CLAS12 Run Group A Jeopardy PAC48

11 GeV Polarized Electrons on Liquid Hydrogen Target to Study Proton Structure, 3D Imaging, and Gluonic Excitations

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For the CLAS Collaboration

Executive Summary

The CLAS12 Run Group A (RG-A) experiments were designed to perform complementary measurements to study proton structure for both the ground and excited states, 3D imaging, and gluonic excitations with the core mission to understand the manner in which the constituents of protons are held together by the strong force and the emergence of the dominant part of hadron mass. The goal of the RG-A science program is to perform precise measurements that shed light on confinement and the nature of hadron mass. Over the last decade, major progress in the theoretical description of the interior structure of the nucleon has led to a breakthrough in our understanding of the theory of quarks and gluons in the regime of strong QCD. This, combined with the discovery of the Generalized Parton Distributions (GPDs), has provided a novel way to describe nucleon structure in 3 dimensions (3D), 2 in transverse coordinate space and 1 in longitudinal momentum space. This discovery has opened up a new avenue of hadronic research that has become one of the flagship programs in nuclear and hadronic physics. The complementary process of semi-inclusive deep inelastic scattering (SIDIS) is also of topical interest to probe the internal structure of the nucleon in 3D momentum space. The science program of RG-A is very broad and encompasses in addition to 3D imaging, the study of the structure of the proton in its ground state, as well as in the many excited states both for baryons and for mesons, including the search for hybrids. These measurements will allow us to connect QCD to the early universe and to confinement. Extension of CLAS N^* program in RG-A experiments toward the highest Q^2 ever achieved in exclusive electroproduction will allow us to explore the emergence of the dominant part of hadron mass and many facets of strong QCD underlying the generation of resonances of different structure.

The experiments require the reconstruction of exclusive or semi-inclusive processes, and hence the detection and reconstruction of mesons and baryons in the final state is vital. Other constraints come from the need of baryon and meson spectroscopy to measure complete angular distributions with precision. In many cases these processes are rare, therefore the measurements demand high luminosity and large acceptance detectors to map out the process in the full kinematic space using polarized beams, and sufficiently high beam energy. CLAS12 with the 12-GeV beam, large acceptance, and operation at high luminosity $L = 10^{35}$ cm^{-2}s^{-1} is ideal for this science program.

The RG-A science program is formed by 13 experiments driven by an international collaboration. See the Appendix of this document for details. These experiments have been grouped in five topical categories:

1. Deep Exclusive Processes (E12-06-119, E12-06-108, and E12-12-00): *Study of Generalized Parton Distributions (GPDs), 3D imaging of the proton, and study of its gravitational and mechanical structure*

2. Deep Inclusive and SIDIS (E12-06-112, E12-06-112A, and E12-06-112B): *Study of the Transverse Momentum Distributions (TMDs) and the 3D structure in momentum space*

3. Quasi-Photoproduction (E12-12-001 and E12-12-001A): *Study of J/ψ Photoproduction, LHCb Pentaquarks, and Time-like Compton Scattering*

4. Nucleon Structure (E12-09-003, E12-06-108A, and E12-06-108B): *Study of nucleon resonance structure at photon virtualities Q^2 from 2.0 GeV^2 to 12 GeV^2*

5. MesonEx Program (E12-11-005 and E12-11-005A): *Study of meson spectroscopy in the search for hybrids*

The collected charge so far for RG-A amounts to roughly half of the full approved RG-A beam time. The experimental data analyses are in a very advanced stage, the first results are currently being finalized for publication. However, to fully realize the goals of the RG-A science program, the full statistics of the approved beam time is required. In this document we provide an update on the science, as well as on the data analysis for each major topic of the RG-A science program.

1 Deep Exclusive Processes (E12-06-119, E12-06-108, and E12-12-007)

1.1 Science Update

Generalized Parton Distributions (GPDs) [BR05; Die03; KLM16] unify the concepts of Form Factors (FFs) and Parton Distribution Functions (PDFs), and encode information on new hadronic matrix elements of QCD local operators such as the Energy Momentum Tensor (EMT) of quarks and gluons inside the nucleon [PS18]. The exploration of GPDs in the valence region is one of the flagship goals of the JLab 12 GeV upgrade and one of the central deliverables for CLAS12 [Bur18].

We express the DVCS experimental observables in terms of Compton Form Factors (CFFs) [BM10]. Using fixed-t dispersion relations, we get the real parts of the CFFs as a function of their imaginary parts and the D-term. $D(0)$ can be considered the last global unknown of the nucleon, a fundamental "gravitational charge" derived from the conserved currents of this bound state, on the same level as its mass, spin, electric charge, magnetic moment, or axial coupling constant [PS18]. New questions arise, such as how the mechanical radius of these force distributions compares to its electrical or mass radii for instance.

The completion of the GPD program necessitates the analysis of DVMP where the produced meson filters quantum numbers and disentangles different flavors. Pseudoscalar meson production is sensitive to chiral odd or transversity GPDs, coupling to twist-3 chiral odd meson transversity Distribution Amplitudes through quark helicity flip [AGL09]. DVπ^0 and η production, being dominated by the transverse amplitude, determines these transversity GPDs. They probe novel spin-orbit structures, such as the deformation of the quark impact parameter distributions depending on the quark or the nucleon spin. Comparisons between chiral even and chiral odd GPDs provide tests for models of dynamical chiral symmetry breaking in QCD.

While the exclusive program at JLab at 12 GeV is primarily geared towards the valence region, a substantial amount of gluons can still contribute to certain exclusive processes, allowing us to probe the nucleon gluonic structure similarly to the quark measurements. One such processes is Deep Exclusive ϕ production. No new data on DVϕP has been published since the approval of E12-12-007.

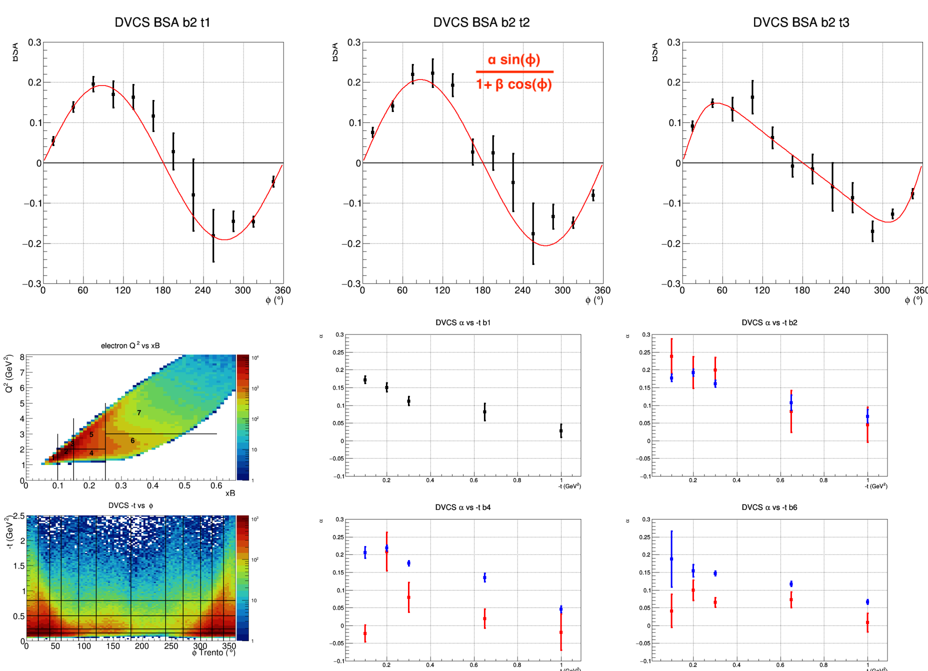

Figure 1: Top: DVCS BSA vs. ϕ. Bottom left: binning. Bottom right: DVCS BSA vs. t. For the higher values of x_B the blue and red points correspond, respectively, to the lower and higher Q^2 bins.

1.2 Current Status of the Analysis

Preliminary results for the DVCS beam spin asymmetries (BSAs) from the analysis of available RG-A data are shown in Fig. 1. The (x_B, Q^2) plane is divided into seven irregular bins roughly adjusted to match the count rates shown on the left in Fig. 1. By the same token the $(\phi, -t)$ plane is divided into 12×5 irregular bins. The BSAs as functions of the angle ϕ between the leptonic and hadronic planes are adjusted with the expected shape $\alpha\ \sin\phi/(1+\beta\cos\phi)$ where the main coefficient α is mostly sensitive to the imaginary part of the CFF $\mathcal{H}$. Fits for three representative bins are shown on the top of Fig. 1. Finally the coefficient α as function of $-t$ is shown for all (x_B, Q^2) bins on the bottom right set of plots in Fig. 1.

Preliminary results for the DVπ^0P and DVηP BSAs are shown in Fig. 2. The ϕ dependence of the BSA is illustrated in the two left plots, before and after background subtraction, respectively, in blue and green points. The results for the $\mathrm{A}_{\mathrm{LU}}^{\sin\phi}$ moment integrated over (x_B, Q^2) is shown on the right as function of $-t$. For the η only the $-t$ integrated results are shown.

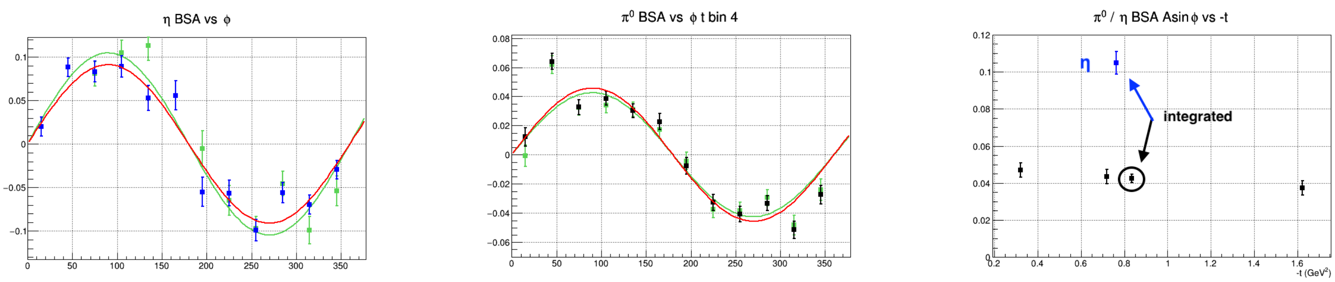

Figure 2: DVπ^0P and DVηP BSAs.

2 Semi-Inclusive Deep Inelastic Scattering (SIDIS) (E12-06-112, E12-06-112A, and E12-06-112B)

2.1 Science Update

Studies of hadron production in semi-inclusive DIS (SIDIS) provides access to 3D partonic distributions through measurements of spin and azimuthal asymmetries. Assuming a single photon exchange, the SIDIS cross section can be decomposed into a sum of various azimuthal modulations coupled to corresponding structure functions (SFs). The asymmetry A_{LU} is defined by ratios of the SFs F_{LU} and F_{UU}, and depends on the kinematic variables x, Q^2, z, P_{hT} and corresponds to azimuthal modulations of the cross section in the azimuthal angle ϕ of the produced hadron, defined in the $\gamma^* N$ CM frame. The first and second subscripts denote, respectively, the lepton and target nucleon polarizations, while the superscript indicates the corresponding azimuthal modulation. For two pion production the cross section has a similar form, but includes additional modulations involving a new azimuthal angle ϕ_R, formed by the difference of the pion momenta and the scattering plane, and its difference with ϕ_H, which is the analog of single hadron ϕ, but formed by the sum of the two hadron momenta.

The SIDIS analysis of the RG-A data set has so far focused on measurements of the multiplicities of single hadrons, and single spin asymmetries (SSAs) in single and di-hadron production. The most prominent leading twist observable is the ϕ-integrated cross section described by the F_{UU} structure function. In the TMD formalism the final state hadron $\mathbf{P}_{hT}$ results from the initial quark $\mathbf{k}_T$ and the fragmenting quark $\mathbf{p}_T$, and the structure function F_{UU} is given by the convolution integral involving the TMD distribution $f_1^q(x, k_T^2)$ and the fragmentation $D_1^q(z, P_{hT}^2)$ functions. Preliminary extraction of the pion multiplicities is shown in Fig. 3.

Large spin-azimuthal asymmetries observed at JLab for a longitudinally polarized beam [Ava+04], which have been interpreted in terms of higher-twist contributions, are also consistent with corresponding higher energy measurements at HERMES [Air+05] and COMPASS [Ado+14]. High precision data from RG-A

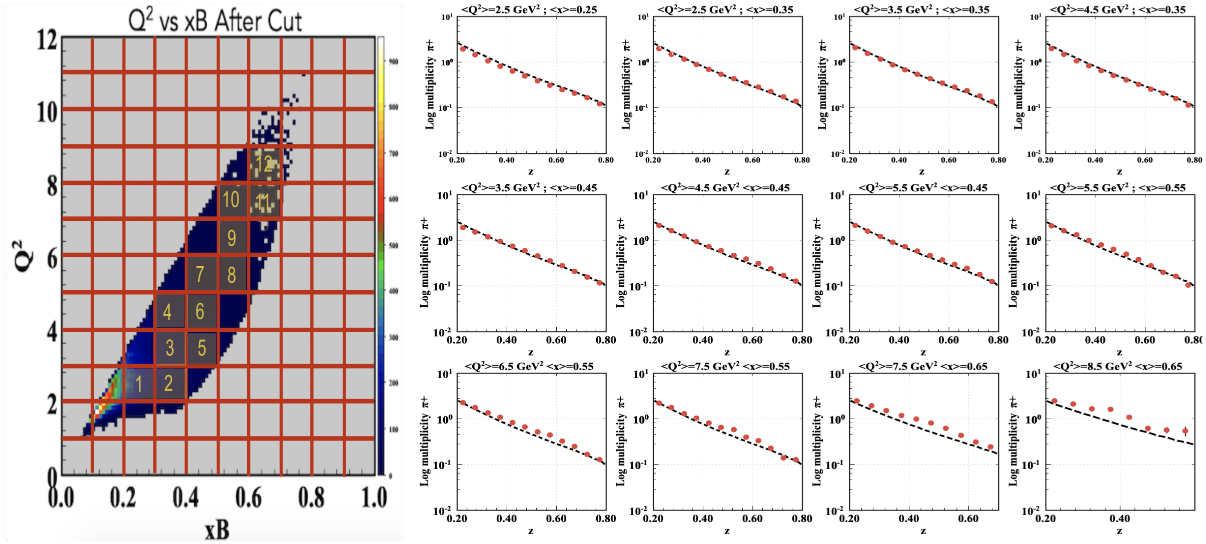

Figure 3: Kinematic coverage in x and Q^2 (left) and the kinematic dependences of the multiplicities in corresponding bins. The curves are calculated using PDFs from Ref. [Ava+07] and the DSS LO Fragmentation Function [FSS07].

allows for fine binning in x and Q^2 to study the elusive Q^2 dependence of the SSAs. The kinematic coverage and binning for the SSA studies is shown in Fig. 4.

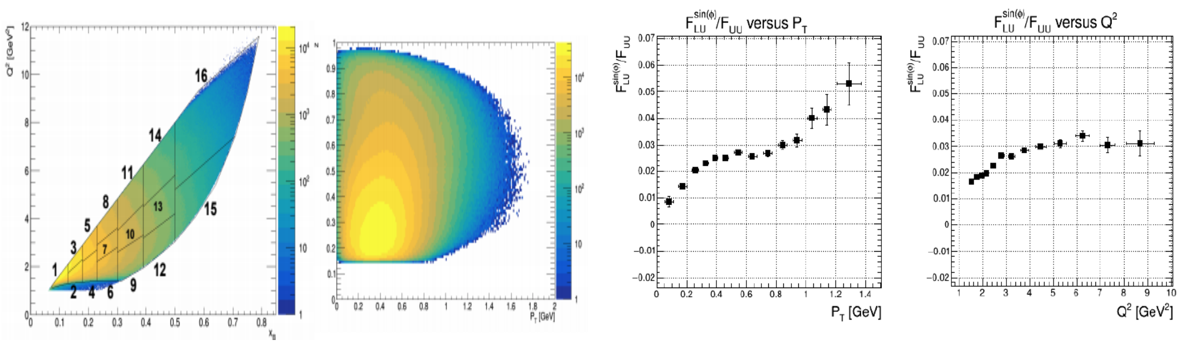

Figure 4: DIS coverage and bins (left) and dependences of the beam SSA on transverse momentum and Q^2.

High statistics allowing for multi-dimensional binning is absolutely crucial for separation of the different contributions to A_{LU} and, in particular, for measurements of the Q^2-dependence of TMDs, which is crucial for testing the theory. The first extraction of the Q^2-dependence of the $\sin\phi$ moment of the beam SSA is shown in Figs. 4-5. While the asymmetry shows a weak dependence on x, in every x bin it tends to increase with Q^2. The P_T-dependence of the asymmetry has also a odd shape, which will be very hard to describe by known theory.

2.2 Di-hadron Production

The invariant mass distributions of di-hadrons from different SIDIS and e^+e^- experiments indicate that the fraction of pions from vector meson (VM) decays may be very significant. The pions coming from VM decays have some peculiar features that can be studied from the SIDIS data, and also investigated in detail in Monte Carlo (MC). The comparison of the di-hadron multiplicities measured by CLAS12 and simulation, based on the Lund fragmentation and the full GEANT4 simulation of the CLAS12 detector, indicates that the fraction of vector mesons in the fragmentation process can be very significant. So far, the best agreement between data and MC was achieved assuming the fraction of spin-1 particles is 70% in fragmentation (spin-0

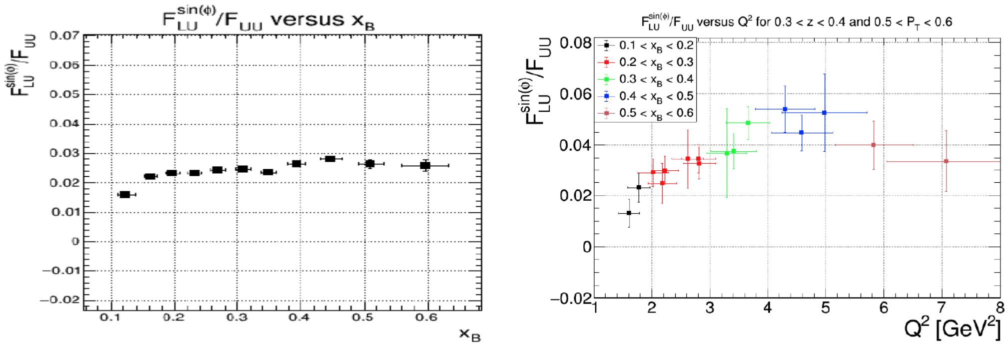

Figure 5: Beam SSA: x-dependence (left) and Q^2-dependence in several x-bins (right) for positive pions $(ep \to e'\pi^+X)$.

pions, only 30%). The interpretation of di-hadron production, as well as the interpretation of single-hadron production is intimately related to contributions to those samples from vector mesons.

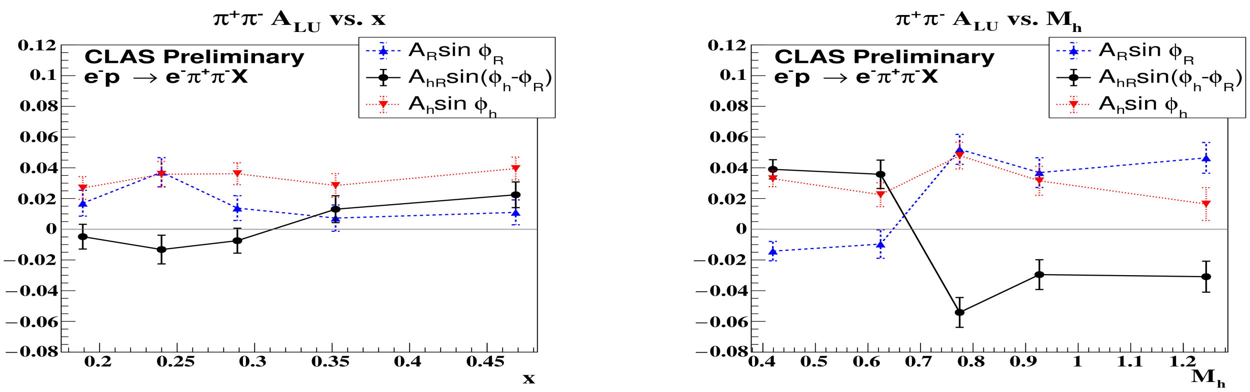

Figure 6: Di-hadron SSA as a function of x (left) and the two-pion invariant mass (right).

Measurements of SSAs performed using the RG-A data set with a lepton and 2 hadrons detected in the final state indicate that there are significant SSAs for different moments in the di-hadron cross section. Figure 6 shows measurements of several azimuthal modulations depending on the combinations of the two involved azimuthal angles. The di-hadron beam spin asymmetries are sensitive to the twist-3 PDF $e(x)$ and the di-hadron fragmentation function $G_1^\perp$. The $\sin(\phi_R)$ amplitude is sensitive to $e(x)$ and provides much tighter constraints, complementing previous CLAS measurements, while the $\sin(\phi_h - \phi_R)$ amplitude provides the first experimental constraints on $G_1^\perp$, probing spin-momentum correlations in hadronization. An interesting sign change of the latter amplitude is observed around the ρ mass, which is consistent with recent spectator model predictions and indicates that this vector meson, which is a resonance state in di-hadron production, plays important role in the formation and correlations.

3 Time-like Compton Scattering and J/ψ Photoproduction (E12-12-001A)

The objective of E12-12-001 and the followup run group proposal E12-12-001A is the study of the production of lepton pairs, e^+e^- and $\mu^+\mu^-$, in the reaction $e^-p \to l^+l^-p(X)$. Events for both analyses, time-like Compton Scattering (TCS) and J/ψ photoproduction, are identified using the exclusivity of the final states in the untagged[1] and the tagged[2] modes.

[1]Scattered electron escapes undetected, quasi-real photoproduction.

[2]Scattered electron is detected in the CLAS12 forward tagger, low-Q^2 electroproduction.

Since the approval of the E12-12-001, new experiments to study TCS and J/ψ photoproduction in other halls at JLab have been approved. The experiment E12-16-007 in Hall C aims to search for P_c^+ hidden charm pentaquarks, the run group proposal E12-12-006A in Hall A will use the SoLID detector to study TCS, as the conditionally approved experiment E12-18-005 in Hall C on a polarized target. Another run group experiment was approved for CLAS12 in Hall B, E12-11-003B, to study J/ψ production on a deuteron target. The main development in the experimental side is the new data from GlueX Collaboration in Hall D on J/ψ photoproduction in the energy range from the threshold to 11.8 GeV [Ali+19]. There are no experimental data on time-like Compton scattering to date.

We have four graduate students who are actively involved in the TCS and J/ψ analysis; Pierre Chatagnon (Orsay), Joseph Newton (ODU), Richard Tyson (Glasgow), and Jiwan Poudel (ODU). The graduate students are actively participating in the calibration and quality assessment of the data. Below we show some of the latest results from a small sample of fully calibrated and processed data. As this initial analysis shows, CLAS12 is well capable of identifying lepton pair photoproduction events in electron scattering data and can measure J/ψ production in both leptonic decay modes and TCS in e^+e^- decay. While we expect to have first physics results with statistics available from the already collected data, to achieve the goals of the experiment, the full approved beam time of E12-12-001 will be needed.

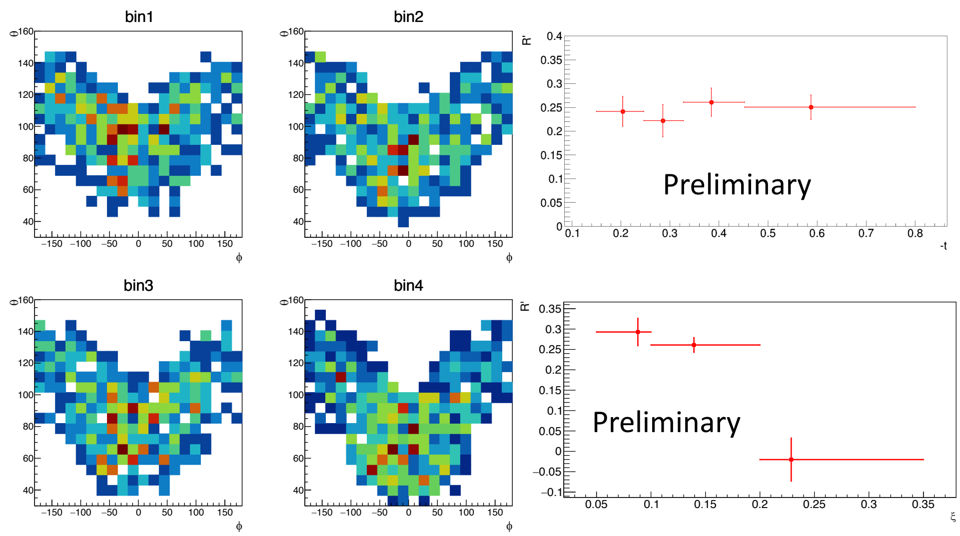

Figure 7: The first look TCS events in the mass region $1.5 < M(e^+e^-)/\mathrm{GeV} < 3$. On the left panel the distribution of events in the CM θ vs. ϕ plane for different four-momentum transferred bins is shown. On the right panel the ratio R', as defined in Eqs.(13) and (14) of PR12-12-001, is shown as a function of four-momentum transferred (top) and the scaling variable ξ (bottom).

3.1 Time-like Compton Scattering with CLAS12

Time-like Compton Scattering remains one of the key reactions for studying Generalized Parton Distributions at JLab. With unpolarized photon beams, the cosine moments of the weighted and θ_{CM}-integrated cross sections [BDP02], as well as the forward-backward (FB) asymmetry will be measured. The real part of the CFF is important to determine the D-term in the GPD parameterization, which in turn can be used to extract the form factor $d_1(t)$ that characterizes the spatial distribution of shear forces experienced by quarks inside the nucleon [BEG18]. Measurements with circularly polarized photons, on the other hand, give access to the imaginary part of CFFs and allow direct comparison with DVCS measurements to test the universality of GPDs. There is a natural complementarity between JLab 12 GeV measurements, where NLO is small but one needs to be careful in accounting for the higher twist, and the EIC where NLO can be considerable but there is sufficient kinematic reach in Q'^2 to understand higher twist. Thus, a detailed study of TCS in a large acceptance detector in 12 GeV kinematics will also be essential for the interpretation of future EIC data.

Significant progress has been made in TCS analysis led by Pierre Chatagnon. We have started to extract the physics observables, cos-moments as defined in Eqs.(13) and (14) of PR12-12-001, and R'. In the left panel of Fig. 7, the CM angular distribution of events in four bins of four-momentum transfer t are shown. The $\cos \phi_{c.m.}$ moments of the decay lepton angular distribution in the acceptance of CLAS12 are shown in the right panel vs. t (top) and the scaling variable ξ (bottom).

3.2 J/ψ Photoproduction with CLAS12

The objective of the near-threshold J/ψ photoproduction is to study the gluonic form factor of the proton through the measurements of the four-momentum transferred dependence of the differential cross section and study the behavior of the total cross section near the threshold to understand the production mechanism. One of the important parts of the analysis is to extract the real part of the $(J/\psi - p)$ elastic scattering amplitude [Kha+99]. The analysis of CLAS12 data just started and is being lead by Joseph Newton (e^+e^- decay channel) and Richard Tyson ($\mu^+\mu^-$ decay channel). In Fig. 8 the distribution of the invariant masses of lepton pairs, (e^+e^-) and $(\mu^+\mu^-)$, are shown.

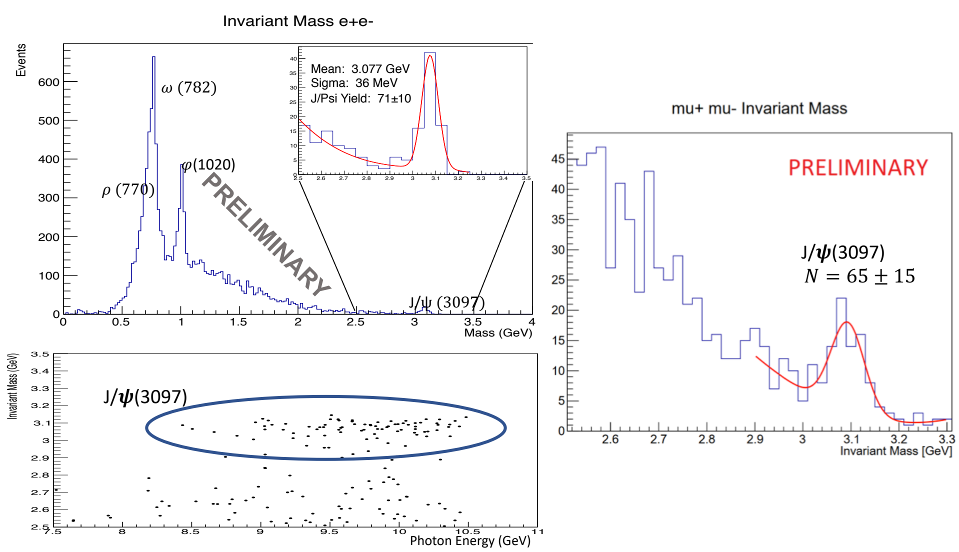

Figure 8: Analysis of J/ψ photoproduction using CLAS12 data. On the left, the invariant mass distribution of e^+e^- pairs. Mass peaks of vector mesons are clearly visible. The inset in the plot shows region of the J/ψ mass fitted with a sum of polynomial and Gaussian functions. The lower left graph distribution of events in the invariant mass vs. photon energy is shown. On the right graph, the invariant mass of muon pairs is shown, where the J/ψ mass peak is clearly visible.

4 Hadron Structure (E12-09-003, E12-06-108A, and E12-06-108B)

4.1 Science Update

Studies of the structure of excited nucleon states in terms of the Q^2-evolution of their $\gamma_v pN^*$ electrocouplings represent the only source of information on many facets of the emergence of strong QCD underlying the generation of N^* states of different quantum numbers [BR19]. Continuum QCD approaches and most available quark models reproduce the nucleon elastic form factors equally well, but predict different behaviors for the electrocouplings. Confronting theory expectations with the data will allow us to shed light on how resonances of distinctively different structure emerge from QCD. The electrocouplings are also of particular importance for gaining insight into the strong QCD dynamics responsible for the generation of hadron mass, which will ultimately make it possible using continuum QCD approaches to connect these quantities with the dressed quark mass function [Rob18; Mok+20].

Together the approved experiments E12-09-003 and E12-06-108A are the cornerstones of the CLAS12 N^* program and will allow us to probe the dressed quark mass function over a range of Q^2 overlapping the existing CLAS data and significantly extending the Q^2 coverage of the data up to 10-12 GeV^2. In this kinematic range, the reactions probe distances where the transition between the almost bare and massless QCD-quarks and the fully dressed constituent quarks of ≈400 MeV mass is expected, addressing the key open question of the Standard Model on the emergence of >98% of hadron mass from QCD. Consistent results on the $\gamma_v p N^*$ electrocouplings from the πN, ηN, $\pi\pi N$, and KY electroproduction channels with completely different non-resonant contributions will further validate the reliable and controlled extraction of these quantities. Analyses of the CLAS results on the electrocouplings has revealed N^* structure as a complex interplay between an inner core of three dressed quarks and an external meson-baryon cloud. The CLAS12 data on different exclusive meson electroproduction channels will shed light on the transition between the core of three confined quarks and the cloud of hadrons in N^* structure.

4.2 Status of Current Analysis Studies

The data analysis related to E12-09-003 and E12-06-108A is being carried out by teams at Jefferson Laboratory, the University of South Carolina, Moscow State University, the University of Connecticut, and Ohio University under the aegis of the CLAS12 Hadron Structure Group. The existing data analysis for both experiments has focused on optimizing the particle identification to allow isolation of the different exclusive reaction channels in their different topologies as a function of kinematics, initial momentum corrections to optimize the signal isolation and enhance the signal to background ratio, initial yield extractions, and detailed comparisons of the event distributions to the CLAS12 Geant4 Monte Carlo for the different channels using event generators based on available data. These studies have allowed for preliminary extractions of acceptance-corrected yields and initial explorations of systematic uncertainties of CLAS12. The status of the ongoing analyses is described in preliminary analysis documents on our Hadron Structure Group wikipage (https://clasweb.jlab.org/wiki/index.php/First_Experiment_Hadron_Structure_Group). Figure 9 highlights the quality of the available data in the $\pi^+\pi^- p$ and K^+Y channels.

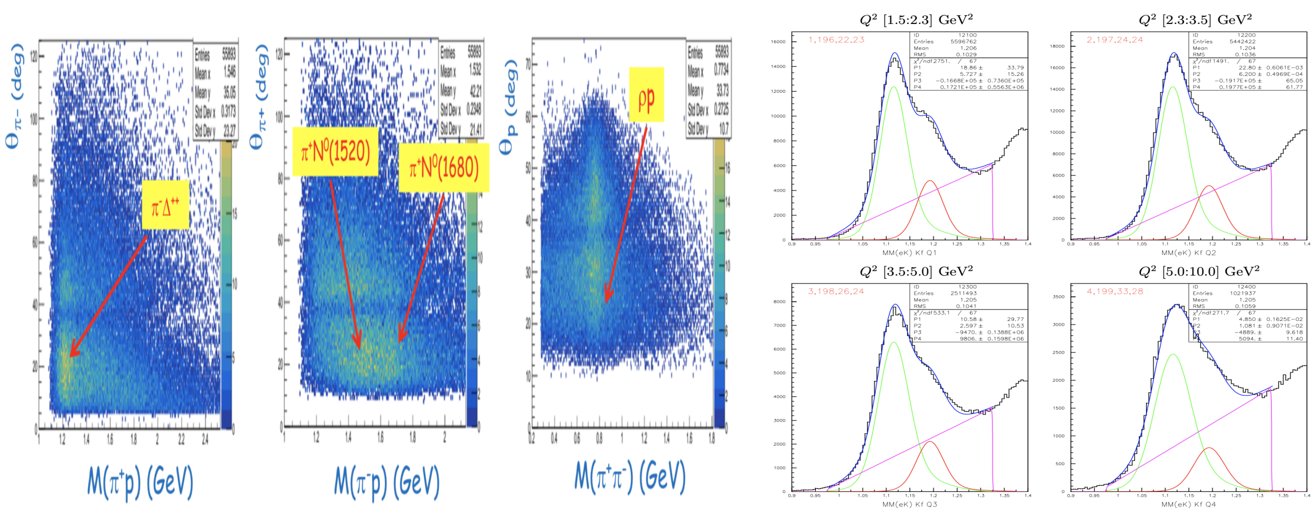

Figure 9: (Left) Preliminary acceptance corrected yields for the exclusive $\pi^+\pi^- p$ final state showing the dominant reaction channels contributing to the corresponding invariant masses for fully exclusive event reconstruction. (Right) Preliminary $e'K^+$ missing mass distributions as a function of Q^2 summed over all other kinematic variables showing the spectrum fits used for yield extraction (green: $K^+\Lambda$ events, red: $K^+\Sigma^0$ events, magenta: background events).

5 MesonEX and VeryStrange Physics (E12-11-005 and E12-11-005A)

5.1 Introduction

Understanding quark and gluon confinement in QCD is one of the outstanding issues in physics. To this end, hadron spectroscopy is a powerful tool to investigate how the QCD partons manifest themselves under the strong interaction at the energy scale of the nucleon mass (GeV). The first experiment (E12-11-005 or MesonEx) aims to study the meson spectrum, searching for exotic states, with precise determination of resonance masses and properties with a high statistics and high resolution experiment. The CLAS12 spectrometer augmented by a Forward Tagger (FT) allows for electron scattering at very low $Q^2(10^{-2} - -10^{-1}\ \mathrm{GeV}^2)$, which provides a high photon flux and a high degree of linear polarization, complementary to the capabilities of Hall D. The quantum numbers of meson resonances are defined via partial wave analysis (PWA) of their decay products. The second experiment (E12-11-005 or VeryStrange) aims at studying the large statistics sample of Ξ baryons photo-produced in the LH_2 target. The data will be used to search for new and missing excited Ξ states with the possibility to measure their quantum numbers, as well as the mass splitting of ground state and excited Ξ doublets. These data samples will also provide the statistics necessary for measuring, for the first time as a function of kinematic variables, the beam polarization transfer and induced polarization of the ground state Ξ^- in the reaction $\gamma p \to \Xi K^+ K^-$.

5.2 Science Update

In the last 10 years, significant progress has occurred in the understanding of the meson spectrum. What concerns this proposal, the most notable are the activities in amplitude analysis, especially carried by the Joint Physics Analysis Center (JPAC). JPAC is providing new tools to extract robust physics information from CLAS12 data. For example, the theoretical analysis reported in Ref. [Rod+19] permitted the identification of the seemingly different peaks in $\eta\pi$ and $\eta'\pi$ seen in the COMPASS data [Agh+18] as a single $\pi_1(1600)$ state, in agreement with QCD expectations [Dud11; SK06]. Complementary to these studies, MesonEx has the potential to understand the microscopic structure of hybrids by measuring the coupling to photons [GYS14]. JPAC has constructed observables sensitive to the presence of mesons with exotic quantum numbers that can be measured by MesonEx with sufficient statistics [Mat+19]. A comprehensive understanding of meson production dynamics is needed to pin down the properties of new resonances. In particular, the mechanisms dominating ordinary meson production must be identified first. Studies of single meson production have been in shown in Refs. [MFS15; Nys+18; Mat+20] and provide predictions for (un)polarized cross sections at CLAS12. Calculations in the double-Regge limit, the main background to exotic resonances, are ongoing at JPAC [JPA].

Another topic of high interest concerns the lightest scalar meson multiplet [PR20; Bri+17; Wil+19]. The heavier iso-scalar scalars are poorly understood. In the PDG, three f_0 states are reported below 2 GeV. This is one more than the quark model expectations, suggesting a contribution from a glueball [Gia+05; KZ07]. However, the existence of three different states is not compelling, as they do not appear together in the same reaction. Data from MesonEx in $\pi\pi$ photoproduction can solve the controversy. The last few years have seen new studies to best represent amplitudes with multi-body final states. This is crucial when resonances in different channels interfere [Pil+18; Mik+20], and in the context of MesonEx is needed to properly take into account the contamination from baryon resonances [Pau+18].

As far as the strangeness sector is concerned, very few new data were published since the original proposal and the study of the spectrum of very-strange baryons remains compelling. Recent results from the BELLE Collaboration on $\Xi^-\pi^+$ spectra are very interesting, particularly for the evidence of the $\Xi(1620)$ [Sum+19]. CLAS results on the $\Xi(1530)$ cross section from a similar channel ($\Xi^0\pi^-$) published in 2007 [Guo+07] did report a bump around 1620 MeV (although not statistically significant). The VeryStrange physics program is still of high interest with a unique opportunity of providing results in unexplored territories: any results of Ξ electroproduction would be new, whether detailed differential cross sections or the total cross section will be measured. The Q^2 dependence can provide us with new valuable and complementary information on these states that no facility other than JLab can obtain. The complementarity of electroproduction vs. photoproduction in looking for missing resonances has been recently illustrated [Mok+20]. The non-resonant background has a strong Q^2 dependence, and is negligible at the largest Q^2. The ground state hyperons ($S = -1$) are very well known. However, there is remarkably little precision data on excited hyperon states. With a full statistics dataset, CLAS RG-A is poised to make major contributions to the spectroscopy of excited hyperons. This is particularly timely in the new era of precision Lattice QCD calculations.

5.3 Assessment and Future Plans

The preliminary results obtained by analyzing a small fraction of the RG-A dataset, show overall good performance of the Forward Tagger to measure quasi-real electrons (low Q^2) and detect the γs from π^0 decay. Final states with three charged particles ($n\pi^+\pi^+\pi^-$, $p\pi^+\pi^-\pi^0$, and $n\pi^+K^+K^-$) clearly show known structures (e.g. $\omega \to \pi^+\pi^-\pi^0$) and a sizable acceptance of CLAS12 in the large mass region where exotic mesons are expected. The addition the two-charged-prong trigger for the RG-A data taking (not included in the original proposal) granted access to benchmark reactions such as ($p\pi^+\pi^-$) and (pK^+K^-) with evidence of the f_0, f_2, ρ, and ϕ exited states. Some selected results are shown in Fig. 10.

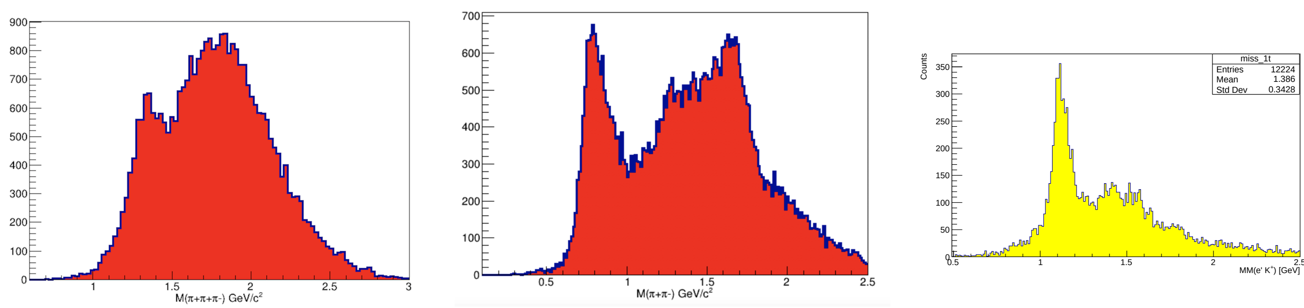

Figure 10: Meson spectra based on 10% of the outbending torus polarity Fall 2018 data set. Left: $\pi^+\pi^+\pi^-$ invariant mass in the reaction $ep \to e'n\pi^+\pi^+\pi^-$. Center: $\pi^+\pi^-$ invariant mass in the reaction $ep \to e'p\pi^+\pi^-$. Right: $p\pi^-$ invariant mass in the reaction $ep \to e'pK^+\pi^-$.

Both the MesonEx and VeryStrange experiments will clearly benefit by collecting the remaining 50% of statistics. For the MesonEx program, PWA requires high statistics to pin down the small exotic signals below the dominant resonances. For the VeryStrange program, we expect sufficient statistics for ground state cascades and excited S=-1 hyperons. But excited cascades and Ω would need as much statistics as we can get. For the existing RG-A data using the beam charge of about 250 mC, we expect about 300 $\Xi(1820)$s using the upper limit of cross section from the CLAS g12 results [Goe18] and consistent with the GlueX results. Considering the lower cross section and the lower virtual photon flux at finite Q^2, the electroproduction part of the VeryStrange proposal can only be studied accumulating the full assigned statistics. We want to stress that this measurement would be the first of its kind.suggesting a contribution from a glueball [Gia+05; KZ07]. However, the existence of three different states is not compelling, as

6 Summary

The RG-A science program is broad and rich and addresses several of the most fundamental questions in hadronic physics. We have demonstrated that CLAS12 has achieved or exceeded in some cases the design specifications. We have also optimized and designed a smart trigger to run successfully all 13 experiments simultaneously. The data calibration, processing and analysis of the 50% of RG-A data that is already on tape is in an advanced stage and preparation of the first publications is underway.

To fully realize the goals of the RGA-science program, the full statistics of the approved beam time is required, allowing the significant extension in Q^2 promised by the CLAS12 12-GeV upgrade, as well as the potential for science discovery.

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7 Appendix: Summary of CLAS12 RG-A Experiments

Proposal	Physics	Spokespersons
E12-06-108	Hard Exclusive Electroproduction of π^0, η	P. Stoler, K. Joo, **V. Kubarovsky**, M. Ungaro, C. Weiss
E12-06-108A	Exclusive $N^* \to KY$ Studies with CLAS12	**D.S. Carman**, R. Gothe, V. Mokeev
E12-06-108B	Transition Form Factor of the η' Meson with CLAS12	**M. Kunkel**, D. Lersch
E12-06-112	Proton's Quark Dynamics in SIDIS Pion Production	**H. Avakian**, K. Joo, Z.E. Meziani, B. Seitz
E12-06-112A	Semi-inclusive Λ Productiuon in Target Fragmentation Region	**M. Mirazita**
E12-06-112B	Higher Twist Colinear Structure of the Nucleon	S. Pisano, **M. Mirazita**
E12-06-119	Deeply Virtual Compton Scattering at 11 GeV	**F. Sabatie**, A. Biselli, H. Egiyan, L. Elouadrhiri, M. Holtrop, D. Ireland, W. Kim
E12-09-003	Excitation of Nucleon Resonances at High Q^2	**R. Gothe**, V. Burkert, P. Cole, K. Joo, V. Mokeev, P. Stoler
E12-11-005	Hadron Spectroscopy with Forward Tagger	**M. Battaglieri**, R. De Vita, C. Salgado, S. Stepanyan, D. Watts, D. Weygand
E12-11-005A	Photoproduction of the Very Strangest Baryons	**L. Guo**, M. Dugger, J. Goetz, E. Pasyuk, I. Strakovsky, D. Watts, N. Zachariou, V. Ziegler
E12-12-001	Timelike Compton Scattering & J/ψ Production in e^+e^-	**P. Nadel-Turonski**, M. Guidal, T. Horn, R. Paremuzyan, S. Stepanyan
E12-12-001A	J/ψ Production and Study of LHCb Pentaquarks	**S. Stepanyan**, M. Battaglieri, A. Celetano, R. De Vita, V. Kubarovsky
E12-12-007	Exclusive ϕ Meson Electroproduction with CLAS12	**F.X. Girod**, M. Guidal, V. Kubarovsky, P. Stoler, C. Weiss