Recent activities of the Bonn Polarized Target Group

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Recent activities of the Bonn Polarized Target Group

Content & Acting people

- Motivation
- Recent experiments
- High field, thin s.c. magnets for DNP
- Combined field magnets
- Conclusion

Cooperation of four partner institutions within the European Horizon 2020 Joint Research activity **CryPTA**: Cryogenic Polarized Target Applications:

UBO: Marcel Bornstein*, Hartmut Dutz, Stefan Goertz, Sascha Heinz, Victoria Lagerquist, Stefan Runkel*

RUB: Gerhard Reicherz

JGU: Andreas Thomas, Mike Biroth

RBI: Milorad Korolija

Russian collaborators (JINR Dubna):

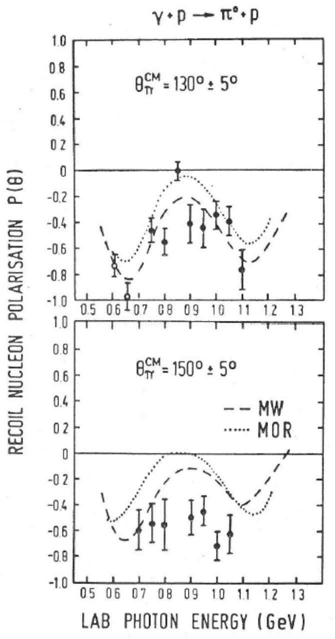
Nicolai Borisov, Alexander Neganov, Ivan Gorodnov, Anton Dolzhikov, Andrey Fedorov, Yury Usov

Recent activities of the Bonn Polarized Target Group

Motivation

universitätbonn

Opening (from recoil polarization to target polarization)



Recoil Nucleon Polarization

The polarization of the recoil particle is determined by measuring the left-right-asymmetry of the scattered particle. The analyzing power A depends on the particle energy and the scattering angle θ. Three different target-types have been used so far. Liquid helium is a good analyzer at lower energies and carbon and liquid hydrogen at high energies. The most important disadvantage of this method is the low efficiency. Only half a percent of the produced particles can be used for the analysis. A low counting rate and large statistical errors are typical. Another uncertainty is the influence of inelastic levels which mostly can not be separated. In spite of these difficulties this method was quite successful before polarized photons and targets were introduced in high energy photon physics.

[Althoff et al., Phys. Lett. 26B (1968)]

Why not using a polarized target? (W. Paul, spring 1968)

$$T = \frac{1}{f} \cdot \frac{1}{P_t} \cdot \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

- suitable target material
- high magnetic field
- low temperatures

1968 Althoff, Herr, Hoffmann, Peschel met Borghini and Mango at CERN

17.09.2015 5

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Motivation

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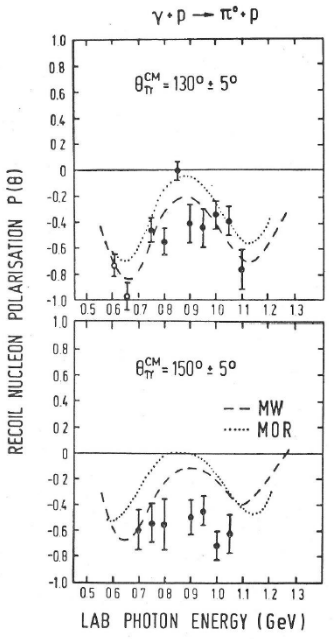

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Our goal since 55 years: maximizing

‘Figure of Merit’: $FoM = n_T\, f^2\, P^2$

Luminosity: $\mathcal{L} = I\, n_T$

by optimizing the target ingredients for

new and innovative polarization experiments

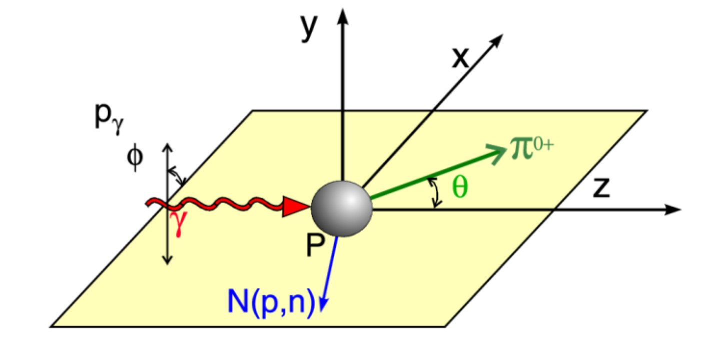
Recent activities of the Bonn Polarized Target Group

Motivation

Domain of the Bonn accelerator facility: real (tagged) photon physics

Structure mapping @ ELSA and Crystal Barrel detector

→ Double polarization experiments
→ Modell independent partial wave analysis
→ Complete experiment



$$\frac{d\sigma}{d\Omega}(\Theta,\phi) = \frac{d\sigma}{d\Omega}(\Theta)\cdot\Big[1 - p_\gamma^{lin}\Sigma(\Theta)\cos(2\phi)$$

$$+ p_t^x \cdot \left(-p_\gamma^{lin} H(\Theta)\sin(2\phi) + p_\gamma^{circ} F(\Theta)\right)$$

$$- p_t^y \cdot \left(+ p_\gamma^{lin} P(\Theta)\cos(2\phi) - T(\Theta)\right)$$

$$- p_t^z \cdot \left(- p_\gamma^{lin} G(\Theta)\sin(2\phi) + p_\gamma^{circ} E(\Theta)\right)\Big]$$

Photon		Target		
		x	y	z
unpolarized	σ	0	T	0
linear	(-Σ)	H	(-P)	(-G)
circularly	0	F	0	(-E)

Tagged (polarized) photon beam + large acceptance detection system
→ Horizontal frozen spin target: DNP@2.5T, 300mK → DT@30mK + internal ‘holding’ coil(s)

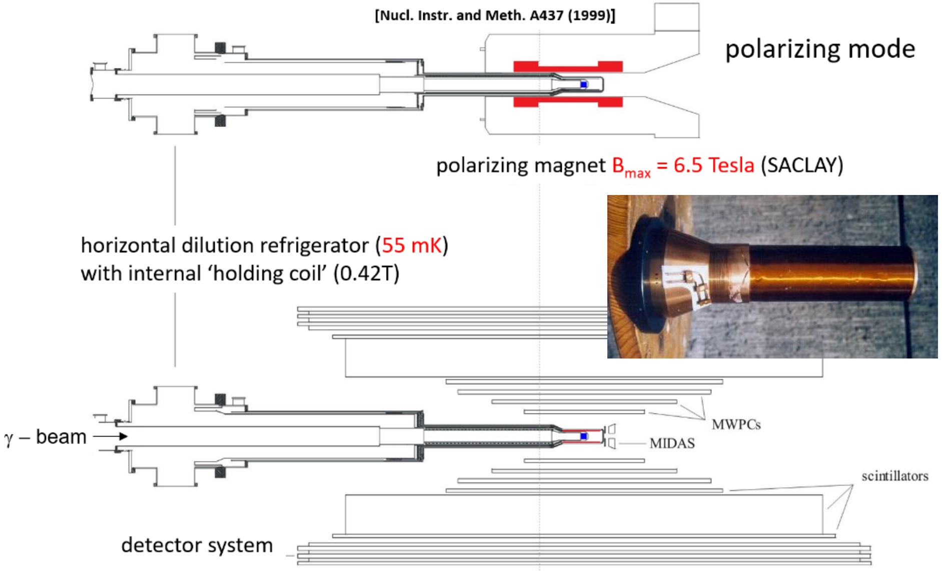
Recent activities of the Bonn Polarized Target Group

Motivation

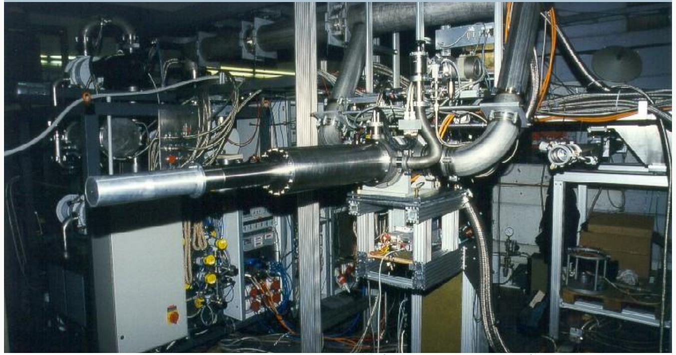
Experiments at ELSA and external facilities (1990 – 2014)

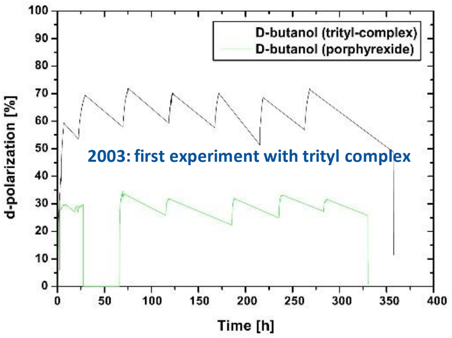
The largest BoFroST: horizontal dilution refrigerator + internal coil (1994-97) [→ Ω]

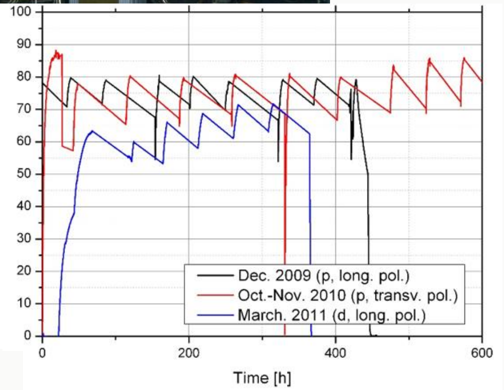
first polarized target for ‚4π – detection - systems‘



The official Set-up picture (1998 GDH @ Mami)







17.09.2015

2014: End of lifetime of the refrigerator due to a super leak

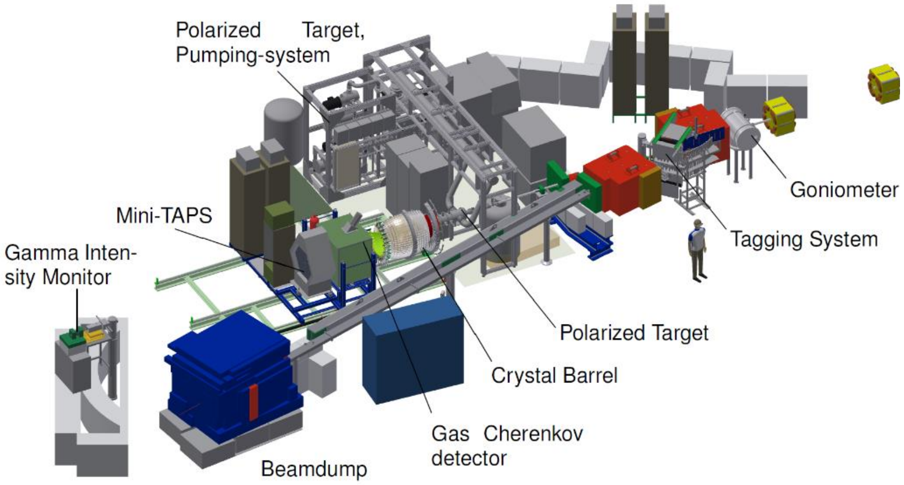
Recent activities of the Bonn Polarized Target Group

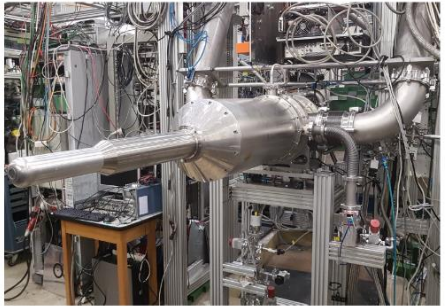
Recent experiments – Bonn/Mainz/Dubna set-up

CBELSA/TAPS horizontal frozen spin target and internal transverse or longitudinal holding magnet

CBELSA/TAPS

To continue the program in Bonn we have on loan the Mainz/Dubna refrigerator





Work in 2017/2018

- Merging the Dubna/Mainz and Bonn Systems.

February Transport of the cryostat, the ^3He-system, temperature measurement to Bonn.
- Connecting the vacuum system.
- Leak test at room temperature.
- Change Front part of the cryostat.
- Implement the Dubna/Mainz DAQ in the Bonn system.
- ...

May First cooling test, $T_{min} = 60$ mK.

September Test of all components, $T_{min} < 30$ mK $P_{max} \approx 45\,\%$.

December First measurement.

- In 2018, two data taking periods (one with proton, one with deuteron target)
- Dubna: Y. Usov, N. Borisov, I. Gorodnov et al. Mainz: A. Thomas et al. Bochum: G. Reicherz Bonn: S. Goertz, H. Dutz, S. Runkel et al

Recent experiments – Bonn/Mainz/Dubna set-up

CBELSA/TAPS horizontal frozen spin target and internal transverse or longitudinal holding magnet

Run-time polarized target (cold cryostat)

2017 (long. polarization) ~ 800h b.o.t.
- → max. pol: p_+ = 63 %, (butanol, TEMPO)
- → $\tau \sim$ 1300h (@ 0.4 T, I ~ 10^8/s), $\bar{P} \sim$ 56 %

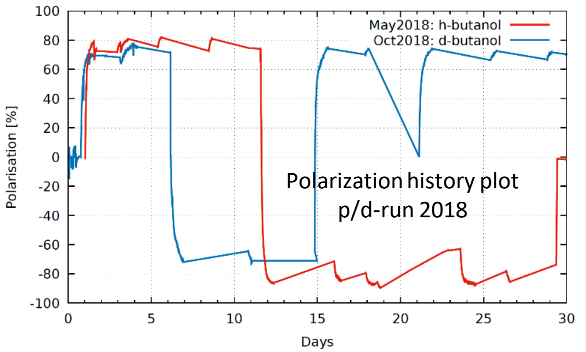
2018 (transv. polarization) ~ 1000h b.o.t.
- → max. pol: p_+ = 83 %, p_- = 87 % (butanol, porphyrexide)
- → $\tau \sim$ 500 h (@ 0.4 T, I ~ 10^8/s), $\bar{P} \sim$ 78 %

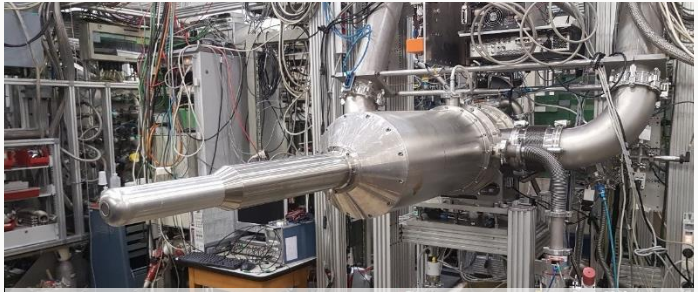
2018 (transv. polarization) ~ 800h b.o.t.
- → max. pol: p_+ = 76 %, p_- = 71 % (d-butanol, trityl)
- → $\tau \sim$ 700 h (@ 0.4 T, I ~ 10^8/s), $\bar{P} \sim$ 70 %

2019 (transv. polarization) ~ 500h b.o.t.
- → max. pol: p_+ = 84 %, p_- = 83 % (butanol, porphyrexide)
- → $\tau \sim$ 800 h (@ 0.4 T, I ~ 10^8/s), $\bar{P} \sim$ 77 %

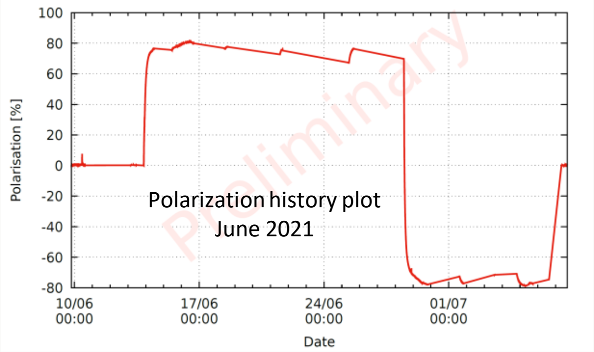
2021 (transv. polarization) ~ 440h b.o.t.
- → max. pol: p_+ = 78 %, p_- = 77 % (butanol, porphyrexide)
- → $\tau \sim$ 700 h (@ 0.4 T, I ~ 10^8/s), $\bar{P} \sim$ 74 %

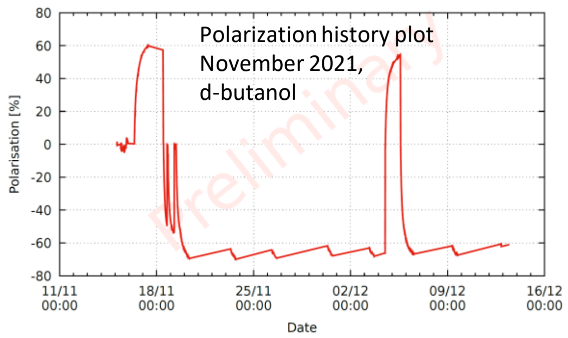
2021 (transv. polarization) ~ 500h b.o.t.
- → max. pol: p_+ = 63 %, p_- = 75 % (d-butanol, trityl)
- → $\tau \sim$ 500 h (@ 0.4 T, I ~ 10^8/s), $\bar{P} \sim$ 68 %





Collaborative target group: Bonn/Dubna/Mainz/Bochum (2015 – 2021)
'Mainz/Dubna frozen spin target' + internal 'holding' coil(s)





Recent activities of the Bonn Polarized Target Group

Recent experiments – Bonn/Mainz/Dubna set-up

CBELSA/TAPS horizontal frozen spin target and internal transverse or longitudinal holding magnet

Run-time polarized target (cold cryostat)

2017 (long. polarization) ~ 800h b.o.t.

→ ma

→ τ ~

2018 (tr

→ ma

→ τ ~

2018 (tr

→ ma

→ τ ~

2019 (tr

→ max. pol: p_+ = 84 %, p_- = 83 % (butanol, porphyrexide)

→ τ ~ 800 h (@ 0.4 T, I ~ 10^8/s), $\bar{P}$ ~ 77 %

2021 (transv. polarization) ~ 440h b.o.t.

→ max. pol: p_+ = 78 %, p_- = 77 % (butanol, porphyrexide)

→ τ ~ 700 h (@ 0.4 T, I ~ 10^8/s), $\bar{P}$ ~ 74 %

2021 (transv. polarization) ~ 500h b.o.t.

→ max. pol: p_+ = 63 %, p_- = 75 % (d-butanol, trityl)

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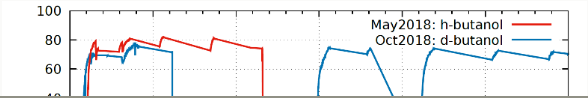
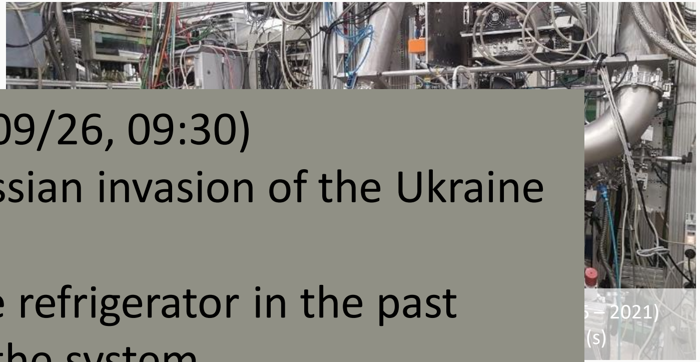




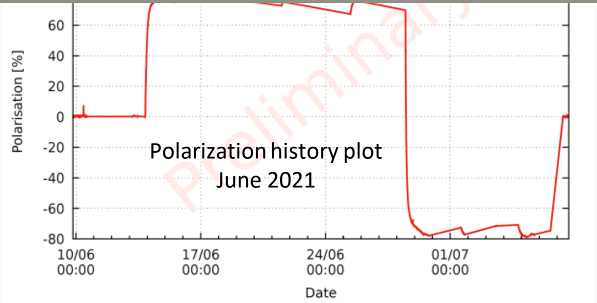
Recent results of the experiment: see talk Annika Thiel (09/26, 09:30)

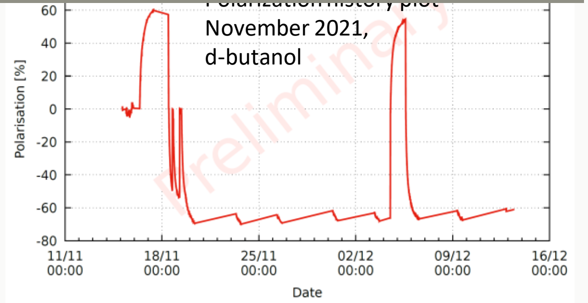
All activities stopped in March 2022, because of the Russian invasion of the Ukraine

→ No reliable planning was (is) possible

→ Since no one (all) of us has operated the refrigerator in the past

→ Nevertheless we decided to cool down the system





Recent activities of the Bonn Polarized Target Group

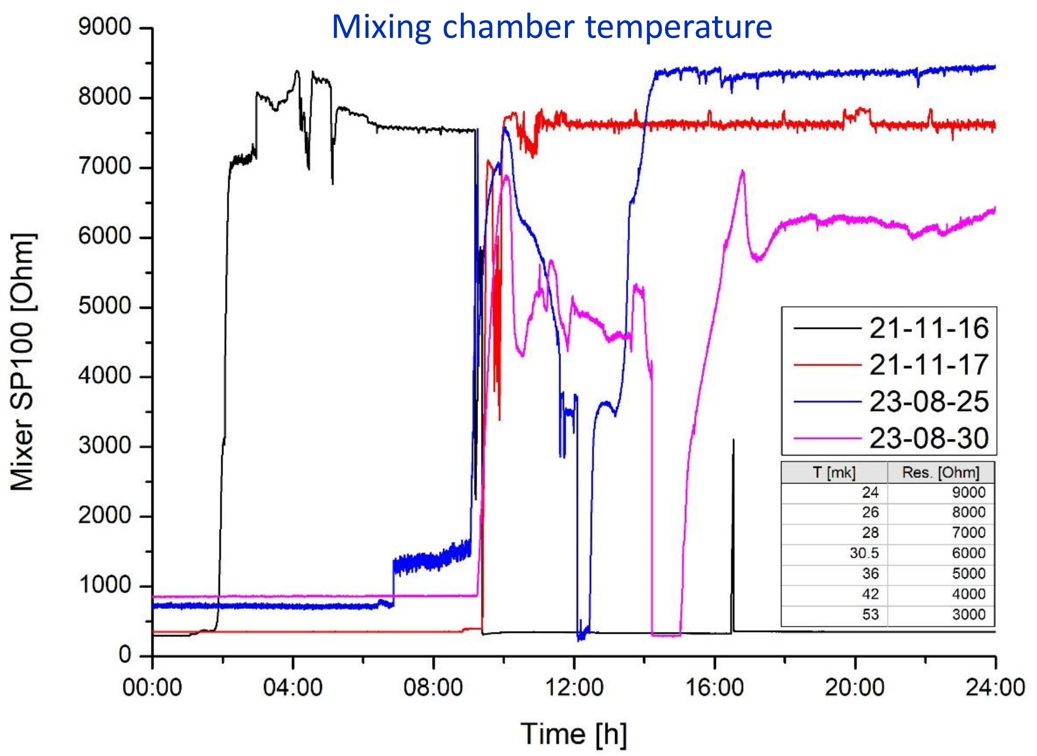
Recent experiments – Bonn/Mainz/Dubna set-up

After one year of learning and testing to cool down to < 26mK

→ Reliable cool down procedure
→ Stable and reproduceable parameters for DNP
→ Sufficient low temperatures (< 31 mK) for long relaxation times in frozen spin mode
→ Stability can (has to) be optimized

Next:

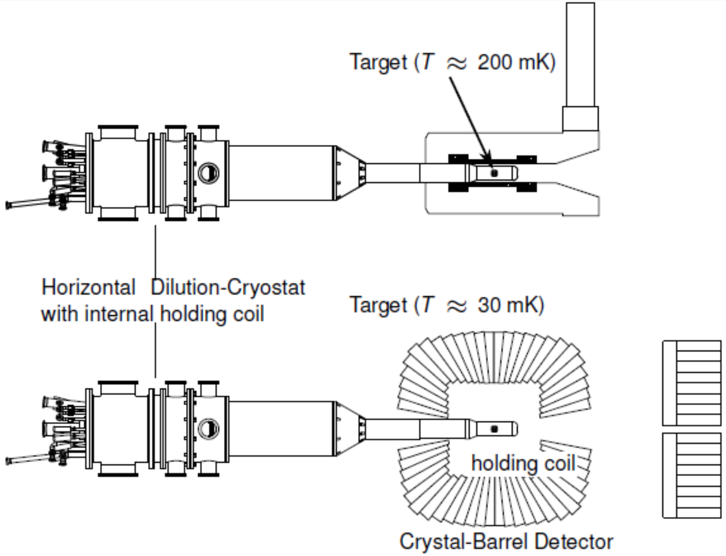
→ Being back in beam in October

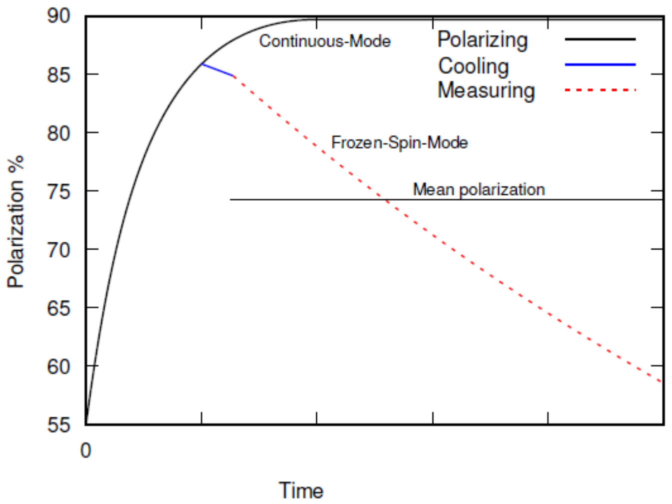


T [mk]	Res. [Ohm]
24	9000
26	8000
28	7000
30.5	6000
36	5000
42	4000
53	3000

High field, thin s.c. magnets for DNP (CryPTA:ScM)

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

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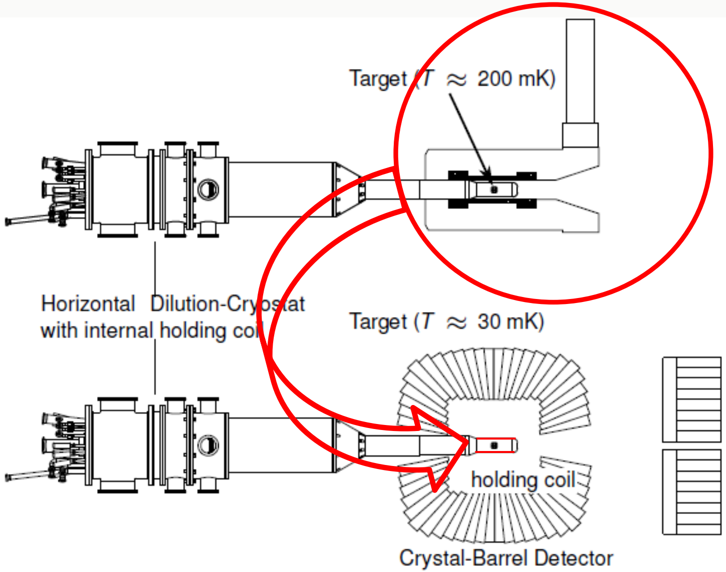
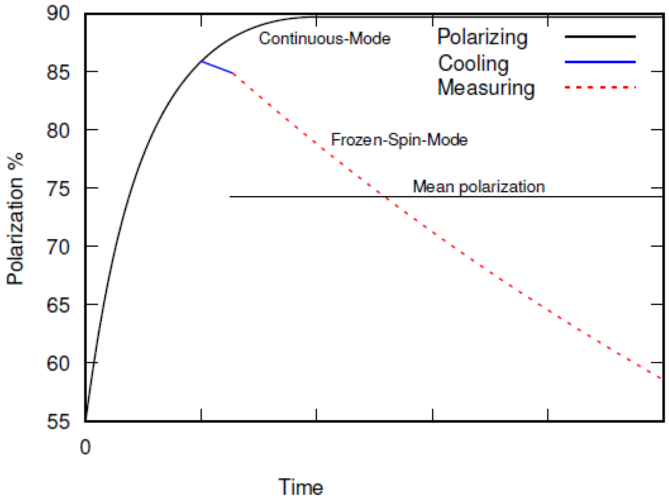
High field, thin s.c. magnets for DNP (CryPTA:ScM)

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





4π-Continuous-Mode Target

Combines the advantages of high polarisation and the large angular acceptance

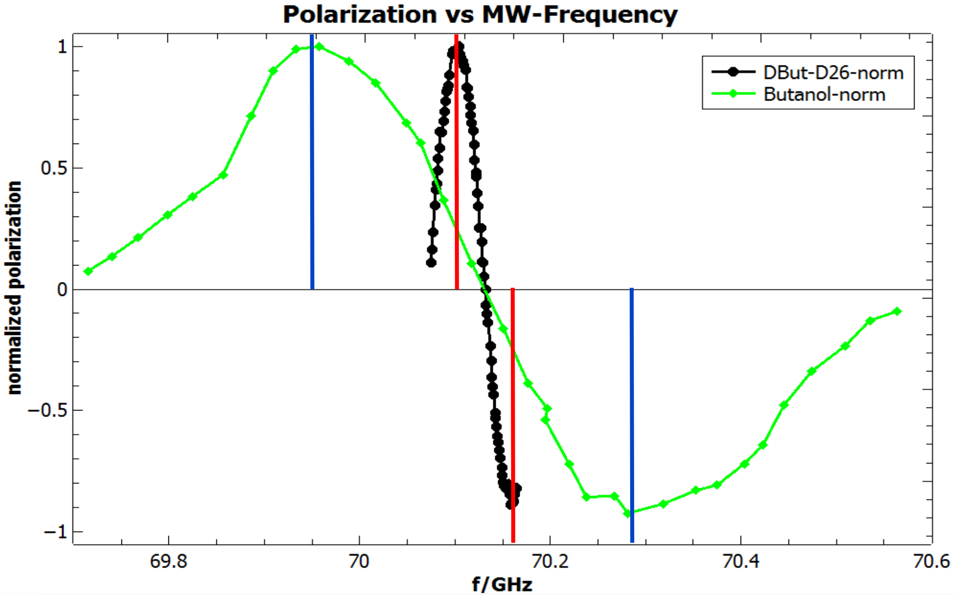
Key element: Internal magnet with the same magnetic properties as the external magnet

Recent activities of the Bonn Polarized Target Group

High field, thin s.c. magnets for DNP (CryPTA:ScM)

Polarized solid state target (DNP @ 0.2 – 0.3 K) (horizontal dilution refrigerator)

- high mag. longitudinal field for DNP (B_{DNP} ~ 2.5 T)
- good homogeneity for DNP $\Delta B/B \leq 10^{-4}$
- thin as possible (like holding coil) < 2mm
- passively cooled



4π – continuous mode target (what do we gain?):

- good angular acceptance (~ 4π)
- high luminosity $L \sim 10^{33}/cm^2s^{-1}$ ($N \approx 10^{10}/s$) [$N < 10^8/s$]
- high mean polarization ($P_p \sim 90\%$, $P_d \sim 85\%$) [$P_P \sim 75\%$]
- good beam time efficiency

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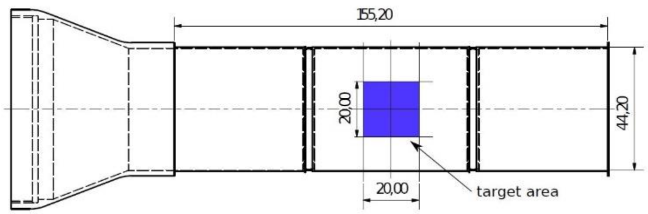
High field, thin s.c. magnets for DNP (CryPTA:ScM)

Internal polarisation magnet - Field calculation



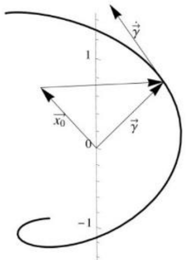
Biot-Savart-Law:

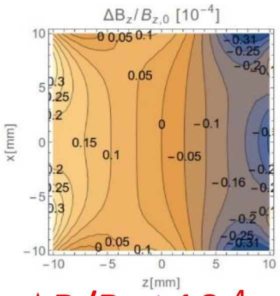
$$\vec{B}(\vec{x}_0) = \frac{\mu_0}{4\pi} I \int \frac{(\vec{\gamma}(t) - \vec{x}_0) \times \frac{\dot{\vec{\gamma}}(t)}{|\dot{\vec{\gamma}}(t)|}}{|(\vec{\gamma}(t) - \vec{x}_0)|^3} \mathrm{d}t$$

Loop parametrization:

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

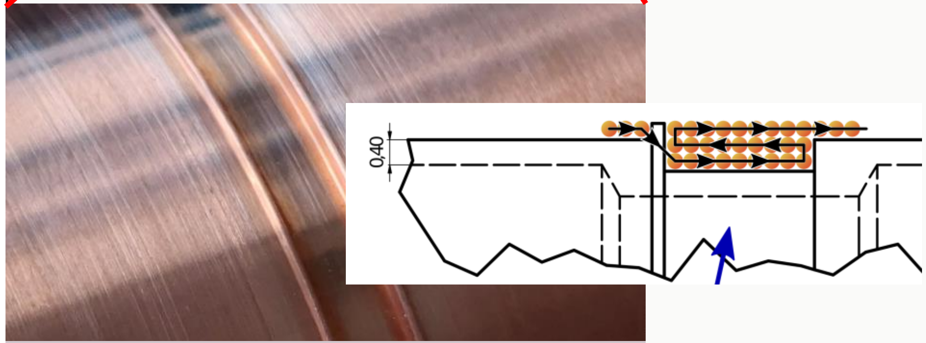
r: radius of each loop
$n \cdot d$: loop position
d: effective distance between 2 wires





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

Coil carrier (cupper core)



Inverse notched coil

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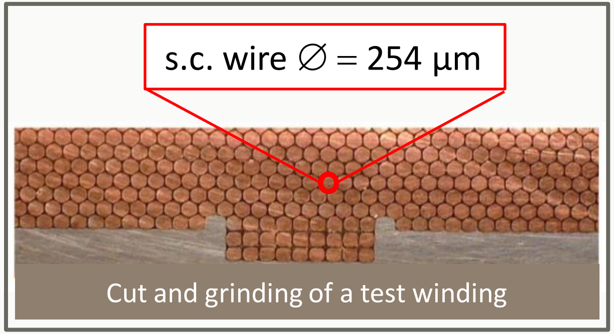
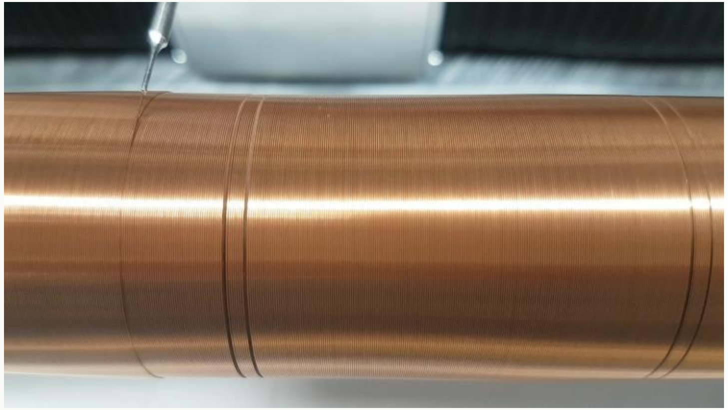
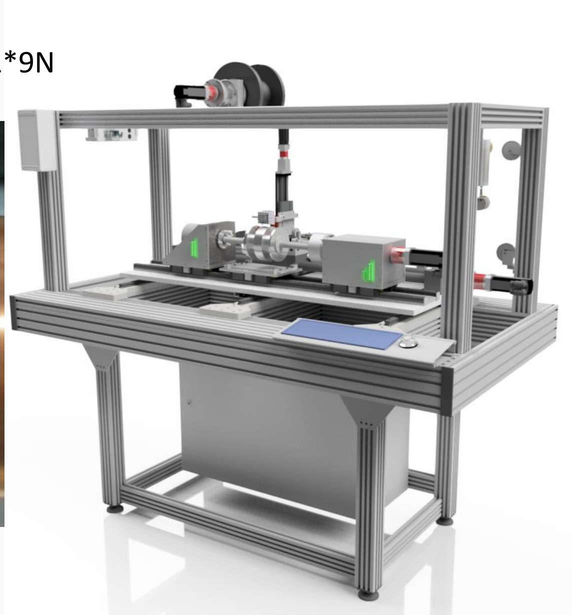
High field, thin s.c. magnets for DNP (CryPTA:ScM)

- Small superconducting magnet (solenoid 150 mm x ∅45 mm x WT 1.8 mm), high field (B=2.5T) and high homogeneity ($\Delta B/B \leq 10^{-4}$, 20 x ∅20 mm)
- Wrap thin s.c. wire (∅254µm) with high precision (orthocyclic, wet winding), 6 layers á 590N + 2*9N
- Displacement ≤ 2.5µm



Cut and grinding of a test winding



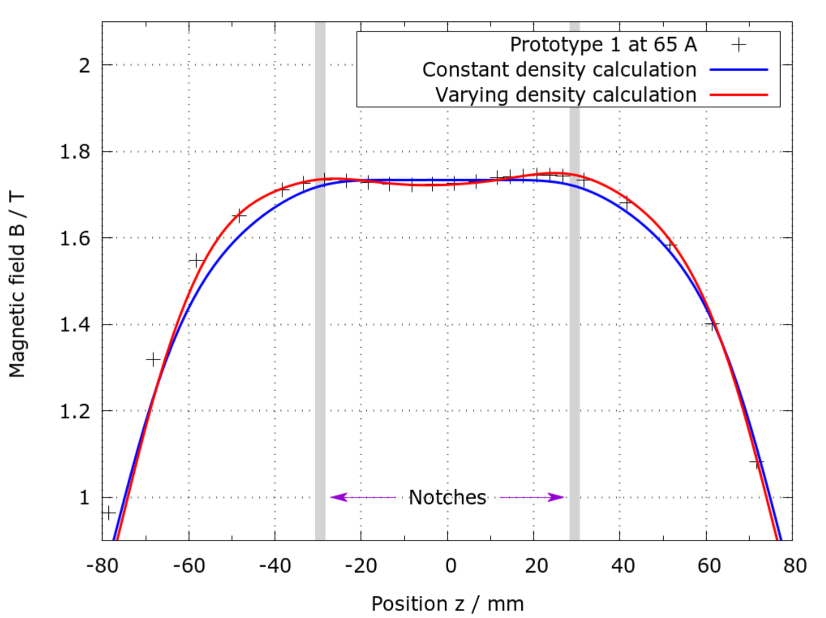


- Not commercially available
- Custom made high precision winding machine fulfill the requirements (MS63, EU JRA10:CryPTA)
- Co financed by a collaborative SME research project (BMWI, ZIM) with CryoVac (Germany) and Physics Institute University Bonn

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

High field, thin s.c. magnets for DNP (CryPTA:ScM)

Why is it so important to do a high precision winding



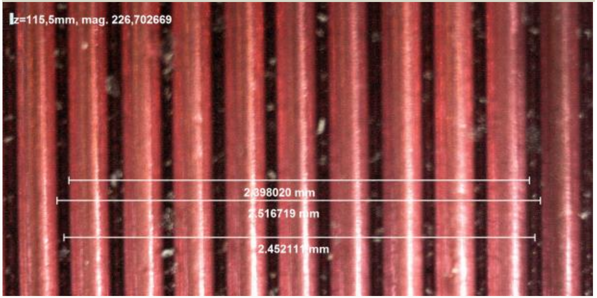
Prototype 1

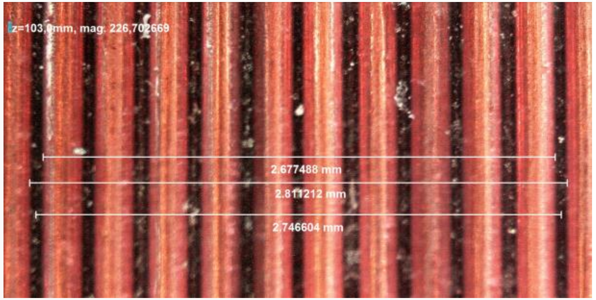
Recent activities of the Bonn Polarized Target Group

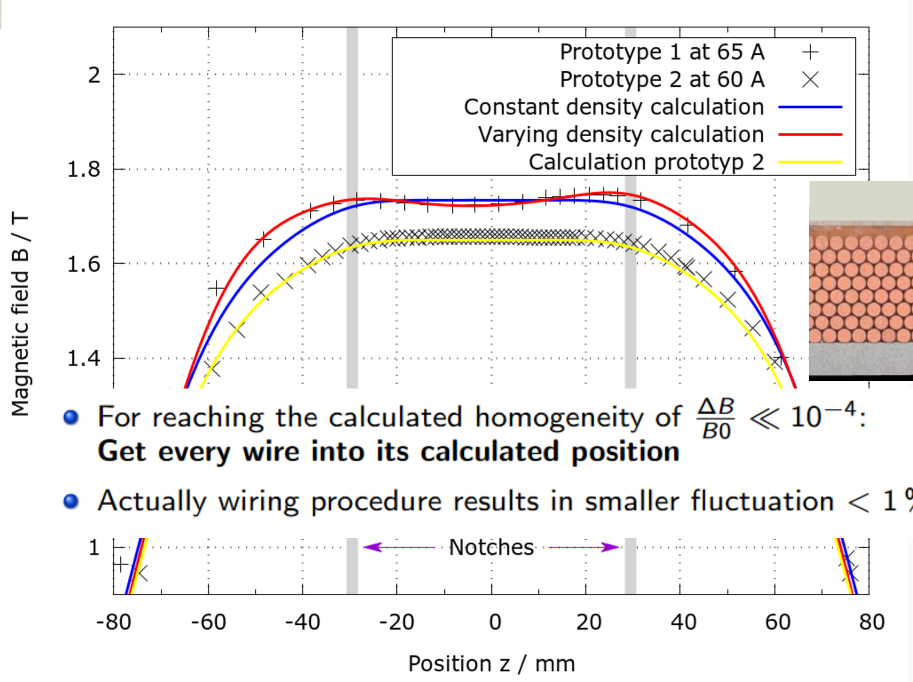
High field, thin s.c. magnets for DNP (CryPTA:ScM)

Why is it so important to do a high precision winding

Prototype 1

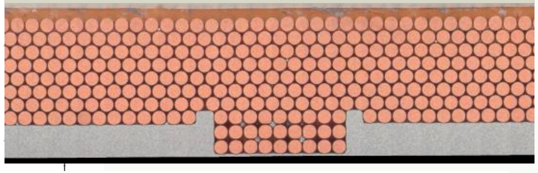






- For reaching the calculated homogeneity of $\frac{\Delta B}{B0} \ll 10^{-4}$: **Get every wire into its calculated position**
- Actually wiring procedure results in smaller fluctuation $< 1\,\%$ of the effective distance

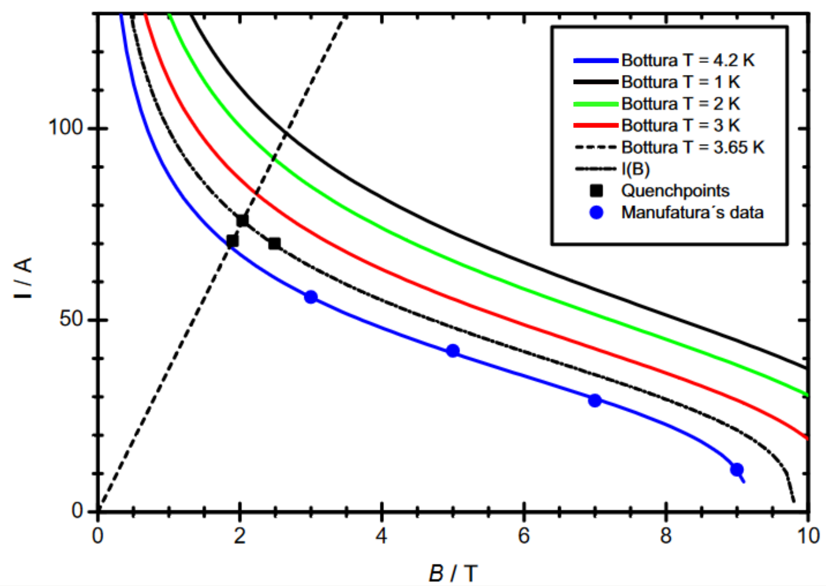
Prototype 2



High field, thin s.c. magnets for DNP (CryPTA:ScM)

Why is it so important to run @ 1K

Estimation[1] and measurement of the critical current $I_c(B)$

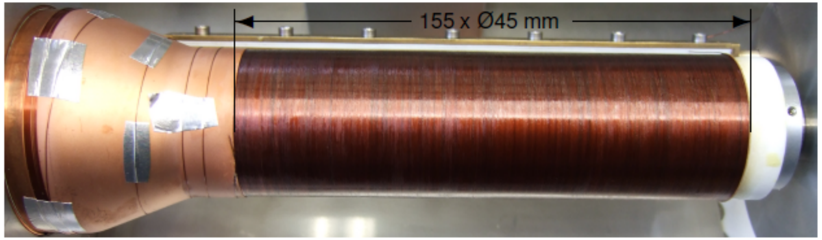


[1] L. Bottura, *A practical fit for the critical surface of NbTi*

	T	B_c	I_c
Bottura	4.2 K	1.86 T	69 A
Bottura	1 K	2.65 T	99 A
Bottura	1 K	2.5 T	101 A
Experimental	4.2 K	1.9 T	70.7 A
Experimental	∼3.5 K	2 T	74 A
Experimental	∼3.5 K	2.5 T[a]	70 A

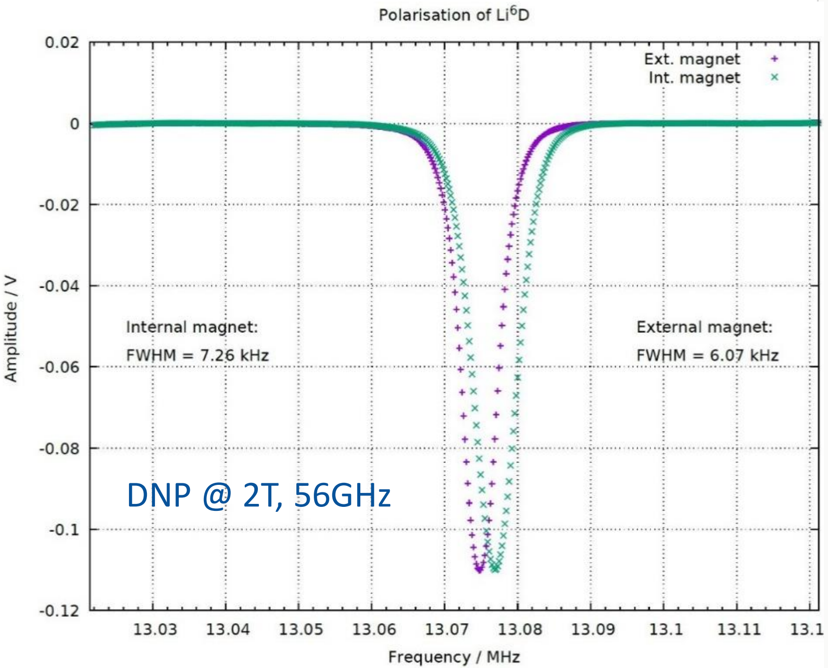
[a] produced with an additional external field

High field, thin s.c. magnets for DNP (CryPTA:ScM)



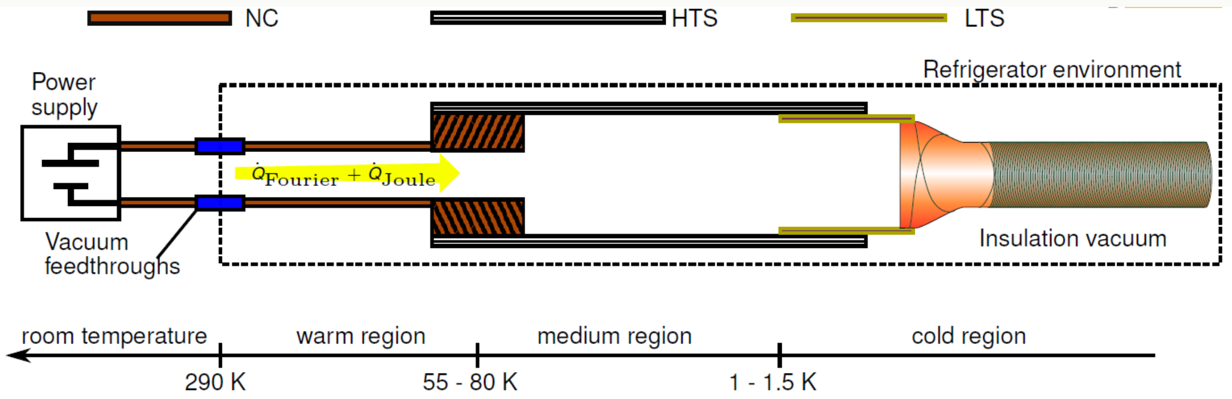
- As thin as possible
  → Overall thinkness ≤ 2 mm
  → Passively cooled
- Internal magnet with $B_0 = 2.5\,\mathrm{T}$ @ 90 A @ 1 K
- $\frac{\Delta B}{B_0} \ll 10^{-4}$ @ $1/40\,V_{\mathrm{overall}}$
- Building process by wet wiring (with epoxy)
- Precondiction: Homogeneous (orthocylcic) wire pattern!

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



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

Hybrid current leads for internal DNP magnets (CryPTA:ScM)



Problems with normal conducting (NC) current leads:

- Large heat load on the cold region due to Fourier's law
- Additional heat load due to Joule heating when energising the magnet
- Cooling of magnet and current leads only by conduction
- Large heat load can lead to a quench of the low temperature superconductor (LTS) / magnet
- There exist a minimum heat flow with $\dot{Q}_{\mathrm{Fourier}} = 0$

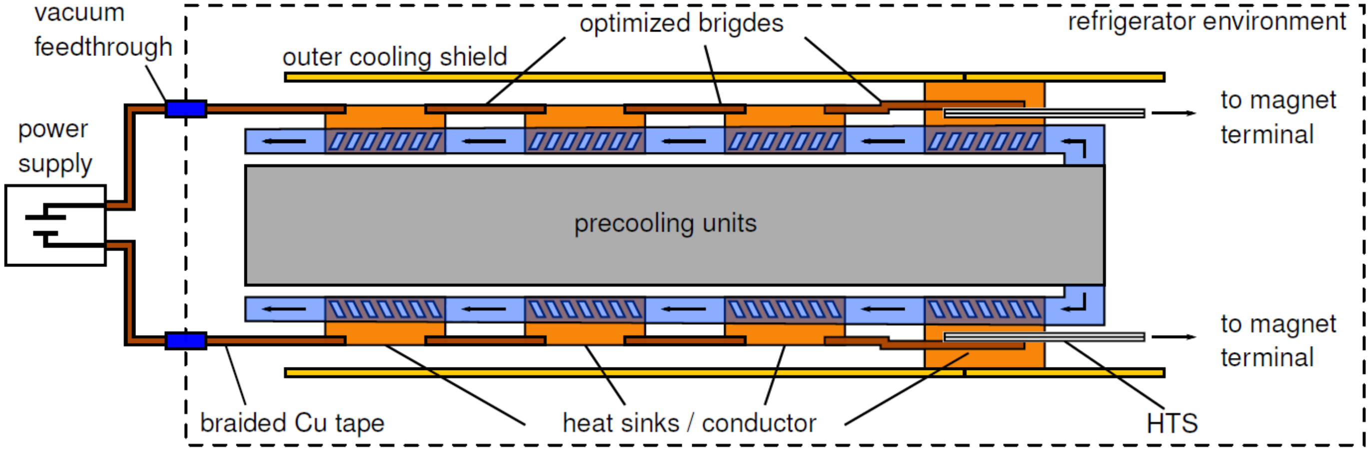
Solution for the cold region:

- Thermal decoupling between warm and cold region/LTS
- Can be archived by using a high temperature superconductor (HTS, here: BSCCO)
- But nontheless: Heat load must be minimised up to the NC-HTS junction for not quenching the HTS

R. McFee, „Optimum input Leads for Cryogenic Apparatus", Rev. Sci. Instr., Vol 30, AIP 1959

Recent activities of the Bonn Polarized Target Group

Hybrid current leads for internal DNP magnets (CryPTA:ScM)



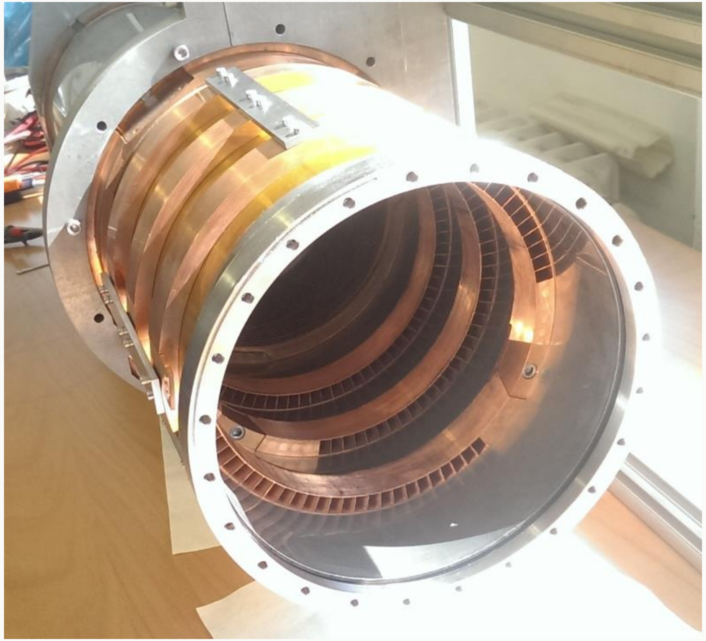
R. McFee, „Optimum input Leads for Cryogenic Apparatus", Rev. Sci. Instr., Vol 30, AIP 1959

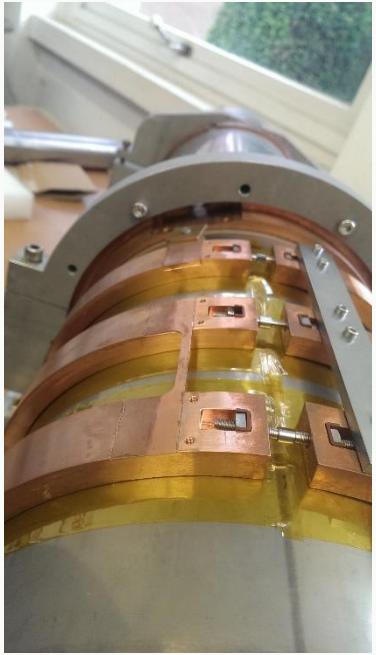
- Braided flexible copper tape ($A = 25\,\text{mm}^2$, $L = 1.4\,\text{m}$)
- 3 (turbine) heat sinks / copper-(half) rings for each terminal ($A = 260\,\text{mm}^2$)
- Ring-conductorss are connected by bridges ($A = 1.5\,\text{mm}^2$, $L = 4\,\text{cm}$))
- Bridges are designed for minimising thermal conduction from one sink to the next when energised
- Thermal decoupling between the heat sinks (McFee)

Recent activities of the Bonn Polarized Target Group

Hybrid current leads for internal DNP magnets (CryPTA:ScM)

minimum heat load NC – HTSC junction for the next new dilution refrigerator



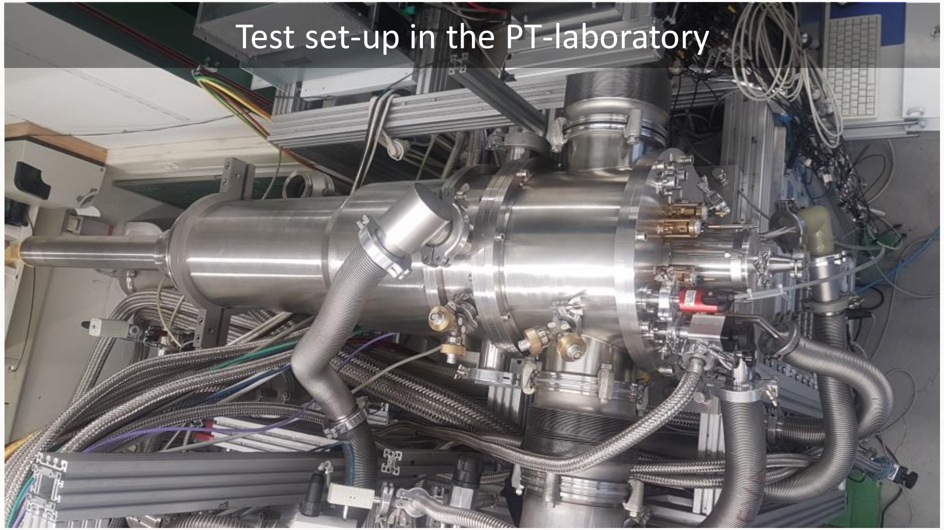


Test is still pending …

Recent activities of the Bonn Polarized Target Group

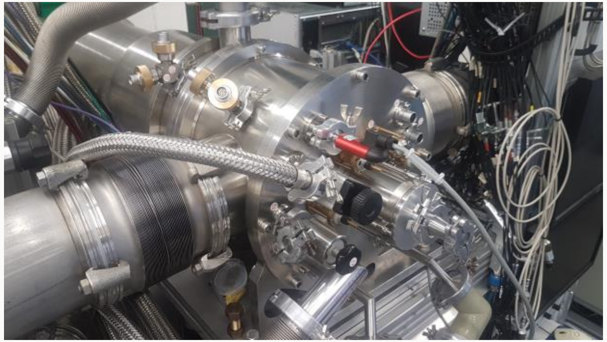
High field, thin s.c. magnets for DNP (CryPTA:ScM)

New horizontal dilution refrigerator for polarization experiments with real photons @ Crystal Barrel detector @ ELSA build by cryogenic department of JINR (Dubna)



Central beam line
Target insert for fast and easy target exchange
Designed for various magnet configurations

→ $T_{min} < 30$ mK , TDNP ~ 250 mK
→ I_{max} ~ 40 A



→ Delivered fall 2020, assembled and first 1K tests in summer 2021, commissioning was planned for spring 2022
→ First polarization experiment @ ELSA planned using the combined sc. holding coil configuration
→ Foreseen for pol. experiments using active polarized target technology (CryPTA:APT)

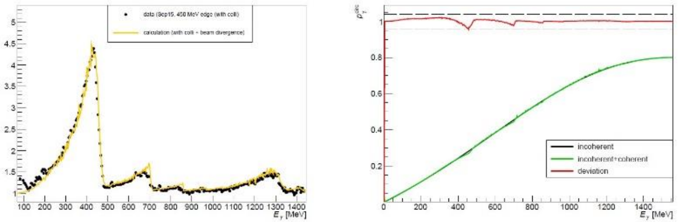
Recent activities of the Bonn Polarized Target Group

combined thin s.c. magnets for frozen spin mode (CryPTA:ScM)

New experimental approach in double polarized photo production experiments:
Longitudinal polarized electrons on a diamond radiator [F. Afzal et al., submitted to PRL. 2023]

Circular polarization degree

- Deviation between (coherent+incoherent) and incoherent below 4%
- In very good agreement with experimental data!



F. Afzal et al., submitted to PRL

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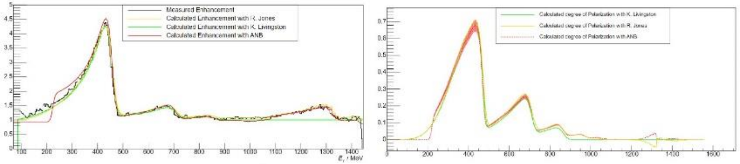
Linear polarization degree - Comparisons between different experiments

- Linear polarization degree does not depend on electron polarization degree
- Systematic checks between different experiments using different methods:
  → K. Livingston's method (A2, CLAS), ANB (CBELSA/TAPS), R. Jones's code (GlueX)



photon		target			recoil nucleon			target and recoil			
		x	y	z	-	-	-	x	z	x	z
		-	-	-	x'	y'	z'	x'	x'	z'	z'
-	σ_0	-	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	$C_{x'}$	-	$C_{z'}$	-	-	-	-

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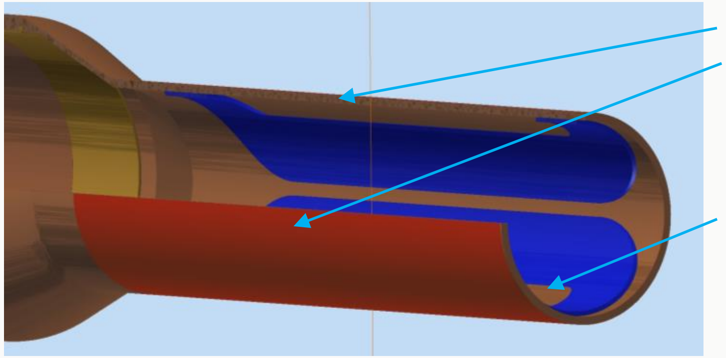
- Advantage of measuring with elliptically polarized photons:
  - Simultaneous measurement of several polarization observables possible
  - Self-consistent set of observables
  - Higher photon flux through coherent edges → high precision data is obtained faster
- Need dedicated tests with elliptically polarized photons at CBELSA/TAPS

Lets rotate the target polarization and measure them all

Recent activities of the Bonn Polarized Target Group

combined thin s.c. magnets for frozen spin mode (CryPTA:ScM)

Combined longitudinal and transverse holding coil for the new dilution refrigerator for a variable polarization direction in plane
Solenoid + ‘race-track’



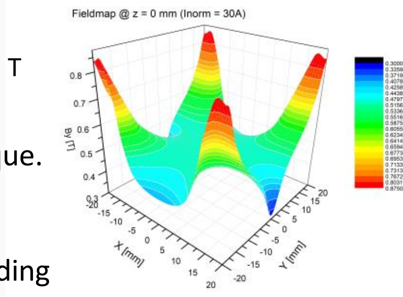
Cu-support (cooling)

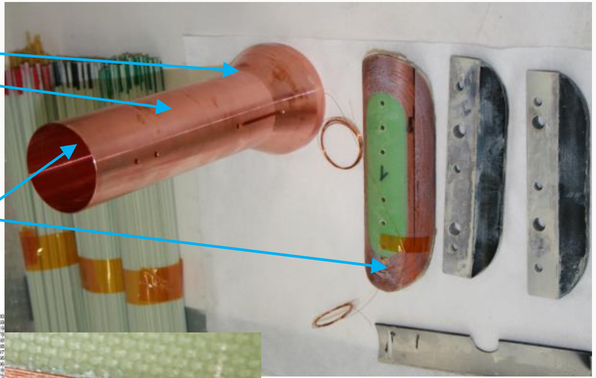
Longitudinal field: solenoid (outside)

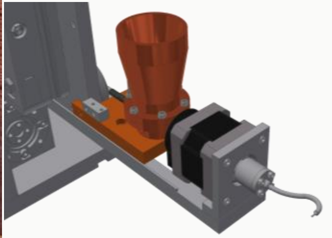
→ 4 layers á N590
→ I_{max} ~ 32 A
→ B_{max} ~ 0.52 T

Transverse field: race track like dipole (inside)

→ 2 x N525
→ I_{max} ~ 30 A
→ B_{max} ~ 0.50 T







- Precision wet winding of a solenoid is a well established technique.
- Tasks to be done for the race-track (V. Lagerquist)
  - Optimize the thickness and shape of the dipoles
  - Wed winding of the dipole package or layer by layer winding and stack them

Or picking up an ‘old’ challenging idea: double helix configuration

Recent activities of the Bonn Polarized Target Group

Tilted coil configuration for frozen spin mode (CryPTA:ScM)

Tilted coil configuration (TCC) for the new dilution refrigerator for a variable polarization direction in plane

- independent tilted coil (solenoid N) wound with α to z-axis

$$B_z = B_S \sin\alpha \qquad B_y = B_S \cos\alpha \qquad B_S \sim \frac{NI}{l}$$

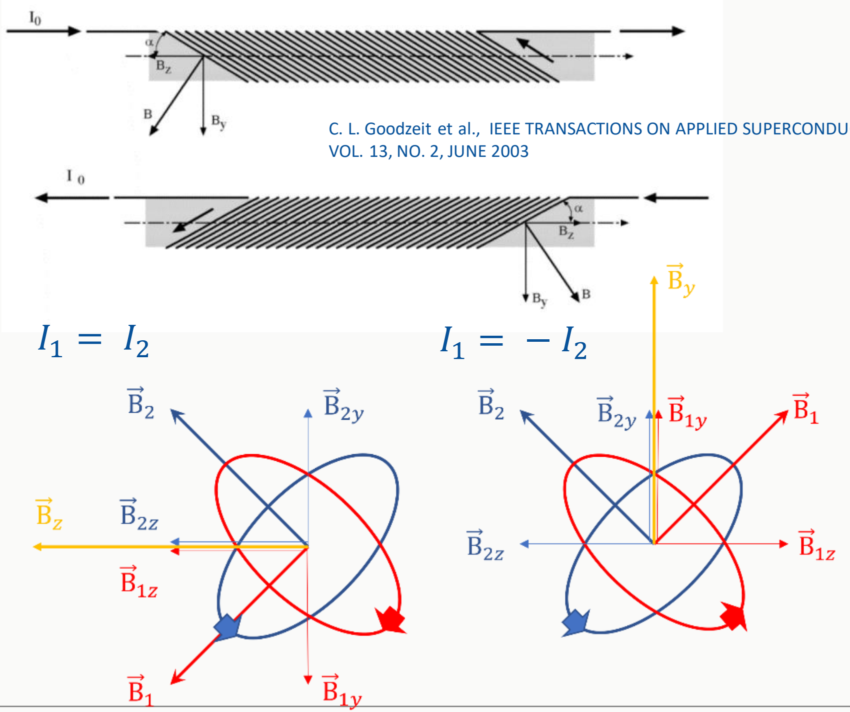
- For α = 45°, symmetric case, 2 independent coils
- 'transverse case' : $I_1 = -I_2$

$$B_y = \sqrt{2} * B_S \qquad B_z = 0$$

- 'longituinal case' : $I_1 = I_2$

$$B_y = 0 \qquad B_z = \sqrt{2} * B_S$$

- In between: any field direction possible $B_{min} = B_S$



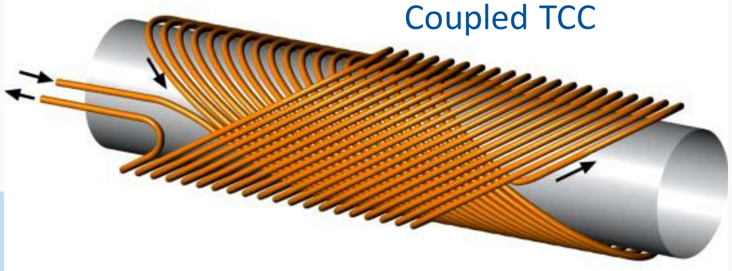
C. L. Goodzeit et al., IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 13, NO. 2, JUNE 2003

Tilted coil configuration for frozen spin mode (CryPTA:ScM)

Tilted coil configuration (TCC) for the new dilution refrigerator for a variable polarization direction in plane

TCC Perfect solution for polarized target experiments:

- homogeneous long. or transv. magnetic field
- adjustable field direction
- homogeneous mass distribution around the target



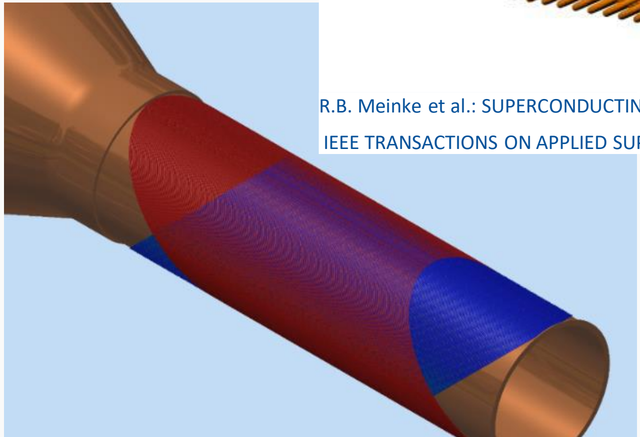
R.B. Meinke et al.: SUPERCONDUCTING DOUBLE-HELIX ACCELERATOR MAGNETS, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 13, NO. 2, JUNE 2003

For a required B in a polarized target:

- TCC needs to be longer than a standard solenoid
- TCC needs more windings/layers or current

The real challenge:

- Winding a 250 µm wire to a tilted coil



Our next task:

- Full simulation needed (B, I, N, n_L, s.c.)
- Wind a demonstrator coil (one layer)

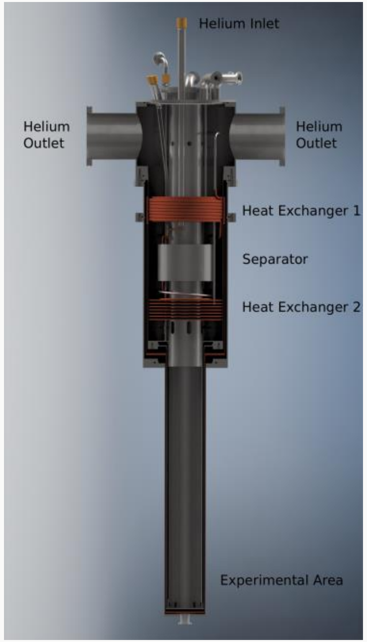
Recent activities of the Bonn Polarized Target Group

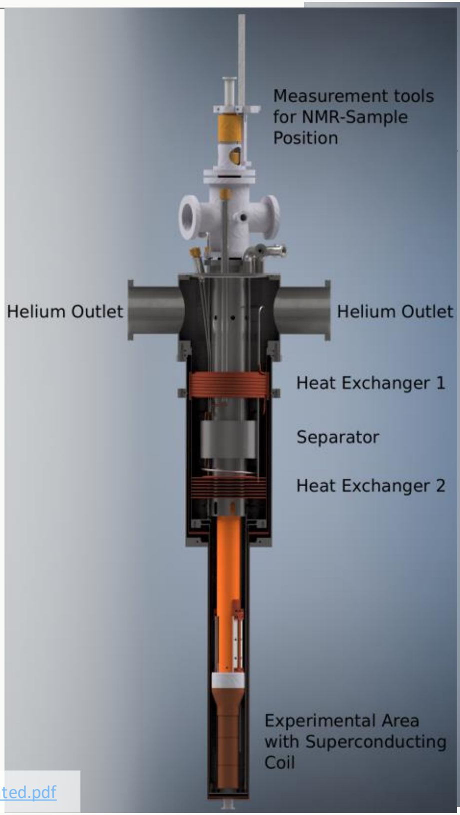
1K magnet test facility (CryPTA:ScM)

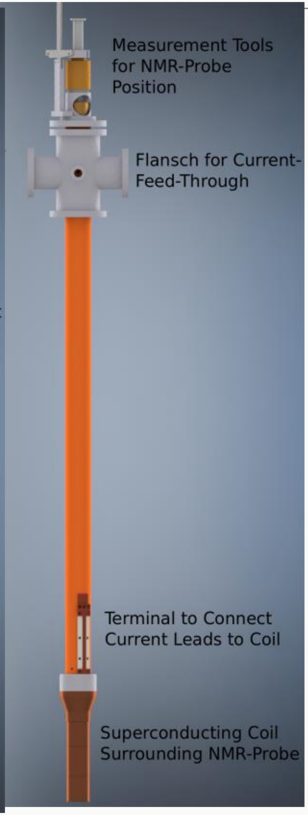
- → Small superconducting magnet designed and build for DNP in a dilution refrigerator
  (magnet operating parameters: 90A @ 1K)
- → For test measurements (performance tests) of the magnets a simple 1K test facility is required

- → New ^{4}He evaporation refrigerator is under construction
  - → Fits into the external high field DNP-magnet (B_{max} = 6.5T)
  - → Variable temperature range (1K – 70K)
  - → Large low temperature volume (500 mm x ∅75 mm, 2.2l)
  - → Flexible and open access via insert tube

- → (already) available magnet test insert
  - → Current leads (I_{max} =100A)
  - → Field measurement (mapping) by pulsed-, cw-NMR, Hall-probe
  - → Equipped for DNP (50 – 140 GHz)







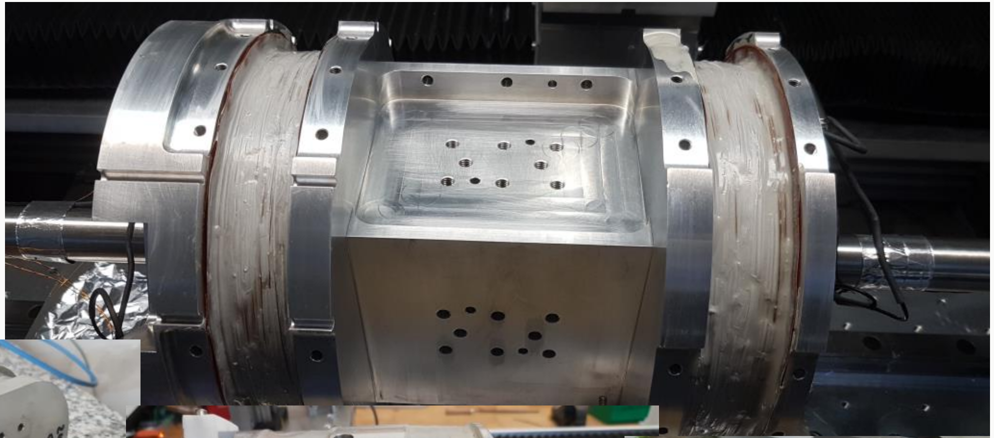
^{4}He evaporation refrigerator for magnet tests: https://www.polarisiertes-target.physik.uni-bonn.de/files/InternalReportEinNeuer4HeKryostat_translated.pdf

Recent activities of the Bonn Polarized Target Group

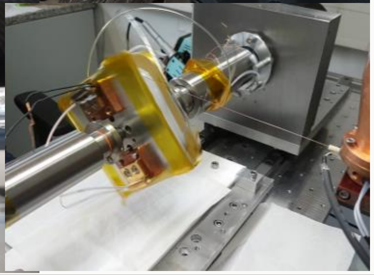
Outreach / Technology transfer to SME

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



Recent activities of the Bonn Polarized Target Group

Conclusion

For 55 years, the polarized solid-state target has remained the first choice for (double) polarization experiments with real photons in Bonn (and elsewhere)

Our focus has always been to improve the polarized target performance:

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

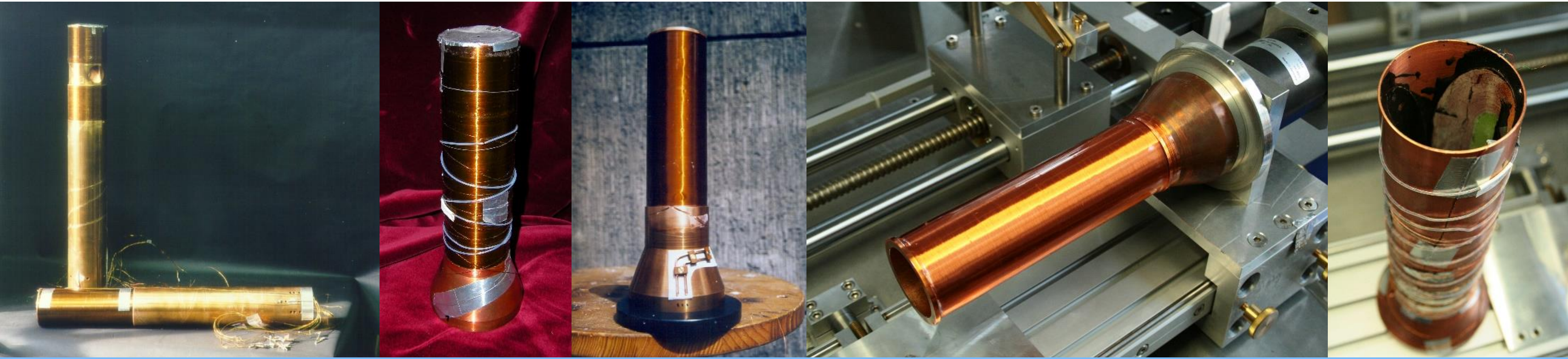
this included

- new target materials: ND_3, ^{6}LiD, Trityl-doped deuterated alcohols
- new refrigerator and magnet systems: internal holding and polarizing magnets

With the new refrigerator and the cooperation with
Mainz/Dubna/Bochum PT-groups
we hope to realize the
'4π continuous mode target concept'
for real photon double polarization experiments at ELSA and MAMI (soon).

Recent activities of the Bonn Polarized Target Group

Thanks



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