BESIII Physics Reach Using a $O(10^9)$ ψ' events data sample

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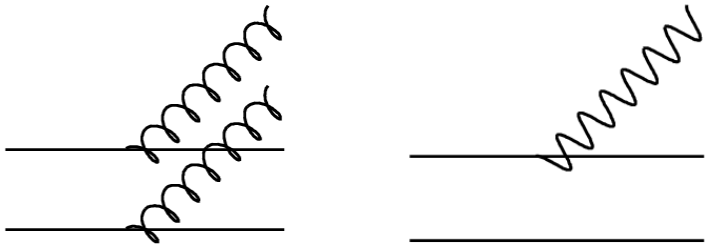
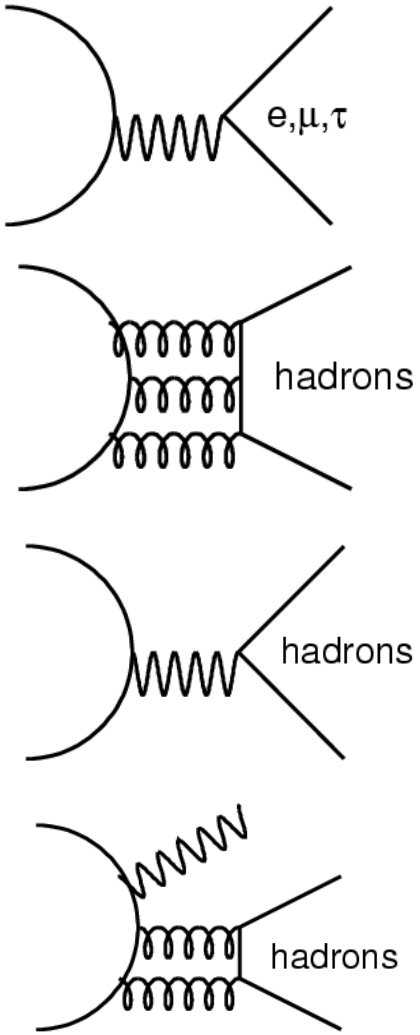
ψ' data sample at BESIII

- BEPCII energy spread: ~1.5 MeV at Ecm=3.7 GeV
- ψ' production cross section: 640 nb
- BEPCII luminosity: $10^{33}cm^{-2}s^{-1}$ at Ecm=3.7 GeV, i.e. L=1 nb^{-1}/s
- BEPCII average luminosity: L_{avg}=0.5 nb^{-1}/s
- BESIII average ψ' events rate: 320 Hz
- BESIII Running time: ~10^7 s/year (1 yr=3.16×10^7 s)
- ψ' events/year = 3.2 × 10^9
  - BESII: 14 × 10^6 now [X200]
  - CLEOc: 3 × 10^6 now (plan 30 × 10^6) [X1000 (X100)]

ψ' decays

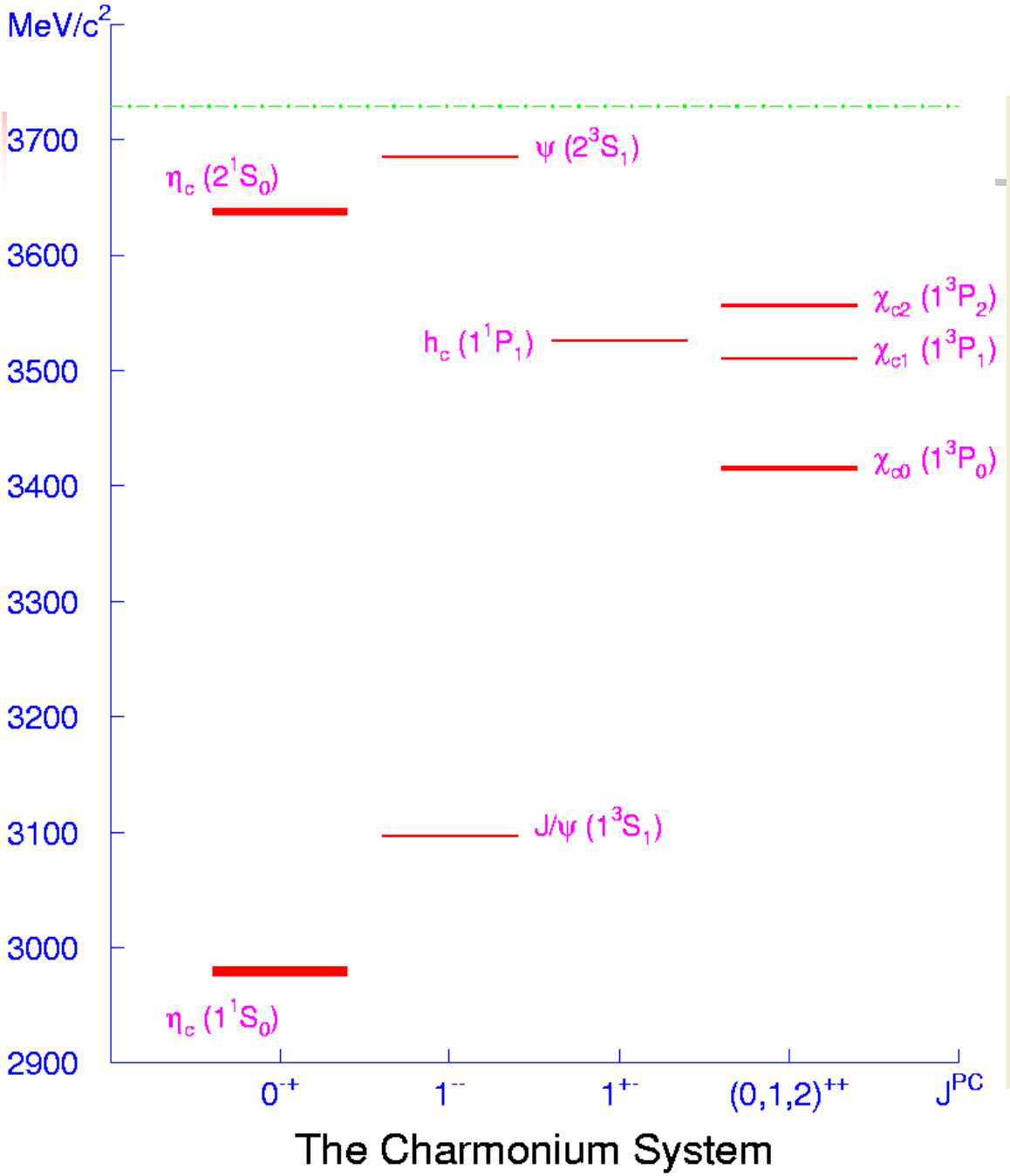


- Transitions (~82%)
  - Hadronic transitions (~54%)
  - Radiative transitions (~28%)
- Leptonic decays (~ 2%)
- Hadronic decays (~15%)
  - Strong decays (~13%)
  - EM decays (~ 2%)
- Radiative decays (~ 1%)
- Rare decays and beyond SM (<<1%)



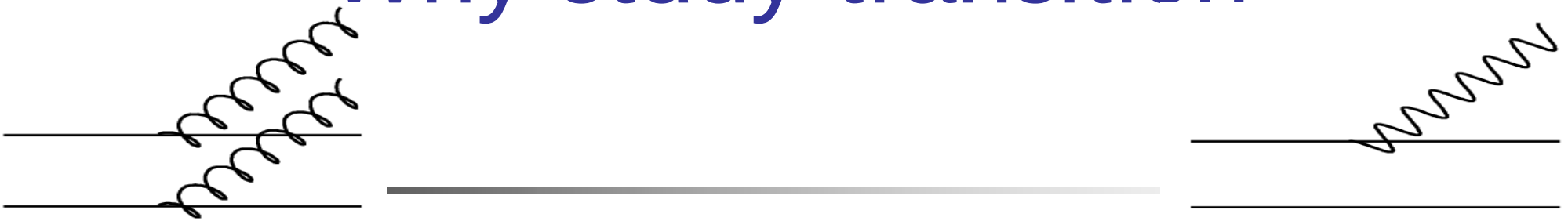
I will talk about what we can measure in experiment.

Charmonium Spectrum



- All charmonia below charm threshold
- All n=1 charmonia
- All S-wave n=2 charmonia
- Mass difference not large (<710 MeV), so not many channels
- Big transition rates
- Study since 1974 (32 years!)
- Great opportunity with (1-3)x10^9 ψ' at BESIII

Why study transition

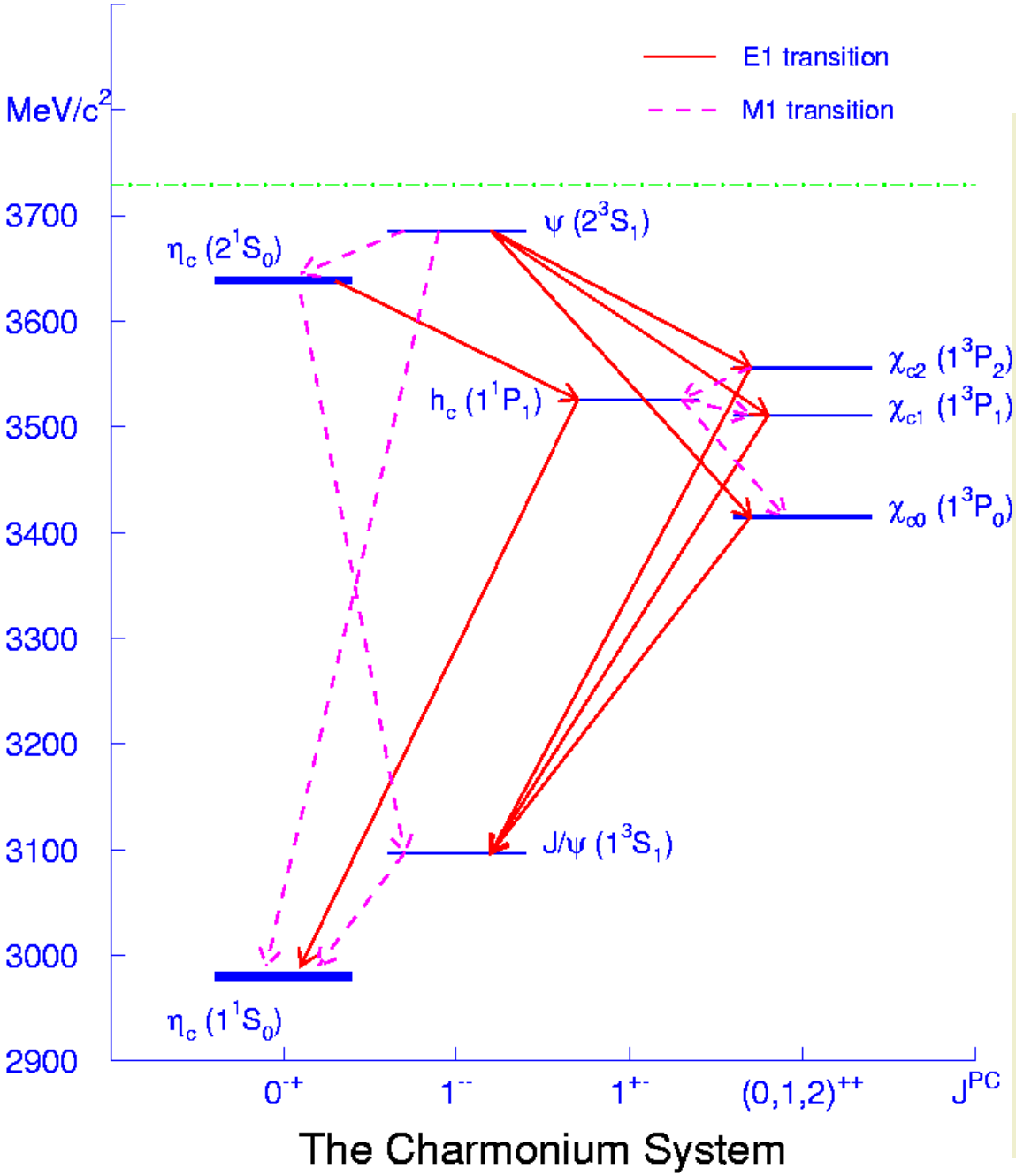


- Largest ψ' decay modes (experimentally interesting)
- Understand how charm and anti-charm quarks interact (detailed information on the potential between cc-bar)
- Multipole amplitudes --- S-D mixing in ψ' and ψ'' (ψ'' charmless decays)
- Channels with low momentum pions --- does chiral theory work?
- Shed light on ψ' hadronic decays and radiative decays (eg. "12% rule")
- Chance to study h_c and η_c' more
- Search for rare and forbidden transitions

What to measure

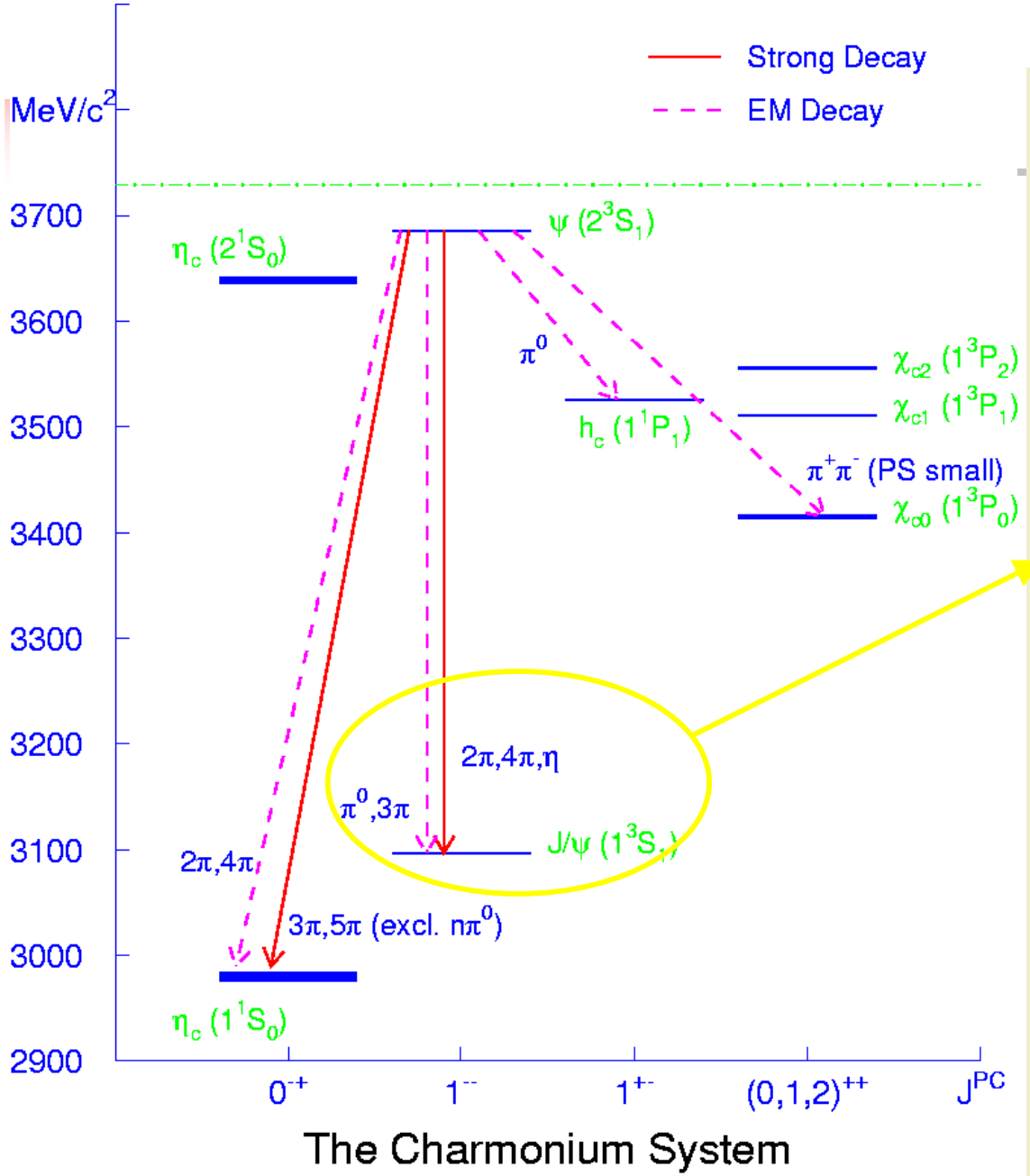
- Masses and widths of the charmonia
- Transition rates
- Multipole amplitudes (helicity amplitudes)
- Mass distributions, intermediate states
- Relations between similar/different modes
- Search for undetected modes
- C-violation, P-violation, CP-violation transitions as a probe of physics beyond SM and/or new physics

Radiative transition



- E1 dominant transitions rates between ψ' and χ, χ and J/ψ were well measured. Multipoles were measured in large uncertainty due to statistics limitation.
- M1 transition between ψ' and η_c, J/ψ and η_c were measured with big uncertainties.
- Hint for E1 transition between h_c and η_c.
- Transitions involve η_c' are not observed.
- Transitions between P-wave spin singlet and triplets?

Hadronic transition of ψ'



The Charmonium System

- Strong and EM transitions between ψ' and J/ψ:
  - $\pi^+\pi^-$, $\pi^0\pi^0$: rates, mass distribution, isospin test, D-wave contribution, multipoles, σ pole, CPV
  - π^0,η: Isospin violation strength, quark mass
  - EM: $\pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$?
  - Strong: $2(\pi^+\pi^-)$, $\pi^+\pi^-\pi^0\pi^0$, $4\pi^0$? PS small, how much?

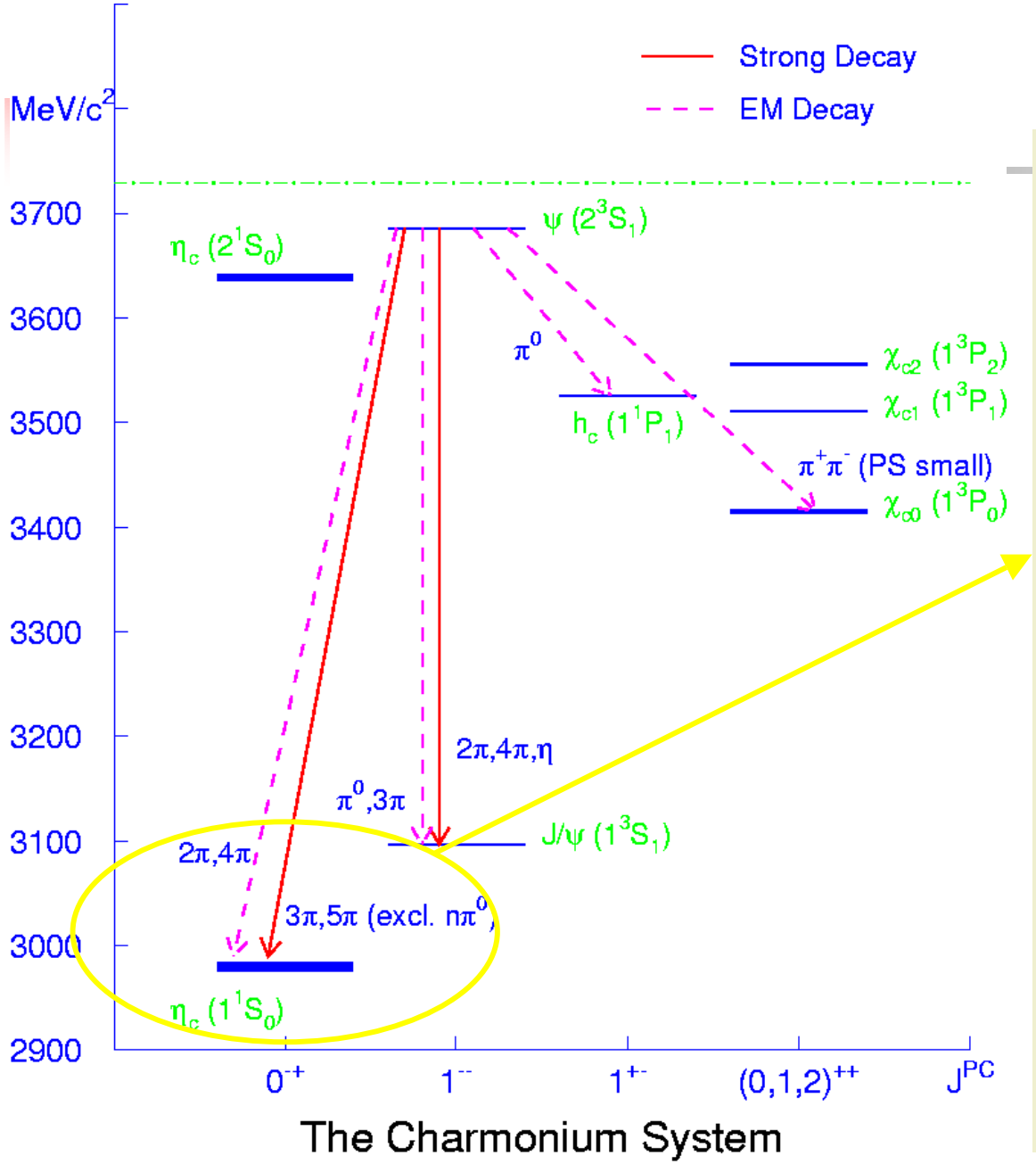
($m_{2(\pi+\pi-)}$ = 0.558 GeV/c^2)

(m_{η} = 0.547 GeV/c^2)

($m_{\psi'}$-$m_{J/\psi}$ = 0.589 GeV/c^2)

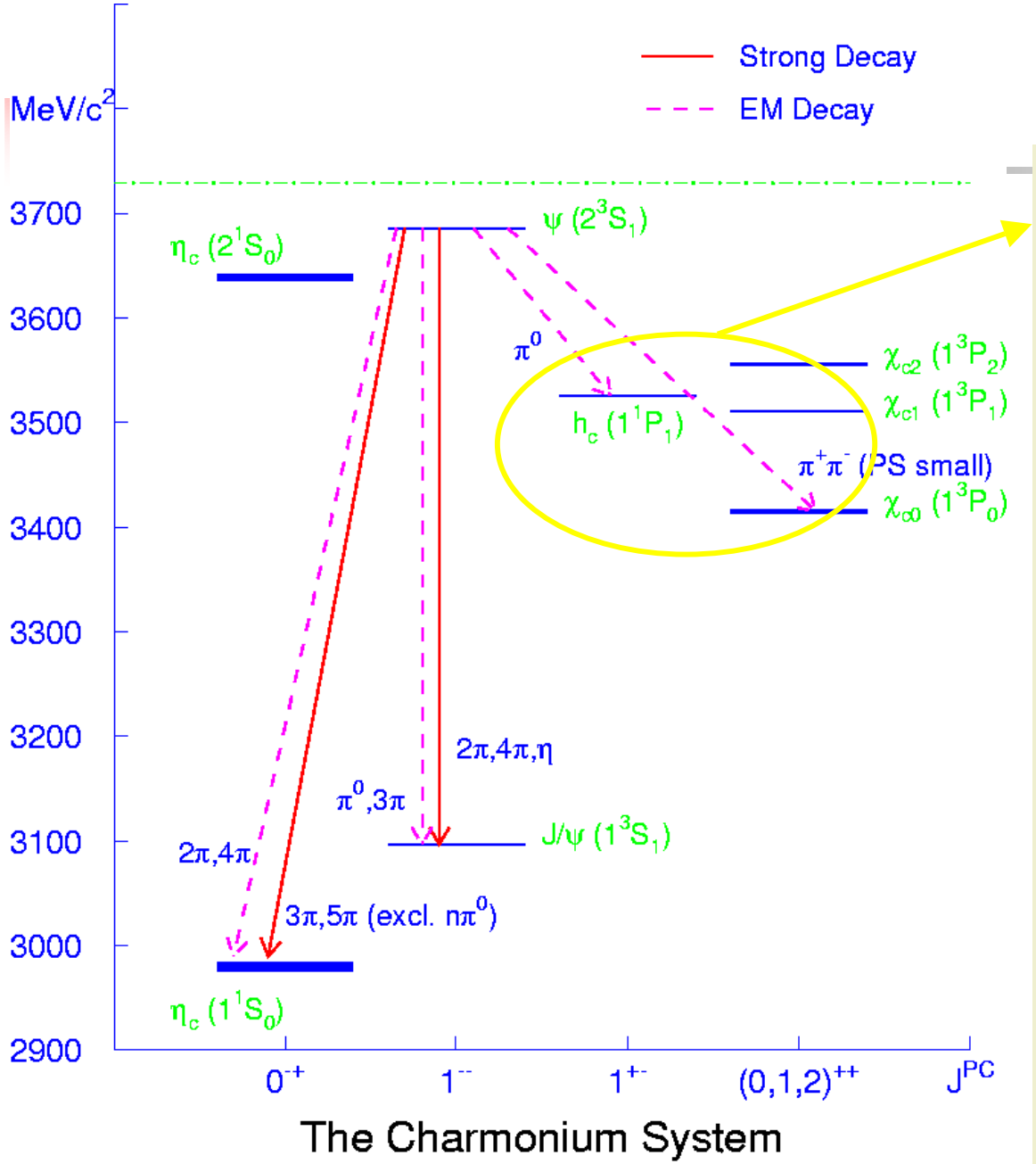
Low momentum π, challenge to BES detector!

Hadronic transition of ψ'



- Gerard et al. predict $\psi' \rightarrow \eta_c \pi^+ \pi^- \pi^0$ at 1% level. CLEOc measures B<0.1% @ 90% C.L.
- No predictions for other final states
- No measurements for all the other modes
- All π^0 modes forbidden by C-parity conservation

Hadronic transition of ψ'



- $\psi' \rightarrow h_c \pi^0$ observed by CLEOc in 3M ψ' events. Joint production rate for $\psi' \rightarrow h_c \pi^0 \rightarrow \gamma \eta_c \pi^0$ was measured.
- Many calculations on $\Gamma(\psi' \rightarrow h_c \pi^0)$, need data to test.
- $\psi' \rightarrow \chi_{c0} \pi^+ \pi^-$: phase space very small.

ψ' transitions VS "12% rule"

$$Q = \frac{B(\psi' \to ggg)}{B(J/\psi \to ggg)}$$

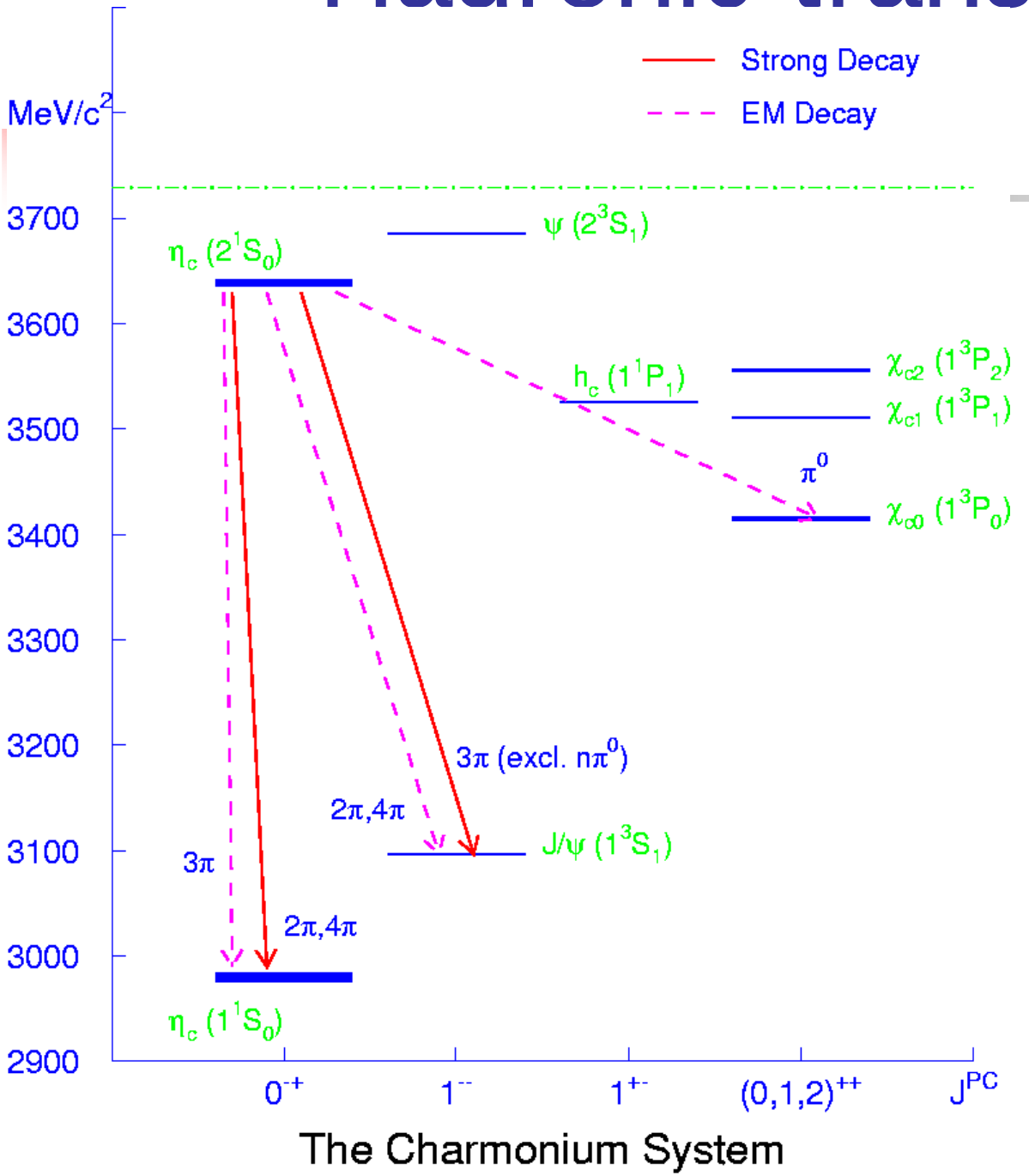
$$\mathcal{B}(ggg) + \mathcal{B}(\gamma gg) + \mathcal{B}(\gamma^*) + \mathcal{B}(c\bar{c}X) = 1$$

- The neglected radiative transitions and hadronic transitions may affect the estimation of the three-gluon annihilation rate, thus overestimates the Q value for inclusive decay.
- Improve precisions of the known modes

Channel	$\mathcal{B}(J/\psi)$	$\mathcal{B}(\psi')$
$\gamma^* \to$ hadrons	$(13.4\pm0.33)\%$	$(1.66\pm0.18)\%$
e^+e^-	$(5.93\pm0.10)\%$	$(7.55\pm0.31)\times10^{-3}$
$\mu^+\mu^-$	$(5.88\pm0.10)\%$	$(7.3\ \pm0.8)\times10^{-3}$
$\tau^+\tau^-$		$(2.8\ \pm0.7)\times10^{-3}$
$\gamma^* \to X$	$(25.22\pm0.43)\%$	$(3.43\pm0.27)\%$
$\gamma\eta_c$	$(1.3\pm0.4)\%$	$(2.8\pm0.6)\times10^{-3}$
$\pi^+\pi^- J/\psi$		$(31.7\pm1.1)\%$
$\pi^0\pi^0 J/\psi$		$(18.8\pm1.2)\%$
$\eta J/\psi$		$(3.16\pm0.22)\%$
$\pi^0 J/\psi$		$(9.6\pm2.1)\times10^{-4}$
$\gamma\chi_{c0}$		$(8.6\pm0.7)\%$
$\gamma\chi_{c1}$		$(8.4\pm0.8)\%$
$\gamma\chi_{c2}$		$(6.4\pm0.6)\%$
$c\bar{c}X$	$(1.3\pm0.4)\%$	$(77.4\pm2.5)\%$

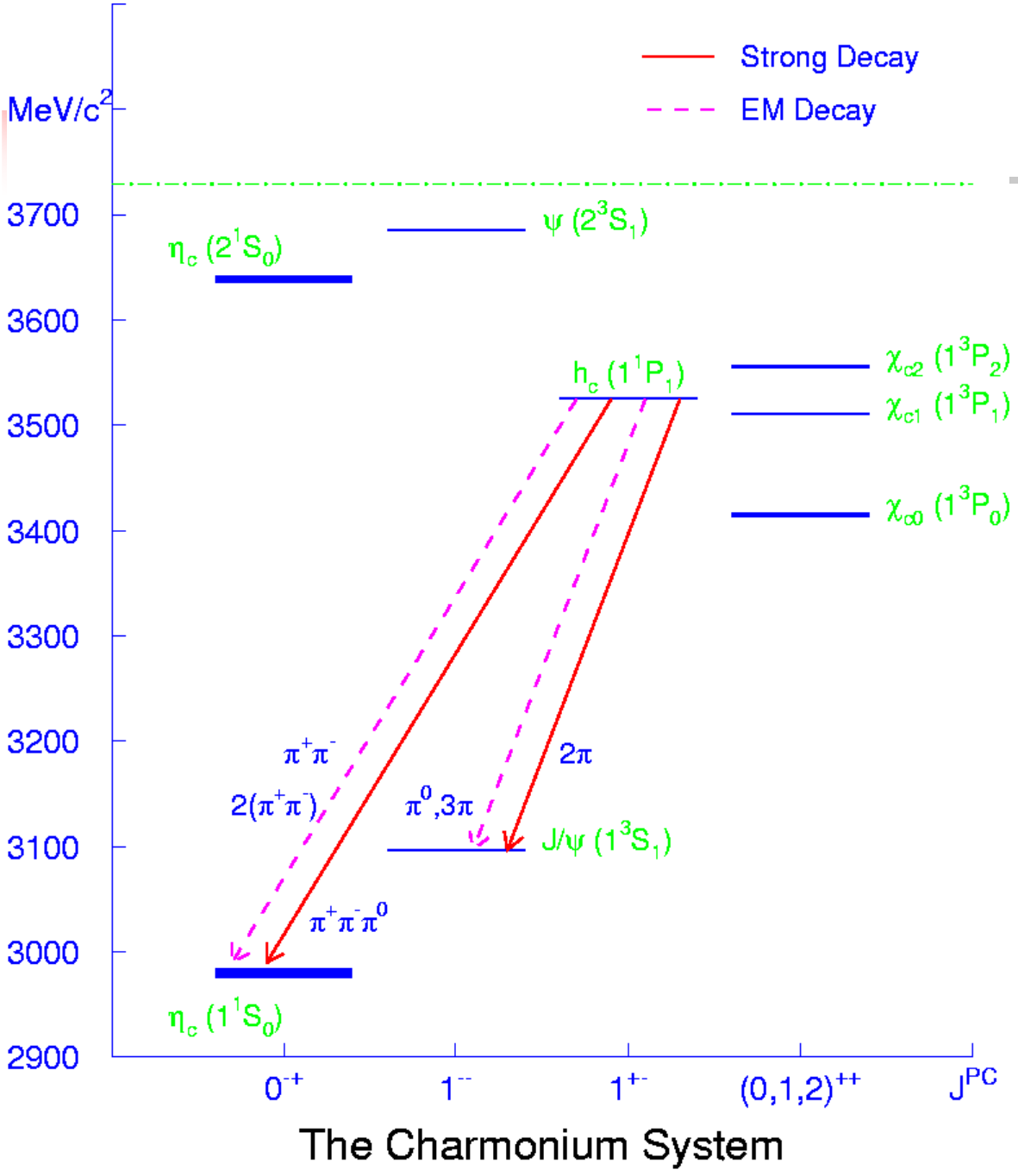
PDG'04

Hadronic transition of η_c'



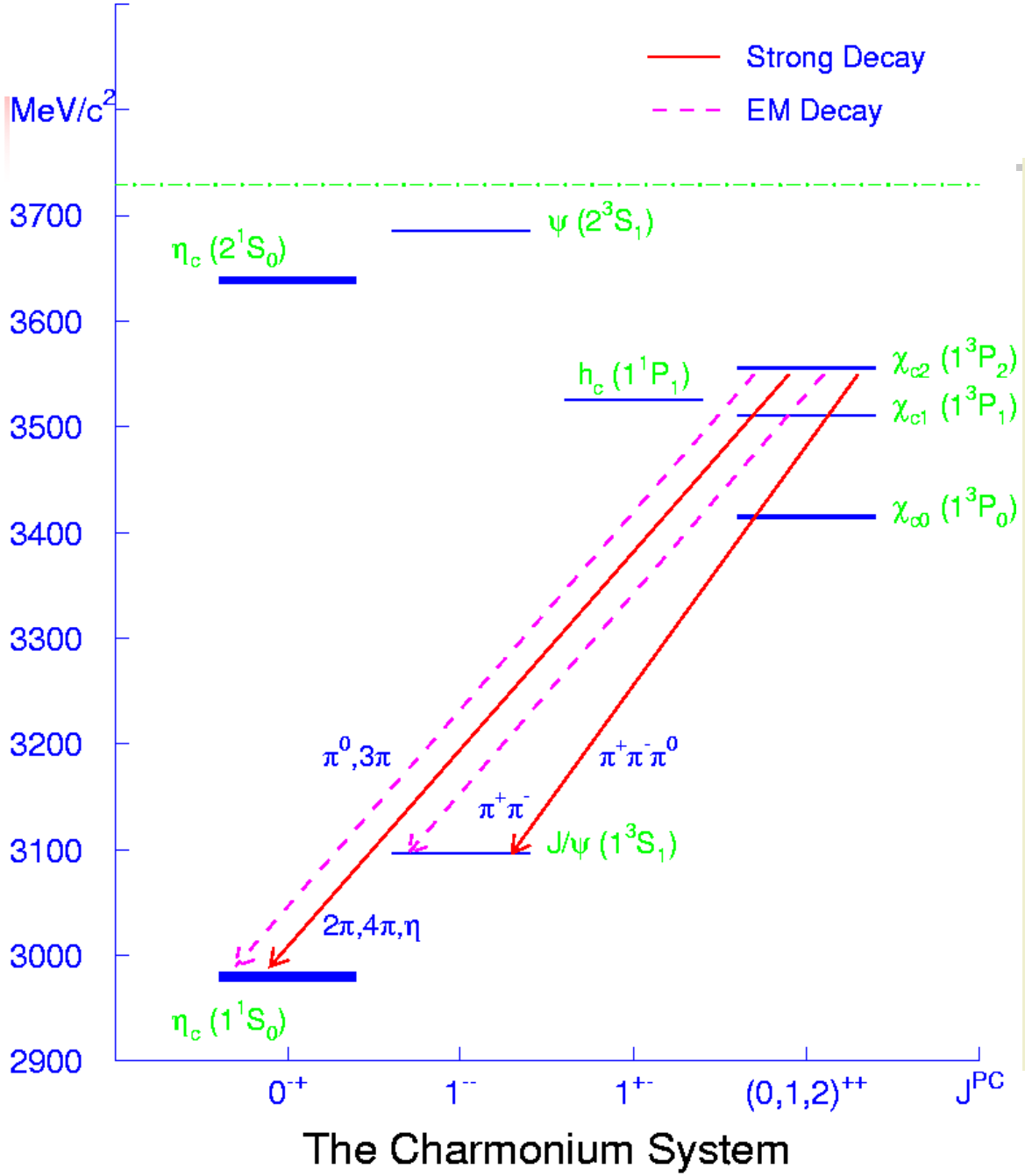
- No experimental information for all the possible transitions
- B(η_c'→$\eta_c\pi\pi$)~5-10% based on B(ψ'→ $\psi\pi\pi$), estimated by Voloshin
- Experimentally hard to study since B(ψ'→$\gamma\eta_c$') is very small
- May try to reconstruct η_c' without reconstructing the radiative photon

Hadronic transition of h_c



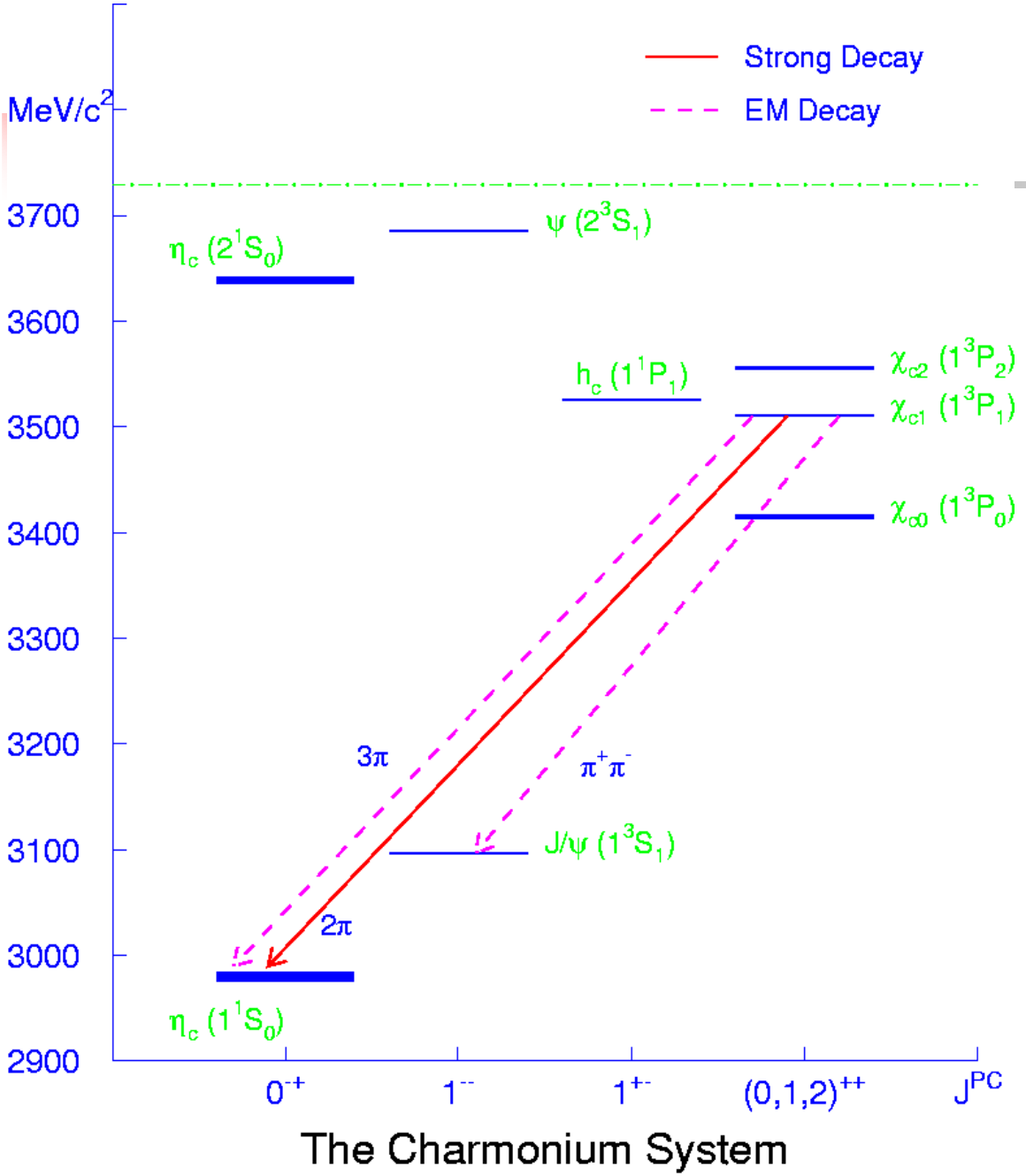
- $h_c \rightarrow J/\psi\pi^0$ was observed at about 3σ by E760, but not confirmed. $h_c \rightarrow J/\psi\pi^+\pi^-$ was not observed by E760
- No experimental information for all other possible transitions
- Theoretical efforts are welcome

Hadronic transition of χ_{c2}



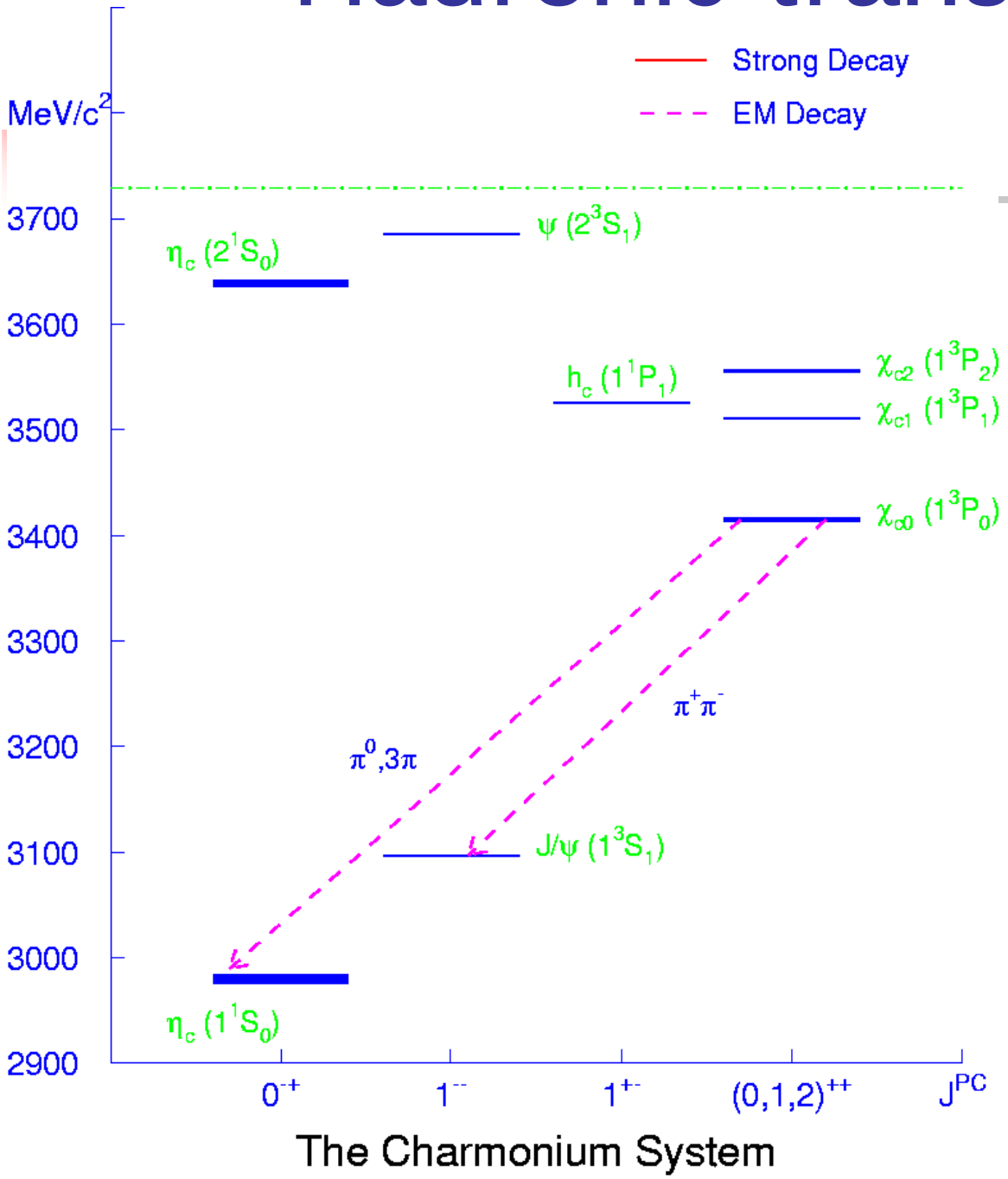
- No experimental information for all the possible transitions
- 3×10^9 $\psi' = 0.3\times10^9$ χ_{c2}
- BESIII can reach
  $B(\chi_{c2}\rightarrow J/\psi X) \sim 10^{-6}$
  $B(\chi_{c2}\rightarrow \eta_c X) \sim 10^{-5}$
- Theoretical efforts are welcome

Hadronic transition of χ_{c1}



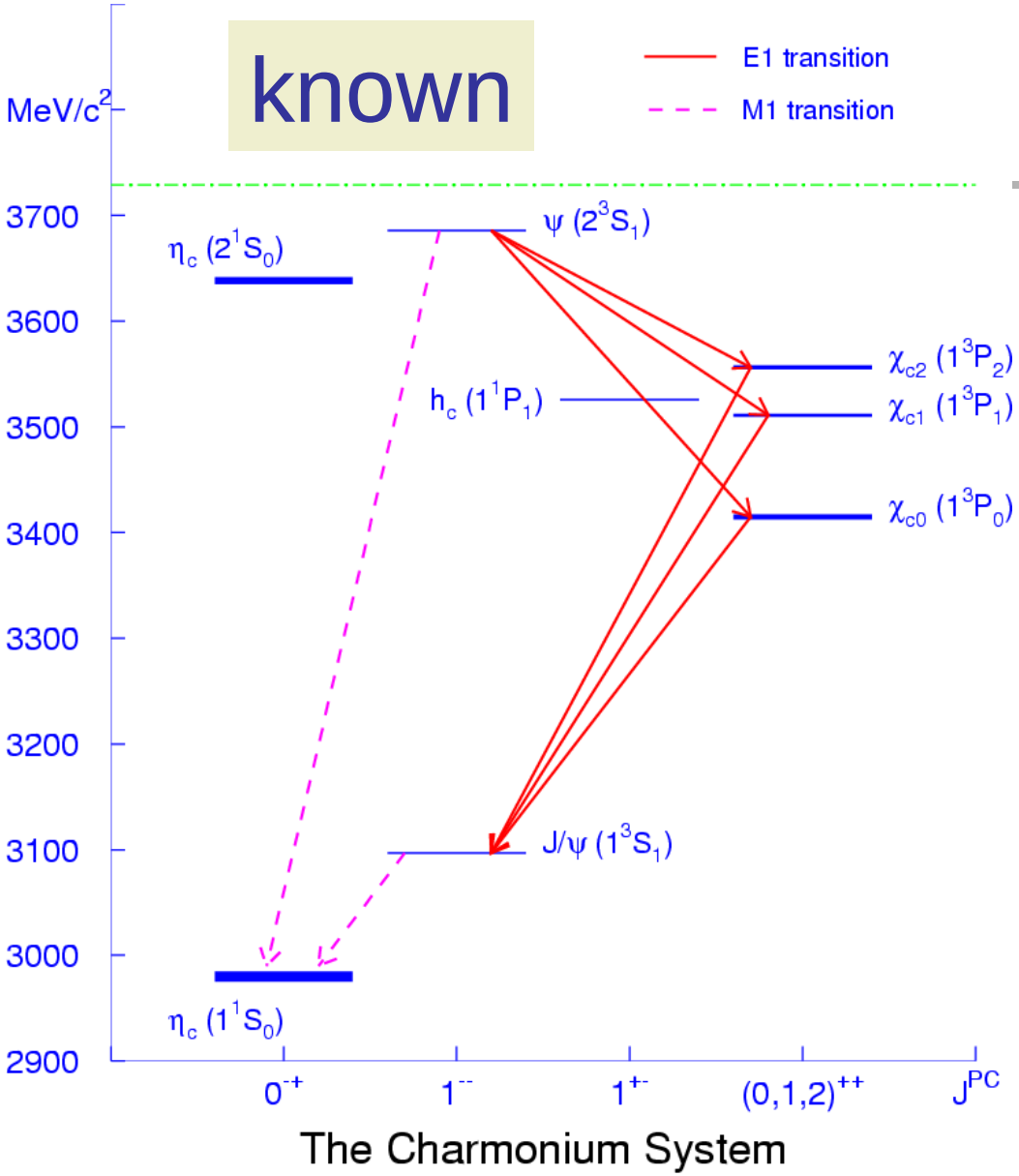
- No experimental information for all the possible transitions
- 3×10^9 $\psi' = 0.3\times10^9$ χ_{c1}
- BESIII can reach
  $B(\chi_{c1}\rightarrow J/\psi X) \sim 10^{-6}$
  $B(\chi_{c1}\rightarrow \eta_c X) \sim 10^{-5}$
- Theoretical efforts are welcome

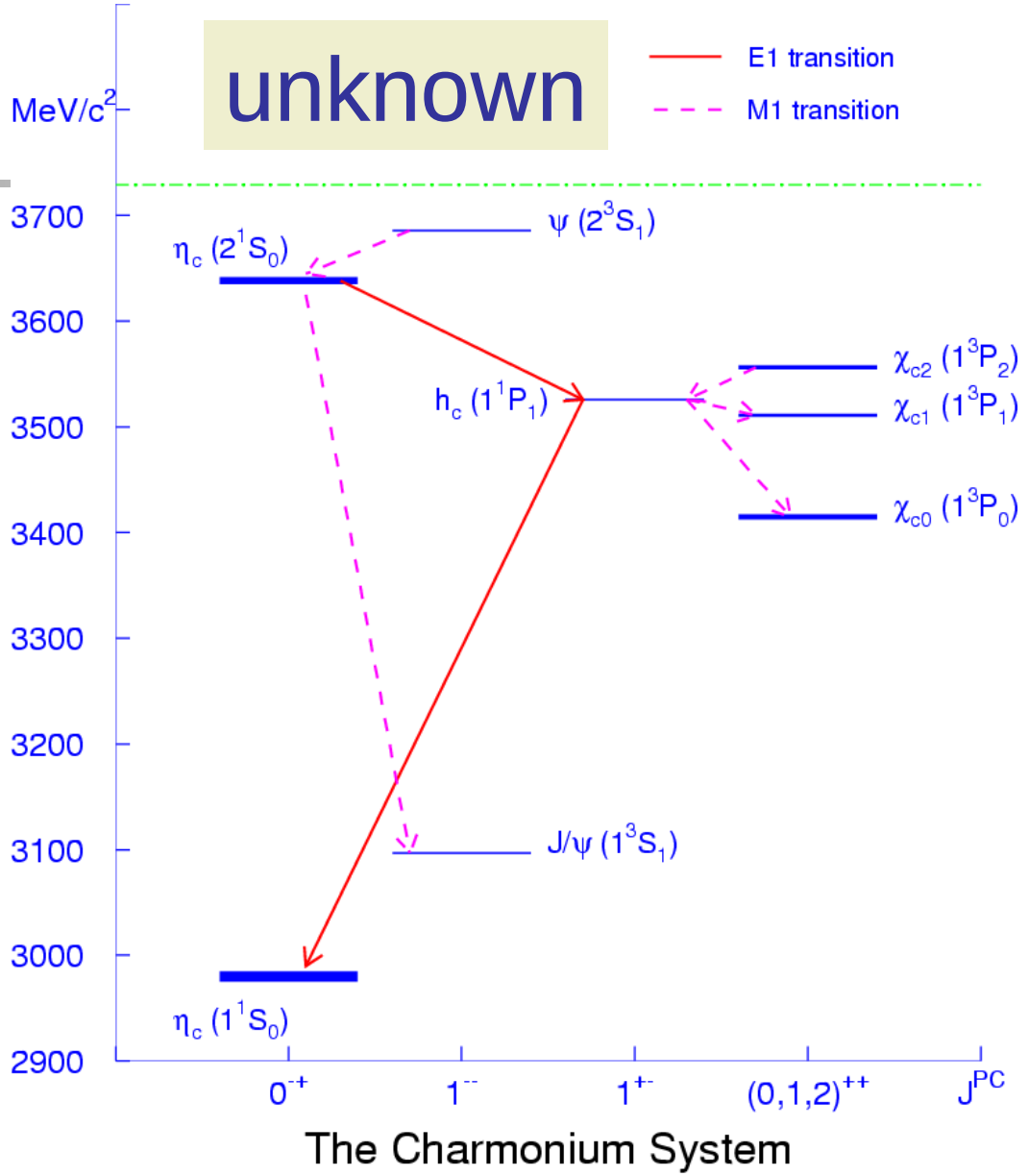
Hadronic transition of χ_{c0}



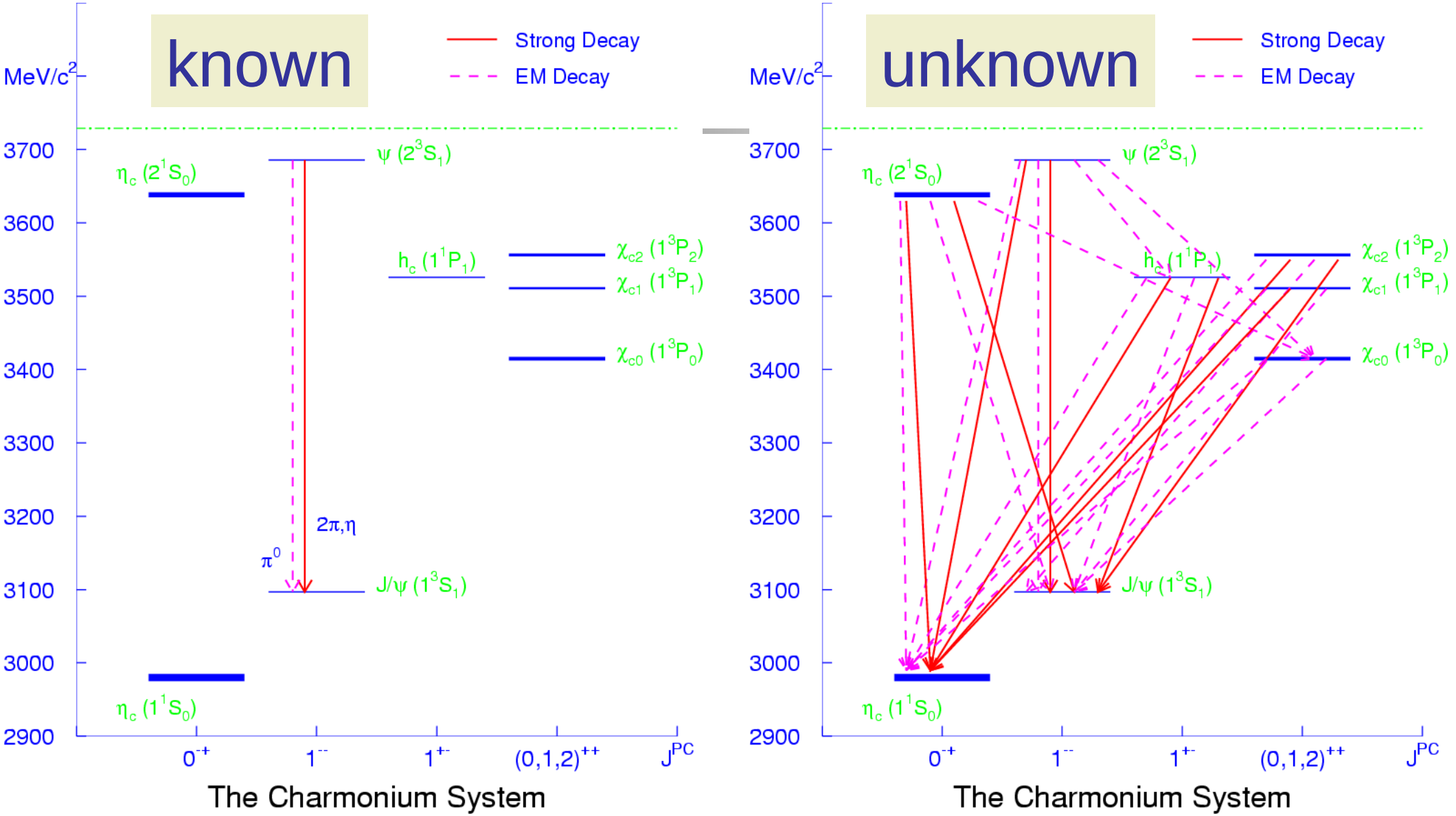
- No strong transition due to C or P-violation.
- No experimental information for all the possible transitions
- 3×10^9 $\psi' = 0.3\times10^9$ χ_{c0}
- BESIII can reach
  $B(\chi_{c0}\rightarrow J/\psi X) \sim 10^{-6}$
  $B(\chi_{c0}\rightarrow \eta_c X) \sim 10^{-5}$
- Theoretical efforts are welcome

Radiative transitions

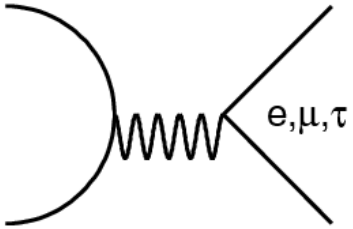




Hadronic transitions



Many work, lots of chance …



Leptonic decays

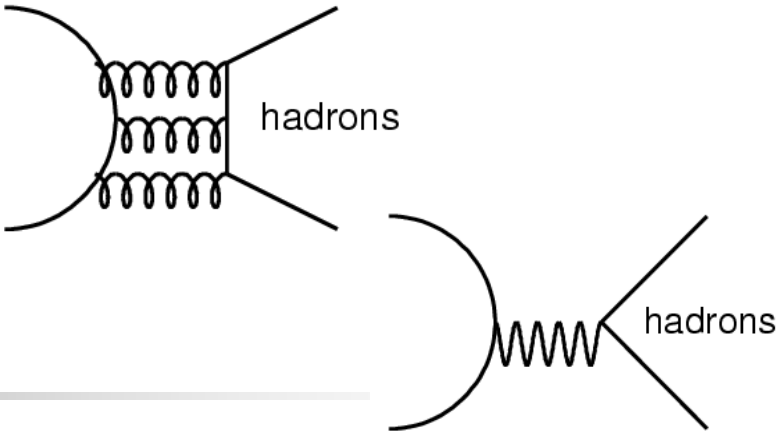
$J/\psi(1S)$

- e^+e^- (J/ψ, ψ')
- $\mu^+\mu^-$ (J/ψ, ψ')
- $\tau^+\tau^-$ (ψ')

$$e^+e^- \quad (5.93 \pm 0.10)\ \%$$
$$\mu^+\mu^- \quad (5.88 \pm 0.10)\ \%$$

- Best precision measurements of J/ψ BRs from ψ' data samples (BES/CLEOc)
- ψ' BRs with large uncertainty

$$\psi(2S) \to e^+e^- \quad (7.41 \pm 0.28) \times 10^{-3}$$
$$\psi(2S) \to \mu^+\mu^- \quad (7.3 \pm 0.8) \times 10^{-3}$$
$$\psi(2S) \to \tau^+\tau^- \quad (2.8 \pm 0.7) \times 10^{-3}$$



Hadronic decays

- Relative phase between strong and EM amplitudes in two-body decays (P. Wang)
- Contribution of continuum (P. Wang)

- “12% rule” and “$\rho\pi$ puzzle”
- Study of meson spectroscopy
- Search for missing excited baryon states

The "12% rule"

M. Appelquist and H. D. Politzer, PRL34, 43 (1975)

$$\Gamma_h = |M_h|^2 |\Psi(0)|^2$$

$$= (2/9\pi)(\pi^2 - 9)\tfrac{5}{18}\alpha_s{}^3(\tfrac{4}{3}\alpha_s)^3 m_{\psi'}. \qquad (3)$$

The leptonic width via one photon into $\bar{l}l$ is

$$\Gamma_l = |M_l|^2 |\Psi(0)|^2 = \tfrac{1}{2}(\tfrac{2}{3}\alpha)^2(\tfrac{4}{3}\alpha_s)^3 m_{\psi'}, \qquad (4)$$

where $\alpha \approx \frac{1}{137}$. Although separately these calculations are not trustworthy, the ratio

$$\frac{\Gamma_l}{\Gamma_h} = \frac{\frac{2}{9}\alpha^2}{(2/9\pi)(\pi^2 - 9)5/\alpha_s{}^3} \qquad (5)$$

is independent of wave-function effects.

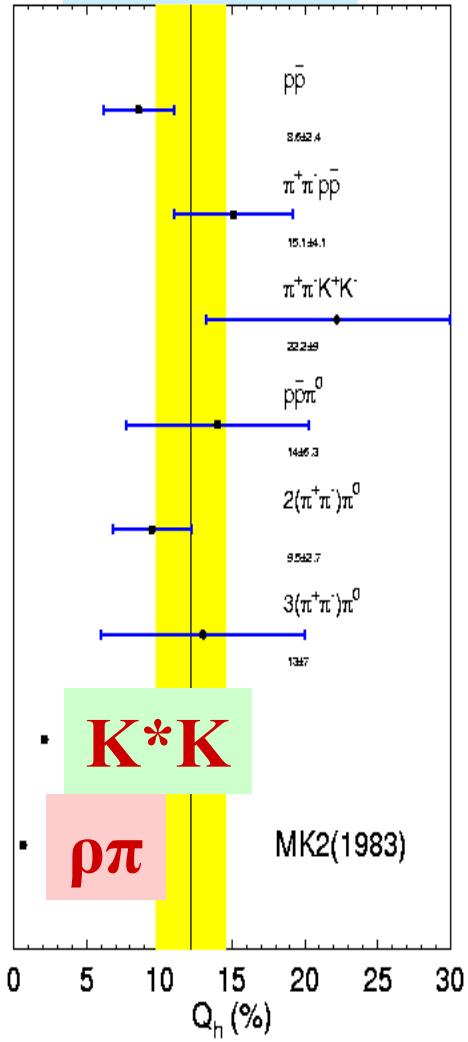
This is the famous (or notorious)

"12% rule".

$$Q_h = \frac{B_{\psi' \to X}}{B_{J/\psi \to X}} = \frac{B_{\psi' \to e^+e^-}}{B_{J/\psi \to e^+e^-}} = 12\%$$

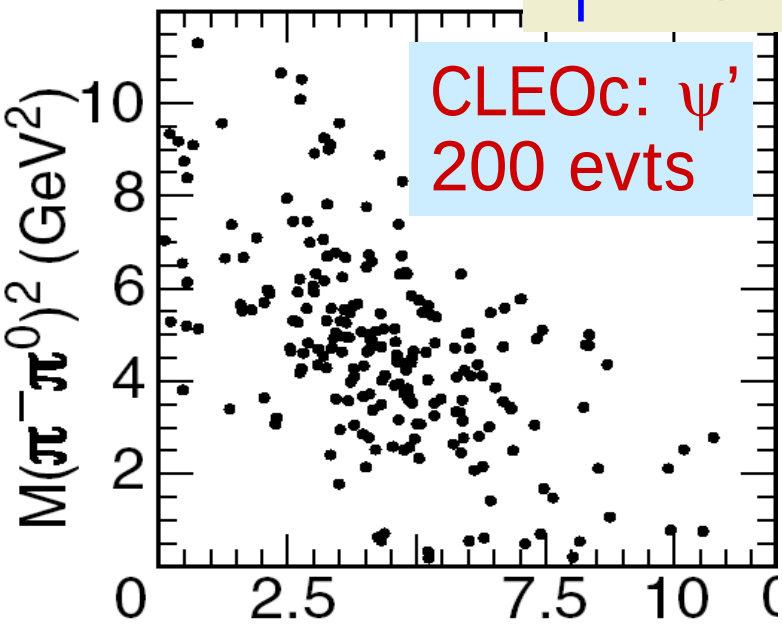
"12% rule" and "ρπ puzzle"

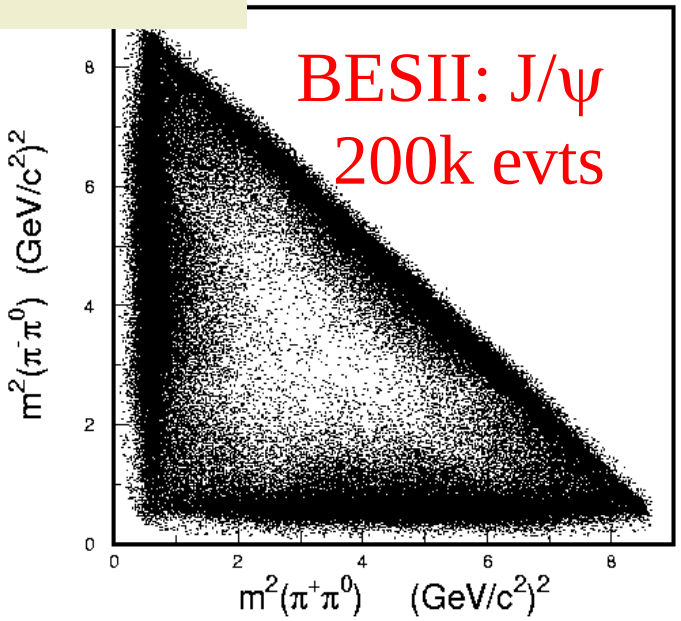
MARK-II



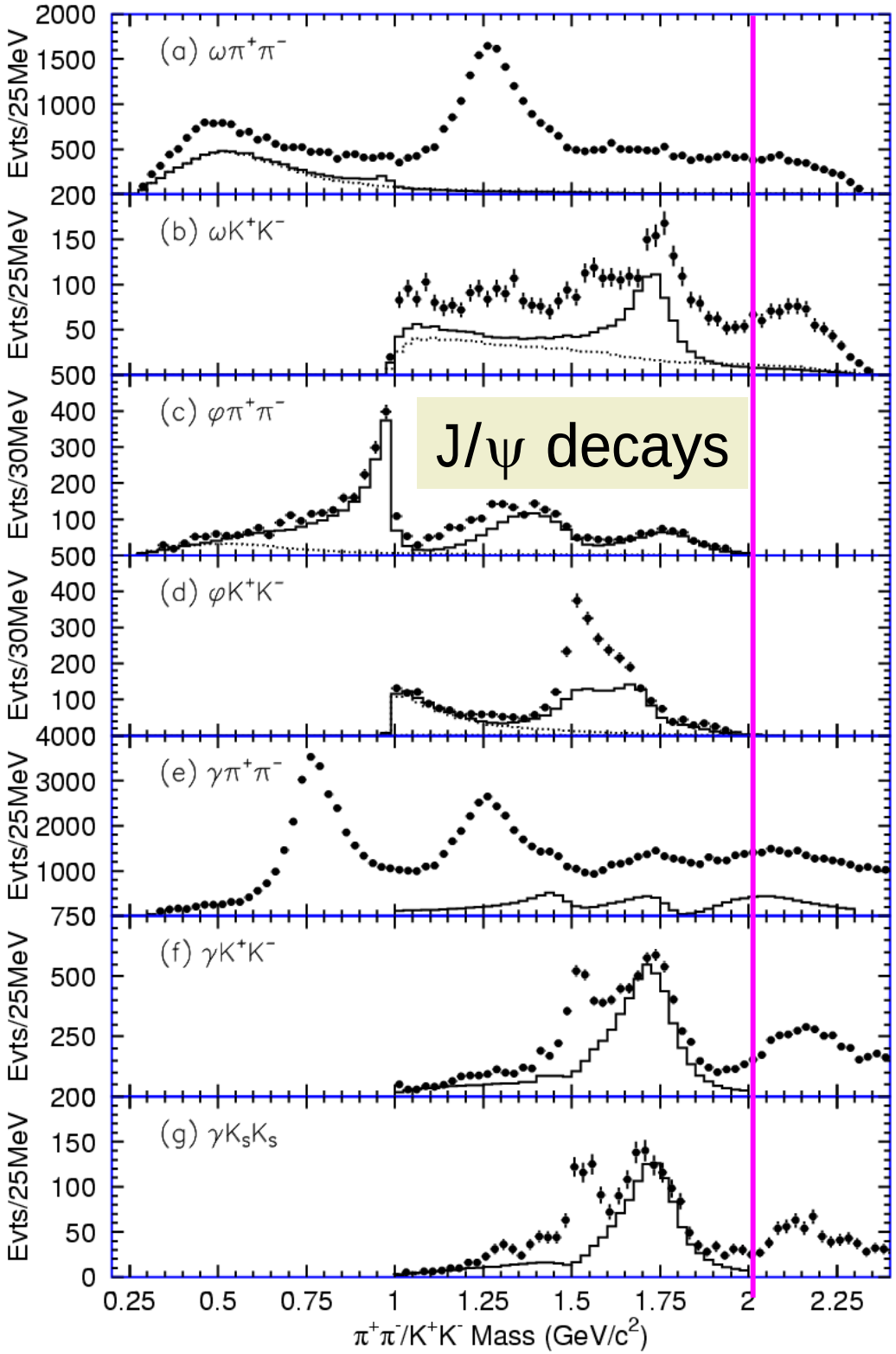
- Violation found by Mark-II , confirmed by BESI at higher sensitivity.
- Extensively studied by BESII/CLEOc
- More channels, higher precision

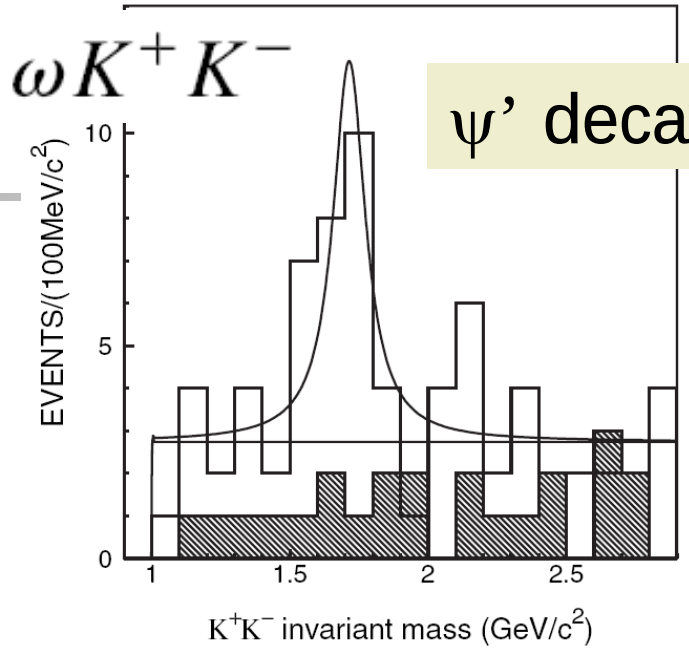
$\psi' \rightarrow \pi^+ \pi^- \pi^0$





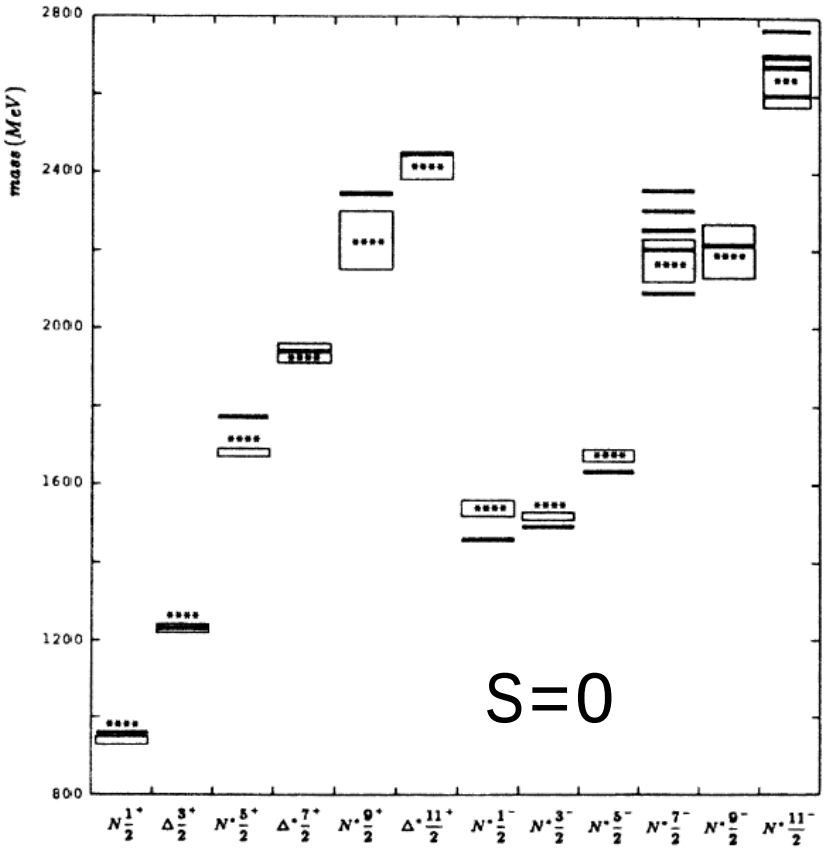
Meson spectroscopy

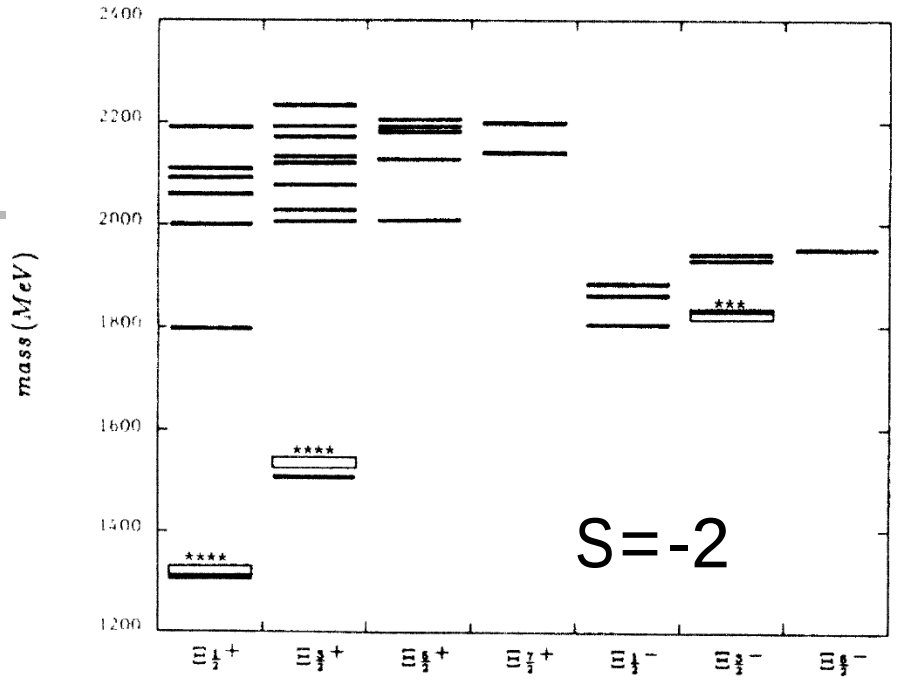




- Good place to study high mass states, especially when recoiling against a vector meson.
- Different dynamics of J/ψ and ψ' decay may result in different backgrounds and different combination of the mesons.

Excited baryon spectroscopy

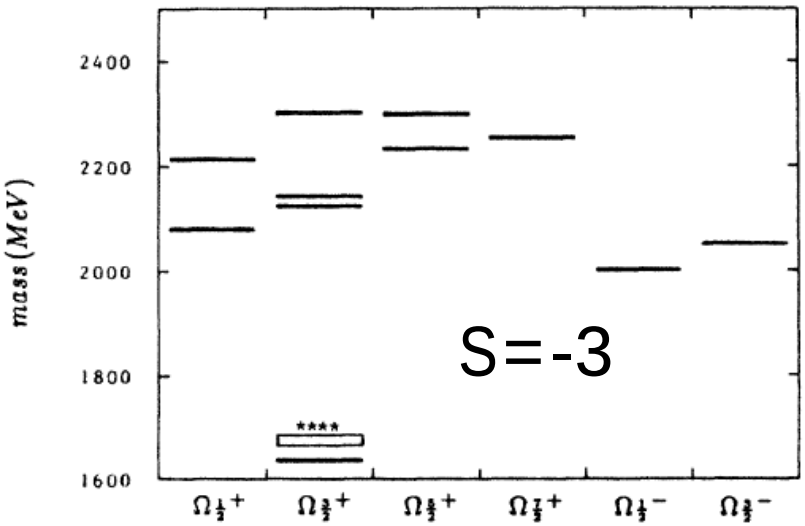




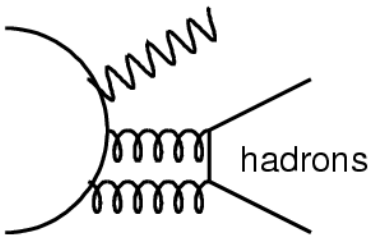
Capstick & Isgur, PRD34 (1986) 2809

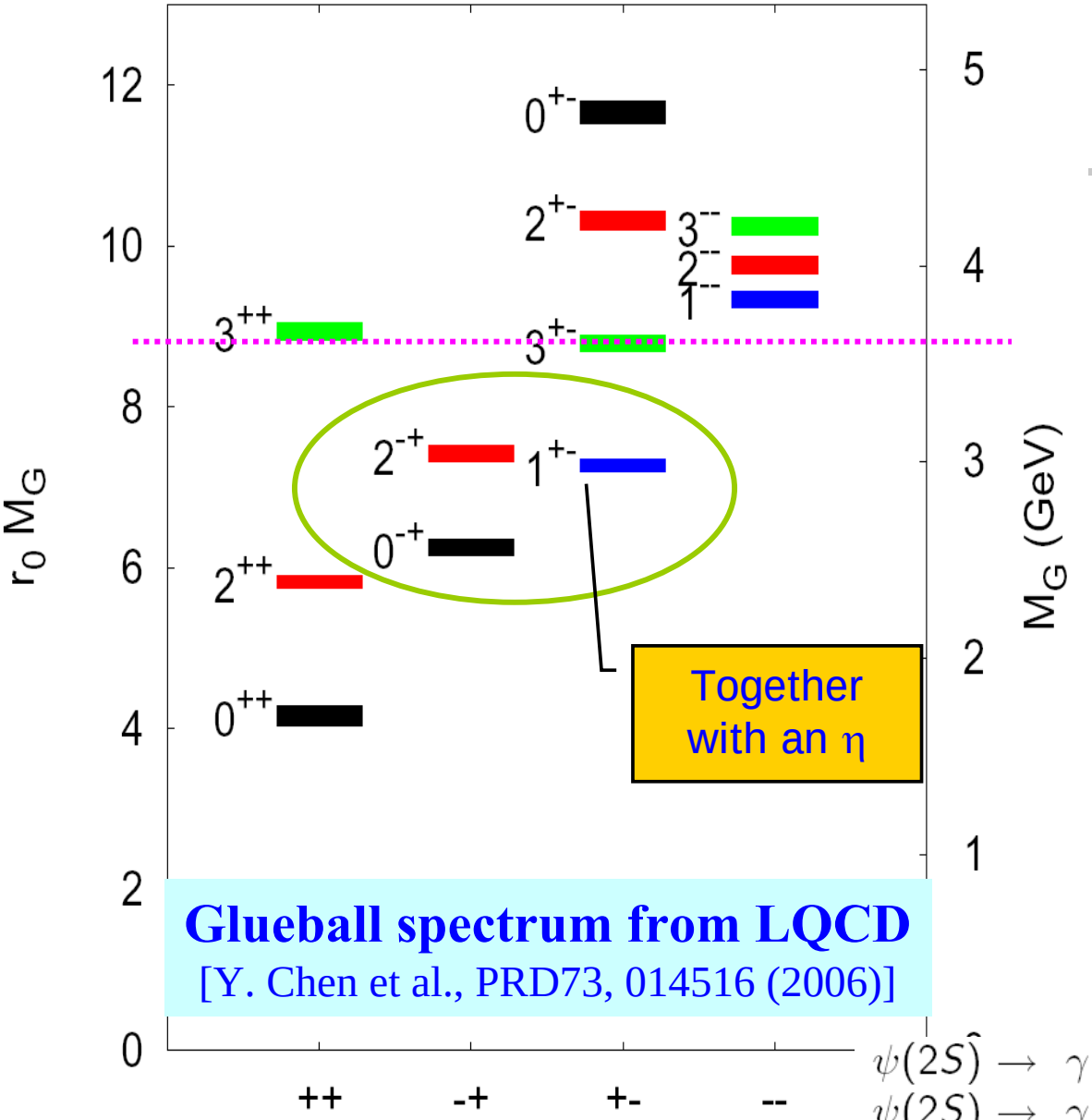
Large ψ' mass allows high mass baryons produced.

Good place to search for the missing N*, Λ*, Σ*, Ξ*, Ω* states.



Radiative decays





Glueball spectrum from LQCD
[Y. Chen et al., PRD73, 014516 (2006)]

- Opportunity for meson spectroscopy
- Complementary to J/ψ decays
- More phase space for high mass states
- Search for 2^{-+}, 1^{+-}, and 0^{-+} glueballs
- Very limited studies so far

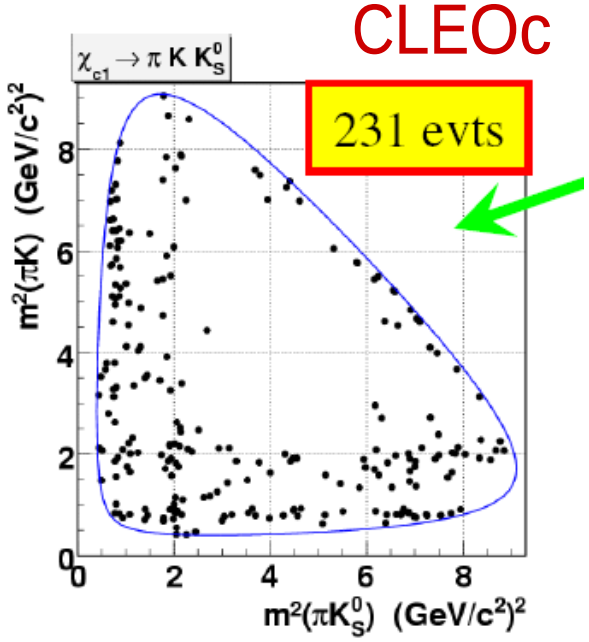
PDG'05

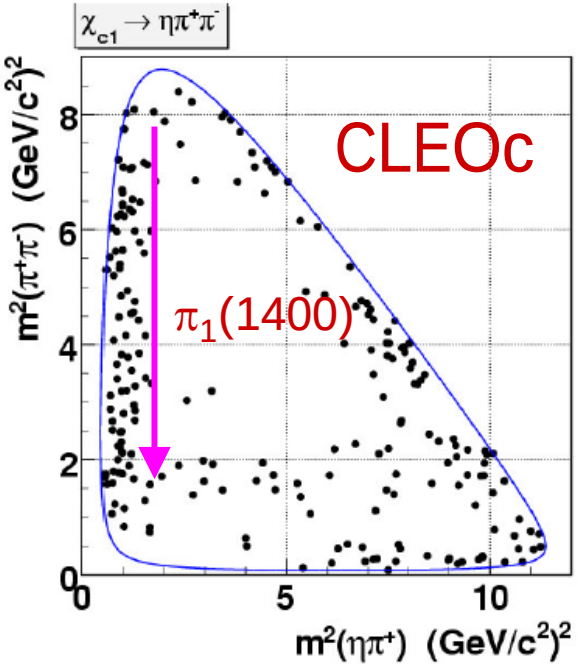
$\psi(2S) \to \gamma\eta'(958)$	$(\ 1.5\ \pm 0.4\ ) \times 10^{-4}$
$\psi(2S) \to \gamma f_2(1270)$	$(\ 2.1\ \pm 0.4\ ) \times 10^{-4}$
$\psi(2S) \to \gamma f_0(1710) \to \gamma\pi\pi$	$(\ 3.0\ \pm 1.3\ ) \times 10^{-5}$
$\psi(2S) \to \gamma f_0(1710) \to \gamma K\overline{K}$	$(\ 6.0\ \pm 1.6\ ) \times 10^{-5}$

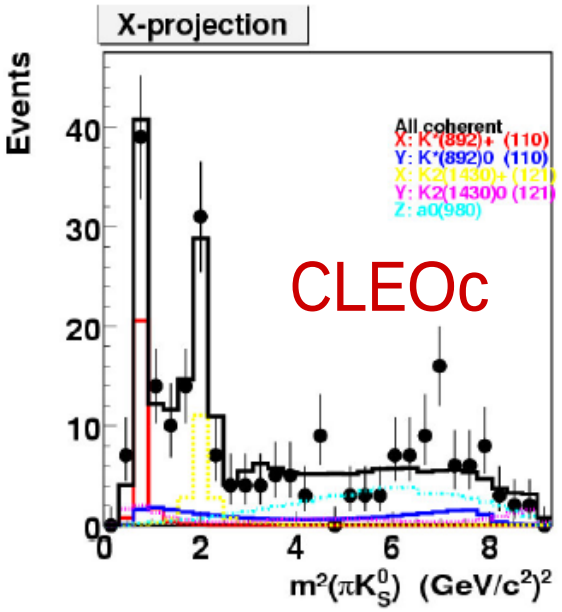
Decays of P-wave states

- 3 billion ψ'=1 billion χ_{cJ}
- COM/QCM
- Exotics from χ_{c1} decays
- Hadron spectroscopy, gluball search

1000 times more data than at CLEOc! Very good lab for light meson study!



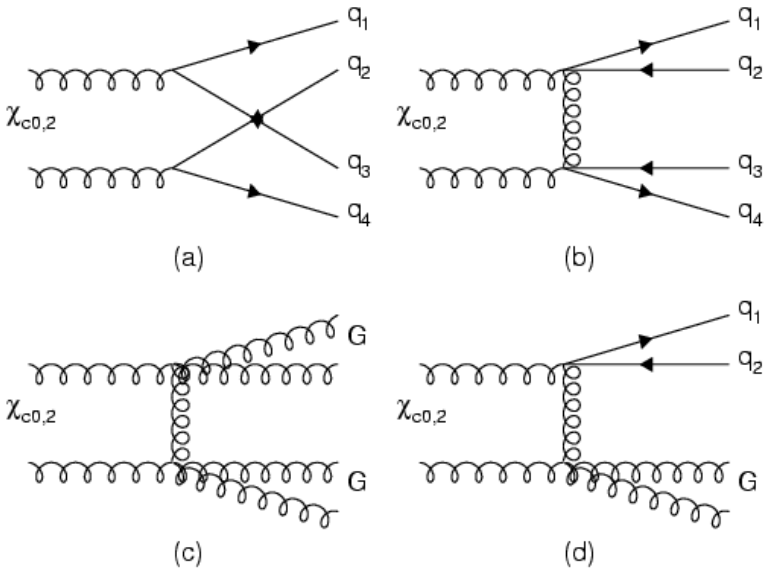




Pair production of scalars

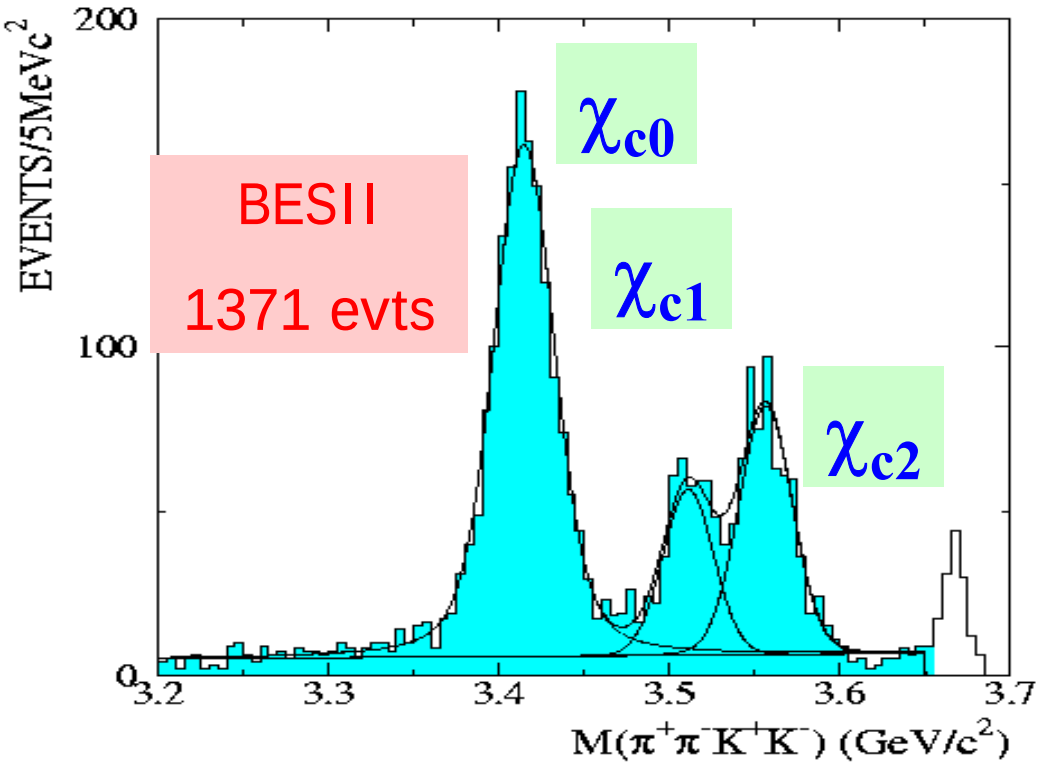
BES: PRD72, 092002 (2005)

$\chi_{c0} \to \pi^+\pi^-K^+K^-$



Different way for scalar study:

1. Start from $J^{PC}=0^{++}, 1^{++}, 2^{++}$
2. Start from gluon+gluon
3. Pair production of scalars, very different information than in J/ψ decays



Can study different kinds of resonances:

- $(\pi^+\pi^-)(K^+K^-)$
- $(K^+\pi^-)(K^-\pi^+)$
- $(K\pi\pi)K$

Also tensors and axle-vectors!

J/ψ study using $\psi' \rightarrow \pi^+\pi^- J/\psi$

- 3 billion ψ'=1 billion produced J/ψ

  ~ 0.5 billion tagged J/ψ
- No continuum background (so no interference …)
- No QED backgrounds
- Precise total number of events (<1% uncertainty)
- Compare with ψ' measurements using the same data sample cancels out many systematic uncertainties

J/ψ study using $\psi' \to \pi^+\pi^- J/\psi$

- $B(J/\psi \to l^+l^-, \pi^+\pi^-\pi^0, \ldots)$: precision
- $J/\psi \to \gamma\gamma$ (CV), $e\mu$, $e\tau$, ep, … (LFV, BV)
- $J/\psi \to n$ nbar
- PWA for J/ψ decays
  - S-wave dominant in $\psi' \to \pi^+\pi^- J/\psi$ decays
  - No ISR background in radiative decays
  - Take beam direction as z-axis, J/ψ almost likes produced in e^+e^- annihilation

Summary

- Lots of work need to do at BESIII
- Lots of measurements can be done at BESIII
- Simulation needed to know the sensitivities
- Theoretical efforts needed to guide the experiment and to interpret data
- Are there unexpected phenomena?
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Thank you!