# Charmonium hadronic transitions at BESIII

Zhentian Sun
Indiana University, Bloomington
On behalf of BESIII collaboration

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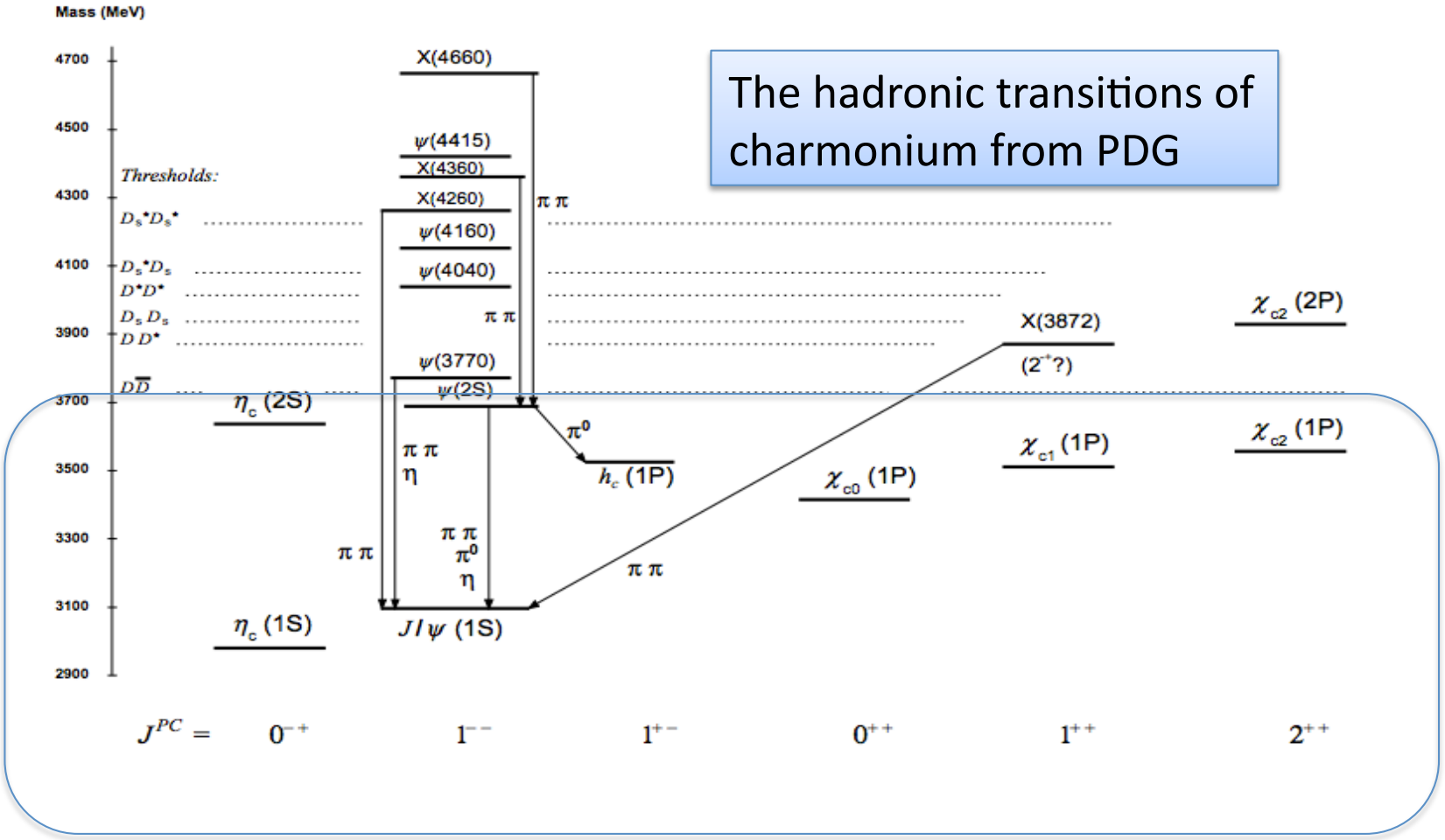
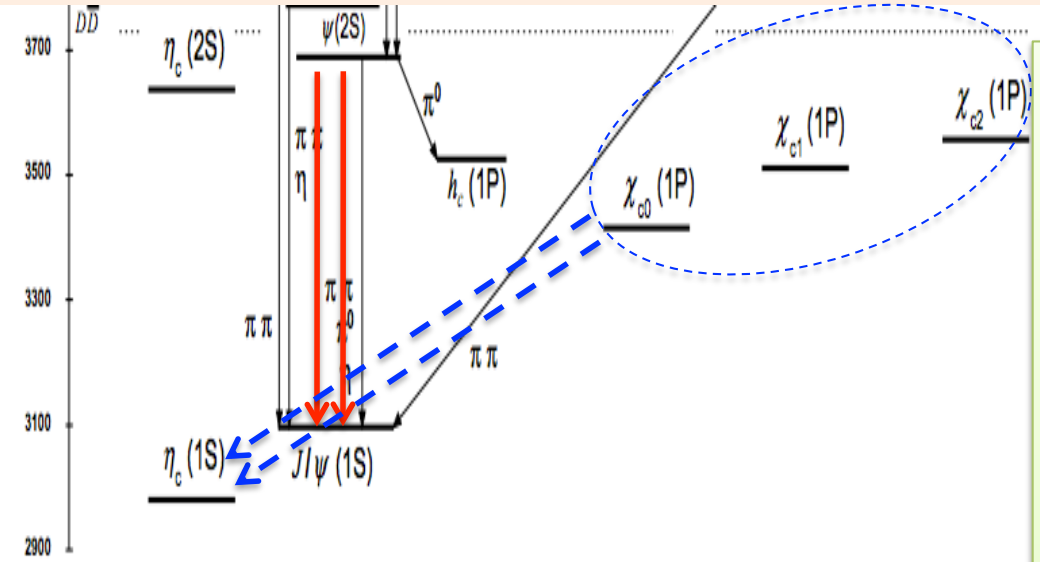
# Introduction

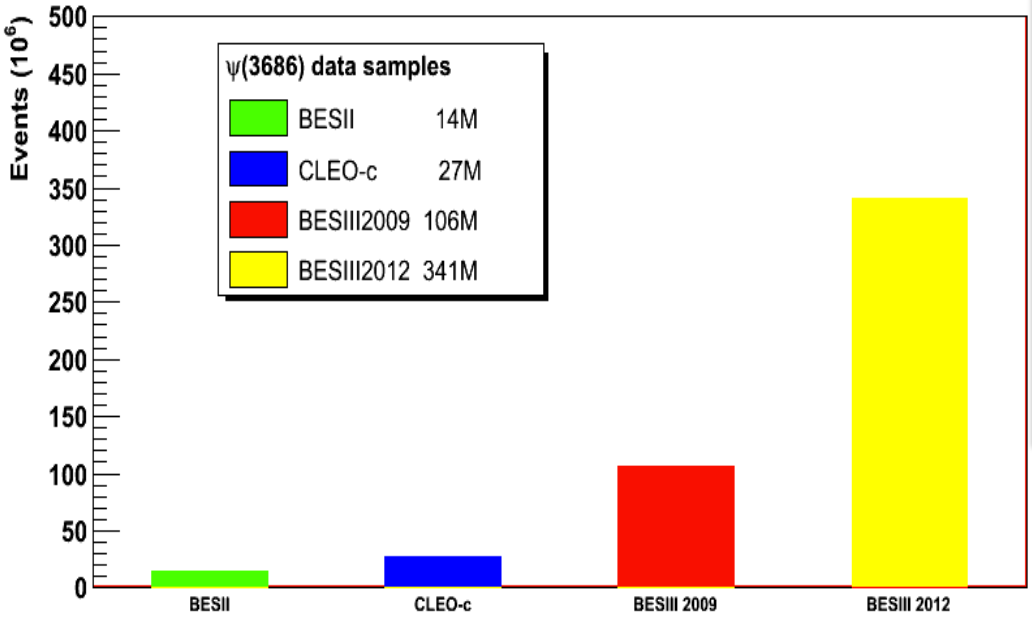



The hadronic transitions of charmonium from PDG

**My talk will focus on the hidden charm range.**

# Introduction




**All the BESIII analysis in this report are based on 106M ψ(3686) events. The analysis with about 341M ψ(3686) events taken at 2012 are ongoing.**

**The following four hadronic transition analysis at BESIII will be reported.**

**Precise measurement:**

**① Ψ(3686)→$\pi^+\pi^-$J/ψ**

**② Ψ(3686)→$\pi^0$J/ψ, ηJ/ψ**

**Searching for new decay**

**③ $\chi_{cJ}\to\pi^+\pi^-\eta_c$**

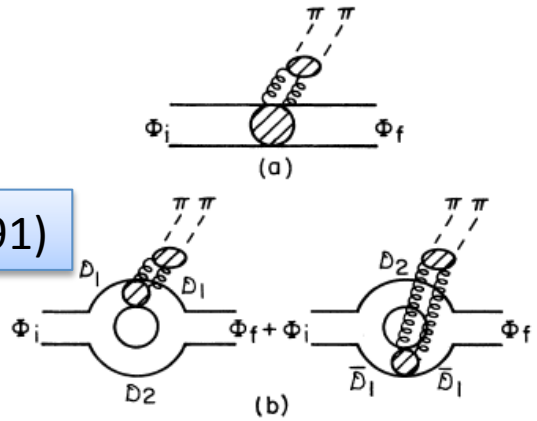
**④ $\chi_{cJ}\to\pi^0\eta_c$**

# $\Psi(3686) \rightarrow \pi^+\pi^- J/\psi$

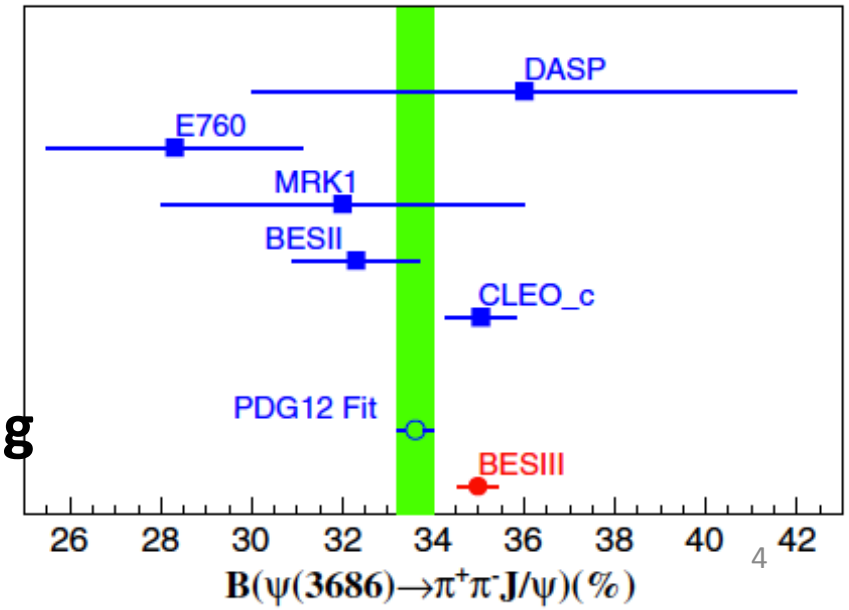
1. The largest branch of Ψ(3686), can provide clean J/ψ samples without the interference with Bhabha process.
2. Large part of the theoretical calculation about hadronic transitions are based on the multipole expansion + meson loop effect.

As a basic decay channel, it's often used as input for theoretical calculation.

PRD 44, 756(1991)




3. There are some discrepancy among previous measurements.



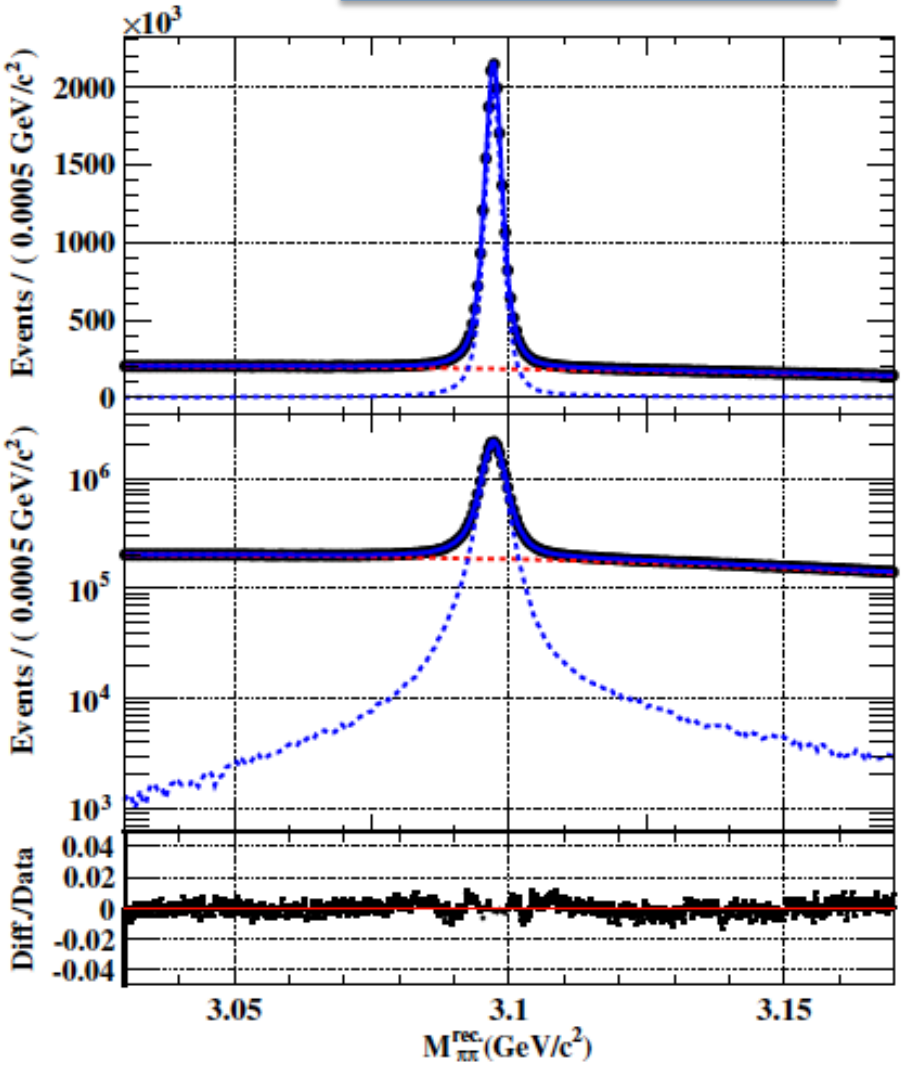
# Ψ(3686)→π⁺π⁻J/ψ@BESIII

- All the charged track pairs satisfy P(Trk⁺Trk⁻)<450MeV are assumed to be π⁺π⁻ pairs, and keep all the combinations with recoiled mass near J/ψ.
- Gamma conversion background is vetoed: cosθ(Trk⁺Trk⁻)<0.95
- Signal is fitted with MC simulated signal shape convolute double-gaussian

$$\mathcal{B}_{\pi\pi J/\psi} = \frac{N_{\pi\pi J/\psi}}{\epsilon_{\pi\pi J/\psi} \times N_{\rm tot}}$$

| | B(Ψ(3686)→π⁺π⁻J/ψ) |
|---|---|
| CLEO-c | (35.04±0.8)% |
| BESIII | (34.98±0.02±0.45)% |

PRD 88, 032007(2013)



# $\Psi(3686) \rightarrow \pi^0 J/\psi,\ \eta J/\psi$

**1. This is an isospin breaking process. The isospin symmetry breaking is due to the electromagnetic interaction and the up- and down-quark mass difference.**

**2. Based on the QCD multipole expansion and Partially Conserved Axial-vector Currents(PCAC)**

$$R = \frac{B(\psi(3686) \rightarrow \pi^0 J/\psi)}{B(\psi(3686) \rightarrow \eta J/\psi)} = \frac{27}{16}\left(\frac{p_\pi}{p_\eta}\right)^3 r^2,$$

Phys. Rep. 194, 1 (1990)

$$r = \frac{m_d - m_u}{m_s - 0.5\cdot(m_d + m_u)}$$

**R=0.0162, based on conventionally accepted quark masses**

Phys. Rev. D 70, 012006 (2004)

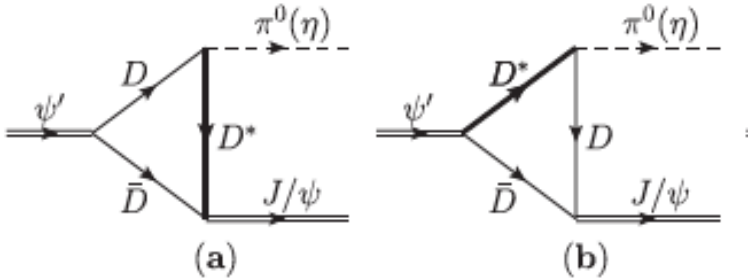
**3. CLEO's measurement: Larger than previous theoretical prediction**

$$R = \frac{B(\psi(3686) \rightarrow \pi^0 J/\psi)}{B(\psi(3686) \rightarrow \eta J/\psi)} = (3.88 \pm 0.23 \pm 0.05)\%$$

Phys. Rev. D 78, 011102 (2008)

# $\Psi(3686)\rightarrow\pi^0 J/\psi,\ \eta J/\psi$

- **Some theorist try to improve the situation by including the intermediate (virtual) charmed meson loops.**



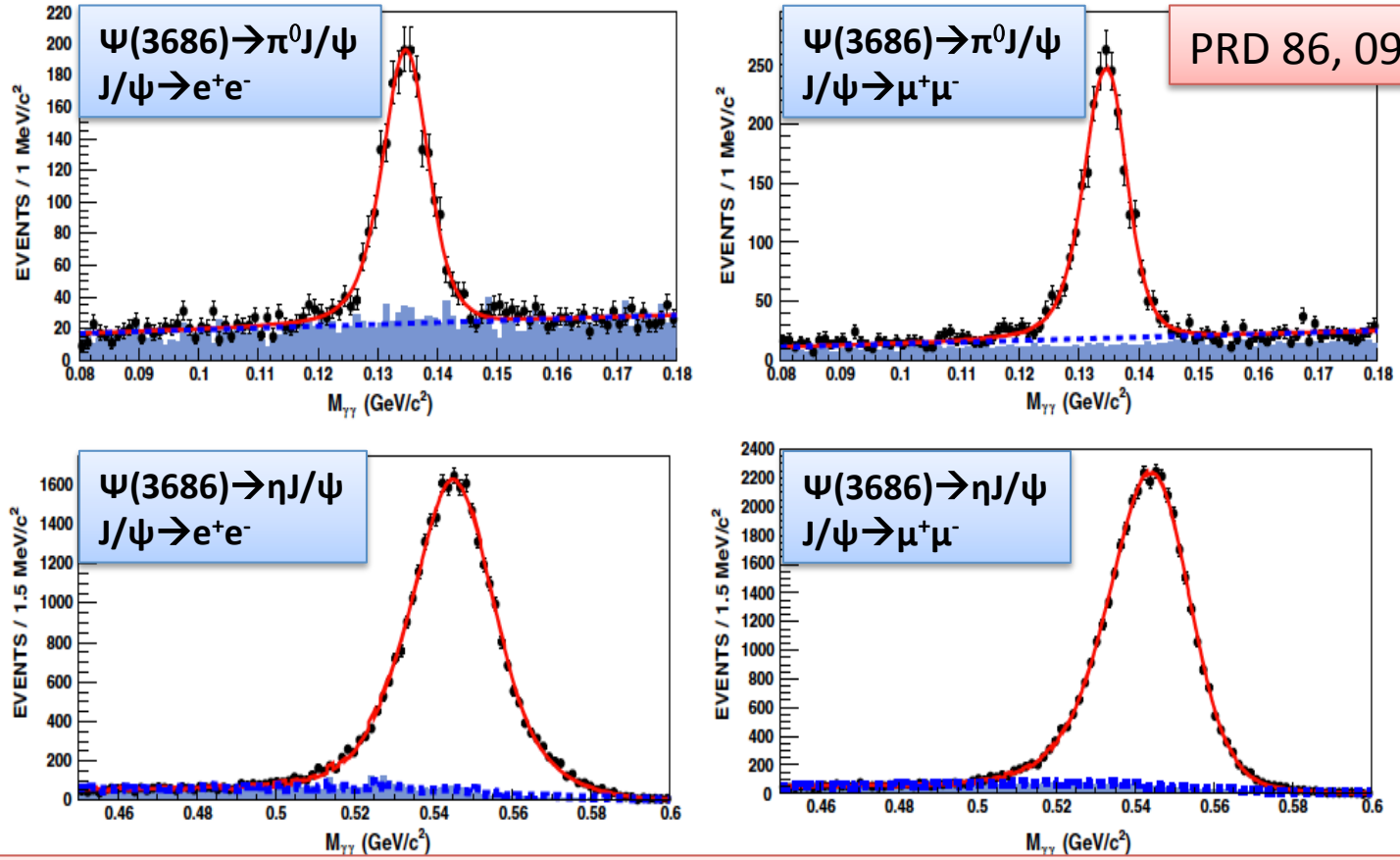

PRL 103, 082003(2009)

- **Assuming the intermediate charmed-meson loop mechanism saturates the decay widths of the $\Psi(3686)\rightarrow\pi^0 J/\psi,\ \eta J/\psi$ we get R=0.11±0.06**

PRL 104, 109901 (2010)

- **0.0162<0.0388<0.11, the experimental result lies between the prediction given by two models →mixture of the two models?**

# $\Psi(3686)\rightarrow\pi^0 J/\psi$, $\eta J/\psi$@BESIII




PRD 86, 092008(2012)

- Two photons, two leptons are reconstructed, 4C kinematic fit is used
- Signal peak is fitted with MC shape ⊗ gaussian function.
- $B(\Psi(3686)\rightarrow\pi^0 J/\psi) = (1.26\pm0.02\pm0.03)\times10^{-3}$

  $B(\Psi(3686)\rightarrow\eta J/\psi) = (33.75\pm0.17\pm0.86)\times10^{-3}$

  $R\pi^0/\eta = (3.74\pm0.06\pm0.04)\%$ agrees with CLEO's measurement

# $\chi_{cJ} \rightarrow \pi^+\pi^-\eta_c$

**1. Hadronic transition of $^3P_J$ states are seldom explored, as $\chi_{cJ}$ can't be produced directly from $e^+e^-$ annihilation.**

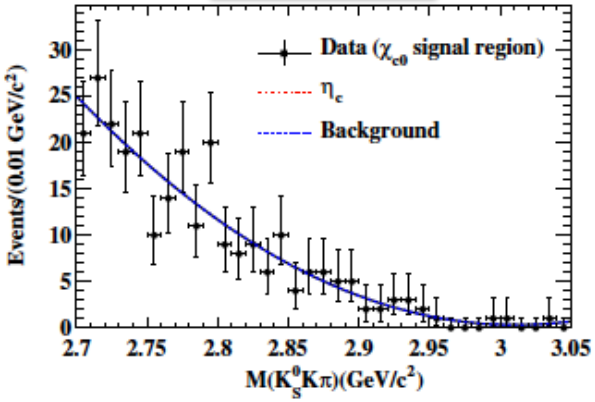
**2. The single previous experimental result was reported by BABAR, $B(\chi_{c2} \rightarrow \pi^+\pi^-\eta_c) < 2.2\%@90\%C.L.$** PRD 86, 092005 (2012)

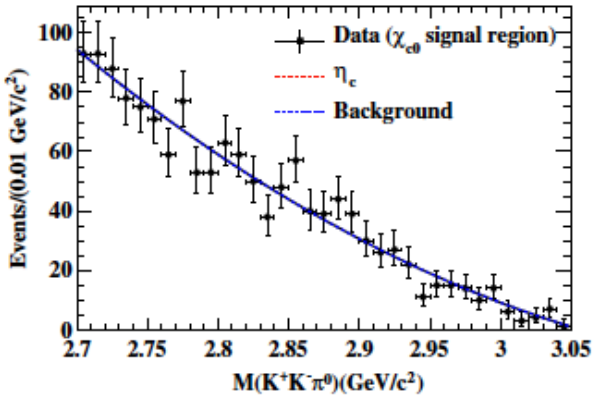
**3. The process $\chi_{c1} \rightarrow \pi^+\pi^-\eta_c$ dominated by E1-M1 transition, calculated in the multipole expansion formalism.**
**$B(\chi_{c1} \rightarrow \pi^+\pi^-\eta_c) = (2.72 \pm 0.39)\%$** PRD 75, 054019 (2007)

# $\chi_{cJ} \rightarrow \pi^+\pi^-\eta_c$

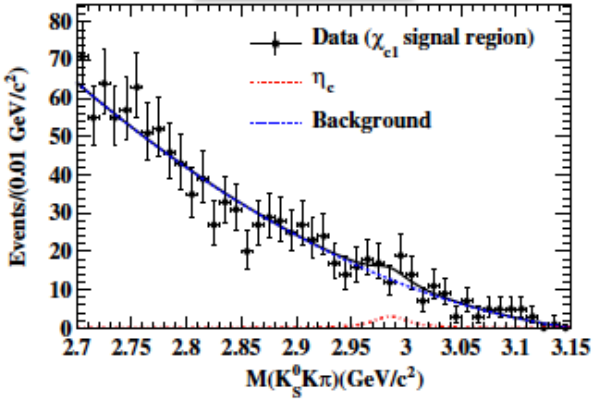
PRD87, 012002(2013)

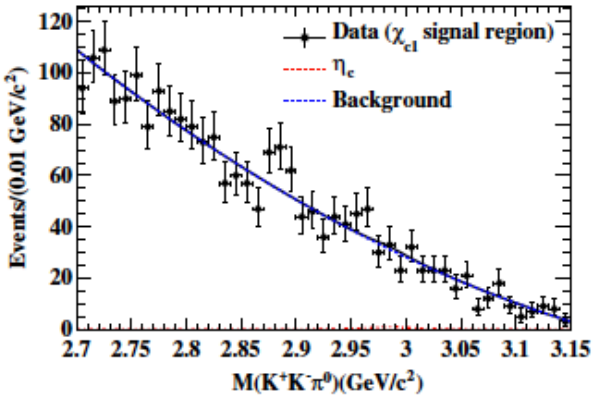
$X_{c0}$ range



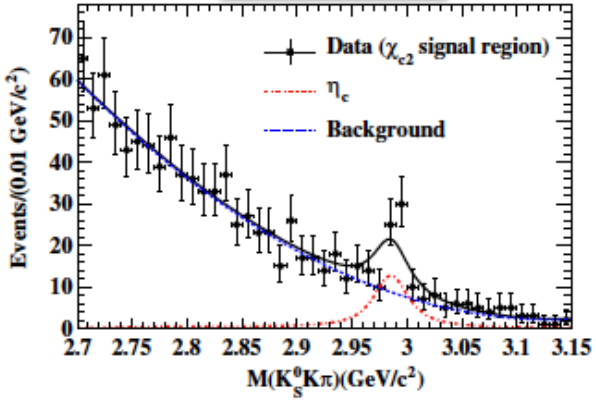



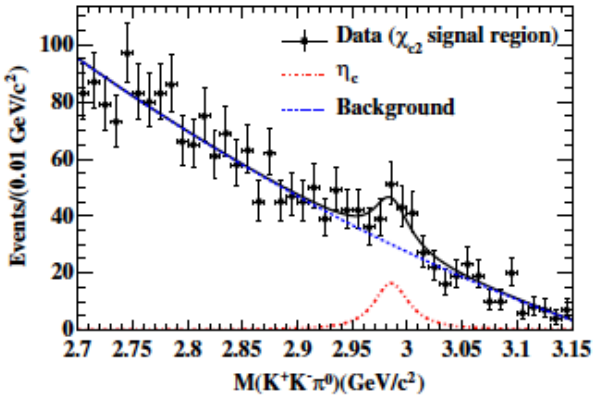

$X_{c1}$ range




$X_{c2}$ range




**BESIII result($\eta_c \rightarrow$KsK$\pi$):**

$B(\chi_{c0} \rightarrow \pi^+\pi^-\eta_c) < 0.07\%$

$B(\chi_{c1} \rightarrow \pi^+\pi^-\eta_c) < 0.32\%$

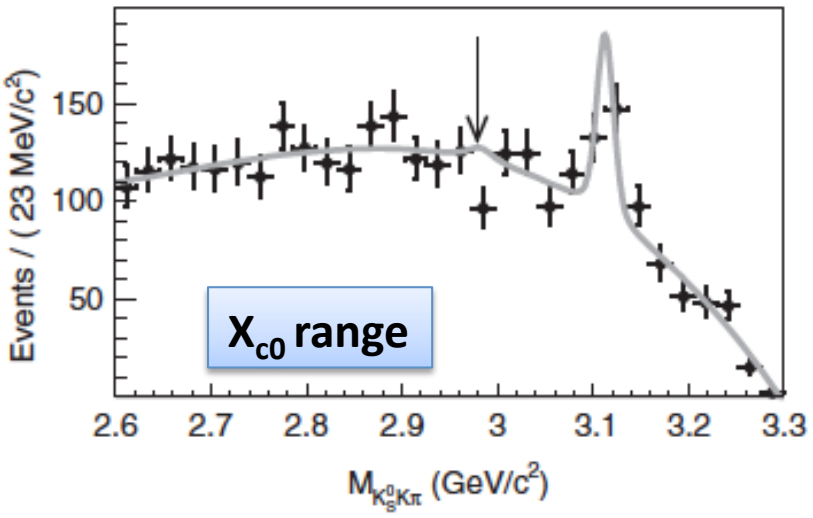
$B(\chi_{c2} \rightarrow \pi^+\pi^-\eta_c) < 0.54\%$

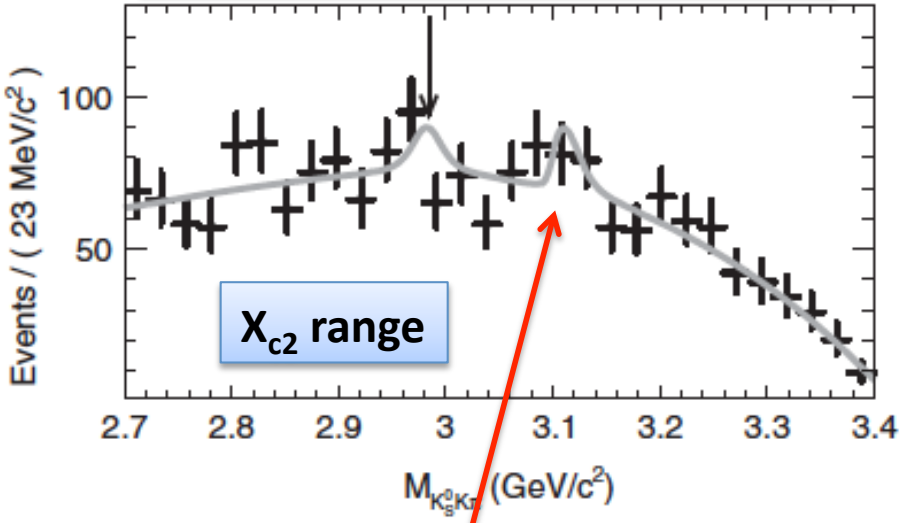
- Two modes: $\eta_c \rightarrow$KsK$\pi$, $\eta_c \rightarrow K^+K^-\pi^0$ is used to search the $\chi_{cJ} \rightarrow \pi^+\pi^-\eta_c$ No clear signal observed.
- The peak in $\chi_{c2}$ is dominated by background $\Psi' \rightarrow \pi^+\pi^- J/\psi$, $J/\psi \rightarrow \gamma\eta_c$
- The uplimit for $\chi_{c2} \rightarrow \pi^+\pi^-\eta_c$ agrees with BABAR's result
- The $\chi_{c1} \rightarrow \pi^+\pi^-\eta_c$ is much smaller than theoretical prediction

# $X_{cJ} \rightarrow \pi^0 \eta_c$

- No measurement before
- Isospin breaking process.

Phys. Rev. D 91, 112018 (2015)




- $\chi_{c1} \rightarrow \pi^0 \eta_c$ is forbidden by $J^{PC}$ conservation law, so only $\chi_{c0}$ and $\chi_{c2}$ are studied.
- $\eta_c \rightarrow K_s^0 K^{\pm} \pi^{\mp}$ is used in the measurement.
- No clear $\eta_c$ signal is observed, in the above fit, the $\eta_c$ is represented by Breit-Wigner function with parameters fixed to PDG then convolute a resolution from MC simulation. The peak around 3.12GeV is from background $\psi(3686) \rightarrow \pi^0\pi^0 J/\psi$, $J/\psi \rightarrow K_s^0 K^{\pm} \pi^{\mp}$

# $\chi_{cJ} \to \pi^0 \eta_c$

- **Our result, the uplimit at 90% CL.**

**$B(\chi_{c0} \to \pi^0 \eta_c) < 1.6 \times 10^{-3}$, $B(\chi_{c2} \to \pi^0 \eta_c) < 3.2 \times 10^{-3}$**

- **There is theoretical calculation predict that**

$$\mathcal{B}(\chi_{c0} \to \eta_c \pi^0) \approx \mathcal{B}(\chi_{c1} \to \eta_c \pi^+ \pi^-).$$

PRD 86, 074003(2012)

**based on the leading order of QCD multipole expansion.**

- **If we compare with our previous result $B(\chi_{c1} \to \pi^+\pi^-\eta_c) < 3.2 \times 10^{-3}$, they are both uplimit→measurement with more data is needed.**

# Summary

- **Result from four analysis are reported**

✓ $B(\Psi(3686)\rightarrow\pi^+\pi^- J/\psi)=(34.98\pm0.02\pm0.45)\%$

✓ $B(\Psi(3686)\rightarrow\pi^0 J/\psi)= (1.26\pm0.02\pm0.03)\times10^{-3}$

$B(\Psi(3686)\rightarrow\eta J/\psi) = (33.75\pm0.17\pm0.86)\times10^{-3}$

✓ $B(\chi_{c0}\rightarrow\pi^+\pi^-\eta_c) < 0.07\%$, $B(\chi_{c1}\rightarrow\pi^+\pi^-\eta_c) < 0.32\%$, $B(\chi_{c2}\rightarrow\pi^+\pi^-\eta_c) < 0.54\%$

✓ $B(\chi_{c0}\rightarrow\pi^0\eta_c) < 1.6\times10^{-3}$, $B(\chi_{c2}\rightarrow\pi^0\eta_c) < 3.2\times10^{-3}$

- **More precise measurement can be expected with total ~450M ψ(3686) events from BESIII.**
- **Other unobserved hadronic transitions of charmonium can also be measured.**

✓ $h_c\rightarrow\pi^+\pi^- J/\psi$, PRL 69, 2337 (1992)

✓ $\Psi(3686)\rightarrow\pi^+\pi^-\pi^0\eta_c$, PRD 75, 011102 (2007)

# Back up slides

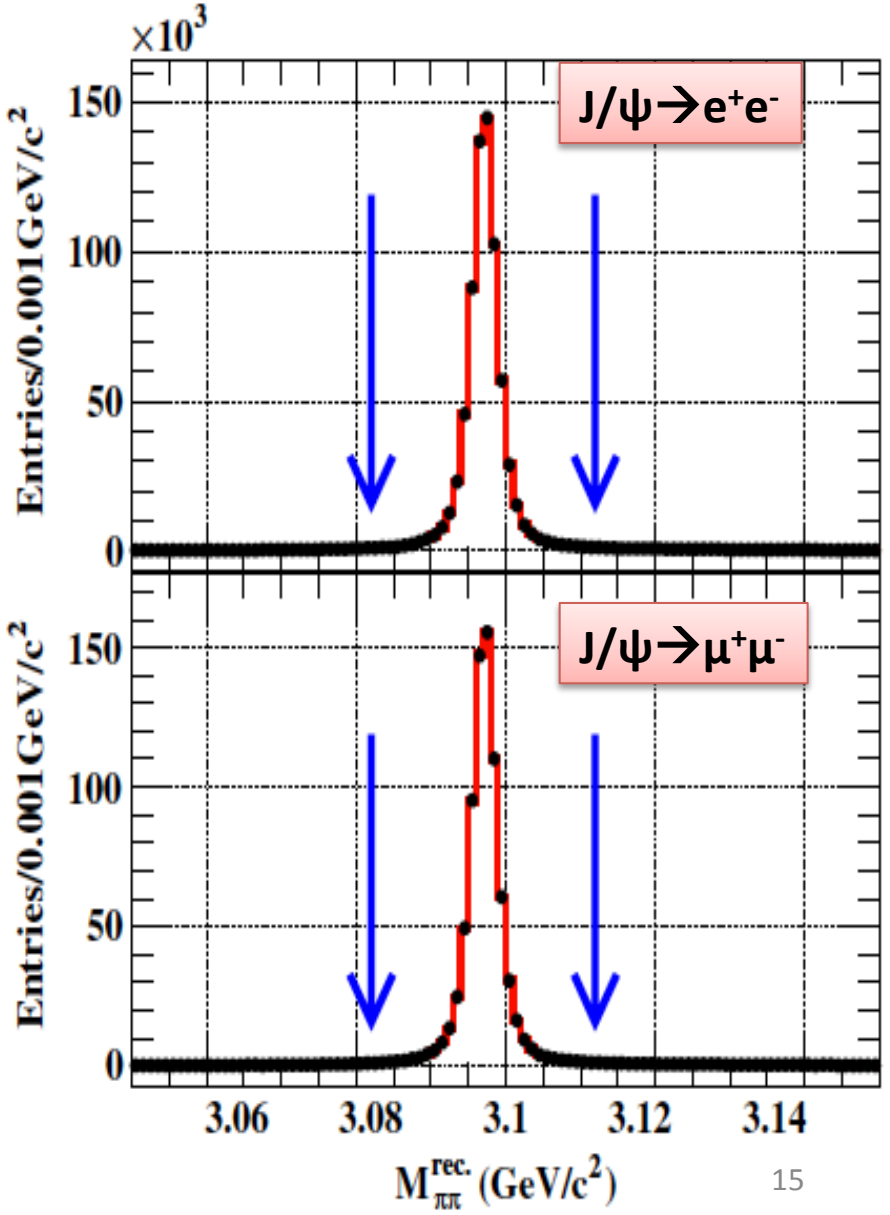
# Ψ(3686)→$\pi^+\pi^-$J/ψ@BESIII

- **By further reconstructing $l^+l^-$ pair, B(J/ψ→ll) are measured. The number of Ψ(3686) is not needed.**

$$\mathcal{B}_{ll} = \frac{\mathcal{B}_{\pi\pi J/\psi} \times \mathcal{B}_{ll}}{\mathcal{B}_{\pi\pi J/\psi}} = \frac{N_{ll}/(\epsilon_{ll} \times N_{\rm tot})}{N_{\pi\pi J/\psi}/(\epsilon_{\pi\pi J/\psi} \times N_{\rm tot})} = \frac{N_{ll}/\epsilon_{ll}}{N_{\pi\pi J/\psi}/\epsilon_{\pi\pi J/\psi}}.$$

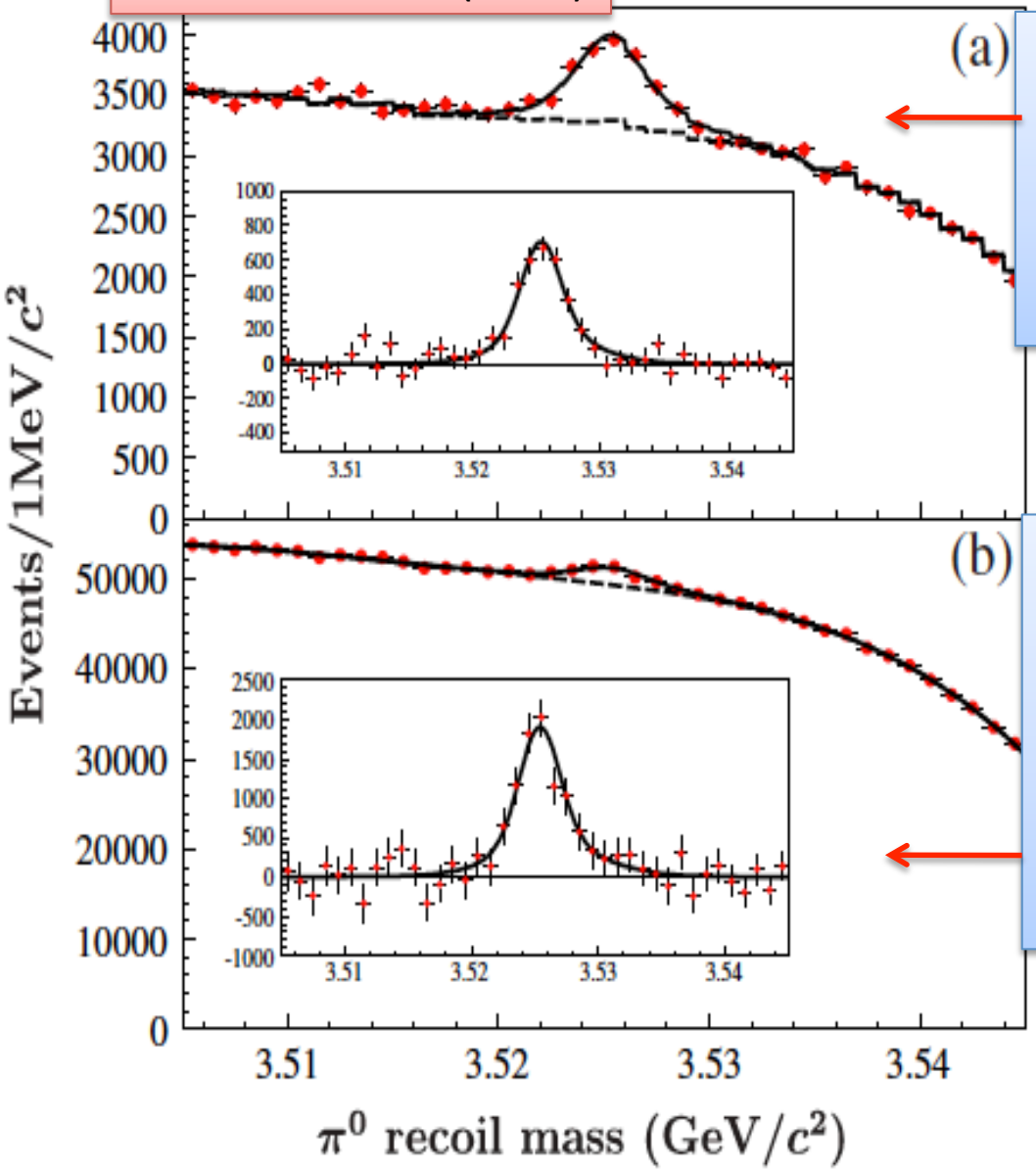
- **B(J/ψ→$e^+e^-$)= (5.983±0.007±0.037)%**
- **B(J/ψ→$\mu^+\mu^-$)= (5.973±0.007±0.038)%**
- **B(J/ψ→$e^+e^-$)/ B(J/ψ→$\mu^+\mu^-$)= 1.0017±0.0017±0.0033**

**Agree with the e-μ universality**



# Measurement of $h_c(^1P_1)$ in $\psi'$ decay inclusive

PRL 104, 132002(2010)




$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ anything

$M(h_c)=3525.40\pm0.13\pm0.18$ MeV

$\Gamma(h_c)<1.44$ MeV@90% C.L.

**$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow$ anything**

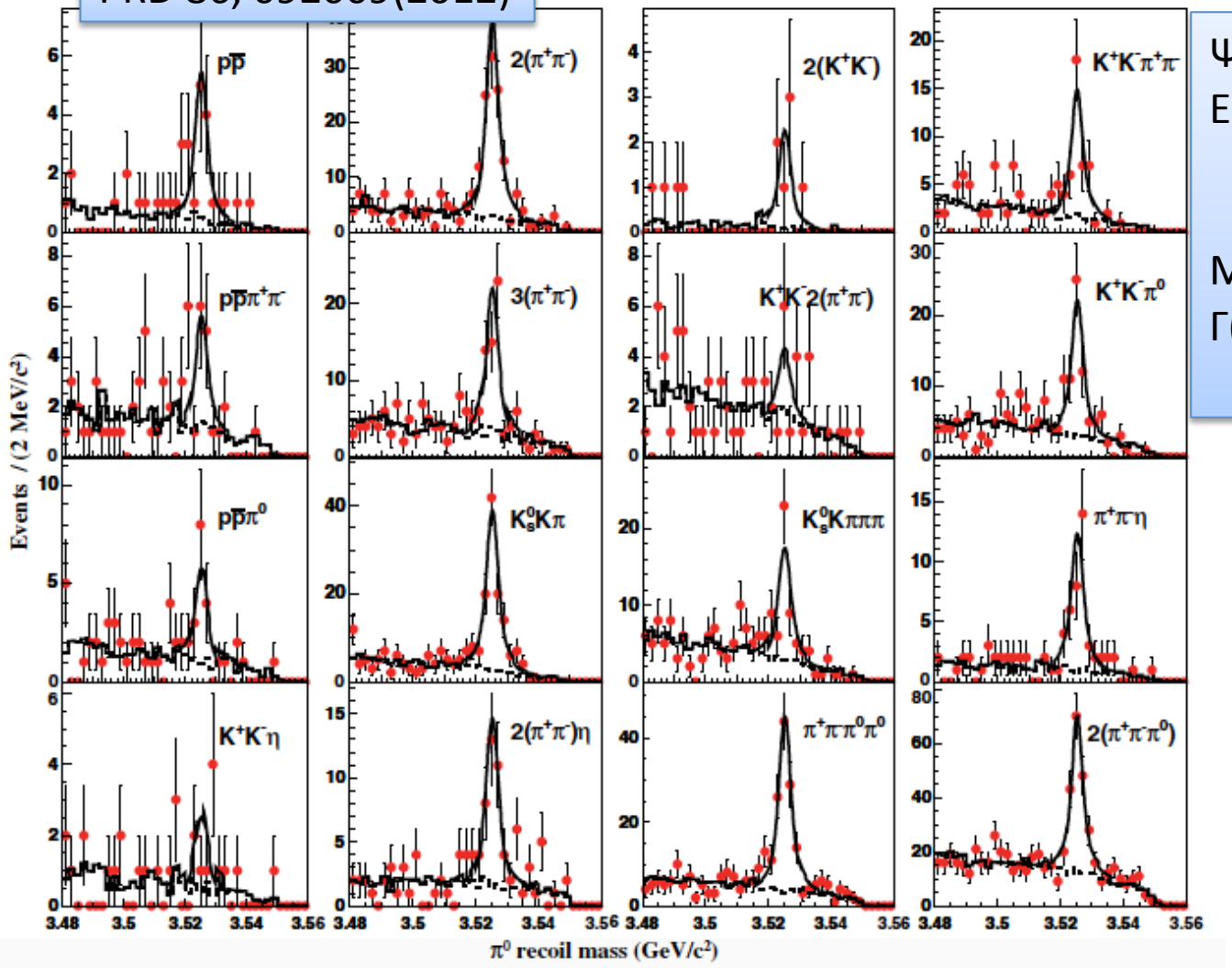
**$Br(\psi' \rightarrow \pi^0 h_c)=(8.4\pm1.3\pm1.0) \times 10^{-4}$**

**$Br(\psi' \rightarrow \pi^0 h_c) \times Br(h_c \rightarrow \gamma\eta_c)$**
**$=(4.58\pm0.40\pm0.50) \times 10^{-4}$**

**$Br(h_c \rightarrow \gamma\eta_c)=(54.3\pm6.7\pm5.2)$ %**

# Measurement of $h_c(^1P_1)$ in $\psi'$ decay exclusive

PRD 86, 092009(2012)




$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$, $\eta_c \rightarrow$ 16 Exclusive modes

$M(h_c)$=3525.40±0.11±0.14 MeV

$\Gamma(h_c)$ =0.70±0.28±0.22 MeV