

Final Technical Report for DE-FG02-97ER41038  
Partial-wave Analyses of  
Scattering Reactions below 3 GeV

RECEIVED  
AUG 02 2000  
O.S.

R.A. Arndt\* and R.L. Workman

Department of Physics, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061  
(June 26, 2000)

Abstract

Over the period that the Department of Energy has funded the Partial Wave Analysis effort at VPI&SU, it has grown from an analysis of elastic  $NN$  scattering, below 500 MeV, to include 10 separate reactions which are summarized below. The group has maintained a repository for scattering data from these important reactions as well as a primary source for partial-wave solutions, including those of "competitors" around the world. Perhaps the most important contribution of the VPI effort has been the development of interactive (Scattering Analysis Interactive Dialin) programs that make accessible both the data bases and the solutions to the Nuclear Physics community.

SUMMARY OF REACTIONS UNDER STUDY

1.  $\pi N$  elastic analysis to  $E_\pi=2.1$  GeV

Our current global(energy-dependent) analyses fit 21698 elastic scattering data with a total of 175 variable parameters. In the most recent analyses of this reaction, we have added fixed- $t$  dispersion-relation constraints on the  $C^+$  amplitude and forward dispersion-relation constraints on the  $E^\pm$  amplitudes in order to facilitate an extraction of the  $\sigma$ -term. A mapping of  $\chi^2$ , as a function of  $g^2/4\pi$ , reveals a very deep minimum at 13.73(0.01).

2.  $NN$  elastic analysis to  $T_{lab}=3$  GeV

The current data base now includes 21797  $pp$  data below  $T_{lab}=3$  GeV and 11472  $np$  data below  $T_{lab}=2$  GeV. These are being fitted with a total 147 variable parameters. As in all our studies, we also bin the data and do single-energy (presumably form-independent) analyses.

3. Pion-photoproduction analysis to  $E_\gamma=2$  GeV

The current data base consists of 16791 data in four different charge-channels. Parameterization for this reaction includes, implicitly, the  $\pi N$  elastic amplitudes obtained in our analysis of that reaction and 142 variable parameters.

\*arndtra@said.phys.vt.edu

We have no objection from a patent  
standpoint to the publication or  
dissemination of this material.

M. P. Orosz July 31, 2000  
Office of Intellectual  
Property Counsel  
DOE Field Office, Chicago

## **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, make any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

## **DISCLAIMER**

**Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.**

#### 4. Pion-electroproduction analysis to $W_{cm}=2$ GeV and $Q^2 < 4$

There are approximately 24000 (old-and-noisy) data in our current base and we have done very preliminary fits, using 80 parameters, to obtain a crude  $Q^2$  dependence. This reaction will consume much of our efforts as new data flows in from Jefferson lab and from European facilities.

#### 5. $K^+N$ elastic analysis to $E_K=2.65$ GeV

This reaction includes 5409 data fitted with 89 parameters. The last solutions were generated in 1992 and no further activity is anticipated.

#### 6. $\pi d$ elastic analysis to $E_\pi=0.5$ GeV

There are 1362 data for this reaction which are fitted (separately) with 66 parameters or in a coupled-channel (with  $\pi d$  to  $NN$  data) representation. Data for this reaction are still being measured.

#### 7. $\pi d \rightarrow pp$ analysis to $E_\pi=0.5$ GeV

There are 4865 data for this reaction which are fitted with 52 parameters or in a coupled-channel (with  $\pi d$  elastic and  $pp$  elastic data) representation. Data for this reaction are still being measured.

#### 8. $\gamma p \rightarrow \eta p$ analysis to $E_\gamma=1.2$ GeV

Current solutions use about 20 variable parameters (in S, P, D waves) to fit approximately 1000 scattering data. This reaction is the subject of intense study at Jefferson Lab and European facilities. Further work will be required to relate results from this reaction to those determined previously from pion photoproduction.

#### 9. $\gamma p \rightarrow K^+\Lambda$ analysis to $E_\gamma=1.6$ GeV

The data base on this reaction is very crude; consisting of 404 data fitted with 11 parameters. This reaction is also the subject of on-going studies.

#### 10. $\pi N \rightarrow \pi\pi N$ below $W_{cm}=2$ GeV

This Isobar analysis of the 1980s is encoded in SAID to display  $\pi N$  production amplitudes to various Isospin channels.

#### 11. Scattering Analysis Interactive Dialin (SAID)

This collection of interactive graphics programs has been available for over 20 years through TELNET. The original system was designed for  $NN$  elastic analyses. SAID is now available through TELNET/ssh or via our website for all of the reactions studied under this contract.

Displaying the information contained in these complicated scattering reactions is difficult, so a variety of graphical plot modes (linear, contour, 3-dimensional) are available to the users. The user can, after ending a session, instruct that plots be converted to postscript pictures and E-mailed back. On the web site the pictures are displayed in JPG form. Numerical results are accumulated in a file that, upon request, can also be E-mailed to the user.

These programs have found wide usage throughout the Nuclear Physics community and are very frequently cited in published articles. We consider the creation of this system one of our most outstanding accomplishments, and we continue to add features which will increase its usefulness.

## 12. Work published or submitted for publication

Below we list our publications [1-16] over the period of the contract. During this period we published revised analyses of nucleon-nucleon elastic scattering [2,5], a coupled-channel analysis of  $NN \rightarrow NN$ ,  $\pi d \rightarrow \pi d$ , and  $\pi d \rightarrow pp$  [4], a coupled-channel fit to  $\pi N \rightarrow \pi N$  and  $\pi N \rightarrow \eta N$  [7], plus a number of photoproduction studies [1,3,12-14,16] concentrated mainly on the  $\Delta$  resonance region. A considerable amount of work was also done on the electroproduction analysis, in support of the Jefferson Lab experimental program.

### Acknowledgment

We wish to express our gratitude for the support of this project given by the Department of Energy (under a variety of different names) since its inception in the 1960s. We are grateful that support has continued as we move the research to our new home with the George Washington University.

## REFERENCES

- [1] *Remarks on the  $\Delta^+$  mass*,  
R.L. Workman,  
Phys. Rev. C 56, 1645-1646 (1997).
- [2] *Nucleon-nucleon elastic scattering analysis to 2.5 GeV*,  
R.A. Arndt, C.H. Oh, I.I. Strakovsky, R.L. Workman, F. Dohrmann,  
Phys. Rev. C 56, 3005-3013 (1997).
- [3] *Analysis of pion photoproduction over the  $\Delta$  resonance region*,  
R.A. Arndt, I.I. Strakovsky, R.L. Workman,  
 $\pi N$  Newsletter 13, 73-75 (1997).
- [4] *Analysis of  $pp \rightarrow pp$ ,  $\pi d \rightarrow \pi d$ , and  $\pi d \rightarrow \pi d$  scattering data*,  
 $\pi N$  Newsletter 13, 338-341 (1997).
- [5] *Nucleon-nucleon analysis to 2.5 GeV*,  
R.A. Arndt, C.H. Oh, I.I. Strakovsky, R.L. Workman, F. Dohrmann,  
 $\pi N$  Newsletter 13, 314-319 (1997).
- [6] *Comment on 'Evidence for narrow baryon resonances in inelastic  $pp$  scattering*,  
I.I. L'vov and R.L. Workman,  
Phys. Rev. Lett. 81, 1346 (1998).
- [7] *The energies and residues of the nucleon resonances  $N(1535)$  and  $N(1650)$* ,  
Phys. Rev. C 58, 3636-3640 (1998).
- [8] *Review of Particle Properties*,  
Particle Data Group,  
Eur. Phys. J C 3, 1-794 (1998).
- [9] *Delta isobar masses, Large  $N_c$  relations, and the quark model*  
S. Capstick and R.L. Workman,  
Phys. Rev. D 59, 014032 (1999).
- [10] *Amplitude analysis*,  
R.L. Workman  
Few Body Syst. Suppl. 11, 94-99 (1999).
- [11]  *$\pi N$  elastic scattering analysis and dispersion relation constraints*,  
R.A. Arndt, I.I. Strakovsky, R.L. Workman, M.M. Pavan,  
e-print archive: nucl-th/9807087.
- [12] *Stability of the  $E2/M1$  ratio at the  $T$ -matrix pole*,  
R.L. Workman, R.A. Arndt,  
Phys. Rev. C 59, 1810-1812 (1999).
- [13] *The  $E2/M1$  ratio, a status report*,  
R.L. Workman  
Talk at the 8th Int. Conf. on the Structure of Baryons  
(Baryons 98), Bonn, Germany, Sept 1998;  
e-print archive: nucl-th/9810013.
- [14] *Problems with extraction of the nucleon to  $\Delta(1232)$  photonic amplitudes*,  
R.M. Davidson, N.C. Mukhopadhyay, M.S. Pierce,  
R.A. Arndt, I.I. Strakovsky, R.L. Workman,  
Phys. Rev. C 59, 1059-1063 (1999).

- [15] *Pole versus Breit-Wigner resonance description of the orbitally excited baryons*,  
R.L. Workman,  
Phys. Rev. C 59, 3441-3443 (1999).
- [16] *Review of  $(\gamma, \pi)$  and the Delta  $E2/M1$  ratio*,  
R.L. Workman,  
 $\pi N$  Newsletter 14, 31-36 (1998).