^{3}He spin hyperpolarization for nuclear physics experiments

Bartosz Głowacz

Jagiellonian University in Kraków

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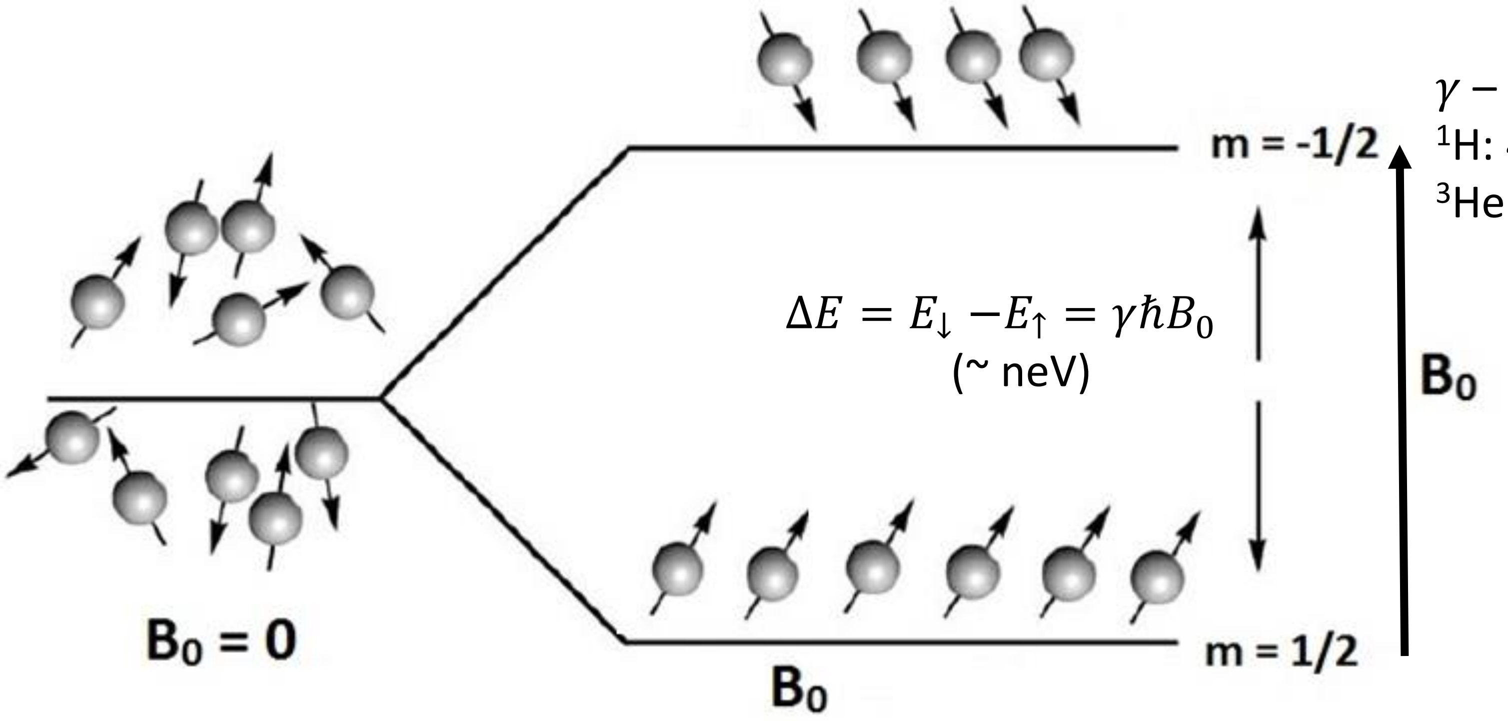
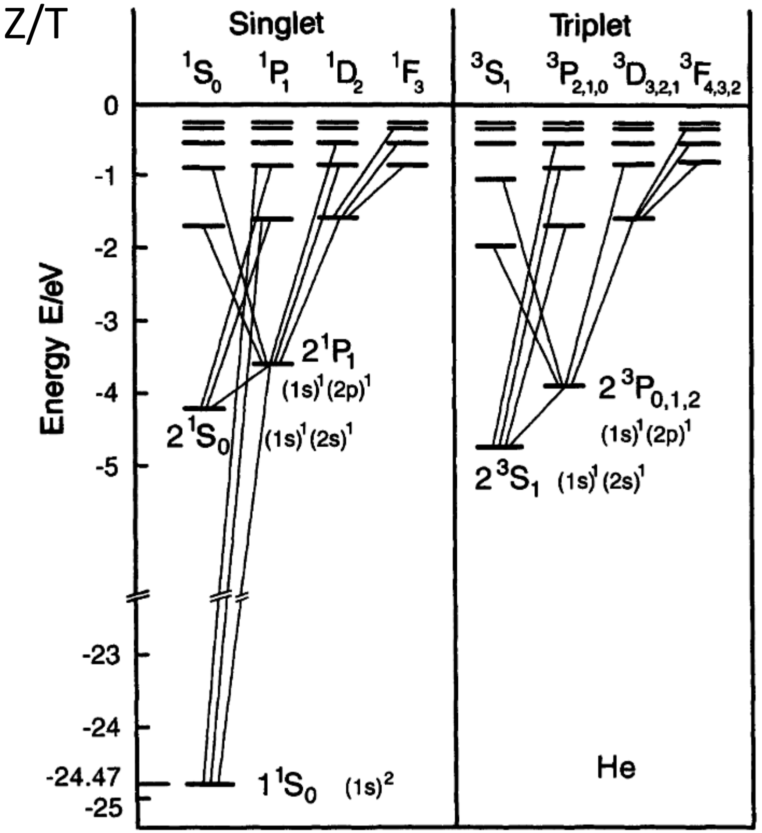
^{3}He Spin (½) nuclei polarization and hyperpolarization



γ – gyromagnetic ratio
^{1}H: 42.576 MHz/T
^{3}He: 32.434 MHZ/T



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

$$P = \frac{e^{\frac{\gamma\hbar B_0}{k_B T}} - 1}{e^{\frac{-\gamma\hbar B_0}{k_B T}} + 1} \approx \frac{\gamma\hbar B_0}{2k_B T}$$

For ^{3}He @T=300K, B =1 T

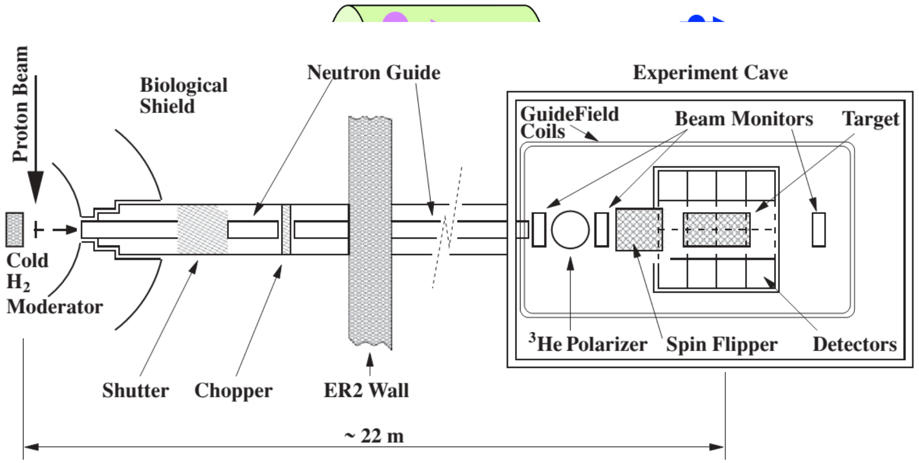
P~10^{-6}

In gaseous phase!

Hyperpolarization: P ~ 10^{-1} !!!

Hyperpolarized ^{3}He applications

- Polarized neutron spin filters



PARITY VIOLATION in NUCLEON-NUCLEON INTERACTIONS

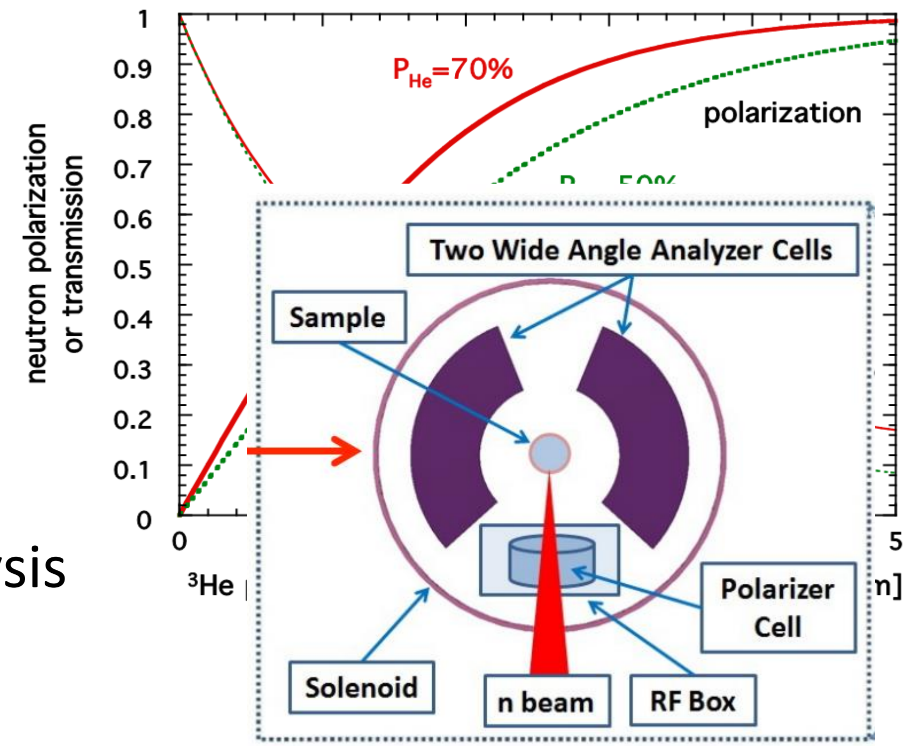
parity-violating γ -ray asymmetry in the capture of polarized cold neutrons on protons M. Gericke et al, Phys. Rev. C 83, 015505 (2011)

- Precision neutron polarimetry

$$P_n = \tanh\left(P_{He} \cdot l \cdot \sigma_a[{}^3He]\right)$$
$$T_n = T_0 \cosh\left(P_{He} \cdot l \cdot \sigma_a[{}^3He]\right)$$
$$P_n = \sqrt{1 - \left(\frac{T_0}{T_n}\right)^2}$$

T_n = transmission of polarized cell
T_0 = T_E exp(-t) = transmission of unpolarized cell
T_E = transmission of empty cell

NEUTRON POLARIZATION determined from transmission

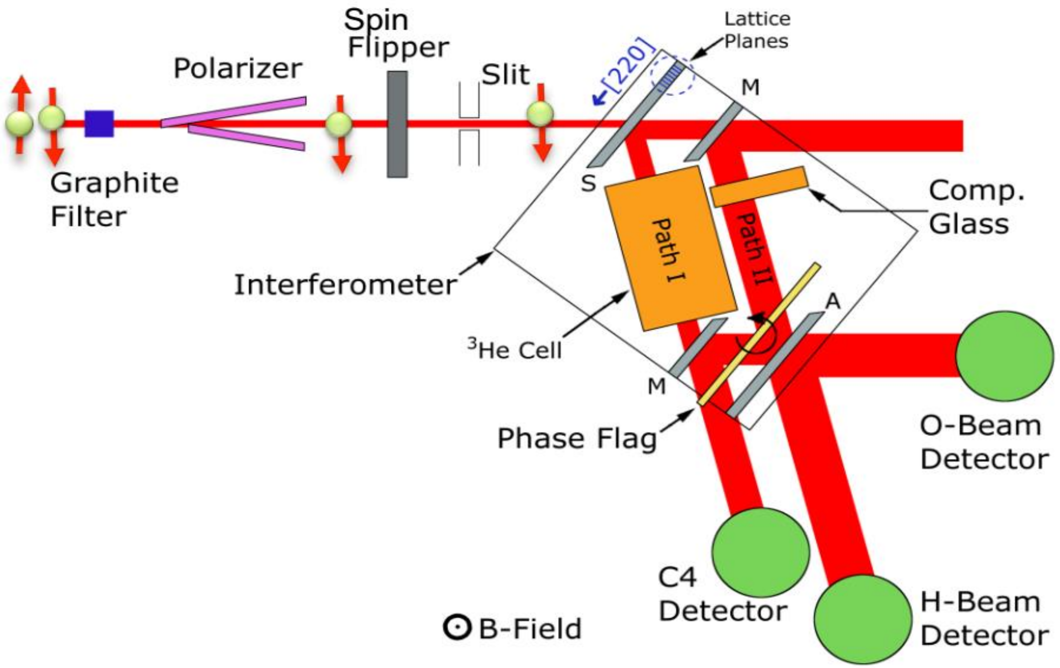


^{3}He-based polarized beam with wide-angle polarizaton analysis

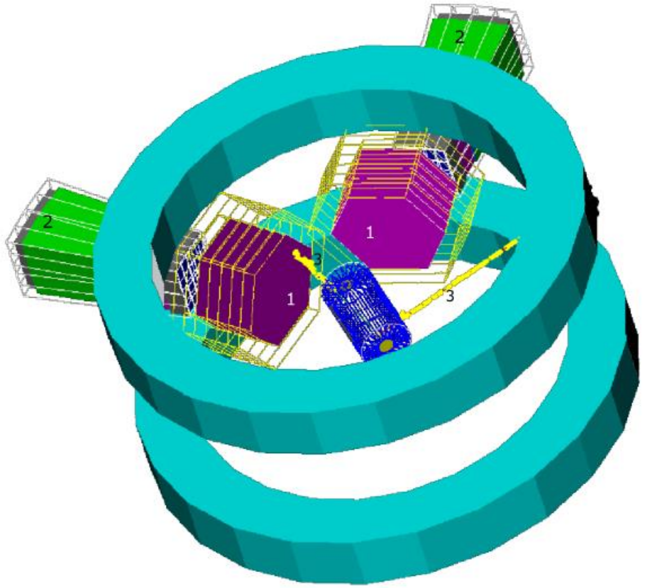
polarizaton analysis for powder neutron diffractometry
Studies on magnetic and ferroelectric domains through neutron diffraction and polarymetry, Cabrera et al. Phys. Rev. Lett. 103, 087201

Studies on 3NF in 4N systems:

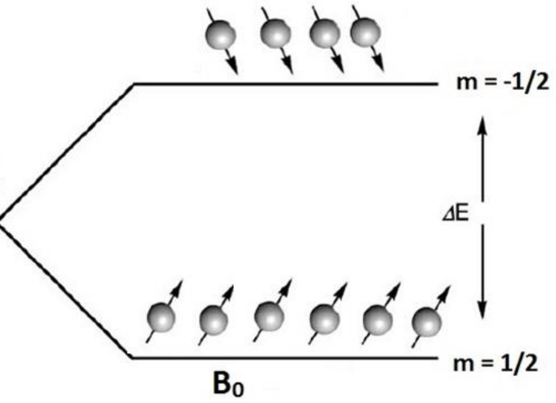
Precision Measurement of the n-^{3}He Incoherent Scattering Length Using Neutron Interferometry
M.G. Huber et al., Phys. Rev. Letters. 102, 200401 (2009)

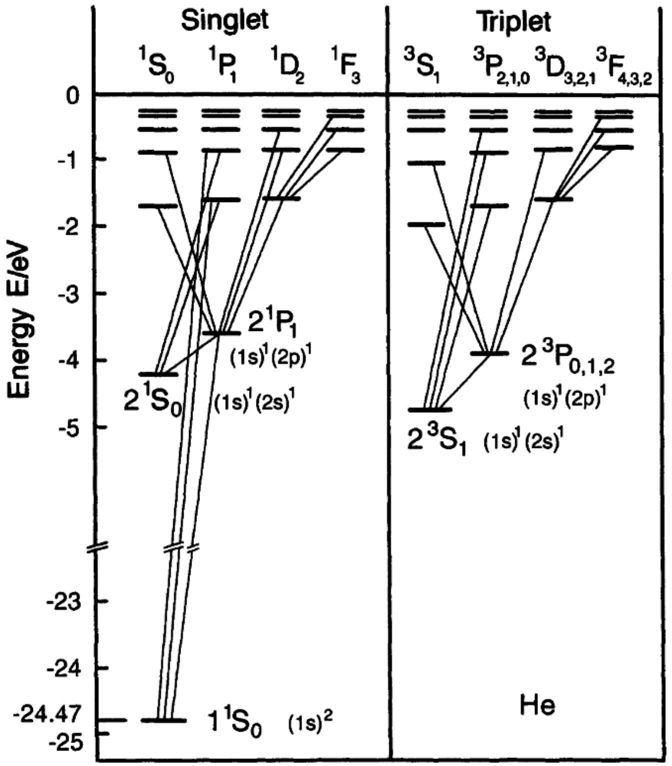


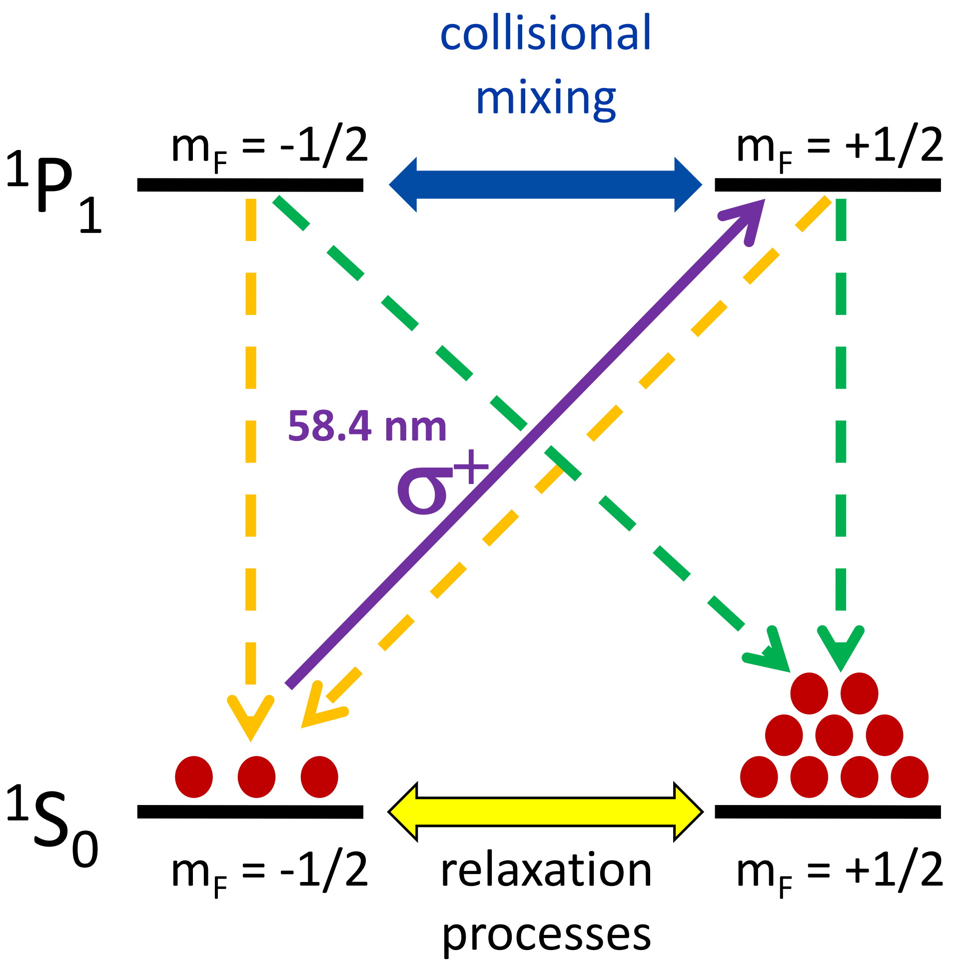
Planned experiment: ^{3}He-p scattering at medium energies (~100 MeV) for testing theoretical findings related to 3NF in 4N systems. Ciepal et. al. *Acta Phys. Pol.*, B47:323, 2016.



Direct polarization of ^{3}He ground state through optical pumping?







Collisional hyperfine mixing time in $^1P_1$ state longer than its lifetime (0.5 ns)

^3He spin hyperpolarization techniques

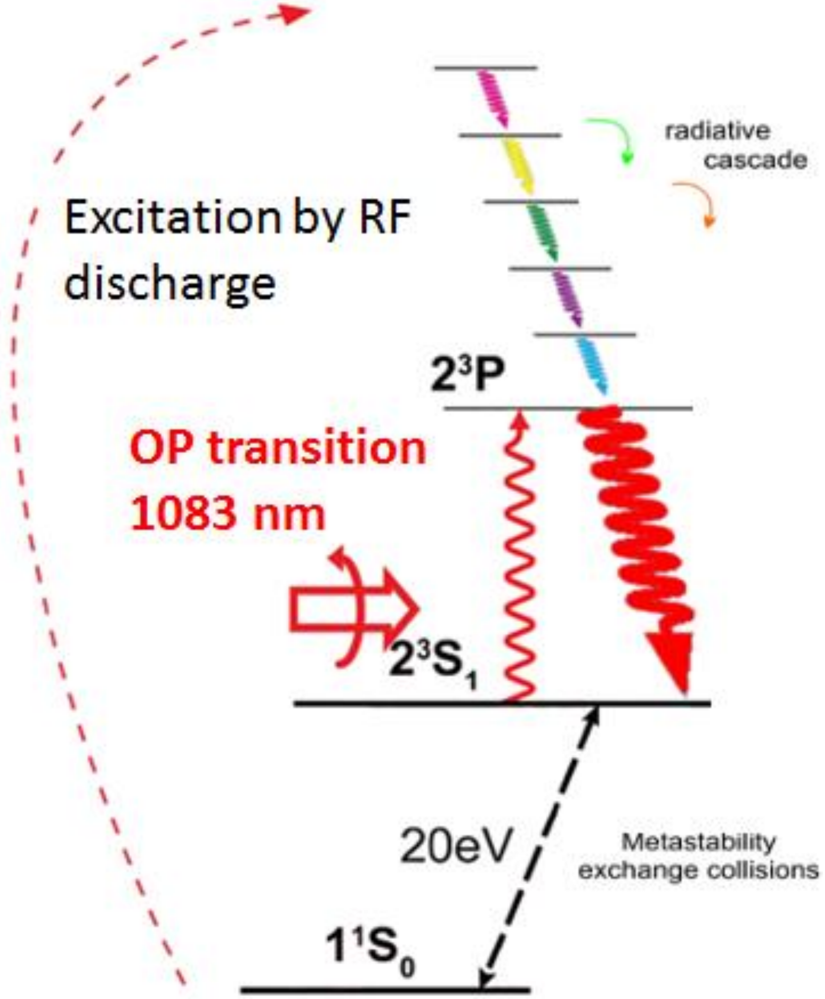
- Metastability Exchange Optical Pumping
- Spin Exchange Optical Pumping

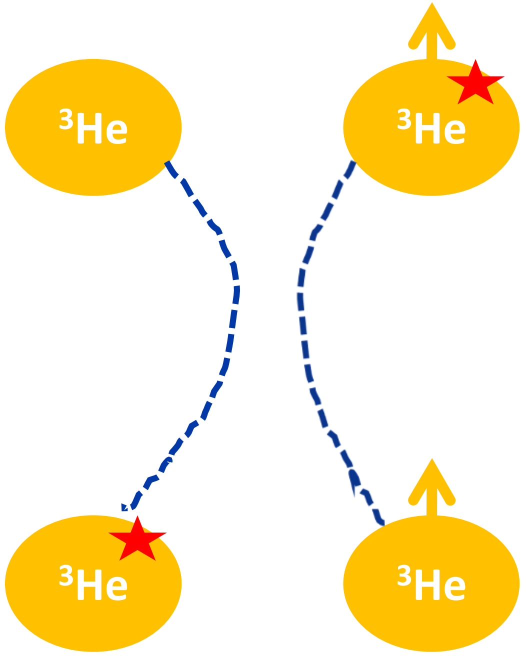
„Indirect" methods

Optical methods! We „manipulate" spin states separated by 10^{-9} eV with the photons of energy ~ 1- eV

Polarization through OP of the ^{3}He metastable state

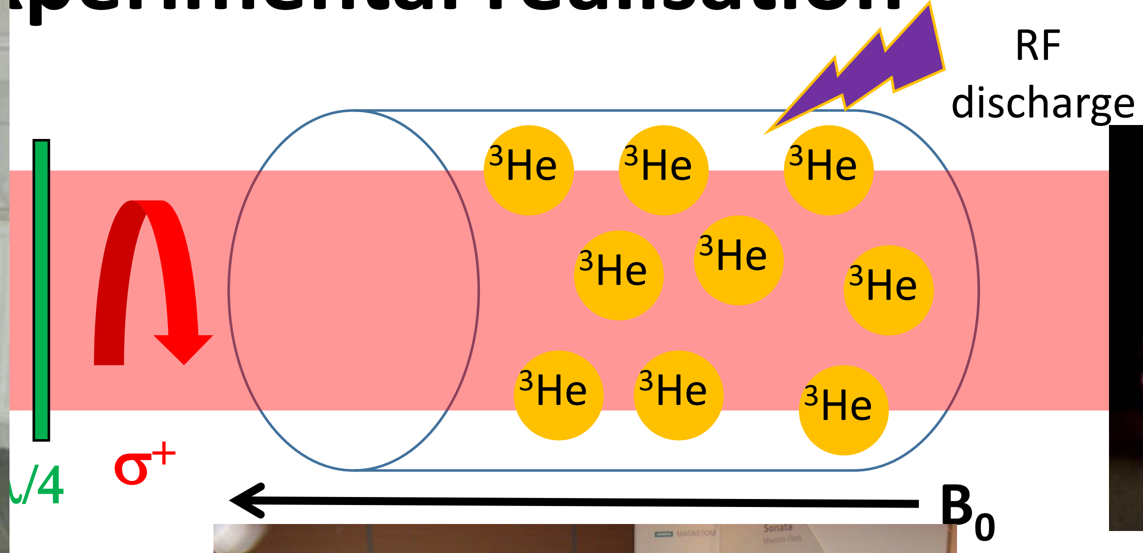
Metastability Exchange Optical Pumping
(MEOP)





$$^3He + {}^3He^*_\uparrow \rightarrow {}^3He^* + {}^3He_\uparrow$$

xperimental realisation



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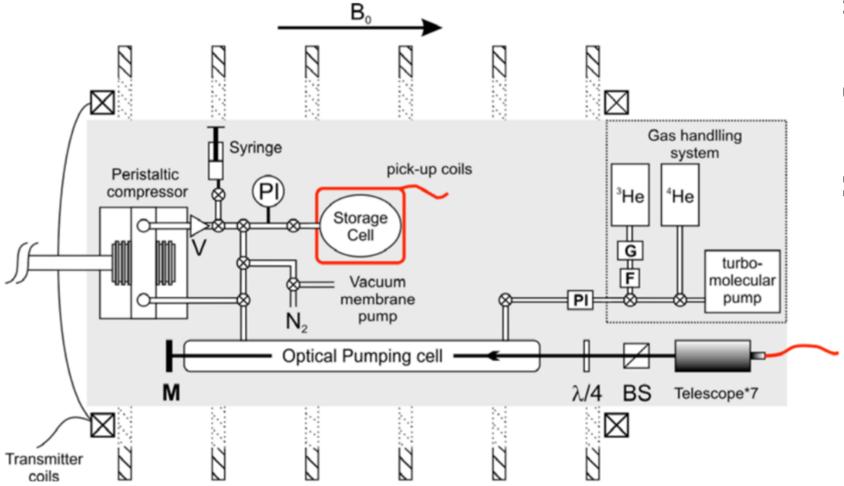
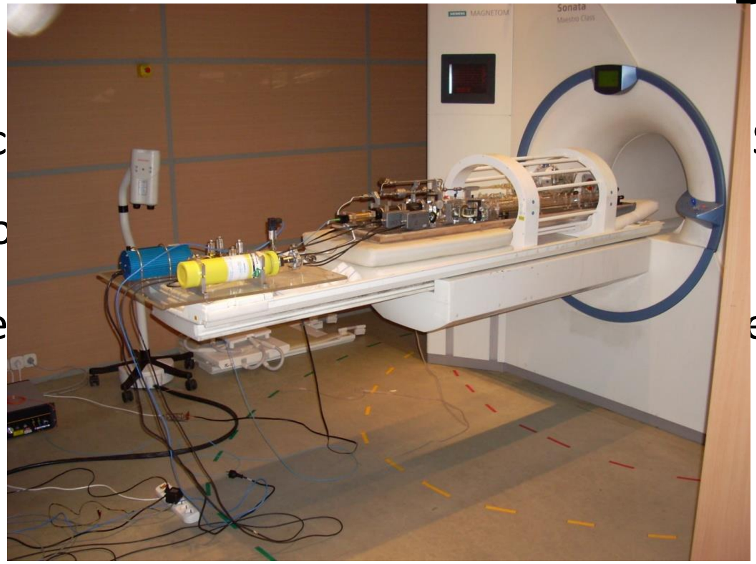
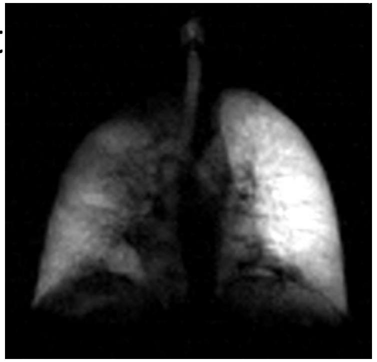


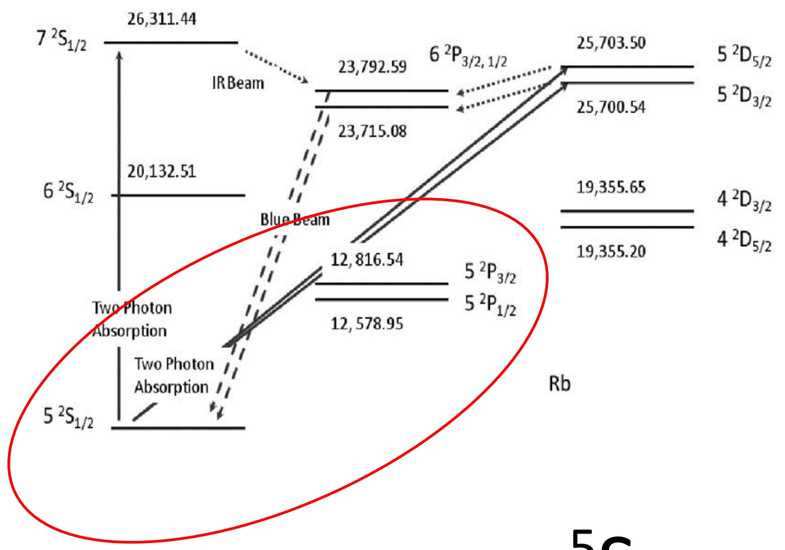


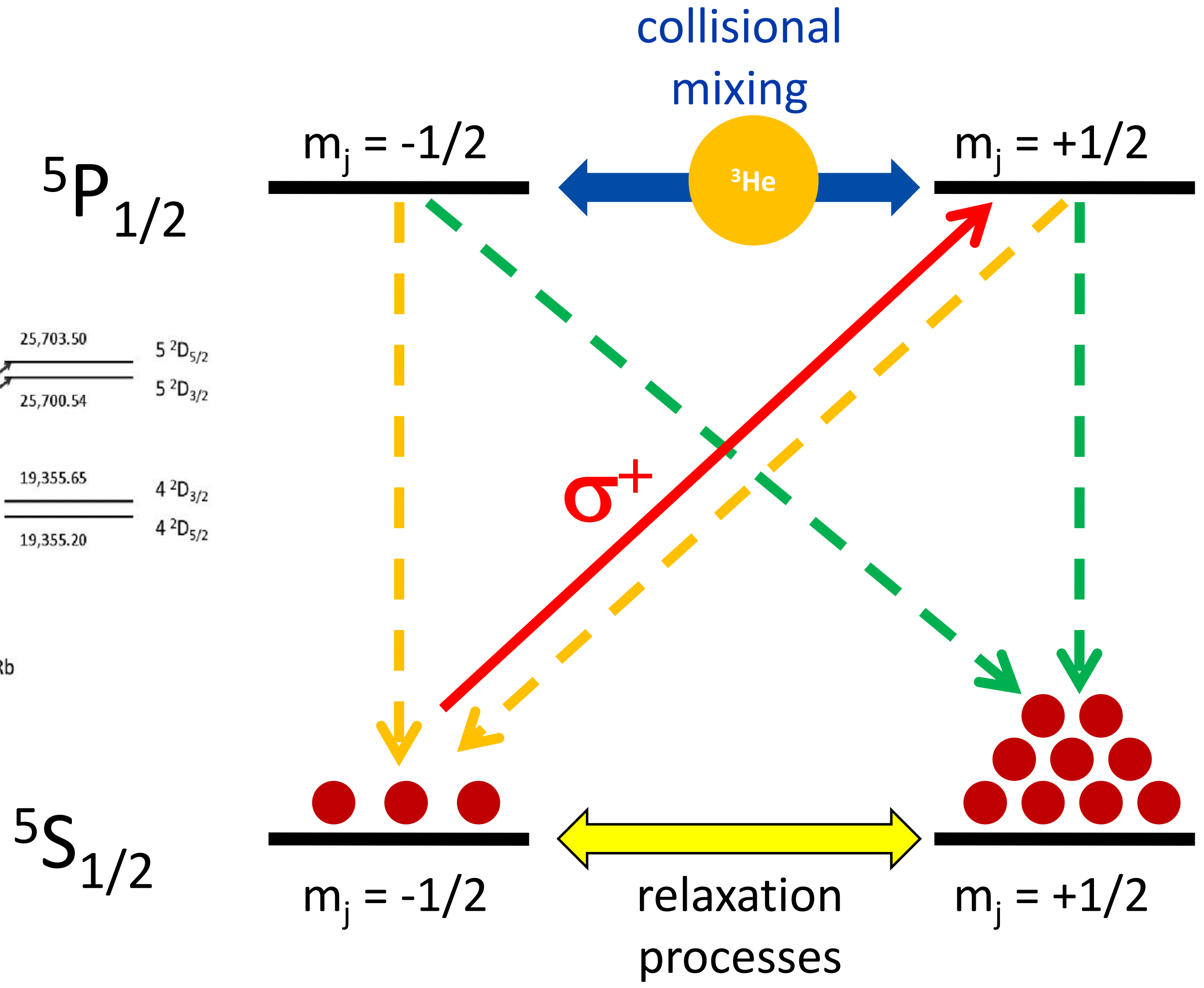


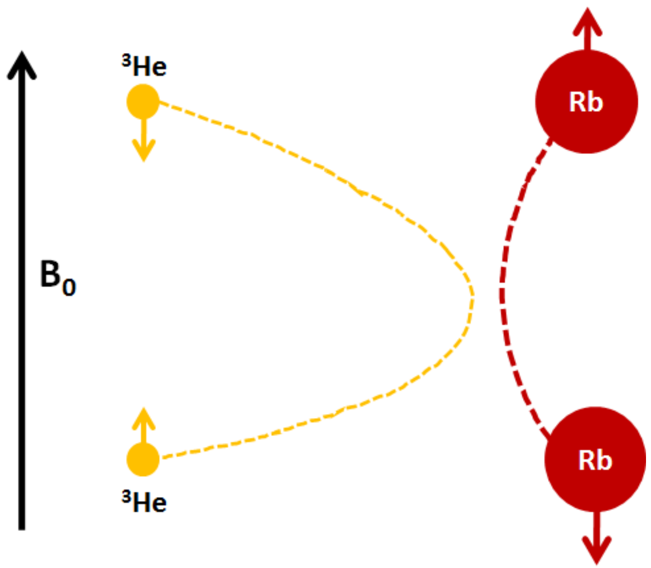
(B~ 1 mT and p~ 1 mbar) or (B~ 1 T and p~ 100 mbar)

Polarization through OP of ^{87}Rb & ^{85}Rb

Spin Exchange Optical Pumping (SEOP) in Rb vapor and ^{3}He mixture







SEOP –experimental realisation

T=500 K

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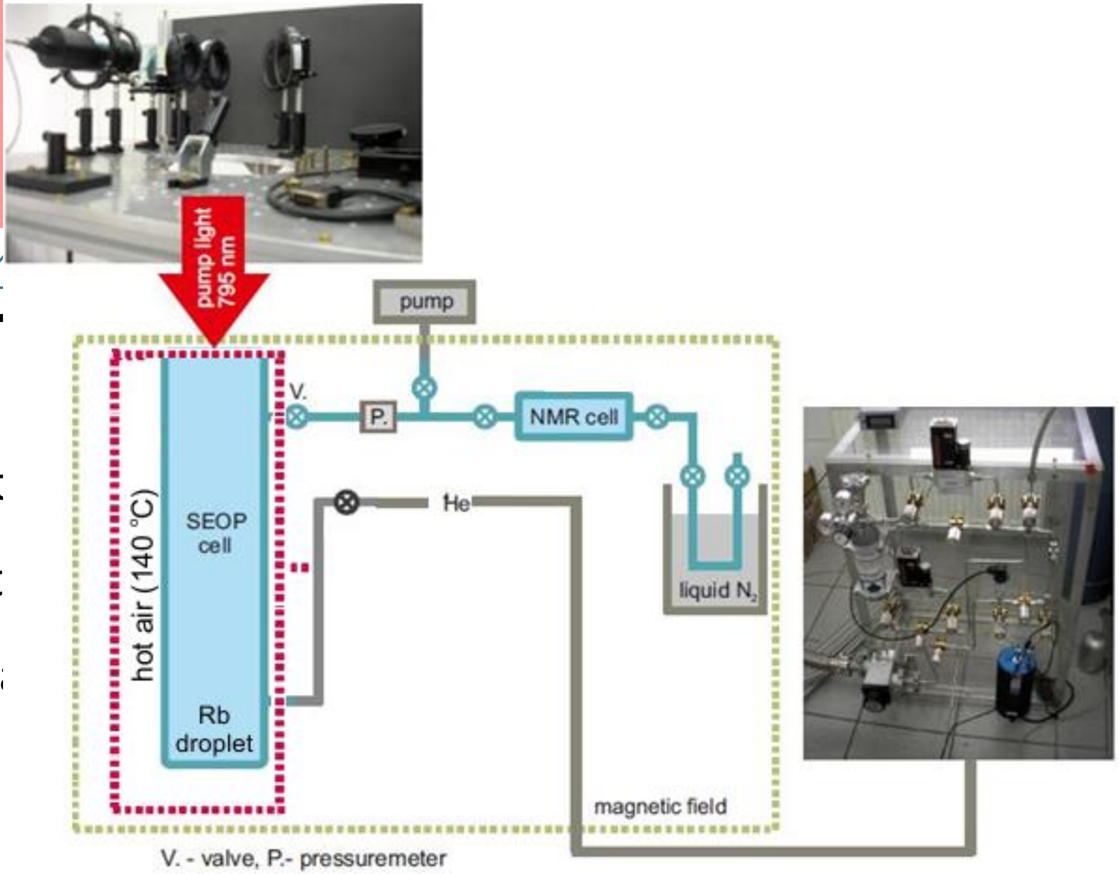
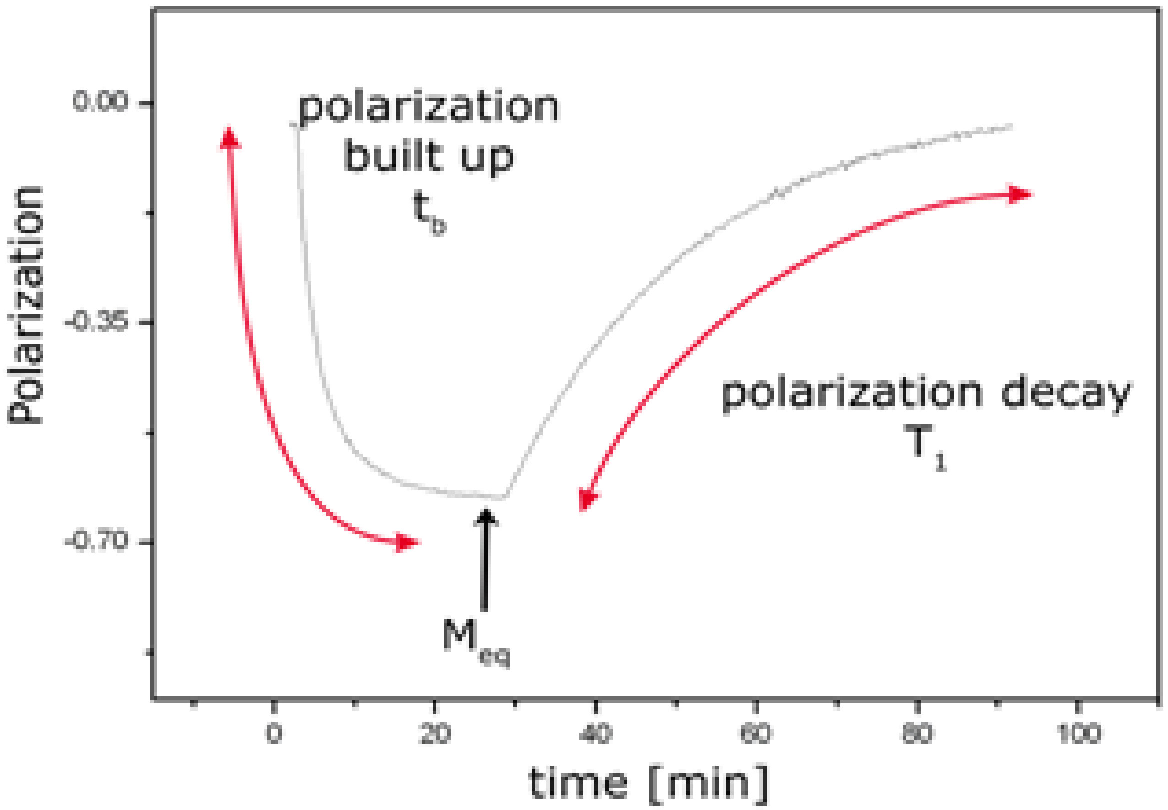


Competing process - relaxtion



Polarization plateau - balance beween OP and relaxation

Non mono-exponential build-up

Purely exponential decay (T_1 relaxation time)

Glass quality issues

Magnetic field homogeneity

Gas purity/ Rb vs He proportions

Polarization methods comparison

MEOP

Fast polarization production (20 min)

Polarization ~ 70-80%

„Clean” method - high gas purity required

Gas compression stage required (+ a few tens of min)

Continuous RF presence

Gas delivery to the experiment

SEOP

Slow polarization production (a few h)

Polarization ~ 70-80%

Gas purification (from Rb) required

Already pressure above 1 bar

B~ 1 mT

OP cell heating

Easy for in-situ polarization

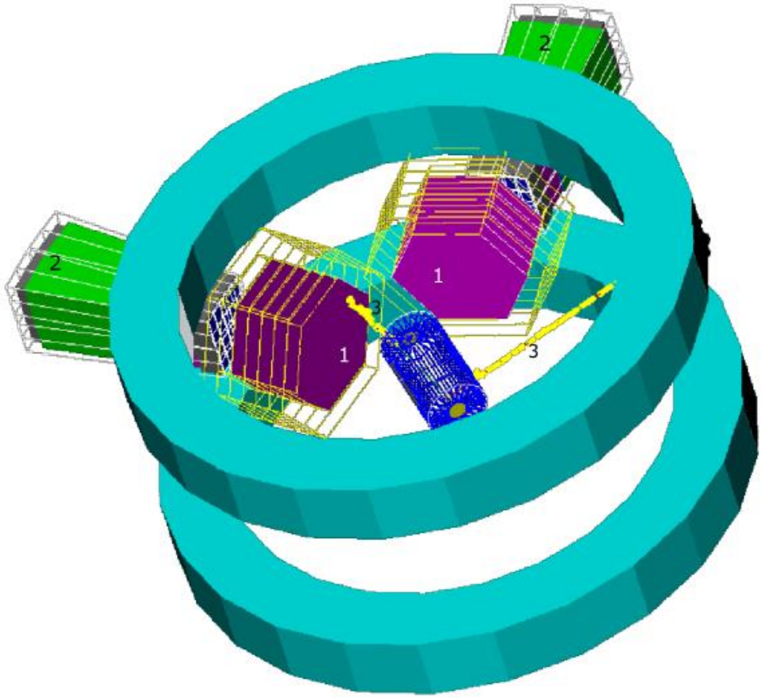
Choice depends on certain application

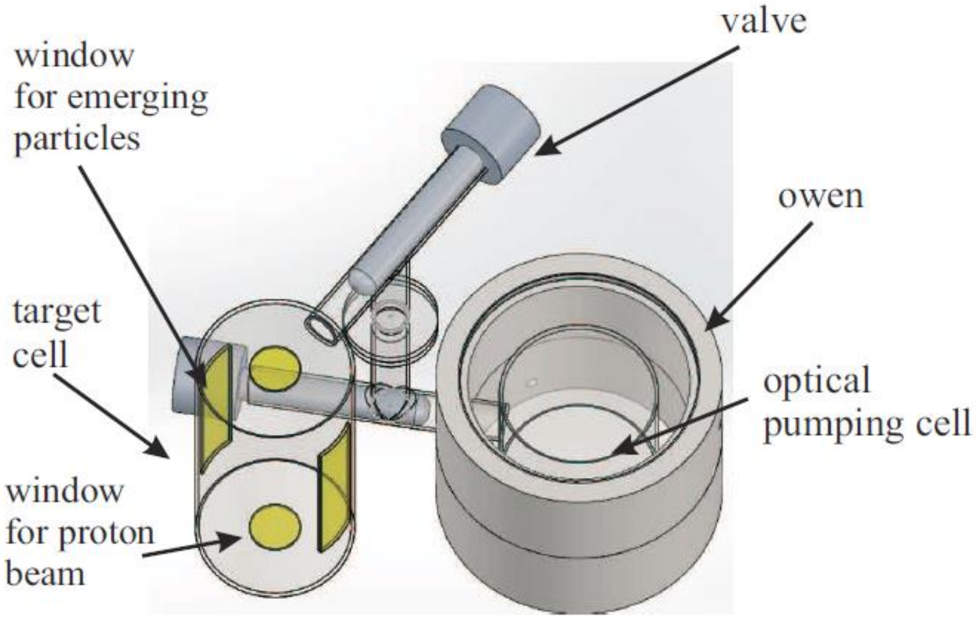
Thank You for attention !

SEOP for ^{3}He+p reaction studies

Measurement of vector analyzing power and differential cross section

for ^{3}He+p elastic scattering and breakups: ^{3}He+p->p+p+d, ^{3}He+p->n+p+p+p @70-230 MeV from cyclotron in CCB, Krakow





Continuous in-situ ^{3}He polarization possible

I. Ciepał et al. Acta Phys. Polon. B 47, 323 (2016)