# Strong QCD Physics from J/Ψ Decays

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**1. Outstanding problems in strong QCD**

**2. J/Ψ radiative decays**

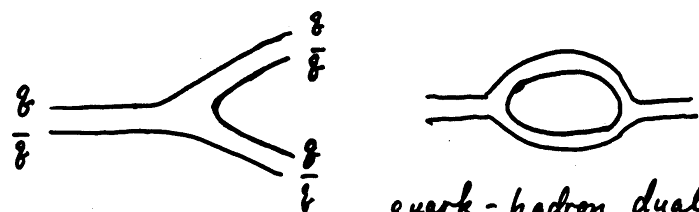
**3. J/Ψ hadronic decays to mesons**

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

**5. Concluding remarks**

# 1. Outstanding problems in strong QCD

## (1) Quark confinement



*quark - hadron duality*

## (2) Gluon degree of freedom in hadron spectroscopy

Glueballs and Hybrids

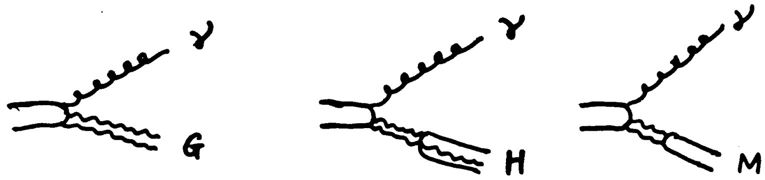
*direct confirmation of non-Abelian property of QCD*

## (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




(a) (b) (c)

**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

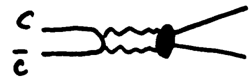
**(3) Extract gg ⇔ $q\bar{q}$ couplings**

3 GeV ⟶ 0.3 GeV

perturbative QCD ⟶ strong QCD

## What are favorable channels for glueball decays?

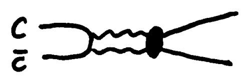
Lessons from $c\bar{c}$ decays :

$\eta_c(0^{-+})$ 

$\eta$ , $K$ , $\eta'$
$\sigma$ , $(K\pi)_s$ , $\sigma$

$\chi_{c0}(0^{++})$ 

$\sigma$ , $(K\pi)_s$ ,
$\sigma$ , $(K\pi)_s$ ,

$\chi_{c2}(2^{++})$ 

$f_2$ , $K_2^*$ ,
$\sigma$ , $(K\pi)_s$ ,

⇓

<u>$\eta\pi\pi$, $K\bar{K}\pi$, $4\pi$ , $K\bar{K}\pi\pi$,</u> $\eta'\pi\pi$

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 ($0^{++}$)

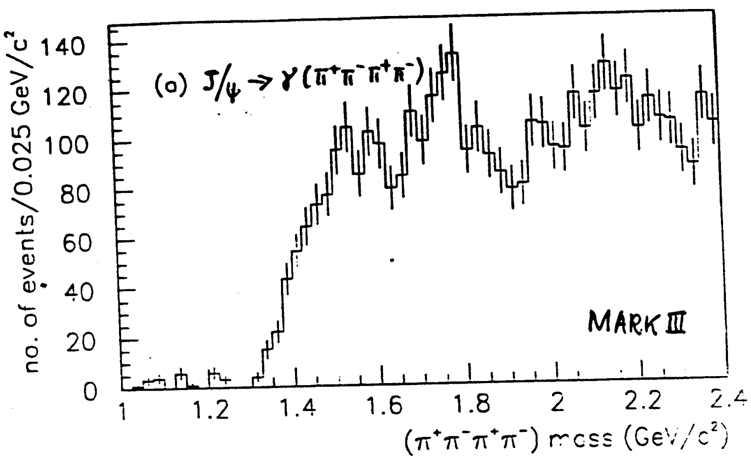
1870 ($2^{-+}$)

1800 ($0^{-+}$)

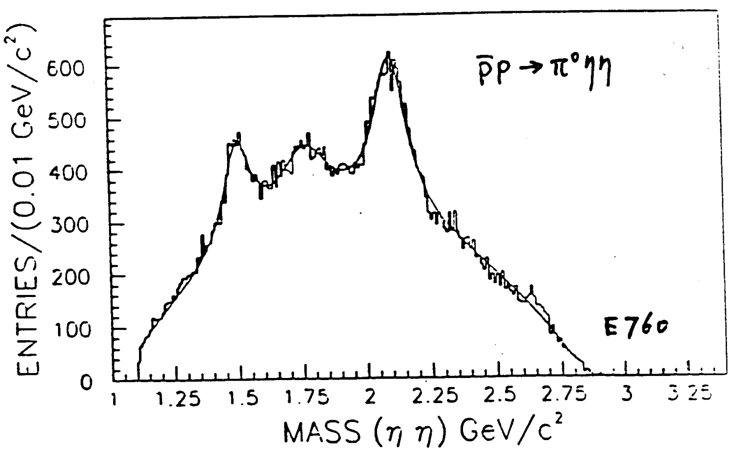
1690 ($2^{++}$)

1500 ($0^{++}$)

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



no. of events/0.025 GeV/c²
(a) J/ψ → γ(π⁺π⁻π⁺π⁻)
MARK III
(π⁺π⁻π⁺π⁻) mass (GeV/c²)

ENTRIES/(0.01 GeV/c²)
p̄p → π°ηη
E760
MASS (η η) GeV/c²

7

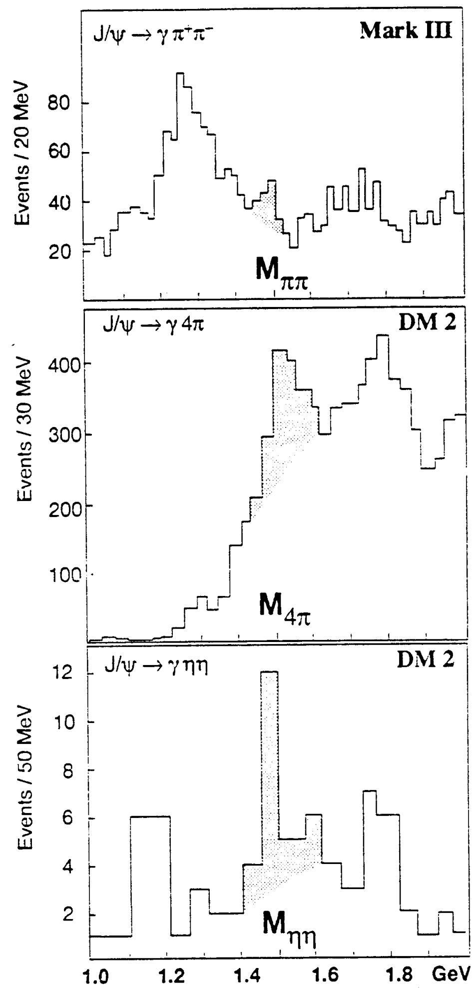



Figure 6: (a) Radiative decay $J/\psi \rightarrow \gamma\pi\pi$. Note the little peak at the high-mass side of the $f_2(1270)$. (b) Radiative decay $J/\psi \rightarrow \gamma 4\pi$ (DM2). The X(1500) has a width of 120 MeV, and—assuming decay via two $(\pi\pi)$s resonances [$J/\psi \rightarrow \gamma X$, $X \rightarrow \sigma(700)\sigma(700)$]—can be fit with spin-parity $0^+$. (c) Radiative decay $J/\psi \rightarrow \gamma\eta\eta$. 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 : $J/\psi \to \gamma \eta \pi^+ \pi^-$ ⑨

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

$BR(J/\psi \to \gamma \eta(1400)) \cdot BR(\eta(1400) \to \eta\pi\pi)$

$= (3.38 \pm 0.33 \pm 0.64) \times 10^{-4}$

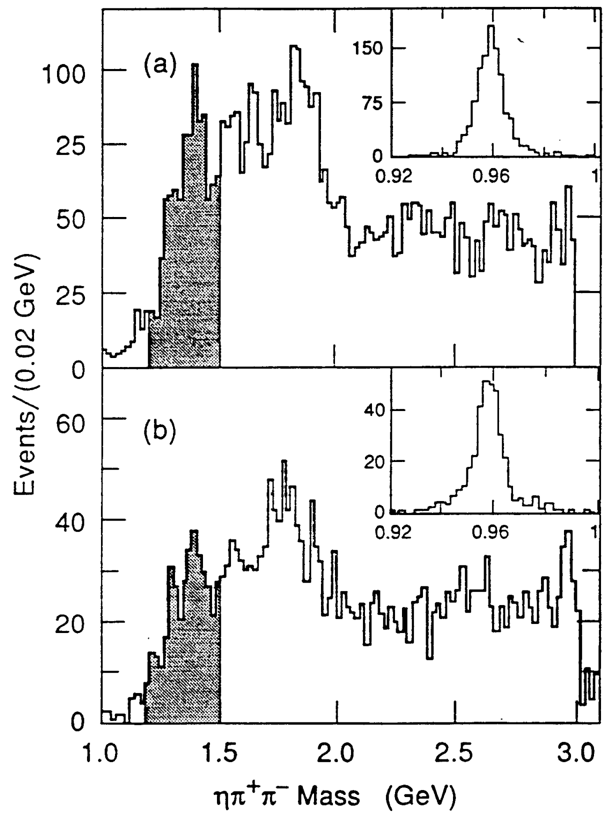
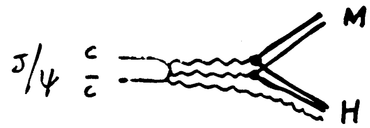
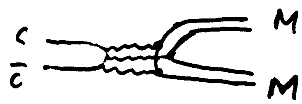



FIG. 1. The $\eta\pi^+\pi^-$ invariant mass distribution above 1 GeV for the (a) $\eta \to \gamma\gamma$ and (b) $\eta \to \pi^+\pi^-\pi^0$ channels. The shaded region is that subjected to the PWA analysis. In both channels, the mass distribution below 1 GeV is shown in the inset with 0.002-GeV bin width.

# 3. J/Ψ hadronic decays to mesons




## (1) Search for Hybrids

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

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

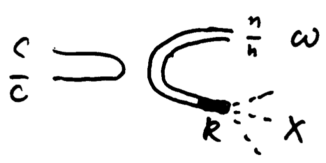
**⇒ The channel to look for $\rho\hat{\rho}$ and $\omega\hat{\omega}$ :**

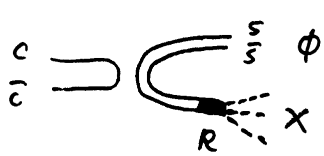
**$\underline{3(\pi^+\pi^-)\pi^0}$**

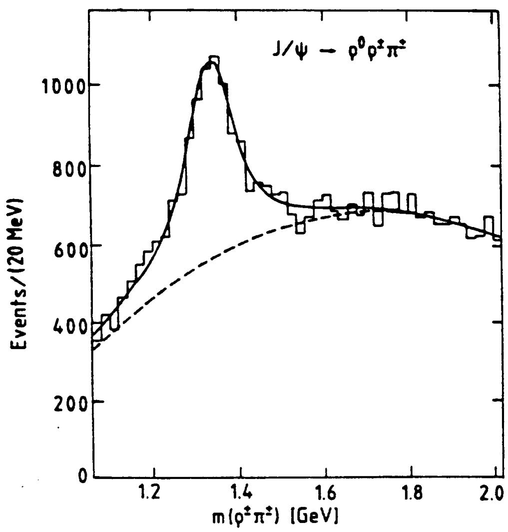
**with $\hat{\rho} \to \pi b_1$ or $\pi f_1$ and $\hat{\omega} \to \pi a_1$ or $\pi\pi(1300)$**

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

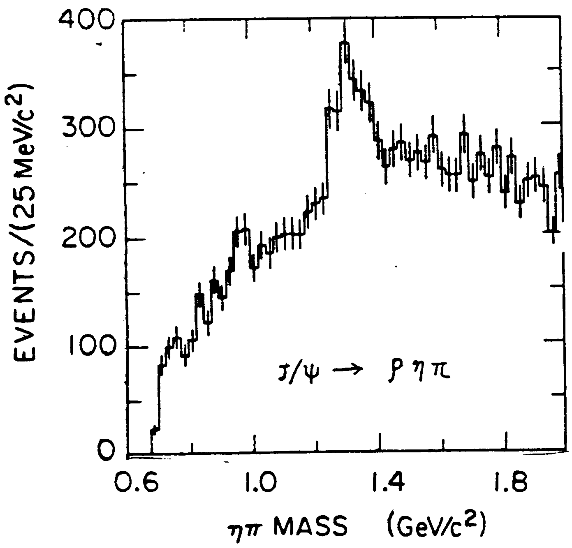
**⇒ $n\bar{n}$, $s\bar{s}$ components of X**



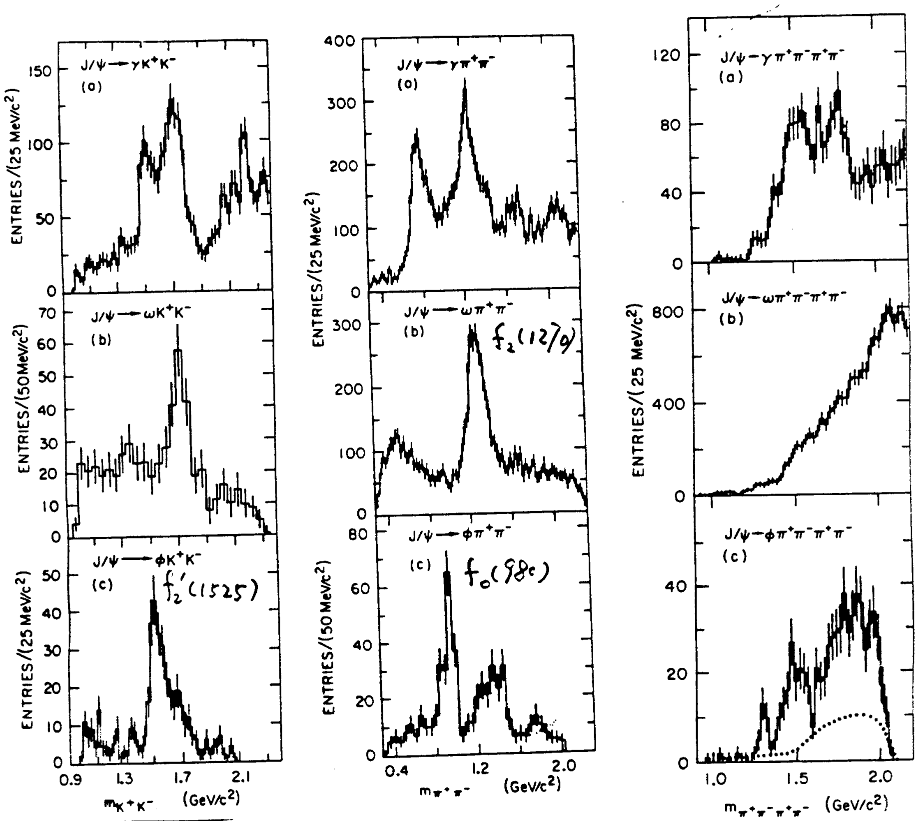

J/ψ → ρ⁰ρ±π∓
Events/(20 MeV)
m(ρ±π∓) [GeV]
1000
800
600
400
200
0
1.2
1.4
1.6
1.8
2.0

DM2


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

MARK III

Mark III

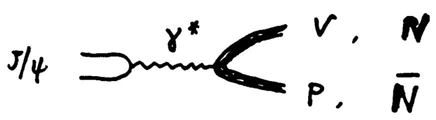

J/ψ → γK⁺K⁻
(a)
J/ψ → ωK⁺K⁻
(b)
J/ψ → φK⁺K⁻
(c)
f₂′(1525)
ENTRIES/(25 MeV/c²)
ENTRIES/(50 MeV/c²)
m K⁺K⁻ (GeV/c²)
J/ψ → γπ⁺π⁻
(a)
J/ψ → ωπ⁺π⁻
(b)
f₂(1270)
J/ψ → φπ⁺π⁻
(c)
f₀(980)
m π⁺π⁻ (GeV/c²)
J/ψ → γπ⁺π⁻π⁺π⁻
(a)
J/ψ → ωπ⁺π⁻π⁺π⁻
(b)
J/ψ → φπ⁺π⁻π⁺π⁻
(c)
m π⁺π⁻π⁺π⁻ (GeV/c²)

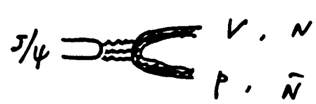
(3) Hadron-Hadron interaction at 3.1 GeV

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

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

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



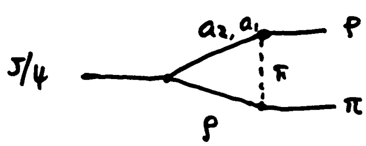



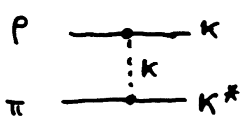

⇓

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

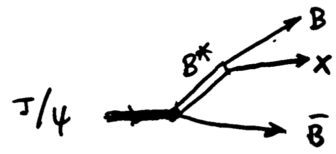
(Suzuki @ LBL) & FENICE Exp.

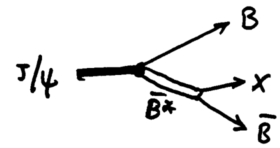
FSI very important !



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




**$N^*$ and Hyperon physics**
**⇒ 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?**

$M = 1430 \sim 1470$, $\Gamma = 250 \sim$ [illegible] MeV,
$\pi N \approx 60 \sim 70\%$, $\pi\pi N$: $30 \sim 40\%$.

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

$M = 15$[illegible]$\sim 1555$, $\Gamma = 100 \sim 250$ [illegible]
$\pi N$: $35 \sim 55\%$, $\eta N$: $30 \sim 55\%$.

**Missing $N^*$ states → ωN, η′N, ππN, …**

**Interesting channels in J/Ψ decays:**

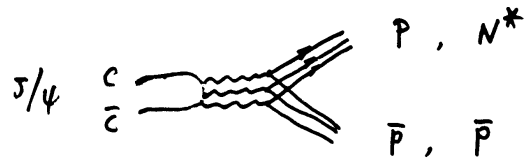
**$p\bar{n}\pi^-$: $(2.0\pm0.1)\times10^{-3}$ , $N^* \rightarrow \pi N$**
**$p\bar{p}\pi^0$: $(1.1\pm0.1)\times10^{-3}$ , $N^* \rightarrow \pi N$**
**$p\bar{p}\pi^+\pi^-$: $(6.0\pm0.5)\times10^{-3}$ , $N^* \rightarrow \pi\pi N$**
**$p\bar{p}\eta$: $(2.1\pm0.2)\times10^{-3}$ , $N^* \rightarrow \eta N$**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

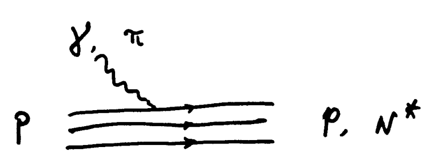
**Advantages of $N^*$ Physics from $J/\Psi$ decays:**

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

**2) Interference between $N^*$ and $\overline{N}^*$ bands on Dalitz plots ⇒ 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. $(1.06 \pm 0.12) \times 10^{-3}$

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

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

⇓

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.**