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Moments of Double Pion Photoproduction

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Outline

- Mesons spectroscopy in QCD
- Experimental status
- Kinematics of two pseudoscalar photoproduction
- Theoretical descriptions:
  - Background: Deck Model with Pumplin Prescription
  - Direct Resonances: Vector mesons
- (Preliminary) Results

Photoproduction for Hadron Spectroscopy

- Photoproduction: clean probe for hadron spectroscopy.
- High quality data at JLab, CERN SPS, ELSA, MAMI, and SPring-8 etc.
  - Including polarization data.
- Photoproduction of pseudoscalars allows investigation of light meson resonances.
- Partial wave projection allows sensitivity to exotic quantum numbers.

- Odd partial waves have exotic quantum numbers
- Moments sensitive to these partial waves

$$\langle Y_{LM} \rangle = \sqrt{4\pi} \int d\Omega \frac{d\sigma}{dt ds_{12} d\Omega} Y_{LM}(\Omega) \tag{1}$$

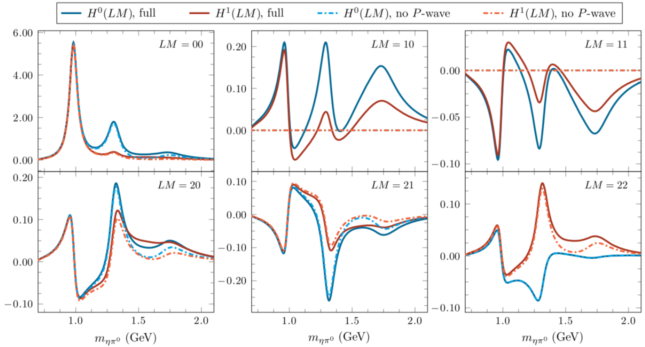
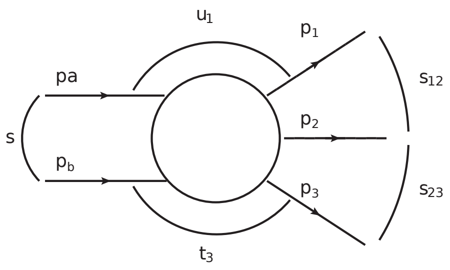


Figure 1: V. Mathieu et al., Phys. Rev. D 100 (2019) 54017

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:

$$s = (p_a + p_b)^2\,, \quad s_{12} = (p_1 + p_2)^2,$$
$$s_{23} = (p_2 + p_3)^2\,, \quad u_1 = (p_a - p_1)^2,$$
$$t_3 = (p_b - p_3)^2$$

or

$$s = (p_a + p_b)^2\,, \quad s_{12} = (p_1 + p_2)^2,$$
$$t_3 = (p_b - p_3)^2$$

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

Overview of Model

- E_γ large: above resonance region, so minimal contribution from s-channel nucleon resonances: currently neglect.
- Continuum production
- Resonant production.

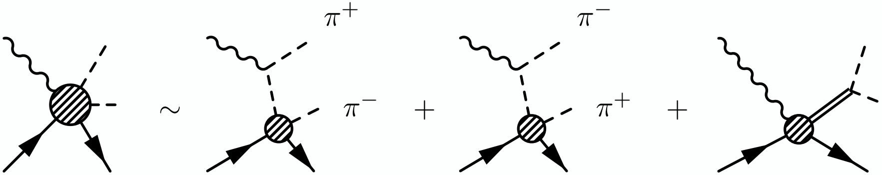
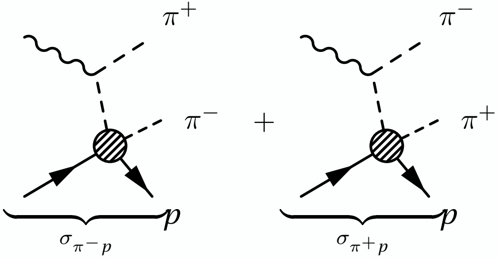


Figure 2: Diagrams currently included in model: sum of continuum and resonant production modes.

Introduction to Deck Mechanism

- 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_1: closest singularities



(2)

Gauge Invariance: The Pumplin Prescription

PHYSICAL REVIEW D VOLUME 2, NUMBER 9 1 NOVEMBER 1970

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

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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:

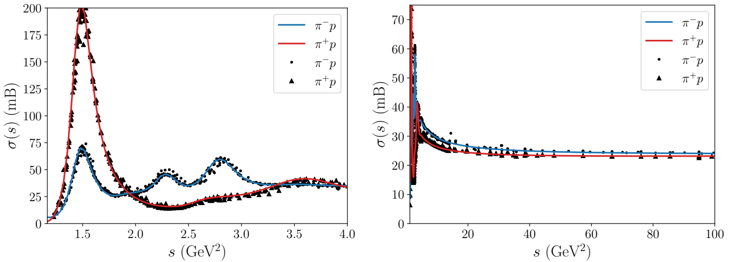
$$i\mathcal{M}_{\text{Deck}} = e\frac{\epsilon_\mu(p_a)(2p_2 - p_a)^\mu}{(p_a - p_2)^2 - m_\pi^2} i\mathcal{M}_+ - e\frac{\epsilon_\mu(p_a)(2p_1 - p_a)^\mu}{(p_a - p_1)^2 - m_\pi^2} i\mathcal{M}_- + \epsilon_\mu(p_a)C^\mu$$

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

$$c = \frac{i\mathcal{M}_+ - i\mathcal{M}_-}{p_a \cdot (p_b + p_3)} \tag{3}$$

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 Model. V. Mathieu et al., Phys. Rev. D 92 (2015) 074004
  - Code available: `http://cgl.soic.indiana.edu/jpac/index.php`



SAID Parameterization

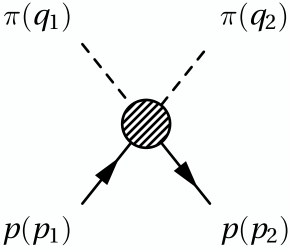
- Most general πN scattering amplitude given by

$$i\mathcal{M}_{\pm} = \overline{u}(p_2, \lambda_2)\left[A_{\pm}(s^*, t^*) + \frac{1}{2}(\not{q}_2 + \not{q}_2)B_{\pm}(s^*, t^*)\right]u(p_1, \lambda_1) \quad (4)$$

- 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.



Off-Shell Parameterization

- Assume scattering amplitude for elastic πN scattering smooth function of kinematic variables.
- Make replacements

$$|\mathbf{p}_1^*| = \frac{\lambda^{1/2}(s_{i3}, m_N^2, u_j)}{2\sqrt{s_{i3}}} \tag{5}$$

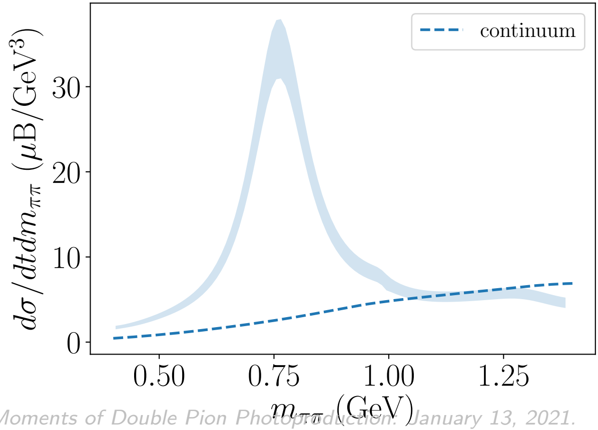
$$|\mathbf{p}_2^*| = \frac{\lambda^{1/2}(s_{i3}, m_N^2, m_\pi^2)}{2\sqrt{s_{i3}}} \tag{6}$$

$$\cos\theta^* = \frac{t - 2m_N^2 + 2E_1^* E_2^*}{2|\mathbf{p}_1^*||\mathbf{p}_1^*|} \tag{7}$$

- Can think of this as scattering a pseudoscalar on the nucleon with mass $u_j < 0$

Continuum Model (Preliminary)

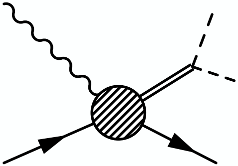
$$\langle Y_{LM} \rangle = \sqrt{4\pi} \int d\Omega \frac{d\sigma}{dt ds_{12} d\Omega} Y_{LM}(\Omega), \qquad \langle Y_{00} \rangle = \frac{d\sigma}{dt ds_{12}} \tag{8}$$



Battaglieri et al. (The CLAS Collaboration), Phys.Rev.D 80 (2009) 072005

Resonant Production

- Currently take resonant production mechanism from Szczurek et al., Phys. Rev. D 71, (2005), 054005
- For small s_{12}, have large contribution from $\rho^0(770)$:

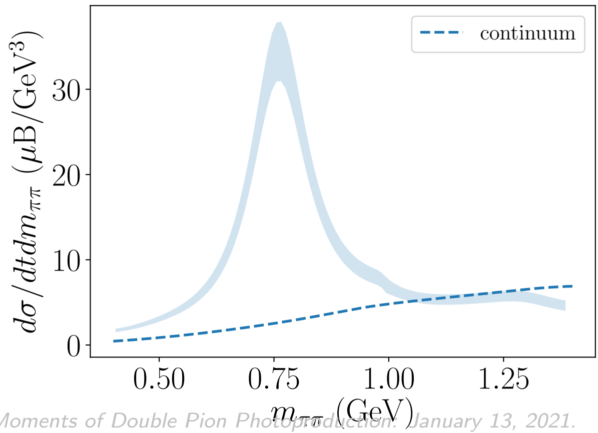


$$\mathcal{M}_{\text{res.}} = \left[\frac{e}{\gamma_\rho}\mathcal{M}^{\rho p}_{\lambda_1\lambda_2}(s,t)\,Y_{1\lambda_\gamma}(\Omega)\right] f_{BW}(s_{12}) \quad (9)$$

- VMD: relate vertex to $\mathcal{M}^{\rho p}_{\lambda_1\lambda_2}$

Continuum + Resonant Model (Preliminary)

$$\langle Y_{LM} \rangle = \sqrt{4\pi} \int d\Omega \frac{d\sigma}{dt ds_{12} d\Omega} Y_{LM}(\Omega), \qquad \langle Y_{00} \rangle = \frac{d\sigma}{dt ds_{12}} \tag{10}$$



Battaglieri et al. (The CLAS Collaboration), Phys.Rev.D 80 (2009) 072005

Continuum + Resonant Model (Preliminary)

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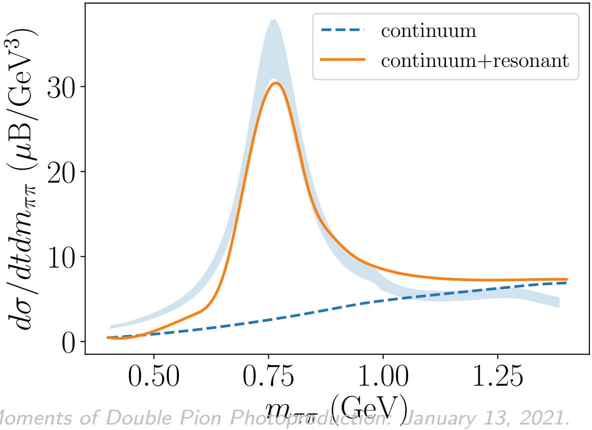


Battaglieri et al. (The CLAS Collaboration), Phys.Rev.D 80 (2009) 072005

Summary and Outlook

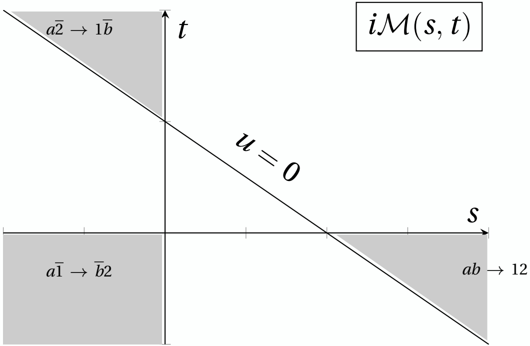
- Final state interactions (π-π rescattering).
- Understand other moments.
- Extra resonances?

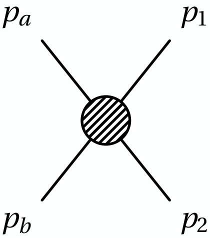
Backup slides

Analyticity, Crossing

- Consider $2 \to 2$ process, $p_i^2 = m^2$. Ignore complications due to spin etc.
- $S = 1 + iT$

$$\langle p_1, p_2 | \, iT \, | p_a, p_b \rangle = (2\pi)^4 \delta(p_a + p_b - p_1 - p_2) i\mathcal{M}(s,t) \tag{11}$$





Good Description of Partial Waves

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

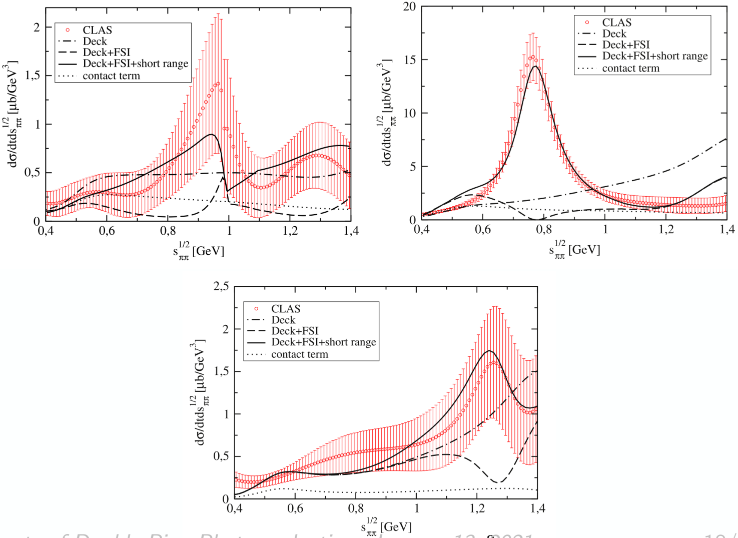
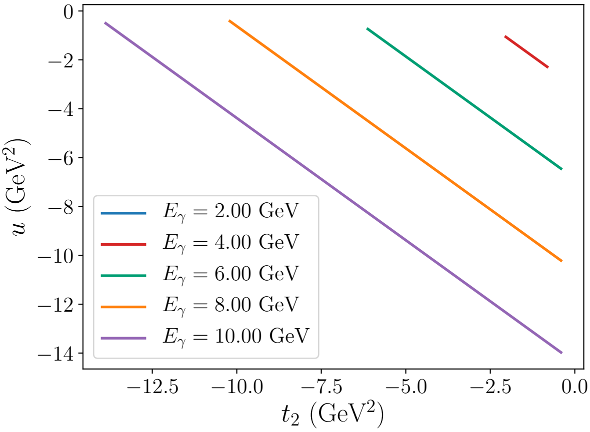


Figure 3: $t_2 = -0.55$ GeV^2

Backward Scattering

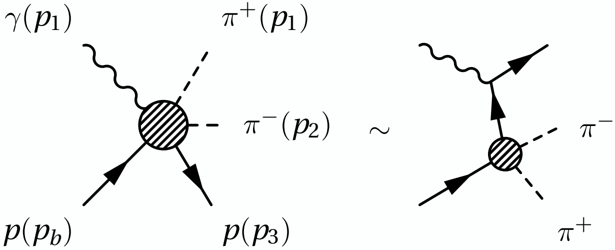
Backward Double Pion Photoproduction

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



Applying Deck

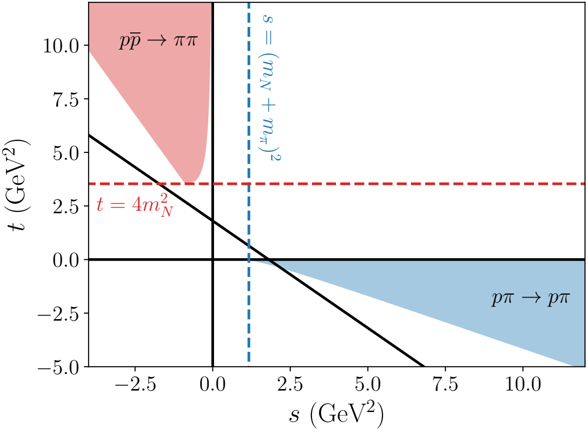
- Large s, small $u \implies$ Regge exchange in u-channel.
- Nucleon pole term leads to Deck description:

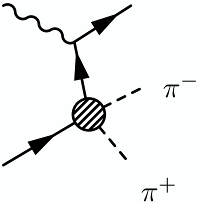


- Need a model for the lower vertex.
- Ideally use πN amplitudes.
- But! Kinematic regions incompatible ($s^* < 0,\ t^* > 0$)

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

- 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