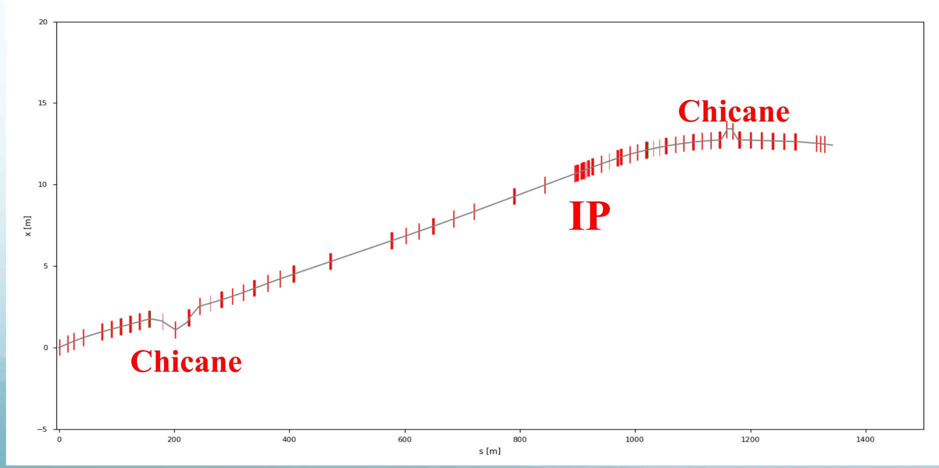
Comparison between standard survey and MonochroM survey

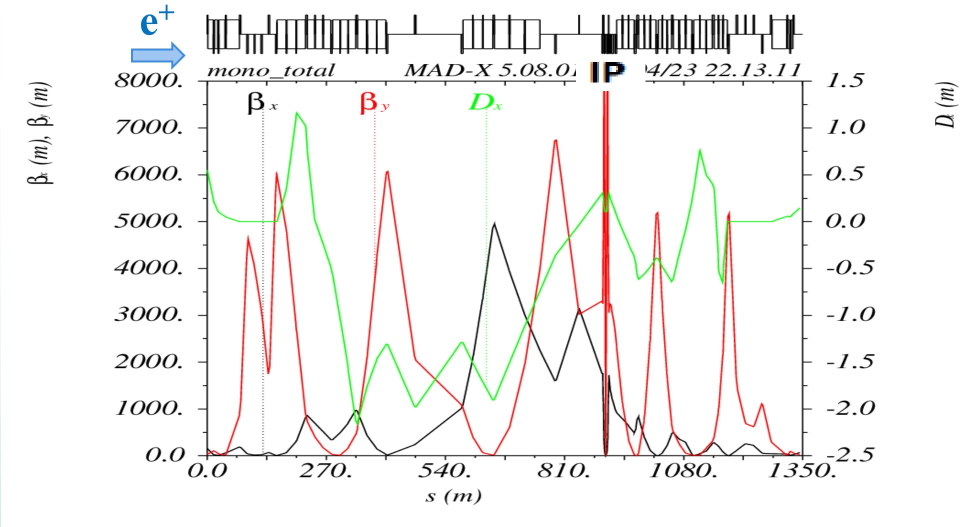
- $D^*_x = 0$ Standard Survey





- $D^*_x = 0.1$ m Monochromatization Survey

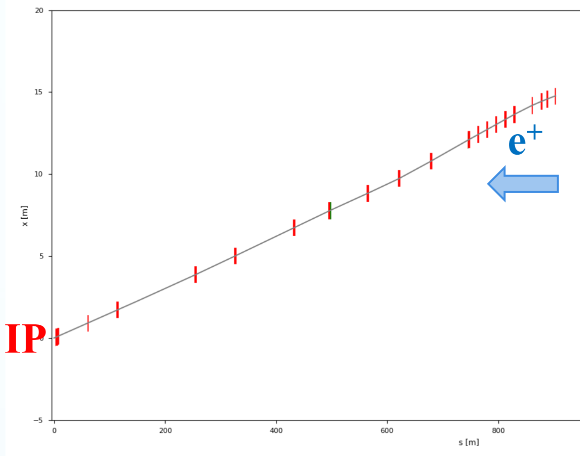




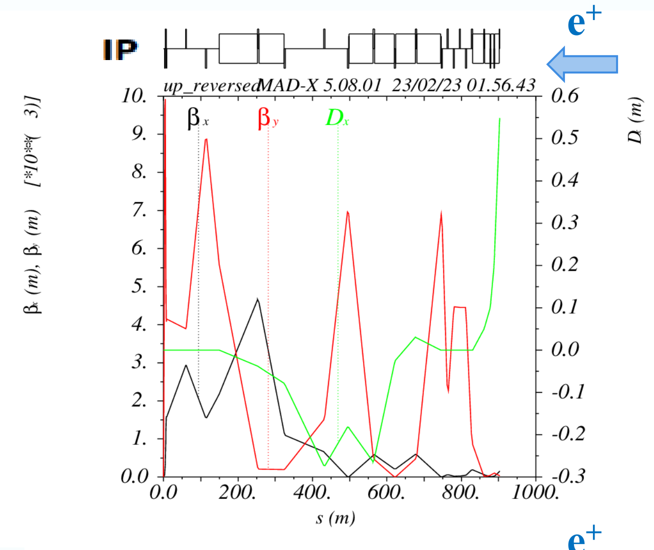
Fcc-ee Monochromatization optic design

Upstream entrance survey point check and beam parameter check

- D^*_x = 0 Standard

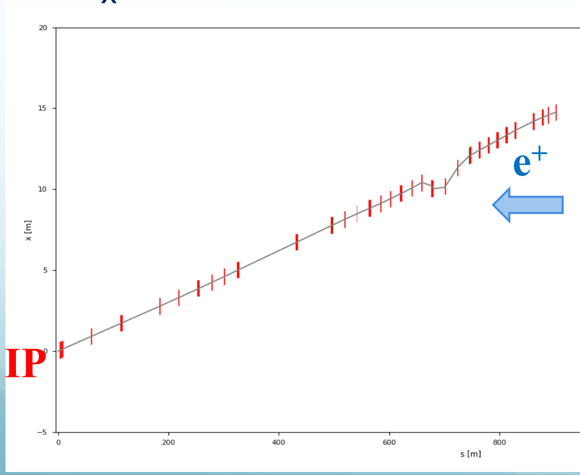


Entrance survey point check
X = 14.77331827
Angle = 0.013272

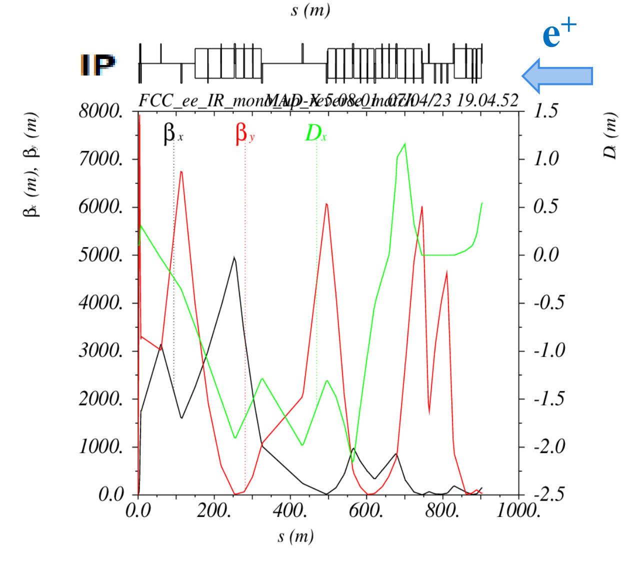


Entrance beam parameters check
β_x = 156.6587437
α_x = -2.264602028
β_y = 35.30306244
α_y = 0.617284605
D_x = 0.5488569734
D_{px} = 0.007526257585

- D^*_x = 0.1 m Monochromatization



Entrance survey point check
X = 14.77337693
Angle = 0.013272

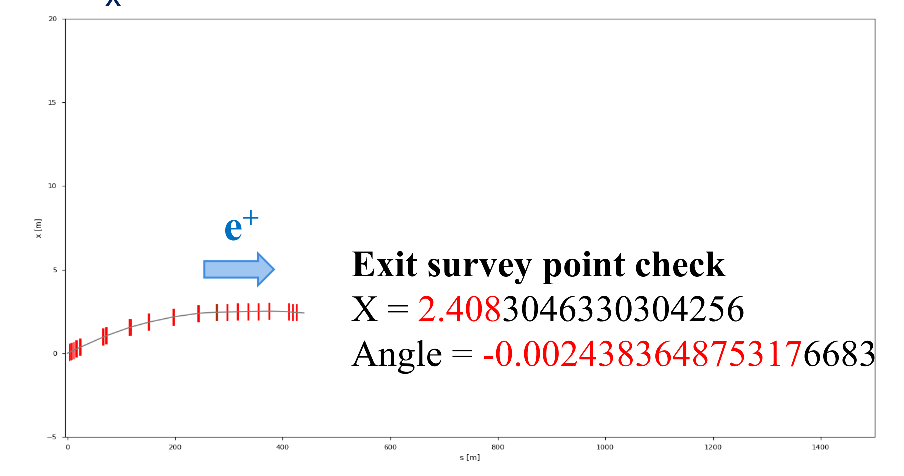


Entrance beam parameters check
β_x = 156.6587412
α_x = -2.264601965
β_y = 35.30306245
α_y = 0.6172845954
D_x = 0.5488569498
D_{px} = 0.007526259176

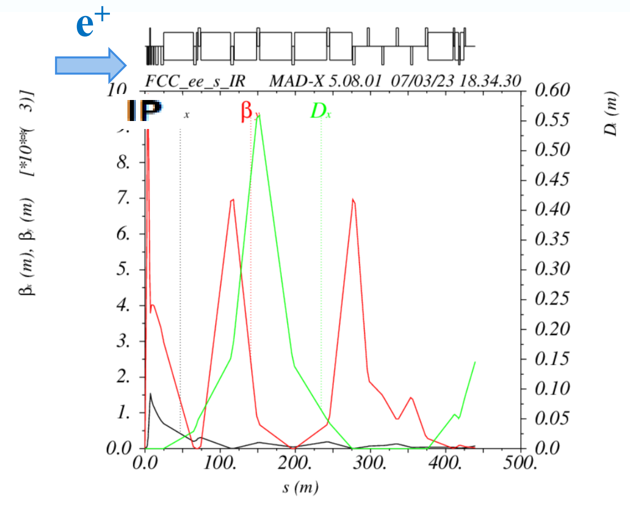
Fcc-ee Monochromatization optic design

Downstream exit survey point check and beam parameter check

- D^*_x = 0 Standard

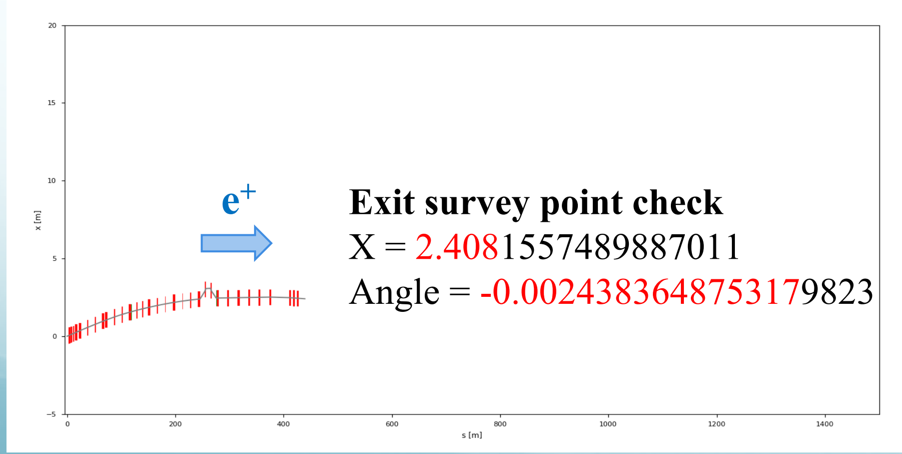


Exit survey point check
X = 2.4083046330304256
Angle = -0.0024383648753176683

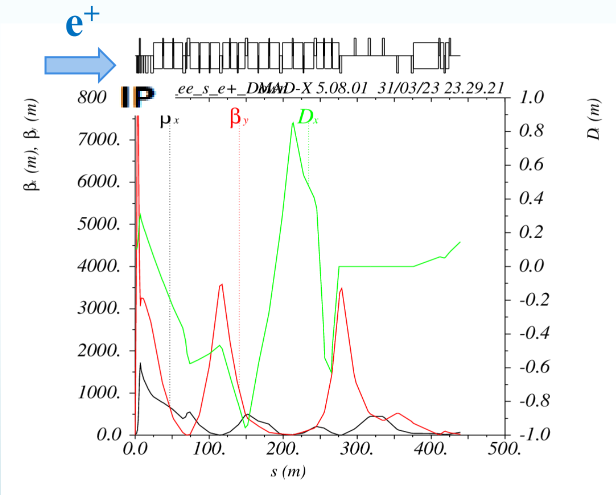


Exit beam parameter check
β_x = 70.69329
α_x = -2.0980736970165381
β_y = 21.4996407
α_y= 0.8124008831436069
D_x = 0.14579546
D_{px} = 0.00429520279

- D^*_x = 0.1 m Monochromatization



Exit survey point check
X = 2.4081557489887011
Angle = -0.0024383648753179823



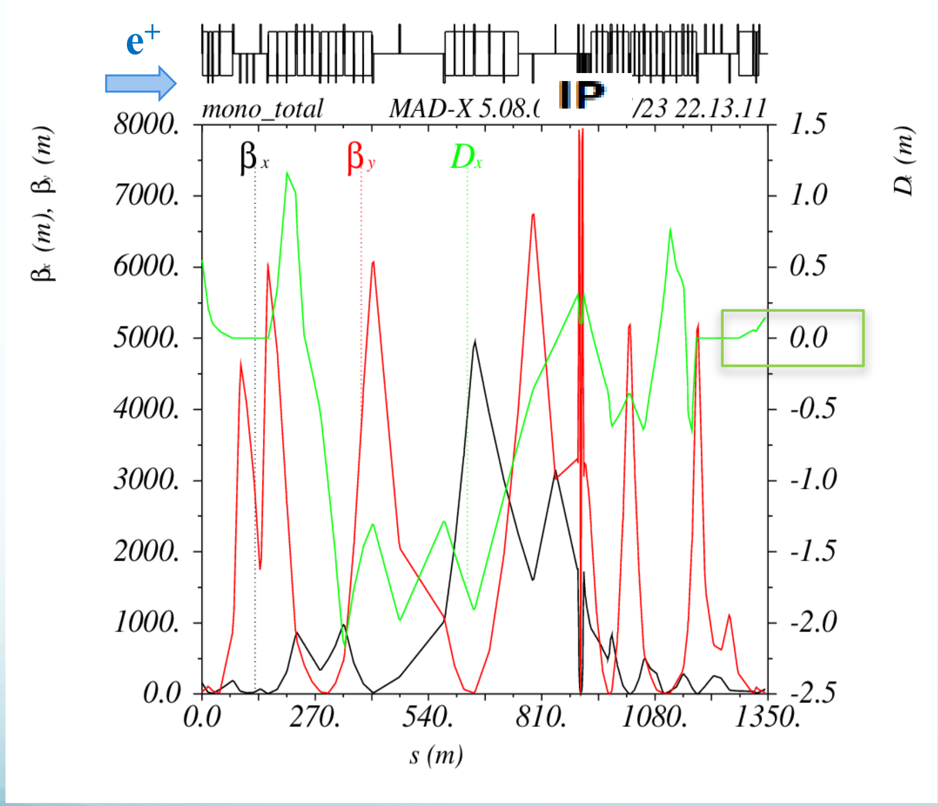
Exit beam parameter check
β_x = 70.694944677848909
α_x = -2.0983903892242135
β_y = 21.499709989732615
α_y = 0.81241870758077928
D_x =0.14579716738239
D_{px} = 0.0042952249464921627

Fcc-ee Monochromatization optics design

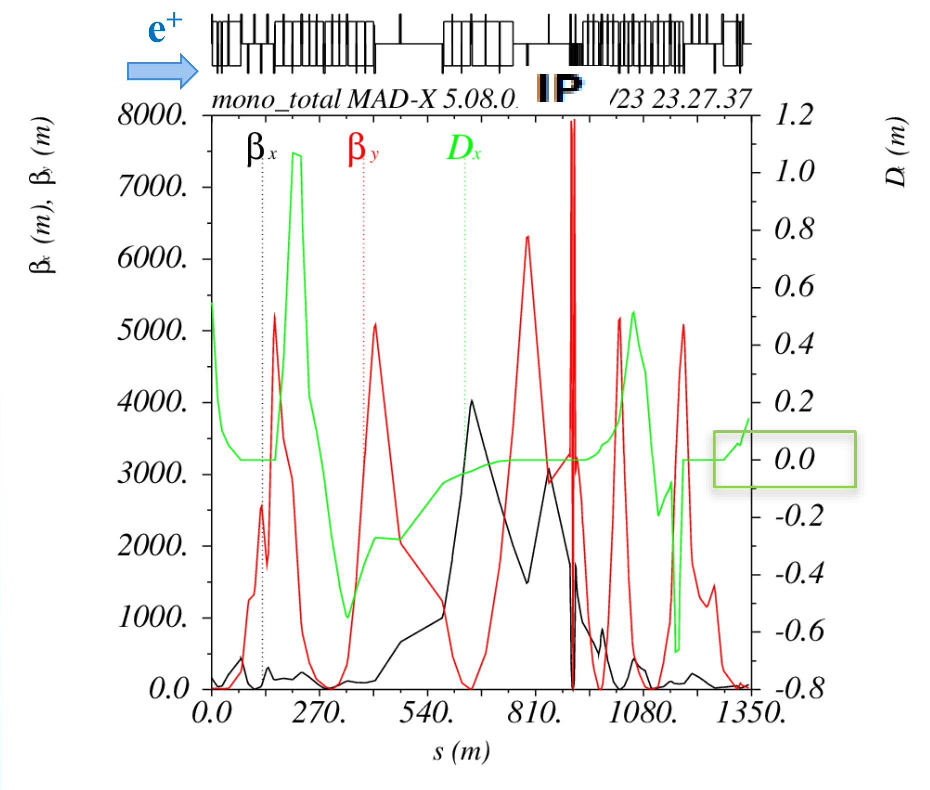
Standard Mode with monochromatization orbit

Frozen the angle of all the dipoles of monochromatization optics (keeping the monochromatization orbit), matching only with the strength of all the quadrupoles to get the dispersion at the IP back to zero.

- $D^*_x = 0.1$ m MonochroM Optics

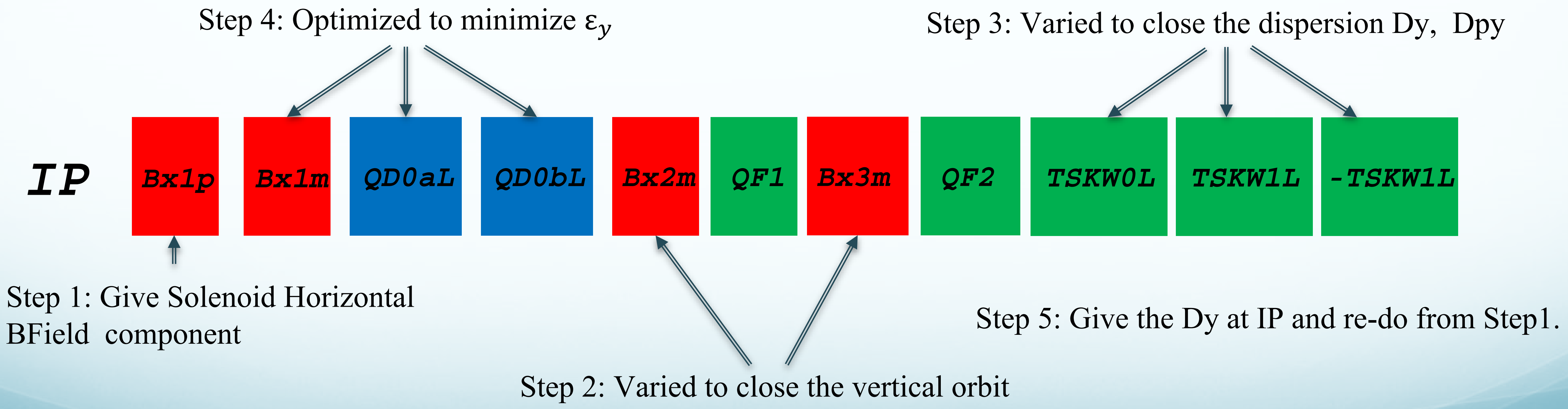


- $D^*_x = 0$ MonochroM Optics



Scheme for Symmetrical Standard IR Optics

Creating the vertical dispersion by adjusting the correctors and skew quadrupoles around the IP solenoid. It will take the following five steps to get the vertical dispersion at the IP.

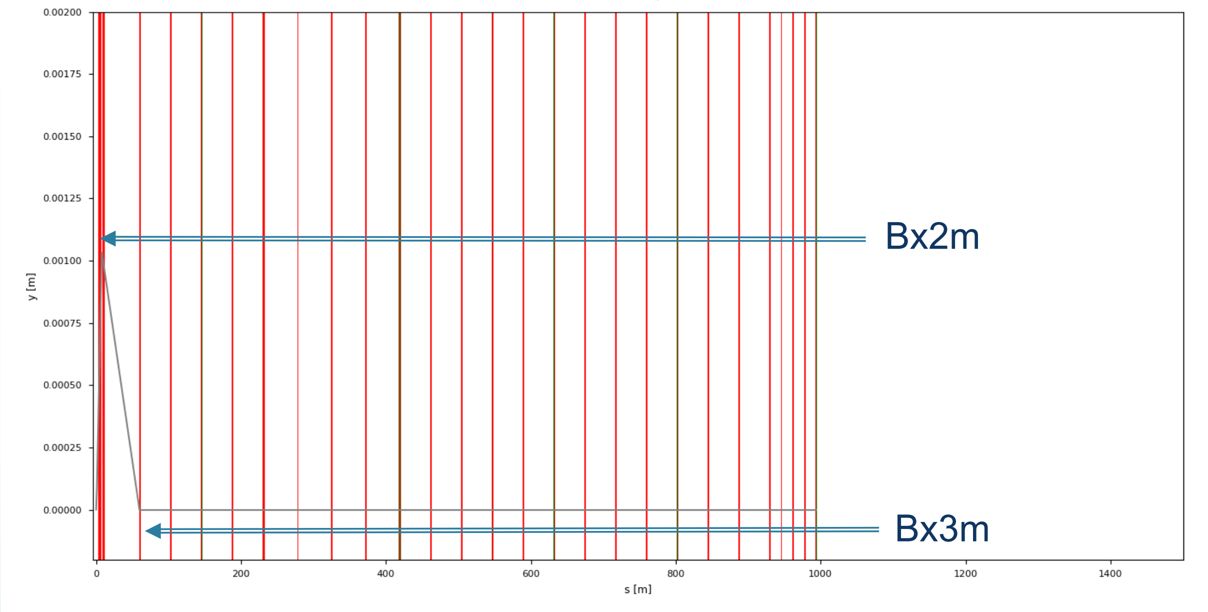


Symmetrical Standard IR Optics

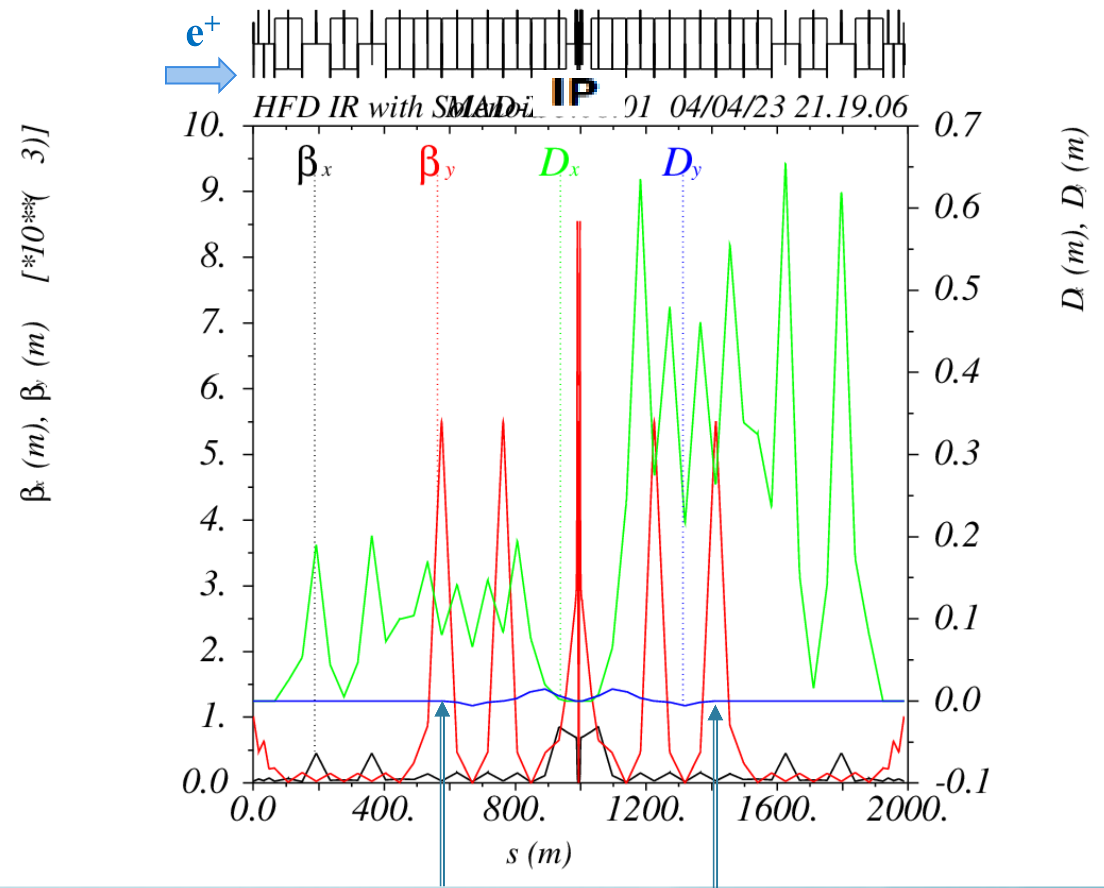
Solenoid implementation

Vertical orbit and vertical dispersion was closed after implementing the solenoid.

Downstream Vertical Survey Plot



Vertical orbit back to 0 after Bx3m



Vertical dispersion closed.

Next step: calculating and minimizing the vertical emittance.

Summary and Outlook

- **Asymmetrical IR Monochromatization Optics design**
  - ✓ The monochromatization optics design for positron
  - ✓ Survey plot and beam parameters check
  - ✓ Standard Mode with monochromatization orbit
  - ➢ Try to insert the monochromatization IR optics to the ring
- **Symmetrical IR Monochromatization Optics design**
  - ✓ Solenoid implement
  - ✓ Closing vertical orbit and vertical dispersion
  - ➢ Calculate and minimize the vertical emittance

Thanks for you attention!