UNIVERSITAT DE BARCELONA

THEORETICAL MODEL OF TWO PION PHOTOPRODUCTION: II

JPAC

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with
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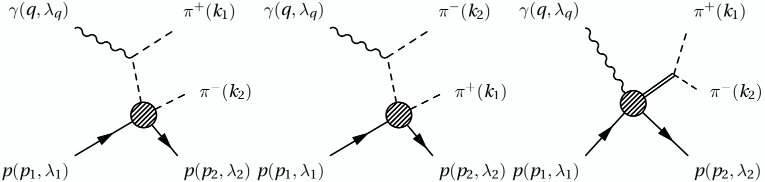
Outline

- Review
- Kinematics variables
- Unpolarized observables
- Polarized Observables:
  - Spin-density matrix elements
  - Beam asymmetry
- Further Work

Review

- Photoproduction important for hadron spectroscopy.
- Study both standard and exotic hadrons.
- JPAC has been developing a model of double pion photoproduction:
  - Gauge invariant Deck
  - Regge amplitude for rho production



Resonances in (πN) system

- For $\vec{\gamma} p \to \pi^+ \pi^- p$ can study
  - $\vec{\gamma} p \to (\pi^\pm \pi^\mp) p$
  - $\vec{\gamma} p \to \pi^\pm (\pi^\mp p)$
- $\vec{\gamma} p \to \pi^- \Delta^{++}$
- Comment: all results are PRELIMINARY!

A note on kinematic variables

- 5 kinematic variables required.

- Angular moments of $\pi\pi$ system:

$$s = (p_1 + q)^2$$
$$t = (p_1 - p_2)^2$$
$$s_{\pi\pi} = (k_1 + k_2)^2$$

and (θ, ϕ) describing the π^+ relative to the production plane

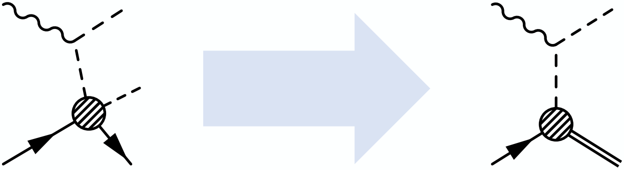
- $\gamma p \to \pi^- \Delta^{++}$

$$s = (p_1 + q)^2$$
$$t = (q - k_2)^2$$
$$s_{\pi N} = (p_2 + k_1)^2$$

and (θ, ϕ) describing the p relative to the production plane

Predictions for $\gamma p \to \pi^- \Delta^{++}$

- Branching ratio $\Gamma(\Delta \to \pi N)/\Gamma_{\text{total}} \sim 1$
- Integrate model over Δ peak to extract $\gamma p \to \pi^- \Delta^{++}$.



- Effectively one-pion-exchange model, couplings not put in by hand.

$d\sigma/dt$

$$\frac{d\sigma}{dt} = \int_{m_\Delta-\delta}^{m_\Delta+\delta} dm_{\pi^+p} \int d\Omega \frac{d\sigma}{dt dm_{\pi^+p} d\Omega}$$

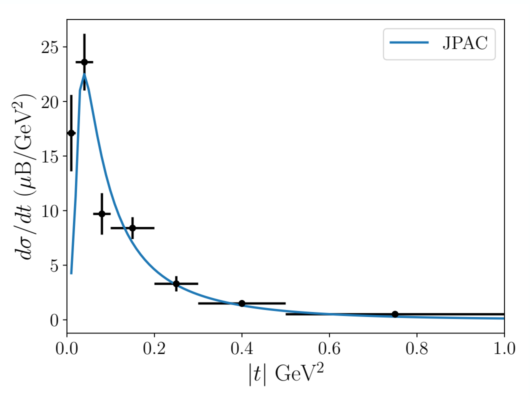


Figure 1: Ballam et al, Phys.Rev.D 5 (1972) 545

Δ production by polarized photons

- Provide a further check of model.
- Linearly polarized photons allow for discrimination between natural $(P(1)^J = 1)$ and unnatural $(P(1)^J = -1)$ parity.
- Φ is angle between polarization vector and production plane.
- Intensity is

$$I(\Omega, \Phi) = I^0(\Omega) - P_\gamma \cos 2\Phi I^1(\Omega) - P_\gamma \sin 2\Phi I^2(\Omega)$$

- P_γ degree of polarization: $0 \leq P_\gamma \leq 1$
- Integrating over the Δ resonance gives

$$\begin{aligned}\tilde{I}(\Omega, \Phi) &= \int_{m_\Delta - \delta}^{m_\Delta + \delta} dm_{\pi N} I(\Omega, \Phi) \\ &= \tilde{I}^0(\Omega) - P_\gamma \cos 2\Phi \tilde{I}^1(\Omega) - P_\gamma \sin 2\Phi \tilde{I}^2(\Omega)\end{aligned}$$

Decay Angular Distribution $\Delta^{++} \to \pi^+ p$

- Up to overall normalization, relate the integrated intensity $\tilde{I}(\Omega, \Phi)$ to decay angular distribution:

$$\begin{aligned}\tilde{I}(\Omega,\Phi) \propto W(\theta,\phi,\Phi) = \frac{3}{4\pi}\Bigg(&\rho^0_{33}\sin^2\theta + (\frac{1}{2}-\rho^0_{33})(\frac{1}{3}+\cos^2\theta) - \frac{2}{\sqrt{3}}\operatorname{Re}\rho^0_{31}\cos\phi\sin 2\theta - \frac{2}{\sqrt{3}}\operatorname{Re}\rho^0_{3-1}\cos 2\phi\sin^2\theta \\ &- P_\gamma\cos 2\Phi\left[\rho^1_{33}\sin^2\theta + \rho^1_{11}(\frac{1}{3}+\cos^2\theta) - \frac{2}{\sqrt{3}}\operatorname{Re}\rho^1_{31}\cos\phi\sin 2\theta - \frac{2}{\sqrt{3}}\operatorname{Re}\rho^1_{3-1}\cos 2\phi\sin^2\theta\right] \\ &- P_\gamma\sin 2\Phi\left[\frac{2}{\sqrt{3}}\operatorname{Im}\rho^2_{31}\sin\phi\sin 2\theta + \frac{2}{\sqrt{3}}\operatorname{Im}\rho^2_{3-1}\sin 2\phi\sin^2\theta\right]\Bigg)\end{aligned}$$

- $\rho^k_{ij}(s,t)$: Spin density matrix elements: encode the angular correlations.

Comparison to Bingham et al. 1970

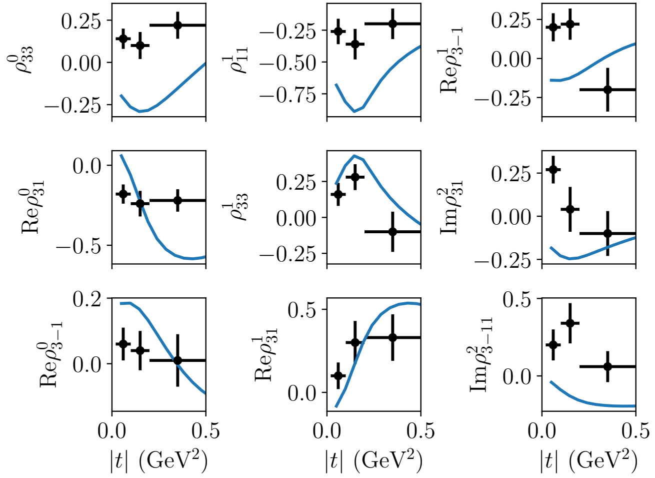


Figure 2: Ballam et al, Phys.Rev.D 5 (1972) 545

- Computable from SDMEs:

$$\Sigma = 2(\rho^1_{11} + \rho^1_{33})$$

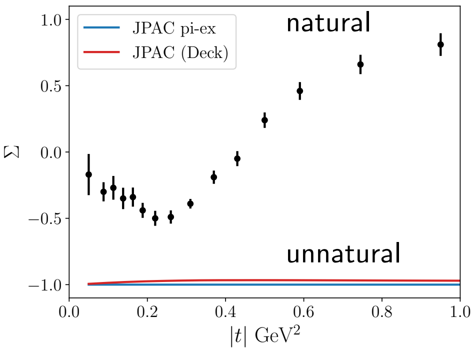
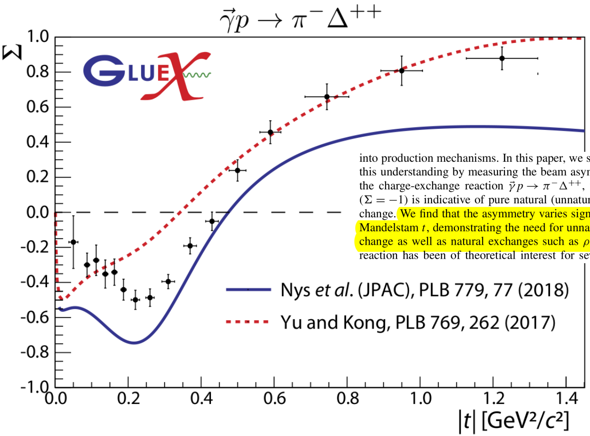


Figure 3: GlueX, Phys.Rev.C 103 (2021) 2, L022201

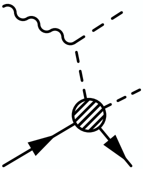


into production mechanisms. In this paper, we seek to extend this understanding by measuring the beam asymmetry Σ for the charge-exchange reaction $\vec{\gamma}p \to \pi^-\Delta^{++}$, where $\Sigma = 1$ ($\Sigma = -1$) is indicative of pure natural (unnatural) parity exchange. We find that the asymmetry varies significantly over Mandelstam t, demonstrating the need for unnatural pion exchange as well as natural exchanges such as ρ and a_2. This reaction has been of theoretical interest for several decades

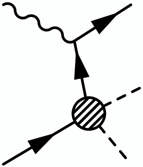
Figure 4: Phys.Rev.C 103 (2021) 2, L022201

Future Work

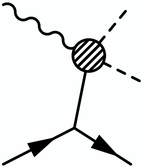
Factorization allows us to leverage excellent knowledge of $2 \to 2$ processes.



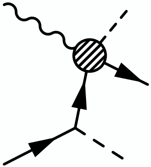
$\pi N \to \pi N$
$\rho N \to \pi N$
VMD: $\gamma N \to \pi N$



$N\overline{N} \to \pi\pi$



$\gamma \mathbb{P} \to \pi\pi$
$\gamma f_2 \to \pi\pi$



$\gamma N \to \pi N$

Conclusions

- Developed model of $\gamma p \to p\pi^+\pi^-$.
- Applied to description of $\gamma p \to \pi^-\Delta$
  - Unpolarized observables reasonable.
  - Polarized observables require more sophisticated model: ρ, a_2 exchange.

JPAC Model