Target Offline Polarization COMPASS 2022

25th iteration of the International Spin Symposium (SPIN 2023)
Duke University - September 24-29

RUHR-UNIVERSITÄT BOCHUM
INSTITUT FÜR EXPERIMENTALPHYSIK I
HADRONENPHYSIK

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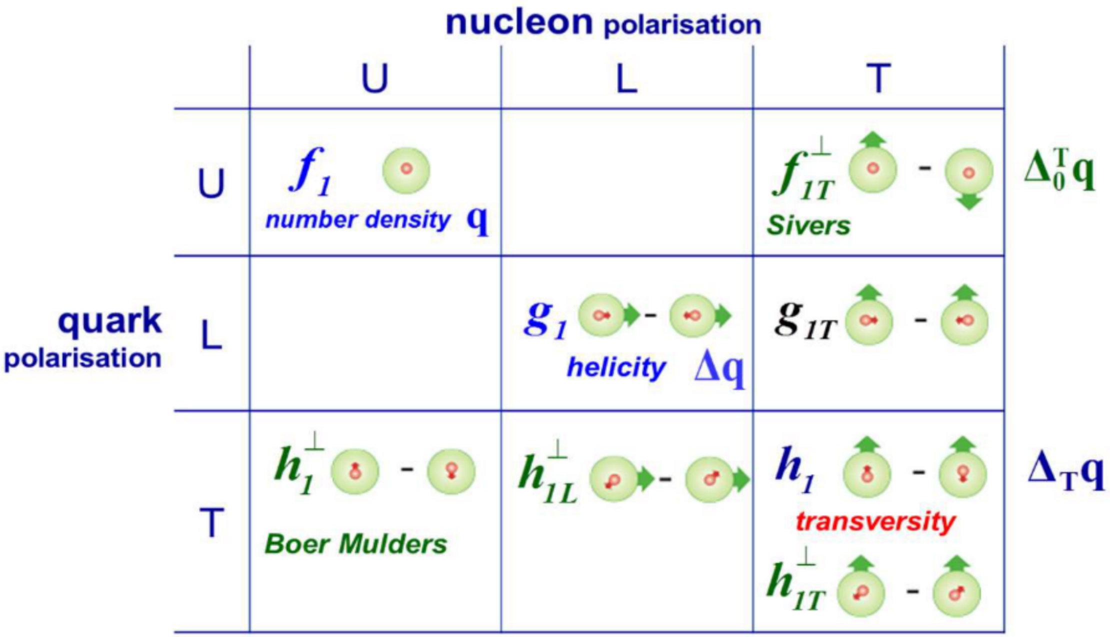
Introduction



SIDIS gives access to all of them

Structure of the nucleon

- 8 intrinsic transverse momentum dependent PDFs
- Asymmetries with different angular dependences on hadron and spin azimuthal angles, *Φh* and *Φs*

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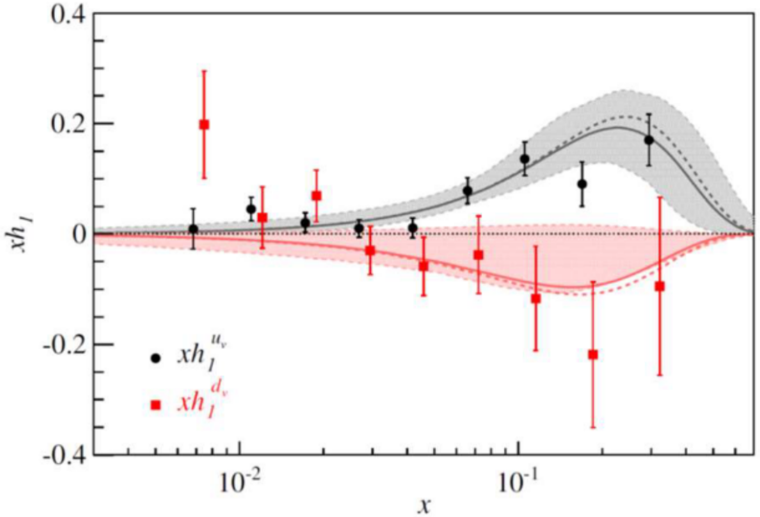
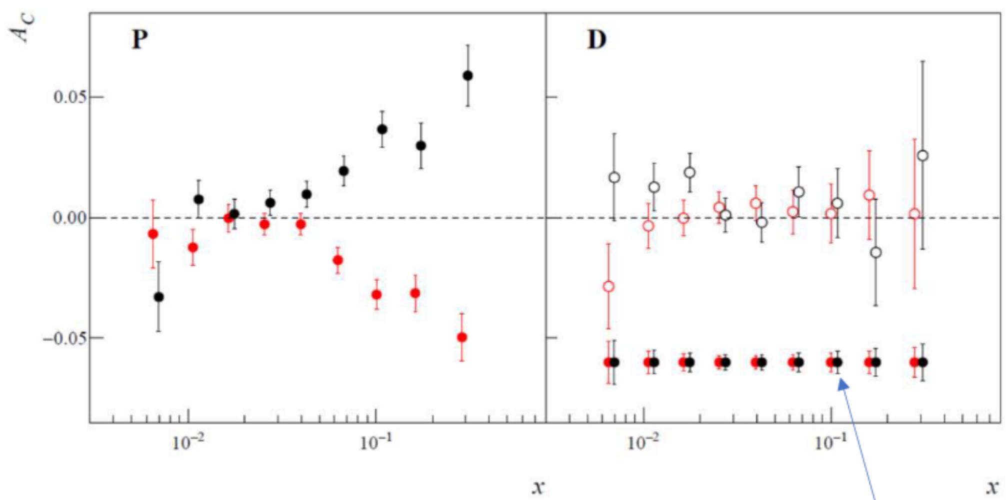
COMPASS 2022 run (d-quark transversity)

The run is aimed at Semi-Inclusive Deep-Inelastic Scattering (SIDIS) of muons off transversely polarized ^{6}LiD target
SIDIS off transversely polarized targets gives access to the transverse spin degrees of freedom of the partons and in particular to the Transversity and Sivers functions

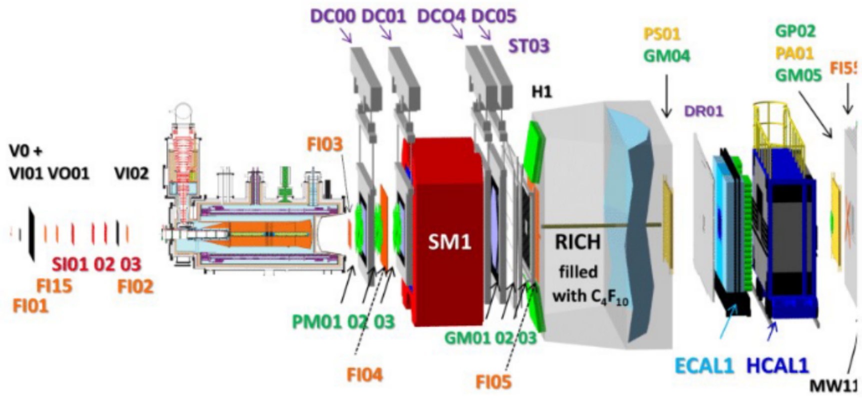


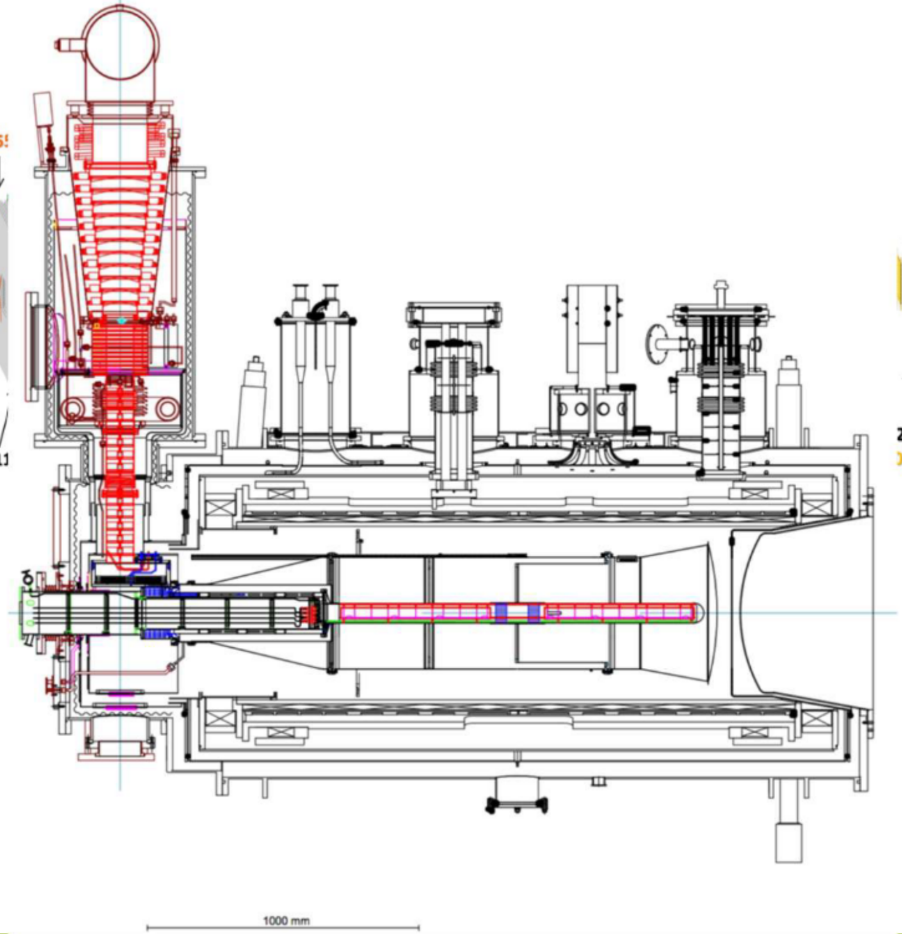


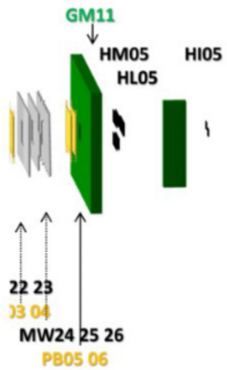
MARTIN, Anna: New measurements of transverse spin asymmetries at COMPASS
PARSAMYAN, Bakur: The COMPASS Spin Program

expected 2022 uncertainties

COMPASS Polarized Target







- 2.5 T solenoid + 0.6 T dipole
- 50 mK dilution refrigerator
- 30+60+30 cm 3 target cells
- ^{6}LiD as deuteron target
- DNP by microwave of 70 GHz
- 10 NMR coils
- Frozen spin mode at 50mK

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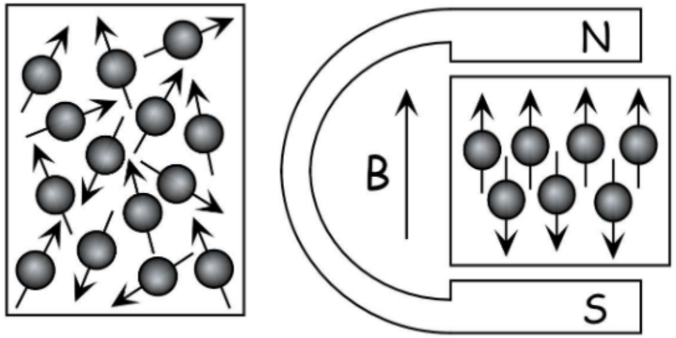
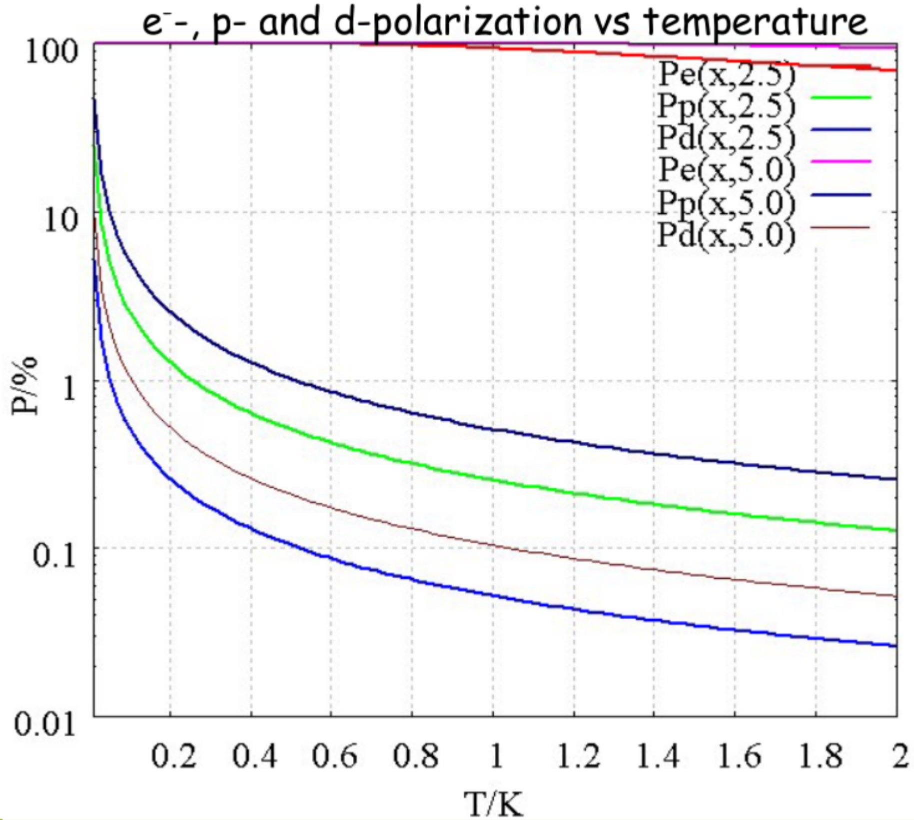
Nucleon Polarization

Polarization = Orientation of Spins in a magnetic field



$$P = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

T=1K	B=2.5 T	B=5T
electron	93.3 %	99.8 %
proton	0.255 %	0.512 %
deuteron	0.052 %	0.105 %

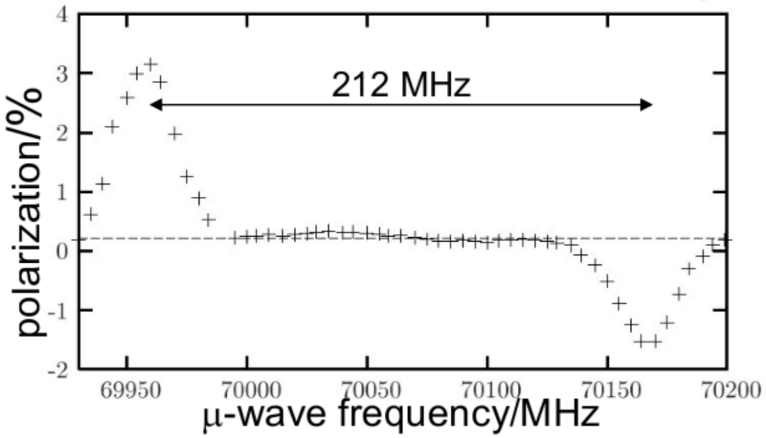


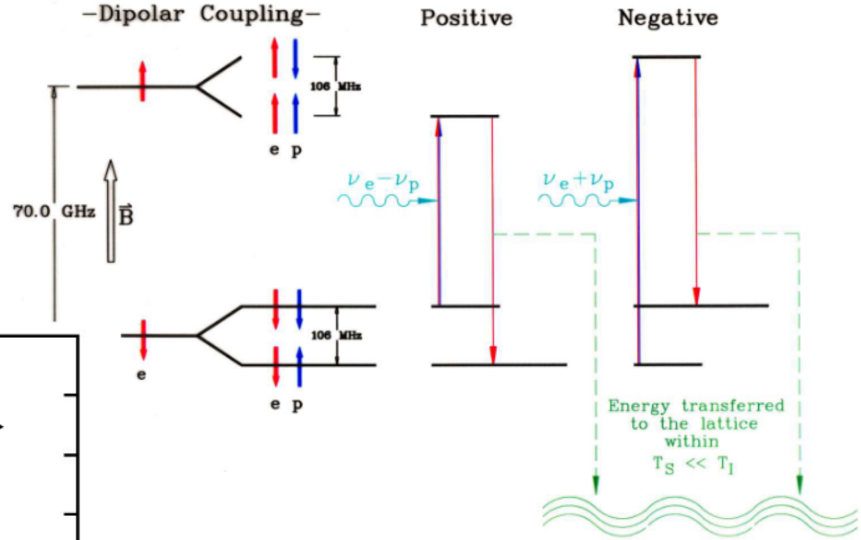
DNP: Solid State Effect(simple)

Idea: Transfer the high $P(e^-)$ to nucleon

B = 2.5T

H-Propanediol with Trityl-Radical





B = 2.5T and T=1K

T_1^{e-} = ms to sec

T_1^{p} = min to hours

$$|P_{max}| < \frac{|P_{TE,e}|}{1+f} \quad \text{mit} \quad f = \frac{N_I}{N_e}\frac{t_{1e}}{t_{1n}}$$

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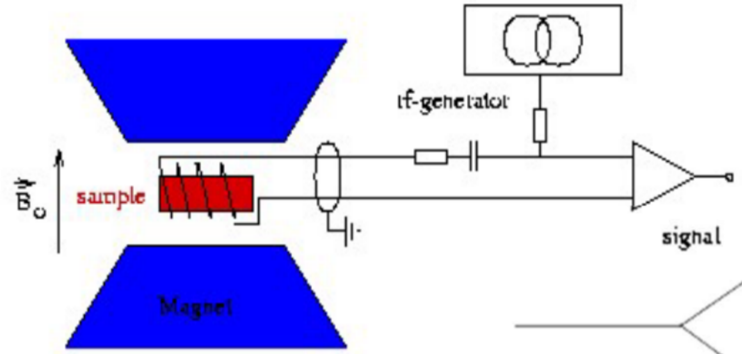
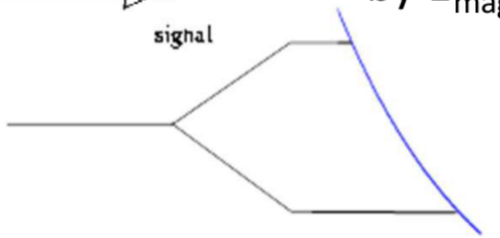
Nuclear Magnetic Resonance NMR



Applying a static magn. field B_0 to a spin ensemble leads to a degeneration into 2s+1 sublevels, the shift of the sublevels is given by $E_{magn}(m) = m \hbar \omega_L$ (ω_L: Larmor-frequency)

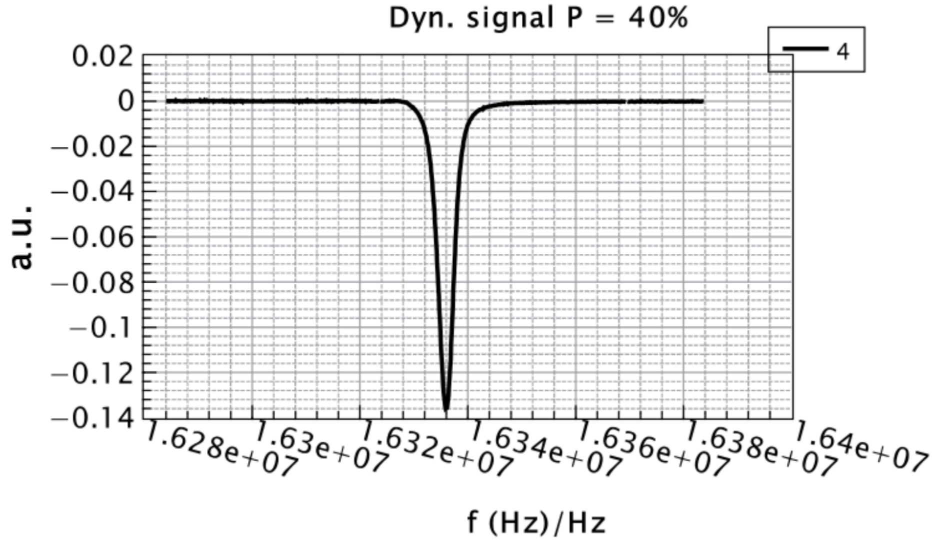


$$N_m \propto \exp\left[-E_{magn}(m)/K_B T\right]$$

Boltzmann-distribution among the m-sublevels:

$$P := \frac{\langle S_Z \rangle}{S} = \frac{\sum_{m=-s}^{+s} m N_m}{S \sum_{m=-s}^{+s} N_m} \qquad \Rightarrow \langle S_Z \rangle = \frac{\sum_{m=-s}^{s} \hbar m \exp\left[-E_{magn}(m)/K_B T\right]}{\sum_{m=-s}^{s} \exp\left[-E_{magn}(m)/K_B T\right]}$$

TE-method



- Area under signal is proportional to polarization

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

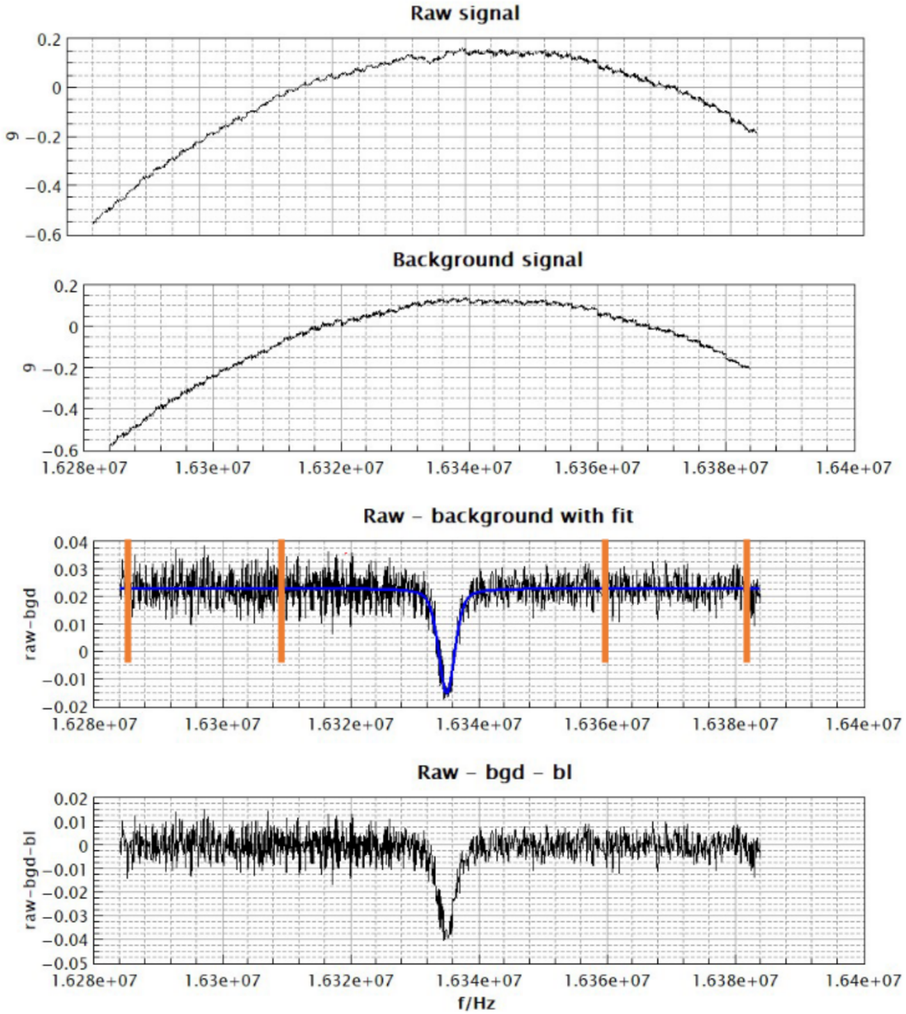
- Constant K needs to be determined for absolute polarization values:
  - Calibration with TE-polarization

$$P_{dyn} = \frac{P_{TE}}{A_{TE}} \cdot A_{dyn} = E \cdot A_{dyn}$$

- P_{TE}: calculated, when sample is in thermal equilibrium
  - Precise measurement of current magnetic field and temperature necessary
- A_{TE}: Signal measurement in thermal equilibrium
- A_{dyn}: Signal area while using DNP
- E: Enhancement factor

Signal analyses

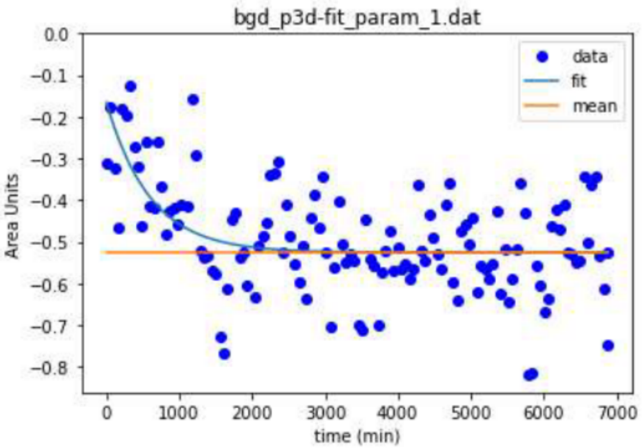
- Sequence of 10 signals and 1 background signal over days
- 10 signals are averaged
- Signals minus averaged last and next background signal
- Analyzed with three different methods
  - Voigt # slightly to small
  - lorentz_complex #area of the signal is overestimated
  - bgd_p3d
    - m1 = 20
    - m2 = 300
    - m3 = 700
    - m4 = 980
  - x0 = 16335000 Hz
  - baseline fit with polynomial 3rd degree is used
- Area is summed up between m2 and m3

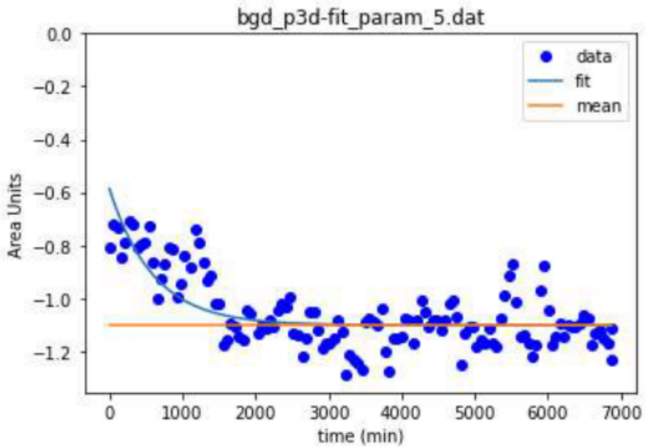


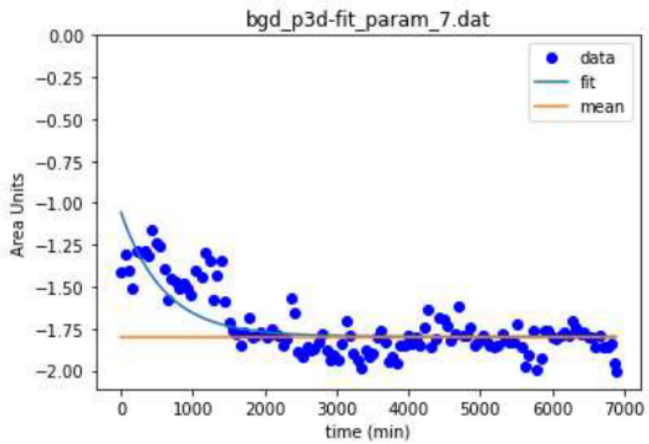
TE build-up curve

- TE build-up curve for every coil and temperature is analyzed
- Mean value is extracted and corresponds the polarization $P_D(T,B)$
- TE is taken for three different temperatures in April 2022
- In November 2022 an additional TE for T=0.99 K was taken get changes over the year into account

Examples for TE build-up curves:







TE Calibration

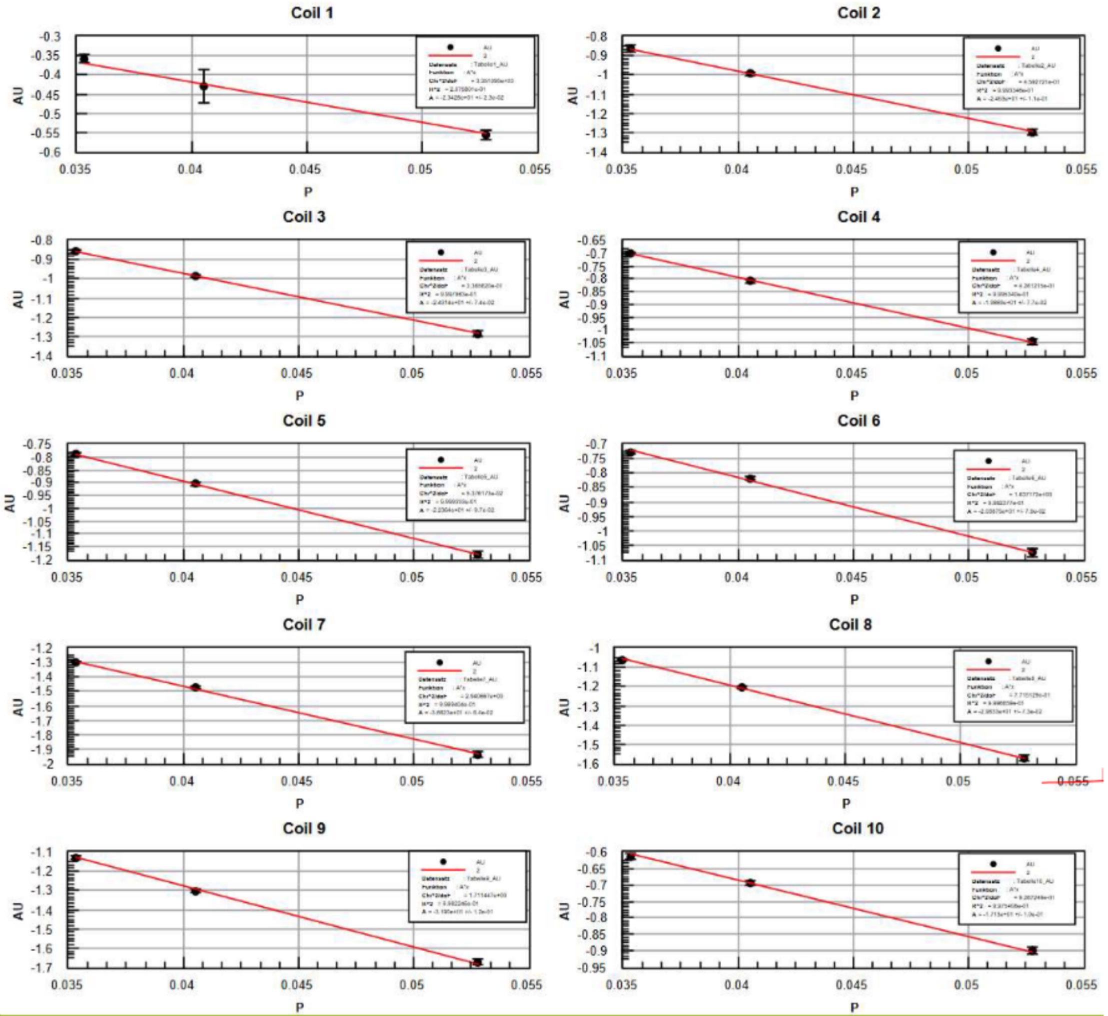
1. 14.04.2022 15:00 - 17.04.2022 13:00 T = 1.48 K
2. 17.04.2022 13:00 - 20.04.2022 14:30 T = 1.29 K
3. 20.04.2022 14:40 – 25.04.2022 10:00 T = 0.99 K

   ...

4. 13.11.2022 20:00 – 19.11.2022 09:20 T = 0.99 K

DC-Offset-Card-Gain = 206

Coil	1/E	d1/E	d1/Erel	E	dE
1	-10.47	0.12	-1.2	-0.09548	0.0011
2	-24.53	0.11	-0.47	-0.04077	0.00019
3	-24.31	0.074	-0.3	-0.04113	0.00013
4	-19.87	0.077	-0.39	-0.05033	0.0002
5	-22.36	0.097	-0.43	-0.04472	0.00019
6	-20.39	0.079	-0.39	-0.04905	0.00019
7	-36.62	0.084	-0.23	-0.0273	6.3e-05
8	-29.83	0.073	-0.25	-0.03352	8.2e-05
9	-31.9	0.12	-0.37	-0.03135	0.00012
10	-17.13	0.1	-0.59	-0.05836	0.00034



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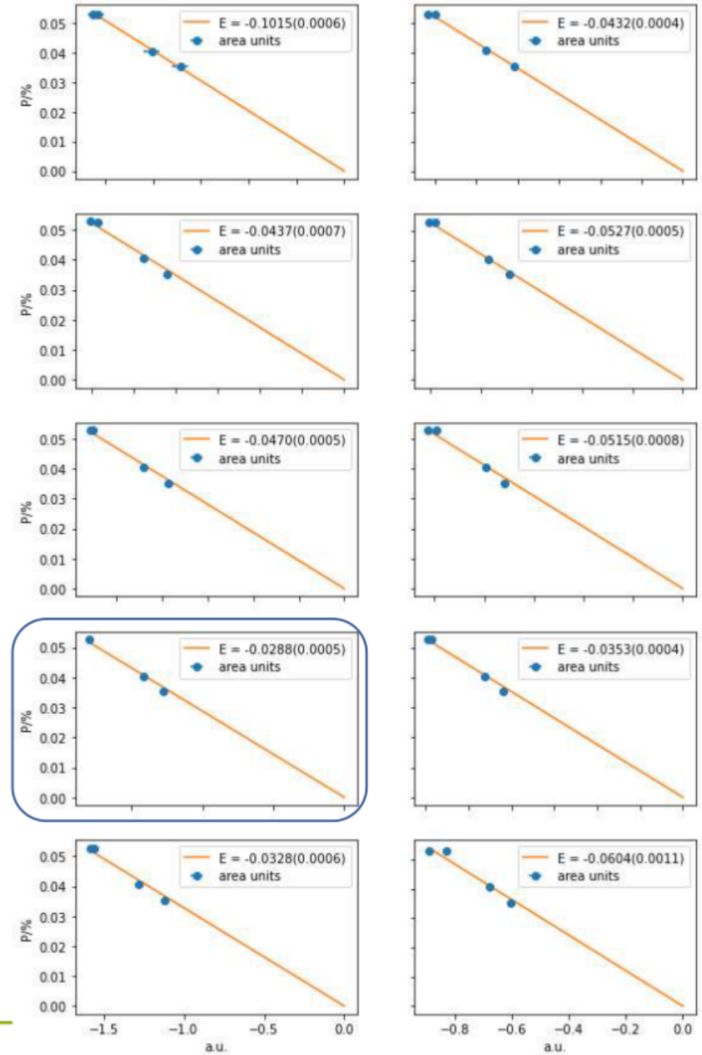
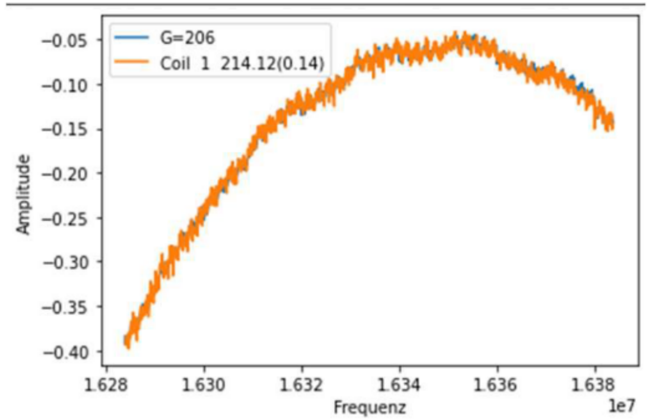
Both TE together

Coil	E	dE
1	-0.10150	0.00064
2	-0.04317	0.00036
3	-0.04373	0.00065
4	-0.05273	0.00048
5	-0.04705	0.00050
6	-0.05151	0.00080
7	-0.02878	0.00049
8	-0.03532	0.00045
9	-0.03284	0.00056
10	-0.06040	0.00115



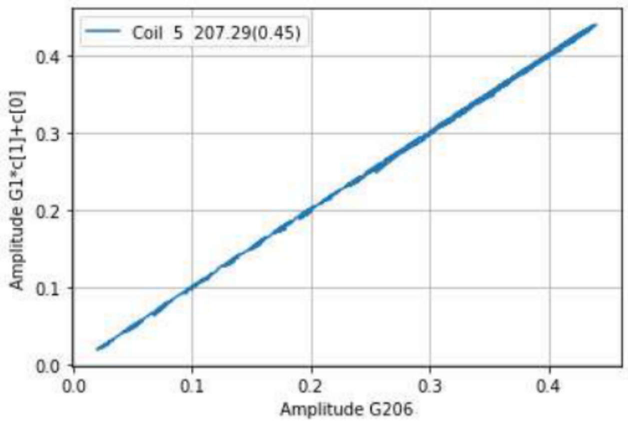
E is the slope of P vs area units

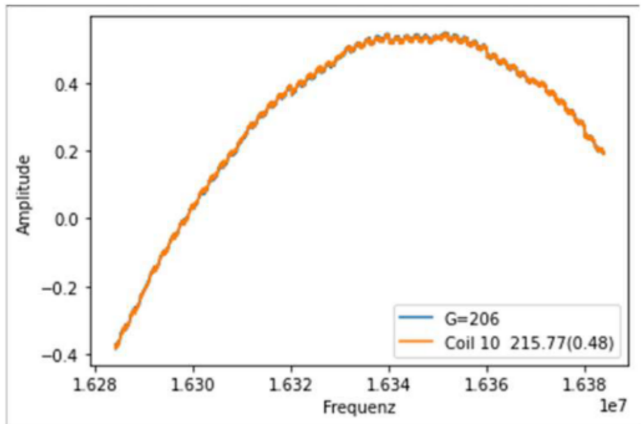
Uncertainties Gain “206”



TE is measured with an additional amplifier
Amplification is measured by comparing Q-curve at gain 1 and gain 206
Both curves are compared ; c, stats = P.polyfit(y1,y206,1,full=True)

coil 1 Gain = 214.12 +-0.14
coil 2 Gain = 213.13 +- 0.26
coil 3 Gain = 214.86 +- 0.2
coil 4 Gain = 214.38 +- 0.31
coil 5 Gain = 207.29 +- 0.45
coil 6 Gain = 208.94 +- 0.33
coil 7 Gain = 216.14 +- 0.32
coil 8 Gain = 211.61 +- 0.55
coil 9 Gain = 211.09 +- 0.97
coil 10 Gain = 215.77 +- 0.48





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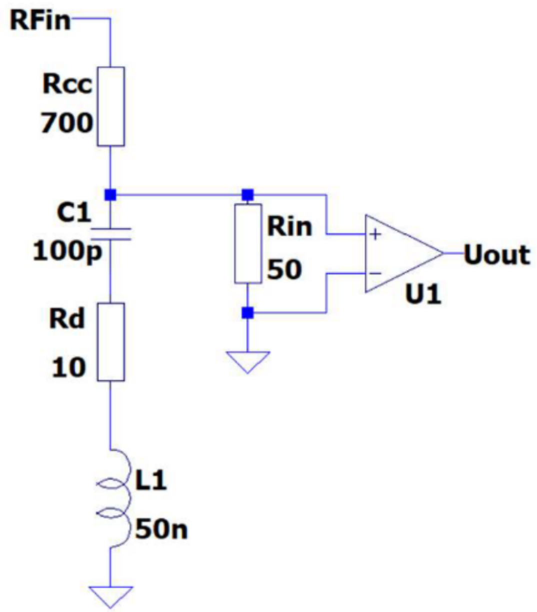
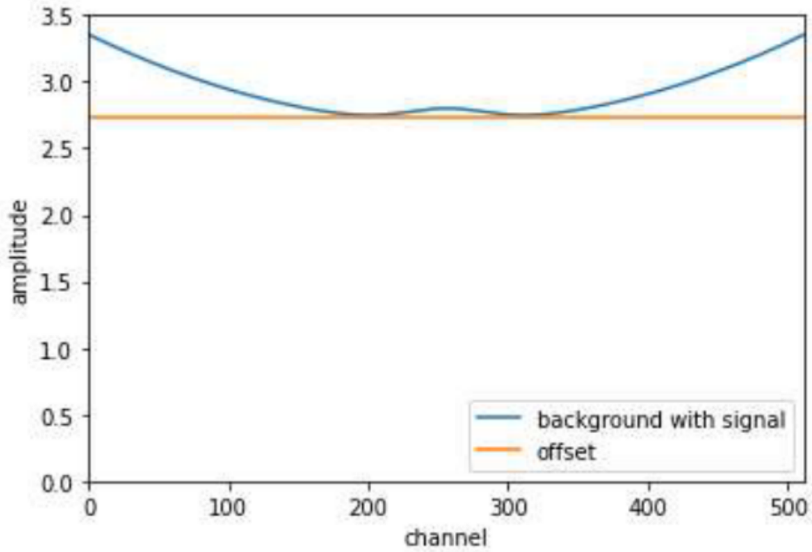
Modulation definition

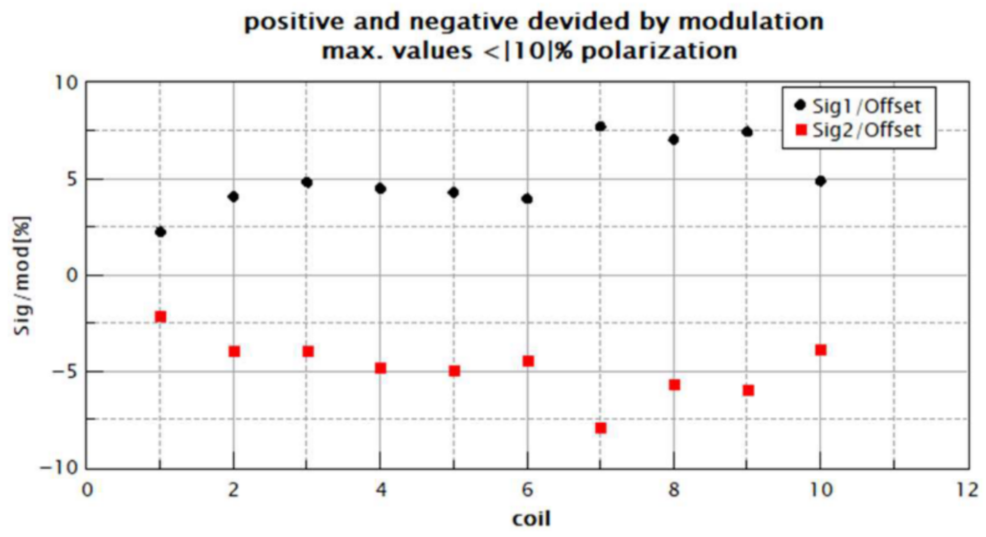




$$M = \frac{signal\ hight}{offset}$$

Modulation ratio (signal height / q-curve offset)

coil	dc-offset	sig1	sig2	sig1/dc	sig2/dc
	V	V	V	%	%
1	3.05	0.06789	-0.0651	2.23	-2.13
2	2.99	0.1218	-0.1179	4.07	-3.94
3	2.71	0.1304	-0.1062	4.81	-3.92
4	2.34	0.1051	-0.1127	4.49	-4.82
5	2.36	0.1011	-0.1174	4.29	-4.97
6	2.49	0.09854	-0.1117	3.96	-4.49
7	2.61	0.2016	-0.2078	7.72	-7.96
8	2.54	0.1786	-0.1453	7.03	-5.72
9	2.42	0.18	-0.1444	7.44	-5.97
10	2.18	0.1065	-0.08466	4.88	-3.88



Uncertainties caused by modulation distortion less than 0.5%

Additional uncertainties

- Temperature over target during TE measurement ~2 %
- Enhancement dE ~1.5 %
- B-Field (0.01 / 16.5MHz) ~0.06 %
- Gain offset-card ~0.5 %
- Modulation (signal distortion) ~0.5 %

dP/P = 2.6 % (rel. per coil)

dP/P = 2.6% + std (c1 … c3, c4 … c6(c7), c8 … c10) rel. per cell about 3.2 to 4.3 % rel.

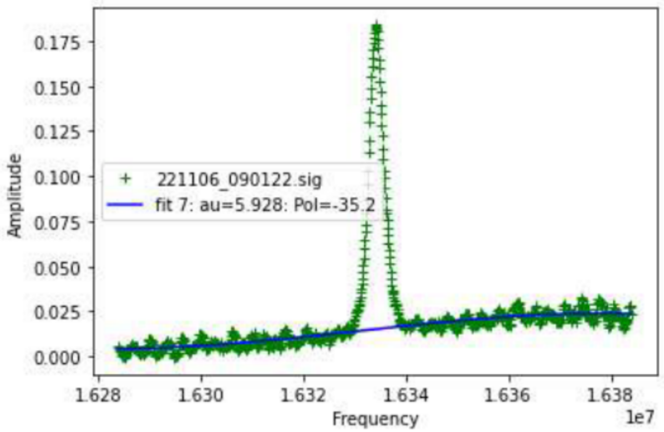
up (c1 … c3) center (c4 … c6(c7)) down (c8 … c10)

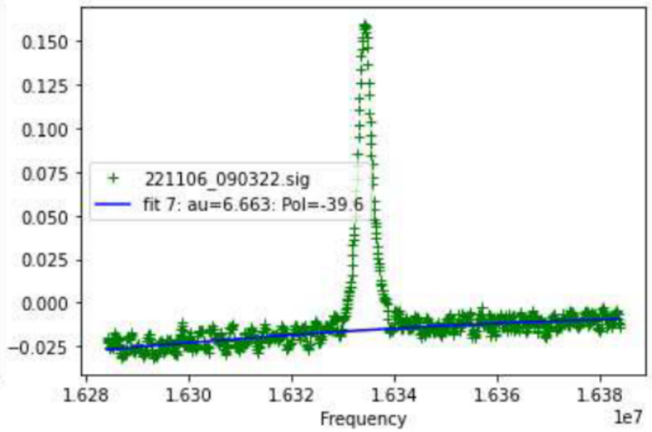
($dP/P = \mathrm{sqrt}(dT^2 + dE^2 + dB^2 + dG^2 + dM^2)$) <- relative uncertainties

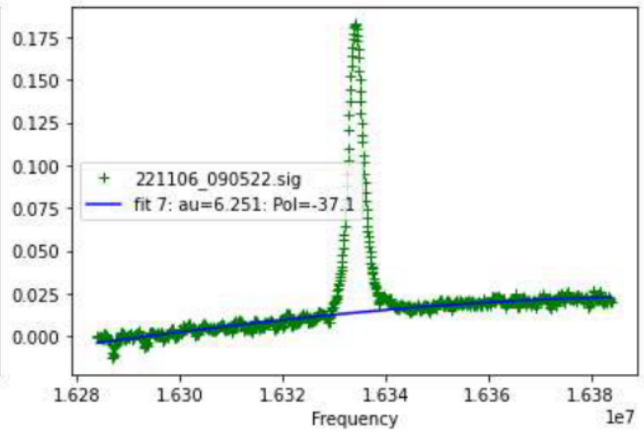
Issues coil 7 beginning on October 20th

From October 20th 2022 coil 7 isn't taken into account because of distortion issues caused by cable problems:

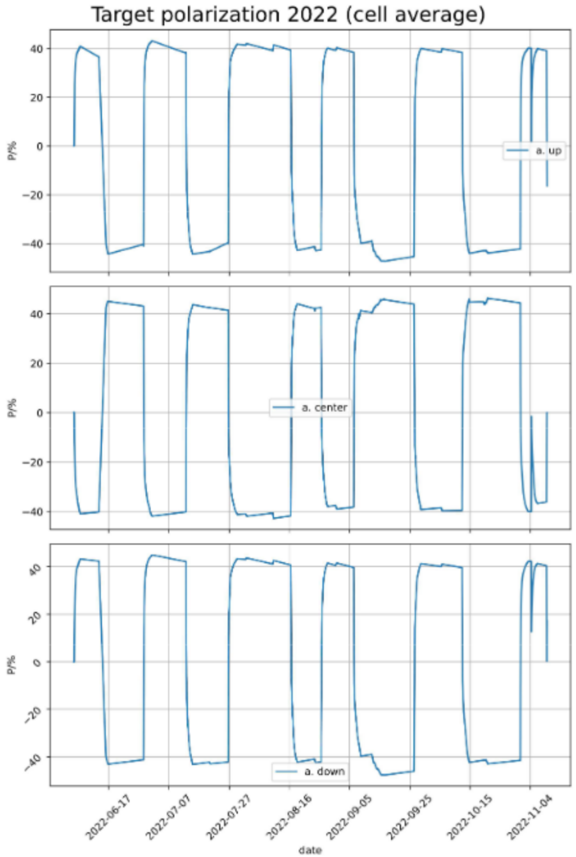
Three consecutive signals are shown here:

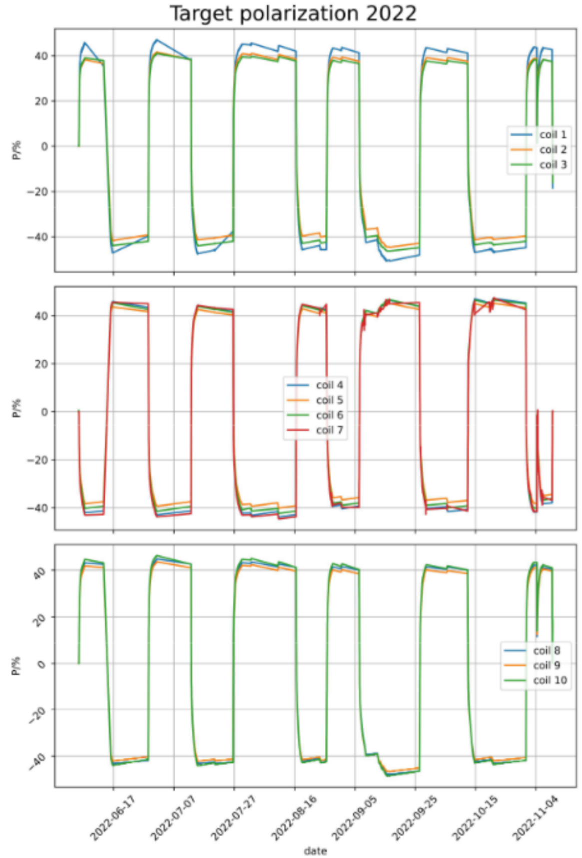






Offline polarization run 2022





Data file format

Data file with polarization values every 10 min
Polarization value during frozen spin interpolated with straight line because of the very long relaxation time

2022-06-24 03:29:20, -41.75, 1.79, 43.91, 1.65, -41.92, 1.34, -40.25, 1.76, 42.36, 1.63, -40.42, 1.31,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0,
-42.43, -40.12, -42.70, 44.39, 42.40, 43.63, 45.22, -42.38, -41.03, -42.36, 0.0

'time', 'u_D','du_D','c_D','dc_D','d_D','dd_D','u_L','du_L','c_L','dc_L','d_L','dd_L',
'u_L7','c_L7','d_L7','u_H','c_H','d_H',
'1','2','3','4', '5','6','7','8','9','10','B'

u_D - upstream cell Deuteron polarization
du_D - error upstream cell Deuteron polarization
....
d_L - Li6 polarization downstream cell
dd_L - err Li6 polarization downstream cell
.....
Li7 polarization and proton polarization is set to 0 with no uncertainty.

Summary

- Maximum average Deuteron polarizations of > |40%| are reached

- Uncertainties
  dP/P = 2.6% + std (c1 … c3, c4 … c6 (c7), c8 … c10)

  up (c1 … c3), center (c4 … c6 (c7)), down (c8 … c10)

  per cell about 3.2 to 4.3 % rel.

- Yuya (student from Yamagata) is doing a cross check analysis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