

# Recent BESIII Results

Stefano Spataro  
for the **BESIII** collaboration



Thursday, 13<sup>th</sup> October, 2011



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# Recent BESIII Results

S. Spataro for the BESIII Collaboration

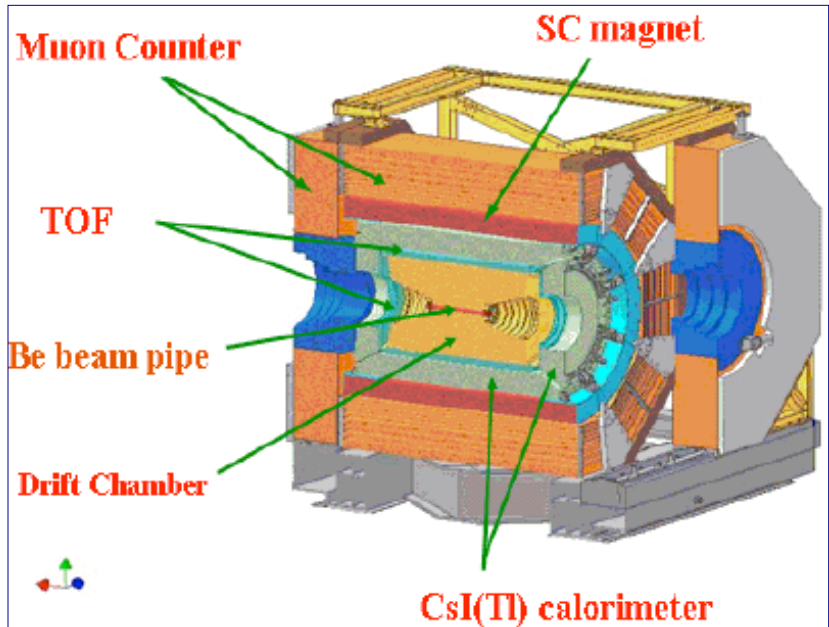


## The BESIII Experiment @ BEPCII

Beijing Spectrometer

$e^+e^-$  collisions  
 $\sqrt{s} \Rightarrow 4.6 \text{ GeV}$

Physics program



- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- $\tau$ -Physics
- ...



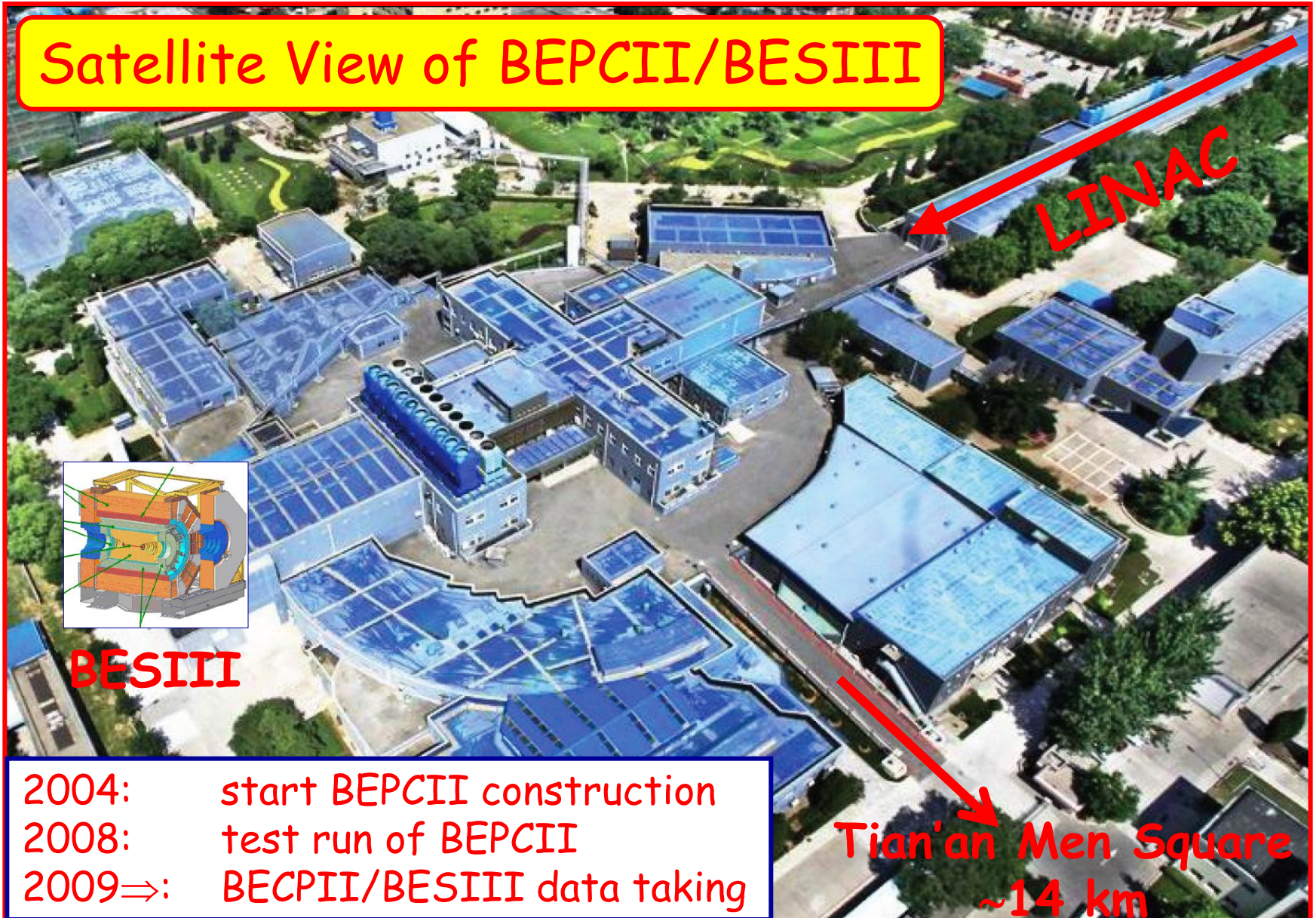
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# Recent BESIII Results

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## Satellite View of BEPCII/BESIII



**BESIII**

- 2004: start BEPCII construction
- 2008: test run of BEPCII
- 2009⇒: BEPCII/BESIII data taking



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## BEP CII Storage Rings Beijing Electron-Positron Collider

□ Beam energy:

1.0-2.3 GeV

□ Design Luminosity:

$1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

□ Achieved Luminosity:

$\sim 0.65 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

□ Optimum energy:

1.89 GeV

□ Energy spread:

$5.16 \times 10^{-4}$

□ No. of bunches:

93

□ Bunch length:

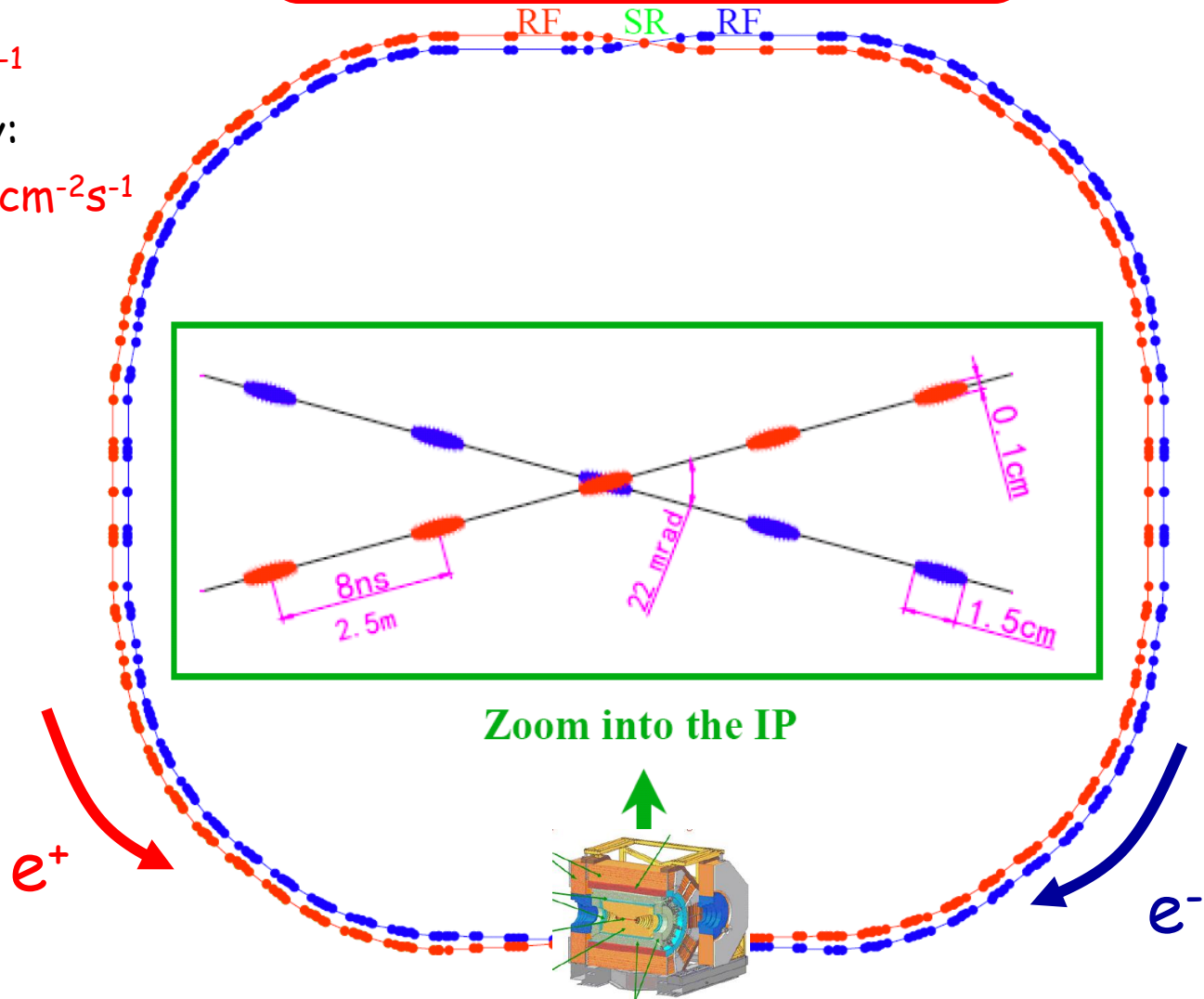
1.5 cm

□ Total current:

0.91 A

□ Circumference:

237m





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## BESIII Detector

EMC: CsI crystals, 28 cm  
 $\Delta E/E = 2.5\% @ 1 \text{ GeV}$   
 $\sigma_z = 0.6 \text{ cm}/\sqrt{E}$

TOF:  
 $\sigma_T = 80 \text{ ps}$  Barrel  
 $110 \text{ ps}$  Endcap

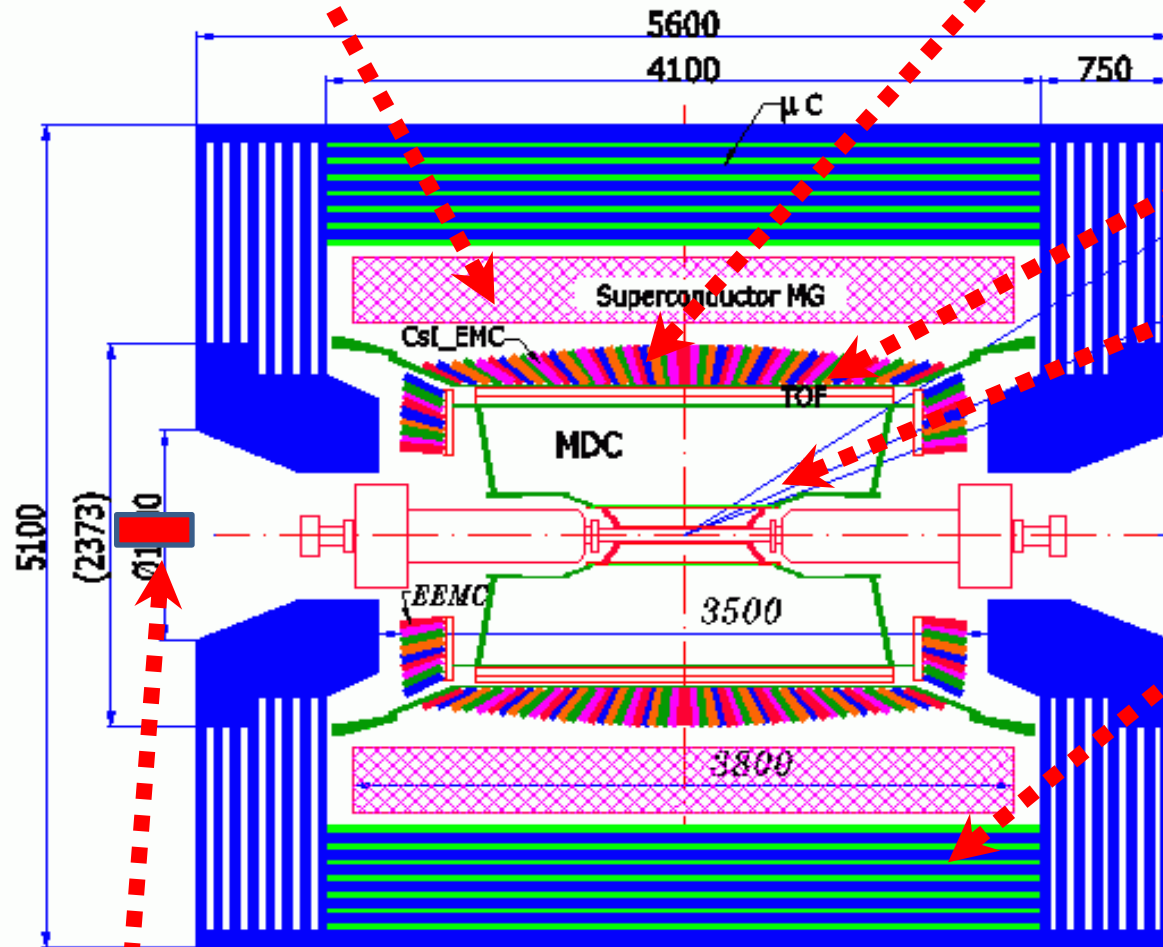
MDC: small cell & He gas  
 $\sigma_{xy} = 130 \mu\text{m}$   
 $\sigma_p/p = 0.5\% @ 1 \text{ GeV}$   
 $dE/dx = 6\%$

Muon ID: 9 layer RPC

Trigger: Tracks & Showers  
 Pipelined; Latency = 2.4 ms

Data Acquisition:  
 Event rate = 3 kHz  
 Thruput  $\sim 50 \text{ MB/s}$

Magnet: 1T Super conducting



Zero Degree Detector (ISR)



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## BESIII Collaboration

### Europe (11)

**Germany:** U. Bochum, U. Giessen, Mainz(2), GSI Darmstadt

**Russia:** JINR Dubna, BINP Novosibirsk

**Italy:** Univ. of Torino and INFN, LN Frascati and INFN

**Netherlands:** KVI/U. Gronigen

**Turkey:** Turkish Accelerator Center

### Korea (1)

Seoul Nat. Univ.

### Japan (1)

Tokyo Univ.

### US (6)

Univ. of Hawaii  
Univ. of Washington  
Carnegie Mellon Univ.  
Univ. of Minnesota  
Univ. of Rochester  
Univ. of Indiana

### Pakistan (1)

Univ. of Punjab

### China (26)

IHEP, CCAST, 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  
Hunan Univ., Liaoning Univ.  
Nanjing Univ., Nanjing Normal Univ.  
Guangxi Normal Univ., Guangxi Univ.

Hong Kong Univ. Hong Kong Chinese Univ.  
GUCAS, Lanzhou Univ.

> 300 physicists  
49 institutions from 10 countries





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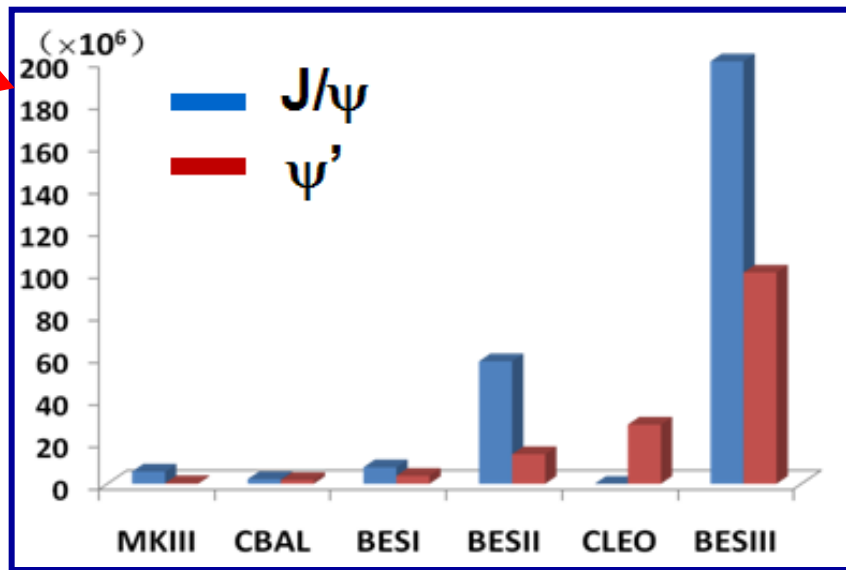
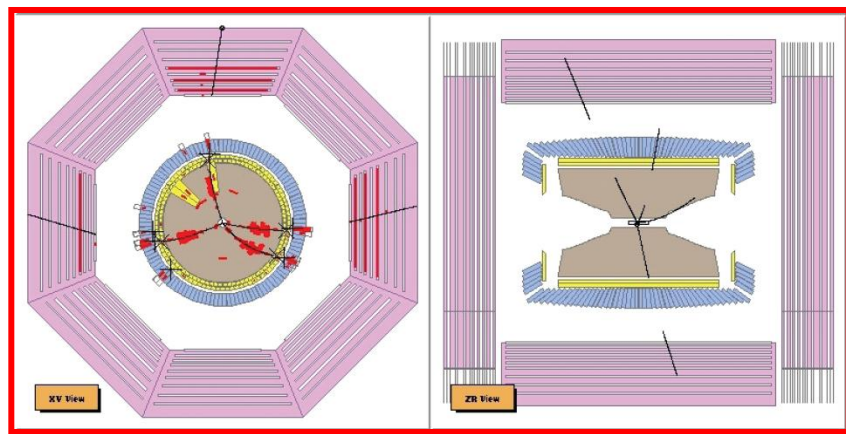
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## Data Sample

➤ So far:

- ❑ 2008: First collision
- ❑ 2009: 225 Million  $J/\psi$
- ❑ 2009: 106 Million  $\psi'$
- ❑ 2010-11:  $2.9 \text{ fb}^{-1} \psi(3770)$   
( $3.5 \times \text{CLEO-c } 0.818\text{fb}^{-1}$ )
- ❑ May 2011:  $0.5\text{fb}^{-1}$  @4010 MeV (one month) for Ds and XYZ spectroscopy



➤ In the next future:

- ❑ more  $J/\psi$ ,  $\psi'$ ,  $\psi(3770)$
- ❑ data at higher energies (for XYZ searches, R scan and Ds physics)



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# Recent BESIII Results

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- Charmonium Spectroscopy and Transitions

- Properties of the  $h_c$  (*PRL 104, 132002 (2010)*)
- $\psi' \rightarrow \gamma\gamma J/\psi$  (to be submitted soon)

- Charmonium Decays

- $\psi' \rightarrow \gamma\pi^0, \gamma\eta, \gamma\eta'$  (*PRL 105, 261801 (2010)*)
- $\chi_{cJ} \rightarrow \pi^0\pi^0, \eta\eta$  (*PRD 81, 052005 (2010)*)
- $\chi_{cJ} \rightarrow \gamma\rho, \gamma\omega, \gamma\phi$  (*PRD 83, 112005 (2011)*)
- $\chi_{cJ} \rightarrow \omega\omega, \phi\phi, \omega\phi$  (*PRL 107, 092001 (2011)*)
- $\chi_{cJ} \rightarrow 4\pi^0$  (*PRD 83, 012006 (2011)*)
- $\chi_{cJ} \rightarrow ppK^+K^-$  (*PRD 83, 112009 (2011)*)
- $\eta' \rightarrow \eta\pi^+\pi^-$  matrix element (*PRD 83, 012003 (2011)*)
- Search for CP/P violation process pseudoscalar decays into  $\pi\pi$  (*PRD 84, 032006 (2011)*)

Publications

- Light Quark States

- $a_0(980) - f_0(980)$  mixing (*PRD 83, 032003 (2011)*)
- X(1860) in  $J/\psi \rightarrow \gamma pp$  (*Chinese Physics C 34, 4 (2010)*)
- X(1835) in  $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$  (*PRL 106, 072002 (2011)*)
- X(1870) in  $J/\psi \rightarrow \omega\eta\pi^+\pi^-$  (accepted by PRL)
- PWA on  $J/\psi \rightarrow \gamma pp$  (to be submitted soon)
- PWA on  $\psi' \rightarrow \eta pp$  (to be submitted soon)





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# Charmonium



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## Charmonium Physics

- Strongly bound  $q\bar{q}$  state
- Non relativistic QM applicable
  - QCD analog to positronium
  - Provide insight into QCD
- Low  $Q^2 \rightarrow$  non perturbative

### New interest in the last years

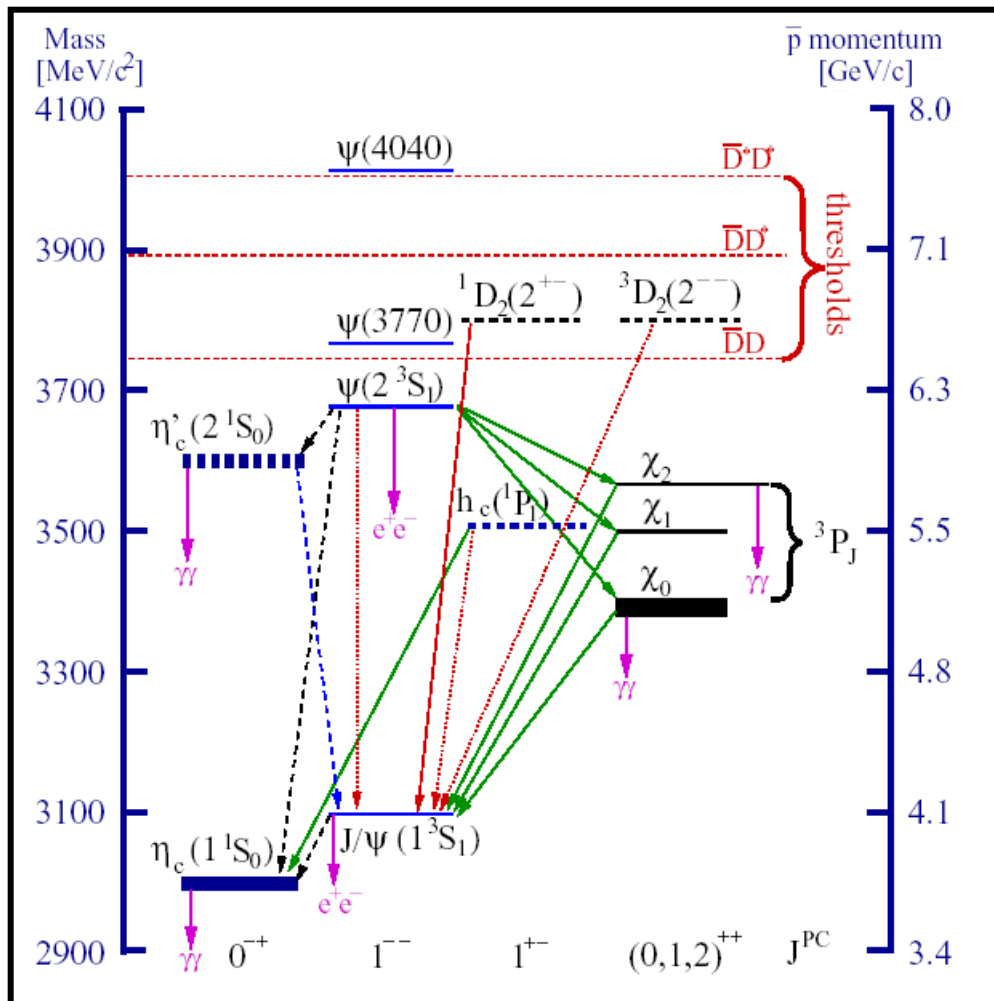
- new measurements of  $\eta_c$  mass

- $\eta'_c$  unambiguously seen

- Open problems

- $h_c$  seen with poor statistics
- State above  $D\bar{D}$  threshold

- New resonances (X, Y, Z)





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## Observation of $h_c(1P_1)$

### ➤ First Evidence: E835

- ❑  $p\bar{p} \rightarrow h_c \rightarrow \gamma \eta_c$
- ❑ PRD 72, 092004 (2005)

### ➤ Observation by CLEO-C

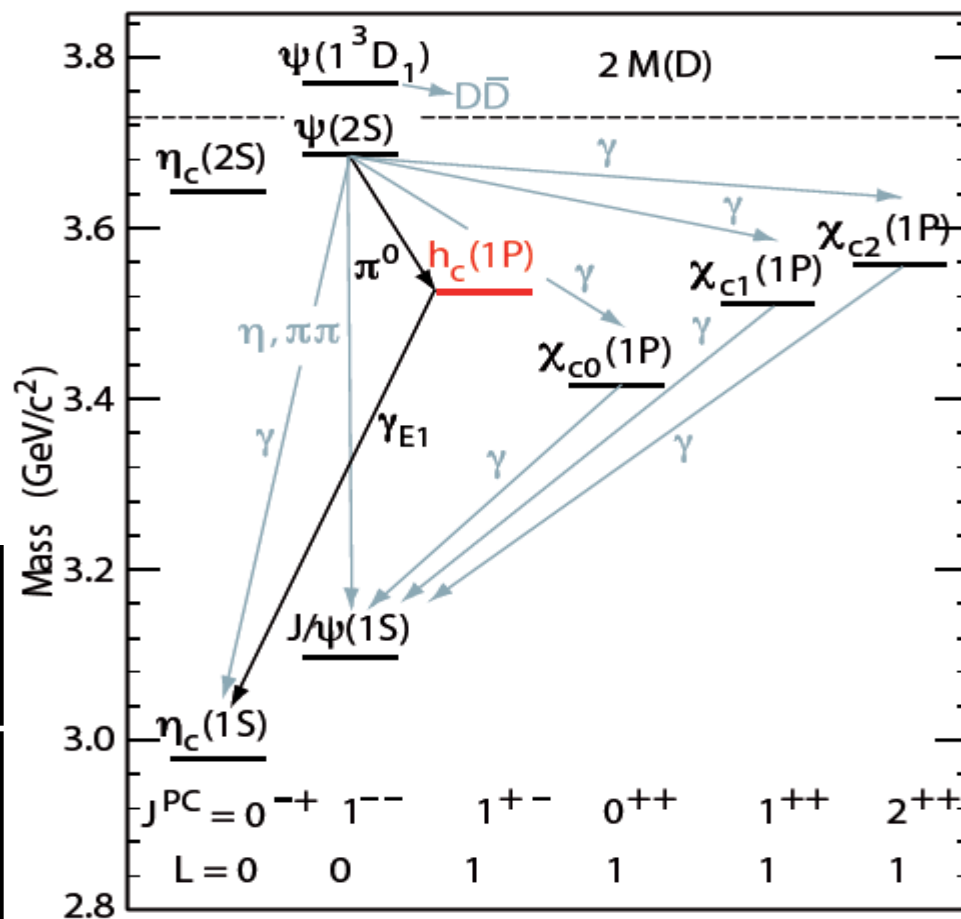
- ❑  $e^+e^- \rightarrow \psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$
- ❑ PRD 72, 092004 (2005)

- $Br(\psi' \rightarrow \pi^0 h_c)$  isospin violating
- $h_c \rightarrow \gamma \eta_c$  E1 transition large BR

### ➤ Hyperfine splitting of 1P states

$$M(h_c) - \frac{1}{9}(M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2}))$$

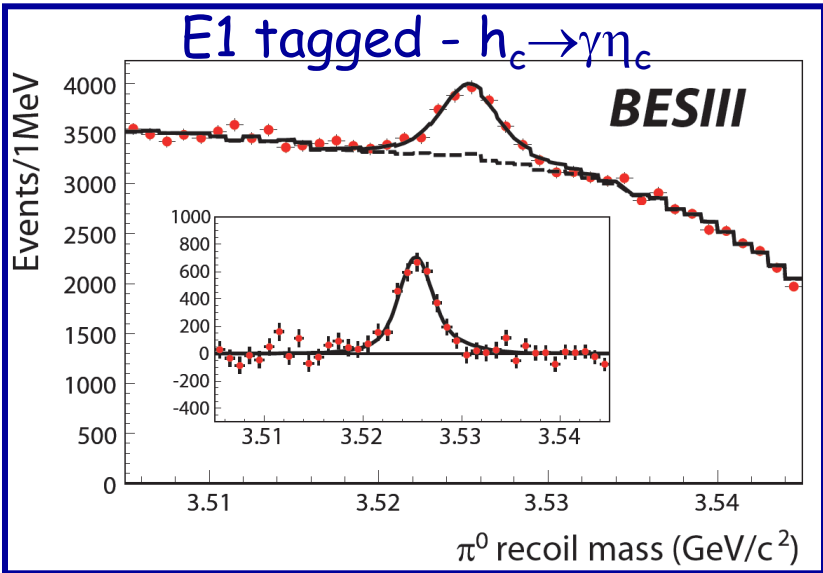
spin-spin interaction ?





# Observation of $h_c$ @ BESIII (inclusive)

BESIII Collaboration: PRL104, 132002, (2010)



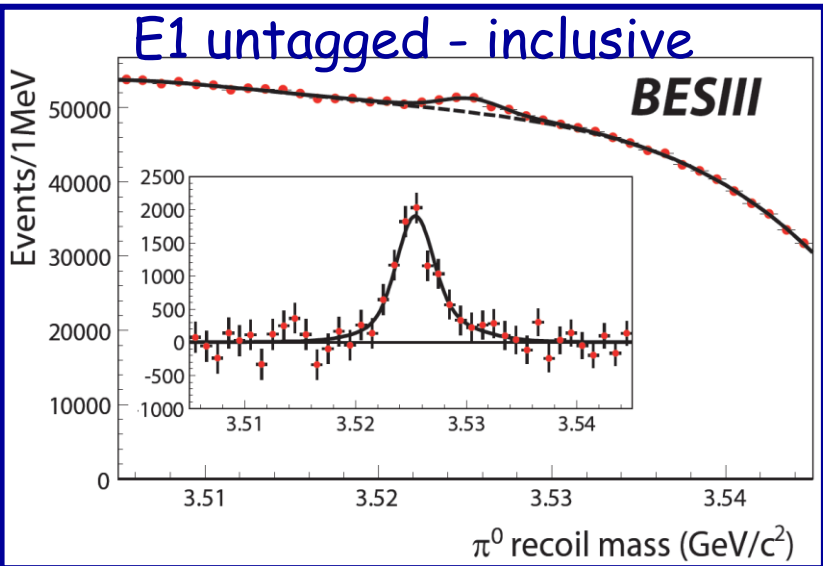
## ➤ E1-tagged analysis

□  $M(h_c) = 3525.40 \pm 0.13 \pm 0.18 \text{ MeV}$   
*consistent with CLEO-C*

( $\Delta M_{hf}(1P) = 0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$ )  
*consistent with no strong spin-spin interaction*

□  $\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}$   
*first measurement*  
 ( $< 1.44 \text{ MeV}$  at 90% CL)

□  $\text{Br}(\psi' \rightarrow \pi^0 h_c) \times \text{Br}(h_c \rightarrow \gamma \eta_c) =$   
 $(4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$   
*consistent with CLEO-C*



## ➤ E1-untagged

□  $\text{Br}(\psi' \rightarrow \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$   
*first measurement*

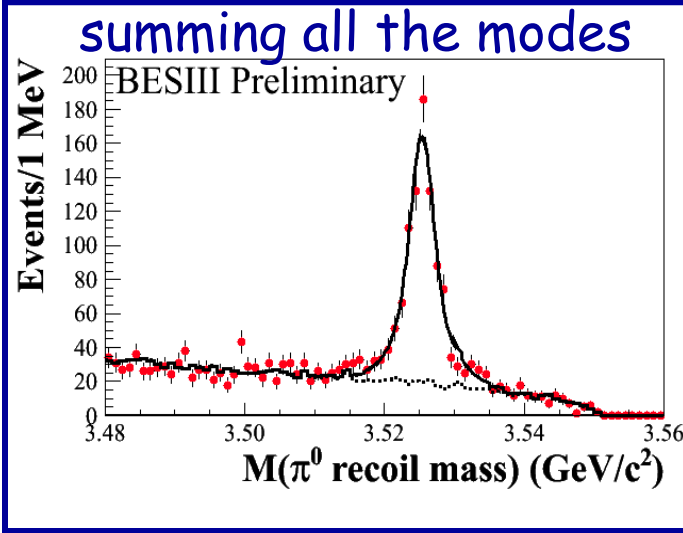
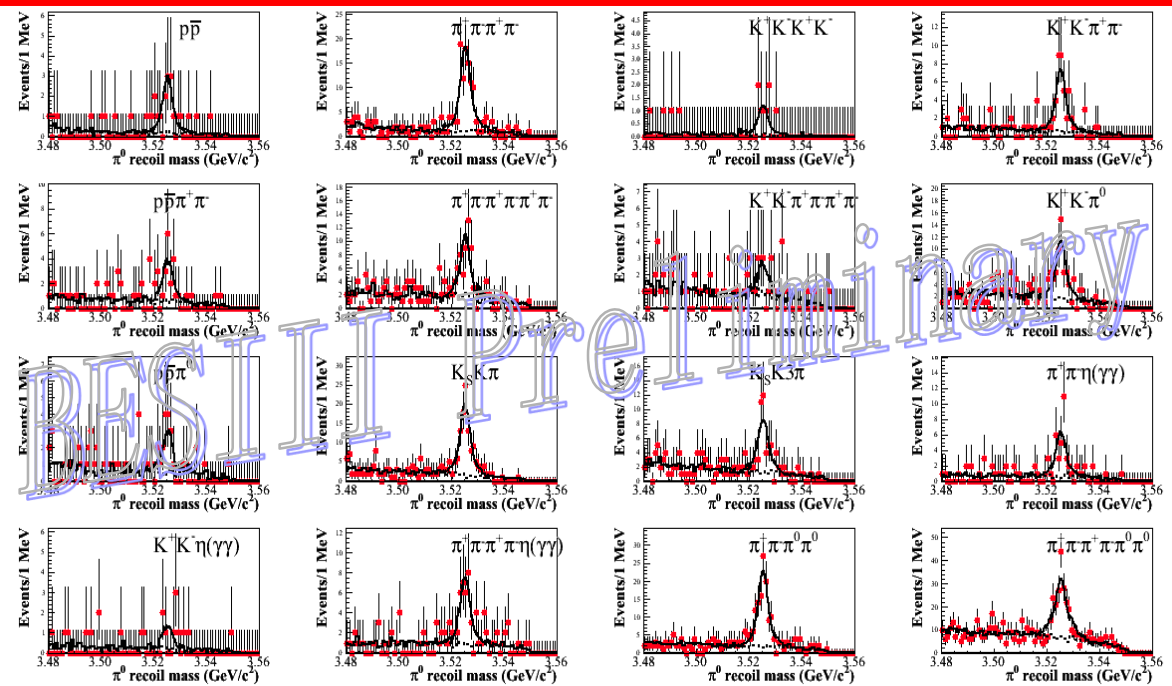
## ➤ Combined

□  $\text{Br}(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$   
*first measurement*



# Measurement of $h_c$ @ BESIII (exclusive)

## 16 decay modes



Simultaneous fit to  $\pi^0$  recoiling mass

$$M(h_c) = 3525.31 \pm 0.11 \pm 0.15 \text{ MeV}$$

$$\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.25 \text{ MeV}$$

$$N = 832 \pm 35$$

$$\chi^2/\text{d.o.f.} = 32/46$$

**BESIII preliminary**

Consistent with BESIII inclusive results PRL104,132002(2010)

CLEOc exclusive results

$$M(h_c) = 3525.21 \pm 0.27 \pm 0.14 \text{ MeV}/c^2$$

$$N = 136 \pm 14$$

PRL101, 182003(2008)



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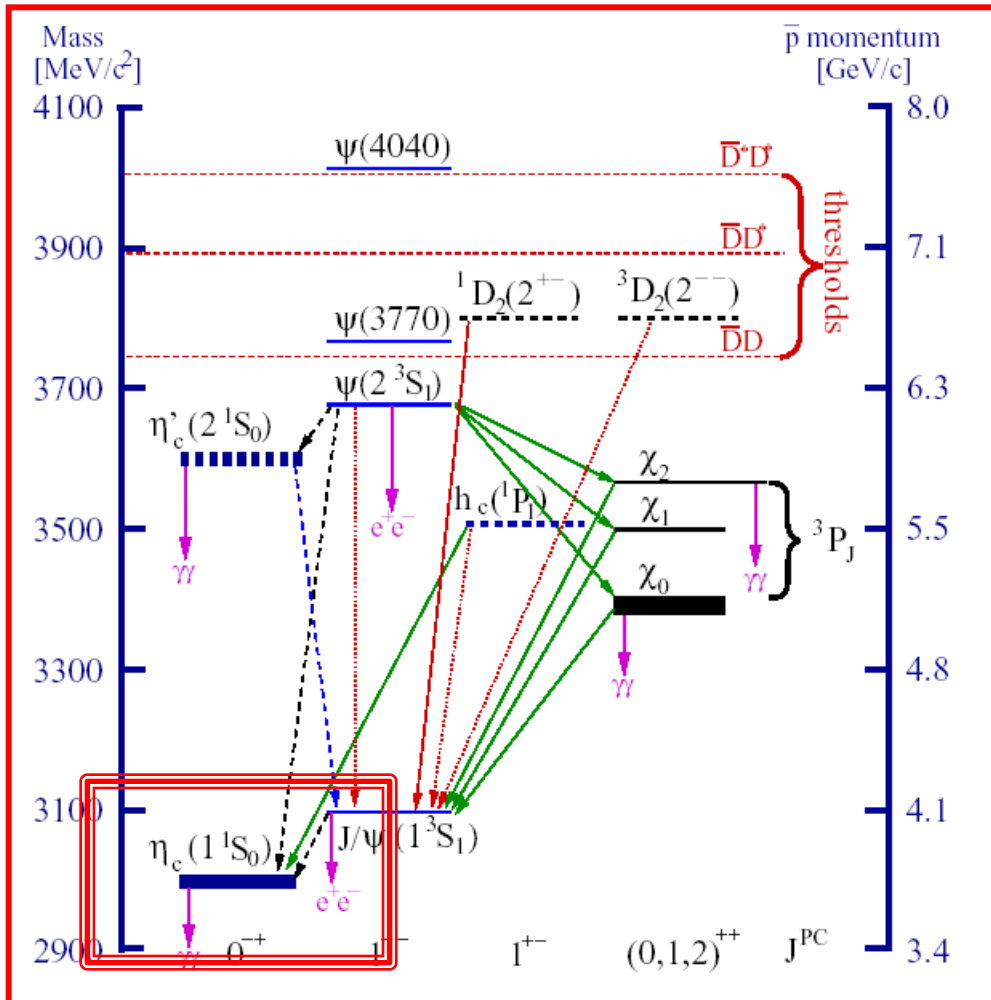
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## Precision Measurement of the $\eta_c$ Properties

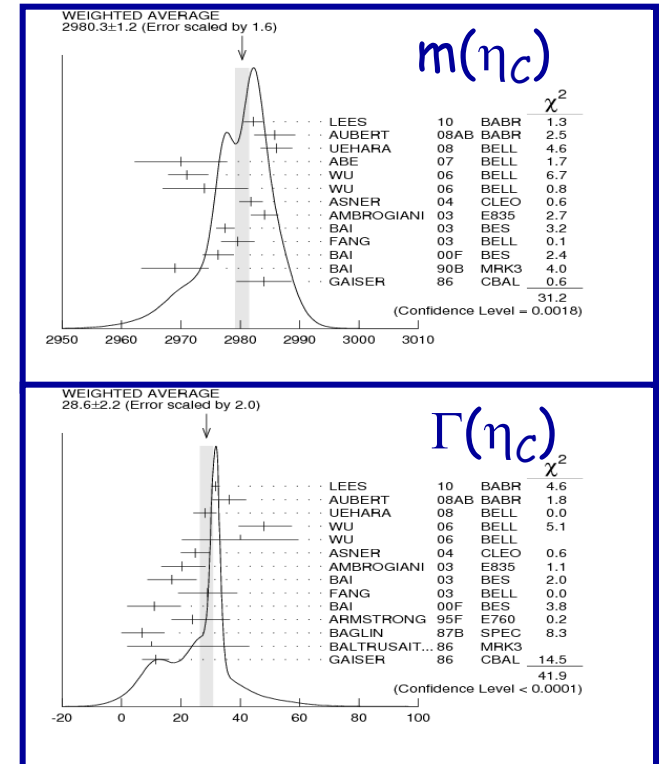
charmonium ground state



PDG

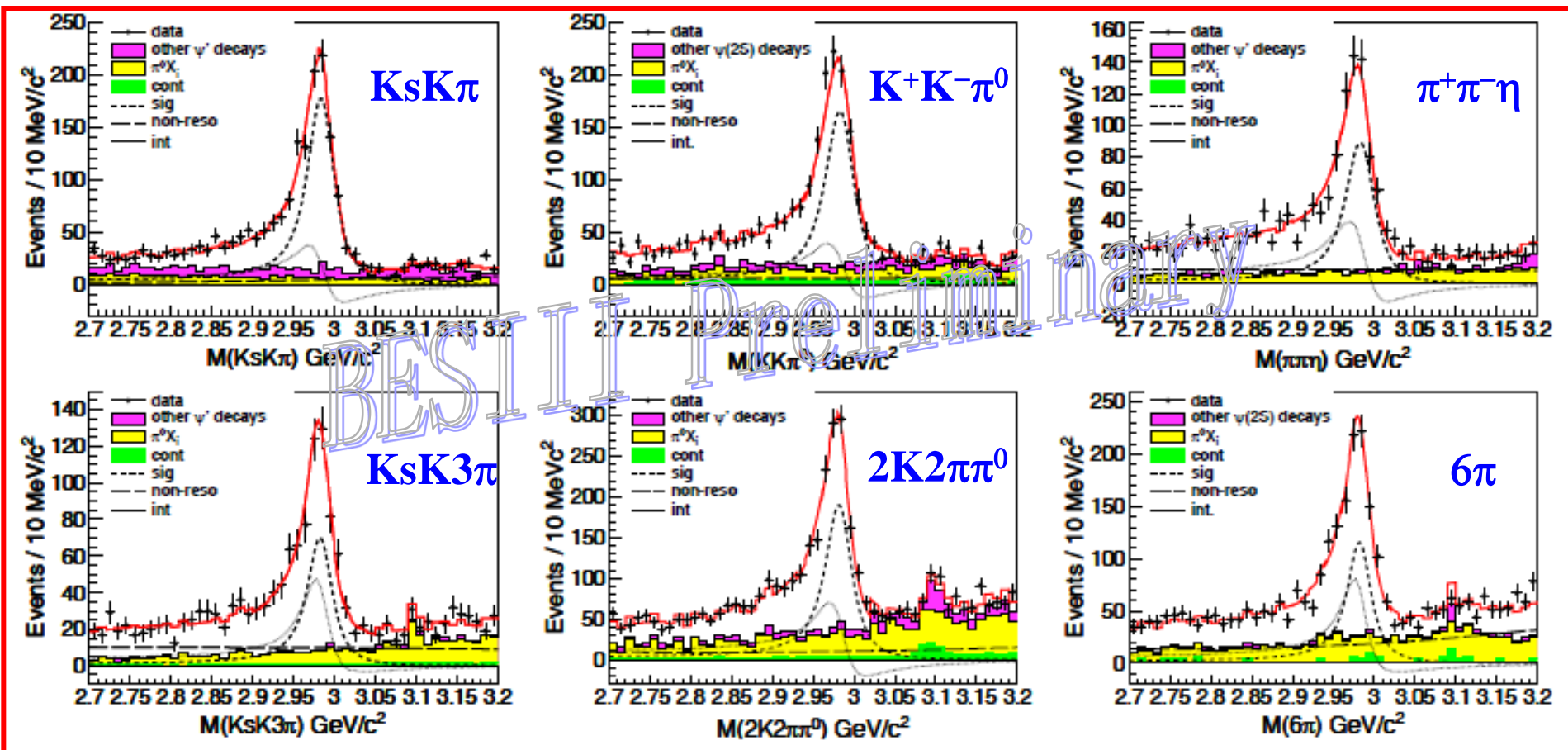
$$M(\eta_c) = 2980.3 \pm 1.2 \text{ MeV}/c^2$$

$$\Gamma(\eta_c) = 28.6 \pm 2.2 \text{ MeV}/c^2$$





# $\eta_c$ Resonance Parameters from $\psi' \rightarrow \gamma \eta_c$



- Simultaneous fit with Breit-Wigner (considering M1 transition)
- Interference between  $\eta_c$  and non  $\eta_c$  decays
- $\eta_c$  mass and width and interference phase  $\phi$  constrained to be the same



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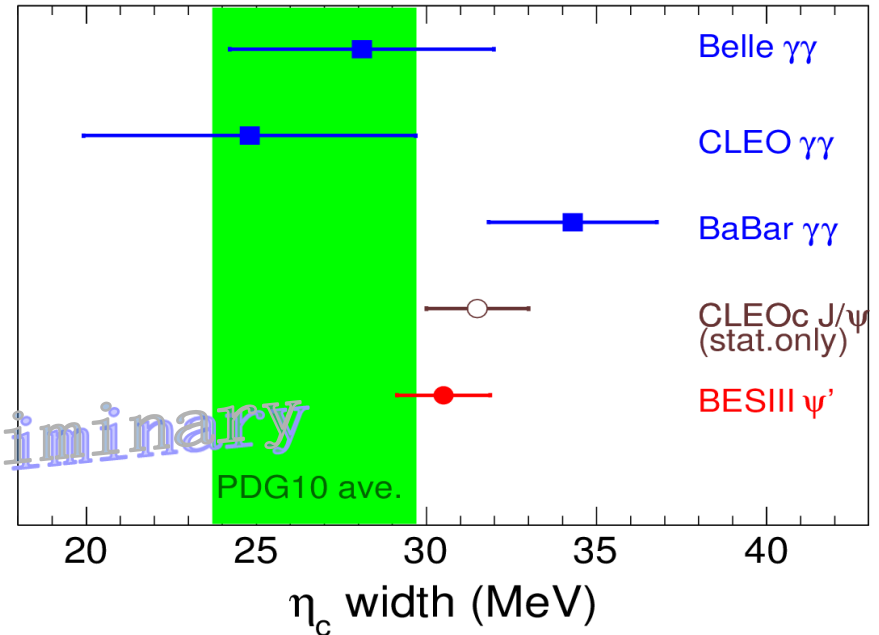
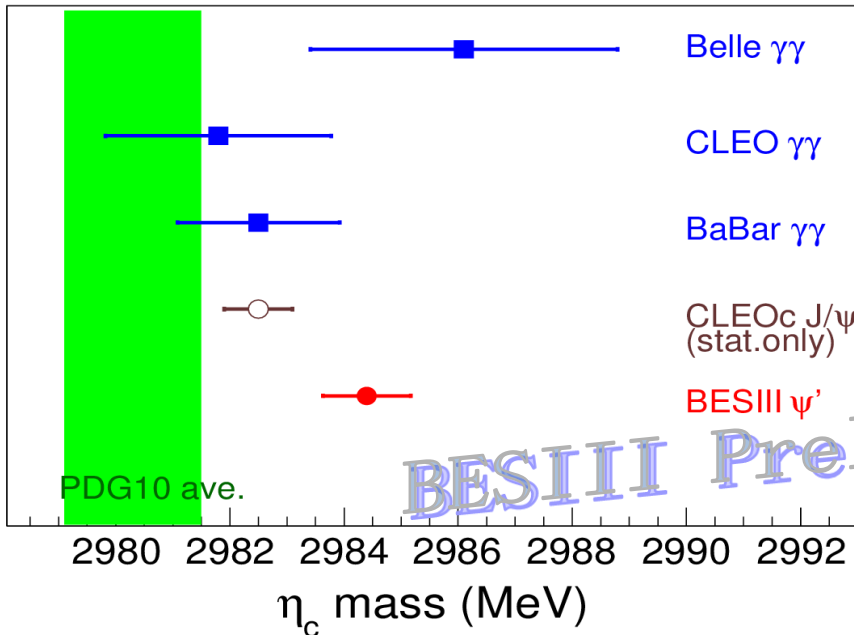
## Mass and Width of $\eta_c$

**BESIII preliminary**

- mass =  $2984.4 \pm 0.5_{\text{stat}} \pm 0.6_{\text{syst}} \text{ MeV}/c^2$
- width =  $30.5 \pm 1.0_{\text{stat}} \pm 0.9_{\text{syst}} \text{ MeV}$
- $\phi = 2.35 \pm 0.05_{\text{stat}} \pm 0.04_{\text{syst}} \text{ rad}$

currently the most  
precise measurement

The world average in PDG2010 was using earlier results

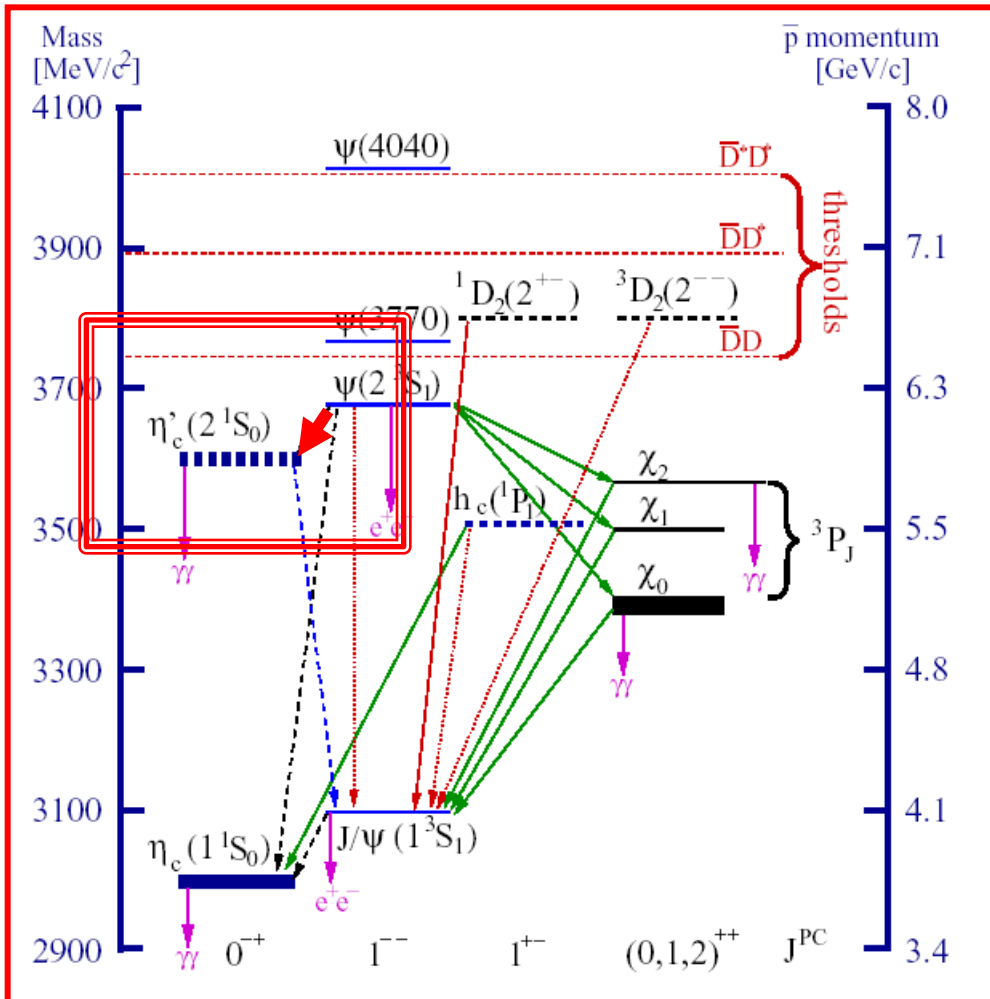






## Searching for $\eta_c(2S)$ in $\psi'$ decays

1<sup>st</sup>  $\eta_c$  excited state



PDG

$$M(\eta_c(2S)) = 3637 \pm 4 \text{ MeV}/c^2$$

$$\Gamma(\eta_c(2S)) = 14 \pm 7 \text{ MeV}/c^2$$

- Observed in B decays and in two-photon processes
- CB observed **M1 transition** in  $\psi' \rightarrow \gamma X$  but never confirmed
- Challenge: real  $\gamma$  @ 50 MeV

BESIII (106M  $\psi'$ )

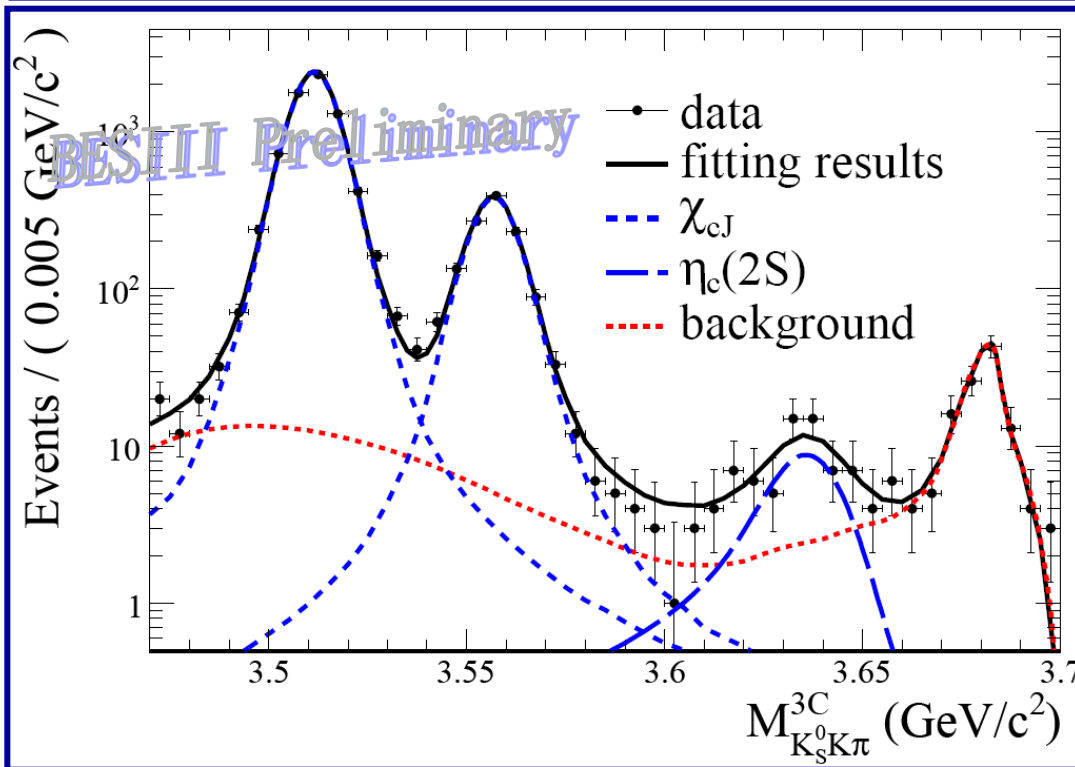
$\psi' \rightarrow \gamma \eta_c(2S) \rightarrow \gamma K_S K \pi$



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Simultaneous fit of  $\eta_c(2S)$  and  $\chi_{cJ}$

- $N(\eta_c(2S)) = 50.6 \pm 9.7$
- Pure **statistical** significance more than  $6\sigma$
- Significance with **systematic** variations **not less than  $5\sigma$**
- $\chi^2/\text{ndf} = 0.9$

- ❑  $\eta_c(2S)$  signal: modified BW (M1) with fixed width (resolution extrapolated from  $\chi_{cJ}$ )
- ❑  $\chi_{cJ}$  signal: MC shape smeared with Gaussian
- ❑ BG from  $e^+e^- \rightarrow K_s K \pi$  (ISR),  $\psi' \rightarrow K_s K \pi$  (FSR),  $\psi' \rightarrow \pi^0 K_s K \pi$ : measured from data



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## Preliminary Measurements from $\psi' \rightarrow \gamma \eta_c(2S) \rightarrow \gamma K_S K \pi$

➤  $M(\eta_c(2S)) = 3638.5 \pm 2.3_{\text{stat}} \pm 1.0_{\text{sys}} \text{ (MeV}/c^2)$

➤  $\text{Br}(\psi' \rightarrow \gamma \eta_c(2S) \rightarrow \gamma K_S K \pi) = (2.98 \pm 0.57_{\text{stat}} \pm 0.48_{\text{sys}}) \times 10^{-6}$

$\text{Br}(\eta_c(2S) \rightarrow \gamma K_S K \pi) = (1.9 \pm 0.4 \pm 1.1)\%$  from BaBar



➤  $\text{Br}(\psi' \rightarrow \gamma \eta_c(2S)) = (4.7 \pm 0.9_{\text{stat}} \pm 3.0_{\text{sys}}) \times 10^{-4}$

CLEO-c:  $< 7.6 \times 10^{-4}$

Potential model:  $(0.1 - 6.2) \times 10^{-4}$

(PRD81,052002(2010))

(PRL89,162002(2002))



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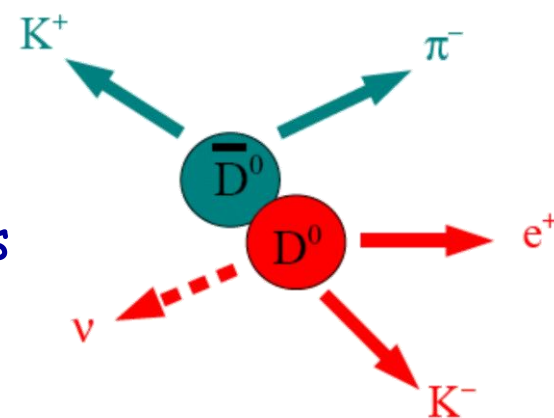


Open Charm



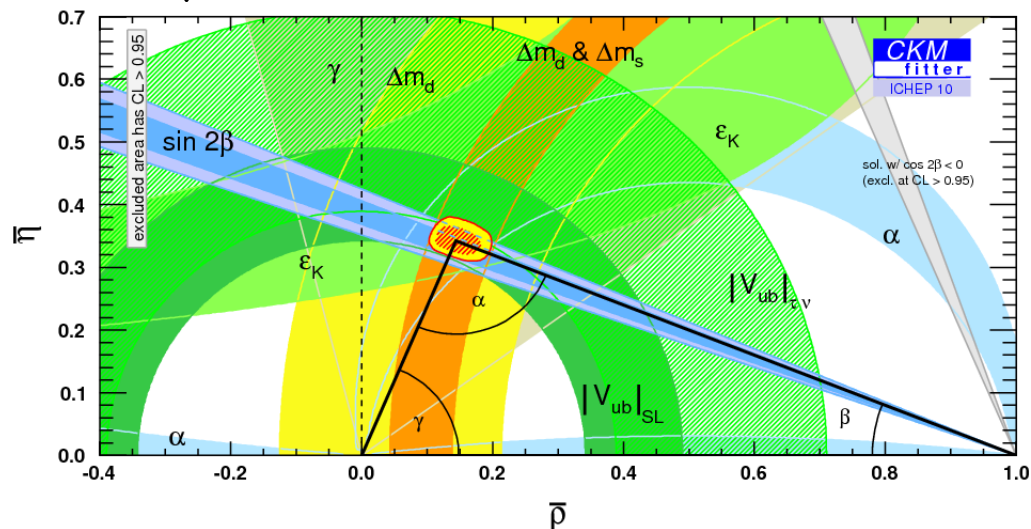
## Open Charm at Threshold

- ❑  $e^+e^- \rightarrow \psi(3770) \rightarrow D\bar{D}$
- ❑ Production of two quantum correlated D mesons (almost) at rest
- ❑ Tag one D meson and study the other



## Measurements with tagged D mesons

- Semileptonic decays
  - ❑  $|V_{cs}|$  and  $|V_{cd}|$  CKM matrix elements, form factor
- Purely leptonic decays
  - ❑  $f_D$  and  $f_{D_s}$  decay constants
- Absolute branching fractions
- CP or T violation
- D- $\bar{D}$  mixing
- ...





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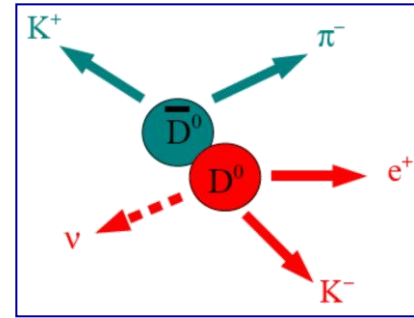
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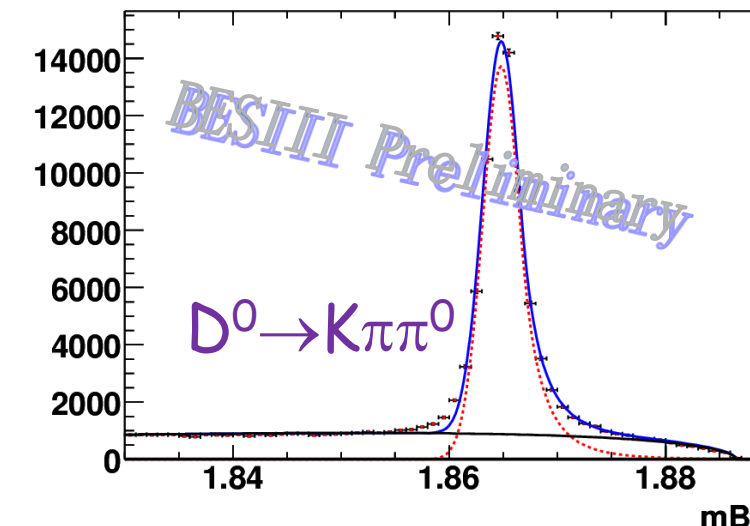
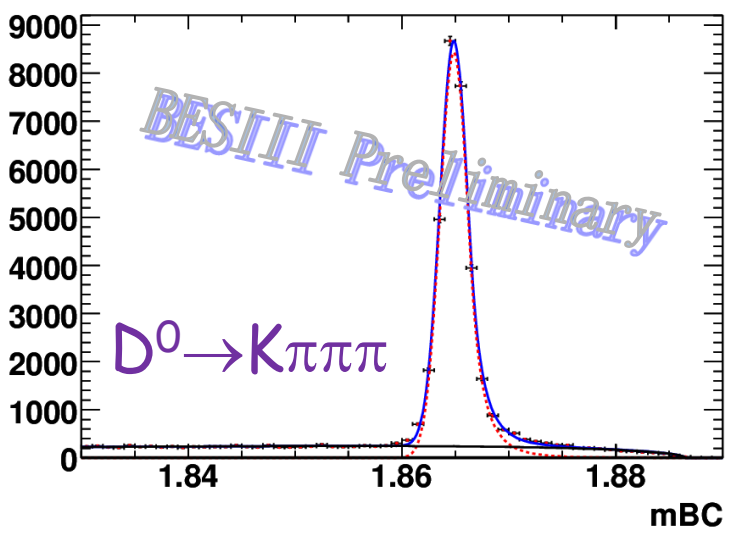
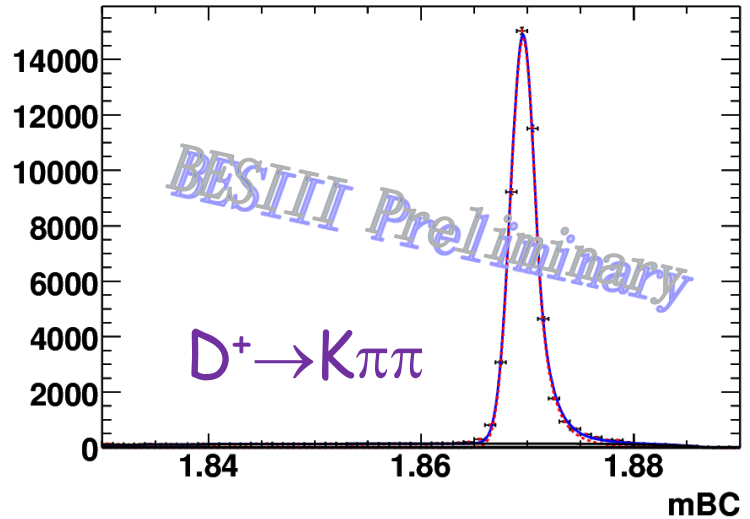
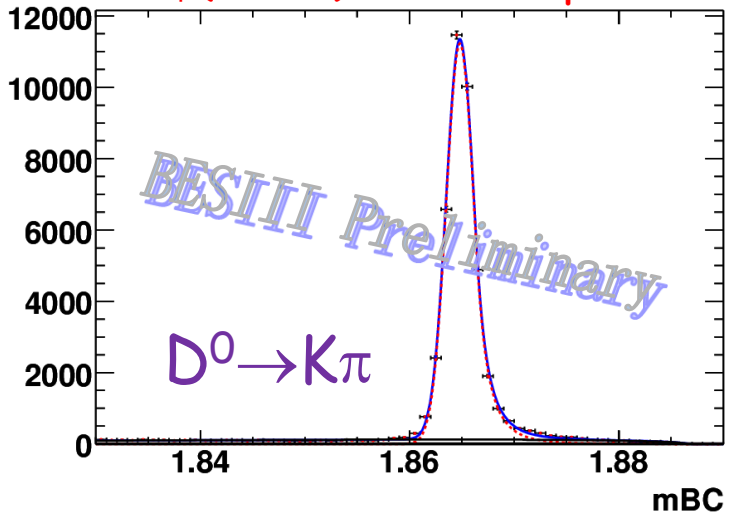
## Single tag at BESIII

@ $\psi(3770)$  with  $420\text{pb}^{-1}$  first clean single tagging sample



$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Very Clean



- Resolution
- $\sim 1.3 \text{ MeV}/c^2$   
pure charged
  - $\sim 1.9 \text{ MeV}/c^2$   
with a  $\pi^0$



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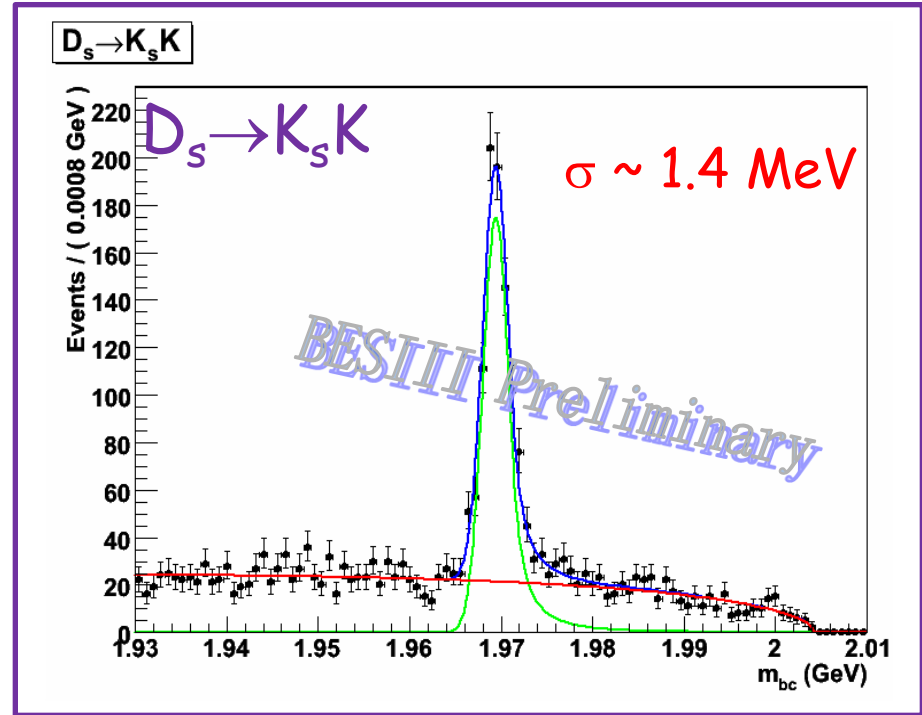
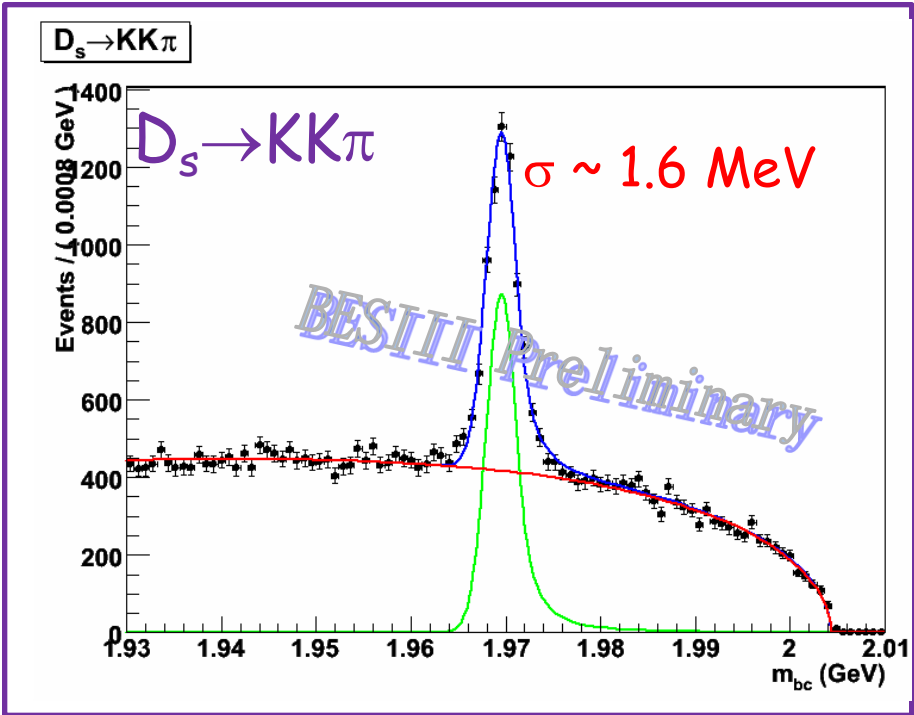
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## D<sub>s</sub> Single Tag

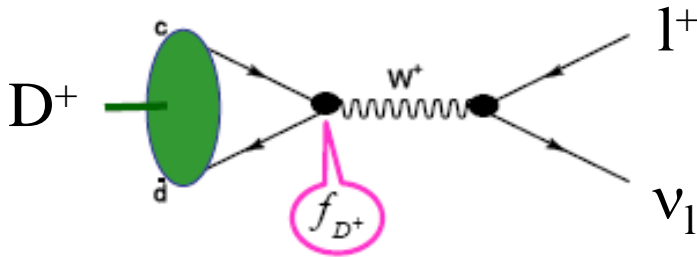
part of data @ 4010 MeV



$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

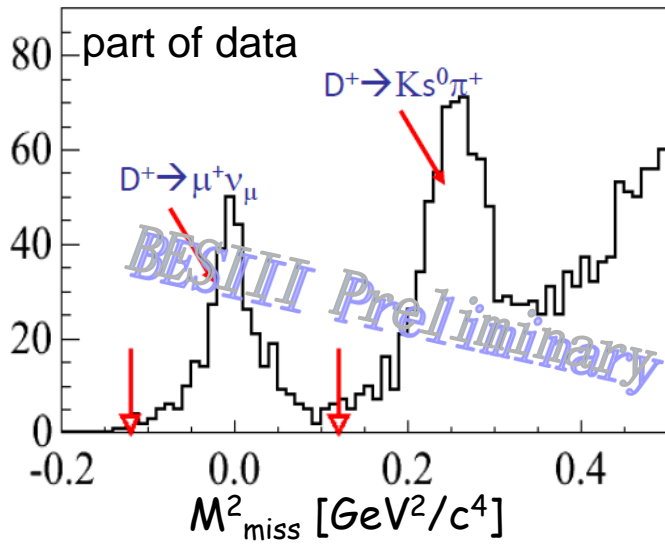


## Leptonic Decays

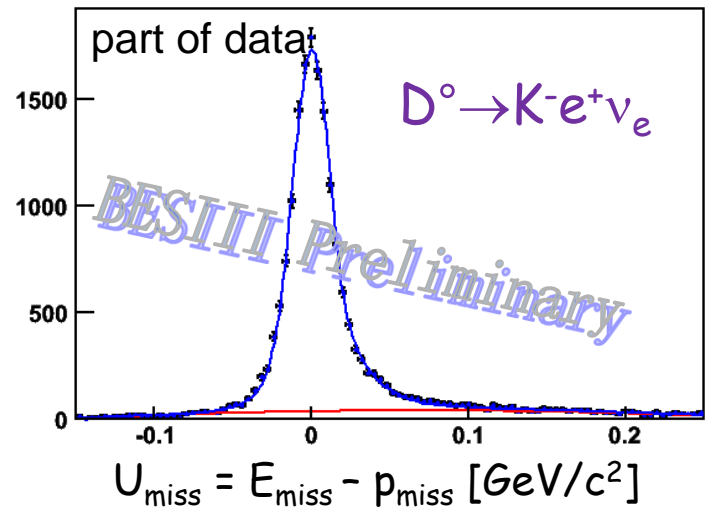
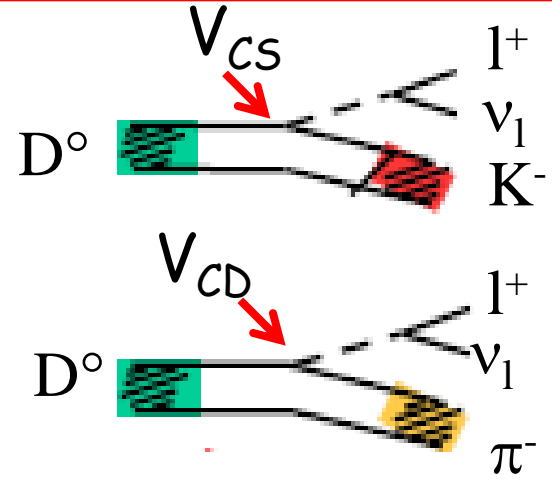


Ongoing measurements:

- $D^+ \rightarrow \mu^+ \nu_\mu$
- $D_s \rightarrow \mu^+ \nu_\mu$



## Semi-leptonic Decays







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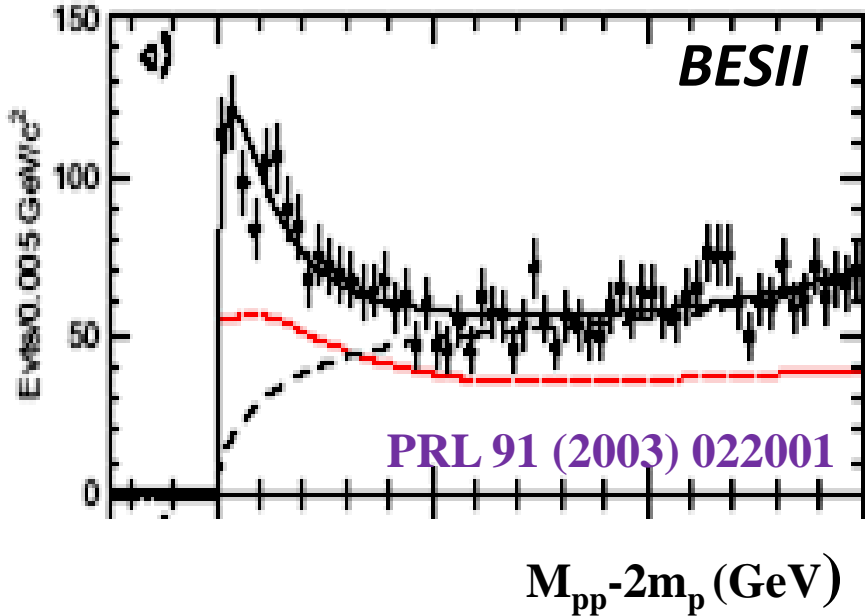


## Light Quark States



## Observation of $p\bar{p}$ mass threshold enhancement

$$J/\psi \rightarrow \gamma p\bar{p}$$

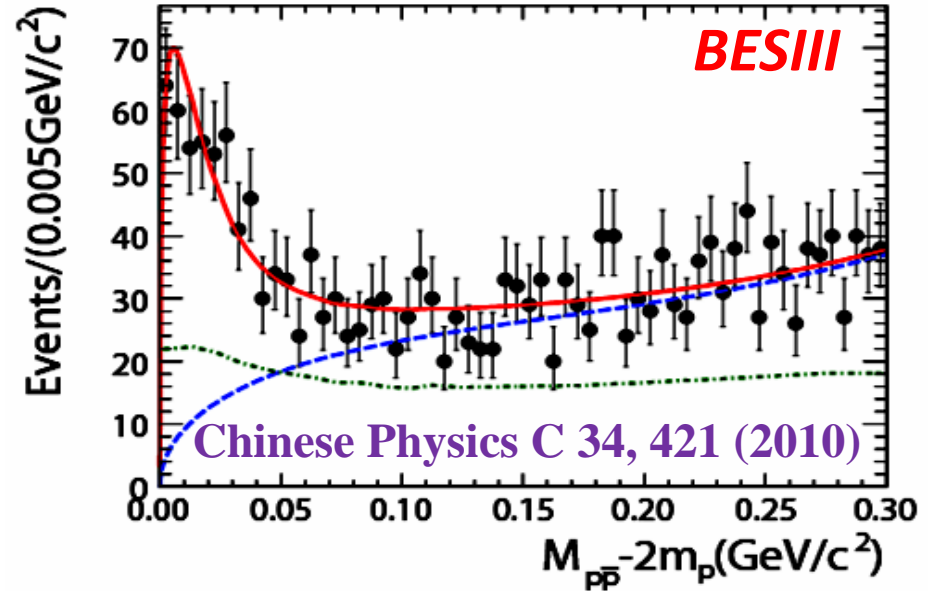


**BESII**

$$M = 1859^{+3}_{-10} {}^{+5}_{-25} \text{ MeV}/c^2$$

$$\Gamma < 30 \text{ MeV}/c^2 \text{ (90\% CL)}$$

$$\psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \gamma p\bar{p}$$



**BESIII**

$$M = 1861^{+6}_{-13} {}^{+7}_{-26} \text{ MeV}/c^2$$

$$\Gamma < 38 \text{ MeV}/c^2 \text{ (90\% CL)}$$

$p\bar{p}$  bound state? FSI effect? ...?



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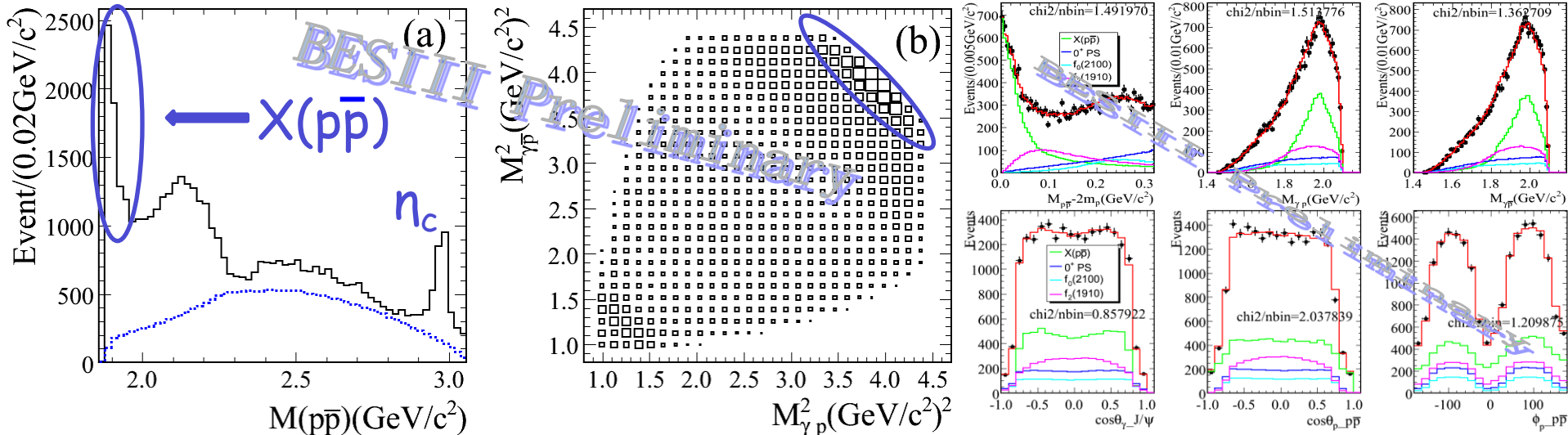
# Recent BESIII Results

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## Observation of $p\bar{p}$ mass threshold enhancement in $J/\psi \rightarrow \gamma p\bar{p}$

### BESIII Preliminary Results from PWA



**$J=0^{++}$  is preferable**  
**FSI corrections improve the results**

$$J^{PC} = 0^{++}$$

$$M = 1832 \pm 5(\text{stat})_{-17}^{+19}(\text{syst}) \pm 19(\text{mod}) \text{ MeV}/c^2$$

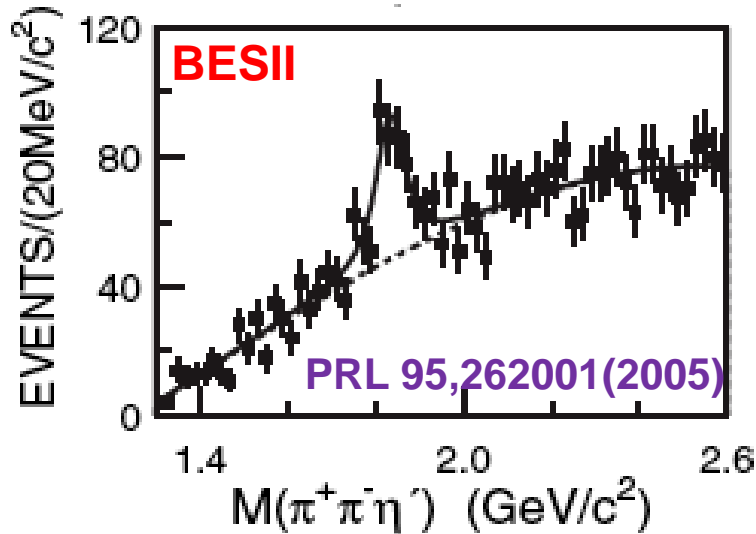
$$\Gamma = 13 \pm 20(\text{stat})_{-33}^{+11}(\text{syst}) \pm 4(\text{mod}) \text{ MeV}/c^2 \text{ or } \Gamma < 48 \text{ MeV}/c^2 \text{ @ } 90\% \text{ C.L.}$$

$$B(J/\psi \rightarrow \gamma X(p\bar{p}))B(X(p\bar{p}) \rightarrow p\bar{p}) = (9.0 \pm 0.7(\text{stat})_{-5.1}^{+1.5}(\text{syst}) \pm 2.3(\text{mod})) \times 10^{-5}$$

BESIII  
Preliminary



# Confirmation of X(1835)



First observed by BESII (50M  $J/\psi$  decays)

$$\text{Decay: } \begin{cases} J/\psi \rightarrow \gamma \eta' \pi^+ \pi^- \\ \eta' \rightarrow \eta \pi^+ \pi^-, \eta' \rightarrow \gamma \rho \end{cases}$$

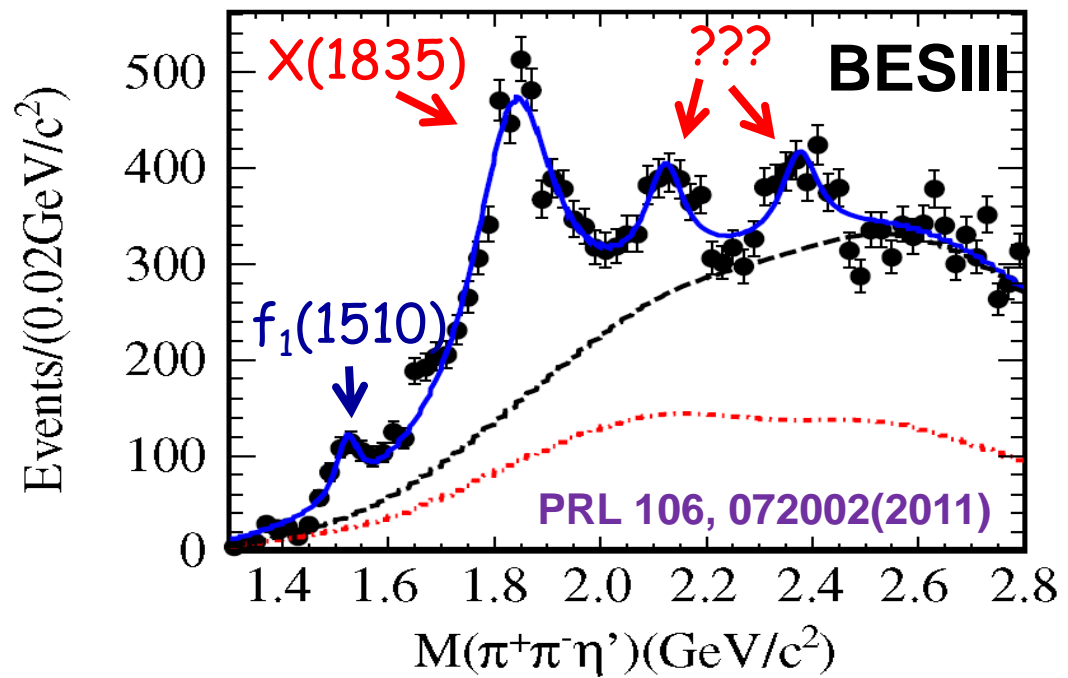
**BESII Results (sig.  $\sim 7.7\sigma$ )**

$$M = 1833.7 \pm 6.1(\text{stat}) \pm 2.7(\text{syst}) \text{ MeV}$$

$$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst}) \text{ MeV}$$

**Confirmed by BESIII**  
(225M  $J/\psi$  decays)

**With two surprises!!!**





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# Recent BESIII Results

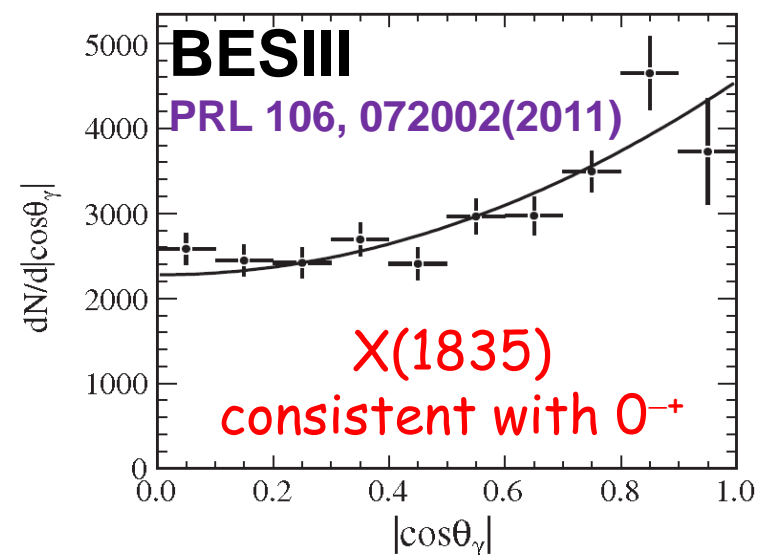
S. Spataro for the BESIII Collaboration



## Confirmation of X(1835) and observation of two new structures

BESIII Results

Resonance	$M$ (MeV/c <sup>2</sup> )	$\Gamma$ (MeV/c <sup>2</sup> )	Stat. Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190 \pm 9^{+38}_{-36}$	$>20\sigma$
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	$7.2\sigma$
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	$6.4\sigma$



### Nature of X(2120)/X(2370)

- Pseudoscalar glueballs?
- $\eta$ ,  $\eta'$  excited states?

PWA needed  
to understand these structures

PRD 82,074026,2010, PRD 83,114007,2011,  
and more...



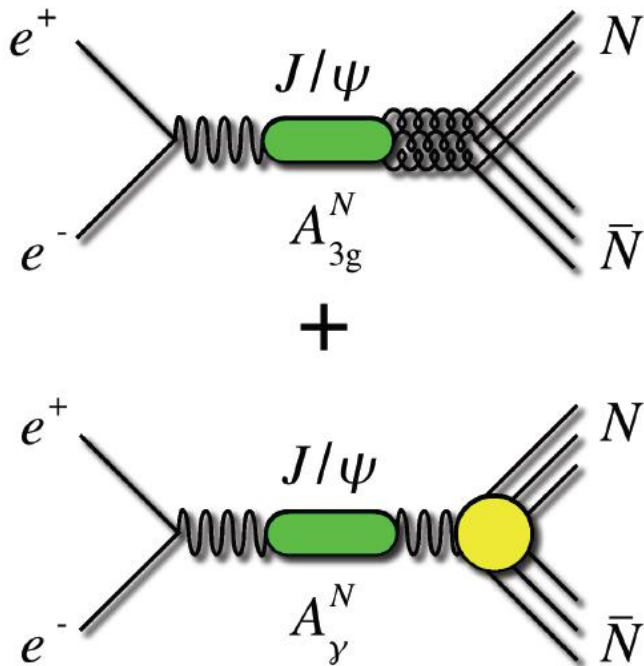
## Measurements of $J/\psi \rightarrow \bar{p}p, \bar{n}n$

pQCD  $\rightarrow$  both amplitudes real

$$R = \frac{Br(J/\psi \rightarrow n\bar{n})}{Br(J/\psi \rightarrow p\bar{p})} = \left| \frac{A_{3g}^n + A_\gamma^n}{A_{3g}^p + A_\gamma^p} \right|^2$$

$$A_{3g}, A_\gamma \in \mathfrak{R} \quad R \ll 1$$

$$A_{3g} \perp A_\gamma \quad R \approx 1$$



High precision

- ❑ **BESII:**  $Br(J/\psi \rightarrow p\bar{p}) = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3}$  (PLB591,42)
- ❑ **FENICE:**  $Br(J/\psi \rightarrow n\bar{n}) = (2.31 \pm 0.49) \times 10^{-3}$  (PLB444,111)

Suffering from a large error



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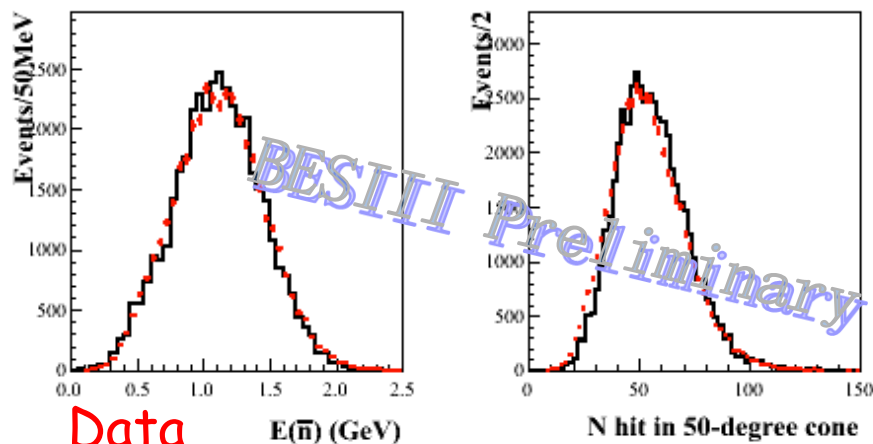
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# Recent BESIII Results

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## Preliminary results of $J/\psi \rightarrow p\bar{p}, n\bar{n}$

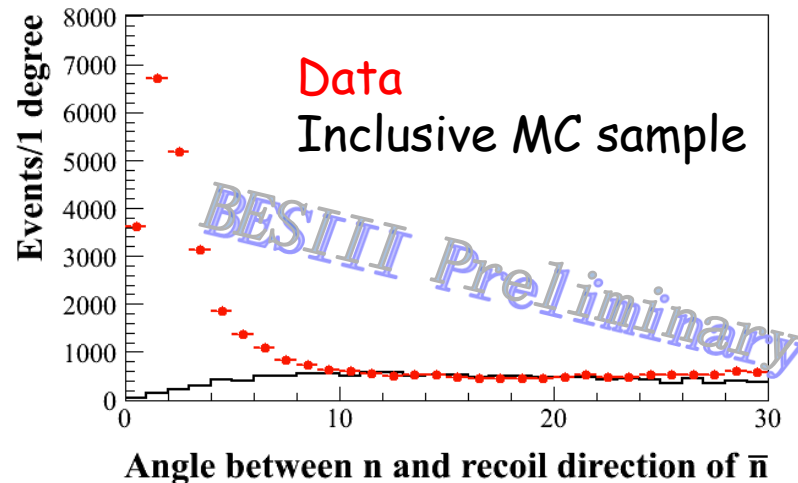


Data

$E(\bar{n})$  (GeV)

N hit in 50-degree cone

$J/\psi \rightarrow p\bar{n}\pi^-$  control sample



Data

Inclusive MC sample

### BESIII Preliminary Results

$$B(J/\psi \rightarrow n\bar{n}) = (2.07 \pm 0.01 \pm 0.14) \cdot 10^{-3}$$

$$B(J/\psi \rightarrow p\bar{p}) = (2.112 \pm 0.004 \pm 0.027) \cdot 10^{-3}$$

PDG

$$B(J/\psi \rightarrow n\bar{n}) = (2.2 \pm 0.4) \cdot 10^{-3}$$

$$B(J/\psi \rightarrow p\bar{p}) = (2.17 \pm 0.07) \cdot 10^{-3}$$

$$B(J/\psi \rightarrow n\bar{n}) \approx B(J/\psi \rightarrow p\bar{p})$$

suggest a phase  $\sim 90^\circ$  between strong and e.m. amplitude



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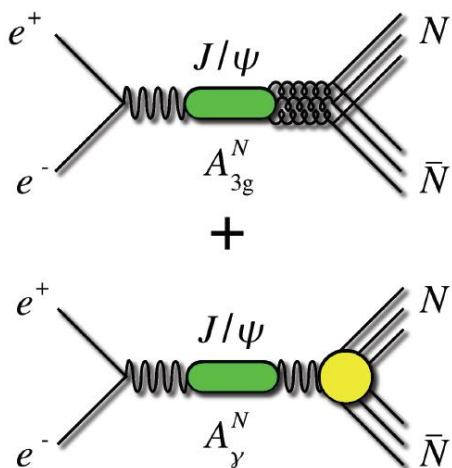
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# Recent BESIII Results

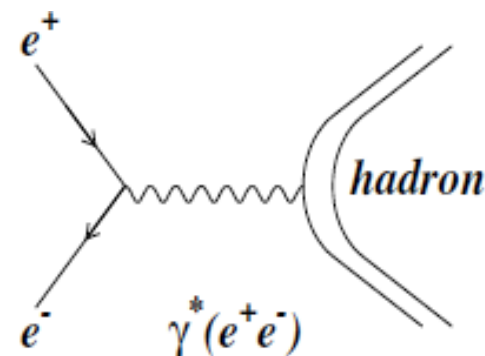
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## Measuring the phase between strong and em amplitudes



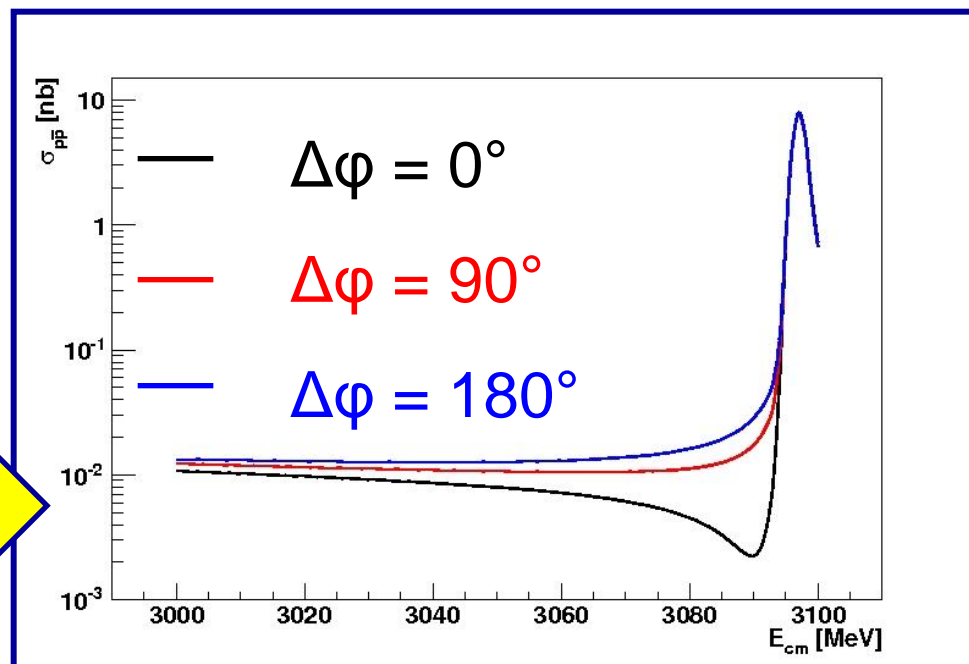
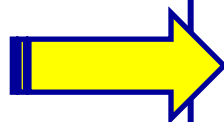
both interfere differently with non-resonant continuum



### J/ψ line-shape scan

Look for interference pattern

(model independent)







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# Recent BESIII Results

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## Summary

BESIII is successfully operating since 2008:

- High Luminosity of BEPCIII
- Good reconstruction performance
- Recorded huge data samples on  $J/\psi$ ,  $\psi'$  and  $\psi(3770)$

- ❑ Precision measurement of hadron properties, decays and new states
- ❑ Improvement of our knowledge of the  $\tau$ -charm energy region
- ❑ More exciting/interesting results are coming...

In the near future:

- More  $J/\psi$ ,  $\psi'$  and  $\psi(3770)$
- $J/\psi$ ,  $\psi'$  lineshape scan
- Data at higher energies (XYZ, R scan,  $D_s$  physics)