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**UPDATE E12-07-105: Scaling Study of the L-T Separated Pion Electroproduction
Cross Section at 11 GeV**

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An update of the Scaling Study of the L-T Separated Pion Electroproduction Cross Section at 11 GeV proposal is presented. Please refer to the E12-07-105 proposal [1] for full details on the scientific justification, experimental method and projected uncertainties.

I. SCIENTIFIC BACKGROUND SUMMARY

A. Introduction

By performing a measurement of separated $p(e, e'\pi^+)n$ cross sections to test the factorization of long-distance from short-distance physics in hard exclusive processes, we have the unique opportunity to lay the foundation for a reliable interpretation of results from one of the highest priority 12 GeV programs at Jefferson Lab, the extraction of Generalized Parton Distributions (GPDs). This measurement is of particular interest for our understanding of hadronic structure in terms of quark gluon degrees of freedom in the transition region from the hadronic to the partonic regime for Q^2 up to 10 GeV².

The extraction of GPDs from pion electroproduction data relies on the dominance of the longitudinal cross section, and the proposed experiments typically assume that the contribution of transversely polarized photons is negligible. However, recent experimental results [2] suggest that the transverse contribution of the cross section is still relatively large at $Q^2=2.45$ GeV², which, if also true at higher values of Q^2 , would limit the interpretability of the data in terms of GPDs.

Before considering the extraction of GPDs from pion electroproduction data, it is necessary to demonstrate that Q^2 scaling applies in the JLab 12 GeV kinematic regime. In particular, we must confirm that $\sigma_L \gg \sigma_T$ as expected from GPD models. This requires measurements of both longitudinal and transverse components, and thus high precision L/T separations.

The goal of this proposal is to test the dominance of the longitudinal cross section in charged pion electroproduction by making a systematic measurement of the Q^2 dependence of the π^+ longitudinal and

transverse cross sections. In the asymptotic limit one expects that the longitudinal cross section evolves towards Q^{-6} scaling [3, 4], while transverse contributions are suppressed by an additional factor of Q^{-2} . This is different from the simple pion pole exchange picture, where σ_L changes more rapidly than σ_T as Q^2 and t_{min} increases, reflecting the decreasing influence of the pion pole. A significant longitudinal response may be indicative of the realization of the scaling expectation of the GPD formalism for charged pion electroproduction.

The results from this measurement may also help to identify missing elements in existing calculations of the pion production cross section, which will help to constrain longitudinal backgrounds in the extraction of the pion form factor from pion electroproduction data.

We propose to measure forward π^+ electroproduction by detecting the produced pion in coincidence with the scattered electron using the Hall C SHMS+HMS configuration. We will extract the separated longitudinal and transverse cross sections via the Rosenbluth separation technique. Measurements in non-parallel kinematics will allow for simultaneous extraction of the interference terms and tests of the $-t$ dependence of the π^+ cross section.

B. Partons and Factorization

A detailed discussion on the theoretical motivations for the measurement of separated $p(e, e'\pi^+)$ cross sections to test the factorization of long-distance from short-distance physics in hard exclusive processes and its impact on existing and future GPD measurements can be found in our 2007 proposal, our recent publication, or analysis [1, 5, 6]. Here, we summarize the main points.

Since our 2007 PAC submission, there has been good progress in the theoretical effort to describe nucleon structure in terms of QCD degrees of freedom, and in particular through the concept of GPDs. New tools for analyzing experimental observables and extracting information about the transverse spatial structure have been developed for various exclusive channels [7]. However, there has been an ongoing debate about the perhaps even more basic question of the exclusive reaction mechanism, and in particular about the distribution of configurations for a given Q^2 and QCD factorization needed to extract the GPDs, and high quality experimental data are needed to guide these discussions.

Recent experimental results suggest that small-size configuration already begin to dominate at moderately high values of Q^2 [8, 9]. For instance, ρ^0 and ω cross sections show relatively good agreement with the Q^2 scaling prediction. However, considerable transverse contributions complicate the isolation of contributions from the handbag mechanism from these data. Additional information on the relative size of longitudinal and transverse components may therefore be of interest for further interpretation of these existing data. Recent analyses also indicate that we are still missing important pieces of the puzzle [5, 6, 10]. As shown in figure 1, the scaling laws are reasonably consistent with the Q^2 -dependence of π^+ σ_L data, the two additional predictions, that $\sigma_L \gg \sigma_T$ and $\sigma_T \sim Q^{-8}$, are not consistent with the data.

Furthermore, new data from Babar on the π^0 transition form factor may suggest insufficient

knowledge about additional soft contributions in the π^0 wave function up to $Q^2=20$ GeV² [11]. However, this is a very difficult measurement, as Babar was not designed to perform spacelike measurements of this nature. Radyushkin and Polyakov [12] have argued that if these data are correct, they indicate a nearly flat shape of the pion DA [13], in contradiction with most theoretical interpretations. This would have implications for charged pion production as well. These measurements only strengthen the case for reliable charged pion production measurements to provide independent tests to guide the discussion on the hard exclusive reaction mechanism.

C. Impact on Existing and Future GPD Measurements

The proposed π^+ electroproduction experiment above the resonance region is essential for a better understanding of both existing data [5, 14] and proposed 12 GeV measurements at Jefferson Lab [15]. The experimental longitudinal cross section data are generally well described by calculations based on Regge theory like the one by Vanderhaeghen, Guidal and Laget (VGL). However, the transverse contribution is significantly underpredicted by the VGL/Regge model up to values of $Q^2=3.91$ GeV² [2, 5, 6]. Since our 2007 PAC submission there have been several theoretical efforts [10, 17–19] to improve the description of σ_T , for instance, an intriguing suggestion that σ_T in exclusive pion production above the resonance region could be described as the limit of semi-inclusive production via the fragmentation mechanism [17]. If confirmed, this could greatly aid the analysis of such processes. We are in close contact with the respective authors and are hopeful that together with our measurement of separated σ_L and σ_T there will be a better understanding the exclusive reaction mechanism up to $Q^2=10$ GeV².

The ratio of the σ_L and σ_T is of significant interest to the study of exclusive π^+ cross sections with CLAS12 at 12 GeV [15]. A large acceptance device like CLAS is well suited to map out the x_B , $-t$, and the Q^2 dependence of various processes to constrain GPD models as thoroughly as possible without the correlations between $-t$ and x_B characteristic of parallel kinematics. Depending on the relative size of σ_L and σ_T , a detailed study of the separated π^+ cross section using CLAS12 alone may be difficult. If σ_L is relatively small, absolute measurements of the separated cross sections may require additional information from a double-arm spectrometer setup like the one in Hall C. The maximum Q^2 value accessible for π^+ production in CLAS12 is about 10 GeV² for unseparated cross sections, which is well matched with the kinematics proposed for this measurement. Provided that meaningful L/T separations can be performed using CLAS12, the maximum Q^2 would be approximately 6 GeV² for separated cross sections.

The separated results from the proposed measurement may play an important part in guiding the 12 GeV GPD π^+ program. Indeed, recent studies of DVCS data have raised new questions about the accessibility of GPDs at JLab energies. There, the experience with inclusive deep-inelastic scattering (DIS) suggests that the leading-twist approximation should be applicable already at values of Q^2 as low as a few GeV², which seems to be consistent with the first results on the Q^2 dependence of DVCS observables [9]. However, recent DVCS cross section results are also well described by the Regge pole exchange model with unitarity constraint [10]. If charged pion electroproduction is going to be useful for testing models of

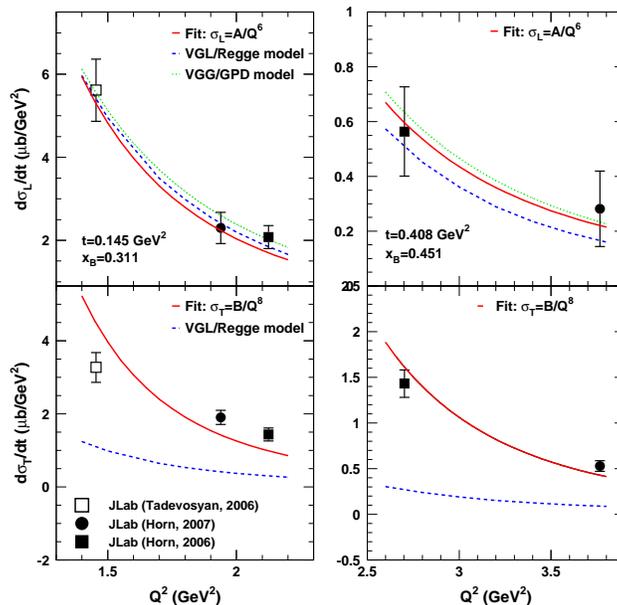


FIG. 1: The Q^2 -dependence of the separated cross sections at fixed values of $-t$ and x_B . The error bars denote statistical and systematic uncertainty combined in quadrature. The red, solid curve indicates a fit of the form Q^{-6} for σ_L , and Q^{-8} for σ_T . The green dotted line is a GPD calculation from reference [16]. In this calculation power corrections to the leading order are included. The blue dashed line is a VGL/Regge calculation using Λ_π^2 from a global fit to F_π .

GPDs at 12 GeV JLab energies, we expect to see evidence of soft-hard factorization or the approach to it. In particular, we must confirm that $\sigma_L \gg \sigma_T$. **If the transverse contribution to the cross section is larger than anticipated, this would dramatically influence the experimental kinematical accessibility of GPDs using charged pion electroproduction in 12 GeV experiments.**

Previous data suggest that the ratio of σ_T/σ_L is about 0.5 for π^- production on the neutron [20]. In addition, the VGL Regge model, which is in relatively good agreement with these data, predicts that σ_T/σ_L continues to decrease as Q^2 increases. Indeed, if the transverse contributions to the cross section are suppressed, the σ_T/σ_L ratio in π^- production provides a way to extract σ_L in the $n(e, e'\pi^-)p$ reaction from unseparated, high ϵ measurements without an explicit L/T separation. A determination of this ratio would thus greatly improve the ability of large acceptance devices like CLAS12 to study this reaction.

II. PROPOSED KINEMATICS

The reasoning behind and justification for our kinematic settings are explained in detail in our 2007 proposal [1]. Here we briefly summarize the main points. We propose to make a coincidence measurement between charged pions in the SHMS and electrons in the HMS. A high luminosity spectrometer

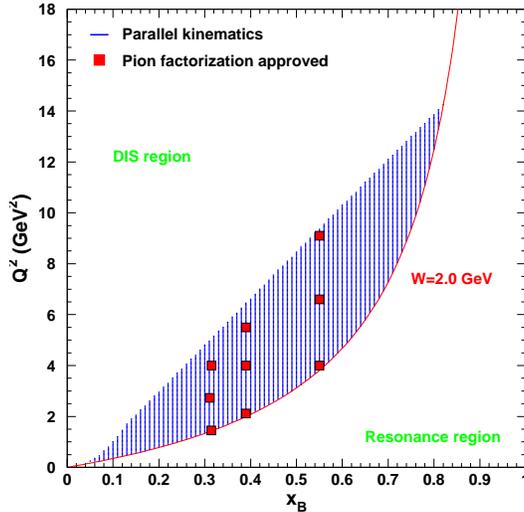


FIG. 2: Q^2 versus x_B phase space available for L-T separations in Hall C at 11 GeV using the SHMS+HMS combination. We propose to measure the Q^2 dependence of the longitudinal cross section at $x_B=0.311$, 0.39 and $x_B=0.55$, and the x_B dependence of the longitudinal cross section at $Q^2=4.0$ GeV². The kinematic reach is limited from below by the requirement on W being above the resonance region and from above by the requirement to maintain a separation of $\Delta\epsilon \sim 0.24$ with the exception of the highest Q^2 data point, where $\Delta\epsilon \sim 0.14$ is the best that can be achieved.

system like the SHMS+HMS combination in Hall C is well suited for such a measurement. The focusing magnetic spectrometers benefit from small point-to-point uncertainties, which are crucial for meaningful L-T separations.

A large acceptance device like CLAS12 is well suited for measuring pseudoscalar meson electroproduction over a large range of $-t$ and x_B . The large azimuthal coverage allows a good determination of the interference terms, but the error amplification in the extraction of longitudinal and transverse components of the cross section is a major constraint. In addition, the rates for the proposed kinematics would decrease significantly due to the lower luminosity in Hall B. The use of the SHMS and HMS in Hall C is proposed here as their characteristics best address the experimental requirements. The existing knowledge of the properties of the HMS is expected to allow for a well understood isolation of the longitudinal cross section on the order of thirty days.

Figure 2 shows the accessible Q^2 - x_B phase space for this experiment. The proposed kinematics allow for a scan of the Q^2 dependence of the cross section at constant x_B while staying above the resonance region. The Q^2 scans at $x_B=0.311$ and $x_B=0.39$ largely repeat the kinematics shown in Figure 1, but also reach a higher value of Q^2 , and do so in one designated measurement, and hence with smaller systematic uncertainties. Since these data points are at relatively low Q^2 and x , they do not significantly contribute to the total beam time request.

One of the goals of the proposed measurement is to extend our knowledge of the relative longitudinal and transverse contributions to the cross section to the largest possible Q^2 that can be reached at JLab 12 GeV. Given the requirement to keep $-t \ll 1 \text{ GeV}^2$, combined with the kinematic reach of the SHMS+HMS configuration in Hall C, the maximum Q^2 is close to 10 GeV^2 . We have chosen to limit the highest Q^2 to 9.1 GeV^2 as the projected ratio R , based on previous pion production data, predict a rapid increase of the uncertainties between 9 and 10 GeV^2 . However, it should be emphasized that the ratio R is effectively unknown, and the run plan only requires minor adjustments to reach a value of $Q^2=10 \text{ GeV}^2$, should new predictions indicate that the uncertainties would be acceptable. The lever arm in Q^2 also facilitates the determination of the Q^2 dependence even if the L/T ratios turn out to be less favorable than predicted by available models.

The proposed kinematic settings are unchanged from our 2007 submission with one exception. To address the PAC32 recommendation to optimize the overlap with the E12-06-101 experiment [21], the central value of the Q^2 scan at $x_B=0.40$ has been lowered to $x_B=0.39$. This is a minor change, which affects the cross section by less than 2%. More details on the kinematics of the two experiments are presented in the Appendix.

In order to examine the contribution and Q^2 dependence of the interference terms, data will also be acquired to the left and right of the \vec{q} . The ϕ coverage allows σ_{LT} and σ_{TT} to be obtained from the measured ϕ dependence of the cross section. The data to the left and right of the \vec{q} will also make it possible to examine the $-t$ dependence of the cross section.

We have chosen kinematics that allow for the highest ever measurement of the L/T separated pion production cross sections in Q^2 keeping a reasonable lever arm in ϵ to allow for the complete separation of the components.

III. PROJECTED ERROR AND TIME ESTIMATE

Rate estimates are slightly higher by about 15 % than in our 2007 proposal. This is due to design changes in the SHMS, which have increased the solid angle from 3.5 msr to 4.5 msr (this will be slightly smaller once an acceptance defining collimator has been added). The corresponding increase in rate is proportional to the increase in solid angle. The gain in rate is partially compensated by a reduction in the maximum beam current from $90 \mu\text{A}$ to $85 \mu\text{A}$, required by the beam current limits at 12 GeV JLab.

To illustrate the sensitivity of the experiment, the projected uncertainties for the Q^2 dependence of the π^+ longitudinal cross section is shown in Figure 3. As in 2007, we assume 5,000 good events at $x_B=0.31$ and $x_B=0.39$, and 10,000 good events at $x_B=0.55$ for each ϵ setting to determine the Q^2 dependence of the reaction. The three points at $x_B = 0.55$, equally spaced in Q^2 for $W > 2 \text{ GeV}$, will provide the first L/T separated π^+ cross section data up to the highest possible Q^2 at JLab 12 GeV. In particular, the highest point at $Q^2 = 9.1 \text{ GeV}^2$, would reach the regime where there seems to be a consensus that factorization should apply, thus providing an important benchmark for scaling studies. The uncertainties on the proposed points have been estimated using a parameterization of both

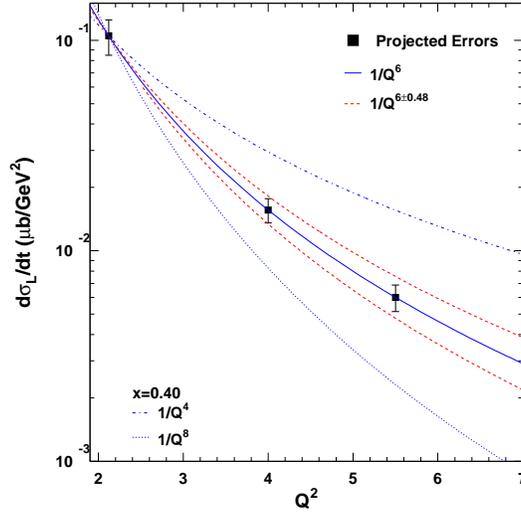


FIG. 3: Projected uncertainties for the Q^2 dependence of σ_L at $x_B=0.39$. The data points are plotted to follow $1/Q^6$ scaling. The uncertainties were determined using a two parameter fit of the form A/Q^n . The red dashed curves assume a form $1/Q^n$ for the Q^2 dependence of the longitudinal cross section, and indicates the precision with which one may fit the exponent. The projected sensitivity for fitting the Q^2 dependence at $x_B=0.39$ and 0.55 is $dn=\pm 0.48$ and $dn=\pm 2$. The projected uncertainty on dn depends on the projected uncertainty for σ_L , which in turn depends on $R=\sigma_L/\sigma_T$. For consistency with the existing data we have used R values predicted from our parameterization. If new data suggests that the VGL prediction is more applicable at higher Q^2 , this would reduce the uncertainties on dn to $dn=\pm 0.2$ and $dn=\pm 1$ respectively.

longitudinal and transverse cross sections from previous pion production data, assuming an uncorrelated systematic uncertainty of 1.7% in the unseparated cross section, and correlated uncertainties as listed in Table III in our 2007 proposal. The projected uncertainty in the fitting exponent in the Q^n dependence are listed in Table IV in our 2007 submission.

To investigate the σ_L/σ_T ratio in π^- production on the neutron, as discussed in section IC, we will repeat the $x_B=0.4$ setting shown in Table I with a LD2 target, using the SHMS spectrometer for both pion polarities. This additional measurement adds three days to the requested beam time. If the measurement is successful, the results can serve as a basis for a future proposal.

Our total time request is for 32 days of data, but additional time (≈ 4 days) will be needed for calibration purposes and beam energy changes. Configuration changes, for instance, target and momentum, have already been included in the time estimate in Table I. We have allocated about one shift at each energy setting for elastic and optics data taking. We assumed an additional 8 hour overhead for each beam energy change. The cryogenic target length is taken to be 8 cm, as explained in our 2007 proposal.

TABLE I: Beam time estimates for the $p(e, e'\pi^+)n$ measurement assuming $85 \mu A$ on a 8-cm LH2 target. The projected number of hours includes three θ_π settings at high ϵ and two θ_π settings at low ϵ .

Q^2 (GeV ²)	x_B	ϵ	LH ₂ hours	Dummy hours	Overhead (hours)	Total (hours)
1.45	0.311	0.52	0.9	0.1	4	5.0
1.45	0.311	0.84	0.3	0.1	4	4.4
2.73	0.311	0.35	4.3	0.3	4	8.6
2.73	0.311	0.74	1.6	0.2	4	5.8
4.00	0.311	0.33	4.0	0.3	4	8.3
4.00	0.311	0.63	2.6	0.2	4	6.8
Subtotal $x_B=0.31$						38.9 (1.6 days)
2.12	0.39	0.54	0.9	0.1	4	5.0
2.12	0.39	0.82	0.5	0.1	4	4.6
4.00	0.39	0.28	9.5	0.7	4	14.2
4.00	0.39	0.63	5.0	0.3	4	9.3
5.50	0.39	0.24	17.4	1.2	4	22.6
5.50	0.39	0.53	11.2	0.8	4	16.0
Subtotal $x_B=0.40$						71.7 (3.0 days)
4.00	0.55	0.32	3.8	0.3	4	8.1
4.00	0.55	0.73	2.3	0.2	4	6.5
6.60	0.55	0.15	83.7	6.0	4	93.7
6.60	0.55	0.55	51.5	3.6	4	59.1
9.10	0.55	0.18	199.3	14.0	4	217.3
9.10	0.55	0.44	182.3	12.8	4	199.1
Subtotal $x_B=0.55$						583.8 (24.3 days)
Subtotals			581.1	41.3	72	694.4
LD2						72.0
Calibrations						48.0
beam energy changes						48.0
Total						862.4 (36.0 days)

IV. SUMMARY

In summary, we propose to measure the $p(e, e', \pi^+)n$ reaction at fixed values of $-t$ and $x_B=0.31$, 0.39, and 0.55, from which the contribution due to longitudinally and transversely polarized photons will be isolated unambiguously. The momentum transferred to the electron will be as large as $Q^2=9 \text{ GeV}^2$, the highest Q^2 for any L/T separation in pion electroproduction. The measurement will constrain the values of Q^2 for which one can reliably apply perturbative QCD concepts and extract Generalized Parton Distri-

butions, which may influence the accessible kinematics for 12 GeV GPD studies. The measured transverse cross section will provide important information for the interpretation of existing and future Hall B data, and may help identifying possible missing elements in existing calculations. The experimental method has been successfully used in previous measurements in Hall C. Due to the anticipated characteristics of the spectrometers and detector packages, the proposed SHMS+HMS spectrometer system is well suited for the proposed measurements.

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V. APPENDIX: THE COMBINED E12-07-105 AND E12-06-101 RUN PLANS

The " F_π experiment", E12-06-101, plans to extract the pion form factor from $p(e, e'\pi^+)n$ data at fixed values of Q^2 . The experiment proposes to acquire 30,000 coincidences per setting for several $-t$ scans. This is in contrast to the E12-07-105 measurement of separated $p(e, e'\pi^+)n$ cross sections to test the factorization of long-distance from short-distance physics in hard exclusive processes, which requires for its Q^2 scans 5000 ($e, e'\pi^+$) coincidences per setting at $x_B=0.3$ and 0.40 Q^2 and 10000 coincidences per setting at $x_B=0.55$ Q^2 at fixed $-t$. While E12-06-101 envisions a measurement over a narrow range

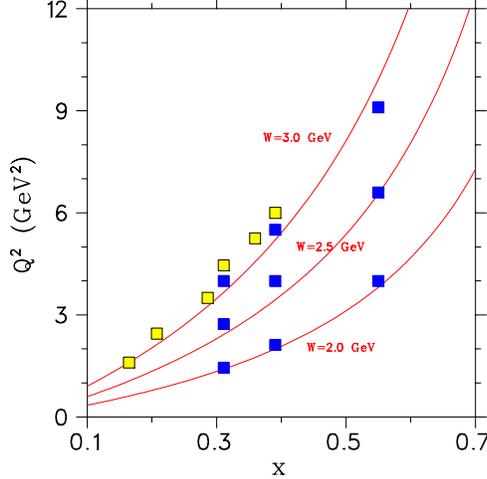


FIG. 4: x_B vs. Q^2 settings planned for the "Pion Scaling" experiment (blue squares) and E12-06-101 (yellow squares).

of x_B and $-t$, the "Pion Scaling" experiment, E12-07-105, requires a large lever arm on both of these variables to determine the Q^2 dependence of σ_L with an acceptable level of uncertainty.

The x_B range of E12-06-101 is designed for values of $t_{min} < 0.2$, and thus limited in Q^2 and x_B as well. In particular, the Pion Scaling high Q^2 scan at $x_B=0.55$, which comprises 70% of the total beam request lies at much higher values of $-t$ than the limit in E12-06-101. Thus any savings by combining kinematic settings are restricted to the Q^2 scans at $x_B=0.31$ and 0.40 , which take 4% and 8% of the total beam request.

The following optimizations of a combined runplan were agreed upon after a meeting of the proponents of both experiments. The Q^2 scan of Pion Scaling at $x_B=0.4$ is extended by adding the $Q^2=6$ GeV² setting from E12-06-101 through a small modification of the central x_B value of this scan from $x_B=0.40$ to $x_B=0.39$. This modification does not save significant beam time, but increases the Q^2 lever arm in Pion Scaling reducing the uncertainty in the determination of the $1/Q^n$ scaling exponent accordingly. To benefit the Q^2 scan at $x_B=0.311$, the $Q^2=4.50$ GeV², $W=3.28$ GeV point originally listed in the E12-06-101 proposal has been moved to $Q^2=4.46$ GeV², $W=3.28$ GeV. This does not change the beam time request of that experiment, but extends the Pion Scaling upper Q^2 range of this setting from 4.00 to 4.46 GeV².

The combined Q^2 , W , x_B coverage of both experiments are shown in Fig. 4. Subject to beam scheduling constraints, we think it likely that both experiments will run concurrently, and we expect both experimental collaborations to work together to optimize the physics output of both experiments. For example, two days of beam could be potentially saved by sharing $e-p$ elastics and optics calibration runs. However, there is no way to know at this point how the two experiments will be scheduled, and therefore we separately request the full elastics and calibration runs required for each experiment.