Sensitivity of the COSY dibaryon candidate to np elastic scattering measurements

R. L. Workman, W. J. Briscoe, and I. I. Strakovsky

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Sensitivity of the COSY Dibaryon Candidate to np Elastic Scattering Measurements

R. L. Workman,[1] W. J. Briscoe,[1] and I. I. Strakovsky[1]

[1] *Institute for Nuclear Studies, Department of Physics, The George Washington University, Washington, DC 20052, USA*

The case for a dibaryon resonance, appearing in np scattering, has support from a WASA-at-COSY measurement of the polarization quantity A_y over a center-of-mass energy region suggested by structures seen earlier in two-pion production experiments. Here we compare fits with and without an associated pole in order to clarify the impact of these COSY data. We then consider what further np scattering measurements would most clearly distinguish between the pole and non-pole fit results.

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I. INTRODUCTION

The longitudinal spin-dependent proton-proton total cross-section difference $\Delta\sigma_L$ measurements at the zero-gradient synchrotron (ZGS) [1] stimulated a high level of experimental and theoretical activity to search for dibaryons, mostly with isospin 1, through the 80's. Details of this period can be found in reviews [2–4]. In the end, the difficulties in distinguishing true and pseudo-resonances [5] led to the demise of these investigations. A post-mortem is given in Ref. [6].

In a recent series of WASA-at-COSY two-pion production measurements [7], a resonance-like structure was reported, corresponding to an isospin 0 resonance mass near 2.38 GeV, with a width of about 70 MeV. This claim gained added weight with the analysis of A_y data from np elastic scattering, also measured by the WASA-at-COSY Collaboration, which showed a rapid variation centered near the 2.38 GeV CM energy [8, 9]. The most recent GW SAID [10] NN partial wave analysis (PWA) was not able to predict this behavior, nor was it present in previous fits [11]. However, a re-analysis of the full database, including the COSY measurements, resulted in the generation of a pole. The location of the pole, seen in the coupled $^3D_3$-$^3G_3$ partial waves, was $[(2380\pm10)$ - $i(40\pm5)]$ MeV, corresponding almost exactly to the earlier resonance mass and width estimates [8, 9, 12]. An associated Argand plot of the $^3D_3$ partial-wave is shown in Fig. 1.

The close correspondence of this resonance energy with a very early prediction, within the SU(6) quark model of Dyson and Huong [13], is also remarkable. Given the resurgence of interest in states beyond the usual $q\bar{q}$ mesons and qqq baryons, there have been numerous publications focused on related states and strategies for their detection [14, 15]. With this motivation, we have made a more detailed study of the structure found through the analysis of np elastic scattering data. In particular, we consider those additional measurements which are most sensitive to the pole structure.

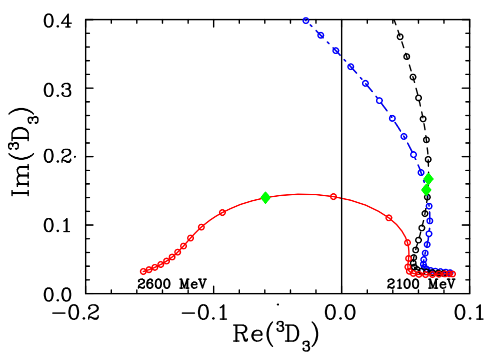

FIG. 1: (Color online) Argand plot for the dimensionless $^3D_3$ np amplitude. Previous SAID SP07 solution shown as a black dashed line [10]. Revised SAID solution without (with) a pole is plotted as a blue dot-dashed (red solid) line. Energies are plotted with open circles in 20-MeV steps. Green filled diamond symbols correspond to the pole mass $W_R = 2380$ MeV.

II. FITS TO THE COSY A_y DATA

The COSY experiment measured 7 angular distributions for A_y in np scattering using a polarized deuteron beam impinging on a hydrogen target [8]. The resulting neutron kinetic energies ranged from 1.108 to 1.197 GeV, corresponding to CM energies between 2.367 and 2.403 GeV. As shown in Fig. 2 the number of existing data, and data types, drops of rapidly beyond a kinetic energy of 1.1 GeV and this limits the reliability of PWA much beyond 1.1 GeV. The GW SAID PWA [10] has an upper limit of 1.3 GeV for an energy-dependent fit and the highest energy for an np amplitude reconstruction is 1.1 GeV in Ref. [17].

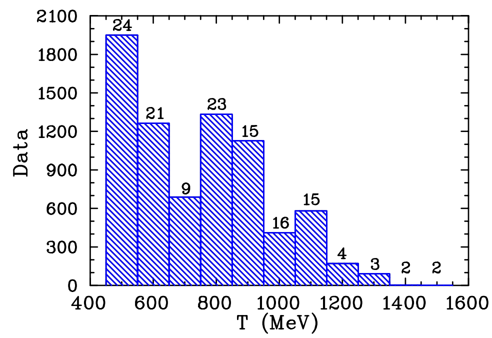

FIG. 2: (Color online) Data available for $np \to np$ as a function of neutron kinetic energy [16]. The number of observable types is given above each vertical bar.

In Fig. 3, the SP07 prediction [10] and the fit containing a pole are compared to data at 85° – where the variation is greatest. The SP07 prediction clearly misses the rapid rise in A_y (top left) while fitting the older data quite well. The pole fit reproduces both the drop in A_y, seen in the lower energy data of Ref. [18], and the rapid rise displayed in the COSY data. Also shown is a revised fit without a pole, which takes an averaging path through the data without any rapid variation.

In Fig. 4, angular distributions for A_y (top row) are compared just above and below the assumed resonance energy. A comparison between the pole and non-pole fits at 2.38 GeV is less dramatic than the comparison made in Ref. [8] using the SP07 prediction. Here the better data description of the pole fit is due to its ability to accommodate the trends of both the older and new data. Given the considerable scatter seen in the data of Ref. [18], the need for a pole would gain confidence if the lower-energy data errors could be reduced.

III. SENSITIVITY TO OTHER OBSERVABLES

In Figs. 4 – 6, the behavior of many other observables is compared to that shown by A_y. Above 2.4 GeV, the fits are almost unconstrained by data and, while the differences are very large, no single measurement would allow a reliable PWA. Observables such as MSSN, MKKN, MSNK, and NKNS, involve 3 spins and are difficult to measure. Of these, only MSSN has been measured, and only for pp scattering, at PSI [16, 19], with a maximum energy below 600 MeV. Triple-polarization measurements are extremely difficult and depend on the apparatus experimentalists have available. A typical case is described by Gülmez *et al.*, at LAMPF which required the measurement of linear combinations of observables [20]. An observable translation guide is given in Table I. The best choice, beyond a single-spin asymmetry [22] $A_y = P = P_{n000} = P_{0n00} = A_{00n0} = A_{000n}$, would be the measurement of 2 spins, allowing a test at or below the energy of the COSY experiment, where more data are available to constrain a fit.

In Figs. 4 – 6, the above observables are given as angular distributions at three energies near to the 2.38 GeV structure. Here, RPT is an interesting possibility, as the pole and non-pole fits differ significantly at CM energies below 2.38 GeV. At angles near 75°, the discrepancy between the non-pole and pole fits is larger than found in a comparison of SP07 and the pole fit. A similar effect is seen in DT for angles near 115°.

Looking over Figs. 3 – 6, one can see that new measurements of np RP, A, DT, and RPT, with a precision comparable to previous measurements from LAMPF will provide important constraints for the fit. For instance, LAMPF data (which have a limit of 800 MeV) have statistical uncertainties of the order $\Delta(RP) \sim 0.05$ and $\Delta(A) \sim 0.05$ [23], $\Delta(DT) \sim 0.03$ [24], and $\Delta(RPT) \sim 0.04$ [25].

The total cross section, $\sigma^{\rm tot}$, and spin-dependent neutron-proton total cross-section differences, $\Delta\sigma_T$ and $\Delta\sigma_L$ are compared to SAID fits and predictions in Fig. 7. The SP07 and pole fits for these quantities were compared in Ref. [9] but are included here for completeness. The pole fit differs most from the non-pole fits in $\Delta\sigma_L$, where existing data

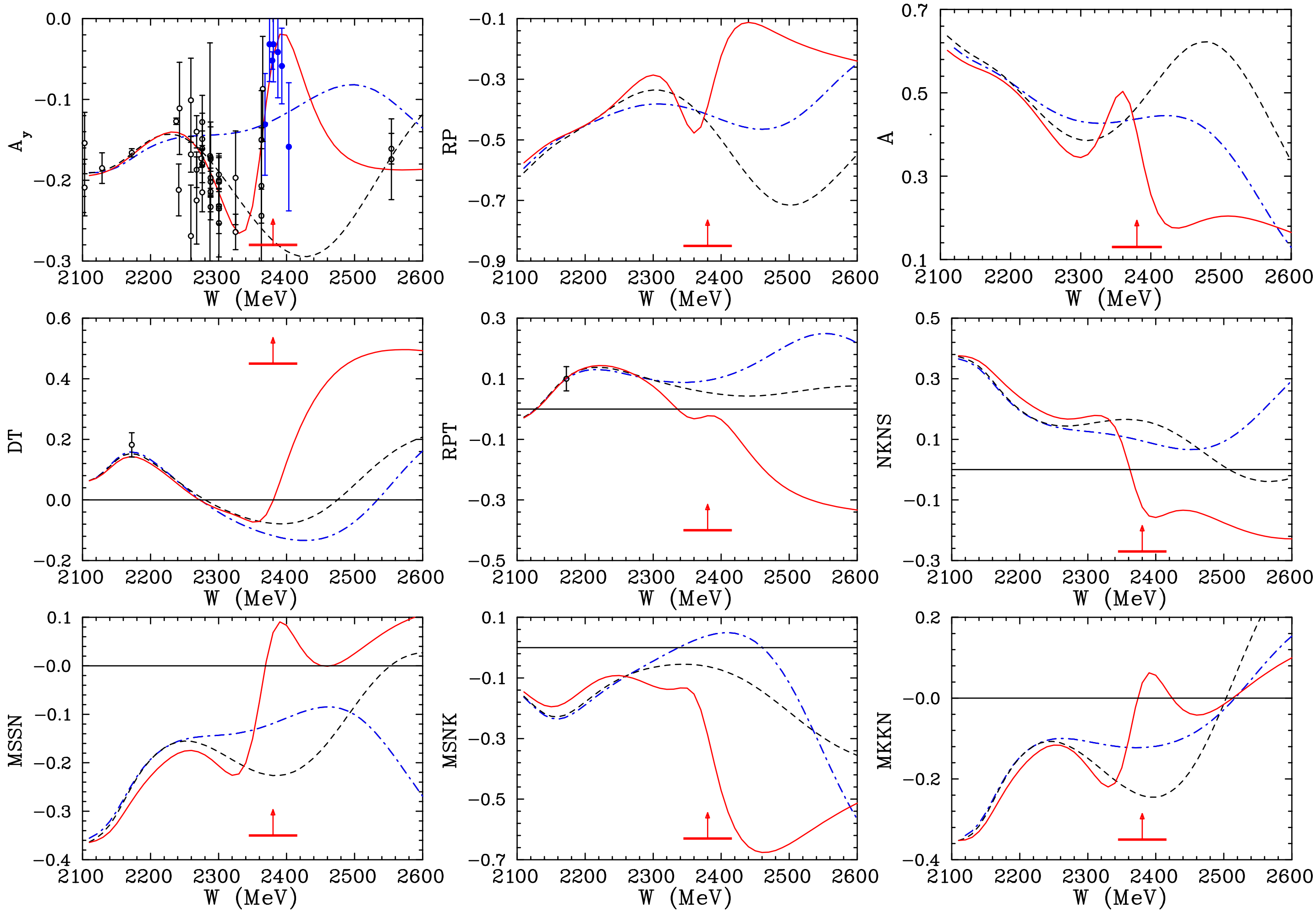

FIG. 3: (Color online) Polarized observables for energies near the COSY resonance [8], at 85°. Data shown as blue solid circles are from the COSY experiment [8]. Previous measurements within $\Delta\theta = \pm 1^\circ$ [16] shown as black open circles. SAID SP07 solution shown as a black dashed line [10]. Revised fit without (with) a pole displayed by blue dot-dashed (red solid) line. Red vertical arrows indicate resonance mass W_R value and red horizontal bar gives the full width Γ [8].

TABLE I: Sign convention and notation. Bystricky, Lehar, and Winternitz [21] give explicit definitions, but some signs differ from SAID [16]. The Bystricky symbols D, K, M, and N denote the depolarization, polarization transfer, and contributions of two initial polarizations to the final polarizations of the of the scattered and recoil particles, respectively.

SAID	Bystricky
A	$D_{s'0k0}$
RP	$D_{k'0s0}$
DT	K_{0nn0}
RPT	$-K_{0k''s0}$
MSNK	$M_{s'0nk}$
MKKN	$M_{k'0kn}$
MSSN	$M_{s'0sn}$
NKNS	$N_{0k''ns}$

is not sufficiently precise to clearly distinguish between these alternatives. Improved measurements of this quantity, with uncertainties comparable to the LAMPF [36] measurements, of order of $\Delta\sigma_L \sim 10\%$ would greatly improve this comparison.

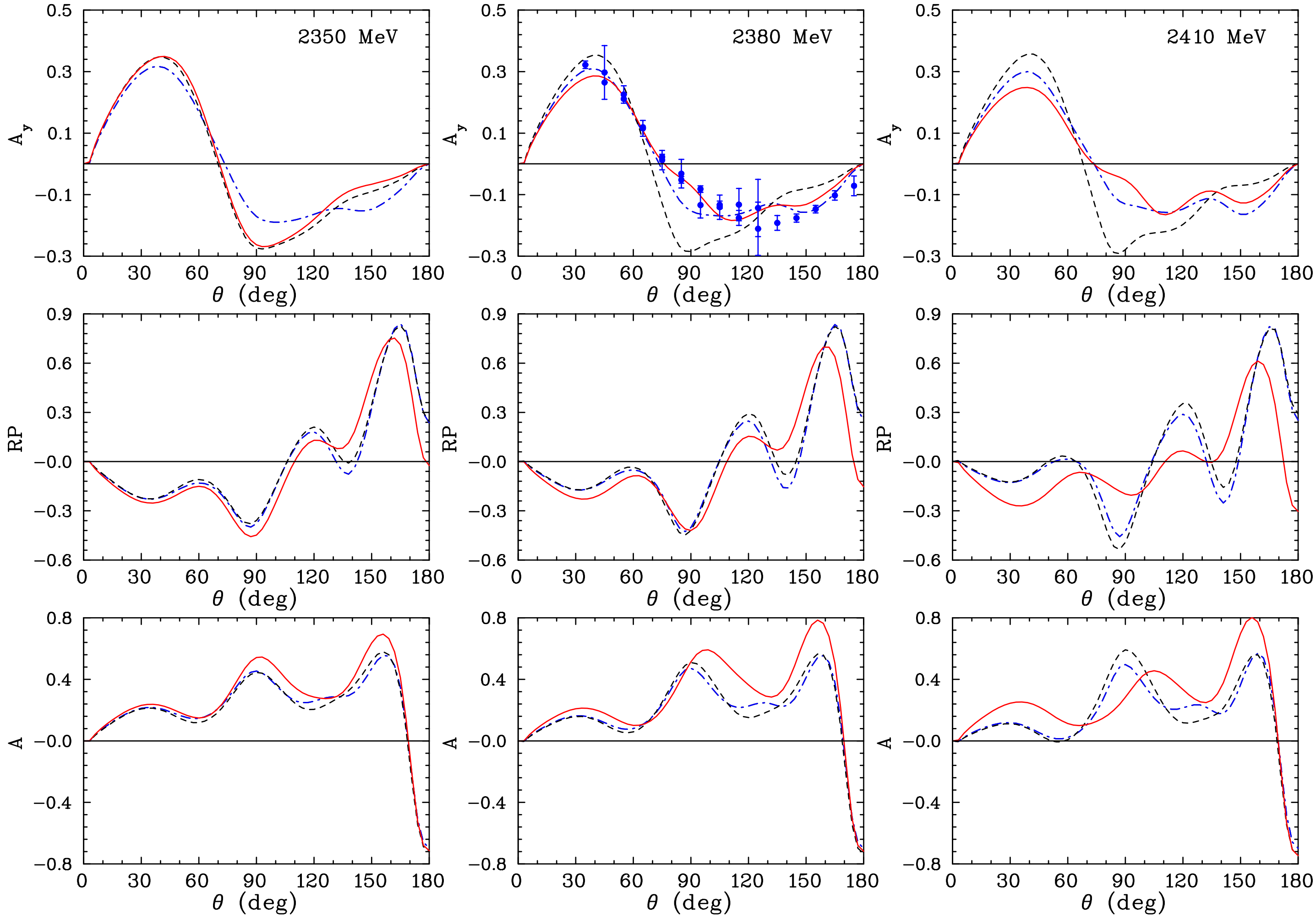

FIG. 4: (Color online) Angular distributions of polarized observables around the COSY resonance [8]: W = 2350 MeV (left panels), 2380 MeV (middle panels), and 2410 MeV (right panels). Previous measurements within $\Delta W = \pm 5$ MeV [16] are plotted. Notation as in Fig. 3.

IV. SUMMARY AND CONCLUSIONS

Motivated by the COSY dibaryon observation, at a CM energy of 2.38 GeV, in np scattering and two-pion production processes, we have made a detailed study of possible fits and predictions for np scattering observables based on the SAID analysis, with and without the contribution of a pole in the $^3D_3$-$^3G_3$ coupled waves.

Given the scarcity of np scattering data above the structure seen in A_y, the most reliable source of information should come from either improved measurements of A_y at energies slightly below the COSY measurement or measurements of two-spin polarization quantities showing sizeable deviations between the pole and non-pole predictions. Improved measurements of $\Delta\sigma_L$ would also be useful.

The precision achieved in previous LAMPF measurements should be sufficient to distinguish between the fit alternatives presented here. For the two-spin observables of interest, measurements could be confined to intermediate angles. The pole fit displays a rapid energy variation which would require a fine energy binning and measurements spanning the width of the COSY dibaryon.

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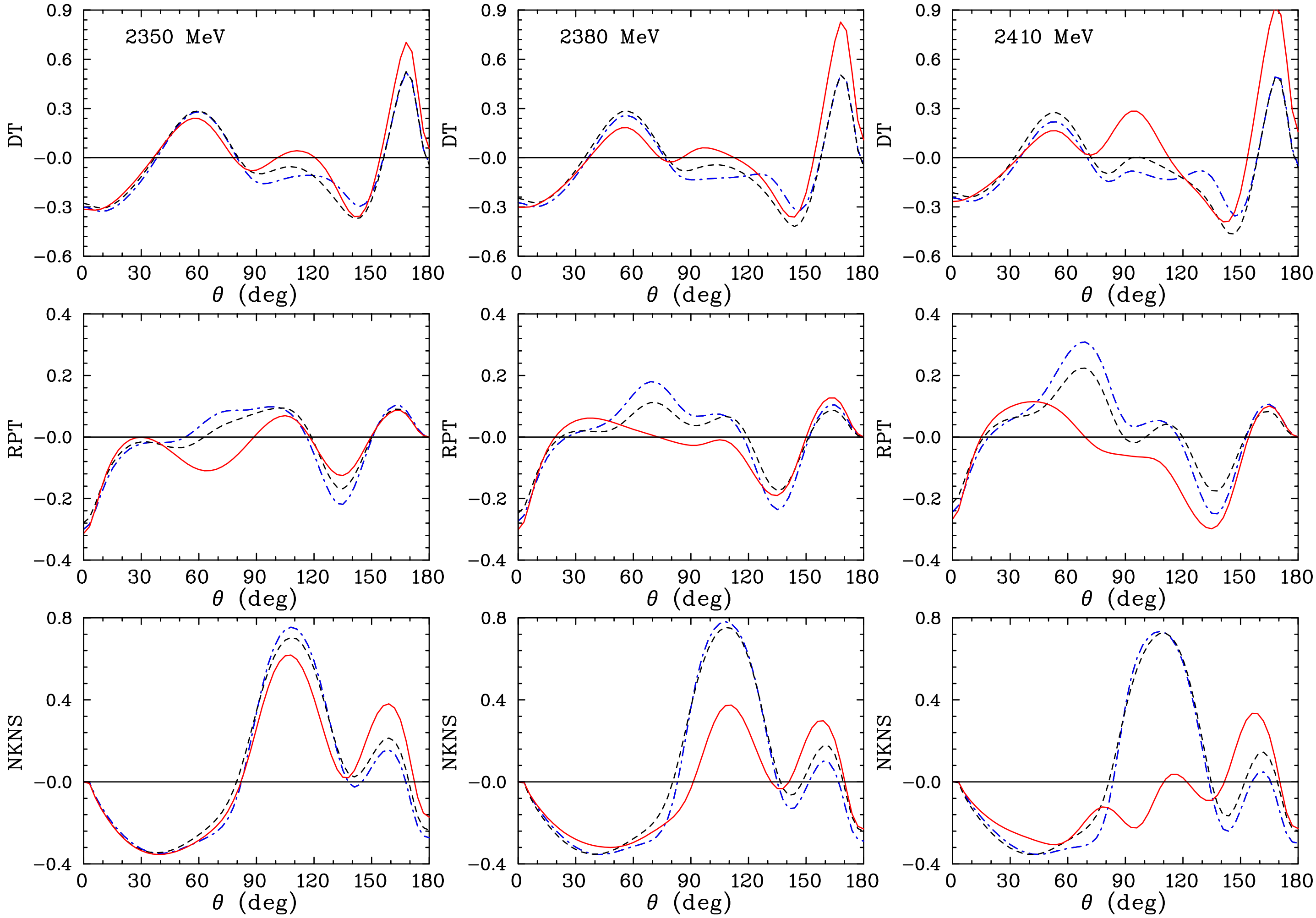

FIG. 5: (Color online) Angular distributions of polarized observables around the COSY resonance [8]: W = 2350 MeV (left panels), 2380 MeV (middle panels), and 2410 MeV (right panels). Notation as in Fig. 3.

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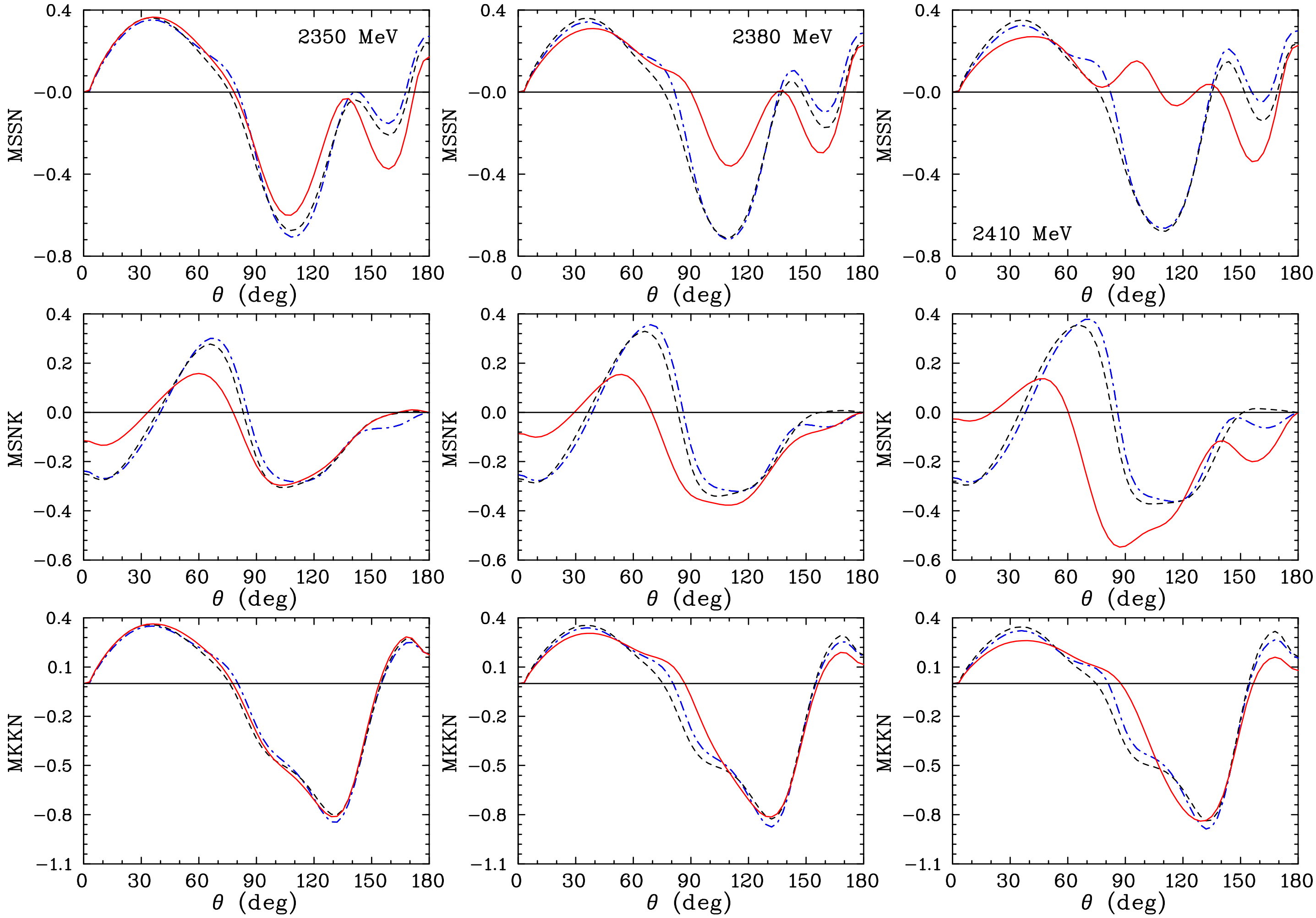

FIG. 6: (Color online) Angular distributions of polarized observables around the COSY resonance [8]: W = 2350 MeV (left panels), 2380 MeV (middle panels), and 2410 MeV (right panels). Notation as in Fig. 3.

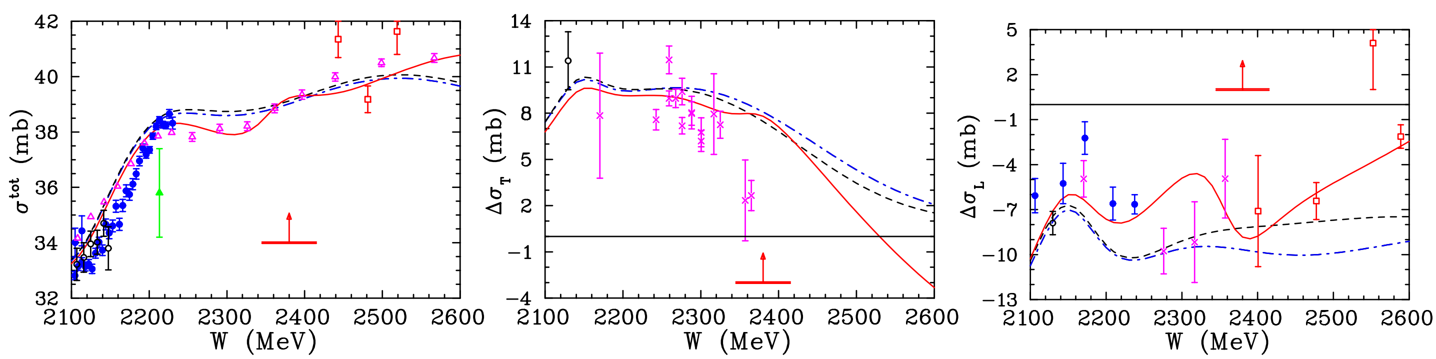

FIG. 7: (Color online) Total cross sections near the COSY resonance [8]: σ^{tot} (left panel) [LAMPF data [26, 27] shown as blue filled circles, PSI data [28] shown as black open circles, PPA data [29] shown as magenta open triangles, BNL data [30] shown as green filled triangles, and JINR data [31] shown as red open sqares], $\Delta\sigma_T$ (middle panel) [PSI data [32] shown as black open circles and SACLAY data [33–35] shown as magenta crosses], and $\Delta\sigma_L$ (right panel) [PSI data [32] shown as black open circles, LAMPF data [36] shown as blue filled circles, Saclay data [33] shown as magenta crosses, and JINR data [31, 37] shown as red open squares]. Notation for SAID curves as in Fig. 3.

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