IR designs & dynamic aperture

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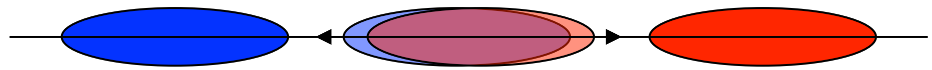
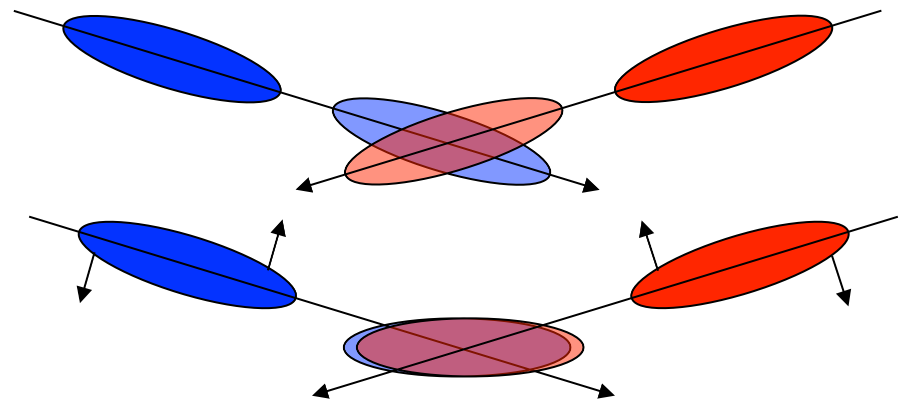
Introduction: three collision schemes

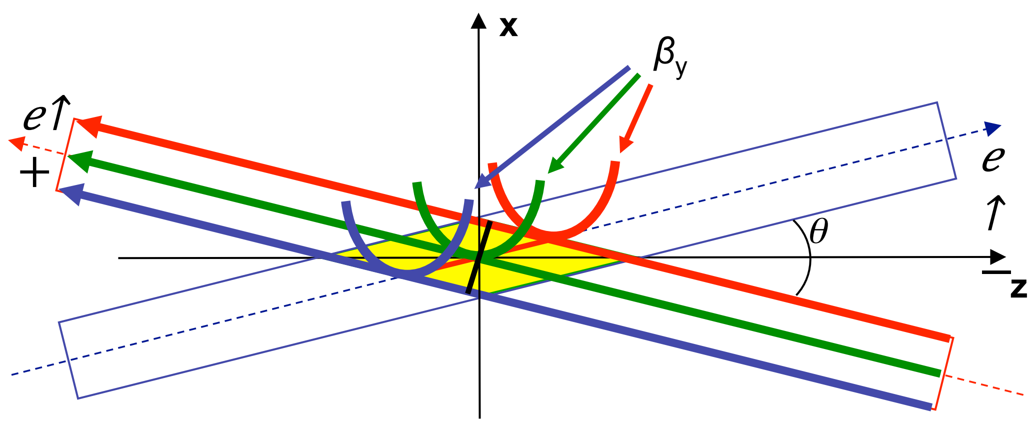
- Head-on



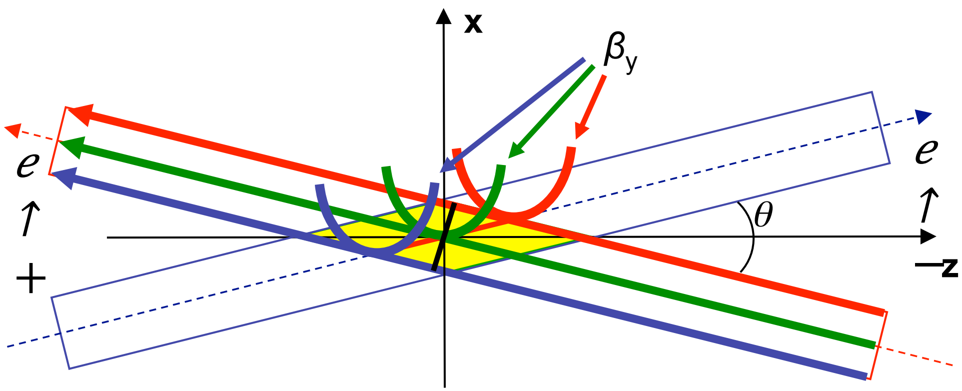
- Crab cavity with small crossing angle 11 mrad



- Crab waist with large crossing angle 30 mrad



Crab waist (P.Raimondi 2006)



1. Large Piwinski angle:

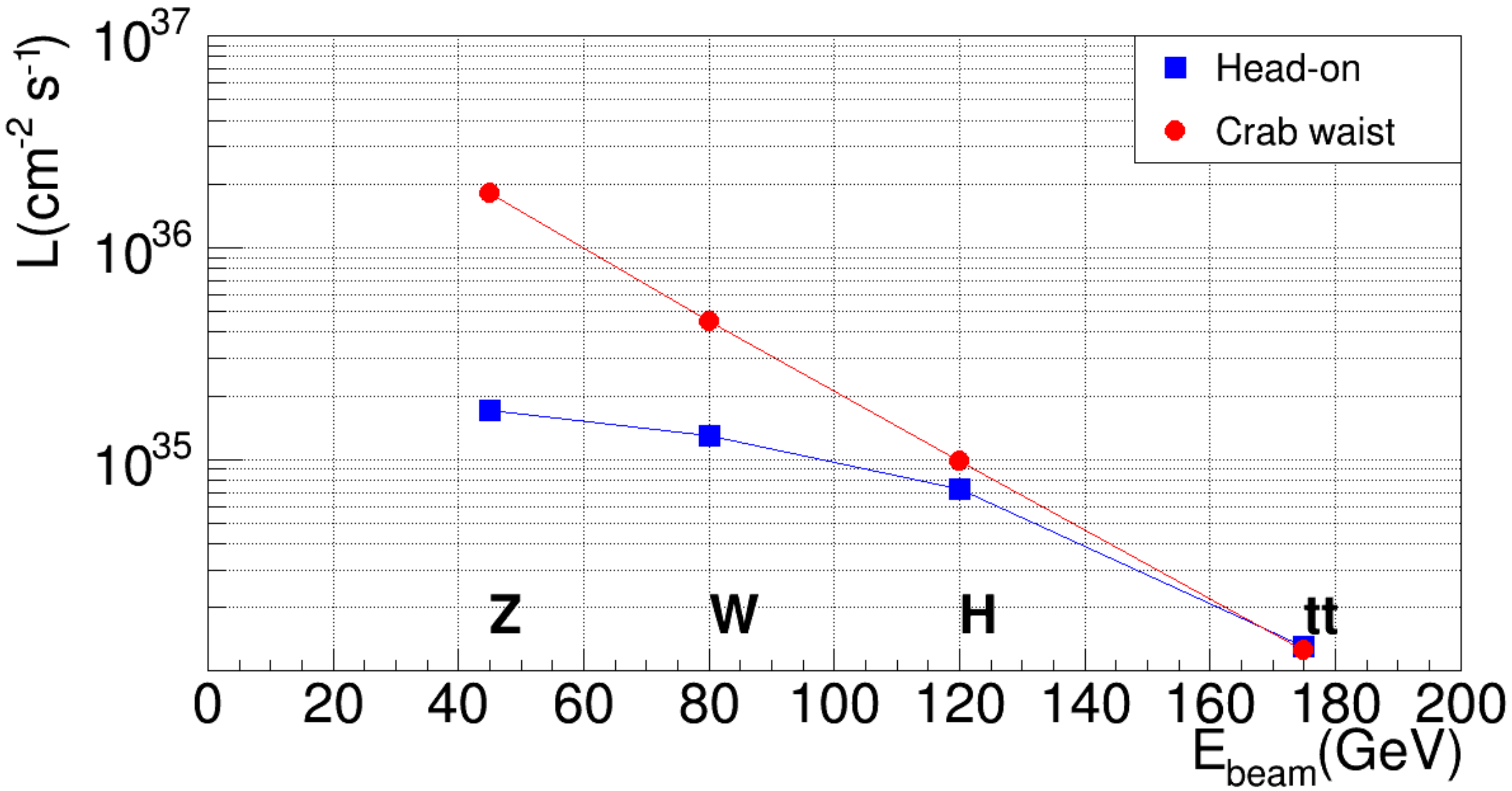
$$\varphi = \frac{\sigma_z}{\sigma_x} \tan\frac{\theta}{2} >> 1$$

2. β_y approximatly equals to overlapping area: $\beta_y \approx \frac{\sigma_z}{\varphi}$
3. Crab Waist: minimum of β_y along the axis of the opposite beam

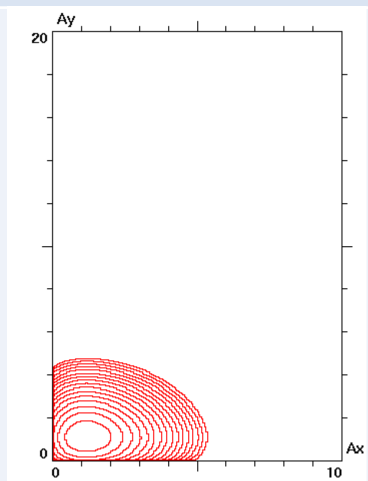
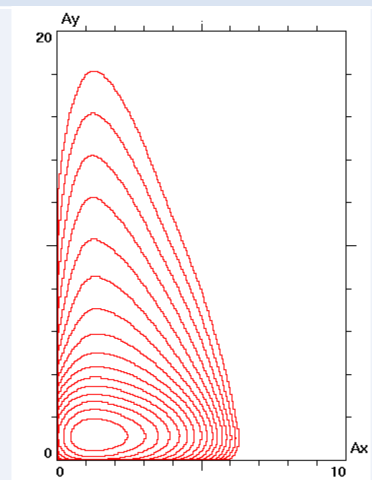
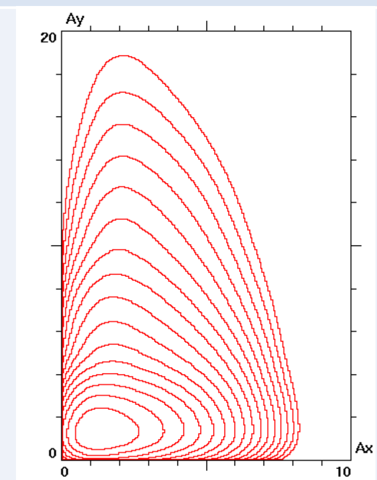
Advantages:

1. Impact of hour-glass is small and does not depend on bunch lengthening.
2. Suppression of betatron coupling resonances allows to achieve $\xi_y \approx 0.2$
3. As a result, luminosity can be significantly increased.

Luminosity (per IP) comparison

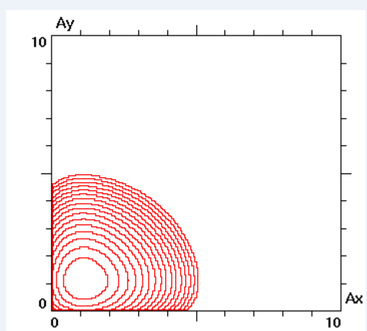
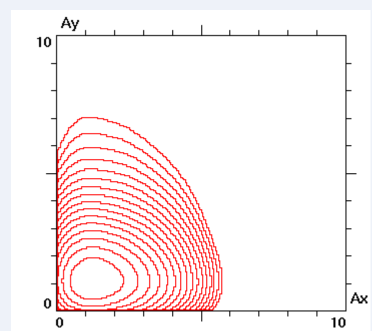
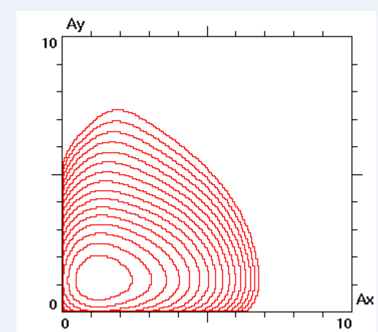


Summary Table (120 GeV, β_y=1 mm)

	Crab Waist	× Head-on ×	Crossing (11 mrad, w/o crab cavities)
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 [$cm^{-2}s^{-1}$]	$9.8 \cdot 10^{34}$	$7.2 \cdot 10^{34}$	$5.8 \cdot 10^{34}$
Luminosity (β_y = 2 mm)	$8.3 \cdot 10^{34}$	$6.8 \cdot 10^{34}$	$5.0 \cdot 10^{34}$
Density contour plots			

D.Shatilov:
https://indico.cern.ch/event/333858/contribution/1/material/slides/0.pptx

Summary Table (175 GeV, β_y=2 mm)

	Crab Waist	× Head-on ×	Crossing (11 mrad, w/o crab cavities)
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			

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Pros and cons of collision schemes

Head-on

- how to separate the beams?
- simple final focus quadrupole

Crab waist

- higher luminosity
- beams are naturally separated
- higher crossing angle allows smaller L^*
- strong crab sextupole

Crab cavity with small crossing angle

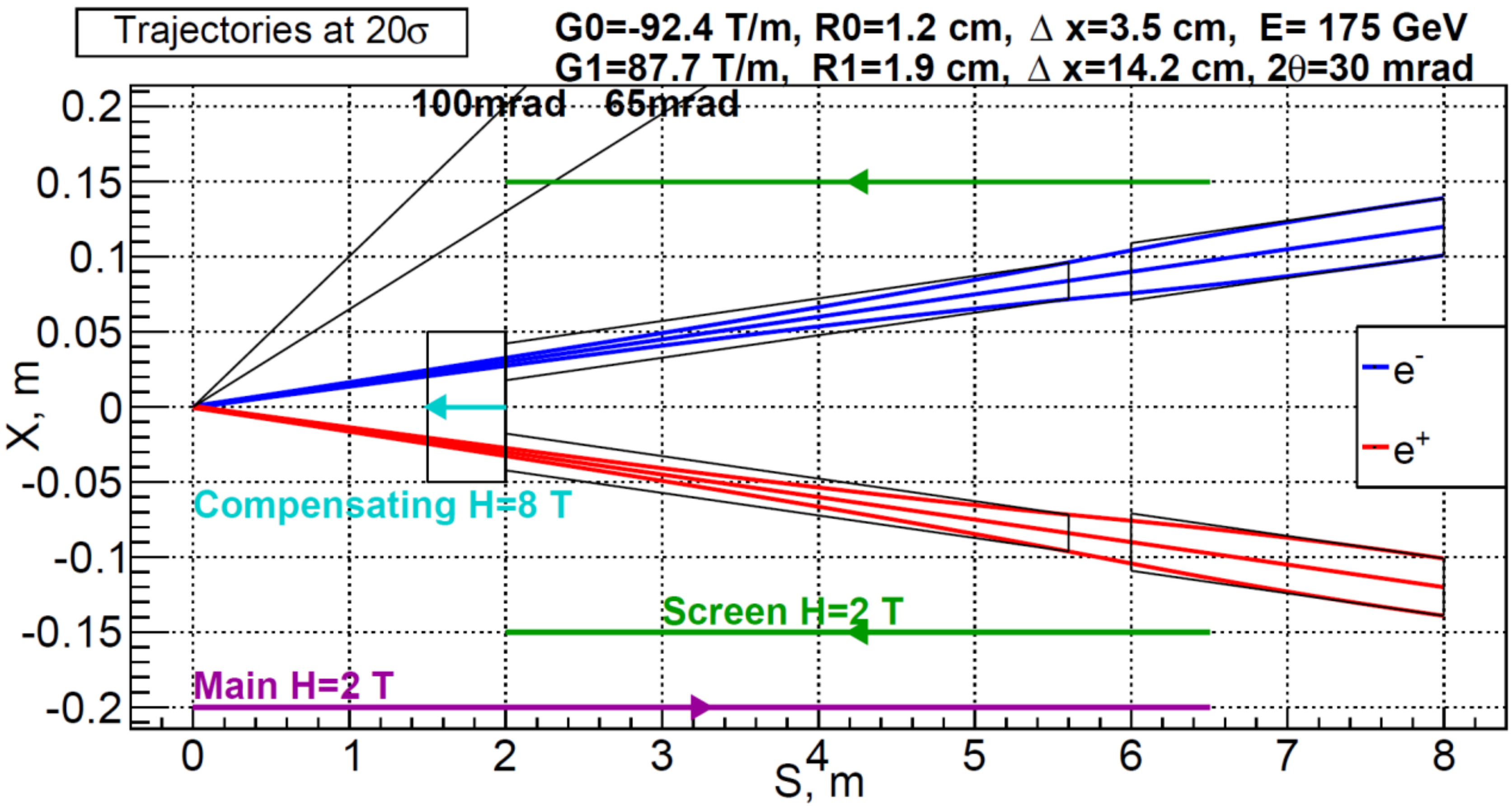
- double aperture quadrupole might require larger L^*, larger maximum β_y
- beams are naturally separated
- technology of crab cavity is being developed

BINP team studies crab waist — unsolved problems (if any) will eliminate this option, solved will help with other options. They want to finish the study and use the learned principles for other variants.

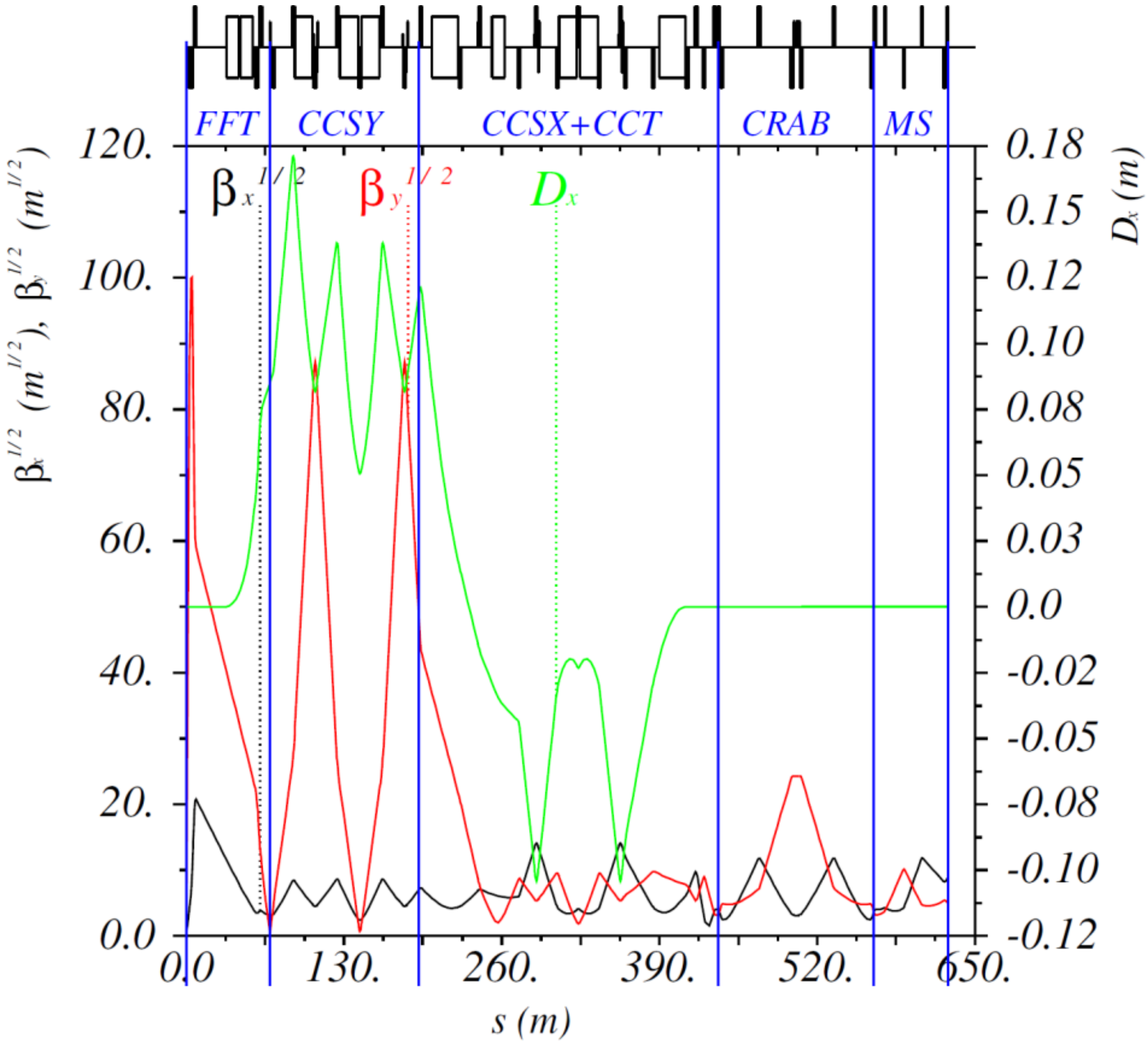
Crab Waist Parameters (being optimized)

	Z	W	H	tt
Energy [GeV]	45	80	120	175
Perimeter [km]	100			
Crossing angle [mrad]	30			
Particles per buch [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	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

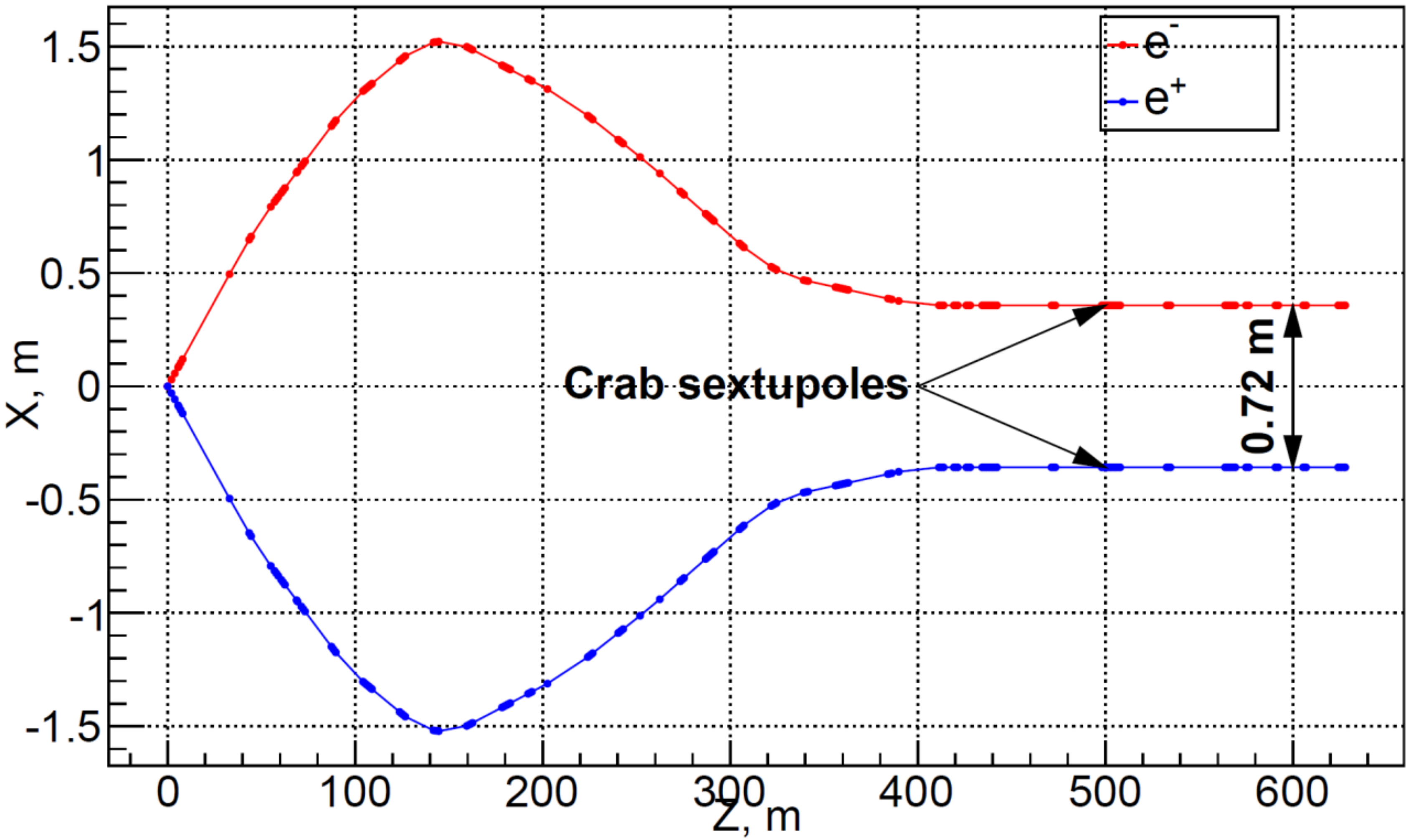
Final focus layout: scetch of solenoids



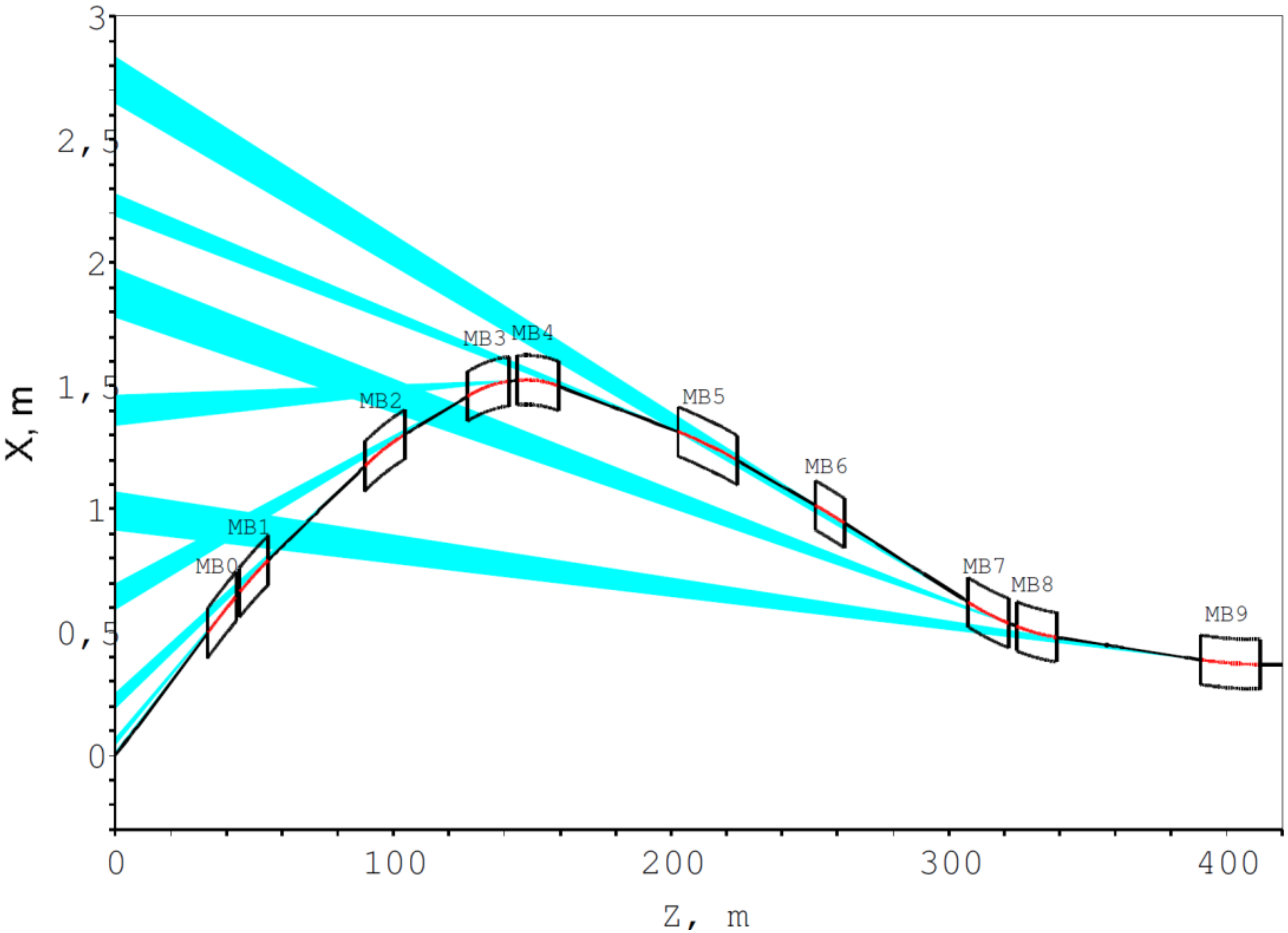
Interaction region: optical functions



Interaction region: layout

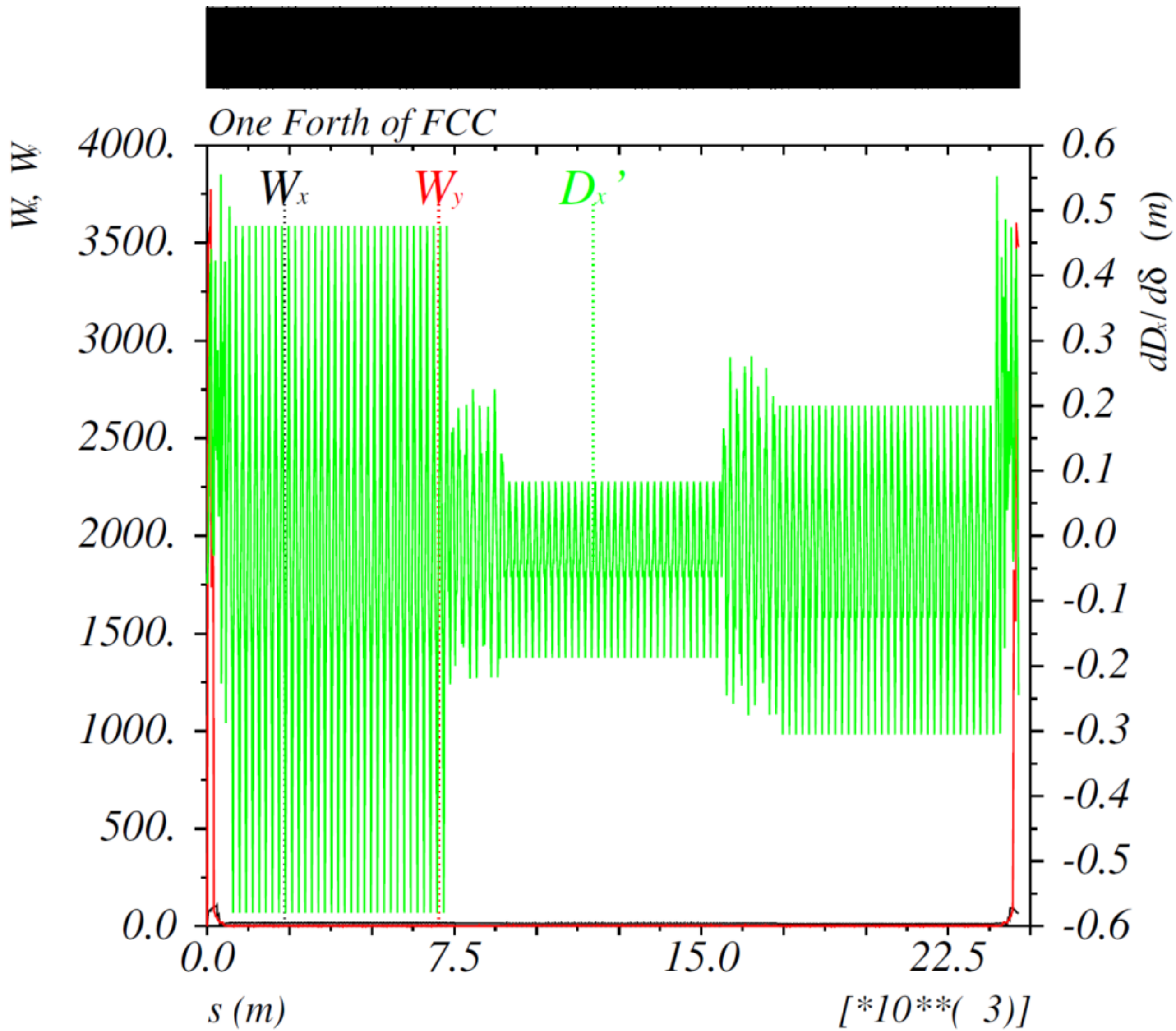


Interaction region: SR fans

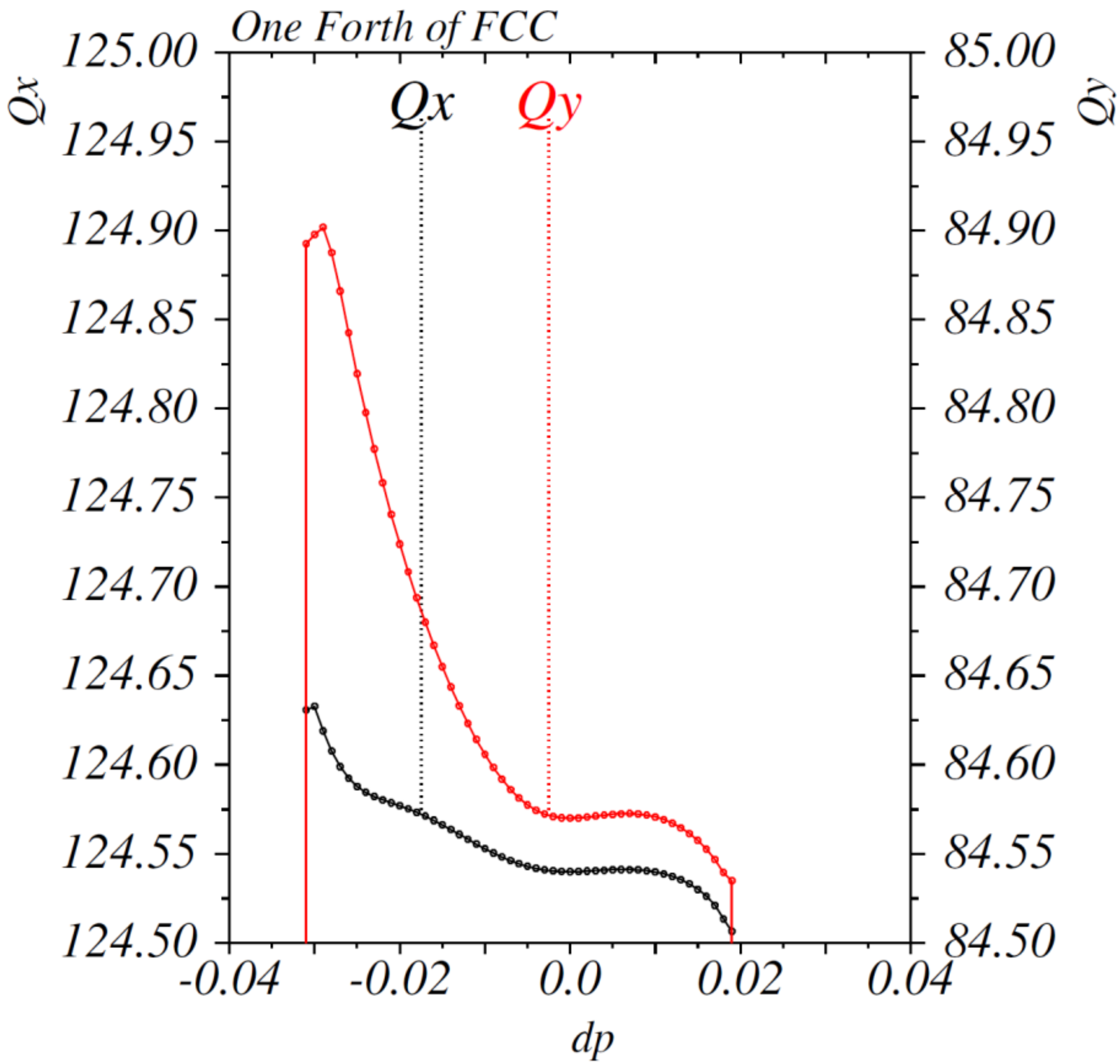


2.2 MW/beam
of SR power
into detector
region
at 175 GeV

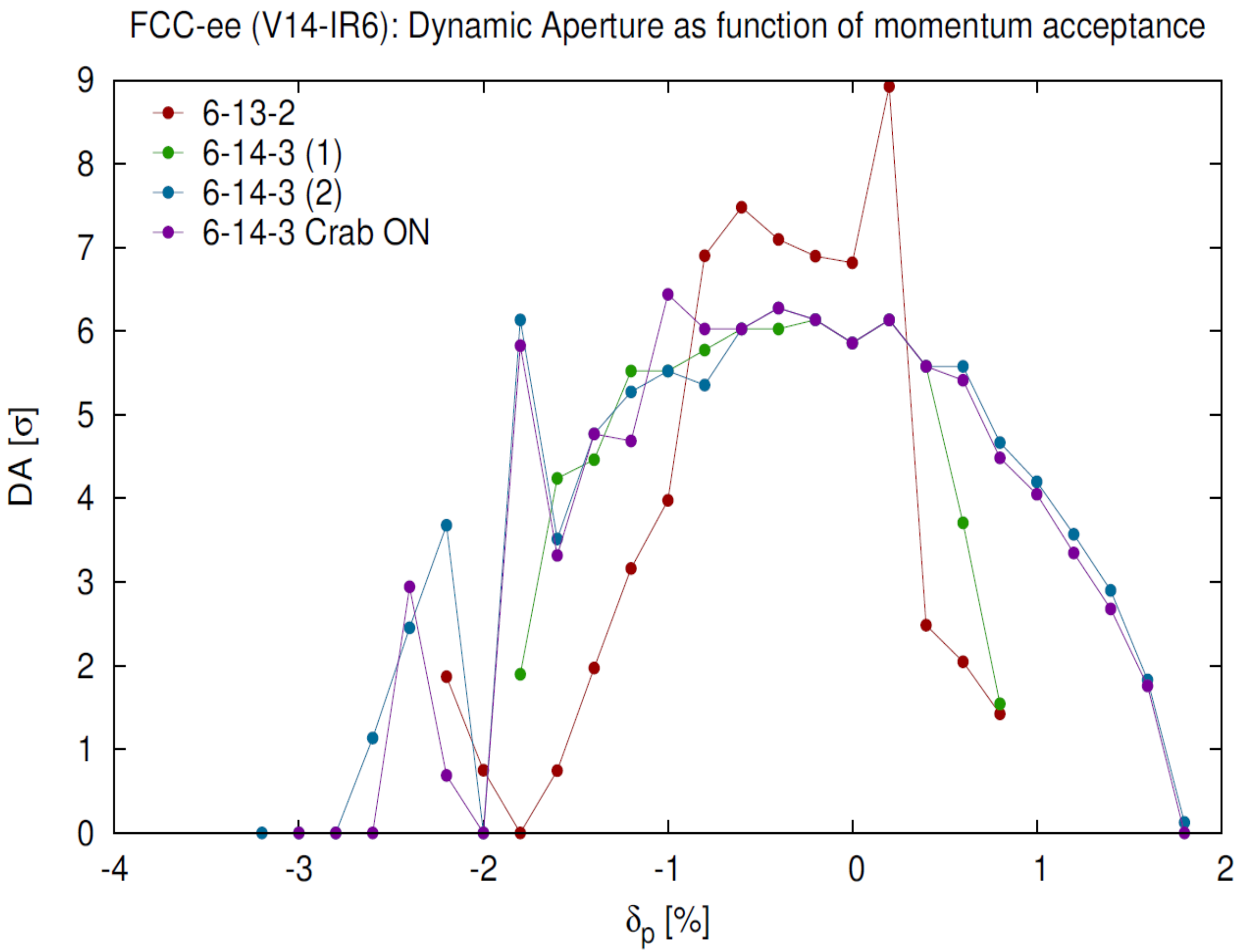
Chromaticity: Montague functions



Energy acceptance [-3.1%;+1.9%]



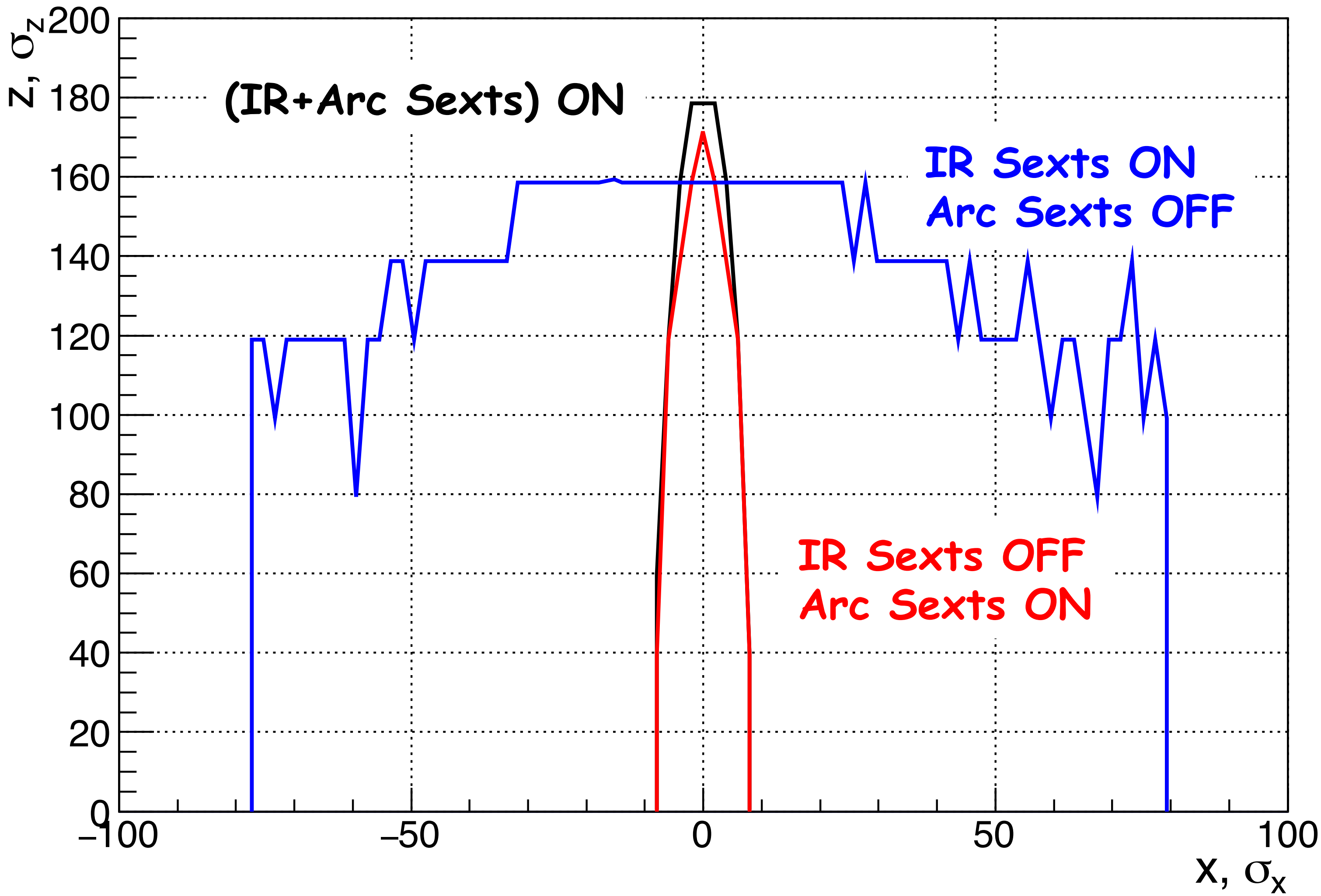
DA tracking studies



Method:

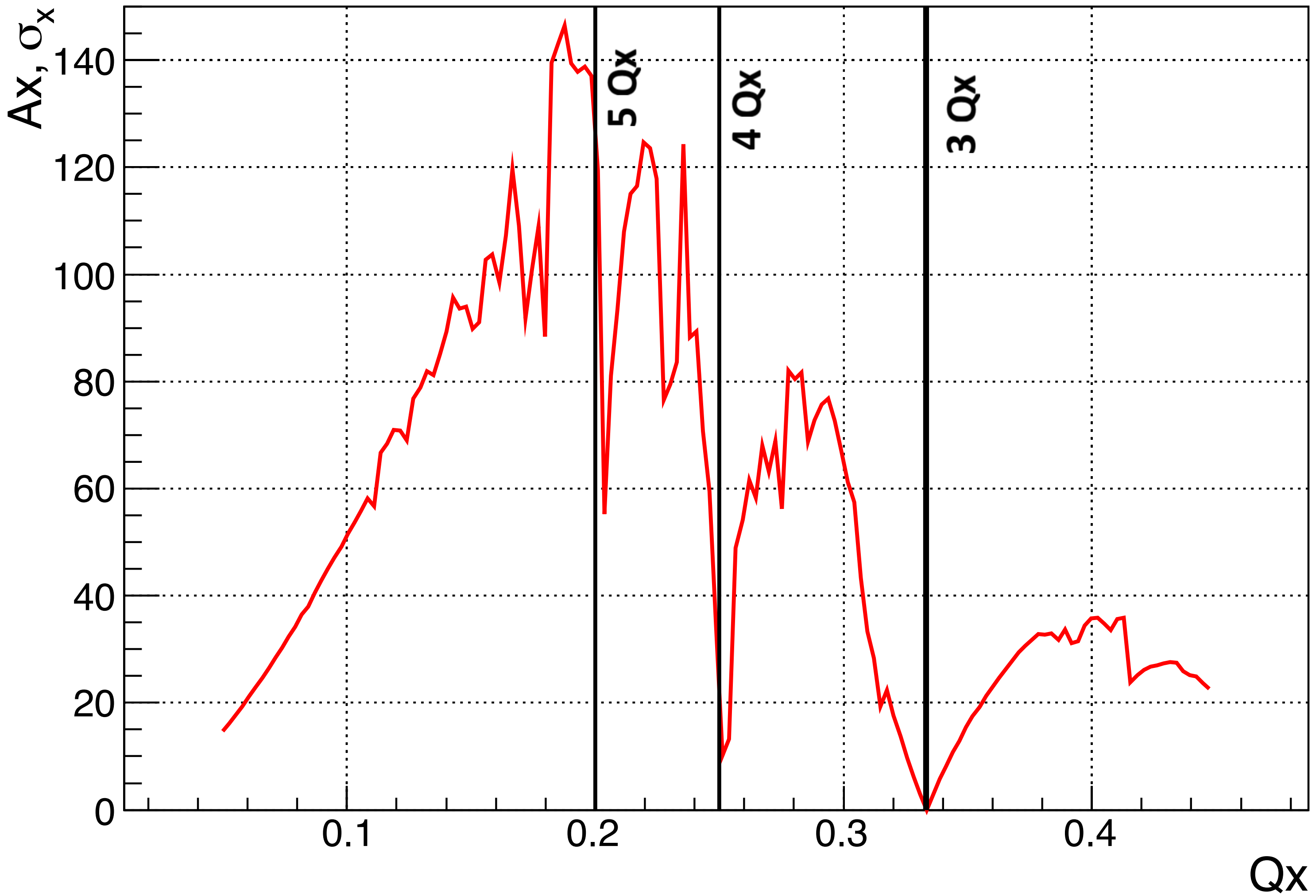
- PTC tracking
- 4 IPs
- Radiation off
- Solenoid off

Dynamic aperture at IP: where is a bottleneck?



E=175 GeV, ε_x=1.3 nm, ε_y=0.002 ε_x, β_x = 0.5 m, β_y = 0.001 m

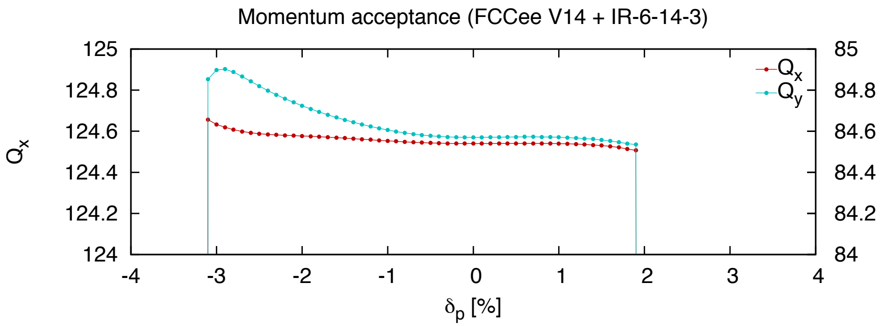
FODO arc cell dynamic aperture

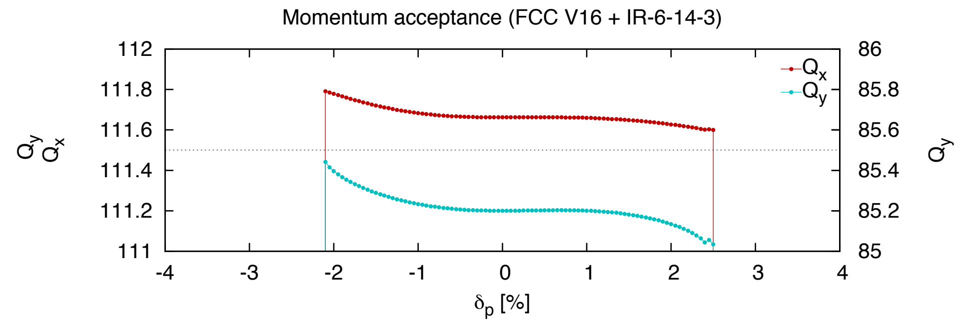


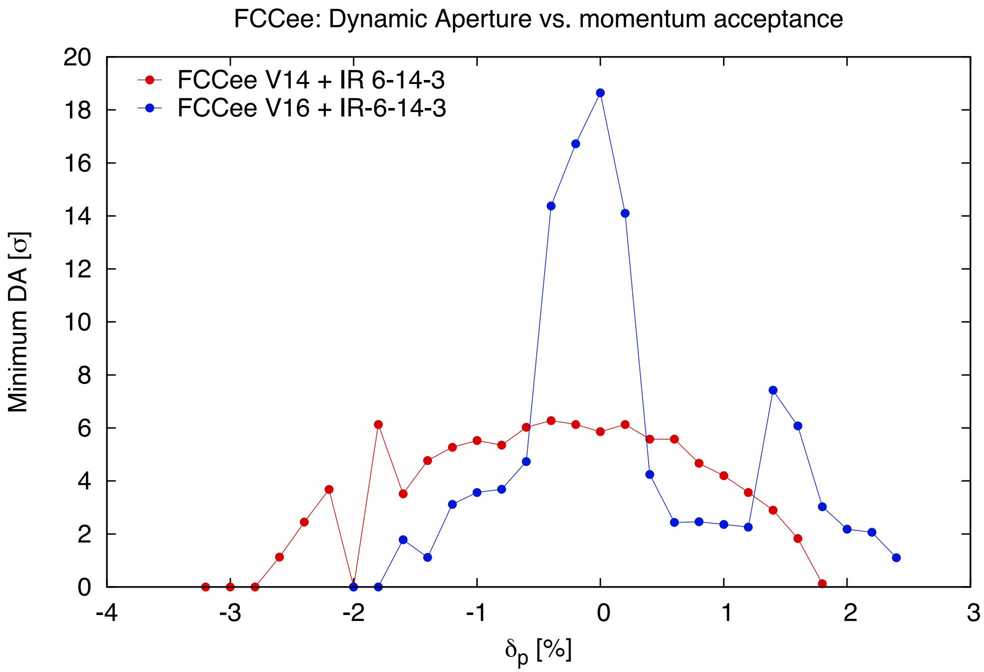
Initial:
$\mu_x = 0.25$
$\mu_y = 0.16$

Proposal:
$\mu_x = 0.22$
$\mu_y = 0.16$

Dynamic aperture vs. FODO phase advance







Initial: $\mu_x = 0.25$

Proposal: $\mu_x = 0.22$

- On-momentum DA improved significantly
- Off-momentum DA decreased

Results show general solution is required

Solenoid fringe and vertical emittance

Anti-solenoid is between IP and FF quadrupole

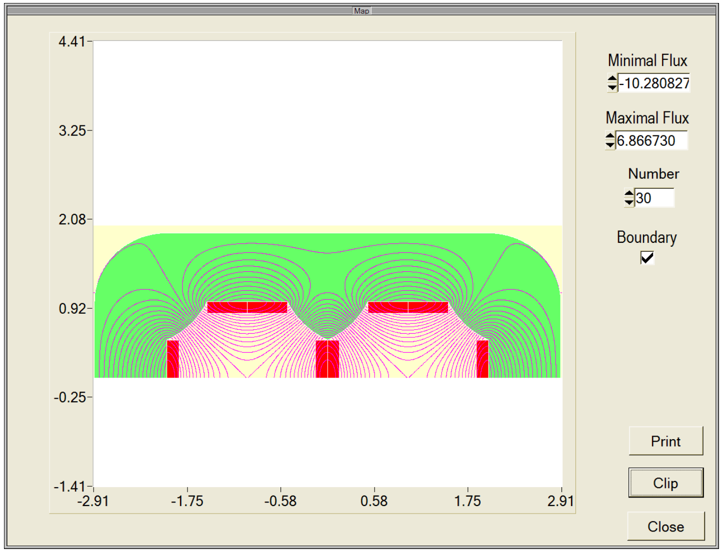
Energy [GeV]	45	45	175	175
Solenoid fringe	OFF	ON	OFF	ON
Main field [T]	2			
Anti solenoid field [T]	6			
ε_x [nm]	0.084	0.080	1.26	1.26
ε_y [pm]	0.04	60 !!!	0.03	1.58
Luminosity / IP [$10^{34}cm^{-2}s^{-1}$]	212	26	1.3	1.3

Solenoid fringe possible mitigation

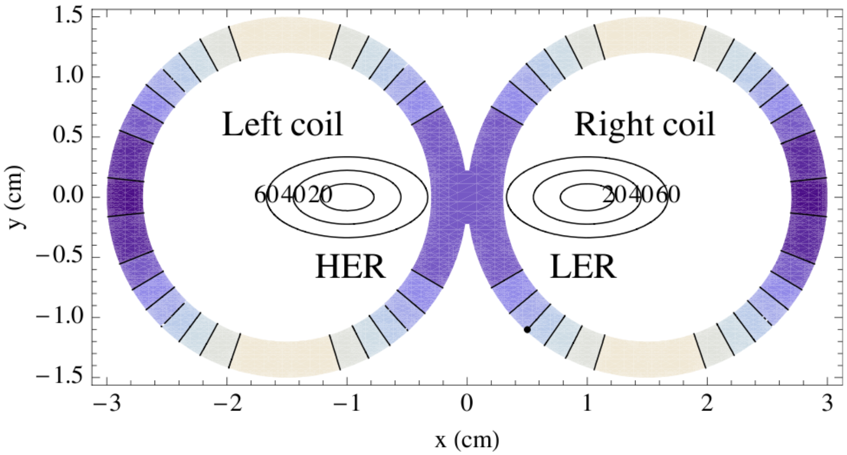
Main field variation with energy.
Anti-solenoid is between IP and FF quadrupole.

Energy [GeV]	45	90	120	175
Solenoid fringe	ON	ON	ON	ON
Main field [T]	0.82	1.42	1.68	2
Anti solenoid field [T]	2.46	4.26	5.05	6
ε_x [nm]	0.084	0.33	0.59	1.26
ε_y [pm]	1	2	2	1.58
Luminosity / IP [$10^{34} cm^{-2} s^{-1}$]	212	36	9	1.3

Small crossing angle concept



Panofsky style quadrupole (P.Vobly, BINP)

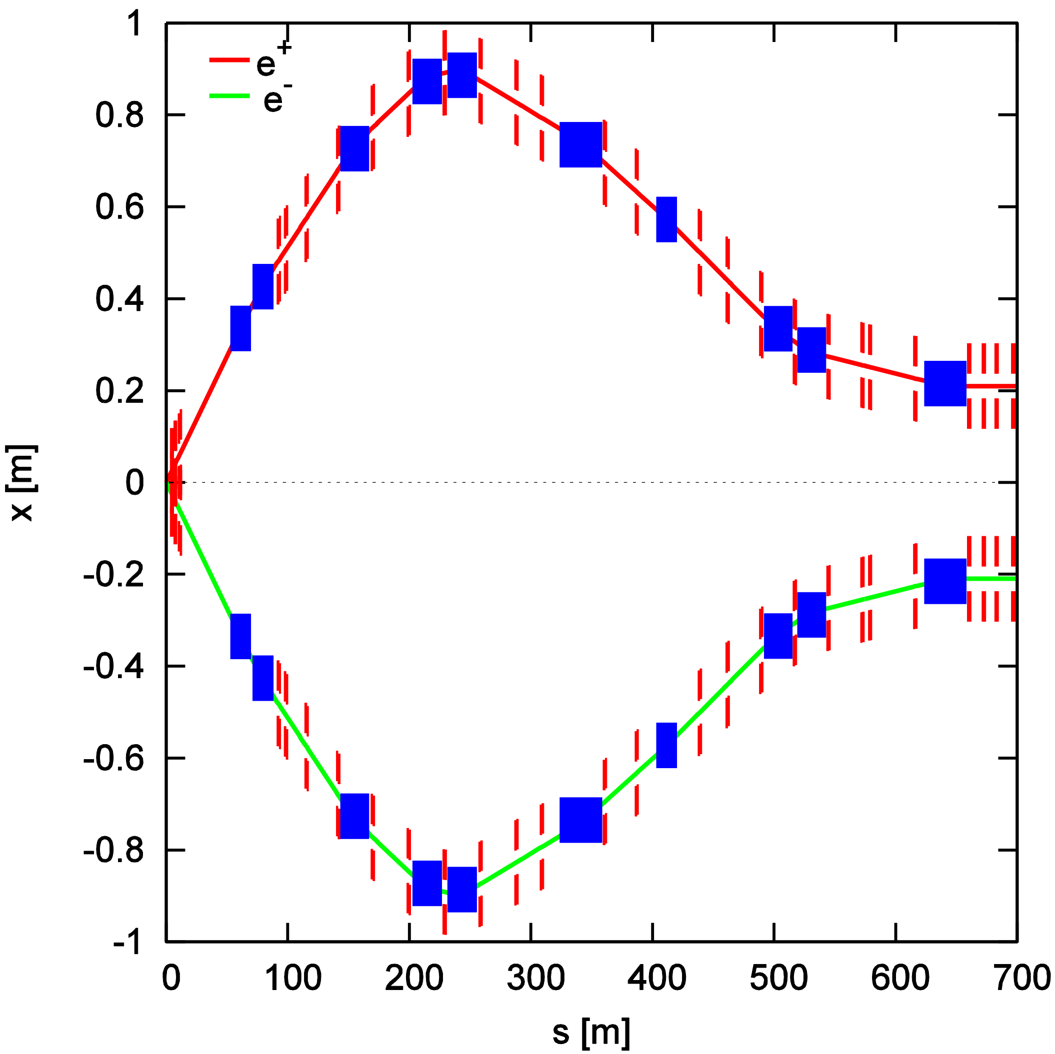


Double helix (E.Paoloni, INFN)

- Crossing angle determined by L* and separation of magnetic centers of QD0
- Based on conceptual designs for FFS quadrupoles:

  $\theta_{min} \geq 11$ mrad
- Possible gradients: 100 – 125 T/m

Small crossing angle concept



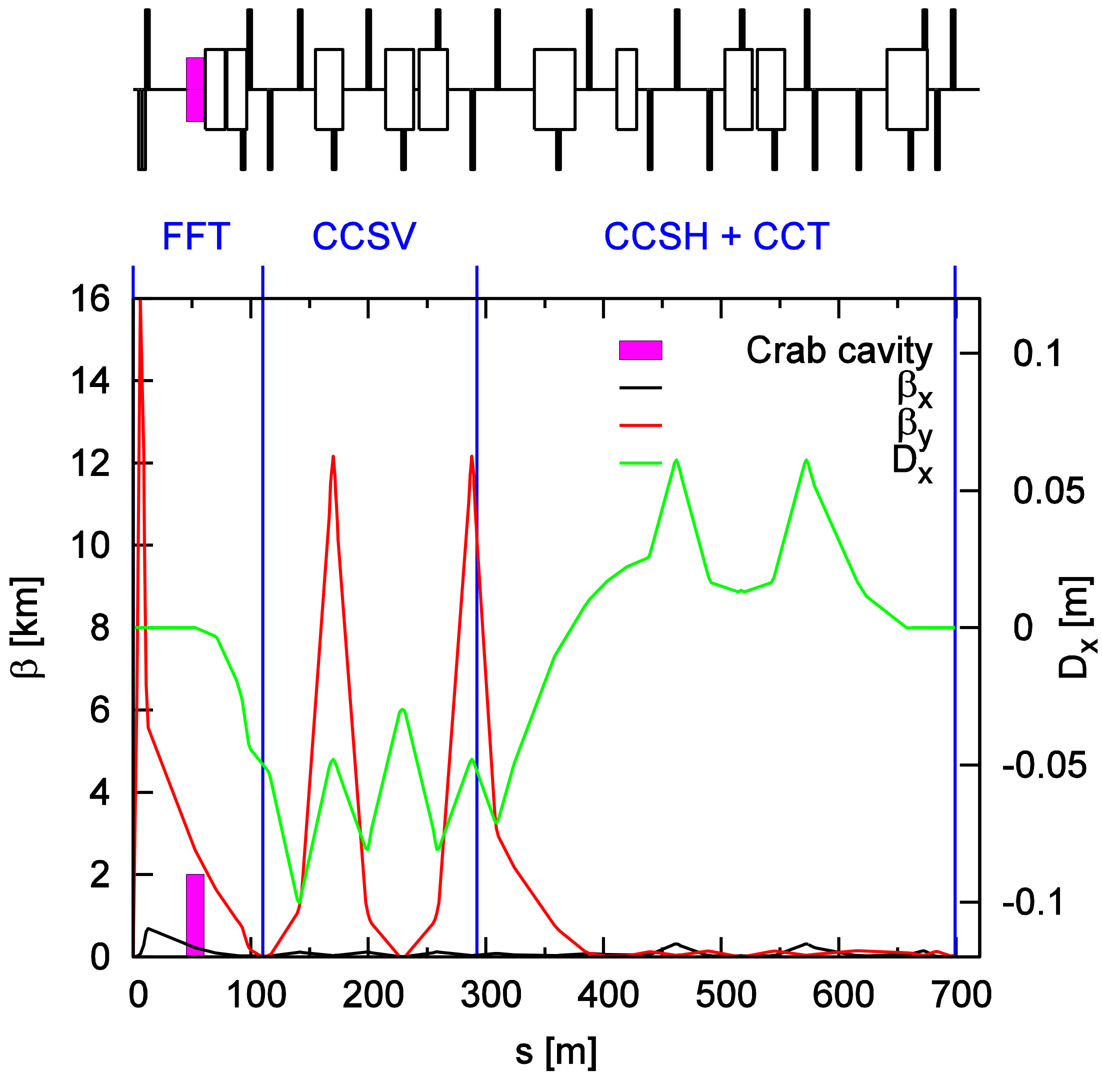
- similar to Crab Waist design, without CRAB section

- More longitudinal space → 1.6x scaled in length

- $L^* = 3.2$ m
- $\beta^*_x = 0.8$ m
- $\beta^*_y = 1.6$ mm

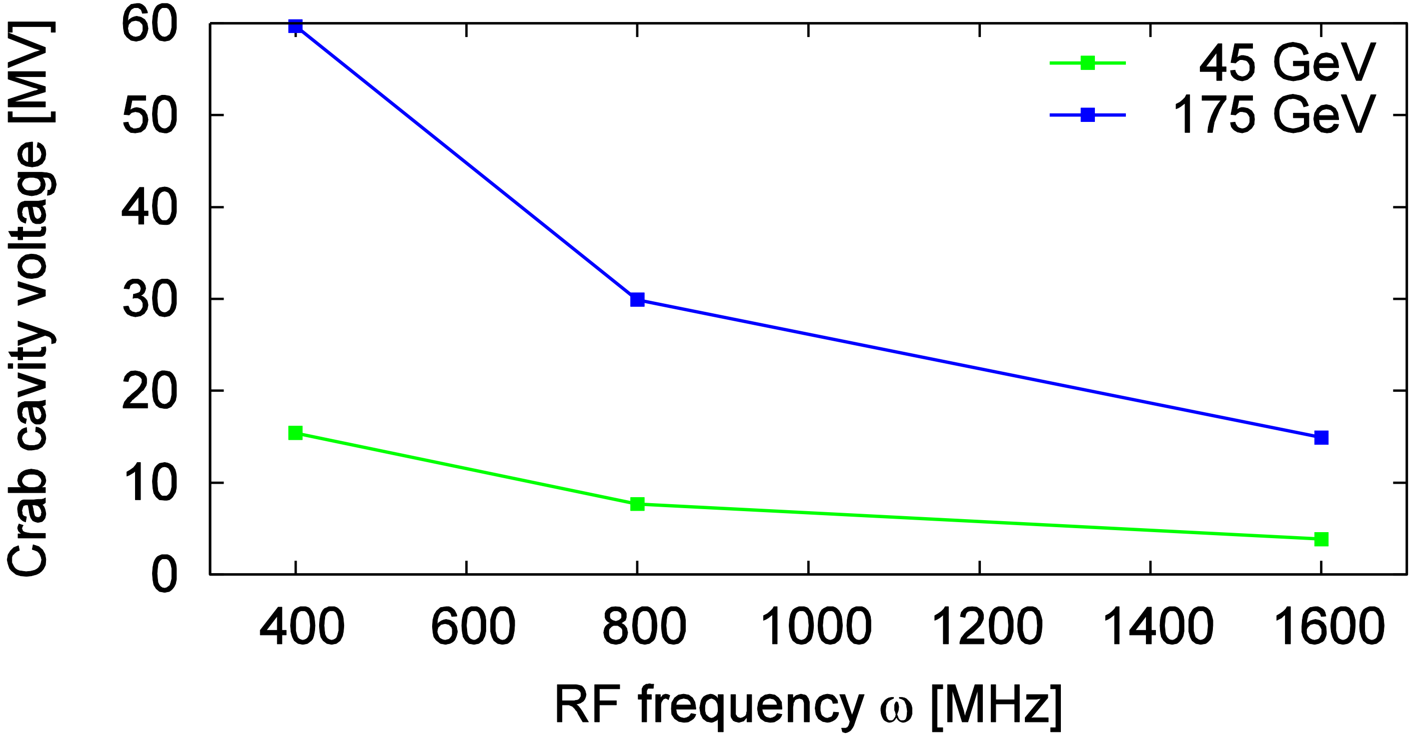
- Beam separation of 0.4m might be insufficient

Small crossing angle concept



- Reduced SR power: 184 kW/beam into detector region at 175 GeV
- Crab cavities required to increase geometric luminosity

Crab cavity voltage



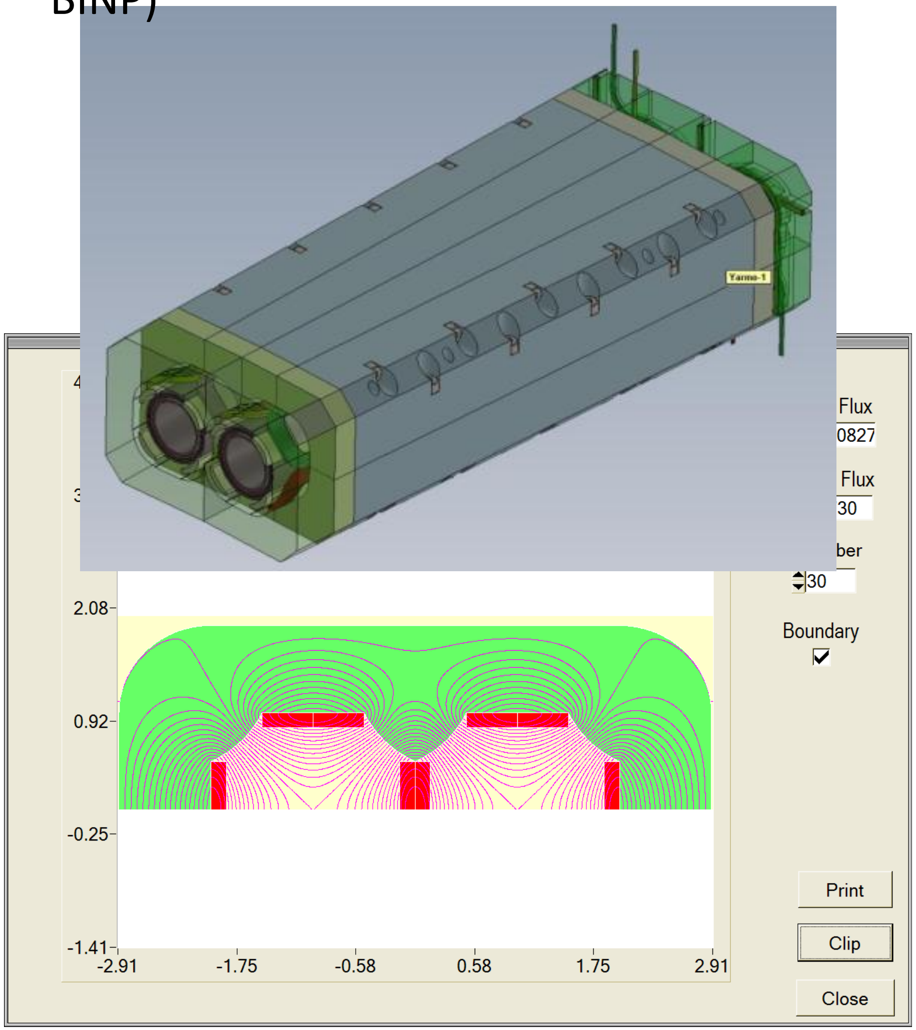
Conclusion

- Lattice for crab waist is developed with feasible FF quadrupoles.
- Geometry is acceptable.
- Energy acceptance and dynamic aperture require further optimization. No unresolvable obstacles are found.
- Lattice principles could be used for head-on, small crossing angle options.
- Synchrotron radiation is an issue, needs to be studied from the detector background view and from the absorption point of view.
- Solenoid field fringe is an issue at 45 GeV. Needs optimization, compromise with respect to detector field, β^*,L^*, luminosity, solenoid design
- Small crossing angle and crab cavities allow reduction of synchrotron radiation at performance similar to head-on

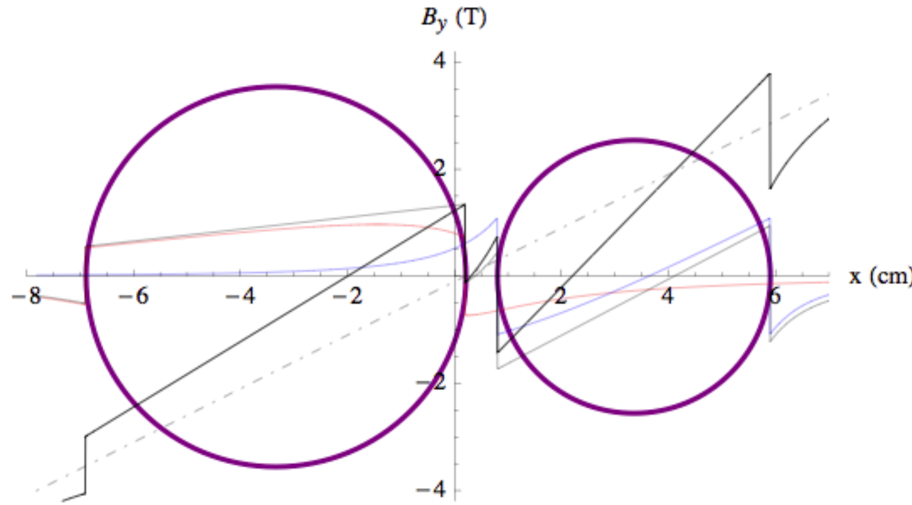
Thank you for your attention

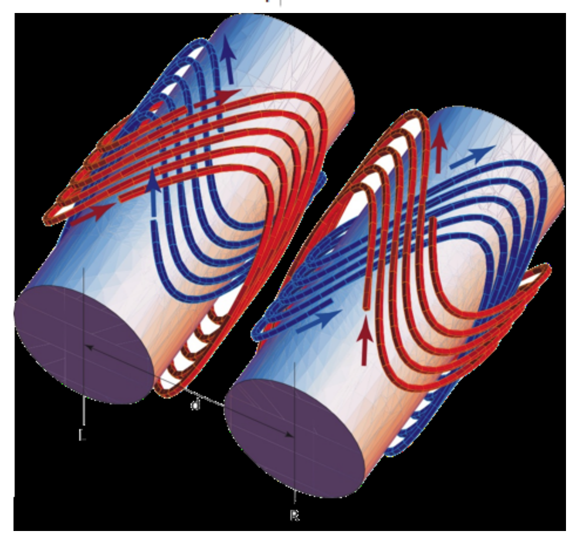
Two types of quadrupoles

Panofsky style quadrupole (P.Vobly, BINP)

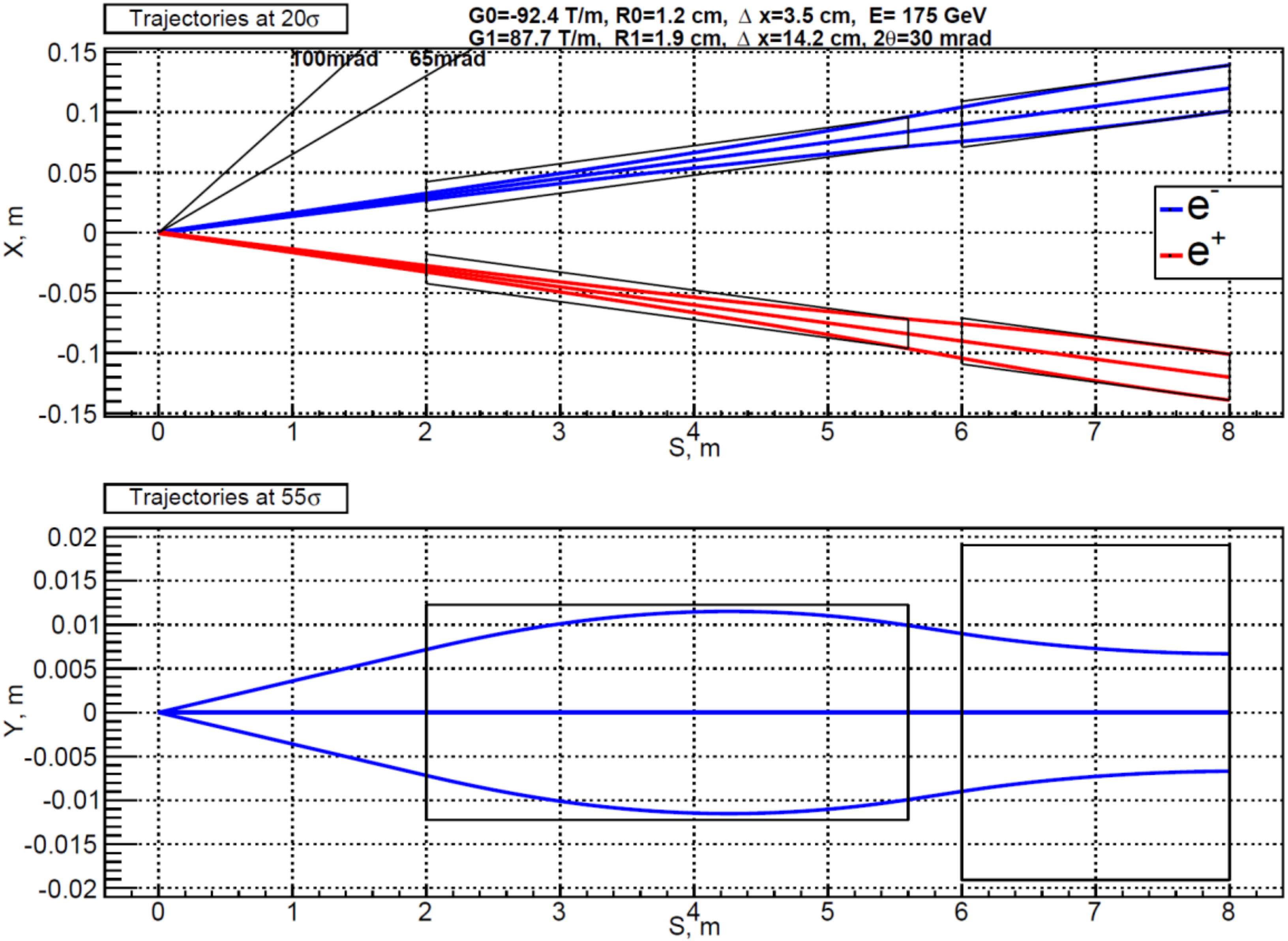


Double helix (E.Paoloni, INFN)

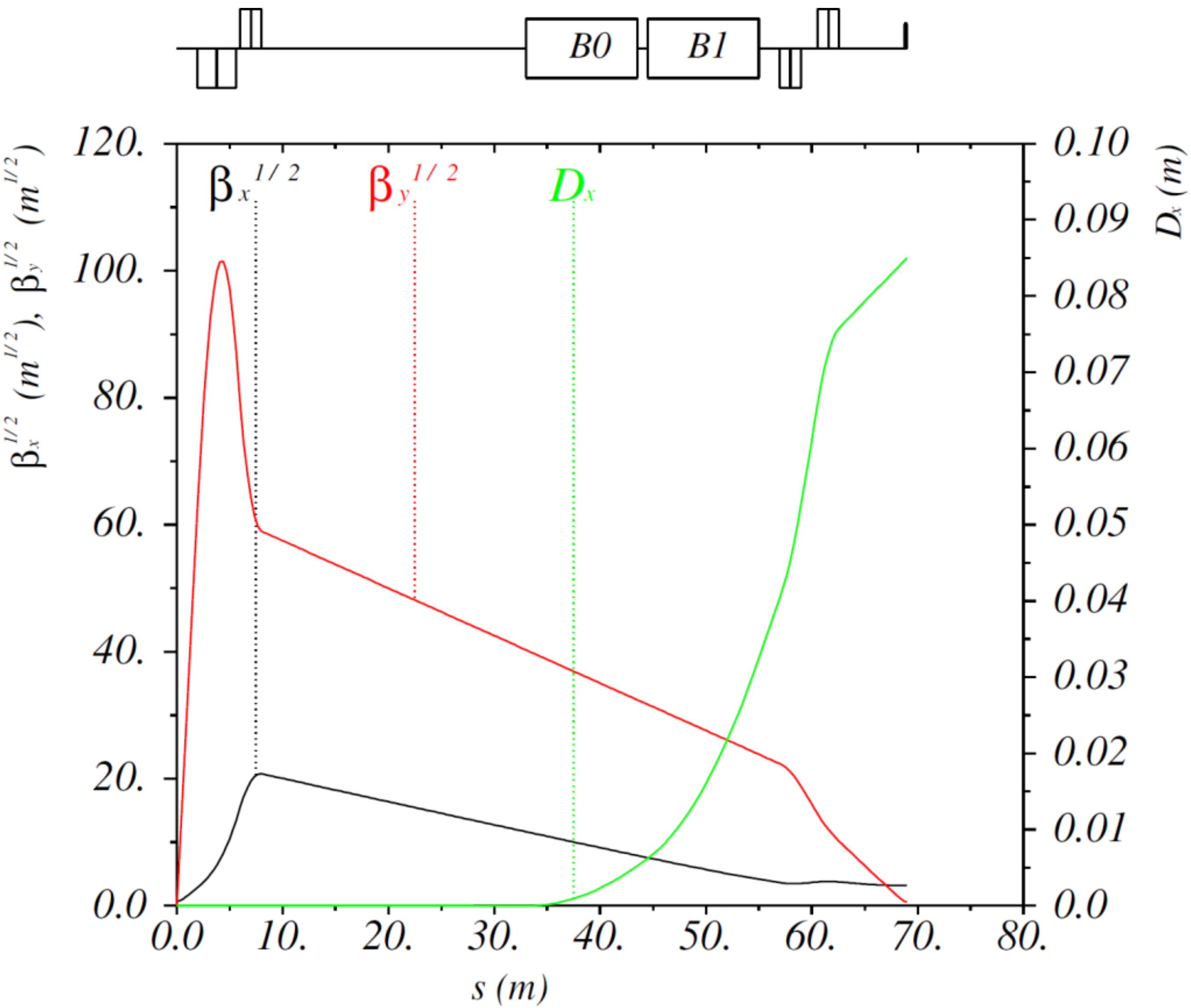




Final focus layout



Final focus telescope



Parameters of one quarter

	tt
Energy [GeV]	175
Circumference [m]	24655.9
Momentum compaction	5.7×10^{-6}
Emittance hor. [nm]	1.3
Energy spread [10^{-3}]	1.6
β_x^* / β_y^*	0.5 / 0.001
Energy loss / turn [GeV]	2.12