Nuclear frozen spin targets for GDH-Experiments

1.-Target Technology: Spin alignment in solid state material

2.-Experimental setup at A2: γ- beam + Tagger + CrystalBall@MAMI + Frozen Spin Target

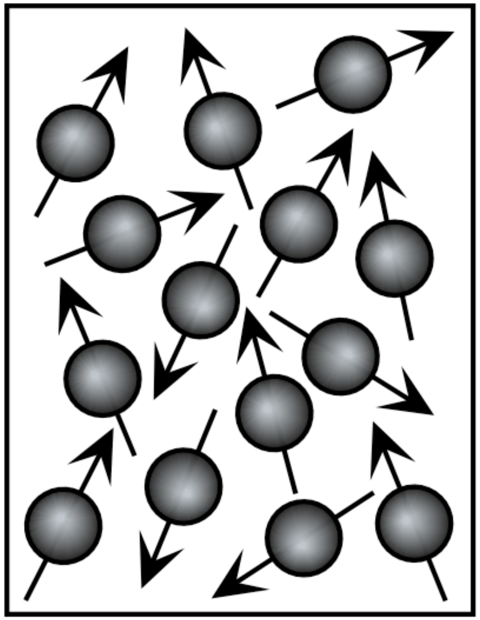
3.-Target Materials

EMMI Workshop
Meson and Hyperon Interactions with Nuclei
14-16 September 2022
Kitzbühel, Austria

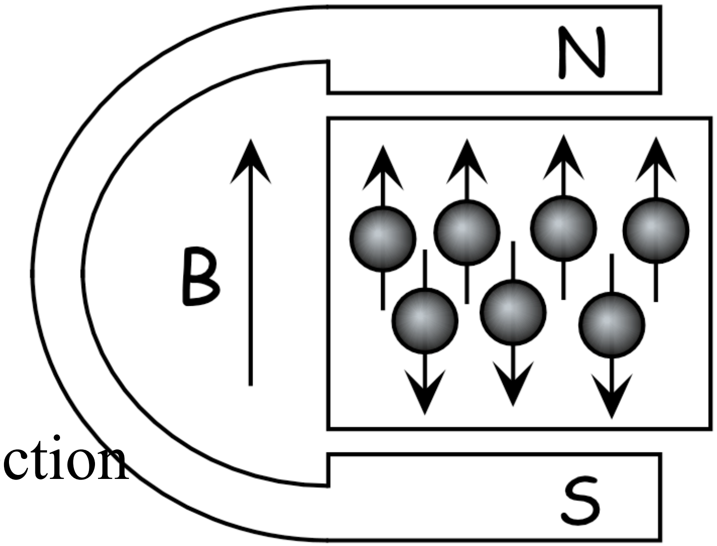
Andreas Thomas

Polarized Target Technology

Polarization = Orientation of Spins in a magnetic field



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



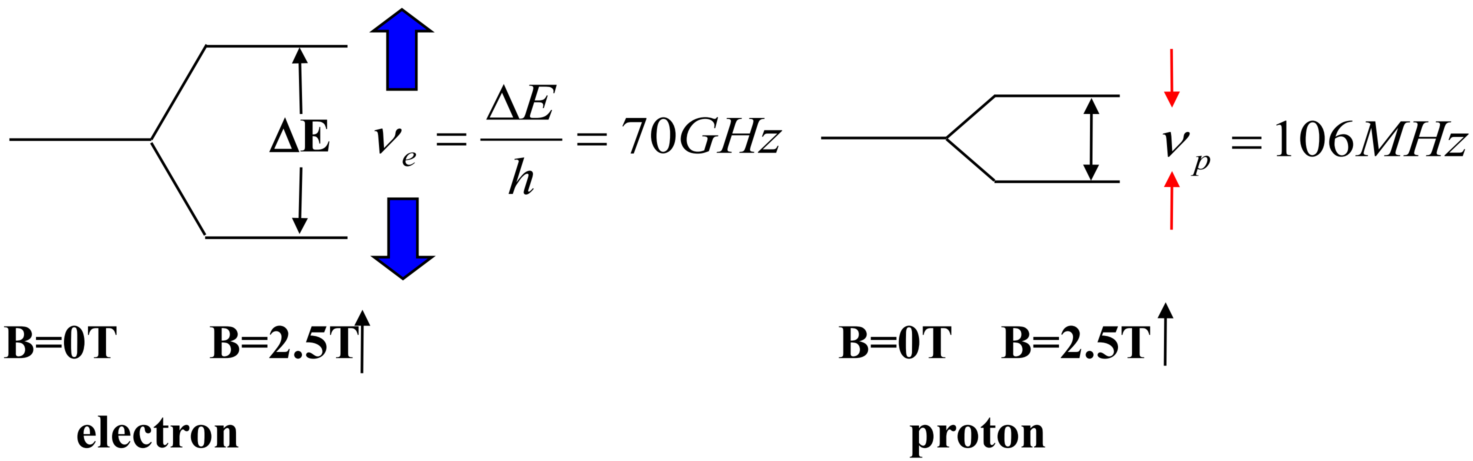
Ideally: All spins in field direction

P=100%

Complicated interplay between

Polarising force	~	magnetic field B
and		
Depolarising force	~	thermal motion of spin particles (temperature T – relaxation)

Magnetic moment in magnetic field: $E = -\vec{\mu} \cdot \vec{B} = -g\mu_o mB$



Thermal equilibrium
Boltzmann distribution $\frac{N(E+\Delta E)}{N(E)} = e^{-\frac{\Delta E}{kT}}$

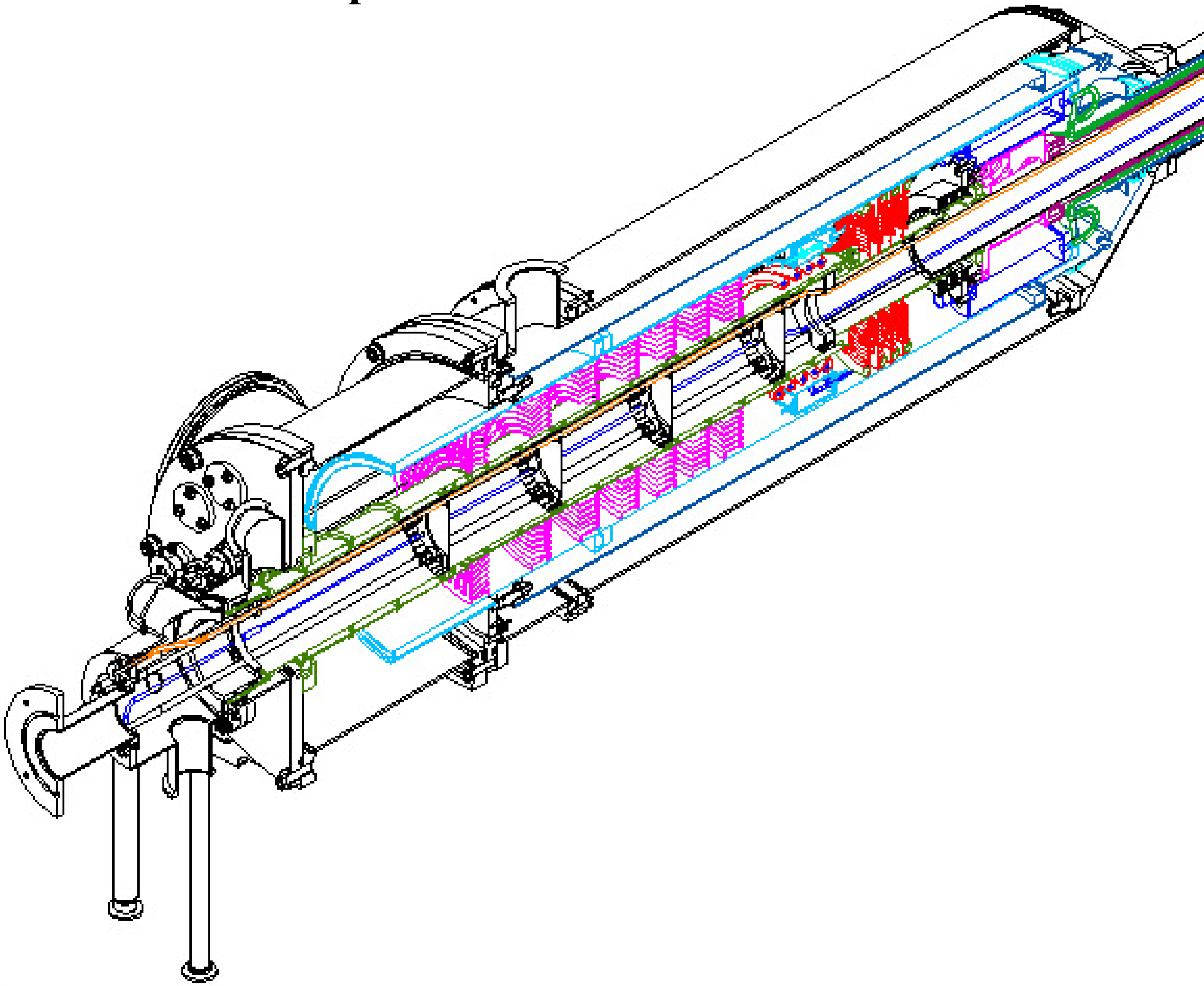
$$P = \frac{N_+ - N_-}{N_+ + N_-} = \tanh\frac{\mu B}{kT}$$

B [Tesla]	T [mK]	e^- [%]	p [%]	d [%]
2,5	100	99,8	0,51	0,10
	1000	93,3	0,25	0,05
5,0	100	100,0	5,09	1,05
	1000	99,8	1,28	0,11

Trick: Transfer of the high electron polarization to the nucleon via μ-wave irradiation (DNP)

Magnet Technology + Cryogenics

DNP at 200mK and 2.5T with 70GHz microwaves.
Frozen spin target (25mKelvin, 0.6T).
Secondary particles punch through holding coil.
All directions of polarization.



Transverse (Saddle coil)

and

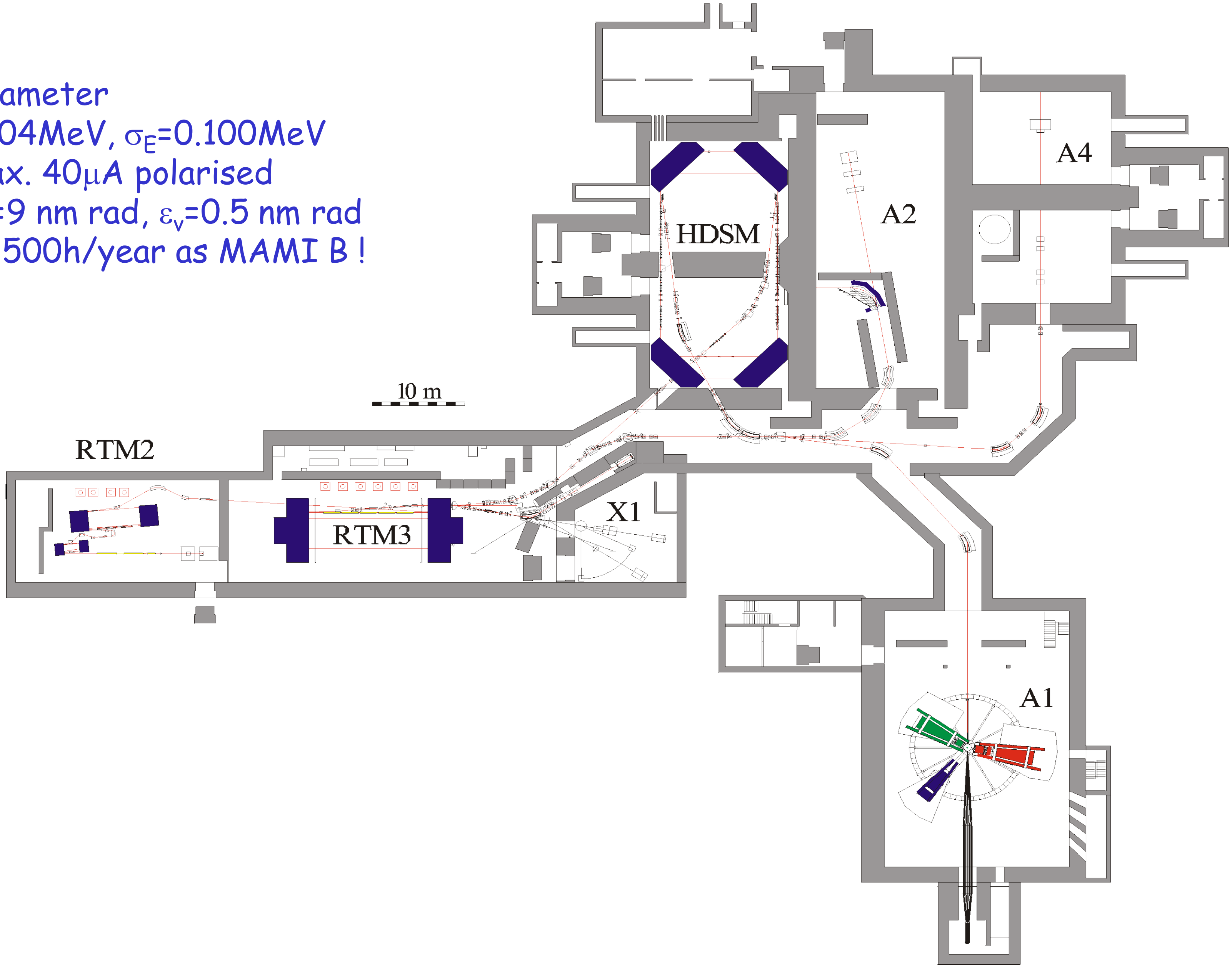
Longitudinal (Solenoid)

Internal

Holding Field (1.2K, 0.6T)

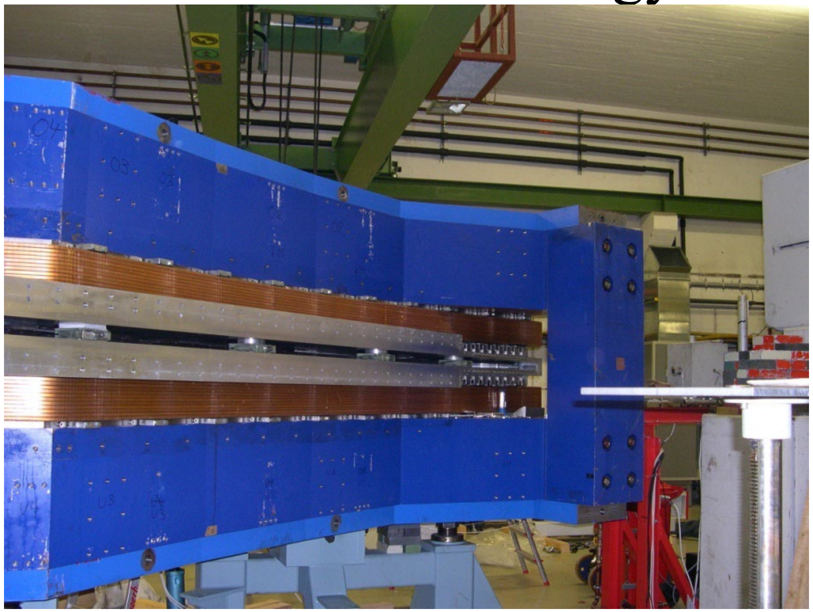
Typical 4π experiment: A2 at MAMI

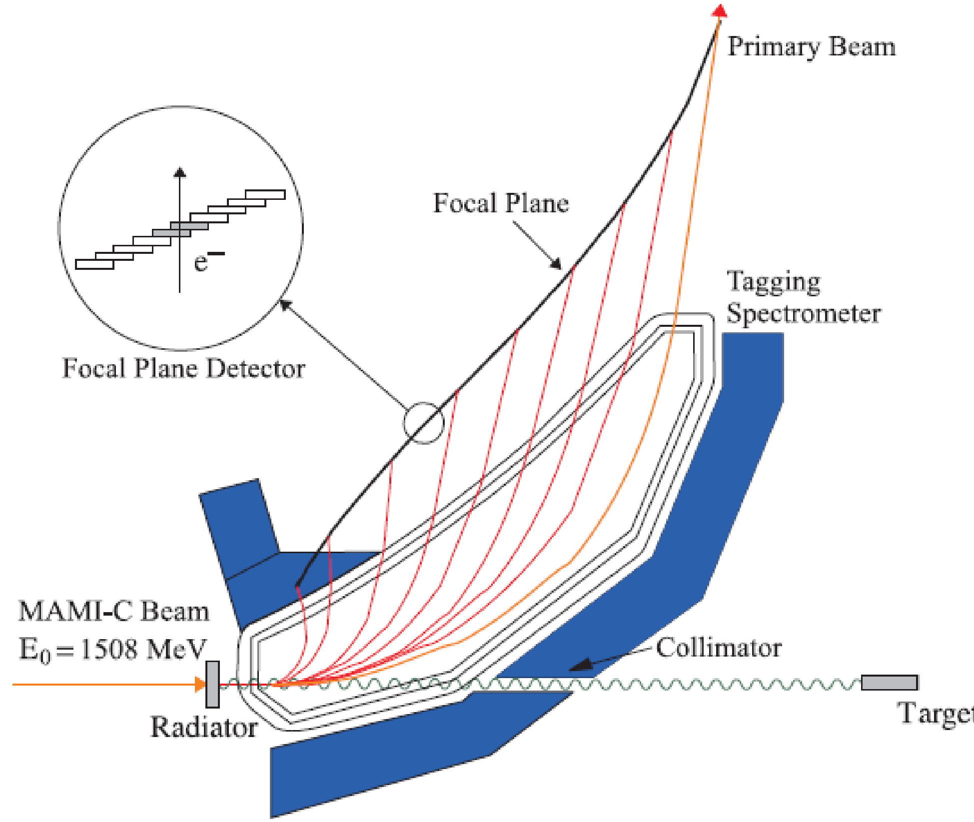
Parameter
- 1604MeV, σ_E=0.100MeV
- max. 40μA polarised
- ε_h=9 nm rad, ε_v=0.5 nm rad
- ~6500h/year as MAMI B !



A2 Tagging system (Glasgow, Mainz)

1. Production and energy measurement of the Bremsstrahlung photons.





Glasgow Tagging Spectrometer
EPJ A 37, 129 (2008)

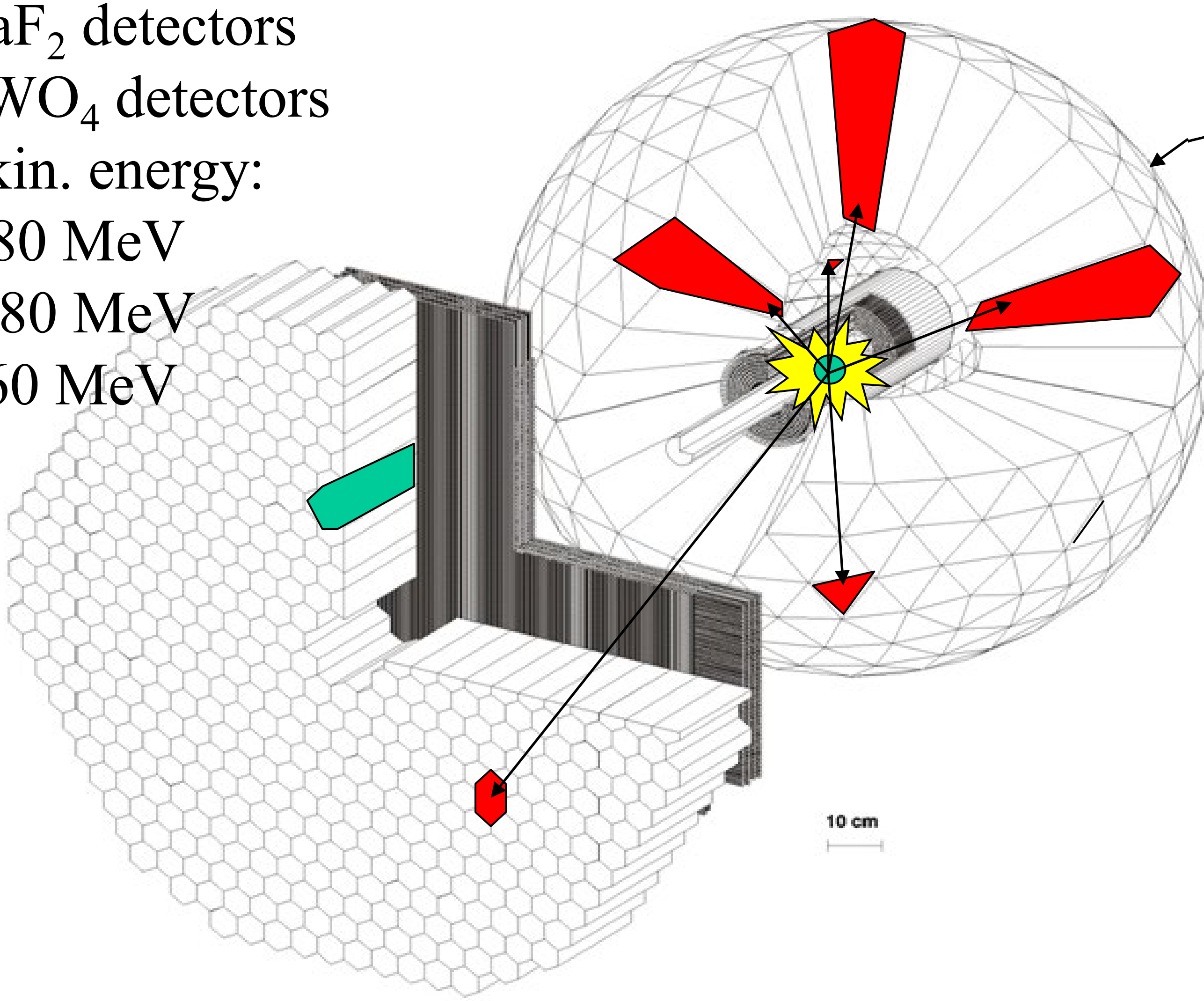
2. Determination of the degree of polarization of the electron beam (Moeller Polarimeter). Circularly pol. photons.

$$A = \frac{N^+ - N^-}{N^+ + N^-} = a\vec{p}_t \vec{p}_b \cos(z)$$

3. Coherent production of linearly polarized photons on a diamond radiator

4π photon Spectrometer @ MAMI

TAPS:
366 BaF_2 detectors
72 $PbWO_4$ detectors
Max. kin. energy:
π^{+-} : 180 MeV
K^{+-} : 280 MeV
P : 360 MeV

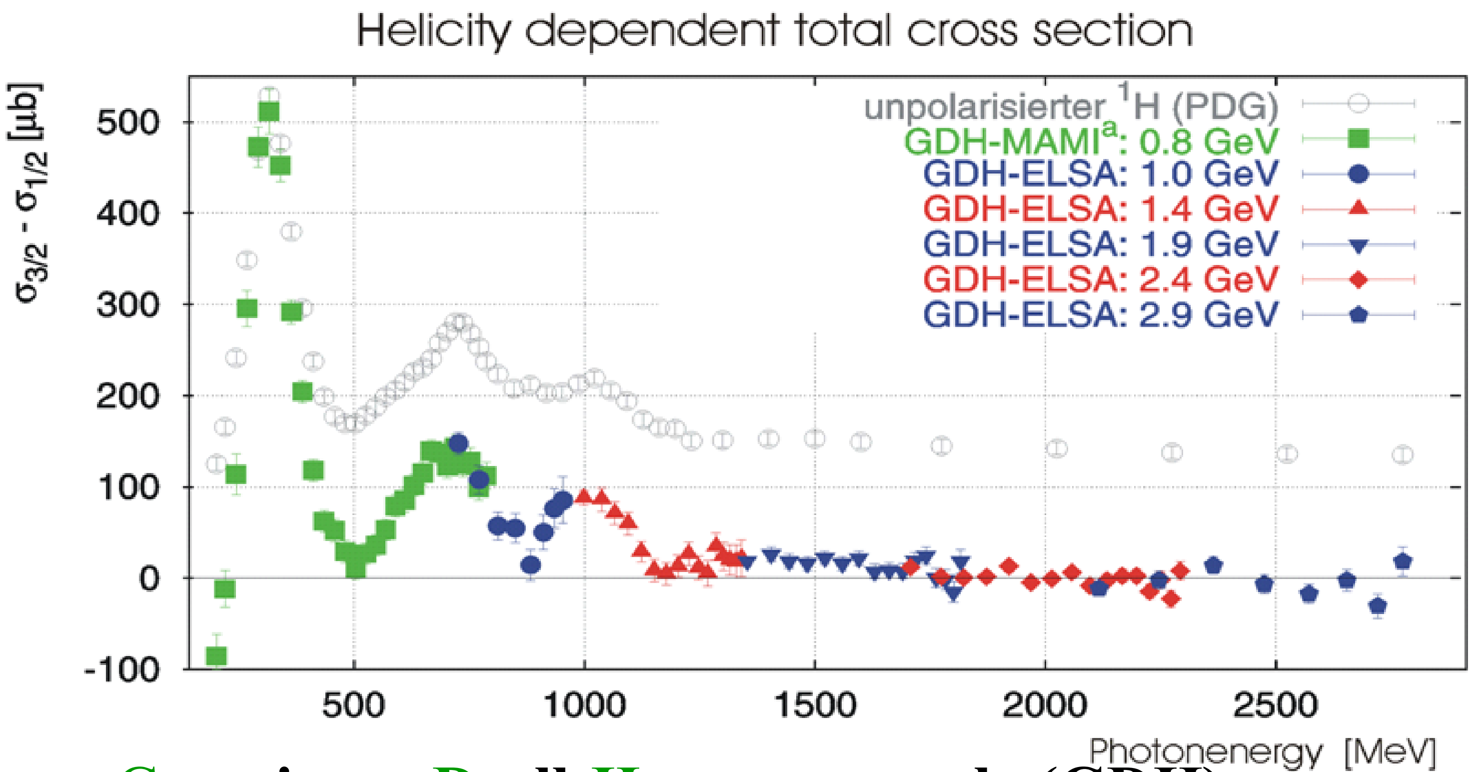


Crystal Ball:
672 NaJ detectors
Max. kin. energy:
μ^{+-} : 233MeV
π^{+-} : 240 MeV
K^{+-} : 341 MeV
P : 425 MeV

Vertex detector:
2 Cylindr. MWPCs
480 wires, 320stripes

PID detector:
24 thin plastic detectors

Helicity Dependence E of Meson Photoproduction on the Proton and Neutron

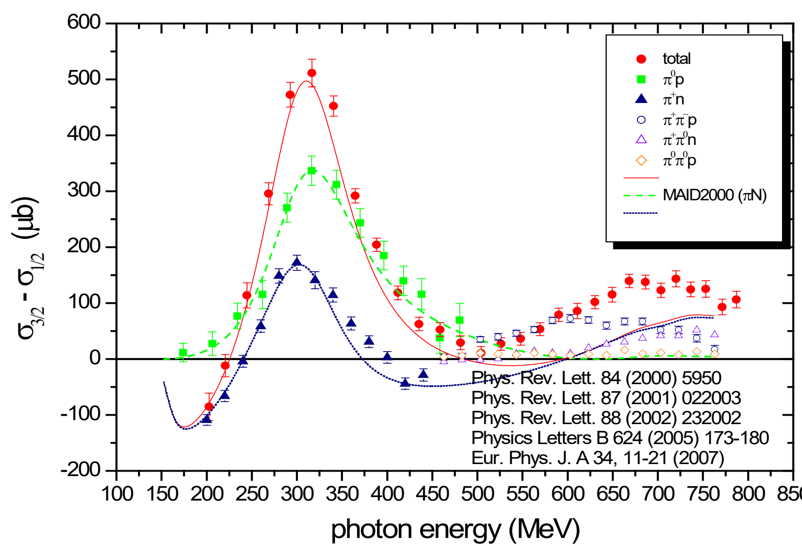


1998-2003 Mainz and Bonn

2010-2016 New Mainz Exp. with CBall

Gerasimov-Drell-Hearn sum rule (GDH)

$$\int_0^\infty \frac{\sigma_{3/2}(\omega)-\sigma_{1/2}(\omega)}{\omega}\,d\omega = \frac{\pi e^2}{2m^2}\kappa^2$$

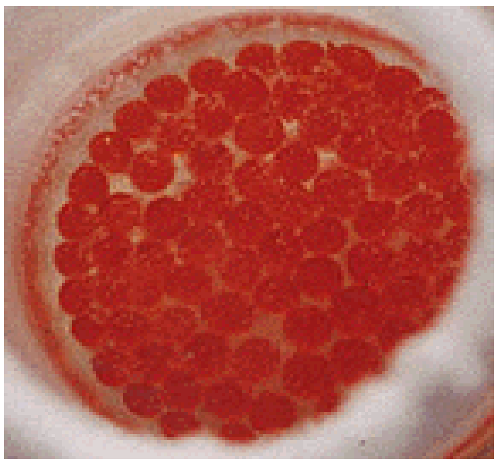


Simultaneous measurement of E and G

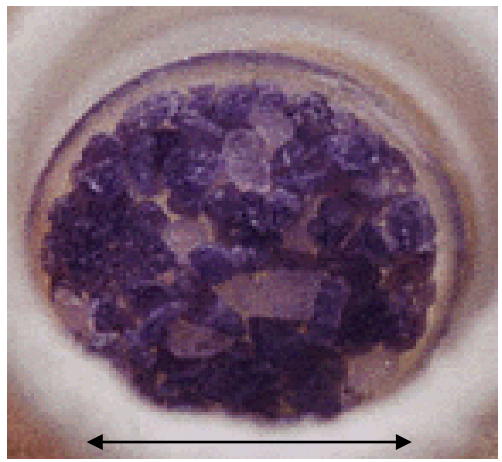
Target materials

Unfortunately, in pure H_2 or D_2 the spin align antiparallel at low temperatures. However, there are experimental effords to polarice HD-ice, but the technology is very complicated.

Frozen Spin Target with chemical compounds and doping are used.



Butanol



30mm
Ammonia

LiD

Small beads or spheres with dimension of 1-3mm are used and cooled in liquid 3He/4He mixture.

Target materials

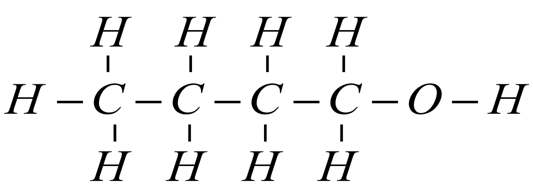
Saturated electrons of target material not polarized (Pauli principle)

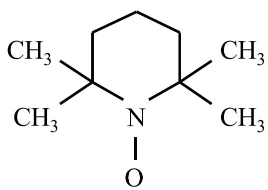
Free electrons ⇨ **Radicals in material by chemical or radiative doping**

$$\frac{\#\,radicals}{\#\,protons} \approx 10^{-4}$$

Dilution factor (e.g. $f_{Butanol}$=10/74) determines quality of target material

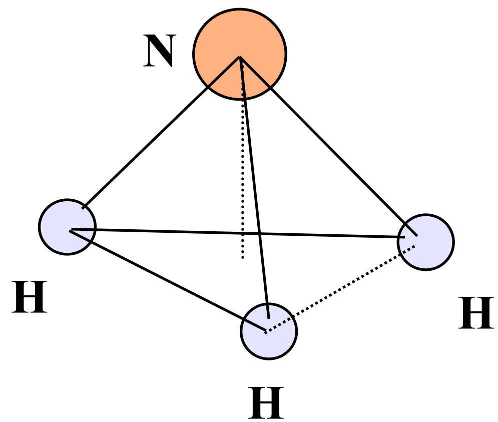
Butanol





Tempo

Ammonia



LiD

Radical is produced by electron irradiation at ~100Kelvin.

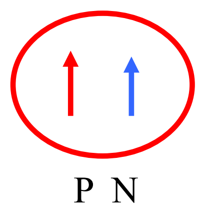
GDH sum rule for nuclei

$$\int_0^\infty \frac{\sigma_a(\omega)-\sigma_p(\omega)}{\omega} d\omega = -4\pi\kappa^2 \frac{e^2}{m^2} S$$

	κ	ω_L [MHz]	I_{GDH} [μB]
Proton	1.79	**106.7**	**-204**
Neutron	-1.91		**-233**
Deuteron	-0.14	**16.4**	**-0.65**
^{3}Helium	-8.38	**81.3**	**-497**
^{6}Lithium	-0.53	**15.7**	**-0.53**
^{7}Lithium	19.84	**41.5**	**-510**

Deuteron

Partial reaction channels on quasifree neutron

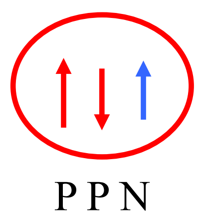


P(Neutron) ~ 0.92 P(Deuteron)

$$I_{\exp}^{d} \approx I_{GDH}^{n} + I_{GDH}^{p} + I_{nucl.eff.}$$

^{3}Helium

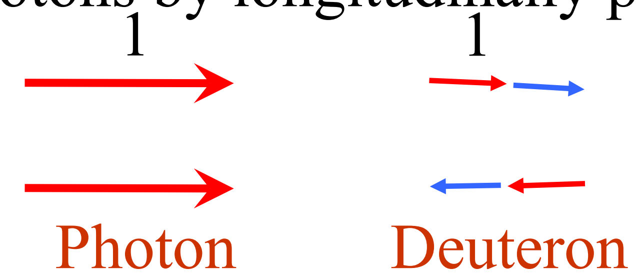
GDH-Integral with small systematic error



$$I_{\exp}^{he} \approx I_{GDH}^{n} + \alpha \cdot I_{GDH}^{p} + I'_{nucl.eff.}$$

$\alpha \approx 0.1$

Absorption of circularly polarized real photons by longitudinally polarized deuterons

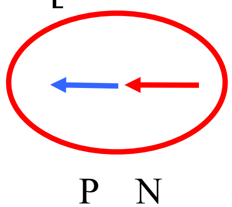


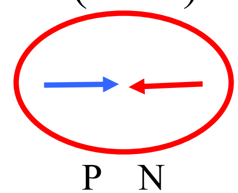
σ_p

σ_a

Helicity dependent deuteron photodesintegration

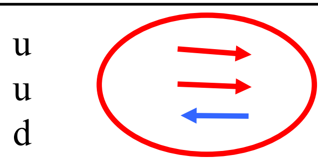
[Arenhövel et al. , Physics Letters B 407 (1997) 1-7]

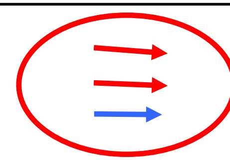




$^3S_1$ deuteron ground state $\quad$ $^1S_0$ resonante state at 68KeV

⇒ The resonante $^1S_0$ state can only be reached if the inital spins are **antiparallel** at energies close to break-up threshold (2-3MeV)



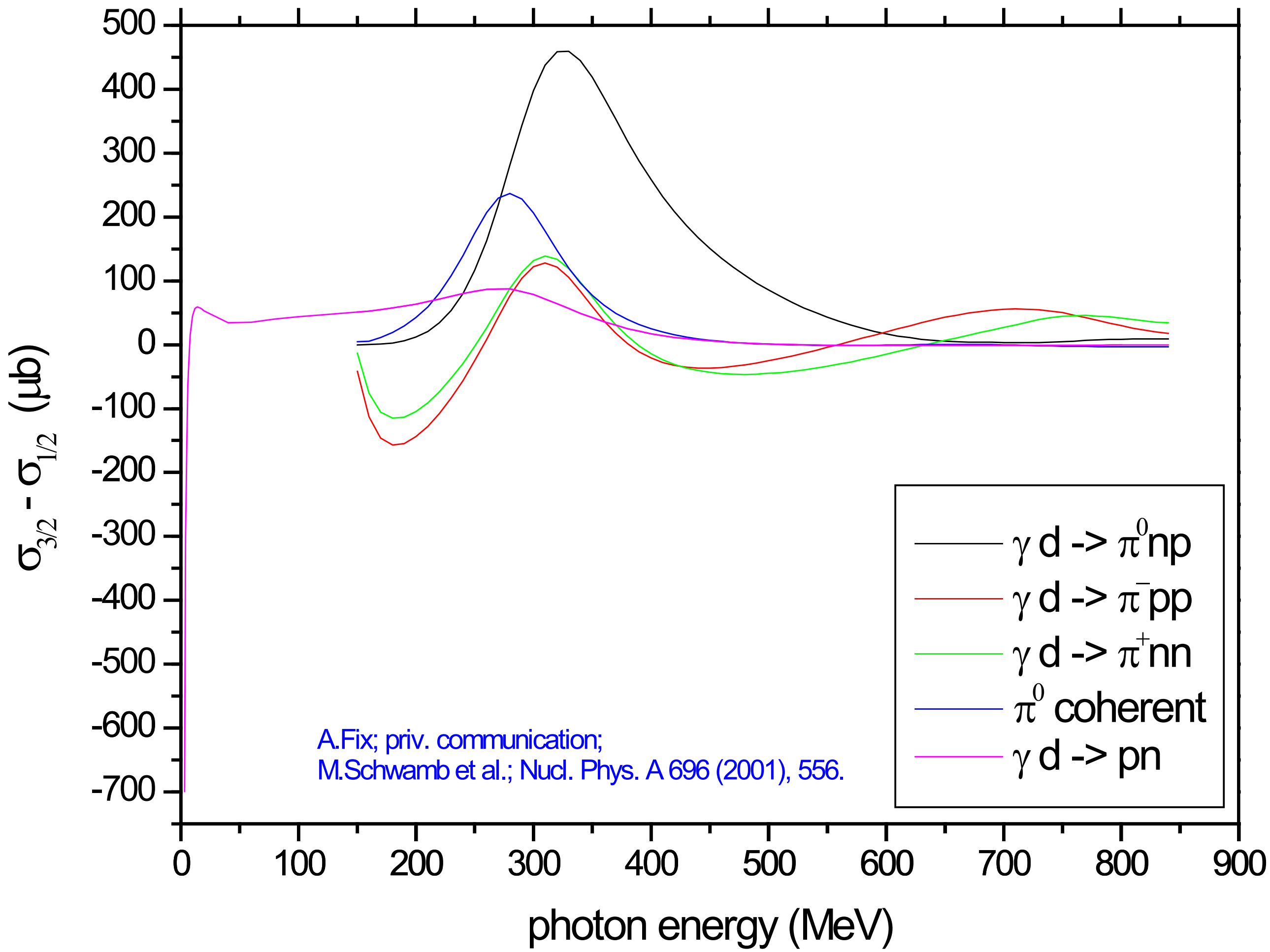


proton (neutron) $\quad$ Δ(1232)-resonance

⇒ The Δ resonance can only be reached if the inital spins are **parallel** at 300MeV

⇒ $I_{GDH} = 0.65 \mu b$

Helicity dependent deuteron photodesintegration



- Nucleon Nucleon Interaction
- Meson Exchange currents
- Final State Interaction
- Relativistic Effects, Retardation

Conclusions

- **Polarised frozen spin targets are a well developed tool to investigate Spin physics in 4π detector systems.**

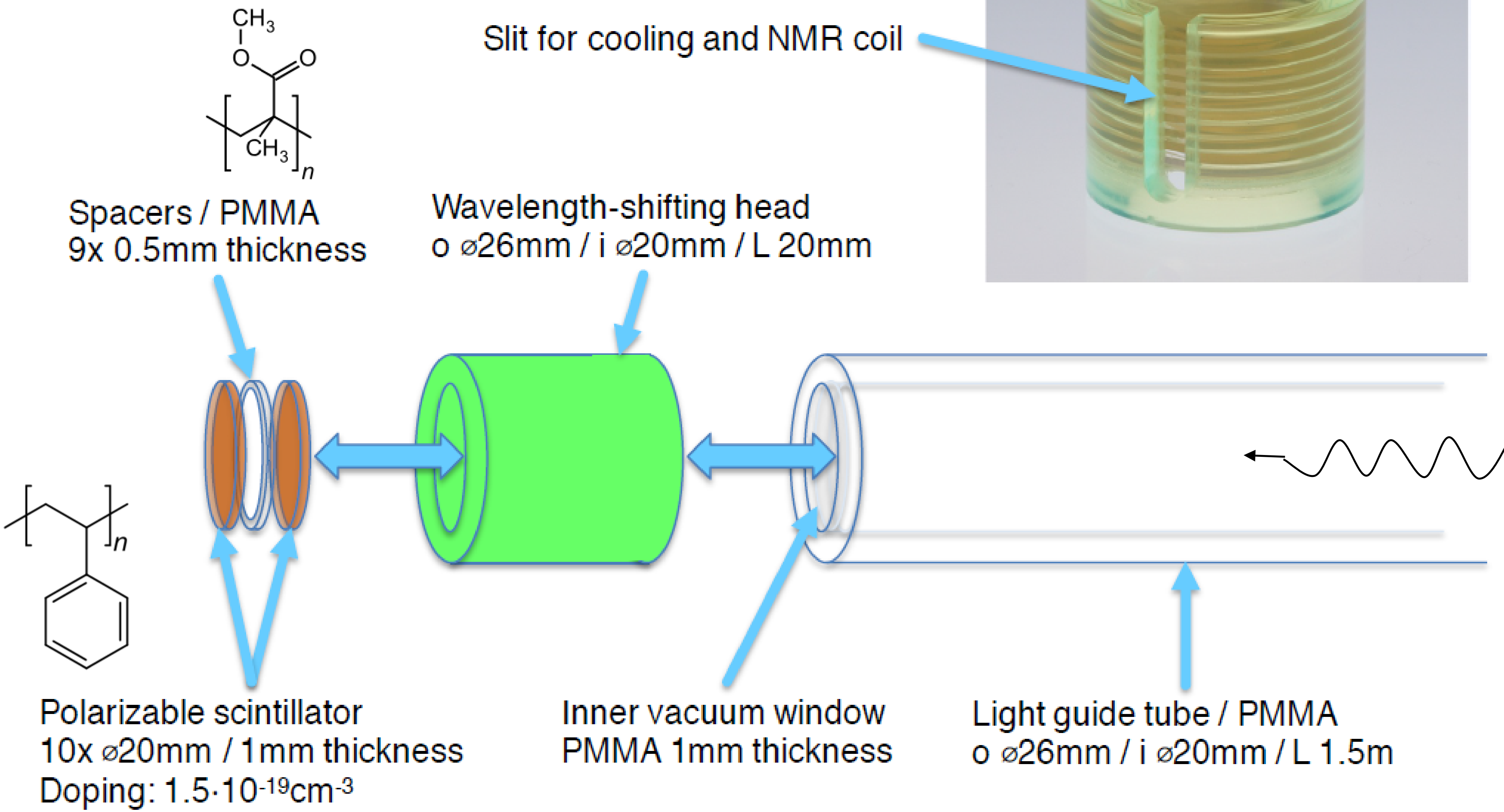
Outlook

- **The complicated technology for the different components (target material, cryogenics, magnets,…) needs an active support and developement from an international community.**

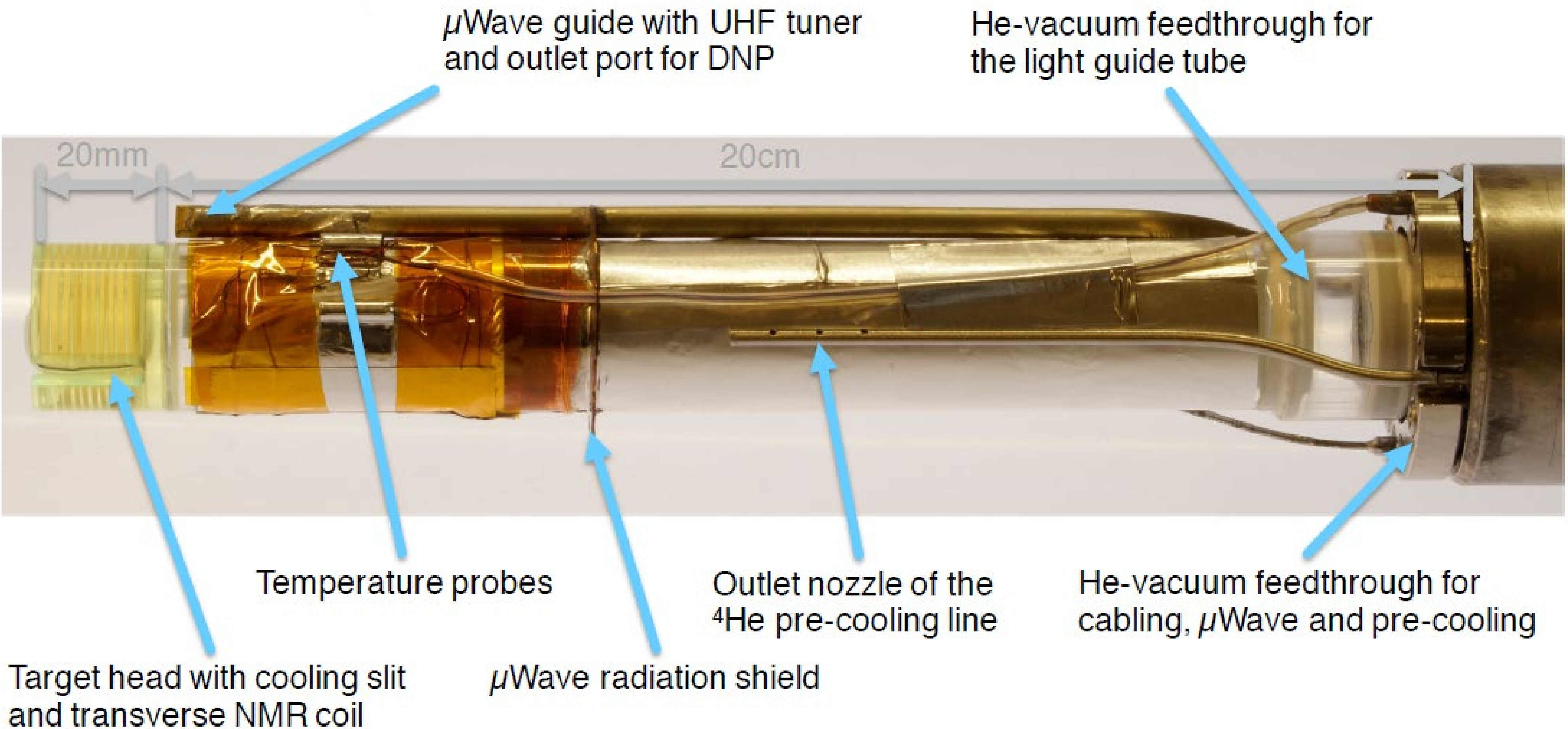
- **R&D for polarised active szintillator target for threshold production and Compton is on the way.**
- **Semi active targets with d-Butanol filling and scintillators in the milli-Kelvin target chamber are another option.**

Thank You!

New Developement:
Active Polarized Target



Active Polarized Target



T=45mKelvin after 5 days by $^3He/^4He$ mixture ← ←Vacuum in beampipe