國立交通大學
National Chiao Tung University

Backwards Double Pseudoscalar Production

Robert J. Perry
Institute of Physics, National Chiao-Tung University, Taiwan
perryrobertjames@gmail.com

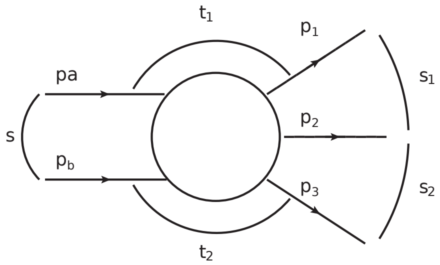
and
Lukasz Bibrzycki
on behalf of
JPAC

Outline

- Kinematics of two pseudoscalar photoproduction:
- Theoretical descriptions: Deck Model and Pumplin Prescription
  - Kinematical constraints: Backward angle
- Analysis of $\pi^- p \to \pi^- \eta p$ data from Compass
- Contributions to forward/backward η
- Some preliminary results and future plans.

Kinematics of two pion photoproduction

- We study the process $\gamma(p_a) + p(p_b) \to \pi^+(p_1) + \pi^-(p_2) + p(p_3)$



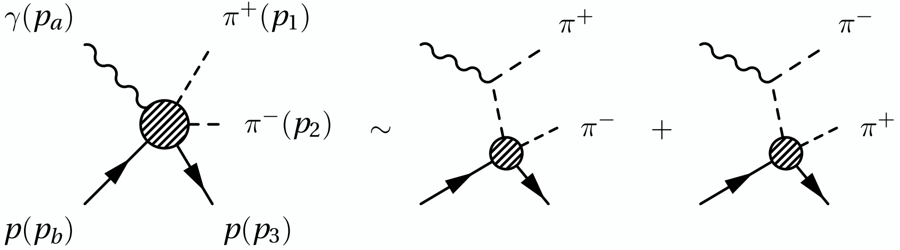
Require 5 kinematical variables to describe the process:

$$s = (p_a + p_b)^2$$
$$s_{\pi\pi} = (p_1 + p_2)^2 = m_{\pi\pi}^2$$
$$t_2 = (p_b - p_3)^2$$

and two angles θ, ϕ to specify Helicity/GJ frames.

Introduction to Deck Model

- Also known as the Drell-Söding mechanism
- Imagine the process proceeds by diffractive process where photon dissociates into a hadronic pair.
- Reaction then proceeds via quasi elastic scattering.
- Small t: closest singularities



Gauge Invariance: The Pumplin Prescription

PHYSICAL REVIEW D VOLUME 2, NUMBER 9 1 NOVEMBER 1970

Diffraction Dissociation and the Reaction $\gamma p \to \pi^+\pi^- p$*

JON PUMPLIN
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305
(Received 6 April 1970)

The diffraction dissociation process for the reaction $\gamma p \to \pi^+\pi^- p$ is analyzed in detail. Much of the analysis is relevant to reactions initiated by hadrons. A procedure is suggested for adding nonresonant background (the "Söding term") to ρ^0 production without double counting, and numerical calculations are presented.

- Must include extra contact term $\epsilon \cdot C$ to ensure gauge invariance of amplitude:

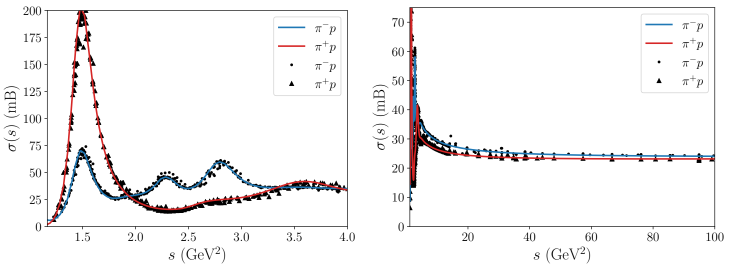
$$i\mathcal{M}_{\text{Deck}} = e\frac{\epsilon_\mu(p_a)(2p_2 - p_a)^\mu}{(p_a - p_2)^2 - m_\pi^2} i\mathcal{M}_+ - e\frac{\epsilon_\mu(p_a)(2p_1 - p_a)^\mu}{(p_a - p_1)^2 - m_\pi^2} i\mathcal{M}_- + \epsilon_\mu(p_a)C^\mu$$

- Pumplin prescription is $C^\mu = c(p_b + p_3)^\mu$, where c is a scalar function.

$$c = \frac{i\mathcal{M}_+ - i\mathcal{M}_-}{p_a \cdot (p_b + p_3)} \quad (1)$$

Advantages of Description

- Allows one to relate 3 body final state to well known πN elastic scattering.
- Wealth of data at low energies allows parameterization of amplitude in terms of partial waves, ie SAID parameterization. R.L. Workman et al., Phys.Rev.C 86 (2012) 035202
- Extension of πN scattering to high energies may be accomplished via Regge Models. V. Mathieu et al., Phys. Rev. D 92 (2015) 074004
  - Code available: `http://cgl.soic.indiana.edu/jpac/index.php`



SAID Parameterization

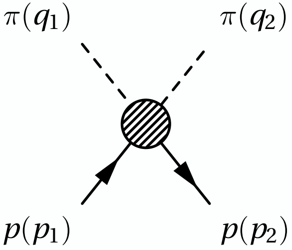
- Most general πN scattering amplitude given by

$$i\mathcal{M}_{\pm} = \overline{u}(p_2, \lambda_2)\left[A_{\pm}(s^*, t^*) + \frac{1}{2}(\not{q}_2 + \not{q}_2)B_{\pm}(s^*, t^*)\right]u(p_1, \lambda_1) \quad (2)$$

- Two body kinematics:

$$s^* = (p_1 + q_1)^2$$
$$t^* = (p_1 - p_2)^2$$

- Must determine 'correct' kinematic variables to use when embedded in photoproduction amplitude.



Good Description of Partial Waves

Bibrzycki et al., Phys. Lett. B 789 (2019)

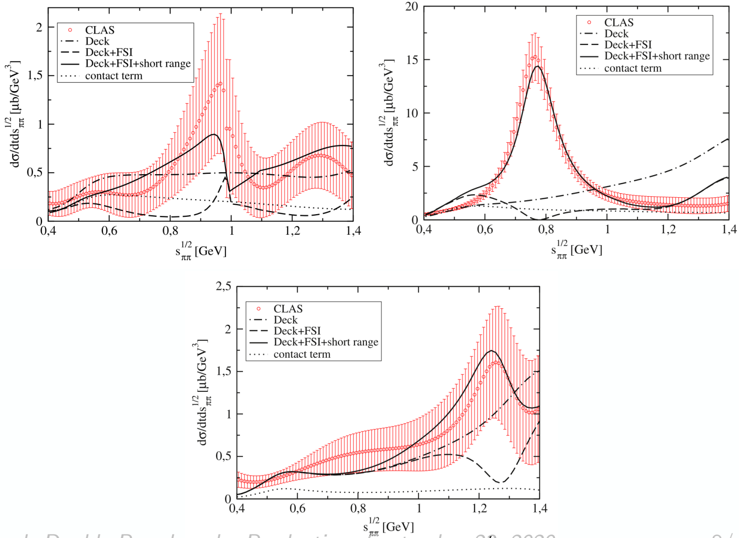
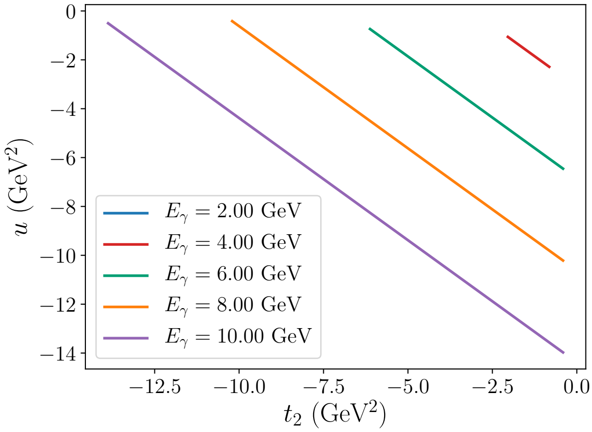


Figure 1: $t_2 = -0.55$ GeV^2

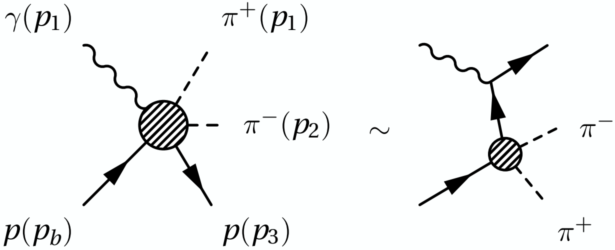
Backward Double Pion Photoproduction

- Seek to apply Deck Model to backwards angle scattering
- Backwards angle $\implies$ large negative t_2, and small negative u.



Applying Deck

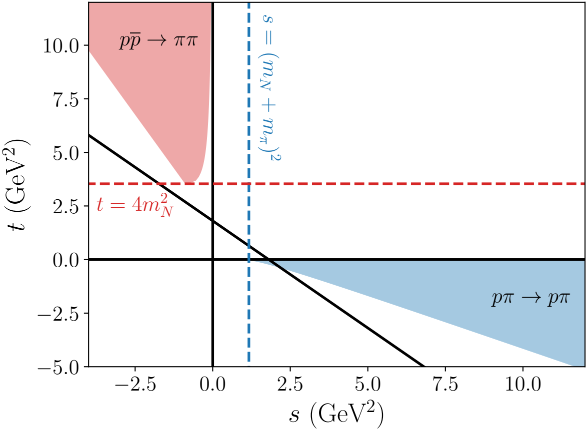
- Large s, small $u \implies$ Regge exchange in u-channel.
- Nucleon pole term leads to Deck description:

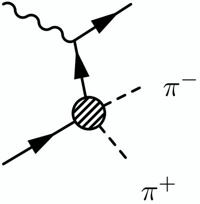


- Need a model for the lower vertex.
- Ideally use πN amplitudes.
- But! Kinematic regions incompatible ($s^* < 0,\ t^* > 0$)

$p\bar{p} \to \pi\pi$

- Instead, propose to start from $p\bar{p} \to \pi\pi$





$p\overline{p} \to \pi\pi$

- Amplitude is

$$i\mathcal{M}_{\lambda_1\lambda_3\lambda_a} = e\epsilon_\mu(p_a,\lambda_a)\overline{u}(p_3,\lambda_3)\left[\gamma^\mu\frac{(\not{p}_3 - \not{p}_a) + m_N}{u - m_N^2} + C^\mu\right] \times \left(A_\pm(s^*,t^*) + \frac{1}{2}(\not{p}_1 - \not{p}_2)B_\pm(s^*,t^*)\right)u(p_b,\lambda_b)$$

- where, ie

$$s^* = (p_1 + p_2)^2 = m_{\pi\pi}^2$$

- This study is ongoing

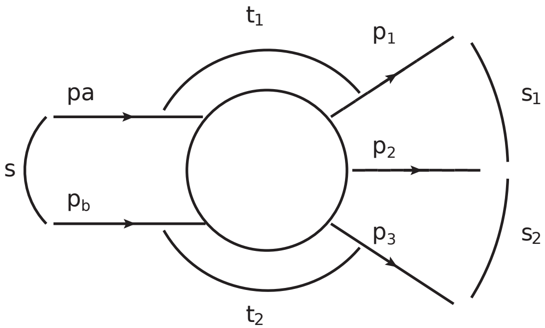
Description of the $\pi^-\eta^{(\prime)}$ production data above the resonance region

Background

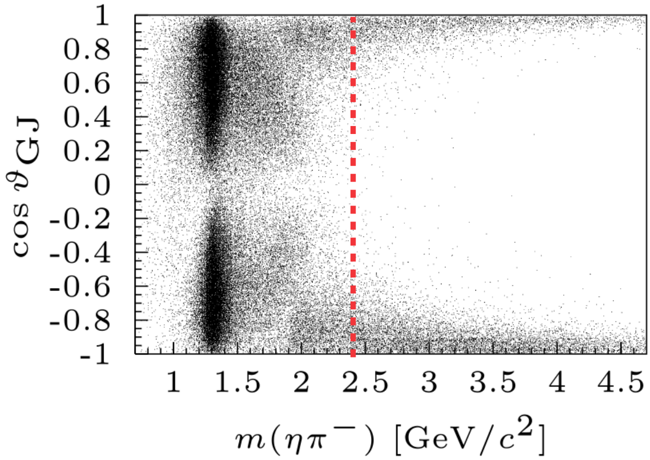
- Work based on measurement of partial waves for $\pi^- p \to \pi^- \eta^{(\prime)} p$ at 191 GeV at Compass Adolph et al., PLB B 740 (2015) 303311
- $\pi\eta^{(\prime)}$ is a *Golden Channel*: Attractive for spectroscopy studies
  - states with odd angular momentum L which coincides with total spin J have non $q\bar{q}$ (exotic) quantum numbers
  - ie $J^{PC} = 1^{-+}, 3^{-+}, 5^{-+}$
- Work conducted by JPAC: not yet complete.

Kinematics

- Above resonance region s, $s_1 = m_{\pi\eta}$, s_2 large: Regge picture.
- Model under study is designed to work in the limit $s_1, s_2, s \to \infty$ with t_1, t_2,$s/s_1 s_2$ - fixed.
- In the Gottfried-Jackson frame $\cos\theta_{GJ}$ is related to t_1 and ϕ_{GJ} is related to s_2.



Measurements



- *Not acceptance corrected. $\cos\theta_{GJ}$ in beam direction (forward).

Adolph et al., PLB B 740 (2015) 303311

General form of the amplitude

- Double reggeon exchange model: Shimada et al. NPB 142, 344 (1978))

$$T^{\tau_1\tau_2} = -K\tilde{T}^{\tau_1\tau_2} = -K\Gamma(1-\alpha_1)\Gamma(1-\alpha_2)$$
$$\left[(\alpha' s)^{\alpha_1-1}(\alpha' s_2)^{\alpha_2-\alpha_1}\xi_1\xi_{21}\hat{V}_1 + (\alpha' s)^{\alpha_2-1}(\alpha' s_1)^{\alpha_1-\alpha_2}\xi_2\xi_{12}\hat{V}_2\right]$$

where

$$\hat{V}_1(\eta, t_1, t_2) = \beta_0 \frac{\Gamma(\alpha_1-\alpha_2)}{\Gamma(1-\alpha_2)}\ {}_1F_1\left(1-\alpha_1, 1-\alpha_1+\alpha_2, -\frac{1}{\eta}\right) \quad (3)$$

and $\hat{V}_2$ is obtained by replacing $\alpha_1 \leftrightarrow \alpha_2$.

General form of the amplitude

- Signature factors are defined as:

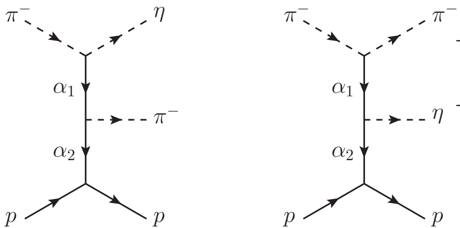
$$\xi_i = \frac{1}{2}(\tau_i + e^{-i\pi\alpha_i}) \qquad \xi_{ij} = \frac{1}{2}(\tau_i\tau_j + e^{-i\pi(\alpha_i - \alpha_j)})$$

  and kinematic singularities factored:
  $K = -4\sqrt{s_1}|\mathbf{p}_a||\mathbf{p}_1||\mathbf{p}_3| \sin\theta_2 \sin\theta_{GJ} \sin\phi_{GJ}$
- Both α_1 and α_2 are of 2^{++} type so we put $\tau_1 = \tau_2 = +1$.
- Regge trajectories:

$$\alpha_{f_2}(t) = \alpha_{a_2}(t) = 0.47 + 0.89t \qquad \alpha_{\mathbb{P}}(t) = 1.08 + 0.25t$$

Double reggeon exchange amplitude

- Consider leading natural exchanges



Type of diagram	α_1	α_2
I (fast/forward η)	α_{a_2}	$\alpha_{\boldsymbol{P}}$
	α_{a_2}	α_{f_2}
II (slow/backward η)	α_{f_2}	$\alpha_{\boldsymbol{P}}$
	α_{f_2}	α_{f_2}
	$\alpha_{\boldsymbol{P}}$	$\alpha_{\boldsymbol{P}}$
	$\alpha_{\boldsymbol{P}}$	α_{f_2}

- Total diagrams: 6
- Individual diagram strength G_i depend on product of 3 vertex couplings:

$$G_i = g_{\text{top}} \times g_{\text{middle}} \times g_{\text{bottom}} \tag{4}$$

- We treat diagram strengths as parameters to be fitted.

Observables

- Full amplitude:

$$T(s, s_1, t_2, \cos\theta, \phi; a_i) = K \sum_{i \in I,II} G_i \tilde{T}_i^{\,\tau_1 \tau_2}(\alpha_1(t_1), \alpha_2(t_2); s, s_1, t_2, \cos\theta, \phi)$$

where: G_i (to be fitted) are the abbreviations for coupling triples.

- Partial wave amplitudes:

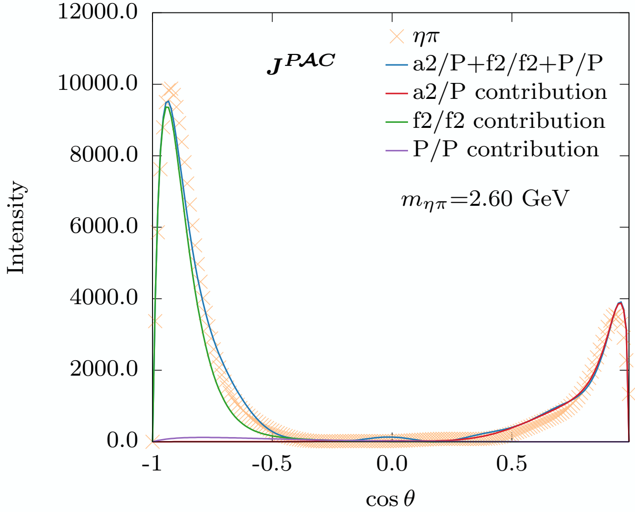
$$T^L_M(s, s_1, t_2; a_i) = \int d\Omega\, Y^L_M(\cos\theta, \phi)^* \, T(s, s_1, t_2, \cos\theta, \phi; a_i).$$

- Reflectivity eigenamplitudes:

$$^{\epsilon}T^L_M = \frac{1}{2}\left[T^L_M - \epsilon(-1)^M T^L_{-M}\right]$$

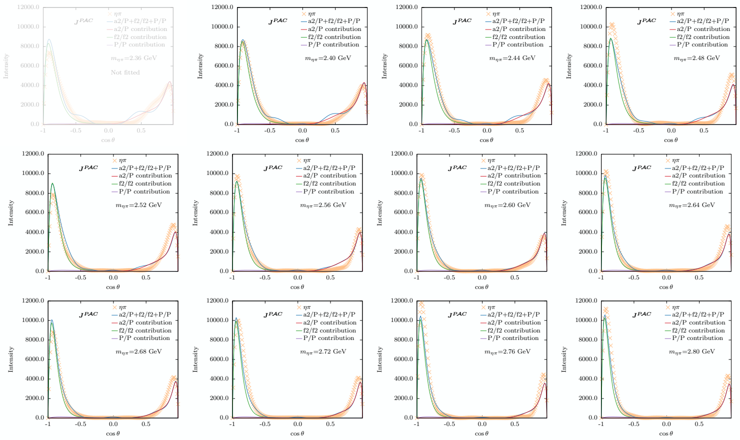
In fits we use ϵ=+1 only (which is implicit in what follows).

Fit results ($\eta\pi$ channel) (Preliminary)

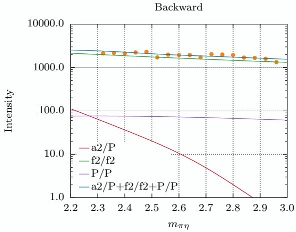


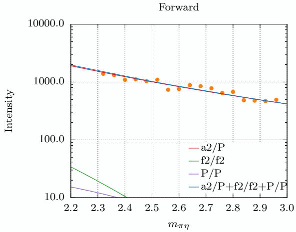
Data binned in $m_{\eta\pi}$

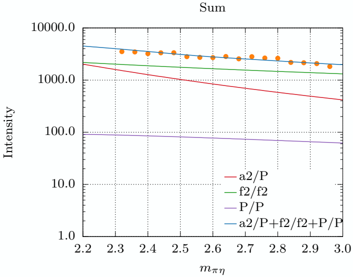
Fit results ($\eta\pi$ channel) (Preliminary)



Backward and Forward Regions Separated







Summary and outlook

- Number of different theoretical approaches to description of three body final states.
- Discussed u-channel contribution through Deck process
  - Proposed $p\overline{p} \to \pi\pi$ as starting point for amplitude Deck amplitude.
- Showed results for Regge description of $\pi\eta$.
- Good agreement with the data; fits still not final.

Backup slides

Observables

- Full amplitude:

$$T(s, s_1, t_2, \cos\theta, \phi; a_i) = K \sum_{i\in I,II} a_i \tilde{T}_i^{\tau_1\tau_2}(\alpha_1(t_1), \alpha_2(t_2); s, s_1, t_2, \cos\theta, \phi)$$

where: G_i (to be fitted) are the abbreviations for coupling triples.

- Partial wave amplitudes:

$$T^L_M(s, s_1, t_2; a_i) = \int d\Omega Y^L_M(\cos\theta, \phi)^* T(s, s_1, t_2, \cos\theta, \phi; a_i).$$

- Reflectivity eigenamplitudes:

$$^{\epsilon}T^L_M = \frac{1}{2}\left[T^L_M - \epsilon(-1)^M T^L_{-M}\right]$$

In fits we use $\epsilon{=}{+}1$ only (which is implicit in what follows).

Observables

- Intensity:

$$I^L_M(m_{\eta\pi}) = N_0 \left| T^L_M(s, m^2_{\eta\pi}, t_2^{\text{eff.}}) \right|^2 \frac{\lambda^{1/2}(m^2_{\eta\pi}, m^2_\pi, m^2_N)}{m_{\eta\pi}},$$

  N_0 absorbs normalisation and t_2 integration.

- Phase difference:

$$\Delta\Phi_L = \text{atan2}(\text{Im}\, T^L_1(s, s_1, t_2), \text{Re}\, T^L_1(s, s_1, t_2)) \\ - \text{atan2}(\text{Im}\, T^2_1(s, s_1, t_2), \text{Re}\, T^2_1(s, s_1, t_2))$$