ESTIMATED ASYMMETRIES DUE TO TWO-PHOTON EXCHANGE EFFECTS

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1. Introduction

The purpose of this document is to get some estimates for the magnitude of target-normal single-spin asymmetries. Unfortunately, the number of data points is extremely limited and the theoretical models are presently not at a level to have any predictive power. The evaluation is based on all the data that could be found in the literature.

2. Simple Estimates

Quasi-elastic Regime: This is just part of the overall data collection and is not really relevant for d_2^n. The data were fit to an exponential function. Since there are only three data points [Zha+15] and the fit function (see below) contains three fit parameters, a perfect fit is a given. It should also be pointed out that the error bars are calculated by adding the statistical and systematic uncertainties in quadrature. This is obviously not correct since the errors are correlated (assuming at least some systematics are common to all data points).

Helium-3 and neutron:

$$A_y^{3He}(Q^2) = A_0 \cdot (1.0 - exp(-Q^2/\Lambda^2)) + A_0^0$$

With fit parameters A_0, Λ^2, and A_0^0.

helium-3		
$A_0 \pm dA_0$	$\Lambda^2 \pm d\Lambda^2$	$A_0^0 \pm dA_0^0$
-0.001356 ± 0.001192	0.2113 ± 0.3371	-0.000647 ± 0.00134

neutron		
$A_0 \pm dA_0$	$\Lambda^2 \pm d\Lambda^2$	$A_0^0 \pm dA_0^0$
0.0351 ± 0.0300	0.2229 ± 0.3135	-0.0484 ± 0.0324

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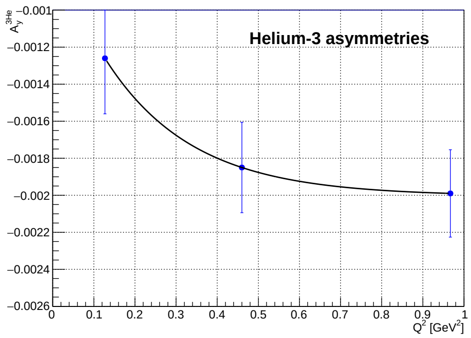

FIGURE 1. ^{3}He quasi-elastic asymmetries.

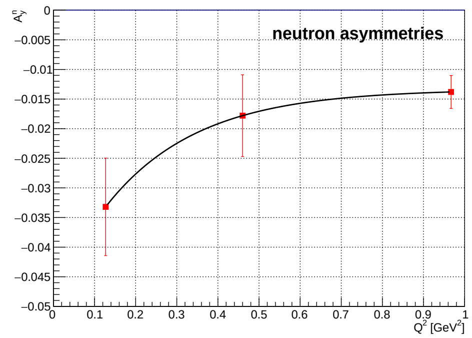

FIGURE 2. Neutron quasi-elastic asymmetries.

Resonance Regime: There is not much information available on A_y^0 in the resonance regime. The only published data result from electron-proton scattering at SLAC [Roc+70] and CEA [Che+68]. All data were taken at Q^2 values < 1.0 GeV^2, the corresponding x-values were not reported. The data clearly indicate no Q^2 dependence. A fit to a constant yields: $A_y^0 = -0.00271 \pm 0.00699$. There is one data point on the proton at $Q^2 = 2.40$ GeV^2 [Air+10], the reported value is $-0.85 \cdot 10^{-3} \pm 1.50 \cdot 10^{-3}(stat) \pm 0.29 \cdot 10^{-3}(sys)$. No data on the neutron yet??

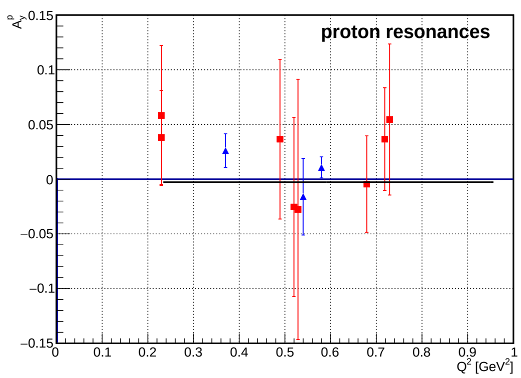

FIGURE 3. A_y^0 vs. Q^2 for the proton in the resonance region.

DIS Regime: There are somewhat more data available in this regime than in the other regimes. Figure 4 shows a summary of the neutron data found un the literature [Kat+14; Zha+15]. The plot on the upper left side shows the Q^2 *vs.* x coverage of the existing data. The yellow rectangle is the approximate range that will be covered by the d_2^n experiment. Please note that these plots actually contain all existing neutron data, i.e. also quasi-elastic data (put at $x = 1$). The red points are quasi-elastic data and the blue points are DIS data. There are also two different fits shown in the bottom two plots (a red line and a magenta line). The red line is a simple first order polynomial fit to all the data and the magenta line is a constant fit to the Q^2 range which will be covered in d_2^n.

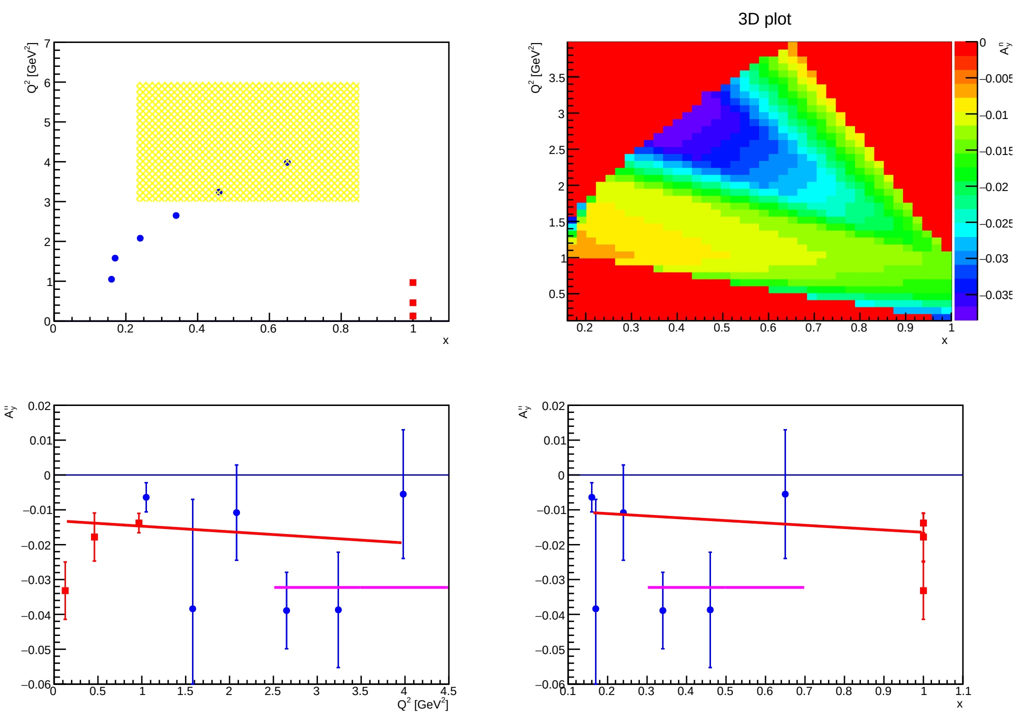

FIGURE 4. A_y^0 plots for the neutron in the QE + DIS regions.

The results for the first order polynomial fit which includes all Q^2 data is shown in Table 1 where we have $A_y^0(Q^2) = slope \cdot Q^2 + constant$. The corresponding asymmetries evaluated at some typical Q^2 values for d_2^n are shown in Table 2.

neutron	
constant ± error	slope ± error
-0.01308 ± 0.00402	-0.00160 ± 0.00332

TABLE 1. Results from linear fit to neutron asymmetries.

A constant fit to the DIS data relevant for d_2^n yields a asymmetry of $A_y^n = -0.0323 \pm 0.0082$ which is obviously the same for all Q^2 values.

neutron	
Q^2 [GeV^2]	$A_y^n \pm dA_Y^n$
3	-0.0179 ± 0.0068
4	-0.0195 ± 0.0100
5	-0.0211 ± 0.0133
6	-0.0227 ± 0.0166

TABLE 2. Predicted neutron asymmetries at typical Q^2 values for d_2^n.

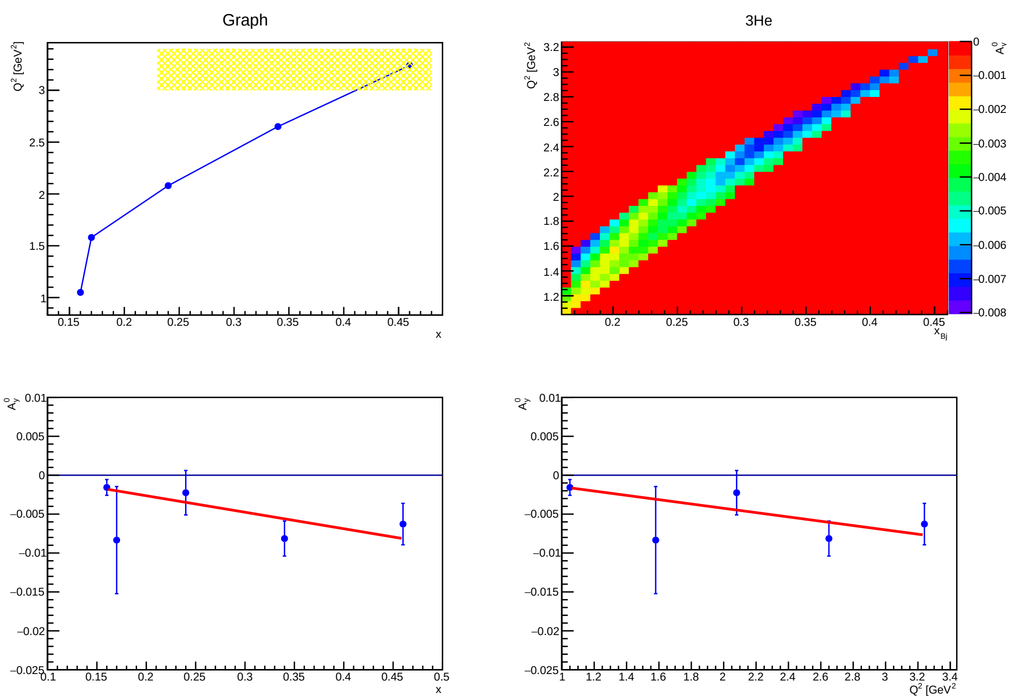

FIGURE 5. A_y^0 plots for ^{3}He in the DIS region.

Now to helium-3 asymmetries. The relevant data are displayed in Fig. 5.

The linear fit to the Q^2 plot, $A_y^{3He} = slope \cdot Q^2 + constant$, yields a *slope*of -0.00277 ± 0.00104 and a *constant* of 0.00129 ± 0.00183. Table 3 shows the predictions to the asymmetries at typical Q^2 values for d_2^n. The second column in the table assumes a polarization of 1 whereas the third column uses a *normal* polarization of 0.04. The 0.04 is based on the assumption that we have a holding field of 1 Gauss out of 25 Gauss in normal direction (P = asin(1/25) = 1/25 = 0.04).

helium-3 direct		
Q^2 [GeV^2]	$A_y^{3He} \pm dA_Y^{3He}[P=1]$	$A_y^{3He} \pm dA_y^{3He}[P=0.04]$
3	-0.0070 ± 0.0017	$-2.80 \cdot 10^{-4} \pm 0.86 \cdot 10^{-4}$
4	-0.0098 ± 0.0027	$-3.92 \cdot 10^{-4} \pm 1.08 \cdot 10^{-4}$
5	-0.0126 ± 0.0037	$-5.04 \cdot 10^{-4} \pm 1.48 \cdot 10^{-4}$
6	-0.0153 ± 0.0047	$-6.12 \cdot 10^{-4} \pm 1.88 \cdot 10^{-4}$

TABLE 3. Predicted normal asymmetries on helium-3 for P=1 and P=0.04.

As a cross check the helium-3 asymmetries can also be estimated by using just the neutron and proton data as input. This is not expected to be very precise but at least it give some more information. Following the paper of Katich *et al.* [Kat+14] the equation

$$A_y^{^3He} = (1 - f_p) \cdot P_n \cdot A_y^n + f_p \cdot P_p \cdot A_y^p$$

in the large Q^2 regime was used. The proton data include the resonance region from CEA and SLAC as well as the two Q^2 points from HERMES. f_p is the proton dilution factor. Katich quotes a range of 0.75 to 0.82 for f_p with an error of less than 10%. Here $f_p = 0.78 \pm 0.08$, $P_n = 0.86 \pm 0.028$, and $P_p = -0.028 \pm 0.0065$ were used for the estimate.

helium-3 using neutron and proton input		
Q^2 [GeV^2]	$A_y^{3He} \pm dA_Y^{3He}[P=1]$	$A_y^{3He} \pm dA_y^{3He}[P=0.04]$
3	-0.0083 ± 0.0029	$-2.44 \cdot 10^{-4} \pm 1.09 \cdot 10^{-4}$
4	-0.0084 ± 0.0029	$-2.46 \cdot 10^{-4} \pm 1.09 \cdot 10^{-4}$
5	-0.0084 ± 0.0029	$-2.48 \cdot 10^{-4} \pm 1.08 \cdot 10^{-4}$
6	-0.0085 ± 0.0029	$-2.50 \cdot 10^{-4} \pm 1.08 \cdot 10^{-4}$

TABLE 4. Predicted normal asymmetries on helium-3 reconstructed from neutron and proton data.

3. Theory

There are basically two relevant theory papers by A. Afanasev *et al.* [ASW08] and A. Metz *et al.* [Met+12]. Representative curves are shown in Fig. 6 which was taken from Katich *et al.* [Kat+14] (Fig. 3 in that paper).

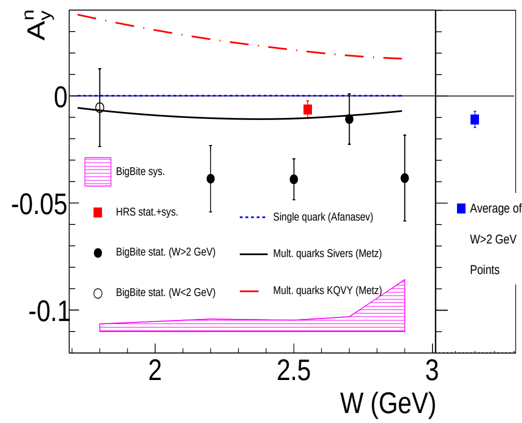

Figure 6. Some models for the asymmetry vs. W.

It seems the predictive power of these theories is not very useful since the general description of the data is not great. Maybe one can conclude that the asymmetries get smaller with increasing W?

3.1. **Implications for A_1^n.** The A_1^n experiment plans to cover a kinematic range from 0.25 to 0.77 in x_{Bj} with a corresponding range from 2.43 GeV^2 to 10.60 GeV^2 in Q^2 and $W > 2$. Additional data will be taken with the HMS for $0.5 < x_{Bj} < 1.0$ and 3.12 GeV^2 $< Q^2 <$ 4.45 GeV^2 in the quasi-elastic and resonance regime [Zhe+18]. The data in the figures above indicate that the quasi-elastic normal asymmetry approaches a constant value of -0.013 ± 0.004 (neutron) or -0.0020 ± 0.0003 (helium-3). The asymmetry in the DIS region reaches $-0.026 +/- 0.009$ (helium-3) and -0.029 ± 0.030 (1^{st} order; (-0.032 ± 0.008), 0^{th} order) (neutron) at $Q^2 = 10$ GeV^2 assuming that one can extrapolate linearly from a $Q^2 < 1$ GeV^2 region too such large Q^2 (that's a BIG IF).

4. Summary

Assuming the there is a 1 Gauss vertical field (with $B_0 = 25$ Gauss), corresponding to a target-normal polarization of 0.04, one could expect target-normal helium-3 asymmetries of several times 10^{-4} in the Q^2 range relevant for the d_2 experiment. This could be as large as ≈20% of some of the expected perpendicular asymmetries. A reduction of the vertical field to the 0.2 - 0.3 Gauss level would be desirable for the d_2^n experiment.

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