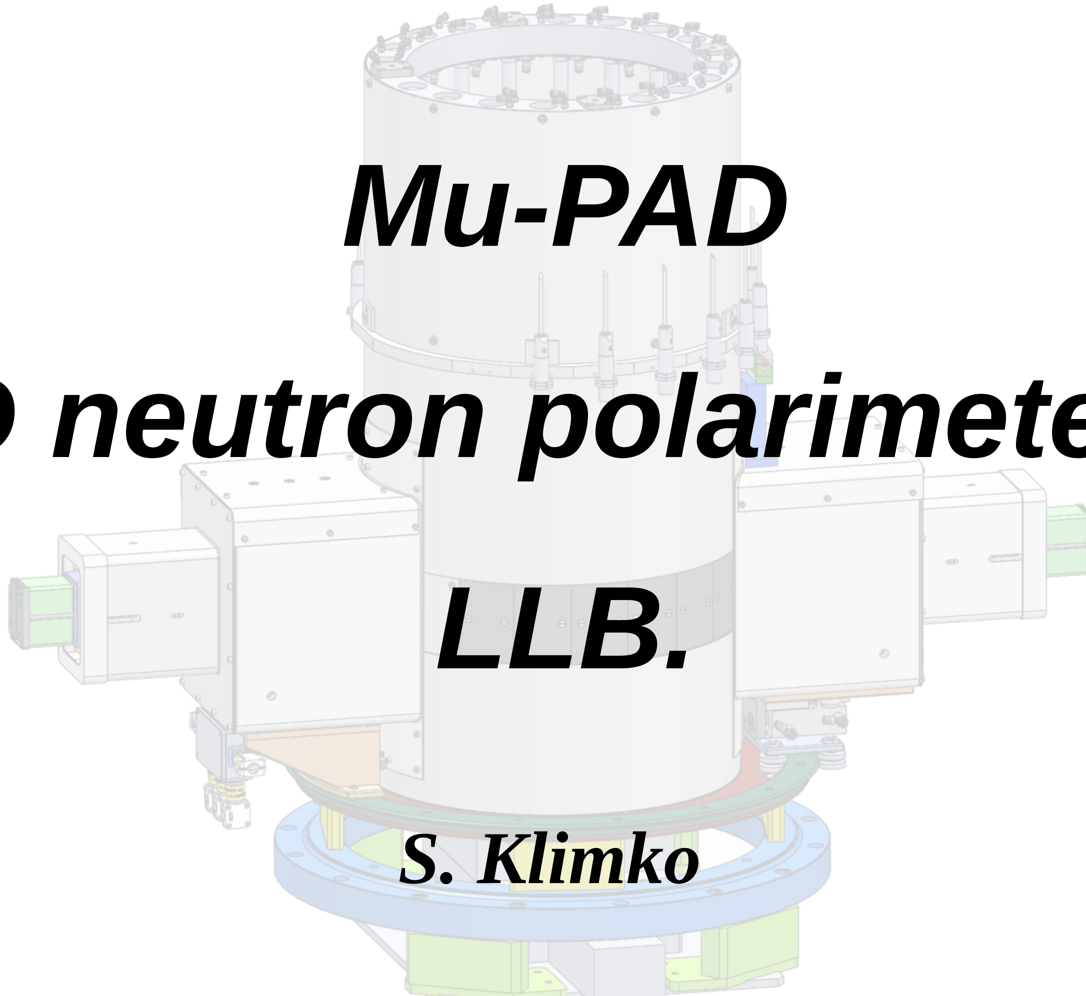


Mu-PAD

3D neutron polarimeter at LLB.

S. Klimko

Polarization in neutron scattering experiment

Polarization dependent scattering

if $\vec{P}_0 = 0$

$$\begin{cases} \sigma_{tot} = \sigma(\text{nuclear}) + \sigma(\text{magnetic}) \\ \sigma_{tot} = N^*_{\vec{Q}} N_{\vec{Q}} + \vec{M}^{*\perp}_{\vec{Q}} \vec{M}^{\perp}_{\vec{Q}} + i\vec{P}_0 \left(\vec{M}^{*\perp}_{\vec{Q}} \times \vec{M}^{\perp}_{\vec{Q}} \right) + \vec{P}_0 \left(N_{\vec{Q}} \vec{M}^{*\perp}_{\vec{Q}} + N^*_{\vec{Q}} \vec{M}^{\perp}_{\vec{Q}} \right) \end{cases}$$

if $\left|\vec{P}_0\right| = 1$

$$\begin{cases} \sigma_{tot} = \sigma(\text{nuclear}) + \sigma(\text{mag.}) + \\ \qquad \sigma(\text{mag.chiral}) + \sigma(\text{nuclear - mag.interference}) \\ \\ \vec{P}_f \sigma_{tot} = \vec{P}_0 N^*_{\vec{Q}} N_{\vec{Q}} + (-1)\vec{P}_0 \vec{M}^{*\perp}_{\vec{Q}} \vec{M}^{\perp}_{\vec{Q}} + \vec{M}^{*\perp}_{\vec{Q}} (\vec{P}_0 \vec{M}^{\perp}_{\vec{Q}}) + (\vec{M}^{*\perp}_{\vec{Q}} \vec{P}_0) \vec{M}^{\perp}_{\vec{Q}} + \\ \qquad (-i)\left(\vec{M}^{*\perp}_{\vec{Q}} \times \vec{M}^{\perp}_{\vec{Q}} \right) + N_{\vec{Q}} \vec{M}^{*\perp}_{\vec{Q}} + N^*_{\vec{Q}} \vec{M}^{\perp}_{\vec{Q}} + i\left(N_{\vec{Q}} \vec{M}^{*\perp}_{\vec{Q}} - N^*_{\vec{Q}} \vec{M}^{\perp}_{\vec{Q}} \right) \times \vec{P}_0 \end{cases}$$

Polarization in neutron scattering experiment

Polarization tensor

$$\vec{P}_f = \hat{\mathrm{P}}\vec{P}_0 + \tilde{\vec{P}} =$$

$$= \begin{pmatrix} (\sigma_N - M^y - M^z)/\sigma_0{}^x & iI^z/\sigma_0{}^y & -iI^y/\sigma_0{}^z \\ -iI^z/\sigma_0{}^x & (\sigma_N + M^y - M^z)/\sigma_0{}^y & M^{mix}/\sigma_0{}^z \\ iI^y/\sigma_0{}^x & M^{mix}/\sigma_0{}^y & (\sigma_N - M^y + M^z)/\sigma_0{}^z \end{pmatrix} \begin{pmatrix} P_0^x \\ P_0^y \\ P_0^z \end{pmatrix} + \begin{pmatrix} iT^{chiral}/\sigma_0{}^{x/y/z} \\ R^y/\sigma_0{}^{x/y/z} \\ R^z/\sigma_0{}^{x/y/z} \end{pmatrix}$$

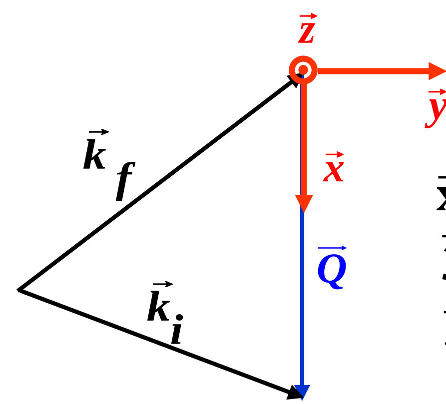
σ_N – nuclear contribution

$M^{y/z}$ – magnetic contribution

$R^{y/z}, I^{y/z}$ – real and imaginary parts of nuclear-magneetic contribution

T^{chiral} – chiral contribution

M^{mix} – mixed magnetic contribution



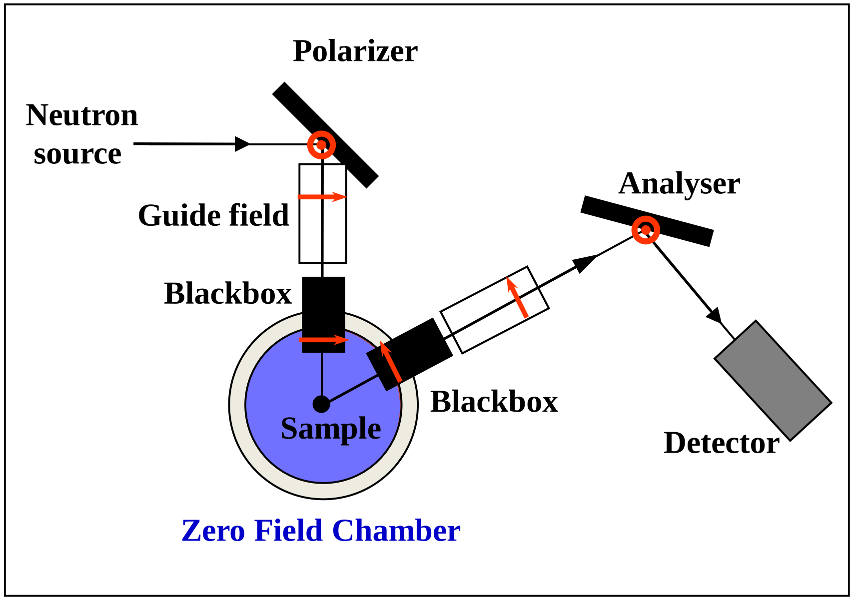
$\vec{x} \parallel \vec{Q}$

$\vec{y} \perp \vec{Q}$ in scattering plane

$\vec{z} \perp \vec{Q}$ out scattering plane

Polarization in neutron scattering experiment

Spherical Polarization Analysis (SPA)



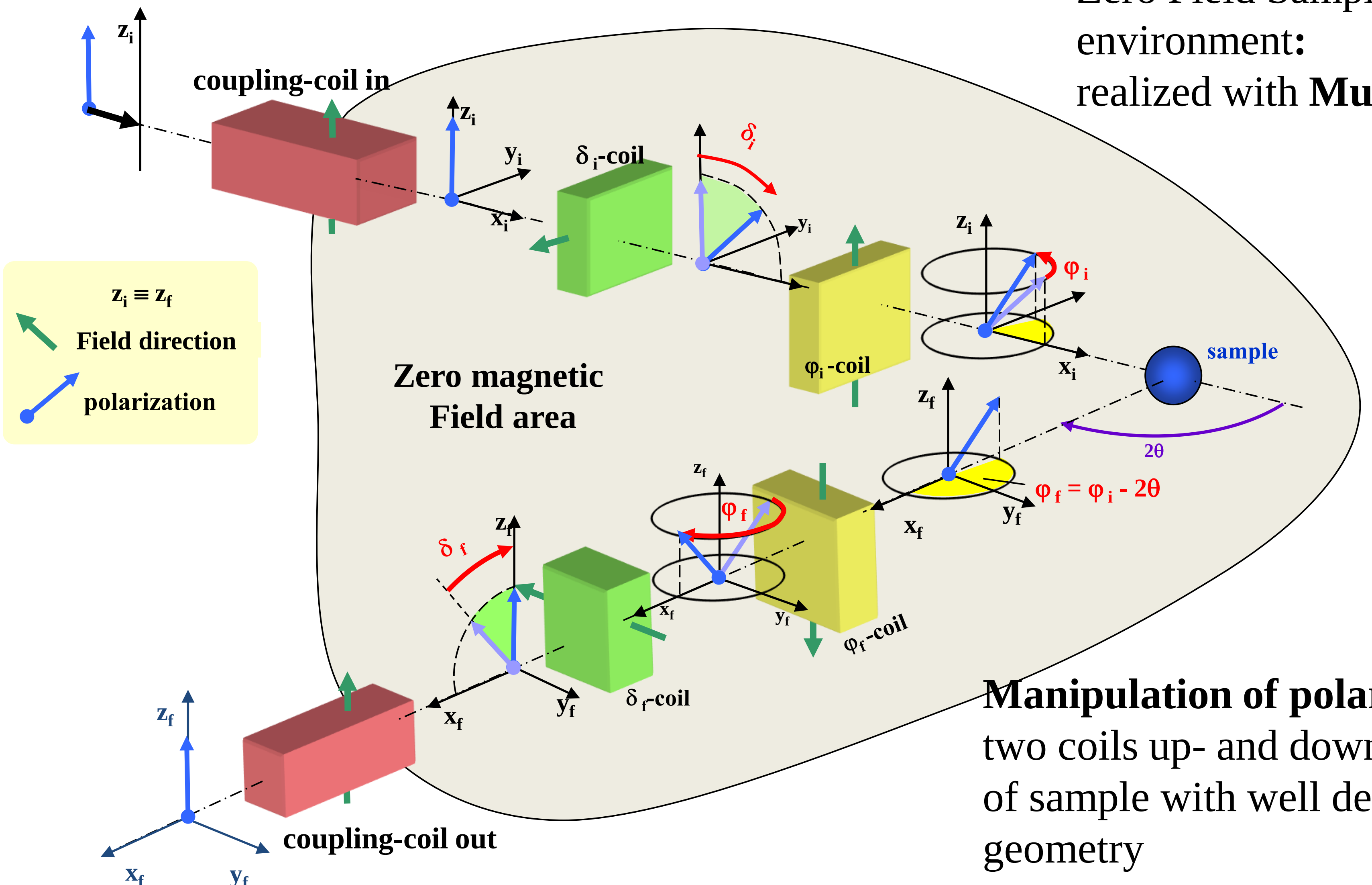
1. Sample should be in ZERO mag. field → Remove guide field for polarization

2. Avoid depolarization due to environment fields → Zero field sample environment

3. To guide polarization into (out of) Zero Field Chamber and measure off-diagonal terms → Special coils geometry for well-defined homogeneous fields to turn and guide polarization

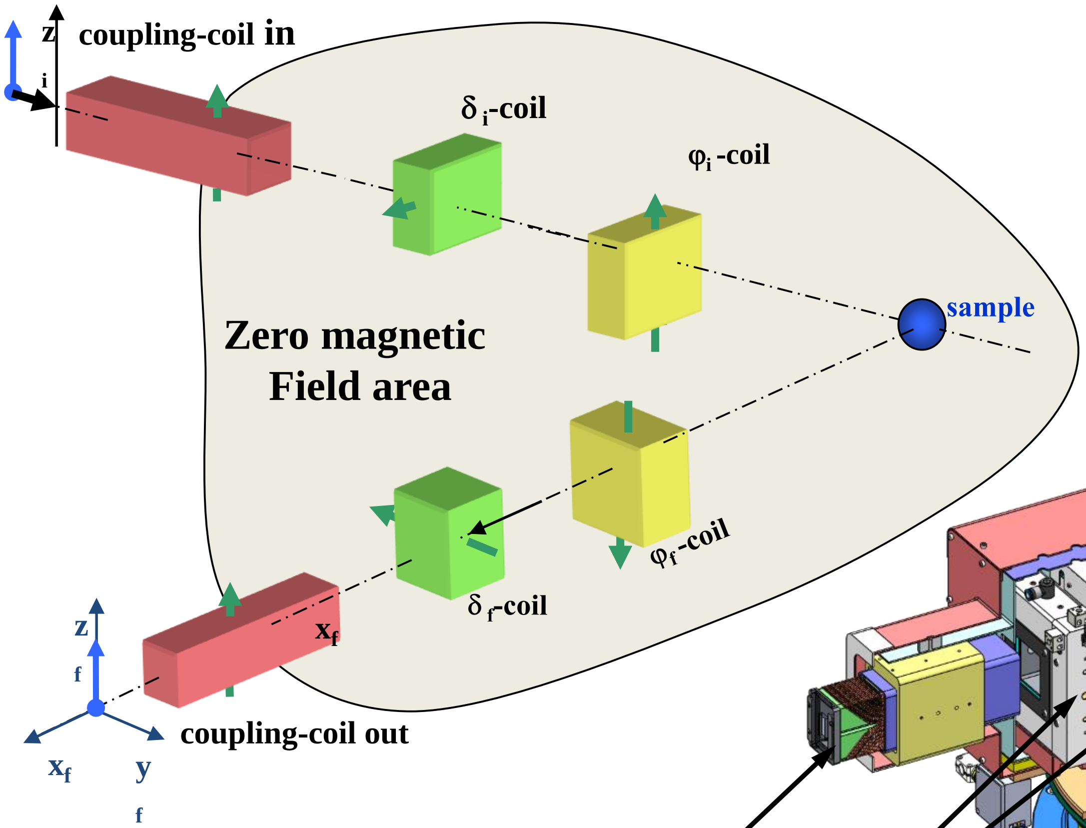
Principle of Mu-PAD

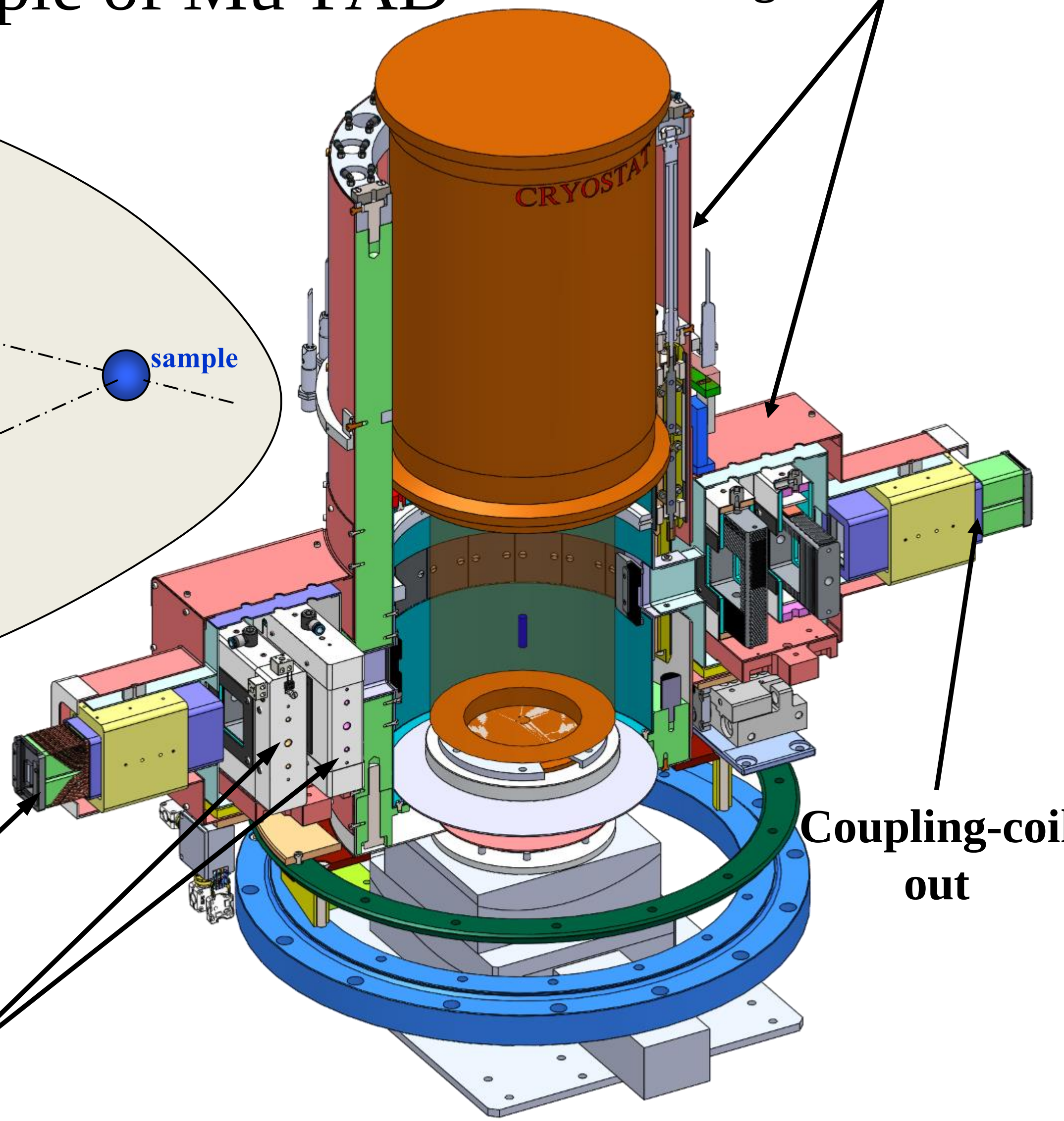
Zero Field Sample environment**:** realized with **Mu-metal**



Manipulation of polarization: two coils up- and downstream of sample with well defined geometry

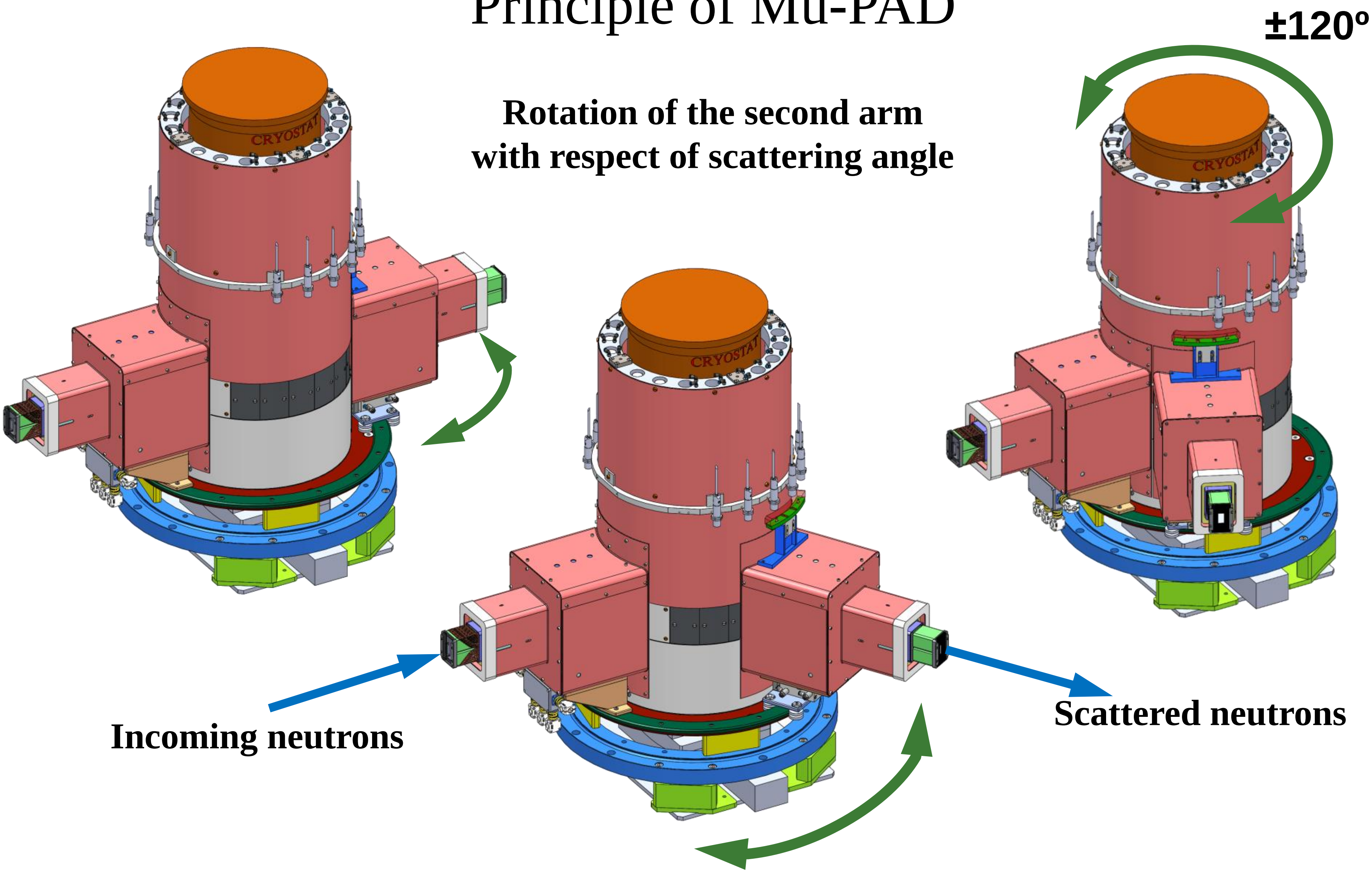
Principle of Mu-PAD



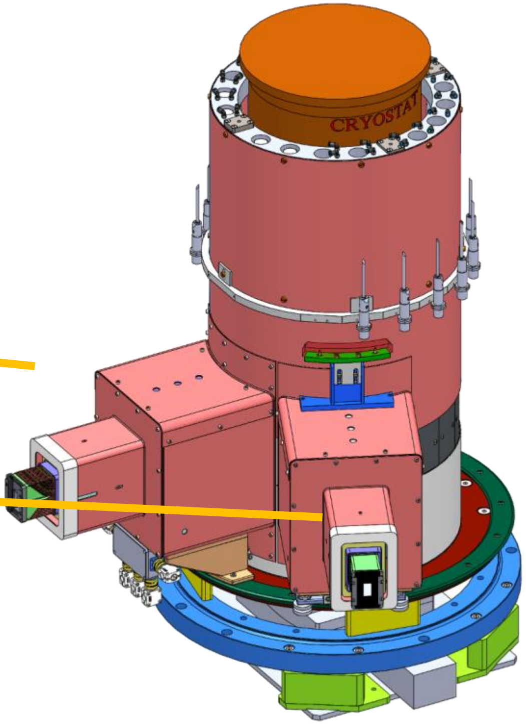


Principle of Mu-PAD

Rotation of the second arm with respect of scattering angle



Principle of Mu-PAD



MuPAD – Mu-metal Polarization Analysis Device

Mu-metal

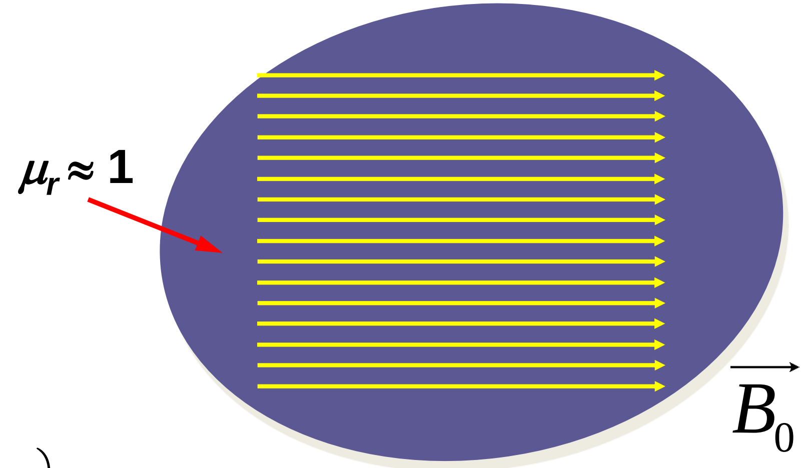
- Zero Field Chamber out of highly permeable (**$\mu_r \approx$ 30.000**) Mu-Metal (alloy 79% Ni, 16% Fe, 5% Cu)

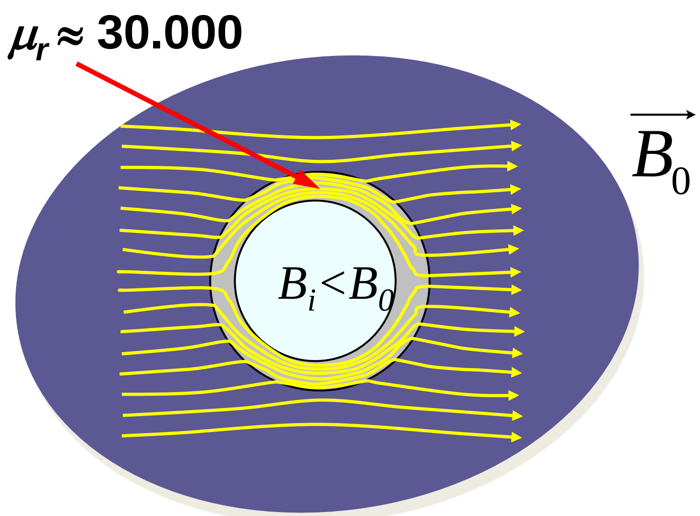
- Reluctance (magnetic resistance) $R_M = l / (\mu_r \mu_0 A)$

- Screening factor $S = \frac{B_0}{B_i}$

For a simple long cylinder S ≈ 100 (∅≈400mm, d=2mm)

Two magnetically decoupled cylinders S ≈10.000 (theoretically)





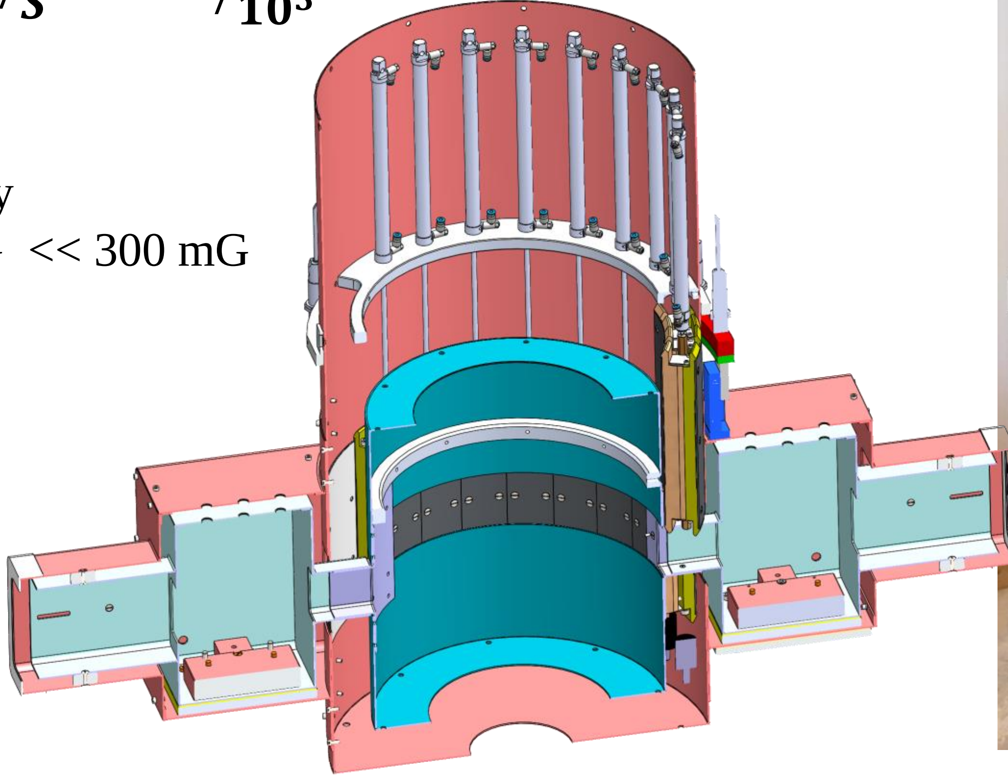
Zero field chamber

- 2 pair of cylinders +2 double arms
- Double screening of earth field $B_{earth} \approx 300$ mG
- field inside of the screen (theoretical):

$$\boldsymbol{B_i = {}^{B_0}/_{S} \approx {}^{0.3G}/_{10^3} =}$$

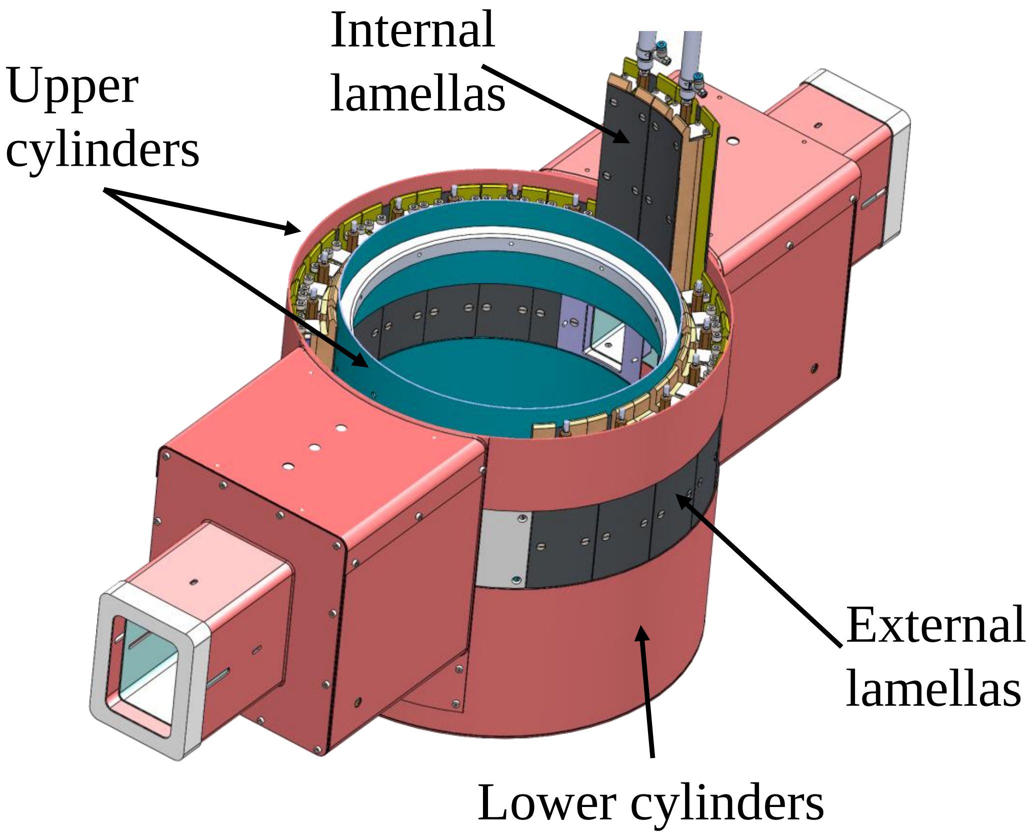
0.3mG

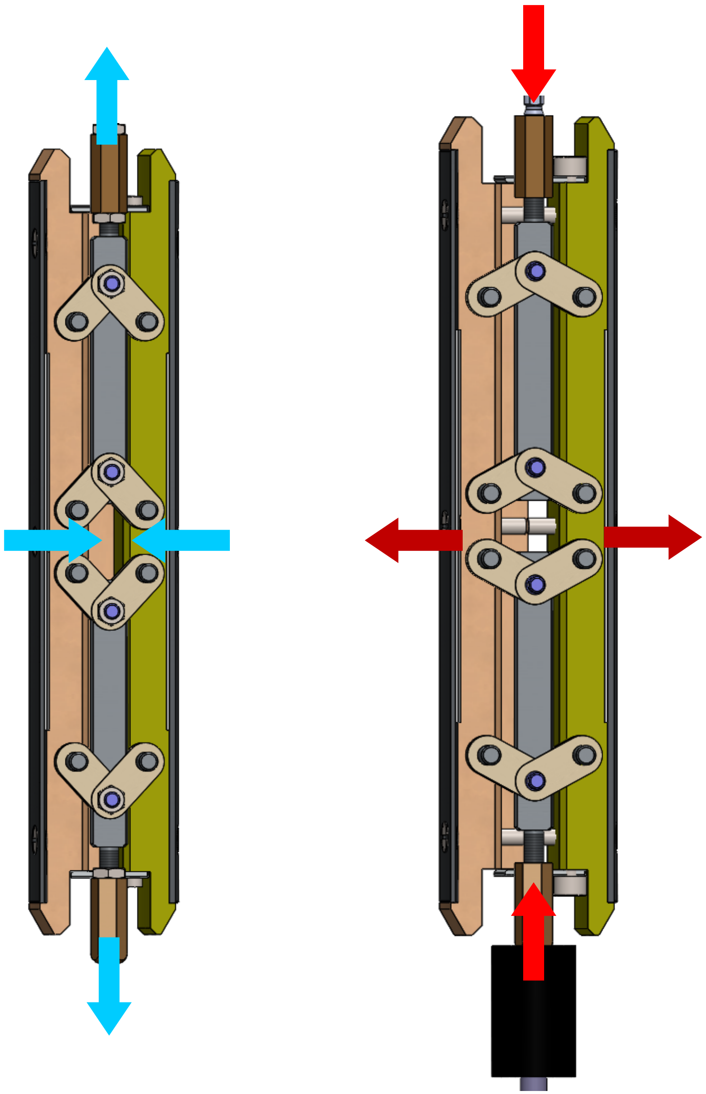
Practically
$B_i < 1$ mG << 300 mG



Zero field chamber

- Gap of 50mm between cylinders
- 2 openings for incoming and scattered beams
- System of lamellas to keep magnetic shielding

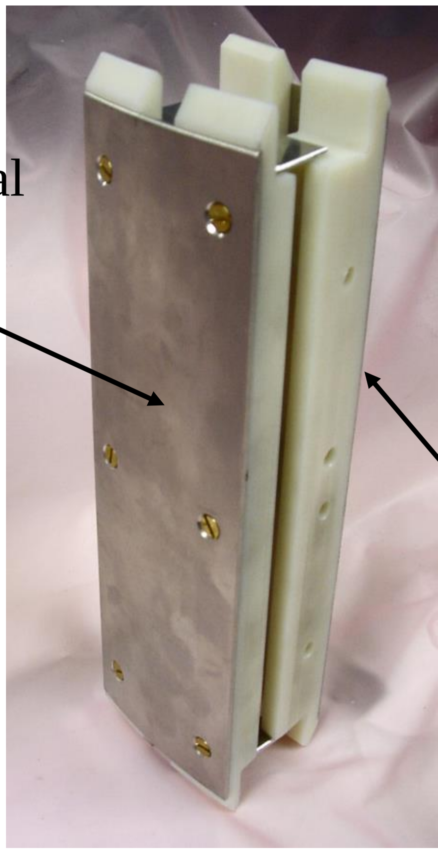




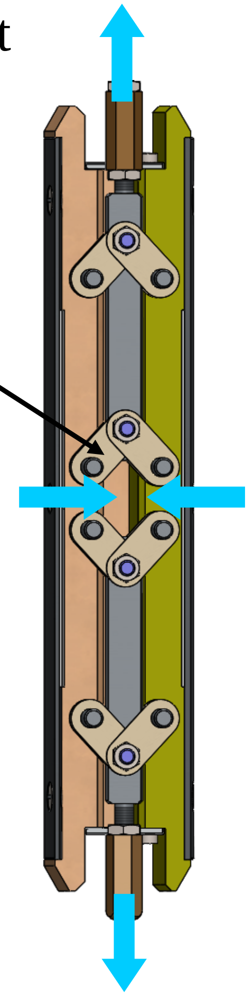
Zero field chamber

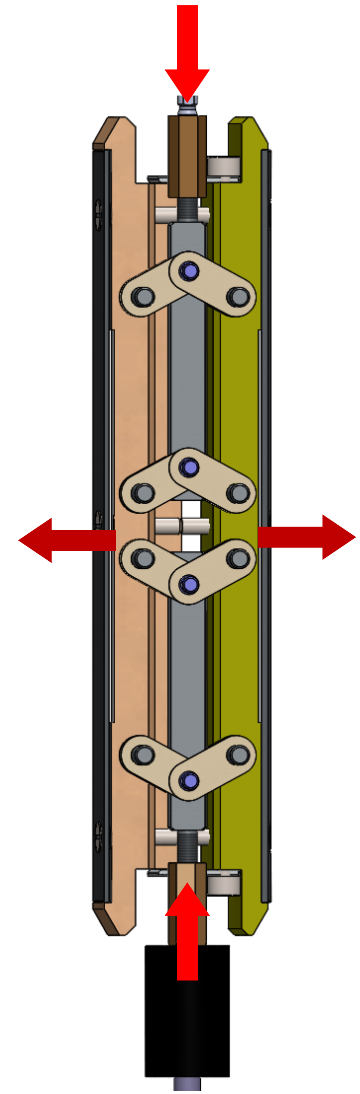
System of vertical-horizontal movement

External lamella

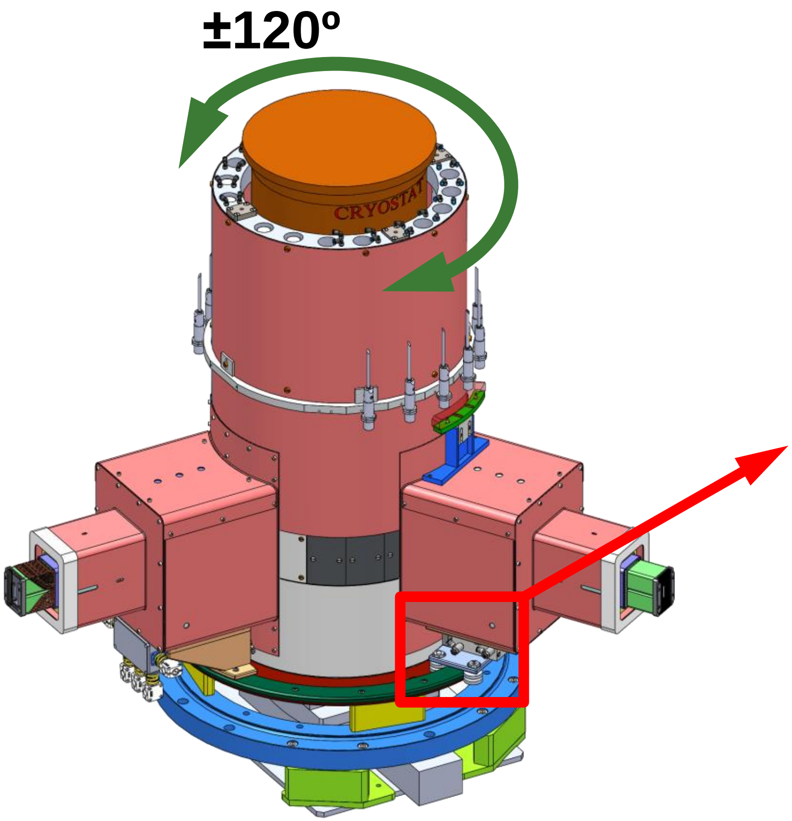


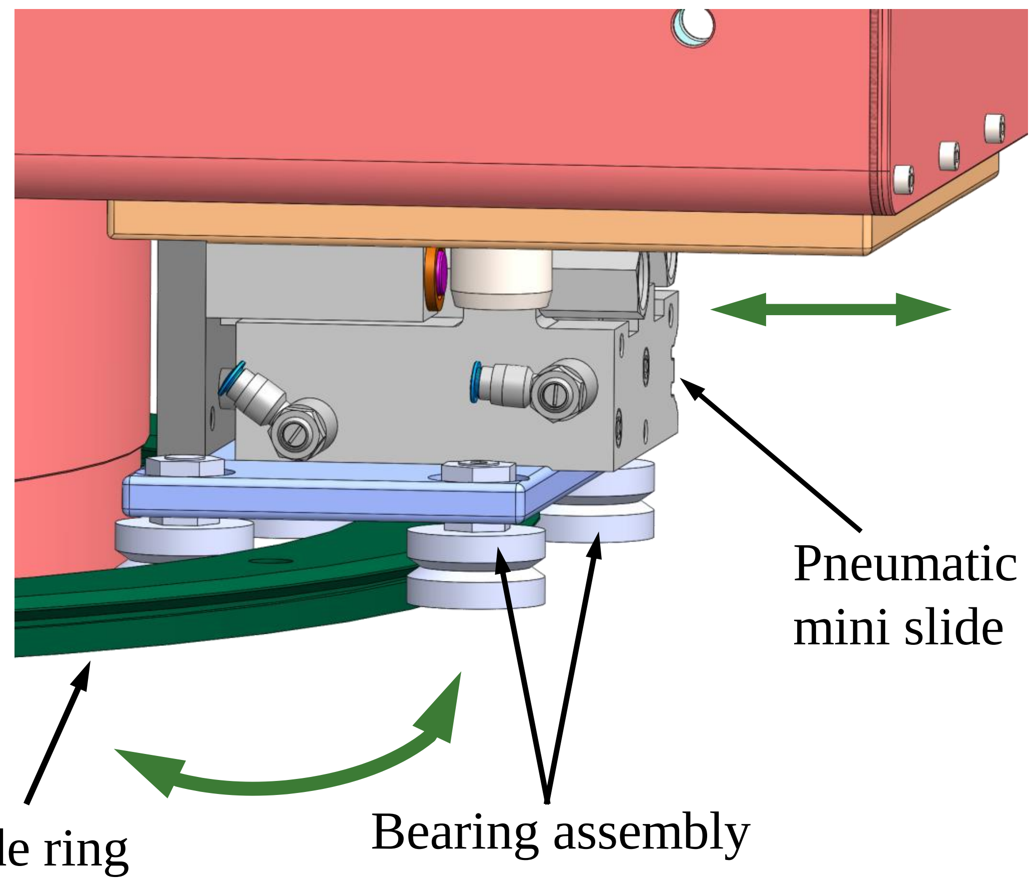
Internal lamella





Second arm positioning





Precession Coils

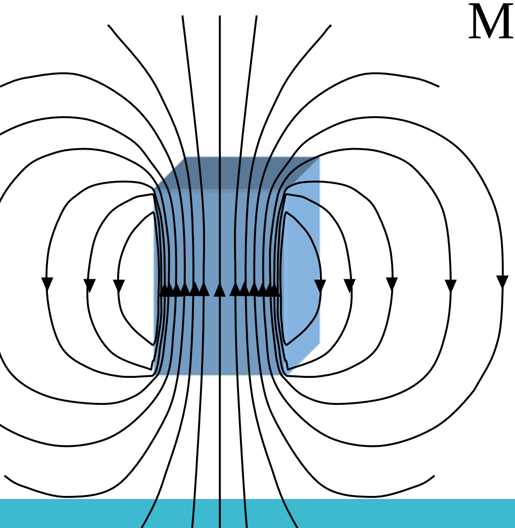
<u>Major requirements on precession field</u>:
- remove return fields of coils from beam area
- homogeneous inner field
- Low stray fields

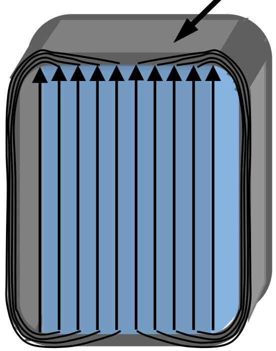
- *Max current: 2,5 A.*
- *R =1.3Ω*
- *L=487μH*

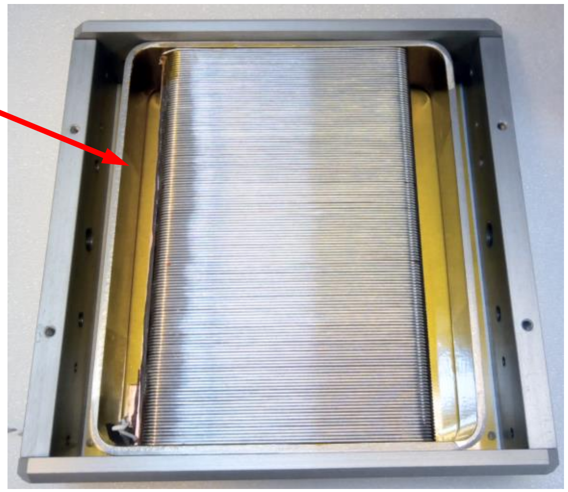
<u>Solution</u>: Mu-metal yoke + outer shield
- outer field is redirected out of beam area
- inner field is more homogeneous
- Stray field captured by outer shield

Mu-metal yoke

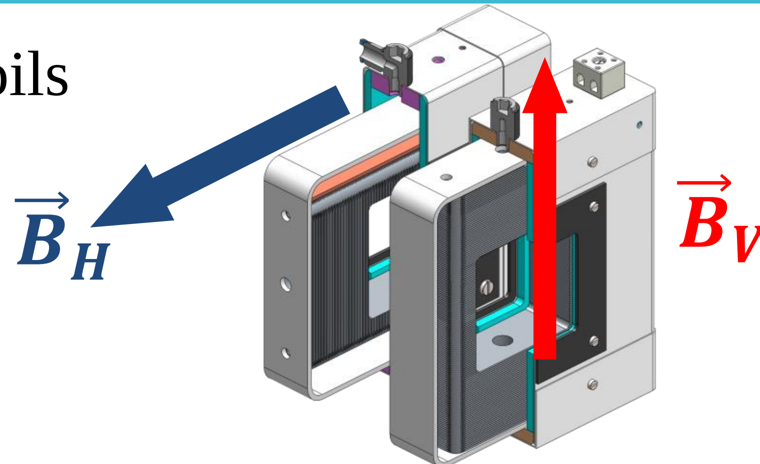
Outer mu-metal shield

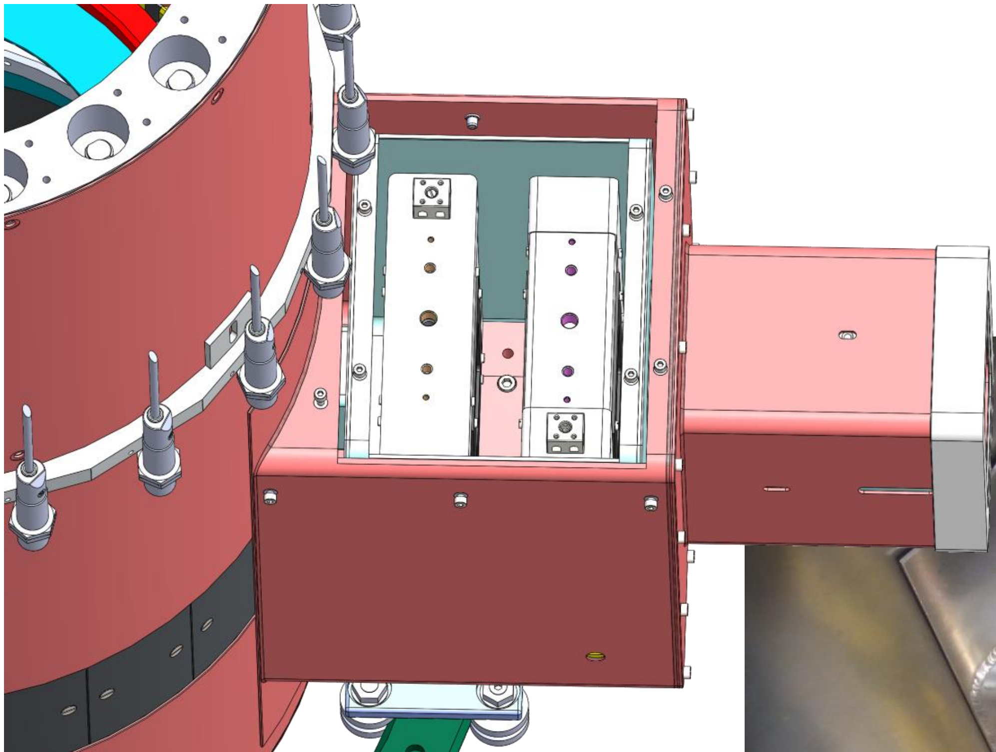


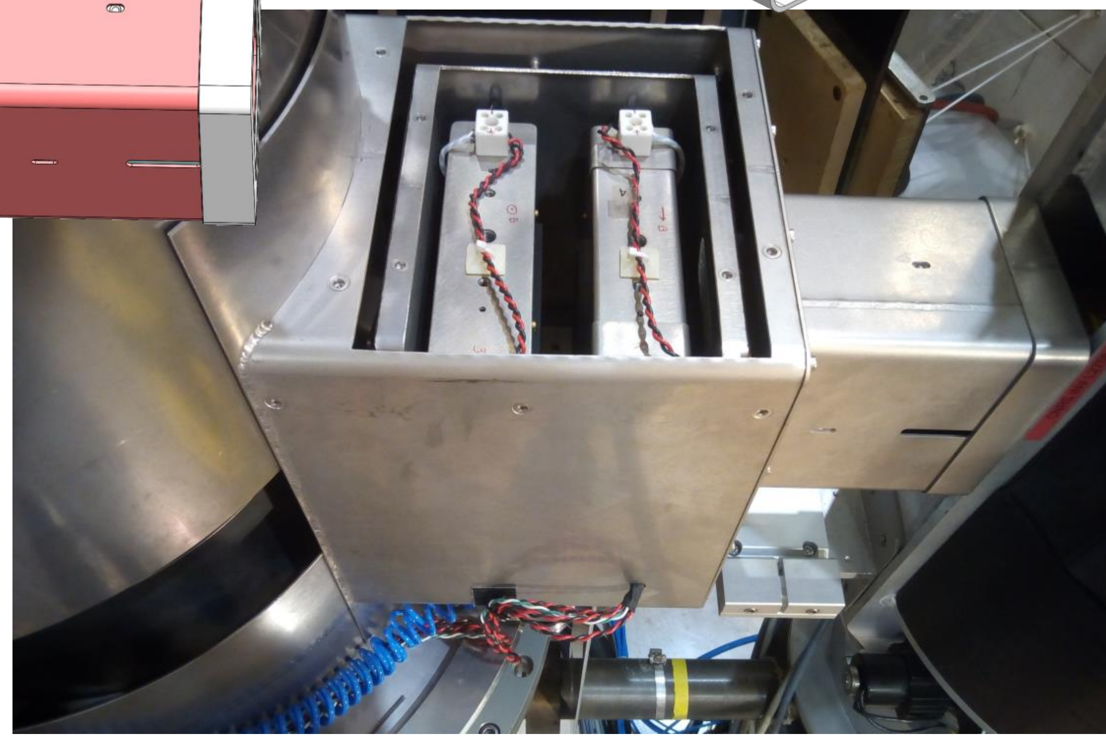




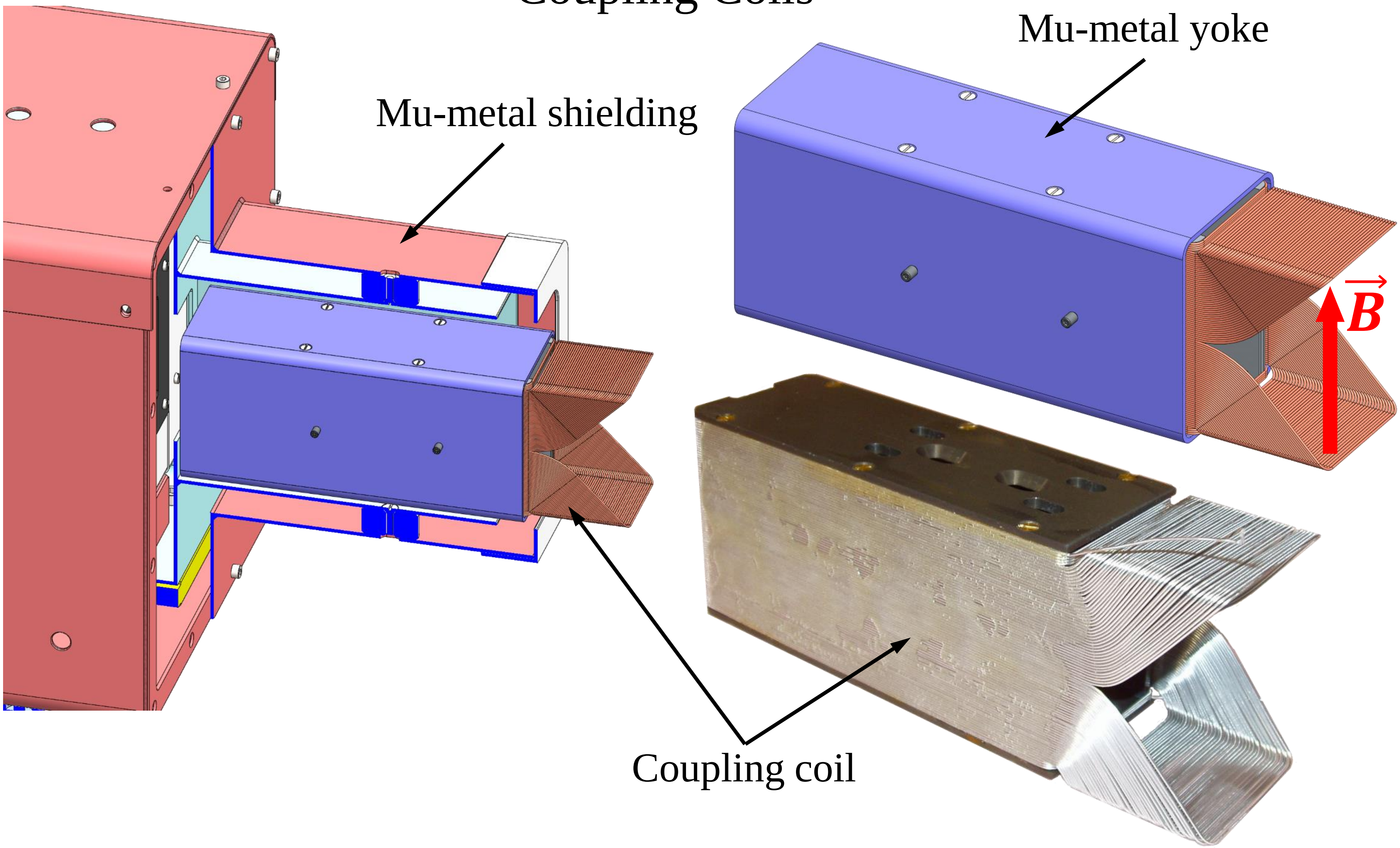
Precession Coils



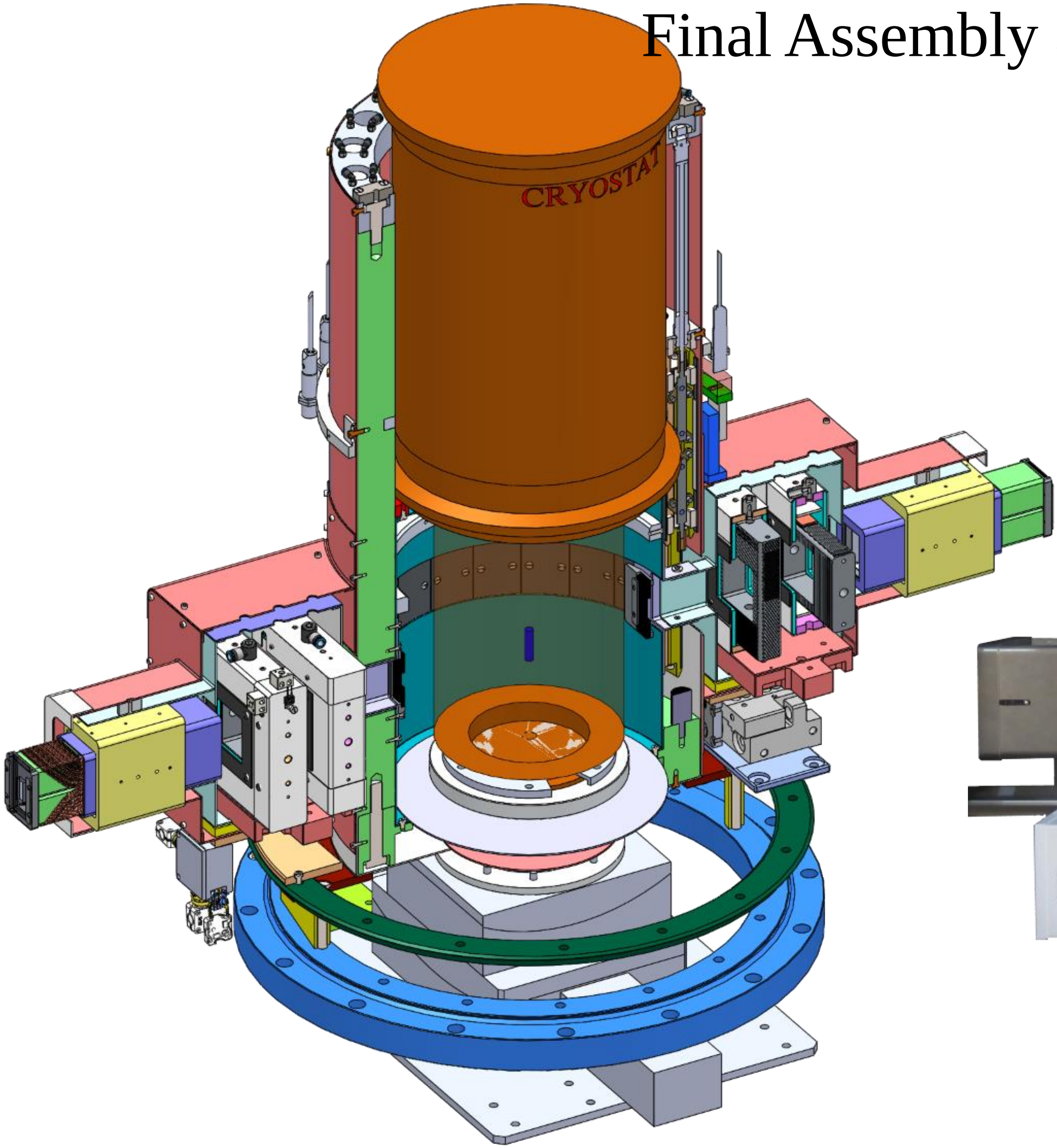




Coupling Coils



Final Assembly and Test



Montage à blanc

Happy technician and engineer

Final Assembly

Serious scientists

Installation on 4F1@LLB

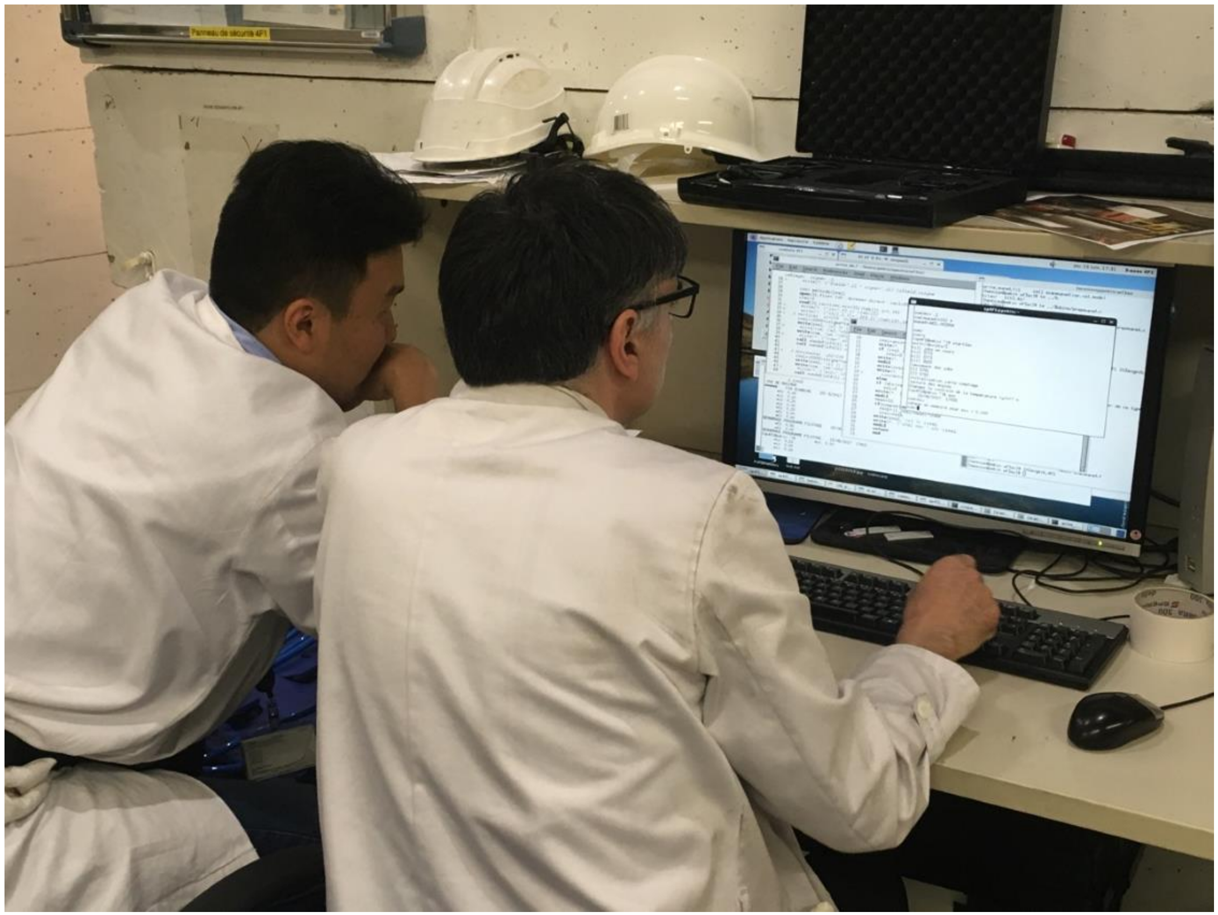
Fatigued by Mu-PAD

Encouraged by Mu-PAD

Mu-PAD installed on 4F1

Mu-PAD Itself

First Measurement with Mu-PAD on 4F1



Happy users

Groupe of instrument development:

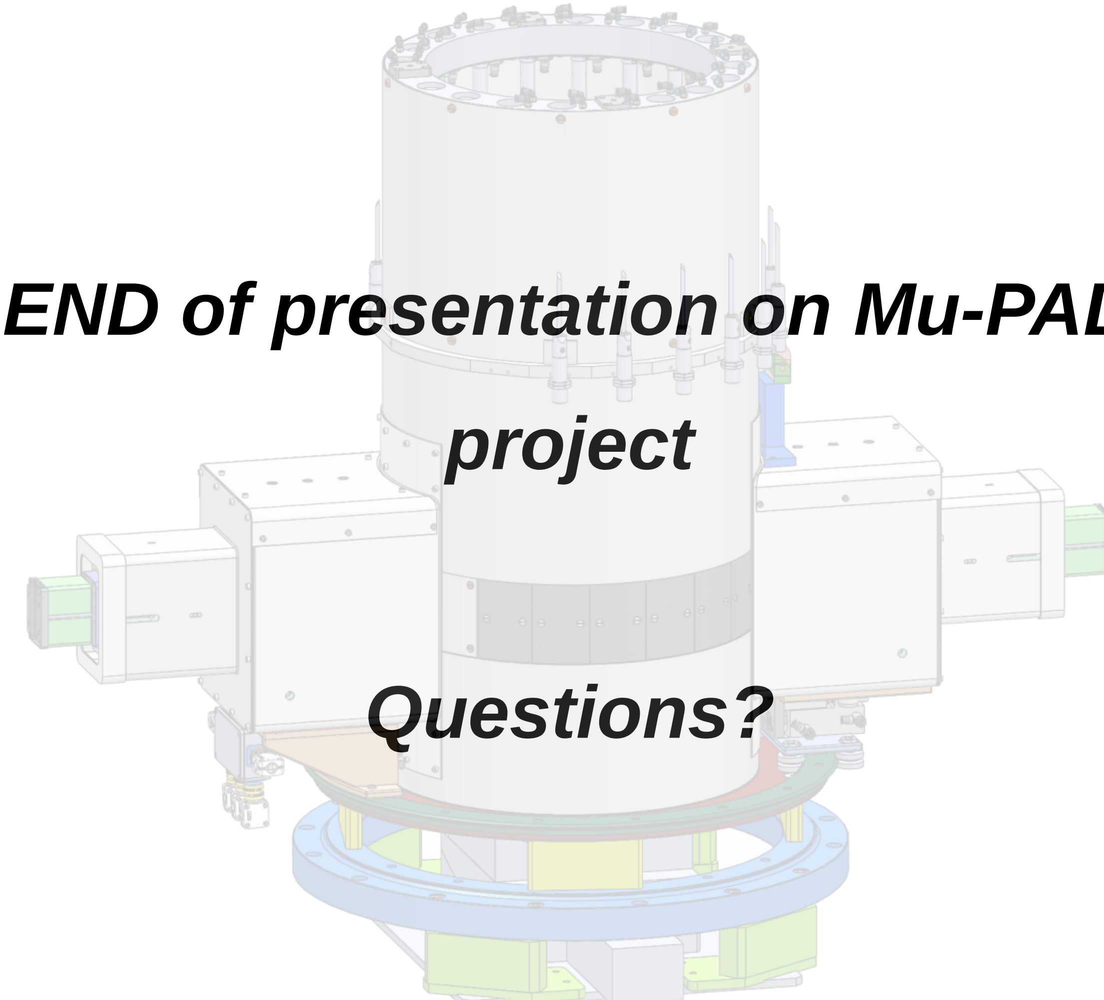
Sylvain RODRIGUES
Patrice PERMINGEAT
Pascal LAVIE
Sylvain DESERT
Alain CAZENAVE

Technical support:

Francois MAIGNEN
Christophe MEUNIER
Philippe BOUTROUILLE

Scientific support:

Yvan SIDIS
Philippe BOURGES
Jean-Michel MIGNOT



END of presentation on Mu-PAD project

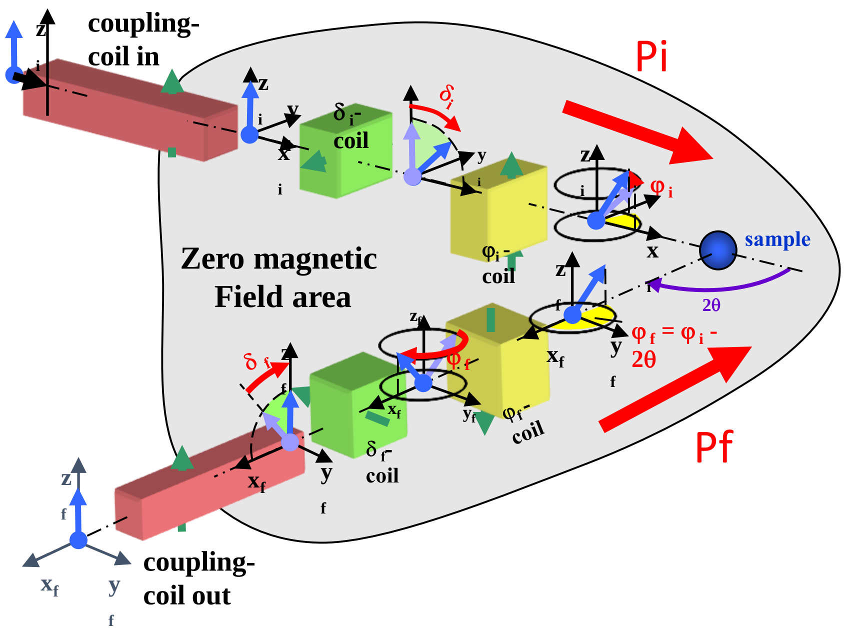
Questions?

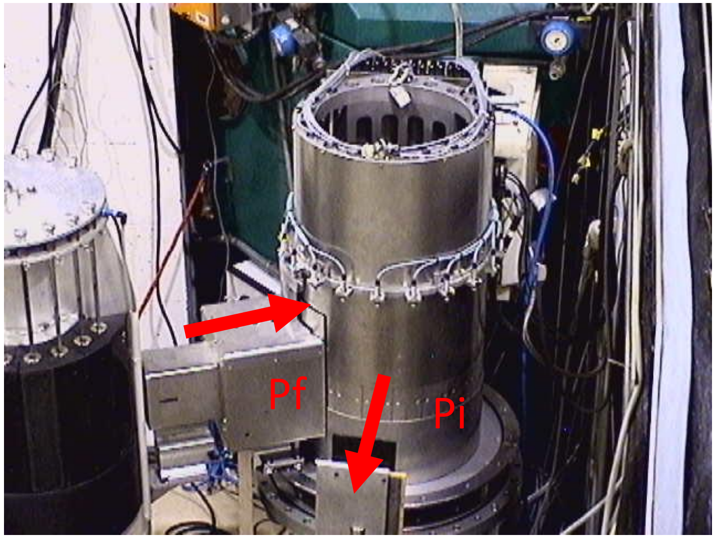
muPAD/4F1 (Serguey, François, Yvan, Jaehong)

- Pilotage courants (2 bobines couplages + 4 bobines $\delta + \varphi$)

- Intégration pilotage spectromètre → contrôle chaque (Q,E)
  (programmes en C et Fortran)

- Polarimétrie
- Pi et Pf indépendantes
- Champ nul (phase supraconductrice)

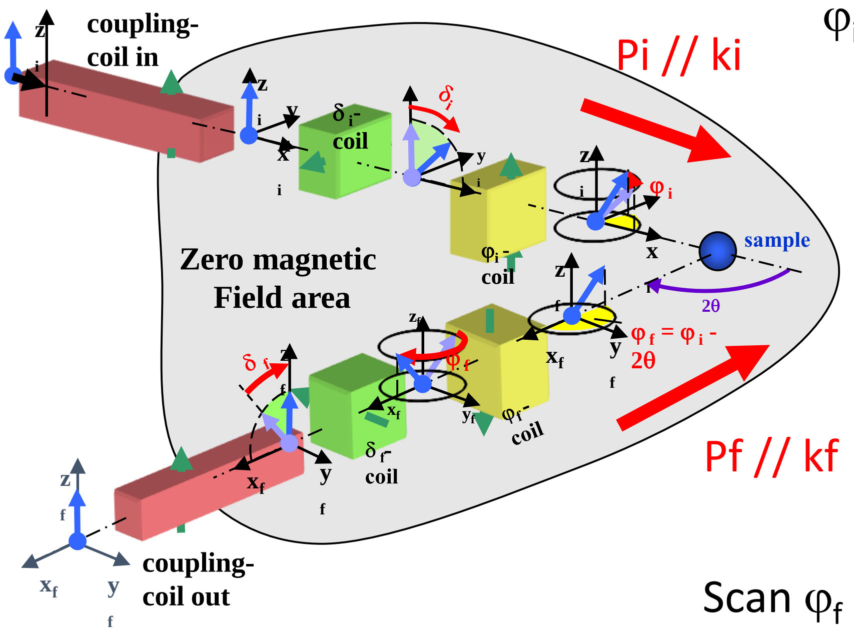


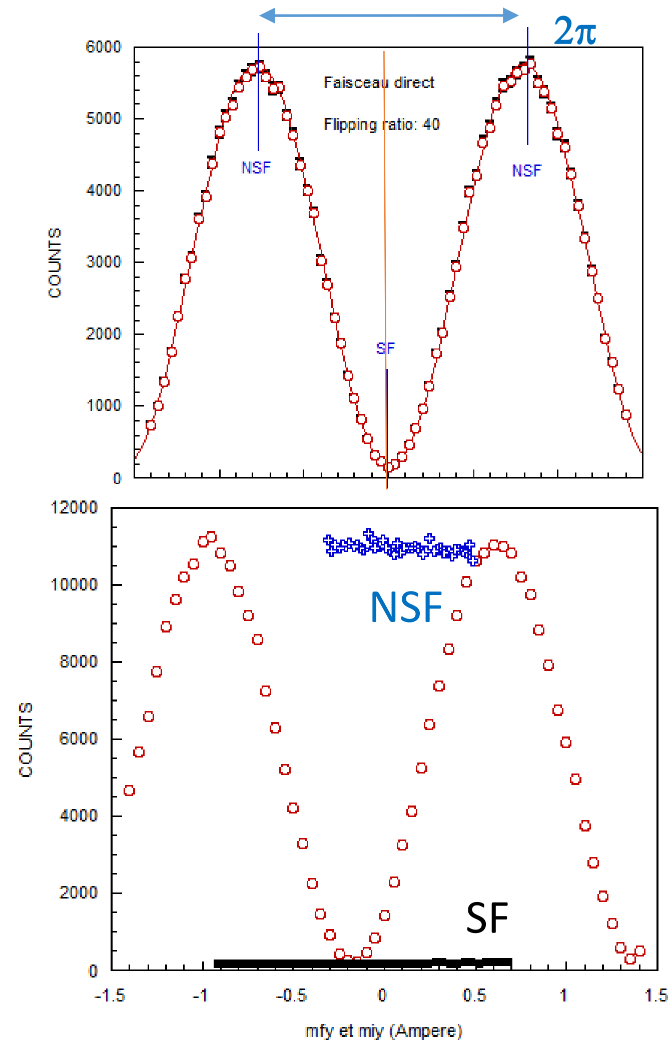


Très bon rapport de flipping: 40-50 ☺ 6 %)

Scan φ_f

$\varphi_i = 0$





2θ=0

2θ≠0

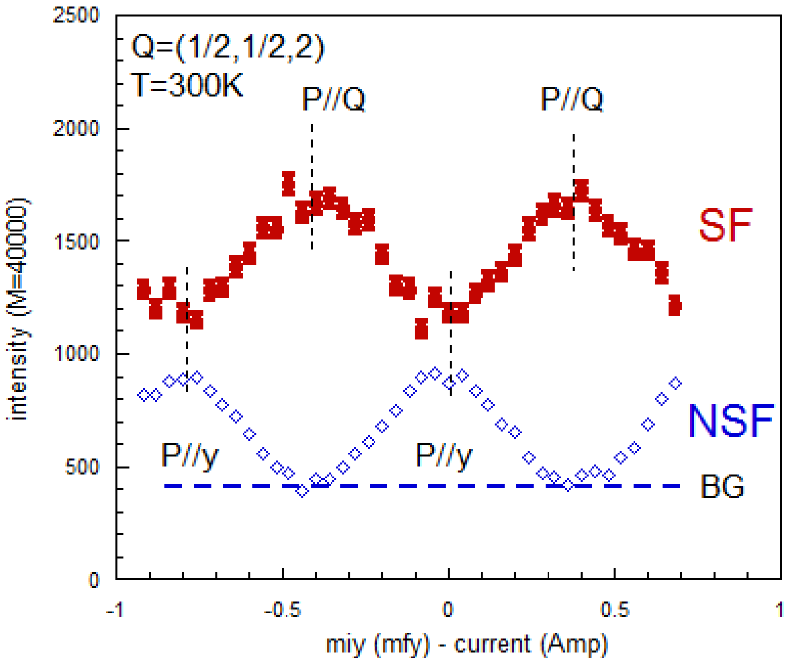
Scan φ_f et φ_i

Pi // Pf

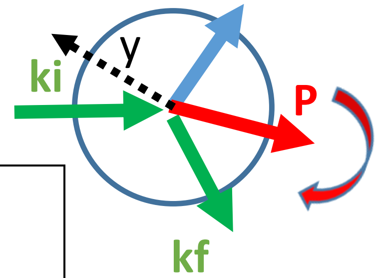
Diffusion nucléaire indépendante polarisation

Echantillon antiferromagnétique: $YBa_2Cu_3O_6$

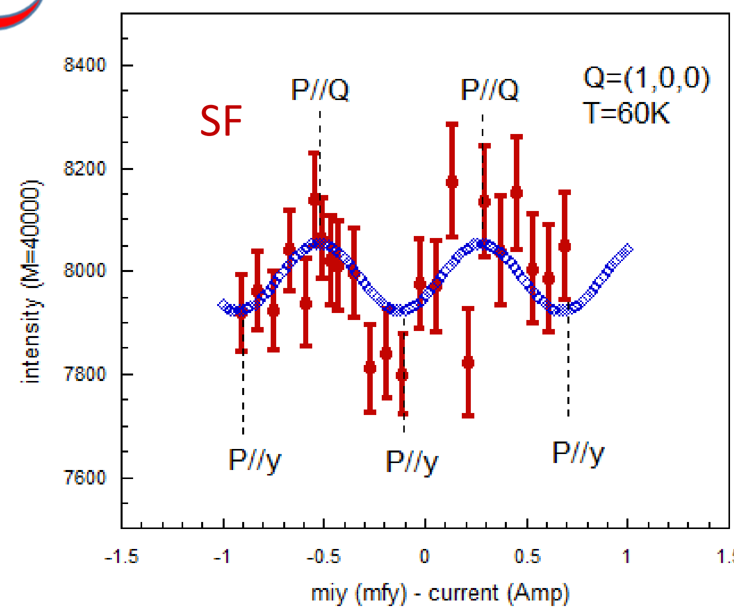
Scan φ_f et φ_i Pi // Pf



Diffusion magnétique dépendante polarisation



Boucle de courant (Varma):
Echantillon CaLaBaCuO
Coll: Amit Keren
(Technion Univ, Israel)



Petit signal magnétique sur pic de Bragg nucléaire