STRONG-2020

HORIZON 2020

Annual Meeting 2024

JRA10:Cryogenic Polarized Target Application

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Plan of presentation

01 **Progress achieved by the WP during the last year**
CryPTA:SCM: Design of a combined holding coil system
CryPTA:APT: Low temperature detection techniques

02 **Highlights of the performed work**
(last year + full project duration)

03 **Tasks and achievements beyond the initial Work Program**

04 **Conclusions**

JRA10: Cryogenic Polarized Target Application

Cooperation of four partners

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

M. Biroth, P. Drexler, H. Dutz, St. Goertz, S. Heinz, A. Klotzbücher, M. Korolija,
O. Kostikov, V. Lagerquist, J.V. Patel, G. Reicherz, A. Thomas

Develop new technologies for polarized solid state targets for future polarization experiments

→ CryPTA:SCM: internal superconducting magnet systems

→ CryPTA:APT: active polarized target (low temperature detection) systems

JRA10: Cryogenic Polarized Target Application

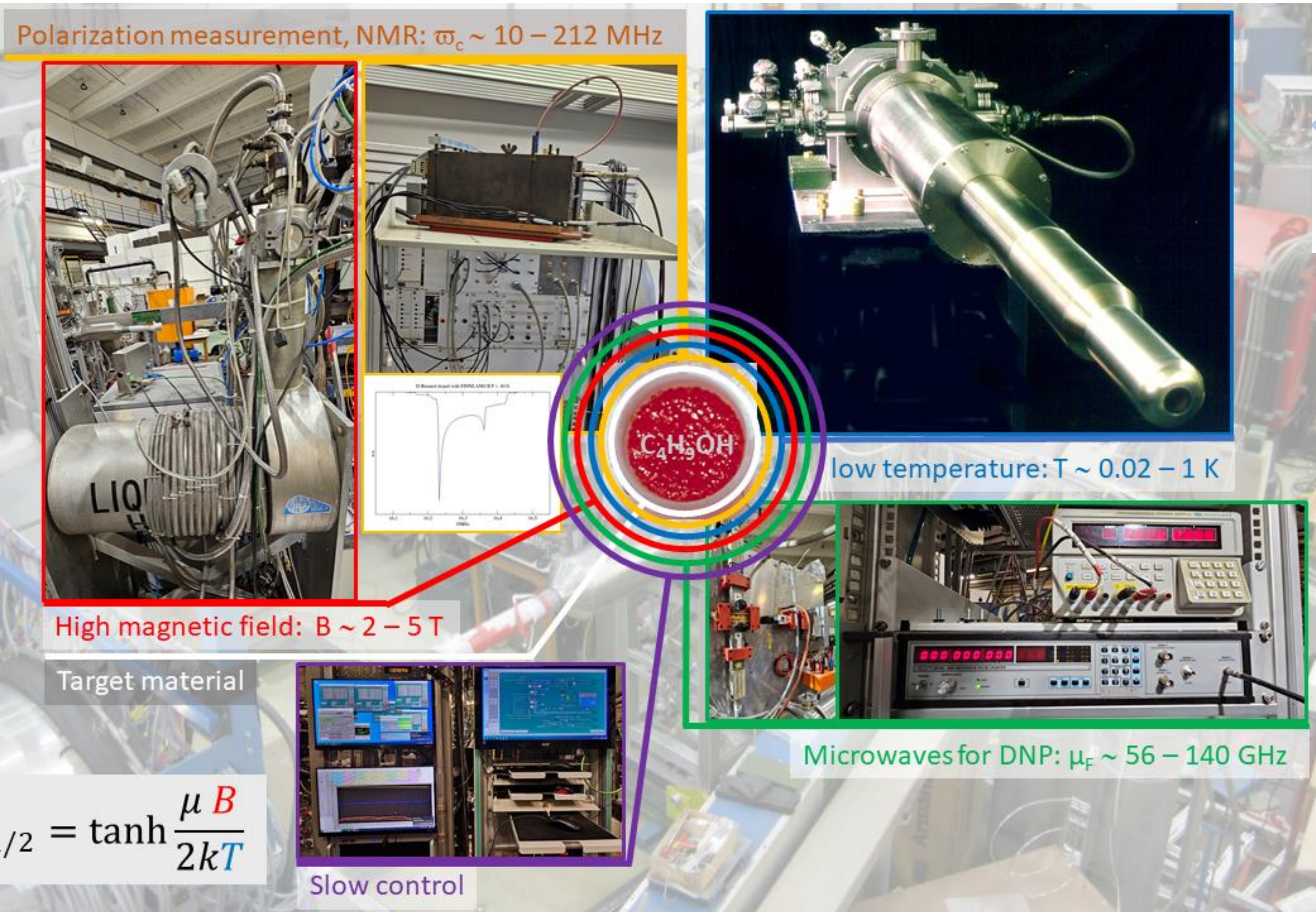
PT-Ingredients and responsibilities

RUB

- NMR
- Target material preparation and research

Polarized Target Bonn

- Target material preparation and research
- Magnet development
- Slow Control
- Cryogenic infrastructure



$$P_{1/2} = \tanh \frac{\mu B}{2kT}$$

Polarized Target Bonn, MAMI (Mainzer Mikrotron)

- Low temperature
- Refrigerator design and operation

MAMI (Mainzer Mikrotron), Ruđer Bošković Institute

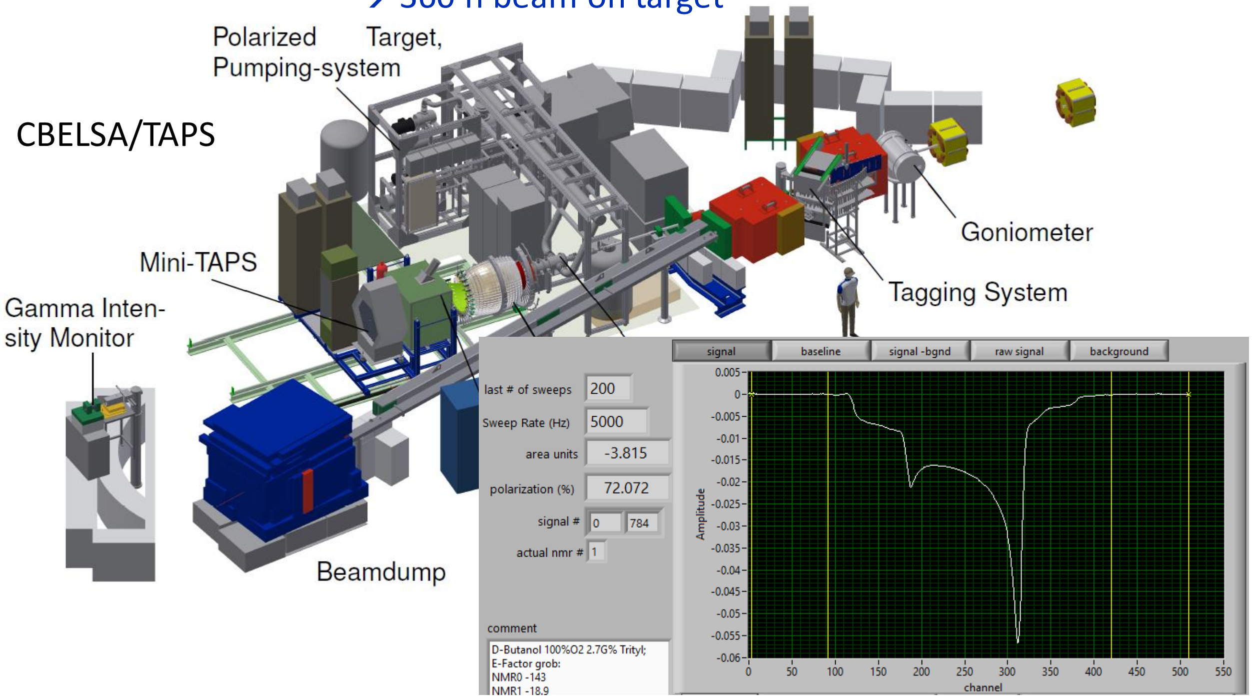
- Microwaves
- Active target material preparation and research

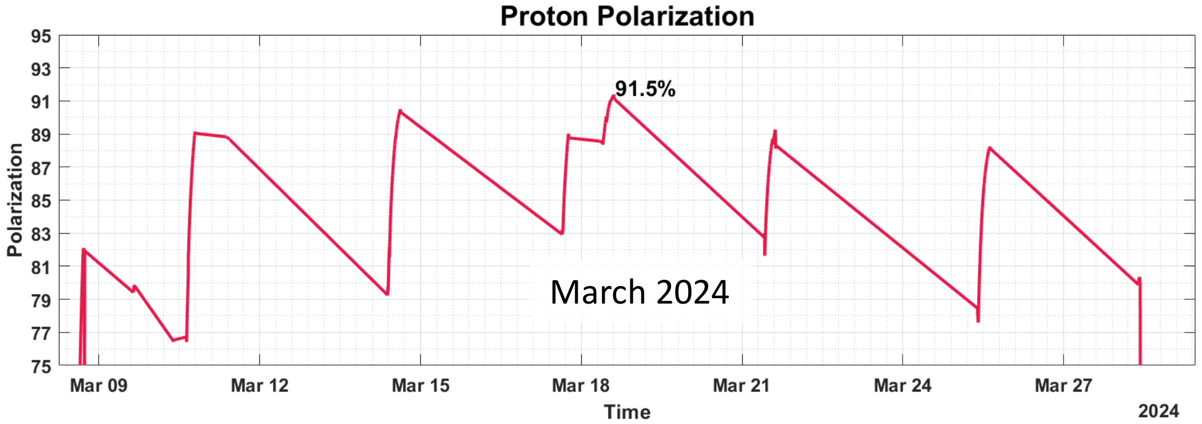
02

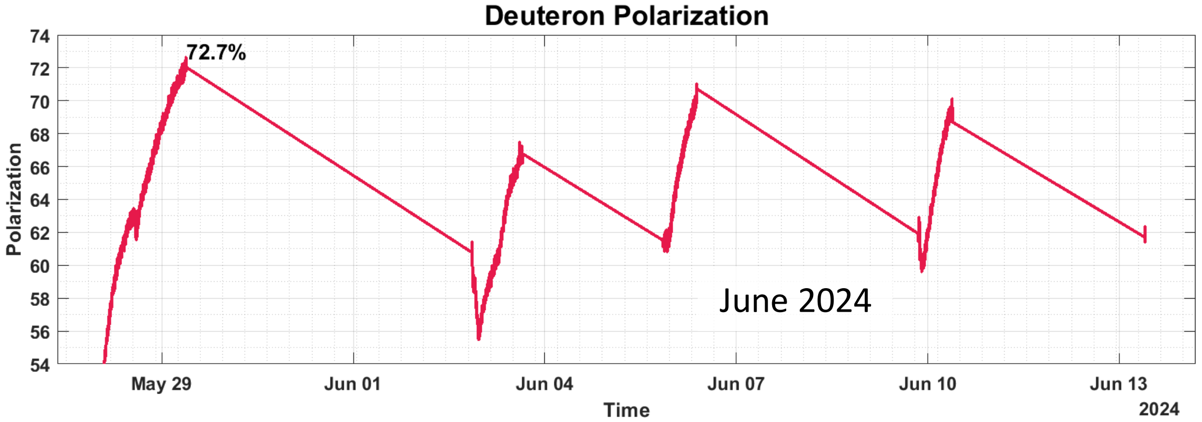
Operation of the frozen spin target @ CBELSA/TAPS @ ELSA

Two successful runs: 03-2024 (protons) 05/06-2024 (deuterons) → transverse polarization + lin. pol. γ - beam

March 2024 (proton) → P_{max} = 91.5%, τ ~ 900 h, P_{mean} ~ 85%
→ 380 h beam on target
April 2024 (carbon) → cold target for subtraction measurement
→ 240 h beam on target
June 2024 (deuteron) → P_{max} = 72%, τ ~ 660 h, P_{mean} ~ 66%
→ 360 h beam on target







After 3 years, the frozen spin target is back in the beam with high polarization and reliability,
we were able to take over the Russian contribution

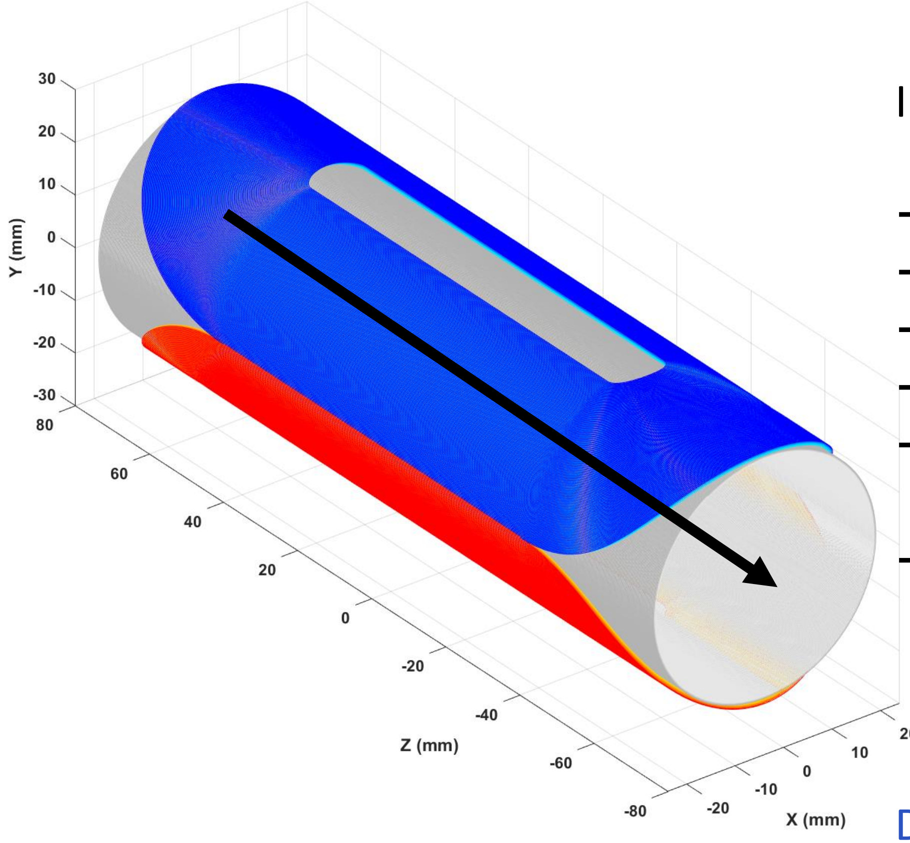
Progress achieved by the WP during the last year

01

Design of a combined holding coil system (CryPTA:ScM)

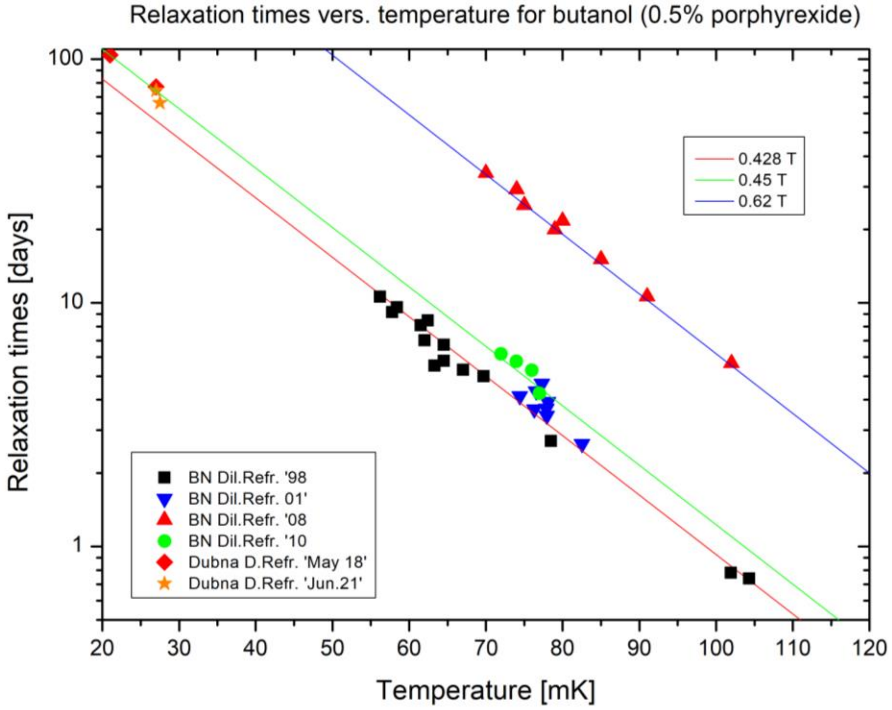
H. Dutz, V. Lagerquist (UBO)

Combined longitudinal and transverse field
for a variable polarization direction in yz-plane or xz-plane
→ Solenoid + 'race-track'



Initial approach:

→ combine solenoid + race track
→ minimize radiation length
→ minimize thickness of the package
→ reduced field strength
→ concept only works as holding field in frozen spin mode
→ 0.4 T < B_H to get reasonable relaxation times



Detailed studies and simulations are underway → V. Lagerquist

01

Design of a combined holding coil system (CryPTA:ScM)

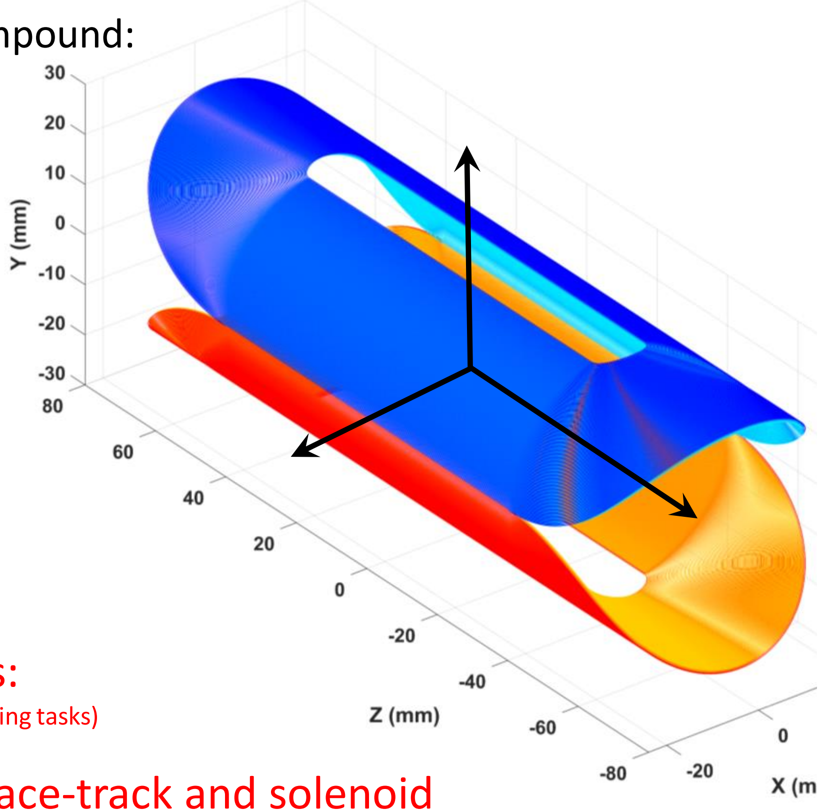
H. Dutz, V. Lagerquist (UBO)

Combined longitudinal and transverse field for a variable polarization direction in yz-plane or xz-plane → Solenoid + 'race-track'

Design / simulation boundary condition for the compound:
(wire: 0.203, Cu-support: 0.3 mm + separating foils)

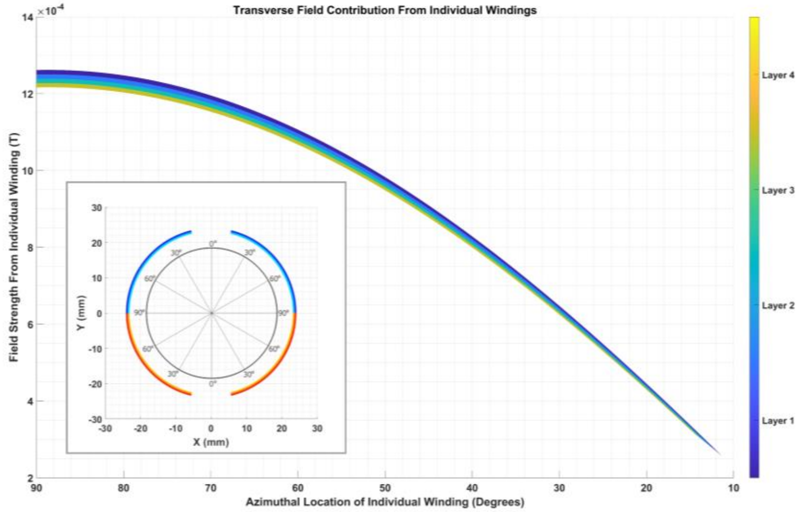
'high current' I = 40 A → B = 0.4 T
→ Solenoid: 2 layers, N = 1280 → thickness: 0.45 mm
→ Race-track: 3 layers, N = 414 → thickness: 0.69 mm
→ Compound thickness: ~ 1.6 mm

Final goal:
Optimize the compound for minimum thickness with an available wire for the race-track (first) and solenoid (easy task)



Maximum field, minimum thickness:

→ Cosine theta shape
→ Equal No. of windings per layer
→ Straight section angle ~ 24°



Next steps:
(Plans and remaining tasks)

→ Wind race-track and solenoid
→ Test the combined coil system

01

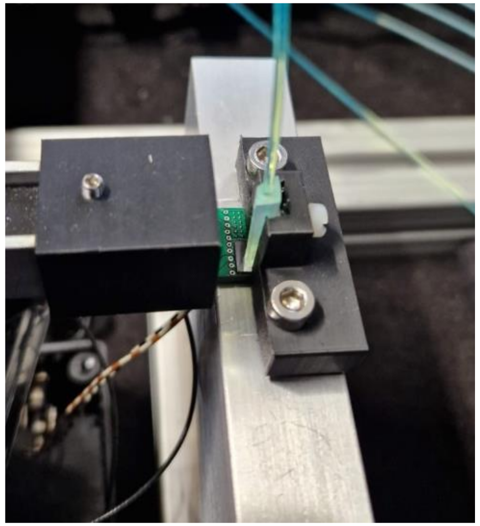
Low temperature detection techniques (CryPTA:APT)

M. Biroth, P.Drexler, A.Thomas, A.Klotzbücher, J.V.Patel (JGU)

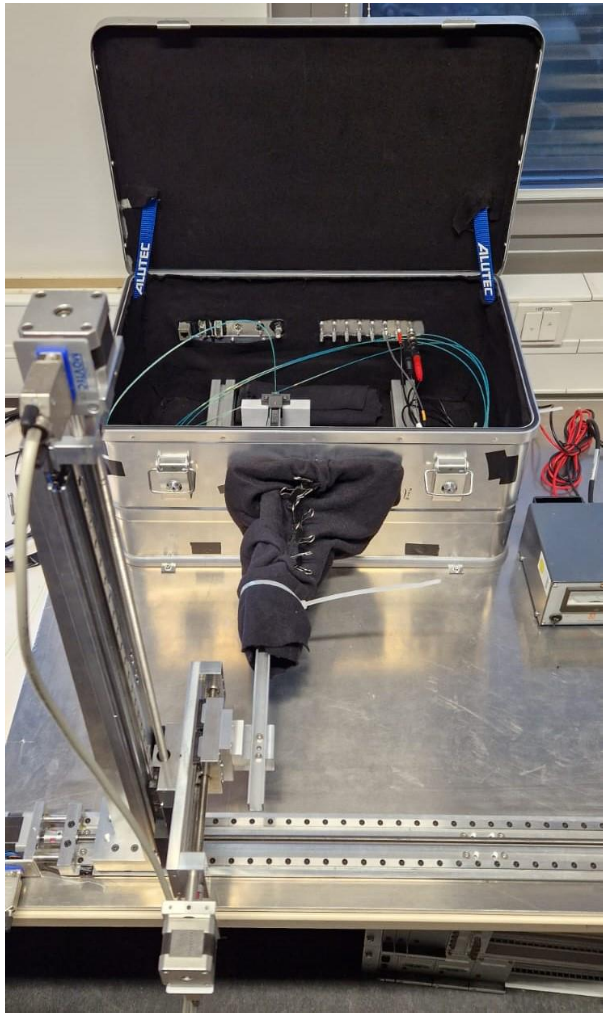
Dr. M. Biroth, Dr. P.Drexler, Dr. A.Thomas
Students (2023/2024): BSc A.Klotzbücher, BSc J.V.Patel

Focus on an improved light efficiency and readout:

- Coupling of the scintillating fibers to the material and SiPMs
- Geometry of the apparatus
- Tests with ^{90}Sr-source in 2023
- Tests with photon beam planned in July 2024



Coincidence technique to improve signal to noise ratio.



New Apparatus:
Light-tight test station has been adopted for the use with liquid nitrogen.

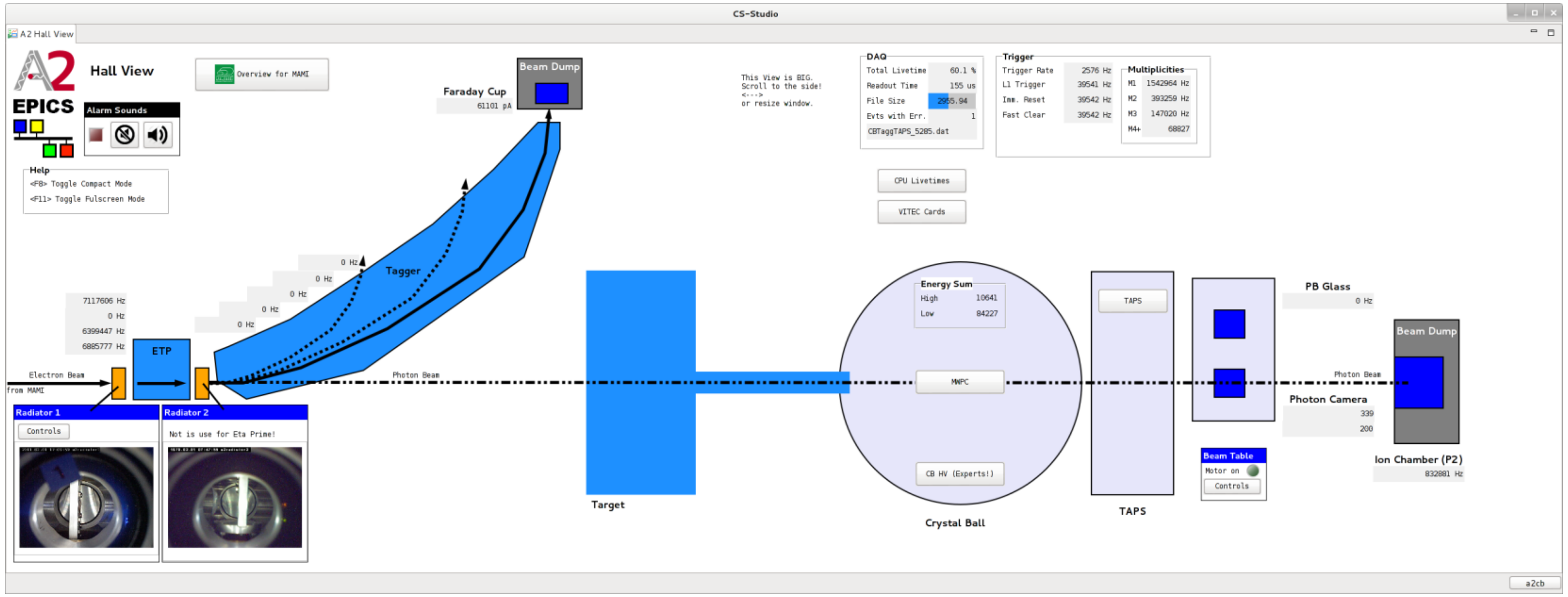
Cryo-box:
Operation in the range 77-300 Kelvin.

01

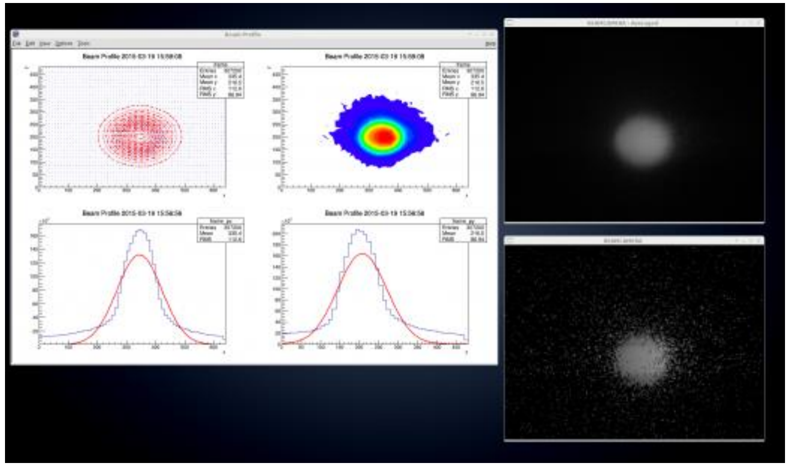
Low temperature detection techniques (CryPTA:APT)

M. Biroth, P.Drexler, A.Thomas, A.Klotzbücher, J.V.Patel (JGU)

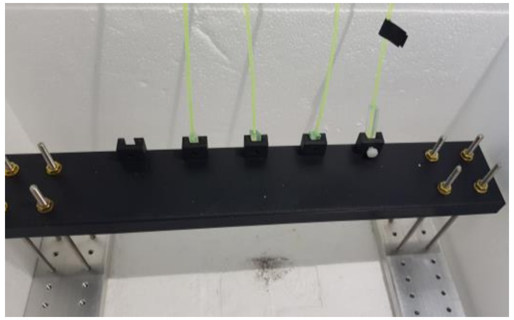
- Investigation of the low temperature behavior of the preamplifiers and the scintillating fibers. Test of the thermal properties of scintillating fibers, plastic detector materials and connection schemes.
- In beam operation at the A2 photon facility in July 2024 to investigate the light output and efficiency of the proposed geometrical concepts.



EPICS control program to move the cryo-box with the active target prototypes.



Photon beam spot in position of the cryo-box.
4 movable detectors.



Promising approach that will be pursued further in the coming months

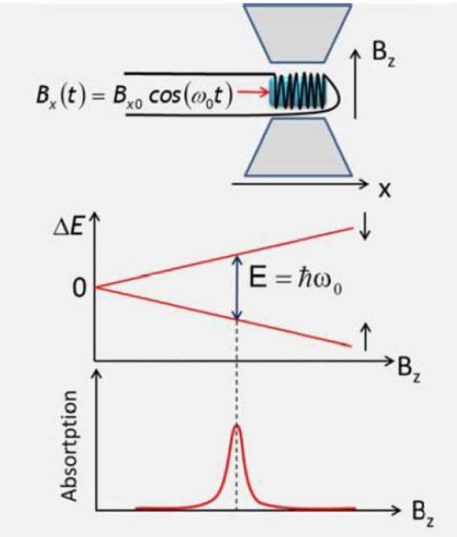
03

The new Bochum high precision NMR-spectrometer system

F. Grimm, G. Reicherz (RUB)

NMR-spectrometer

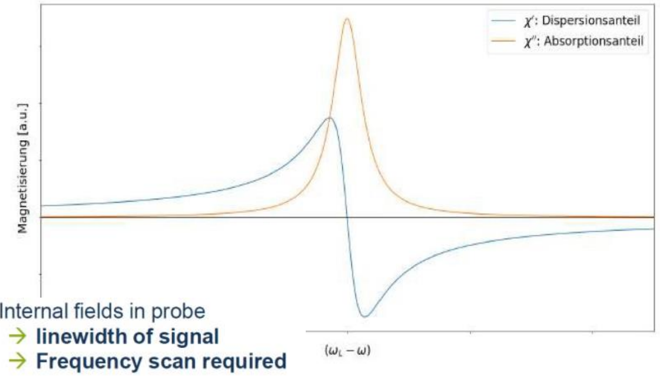
- Zeeman effect
- Magnetic field in z-direction leads to energy splitting
- Radio frequency coil provides oscillating magnetic field in x-direction
  - Realized as LC-circuit
- $B_x(t) = B_{x,0}\cos(\omega_0 t)$
- **Alternating magnetic field drives spin-flip transitions:**
  $\Delta E = \hbar\omega_0 = \hbar\omega_L$
- Resonance condition can be achieved in two ways:
  - **Frequency-sweep: Constant B-field and sweep frequency**
  - **Field-sweep: Constant frequency and sweep B-field** (not practicable during DNP)
- Two types:
  - Continues wave NMR
  - Pulsed NMR (not used because one loose important information during ringing down of the pulse)



Polarization

- **Polarization is connected with susceptibility**
- **complex susceptibility** of sample:
  $\chi(\omega) = \chi'(\omega) - i\chi''(\omega)$
- Target material in coil modifies inductance:
  $L(\omega) = L_0(1 + 4\pi\eta\chi(\omega))$ η: effective filling factor
- Resonate coil with capacitor → LC-circuit
- Resonance frequency: $\omega_0 = 1/\sqrt{L_0 C}$
- Changes in $\chi''(\omega)$
  → changes in Q-factor of LC-circuit
  → Changes in mean power loss of coil
  → for constant current: change in voltage

→ $P = K\int_{-\infty}^{+\infty}\chi''(\omega)d\omega$

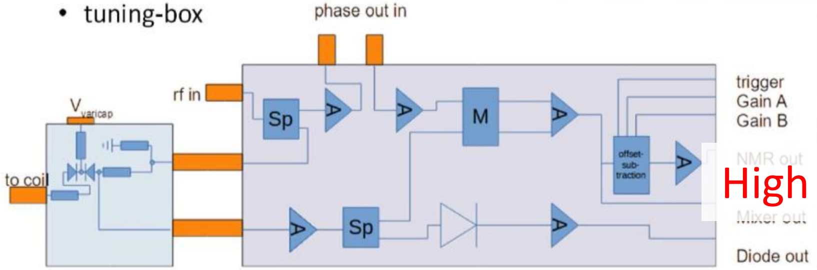


- Internal fields in probe
  → **linewidth of signal**
  → **Frequency scan required**

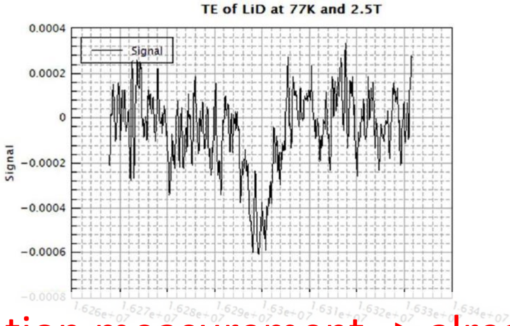
Polarization ∝ Area under signal

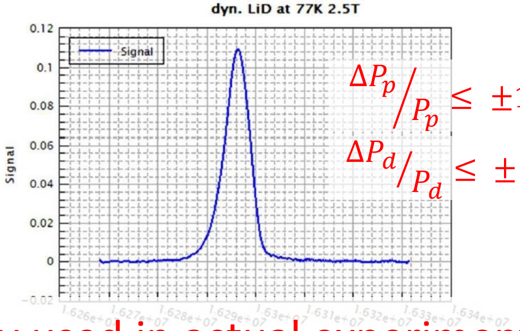
Bochum NMR - box

Consists of three parts:
- RF – board
- dc-offset board
- tuning-box



Signals of [6]LiD at 77K ad 2.5 T





$\Delta P_p / P_p \leq \pm 1.5\%$

$\Delta P_d / P_d \leq \pm 1.5\%$

High precision polarization measurement -> already used in actual experiments

Result: SNR is slightly better than that of the well known Liverpool NMR Modul!

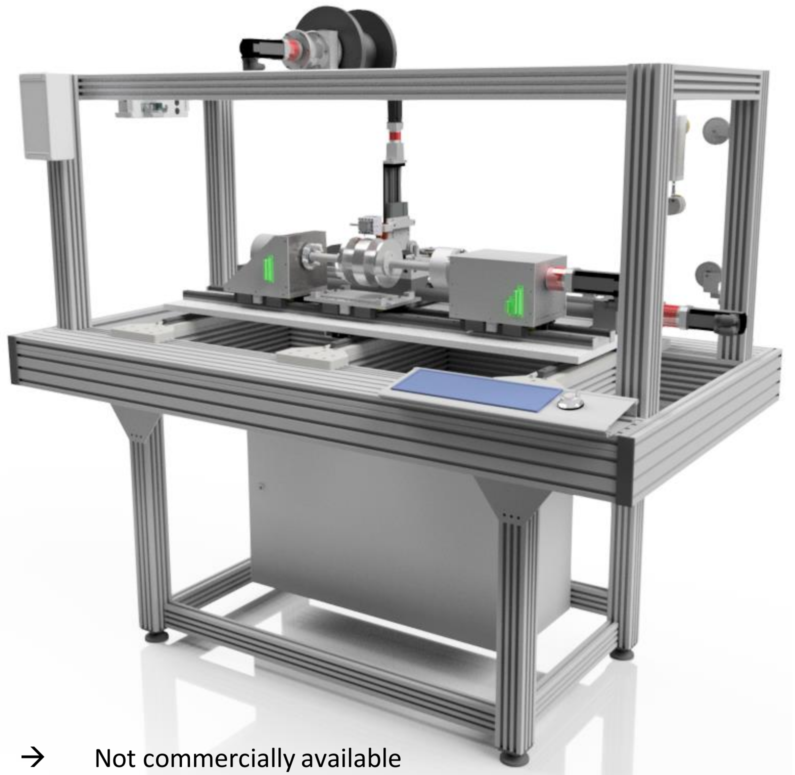
Highlights of the performed work

02

Production and test of a small size low mass polarizing solenoid with high homogeneity

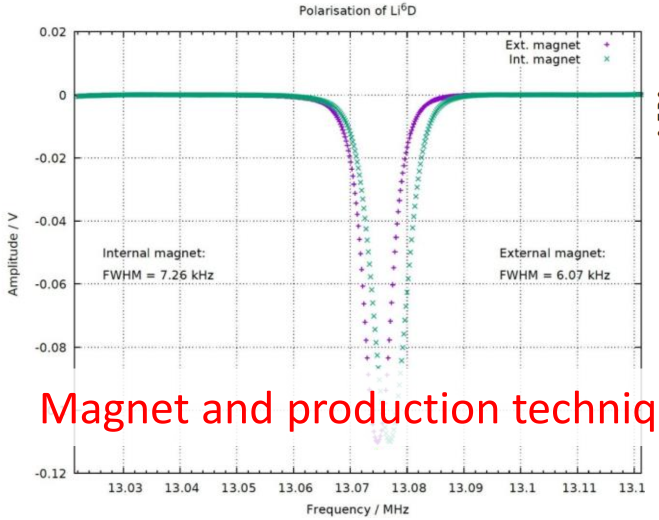
Permanent dyn. polarization:
CryPTA:ScM (UBO, RUB)

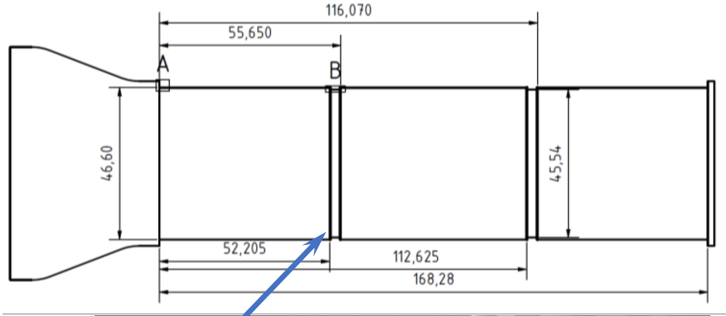
High precision winding machine for thin superconducting wires

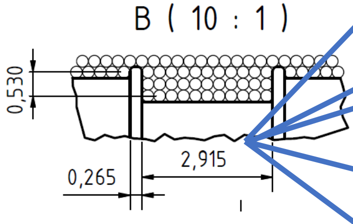


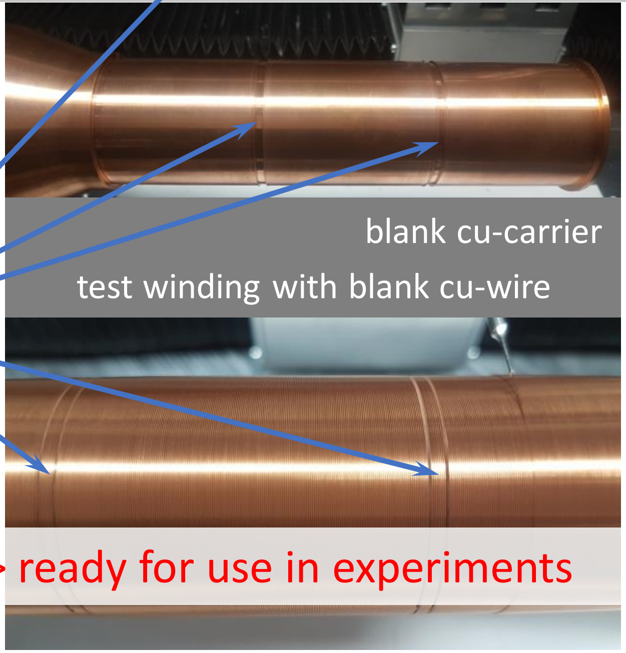
- → Not commercially available
- → Custom made high precision winding machine fulfill the requirements (MS63), displacement ≤ 2.5µm
- → Co financed by a collaborative SME research project (BMWI, ZIM) with CryoVac (Germany) and Physics Institute University Bonn

B=2.5T, $B/B_0<10^{-4}$ for DNP, WD=2mm









Magnet and production techniques now available -> ready for use in experiments

MS63: High precision winding machine for thin superconducting wires: https://www.polarisiertes-target.physik.uni-bonn.de/files/internalreportmilestonewindingmaschine.pdf

JRA10:Cryogenic Polarized Target Application

STRONG-2020 opened the door to the development of new technologies for polarized solid-state targets.

The final goal of CryPTA was to develop s.c. magnet structures and low temperature detector techniques for new and innovative polarization experiments using polarized solid state targets in 4π-detection systems for hadron physics experiments.

CryPTA:ScM → internal high field polarizing magnet is well tested and available for experiments
→ the combined holding magnet is under construction and will be available soon.
CryPTA:APT → detailed design concepts for low temperature polarized active targets are defined.
→ the preparation of an improved target insert with optical fiber readout is on the way .

Still missing: a suitable dilution refrigerator which allow us to use the new technologies in scattering experiments

Joint efforts are required to get a horizonal dilution refrigerator from a reliable manufacturer for future double polarization experiments

CryPTA2022 Annual Meeting, September 20-22, Boppard

20 participants from 10 institutions / polarized target labs

R. Beck (UBO), M. Biroth (Umainz), M. Bornstein (CryoVac), G. Ciullo (INFN/Ferrara), N. Doshita (Yamagata/CERN), H. Dutz (UBO), St. Goertz (UBO), S. Heinz (UBO), T. Iwata (Yamagata), C. Keith (Jlab), A. Klotzbücher (Umainz), V. Lagerquist (ODU), E. Long (UNH), F. Maas (HMI Mainz), W. Meyer (RUB), M. Ostrick (Umainz), G. Reicherz (RUB), Y. Takanashi (Yamagata), A. Thomas (Umainz)

CryPTA2022 Annual Meeting, September 20-22, Boppard

Evening speech

- Werner Meyer (RUB): 60 years polarized solid targets for particle physics experiments

CryPTA:ScM and CryPTA:ScS for field generation and shielding

- Victoria Lagerquist (Old Dominion): Optimization and Implementation of Magnet Correction Coils for the Jefferson Lab Polarized Target
- Andre Klotzbücher (JGU): Field Measurement and Correction of a Solenoid for Polarised Targets
- Hartmut Dutz (UBO): Status of CryPTA:ScM
- Giuseppe Ciullo (INFN): A versatile bulk superconducting MgB_2 cylinder for the production of holding magnetic field for polarized targets and nuclear fusion fuels
- Frank Maas (HMI Mainz): Investigation on intense axial magnetic field shielding with Bi-2212 tube

CryPTA:APT active polarized targets and target materials

- Stefan Goertz (UBO): Polarized Solid State Target Materials: A short Inventory
- Elena Long (UNH): Tensor polarized target
- Mike Biroth (UMainz): The Mainz Active Polarized Proton Target - Review and Perspectives

CryPTA outreach / technology transfer to SME

- Marcel Bornstein (CryoVac): A 3T UHV-compatible superconducting magnet for STM-experiments at low temperatures

New developments and group reports

- Chris Keith (Jlab): Activities of the Jefferson Lab Target Group
- Takahiro Iwata (Yamagata): Dynamic nuclear polarization for nano particles dispersed in epoxy resin doped with free radicals
- Norihiro Doshita (Yamagata/CERN): The COMPASS 6LiD polarized target in 2022
- Andreas Thomas (UMainz): Status of the polarized target at MAMI
- Gerhard Reicherz (RUB): The new Bochum NMR box and measurements with the VNA

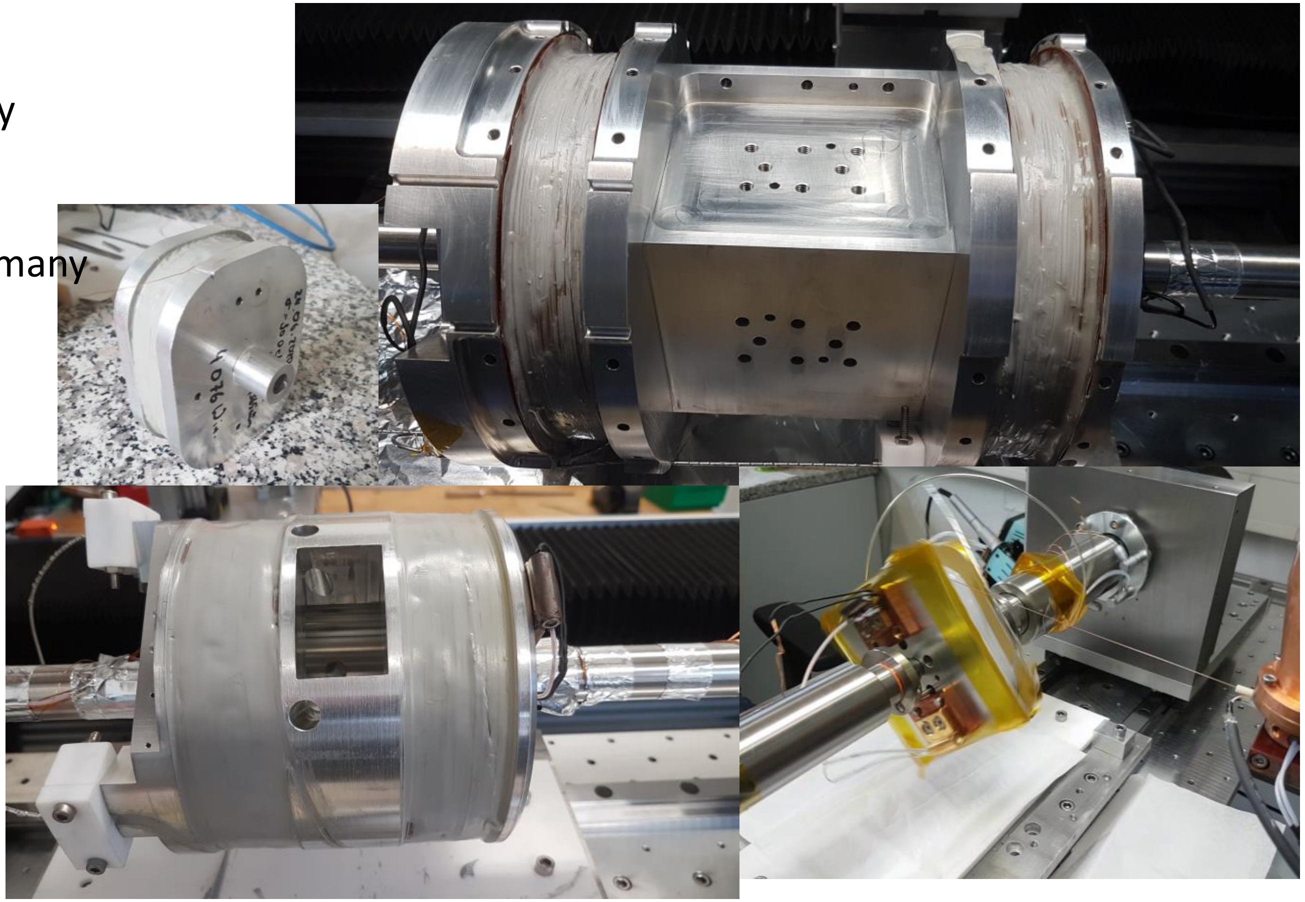
03

Outreach / Technology transfer to SME

M. Bornstein (CryoVac), H. Dutz (UBO)

Design and construction of small sc-magnets using thin sc-wires leads to a new type of sc-magnets for UHV applications

- → Wet winding process of thin sc-wires is the key technology
- → High field, low current, indirect cooled (dry cooling), bakeable and UHV qualified magnet for RTMs
- → Collaborative research program with CryoVac GmbH, Germany funded by BMWi (ZIM)
- → Wet winding of a one component epoxy resin
- → Winding and curing in one process
- → Classical and 3D magnet geometries for UHV-RTMs



Good example for successful technology transfer from a hadron physics project to new commercial products