Crab waist interaction region of FCC-ee BINP design

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Preface

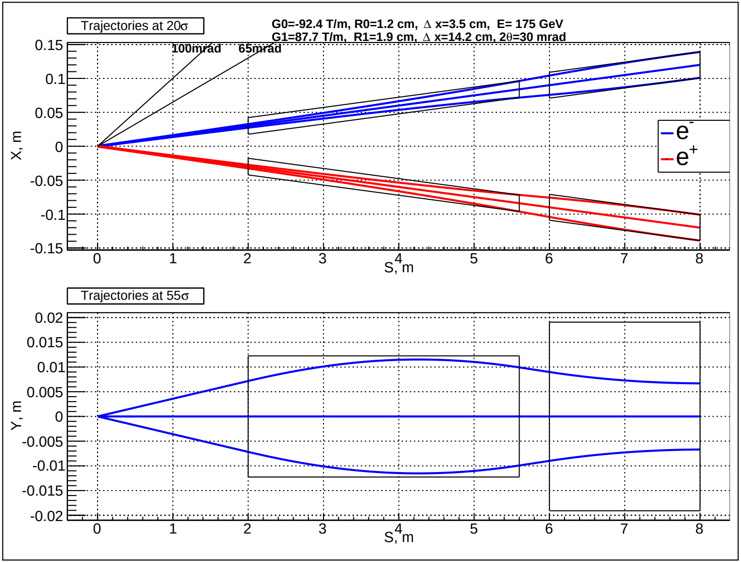
There are two variants of interaction region. The first one is developed by BINP. The second one belongs to K.Oide and appeared a month ago. Both variants need feedback from the detector for further optimization. The presentation is about BINP design.

Parameters for crab waist (being optimized)

	Z	W	H	tt
Energy [GeV]	45	80	120	175
Perimeter [km]	100			
Crossing angle [mrad]	30			
Particles per bunch [10^{11}]	1	4	4.7	4
Number of bunches	29791	739	127	33
Energy spread [10^{-3}]	1.1	2.1	2.4	2.6
Emittance hor. [nm]	0.14	0.44	1	2.1
Emittance ver. [pm]	1	2	2	4.3
β_x^*/β_y^* [m]	0.5 / 0.001			
Luminosity / IP [$10^{34}\,cm^{-2}s^{-1}$]	212	36	9	1.3
Energy loss / turn [GeV]	0.03	0.3	1.7	7.7

PHYS. REV. S.T. - AB 17, 041004 (2014)

Final Focus layout



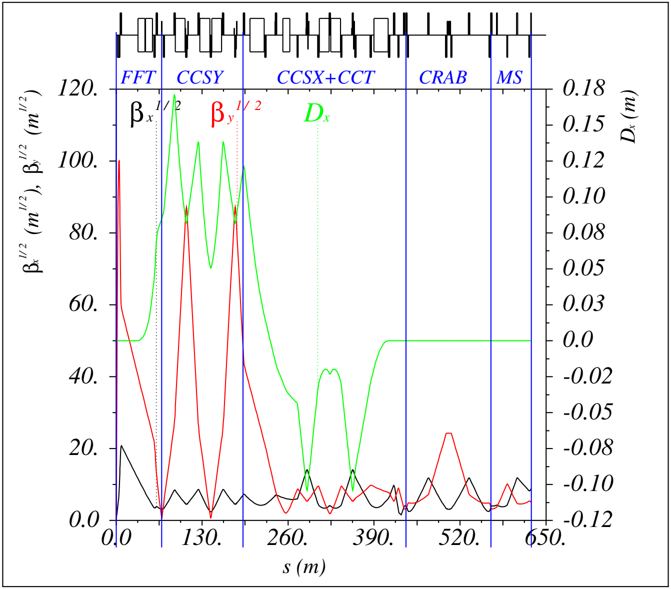
Rectangles are bare apertures.

	L [m]
Q0	3.6
Q1	2

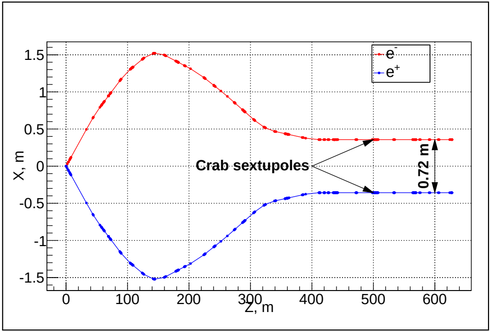
	R [m]
Q0	0.012
Q1	0.019

	B [T]
Q0	1.1
Q1	1.7

Interaction Region optical functions



Interaction Region layout



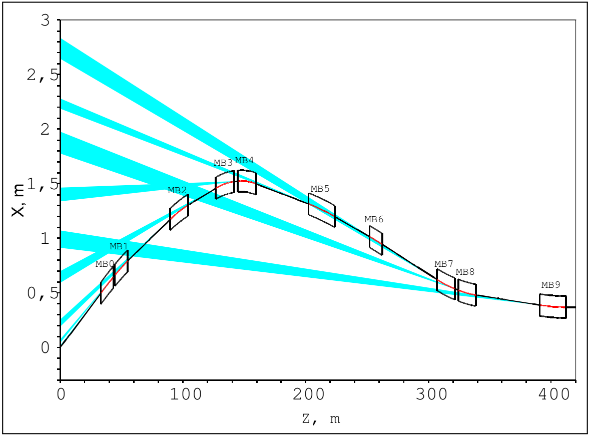
Energy loss $\Delta U = 0.1$ GeV

	L [m]	B [T]	ϕ [mrad]
B0	10.5	0.06	1
B1	10.5	0.17	3
B2	14.5	0.17	4.2
B3	15	0.22	5.6
B4	15	0.22	5.6
B5	21.5	0.06	2.2
B6	10.5	0.04	0.7
B7	14.5	-0.11	-2.7
B8	14.5	-0.11	-2.7
B9	21.5	-0.05	-1.8

Requirement

The tunnel should be straight in order to accommodate IR for FCC-pp!

Synchrotron radiation fans



$E_b = 175$ GeV
$I = 6.3$ mA

	E_γ, keV	P (kW)
B0	1132	7.9
B1	3397	71
B2	3416	99.6
B3	4428	173
B4	4428	173
B5	1218	18.7
B6	827.1	4.2
B7	2238	42.7
B8	2238	42.7
B9	1002	12.7

Detector solenoid field compensation

Reasons for anti solenoid

1. High luminosity crab waist scheme requires flat beams at IP $\sigma_y \ll \sigma_x$.
2. The lower emittance is the higher luminosity will be.
3. Vertical emittance is proportional to horizontal one through coupling coefficient. Coupling is introduced by solenoids, skew quadrupoles, quadrupole's tilt etc.
4. The major source of coupling is detector solenoid.

Coupling compensation

1. Anti solenoid is in front of the first quadrupole.
2. Anti solenoid is behind the first two quadrupoles..

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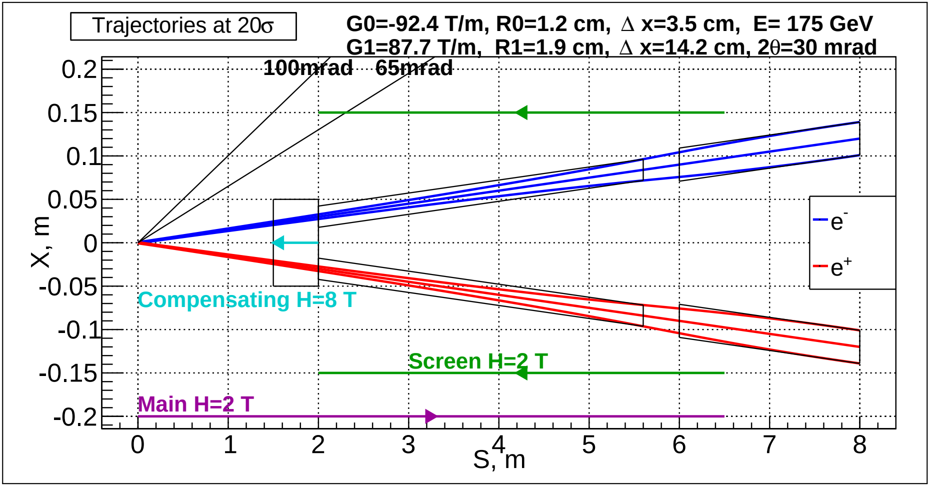
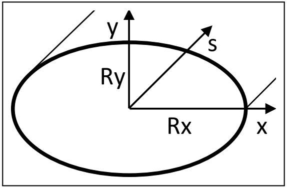
Coupling compensation: variant 1



Elliptical solenoid: field expansion



$$\begin{cases} B_x = -x\dfrac{B_0' R_y^2}{R_x^2 + R_y^2}, & B_0' \approx \dfrac{B_0}{L}, \\ B_y = -y\dfrac{B_0' R_x^2}{R_x^2 + R_y^2}, & L \approx 2R_x, \\ B_s = B_0 + sB_0', & x = \theta s. \end{cases}$$

$$\varepsilon_y = C_q \gamma^2 \frac{I5_y}{I2}, \quad I5_y = \left(\frac{B_x L}{B\rho}\right)^5 \frac{1}{60L^2}(-15L\alpha_y + 20\beta_y + 3L^2\gamma_y),$$

$C_q = 3.84 \cdot 10^{-13}$ m, $I2 = 1.68 \cdot 10^{-4}$ m^{-1}, $B\rho(\mathrm{Tm}) = E(eV)/c(m/c)$,
$\alpha_y = s/\beta_{0,y}$, $\beta_y = \beta_{0,y} + s^2/\beta_{0,y}$, $\gamma_y = 1/\beta_{0,y}$.

Vertical emittance estimation: variant 1

The biggest contribution if from the furthest fringe of anti solenoid.

$$B_0 = 8\ \mathrm{T},\ s = 2\ \mathrm{m},\ \varepsilon_y \propto \frac{B_0^5}{E^3}\left(\frac{R_y^2}{R_x^2 + R_y^2}\right)^5.$$

Round at E=45 GeV,

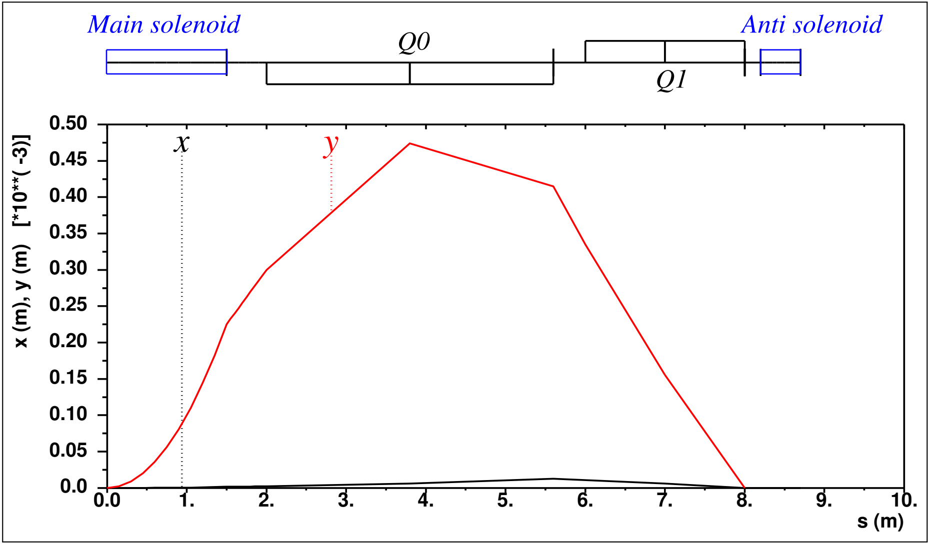
Rx/Ry	15 cm/15 cm
B_x	0.4 T
ε_y	76 pm
$\mathcal{L}$	$\mathcal{L}_{design}/\sqrt{76}$

Elliptical at E=45 GeV

Rx/Ry	15 cm/2.4 cm
B_x	0.02 T
ε_y	$2.4 \cdot 10^{-5}$ pm
$\mathcal{L}$	$\mathcal{L}_{design}$

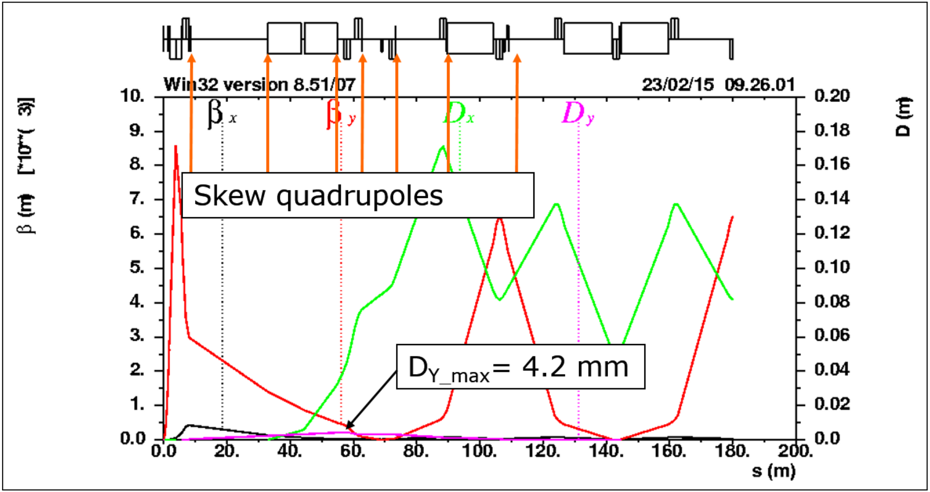
Coupling compensation: variant 2

Orbit distortion at E=45 GeV



Coupling compensation: variant 2

Optical functions at E=175 GeV



Coupling compensation

Summary of two variants coupling compensation

Version	1	1	2
Energy [GeV]	45	45	45
Solenoid	round	elliptical	round
Vertical emittance, pm	60	1	3.6
Luminosity	$\frac{\mathcal{L}_{design}}{\sqrt{60}}$	$\mathcal{L}_{design}$	$\frac{\mathcal{L}_{design}}{\sqrt{3.6}}$

Summary

What is done?

1. Interaction region providing designed luminosity.
2. Estimation of synchrotron radiation.
3. Two variants of solenoid compensation.

Questions

1. From what dipoles synchrotron radiation is dangerous?
2. What critical energy of synchrotron radiation photons should be?
3. Anti solenoid with 8 T is challenging. Could we make it 1m long instead of 0.5 m?
4. Details about luminosity monitor?!