Comments on

"Study of ~~Vector~~ Meson Photoproduction resulting in Multitrack-Final States using CLAS-g12 Data"

by Z. Akbar, V. Credé *et al.* [FSU group]

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CLAS Analysis Review Committee

This paper reports on analysis done with the g12 dataset on several processes on the photoproduction of vector mesons. At this point, the analysis document is incomplete, but some preliminary comments can be made. The states quoted in the introduction are: $\gamma p \to p\,\phi$, $\gamma p \to p\,\omega$, $\gamma p \to p\,\eta$, and $\gamma p \to K^0\,\Sigma^+$. Note that the latter two processes do not include a vector meson.

Acknowledged, we have removed the word *Vector* from the title and also made the change from *decaying to Multitrack-Final States* to *resulting in Multitrack-Final States*.

In this context, the observables claimed to have been studied are: the beam-helicity asymmetry $I^{\odot}$ for the process $\gamma p \to p\,\pi^+\pi^-$; the cross sections for the processes $\gamma p \to p\,\pi^+\pi^-\,(\pi^0)$ and $\gamma p \to p\,K^+K^-$; and the spin-density matrix elements for the ω and ϕ.

It should be noted that this document is not complete. The document is missing results for the ϕ cross section and for the $\omega \to \pi^+\pi^-\pi^0$ Dalitz plot. The latter is reportedly ready for nclusion in the next round of review. For the time being, we will work with the document we have, and assume that all of the items in blue text in the analysis note will be rectified in the next version.

Unfortunately, we are not yet ready for various reasons to present the ϕ analysis and the results on the ω Dalitz-plot analysis. At this point, the document is complete regarding the reactions $\gamma p \to p\,\pi^+\pi^-$ ($I^{\odot}$ observable), $\gamma p \to K^0\,\Sigma^+$ (cross sections and recoil observable), $\gamma p \to p\,\omega$ (cross sections and SDMEs), and $\gamma p \to p\,\eta$ (cross sections). We would like to move forward with the latter results and we will add the remaining projects later, probably asking for a different review comittee.

1. The choice of event topologies on page 8 could be better motivated. Was any consideration given to the possibility of combinatoric background?

   For any given topology, all particles in the final state are different. We are slightly confused about the request for studying combinatorial background. Can you elaborate on this?

   The initial goal of our analysis projects was to extract the $\gamma p \to p\,\pi^+\pi^-$ (which includes the ρ meson) as well as the $\gamma p \to p\,\omega$ cross sections to study non-strange vector-meson production. This motivated us to study and label the different topologies listed in Table 3. Unfortunately, the dominant three-track trigger condition in the g12 experiment did not allow us to eventually include those events with only two charged tracks in the final state (Topologies 1-3).

Along the way, we realized that the reactions $\gamma p \to p\,\eta$ and $\gamma p \to K^0\,\Sigma^+$ resulted in the same $\gamma p \to p\,\pi^+\pi^-(\pi^0)$ final state as $\gamma p \to p\,\omega$ and more importantly, that these could be analyzed in parallel as a side-product with minimal additional effort. This turned out to be extremely useful in understanding the systematics of the cross sections. To complete the set of vector mesons, we finally added the ϕ with the intention to reconstruct this meson via its $\pi^+\pi^-\pi^0$ decay mode. A possible Dalitz-plot analysis (in analogy to the ω) is still an interesting idea but the available statistics is too low for cross-section measurements. Unfortunately, the systematics of K's in the final state is slightly different from π's in the final state and as mentioned earlier, we are not yet ready to present results.

2. On page 7, it states that "Events were pre-selected based on the particles identification number (PID), which was determined during the cooking process." Does this mean that you accepted the particle ID supplied by the PART bank, and did not attempt to verify it?

   Every CLAS analysis initially pre-selects events based on the particle ID made in the offline reconstruction. In our case, we accepted the identification number from the PART bank. In subsequent steps, the track PID is usually tested and events are possibly rejected, but PID itself is hardly ever changed (for non-strange final states).

   One way to clean up the event sample is by applying $\Delta\beta$ cuts. We initially applied these cuts to all our tracks but noticed that these cuts led to a (10 - 15) % systematic effect in the cross sections; the CLAS Monte Carlo could not sufficiently well reproduce the $\Delta\beta$ cuts on the data. Apparently, most of the CLAS-g11a cross-section measurements had similar problems and we eventually decided to follow the g11a recipe (Mike Williams *et al.*) and applied $\Delta\beta$ cuts as an OR-cut on just the positively-charged tracks.

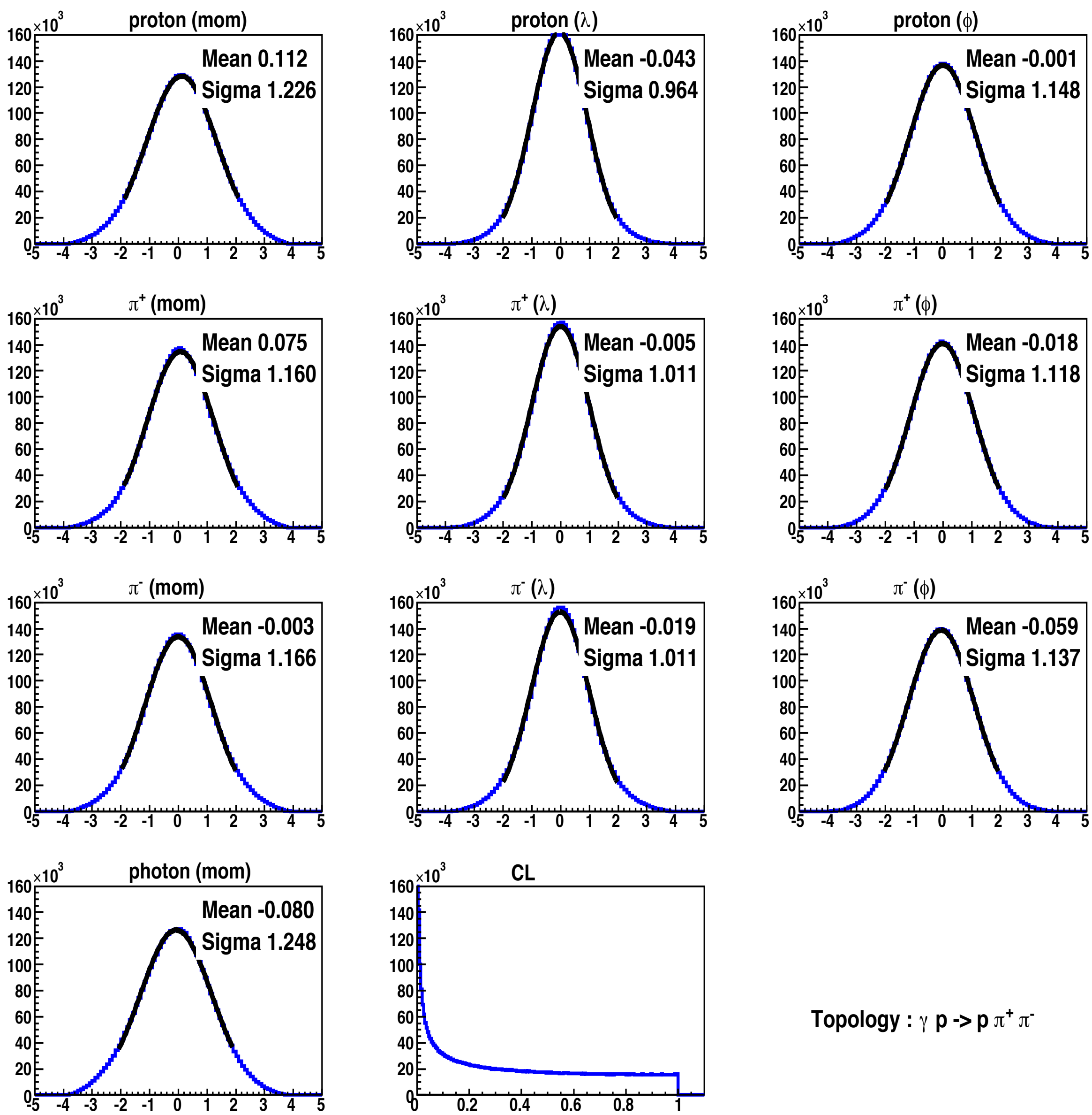
   Particle ID was further verified in kinematic fitting where any substantial misidentification of either the proton or one of the π tracks would lead to systematic effects in the pull distributions. We did not observe this. Particle misidentification is more a concern for K tracks, which usually suffer from significant π contamination.

3. On page 10, it appears that the method for dealing with tagger accidental background is to ignore any events which appear to have multiple tagger hits. Is this the best approach?

   We decided that this was indeed the best approach, no consensus on this issue was reached in the g12 run group. Rejecting events with multiple tagger hits resulted in the loss of about 13 % of all events, but it was fairly easy to determine a scale factor that accounted for this cut in the final normalization of the cross sections. Alternatively, we could have randomly chosen a photon (or always chosen the highest-energy photon as others have done) or treated all photons equally and analyzed them as individual events. These are all good alternatives if no absolute normalization is needed. However, we believe that any of the latter options of deciding on a photon would have increased our systematic uncertainty more than a clean cut on events with multiple tagger hits.

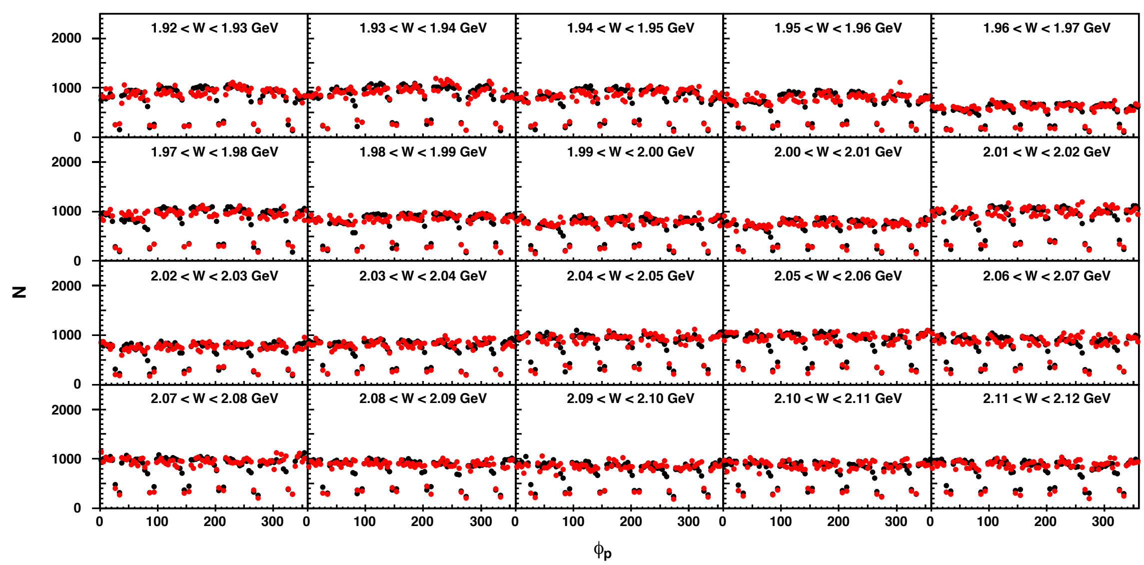
4. In the histograms on pages 16 and 18, the pull confidence levels seem to come from an old version of the kinematic fitter. Specifically, the rise in the CL distribution toward 1 is troubling.

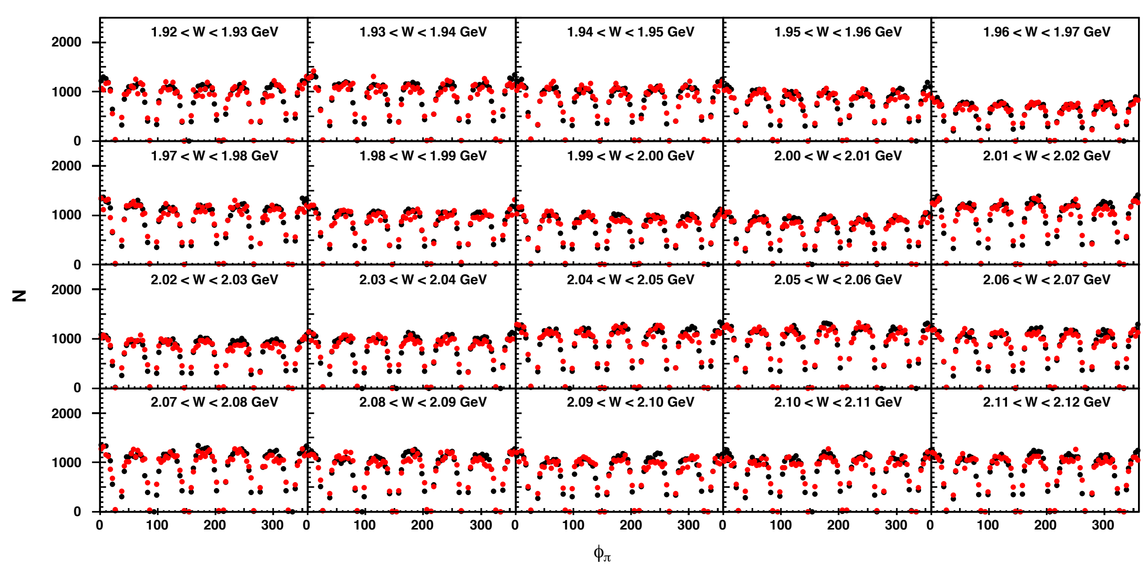
   We acknowledge the problem and confirm that an older version of the kinematic fitter was used for the distributions in Figure 6; it has been fixed. The final g12 pull and CL distributions for the exclusive reaction $\gamma p \to p\,\pi^+\pi^-$ (full statistics of Period 2) are shown below. We have used the tuning parameters for the covariance matrix that were developed by Daniel Lersch (FZ Jülich). This set of parameters is recommended for any analysis involving multiple pions by the g12 run group.



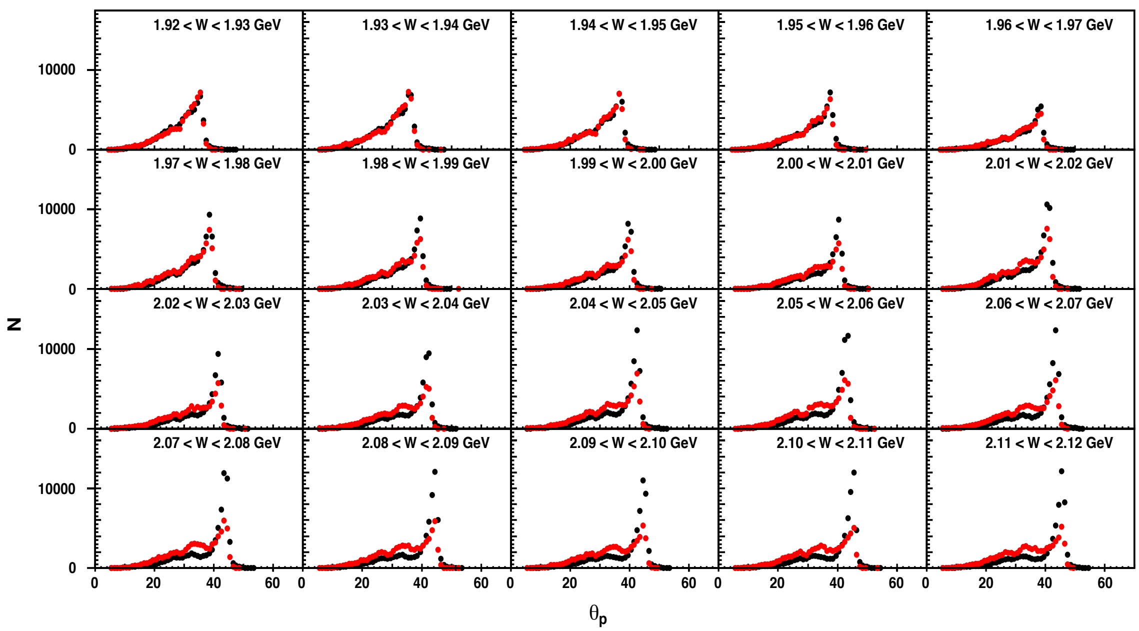
5. The discussion of the comparison between the simulation and the data in section 3.7 has some issues. The comparison seen in the figures does not seem to be as good as the authors claim in the text; perhaps the trigger efficiency study results were not applied to the simulation?

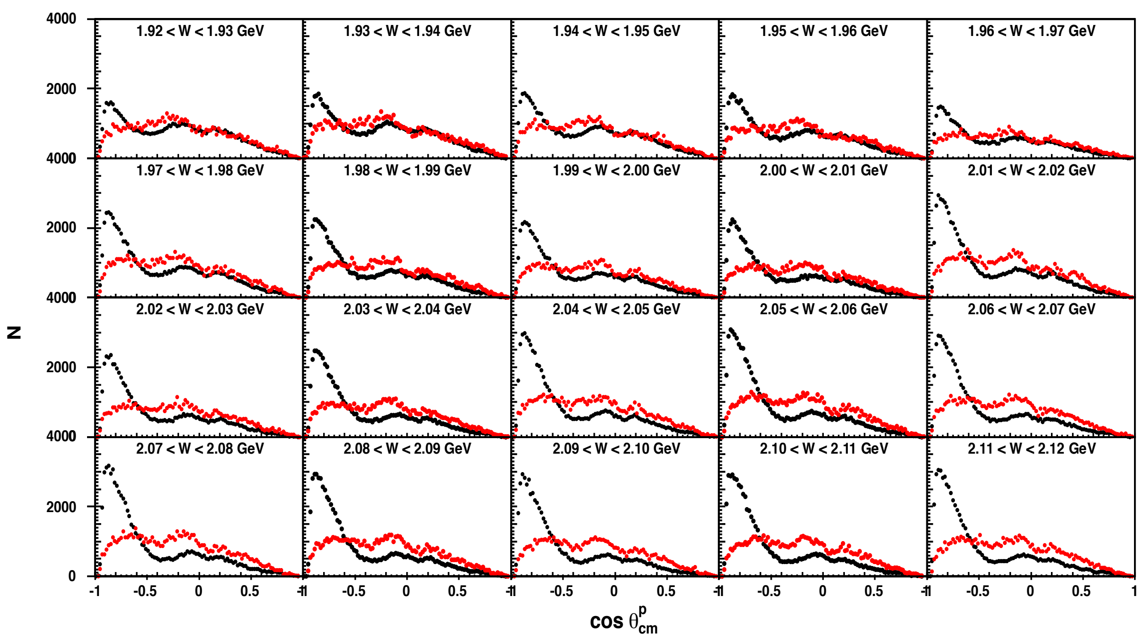
   The initial pictures in the analysis note were prepared by simply comparing the same number of data and Monte Carlo events, however, integrated over different kinematics. This leads to the observed discrepancies in Fig. 10. The distributions below show the MC/data comparison in the azimuthal (ϕ) angle for the proton and the π^+. We believe the agreement looks better than in Fig. 10 of the note and sufficiently good for our analysis.

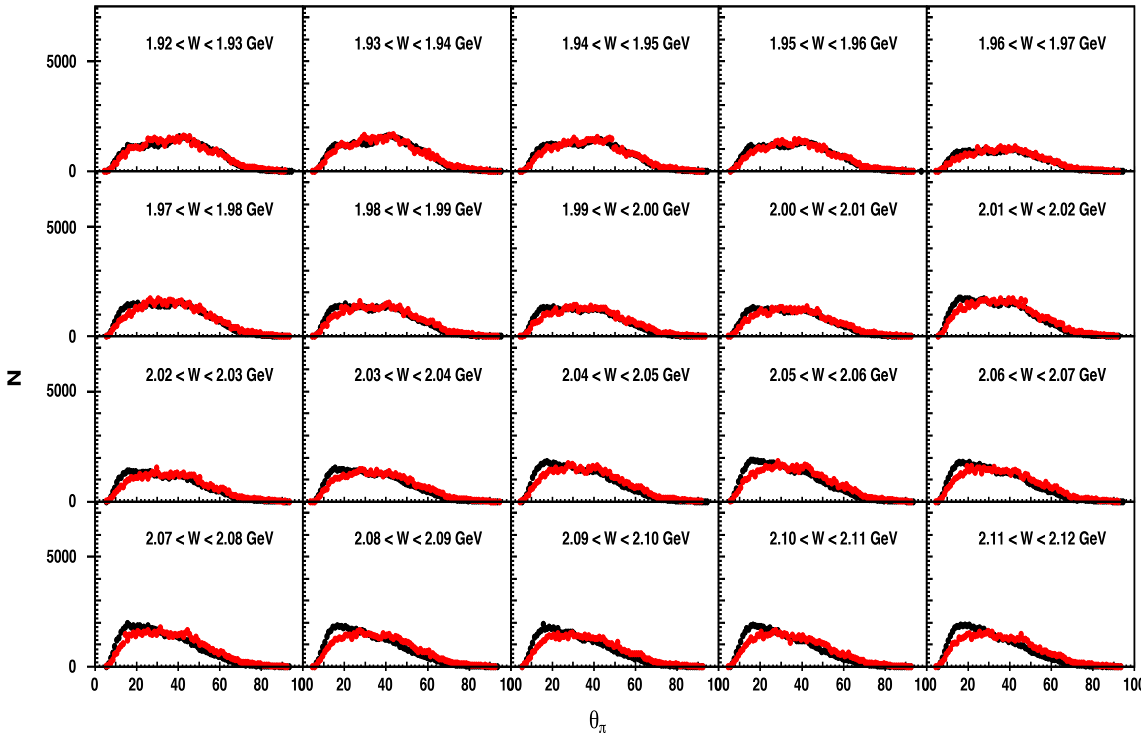




The following distributions show the MC/data comparison in the polar (θ) angle for (1) the proton in the lab frame, (2) the proton in the center-of-mass frame, (3) the π^+ in the lab frame, and (4) the π^- in the ω rest frame. Please note that the ω meson decays fairly symmetrically into $\pi^+\pi^-\pi^0$ (symmetric Dalitz plot) so that the π distributions are almost isotropic. For this reason, the agreement between Monte Carlo and data is almost perfect for the pion. Any deviations from the symmetric decay form part of the motivation for our ω Dalitz-plot analysis. For the proton, the full physics dynamics of the ω production leads to larger deviations from the isotropic phase space distributions.







1.92 < W < 1.93 GeV
1.93 < W < 1.94 GeV
1.94 < W < 1.95 GeV
1.95 < W < 1.96 GeV
1.96 < W < 1.97 GeV
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1.98 < W < 1.99 GeV
1.99 < W < 2.00 GeV
2.00 < W < 2.01 GeV
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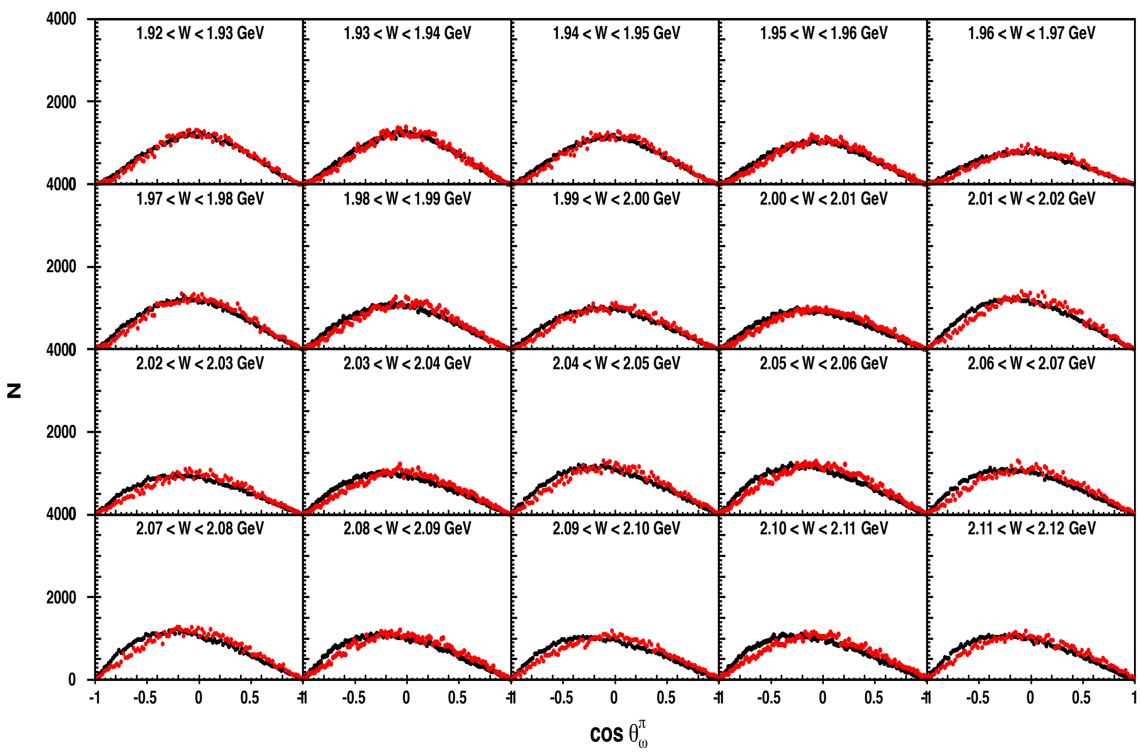
2.02 < W < 2.03 GeV
2.03 < W < 2.04 GeV
2.04 < W < 2.05 GeV
2.05 < W < 2.06 GeV
2.06 < W < 2.07 GeV
2.07 < W < 2.08 GeV
2.08 < W < 2.09 GeV
2.09 < W < 2.10 GeV
2.10 < W < 2.11 GeV
2.11 < W < 2.12 GeV
N
θ_π



1.92 < W < 1.93 GeV
1.93 < W < 1.94 GeV
1.94 < W < 1.95 GeV
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2.04 < W < 2.05 GeV
2.05 < W < 2.06 GeV
2.06 < W < 2.07 GeV
2.07 < W < 2.08 GeV
2.08 < W < 2.09 GeV
2.09 < W < 2.10 GeV
2.10 < W < 2.11 GeV
2.11 < W < 2.12 GeV
N
$\cos\theta_\omega^\pi$

6. In the discussion of the trigger simulation on page 28, what effect did this have compared to the effect of the fiducial cuts and knockouts due to bad detector elements?

   Playing with various *knockout scenarios* due to different lists of bad detector elements requires to completely reprocess the data and Monte Carlo events. This is a very time-consuming procedure and, in all honesty, we have not studied the overall effect of this compared to the trigger simulation. However, *knowcking out* TOF paddles and fiducial $\phi_{\rm lab}$ cuts introduce an azimuthal dependence and any major issues should be visible in the sector comparison between data and Monte Carlo. The distributions on Page 4 of this document indicate that no major problems occur; the $\phi_{\rm lab}$ agreement for both the proton and the π^+ meson is very reasonable in our opinion.

   As far as the trigger simulation is concerned, we followed the g11a (M. Williams) recipe and determined an overall effect of about 16 %. This is comparable with the g11 studies, which resulted in an effect of the trigger simulation of roughly 15 %.

7. On pages 45 through 48 are several invariant mass distributions for the +0 system, but only every sixth distribution is being shown. While it is understandable that the authors do not want to inundate us with data, that is precisely what this level of review is for. All data planned for publication should be shown here.

   As requested, all invariant $\pi^+\pi^-\pi^0$ mass distributions for the reaction $\gamma p \to p\,\omega$ are now shown on pages XX through YY.

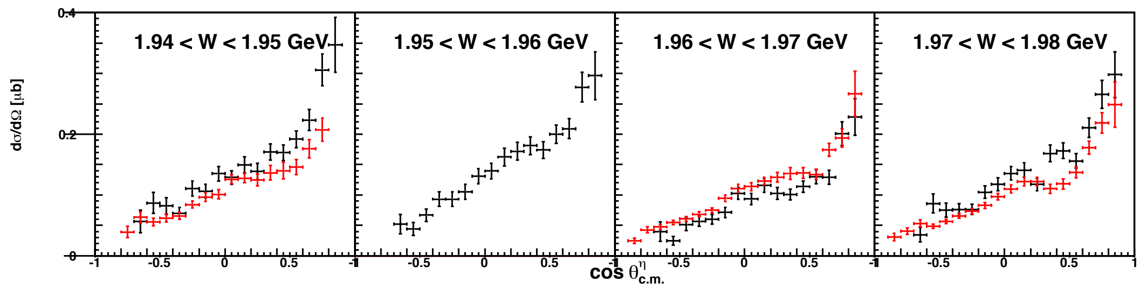
8. The plots on pp. 84-89 are troubling. Note that the systematic uncertainty for the $p\omega$ analysis, shown in Table 20 on page 83, shows numbers around 5.9 % for the sector-sector variation, and 2.4 % for the fiducial selection. Figure 49 appears to be an attempt to quantify the discrepancy between g12 and g11 with a pseudo-Gaussian (the authors correctly state that this should not necessarily be a Gaussian), but the width of the peak is far greater than would be expected for the roughly 8 % systematic indicated in the note. Additionally, it appears that several of the energy bins have marked discrepancies throughout the entire angular range, which needs to be addressed. Note, for instance, that in the energy bin 1.94-1.95 GeV, g12 is about 50 % higher than g11 for all backward angles.

   See below.

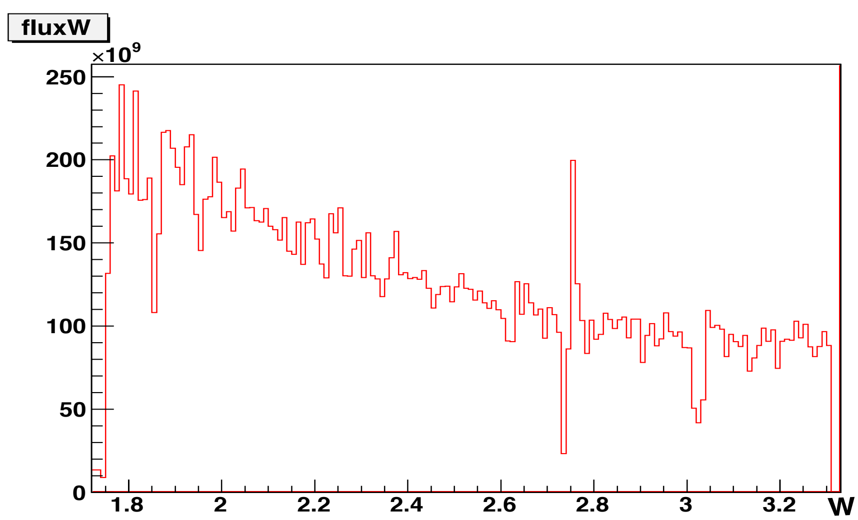
9. A similar effect is seen in the $p\eta$ cross sections. Several of the energy bins in Figs. 73-76 show good agreement between the g12 and g11 data sets; others have the entire angular range off by 30 % between the two. This is argued away by Fig. 72, which shows that, on average, the agreement between g12 and g11 is "good." Because the two experiments have comparable statistics, more effort should be made to understand the discrepancy. Is it possible that the above-mentioned concerns with the simulation could be affecting this comparison?

Most of the systematic discrepancies between CLAS-g12 and CLAS-g11a seem to emerge at lower energies, $W < 2$ GeV, in both the η and ω cross sections. A few other discrepancies can be seen in our data but these appear to be more isolated cases.

As an example at lower energies, the figure below shows the η cross section for four consecutive W bins, $W \in [1.94, 1.98]$ GeV, comparing CLAS-g12 (black points) and CLAS-g11a (red points). While the angular shapes seem to be in reasonable agreement, the g12 cross section appears to be fluctuating around the g11a cross section: above in the first, below in the third, and again above in the fourth picture (g11 data are not available for the second energy bin due to a tagger inefficiency in the g11 experiment). Similar fluctuations can be observed for the ω in the same W bins. Therefore, we conclude that the problem is related to some fluctuations in the photon flux.



The distribution below shows the photon flux for center-of-mass energy bins. In particular at low energies, $W < 2.1$ GeV, large fluctuations can be observed. Remember that the CLAS-g12 experiment was running at a CEBAF energy of 5.715 GeV resulting in about 1200 MeV as the lowest available tagged photon energy. In the figure below, a center-of-mass energy of $W = 1.8$ GeV corresponds to $E_\gamma \approx 1.26$ GeV in incident photon energy.



We conclude that some of the discrepancies between CLAS-g11a and g12 are related to the g12 resolution at the very low end of the tagging range. The element in the covariance matrix for the g12 photon measurement is:

$$\sigma^2 = \frac{(0.001 \times 5715 \text{ MeV})^2}{3} = 10.89 \text{ MeV}^2 .$$

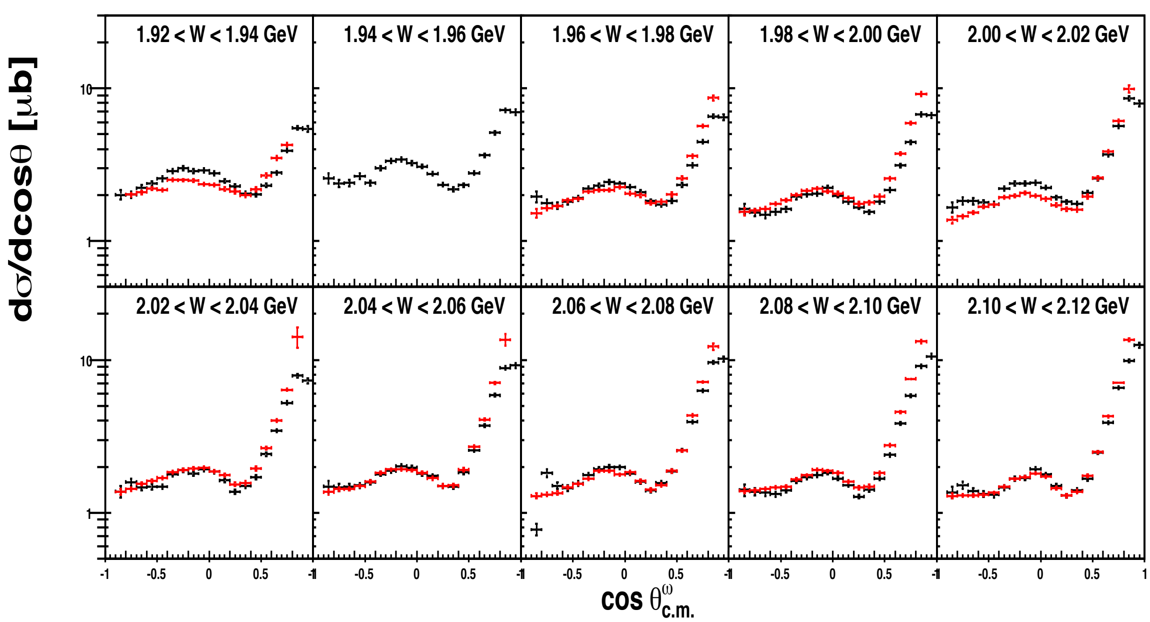
Close to the ω threshold of 1109.1 MeV, a 10-MeV-wide W bin corresponds to a fairly big 18 MeV-wide E_γ bin; the measurement uncertainty is thus about $\sigma/18 \approx 18\,\%$. Following the example of the published CLAS-g11a results, we have used the following W binning scheme for the η and ω reactions:

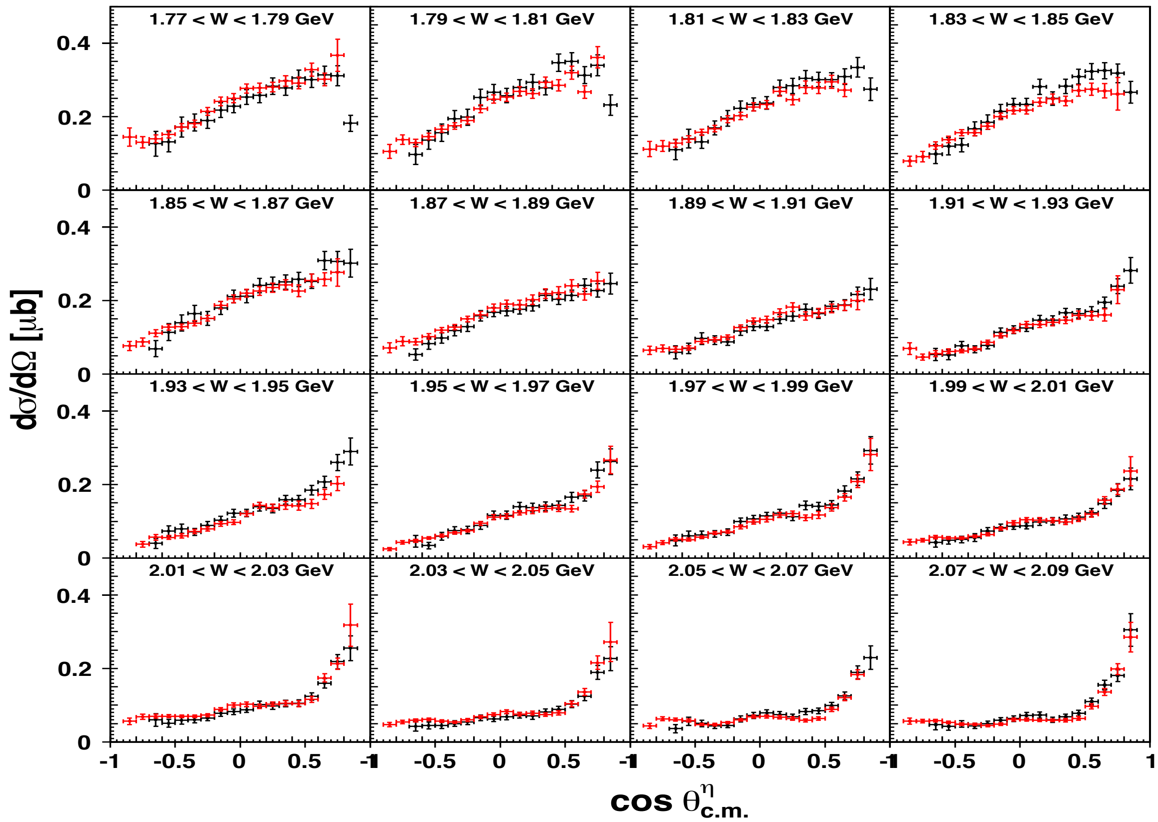
	$<$ 2.1 GeV	2.10 - 2.36 GeV	$>$ 2.36 GeV
$\gamma p \to p\,\eta$	10 MeV	20 MeV	40 MeV

	1.92 - 2.92 GeV
$\gamma p \to p\,\omega$	10 MeV

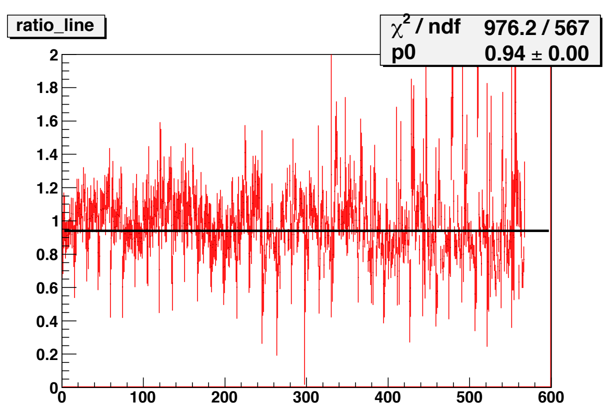
We conclude that the CLAS-g12 experiment does not provide the resolution to use 10-MeV-wide W bins below $W \approx 2.0$ GeV. For this reason, we decided to use broader, 20-MeV-wide W bins at these energies. Note that this resolution effect does not affect the $K^0\,\Sigma^+$ channel since we use broader energy bins.

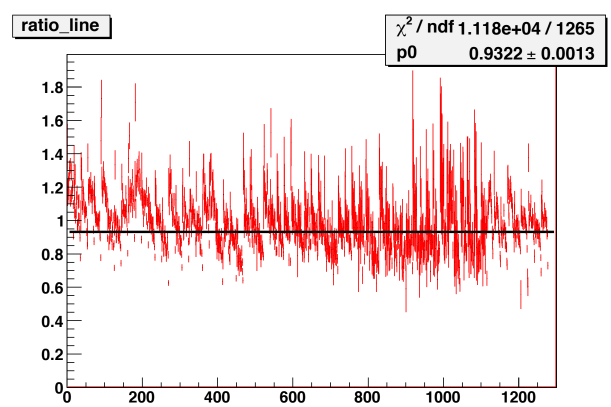
The two following figures show the ω and η cross sections at $W < 2.12$ GeV using 20-MeV-wide W bins instead of the earlier 10-MeV-wide W bins.





The agreement between g12 and g11a has significantly improved. To quantify the agreement, we have fitted the cross section ratios across all energies using a zeroth-order polynomial (left: η and right: ω).





Conclusion: We believe we understand the overall reason for the discrepancies between g11a and g12, which we can trace back to the photon-flux resolution at the low end of the tagging range. Since g12 does not provide the energy resolution for a 10-MeV-wide W binning at the lowest energies, we suggest to switch to 20-MeV-wide bins.