# 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.

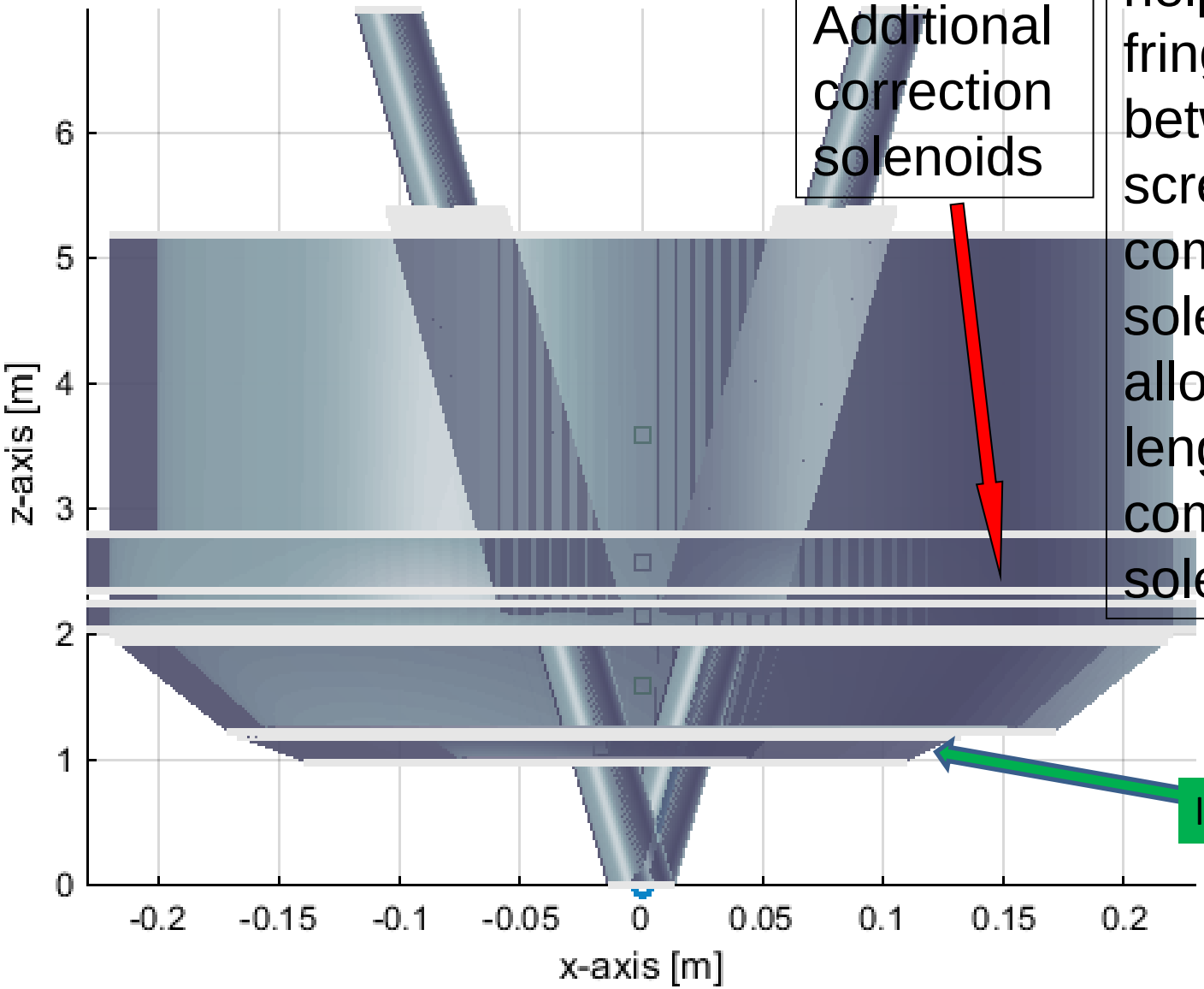
# Latest parameters of solenoids

- 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.
  - $\kappa$ =0.7 % – betatron coupling,
  - $\varepsilon_x$ = 100 pm*rad – radial emittance,
- Conical compensating solenoid
  - $\varepsilon_{y\_cylindrical\_solenoid} / \varepsilon_{y\_conical\_solenoid} \sim 3$

# Latest layout

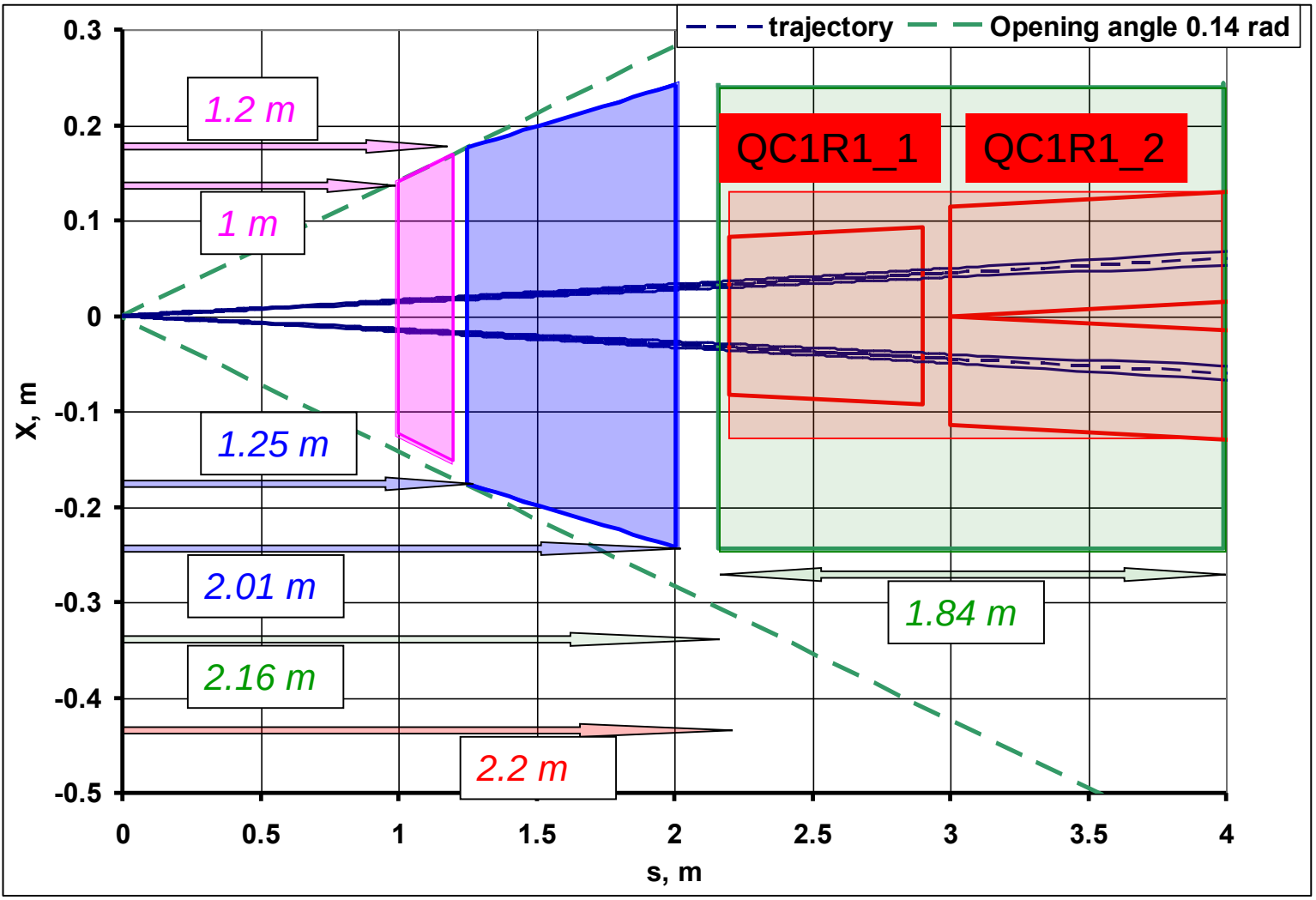
Additional correction solenoids

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

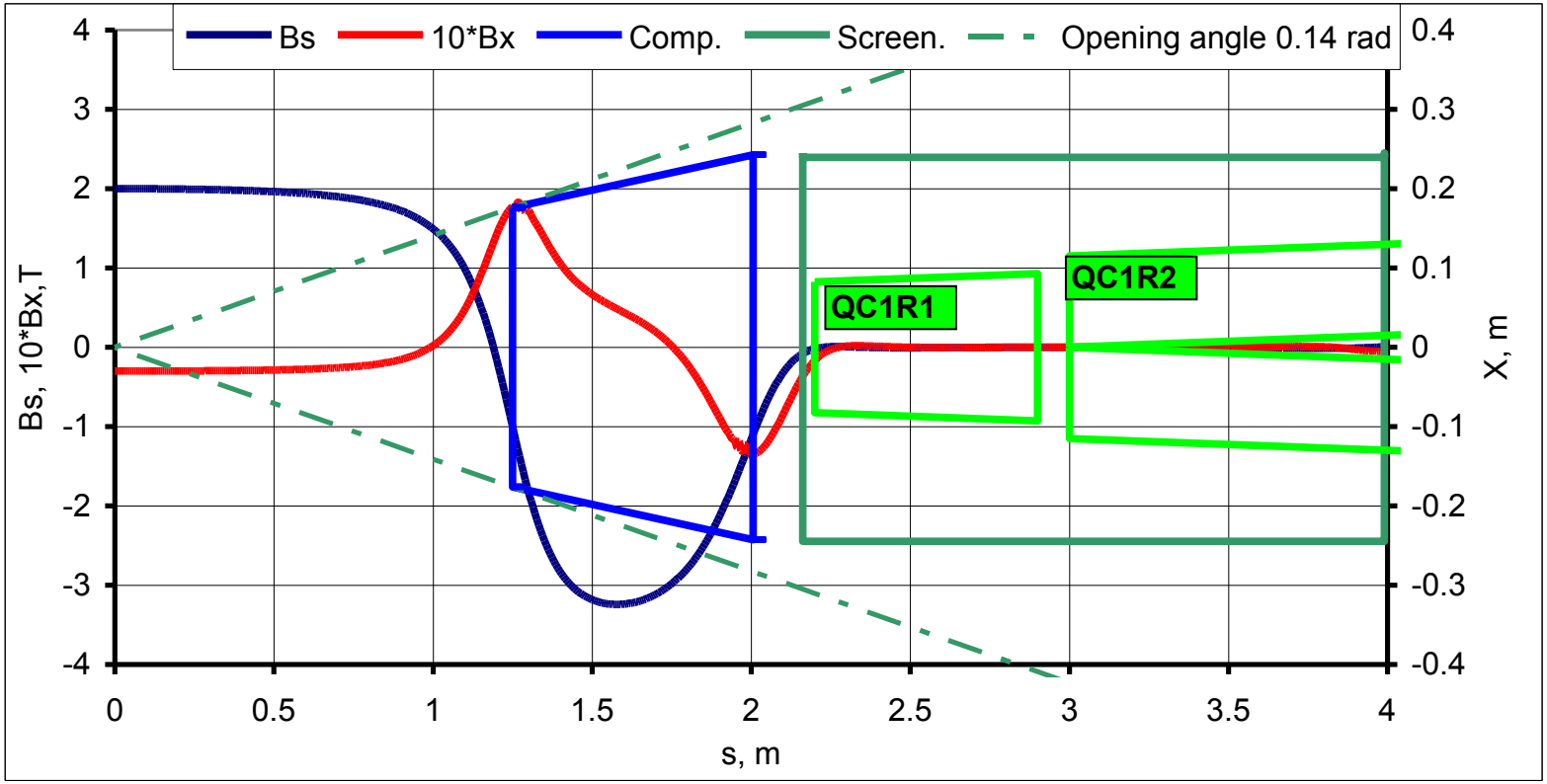
QC1R1_1: L= 0.7 m, K1=-75 / -75 T/m, R = 0.015 m

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 | |

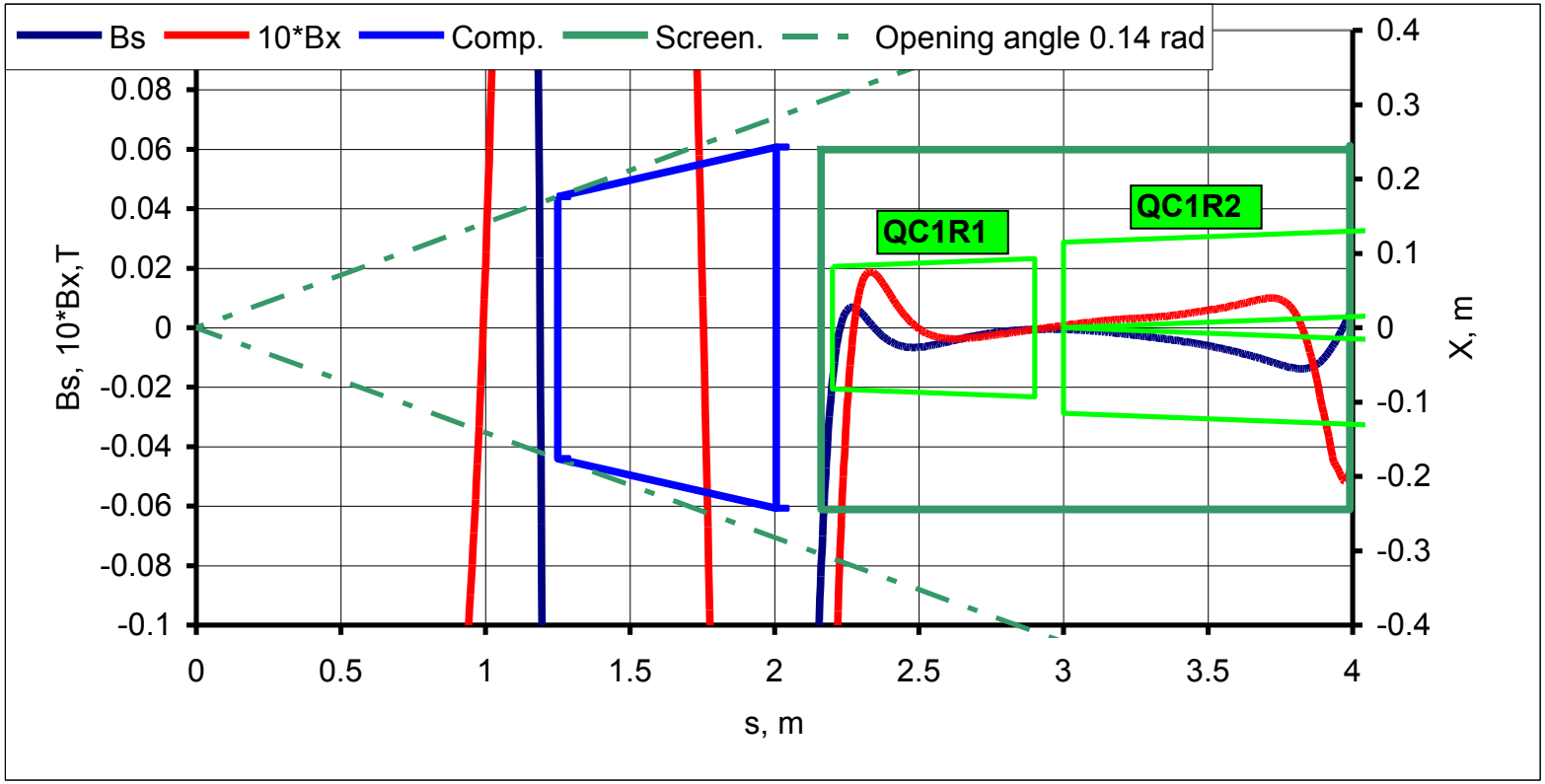
# Field distribution with detector iron yoke




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

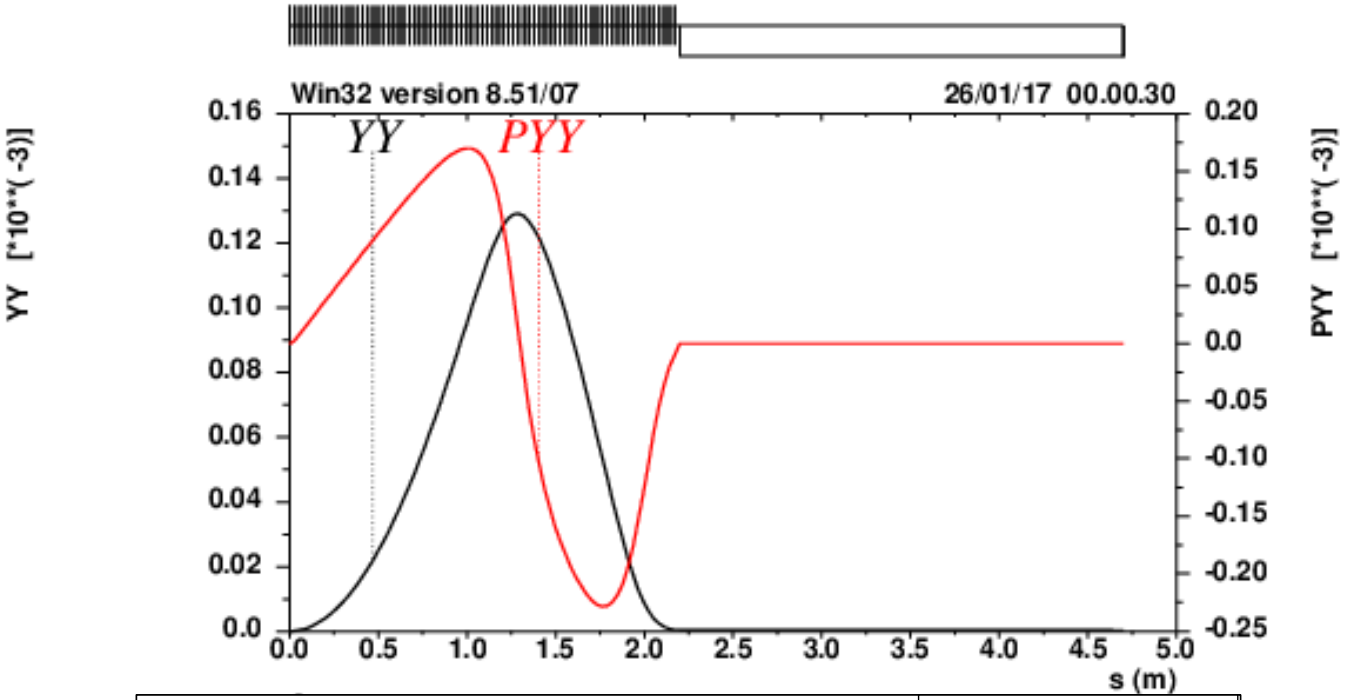
# Field distribution with detector iron yoke

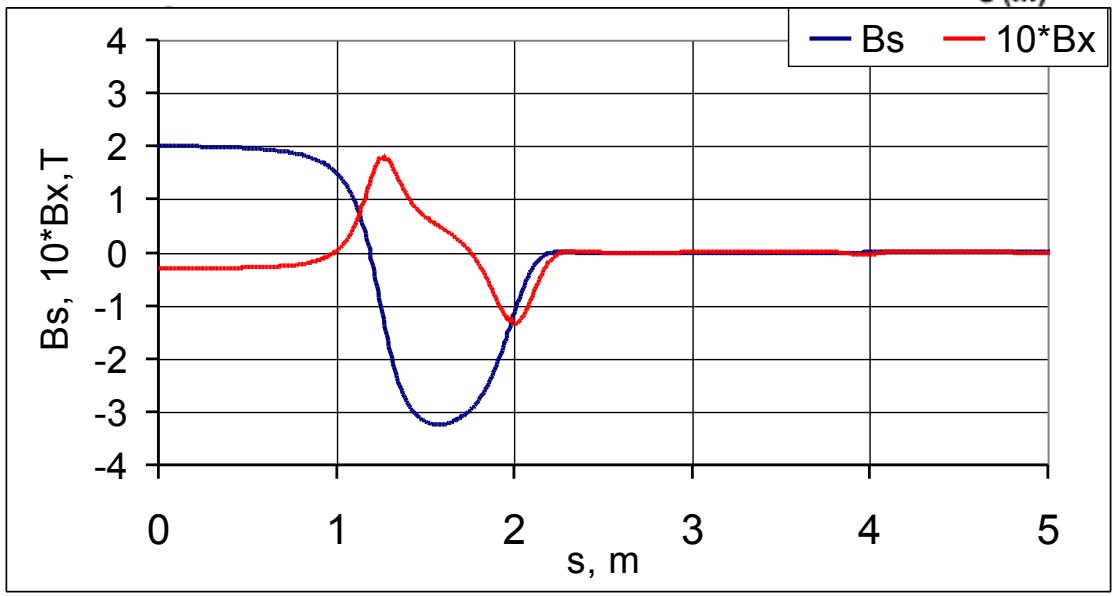



Edge field in quad area: $B_s$<0.01 T $B_x$<0.002 T

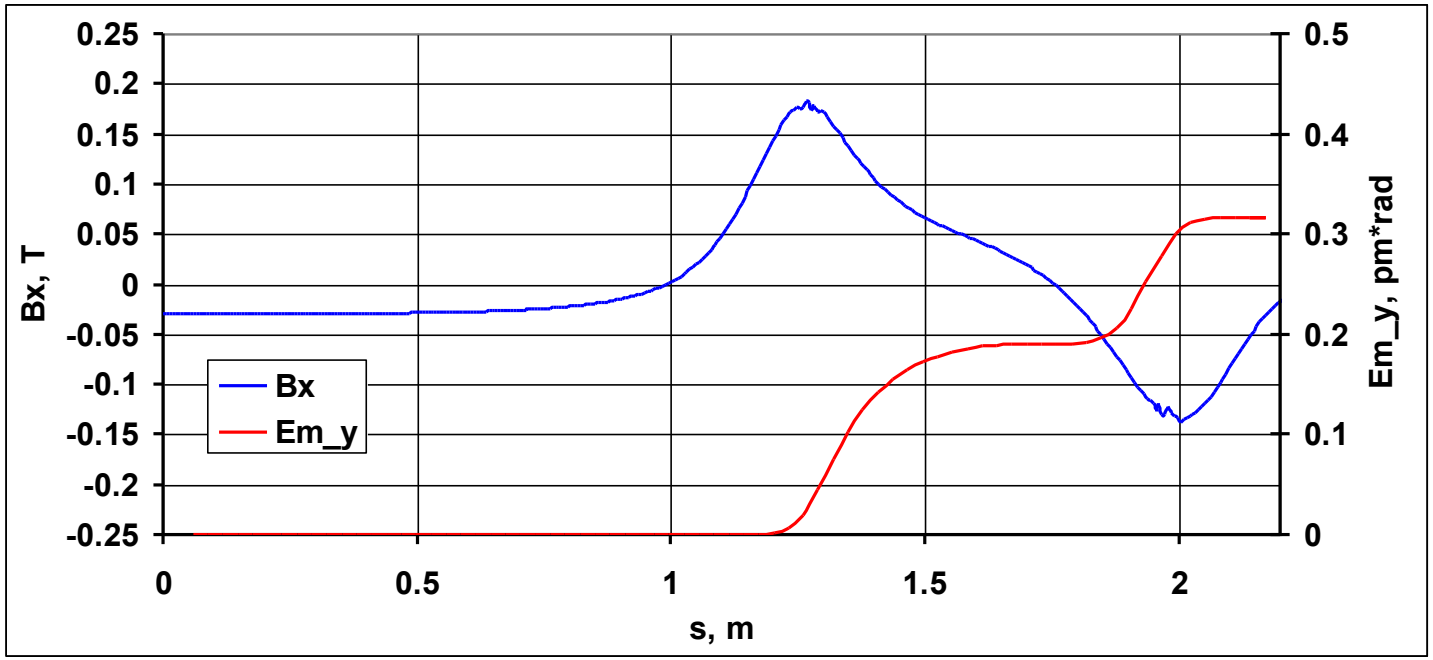
It is necessary to introduce additional corrections in the screening area and at the detector's yoke end cap.

# Beam Orbit at IR



# Emittance calculation




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

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

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

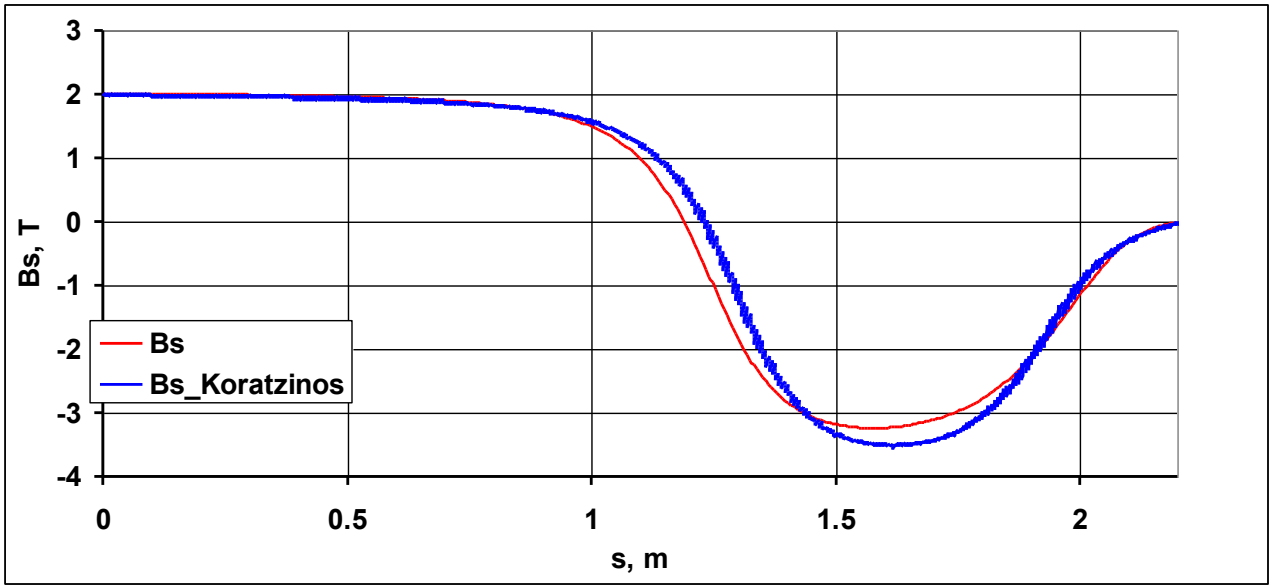
For 2 IP

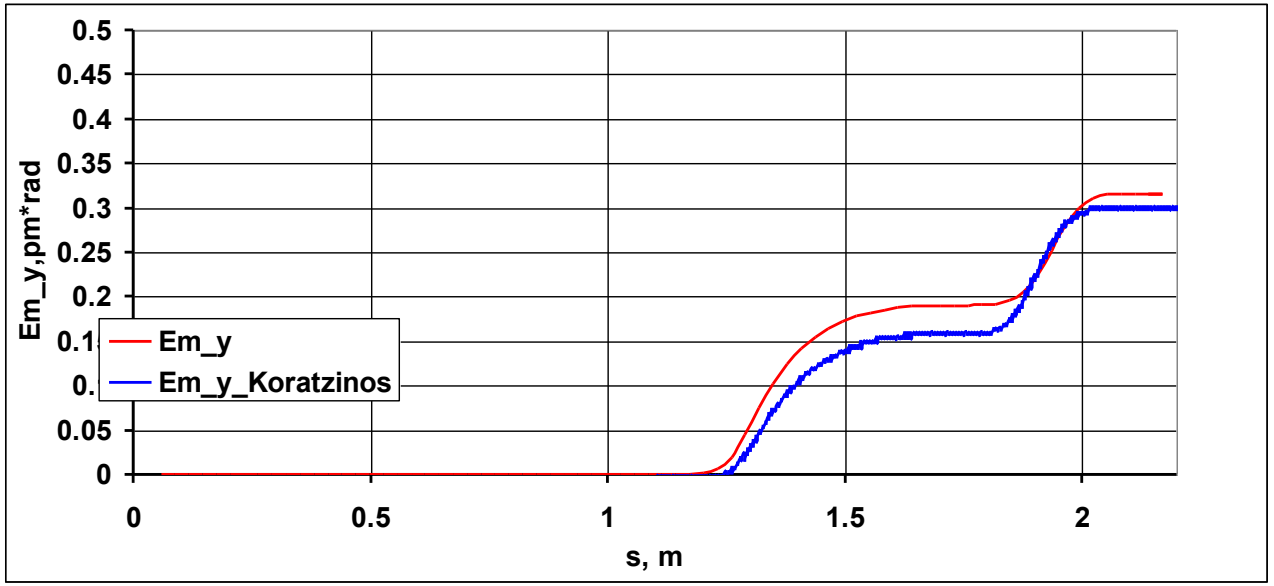
$$I_{5y} \sim B_x^5 \sim B_s^5 \qquad \varepsilon_y \sim B_x^5 \sim B_s^5$$

# Beam parameters

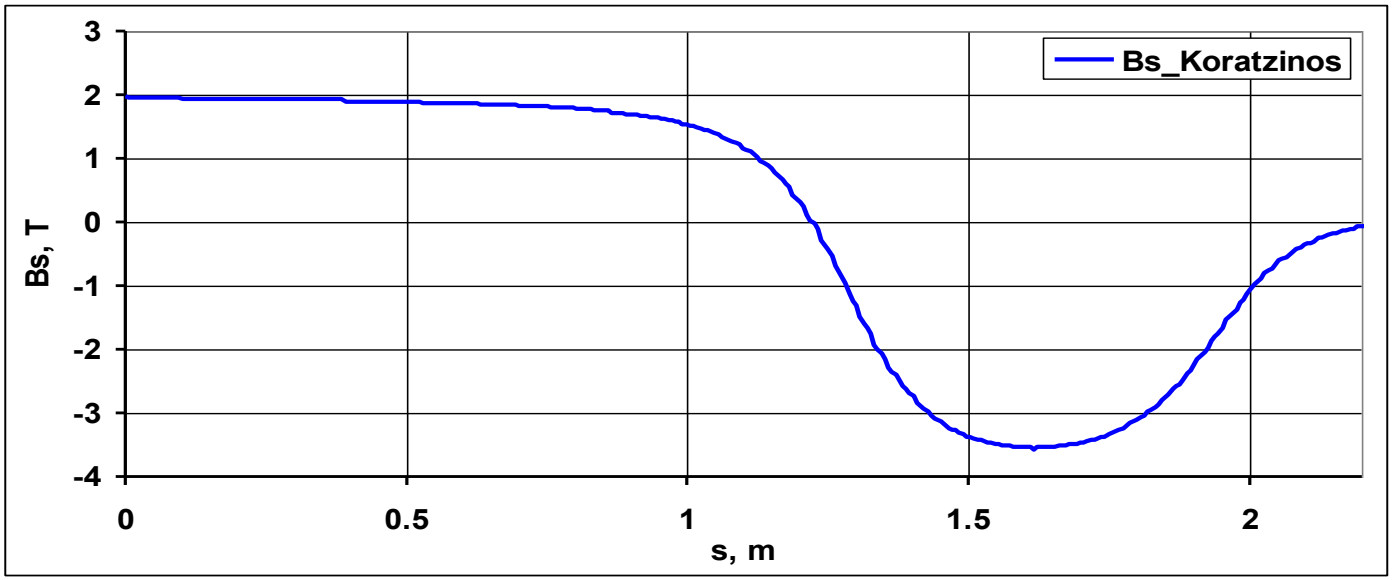
| Parameter | Unit |
|---|---|
| Beam energy, GeV | 45 |
| $Q_x$ | 0.08 |
| $Q_y$ | 0.14 |
| $\beta_{x\ IP}$, m | 0.5 |
| $\beta_{y\ IP}$, m | 0.001 |
| Emittance, pm*rad | 105 |
| Ver. Emittance, pm*rad | 0.316 |
| Emittance Ratio (v./h.) | 0.003 |
| Energy spread | 2.4E-04 |
| Energy loss of particle 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) | $6.00*10^{-14}$ |

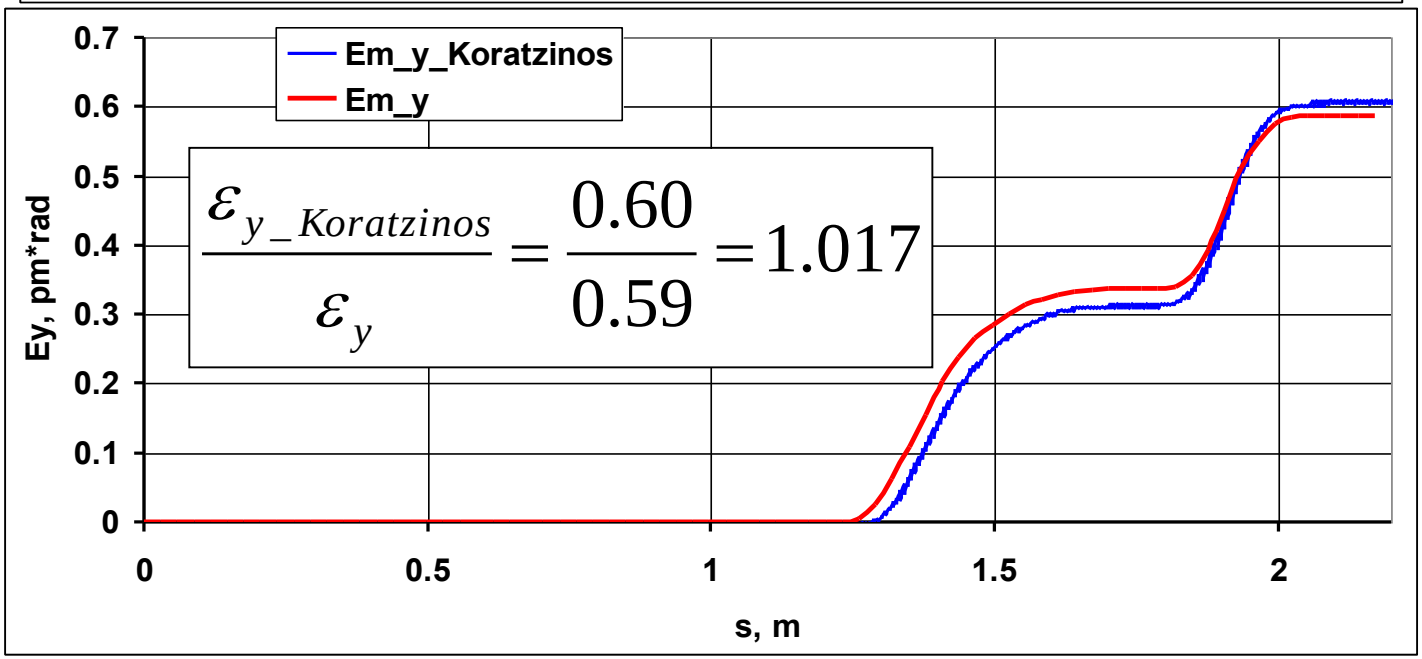
# Comparison of latest results



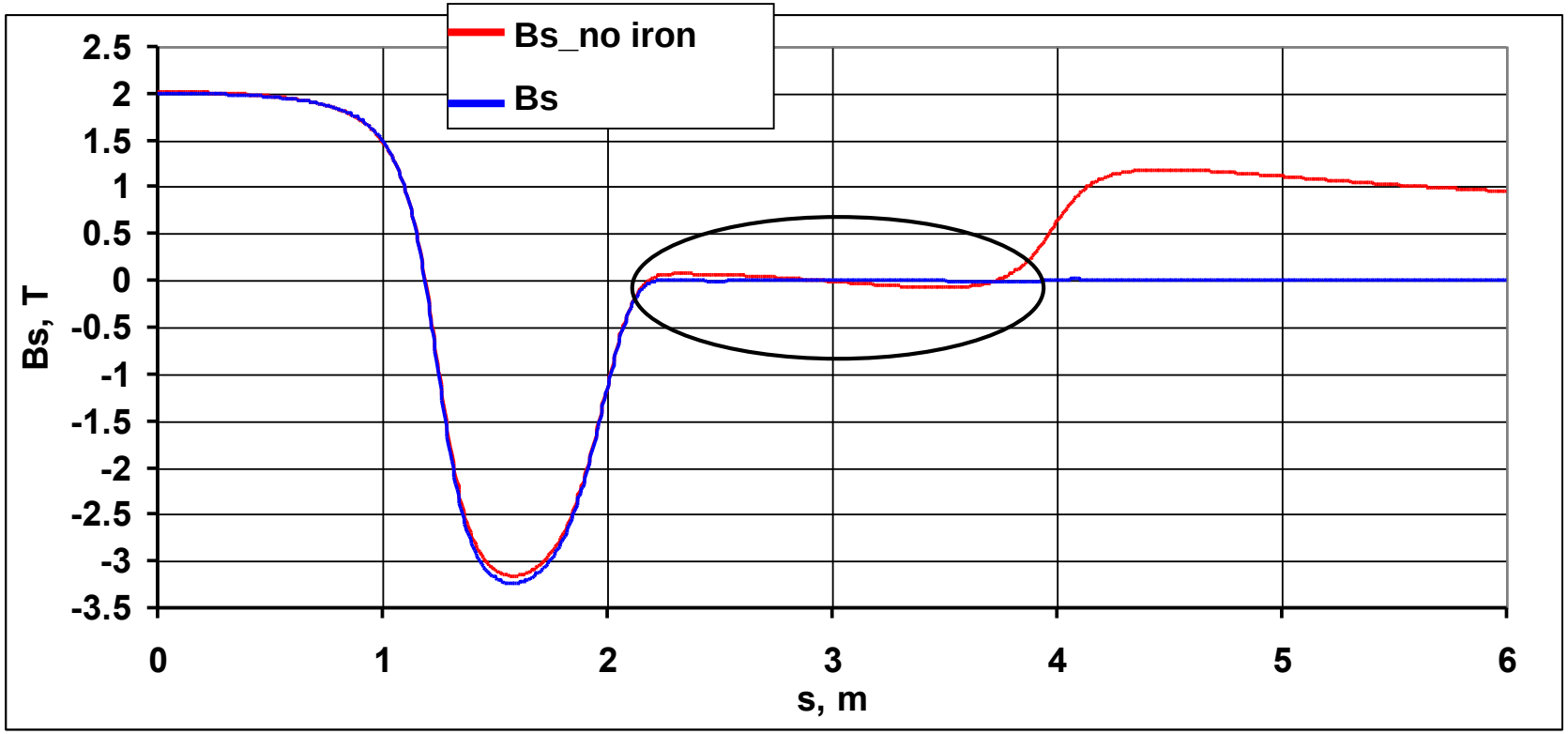



# Discrepancy of results



# 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.