Measurement of the Coulomb quadrupole amplitude in the $\gamma^* p \to \Delta(1232)$ in the low momentum transfer region

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Abstract

We propose to make a measurement of the $p(e, e'p)\pi^o$ reaction in the Δ resonance at the low momentum transfer region using the two HRS spectrometers in Hall A. The primary goal of this experiment is to precisely determine the Coulomb quadrupole amplitude behavior at low Q^2 and to provide valuable information regarding the mechanisms that contribute to the nucleon deformation. Measurements will be performed at three momentum transfer settings. The first one at $Q^2 = 0.040$ (GeV/c)^2 will extend even lower the Coulomb quadrupole amplitude measurements (from the currently lowest measured value at $Q^2 = 0.060$ (GeV/c)^2). The other two will be performed at $Q^2 = 0.090$ (GeV/c)^2 and $Q^2 = 0.125$ (GeV/c)^2. The $Q^2 = 0.125$ (GeV/c)^2 one will bridge and validate previous measurements from other labs while providing results of significantly inproved experimental uncertainty. The cross section will be measured at various proton angles with respect to the momentum transfer direction and for azimuthal proton angles 0° and 180° relative to the momentum transfer direction and the reaction plane. The σ_{LT} response function, which exhibits significant sensitivity to the Coulomb quadrupole amplitude, will be extracted as well as the combination cross section $\sigma_o + \epsilon \cdot \sigma_{TT}$. Cross section measurements will also be performed along the momentum transfer direction for various invariant mass values in order to address the Bates and MAMI experimental differences exhibited to the parallel cross section measurements as a function of W. Both the Coulomb quadrupole and the magnetic dipole amplitudes will be very precisely determined. The Q^2 evolution of the Coulomb quadrupole amplitude will be precisely mapped. The extracted measurements will provide significant information into understanding the role of the pionic cloud contribution to the nucleon deformation which is expected to maximize in the low momentum transfer region and will offer strong constraints and guidance to the most recent theoretical calculations. We request for a $E_o = 1115\,MeV$ beam at $I = 75\,\mu A$, a 6 cm liquid hydrogen target and a total of 3 experiment days for the proposed experiment.

I. INTRODUCTION

Understanding the origin of possible non-spherical components in the nucleon wavefunction has been the subject of an extensive experimental and theoretical effort in recent years [1–27]. The complex quark-gluon and meson cloud dynamics of hadrons give rise to non-spherical components in their wavefunction which in a classical limit and at large wavelengths will correspond to a "deformation". The signature of the deformation of the proton is sought in the presence of resonant quadrupole amplitudes ($E_{1+}^{3/2}, S_{1+}^{3/2}$) in the predominantly magnetic dipole ($M_{1+}^{3/2}$) $\gamma^* N \rightarrow \Delta$ transition [28, 29]. Nonvanishing resonant quadrupole amplitudes will signify that either the proton or the $\Delta^+(1232)$ or more likely both are deformed. The ratios CMR $= Re(S_{1+}^{3/2}/M_{1+}^{3/2})$ and EMR $= Re(E_{1+}^{3/2}/M_{1+}^{3/2})$ are routinely used to present the relative magnitude of the amplitudes of interest.

The origin of the deformation is attributed to a number of different processes depending on the interpretative framework adopted. In the constituent-quark picture of hadrons, it arises as a consequence of the non-central color-hyperfine interaction among quarks [1, 2], while in dynamical models of the πN system, deformation also arises from the asymmetric coupling of the pion cloud to the quark core. Our current understanding of the nucleon suggests that at long distances (low momenta) the pionic cloud effect dominates while at short distances (high momenta) intra-quark forces dominate. Recent precise experimental results [3–20] are in reasonable agreement with predictions of models invoking deformation and in strong disagreement with all nucleon models that assume sphericity for the proton and the delta; they thus confirm the conjecture of deformed hadrons. With the existence of non-spherical components in the nucleon wavefunction well established, recent investigations have focused on understanding the various mechanisms that could generate it.

In this proposal we focus on the low moment transfer region where the pionic cloud effects are expected to dominate (see Fig. 1). While the behavior of EMR is well understood in this region, more work needs to be done as far as CMR is concerned. In order to understand the underlying physics and to precisely identify the mechanisms involved to the nucleon deformation a better mapping of the CMR is essential in the low momentum transfer region. CMR measurements have not yet been achieved lower than $Q^2 = 0.060$ (GeV/c)^2 while at the same time the picture remains relatively unclear at the $Q^2 = 0.127$ (GeV/c)^2 point where the measurements from various experiments [6, 13, 17, 30] either barely agree within the experimental error bars while exhibiting differences in their central values or in some cases the experimental uncertainties exceed the desired ones. As a result the CMR picture at this Q^2 value remains relatively cloudy compared to the level of experimental uncertainty that is both required but that is also currently achieveable. Furthermore, clear discrepancies of the parallel cross section as a function of the invariant mass have been observed between the Bates and MAMI measurements [30] which are not able to be justified by the experimental uncertainties. In this work we propose to perform a set of measurements of the $p(e, e'p)\pi^0$ reaction on the $\Delta(1232)$ resonance that will allow us to determine the CMR at $Q^2 = 0.125$ (GeV/c)^2 with the best precision at this Q^2 value and that will also allow to clarify the parallel cross section discrepancies between the other labs. Furthermore we will also perform a set of measurements at $Q^2 = 0.090$ (GeV/c)^2 and $Q^2 = 0.040$ (GeV/c)^2 that will also provide a very precise value for the CMR while extending our knowledge of the Coulomb quadrupole amplitude to a new momentum transfer squared minimum. Acquiring the above measurements one provides theory with very precise constraints regarding the model descriptions and allows the determination of the mechanisms involved in the effect of nucleon deformation.

The cross section of the $p(e, e'p)\pi^0$ reaction is sensitive to four independent partial cross sections ($\sigma_T, \sigma_L, \sigma_{LT}$ and σ_{TT}) [26] :

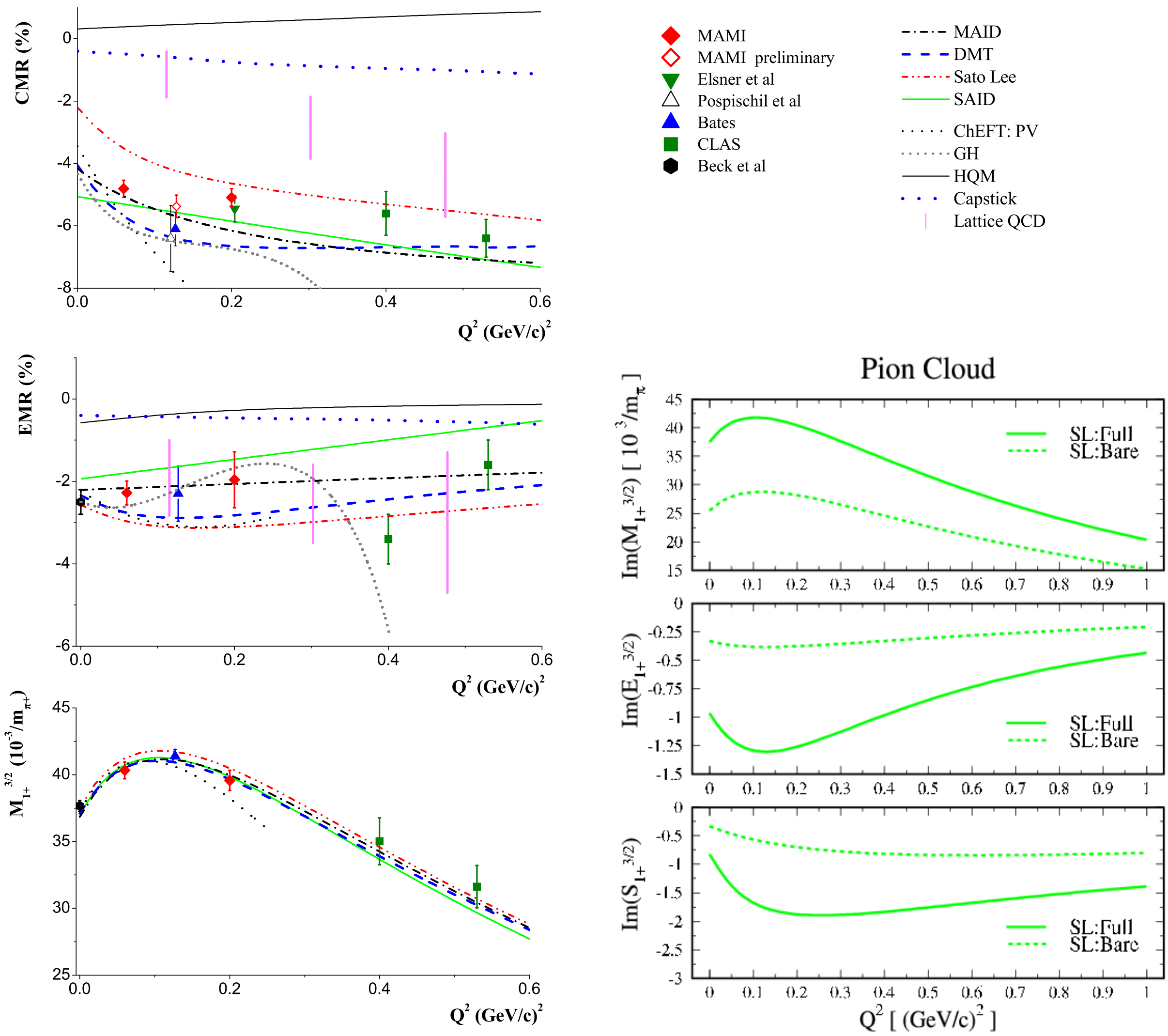

FIG. 1: The CMR, EMR and magnetic dipole amplitude are shown as measured in the low momentum transfer region by [4, 6, 10, 13, 15–17, 32]. The theoretical calculations of [2, 21–25, 27, 33–35] are also presented. On the right the effect of the pionic cloud to the resonant amplitudes is exhibited as predicted by the Sato-Lee calculation.

$$\frac{d^5\sigma}{d\omega d\Omega_e d\Omega_{pq}^{cm}} = \Gamma(\sigma_T + \epsilon\cdot\sigma_L - v_{LT}\cdot\sigma_{LT}\cdot\cos\phi_{pq}^* + \epsilon\cdot\sigma_{TT}\cdot\cos 2\phi_{pq}^*)$$

where ϵ is the transverse polarization of the virtual photon, $v_{LT} = \sqrt{2\epsilon(1+\epsilon)}$, Γ the virtual photon flux, and ϕ_{pq}^* is the proton azimuthal angle with respect to the electron scattering plane. The differential cross sections $(\sigma_T, \sigma_L, \sigma_{LT}, \sigma_{TT})$ are all functions of the center of mass energy W, the four momentum transfer squared Q^2, and the proton center of mass polar angle θ_{pq}^* (measured from the momentum transfer direction) [26]. The $\sigma_0 = \sigma_T + \epsilon\cdot\sigma_L$ cross section is dominated by the M_{1+} resonant multipole. The interference of the $C2$ and $E2$ amplitudes with the $M1$ dominates the

Longitudinal - Transverse (LT) and Transverse - Transverse (TT) responses respectively:

$$R_L \frac{\omega_{cm}^2}{Q^2} = \mid L_{0+} \mid^2 + 4 \mid L_{1+} \mid^2 + \mid L_{1-} \mid^2 - 4Re\{L_{1+}^* L_{1-}\} + 2cos\theta Re\{L_{0+}^*(4L_{1+} + L_{1-})\} + 12cos^2\theta(\mid L_{1+} \mid^2 + Re\{L_{1+}^* L_{1-}\})$$

$$R_T = \mid E_{0+} \mid^2 + \frac{1}{2} \mid 2M_{1+} + M_{1-} \mid^2 + \frac{1}{2} \mid 3E_{1+} - M_{1+} + M_{1-} \mid^2 + 2cos\theta Re\{E_{0+}^*(3E_{1+} + M_{1+} - M_{1-})\}$$
$$+ cos^2\theta(\mid 3E_{1+} + M_{1+} - M_{1-} \mid^2 - \frac{1}{2} \mid 2M_{1+} + M_{1-} \mid^2 - \frac{1}{2} \mid 3E_{1+} - M_{1+} - M_{1-} \mid^2)$$

$$R_{LT} \sqrt{\frac{\omega_{cm}^2}{Q^2}} = -sin\theta Re\{L_{0+}^*(3E_{1+} - M_{1+} + M_{1-}) - (2L_{1+}^* - L_{1-}^*)E_{0+} + 6cos\theta(L_{1+}^*(E_{1+} - M_{1+} + M_{1-}) + L_{1-}^* E_{1+})\}$$

$$R_{TT} = 3sin^2\theta(\frac{3}{2} \mid E_{1+} \mid^2 - \frac{1}{2} \mid M_{1+} \mid^2 - Re(E_{1+}^*(M_{1+} - M_{1-}) + M_{1+}^* M_{1-}))$$

In this experiment we will focus on the measurement of the σ_{LT} and on the precise extraction of the Coulomb quadrupole amplitude in the low momentum transfer region. With the proposed experiment we will perform cross section measurements at $\phi_{pq}^* = 0°, 180°$ for various θ_{pq}^* angles and along the momentum transfer direction and we will extract σ_{LT}, $\sigma_o + \epsilon \cdot \sigma_{TT}$ and the A_{LT} asymmetry at various proton angles. A set of parallel cross section (σ_o) measurements as a function of the invariant mass W will also be performed. The experimental cross sections will enable us to determine precisely the CMR and the magnetic dipole amplitude from $Q^2 = 0.040$ (GeV/c)^2 up to $Q^2 = 0.125$ (GeV/c)^2. Strong constraits to the theoretical calculations and insight into the mechanisms that contribute to the nucleon deformation will be provided.

II. THE EXPERIMENT

For the proposed experiment standard Hall A equipment will be used. The two HRS spectrometers will be used to detect electrons and protons, respectively. A 6 cm liquid hydrogen target and an electron beam of $E_o = 1115\,MeV$ and $I = 75\,\mu A$ will also be required. The beam energy will be the same throughout the experiment. The standard detector packages of the HRS spectrometers will be used [36]; The timing information will be provided from scintillators, tracking will be provided by the VDCs while the particle identification will be obtained from the Cherenkov detectors and the lead-glass shower counters.

A set of measurements will be taken at $Q^2 = 0.040$, 0.90 (GeV/c)^2 and 0.125 $(GeV/c)^2$ and for θ_{pq}^* up to 55°. The currently lowest CMR measurement was performed at MAMI [16]; space limitations not allowing the spectrometers to be placed at an in-plane angle smaller than 15.0° was the reason that limited this measurement to $Q^2 = 0.060$ (GeV/c)^2. The Hall A experimental setup allows the spectrometers to be placed down to 12.5° thus allowing to access a new lowest of $Q^2 = 0.040$ (GeV/c)^2. This along with the high resolution provided by the HRS spectrometers form the ideal conditions for performing the proposed measurements in Hall A.

For every fixed θ_{pq}^* value measurements will be taken at $\phi_{pq}^* = 0°$ and 180°. By taking advantage of the $\cos\phi_{pq}^*$ dependence of σ_{LT} and the $\cos 2\phi_{pq}^*$ of the σ_{TT} to the total cross section one can isolate the σ_{LT} and the $\sigma_o + \epsilon \cdot \sigma_{TT}$ as well as the A_{LT} asymmetry. Measurements along the momentum transfer direction will also be taken on the top and at the wings of the resonance. The experimental results will allow the precise extraction of both CMR and the magnetic dipole amplitude at all measured Q^2 points. The details of all the experimental settings along with the required run time are summarized in Table I.

At the requested beam energy of $E_o = 1115\,MeV$ one is able to access the lowest Q^2 possible given the space limitations in the Hall. Nevertheless, if needed, and in order to accommodate the beam requirements of other experiments (such as Qweak) there will be flexibility for the beam energy to be adjusted. A beam energy range of 60 MeV range from $E_o = 1100\,\mathrm{MeV}$ to $E_o = 1160\,MeV$ will not affect the requested beam time nor the extracted uncertainties of the experiment; it will only have a slight effect of a shift to the Q^2 central value of the lowest momentum transfer setting; a beam energy of $E_o = 1160\,\mathrm{MeV}$ (where this shift would be maximal) will result to a measurement at $Q^2 = 0.043$ $(\mathrm{GeV}/c)^2$ instead of $Q^2 = 0.040$ $(\mathrm{GeV}/c)^2$.

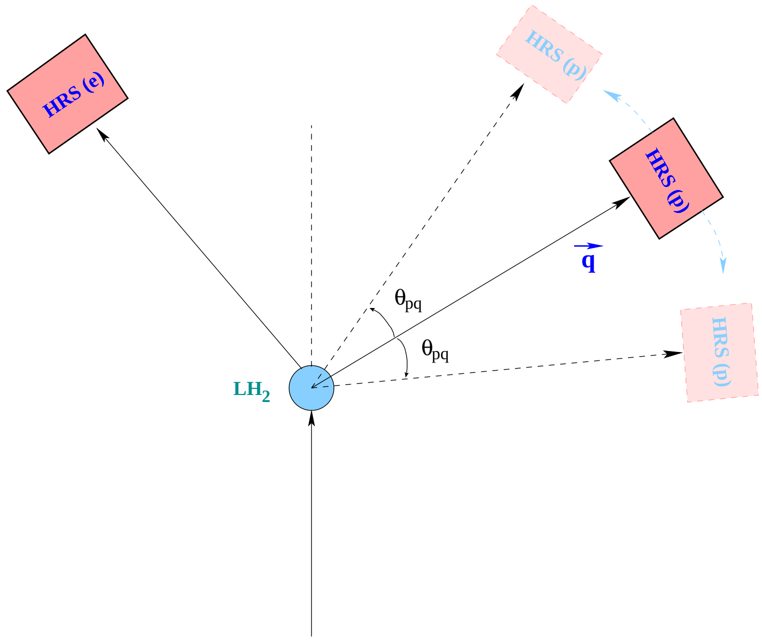

FIG. 2: Schematic of the experimental setup.

III. DATA ANALYSIS AND COUNT RATE ESTIMATES

Monte-Carlo studies have been performed for all the proposed kinematics using the computer code MCEEP [37]. This code averages a physics model over the finite acceptances of the experimental apparatus and includes the effects of offsets and finite resolutions. The phase space results and the kinematical correlations of W, θ^*_{pq} and Q^2 for the measurements taken at $\phi^*_{pq} = 0°$ and 180° settings are presented in Fig. 3 and Fig. 4. For the extraction of σ_{LT} in particular the phase space volumes of the two ϕ^*_{pq} measurements will be matched. Analysis bins will be selected to be of ±4 MeV width in W and ±2.5° in θ^*_{pq}. For the $Q^2 = 0.040$, 0.90 $(\mathrm{GeV}/c)^2$ and $Q^2 = 0.125$ $(\mathrm{GeV}/c)^2$ measurements the bin size width will be $\pm 0.003\,(\mathrm{GeV}/c)^2$, $\pm 0.004\,(\mathrm{GeV}/c)^2$ and $\pm 0.0045\,(\mathrm{GeV}/c)^2$ respectively. Cross sections will be measured for these bins and from them the σ_{LT} will be extracted. The average cross section over the analysis bin will first be defined. Then by using theoretical model calculations (MAID, SAID, Sato-Lee, DMT) and folding them over the analysis bin acceptance one is able to extract the point cross sections at the desired kinematical point (W, Q^2, θ^*_{pq}) at the center of the analysis bin. The transition from average to point cross section has been studied with MCEEP for all proposed setups and for the size of the analysis bins that we have selected it will result into a less than 2.5% correction to the extracted central value with an uncertainty of less than 0.4% as

$Q^2 (GeV/c)^2$	$W (MeV)$	$\theta_{pq}^{*\circ}$	θ_e°	$P_e^{'} (MeV/c)$	θ_p°	$P_p^{'} (MeV/c)$	*Time (hrs)*
0.040	1221	0	12.52	767.99	24.50	547.54	1.5
0.040	1221	30	12.52	767.99	12.52	528.12	2
0.040	1221	30	12.52	767.99	36.48	528.12	3.5
0.040	1260	0	12.96	716.42	21.08	614.44	1.5
0.090	1230	0	19.14	729.96	29.37	627.91	1.5
0.090	1230	40	19.14	729.96	14.99	589.08	3
0.090	1230	40	19.14	729.96	43.74	589.08	4.5
0.125	1232	0	22.94	708.69	30.86	672.56	3.5
0.125	1232	30	22.94	708.69	20.68	649.23	7
0.125	1232	30	22.94	708.69	41.03	649.23	7
0.125	1232	55	22.94	708.69	12.52	596.43	3.5
0.125	1232	55	22.94	708.69	49.19	596.43	3.5
0.125	1170	0	21.74	788.05	37.31	575.57	3
0.125	1200	0	22.29	750.16	34.06	622.63	2
Configuration changes							17
Calibrations							8
							Total: 72 hrs

TABLE I: The kinematical settings of the experiment and the beam time request for each one. The beam energy will be $E_o = 1115\,MeV$ throughout the experiment. A 6 cm liquid hydrogen target and a beam current of $I = 75\,\mu A$ have been used for the count rate estimates.

quantified by the small deviation resulting by applying the extraction of the point cross section using the different model calculations.

For the calculations of the count rates and the beam time request the MAID parametrization of the multipole amplitudes was used and folded over the experimental acceptance using the code MCEEP. The beam time request for all the proposed kinematical settings is summarized in Table I. With the beam time requested we will have a better than ±1% statistical uncertainty for the cross sections in each analysis bin. A 6 cm liquid hydrogen target and a beam of $I = 75\,\mu A$ and $E_o = 1115\,MeV$ have been used for the calculations and the count rate estimates. A very conservative estimate of 20% dead time and a 99% detection efficiency have been assumed.

From the two cross sections ($\phi_{pq}^* = 0^\circ, 180^\circ$) matched at the kinematical phase space (W, Q^2, θ_{pq}^*) the σ_{LT} and $\sigma_o + \epsilon \cdot \sigma_{TT}$ will be extracted while the measurements along the momentum transfer direction will provide the σ_o directly. The effect of the systematic uncertainties (uncertainties of the beam energy, scattering angle, beam charge, target density, spectrometer acceptance, detector efficiency, dead time, etc) has been studied and taken into account in the expected errors for the cross sections, responses and resonant amplitudes. The effect of the systemetic uncertainties to the cross sections will be ±3%. The resulting total uncertainty (statistical+systematic) for the σ_{LT} will range from 6% to 8% (or better) depending on the kinematics . The fact that for each Q^2 set of measurements the beam energy and scattered electron kinematics are kept fixed (while the proton angle and momentum are the only experimental quantities varied) is an advantage for providing a better control of systematic effects. A good control of the extracted results and the systematics will also be provided by the variation of the analysis bin size; variations of the analysis bin size will allow us to test the stability of the extracted results and our understanding of the systematic uncertainties. The projected σ_{LT} and σ_o for the central kinematics of $Q^2 = 0.040$ (GeV/c)^2, 0.090 (GeV/c)^2 and $Q^2 = 0.125$ (GeV/c)^2 are presented in Fig. 5 where the exhibited uncertainties correspond to the total statistical and systematic ones.

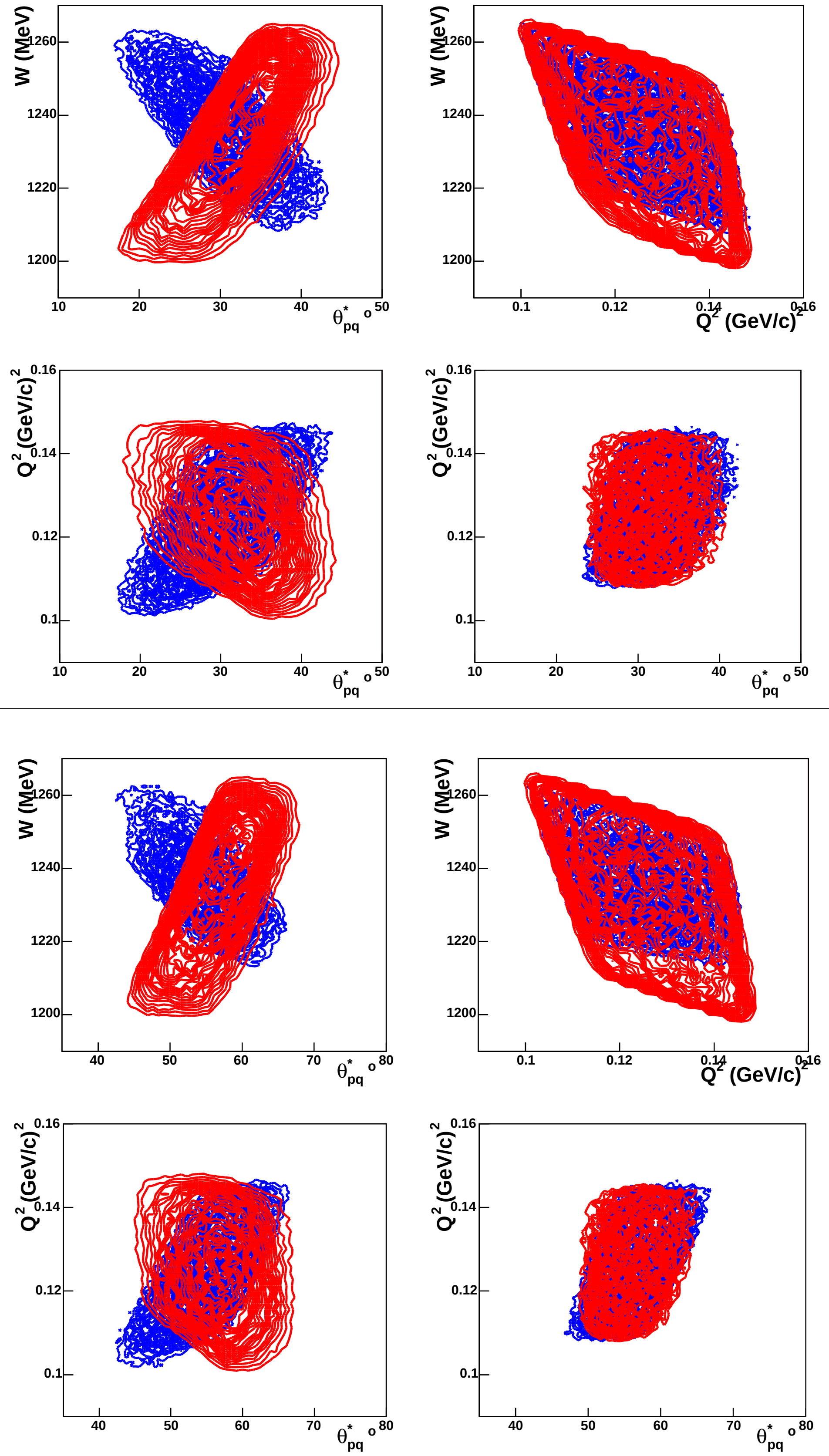

FIG. 3: Phase space overlap and correlation of the kinematical variables at $Q^2 = 0.125$ (GeV/c)^2 for the $\phi^*_{pq} = 0^\circ$ and $\phi^*_{pq} = 180^\circ$ measurements (top for $\theta^*_{pq} = 30^\circ$ and bottom for $\theta^*_{pq} = 55^\circ$). Bottom-right figure in both panels includes a ± 5 MeV cut in W at the center of the acceptance.

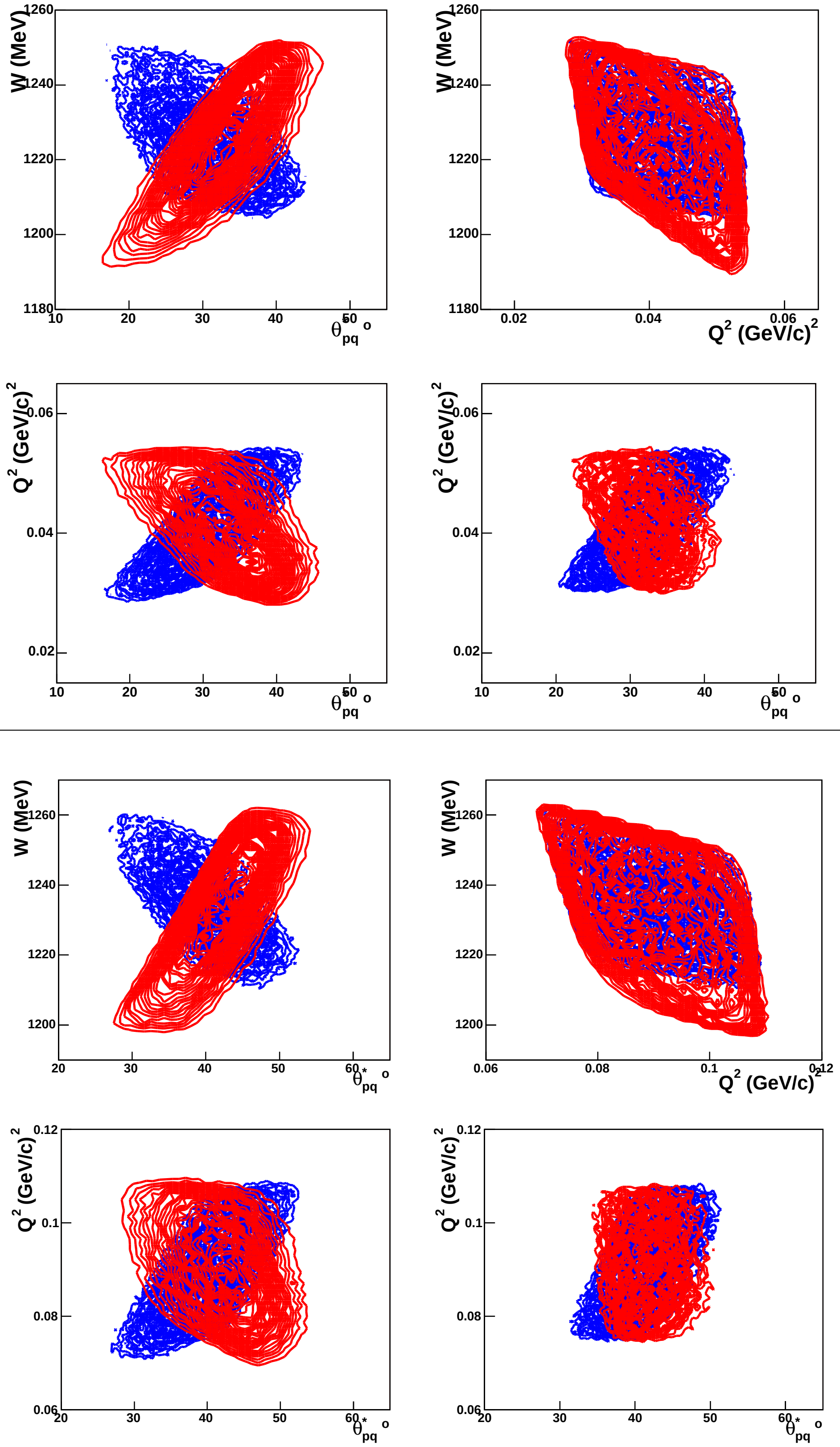

FIG. 4: Phase space overlap and correlation of the kinematical variables at $Q^2 = 0.040$ (GeV/c)^2 (top) and $Q^2 = 0.090$ (GeV/c)^2 (bottom) for the $\phi^*_{pq} = 0^\circ$ and $\phi^*_{pq} = 180^\circ$ measurements. Bottom-right figure in both panels includes a ±5 MeV cut in W at the center of the acceptance.

$Q^2(GeV/c)^2$	$W(MeV)$	θ^*_{pq} °	ϕ^*_{pq} °	R_{accid} (Hz)	$R(e,e'p)$ (Hz)
0.040	1221	0	–	21.7	202
0.040	1221	30	0	25.2	111
0.040	1221	30	180	16.3	268
0.040	1260	0	–	12.4	77
0.090	1230	0	–	5.1	85
0.090	1230	40	0	7.0	51
0.090	1230	40	180	2.9	108
0.0125	1232	0	–	2.4	56
0.0125	1232	30	0	3.4	40
0.0125	1232	30	180	1.5	79
0.0125	1232	55	0	3.9	37
0.0125	1232	55	180	0.9	128
0.0125	1170	0	–	2.2	56
0.0125	1200	0	–	2.8	85

TABLE II: The trues and accidentals coincidence rates for the various settings. Note that for the calculations a wide missing-mass cut of 60 MeV around the pion mass has been applied; the missing mass cut which will be used during the analysis will be more tight and thus the accidentals rates will be further reduced. A coincidence time window of 2 ns has been assumed.

Regarding the case of the lowest Q^2 kinematics, since measuring as low as possible in Q^2 is very essential, the phase space coverage of the two spectrometers will enable us to match the phase space acceptances and to extract the σ_{LT} also at $Q^2 = 0.038$ (GeV/c)^2 and $\theta^*_{pq} = 30°$. Additional cross section measurements will be extracted for $Q^2 = 0.036$ (GeV/c)^2 at ($\theta^*_{pq} = 27°, \phi^*_{pq} = 0°$) and ($\theta^*_{pq} = 36°, \phi^*_{pq} = 180°$). These cross sections will not be matched between the two spectrometers in order to provide the σ_{LT} but they nevertheless are quite important because of their lowest Q^2 kinematics. All of the these measurements will also be characterized by a better than 1% statistical uncertainty.

The resonant amplitudes will be fitted to the measured cross sections in the same procedure as previously followed with measurements in the low momentum transfer region in [15, 16] where the background contributions to the extraction of the resonant amplitudes will be evaluated by taking into account the background amplitudes from the available theoretical models (MAID, DMT, SAID and Sato-Lee) into the fits. The result will be derived by the χ^2 weighted average of the fits. The RMS deviation of the fitted results wil be indicative of the model uncertainty. The Coulomb quadrupole and the magnetic dipole amplitudes will be precisely determined from the measured cross sections at $Q^2 = 0.040$, 0.090 (GeV/c)^2 and 0.125 $(GeV/c)^2$. The extracted experimental (statistical+systematic) CMR uncertainties will be better than 0.20%, 0.25% and 0.28% for $Q^2 = 0.125$, 0.090 (GeV/c)^2 and $Q^2 = 0.040$ (GeV/c)^2, respectively. The model uncertainty introduced by the contribution of the non-resonant amplitudes will be at the level of 0.30% in all cases. The CMR value at $Q^2 = 0.125$ (GeV/c)^2 will be the most precise one at this momentum transfer. The CMR at $Q^2 = 0.040$ (GeV/c)^2, along with one σ_{LT} measurement at $Q^2 = 0.038$ (GeV/c)^2 and a set of spectrometer cross sections at $Q^2 = 0.036$ (GeV/c)^2, will extend our knowledge of the Coulomb quadrupole amplitude to a new lowest Q^2.

The θ^*_{pq} range covered by the proposed measurements exhibits great similarities to the coverage of the previous MAMI measurements in the low Q^2 region[15, 16]; at the proposed $Q^2 = 0.125$ (GeV/c)^2 kinematics the cross sections will be measured up to $\theta^*_{pq} = 57.5°$ (equivalent to the MAMI measurements at $Q^2 = 0.20$ (GeV/c)^2 [15]) while at the $Q^2 = 0.040$ (GeV/c)^2 kinematics we will cover up

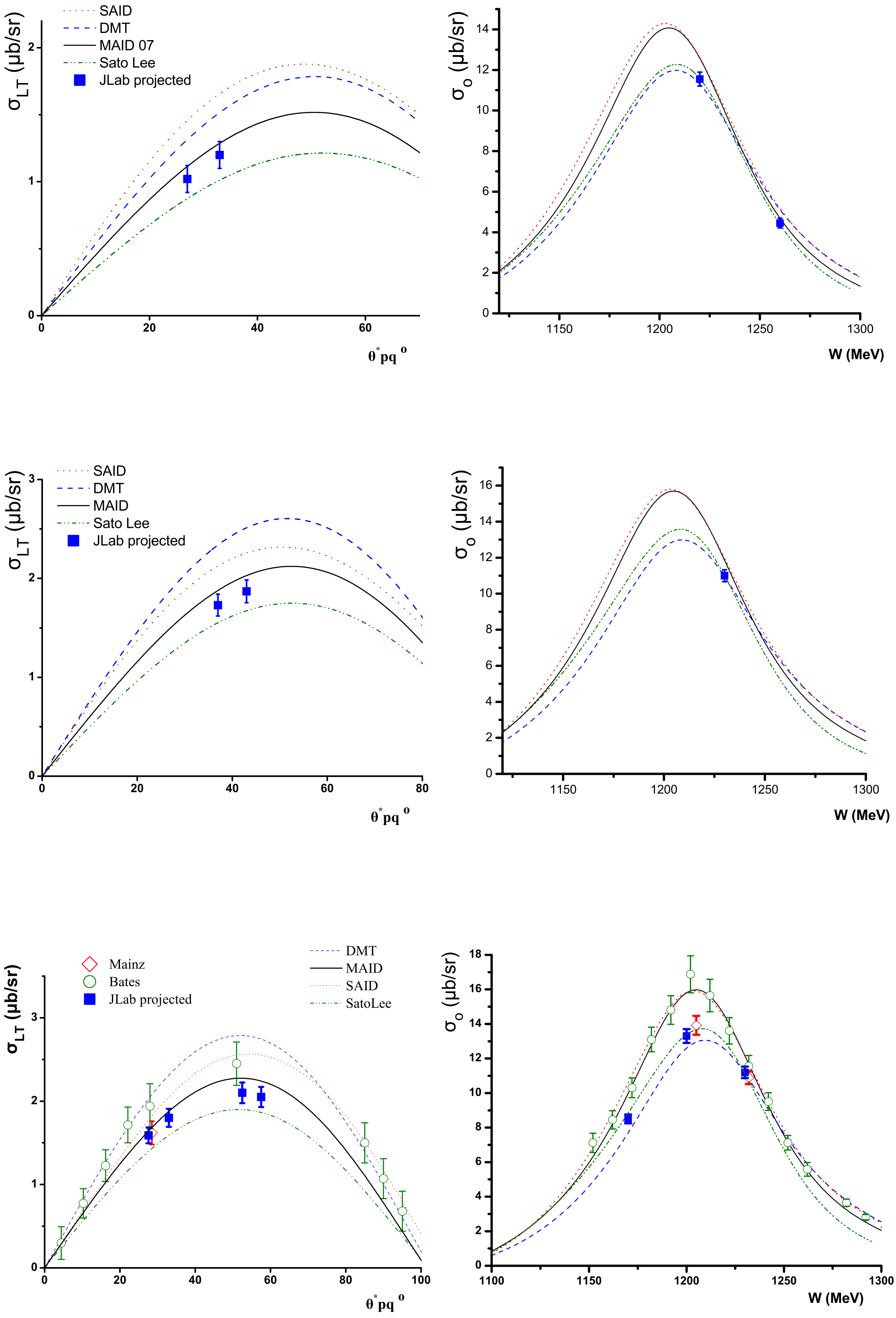

FIG. 5: Extracted (projected) σ_{LT} and σ_o at $Q^2 = 0.040$ (GeV/c)^2 (top), $Q^2 = 0.090$ (GeV/c)^2 (middle) and $Q^2 = 0.125$ (GeV/c)^2 (bottom). The $Q^2 = 0.125$ (GeV/c)^2 ones are presented along with the corresponding MAMI and Bates results.

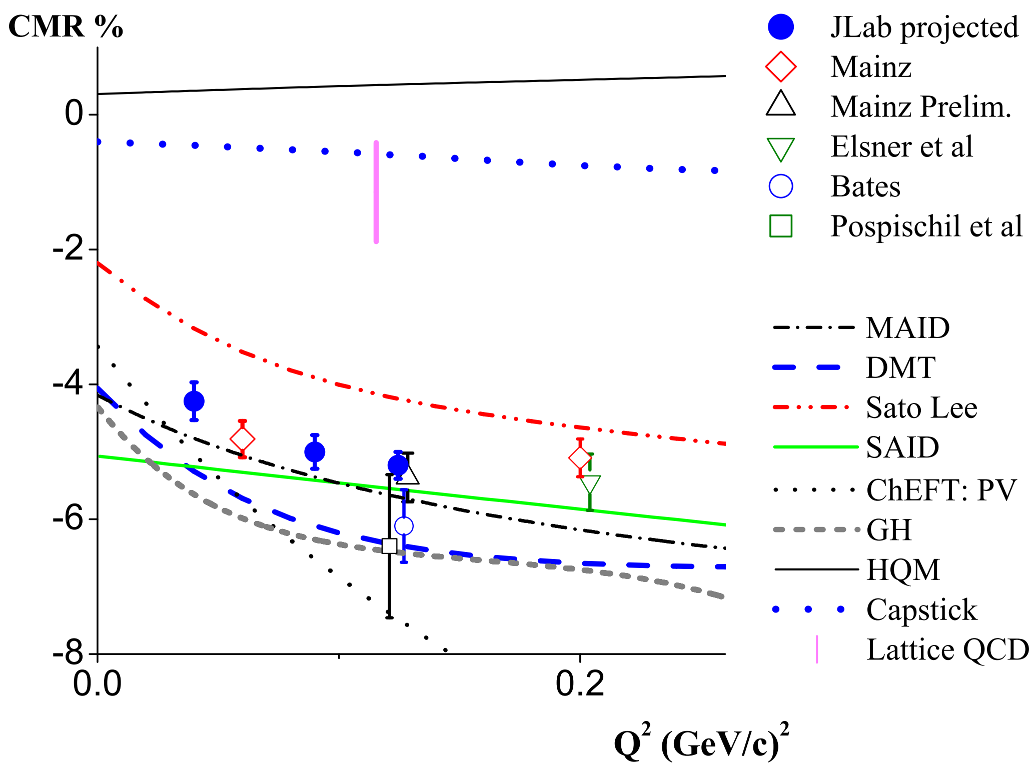

FIG. 6: The CMR measurements at the low momentum tranfer region along with the theoretical predictions of MAID, DMT, SAID, Sato-Lee, Capstick, HQM, the linearly extrapolated Lattice-QCD calculation, ChEFT of Pascalutsa-Vanderhaegen and the Gail-Hemmert. The projected JLab results from the proposed measurements are also presented.

to $\theta^*_{pq} = 33°$ (similar to the MAMI ones at $Q^2 = 0.060$ (GeV$/c)^2$ [16]). Furthermore the proposed data will be more precise than the [15, 16] ones since the higher angles of the MAMI measurements due to space limitations were not taken at ($\phi^*_{pq} = 0°, \phi^*_{pq} = 180°$) but at ($\phi^*_{pq} = 40°, \phi^*_{pq} = 180°$) thus resulting to a larger uncertainty to the extraction of σ_{LT}. As a result the CMR will be extracted with an uncertainty equivalent or smaller than the values extracted at [15, 16].

The experimental results, as exhibited in Fig. 5, will provide very strong constraints on all modern theoretical calculations. The precision of the σ_{LT} results will definitely force the various theoretical frameworks to readjust their parameters and the description of the resonant amplitudes; this could ideally lead to the convergence of the various models thus providing a set of consistent solutions to the same physical problem within different theoretical frameworks. Furthermore issues such as the discrepancies between the MAMI and the Bates results at $Q^2 = 0.127$ (GeV$/c)^2$ will be resolved. There is a definite disagreement to the description of the parallel cross section σ_o as a function of the invariant mass as exhibited in Fig. 5; there is also some potential systematic overestimation of the Bates cross sections on resonance relative to the MAMI ones which are nevertheless in good agreement within errors. The Bates parallel cross section measurements point to an excellent agreement with the MAID and SAID description while on the other hand, although limited in their extent, the MAMI ones indicate disagreement with MAID and SAID and agreement with the Sato-Lee prediction. A very extensive mapping of the parallel cross section as a function of W performed at MAMI [15, 16, 30] both lower and higher of this Q^2 point (at $Q^2 = 0.060$ (GeV$/c)^2$ and $Q^2 = 0.20$ (GeV$/c)^2$)

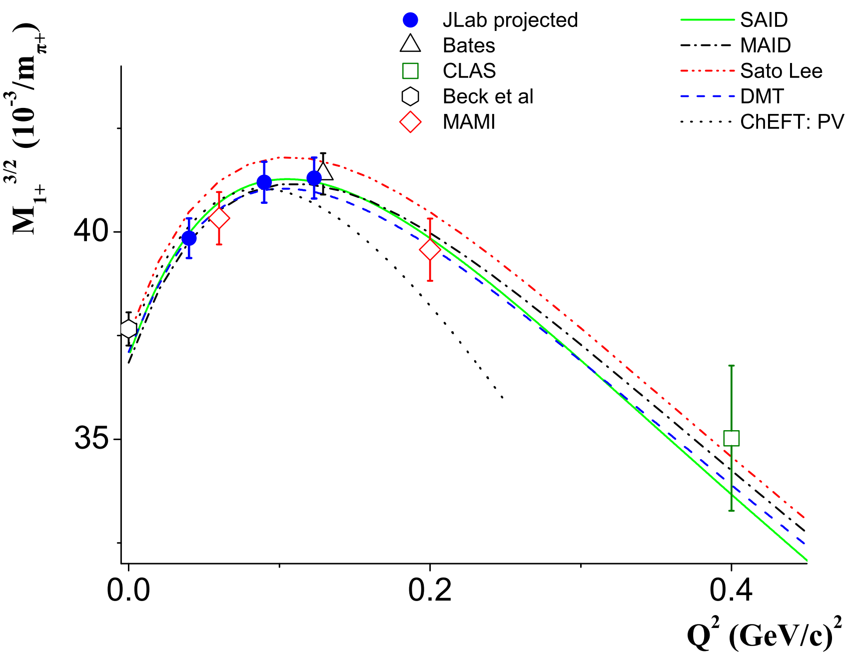

FIG. 7: The magnetic dipole amplitude measurements at the low momentum tranfer region along with the theoretical predictions of MAID, DMT, SAID, Sato-Lee, and the ChEFT of Pascalutsa-Vanderhaegen. The projected JLab results from the proposed measurements are also presented.

also exhibited excellent agreement to the Sato-Lee description and disagreement to the MAID and SAID ones. Clarifying the picture at this Q^2 point is very important in order to be able to have a precise and clear understanding of the low momentum transfer picture of the quadrupole amplitudes. The proposed measurements will clarify this open point.

In Fig. 6 the current experimental and theoretical status of the CMR at the low momentum tranfer region is presented along with the projected JLab results from the proposed measurements. The precision of these results will contribute maximally to the precise description of this regime, will provide insight to the behavior of CMR as we approach the $Q^2 = 0$ (GeV$/c)^2$ point and will provide the experimental information required in order to precisely identify the pionic cloud effects that contribute significantly to the deformation at this region.

IV. SUMMARY

We propose to make a measurement of the $p(e, e'p)\pi^o$ reaction at the Δ resonance in the low momentum transfer region using the two HRS spectrometers in Hall A. Exploiting the unique capabilities of Hall A, namely high precision kinematic definition and ability to place the spectrometers at a small angle, the Coulomb quadrupole amplitude will be measured with high precision, its Q^2 behavior will be studied while a measurement will be provided at a new Q^2 lowest value of 0.040 (GeV$/c)^2$. Cross sections providing additional information on the low Q^2 dependence of the CMR will also be extracted down to 0.036 (GeV$/c)^2$. Discrepancies among the measurements of other labs will be addressed. Strong constraints will be provided to the recent theoretical calculations as well as valuable insight into the mechanisms that contribute to the nucleon deformation, especially the pionic cloud contributions which are expected to dominate in this region. Hall A standard equipment will be used for this experiment. **We request for a $E_o = 1115\,MeV$ beam at $I = 75\,\mu A$, a 6 cm liquid hydrogen target and a total of 3 experiment days (as described in Table I) for the proposed experiment.**

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