STANDARD SOLENOID COMPENSATION SCHEME

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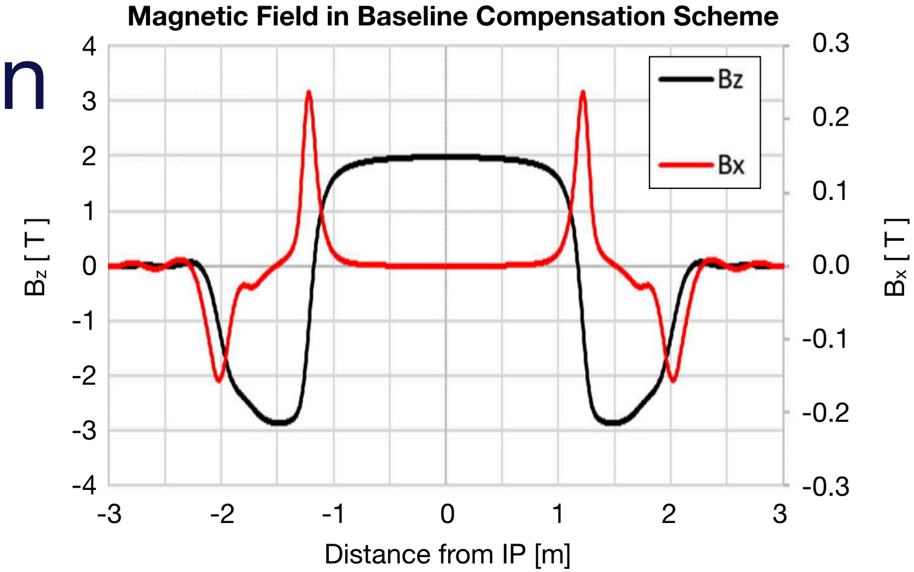
Outline

- Description of the Baseline and Standard solenoid compensation schemes
- Application of the Standard scheme to the LCCO_v87a lattice
  - Longitudinal component Bs -> Correction of coupling
  - Horizontal component Bx -> Correction of orbit
- Summary

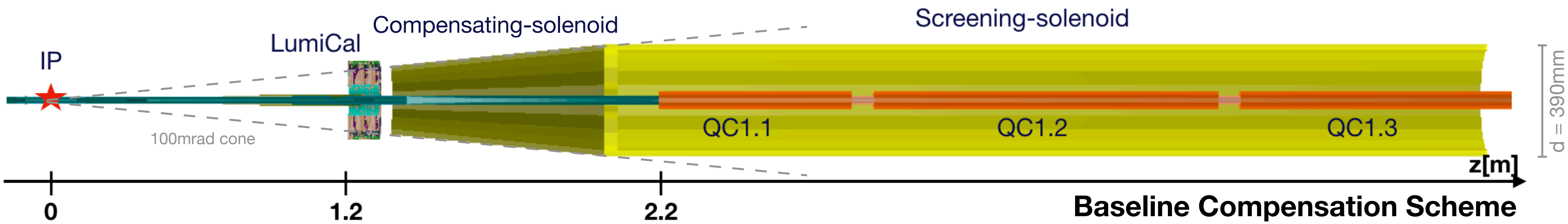
Baseline Solenoid Compensation

- -5T Compensating solenoids cancel the $\int B_z ds$ **before the FD.**
- Screening solenoids nullify the detector field in the quadrupole region



ϵ_y blowup at Z is **0.24pm** for the **2IP CDR** lattice, and **twice** this value for the 4IP lattice (nominal $\epsilon_y = 1pm$).

- mostly caused by **fringe fields** from the compensating solenoid Bx~0.2T



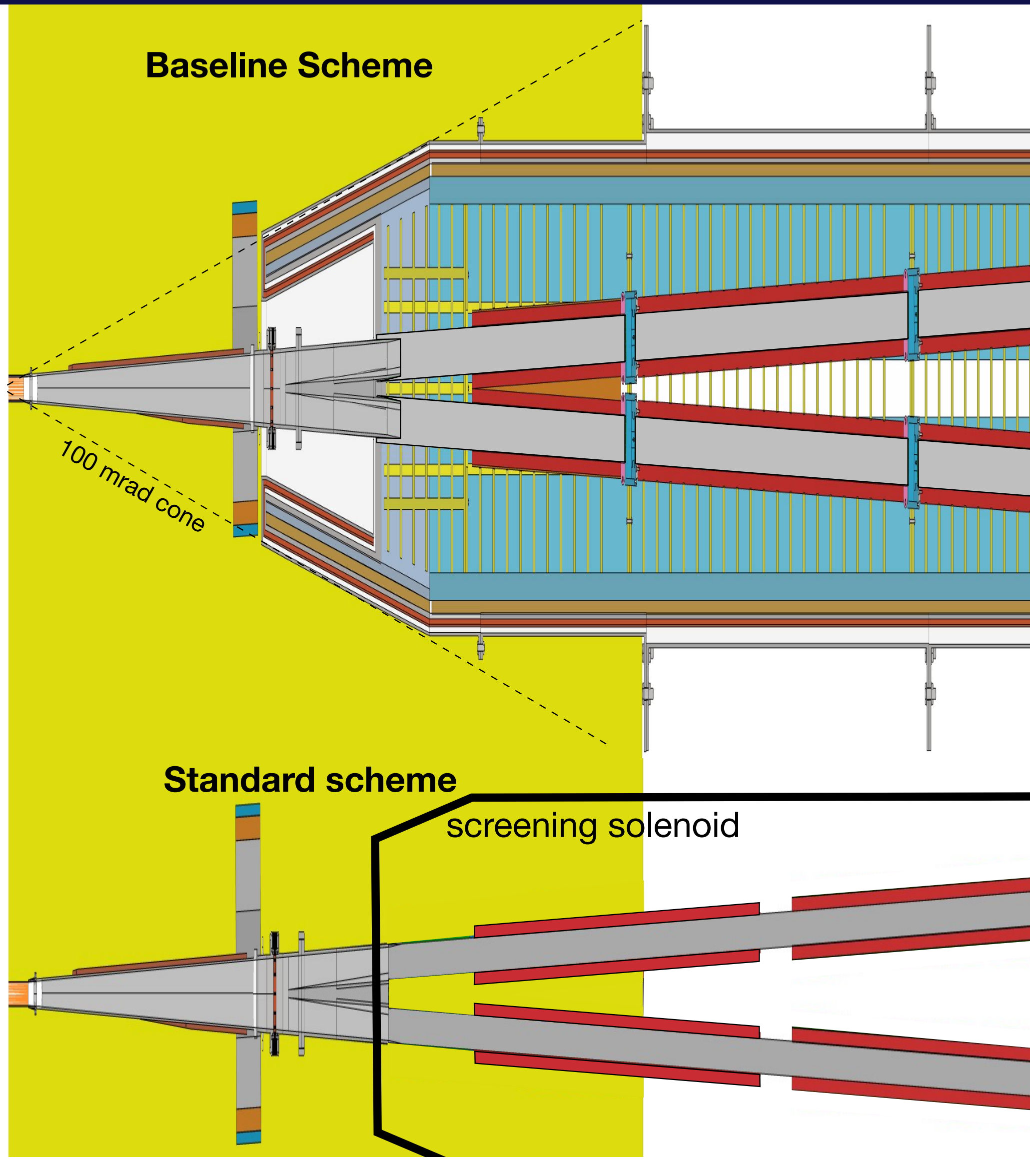
Standard Solenoid Compensation Scheme

A compensation scheme similar to that used in DAΦNE would allow for the **removal of the -5T Compensating Solenoid**

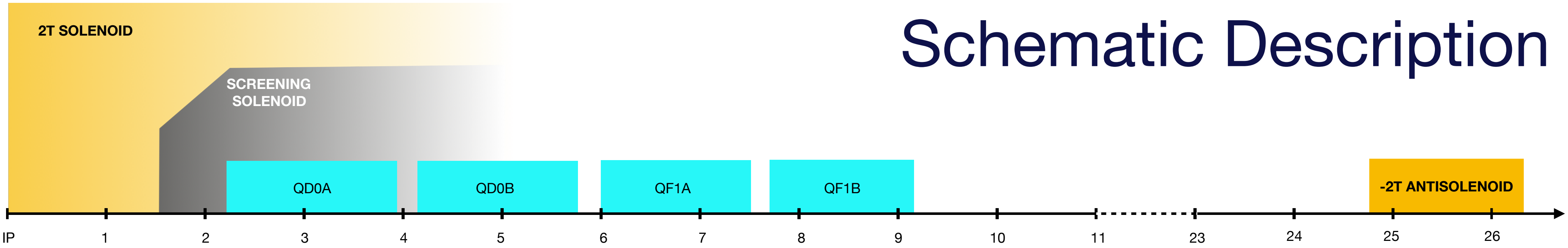
- reduced Synchrotron Radiation (now 80kW)
- avoid R&D challenges of a 5T magnet
- overall simplification of hardware requirements

Compensation is mainly achieved by **weak correctors** in the IR and **skew components** winded around the Final Focus quadrupoles.

The **Screening Solenoid** is preserved and will start as close as possible to the IP, according to mechanical constraints (bellows, flanges, acceptance, …)



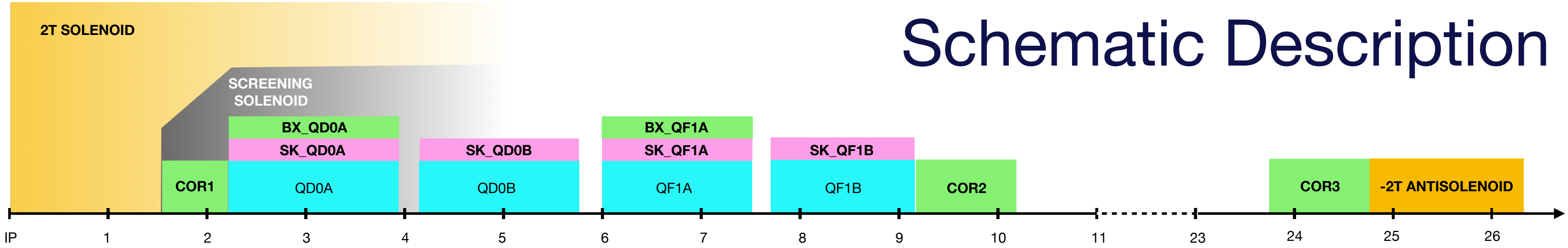
Schematic Description



Application of the Standard solenoid compensation scheme to the LCCO_v87a lattice @Z
Same elements are both Upstream and Downstream, but currents may be different due to asymmetric lattice.

- The Screening Solenoid starts at **1.5m from IP** and cancels the detector field in the FFQs region
  - may be **conical or cylindrical** according to detector angular acceptance and magnet radius
  - starting point can be varied for mechanical constraints
  - outer part will be **tapered** to match main solenoid fringe fields
- The antisolenoid is placed before the first dipole to cancel the $\int B_z ds$

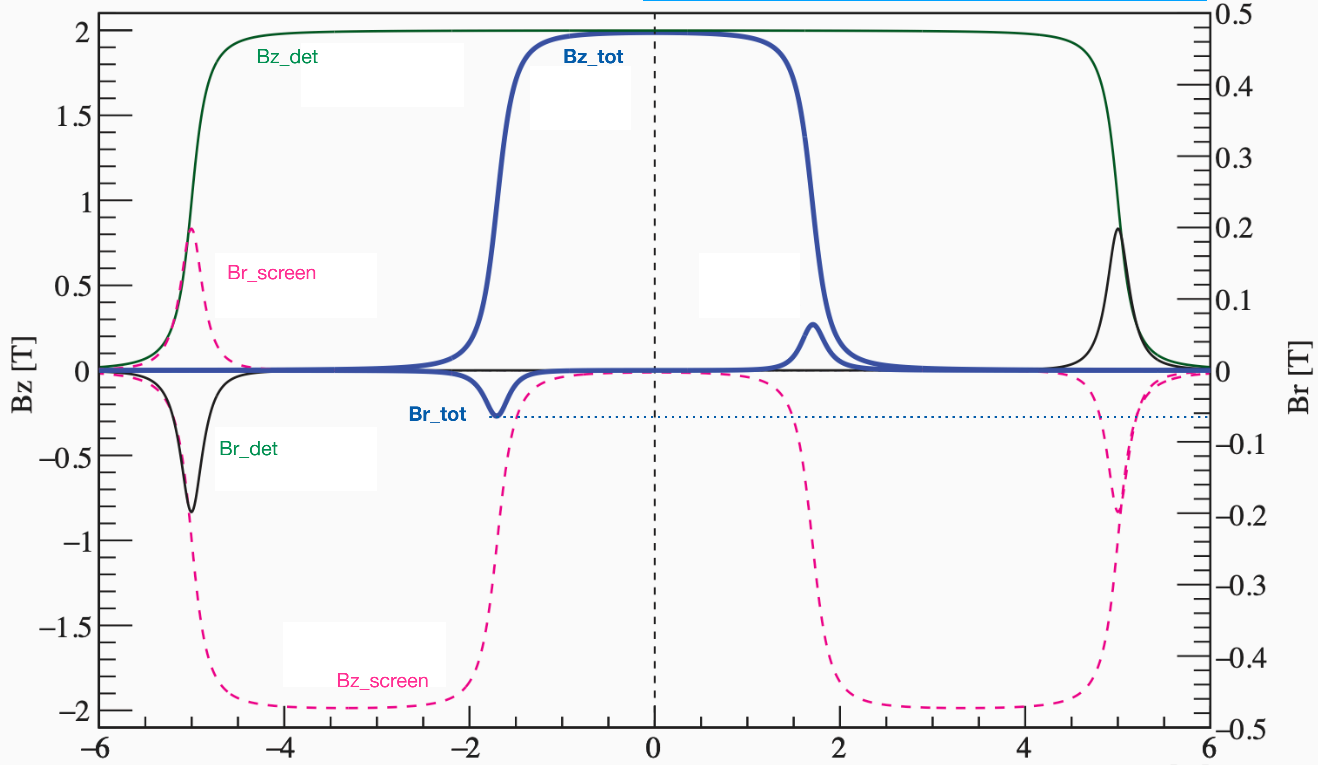
Schematic Description



- Skew components are winded around the FFQs to correct coupling due to beam transverse space rotation under Bs
- 3 **H/V correctors** (COR1, COR2, COR3) are used to close the orbit bumps due to tilted solenoid Bx
    - 3 families of **skew quadrupoles** placed at Image Point 2 and CC_Sextupoles location help matching the vertical dispersion
    - Orbit correctors are **needed regardless of correction scheme**, these are not additional elements
- **Bx components** are winded around QD0A and QF1A to control emittance growth, orbit bump and dispersion bump

Field Profile

courtesy of H. Burkhardt

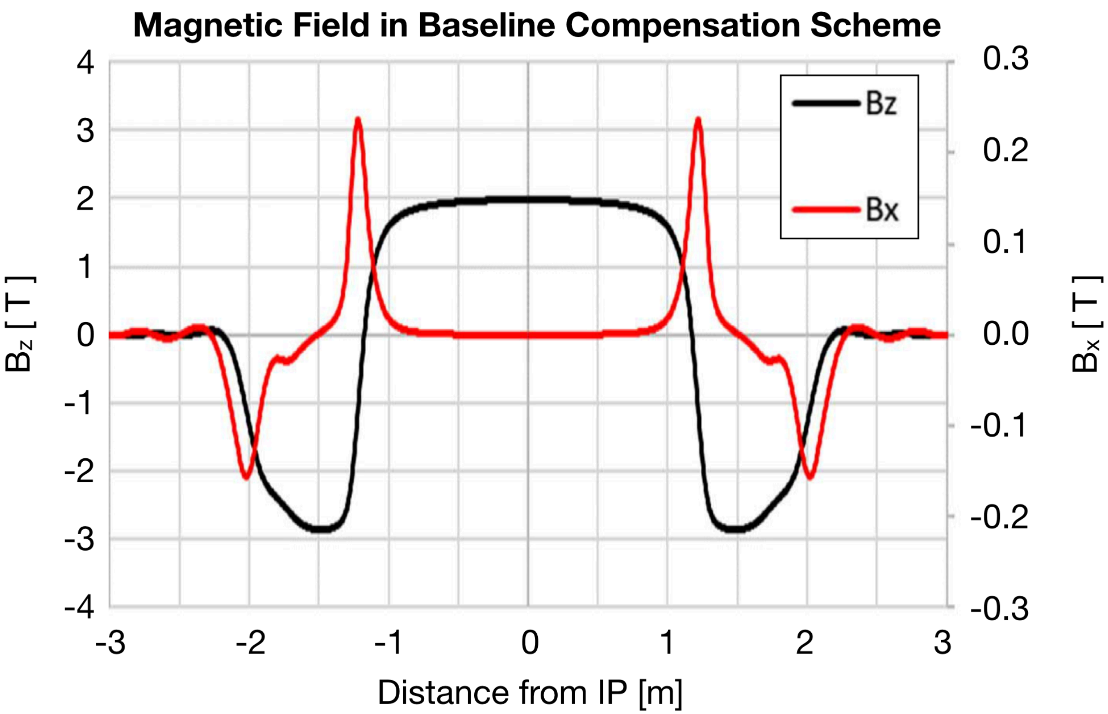


(In this plot the Screening solenoid starting point assumed to be 1.7m)

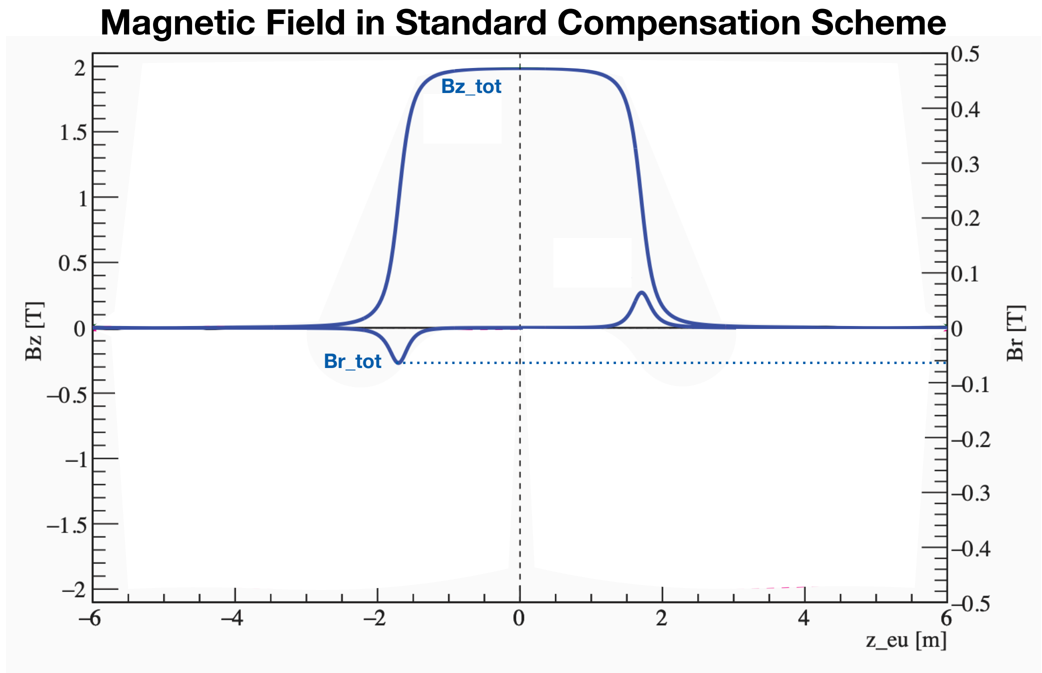
The **net effect** of both the **detector** and **screening** solenoids is similar to the field produced by a single 2T solenoid ending at the screening solenoid starting point.

The MAD-X description therefore uses only a 2T solenoid from ±1.5m for the Bs component.

Comparison of the two compensation scheme field maps



Two fringe field region (two transitions), Bx ~ 0.2T



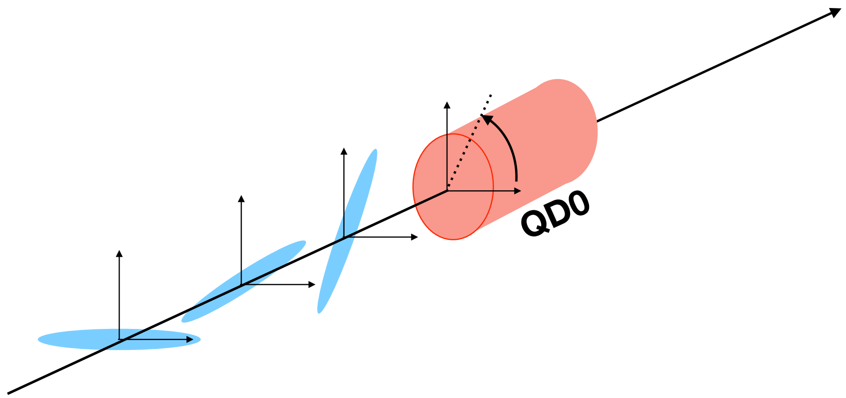
One fringe field region (only one transition), Bx ~ 0.05T

Longitudinal component B_s

The flat beam will **rotate in the transverse space** under the B_s, until it enters the screening solenoid.

$$M_{solenoid} = \begin{pmatrix} C^2 & \frac{SC}{K} & SC & \frac{S^2}{K} \\ -KSC & C^2 & -KS^2 & SC \\ -SC & -\frac{S^2}{K} & C^2 & \frac{SC}{K} \\ KS^2 & -SC & -KSC & C^2 \end{pmatrix}$$

$$K = \frac{B_z}{2B\rho} \qquad C = cos(KL) \qquad S = sin(KL)$$



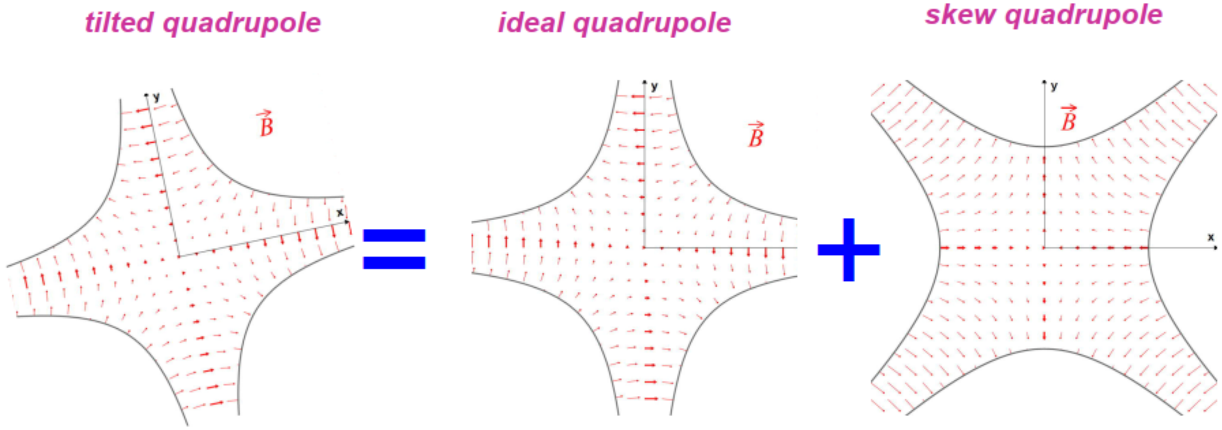
The rotation induced by a solenoid with strength $K_s = \frac{B_0}{B\rho}$ and length L is:

$$p'_y = -SCp_x \simeq -p_x KL = -p_x \frac{B_0 L}{2B\rho} = -p_x \frac{K_s}{2} L \quad \rightarrow \quad \boxed{\theta = \frac{K_s}{2} L}$$

At the Z-pole, for our scheme: $\theta = 0.00986$ rad (starting from the IP)

The beam will see a **tilted quadrupole**, which is equivalent to an **additional skew component**.

This induces coupling and therefore vertical emittance growth.



To correct this effect, we add an **opposing skew component** to the final focus quadrupoles.

This is conceptually identical to rotating the magnets on the beam reference frame, **successfully cancelling** the vertical emittance growth due to this effect.

For our scenario the corresponding skew component is: $K_{1s} = K_1 \ sin(2\theta) \sim 0.02 K_1$

MAD-X solenoid also includes the focusing effect of the fringe fields, which are very weak and are corrected by rematching the insertion.

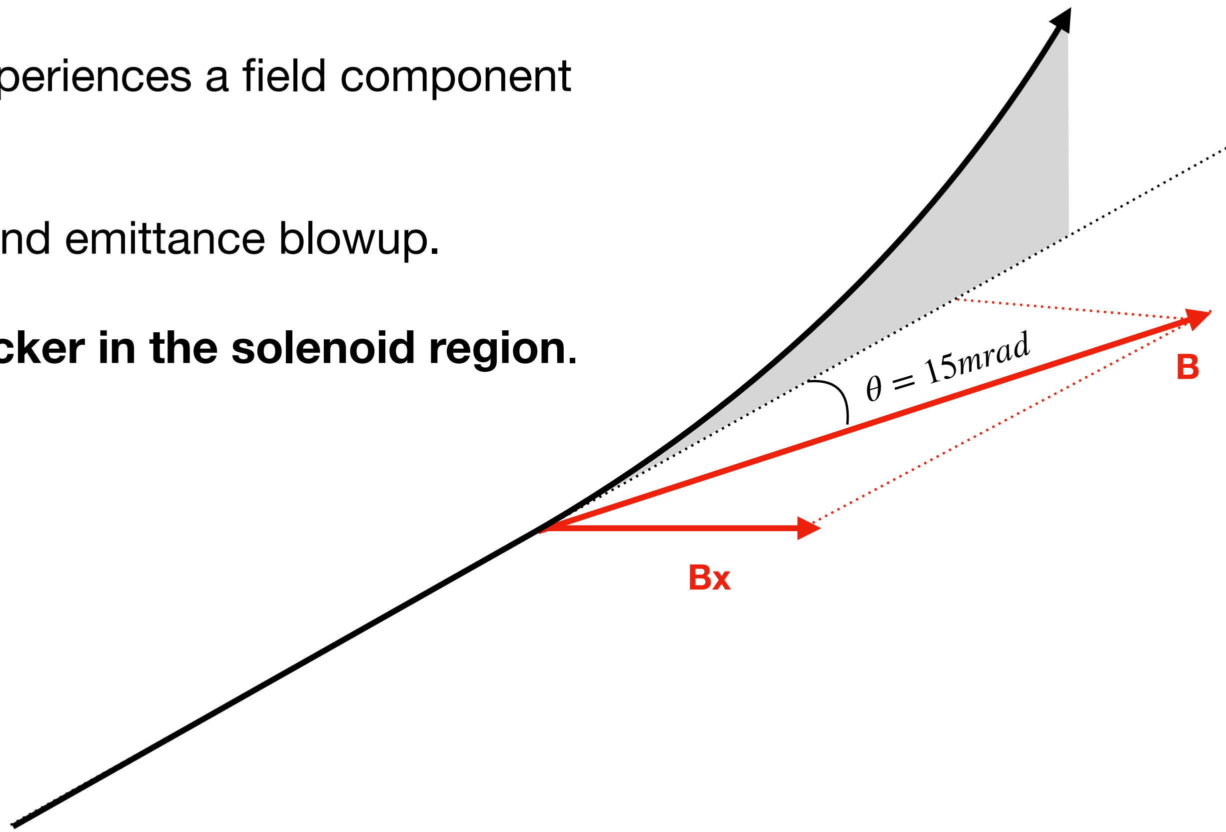
Horizontal component B_x

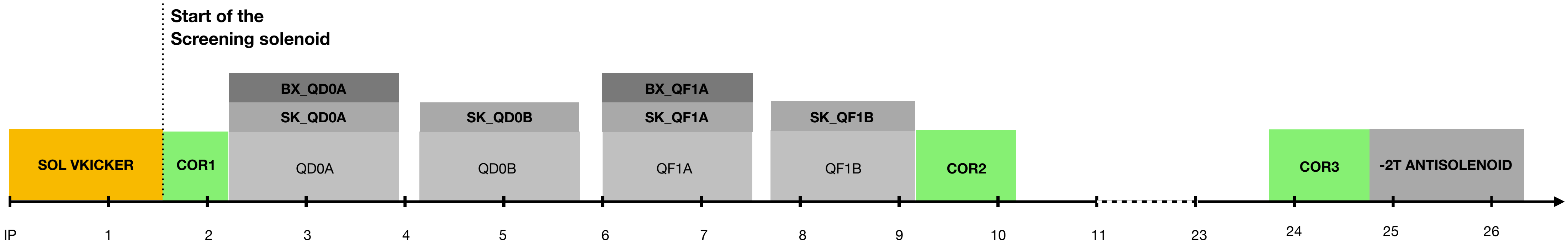
Due to the 15mrad crossing angle, the beam experiences a field component **transverse** to its direction.

This acts as a **vertical kick**, and induces orbit and emittance blowup.

In MAD-X this effect is simulated by having a **kicker in the solenoid region.**

$$\delta p_y / p_0 = \frac{B_0 L}{B\rho} sin(0.015)$$

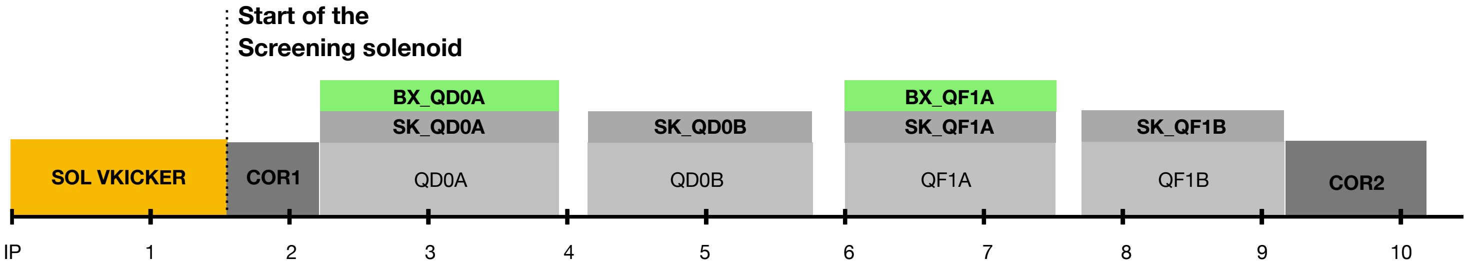




The vertical kick coupled with the rotating motion induced by the solenoid causes both **horizontal and vertical orbit.**

The bumps are closed **before reaching the antisolenoid** using the 3 H/V correctors COR1, COR2, COR3.

Matching with the optical functions of the arc is obtained using 3 **skew quadrupoles families** at the image point and at the location of the chromaticity correction sextupoles (CCS).



Vertical dipole components of QD0A and QF1A are used to adjust:

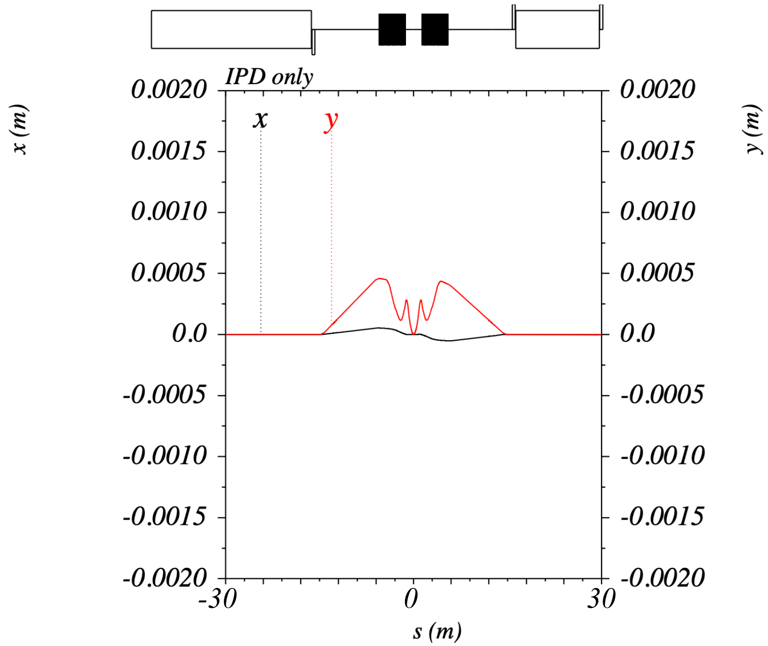
- vertical emittance < 0.05pm
- Dy bump < 1cm
- horizontal/vertical orbit bump < 0.5mm

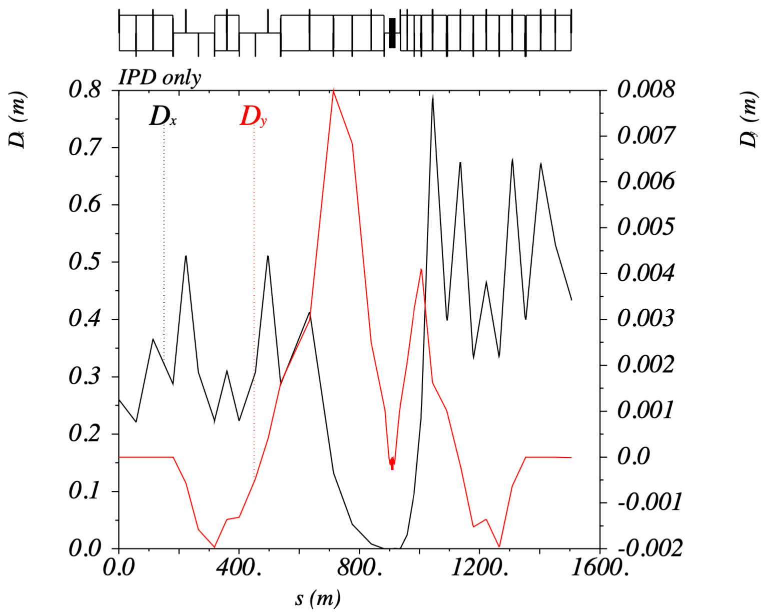
In MAD-X this is simulated by a vertical offset of the quadrupoles, which is equivalent to a vertical dipole component.

The best solution found has BX_QD0A and BX_QF1A in the order of $\mathcal{O}(0.01T)$, and produces a total vertical emittance increase of:

$$\epsilon_y = 0.039\ [pm\ rad]$$

Emittance obtained using MAD-X EMIT command





Summary

The Standard solenoid compensation scheme is described and compared to the baseline:

- Removal of the -5T Compensating Solenoid
  - SR reduction: 80kW -> 10~15kW
  - avoid R&D challenges on 5T solenoid
  - overall simplification of HW requirements

The application of the Standard solenoid compensation scheme to lattice LCCO_v87 has been presented

- Correction achieved with magnetic elements already foreseen in the lattice
  - coupling production is effectively corrected by **weak skew components** in FFQs
  - dispersion and orbit bumps are closed using **weak H/V correctors** and **skew quadrupoles**
- vertical emittance growth in the 4IP lattice: $\epsilon_y = 0.039\ [pm\ rad]$

The exact current values and position of the knobs may vary with different optics, as the correction happens **within the Final Focus region.**

Next steps: compare Baseline and Standard compensation schemes on the same lattice; improve description of solenoid fringe fields using dedicated set of kickers.

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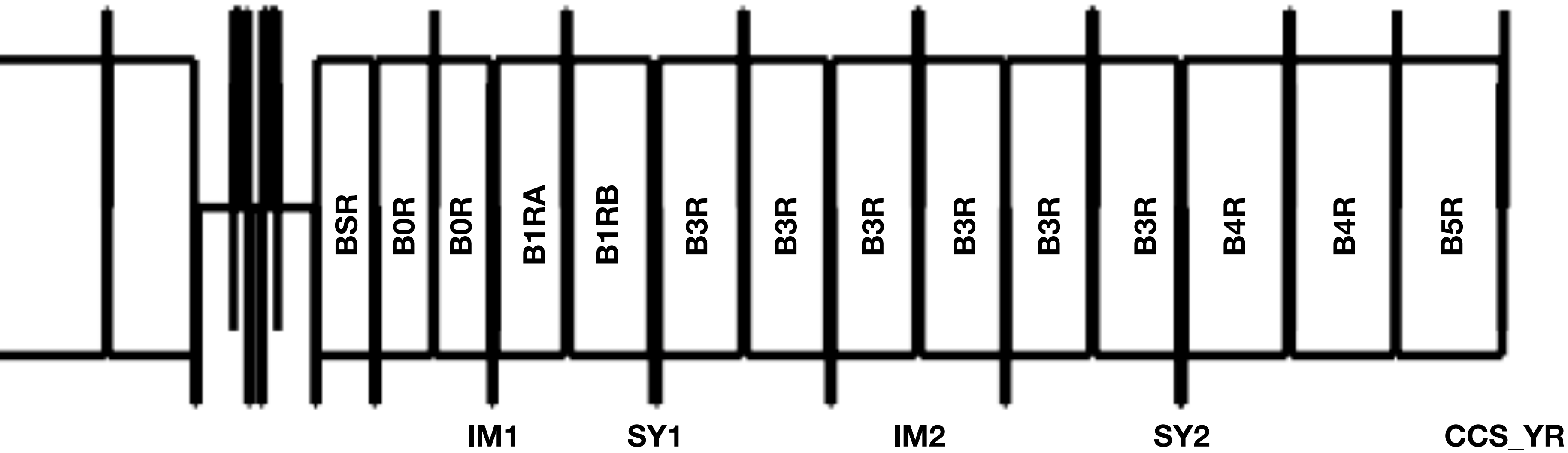
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B5R
IM1
SY1
IM2
SY2
CCS_YR