Search for charmonium rare decays at BESIII

第12届全国粒子物理学术会议

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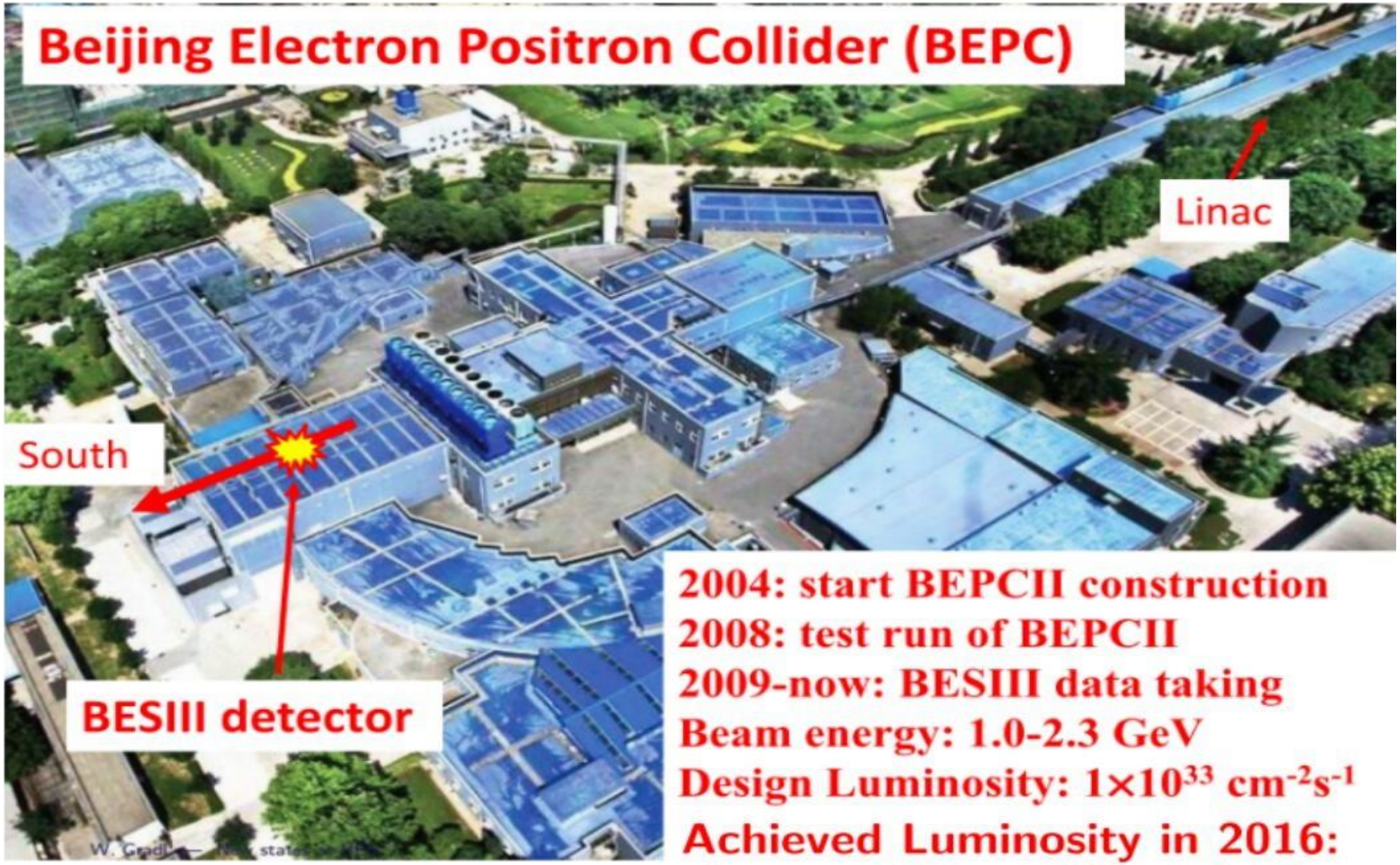
On behalf of the BESIII Collaboration

Overview

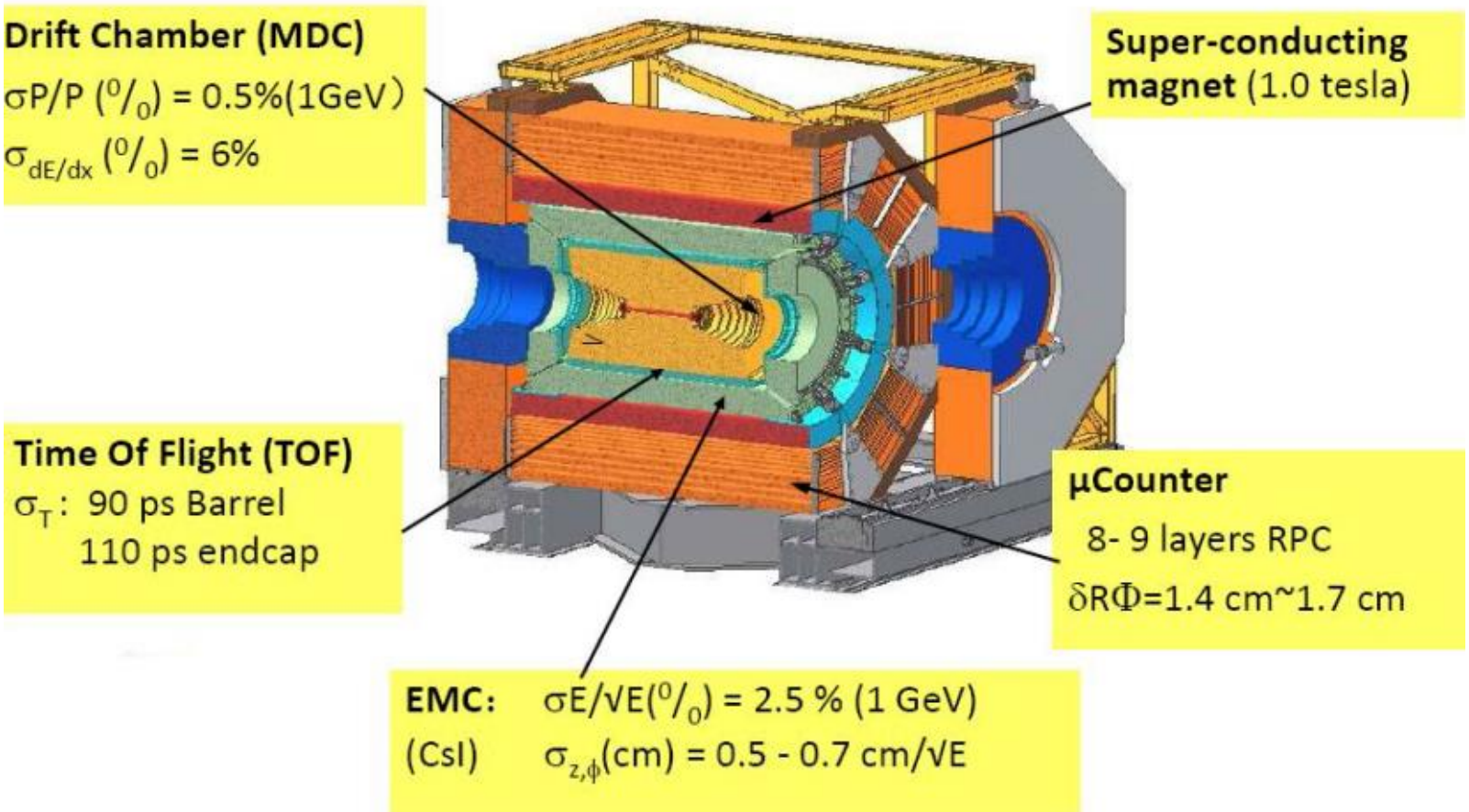
1. Introduction
   - An overview of BESIII experiment
   - Charmonium states produced at BESIII
2. Charmonium rare decays at BESIII
   - Lepton flavor violationg process of $J/\psi \to e\mu$
   - Flavor changing weak decays of $J/\psi \to D_s^- \rho^+$ & $J/\psi \to \bar{D}^0 \bar{K}^{*0}$
   - C-parity violation in $J/\psi \to \gamma\gamma$ & $J/\psi \to \gamma\phi$
   - Doubly OZI-suppressed decay $J/\psi \to \phi\pi^0$
   - Isospin-violating decay $J/\psi \to \phi\pi^0 f_0(980)$
   - Isospin-violating decay $\chi_{c0,2} \to \pi^0 \eta_c$
3. Summary

Beijing Electron Positron Collider (*BEPC-II*)



2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BESIII data taking
Beam energy: 1.0-2.3 GeV
Design Luminosity: 1×10^{33} $cm^{-2}s^{-1}$
Achieved Luminosity in 2016:
$1 \times 10^{33}\ cm^{-2}s^{-1}$

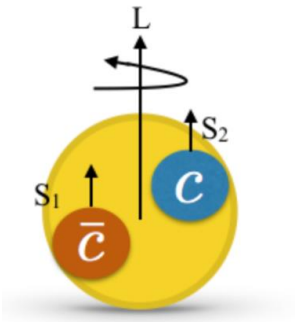
BESIII detector

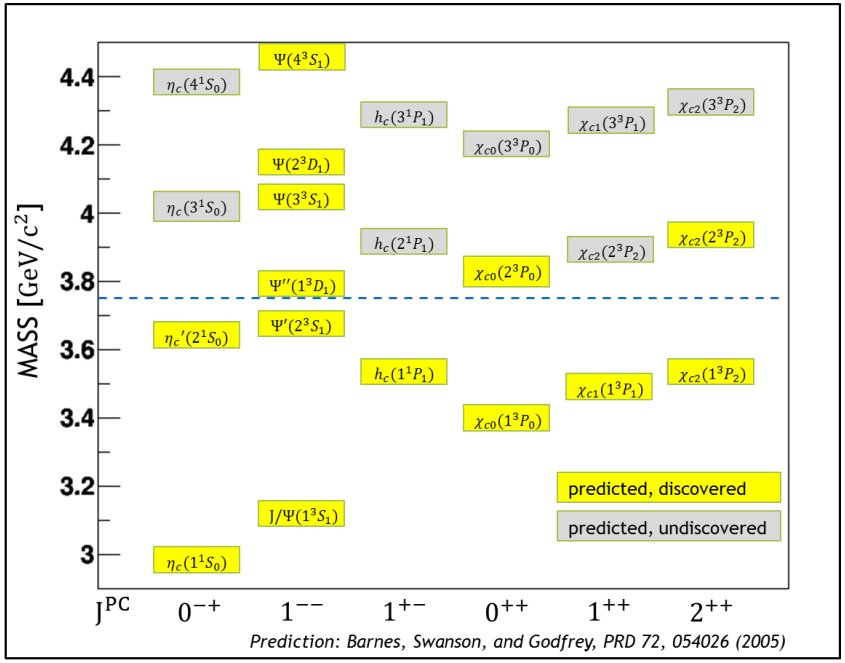


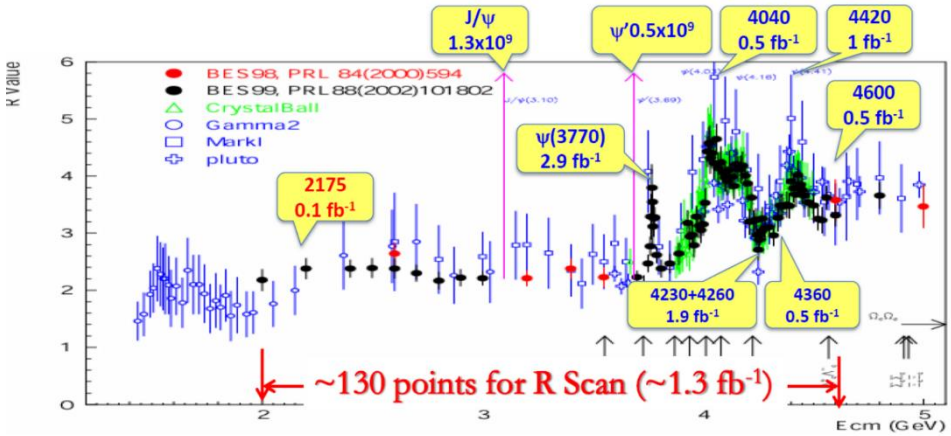
The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID and large coverage.

Charmonium states at BESIII

Charmonium states:







Charmonium states	N_{events} at BESIII
J/ψ	1310 M
$\psi(3686)$	448 M
$\psi(3770)$	265.5 M
…	

BESIII is a excellent place to study the charmonium states.

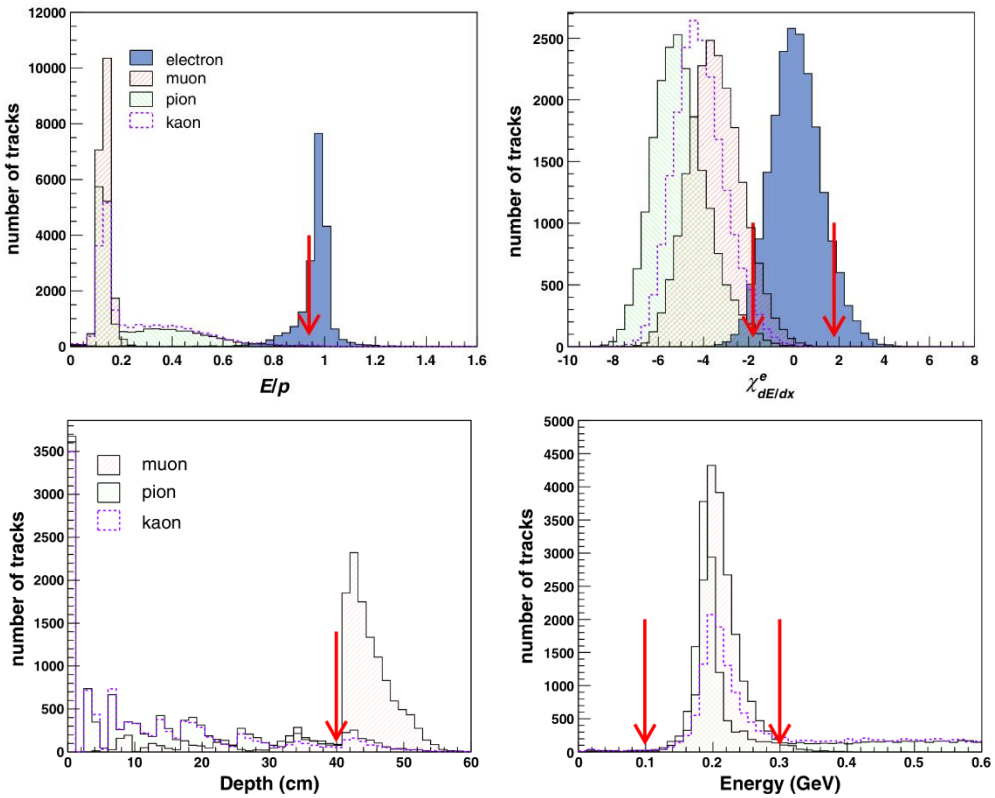
Lepton flavor violationg process of $J/\psi \to e\mu$

PRD 87, 112007 (2013)

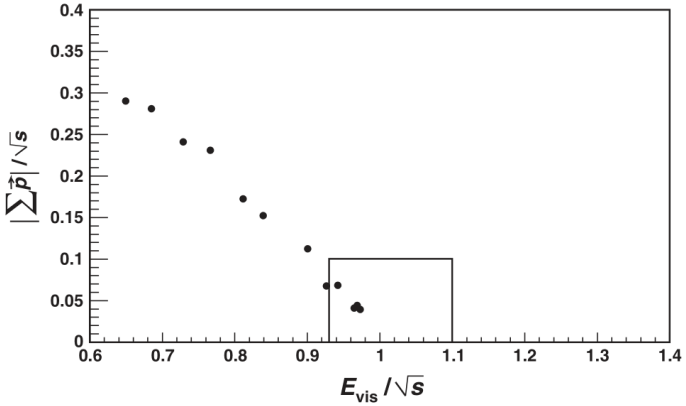
Backgrounds:

processes $J/\psi \to e^+e^-$, $J/\psi \to \mu^+\mu^-$, $J/\psi \to \pi^+\pi^-$, $J/\psi \to K^+K^-$, $e^+e^- \to e^+e^-(\gamma)$ and $e^+e^- \to \mu^+\mu^-(\gamma)$.

Particle identification:



Signal yields:



Upper limits:

$$\mathcal{B}(J/\psi \to e\mu) < \frac{N^{UL}_{\rm obs}}{N_{J/\psi} \cdot \epsilon}$$

$$\mathcal{B}(J/\psi \to e\mu) < 1.6 \times 10^{-7} \text{ (90\% C.L.)}$$

Methods:

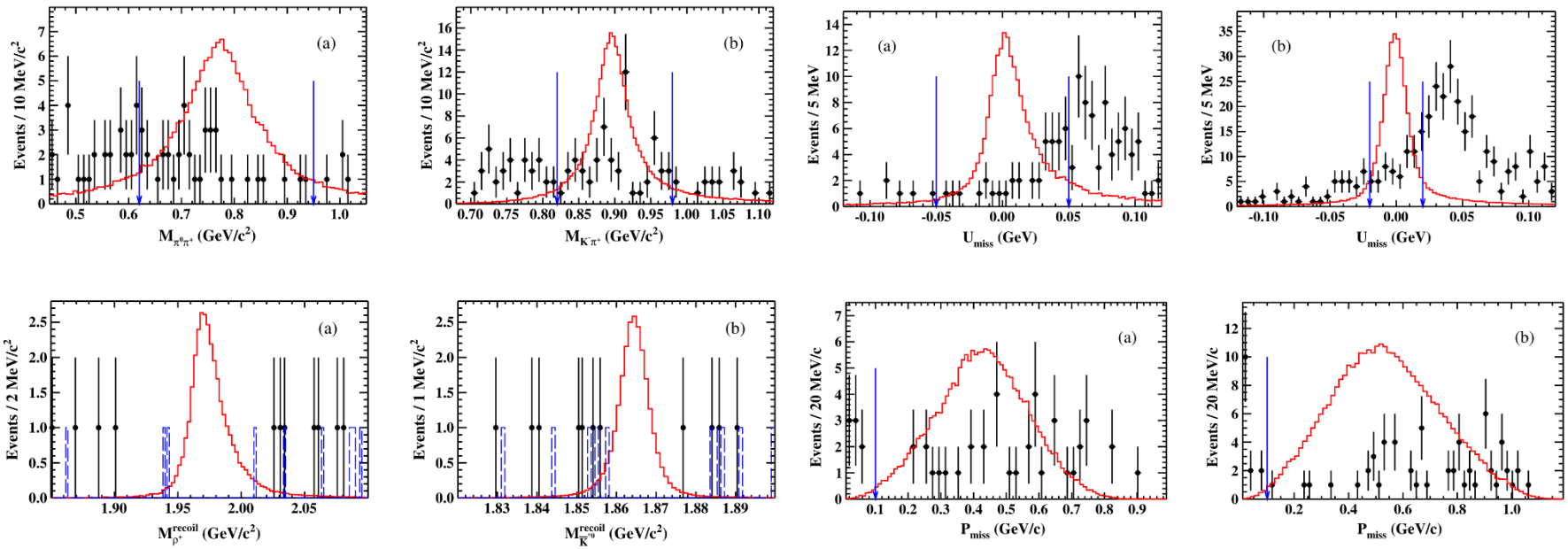
Blind analysis

Feldman-Cousins method

Flavor changing weak decays of $J/\psi \to D_s^- \rho^+$ & $J/\psi \to \bar{D}^0 \bar{K}^{*0}$

PRD 89, 071101 (2014)

Event selections & background veto:



Results:

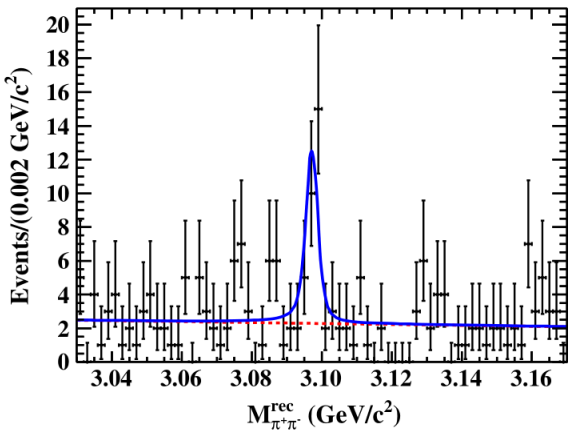
$$\mathcal{B} < \frac{N_{\rm UL}}{N_{J/\psi}\varepsilon\mathcal{B}_{\rm inter}(1-\sigma^{\rm sys})}$$

Decay mode	Intermediate decay	ε	$\mathcal{B}_{\rm inter}$	$\sigma^{\rm sys}$	$N_{\rm UL}$	$\mathcal{B}$ (90% C.L.)
$J/\psi \to D_s^-\rho^+$	$D_s^- \to \phi e^-\bar{\nu}_e$, $\phi \to K^+K^-$, $\rho^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$	7.79%	1.20%	8.6%	2.5	$< 1.3 \times 10^{-5}$
$J/\psi \to \bar{D}^0\bar{K}^{*0}$	$\bar{D}^0 \to K^+e^-\bar{\nu}_e$, $\bar{K}^{*0} \to K^-\pi^+$	21.83%	2.37%	7.5%	2.7	$< 2.5 \times 10^{-6}$

C-parity violation in $J/\psi \to \gamma\gamma$ & $J/\psi \to \gamma\phi$

PRD 90, 092002 (2014)

$J/\psi \to \gamma\gamma$ signals:

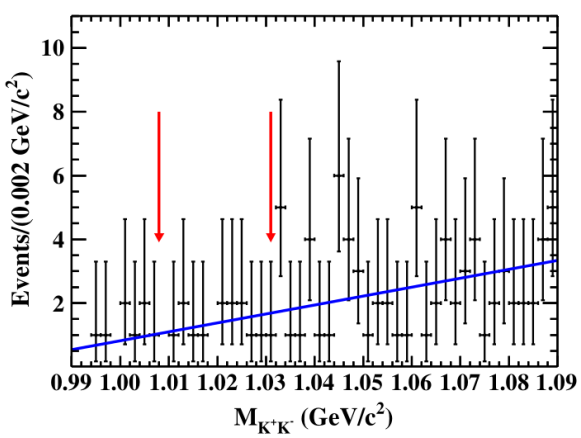


Peaking backgrounds:

Background channel	Expected counts ($N^{\rm bkg}$)
$J/\psi \to \gamma\pi^0$, $\pi^0 \to 2\gamma$	18.5 ± 1.9
$J/\psi \to \gamma\eta$, $\eta \to 2\gamma$	24.6 ± 1.6
$J/\psi \to \gamma\eta_c$, $\eta_c \to 2\gamma$	1.3 ± 0.3
$J/\psi \to 3\gamma$	0.9 ± 0.3
Total	45.3 ± 2.5

Method: Feldman-Cousians method

$J/\psi \to \gamma\phi$ signals:



No peaking backgrounds.

Method:

Bayesian method

Results:

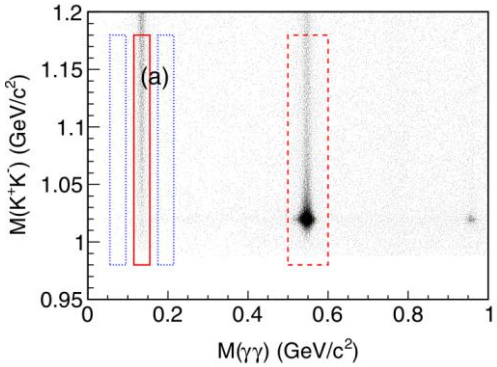
$$\mathcal{B}(J/\psi \to f) < \frac{N^{\rm up}_{\rm sig}}{N^{\rm tot}_{\psi(3686)} \times \epsilon \times \mathcal{B}_i \times (1 - \Delta_{\rm sys})}$$

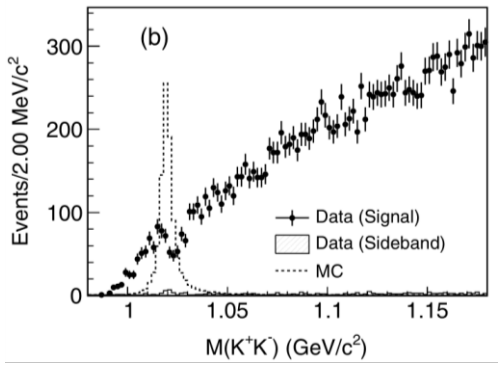
	$\gamma\gamma$	$\gamma\phi$
$N^{\rm obs}$	29.2 ± 7.1	0.0 ± 4.6
$N^{\rm bkg}$	46.5 ± 2.5	negligible
$N^{\rm up}_{\rm sig}$ (90% C.L.)	2.8	6.9
ϵ (%)	30.72 ± 0.07	30.89 ± 0.07
$\mathcal{B}(J/\psi \to)$ (this work)	$< 2.7 \times 10^{-7}$	$< 1.4 \times 10^{-6}$
$\mathcal{B}(J/\psi \to)$ (PDG [1])	$< 50 \times 10^{-7}$	–

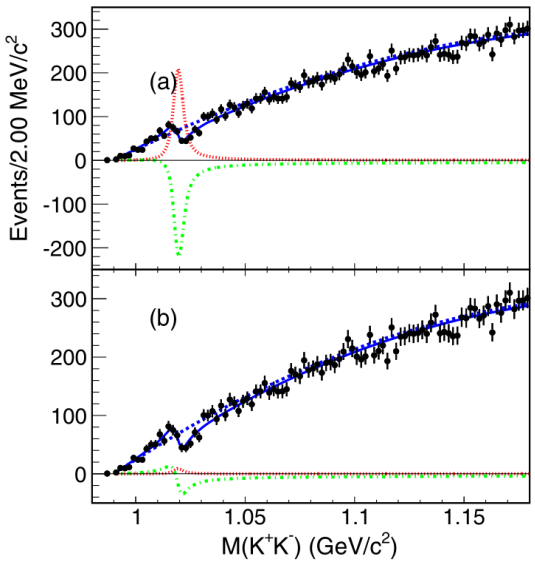
Doubly OZI-suppressed decay $J/\psi \to \phi\pi^0$

PRD 91, 112001 (2015)

No signal observed.







Backgrounds:

TABLE I. Background analysis for the decay $J/\psi \to \phi\pi^0$.

Type	Reactions
Coherent	$J/\psi \to K^+K^-\pi^0$
ϕ peaking	$e^+e^- \to \gamma_{\rm ISR}\phi$, $J/\psi \to \phi\pi^0\pi^0/\phi\gamma\gamma$
π^0 peaking	$J/\psi \to \gamma\eta_c(1S) \to \gamma K^+K^-\pi^0$
Other	$J/\psi \to \gamma K^+K^-/\gamma\pi^0K^+K^-/\pi^0\pi^0K^+K^-$

Solution	$N^{\rm sig}$	δ	$2\Delta\log\mathcal{L}/N_f$	Z
I	838.5 ± 45.8	$-95.9° \pm 1.5°$	45.8/2	6.4σ
II	35.3 ± 9.3	$-152.1° \pm 7.7°$	45.8/2	6.4σ

Two solutions:

Two solutions with two different phase angles between the ϕ resonance and the non-ϕ contributions

Results of 2 solutions:

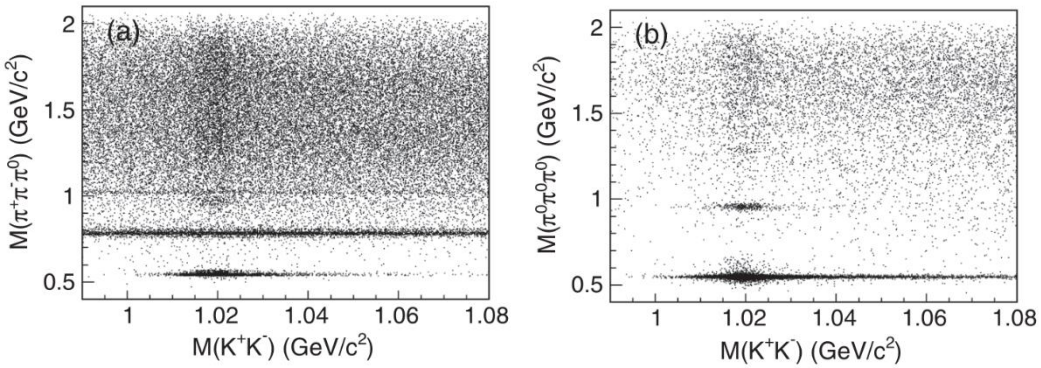
$$[2.94 \pm 0.16(\text{stat}) \pm 0.16(\text{syst})] \times 10^{-6}$$

$$[1.24 \pm 0.33(\text{stat}) \pm 0.30(\text{syst})] \times 10^{-7}$$

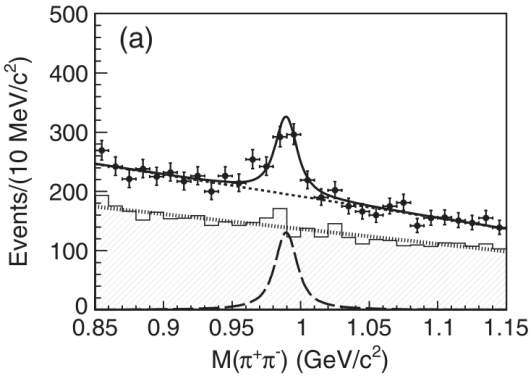
Isospin-violating decay $J/\psi \to \phi\pi^0 f_0(980)$

PRD 92, 012007 (2015)

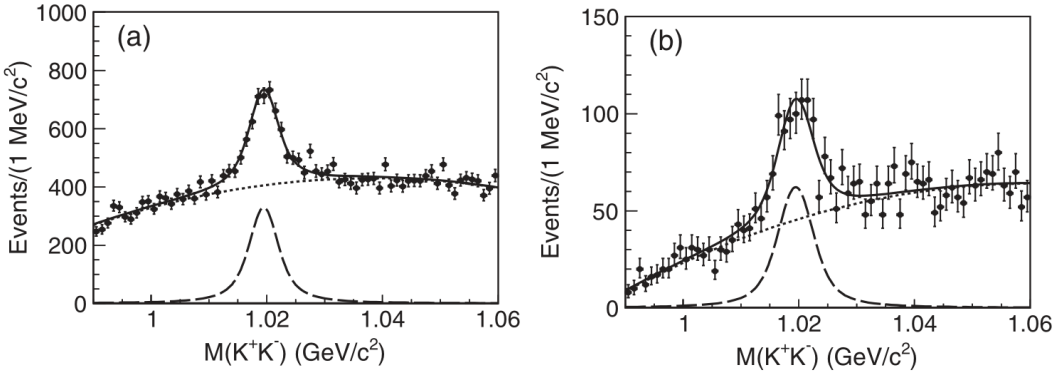
Scatter plots:

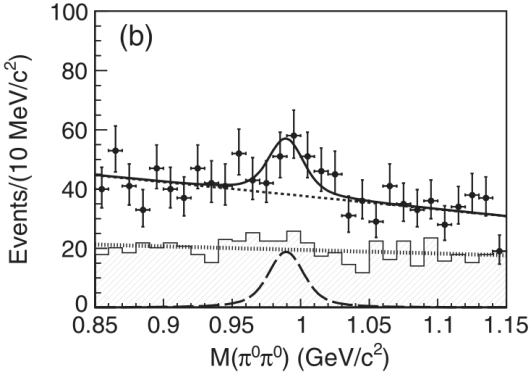


$M_{\pi\pi}$:



$M_{K^+K^-}$:

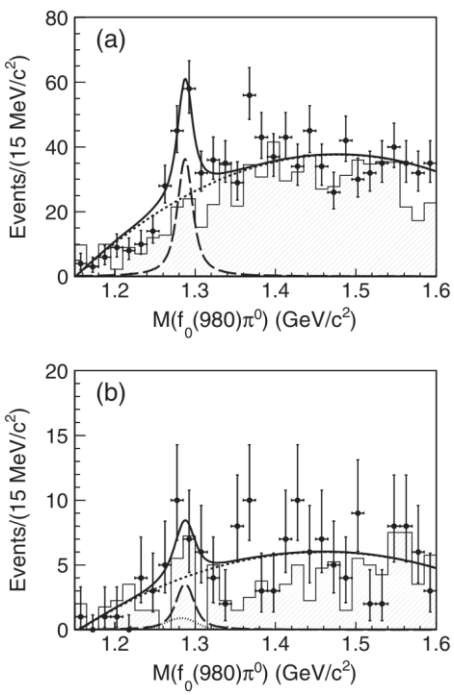




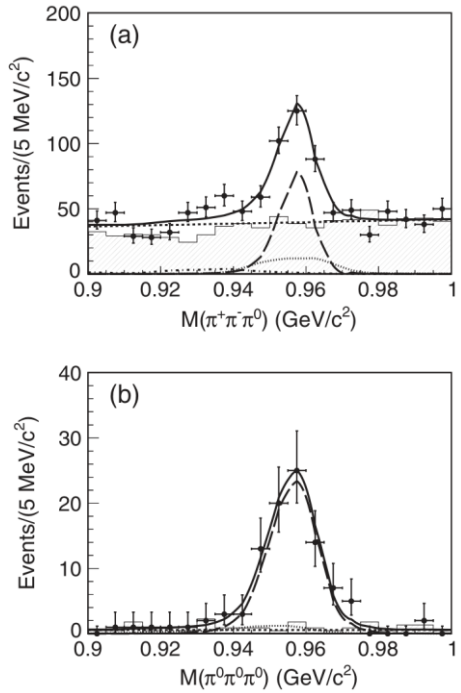
Isospin-violating decay $J/\psi \to \phi\pi^0 f_0(980)$

PRD 92, 012007 (2015)

$M_{f_0\pi_0}$:



$M_{3\pi}$:



Results:

$$\mathcal{B}(J/\psi \to \phi X) = \frac{N^{\rm obs}}{N_{J/\psi}\epsilon B^{\phi}_{K^+K^-}(B^{\pi^0}_{\gamma\gamma})^n},$$

$$\mathcal{B}(\eta' \to X) = \frac{N^{\rm obs}}{N_{J/\psi}\epsilon B^{J/\psi}_{\phi\eta'} B^{\phi}_{K^+K^-}(B^{\pi^0}_{\gamma\gamma})^n},$$

$$\mathcal{B}(J/\psi \to \phi X) < \frac{N^{\rm obs}_{\rm upp}}{N_{J/\psi}\epsilon B^{\phi}_{K^+K^-}(B^{\pi^0}_{\gamma\gamma})^n(1-\sigma^{\rm sys})},$$

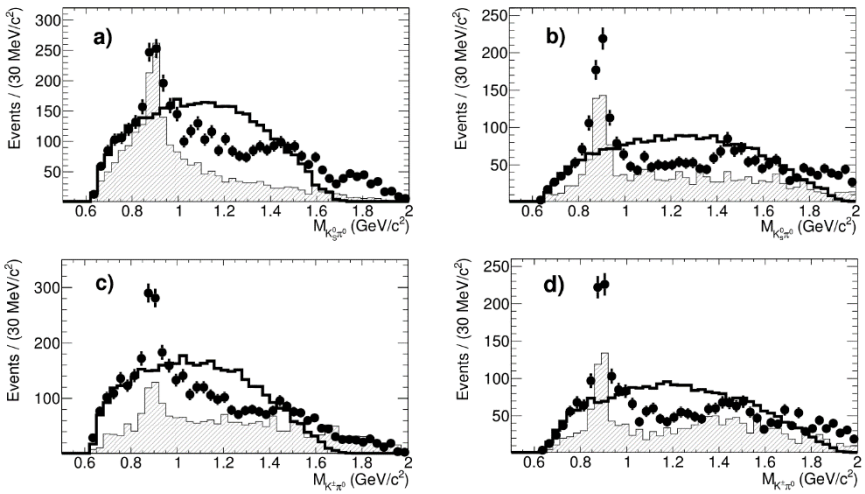
$$r_{3\pi} \equiv \mathcal{B}(\eta' \to \pi^0\pi^0\pi^0)/\mathcal{B}(\eta' \to \pi^+\pi^-\pi^0) = \frac{N^{\rm obs}(\pi^0\pi^0\pi^0)}{N^{\rm obs}(\pi^+\pi^-\pi^0)}\frac{\epsilon(\pi^+\pi^-\pi^0)}{\epsilon(\pi^0\pi^0\pi^0)}\frac{1}{(B^{\pi^0}_{\gamma\gamma})^2}.$$

Decay mode	Efficiency (%)	Branching fractions
$J/\psi \to \phi\pi^0 f_0, f_0 \to \pi^+\pi^-$	12.44 ± 0.10	$(4.50 \pm 0.80 \pm 0.61) \times 10^{-6}$
$J/\psi \to \phi\pi^0 f_0, f_0 \to \pi^0\pi^0$	6.76 ± 0.08	$(1.67 \pm 0.50 \pm 0.24) \times 10^{-6}$
$J/\psi \to \phi f_1, f_1 \to \pi^0 f_0 \to \pi^0\pi^+\pi^-$	13.19 ± 0.11	$(9.36 \pm 2.31 \pm 1.54) \times 10^{-7}$
$J/\psi \to \phi f_1, f_1 \to \pi^0 f_0 \to \pi^0\pi^0\pi^0$	6.76 ± 0.08	$(2.08 \pm 1.63 \pm 1.47) \times 10^{-7}$
		$<6.98 \times 10^{-7}$ (90% C. L.)
$\eta' \to \pi^+\pi^-\pi^0$	16.92 ± 0.12	$(4.28 \pm 0.49 \pm 0.22 \pm 1.09) \times 10^{-3}$
$\eta' \to \pi^0\pi^0\pi^0$	6.55 ± 0.08	$(4.79 \pm 0.59 \pm 0.33 \pm 1.09) \times 10^{-3}$
$r_{3\pi}$		$1.12 \pm 0.19 \pm 0.06$

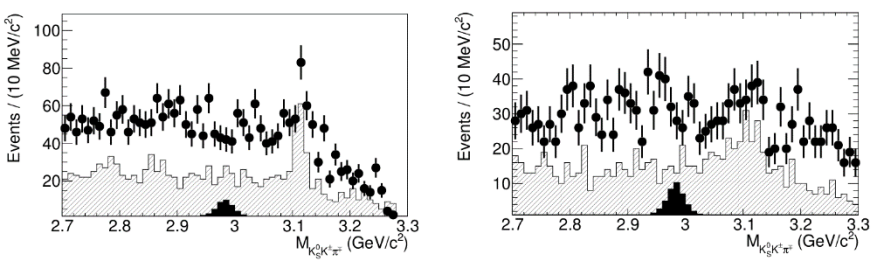
Isospin-violating decay $\chi_{c0,2} \to \pi^0 \eta_c$

PRD 91, 112018 (2015)

$M_{K\pi}$:



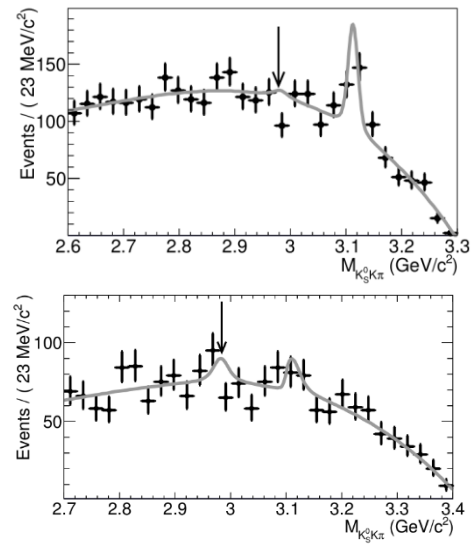
$M_{KK\pi}$:



Peaking background:

$$\psi(3686) \to \pi^0\pi^0 J/\psi,\ J/\psi \to K_S^0 K^\pm \pi^\mp$$

Fits:



Results:

$$B(\chi_{cJ} \to \pi^0\eta_c) < \frac{N_J^{UL}}{N_\psi \varepsilon_J B(\psi(3686) \to \gamma\chi_{cJ}) B_{int}(1-\delta_J)}$$

	$\chi_{c0} \to \pi^0\eta_c$	$\chi_{c2} \to \pi^0\eta_c$
N_J^{UL}	14.1	35.9
ε_J	5.8%	8.6%
δ_J	13.8%	20.2%
$B(\chi_{cJ} \to \pi^0\eta_c)(10^{-3})$	< 1.6	< 3.2

Summary

Upper limits:

Lepton flavor violationg process of $J/\psi \to e\mu$

Flavor changing weak decays of $J/\psi \to D_s^- \rho^+$ & $J/\psi \to \bar{D}^0 \bar{K}^{*0}$

C-parity violation in $J/\psi \to \gamma\gamma$ & $J/\psi \to \gamma\phi$

Isospin-violating decay $\chi_{c0,2} \to \pi^0 \eta_c$

Observations:

Doubly OZI-suppressed decay $J/\psi \to \phi\pi^0$

Isospin-violating decay $J/\psi \to \phi\pi^0 f_0(980)$

These analyses are carried out from 2013 to 2016.

Thanks for your attention !