The Sounds of Silence
An attempt to explain the anomalous J/ψ strong decay phase δ

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An attempt to explain the anomalous J/ψ strong decay phase δ

- The J/ψ strong decay phase puzzle
- Freund-Nambu model
- Φ and Y(1S) phases
- Narrow Vector Quarkonium Decay and $\alpha_S(s)$
- Modelling $\alpha_S(s)$ for timelike s
- $\alpha_S(s)$ imaginary part and J/ψ , Φ, Y(1S) phases
- Next to do

Heavy Vector Quarkonium decay mechanisms assumptions

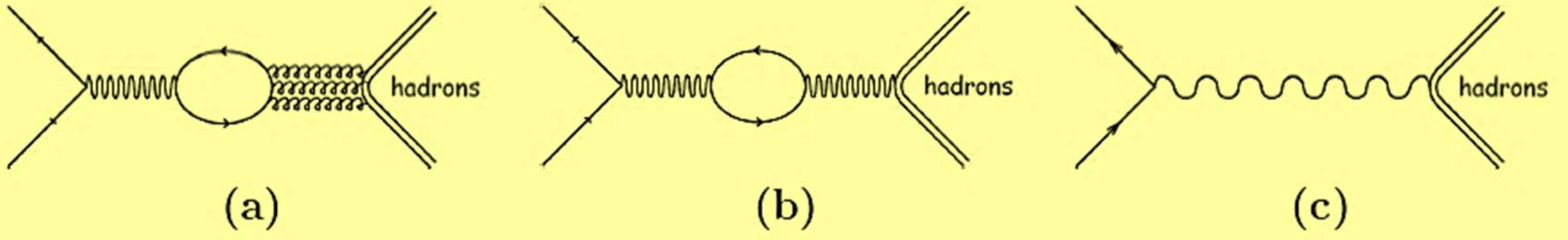


Figure 1: *Diagram for the process $e^+e^- \to$ hadrons: (a) strong A_{3g}, (b) EM A_γ, and (c) non resonant A_C contributions.*

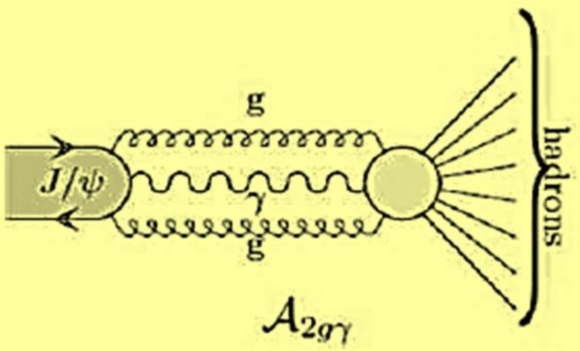


Figure 2: *Diagram for the process $e^+e^- \to$ hadrons, for the $A_{2g1\gamma}$ contribution.*

Heavy Vector Quarkonium decay mechanisms assumptions

The em decay branching ratio $B_{em} = |A_{em}|^2$ [diagram (b)] and the continuum $|C|^2$ [diagram (c)] are related by:

$$BR_{J/\psi\to\gamma^*\to f} = \sigma_{ee\to f,\ outside\ J/\psi} * BR_{J/\psi\to\mu\mu}/\sigma_{ee\to\mu\mu,\ outside\ J/\psi}.$$

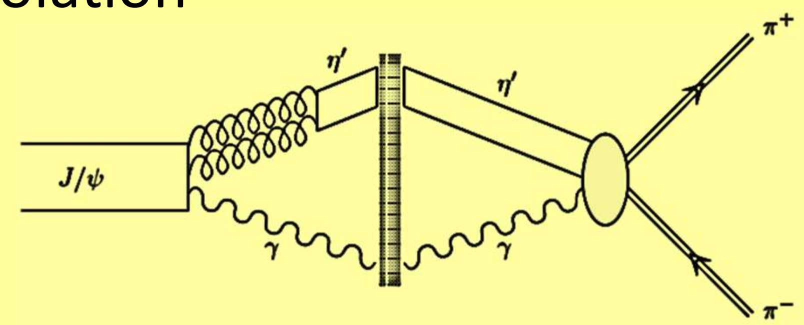
but A_{em} (2 virtual γ propagator) and C (1 virtual γ propagator) (each γ propagator brings a minus sign) have opposite sign.

Therefore the interference dip in pure em decays is on the resonance left side.

Heavy Vector Quarkonium decay mechanisms assumptions

Diagram in Fig.2 may affect this relationship.
In pure em J/ψ decay is verified, with a remarkable exception $J/\psi \to \pi\pi$.

BR($J/\psi \to \pi\pi$) ≈ 3 times the expectation from $\sigma(ee \to \pi\pi)$,
consistent with an additional contribution from $\eta' \to \rho\,\gamma$ analytic extrapolation



R. Baldini Ferroli et al., Phys. Rev. D95, 034038 (2017); R. Baldini Ferroli et al., Phys. Rev. C98, 045210 (2018).

Heavy Vector Quarkonium decay mechanisms assumptions

- Narrow resonances: Perturbative Regime (α_S <1):
  lowest allowed order (3 gluons intermediate state)
  assumed to dominate strong decay.
- Continuum σ flat behaviours: still Perturbative Regime
- All amplitudes expected to be almost real, accordingly
  That is the phase δ between strong and em decay
  amplitudes is equal to 0^0 or 180^0
  See for instance
  (L. Chernyak, I.R.Zhitnitsky, Nucl.Phys. B240 (1984) 52)

Heavy Vector Quarkonium

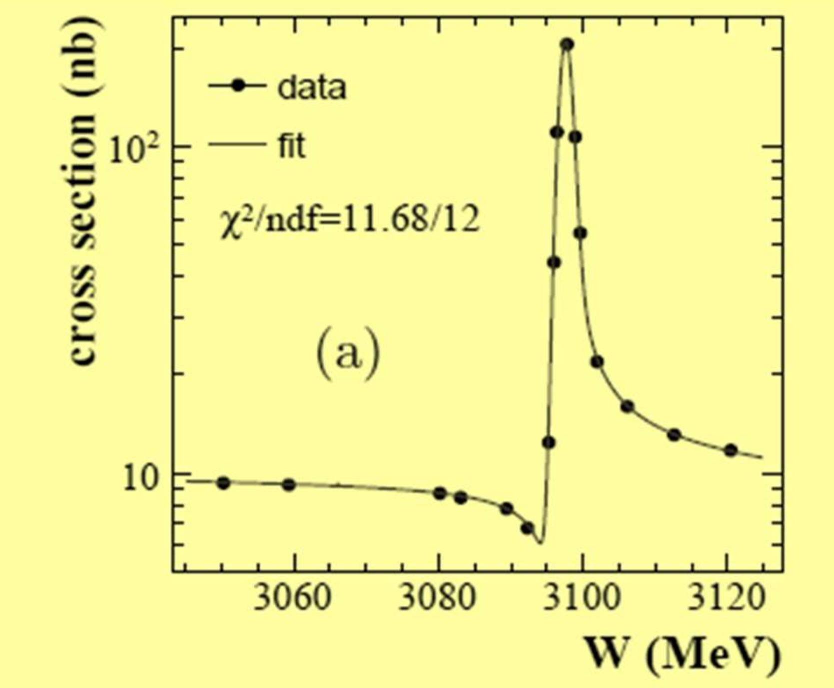
- In fact Φ strong decay amplitude looks like being mostly real. (Y(1S) not clear)
- On the contrary J/ψ strong decay amplitudes, according to present data, are mostly imaginary .
- In other words there is no dip in the W scan and phases δ between strong and em decay amplitudes are **all $\delta \approx 90^0$.**
- **Actually, in the W scan, δ comes from interference between strong amplitude S and continuum C, sensitive mostly to cos(δ) -> |δ| is measured. Methods have been suggested to get δ sign**

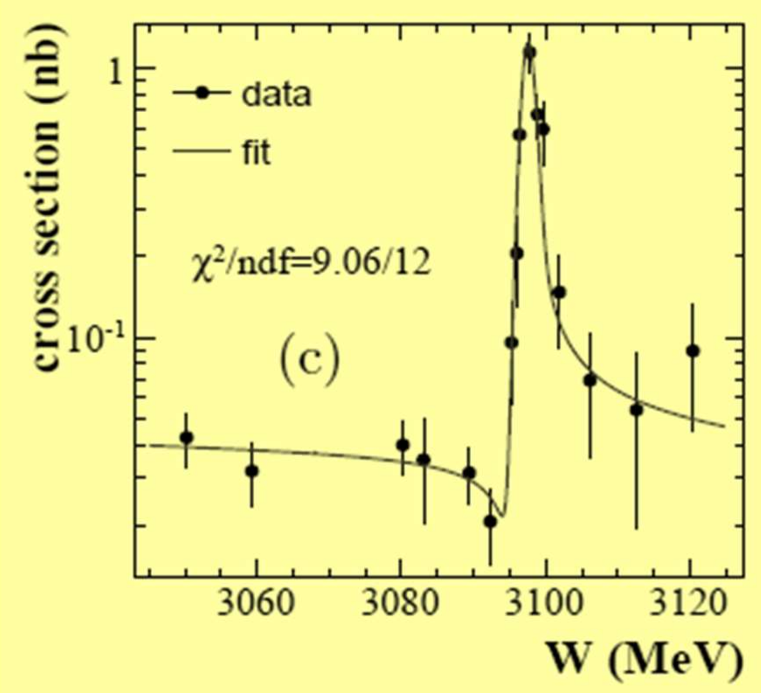
J/ψ decay modes where $|\delta| \approx 90^0$

- VP according to Broken SU_3
- Assuming $\sigma(ee\text{->}nn_{bar}) \approx \sigma(ee\text{->}pp_{ba})$:
  $BR(J/\psi \text{–>} nn_{bar}) / BR(J/\psi \text{–>} pp_{bar}) \approx 1$
- In the case of pure em decays there must be an interference pattern just before the resonance in a W scan:
  ee->$\mu\mu$, ee->$\rho\eta$ $\delta \approx 0^0$
- If the phase between strong and em decay, as well as the continuum, is 90^0 there is no interference pattern in a W scan, if the strong decay dominates the em one

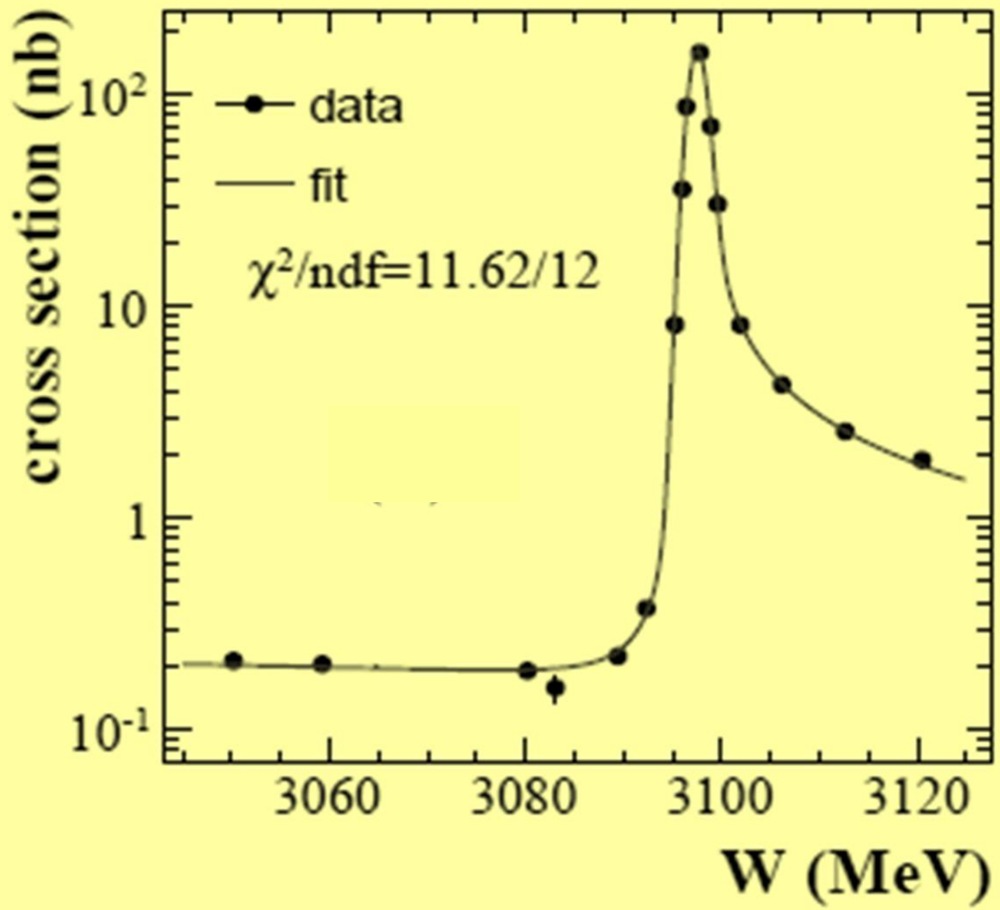
- ee->5 π $\delta = |85 \pm \mathbf{4}|^{\mathbf{0}}$
- ee->3 π $\delta = |107 \pm \mathbf{27}|^{\mathbf{0}}$
- and in other decay modes (pp_{bar} , K^+K^-, $\Lambda\Lambda_{bar}$ …) presented but not approved yet

J/ψ em decays , where |δ| ≈ 0⁰





J/ψ decay-> 5 π , where |δ| ≈ 90⁰

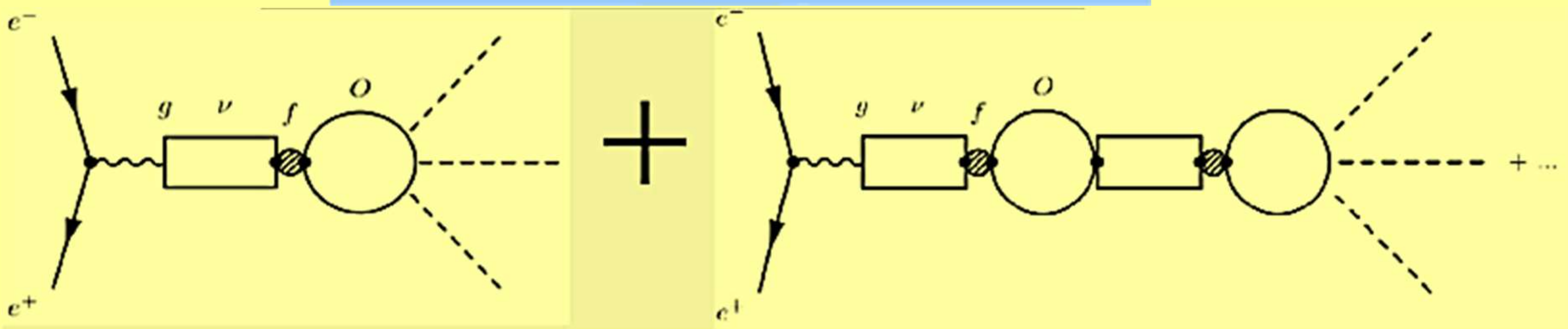


Quarkonium OZI breaking decay as Freund and Nambu (PRL 34(1975), 1645)

- Quarkonium as a superposition of
  - A narrow V (coupled to the virtual photon, but not directly to hadrons)
  - A wide one (a glueball o)

    (not coupled to leptons I.e. to a virtual photon, but strongly coupled to hardrons)

***f* is the coupling between v and $\mathcal{O}$**



Iterated in f

Narrow V and wide glueball O superposition

(P. J. Franzini, F. J. Gilman, PR D32, 237 (1985)

$$A_{strong} = \frac{\sqrt{\Gamma_{ee}} M_V M_O f \sqrt{\Gamma_O}}{(M_V^2 - W^2 - iM_V\Gamma_V)(M_O^2 - W^2 - iM_O\Gamma_O) - M_V M_O f^2}$$

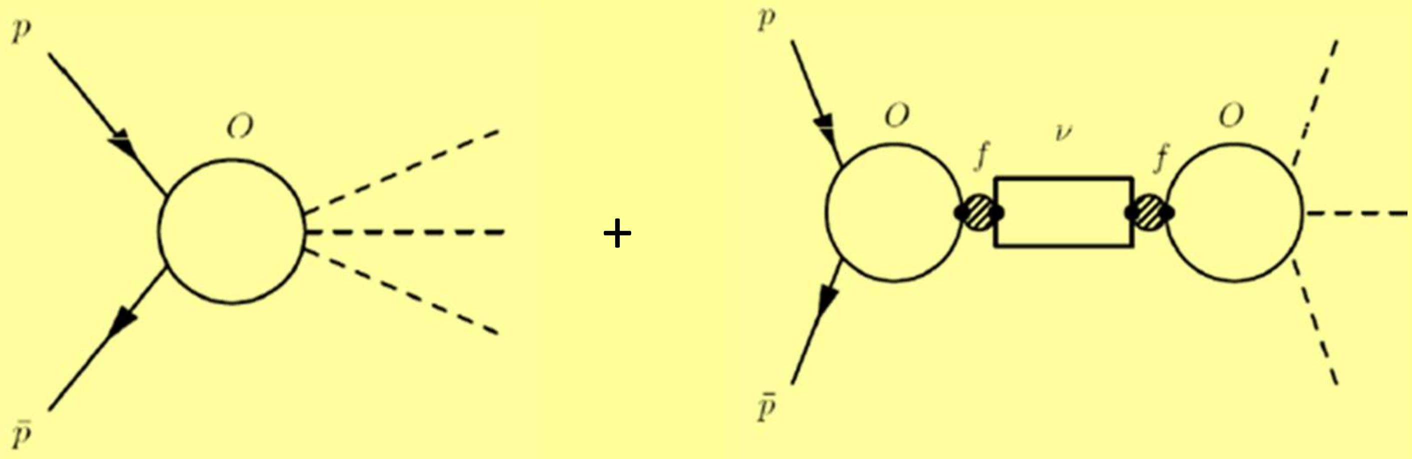
assuming $\Gamma_O >> \Gamma_{J/\psi}$, $f^2 \sim \Gamma_O (\Gamma_{J/\psi} - \Gamma_V)$

$$A_{strong} \sim \frac{ⓘ\sqrt{B_{ee}}\, M_V f\, \sqrt{B_h}}{M_{J/\Psi}^2 - W^2 - iM_{J/\Psi}\Gamma_{J/\Psi}} \qquad A_{em} = \frac{\sqrt{B_{ee}}\, M_V \Gamma_{J/\Psi}\, \sqrt{B_{em}}}{M_{J/\Psi}^2 - W^2 - iM_{J/\Psi}\Gamma_{J/\Psi}}$$

- **The additional 90° phase is naturally achieved**
- J/ψ shape reproduced if: $|f| \sim$ 0.012 GeV , $M_O \sim M_{J/\psi}$, $\Gamma_O \sim$ 0.5 GeV
- nly far from the J/ψ (no contradiction with BES, PR 54(1996)1221)
- ψ "(3770) decay phases agree with Nambu suggestion.
- **ψ ' unclear; ψ ' -> J/ψ ππ (?)**

A proposal for PANDA

Contributions to p p_{bar} -> J/Ψ -> hadrons, according to the FN model



A proposal for PANDA

- According to the FN approach

$$\sigma_{FN} = \frac{B_p \ \left[(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_V)^2)\right] \ B_h}{(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_{J/\Psi})^2}$$

Taking into account that $\Gamma_V << \Gamma_{\vartheta/\Psi}$

$$\sigma_{FN} = \frac{B_p (M^2_{J/\Psi} - W^2)^2 \ B_h}{(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_{J/\Psi})^2}$$

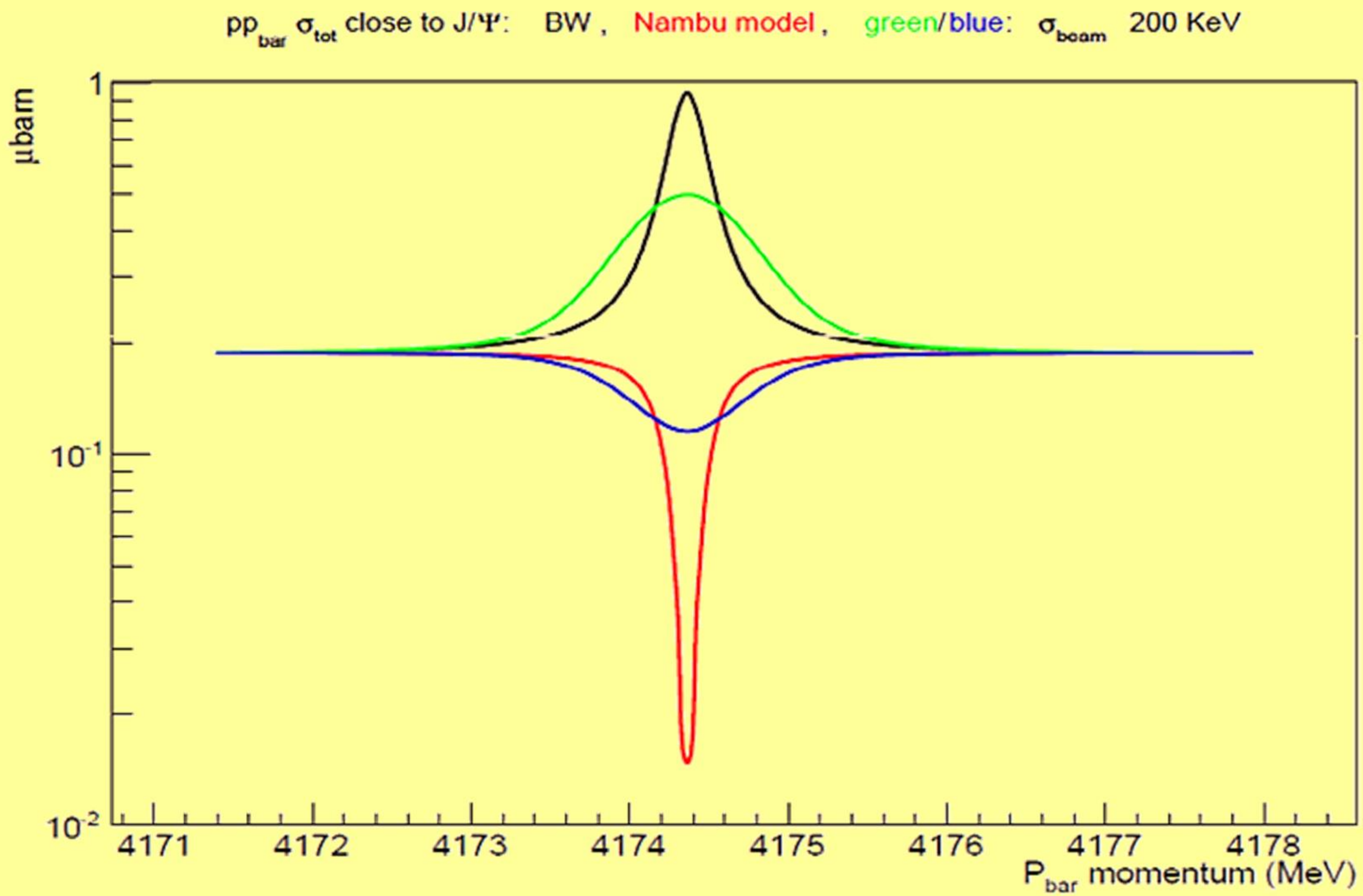
a zero -> a dip in σ_h

- To be compared to a Breit Wigner

$$\sigma_{BW} = \frac{B_p \ \Gamma^2_{J/\Psi} \ B_h \ M^2{}_{J/\Psi}}{(M^2_{J/\Psi} - W^2)^2 + (M_{J/\Psi}\Gamma_{J/\Psi})^2}$$

A proposal to PANDA

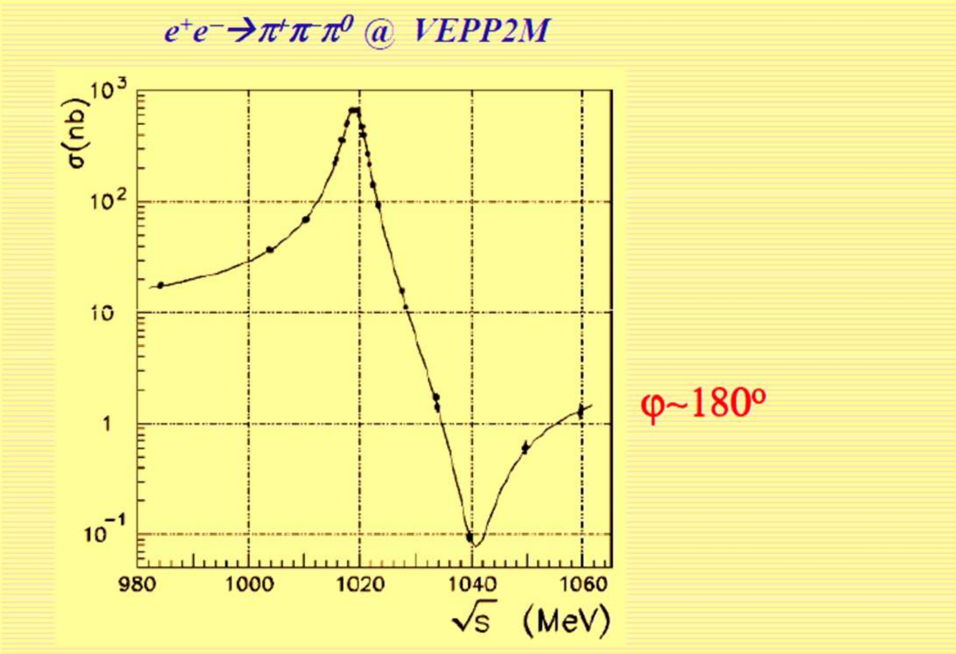
PANDA inv mass resolution: small beam energy spread and no ISR



FΦ strong phase δ close to 180^0

- Interference on the resonance right side between Φ and continuum, that is the ω tail, as expected if δ close to 180^0
  $|\delta_\Phi - \delta_\omega| = |163 \pm 7|^0$ *[SND Coll, Phys.Rev. D68 (2003)]*

- δ_ω not known



Phys. Rev.D 63, 072002

FY(1S) strong phase δ

- Unfortunately there are data on BR and continuum, to get δ, two processes only, at the moment [P.R. D88,052019 (2013)]:
  $K^{*0}(892)\ K^0$ BR=$(2.9\pm0.9) \times 10^{-6}$
  $K^{*+(}892)\ K^-$, $K^{*-(}892)\ K^+$ BR=$(0.3\pm0.3) \times 10^{-6}$

- at W_0=10.58 GeV (703 fb^{-1}) :
  σ_0 = (7.5 ± 0.8) fb
  σ_c = (0.2 ± 0.15) fb
  σ are extrapolated to $M_{Y(1S)}$ according to $(W_0 / M_{Y(1S)})^8$
  $|E|^2$ = BR[Y(1S)-> $\mu\mu$)/σ(ee->$\mu\mu$) x σ
  $|E_0|^2 \approx 0.47 \times 10^{-6}$
  $|E_c|^2 \approx 0.01 \times 10^{-6}$

FY(1S) strong phase δ

- U spin invariance, that should hold at high energy, would predict a factor of 2 between neutral and charged modes and is largely violated in the continuum as well at the resonance.

- Assuming

  $BR_0 - |E_0|^2 = S^2 + 2\,S\,E_0\cos(\delta)$

  $BR_c - |E_c|^2 = S^2 - 2\,S\,E_c\cos(\delta)$

  δ close to 90^0 is clearly excluded, if S is not vanishing. Adding and subtracting these two equations S^2 and δ can be obtained, but this global solution does not fulfill at all single equations.

FY(1S) strong phase δ

- Assuming E_c (or E_0) being negative

  $BR_0 - |E_0|^2 = S^2 + 2 S E_0 \cos(\delta)$

  $BR_c - |E_c|^2 = S^2 + 2 S E_c \cos(\delta)$

  S^2 and δ can be obtained in this way, fulfilling each equation.

  fluctuating BR's and σ's withiñ their large errors:

- in 35% cases $S^2 > 0$ and $S^2 = (0.3 \pm 0.2) \times 10^{-6}$

  Indeed small, confirming Y(1S)-> $K^*(892)$ K is mostly em

  consistent with U spin invariance violation in and out Y(1S)

- in 10% cases $|\cos(\delta)| < 1$ and $S^2 = (0.5 \pm 0.2) \times 10^{-6}$, $\delta \approx |65^0|$

Freund-Nambu dual model failuresF

- The Freund-Nambu inspired model try to find a dual interpretation of the Zweig rule consistent with a phase δ close to 90^0
- **The assumptions that $M_G \approx M_V$ and $\Gamma_G >> \Gamma_V$ are basic**
- Φ and Y(1S) strong phase δ are not close to 90^0 .
  The model can be restored, assuming $M_G \neq M_V$,
  but duality is lost and it looses its entirety.
- Looking for another possible explanation
  of all the phases: J/ψ , Φ and Y(1S)

A new attempt to explain the anomalous J/ψ strong decay phase Exploiting $\alpha_S(s_{tl})$ Imaginary Part

- The J/ψ width is related to $|\alpha_S(s)|$, according to PQCD, by:

-
$$\Gamma(J/\psi \to ggg) = \frac{5}{18\pi}(\pi^2 - 9)\frac{\alpha_s^3}{\alpha^2}\cdot\Gamma(J/\psi \to l^+ l^-)\cdot\left(1 + 10.3\,\frac{\alpha_s}{\pi}\right)$$

- The running QCD coupling constant $\alpha_S(s)$ enters as $|\alpha_S(s)|$
- Since each gluons carries ≈ 1/3 of the Quarkonium mass M in the following $|\alpha_S(M)| \approx |\alpha_S(M/3)|$.
  Sharing M differently should not affect too much the result since eventually bigger and smaller α_S are then multiplied.

A new attempt to explain the anomalous J/ψ strong decay phase Exploiting $\alpha_S(s_{tl})$ Imaginary Part

- Solving the quadratic equation in $|\alpha_S|$ from $|\Gamma_{3g}|^{1/3}$ assuming $[1+10.3\,|\alpha_S|/\pi]^{1/3} \approx [1+10.3\,|\alpha_S|/(3\pi)]$:

QQ_{bar}	$\|\Gamma_{3g}\|$ (KeV)	$\|\Gamma_{em}\|$ (KeV)	$\|\alpha_S\|_{exp}$
Φ	654.	1.3	0.33
J/ψ	59.	5.5	0.17
$\psi(3686)$	31.	2.3	0.18
Y(1S)	44.	1.4	0.16

- The running coupling constant $\alpha_S(s)$ is supposed to scale from μ^2 to s (in principle at large s ?)

A new attempt to explain the anomalous J/ψ strong decay phase Exploiting $\alpha_S(s_{tl})$ Imaginary Part

- $\alpha_S(s) \approx \alpha_S(\mu^2) /\{1+b\, \alpha_S(\mu^2)\cdot \ln(s/\Lambda^2)\} \approx 1 /\{ 1/ \alpha_S(\mu^2)+b \ln(s/\Lambda)$
  where $b=1/(12\pi)\,(33-2f)$, f = n. flavours , $\Lambda \approx 200$ MeV
- $\alpha_S(s)$ evolution as been mostly formulated for spacelike s.
- To go from spacelike to timelike, analiticity would require
  Spacelike s_{sl}-> Timelike s_{tl} : s -> -|s| => $\mathbf{\ln(s_{sl}) = \ln(|s_{tl}|) + i\,\pi}$
  [see, for instance, S. J. Brodsky, SLAC-PUB-10250 (2003)]

A new attempt to explain the anomalous J/ψ strong decay phase Exploiting $\alpha_S(s_{tl})$ Imaginary Part

Two possibilities have been considered in the following:

- $\mu^2 \approx \Lambda^2$ => $\alpha_S(\mu^2)$ large => $1/\alpha_S(\mu^2) \approx 0$

  Therefore $\alpha_S(M) \approx 1/\{b\,[2\ln(M/(3\Lambda) + i\,\pi]\}$

  $|\alpha_S(M)| \approx 1/\{b\,\sqrt{[(2\ln(M/(3\Lambda))^2 + \pi^2)]}\}$

  In the case of Φ:

  $\ln(M/(3\Lambda)$ is small and $\alpha_S(M_\Phi)$ have a large imaginary part

- $\mu^2 \approx M_\Phi{}^2$ $\alpha_S(M) \approx 1/\{1/\alpha_S(M_\Phi{}^2) + b\,[2\ln(M/(3\Lambda) + i\,\pi]\}$

A new attempt to explain the anomalous J/ψ strong decay phase Exploiting $\alpha_S(s_{tl})$ Imaginary Part

- $\alpha_S(M)$ experimental versus "theoretical"

QQ_{bar}	$\|\alpha_S(M)\|_{exp}$	$\mu^2 \approx \Lambda^2$	$\mu^2 \approx M_\Phi{}^2$
Φ	0.33	0.39	0.39
J/ψ	0.17	0.31	0.18
$\psi(3686)$	0.18	0.29	0.17
Y(1S)	0.16	0.24	0.16

- $\mu^2 \approx \Lambda^2$ is a zero approximation, $\mu^2 \approx M_\Phi{}^2$ a better one, in agreement on $|\alpha_S(M)|$ with the experimental value

A new attempt to explain the anomalous J/ψ strong decay phase Exploiting $\alpha_S(s_{tl})$ Imaginary Part

○ $\mu^2 \approx \Lambda^2$ $\delta(M) \approx -3/2\,\mathrm{arctg}\{\pi/[2\ln(M/(3\Lambda)]\}$

$i\pi$ in denominator-> δ always negative

no arctg ambiguity

α_S^3 -> x3, Amplitude -> x 1/2

QQ_{bar}	$\lvert\delta(M)\rvert_{exp}$	$\mu^2 \approx \Lambda^2$	$\mu^2 \approx M_\Phi^2$
Φ	$\lvert 163 \pm 7\rvert^0 - \delta_\omega$	-107.	-107.
J/ψ	$\lvert 85 \pm 4\rvert^0$	-66.	**-84.**
$\psi(3686)$	(?)	-61.	-81.
Y(1S)	~ $\lvert 64\rvert^0$	-44.	-68.

M. Fukugita and J. Kwiecinski
RL-79-045

The real to imaginary ratio of the amplitude

$$F^{(n_G)}(M^2) = \frac{1}{\pi}\int_0^\infty ds \, \frac{\left(\frac{\alpha(s)}{\alpha(\mu^2)}\right)^{n_G}}{s - M^2 - \varepsilon}$$

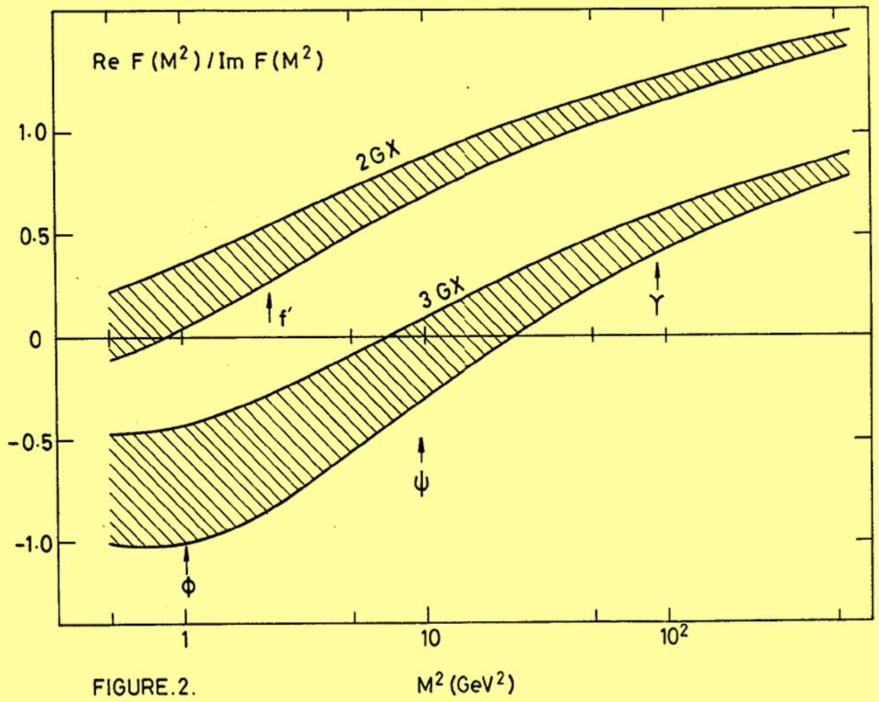


FIGURE.2.

Next To Do

- **Improve theory on $\alpha_s(s)$ imaginary part evaluation**
  ($\alpha_s(M)$ large imaginary part conflicts with unitarity ?)
- **Analyze $\psi(3686)$ scan data**
- **Get more Belle (Belle2) data in and out Y(1S) as well as hopefully Y(1S) W scan**

rúgǔo bú zhèngquè， nà jiù shì yígè bùkěsiyì dè qiǎohé

谢谢！