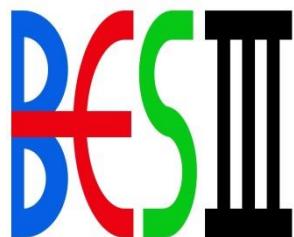


# Isospin Violations at BESIII

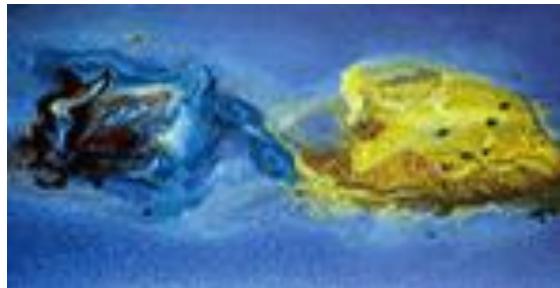
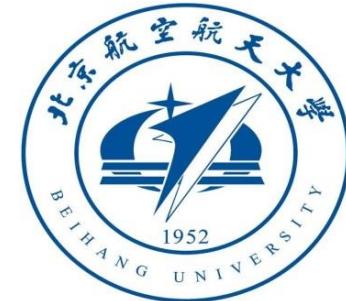


(On behalf of the BESIII Collaboration)

Hongrong Qi

Beihang University

qihongrong@buaa.edu.cn



**Maynooth  
University**  
National University  
of Ireland Maynooth

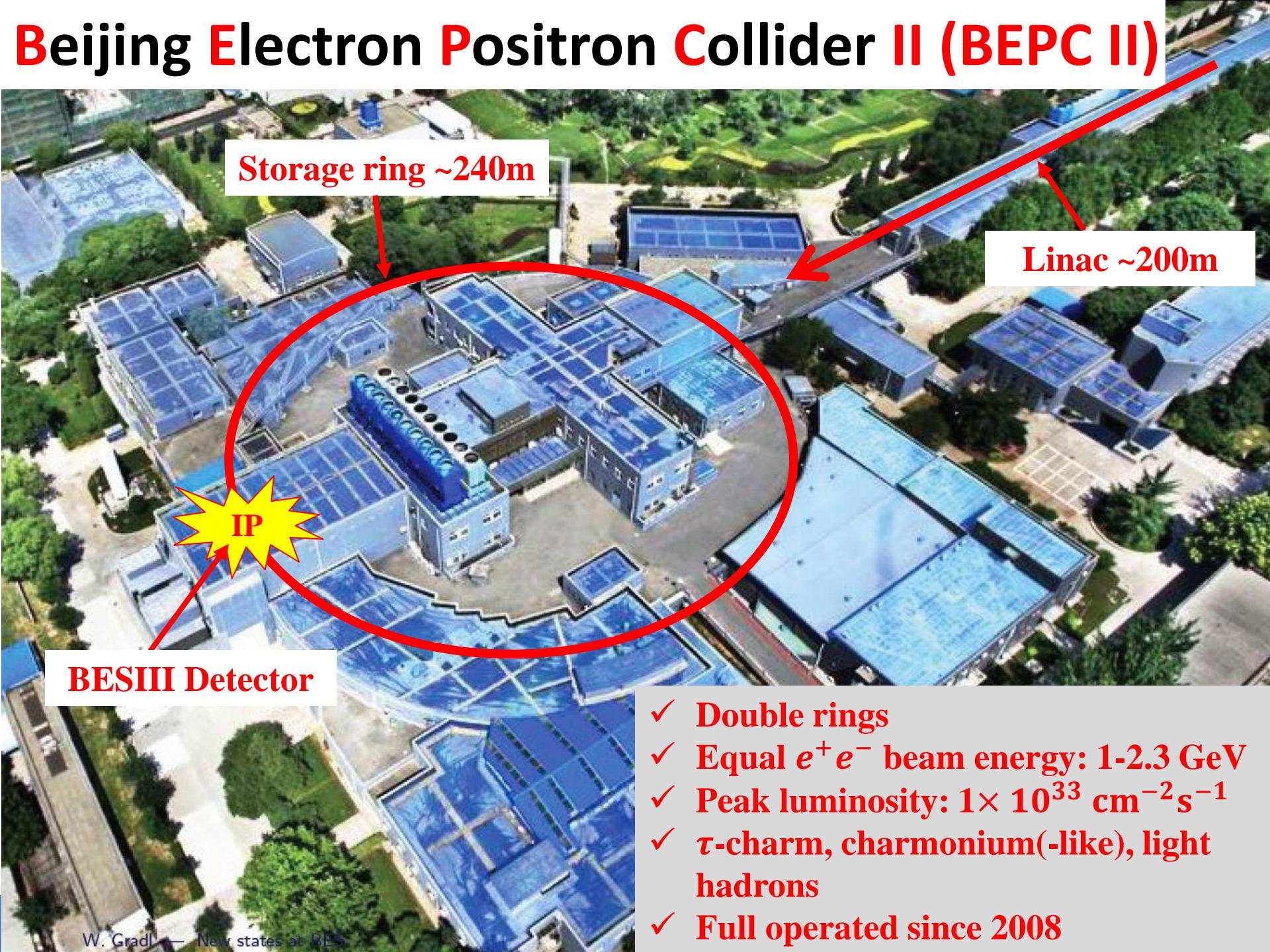
XIIIth Quark Confinement and the Hadron Spectrum

**Maynooth U., Ireland 1<sup>st</sup> - 6<sup>th</sup> August 2018**

# OUTLINE

- BESIII experiment
- Isospin violations with  $f_0(980)/a_0^0(980)$  production
- Isospin violating transitions with  $\pi^0$  production
- Isospin violations in baryon final states
- Summary

# Beijing Electron Positron Collider II (BEPC II)



- ✓ Double rings
- ✓ Equal  $e^+ e^-$  beam energy: 1-2.3 GeV
- ✓ Peak luminosity:  $1 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
- ✓  $\tau$ -charm, charmonium(-like), light hadrons
- ✓ Full operated since 2008

# BESIII Detector

Superconducting solenoid (1T)

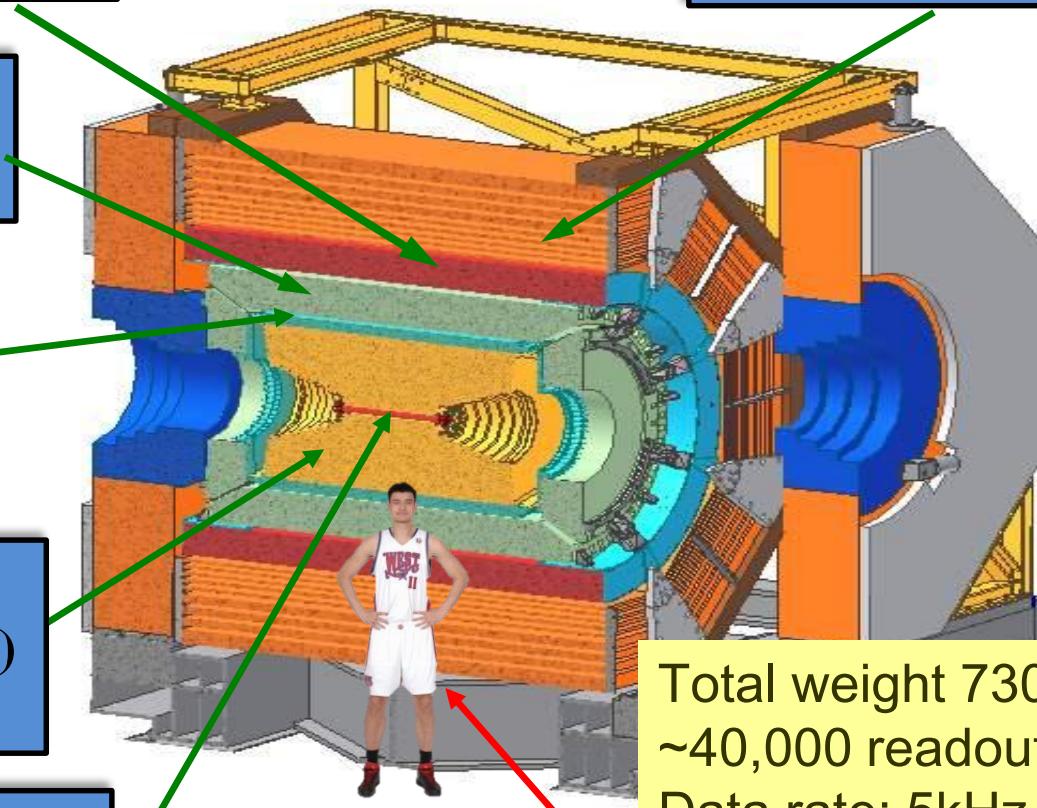
Electromagnetic CsI(Tl)  
Calorimeter, 2.5% @ 1 GeV

Time of Flight  
 $\sigma_t = 90 \text{ ps}$  (barrel)  
 $\sigma_t = 120 \text{ ps}$  (end caps)

Main Drift Chamber  
 $\sigma_{r\phi} = 130 \mu\text{m}$  (single wire)  
 $\sigma_{pt}/p_t = 0.5 \%$  @ 1 GeV

Be beam pipe

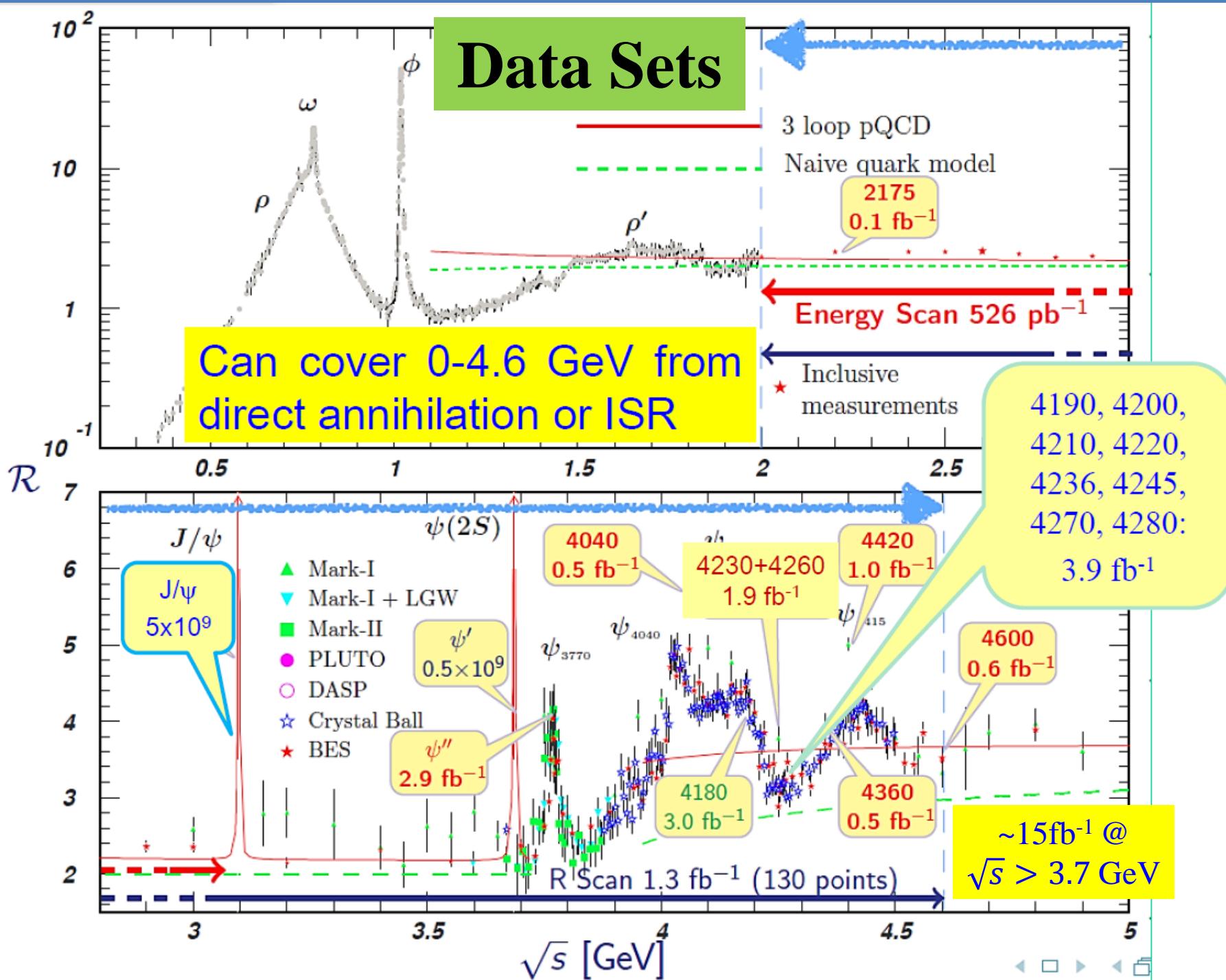
RPC Muon Detector



Total weight 730 ton,  
~40,000 readout chnls,  
Data rate: 5kHz, 50Mb/s

Yao Ming,  
height of 2.29 m

# Data Sets



# Isospin violations with $f_0(980)/a_0^0(980)$ production

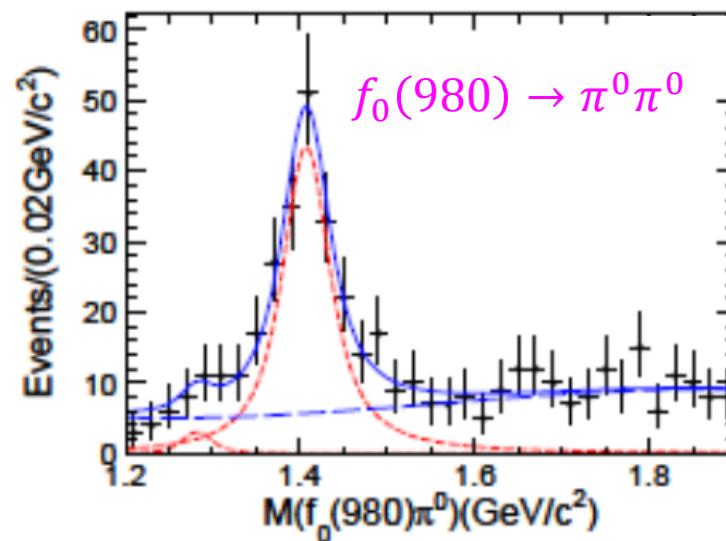
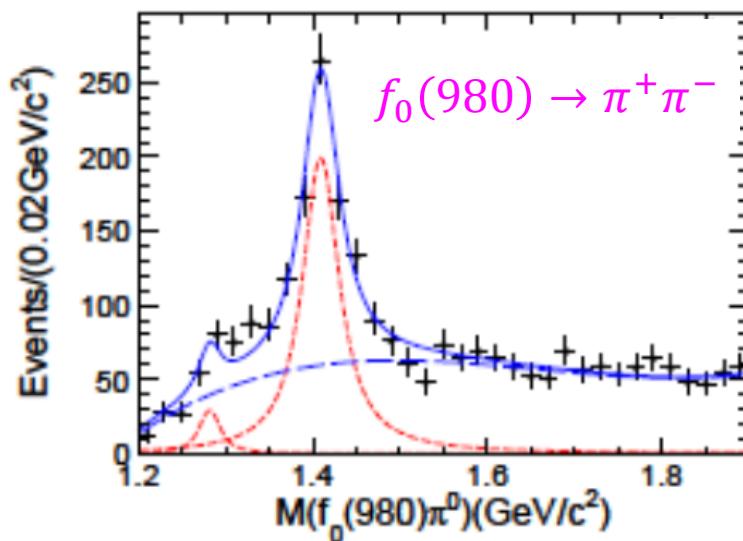
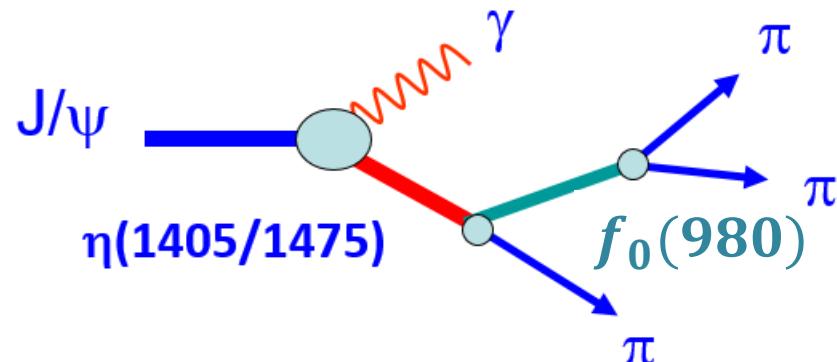
1.  $J/\psi \rightarrow \gamma\pi^0 f_0(980)$
2.  $J/\psi \rightarrow \phi\pi^0 f_0(980)$
3.  $J/\psi \rightarrow \phi a_0^0(980)$
4.  $\chi_{c1} \rightarrow \pi^0 f_0(980)$

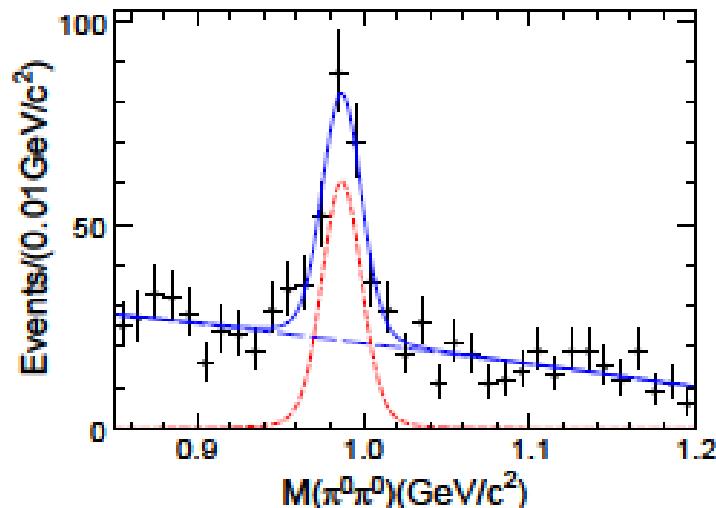
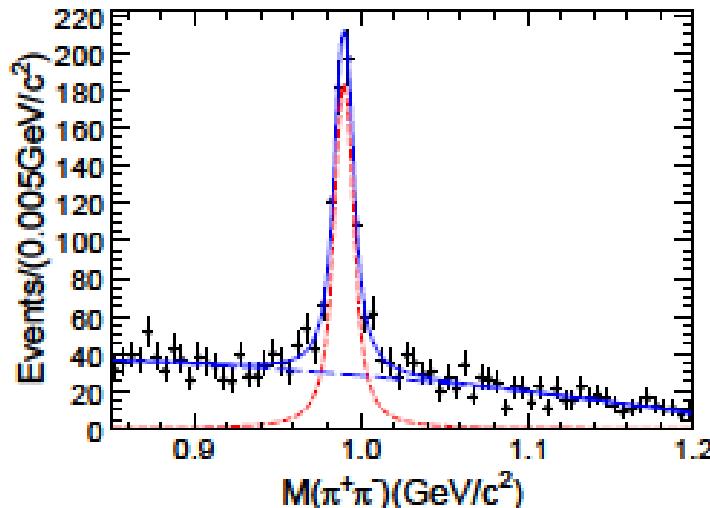
# $f_0(980)/a_0^0(980)$ in isospin-violating processes

- ◆ Firstly,  $f_0(980)$  and  $a_0^0(980)$  are explained as  $q\bar{q}$  mesons, tetraquarks,  $K\bar{K}$  molecules,  $q\bar{q}g$  hybrids and so on.
- ◆  $f_0(980)$  width in isospin-violating processes is always narrow:  $\Gamma \cong 10$  MeV ! But it was 40-100MeV in isospin conservations (see 2014 PDG and before. In 2016 and 2018 PDG, since several  $f_0(980)$  width in isospin-violating processes were considered,  $\Gamma = 10-100$  MeV).
- ◆ Theorists proposed to examine the  $f_0(980) \leftrightarrow a_0^0(980)$  mixing mechanism with isospin-violating processes  $J/\Psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi \eta \pi^0$  and  $\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-$ . [PRD 75 114012(2007), PRD 78 074017(2008)]
- ◆ Anomalously large violation in the following discussed channels with  $f_0(980)/a_0^0(980)$ .

**BESIII**First Observation of  $\eta(1405)$  Decays into  $f_0(980)\pi^0$ 

**Isospin-violating decay  
of  $J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma f_0\pi^0$**





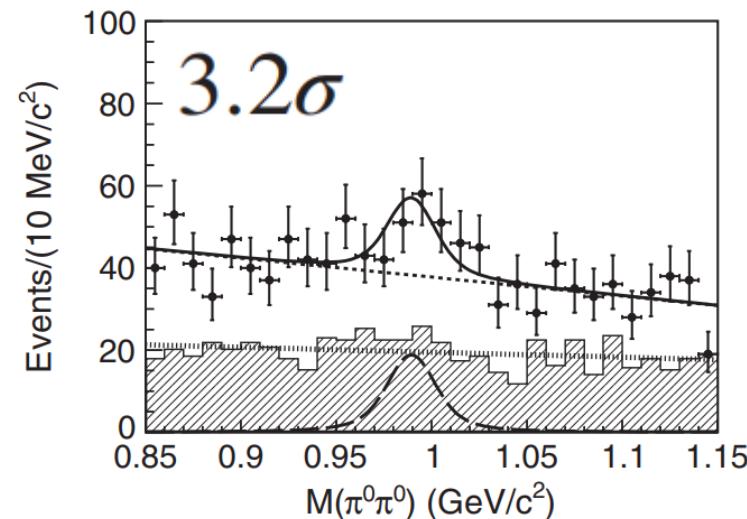
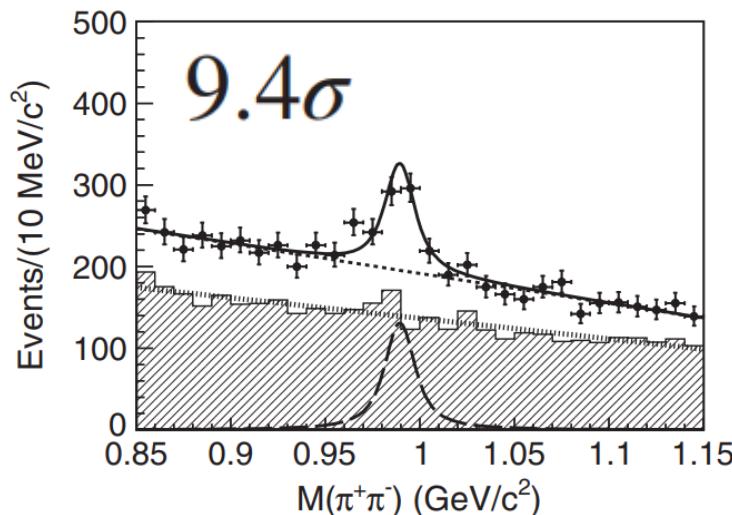
- **f<sub>0</sub>(980) width is narrow:  $\Gamma \cong 10 \text{ MeV} !$**

2014 PDG (and before):  $\Gamma \cong 40 \sim 100 \text{ MeV}.$

- **Anomalously large isospin violation!**

$$\frac{\text{Br}(\eta(1405) \rightarrow f_0(980)\pi^0 \rightarrow \pi^+\pi^-\pi^0)}{\text{Br}(\eta(1405) \rightarrow a_0^0(980)\pi^0 \rightarrow \eta\pi^0\pi^0)} \approx (17.9 \pm 4.2)\%$$

- ✓  $a_0^0(980) \rightarrow f_0(980)$  mixing [1]?
  - ✓ triangle singularity mechanism [2]?
- [1] PRL108, 081803 (2012)  
[2] PRD 75 114012(2007)

Observation of the isospin-violating decay  $J/\psi \rightarrow \phi\pi^0f_0(980)$ 

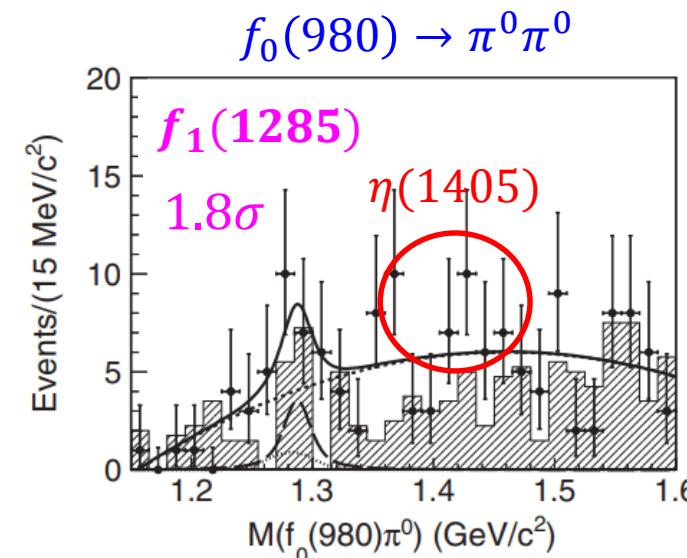
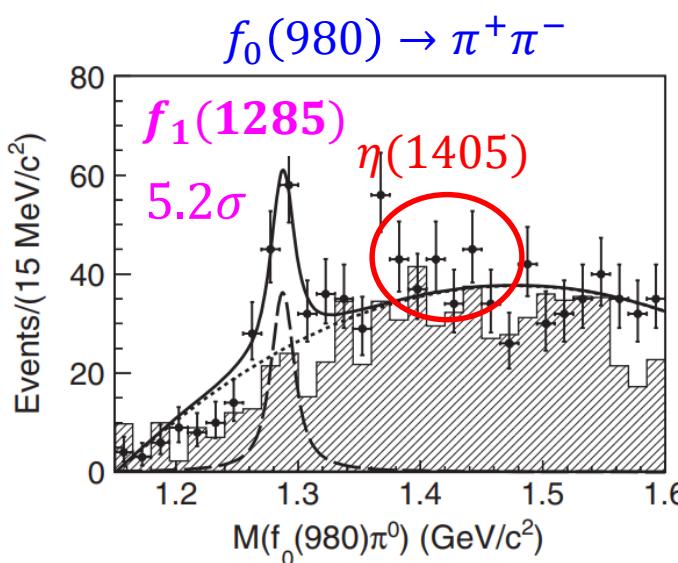
Combined two channels:

$$M(f_0) = 989.4 \pm 1.3 \text{ MeV}/c^2$$

$$\Gamma(f_0) = 15.3 \pm 4.7 \text{ MeV}/c^2 \quad (\text{Narrow})$$

## Observation of the isospin-violating decay $J/\psi \rightarrow \phi\pi^0f_0(980)$

Decay  $J/\psi \rightarrow \phi f_1(1285) \rightarrow \phi\pi^0f_0(980)$



$$M(f_1) = 1287.4 \pm 3.0 \text{ MeV}/c^2$$

$$\Gamma(f_1) = 18.3 \pm 6.3 \text{ MeV}/c^2$$

$$\mathcal{B}(f_1 \rightarrow \pi^0 f_0 \rightarrow \pi^0 \pi^+ \pi^-) / \mathcal{B}(f_1 \rightarrow \pi^0 a_0^0 \rightarrow \pi^0 \pi^0 \eta) = (3.6 \pm 1.4)\%$$

No  $\eta(1405)$  in  $\pi^0f_0(980)$  system observed in  $J/\psi \rightarrow \gamma\pi^0f_0(980)$ , but  $f_1(1285)$  is more clear.  
Very different!

# $f_0(980) - a_0^0(980)$ mixing in isospin-violating decays

Theorists proposed to directly measure

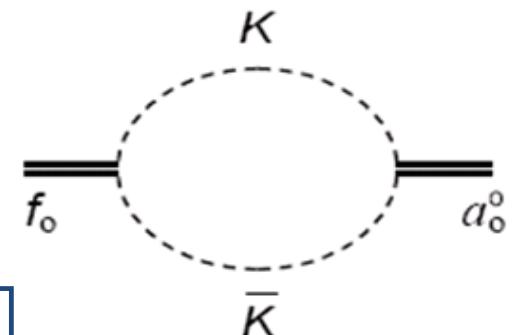
$f_0(980) \leftrightarrow a_0^0(980)$  mixing via isospin-violating processes  $J/\psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi \eta \pi^0$  and  $\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-$ .

[PRD 75 114012(2007), PRD 78 074017(2008)]

The references predicted the intensities of mixing:

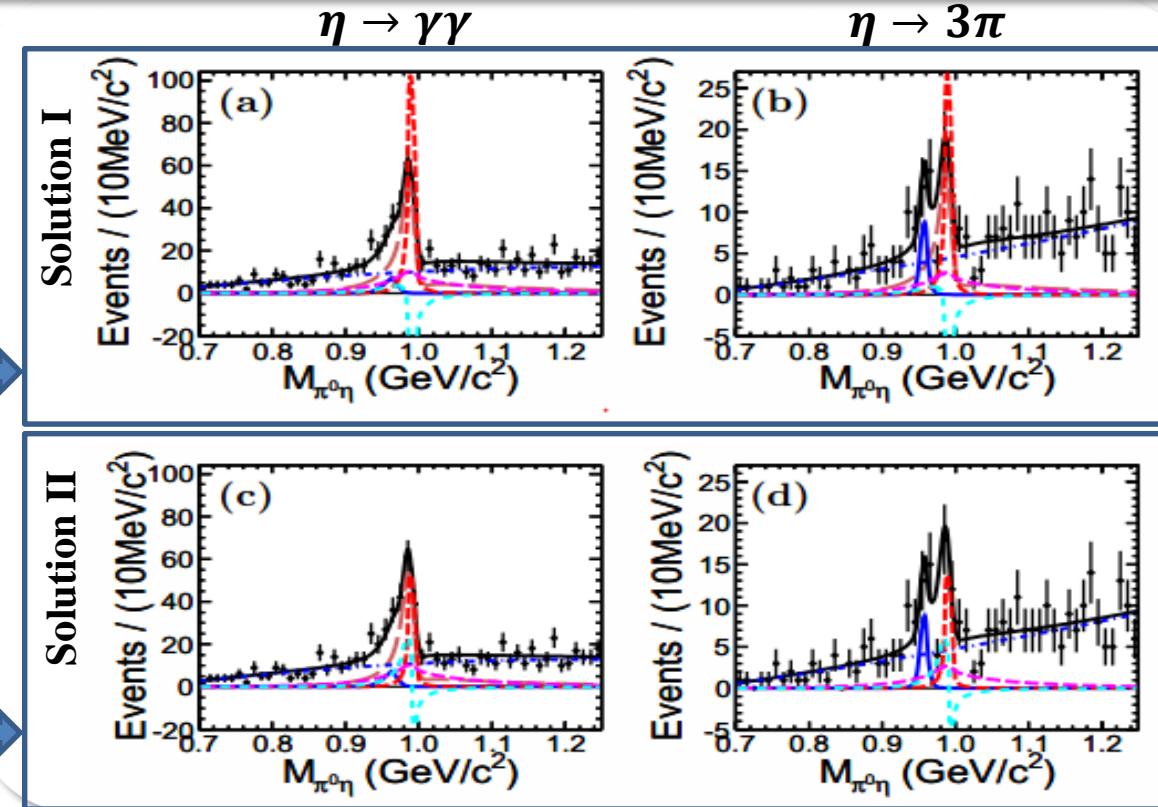
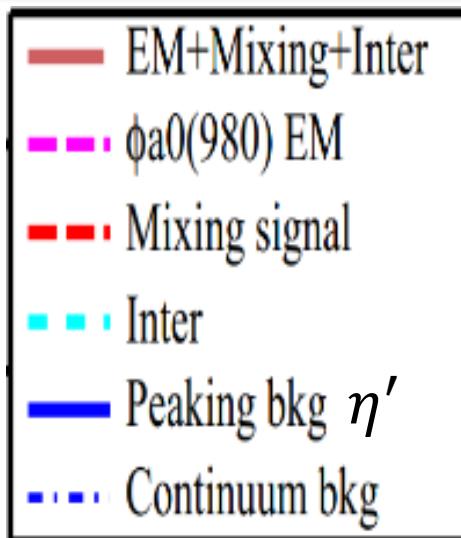
$$\xi_{fa} = \frac{\mathcal{B}(J/\psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi \eta \pi^0)}{\mathcal{B}(J/\psi \rightarrow \phi f_0(980) \rightarrow \phi \pi \pi)}$$

$$\xi_{af} = \frac{\mathcal{B}(\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-)}{\mathcal{B}(\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 \pi^0 \eta)}$$



# $J/\psi \rightarrow \phi f_0(980) \xrightarrow{\text{mixing}} \phi a_0^0(980)$

- ◆  $a_0^0(980)$  is reconstructed from  $\pi^0\eta$ .
- ◆ Interference between EM and mixing signal.

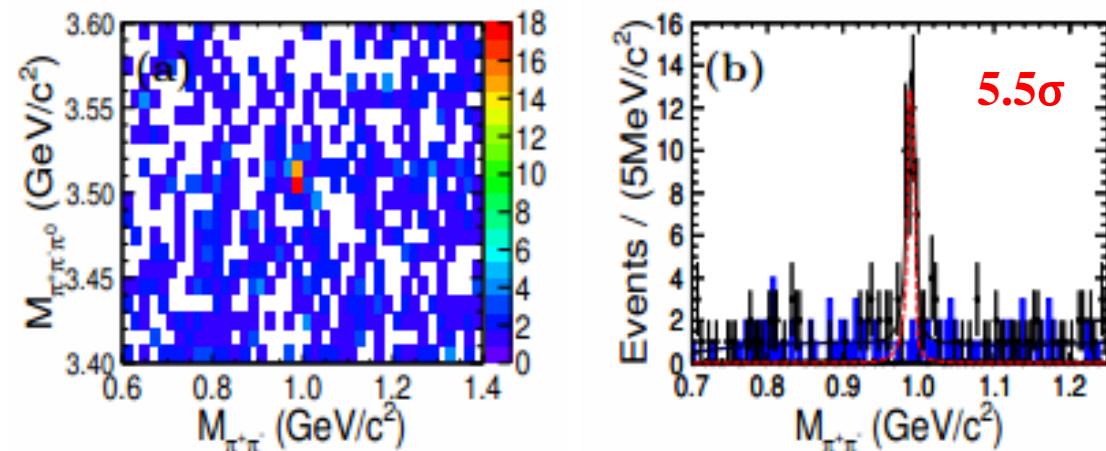


PRL 121, 022001 (2018)

	$f_0(980) \rightarrow a_0^0(980)$	
	Solution I	Solution II
$7.4\sigma$ $\mathcal{B}(\text{mixing}) (10^{-6})$	$3.18 \pm 0.51 \pm 0.38 \pm 0.28$	$1.31 \pm 0.41 \pm 0.39 \pm 0.43$
$4.6\sigma$ $\mathcal{B}(\text{EM}) (10^{-6})$	$3.25 \pm 1.08 \pm 1.08 \pm 1.12$	$2.62 \pm 1.02 \pm 1.13 \pm 0.48$
$\mathcal{B}(\text{total}) (10^{-6})$	$4.93 \pm 1.01 \pm 0.96 \pm 1.09$	$4.37 \pm 0.97 \pm 0.94 \pm 0.06$
$\xi (\%)$	$0.99 \pm 0.16 \pm 0.30 \pm 0.09$	$0.41 \pm 0.13 \pm 0.17 \pm 0.13$

$\chi_{c1} \rightarrow \pi^0 a_0^0(980)^{\text{mixing}} \rightarrow \pi^0 f_0(980)$ 

- ◆ Very narrow peak around 1.0 GeV
- ◆ EM contribution is weak ( $0.2\sigma$ ) and neglected
- ◆ Interference is negligible
- ◆ Significance of mixing  $a_0^0(980) \rightarrow f_0(980)$  is  $5.5\sigma$




---

Channel	$a_0^0(980) \rightarrow f_0(980)$
$\mathcal{B}(\text{mixing}) (10^{-6})$	$0.35 \pm 0.06 \pm 0.03 \pm 0.06$
$\mathcal{B}(\text{EM}) (10^{-6})$	—
$\mathcal{B}(\text{total}) (10^{-6})$	—
$\xi (\%)$	$0.40 \pm 0.07 \pm 0.14 \pm 0.07$

---

PRL 121, 022001 (2018)

# Isospin violating transitions with $\pi^0$ production

1.  $\psi' \rightarrow \pi^0 J/\psi$

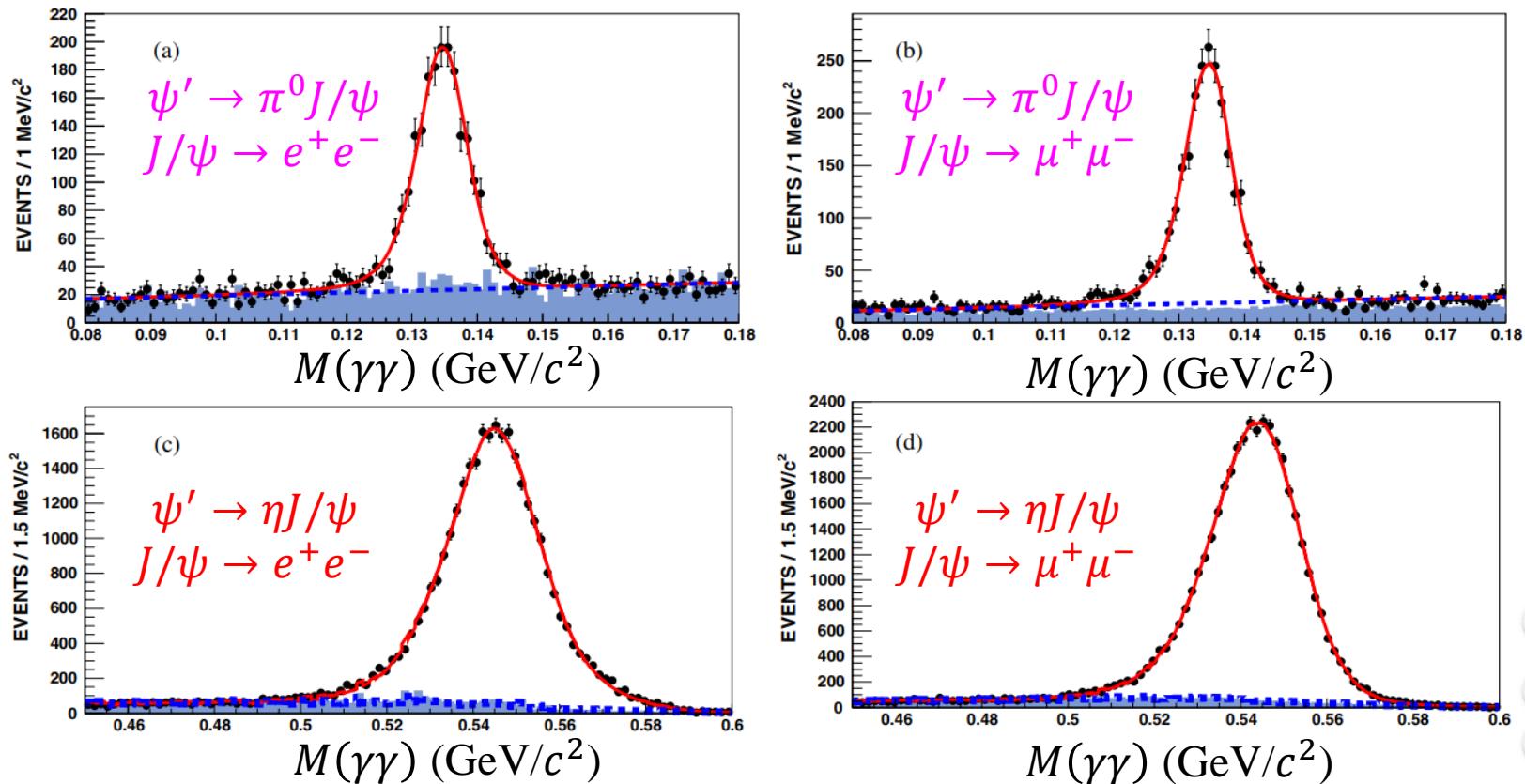
2.  $\psi' \rightarrow \pi^0 h_c$

3.  $\psi' \rightarrow \pi^0 \phi$

4.  $Y(4260) \rightarrow J/\psi \eta \pi^0$

5.  $D_{s0}^*(2317)^\pm \rightarrow \pi^0 D_s^\pm$

# Precision measurements of branching fractions for $\psi' \rightarrow \pi^0 J/\psi$ and $\eta J/\psi$

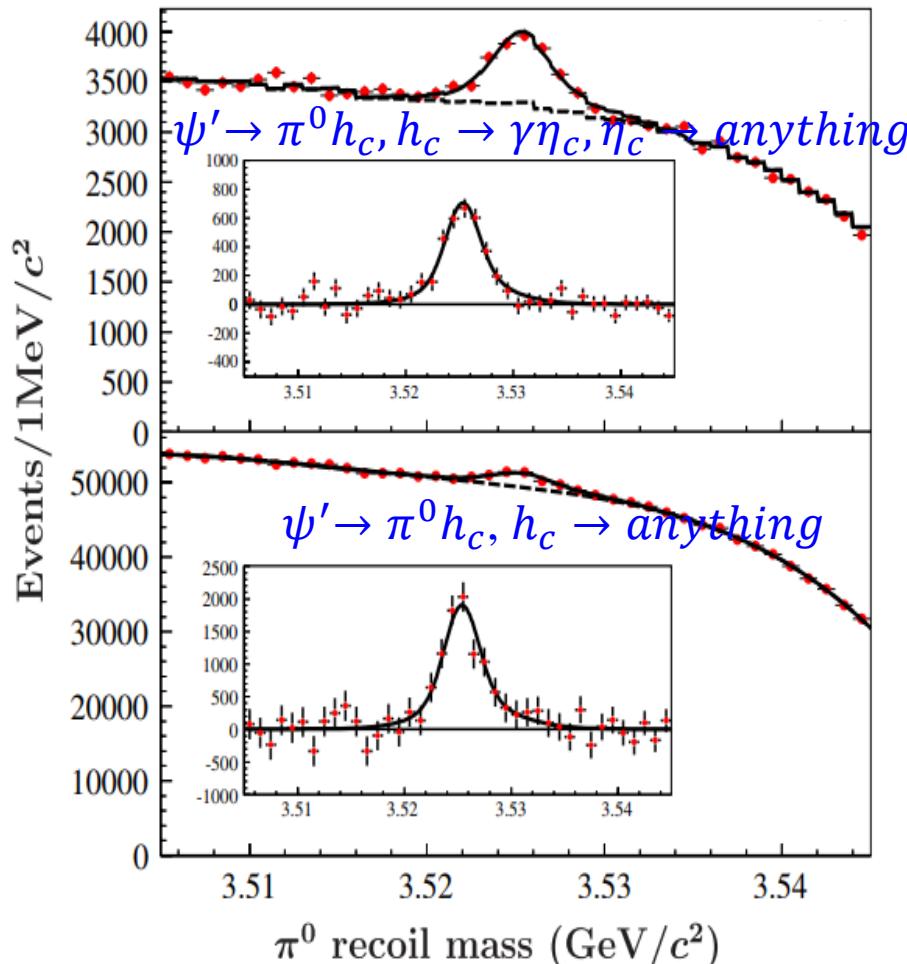


$$\mathcal{B}(\psi' \rightarrow \pi^0 J/\psi) = (1.26 \pm 0.02(\text{stat.}) \pm 0.03(\text{syst.})) \times 10^{-3}$$

$$\mathcal{B}(\psi' \rightarrow \eta J/\psi) = (33.75 \pm 0.17(\text{stat.}) \pm 0.86(\text{syst.})) \times 10^{-3}$$

$$R = \frac{\mathcal{B}(\psi' \rightarrow \pi^0 J/\psi)}{\mathcal{B}(\psi' \rightarrow \eta J/\psi)} = (3.74 \pm 0.06(\text{stat.}) \pm 0.04(\text{syst.})) \times 10^{-2}$$

# Isospin-violating decay $\psi' \rightarrow \pi^0 h_c$



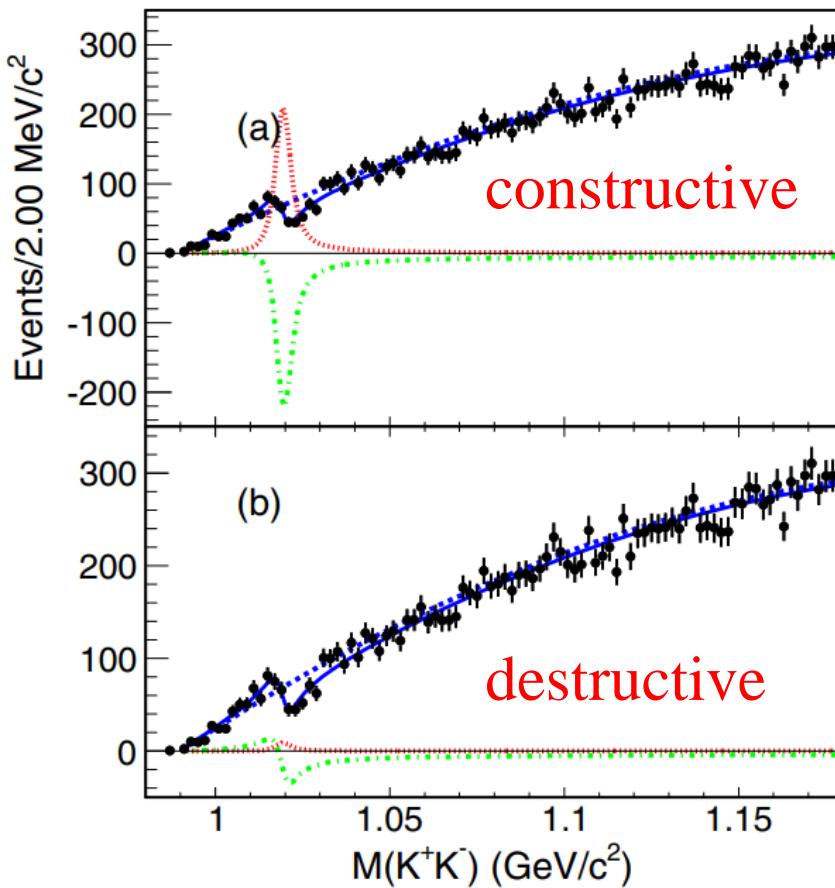
Phys. Rev. Lett. 104, 132002 (2010).

$$\mathcal{B}(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$$

$$R = \frac{\mathcal{B}(\psi' \rightarrow \pi^0 h_c)}{\mathcal{B}(\psi' \rightarrow \pi^0 J/\psi)} \cong 0.7$$

Taken into account phase space effect,  
the intensity of isospin violation would  
be equal between the two modes.

# Isospin-violating decay $J/\psi \rightarrow \pi^0\phi$



Phys. Rev. D 91, 112001 (2015)

Considering the interference between  
 $J/\psi \rightarrow \pi^0\phi$  and  $J/\psi \rightarrow \pi^0K^+K^-$ ,  
 $\mathcal{B}(J/\psi \rightarrow \pi^0\phi)$   
 $= (2.94 \pm 0.16 \pm 0.16) \times 10^{-6}$   
and  $(1.24 \pm 0.33 \pm 0.30) \times 10^{-7}$

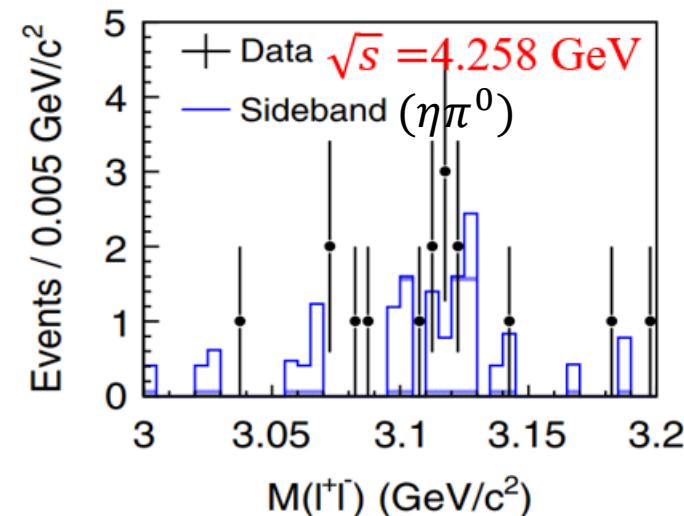
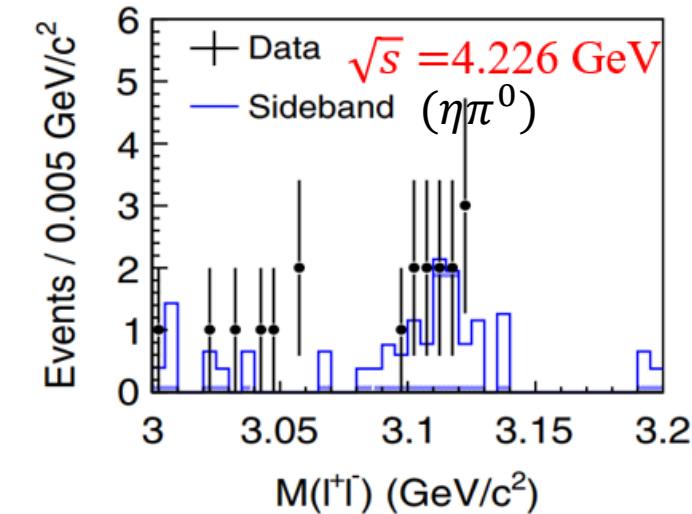
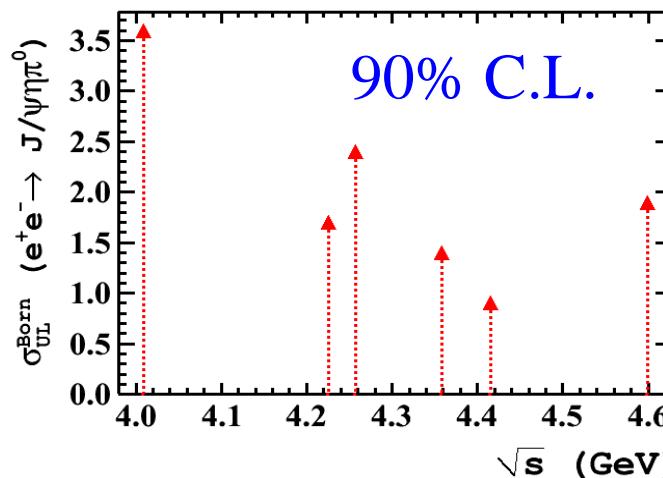
$$R = \frac{\mathcal{B}(J/\psi \rightarrow \pi^0\phi)}{\mathcal{B}(J/\psi \rightarrow \eta\phi)} \cong (0.2 - 4) \times 10^{-3}$$

# Search for the isospin violating decay $Y(4260) \rightarrow J/\psi\eta\pi^0$

- ✓ The tetraquark model [1] predicts that  $Z_c(3900)^0$  can be produced in  $Y(4260) \rightarrow J/\psi\eta\pi^0$  with  $Z_c(3900)^0$  decaying into  $J/\psi\pi^0$  and possibly  $J/\psi\eta$  in the presence of sizable isospin violation.
- ✓ The molecular model [2] predicts a peak in the cross section of  $Y(4260) \rightarrow J/\psi\eta\pi^0$  at the  $D_1\bar{D}$  threshold and a narrow peak in the  $J/\psi\eta$  invariant mass spectrum at the  $D\bar{D}^*$  threshold.

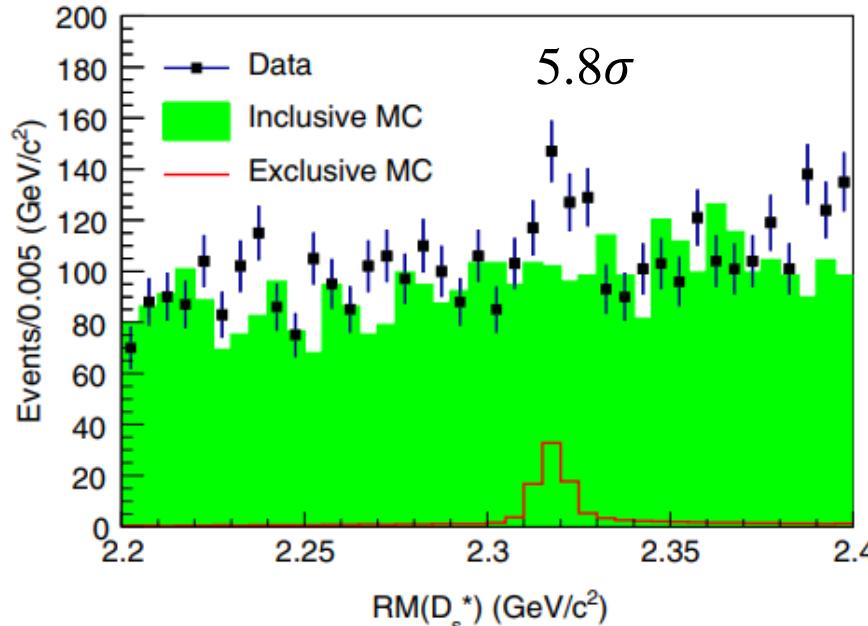
[1]Phys. Rev. D 87, 111102 (2013)

[2]Phys. Rev. D 89, 054038 (2014)

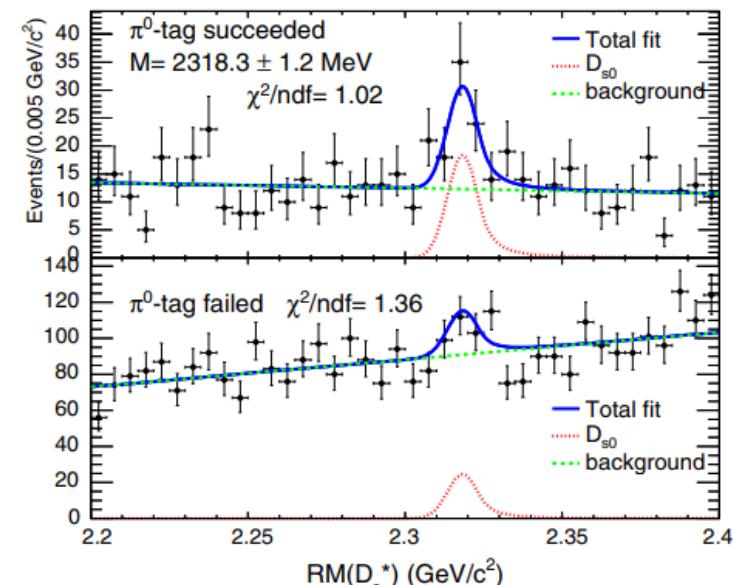


# Isospin-violating decay $D_{s0}^*(2317)^\pm \rightarrow \pi^0 D_s^\pm$

PRD 97, 051103 (2018)



via  $e^+e^- \rightarrow D_s^{*\mp} D_{s0}^*(2317)^\pm$



The absolute branching fraction  $\mathcal{B}(D_{s0}^*(2317)^\pm \rightarrow \pi^0 D_s^\pm)$  is measured as  $1.00^{+0.00}_{-0.14}(\text{stat})^{+0.00}_{-0.14}(\text{syst})$  for the first time.

It indicates that  $D_{s0}^*(2317)^-$  tends to have a significantly smaller branching fraction to  $\gamma D_s^-$  than to  $\pi^0 D_s^-$ , and this differs from the expectation of the conventional  $\bar{c}s$  hypothesis of the  $D_{s0}^*(2317)^-$  [PRD 74, 032007 (2006)], but agrees well with the calculation in the molecule picture [PLB 568, 254 (2003)].

# Isospin violations in baryon final states

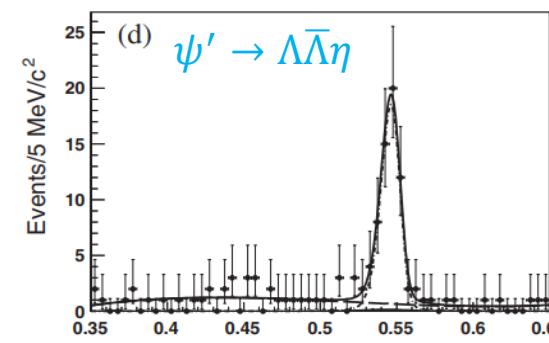
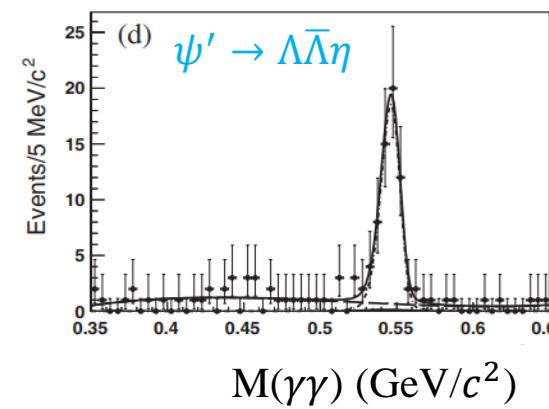
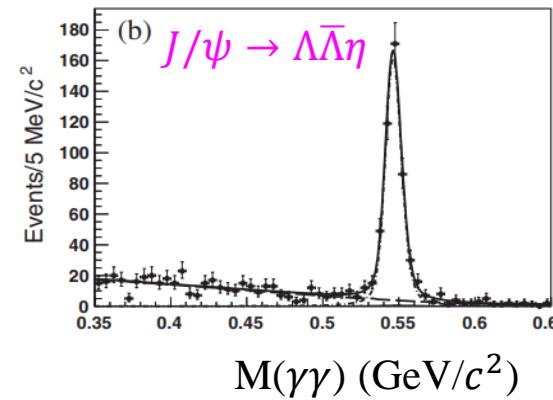
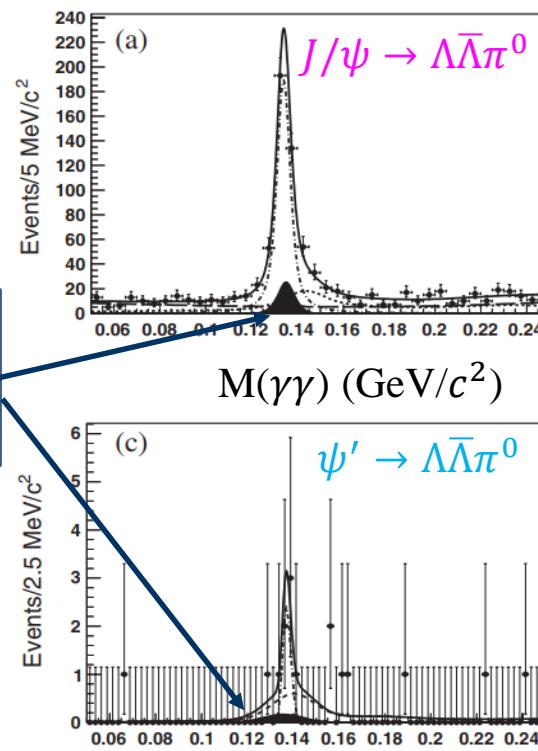
1.  $J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^0$

2.  $J/\psi \rightarrow \Lambda\bar{\Sigma} + c.c.$

3.  $e^+e^- \rightarrow \Lambda(1520)\bar{n}K^0 + c.c.$   
 $\neq e^+e^- \rightarrow \Lambda(1520)\bar{p}K^+ + c.c.$

# $J/\psi$ and $\psi'$ → $\Lambda\bar{\Lambda}\pi^0$ and $\Lambda\bar{\Lambda}\eta$

Peaking:  
 $\Lambda\bar{\Lambda}^0\pi^0$



PRD 87, 052007 (2013)

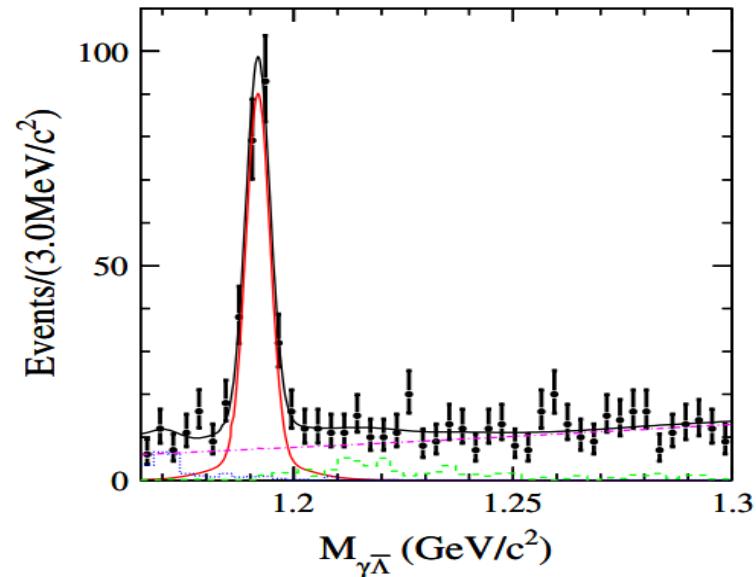
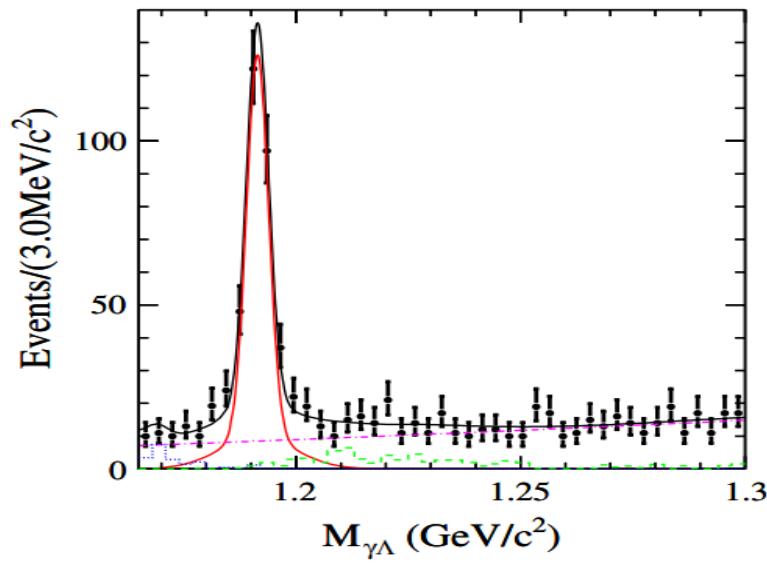
Extremely  
large!

$$R = \frac{\mathcal{B}(J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^0)}{\mathcal{B}(J/\psi \rightarrow \Lambda\bar{\Lambda}\eta)} = \frac{(3.78 \pm 0.27 \pm 0.30) \times 10^{-5}}{(15.7 \pm 0.80 \pm 1.54) \times 10^{-5}} = 0.24$$

$$R = \frac{\mathcal{B}(\psi' \rightarrow \Lambda\bar{\Lambda}\pi^0)}{\mathcal{B}(\psi' \rightarrow \Lambda\bar{\Lambda}\eta)} = \frac{0.29 \times 10^{-5} @ 90\% C.L.}{(2.48 \pm 0.34 \pm 0.19) \times 10^{-5}} < 0.12$$

# First observation of the isospin violating decay $J/\psi \rightarrow \Lambda \bar{\Sigma}^0 + \text{c.c.}$

$\gamma \bar{\Lambda}$

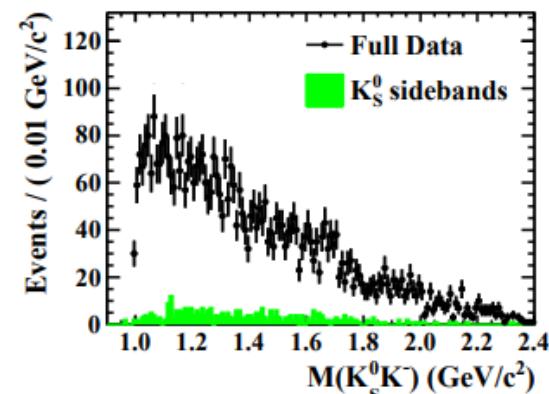
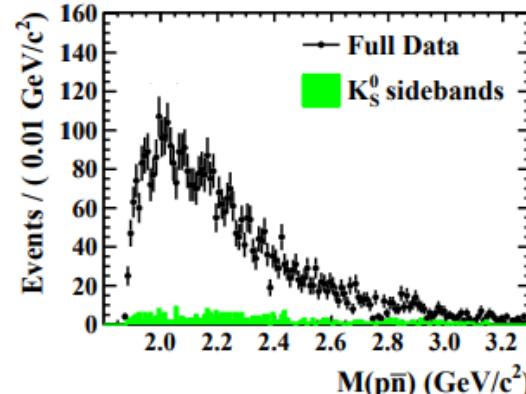
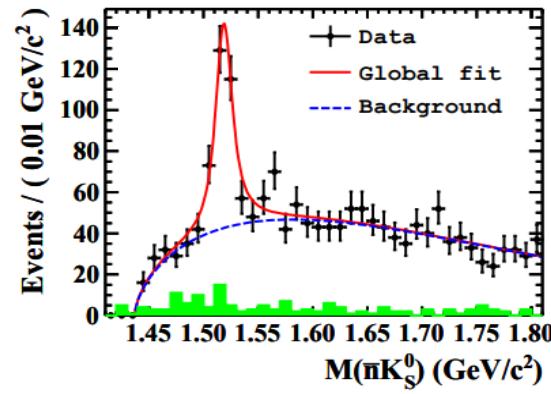
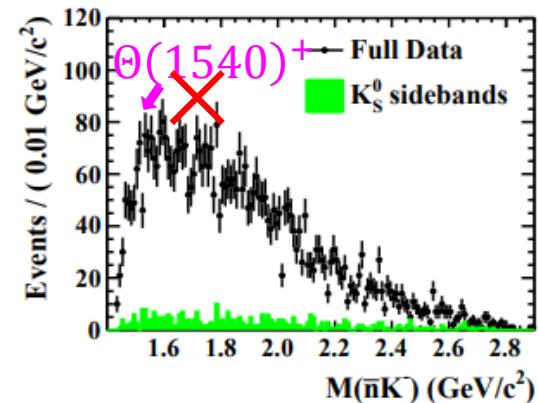
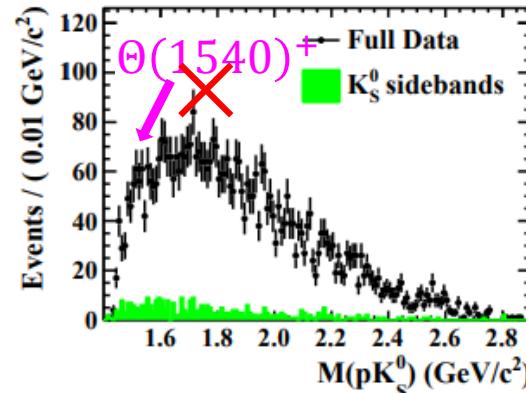
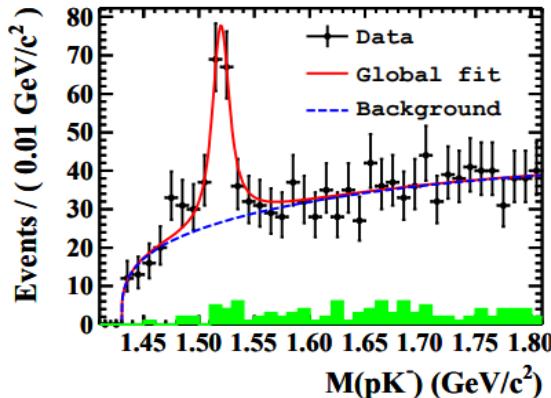


$$\mathcal{B}(J/\psi \rightarrow \bar{\Lambda}\Sigma) = (1.46 \pm 0.11 \pm 0.12) \times 10^{-5}$$
$$\mathcal{B}(J/\psi \rightarrow \Lambda\bar{\Sigma}) = (1.37 \pm 0.12 \pm 0.11) \times 10^{-5}$$

First measurement of  $e^+e^- \rightarrow pK_S^0\bar{n}K^- + c.c.$ 

arXiv: 1807.03468

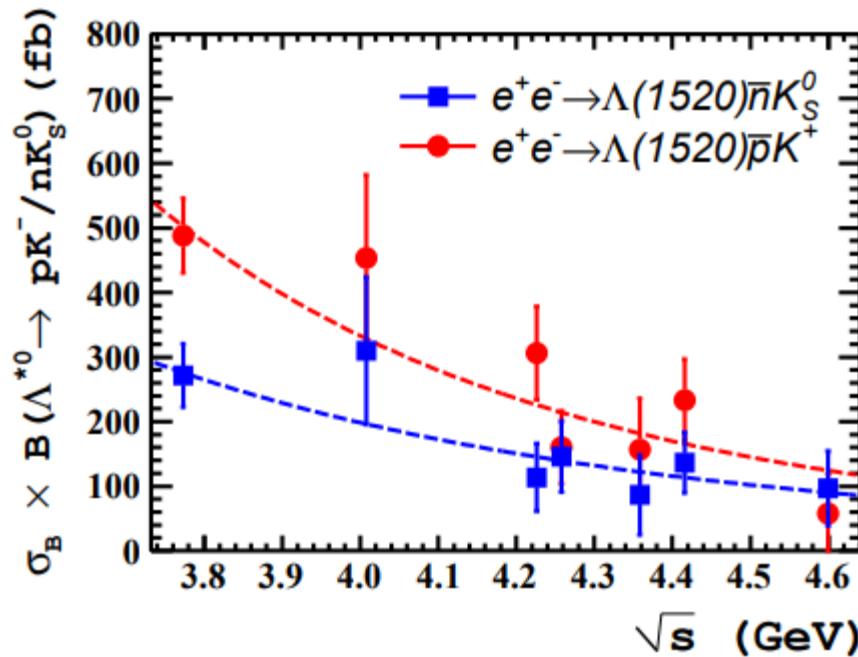
above open charm threshold

Except for  $\Lambda(1520)$ , no significant signal is observed.

# First measurement of $e^+e^- \rightarrow pK_S^0\bar{n}K^- + c.c.$

above open charm threshold

arXiv: 1807.03468



$$\frac{\sigma_{Born}[e^+e^- \rightarrow \Lambda(1520)\bar{n}K_S^0 + c.c.] \times \mathcal{B}[\Lambda(1520) \rightarrow pK^-]}{\sigma_{Born}[e^+e^- \rightarrow \Lambda(1520)\bar{p}K^+ + c.c.] \times \mathcal{B}[\Lambda(1520) \rightarrow pK^-]} \neq 1$$

The statistical significance of the cross section difference at center-of-mas energy of 3.773 GeV is determined to be  $3.1\sigma$ .

# Summary

- Exotic mesons  $f_0(980)$  and  $a_0^0(980)$  in isospin-violating decays are investigated.
- BESIII has accumulated 5 billion  $J/\psi$  events, 0.5 billion  $\psi'$  events and  $\sim 15 \text{ fb}^{-1}$  data above open charm threshold, and is an ideal place to study isospin violations.
- More interesting results are expected at BESIII.

**Thank you for your attention!**

# Backup

# BESIII Collaboration

Political Map of the World, June 1999



**~500 members  
66 institutions  
14 countries**

## Europe (16)

**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

**UK:** Oxford Univ., Univ. of Manchester

<http://bes3.ihep.ac.cn>

## Mongolia (1)

Ins. of Phy. & Tech.

## Korea (1)

Seoul Nat. Univ.

## Japan (1)

Tokyo Univ.

## China (38)

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.

Jinan Univ., Fudan Univ.

Hunan Normal Univ.