Annual Meeting

JRA10:Cryogenic Polarized Target Application

Hartmut Dutz
Physikalisches Institut, Universität Bonn

Plan of the presentation

1. Progress achieved by the WP during the last year
   i. Recommissioning of the Dubna-Mainz dilution refrigerator (CryPTA:ScM, CryPTA:APT)
   ii. Design of a combined holding coil system (CryPTA:ScM)
   iii. Improved light efficiency read out (CryPTA:APT)
2. Important highlights of the performed work
3. Plans and remaining tasks until the end of the project (31 July 2024)
   i. Tilted coil configuration for frozen spin mode (CryPTA:ScM)
4. Conclusions

JRA10:CryPTA

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, H. Dutz, St. Goertz, S. Heinz, A. Klotzbücher, M. Korolija,
O. Kostikov, V. Lagerquist, G. Reicherz, A. Thomas

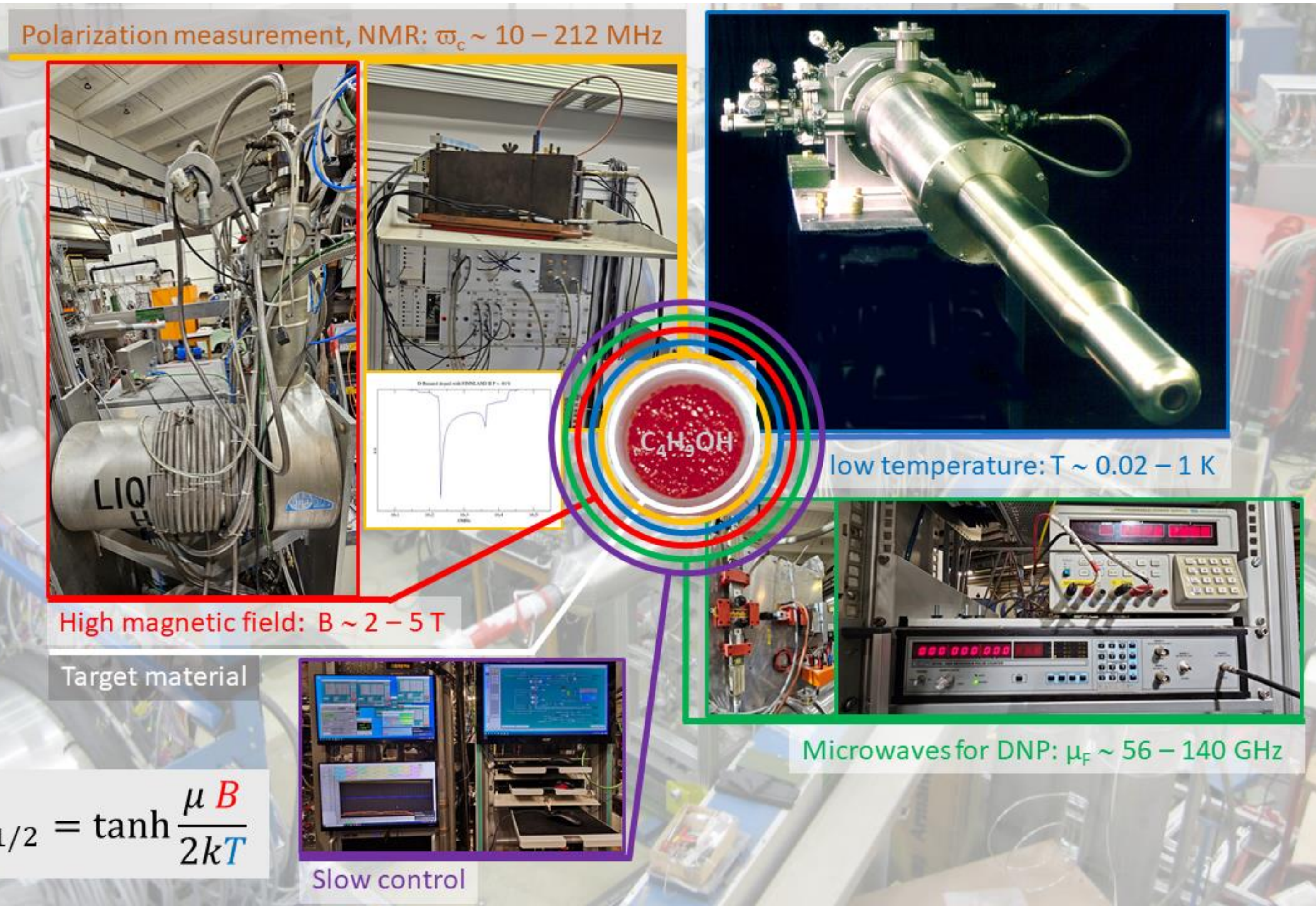
→ Develop new polarized target technologies for future polarization experiments

JRA10:CryPTA

PT-Ingrediencies and responsibilities

RUB
- NMR
- Target material preparation and research

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



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

JINR Dubna, MAMI
- Low temperature
- Refrigerator design and operation

MAMI (Mainzer Mikrotron)
- Microwaves
- Active target material preparation and research

Recommissioning of the Dubna-Mainz dilution refrigerator

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

Run-time polarized target (cold cryostat)

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

→ p_p = 63 %, (butanol, TEMPO), τ ~ 1300h

2018 (transv. polarization) ~ 1000h b.o.t.

→ p_p = 87 %, τ ~ 500 h

2018 (transv. polarization) ~ 800h b.o.t.

→ p_d = 76 %, τ ~ 700 h

2019 (transv. polarization) ~ 500h b.o.t.

→ p_p = 84 %, τ ~ 800 h

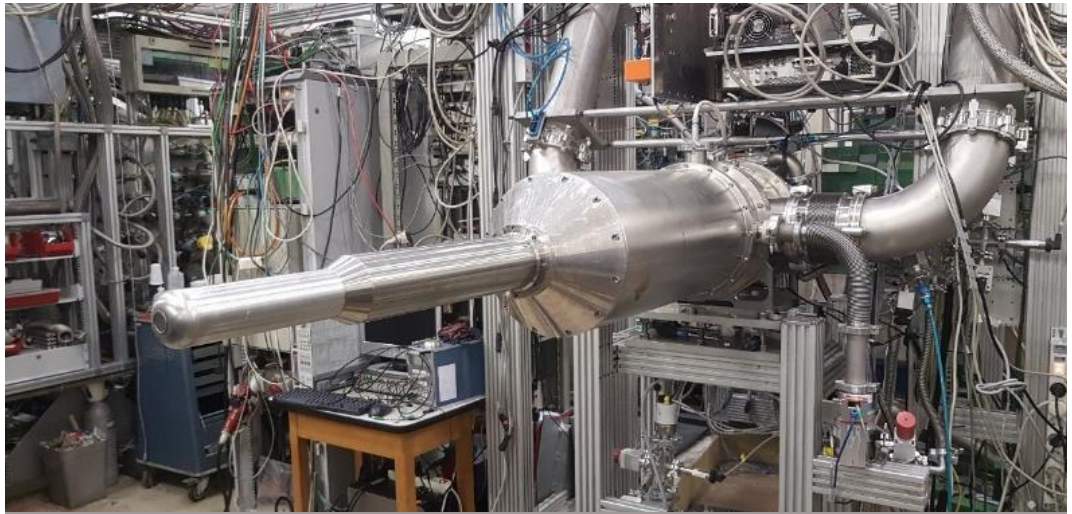
2021 (transv. polarization) ~ 440h b.o.t.

→ p_p = 78 %, τ ~ 700 h

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

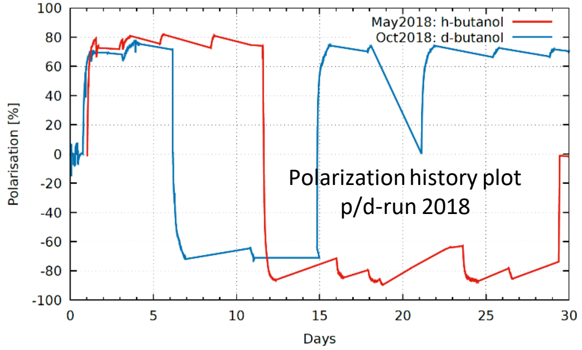
→ p_d = 75 %, τ ~ 500 h

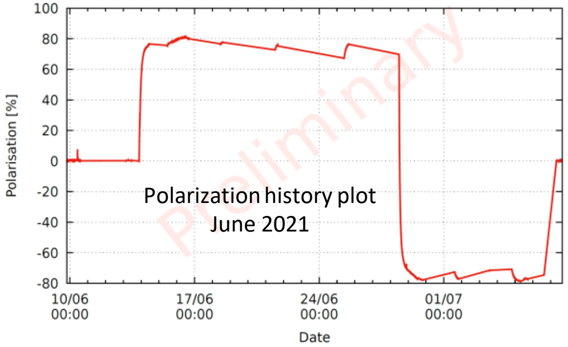
Five years of successful operation on beam

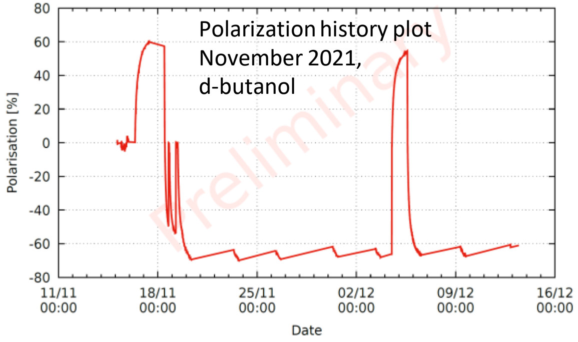


Collaborative target group: Bonn/Dubna/Mainz/Bochum (2015 – 2021)
'Mainz/Dubna frozen spin target' + internal 'holding' coil(s)

Dubna/Mainz dilution refrigerator is the working horse for the PT projects

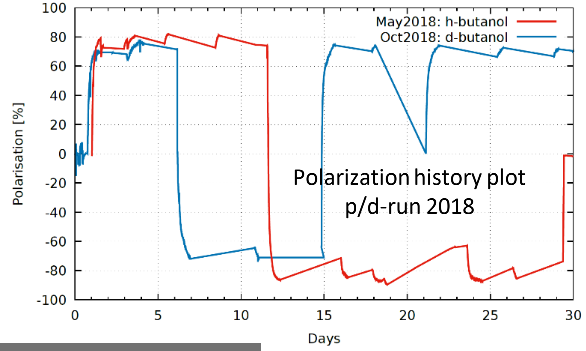






Recommissioning of the Dubna-Mainz dilution refrigerator

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



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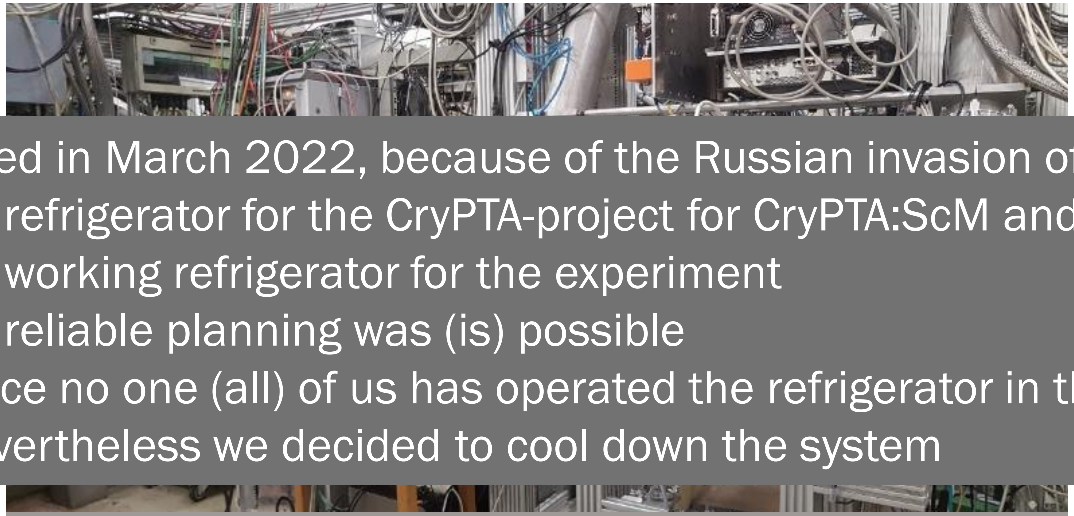


All activities stopped in March 2022, because of the Russian invasion of the Ukraine

→ No refrigerator for the CryPTA-project for CryPTA:ScM and CryPTA:APT

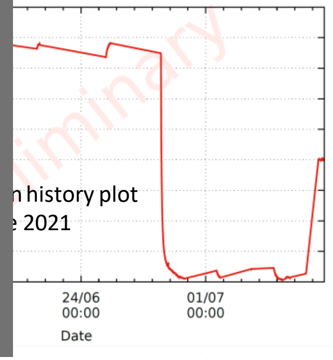
→ No working refrigerator for the experiment

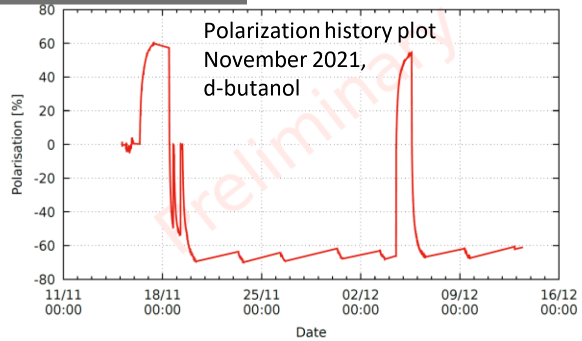
→ No reliable planning was (is) possible

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

→ Nevertheless we decided to cool down the system

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





Dubna/Mainz dilution refrigerator is the working horse for the PT projects

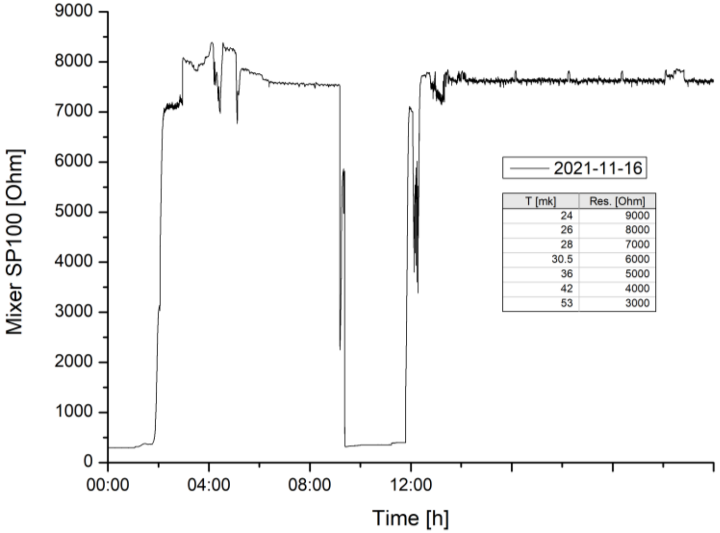
Recommissioning of the Dubna-Mainz dilution refrigerator

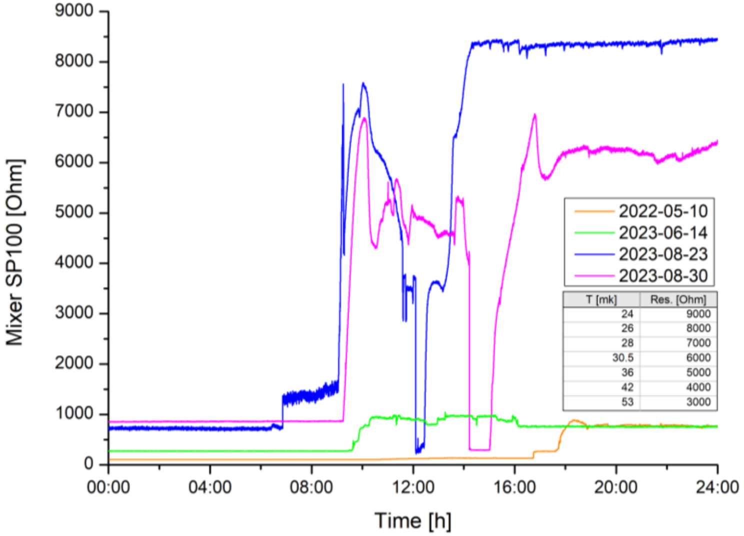
After one year of learning to cool down to < 28mK and testing, we could reestablish:

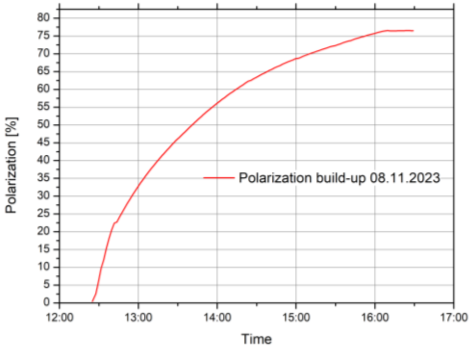
- → Reliable cool down procedure
- → Stable and reproduceable parameters for DNP
- → Good polarization for Butanol (76% in 4h)
- → Sufficient low temperatures (< 28 mK) for long relaxation times in frozen spin mode ($\tau \sim 2000h$)

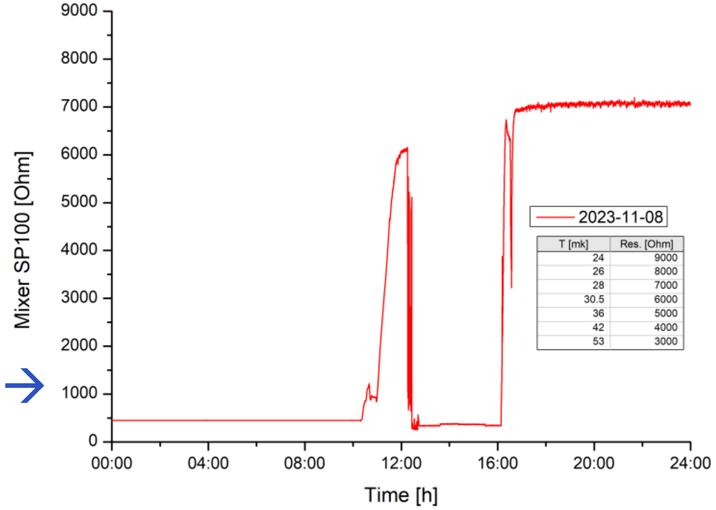
Next:

- → Being back in beam beginning next year
- → Combined internal coil project is now a high-priority work in progress









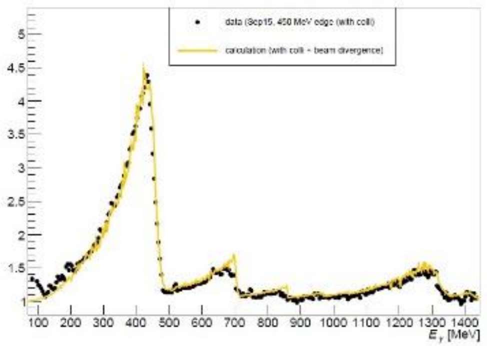
→ Important highlight of the performed work in 2023 →

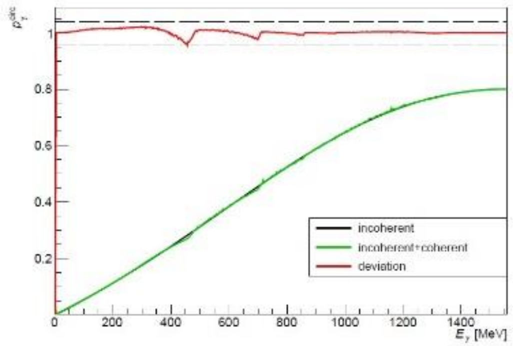
Design of a combined holding coil system (CryPTA:ScM)

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!



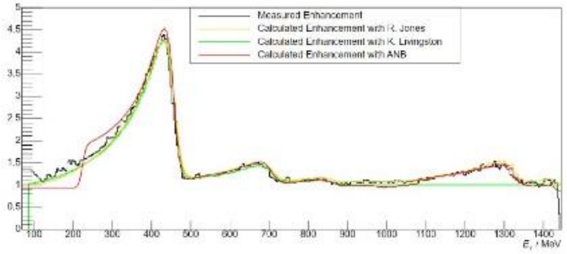


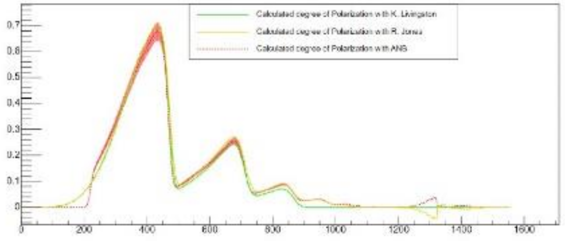
F. Afzal et al., submitted to PRL

- 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

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)





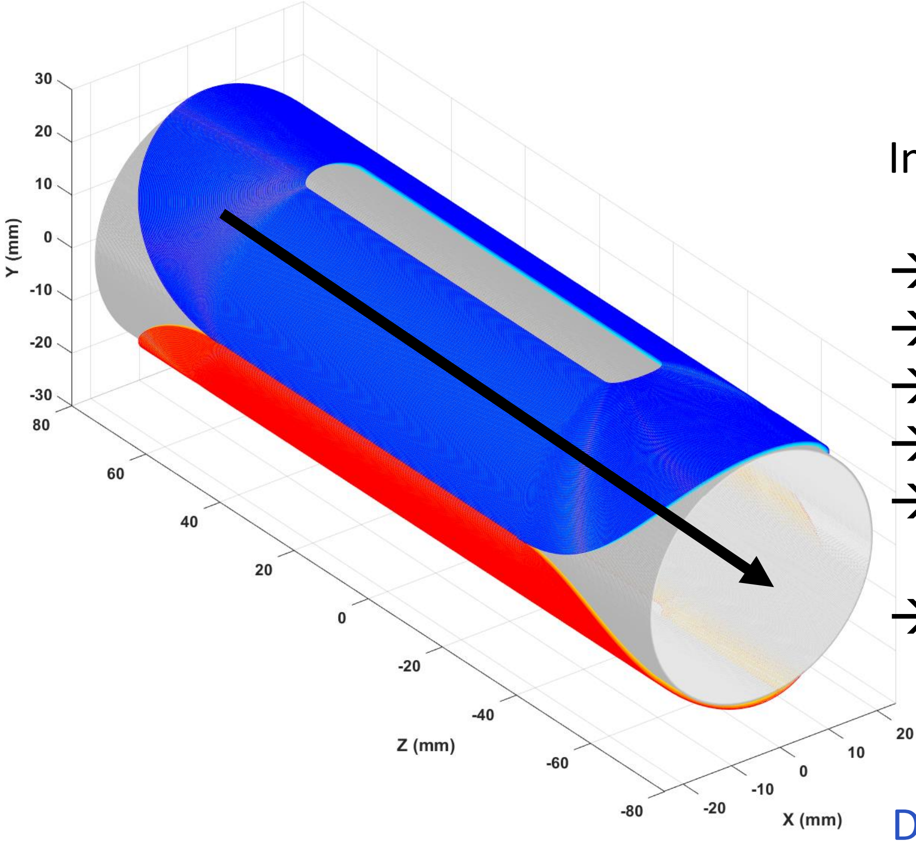
L. Reschke

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	$C_{x'}$	-	$C_{z'}$	-	-	-	-

Lets rotate the target polarization and measure them all

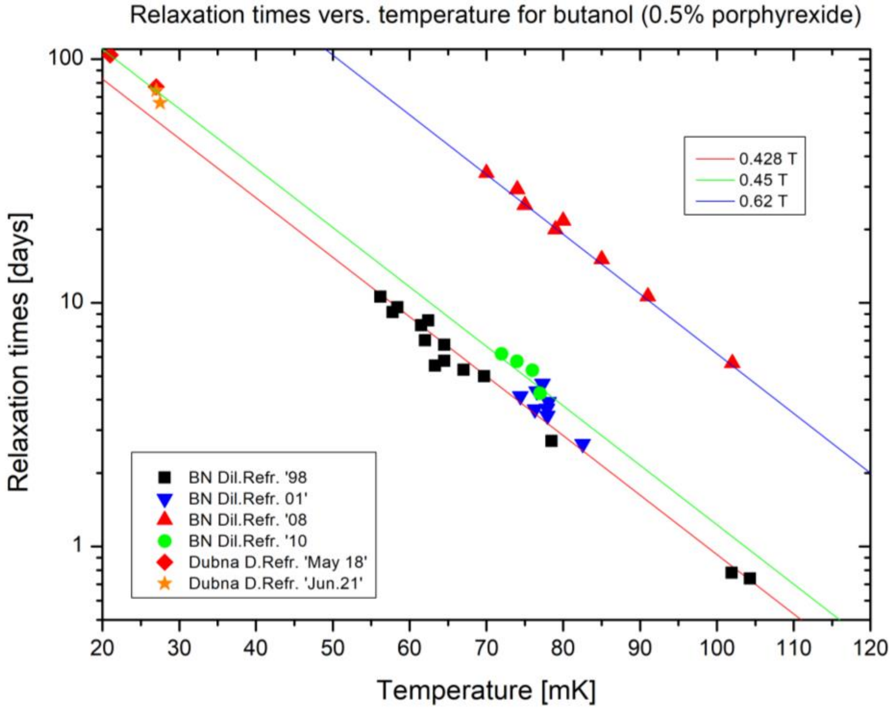
Design of a combined holding coil system (CryPTA:ScM)

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
→ $0.4\ \mathrm{T} < B_H$ to get reasonable relaxation times



Detailed studies and simulations are underway → V. Lagerquist

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

Combined longitudinal and transverse field
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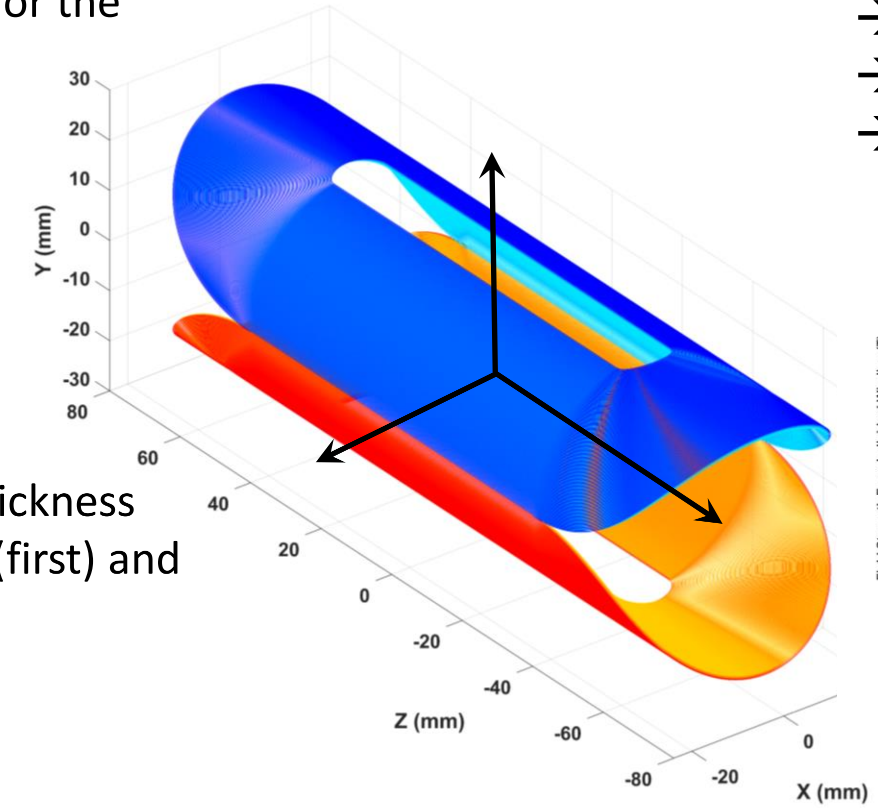
→ Solenoid + ‘race-track’

Victoria Lagerquist, UBO

Design / simulation boundary condition for the compount:

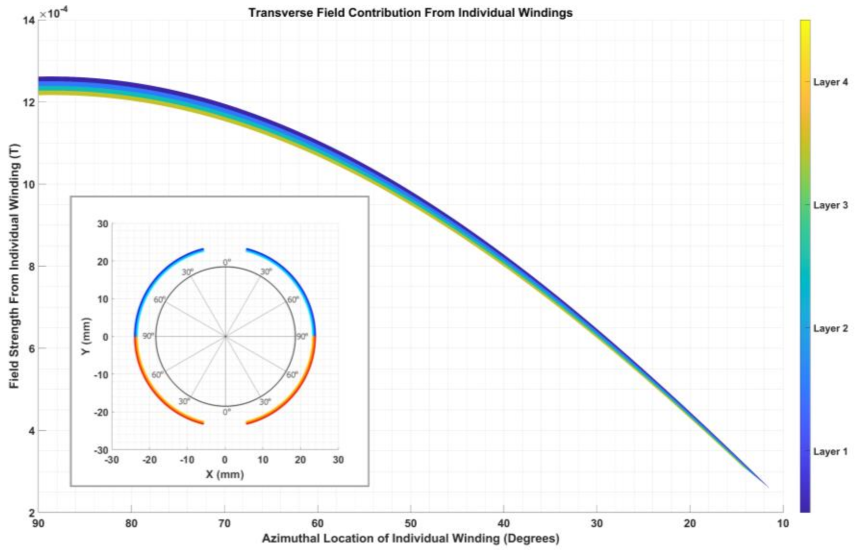
- → field solenoid / race track B > 0.4 T
- → $I_{nom} \leq 40A$
- → D = 45 mm / length = 150 mm
- → Almost homogeneous mass distribution

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°



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Maximum field, minimum thickness:

→ Cosine theta shape
→ Equal No. of windings per layer
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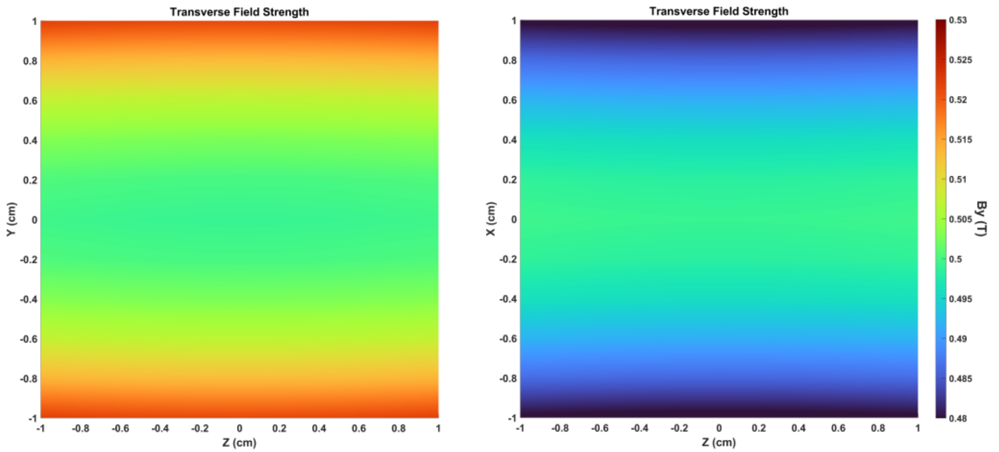
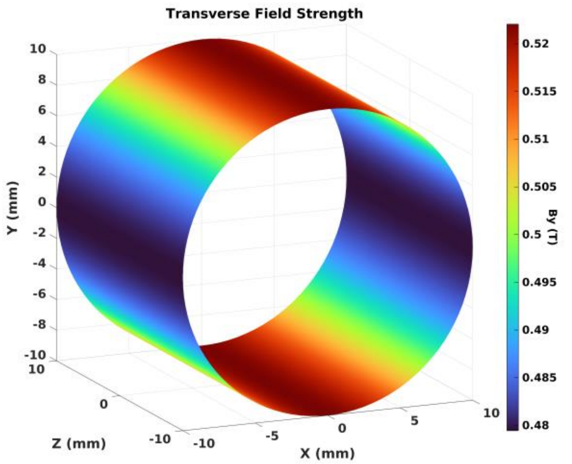
→ Price to pay:
→ Field variation in target area ~ 5%
→ Corresponding τ variation has to be measured



Field variation in yz-, xz-plane in target area



Field variation on target surface

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

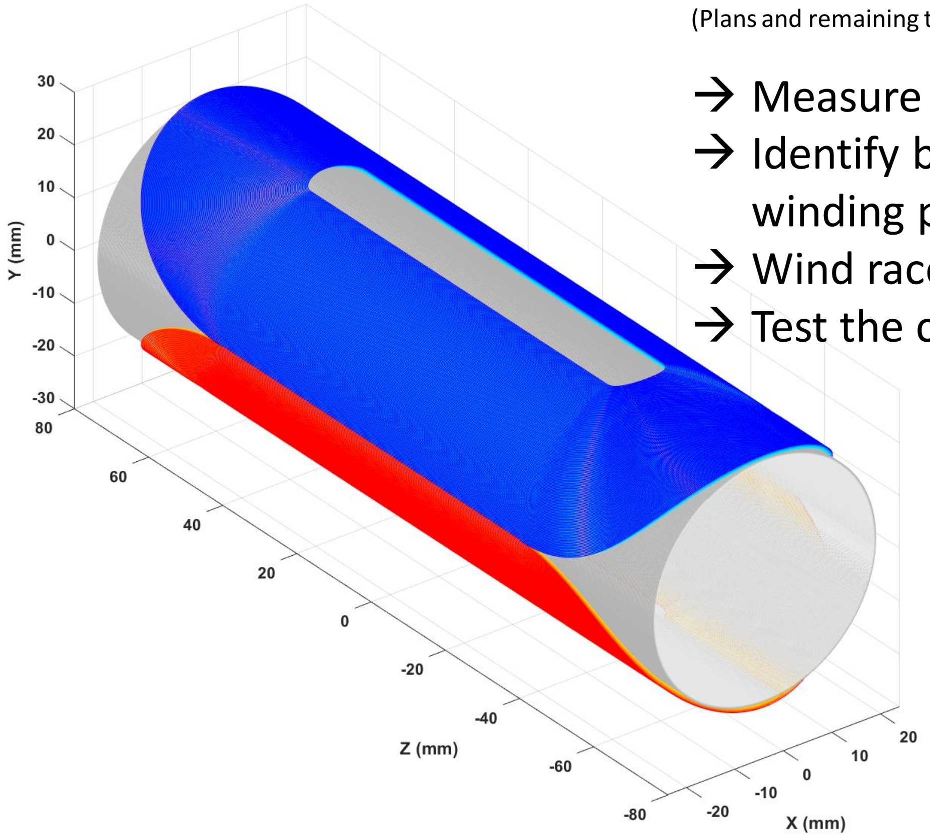
Combined longitudinal and transverse field
for a variable polarization direction in yz-plane or xz-plane
→ Solenoid + ‘race-track’

Victoria Lagerquist, UBO

2 compound scenarios possible:
(wire: 0.203/0.229 mm, 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

‘low current’ I = 35 A → B = 0.5 T
→ Solenoid: 3 layers, N = 1920 → thickness: 0.63 mm
→ Race-track: 4 layers, N = 552 → thickness: 0.92 mm
→ Compound thickness: ~ 2.2 mm



Next steps:
(Plans and remaining tasks until the end of the project (31 July 2024))

→ Measure more τ(B)
→ Identify best scenario and winding procedure
→ Wind race-track and solenoid
→ Test the combined coil system

Already strong interest in the technology by a SME for 3D-magnets

Or picking up an ‘old’ challenging idea: double helix configuration or canted cosine theta (cct) magnet

Improved light efficiency read out (CryPTA:APT)

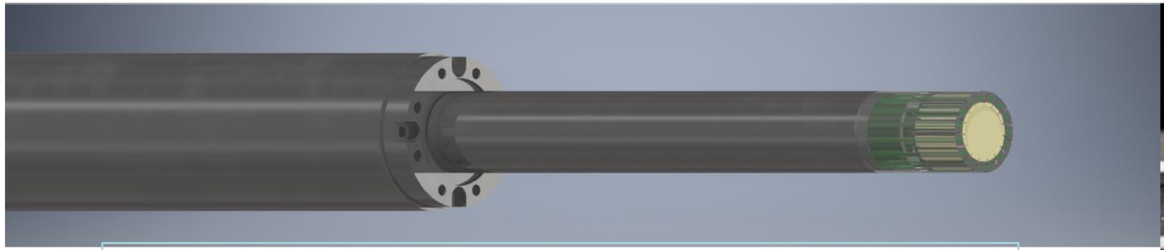
26

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.

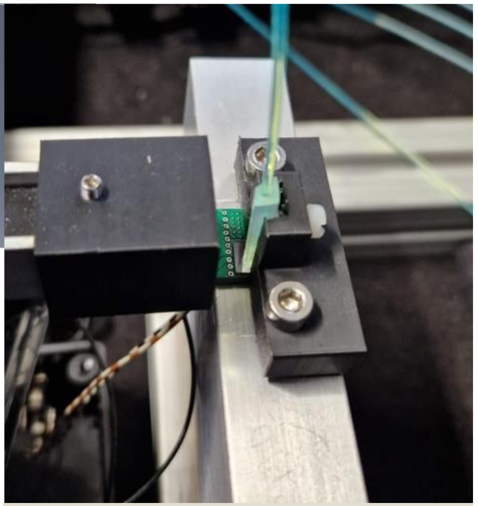
- Fiber readout minimizes the intensity attenuation
- Enables carbon subtraction using an carbon foam
- Doped pellets can be H- or D-Butanol

M. Biroth, 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
- Tests with photon beam planned

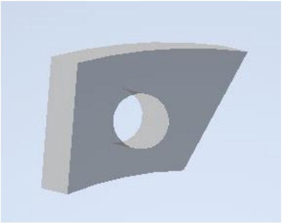


Coincidence technique to improve signal to noise ratio.

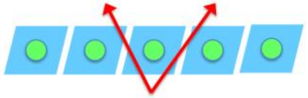
New Apparatus:

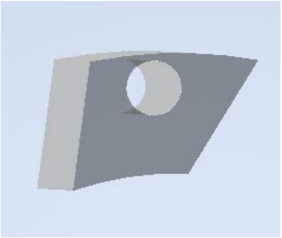
Light-tight test station with ^{90}Sr-Source and 3d-positioning

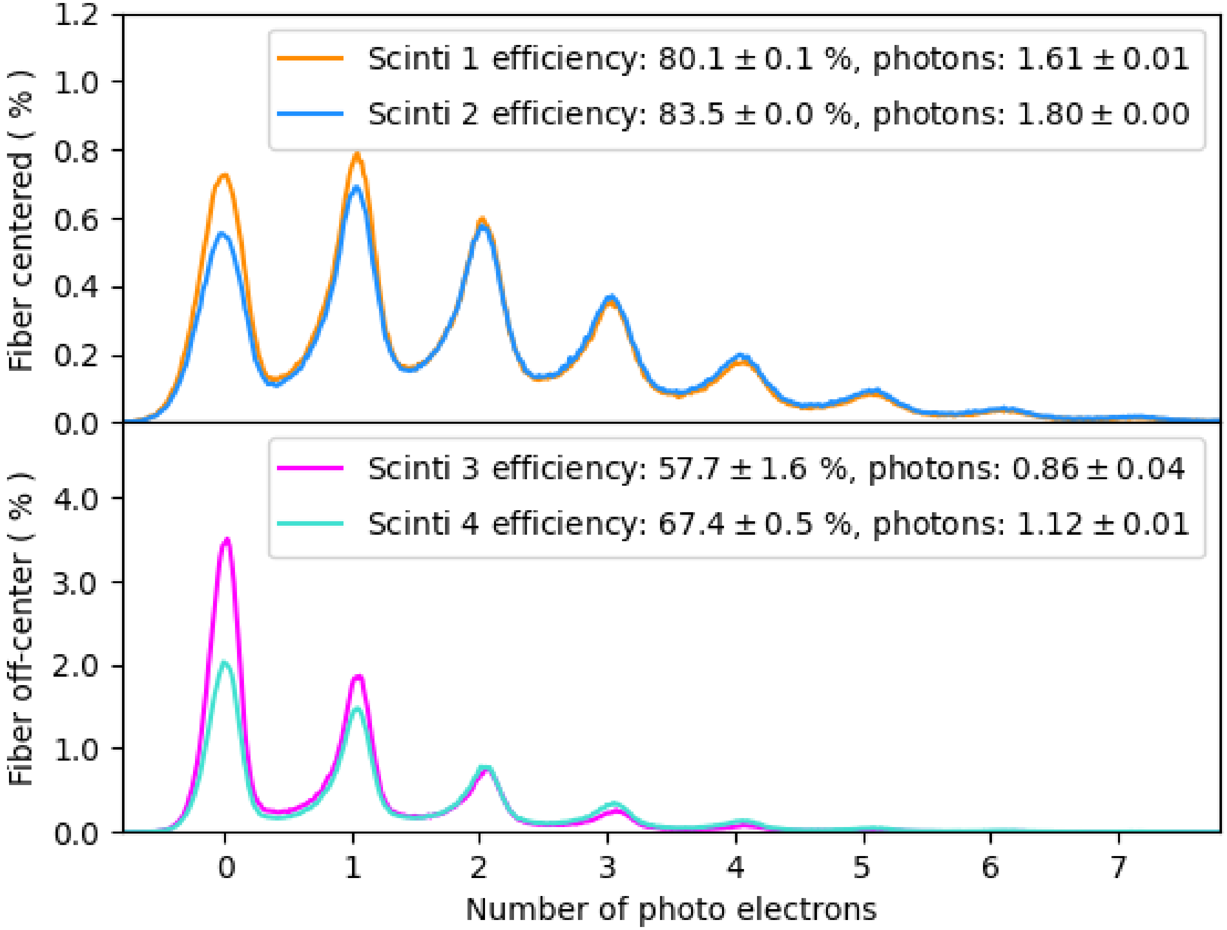
Improved light efficiency read out (CryPTA:APT)



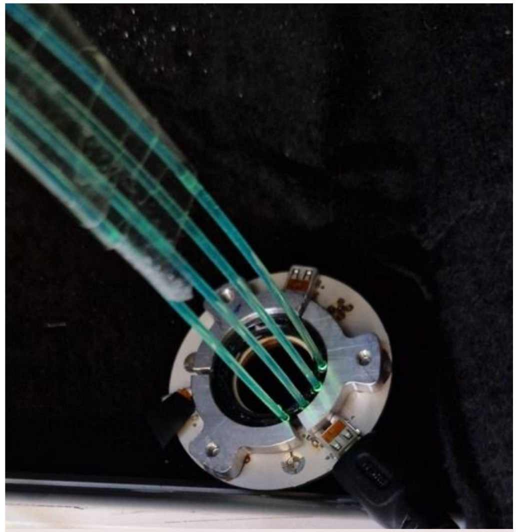
- Segmentation provides ϕ-resolution. Efficiency gaps are avoided by dovetailing of the scintillator bars.







Spectra for different geometrical configurations to specify the optimum with respect to the small dimensions (target 2cm x 2cm diameter) and the way of the fibers to the SiPMs in the cryostat.



Readout via optical fiber

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
'canted cosine theta (CCT) magnet'

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

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

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

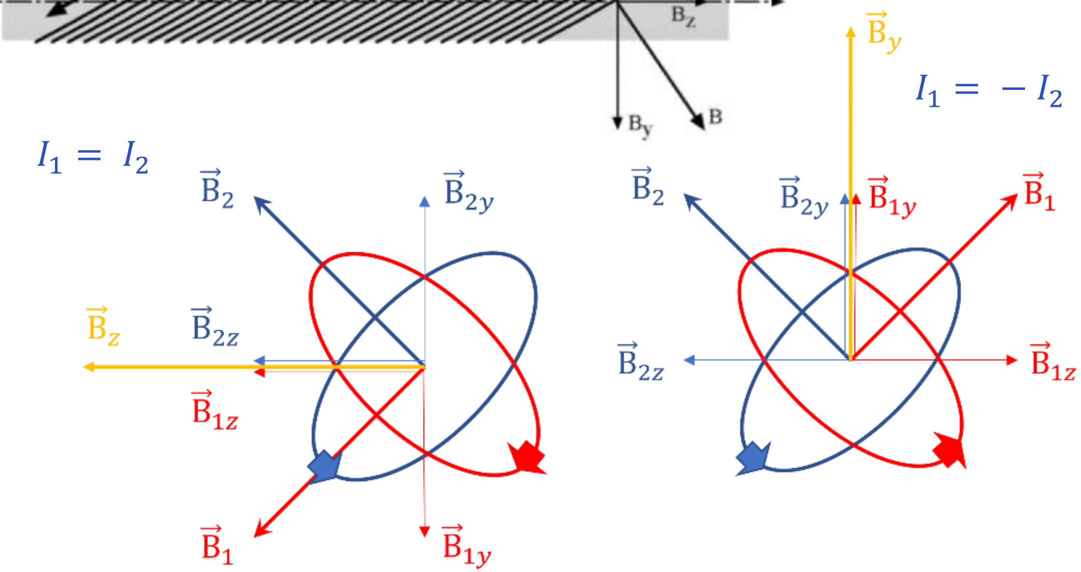
- For a = 45°, symmetric case, 2 independent coils
- 'transverse case' : $I_1 = -I_2$

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

- 'longituinal case' : $I_1 = I_2$

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

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



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
'canted cosine theta (CCT) magnet'

TCC Perfect solution for polarized target experiments:

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

For a required B in a polarized target:

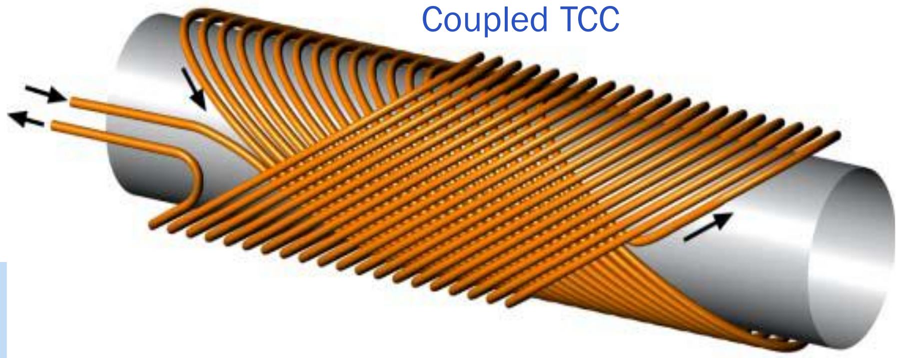
- TCC needs to be longer than a standard solenoid
- TCC needs more windings/layers or current

The real challenge:

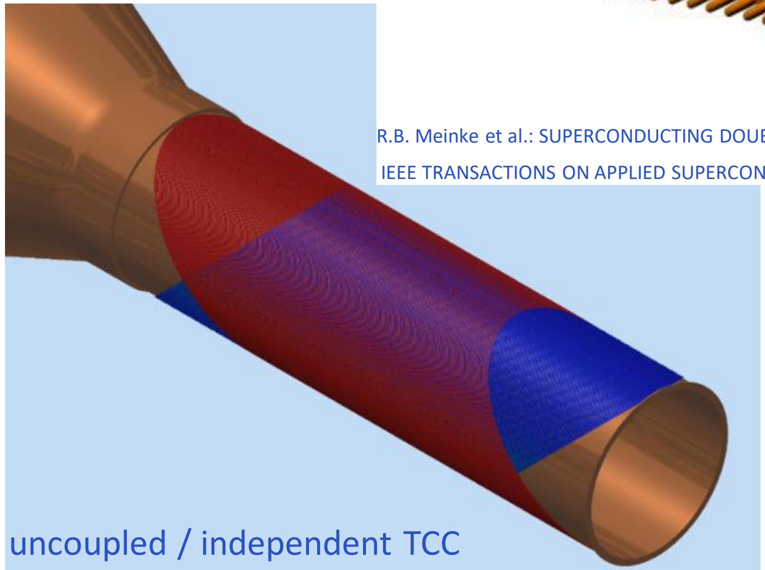
- Winding a 250 µm wire to a tilted coil

Our next task:

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



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



Conclusions

Despite the unfavorable circumstances in the last 3 years

- The complete target set-up is again available for experiments and the CryPTA project

CryPTA:ScM → the combined holding magnet for the dilution refrigerator and the near future data taking campaign is in progress.
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 .

The extension gives us the opportunity to complete the project