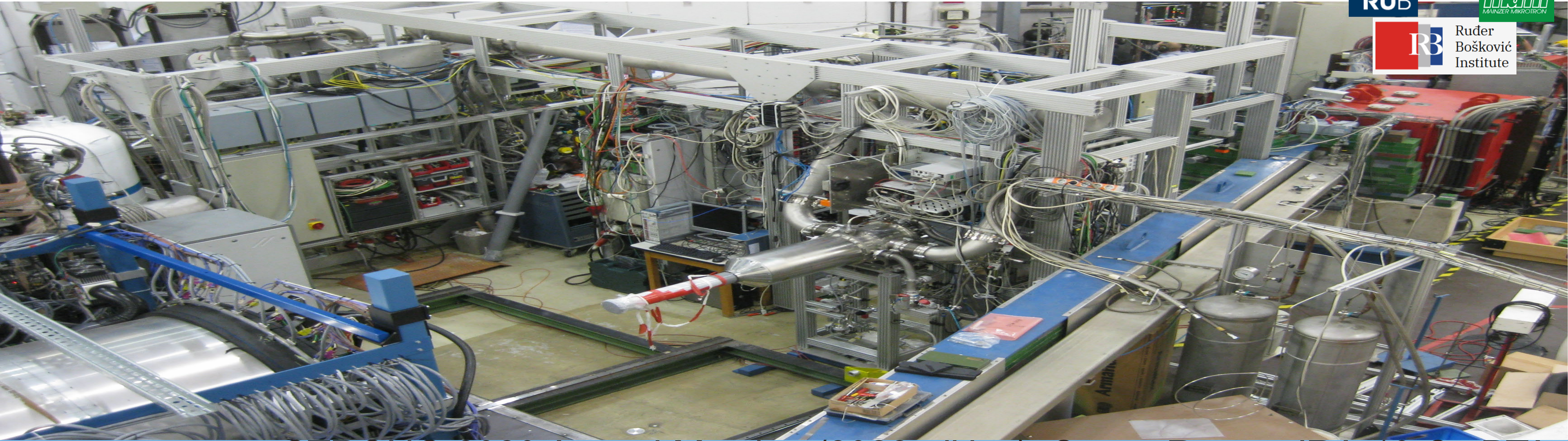


STRONG-2020 Annual Meeting (2022edition) Status Report JRA-10 CryPTA

Andreas Thomas
Institut für Kernphysik Universität Mainz

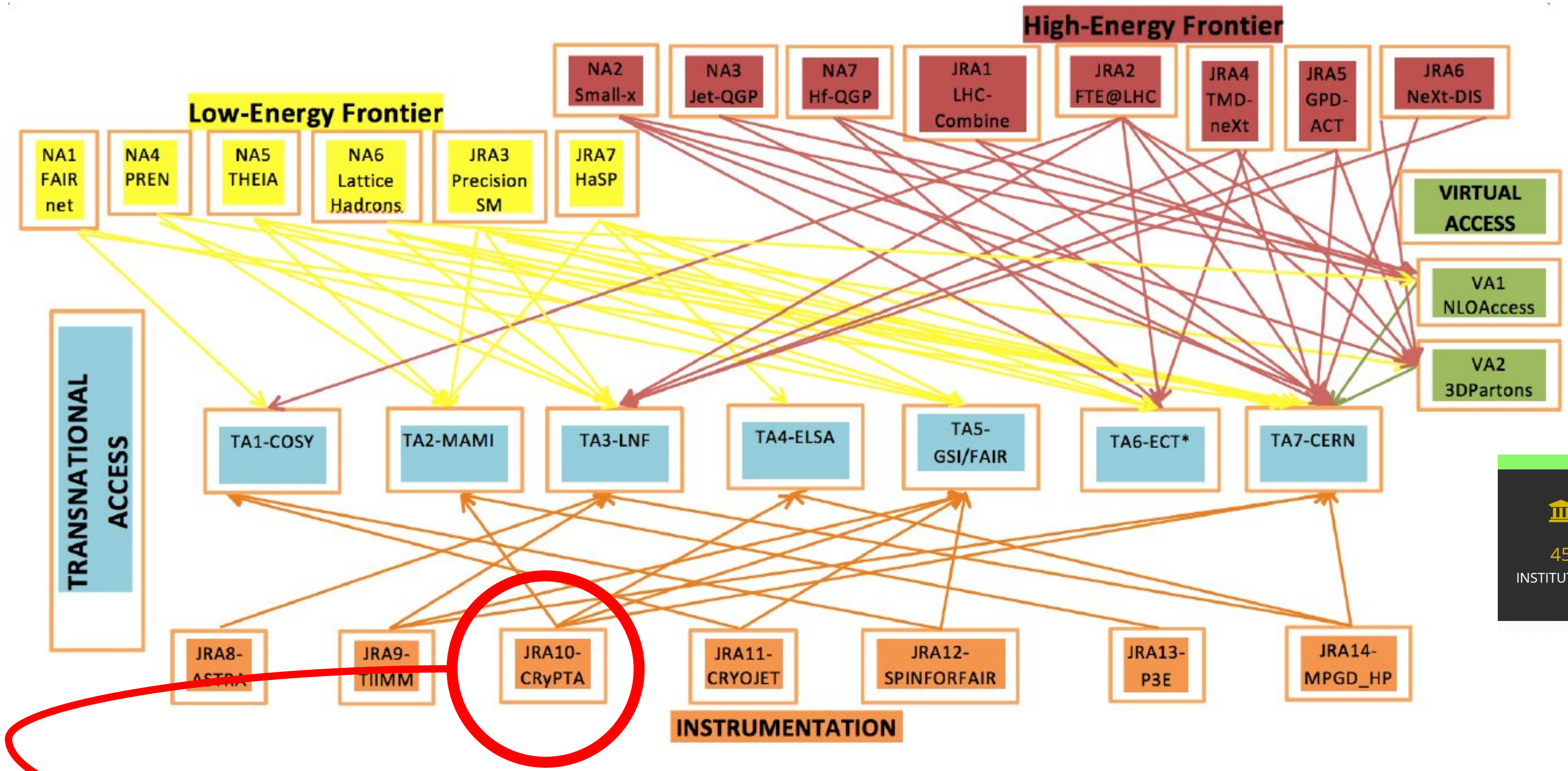
thanks to Hartmut Dutz
Physikalisches Institut Universität Bonn

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

CryPTA2022, Status Report

STRONG-2020

“The strong interaction at the frontier of knowledge: fundamental research and applications”



45 INSTITUTIONS | 36 COUNTRIES | 32 WORK PACKAGES

CryPTA : Cryogenic Polarized Target Applications

CryPTA2022, Status Report

JRA10:CryPTA:Consortium

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

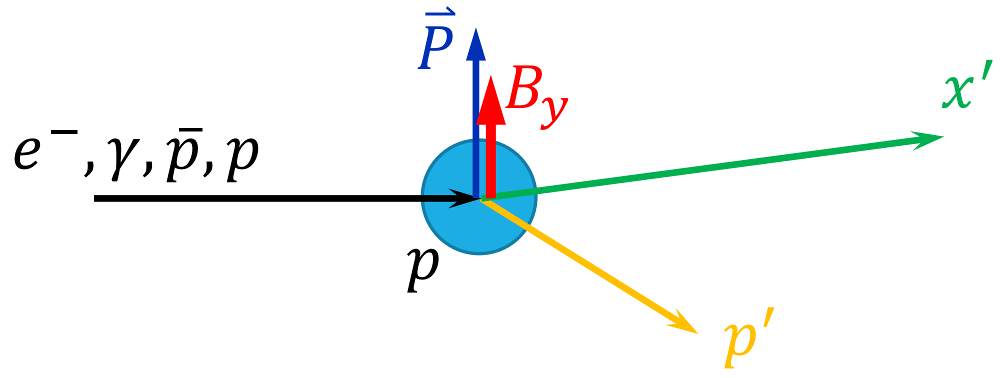
M. Biroth, M. Bornstein, A. Dbeyssi, H. Dutz, B. Fröhlich, St. Goertz, S. Heinz, A. Klotzbücher, M. Korolija, O. Kostikov, F. Maas, W. Meyer, G. Reicherz, St. Runkel, A. Thomas

CryPTA2022, Status Report

JRA10:CryPTA:Research Objectives

Polarized Target: Vector polarization of Spin ½ particles: $P_z = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = \vec{P} \sim \tanh {}^{\mu\vec{B}}/_{kT}$

Prepare the polarization for the polarization observable of interest by choosing a suitable magnetic field



→ **Guiding magnetic field conflicts** with the (large acceptance) detection system
→ **Guiding magnet conflicts** with the outgoing particles

→ Develop new polarized target technologies for future polarization experiments

CryPTA2022, Status Report

JRA10:CryPTA:Research Objectives

The tasks (topics) of the CryPTA project

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

Key technology to improve the polarized target performance:

- increase the luminosity, FoM and availability
- gain to new polarization observables

CryPTA:APT Detection of recoil particles in active polarized targets

Active target materials and cold read out systems for small size targets

- extend the kinematic rage of 4π continuous mode pol. solid state targets

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

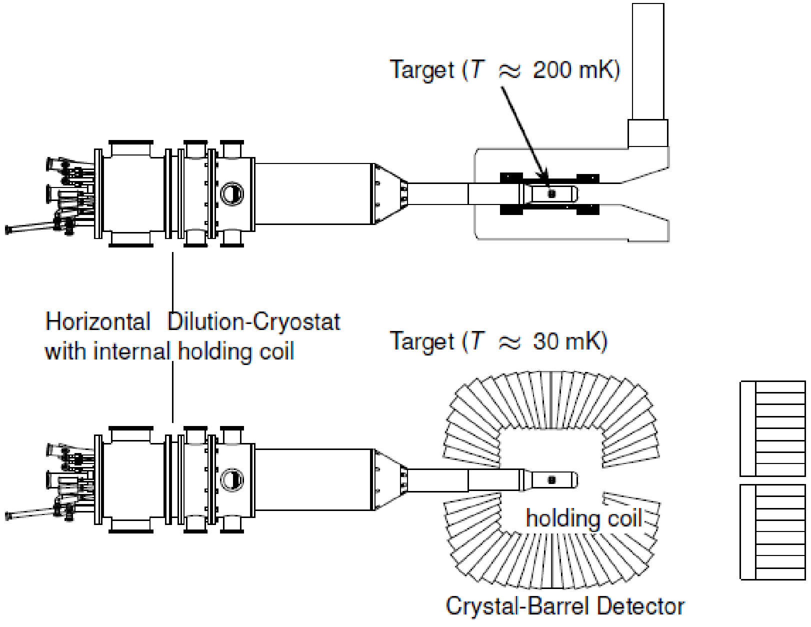
CryPTA2022, Status Report

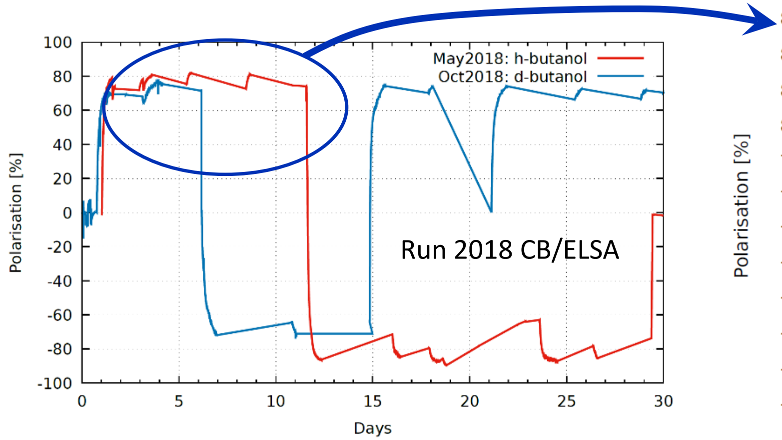
Superconducting magnet structures → CryPTA:ScM (UBO, RUB)

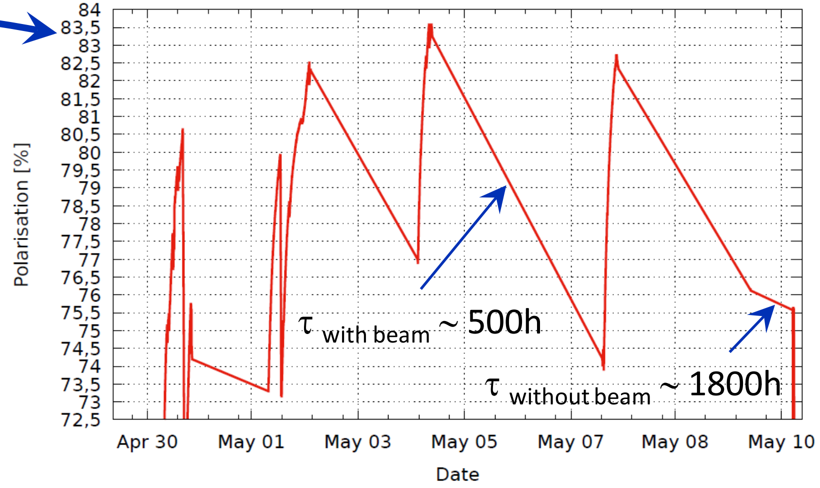
Structure mapping @ ELSA and MAMI (i.e. baryon spectroscopy) in a large acceptance detector system (Crystal Barrel / Ball)

→ (double) polarization experiments with real photons

State of the art set-up: horizontal frozen spin target and internal holding magnet:







Frozen spin target:

- Set-up: external polarizing magnet (2.5 T), internal holding coil (0.6T)
- Advantage: large angular acceptance, 4π detector
- Disadvantage: loss of polarization, complex handling, limited beam intensity

CryPTA2022, Status Report

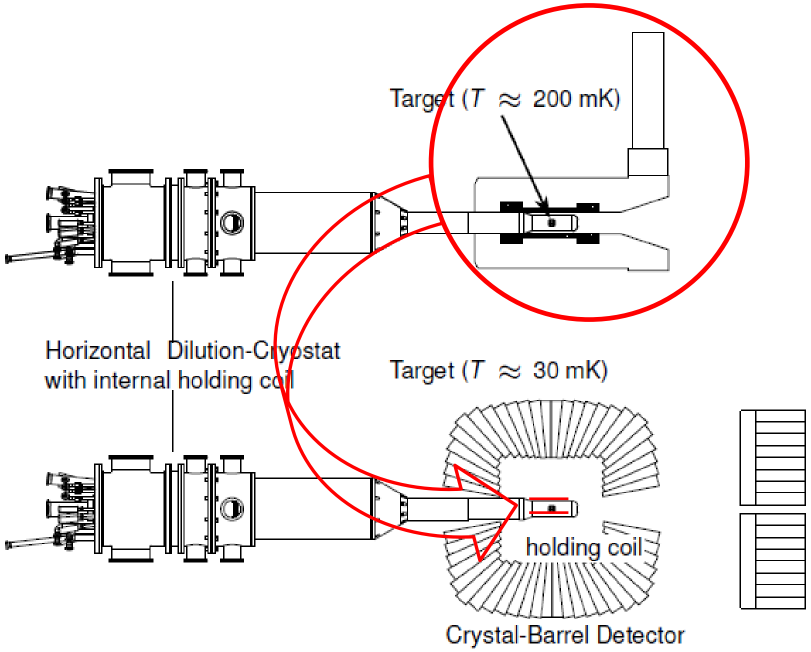
Superconducting magnet structures → CryPTA:ScM (UBO, RUB)

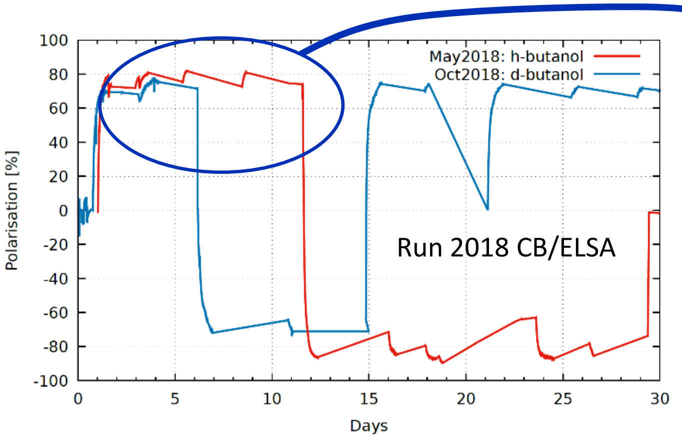
RUB
POLARIZED TARGET BONN
MAMI MAINZER MIKROTRON
Ruđer Bošković Institute

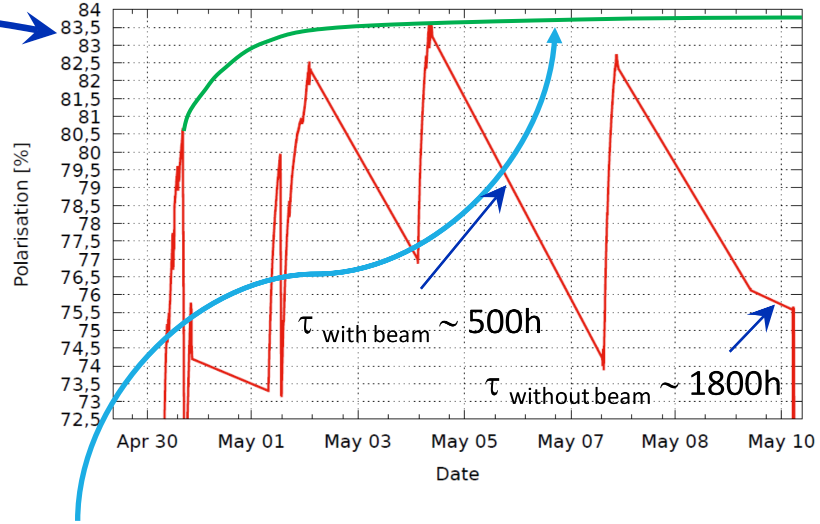
Structure mapping @ ELSA and MAMI (i.e. baryon spectroscopy) in a large acceptance detector system (Crystal Barrel / Ball)

→ (double) polarization experiments with real photons

Shrink the external magnet to the dimensions of the internal holding coil:







4π-Continuous-Mode Target (permanent DNP)

Combines the advantages of high polarisation and the large angular acceptance

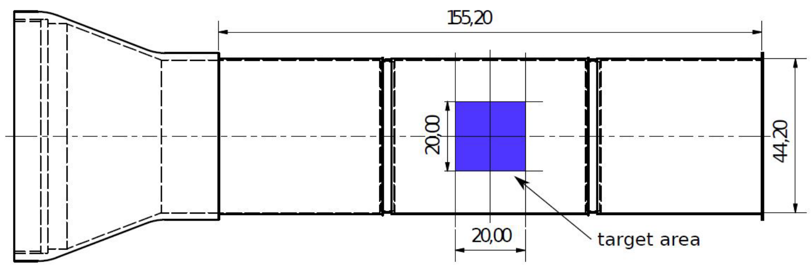
Key element: Internal magnet with the same magnetic properties as the external magnet

CryPTA2022, Status Report

Superconducting magnet structures → CryPTA:ScM (UBO, RUB)

→ Small s.c. magnet (150 mm x ∅45 mm x WT 1.8 mm), 6 layers á 590N, high field (B=2.5T) and high homogeneity ($\Delta B/B \leq 10^{-4}$, 20 x ∅20 mm)

universitätbonn — Internal polarisation magnet - Field calculation



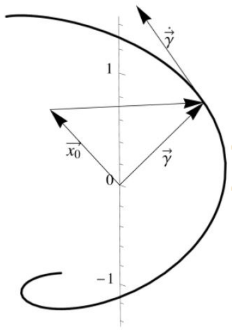
Biot-Savart-Law:

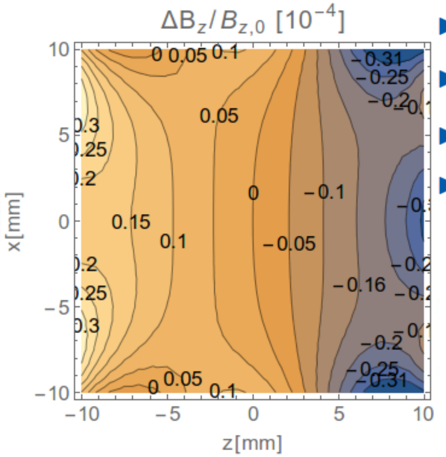
$$\vec{B}(\vec{x_0}) = \frac{\mu_0}{4\pi} I \int \frac{(\vec{\gamma}(t) - \vec{x_0}) \times \frac{\dot{\vec{\gamma}}(t)}{|\dot{\vec{\gamma}}(t)|}}{|(\vec{\gamma}(t) - \vec{x_0})|^3} \mathrm{d}t$$

Loop parametrization:

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

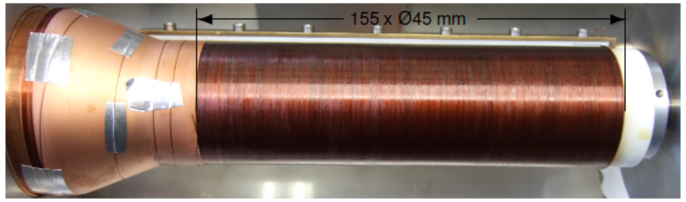
r: radius of each loop
$n \cdot d$: loop position
d: effective distance between 2 wires





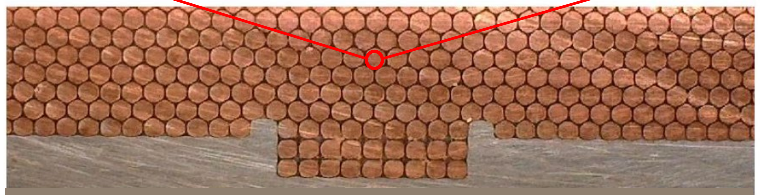
DNP requires $\Delta B/B \leq 10^{-4}$

Internal magnet developments for polarized targets 7/14



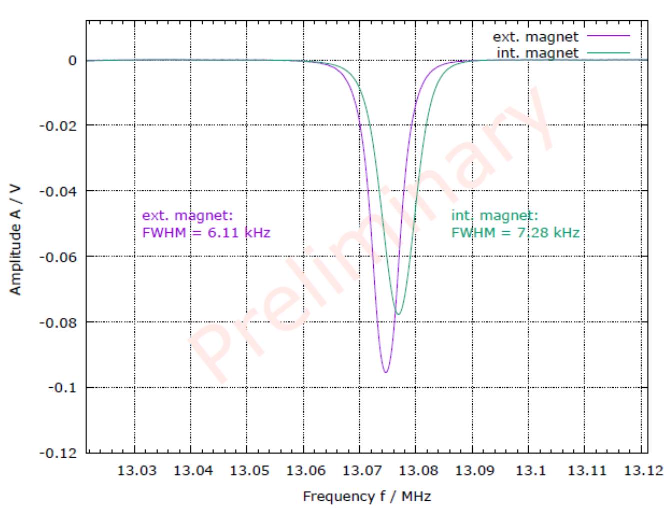
- As thin as possible
  - → Overall thinkness ≤ 2 mm
  - → Passively cooled
- Internal magnet with $B_0 = 2.5$ T @ 90 A @ 1 K
- $\frac{\Delta B}{B_0} \ll 10^{-4}$ @ $1/40 V_{\mathrm{overall}}$
- Building process by wet wiring (with epoxy)
- Precondiction: Homogeneous (orthocylic) wire pattern!

s.c. wire ∅ = 254 µm



Cut and grinding of a test winding

Tests in ^{4}He Kryostat: 6LiD at 1 K



- A proton and a deuteron target could be dynamically polarized with an internal magnet

→ Wrap thin s.c. wire (∅254µm) with high precision (orthocyclic, wet winding)

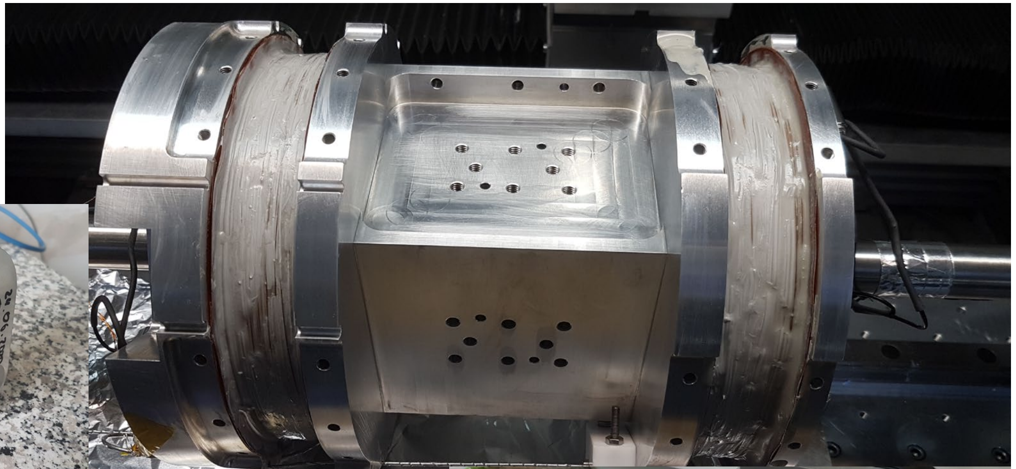
→ Displacement ≤ 2.5µm

CryPTA2022, Status Report

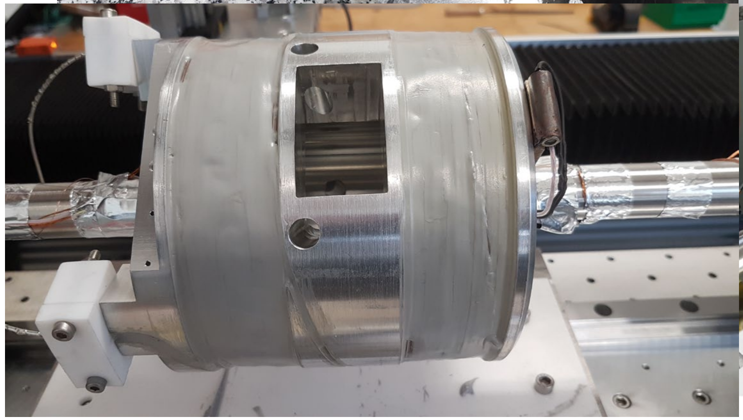
Outreach / Technology transfer to SME: M. Bornstein (CryoVac)

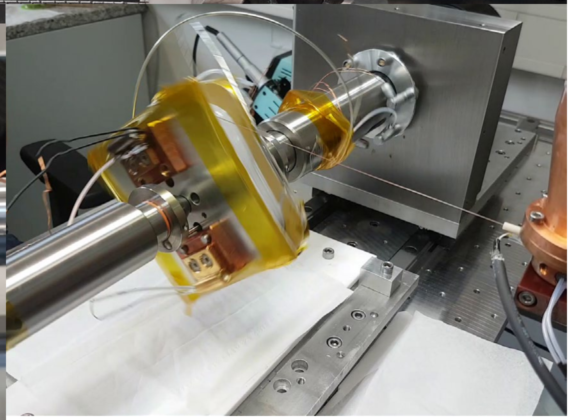
The design and construction of small sc-magnets using thin sc-wires leads to a new type of sc-magnets for UHV applications

- → 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





CryPTA2022, Status Report

Superconducting magnet structures → CryPTA:ScS (Umainz, UBO)

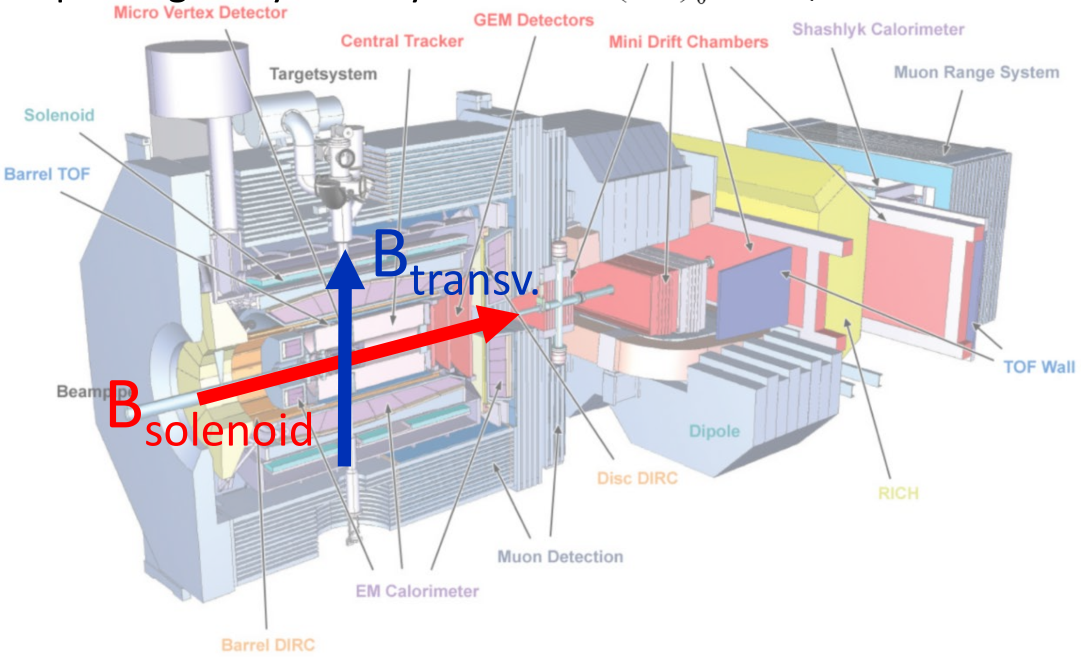
Polarized gas target (ABS plus storage cell): transverse polarization + spectrometer + 4π detection systems

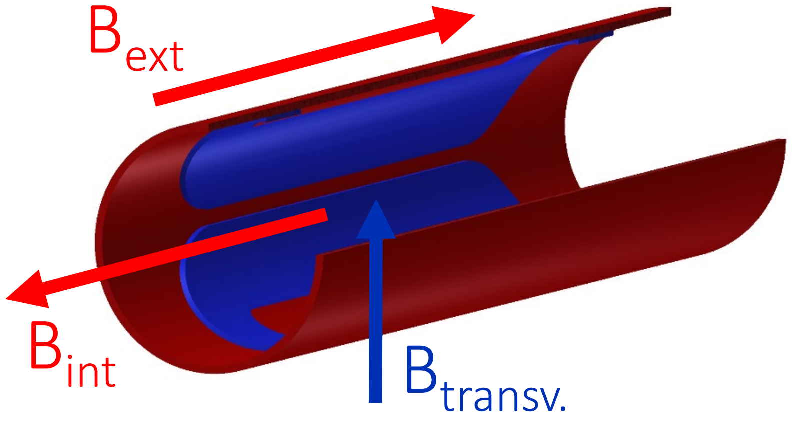
Imaginary part of time like FF single spin target asymmetry

$$\left(\frac{d\sigma}{d\Omega}\right)_0 A_{1,y} = \frac{N}{\sqrt{\tau}} \sin 2\Theta \, \mathrm{Im}\left(G_M G_E^*\right)$$

→ Transverse polarization:

(A. Dbessy, B. Fröhlich, F. Maas, UMainz)





shield main field and generate a transverse field

CryPTA2022, Status Report

Superconducting magnet structures → CryPTA:ScS (Umainz, UBO)

During the reporting period, we continued the simulations and investigations on the shielding behavior of the high-temperature superconductors in a cylindrical geometry. Our focus was on looking at the dependence of the current density of the high-temperature superconductor on the ambient temperature. The use and combination of different superconducting materials was also considered.

The working group was still able to reach milestone MS65: "Magnet field calculations for PANDA low mass superconducting passive" in June 2021, but due to the current situation, the work on Task 2 as described in the application cannot be continued. The reason for this decision is the pandemic-related staff shortages within the working group and the necessary concentration of the working group on the activities within the framework of the FAIR phase 0 commissioning. Therefore, the measurements in the CryPTA project cannot be continued with the necessary care and conscientiousness. The consortium member "HIM JGU-Mainz" has therefore left the Joint Research Activity CryPTA at its own request on January 1, 2022.

Superconducting magnet structures → CryPTA:ScS (Umainz, UBO)

F. Maas: Experimental tests of the shielding tube BSCCO-2212

Bi-2212 schielding tube

- ✧ High temperature superconductor
- ✧ A large melt cast Bi2 Sr2 CaCu2 O8 hollow cylinder (from Nexans); manufactured with centrifugal technique

[J. Bock, S. Elschner, P. Herrmann, IEEE Transactions on Applied Superconductivity 5 (2) (1995) 1409-1412]

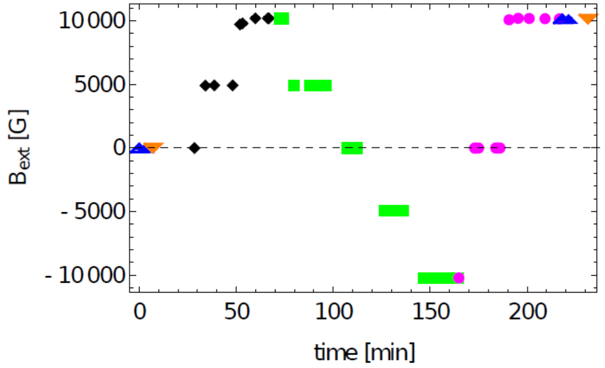
Length	150 mm
Outer radius	25 mm
Wall thickness	3.5 mm

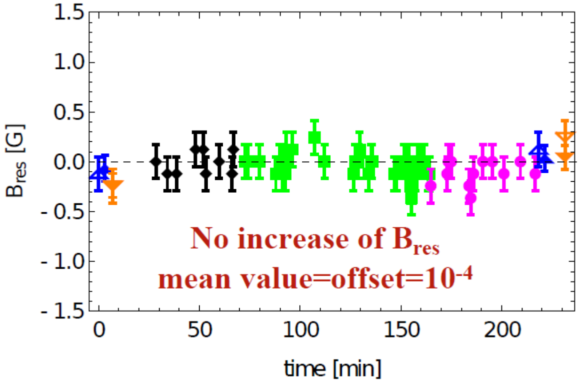
- ❖ **At 10 K**, a 1 T magnetic field is shielded with **a shielding factor of 10^3 with** Bi-2212 tube (80 mm length, 8 mm inner radius and 5 mm wall thickness)

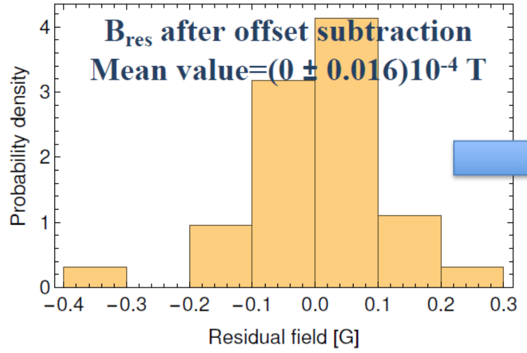
J.-F. Fagnard, et al., Superconductor Science and Technology 23 (9) (2010) 095012

Measurement of the residual magnetic flux density (B_{res}) at 1 T

✧ Measurement of B_{res} at the center of the Bi-2212 tube [Setup-B] @ T = 4.2K







B_{ext} = (10140 ± 14)10^{-4} T

B_{res} = (0 ± 0.016)10^{-4} T

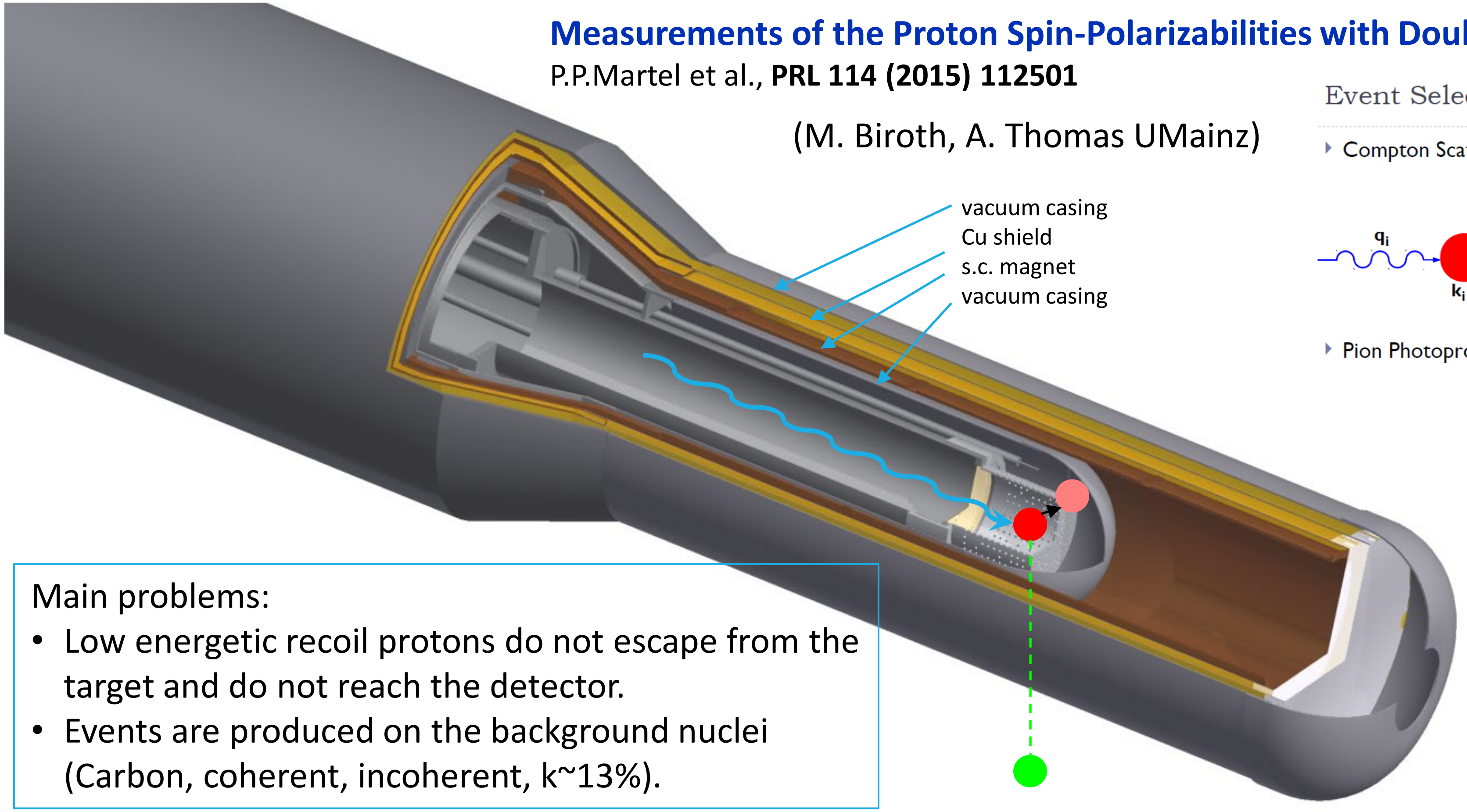
Shielding factor (SF=B_{ext}/B_{res})= 3.2 10^5 at 95% confidence level

CryPTA2022, Status Report

Low temperature detection techniques → CryPTA:APT (Umainz, RBI, RUB)

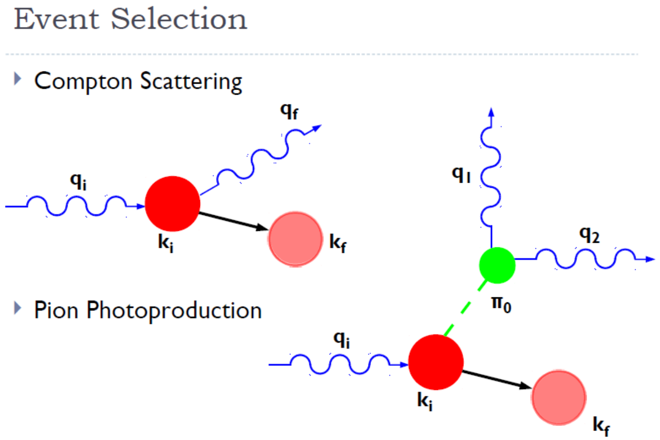
Measurements of the Proton Spin-Polarizabilities with Double-Polarized Compton Scattering @ MAMI,
P.P.Martel et al., **PRL 114 (2015) 112501**

(M. Biroth, A. Thomas UMainz)



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%).

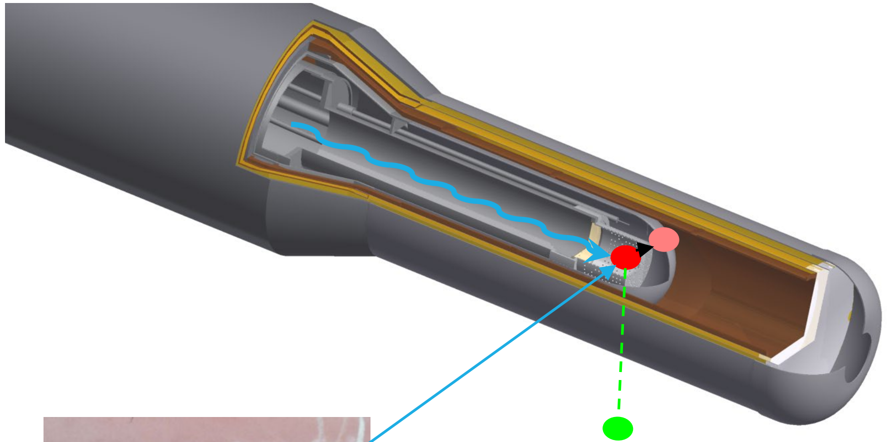


Pion photoproduction off of a proton is 75-100 times more likely than Compton (in the 240-280 MeV range)

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

Low temperature detection techniques → CryPTA:APT (Umainz, RBI, RUB)

Mike Biroth (UMainz):
The Mainz Active Polarized Proton Target - Review and Perspectives

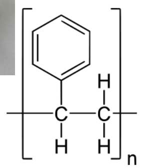


butanol ($C_4H_9[OH]$)

replace

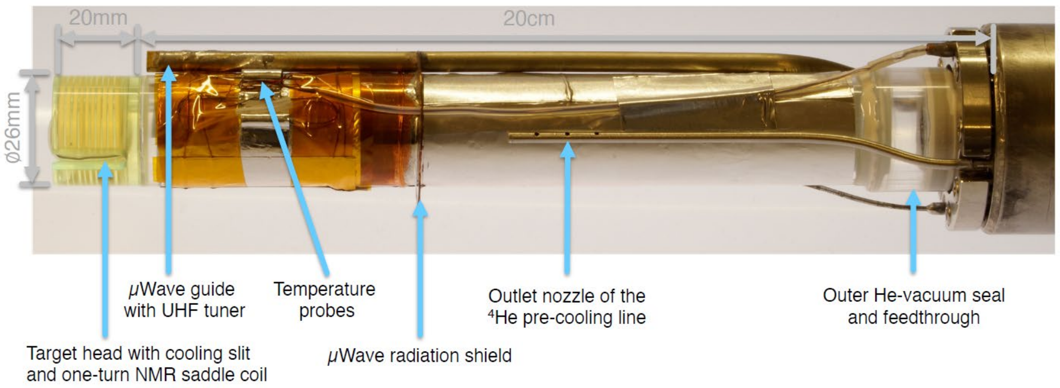
- find a suitable radical for DNP
- polarize
- get the light out

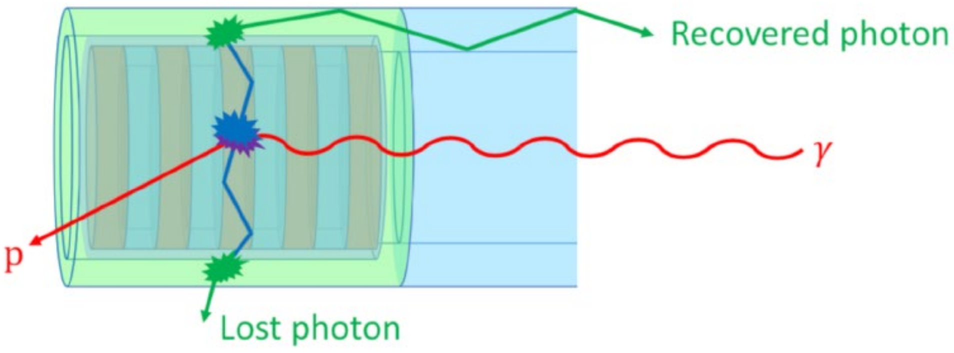
polystyrene



Active Target Operated in the Experiment

Photograph of the target part installed in the mixing chamber:





CryPTA2022, Status Report

Low temperature detection techniques → CryPTA:APT (Umainz, RBI, RUB)

Mike Biroth (UMainz):
The Mainz Active Polarized Proton Target - Review and Perspectives

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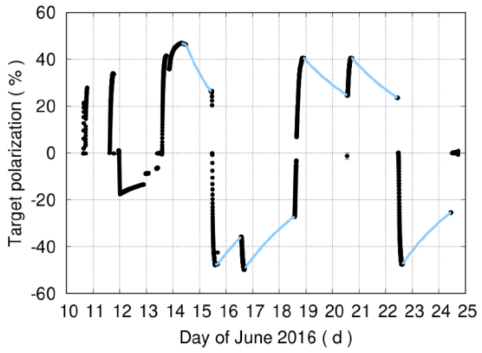
Achieved Degree of Polarization and Relaxation Time

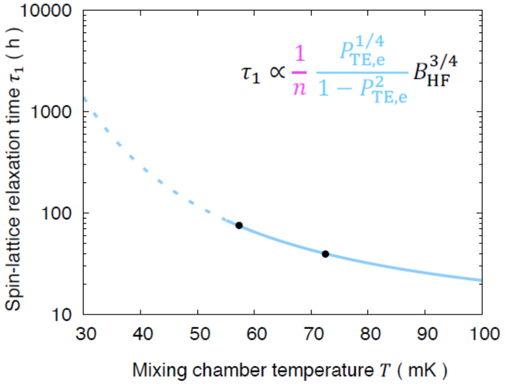
Maximum polarization and spin-lattice relaxation time are low compared to TEMPO-doped Butanol:

Property	Active Target		Butanol target
	Positive	Negative	
Temperature	> 45 mK		28 mK
Max. Polarization	46.2 %	−49.2 %	$\lvert P \rvert > 80$ %
Relaxation time	78.5 h	75.4 h	$> 1200\ h$



Approaches to optimize the polarization:

1. Reducing the spin density ($n < 1.5 \times 10^{19}\ \mathrm{cm}^{-3}$)
1. Reducing the temperature to $T < 30$ mK predicts relaxation times of $\tau_1 > 1000$ h
2. Doubling the high field $B_0 = 5$ T corresponds to halving the temperature during DNP

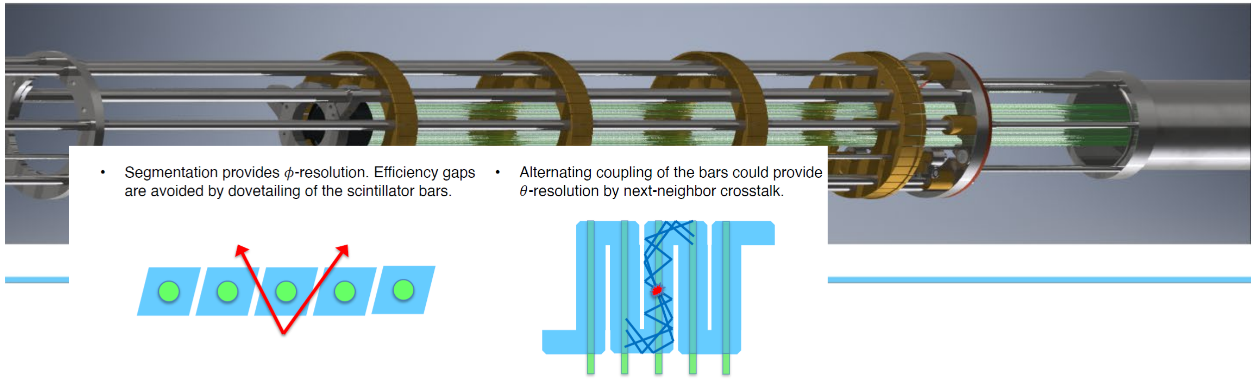


26

Next Generation Active Target and Polarizable Scintillator

Semi-active Target Concept: A cage of segmented standard plastic scintillators surrounds a Teflon container with doped Butanol inside.

- Fiber readout minimizes the intensity attenuation
- Enables carbon subtraction using an carbon foam
- Doped pellets can be H- or D-Butanol



CryPTA2022, Status Report

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, Status Report

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 MgB2 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

Conclusion

The final goal is to provide low mass sc. magnets and shielding for polarized targets operated in a 4π-detection system, as well as active polarized solid state targets for recoil detection of protons.

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

Key technology to improve the polarized target performance:

- increase the luminosity, FoM and availability
- gain to new polarization observables

CryPTA:APT Detection of recoil particles in active polarized targets

Active target materials and cold read out systems for small size targets

- extend the kinematic rage of 4π continuous mode pol. solid state targets

CryPTA is a challenging R&D work package for new polarized target experiments