Dynamic Nuclear Polarization

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COMPASS PT- team at CERN:
Dynamically Polarized Targets

- How the dynamically polarized targets work?
- Basic apparatus required and techniques
- Recent developments and topics
Elementary consideration $S=I=1/2$

$$P_{e,p}(S = I = \frac{1}{2}) = \frac{n^+ - n^-}{n^+ + n^-} = \tanh\left(\frac{\mu_{e,p} B}{k_B T}\right)$$

$\mu_e, \mu_p$ are electron and proton magnetic moments

$\mu_e \approx 1000 \times \mu_p$

One can see that all parameters in this formulae are fixed but the temperature

$B=2.5 \text{ T}$

$T=1 \text{ K}$

$P_e = 92\%$

$P_p = 0.25\%$

large magnetic moment of electron

small magnetic moment of nuclei
Dilution refrigerator may cool the nuclear spins down $T \sim 0.1$ K, but practice shows that this process takes about 1000 hour due to excellent isolation of nuclear spins from the lattice!
On the other hand, the electron and nuclear spins interact with electromagnetic irradiation, therefore, to reach lower temperatures, it was elaborated a very specific method called the Dynamic Nuclear Polarization (DNP).

Thermodynamic equilibrium

\[ T_{SS} = T_Z = T_L \]

\[ T_{SS} \approx \frac{v_e - v}{v_e} T_Z \approx \frac{T_Z}{300 \div 400} \]

without Microwave

with MW at

SS-Reservoir Cooled down

SS-Reservoir Heated up

\[ T_{SS} \approx \frac{v_e - v}{v_e} T_Z \approx \frac{T_Z}{300 \div 400} \]
To realize DNP we need the free electrons in a target material.

Free electron spins are induced by electron beam irradiation at about 90 K temperature with the dose of $10^{16}$~$10^{17}$ electrons/cm$^2$ which generates about $10^{19}$ spins/cm$^2$.

Ammonia: $\text{NH}_3$, $\text{ND}_3$

Lithium Hydrides: $^7\text{LiH}$, $^6\text{LiH}$, $^6\text{LiD}$

$^6\text{LiD}$: $^6\text{Li}=\alpha$+ deuteron
THE COMPASS CAVITY FOR OD-MAGNET

All of cavity elements provide a very long use
General view of the new microwave cavity in PT control room
High magnetic field, low temperature and microwave irradiation

Polarizing magnet: 2.5T with field uniformity, ~100ppm
Overview of the COMPASS Polarized Targets
First polarization with our new set-up (measured June 14th)

D-butanol

Upstream cell

Central cell

Downstream cell

P = -36 ± 2% in ~ 2-3 hours

Built-up the target polarizations
Polarization measurements

The typical signal-to-noise for protons on the display

After the signal accumulation Kaori receives almost an the free electrons ideal proton signal
Summary

• Dynamically Polarized targets have been used in many experiments.
• The techniques are well established although complicated apparatus is needed.
• The targets are still being developed for various applications.