Measurement of analyzing powers for neutrons scattering on CH$_2$, CH, C and Cu targets at the momenta from 3.0 to 4.2 GeV/c


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Nucleon formfactors

Dyson-Schwinger approach for neutron predicts a (second) zero for $G_{E_n}$, also near 10 GeV^2.

Will $G_{E_p}$ become zero?

Will $G_{E_n}$ also become zero?

Transferred polarization is: (Akhiezer & Rekalo)

\[ P_n = 0 \]
\[ \pm hP_t = \pm h 2 \sqrt{\tau(1+\tau)} G_E^p G_M^p \tan \left( \frac{\theta_e}{2} \right) / I_0 \]
\[ \pm hP_t = \pm h (E_e + E_{e'}) (G_M^p)^2 \sqrt{\tau(1+\tau)} \tan^2 \left( \frac{\theta_e}{2} \right) / M / I_0 \]

Where, $h = |h|$ is the beam helicity

\[ I_0 = (G_E^p(Q^2))^2 + \frac{\tau}{\epsilon} (G_M^p(Q^2))^2 \]

\[ \frac{G_E^p}{G_M^p} = \frac{P_t}{P_l} \frac{E_e + E_{e'}}{2M} \tan \left( \frac{\theta_e}{2} \right) \]

No error contributions from analyzing power and beam polarization measurements.
The existing data for $A_y$ in np elastic scattering indicate that the analyzing power decreases faster than the pp analyzing power, becoming very small, then negative around 6 GeV/c neutron momentum.
The dependence of the maximum of $A_y$ on $1/p_{\text{lab}}$.

Deuteron fragmentation

Polarization transfer

Polarized proton (neutron) beam

First order

Second order

\[ k_0 = \frac{P_p}{P_d} \]

Nuclotron, \(\sim 13\) GeV/c

neutrons, 6.5 GeV/c

protons, upto 7.5 GeV/c
Polarized proton and neutron beams

Scheme of transportation polarized beams from Nuclotron to the ALPOM2 setup and the location of F3 polarimeter and production target for proton and neutron beams
Beau polarization measurements

About 5 hours

each point corresponds to one spill.

The polarization in one mode is two times lower than the other one

Nov16 Feb17
-0.30 -0.43
0.59 0.56
Layout of the setup

Hadron calorimeter

Drift chambers

At the CH2 target

CH2, C, CH, Cu target

Neutron or proton beam
Energy deposit measurements in the hadron calorimeter, 3.75 GeV/c

Azimuthal segmentation available from the hadron calorimeter for asymmetry measurements
**Measured asymmetries**

$p+\text{CH}_2, 3.0 \text{ GeV/c}$, tracks, scattering angles 0.03–0.24 rad

$p+\text{CH}_2, 3.0 \text{ GeV/c}$, hadcal, max amplitude without the central part

Negative mode of nucleon polarization is two times bigger than positive one
Combining of two polarization modes

The asymmetry as a function of the azimuthal angle from the calorimeter (blue squares) and from the drift chambers (red circles).

A very good agreement between tracking and energy deposit data allow us in future experiments used one of these methods.
Control measurements, proton beams

Good agreement with old data
**Neutrons**

**different momenta, CH2 - target**

Energy dependence of the neutron asymmetry on CH2 target.

**different targets, 3.75 GeV/c**

Neutron asymmetry dependence of different target material.

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\[ n(p)^\uparrow + \text{Cu} \rightarrow \text{one charge particle} + X \]

\[ 3.75 \text{ GeV/c} \]

Full squares – no cut; 
open circles – energy deposit cut, 6000.
Advantage of a copper target as an analyzer one

1) The observed asymmetry is unpredictably bigger then in np elastic scattering that usually used for neutron polarimetry
2) The length of the copper target is only 4 cm in comparison with the CH one (> 30 cm) used in the elastic np scattering, which makes it possible to improve the accuracy of determining the interaction vertex and the scattering angle.
3) Registration of charged particles moving forward is much easier than detection the recoil proton in np elastic scattering

The inverse reaction p+Cu (W) with detection neutron in forward direction by the hadron calorimeter can be used for measurement of the proton polarization at the NICA collider.
Measurement of the Ratio $G^n_E/G^n_M$ by the Double-polarized $^2\text{H}(\vec{e}, e'\vec{n})$ Reaction

Neutron Form Factor Ratio $G^n_E/G^n_M$ - 3

- E12-17-004 in Hall A (Annand, Bellini, Kohl, Piskunov, Sawatzky, Wojtsekhowski).
- Polarization transfer using $^2\text{H}(\vec{e}, e'\vec{n})p$:
  \[ \frac{G^n_E}{G^n_M} = -\frac{P_t}{P_i} \frac{E + E'}{2M} \tan \left( \frac{\theta_e}{2} \right) \]
- Electron arm: Super Big Bite Spectrometer.
- Neutron arm: HCal, neutron polarimeter, CDet coordinate detector, scintillation counter.
- Kinematics: $Q^2 = 4.5$ (GeV/c)$^2$.
- Beamtime: 5 days.
- Systematic uncertainties about 3%.
- Statistical uncertainties about 8%.
- Will test extension of neutron polarimetry to high $Q^2$.
- Expected in the next 2-3 years.
The ALPOM2 setup was designed to measure analyzing powers from different analyzer targets, for protons and neutrons. It includes a large size calorimeter to help eliminate multi-particle final states, and correspondingly increase the analyzing power. So far protons and neutrons of 3.0, 3.75 and 4.2 GeV/c momentum have been used. Polarized protons of up to 7.5 GeV/c should become available in the near future.

The proton data in the momentum range available at this point in time are in general agreement with data from various laboratories.

We now have, for the first time, analyzing power data for the charge exchange (pol)n+CH2->n+X reactions, as well as for C, CH (scintillator) and Cu analyzers. Based on the available (and ancient) charge exchange analyzing power data for np->pn, the expectation was that the same reaction channel for the complex target available (C, CH, CH2 and Cu) would be significantly larger than for the forward process, np->np. The new data fully support this expectation.

The consistency of these data clearly indicates that the experimental setup is adapted to the challenge, that the beam polarization, intensity and stability are appropriate for this.
Asymmetries vs $Q^2$

Future runs

End of 2019

Protons, 7.5 GeV/c

Neutrons, 5 & 6 GeV/c

Exp data: 2001 & 2016
We are planning to continue the measurements at higher proton and neutron energies.

Thank you for your attention.
\[ n(p) + Cu(CH_2) \rightarrow \text{one charge particle} + X \]

### n + Cu

Scattering angle, rad

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### p + Cu

Scattering angle, rad

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### n + CH_2

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### p + CH_2

Scattering angle, rad

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Figure 8: Neutron polarimeter figure of merit as a function of incident neutron momentum for two styles of polarimeter within the SBS apparatus using preliminary data from the recent Dubna measurement. Blue squares: standard $n-p$ scattering from CH scintillator, black circles: charge-exchange $n-p$ scattering from Cu. The red arrow marks the neutron momentum at which a charge-exchange measurement of the analyzing power of Cu was made at Dubna.
Hadron calorimeter

(20 mm Fe +10 mm Sc) x 34 layers

(10 mm Sc+10 mm Pb) x 18 layers + (10 mm Sc +20 mm Fe) x 20 layers

(10 mm Sc +10 mm Pb) x 50 layers

75 x 75 mm²

150 X 150 mm²
1) The observed asymmetry is unpredictably bigger than in np elastic scattering that usually used for neutron polarimetry.

2) The length of the copper target is only 4 cm in comparison with the CH one (> 30 cm) used in the elastic np scattering, which makes it possible to improve the accuracy of determining the interaction vertex and the scattering angle.

3) Registration of charged particles moving forward is much easier than detection the recoil proton in np elastic scattering.

The inverse reaction p+Cu (W) with detection neutron in forward direction by the hadron calorimeter can be used for measurement of the proton polarization at the NICA collider.
<table>
<thead>
<tr>
<th>target</th>
<th>Z/A</th>
<th>g/cm^3</th>
<th>L, cm</th>
<th>N_A /cm^3</th>
<th>GeV/c</th>
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<tbody>
<tr>
<td>CH2</td>
<td>0.57034</td>
<td>0.919</td>
<td>30 (40)</td>
<td>15.75</td>
<td>3.0; 3.75; 4.2</td>
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<tr>
<td>CH</td>
<td>0.53768</td>
<td>1.06</td>
<td>30</td>
<td>17.09</td>
<td>3.75</td>
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<td>C</td>
<td>0.49955</td>
<td>1.68</td>
<td>20</td>
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<td>Cu</td>
<td>0.45636</td>
<td>8.96</td>
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