Summary of crab waist interaction region for FCC-ee and the arc (one quarter of the ring IR: v. 6-14-3, arc: v16)

A. Bogomyagkov

Budker Institute of Nuclear Physics
Novosibirsk

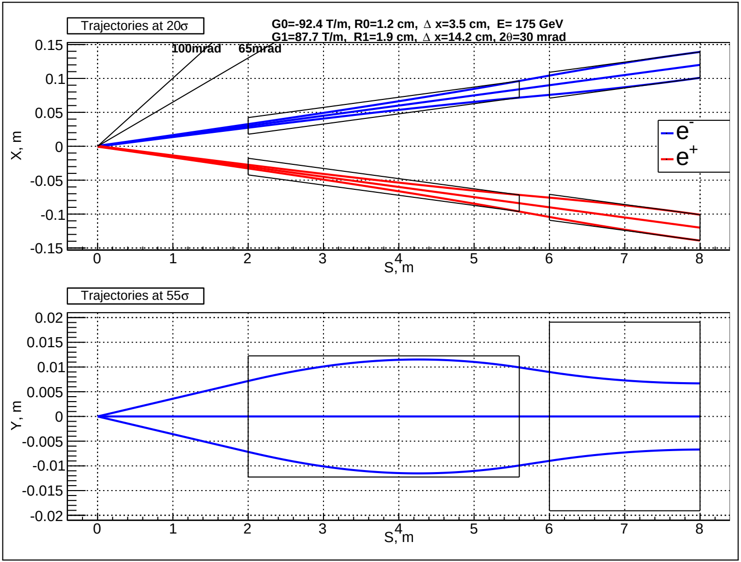
19 June, 2015

Parameters for crab waist

	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



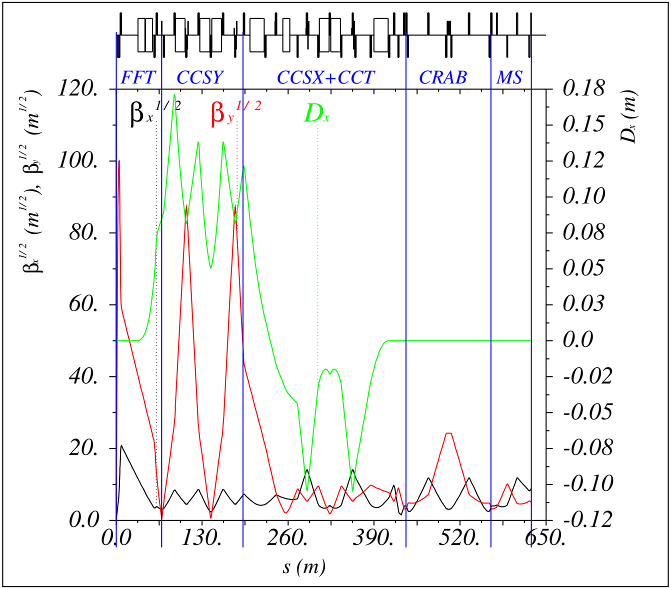
Rectangles are bare apertures.

	L [m]
Q0	3.6
Q1	2

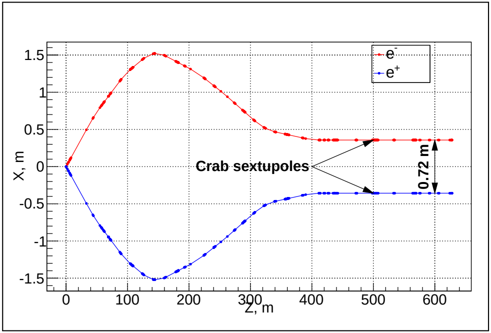
	R [m]
Q0	0.012
Q1	0.019

	B [T]
Q0	1.1
Q1	1.7

Interaction Region optical functions



Interaction Region layout



Energy loss $\Delta U = 0.1$ GeV

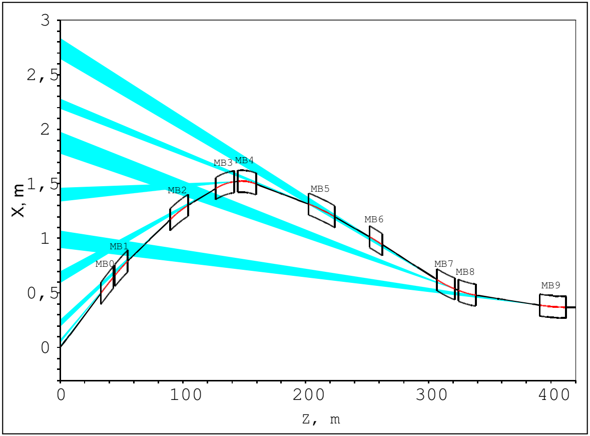
	L [m]	B [T]	ϕ [mrad]
B0	10.5	0.06	1
B1	10.5	0.17	3
B2	14.5	0.17	4.2
B3	15	0.22	5.6
B4	15	0.22	5.6
B5	21.5	0.06	2.2
B6	10.5	0.04	0.7
B7	14.5	-0.11	-2.7
B8	14.5	-0.11	-2.7
B9	21.5	-0.05	-1.8

Requirement from FCC-pp

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

Synchrotron radiation fans

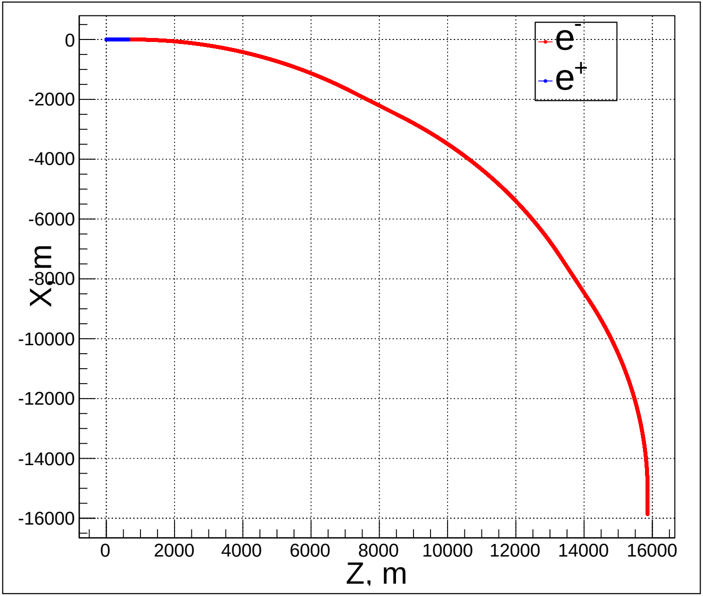
$E_b = 175$ GeV, $I = 6.3$ mA



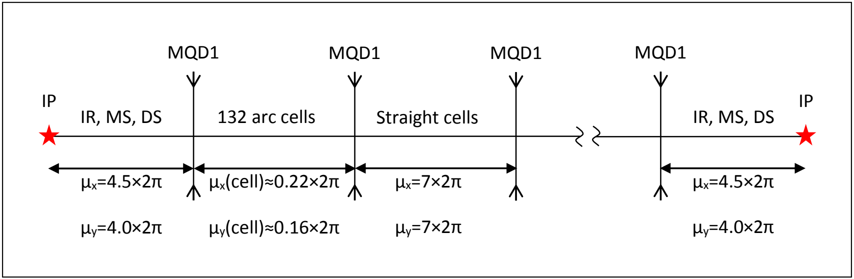
	E_γ, keV	P (kW)
B0	1132	7.9
B1	3397	71
B2	3416	99.6
B3	4428	173
B4	4428	173
B5	1218	18.7
B6	827.1	4.2
B7	2238	42.7
B8	2238	42.7
B9	1002	12.7

We are optimizing IR to have dipoles field not larger than in the arcs.

Quarter layout



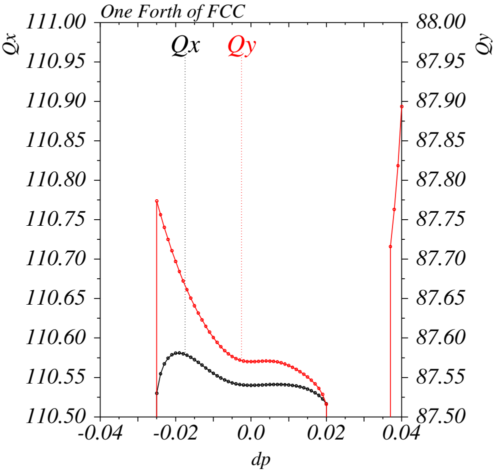
One quarter rematched



Global tune of one quarter

$$q_x = 2 \cdot \mu_x(SC) + 3 \cdot 132 \cdot \mu_x(cell) + \mu_x(IR)$$
$$q_y = 2 \cdot \mu_y(SC) + 3 \cdot 132 \cdot \mu_y(cell) + \mu_y(IR)$$

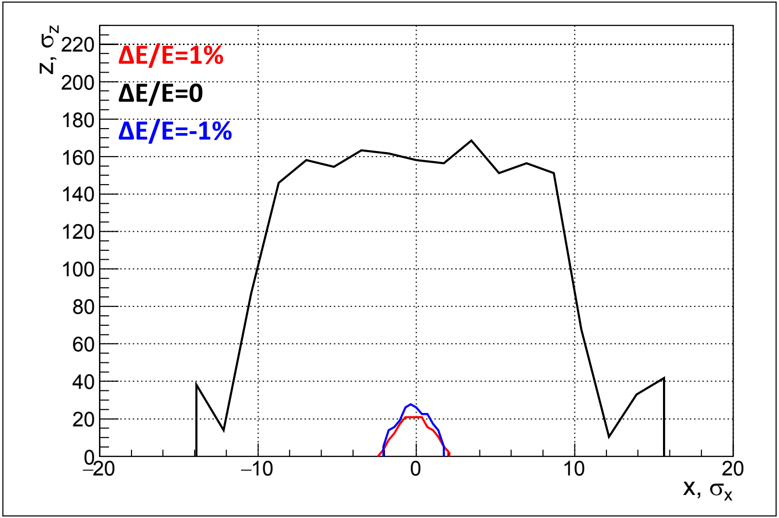
Energy acceptance II: [-2.5%;+2%]



	Value	$\Delta Q(2\%)$
Q_x	110.54	
Q_x'	0	0
Q_x''	156	0.031
Q_x'''	$-5.7 \cdot 10^4$	-0.076
Q_x''''	$3.4 \cdot 10^6$	-0.023
Q_y	87.57	
Q_y'	0	0
Q_y''	300	0.06
Q_y'''	$-1.5 \cdot 10^5$	-0.202
Q_y''''	$-3.8 \cdot 10^6$	-0.026

Dynamic aperture

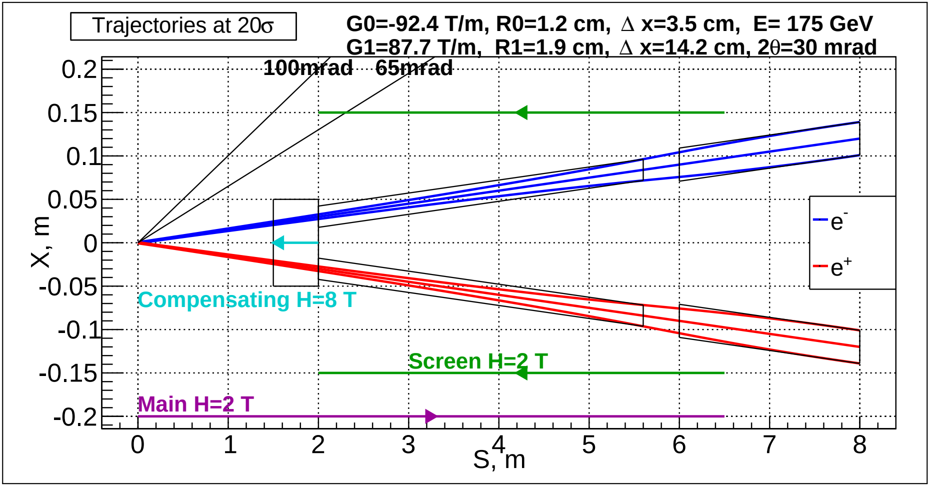
Thick sextupoles, quadrupole fringes, kinematic term.
RF is ON. Crab sextupole is ON.



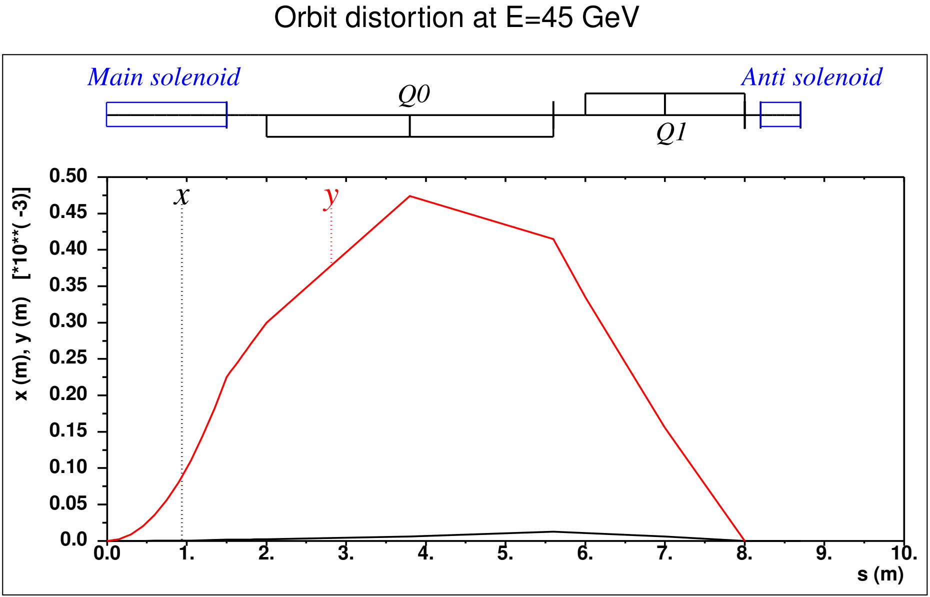
Parameters of one quarter of the ring

	tt
Energy [GeV]	175
Perimeter [m]	24987.2
Momentum compaction	$6.96 \cdot 10^{-6}$
Emittance hor. [nm]	1.66
Energy spread [10^{-3}]	1.6
β_x^* / β_y^* [m]	0.5 / 0.001
Energy loss / turn [GeV]	2.22

Coupling compensation: variant 1

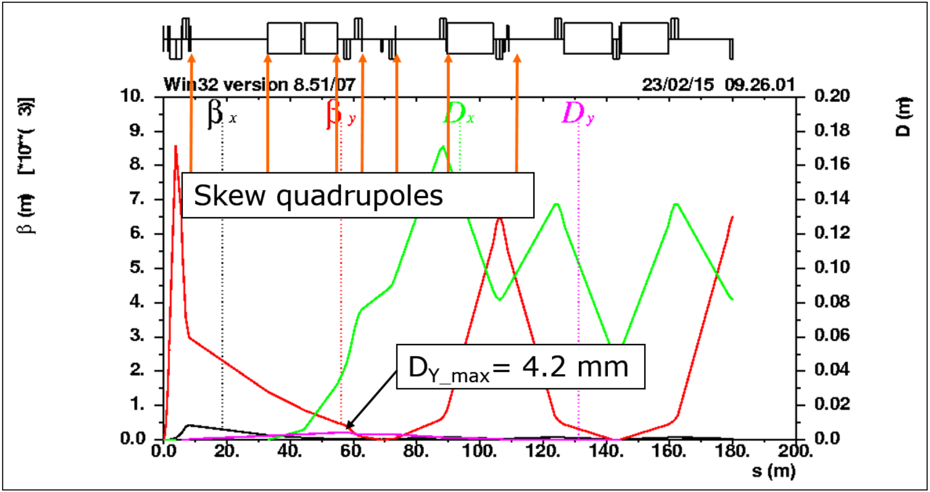


Coupling compensation: variant 2



Coupling compensation: variant 2

Optical functions at E=175 GeV



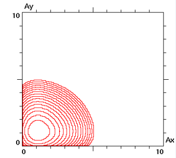
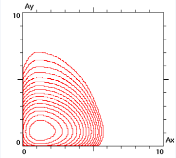
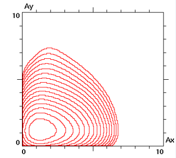
Coupling compensation

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	$\frac{\mathcal{L}_{design}}{\sqrt{60}}$	$\mathcal{L}_{design}$	$\frac{\mathcal{L}_{design}}{\sqrt{3.6}}$

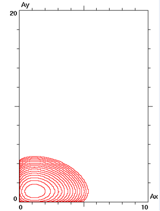
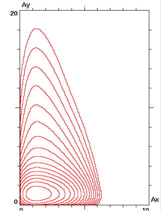
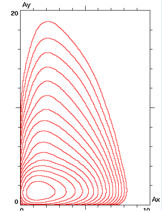
175 GeV, β_y= 2 mm

(Simulation Results of December 2014, to be updated)

Collision scheme	Crab Waist	Head-on	Crossing (11 mrad)
RF voltage [GV]	9.5	11	11
RF frequency [MHz]	400	400	400
Tunes $\nu_x / \nu_y / \nu_s$	0.54 / 0.57 / 0.0132	0.54 / 0.61 / 0.0172	0.52 / 0.57 / 0.0172
Bunch length [mm]	2.75 / 3.74	2.11 / 2.56	2.11 / 2.68
Bunch population	$2.0 \cdot 10^{11}$	$1.1 \cdot 10^{11}$	$1.2 \cdot 10^{11}$
Footprint size $\Delta\nu_x / \Delta\nu_y$	0.023 / 0.079	0.071 / 0.137	0.047 / 0.106
Lifetime τ_{bs} [min]	18	35	25
Luminosity [$cm^{-2}s^{-1}$]	$1.15 \cdot 10^{34}$	$1.3 \cdot 10^{34}$	$1.2 \cdot 10^{34}$
Luminosity (β_y = 1 mm)	$1.25 \cdot 10^{34}$	$1.3 \cdot 10^{34}$ (800 MHz)	$1.25 \cdot 10^{34}$ (800 MHz)
Density contour plots $10\sigma_x \times 10\sigma_y$			

120 GeV, β_y= 2 mm

(Simulation Results of December 2014, to be updated)

Collision scheme	Crab Waist	Head-on	Crossing (11 mrad)
RF voltage [GV]	2.3	5.5	5.5
RF frequency [MHz]	400	800	800
Tunes $\nu_x / \nu_y / \nu_s$	0.54 / 0.57 / 0.009	0.54 / 0.61 / 0.0255	0.52 / 0.57 / 0.0255
Bunch length [mm]	2.76 / 6.77	0.98 / 1.47	0.98 / 1.62
Bunch population	$3.5 \cdot 10^{11}$	$5 \cdot 10^{10}$	$6 \cdot 10^{10}$
Footprint size $\Delta\nu_x / \Delta\nu_y$	0.019 / 0.126	0.087 / 0.128	0.063 / 0.104
Lifetime bb+bs [min]	17	120	200
Luminosity [$cm^{-2}s^{-1}$]	$8.3 \cdot 10^{34}$	$6.8 \cdot 10^{34}$	$5.0 \cdot 10^{34}$
Luminosity (β_y = 1 mm)	$9.8 \cdot 10^{34}$	$7.2 \cdot 10^{34}$	$5.8 \cdot 10^{34}$
Density contour plots $10\sigma_x \times 20\sigma_y$			

Beam beam: 45-80 GeV

Low Energy, β_y= 1 mm

(Simulation Results of October 2014, to be updated)

Energy [GeV]	45.5		80	
Collision scheme	Head-on	Crab Waist	Head-on	Crab Waist
N_p $[10^{11}]$	1.8	1.0	0.7	4.0
θ [mrad]	0	30	0	30
σ_z [mm]	1.64 / 3.0	2.77 / 7.63	1.01 / 1.76	4.13 / 11.6
ε_x [nm]	29.2	0.14	3.3	0.44
ε_y [pm]	60.0	1.0	7.0	1.0
ξ_x / ξ_y [nominal]	0.03 / 0.03	0.02 / 0.14	0.06 / 0.06	0.02 / 0.20
L $[10^{34}\ cm^{-2}s^{-1}]$	17	180	13	45

At 45.5 GeV ξ_y can be raised up to 0.2. If we try to achieve this by 50% increase of N_p, additional bunch lengthening will occur due to beamstrahlung, so ξ_y will increase by 15% only. Decrease of ε_y would be much more efficient, since for flat bunches beamstrahlung does not depend on the vertical beam size.

Summary

- There is much synergy between baseline and crab waist lattice parameters and requirements, especially at high energies.
- At high energies β_y^* can be relaxed to 2 mm, and we need large $\eta \sim 0.02$.
- At low energies β_y^* should be ~ 1 mm, but η can be smaller (~ 0.01 at 45.5 Gev.)
- β_x^* should be increased from 0.5 to 1 m.
- At the top energy (175 GeV) the performances of baseline and crab waist schemes are almost equal.
- At 120 GeV crab waist has an advantage ~ 50% which growth with lowering the energy. At 45.5 GeV the advantage may reach factor of 10.
- Parameters optimization and comparative analysis of different collision schemes is now performing with the use of more accurate models and techniques. Work in progress.
- When the real nonlinear lattice is ready, more reliable beam-beam simulations will be possible.

Summary

What is done?

1. Interaction region with four interaction points and designed luminosity

Plans

1. Optimize IR in order to minimize SR critical energy.
2. Obtain reasonable geometry of the IR.
3. Increase $\beta_x^* = 1$ m.
4. Drop horizontal chromaticity section.
5. Continue with four interaction points.

Summary

What is done?

1. Interaction region with four interaction points and designed luminosity

Plans

1. Optimize IR in order to minimize SR critical energy.
2. Obtain reasonable geometry of the IR.
3. Increase $\beta_x^* = 1$ m.
4. Drop horizontal chromaticity section.
5. Continue with four interaction points.