The ELENA Electron Cooler - Requirements and Magnet System

Lars V. Jørgensen, BE-OP

ELENA Review – Oct. 14, 2013

The Need for Electron Cooling

- Electron cooling essential in ELENA to counter emittance blow-up caused by the deceleration process.

- To prepare bunches with sufficiently low emittance for extraction to the experiments via the electrostatic extraction lines.

- Cooling needed at 2 momenta: 35 MeV/c and 13.7 MeV/c.

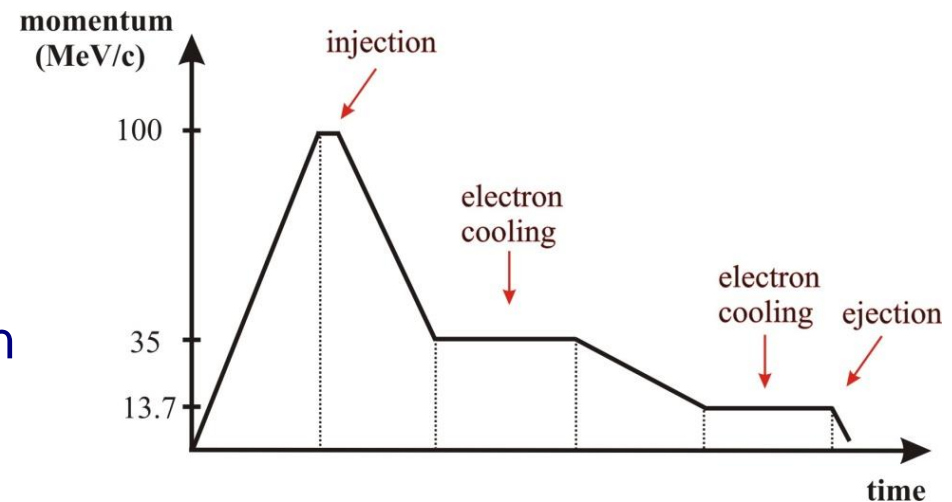- Expected emittances prior

  to cooling:

  @ 35 Mev/c:

  $\varepsilon \sim 50 \ \pi$ mm mrad

  $(\Delta p/p) = \pm \ 2 \ \times \ 10^{-3}$

- Needed emittances at extraction

  $\varepsilon \leq \ \sim 3 \ \pi$ mm mrad

  $(\Delta p/p) \leq \pm \ 1 \ \times \ 10^{-3}$

Must be very compact!

E-cooler length

Must fit in Section 4 incl. solenoid compensators and correctors.

~ 2 meters available for the electron cooler.

Space constraints also necessitate 90° bends on relatively small radius (25 cm)

Further requirements

- Operate at very low electron energies (down to 55 eV).
- Operate at very low magnetic field to minimize disturbance to circulating low energy antiprotons – we have chosen 100 Gauss in the cooler.
- Have extremely good vacuum.
- Adiabatic expansion to reduce transverse temperatures.
- Very good field quality – especially in the cooler solenoid ($B_{\perp}/B_{\parallel} < 5 \times 10^{-4}$).
- Orbit correctors and solenoid compensators.

Electron Cooler parameters

Momentum (MeV/c)	35	13.7
β	0.037	0.015
Electron beam energy (eV)	355	55
Electron current (mA)	5	2
Electron beam density (m^{-3})	1.38×10^{12}	1.41×10^{12}
B_{gun} (G)	1000	
B_{drift} (G)	100	
Expansion factor	10	
Cathode radius (mm)	8	
Electron beam radius (mm)	25	
Twiss parameters (m)	β_h=2.103, β_v=2.186, D=1.498	
Flange-to-flange length (mm)	1930	
Drift solenoid length (mm)	1000	

 - requirements lead us to look for inspiration at the very compact and relatively low energy e-cooler built by Toshiba Corp. for the S-LSR ring in Kyoto.

S-LSR electron cooler	
Magnetic field uniformity in drift solenoid	5×10^{-4}
Electron beam energy (keV)	1-5
Electron current (mA)	50-400
Gun perveance (µP)	2.2
B_{gun} (G)	1500
B_{drift} (G)	500
Expansion factor	3
Cathode radius (mm)	15
Electron beam radius (mm)	25
Twiss parameters	$\beta_h=1.7$, $\beta_v=2.4$
Bending radius (mm)	250
Drift solenoid length (mm)	800

Magnetic system components

- Main cooler solenoid
- Gun solenoid
- Collector solenoid
- Expansion solenoid
- Reverse coil at collector
- 2 x Toroid section consisting of
    9 racetrack coils each
- Various corrector coils to
    ensure good field quality
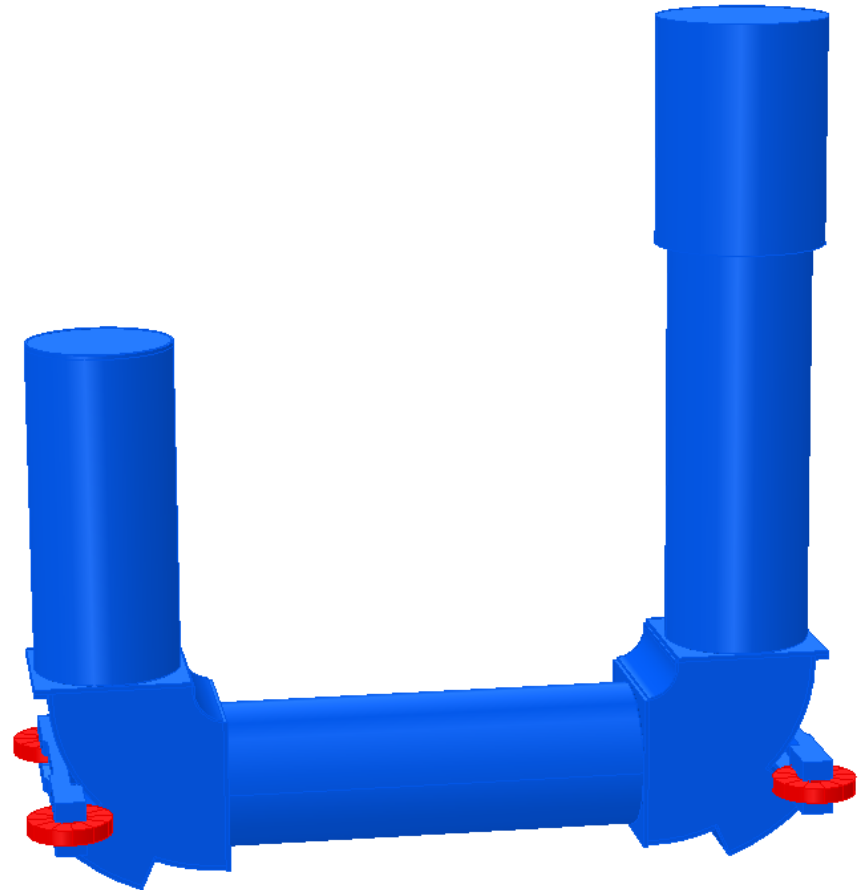- Orbit correctors
- Solenoid compensators
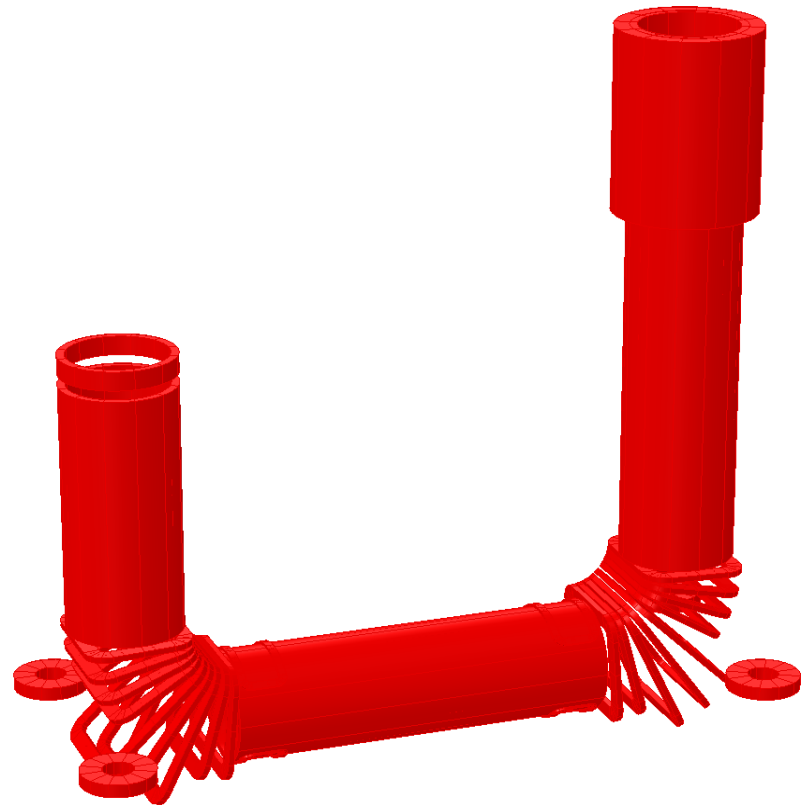
Correction coils

- Double Helmholtz transverse correctors for the 3 main solenoids – *to correct for stray fields and other remnant static fields*

- End winding correctors on 3 main solenoids – *in case it is needed!*

- Main Y correctors at the end of the cooler solenoid – *crucial to extend the good field region*

- Several (up to 8) small Y correctors inside the cooler solenoid – *for fine tuning the good field region*

- Coils inside the toroid section to steer the electrons – *if needed*

- Toroid kick orbit correctors just outside the toroids – *to cancel out the kick to the antiprotons from the toroids*

- Solenoid compensators further out – *to cancel out the horizontal-vertical coupling induced by the solenoid field*
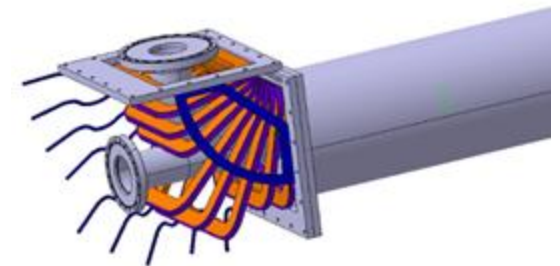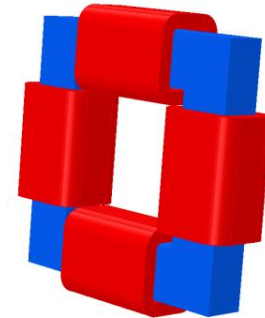
The whole package

- The whole system will be shielded to attain better field quality and to exclude stray fields - ~ 1 Gauss in the area of the AD where it will be installed.

- The electron cooler will be mounted horizontally for ease of maintenance.

Two types of orbit correctors have been studied:
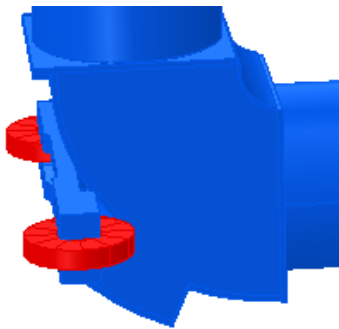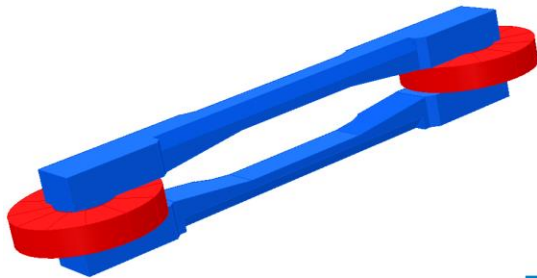
Kyoto-style
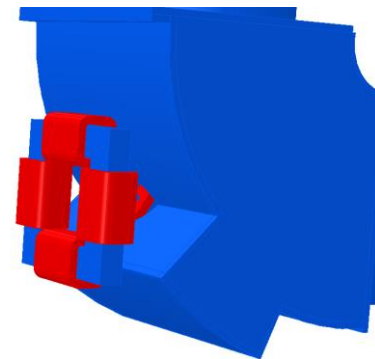
Standard

Kyoto-style is more compact
Standard is based on an existing LINAC4 design and offers the
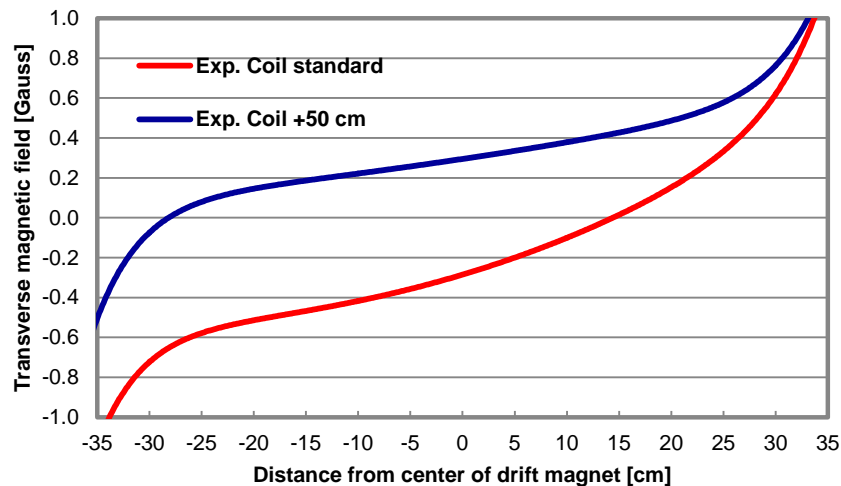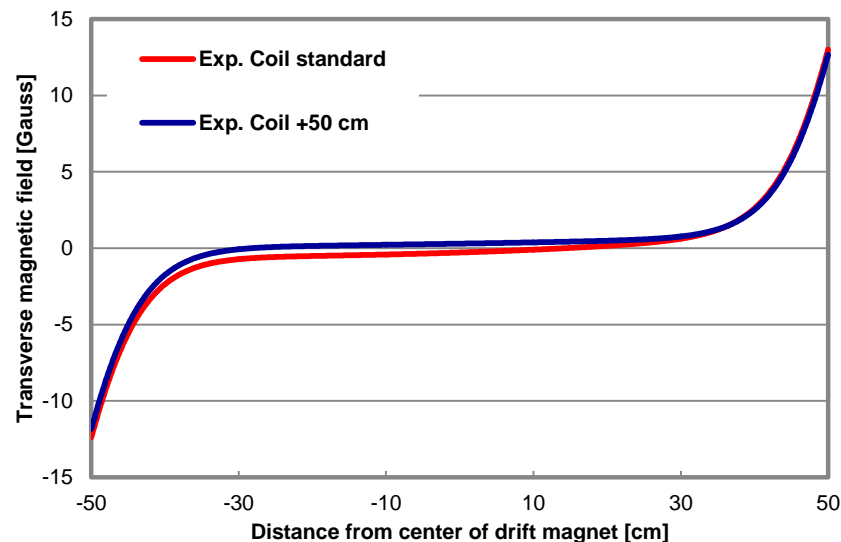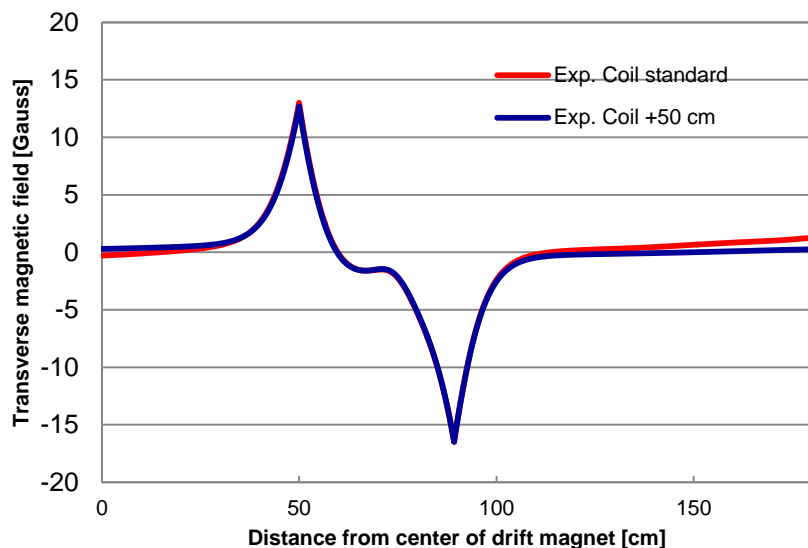possibility of a local bump (steering in both directions)

Axial field - electrons

Axial field without correction

Conclusion: The expansion coil has a significant influence on the axial field in the drift solenoid.
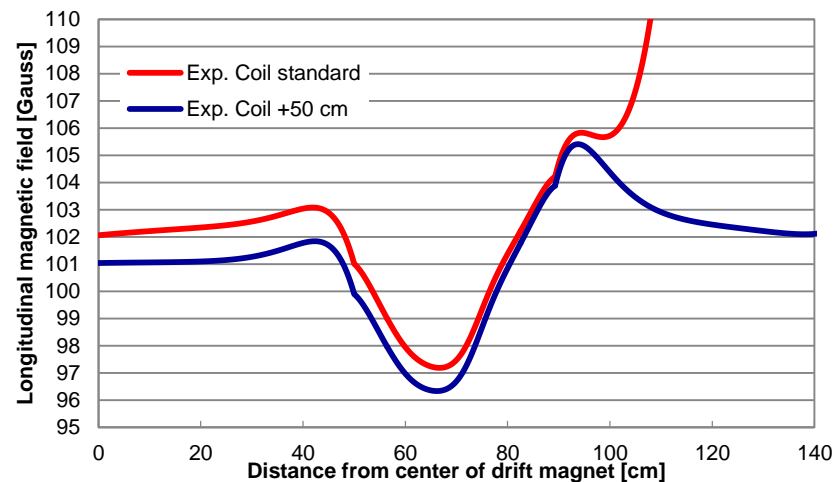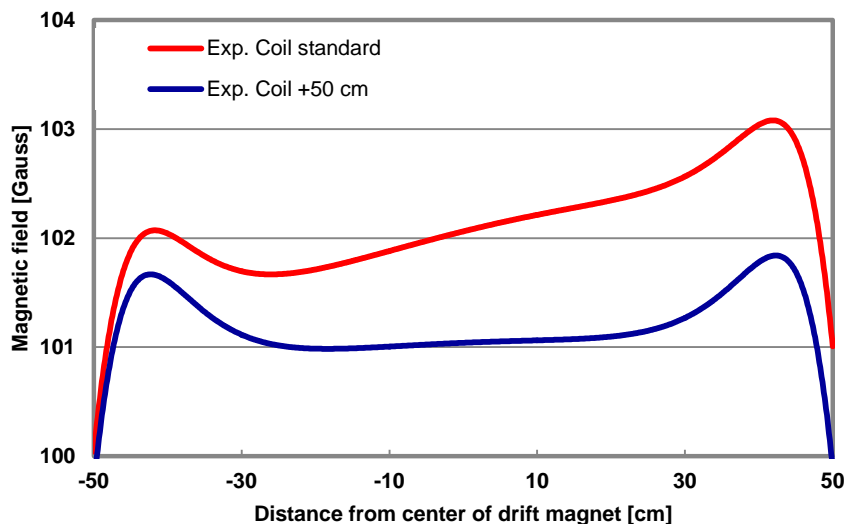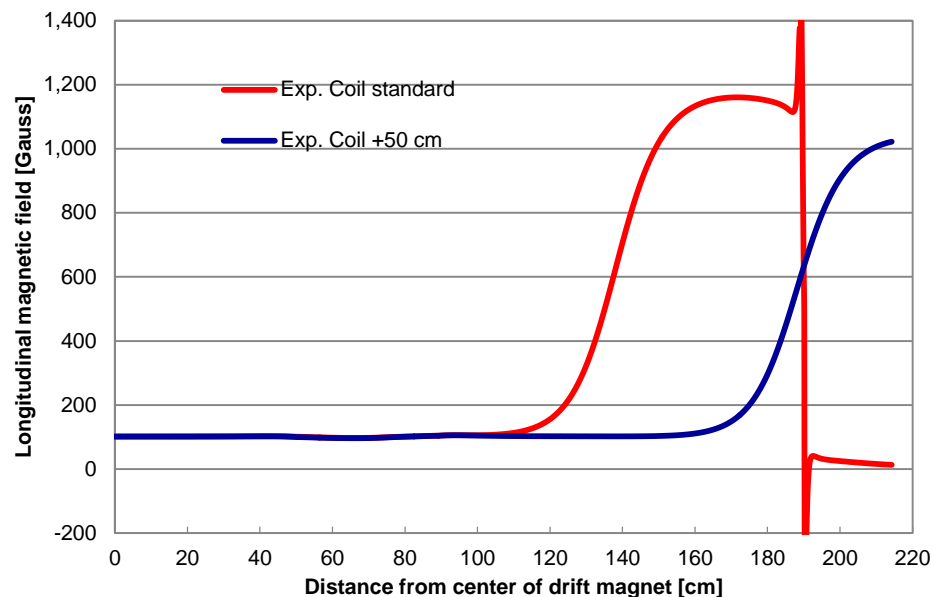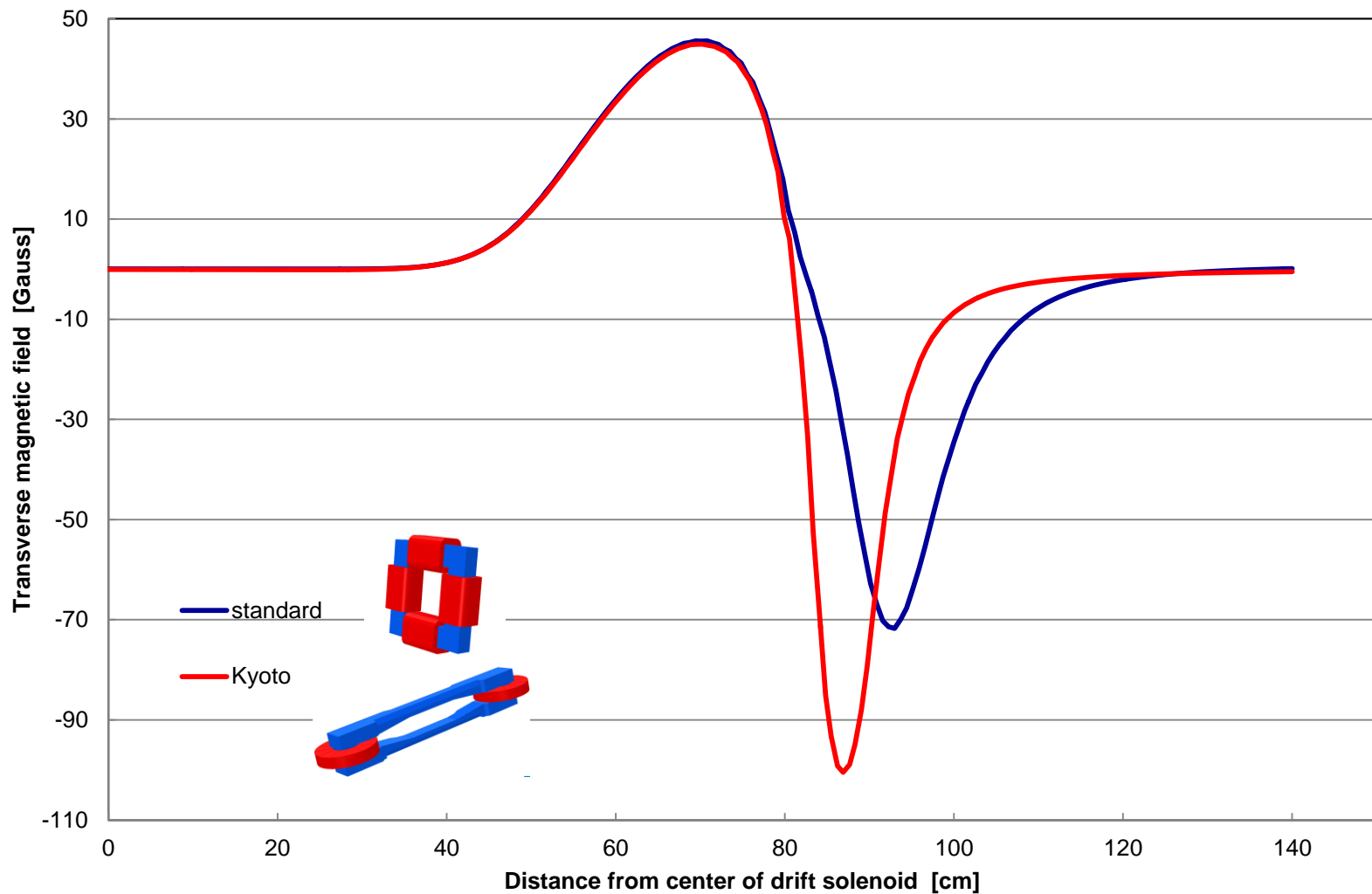
Transverse field - electrons
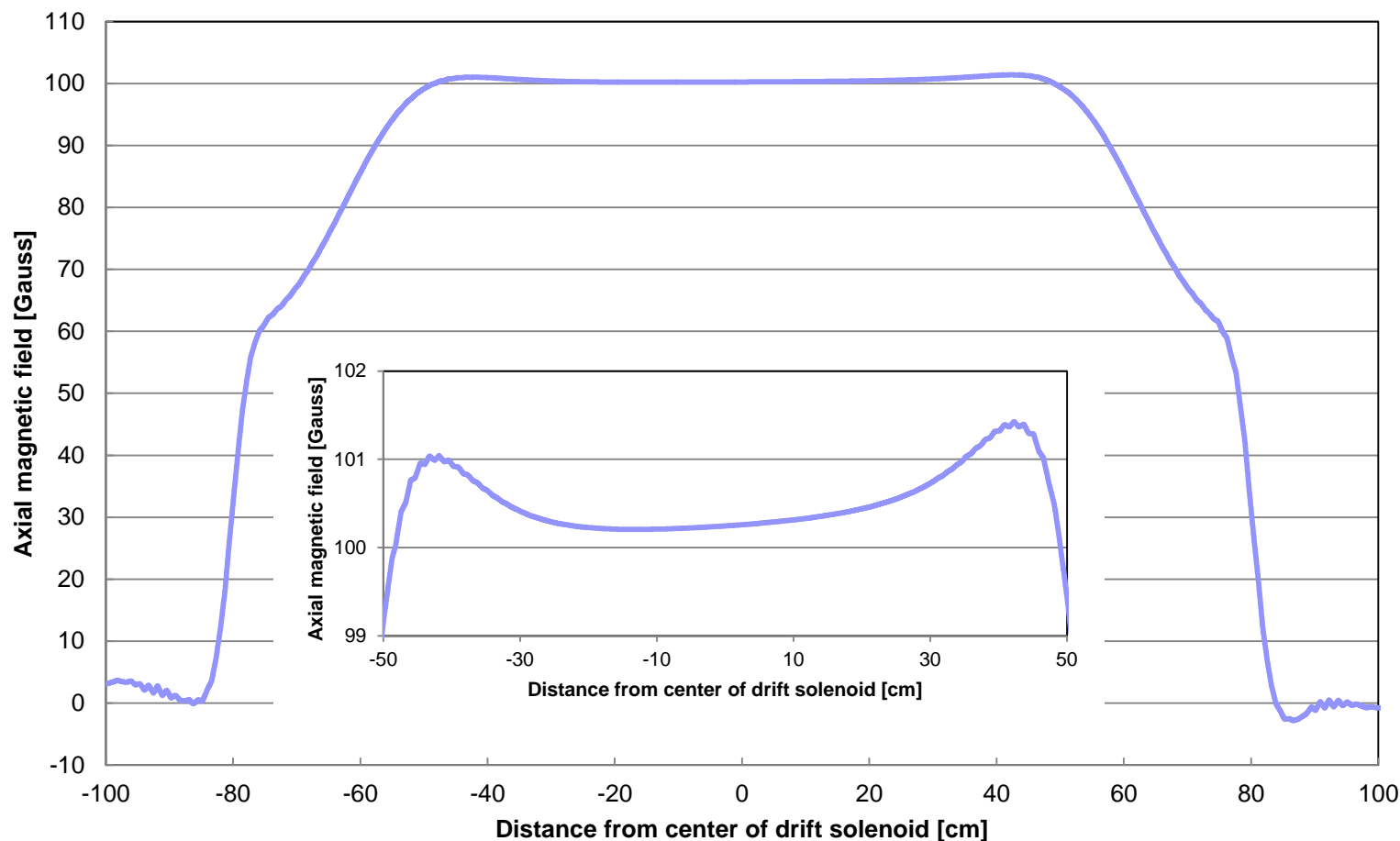

Transverse field without correction

Conclusion: Moving the expansion coil further away makes the field at the center of the drift solenoid flatter and much easier to correct.
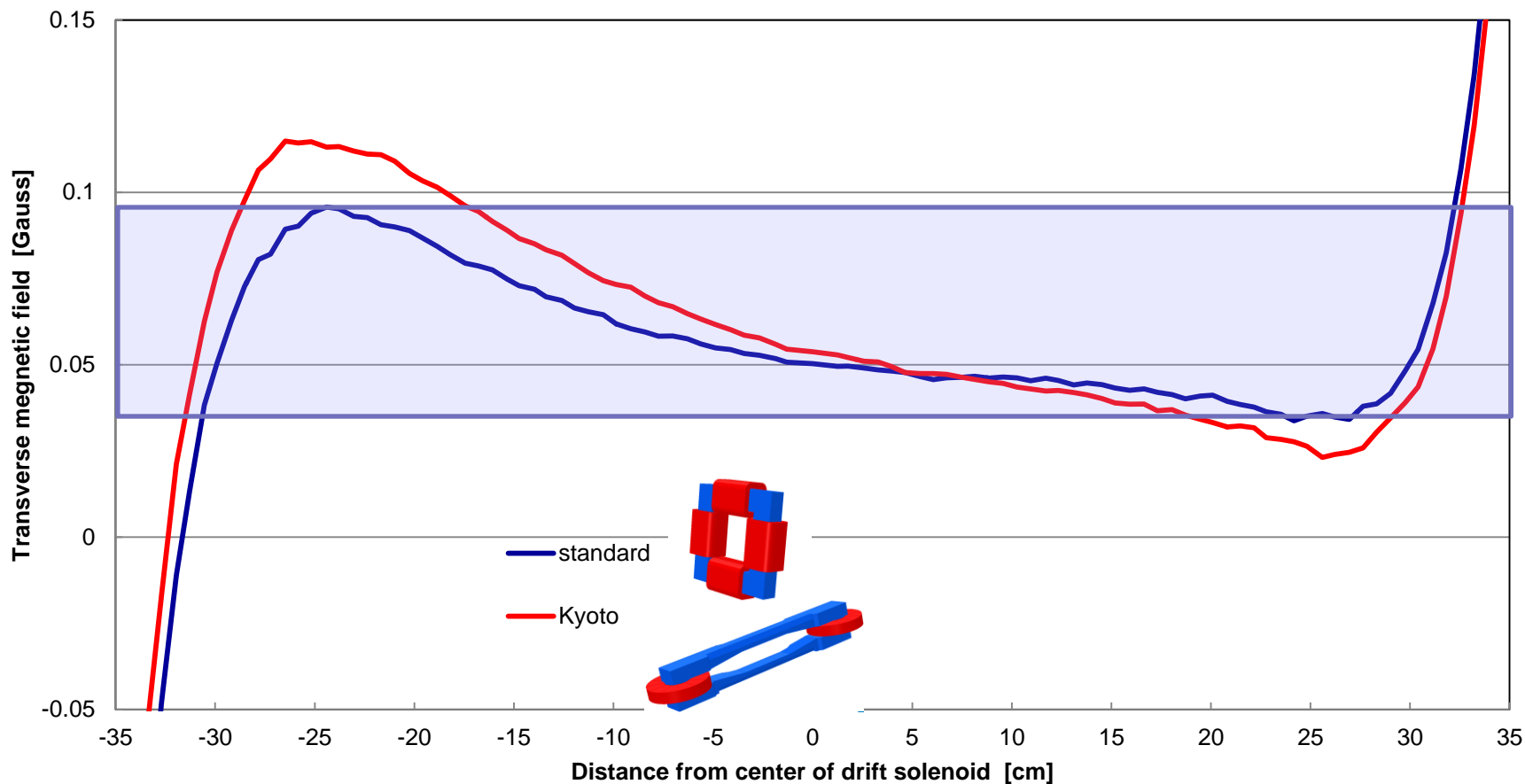
Orbit correctors

Axial field - antiprotons

Final field incl. all transverse and orbit correctors

The good field region

Standard: $B_\perp/B_\parallel < \pm 3 \times 10^{-4}$ for 63 cm

Kyoto: $B_\perp/B_\parallel < \pm 5 \times 10^{-4}$ for 65 cm

77 A/cm2 in orbit correctors
14 A/cm2 in US transverse corrector
7 A/cm2 in DS transverse corrector

32 A/cm2 in orbit correctors
14 A/cm2 in US transverse corrector
7 A/cm2 in DS transverse corrector

The standard orbit correctors take up more space – and we would have to go to a different design to be able to make a sizeable local bump – but luckily we have a little space left over!