# Studies of charmonium at BESIII


**Wenbiao Yan**

**University of Science and Technology of China**

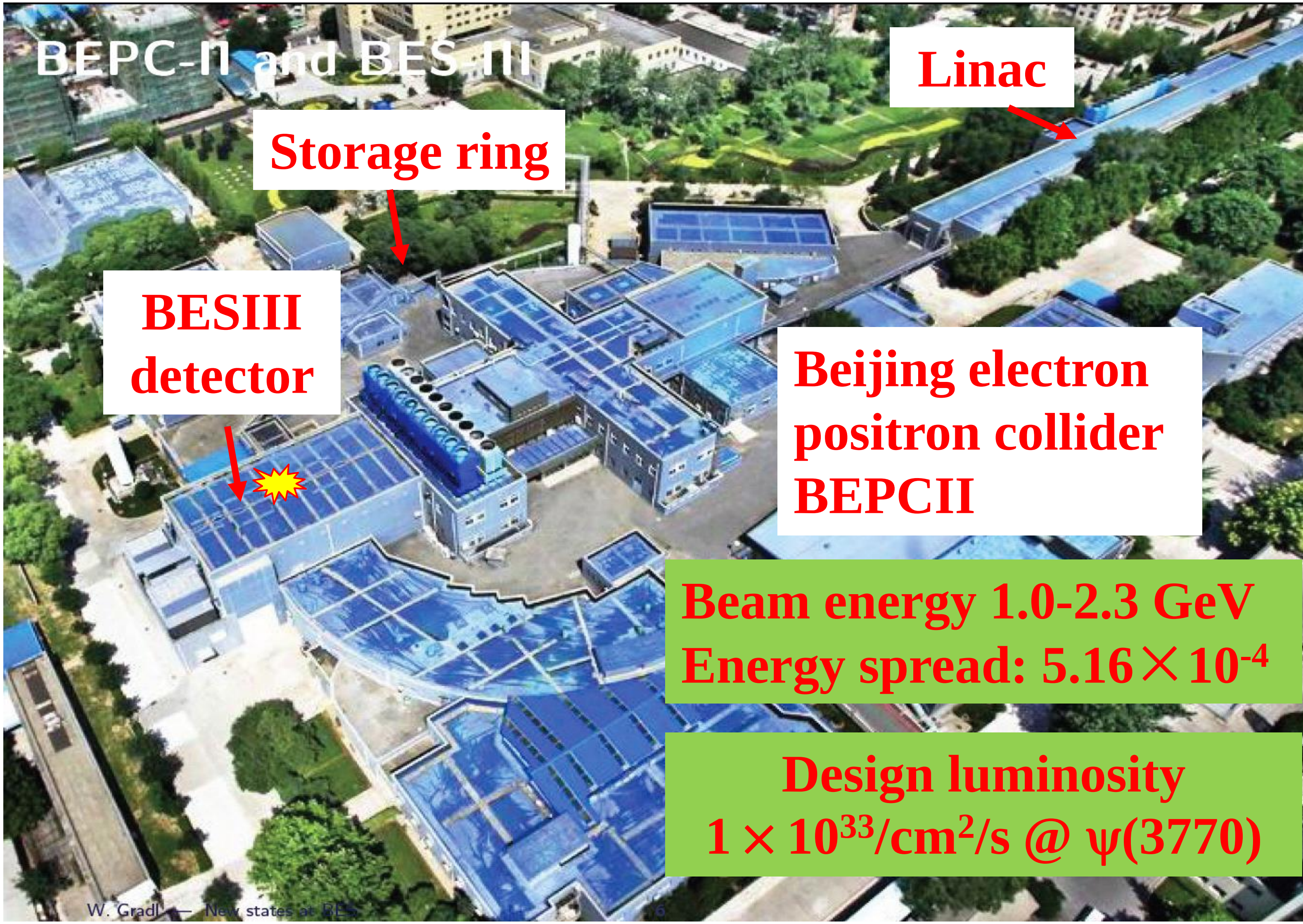
**On behalf of BESIII Collaboration**


**50th of Rencontres de Moriond**

**QCD and High Energy Interactions**

**La Thuile, March 21-28, 2015**

# Bird's View of BEPCII & BESIII



# BESIII Collaboration


**US (5)**
Univ. of Hawaii
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

**Europe (13)**
Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Univ. of Ferrara, Frascati Lab
Netherland：KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

**Korea (1)**
Seoul Nat. Univ.

**Japan (1)**
Tokyo Univ.

**Pakistan (2)**
Univ. of Punjab
COMSAT CIIT

**China(31)**
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Beihang Univ., Beijing Petrol Chemical Univ.

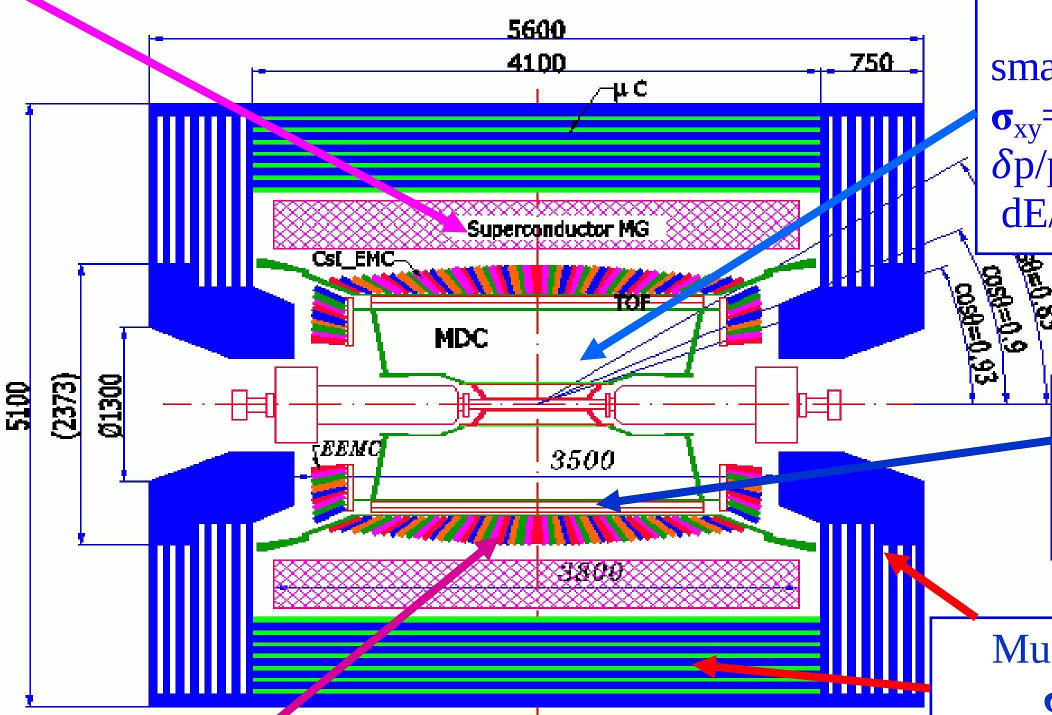
**~400 members**
**53 institutions from 11 countries**

# BESIII Detector

Solenoid Magnet: 1 T Super conducting

MDC
small cell & He gas
$\sigma_{xy}$=130 μm
$\delta p/p$ = 0.5%@1GeV
dE/dx=6%

**NIM A614 345 (2010)**




TOF
$\sigma_T$ = 90 ps Barrel
110 ps Endcap

Muon ID: 8~9 layer RPC
$\sigma_{R\Phi}$=1.4 cm~1.7 cm

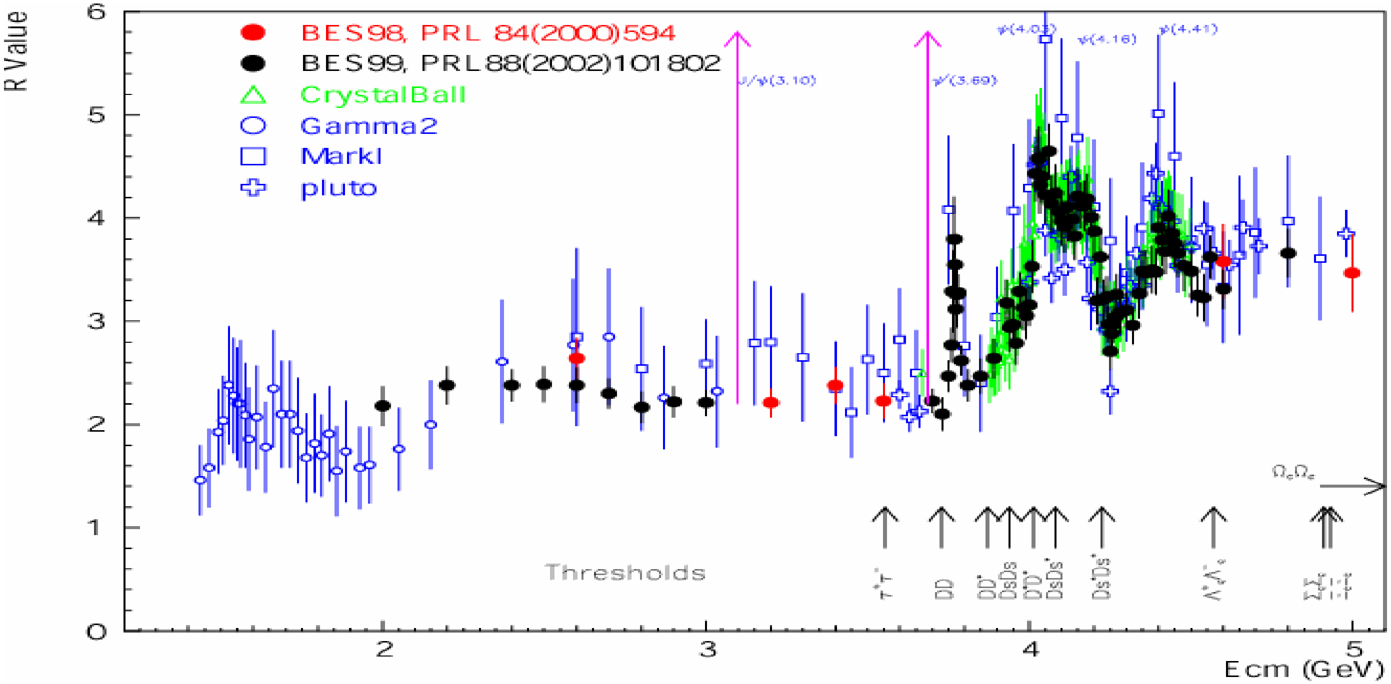
EMCAL: CsI crystal
$\Delta E/E$ = 2.5% @1 GeV
$\sigma_{\varphi,z}$ = 0.5~0.7 cm/$\sqrt{E}$

Data Acquisition:
Event rate = 3 kHz
Throughput ~ 50 MB/s

Trigger: Tracks & Showers
Pipelined; Latency = 6.4 μs

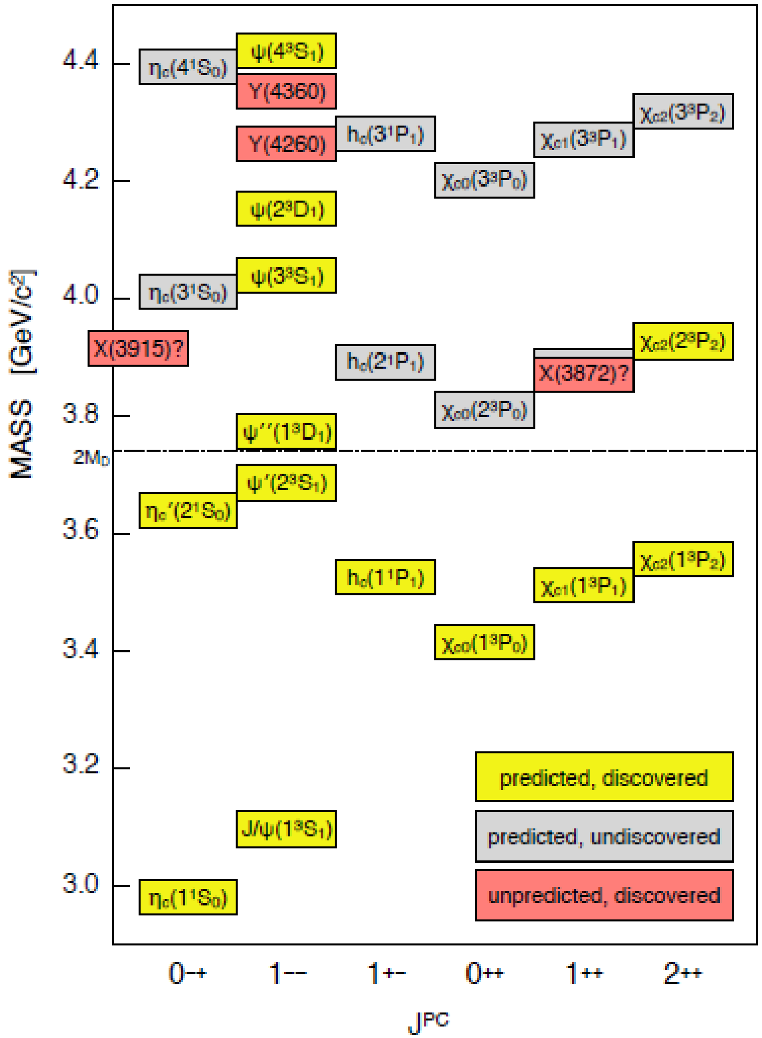
**Hermetic spectrometer for neutral and charged particle with excellent resolution, PID, and large coverage**

# Features of the BEPCII Energy Region




- **Rich of** **resonances**, **charmonium and charmed mesons**
- **Threshold** **characteristics (pairs of τ, D, $D_s$, charmed baryons…)**
- **Transition between** **smooth and resonances, perturbative and non-perturbative QCD**
- **Energy location of the** **gluonic matter** **and** **glueball**, **exotic states** **and** **hybrid**

# Charmonium spectroscopy




- **Charmonium in QCD is like positronium in QED**
- **Below open charm threshold, all states have been observed**
  - **Rare decays**
  - **Radiative decays**
- **Above open charm threshold, situation is complex**
  - **Many missing states**
  - **Some states do not fit into $c\bar{c}$ slots**
  - **Details @ Kai's talk**

# Charmonium rare decays

- **Standard model has surved decades of experimental tests. But there are still room for physics beyond standard model. Search for it @ energy frontier , e.g. LHC; @ low energy collision with high luminosity.**
- **Search for SM-forbidden processes with charmonium samples**
  - ✓ **C-parity violation decays @ EM interaction: $J/\psi \rightarrow \gamma\gamma$ and $\gamma\phi$**
- **Charmonium decays are dominated by electromagnetic and strong interaction, weak decays are rare.**
  - ✓ **Highly suppressed @ SM, observation maybe due to new physics**
  - ✓ **Semileptonic weak decays: $J/\psi \rightarrow D_s^* l\nu$, $J/\psi \rightarrow D_s l\nu$**
  - ✓ **Two-body hadronic weak decays: $J/\psi \rightarrow D_s^*\rho$ and $D^0K^{*0}$**

# C-parity violation decays

- **In Standard model , C invariance is held in strong and electromagnetic interactions. Evidence for C violation in the EM sector would immediately indicate physics beyond SM.**
- **Untill now, No C-violating processes have been observed in electromagnetic interactions**

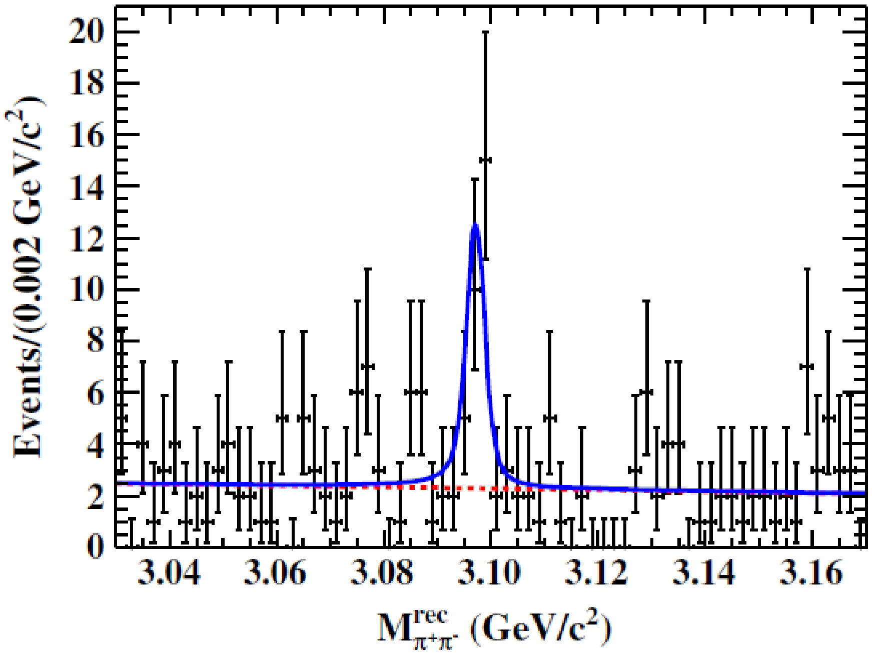
**$\Gamma(\gamma\gamma)/\Gamma_{total}$** **$\Gamma_{197}/\Gamma$**

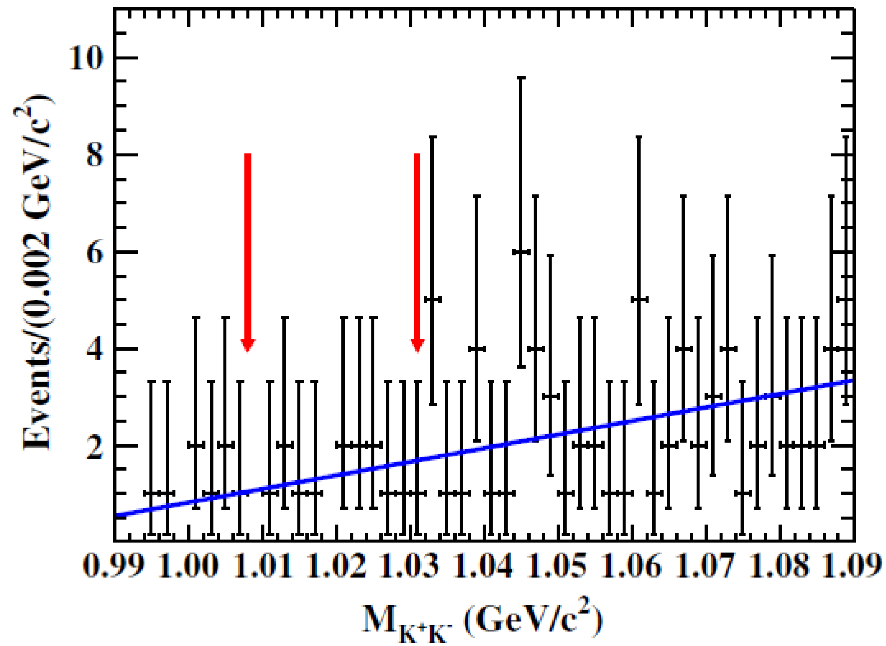
| *VALUE* (units $10^{-5}$) | *CL%* | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|---|
| **< 0.5** | 90 | ADAMS | 08 | CLEO | $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| <16 | 90 | [1] WICHT | 08 | BELL | $B^{\pm} \rightarrow K^{\pm}\gamma\gamma$ |
| < 2.2 | 90 | ABLIKIM | 07J | BES2 | $\psi(2S) \rightarrow J/\psi\pi^+\pi^-$ |
| <50 | 90 | BARTEL | 77 | CNTR | $e^+e^-$ |

- **Use $\psi(3686) \rightarrow J/\psi\ \pi^+\pi^-$ for $J/\psi$ sample, and search for $J/\psi \rightarrow \gamma\gamma$ and $J/\psi \rightarrow \gamma\phi$**

# J/ψ →γγ and γϕ

PRD90 (2014) 092002



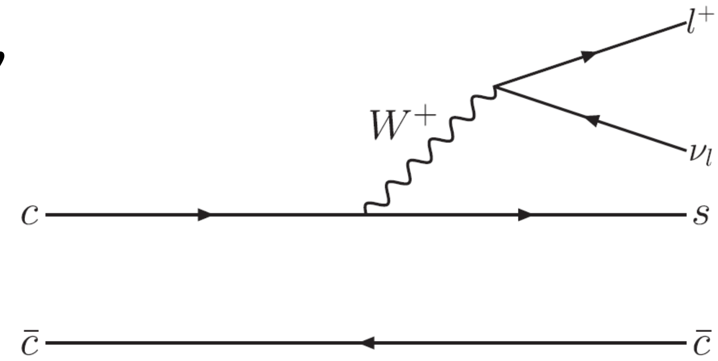

- J/ψ →γγ via ψ(3686)→J/ψ $\pi^+\pi^-$
- Check recoil mass of $\pi^+\pi^-$ , peak due to background contribution
- Br(J/ψ →γγ ) < 2.7×$10^{-7}$@90%CL
- Best @ PDG2014: 5.0×$10^{-6}$

- J/ψ →γϕ via ψ(3686)→J/ψ $\pi^+\pi^-$
- invariant mass of $K^+K^-$ for ϕ signal
- Br(J/ψ →γϕ) < 1.4×$10^{-6}$@90%CL
- First upper limit for J/ψ →γϕ

# Semileptonic weak decays

- **J/ψ could decay into a single charmed meson via weak decay**

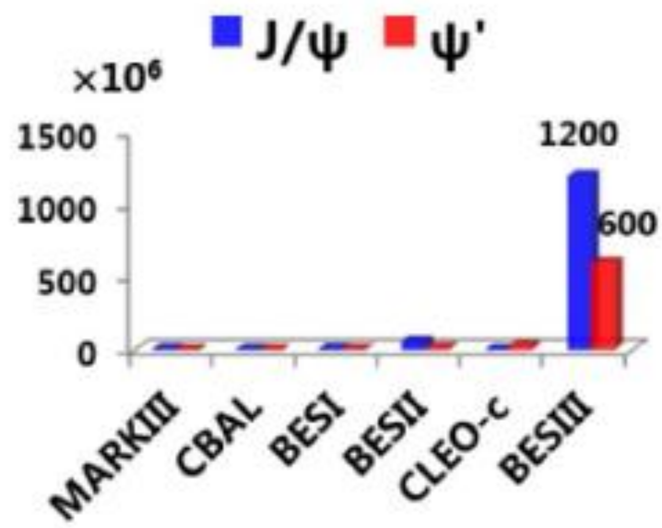
- **SM predicts ~$10^{-10}$ for J/ψ →Ds*lν by using QCD sum rule**



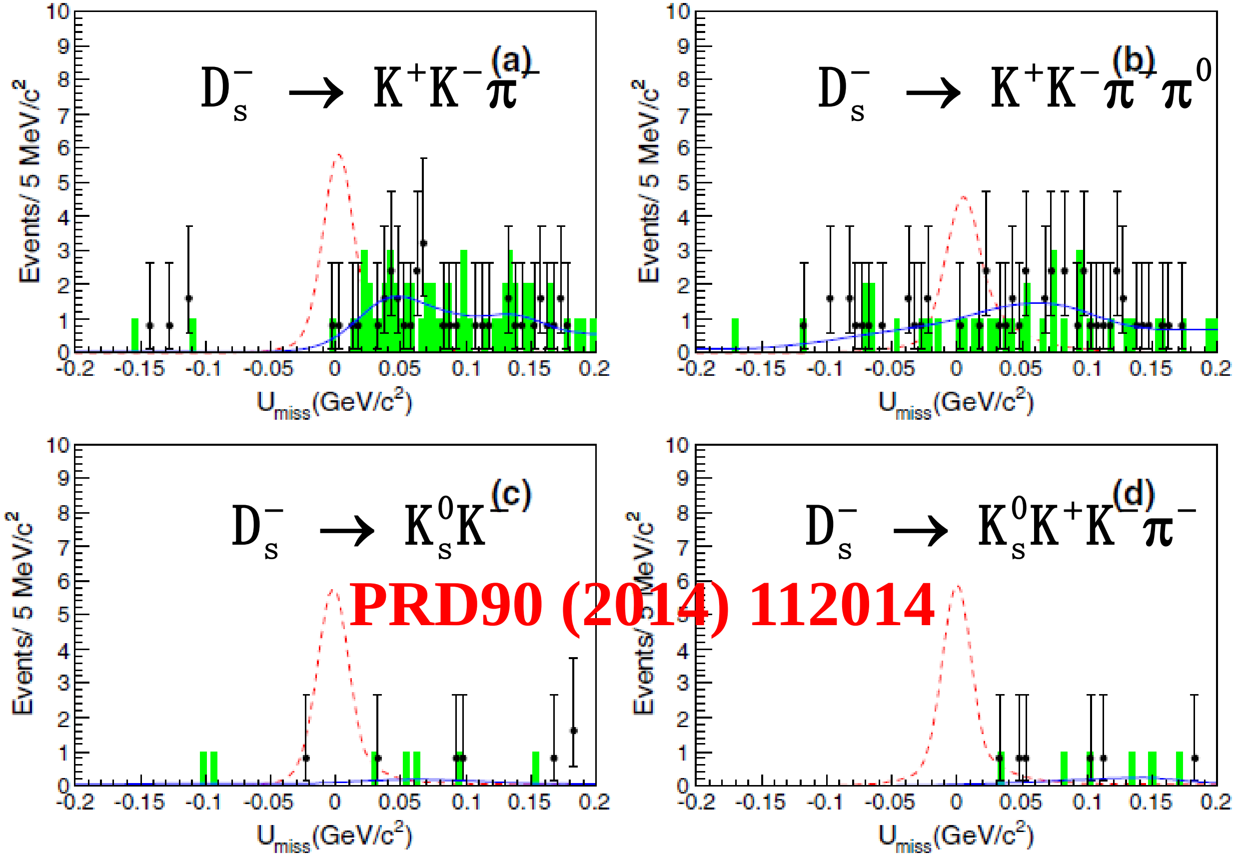

- **Some new interaction couplings could enhance**

  - **Top color model**
  - **Minimal Supersymmetric SM**
  - **Two-Higgs-doublet model**

$$\frac{Br(J/\psi \to D_s^* l\nu)}{Br(J/\psi \to D_s l\nu)} \approx 1.5 \sim 3.1$$



# Search for $J/\psi \to D_s^- e^+ \nu_e$ + c.c




**PRD90 (2014) 112014**

$$J/\psi \to D_s^- e^+ \nu_e + c.c$$

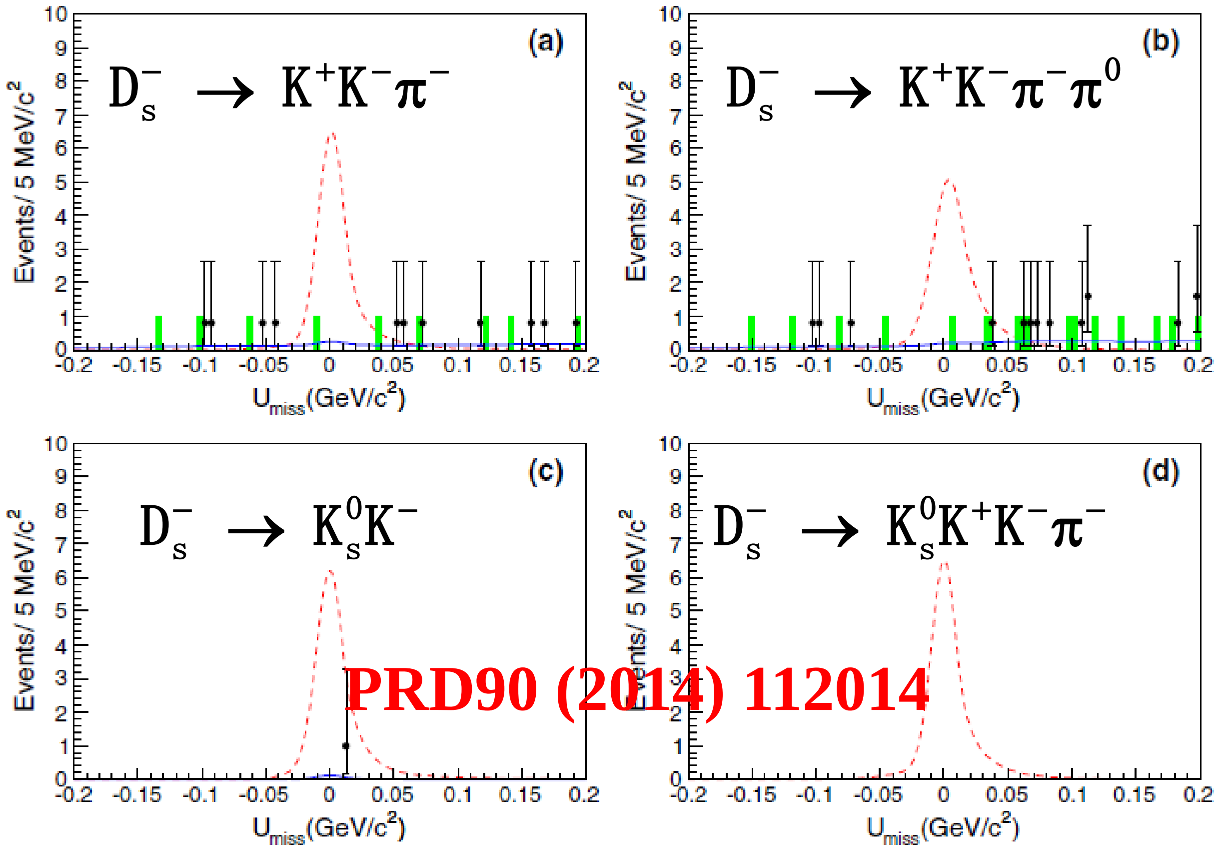
$$E_{miss} = E_{J/\psi} - E_{D_s^-} - E_{e^+}$$

$$\vec{p}_{miss} = \vec{p}_{J/\psi} - \vec{p}_{D_s^-} - \vec{p}_{e^+}$$

$$U_{miss} = E_{miss} - |\vec{p}_{miss}|$$

$$Br(J/\psi \to D_s^- e^+ \nu_e + c.c) < 1.3 \times 10^{-6} @90\%CL$$

# Search for $J/\psi \to D_s^{*-} e^+ \nu_e$ + c.c




PRD90 (2014) 112014

- **Reconstructe Ds* with $\gamma D_s$**

$$Br(J/\psi \to D_s^{*-} e^+ \nu_e + c.c) < 1.8 \times 10^{-6} @90\%CL$$

# Two-body hadronic weak decays

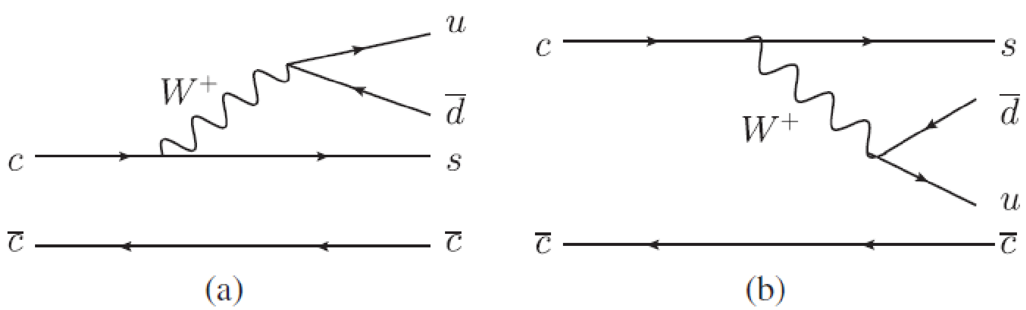



FIG. 1. Leading-order Feynman diagrams for (a) $J/\psi \to D_s^- \rho^+$ and (b) $J/\psi \to \bar{D}^0 \bar{K}^{*0}$.

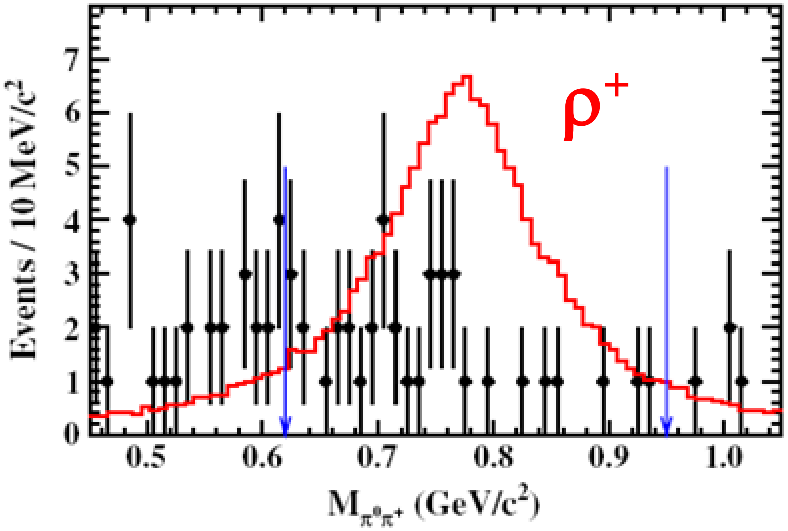
$$\frac{Br(J/\psi \to D_s^+ \rho^-)}{Br(J/\psi \to D_s^+ \pi^-)} \approx 5$$

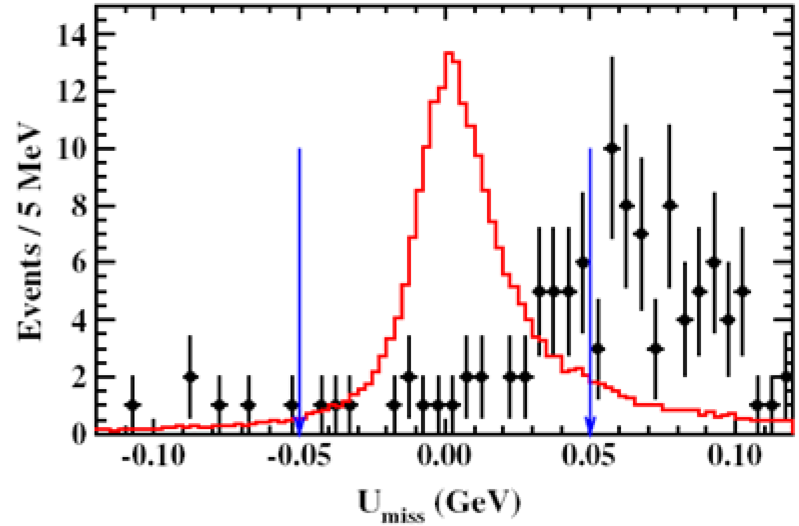
$$\frac{Br(J/\psi \to D^0 K^{*0})}{Br(J/\psi \to D_s^+ \rho^-)} \approx 0.1$$

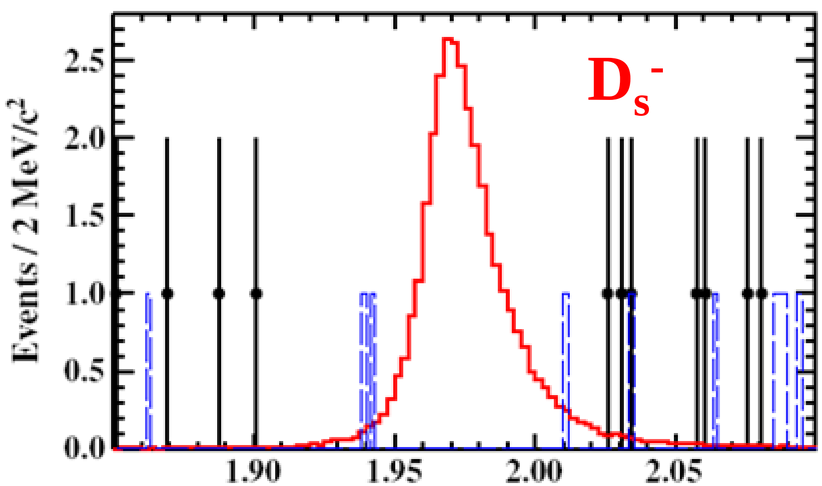
**PLB252 (1990) 690**

- **SM predicts ~$10^{-9}$-$10^{-10}$ by factorization model**
- **physics beyond SM predict ~$10^{-6}$-$10^{-5}$**
  - **Top color model**
  - **Minimal Supersymmetric SM**
  - **Two-Higgs-doublet model**

# Search for J/ψ --> $D_s^- \rho^+$



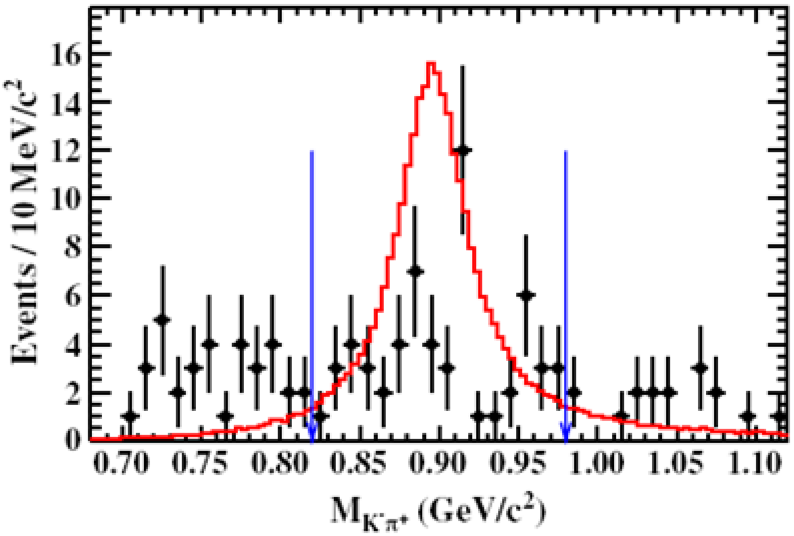

$$J/\psi \rightarrow D_s^- \rho^+$$

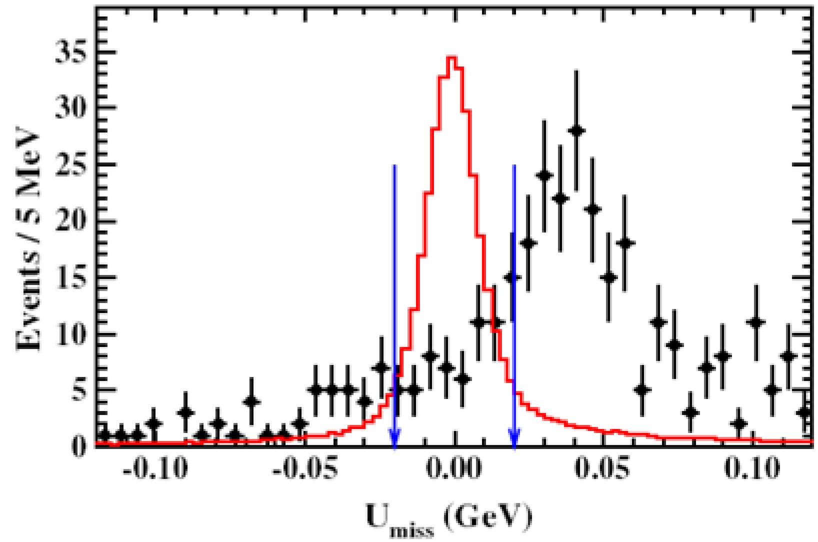
$$D_s^- \rightarrow \phi e^- \nu_e \qquad \phi \rightarrow K^+ K^-$$

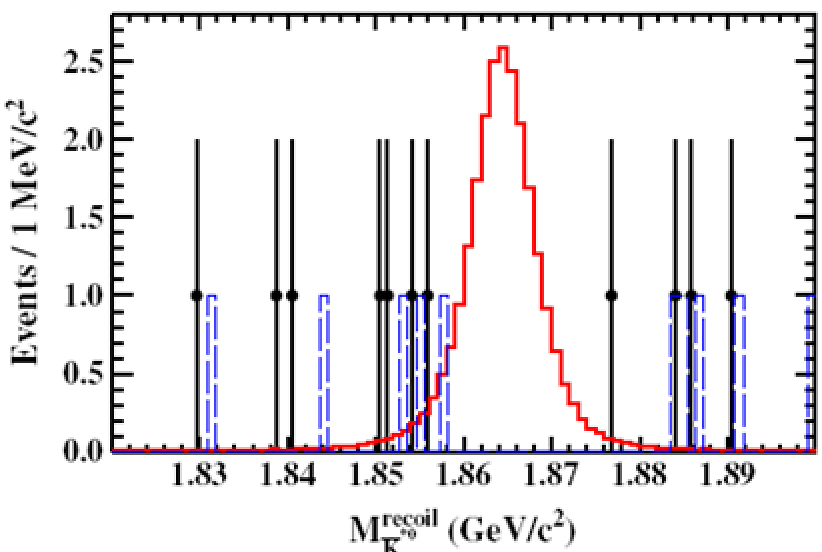
$$Br(J/\psi \rightarrow D_s^- \rho^+) < 1.3 \times 10^{-5}$$

**PRD89 (2014) 071101(R)**

# Search for J/psi --> $D_0$-bar $K^{*0}$-bar




$$J/\psi \to \bar{D}^0 \bar{K}^{*0}$$

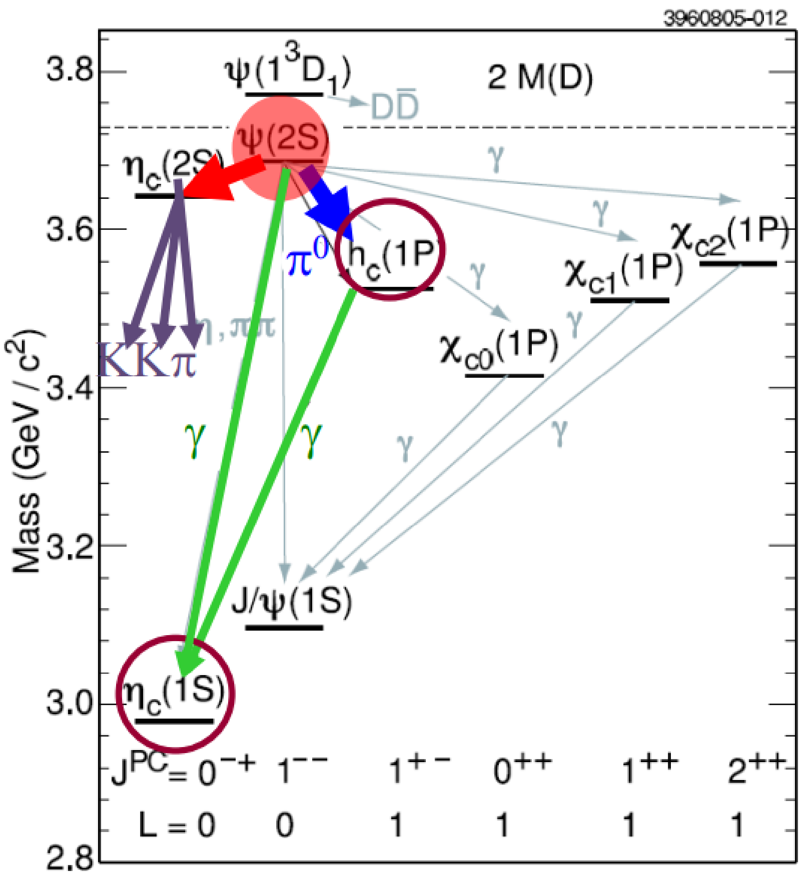
$$\bar{D}^0 \to K^+ e^- \nu_e$$

$$\bar{K}^{*0} \to K^- \pi^+$$

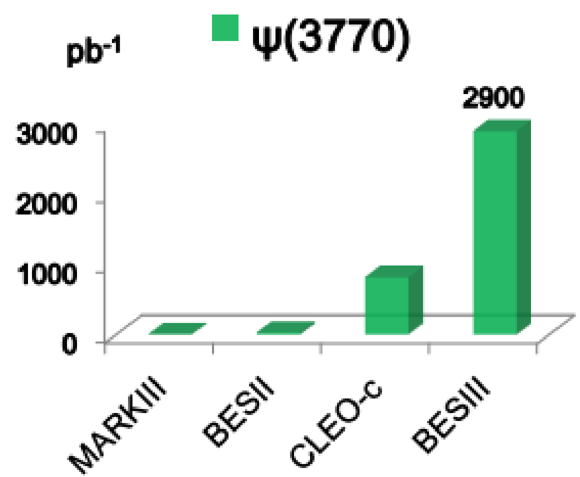
$$Br(J/\psi \to \bar{D}^0 \bar{K}^{*0}) < 2.5 \times 10^{-6}$$

**PRD89 (2014) 071101(R)**

# Charmonium radiative decays

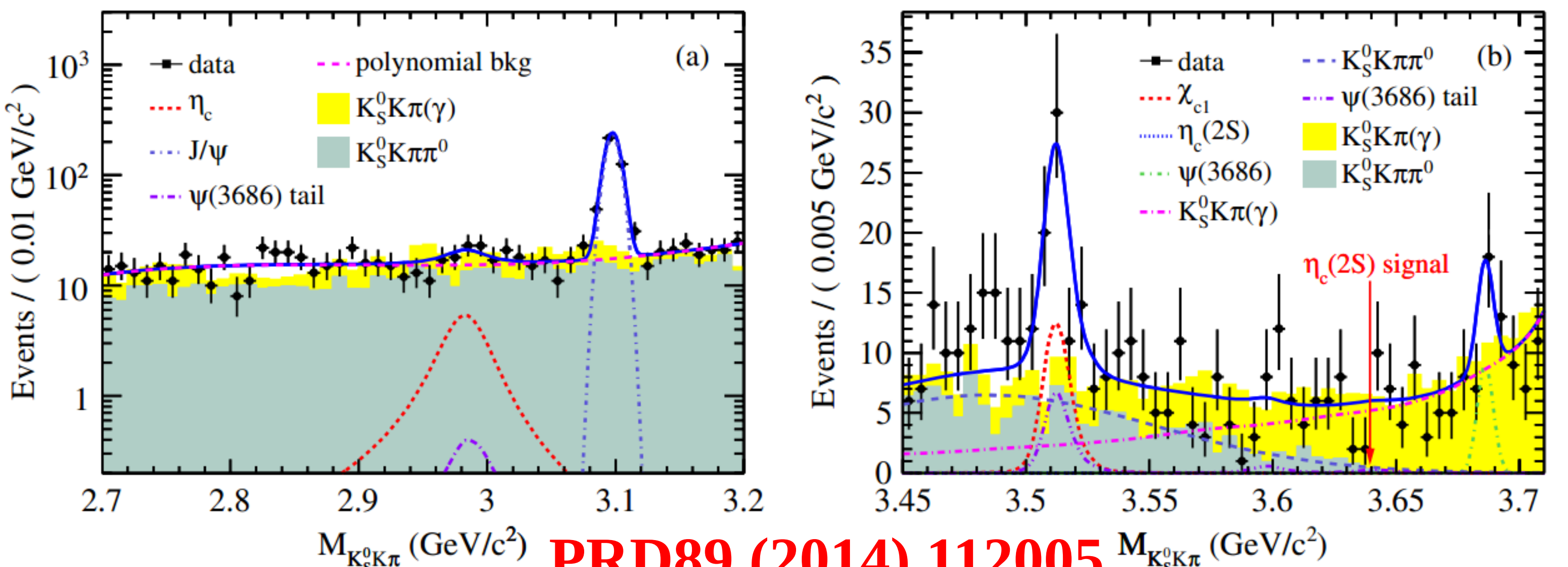



- $J^{PC}= 1^{--}$ ψ states can be produced directly at $e^+e^-$ collider.
- Other $J^{PC}$ ψ states samples via by $J^{PC}= 1^{--}$ states radiative or hadronic decay.



# Search for ψ (3770)→$\gamma\eta_c$ and $\gamma\eta_c(2S)$

- **Use $K_sK\pi$ decay mode to reconstructe $\eta_c$ and $\eta_c(2S)$**




**PRD89 (2014) 112005**

$$Br(\psi(3770) \to \gamma\eta_c) < 6.8 \times 10^{-4} @90\%C.L.$$

$$Br(\psi(3770) \to \gamma\eta_c(2S)) < 2.0 \times 10^{-3} @90\%C.L.$$

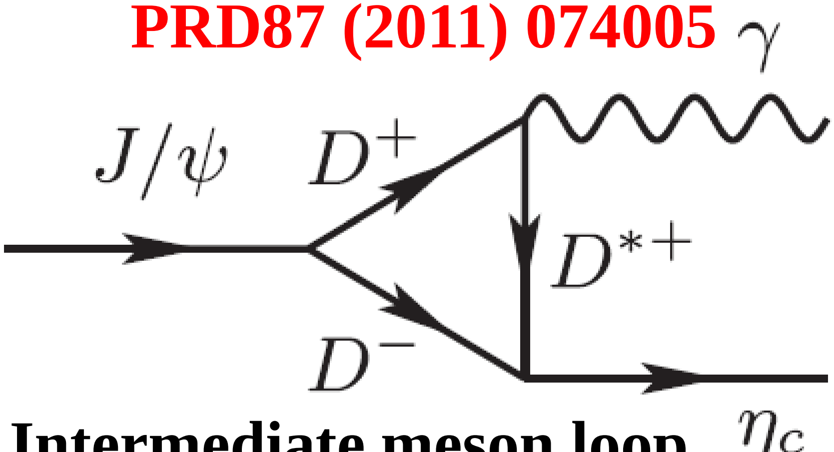
$$Br(\psi(3770) \to \gamma\chi_{c1}) = (2.33 \pm 0.65 \pm 0.43) \times 10^{-3}$$

# Search for $\psi(3770)\to\gamma\eta_c$ and $\gamma\eta_c(2S)$

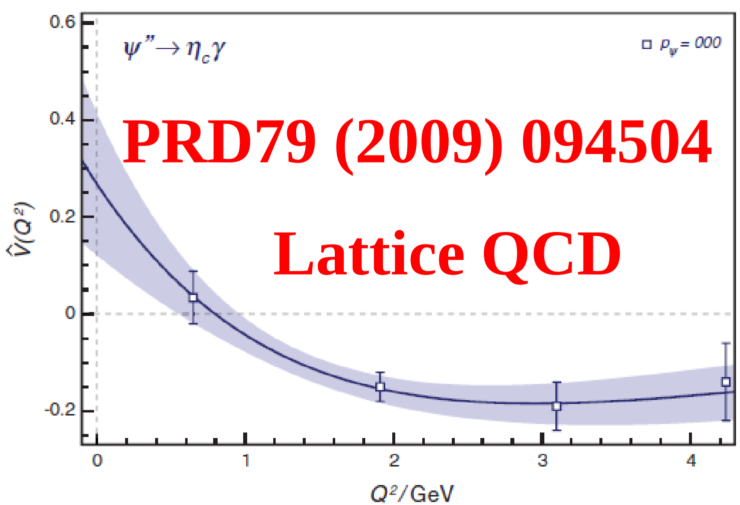
**PRD89 (2014) 112005**

| Quantity | $\eta_c$ | $\eta_c(2S)$ | $\chi_{c1}$ |
|---|---|---|---|
| $N_{\rm obs}$ | $29.3 \pm 18.2$ | $0.4 \pm 8.5$ | $34.9 \pm 9.8$ |
| $N_{\rm up}$ | 56.8 | 16.1 | ... |
| $\epsilon$ (%) | 27.87 | 25.24 | 28.46 |
| $\mathcal{B}(\psi(3770) \to \gamma X \to \gamma K_S^0 K^\pm \pi^\mp)$ $(\times 10^{-6})$ | $< 16$ | $< 5.6$ | $8.51 \pm 2.39 \pm 1.42$ |
| $\mathcal{B}(\psi(3770) \to \gamma X)$ $(\times 10^{-3})$ | $< 0.68$ | $< 2.0$ | $2.33 \pm 0.65 \pm 0.43$ |
| $\mathcal{B}_{\rm CLEO}(\psi(3770) \to \gamma X)$ $(\times 10^{-3})$ | ... | ... | $2.9 \pm 0.5 \pm 0.4$ |
| $\Gamma(\psi(3770) \to \gamma X)$ (keV) | $< 19$ | $< 55$ | ... |
| $\Gamma_{\rm IML}$ (keV) | $17.14^{+22.93}_{-12.03}$ | $1.82^{+1.95}_{-1.19}$ | ... |
| $\Gamma_{\rm LQCD}$ (keV) | $10 \pm 11$ | ... | ... |

**PRD87 (2011) 074005**

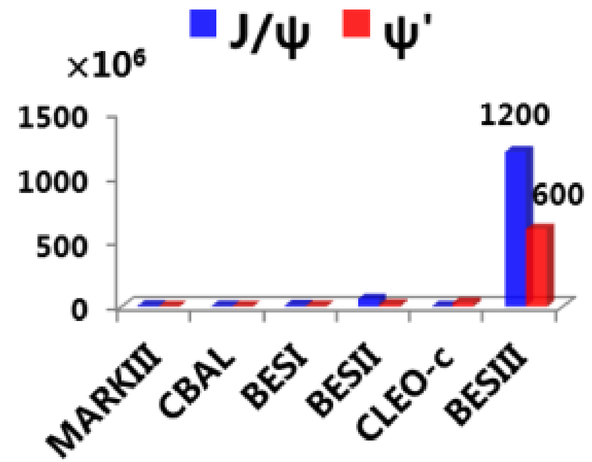



**Intermediate meson loop**

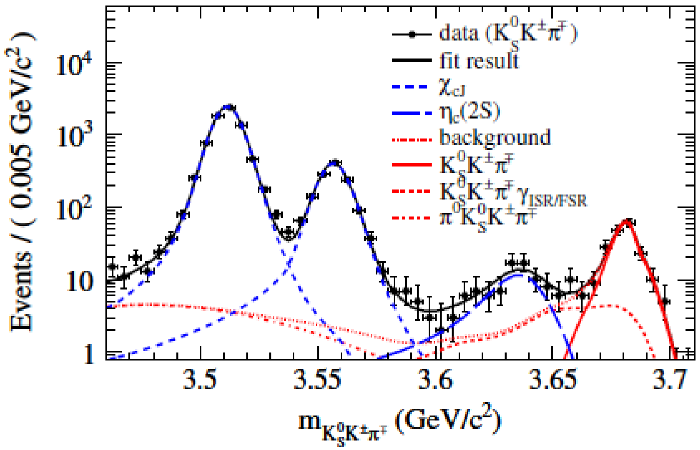


# $J/\Psi \rightarrow \gamma\eta_c$ and $\psi(3686) \rightarrow \gamma\eta_c(2S)$

- $\Gamma(J/\psi \rightarrow \gamma\eta_c)$
  - **PDG2014: 1.58±0.37KeV**
    - ✓ **Large uncertainty**
  - **Lattice QCD: 2.49±0.19KeV**
  - **Working but challenge for calorimeter: 50MeV photon**




- $\psi(3686) \rightarrow \gamma\eta_c(2S)$ **PRL 109 (2011) 042003**




- **With 106M ψ(3686) data at 2009**
- **Working with about 350M ψ(3686) data at 2012**

# Summary and outlook

- **BESIII Collaboration studied some charmonium rare decays and obtained some best upper limit with 225M J/Ψ and 106M Ψ(3686) data samples.**

$$Br(J/\psi \to D_s^- e^+ \nu_e + c.c.) < 1.3\times10^{-6} \qquad < 3.6\times10^{-5}$$

$$Br(J/\psi \to D_s^{*-} e^+ \nu_e + c.c.) < 1.8\times10^{-6} \qquad Br(J/\psi \to D_s^- \rho^+) < 1.3\times10^{-5}$$

$$Br(J/\psi \to \bar{D}^0 \bar{K}^{*0}) < 2.5\times10^{-6} \qquad Br(J/\psi \to \gamma\phi) < 1.4\times10^{-6}$$

$$Br(J/\psi \to \gamma\gamma) < 2.7\times10^{-7} \qquad < 5\times10^{-6}$$

- **BESIII Collaboration also searched for charmonium radiative decays ψ(3770)→$\gamma\eta_c$ and $\gamma\eta_c$(2S).**

- **With 1.3B J/ ψ and 0.5B ψ(3686) data samples, we expect more results on charmonium rare and radiative decays**