‘The strong interaction at the frontier of knowledge: fundamental research and applications’

JRA10: CryPTA

Cryogenic Polarized Target Applications

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Physikalisches Institut Universität Bonn

STRONG-2020 Kick-off meeting

October 23-25, 2019

JRA10:CryPTA

Cryogenic Polarized Target Applications

Cooperation of four partners

Organization legal name	Short name	Activity leaders
Ruder Boskovic Institute	RBI	M. Korolija
Ruhr-Universität Bochum	RUB	G. Reicherz
Rheinische Friedrich-Wilhelms-Universität Bonn	UBO	H. Dutz
Johannes Gutenberg Universität Mainz	UMainz	A. Thomas

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

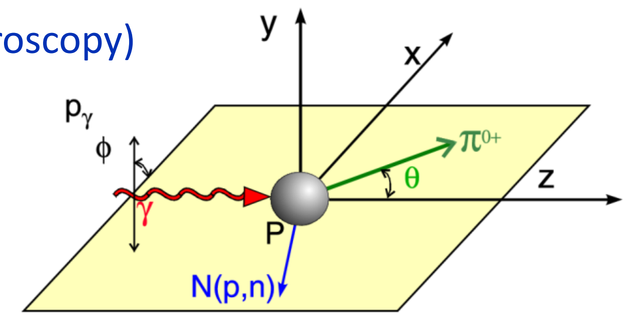
JRA10:CryPTA

Cryogenic Polarized Target Applications

Research (WP) Objectives

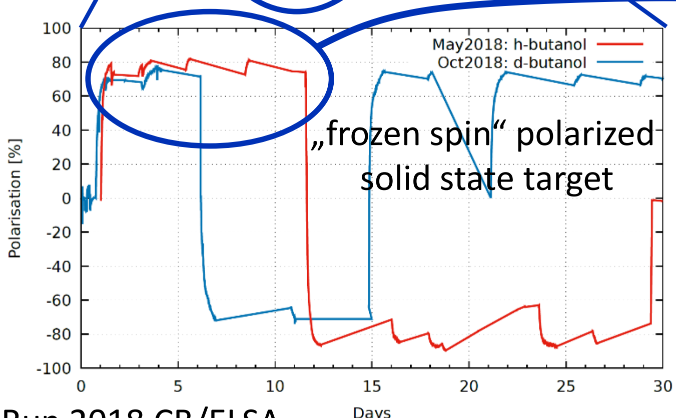
Structure mapping @ ELSA and MAMI (i.e. baryon spectroscopy)

→ Modell independent partial wave analysis
→ Complete experiment

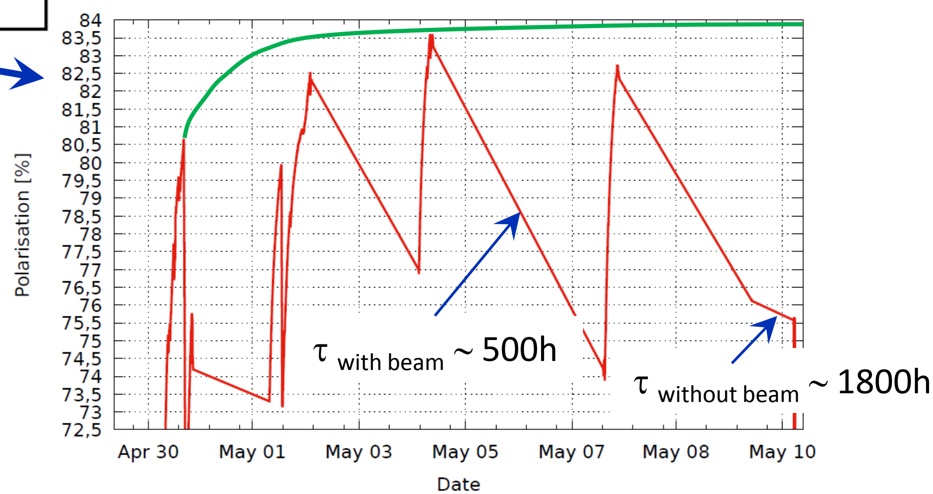


Photon polarization		Target polarization			Recoil nucleon polarization			Target and recoil polarizations			
		X	Y	Z(beam)	X'	Y'	Z'	X' X	X' Z	Z' X	Z' Z
unpolarized	σ	-	T	-	-	P	-	$T_{x'}$	$L_{x'}$	$T_{z'}$	$L_{z'}$
linear	Σ	H	(-P)	-G	$O_{x'}$	(-T)	$O_{z'}$	$(-L_z)$	(T_z)	(L_x)	$(-T_x)$
circular	-	F	-	-E	$C_{x'}$	-	$C_{z'}$	-	-	-	-

Permanent dyn. polarization: CryPTA:ScM



Run 2018 CB/ELSA



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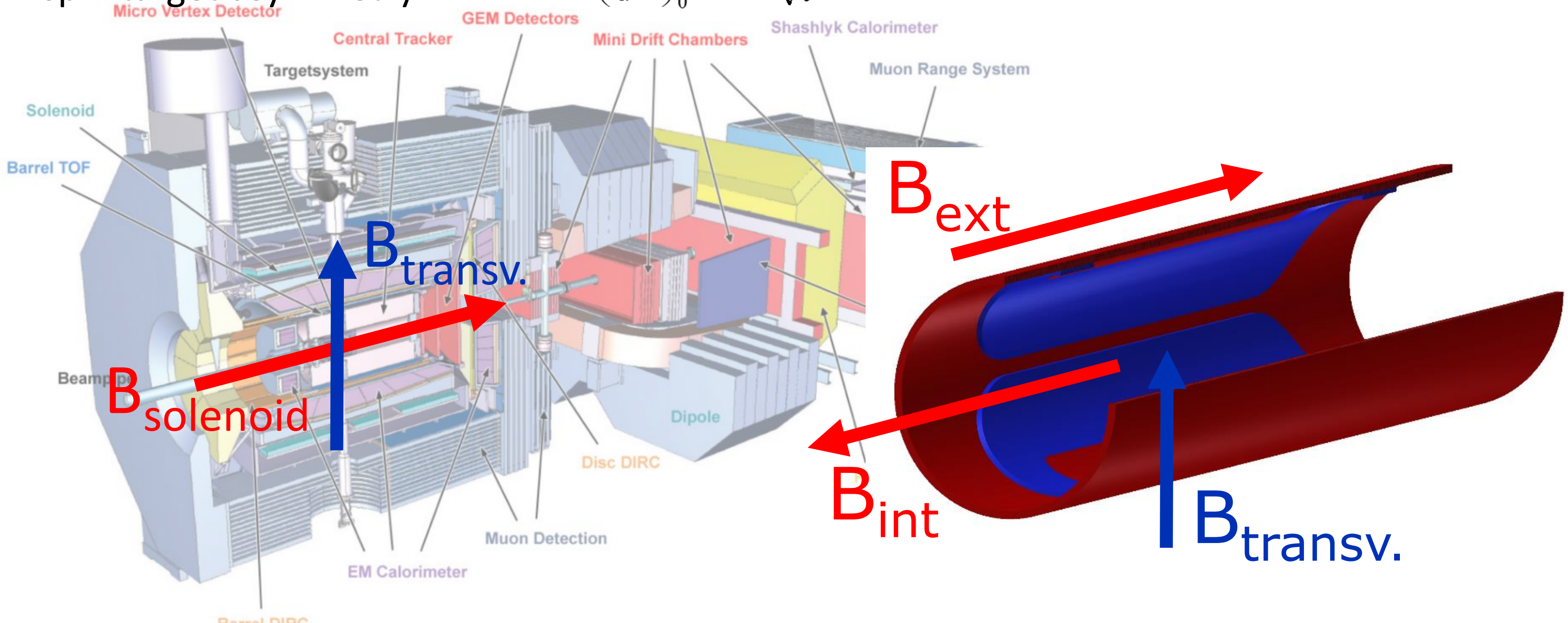
Cryogenic Polarized Target Applications

Research (WP) Objectives

Antiproton annihilation @ PANDA opens a new window to
Precision electromagnetic (EM) probe hadron structure observables

Imaginary part of time like FF single spin target asymmetry $\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}\right)_0 A_{1,y} = \frac{N}{\sqrt{\tau}} \sin 2\Theta \,\mathrm{Im}\left(G_M G_E^{*}\right)$ → Transverse polarization:



shield main field and generate a transverse field: CryPTA:ScS

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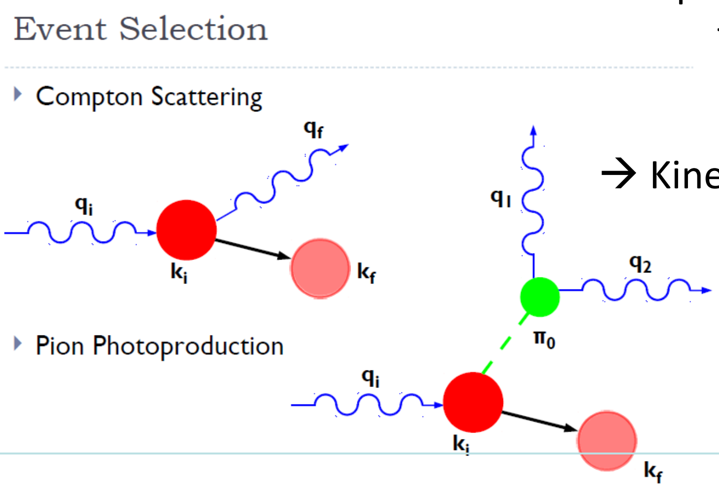
JRA10:CryPTA

Cryogenic Polarized Target Applications

Research (WP) Objectives

Measurements of the Proton Spin-Polarizabilities with Double-Polarized Compton Scattering @ MAMI,
P.P.Martel et al., **PRL 114 (2015) 112501**



Pion photoproduction off of a proton is 75-100 times more likely than Compton (in the 240-280 MeV range)

→ Kinematic overdetermination used for cuts (missing mass, proton angle, …).

Main problems:

- Low energetic recoil protons do not escape from the target and do not reach the detector.
- Events are produced on the background nuclei (Carbon, coherent, incoherent, k~13%).

detect the recoil proton in-situ, inside the target: CryPTA:APT

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JRA10:CryPTA

Cryogenic Polarized Target Applications

Research Objectives (WP tasks)

1. **CryPTA:S**uper**c**onducting**M**agnet for permanent DNP in polarized solid state targets.

   Low temperature combined ScMs for small size targets to increase the luminosity, FoM and gain to new polarization observables to be used in “frozen spin” or “continuous mode” polarized targets
   (RUB, UBO, UMainz)

2. **CryPTA:S**uper**c**onducting**S**hield for passive shielding of the PANDA spec. field for transv. polarization

   High temperature ScM for passive or active magnetic field shielding for polarization experiments.
   (Umainz, UBO)

3. **CryPTA:A**ctive**P**olarized**T**arget materials to detect the recoil proton in-situ, inside the target.

   Active target materials, cold scintillator arrangements and cold read out systems for small size targets.
   (RUB, UMainz, RBI)

Research Objectives

Objectives: The final goal of CryPTA is to develop groundbreaking s.c. magnet structures and target materials for new and innovative polarization experiments using polarized targets in 4π-detection systems for hadron physics experiments in Europe

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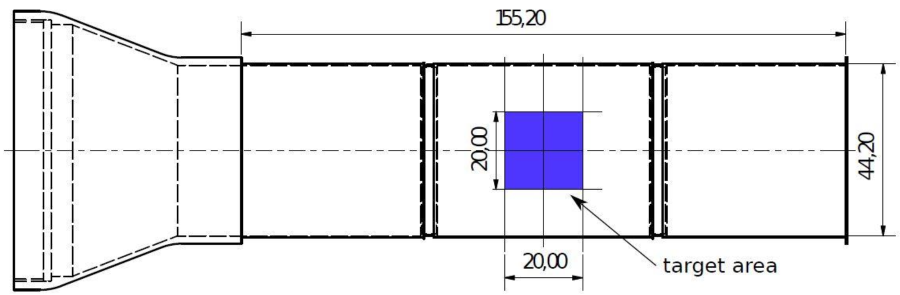
JRA10: Update on progress CryPTA:ScM

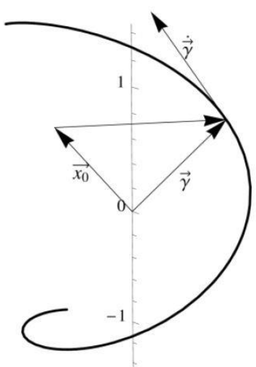
Experimental tests of an internal thin s.c. polarizing magnet

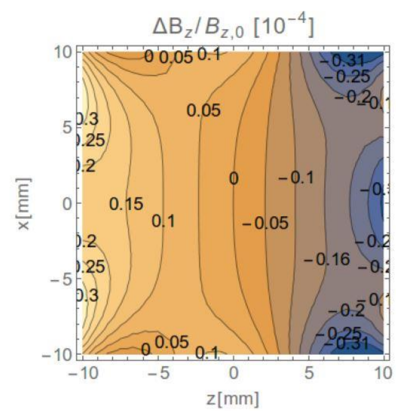
Internal polarisation magnet - Field calculation



Biot-Savart-Law:

$$\vec{B}(\vec{x_0}) = \frac{\mu_0}{4\pi} I \int \frac{(\vec{\gamma}(t) - \vec{x_0}) \times \frac{\dot{\vec{\gamma}}(t)}{|\dot{\vec{\gamma}}(t)|}}{|(\vec{\gamma}(t) - \vec{x_0})|^3} \mathrm{d}t$$





Loop parametrization:

$$\vec{\gamma} = (r\cos(t), r\sin(t), n \cdot d)$$

r: radius of each loop
$n \cdot d$: loop position
d: effective distance between 2 wires

DNP requires $\Delta B/B \leq 10^{-4}$

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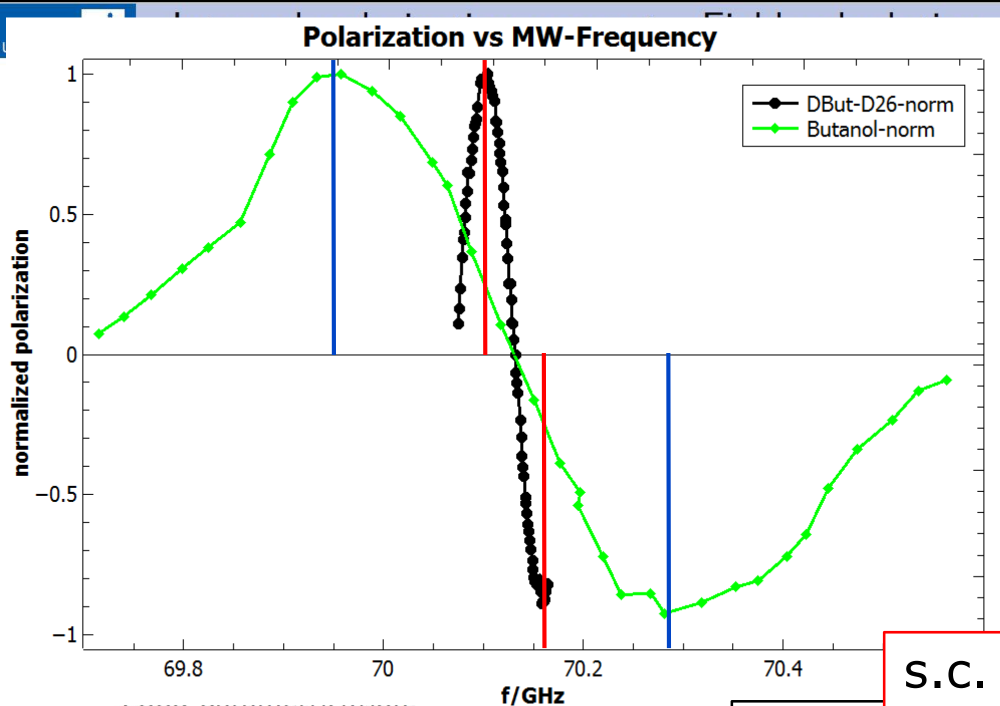
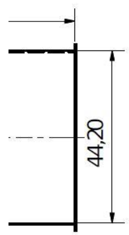
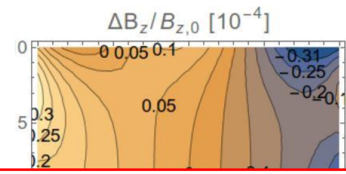
JRA10: Update on progress CryPTA:ScM

Experimental tests of an internal thin s.c. polarizing magnet







Loop parametrization:

$$\vec{\gamma} = (r\cos(t), r\sin(t), n \cdot d)$$

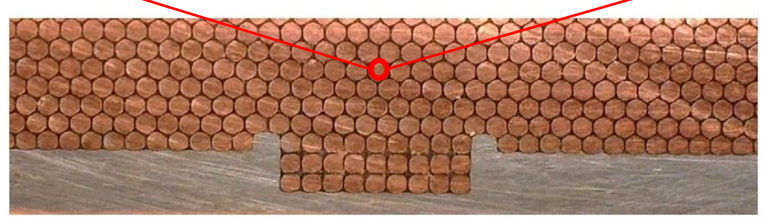
r: radius of each loop

$n \cdot d$: loop position

d: effective distance between 2 wires

DNP requires $\Delta B/B \leq 10^{-4}$

s.c. wire $\varnothing = 254\ \mu m$



High precision winding technique to guarantee 'orthozyclic winding'

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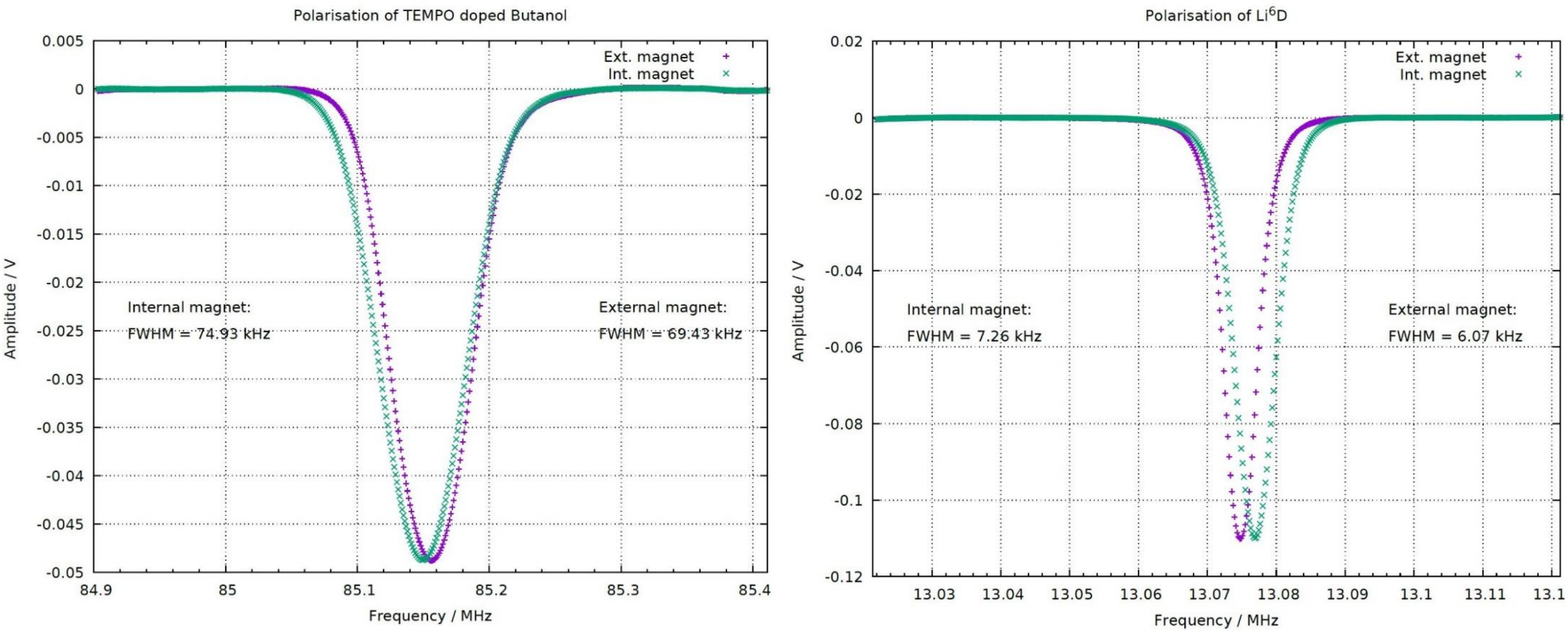
JRA10: Update on progress CryPTA:ScM

First DNP-signals in the new internal thin s.c. polarizing magnet

4 layers, 2.4 mm thickness, T_P = 1K!, B_P = 2 Tesla (78A), $F_{\mu w}$ = 56 GHz !



Permanent dyn. polarization scheme in a thin ScM has been proven

Next: 8-layers coil for the new refrigerator (less current)

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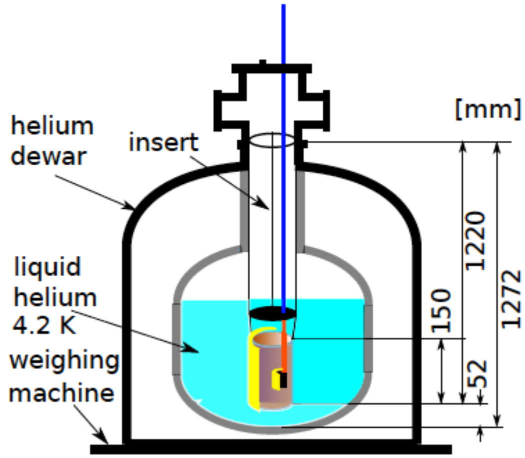
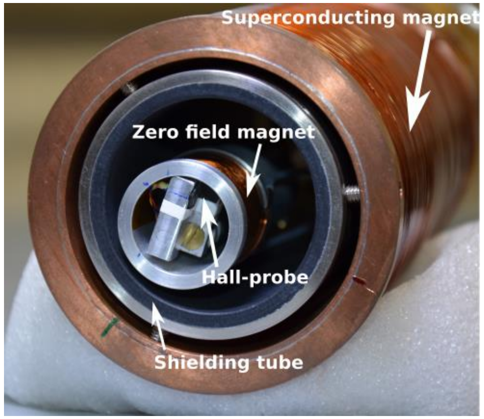
JRA10: Update on progress CryPTA:ScS

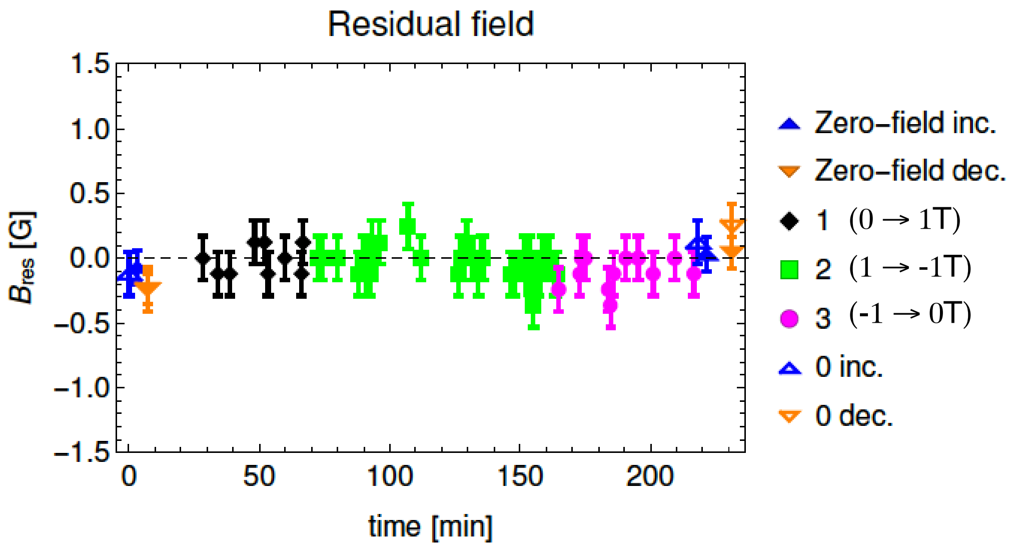
Experimental tests of the shielding tube BSCCO-2212





B. Fröhlich, PhD thesis 2018, Mainz

Demonstration of shielding at least 1 T at the center of the BSCCO-2212 tube (3.5 mm wall thickness):



- A magnetic flux density of (10140±14) G can be shielded with a vanishing residual field and an uncertainty of 0.016 G
- The shielding factor is 3.21×10^5 at a 95% confidence level

- YBCO tube (3.5 mm wall thickness) does not show any shielding effect

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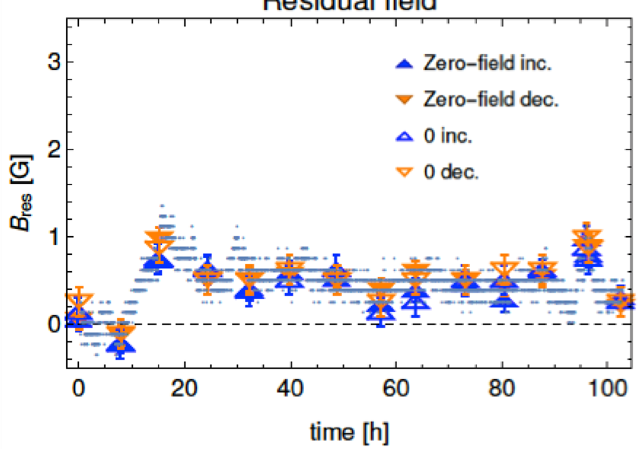
JRA10: Update on progress CryPTA:ScS

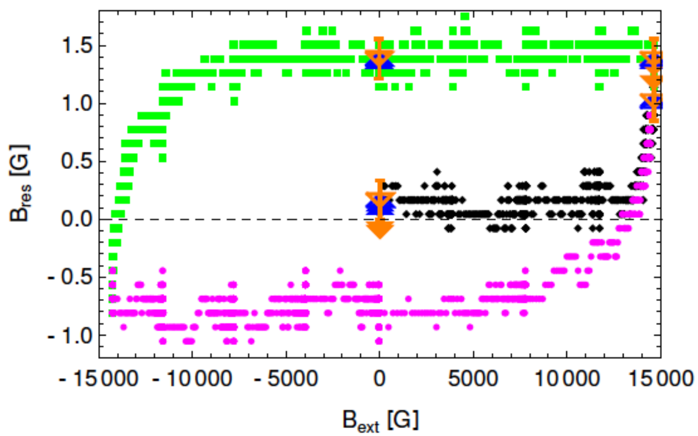
Helmholtz-Institut Mainz

Experimental tests of the shielding tube BSCCO-2212

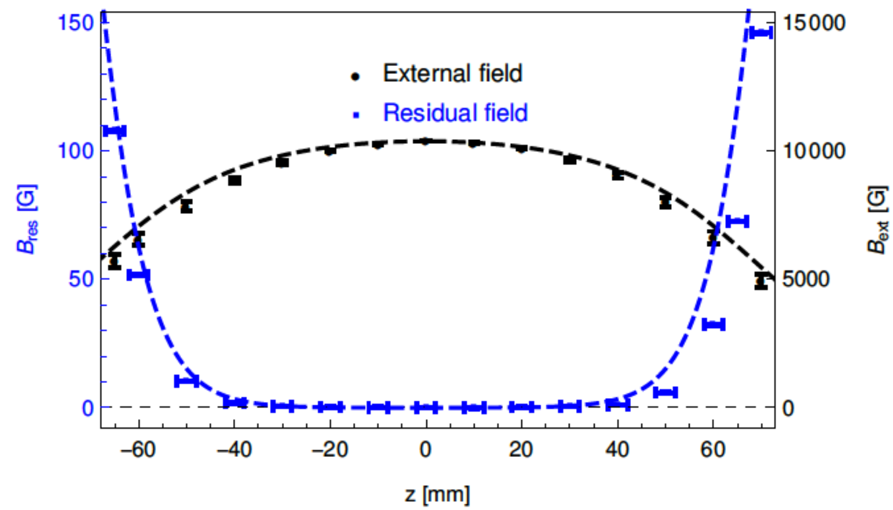
Measurement of the stability of the shielding (B_{ext}=1T) in time:



Maximum external field of 1.4 T:



Measurement of the homogeneity along the axis of the shielding tube



- Stabilization for at least 4 days (B_{ext}=1T)
- The residual field along the axis of the shielding tube has a good homogeneity
- The numerical model was compared and validated with the experimental field map
- Residual field increases to (1.6 ± 0.06) G at B_{ext}=1.4T

B. Fröhlich, PhD thesis 2018, Mainz

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JRA10: Update on progress CryPTA:ScS

Future Plan

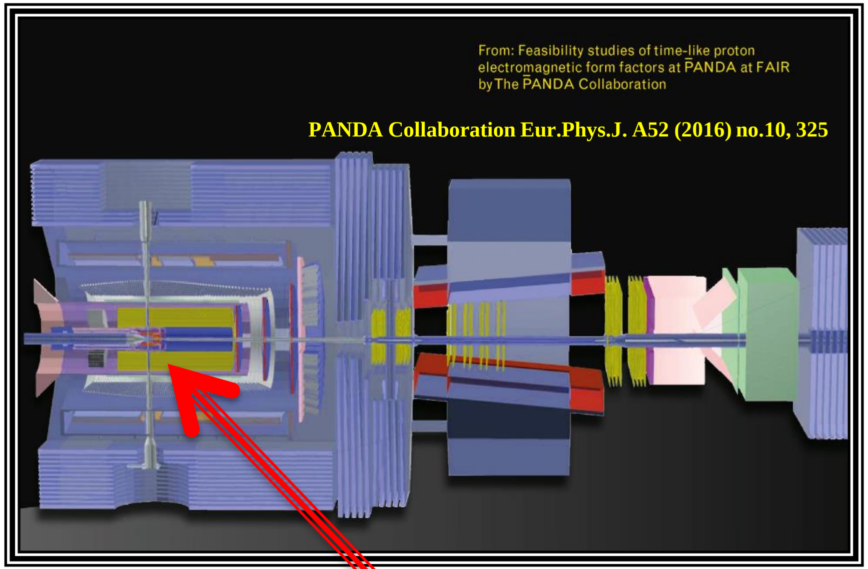
- A transversally polarized target at PANDA requires the shielding of the PANDA 2T longitudinal magnetic field

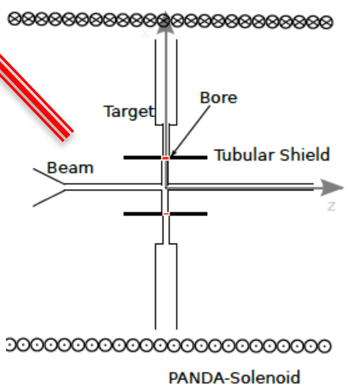
➢ **Experimental hardware and simulations studies for the development of a transversely polarized target for the PANDA experiment:**

– Design of the transversally PANDA polarized target region

– Experimental shielding tests of high magnetic field (2T):
  - – tests with BSCCO and YBCO tubes using in the test cryostat at Bonn
  - – tests with modified tube geometry/setup (based on the target design requirements)

– Simulation studies of the impact of such a polarized target setup on the particle identification properties and performance of the PANDA detector.





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JRA10: CryPTA:ScM, CryPTA:ScS

1K (^{4}He-evaporation) cryostat as s.c. magnet test facility

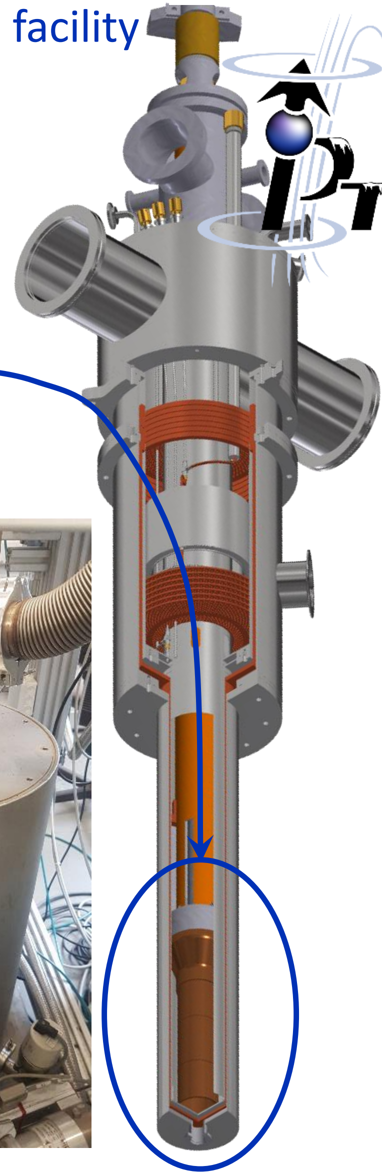
Vertical ^{4}He-evaportion refrigerator with easy to change magnet test insert and external s.c. 6.5 Tesla magnet

- Magnet size: cylindrical shape 42≤∅≤70 mm, length≤250 mm
- Current leads: up to 100A
- Second insert for DNP; cw- and pulsed NMR or Hall-probe for field mapping
- µw: 50 GHz – 140 GHz (1.8 T – 5 T)
- Temperature: 1K, 4.2K, 70K
- Common project RUB, UBO, UMainz

CryPTA:ScM Ideal tool to test small superconducting magnets (general parameters) and for DNP

CryPTA:ScS field shielding and field transfer with external 6.5T s.c. magnet @ diff. temperatures

Cryostat is under construction



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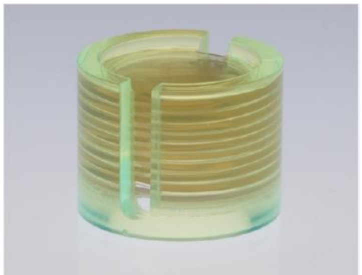
JRA10: Update on progress CryPTA:APT

Design of the Active Polarized Proton target

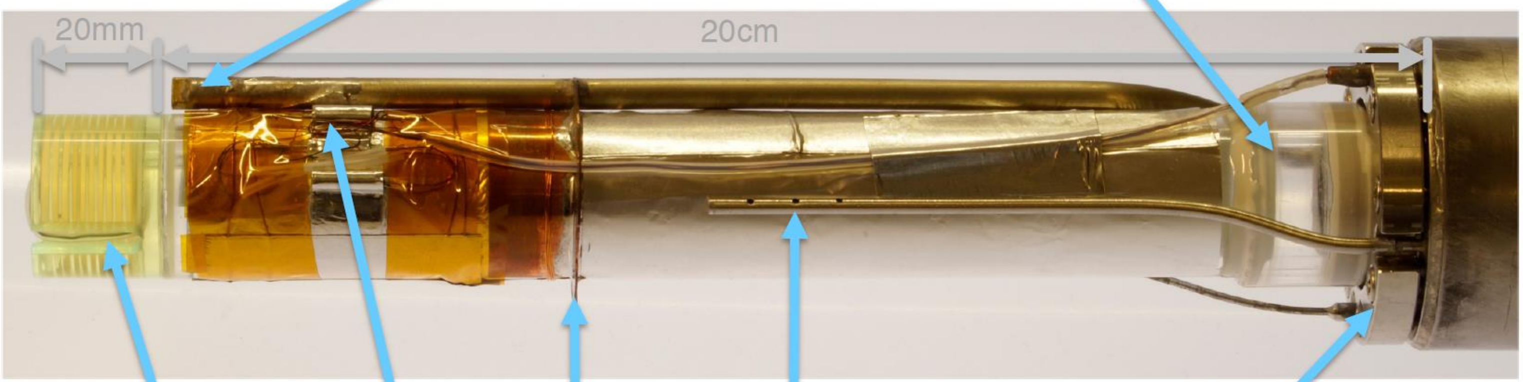


Target stack at T = 45 mK

- Polarizable scintillator
  10x ⌀ 20mm / 1 mm thickness
  Doping: 1.5 x 10^{-19} cm^{-3}
- Wavelength shifting head coupled to light guide tube

Readout board at T = 150 K

- 15x 3x3 mm^2 SiPMs coupled to the light guide tube
- Fully differential readout over HDMI
- Temperature probes for SiPM HV control



In Collaboration with JINR, Dubna, Russia

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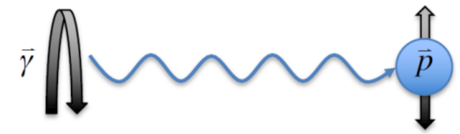
JRA10: Update on progress *CryPTA:APT*

Key Data of the Experiment in June 2016

- Σ_{2x} experimental setup
  - Longitudinal polarized photons
  - Transverse polarized protons
- Two datasets with different beam currents



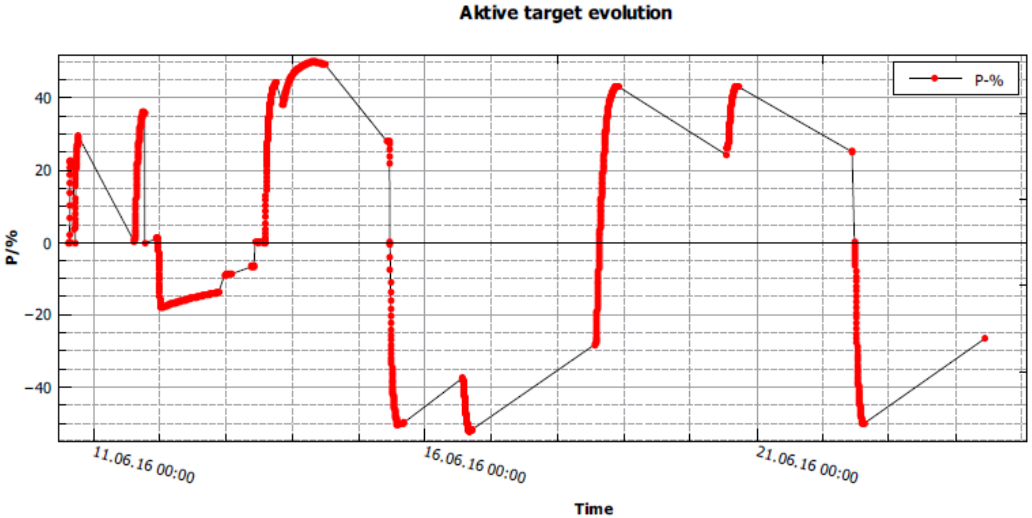
Polarization	Max. Value	Max. Relaxation Time
+	46 %	78.3 h
-	49 %	74.1 h

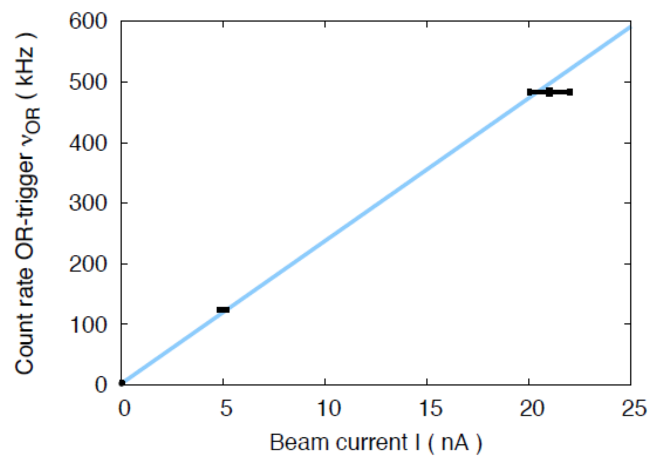
Temperature: 45 mK, holding field: 437.5 mT

In Collaboration with G. Reicherz, Ruhr-Universität, Bochum

e^- Beam Current	Max. Photon E	Target Count Rates
5 nA	300 MeV	(24±1) kHz nA^{-1}
20 nA	150 MeV	(23±1) kHz nA^{-1}

No saturation effects





Maik Biroth, Institut für Kernphysik, Mainz, Germany

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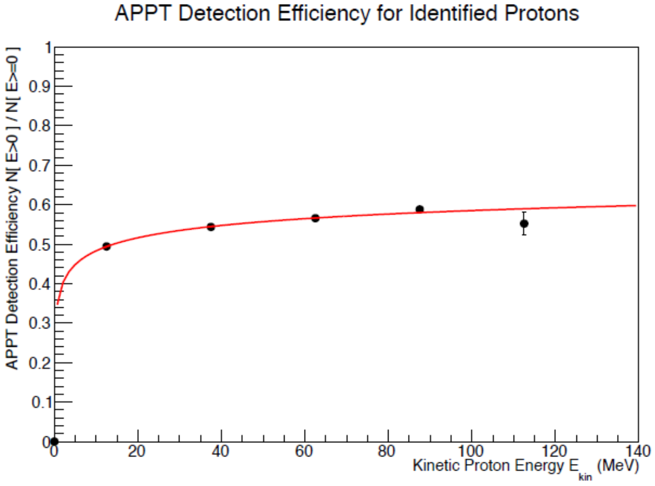
Important Analysis Results

Integral recoil detection efficiency over all trajectories and kinematics

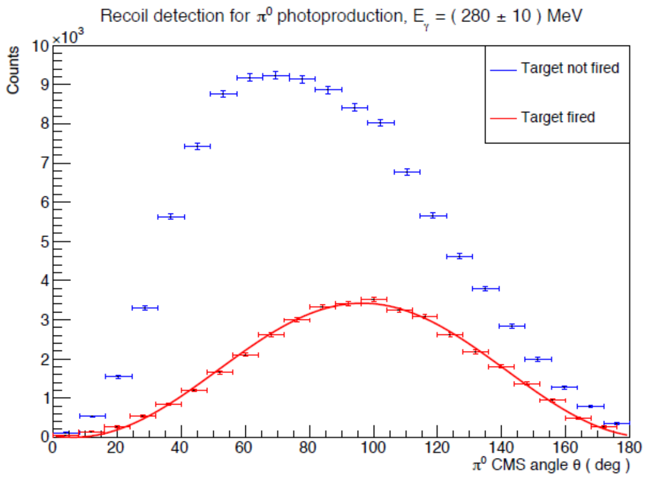


Energy cut-off: $E_{1/e} = (4 \pm 1)\ MeV$

Maximum detection efficiency: $\varepsilon_{\infty} = (55 \pm 1)\ \%$

Separation of coherent and incoherent events in case of π^0 photoproduction:

- If target fires, kinematic follows expected $1 - \cos^2\theta$ distribution



Acceptance at small angles is limited while the forward-detector TAPS is not included.

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JRA10: Update on progress CryPTA:APT

Summary and Future Developments

Findings:

- Angular resolution is essential (Readout by optical fibers, Scintillator segmentation)
- Increasing energy resolution (Improving scintillator fabrication process)

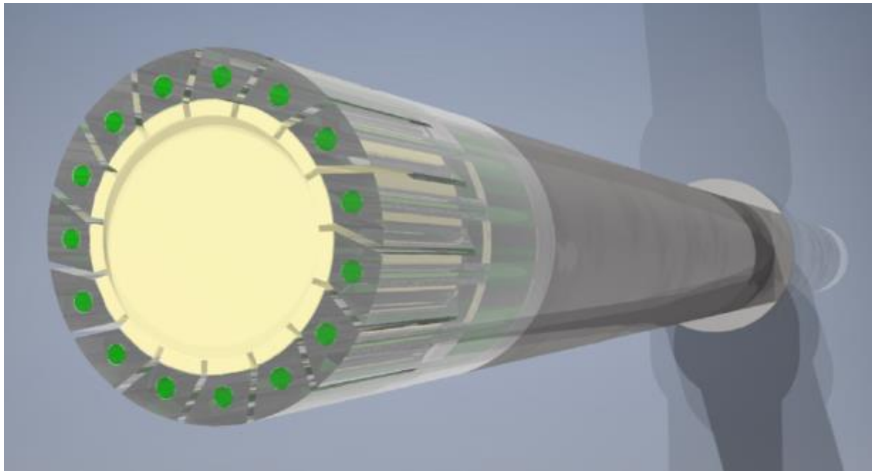
Two ongoing developments:

1. Active targets with polarizable scintillator

   a) Irradiated material produced at ELSA, Bonn
   b) Doped material developed in the PRISMA+ Scintillator Lab, Mainz

2. Semi-active targets with doped pellets

   - Cage of segmented standard plastic scintillator surrounding Teflon container with doped pellets inside
   - Use of H-, D-Butanol and doped granules
   - Scattering on Proton and Deuteron
   - Use of carbon foam for carbon subtraction



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JRA10: Deliverables

- There are no deliverables due for Reporting Period 1 (18 months, June 2019-November 2020)

JRA10: Milestones

- MS63 has to be achieved M9 (February 2020)

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS63	High precision winding machine for thin superconducting wires	10 - UBO	9	Internal Report

JRA10: Conclusions

1. **CryPTA:S**uper**c**onducting**M**agnet for permanent DNP in polarized solid state targets.

   First demonstrator has shown feasibility, next: insert the coil in a dil. refrigerator and use it in an experiment
2. **CryPTA:S**uper**c**onducting**S**hield for passive shielding of the PANDA magnet field for transv. polarization.

   Further material studies are needed and concept studies of a realistic target scheme in PANDA
3. **CryPTA:A**ctive**P**olarized**T**arget materials to detect the recoil proton in-situ, inside the target.

   APT works, now: improve the polarization behavior of APT and read out or focus on semi active target scheme.

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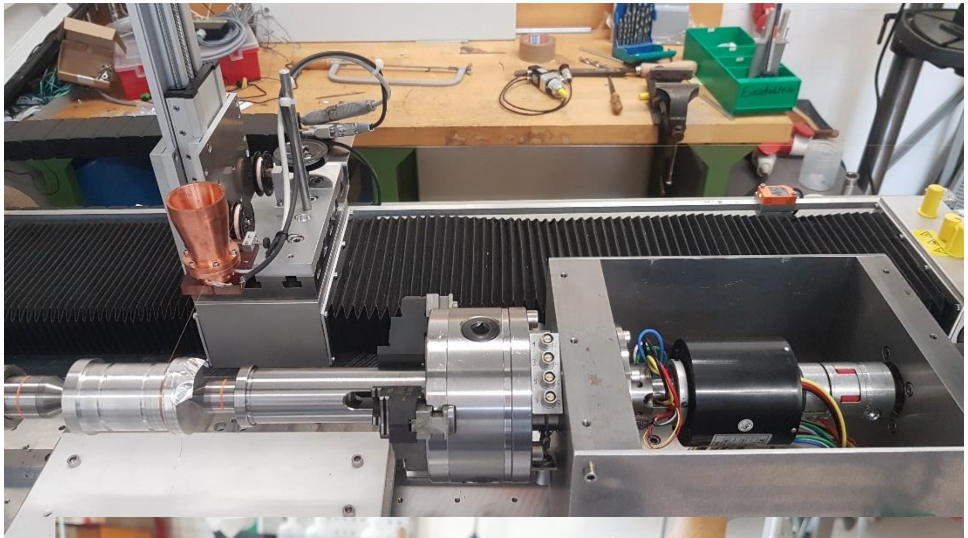
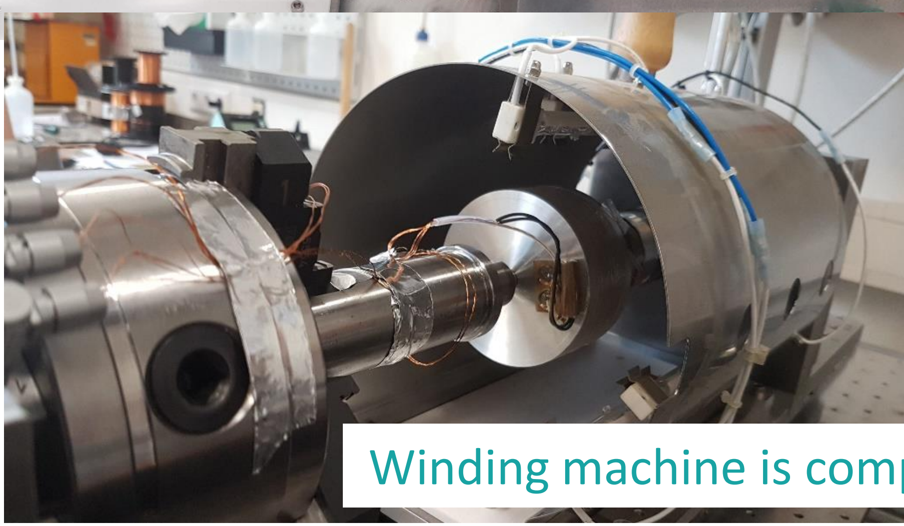
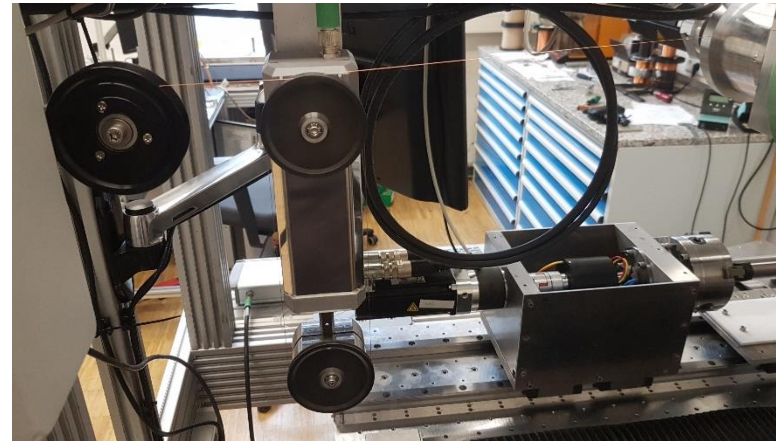
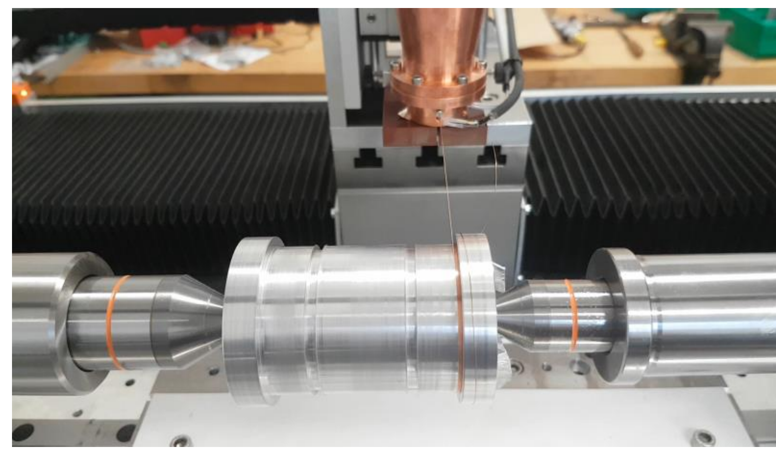
JRA10: *Milestones*

Status of MS63 (has to be achieved M9 (February 2020))









Winding machine is completed and under commissioning

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