Holding Coil Advancements for Frozen Spin Experiments at the University of Bonn

Workshop on Polarized Sources, Targets, and Polarimetry

Sept 23, 2024

Presented by:
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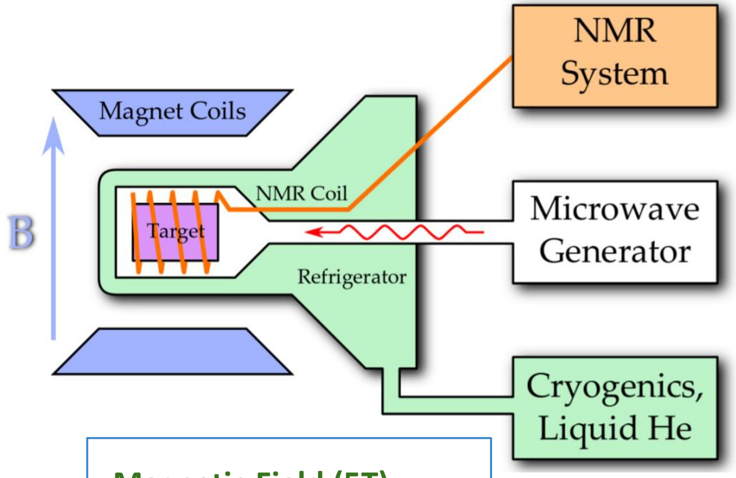
Physikalisches Institut Universität Bonn

POLARIZED TARGET BONN

UNIVERSITÄT BONN

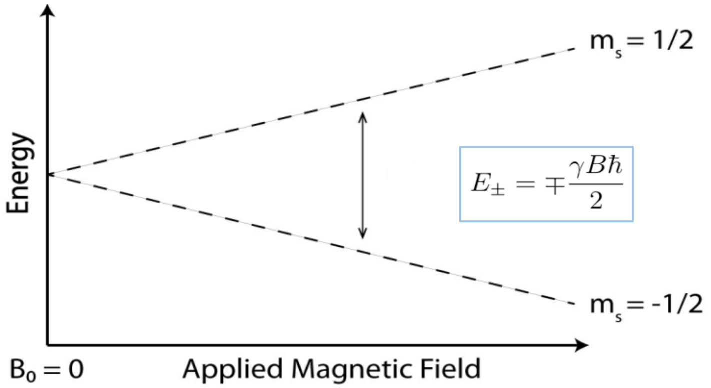
Dynamic Nuclear Polarization

DNP Requirements



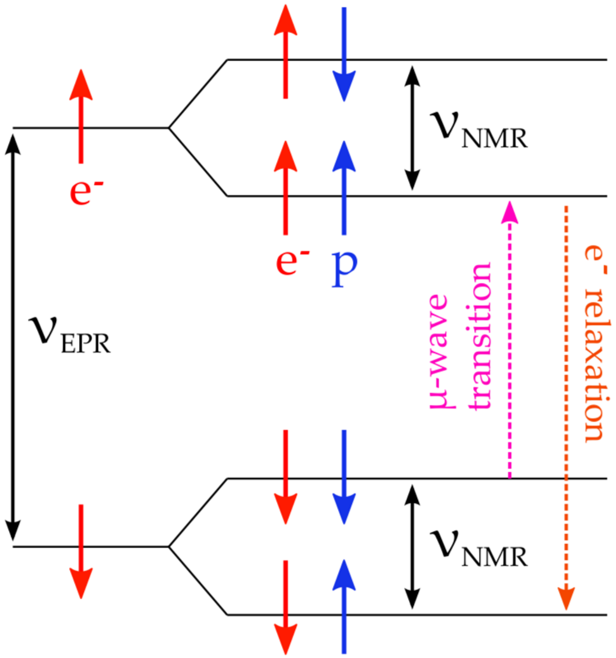
- **Magnetic Field (5T)**
- **Low Temperature (1K)**
- **Paramagnetic Material**
- **Microwaves (140 GHz)**
- **Monitoring (NMR)**

Thermal Equilibrium Polarization



$$P_{TE} = \frac{e^{\frac{\mu B}{kT}} - e^{\frac{-\mu B}{kT}}}{e^{\frac{\mu B}{kT}} + e^{\frac{-\mu B}{kT}}} = \tanh\left(\frac{\mu B}{kT}\right)$$

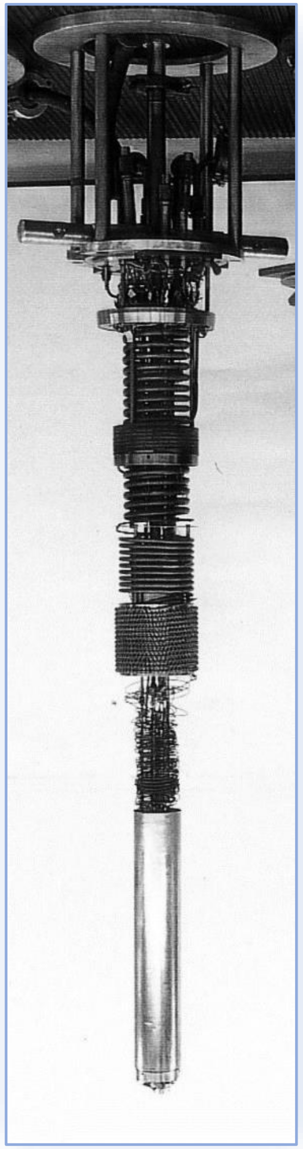
Enhanced Polarization

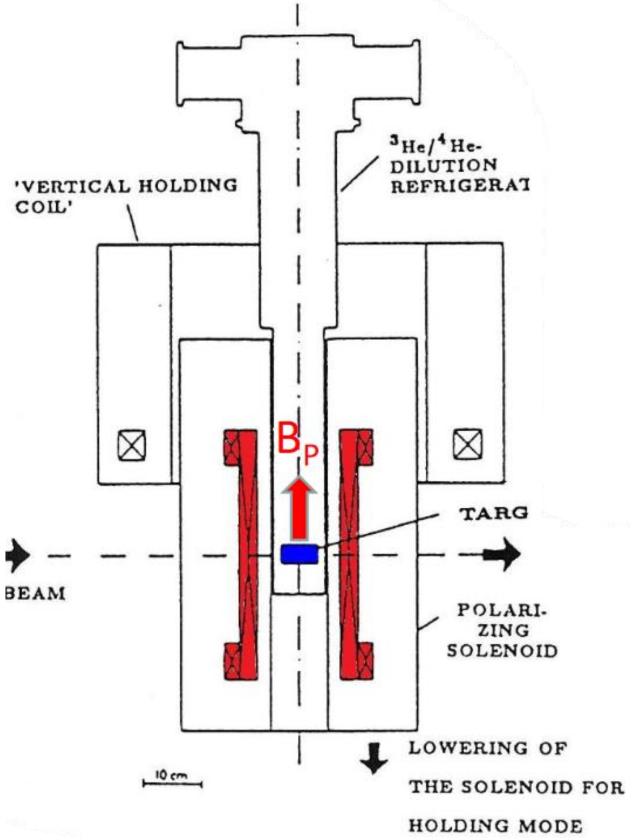


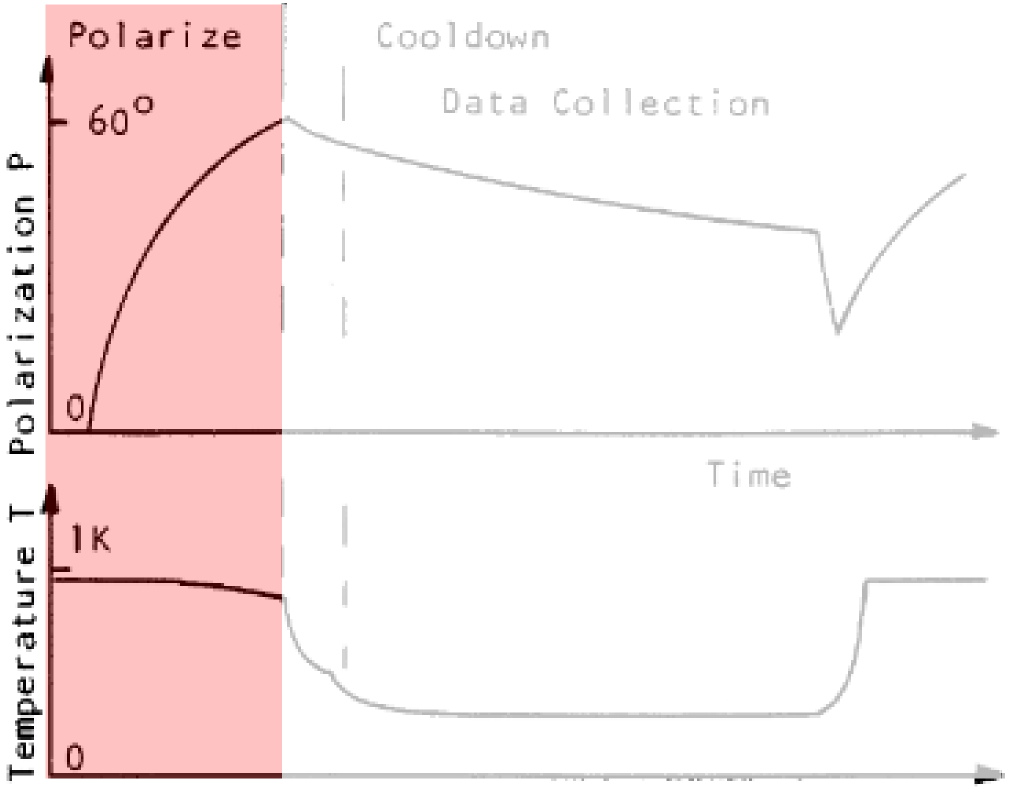
Bonn Frozen Spin Target (1989)

Active Polarizing Mode:

- 5T External Field
- Polarization ~90%



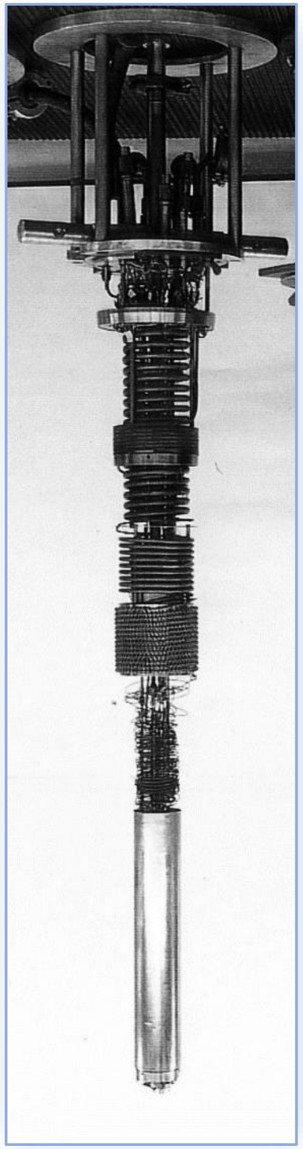


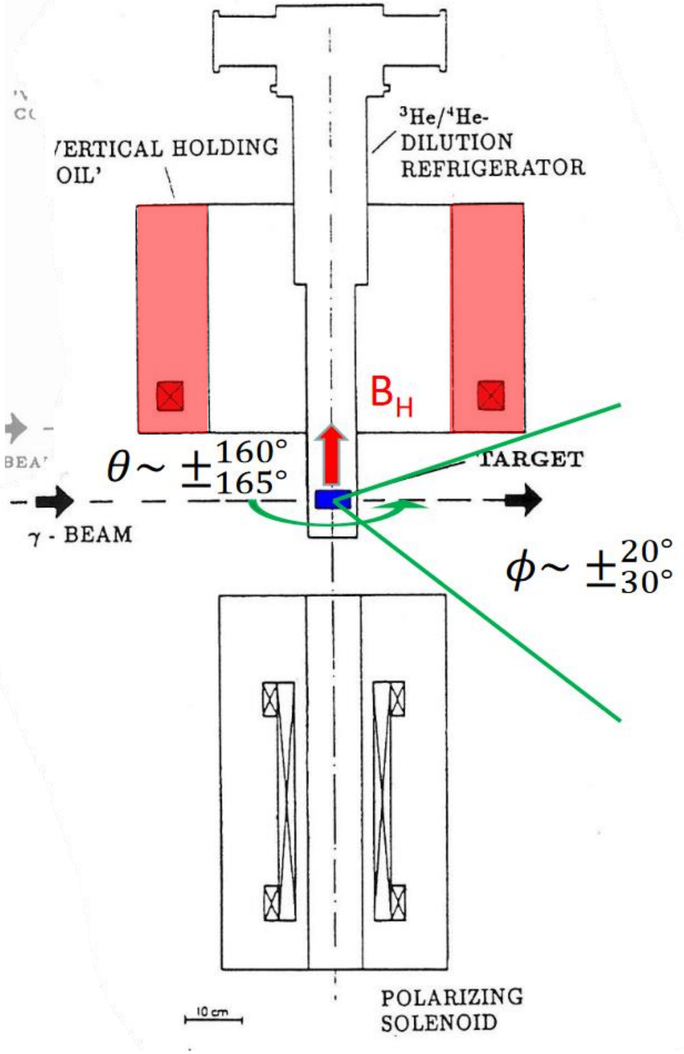


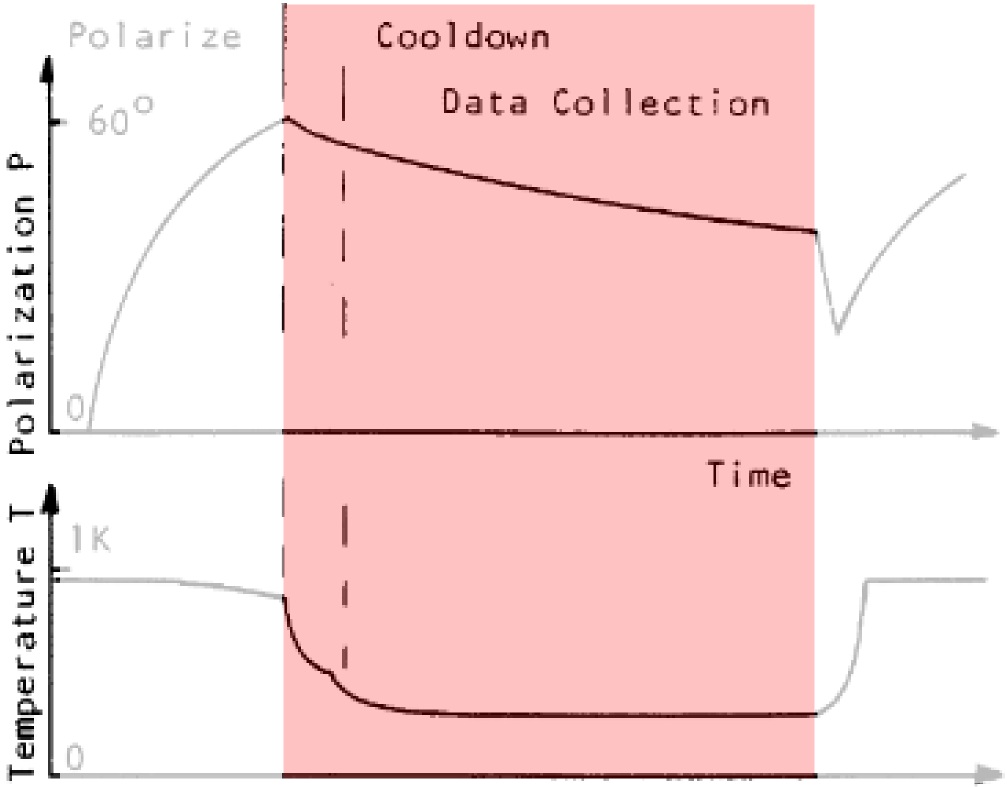
[Nucl. Instr. and Meth. A340 (1994)]

Bonn Frozen Spin Target (1989)

Frozen Spin / Data Taking Mode:
- 0.5T External Holding Coil
- 0.065 K Temperature
- Relaxation Time ~250 h

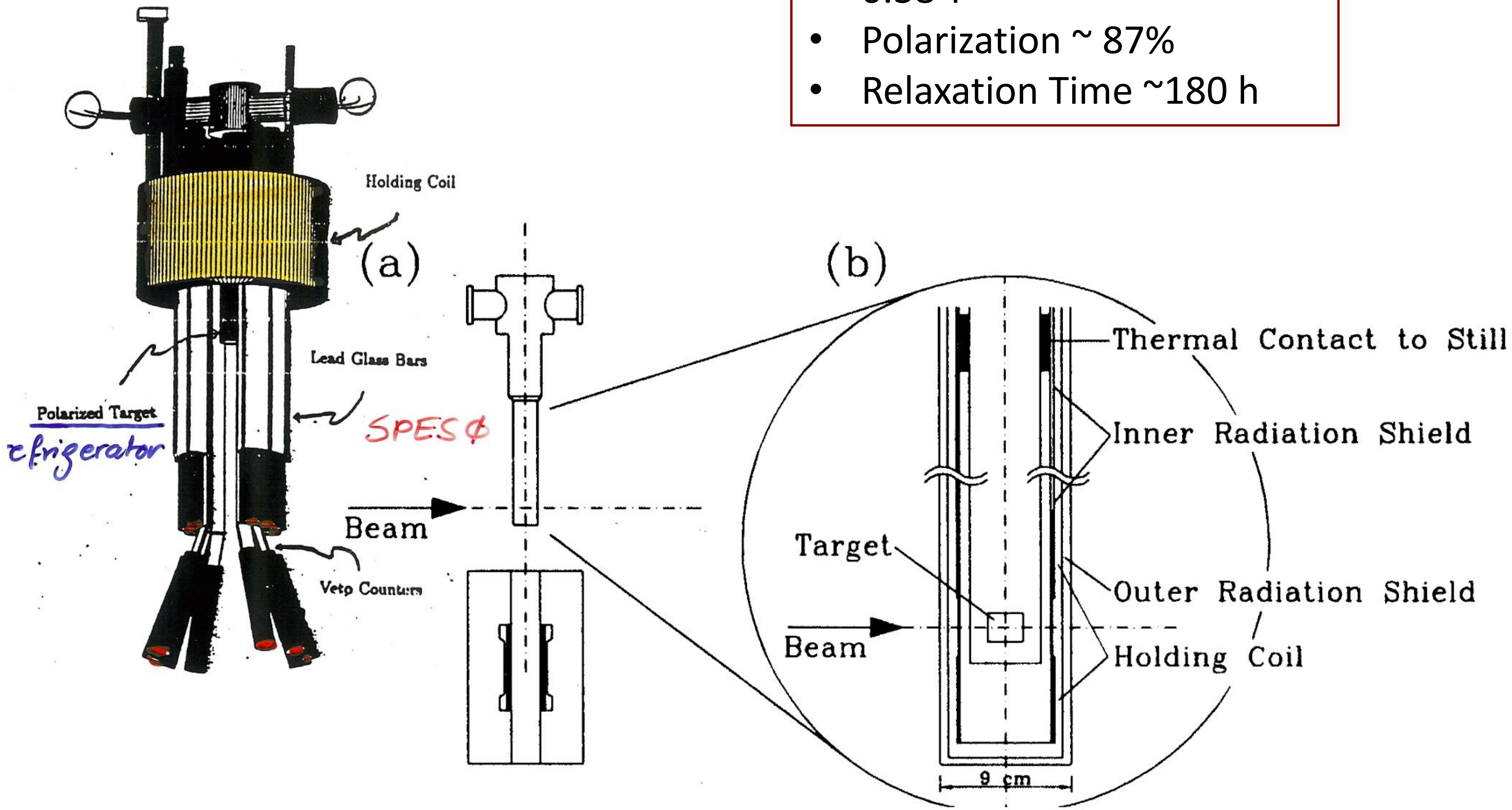


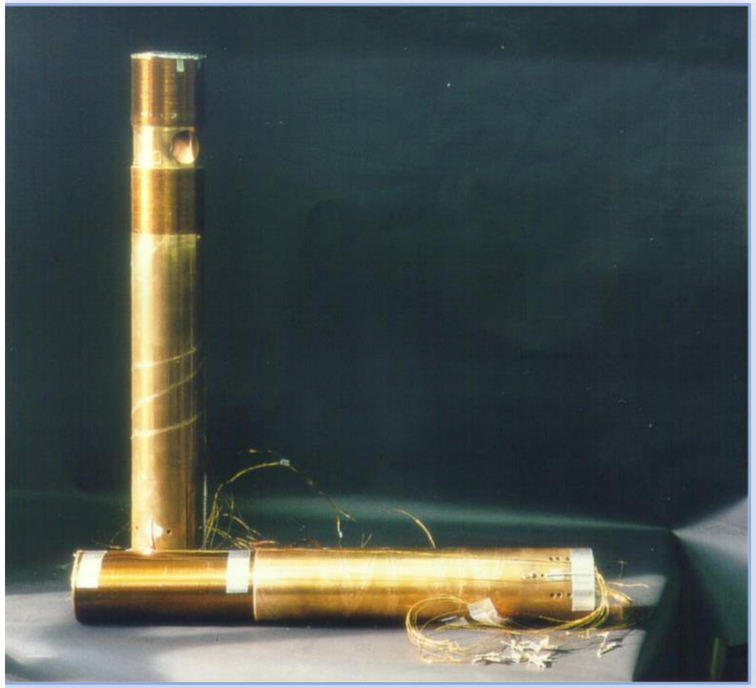




[Nucl. Instr. and Meth. A340 (1994)]

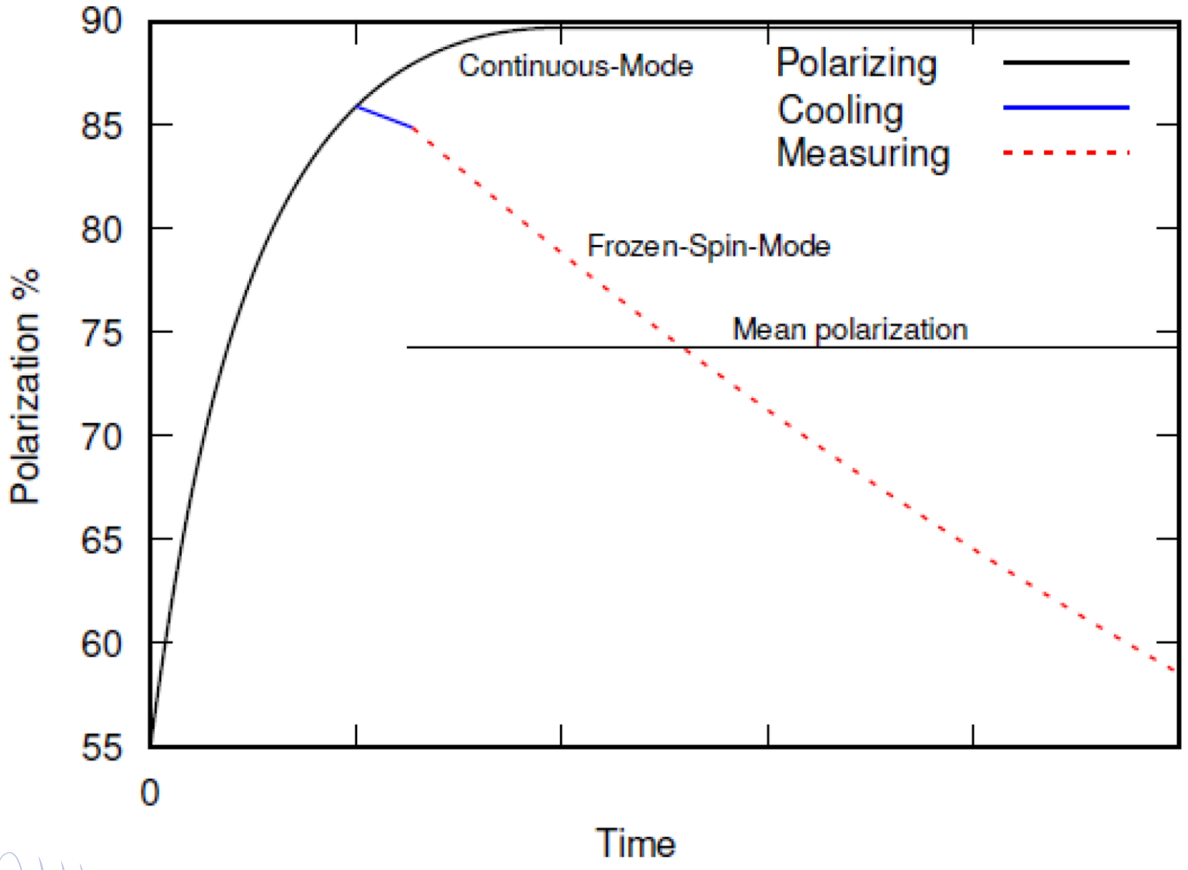
First Internal Holding Coil:
- 0.38 T
- Polarization ~ 87%
- Relaxation Time ~180 h

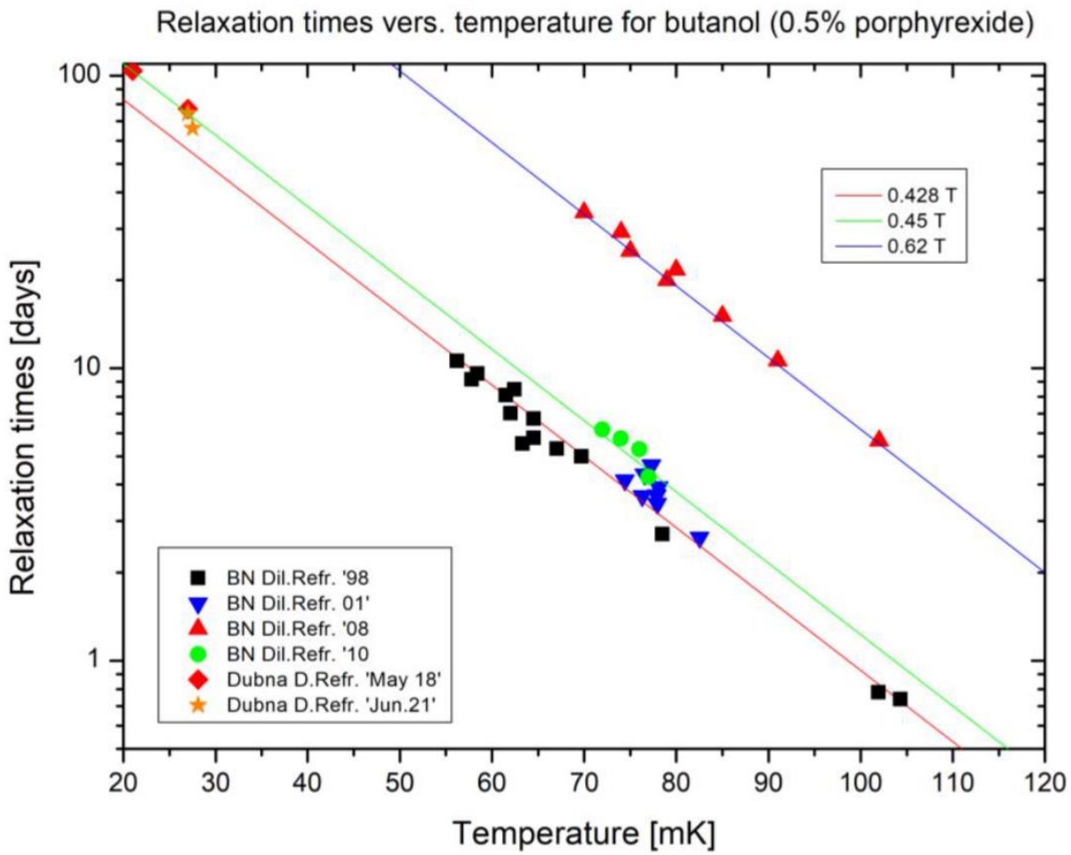




[Nucl. Instr. and Meth. A356 (1996)]

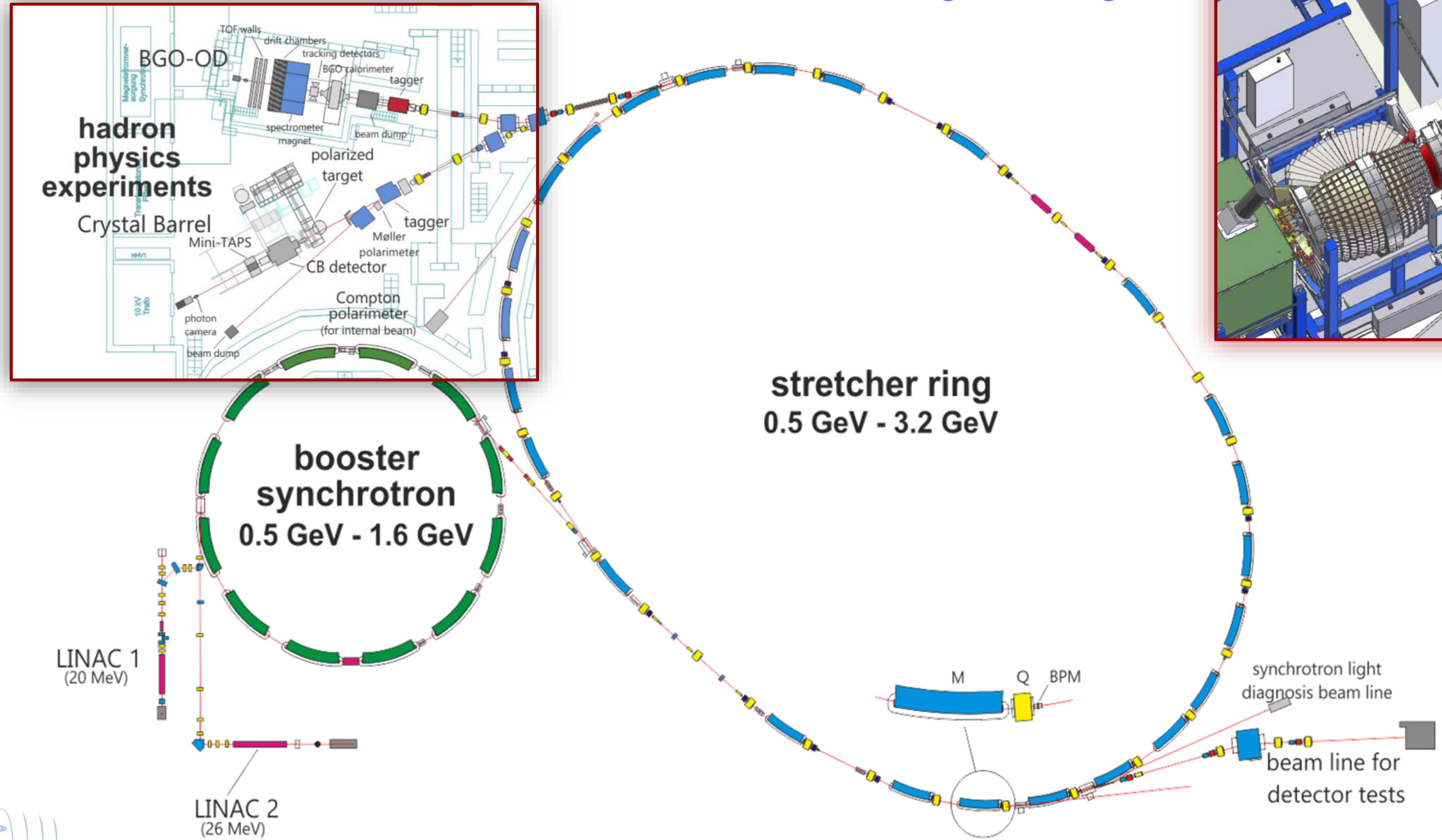
Temperature reduced to tens of mK to 'Freeze' in the enhanced polarization

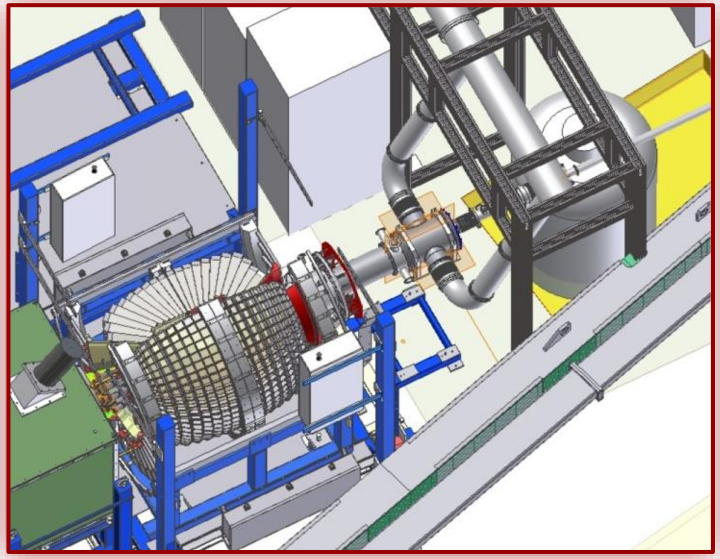




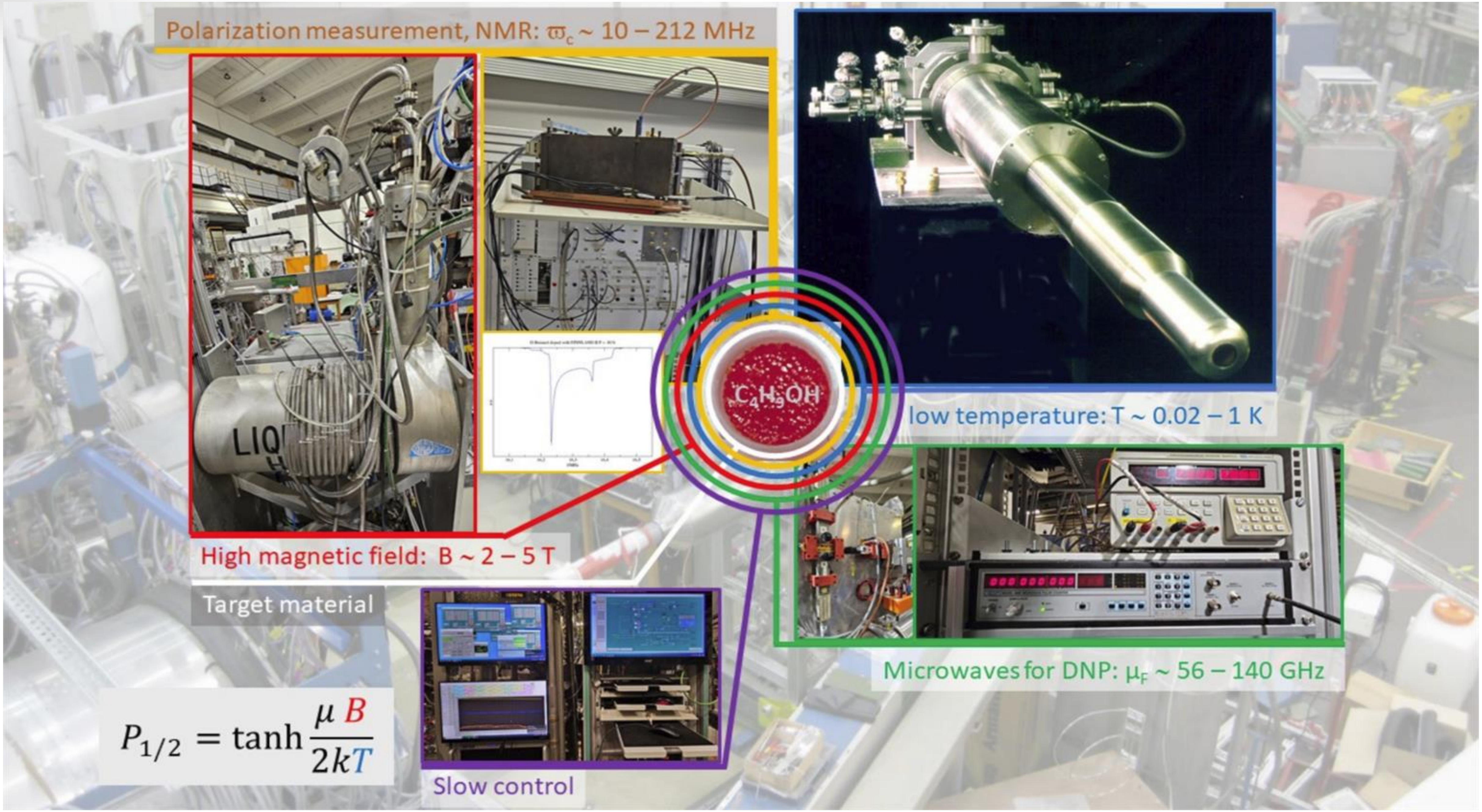
Relaxation time extended to hundreds of hours

1320 CsI(Tl) crystals
97.8% solid angle coverage

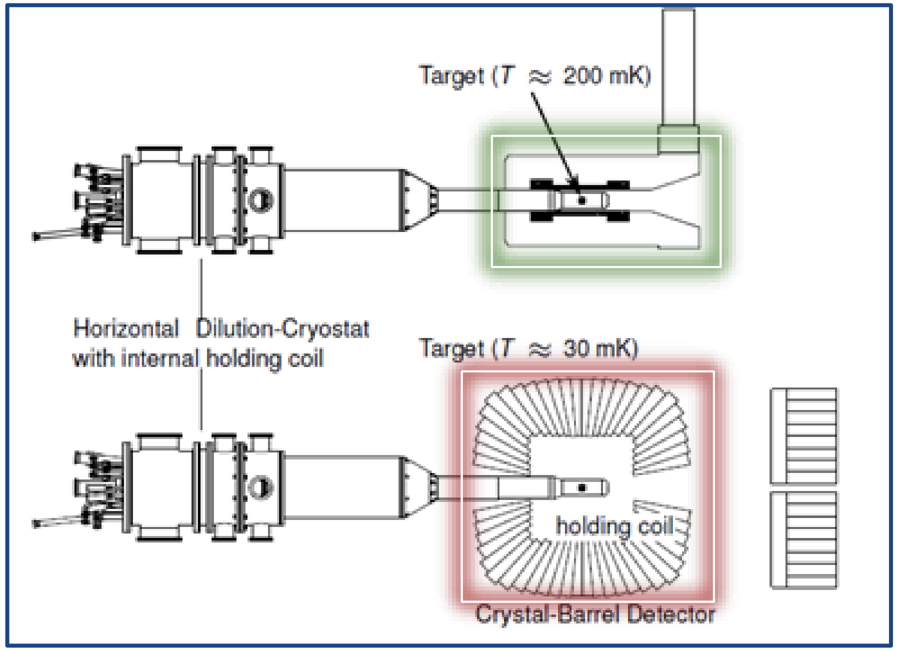




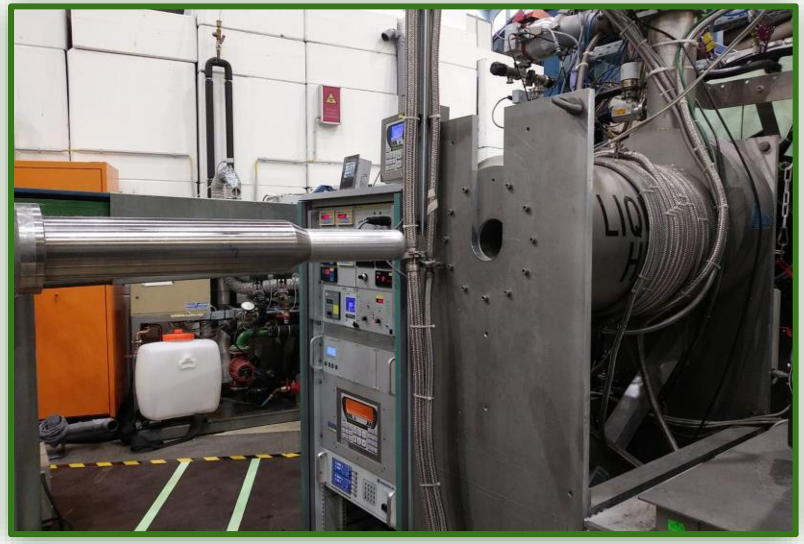
Mainz-Dubna Target



Mainz-Dubda
Helium-3 Dilution Cryostat

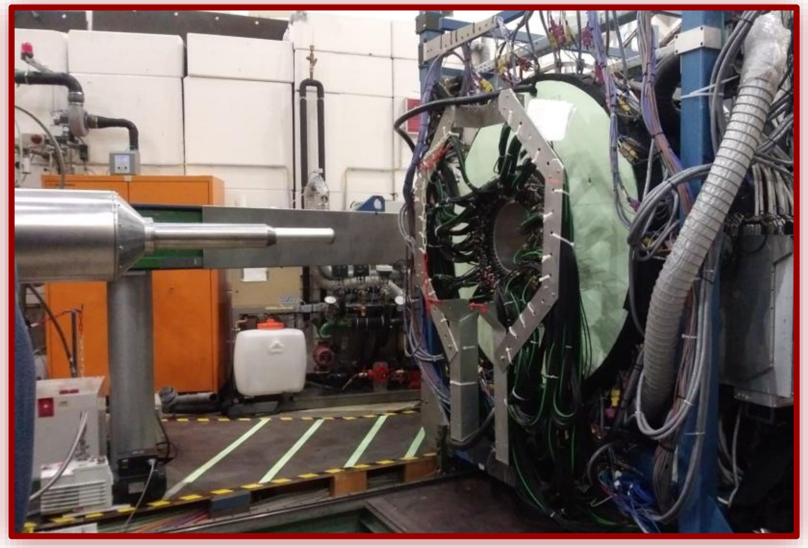


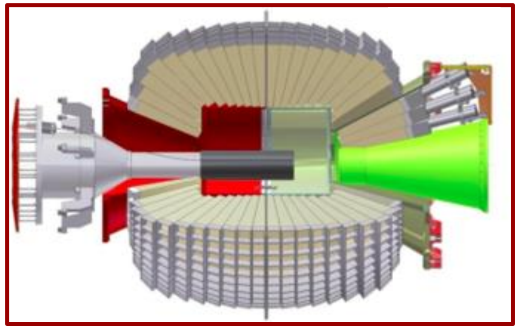
Frozen Spin
Mode:
1 K → 30 mK



Saclay Magnet:
2.5 T

Holding coils:
0.5 T





Mainz-Dubna Target, Previous Runs

Operation of the polarized target (cold cryostat) at Crystal Barrel @ ELSA (CBELSA)

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

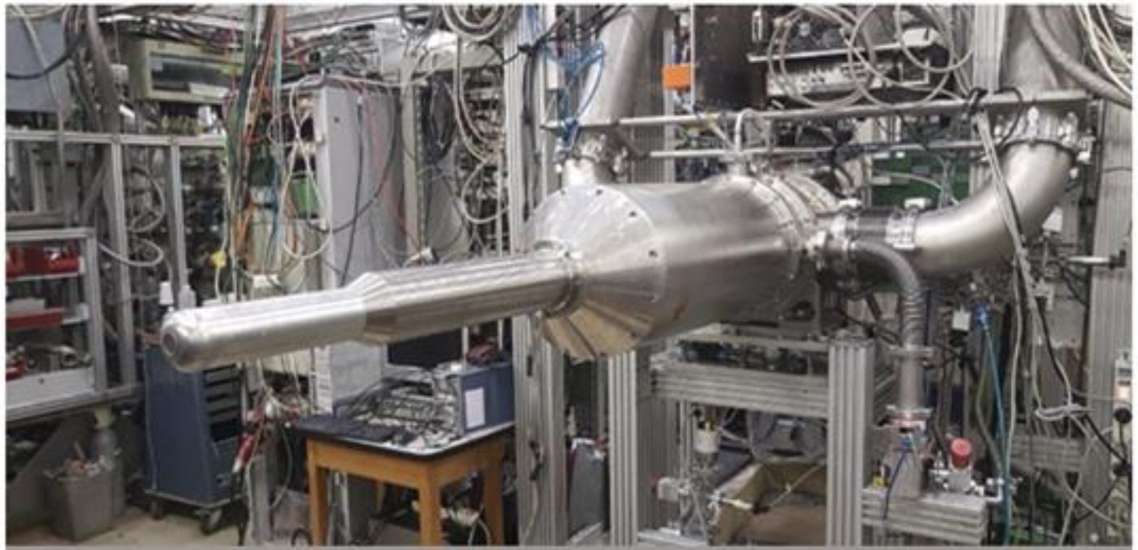
2018 (transv. polarization) ~ 800h b.o.t.
→ p_d = 76 %, τ ~ 700 h

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

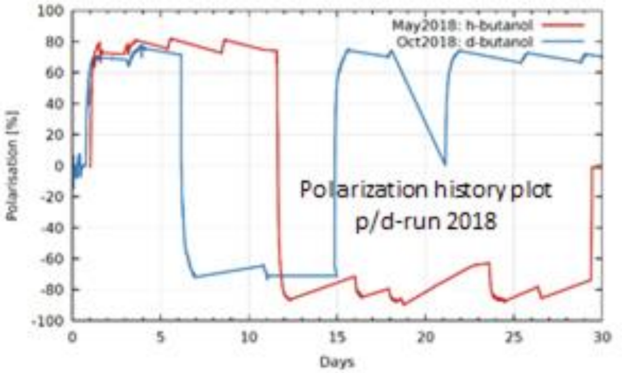
2021 (transv. polarization) ~ 500h b.o.t.
→ p_d = 75 %, τ ~ 500 h

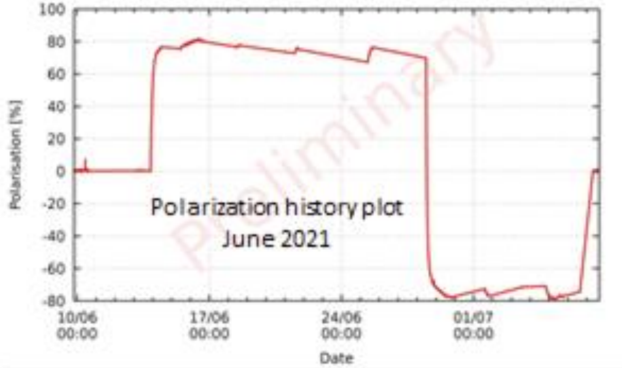
Five years of successful operation on beam in Bonn and 8 years before at A2@MAMI

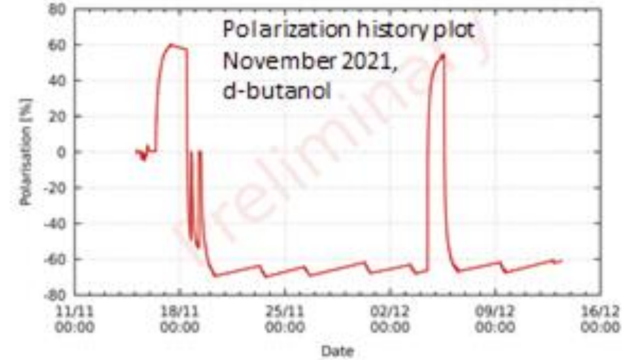


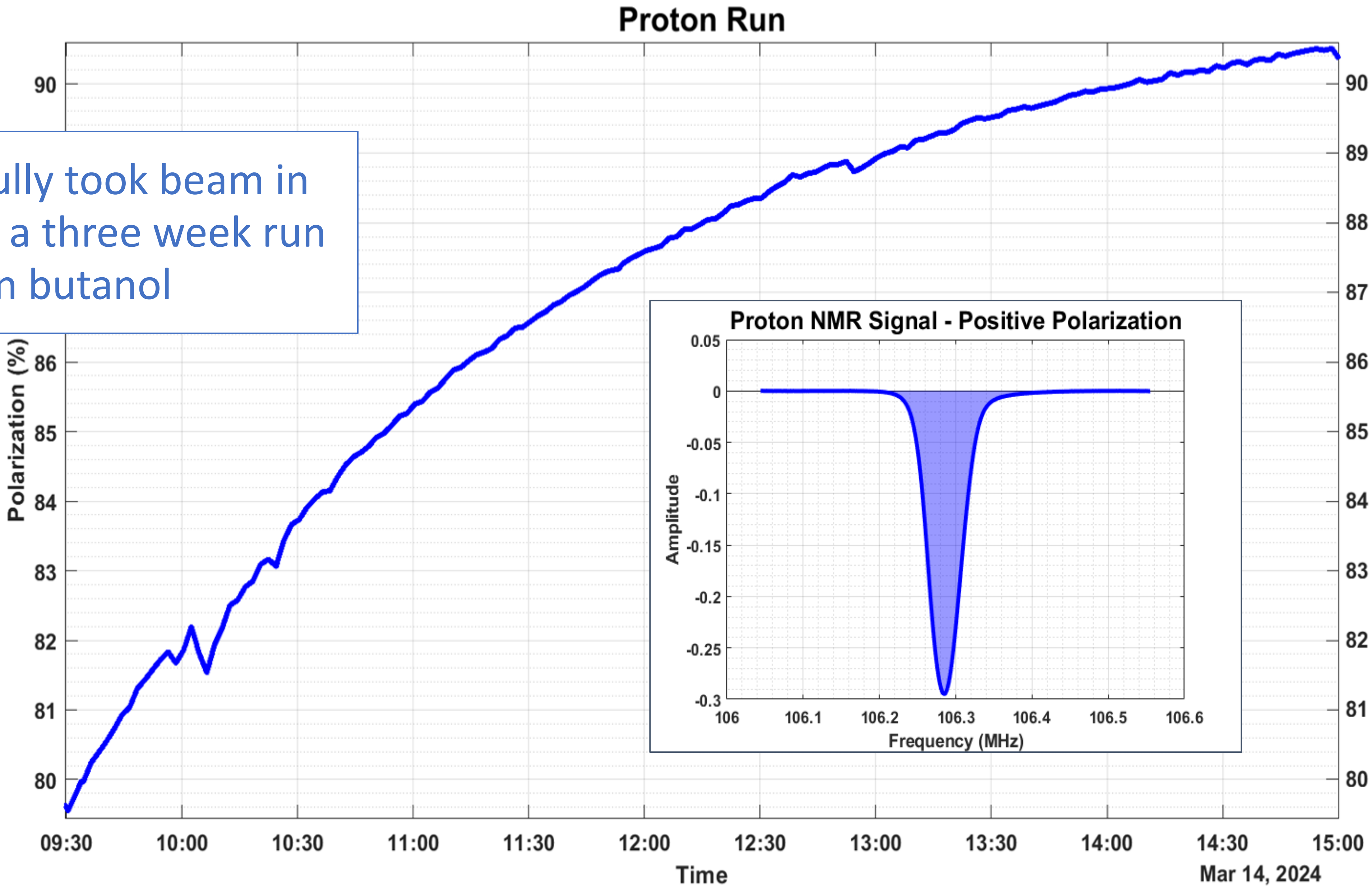
Collaborative target group: Bonn/Dubna/Mainz/Bochum (2015 – 2021)
'Mainz/Dubna frozen spin target' + internal 'holding' coil(s)

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







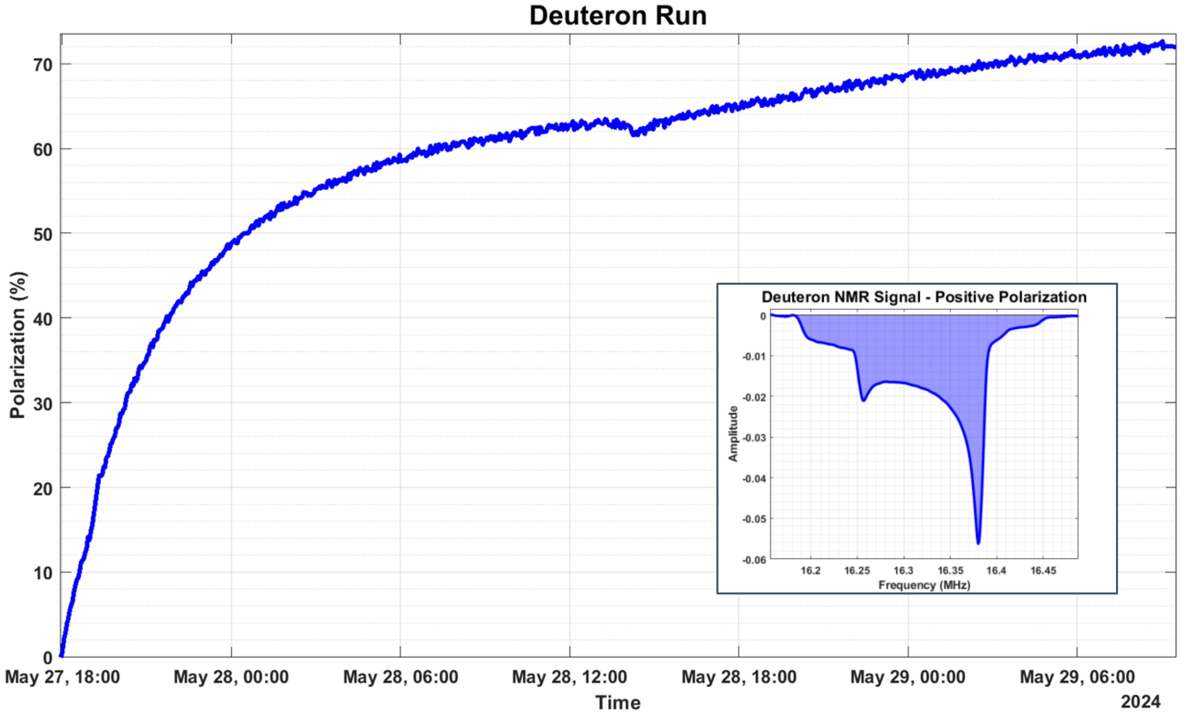


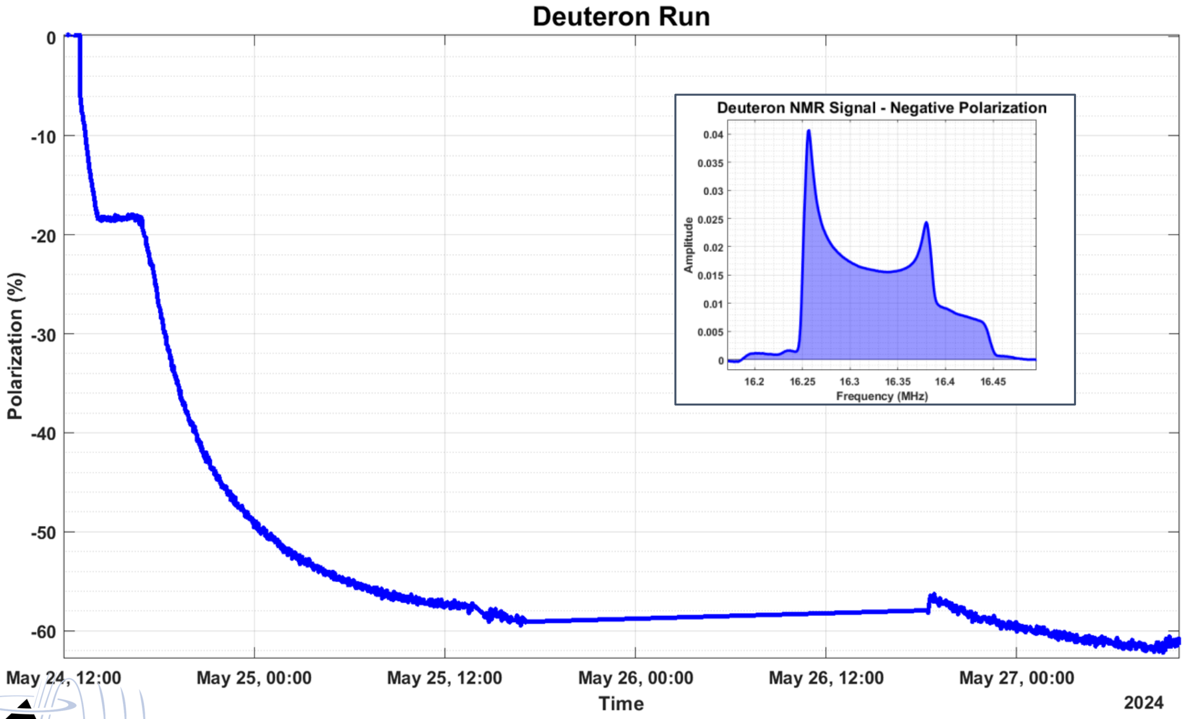
Successfully took beam in March for a three week run on butanol

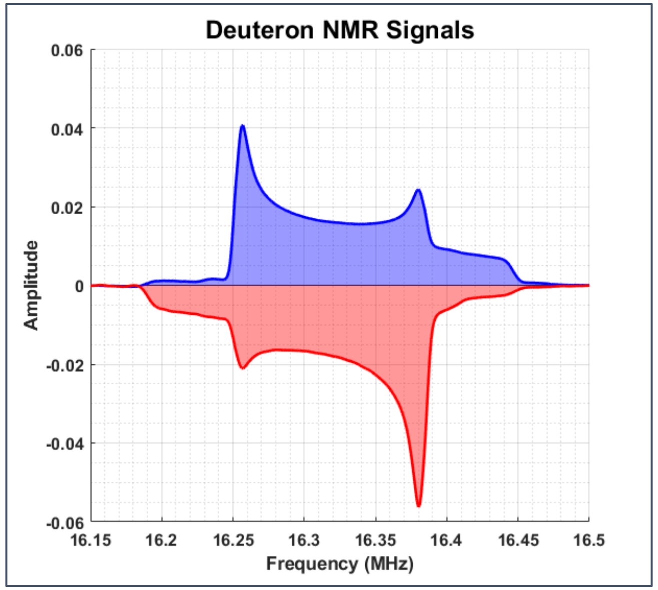
320 hr
17 days
92% Polarization

CB-ELSA 2023, May 22 - June 12

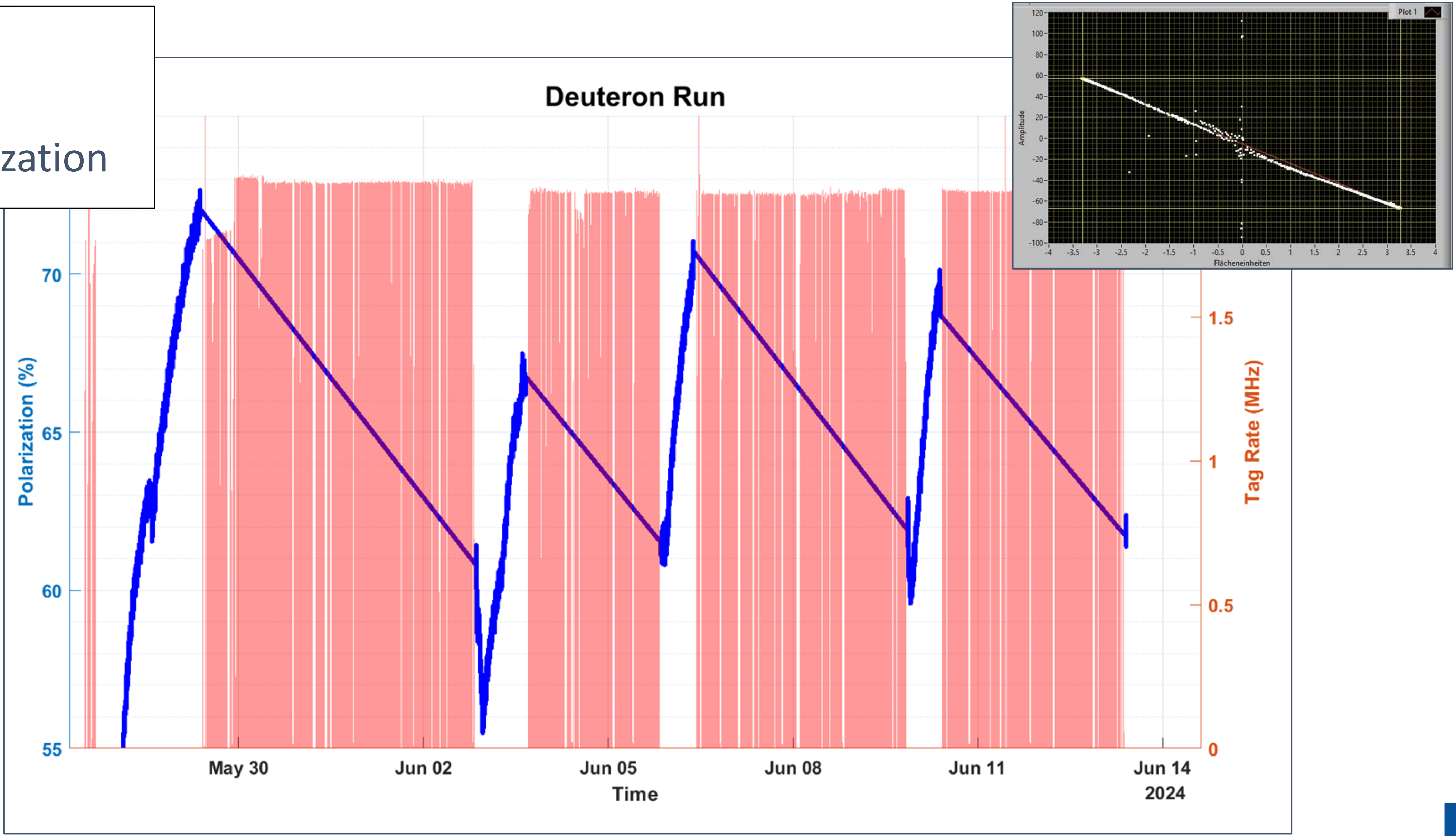
Followed up in April with a carbon run then in May / June with deuterated butanol

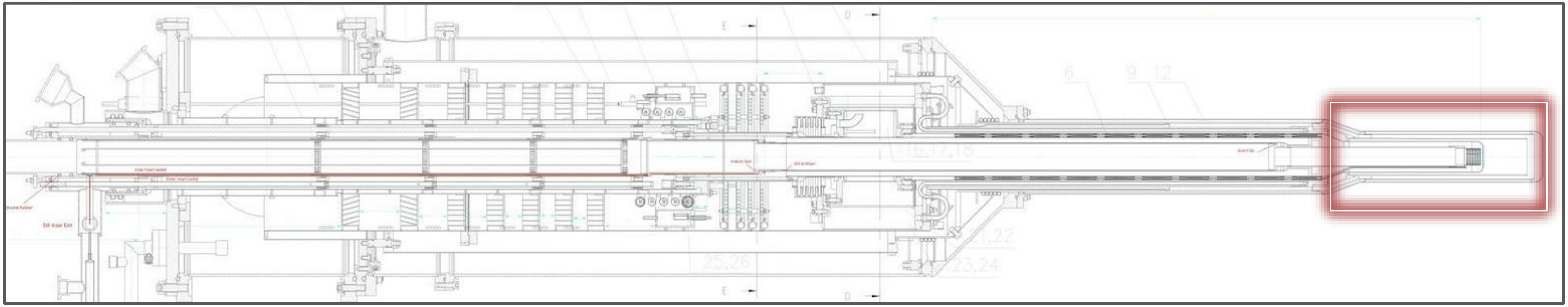


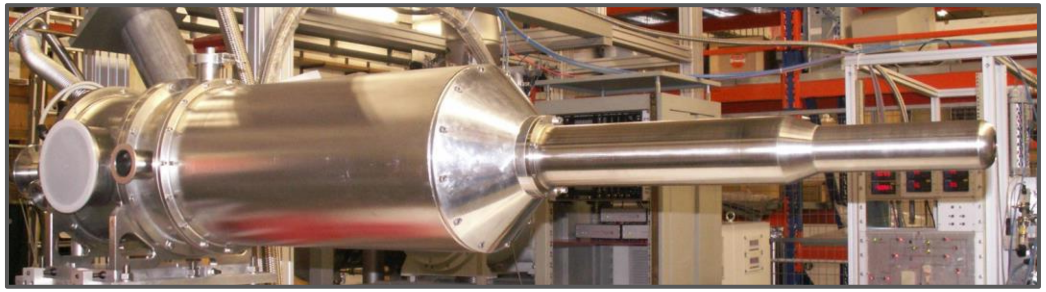


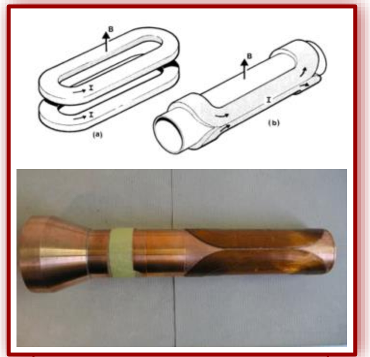


287 hr
17 days
73% Polarization









Transverse

Longitudinal

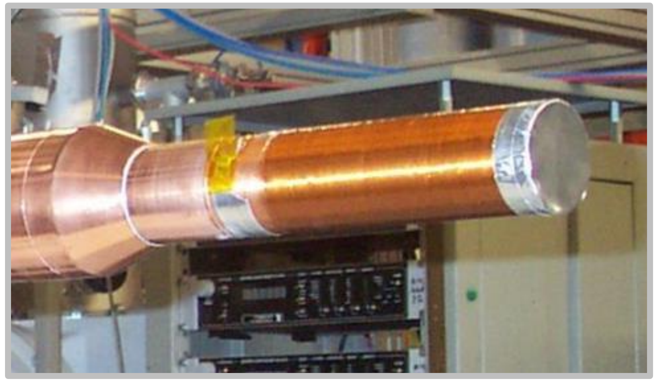
Operates at < 1.5 K

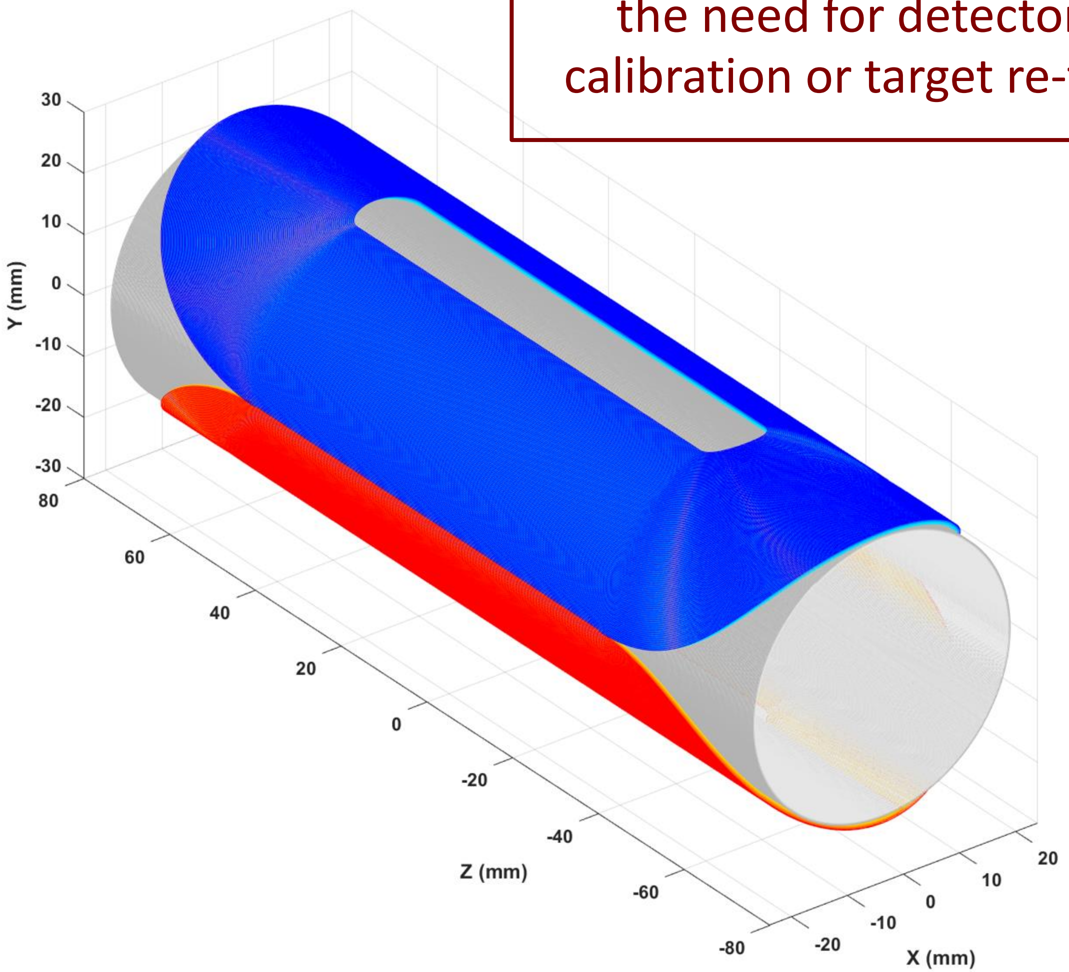
Longitudinal Coil:
4 layers, 2400 turns, 0.6 T

Transverse Coil:
4 layers, 845 turns, 0.45 T (@35A)

Approx. 1 week to transition between coils

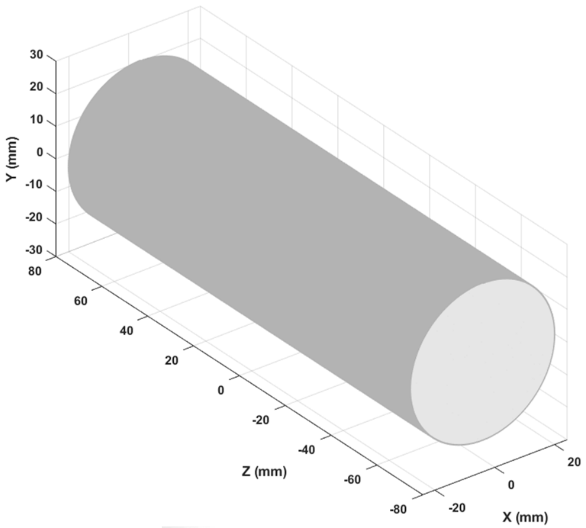
A combined coil would allow for trivial adjustment of polarization orientation without the need for detector re-calibration or target re-tuning

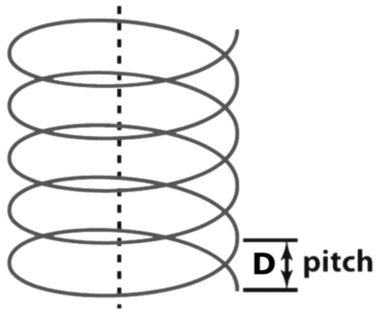




Biot Savart Law

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int_C \frac{I\,d\boldsymbol{\ell} \times \mathbf{r}'}{|\mathbf{r}'|^3}$$

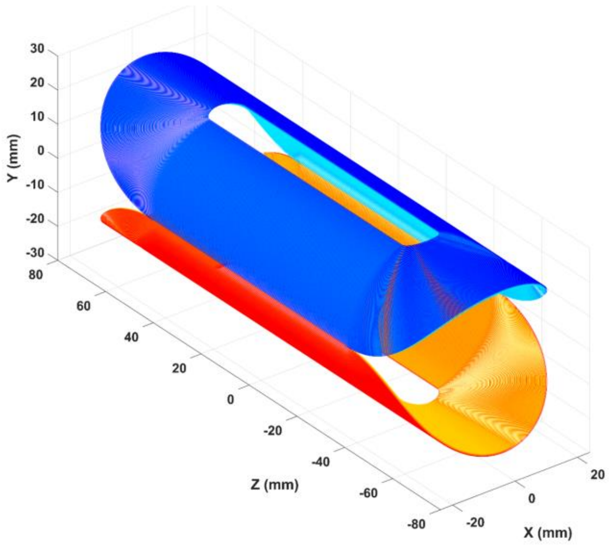


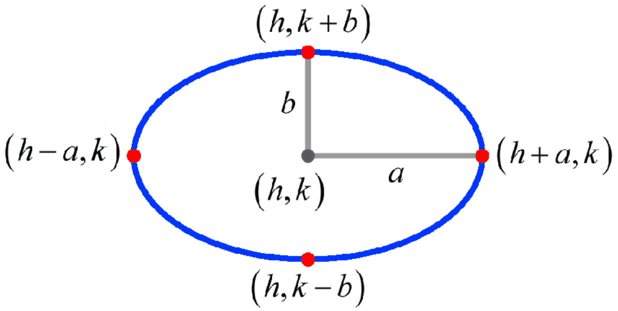


$$y = R\sin(\theta)$$
$$x = R\cos(\theta)$$

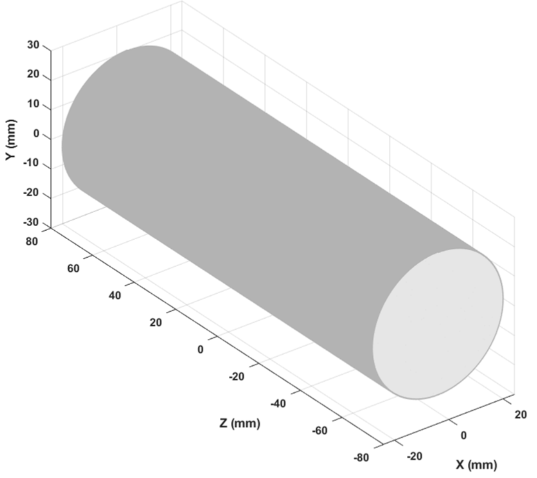
$$z = D\left(\frac{\theta}{2\pi}\right) + z_0$$

$$z = a\sqrt{1 - \left(\frac{\theta - k}{b}\right)^2} + h$$



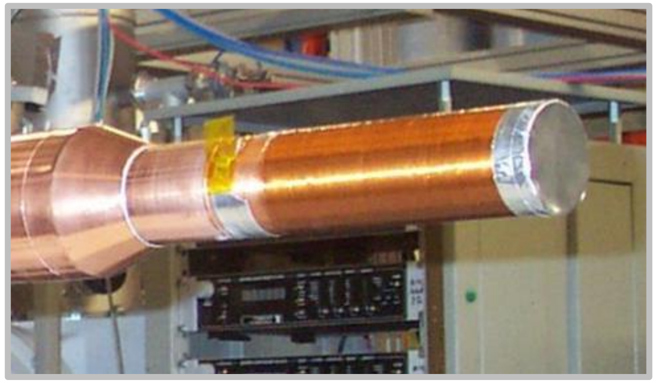


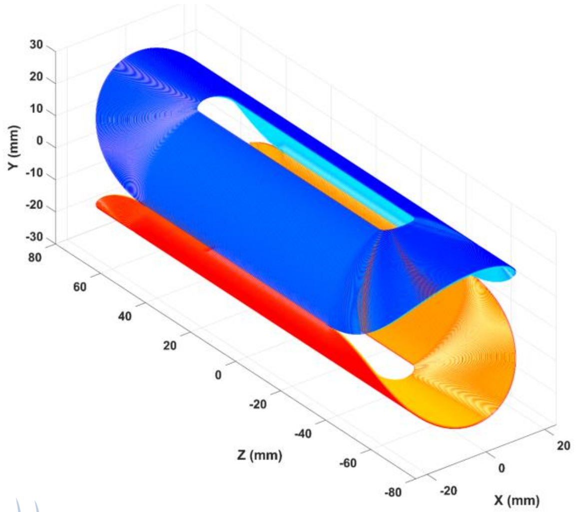
Goal: Minimize radiation length while maintaining sufficient field strength



Solenoid - Two options:

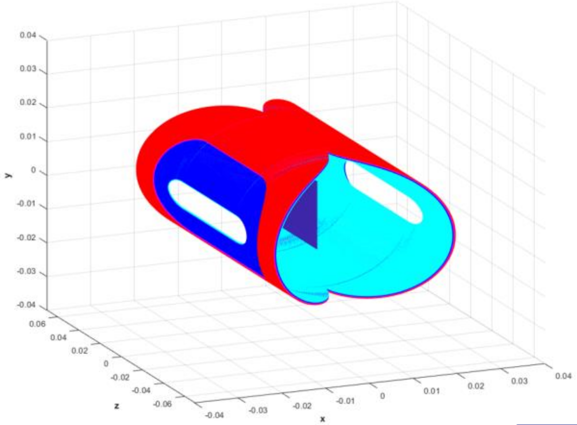
- 3 layers (0.5 T, 0.63 mm)
- 2 layers (0.4 T, 0.45 mm)

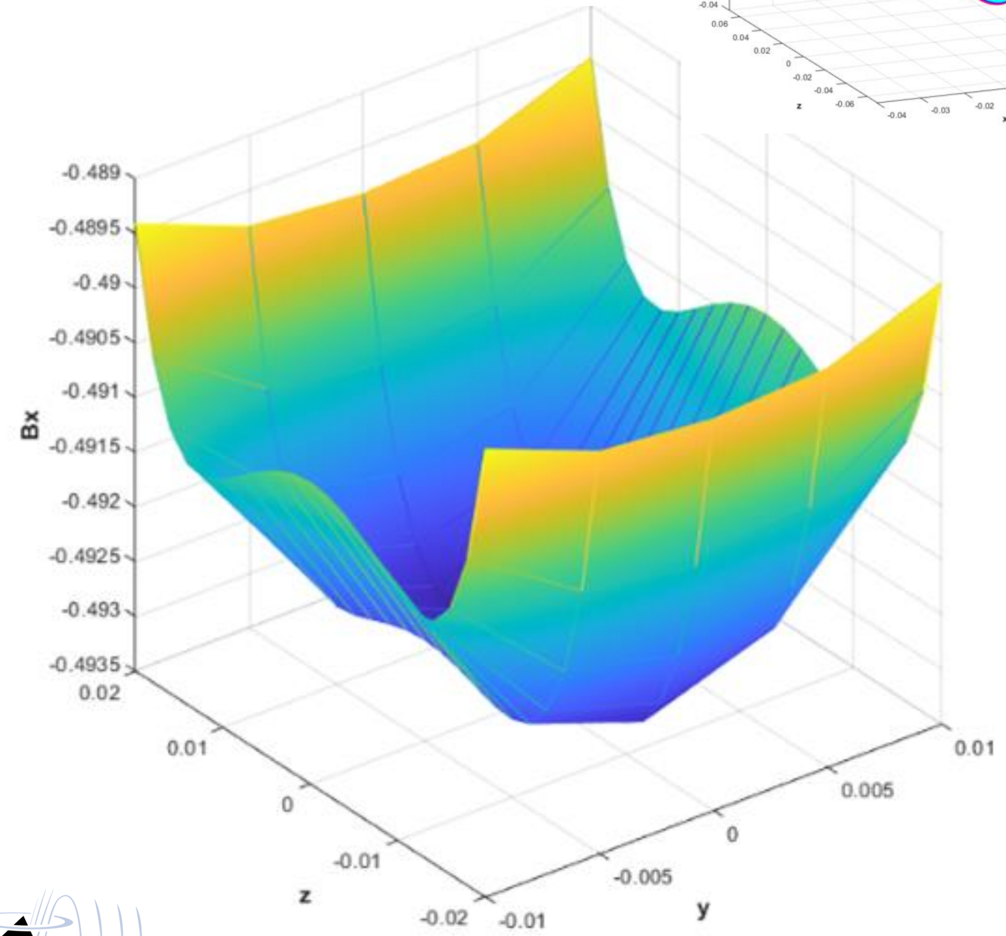




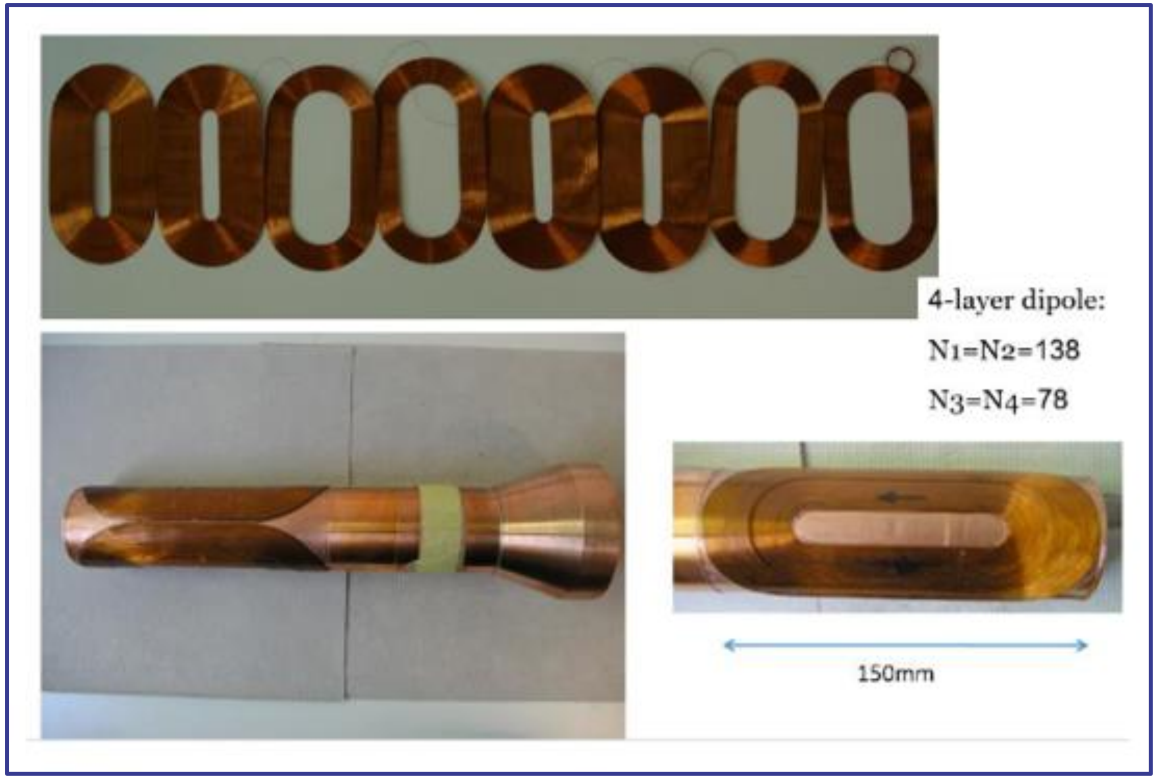
Saddle Coil:

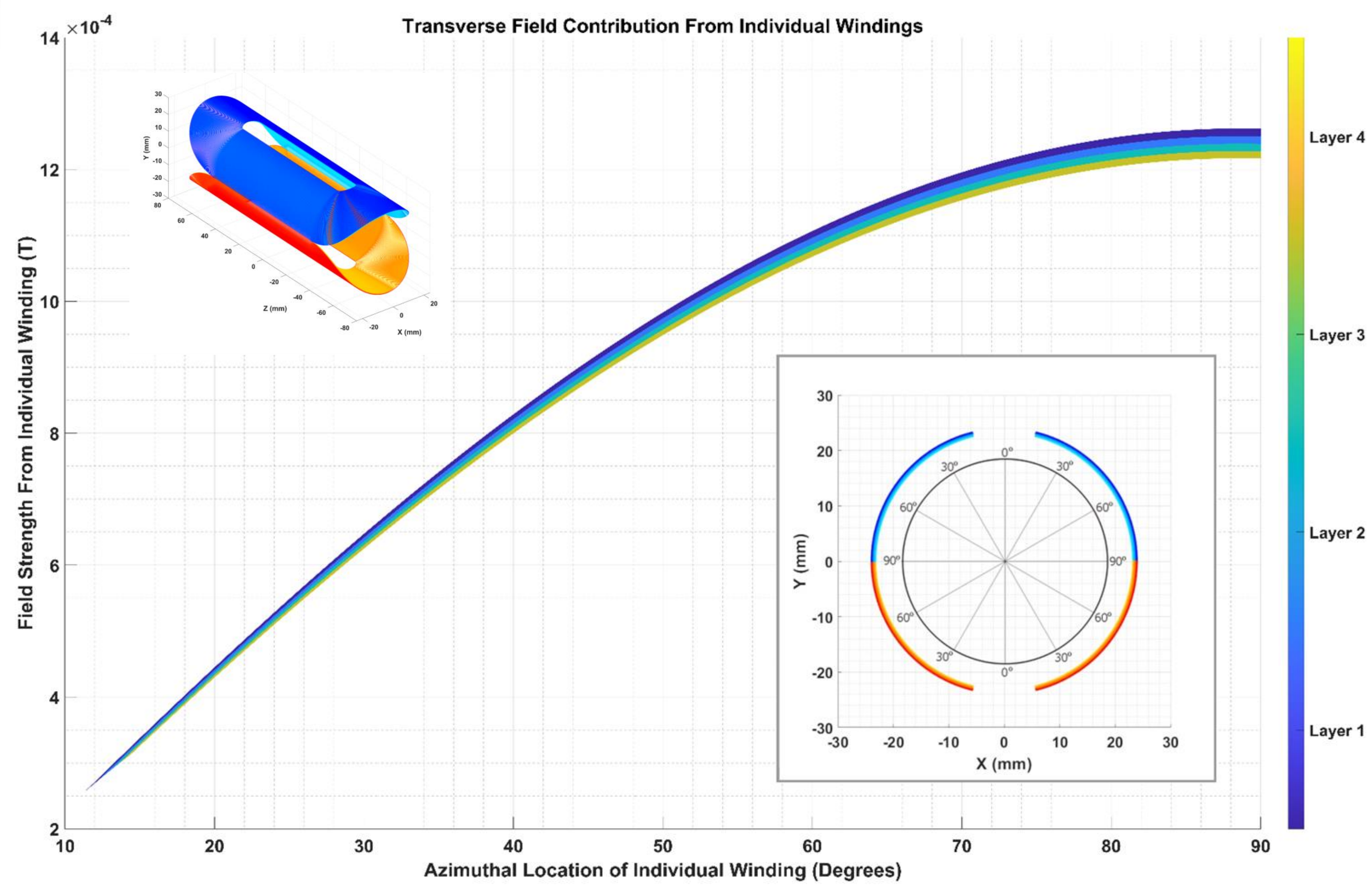
?...



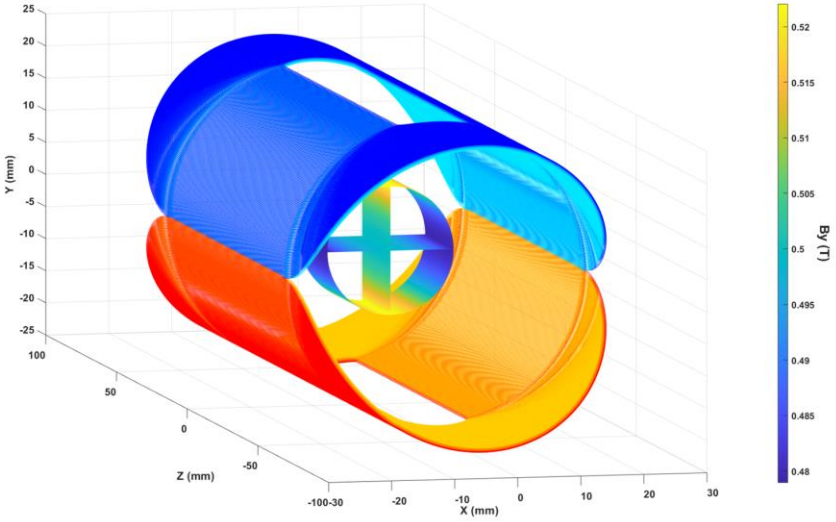


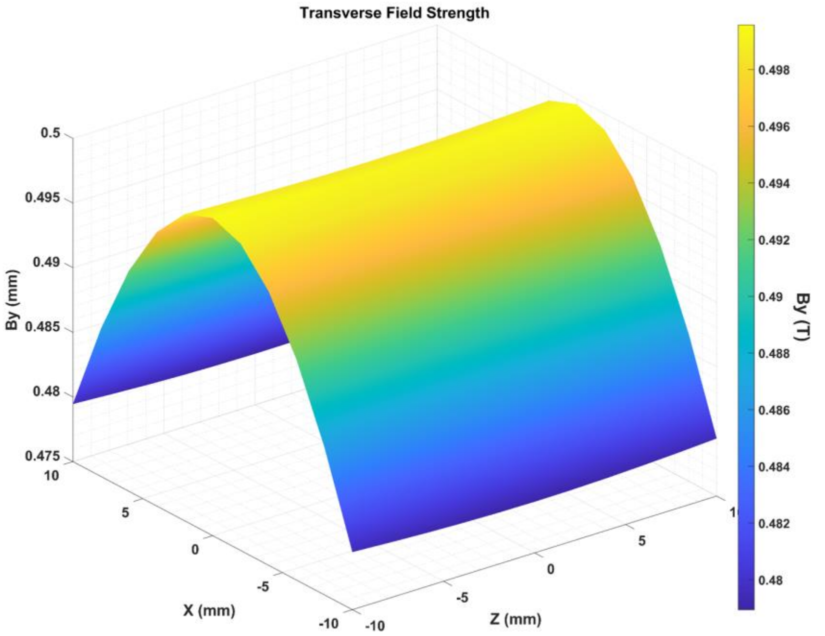
Original coil designed to optimize field homogeneity - not maximum field or material budget.





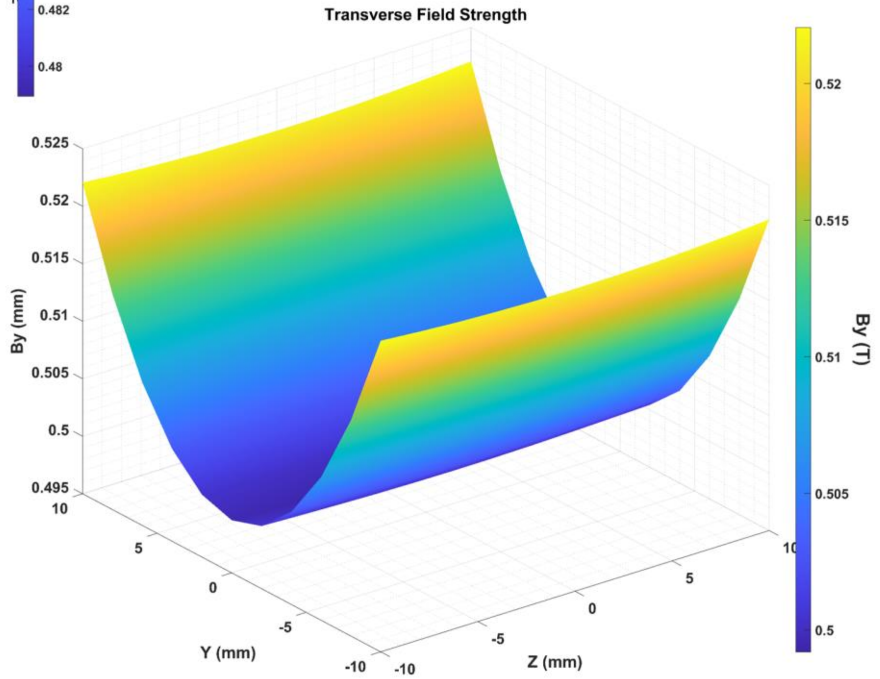
Transverse Field Contribution From Individual Windings
Field Strength From Individual Winding (T)
×10^-4
Azimuthal Location of Individual Winding (Degrees)
Layer 4
Layer 3
Layer 2
Layer 1
Y (mm)
X (mm)
Z (mm)





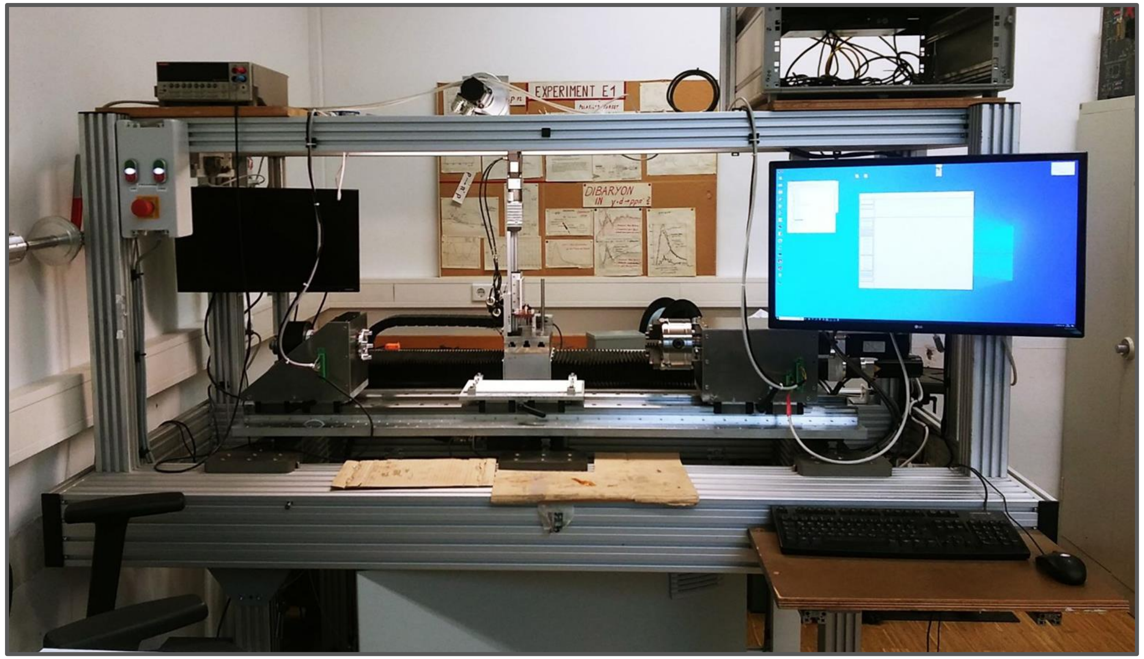
Saddle Coil - Two options:

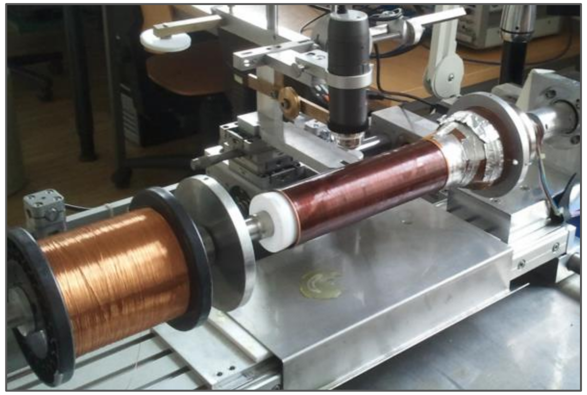
- 3 layers (0.4 T, 0.63 mm)
- 4 layers (0.5 T, 0.92 mm)



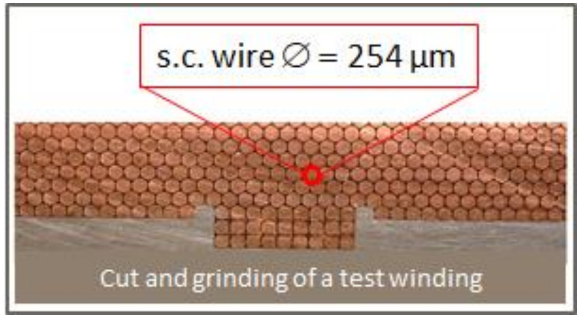
Saddle: 3 layers (0.4 T, 0.63 mm)
Solenoid: 2 layers (0.4 T, 0.45 mm)

Future





Prototype coming soon!



Thank You

POLARIZED TARGET BONN

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