Measurement of the product of beam and target polarization $P_h \cdot P_t$ for the GEN experiment by ($\vec{e}$,$^3\vec{\mathrm{He}}$) elastic scattering

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The elastic ($\vec{e}$,$^3\vec{\mathrm{He}}$) scattering can be used to define the product of electron beam and target polarization. Indeed this process is simple from the theoretical point of view, and this reaction provides large statistics and a sufficiently large analyzing power.

In one–photon exchange approximation the differential cross section of the reaction can be written as :

$$\frac{d\sigma}{d\Omega} = \sigma_{Mott}\left[\frac{G_C^2+\tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2\frac{\theta}{2} + 2P_hP_t\sqrt{\frac{\tau}{1+\tau}}\tan\frac{\theta}{2}(G_CG_M\sin\theta^*\cos\phi^* + \sqrt{\tau}G_M^2\cos\theta^*)\right], \tag{1}$$

where σ_{Mott} is the Mott cross section, θ is electron scattering angle, $\tau = Q^2/4M^2$ (here M is the mass of ^{3}He), Q is the four-momentum transfer, P_h and P_t are the polarization of the electron beam and the ^{3}He target accordingly, $G_C(Q^2)$ and $G_M(Q^2)$ are the charge and magnetic form factors of ^{3}He, θ^* and ϕ^* are the angles between the momentum transfer vector and the direction of target polarization.

At small momentum transfers the form factors of ^{3}He are well known (see Fig.1 and 2). Note $G_C = F_C$ and $G_M = \mu F_M$, where $\mu = -2.127$ is the magnetic moment of ^{3}He. For the following part of this document, the values of the form factors will be approximated using $G_C = e^{-Q^2/2}$ and $G_M = \mu e^{-Q^2/2}$, where Q^2 is in fm^{-2}.

For the polarization measurement one of the high resolution spectrometer of Hall A (HRS) will be used to detect the scattered electron. To estimate the counting rates, the presented calculations are performed using the following parameters:

- target thickness $10^{22} at/cm^2$
- length of target 40 cm
- electron beam current 12 μA

- degree of target polarization $P_t = 0.4$
- degree of electron beam polarization $P_h = 0.7$
- standard angular and transverse length acceptance of HRS
- time of polarization measurement $10^4 sec$
- direction of target polarization will be fixed by special magnet in horizontal plane with $\theta_t = 60^o$, at the right side of the electron beam line.

The product of target and electron-beam polarizations can be extracted through a measurement of the asymmetry, connected to the change of the electron beam helicity:

$$A_h = 2P_h P_t \sqrt{\tau(1+\tau)} \tan\frac{\theta}{2} \frac{G_C G_M \sin\theta^* \cos\phi^* + \sqrt{\tau} G_M^2 \cos\theta^*}{G_C^2 + \tau G_M^2 + 2\tau(1+\tau) G_M^2 \tan^2\frac{\theta}{2}} \tag{2}$$

The product $P_h \cdot P_t$ is just what one needs know for the GEN experiment. The only challenge is to keep P_h and P_t either constant during the experiment itself and during the measurement of A_h, or at least measure their relative changes. Fortunately these relative measurements of both P_h and P_t are possible - with a sufficient accurancy - and will be performed during the runs. The target polarization will be monitored using EPR and NMR, the beam polarization can and will be measured with the Compton and the Moller polarimeters.

For a given beam time and a fixed θ, the statistical uncertainty of A_h decreases with smaller electron beam energies. Although the asymmetry decreases as $A_h \sim \sqrt{\tau} \sim Q$, the increase in cross section is huge and more than compensates: $d\sigma/d\Omega \sim e^{-Q^2}/Q^2$.

However the data acquisition system of the HRS is only able to handle counting rates not exceeding 3 kHz. Therefore the decrease in beam energy is restricted. The upper-left panel of Fig.3 shows the minimum beam energy E_0^{min} as function of the different electron scattering angles (taking above restriction into account.) The horizontal line on this panel shows the lowest available beam energy from the accelerator for the anticipated GEN running period. From Eq.2 follows, that at small Q^2, where $\sqrt{\tau}\ G_M^2$ becomes small, the contribution in the asymmetry from the interference term dominates (despite the additional power of μ in G_M^2).

HRS will be placed at the right side of the electron beam line because in this case the statistical relative uncertainty in the measurement of A_h is smaller (see lower-left panel in Fig.3). Indeed for the electron scattering angle range $15-28^o$ and with the corresponding E_0^{min} , the θ^* range is $139-133^o$ (with $\phi^* \sim 180^o$), if the right HRS is used. Using the left HRS, the range for θ^* is $19-13^o$ (with $\phi^* \sim 0^o$). It is clear that $sin(\theta^*)$ (and hence A_h) is larger in the first case, while the absolute uncertainty is practically equal for both cases (see the upper-right and lower-right panels in the Fig.3). It has to be noted, that the contributions of the term with $G_C G_M$ and the term with G_M^2 to the asymmetry A_h have a different sign in either case.

Using the optimal electron scattering angle ($\approx 23.5^o$), an electron beam energy of $840 MeV$, the right HRS and other parameters as described above, a measurement of A_h

with a relative statistical uncertainty of $\delta A_h/A_h \approx 2\%$ can be achieved. Possible sources of systematic errors for A_h are:

- Uncertainty in the knowledge of the form factors G_C and G_M is $\approx 2\%$ for each of them, it contributes to 2.3% in the uncertainty of A_h.
- Uncertainty in relative measurements of P_h and P_t ($\approx 1\%$ for each of them) contributes to 1.4% in the A_h uncertainty.
- A HRS angle determination accuracy of 0.5^o will result in a uncertainty of 1%.
- The direction of the polarization will only be known to 0.5^o, this results in a 1.1% uncertainty of A_h.
- The electron beam energy uncertainty $\delta E_0 = 1 MeV$ contributes another 0.1% uncertainty of A_h.

Adding all these contributions, the resulting systematic uncertainty of A_h is 3.1%.

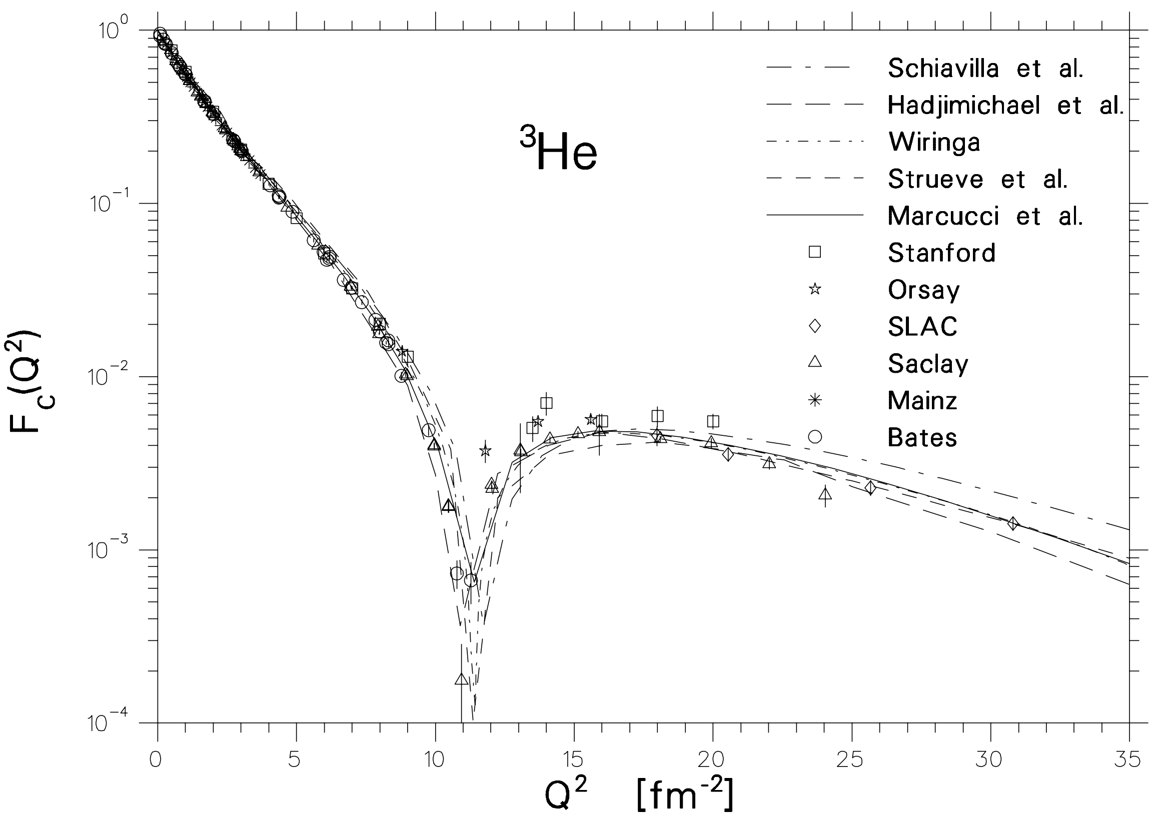

Figure 1: The charge form factor of ^{3}He.

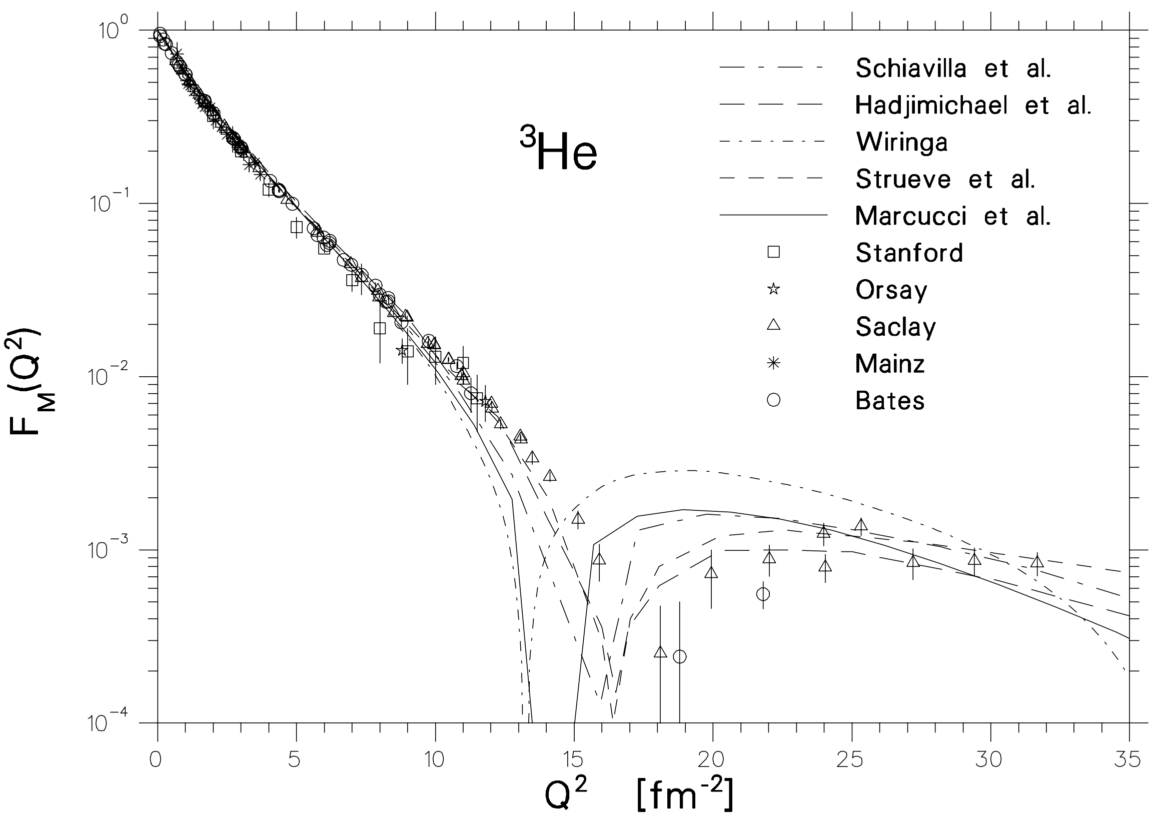

Figure 2: The magnetic form factor of ^{3}He.

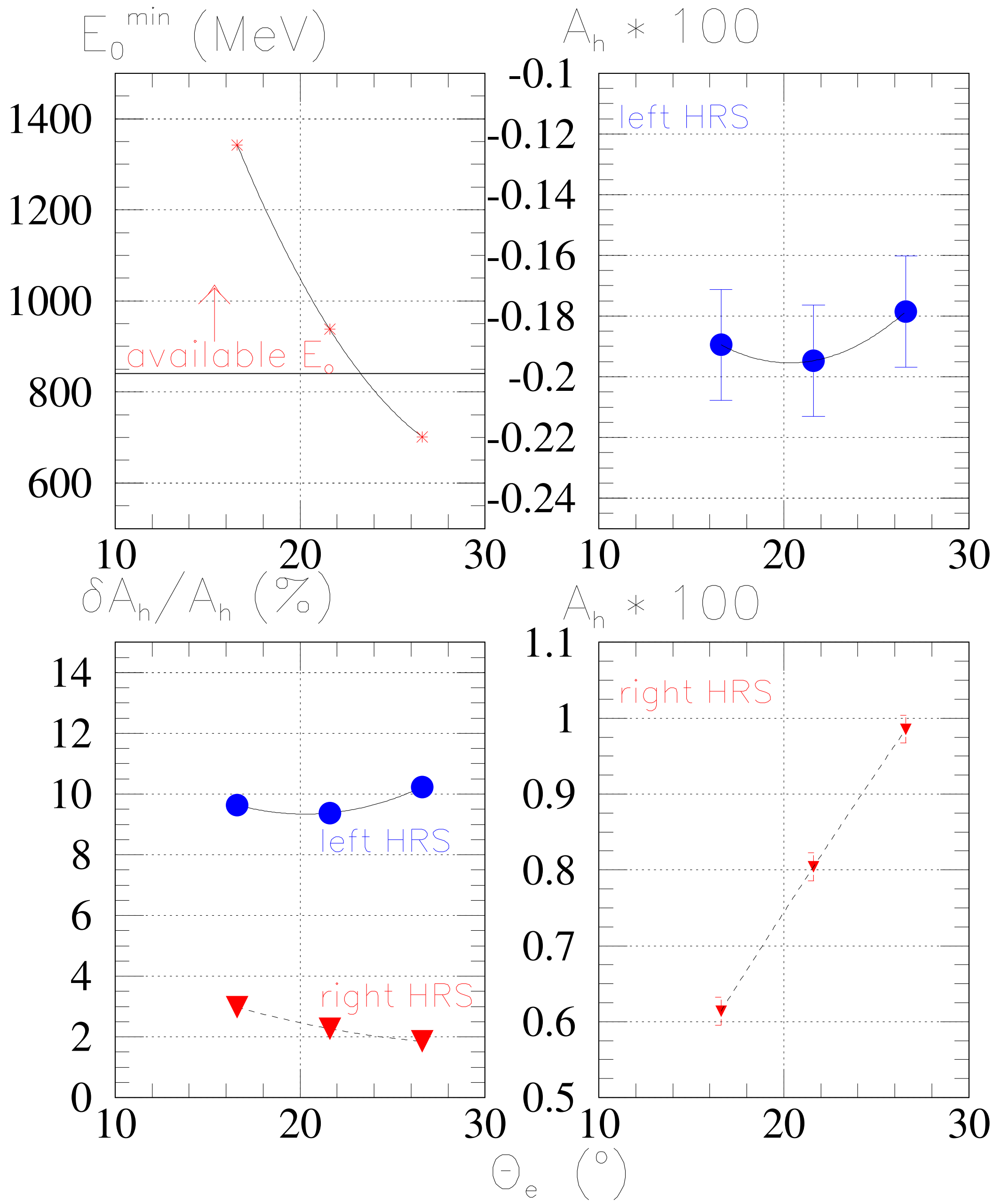

Figure 3: **Upper-Left**:the minimal electron beam energy for the data acquisition system of HRS with a counting rate of 3 kHz as function of the electron scattering angle; the horizontal line shows the minimal available energy of the accelerator. **Upper-right** and **lower-right**: the expected asymmetry A_h (and its statistical uncertainty) as function of the scattering angle with the left HRS (top) and right HRS (bottom). **Lower-left**: relative statistical uncertainty of A_h.