RSS Deuteron and Neutron Analyses

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Abstract

A summary and status report on RSS deuteron and neutron data analyses is given. All results are preliminary.

1 Deuteron Analysis

RSS Deuteron analysis is mainly performed by M. K. Jones [1].

1.1 Deuteron quasi-elastic asymmetries by Arenhövel

Arenhövel calculated the deuteron quasi-elastic (QE) asymmetries at the RSS kinematics with target polarization being parallel or perpendicular to the beam direction. The Lomon parametrization of proton and neutron form factors (G_E and G_M) were used in his calculations. The QE asymmetries are obtained at 6 beam energies (5.755, 5.355, 4.955, 4.555, 4.155 and 3.755 GeV) and 5 electron scattering angles (11^o, 12^o, 13^o, 14^o, and 15^o) for a total of 30 grid points. The results are obtained for W range between 0.605 and 2.0 GeV. The QE asymmetries obtained were compared with the predicted QE asymmetries calculated using the simple PWIA with D-State correction. They basically agree with each other.

1.2 Deuteron cross sections by P. Bosted

We use the deuteron QE and inelastic cross sections codes by P. Bosted in the deuteron data analysis. These cross sections are obtained from the fit to the world data. We can obtain the smeared unpolarized structure functions from his code, F1F2IN06.f.[1] The invariant mass of the offshell nucleon, W',

[1] He is working on improving this routine, especially for $A > 2$ but the deuteron fit results should not change much [2]. The new one is called F1F2IN07.f .

is given as[2] (ignoring a term containing the kinetic energy of the off-shell proton)

$$W'^2 = (M_d - \nu - M_p)^2 - |\vec{q}|^2 - 2\vec{q}\,\vec{P}_f - P_f^2, \qquad (1)$$

where M_d and M_p are deuteron and proton masses, ν is the electron energy transfer, $\vec{q}$ is the electron momentum transfer vector, and $\vec{P}_f$ is the fermi momentum of proton inside deuteron. The last term of Equation 1 is introduced to make a better agreement with world data of deuteron[2]. This offshell W' is passed to christy806.f routine (a newer version of the proton inelastic routine) to obtain F_1. This F_1 weighted by the fermi momentum distribution is integrated over the Fermi momentum space to get the *smeared* F_1. Similarly, the cross sections σ_t and σ_l are smeared to calculate smeared R. The deuteron subroutine called 'pind' outputs smeared R and F_1. It should be noted that outputs of structure functions (F_1, F_2) from his code are *per nucleus.*

1.3 Results of radiative Corrections

The procedure for the radiative corrections for the deuteron is similar to that of the proton [3]. Given below are our preliminary results as of Apr, 2007. The nitrogen corrections have been applied. Figure 1 shows the Born and radiated cross sections of the deuteron. The QE, inelastic and total(QE+inelastic) cross sections are plotted. Figure 2 (Figure 3) shows the results of $A_{||}$ and $A_\perp$ (A_1 and A_2) for the deuteron. Comparison of RSS deuteron A_1 data with eg1a and eg1b data are shown in Figure 4.

1.4 Fit Results and error band

Using the fitting procedure similar to that of the proton [3] , RSS deuteron A_1 data are fit after the QE subtraction. For proton data, we observed four resonances: Delta, R1, R2, and R3, and we use the same notations for the deuteron resonances. Fit parameters from the V6c fit to the proton A_1 were used as the *initial* fit parameters for the deuteron. We assume the contribution from DIS part has the form $x^\alpha(b_1 + b_2 x + b_3 x^2 + b_4 x^3)$, where

[2] in his code, the sign in front of $2\vec{q}\,\vec{P}_f$ is *positive* but I believe *minus* is right. However, the result of a smeared quantity obtained after integration does not depend on this sign because integration is done over all Fermi momentum space.

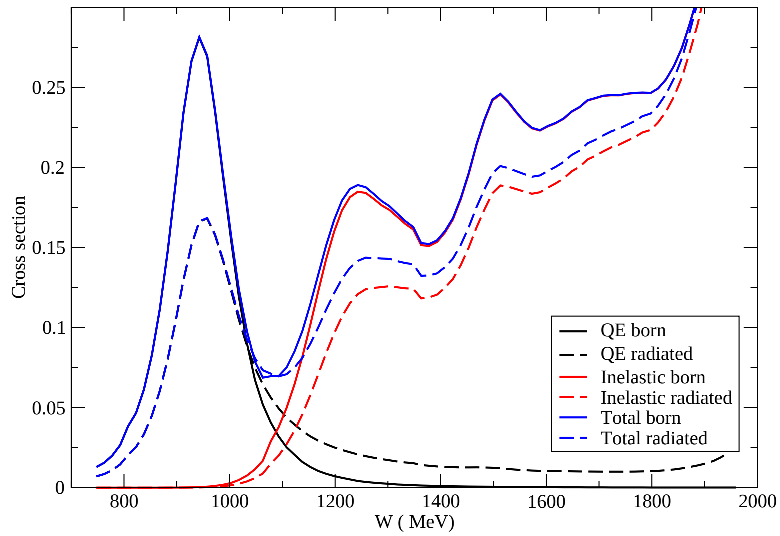

Figure 1: Comparison of Born and radiated deuteron cross sections. Plot made by M. K. Jones

$\alpha, b_1, b_2, b_3, b_4$ are the fit parameters. However, due to less number of RSS deuteron data points, only 6 parameters (Delta centroid and amplitude, R2 and R3 amplitudes, and b_1 and b_2 parameters for DIS) are varied as opposed to the 17 parameters for the proton. The 4 parameters (R1 peak height, b_2, b_3, and α) are set to zero while the other parameters remain the same as the proton fit parameters. Table 1 shows the fit parameters for deuteron A_1. We did not include the R1 resonance in the fit as it is not seen from our deuteron data. Figure 5 shows the fit functions and the corresponding error band. The fit results in low W region greatly depend on the choice of DIS fit form. For $W > 1200$ MeV, the results using different DIS forms basically agree except for the fit with DIS=0. The error band is calculated from the error matrix for the 6 fit parameters. For deuteron A_2, the error bars are so large that the resonance structures are not clearly seen. Furthermore, most of the data points in the inelastic region are consistent with zero unlike the RSS proton A_2 [3]. Instead of making a fit to the data, we report the weighted average of the data, $A_2^d = 0.081 \pm 0.017$ as shown on the right plot of Figure 3.

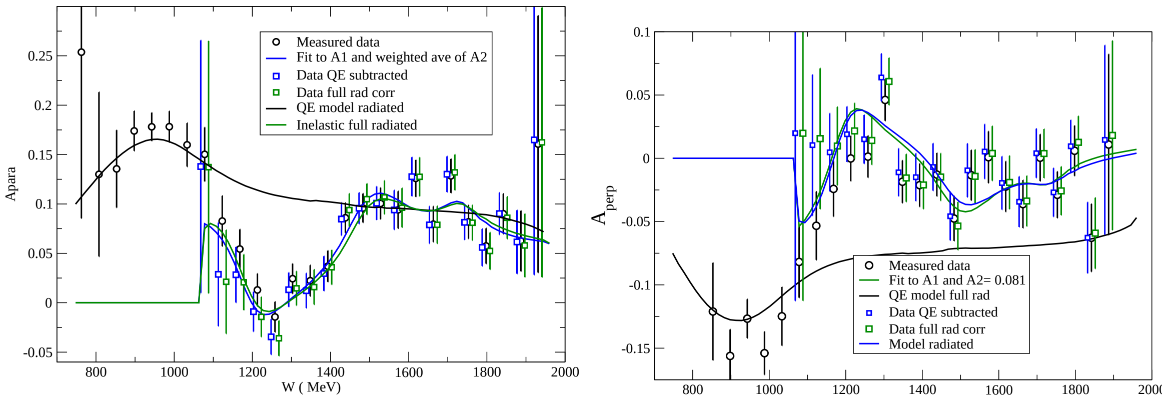

Figure 2: Preliminary Results of RSS deuteron $A_{||}$ (left) and $A_{\perp}$ (right). Plots made by M. K. Jones

2 Neutron Extraction

2.1 Extraction procedure and proton smearing

Spin structure functions (SSFs) of the neutron can be extracted from the proton and deuteron data from RSS. Because of the fermi motion of a nucleon inside deuteron, proton SSF needs to be smeared and then subtracted from deutron SSF. We follow the smearing procedures described in detail in [4], which is based on the work of Atwood-West [5]. Due to the Fermi motion, the invariant mass W and the energy transfer of the off-shell nucleon (W' and ν', respectively) differ from the on-shell ones, which can be calculated as a function of Fermi momentum. To obtain a smeared SSF of an on-shell one, the convolution of the on-shell quantity ($g_1^p(Q^2, W', \nu')$, etc) and the Fermi momentum distribution function is formed and integrated over the Fermi momentum space. We use the Paris wave function of the deuteron to get the deuteron Fermi momentum distribution. (We have two other WFs: Bonn and Hulthen-Yamaguchi, but any of the the WFs gives nearly the same smearing results because all three WFs are not so different from each other. Because $\Delta\sigma_{||}^p$ and $\Delta\sigma_{\perp}^p$ are *linear* functions of g_1^p and g_2^p (see Eq.(4) of [4]), *smeared* cross section differences, $\Delta\sigma_{||}^{ps}$ and $\Delta\sigma_{\perp}^{ps}$, are first obtained using the Eq.(5) of the tech note [4], and then they are converted to give *smeared* proton SSFs, g_1^{ps} and g_2^{ps}. Figure 6 shows the smearing effects on g_1^p and g_2^p.

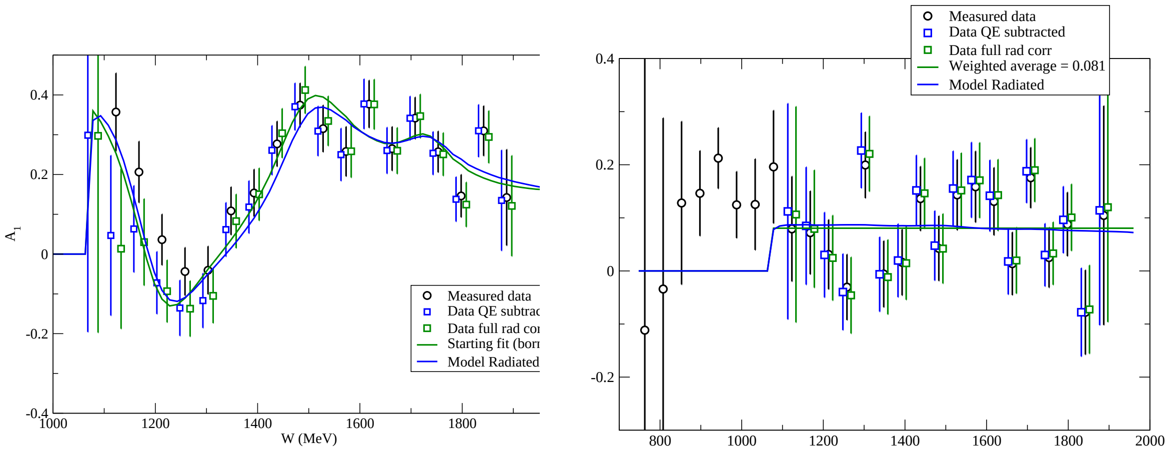

Figure 3: Preliminary Results of RSS deuteron A_1 (left) and A_2 (right). Plots made by M. K. Jones

2.2 Neutron g_1 and g_2

We subtract the smeared g_1^{ps} from g_1^d to get g_1^n. Similarly for g_2^n extraction.

$$g_1^n = g_1^d / C_{depol} - g_1^{ps} \tag{2}$$

where $C_{depol} = 1 - 1.5\omega_D$ is the depolarization factor of the deuteron. $C_{depol} = 0.925$ with $\omega_D = 0.05$. The D-State correction factor is defined as $1/C_{depol}$. However, the constant depolarization factor given above is valid for $x_{BJ} <\sim 0.7$ only. For higher x_{BJ} region, the depolarization factor deviates from 0.925 and start increasing as x_{BJ} becomes larger [6]. Figures 7 and 8 show the extracted smeared g_1^n and g_2^n. The bin width is 180 MeV ($x < 0.576$ or $W > 1.37$) and 60 MeV otherwise. Our preliminary results agree with world data measured in the DIS regime, and are basically consistent with zero except for one g_2^n data point at $x_{BJ} = 0.65$.

2.3 Neutron A_1 and A_2

Neutron A_1 and A_2 can be obtained from the extracted g_1^n and g_2^n.

$$\begin{aligned} A_1^n &= (g_1^n - \gamma^2 g_2^n)/F_1^n \qquad (3)\\ A_2^n &= \gamma(g_1^n + g_2^n)/F_1^n, \qquad (4) \end{aligned}$$

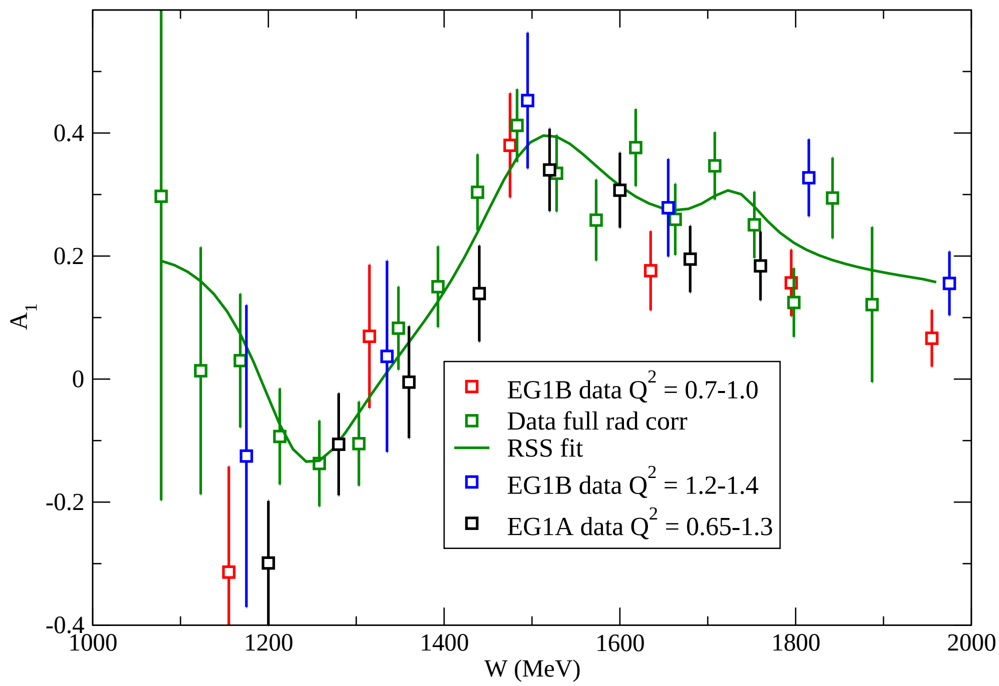

Figure 4: Comparison of RSS deuteron A_1 with eg1a and eg1b. Plot made by M. K. Jones

where $\gamma = \sqrt{Q^2/\nu}$. Here, both g_1^n and g_2^n are smeared quantities. Therefore, we also need to have smeared F_1^n in order to extract A_1^n and A_2^n. Because the inelastic code by P. Bosted, F1F2IN06.f, outputs the unsmeared F_1^n, the code was modified slightly to return smeared F_1^n. Figure 9 shows the results of F_1 for proton, deuteron, and neutron. Smeared F_1 for proton and neutron are also plotted. The results of extracted A_1^n and A_2^n are shown in Figure 10. The bin size is 60 MeV. Comparison of different D-state corrections are also shown. The errors on A_1^n and A_2^n are calculated from the errors on g_1^n and g_2^n as well as 10% relative error on F_1^n that we *assumed*. However, I was told that the systematic error on F_1^n would be about 6% because the world data of deuteron used in the fit have statistical error of about 5%, and the proton data error is much smaller than that [2]. Our preliminary results are consistent with zero except for A_1^n at $W \sim 1.3 GeV$.

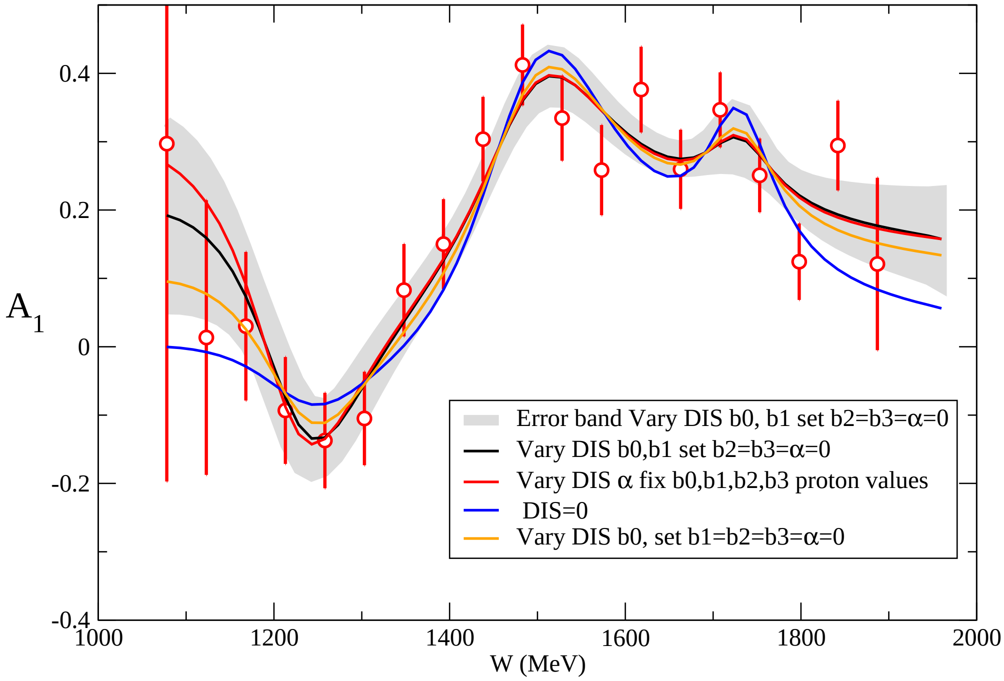

Figure 5: Results of the deuteron A_1 fit and the error band using different DIS function forms. The error band plotted is for the linear DIS fit (shown in black). The χ^2 values for the different fits are nearly the same and they are between 1.4 and 1.5. Plot made by M. K. Jones

References

[1] M. K. Jones. More detailed analysis on the deuteron including the preliminary data tables can be found at the following site: http://www.jlab.org/~jones/rss/Deuteron_radiative_corrections.html

[2] P. Bosted Private communications.

[3] F. R. Wesselmann *et al.*, Phys. Rev. Lett. **98** 132003, 2007

[4] O. A. Rondon, RSS Tech note, *Smearing procedure to get Neutron S. S. F.'s*

[5] W. B. Atwood and G. B. West, Phys. Rev. D **7**, 773 (1973)

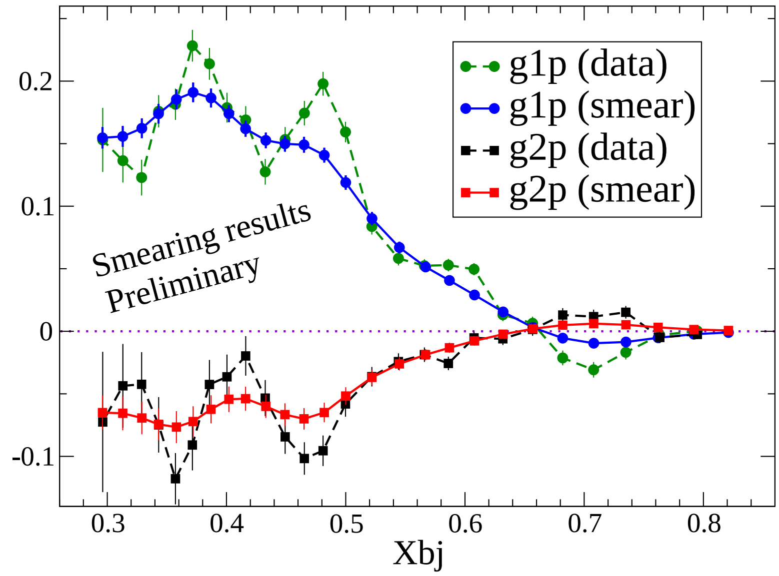

Figure 6: Smearing effects on proton g_1 and g_2.

[6] W. Melnitchouk, G. Piller, A. W. Thomas. Phys. Lett. **B** 346 (1995) 165-171

[7] S. Tajima. More detailed analysis on the neutron extraction including the preliminary data tables can be found at the following site: http://www.jlab.org/~tajima/rss/ssf/

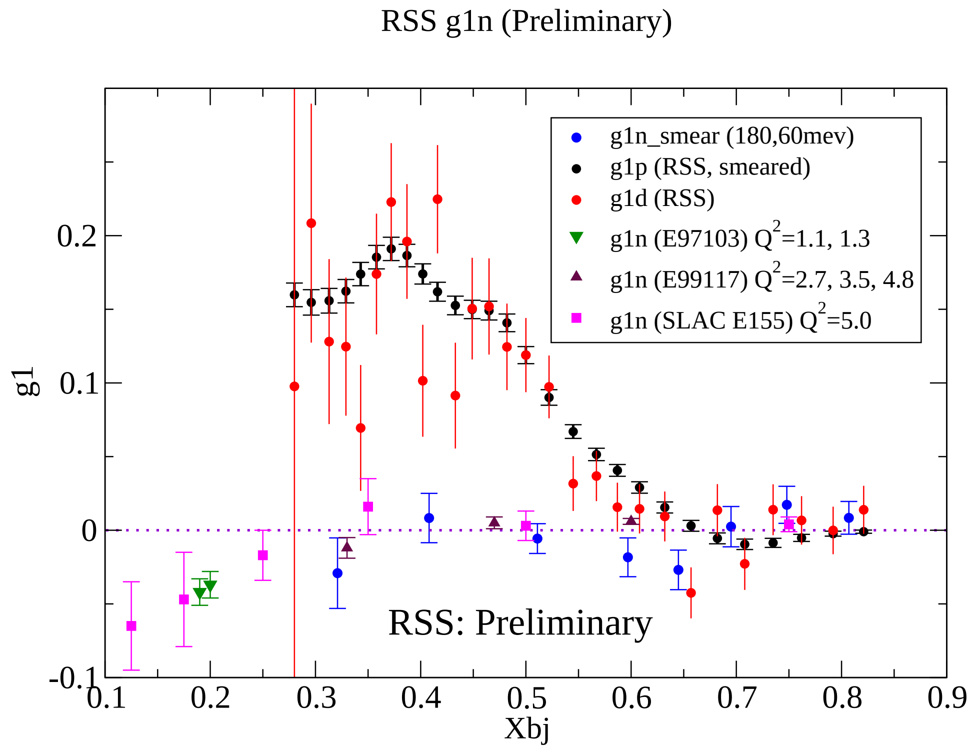

Figure 7: Preliminary results of g_1^n extracted from RSS deuteron g_1 (data) and smeared proton g_1. Our results basically agree with the world data measured at the DIS regime, and are also consistent with zero.

Table 1: Deuteron A_1 fit parameters

Resonance	Center	width	Amplitude
Delta	1.270 ± 0.017	0.198	-0.301 ± 0.122
R1	–	–	0.0
R2	1.545	0.264	0.269 ± 0.063
R3	1.734	0.098	0.097 ± 0.075
DIS α	b_1	b_2	b_3 and b_4
0.0	0.110 ± 0.124	0.100 ± 0.281	0.0

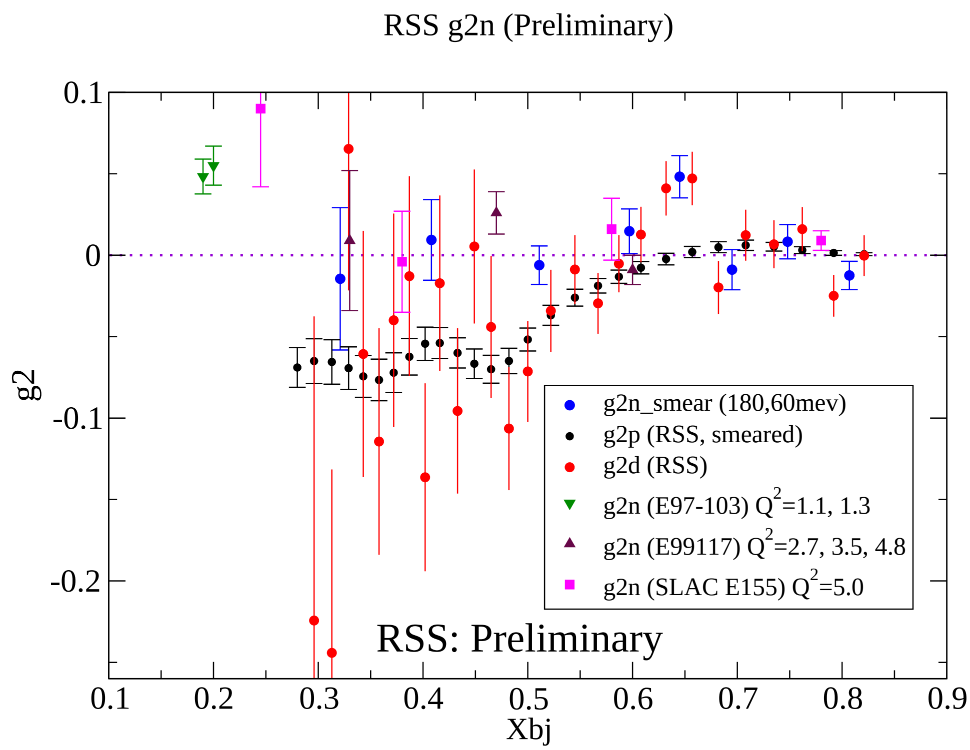

Figure 8: Preliminary results of g_2^n extracted from RSS deuteron g_2 (data) and smeared proton g_2. Our results basically agree with the world data measured at the DIS regime, and are also consistent with zero except for one data point at $x_{BJ} = 0.65$.

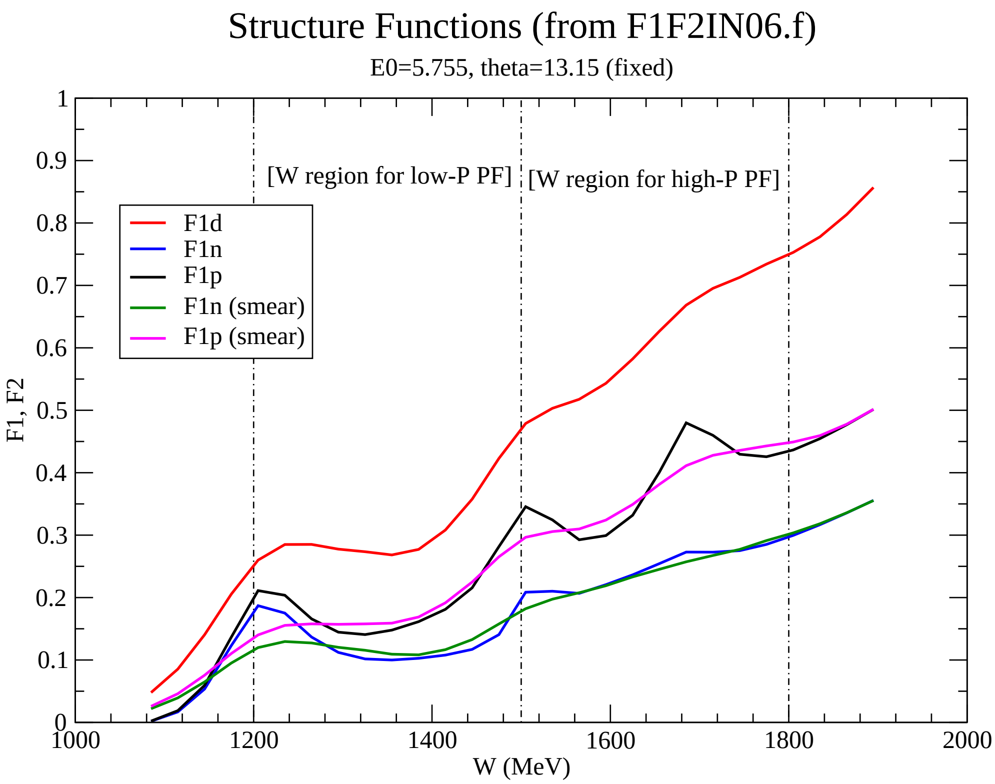

Figure 9: Structure functions F_1 for proton, deuteron and neutron. These are outputs from F1F2IN06.f. Also plotted are smeared F_1^p and F_1^n from this code.

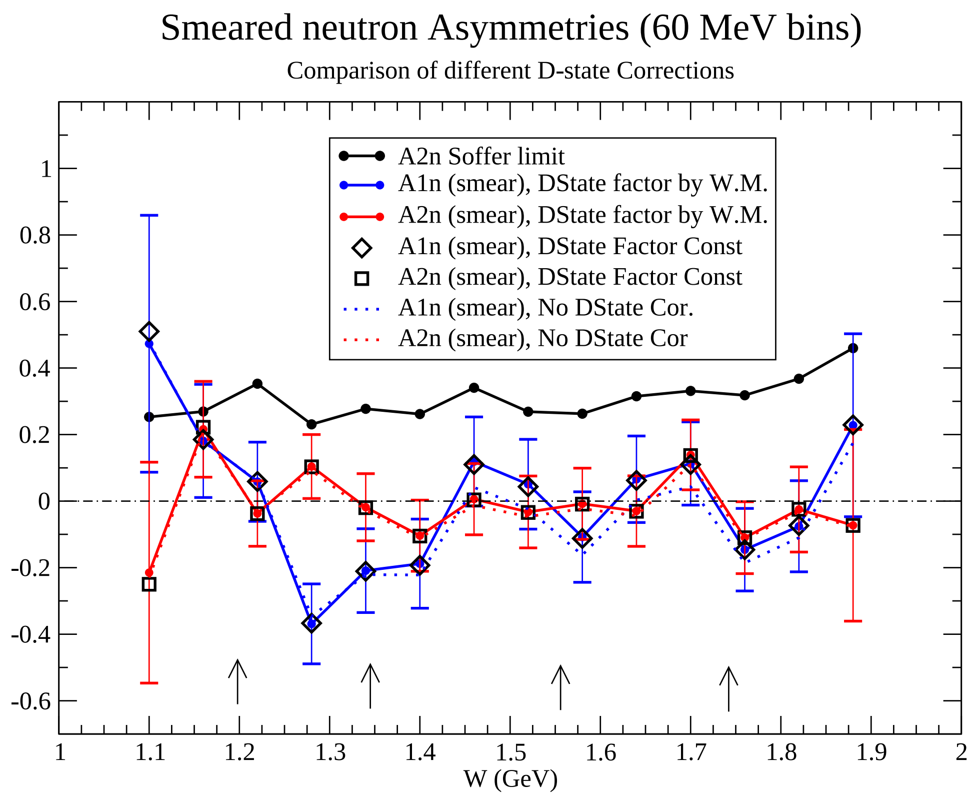

Figure 10: Preliminary results of A_1^n and A_2^n (shown in blue and red solid lines, respectively). Also shown are the results using different D-State corrections (correction factor=1.0 (no correction), const factor=1/0.925, and full correction by Melnitchouk et al [6].) The arrows in the figure indicate the centroid positions of the resonances found from the fit to the RSS proton data [3].