SPD FIRST STEPS

Spin dichroism for nuclei with spin S≥1

Two stages for the First Steps for

Complex Nuclotron M - NICA:

1. Fixed nonpolarized target@Nuclotron
2. Beam-beam interaction in NICA

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Nonpolarized deuterons in nonpolarized target

$\sigma_1 \neq \sigma_0$ ⇒ spin dichroism $A(z) = \dfrac{I_0(z) - I_{\pm1}(z)}{I_0(z) + I_{\pm1}(z)} = \dfrac{1}{2}\rho z(\sigma_1 - \sigma_0)$

z is the path length for a particle in the target.

Tensor polarization p_{zz} after passing through a target with density ρ and thickness l is expressed via intensities $\boldsymbol{I_{\pm 1}}$ and $\boldsymbol{I_0}$ for deuterons with spin projection m=±1 and 0 as follows

$$p_{zz}(l) = \frac{I_{+1}(l) + I_{-1}(l) - 2 \cdot I_0(l)}{I_{+1}(l) + I_{-1}(l) + I_0(l)} \approx \frac{2}{3}\rho\, l(\sigma_0 - \sigma_1) = -\frac{8\pi}{3}\,\rho\, l\,\frac{\mathrm{Im}(d_1)}{k}$$

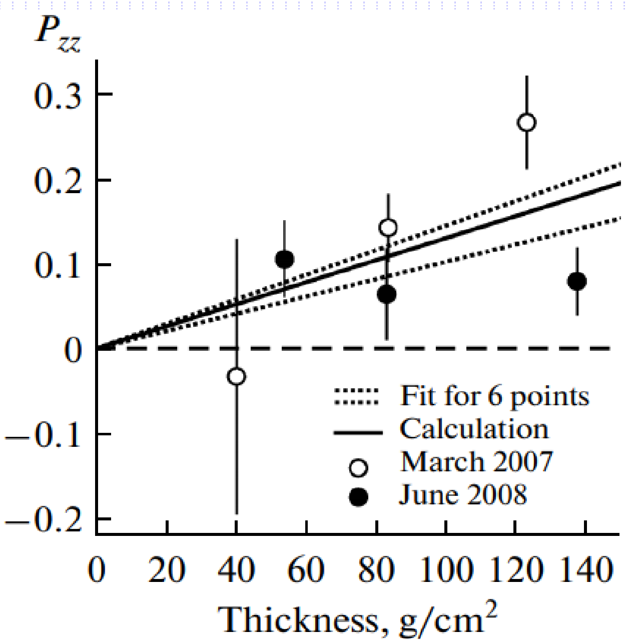
Deuteron spin dichroism: experimental observation

Germany-Belarus experiment	20MeV	2005 year
JINR experiments	5 GeV/c	2008-2010 years

Observation of Tensor Polarization of Deuteron Beam Traveling through Matter

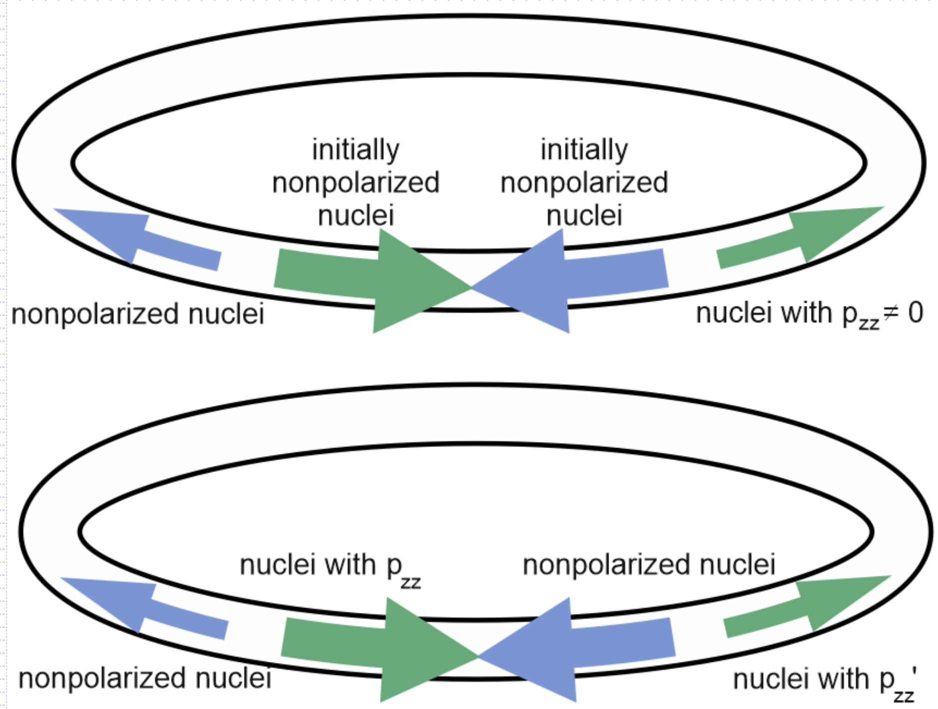
L.S.Azhgirei, Yu.V.Gurchin, A.Yu.Isupov, A.N.Khrenov, A.S.Kiselev, A.K.Kurilkin, P.K.Kurilkin, V.P.Ladygin, A.G.Litvinenko, V.F.Peresedov, S.M.Piyadin, S.G.Reznikov, P.A.Rukoyatkin, A.V.Tarasov, T.A.Vasiliev, V.N.Zhmyrov, and L.S.Zolin,

Physics of Particles and Nuclei Letters 5, 5 (2008) 432.
Phys. of Particles and Nuclei Lett. 7, 1 (2010) 27–32.



Tensor polarization of deuterons vs. thickness of target The dashed region shows the error corridor, the solid curve is the calculation result.

Spin dichroism effects: evaluations for NICA



Particles	$N_{particles}$	σ, b	L, $cm^{-2}s^{-1}$	∫Ldt, cm^{-2}	Δσ/σ	p_{zz}	T
d-d	10^{12}	0.2	10^{30}-10^{31}	~10^{34}-10^{35}	0.01	~10^{-4}	2 hours
d-C	$2\cdot10^{10}$	0.8	$1\cdot10^{30}$	~10^{34}	0.013	$2.5\cdot10^{-3}$	2 hours
^{153}Eu-d	$2\cdot10^{10}$	3	$1\cdot10^{29}$	~10^{33}	0.1	0.005	2 hours
^{159}Tb-d	$2\cdot10^{10}$	3	$1\cdot10^{29}$	~10^{33}	0.1	0.005	2 hours

Deuteron spin rotation and dichroism:

two stages for SPD FIRST STEPS

There is no possibility to carry on experiments in the ring with colliding beams of polarized protons, deuterons and nuclei at NICA now.

Therefore, it is reasonable to start from experiments at Nuclotron with fixed targets (either external or internal).

Stage 1. Fixed nonpolarized target @ Nuclotron

Stage 2. Beam-beam interaction at NICA

Stage 1: Internal nonpolarized fixed target@Nuclotron

Measurements of spin dichroism at the internal target is important for testing and verification of polarization measurements at NICA for colliding beams of nuclei (deuterons and other).

Evaluations and requirements for probable experiments are under discussion now with Vladimir Ladygin (in the framework of theme DSS 02-1-1097-2010 “Study of Polarization Phenomena and Spin Effects at the JINR Nuclotron-M/NICA Facility”)

Stage 1: External nonpolarized fixed target@Nuclotron

Only spin dichroism for dueterons was observed in the first experiment at Nuclotron. Deuteron spin rotation is not measured yet.

Angle of rotation for polarization vector (polarization tensor) for a deuteron beam passing distance l in a target with density ρ (the number of nuclei per cm^3) reads

$$\vartheta = 2\pi\rho l \lambda_c \frac{1}{\gamma} \mathrm{Re} d_1$$, where $$\lambda_c = \frac{\hbar}{Mc}$$

Analysis shows that for deuterons of several GeV energies passing through a carbon target with thickness of several nuclear interaction lengths angle of polarization vector (polarization tensor) rotation is about

ϑ ~ $5 \cdot 10^{-3}$ rad.

Stage 1: External nonpolarized fixed target@Nuclotron

Initially nonpolarized beam of heavy nuclei with spin $S \geq 1$ passing through a nonpolarized external target at Nuclotron would acquire tensor polarization due to spin dichroism.

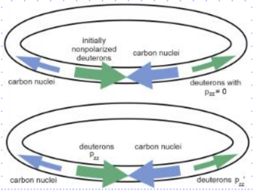
Effect evaluation: for nonpolarized heavy nuclei with high spherical asymmetry (for example, Ne or Eu) passing through the external carbon target of thickness about 40 g/cm^2 at Nuclotron the value of tensor polarization is about

$$p_{zz} \approx 0.5 \equiv 50\%$$

Great value of tensor polarization appearing due to spin dichroism for many nuclei, gave possibility to V.Lebedev and C.Shimansky to formulate an idea for application of nuclei, which acquire tensor polarization at low energies, for further acceleration and bringing into NICA ring. Therefore, one gains possibility to study reactions induced at collisions of tensor polarized nuclei beams.

Stage 2: Beam-beam collisions at NICA

See the first slide. For measurement of beam polarization it would be useful to have the internal target station at the NICA ring.



Time interval T2 is convenient for effect measurement with the use internal target for polarization analysis

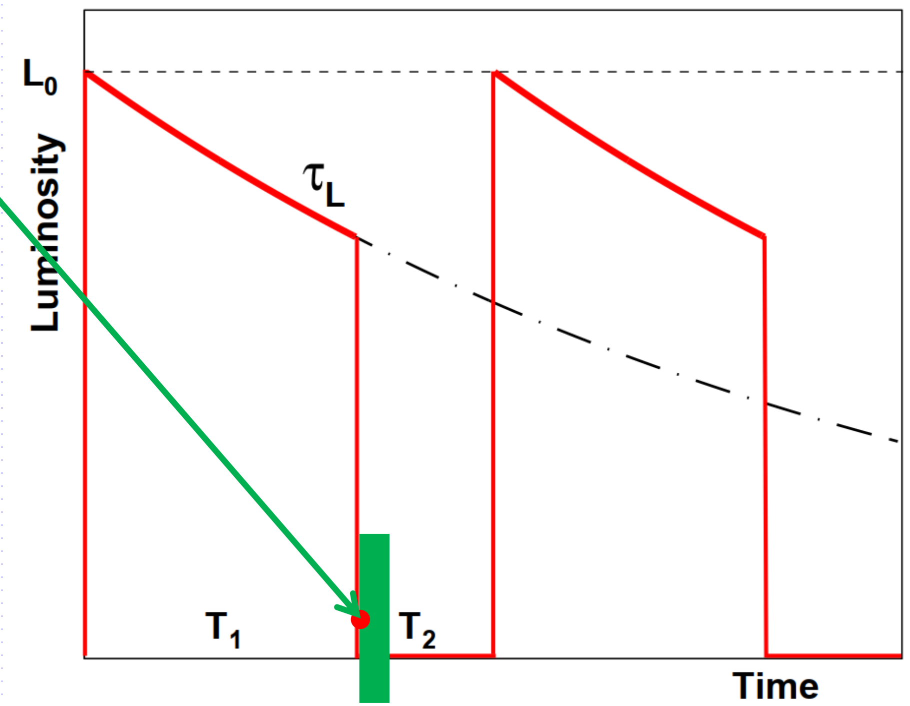


Figure 3.4: Cycle of the collider operation (design report)

The minimal number of particles required for observation of the effect at acceptable signal-to-noise ratio is $N_{min} > 1/\delta^2$, where $\delta = p_{zz}$ (detector efficiency is not considered).

In all the examples $N_{particles} \gg N_{min}$.

Question: Is it possible to have internal target station at the NICA ring similar that at Nuclotron?

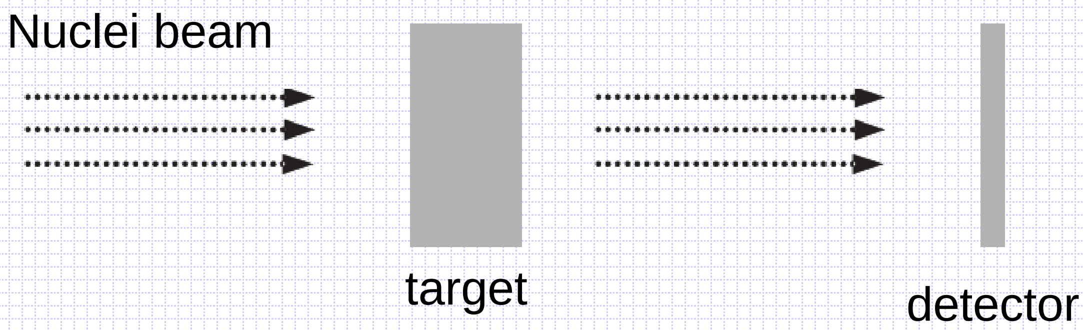
Thank you for attention!!

SPD FIRST STEPS

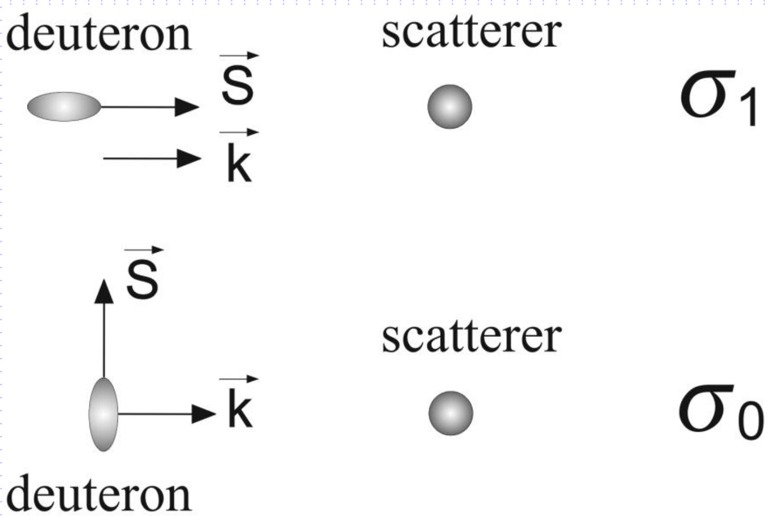
According to «Technical Design Report of the Spin Physics Detector at NICA» page 18: «We expect that for the first stage, the collider will be able to operate with polarized protons and deuterons in the spin transparency mode… We also expect that it will be possible to operate in the mode of heavy-ion collision».

Transmission (filtering) experiments

Further discussion deals with the effects to be observed in beams passing through a fixed or a moving target in the direction of particle initial momentum rather than in the direction of scattered particles momentum as it usually occurs in scattering experiments.



Birefringence phenomenon (spin rotation@dichroism)



The ground state of a deuteron is non-spherical, therefore, the scattering cross-section depends on the angle between its spin and momentum. Unlike optical birefringence, the birefringence effect for particles appear in isotropic matter (and even if the spin of matter nuclei is either zero or nonpolarized !).

Anisotropy is provided by the particle itself (a particle with spin S ≥ 1 and nonzero mass has the intrinsic anisotropy. This anisotropy also results in appearance of electric quadrupole moment, however birefringence effect does not deal with deuteron scattering because of interaction of deuteron electric quadrupole moment with the scatterer electric field, though this interaction contributes to.

$$\sigma_{m=-1} = \sigma_{m=+1} \equiv \boxed{\sigma_1 \neq \sigma_0} \equiv \sigma_{m=0}$$

$$\boxed{\Delta\sigma = \sigma_0 - \sigma_1 \neq 0}$$

Birefringence phenomenon

$$\frac{k}{4\pi}\sigma_0 = \boxed{\mathrm{Im}(f_{m=0}(0)) \ \neq \ \mathrm{Im}(f_{m=\pm1}(0))} = \frac{k}{4\pi}\sigma_1$$

$$\boxed{\mathrm{Re}(f_{m=0}(0)) \ \neq \ \mathrm{Re}(f_{m=\pm1}(0))}$$

Forward scattering amplitude of a particle in a nonpolarized target (oz || particle momentum, contribution of weak interactions is omitted) reads:

$$\boxed{\hat{f}(0) = d + d_1 S_z^2} + d_2 S_z^4 \ldots + d_s S_z^{2s}$$

For particles with spin 1 and 3/2

$$\boxed{N(m) = 1 + \frac{2\pi\rho}{k^2}(d + d_1 m^2)}$$

index of refraction

$$\psi = \sum_{m=\pm1,0} a^m \chi_m = \left\{ \begin{array}{c} a^1 \\ a^0 \\ a^{-1} \end{array} \right\} = \left\{ \begin{array}{c} a\, e^{i\delta_1} e^{ikN(m=1)z} \\ b\, e^{i\delta_0} e^{ikN(m=0)z} \\ c\, e^{i\delta_{-1}} e^{ikN(m=-1)z} \end{array} \right\} = \left\{ \begin{array}{c} a\, e^{i\delta_1} e^{ikN_1 z} \\ b\, e^{i\delta_0} e^{ikN_0 z} \\ c\, e^{i\delta_{-1}} e^{ikN_1 z} \end{array} \right\}$$

Deuteron spin dichroism: experiments

20 MeV

First observation of spin dichroism with deuterons up to 20 MeV in a carbon target

V. Baryshevsky, A. Rovba, R. Engels, F. Rathmann, H. Seyfarth, H. Stroher, T. Ullrich, C. Duweke, R. Emmerich, A. Imig, J. Ley, H. Paetz gen. Schieck, R. Schulze, G. Tenckhoff, C. Weske, M. Mikirtytchiants, A. Vassiliev *(LANL arxive: hep-ex/0501045)*

Proceedings of the 17th Int. spin phys. symp.,SPIN 2006, Kyoto, Japan, 2–7 October 2006. / AIP Conf. Ser, v.915 (2007) 777-780

Production of a beam of tensor-polarized deuterons using a carbon target

Phys. Rev. Lett. 104, 22 (2010) 222501

Stage 2: Beam-beam collisions at NICA

Collisions of nuclei

both of two interacting beams of nuclei acquire tensor polarization

Initially nonpolarized colliding bunches of nuclei with spin S≥1 during their motion in NICA ring would acquire tensor polarization due to spin dichroism. Observation and study of tensor polarization acquired by initially nonpolarized heavy nuclei with spin S≥1 make it possible to evaluate and take into account particular contributions from tensor polarization in experimental data at nucleus-nucleus collisions at NICA in future experiments and extract these contributions for analysis of other effects.