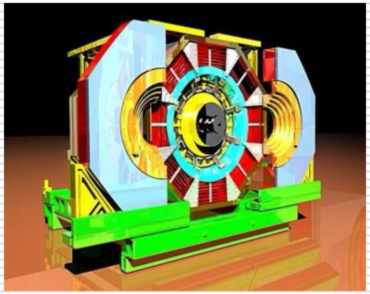
Baryons strike back in BESIII

Evidence for a new $2g1\gamma_{virtual}$ charmonium decay ?

K.Zhu[a], J.Bian[b], P.Wang[a], F.Harris[c]

R.BaldiniFerroli[d], M.Destefanis[e], M.Maggiora[e], G.Mezzadri[f], S.Pacetti[g], L.Yan[e]

a. Institute of High Energy Physics, IHEP, Beijing, China
b. University of Minnesota, USA
c. Haway University, Manoa Honolulu, USA
d. INFN, LNF, Frascati, Italy and Institute of High Energy Physics, Beijing, China
e. INFN and University Torino, Italy
f. INFN and University Ferrara, Italy
g. INFN and University Perugia, Italy



Why to understand Baryons is important

- Visible mass in the Universe is due essentially to the strong force binding quarks inside the Nucleon

- Many Meson features come from QED->QCD, once $\alpha \rightarrow \alpha_S$
  Baryons: no analogue in QED and unique QCD feature

  - But why Baryon Skyrme model (no q, π's soliton) so successful ?
    Baryons really fully understood ?

- Vector charmonium, $^3S_1$, and BB_{bar} linked: 3 gluons -> 3 qq_{bar} pairs
  - $^3S_1$ -> BBbar fully understood ?
  - Not the angular distributions $1+\alpha\cos^2\theta$:
    why α change sign in J/ψ or $\psi(3686) \rightarrow \Lambda\Lambda / \Sigma\Sigma$?

why $\alpha_p \neq \alpha_n$, while $B_p \sim B_n$, in ψ (3686) -> NN_{bar} ?

$\Psi(3686) \to NN_{bar}$ Branching Ratios

- $\sim$ 23400 pp_{bar} and 2650 nn_{bar} events have been selected, obtaining
  $B[\psi(3686) \to pp_{bar}] = (3.06 \pm 0.02 \pm 0.13) \cdot 10^{-4}$,
  $B[\psi(3686) \to nn_{bar}] = (3.09 \pm 0.06 \pm 0.14) \cdot 10^{-4}$.

- The close B values, within small errors, would suggest interference between strong and em decay is small (positive in the pp_{bar} and negative in the nn_{bar} decay), i.e. their relative phase $\phi \sim 90^0$.

- In the case of $J/\psi \to NN_{bar}$, close B values were also achieved :
  $B[J/\psi \to pp_{bar}] = (2.112 \pm 0.004 \pm 0.031) \cdot 10^{-3}$,
  $B[J/\psi \to nn_{bar}] = (2.07 \pm 0.01 \pm 0.17) \cdot 10^{-3}$.

- So far, so good. Up to a certain point.

$\Psi(3686) \to N N_{bar}$ Angular Distributions

- Fitting ψ**(3686)** -> NN_{bar} with $1+\alpha \cos^2 \theta$:

  $\boldsymbol{\alpha_p = 1.03 \pm 0.06 \pm 0.03}$ **,** $\boldsymbol{\alpha_n = 0.47 \pm 0.15 \pm 0.15}$

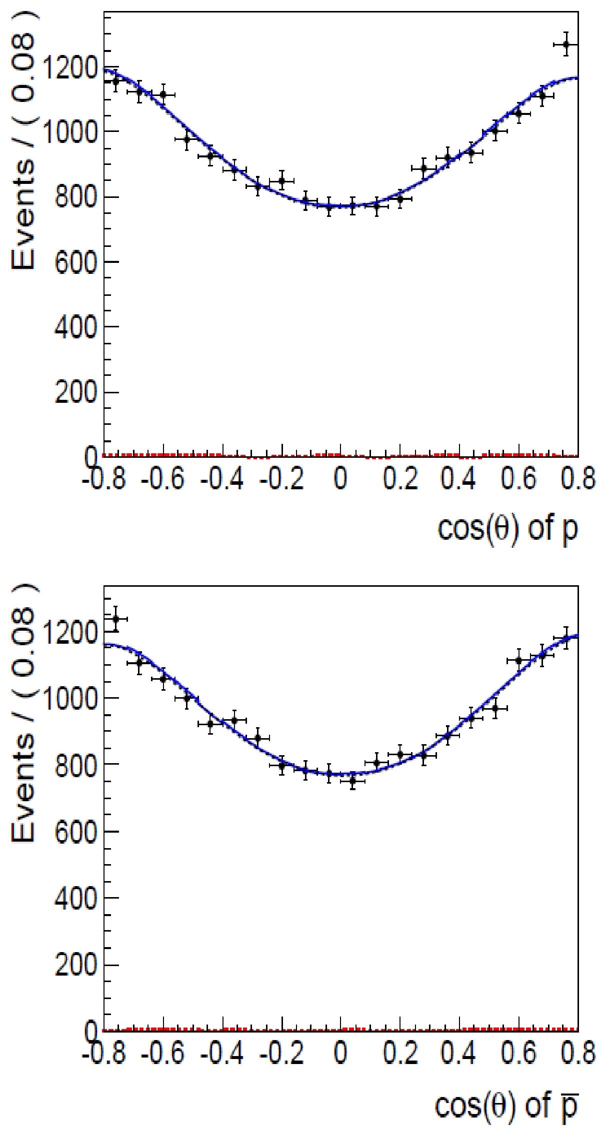
  - **i.e. pp_{bar} and nn_{bar} angular distribution are quite different, in spite of similar B.**
  - **Furthermore α_p is close to the limit $|\alpha_p| \le 1$.**
  - No evidence of a $\cos \theta$ term, i.e. no forward/backward asymmetry.

- Conversely, in the case of **J/ψ** -> NN_{bar} it was obtained:

  $\boldsymbol{\alpha_p = 0.595 \pm 0.012 \pm 0.015}$ **,** $\boldsymbol{\alpha_n = 0.50 \pm 0.04 \pm 0.21}$

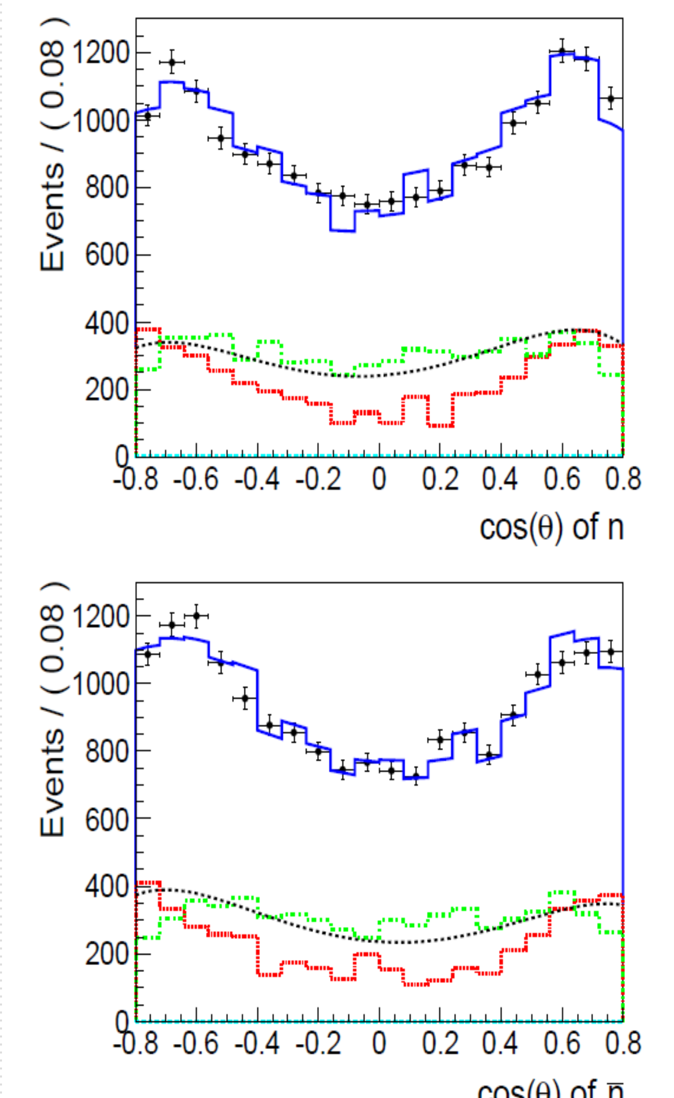
  consistent with a phase, between strong and em decay, $\phi \sim 90^0$.

$\Psi(3686) \to pp_{bar}$ Angular Distribution



. Fit to $\cos(\theta)$ of p and $\bar{p}$ with the formula $N_{sig}[(1 + \alpha\cos^2(\theta)]\epsilon(\theta) + N_{bg}f_{bg}$. The top one is of p, the bottom one is of $\bar{p}$. The error bars are data, the solid blue lines are the fit curves, the dashed red lines at the bottom of each plot are the backgrounds.

$\Psi(3686)$ ->nn_{bar} Angular Distribution



Separated fits to $\cos\theta$ distributions of n and $\bar{n}$. The data is shown in error bars. The fitted result is shown in solid blue curve. The signal shape is from the formula $(1+\alpha\cos^2\theta)\epsilon(\theta)$, and is drawn on the plot in dashed black curve. Backgrounds are described by three components: shapes from continuum in dotted red, inclusive MC in dash-dotted green, and tiny contribution from $\psi' \to \gamma\chi_{cJ}, \chi_{cJ} \to n\bar{n}$ (not included in inclusive MC) in long-dashed cyan. All the amplitudes are fixed to the results from the fit to $\theta_{\rm open}$, only the variable of α is floating in the fit.

Magnetic B_M and Electric B_E Branching Ratios

- In e^+e^- annihilation the FF squared $|G_M|^2$ and $|G_E|^2$ are defined:
  - $d\sigma(e^+e^- \to BB_{bar})/d\cos\theta \sim [|G_M|^2(1+\cos^2\theta)+4(M_B/W)^2|G_E|^2\sin^2\theta]$
  - $\sigma(e^+e^- \to BB_{bar}) \sim [|G_M|^2+2(M_B/W)^2|G_E|^2]$

- Accordingly, in a Vector Meson V decay B_M and B_E can be defined:
  - $B(V \to Bb_{bar}) = B_M + \tau \cdot B_E$, $\tau = 2\cdot[M_N/M\psi`]^2 \sim 0.13$
  - $d\sigma(V \to BB_{bar})/d\cos\theta \sim B\cdot[1+\alpha\cdot\cos^2\theta]$

    $\alpha = [B_M - 2\cdot\tau\cdot B_E]/[B_M + 2\cdot\tau\cdot B_E]$ (by def. $|\alpha| \leq 1$).

  - τ small -> B_E small effect on B
  - B and α -> B_M and B_E

Magnetic B_M and Electric B_E Branching Ratios

- **Toy MC to evaluate B_M and B_E errors from B and α:**
  Statistical and systematic errors added in quadrature

  $B_M[\psi(3686)\to n n_{bar}] = (2.60 \pm 0.26)\cdot 10^{-4}$,

  $B_E[\psi(3686)\to n n_{bar}] = (3.77 \pm 1.74)\cdot 10^{-4}$.

- In the pp_{bar} case, to avoid unphysical values, toy MC gaussian error simulation rejected any time $|\alpha_p| > 1$:

  $B_M[\psi(3686)\to p p_{bar}] = (3.02 \pm 0.13)\cdot 10^{-4}$,

  $B_E[\psi(3686)\to p p_{bar}] = (0.28 \pm 0.23)\cdot 10^{-4}$.

- Or, even better, simulating $0.95 \le \alpha_p \le 1$ with 68% probability, according to a Bayes approach:

  $B_M[\psi(3686)\to p p_{bar}] = (3.02 \pm 0.13)\cdot 10^{-4}$,

  $B_E[\psi(3686)\to p p_{bar}] = (0.24 \pm 0.18)\cdot 10^{-4}$.

Phases between Strong and EM decays

- PQCD: asymptotically B_E/B_M -> 0, due to helicity conservation.
  But it cannot be the explanation of $\psi(3686)$ B_E behaviour, since it should be the same for pp_{bar} and nn_{bar} .

- Let exploit a possible interference between strong and em decay, assuming it is not the same for pp_{bar} and nn_{bar} .
  - Unfortunately the continuum $e^+e^- \to pp_{bar}$ is poorly measured at W ~ 3.68 GeV and there are poor information on $|G_E/G_M|$.
  - BaBar and BESIII: $\sigma(e^+e^- \to pp_{bar}) \sim (1.6 \pm 0.5)$ pb at W~3.68 GeV
    $B_E/B_M \sim 1$ within a large uncertainty
    (arXiv:1302.0055[hep-ex]1Feb2013 , X.Zhu thesis)
  - Lacking any information, assume the same for $e^+e^- \to nn_{bar}$
  - Therefore $B_{em} = B[\psi(3686) \to \mu\mu]/\sigma(e^+e^- \to \mu\mu) \cdot \sigma(e^+e^- \to NN_{bar}) \sim 2 \cdot 10^{-6}$

For pp_{bar} and nn_{bar} assume: $B_M \sim B_E \sim B_{em}$

Phases between Strong and EM decays

- Connecting pp_{bar} and nn_{bar} , it is assumed:
  - $B_M^p = |S_M \cdot e^{i\phi} + E_M^p|^2 = |S_M|^2 + |E_M^p|^2 + 2 \cdot |S_M| \cdot |E_m^p| \cdot \cos\phi$
  - $B_M^n = |S_M \cdot e^{i\phi} + E_M^n|^2 = |S_M|^2 + |E_M^n|^2 - 2 \cdot |S_M| \cdot |E_m^n| \cdot \cos\phi$
  - Opposite sign in the interference term comes from opposite E_M sign

The two equations with two unknown (S_M and $\cos\phi$) can be solved.

Fluctuating B_M and E_M within the quoted errors, it is found:

$S_M^2 = 2.79 \pm 0.15$, $\phi_M = 63^0 \pm 19^0$

$S_M^2 > 0$, $|\cos\phi| < 1$: 94% C.L.

Results consistent with the expectation.

A better ϕ measurement requires a better continuum knowledge that is a scan below and at $\psi(3686)$!

A G parity violating Amplitude in $\psi(3686) \to pp_{bar}$?

- **No chance to find a solution for pp_{bar} Electric decay, B_E^p : 0.2% C.L. to have $S_E^2 > 0$, $|\cos\phi| < 1$.**

- Therefore, additional to the strong amplitude S, it is assumed a G parity Violating Amplitude $\underline{T}$ in $B_E[\psi(3686) \to pp_{bar}]$, that is added to S negatively, to explain vanishing B_E in pp_{bar} , while there will be S only in B_E in nn_{bar} .

- In the following this assumption will be exploited, trying to determine T and the consistency of this approach

A G parity violating Amplitude in $\psi(3686) \to p p_{bar}$?

- Still assuming E^n and E^p have opposite signs,
  em decays may interfere negatively too
  or don't, as in the B_M case
  however T values achieved are the same, within the errors

- $\phi = 180^0$

$$\sqrt{B_E^n} = S^n + |E^n| \quad , \quad \sqrt{B_E^p} = S^p + |E^p| ,$$

$$S^p = S^n + T$$

$$T = \sqrt{B_E^p} - \sqrt{B_E^n} - (|E^p| - |E^n|) \qquad (< 0)$$

or

○ $\phi = 90^0$

$$B_E^n = |S^n|^2 + |E^n|^2 \ , \ B_E^p = |S^p|^2 + |E^p|^2 ,$$

$$S^p = S^n + T$$

$$T = \sqrt{(B_E^p - |E^p|^2)} - \sqrt{(B_E^n - |E^n|^2)} \qquad (< 0)$$

A G parity violating Amplitude in $\psi(3686) \to p\bar{p}$?

- Systematic errors in B^p and in B^n are partially correlated, so in the following statistical errors only are considered, extracting T from B_E^p and B_E^n :

  $B_E [\psi(3686) \to n\bar{n}] = (3.69 \pm 1.20) \cdot 10^{-4}$,

  $B_E [\psi(3686) \to p\bar{p}] = (0.22 \pm 0.16) \cdot 10^{-4}$

- Therefore

  $|\tau T^2| \sim (2.7 \pm 1.0) \cdot 10^{-5}$ at the $\psi(3686)$

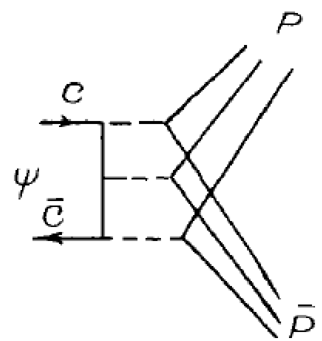
  - 99.9 % C.L. that $\tau T^2 < 0$
  - **90. % C.L.** that **$\tau T^2 > 0.8 \cdot 10^{-5}$** **(in comparison $B^p \sim 3 \cdot 10^{-4}$)**

A further Strong Amplitude in $J/\psi \to p\bar{p}$ too ?

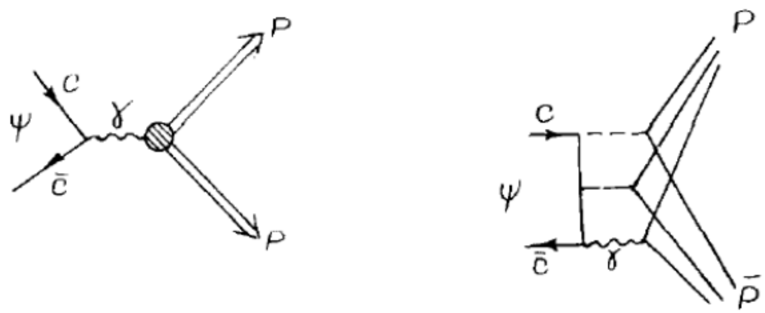
- $\tau = 2\cdot[M_N/M_{J/\psi}]^2 \sim 0.18$
  Statistical and systematic errors still added in quadrature
  - $B_M[J/\psi \to n\bar{n}] = (17.6\pm2.0)\cdot10^{-4}$,
    $B_E[J/\psi \to n\bar{n}] = (16.7\pm7.8)\cdot10^{-4}$.
    $B_M[J/\psi \to p\bar{p}] = (18.7\pm0.3)\cdot10^{-4}$,
    $B_E[J/\psi \to p\bar{p}] = (13.0\pm0.7)\cdot10^{-4}$.
  - $S_M^2 = 17.6\pm1.0$, $\phi_M = 84.7^0 \pm 9.5^0$,
    $S_E^2 = 14.2\pm3.9$, $\phi_E = 100.8^0 \pm 32.2^0$
  - $|\tau T^2| \sim (0.9 \pm 3.4)\cdot 10^{-5}$ at the J/ψ
- S_E too big to extract the G parity Violating Amplitude, if any

$\psi(3686)\text{->}pp_{bar}$ decay via $2g1\gamma_{virtual}$

- A contribution from $\psi(3686)\text{->}\ 2g1\gamma_{virt}\ \text{->}NN_{bar}$ is expected.



The strong interaction contribution into the decay $^3S_1 \rightarrow \bar{p}p$.



1 . The electromagnetic contributions into the decays $^3S_1 \rightarrow \bar{p}p, \bar{n}n$.

$\psi(3686) \to pp_{bar}$ decay via $2g1\gamma_{virtual}$

- There will be 3 amplitudes, where the virtual γ will produce alternatively one of the 3 possible qq_{bar} pairs, inside NN_{bar}. Each amplitude will be proportional to the charge of the corresponding q, so that, adding the 3 amplitudes, the total will be proportional to the Baryon charge.

- Therefore the **contribution to nn_{bar} will vanish.** While the **contribution to pp_{bar} should be negative**.

- Conversely in the case of **a negative Baryon, like Σ^-**, $2g1\gamma_{virt}$ **contribution should interferes positively**, increasing B_E in pp_{bar} with respect to nn_{bar} .
It has to be evaluated.

- Since the $2g1\gamma_{virt}$ amplitude is small, it is difficult to check if contributes to B_M too

$\psi(3686)\to p\bar{p}$ decay via $2g1\gamma_{virtual}$

- S. Pacetti (BESIII 2015 Coll. Meeting, Shanghai Jiao Tong Un, June) has already discussed the $2g1\gamma_{virtual}$ contribution, showing the experimental evidence, according the present data on $J/\psi \to \pi\pi$ decay and $e^+e^- \to \pi\pi$, close to J/ψ :

$$\mathbf{B(J/\psi \to 2g1\gamma_{virt} \to \pi\pi) \sim 10^{-4},}$$
$$\mathbf{B(\psi(3686) \to 2g1\gamma_{virt} \to \pi\pi) \sim 0.5 \cdot 10^{-5},}$$

and a quantitative successful **model:** $\gamma_{virt} \leftarrow \eta' \to \pi\pi$.

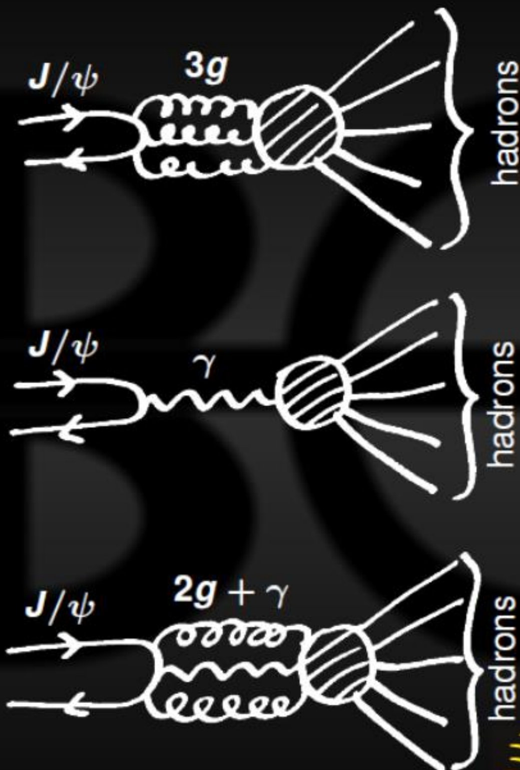
- The order of magnitude of the present result is close:

$$\mathbf{B(\psi' \to 2g1\gamma_{virt} \to NN_{bar}) \sim (2.7 \pm 1.0) \cdot 10^{-5}}$$

$$\mathbf{B(\psi' \to 2g1\gamma_{virt} \to NN_{bar})/B(\psi' \to 3g \to NN_{bar}) \sim 0.09 \pm 0.03}$$

Simone Pacetti
(BESIII 2015 Coll. Meeting, Shanghai Jiao Tong Un, June)

What is missing?



$$\mathcal{B}(J/\psi \to 3g) = \alpha_s^3(M_{J/\psi}) \frac{|\psi(0)|^2 D_{\rm QCD}}{\Gamma_{J/\psi}}$$

$$\mathcal{B}(J/\psi \to \mu^+\mu^-) = \alpha^2 \frac{|\psi(0)|^2 D'_{\rm QCD}}{\Gamma_{J/\psi}}$$

$$\mathcal{B}(J/\psi \to 2g+\gamma) = \alpha_s^2(M_{J/\psi})\alpha \frac{|\psi(0)|^2 D''_{\rm QCD}}{\Gamma_{J/\psi}}$$

Strong *G*-parity violation?

BESIII 2015 Summer Collaboration Meeting - SJTU Shanghai

Simone Pacetti

(BESIII 2015 Coll. Meeting, Shanghai Jiao Tong Un, June)

DECAYS OF J/ψ AND $\psi(2S)$ INTO $\pi^+\pi^-$

$M \to \pi^+\pi^-$	$\sigma(e^+e^- \to \pi^+\pi^-)$ (nb)	$\mathcal{B}_\gamma(M \to \pi^+\pi^-)$	$\mathcal{B}_{\text{PDG}}(M \to \pi^+\pi^-)$
$M = J/\psi$	$(9 \pm 3)\times 10^{-3}$ at $\sqrt{q^2} = 3$ GeV	$(0.54 \pm 0.18)\times 10^{-4}$	$(1.47 \pm 0.14)\times 10^{-4}$
$M = \psi(2S)$	$(2.4 \pm 0.8)\times 10^{-3}$ at $\sqrt{q^2} = M_{\psi(2S)}$	$(2.2 \pm 0.7)\times 10^{-6}$	$(7.8 \pm 2.6)\times 10^{-6}$

- Cross sections have been obtained by **extrapolating** BaBar data by means of the Gounaris-Sakurai model
- In case of J/ψ the discrepancy between $\mathcal{B}_\gamma$ and $\mathcal{B}_{\text{PDG}}$ is

$$\left.\frac{\mathcal{B}_{\text{PDG}} - \mathcal{B}_\gamma}{\delta\left[\mathcal{B}_{\text{PDG}} - \mathcal{B}_\gamma\right]}\right|_{J/\psi} = 4.1 \pm 1.0$$

4.1 sigma effect for J/ψ

- Also in case of $\psi(2S)$ there is discrepancy but, due to the larger error

$$\left.\frac{\mathcal{B}_{\text{PDG}} - \mathcal{B}_\gamma}{\delta\left[\mathcal{B}_{\text{PDG}} - \mathcal{B}_\gamma\right]}\right|_{\psi(2S)} = 2.1 \pm 1.0$$

2.1 sigma effect for $\psi(2S)$

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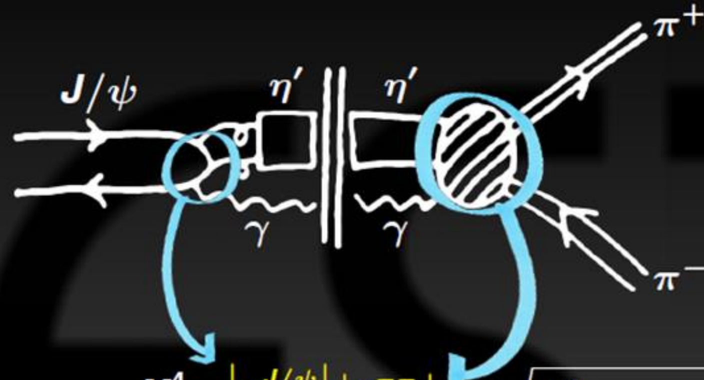
An estimate of $\mathcal{A}_{2g\gamma}$ for the decay $J/\psi \to \pi^+\pi^-$



$$|\mathrm{Im}\,[\mathcal{A}_{\eta'\gamma}]| = \frac{1}{48\pi}\frac{M^4_{J/\psi}\left|g^{J/\psi}_{\eta'\gamma}\right|\left|g^{\pi\pi}_{\eta'\gamma}\right|}{\sqrt{\left(M_\rho^2 - M^2_{J/\psi}\right)^2 + \Gamma_\rho^2 M_\rho^2}}\sqrt{\frac{M^2_{J/\psi}}{4} - M_\pi^2}\left(1 - \frac{M^2_{\eta'}}{M^2_{J/\psi}}\right)^3$$

The coupling constants are obtained from experimentally known decay rates

* $\Gamma(\eta' \to \pi^+\pi^-\gamma) \longrightarrow \left|g^{\pi\pi}_{\eta'\gamma}\right|$
* $\Gamma(J/\psi \to \eta'\gamma) \longrightarrow \left|g^{J/\psi}_{\eta'\gamma}\right|$

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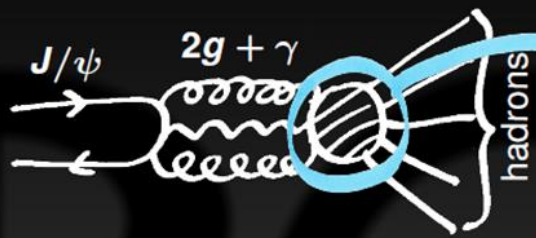
HOW TO ESTIMATE THE $2g+\gamma$ CONTRIBUTION



- It is difficult to compute the $\mathcal{A}_{2g\gamma}$ contribution to $\mathcal{A}(J/\psi \to \mathcal{H}_q)$
- In particular, the hadronization mechanism $2g+\gamma \to \mathcal{H}_q$ is unknown
- Only $3g/(2g+\gamma)$ relative rates are easily computable, having the same number of vector bosons...

In case of G-parity-conserving decays $J/\psi \to \mathcal{H}_q$

$$\frac{\mathcal{B}(J/\psi \to 3g \to \mathcal{H}_q)}{\mathcal{B}(J/\psi \to 2g+\gamma \to \mathcal{H}_q)} = \frac{\alpha_s(M_{J/\psi})}{\alpha}\,\frac{D_{\text{QCD}}}{D''_{\text{QCD}}} = 7.28 \pm 0.92$$

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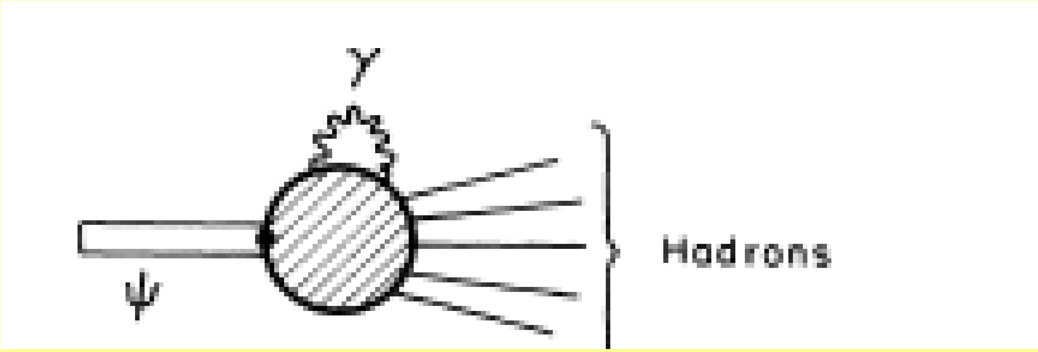
$\psi(3686)\text{->}p p_{bar}$ decay via $2g1\gamma_{virtual}$

- M.S.Chanowitz (P.R. D12 (1975) 918) also considered 1 γ_{virt}



- and made an estimation, assuming $\alpha_s \sim 0.3$ at the $\psi(3686)$:

$B(J/\psi\text{->}2g1\gamma_{virt}\text{->}H)/\ B(J/\psi\text{->}3g\text{->}H) \sim 16/5\ \alpha/\alpha_s\ P \sim 0.08\ P$,

- P is a factor to take into account “the effective coupling of the photon to qq_{bar} in the cc_{bar} decay volume”, ranging from α to 1. According the present results P should be close to 1.

$\psi(3686) \to p\bar{p}$ decay via $2g1\gamma_{virtual}$

- V.L.Cherniak and A.R.Zitniski (Phys.Rep. 112, 3 (1984) 173) also considered 1 γ_{virt} , and made an estimation, on the basis of PQCD, applied on both 1 γ_{virt} vertices (generation and hadronization), assuming $\alpha_S \sim 0.3$:

$$A(J/\psi \to 2g1\gamma_{virt} \to H) / A(J/\psi \to 3g \to H) \sim -4/5\, \alpha/\alpha_S$$

$$\mathbf{B(J/\psi \to 2g1\gamma_{virt} \to H) / B(J/\psi \to 3g \to H) \sim 0.4 \cdot 10^{-3}}$$

- Chanowitz questioned the factor 4/5 and the validity of PQCD in the hadronization regime.
  - Actually, according V.L.Cherniak and A.R.Zitniski, by the same token : $A(J/\psi \to 2g1\gamma_{virt} \to \pi\pi) \sim 0$ in contradiction with present data, as shown by Simone.

Temporary Conclusions

- A contribution from $\psi(3686) \to 2g1\gamma_{virt} \to NN_{bar}$ is expected and likely found in the vanishing Electric Proton Branching Ratio $B_E^{\,p}$, with respect to the Electric Neutron Branching Ratio $B_E^{\,n}$.
  - It turns out:

    $B(\psi(3686) \to 2g1\gamma_{virt} \to NN_{bar}) \sim (2.8 \pm 1.9) \cdot 10^{-5}$

    (99.4% CL that B >0, 90% CL that $B > 3 \cdot 10^{-6}$)

  and there is **a negative interference between 3g and $2g1\gamma_{virt}$**

- The evidence of this G parity violation is good, according the achieved CL. Unfortunately statistics is not enough to get also good accuracy

- Present theoretical predictions are affected by lack of knowledge concerning the hadronization

Temporary Conclusions

- Opposite behaviour is expected in the Σ^- and Σ^+ branching ratios, to be evaluated
- A better determination would shed light on the hadronization mechanism (validity of PQCD)
- B_M phase, between strong and em decay, $\boldsymbol{\phi_M = 63^0 \pm 19^0}$,
  but present continuum knowledge has large uncertainties->
  scan below and at $\psi(3686)$!
- Work in progress,
  however, once more……

BARYONS STRIKE BACK IN BESIII