Polarized Target at COMPASS

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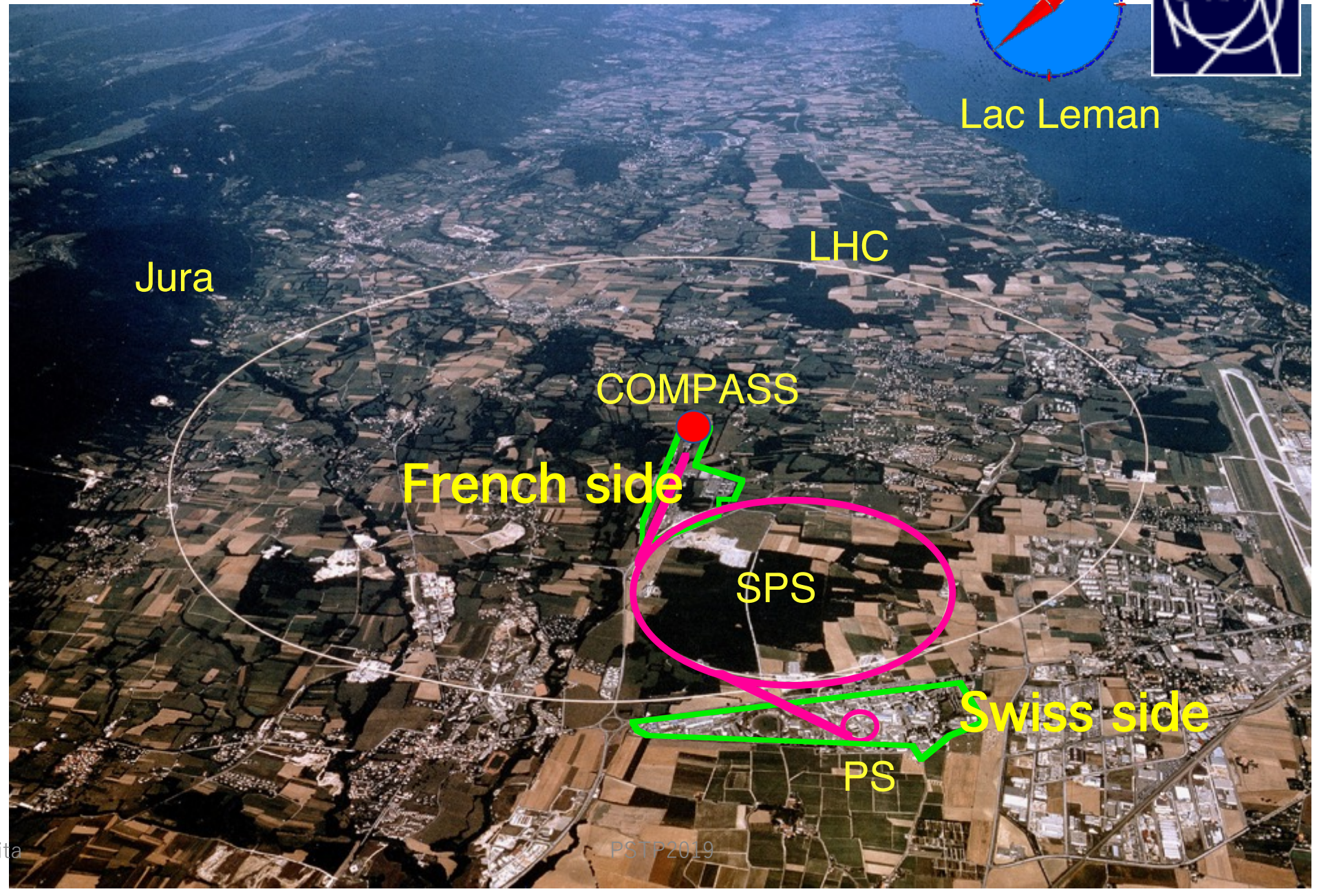
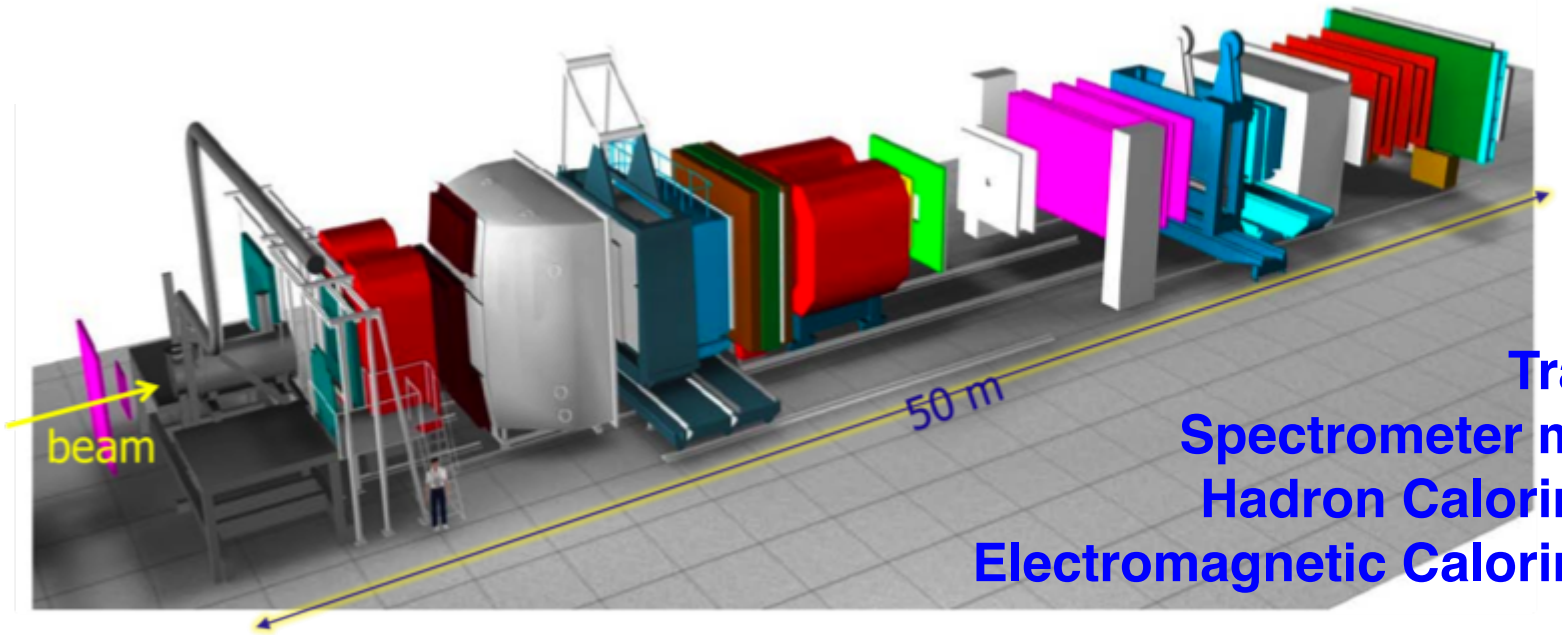
CERN and COMPASS



Outline

- Introduction of physics motivation in the 2018 run
- COMPASS Polarized target system
- Polarization, relaxation time and radiation
- Transversally polarized deuteron target in 2021
- New collaboration for the future : COMPASS++/AMBER

Beam and target with COMPASS spectrometer



Beam :

Polarized lepton beam : μ^+, μ^- 50-280 GeV/c (80% polarization @ 160GeV)

Hadron beam : π^+,π, K^+, K^-,P

Target :

Polarized proton and deuteron target

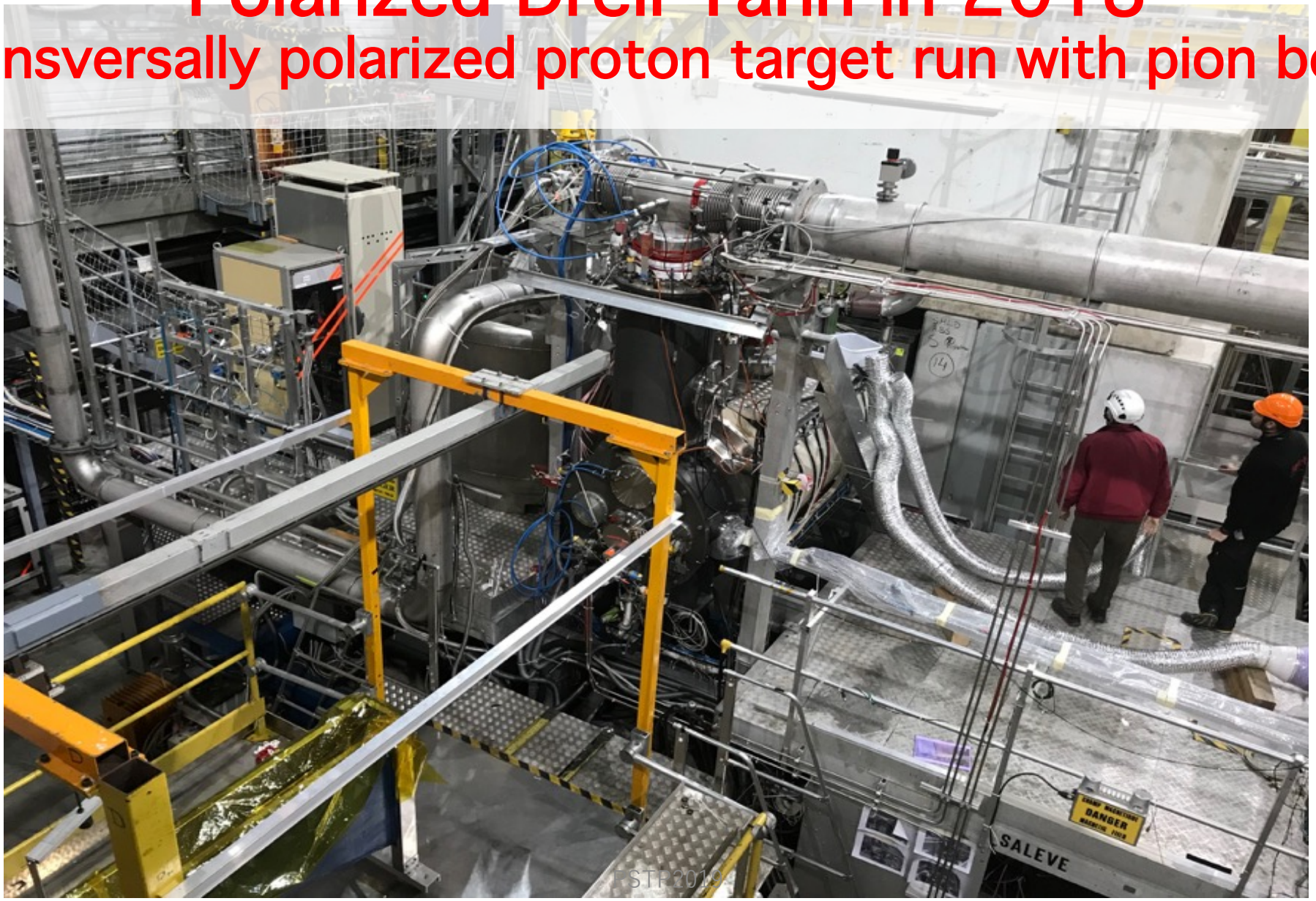
Liquid hydrogen target

Nuclear target

Many combinations of the beam & the target

Polarized Drell-Yann in 2018

Transversally polarized proton target run with pion beam



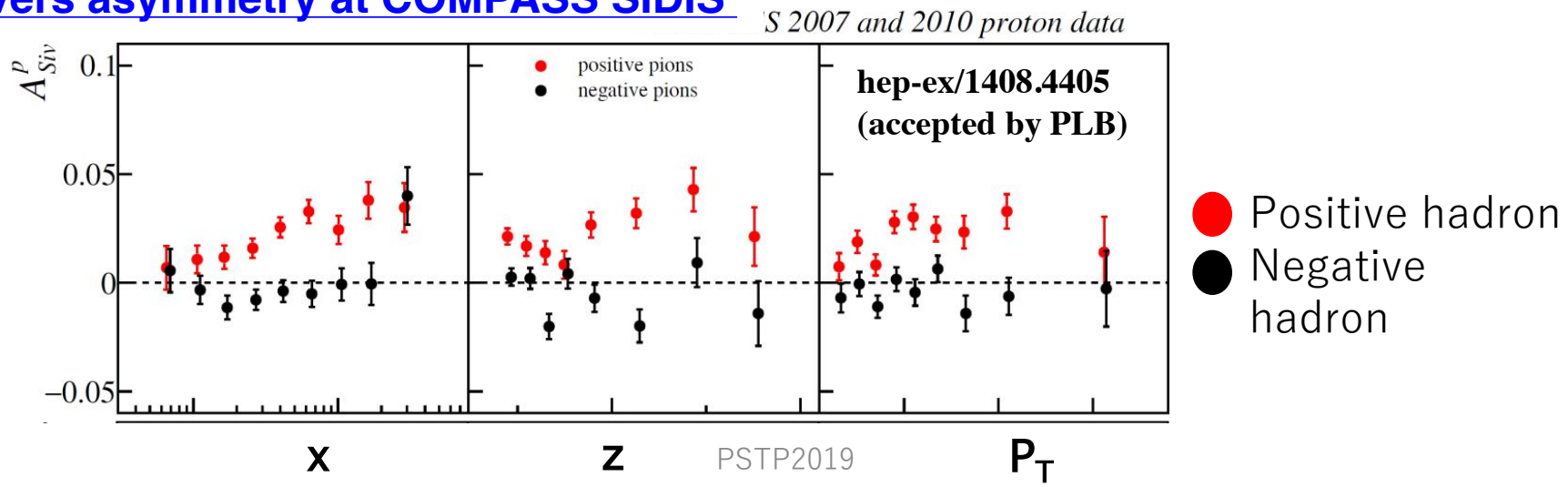
Universality of TMD PDFs

Because Sivers and Boer-Mulders PDFs are “Time-reversal odd”, they are expected to change the sign when measured from SIDIS or from DY:

$$f_{1T}^{\perp}\big|_{DY} = -f_{1T}^{\perp}\big|_{SIDIS} \qquad h_1^{\perp}\big|_{DY} = -h_1^{\perp}\big|_{SIDIS}$$

We have the opportunity to test this sign change using the same spectrometer and the transversely polarized target at COMPASS.

Sivers asymmetry at COMPASS SIDIS



COMPASS polarized solid target system in 2015 and 2018

Transverse polarization

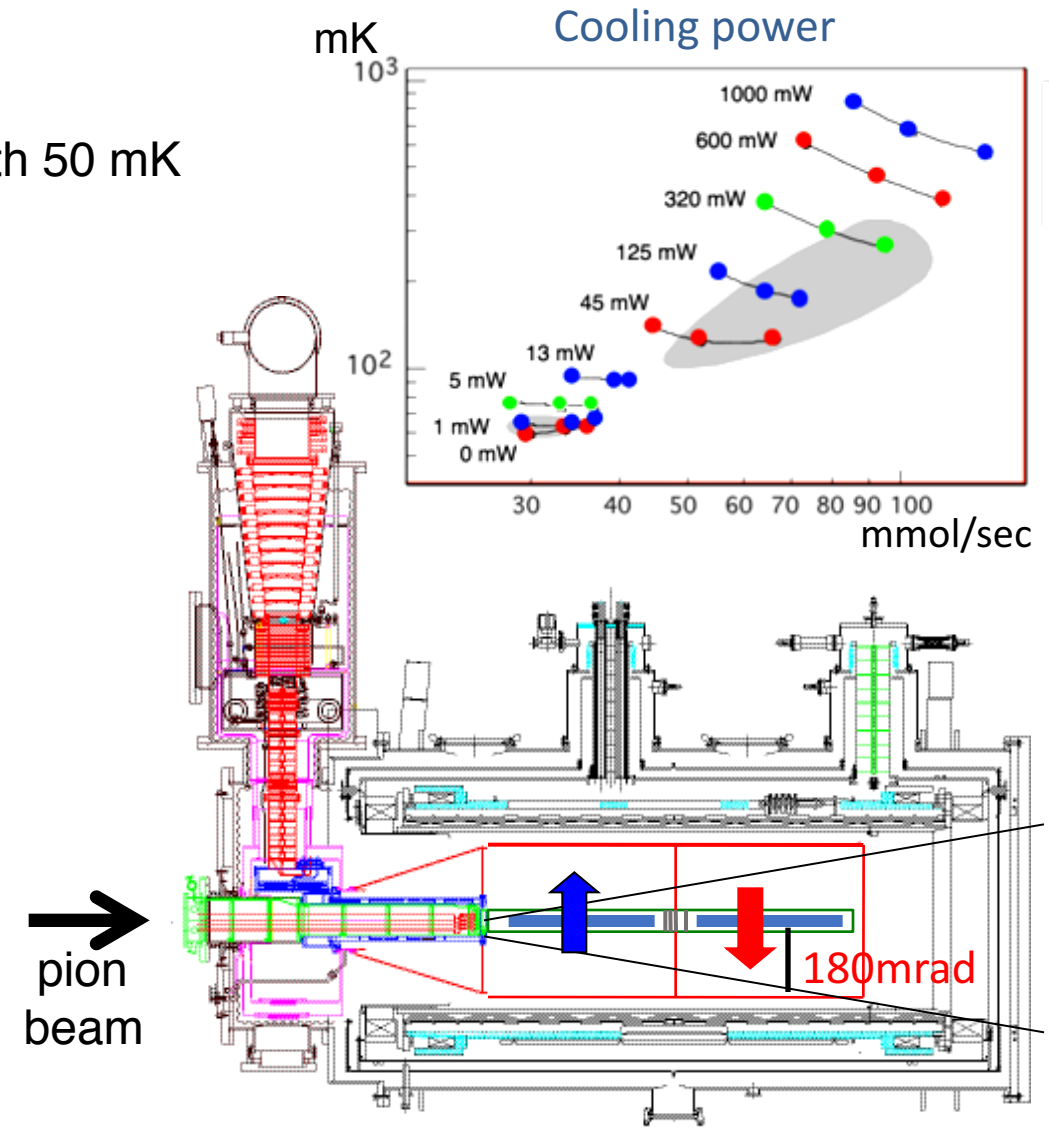
- Frozen spin target at 0.6 T dipole magnet with 50 mK
  (after polarizing at 2.5 T solenoid)

Cooling power

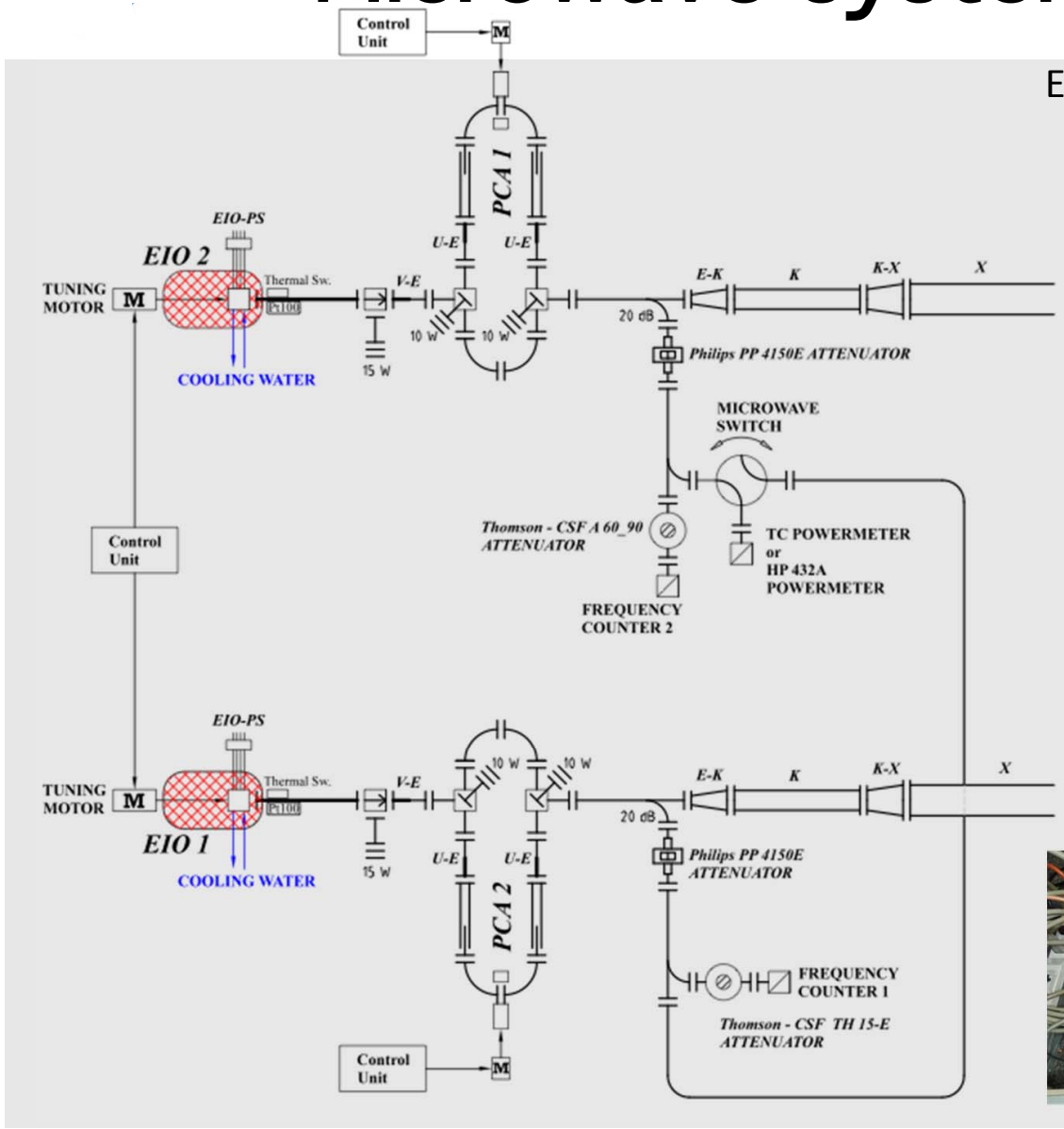
- Many secondly particles
- ~10 mW heat input expected
  with 1 x 10^8 pions/s
- 13 mW cooling power at 100mK

Target cell

- Target area: 130 cm long
- 2 cells (55, 55 cm long with 4 cm diameter)
  20 cm gap
- NH3 material with 10 NMR coils

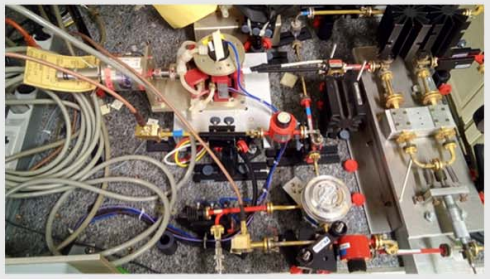


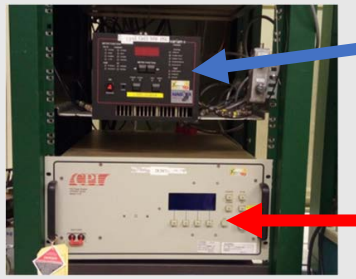
Microwave system for DNP



Equipment

- M.W. generator **70 GHz**
  extended interaction oscillator , 20 W
- Power supplies
  - Varian VPW2838 and → FM function
    CPI VPW2827 → Without FM
- Power control
- Frequency counters
  - Phase Matrix EIP-548-B
- Power meter
  - Millitech DET-12-RPFW0



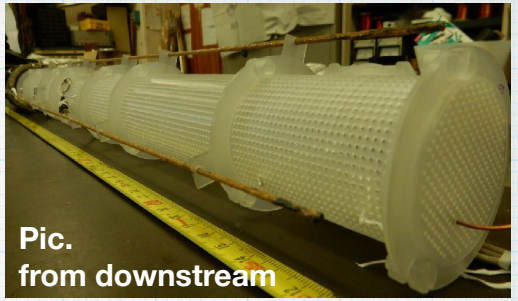


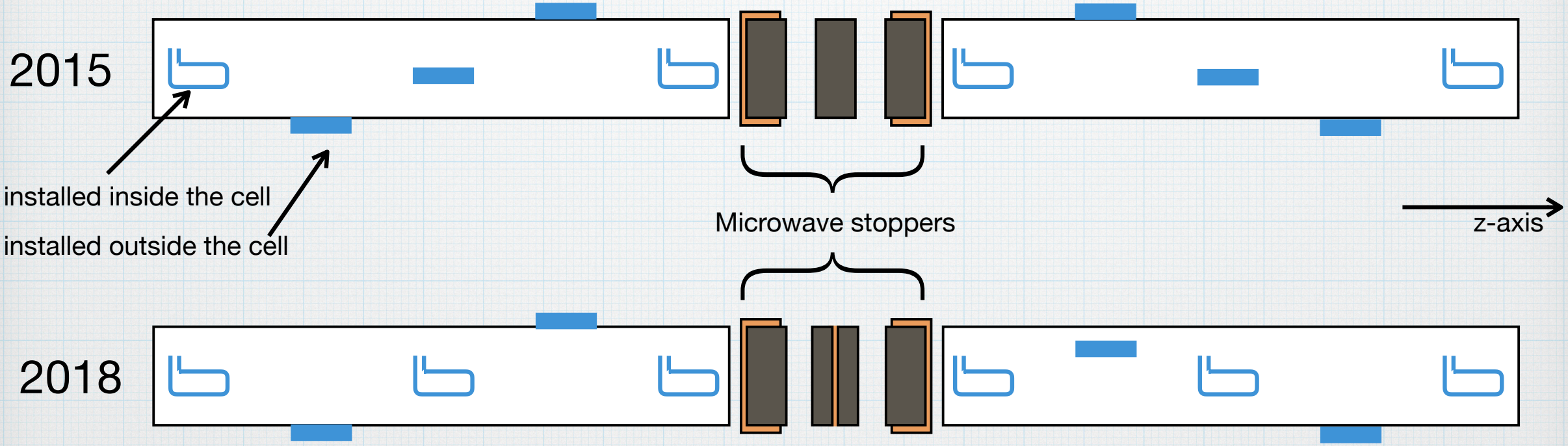
Varian

CPI

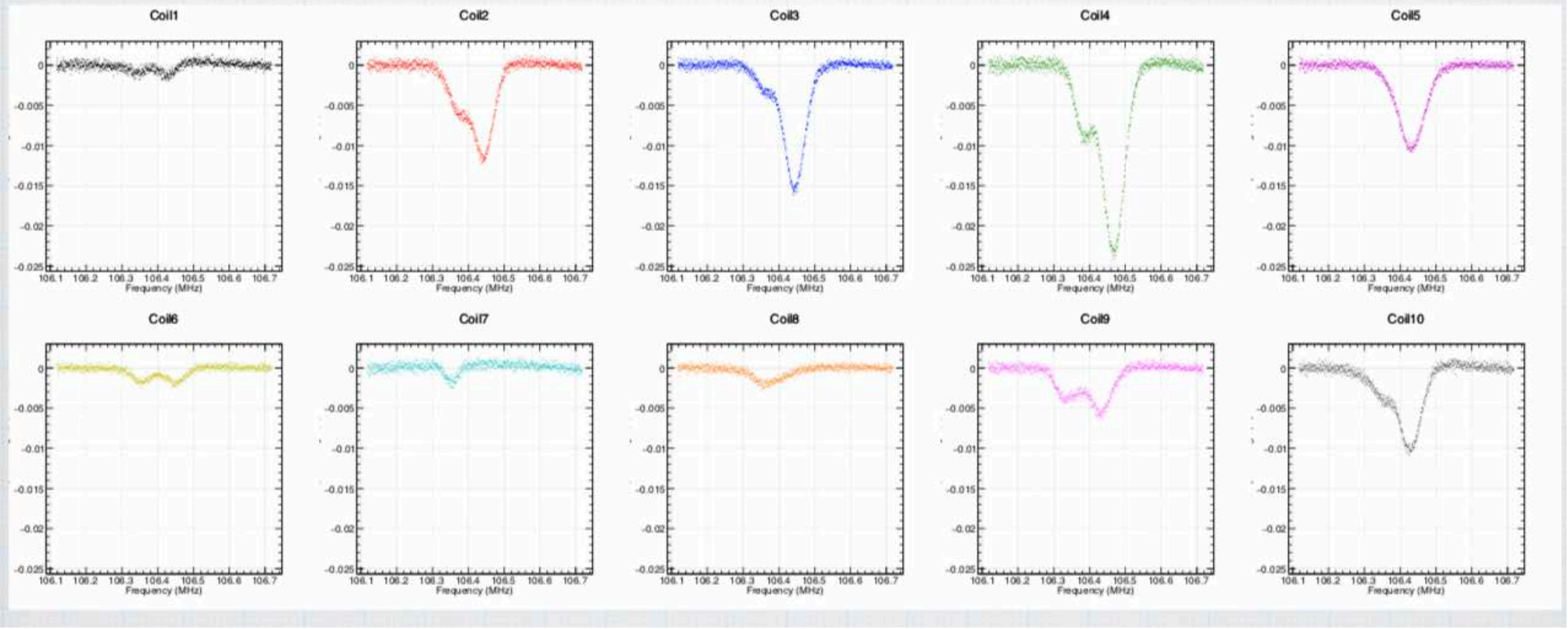
Target cells and NMR coils

- 2 sets of 55cm long with 4cm diameter
- Proton free material (C2F3Cl)n
- 2015 : 4 inner and 6 outer coils
- 2018 : 6 inner and 4 outer coils





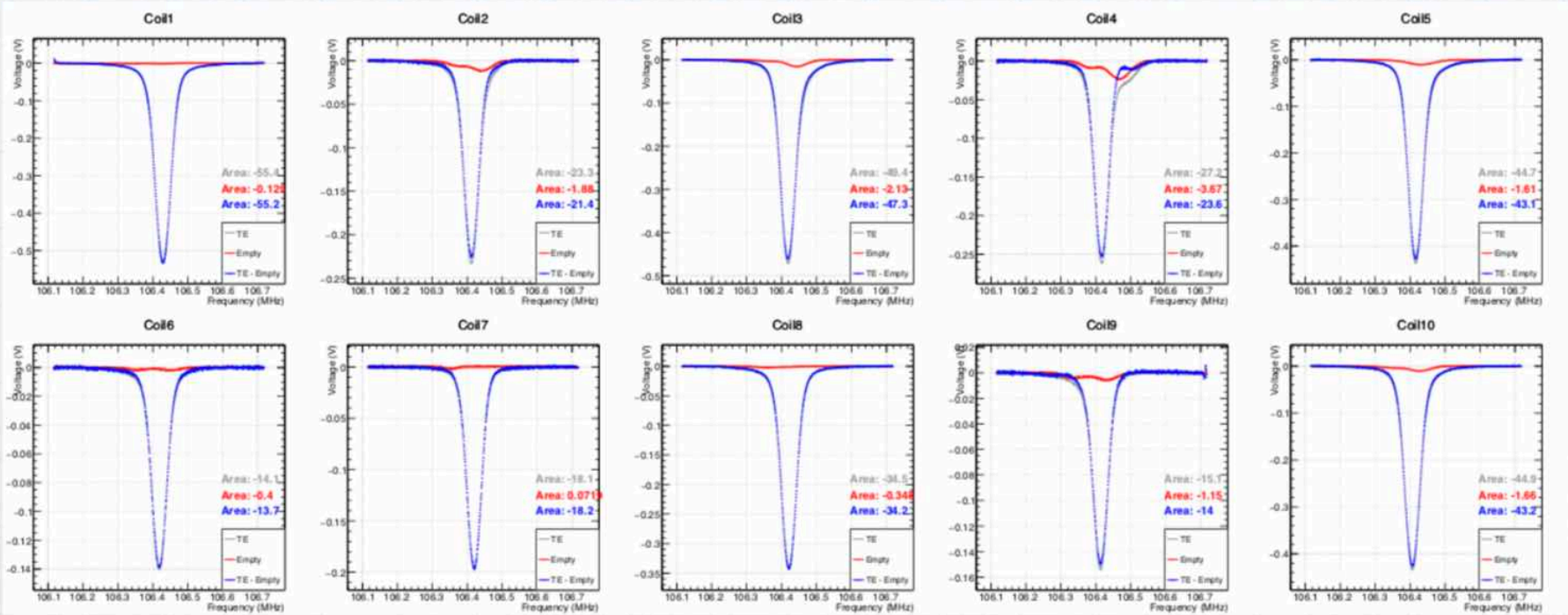
Empty target cell TE signals at 1K 2.5T



Polarization Analysis, Empty cell measurement

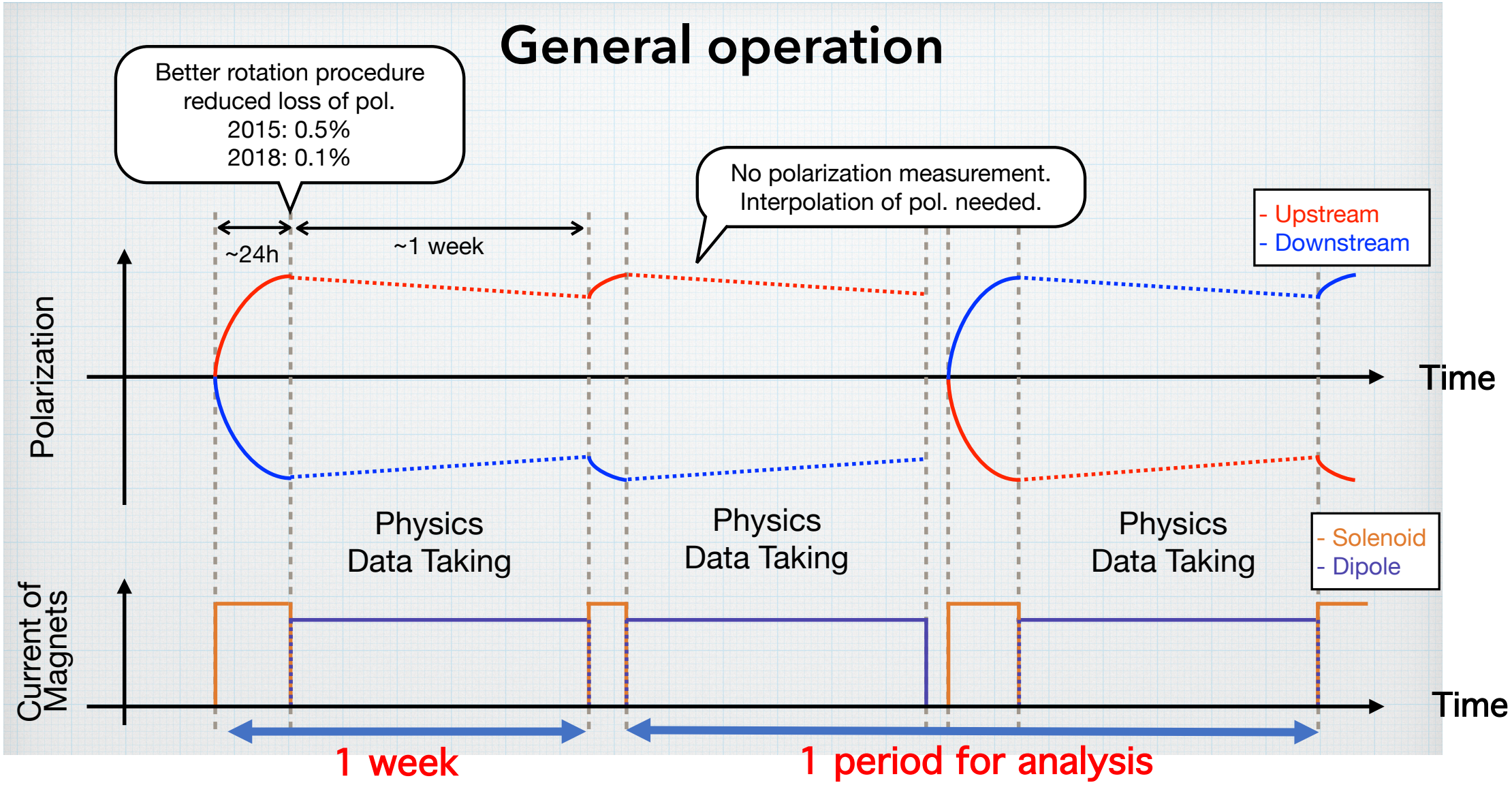
Due to the fact that some protons which cannot be polarized by DNP exists in the target, contribution to NMR by them should be estimated and subtracted.

NMR measurement without the target material can estimate the contributions.



	Coil1	Coil2	Coil3	Coil4	Coil5	Coil6	Coil7	Coil8	Coil9	Coil10
Signal area	-0.13	-1.88	-2.13	-3.67	-1.61	-0.40	0.07	-0.35	-1.15	-1.66
Contribution to TE@1K (relative)	0.2%	8%	4%	13%	4%	3%	0.4%	1%	8%	4%

General operation

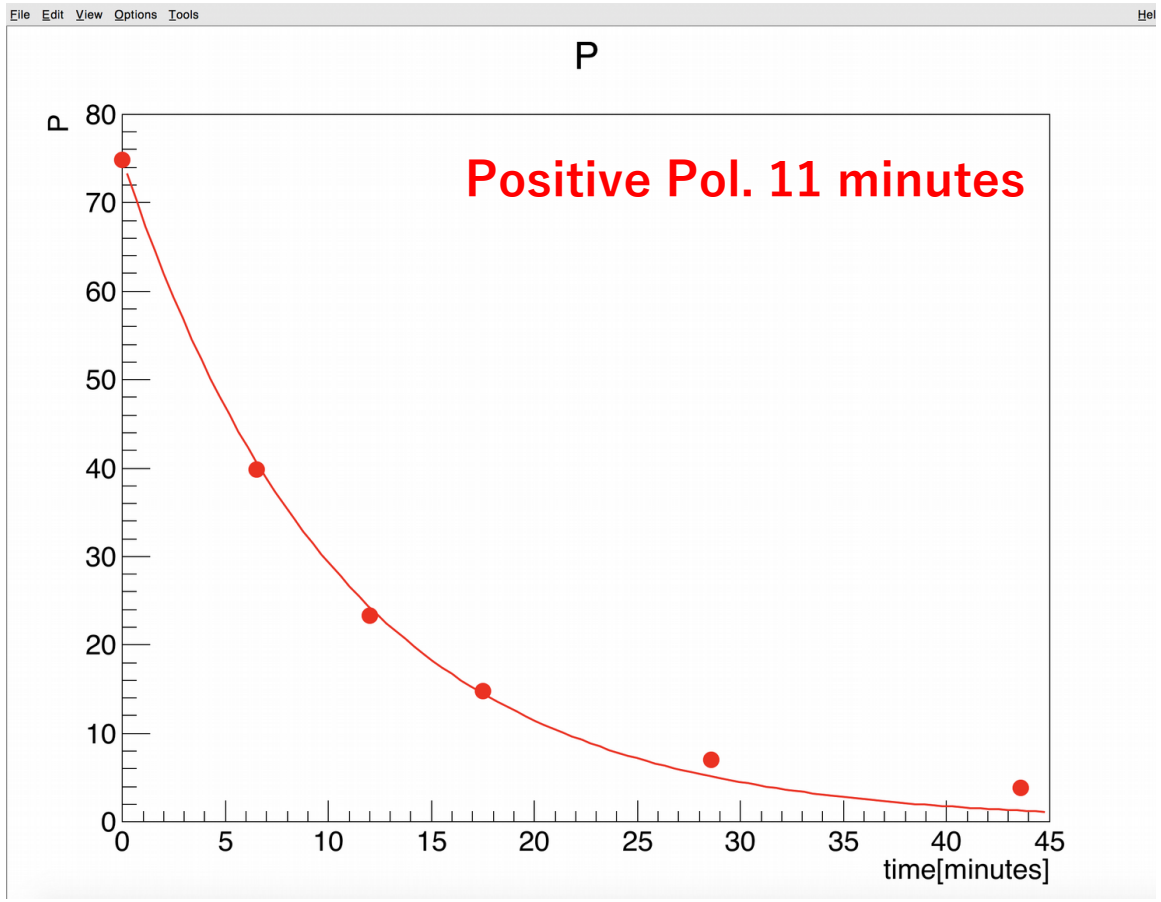


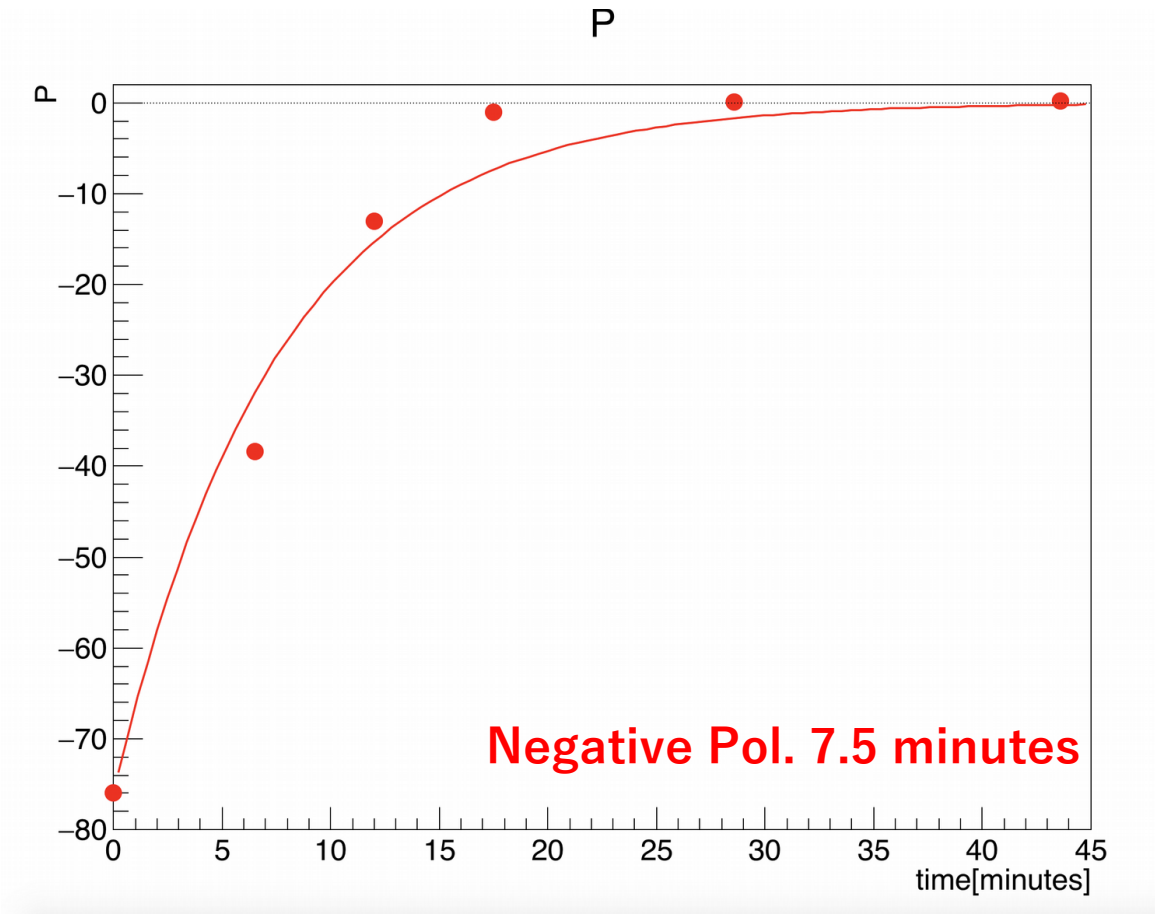
Beam intensity : 10^8 /s for 5 s and then no beam for 10 s or more

Typical values in the 2018 run

- Typical proton polarization after 26h
  - 80 %
- Typical relaxation time at 0.6 T in the beginning of the data taking
  - 1500 h for positive, 1200 h for negative
  - downstream coil faster because of multiplicity of the beam
- Relaxation time without beam
  - ~ 2500 h for positive, ~ 1800 h for negative

Relaxation time at 0 T





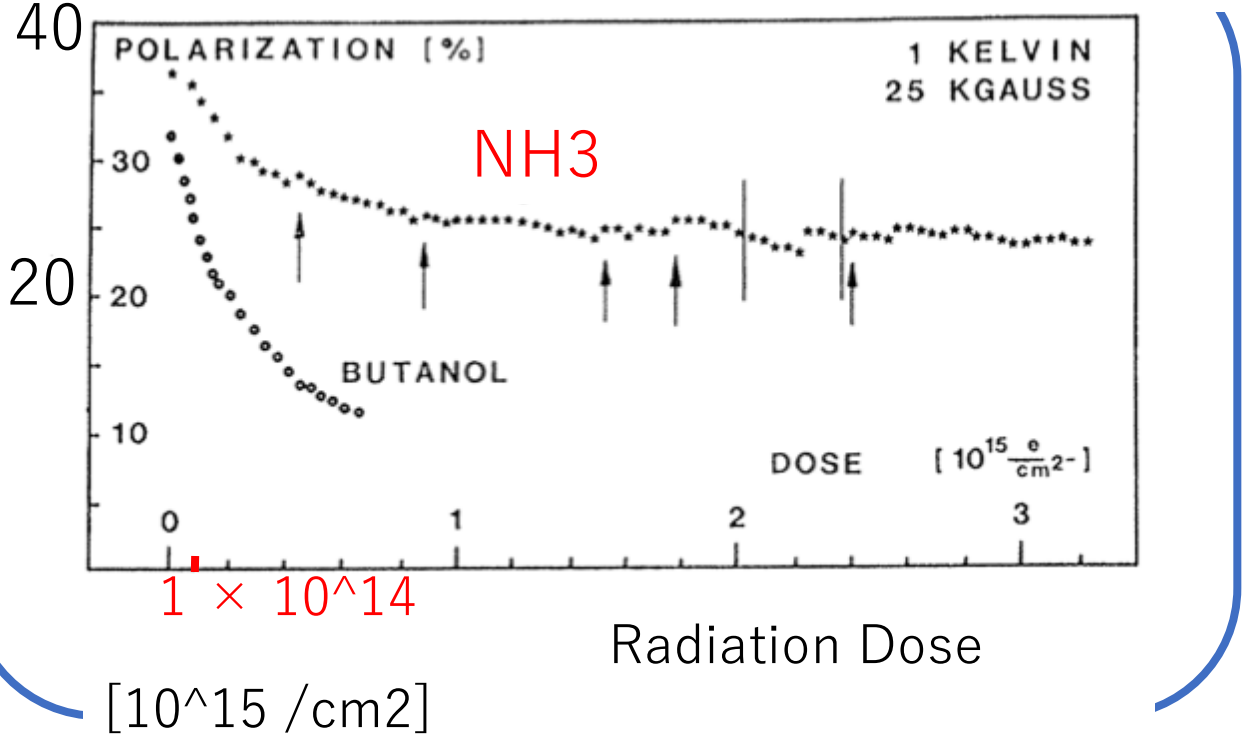
Radiation damage

Additional radicals are produced by beam.

W. Meyer et. al., Proceedings of the 4th international workshop on Polarized target materials and techniques (1984)

The polarization drops to 1/e of maximum polarization is 7 × 10^15 particles/cm2 (electrons) for ammonia

Radiation effect to polarization at 1K and 2.5T

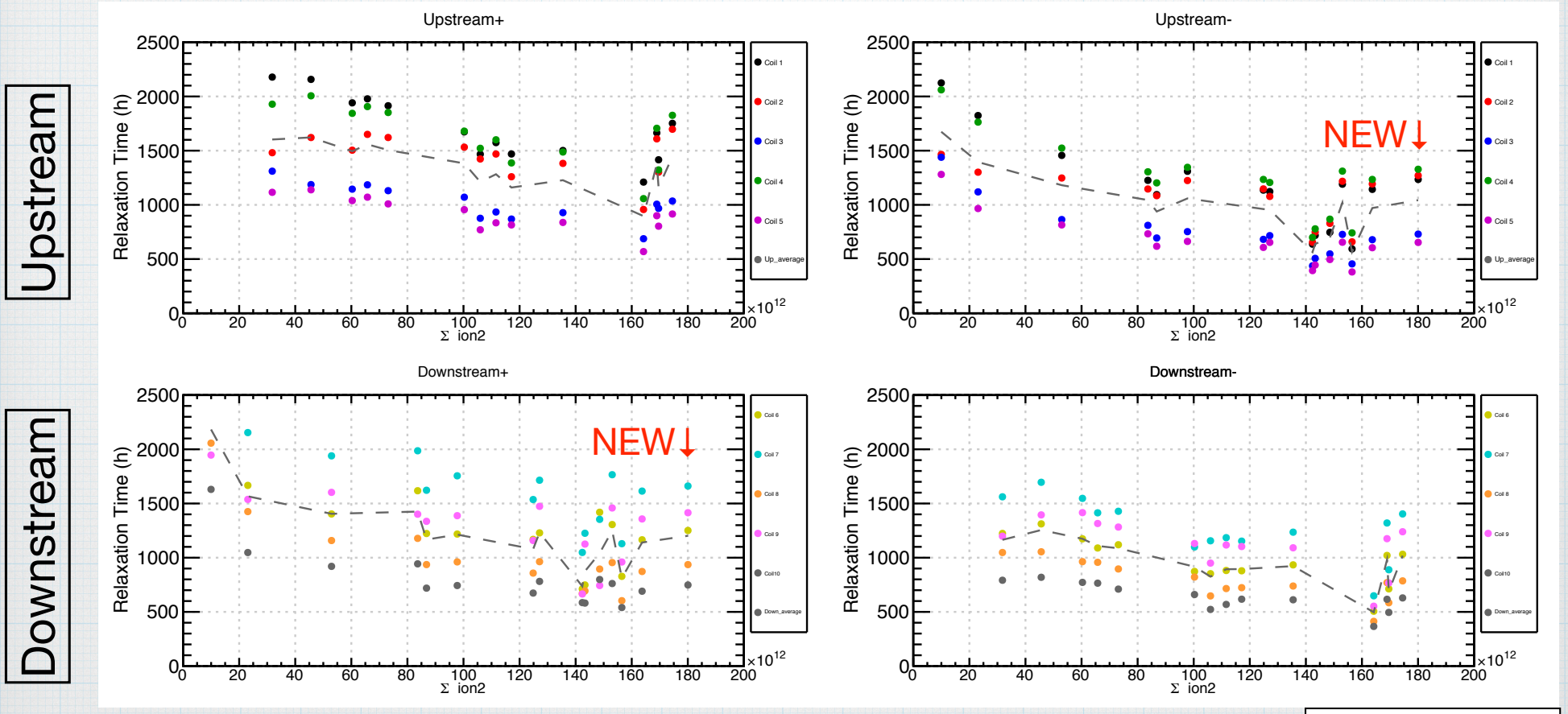


Accumulated doses in 2018 : 0.7× 10^14 /cm2

Relaxation time in 2018 vs accumulated doses

0.7 x 10^14 doses/cm^2 in 2018

Positive Pol. **Results, Relaxation time (Σ ion2)** Negative Pol.



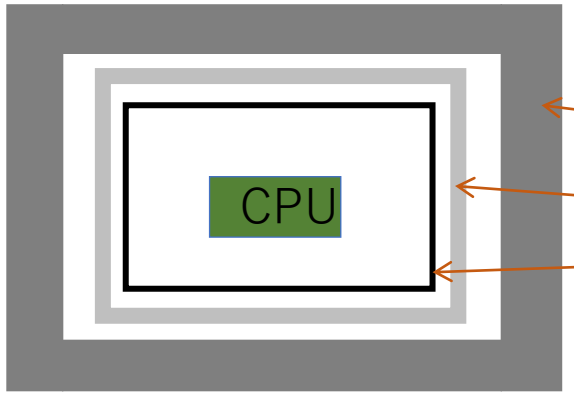
$\rightarrow \sum$ ion2 4/April

100 x10^12 = 0.4 x 10^14 doses/cm2

- - - : trend of average

Protection of PLC CPU for the magnet

Not only material but also PLC CPU suffered from radiation (neutron).



Concrete : For high energy neutrons
Polyethylene : for low energy neutrons
Boron-carbid : to stop thermal neutrons

Top cover of Polyethylene with Boron-carbid

Boron-carbid

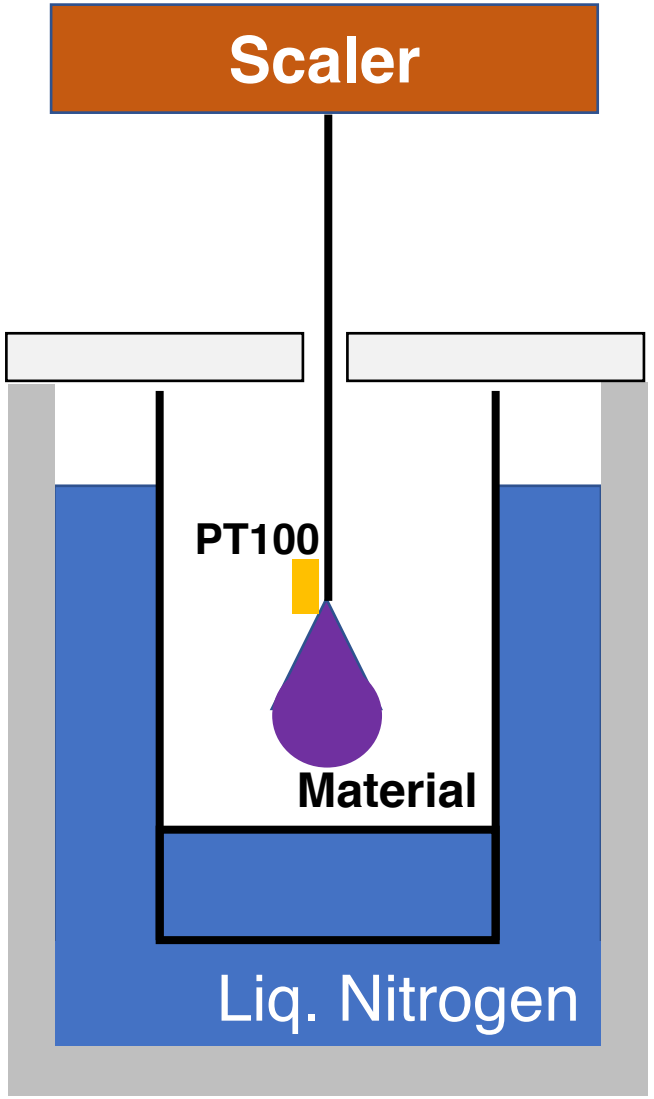
~10 μSv/h area

No interruption in 2018

Results of the measurement

- Material kept in Liq. N2 bath
- Four socks (two for upstream and two for downstream)
- 10 hours for one measurement
- Kept the sock below 100 K

	Weight (g)	Packing factor
upstream	329 +/- 1	0.558 +/- 0.002
downstream	310 +/- 1	0.526 +/- 0.002



Deuteron run in 2021

- SIDIS with muon beam
- Transversally frozen spin deuteron target

  - better statistics for Collins asymmetry and so on..
- ^{6}LiD as used in 2002 - 2004
- 3-cells with 3 cm diameter
- Microwave frequency modulation

Deuteron target materials

Figure of Merit

$$PT_{FoM} = f^2 \times P_T^{\,2} \times \rho \times F_f$$

f : dilution factor

ρ : density

F_f : packing factor

	ND_3	D- butanol	^6LiD
P_T	0.40	0.80 **	0.55 (D) 0.54 (^{6}Li)
ρ	1.00	1.12	0.820
f	0.300	0.238	0.250 (D) 0.250 (^{6}Li)
F_f	0.58	0.62	0.52
PT_{FoM}	1.8	5.4	6.9

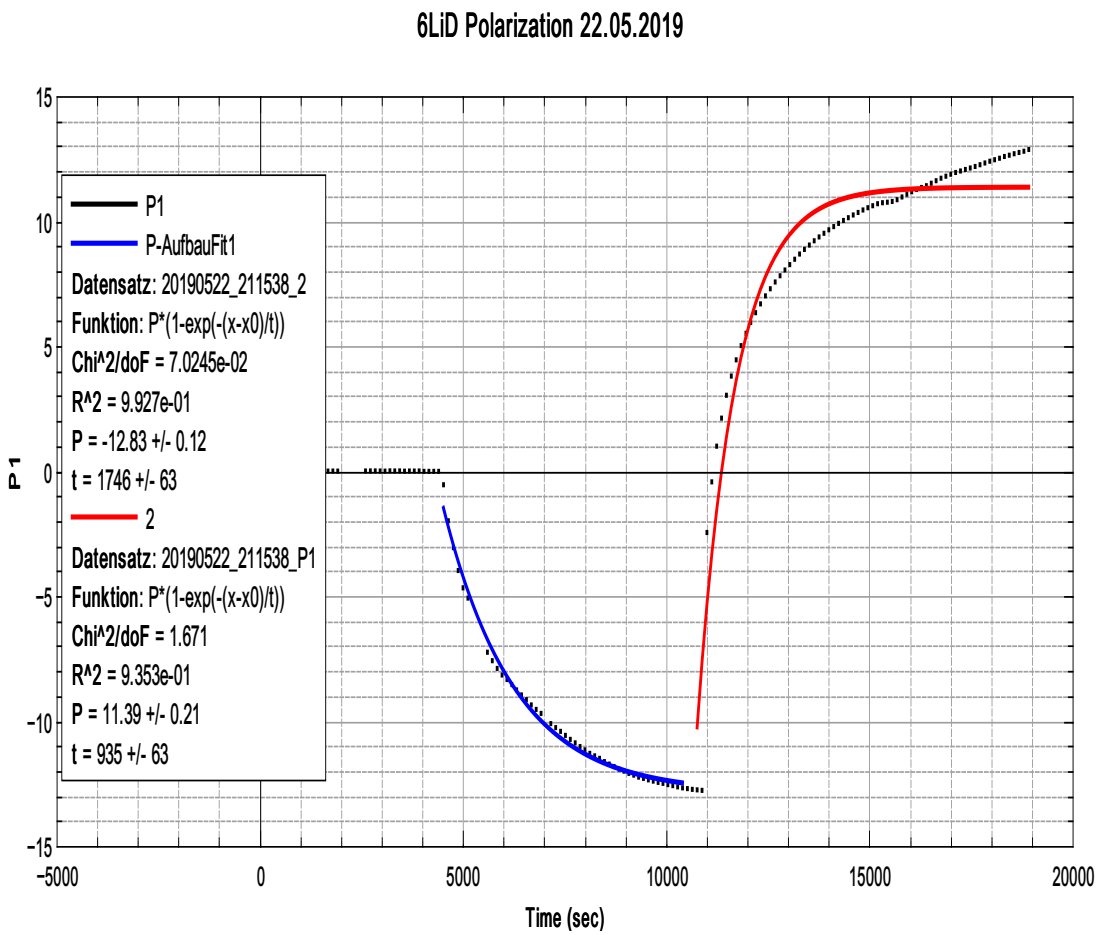
-Normalized by ND_3 .
-Magnetic field 2.5T
- Relaxation time
^{6}LiD 1500h at 0.42T and 60 mK.

** S.T. Goertz et al, NIM. A 526 (2004) 43.

^{6}LiD polarization test

- Deuteron of ^{6}LiD polarization
- A small amount of sample stored at Bochum and Bonn
- Tested with a 1 K refrigerator at Bochum
- 12 % with a 0.5 h build up time

→ compatible to the result when it was produced



Microwave for ^{6}LiD in 2002

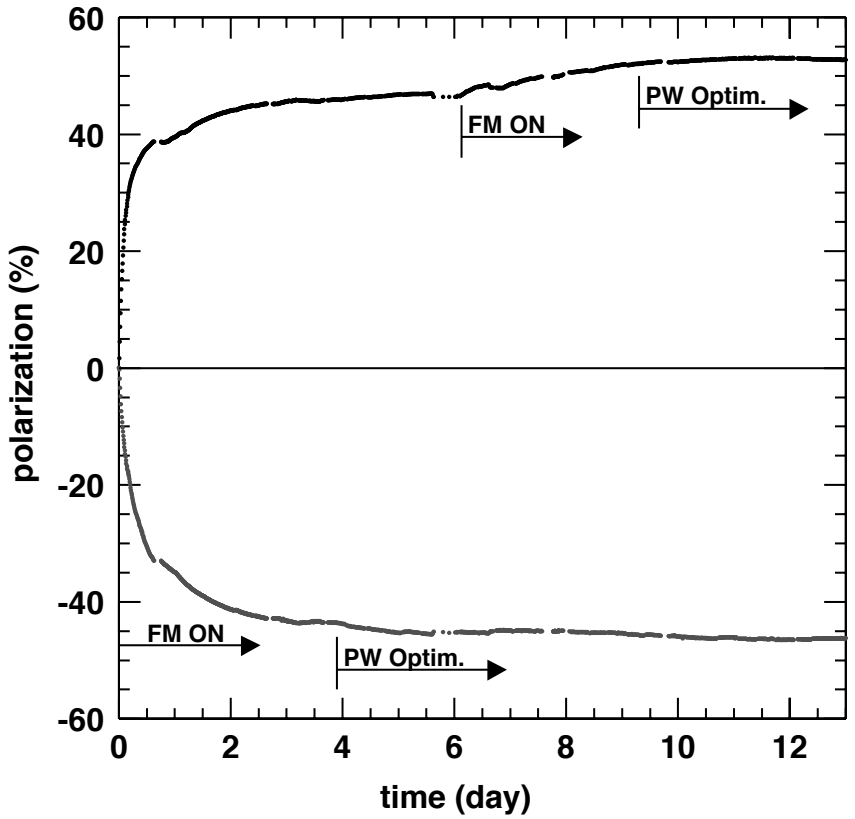


Fig. 5. Example of the deuteron polarization build-up. The upstream (downstream) cell is polarized positively (negatively). The interruptions of the data points correspond to a magnetic field rotation or to a technical interruption of the NMR data taking. The start time of the microwave frequency modulation is indicated by 'FM-ON' and that of the microwave power optimization by 'PW Optim'.

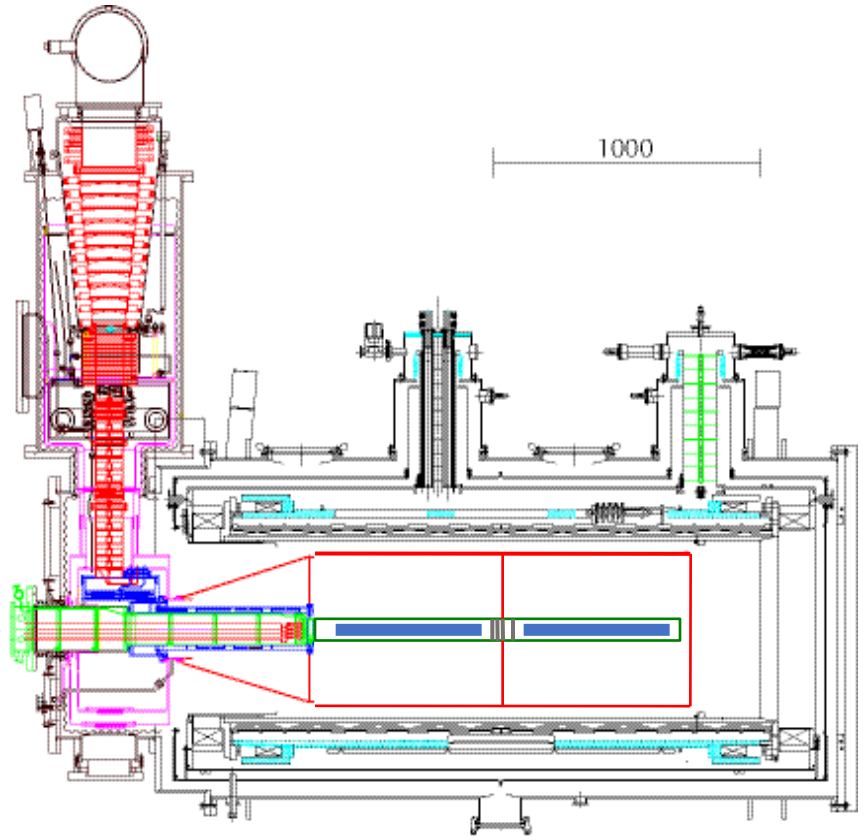
NIMA498(2003)101

- Slower polarization build up
- Higher polarization by frequency modulation : 45 % → 50 %
- Faster build up by frequency modulation
- ^{6}LiD : small difference between positive and negative polarization
  - Positive polarization : 70.20 GHz → 70.23 GHz
  - Negative polarization : 70.27 GHz → 70.24 GHz

- Cooling test in 2020
- 2W gunn oscillator (ELVA) set next to DR
  - easy to control with FM

COMPASS++/AMBER (2022 ~)

- New collaboration after COMPASS
- Many new programs
- GPD with transversely polarized proton target
- Recoiled proton from the target in DVCS process
- 4 pi detector needed with the target system



Summary

- COMPASS Drell-Yan program in 2015 and 2018
- Transversally polarized proton target with NH3
- Beam intensity 10^8 /s
- Radiation damage was observed in the relaxation time measurements

- COMPASS SIDIS program in 2021
- Transversally polarized deuteron target with 6LiD
- 30-60-30 cm with 3cm diameter cell
- Microwave frequency modulation

Backup

History of COMPASS PT

Year	Spin	Material	Cell configuration
2002 – 2004	L, T	^{6}LiD	60-60 cm long, 3 cm diameter
2006	L	^{6}LiD	30-60-30 cm long, 3 cm diameter
2007	L, T	NH_3	30-60-30 cm long, 4 cm diameter
2010	L	NH_3	30-60-30 cm long, 4 cm diameter
2011	T	NH_3	30-60-30 cm long, 4 cm diameter
2014 -2015	T	NH_3 with pion beam	55-55 cm long, 4 cm diameter
2018	T	NH_3 with pion beam	55-55 cm long, 4 cm diameter
2021	T	^{6}LiD	30-60-30 cm long, 3 cm diameter

Polarization after 26h in 2015 and 2018

	Upstream Cell	Downstream Cell
Positive Polarization	+ 75 % + 79 %	+73 % + 79 %
Negative Polarization	- 74 % - 84 %	-72 % -80 %

Relaxation time with beam in 2015 and 2018 (May-June)

	Upstream Cell	Downstream Cell
Positive Polarization	~ 1200 h ~ 1500 h	~ 1000 h ~ 1500 h
Negative Polarization	~ 900 h ~ 1300 h	~ 700 h ~ 1100 h

Relaxation time at 0.6 T without beam in 2015 and 2018

	Upstream Cell	Downstream Cell
Positive Polarization	2070 h (Sep.3) 2890 h (Jun.4)	1400 h (Aug.19) 2130 h (Jun.6)
Negative Polarization	1250 h (Aug.19) 1590 h (Jun.6)	1100 h (Sep.3) 2180 h (Jun.4)

EST Concept

- Polarizing deuteron at first
- Measured 6Li and 7Li polarization

→ Support the EST concept

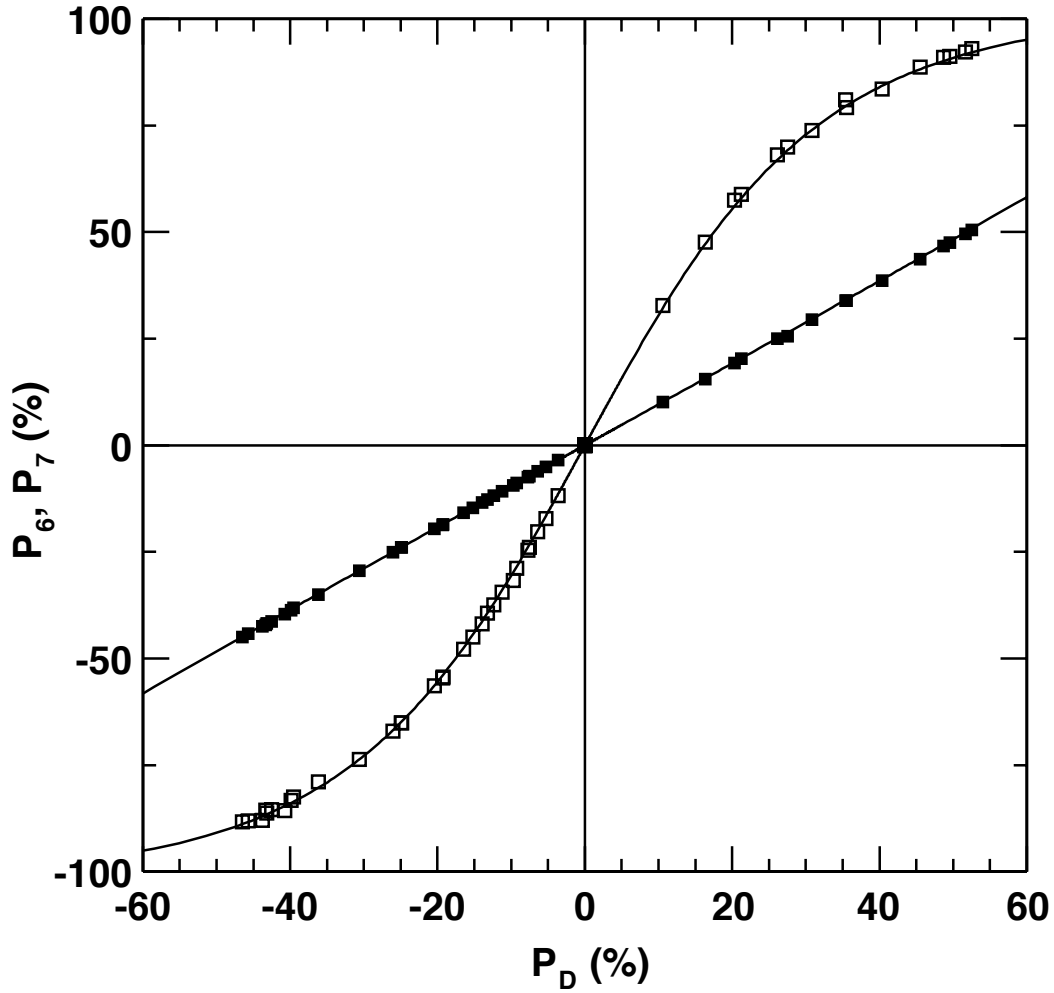


Fig. 6. The polarizations of the ^{6}Li and the ^{7}Li nuclei versus that of the deuteron. The closed (open) squares are the measured polarization of ^{6}Li (^{7}Li). The lines are the prediction by EST concept. The measurements are consistent with the EST concept.

NIMA498(2003)101

Proton target materials

Figure of Merit

$$PT_{FoM} = f^2 \times P_T^{\,2} \times \rho \times F_f$$

f : dilution factor

ρ : density

F_f : packing factor

	H-butanol	NH_3	^7LiH
P_T	0.90	0.90	0.56 (H) * 0.38 (^{7}Li)
ρ	0.985	0.853	0.820
f	0.135	0.176	0.125 (H) 0.125 (^{7}Li)
F_f	0.62	0.50	0.55
PT_{FoM}	1	1.2	0.7

-Normalized by H-butanol

-Magnetic field 2.5T

- Relaxation time NH_3 4000h at 60 mK and 0.6T

- If ^{7}LiH reach 90%, PT_{FoM} is 2.1.

* J. Ball, NIM. A 526 (2004) 7.