UPDATE E12-09-011: Studies of the L-T Separated Kaon Electroproduction

Cross Section from 5-11 GeV

July 1, 2011

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An update of the Studies of the L-T Separated Kaon Electroproduction cross section at 11 GeV proposal is presented. Please refer to the E12-09-011 proposal [1] for full details on the scientific justification, experimental method, and projected uncertainties.

I. SCIENTIFIC BACKGROUND SUMMARY

A. Introduction

The $p(e, e'K^+)\Lambda$ and $p(e, e'K^+)\Sigma^0$ reactions are important tools in our study of hadron structure. These reactions have been relatively unexploited to date because of the lack of the necessary experimental facilities. As a result, there are practically no L/T separated data for exclusive K^+ production from the proton above the resonance region.

With the higher beam energies and the new SHMS spectrometer planned for Hall C, we have the opportunity to dramatically improve upon this situation after the 12 GeV upgrade. This proposal has the following primary goals:

1. $1/Q^n$ Scaling and Factorization

   Separated $p(e, e'K^+)\Lambda, \Sigma^0$ cross sections allow investigations of the transition from hadronic to partonic degrees of freedom in exclusive processes. Recent π^+ data from JLab suggest that the power law behavior expected from the hard scattering mechanism is reasonably consistent with the Q^2-dependence of longitudinal cross section data. The Q^2-dependence of the pion form factor is also consistent with the Q^2 scaling expectation already at values of $Q^2 > 1$ GeV^2, even though the observed magnitude is larger than the hard QCD prediction. The latter may, for instance, be due to QCD factorization not being applicable in this regime or due to insufficient knowledge about additional soft contributions from the wave function in meson production. A direct comparison of the scaling properties of the K^+ separated cross

sections would thus provide an important tool for the study of the onset of factorization in the transition from the hadronic to the partonic regime, and provide for the first time a study of scaling in a strange system.

2. <u>Studies of the Kaon Production Mechanism</u>

Prior studies to determine whether the K^+ pole term dominates σ_L at low $-t$ have been complicated in their interpretation by potential resonance contributions, and questions have been raised of the roles of K and K^* t-channel exchanges, and the contributions of higher transitions on the corresponding Regge trajectories. Even the relative importance of σ_L compared to σ_T is not well understood due to the lack of sufficiently precise data. As a result, it is yet to be demonstrated whether the kaon electromagnetic form factor can be extracted from exclusive K^+ production, as has been done recently at JLab for the π^+ case. The proposed measurement will for the first time acquire high quality L/T separated data above the resonance region, which is essential for a better understanding of the K^+ reaction mechanism. The results from the proposed measurement may also help to identify missing elements in existing calculations of the kaon production cross section. If these studies indicate K^+ pole dominance at low $-t$, then we would use these data to extract the K^+ charge form factor for $Q^2 > 0.35$ GeV^2.

We propose to measure forward K^+ electroproduction by detecting the produced kaon in the SHMS in coincidence with the scattered electron in the HMS. 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 measurements of the $-t$ dependence of the K^+ cross section.

Because of the relatively low K^+ counting rates, the experimental uncertainties are expected to be statistics dominated and so it is more tolerant of higher systematic uncertainties than many other experiments already approved for the SHMS. This, coupled with the experiment's extensive use of 5-9 GeV beams, makes it an excellent early experiment candidate for the SHMS.

A detailed discussion on the theoretical motivations for the measurement of separated $p(e, e', K^+)\Lambda, \Sigma^0$ cross sections to test the factorization of long-distance from short-distance physics in hard exclusive processes and its impact can be found in our 2009 proposal [1]. Here, we summarize the main points.

B.   Scaling of the Separated Cross Sections

Since our 2009 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 [2].

However, there has been an ongoing debate about the nature 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. High quality experimental data are needed to guide these discussions. In particular, the strange channel has thus far practically been unexplored.
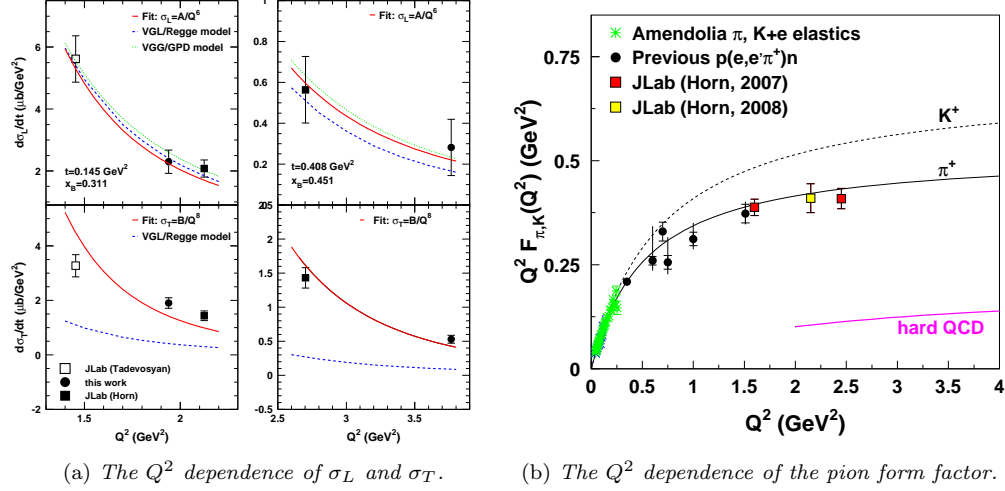

(a) The Q^2 dependence of σ_L and σ_T. (b) The Q^2 dependence of the pion form factor.

FIG. 1: *The apparent scaling puzzle in pion electroproduction. The data are from [3–5]. These recent π^+ data from JLab indicate a Q^2-scaling of the longitudinal cross section (σ_L) that is consistent with a hard scattering mechanism already at values of $Q^2 > 1$ GeV [5], but the transverse cross section (σ_T) does not show a corresponding behavior. The Q^2-dependence of the pion form factor is also consistent with the Q^2 scaling expectation for $Q^2 > 1$ GeV^2, even though the observed magnitude is larger than the hard QCD prediction.*

Recent π^+ data from JLab indicate a $1/Q^6$-scaling of the longitudinal cross section (σ_L) that is consistent with a hard scattering mechanism already at values of $Q^2 > 1$ GeV [5], but the transverse cross section (σ_T) does not show a corresponding $1/Q^8$ behavior. The Q^2-dependence of the pion form factor is also consistent with the $1/Q^2$ scaling expectation for $Q^2 > 1$ GeV^2, even though the observed magnitude is much larger than the hard QCD prediction. The latter puzzle may, for instance, be due to QCD factorization not being applicable in this regime, or due to insufficient knowledge about additional soft contributions from the wave function in meson production. Results from recent analysis of the ρ^0 and ω channels [6] seem to support the former, while large angle Compton scattering data suggest that higher order corrections are dominant at currently available energies [7].

It would thus be of great interest to determine whether the scaling observed for the pion form factor and σ_L also manifests itself in other similar systems. The kaon, where one of the light quarks is replaced by a heavier strange one, makes a natural comparison. Analogous to the pion production reaction, one would expect to observe Q^{-6} scaling of σ_L at sufficiently high values of Q^2. The threshold for the onset of factorization may be slightly higher due to the increased strange quark mass, and is expected to occur for values of $Q^2 > 5$ GeV^2. SU(3) flavor symmetry

relates the $p\Lambda$ GPDs to the usual GPDs in the proton, which may then allow for the extraction of information on quark transverse momentum distributions and angular momentum.

We propose a systematic measurement of the Q^2 dependence of the longitudinal and transverse cross sections above the resonance region at fixed x_B=0.25, 0.40 in K^+ electroproduction. These data will play an important part in guiding the 12 GeV GPD program. If charged kaon electroproduction is going to be useful for testing models of GPDs at 12 GeV JLab energies, we expect to see evidence of soft-hard factorization or the approach to it. If the transverse contribution to the cross section is larger than anticipated, this would dramatically influence the experimental kinematical accessibility of strangeness GPDs using charged kaon electroproduction in 12 GeV experiments.

C.   Studies of the Kaon Electroproduction Mechanism above the Resonance Region

Since our 2009 submission there has been a renewed interest in the reaction mechanism underlying strangeness production from a proton as it offers a new flavor to resolve puzzles that cannot be resolved by studying one channel alone.

One of the main interests in the Q^2 dependence of kaon electroproduction is whether there is evidence for a large longitudinal cross section. This may be expected from analogy to the forward peak observed in charged pion production due to the pion pole at small values of $-t$. However, it is not clear from the available data if there are significant enhancements above the resonance region due to t channel exchange. An extrapolation of electroproduction data to the photoproduction point suggests that σ_L may indeed be large for the $K^+\Lambda$ final state [8]. This would be in conflict with the general expectation that the kaon pole, being farther away from the physical region, is of less consequence compared to the pion case [9]. Measurements of kaon production over a wide kinematic range extending to small values of Q^2, would address this issue.

We propose to measure L/T separated cross sections for $W > 2.4$ GeV as a function of both $-t$ and Q^2 providing the first K^+ data above the resonance region. Should we conclude that the extraction of the K^+ form factor is feasible, this experiment would be the first determination of the K^+ form factor above the upper limit of the CERN SPS data [10].

Looking at the t dependence over the full kinematic range in x_B allows for probing the hadron structure beyond the t pole. A priori it is not clear if this mechanism will be dominant everywhere, and if trends in non-strange and strange systems should be similar. For instance, u-quark scattering deep inside the nucleon would predict no difference in the t-dependence for pions and kaons. On the other hand, a Reggeized t-channel model of kaon electroproduction is unable to correctly reproduce the energy and t-dependences of the existing unseparated data, possibly because of the greater distance of the kaon t pole from the physical region and the role of unexplored transitions between the kaon and higher spin orbital excited states lying on the kaon Regge trajectory [9]. Measurements of the "t-slope" of separated cross sections at fixed values of
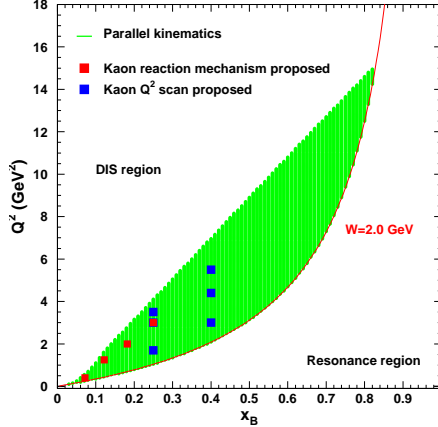
FIG. 2: Q^2 versus x_B phase space available for L-T separations in Hall C at 11 GeV using the SHMS+HMS combination. We propose to measure the Q^2 dependence of the longitudinal cross section at x_B=0.25 and x_B=0.40, and the t dependence of the longitudinal cross section for values of Q^2=0.40 to 3.00 GeV^2. 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 $\Delta\epsilon \sim 0.20$.

x would shed a first light on the interplay of pole and non-pole contributions in strange meson production.

These data may also shed light on a question raised by our recent $p(e, e'\pi^+)n$ L/T separations up to $Q^2 = 2.45$ GeV^2, $W = 2.2$ GeV [4]. While the VGL Regge model provides an acceptable description of the σ_L data, it has consistently underestimated the magnitude of σ_T, for which the model seems to have limited predictive power. Various improvements to the reaction mechanism in the model have recently been suggested [12]. Unfortunately, separated kaon cross section data above the resonance region that could help guide this discussion are extremely rare (see Fig. 3(b)). Our recent analysis of the global uncertainty of exclusive pion and kaon production world data [13] suggests that the precision and kinematic reach of such a superset is limited for analyzing the reaction mechanism in the transition from soft to hard scattering and guiding theoretical models. The difficulty in describing the existing pion data and the lack of suitable kaon data emphasizes the need for new L/T separation experiments in these kinematics.

II. PROPOSED KINEMATICS

The reasoning and justification for our kinematic settings are explained in detail in our 2009 proposal [1]. Here, we briefly summarize the main points. We propose to make coincidence measurements between kaons in the SHMS and electrons in the HMS. A high luminosity spectrometer system like the SHMS+HMS combination in Hall C is well suited for such a measurement.

The focusing 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. Though the large azimuthal coverage allows for a good determination of the interference terms, the error amplification in the extraction of longitudinal and transverse components favors the use of focusing spectrometers. 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 best address the experimental requirements, and 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 forty 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. This is important, as our proposed measurement will provide the first data in this region, and allow for reliable tests of the reaction mechanism.

The Q^2 scans at fixed values of x_B=0.25 and x_B=0.40 for the first time accesses the regime between 1.0-5.5 GeV^2 above the resonance region, and will provide reliable L/T separated data for investigations for the onset of $1/Q^n$ scaling in strange systems. Since the measurement at x_B=0.25 is at relatively low Q^2, these data are acquired quickly and 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. Given the constraint imposed by the requirement to keep $-t \ll 1$ GeV^2, combined with the maximum available beam energy of the upgraded CEBAF and the kinematic reach of the SHMS+HMS configuration in Hall C, the maximum Q^2 is near 10 GeV^2. In the proposal, we have chosen to limit the maximum Q^2 to 6 GeV^2, as the ratio R is effectively unknown, and the projected ratio based on previous kaon production data predict a rapid increase of the uncertainties at higher values of Q^2. However, it should be emphasized that the run plan requires only minor adjustments to reach a value of Q^2=8 GeV^2, should new data indicate that the uncertainties would be acceptable. In order to examine the contribution from 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 scan of the $-t$ dependence at Q^2=0.40, 1.25, 2.00 and 3.00 GeV^2 will provide L/T separated data, from which the contributions of σ_L and σ_T to Λ and Σ^0 final states can be determined. This would provide important information about the role of K and K^* exchange contributions (in the t-channel). If the K pole contribution at low $-t$ for the $K^+\Lambda$ channel dominates σ_L, these data could be used to extract the kaon form factor analogous to the π^+ case [14]. In particular, a comparison of F_K extracted from the Q^2=0.40 GeV^2 point with the elastic form factor data at CERN will allow for a check of the overall normalization. To avoid introducing additional experimental uncertainties, it is preferable that such a test be conducted as
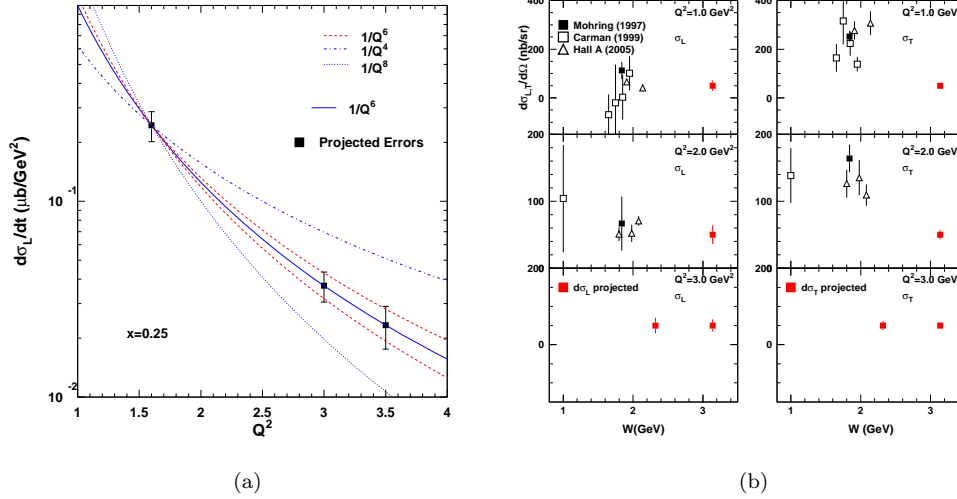
FIG. 3: *(a) Projected uncertainties for the Q^2 dependence of σ_L at x_B=0.25. The red dashed curves assume a form $1/Q^n$, and indicate the precision with which one may fit the exponent. The numerical values of the projected sensitivity for fitting the Q^2 dependence are listed in Table IV in our 2009 submission. (b) Projected uncertainties of the first L/T separated kaon cross sections above the resonance region at Q^2=1,2,3 GeV^2.*

close as possible to the elastic data. The data at higher Q^2 could provide the first such extraction of the form factor above the resonance region. Keeping the low $-t$ constraint in mind, we have chosen kinematics with values of $-t$ that are less than three times the pole value.

A. Particle Identification

A detailed discussion on hadron identification in the SHMS can be found in our 2009 submission. Here, we discuss recent developments on additional instrumentation needed to distinguish kaons with momenta above 2.6 GeV/c from protons, which is necessary to successfully carry out this experiment. The simplest and most economical way of meeting this requirement is with a kaon aerogel Čerenkov detector. One of us is leading a consortium of four universities, with non-lead partners the Jefferson Lab and Yerevan Physics Institute, and was awarded a major research instrumentation grant by the National Science Foundation in October 2010 to build this detector. Further details can be found in the Appendix.

III. PROJECTED ERROR AND TIME ESTIMATE

Rate estimates are slightly higher by about 15 % than in our 2009 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

TABLE I: *Beam time estimates for the $p(e, e'K^+)\Lambda$ (Σ^0) measurement assuming 85 μA and SHMS solid angle of 4.5 msr on a 8-cm LH2 target. The projected number of hours includes three θ_K settings at high ϵ and two θ_K settings at intermediate and low ϵ.*

Q^2 (GeV^2)	x_B	ϵ	LH$_2$ hours	Dummy hours	Overhead (hours)	Total (hours)
0.40	0.072	0.411	94.1	6.4	4	104.5
0.40	0.072	0.692	62.1	4.3	4	70.4
Subtotal charge radius			156.2	10.7	8.0	174.9 (7.3 days)
1.25	0.122	0.477	13.6	1.0	4	18.6
1.25	0.122	0.696	10.6	0.7	4	15.3
2.00	0.182	0.396	44.2	3.0	4	51.2
2.00	0.182	0.584	24.7	1.7	4	30.4
2.00	0.182	0.751	24.5	1.7	4	30.2
3.00	0.250	0.393	77.2	5.4	4	86.6
3.00	0.250	0.689	54.0	3.8	4	61.8
Subtotal reaction mech.			248.8	17.3	28.0	294.1 (12.3 days)
1.70	0.249	0.587	20.4	1.4	4	25.8
1.70	0.249	0.858	11.9	1.0	4	16.9
3.50	0.250	0.357	46.4	0.4	4	50.8
3.50	0.250	0.555	38.8	0.3	4	43.1
Subtotal x_B=0.25			117.5	3.1	16.0	136.6 (5.7 days)
3.00	0.401	0.634	9.9	0.7	4	14.6
3.00	0.401	0.887	6.0	0.4	4	10.4
4.40	0.400	0.480	30.2	2.1	4	36.3
4.40	0.400	0.734	21.4	1.5	4	27.0
5.50	0.400	0.366	79.3	5.5	4	88.8
5.50	0.400	0.560	68.7	4.8	4	77.5
Subtotal x_B=0.40			215.5	15.0	24.0	254.5 (10.6 days)
Subtotals						860.1
Calibrations						48.0
beam energy changes						48.0
Total						956.1 (39.8 days)

will be slightly smaller once an acceptance defining collimator has been added). The corresponding increase in rate is largely directly proportional to the increase in solid angle. The gain in rate is partially compensated by a reduction in the maximum beam current from $90\mu A$ to 85 μA, required by the maximum beam current limits at 12 GeV JLab.

To illustrate the sensitivity of the experiment, the projected uncertainties of the Q^2 depen-

dence of the K^+ longitudinal cross section are shown in Figure 3(a). The filled symbols indicate the proposed K^+ measurement. We assume at least 1,000 good events at x_B=0.25 and 800 good events at x_B=0.40 for each ϵ setting to determine the Q^2 dependence of the reaction. The uncertainties on the proposed points have been estimated using the VGL/Regge model for both longitudinal and transverse cross sections, assuming an uncorrelated systematic uncertainty of 2.1% in the unseparated cross section, and correlated uncertainties as listed in Table III in our 2009 proposal. The projected uncertainty in the fitting of the exponent in the Q^n dependence are listed in Table IV in our 2009 submission.

To investigate the normalization of the kaon form factor, we will take a data point at the very low Q^2=0.4 GeV^2 setting, which is in close proximity to the elastic e-K scattering kaon form factor results from CERN.

Our total time request is for 35.8 days of data, but additional time ($\approx$ 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 and additional 8 hour overhead for each beam energy change. The cryogenic target length is taken to be 8 cm, as explained in our 2009 proposal.

IV.   SUMMARY

In summary, we propose to use the SHMS and HMS spectrometers in Hall C to perform L/T separations of the $p(e, e', K^+)\Lambda, \Sigma^0$ reactions over a broad region of Q^2 and x. These will be the first high quality L/T separations for exclusive strangeness production from the proton above the resonance region.

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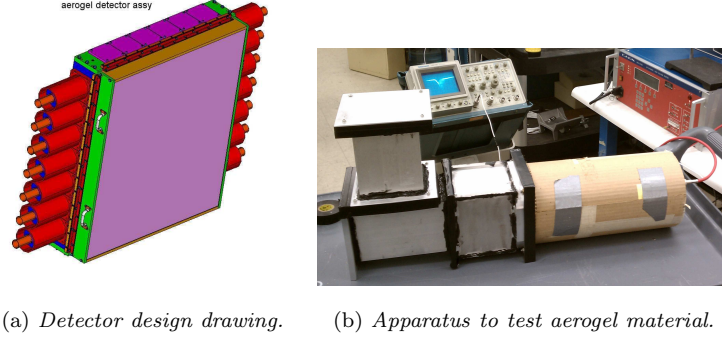(a) *Detector design drawing.* (b) *Apparatus to test aerogel material.*

FIG. 4: *SHMS kaon aerogel detector.*

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V.   APPENDIX A: CHARGED KAON IDENTIFICATION

The Catholic University of America (CUA) has received a major research instrumentation grant (MRI) from the NSF to obtain a working kaon aerogel Cerenkov detector to carry out the strange physics program in Hall C at 12 GeV. The detector will consist of a layer of silica aerogel in a diffuse reflection box. The light will be collected on the long sides by 5-inch (12.7 cm) photomultiplier tubes (PMTs). Figure 4 shows the design of the detector.

The detector project is well underway. Since the start of the award, simulations and mechanical design were completed and component selection was finalized. The procurement of the components is ongoing. In this process, CUA is taking advantage of an unique opportunity to obtain large-diameter photomultiplier tubes and aerogel of two refractive indeces from the successful BLAST experiment at MIT/Bates. The delivery of these components is expected in July. Their performance will be evaluated during the summer and fall, for instance, with a prototype to evaluate the aerogel. The construction of the diffusion box will begin in the next few months at the CUA machine shop. The detector will be assembled and tested in 2012, making it ready for checkout and data taking from the start of the 12 GeV era in Hall C. If needed, the capability of the detector can be further expanded in the future by adding other indices.