Shielding of FCC CLD fringe field: a few initial thoughts

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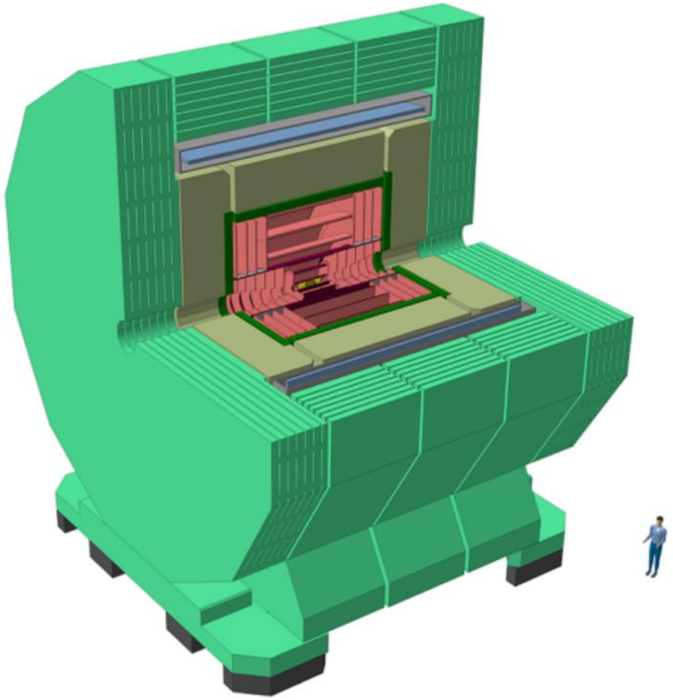
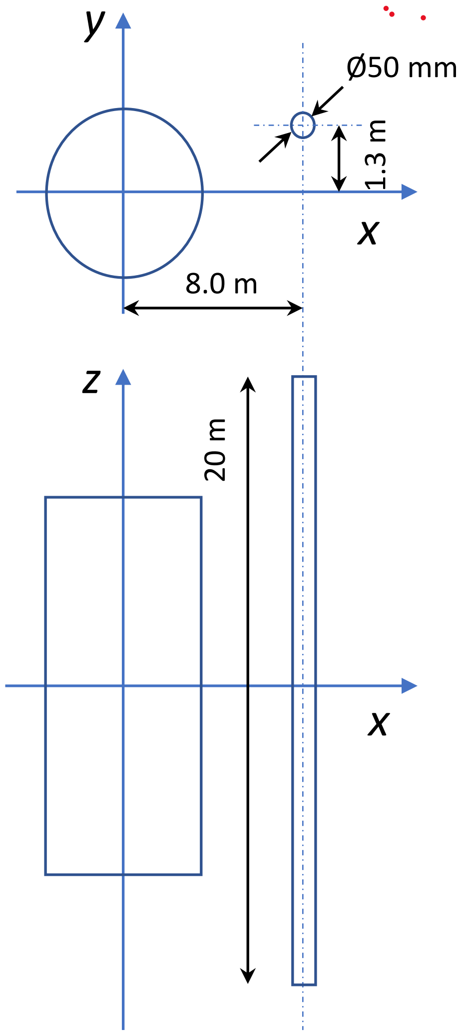
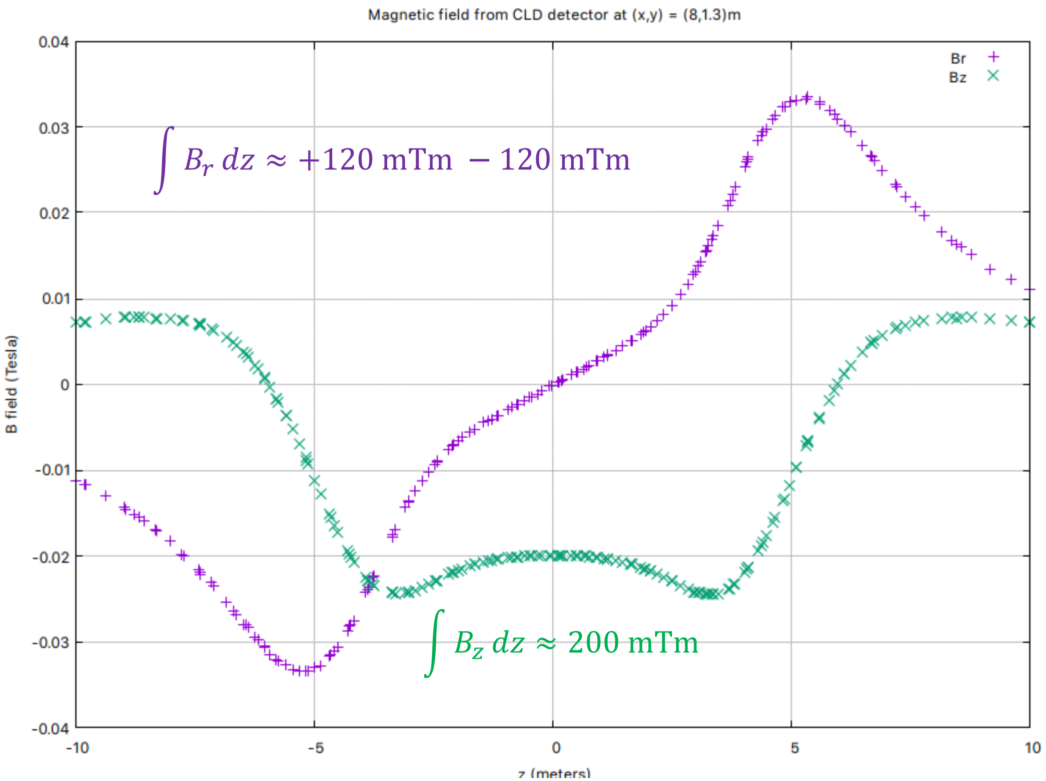


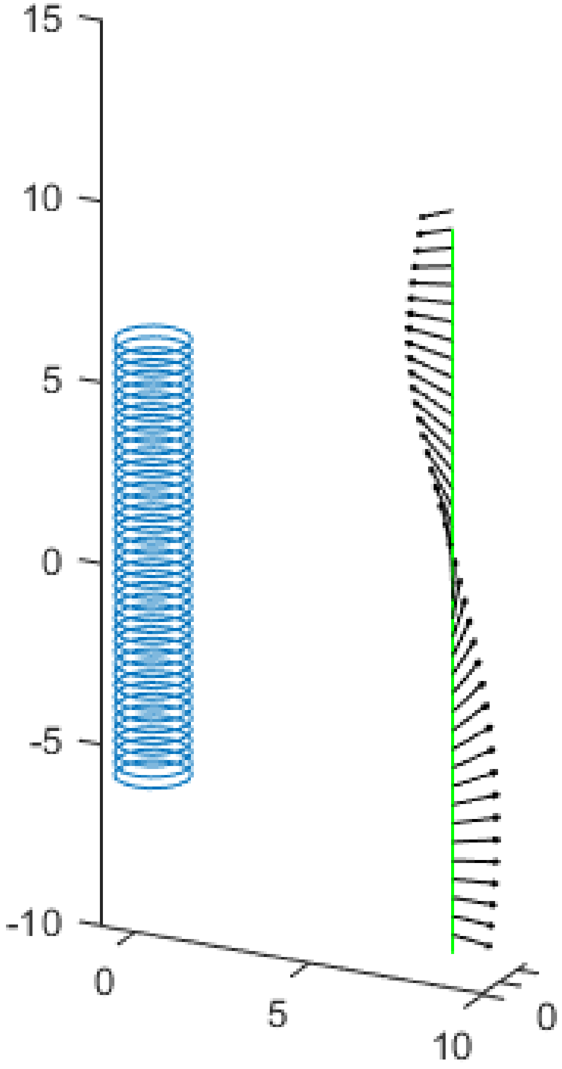
FUTURE CIRCULAR COLLIDER
Detector Concepts Meeting
Monday 3 Apr 2023, 14:30 → 16:00 Europe/Zurich

Fringe field of CLD solenoid at booster beam line





$\|\boldsymbol{B}\| \leq 35\text{ mT}$



Qualitative Biot-Savart model

A few questions:

- Definition of B_r (modulus of component transverse to booster beam line ?)
- Must we cancel out B_r on average, or everywhere ? Down to what level ?
- Must we shield also B_z ?
- Length of booster beam line to shield ?

Mitigation of fringe field effects – an aide-memoire

- Increase size of source magnet iron yoke (very costly ! And probably it is already optimized….)
- Passive ferromagnetic shields: *see next slides*

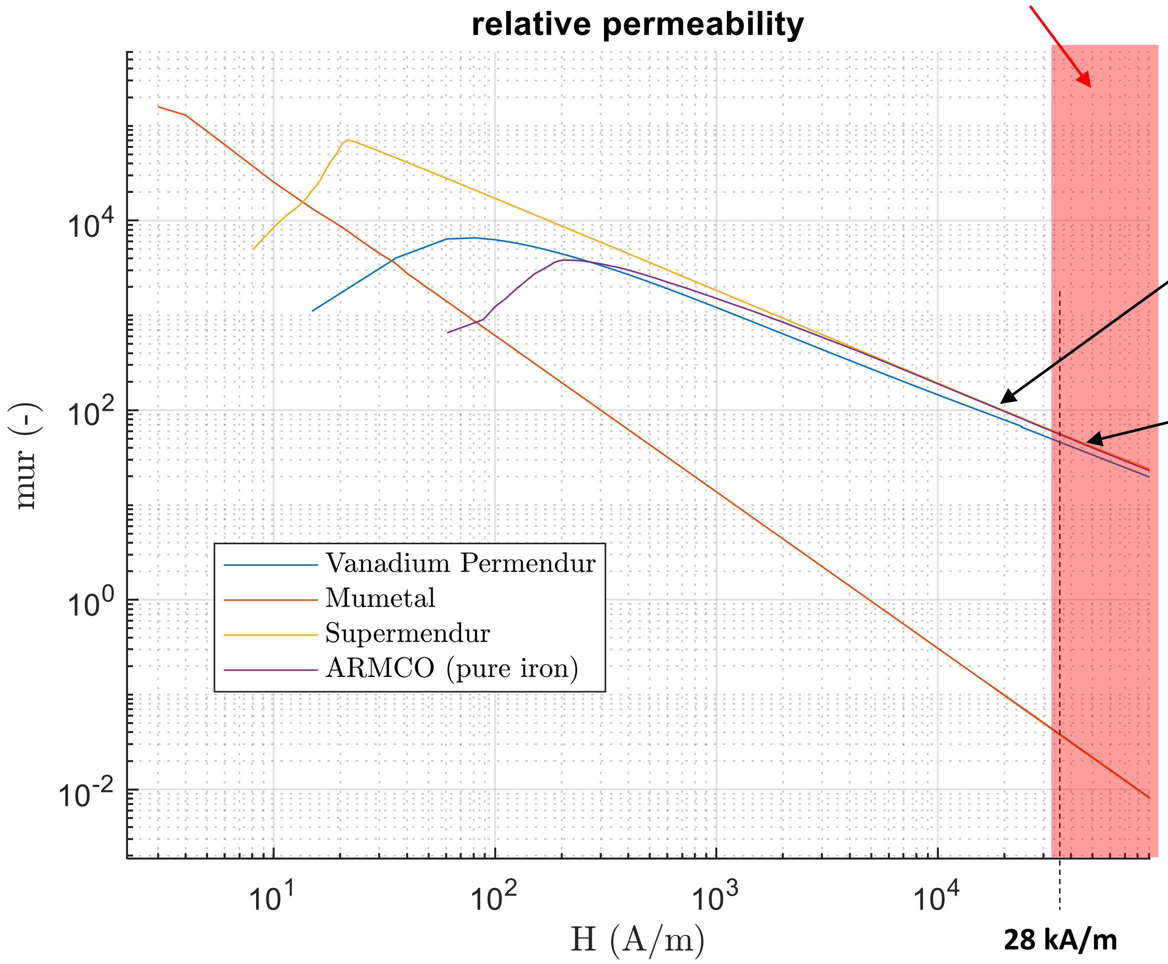
  - massive shield between magnet and beam line
  - thin shell around beam line
- Passive superconducting shields (SuShi-style): complexity, cost …
- Active shielding:

  - counter solenoids (like in MRI magnets): best results, costly, require full redesign
  - distributed compensation coils at beam line *see next slides*
- Classic correction with lumped magnetic elements

MNPA25-04 SPS corrector
200 mTm @ 600 A

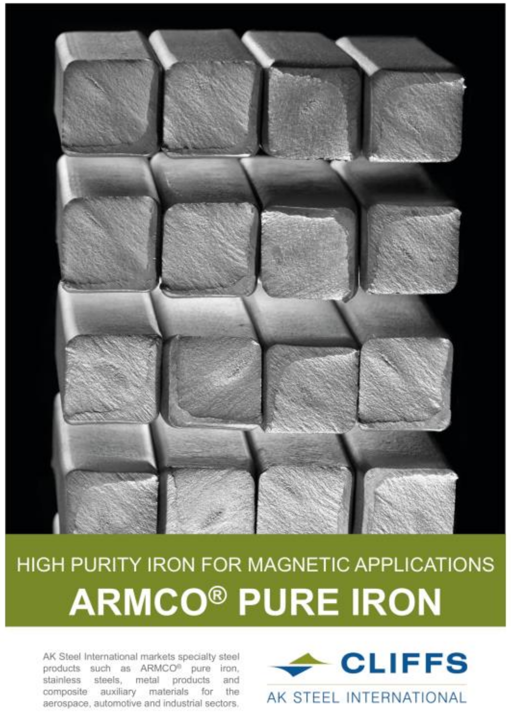
Choice of ferromagnetic shielding material for *B*=35 mT, *H*=28 kA/m

Extrapolated values
(current RT test limit 24 kA/m)



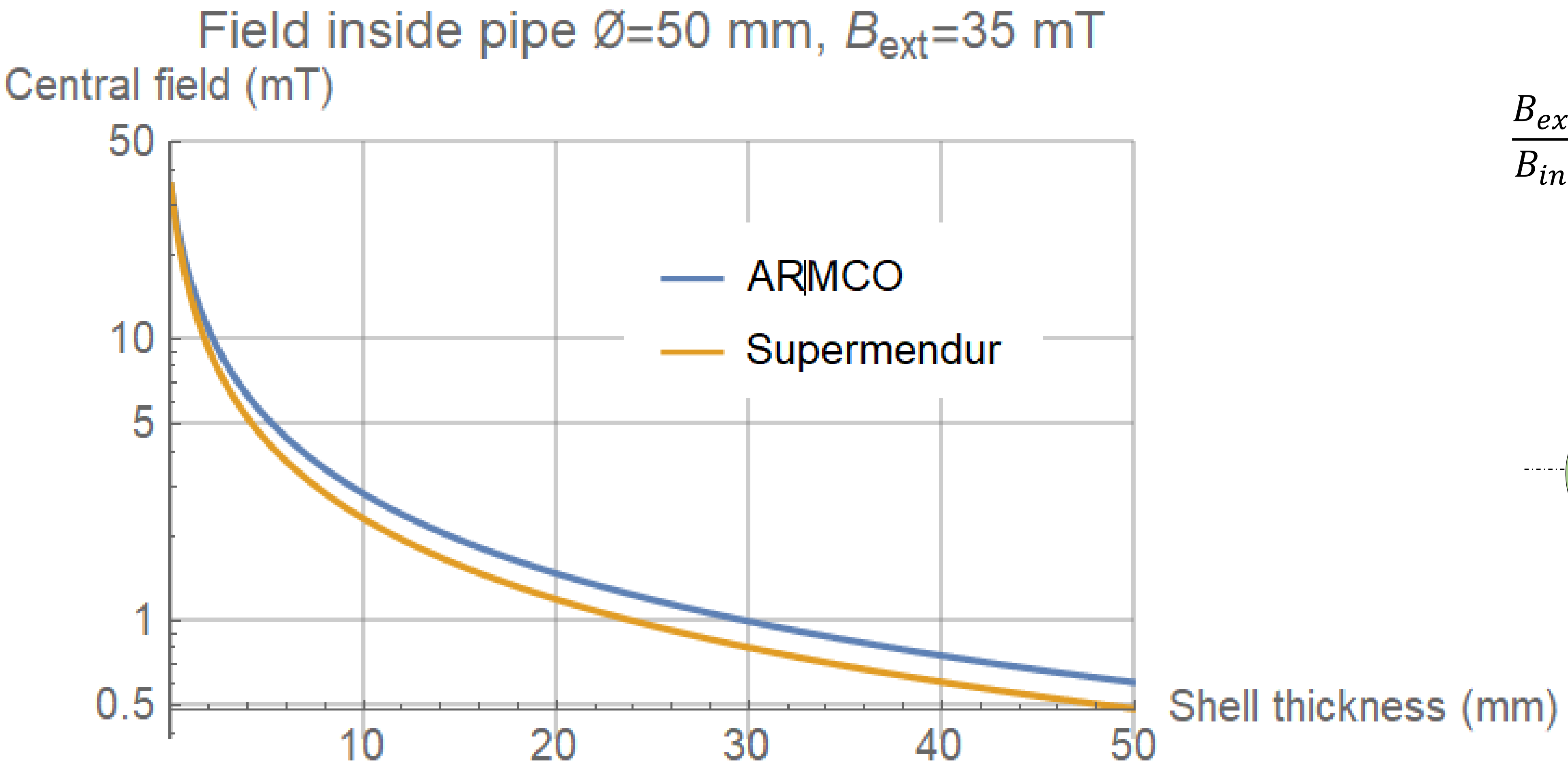
Supermendur Co50Fe48Ni1 $\mu_r \approx$ **71**
(tape 180 USD/kg on Alibaba)

ARMCO pure iron $\mu_r \approx$ **57**
(sheet 4 CHF/kg in CERN stores)

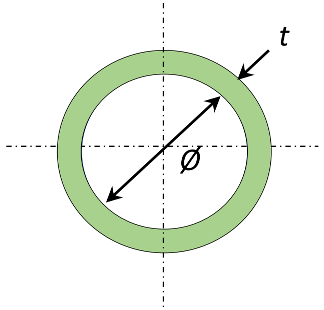


Thin, single-layer cylindrical ferromagnetic shield – transverse field attenuation

- 10 mm of Permendur → attenuation factor ≈ 15
- Multi-layer shields (external shells with higher permability) commonly used



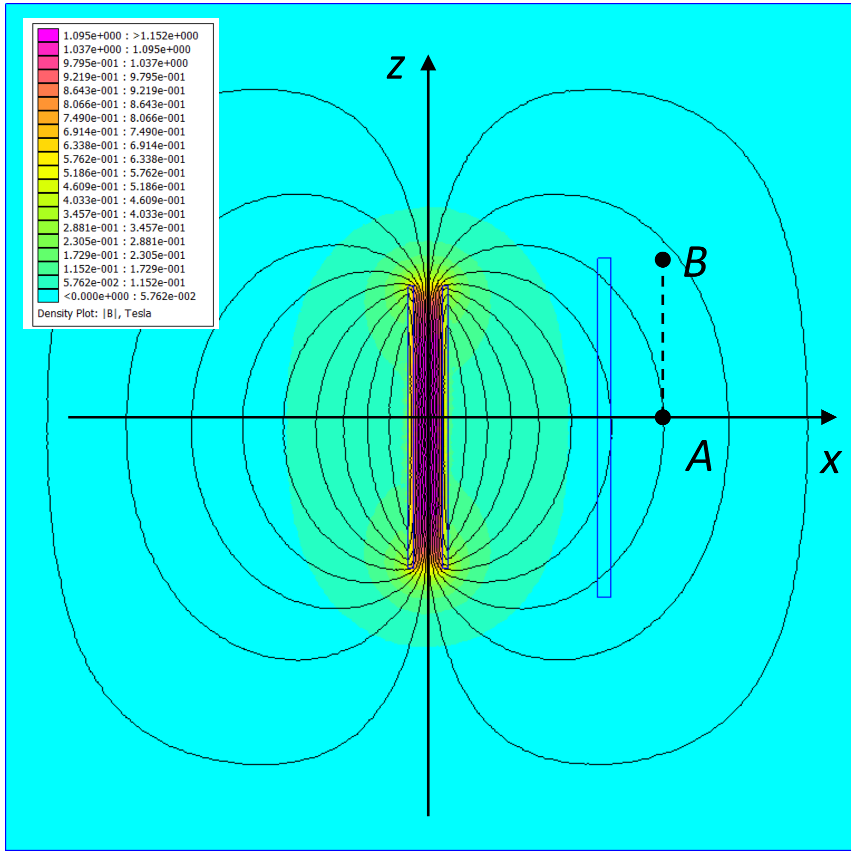
$$\frac{B_{ext}}{B_{int}} \approx 1 + \mu_r \frac{t}{\emptyset}$$

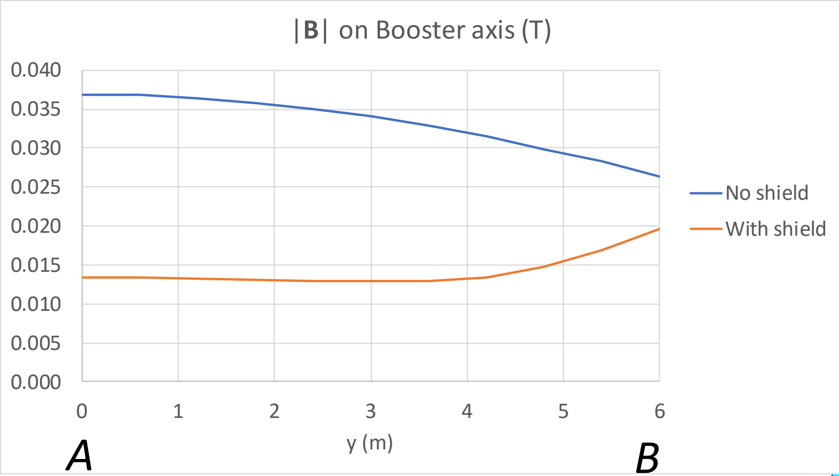


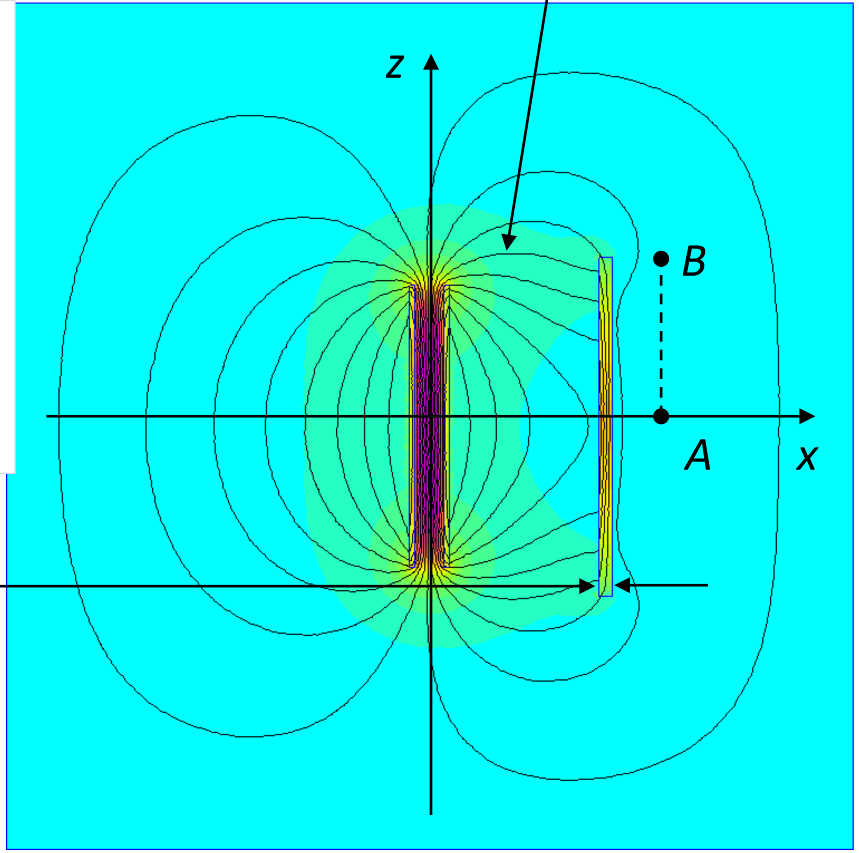
Massive iron shield between CDS solenoid and booster beam line

- Example 2D calculation: yokeless solenoid B_0=1.16 T
- Unshielded fringe field along booster beam line (A-B) 26~37 mT
- 0.5 m thick solid ARMCO shield, μ_r=50
- Shielded field 13~20 mT, mean attenuation factor ≈ 2.8

Some field distortion to be expected end regions (even with iron yoke)







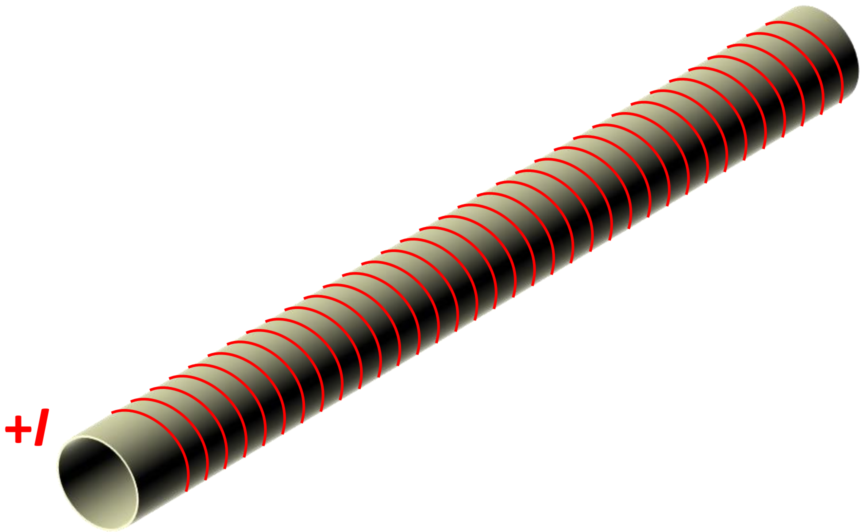
0.5 m ARMCO steel

Active shielding – compensation coils

- Longitudinal component $\mathbf{B_z}$ **= 20 mT**

  Solenoidal winding $\rightarrow$ $\frac{N_t I}{L} = \frac{B_z}{\mu_0} \approx 16\ \mathrm{A/mm}$

- (e.g. ~8 mm^2 of air-cooled Cu/longitudinal mm)

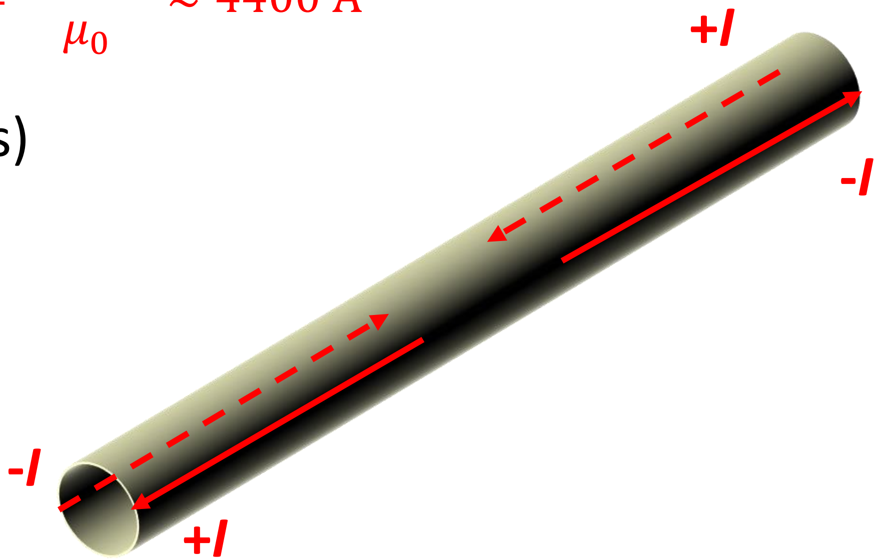


- Transverse component $\mathbf{B_r}$**=35 mT**:

  If local shielding needed in each half beam pipe $\rightarrow$ $I = \frac{\pi\ \text{Ø}\ B_r}{\mu_0} \approx 4400\ \mathrm{A}$

  (e.g. 440 mm^2 of water-cooled Cu on either side)

  (Possible alternatives: SC windings, permanent magnets)



Preliminary conclusions

Shielding a 35 mT stray field is not entirely trivial ….

- Passive shielding at source generally much more costly/impactful than shielding at target
- Passive shielding with ferromagnetic material around beam pipe: looks feasible, available clearance should be checked
- Passive shielding with bulk superconductor (SuShi style): absolutely best performance, at a cost …
- Active local compensation also seems feasible
- Classic integral lumped correction: probably the simplest solution

Requirements and mechanical constraints to be detailed, for a reasonable choice to be made