Strong QCD Physics from J/Ψ Decays

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1. Outstanding problems in strong QCD

2. J/Ψ radiative decays

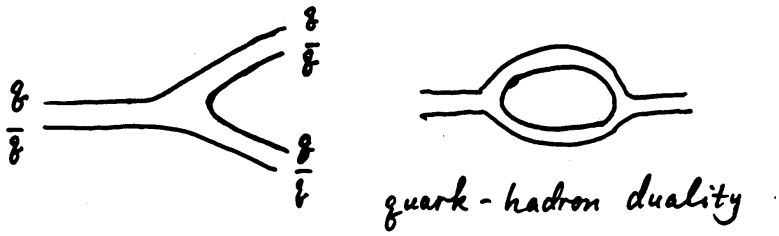
3. J/Ψ hadronic decays to mesons

4. $J/\Psi \to B \bar{B} X$

5. Concluding remarks

1. Outstanding problems in strong QCD

(1) Quark confinement



(2) Gluon degree of freedom in hadron spectroscopy

Glueballs and Hybrids

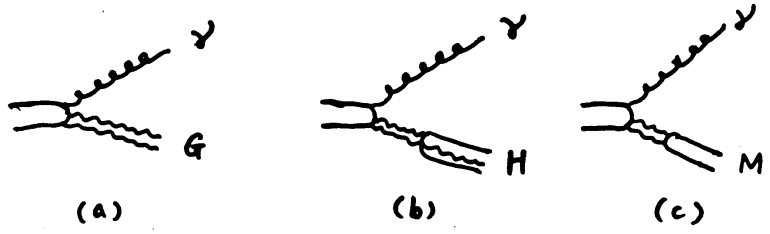
direct confirmation of non-Abelian property of QCD

(3) Quark structure of hadrons & nuclei

(4) Quantitative treatment of strong QCD

Hadron-hadron interaction,
Low-energy gluon-quark couplings

2. J/Ψ radiative decays



Three main physics objectives:

(1) Search for glueballs and Hybrids

$$\Gamma(\gamma G) > \Gamma(\gamma H) > \Gamma(\gamma M)$$

(2) Study 0.3 ~ 3 GeV light quark meson spectroscopy and their decays

crucial for identifying glueballs and understanding quark confinement

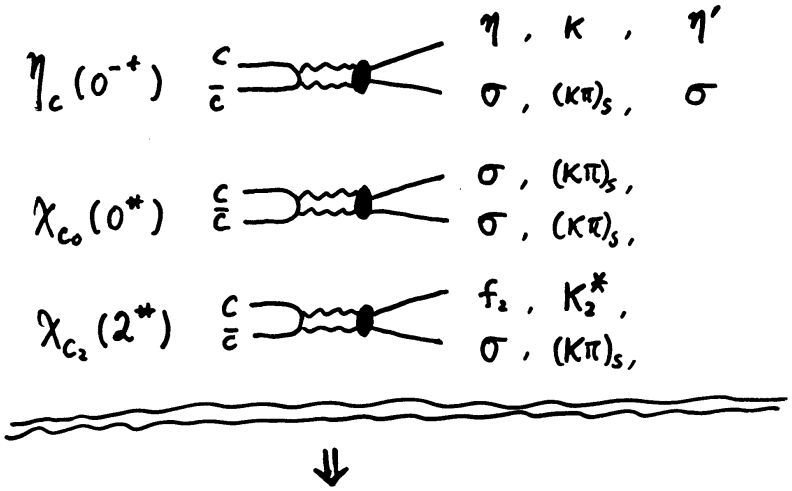
(3) Extract gg ⇔ $q\bar{q}$ couplings

3 GeV → 0.3 GeV

perturbative QCD → Strong QCD

What are favorable channels for glueball decays?

Lessons from $c\bar{c}$ decays :



$\Downarrow$

$\eta\pi\pi$, $K\bar{K}\pi$, 4π, $K\bar{K}\pi\pi$, $\eta'\pi\pi$

4 largest channels in $J/\psi \to \gamma X$!

$\sim 60\%$!

other interesting channels :

$\pi^+\pi^-$, $\pi^0\pi^0$, $K\bar{K}$, $\eta\eta$, $\eta\eta'$, $\eta'\eta'$, $p\bar{p}$

$4K$, $\gamma\rho$, $\gamma\phi$, ...

Experimental Glueball Candidates

2230 (2^{++})

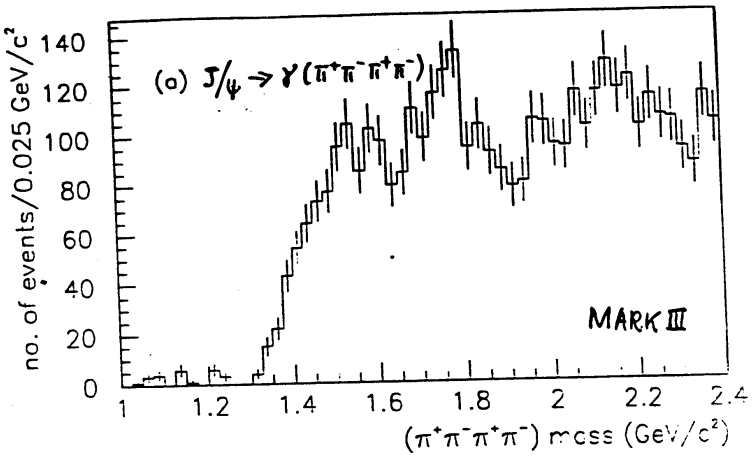
2100 (0^{++})

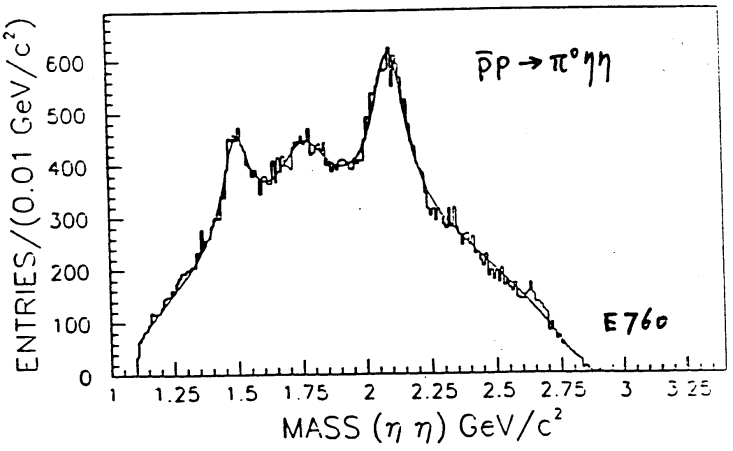
1870 (2^{-+})
1800 (0^{-+})

1690 (2^{++})

1500 (0^{++})

$(TE1)^2$ (TE1)(TM1) $(TM1)^2$


(a) $J/\psi \to \gamma(\pi^+\pi^-\pi^+\pi^-)$
MARK III
no. of events/0.025 GeV/c²
0
20
40
60
80
100
120
140
1
1.2
1.4
1.6
1.8
2
2.2
2.4
$(\pi^+\pi^-\pi^+\pi^-)$ mass (GeV/c²)


$\bar{p}p \to \pi^0\eta\eta$
E760
ENTRIES/(0.01 GeV/c²)
0
100
200
300
400
500
600
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
MASS $(\eta\,\eta)$ GeV/c²

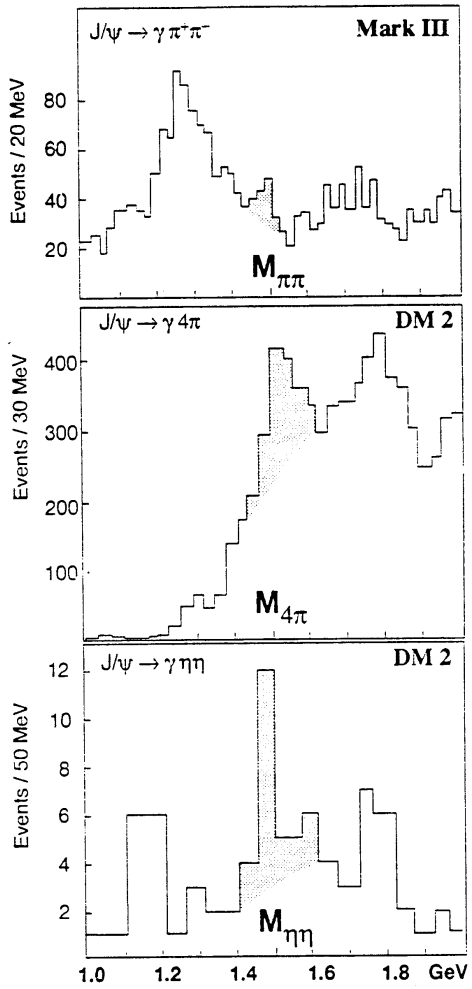


Figure 6: (a) Radiative decay $J/\psi \to \gamma\pi\pi$. Note the little peak at the high-mass side of the $f_2(1270)$. (b) Radiative decay $J/\psi \to \gamma 4\pi$ (DM2). The X(1500) has a width of 120 MeV, and—assuming decay via two $(\pi\pi)$s resonances $[J/\psi \to \gamma X$. $X \to \sigma(700)\sigma(700)]$—can be fit with spin-parity 0^{++}. (c) Radiative decay $J/\psi \to \gamma\eta\eta$. The broad structure between 1450 and 1800 MeV is most likely composed of two resonances, and the more massive one is usually associated with the $f_J/\Theta(1710)$.

MARK III : $J/\psi \to \gamma \eta \pi^+ \pi^-$

0^{-+} : $M = 1400 \pm 6$, $\Gamma = 47 \pm 13$

$BR(J/\psi \to \gamma \eta(1400)) \cdot BR(\eta(1400) \to \eta\pi\pi)$
$= (3.38 \pm 0.33 \pm 0.64) \times 10^{-4}$

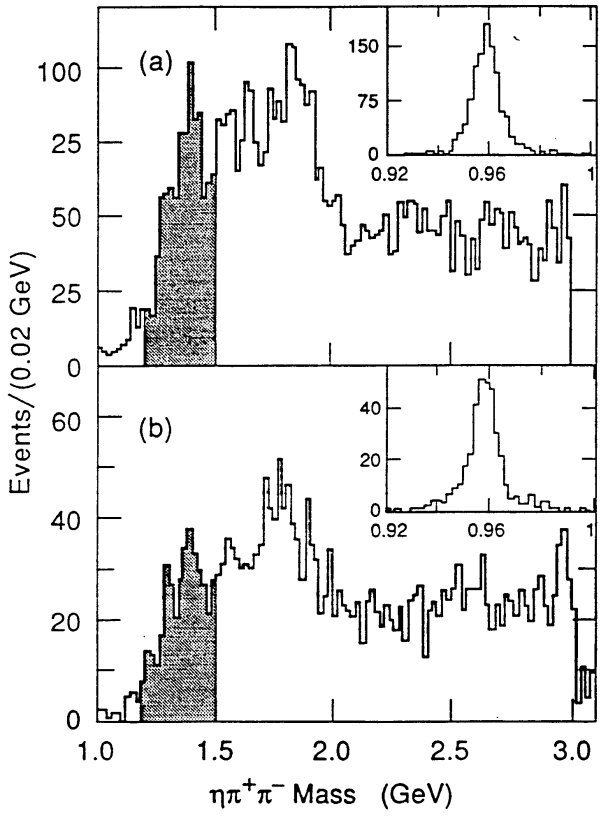
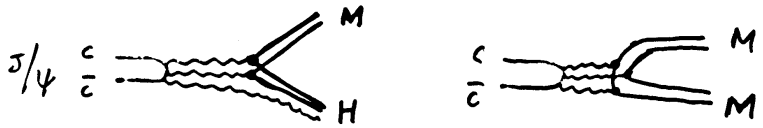


FIG. 1. The $\eta\pi^+\pi^-$ invariant mass distribution above 1 GeV for the (a) $\eta \to \gamma\gamma$ and (b) $\eta \to \pi^+\pi^-\pi^0$ channels. The shaded region is that subjected to the PWA analysis. In both channels, the mass distribution below 1 GeV is shown in the inset with 0.002-GeV bin width.

3. J/Ψ hadronic decays to mesons



(1) Search for Hybrids

BNL claimed two I=1 $J^{PC}=1^{-+}$ hybrids
$\hat{\rho}(1390) \rightarrow \pi\eta$, $\hat{\rho}(1600) \rightarrow \pi\rho$

How about $J/\Psi \rightarrow \rho\hat{\rho}$?
No obvious evidence in $J/\Psi \rightarrow \rho\eta\pi, \rho\rho\pi$

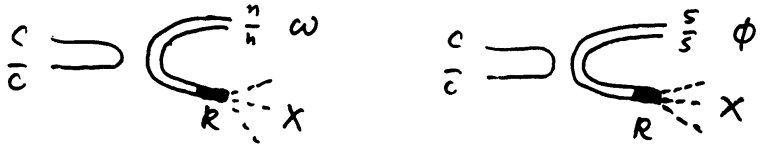
$\Rightarrow$ The channel to look for $\rho\hat{\rho}$ and $\omega\hat{\omega}$:

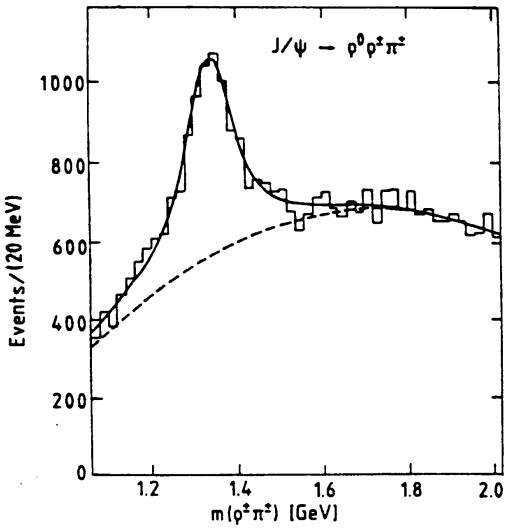
$$\underline{3(\pi^+\pi^-)\pi^0}$$

with $\hat{\rho} \rightarrow \pi b_1$ or πf_1 and $\hat{\omega} \rightarrow \pi a_1$ or $\pi\pi(1300)$

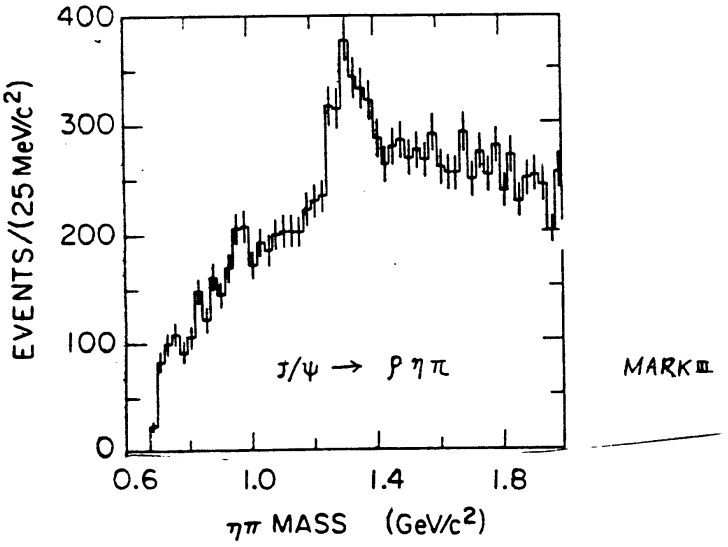
(2) $J/\Psi \rightarrow \omega X, \phi X$

$\Rightarrow n\bar{n}$, $s\bar{s}$ components of X



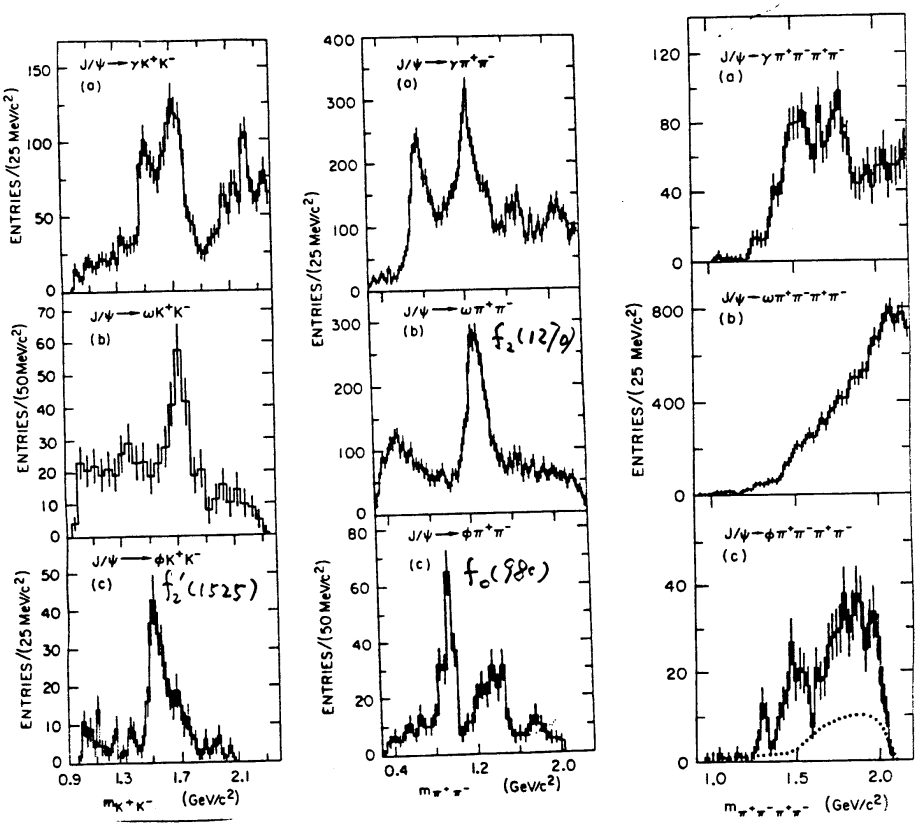

J/ψ → ρ⁰ρ±π∓
Events/(20 MeV)
1000
800
600
400
200
0
1.2
1.4
1.6
1.8
2.0
m(ρ±π∓) [GeV]

DM2


EVENTS/(25 MeV/c²)
400
300
200
100
0
J/ψ → ρ η π
0.6
1.0
1.4
1.8
ηπ MASS (GeV/c²)

MARK III

Mark III

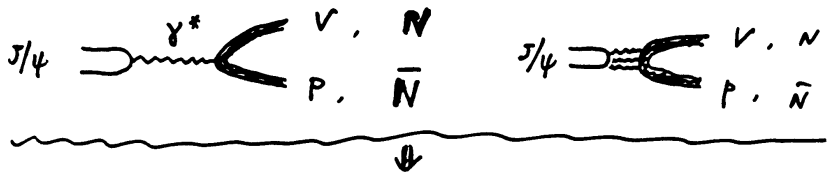

J/ψ → γK⁺K⁻
(a)
J/ψ → ωK⁺K⁻
(b)
J/ψ → φK⁺K⁻
(c)
f₂'(1525)
ENTRIES/(25 MeV/c²)
ENTRIES/(50MeV/c²)
0.9 1.3 1.7 2.1
m_K⁺K⁻ (GeV/c²)
J/ψ → γπ⁺π⁻
(a)
J/ψ → ωπ⁺π⁻
(b)
f₂(1270)
J/ψ → φπ⁺π⁻
(c)
f₀(980)
ENTRIES/(25 MeV/c²)
ENTRIES/(50 MeV/c²)
0.4 1.2 2.0
m_π⁺π⁻ (GeV/c²)
J/ψ → γπ⁺π⁻π⁺π⁻
(a)
J/ψ → ωπ⁺π⁻π⁺π⁻
(b)
J/ψ → φπ⁺π⁻π⁺π⁻
(c)
ENTRIES/(25 MeV/c²)
1.0 1.5 2.0
m_π⁺π⁻π⁺π⁻ (GeV/c²)

(3) Hadron-Hadron interaction at 3.1 GeV

$\sqrt{s} \geq 5$ GeV : Regge Model

$\sqrt{s} \leq 2$ GeV : One Particle Exchange

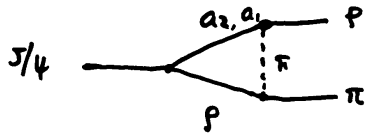
$2 \leq \sqrt{s} \leq 5$ GeV : ?

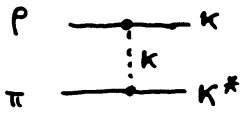


$$|\delta_{\gamma\pi} - \delta_{3g}| \sim 80^\circ$$

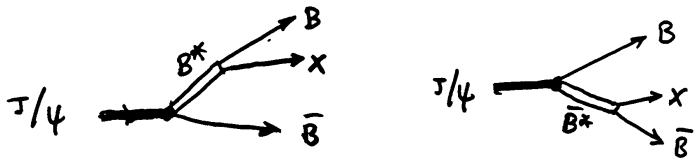
(Suzuki @ LBL) & FENICE Exp.

FSI very important !





4. $J/\Psi \rightarrow B\,\bar{B}\,X$



N^* and Hyperon physics
$\Rightarrow$ quark structure of baryons

CEBAF @ JLAB	ELSA@Bonn
ep, eA: 4-10 GeV	1-3.5 GeV

$\gamma p \rightarrow \gamma p, \pi^0 p, \eta p, \pi^+ n, \pi^0\pi^0 p, K\Lambda, K\Sigma, \ldots$

GRAAL @ Grenoble, MAMI @ Mainz
$\gamma p \rightarrow \ldots$

Crystal Ball @ Brookhaven:
AGS E913: $\pi^- p \rightarrow \gamma n, \pi^0 n, \eta n, \pi^0\pi^0 n$

N^* Physics

N(1440) : the lowest radial excitation state?

N(1535) : the lowest L=1 excitation state?

Missing N^* states → ωN, η′N, ππN, …

Interesting channels in J/Ψ decays:

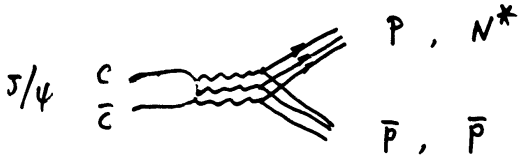
$p\bar{n}\pi^-$: $(2.0\pm0.1)\times10^{-3}$, $N^* \rightarrow \pi N$
$p\bar{p}\pi^0$: $(1.1\pm0.1)\times10^{-3}$, $N^* \rightarrow \pi N$
$p\bar{p}\pi^+\pi^-$: $(6.0\pm0.5)\times10^{-3}$, $N^* \rightarrow \pi\pi N$
$p\bar{p}\eta$: $(2.1\pm0.2)\times10^{-3}$, $N^* \rightarrow \eta N$
$p\bar{p}\eta'$: $(0.9\pm0.4)\times10^{-3}$, $N^* \rightarrow \eta' N$
$p\bar{p}\omega$: $(1.3\pm0.3)\times10^{-3}$, $N^* \rightarrow \omega N$

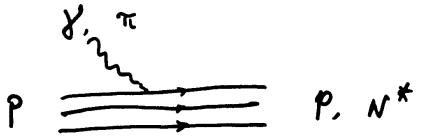
Advantages of N^* Physics from J/Ψ decays:

1) **Little I=3/2 contamination $\Rightarrow$ better determination of branching ratios, mass and width of N^* resonances.**

2) **Interference between N^* and $\overline{N}^*$ bands on Dalitz plots $\Rightarrow$ better determination of J^{PC}.**

3) **$J/\Psi \rightarrow NN^*$ couplings provides a new way to study quark structure of N^*.**





Interesting hyperon channels from J/Ψ decays:

$\Lambda \Sigma^- \pi^+ + c.c.$ $\quad (1.06 \pm 0.12) \times 10^{-3}$

$p K^- \bar{\Lambda}$ $\quad (0.89 \pm 0.16) \times 10^{-3}$

$p K^- \bar{\Sigma}^0$, $\Lambda \bar{\Lambda} \pi^0$, $\bar{p} p K^+ K^-$, $\Sigma^+ \bar{p} K^+ \pi^-$, ...

Hyperon spectroscopy, KN, $\pi\Lambda$, $\pi\Sigma$, $K\Lambda$, $p\bar{\Lambda}$ ... interactions

SU(3) quark model, Meson-exchange theory.

$N^* \to K\Lambda$, $K\Sigma$, ...

5. Concluding remarks

J/Ψ decay has advantages in studying glueballs, hybrids, quark structure of mesons and baryons, comparing with other experiments.
It can play a major unique role in strong QCD physics.

Higher statistics $10^9 \sim 10^{10}$ is needed.