JPAC update

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FOR JPAC COLLABORATION

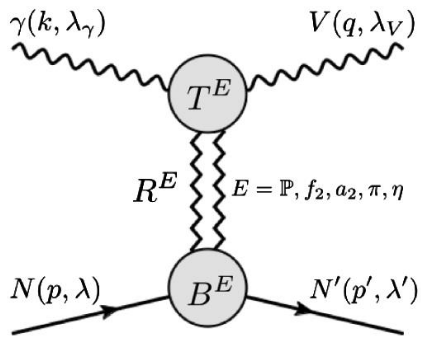
Vector meson photoproduction with linearly polarized photons

V. Mathieu et al. PRD 97 (2018)

- Motivation:
  - Testing the mechanisms of production (dominanace of natural exchanges like *IP*, f_2, a_2)
  - Testing models of residues (couplings, helicity dependence)
  - Confronting model with experimental spin density matrix elements (SDME)
  - Description of the CLAS12 and GlueX data
- Immediate purpose: description of the ρ, ω and φ photoproduction at $E\gamma$=8.5 GeV

Vector meson photoproduction with linearly polarised photons

- At forward direction the amplitude is dominated by Reggeon exchange



- Quantum numbers describing trajectory:
  - Isospin *I*, naturality $\eta = P(-1)^J$, signature $\tau = (-1)^J$, charge conjugation *C*, *G*-parity $C(-1)^I$
- Model includes both natural ($I\!P$, f_2, a_2) and unnatural (π,η) exchanges
- Residue factorisation enables the independent parametrization of helicity dependence in beam and target vertices
- Parity conservation reduces the number of helicity components in each vertex

- Amplitude structure:

$$\mathcal{M}^{E}_{\substack{\lambda_V,\lambda_\gamma \\ \lambda',\lambda}}(s,t) = T^{E}_{\lambda_V\lambda_\gamma}(t) R^{E}(s,t) B^{E}_{\lambda'\lambda}(t)$$

- Regge propagators:

$$R^{U}(s,t) = \frac{1+e^{-i\pi\alpha_U(t)}}{\sin \pi\alpha_U(t)} \hat{s}^{\alpha_U(t)} \qquad U = \pi, \eta$$

$$R^{N}(s,t) = \frac{\alpha_N(t)}{\alpha_N(0)} \frac{1+e^{-i\pi\alpha_N(t)}}{\sin \pi\alpha_N(t)} \hat{s}^{\alpha_N(t)} \qquad N = \mathbb{P}, f_2, a_2$$

- Vertex functions:
  - Unnatural exchanges: $T^{U}_{\lambda_V\lambda_\gamma}(t) = \beta^{U}_{\gamma V}\left(\lambda_\gamma \delta_{\lambda_V,\lambda_\gamma} - \sqrt{2}\frac{\sqrt{-t}}{m_V}\delta_{\lambda_V,0} + \frac{-t}{m_V^2}\lambda_\gamma \delta_{\lambda_V,-\lambda_\gamma}\right)$

$$B^{U}_{\lambda'\lambda}(t) = \beta^{U}_{pp}\left(\delta_{\lambda,-\lambda'}\frac{\sqrt{-t}}{2m_p}\right)$$

  - Natural exchanges: $T^{N}_{\lambda_V\lambda_\gamma}(t) = \beta^{N}_{\gamma V} e^{b_N t}\left(\delta_{\lambda_V,\lambda_\gamma} + \beta^{N}_{1}\frac{\sqrt{-t}}{m_V}\frac{\lambda_\gamma}{\sqrt{2}}\delta_{\lambda_V,0} + \beta^{N}_{2}\frac{-t}{m_V^2}\delta_{\lambda_V,-\lambda_\gamma}\right)$

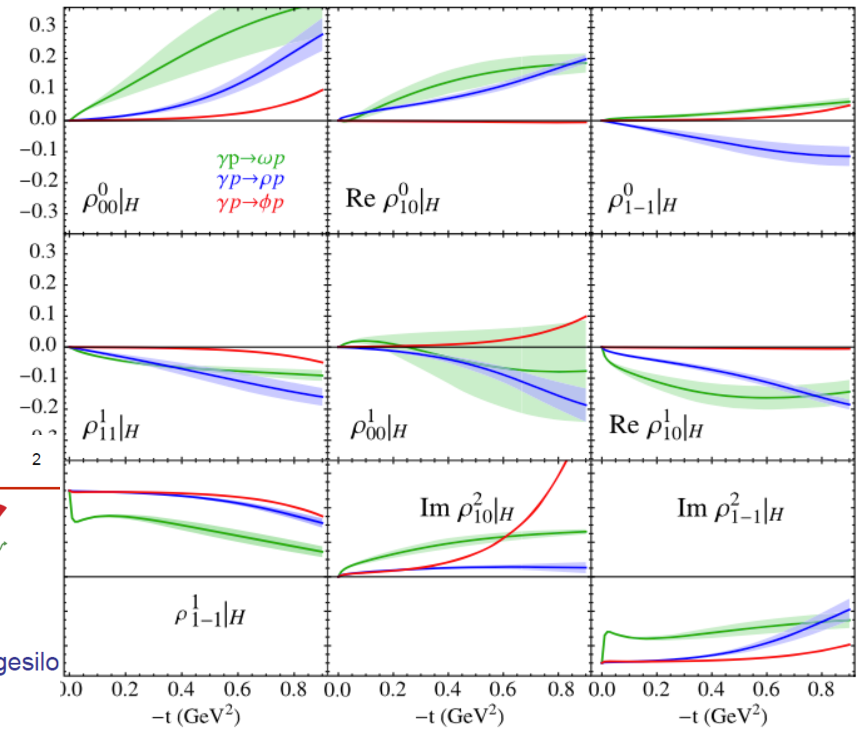
$$B^{N}_{\lambda'\lambda}(t) = \beta^{N}_{pp}\left(\delta_{\lambda,\lambda'} + 2\lambda\kappa_N \frac{\sqrt{-t}}{2m_p}\delta_{\lambda,-\lambda'}\right)$$

  - β_1^N and β_2^N assumed to be equal in order to limit the number of parameters

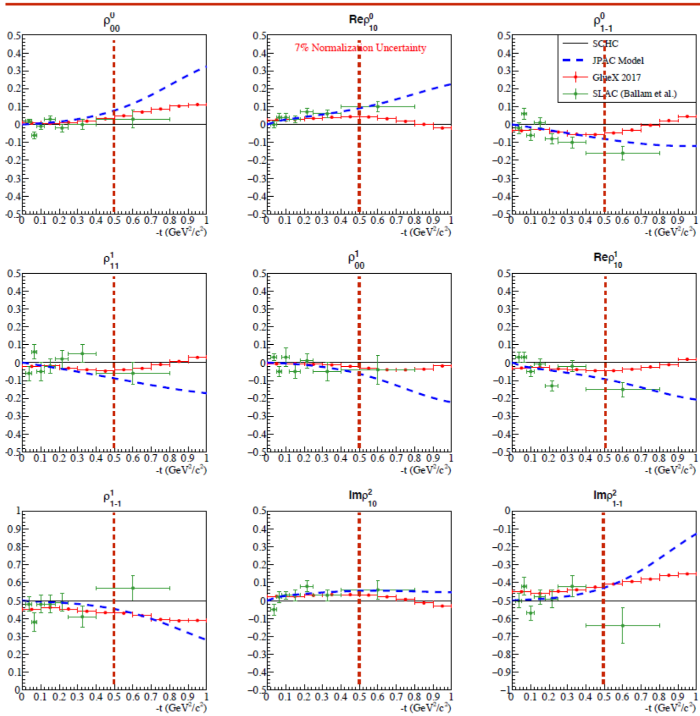
Predictions for SDME

Observations

- For ω and ρ photoproduction small f_2 exchange double helicity flip contribution required along with dominant single halicity flip
- For isovector a_2 exchange only sigle helicity flip occurs



$\vec{\gamma} p \to \rho^0 p$



Preliminary

Courtesy of A. Austregesilo

kinematics expanded in power of $\frac{-t}{m_\rho^2}$

$$\rho^1_{1-1} = \pm\frac{1}{2} + \mathcal{O}(t^2)$$

$$\text{Im}\ \rho^2_{1-1} = \mp\frac{1}{2} + \mathcal{O}(t^2)$$

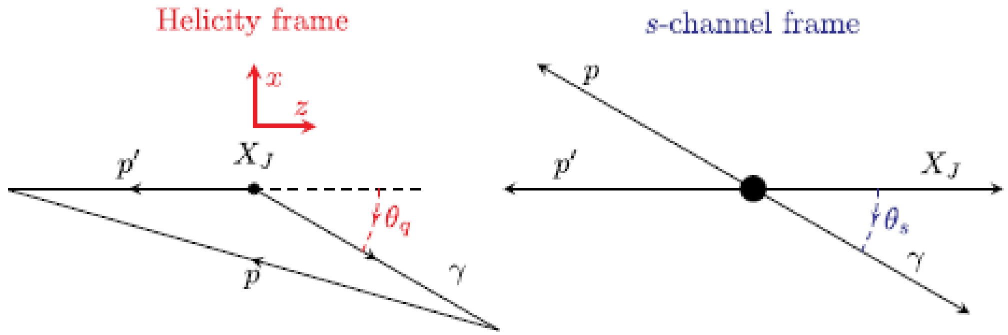
top sign for natural exchange
bottom sign for unnatural exch.

Moments and beam asymmetries in $\eta\pi$ photoproduction at GlueX

V. Mathieu et al. PRD 100 (2019)

- Motivation
  - Searching for exotic hybrids in the $\eta^{(\prime)}\pi$ channels
  - Description of data to be taken at JLab
  - Testing the sensitivity of the observables to the exotic P-wave
  - Testing the s-channel helicity conservation

- Frames used:



- s-channel frame is obtained from helicity frame by boosting the $\pi\eta$ system along the z-axis (which is directed opposite to recoil momentum)
- Cross section:

$$I(\Omega,\Phi) \equiv \frac{d\sigma}{dt\, dm_{\eta\pi^0}\, d\Omega\, d\Phi} = \kappa \sum_{\substack{\lambda,\lambda' \\ \lambda_1,\lambda_2}} A_{\lambda;\lambda_1\lambda_2}(\Omega)\rho^{\gamma}_{\lambda\lambda'}(\Phi)A^*_{\lambda';\lambda_1\lambda_2}(\Omega),$$

- Explicit form:

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

- Partial wave amplitude in the reflectivity basis:

$$^{(\epsilon)}T^{\ell}_{m;\lambda_1\lambda_2} \equiv \frac{1}{2}[T^{\ell}_{+1m;\lambda_1\lambda_2} - \epsilon(-1)^m T^{\ell}_{-1-m;\lambda_1\lambda_2}],$$

- In the high energy limit the +1(-1) reflectivity amplitudes are dominated by t-channel exchange amplitudes with naturality +1(-1)
- Parity invariance implies:

$$^{(\epsilon)}T^{\ell}_{m;-\lambda_1-\lambda_2} = \epsilon(-1)^{\lambda_1-\lambda_2}\,{}^{(\epsilon)}T^{\ell}_{m;\lambda_1\lambda_2},$$

- Consequently one can use two sets of partial wave amplitudes corresponding to nucleaon flip/nonflip:

$$[\ell]^{(\epsilon)}_{m;0} = {}^{(\epsilon)}T^{\ell}_{m;++}, \qquad [\ell]^{(\epsilon)}_{m;1} = {}^{(\epsilon)}T^{\ell}_{m;+-},$$

- In analysis only ϵ=+1 and nucleon non-flip amplitudes were taken into account (dominance of natural parity exchange):

$$[\ell]^{(\epsilon)}_{m;k} = \{S^{(+)}_0, P^{(+)}_{0,1}, D^{(+)}_{0,1,2}\}_{k=0}.$$

- Resonances included in the model: $\mathbf{a_0(980)}$, $\boldsymbol{\pi_1(1600)}$, $\mathbf{a_2(1320)}$ and $\mathbf{a'_2(1700)}$

- They are parametrized by Breit-Wigners: $$\Delta_R(m_{\eta\pi}) = \frac{m_R\Gamma_R}{m_R^2 - m_{\eta\pi}^2 - i m_R \Gamma_R}$$

- Moments:

$$H^0(LM) = \frac{P_\gamma}{2}\int_\circ I(\Omega,\Phi) d^L_{M0}(\theta)\cos M\phi,$$
$$H^1(LM) = \int_\circ I(\Omega,\Phi) d^L_{M0}(\theta)\cos M\phi \cos 2\Phi,$$
$$\mathrm{Im}H^2(LM) = -\int_\circ I(\Omega,\Phi) d^L_{M0}(\theta)\sin M\phi \sin 2\Phi$$

where: $$\int_\circ = (1/\pi P_\gamma)\int_0^\pi \sin\theta \mathrm{d}\theta \int_0^{2\pi}\mathrm{d}\phi \int_0^{2\pi}\mathrm{d}\Phi$$

- Beam asymmetry for two meson production: $$\Sigma_\mathcal{D} = \frac{1}{P_\gamma}\frac{\int_\mathcal{D}[I(\Omega,0) - I(\Omega,\frac{\pi}{2})]\mathrm{d}\Omega}{\int_\mathcal{D}[I(\Omega,0) + I(\Omega,\frac{\pi}{2})]\mathrm{d}\Omega}$$

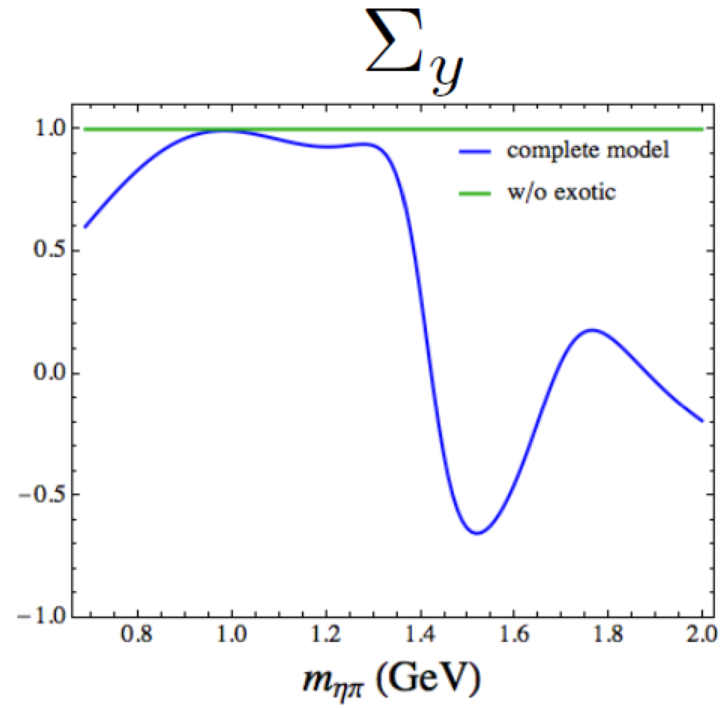
- 4π integrated beam asymmetry: $$\Sigma_{4\pi} = \frac{-1}{P_\gamma}\frac{\int_{4\pi} I^1(\Omega)\mathrm{d}\Omega}{\int_{4\pi} I^0(\Omega)\mathrm{d}\Omega}$$

- Beam asymmetry along the y-axis: $$\Sigma_y = \frac{1}{P_\gamma}\frac{I(\Omega_y,0) - I(\Omega_y,\frac{\pi}{2})}{I(\Omega_y,0) + I(\Omega_y,\frac{\pi}{2})}$$

Beam Asymmetries

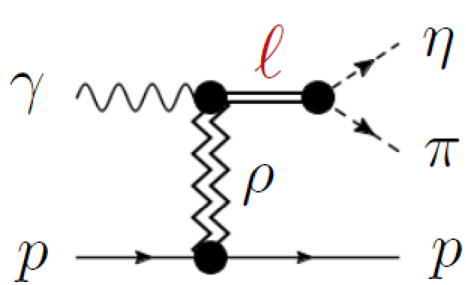
VM et al (JPAC), PRD100 (2019)

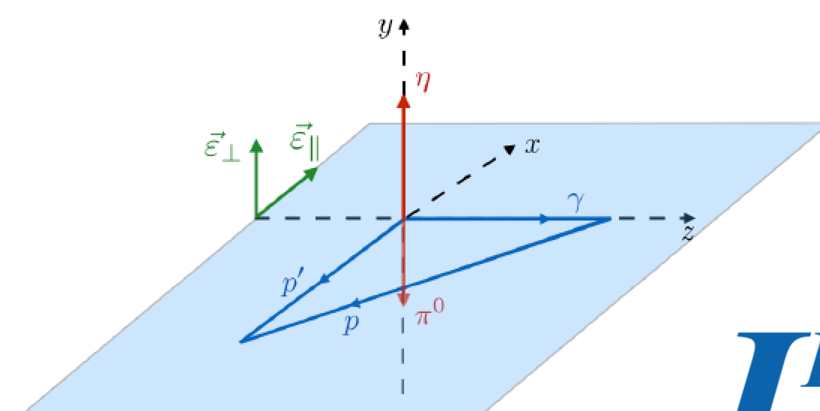
$$\Sigma_y = \frac{1}{P_\gamma}\frac{I(\Omega_y,0) - I(\Omega_y,\frac{\pi}{2})}{I(\Omega_y,0) + I(\Omega_y,\frac{\pi}{2})} = -\frac{I^1(\Omega_y)}{I^0(\Omega_y)}$$



Intensities can be computed from moments:

$$I^0(\Omega_y) = H^0(00) - \frac{5}{2}H^0(20) - 5\sqrt{\frac{3}{2}}H^0(22) + \frac{27}{8}H^0(40) + \frac{9}{2}\sqrt{\frac{5}{2}}H^0(42) + \frac{9}{4}\sqrt{\frac{35}{2}}H^0(44)$$





N* in inclusive electron scattering

A. N. Hiller Blin et al. PRC 100 (2019)

- Motivation
  - Evaluating the resonant contributions to the inclusive electron-proton scattering observables
  - Employing the $\gamma_v pN^*$ electrocouplings obtained in exclusive reaction studies in CLAS
  - Obtaining virtual photon and electron scattering cross sections and F_2 structure function
- Resonances included in the analysis

N^*	M_r (MeV)	Γ_r (MeV)	L_r	$\beta_{\pi N}$	$\beta_{\eta N}$	$\beta_{r.}$	X (GeV)
$\Delta(1232)\,3/2^+$	1232	117	1	1.00	0	0	
$N(1440)\,1/2^+$	1430	350	1	0.65	0	0.35	0.3
$N(1520)\,3/2^-$	1515	115	2	0.60	0	0.40	0.1
$N(1535)\,1/2^-$	1535	150	0	0.45	0.42	0.13	0.5
$\Delta(1620)\,1/2^-$	1630	140	0	0.25	0	0.75	0.5
$N(1650)\,1/2^-$	1655	140	0	0.60	0.18	0.22	0.5
$N(1675)\,5/2^-$	1675	150	2	0.40	0	0.60	0.5
$N(1680)\,5/2^+$	1685	130	3	0.68	0	0.32	0.2
$\Delta(1700)\,3/2^-$	1700	293	2	0.10	0	0.90	0.22
$N(1710)\,1/2^+$	1710	100	1	0.13	0.30	0.57	0.5
$N(1720)\,3/2^+$	1748	114	1	0.14	0.04	0.82	0.5
$N'(1720)\,3/2^+$	1725	120	1	0.38	0	0.62	0.5

- Resonant contributions to the transverse and longitudinal inclusive virtual photon-proton cross sections:

$$\sigma^R_{T,L}(W,Q^2) = \frac{\pi}{q_\gamma^2}\sum_{N*}(2J_r+1)\frac{M_r^2\Gamma_{\rm tot}(W)\Gamma_\gamma{}^{T,L}(M_r,Q^2)}{\left(M_r^2-W^2\right)^2+M_r^2\Gamma^2_{\rm tot}(W)},$$

with

$$\Gamma_\gamma^T(W=M_r,Q^2) = \frac{q^2_{\gamma,r}(Q^2)}{\pi}\frac{2M_N}{(2J_r+1)M_r} \times [|A_{1/2}(Q^2)|^2+|A_{3/2}(Q^2)|^2],$$

$$\Gamma_\gamma^L(W=M_r,Q^2) = 2\frac{q^2_{\gamma,r}(Q^2)}{\pi}\frac{2M_N}{(2J_r+1)M_r}|S_{1/2}(Q^2)|^2$$

- Total width: $\Gamma_{\rm tot}(W) = \Gamma_{\pi N}(W)+\Gamma_{\eta N}(W)+\Gamma_{\rm r.}(W),$
- Energy dependence of decay widths:

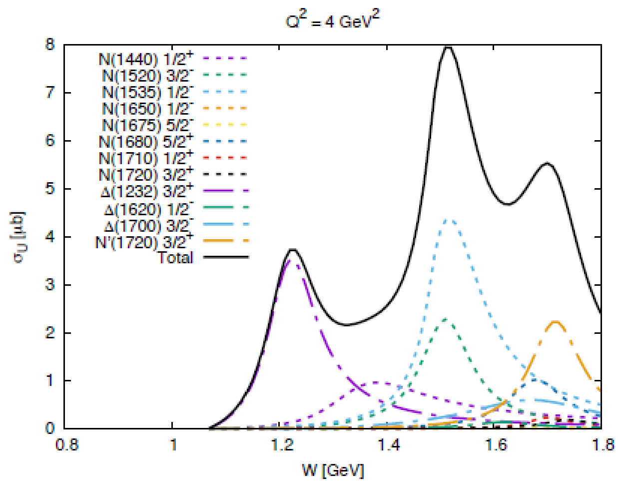
$$\Gamma_{\pi(\eta)N}(W) = \Gamma_r\,\beta_{\pi(\eta)N}\left(\frac{p_{\pi(\eta)}(W)}{p_{\pi(\eta)}(M_r)}\right)^{2L_r+1} \times\left(\frac{X^2+p_{\pi(\eta)}(M_r)^2}{X^2+p_{\pi(\eta)}(W)^2}\right)^{L_r},$$

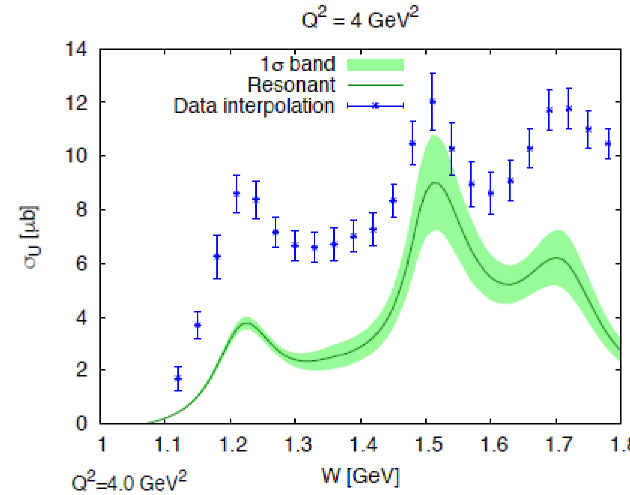
$$\Gamma_{\rm r.}(W) = \Gamma_r\,\beta_{\rm r.}\left(\frac{p_{\pi\pi}(W)}{p_{\pi\pi}(M_r)}\right)^{2L_r+4} \times\left(\frac{X^2+p_{\pi\pi}(M_r)^2}{X^2+p_{\pi\pi}(W)^2}\right)^{L_r+2},$$

N* in inclusive electron scattering

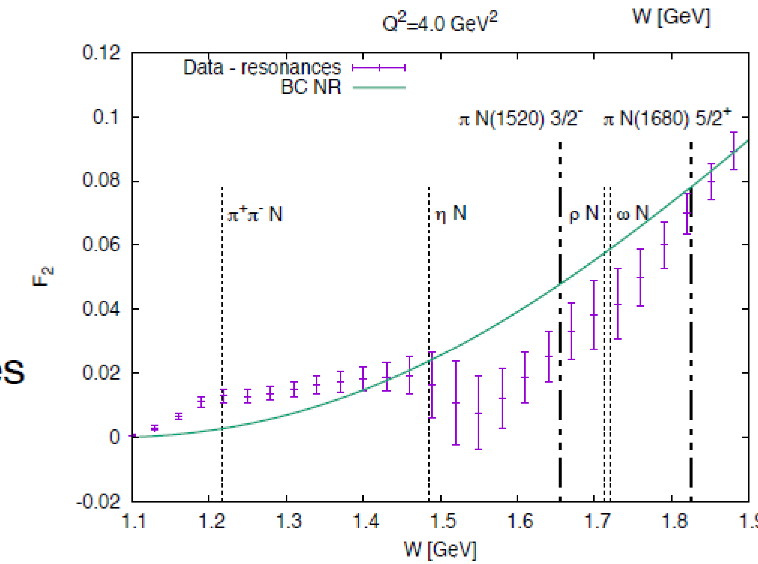
A. N. Hiller Blin et al., PRC 100 (2019) 035201

Exclusive CLAS data for computation of N* contribution to inclusive observables: non-trivial Q^2 dependence and interplay between resonance tails





Useful tool for CLAS12 and understanding of non-resonant background: quark-hadron duality studies

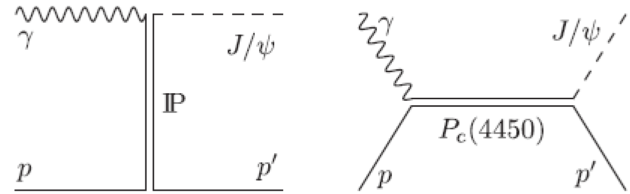


Polarization in P_c photoproduction

D. Winney et al. PRD 100 (2019)

- Motivation
  - Observation a resonance like structures $P_c(4380)$, $P_c(4449)$ in the $J/\psi pK^-$ channel of $\Lambda^0{}_b$ decay
  - The prospect to observed these structures in photoproduction experiments at CLAS12 and GlueX
  - Photoproduction is especially advantageous environment for studying the J/ψ p system because:
    - Background is supposed to be smaller that in hadronic decays
    - There is no "third particle"
  - Test of spin parity assignments: $3/2^-$ for the lighter and $5/2^+$ for the heavier resonance

- Sketch of the model



- Resonant contribution:

$$\langle \lambda_\psi \lambda_{p'} | T_r | \lambda_\gamma \lambda_p \rangle = \frac{\langle \lambda_\psi \lambda_{p'} | T_{\rm dec} | \lambda_r \rangle \langle \lambda_r | T^\dagger_{\rm em} | \lambda_\gamma \lambda_p \rangle}{M_r^2 - W^2 - i\Gamma_r M_r}$$

- with
  - Decay amplitude (the dominance L=0,1 and 2 is assumed for 3/2-; 3/2+,5/2+ and 5/2- respectively):

$$\langle \lambda_\psi \lambda_{p'} | T_{\rm dec} | \lambda_r \rangle = g_{\lambda_\psi \lambda_{p'}} d^J_{\lambda_r, \lambda_\psi - \lambda_{p'}}(\cos\theta)$$

  - EM amplitude:

$$\langle \lambda_\gamma \lambda_p | T_{\rm em} | \lambda_r \rangle = \frac{W}{M_r} \sqrt{\frac{8 M_N M_r \bar{p}_i}{4\pi\alpha}} \sqrt{\frac{\bar{p}_i}{p_i}} A_{\lambda_r}$$

- Background contribution (isoscalar vector pomeron model):

$$\begin{aligned} \langle \lambda_\psi \lambda_{p'} | T_P | \lambda_\gamma \lambda_p \rangle &= F(s,t) \bar{u}(p_f, \lambda_{p'}) \gamma_\mu u(p_i, \lambda_p) \\ &\times [\varepsilon^\mu(p_\gamma, \lambda_\gamma) q^\nu - \varepsilon^\nu(p_\gamma, \lambda_\gamma) q^\mu] \\ &\times \varepsilon^*_\nu(p_\psi, \lambda_\psi). \end{aligned}$$

- Polarization observables - correlations between helicities of the incoming photon and incoming (outgoing) proton:

$$A(K)_{LL} = \frac{1}{2}\left[\frac{d\sigma(++) - d\sigma(+-)}{d\sigma(++) + d\sigma(+-)} - \frac{d\sigma(-+) - d\sigma(--)}{d\sigma(-+) + d\sigma(--)}\right]$$

Polarization in P_c photoproduction

D. Winney et al., PRD 100 (2019) 034019

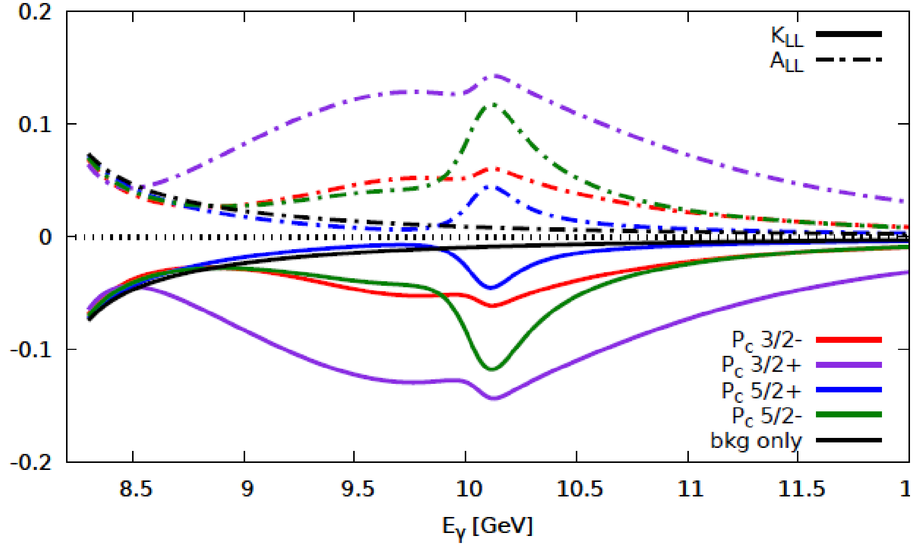
Polarization observables expected to have higher sensitivity to signals

$$A(K)_{LL} = \frac{d\sigma(\uparrow\uparrow) - d\sigma(\uparrow\downarrow)}{d\sigma(\uparrow\uparrow) + d\sigma(\uparrow\downarrow)}$$

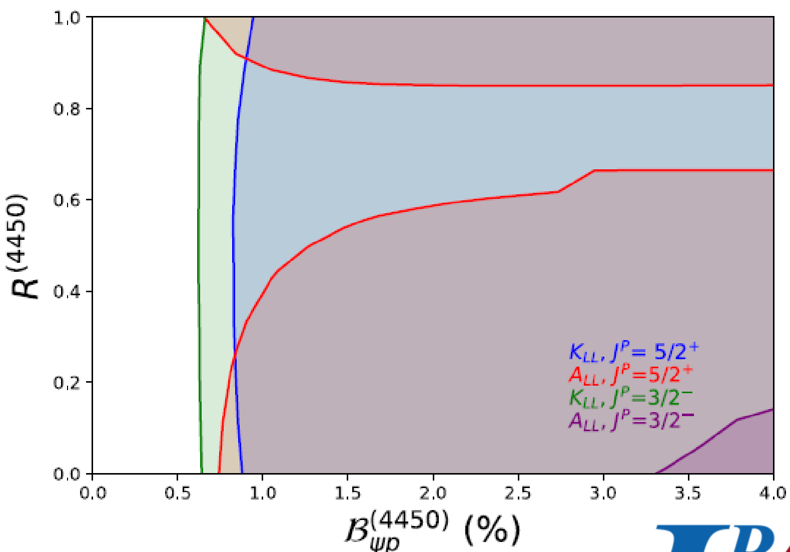
Letter of intent accepted for SBS experiment in Hall A

LoI12-18-001 (PAC 46)
C. Fanelli, L. Pentchev, B. Wojtsekhowski

Signals in polarization observables: two resonances assumed



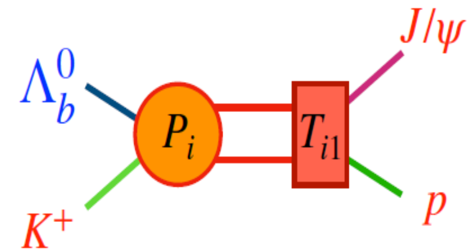
Sensitivity studies (different branching ratio and photocoupling sizes) to 5σ



Analysis of the $P_c(4312)^+$ signal

$$\frac{dN}{d\sqrt{s}} = \rho(s)\left[\,|F(s)|^2 + B(s)\right]$$

$F(s) =$



$1: J/\psi p$

$2: \Sigma_c^+ \bar{D}^0$

$$F(s) = P_1(s)T_{11}(s) \qquad \left(T^{-1}\right)_{ij} = M_{ij} - ik_i\delta_{ij}$$

$$M_{ij}(s) = m_{ij} - c_{ij}s$$

Matrix elements M_{ij} are singularity free and can be Taylor expanded

Fernández-Ramírez et al. PRL123 (2019) 092001

Dalitz plot decomposition

M. Mikhasenko et al. arXiv:1910.04566 (2019)

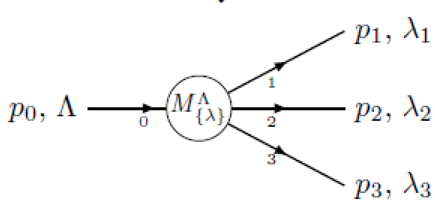
- Motivation
  - Establishing the framework to describe multibody decay processes where rotational degrees of freedom controlled by the spin of decaying particle are separated from dynamical functions depending on subchannel invariant masses
  - Demonstration of the method’s applicability in several processes of interest:

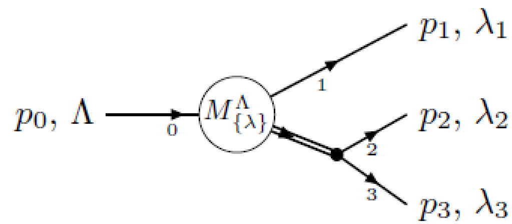
Conventional helicity approach

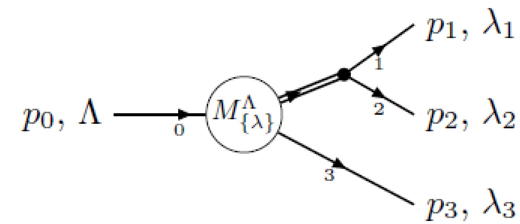
Complicated cases: particles with spin in isobar model [Herndon(1975)], [Hansen (1974)]

$$M^{\Lambda}_{\{\lambda\}} = M^{\Lambda}_{1,\{\lambda\}} + M^{\Lambda}_{2,\{\lambda\}} + M^{\Lambda}_{3,\{\lambda\}}$$

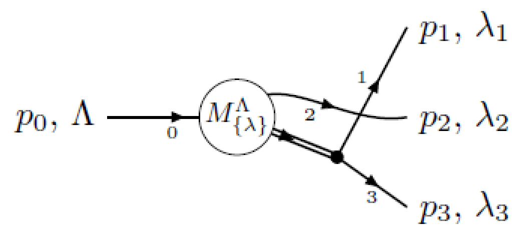
$$\underbrace{M^{\Lambda}_{\{\lambda\}}} \quad = \underbrace{H_1 D(\phi_1, \theta_1, 0)\, D(\phi_{23}, \theta_{23}, 0) W_1(\dots)} + \underbrace{H_3 D(\phi_3, \theta_3, 0)\, D(\phi_{12}, \theta_{12}, 0) W_3(\dots)}$$







$$+ \underbrace{H_2 D(\phi_2, \theta_2, 0)\, D(\phi_{31}, \theta_{31}, 0) W_2(\dots)}$$



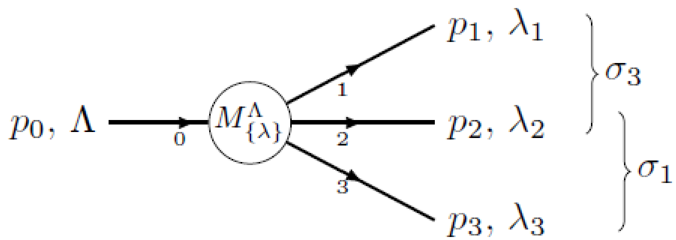
- A special set of angles for every decay chain
- Consistently of quantization direction – **Wigner rotations**

$$W_i(\dots) = D^{j_1}(\tilde{\phi}^i_1, \tilde{\theta}^i_1, 0)\, D^{j_2}(\tilde{\phi}^i_2, \tilde{\theta}^i_2, 0)\, D^{j_3}(\tilde{\phi}^i_3, \tilde{\theta}^i_3, 0)$$

The Dalitz-Plot decomposition

[MM et al.(JPAC), arXiv:1910.04566]

Reformulation of the helicity approach



$$= \sum_{\nu} \underbrace{D^{J*}_{\Lambda\nu}(\phi_1, \theta_1, \phi_{23})}_{\text{Decay-plane orientation}} \times \underbrace{O^{\nu}_{\{\lambda\}}(\{\sigma\})}_{\text{Dalitz-plot function}}$$

Model-independent factorization of the overall rotation:

- Exploits properties of the Lorentz group (orientation – just three Euler angles)
- Dalitz-plot function depends entirely on 2 variables, $\{\sigma\} \equiv \{\sigma_1, \sigma_2, \sigma_3\}$
- No azimuthal phase factors in $O^{\nu}_{\{\lambda\}}$.

Gives significant benefits to

- Pentaquark analysis, Λ_b/Λ_c polarionation measurements, Baryonic decay chains,. . .

Dalitz-Plot function

[MM et al.(JPAC), arXiv:1910.04566]

Master formula $0 \to 1\,2\,3$ decay with arbitrary spins

$$O^{\nu}_{\{\lambda\}}(\{\sigma\}) = \sum_{(ij)k} \sum_{s}^{(ij)\to i,j} \sum_{\tau} \sum_{\{\lambda'\}} n_J n_s \, d^J_{\nu,\tau-\lambda'_k}(\hat{\theta}_{k(1)}) X_s^{\tau,\lambda'_k;\lambda'_i,\lambda'_j}(\sigma_k) \, d^s_{\tau,\lambda'_i-\lambda'_j}(\theta_{ij})$$
$$\times\, d^{j_1}_{\lambda'_1,\lambda_1}(\zeta^1_{k(0)}) \, d^{j_2}_{\lambda'_2,\lambda_2}(\zeta^2_{k(0)}) \, d^{j_3}_{\lambda'_3,\lambda_3}(\zeta^3_{k(0)}),$$

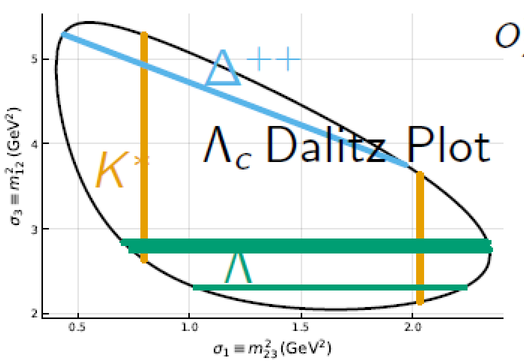
- Three decay chains, $(ij)k \in \{(12)3, (23)1, (31)2\}$.
- $\theta_{ij} = \theta_{ij}(\{\sigma\})$ is an isobar decay angle
- $\hat{\theta}_{k(1)} = \hat{\theta}_{k(1)}(\{\sigma\})$ is the particle-0 Wigner angle
- $\zeta^i_{k(0)} = \zeta^i_{k(0)}(\{\sigma\})$ is the particle-i Wigner angle
- $X_s^{\tau,\lambda'_k;\lambda'_i,\lambda'_j}(\sigma_k) \Rightarrow X_s^{LS;l's'}(\sigma_k)$ is the only model-dependent input (lineshape functions)

$\Lambda_c \to pK\pi$ polarization studies

- proposal for the electromagnetic dipole moments of charmed baryons
  [EPJC 77 (2017) 181, arXiv:1708.08483]
- polarization information for complex decay chains

$$M^{\Lambda}_{\lambda} = \sum_{\nu} D^{1/2*}_{\Lambda\nu}(\phi_1, \theta_1, \phi_{23}) O^{\nu}_{\lambda}(\sigma_1, \sigma_3),$$

- Resonances in all channels, Λ^0, K^{*0}, Δ^{++}
- Possible Triangle Singularity near $\Lambda\eta$ threshold [Liu, Xiao-Hai et al., PRD100 (2019)]



$$\begin{aligned} O^{\nu}_{\lambda}(\sigma_1, \sigma_3) = & \sum_{s}^{K^*\to K\pi} \sum_{\tau} d^{1/2}_{\nu,\tau-\lambda}(0)\, X_s^{\tau,\lambda}(\sigma_1)\, d^{s}_{\tau,0}(\theta_{23}) \\ & + \sum_{s}^{\Delta\to\pi p} \sum_{\tau,\lambda'} d^{1/2}_{\nu,\tau}(\hat{\theta}_{2(1)})\, X_s^{\tau,\lambda'}(\sigma_2)\, d^{s}_{\tau,-\lambda'}(\theta_{31})\, d^{1/2}_{\lambda',\lambda}(\tilde{\theta}^{1}_{2(1)}) \\ & + \sum_{s}^{\Lambda\to pK} \sum_{\tau,\lambda'} d^{1/2}_{\nu,\tau}(\hat{\theta}_{3(1)})\, X_s^{\tau,\lambda'}(\sigma_3)\, d^{s}_{\tau,\lambda'}(\theta_{12})\, d^{1/2}_{\lambda',\lambda}(\tilde{\theta}^{1}_{3(1)}). \end{aligned}$$

Photoproduction of $K+$ within a Regge-plus-resonance model

P. Bydžovský et al. PRC 100 (2019)

- Motivation
  - Reformulating the hybrid Regge+resonance model in a fully gauge invariant fashion
  - Identification of the proper strong vertex coupling (pseudoscalar vs. pseudovector)

Regge-plus-resonance model for $\gamma + p \longrightarrow \Lambda + K^+$

[P.Bydžovský, D.Skoupil, Phys. Rev. C 100, 035202 (2019)]

Invariant amplitude: $\mathcal{M} = \mathcal{M}_{Regge} + \mathcal{M}_{res} + \mathcal{M}_{int}$

- the Regge part
  - exchanges of degenerate K^+ and K^* trajectories
  - Regge propagators with the rotating phase
  - residua of the lowest poles are from the K^+ and K^* exchanges using either pseudo-scalar or vector coupling in the $p\Lambda K^+$ vertex
  - only 3 parameters fixed mainly by high-energy data ($W > 2.6$ GeV)
- the resonant part
  - exchanges of nucleon resonances in the s-channel
  - dipole, multidipole, multidipole-Gaussian hadron form factors included
  - selected resonances: $S_{11}(1535)$, $S_{11}(1650)$, $D_{15}(1675)$, $F_{15}(1680)$, $D_{13}(1700)$, $P_{13}(1720)$, $F_{15}(1860)$, $D_{13}(1875)$, $P_{13}(1900)$, $F_{15}(2000)$, $D_{15}(2570)$
- the contact term
  - restoring gauge invariance [H. Haberzettl et al, Phys. Rev. C 92, 055503 (2015)]
  - proton exchange in the Regge part *is not needed* but it is included in $\mathcal{M}_{res}$

Results with the RPR-BS model for $\gamma + p \longrightarrow \Lambda + K^+$

Total cross-section in comparison with the CLAS 2005 data,
R. Bradford et al.,
Phys. Rev. C 73, 035202 (2006).

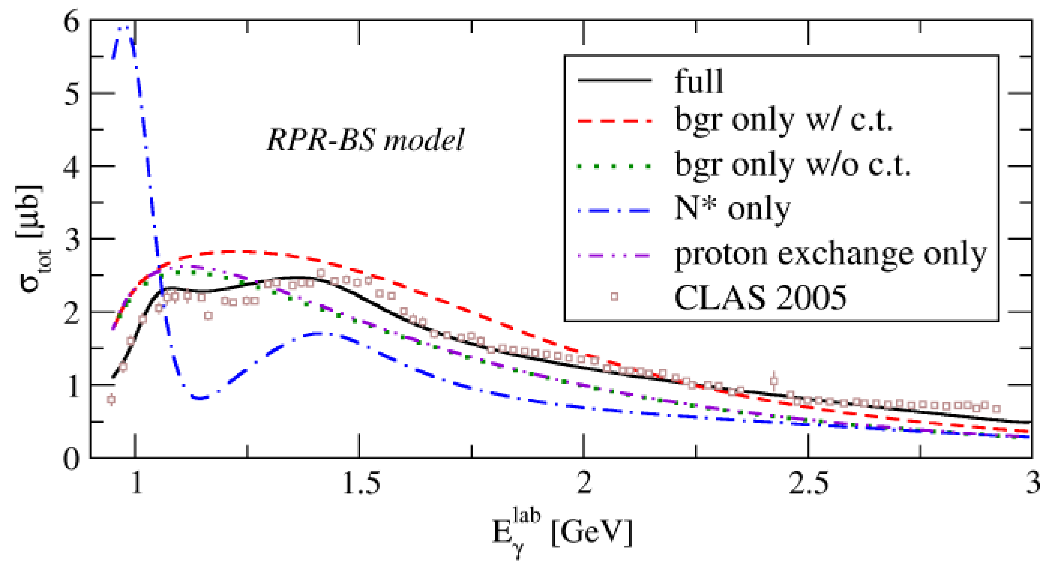
The upper part shows contributions to the RPR-BS model from

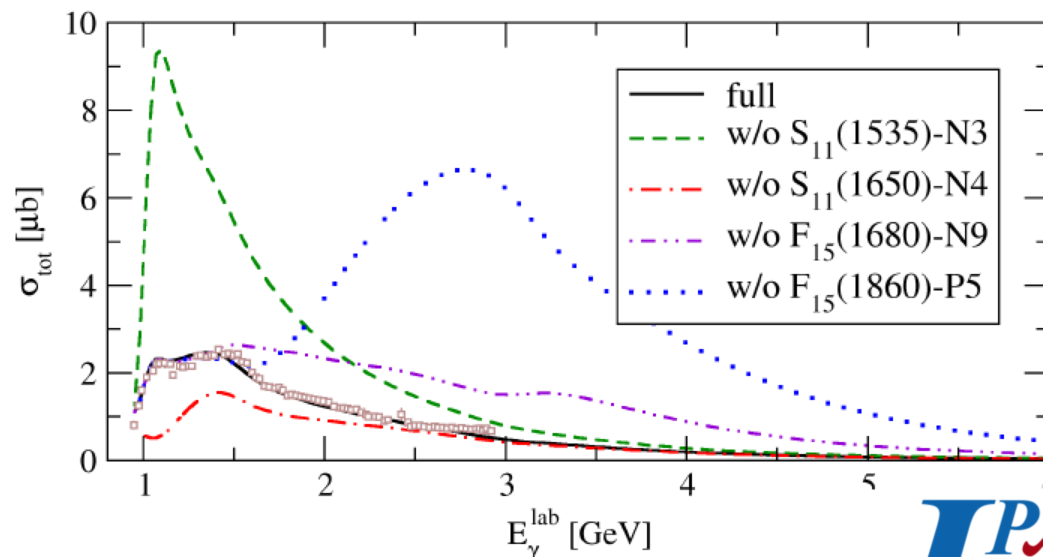
– background (dashed line),

– background without the contact term (dotted line),

– all nucleon resonances (dash-dotted line)

The lower figure shows behavior of the RPR-BS model when a particular N* state is omitted

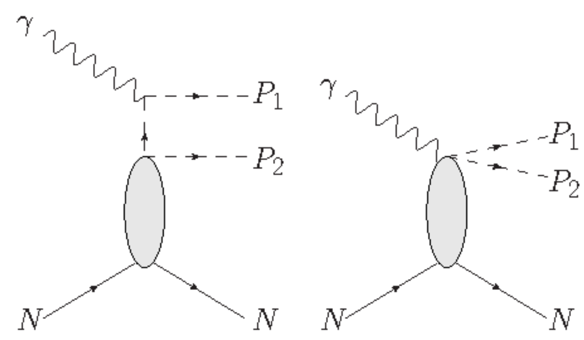




JPAC

Photoproduction of pseudoscalar pairs

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

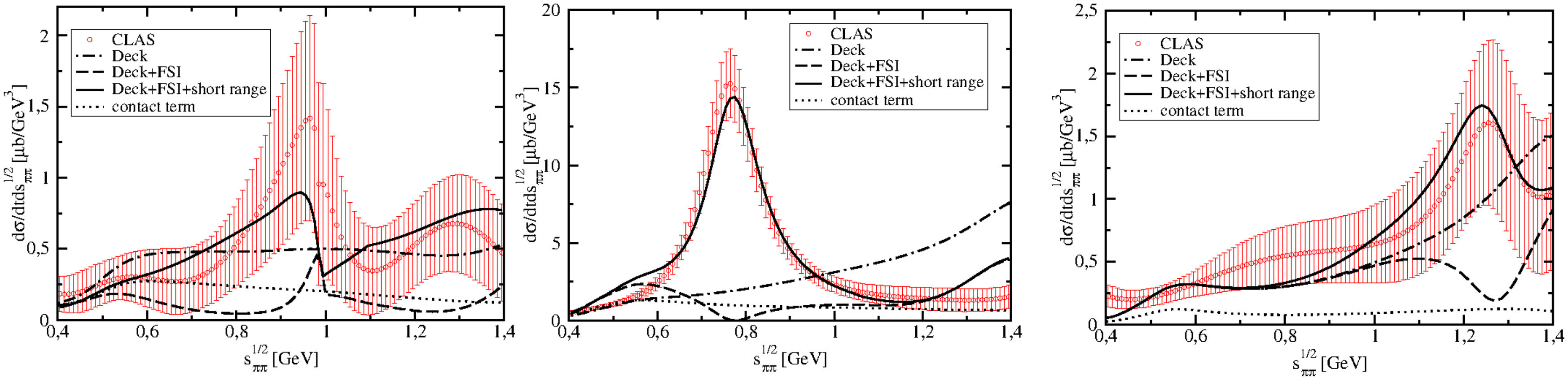


- Deck + „short range" approach to P_1P_2N photoproduction

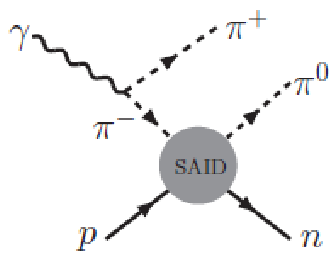
- Photon dissociates to *π+ π-*. One *π* in a pair is on shell, other one is brought on shell by scattering of *N*
- πp scattering is described in terms SAID PWA
- P_1P_2N can be: π+ π-p, π+ π0n (in theory also K+K-p,… but we don't have reliable KN PW amplitudes)
- General form of unitary amplitude: $M = M_{\text{diffuse}} e^{i\delta_{\pi\pi}} \cos\delta_{\pi\pi} + M_{\text{compact}} e^{i\delta_{\pi\pi}} \sin\delta_{\pi\pi}$
- Charge πp amplitudes constructed from isospin SAID partial waves

$A(\pi^+p)=A(3/2)$ $A(\pi^-p)=1/2[A(3/2)+2A(1/2)]$

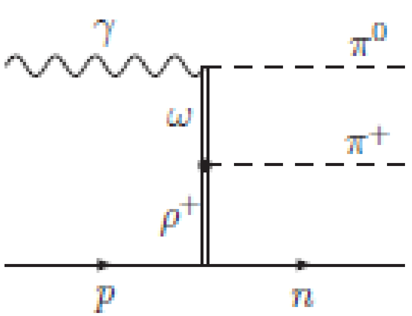
- Partial wave mass distributions for π+π- photoproduction



- Similar analysis for $\pi^+ \pi^0$ n final state is underway



$A(\pi^- p \to \pi^0 p) = 1/2[A(3/2)+2A(1/2)]$



- The dominant component of the short range amplitude:
- When both *π π* and *πp* energies are large the double Regge amplitude should be conidered