STUDY OF THE Δ STRUCTURE AND NΔ INTERACTIONS WITH N(e, e'p) AND d(e, e'p) REACTIONS

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A dynamical approach for using the γN → πN and N(e, e'π) reactions to test the chiral constituent quark model is reviewed. Recent results for the Δ excitations and predictions for future experiments are presented. It is shown that the polarization observables of d(e, e'π) reactions are useful for investigating the NΔ interactions which are crucial in exploring the Δ components in nuclei and the properties of Δ-rich systems created in relativistic heavy-ion collisions.

1 Introduction

With the developments of new electron beam facilities and the associated sophisticated detectors, the opportunities for exploring the nonperturbative QCD aspects of hadron and nuclear dynamics will be unprecedented in the next few years. In this talk, I will focus on two subjects that can be studied with the BLAST at MIT-Bates. I will first discuss how to use the γN → πN and N(e, e'π) reactions to test the chiral constituent quark model of hadron structure. I then will discuss how the d(e, e'π) reaction can be used to investigate the NΔ interactions which are crucial in determining the Δ components in nuclei and the properties of Δ-rich systems created in relativistic heavy-ion collisions; a subject of current interest.

All of the existing theoretical studies of πN and γN reactions can be classified into two different formulations. The first one is the dispersion-relations approach. In this approach, the dynamics is defined by imposing crossing symmetry, analyticity, high-energy behavior, and appropriate subtraction terms on the reaction amplitudes. This approach was developed by Chew, Goldberger, Low and Nambu in 1950's and has been revived recently by the Mainz group. The second formulation is based on effective lagrangians. Within this framework, there are three different approaches. The first one is the K-matrix approach which uses only the πN scattering phase shifts to account for the πN final state interactions. The second one is the Chiral Perturbation Theory which is applicable only at energies near the production threshold and for low momentum-transfer processes. The third approach is the dynamical approach which is aimed at testing the QCD-based hadron structure models. In this talk I will focus on the development of the dynamical approach and present
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our recent results.

2 Dynamical Approach

The starting point of a dynamical approach is a hadron structure calculation which predicts the masses of the excited states ($N^*$) of the nucleon. In practice, this calculation can be done accurately only in the absence of the couplings with decay channels. These masses are therefore called the bare masses which do not correspond to either the resonance positions of the $\pi N$ and $\gamma N$ data or the resonance poles determined in the empirical amplitude analyses. At the present time, the most complete baryon structure calculations are based on various constituent quark model\(^7\).\(^8\). But the predictions from other hadron structure calculations, such as the Lattice QCD calculations, can also be identified with the bare masses of the dynamical approach.

The next step is to introduce the couplings of these bare states with the meson and photon fields. In the earlier studies, the forms of these couplings are chosen phenomenologically according to the observed symmetries such as isospin conservation, chiral symmetry, and gauge invariance. For some starting hadron models, such as the chiral bag model\(^8\) or the chiral constituent quark model\(^8\)\(^,\)\(^9\) we are going to discuss later, the couplings can be related to the predicted quark substructure of $N$ and $N^*$ states.

In Ref\(^5\), we focus on the $N \rightarrow \Delta$ transition. By including the interactions with $\pi, \rho, \omega$ and $\gamma$ fields and applying a unitary transformation method, we obtain an effective Hamiltonian for describing the $\pi N$ scattering and $\gamma N \rightarrow \pi N$ reactions up to the $\Delta$ excitation energy region. It takes the following form:

$$H_{\text{eff}} = H_0 + \sum_{\alpha=\gamma N, \pi N} \Gamma_{\Delta^* \alpha} + \sum_{\alpha, \beta=\gamma N, \pi N} v_{\alpha, \beta}, \quad (1)$$

where the two-body interactions $v_{\alpha, \beta}$ are defined by the meson-exchange mechanisms. The bare masses for defining the free Hamiltonian $H_0$ and the bare vertex interactions $\Delta \rightarrow \pi N, \gamma N$ are identified with the predictions from the starting hadron structure calculation.

It is straightforward to derive from Eq.(1) the scattering amplitudes for $\pi N \rightarrow \pi N$ and $\gamma N \rightarrow \pi N$ reactions. The essential step is to apply the standard projection operator technique of nuclear reaction theory\(^1\). The resulting scattering amplitude can be cast into the following form

$$T_{\alpha, \beta}(E) = t_{\alpha, \beta}(E) + \tilde{\Gamma}_{\alpha \rightarrow \Delta}(E) G_{\Delta}(E) \tilde{\Gamma}_{\Delta \rightarrow \beta}(E). \quad (2)$$

The first term is the nonresonant amplitude determined only by the two-body
meson-exchange interactions

\[ t_{\pi N,\pi N}(E) = v_{\pi N,\pi N} + v_{\pi N,\pi N}G_{\pi N}(E)t_{\pi N,\pi N}(E), \]
\[ t_{\gamma N,\pi N}(E) = v_{\gamma N,\pi N} + v_{\gamma N,\pi N}G_{\pi N}(E)t_{\pi N,\pi N}(E), \]

with

\[ G_{\pi N}(E) = \frac{P_{\pi N}}{E - E_N(k) - E_\pi(k) + i\epsilon}, \]

where \( P_{\pi N} \) is the projection operator for the \( \pi N \) subspace. The second term of Eq. (2) is the resonant amplitude determined by the dressed \( \Delta \) propagator and the dressed vertex functions. They are defined by

\[ G_\Delta(E) = \frac{P_\Delta}{E - m_\Delta - \Sigma_\Delta(E)}, \]

and

\[ \Gamma_{\pi N \rightarrow \Delta}(E) = \Gamma_{\pi N \rightarrow \Delta} + t_{\pi N,\pi N}(E)G_{\pi N}(E)\Gamma_{\pi N \rightarrow \Delta}, \]
\[ \Gamma_{\gamma N \rightarrow \Delta}(E) = \Gamma_{\gamma N \rightarrow \Delta} + \gamma_{\gamma N,\pi N}(E)G_{\pi N}(E)\Gamma_{\pi N \rightarrow \Delta}(E), \]

where \( P_\Delta \) is the projection operator for the \( \Delta \) state, and the \( \Delta \) self-energy is defined by

\[ \Sigma_\Delta(E) = \Gamma_{\pi N \rightarrow \Delta}G_{\pi N}(E)\Gamma_{\Delta \rightarrow \pi N}(E). \]

In the work of Ref.\(^5\), we did not start with a hadron structure calculation. Therefore the bare mass of the \( \Delta \) and the bare vertex interactions \( \Gamma_{\Delta \rightarrow \pi N} \) of the effective Hamiltonian are treated phenomenologically. Our first task was to determine the parameters of the hadronic part of the effective Hamiltonian Eq.(1) by fitting the \( \pi N \) phase shifts. Our results were presented and discussed in Ref.\(^5\). For this talk, it is only necessary to emphasize that the resulting bare mass of the \( \Delta \) is \( \sim 1300 \text{ MeV} \) which is considerably higher than the resonance position 1236 MeV of the \( \pi N \) cross section data. Furthermore, the resulting \( N \rightarrow \pi N \) and \( \Delta \rightarrow \pi N \) form factors are very soft with an about 650 MeV cutoff for a dipole parameterization.

We now turn to discussing our results of pion photoproduction. With the vertices associated with \( \pi \) and \( \rho \) mesons determined by the \( \pi N \) scattering, the effective Hamiltonian Eq.(1) still has unknown parameters associated with the \( \omega \) meson and the \( \gamma N \rightarrow \Delta \) vertex. We assume that the tensor coupling \( \kappa_{\omega NN} = 0 \) and the \( \omega NN \) form factor is identical to the \( \rho NN \) form factor. The coupling
constant $g_{\omega NN}$ is not well determined in the literature and is therefore treated as a free parameter. Thus, our investigation of pion photoproduction has three adjustable parameters: $G_M(0)$ and $G_E(0)$ of the bare $\Delta \leftrightarrow \gamma N$ vertex, and the coupling constant $g_{\omega NN}$ of $\omega$ exchange. With $G_M(0) = 1.85, G_E(0) = +0.025$ and $g_{\omega NN} = 10.5$, we find that all of the available $\gamma N \rightarrow \pi N$ data can be reproduced very well, as illustrated in Fig. 1 for the LEGS data\(^6\).

Fig. 1. The calculated $d\sigma/d\Omega$ and $R_\gamma = d\sigma_\parallel/d\sigma_\perp$ of the $\gamma p \rightarrow \pi^0 p$ reactions are compared with the data\(^6\).

We also find that the data can be fitted equally well with $G_M(0) = 1.95, G_E(0) = -0.025$ and $g_{\omega NN} = 7.0$.

We now focus on the theoretical interpretations of the $\Delta \leftrightarrow \gamma N$ vertex. The dressed $\Delta \leftrightarrow \gamma N$ vertex, defined by Eq. (8), is a complex number. By making the usual partial-wave decomposition, its magnetic $M_1$ and electric $E_2$ components can be written as $\Gamma(\alpha) = [\Gamma(\alpha)]e^{i\phi(\alpha)}$ with $\alpha = M_{1+}, E_{1+}$. The
predicted dressed vertex functions $\Gamma(\alpha)$ are displayed in Fig. 2. We see that their magnitudes $|\Gamma(\alpha)|$ are very different from the corresponding values of the bare $\Delta \leftrightarrow \gamma N$ vertex. The differences are due to the very large contribution of the nonresonant reaction mechanism described by the second term of Eq. (8).

Our results in Fig. 2 indicate that it could be misleading in comparing the branching ratios predicted by the constituent quark models $^{7,8,9}$ with the values extracted from the empirical amplitude analyses. In those analyses, the $\pi N$ final-state interactions and the intrinsic quark excitations are both included in the extracted resonant amplitudes. This can be seen by comparing the predicted helicity amplitudes with the values listed by the Particle Data Group (PDG)$^{7}$. We show in Ref$^{5}$ that our bare values are close to the constituent quark model predictions$^{8,9}$, and the dressed values are close to the values of PDG$^{7}$. This suggests that the large differences between the constituent quark model predictions and the PDG values are due to the nonresonant meson-exchange production mechanisms. Similar considerations must be taken into account in comparing the PDG values with the predictions of other hadron structure calculations and in investigating the higher mass $N^*$ resonance parameters.

![Graphs showing dressed and bare vertex functions](image)

Fig. 2 The dressed vertex $\tilde{\Gamma}_{\gamma N \rightarrow \Delta}$ and the bare $\Gamma_{\gamma N \rightarrow \Delta}$ are compared.
The dynamical model of Ref 5 has been extended to make predictions for 
$N(e, e'\pi)$ reactions. Here we focus on the results relevant to several experi-
ments being conducted at MIT-Bates. As a first step to help the experimental 
efforts in the past few years, we had made predictions based on the simplest 
assumption that the electromagnetic form factors for the $\gamma N \rightarrow \Delta$ transition 
are taken to be $G_M(q^2) = G_M(0)G_E^p(q^2)$ and $G_E(q^2) = G_E(0)G_E^p(q^2)$, where 
$G_E^p(q^2) = 1/(1-q^2/\Lambda^2)^2$ with $\Lambda^2 = 0.71 (\text{GeV/c})^2$ is the well measured proton 
form factor. The charge component $G_C(q^2)$ of the $\gamma N \rightarrow \Delta$ form factor is cal-
culated from $G_M(q^2)$ and $G_E(q^2)$ using the long wavelength approximation. 
In Fig.3, we see that our predictions are in good agreement with the avail-
able data. The comparison of our predictions of $A = [d\sigma(\phi = 0) - d\sigma(\phi = 180)]/[d\sigma(\phi = 0) + d\sigma(\phi = 180)]$ with the most recent data18 from MIT-Bates 
are shown in Fig.4. Here we see some significant deviations with the data at 
$W = 1236 \text{ MeV}$. This could be mainly due to our use of the very naive form 
factors for the $\gamma N \rightarrow \Delta$ transition.

![Diagram](image)

**Fig.3** The predicted differential cross sections of $p(e, e'\pi^0)$ reactions are 
compared with the data.
3 Chiral Constituent Quark Model Calculations

Encouraged by the results of Ref.3, as briefly described above, we have started to apply our dynamical approach to test various constituent quark models in conjunction with the new experiments being conducted at MIT-Bates and Jefferson Laboratory. In this talk, I will briefly describe our approach and present some preliminary results for the $\Delta$ excitation. Our complete results will be published elsewhere6.

![Graph](image)

Fig.4 The predicted $A_\theta$ are compared with the recent data8 from MIT-Bates.

It is now well recognized that the chiral constituent quark model can be qualitatively related to QCD. Here I just mention the essential steps in reaching this conclusion. Because the masses of up, down, and strange quarks are small compared with the typical hadron scale about 1 GeV, the QCD is approximately invariant under $[SU(3)]_L \times [SU(3)]_R$ chiral symmetry. Since the
parity-doubling spectra are not observed experimentally, this symmetry must be broken spontaneously. The hadron structure can then be described equivalently by an effective lagrangian for constituent quarks interacting with octect mesons. It must also include a part containing all complications due to gluons. In the low energy region, one can integrate out the short-range or high momentum dynamics and obtain a Hamiltonian with interactions between constituent quarks due to the low-order gluon-exchange and boson-exchange mechanisms. The forms of these interactions and the relative importance between them are not known and can only be determined phenomenologically.

The above rationale is further supported by a recent Lattice QCD calculation\textsuperscript{10}. It is therefore reasonable to assume that a Hamiltonian for relating the $\pi N$ and $\gamma N$ reactions to the quark-substructure of $N$ and $\Delta$ is of the following form

$$H = H_B + \sum_{B,B'} \left[ (h_{\pi B,B'} + h_{\gamma B,B'}) + (h.c.) \right],$$

where $B$ and $B'$ are the eigenstates of an one-baryon Hamiltonian $H_B$. In the simplest nonrelativistic model, it is defined by

$$H_B = \sum_i \left( m_q + \frac{p_i^2}{2m_q} \right) + V + V_{\text{conf}},$$

where $V_{\text{conf}} = \sum_{i>j} \alpha_i \delta_{ij}$ is the usual linear confinement potential. The quark-quark residual interaction $V$ is due to the exchange of Goldstone bosons and gluons. The vertex interactions in Eq.(10) are calculated from the baryon wavefunctions and quark operators

$$f_{B,\pi B'} = \langle B | \sum_i f_{\pi q,q}(i) | B' \rangle,$$

$$f_{B,\gamma B'} = \langle B | \sum_i f_{\gamma q,q}(i) | B' \rangle.$$

In the simplest nonrelativistic model, the above quark-meson and quark-photon interactions are defined by the following matrix elements

$$\langle \vec{p}'_i | f_{\gamma q,q} | \vec{p}_i \rangle = \frac{1}{\sqrt{2k}} \frac{1}{\sqrt{(2\pi)^3}} \frac{e_i}{2m_q} \left( \vec{p}_i + \vec{p}'_i - i\vec{q}_i \times \vec{k} \right) \cdot \vec{\epsilon}_\lambda(\vec{k}) \delta(\vec{p}'_i - \vec{p}_i + \vec{k}),$$

$$\langle \vec{p}'_i | f_{\pi q,q} | \vec{p}_i \rangle = \frac{1}{\sqrt{2E_\pi(k)}} \frac{1}{\sqrt{(2\pi)^3}} \frac{f_{\pi q q}(i)}{m_\pi} \left( i\sigma_i \cdot \vec{k} - \frac{E_\pi(k)}{2m_q} (\vec{p}_i + \vec{p}') \right) \delta(\vec{p}'_i - \vec{p}_i + \vec{k}).$$
Within the dynamical approach of Ref\textsuperscript{5}, the vertices defined by Eqs. (12)-(15) for \( B = \Delta \) and \( B' = N \) are identified with the vertices \( \Gamma_{\Delta,\gamma N} \) and \( \Gamma_{\Delta,\pi N} \) of the bare vertices in Eq.(1). Accordingly the \( \Delta \) mass generated from the model Eq. (11) must be identified with the mass 1300 MeV of the bare \( \Delta \) of Eq.(1). To see whether this connection between the dynamical approach and the chiral constituent quark model can be established, we need to define the residual interaction \( V \) between constituent quarks.

To make the contact with the previous works, we assume that the interactions between constituent quarks can be written as

\[
V = f_G V_{oge} + f_M V_{ome} ,
\]

where the one-gluon-exchange(oge) potential in momentum space is

\[
V_{oge} = \sum_{i<j} \frac{4 \pi \alpha_s}{4} \lambda_i \cdot \lambda_j \left( \frac{1}{2m^2} \right) \frac{1}{4m^2} \left[ \frac{1}{q^2} \frac{1}{4m^2} \frac{1}{4m^2} \right] \left( \vec{\sigma} \cdot \vec{q} \right) \left( \vec{\sigma} \cdot \vec{q} \right) F_\pi^2(q).
\]

\( \lambda_i \) are the color SU(3) generators. Considering only the \( u \) and \( d \) quarks, the one-meson-exchange(ome) potential is then only due to the exchange of pion and eta mesons

\[
V_{ome} = V_{ome}^\pi + V_{ome}^\eta,
\]

where

\[
V_{ome}^\pi = -\sum_{i<j} \left( \frac{f_{\pi qq}}{m_\pi} \right)^2 \frac{2}{(2\pi)^3} \frac{1}{q^2} \left( \vec{\sigma} \cdot \vec{q} \right) \left( \vec{\sigma} \cdot \vec{q} \right) F_\pi^2(q)
\]

and

\[
V_{ome}^\eta = -\sum_{i<j} \left( \frac{f_{\eta qq}}{m_\eta} \right)^2 \frac{1}{(2\pi)^3} \frac{1}{q^2} \left( \vec{\sigma} \cdot \vec{q} \right) \left( \vec{\sigma} \cdot \vec{q} \right) F_\eta^2(q)
\]

Both the oge and ome potentials are regularized by a form factor of the form \( F_\pi^2(q^2) = (\Lambda^2/(q^2 + \Lambda^2)) \). This regularization is needed to remove the singular \( \delta \)-function interaction terms from the potentials. To reduce the number of parameters, we further assume that the coupling constant \( f_{\pi qq} \) can be fixed by the \( \pi NN \) coupling constant in the simple \((0s)^3\) harmonic oscillator model of nucleon. The \( f_{\pi qq} \) coupling constant is then fixed by the SU(3) relation

\[
f_{\pi qq} = \frac{m_\pi}{\sqrt{3} m_s} f_{\pi qq}.
\]
With the above formulation, we can investigate whether the $\pi N$ and $\gamma N$ reactions can distinguish three possible constituent quark models. For $f_G = 1$ and $f_M = 0$, the above equations define the traditional constituent quark model. For $f_G = 0$ and $f_M = 1$ we have an one-meson-exchange model that is similar, but not identical, to the form proposed by Glozman and Riski. The model with $f_G = f_M = 1$ contains both the boson-exchange and gluon-exchange interactions between constituent quarks. Such a model is similar to that considered in Ref.\textsuperscript{13}.

In the $f_M = f_G = 1$ model (ogme), there are 6 parameters: $m_q$ for the quark mass, $\alpha_c$ for the linear confinement potential, $\alpha_s$ and $\Lambda_g$ for the strength and cutoff of the gluon-exchange potential, and the cutoff $\Lambda = \Lambda_\pi = \Lambda_\eta$ for the one-meson-exchange potential. Obviously, the one-gluon-exchange (oge) model with $(f_G = 1, f_M = 0)$ and the one-meson-exchange (ome) model with $(f_G = 0, f_M = 1)$ have fewer parameters.

To be consistent with the dynamical model of Ref.\textsuperscript{5}, the parameters of each considered model must be chosen to reproduce (1) $m_\Delta - m_N = (1300 - 938.5)\text{ MeV}$, (2) $G_M(0) \sim 2.0, G_E(0) \sim \pm 0.025$, (3) the magnetic moment $\mu_p$ of the proton, (4) the proton charge radius $\langle r^2 \rangle_p \sim 0.8$ fm, (5) the form factors $f_{\pi N,\Delta}(k)$ and $f_{\pi N,N}(k)$ with a cutoff of about 650 MeV/c in dipole form. By using the variational method developed in Ref.\textsuperscript{10}, we solve the three-body bound state problem by diagonalizing the model Hamiltonian, defined by Eqs. (11) and (16), in the space spanned by the harmonic oscillator wavefunctions. The convergent solutions are obtained when up to about $N=9$ orbitals are included. As a check of our calculation, we are able to reproduce the results of Glozman, Rapp and Plessas\textsuperscript{2} if their short-range form of Goldstone boson exchange potential is used in our calculation.

We first adjust the parameters to fit the data (1)-(3) listed above. It turns out that all of the possible constituent quark models fitted to these data yield a proton radius of only about 0.4 fm. Consequently, the predicted $\pi NN$ and $\pi N \Delta$ form factors are too hard in comparison with that of Ref.\textsuperscript{5}. It is not clear how to remove this difficulty. One obvious possibility is to carry out a relativistic calculation and to consider interactions between constituent quarks due to higher-order gluon-exchange and boson-exchange. Nevertheless, our results so far at least have demonstrated that the $\pi N$ and $\gamma N$ reactions can be useful in distinguishing the three considered constituent quark models, since their predicted form factors have significant differences. This is illustrated in Fig.5 for the $\Delta \rightarrow \gamma N$ form factors.

Clearly, much have to be done before we can use the $N(e,e'\pi)$ data, like the data of $A_H$ shown in Fig.4, to distinguish different constituent quark models. This is the focus of our current effort in order to make more realistic
predictions for the on-going OOPS measurements at MIT-Bates and possible future experiments using BLAST. Such an effort is also needed to confront the new data at high $Q^2$ from Jefferson Laboratory. This theory-experiment joint effort is needed to give a crucial test of the constituent quark model and its dynamical content.

Fig.5 The predicted $G_M$, $G_E$, and $G_C$ form factors for the $\Delta \to \gamma N$ transition. The solid, dotted and dashed curves are respectively from the oge, ome, and ogme models. See text for the definitions of these models.

4 Study of the $N\Delta$ interactions with $d(e,e'\pi)$ reactions

I now turn to pointing out one possible way of using the results from the $N(e,e'\pi)$ study described above to extract an interesting and important new physics from future experiments. We first note that a dynamical approach
based on a Hamiltonian defined by Eq.(1) will allow us to predict the electro-
production of pion on an off – shell nucleon inside a nucleus. Second, the
constructed chiral constituent quark model defined by Eqs.(10)-(15) can be
used to predict all pion and photon form factors associated with the \( \Delta \) and
higher mass \( N^* \) states. Let us focus on the \( \Delta \) state which can be studied at
MIT-Bates. The predicted \( \Delta \leftrightarrow \pi \Delta \) form factor is of particular importance
since it determines the long-range part of the \( N\Delta \) and \( \Delta \Delta \) interactions which
are crucial in understanding the properties of \( \Delta \)–rich systems created in rel-
ativistic heavy-ion collisions; a subject of current interest. Obviously, these
two interactions have short-range mechanisms which must also be determined
to make progress. Here I would like to demonstrate that this part of the
interaction can be probed by using \( d(e, e'\pi) \) reactions.

Assuming that the \( N\Delta \) interaction is due to the one-pion-exchange, the
leading amplitudes for the \( \gamma^*d \rightarrow \pi NN \) reaction are illustrated in Fig.6. With
the well developed meson-exchange model for \( NN \) scattering up to 1 GeV
and the dynamical model described above, the amplitudes of Fig.6 can be
computed with no adjustable parameters.

![Graphical representation of the leading amplitudes of \( \gamma^*d \to \pi NN \) reaction.](image)

We have performed some preliminary calculations to explore which observ-
ables of the \( d(e,e'\pi) \) reaction are most sensitive to the \( N\Delta \) interaction term
Fig.6d. We first find that the predicted cross sections are in good agreement
with the old data from Saclay. The \( N\Delta \) interaction (Fig.6d) however only gives
small effects. We have found that it is necessary to have data from experiments
with polarized deuteron targets and/or polarized incident electrons. This is il-
lustrated in Fig.7 for the kinematics that is accessible to MIT-Bates. It is clear
from Fig.7 that the polarization observables can be used to test the extent to
which the \( N\Delta \) interaction is determined by the one-pion-exchange mechanism
predicted by the chiral constituent quark model. Any deviations with the fu-
ture data will give us some information about the short-range parts of the \( N\Delta \)
interactions. One can then, for example, test the \( N\Delta \) interactions predicted
Figure 1: The predicted differential cross sections (in unit of $pb/sr^2 MeV^2$) and asymmetries for $d(e,e'\pi$) reaction at $E_e = 880$ MeV, $E_{e'} = 580$ MeV, $\theta_{e,e'} = 20^0$ and $\theta_{T,n} = 30^0$. The x-axis is the pion momentum in unit of MeV/c. The asymmetries are defined as $A(B,T)$ with B and T denoting respectively the beam and target polarization directions. The solid curves are the full calculations. The dotted curves are obtained when the $N\Delta$ interaction (Fig.6d) is turned off.
by the resonant group calculations based on the chiral constituent quark model defined by Eq.(11). One can also test some phenomenological $N\Delta$ interaction models that were constructed in the study of $\pi$-nucleus reactions. Our objective is to obtain a reliable model of $N\Delta$ interactions which can be used to determine the $\Delta$ components in nuclei and the properties of $\Delta$-rich systems created in relativistic heavy-ion collisions.

5 summary

We have reviewed the development of a dynamical approach for investigating the photoproduction and electroproduction of pions on the nucleon. Our current focus is on the test of the chiral constituent quark model which can be related to QCD. With such a hadron model, all pion and photon form factors associated with the $\Delta$ and higher mass $N^*$ states can be predicted. With this theoretical input, we have demonstrated that the polarization observables of $d(e,e'\pi)$ reactions can be used to determine a reliable model of $N\Delta$ interactions for investigating the $\Delta$ components in nuclei and the properties of $\Delta$-rich systems created in relativistic heavy-ion collisions. The BLAST being constructed at MIT-Bates can make important contributions in this direction.

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18. As reported by Costas Vellidis at this workshop.