CW test facility at VEPP-4M

A. Bogomyagkov
E. Levichev
S. Sinyatkin

Initial conditions

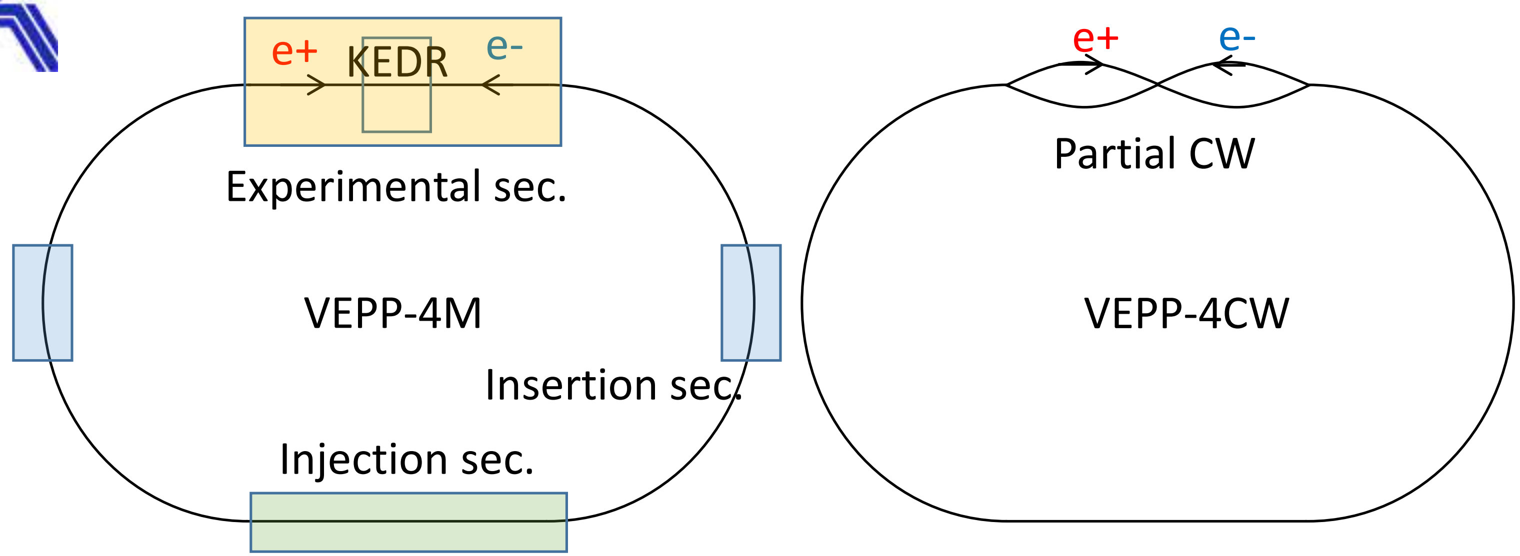
- Complexity of Crab Waist (CW) Colliders
- Testing «key» ideas in a short time
- Risks of projects without preliminary testing on prototypes

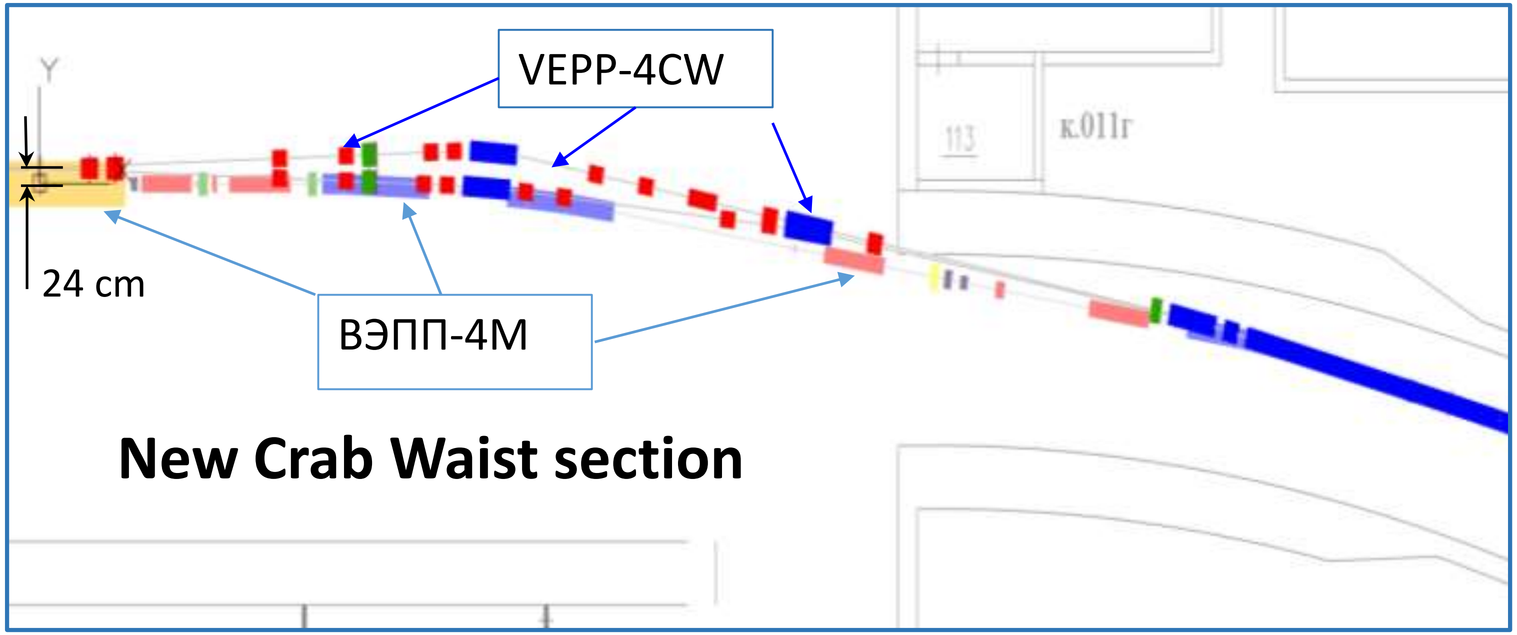
- To test the "solutions" of CW colliders, small machines (or machines with minor modifications) are needed.

Questions and problems of CW colliders

- Beam-Beam Effects with a large Piwinsky angle and CW
- Dynamic aperture and Touschek lifetime limitation due to nonlinear dynamics and crab sextupoles
- Dependence between beam-beam parameter and beam energy
- Backgrounds in the detector area
- Design of Final Focus (FF) Quadrupole and Solenoids
- Design of a cryostat and cryosystem
- Design and cooling of the vacuum chamber at interaction point (IP)
- Vacuum chamber impedance in IP
- Estimation of the required tolerances of assembly and alignment of FF elements
- Detector field influence on the mechanical stability of the FF system and beam dynamics
- ....

VEPP-4CW. Partial Crab-Waist.



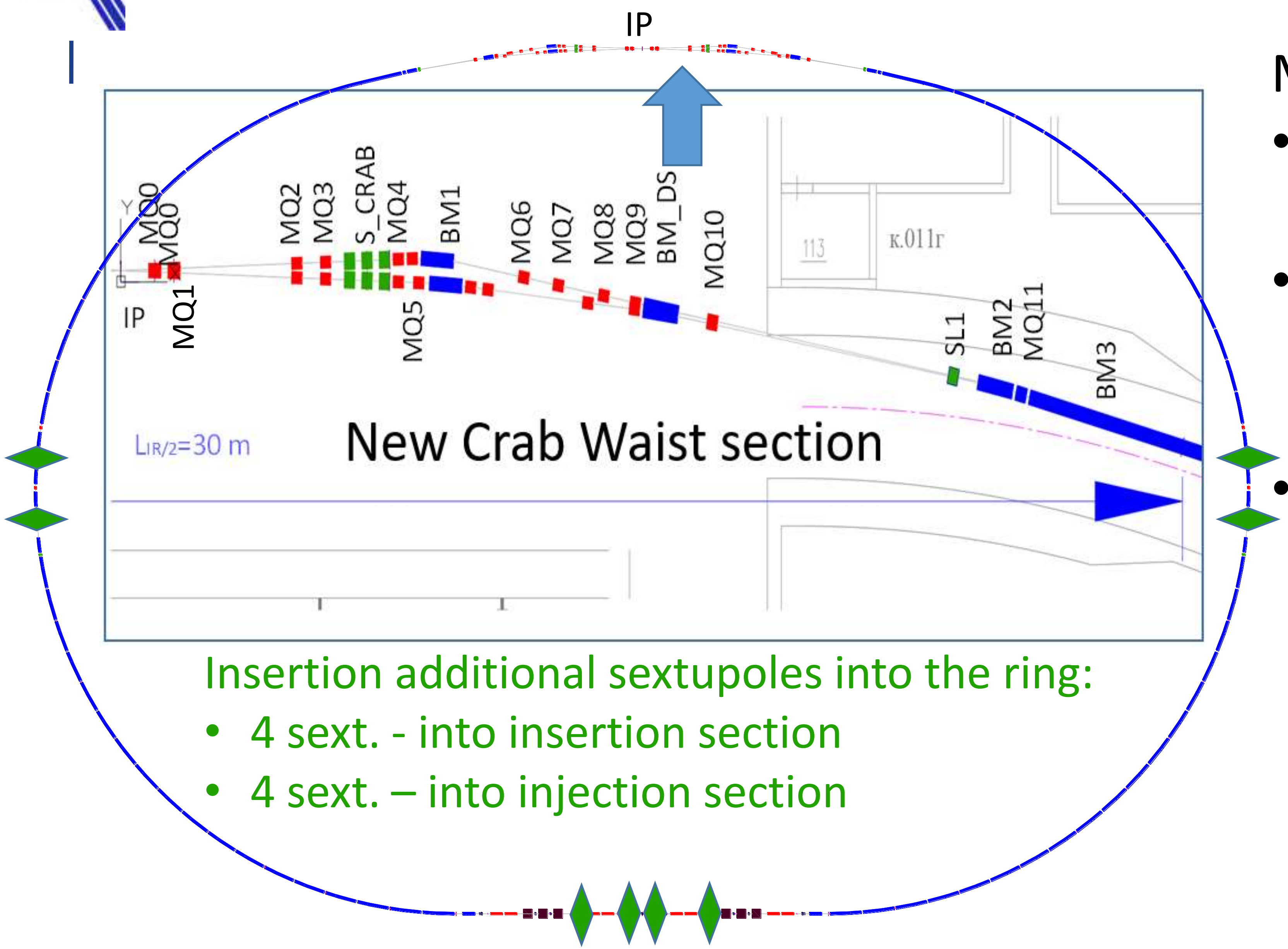


The experimental section is modified for partial CW.

Testing :

- Final focus (design, assembly, mechanical stability).
- Cryogenic system.
- Beam-Beam effects, limitation of ξ.
- Parameters study at energy change.
- Detector field influence on FF fields.
- Influence and optimization of "crab" sextupoles.
- Vacuum chamber and impedances at IP.
- Nonlinear dynamics.
- Particle losses and superconductivity.
- Detector backgrounds.
- Luminosity measurement.
- Etc.

VEPP-4CW. Partial Crab-Waist.



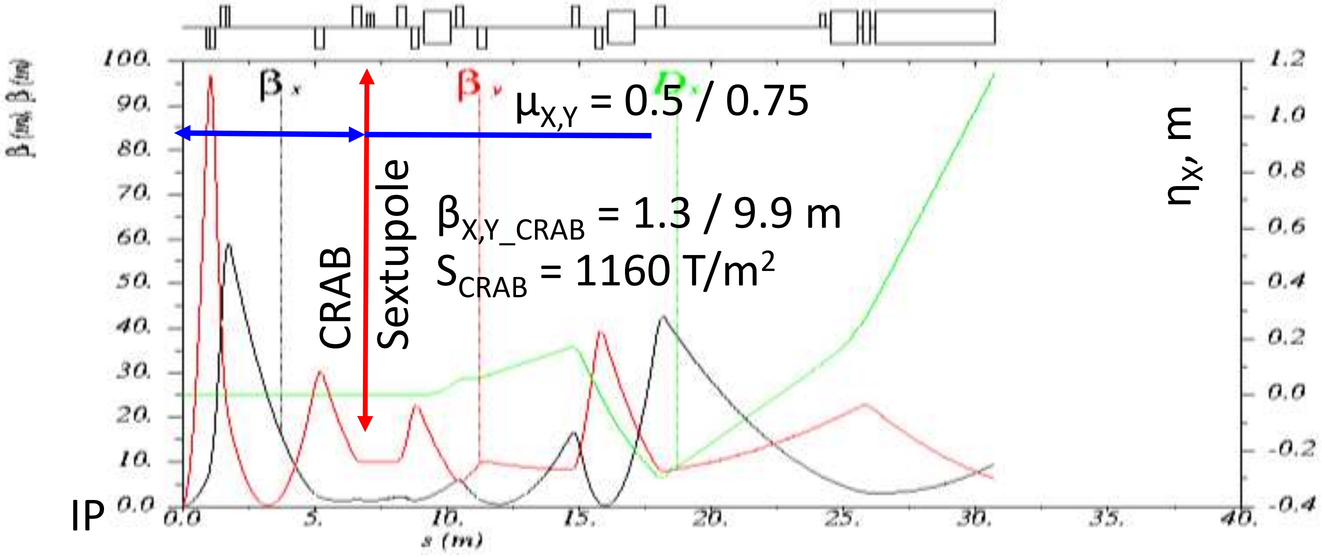
Insertion additional sextupoles into the ring:

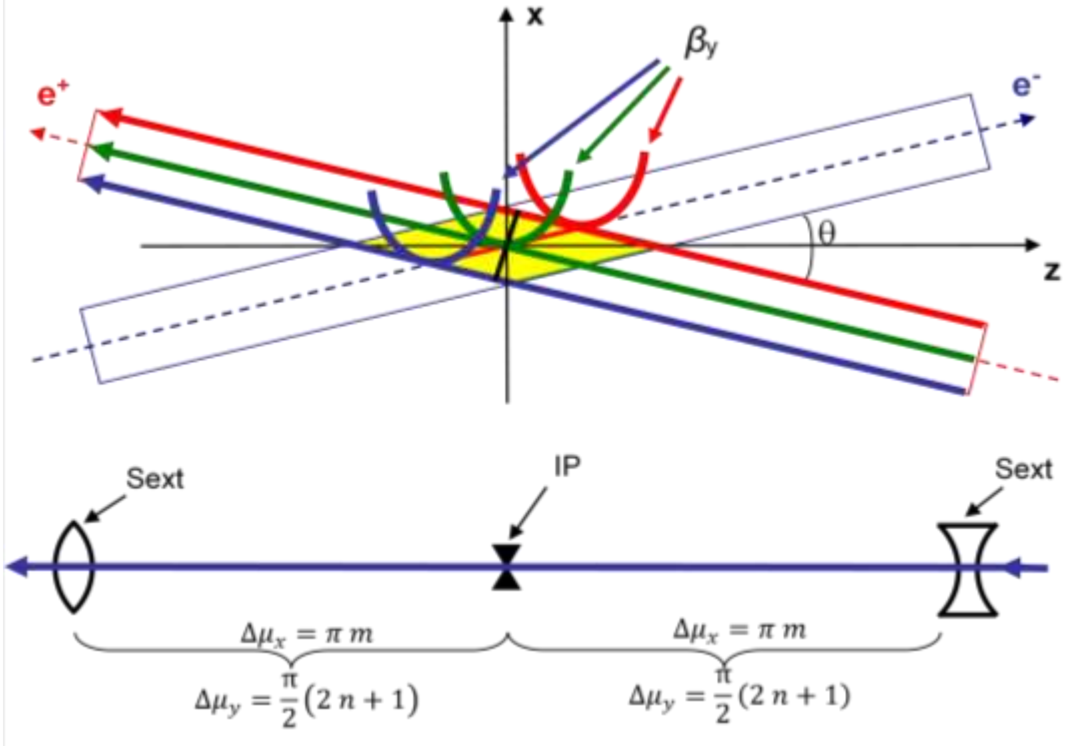
- 4 sext. - into insertion section
- 4 sext. – into injection section

Modifications:

- New experimental section with partial CW.
- Electrostatic separation sections are inserted (**BM3**).
- New elements:
  - 8 dipoles
  - 38 quadrupoles
  - 14 (6) sextupoles at experimental section.

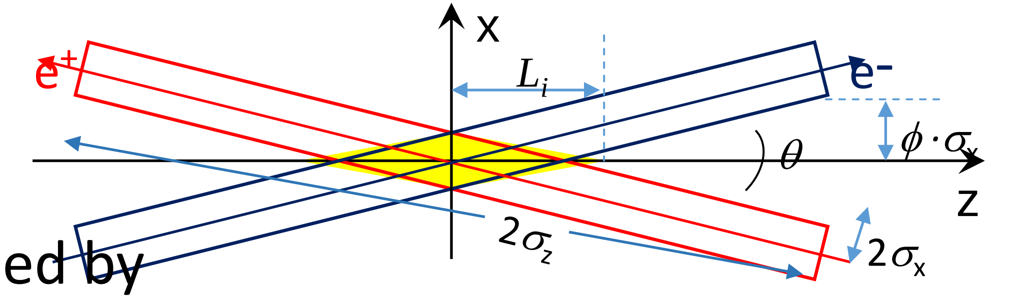
VEPP-4CW. Partial Crab-Waist. (P.Raimondi 2006)



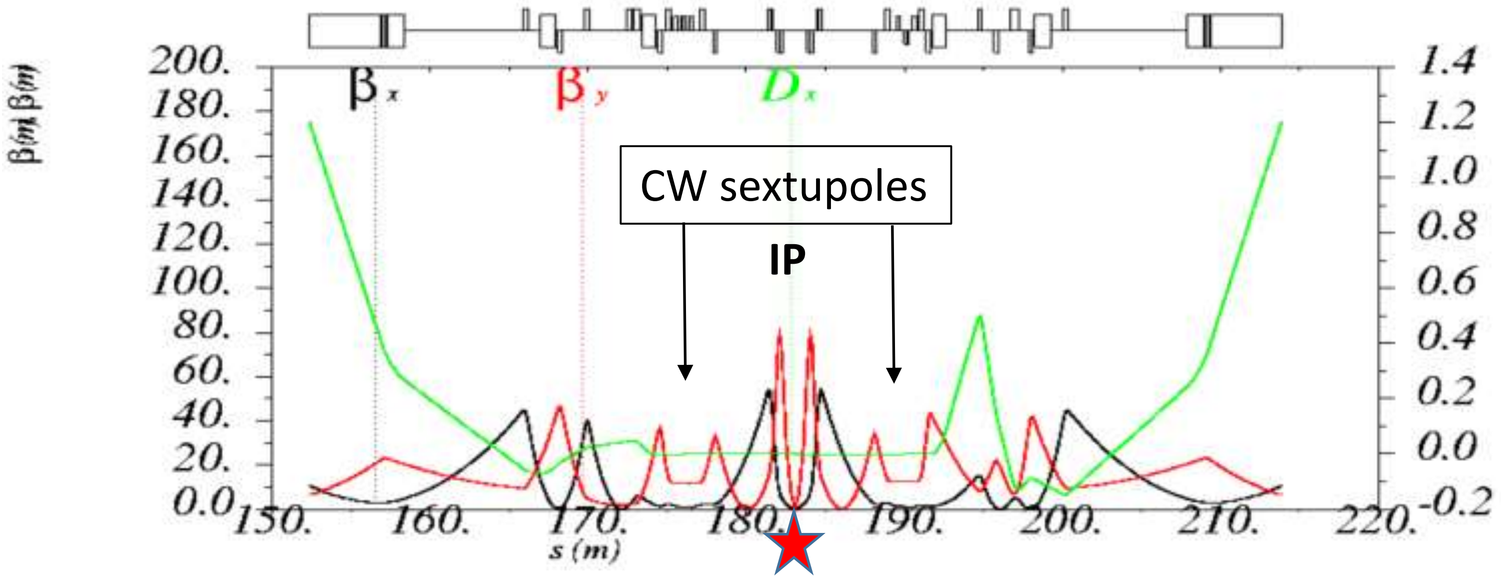


- Luminosity: $L = \frac{\gamma}{2er_e} \cdot \frac{I_{tot}\xi_y}{\beta_y^*} R_H$
- Piwinsky angle: $\phi = \frac{\sigma_z}{\sigma_x} \tan\left(\frac{\theta}{2}\right)$
- Interection length: $L_i \ll \sigma_z$
  - $\beta_y^* \approx L_i \ll \sigma_z$ suppresed «hour-glass»
- Betatron/synchro-betatron resonances are suppressed by

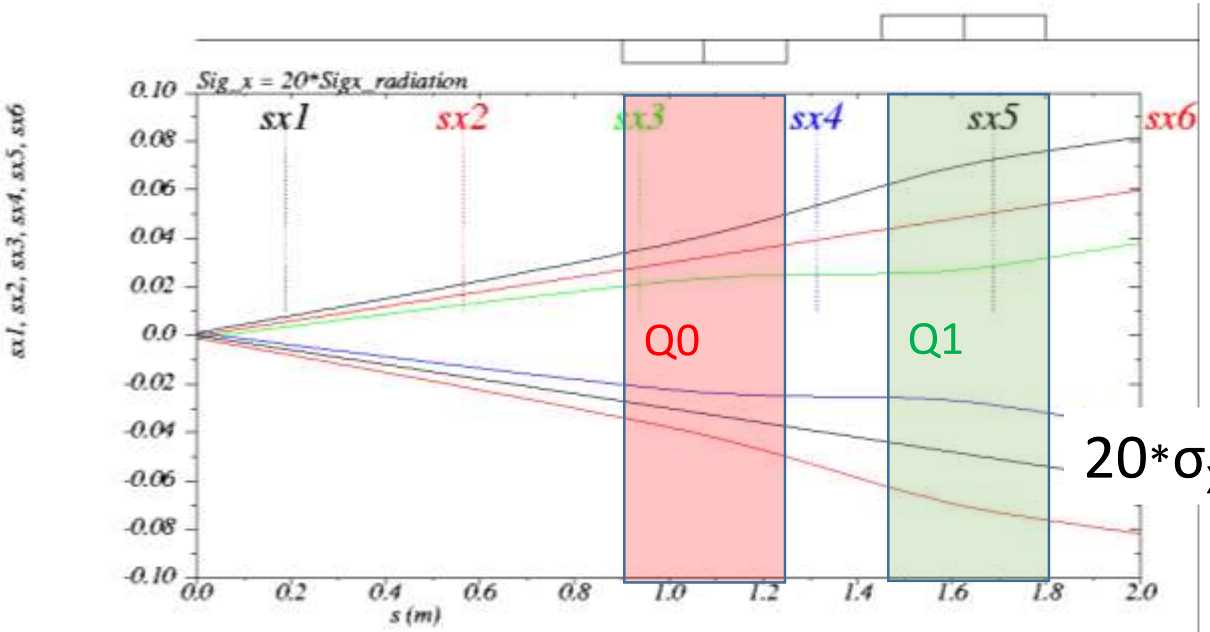
CRAB sextupoles $\xi_y \sim 0.2 \quad K2L = \pm \frac{1}{\theta \beta_y^* \beta_y} \sqrt{\frac{\beta_x^*}{\beta_x}}$



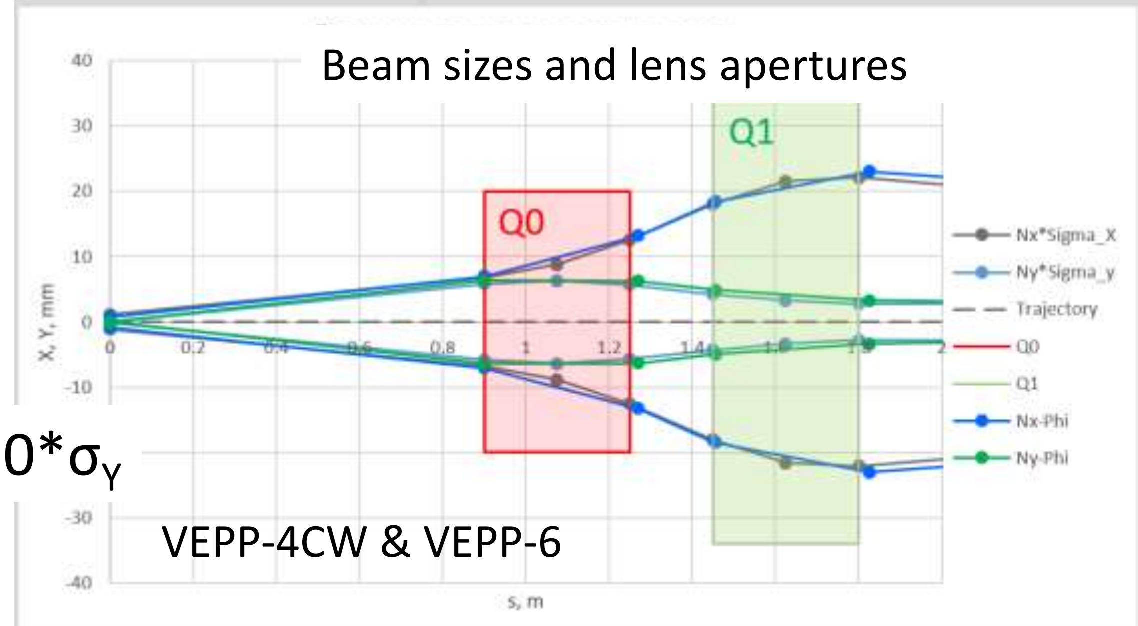
VEPP-4CW. Interaction region.



- IP:
  - Lstar = 0.9 m
  - βx = 15 cm
  - βy = 1 cm
  - ηx = 0 cm
- Full crossing angel 60 mrad
- Q0: G = 39 T/m, L=0.3m< R >13 mm
- Q1: G = 28 T/m, L=0.3 m, R > 23 mm

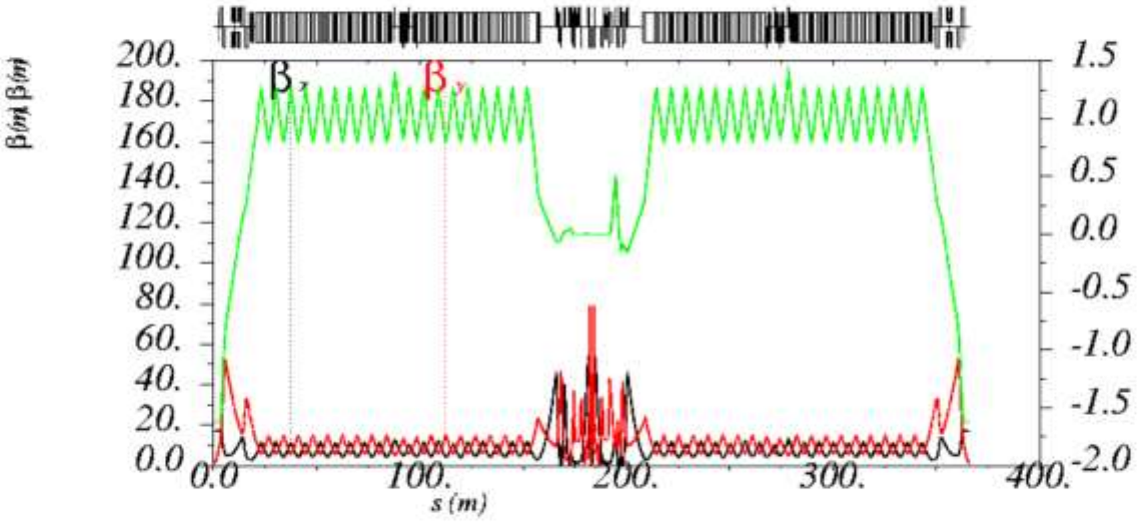


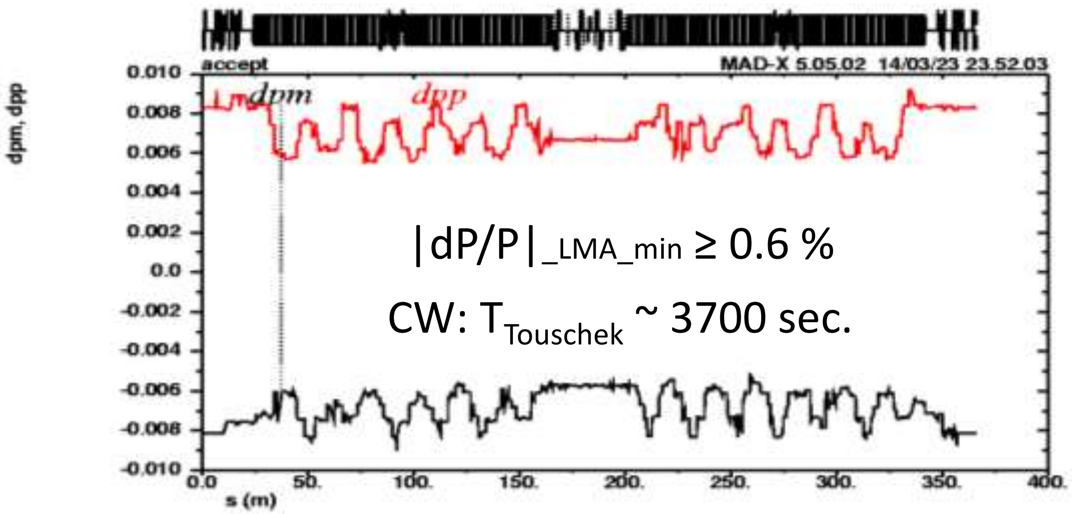
$20*\sigma_X$ $30*\sigma_Y$



VEPP-4CW. Parameters.

1 x 1 bunch





$|dP/P|_{LMA\_min} \geq 0.6$ %

CW: $T_{Touschek}$ ~ 3700 sec.

	VEPP -4M	VEPP -4 CW	VEPP -4 CW
E, GeV	1.85		
C, m	366.09	366.21	366.21
θ, mrad	0	±30	±30
I, мA	3.3	15.7	15.7
$N_e \times 10^{-10}$	2.5	12	12
N_b	1	1	1
Q_x/Q_y	8.54/7.58	11.54/7.58	11.54/7.58
C_x/C_y	-14/-20	-27/-43	-27/-43
$\alpha \times 10^2$	1.7	1.6	1.6
ε_x, nm*rad	25.8	23.8	25.6
κ	0.1	0.05	0.025
$\sigma_e \times 10^4$	3.2	4.4	4.6
σ_s, mm	27.8	26.8	26.3
β_x^*/β_y /D , cm	75/7/83	15/1/0	15/1/0
ξ_x/ξ_y	0.026/0.051	0.002/0.038	0.003/0.072
$\tau_x/\tau_y/\tau_e$, sec	0.12/0.13/0.07	0.09/0.11/0.06	0.11/0.11/0.06
L, $см^{-2}с^{-1} \times 10^{-30}$	1	24	46

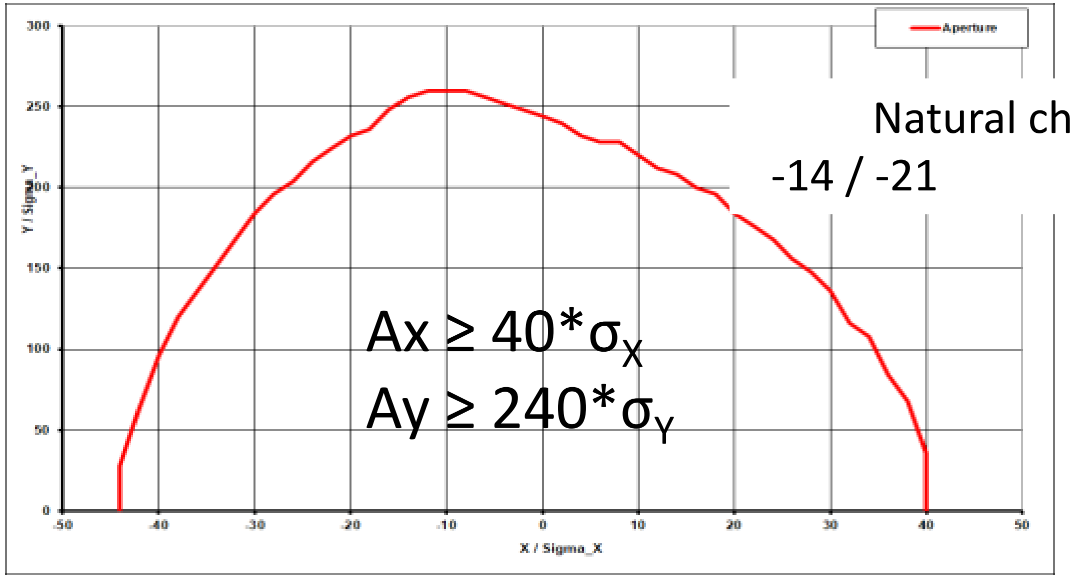
IBS blow up: VEPP-4M dε/ε = 1.4 %, σE/E = 0.8 %
VEPP-4CW dε/ε = 5.3 %, σE/E = 3.7 %

Dynamic aperture

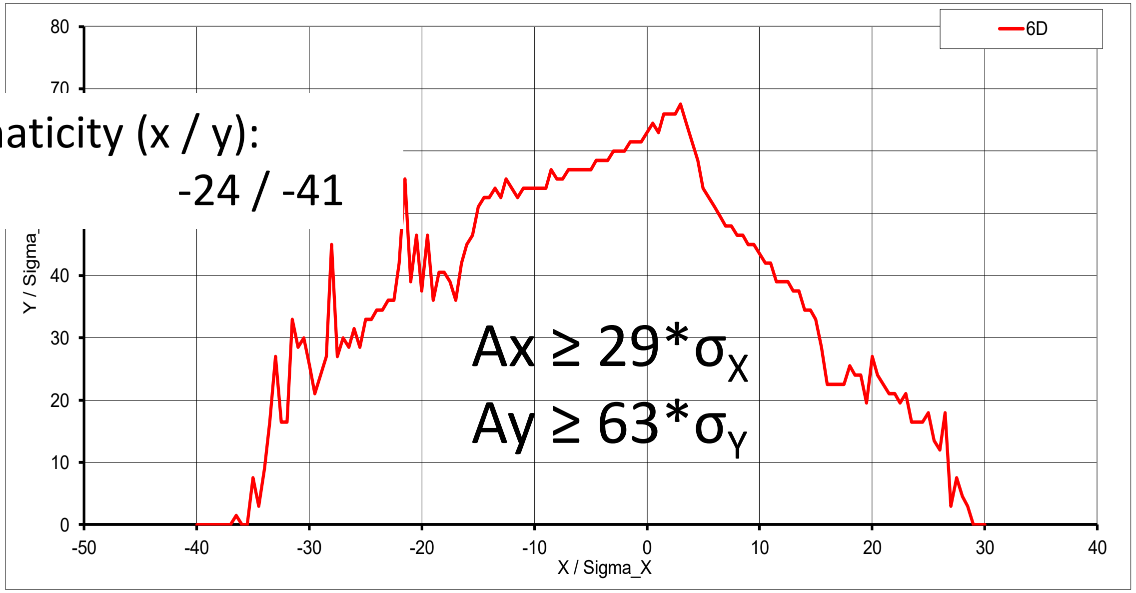
VEPP-4M	VEPP-4CW

Natural chromaticity (x / y):

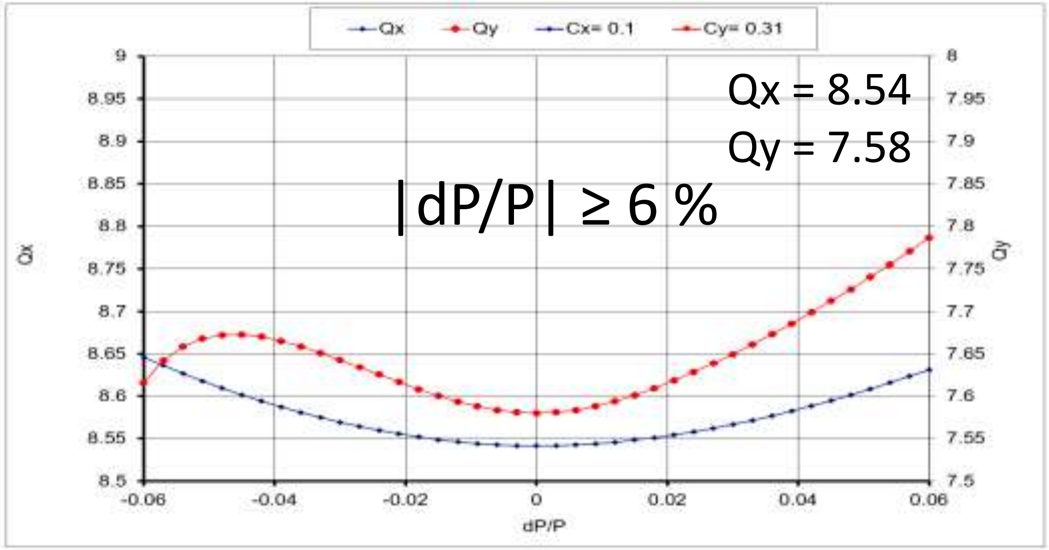
VEPP-4M	VEPP-4CW
-14 / -21	-24 / -41



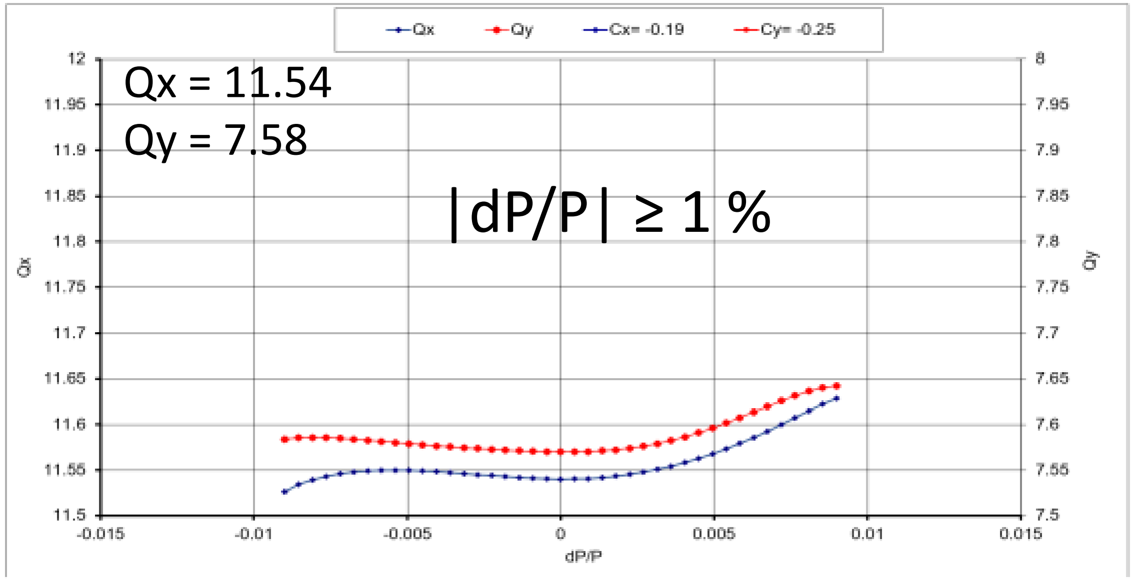
$A_x \geq 40 \cdot \sigma_X$
$A_y \geq 240 \cdot \sigma_Y$



$A_x \geq 29 \cdot \sigma_X$
$A_y \geq 63 \cdot \sigma_Y$

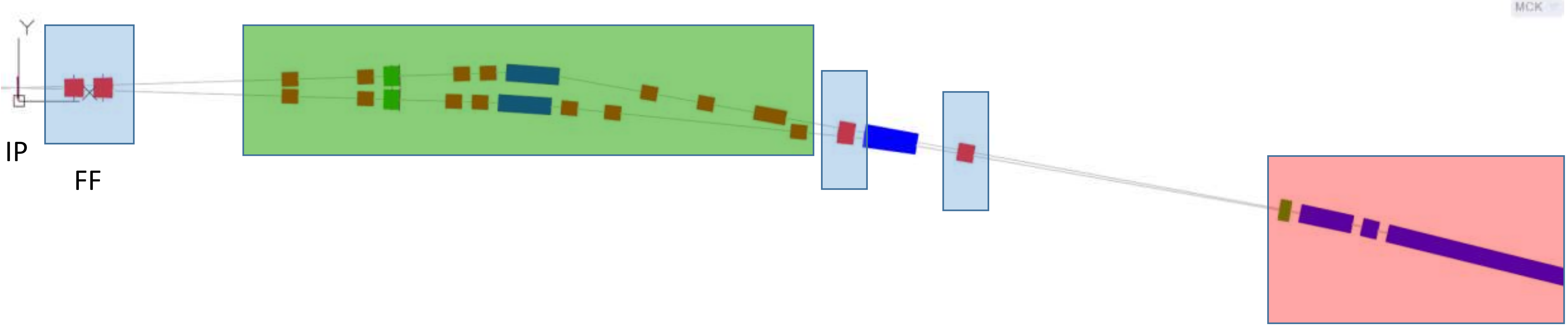


Qx = 8.54
Qy = 7.58
|dP/P| ≥ 6 %



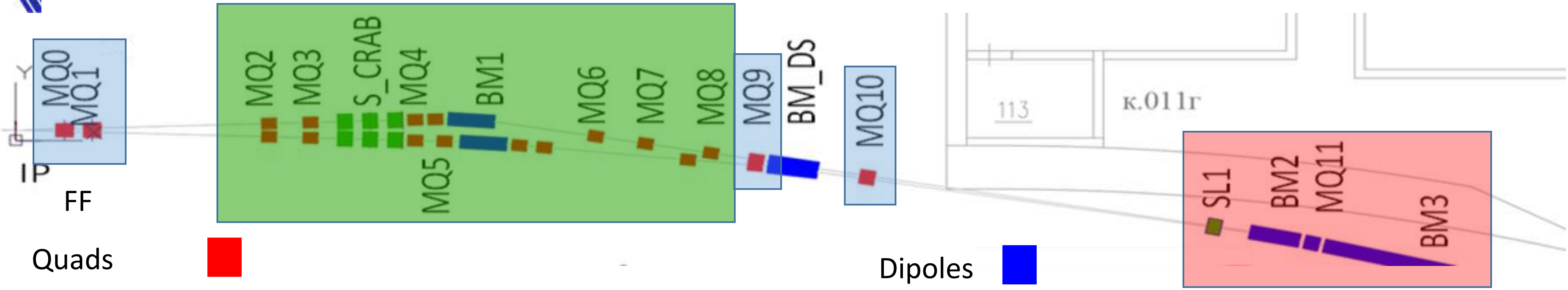
Qx = 11.54
Qy = 7.58
|dP/P| ≥ 1 %

VEPP-4CW. Magnet elements of experimental section.



- Double aperture CCT lenses. ΔXmin = 54 mm (QD0).
- Ordinary elements. ΔWmax = 280 mm. R= 20 mm.
- Single aperture elements for e- and e+. R>20 mm.

VEPP-4CW. Magnet elements of experimental section.



Quads

Имя	Тип	N	L, m	G, T/m	R, mm	W, mm
Q0	CCT	2	0.35	39	19	51
Q1	CCT	2	0.35	28	30	74
Q2-8	Ord.	28	0.3	8 - 29	20	~270
Q9-10	CCT	4	0.3	10 - 19	20	50
Q11	Ord.	2	0.3	4	30	-

Dipoles

Имя	N	L, m	alf,mrad	B,T	Comment
BM3	2	4.5	3	-	Electrostatic separation U=24.7 kV, h =4 cm
BM2	2	1.0	62.5	0.386	
BM_DS	2	1.0	70	0.432	DC septum
L.BM1	1	1.0	68.5	0.423	
R.BM1	1	1.0	204.5	1.262	

Sextupoles

Имя	N	L, m	S, T/m^2
S1	2	0.2	8 – 87
S_CRAB	4	0.3	±1155.7

VEPP-4CW. Main magnet elements of arcs.

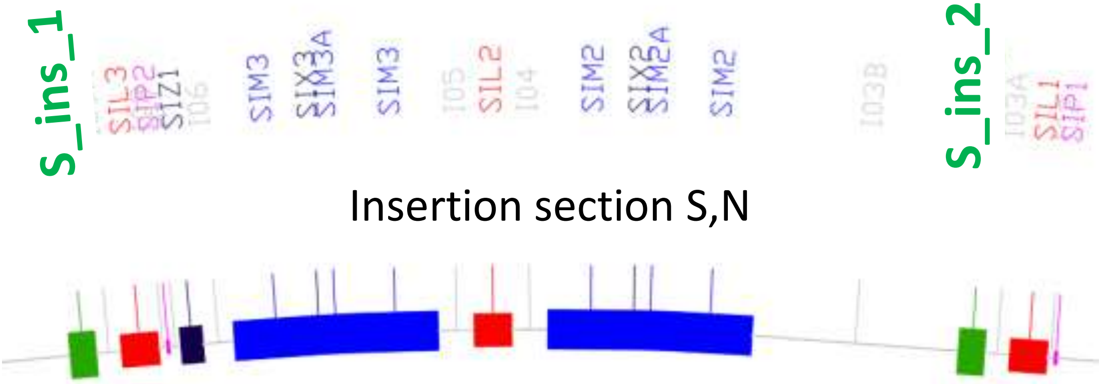
		VEPP-4M	VEPP-4CW
Name	L, m	S, T/m^2	S, T/m^2
D7	1.11387	-1.415	-1.678
F7	1.11309	0.893	1.114
FS	0.342	7.175	17.415
DS	0.342	-11.76	-33.821

There are no changes in the strengths of the quadrupole lenses outside the experimental section.

VEPP-4CW. Magnet elements of insertion sections.

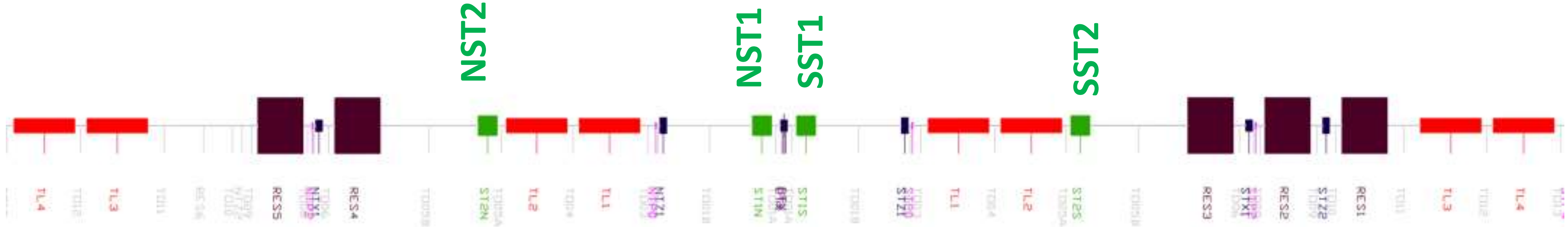
Additional sextupoles are inserted.

Sextupoles



Insertion section S,N

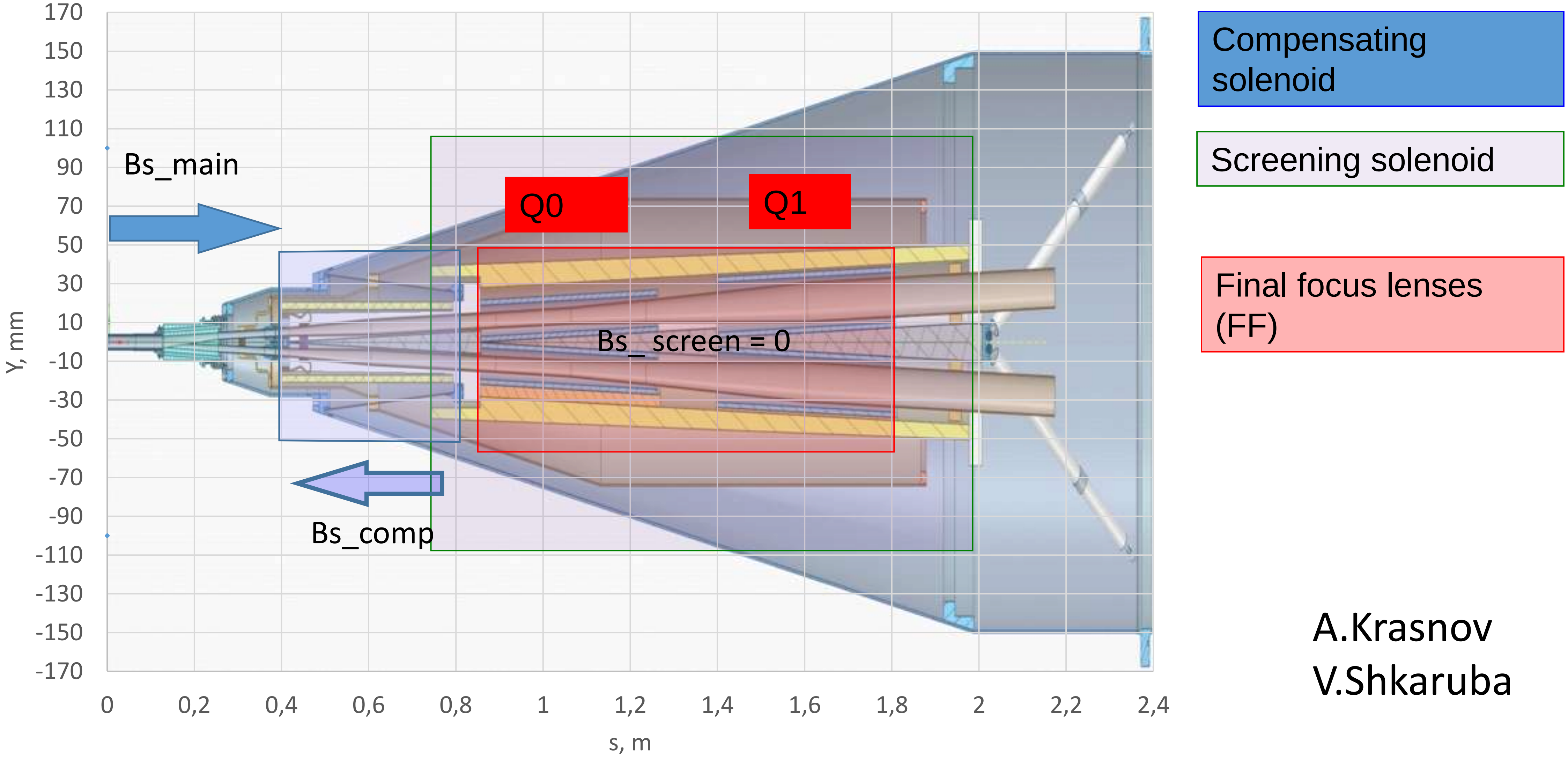
Name	L, m	S, T/m^2
SST1	0.4	90.6
NST1	0.4	-204.8
SST2	0.4	-20.9
NST2	0.4	-60.7
SS_INS1	0.2	-191.0
NS_INS1	0.2	-417.0
NS_INS2	0.2	8.7
SS_INS2	0.2	3.1
SS_INS3	0.2	78.9
NS_INS3	0.2	13.2



VEPP-4CW. Interaction region (IR).

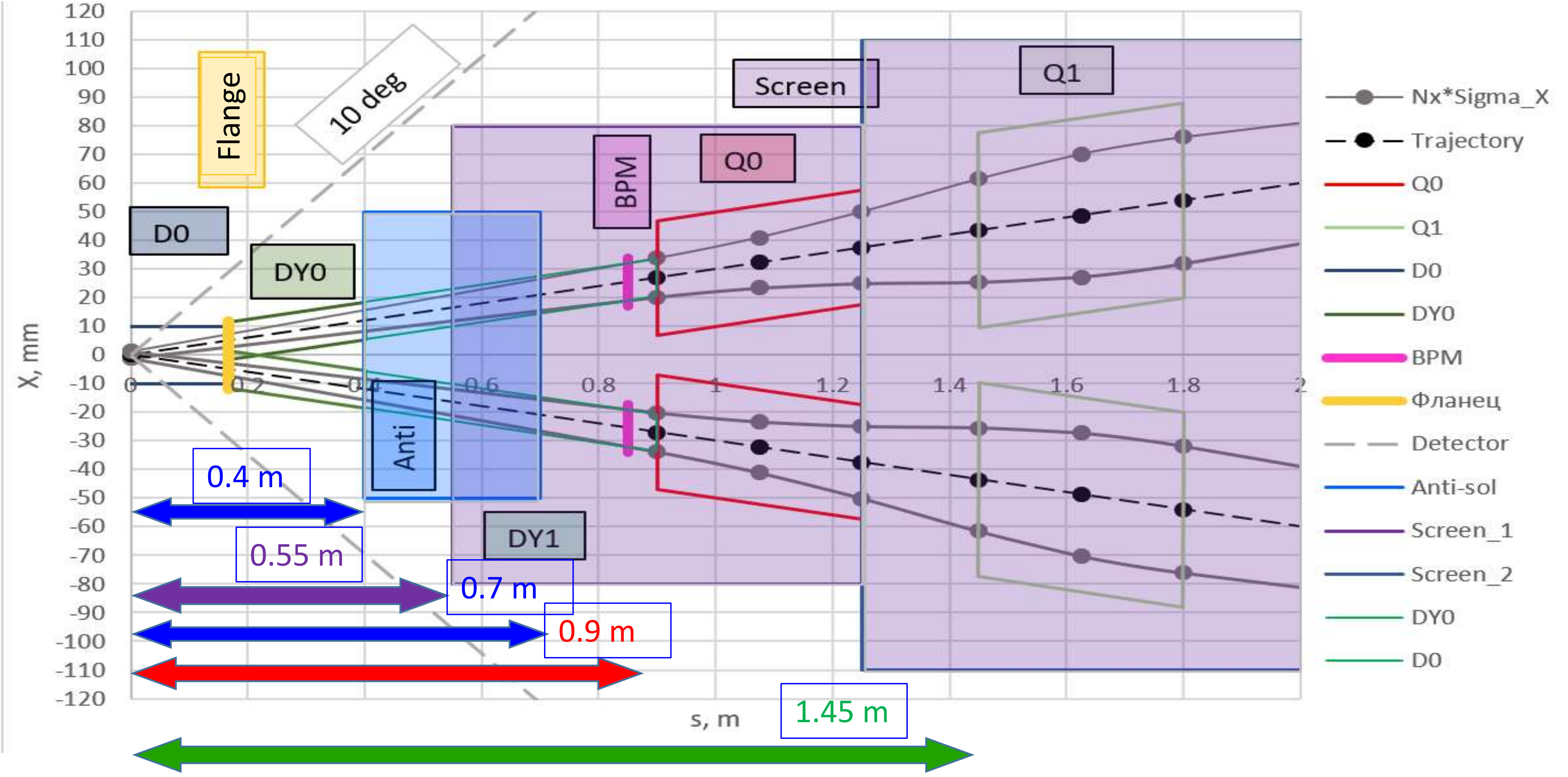
- The field of the main solenoid is 1.5 T in the region of $\pm$ 0.4 m main devices (elements) free.
- Opening detector cone angle $\phi \leq 10°$.
- L* = 0.9 m is the distance between IP and QD0s.
- Total crossing angle is 60 mrad – “Crab-Waiste” scheme. Horizontal field is produced.
- Blow up of vertical emittance in the final focus region is produced by radial fields and skew gradient of compensating and main solenoids.
- Solenoid fields in the region of FF lenses should be suppressed by a screening solenoid.

VEPP-4CW. Solenoid field compensating.

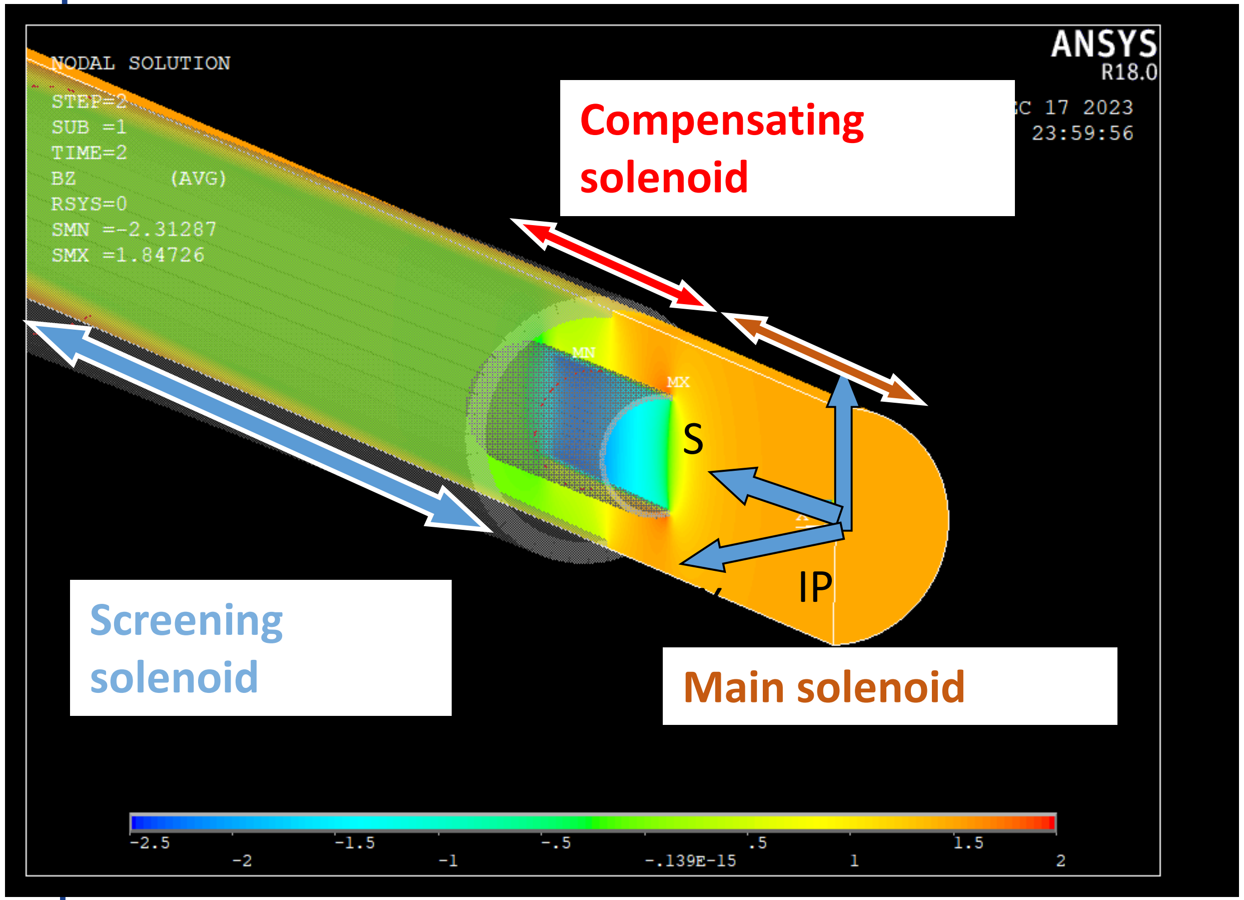


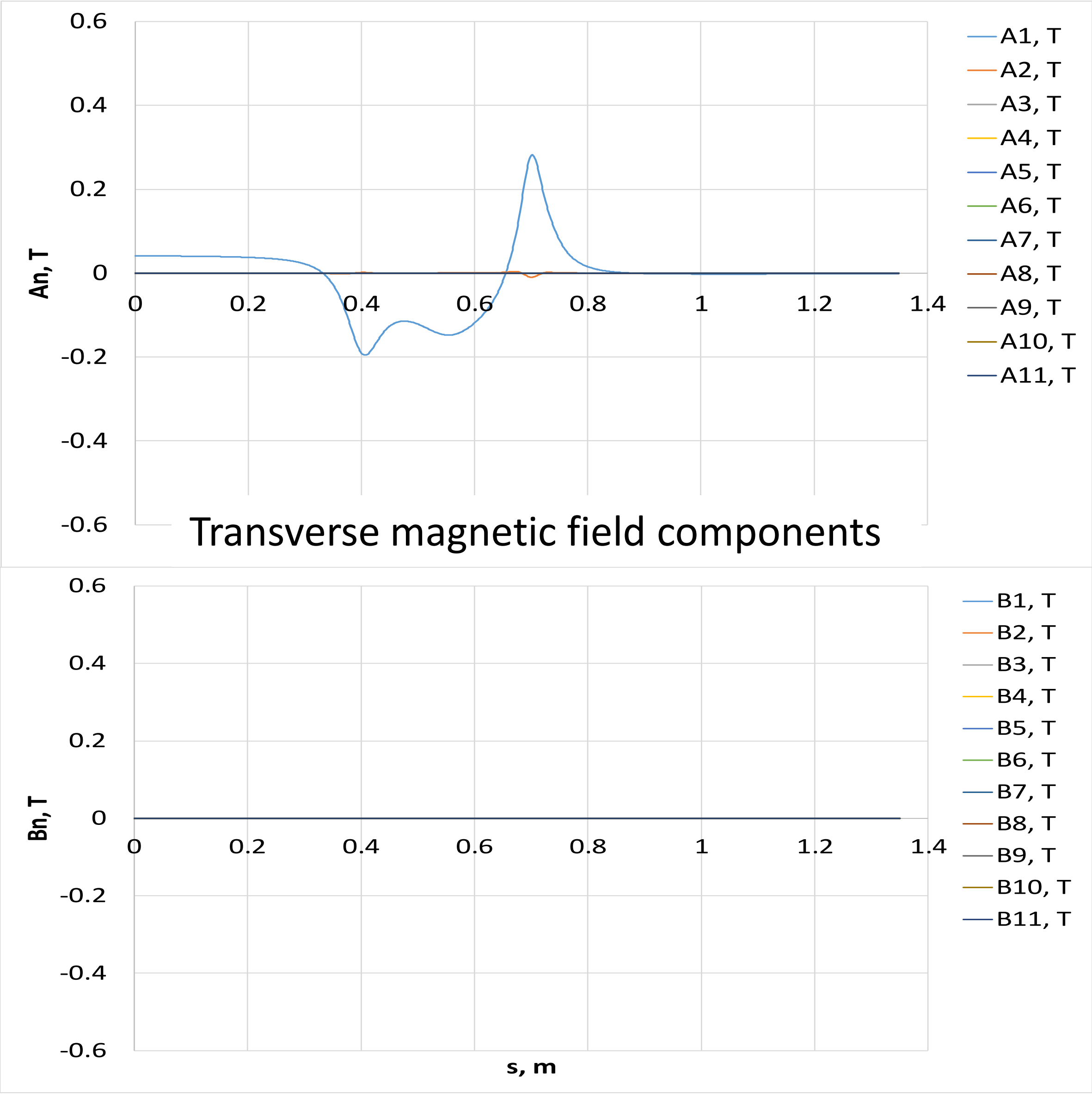
A.Krasnov
V.Shkaruba

VEPP-4CW.
Horizontal cross section of Interaction Region.



VEPP-4CW. Magnetic field simulation.



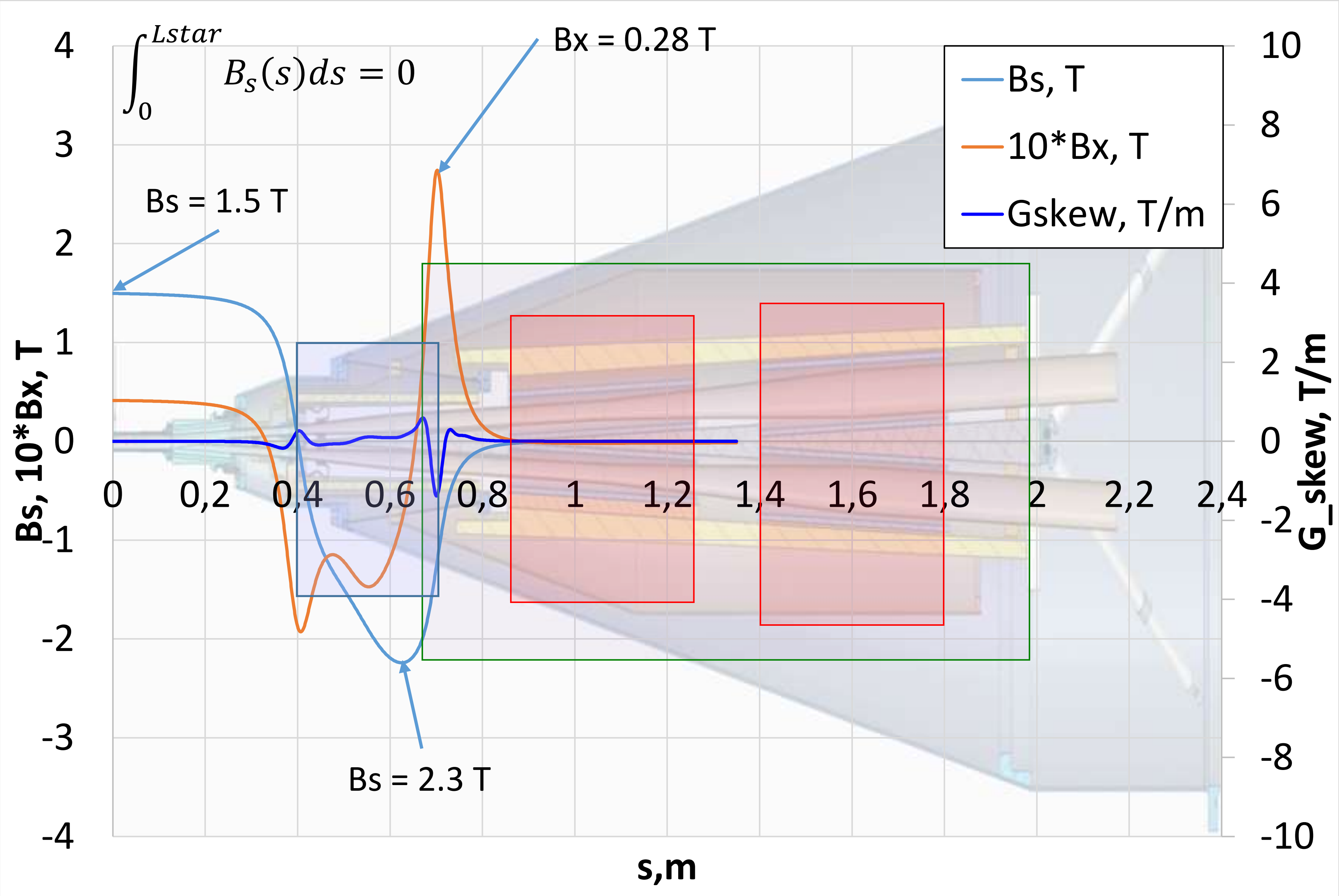


$R_{harmonic}$ = 7 mm

An << 10^{-4} T, n≠1

Bn << 10^{-4} T

VEPP-4CW. Interaction region.
Magnetic field distribution along beam trajectory.



Magnetic field (Q0, at 0.9 m):

- Bx < 8 Gs
- Bs < 110 Gs
- G_skew< 0.23 Gs/cm

$R_{harmonic}$ = 10 mm

$A_n < 10^{-4}$, $n \neq 1$

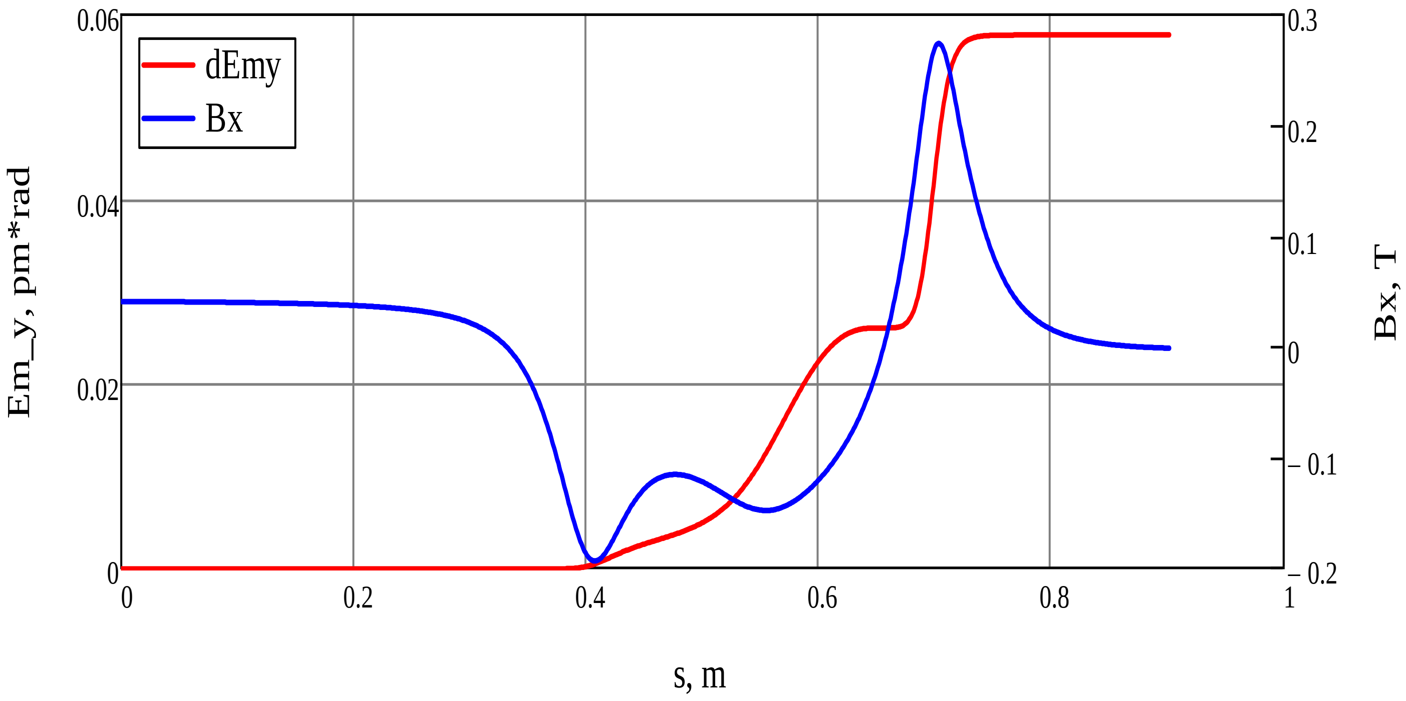
$B_n < 10^{-4}$

Compensating solenoid

Screening solenoid

Final focus lenses (FF)

VEPP-4CW. Interaction region.
Magnetic field distribution along beam trajectory.



I_2 = 0.233 m^{-1} β_y^* = 10 mm

Estimation

E = 1.85 GeV

$$I_{5y} = h_y^3 \oint H_y(s)ds = 1.5 \cdot 10^{-9}\, m^{-1}$$

$$\varepsilon_y = 3.83 \cdot 10^{-13} \cdot \frac{\gamma^2}{J_y} \cdot \frac{I_{5y}}{I_2} = 0.058\, pm \cdot rad$$

$$I_{5y} \sim B_x^5 \sim B_s^5 \qquad \varepsilon_y \sim B_x^5 \sim B_s^5$$

$$\varepsilon_Y / \varepsilon_X = 3 \cdot 10^{-6}$$

VEPP-4CW. Interaction region. Vertical emittance blow up.

- Variation of main solenoid field area (L_{main}) & compensating solenoid area (L_{comp})

$$\frac{\varepsilon_{y\_new}}{\varepsilon_y} \approx \left(\frac{L_{main\_new}}{L_{main}} \cdot \frac{L_{comp}}{L_{comp\_new}}\right)^5 \left(\frac{L_{main}/2 + L_{comp\_new}}{L_{main}/2 + L_{comp}}\right)^7$$

For:
Lmain_new = 1.2 m, Lmain = 0.8 m
Lcomp_new =0.2 m, Lcomp = 0.3 m

$$\frac{\varepsilon_{y\_new}}{\varepsilon_y} \approx 20$$

- Beta functions variation (β_{y_IP}) at IP:

$$\varepsilon_{y\_new} = \varepsilon_y \cdot \frac{\beta_{y\_IP}}{\beta_{y\_IP\_new}}$$

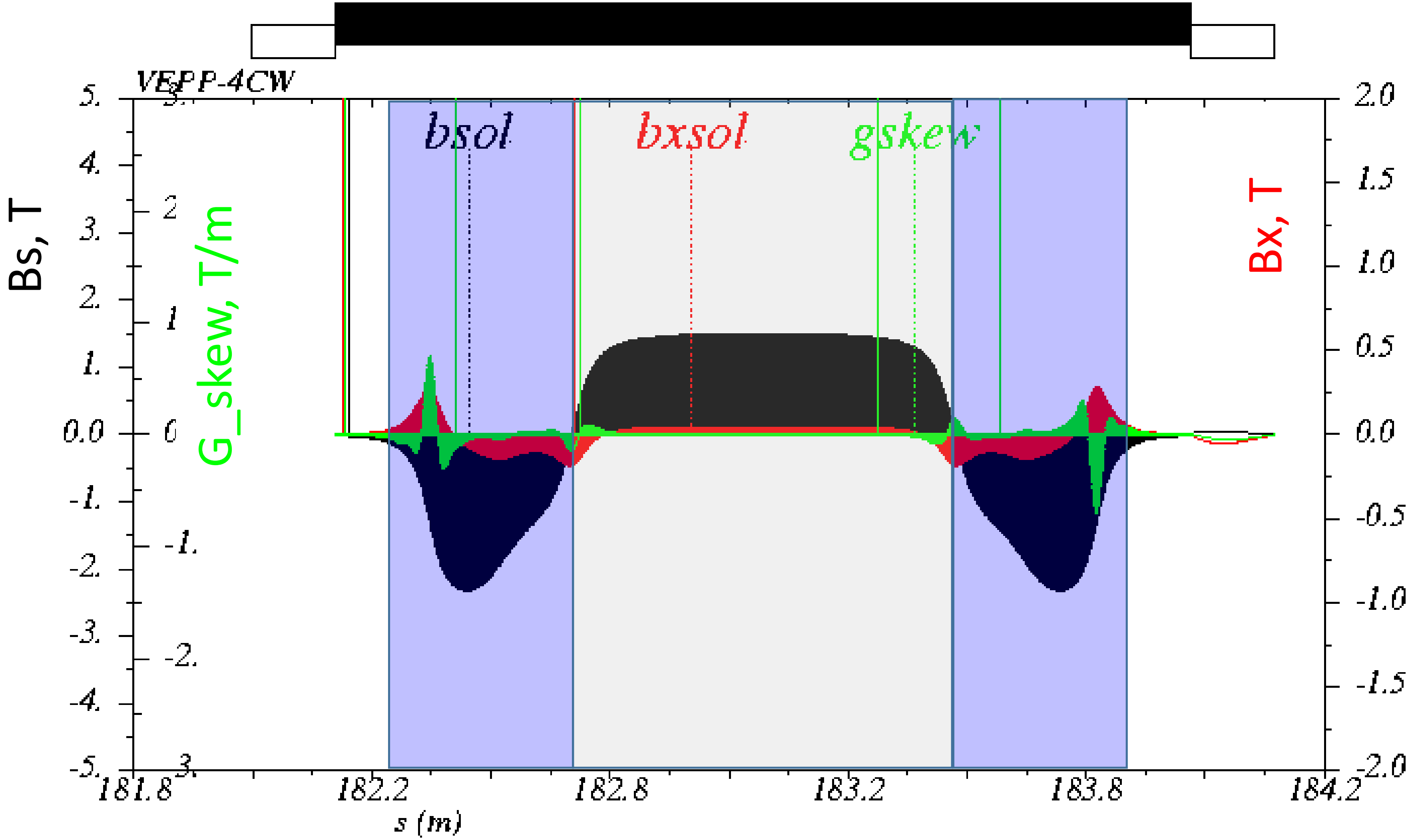
For β_{y_IP} = 1 mm (C-Tau,VEPP-6):

$$\varepsilon_{y\_CTAU} = \varepsilon_{y\_VEPP-4CW} \cdot 10$$

- Variation of main solenoid magnetic field:

$$\varepsilon_y \sim I_{5,y} \sim B_x^5 \sim B_s^5$$

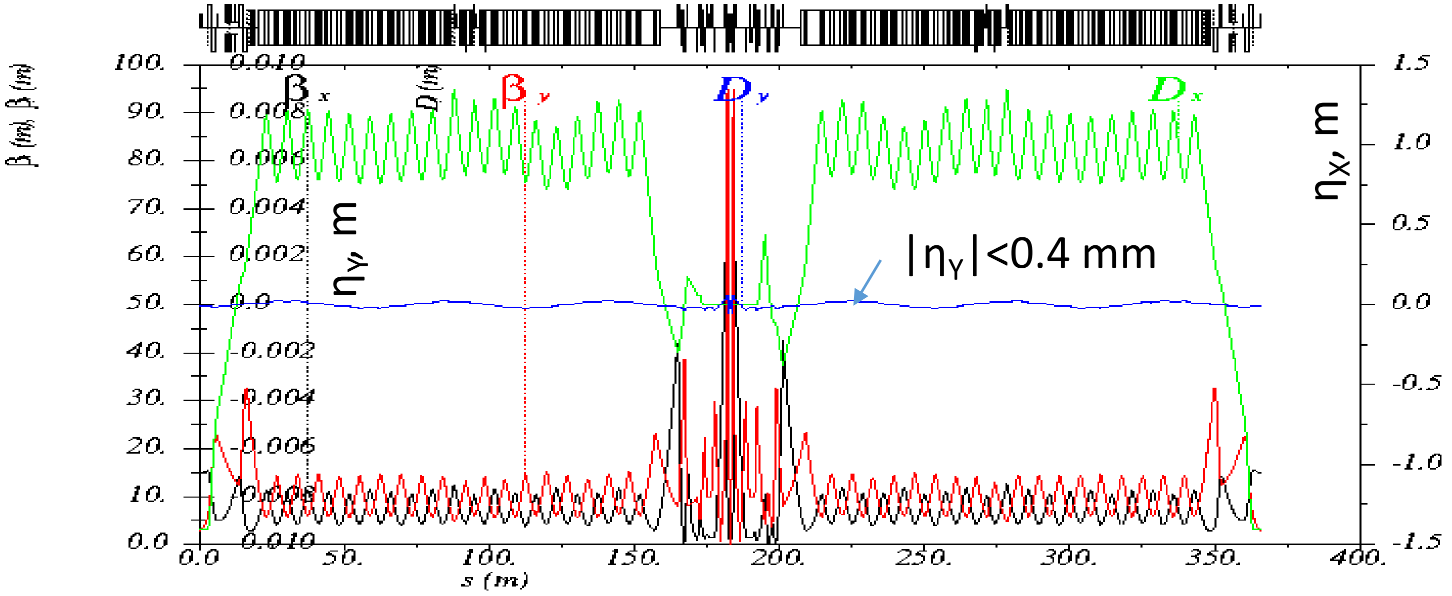
VEPP-4CW. Interaction region.
MAD-X calculation based on magnetic field.

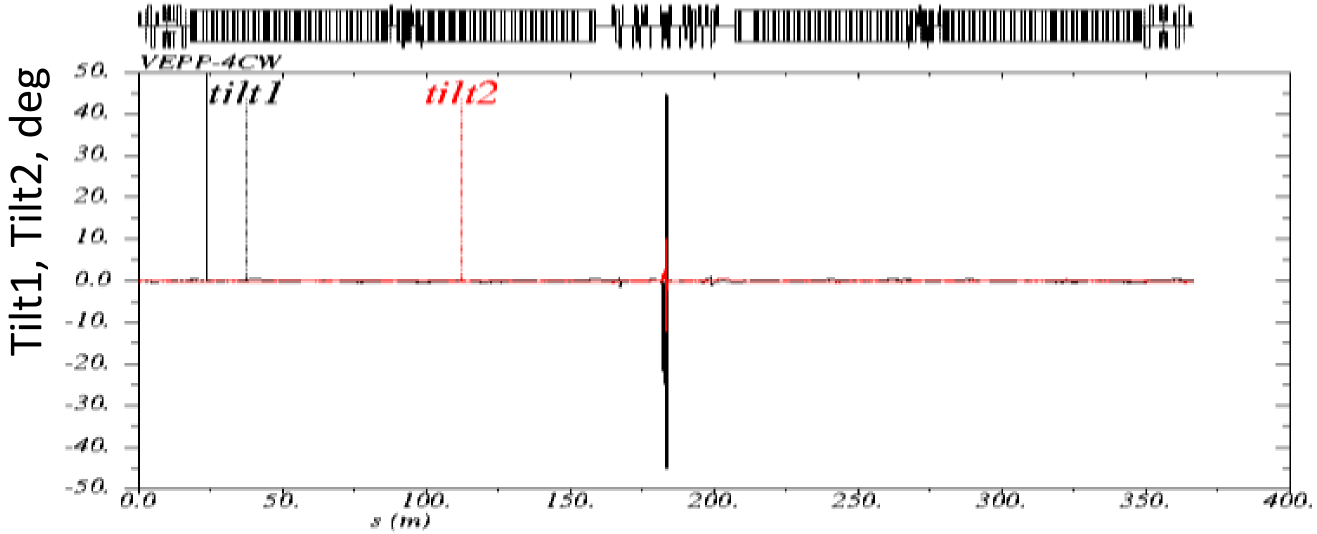


Correction of solenoid focusing:

Name	G, T/m	G, T/m	Deviation
r.kq0	-38.94	-38.89	-0.12%
r.kq1	27.58	27.57	-0.05%
r.kq2	-17.74	-17.72	-0.07%
r.kq3	11.01	11.01	-0.01%
r.kq4	28.78	28.72	-0.22%
l.kq4	21.77	21.79	0.07%
r.kq5	-22.85	-22.82	-0.15%
l.kq5	-22.77	-22.79	0.08%

VEPP-4CW. Interaction region.
MAD-X calculation based on magnetic field.





Energy, GeV	1
Qx	11.54
Qy	7.57
εx, nm*rad	21
εy, pm*rad	**0.45**
εy / εx	2e-5
βx_IP, m	0.150
alfx_IP	-0.00
βy_IP, mm	10
alfy_IP	0.00
ηx_IP, m	0.00
ηy_IP, m	0.00

MAD-X (Skew component - off)
εy = 0.039 pm*rad

Estimation:
εy = 0.058 pm*rad

Conclusion

- Upgrade is possible. VEPP-4M -> VEPP-4CW ….-> VEPP-6.
- Many effects associated with the Crab Waist can be estimated at this stand.
- For VEPP-4CW the influence of the detector solenoids is small.
- For C-Tau, VEPP-6 the optimization of the solenoids edge fields will be required.
- The chosen arrangement of the solenoids provides small fields in the area of the FF lenses.