Solenoid Compensation Scheme for FCC-ee FF

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Latest parameters of solenoids

- Main solenoid magnetic field: 2 T.
- L* = 2.2 m (from IP to the face of quadrupole).
- Length of main solenoid coil: ±4 m.
- Inner radius of main solenoid coil: 3.76 m.
- Outer radius of main solenoid coil: 3.818 m.
- No iron yoke?
- From IP to the face of compensating solenoid: 1.25 m.
- Detector’s opening angle: 0.14 rad.
- Full crossing angle is 0.03 rad.

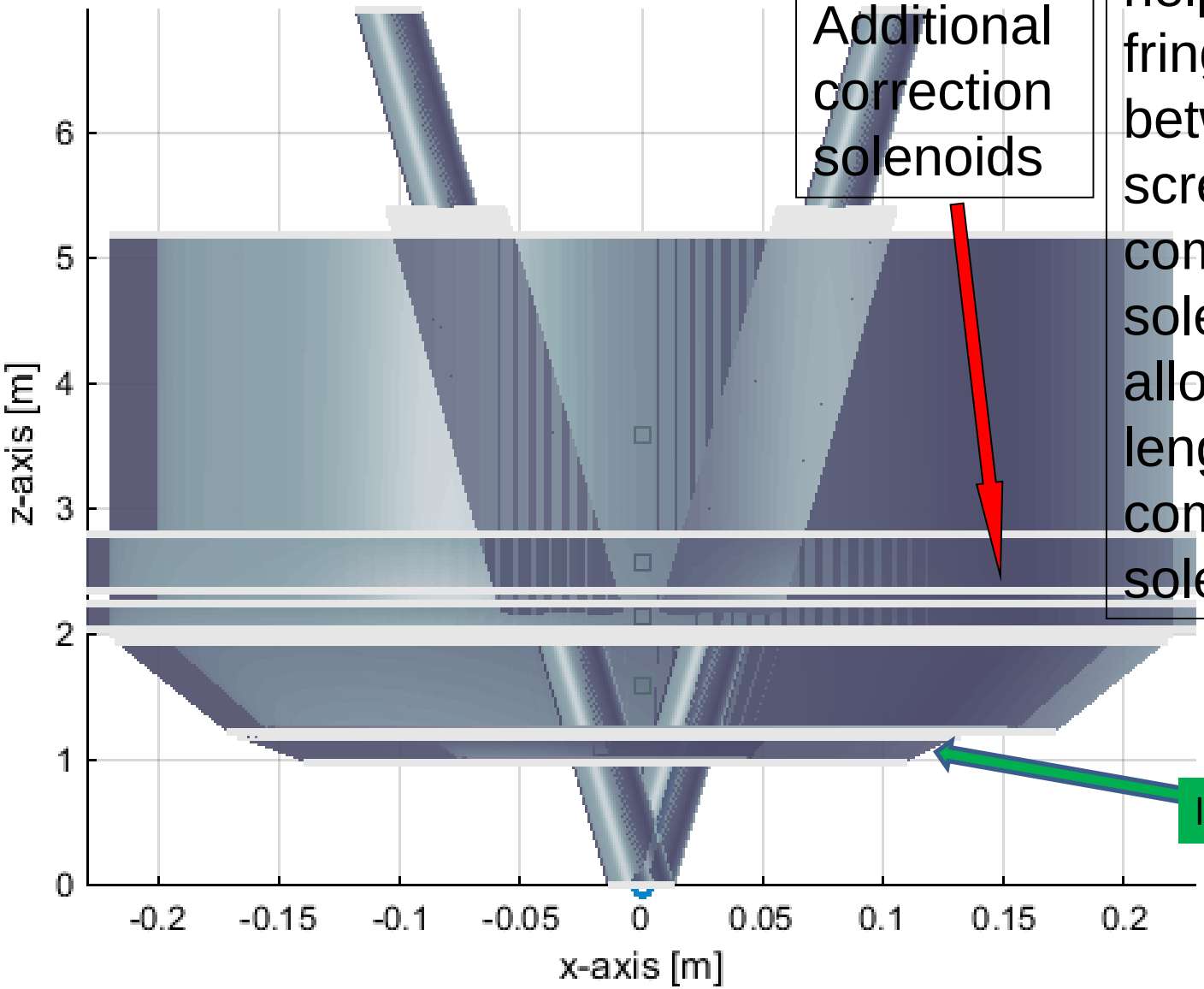
Latest parameters of solenoids

- Vertical emittance:
  - $\varepsilon_y = \kappa \cdot \varepsilon_x + \varepsilon_{y\_solenoid} \leq 1$ pm·rad
  - $\varepsilon_{y\_solenoid}$ = 0.3 pm*rad – vertical emittance created by solenoids field.
  - κ =0.7 % – betatron coupling,
  - ε_x = 100 pm*rad – radial emittance,
- Conical compensating solenoid
  - $\varepsilon_{y\_cylindrical\_solenoid} / \varepsilon_{y\_conical\_solenoid} \sim 3$

Latest layout

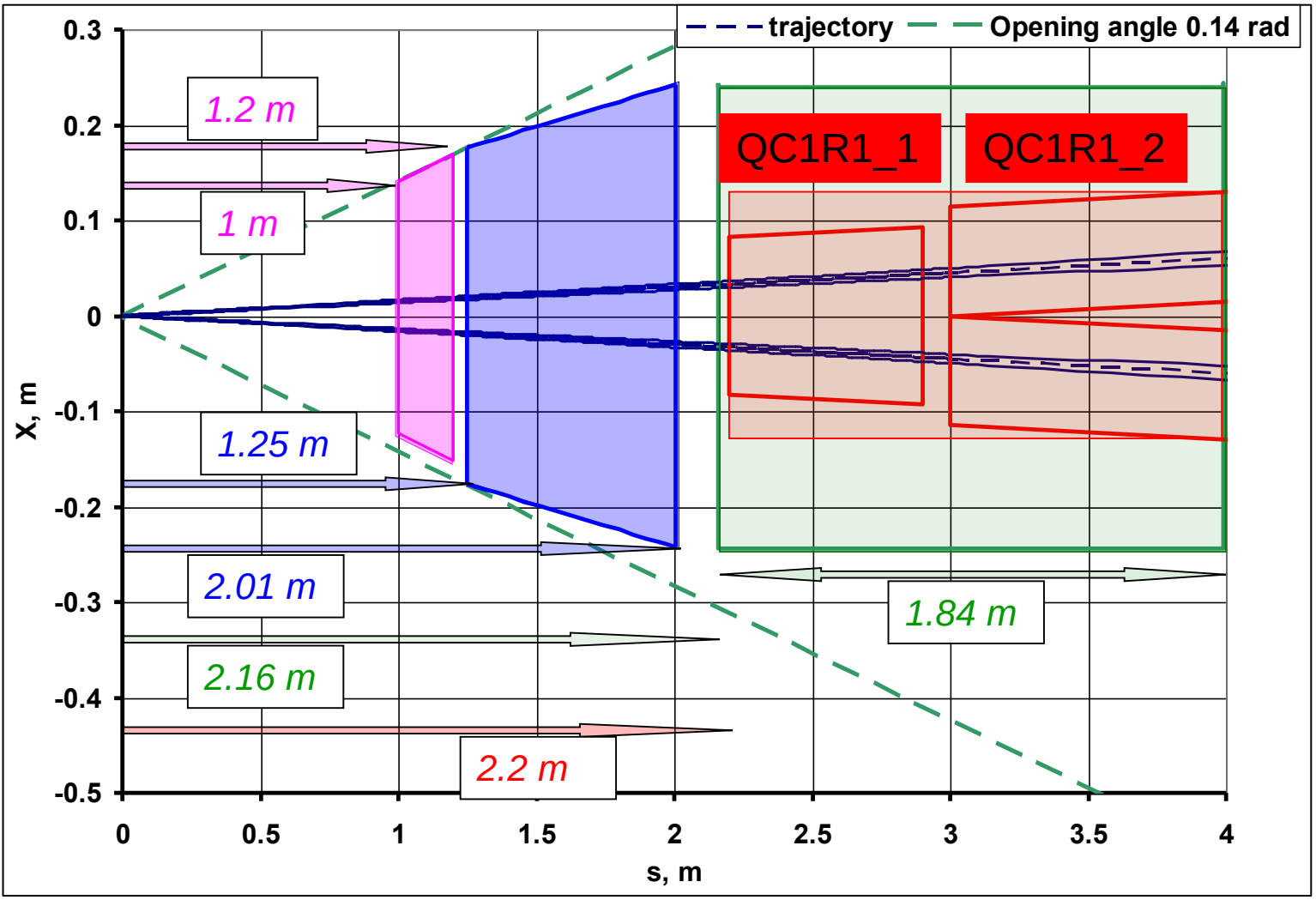
Additional correction solenoids

Additional coils help to optimize fringe fields between screening and compensating solenoids. This allows to increase length of compensating solenoid.



M. Koratzinos

Layout



Luminometer

Compensating Solenoid

Screening Solenoid

Defocusing Quads

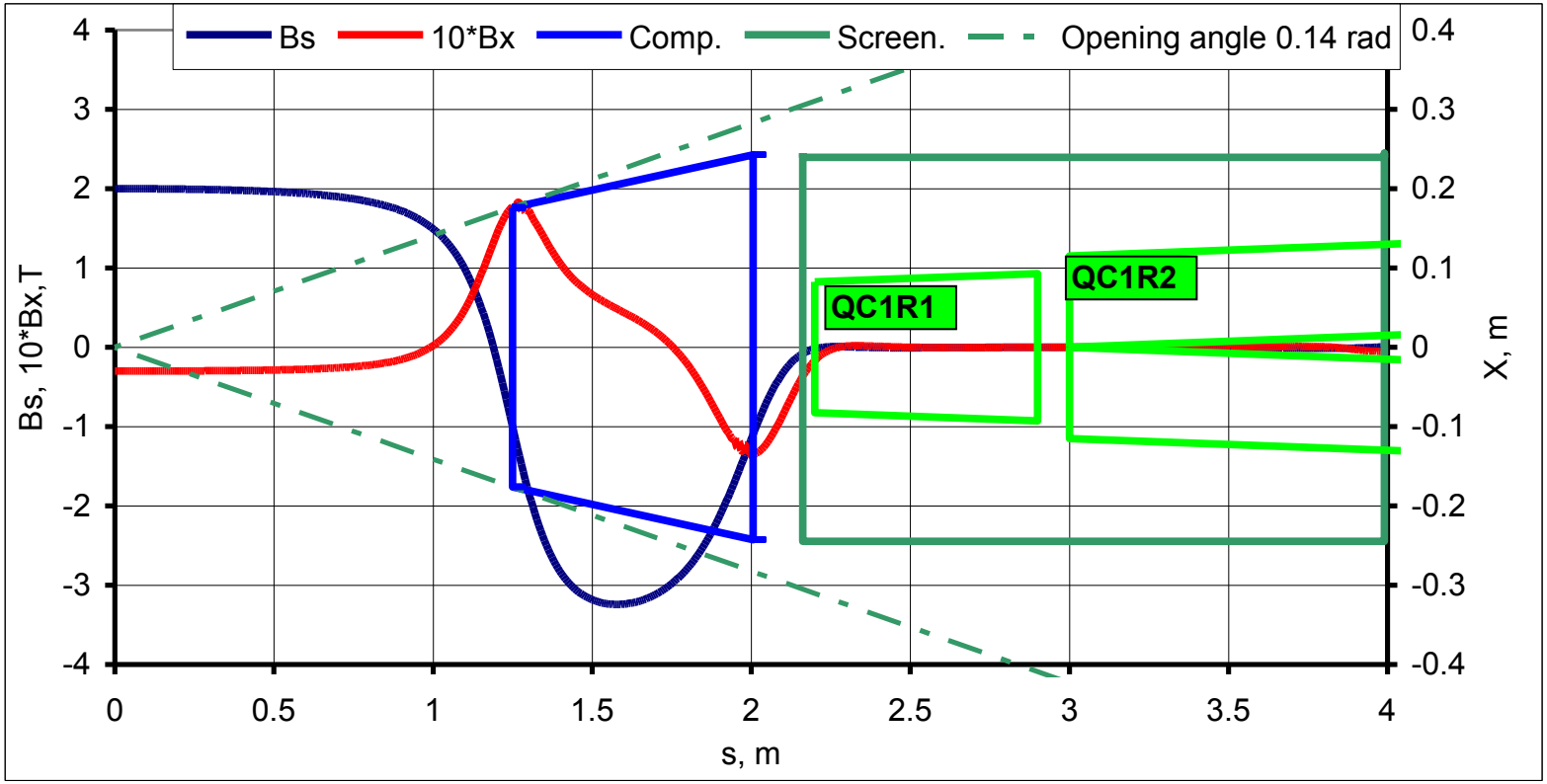
QC1R1_1: L= 0.7 m, K1=-75 / -75 T/m, R = 0.015 m

QC1R1_2: L= 1.4 m, K1=-173 / -166 T/m, R = 0.0175 m

Layout

Name	Initial azimuth	Initial radius	Final azimuth	Final radius	Length	Coil thickness
	m	m	m	m	m	m
IP	0		0		0	
Luminometer	1	?	1.2	?	0.2	
Main Solenoid	0	3.818	4	3.818	8	0.058
Compensating Solenoid	1.25	0.176	2.006	0.243	0.756	0.02
Screening Solenoid	2.162	0.245	4	0.245	1.838	0.03
QC1R1_1	2.2	0.083	2.9	0.093	0.7	
QC1R1_2	3	0.058	4.4	0.058	1.4	
QC2R1_1	5.7	0.058	6.95	0.058	1.25	
QC2R1_2	7.05	0.058	8.3	0.058	1.25	

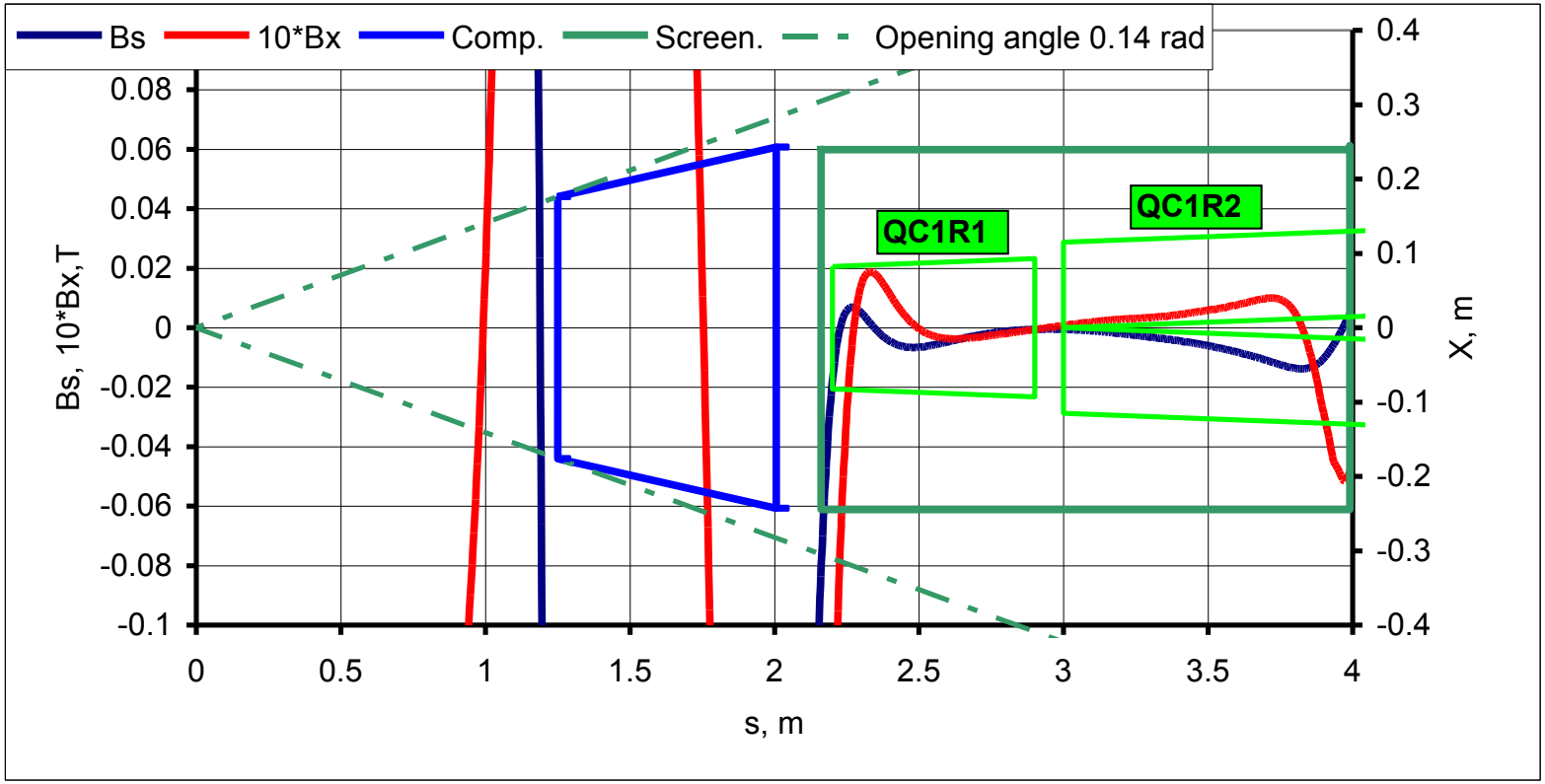
Field distribution with detector iron yoke



Transverse half size:

- main solenoid field - L_{geom} = 1.25 m, B_s = 2 T
- compensating solenoid - R = 0.176 / 0.243 m, L_{geom}= 0.756 m, B_s ~ 3.3 T
- screening solenoid - R = 0.245 m , L_{geom} = 1.838 m

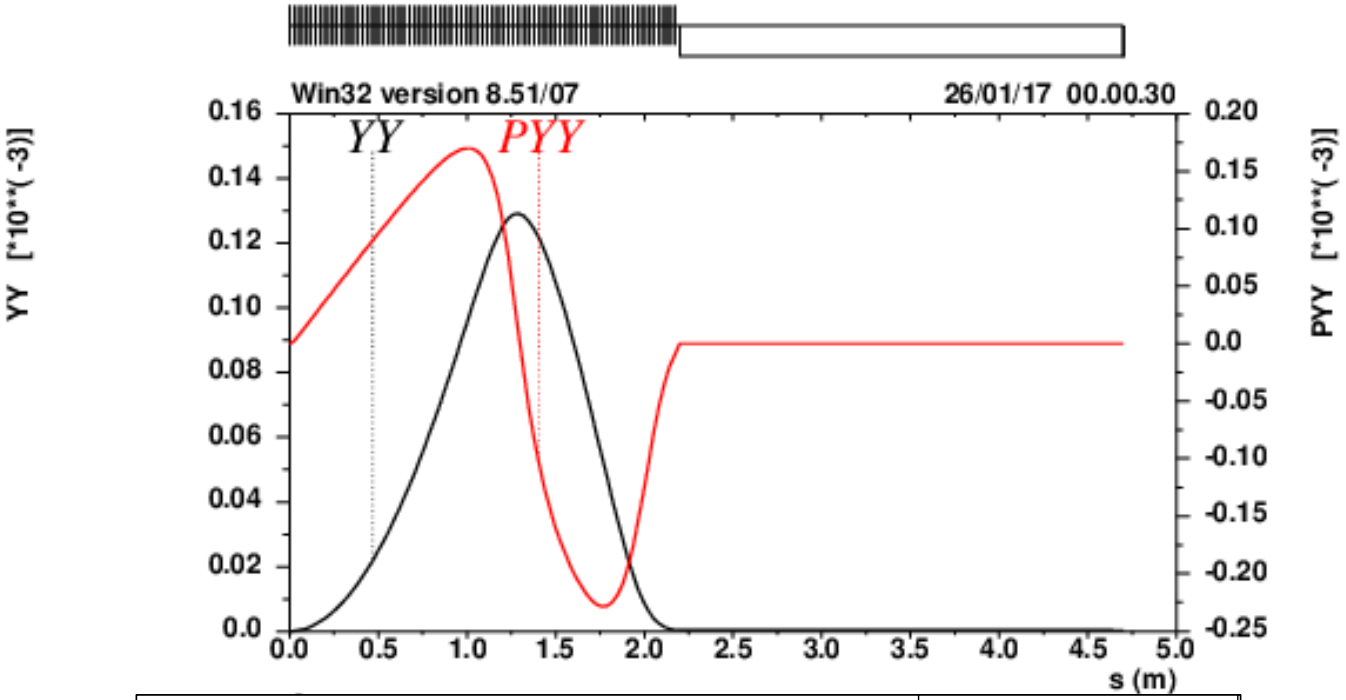
Field distribution with detector iron yoke

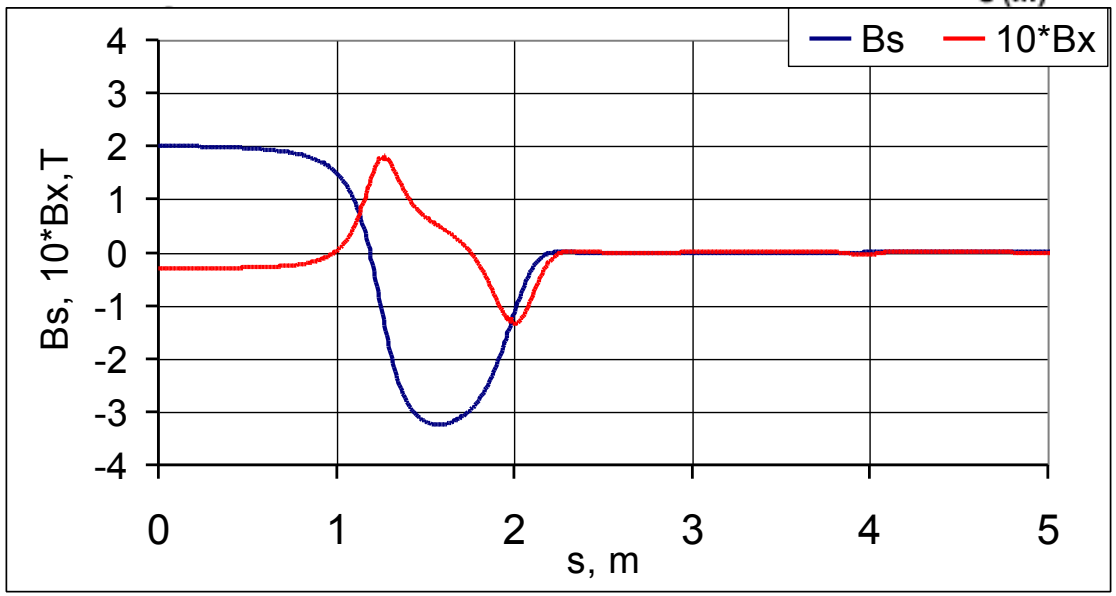


Edge field in quad area: B_s<0.01 T B_x<0.002 T

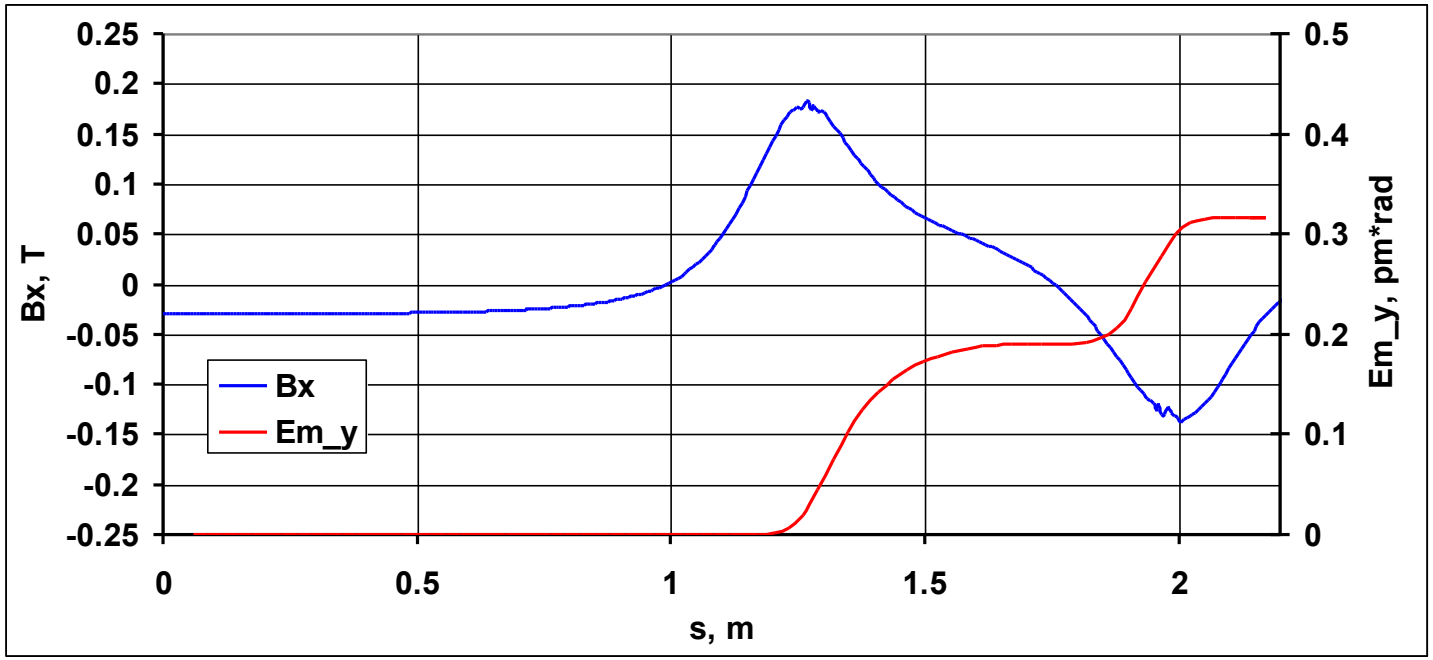
It is necessary to introduce additional corrections in the screening area and at the detector's yoke end cap.

Beam Orbit at IR





Emittance calculation



- I_2 = 5.65*10^{-4} m^{-1}
- I_5 = 1.99*10^{-11} m^{-1}

$$I_{5y} = h_y^3 \oint \mathrm{H}_y(s)ds = 6.00 \cdot 10^{-14}\ m^{-1}$$

$$\varepsilon_y = 3.83 \cdot 10^{-13} \cdot \frac{\gamma^2}{J_y} \cdot \frac{I_{5y}}{I_2} = 0.32\ pm*rad$$

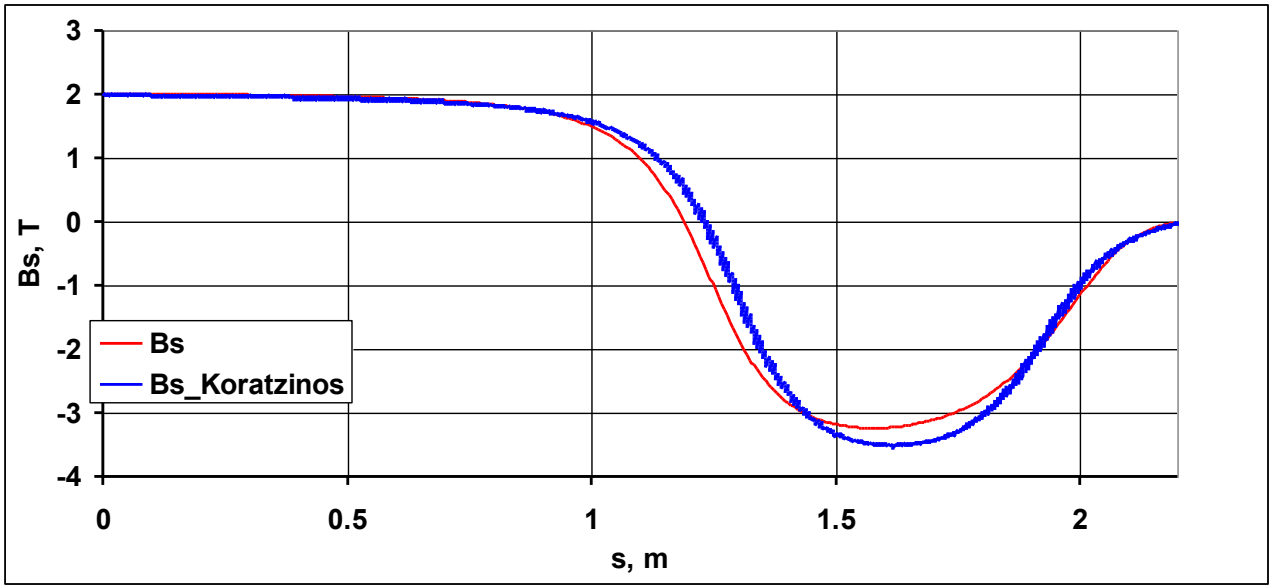
For 2 IP

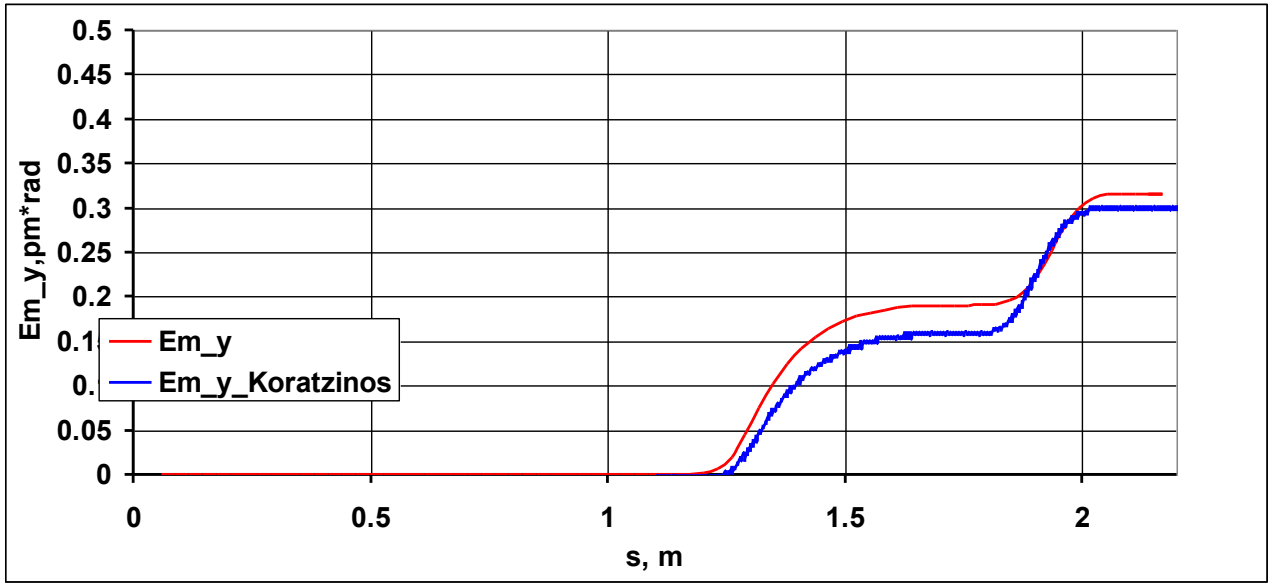
$$I_{5y} \sim B_x^5 \sim B_s^5 \qquad \varepsilon_y \sim B_x^5 \sim B_s^5$$

Beam parameters

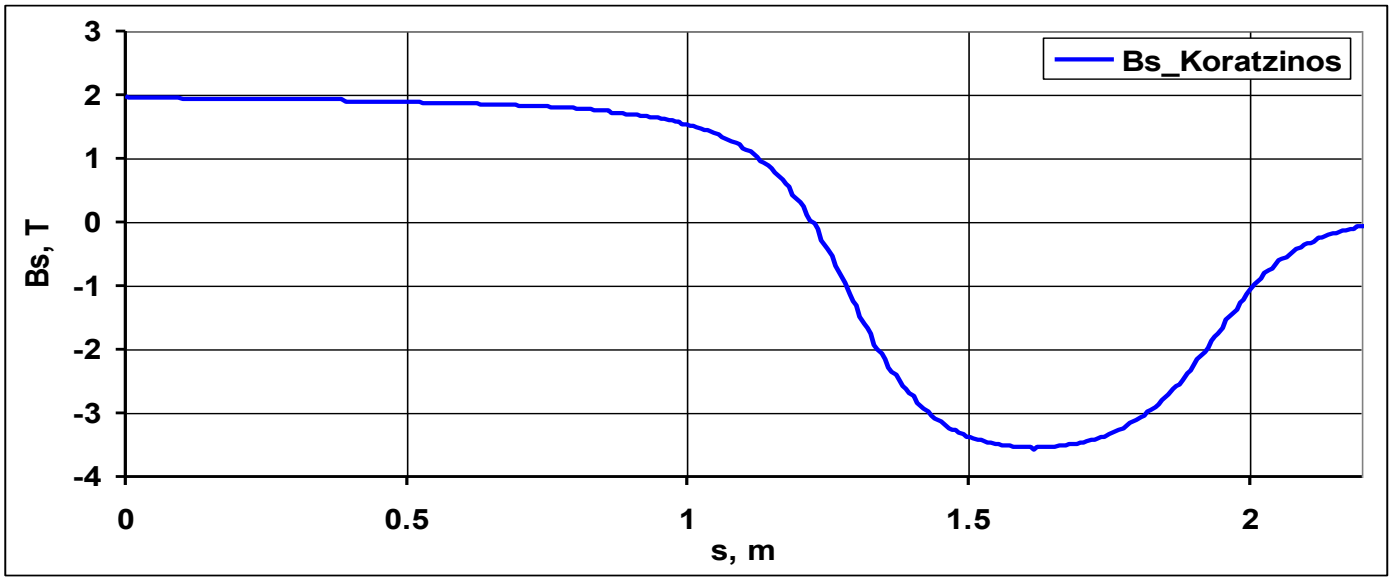
Parameter	Unit
Beam energy, GeV	45
Q_x	0.08
Q_y	0.14
$\beta_{x\ IP}$, m	0.5
$\beta_{y\ IP}$, m	0.001
Emittance, pm*rad	105
Ver. Emittance, pm*rad	0.316
Emittance Ratio (v./h.)	0.003
Energy spread	2.4E-04
Energy loss of particle per turn, MeV	32.64
Energy loss of particle (in solenoids), keV	76.5
I2, m^{-1}	$5.65*10^{-4}$
I5, m^{-1}	$1.99*10^{-11}$
I2_solenoid, m^{-1} (2 IP)	$1.97*10^{-6}$
I5_solenoid, m^{-1} (2 IP)	$6.00*10^{-14}$

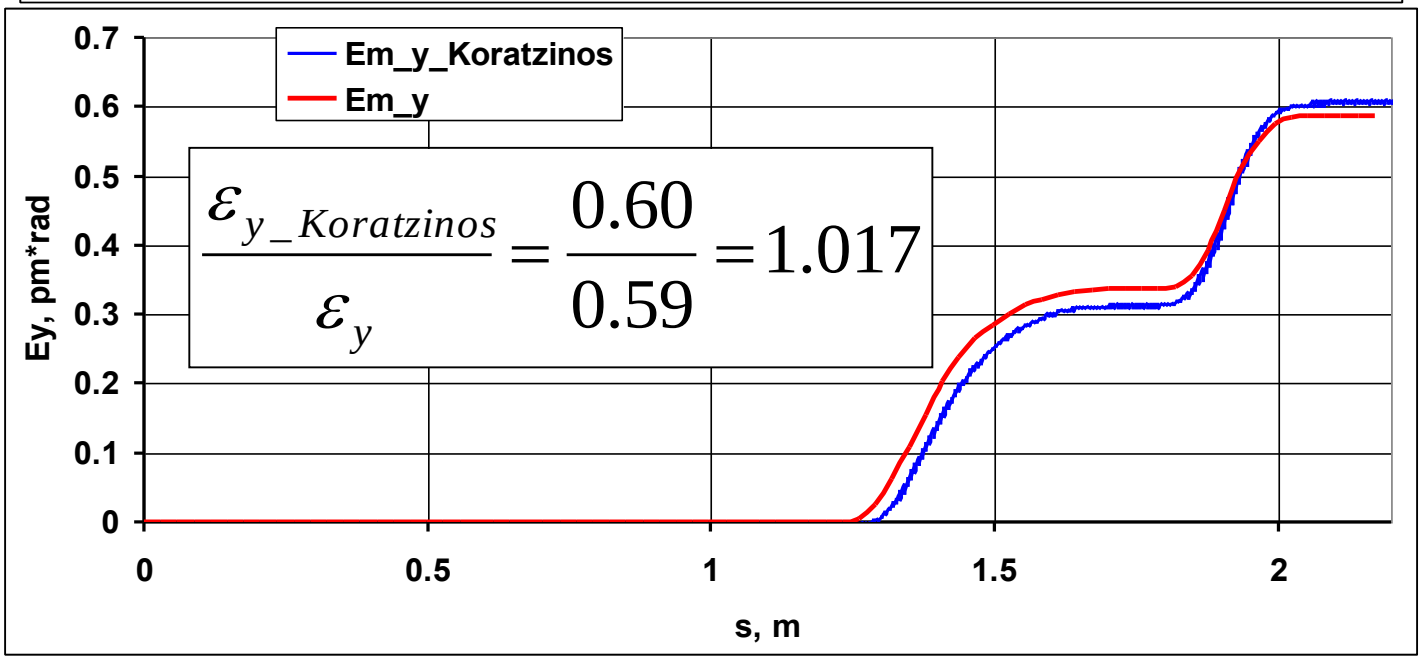
Comparison of latest results





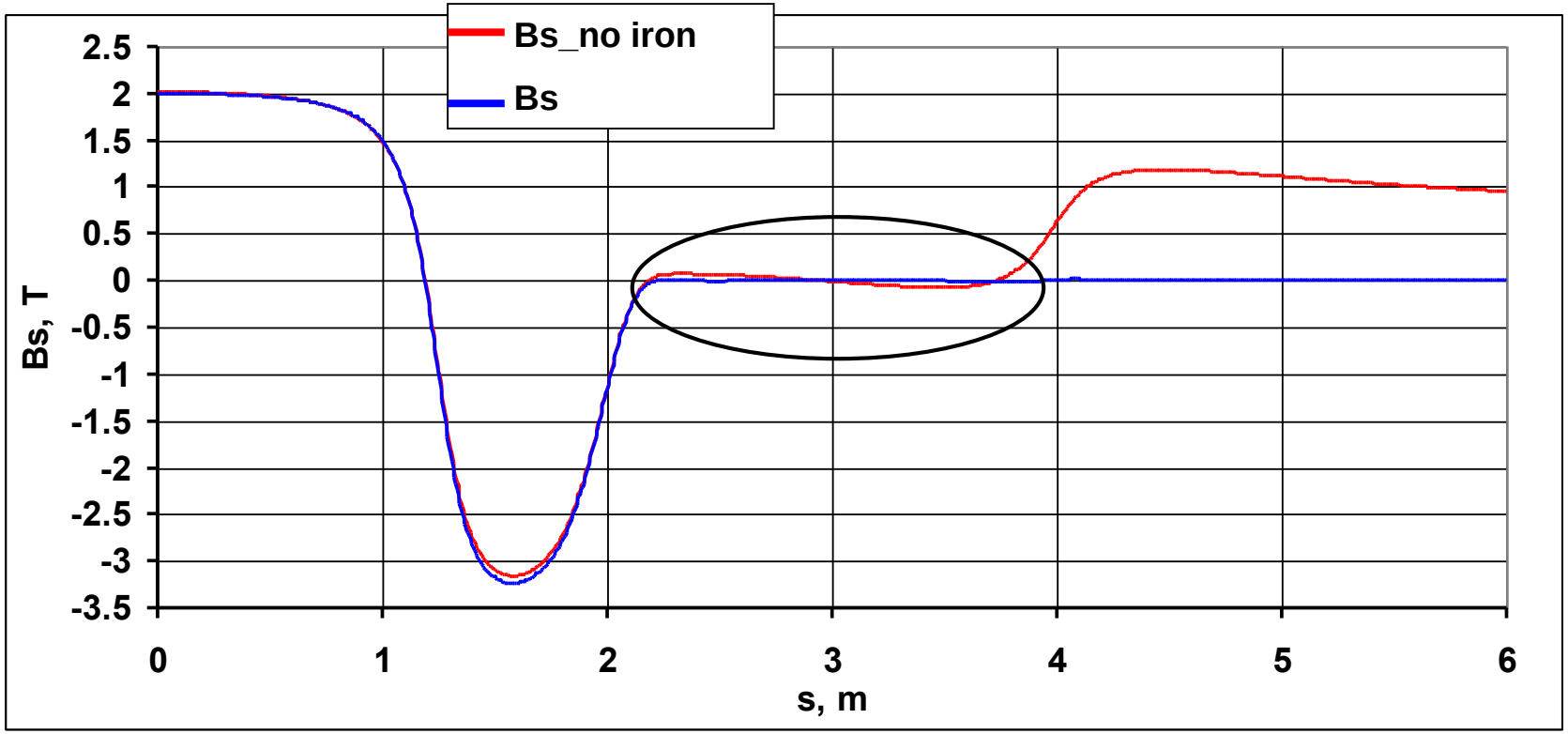
Discrepancy of results





$$\frac{\varepsilon_{y\_Koratzinos}}{\varepsilon_y} = \frac{0.60}{0.59} = 1.017$$

Field distribution



Nonuniformity:

- No iron: Bs ~ 1 kGs
- With iron: Bs ~ 50 Gs

- Insert of distributed screening solenoid coils
- Screening area up to 6 – 10 m by distributed screening solenoids

Summary

- Vertical emittance for current geometry is small.
- Residual magnetic field in FF area is less than 50 - 100 Gs.
- Absence of detector’s solenoid iron yoke requires distributed solenoid coils.

Next steps

- Estimation and correction of residual magnetic field on reference trajectory for the case of detector without iron yoke.
- Create MAD model with multipole field components.
- Estimation of misalignment errors influence on vertical emittance.