IR Optics design for the FCC-ee s-channel monochromatization scheme

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Outline

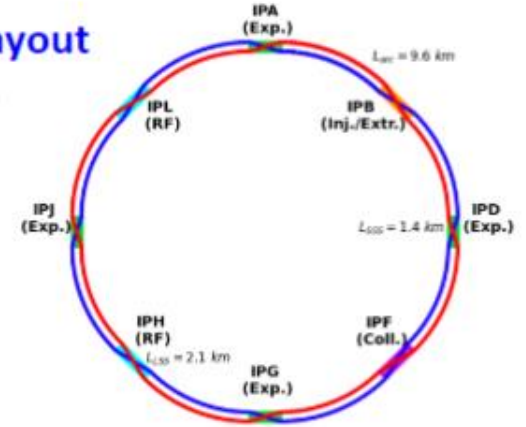
- Introductions
- The trade-off between energy spread and luminosity
- The standard FCC-ee IR Optics design
- The IR optics for the monochromatization scheme
- The continuing optimization of the mono-scheme

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

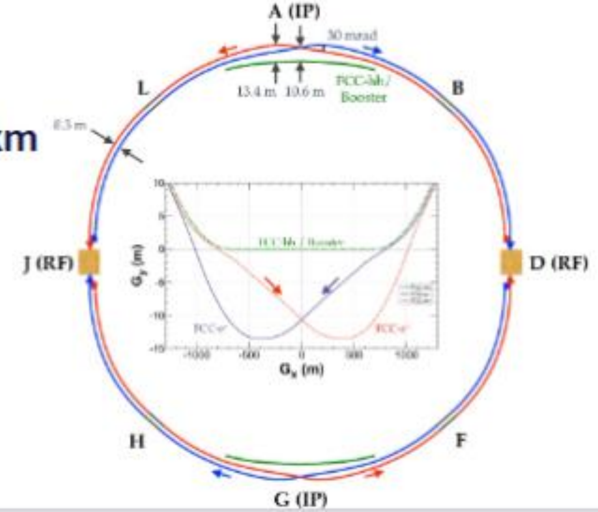
      Z, WW,H(ZH) and ttbar
  - The optional fifth mode: s-channel Higgs production mode
    - The measurement of the electron Yukawa coupling, in dedicated runs at 125 GeV with center-of-mass (CM) energy spread(5-10 MeV). But the natural collision energy spread, due to the synchrotron radiation, is about 50MeV.
- **Requirements:**
  - reduce the CM energy spread from 50MeV to 5MeV, which is comparable to the resonant width of the standard model Higgs Boson itself (4.2MeV) [1]

[1]Abada, A., Abbrescia, M., AbdusSalam, S.S. et al. FCC-ee: The Lepton Collider.

evolution of layout
8 surface sites
4 IPs
C=91 km



CDR
C=97 km
2 IPS



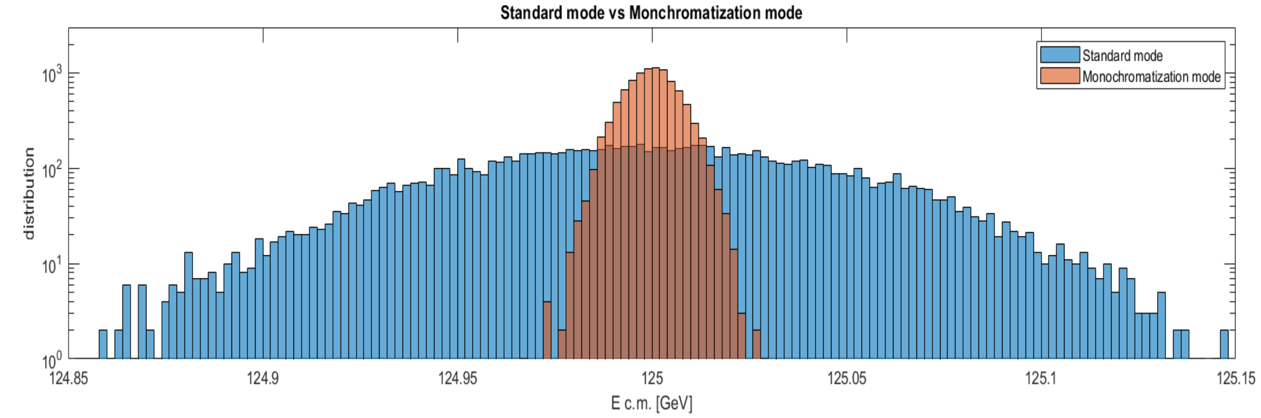
FCC-ee Parameters (including s channel mode)

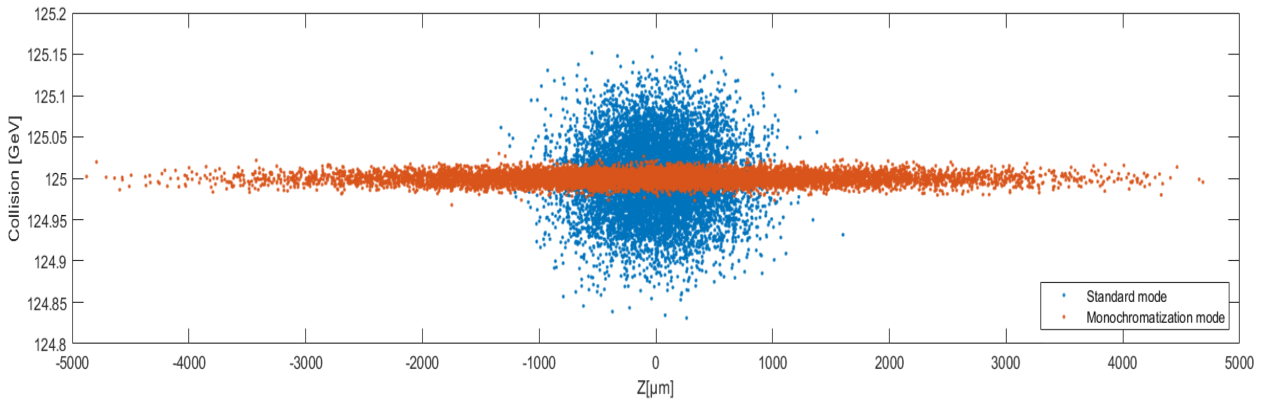
FCCWEEK22, K. Oide, D. Shatilov

Parameter [4 IPs, 91.1 km, T_{rev}=0.3 ms]	S-Channel[1]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	62.5	45	80	120	182.5
beam current [mA]	395	1280	135	26.7	5.0
number bunches/beam	13420	10000	880	248	40
bunch intensity [10^{11}]	0.6	2.43	2.91	2.04	2.37
SR energy loss / turn [GeV]	0.126	0.0391	0.37	1.869	10.0
total RF voltage 400 / 800 MHz [GV]		0.120 / 0	1.0 / 0	2.08 / 0	2.5 / 8.8
long. damping time [turns]		1170	216	64.5	18.5
horizontal beta* [m]	0.09	0.1	0.2	0.3	1
vertical beta* [mm]	1	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.51	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	2	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	15	8	21	14	39
vertical rms IP spot size [nm]	45	34	66	36	69
beam-beam parameter ξ_x / ξ_y		0.004 / 0.159	0.011 / 0.111	0.0187 / 0.129	0.093 / 0.140
rms bunch length with SR / BS [mm]		4.38 / 14.5	3.55 / 8.01	3.34 / 6.0	1.95 / 2.75
luminosity per IP [10^{34} cm^{-2}s^{-1}]	76	182	19.4	7.26	1.25
total integrated luminosity / year [ab^{-1}/yr]	36	87	9.3	3.5	0.65
beam lifetime rad Bhabha + BS [min]		19	18	6	9

- The transverse monochromatic scheme(Guinea-Pig simulation results)

Monochromatization:
D*x=±0.2m
c.m. Energy spread
6.9MeV





Standard:
D*x=0
c.m. Energy spread
46MeV

Example IP parameters for monochromatization scenario for FCC-ee

- The example IP parameters and performance for typical monochromatization scenario for FCC-ee $D_x^* = \pm 0.1m$

Parameter		Units
CM Energy, W	125	[GeV]
Horizontal, vertical RMS emittances with (without) beamstrahlung, ε_{xy}	2.5 (0.51), 0.002	[nm]
Relative RMS momentum deviation, σ_δ	0.052	%
RMS bunch length, σ_z	3.3	[mm]
Horizontal dispersion at IP, D^*_x	0.105	[m]
Beta functions at the IP, β^*_{xy}	90, 1	[mm]
RMS beam size at the IP, σ^*_{xy}	55, 0.045	[µm]
Full crossing angle, θ_c	30	[mrad]
Vertical beam-beam tune shift, ξ_y	0.106	
Total beam current, I_e	395	[mA]
Bunch population, N_b	6.0×10^{10}	
Bunches per beam, n_b	13420	
Luminosity (without crab cavities) per IP, L	$2.6\ (2.3) \times 10^{35}$	[$cm^{-2}s^{-1}$]
RMS CM energy spread (without crab cavities), σ_W	13(25)	[MeV]

The monochromatization factor:

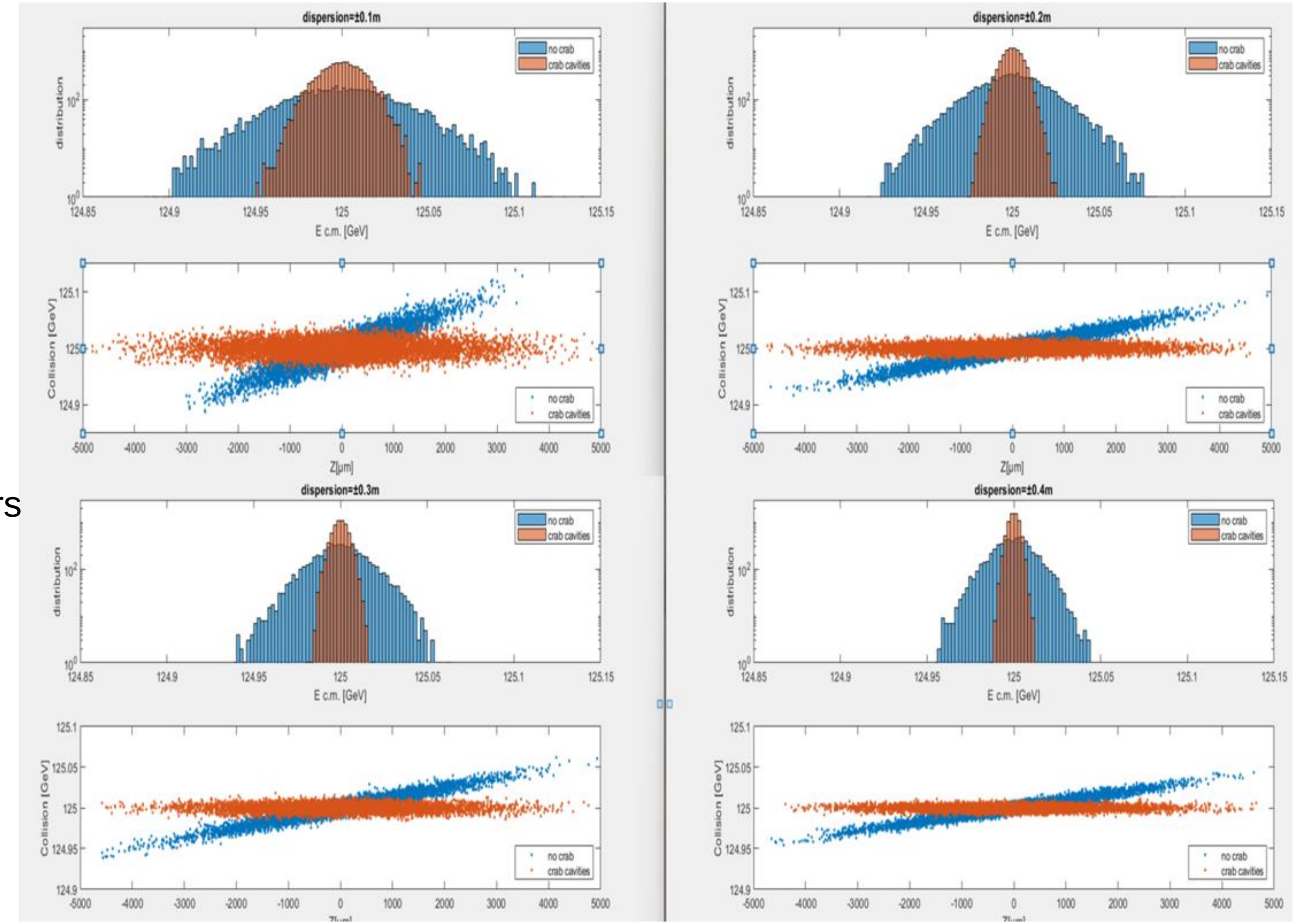
$$\lambda = \sqrt{1 + \frac{D_x^{*2}\sigma_\varepsilon^2}{\epsilon_x \beta_x^*}}$$

The correlation D*x and Mono-factor				
D_x^*	$\pm$0.1m	$\pm$0.2m	$\pm$0.3m	$\pm$0.4m
λ	3.6	7.0	10.4	13.9

- The monochromatic scheme reduces the c.m. energy spread but decreases the luminosity.

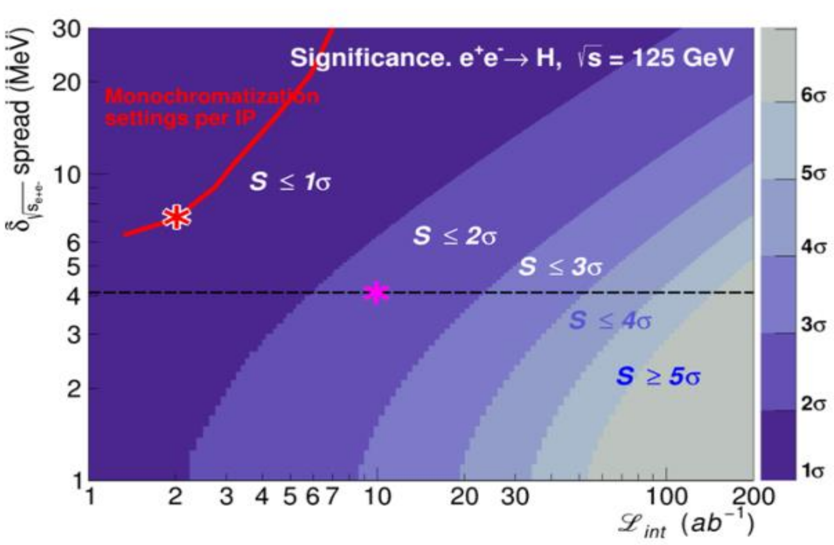
Guinea-pig simulations:
The relationship between luminosity and c.m. energy spread for different
D_x^*= 0.1, 0.2, 0.3, 0.4m

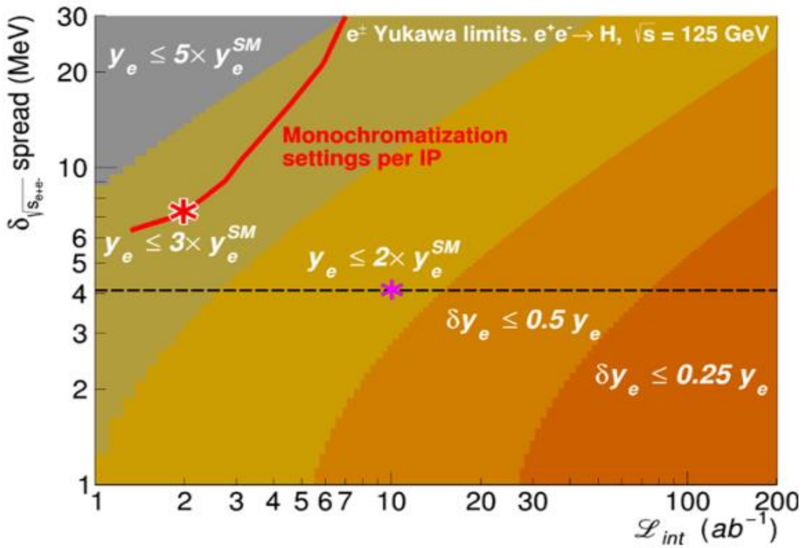
The initial beam distribution:
Generated by mathematica with parameters shown in FCC-ee parameters table and different D_x^*



The relationship between dispersion and luminosity and c.m. energy spread

Dispersion	0.1m	0.2m	0.3m	0.4m
RMS energy spread with crab cavities	12.8 MeV	6.9 MeV	4.6MeV	3.6 MeV
RMS energy spread without crab cavities	30.6 MeV	21.1MeV	14.8MeV	11.6MeV
Luminosity($10^{35}cm^{-2}s^{-1}$)	2.6	1.25	0.84	0.63
Monochromatization factor	3.3	6.1	9.1	12



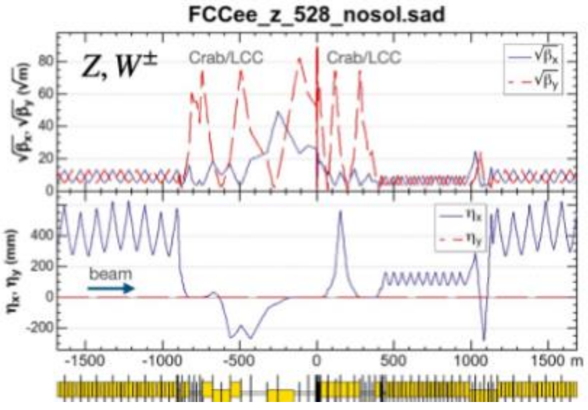


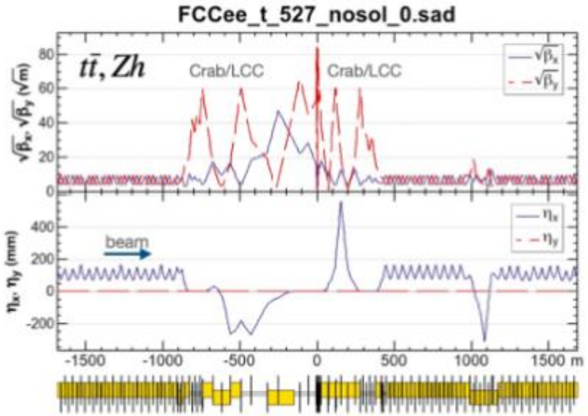
Significance(left) and associated upper limits contours on the electron Yukawa ye. (Right) in the c.m. energy spread vs. integrated luminosity[1]

Driven by synchrotron radiation:

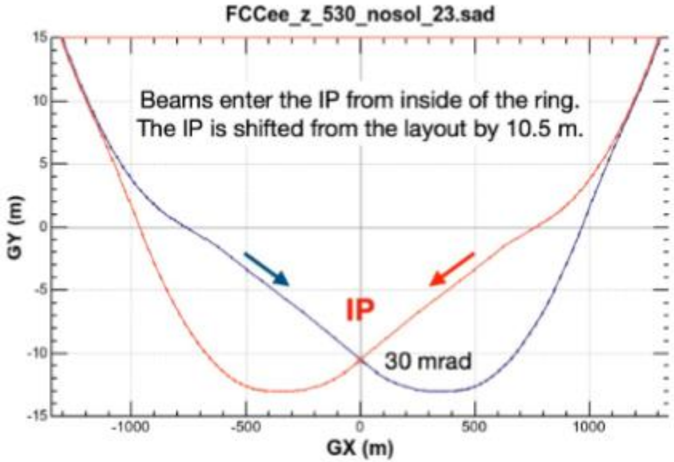
$E_{critical}$ <100 keV from 450 m from the IP at ttbar (detector requirement from LEP experience)

→ Very Asymmetric IR optics



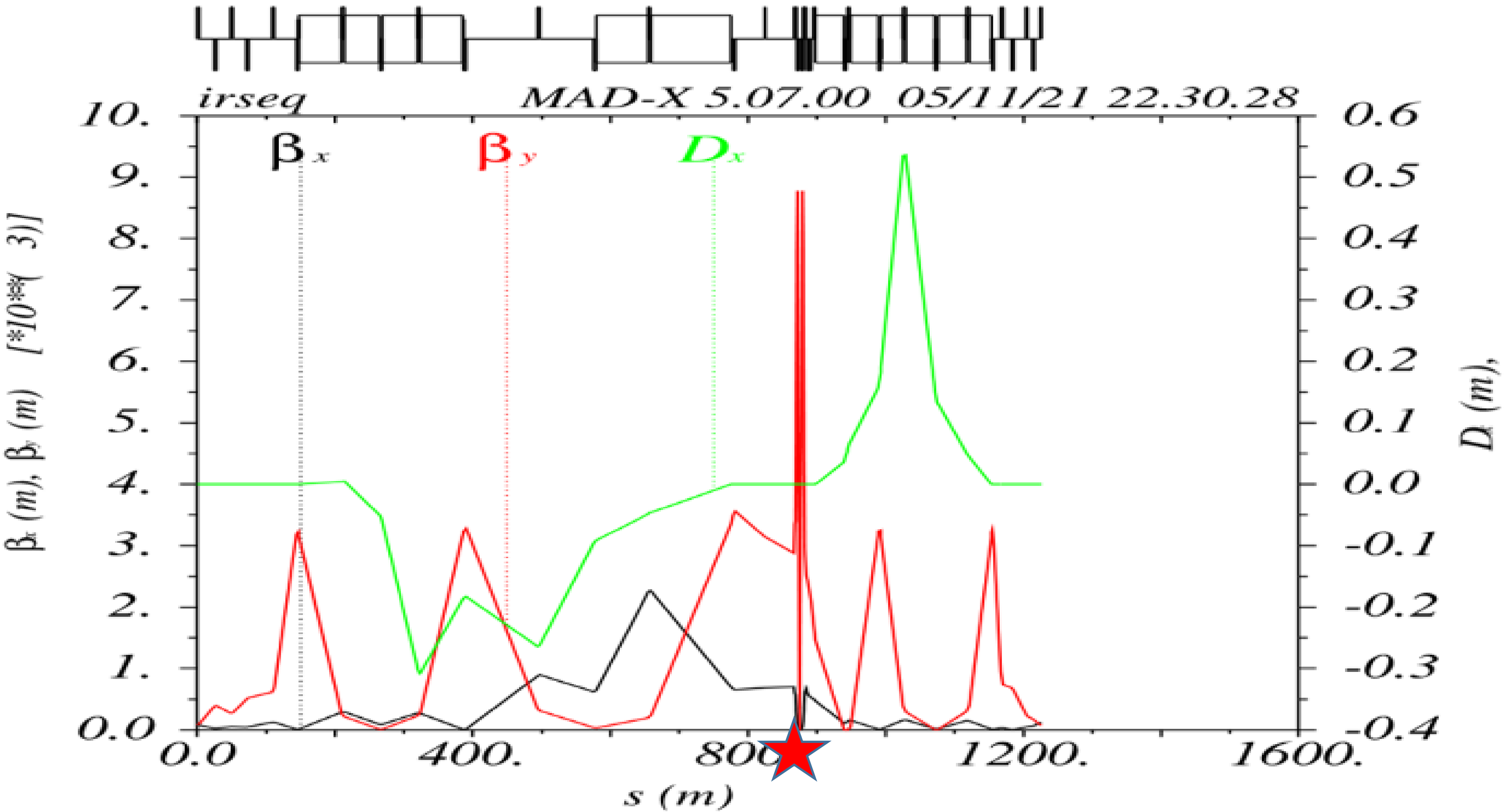


FCC-ee IR geometry
Crossing angle:30mrad



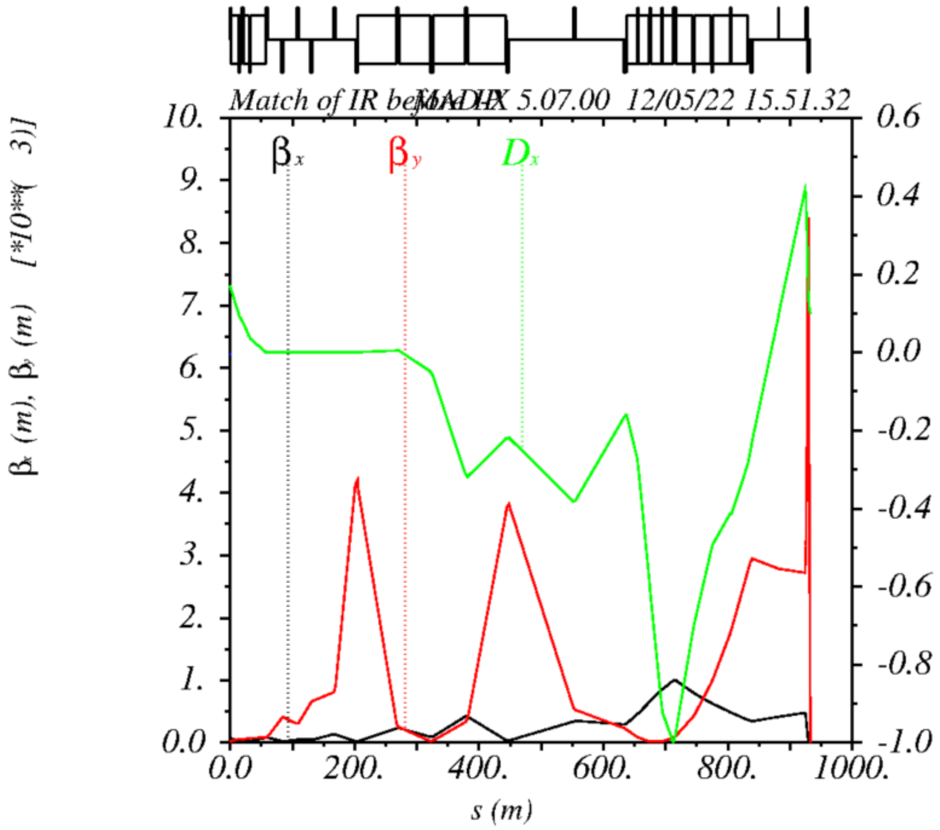
The baseline S-channel standard IR Optics

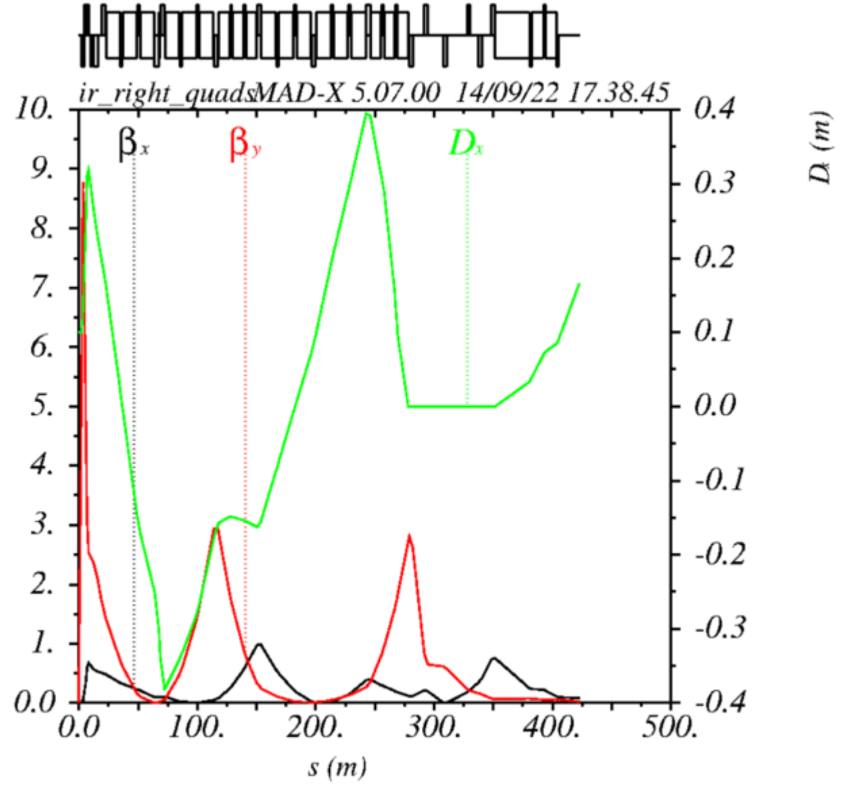
- The asymmetric Standard mode IR Optics (from dispersion-free to dispersion-free region)



The Preliminary IR Optics for transversal mono-schemes

Before the Interaction Point: **D*x=±0.1m** After the Interaction Point:





Next steps

- D_x^* scanning and limits
- Redesign and Correction of local chromaticity correction (LCC system)
- Beam dynamic aperture (DA) analysis
- Beam-beam effects

Bled lake, Slovenia