Development of the curved NRSE flippers for Multi-MUSES spectrometer at LLB

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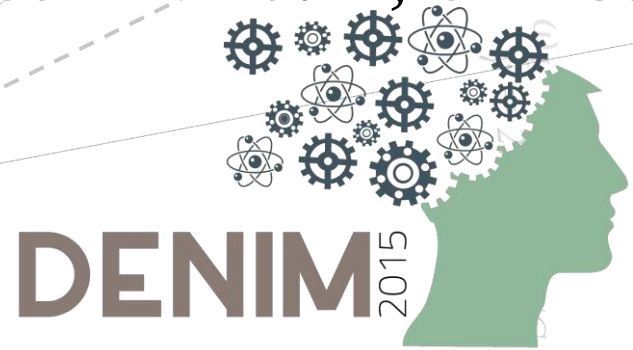
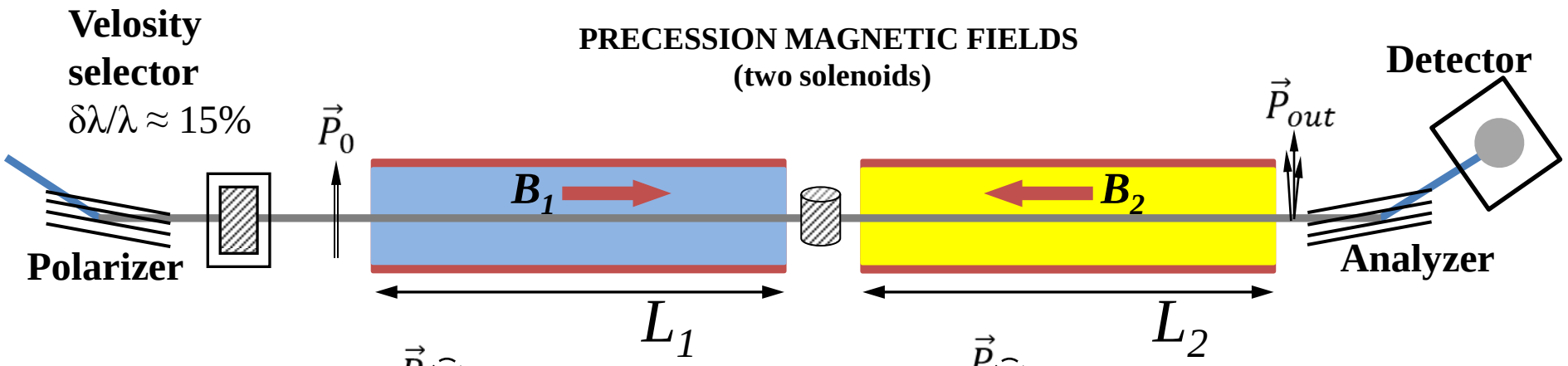
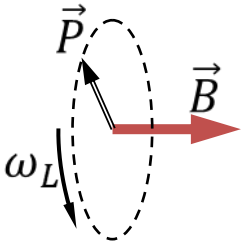


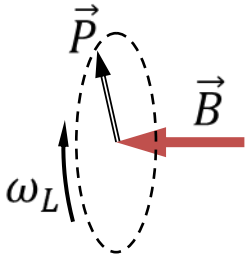
Conventional Neutron Spin Echo



$$\omega_L = \gamma B$$



$$\varphi_1 = \gamma B_1 \frac{L_1}{v_1}$$



$$\varphi_2 = -\gamma B_2 \frac{L_2}{v_2}$$

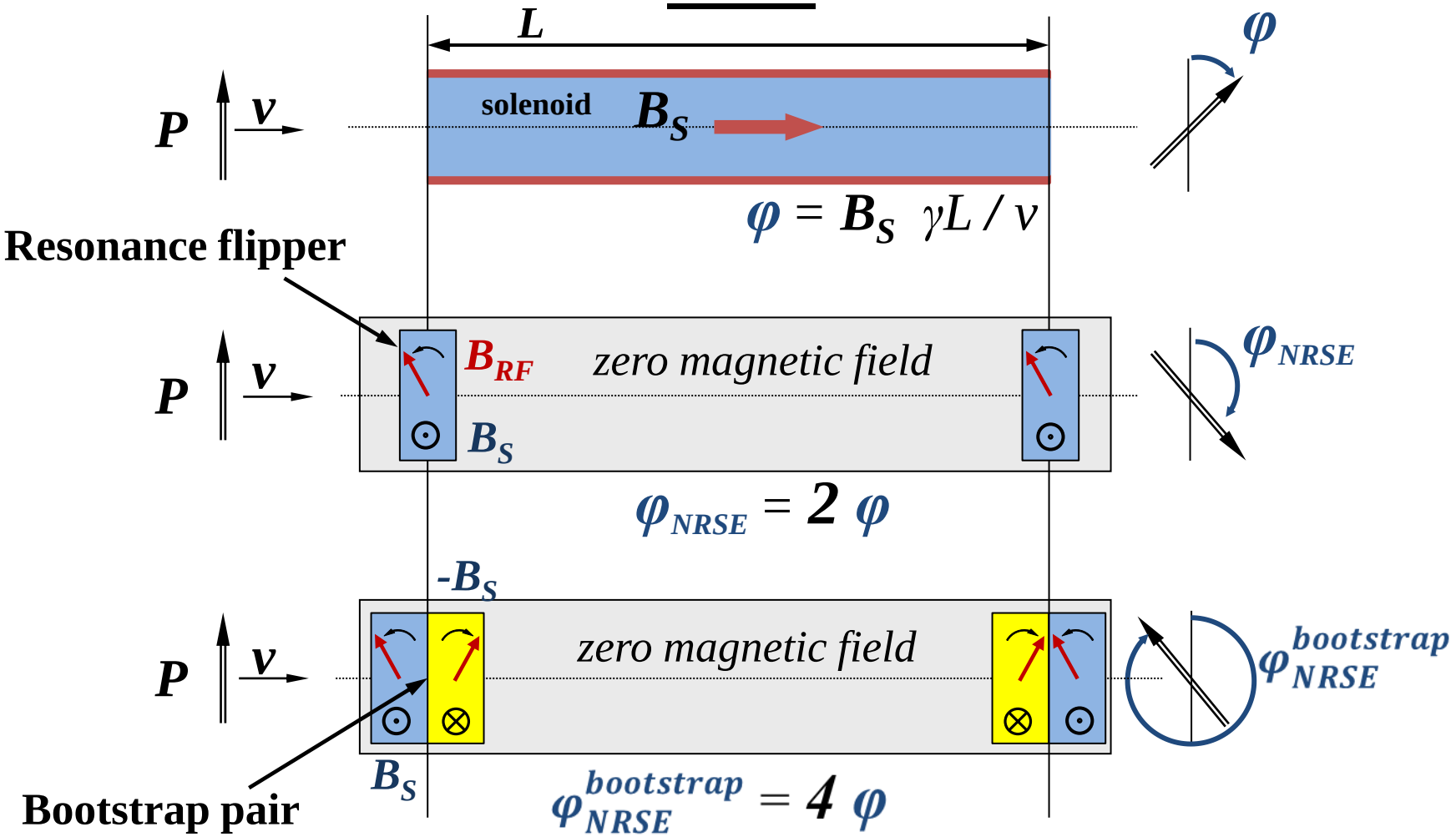
$$\varphi_{NSE} = \varphi_1 + \varphi_2 = \gamma \left(B_1 \frac{L_1}{v_1} - B_2 \frac{L_2}{v_2} \right)$$

$$P_{out} = \langle \cos(\varphi_{NSE}) \rangle$$

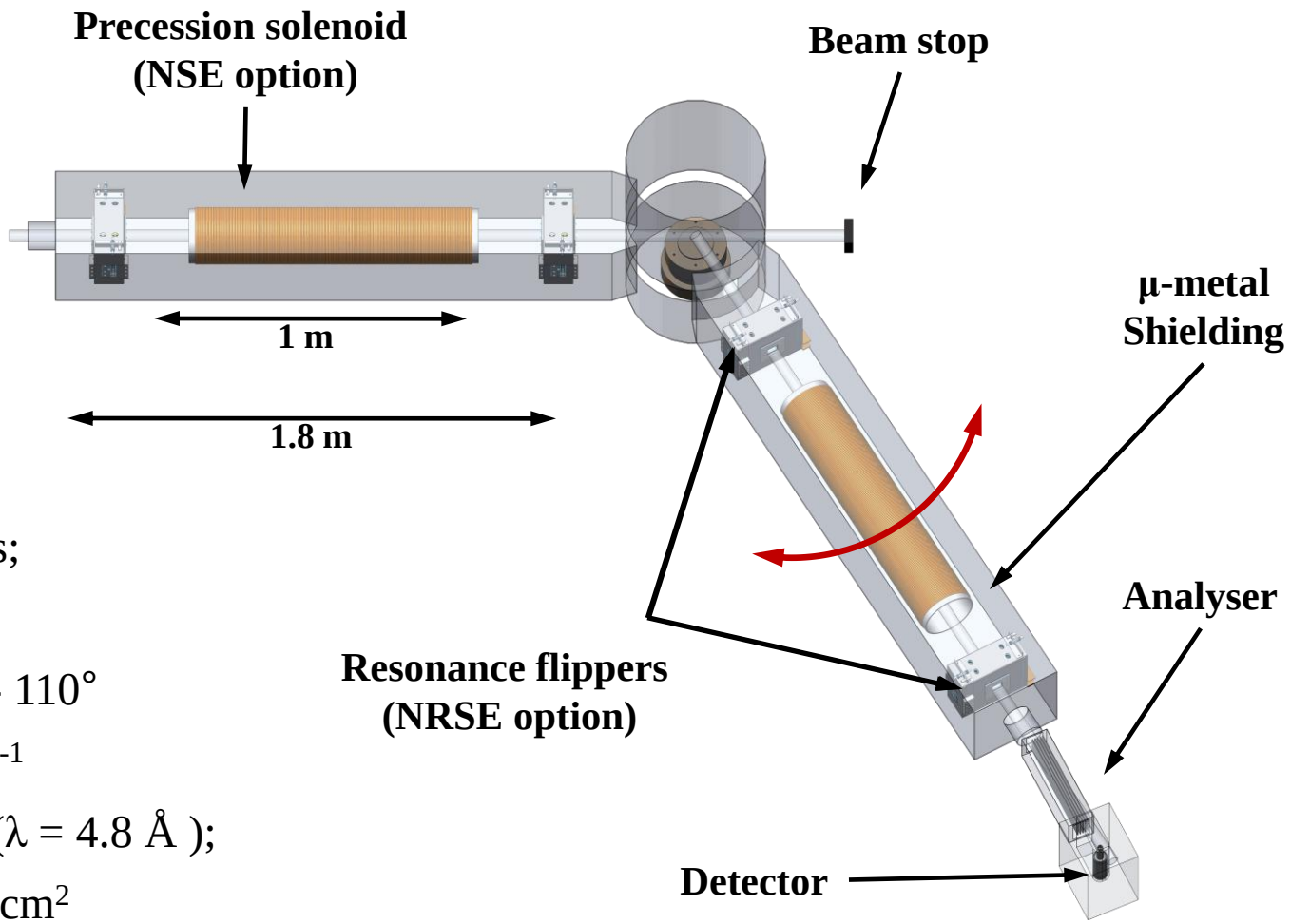
$$\frac{\Delta v}{v_1} = \frac{\varphi_{min}}{\varphi_1} \approx \frac{0.1\,rad}{1000\,rad} = 10^{-4}$$

Neutron Resonance Spin Echo

NRSE

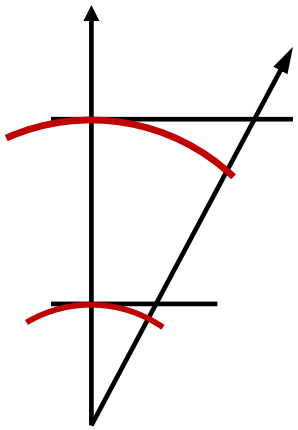


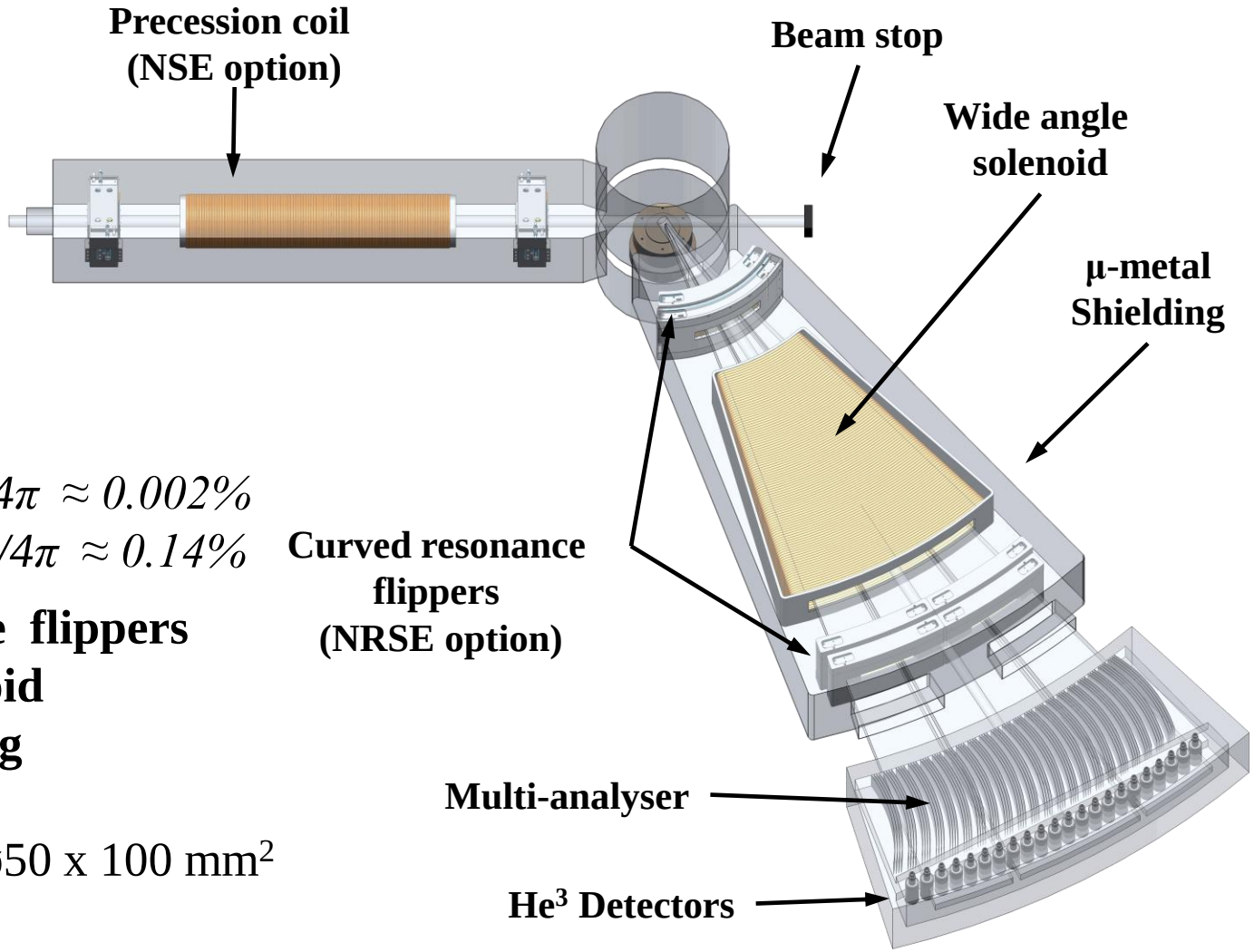
MUSES ($G_{1\ bis}$) NSE + NRSE



- τ_{NSE} : 0.2 ps - 20 ns;
- $\Delta\lambda/\lambda \approx 15\%$;
- Scattering angle: 5 - 110°
- Q range: 0.05 - 4 $Å^{-1}$
- $\Phi s = 10^7$ n $cm^{-2}s^{-1}$ (λ = 4.8 Å);
- beam section: 4x4 cm^2
- λ: 3.5 - 14 Å

Multi - MUSES



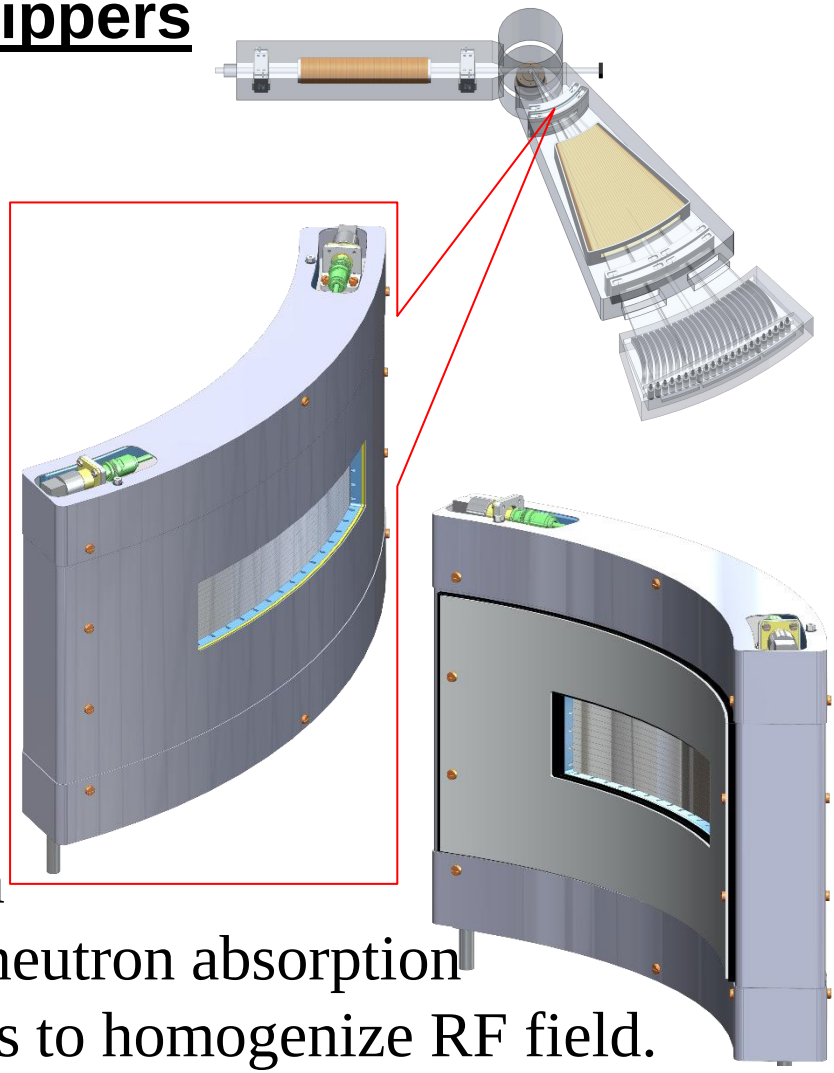


Single detector : $\delta\Omega/4\pi \approx 0.002\%$

'Multi'- detector : $\delta\Omega/4\pi \approx 0.14\%$

- **Curved resonance flippers**
- **Wide angle solenoid**
- **Magnetic shielding**
- **Multi – Analyser**
- **22 He^3 detectors** ø50 x 100 mm^2

Resonance Flippers



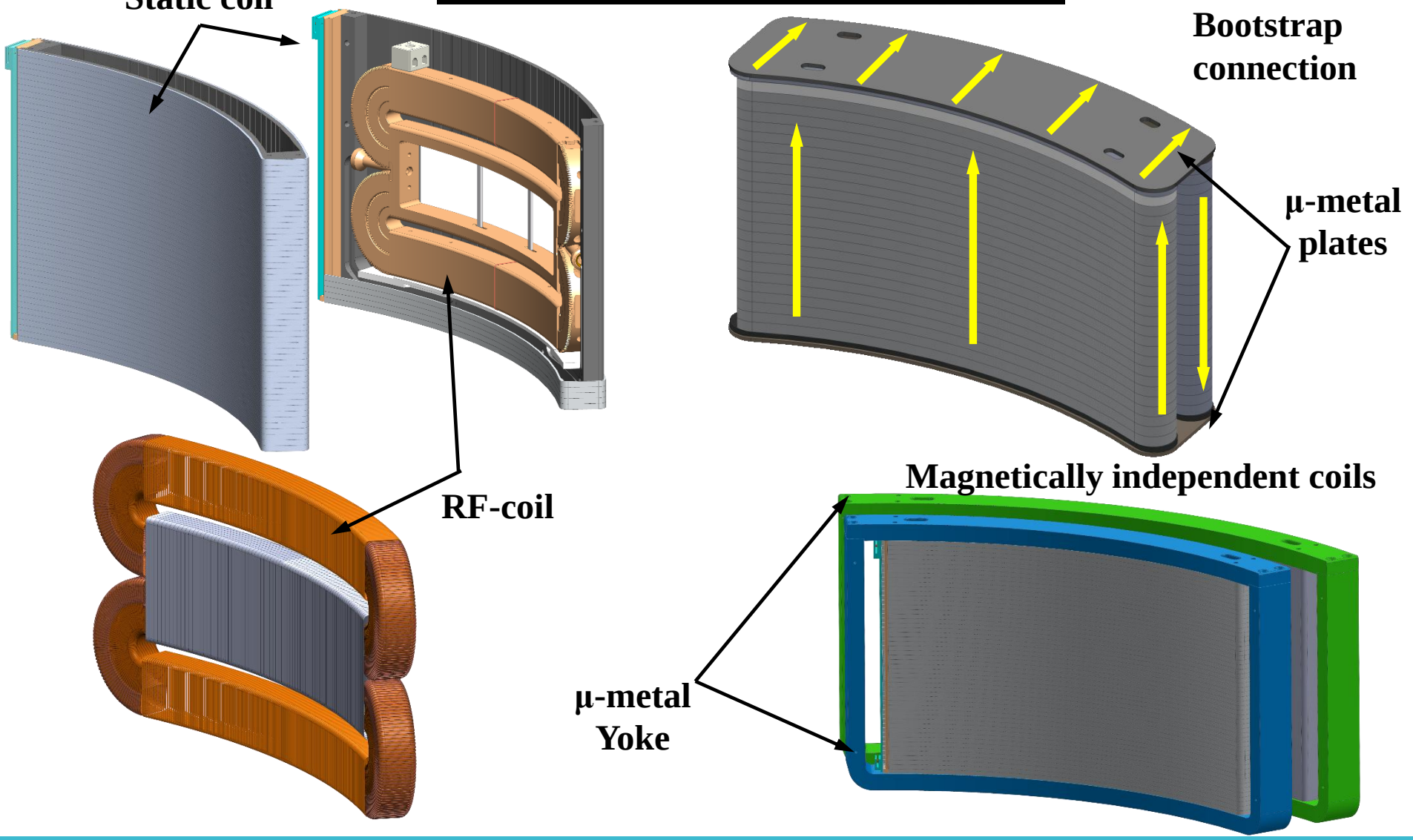
Requirements on the flippers:

- Curvature radius ~ 400 mm;
- Static magnetic field: 10 – 300 G;
- Frequency range: 50 kHz – 1 MHz;
- Homogeneity of the Static and RF field;
- Mechanical precision ~ 0.1mm;

New design for:

- Bootstrap coil → separated coils design
- Static field coil → low stray fields, low neutron absorption
- RF coil → additional compensation coils to homogenize RF field.
- Cooling plates → curved geometry.

Curved Resonance Flippers



Curved RF Coil

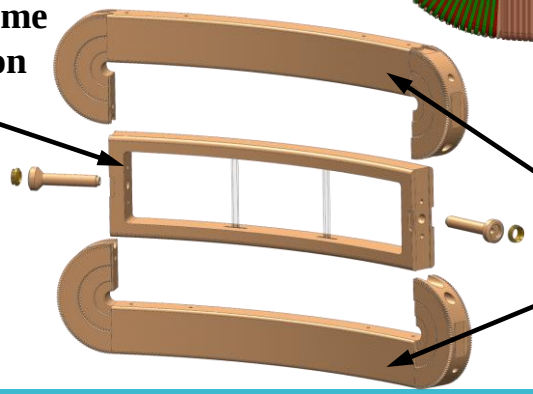
Trifilar cupper wire
⌀ 1mm

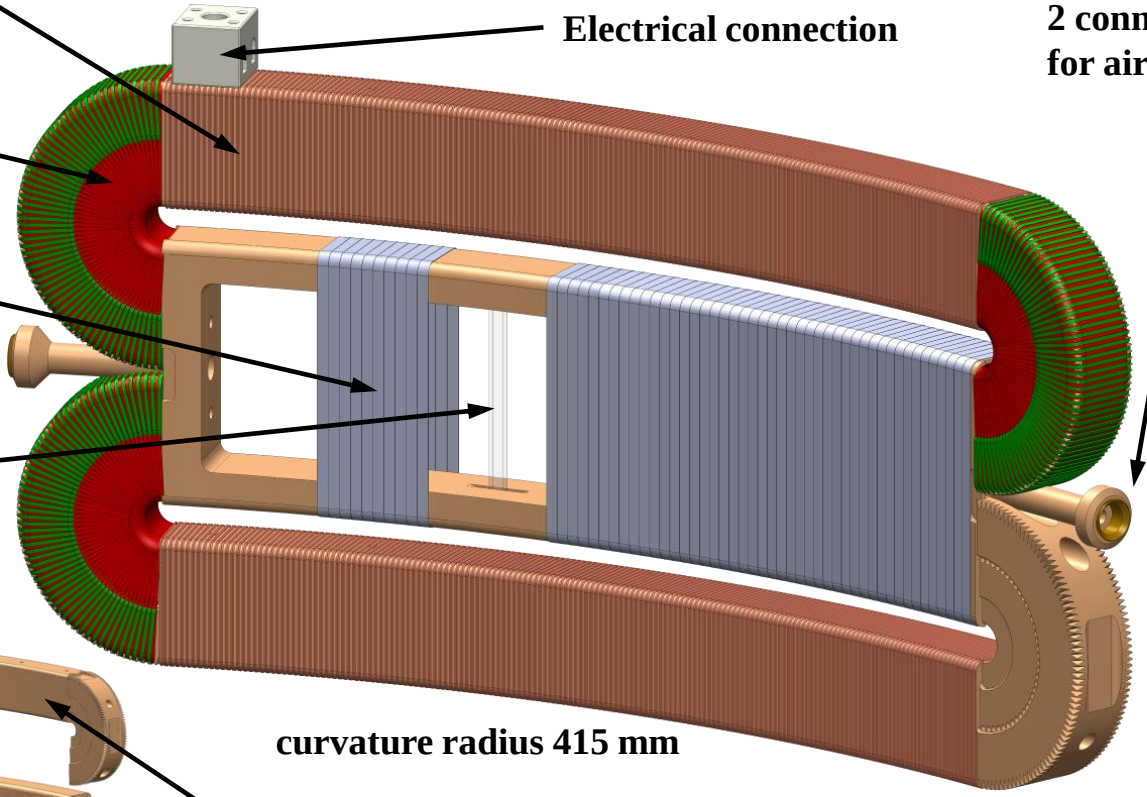
RF-litz wire

Anodized Al band
(0.3x3 mm^2)

Sapphire insert
2mm thickness
(neutron transparency 98%)

Central frame
with neutron
window





Electrical connection

2 connection tubes
for air cooling

curvature radius 415 mm

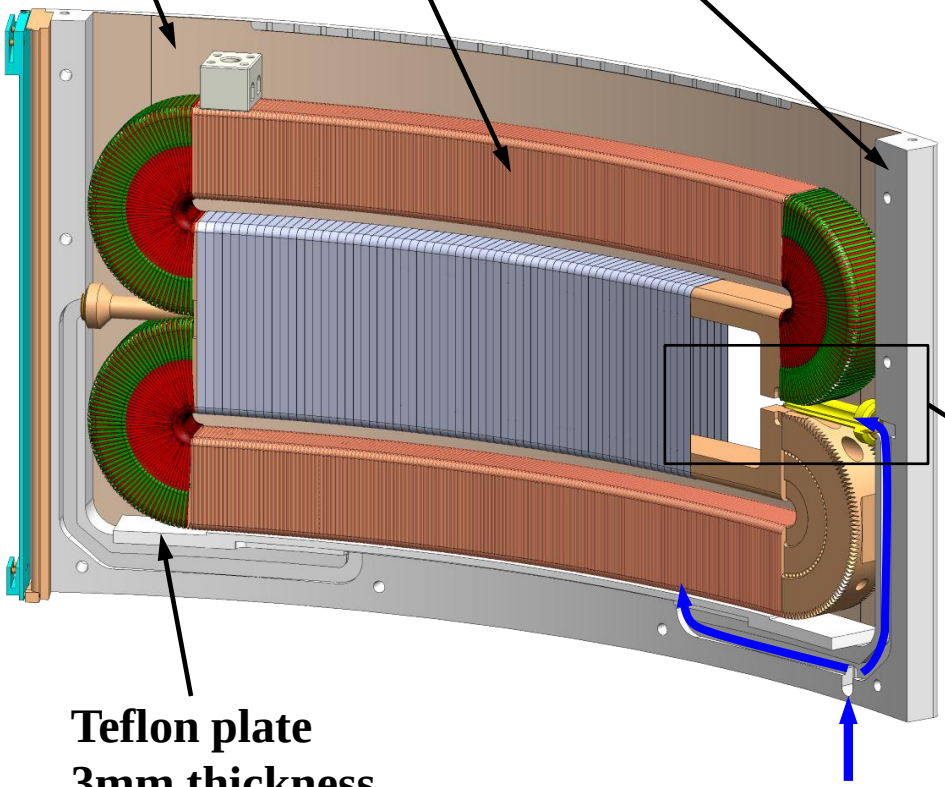
2 U–shape frames

Frames: fiberglass reinforced plastic G11

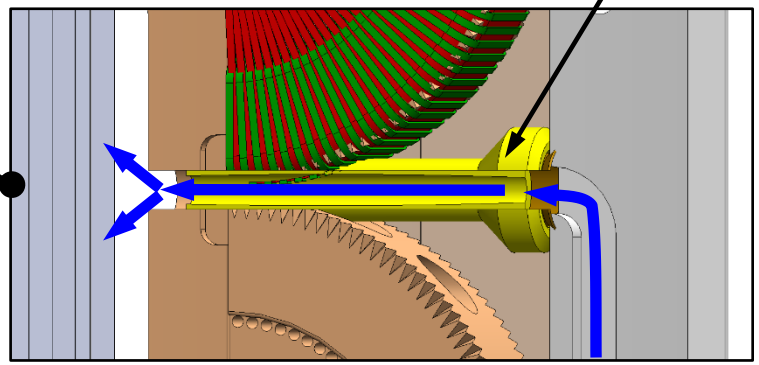
Curved RF Coil

Mica insulation between Al frame and RF coil

- *Freq. range: 50 kHz – 1 MHz*
- *RF-current: 4 - 10 A*
- *Wmax = 150Watt*



Air connection tube

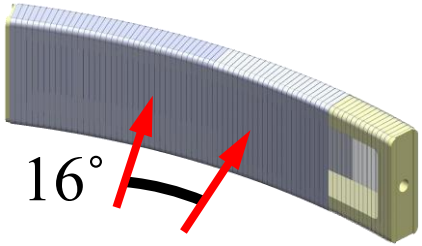


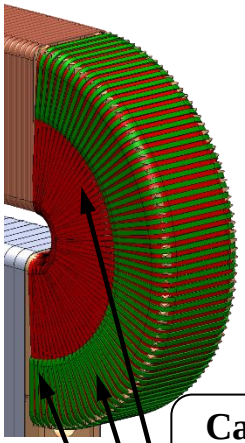
Teflon plate
3mm thickness

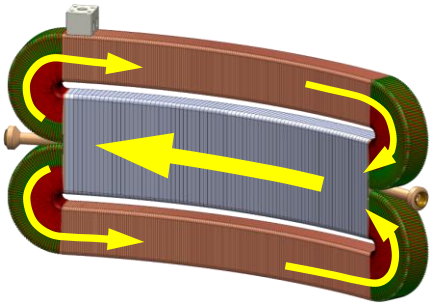
Compressed air coming directly to RF coil

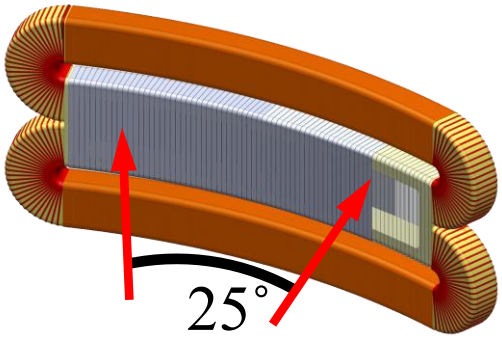
Curved RF Coil

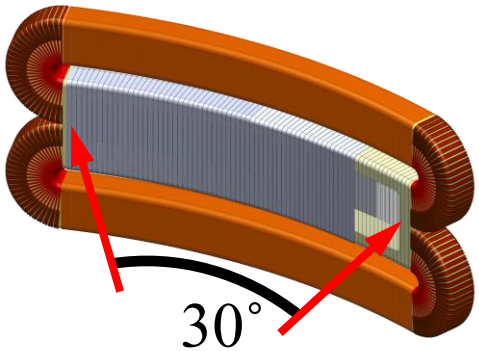
- $\delta B_{RF}/B_{RF}$ $<3\cdot10^{-2}$ *for aperture 30 °*
- *Freq. range: 50 kHz – 1 MHz*
- *Max current: 10 A.*





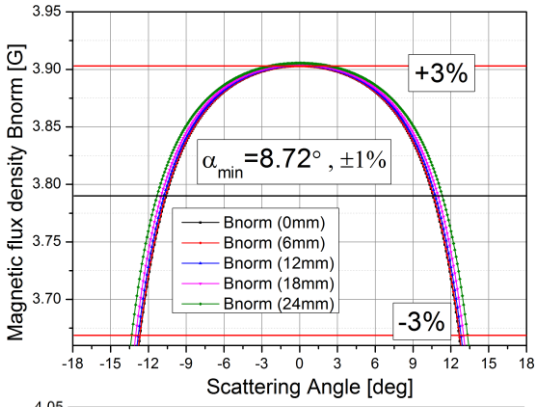


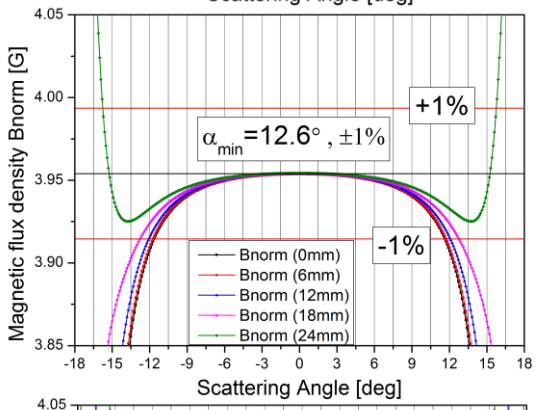


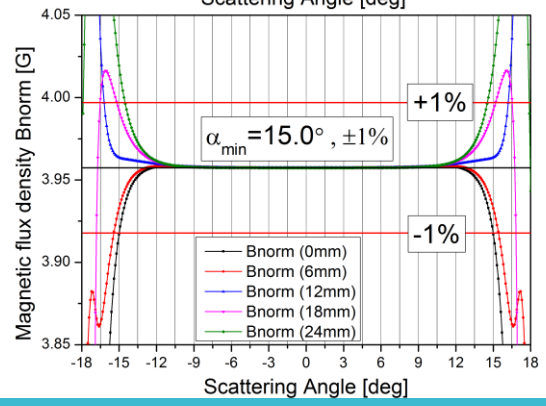


Calculation Mathematica+Radia
Optimization *modeFRONTIER*

- Number of the turns of half-torus
- Number of the turns of additional half-torus
- Internal radius of additional half-torus



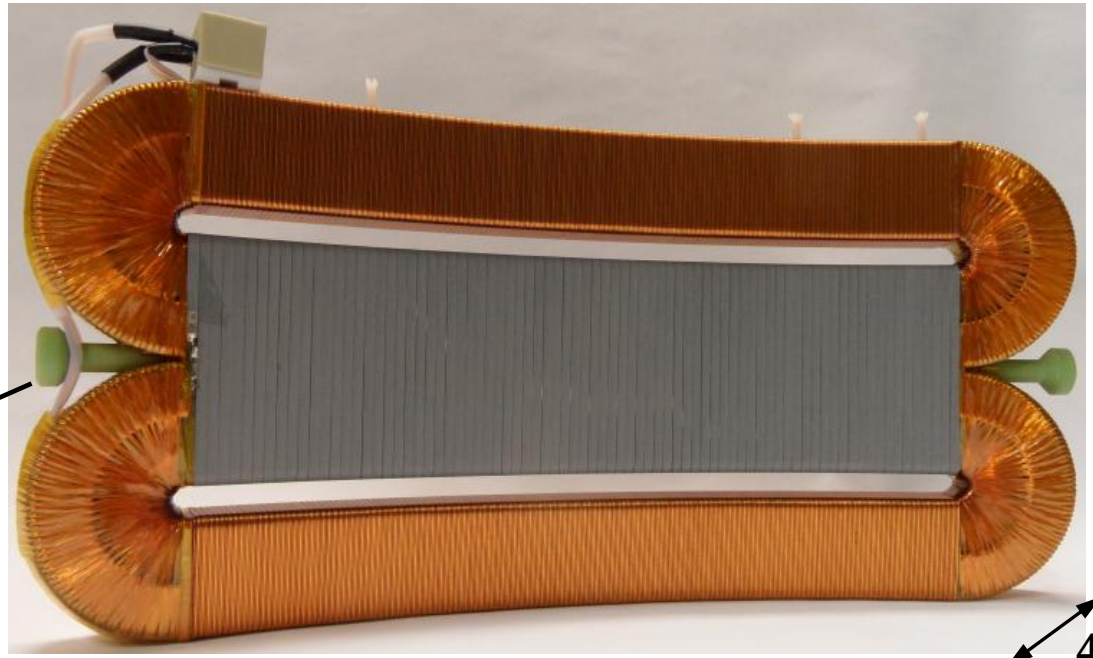


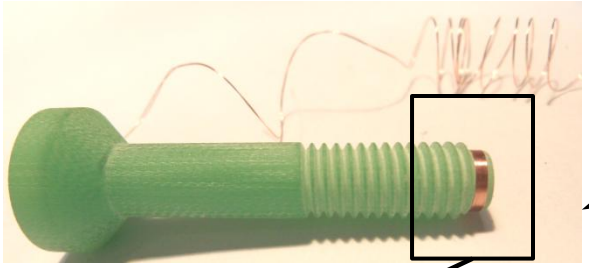


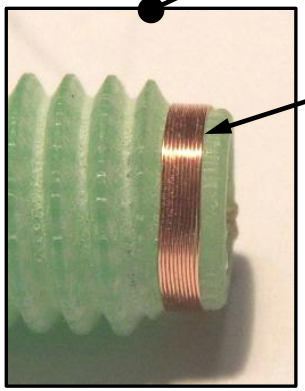
Curved RF Coil

- *Max current: 10 A.*
- *R =1.33Ω*
- *Wmax = 150Watt*
- *L=112.8μH*

Realization



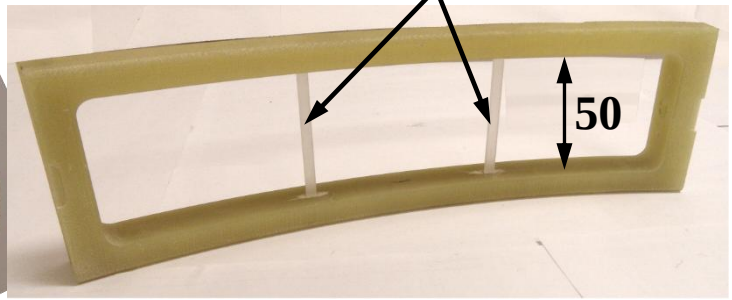




Pick-up coil

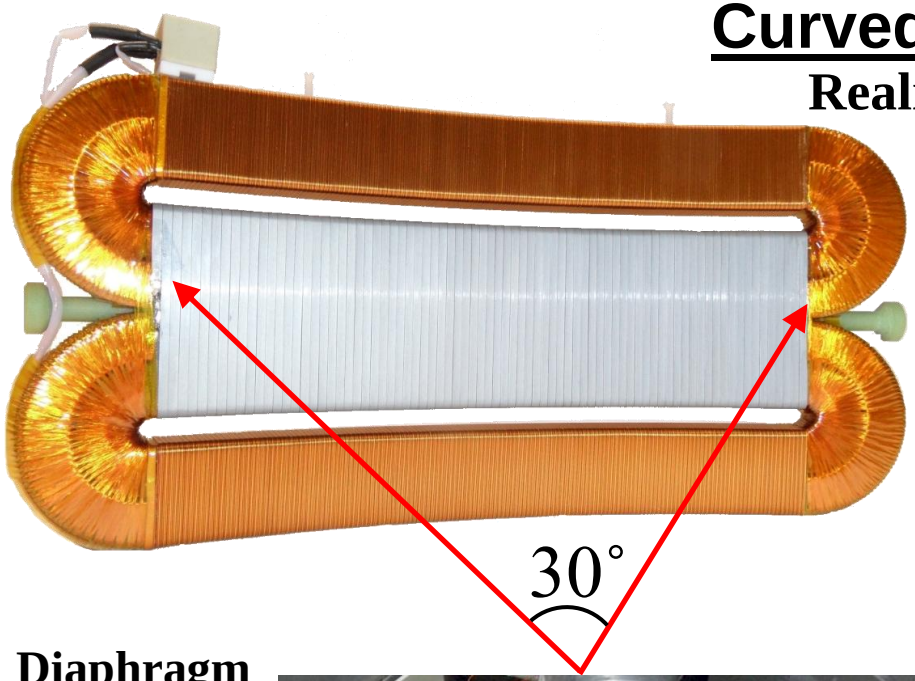
Additional torus coils

Sapphire inserts

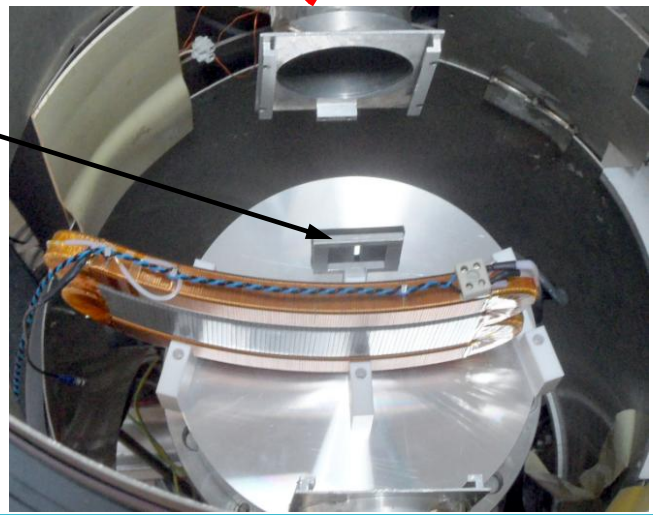


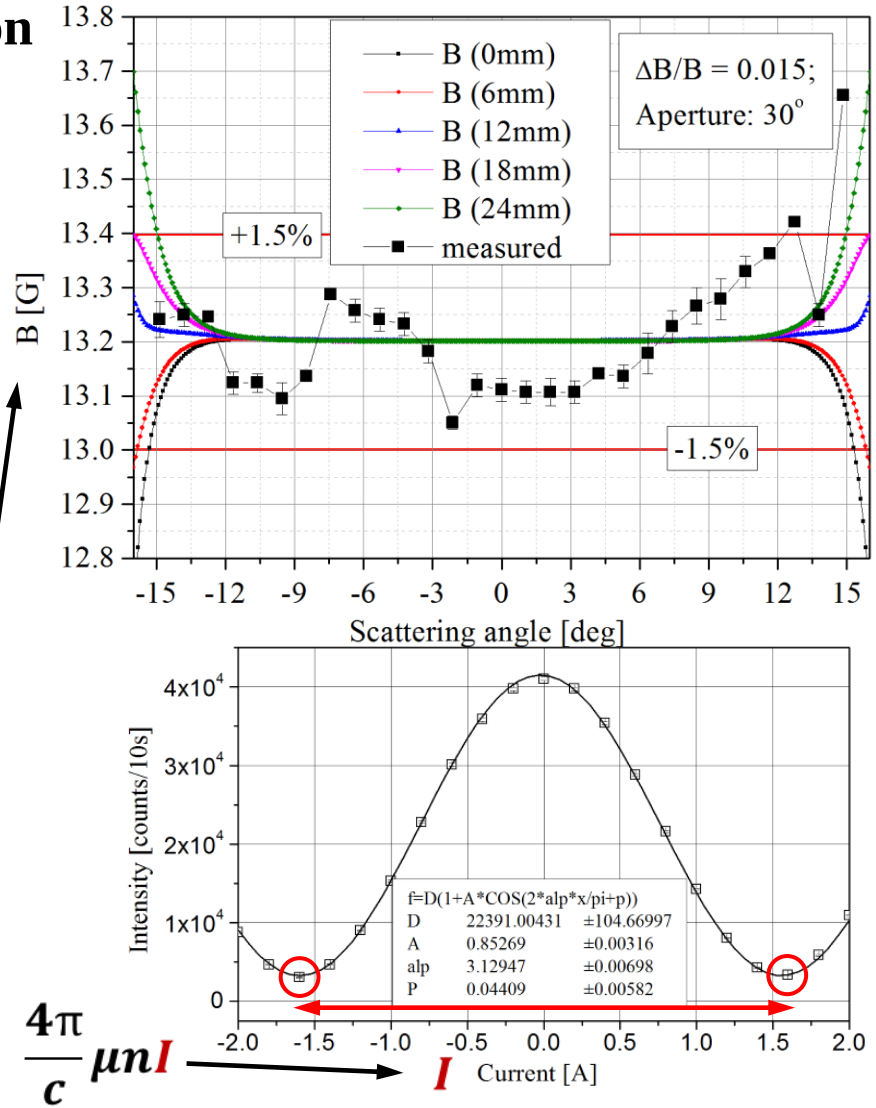
Curved RF Coil

Realization



Diaphragm
3mm width



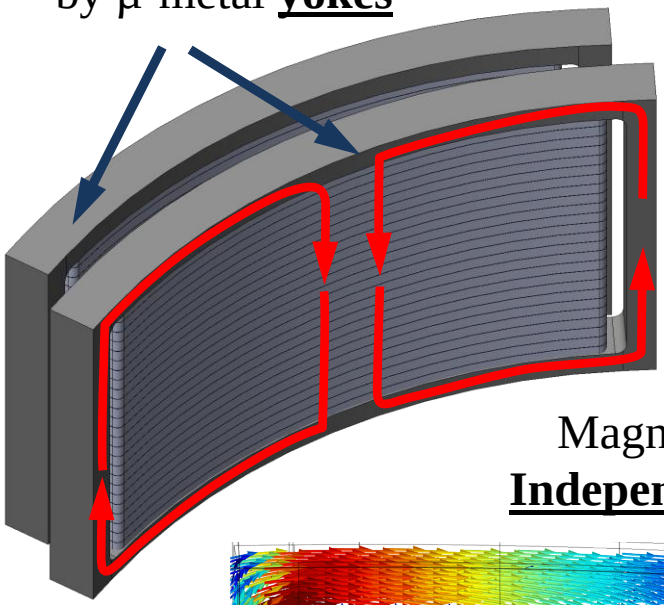


$$B = \frac{4\pi}{c}\mu n I$$

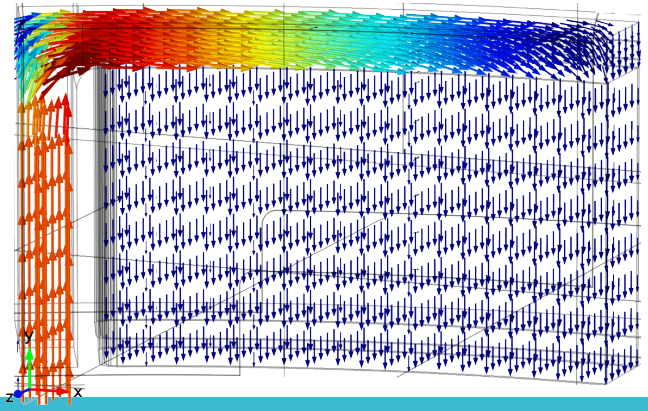
Curved Static Coil

•New design of the coil to compensate stray magnetic fields

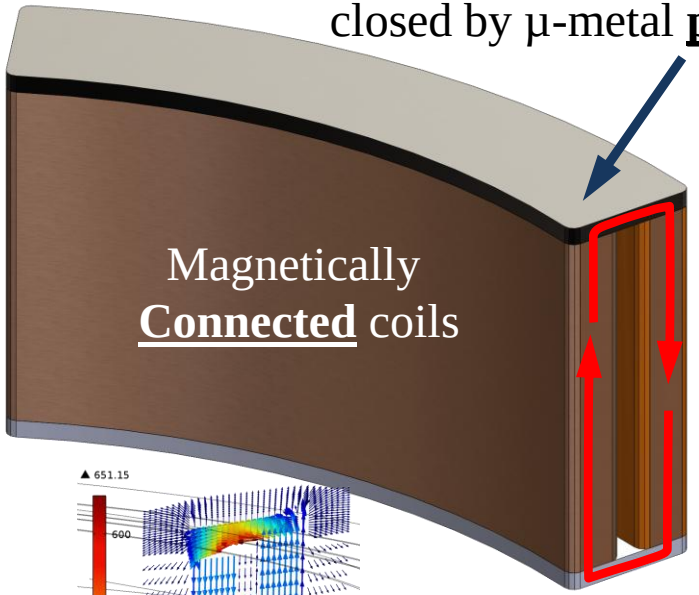
Magnetic field closed by µ-metal **yokes**

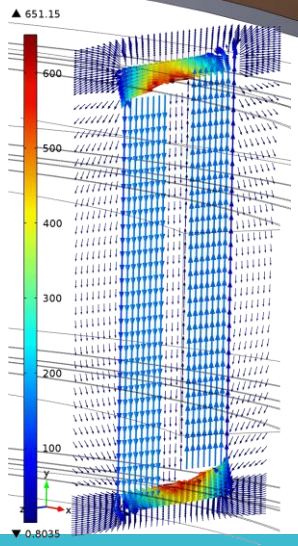


Magnetically **Independent** coils

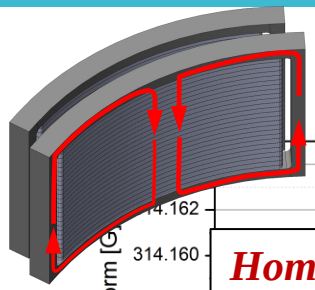


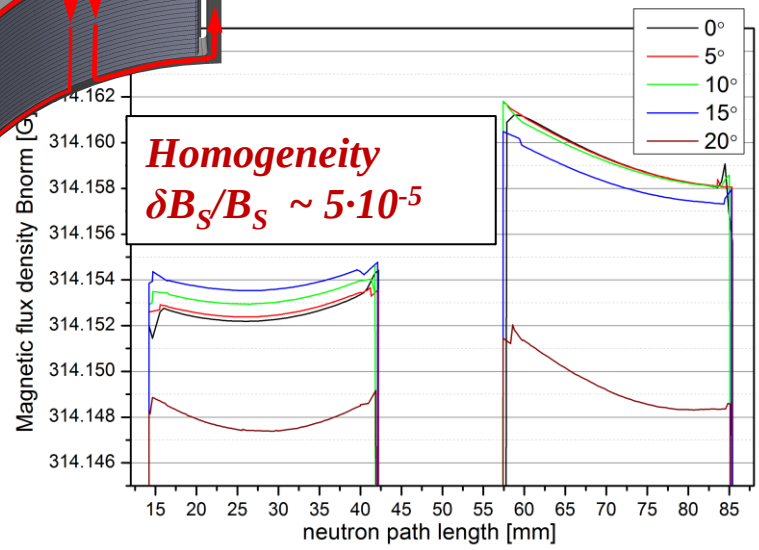
Magnetic field closed by µ-metal **plates**

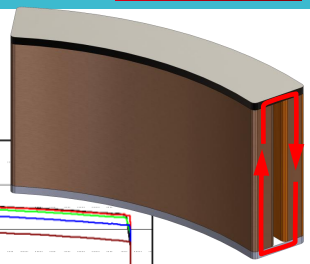


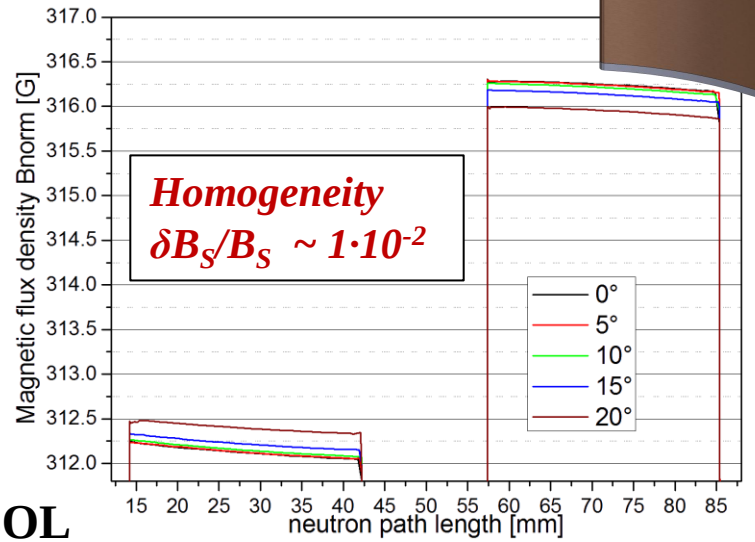


Curved Static Coil

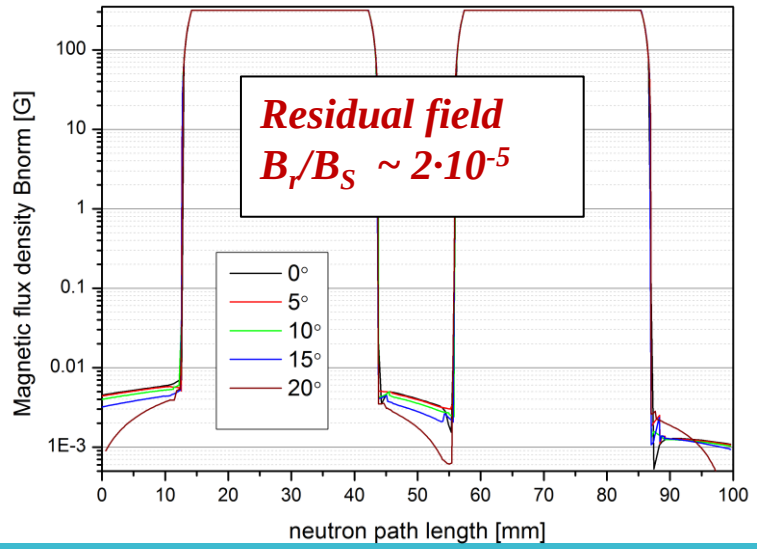


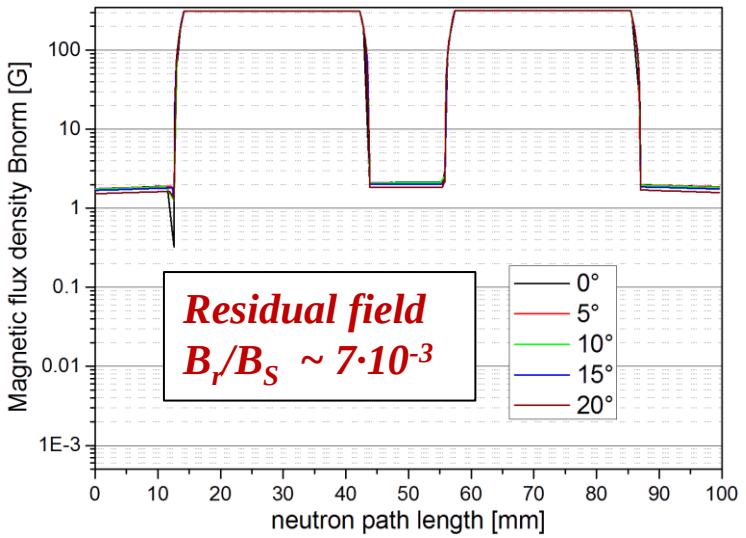






COMSOL



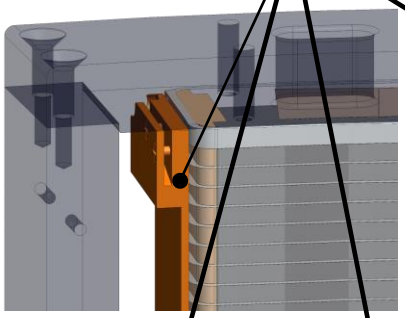


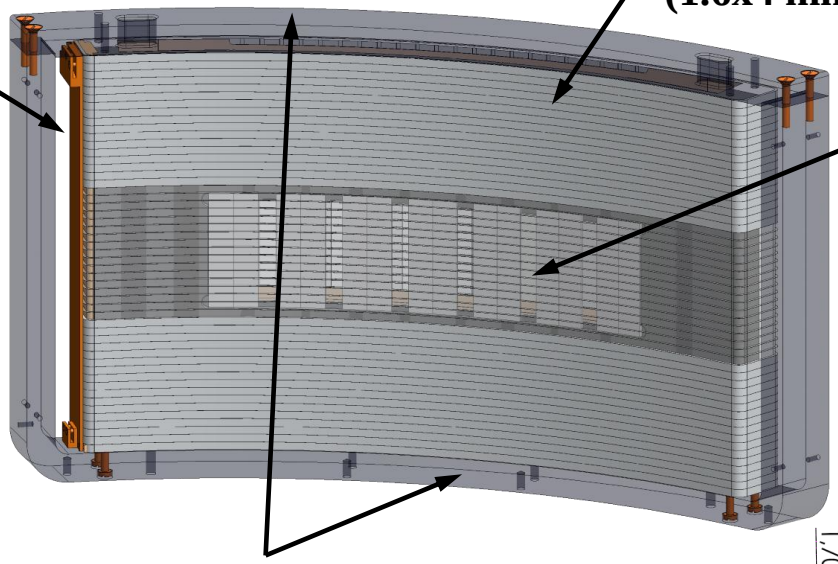
Curved Static Coil

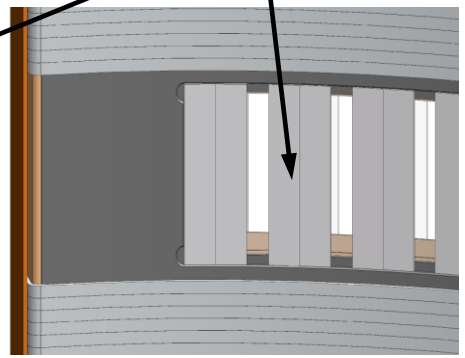
Back current bar

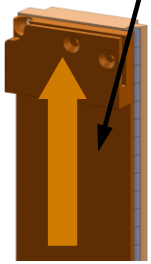
Anodized Al band
(1.6x4 mm^2)

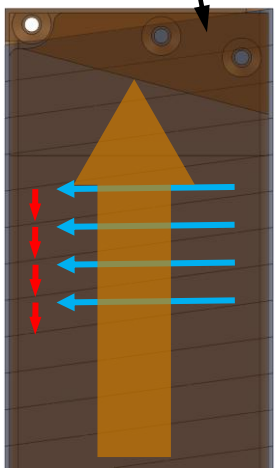
Sapphire plates



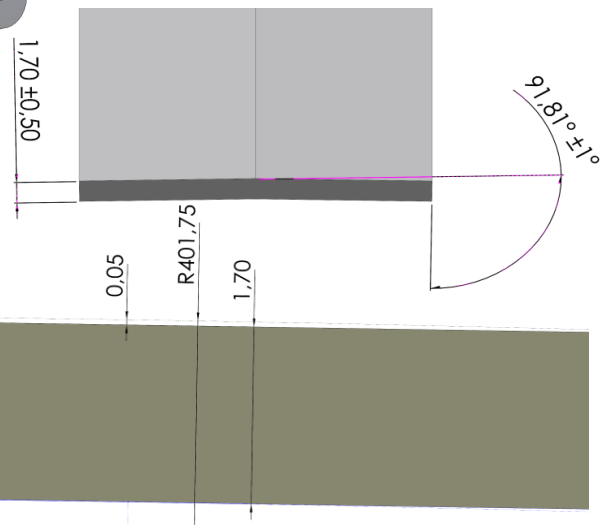








Mu-metal yoke
to loop stray fields

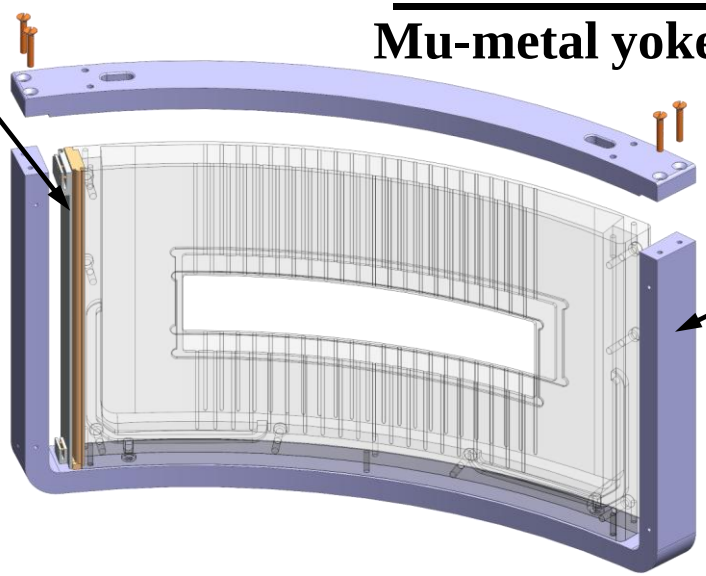


Neutron transmittance of sapphire 1.7mm - 99.3% at λ=5 Å,
1.7*16 - 89.2%

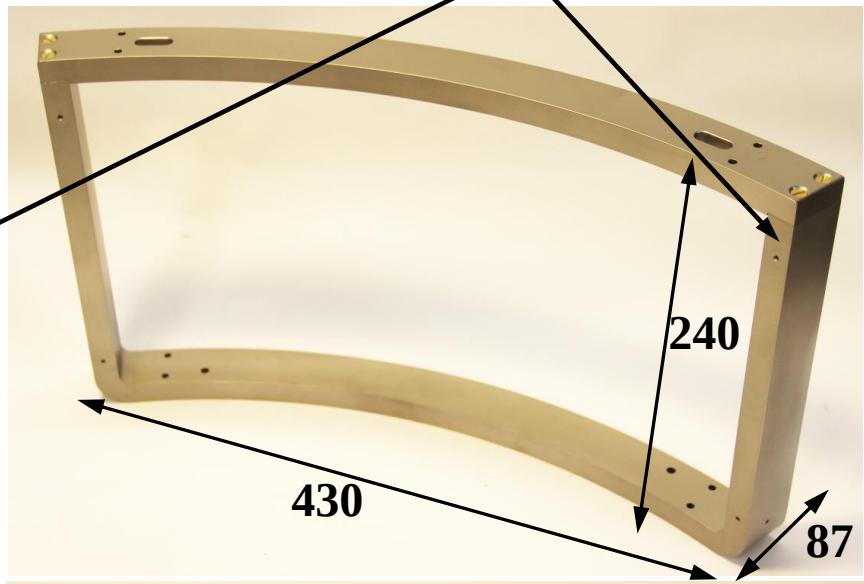
Curved Static Coil

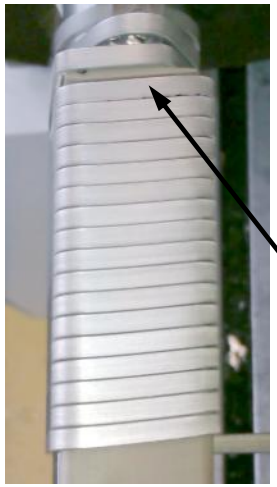
Mu-metal yoke realization

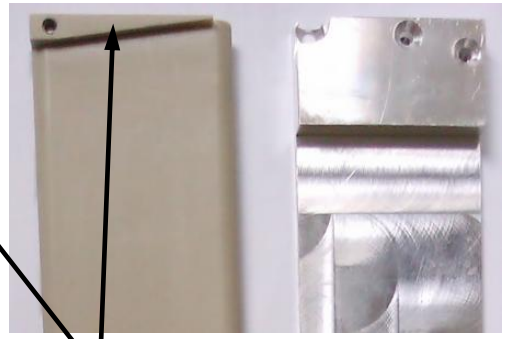
Back current bar



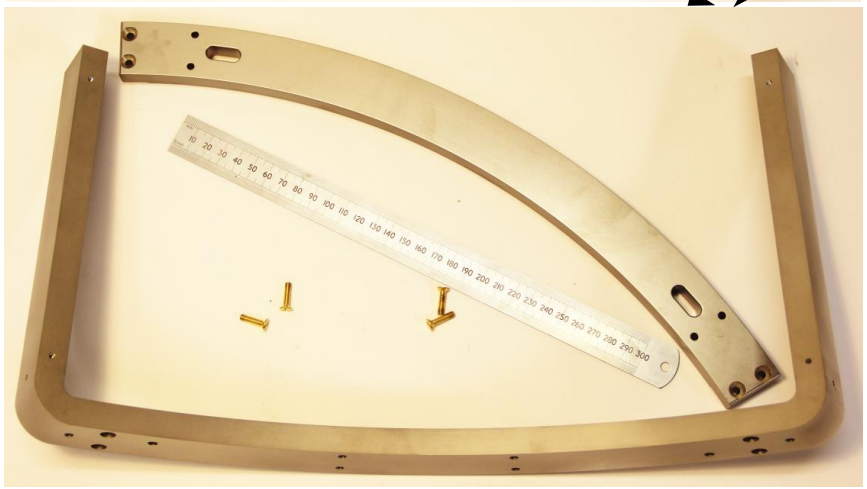
Mu-metal yoke





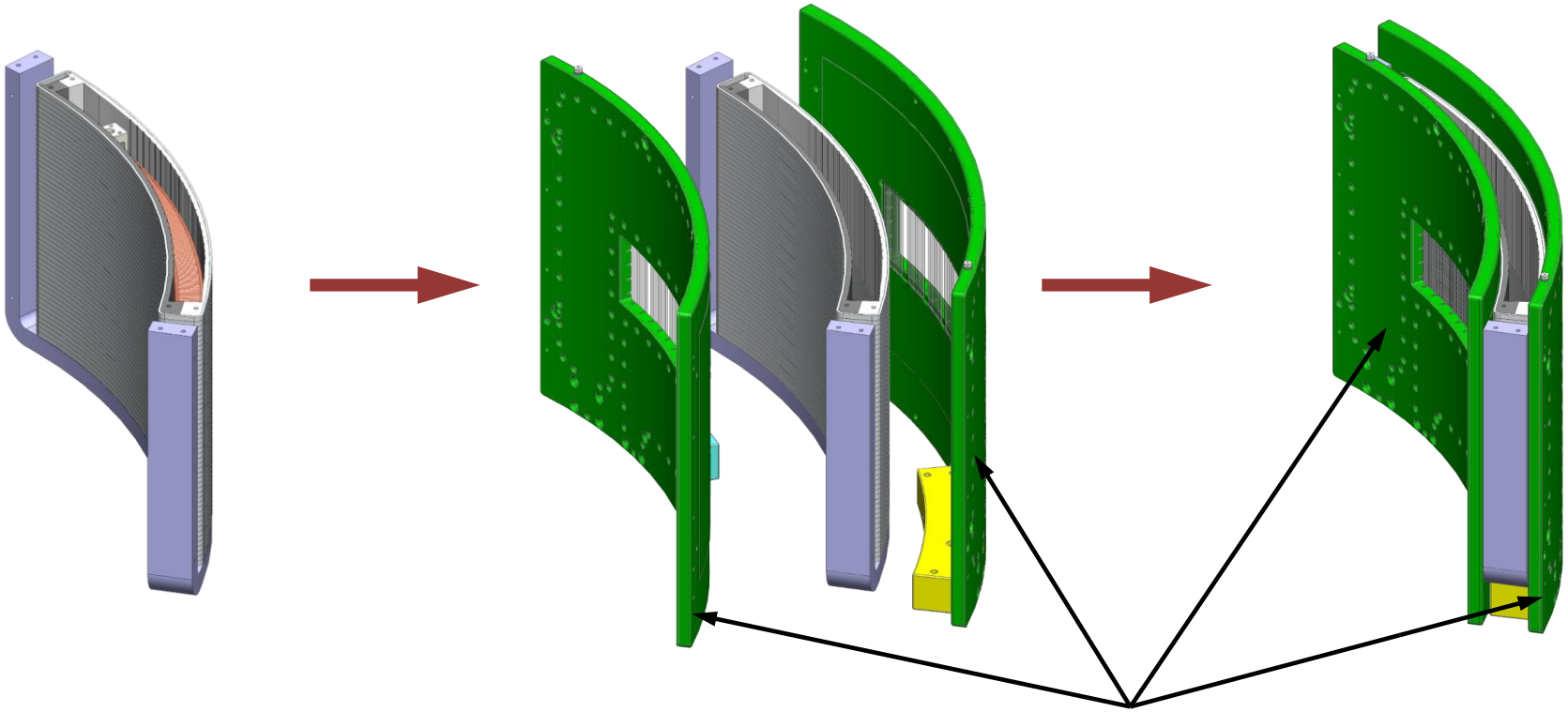


Inclination of the aluminum band on one side of the coil



Curved Static Coil

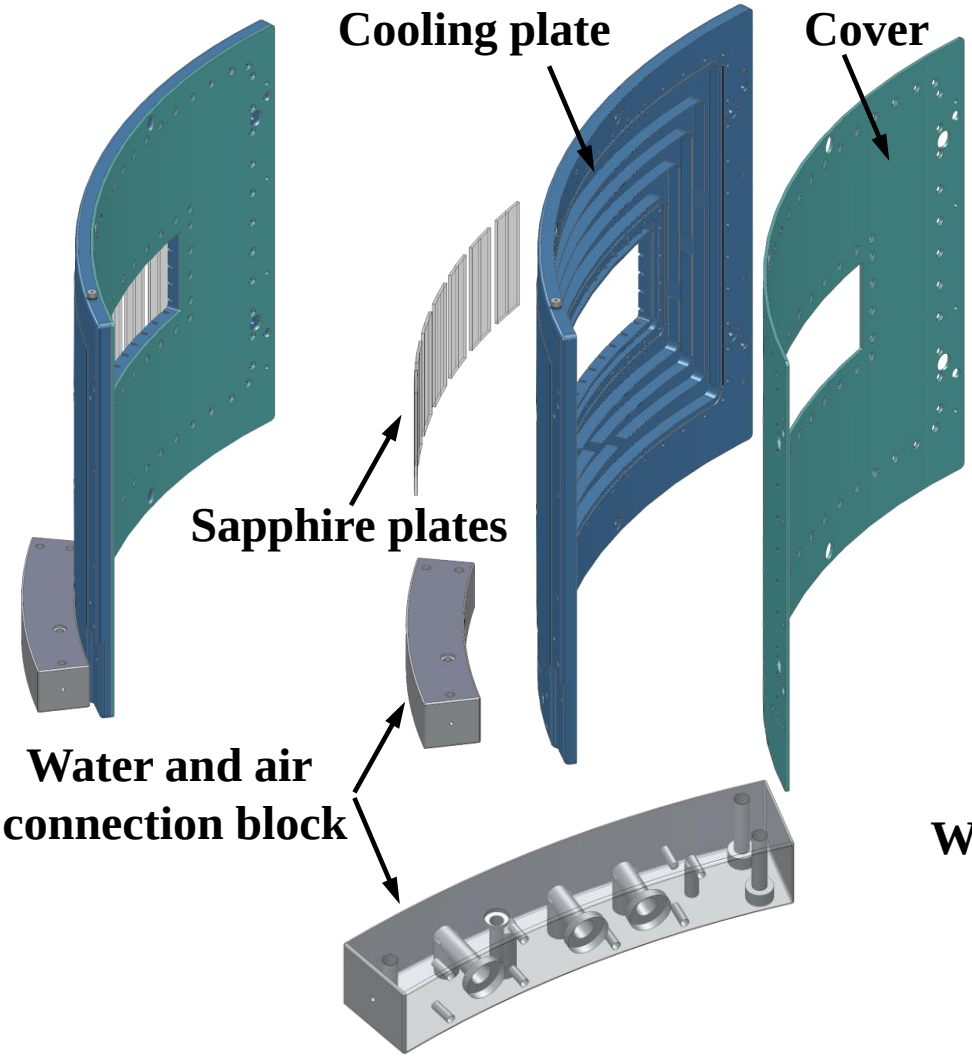
Estimated resistance of the static coil R = 0.178Ω → Wmax(100A) ~ 1800Watt

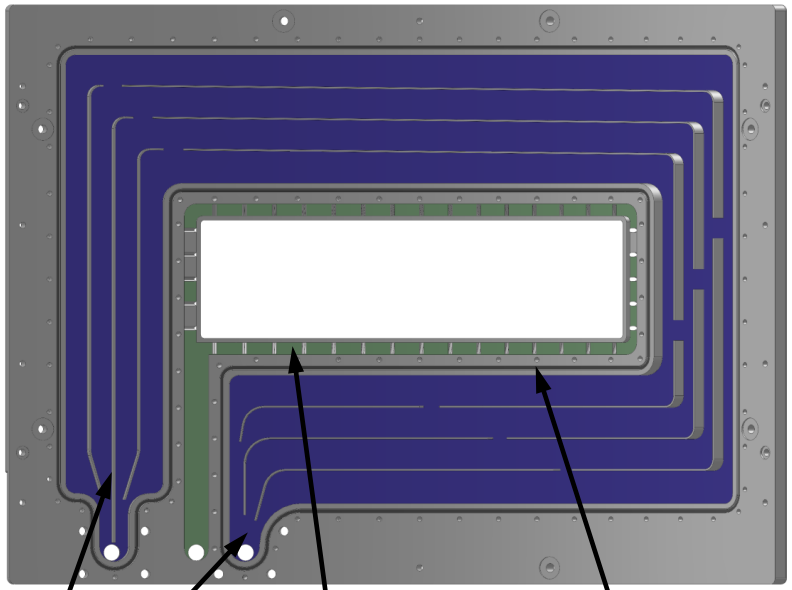


Thermally conductive paste
Gap Filler 3500s35

Cooling plates

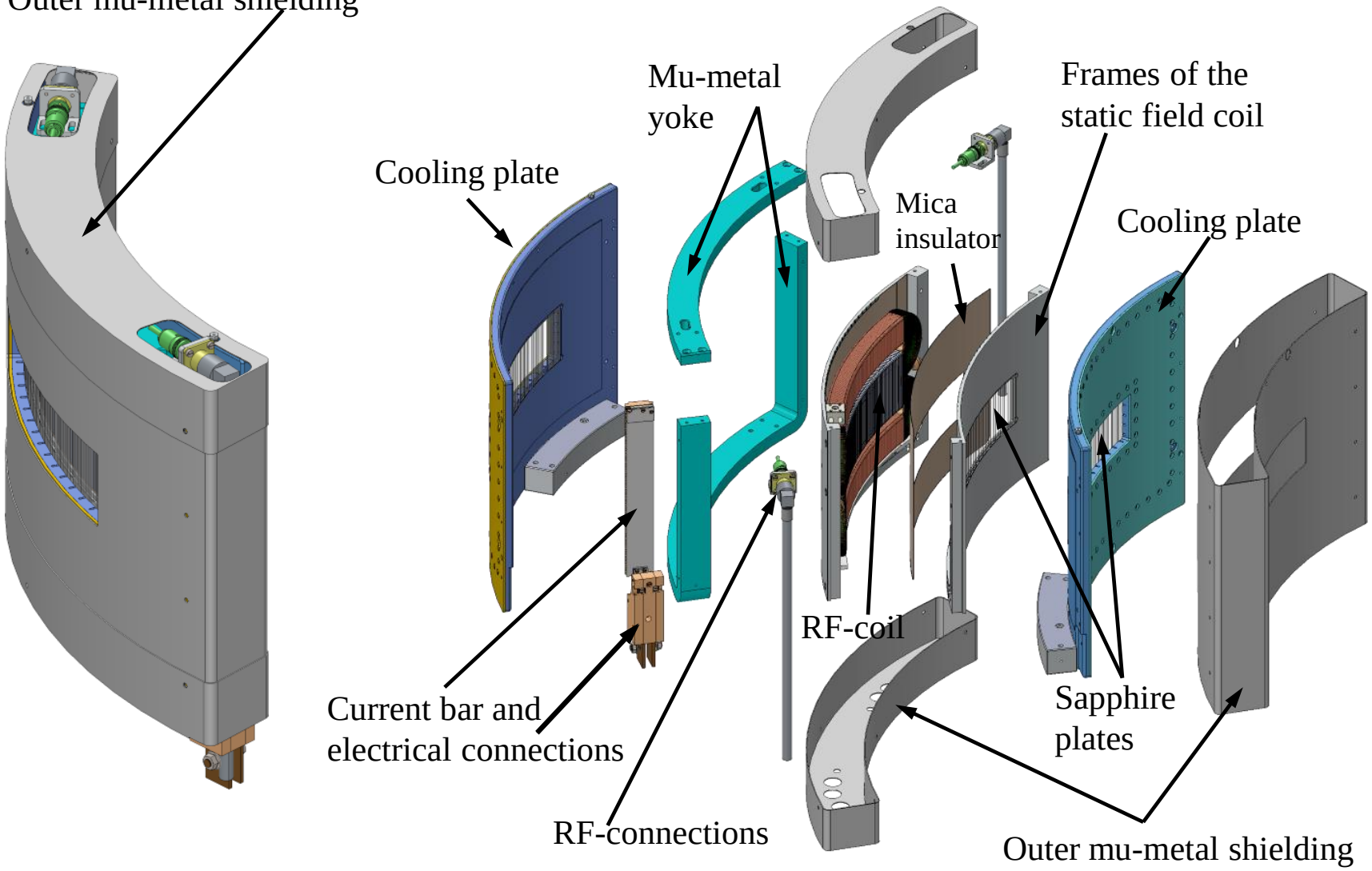
Curved Static Coil



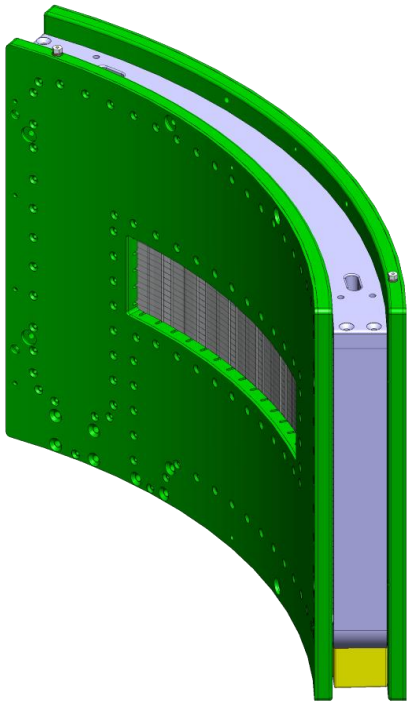


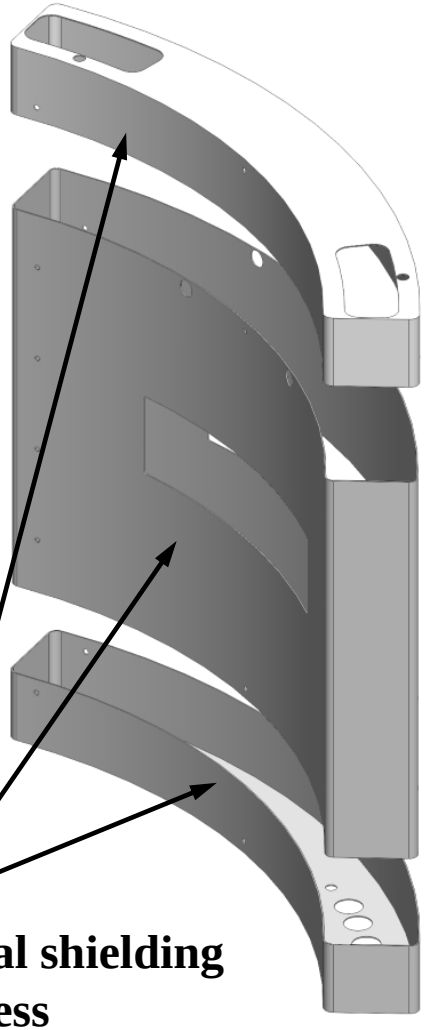
Water cooling
Air cooling
Rubber sealing

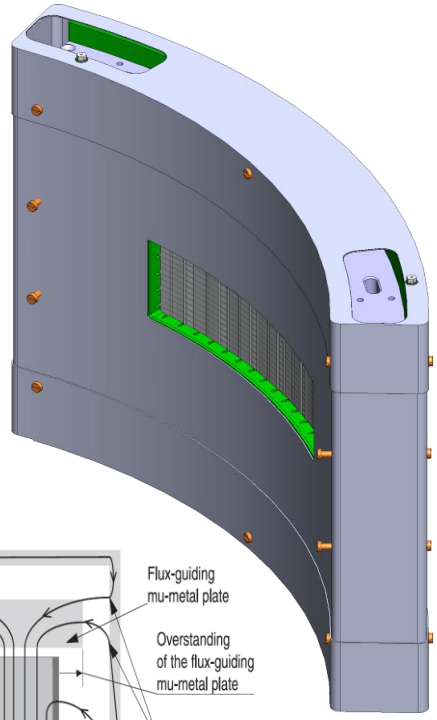
Curved Static Coil



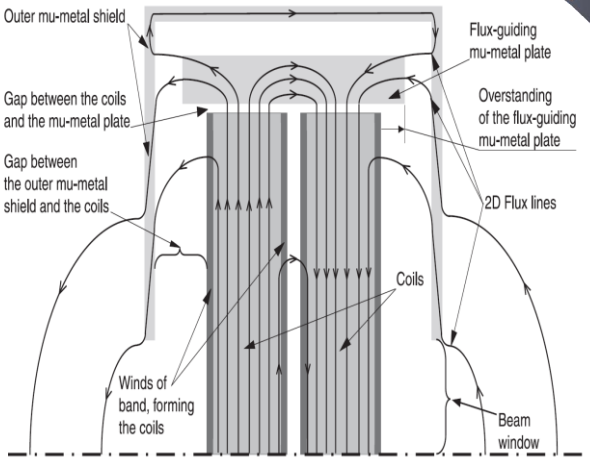
Curved Static Coil





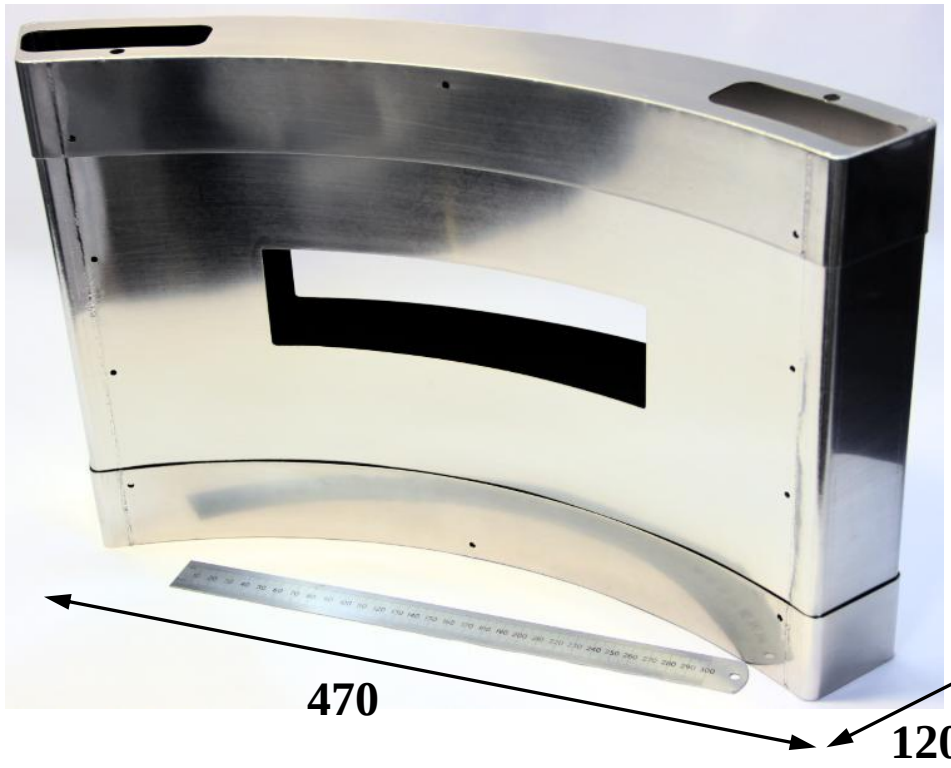


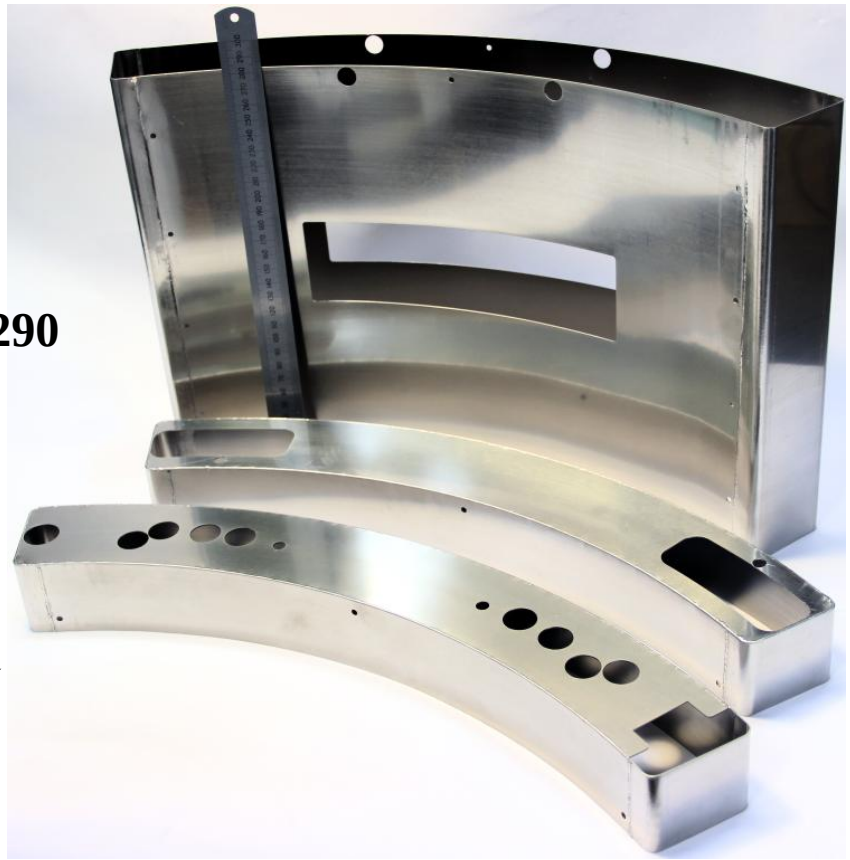
Outer mu-metal shielding
0.8 mm thickness



Curved Static Coil

Outer mu-metal shielding realization





Produced by “Magnetic Shields”

Winding of RF-coil

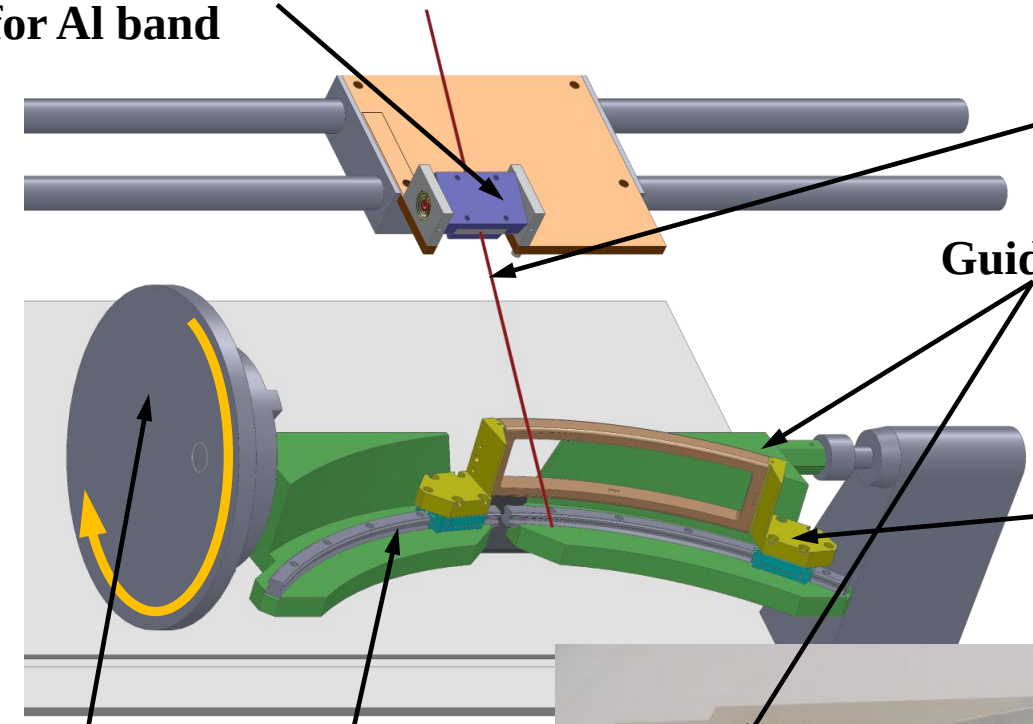
Guide and tension system for Al band

Al band – 3 x 0.3 mm

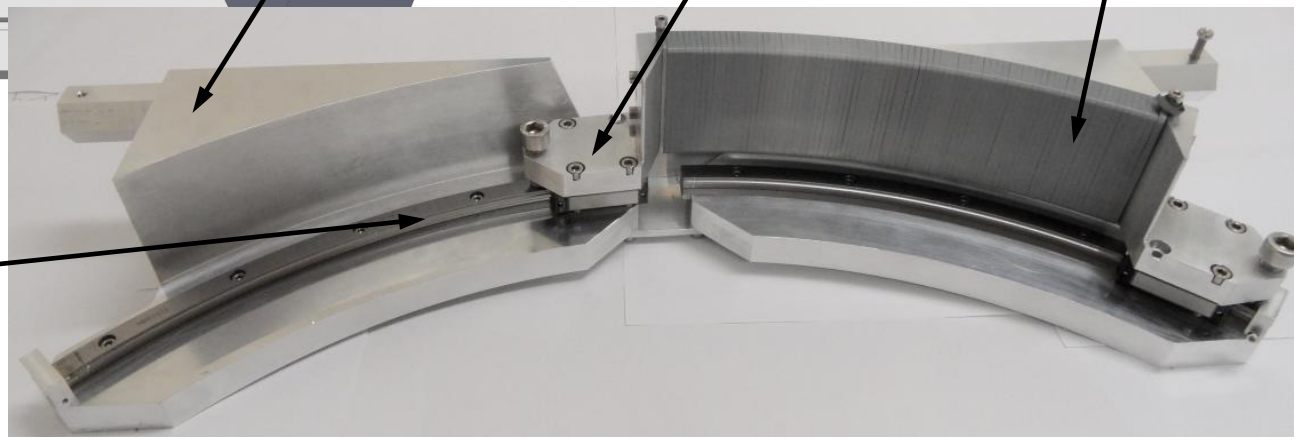
Guide supports

Curved RF-coil

Adaptors between carts and RF-coil

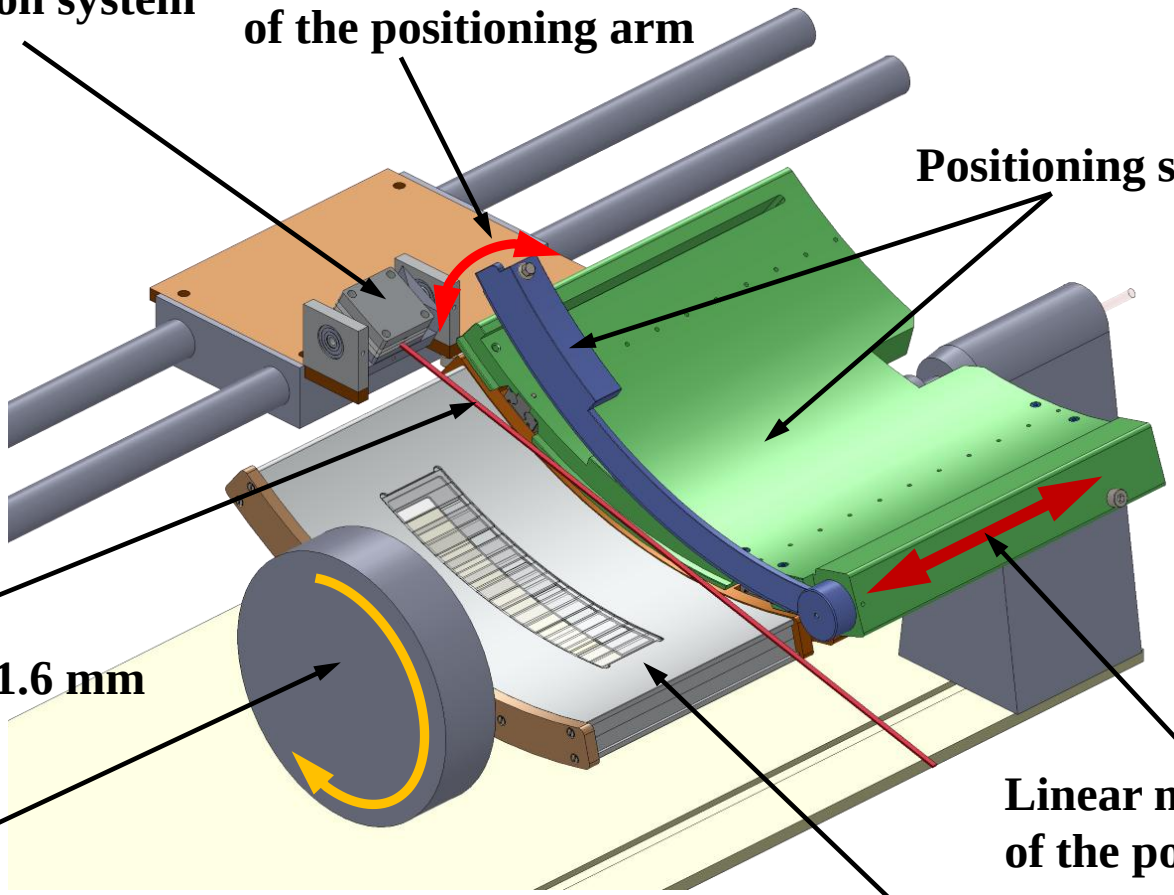


Winding machine



“THK” HCR curved guides and carts

Winding of static coil



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Technical support:

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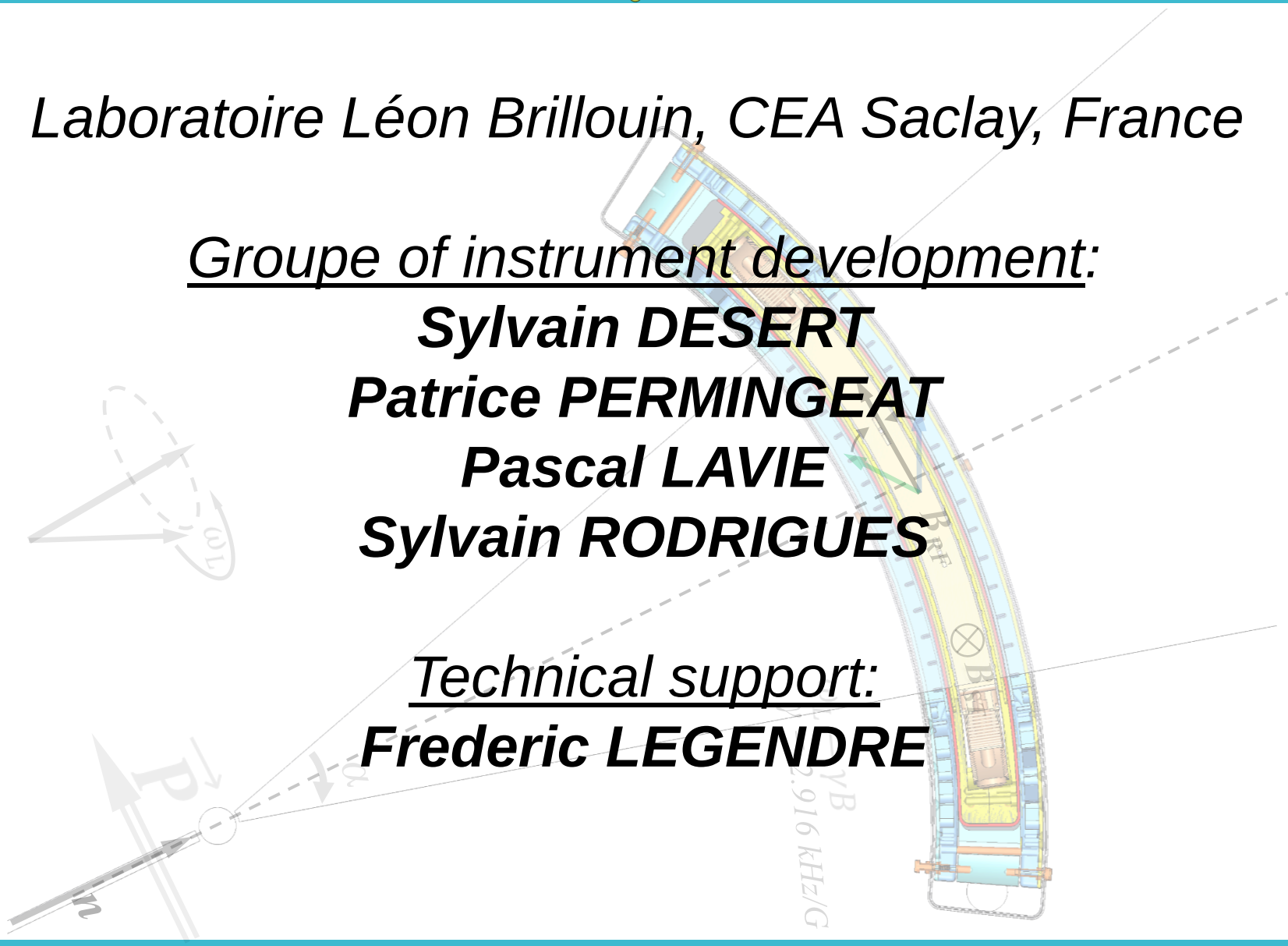
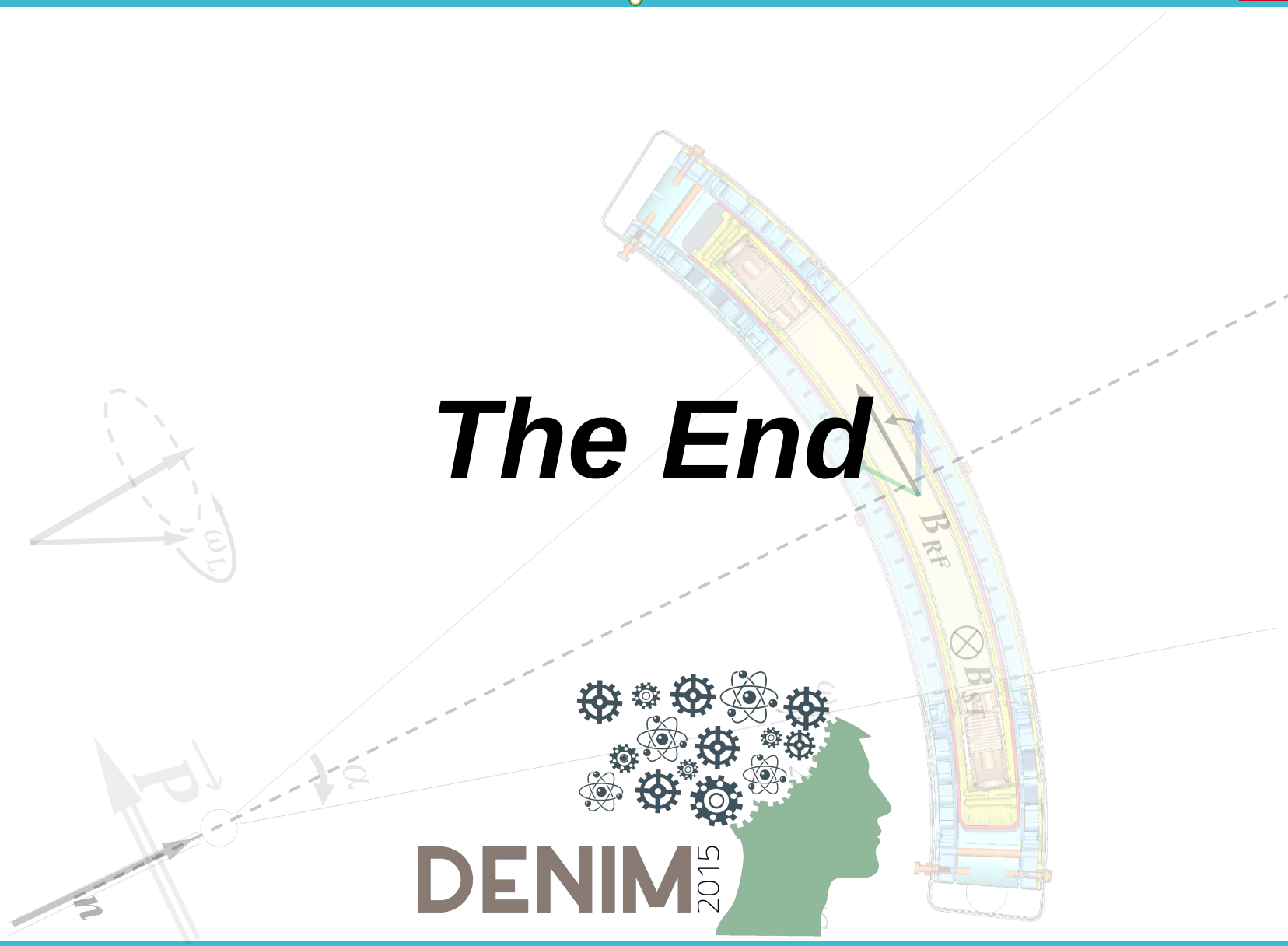


The End

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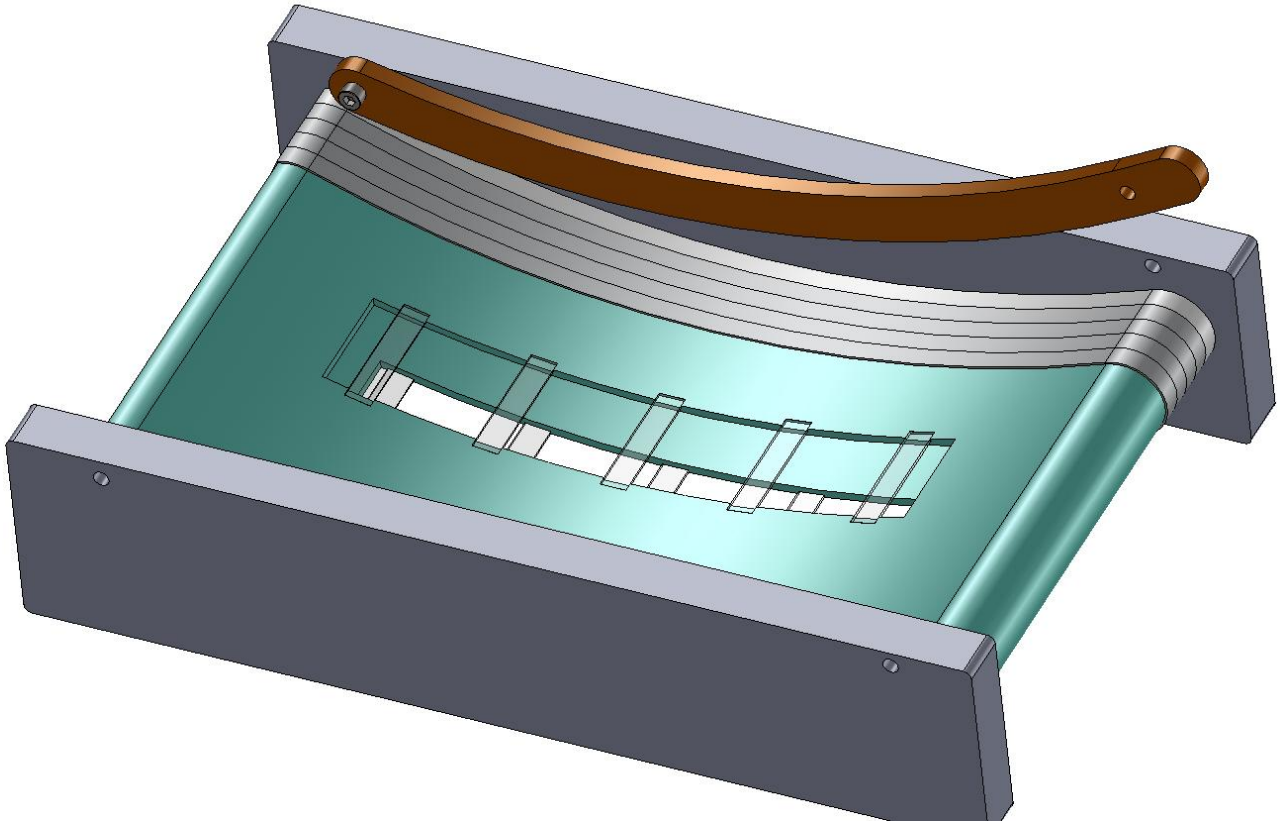
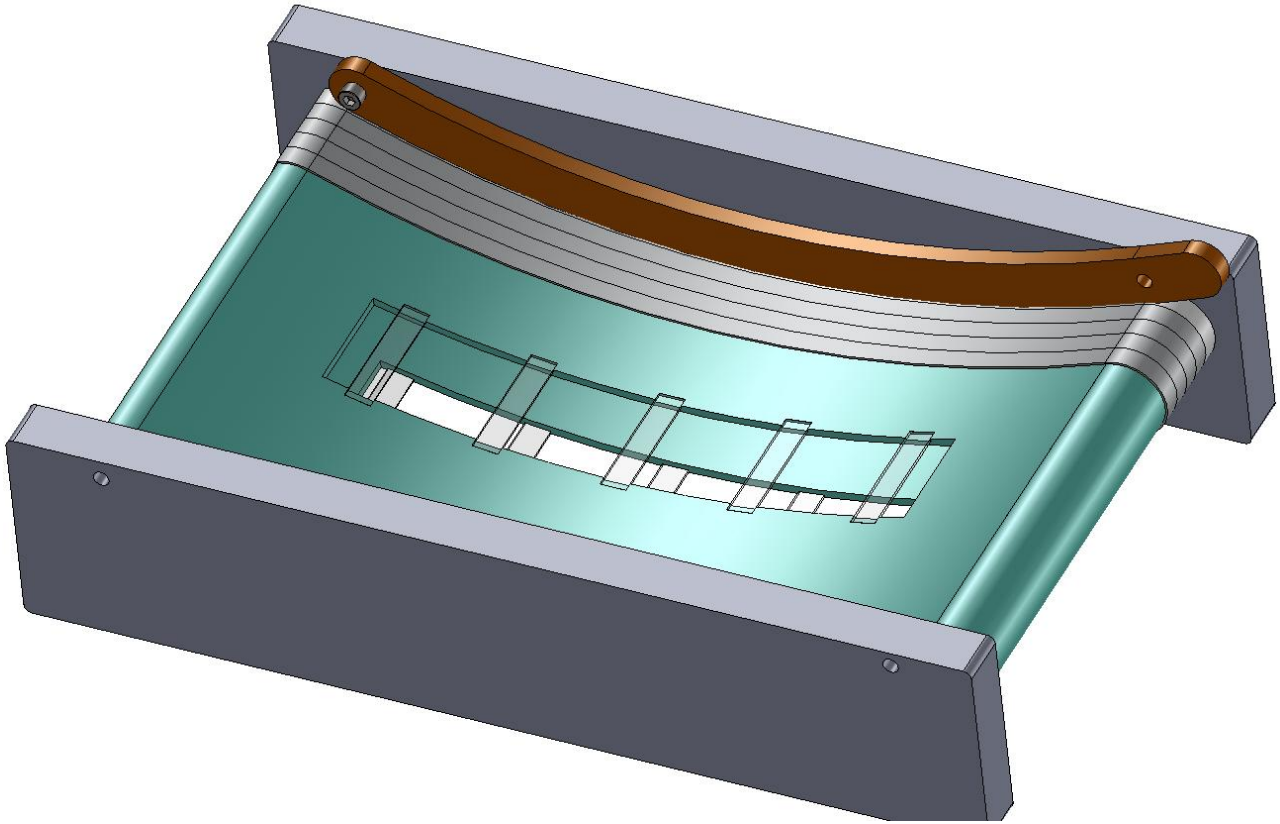
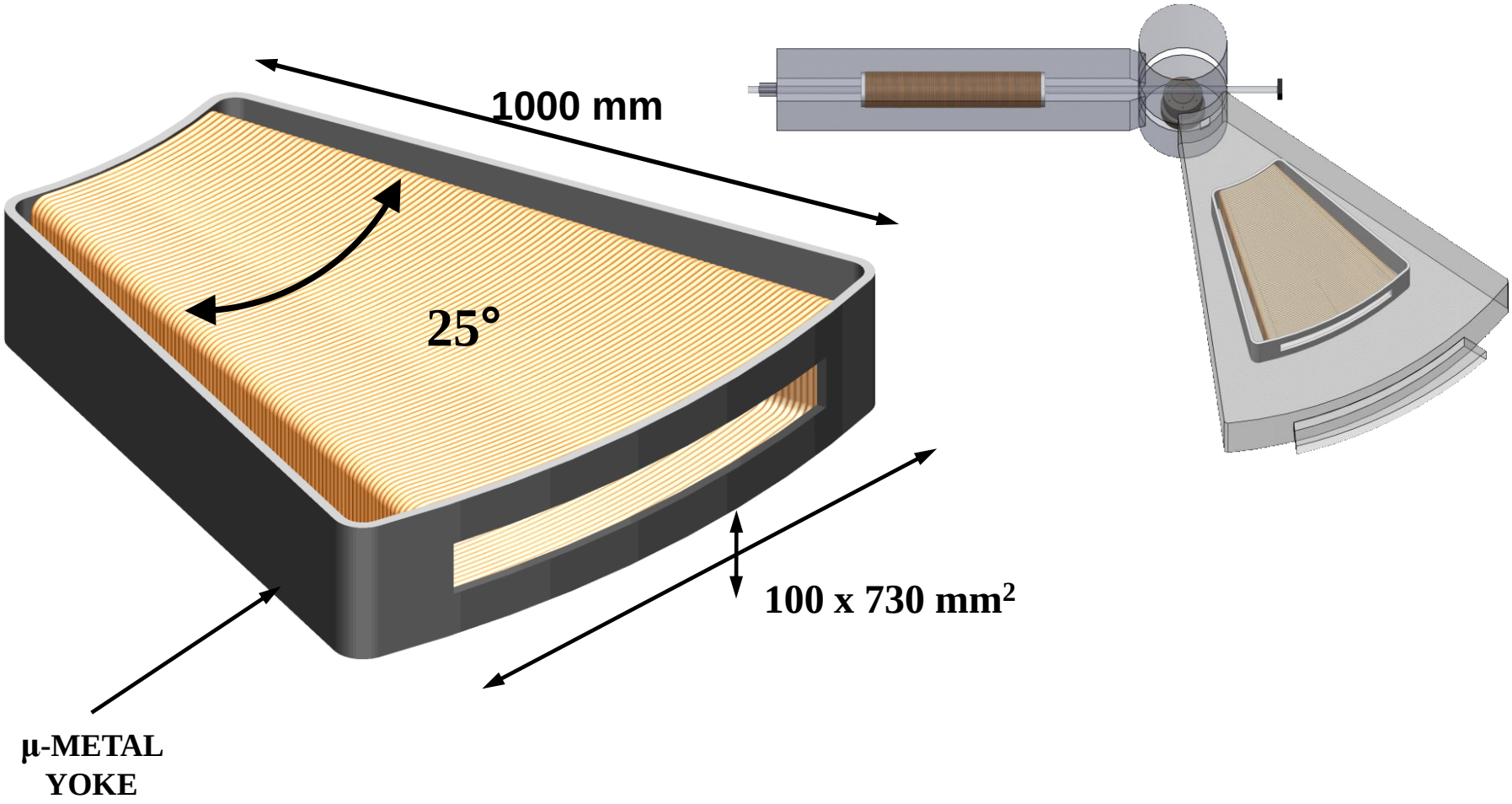




Wide Angle Solenoid



Magnetic Shielding

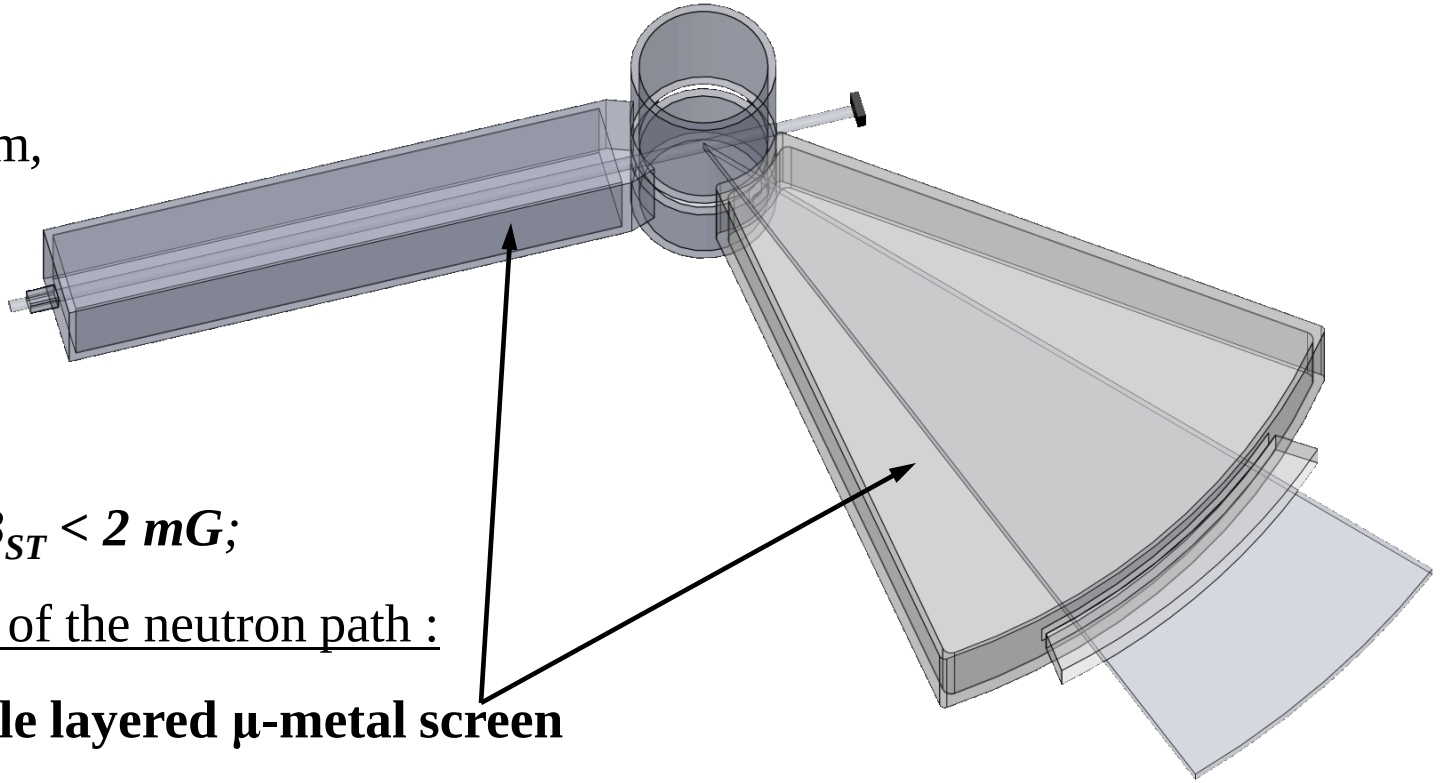
Deviation angle of polarization due to the stray fields:

$\varphi_d = \gamma B_{ST} L / v$;

$B_{ST} \approx 2$ mG, $L = 5$ m,

$\lambda = 10$ Å;

$\varphi_d \approx \mathbf{24}^\circ$;



B_{ST} < 2 mG;

Magnetic shielding of the neutron path :

Double layered μ-metal screen

Multi – Analyser

- C-benders, supermirrors
- Variable radius of analyser curvature (diff. λ)
- System of curvature changing
- Magnetic circuit (magnetic saturation of supermirrors)
- Shielding (magnetic, neutron)