Influence of the magnetization features of the HTS tape on the magnetic field homogeneity inside the superconducting unclosed shield

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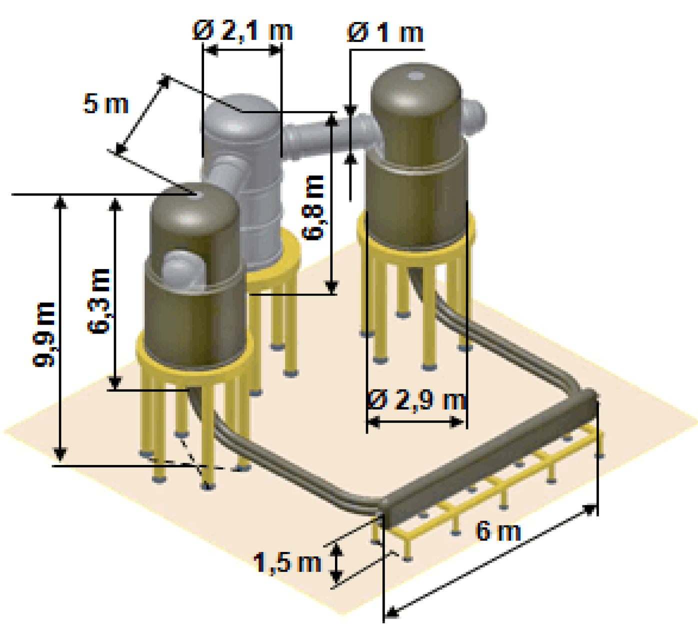
Absrtact

Measurements of the magnetic field were performed in a copper solenoid with the high-temperature superconductor shield. The experiments were carried out under quasi-stationary conditions, magnetic fields up to 1 kG at 77K. The shield is a lengthwise winding made from (Y)BCO tapes, 442 mm long each. Each layer is laid with the piece shift from layer to layer equal to one-half of the tape width, forming a "tile". When the radial component of the magnetic field was being measured near the shield, the magnetic field irregularity was detected. It is related to the magnetization features of the 2G-HTS tape. It is shown that the absolute value of the field irregularity reaches some G near the inner surface of the shield and sharply decreases with the distance from it as well as r^{-2}.
The obtained results allow selecting the optimum radial shield size to get the required magnetic field homogeneity in the operating area for the electron cooling system of charge particle beams.

Electron Cooling System (ECS) for NICA



Electron cooling is an extremely useful method to obtain high intensity ion beams with a low momentum spread.
Friction force equation:

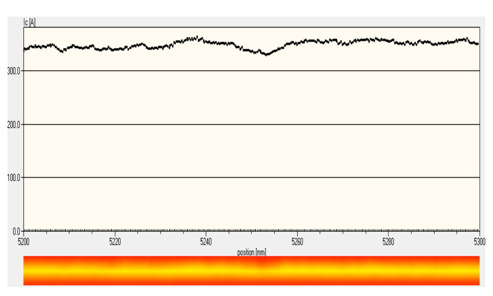
$$\vec{F} = -\vec{V}\frac{4Z^2e^4n_eL_p}{m}\frac{1}{\sqrt{\left(V^2+\Delta_{e,\mathrm{eff}}^2\right)^3}}$$

$\Delta_{e,\mathrm{eff}}$ is effective electron velocity spread **depends on the magnetic field line position in the transverse direction!** Full- size HTS shield was proposed to obtain the required magnetic field homogeneity (about 10^{-5}) in the 6 meters length solenoid of the electron cooling section which will be installed in the heavy ion collider of the NICA project

HTS shield prototype & experimental set-up

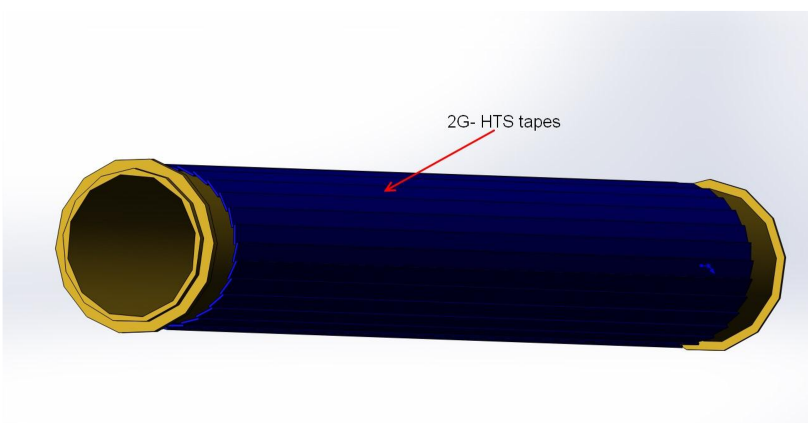
Material

2-G (Y)BCO - HTS ceramic tape (Super Ox Co.) Tape width -12 mm



СуперОкс
SuperOx
Japan LLC

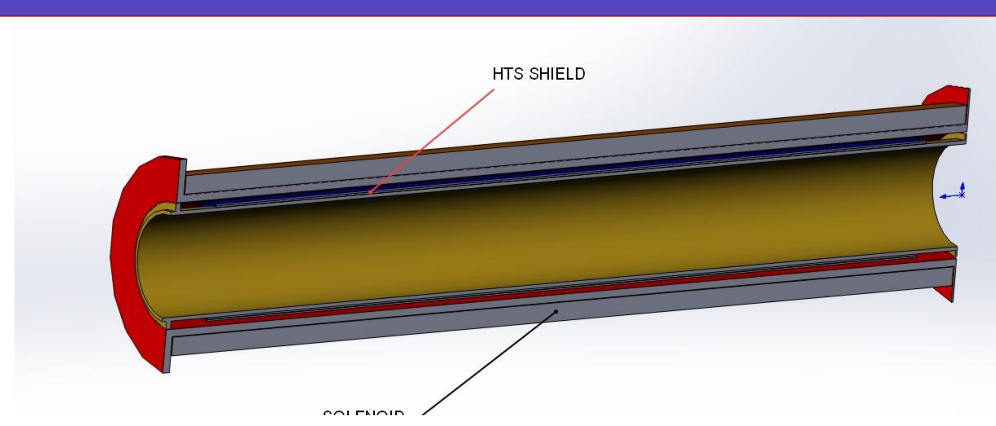
HTS shield

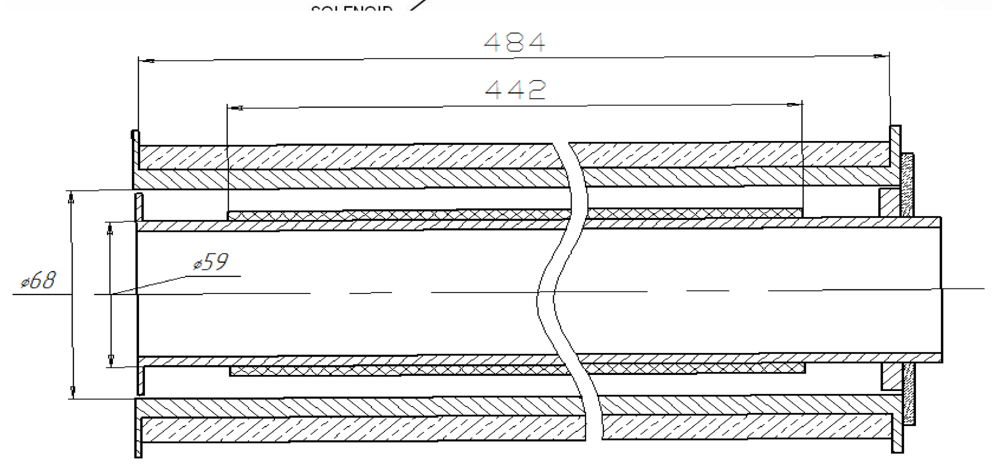


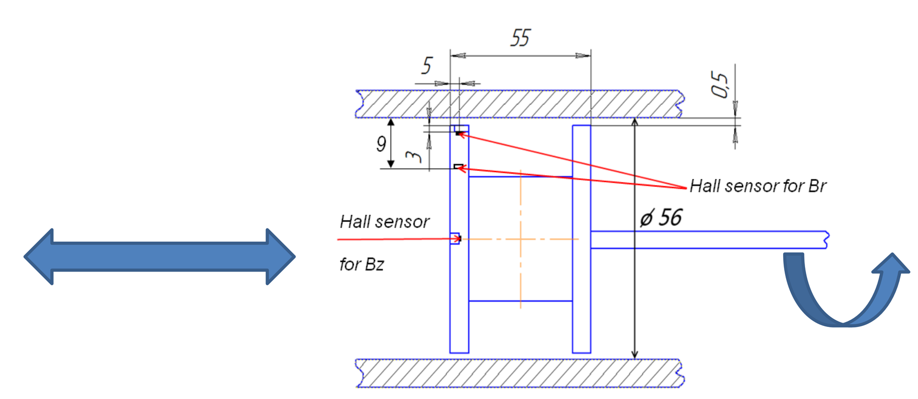
➤ **The HTS shield is the multilayer lengthwise winding *(in figure- one "tile" layer)***

Number of layers is 2

cooling-down of the shield – LN (77K)

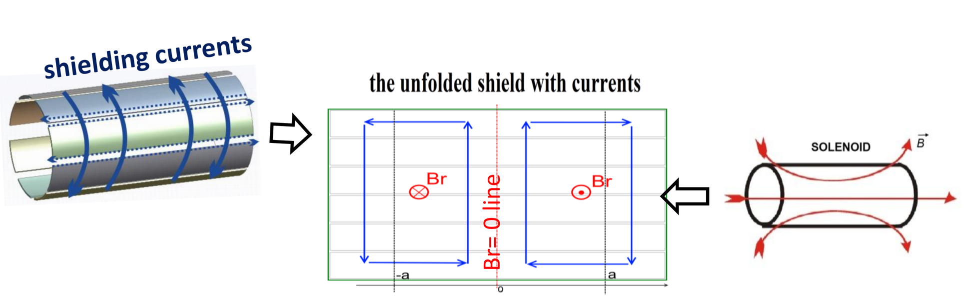






2D Hall probe to measure of the magnetic fields inside of the shield

Physical conception



The unclosed shield screens only magnetic field perpendicular component at the centre and transmits the longitudinal component!

Region (*a*) with *Br*=0 inside the shield is defined by (in CGS)

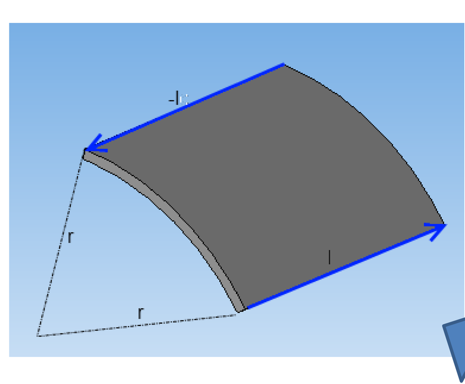
$$2aB^{ext}_{\rho}(a) = \frac{4\pi}{c}\cdot J_c\delta\left(L_s - a\right)$$

$$I(z) = \frac{2}{\mu_0}\frac{\partial B^{ext}_{\rho}}{\partial z}a\delta$$ - the effective shielding current at the point Z

The radial magnetic field on the external shield surface:

$$B_{\rho}(x) \approx \int_{-a}^{a}\frac{\mu_0}{2\pi}\frac{I(z)}{\delta}\frac{dz}{z-x} + \frac{\mu_0}{2\pi}J_c\delta\times\ln\left|\frac{L-x}{L+x}\frac{a+x}{a-x}\right| - B^{ext}_{\rho}(x)$$

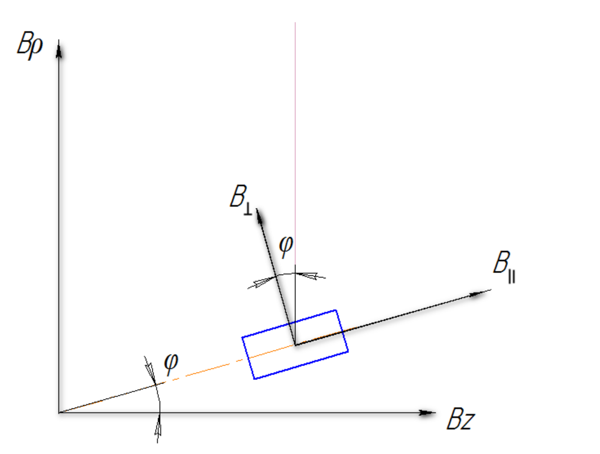
a - the half-width of the area occupied by the non-saturated currents *I*(z)
L- the half-length of the shield
Jc - critical current density
δ - the shield thickness



$$B_{\rho} \sim \frac{I}{r^2}$$

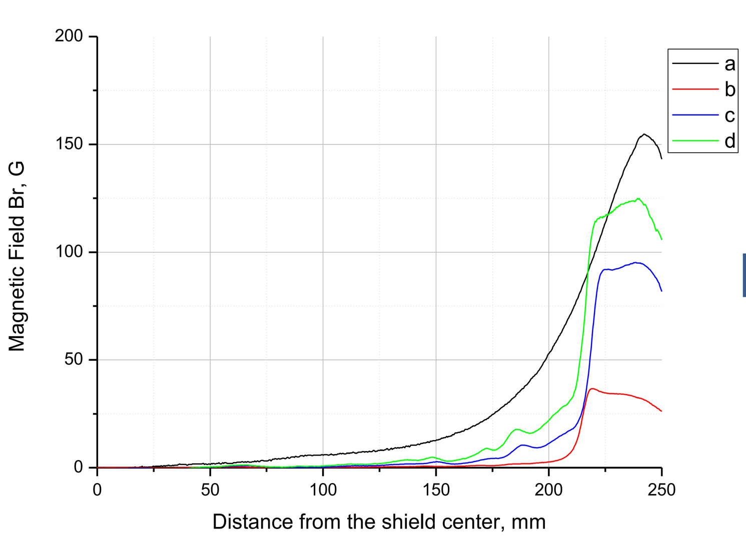
Estimation of errors & precision

The tilt in the Hall probe axis

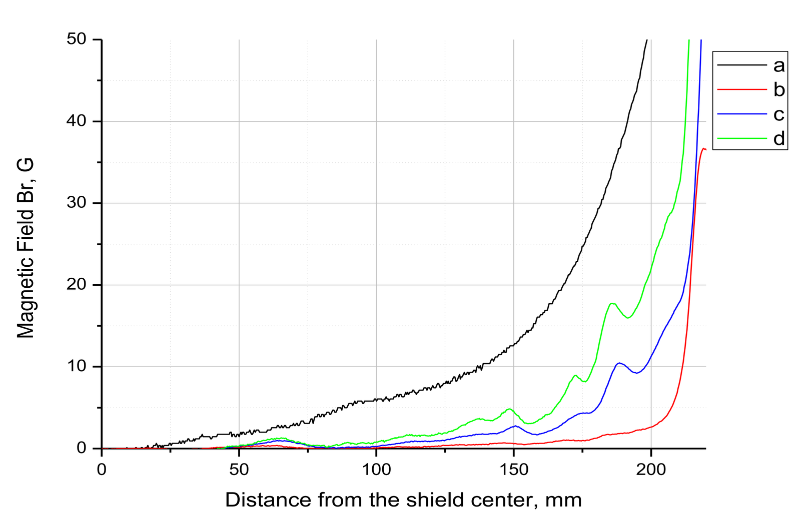


$$B_{\rho} = B_{\|}\sin(\varphi) + B_{\perp}\cos(\varphi)$$
$$B_Z = B_{\|}\cos(\varphi) - B_{\perp}\sin(\varphi)$$
$$\Delta B = \sqrt{\left(\frac{\partial B}{\partial\varphi}\Delta\varphi\right)^2}$$
$$\varphi \approx 5\times10^{-3} << 1:$$
$$\Delta B_{\rho} \approx B_{\|}\Delta\varphi$$
$$\Delta B_z \approx B_{\perp}\Delta\varphi$$
$$\Delta_{\Sigma} = \Delta\varphi\sqrt{1+\left(\frac{B_{\perp}}{B_{\|}}\right)^2} \approx \Delta\varphi = 5\times10^{-3}$$

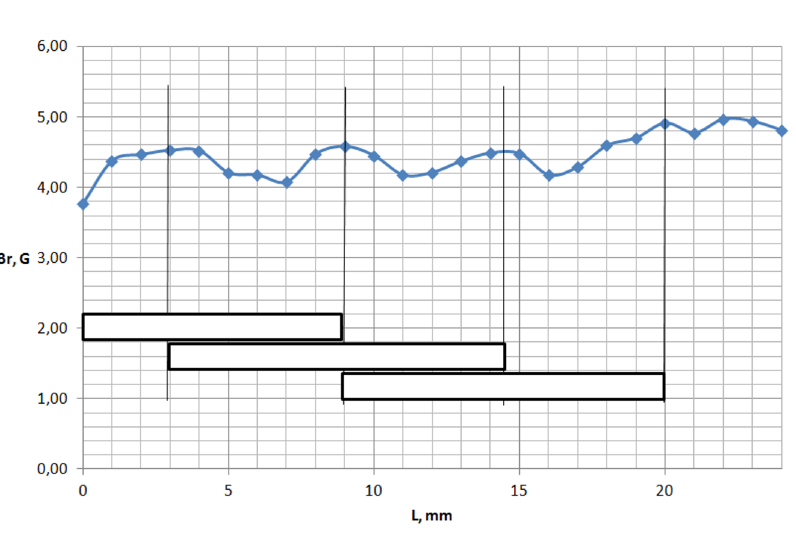
Results



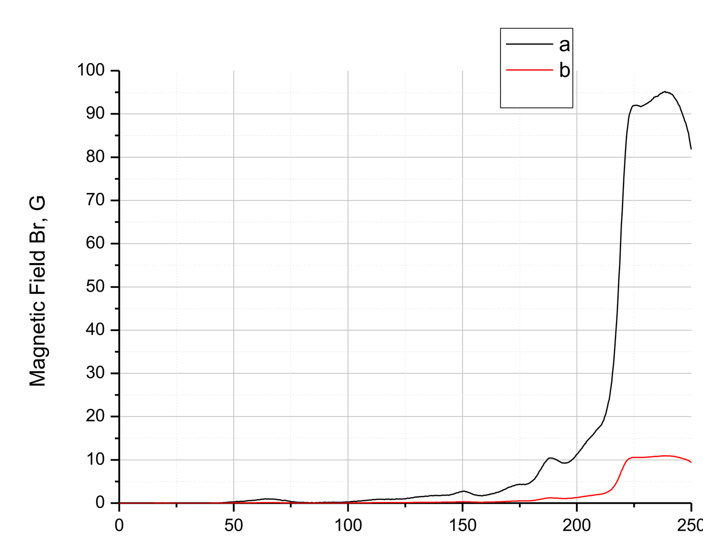
Penetrate of the radial magnetic field into the shield under different magnetic fields in the solenoid :
a- without shield, 1000 G;
with shield:
b- 260G; **c-** 780 G; **d-** 1000 G



Homogeneity area of the shield under different magnetic fields in the solenoid :
a- without shield, 1000 G;
with shield:
b- 260G; **c-** 780 G; **d-** 1000 G

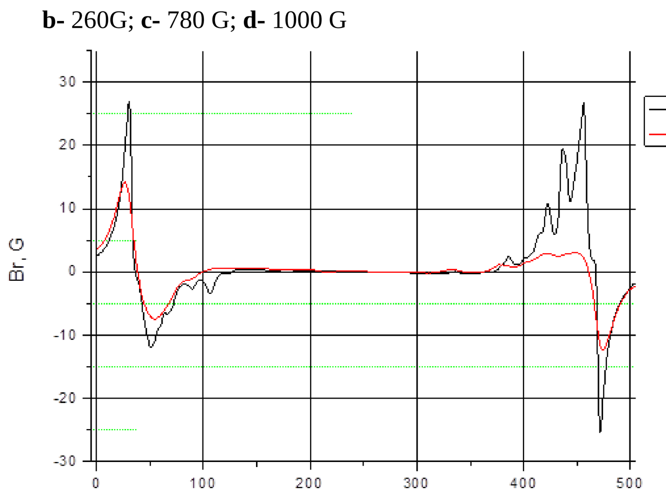


Penetrate of the radial magnetic field into the shield vs. HTS tape width



The radial magnetic field component under different distance from shield and 780 G:
a- r =3 mm
b- r = 9 mm

$$B_{\rho} \sim \frac{1}{r^2}$$



Residual magnetic field under different distance from shield and 780 G:
a- r =3 mm
b- r = 9 mm

References

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