Interaction Region optics solutions

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Many thanks to M. Benedikt, H. Burkhardt, B. Haerer, B. Holzer, M. Koratzinos, P. Vobly, F. Zimmermann

Luminosity vs beam energy
(theoretical estimations)

	Z	W	H	tt
Energy [GeV]	45	80	120	175
Perimeter [km]	100			
Emittance hor. [nm]	0.14	0.44	1	2.1
Emittance ver. [pm]	1	2	2	4.3
β_x^*/β_y^*	0.5/0.001			
Crossing angle [mrad]	30			
Luminosity / IP [$10^{34} cm^{-2} s^{-1}$]	212	36	9	1.3
Crossing angle [mrad]	26			
Luminosity / IP [$10^{34} cm^{-2} s^{-1}$]	255	43	10	1.4

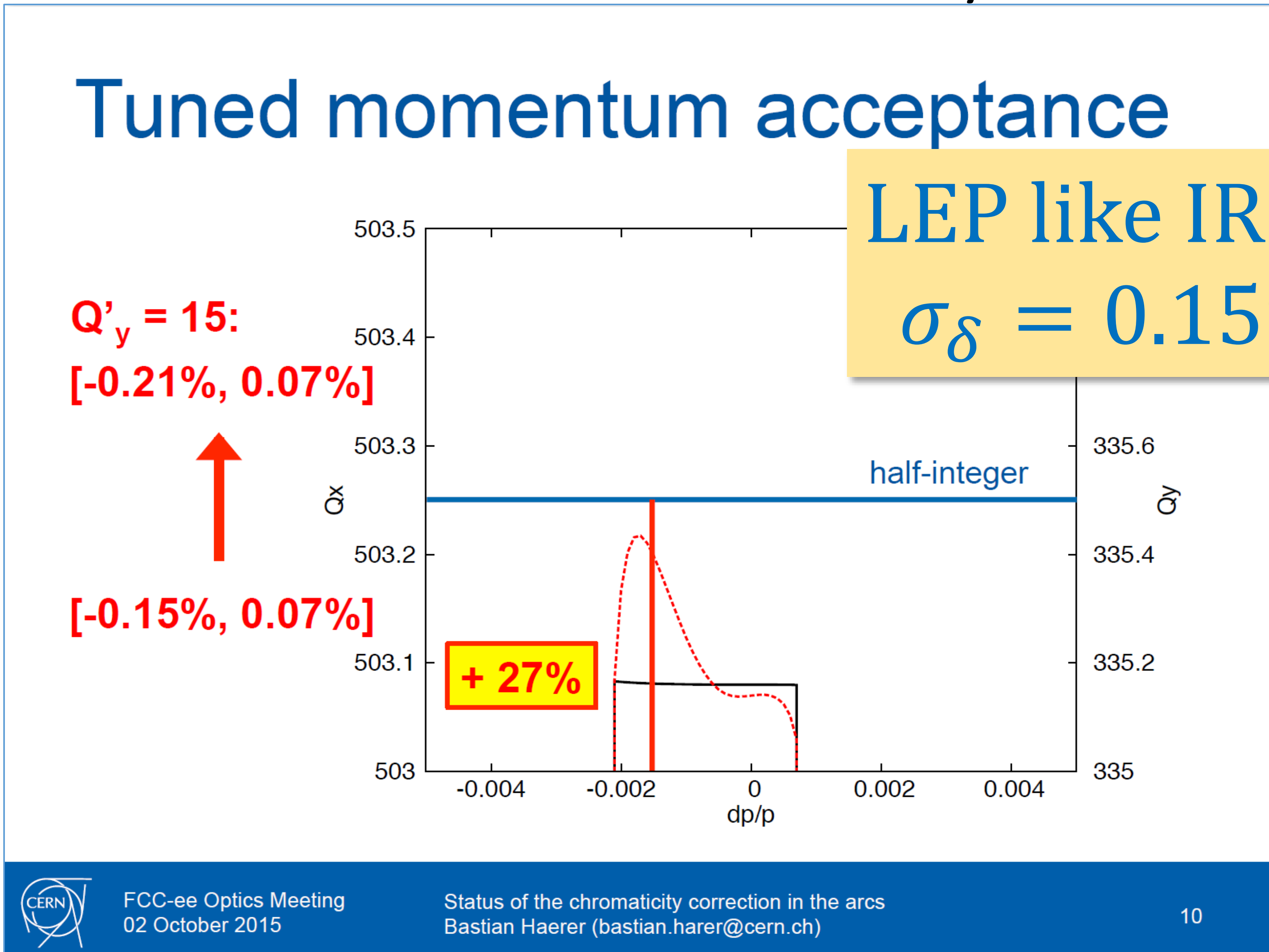
Requirements

1. Must fit hadron collider tunnel. Perimeter 100 km.
2. Two interaction points (defined by FCC-hh and price).
3. $\beta_x^*/\beta_y^* = 0.5m/0.001m(1m/0.002m)$.
4. Vertical emittance is less or equal than 1 pm at 45 GeV.
5. Horizontal emittance is 1-2 nm at 175 GeV.
6. Energy acceptance $\pm$2%.
7. **$E_{\gamma,c} < 100$ keV within $\pm$250 m from IP (Helmut Burkhardt).**

Solutions

1. Strong requirement of $E_{\gamma,c} < 100$ keV within $\pm$250 m from IP and FFC-hh tunnel dictates asymmetric solutions. There are two variants by K. Oide and A. Bogomyagkov.
2. Another solution is to have head-on for 175 GeV by S. Sinyatkin and crab waist for lower energies (rejected).
3. Geometry constraints hint about crossing angle optimization (30 mrad or 26 mrad).
4. Small vertical emittance at 45 GeV demands local solenoid compensation.
5. Local chromaticity correction sections (CCS) to provide energy acceptance.

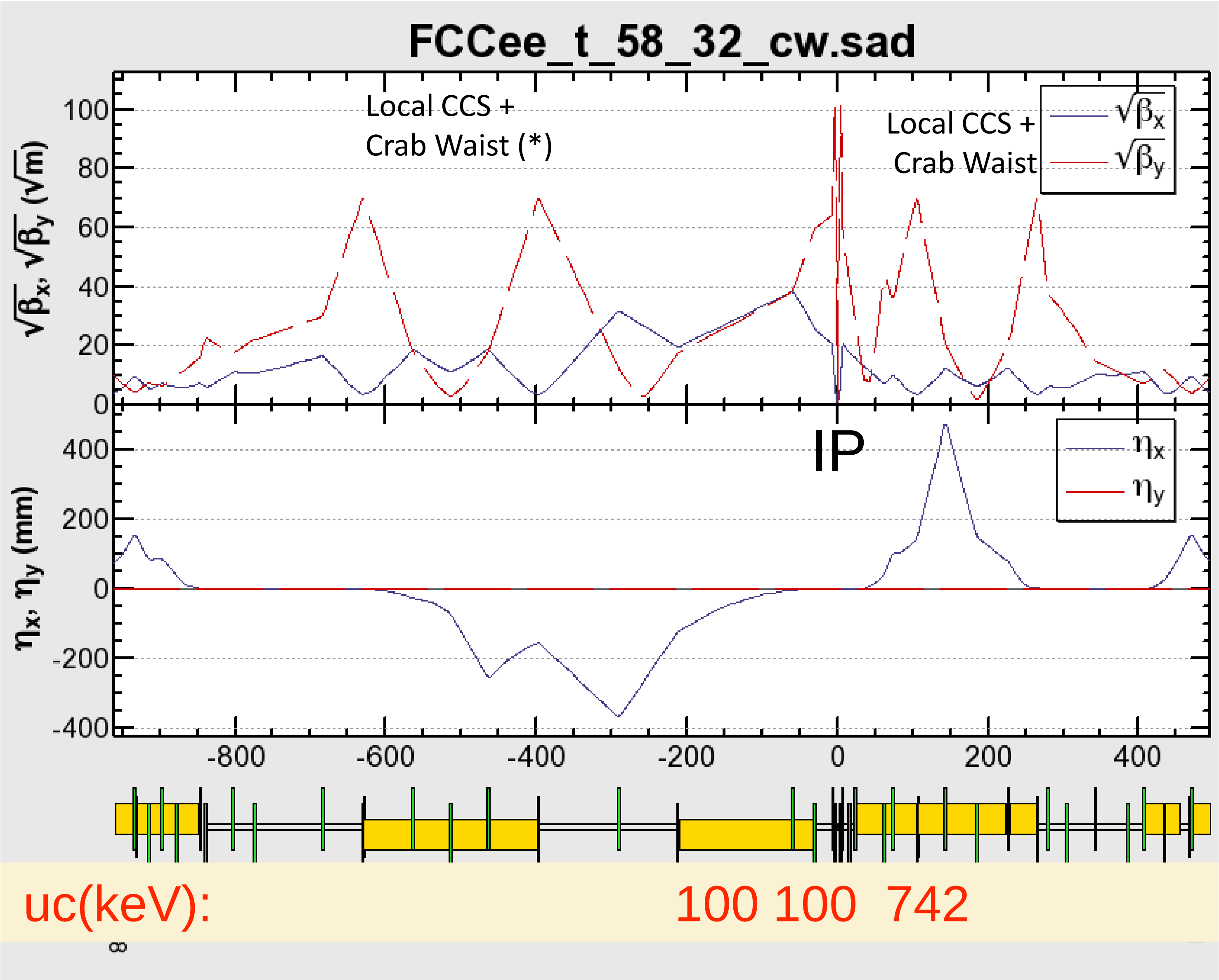
The reason for chromaticity sections



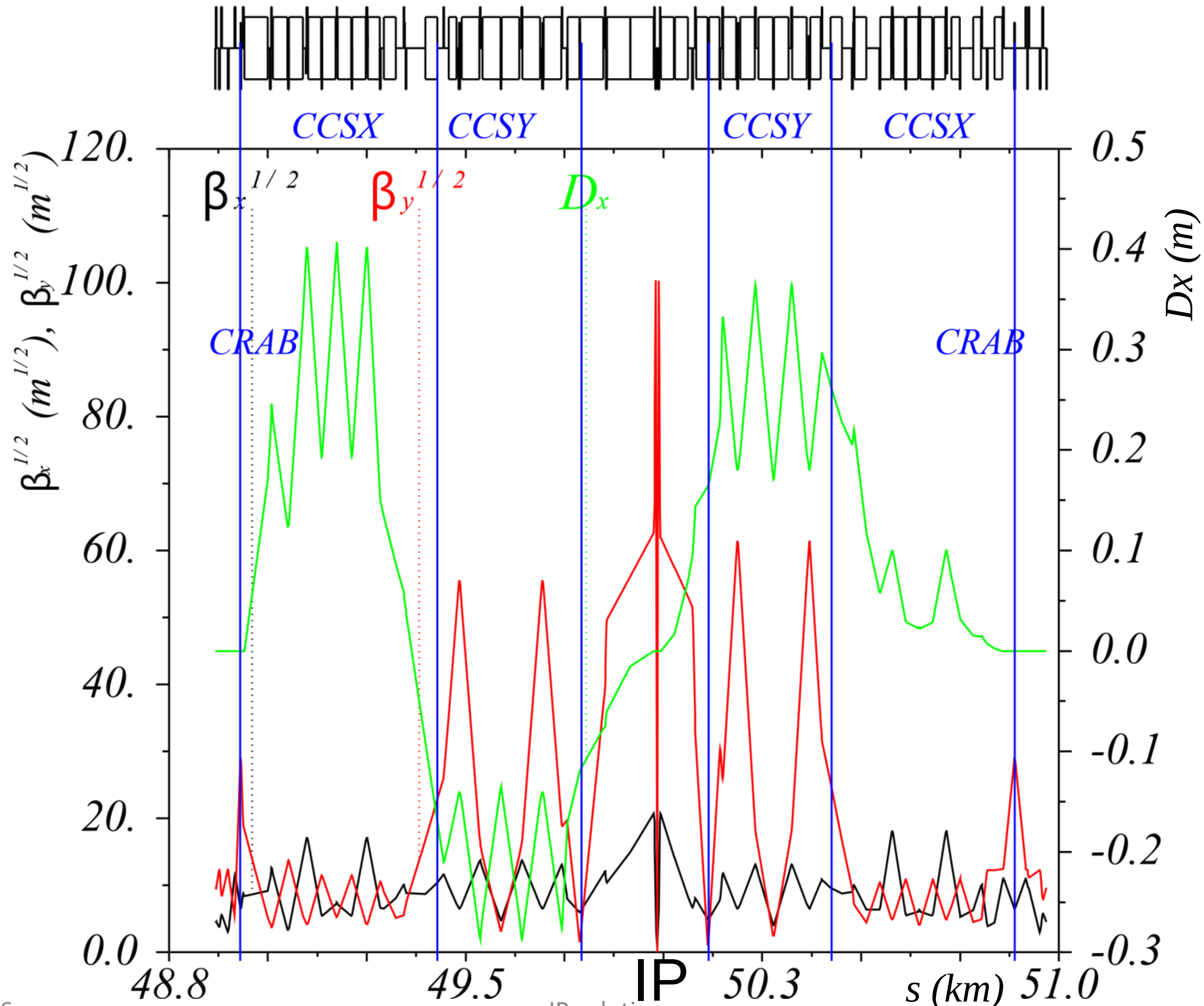
LEP like IR

$\sigma_\delta = 0.15\%$

IR1: asymmetric by KO, 30 mrad



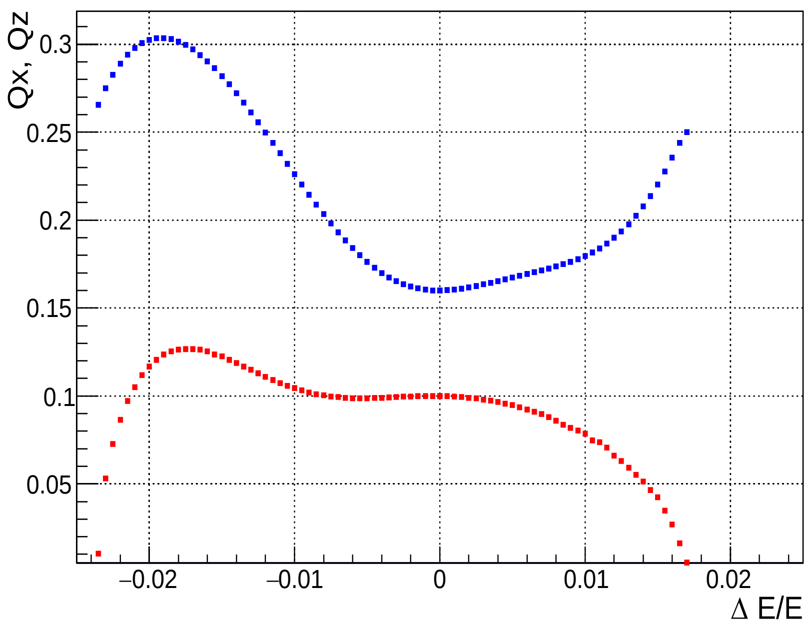
IR2: asymmetric AB, 26 mrad

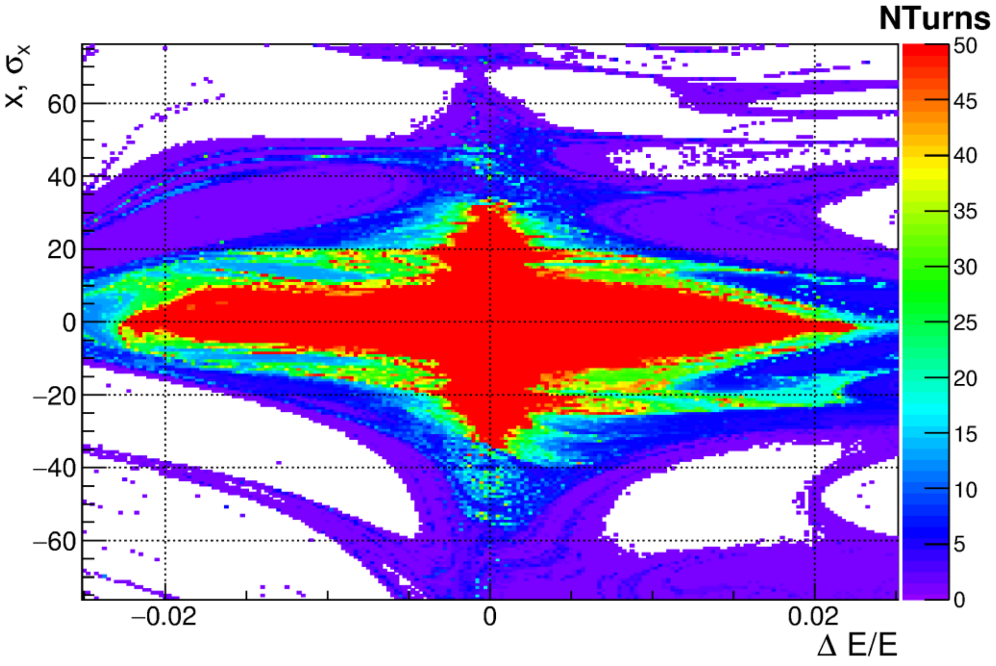


Dynamic aperture: AB, 26 mrad

50 Turns without damping, CRAB is OFF, RF is ON.

$$\varepsilon_x = 1.4\,nm, \nu_s = 0.0807, U_{RF} = 11\,GV, \tau_x = 44\,turns$$

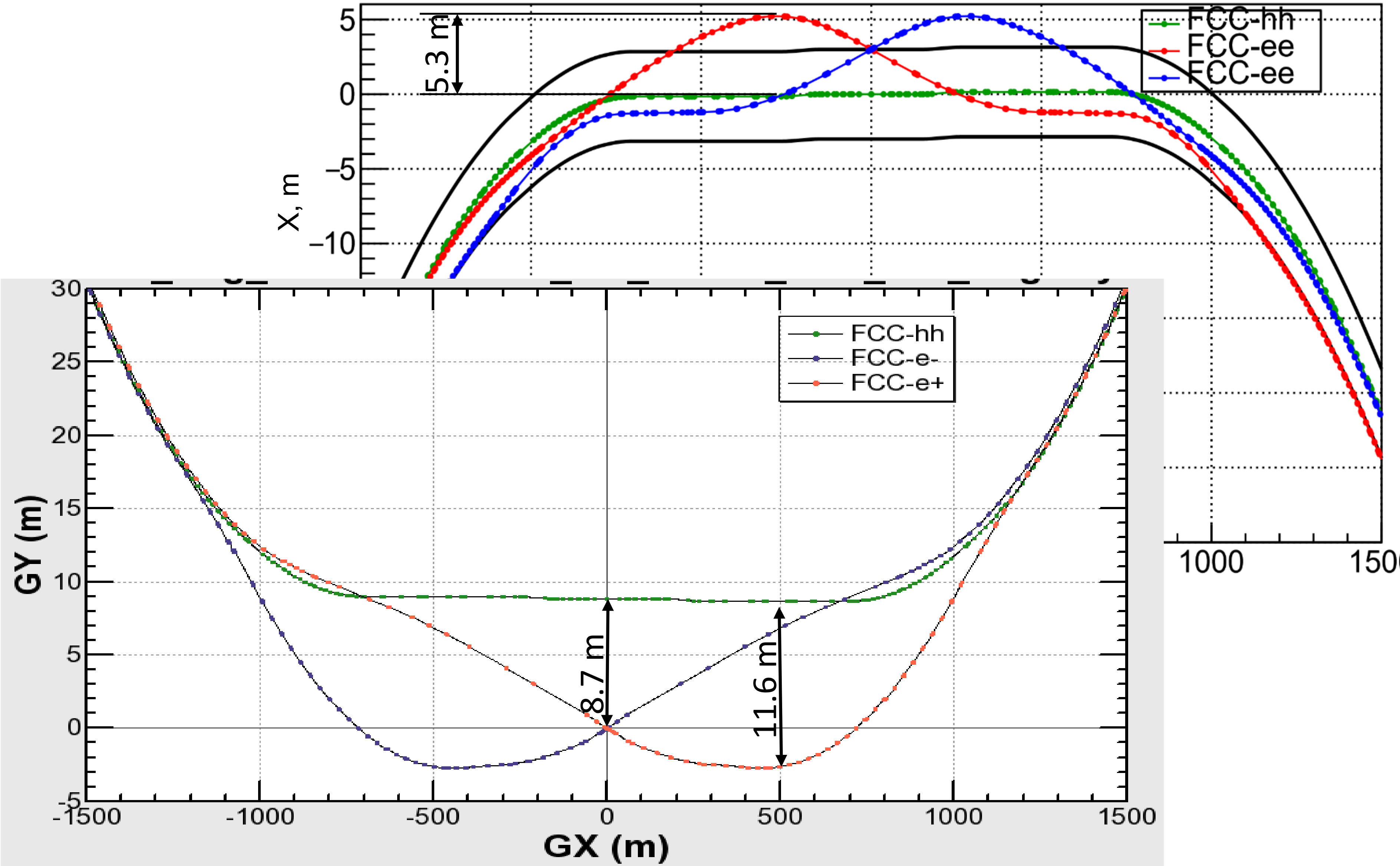




Synchrotron radiation towards IP

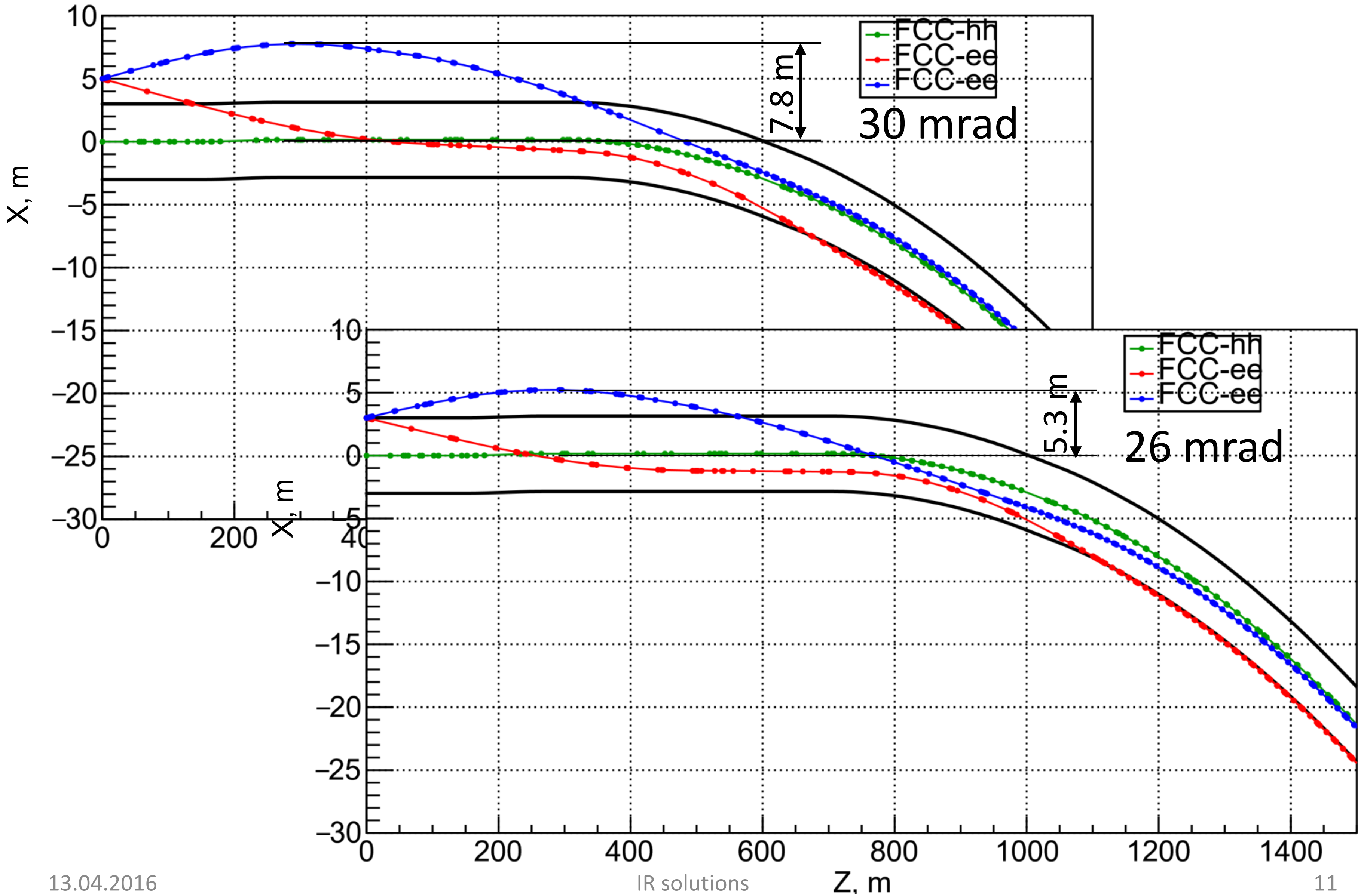
Dipole	L, m	S(end), m	Ec, keV
IR1: asymmetric by KO, 30 mrad (v.58-32)			
BWL.2	37	76.5	100
BC1L.2	105.7	186	100
IR2: asymmetric by AB, 26 mrad (v.9-5)			
B0	59	67.5	100.8
B1	59	127	100.8
B2	59	195.2	201.5
B3	30	226.4	310.5
B4	45	287.2	494

Layout: KO 30 mrad and AB 26 mrad

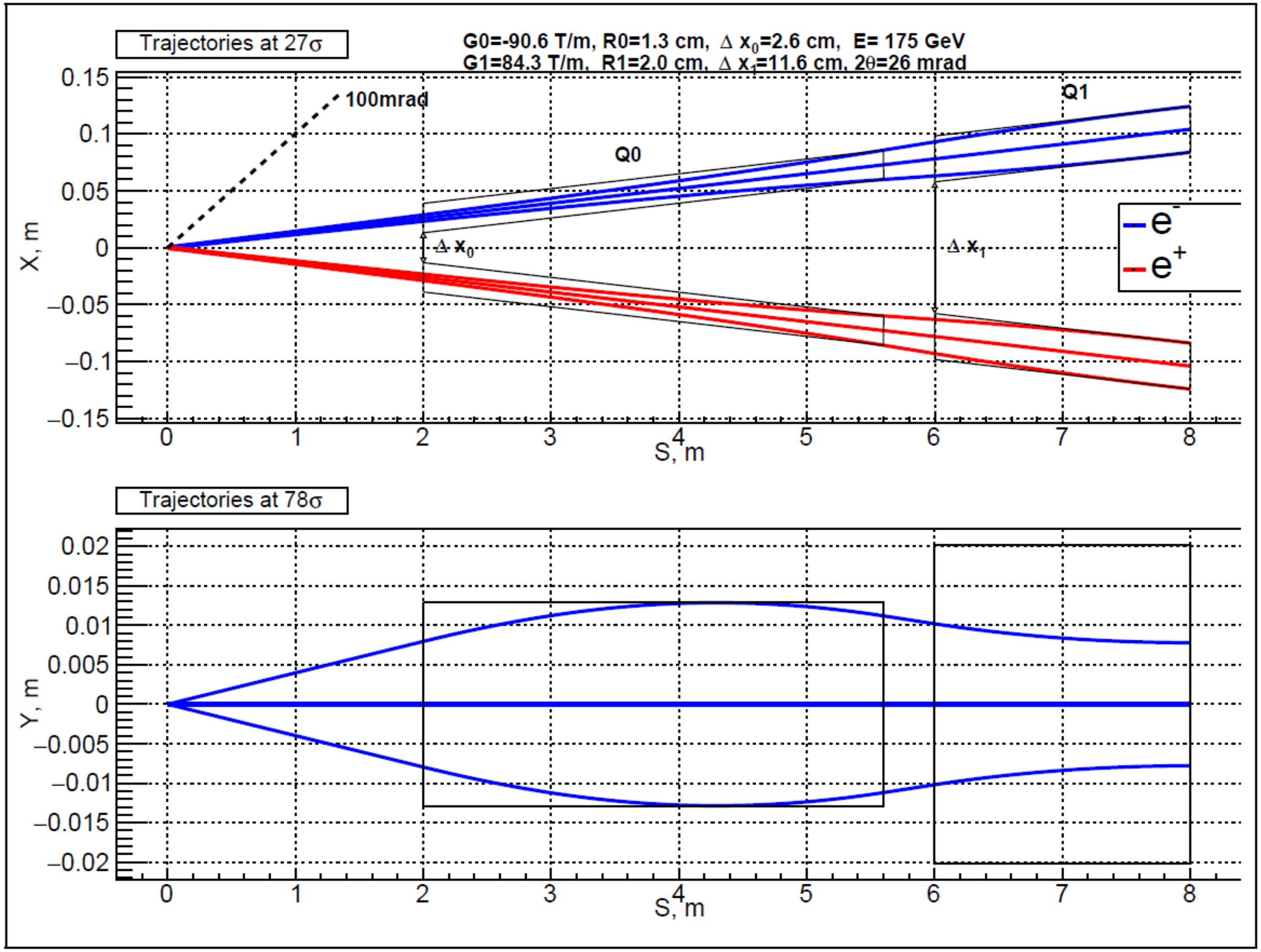


Wide tunnel: ±1,150 m

Layout: AB 30 mrad and AB 26 mrad



IP trajectories 1



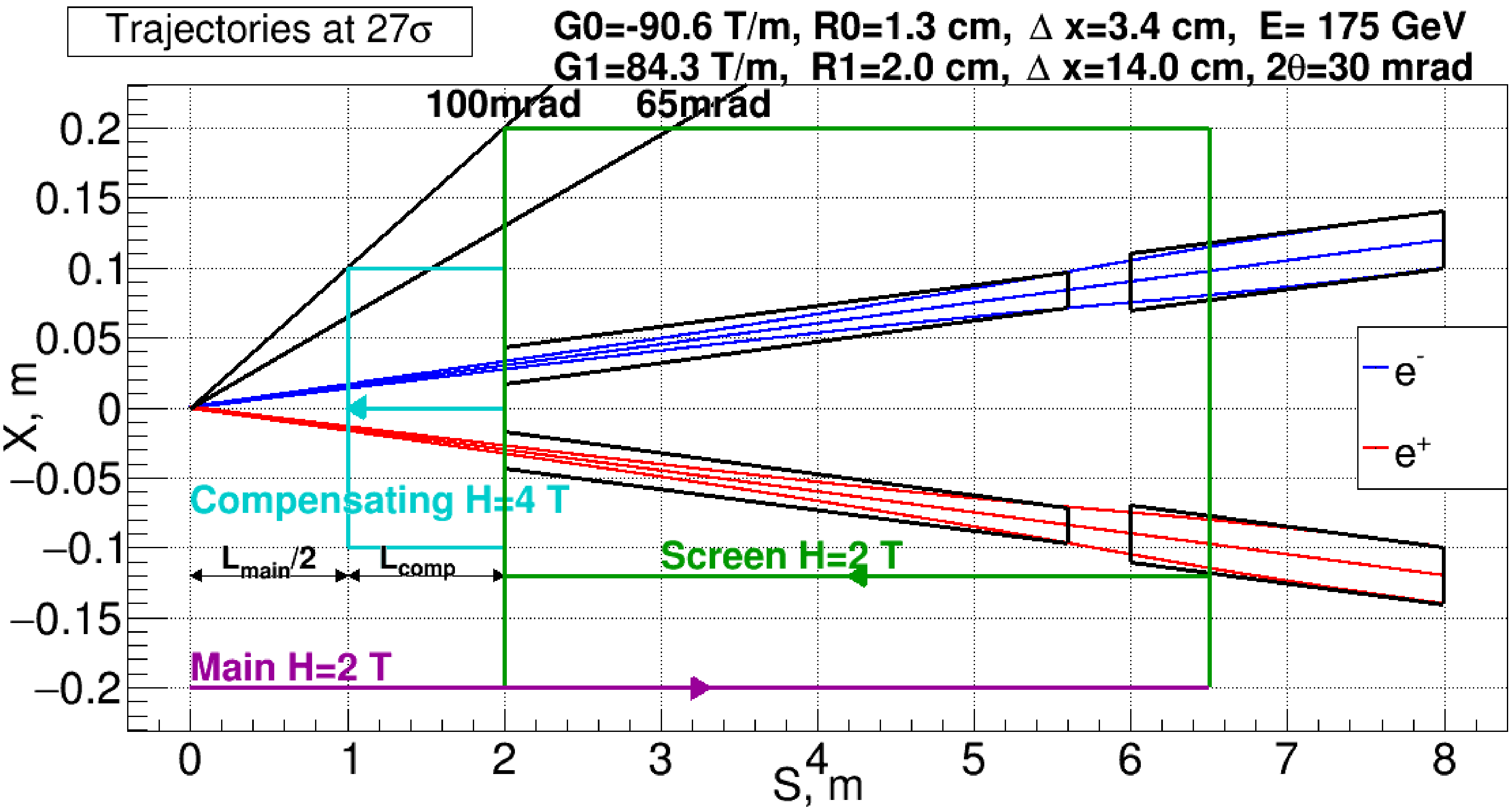
Rectangles are bare apertures.

	L [m]
Q0	3.6
Q1	2

	G [T/m]
Q0	90.6
Q1	84.3

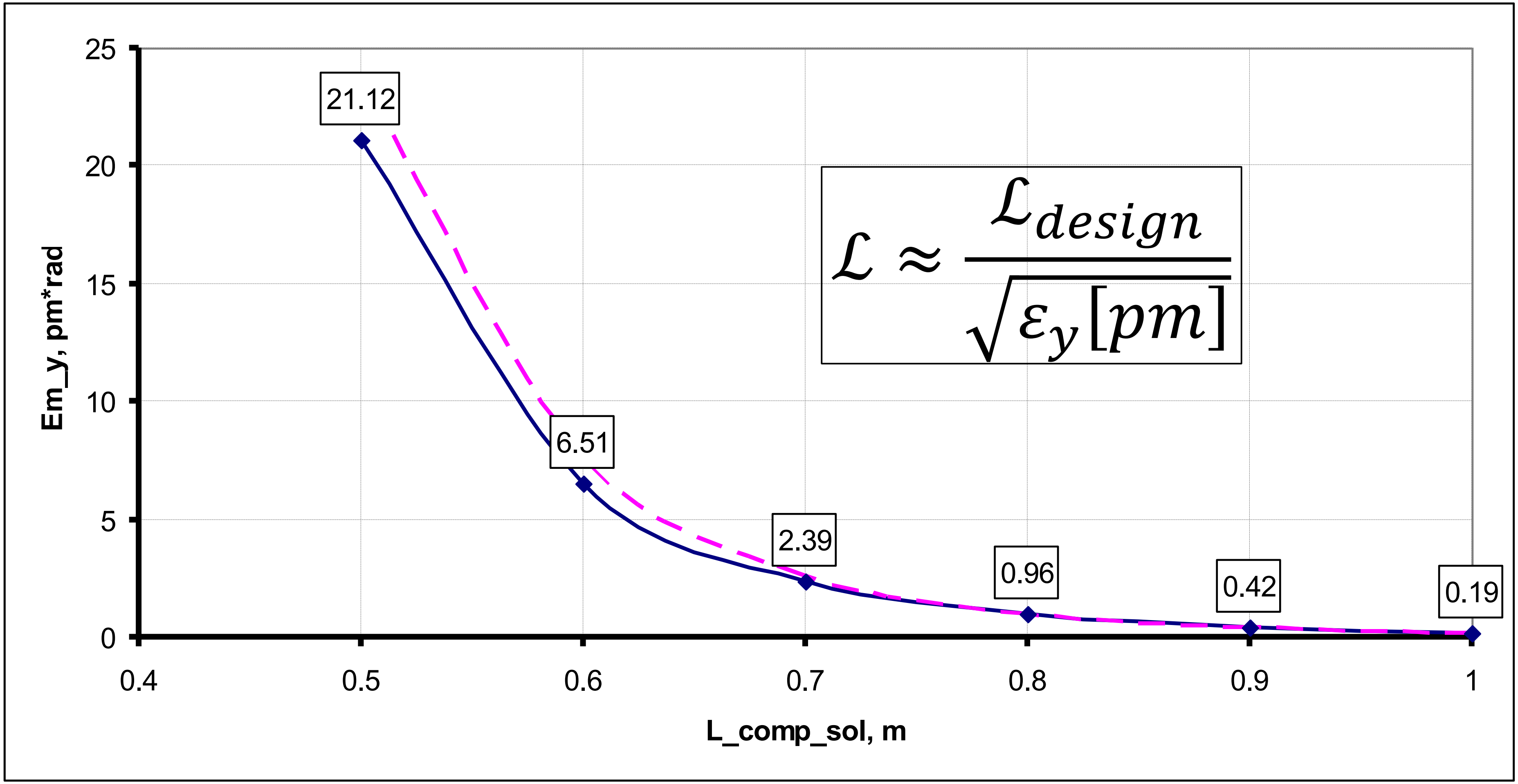
	L [cm]
Q0	1.3
Q1	2

Solenoid compensation for IP1



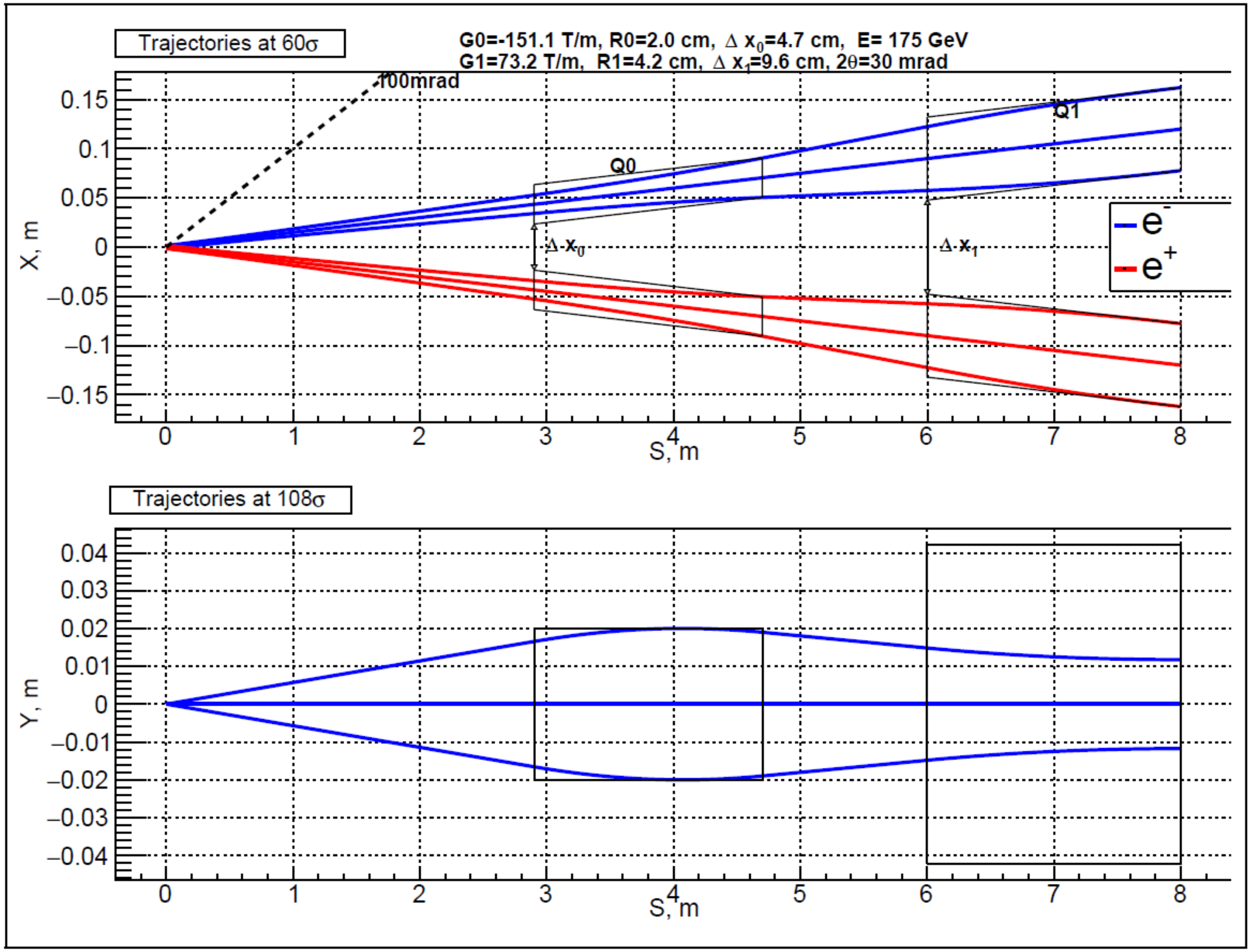
Compensating solenoid R = 0.1 m, screening solenoid R = 0.2 m.

Emittance vs Lcomp: E=45 GeV, IP1



$$\mathcal{L} \approx \frac{\mathcal{L}_{design}}{\sqrt{\varepsilon_y[pm]}}$$

IP trajectories 2



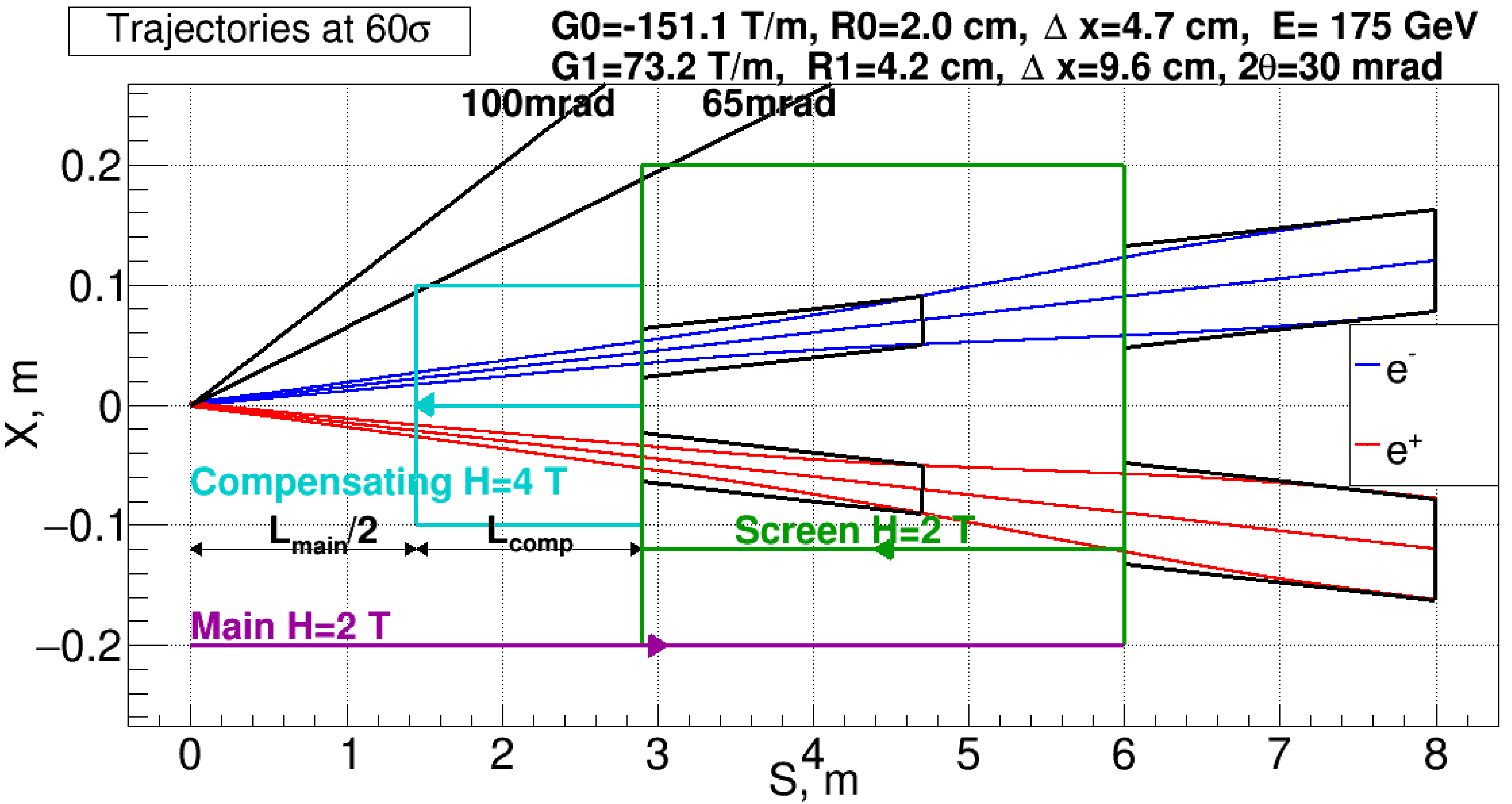
Rectangles are bare apertures.

	L [m]
Q0	1.8
Q1	2

	G [T/m]
Q0	151
Q1	73

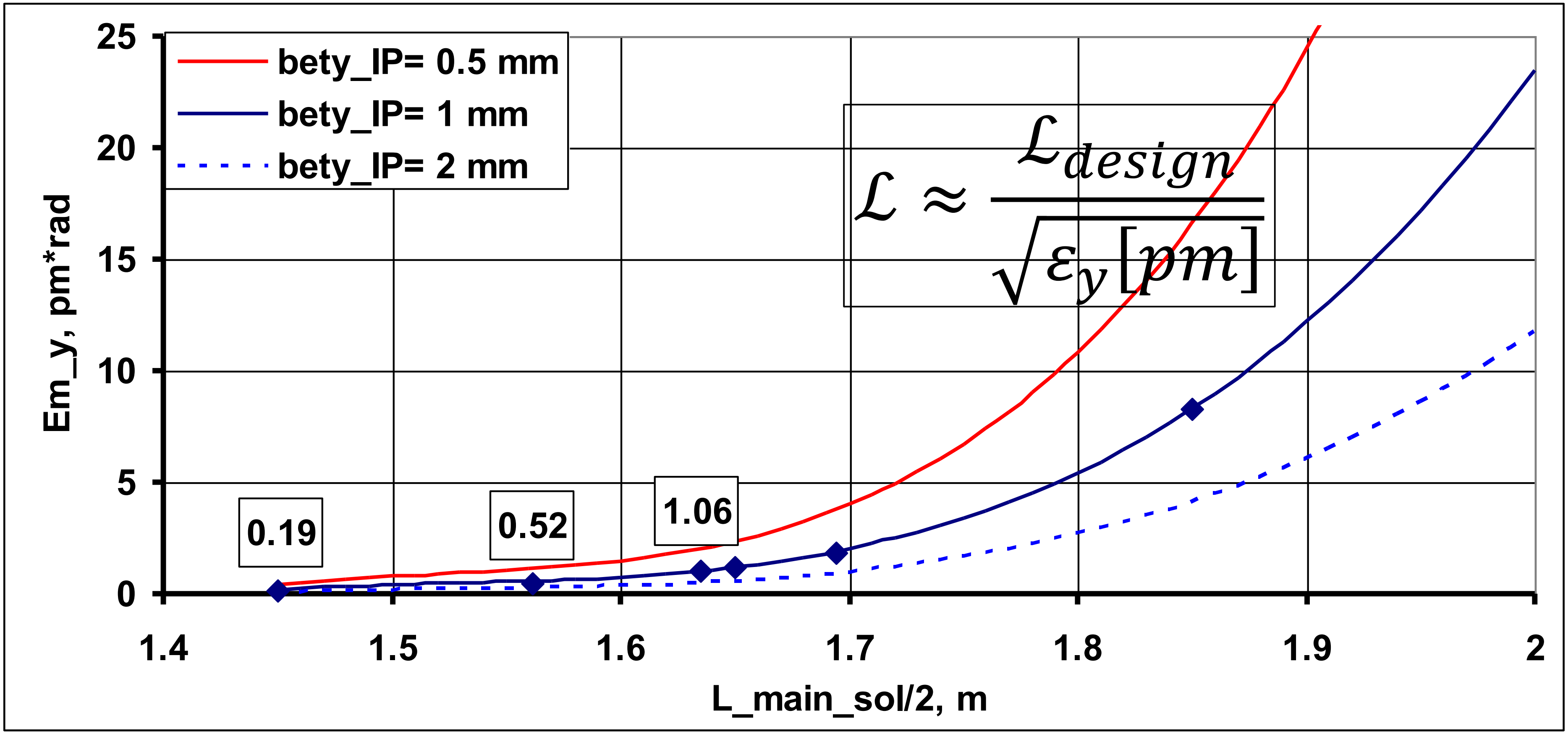
	L [cm]
Q0	2
Q1	4.2

Solenoid compensation for IP2



Compensating solenoid R = 0.1 m, screening solenoid R = 0.2 m.

Emittance vs Lcomp: E=45 GeV, IP2



Head-on at 175 GeV (rejected)

Because there is no significant gain in luminosity from crossing angle and crab waist at 175 GeV.

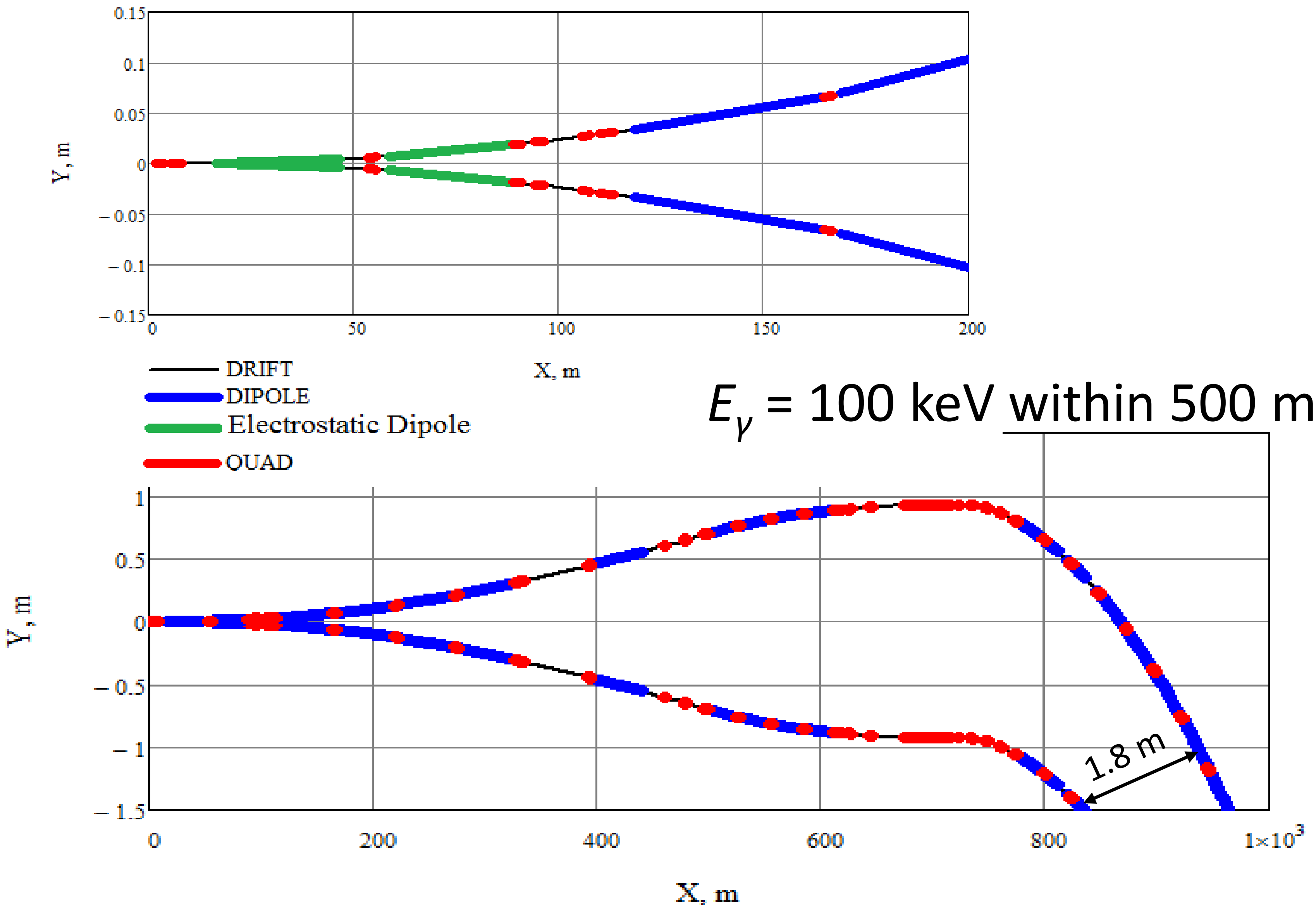
The benefits are:

1. single aperture of final focus elements, magnets are simple,
2. no crab sextupole, therefore IR is shorter,
3. easy to satisfy $E_{\gamma,c} < 100$ keV within $\pm$250 m from IP,
4. no limitation of dynamic aperture from crab sextupole.

The disadvantage:

1. Rearrange the whole IR.

IR3: head on



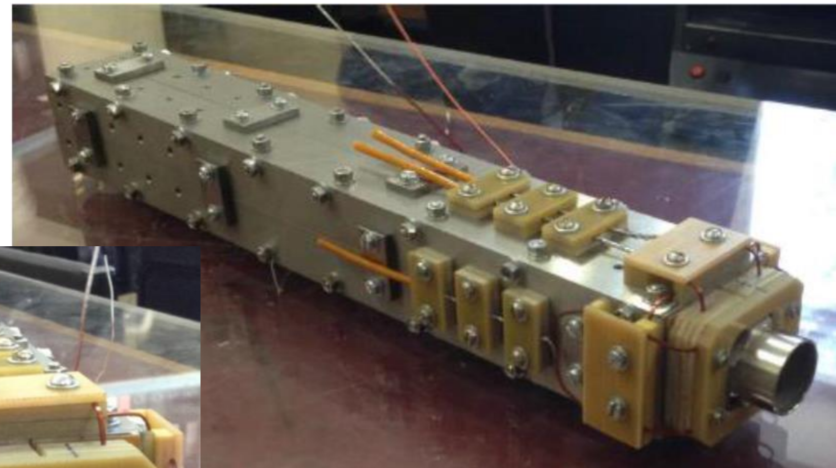
E_γ = 100 keV within 500 m.

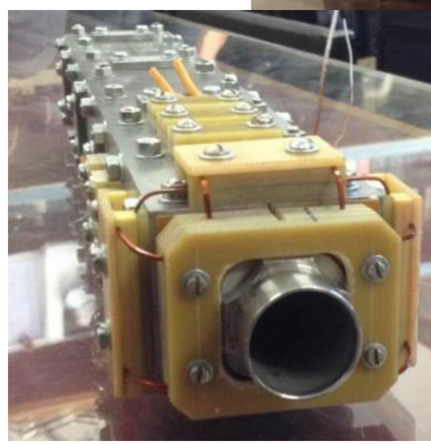
Comparison

KO	AB
Vertical chromaticity correction section is combined with crab sextupole, no horizontal chromaticity correction section.	Separate vertical, horizontal, crab sextupole sections.
Chromaticity is corrected by 300 independent pairs of arc sextupoles.	Chromaticity is corrected by 8 sextupole families in the IR and 8 families in the arcs.
Wider and longer tunnel in the IR, but flexible with the entrance angle to the arc tunnel.	Narrower and shorter tunnel of the IR, but stiff entering the arc tunnel.
$E_{\gamma,c} < 100$ keV within 250 from IP.	$E_{\gamma,c} < 100$ keV within 130 m, $E_{\gamma,c} < 200$ keV within 200 m, $E_{\gamma,c} < 300$ keV within 225 m.

QD0 prototype 100 T/m

New version of QD0 was developed at BINP recently and a single-aperture prototype was manufactured.



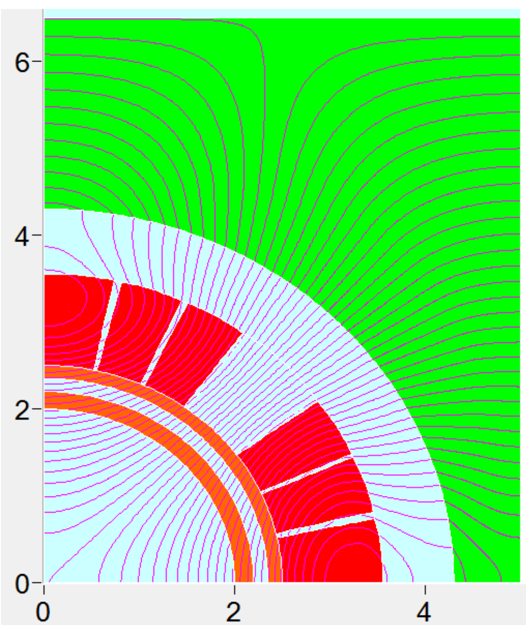


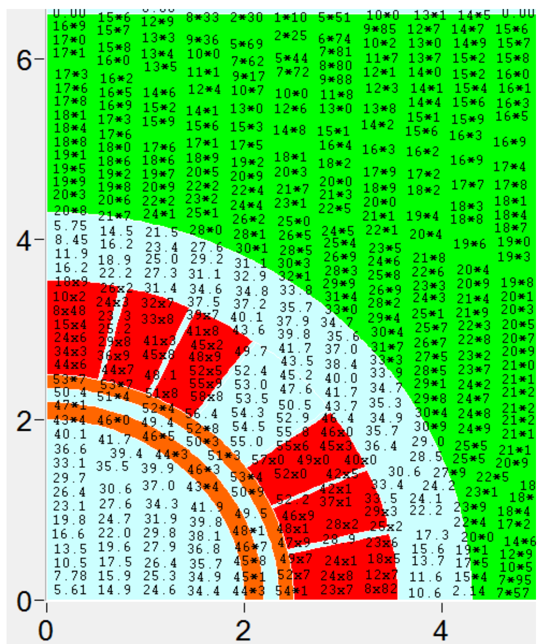
Main parameters:
Max.gradient 100 T/m
Max.current 1100 A
Length 40 cm
Aperture 2 cm
NbTi 1.8 x 1.4 mm^2
Saddle-type coils

During the first cryo-test (01.02.16) the current of 1060 A was achieved after 3 quenches.

QD0 design 200 T/m

Pros	Cons	Main parameters
Larger aperture to avoid • higher order HOMS • SR hitting the walls	Higher SR	• Maximum gradient 217 T/m. • Length 180 cm.
More room for luminometer		• Radius 2 cm.





	An	Bn	an	bn
1	0.0000000	0.0000000	0.0000000	0.0000000
2	21.7186393	0.0000000	21.7186393	0.0000000
3	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0024942	0.0000000	0.0149654	0.0000000
5	0.0000000	0.0000000	0.0000000	0.0000000
6	0.0029498	0.0000000	0.3539802	0.0000000
7	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000048	0.0000000	0.0239750	0.0000000
9	0.0000000	0.0000000	0.0000000	0.0000000
10	-0.0001845	0.0000000	-66.9473869	0.0000000
11	0.0000000	0.0000000	0.0000000	0.0000000
12	0.0000459	0.0000000	1830.9513791	0.0000000
13	0.0000000	0.0000000	0.0000000	0.0000000
14	-0.0000359	0.0000000	23745.70129	0.0000000
15	0.0000000	0.0000000	0.0000000	0.0000000
16	0.0000265	0.0000000	592924.54556	0.0000000
17	0.0000000	0.0000000	0.0000000	0.0000000
18	-0.0000253	0.0000000	4644816.475	0.0000000

Conclusion

I. There are two asymmetric IR:
   1. KO with 30 mrad and $E_{\gamma,c} < 100$ keV within $\pm$250 m but wide tunnel or two tunnels,
   2. AB with 26 mrad and smaller tunnel but with $E_{\gamma,c} < 100$ keV within $\pm$130 m, $E_{\gamma,c} < 200$ keV within $\pm$200 m, $E_{\gamma,c} < 300$ keV within $\pm$225 m.

II. Head-on option for 175 GeV, but with complete IR rearrangement.

III. The 200 T/m quadrupole is possible therefore we could implement it in the optics, giving more room for luminosity monitor.