Charting the evolution of the Strong Interaction's degrees of freedom

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Abstract Knowledge of the Universe as constructed by human beings can be thought to be organized at varying scales of observation to tackle its complexity. Implicit in such an approach is the idea of a smooth evolution of knowledge between scales and, therefore, access to how Nature constructs the visible Universe, beginning from its most fundamental constituents. New and, in a sense, fundamental phenomena may typically be emergent as the scale of observation changes. The study of the Strong Interactions, which is responsible for the contruction of the bulk of the visible matter in the Universe (98% by mass), in this sense, is a labor of exploring evolutions and unifying aspects of its knowledge found at varying scales: from interaction of quarks and gluons as represented by the theory of pQCD at high four momentum transfers (Q^2) to emerging dressed quark and even meson-baryon degrees of freedom mostly described by effective models as Q^2 decreases. In this paper we will introduce a collaborative research framework that is directly dedicated to this effort and note how our ongoing experimental analysis – extraction of observables from electro-production of $\pi^+\pi$ off the proton – will provide data towards this end.

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* This work is in parts supported by the US National Science Foundation under the Grant PHY-1205782

1 N* program

The N* program is an international collaborative effort that uses the electromagnetic excitation and the subsequent decay of nucleon resonances as a basis to investigate the dynamics of the Strong Interaction. Experimentally measured cross-sections (or observables) from photo- ($Q^2 = 0\ GeV^2$) and electro-production reactions ($Q^2 > 0\ GeV^2$) off the nucleon, at various values of W ($\sqrt{s}$; the invariant mass of the photon and nucleon system) serve as an input to reaction models that strive to extract all contributing, independent resonant and non-resonant reaction amplitudes that encapsulate the dynamics of the Strong Interaction. The information contained in the resonant reaction amplitudes provides a basis for comparison of predictions from models and QCD based calculations. Figure 1 illustrates this process.

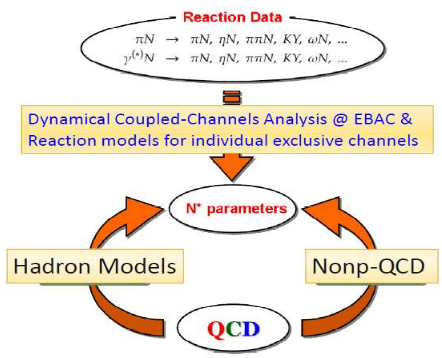

Fig. 1 Epistemological framework of the N* program [1]

A key goal of the process is to be able to define and measure a complete set of observables such that all independent resonant reaction amplitudes can be unambiguously extracted.

Tables II and I in Ref. [2] list the observables defined for the simplest case of pseudoscalar meson photo- and electro-production, respectively. The definitions are based on the various combinations of photon-/beam- (photo-/electro-production), target- and recoil-polarization that can, at least in theory, be determined in the initial and final state of the reaction. Note that not all observables need to be measured: the number of complex independent resonant reaction amplitudes for photo- and electro-production are 4 and 6, respectively, corresponding to a minimal set of 8 and 12 real observables, respectively. Often in the literature experiments in which the minimal set of observables can be measured are called complete experiments.

Photo- in contrast to electro-production experiments are closer to measuring the minimal set of observables and a significant part of the collaborative effort is dedicated towards this end. While photo-production experiments at the real photon point have been vital in the area of Baryon Spectroscopy and in establishing resonant reaction amplitudes at $Q^2 = 0\ GeV^2$, it is the relatively, recently successful electro-production experiments with tunable Q^2 that serve to probe the evolving dynamics of the Strong Interaction, the importance of which was used as a motivation for this paper.

In the next section we will briefly present a preliminary set of observables measured from electro-production of $\pi^+\pi$ off the proton that will serve as an input to the Jefferson Laboratory-Moscow State University (JM) reaction model.

2 Observables from the electro-production of $\pi^+\pi$ off the proton

For the first time the observables $(R_L^{00}+R_T^{00}), R_{LT}^{00}$ and R_{TT}^{00} [2] are being measured in the reaction channel $p\pi^+\pi$ and will add to the single-differential cross-sections – observables that are defined irrespective of polarization – that were thus far measured. Each observable is obtained as a function of Q^2, W, and X^{ij}, where X^{ij} is a variable taken from one of the 3 sets of the 5 kinematical d.o.f. (expressed in center of mass system (CMS) of the reaction) in which the fully differential reaction cross-section can be expressed. Three sets of variables are employed because the intermediate N* resonance can decay in 3 different modes and each one of the 3 sets of variables is sensitive to a particular decay mode and therefore sensitive to extracting different resonant reaction amplitudes. Note that X^{ij} includes only variables that are unique in each variable set and excludes the ϕ degree of freedom. The X^{ij} in which the observables are obtained are listed below, and Figure 2 illustrates the angular kinematics of variable set 1.

1. $M_{p\pi^+}, \theta_{\pi^-}, \alpha_{[p'\pi^+][p\pi^-]}$
2. $M_{\pi^+\pi^-}, \theta_p, \alpha_{[\pi^+\pi^-][p'p]}$
3. $M_{p\pi^-}, \theta_{\pi^+}, \alpha_{[p'\pi^-][p\pi^+]}$

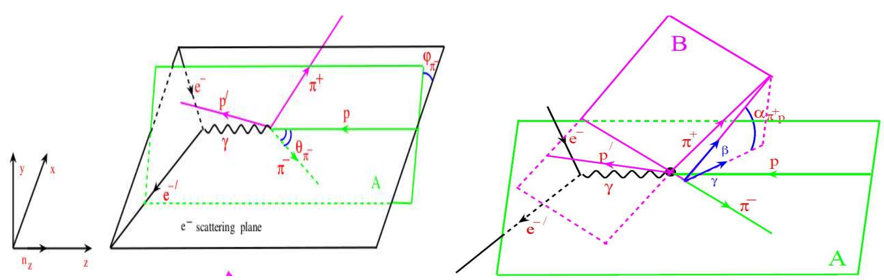

Fig. 2 Illustration of angular kinematics of variable set 1. Left side: $\theta_{\pi^-}, \phi_{\pi^-}$. Right side: $\alpha_{[p'\pi^+][p\pi^-]}$

The Q^2 and W coverage of the analysis is between 1.25-5.25 GeV^2 and 1.30-3.00 GeV, and the observables are measured in bins of width 0.5 GeV^2 and 0.025 GeV, respectively. This is illustrated in Figure 3, in which the bin bound by Q^2 =

[1.25,1.75] GeV^2 and W = [1.625,1.650] GeV is highlighted to note that the preliminary observables shown in this paper belong to this bin.

Figure 4 shows preliminary results for the single-differential yields that are obtained independent of the photon polarization and the observable $(R_L^{00} + R_T^{00})$, whereas Figure 5 shows preliminary results for the observables R_{LT}^{00} and R_{TT}^{00}.

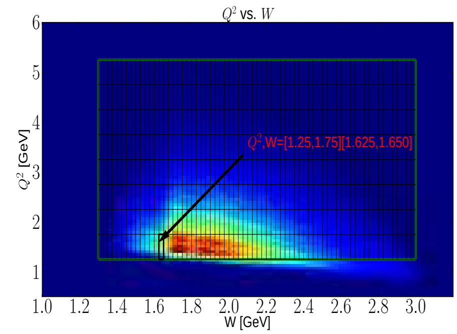

Fig. 3 Q^2 and W coverage of the $p\pi^+\pi$ reaction channel. The bin bound by Q^2 = [1.25,1.75] GeV^2 and W = [1.625,1.650] GeV is highlighted to note that the preliminary observables shown in this paper belong to this bin.

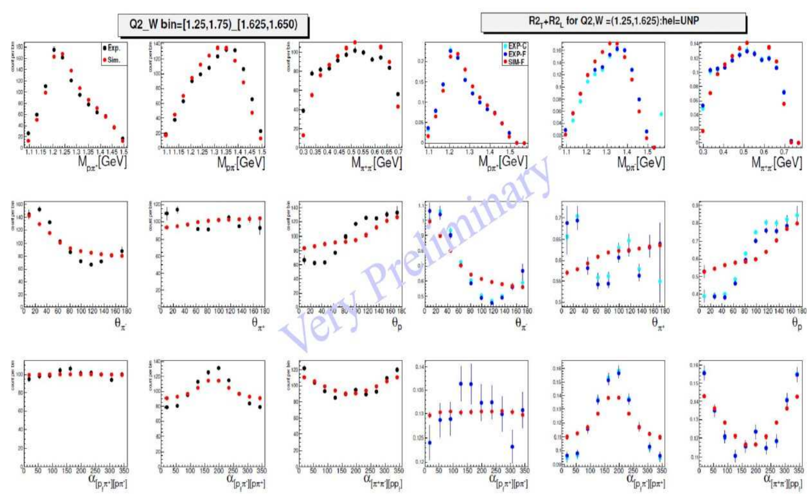

Fig. 4 Left side: Single differential yields that are obtained independent of the photon polarization. Black points are from experimental data and the red points represent information currently encapsulate in the JM reaction model. Right side: Observable $(R_L^{00} + R_T^{00})$. Blue and cyan points are from experimental data, representing model-dependent (JM) and model-independent results, respectively; the red points represent information currently encapsulated in the JM reaction model.

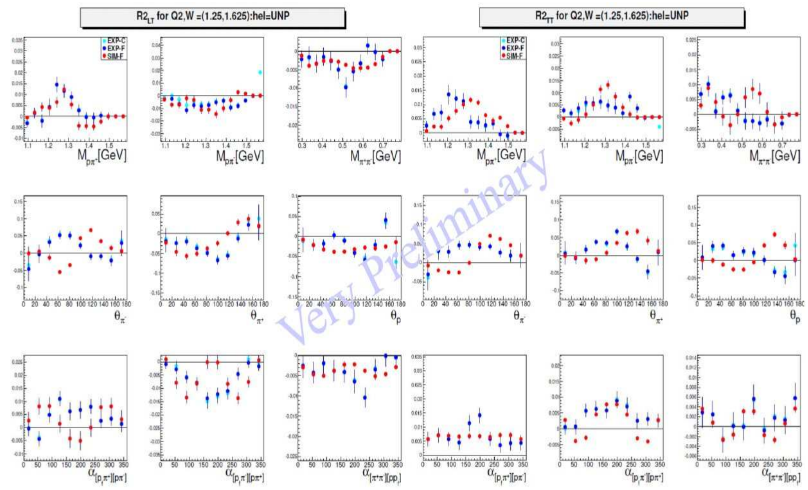

Fig. 5 Left side: Observable R^{00}_{LT}. Right side:R^{00}_{TT}. For both, blue and cyan points are from experimental data, representing model-dependent (JM) and model-independent results, respectively; the red points represent information currently encapsulated in the JM reaction model.

3 Summary and outlook

Once the observables presented in the previous section are finalized, they will serve as input to the JM reaction model, from which resonant reaction amplitudes will be extracted and compared with theoretical predictions.

In this epistemological model of interplay between experiment and theory, the N* collaboration strives to chart the scale dependence of the knowledge of the Strong Interaction, which is fundamental to understanding the synthesis of the visible Universe from its fundamental constituents. Ref. [3] contains an overview of significant results from the N* program and developments in this direction.

References

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