JPAC update

CLAS Collaboration Meeting

Jefferson Lab

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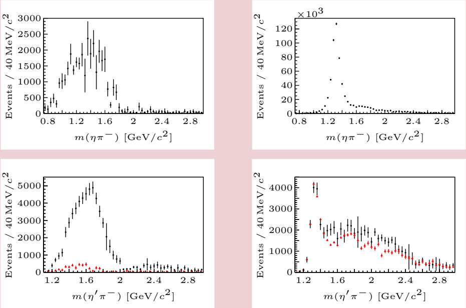
November 15, 2018

JPAC clas

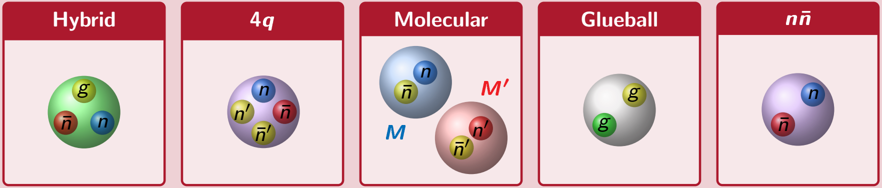
Introducing $\pi_1(1400)$, $\pi_1(1600)$

- $\eta^{(\prime)}\pi$ system with odd L gives $J^PC = (1, 3, \ldots)^{-+}$, **exotic ("non-$q\bar{q}$")** quantum numbers.
- **$\pi_1(1400)$** claimed in the $\eta\pi$ final state (E852, Crystal Barrel)
- **$\pi_1(1600)$** claimed in the $\rho\pi$ and $\eta'\pi$ (E852, VES), different from $\pi_1(1400)$.
- COMPASS experiment
  - confirms a peak in $\rho\pi$ and $\eta'\pi$ at ~ 1.6 GeV,
  - observes an additional structure at around ~ 1.4 GeV.
- Two different states are considered in the **PDG**...



COMPASS, PL,B740,303('15)

π_1: Introduction



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- $I = 1$ discards **glueball**.
- **Molecular** interpretation is very difficult.
- **Tetraquark? Hybrid?**
  - π_1**(1600)** is consistent with the expected lightest hybrid ($1.7 - 1.9$ GeV).
  - π_1**(1400)** *could* be interpreted as a tetraquark, but this brings more problems than solutions...

In this work...

We study COMPASS data ($\pi p \to \eta^{(\prime)} \pi p$) to shed some light into the π_1 puzzle

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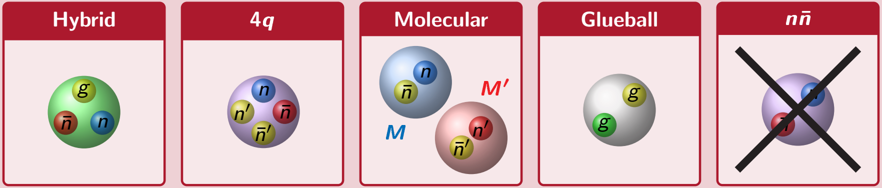

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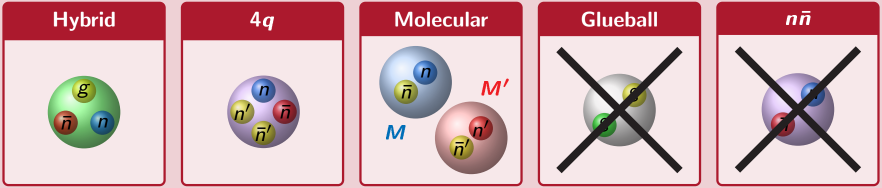

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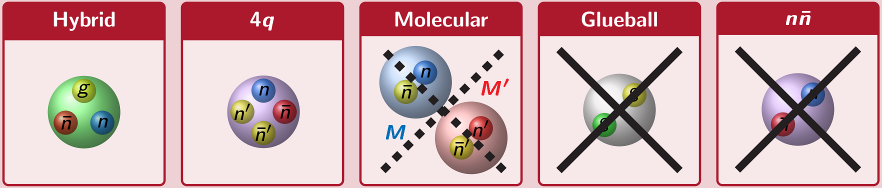

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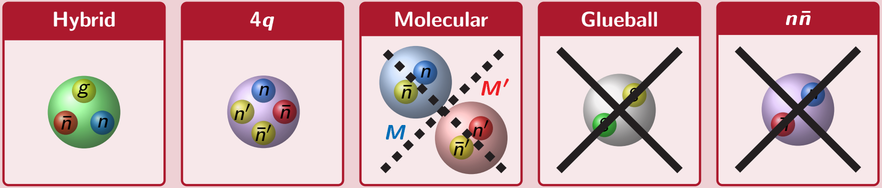

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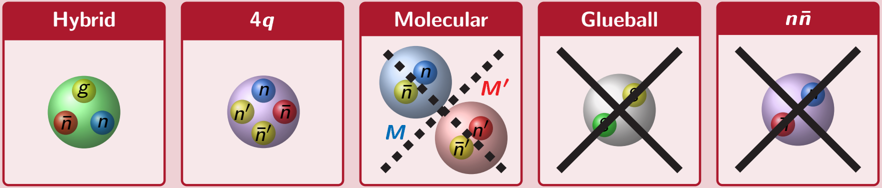

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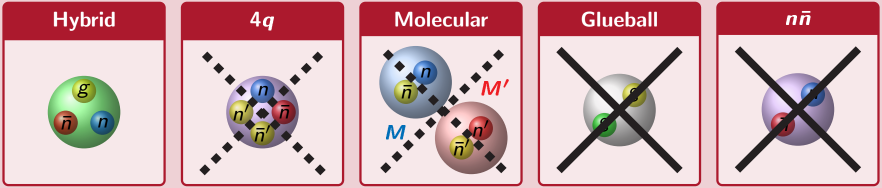

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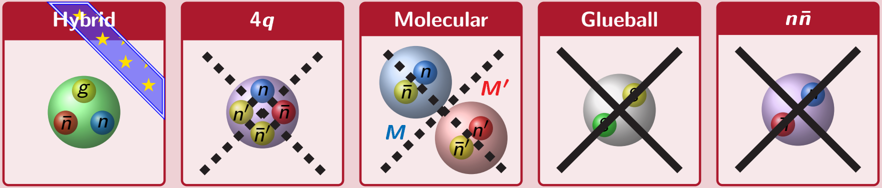

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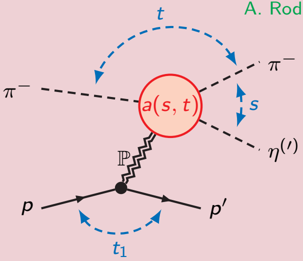
The model

A. Rodas *et al.* (JPAC), 1810.04171



- COMPASS reaction $\pi p \to \eta^{(\prime)} \pi p$ (190 GeV pion beam).
- Peripheral production dominated by Pomeron exchange ($\mathbb{P}$).
- Effectively treated as a $\mathbb{P}\pi \to \eta^{(\prime)}\pi$ process ($t_1 \simeq -0.1$ GeV^2).

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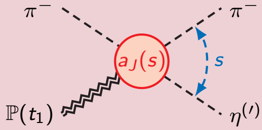

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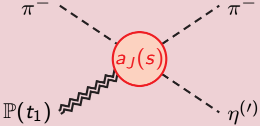

- Production amplitudes parameterized with N/D method:

$$a_i^J(s) = q^{J-1}(s) p^J(s) \sum_k n_k^J(s) \left[D_J^{-1}(s) \right]_{ki} \ ,$$

- $\eta^{(\prime)}\pi$ FSI embedded into $D^J(s)$ matrix:

$$D^J(s) = K_J^{-1}(s) - \frac{s}{\pi} \int \mathrm{d}s' \, \frac{\rho N_J(s')}{s'(s'-s)} \ ,$$

- $K_J(s)$ matrix standard parameterization:

$$\left[K^J(s) \right]_{ij} = \sum_R \frac{g_i^R g_j^R}{m_R^2 - s} + c_{ij}^J + d_{ij}^J s \quad (+\cdots)$$

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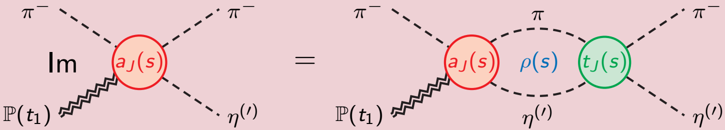

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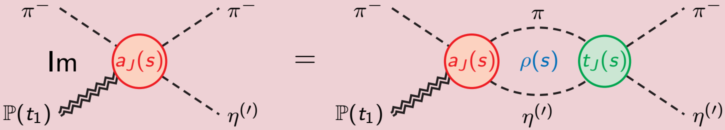

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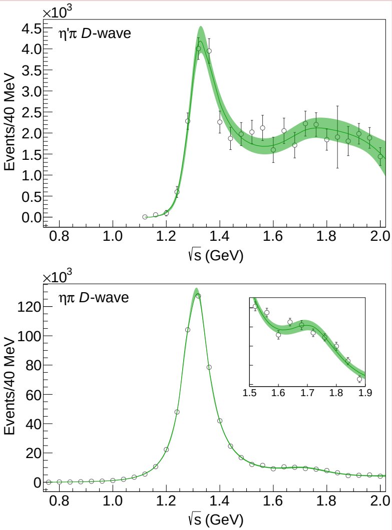

Our reference model/fit

■ Two *K*-matrix poles for *D*-wave (two a_2 states?)
■ One single *K*-matrix pole for *P*-wave (one π_1 state?)

- $\chi^2_{\text{d.o.f.}} = 1.3$
- *D*-wave amplitudes show two peaks: two a_2 states?
- *P*-wave amplitudes show also two peaks, $\sim$ 200 MeV apart.
- They are commonly attributed to two different π_1 states.
- Important differences between *P* and *D* waves:
  - **both a_2** show up in one channel ($\eta\pi$).
  - $a_2(1320)$ is very narrow.
- *P* wave is different. . . How to know?

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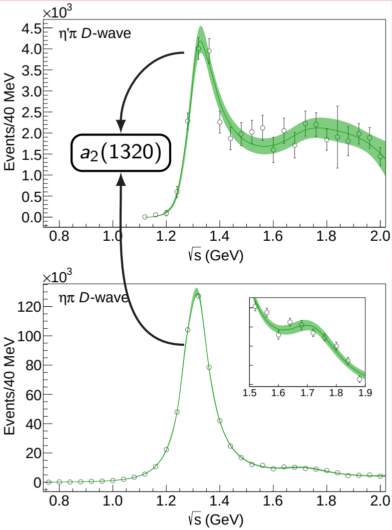

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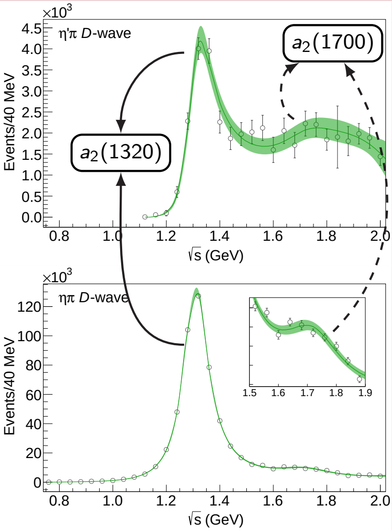

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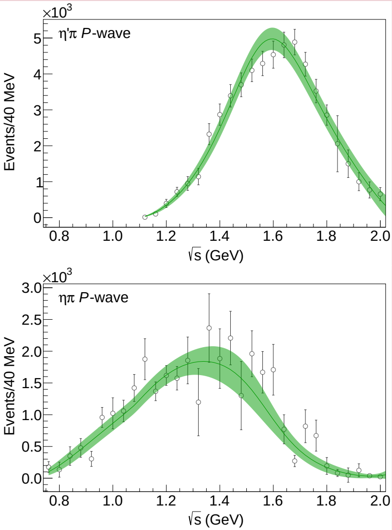

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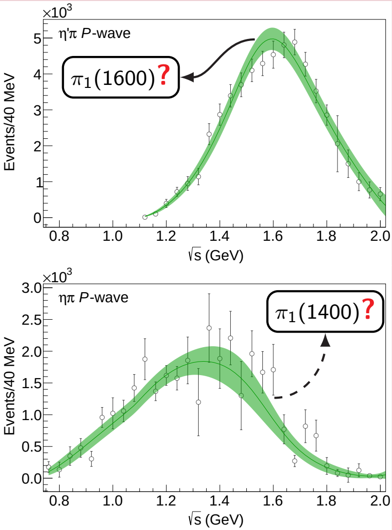

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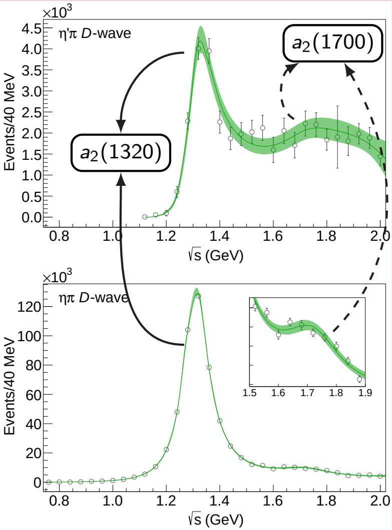

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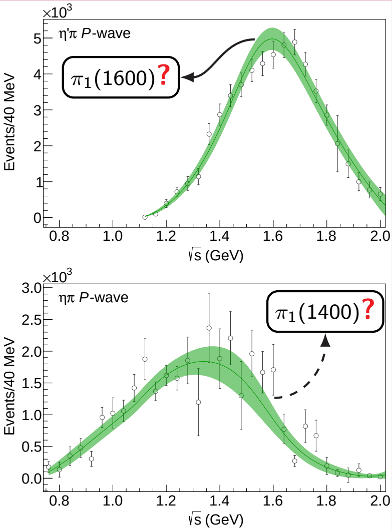

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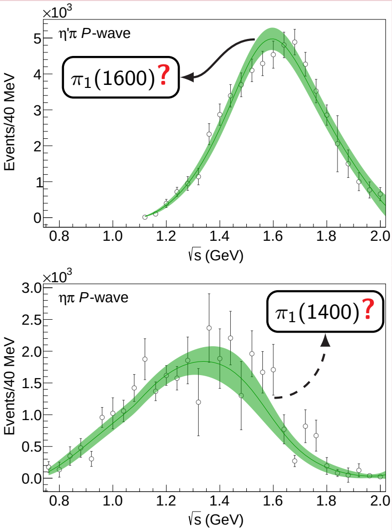

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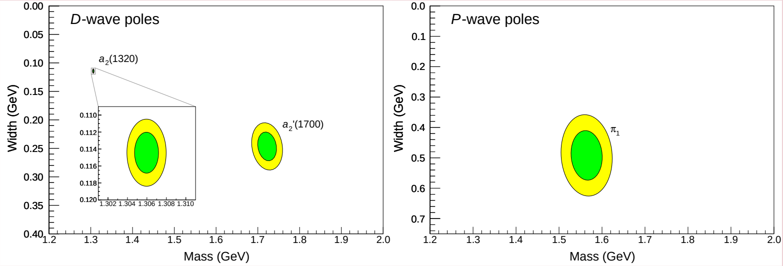
Go to the complex plane!

Spectroscopy

A. Rodas *et al.* (JPAC), 1810.04171



Pole	Mass (MeV)	Width (MeV)
$a_2(1320)$	1306.0(0.8)(1.3)	114.4(1.6)(0.0)
$a_2(1700)$	1722(15)(67)	247(17)(63)
π_1	1564(24)(86)	492(54)(102)

Conclusion

A single broad π_1 state ($\sim$ 1600 MeV) is able to reproduce both set ($\eta\pi$ and $\eta'\pi$) of data

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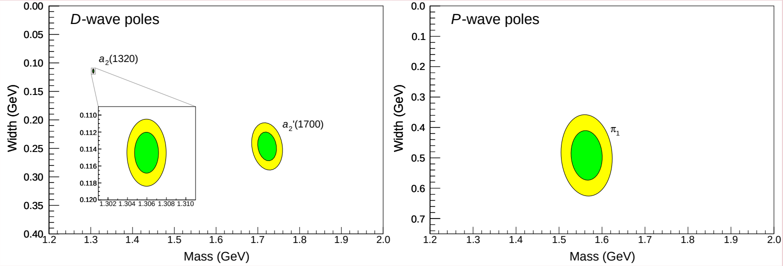

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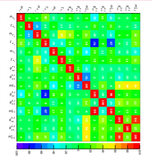
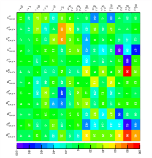
Q: Is it possible to find two poles?
A: Yes, but those fits:

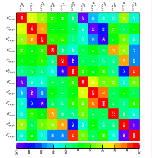
1. do not improve the fit quality,
2. the second poles is very unstable/not constrained,
3. requires a peculiar behaviour of the phase above 1.8 GeV.

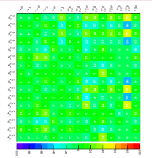
Correlations (inputs & outputs)

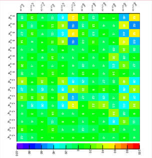
A. Rodas *et al.* (JPAC), 1810.04171

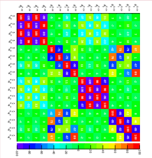












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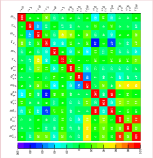

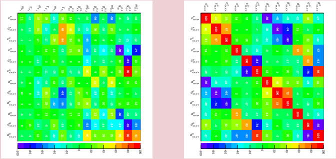

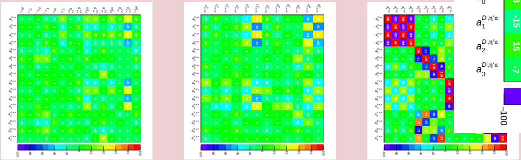

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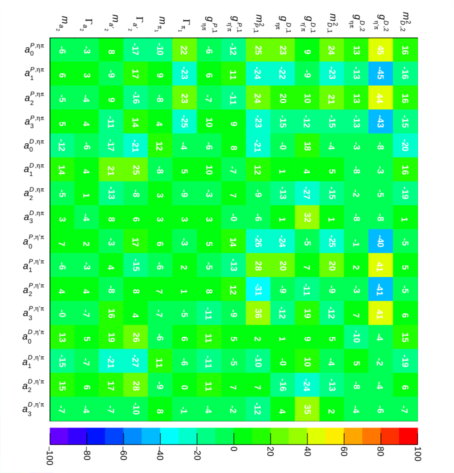

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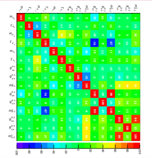

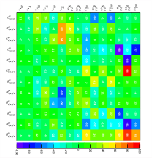

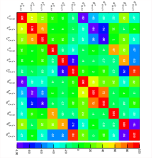

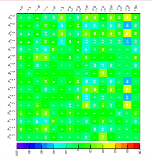

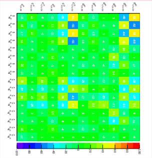

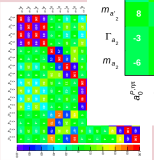

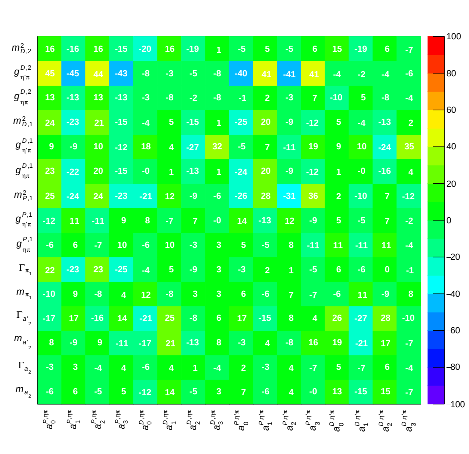

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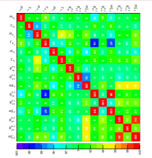

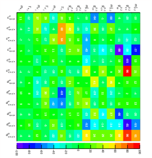

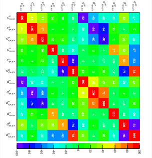

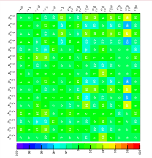

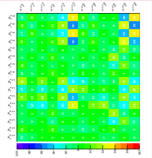

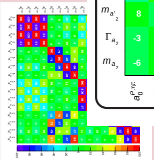

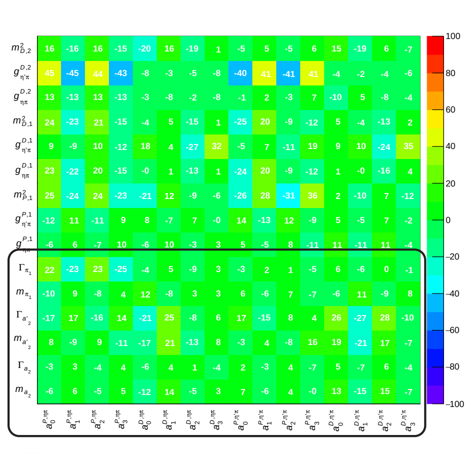

	$a_0^{P,\eta\pi}$	$a_1^{P,\eta\pi}$	$a_2^{P,\eta\pi}$	$a_3^{P,\eta\pi}$	$a_0^{D,\eta\pi}$	$a_1^{D,\eta\pi}$	$a_2^{D,\eta\pi}$	$a_3^{D,\eta\pi}$	$a_0^{P,\eta'\pi}$	$a_1^{P,\eta'\pi}$	$a_2^{P,\eta'\pi}$	$a_3^{P,\eta'\pi}$	$a_0^{D,\eta'\pi}$	$a_1^{D,\eta'\pi}$	$a_2^{D,\eta'\pi}$	$a_3^{D,\eta'\pi}$
$m^2_{D,2}$	16	-16	16	-15	-20	16	-19	1	-5	5	-5	6	15	-19	6	-7
$g^{D,2}_{\eta'\pi}$	45	-45	44	-43	-8	-3	-5	-8	-40	41	-41	41	-4	-2	-4	-6
$g^{D,2}_{\eta\pi}$	13	-13	13	-13	-3	-8	-2	-8	-1	2	-3	7	-10	5	-8	-4
$m^2_{D,1}$	24	-23	21	-15	-4	5	-15	1	-25	20	-9	-12	5	-4	-13	2
$g^{D,1}_{\eta'\pi}$	9	-9	10	-12	18	4	-27	32	-5	7	-11	19	9	10	-24	35
$g^{D,1}_{\eta\pi}$	23	-22	20	-15	-0	1	-13	1	-24	20	-9	-12	1	-0	-16	4
$m^2_{P,1}$	25	-24	24	-23	-21	12	-9	-6	-26	28	-31	36	2	-10	7	-12
$g^{P,1}_{\eta'\pi}$	-12	11	-11	9	8	-7	7	-0	14	-13	12	-9	5	-5	7	-2
$g^{P,1}_{\eta\pi}$	-6	6	-7	10	-6	10	-3	3	5	-5	8	-11	11	-11	11	-4
Γ_{π_1}	22	-23	23	-25	-4	5	-9	3	-3	2	1	-5	6	-6	0	-1
m_{π_1}	-10	9	-8	4	12	-8	3	3	6	-6	7	-7	-6	11	-9	8
$\Gamma_{a'_2}$	-17	17	-16	14	-21	25	-8	6	17	-15	8	4	26	-27	28	-10
$m_{a'_2}$	8	-9	9	-11	-17	21	-13	8	-3	4	-8	16	19	-21	17	-7
Γ_{a_2}	-3	3	-4	4	-6	4	1	-4	2	-3	4	-7	5	-7	6	-4
m_{a_2}	-6	6	-5	5	-12	14	-5	3	7	-6	4	-0	13	-15	15	-7

The masses and widths of π_1 and both a_2 states are mostly not correlated to the production mechanism parameters.

Impact on GlueX and CLAS12

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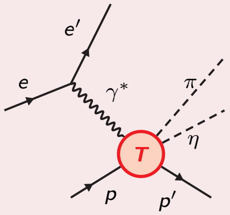
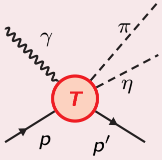
CLAS12



GlueX



- Moments $H(LM)$ techniques [*e.g.* Chung, PR,D56('97)] have been developed and used for spinless/unpolarized beam.
- For polarized beams, the spin-density matrix elements $\rho_{\lambda\lambda'}$ have been used, for instance, for vector meson production [*e.g.* Schilling, Seyboth, Wolf, NP,B15('70)].

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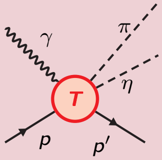

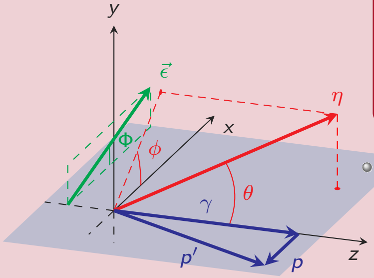

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■ To **develop** the necessary **formalism** to extract moments from the photoproduction of two pseudoscalar mesons with a polarized beam.
■ Demonstrate with a **simple model** the usage of this generalization of the formalism.

- Start from:

$$\frac{d\sigma}{d\Omega} = I(\Omega,\Phi) = \sum_{\substack{\lambda,\lambda' \\ \lambda_1,\lambda_2}} T_{\lambda;\lambda_1,\lambda_2}(\Omega)\, \rho_{\lambda,\lambda'}(\Phi)\, T^*_{\lambda';\lambda_1,\lambda_2}(\Omega)$$

- And introduce **polarized moments** $H^\alpha(LM)$

Polarized moments: summary

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- Introduce polarized intensities:

$$I(\Omega,\Phi) = I^0(\Omega) + \vec{P}_\gamma(\Phi)\cdot\vec{I}(\Omega)\ .$$

- Decompose $I^\alpha(\Omega)$ into moments $H^\alpha(LM)$,

$$I^\alpha(\Omega) = \sum_{L,M} \frac{2L+1}{4\pi} H^\alpha(LM) D^{L*}_{M0}(\Omega)\ ,$$

$$H^\alpha(LM) = \int \mathrm{d}\Omega\ I^\alpha(\Omega)\ D^L_{M0}(\Omega)\ .$$

- Expand $T_{\lambda;\lambda_1,\lambda_2}$ in $\eta\pi$ partial waves:

$$T_{\lambda;\lambda_1,\lambda_2}(\Omega) = \sum_{\ell,m} T^{\ell m}_{\lambda;\lambda_1,\lambda_2} Y^m_\ell(\Omega)\ ,$$

- SDME for arbitrary ℓ,ℓ':

$$(\rho_\alpha)^{\ell\ell'}_{mm'} = \sum_{\substack{\lambda,\lambda'\\ \lambda_1,\lambda_2}} T^{\ell m}_{\lambda;\lambda_1,\lambda_2} \frac{\sigma^\alpha_{\lambda\lambda'}}{2} T^{\ell' m' *}_{\lambda';\lambda_1,\lambda_2}$$

- Express $H^\alpha(LM)$ in terms of SDME:

$$H^\alpha(LM) = \sum_{\substack{\ell,\ell'\\ m,m'}} \left(\frac{2\ell'+1}{2\ell+1}\right) \langle \ell' 0, L0 |\ \ell 0\rangle \times \langle \ell' m', LM |\ \ell m\rangle (\rho_\alpha)^{\ell\ell'}_{mm'}$$

Predictions with a simple model

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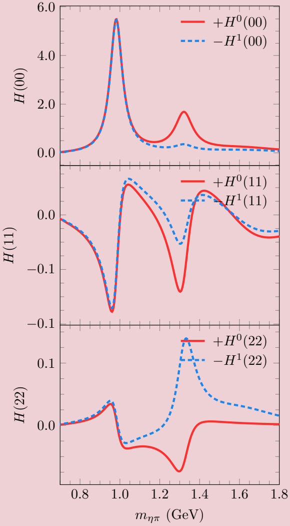
Simplifying assumptions:

- $\ell_{\text{max}} = 2$ in $\eta\pi$ system ($L_{\text{max}} = 4$ in $H(LM)$),
- $|\lambda - m| \leqslant 1$,
- Only **positive naturality** waves are included,
- **Three resonances** are included: $a_0(980)$, $\pi_1(1600)$, $a_2(1320)$.

$$[\ell]_m^{(+)} = N_R \left(\delta_R \frac{\sqrt{-t}}{m_R} \right)^{|m-1|} \Delta_R(m_{\eta\pi}) P_V(s,t) \,,$$

$$\Delta_R(m_{\eta\pi}) = \frac{x_R m_R \Gamma_R}{m_R^2 - m_{\eta\pi}^2 - i m_R \Gamma_R} \,,$$

$$P_V(s,t) = \Gamma\left(1 - \alpha_V(t)\right) \left(1 - e^{-i\pi\alpha(t)}\right) s^{\alpha}(t) \,,$$



Predictions with a simple model (II)

Beam asymmetry Σ:

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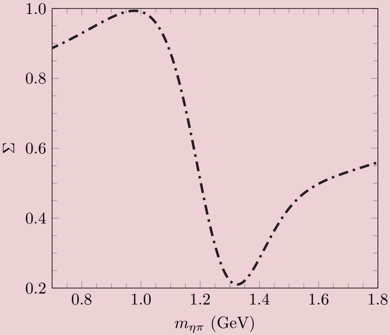
$$\int \mathrm{d}\Omega \; I(\Omega,\Phi) \equiv \sigma^0 \left(1 + P_\gamma \Sigma \cos(2\Phi)\right)$$

Equivalently,

$$\Sigma = -\frac{H^1(00)}{H^0(00)} = -\frac{\int \mathrm{d}(\Omega)\; I^1(\Omega)}{\int \mathrm{d}(\Omega) I^0(\Omega)}$$
$$= \frac{1}{P_\gamma} \frac{\int \mathrm{d}(\Omega)\; \left(I(\Omega,\pi/2) - I(\Omega,0)\right)}{\int \mathrm{d}(\Omega)\; \left(I(\Omega,\pi/2) + I(\Omega,0)\right)}$$



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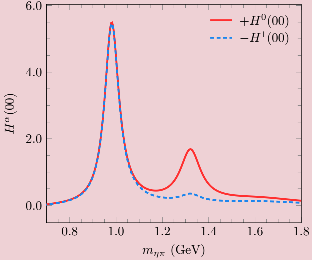

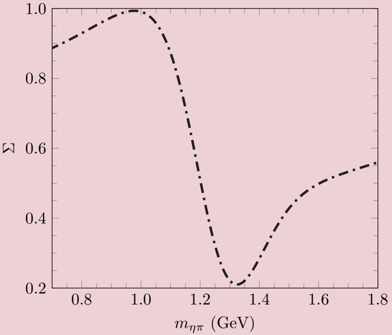

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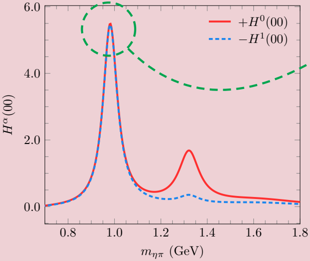

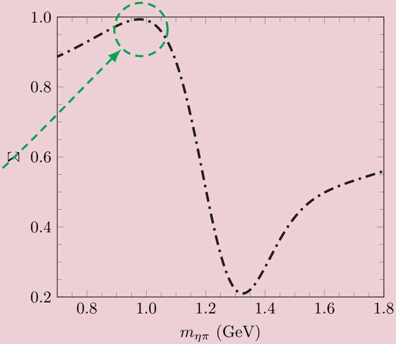

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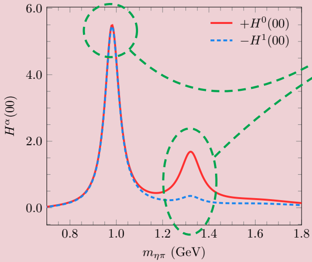

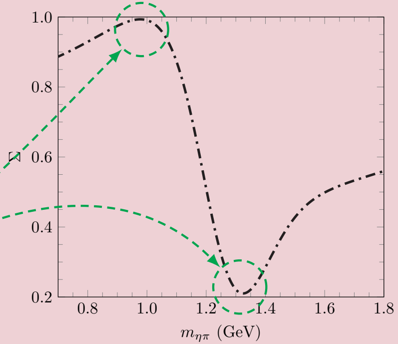

Summary

- We have shown that a **single π_1** state is able to describe the $\eta^{(\prime)}\pi$ lineshape in $\pi p \to \eta^{(\prime)}\pi p$ data by COMPASS. We find **no evidence** for two separate states [$\pi_1(1400)$ and $\pi_1(1600)$].

  A. Rodas *et al.* (JPAC), 1810.04171

- We are currently working in the formalism of **polarized moments** $H^\alpha(LM)$ for the production of $\eta\pi$ with polarized photon beam (GlueX, CLAS).

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- We are also working in many other projects: KT equations for $\pi\pi$ FSI and crossing in processes $X \to 3\pi$, 3 body unitarity,...
- Suggestions of projects to work in are welcome!