Update of Experiment E12-09-017

Transverse Momentum Dependence of Semi-Inclusive Pion and Kaon Production

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Executive Summary

E12-09-017 plans to make precise measurements of cross sections of semi-inclusive charged-pion ($\pi^{\pm}$) electroproduction at deep inelastic scattering kinematics and low transverse momentum ($P_{h\perp}$) from hydrogen and deuterium targets. The experiment will simultaneously, albeit with a factor of ten lower rates, accumulate charged-kaon ($K^{\pm}$) cross secion measurements, and obtain high-precision measurements of the azimuthal single beam spin asymmetries at low $P_{h\perp}$, through the use of longitudinally polarized electron beams. The proposed measurements cover the range $0.2 < x < 0.5$, $2 < Q^2 < 5$ GeV^2, $0.3 < z < 0.5$, and $P_{h\perp} < 0.5$ GeV.

The Hall C HMS spectrometer and the projected SHMS with its first-generation detector package will be used for electron and meson detection. The chosen setup of highly-focusing magnetic spectrometers with well-understood acceptances and redundant detector packages will allow precise determination of the $P_{h\perp}$ dependence of the *ratios* of π^+ to π^- cross sections. The proposed measurements correspond to a beam time request of 32 days, and assume a longitudinally polarized electron beam to also include azimuthal asymmetry measurements, beam energies of 8.8 and (predominantly) 11.0 GeV, and varying beam currents of up to 75 μA.

The precision ratios will be combined with maps of the azimuthal asymmetries in semi-inclusive electroproduction of pions as approved for the unpolarized hydrogen target (E12-06-112, "Probing the Proton's Quark Dynamics in Semi-Inclusive Pion Production at 12 GeV") and envisioned for the unpolarized deuteron target (LOI12-07-103, LOI12-09-005). In the context of a simple model, such combination of the proposed Hall C maps and the CLAS12 large-acceptance measurements constrain the initial transverse momentum widths of up and down quarks, and the transverse momentum widths of favored and unfavored fragmentation functions, respectively. We give a more detailed outline along the lines of this simple model below, using results of semi-inclusive pion electroproduction cross section measurements of the E00-108 experiment in Hall C, performed in 2003 with a 5.5 GeV beam energy, as an example. The latter also shows that although the physics proposed here benefits from its companion CLAS12 experimental program, it can stand on its own.

The proposed cross section measurements will provide basic tests of the theoretical understanding of semi-inclusive deep inelastic scattering in terms of factorized parton distributions convoluted with fragmentation functions, augmenting the CLAS12 program with precision charged-pion and charged-kaon cross section ratios. These precision cross section measurements will provide a critical role in establishing and/or validating the entire semi-inclusive deep inelastic scattering program in studying the partonic structure of the nucleon.

We are pleased to note that PAC-37 approved this experiment, and concurred with PAC-34 to strongly recommend that these measurements occur in the early years of 12-GeV operation. Members of the collaboration have spearheaded the now-flourishing semi-inclusive deep inelastic scattering physics program at Jefferson Lab, and are now actively working on a variety of hardware components related to Hall C's new Super-High Momentum Spectrometer, such as all base equipment detectors: wire chambers (Hampton), scintillators (JMU), quartz detector (NCA&T), both low-pressure (UVa) and C4F8O heavy-gas (Regina) Cherenkov detectors, the pre-shower and electromagnetic calorimeter (Yerevan), and also additional particle identification detectors such as a kaon identification system (CUA).

1 Introduction

One of the central questions in the understanding of nucleon structure is the orbital motion of partons. Much is known about the light-cone momentum fraction, x, and virtuality scale, Q^2, dependence of the up and down quark parton distribution functions (PDFs) in the nucleon. In contrast, very little is presently known about the dependence of these functions on their transverse momentum $\mathbf{p}_T$.

Partons are confined inside protons. Thus, a simple estimate of the intrinsic transverse parton momenta is possible and given that the spatial size of the proton is of order 1 fm we obtain that $\langle \mathbf{p}_T \rangle$ is of order a few hundred MeV. Once sea quarks at small Bjorken x start dominating one might argue that the charachteristic scale is not the size of the proton, but rather the size of the quark-antiquark vacuum excitations which occur at short distances, and thus $\langle \mathbf{p}_T \rangle$ becomes larger [1].

Increasingly precise studies of the nucleon spin sum rule [2, 3, 4, 5] strongly suggest that the net spin carried by quarks and gluons does not account completely to the net value of the spin of the nucleon, and therefore an orbital angular momentum contribution of partons to the spin of the nucleon must be significant. This in turn implies that transverse momentum of quarks should be non-zero and correlated with the spin of the nucleon itself.

Once one realizes that transverse motion of partons is important, naturally arising questions include: what are the flavor and helicity dependence of the transverse motion of quarks and gluons, and how can these be measured experimentally; and what is the appropriate formalism for a description of transverse motion of quarks from a theoretical point of view?

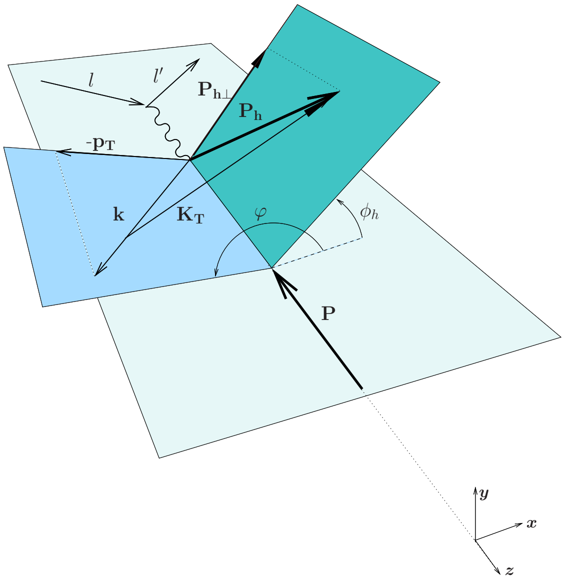

Figure 1: Kinematics of the SIDIS process in the $\gamma^* p$ center of mass frame.

The so-called Transverse Momentum Dependent (TMD) factorization was first shown [6] for Semi-Inclusive Deep Inelastic scattering (SIDIS), $lN \to l'hX$ for high values of $Q^2 \gg \Lambda^2_{QCD}$ and moderate values of transverse momenta of the produced hadron, $P_{h\perp} \sim \Lambda_{QCD}$. High Q^2 assures QCD factorization, while the small transverse momenta $P_{h\perp}$ of the electro-produced hadrons make it sensitive to intrinsic motion of the partons. The factorization is formulated in terms of so-called Transverse Momentum Dependent (TMD) parton distribution (and fragmentation functions), that in addition to their usual dependence on x and Q^2 also depend on the transverse momentum of partons $\mathbf{p}_T$.

The unpolarised SIDIS cross section [7, 8] can be written in terms of four structure functions

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$

$$\frac{\alpha^2}{xyQ^2}\,\frac{y^2}{2\,(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Bigg\{F_{UU,T}+\varepsilon\,F_{UU,L}+\sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h}$$
$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{2\cos\phi_h}\Bigg\} \tag{1}$$

where the experimentally measured structure functions are $F_{UU,T}+\varepsilon\,F_{UU,L}$ (separable through Rosenbluth separations as *e.g.* in experiment E12-06-104), which are ϕ_h independent, and $F_{UU}^{\cos\phi_h}$ and $F_{UU}^{2\cos\phi_h}$ which are $\cos\phi_h$ and $\cos 2\phi_h$ modulations, respectively.

At leading twist, the spin structure of a spin-1/2 hadron can be described by 8 TMDs [7, 8, 9]. Each TMD represents a particular physical aspect of spin-orbit correlations at the parton level. The dependence of the SIDIS cross section on the azimuthal angle of the electro-produced hadron with respect to the lepton scattering plane and on the nucleon polarization azimuthal angle allows a term-by-term separation of the different azimuthal contributions to the measured unpolarized and polarized cross sections and spin asymmetries. The unpolarized SIDIS cross-section can be used not only to study the unpolarized TMD distribution function $f_{q/p}(x,\mathbf{p}_T^2)$ and the unpolarized TMD fragmentation function $D_{h/q}(z,\mathbf{k}_T^2)$ that encode the intrinsic dynamics of unpolarized partons, but also the Boer-Mulders distribution and the Collins fragmentation functions, which carry information about the dynamics of transversely polarized partons inside the hadron and give rise, for instance, to a $\cos 2\phi_h$ modulation of the cross section.

The existence of partonic intrinsic transverse momenta is unequivocally signaled by a $\cos\phi_h$ modulation, which is a subleading twist effect suppressed by one power of Q. This contribution to the unpolarized cross section consists of a purely kinematical term, the Cahn effect [10], proportional to the convolution of unpolarized distribution and fragmentation functions, together with other twist-3 contributions, as pointed out in Ref. [8].

We define here the following variables describing the kinematics:

$$\begin{aligned} s &= (p+l)^2 && \text{energy of the ep system}\\ W^2 &= (p+q)^2 && \text{energy of the }\gamma^*\text{p system}\\ Q^2 &= -q^2 > 0 && \text{photon's virtuality} \end{aligned} \tag{2}$$

and

$$x=\frac{Q^2}{2\,P\cdot q},\quad y=\frac{P\cdot q}{P\cdot l},\quad z=\frac{P\cdot P_h}{P\cdot q},\quad \gamma=\frac{2Mx}{Q},\quad \varepsilon=\frac{1-y-\frac{1}{4}\gamma^2y^2}{1-y+\frac{1}{2}y^2+\frac{1}{4}\gamma^2y^2}. \tag{3}$$

A partonic interpretation of the measured structure functions can be obtained as convolution of distribution and fragmentation functions [7, 8]

$$F_{AB}=\mathcal{C}[w\,f\,D], \tag{4}$$

where $\mathcal{C}[...]$ is defined as

$$\boldsymbol{\mathcal{C}[w\,f\,D] = x\sum_a e_a^2\int d^2p_T\,d^2k_T\,\delta^{(2)}(zp_T+k_T-P_{h\perp})\,w\left(p_T,-\frac{k_T}{z}\right)\,f^a(x,p_T^2)\,D^a(z,k_T^2),} \tag{5}$$

and $w\left(p_T,-\frac{k_T}{z}\right)$ is a function depending on partonic momenta, $f^a(x,p_T^2)$ is a TMD parton distribution and $D^a(z,k_T^2)$ is a transverse-momentum dependen fragmentation function.

Eq. 5 indicates a summation over the various quark flavors. Thus, to go beyond and study a possible flavor dependence of the TMDs one has to measure different species of hadrons produced. This can be most readily accomplished with charged-pions and charged-kaons (and neutral pions). Within a simple gaussian Ansatz for TMDs one can show [11] that $\mathbf{P}_{h\perp} = z\mathbf{p}_T + \mathbf{k}_T$ and thus $\langle \mathbf{P}^2_{h\perp} \rangle = z^2 \langle \mathbf{p}^2_T \rangle + \langle \mathbf{k}^2_T \rangle$.

The fragmentation process is traditionally described with both "favored" and "unfavored" fragmentation functions $D^{fav}(z, \mathbf{k}_T)$ and $D^{unf}(z, \mathbf{k}_T)$, that refer to cases when the electro-produced pion either contains or does not contain the same flavor as the struck quark. In the latter unfavored case, the quark content is picked up from the vacuum, and the process of fragmentation is suppressed.

At small values of $\mathbf{p}_T$ one expects that distribution of momenta are approximately gaussian [11] and experimental data confirm this finding. Hard QCD processes are expected to generate large non-Gaussian tails for $P_{h\perp} \gg \Lambda^2_{QCD}$. However, at small $P_{h\perp} < 0.5$ GeV, the subject of this proposal, one might use TMD factorization without worrying about gluon radiation effects. The TMDs can then be parameterized as gaussians

$$\begin{aligned} f_1^q(x, p_T^2) &= f_1^q(x) \frac{1}{\pi \langle p_T^2 \rangle} \exp\left(- \frac{\mathbf{p}_T^2}{\langle p_T^2 \rangle} \right), \\ D_{1q}^h(z, K_T^2) &= D_{1q}^h(z) \frac{1}{\pi \langle k_T^2 \rangle} \exp\left(- \frac{\mathbf{k}_T^2}{\langle k_T^2 \rangle} \right) \end{aligned} \tag{6}$$

where the widths of distributions are $\langle p_T^2 \rangle$ and $\langle k_T^2 \rangle$. Usually these widths are taken to be flavor independent, but this is just an assumption.

In the present experiment the use of both proton and deuteron targets (the latter with a higher d quark content than the former) and the detection of both π^+ and π^-, and also charged kaons, then permits a first dedicated study of the flavor dependence of such TMD widths.

2 Physics

The possibility of a study of the k_t widths of up and down quarks under the main assumption that the fragmentation functions do not depend on quark flavor (and multiple other assumptions) was first indicated following the results of the E00-108 experiment in Hall C at Jefferson Lab [12]. Ongoing work also shows indications of an x [13] and energy [14] dependence of these k_t widths.

E00-108 [15, 12, 16] measured semi-inclusive electroproduction of charged pions ($\pi^\pm$) from both proton and deuteron targets, using 5.5 GeV energy electrons at Jefferson Lab. As part of this experiment, a $P_{h\perp}$ scan was performed, with the extracted cross sections shown in Fig. 2.

A recent study [14] analyzed these data in combination with the CLAS data [17], and concluded that in the kinematics similar to the CLAS data, the Hall C data could be relatively well described by a Gaussian model with average transverse momentum width of 0.24 GeV^2. The good description of the $\pi^\pm$ cross sections from different targets was argued to indicate that the assumption of flavor-independent Gaussian widths for both the transverse widths of quark and fragmentation functions was reasonable, in the valence-x region for $z = 0.55$.

If taken as standalone data, a careful examination of Fig. 2 shows however that the $P_{h\perp}$-dependent slopes for the deuteron target are somewhat smaller than those for the proton. For a more quantitative understanding of the possible implications of this, we studied the data in the context of a simple model in which the $P_{h\perp}$ dependence is described in terms of two Gaussian distributions for each case. Following Ref. [11], we assume that the widths of quark and fragmentation functions are Gaussian in k_T and p_T, respectively, and that the convolution of these distributions combines quadratically. The main difference from Ref. [11] is that we allow separate widths for up and down quarks, and separate widths for favored and unfavored fragmentation functions. The widths of the up and down distributions are given by μ_u and μ_d, resp., and the favored (unfavored) fragmentation widths are given by μ_+ (μ_-).

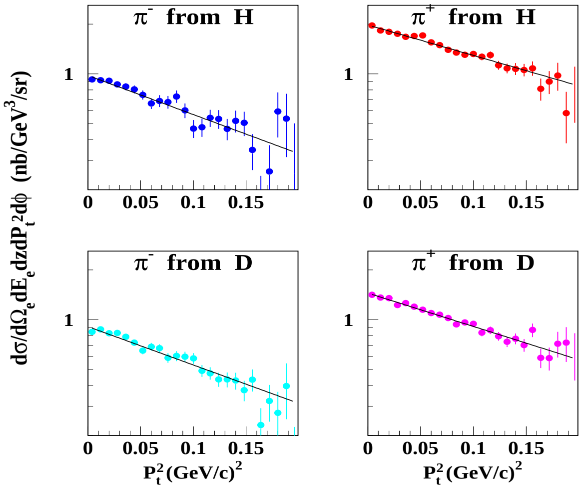

Figure 2: The $P_{h\perp}^2$ dependence of differential cross-sections per nucleon for $\pi^\pm$ production on hydrogen (H) and deuterium (D) targets at $\langle z\rangle$=0.55 and $\langle x\rangle$=0.32. The solid lines are exponential fits. The error bars are statistical only. Systematic errors are typically 4% (relative, see text in Ref. [12]).

In the context of this simple model, with only valence quarks and only two fragmentation functions, E00-108 finds the (valence) quark k_t widths to be smaller than the (favored and unfavored) fragmentation p_t widths. The favored and unfavored fragmentation widths are found to be correlated, and the central values are found to be in reasonable agreement with both each other and the flavor-averaged value of 0.20 GeV^2 of Anselmino *et al.* [11].

This can only be considered as suggestive at best, due to the limited kinematic range covered and the simple model assumptions. Many of these limitations could be removed with future experiments covering a wide range of Q^2 (to resolve additional higher twist contributions), full coverage in ϕ, a larger range of $P_{h\perp}$, a wide range in z (to distinguish quark width terms, weighted by powers of z, from fragmentation widths, which likely vary slowly with z), and including the π° final state for an additional consistency check (particularly on the assumption that only two fragmentation functions are needed for charged pions from valence quarks). These goals should be attainable with this E12-09-017 experiment, emphasizing semi-inclusive charged-pion (and kaon) electroproduction, in combination with the approved and planned experimental 12-GeV program with the CLAS12 detector (where one would also more naturally include a $P_{h\perp}$ scan for π°). The data foreseen with this E12-09-017 experiment should then provide potential crucial information on how hadron transverse momentum in SIDIS is split between fragmentation and intrinsic quark contributions.

3 Experiment

The proposed experiment will use the HMS and SHMS magnetic spectrometers for coincidence measurement of scattered electrons and charged pions from the semi-inclusive electroproduction reaction $(e, e'\pi^\pm)$X. HMS will be used to measure the scattered electrons, whereas SHMS, with its most forward angle of 5.5°, will detect the electroproduced pions. The HMS can reach scattering angles down to 10.5°, and sub-tends a scattering angle acceptance of about 3° (for a point source). The minimum *separation* angle of HMS and SHMS is 17.5°, which prevents the HMS and SHMS from both being at their most forward angle simultaneously.

The experiment will use an 11-GeV beam energy to map a region in Bjorken x between 0.2 and 0.5, in z between 0.3 and 0.5, and in θ_{pq} to cover a range in $P_{h\perp}$ up to 0.5 GeV. To better constrain the possible

Table 1: Main kinematic settings for HMS.

E (GeV)	E' (GeV)	θ_e (deg)	W^2 (GeV^2)	θ_γ (deg)	q_γ (GeV)	Kinematics	x	Q^2 (GeV^2)
11.0	5.67	10.27	8.88	10.57	5.513	I	0.20	2.0
11.0	5.67	12.59	7.88	12.75	5.603	II	0.30	3.0
11.0	5.67	14.55	6.88	14.49	5.692	III	0.40	4.0
11.0	5.67	16.28	5.88	15.96	5.779	IV	0.50	5.0
8.8	5.60	10.96	5.08	17.90	3.467	V	0.30	1.8
11.0	5.67	21.26	11.38	7.57	8.270	VI	0.30	4.5

(x, z) entanglement, we plan to measure over a range in Q^2 for *fixed* value of $x = 0.30$, while still varying z between 0.3 and 0.5 (or 0.25 and 0.6 or so, within the spectrometer momentum acceptances). To cover a wide range in Q^2, from 1.8 to 4.5 GeV^2, a limited time of 8.8 GeV beam energy running is required.

We plan to use the base equipment detector packages for HMS and SHMS, augmented with an aerogel detector for kaon/proton separation. The latter allows us to also independently map the kaon yields, albeit with about an order of magnitude less rate. This would still render yield greater than 1,000 counts per setting.

4 Proposed Measurements

We propose to map the transverse momentum dependence of charged pion $\pi^\pm$ electroproduction off hydrogen and deuterium targets, at small transverse momentum (scale $P_{h\perp} \approx \Lambda$), where the cross sections have been recently calculated at tree level in terms of transverse-momentum dependent parton distribution and fragmentation functions [8]. Recent measurements hint at a possibility to extract information on the average transverse momentum of (unpolarized) valence quarks from such studies. Regardless, the measurements are to date hardly constrained.

4.1 Choice of Kinematics

We propose to map the x, z, and $P_{h\perp}$ dependence of the semi-inclusive pion electroproduction process off both proton and deuteron targets by variation of angle and momentum of electron arm (HMS) and hadron arm (SHMS) (see Table 1). We will measure the semi-inclusive charged-pion electroproduction yields over the range in z and θ_{pq} for all six kinematics, I-VI.

In all cases, we have made sure that the laboratory angle of SHMS is at least 5.5°, and the laboratory angle of HMS at least 10.5°. For the first kinematics, at $(x,\ Q^2) = (0.20,\ 2.00\ \text{GeV}^2)$, we will park the HMS at 10.5° and benefit from the ≈3° angular acceptance of HMS to cover the nominal 10.27° scattering angle. The spectrometer momentum settings are well within the allowable ranges for the HMS and SHMS, and we assumed a 2.5° step in θ_{pq} to cover a large $P_{h\perp}$ range, up to 0.5 GeV, with sufficient overlap between the various settings. See Fig. 3 to illustrate the $(P_{h\perp}, \phi)$ coverage for the various kinematics.

4.2 Systematic Uncertainties

Since both the SHMS mechanical and optics design, and also the planned SHMS detector package, are essentially a clone of the HMS, we expect to achieve a similar high level of understanding of the SHMS acceptance function and detector properties. In this experiment, we plan to analyze the data in terms of a *comparison* of transverse momentum dependences of positive- and negative-charged pions, π^+ and π^-, and off hydrogen and deuterium targets.

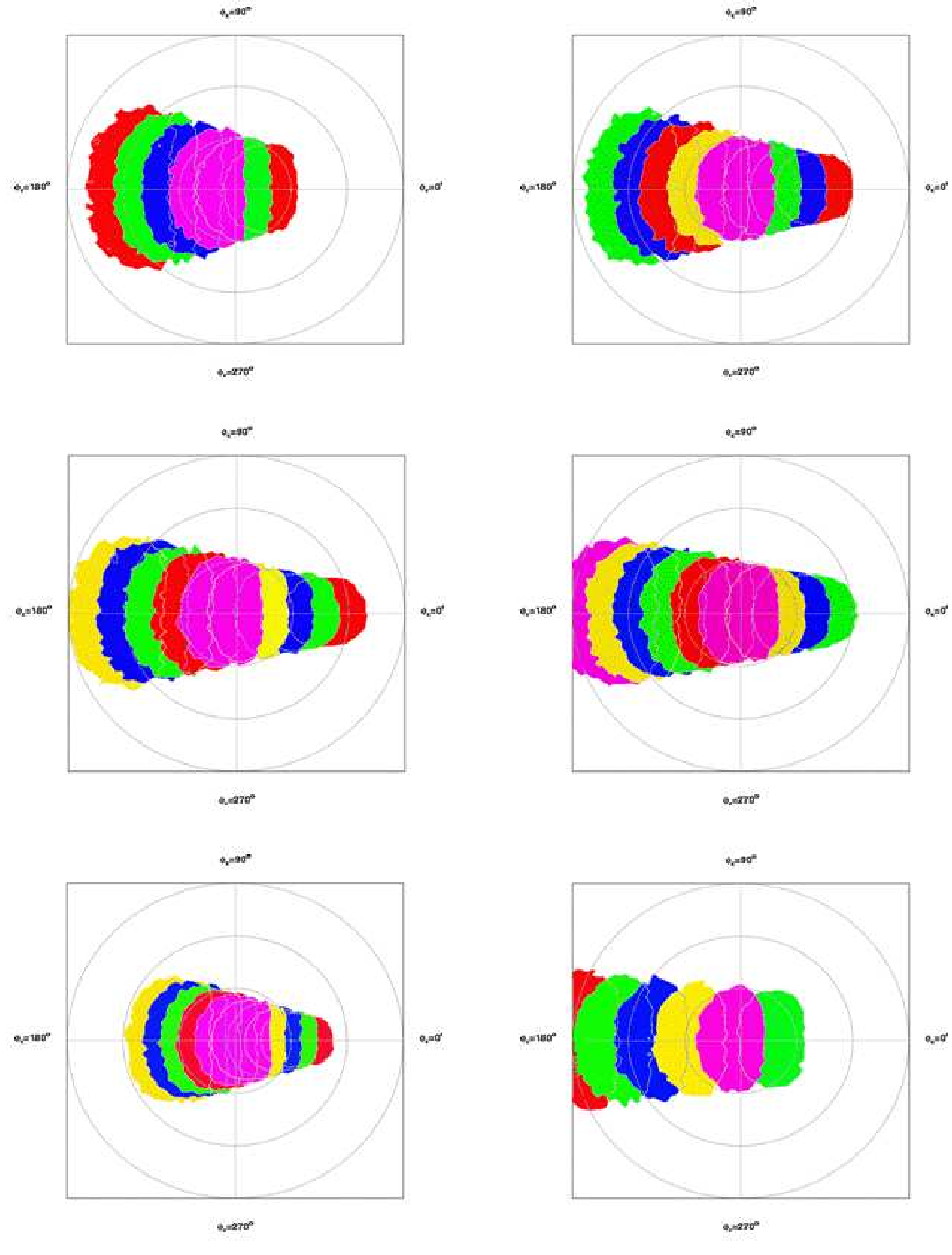

Figure 3: Coverage of proposed measurements in transverse momentum $P_{h\perp}$ and azimuthal angle ϕ (from top to bottom, left to right) for $(x,\ Q^2) = (0.20,\ 2.00\ \text{GeV}^2)$, $(x,\ Q^2) = (0.30,\ 3.00\ \text{GeV}^2)$, $(x,\ Q^2) = (0.40,\ 4.00\ \text{GeV}^2)$, $(x,\ Q^2) = (0.50,\ 5.00\ \text{GeV}^2)$, $(x,\ Q^2) = (0.30,\ 1.80\ \text{GeV}^2)$, $(x,\ Q^2) = (0.30,\ 4.50\ \text{GeV}^2)$ and $z = 0.40$. The different colors represent different θ_{pq} settings. The circles indicate $P_{h\perp} = 0.2$, 0.4, and 0.6 GeV, respectively.

Given the redundancy in detector package in the SHMS, and the relatively low requirements for particle identification, we expect to understand the SHMS detector efficiencies to be at least as well as the HMS ones. Hence, we anticipate uncertainties for these *ratios* as given in Table 2. More details are given in the E12-09-017 proposal submitted to PAC-37. We note that Hall C has established point-to-point uncertainties for inclusive measurements in the range of 1.1-1.5%, and anticipates to obtain point-to-point uncertainties for far more challenging pion form factor measurements [19], pion and kaon factroization measurements [20, 21] and measurements of the ratio $R = \sigma_L/\sigma_T$ in SIDIS [22] of 1.6-1.8%. The quoted uncertainties in Table 2 are largely based upon projections of those experiments.

Table 2: Anticipated systematic uncertainties (in ratios of transverse momentum dependences). Note that this table assumes the combined use of CLAS12 experiments to fully constrain the $(P_{h\perp}, \phi)$ dependency.

Project Source	HMS	SHMS
Spectrometer Acceptance	0.1%	0.4%
Tracking Efficiency	0.1%	0.4%
Detection Efficiency	0.1%	0.4%
Pion Absorption Correction		0.1%
Pion Decay Correction		0.1%
Radiative Corrections		0.5%
Added in Quadrature		0.9%

5 Projected Results

In order to get an idea of how well we can determine μ_d and μ_u from the proposed charged pion data, we binned the projected data into eight bins of $P_{h\perp}$, fifteen bins in ϕ^*, and three bins in z for each of the six kinematic settings. We generated pseudo-data with ${\mu_d}^2 = {\mu_u}^2 = 0.2$ GeV^2. Each data point was randomly moved from it's ideal point using a Gaussian distribution about the expected statistic error for that point. We fit the data with the same seven parameters as for the previous Hall C experiment. With these assumptions, we found an error ellipse that is so small that it essentially looks like *a single point* on a plot of ${\mu_d}^2$ and ${\mu_u}^2$, when all six kinematics are included in the fit simultaneously.

We then added four more parameters, all reflecting different simplifications generally assumed in the analysis of SIDIS data. The first treats the power of $(1 - z)$ for the ratio of favored to unfavored fragmentations as a free parameter, rather than this power being fixed at -2. The next two allow for the possibility that there are two different favored fragmentation functions (one for π^+ from u quarks, and a different one for π^- from d quarks), differing by an unknown power of $(1 - z)$. This similarly allows for two unfavored fragmentation functions. A fourth parameter allows for a charge-symmetry violation between neutron and proton, along the lines of the recent MRST fit [23]. With all six kinematic settings averaged together, the error ellipse *remains small, with a diameter of less than 0.01 GeV^2*.

We also fitted each kinematic setting separately. This checks that the data is consistent with the model, if the error ellipses overlap. We show the result for the eleven parameter fit described above in Fig. 4a. The error ellipse is smallest for the $x = 0.2$ setting (black), due to the high rates, and largest for the low-rate $x = 0.3$, $Q^2 = 4.5$ GeV^2 setting (green). Each setting on it's own still makes a reasonable determination. Combining the settings together results in the very small error refered to above (an error ellipse with diameter of less than 0.01), due the constraints in the x and Q^2 variations in the fit form.

The very high statistical precision and broad coverage in most kinematic variables (except ϕ^* at larger $P_{h\perp}$), allows for even more fit parameters. Thus, as a next step we added eight more parameters to this exercise to mimic a possible higher-twist contribution. Four of these reflect (one each for proton

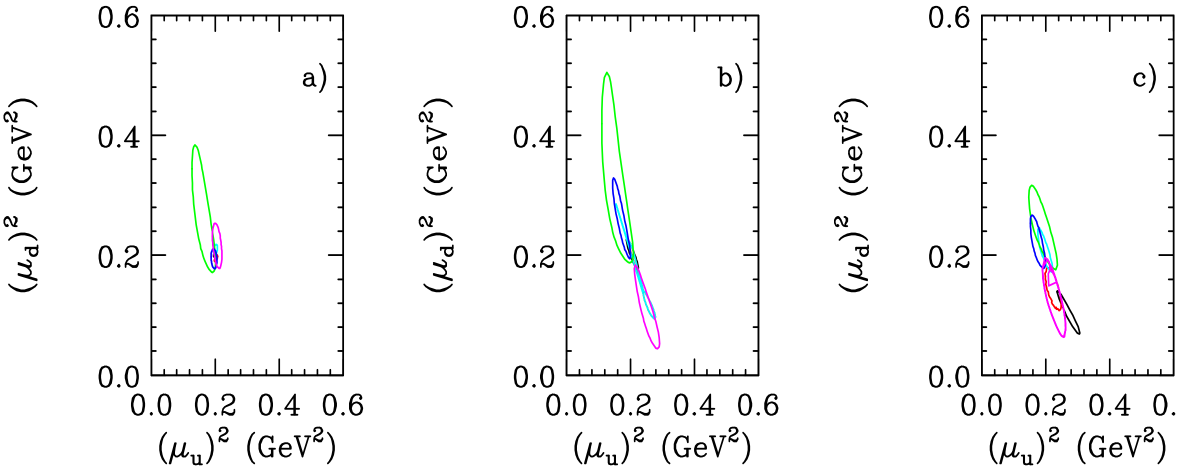

Figure 4: Error contours for ${\mu_u}^2$ versus ${\mu_d}^2$ for: a) Cahn term on, no higher twist terms; b) Cahn term on, with higher twist terms; c) Cahn term off, with higher twist terms. On each plot, kinematics I, II, III, IV, V, and VI are colored black, cyan, blue, magenta, red, and green, respectively. Fits taking all six kinematics simultaneously into account render an error ellipse of diameter 0.01 GeV^2 for panel a), and 0.02 GeV^2 for panels b) and c) (see text).

and deuteron for π^+ and π^-) a possible higher-twist correction of the form $P_{h\perp}^2/Q^2\cos(\phi^*)$. Four more parameters reflect higher-twist terms of the form $(P_{h\perp}^2/Q^2)\cos(2\phi^*)$. While the coefficients of these terms are relatively poorly determined, the errors on ${\mu_u}^2$ and ${\mu_d}^2$ only increased by about a factor of two, as shown in Fig. 4b.

As a last step, we investigated one of the larger uncertainties in the model we used: the strength of the Cahn term. To investigate this, we simulated the data without this term, and also assumed it was absent in the fit. The results are shown in Fig. 4c, and remain rather similar to those with the Cahn term included (Fig. 4b). If we again do a simultaneous fit to *all* six kinematic settings, we still obtain a small error ellipse, with an average diameter of 0.02 GeV^2.

There are many other parameters that could potentially be added to the model, such as those describing sea quark contributions, and additional terms in $P_{h\perp}$. Ideally, the analysis should be done in NLO rather than LO QCD. All of this will be possible due to the significant range in x, Q^2, z, and $P_{h\perp}$ of this proposal. Nonetheless, the above studies already give strong indications that a robust determination of transverse quark momentum widths should be possible, even with more complex treatments. Finally, we also illustrate the projected uncertainties for charged kaons as a function of $P_{h\perp}$ in Fig. 5. The projected data are shown for $x = 0.30$, $Q^2 = 3.0$ GeV^2, and $z = 0.4$ (at a beam energy of 11.0 GeV). It is clear that a high-quality set of charged-kaon data off proton and deuteron targets will be attained in this experiment, over a range of x, Q^2, and z compatible with the proposed charged-pion data.

6 Summary and Beam Time Request

We request a total of 32 days of beam time to map the transverse momentum ($P_{h\perp}$) dependence for semi-inclusive electroproduction of charged pions ($\pi^{\pm}$) and kaons ($K^{\pm}$) from both proton and deuteron targets over the range $0.2 < x < 0.5$, $2 < Q^2 < 5$ GeV^2, $0.3 < z < 0.5$, and $P_{h\perp} < 0.5$ GeV, with the Hall C HMS-SHMS magnetic spectrometer coincidence pair. We request a polarized electron beam to add the possibility to determine single-spin asymmetries from these measurements.

The E12-09-017 measurements emphasize the low $P_{h\perp}$ region, $P_{h\perp} \sim \Lambda$. To better constrain possible

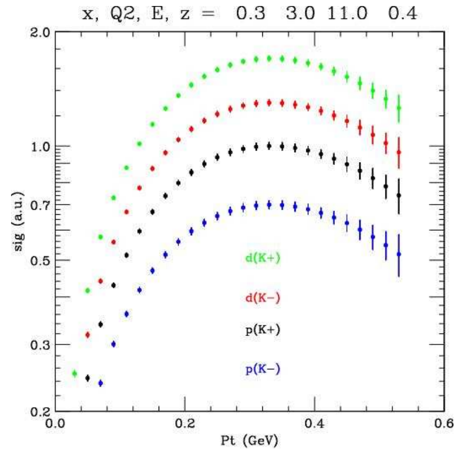

Figure 5: Example of projected charged-kaon data for $x = 0.30$, $Q^2 = 3.0$ GeV^2, and $z = 0.4$.

Table 3: Beam time request

E (GeV)	Target	Time (Hours)
8.8	LH2	54
	LD2	54
	Al	14
11.0	LH2	206
	LD2	206
	Al	52
	Checkout	0 (overlap with E12-06-104)
	Momentum Changes (36)	18
	Angle Changes (306)	20
	Target Changes (918)	150
	Pass Changes (1)	0 (overlap with E12-06-104)
	Beam Energy Measurements (2)	0 (overlap with E12-06-104)
	Total Request	774

$P_{h\perp} - \phi$ correlations in the region $0.2 < P_{h\perp} < 0.5$ GeV, this experiment can be seen as companion of the experimental program with the large acceptance CLAS12 detector, such as that approved for E12-06-112 [18] using unpolarized hydrogen targets. E12-09-017 will provide the very best measurements of the *ratios* of π^+ to π^- cross sections, both for hydrogen and deuterium targets, given the close symmetry between detection of positive- and negative-charged pions with a focusing magnetic spectrometer pair setup.

A summary of our beam time request is given in Table 3, and amounts to 32 days.

We assume one-hour runs for hydrogen and deuterium targets each, for each setting of x, Q^2, z and θ_{pq}, which will give at least 10K clean coincidence events for each setting (possibly barring a few selected cases, where we will accumulate a few thousand coincidences). For electro-produced charged kaons, the rates will be close to a factor of ten reduced. We further assume to run 25% of the time on the Al "dummy" target (15-minute runs), for subtraction of end-wall purposes. By choice of kinematics of overlap with experiment E12-06-104, we have saved several settings, and overhead for checkout, pass changes and beam energy measurements, corresponding to about 5 days of beam time. Time for further configuration changes has been outlined.

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