RUHR-UNIVERSITÄT BOCHUM
FAKULTÄT FÜR PHYSIK UND ASTRONOMIE

RUB

The 11th Circum-Pan-Pacific Symposium on High Energy Spin Physics

August 27-30, 2019 at Miyazaki, Japan

Polarized targets for experiments with high energy beam

G. Reicherz

Content

- Introduction
- Examples polarized frozen spin targets
- Impact of beam on polarized target
- 4π-Continuous Target
- Summary

Introduction

Reaction counting rate

$$N = \mathcal{L} \frac{d\sigma}{d\Omega} \Delta\Omega$$

cross section of interest

detector solid angle

Luminosity

$$\mathcal{L} = I \cdot n_t$$

In general, the luminosities possible with polarized targets are smaller compared with typical luminosities of 10^{36}–10^{37} cm^{-2} s^{-1} in present experiments using unpolarized targets.

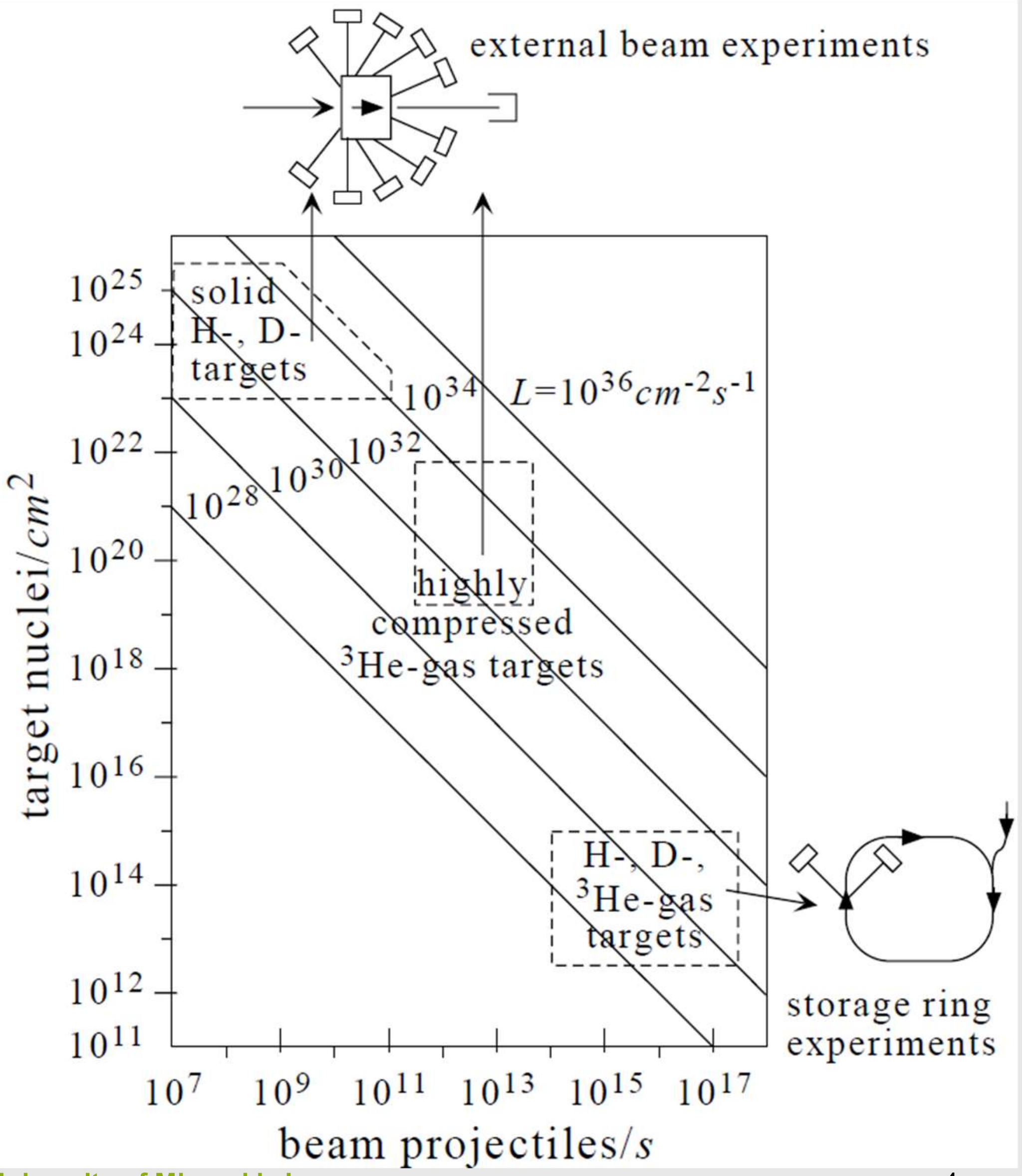
Introduction

Internal targets operated in storage rings very thin ($\leq 10^{15}$ atoms per cm^2) polarized H targets densities $n_t \approx 10^{13} - 10^{14}\ cm^{-2}$
Beam current $I \approx 50mA \mathrel{\widehat{=}} 3{\cdot}10^{17} e^{-} s^{-1} \Rightarrow$
Luminosities of $3{\cdot}10^{30} - 3{\cdot}10^{31}\ cm^{-2}s^{-1}$

External targets solid as H targets with densities of 10^{23} cm^{-2} with beam currents < 100nA yielding in a luminosity of $6 \cdot 10^{34}$ cm^{-2} s^{-1}

or

highly compressed optical pumped ^{3}He gas target density of 10^{21} cm^{-2} but tolerable beams currents up to 30uA



Targets

Counting rate target asymmetry

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

Dilution factor *f*

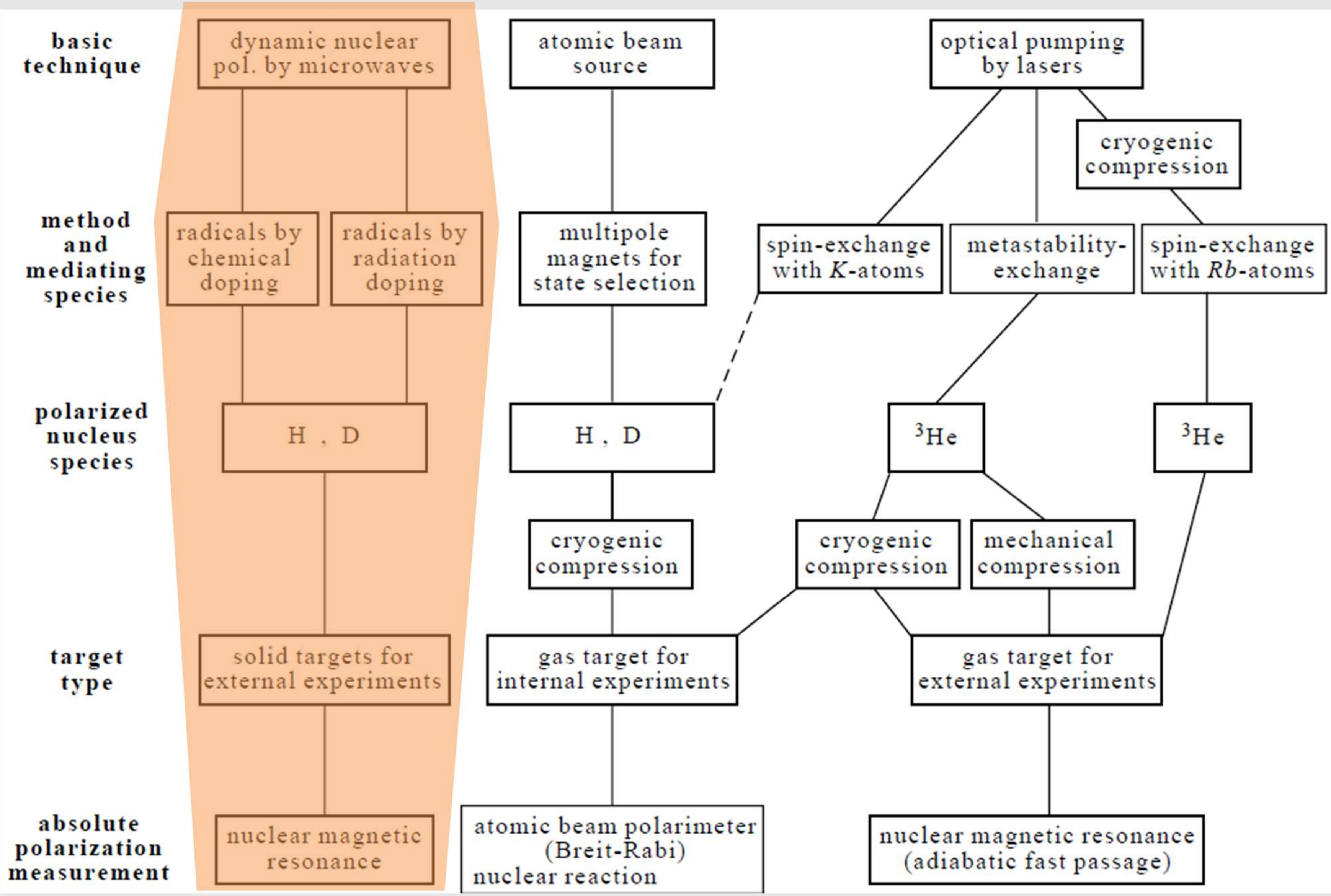
$$f = \frac{f_A \sigma}{(1 - f_A)\sigma_0 + f_A \sigma}$$

$$f = \frac{\text{number of polarizable nuclei}}{\text{total number of nuclei in the target material}}$$

figure of merit

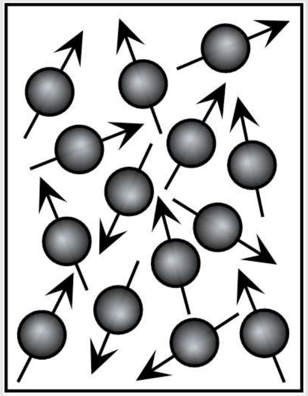
$$FOM_{ext} = n_t \cdot P_t^2 \cdot f^2$$

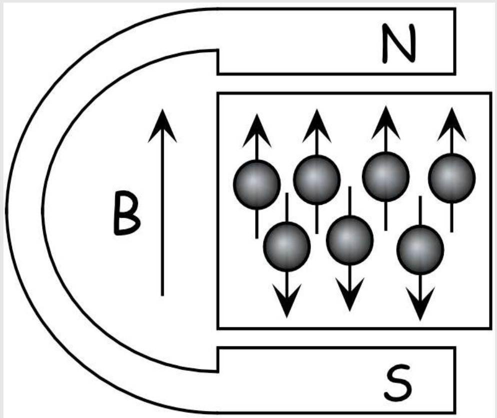
Target: polarization techniques



Nucleon Polarization

Polarization = Orientation of Spins in a magnetic field

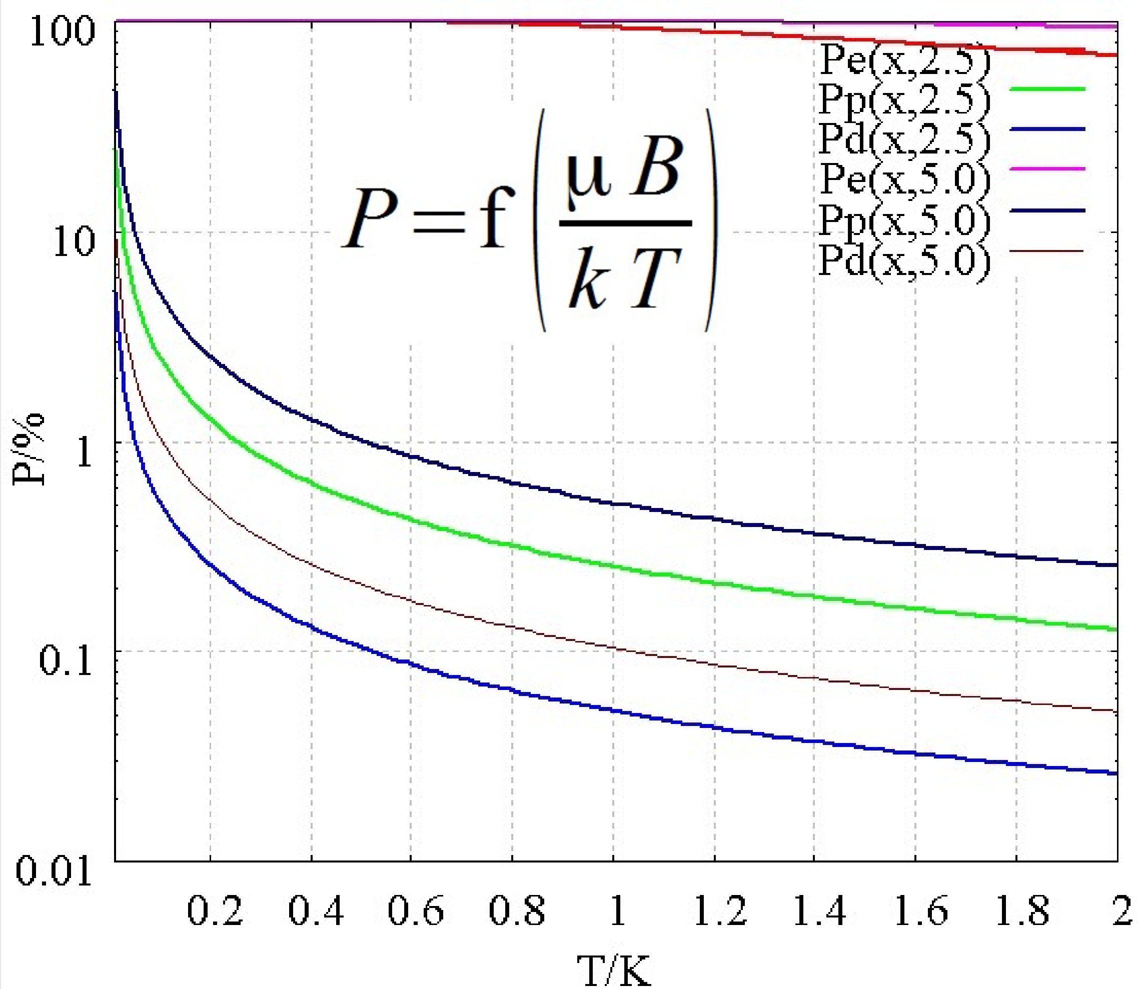




$$P = \frac{N\uparrow - N\downarrow}{N\uparrow + N\downarrow}$$

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

e^--, p- and d-polarization vs temperature

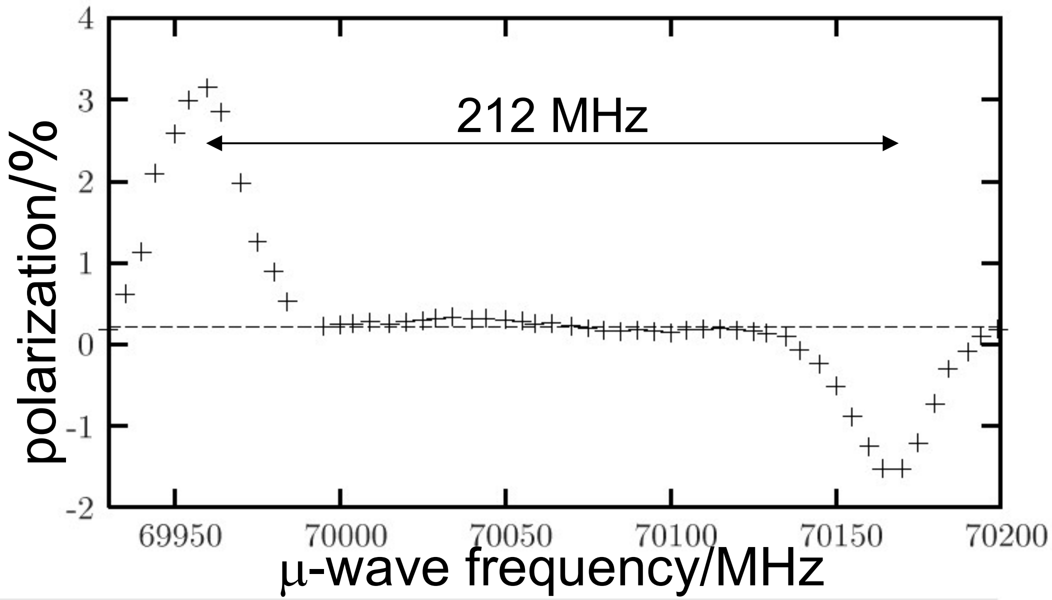


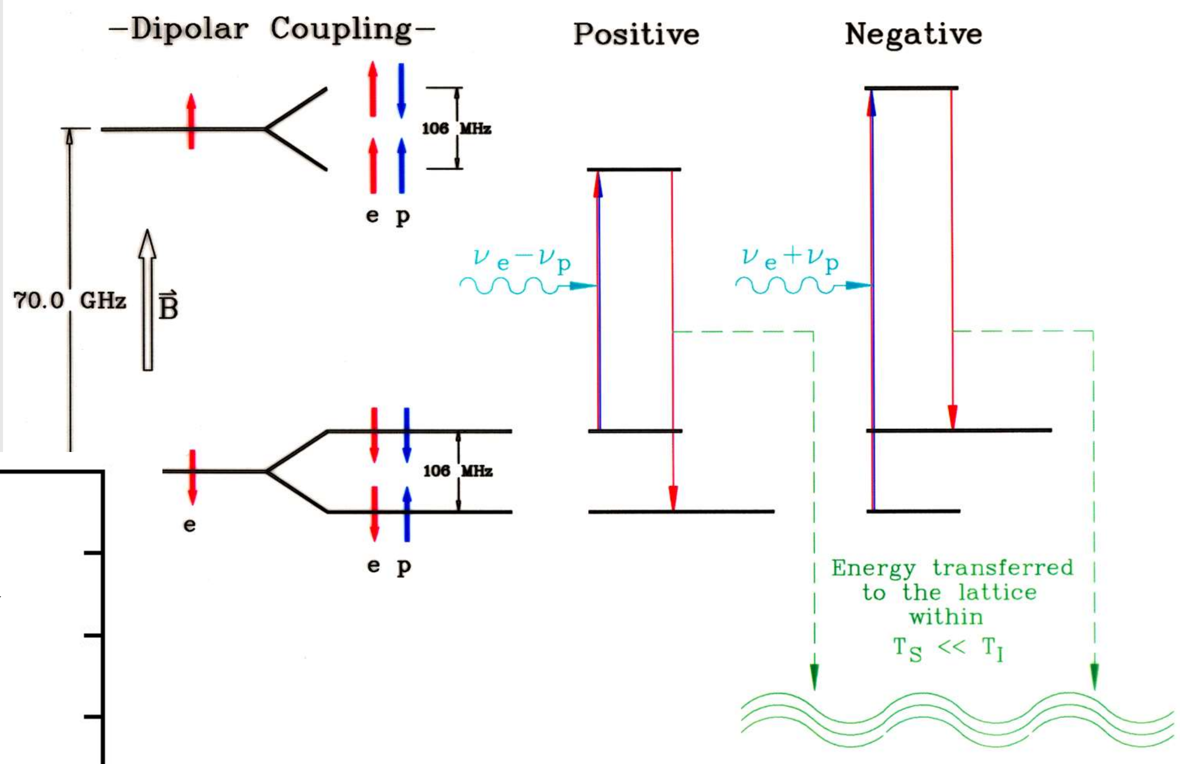
DNP: Solid State Effect(simple)

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

B = 2.5T

H-Propanediol with Trityl-Radical





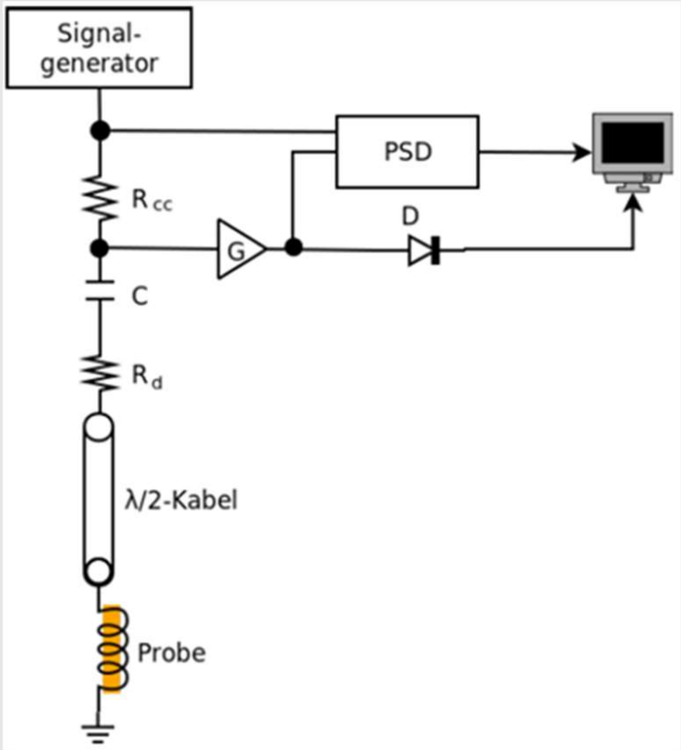
B = 2.5T and T=1K

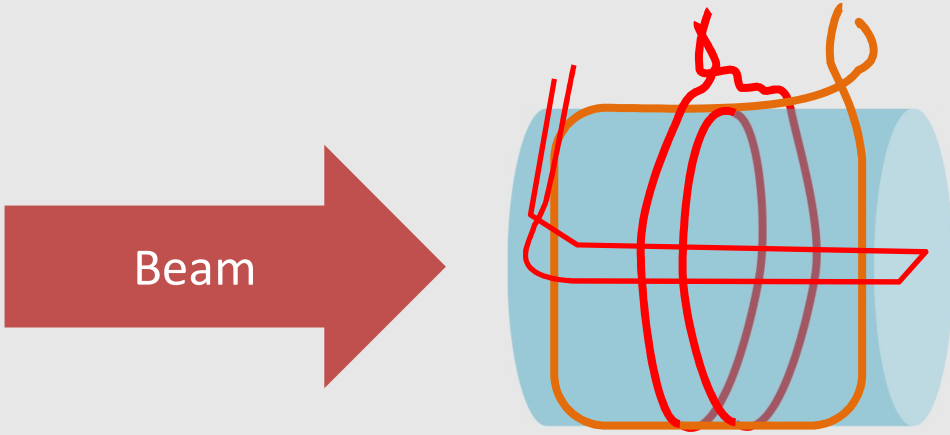
T_1^{e-} = ms to sec

T_1^{p} = min to hours

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

Polarization measurement by NMR





The nmr coil measures integrally and the sensitivity depends on the distance to the wire!
Polarization differences smaller than coil size are not resolved,
Inhomogeneous polarization differences caused by the beam must be avoided.

Influence beam on target polarization

Radiation hardness of the target material especially the paramagnetic center (DNP)

Beam heats material to this causing depolarization due to shorter relaxation times

High cooling power is needed, but is limited by the Kapitza resistance R_k (Interfacial thermal resistance $Q = \frac{\Delta T}{R_k}$)

$\Rightarrow$

choice of a continues dynamic polarization or frozen spin target

$\Rightarrow$

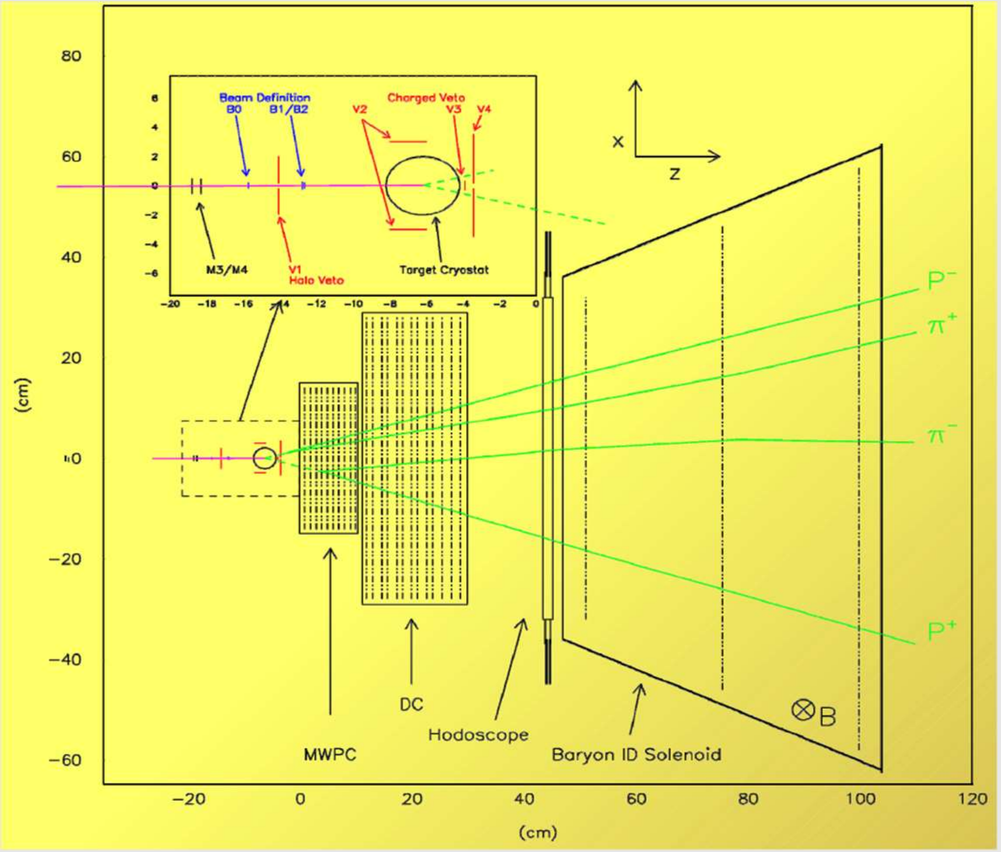
$^3He^4He$ dilution refrigerator or a 1K evaporation cryostat

additionally

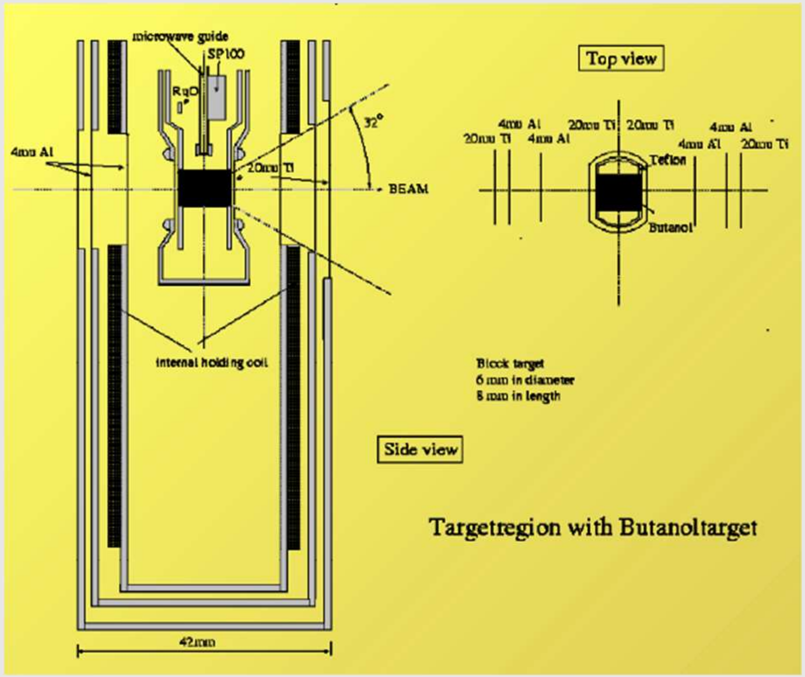
high magnetic fields of 2.5 T and more to reach a sufficient polarization

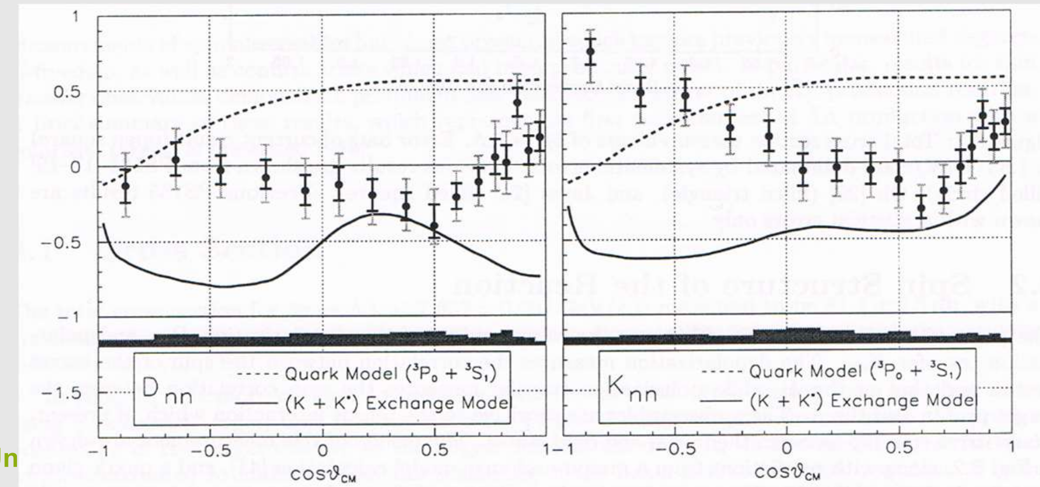
PS185 (1996)

Depolarization D_{nn} and Spin Transfer K_{nn} in $\bar{p}\,p \uparrow \rightarrow \bar{\Lambda}\,\Lambda$ (1525 – 1800 MeV/c)



P.D. Barnes *et al.,* Phys. Lett. **B189** (1987) 249





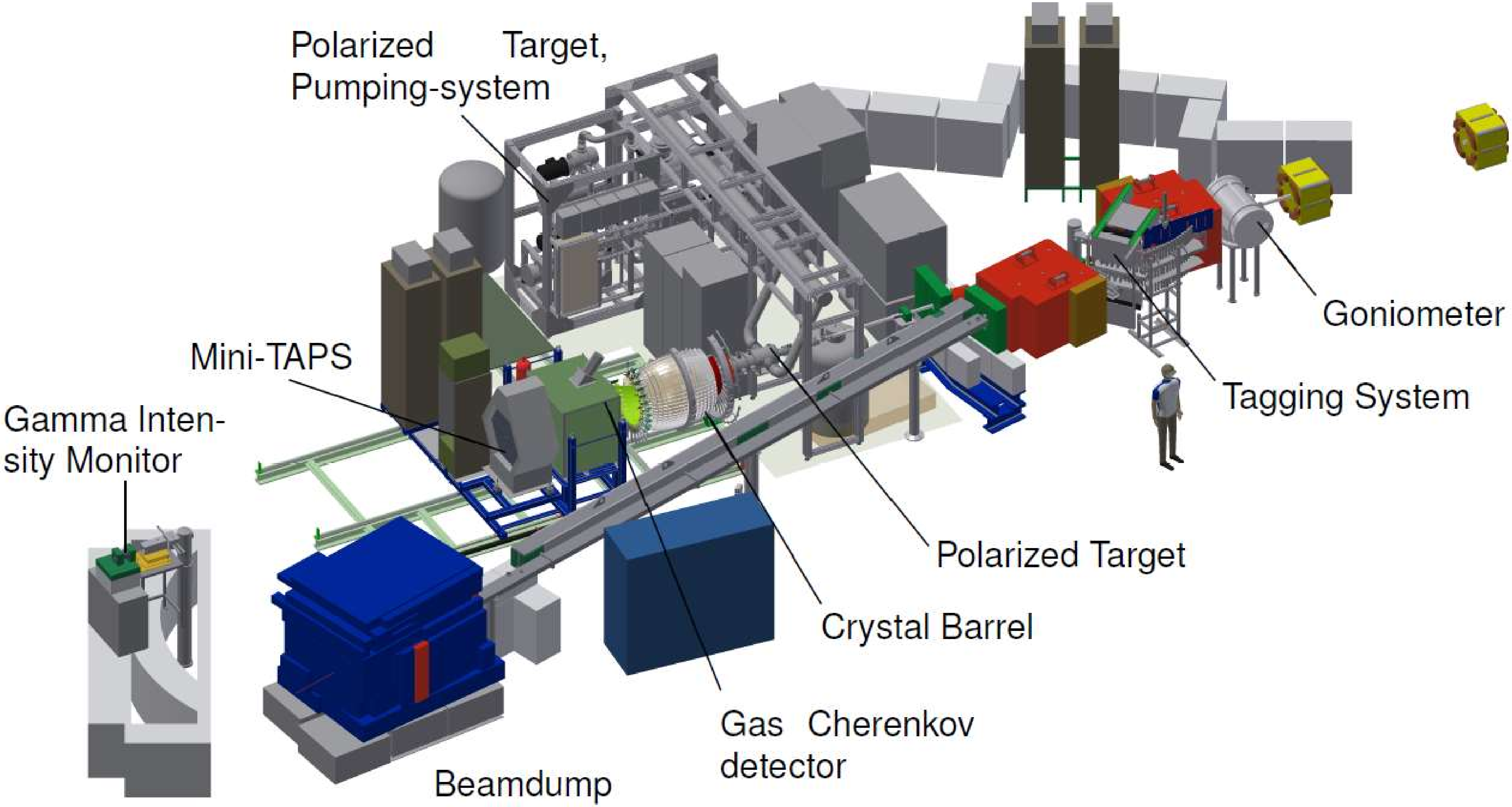
Beam intensity average 500000 $\bar{p}\ /s$

~ 10^{-13}A, Target: Cylinder block 6mmx8mm

$^3He/^4He$ dilution fridge 60mK

Basseleck et al., accepted by Phys. Rev. Letters (2002)

CBELSA/TAPS

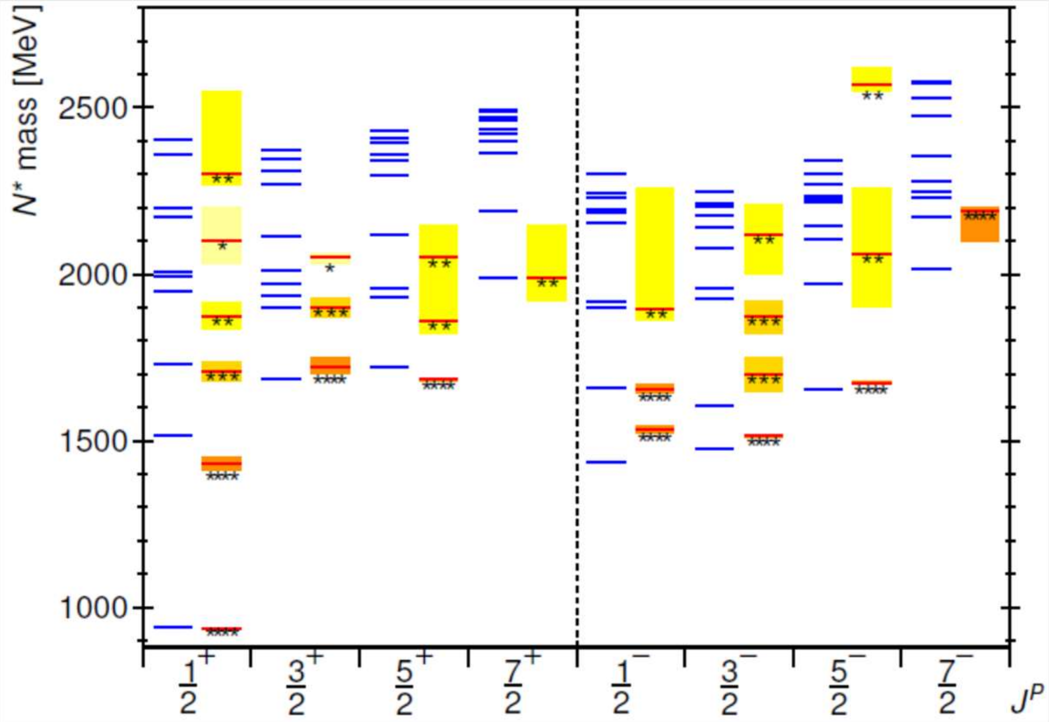

Polarized Target,
Pumping-system
Mini-TAPS
Gamma Intensity Monitor
Goniometer
Tagging System
Polarized Target
Crystal Barrel
Gas Cherenkov detector
Beamdump

RUB

Baryon Spectroscopy

Aim: Better understanding of QCD and the structure of hadrons:
How does QCD give rise to hadrons?
Which hadrons – bound states of QCD – do exist?
-> Baryon spectroscopy

Fully relativistic quark model



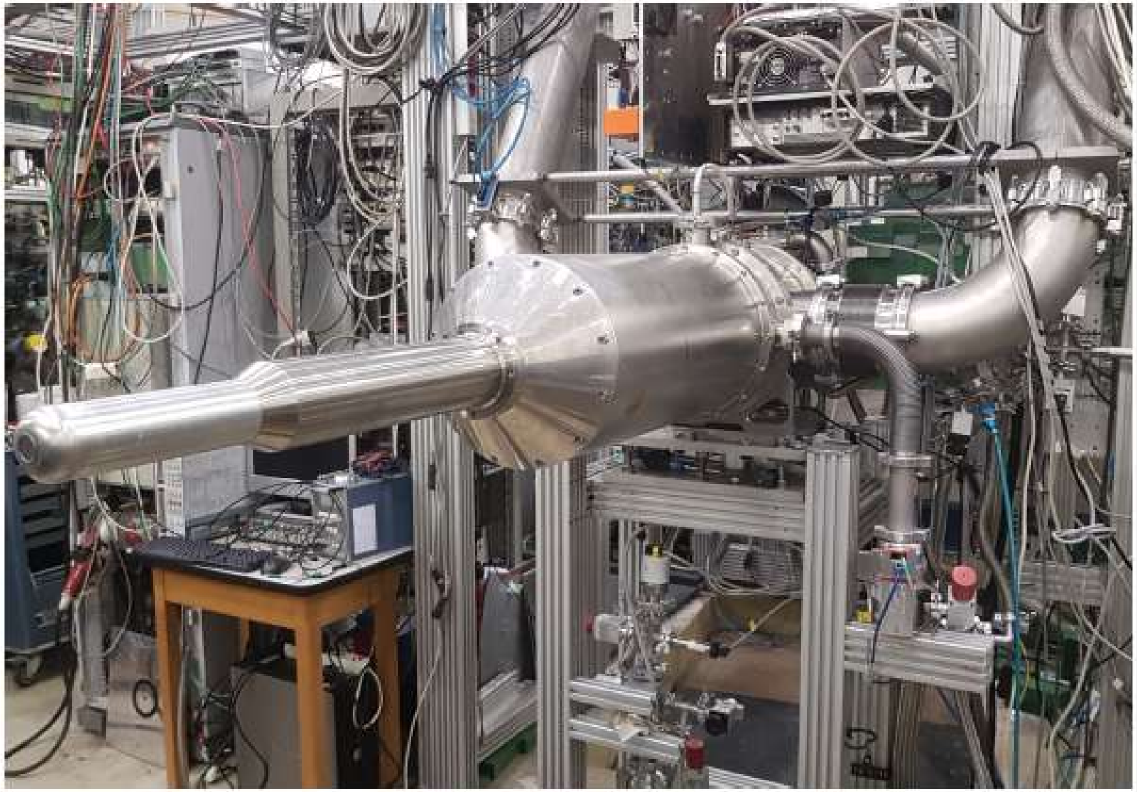
U. Löring, B. Metsch, H. Petry, Eur. Phys. J. A10 (2001) 395

Quark models:

- Many more resonance expected than observed
- Certain configurations completely missing:
  - Wrong degrees of freedom in quark model?
  - Experimentally not found yet?

RUB

CBELSA/TAPS – Polarized Target



Work in 2017

- I Merging the Dubna/Mainz and Bonn Systems.

T_{min} < 30mK

2018 $\gamma p \rightarrow \pi N$

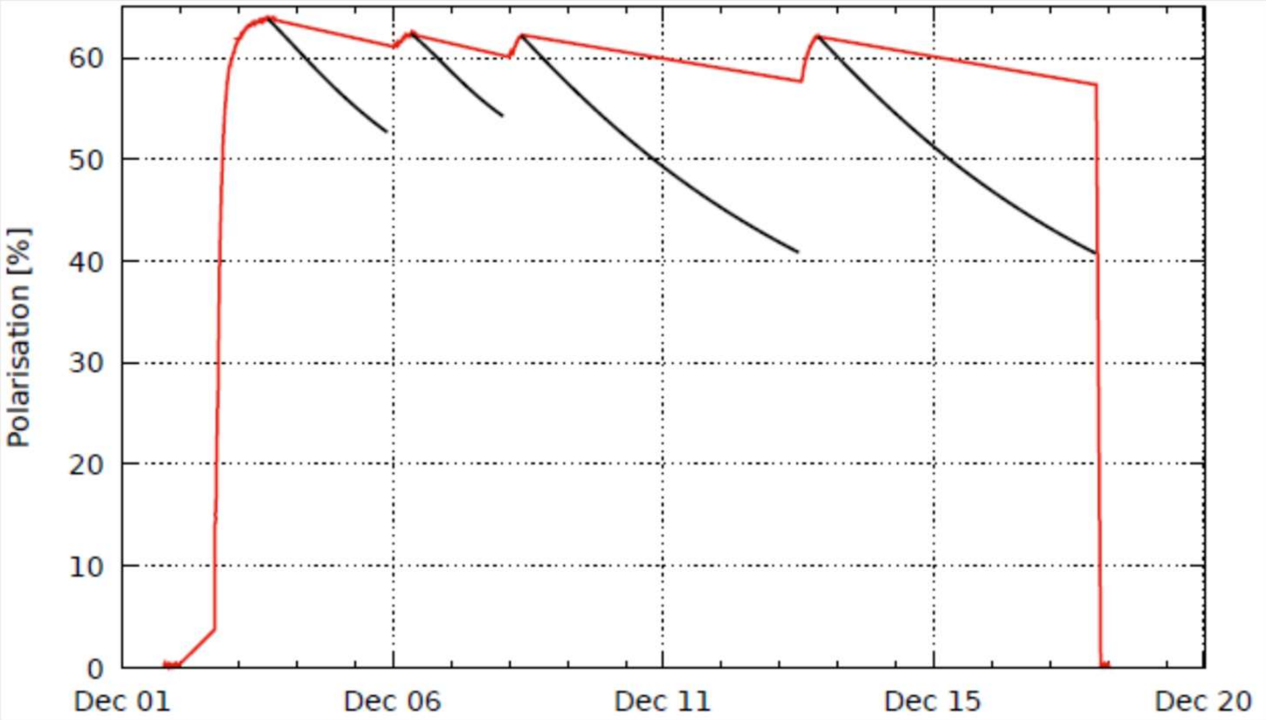
two periods with Butanol
and one with D-Butanol

Frozen spin with a holding field 0.6T
Genereted by very thin magnet mount
on inner warming shield $\rightarrow\uparrow$

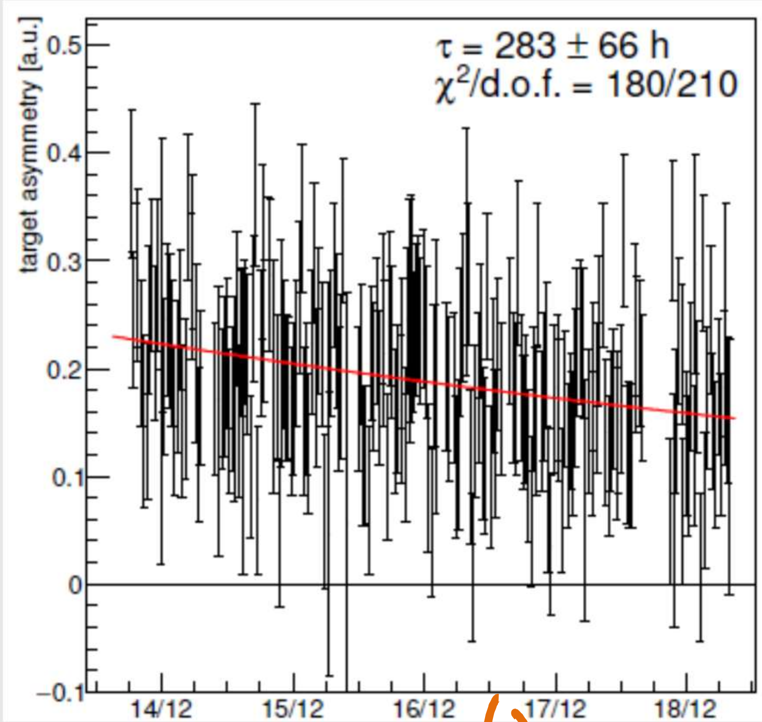
- Dubna: Y. Usov, N. Borisov, I. Gorodnov et al. Mainz: A. Thomas et al. Bochum: G. Reicherz. Bonn: S. Goertz, H. Dutz, S. Runkel et al

Targetpolarization and beam heating December 2017

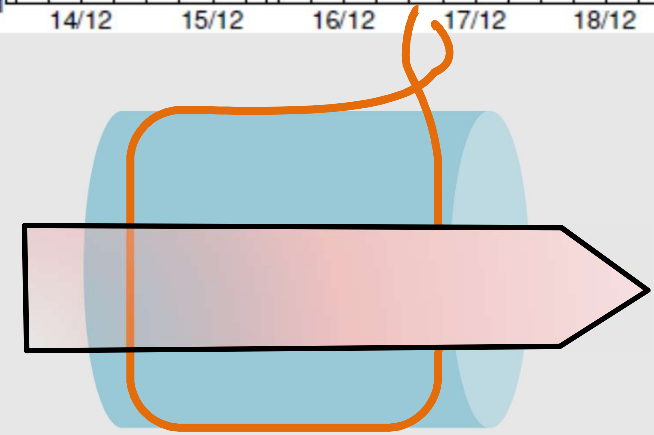
target polarization (NMR):



target asymmetry ($\gamma p \rightarrow p\pi^0$):

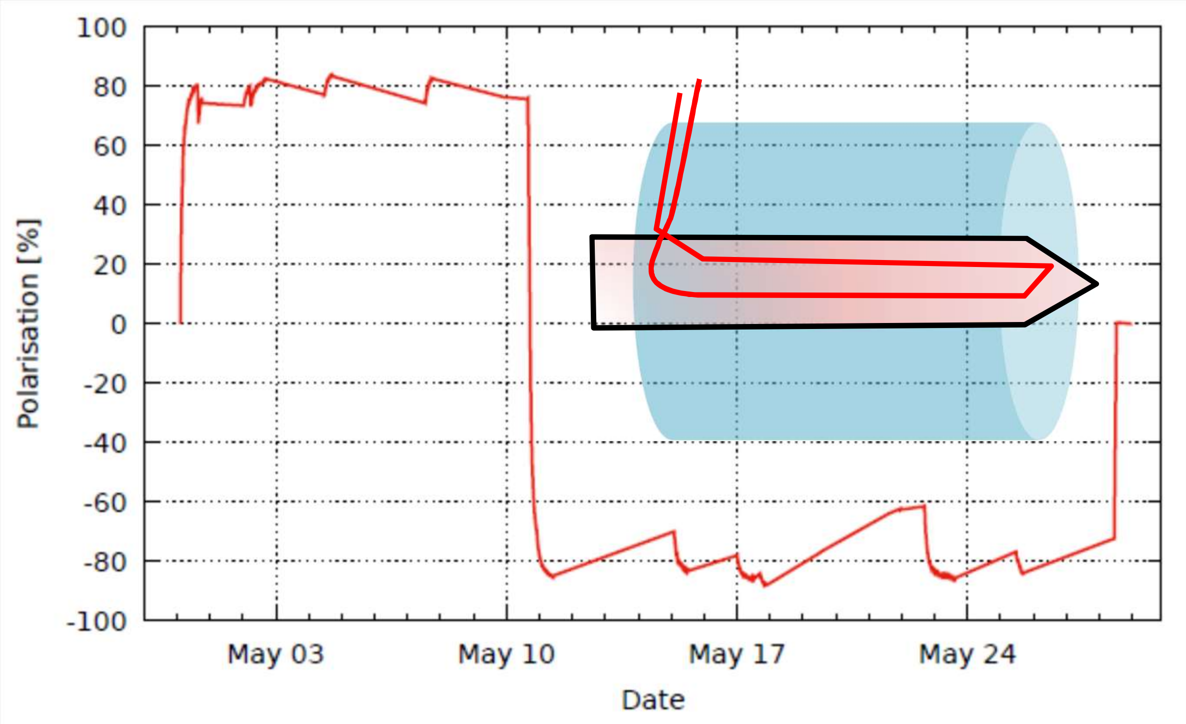


- NMR coil at the edge of the container.
- The polarization lost due to the beam was not measured with the NMR system.
- Change of the geometry for the NMR coil.



May 2018: target polarization - beam heating

May 2018 beamtime: NMR coil close to beam axis



- Butanol doped with 0.45% Porphyrexide.
- P_{max} + = 83%,
  P_{max} - ≈ 86%,
  τ_{rel}, without beam 1800 h,
  $r_{\tau el}$, with beam ≈ 500 h.
- Coil wound through the Target container and the beam axis.
- Difference in the relaxation time with and without beam can be seen directly.

- To minimize the beam heating effect, the temperature of the helium bath in the mixing chamber was increased to 27 mK.
- Two production runs in 2018
- Measurement with D-Butanol in October 2018

COMPASS II

approved by CERN Research Board in 2010

- Polarized Drell-Yan measurement
  TMD PDFs — *π^{-} beam with polarized proton target*
- GPD measurement
  Transverse imaging — *μ^{+} μ^{-} beam with liquid hydrogen target*
- Pion and Kaon polarizability
  Chiral perturbation theory — *π^{-}, K^{-} (μ^{-}) beam with nucleus target*

With a upgraded COMPASS spectrometer

2014	Test beam Drell-Yan process with π beam and T polarized proton target
2015	**Drell-Yan process with π beam and T polarized proton target**
2016	**DVCS / SIDIS with μ beam and unpolarized proton target**
2017	**DVCS / SIDIS with μ beam and unpolarized proton target**
2018	**Drell-Yan process with π beam and T polarized proton target**

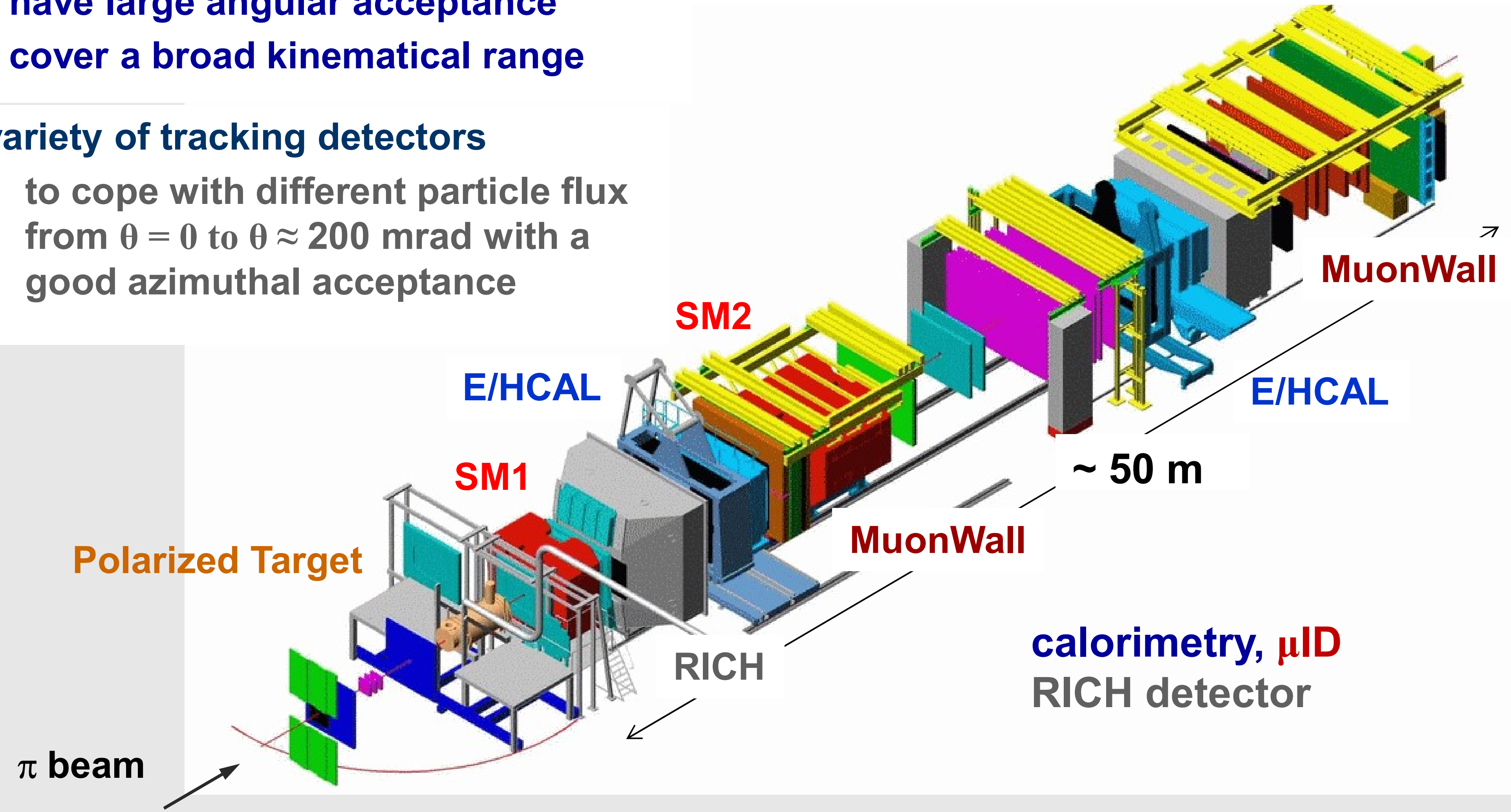
COMPASS setup in 2018

designed to
- use high energy beams
- have large angular acceptance
- cover a broad kinematical range

variety of tracking detectors

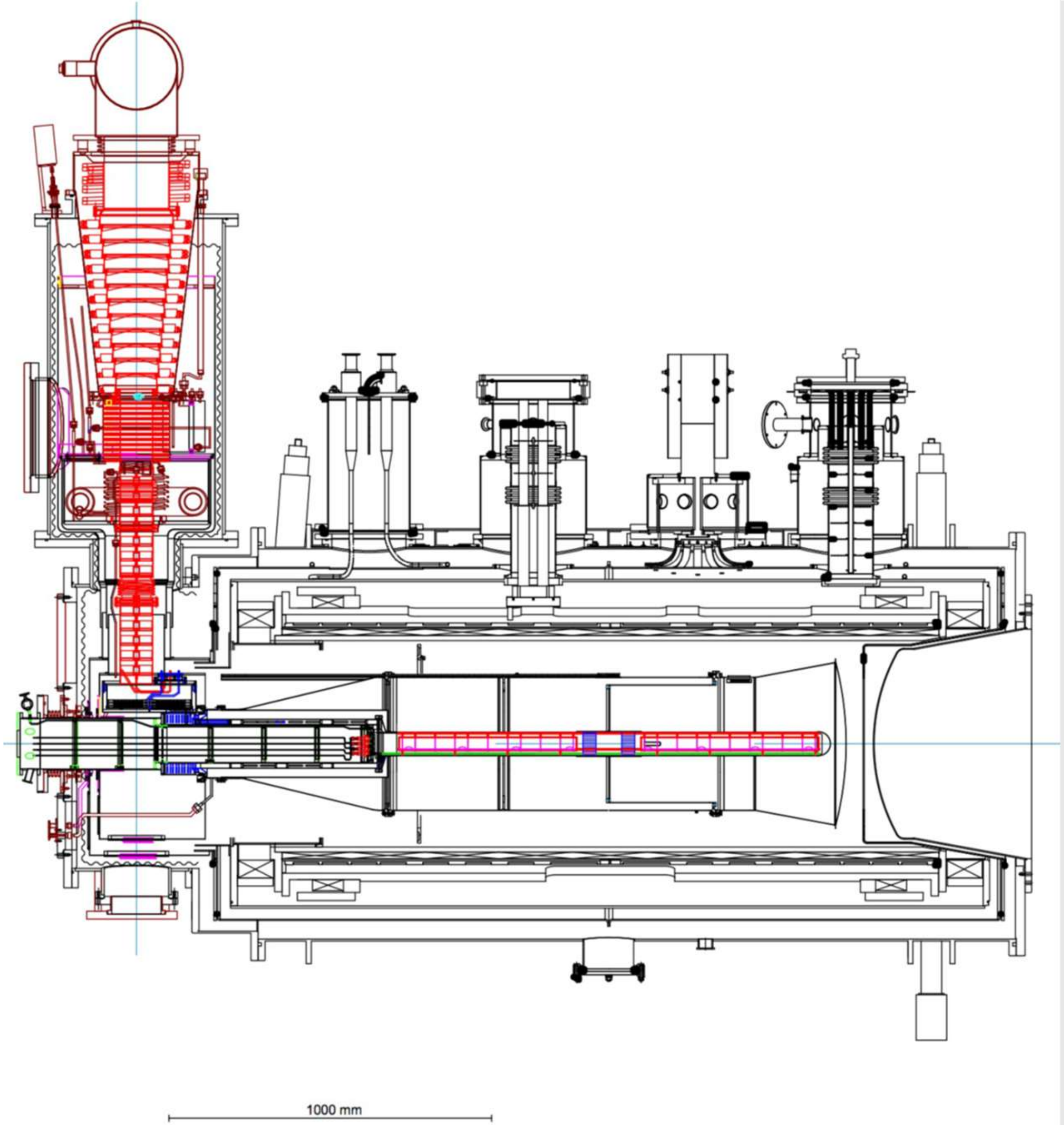
to cope with different particle flux from $\theta = 0$ to $\theta \approx 200$ mrad with a good azimuthal acceptance

Two stages spectrometer
- Large Angle Spectrometer (SM1)
- Small Angle Spectrometer (SM2)



calorimetry, μID
RICH detector

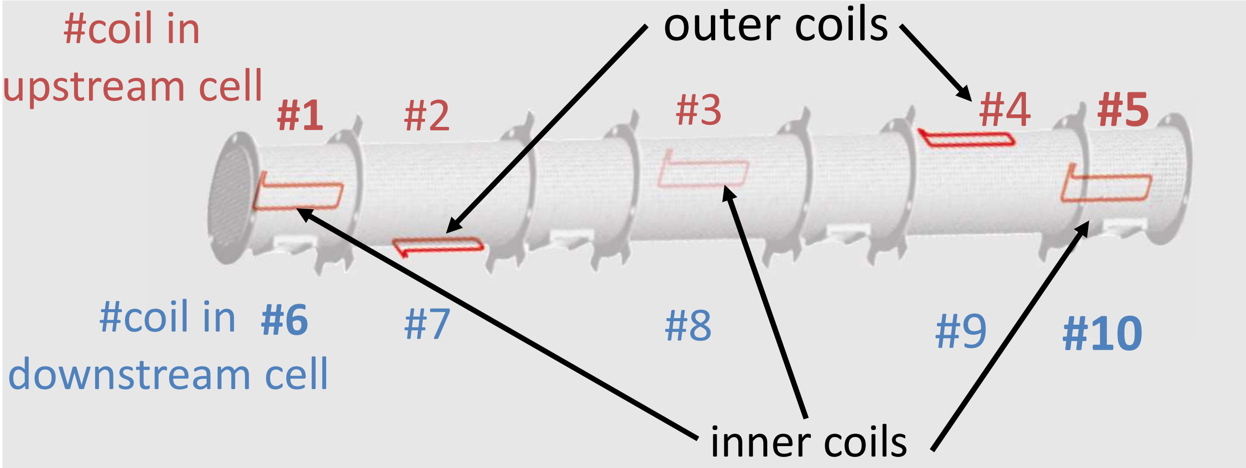
COMPASS Polarized Target



First time hadron beam was used with the COMPASS PT system

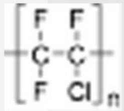
- 2.5 T solenoid + 0.6 T dipole
- 50 mK dilution refrigerator
- 2 x 55 cm long target cells
- NH_3 as proton target (17% df)
- DNP by microwave of 70 GHz
- 10 NMR coils
- Frozen spin mode at 50mK

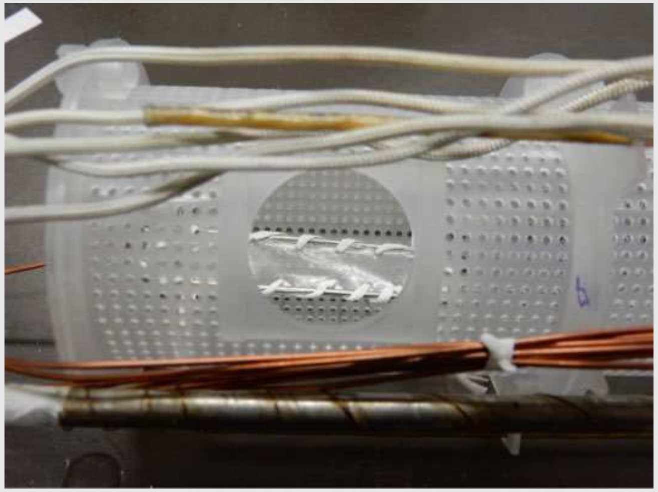
Target cells and NMR coils



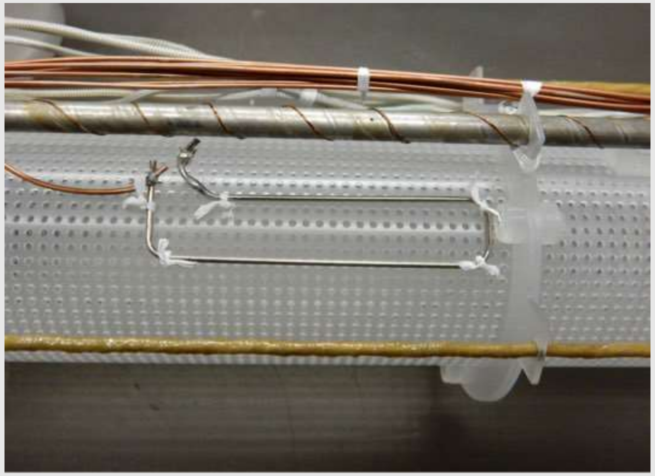
Target cell

- 55 cm × ∅ 4 cm
- made with $(C_2F_3Cl)_n$ to reduce the effect on polarization measurement
- 2(3) outer coils and 3(2) inner coils for each cell
- Since high intensity hadron beam on PT is the first attempt in COMPASS, we installed inner coils which are more sensitive to the effect of the beam
- 2 cells were placed 20 cm apart
- in 2018 old SMC NH_3 material is added to fill up the cells



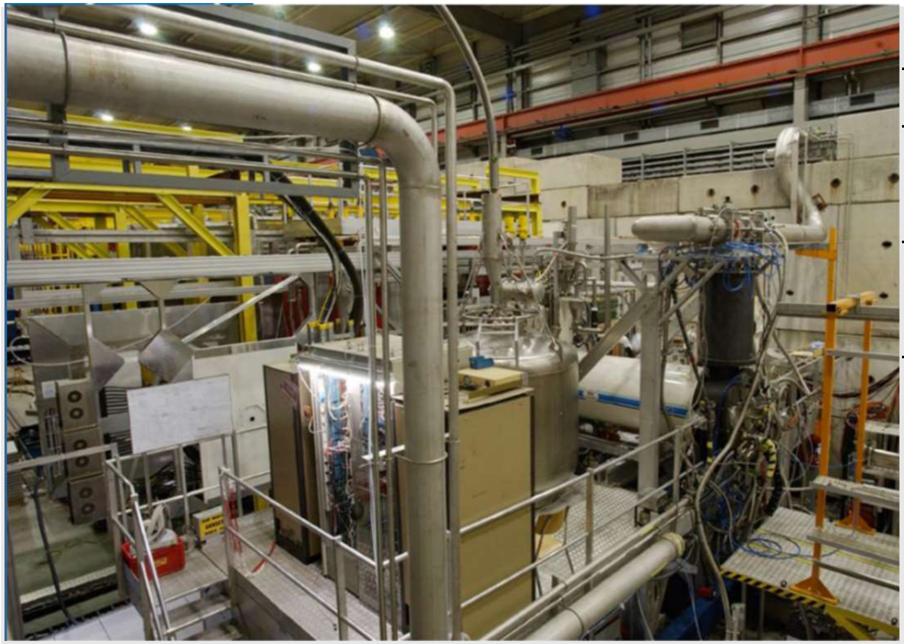


Picture of coil1 (inner)

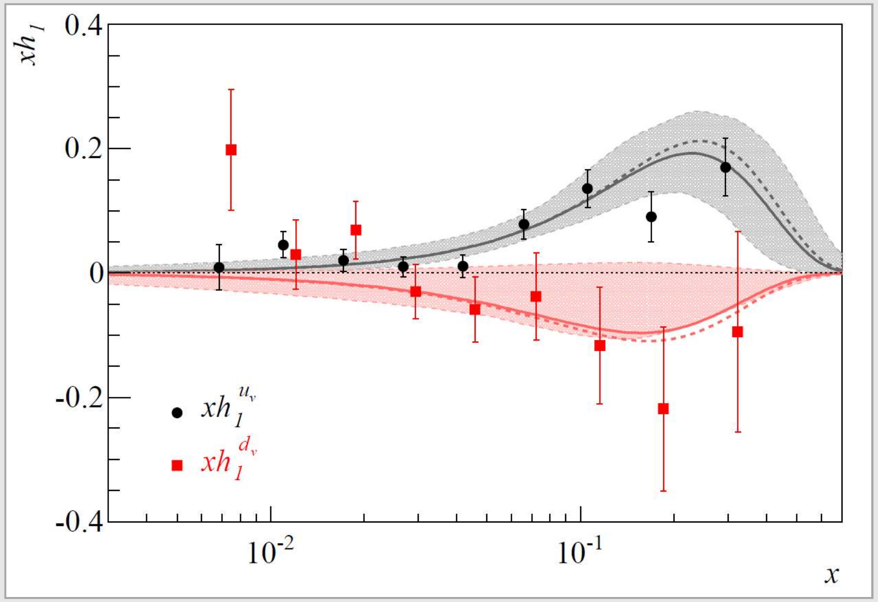


Picture of coil2 (outer)

SIDIS – transversely polarized Deuteron Target Transversity/Sivers PDF extraction



- TMD PDFs and Transversity $h_1(x)$ are flavor dependent
- Flavour separation -> data on both proton and deuteron transversely polarized targets
- Proton data set is factor 4 compared to deuteron (see error bars for transversity $h_1(x)$ in the plot below)
- It's logical to increase the deuteron data set (so far the only data sets available are COMPASS (^{6}LiD) and CLAS (^{3}He) target

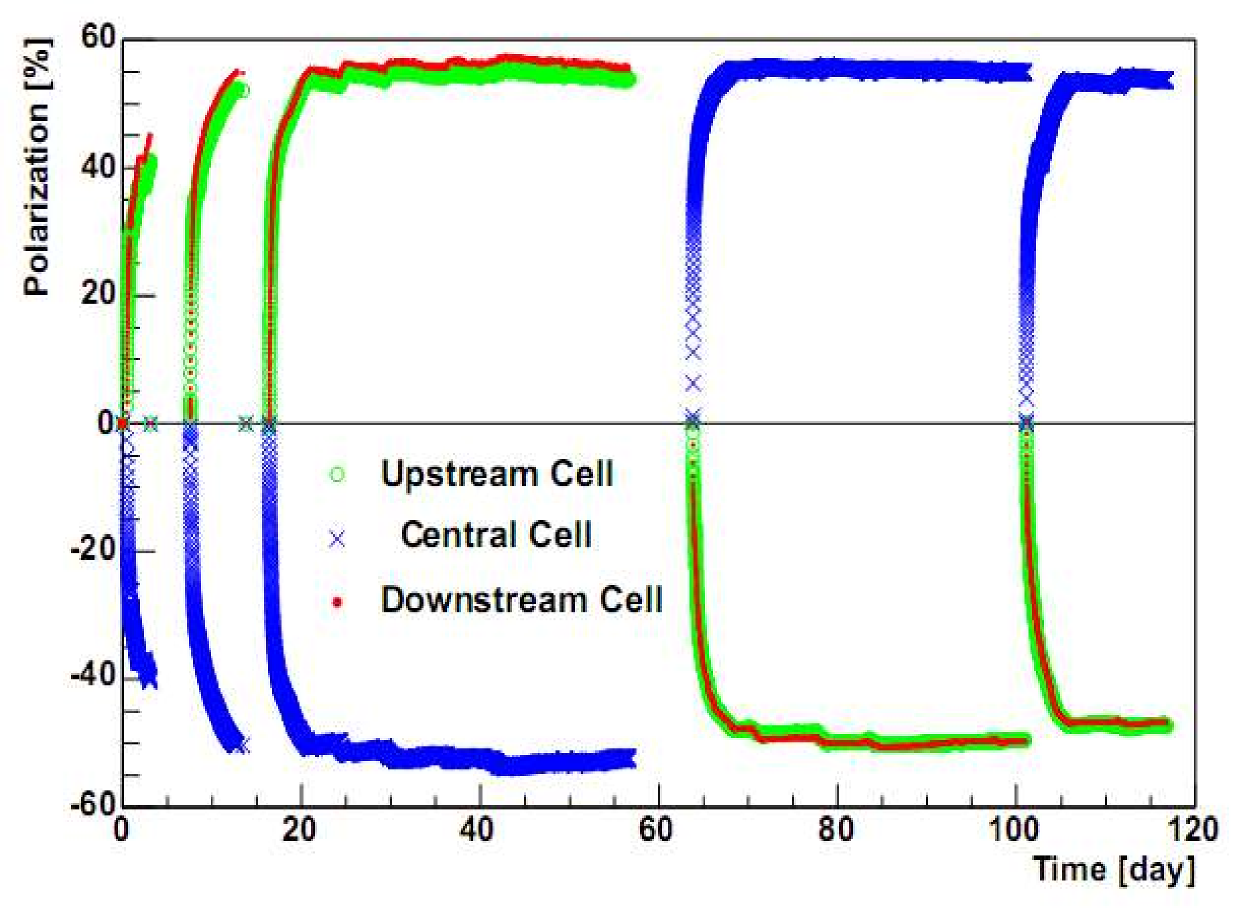


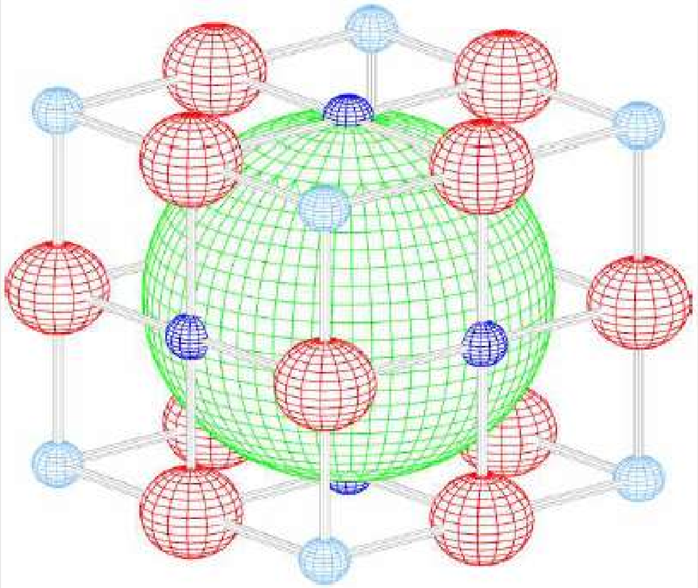
A. Martin, F.B., V. Barone PRD91 (2015) 014034

A new measurement of SIDIS on transversely polarized deuteron is planed in 2021

2021 Target material ^{6}LiD

Preparation by irradiation with electrons
(E_e= 20 MeV, T=190K)
f = 4/8 = 0.5 (^{6}Li: α + D)





COMPASS 2006
P+ = +56%
P- = -52%

Beam intensities and polarized target

$^3He^4He$ dilution refrigerator

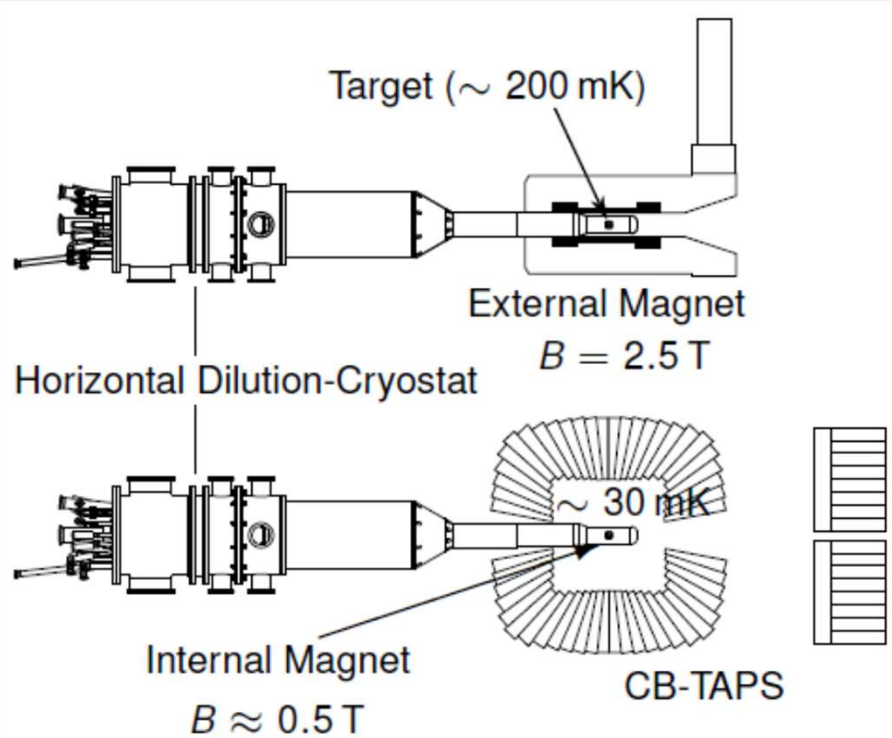
- PS185 ($\bar{p}p \rightarrow \bar{\Lambda}\Lambda$) 5 x $10^5\ \bar{p}\ s^{-1}cm^{-2}$
  Butanol block target 6mmx8mm
- CB-ELSA/TABS (Meson-Photoproduction) $\mathrm{I} \leq 10^7\gamma \cdot cm^{-2}s^{-1}$
  (D-) Butanol 2cmx2cm
- COMPASS (Drell-Yan-process) beam intensity COMPASS (π^- -> P) $\leq 10^8\ \pi^- s^{-1}cm^{-2}$
  NH_3 2x55cm, 2021 LiD 3 cell target

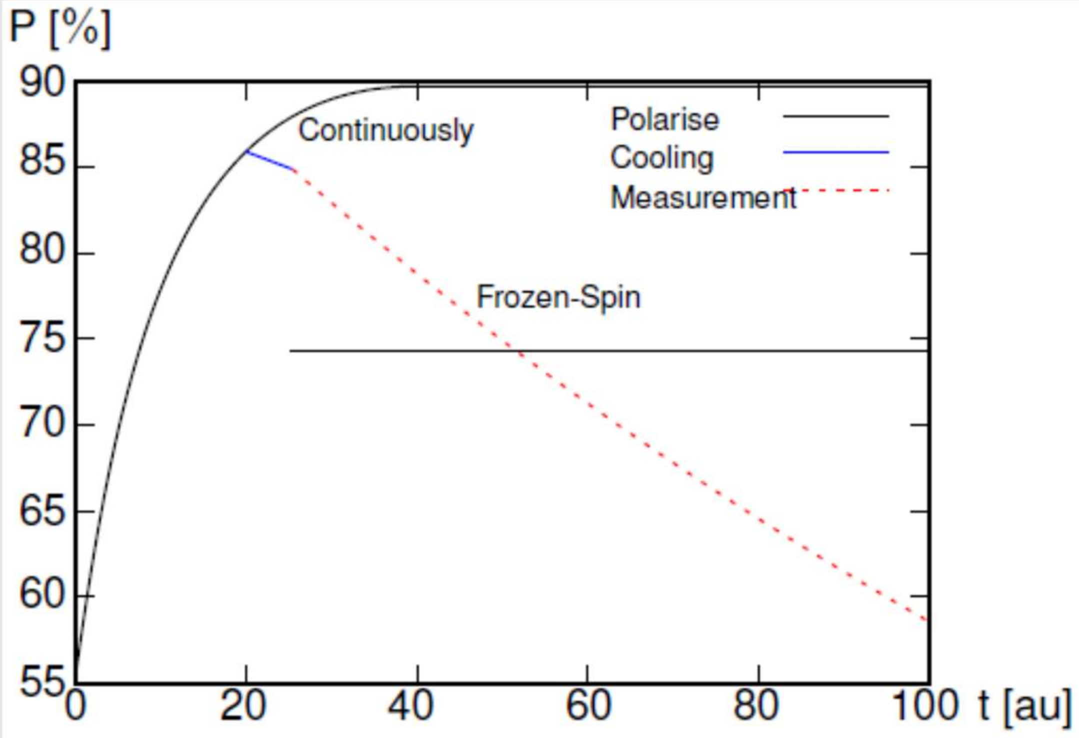
^4He evaporator (high cooling power, short t_R -> cw DNP, B $\geq$ 5T, NH_3 ND_3)

- High intense electron beams $\sim 20\ (-50)\mathrm{n}A \sim 2 * 10^{11}\ e^-\ s^{-1}cm^{-2}$
  e.g. CLAS12 e^- L up to $10^{33}cm^{-2}s^{-1}$ max. beam current 30nA($\approx 5*10^{11}$)

- Drell-Yan- Process $pp\ (\bar{u}\ u\ \rightarrow \gamma^*\ \rightarrow \bar{\mu}\,\mu)$
  high energetic and high intense beam is needed
  SpinQuest $4 * 10^{12}p$ for 4sec (56sec)

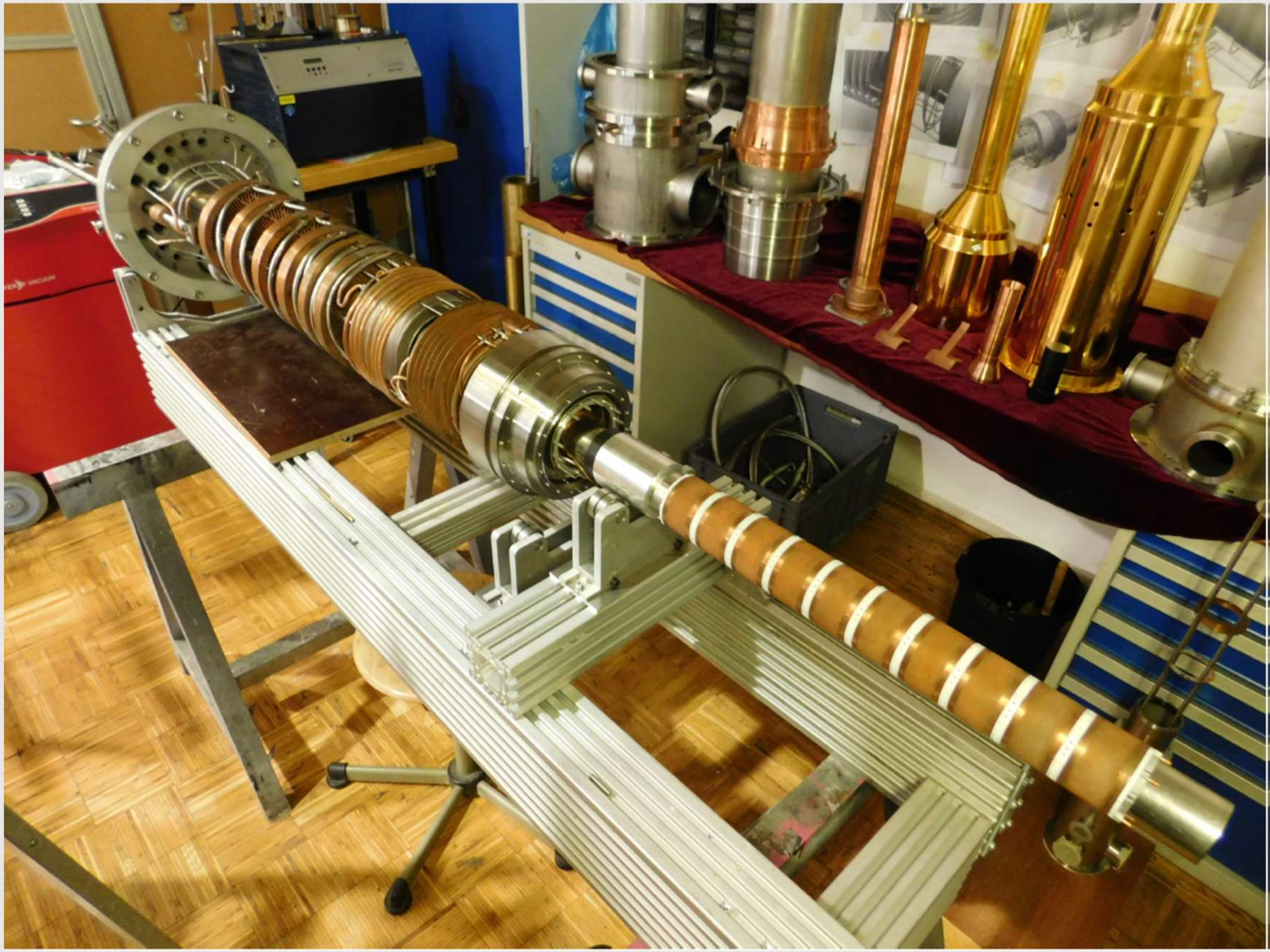
Continuous and Frozen-Spin Target





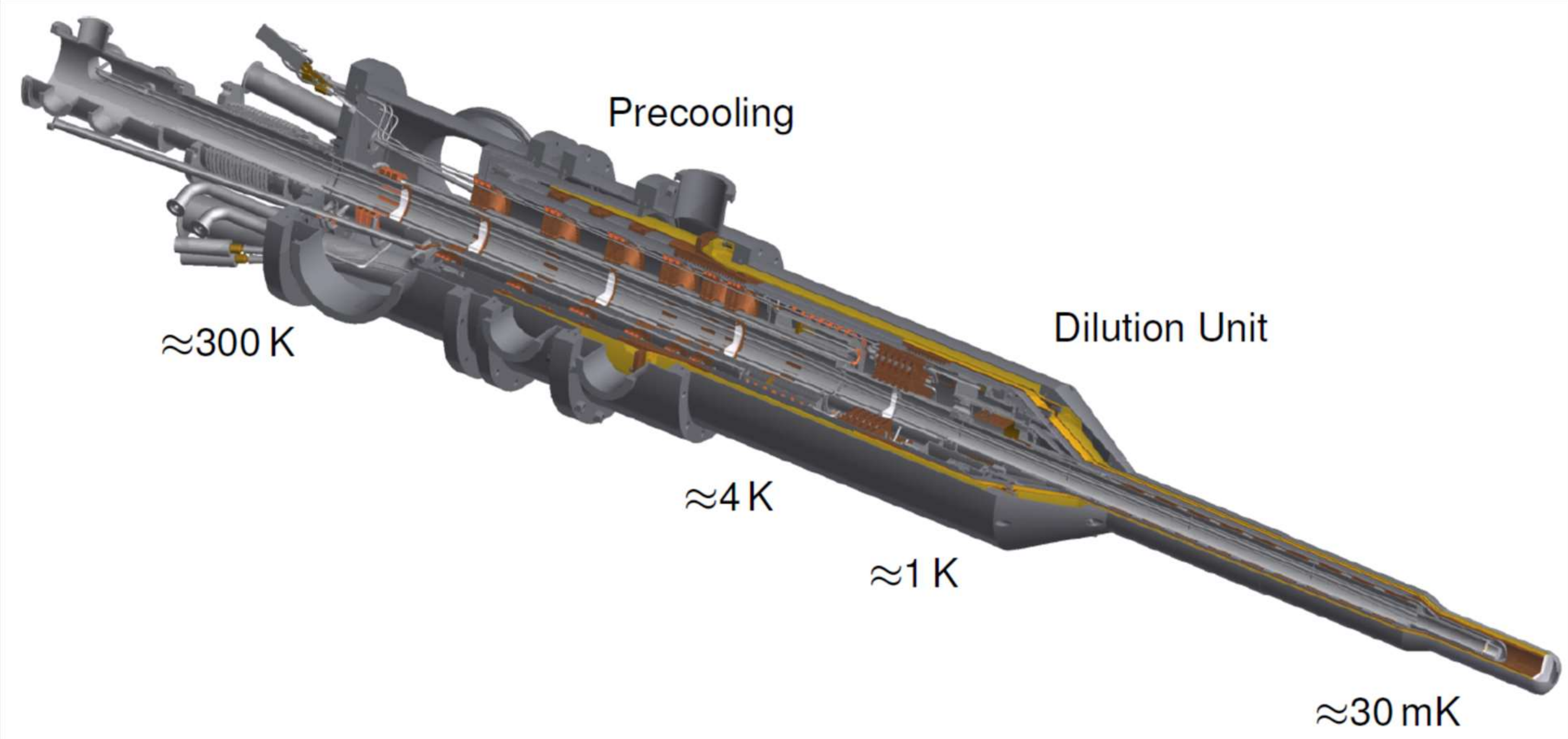
- 2018/2019: Measurements in Bonn with the Dubna/Mainz frozen-spin target.
- A new frozen-spin cryostat is under construction by Dubna and will be finished in 2019
- A continuous mode target is under construction by Bonn.

4π-Continuous Target



4π-Continuous Target

Collaborative target group: Dubna/Mainz/Bochum/Bonn (2015 –202X)
‘Dubna horizontal dilution refrigerator’ + internal ‘polarizing magnet’

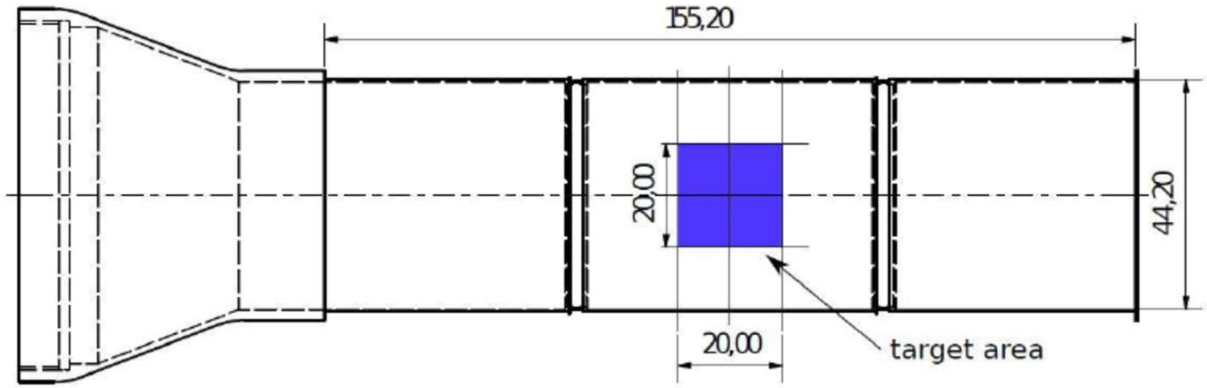


Design conditions:

- Current of 90 A for internal, longitudinal polarization-magnet.
- Cooling power of 100mW at 200mK for DNP.
- Minimal temperature 30mK for transverse polarized targets (saddle coil).

PHD: Stefan Runkel

4π-Continuous Target
high field thin s.c.magnets



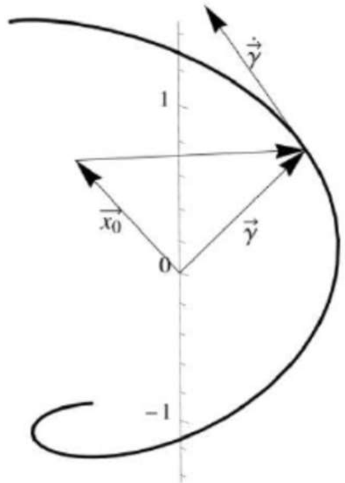
Biot-Savart-Law:

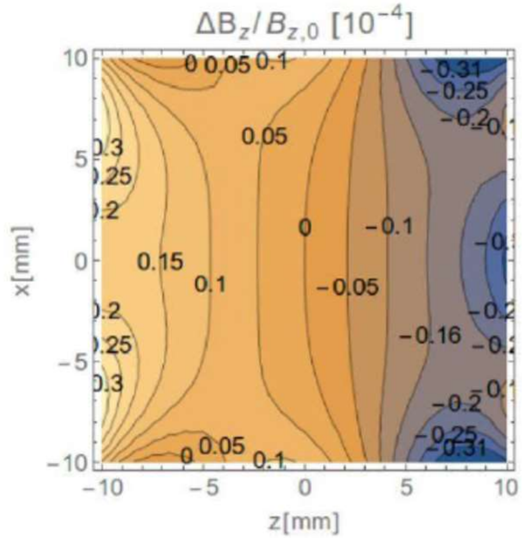
$$\vec{B}(\vec{x_0}) = \frac{\mu_0}{4\pi} I \int \frac{(\vec{\gamma}(t) - \vec{x_0}) \times \frac{\dot{\vec{\gamma}}(t)}{|\dot{\vec{\gamma}}(t)|}}{|(\vec{\gamma}(t) - \vec{x_0})|^3} \mathrm{d}t$$

Loop parametrization:

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

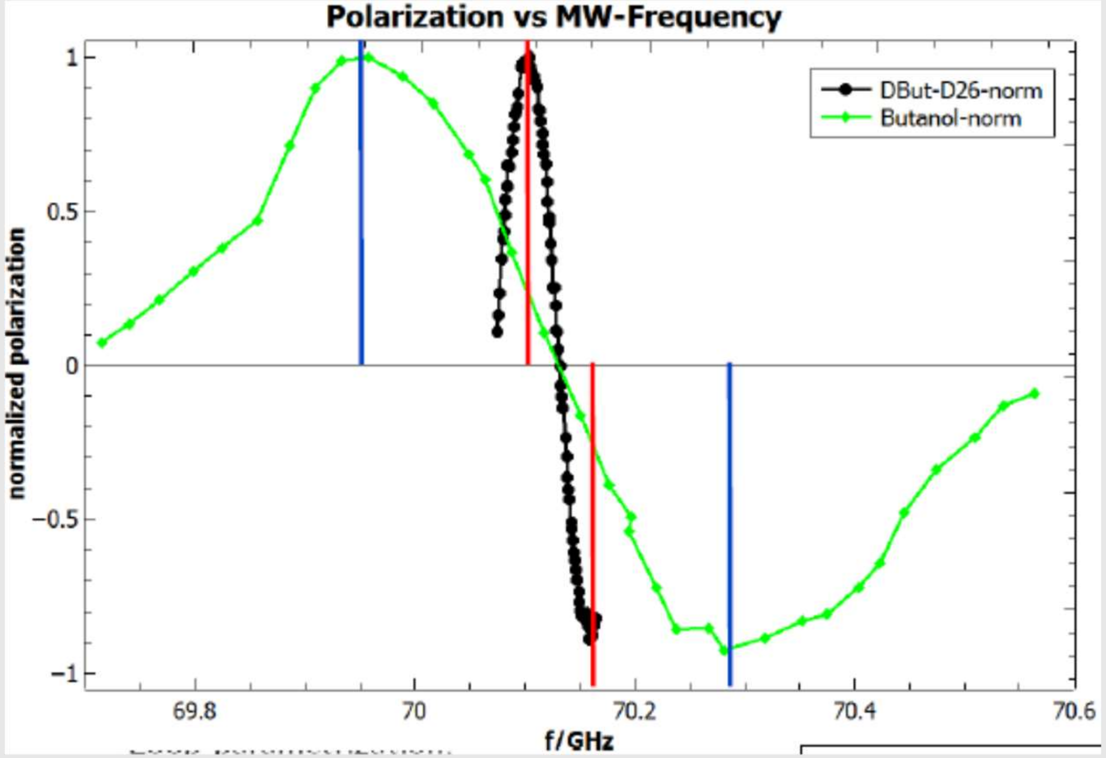
r: radius of each loop
$n \cdot d$: loop position
d: effective distance between 2 wires

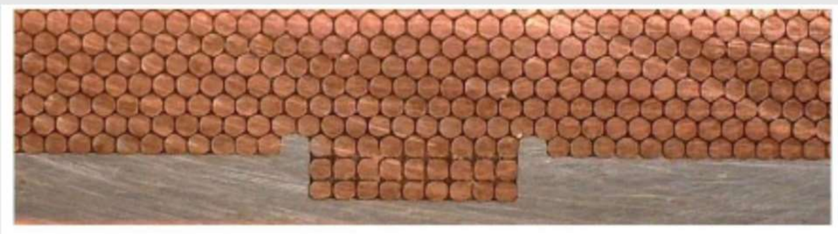




DNP requires $\Delta B/B \leq 10^{-4}$

4π-Continuous Target
high field thin s.c.magnets



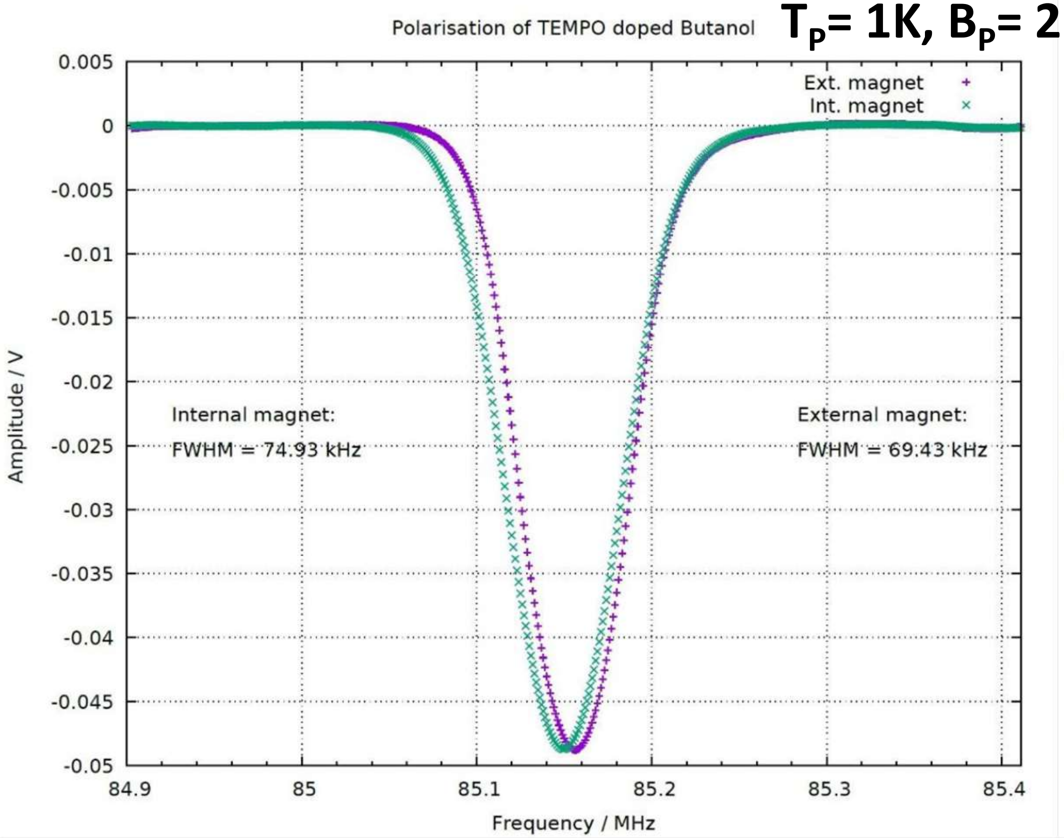


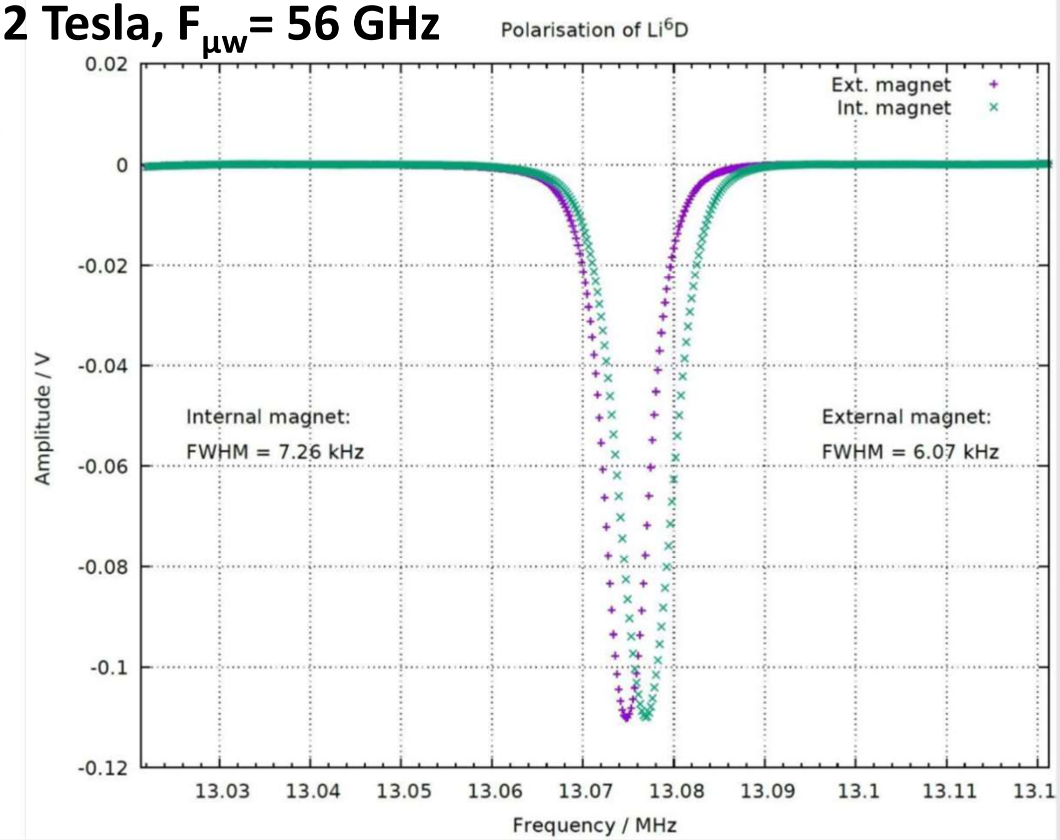
High precision winding technique to guarantee 'ortho zyclic winding'

PHD: Marcel Bornstein

First DNP-signals in the new internal thin s.c.polarizing magnet

T_P= 1K, B_P= 2 Tesla, $F_{\mu w}$= 56 GHz





4π-continiuous mode scheme has been proven

Next: 8-layers coil for the new refrigerator

PHD: Marcel Bornstein

Summary

High energy high intense beams on polarized target have some constrains due to Cryostat, target material, polarization magnet acceptance …

The recent activities leads to 4π continues mode target concept for real photon double polarization experiments at ELSA and MAMI

The scheme has been proven @ 1K, 2 Tesla and will be realized in cooperation with Mainz/Dubna/Bochum PT-groups