E93-026 Technical Note ???
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Angular dependence of the asymmetry $\mathbf{A^{v}_{ed}}$ and $\mathbf{G^{n}_{E}}$.

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The neutron electric form factor $\mathbf{G^{n}_{E}}$ will be extracted in E93-026 from the measured *e-d* asymmetry $\mathbf{A^{v}_{ed}}(\theta^{*}_{np})$**,** where θ^{*}_{np} is the angle between the ejected neutron and the direction of the three-momentum transfer in the center of mass of the *n-p* (or *γ-d*) system. The reliable extraction of the form factor requires that data for the asymmetry be available in those regions of θ^{*}_{np} where the variations in $\mathbf{A^{v}_{ed}}$ due to effects other than different models of $\mathbf{G^{n}_{E}}$ (*NN* potentials, non-nucleonic degrees of freedom and other corrections,) are significantly smaller than its dependence on the different $\mathbf{G^{n}_{E}}$ models. The work of ref.[1] shows two examples of the angular dependence of the asymmetry, at $Q^2 = 12$ fm^{-2} (0.5 GeV^2) for relative nucleon energies $E^{*}_{np} = 120$ MeV (quasi-free region - shown in Fig. 1 below) and 36 MeV (small energy loss side of the quasi-elastic peak). From those examples it can be seen clearly that:

- The effect of different form factor models can be distinguished with reasonable statistical and systematic uncertainties for the asymmetry only for $\theta^{*}_{np} > \sim 20°$. $\mathbf{A^{v}_{ed}}$ displays a substantial dependence on $\mathbf{G^{n}_{E}}$ models in this angular range, and the effects of other corrections are small in quasi-free scattering.

- The influence of the other corrections, especially that of the non-nucleonic degrees of freedom, increases substantially at all angles, when the asymmetry is measured away from quasi-free scattering, as the example at $E^{*}_{np} = 36$ MeV shows.

The implication of these observations for any experiment measuring $\mathbf{G^{n}_{E}}$ is that the important quantity to determine is the angular dependence of the asymmetry in quasi-free scattering, in a favorable region of θ^{*}_{np}. All other approaches will be plagued by the theoretical uncertainties that affect the older data on this form factor. To meet these two conditions, the kinematics for the measurement must be chosen to optimize the number of counts in the appropriate range of θ^{*}_{np}. The resolution in θ^{*}_{np} also plays an important role, since the predictions for the asymmetry need to be integrated over the corresponding measured bins in θ^{*}_{np} and the predictions could be rapidly changing functions of the angle.

Two examples of the consequences of choices of kinematics on the variables θ^{*}_{np} and E^{*}_{np} are given in the tables below. The first column indicates the central value of the four-momentum transfer for quasi-free scattering. The second column displays the associated beam energy *E*. Two values of *E* (high and low) are shown in each table. The high values (first row) correspond to those actually used in the first E93-026 data taking period. The low values correspond to alternative kinematic settings that may improve a given figure of merit[a]. The 3[rd] column shows the three-momentum transfer which corresponds to the final electron energy associated with the 4[th] column, where p_0 is the spectrometer central momentum for quasi free scattering, e.g. in the first row of Table 1, $\mathbf{q}(1.02\ p_0) = 0.747$ GeV/c. Only positive values of $\Delta p/p_0$ are considered, because they are related to the lower relative energies E^{*}_{np} of the final nucleons, between threshold and the quasi free peak. The 5[th] column shows the maximum c.m. angle that can be measured at the corresponding kinematics.

[a]For example the G figure of merit in T.Eden and D. Madey E93-038 draft T.N.

Table 1. $Q^2 = 0.5$ GeV²

Q^2_0 GeV²	*E* GeV	q GeV/c	$\Delta p/p_0$	θ^*_{np}	E^*_{np} MeV
0.5	2.724	0.747	+2%	8°	80
		0.741	+4%	16.5°	29
0.52	1.005	0.777	+4%	4.7°	101
		0.780	+6.5%	8.1°	77

Table 2. $Q^2 = 1.$ GeV²

Q^2_0 GeV²	*E* GeV	q GeV/c	$\Delta p/p_0$	θ^*_{np}	E^*_{np} MeV
.997	4.232	1.108	+2%	8.3°	178
		1.089	+4%	17.4°	104
1.00	1.965	1.130	+2%	3.3°	220
		1.126	+4%	6.7°	189

It is clear that the low energy kinematics settings cover a much narrower angle. It is not possible to explore in those settings the angular dependence of the asymmetry, except near the endpoint. Moreover, since the laboratory angle θ_{np} is less than ½ of the c.m. angle, the neutron detector must have very good angular resolution for the low energy kinematics. Otherwise, all the events in the Δp range will have to be assigned to only one or two bins in θ^*_{np}, especially at the $Q^2 = 0.5$ GeV² point.

On the other hand, for the high energy kinematics, we see that the final relative energy decreases significantly with increasing Δp. Since low E^*_{np} implies large corrections, the $+\Delta p$ range for $Q^2 = 0.5$ GeV² is limited by the minimum acceptable E^*_{np} to <4%. There is no limitation on the $-\Delta p$ range, at any Q^2. The low *E* kinematics is much less affected by this restriction.

The advantage of measuring the angular dependence of the asymmetry is that one does not need to extract the form factor itself, since the experimental results can be directly compared to the asymmetry calculations with different form factor inputs. In fact, this approach would solve the insensitivity problem since the calculations can be exact, while the measured form factor has experimental uncertainties that propagate unfavorably (eq. (19) of the E93-026 proposal). This is particularly important for the proton measurement, for which we have a very good determination of the asymmetry, but the sensitivity of the asymmetry to the $\mathbf{G^p_E}$ form factor is poor at low Q^2.

Taking for example the calculations of ref.[1] for the neutron for $163° \le \theta^*_{np} \le 180°$ (the range that was covered in E93-026 with $\Delta p/p_0 = 4\%$) $\mathbf{A^v_{ed}}(\mathbf{G^n_{E,M}} =$ Galster) = -1.2%, but $\mathbf{A^v_{ed}}(\mathbf{G^n_{E,M}} =$ Gari-Krümpelmann) = -8.8%, a difference of 86% relative to the Gari-Krümpelmann[2] (G-K) model, or 600% relative to the Galster[3] parameterization. On the other hand, the average asymmetry integrated over all θ^*_{np} is 8.01% for the G-K model and 5.04% for the Galster model, or a mere 45% difference relative to Galster. The integrated asymmetry is measured in the single arm data. The exclusive data measures the asymmetry only in a limited range of θ^*_{np} , so the exclusive data cannot be used to calculate $\mathbf{G}^{\mathbf{n}}_{\mathbf{E}}$ directly. It is very difficult to distinguish between models if one uses the single arm integrated asymmetry to extract $\mathbf{G}^{\mathbf{n}}_{\mathbf{E}}$, but the angular dependence of $\mathbf{A}^{\mathbf{v}}_{\mathbf{ed}}$ should give a clean separation between models, without exaggerated demands on the precision of the measurement.

These considerations can also answer some objections raised about the simultaneous exclusive measurement of the proton from factor. Calculations of the angular dependence of the proton asymmetry for different form factor models are needed. Moreover, while the form factors $\mathbf{G}^{\mathbf{n}}_{\mathbf{E,M}}$($Q^2$=fixed) are independent of the beam energy E and electron scattering angle θ_e, the asymmetry $\mathbf{A}^{\mathbf{v}}_{\mathbf{ed}}(E,\theta_e,\mathbf{G}^{\mathbf{n}}_{\mathbf{E,M}})$ is not. Thus, we also need calculated neutron asymmetries for our actual kinematics settings, for at least three $\mathbf{G}^{\mathbf{n}}_{\mathbf{E,M}}$ models, to compare with our analysis.

Finally, these considerations question the usefulness of optimizing figures of merit based on the errors for the extracted form factor, or ratio of form factors, because they are irrelevant when the angular dependence is measured.

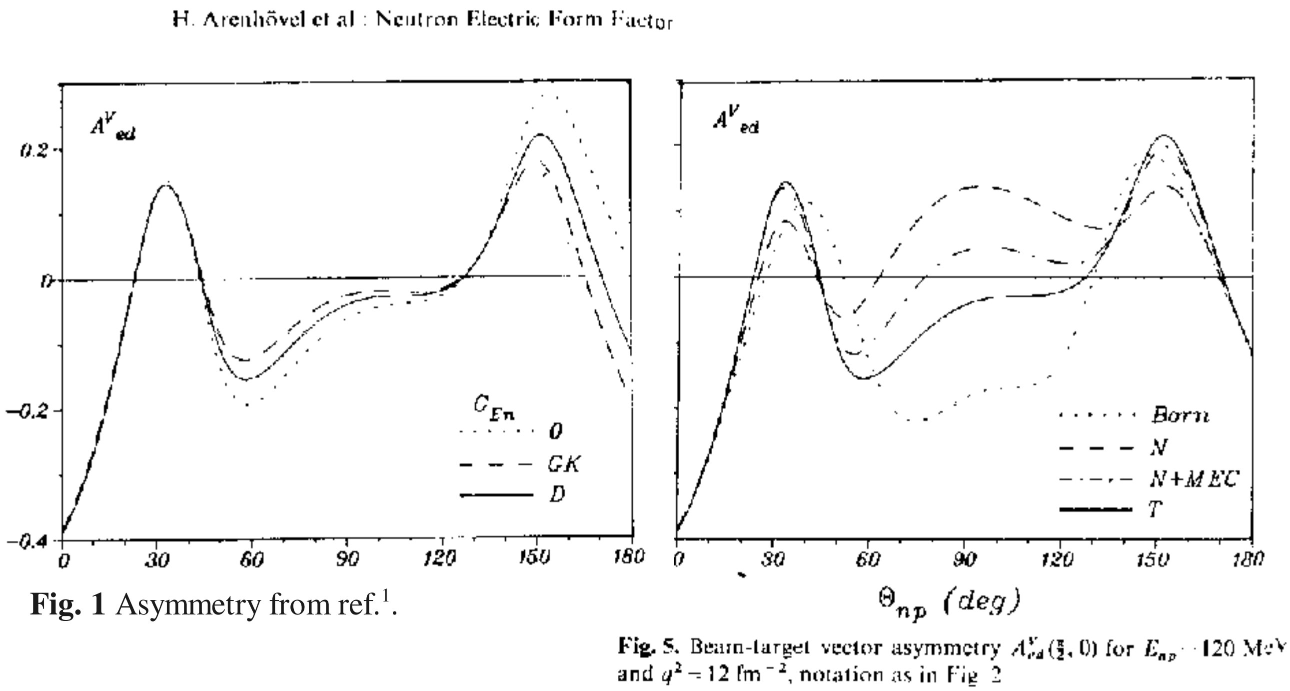

Fig. 1 Asymmetry from ref.[1].

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