Superconducting solenoid optimization and fields measurement

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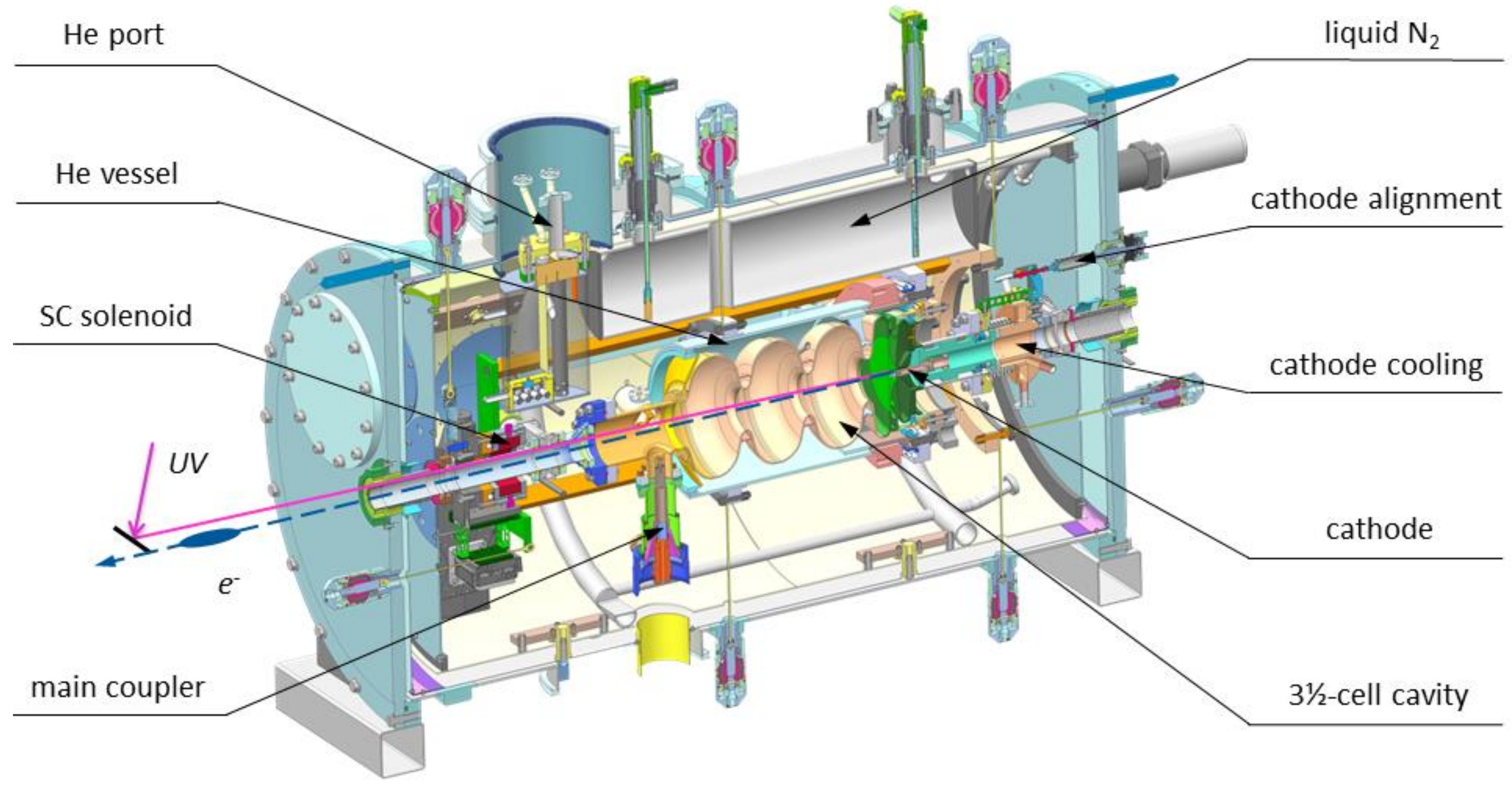
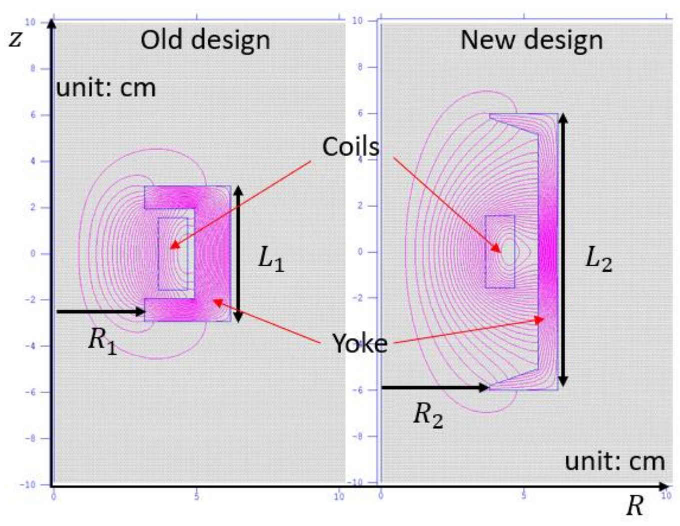
Introduction

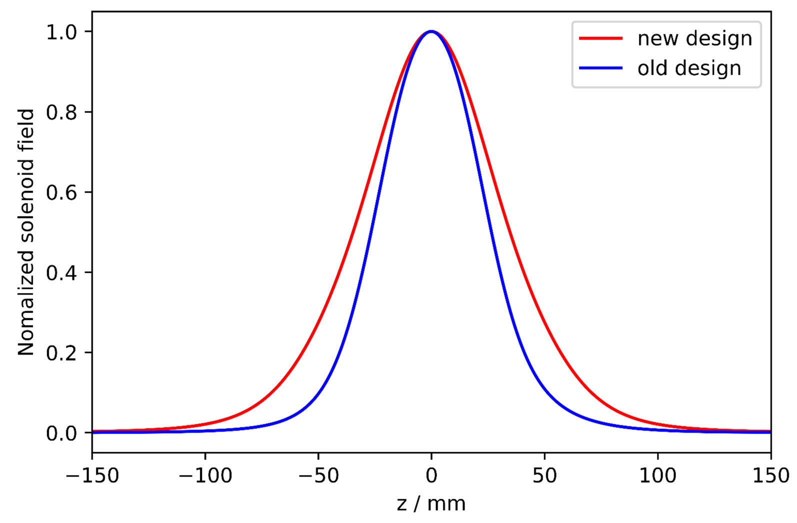
To compensate the projected transverse beam emittance, a solenoid is usually used at normal conducting and superconducting radio frequency (SRF) photoinjectors. At the ELBE SRF Gun-II, a superconducting solenoid is located inside the gun's cryomodule about 0.7 m far from the end of the gun cavity. The spherical aberration and multipole fields due to offset and tilt limit the beam emittance decrease. We has designed a new superconducting (SC) solenoid with lower spherical aberration coefficient. Both longitudinal field and transverse field are measured and analyzed by formalism fitting method to evaluate the SC solenoid status in the cryomodule and the influence on beam emittance.

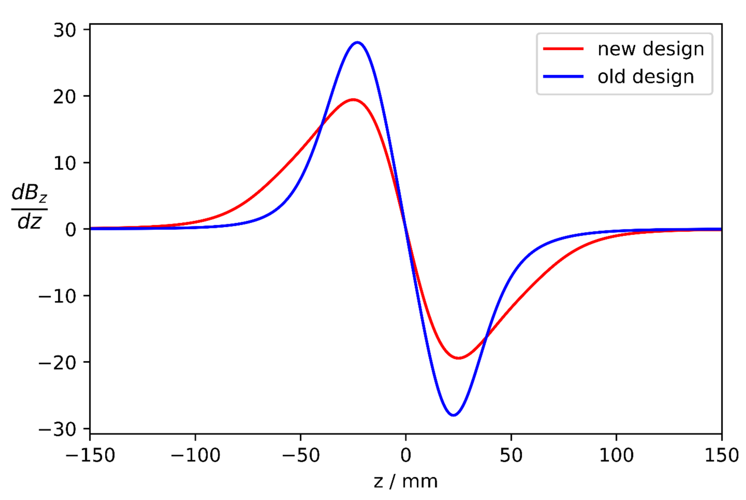


Solenoid magnetic field analysis

SC solenoid optimization





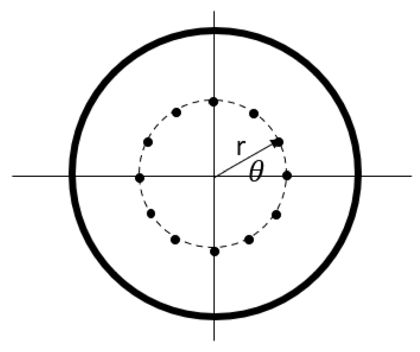


Parameter	Old design (SRF Gun II)	New design (SRF Gun III)
Outer diameter d_A	123.8 mm	123.8 mm
Length (iron circuit) L	58.6 mm	120.0 mm
Inner diameter (coil) d_I	63.5 mm	63.5 mm
Number of NbTi wire turns	2236	2236
B_0 @ 10 A coil current	0.45 T	0.357 T
Integral $B_0 \times I_\varphi$ @ 10 A	0.02689 Tm	0.02794 Tm
Integral I_φ	0.05976 m	0.07827 m
Image rotation @ E_{kin} = 4.0 MeV	5.15°/A	5.35°/A
Integral B_0^2 x I_1 @ 10 A	0.008214 T^2m	0.00666 T^2m
Integral I_1	0.04056 m	0.05227 m
Integral I_2	37.82 m^{-1}	27.05 m^{-1}
Spherical aberration coeff. C_s	466.3 m^{-2}	258.8 m^{-2}
Inductance	0.689 Vs/A	0.489 Vs/A

Solenoid multipole field analysis

Method one

Analyze the solenoid field from Laplace's equation using Fourier series.



$$B_r(r,\theta) = |B_{r0}| + |B_{r0}| \sum_{n=1}^{\infty} r^n [b_n \cos(n\theta) - a_n \sin(n\theta)]$$

a_n and b_n are the skew and normal 2(n+1)-pole coefficients, respectively.

$$a_n = -\frac{2}{M|B|r^n} \sum_{m=0}^{M-1} |B_m| \sin(\frac{2\pi nm}{M})$$

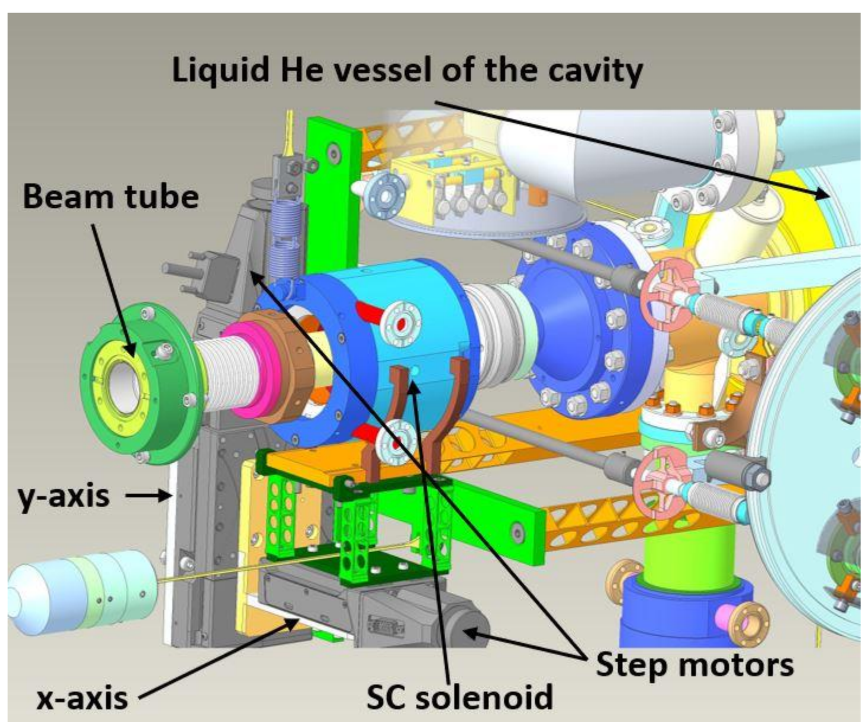
$$b_n = \frac{2}{M|B|r^n} \sum_{m=0}^{M-1} |B_m| \cos(\frac{2\pi nm}{M})$$

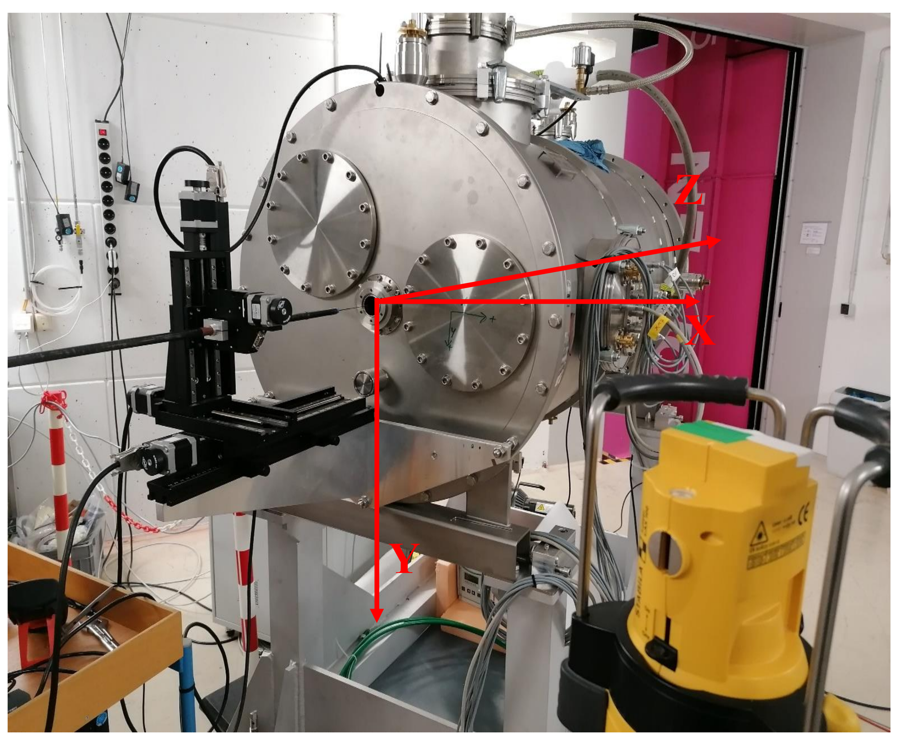
Method two

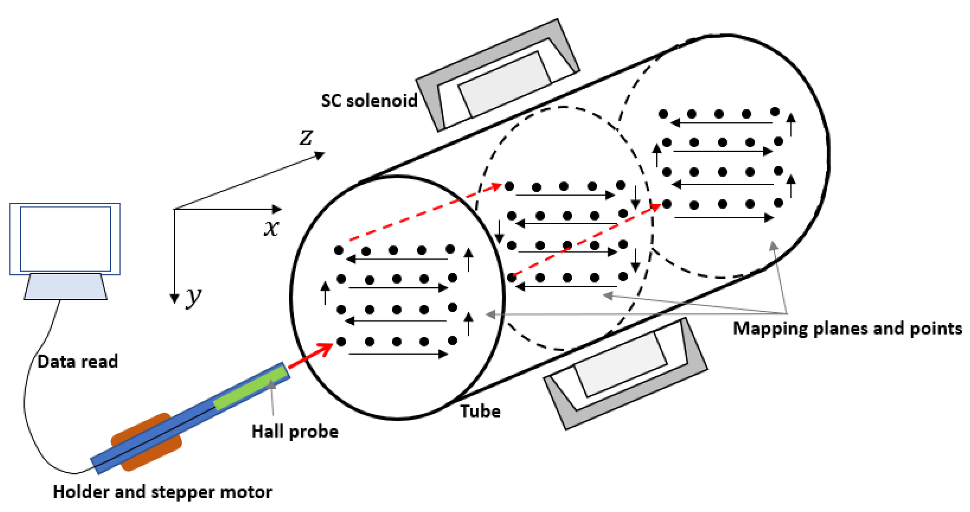
Linear fitting using the feature of the field depending on the cartesian coordinate system.

Transverse field	$\overrightarrow{B_t} = k_t x \widehat{e_x} + k_t y \widehat{e_y}$
Dipole component	$\overrightarrow{B_b} = k_{bx} \widehat{e_x} + k_{by} \widehat{e_x}$
Normal quadrupole component	$\overrightarrow{B_n} = k_n y \widehat{e_x} + k_n x \widehat{e_y}$
Skew quadrupole component	$\overrightarrow{B_s} = k_s x \widehat{e_x} - k_s y \widehat{e_y}$
Horizontal magnetic field	$B_x = (k_t + k_s)x + k_n y + k_{bx}$
Vertical magnetic field	$B_y = (k_t - k_s)y + k_n x + k_{by}$

Measurement setup

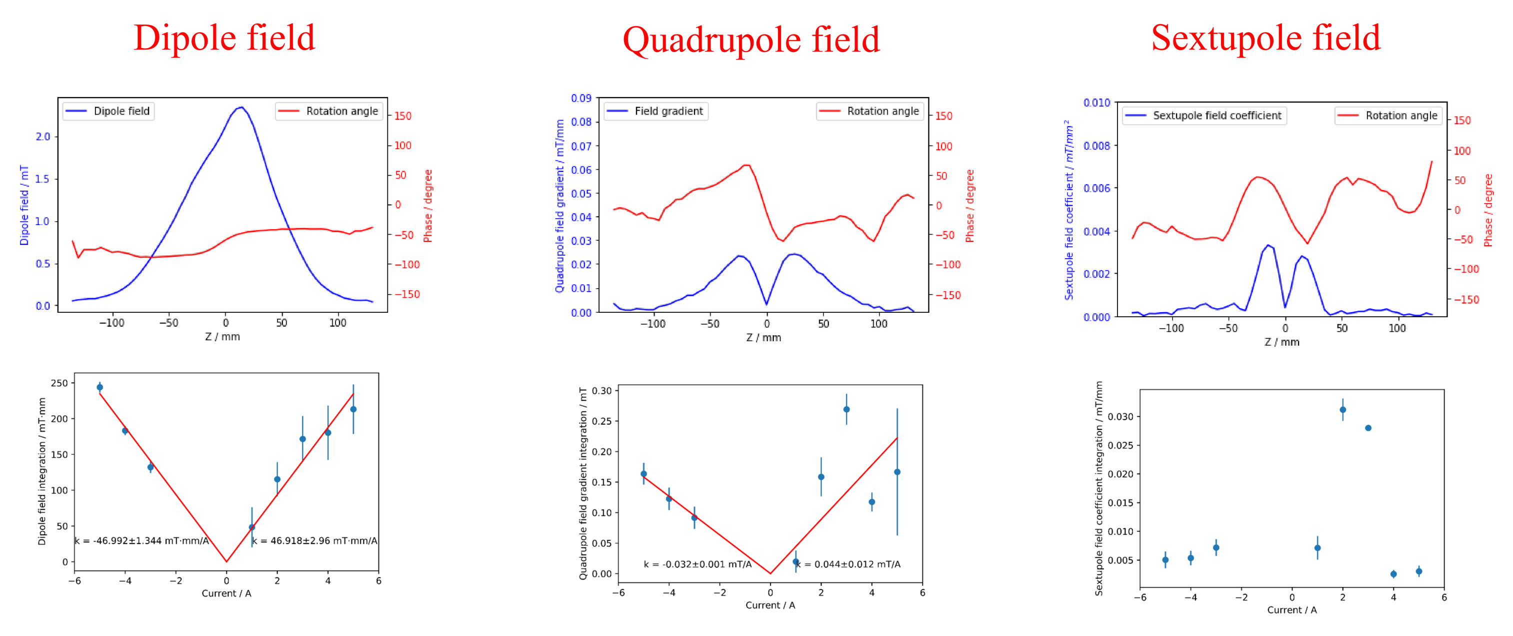






From A photograph of the magnetic field measurement system is shown in Fig. For the 3-D coordinate measuring of components and mechanical alignment, a Quantum Max metrology tool (mechanical measuring arm) of FARO company was used. Before closing the cryomodule, the mechanical axis and position of the solenoid were determined by means of this measuring tool. As a reference plane the large flange for the front-side lid of the cryomodule was chosen. The three-axis movement of the measuring probes for the magnetic field mapping was realized by a combination of three motorized linear stages (OWIS GmbH). The stage for the z-axis motion had a travel range of 270 mm, and thus the magnet probes were mounted in such a position that the maximum of the the longitudinal field was located at about z = 135 mm.

Measurement results



Parameters	Simulation	Measured
B_z @ 8 A [mT]	286	282 ± 0.705
$\frac{dB_z}{dI}$ [mT/A]	35.7	35.232 ± 0.021
Effective Length [mm]	52.27	50.990 ± 0.068
Holder axis tilt x [mrad]	0	-0.667
Holder axis tilt y [mrad]	0	0.889
Field axis tilt x [mrad]	-	9.739 ± 7.239
Field axis tilt y [mrad]	-	-22.043 ± 2.262
Field axis offset x [mm]	-	1.599 ± 1.193
Field axis offset y [mm]	-	-0.798 ± 0.561
Max. integrated quadrupole field @ 5A	-	0.166 ± 0.085 mT
Max. integrated sextupole field @5 A	-	∼ 0.03 mT/mm

Acknowledgement

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Reference:
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