Data Analysis for EG1

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Organization of runs

Database of runs

a) Update beam polarization data from analysis of Møller runs (after all corrections are known). Ideally, incorporate information from Møller measurements in Hall A and Mott measurements done by the accelerator. Check that the status of the $\lambda/2$ plate, the setting of the Wien filter (the spin launch angle), and the number of spin precessions in the beam line (depending on energy) are consistent with the measured sign. NOTE: Sometimes the status of the $\lambda/2$ plate changes without a sign change in the recorded beam polarization until the next Møller run. In this case, the sign must be changed by hand in the database.

b) Update beam energy based on Hall A measurements and accelerator log entries.

c) Update target polarization based on a re-analysis of the NMR measurements. Ideally, this would also include some estimate of polarization decay as function of deposited dose between anneals. The goal is to have a best estimate of the target polarization for each production run entered in the database.

d) Check all logbooks for additional important information, especially on trigger configurations (and changes), unusual detector parameters and status, etc.

e) Add information on raster settings if they can be obtained, and target magnetic field direction (and whether it's on or off)

f) Run “Tester” to find major breaks (detectors off etc.).

All "chefs" and other analysis workers are supposed to add information to the offline database/logbook on each run they work with.

Lists of runs

a) Non-standard Calibration runs - any runs with non-standard running conditions that can be used to study aspects of the detector calibration (e.g., torus field or target field off, no LHe, no rastering, or overrastering, non-standard triggers for efficiency studies, pedestal and cosmic runs, and of course Møller runs).

a) Junk runs - any runs where software or hardware failures make successful analysis unlikely. Examples are runs where vital detector/beam parameters were being changed for studies, or where the target polarization was varying rapidly, or any other known problems exist that make it impossible or exceedingly difficult to extract reliable data. Those runs for which we KNOW their "junk" status are either not in the database at all, or marked by comments. However, some of these runs will only be eliminated by offline inspection of histograms or cuts.

a) Production runs - any runs on NH_3, ND_3, Carbon, ^{15}N and empty targets that don't fall under the first 2 categories. These are the runs that are cooked in Pass 1.

Runs can be moved from one category to another later on, as information is added to the database. For instance, runs during which the charge asymmetry of the beam exceeded 10^{-2} might be declared junk runs.

Cuts

1) Remove junk runs and non-standard runs (see list above).

1) Sector-dependent time slices: For each sector, we need to determine time periods where some part of it was off or non-standard. The corresponding runs (or at least files) need to be excluded **for the affected sectors**. This also means we need to keep track of integrated charge separately for each sector, so we can properly cross-normalize Empty and Carbon runs.

1) Time slices for all 6 sectors: Whenever the beam was unstable (number of electrons, Faraday cup clicks, BPMs varies more than a few percent from helicity bin to the next). Whenever beam was off. Whenever beam asymmetry exceeded 0.2%. Whenever the exact helicity sequence and bucket pair matching fails. NOTE: time slices have to be removed in units of helicity complement bucket pairs only!

1) Fiducial cuts: Using Alex Vlassov's Cerenkov code, select a region of phase space where the Cerenkov is at least 80% efficient (dependent on Cerenkov cut, see below).

1) Dead region cut: After binning all events in p, theta and phi and normalizing to FC (for each sector separately), plot the relative deviation of a given bin from the average over all phi bins at the same theta and p. This should show us where dead or highly inefficient regions of the CLAS affected the data over a significant amount of time. These regions should be removed using "fiducial-like" cuts (strips).
1) Vertex: Ideally involving the raster beam position and corrections for beam axis offset. Main purpose is to remove window foils and also badly reconstructed events.
1) Electron ID: Below 3 GeV momentum, require >2.5 photoelectrons in Cerenkov; above require >0.5 photoelectrons. Use separate cuts in Einner/p vs. Etotal/p (EC) for both momentum ranges.
1) Electron energy: Both low and high momentum electrons need to be cut, e.g. 0.15*E < E' < E. The low momentum cut is to avoid the region where large radiative effects, e^+e^- and pion contamination and misreconstructed electrons are most severe.

Corrections

The following is a list of corrections we need to apply:

1) Momentum correction: Optimize elastic peak width and position (NH_3 runs). Check by finding width and position of S_{11}. Other checks? Other particles?
2) Vertex correction: Ideally, correct reconstructed θ, ϕ and p for beam position (raster).

Sorting

Events that pass all cuts need to be sorted into histograms or ntuples. For the inclusive data, we need two 2D histogram of Q2 vs. W for each helicity separately, normalized to (deadtime-gated) beam current integral. These 2 histograms need to be created for each sector and each uniform run group separately, as well as for all different target types. A uniform run group consists of all runs that have identical beam energy, torus current, beam and target polarization direction, and indication of uniform conditions (uniformly high P_bP_t, no major detector breakdowns, same trigger etc.) and encompass Carbon, Empty and Ammonia runs.

We also need histograms for possible background events from π^-, charge symmetric events (π^0 decay into electron-positron pair), accidental coincidences (hadron plus photon?), non-beam related events (cosmics, noise) and non-target related events (Møller electrons, "junk" from downstream and upstream). We will probably correct (not subtract) these contributions, so we need to know what the background/signal rates and raw asymmetries are. The easiest way to do this correction is via

$$A_S = A_{meas} + \frac{B}{S}\left(A_{meas} - A_B\right) ,$$

where A_S is the desired “Signal” asymmetry, A_B is the background asymmetry, and S and B are the properly normalized signal and background rates.

Physics results

Dilution factor

The raw asymmetry can be corrected for contributions from non-hydrogen (non-deuteron) nucleons in several different ways. All methods require the following initial step:

For each sector and run group, calculate the two 2-D histograms described above for Ammonia (A), Carbon (C) and Empty (MT) target, as well as ^{15}N (N) where available. For the unpolarized targets (all but A), add both helicities together and divide by the sum of both dead-time corrected Faraday Cup (FC) counts:

$$n_{C,MT,N} = \left(N^+_{C,MT,N} + N^-_{C,MT,N}\right) / \left(FC^+ + FC^-\right)$$

For the Ammonia runs, we must correct the two helicity states individually and then average:

$$n_A = \left(N^+_A / FC^+ + N^-_A / FC^-\right) / 2$$

We can then write these Faraday Cup normalized counts for all four targets as sums of contributions from entrance and exit foils (F), liquid Helium-4 coolant (He), Carbon-12 (C), Nitrogen-15 (N) and Deuterium (D – all formulas can be modified for NH_3 by using H instead of D):

$$n_{MT} = \left[\rho_F \ell_F \frac{\sigma_F}{\sigma_D} + \rho_{He} L \frac{\sigma_{He}}{\sigma_D}\right] F \sigma_D = \left[\rho_C \ell_C f \frac{\sigma_C}{\sigma_D} + \rho_{He} L \frac{\sigma_{He}}{\sigma_D}\right] F \sigma_D \; ; \quad f = \frac{\rho_F \ell_F \sigma_F}{\rho_C \ell_C \sigma_C}$$

$$n_C = \left[\rho_C \ell_C (1+f) \frac{\sigma_C}{\sigma_D} + \rho_{He} (L - \ell_C) \frac{\sigma_{He}}{\sigma_D}\right] F \sigma_D$$

$$n_N = \left[\rho_C \ell_C f \frac{\sigma_C}{\sigma_D} + \rho_{He} (L - \ell_N) \frac{\sigma_{He}}{\sigma_D} + \rho_N \ell_N \frac{\sigma_N}{\sigma_D}\right] F \sigma_D$$

$$n_A = \left[\rho_C \ell_C f \frac{\sigma_C}{\sigma_D} + \rho_{He} (L - \ell_A) \frac{\sigma_{He}}{\sigma_D} + \rho_A \ell_A \left(\frac{\sigma_N}{\sigma_D} + 3\right)\right] F \sigma_D$$

Here, the density ρ for each component is the number of mol per cm^3 (the density in g/cm^3 divided by atomic/molecular mass number A – e.g., 21 for ND_3) and the length (thickness) *l* is in cm. The cross sections are in cm^2 per nucle**us** (so roughly $\sigma_C = 3\sigma_{He} = 6\sigma_D$). The factor *F* contains all conversion factors (from Faraday cup clicks and mol to atoms and incident electrons) and the acceptance and overall efficiency of CLAS at a given kinematic point. We assume that the contribution to the count rate from all foils combined can be expressed as a fixed fraction *f* of the contribution from Carbon-12 in the Carbon target. The following table lists what I know about the constants.

Item	Value	Comments
$\rho_F l_F$	Al: 71+25+71 μm = 0.045 g/cm^2 Kapton: 127+50+127 μm =0.0432 g/cm^2 before 27997; +80 μm => 0.055 g/cm^2 after. Tot: 0.0882 g/cm^2 / 0.0996 g/cm^2 (I've tried to account for all material within 5 cm of the target center)	This is from measurements by Chris and Raffaella. 50 μm Kapton could be up to 85 μm (or less because of perforation). Extra 80 μm Kapton foil was added **after run 27997** (Assume ρ_F is proportional to mass number A, so mass density is needed here).
$\rho_C l_C$	0.498 g/cm^2 = 0.0415 mol/cm^2	Needed to calculate *f*
f	0.177 (0.200 after run 27997)	Ratio of previous two numbers
ρ_{He}	0.145 g/cm^3 = 0.0362 mol/cm^3	Triple-checked
L	1.90 cm	From analysis of n_{MT}/n_C;[*] measurement by Chris Keith and Stephen Bueltmann, gave 1.80 cm. Drawing says 2.26 cm; post mortem measurement 1.66 cm (windows bulging **in** – not likely for run)
ρ_C	2.17 g/cm^3 = 0.180 mol/cm^3	Could be 2.16 g/cm^3 (measurement) or 2.267 g/cm^3 (standard literature) or 2.2 g/cm^3 (SLAC number)
l_C	0.23 cm	Other numbers quoted include 0.225 cm and 0.24 cm
ρ_N	1.1 g/cm^3 = 0.07325 mol/cm^3	Some uncertainty (packing fraction?); could be as little as 0.93 g/cm^3
l_N	0.65 cm	Ideally, should be extracted from data
ρ_A (NH3) ρ_A (ND3)	0.917 g/cm^3 = 0.0508 mol/cm^3 1.056 g/cm^3 = 0.0502 mol/cm^3	These numbers disagree a bit – they should be the same in mol/cm^3.
l_A	0.55 cm	Must be extracted from data (packing fraction); this is just a wild guess

[*] Using the ratio $r = n_{MT}/n_C$ in the region of W = 1.5…2 one can show that

$$L = \left[\frac{3\rho_C l_C \left[(1+f) r - f \right]}{\rho_{He}} - r l_C \right] \Big/ (1 - r)$$

Method 1

Use the standard fit of n_C to n_A in a region where the true hydrogen cross section is (close to) zero (low W "tail"): $n_A = c*n_C$. This works better for NH_3, but may also work for ND_3 if the W cut is generous enough. The undiluted asymmetry is then:

$$A_{raw} = \frac{N_A^+ / FC^+ - N_A^- / FC^-}{N_A^+ / FC^+ + N_A^- / FC^- - 2cn_C}$$

The standard error calculations of my EG1a note apply.

This is the most straightforward and least sophisticated method, which should not be used in the final analysis (except to estimate systematic errors). There are two reasons for this:
1) the Carbon target contains a different amount of LHe than the ammonia target
2) the nitrogen-15 in ammonia has a different cross section shape than carbon-12 (because of different neutron/proton ratio, and possibly different nuclear effects).

Gail Dodge et al. have developed a method to account for the different LHe contribution – see http://www.jlab.org/Hall-B/secure/eg1/gail/Background.htm for details. In the following, we will lay out a method that also takes the ^{15}N - ^{12}C difference into account.

Method 1b)

We begin by defining two new spectra which can be calculated from the empty and Carbon target spectra:

$$n'_{^{12}C} = \frac{L}{L + f\ell_C} n_C - \frac{L - \ell_C}{L + f\ell_C} n_{MT} = 0.979 n_C - 0.861 n_{MT} \overset{!}{=} \square_C \ell_C \frac{\square_C}{\square_D} F \square_D$$

$$n'_{^4He} = \frac{1 + f}{L + f\ell_C} n_{MT} - \frac{f}{L + f\ell_C} n_C = 0.606(0.616) n_{MT} - 0.091(0.103) n_C \overset{!}{=} \square_{He} \frac{\square_{He}}{\square_D} F \square_D$$

These new spectra should be calculated for each W – Q^2 bin. The first one gives the normalized counts from the ^{12}C slab only, and the second one gives counts per 1 cm length of liquid ^4He. The numbers given are from the table; the numbers in parentheses refer to runs after 27997.

We can now express the nitrogen target spectra as

$$n_N = f\, n'_{^{12}C} + (L - \ell_N) n'_{^4He} + \ell_N \square_N \frac{\square_N}{\square_D} F \square_D =$$

$$= n_{MT} - \ell_N\, n'_{^4He} + \frac{\ell_N}{\ell_C} \frac{\square_N}{\square_C} \left(a + b \frac{\square_n}{\square_D} \right) n'_{^{12}C} \; ; \quad \frac{\square_N}{\ell_C \square_C} = 1.77 / cm$$

The expression in parentheses indicates a simple assumption for the ratio between the cross sections of nitrogen-15 and carbon-12. One can fit this expression (using MT and C target runs taken in conjunction with the N runs) to the measured n_N, spectrum using *a, b* and l_N as fit parameters (if the fit is unstable, one might have to constrain l_N to a "best guess value" taken from the physical dimensions of the nitrogen target – see table, or by setting a = 7/6). This obviously requires a table of the neutron/deuteron cross section ratio σ_n/σ_D for all W-Q^2 bins (separately for all beam energies). I posted the result for 5.6 GeV kinematics in the file `nOVERd5p6.txt` (other energies to be added) on http://www.jlab.org/Hall-B/secure/eg1/AnalysisDoc/ , The first column contains W and the remaining columns contain σ_n/σ_D for each of "my" Q2-bins accessible at 5.6 GeV inbending **and** outbending kinematics (see headers in first row). The fit may have to be restricted to a lower W region, since at very high W the elastic radiative tail from carbon/nitrogen nuclei as a whole might become important (and different since it is proportional to Z^2). The resulting fit parameters can then be used to convert empty and carbon run spectra into nitrogen-15 spectra for the whole range of runs at a given energy, and even extrapolate to energies where no nitrogen spectra exist.

We can now write the contribution of the non-deuteronic part of the ammonia target as

$$n_{A-D} = \left[\left(\frac{\sigma_A \ell_A}{\sigma_C \ell_C}\right)\left(a + b\frac{\sigma_n}{\sigma_D}\right) + f\right] n'_{^{12}C} + \left(L - \ell_A\right) n'_{^4He} =$$
$$n_{MT} + \ell_A\left[\left(\frac{\sigma_A}{\sigma_C \ell_C}\right)\left(a + b\frac{\sigma_n}{\sigma_D}\right) n'_{^{12}C} - n'_{^4He}\right]; \quad \frac{\sigma_A}{\sigma_C \ell_C} = 1.22/cm \qquad (1)$$

where the only remaining unknown is the length (times packing fraction) occupied by ammonia granules, l_A .This can be determined again by comparing the ammonia target spectrum and the combined C and He spectra in a region where hydrogen/deuterium does not contribute (low W tail):

$$\ell_A = \left(n_A - n_{MT}\right) \Big/ \left[\left(\frac{\sigma_A}{\sigma_C \ell_C}\right)\left(a + b\frac{\sigma_n}{\sigma_D}\right) n'_{^{12}C} - n'_{^4He}\right],$$

where both the numerator and denominator are integrated over a suitable range in W (<0.85 GeV) and Q^2. The undiluted asymmetry becomes then

$$A_{raw} = \frac{N_A^+/FC^+ - N_A^-/FC^-}{N_A^+/FC^+ + N_A^-/FC^- - 2n_{A-D}}, \qquad (2)$$

where n_{A-D} is calculated from equation (1) for each bin in W and Q^2.

An alternative way to determine l_A is described below under "Method 2".

Method 2

Extracting the length times packing fraction l_A from matching the low-W tails of the ammonia and nitrogen spectra is sensitive to a small part of the nuclear wave functions in extreme kinematics, which then gets extrapolated to the whole W range. In particular for ND_3 targets, there is considerable uncertainty since the deuteron also has a large-momentum tail, and it is not clear which W range can be considered "safely dominated by non-deuteronic material".

Instead, one can use the high-W region (W>1.5 or, better, W>1.8) and make the assumption that the ratio of cross sections for different target materials is well approximated by the number of protons and neutrons in each. This method is described in Renee Fatemi's inclusive proton analysis note for EG1a (see http://www.jlab.org/Hall-B/secure/eg1/Renee/CLAS_note/). The assumption that we know the ratio between cross sections on all nuclear targets to those on hydrogen is not trivial (due to Fermi smearing, EMC effect, shadowing, radiative effects etc.) even if we have a good model for both F_{2n} and F_{2p}. This method should be more reliable for the ND_3 analysis, since at least the n/p ratio is similar for all target components and some Fermi-smearing effects are already present in deuterium. In this case we can write

$$n_A = \left[\rho_A \ell_A \left(a + b\frac{\sigma_n}{\sigma_D} + 3\frac{\sigma_D}{\sigma_C}\right) + \rho_C \ell_C f\left(\frac{n'_{^{12}C}}{\rho_C \ell_C} + (L - \ell_A) n'_{^4He}\right)\right] =$$

$$n_{MT} + \ell_A \left[\left(\frac{\rho_A}{\rho_C \ell_C}\right)\left(a + b\frac{\sigma_n}{\sigma_D} + 3\frac{\sigma_D}{\sigma_C}\right) n'_{^{12}C} - n'_{^4He}\right]$$

The expression inside the brackets can be calculated under the assumption that $\sigma_D=\sigma_C/6$ (for deuterium; for an NH_3 target the proper expression is $\sigma_H= (1-\sigma_n/\sigma_D).\sigma_C/6$), and l_A can be determined from

$$\ell_A = (n_A - n_{MT}) \Big/ \left[\left(\frac{\rho_A}{\rho_C \ell_C}\right)\left(a + b\frac{\sigma_n}{\sigma_D} + 0.5\right) n'_{^{12}C} - n'_{^4He}\right]; \quad \frac{\rho_A}{\rho_C \ell_C} = 1.22/cm$$

This result can be used together with Equation (1) under "Method 1b" to calculate the undiluted asymmetry. For NH_3 runs, the "0.5" has to be multiplied by $(1-\sigma_n/\sigma_D)$. A better approach would be to replace the "0.5" in both cases with the fully radiated cross section ratio of 3*H (3*D) to ^{12}C, where the radiative corrections include the full target in both cases.

Note that we only had to make an assumption about the deuteron to carbon cross section ratio. If you really believe that for some kinematic bin you know all the required input values, you can derive a very simple formula for the undiluted asymmetry **in those bins**:

$$A_{raw} = \frac{N_A^+/FC^+ - N_A^-/FC^-}{\left(N_A^+/FC^+ + N_A^-/FC^- - 2n_{MT}\right)\Big/\left(1+\sigma_N/3\sigma_D + \rho_{He}\sigma_{He}/3\rho_A\sigma_D\right)}$$

Beam times target polarization

The raw asymmetry can be corrected for the product of beam and target polarization in two different ways: inclusive (quasi-) elastic scattering p/d(e,e') and exclusive elastic scattering off a (bound) proton p/d(e,e'p).

Peter Bosted has written a note on the exclusive method for 5.6 GeV – see http://www.jlab.org/Hall-B/secure/eg1/EG2000/Bosted/ . Note that this works equally for NH_3 and ND_3 runs – the same "theoretical" asymmetry for scattering off a free proton applies (since the cuts are chosen such that the D-state of deuterium does not contribute). One can maybe improve the estimation of the remaining dilution after applying all cuts by using the same formula for $n_{A\text{-}D}$ ($n_{A\text{-}H}$) as above; however, since one cannot produce a proton off a neutron target through elastic scattering, one has to set the value σ_n/σ_D to zero in this case. However, all the other constants should be the same (no need to recalculate packing fractions, a's etc.).

For the inclusive method, one has to first correct the (quasi-)elastic peak for dilution as described above; in that case, the theoretical asymmetry for deuterium is different from that for protons and has to be calculated for each Q^2 bin (and each beam energy) separately, depending on the cuts in W used.

Radiative, resolution and nuclear corrections

The final step to get Physics results requires 3 corrections (that I can think of right now) for the inclusive data.

1) False asymmetries: We need to correct for the (small) contamination from the polarized proton in ^{15}N and possibly for residual ^{14}N contributions and/or H contributions in the ND_3 case. This correction should be small (even if ^{15}N were 100% polarized, which it isn't - its more like in the 10% ballpark, the contribution would be only 1/9 of the H signal since there is only 1 bound proton for every 3 free ones, and according to the shell model its polarization is only 1/3 carried by its spin and 2/3 by its orbital angular momentum). This correction can be done with a simple Fermi-gas type model of ^{15}N; the other contributions require some more work (combining proton and deuteron results). Other false asymmetries include the electroweak asymmetry, which can be quantified and eliminated by comparing runs with opposite target polarization. Beam-related false asymmetries (except for

deadtime and charge asymmetries, which we "automatically" take care of) are also canceled between opposite target polarizations and also lambda/2 plate reversals.

2) We need to account for the finite resolution of CLAS. This can be treated together with 3).
3) We need to correct for radiative effects. For this purpose, we need reliable models for cross sections and asymmetries, including adjustable parameters to fit our data. These models can be used to predict both Born cross sections for H/D(e,e') and, after running them through a radiative code (I propose RCSLACPOL) and smearing them, be compared to our actual data. There is a standard method how to use the results to extract radiative corrections in terms of an additive and a multiplicative term. We will also need a reasonable target model for external radiative corrections.

The end result of these corrections will be to extract $A_{\parallel}$(Born).

Final results

Convert $A_{\parallel}$(Born) to quantities of interest: A_1, A_2, g_1, g_2, integrals. Requires the same models as radiative corrections. Systematic errors are correlated!

Publish

Write theses, publications, go to beautiful, exotic places to give talks,…