Recent results from JPAC collaboration

CSIC
Consejo Superior de Investigaciones Científicas

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

Miguel Albaladejo (IFIC)

Recent results and perspectives in hadron physics
(Institute Pascal, Orsay, Oct. 17th, 2022)

GENERALITAT VALENCIANA

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

STRONG-2020

JPAC: Joint Physics Analysis Center

- Joint IU and JLab venture to extract physics results from **JLab12**
- Work in **theoretical/experimental/phenomenological** analysis
- Light/heavy meson **spectroscopy**
- Interaction with many **experimental collaborations**: (GlueX, CLAS, BES, ...) and **LQCD groups**

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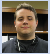
S. González-Solís (Los Álamos) 	C. Fernández-Ramírez (UNAM) 	A. Hiller-Blin (Tubingen) 	A. Jackura (JLab) 
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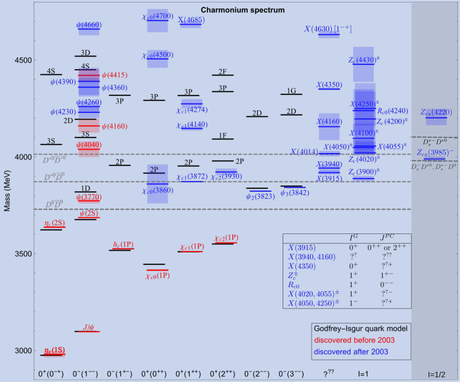
Outline

1. *XYZ* photoproduction:
   - **Exclusive photoproduction** [JPAC Collab., PR,D102,114010('20)]
   - **Inclusive photoproduction** [JPAC Collab., 2209.05882 (accepted PRD)]
2. Khuri-Treiman equations and $V \to 3\pi$ decays:
   - $\boldsymbol{\omega \to 3\pi}$ **and** $\boldsymbol{\omega \to \gamma^* \pi^0}$ [JPAC Collab., EPJ,C80,1107('20)]
   - $\boldsymbol{J/\psi \to 3\pi}$ [Work in progress...]

XYZ states and photoproduction

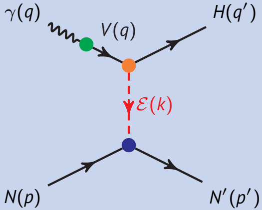


Taken from [Guo *et al.*, 2203.07141]

- A new method to confirm or discard these new *XYZ* states
- In principle, photoproduction is free of triangle-singularities that can give rise to resonance-like effects
- Photoproduction framework has been used before

Exclusive *XYZ* photoproduction amplitude

JPAC Collab., PR,D102,114010('20)

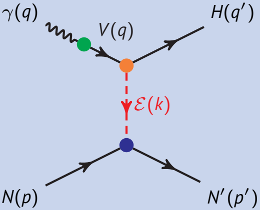


$$\langle \lambda_H \lambda'_N | T | \lambda_\gamma \lambda_N \rangle = \sum_{V,\,\mathcal{E}} \underbrace{\frac{e f_V}{m_V}}_{\text{VMD}} \overbrace{\mathcal{T}^{\alpha_1\cdots\alpha_j}_{\lambda_V=\lambda_\gamma,\lambda_{\mathcal{Q}}}}^{VH\mathcal{E}\text{ vertex}} \underbrace{\mathcal{P}_{\alpha_1\cdots\alpha_j;\beta_1\cdots\beta_j}}_{\text{propagator}} \overbrace{\mathcal{B}^{\beta_1\cdots\beta_j}_{\lambda_N\lambda'_N}}^{NN\mathcal{E}\text{ vertex}}$$

- VMD couples $V(=J/\psi, \Upsilon(nS))$ to photon $\quad \Gamma(V\to e^+e^-) = 4\pi\alpha^2 \dfrac{f_V^2}{3m_V}$
- Top vertex $VH\mathcal{E}$ $\quad \Gamma(H\to V\,\mathcal{E}) = \dfrac{1}{2J_H+1}\dfrac{p}{8\pi\, m_H^2}\sum_{\text{pol.}}\left|\mathcal{T}^{\alpha_1\cdots\alpha_j}_{\lambda_V\lambda_H}\,\varepsilon^*_{\alpha_1\cdots\alpha_j}(k,\lambda_{\mathcal{E}})\right|^2$
- Bottom vertex $NN\mathcal{E}$ Taken from standard phenomenology (*e.g.* $NN\pi \to g_{NN\pi}$)

Exclusive *XYZ* photoproduction amplitude

JPAC Collab., PR,D102,114010('20)



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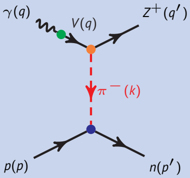
$Z_{c,b}$ exclusive photoproduction

JPAC Collab., PR,D102,114010('20)



Z	m_Z (MeV)	Γ_Z (MeV)	$g_{\gamma Z\pi}$ $(\times 10^{-2})$	V	$\mathcal{B}(Z \to V\pi)$ (%)	$g_{VZ\pi}$
$Z_c(3900)^+$	3888.4(2.5)	28.3(2.5)	5.17	J/ψ	10.5 ± 3.5	1.91
$Z_b(10610)^+$	10607.2(2.0)	18.4(2.4)	5.80	$\Upsilon(1S)$	$0.54^{+0.19}_{-0.15}$	0.49
				$\Upsilon(2S)$	$3.6^{+1.1}_{-0.8}$	3.30
				$\Upsilon(3S)$	$2.1^{+0.8}_{-0.6}$	9.22
$Z_b'(10650)^+$	10652.2(1.5)	11.5(2.2)	2.90	$\Upsilon(1S)$	$0.17^{+0.08}_{-0.06}$	0.21
				$\Upsilon(2S)$	$1.4^{+0.6}_{-0.4}$	1.47
				$\Upsilon(3S)$	$1.6^{+0.7}_{-0.5}$	4.80

- Top vertex $Z \to V\pi$: Sizeable branching fractions

$$\mathcal{T}_{\lambda_V \lambda_Z} = \frac{g_{VZ\pi}}{m_Z} \varepsilon_\mu(q, \lambda_V)\, \varepsilon^*_\nu(q', \lambda_Z) \left[(q \cdot k)\, g^{\mu\nu} - k^\mu\, q^\nu\right] \qquad \left[g_{\gamma Z\pi} = \sum_V \frac{e f_V}{m_V} g_{VZ\pi}\right]$$

- Bottom vertex $NN\pi$:

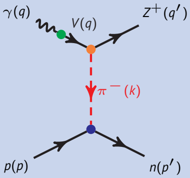
$$\mathcal{B}_{\lambda_N \lambda_N'} = \sqrt{2}\, g_{\pi NN}\, \beta(t)\, \bar{u}(p', \lambda_N')\, \gamma_5\, u(p, \lambda_N)$$

  - $g^2_{\pi NN}/(4\pi) \simeq 13.81(0.12)$ and $\beta(t) = \exp\left(t'/\Lambda_\pi^2\right)$ with $\Lambda_\pi = 0.9$ GeV

- Propagator:
  - Fixed spin up to $W_{\gamma p} \lesssim E_{\text{th}} + 10$ GeV
  - Reggeized pions: $\alpha(t) = \alpha'(t - m_\pi^2)$ with $\alpha' = 0.7\ \text{GeV}^{-2}$

$Z_{c,b}$ exclusive photoproduction

JPAC Collab., PR,D102,114010('20)



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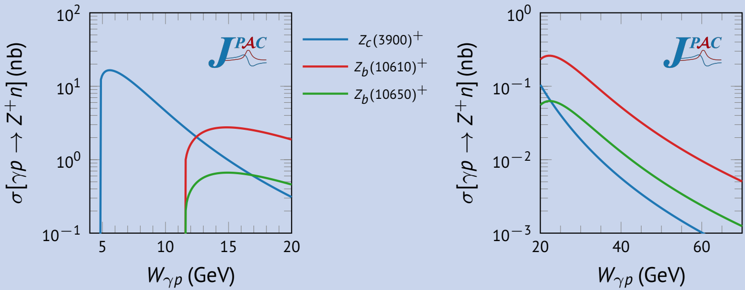
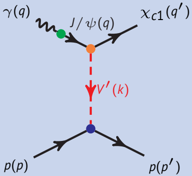


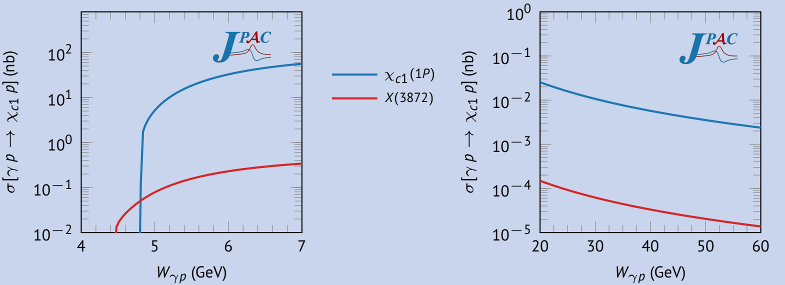
$\chi_{c1}(1P)$ and $X(3872)$ photoproduction

JPAC Collab., PR,D102,114010('20)



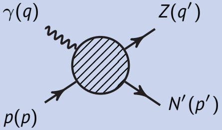
X	m_X (MeV)	Γ_X (MeV)	V'	$\mathcal{B}(X \to \gamma V')$ (%)	$g_{\gamma X V'}$ $(\cdot 10^{-3})$
$\chi_{c1}(1P)$	3510.67(0.05)	0.84(0.04)	ρ	$2.16(0.17) \cdot 10^{-4}$	0.92
			ω	$6.8(0.8) \cdot 10^{-5}$	0.52
			ϕ	$2.4(0.5) \cdot 10^{-5}$	0.42
			J/ψ	34.3(1.0)	$1.0 \cdot 10^{3}$

				$\mathcal{B}(X \to J/\psi\,\mathcal{E})$ (%)	$g_{\psi X \mathcal{E}}$	$g_{\gamma X \mathcal{E}}$ $(\cdot 10^{-3})$
$X(3872)$	3871.69(0.17)	1.19(0.19)	ρ	$4.1^{+1.9}_{-1.1}$	0.13	3.6
			ω	$4.4^{+2.3}_{-1.3}$	0.30	8.2



Inclusive $Z_{c,b}$ photoproduction (I)

JPAC Collab., 2209.05882 (accepted PRD)



$$E_Z \frac{d^3\sigma}{d^3 q_f} = \mathcal{K} \sum_{[\lambda]} \sum_{Q} \int \prod_n \frac{d^3 p_n}{(2\pi)^3\, 2E_n} \left| A_{[\lambda]}^{\gamma N \to Z\, Q} \right|^2 (2\pi)^4\, \delta^4\left(q + p - q' - P_Q\right)$$

$$= 2\mathcal{K} \sum_{[\lambda]} \text{Disc } A_{[\lambda]}^{\gamma N \bar{Z}}$$

$$\simeq \frac{1}{16\pi^3} \frac{\lambda^{1/2}(M_Q^2, t, m_N^2)}{2E_\gamma \sqrt{s}} \left| T_\pi(t)\, \mathcal{P}_\pi(t,s) \right|^2 \sigma^{\pi^* N}(t, M_Q^2)$$

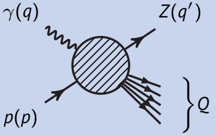
- Generalized optical theorem to relate $\gamma N \to Z\, Q$ with $\gamma N \bar{Z}$ amplitude
- Pion-exchange model (as in exclusive) to write $\sigma_{\gamma N \to Z Q}$ in terms of $\sigma^{\pi^* N}(t, M_Q^2)$

$$\frac{1}{t - m_\pi^2} \xleftrightarrow{P_\pi(t,s)} -\alpha' \, \Gamma(-\alpha(t)) \frac{1 + e^{-i\pi\alpha(t)}}{2} \left(\frac{s}{M_Q^2}\right)^{\alpha(t)}$$

- Model benchmarked in $b_1(1235)$ inclusive photoproduction [right plot]

Inclusive $Z_{c,b}$ photoproduction (I)

JPAC Collab., 2209.05882 (accepted PRD)



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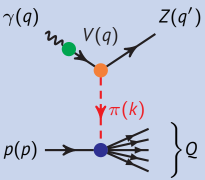

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- Model benchmarked in $b_1(1235)$ inclusive photoproduction [right plot]

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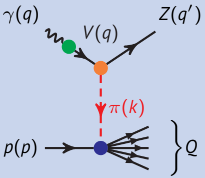
JPAC Collab., 2209.05882 (accepted PRD)



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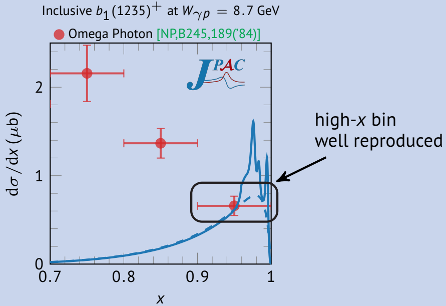
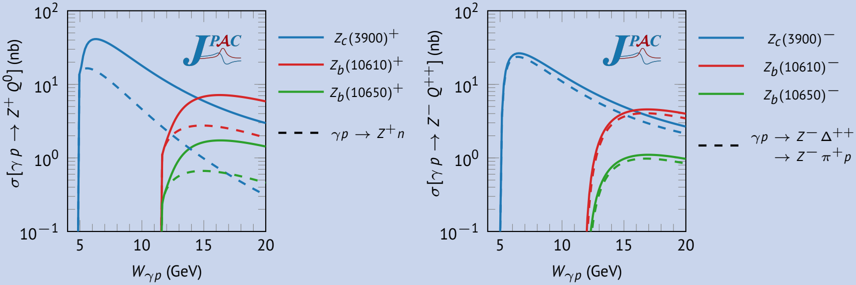
- Model benchmarked in $b_1(1235)$ inclusive photoproduction [right plot]



Inclusive $Z_{c,b}$ photoproduction (II)

JPAC Collab., 2209.05882 (accepted PRD)

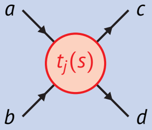
- Near threshold:
  - Relevant contribution from inelastic for Z^+ prod. [left plot]
  - Dominant contribution from Δ^{++} in Z^- prod. [right plot]



- High energy:

	$\sigma(\gamma p \to H^\pm Q)$ [pb]			$\sigma(\gamma p \to H^+ n)$ [pb]		
H	30 GeV	60 GeV	90 GeV	30 GeV	60 GeV	90 GeV
$b_1(1235)$	$60 \cdot 10^3$	$60 \cdot 10^3$	$61 \cdot 10^3$	43	2.3	$< 10^{-8}$
$Z_c(3900)$	187	146	140	19	1.0	$< 10^{-8}$
$Z_b(10610)$	163	15	5	150	10	$< 10^{-8}$
$Z_b(10650)$	40	4	1	37	2.4	$< 10^{-8}$

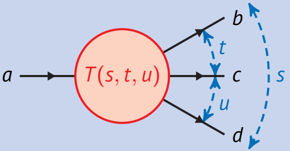
Introduction: Khuri-Treiman equations in a nutshell



- Partial wave expansion **in the s-channel**:

$$T(s,t,u) = \sum_{\ell=0}^{\infty} (2\ell+1) P_\ell(z_s) t_\ell(s)$$

- Two main (connected) problems:
  - Infinite number of PW
  - PW have RHC and LHC
- Only RHC: BS equation, K-matrix, DR,...
- Problem with “truncation”: $t_\ell(s)$ only depends on s, so singularities in the t-, u-channel can only appear suming an infinite number of PW.



- In many decay processes one wants to take into account unitarity/FSI interactions in the three possible channels.

Introduction: Khuri-Treiman equations in a nutshell

- Khuri-Treiman equations are a tool to achieve this **two-body unitarity** in the **three channels**
  [N. Khuri, S. Treiman, Phys. Rev. **119**, 1115 (1960)]
- Consider three (s-, t-, u-channels) **truncated** “isobar” expansions.
- Isobars $f_\ell^{(s)}(s)$ have only RHC: amenable for **dispersion relations**.

$$
\begin{aligned}
T(s,t,u) &= \sum_{\ell=0}^{\infty} (2\ell+1) P_\ell(z_s)\, t_\ell(s) \\
&= \sum_{\ell=0}^{n_s} (2\ell+1) P_\ell(z_s) f_\ell^{(s)}(s) + \sum_{\ell=0}^{n_t} (2\ell+1) P_\ell(z_t) f_\ell^{(t)}(t) + \sum_{\ell=0}^{n_u} (2\ell+1) P_\ell(z_u) f_\ell^{(u)}(u)
\end{aligned}
$$

- s-channel singularities appear in the s-channel isobar, $t_\ell^{(s)}(s)$.
- Singularities in the t-, u-channel are recovered!
- The LHC of the partial waves are given by the RHC of the crossed channel isobars

$$
t_\ell(s) = \frac{1}{2}\int \mathrm{d}z\, P_\ell(z) T(s,t',u') = f_\ell^{(s)}(s) + \frac{1}{2}\int \mathrm{d}z\, Q_{\ell\ell'}(s,t') f_{\ell'}^{(t)}(t') \,.
$$

$\omega \to 3\pi$ amplitude. Phenomenology

JPAC Collab., EPJ,C80,1107('20)

- Amplitude:

$$\mathcal{M}_+(s,t,u) = \frac{\sqrt{\phi(s,t,u)}}{2} F(s,t,u)\,. \qquad \left(\phi(s,t,u) = 4sp^2(s)q^2(s)\sin^2\theta_s\right)$$

- Decay width: $d^2\Gamma \sim \phi(s,t,u)\,|F(s,t,u)|^2$
- Dalitz plot parameters (α, β, γ) "equivalent" to bins... $(X,Y) \leftrightarrow (Z,\varphi) \leftrightarrow (s,t,u)$

$$|F(s,t,u)|^2 = |\mathcal{N}|^2 \left(1 + 2\alpha Z + 2\beta Z^{\frac{3}{2}} \sin 3\varphi + 2\gamma Z^2 + \cdots\right)$$

- **Why revisit $\omega \to 3\pi$?**

	Bonn (2012) Eur. Phys. J., C72, 2014 (2012)		JPAC (2015) Phys. Rev., D91, 094029 (2015)		BESIII (2018) Phys. Rev., D98, 112007 (2018)
	w/o KT	w KT	w/o KT	w KT	Exp.
α	130 ± 5	79 ± 5	125	84	$120.2 \pm 7.1 \pm 3.8$
β	31 ± 2	26 ± 2	30	28	$29.5 \pm 8.0 \pm 5.3$

- One (or more) out of three is wrong...
  1) Experiment?
  2) KT eqs., in general?
  3) Something particular?

$\omega \to 3\pi$ amplitude. Phenomenology

JPAC Collab., EPJ,C80,1107('20)

- Amplitude:

$$\mathcal{M}_+(s,t,u) = \frac{\sqrt{\phi(s,t,u)}}{2} F(s,t,u)\,. \qquad \left(\phi(s,t,u) = 4 s p^2(s) q^2(s) \sin^2\theta_s\right)$$

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β	31 ± 2	26 ± 2	30	28	$29.5 \pm 8.0 \pm 5.3$

- One (or more) out of three is wrong... 1) Experiment? 2) KT eqs., in general? 3) Something particular?

$\omega \to 3\pi$ amplitude. Phenomenology

JPAC Collab., EPJ,C80,1107('20)

- Amplitude:

$$\mathcal{M}_+(s,t,u) = \frac{\sqrt{\phi(s,t,u)}}{2} F(s,t,u)\,. \qquad \left(\phi(s,t,u) = 4sp^2(s)q^2(s)\sin^2\theta_s\right)$$

- Decay width: $d^2\Gamma \sim \phi(s,t,u)\,|F(s,t,u)|^2$
- Dalitz plot parameters (α, β, γ) "equivalent" to bins… $(X,Y) \leftrightarrow (Z,\varphi) \leftrightarrow (s,t,u)$

$$|F(s,t,u)|^2 = |\mathcal{N}|^2 \left(1 + 2\alpha Z + 2\beta Z^{\frac{3}{2}} \sin 3\varphi + 2\gamma Z^2 + \cdots\right)$$

- **Why revisit $\omega \to 3\pi$?**

	Bonn (2012)		JPAC (2015)		BESIII (2018)
	Eur. Phys. J., C72, 2014 (2012)		Phys. Rev., D91, 094029 (2015)		Phys. Rev., D98, 112007 (2018)
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- One (or more) out of three is wrong…
  1) Experiment?
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  3) Something particular?

KT equations: DR, subtractions, solutions, and all that...

- PW decomposition: $F(s,t,u) = \sum_{j\,\mathrm{odd}} P_j'(\cos\theta_s)[p(s)q(s)]^{j-1} f_j(s) = f_1(s) + \cdots$
- KT/isobar decomposition: consider only $j = 1$ (ρ) isobar, $F(s)$:

$$F(s,t,u) = F(s) + F(t) + F(u)$$

- PW projection of the KT decomposition:

$$f_1(s) = F(s) + \hat{F}(s)\,, \qquad \hat{F}(s) = \frac{3}{2}\int_{-1}^{1} \mathrm{d}z_s (1 - z_s^2) F(t(s,z_s))$$

- Discontinuity:

$$\Delta F(s) = \Delta f_1(s) = \rho(s) t_{11}^*(s) f_1(s) = \rho(s) t_{11}^*(s) \left(F(s) + \hat{F}(s)\right)$$

Unsubtracted DR

$$F(s) = a\,F_0(s)$$

$$F_0(s) = \Omega(s)\left[1 + \frac{s}{\pi}\int_{4m_\pi^2}^{\infty} \frac{ds'}{s'} \frac{\sin\delta(s')\hat{F}_0(s')}{|\Omega(s')|(s'-s)}\right]$$

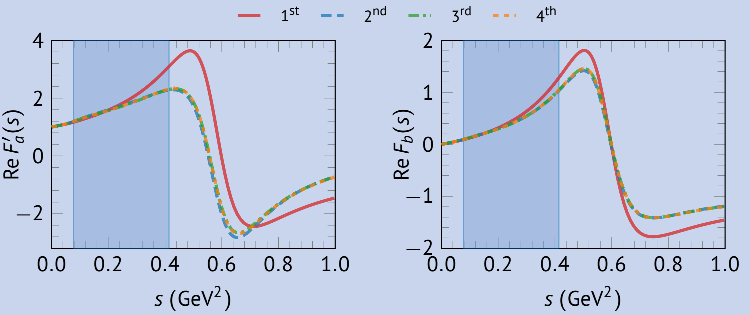
Once-subctracted DR

$$F(s) = a\left(F_a'(s) + b\,F_b(s)\right)$$

$$F_a'(s) = \Omega(s)\left[1 + \frac{s^2}{\pi}\int_{4m_\pi^2}^{\infty} \frac{ds'}{s'^2} \frac{\sin\delta(s')\hat{F}_a'(s')}{|\Omega(s')|(s'-s)}\right]$$

$$F_b(s) = \Omega(s)\left[s + \frac{s^2}{\pi}\int_{4m_\pi^2}^{\infty} \frac{ds'}{s'^2} \frac{\sin\delta(s')\hat{F}_b(s')}{|\Omega(s')|(s'-s)}\right]$$

KT equations: DR, subtractions, solutions, and all that…



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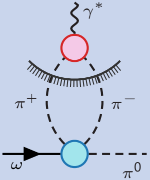
$\omega \to \pi^0$ transition form factor

- The decays $\omega(\to \pi^0\gamma^*) \to \pi^0 l^+ l^-$ and $\omega \to \pi^0\gamma$ governed by the TFF $f_{\omega\pi^0}(s)$.

$$\mathcal{M}(\omega \to \pi^0\ell^+\ell^-) = f_{\omega\pi^0}(s)\, \epsilon_{\mu\nu\alpha\beta}\epsilon^\mu(p_\omega,\lambda)p^\nu q^\alpha \frac{ie^2}{s}\bar{u}(p_-)\gamma^\beta v(p_+)\,,$$

$$\Gamma(\omega \to \pi^0\gamma) = \left|f_{\omega\pi^0}(0)\right|^2 \frac{e^2(m_\omega^2 - m_{\pi^0}^2)^3}{96\pi m_\omega^3}\,,$$

- Dispersive representation:



$$f_{\omega\pi^0}(s) = f_{\omega\pi^0}(0) + \frac{s}{12\pi^2}\int_{4m_\pi^2}^{\infty} ds' \frac{q_\pi(s')^3}{s'^{\frac{3}{2}}(s'-s)}\left(F(s') + \hat{F}(s')\right)F_\pi^V(s')^*$$

- $f_{\omega\pi^0}(0) = \left|f_{\omega\pi^0}(0)\right| e^{i\phi_{\omega\pi^0}(0)}$
- Experimental information: $F_{\omega\pi^0}(s) = \frac{f_{\omega\pi^0}(s)}{f_{\omega\pi^0}(0)}$
- Only the relative phase $\frac{a}{f_{\omega\pi^0}(0)} = \frac{|a|}{\left|f_{\omega\pi^0}(0)\right|}\frac{1}{e^{i(\phi_{\omega\pi^0}(0)-\phi_a)}}$.

Summary of amplitudes/free parameters/exp. input

$\omega \to 3\pi$ amplitude [$F(s,t,u)$]

Free parameters: $|a|$, $|b|$, ϕ_b

Experimental input:

- $\Gamma_{3\pi}$
- Dalitz plot parameters

$\omega \to \gamma^{(*)}\pi^0$ TFF [$f_{\omega\pi^0}(s)$]

Free parameters: $\left|f_{\omega\pi^0}(0)\right|$, $\phi_{\omega\pi^0}(0)$
($\bigoplus$ $|a|$, $|b|$, ϕ_b)

Experimental input:

- $\Gamma_{\gamma\pi^0}$
- $\left|F_{\omega\pi^0}(s)\right|^2$

First analysis in three steps

JPAC Collab., EPJ,C80,1107('20)

1. Fix $|b| \simeq 2.9$, $\phi_b \simeq 1.9$ with the **DP parameters**.
2. Fix $|a| \simeq 280\ \text{GeV}^{-3}$, $|f_{\omega\pi^0}(0)| \simeq 2.3\ \text{GeV}^{-1}$ from $\Gamma_{\omega\to 3\pi}$, $\Gamma_{\omega\to\gamma\pi}$.
3. You are left with $\phi_{\omega\pi^0}(0)$ and the TFF Data.

(1) $$\chi^2_{\rm DP} = \left(\frac{\alpha^{(t)} - \alpha^{(e)}}{\sigma_\alpha}\right)^2 + \cdots$$

(2) $$\chi^2_\Gamma = \left(\frac{\Gamma^{(t)}_{3\pi} - \Gamma^{(e)}_{3\pi}}{\sigma_{\Gamma_{3\pi}}}\right)^2 + \left(\frac{\Gamma^{(t)}_{\gamma\pi} - \Gamma^{(e)}_{\gamma\pi}}{\sigma_{\Gamma_{\gamma\pi}}}\right)^2$$

(3) $$\chi^2_{\rm A2,NA60} = \sum_i \left(\frac{|F_{\omega\pi}(s_i)|^2 - \left|F^{(i)}_{\omega\pi}\right|^2}{\sigma_{F^{(i)}_{\omega\pi}}}\right)^2$$

- Two different minima (low and high $\phi_{\omega\pi^0}(0)$) are found.
- Both have similar χ^2 of the TFF.

Make a **global, simultaneous** analysis

$$\overline{\chi}^2 = N\left(\frac{\chi^2_{\rm DP}}{N_{\rm DP}} + \frac{\chi^2_\Gamma}{N_\Gamma} + \frac{\chi^2_{\rm NA60}}{N_{\rm NA60}} + \frac{\chi^2_{\rm A2}}{N_{\rm A2}}\right)$$

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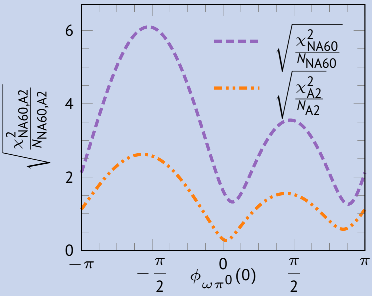

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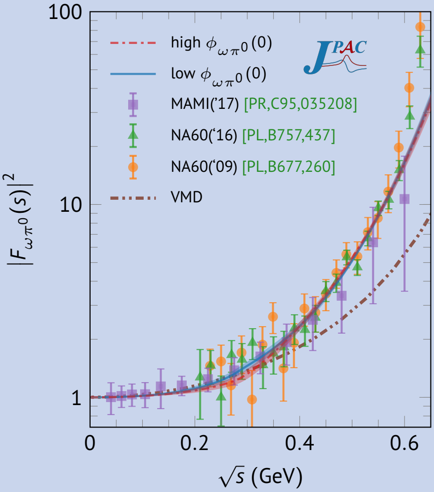
Results

JPAC Collab., EPJ,C80,1107('20)



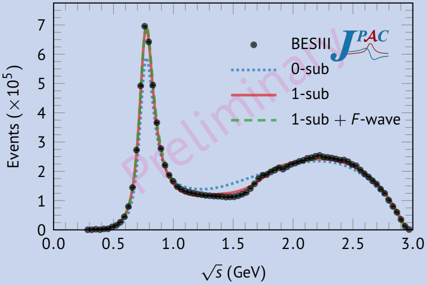
	α	β	γ
BESIII	111(18)	25(10)	22(29)
low	112(15)	23(6)	29(6)
high	109(14)	26(6)	19(5)

Using once-subtracted DR for KT:

- Agreement is restored with DP parameters by BESIII
- One can also describe the $\omega\pi^0$ TFF

$J/\psi \to 3\pi$ decays

- Completely analogous formalism (V)
- BESIII data [PL,B710('12)]
- The decay is dominated by ρ, even if there is a larger phase space
- **0-sub** (prediction) get the basic features
- **1-sub** (fit) improves the description
- **1-sub + *F*-wave** [$\rho_3(1690)$] describes better the movements above $\gtrsim 1.5$ GeV.



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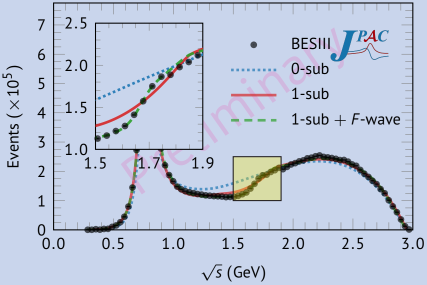
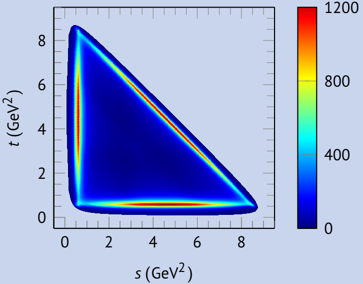
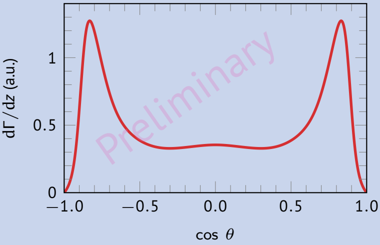


$J/\psi \to 3\pi$ decays

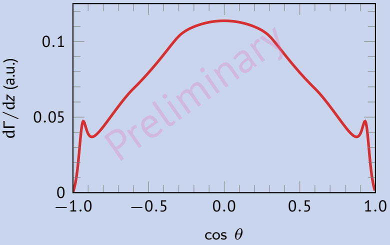
- Dalitz plot distribution similar to exp. one
- More statistics will allow to unveil other effects (resonances, interferences,...)
- Predictions can be done for angular [$z = \cos\theta_s$] distributions, specially restricted to ρ-mass region.



Full $\sqrt{s}$ range



$\left|\sqrt{s} - m_\rho\right| \leqslant 50$ MeV



Summary

- JPAC very active in several hadron physics topics
- *XYZ* photoproduction — JPAC Collab., PR,D102,114010('20); JPAC Collab., 2209.05882 (accepted PRD)
  - **Photoproduction of *XYZ*** offers the opportunity of investigating these enigmatic states in a new, perhaps cleaner, way.
  - Exclusive photoproduction studied with quite **general formalisms** for both for low (fixed-spin) and high (reggeized) γN energy
  - Vertices extracted as much as possible from known experimental information and phenomenology.
  - Inclusive reactions improves perspective (role of Δ)
  - Code can be found at `https://github.com/dwinney/jpacPhoto`
- KT equations and $V \to 3\pi$:
  - KT equations are a powerful tool to study **3-body decays**
  - They allow to implement **two-body unitarity** in all the **three channels** (s, t, u).
  - For $\omega \to 3\pi$ decays: — JPAC Collab., EPJ,C80,1107('20)
    - Using once-subtracted DRs, we are able to reproduce the $\omega \to 3\pi$ DP parameters,
    - and the $\omega \to \pi^0\gamma^*$ transition form factor data.
  - For $J/\psi \to 3\pi$ decays, good agreement with the data is found assuming elastic (*P*- and *F*-waves).

Recent results from JPAC collaboration

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

Miguel Albaladejo (IFIC)

Recent results and perspectives in hadron physics
(Institute Pascal, Orsay, Oct. 17th, 2022)

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