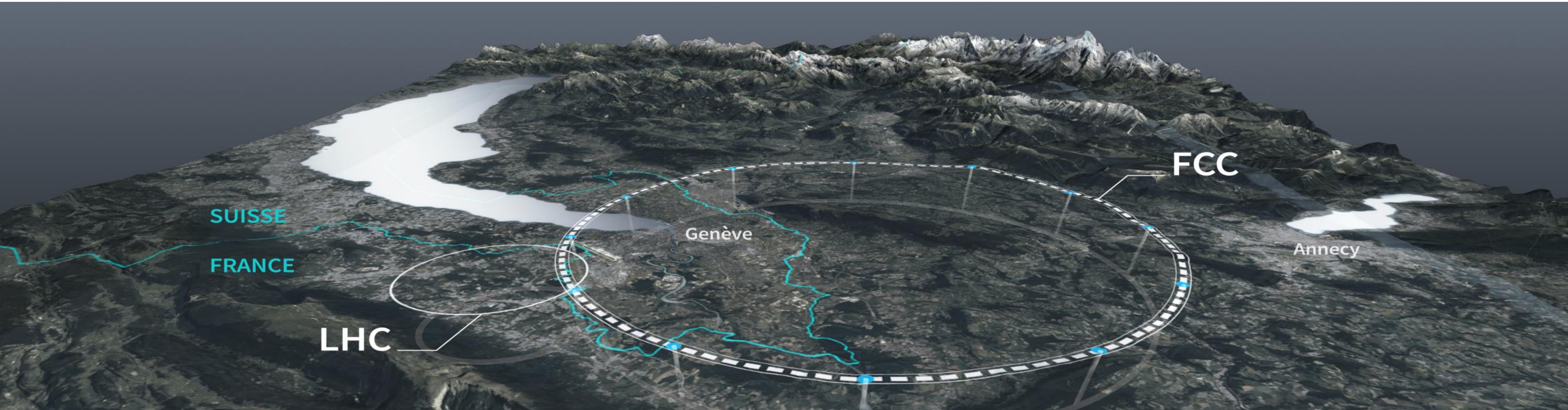


Monochromatization Optics for FCC-ee Lattices

Z. Zhang (IJCLab & IHEP), A. Faus-Golfe (IJCLab)
H. Jiang, B. Bai (HIT)
F. Zimmermann (CERN)
K. Oide (UGE & KEK)
P. Raimondi (SLAC)

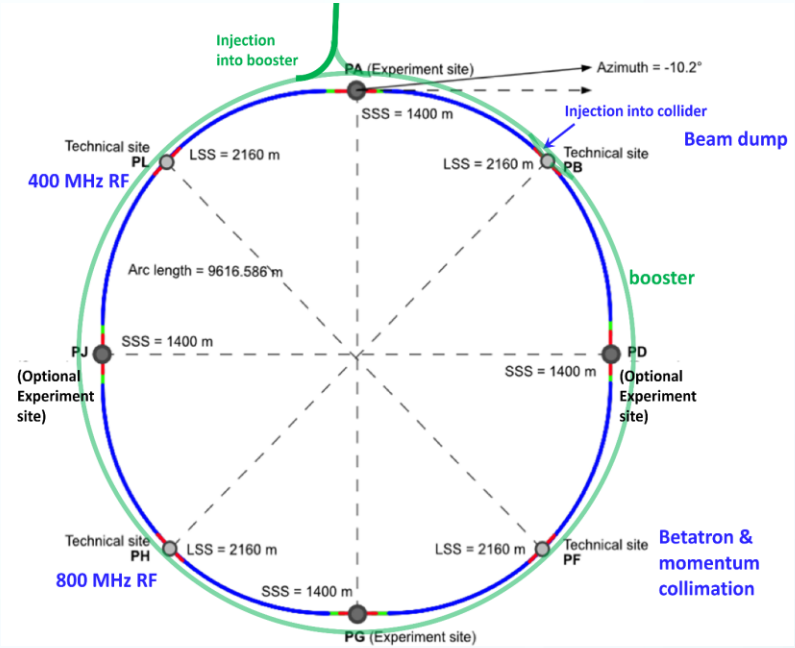
Outline

- Introduction: Physics Requirements
- Transverse Monochromatization Principle
- FCC-ee Monochromatization Self-consistent Parameters
- FCC-ee Monochromatization Schemes
  - Asymmetric
  - Symmetric
- FCC-ee Monochromatization Optics Design
  - Asymmetric
  - Symmetric
- Summary and Outlook

Introduction: Physics Requirements

- FCC-ee modes:
  - The FCC-ee standard modes:
    - Four different energy operation modes:

      Z, $W^{\pm}$, Zh **and** $t\bar{t}$
  - The optional fifth mode: s-channel Higgs production mode
    - The measurement of the electron Yukawa coupling, in dedicated runs at 125 GeV with center-of-mass (CM) energy spread (5-10 MeV). But the natural collision energy spread, due to the synchrotron radiation, is about 50 MeV.



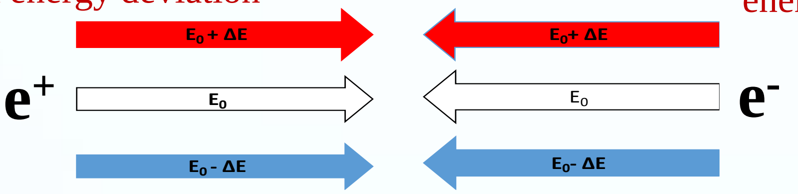
- **Requirements:**
  - Reduce the CM energy spread from 50 MeV to 5 MeV, which is comparable to the resonant width of the standard model Higgs Boson itself (4.2 MeV)

Transverse Monochromatization Principle

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

correlation between transverse spatial position and energy deviation

IP

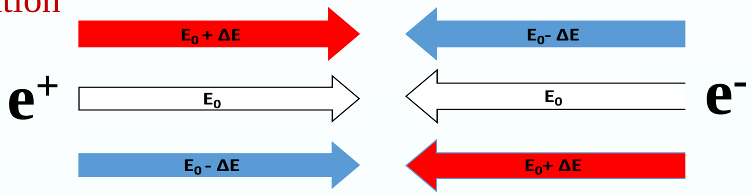


Monochromatization

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

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

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

Monochromatization factor

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

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

Revolution frequency
Number of bunches
Particles per bunch

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

Betatronic beam sizes at the IP
Dispersive beam size at the IP

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

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

Monochromatization Self-consistent Parameters

Taking into account the baseline optics layout and parameters of the FCC-ee, 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 are summarized below.

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	0.001
Monochromatization factor (λ)	/	8.1209	11.6705

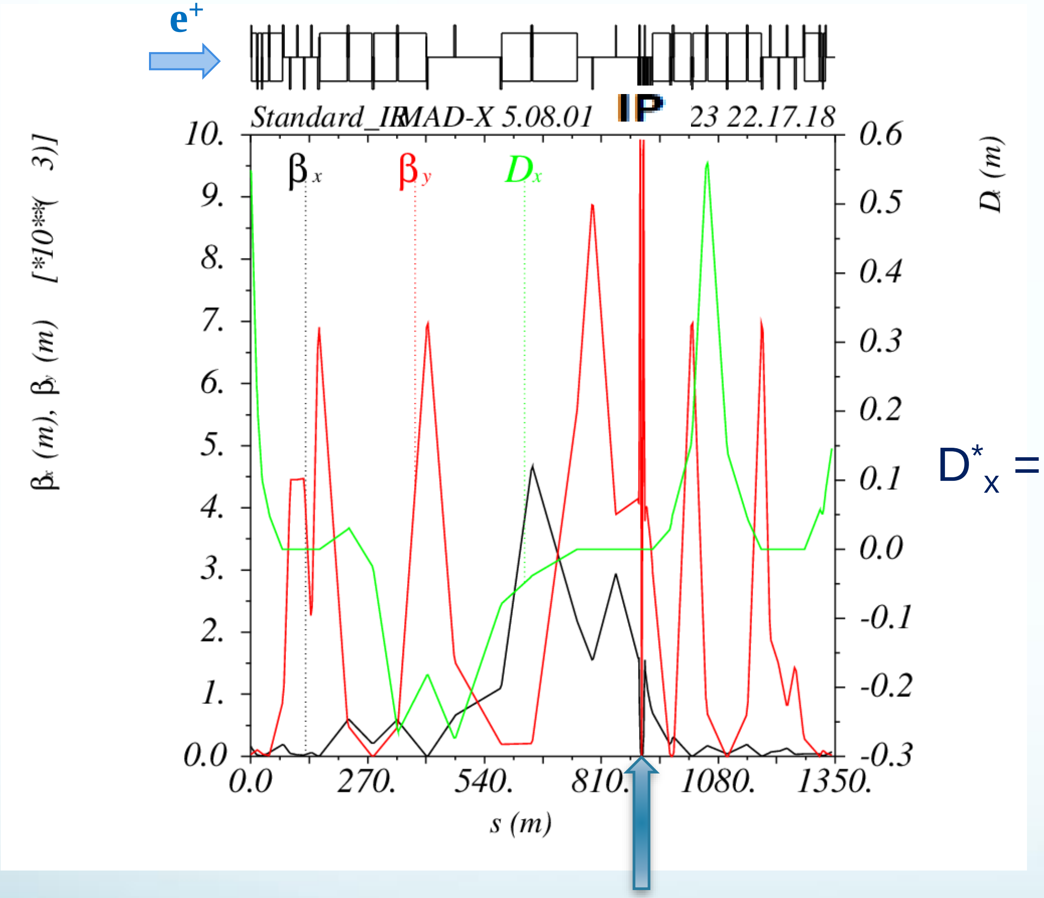
Monochromatization factor

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

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.

FCC-ee Monochromatization Schemes

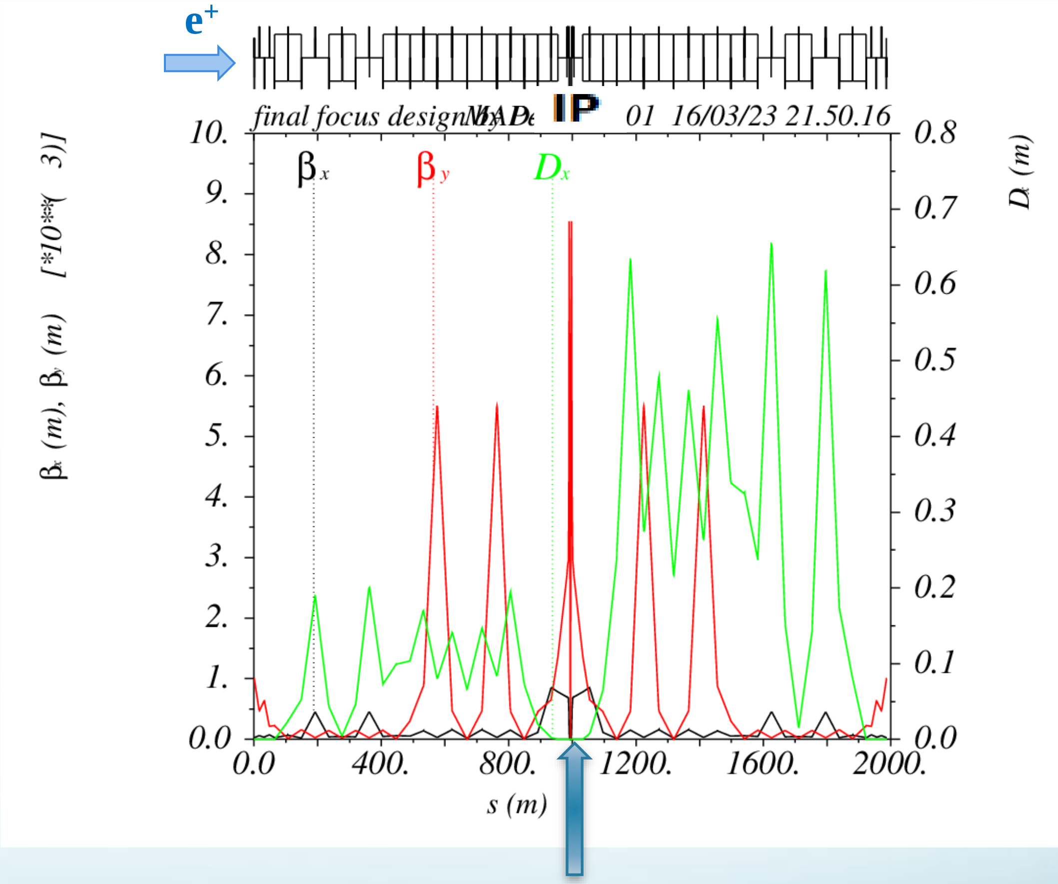
Scheme for Asymmetrical Standard IR Optics (K. Oide)



$D^*_x = 0$ at IP

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

Scheme for Symmetrical Standard IR Optics (P. Raimondi)

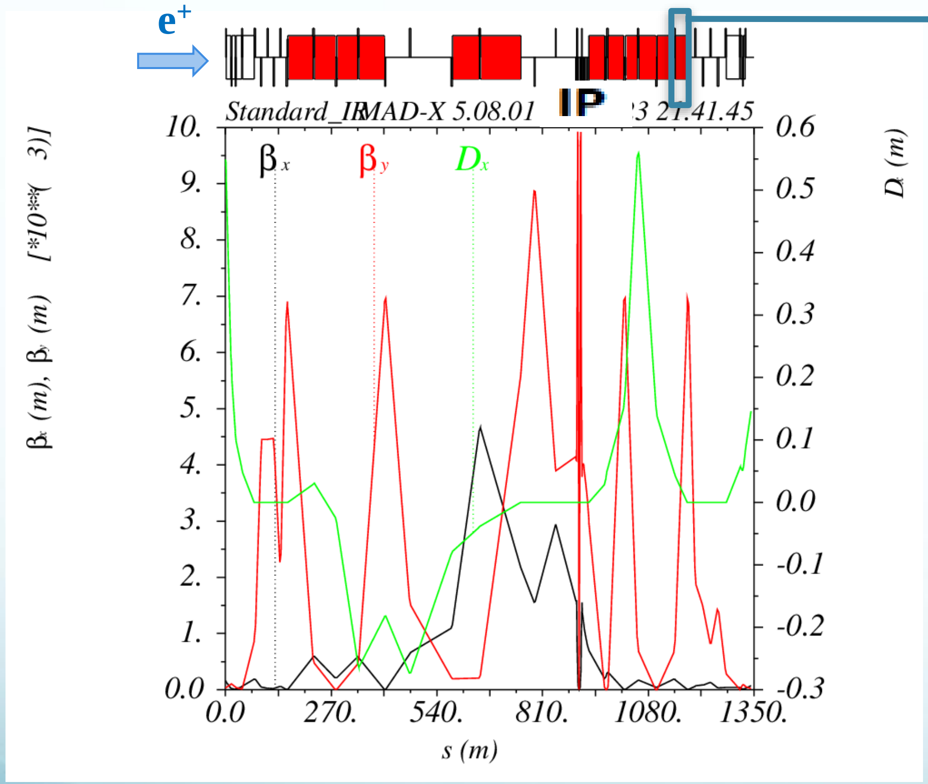


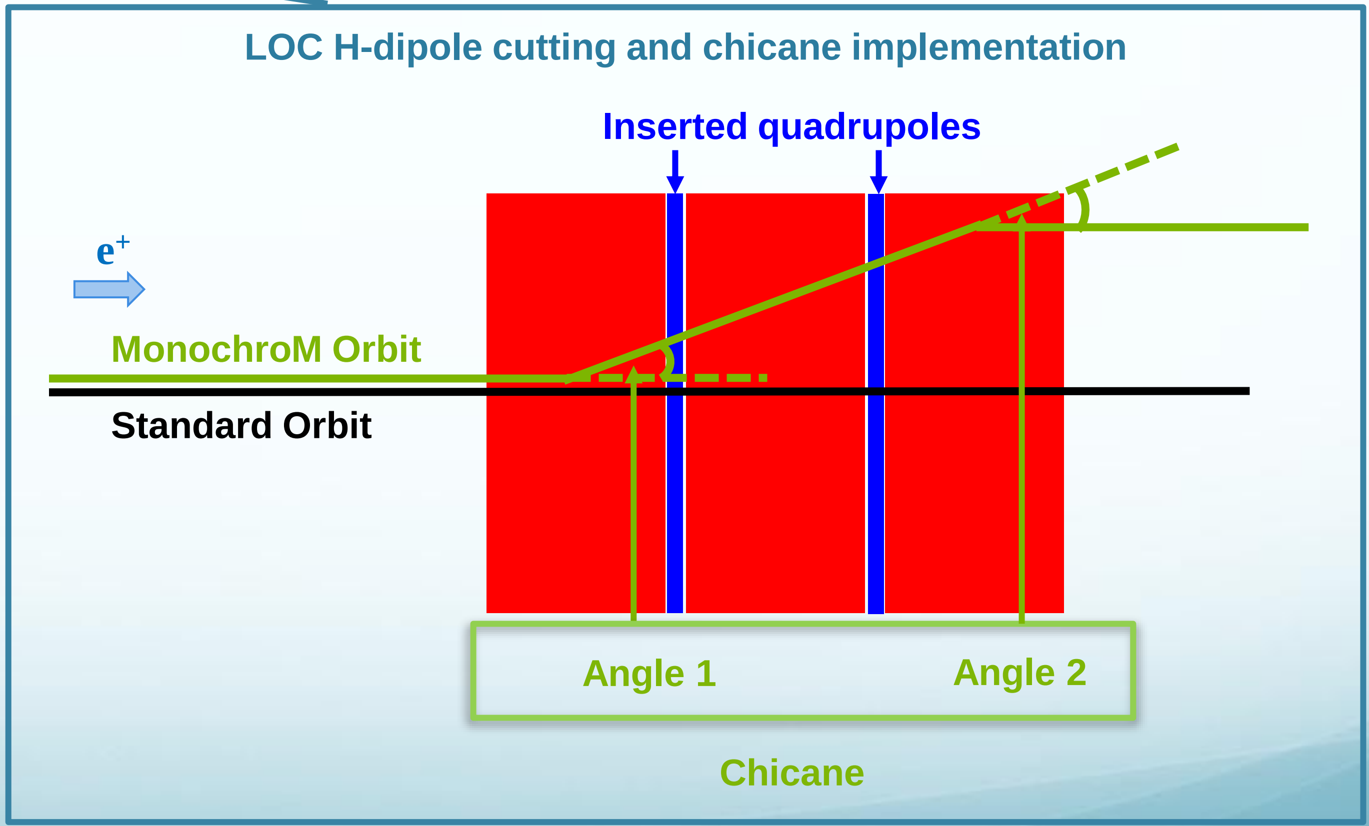
Creating vertical dispersion ($D^*_y = 0.001$m)

Scheme for Asymmetrical Standard IR Optics

- **First Optics Design**

All local vertical chromaticity horizontal dipoles (LOC H-dipole) in standard IR Optics are cut into three pieces and quadrupoles are inserted between them. One half-chicane is implemented in the last dipole in each upstream and downstream to create the dispersion at the IP to match the dispersion in the arcs.

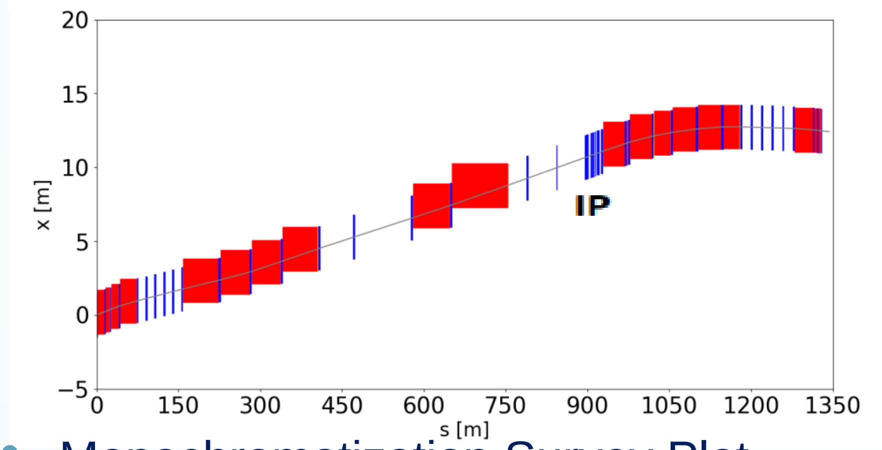


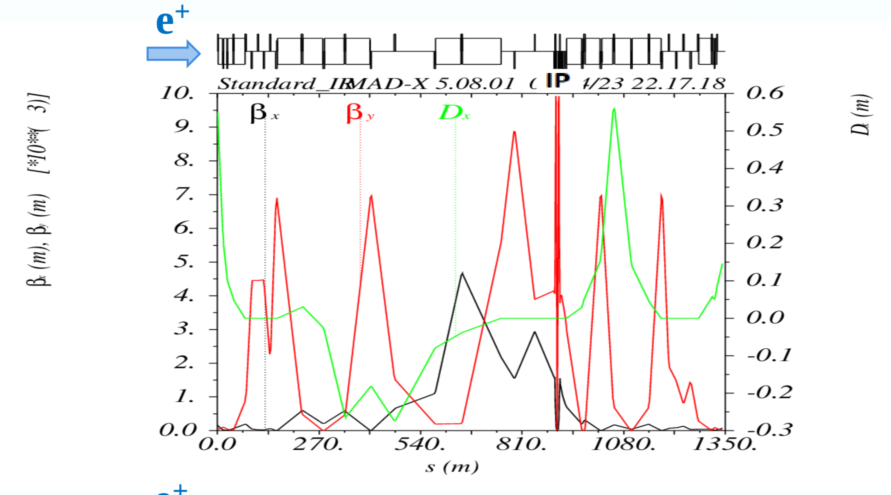


Scheme for Asymmetrical Standard IR Optics

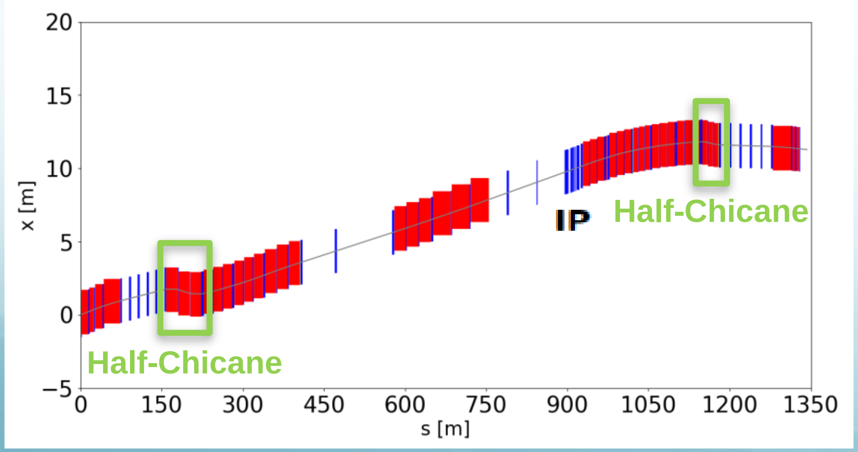
The dispersion at the IP is successfully matched to 0.105m, but the orbit is changed at the position of the two half-chicane.

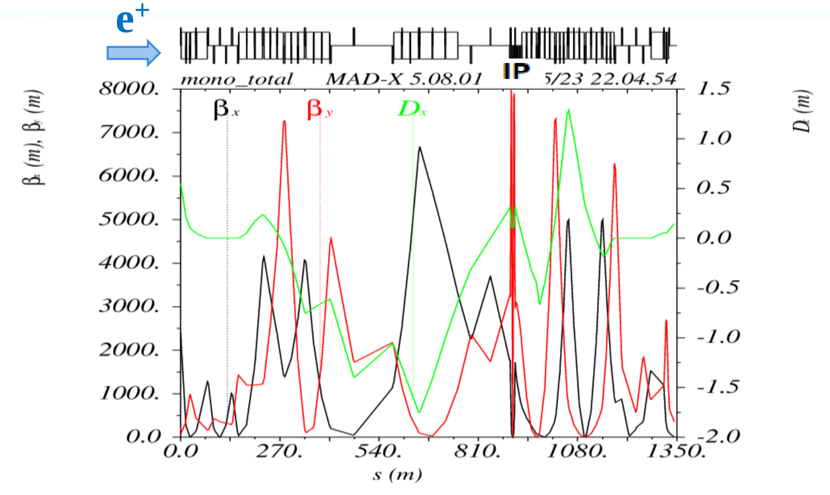
- Standard Survey Plot





- Monochromatization Survey Plot

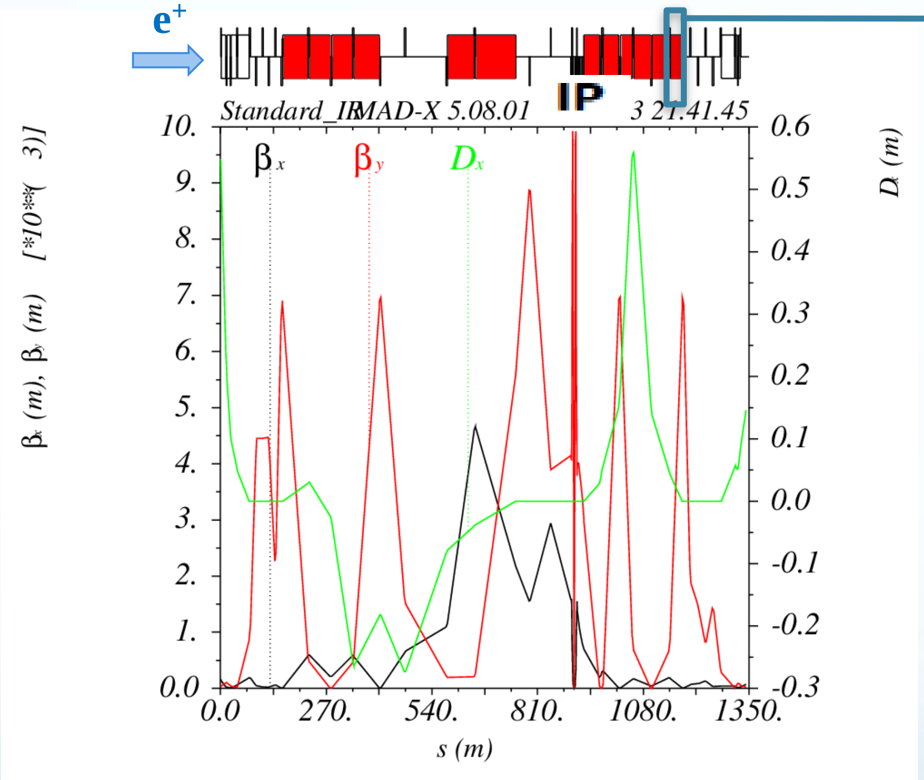


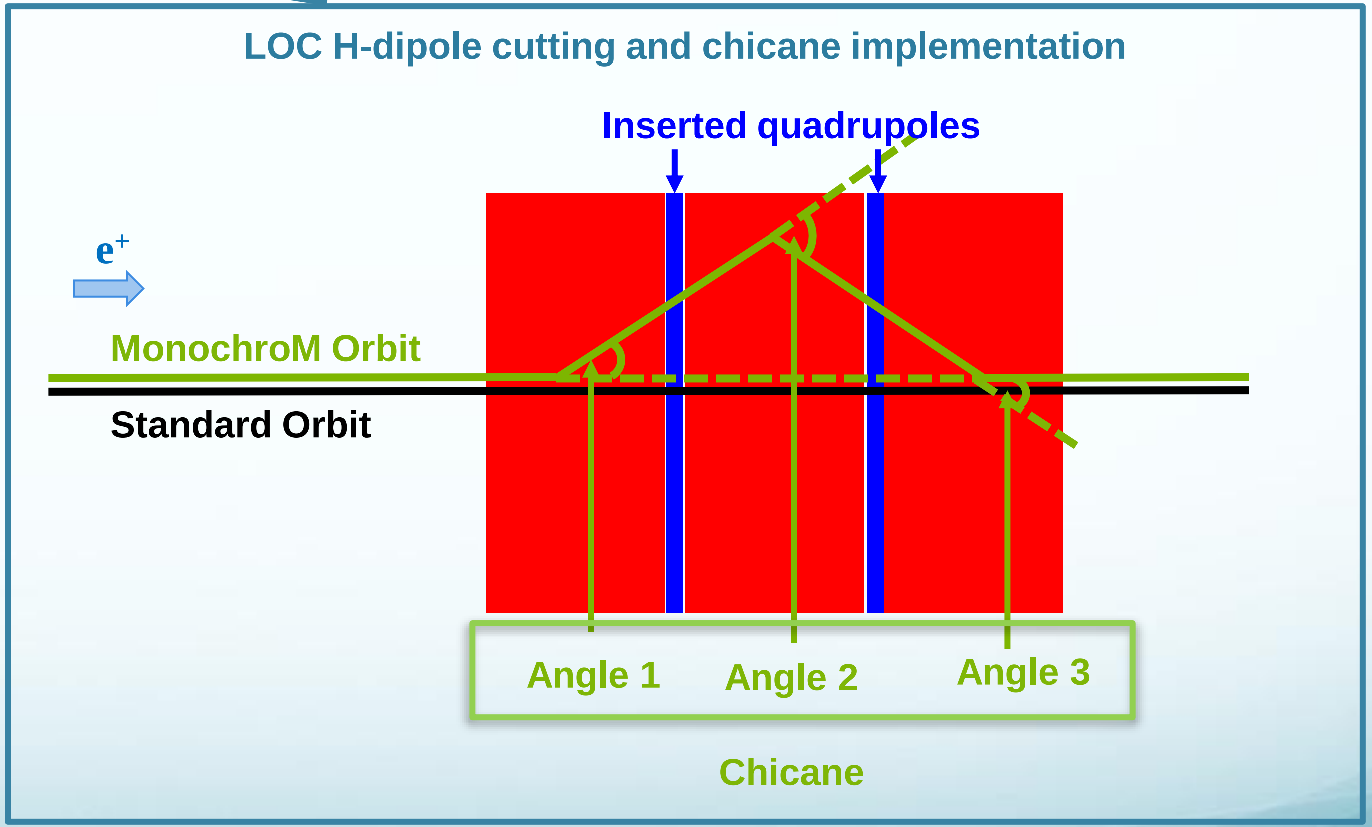


Scheme for Asymmetrical Standard IR Optics

- **First Optics Design Orbit Closing**

One another kind of chicane is implemented in the last dipoles in each upstream and downstream to chose the orbit.

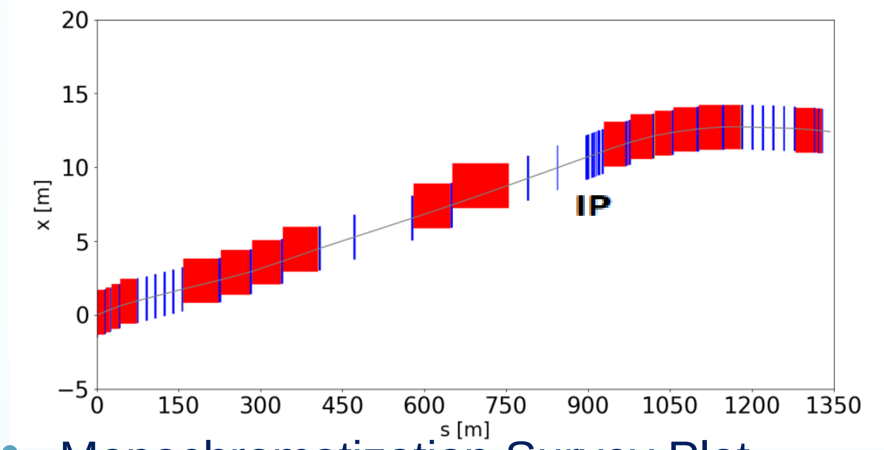




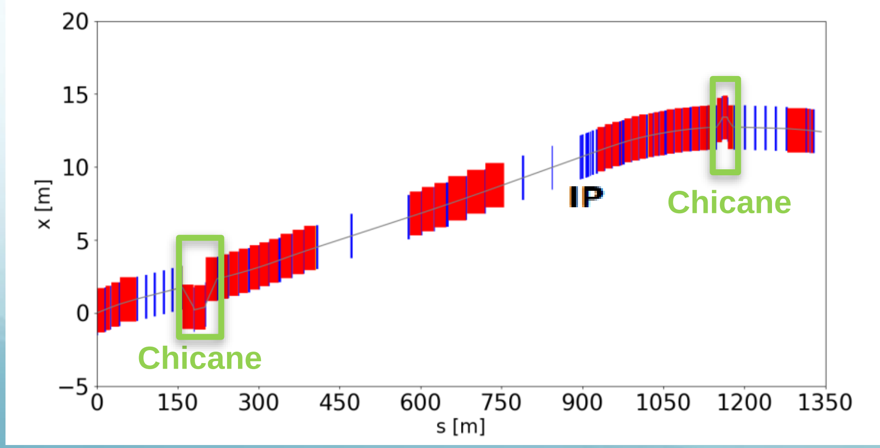
Scheme for Asymmetrical Standard IR Optics

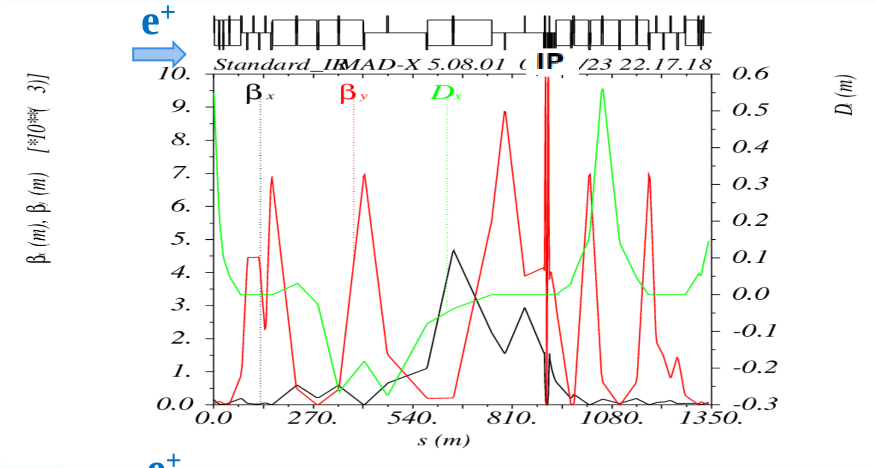
The survey plot shows that the monochromatization orbit is different from the standard one only at the position of the two chicanes. However, the angle of chicane is too high for the synchrotron radiation control.

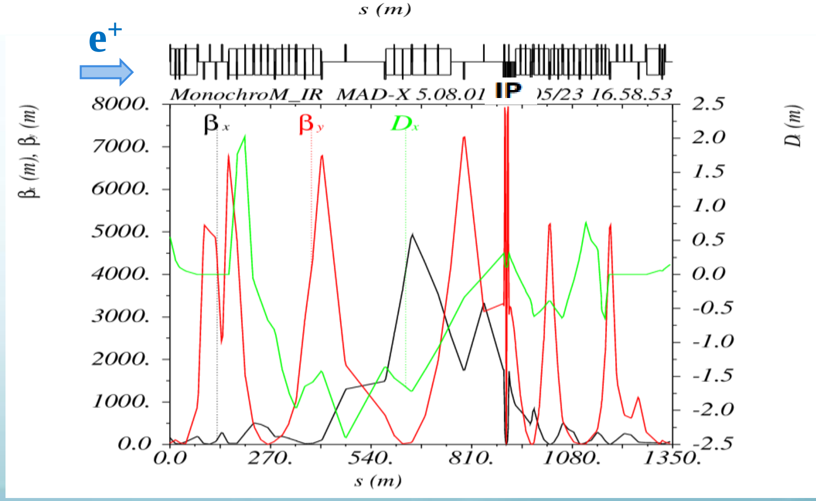
- Standard Survey Plot



- Monochromatization Survey Plot



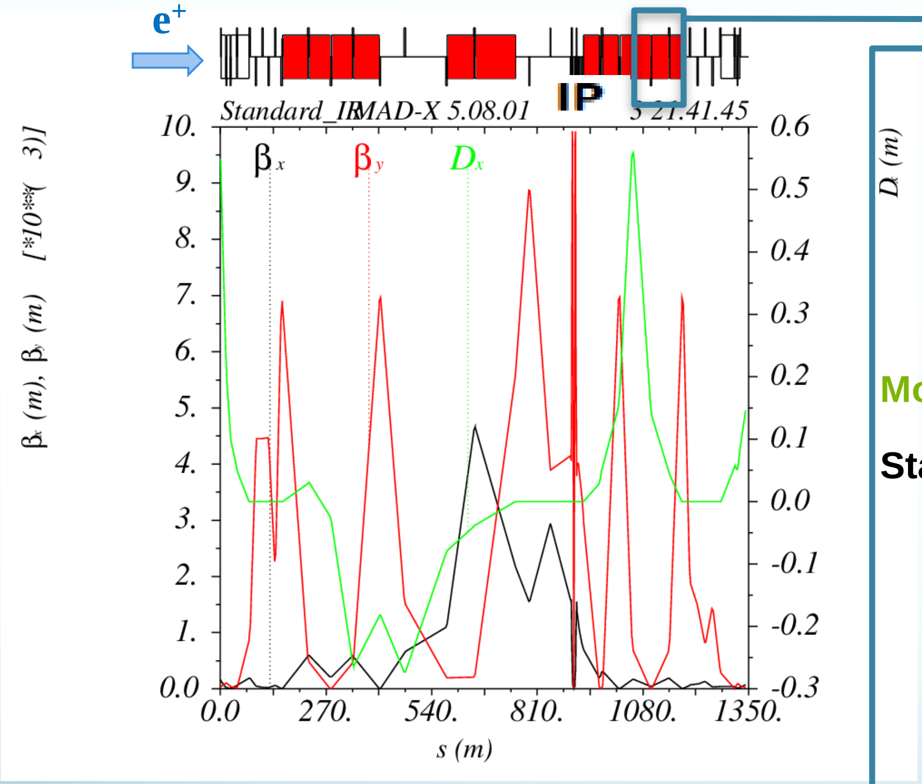


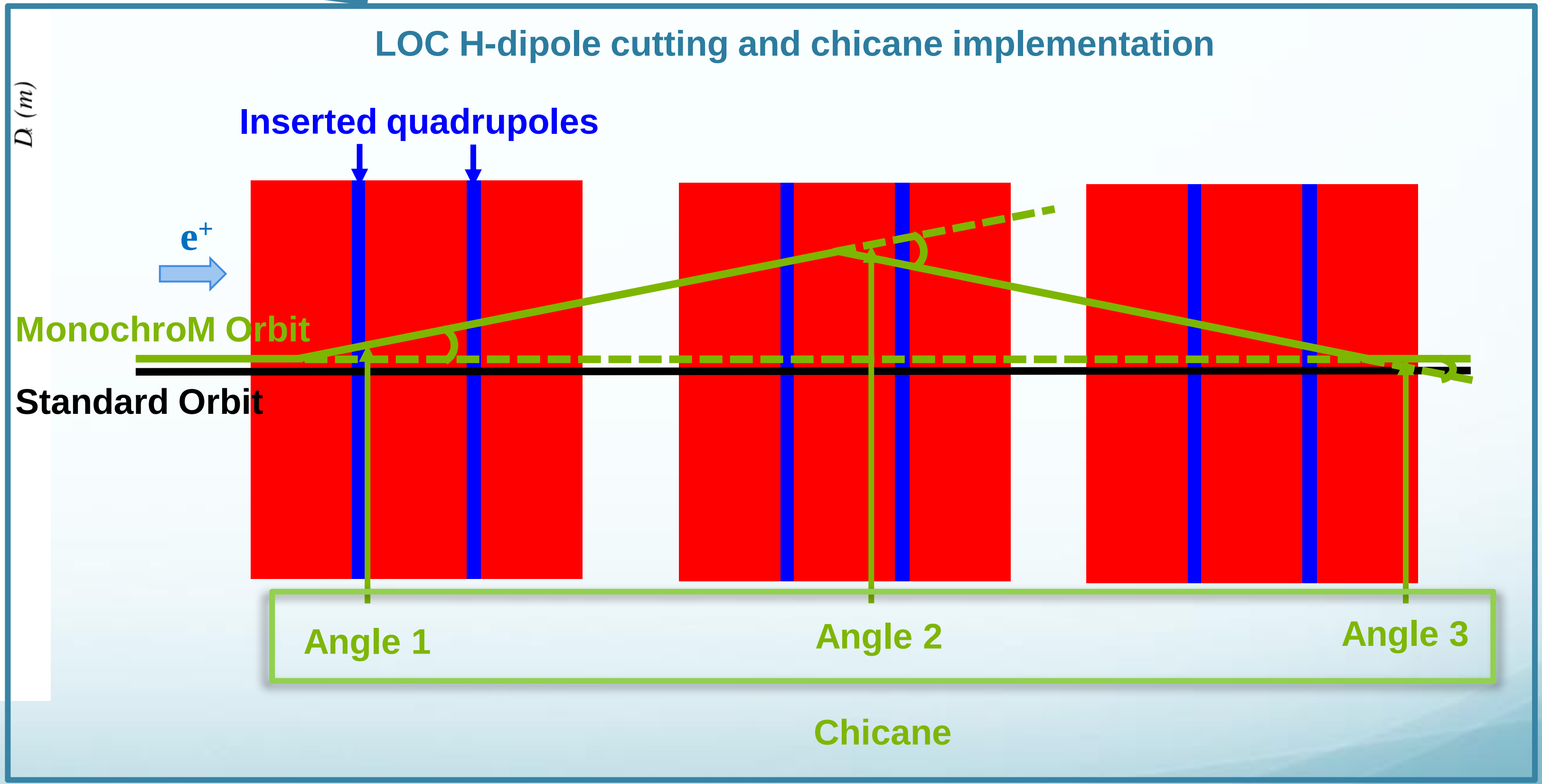


Scheme for Asymmetrical Standard IR Optics

- **Optimization of Chicane Angle**

In order to reduce the angle of chicane, the chicane is implemented in the last three dipoles instead of one.

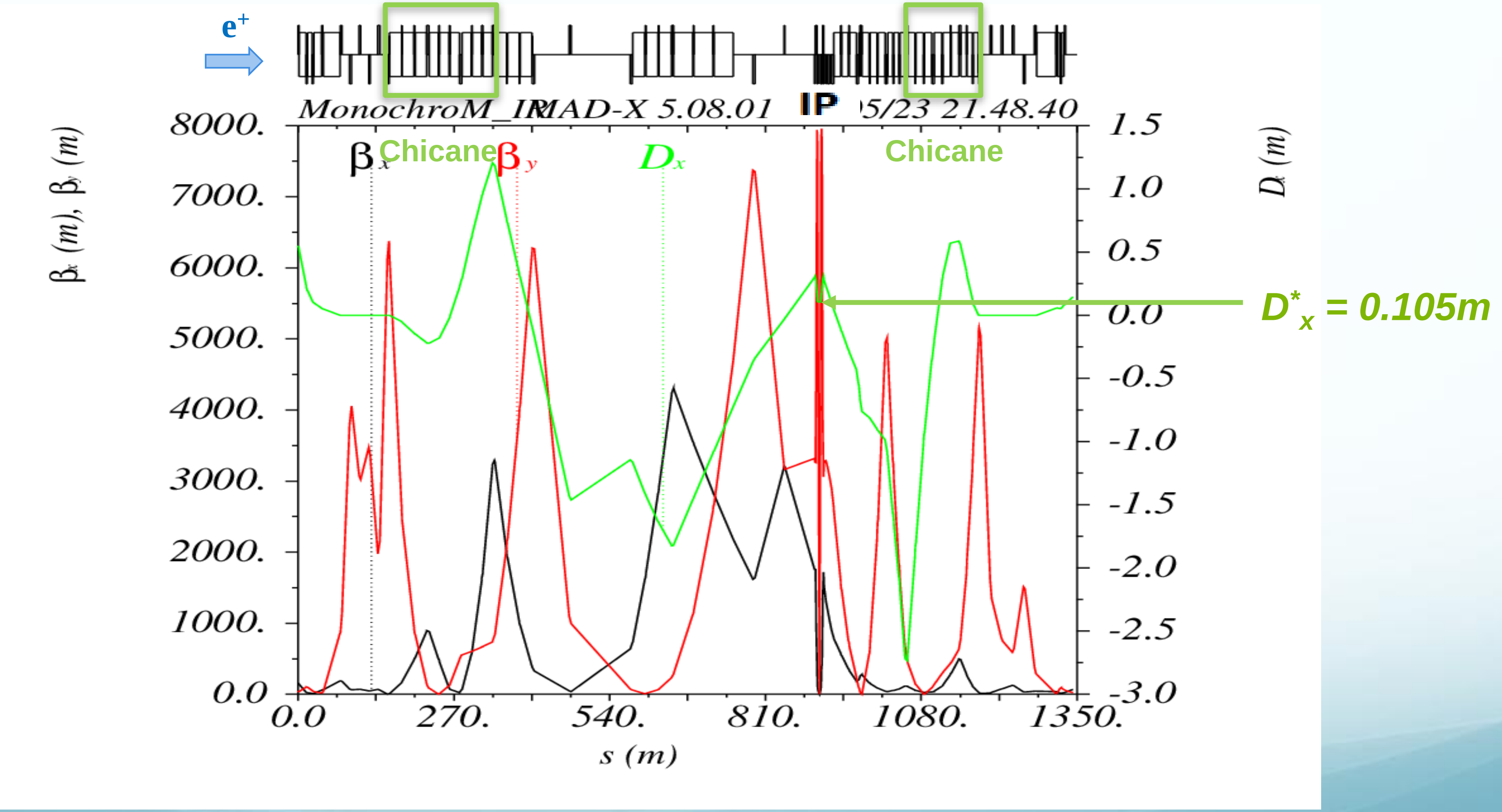




Asymmetrical Monochromatization IR Optics Design

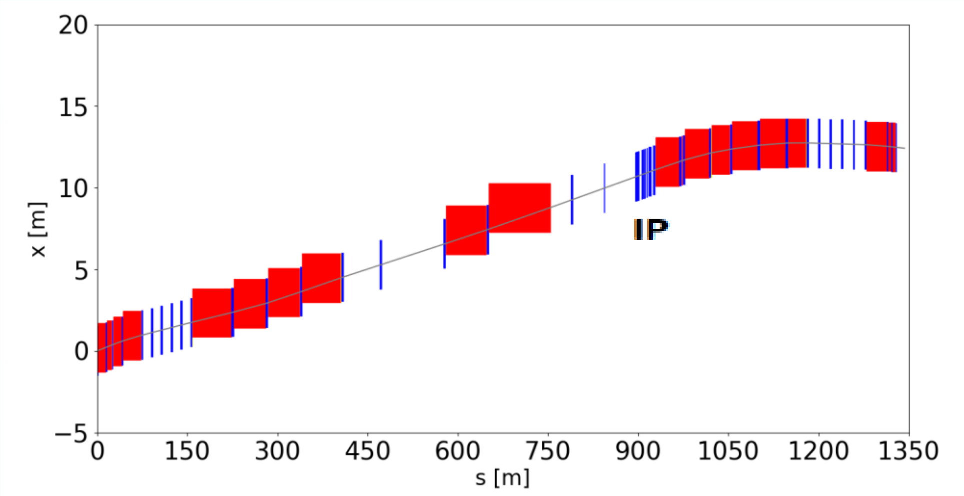
- **Asymmetrical Monochromatization IR Optics**

The beam parameters at the IP are matched to be same with the FCC-ee monochromatization self-consistent parameters.

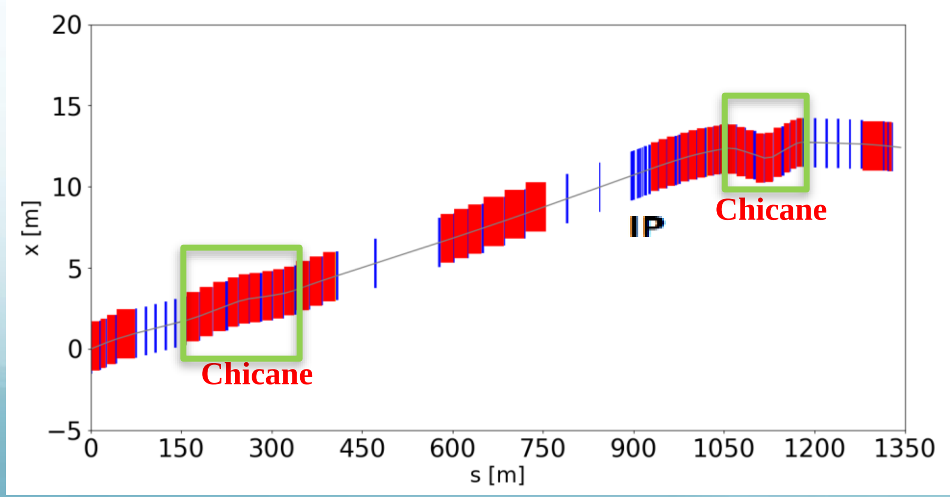


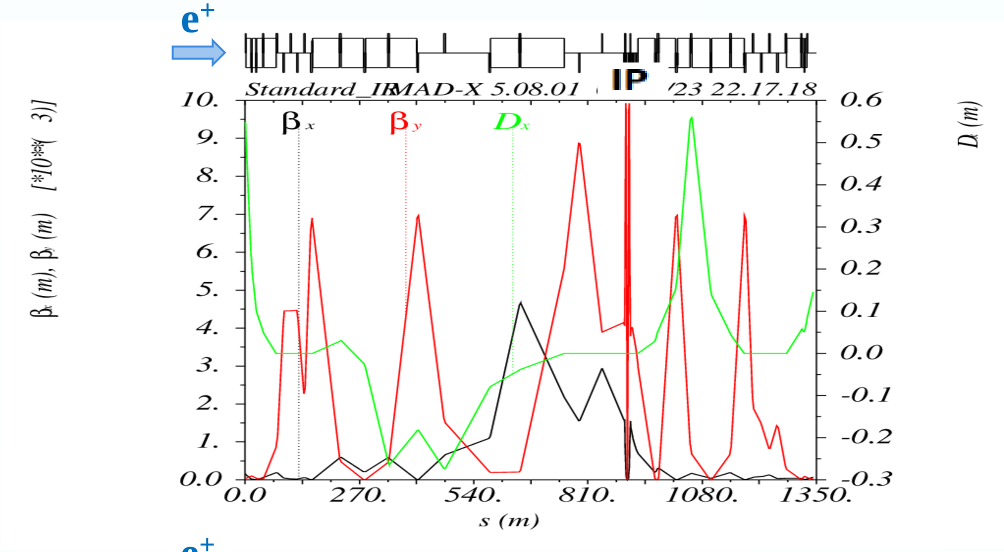
Asymmetrical Monochromatization IR Optics Design

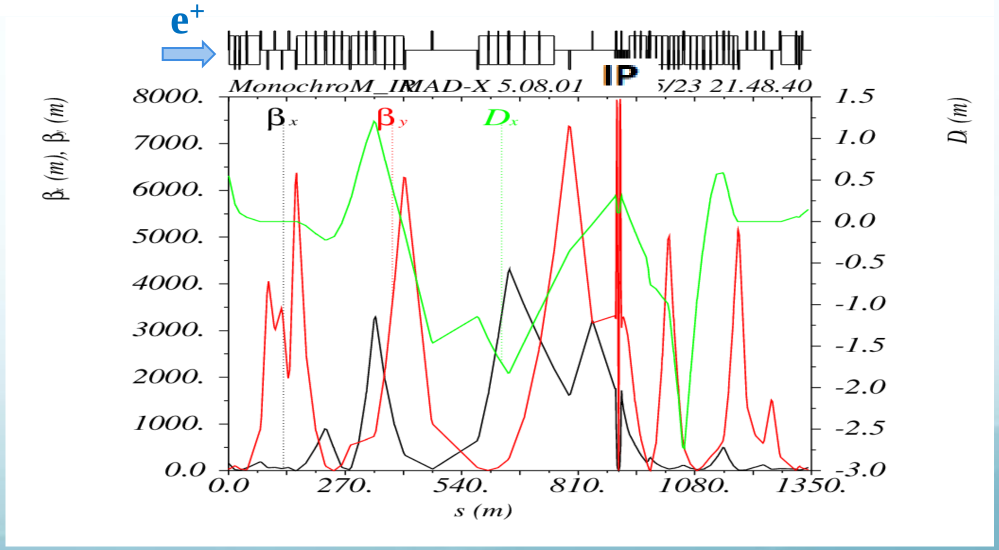
- **Comparison between standard survey and monochromatization survey**
  - Standard Survey Plot



  - Monochromatization Survey Plot

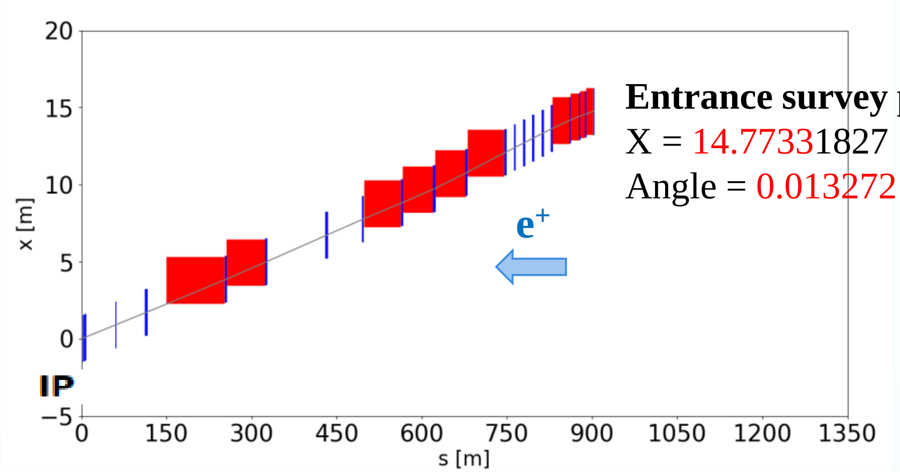




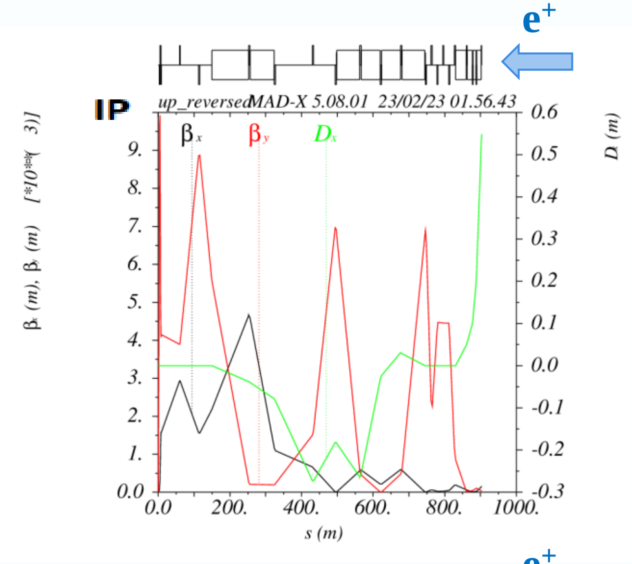


Asymmetrical Monochromatization IR Optics Design

- Entrance Survey Point Check and Beam Parameter Check
  - Standard

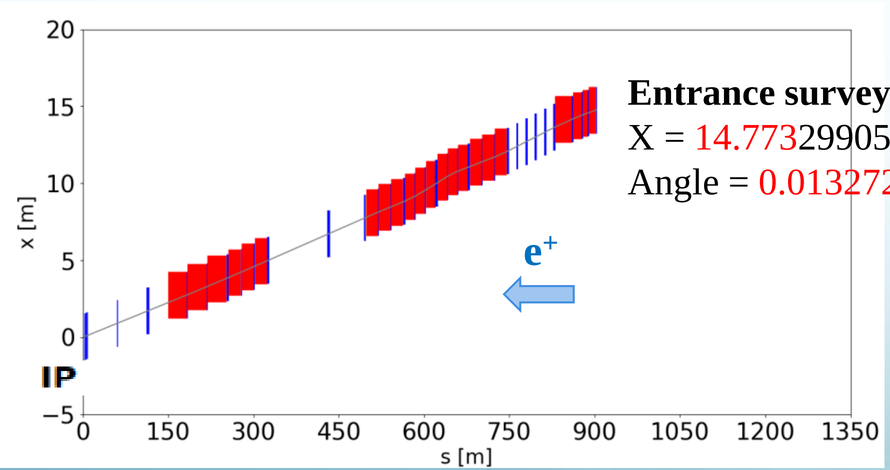


Entrance survey point check
X = 14.77331827
Angle = 0.013272

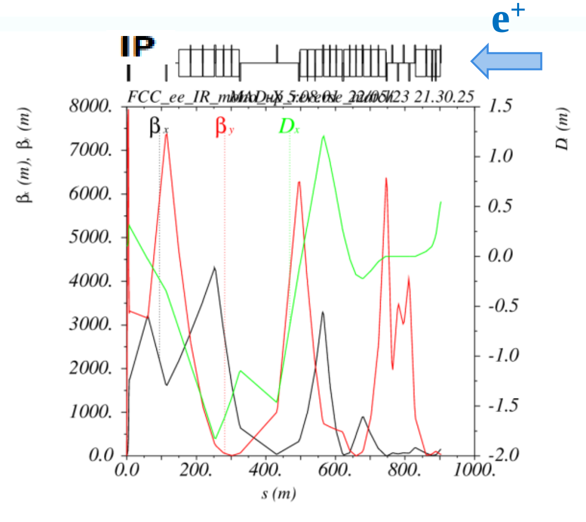


Entrance beam parameters check
β_x = 156.6587437
α_x = -2.264602028
β_y = 35.30306244
α_y = 0.617284605
D_x = 0.5488569734
D_{px} = 0.007526257585

  - Monochromatization



Entrance survey point check
X = 14.77329905
Angle = 0.013272

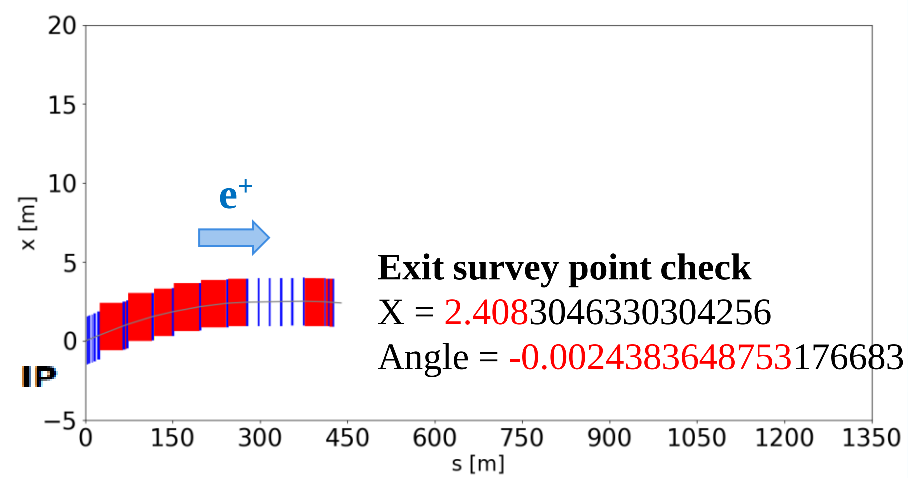


Entrance beam parameters check
β_x = 156.658721
α_x = -2.264601911
β_y = 35.30305802
α_y = 0.6172849609
D_x = 0.5488569538
D_{px} = 0.007526259165

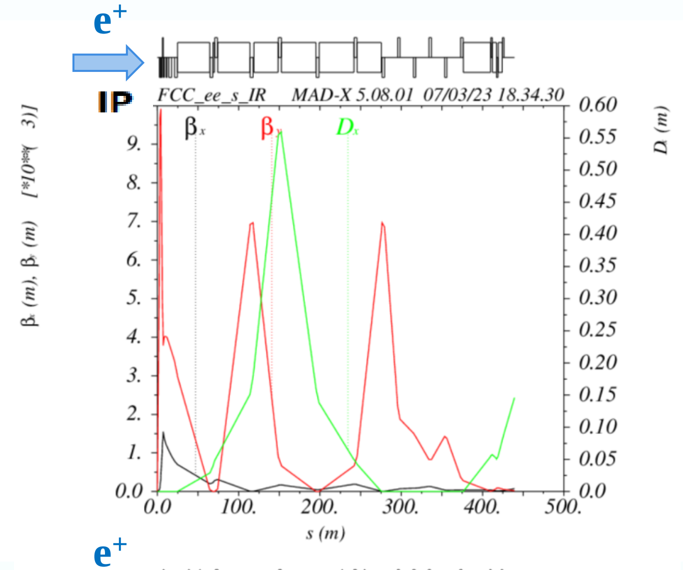
Asymmetrical Monochromatization IR Optics Design

- Exit Survey Point Check and Beam Parameter Check

  - Standard

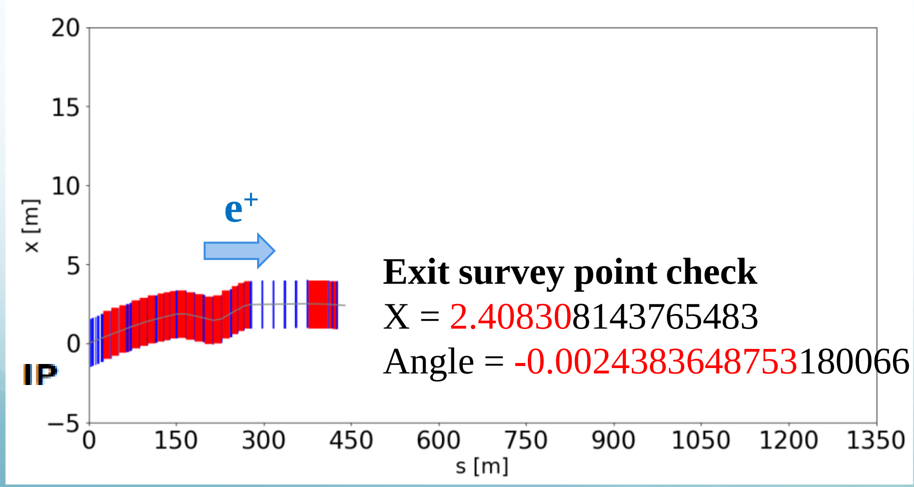


Exit survey point check
X = 2.4083046330304256
Angle = -0.0024383648753176683

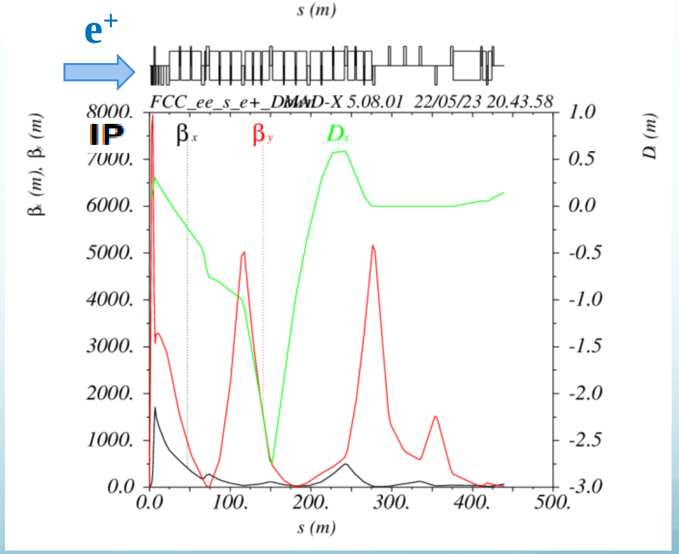


Exit beam parameter check
β_x = 70.69329
α_x = -2.0980736970165381
β_y = 21.4996407
α_y= 0.81240088314360692
D_x = 0.14579546
D_{px} = 0.00429520279

  - Monochromatization



Exit survey point check
X = 2.408308143765483
Angle = -0.0024383648753180066



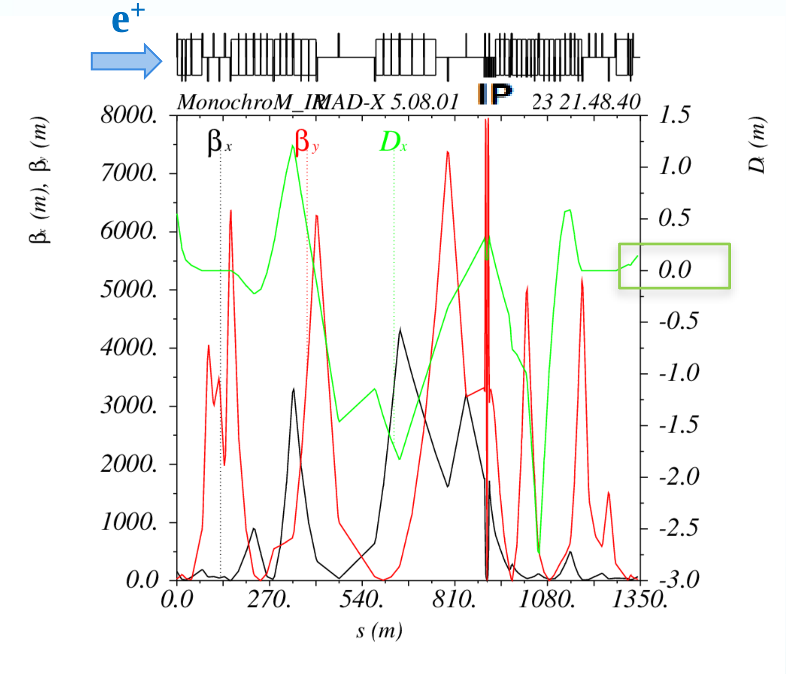
Exit beam parameter check
β_x = 70.6932896739358
α_x = -2.09807369214622
β_y = 21.49964041486609
α_y = 0.81240098800501
D_x = 0.14579548213956553
D_{px} = 0.00429520637517791

Asymmetrical Monochromatization IR Optics Design

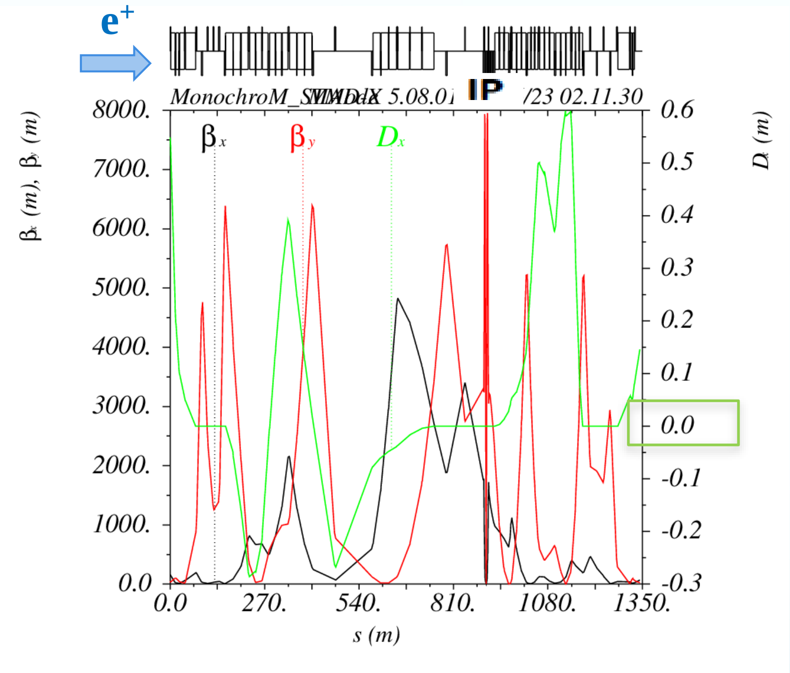
- **Standard Mode with monochromatization orbit**

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.

- $D^*_x = 0.105$ m Monochromatization mode



- $D^*_x = 0$ Standard mode



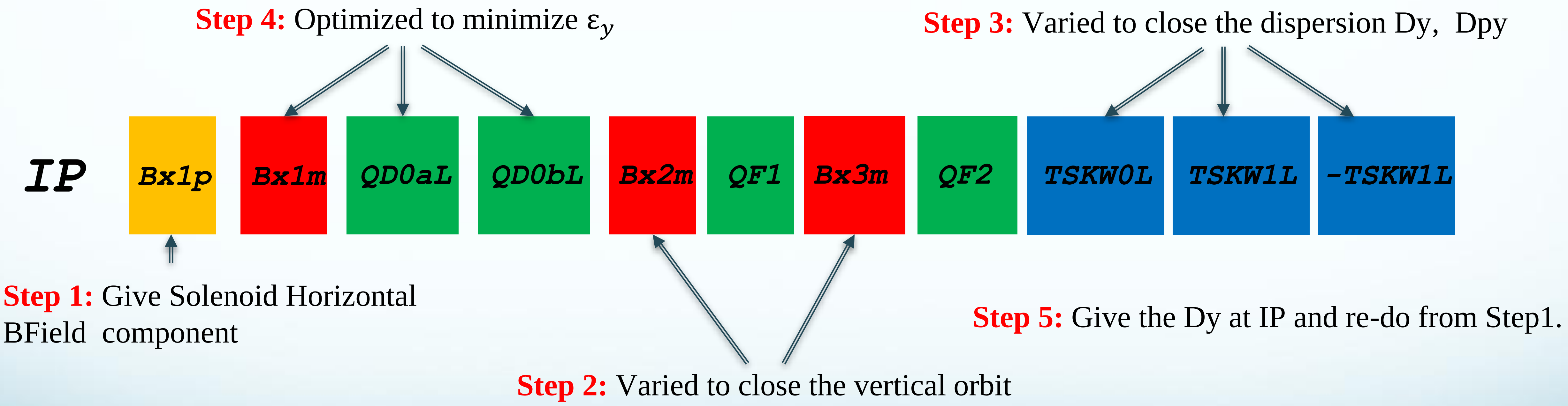
- **Next step**

Implementation of the monochromatization IR optics in the whole ring and simplification of the dipoles slicing.

Scheme for Symmetrical Standard IR Optics

- **Preliminary Scheme**

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

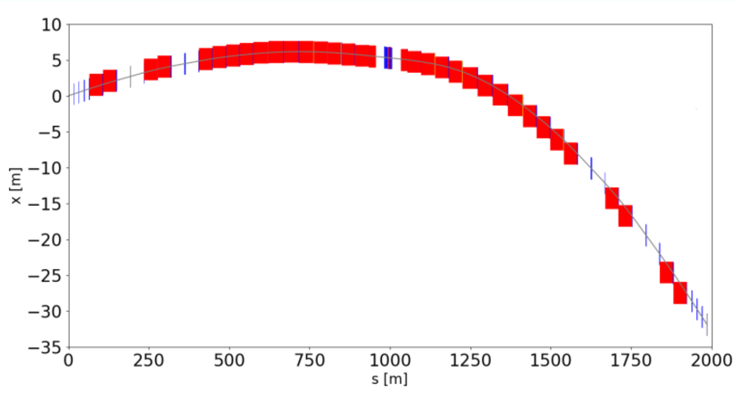


Symmetrical Monochromatization IR Optics Design

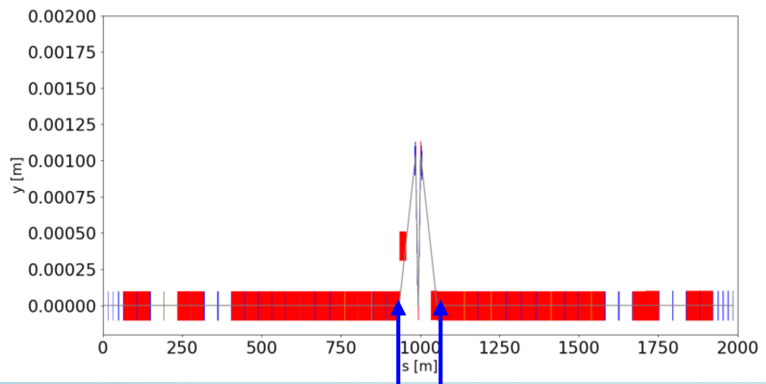
- **Solenoid Implementation**

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

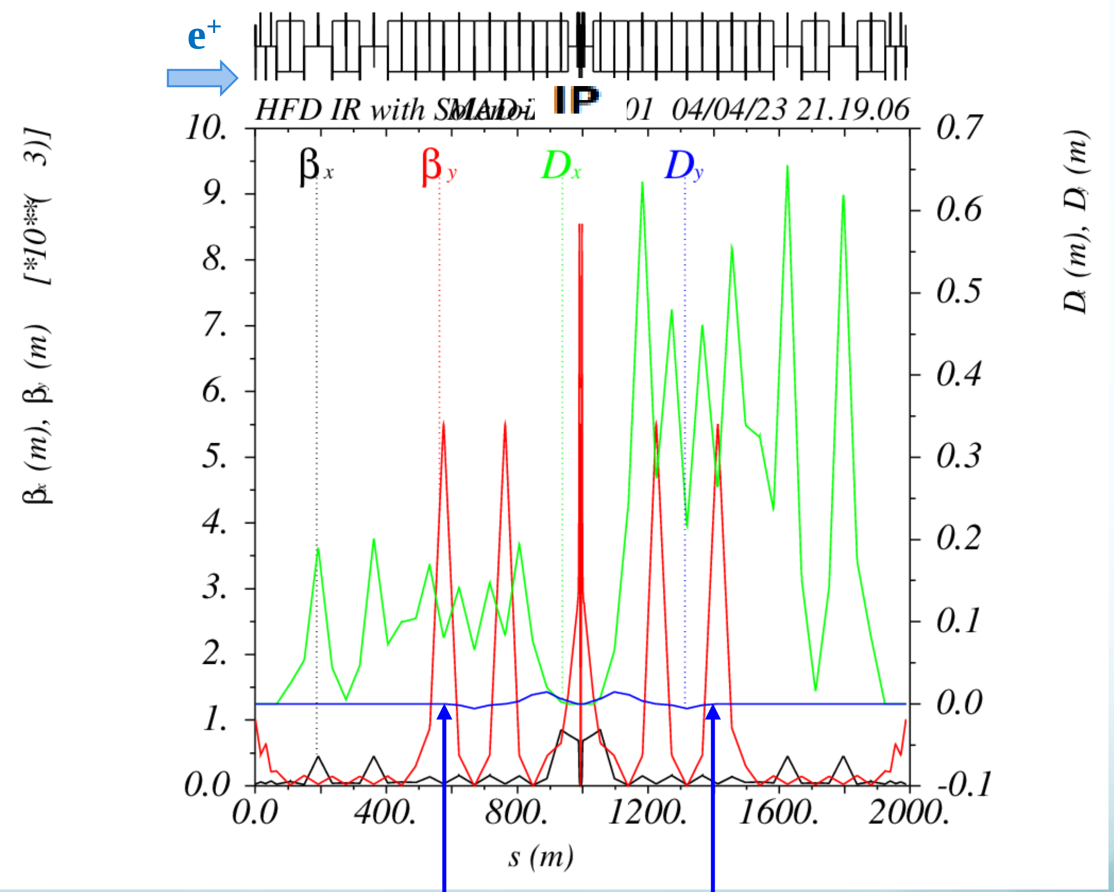
Horizontal survey plot



Vertical survey plot



Vertical orbit back to 0 after Bx3m

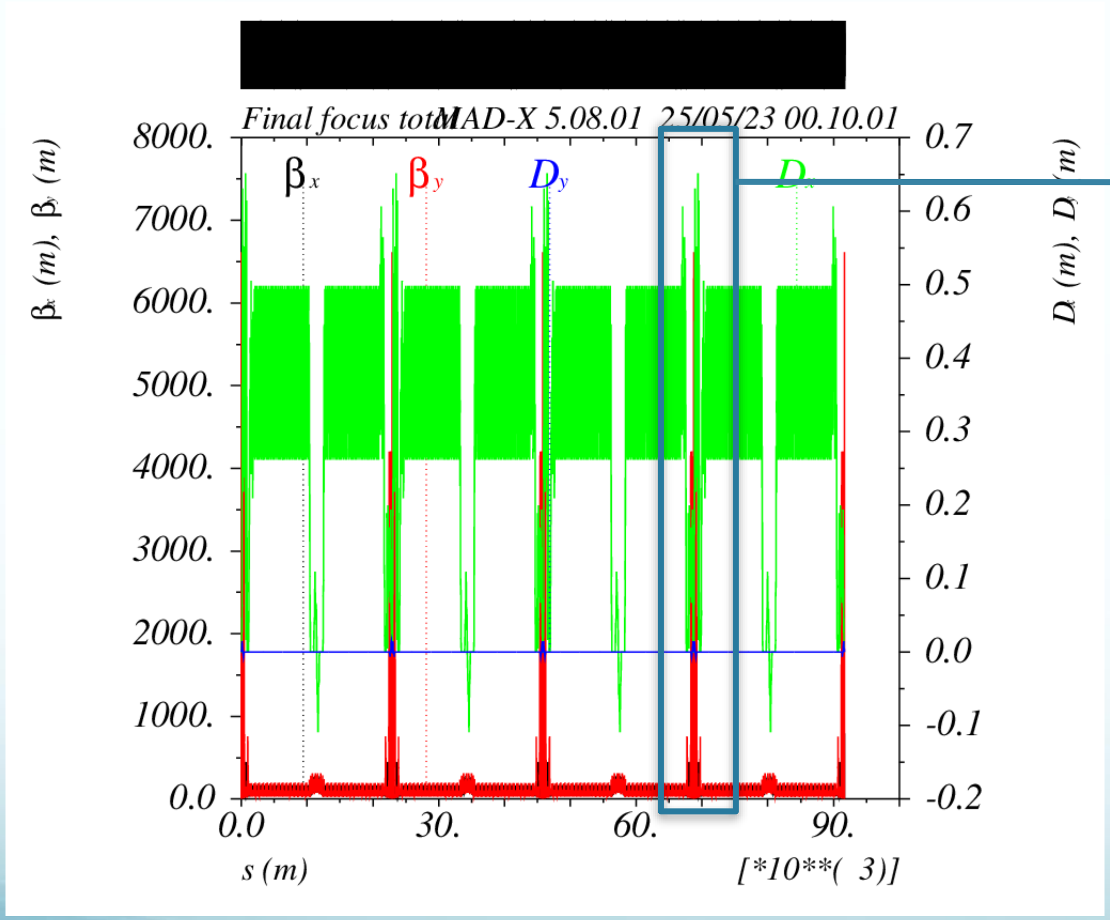


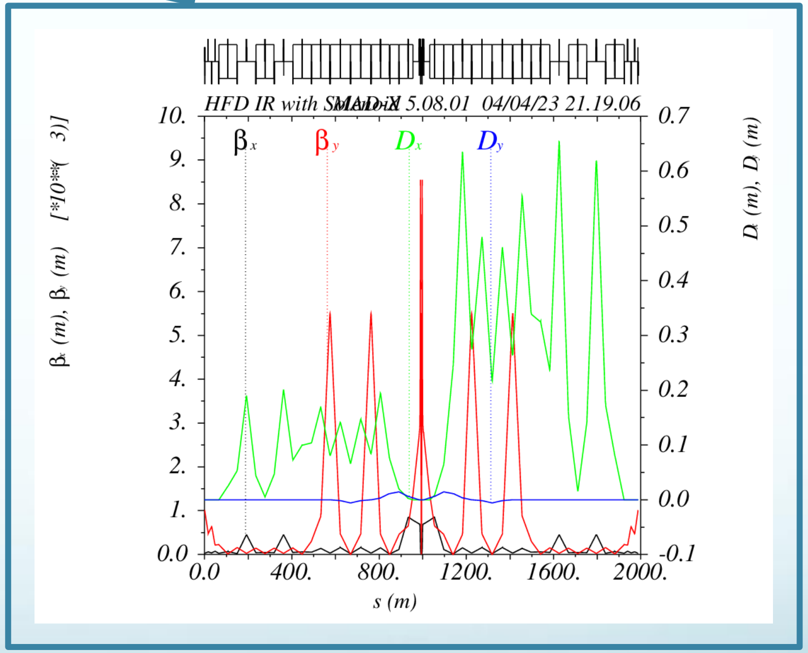
Vertical dispersion closed.

Symmetrical Monochromatization IR Optics Design

- **Calculation and minimization of the vertical emittance**

The IR lattice with solenoid was implemented in the whole ring successfully. A script for the minimization of the vertical emittance is being developed.





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

➢ Implementation of the monochromatization IR optics in the whole ring is in progress

➢ Simplification of the dipoles slicing is in progress

- **Symmetrical IR Monochromatization Optics design**

✓ Solenoid implementation

✓ Closing vertical orbit and vertical dispersion

➢ Calculation and minimization of the vertical emittance is in progress

➢ Experimental proof of concept in DAFNE

Thanks for you attention!