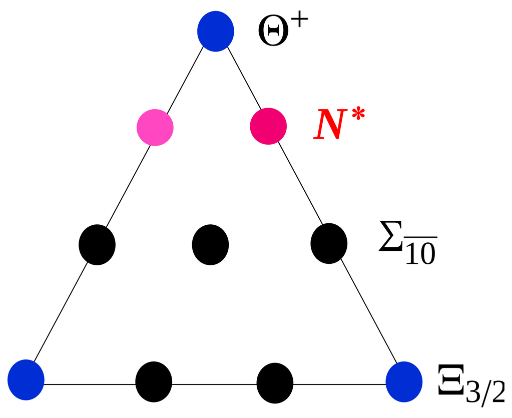
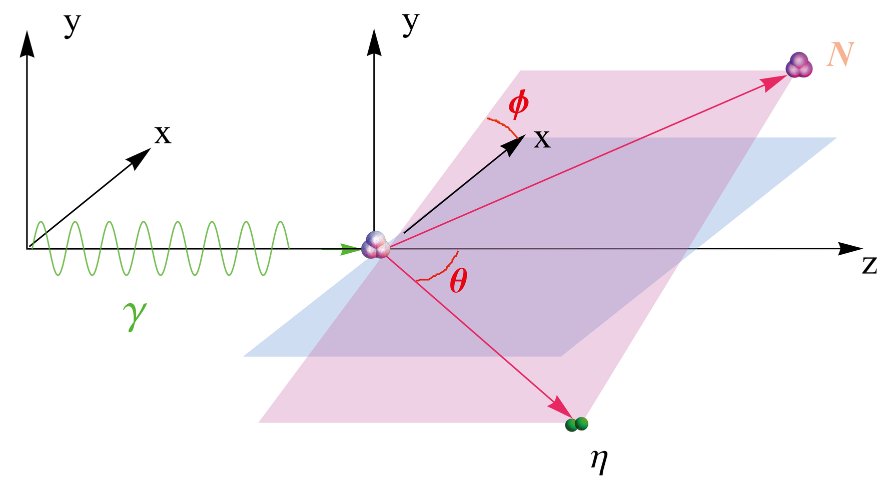
Double Polarization Observables in η Photoproduction off the Nucleon

Ghil-Seok Yang, M. V. Polyakov

Institut für Theoretische Physik II, Fakultät für Physik und Astronomie
Ruhr-Universität Bochum, Germany





Breit-Wigner Form

The double polarization observables for beam-target asymmetries, E, F, G, and H, for η photoproduction on the free proton is estimated with the recent electromagnetic multipole decompositions based on the E429 solution of the SAID partial wave analysis including the narrow state P_{11} in the Breit-Wigner form.
The relevant multipoles of η photoproduction can be constructed by simply adding a nonresonant background contribution and the resonant one with the Breit-Wigner energy dependence as follows:

$$\mathcal{M}^{\rm non}_{l\pm} + A_{l\pm} e^{i\delta_{l\pm}} \frac{M_R \Gamma_{\rm tot}}{M_R^2 - W^2 - i M_R \Gamma_{\rm tot}(W)} \left[\frac{1}{(2J+1)\pi} \frac{k_W M_N}{|\vec{\mathbf{q}}|} \frac{1}{M_R \Gamma_{\rm tot}} \right]^{1/2}$$

The resonant term is reparametrized by the amplitude $A_{l\pm}$ and the phase $\delta_{l\pm}$ with total decay width $\Gamma_{\rm tot}$, resonance mass M_R, nucleon mass M_N, spin J, and photon and meson momenta, k_W and $\vec{\mathbf{q}}$, respectively. The two resonance parameters, A_{1-} and δ_{1-} for the case with only P_{11} state, are directly related to corresponding the photocouplings multiplied by square of ηN branching ratio.
With those multipole data and the derivatives of the Legendre polynomials, helicity amplitudes can be established via CGLN amplitudes and the final expressions for the single and double polarization observables can be obtained in terms of helicity amplitudes. Denoting

$$S = |H_1|^2 + |H_2|^2 + |H_3|^2 + |H_4|^2 ,$$

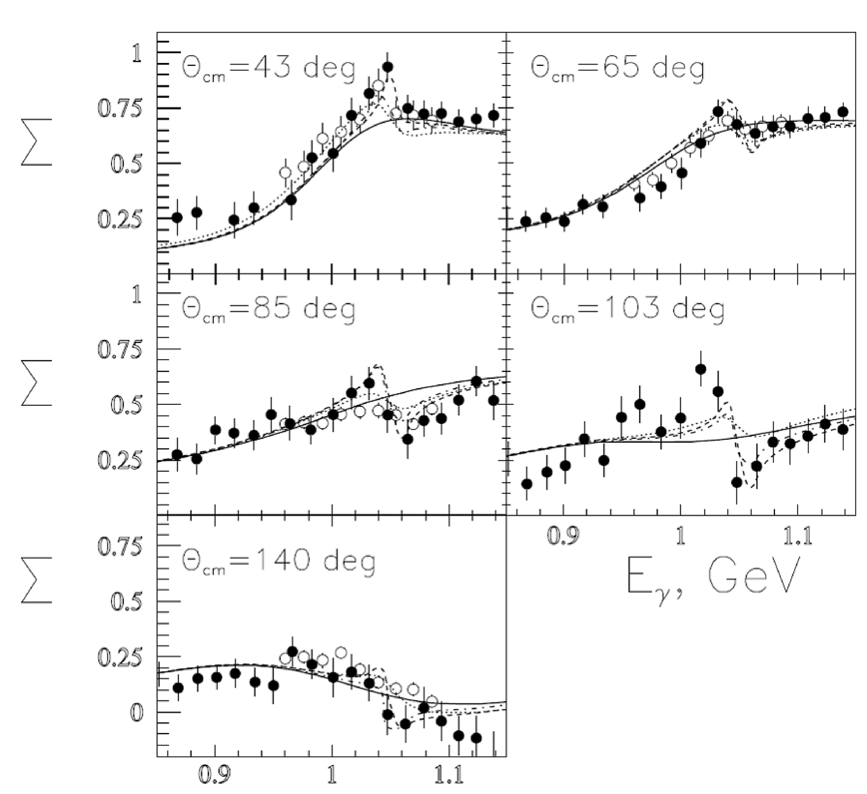
the single polarization observables, i.e, hyperon polarization asymmetry P, polarized photon asymmetry Σ, and polarized target asymmetry T, are given by

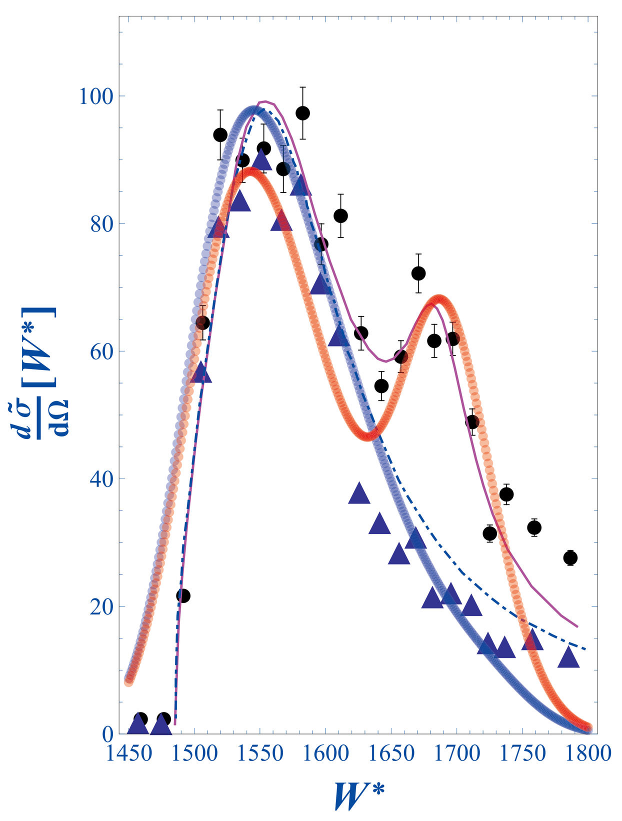
$$\begin{aligned} P &= -2\,\mathcal{I}m\,(H_1 H_3^* + H_2 H_4^*)\,/S \\ \Sigma &= 2\,\mathcal{R}e\,(H_1 H_4^* - H_2 H_3^*)\,/S \\ T &= 2\,\mathcal{I}m\,(H_1 H_2^* + H_3 H_4^*)\,/S \end{aligned}$$

while the double polarization observables for beam-target asymmetries may be expressed as

$$\begin{aligned} E &= \left(-|H_1|^2 + |H_2|^2 - |H_3|^2 + |H_4|^2 \right) /S \\ F &= 2\,\mathcal{R}e\,(H_1 H_2^* + H_3 H_4^*)\,/S \\ G &= -2\,\mathcal{I}m\,(H_1 H_4^* + H_2 H_3^*)\,/S \\ H &= -2\,\mathcal{I}m\,(H_1 H_3^* - H_2 H_4^*)\,/S \end{aligned}$$

The Single Polarization Observables





The left figure shows the fit of experimental data for the polarized photon beam asymmetry which is one of the single polarization observables. (● obtained in present analysis, ○ are results of data analysis for the meson production at GRAAL). Solid lines show our calculations based on the SAID mulitpoles only, dotted lines include the P_{11} resonance($\Gamma_R \sim 20\,\mathrm{MeV}$), the dashed lines are calculations with the P_{13}($\Gamma_R \sim 8\,\mathrm{MeV}$), while the dash-dotted lines are calculations with the D_{13}($\Gamma_R \sim 8\,\mathrm{MeV}$).

The right figure shows that the M(ηn) spectrum from CBELSA/TAPS (●) in comparison with M(ηp) spectrum (▲). The blue-colored line from our studies indicate the non-resonant contribution for the differential cross section and the red-colored one is with resonant state P_{11} ($M_R \sim 1685\,\mathrm{MeV}$, $\Gamma_R \sim 20\,\mathrm{MeV}$, $\theta = 130^o$, $\sqrt{\mathrm{Br}_\eta N} A^n_{1/2} \sim 26.7 \cdot 10^{-3}\,\mathrm{GeV}^{-1/2}$). The anomalous behaviour of the quasi-free neutron cross section and the narrow peak the ηn invariant mass spectrum calls for a theoretical explanation. A partial-wave analysis of the quasi-free neutron cross section is rather complicated because the target neutron is bound in the deuteron. That is why the search for this narrow structre (possibly strongly suppressed) in the η photoproduction off the free proton is important.
The obtained value of $\sqrt{\mathrm{Br}_\eta N} A^p_{1/2}$ from this study is

$$\sqrt{\mathrm{Br}_\eta N} A^p_{1/2} \sim 1 \cdot 10^{-3} \mathrm{GeV}^{-1/2}$$

for the P_{11} resonance. This value of $\sqrt{\mathrm{Br}_\eta N} A^p_{1/2}$ for the narrow P_{11} resonance is in good agreement with estimates for the non-strange pentaquark from the antidecuplet performed in the Chiral Quark-Soliton Model. Comparing the value with the analogous quantity for the neutron extracted in the phenomenological analysis of the GRAAL and CBELSA/TABS data, we obtained the ratio

$$A^n_{1/2} \,/\, A^p_{1/2} \sim 10 - 20$$

This ratio is close to that expected for the non-strange pentaquark in the Chiral Quark-Soliton Model. Such large of photoproduction amplitudes indicates the strong suppression of photoexcitation of this resonance off the proton. the result of this report is the existence of a narrow nucleon resonance $N^*(1685)$ with much stronger photocoupling to the neutron than to the proton. Being a candidate for the non-strange member of the exotic anti-decuplet, such resonance supports the existence of the exotic Θ^+ pentaquark.

The Double Polarization Observables, E, F, G, and H

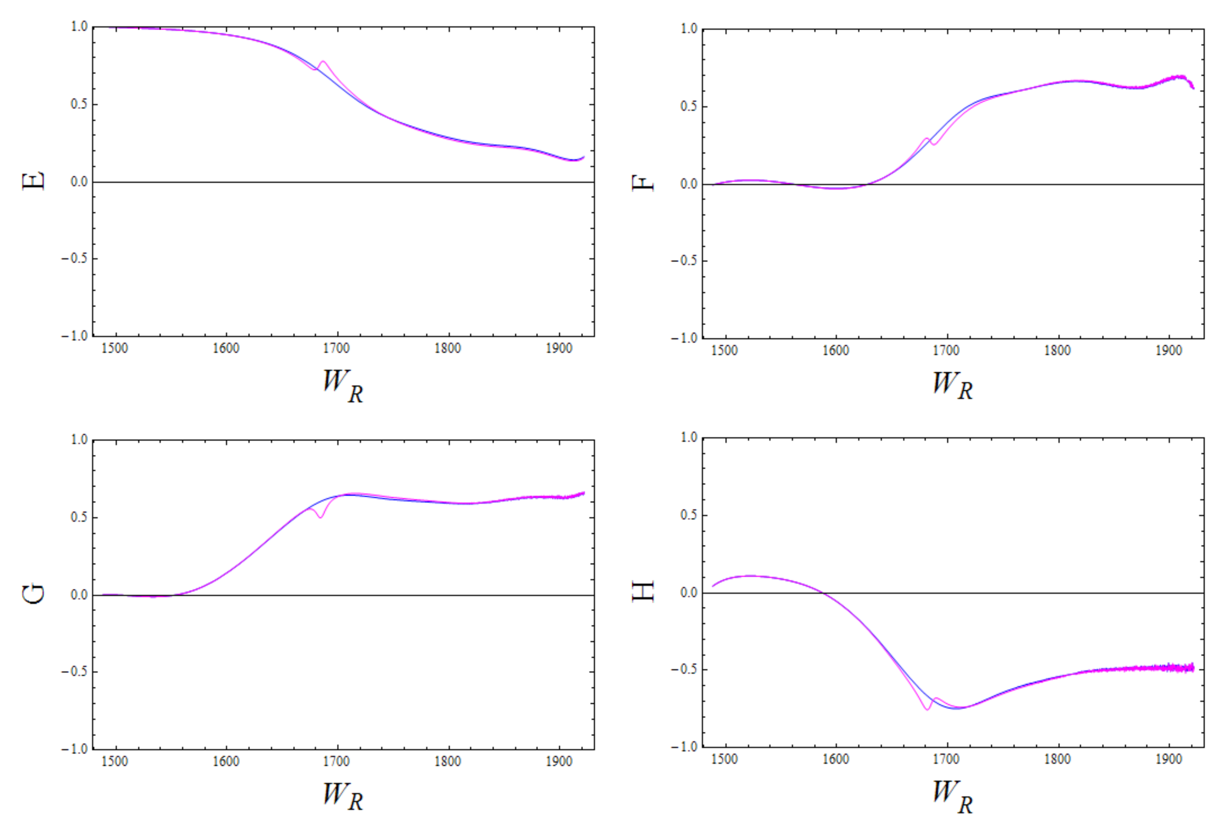


Figure 1: $\sqrt{\mathrm{Br}_\eta N} A^p_{1/2} \sim 2 \cdot 10^{-3}\,\mathrm{GeV}^{-1/2}$

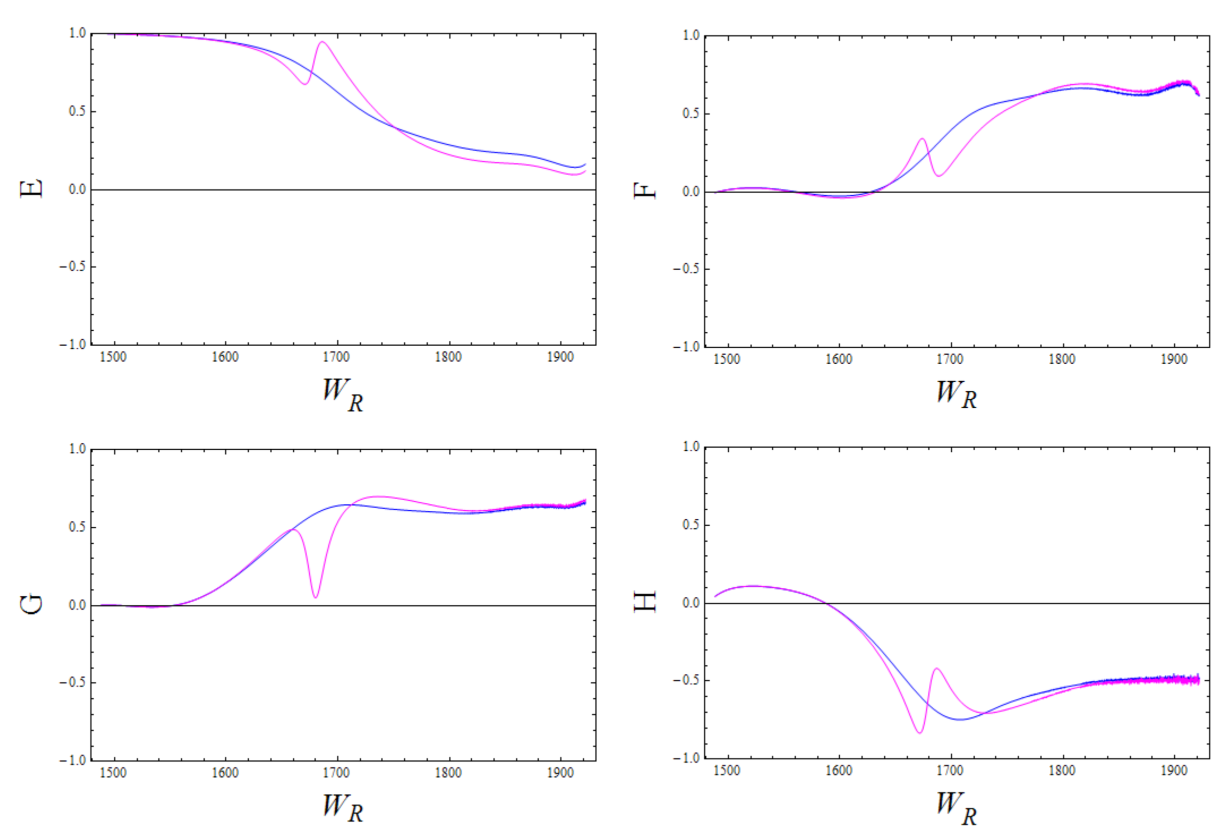


Figure 2: $\sqrt{\mathrm{Br}_\eta N} A^n_{1/2} \sim 15 \cdot 10^{-3}\,\mathrm{GeV}^{-1/2}$

In the above figures, red-colored lines are for the resonant contributions with P_{11} state and blue-colored ones are for nonresonant contributions. The calculated values from the previous studies are taken as inputs with $\theta = 130^o$, $M_R = 1685\,\mathrm{MeV}$, $\Gamma_R = 10\,\mathrm{MeV}$ for the double polarization observables, E, F, G, and H .

Summary and Outlooks

If the narrow resonance is considered within the Breit-Wigner energy dependece form, in the double polarization observables, E, F, G, and H, the resonant contributions (red-colored lines) with P_{11} state have much remarkable peak/dip structures for the neutron than for the proton and we expect that the experimental data of the double polarization observables from ELSA, MAMI, and JLab in a close future.