Amplitude analysis of $J/\psi \to \gamma\, \pi^0 \pi^0$

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Joint Physics Analysis Center

Krakow, June 6th, 2016

Joint Physics Analysis Center (JPAC)

- The Joint Physics Analysis Center (JPAC) formed in October 2013
- We support physics analysis of experimental data for accelerator facilities (JLab, COMPASS, ...)

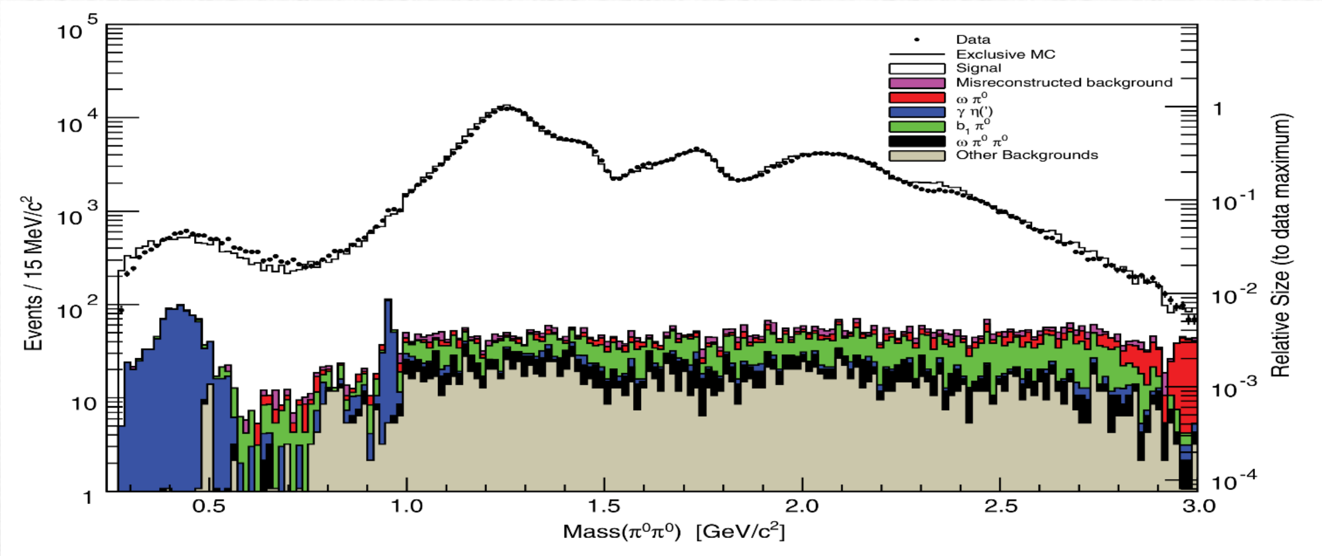
http://www.indiana.edu/jpac/

Review of JPAC Talks

- Andrew Jackura (Thursday Parallel B)
- Vladyszlav Pauk (Thursday Parallel B)
- Adam Szczepaniak (Friday Plenary)
- Emilie Passemar (Friday Parallel A)
- Vincent Mathieu (Poster Session)

$J/\psi \to \gamma\, \pi^0\pi^0$

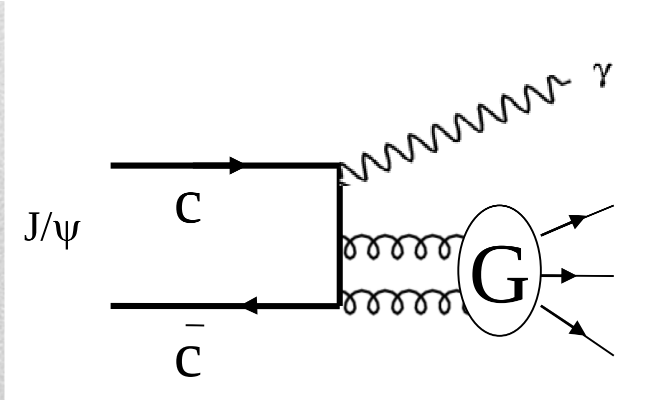
BESIII published in 2015 a partial wave analysis of $J/\psi \to \gamma\, \pi^0\pi^0$



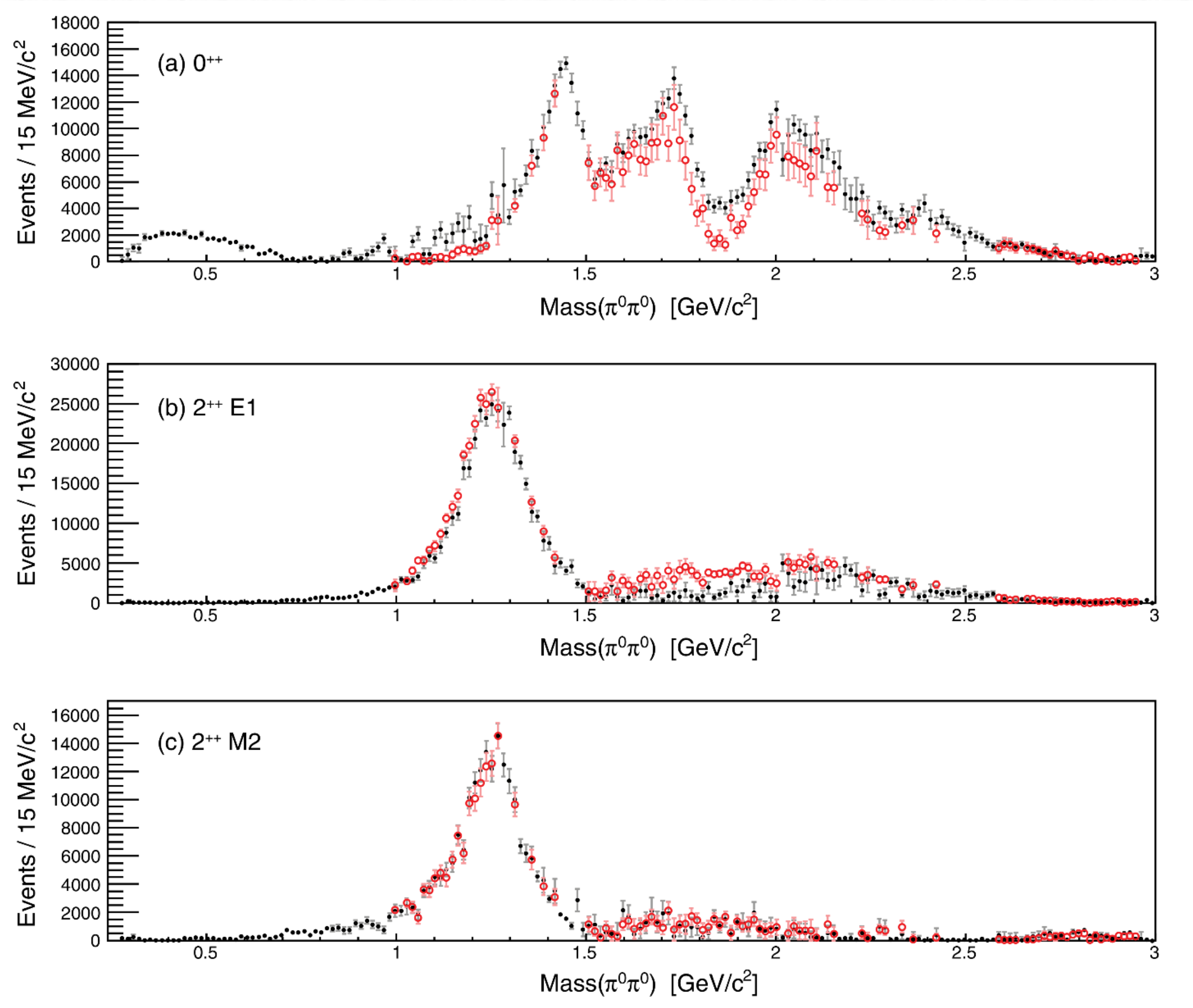
BESIII
PRD92, 052003

Bose symmetry and charge conjugation force the dipion to have $J^{PC}\ I^G = (\text{even})^{++}\ 0^+$

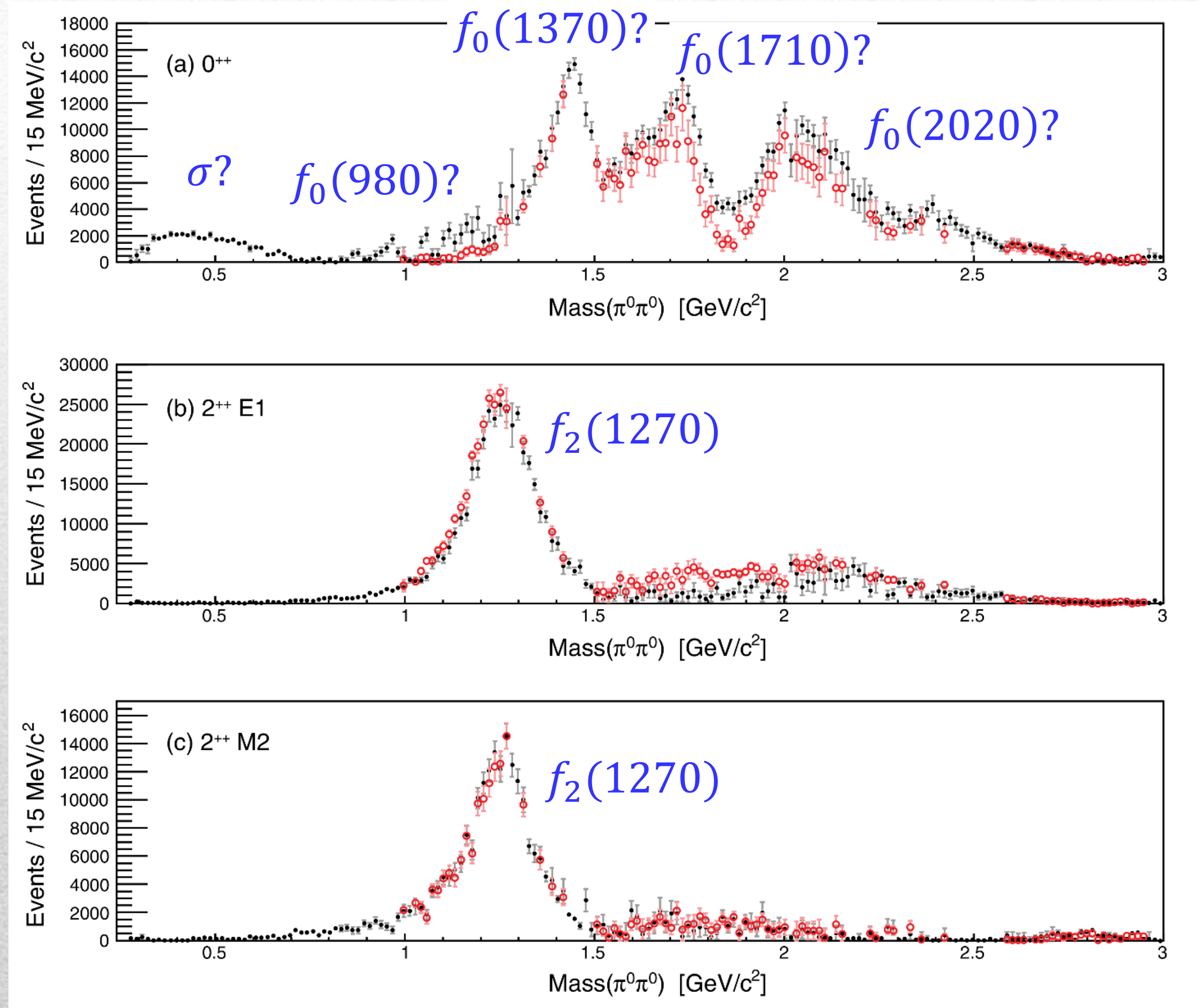
This is a gluon-rich process, expected to be one of the golden channels for the search of the scalar glueball (see F. Giacosa talk)



Partial Waves intensities



Partial Waves intensities



Some structures appear in the scalar channel

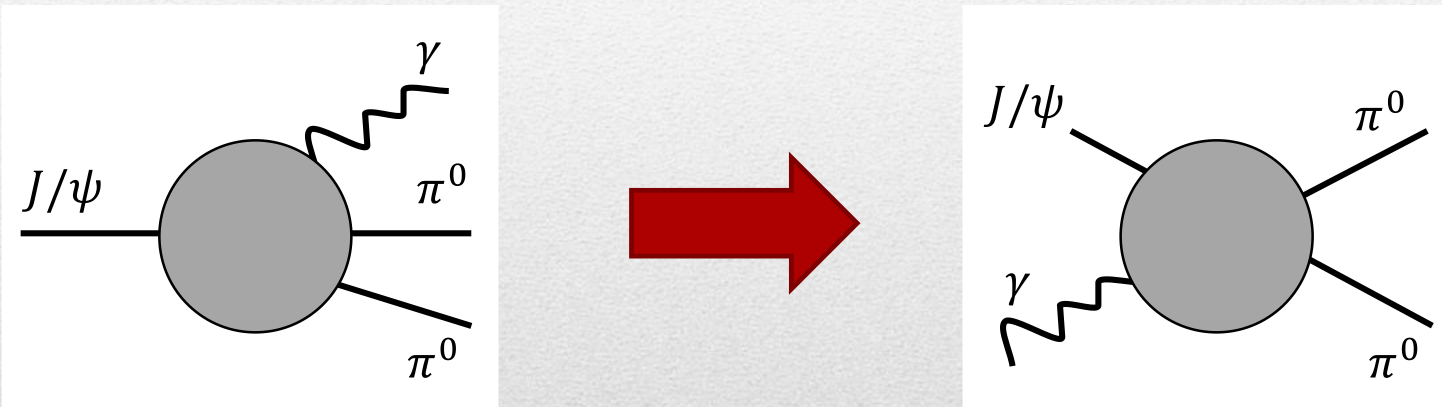
They do not exhibit a clear Breit-Wigner form

Given the peculiar interference pattern, one must give a particular care in writing an amplitude with the correct properties.

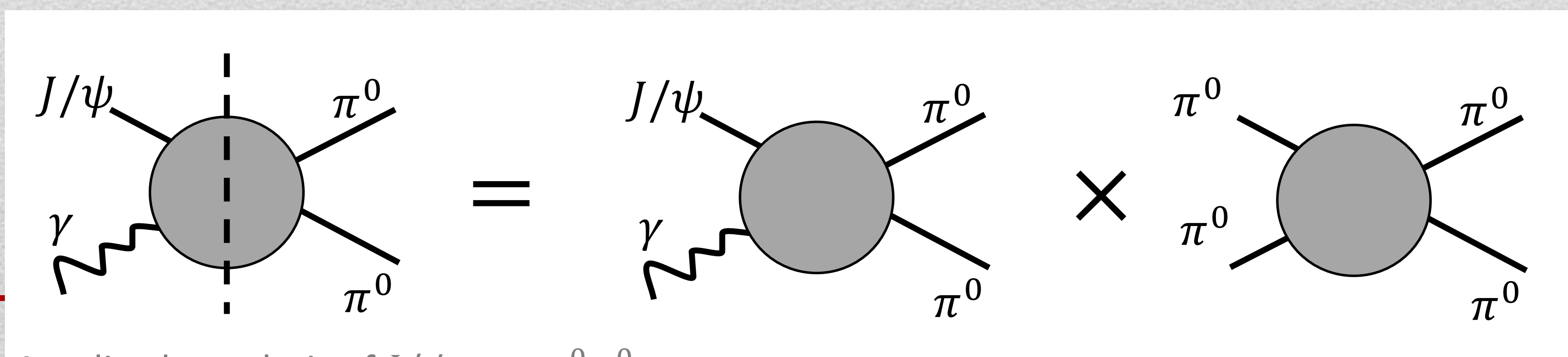
The tensor channel is clearly dominated by the lowest $f_2(1270)$

S-Matrix principles

- **Analyticity**: the amplitude can be analytically continued for complex values of s, t
  no singularities in the Ist Riemann sheet (out of the real axis)
- **Crossing symmetry**: different physical processes are described by the same analytic function



- **Unitarity**: the production is related to the $\pi\pi$ scattering



Kinematical singularities

External particles have spin, so kinematical singularities appear
They have to be removed before writing dispersion relations

$$\begin{aligned}
T_{\lambda_\gamma,\lambda_\psi} &= \sum_J \frac{2j+1}{2} t^J_{\lambda_\gamma,\lambda_\psi} d^J_{\mu 0}(\cos\theta) \\
&= \sum_{J\geq\mu} \frac{2j+1}{2} t^J_{\lambda_\gamma,\lambda_\psi} \sqrt{\frac{(j-\mu)!}{(j+\mu)!}} (-)^\mu \sin^\mu\theta \frac{\partial^\mu}{d(\cos\theta)^\mu} P_J(\cos\theta) \\
&= \frac{(\sqrt{s}\, p_i p_f \, \sin\theta)^\mu}{s-M_\psi^2} \\
&\quad \times \sum_{J\geq\mu} \frac{2j+1}{2} f^J_{\lambda_\gamma,\lambda_\psi} \sqrt{\frac{(j-\mu)!}{(j+\mu)!}} (-)^\mu (p_i p_f)^{J-\mu} \frac{\partial^\mu}{d(\cos\theta)^\mu} P_J(\cos\theta) \\
&\equiv \frac{(\sqrt{s}\, p_i p_f \, \sin\theta)^\mu}{s-M_\psi^2} F_\mu
\end{aligned}$$

$$f^J_{\lambda_\gamma,\lambda_\psi} = \frac{(s-M_\psi^2)}{\sqrt{s}^\mu (p_i p_f)^J}\, t^J_{\lambda_\gamma,\lambda_\psi}$$

The model/1

We start approximating the problem to 1 channel, i.e. neglecting inelasticities.
Unitarity and dispersion relations allow us to write the solution in terms of the Omnès function

$$\mathrm{Disc}_R\, f^J_\mu = \rho(s) f^J_\mu A^{J*}_{\pi\pi} = f^J_\mu e^{-i\delta_J} \sin\delta_J$$

Only RHC

$$f^J_\mu(s) = v^J_\mu(s) + \frac{1}{\pi}\int_{4m_\pi^2}^{\infty} ds' \frac{f^J_\mu(s') e^{-i\delta_J(s')} \sin\delta_J(s')}{s'-s}$$

Only LHC

$$f^J_\mu(s) = v^J_\mu(s) + \Omega(s)\left(P_k(s) + \frac{1}{\pi}\int_{4m_\pi^2}^{\infty} ds' \frac{v^J_\mu(s') e^{i\delta_J(s')} \sin\delta_J(s') \Omega^{-1}(s')}{(s')^k (s'-s)}\right)$$

Need a model

$$\Omega(s) = \exp\left(\frac{s}{\pi}\int ds' \frac{\delta(s')}{s'(s'-s)}\right)$$

Need a model

The model/2

The scattering phase can be expressed in terms of a K-matrix parametrization

$$\delta = \delta_\pi + \delta_R$$

$$K_\pi = \frac{m_\pi^2 - 2s}{2f_\pi^2}$$

$$K_R = \sum_i \frac{g_i}{M_i^2 - s} + \sum_j \gamma_j s^j$$

Adler zero
describes the σ region

K-matrix poles

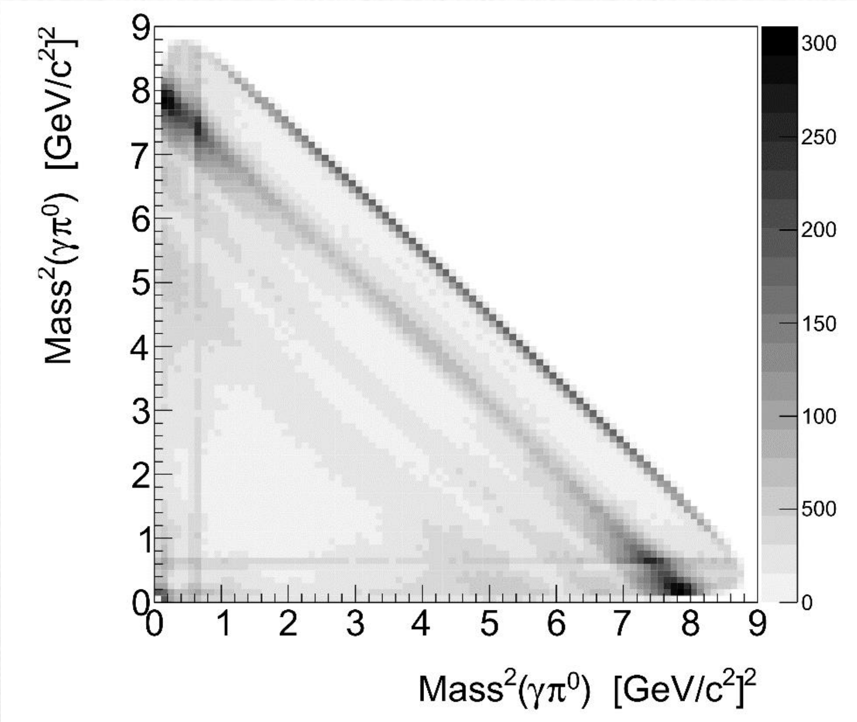
Background terms
(effective LHC)

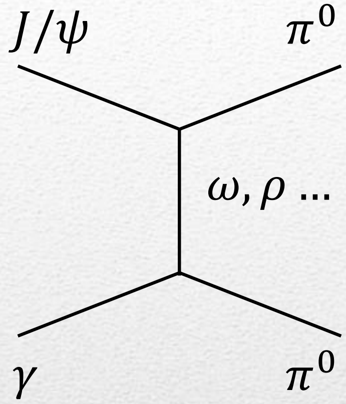
$$A_{\pi\pi} = \frac{1}{K^{-1} - G_\pi}$$

G_π is the Chew-Mandelstam factor (dispersed phase space)

$$Im\ G_\pi = \rho$$

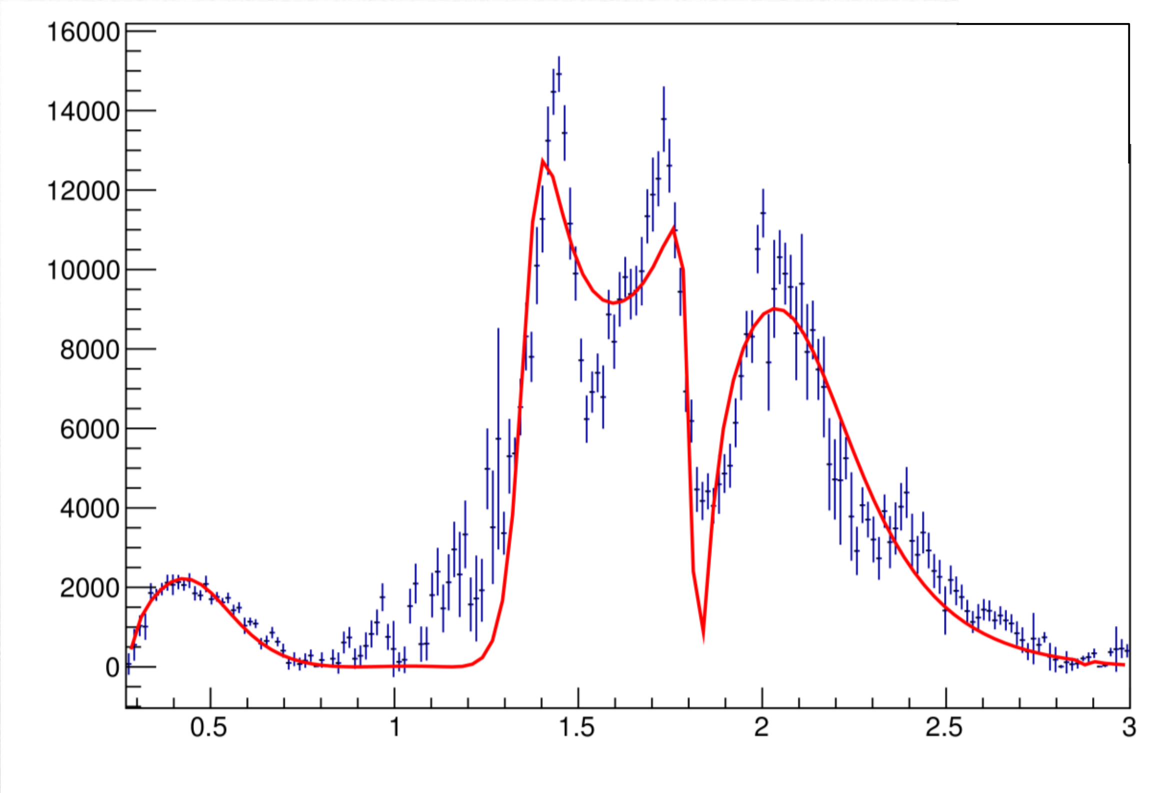
Left hand cut parametrization





Since for the J/ψ the light exchanges have little impact on the production, one can neglect the backreaction of the denominator in the v.
The most relevant exchange in data is the ω, so we use as v the partial wave projection of a BW vector meson

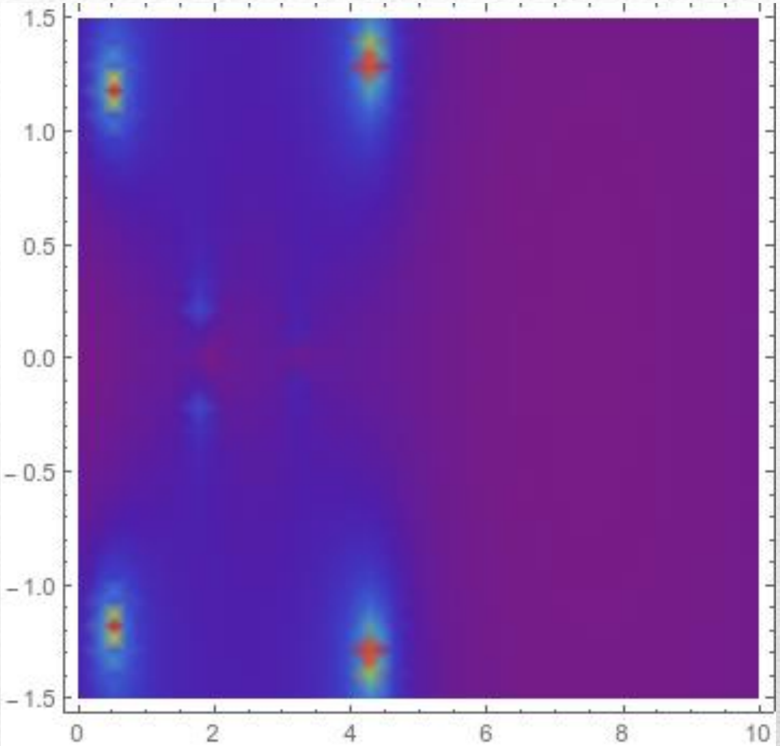
Fit (preliminary)



This is a preliminary version of the fit, just to check if the model is elastic enough to fit the S-wave data

The fit qualitatively reproduces the σ region and the higher resonances, but as expected fails to describe the $f_0(980)$ region:
an effective $K\bar{K}$ threshold has to be included

Hunting for poles



Our parametrization is fully analytical, so it allows us to continue the function onto the unphysical Riemann sheet, and looking for poles

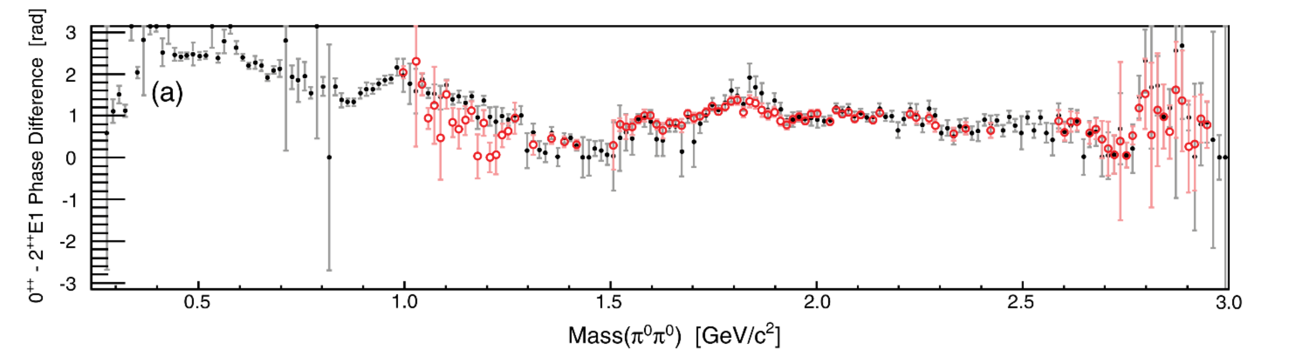
For example, with this preliminary fit we get

$$M_1 = 1362\ \text{MeV} \qquad M_2 = 1810\ \text{MeV}$$
$$\Gamma_1 = 150\ \text{MeV} \qquad \Gamma_2 = 55\ \text{MeV}$$

These look fairly close to the $f_0(1370)$ and $f_0(1710)$.
The improving of the fit will lead to a more precise determination of these two poles, and likely to the finding of the higher ~ 2.2 GeV state.

Next steps

- No proper coupled channel analysis can be performed without $J/\psi \to \gamma\, K\, \bar{K}$ data; still, an effective threshold can be introduced to describe the $f_0(980)$ region
- One can use founded statistical methods to constrain the actual number of poles; this can give a robust answer to whether the three $f_0(1370), f_0(1500), f_0(1710)$ actually show up in this channel
- The combined fit of intensities and phases of the 0^{++} and 2^{++} can constrain even more the scalar sector



Conclusions

- The decay $J/\psi \to \gamma\ \pi\pi$ is a gluon-rich process, particularly interesting for the search and identification of the scalar glueball.
- The S-wave exhibits clear structures, but the interference pattern and the shape of the peaks do not allow for simple Breit-Wigner fits.
- A more robust dispersive analysis is needed for extracting the poles and the couplings of the scalar states.
- The formalism developed is tuned on this system, but can be generalized to other $\pi\pi$ systems, particularly in the region $> 1\ \mathrm{GeV}$

BACKUP

Joint Physics Analysis Center (JPAC)

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Viktor Mokeev (JLab)
HASPECT:
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- Derek Glazier (Glasgow)
- …

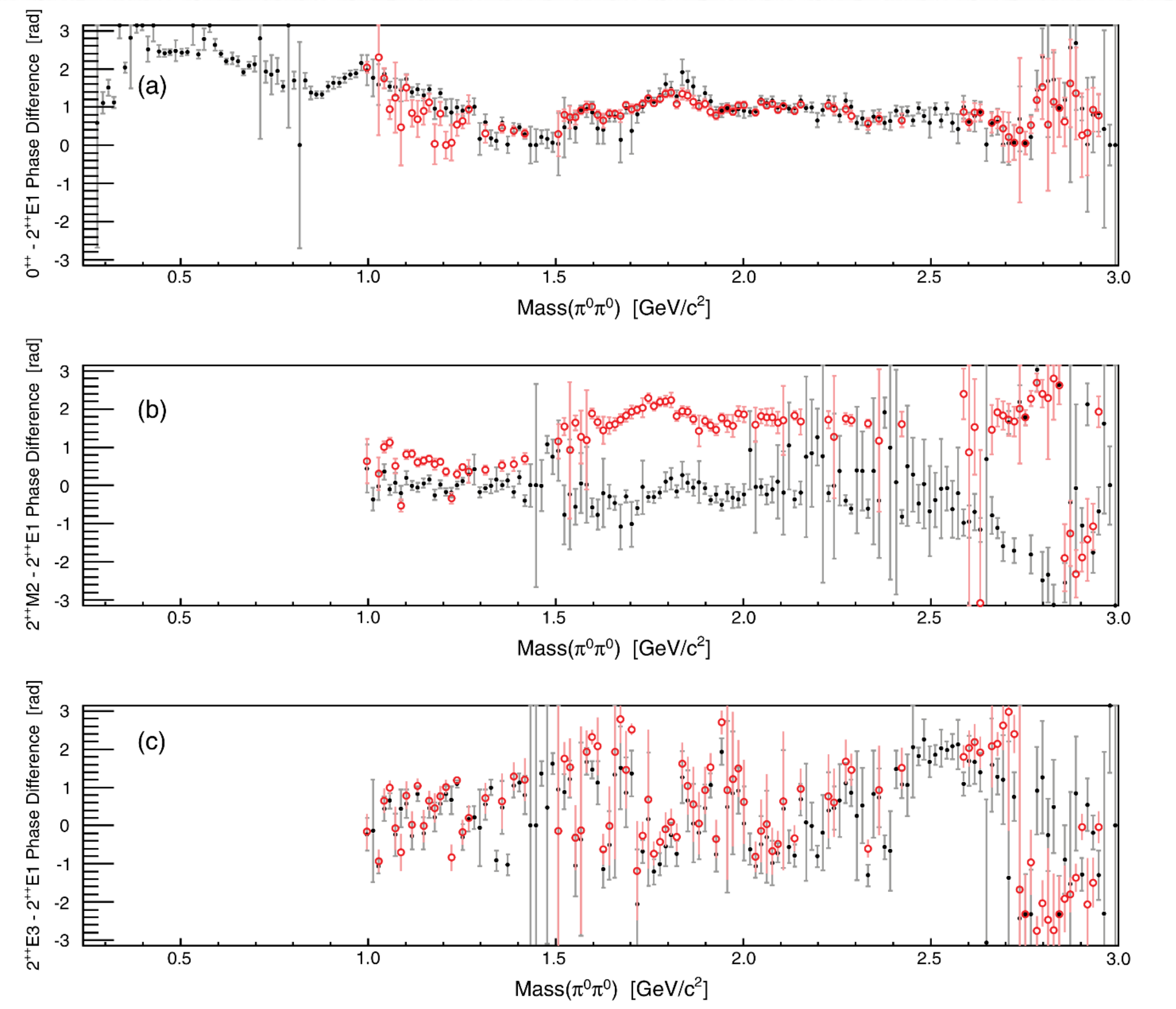
GlueX collaboration

Matthew Shepherd (IU)
Justin Stevens (JLab)
…

COMPASS collaboration

Mikhail Mikhasenko (Bonn)
Fabian Krinner (TUM)
Boris Grube (TUM)
…

Phases


(a)
0^{++} - 2^{++}E1 Phase Difference [rad]
Mass($\pi^0\pi^0$) [GeV/c^2]
(b)
2^{++}M2 - 2^{++}E1 Phase Difference [rad]
Mass($\pi^0\pi^0$) [GeV/c^2]
(c)
2^{++}E3 - 2^{++}E1 Phase Difference [rad]
Mass($\pi^0\pi^0$) [GeV/c^2]