（I）研究計畫之背景及目的 (Background and Motivation)

The quest to understand the structure and interaction of hadrons has been the focus of hadron physics for decades. Electromagnetic probe is known to be a powerful tool to investigate the hadron structure. For example, electron-nucleon elastic scattering determines the e.m. form factors of the nucleon which describe the charge and magnetization distribution within the nucleon while meson e.m. production provides important information for the baryon spectroscopy, besides πN scatterings. In this project, we propose to investigate the following two topics next year.

(A) Nucleon resonances

There are 47 nonstrange baryon states listed in the 2006 version of the Particle Data Group [19]. However, the partial decay widths of most of these baryon resonances have very large uncertainties in most cases. For some decay channels, such as ηN, $K\Sigma$, and ωN, the large uncertainties are mainly due to insufficient data. But the discrepancies between results from using different amplitudes analysis method is also a source of the uncertainties. One example is the extracted width of the four-star S_{11}(1535) state given as 66 MeV [20], 120 ± 20 MeV [21], 151 ± 27 MeV [22], 151-198 MeV [23], and 270 ± 50 MeV [24]. This problem can be resolved only with a sufficiently large data base which would allow a much stronger constraints on amplitude analyses, and a strong reduction of the model dependence in the extraction of N^* parameters like partial widths etc. This requires a large set of data which must be precise and cover a large kinematical region. The polarization observables should also be as extensive as possible. Those experimental challenges are being met at Jlab, MAMI, ELSA, MIT-Bates, Brookhaven-LEGS, and GRAAL at Grenoble.

On the other hand, the theoretical interpretation of the N^* parameters poses a long-standing challenge. For example, most of the model predictions on $N^* \to \gamma N$ helicity amplitudes are only in a very qualitative agreement with the PDG values. In some cases, they even disagree in signs. One can attribute this to the large experimental uncertainties, as discussed above. However, even the well determined empirical values of the most unambiguous $\Delta \to \gamma N$ helicity amplitudes are about 40% larger than the predictions from practically all of the existing hadron models. This raises the question about how the hadron models as well as the lattice

QCD calculations are to be related to the N^* parameters extracted from the amplitude analyses. We need to critically examine their relationship from the point of view of fundamental reaction theory. Our DMT model represents an effort in this direction. In summary, on the theoretical side, we need to use lattice QCD calculations and/or hadron models to predict the properties of the nucleon resonances such as the $N-N^*$ transition form factors. On the experimental side, we need to accumulate sufficiently extensive and precise data of meson production reactions. In between we must develop reaction models like DMT model, for interpreting the data in terms of the hadron structure calculations.

At present, most of the resonance properties are extracted from πN scattering and pion photoproduction. We have recently developed a meson-exchange (MEX) model [7] for πN scattering which gives good agreement with the data up to 400 MeV pion lab energy. In addition, we have also constructed a DMT dynamical model for pion electromagnetic production [1,2] which describes well the π^0 photo- and electro-production data near threshold [3] and most of the existing pion electromagnetic production data up to the first resonance region.

Recently, we have successfully extended [9] our meson-exchange πN model in the S_{11} channel up to 2 GeV by explicitly introducing the known S_{11} resonances into the model. The resulting πN model in the S_{11} channel is then fed into the pion photoproduction model to analyze the existing ${}_pE_{0+}$ multipole. A number of interesting results were obtained as mentioned in I.2. The extension as accomplished in [8] has further been applied to all other πN partial-wave channels up to F-wave [9]. This extended πN model will now be combined with DMT model and used to analyze the abundant amount of data which have been compiled at Jlab and other high energy electron facilities such that the properties of the nucleon resonances, especially the high-lying ones can be more reliable extracted and confront them with LQCD results and quark model predictions.

Special attention will be paid to the Roper $N^*(1440)$ and $S_{11}(1535)$ resonances in regard to their quark content. Several models have been put forth for the Roper, like the excitation of 2hω of the h.o.s. confining potential [25], breathing mode of the bag model or Skyrmion [26-29], hybrid model [30], pentaquark [31], and the recent proposition as a partner of the ground state of the nucleon in the quark-diquark model [32].

For $S_{11}(1535)$, recent BES data on $J/\psi \to \bar{p}p\eta$ and $\psi \to \bar{p}K^{+}\Lambda$ indicate that it might have a large 5q component [33]., while the conventional suggestions include the excitation of one ħω of the h.o.s. confining potential, quark-core-meson-cloud resonance [8], and the [KΛ-KΣ] molecule [34]. We will try to see whether the electromagnetic excitation strength which we extract from the data can be used to differentiate the various proposed models for $S_{11}(1535)$ as expounded above. In addition, Xie et. al recently [35] claimed to have deduced a large coupling of $S_{11}(1535)$ to $N\phi$ from a study of $\pi^{-}p \to n\phi$ and $pp \to pp\phi$ near threshold. We will try to see whether it can be substantiated in a consistent treatment of both $\pi N \to \phi N$ and $\gamma N \to \phi N$.

(B) Two-photon-exchange and γZ -exchange effects

The observation of the discrepancy of unpolarized and polarized measurements of the ratio of electric to magnetic proton form factors at large momentum transfers [10,11] has prompted an intensive interest in the search of two-photon exchange (TPE) effects in large momentum transfer reactions as well as in parity-violating scattering [36]. In addition, it also raises an interesting new question. Namely, the effects of the γZ -exchange on the parity-violating electron-proton elastic scattering which has been the main source to extract the proton strange form factors. We have finished a calculation to evaluate the combined effects of the TPE and γZ -exchange on the parity-violating electron-proton elastic scattering and find the latter to be more important than the former for $Q^2 \leq 1.0\ \mathrm{GeV}^2$ [17], as explained in I.4. Recently, our calculation of [17] has been further extended to include the excitation of $\Delta(1232)$ in the intermediate states which has very interesting cancellation with that arised from the elastic nucleon intermediate states. We propose, in collaboration with C.W. Kao, to continue investigation along this direction and will study the following questions.

(1) Effect of TPE in the electro-excitation of $\Delta(1232)$

The possibility that hadrons would have non-spherical amplitudes is one of the most intriguing topics in hadron structure and has attracted concerted experimental and theoretical efforts to measure and understand it [37]. It was first suggested by Glashow in 1979 on the basis of non-central (tensor) interactions between quarks [38]. This conjecture was based on the premise that there is a color spin-spin interaction between quarks [39] which is modeled after the interaction between magnetic dipoles in electromagnetism. Later, Isgur et. al. proposed the E2 transition in the $\Delta \to N\gamma$ as being the most definite test of this hypothesis. Since $\Delta(1232)$ decays almost exclusively to the channel of πN, the photo- and electroproduction of pion has become the most natural arena for study in this regard.

However, the above-mentioned argument is valid under the assumption of one-photon-exchange approximation. Since it has been established that two-photon-exchange does give rise to non-negligible contribution in elastic electron-proton scattering at higher momentum transfer, the role of two-photon-exchange should hence be carefully examined to ensure a reliable extraction of the $\Delta \to N\gamma$ amplitude from $eN \to e'N\pi$. A partonic calculation on this issue has already been carried out in [40]. We propose to undertake a calculation on this important question within the hadronic model which we have employed for the elastic electron scattering [17,18].

(2) Effect of TPE in neutron β-decay

Neutron β-decay has been used to determine parameters in CKM matrix elements. It is clear that TPE process could also take place there. We plan to carry out such an investigation at our earliest possible time.

（II）研究方法、進行步驟及執行進度 (Method, Procedure, and Schedule)

(A) Nucleon resonances

The key ingredients in our extensions of the Taipei-Argonne πN model and the DMT dynamical model for poin e.m. production to higher energies are the explicit inclusion of ηN channel in the calculation and the addition of a few more bare resonances as would be required to explain the data. Furthermore, the effect of 2π continuum is accounted for by adding a phenomenological term $\Gamma_{2\pi}^{R}(E)$ in the resonance propagator. Such a procedure has already been applied to the S_{11} channel up to 2.2 GeV with considerable success [8], as explained in I.2 and recently to all other partial wave channels up to F-waves [9].

In this work, we'll try to combine our newly finished πN model [9] and the DMT dynamical model for poin e.m. production to higher energies with the explicit inclusion of ηN channel as was done in [8]. This will be carried out in collaboration with Kamalov of Dubna, and Dreschel and Tiator of Mainz.

In regard to the question on the quark content of Roper and S_{11}(1535) resonances, we will tackle the S_{11}(1535) first since we have already finished two studies concerning it. One is the extraction of resonances parameters in S_{11} channel from a consistent analysis of πN, $\pi\eta$, $\gamma\pi$, and $\gamma\eta$ reactions as done in [8]. The other is on the magnetic dipole moment of S_{11}(1535) [41]. Based on these experiences, it will be straightforward to calculate the predictions on the helicity amplitudes of S_{11}(1535) of different quark models as described in II.A and compare them with our extracted values.

Since J.J. Xie, the author of [35] is now with us, it will be straightforward for him to carry out a consistent treatment of both $\pi N \to \phi N$ and $\gamma N \to \phi N$ and see whether indeed the large coupling of S_{11}(1535) to Nϕ, as claimed in [35], manifest itself in $\gamma N \to \phi N$ where more data exist.

(B) Two-photon-exchange and γZ -exchange effects

Since we plan to study the effects of TPE and γZ -exchange in parity-violating elastic electron-proton scattering and beta decay at the hadron level, the techniques we employed in [17,18] is readily applicable to both pion electroproduction and β -decay. However, for pion electroproduction, a general formulation for the amplitude of this reaction beyond the one-photon-exchange approximation will have to be set up so that we have a systematic scheme to remove the TPE effects. This probably will be the biggest challenge in such an effort.

References:

1. S. S. Kamalov and S. N. Yang, Phys. Rev. Lett. 83 (1999) 4494
2. S. S. Kamalov, S. N. Yang, D. Drechsel, O. Hanstein, and L. Tiator, Phys. Rec. C 64 (2001) 032201(R).
3. S. S. Kamalov, G.-Y. Chen, S. N. Yang, D. Drechsel, and L. Tiator, Phys. Lett. B 522 (2001) 27.
4. M. Weis et al., Euro. Phys. J. A 38 (2008) 27.

5. See, e.g., V.D. Burkert and T.-S.H. Lee, nucl-ex/0407020, Int'l J. Mod. Phys. E 13 (2004) 1035..
6. V. Pascalutsa, M. Vanderhaeghen, and S.N. Yang, Phys. Rept. **437**, (2007) 125.
7. C.T. Hung, S. N. Yang, and T.-S.H. Lee, Phys. Rev. C64 (2001) 034309.
8. G.Y. Chen, S.S. Kamalov, S.N. Yang et al., Nucl. Phys. A 723 (2003) 447.
9. G.Y. Chen, S.S. Kamalov, S.N. Yang, D. Drechsel, and L. Tiator, Phys. Rev. C 76 (2007) 035206.
10. M.K. Jones et al., Phys. Rev. Lett. 84 (2000) 1398 .
11. O. Gayou et al., Phys. Rev. Lett. 88 (2002) 092301
12. P. G. Blunden, W. Melnitchouk and J. A. Tjon, Phys. Rev. Lett. 91, 142304 (2003)
13. Y.C. Chen, A. Afanasev, S.J. Brodsky et al., Phys. Rev. Lett. 93 (2004) 122301.
14. A. Afanasev et al., Phys. Rev. D 72 (2005) 013005.
15. Y.C. Chen, C.W. Kao, and S.N. Yang, Phys. Lett. B 652 (2007) 269.
16. Y.B. Dong, C.W. Kao, S.N. yang, and Y.C. Chen, Phys. Rev. C 74 (2006) 064006.
17. H.Q. Zhou, C.W. Kao, and S.N. Yang, Phys. Rev. Lett. 99 (2007) 261802.
18. K. Nagata, H.Q. Zhou, C.W. Kao, and S.N. Yang, arXiv:0811.3539, submitted to PRL, 2008.
19. C. Amsler et al. (PDG), Phys. Lett. B 667 (2008) 1.
20. R.A. Arndt, I.I. Strakovsky, R.L. Workman, and M.M. Pavan, Phys. Rev. C 52 (1995) 2120.
21. G. Hoehler, F. Kaiser, R. Koch, and E. Pietarinen, Handbook of Pion-Nucleon Scattering, Physics Data No. 12-1 (1979).
22. D.M. Manley and E.M. Saleski, Phys. Rev. D 45 (1992) 4002.
23. T. Feuster and U. Mosel, Phsy. Rev. C 58 (1998) 457.
24. R.E. Cutkovsky, C.P. Forsyth, R.E. Hendrick, and R.L. Kelly, Phys. Rev. D 20 (1979) 2839.
25. L.Y. Glozman and D.O. Riska, Phys. Rept. 268 (1996) 263.
26. G. E. Brown, J.W. Durso, and M.B. Johnson, Nucl. Phys. A 397 (1983) 447.
27. T. Hatsuda, Nucl. Phys. A 458 (1986) 583.
28. J.D. Breit, and C.R. Nappi, Phys. Rev. Lett. 53 (1984) 889.
29. I. Zahed, U.G. Meissner, and U.B. Kaulfuss, Nucl. Phys. A 426 (1984) 525.
30. E. Golowich, E. Haqq, and G. Karl, Phys. Rev. D 28 (1983) 160.
31. R. Jaffe and F. Wilczek, Phys. Rev. Lett. 91 (2004) 232003.
32. K. Nagata and A. Hosaka, J. Phys. G 32, (2006) 777.
33. B.C. Liu and B.S. Zou, Phys. Rev. Lett. 96 (2006) 042002.
34. N. Kaiser, P.B. Siegel, and W. Weise, Phys. Lett. B 362 (1995) 23; N. Kaiser, T. Waas, and W. Weise, Nucl. Phys. A 612 (1997) 297.

35. Ju-Jun Xie, Bing-Song Zou, and Huan-Ching Chiang , Phys. Rev. C 77, 015206 (2008)
36. A.V. Afanasev and C.E. Carlson, Phys. Rev. Lett. 94 (2005) 212301.
37. See, for example, ”Shapes of Hadrons”, eds. C.N. Papanicolas and A.M. Bernstein, AIP conference Proc. 904, AIP, Melville, N.Y. 2007.
38. S.L. Glashow, Physica, A 96, 27 (1979).
39. A. de Rujula, H. Georgi, and S.L. Glashow, Phys. Rev. D, 147 (1975).
40 V. Pascalutsa, C.E. Carlson, M. Vanderhaeghen, Phys. Rev. Lett. 96, 012301 (2006).
41. W.T. Chiang, S.N. Yang, M. Vanderhaeghen, and D. Drechsel, Nucl. Phys. A 723 (2003) 205.