Hunting glueballs with BESIII

Complutense University of Madrid, April 3rd, 2019

A. Rodas

UNIVERSIDAD COMPLUTENSE MADRID

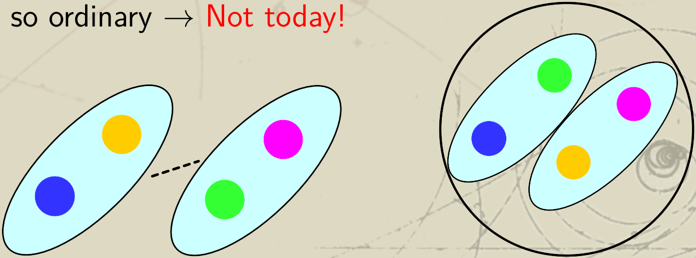
JPAC/BESIII: A workshop on Theory-Experiment collaboration.

Index

This work: Motivation

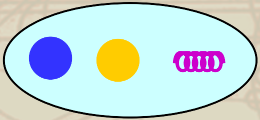
- In this talk: Ongoing phenomenological analysis on spectroscopy
- Ordinary hadrons → Boring!!

- Not so ordinary → Not today!



This work: Motivation

- In this talk: Glueball spectroscopy?
- Hybrid→ part of this talk

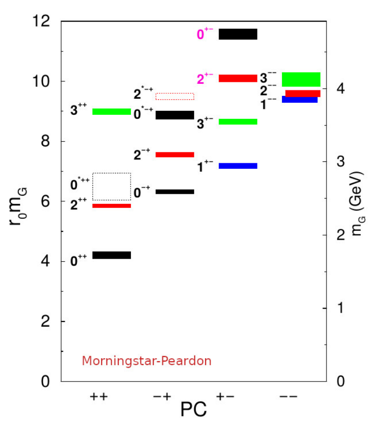


- **Glueball**

This work: Motivation

- Glueball expected at around 1.5-2 GeV.
- $J^{PC} = 0^{++}$ → lightest glueball candidate(s).

J^{PC}	Other J	$r_0 m_G$	m_G (MeV)
0^{++}		4.21 (11)(4)	1730 (50) (80)
2^{++}		5.85 (2) (6)	2400 (25) (120)
0^{-+}		6.33 (7) (6)	2590 (40) (130)
0^{*++}		6.50 (44)(7)†	2670 (180)(130)
1^{+-}		7.18 (4) (7)	2940 (30) (140)
2^{-+}		7.55 (3) (8)	3100 (30) (150)
3^{+-}		8.66 (4) (9)	3550 (40) (170)
0^{*-+}		8.88 (11)(9)	3640 (60) (180)
3^{++}	6, 7, 9, ...	8.99 (4) (9)	3690 (40) (180)
1^{--}	3, 5, 7, ...	9.40 (6) (9)	3850 (50) (190)
2^{*-+}	4, 5, 8, ...	9.50 (4) (9)†	3890 (40) (190)
2^{--}	3, 5, 7, ...	9.59 (4) (10)	3930 (40) (190)
3^{--}	6, 7, 9, ...	10.06 (21)(10)	4130 (90) (200)
2^{+-}	5, 7, 11, ...	10.10 (7) (10)	4140 (50) (200)
0^{+-}	4, 6, 8, ...	11.57 (12)(12)	4740 (70) (230)



PDG status

- Glueball expected at around 1.5-2 GeV.
- Three different candidates measured close by.

$f_0(1370)$ [j] $I^G(J^{PC}) = 0^+(0^{++})$

Mass m = 1200 to 1500 MeV
Full width Γ = 200 to 500 MeV

$f_0(1370)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\pi\pi$	seen	672
4π	seen	617
$4\pi^0$	seen	617
$2\pi^+2\pi^-$	seen	612
$\pi^+\pi^-2\pi^0$	seen	615
$\rho\rho$	dominant	†
$2(\pi\pi)_{S\text{-wave}}$	seen	–
$\pi(1300)\pi$	seen	†
$a_1(1260)\pi$	seen	35
$\eta\eta$	seen	411
$K\overline{K}$	seen	475
$K\overline{K}n\pi$	not seen	†
6π	not seen	508
$\omega\omega$	not seen	†
$\gamma\gamma$	seen	685
e^+e^-	not seen	685

$f_0(1500)$ [n] $I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1504 \pm 6$ MeV (S = 1.3)
Full width $\Gamma = 109 \pm 7$ MeV

$f_0(1500)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$\pi\pi$	(34.9 ± 2.3) %	1.2	740
$\pi^+\pi^-$	seen		739
$2\pi^0$	seen		740
4π	(49.5 ± 3.3) %	1.2	691
$4\pi^0$	seen		691
$2\pi^+2\pi^-$	seen		686
$2(\pi\pi)_{S\text{-wave}}$	seen		–
$\rho\rho$	seen		†
$\pi(1300)\pi$	seen		143
$a_1(1260)\pi$	seen		217
$\eta\eta$	(5.1 ± 0.9) %	1.4	515
$\eta\eta'(958)$	(1.9 ± 0.8) %	1.7	†
$K\overline{K}$	(8.6 ± 1.0) %	1.1	568
$\gamma\gamma$	not seen		752

$f_0(1710)$ [t] $I^G(J^{PC}) = 0^+(0^{++})$

Mass $m = 1723^{+6}_{-5}$ MeV (S = 1.6)
Full width $\Gamma = 139 \pm 8$ MeV (S = 1.1)

$f_0(1710)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\overline{K}$	seen	706
$\eta\eta$	seen	665
$\pi\pi$	seen	851
$\omega\omega$	seen	360

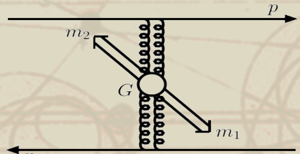
Consensus?

- The glueball is expected to be predominant in either the $f_0(1500)$ or the $f_0(1710)$.
- Not much of a consensus $\rightarrow$ **V. Mathieu et al. Int.J.Mod.Phys. E18 (2009) 1-49**.
- Recent years $\rightarrow$ not much of an improvement.
- $f_0(1500) \rightarrow 0.89|gg\rangle$ **Giacosa et al. Phys.Rev. D72 (2005) 094006**.
- $f_0(1710) \rightarrow 0.93|gg\rangle$ **Albaladejo-Oller Phys.Rev.Lett. 101 (2008) 252002**.

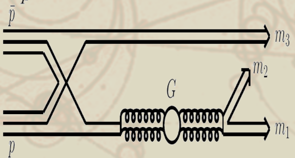
Table of Content

Data: Glueball “rich" experiments

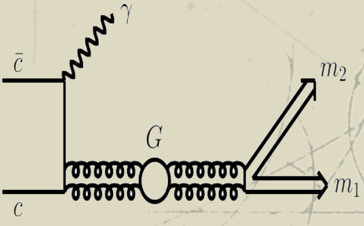
- Pomeron collisions



- $p\bar{p}$ anihilation

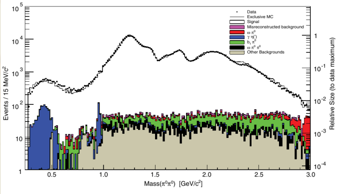


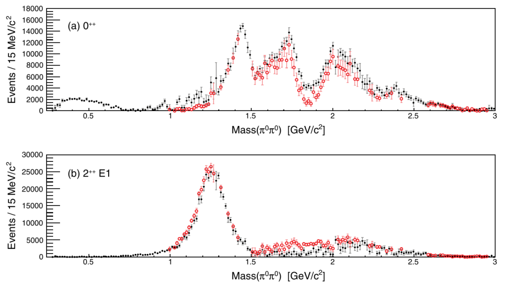
- J/ψ radiative decays considered the golden channel for glueballs.



Data: BESIII $J/\psi \to \gamma\pi\pi$

- Data on $J/\psi \to \gamma\pi\pi$ half a million events.

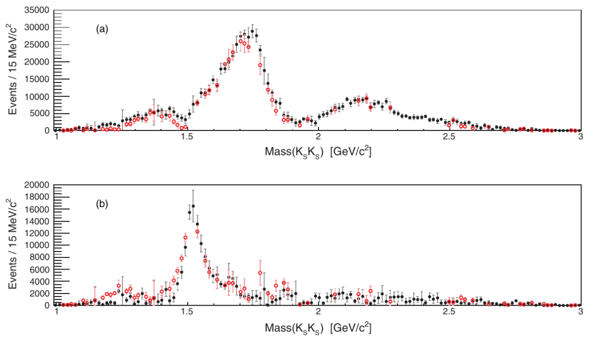




- 3 prominent f_0's with similar couplings.
- The $2^{++}E1$ partial wave is dominated by the $f_2(1270)$.

Data: BESIII $J/\psi \to \gamma K\bar{K}$

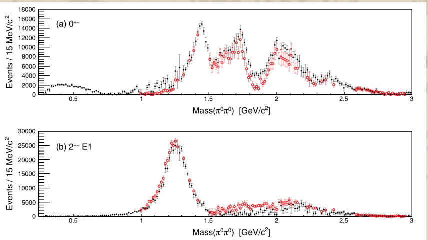
- Another 3 prominent f_0's

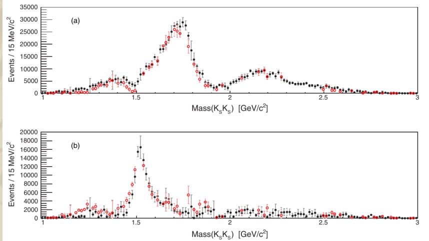


- The couplings are fairly different, with a way more prominent $f_0(1710)$.
- The $2^{++}E1$ partial wave is dominated by the $f_2'(1525)$.

Data: BESIII J/ψ

- How many f_0 do we have here?



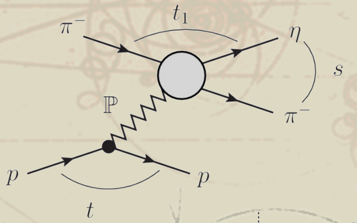


- Is the coupling of the $f_0(1710)$ greater$\rightarrow$ glueball hint?

Table of Content

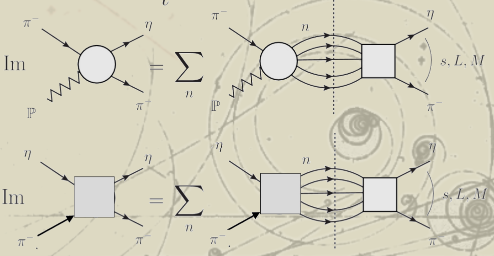
Method

- Based on AR et al. Phys.Rev.Lett. (2019), A.Jackura et al. Phys.Lett.B (2018)
- Peripheral production ⇒ factorization of the pomeron ⇒ $Im a(s) = \rho(s) t^*(s) a(s)$.



- Amplitude built around $t(s) = \frac{N(s)}{D(s)}$ method $\Rightarrow a(s) = p^2 q \frac{n(s)}{D(s)}$.

- They are smooth polynomials $n(s) = \sum_j a_j w^j(s)$, where $w(s) = \frac{s}{s+s_0}$.



Method

- N(s) and n(s) are process dependent, they have only left hand cuts.
- D(s) has a right hand cut, altogether $t(s)$ has the correct analytic structure.

- By adding this discontinuity over the RHC one could go to the direct continuous Riemann sheet.

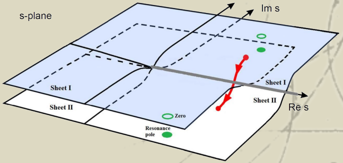


Table of Content

Coupled channel

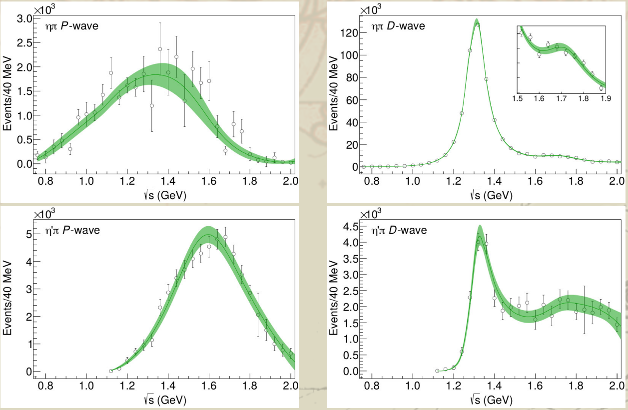
- $\eta^{(\prime)}\pi$ coupled channel up to 2 GeV.
- We use a K-matrix approach with a Chew-Mandelstam phase space.

$$
\begin{aligned}
D^J(s)_{ki} &= (K^J(s)^{-1})_{ki} - \frac{s}{\pi}\int_{s_k}^{\infty} ds' \frac{\rho(s') N^J_{ki}(s')}{s'(s'-s-i\varepsilon)}, \\
\rho N^J_{ki}(s') &= \delta_{ki} \frac{\lambda^{J+1/2}\left(s', m^2_{\eta^{(\prime)}}, m^2_\pi\right)}{(s'+s_L)^{2J+1+\alpha}} \\
K^J_{ki}(s) &= \sum_R \frac{g_k^{J,R} g_i^{J,R}}{m_R^2 - s} + c^J_{ki} + d^J_{ki} s.
\end{aligned}
$$

- Just 1 K-matrix pole for the P-wave.

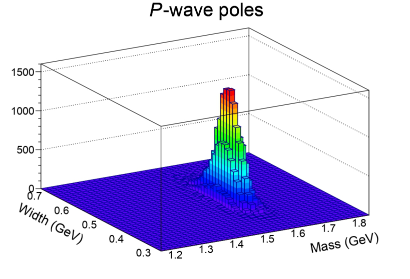
Coupled channel analysis

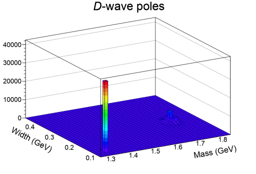
- We use an average of 6 parameters for each figure.
- $\chi^2 \approx 1.3$, no significant deviation for any partial wave.
- 1 K-matrix pole produces 2 different peaks for the P-wave $\rightarrow$ 300 MeV distance.

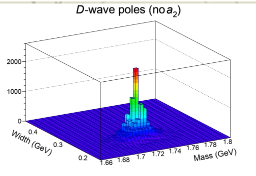


Poles

- Statistical uncertainties calculated through bootstraping
- $m(a_2) = 1306.0 \pm 0.8 \pm 1.3$ MeV $\quad \Gamma(a_2) = 114.4 \pm 1.6 \pm 0.0$ MeV
- $m(a_2') = 1722 \pm 15 \pm 67$ MeV $\quad \Gamma(a_2') = 247 \pm 17 \pm 63$ MeV
- $m(\pi_1) = 1564 \pm 24 \pm 86$ MeV $\quad \Gamma(\pi_1) = 492 \pm 54 \pm 102$ MeV.
- All systematics (diferent LHC masses, numerator models ...) included.

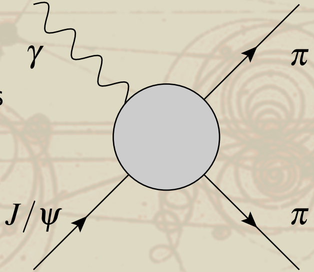




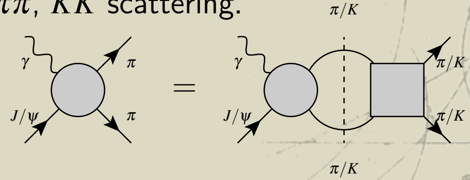


$J/\psi \to \gamma\, m_1\, m_2$

- Slightly different kinematics

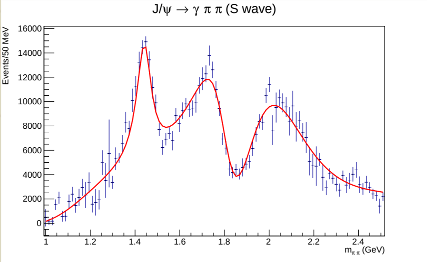


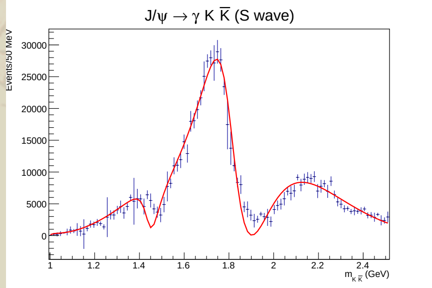
- Left hand cut $\to s = 0$ GeV.
- $Ima(s) = \rho(s)t(s)^{*}a(s)$
- $t(s) \to \pi\pi$, $K\bar{K}$ scattering.



Coupled-channel scenario

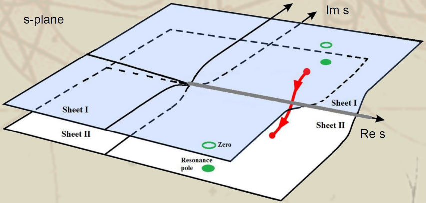
- Fit from 1 GeV to 2.5 GeV, $\chi^2 \approx 1.5$.
- Interested in the f_0.
- Coupled channel between just $\pi\pi$ and $K\bar{K}$.





Complex plane

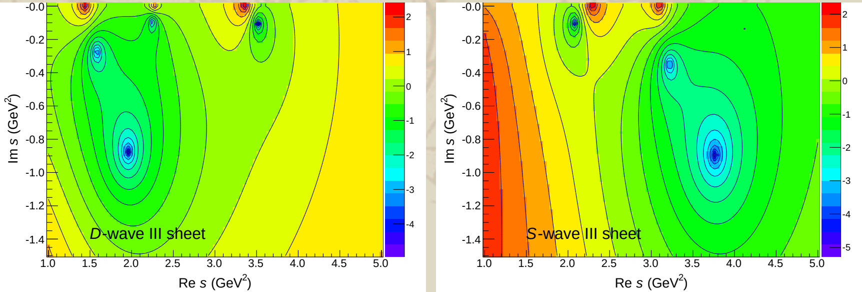
- We use the analytical properties of the parameterization $\rightarrow$ complex plane continuation.



- $m(f_0(1500)) = 1460$ MeV $\Gamma(f_0(1500)) = 85$ MeV.
- $m(f_0(1710)) = 1800$ MeV $\Gamma(f_0(1710)) = 190$ MeV.
- $m(f_0(210)) = 1970$ MeV $\Gamma(f_0(1710)) = 490$ MeV.

Scalar poles

- Complex plane plots



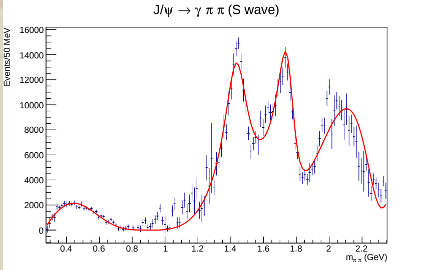
- Few “spurious” poles, all far from real axis

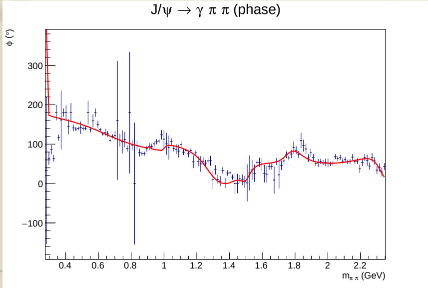
Improvements: σ description

- Tree level ChPT $\rightarrow T^0(s,t) \propto \frac{s-M_\pi^2/2}{f_\pi^2}$.
- *PCAC* $\rightarrow$ Adler zero $\rightarrow K^J_{ki} \propto (s-s_A)$.

$$K^J_{ki}(s) = \frac{s-s_A}{s}\left[\sum_R \frac{g_k^{J,R} g_i^{J,R}}{m_R^2 - s} + c^J_{ki} + d^J_{ki}\right],$$

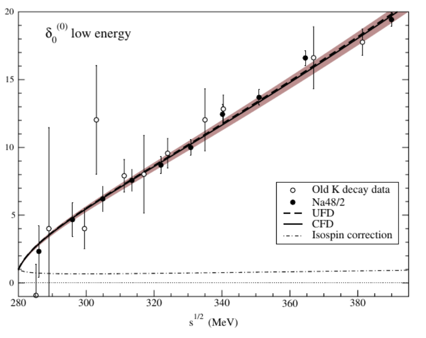
- Dispersive Adler zero located at $s_A = 85$ MeV^2. **GKPRY Phys.Rev.D (2012)**





Improvements: σ description

- Wrong behavior at low energies.
- Even the Adler zero is not sufficent to directly accommodate the σ pole.
- Bump produced by the background+phase space
- Solution $\rightarrow$ including $\pi\pi$ data.



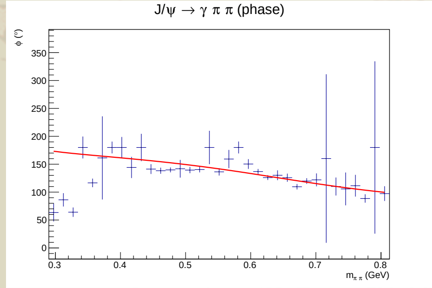
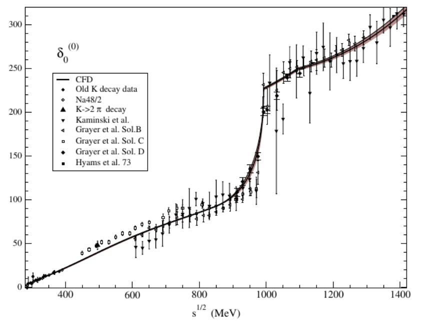
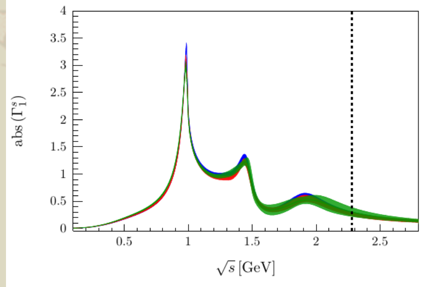


Table of Content

Future Prospects: Dispersive $\pi\pi$ description

- Can be done using $T = V + VGT$, **Ropertz-Kubis-Hanhart Eur.Phys.J. C78 (2018)** $\bar{B}_s^0 \to J/\psi\pi\pi/K\bar{K}$.
- Omnés-like factorization of the $\sigma \to T = T_\sigma + \Omega\left[1 - V_R\Sigma\right]^{-1}\Omega^t$.
- $Im\Omega_{ij} = (T_0)^*_{im}\sigma_m\Omega_{mj}$.
- Used to accommodate the low energy $\pi\pi$ dispersive input.





Summary

- Implementation of a coupled-channel formalism $\rightarrow$ In progress.
- Description of the features of 3 f_0's.
- Description of the σ $\rightarrow$ In progress.
- Inclusion of the dispersive $\pi\pi$ result $\rightarrow$Next step.

Thank you for your attention!