BESIII物理最新成果

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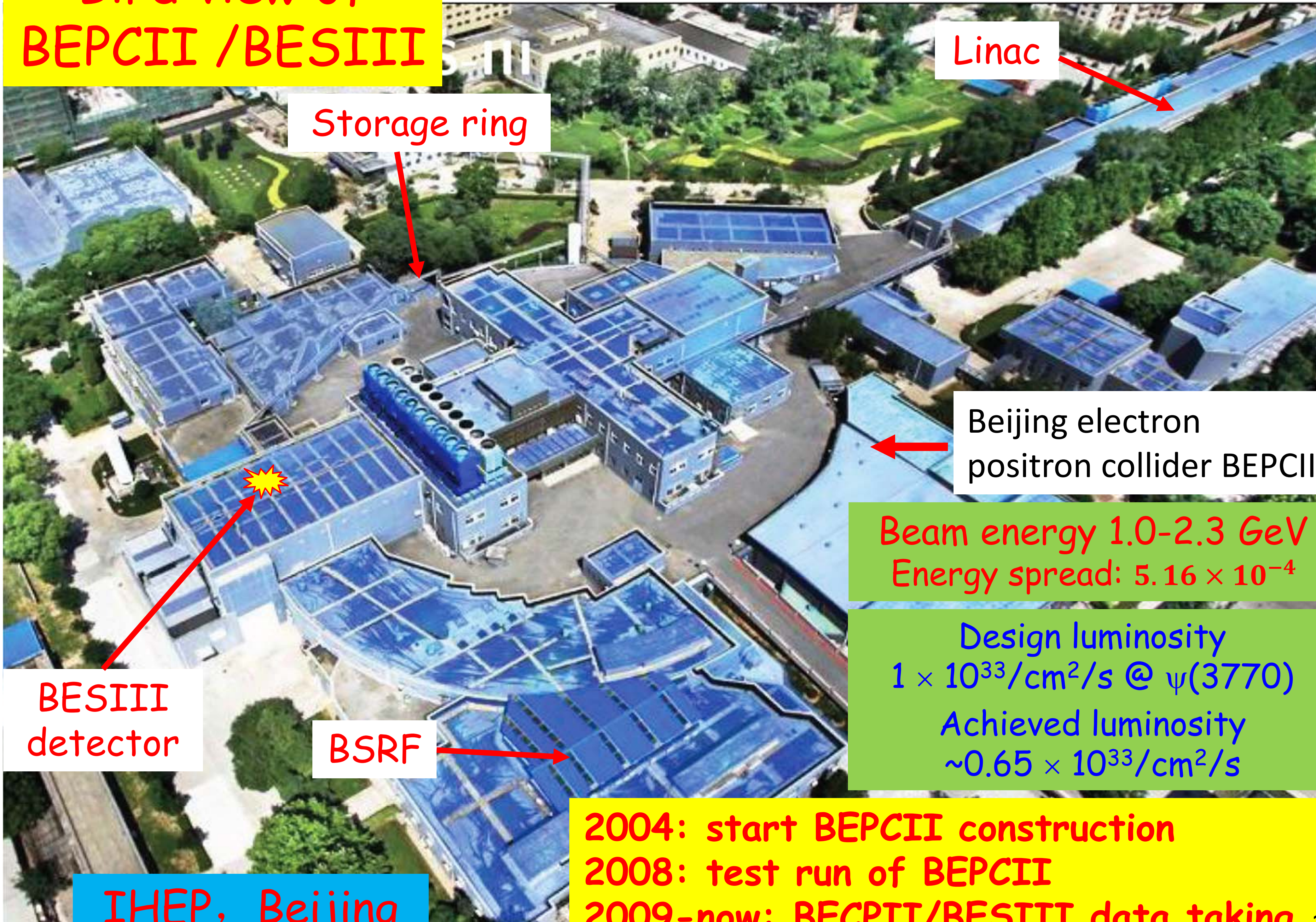
Outline

- Status of BEPCII/BESIII
- Selected Results from BESIII
  - Light Hadron Spectroscopy
  - Charmonium Transitions
  - Charmonium Decays
  - Charm Decays (in progress)
- Summary

Bird view of BEPCII /BESIII



Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$
Achieved luminosity
$\sim 0.65 \times 10^{33}/cm^2/s$

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

NIM A614, 345 (2010)

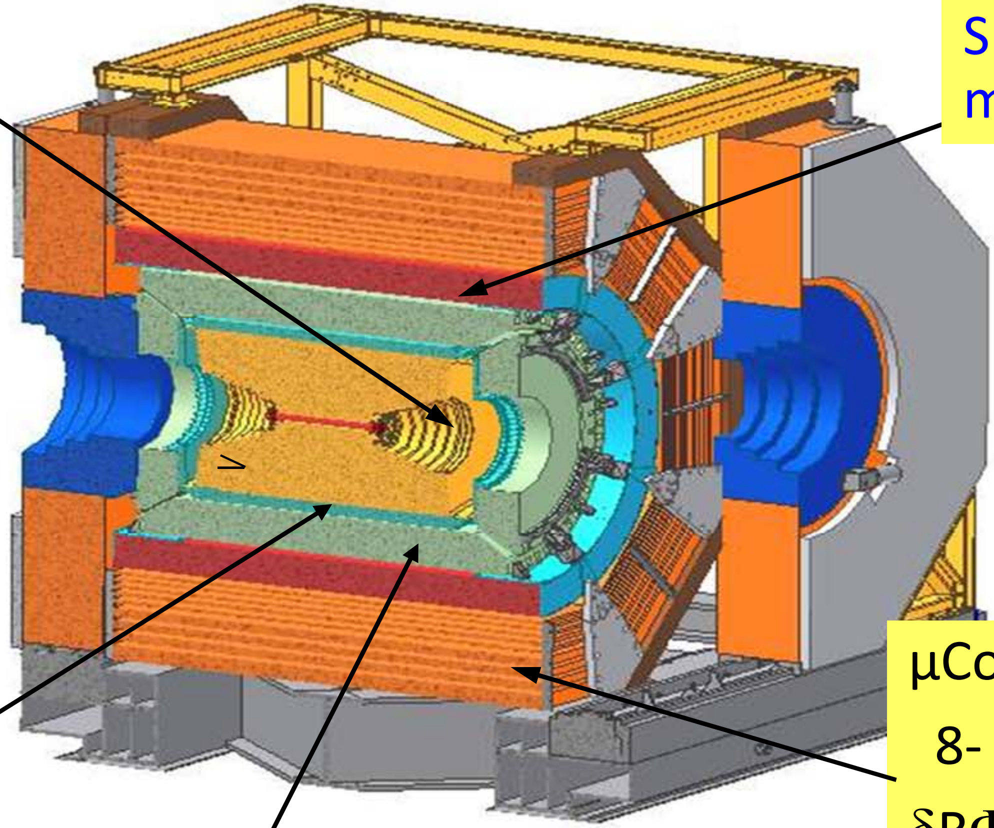
The BESIII Detector

Drift Chamber (MDC)

$\sigma P/P$ ($^0/_0$) = 0.5%(1GeV)

$\sigma_{dE/dx}$ ($^0/_0$) = 6%

Super-conducting magnet (1.0 tesla)



Time Of Flight (TOF)

σ_T : 90 ps Barrel

110 ps endcap

μCounter

8- 9 layers RPC

$\delta R\Phi$=1.4 cm~1.7 cm

EMC: $\sigma E/\sqrt{E}$($^0/_0$) = 2.5 % (1 GeV)

(CsI) $\sigma_{z,\phi}$(cm) = 0.5 - 0.7 cm/$\sqrt{E}$

The BESIII Collaboration

http://bes3.ihep.ac.cn

US (6)

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

Europe (11)

Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. ofJohannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino， Frascati Lab
Netherland: KVI/Univ. of Groningen
Turkey: Turkey Accelerator Center

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (1)

Univ. of Punjab

China(30)

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.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.
Hong Kong Univ., Hong Kong Chinese Univ.
Univ. of South China, GUCAS.

>300 physicists
50 institutions from 10 countries

BESIII commissioning

- July 19, 2008: first e^+e^- collision event in BESIII
- Nov. 2008: ~ 14M $\psi(2S)$ events for detector calibration
- 2009: 106M $\psi(2S)$ 4×CLEOc
  225M J/ψ 4×BESII
- 2010: 900 pb^{-1} $\psi(3770)$
- 2011: 2000 pb^{-1} $\psi(3770)$
  } 3.5×CLEOc
  470 pb^{-1} @ 4.01 GeV
- 2012: tau mass measurement
  $\psi(2S)$: 0.3 billion; J/ψ: from ~April 1

World's largest sample of J/ψ,$\psi(2S)$ and $\psi(3770)$ (and still growing)

Tentative future running plans:

2013: D_s physics (E_{cm}=4170 MeV) + R scan (E_{cm} > 4 GeV)
2014: ψ'/τ /R scan (E_{cm} > 4 GeV);
2015: $\psi(3770)$: 5-10 fb^{-1} for DD physics (our final goal)

physics at BESIII

Charmonium physics:
- precision spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- multiquark states
- glueball & hybrid
- two-photon physics
- form factors

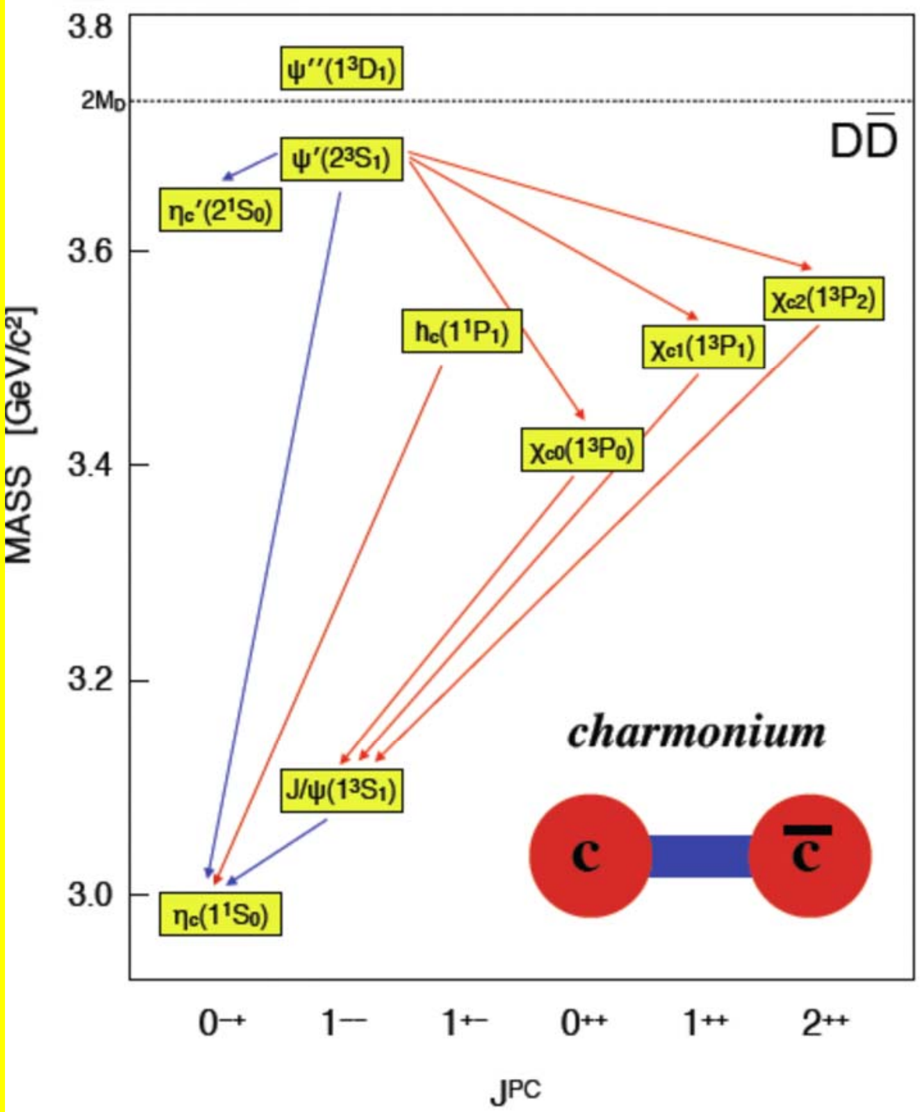
Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

Tau physics:
- Tau decays near threshold
- tau mass scan

…and many more.

This Talk

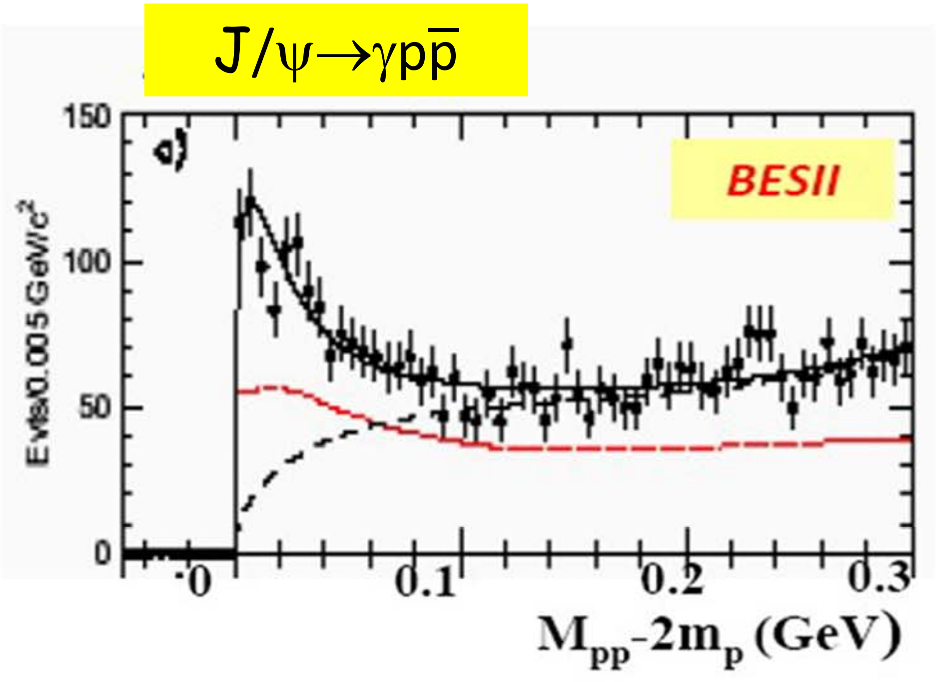
arXiv:0809.1869 [hep-ex]
IJMP A V24, No1(2009)supp

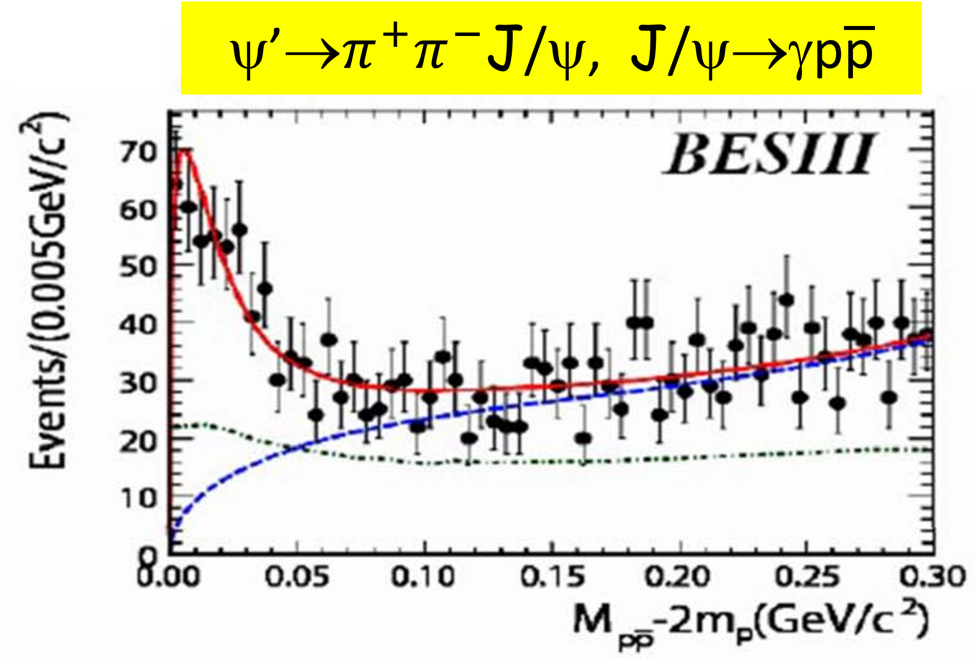


Recent Results on Light Hadron Spectroscopy

- **$p\bar{p}$ mass threshold structure in $J/\psi \to \gamma p\bar{p}$**
- X(1835) and two new structures in $J/\psi \to \gamma \eta' \pi^+ \pi^-$
- X(1870) in $J/\psi \to \omega a_0(980)\pi$
- $\eta(1405)$ in $J/\psi \to \gamma\, f_0(980)\pi^0$, $f_0(980) \to 2\pi$
- 3π Decays of J/ψ and $\psi(2S)$

Enhancement at $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$





Observed at BESII in 2003 (PRL,022001)
agree with spin zero expectation
M $=1860^{+3}_{-10}{}^{+5}_{-25}$ MeV, Γ< 38 MeV (90% CL)

Confirmed at BESIII in 2010
(CPC 34,421 (2010))
M $=1859^{+6}_{-13}{}^{+6}_{-26}$ MeV, Γ< 30 MeV (90% CL)

Many possibilities:

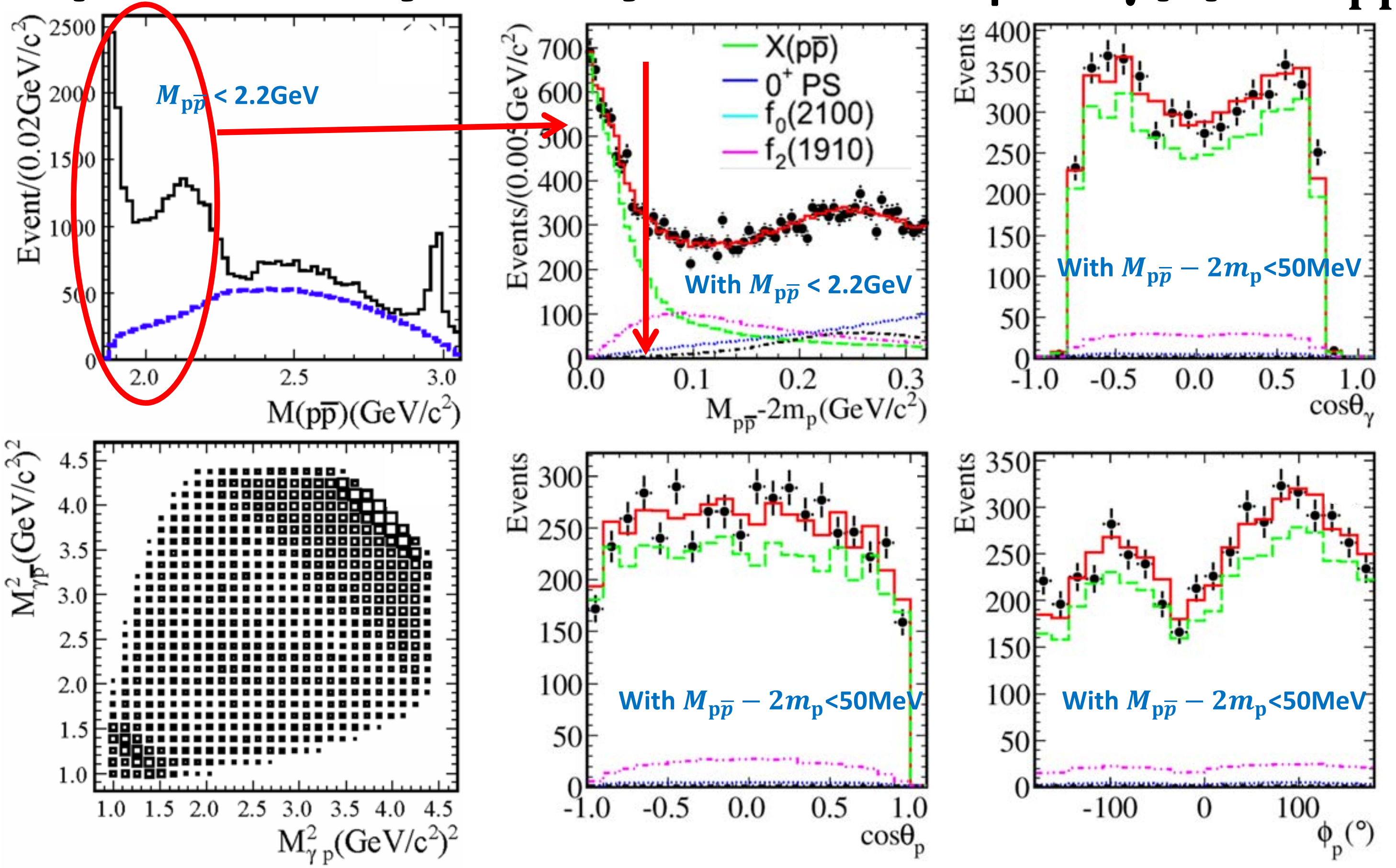
normal meson/ $p\bar{p}$ bound state/multiquark/glueball/Final state interaction effect(FSI)……

Spin-parity analysis

is essential for determining place in the spectrum and possible nature.

arXiv: 1112.0942 Accepted by PRL

Spin-Parity analysis of $J/\psi \to \gamma p\bar{p}$ ($M_{p\bar{p}} < 2.2$GeV)



Four components:

$X(p\bar{p})$, $f_2(1910)$, $f_0(2100)$, and 0^{++} phase space

Include the FSI effect

Fit features:

- The fit with BW and S-wave FSI(I=0) factor can well describe $p\bar{p}$ mass threshold structure.
- It is much better than that Without FSI effect (7.1σ)

Spin-parity, mass, width and Br. of $X(p\bar{p})$:

$J^{PC} = 0^{-+}$ >6.8 σ better than other J^{PC} assignments.

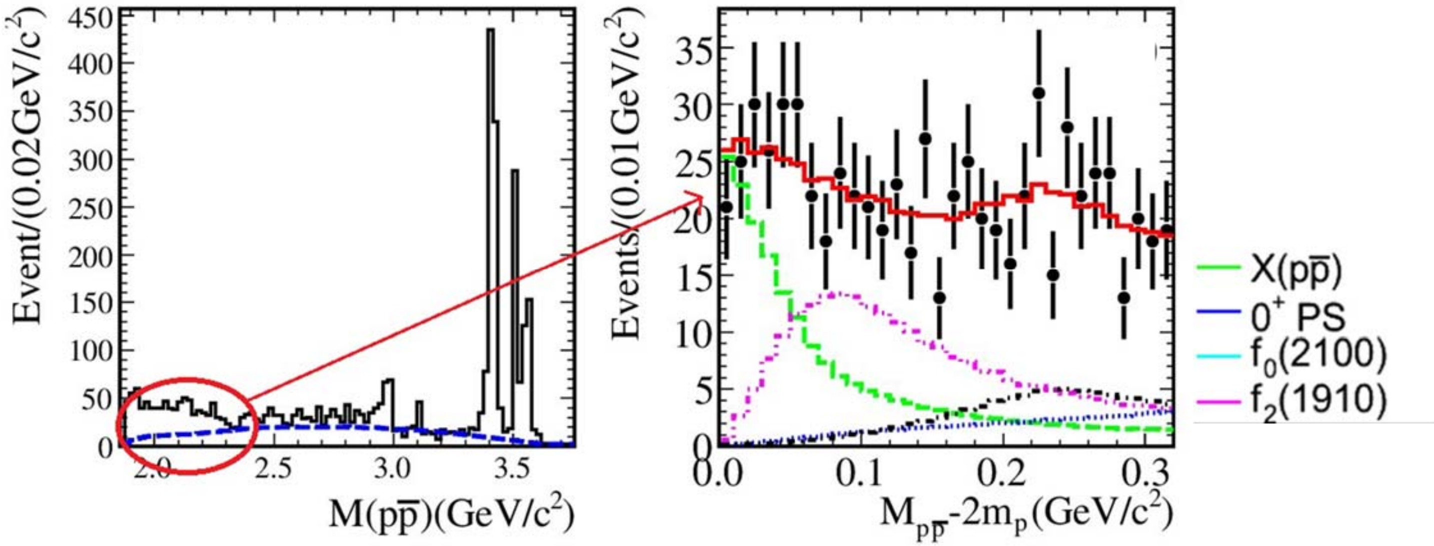
$M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{model})\ \text{MeV}/c^2$ model: Model dependent uncertainty (Different FSI models)

$\Gamma = 13 \pm 39(\text{stat})^{+10}_{-13}(\text{syst}) \pm 4(\text{model})\ \text{MeV}/c^2$ or $\Gamma < 76\ \text{MeV}/c^2$ @ 90% C.L.

$Br(J/\psi \to \gamma X(p\bar{p}))Br(X(p\bar{p}) \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(\text{stat})^{+1.5}_{-5.0}(\text{syst}) \pm 2.3(\text{model})) \times 10^{-5}$

arXiv: 1112.0942 Accepted by PRL

Spin-Parity analysis of $\psi(2S)\to\gamma p\bar{p}$ ($M_{p\bar{p}}$< 2.2GeV)



M , Γ and J^{PC} of $X(p\bar{p})$ are fixed to the results obtained from J/ψ decays.

$$Br\big(\psi(2S)\to\gamma X(p\bar{p})\big)Br(X(p\bar{p})\to p\bar{p})$$
$$= (4.57 \pm 0.36(\mathrm{stat})^{+1.23}_{-4.07}(syst) \pm 1.28(\mathrm{model})) \times 10^{-6}$$

The production ratio R:

$$\mathrm{R}=\frac{Br(\psi(2S)\to\gamma X(p\bar{p}))}{Br(J/\psi\to\gamma X(p\bar{p}))} = \left(5.08^{+0.71}_{-0.45}(\mathrm{stat})^{+0.67}_{-3.58}(syst) \pm 0.12(\mathrm{model})\right)\%$$

It is suppressed compared with 12% rule.

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- X(1870) in $J/\psi \to \omega a_0(980)\pi$
- $\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0$, $f_0(980) \to 2\pi$
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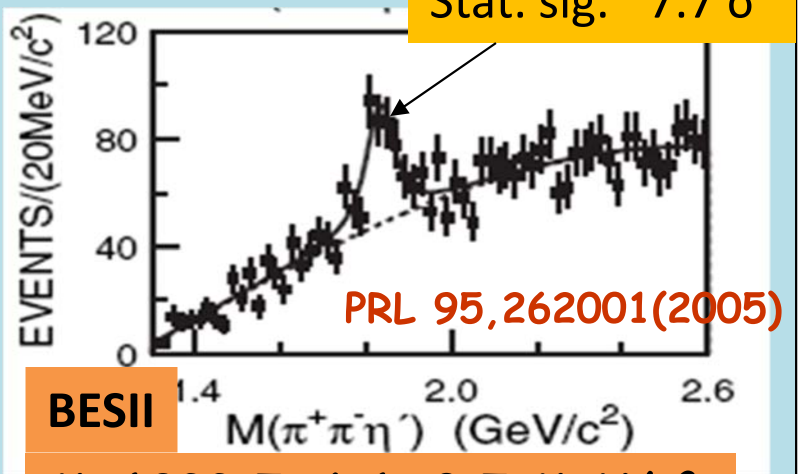
PRL 106, 072002 (2011)

Confirmation of X(1835) and two new structures

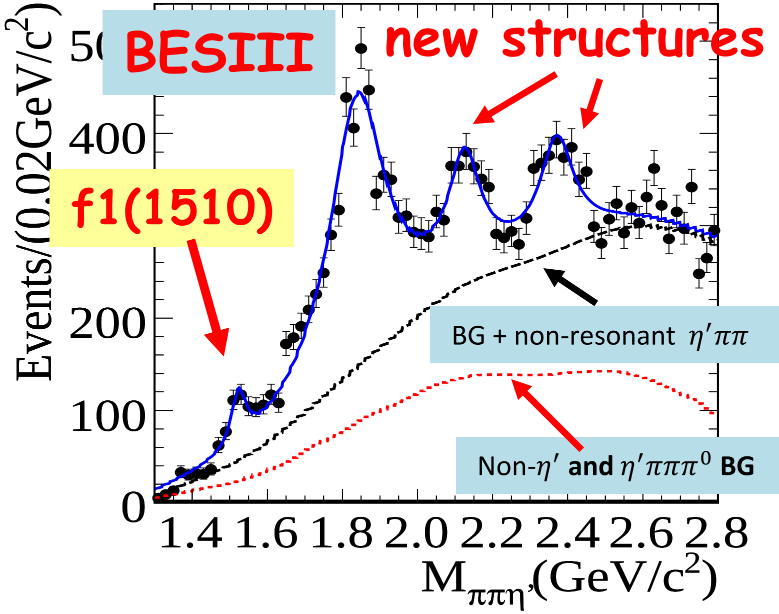


BESII

$M=1833.7\pm6.1\pm2.7$ MeV/c^2
$\Gamma=67.6\pm20.3\pm7.7$ MeV/c^2

BESIII: 225M J/ψ events,

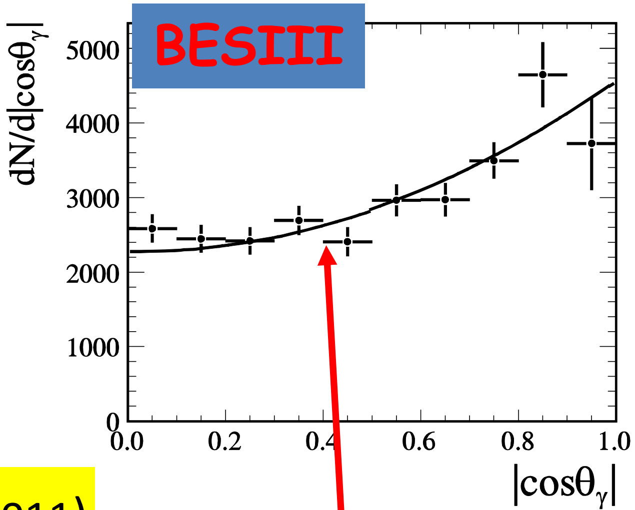
Decay modes:
$J/\psi\to\gamma\eta'\pi^+\pi^-$
$\eta'\to\eta\pi^+\pi^-$
$\eta'\to\gamma\rho$



BESIII results:

width much larger

Resonance	M(MeV/c^2)	Γ(MeV/c^2)	Stat.Sig.
X(1835)	$1836.5\pm3.0^{+5.6}_{-2.1}$	$190.1\pm9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4\pm6.7^{+4.7}_{-2.7}$	$83\pm16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3\pm8.7^{+3.2}_{-4.3}$	$83\pm17^{+44}_{-6}$	6.4σ



Nature of X(2120)/X(2370): (PRD82,074026,2010, PRD83:114007,2011)
pseudoscalar glueball ? η/η' excited states?

Expect spin-parity analysis in the future

X(1835) consistent with 0^{-+}, but the others are not excluded

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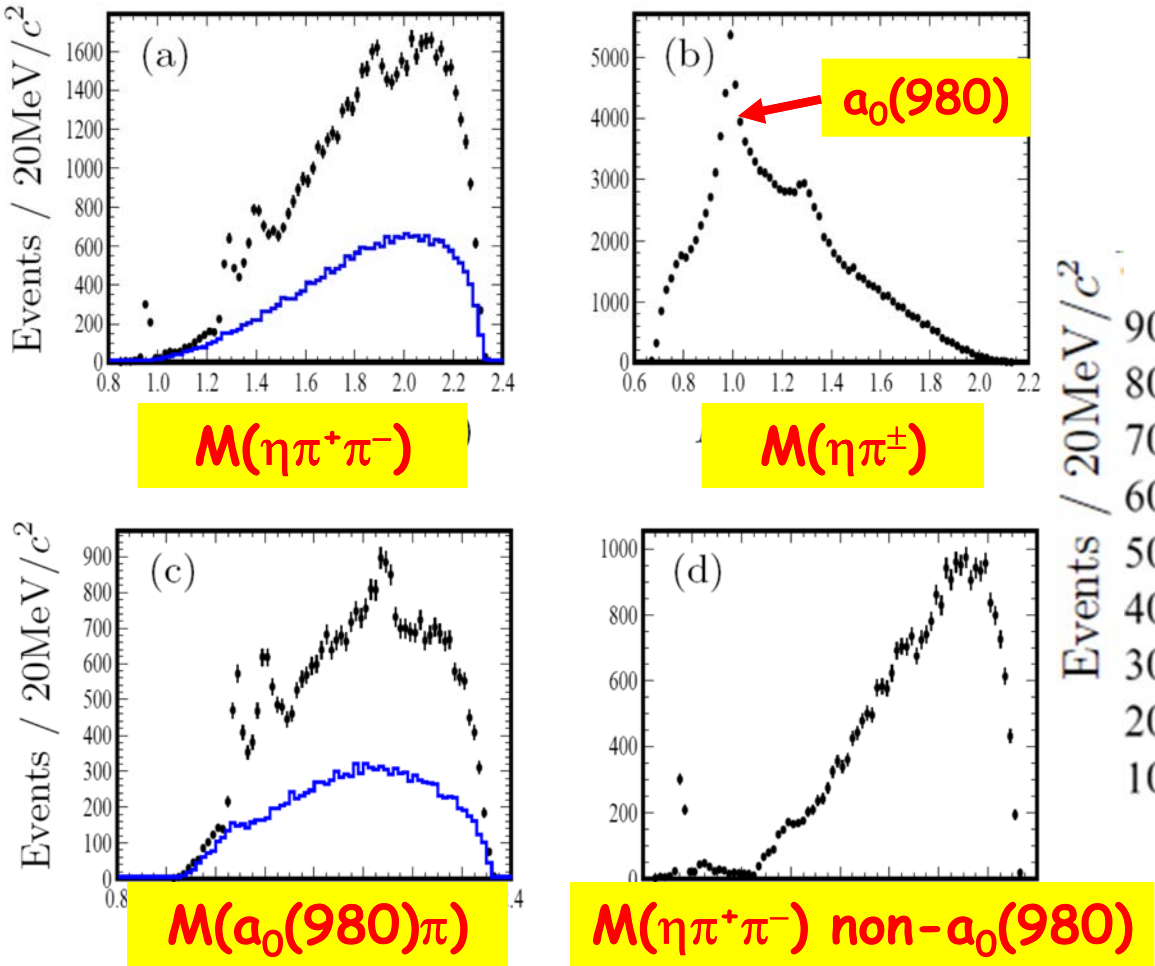
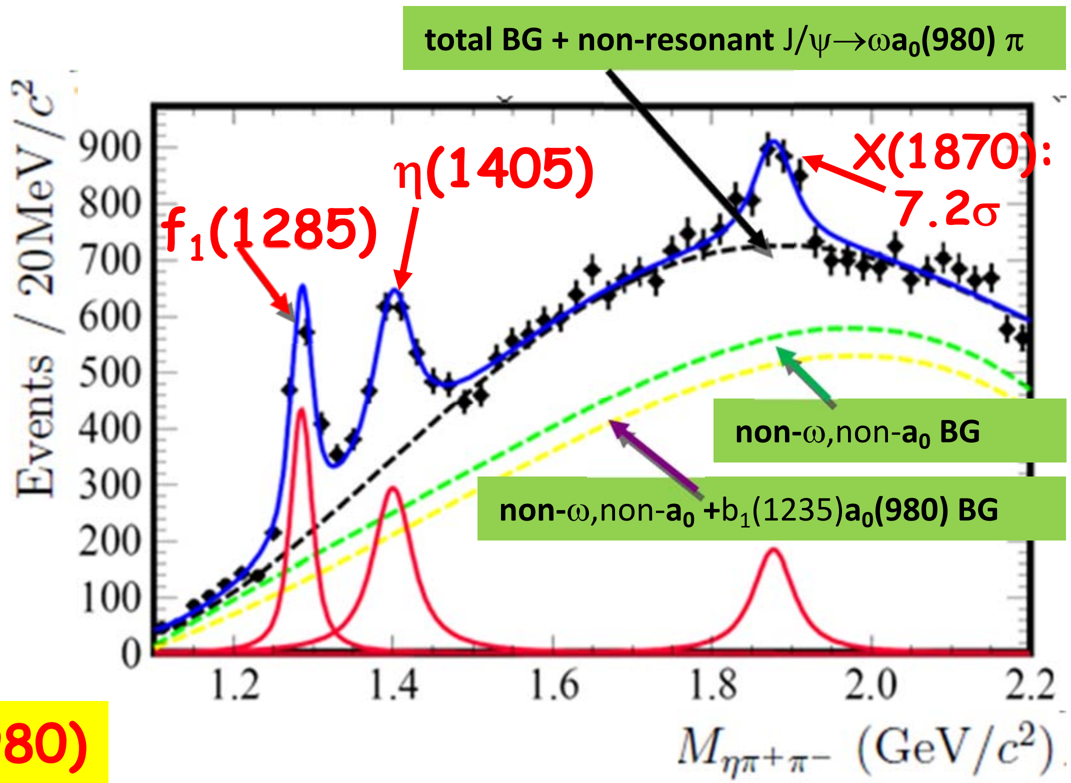
X(1870) in $J/\psi \to \omega X, X \to a_0^{\pm}(980)\pi^{\mp}$

PRL 107, 182001(2011)



Decay mode: $J/\psi \to \omega\eta\pi^+\pi^-$, $a_0(980)$ reconstructed in $\eta\pi^{\pm}$



Results:

$Br(J/\psi \to \omega X, X \to a_0^{\pm}(980)\pi^{\mp})$

Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Branch ratio (10^{-4})
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$	$57 \pm 12^{+19}_{-4}$	$1.50 \pm 0.26^{+0.72}_{-0.36}$

Identification of X(1870): 0^{-+}(?)
It is X(1835) or a new resonance ?
Need PWA!

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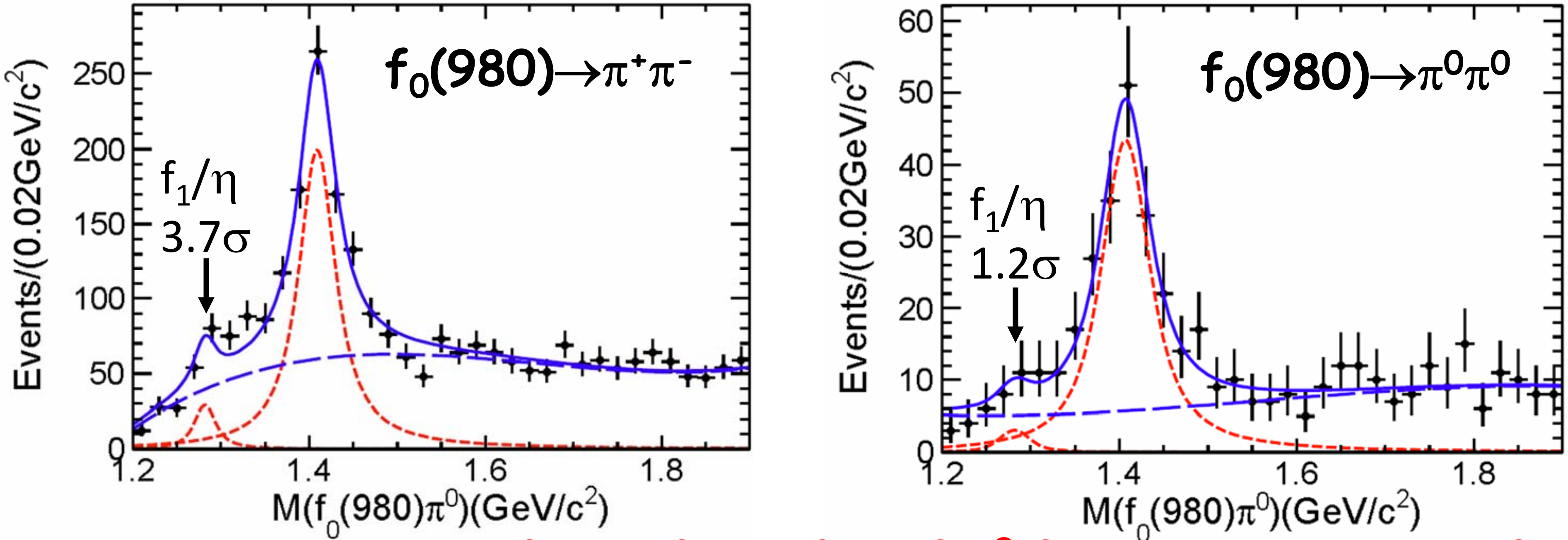
arXiv: 1201.2737v1 Accepted by PRL

$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0$, $f_0(980) \to 2\pi$



First observed: $\eta(1405) \to f_0(980)\pi^0$ (isospin breaking)

- Helicity analysis indicates the peak at 1400MeV is from $\eta(1405)$, not from $f_1(1420)$

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11(stat.) \pm 0.11(syst.)) \times 10^{-5}$$

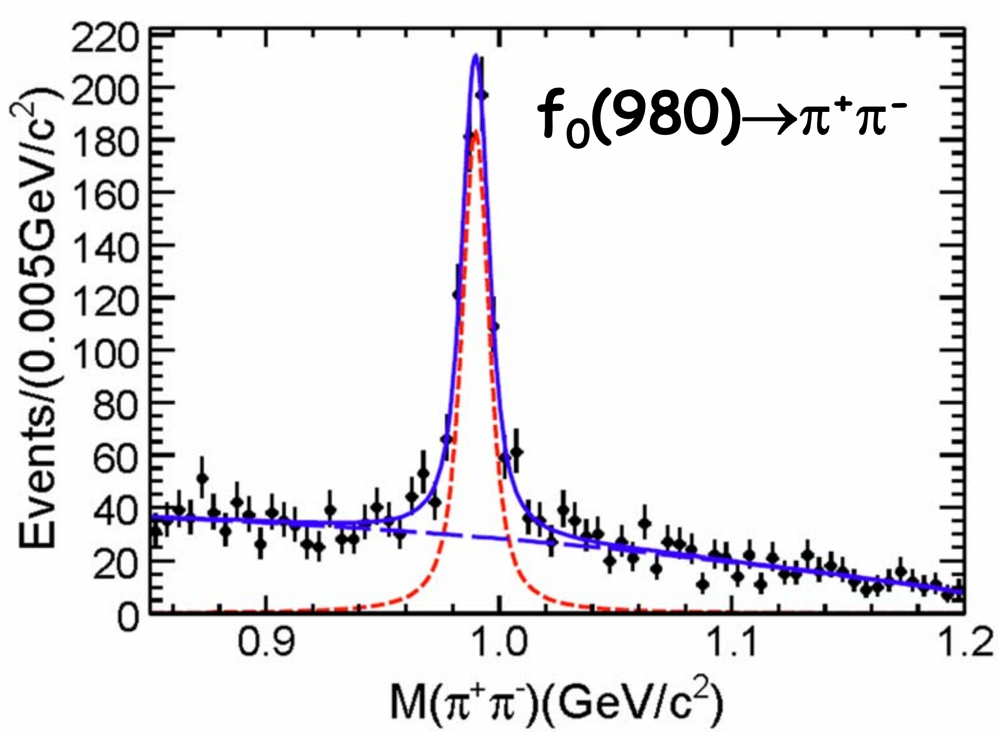
$$Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0 \to \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82(stat.) \pm 0.72(syst.)) \times 10^{-6}$$

- Large Isospin-violating decay rate:

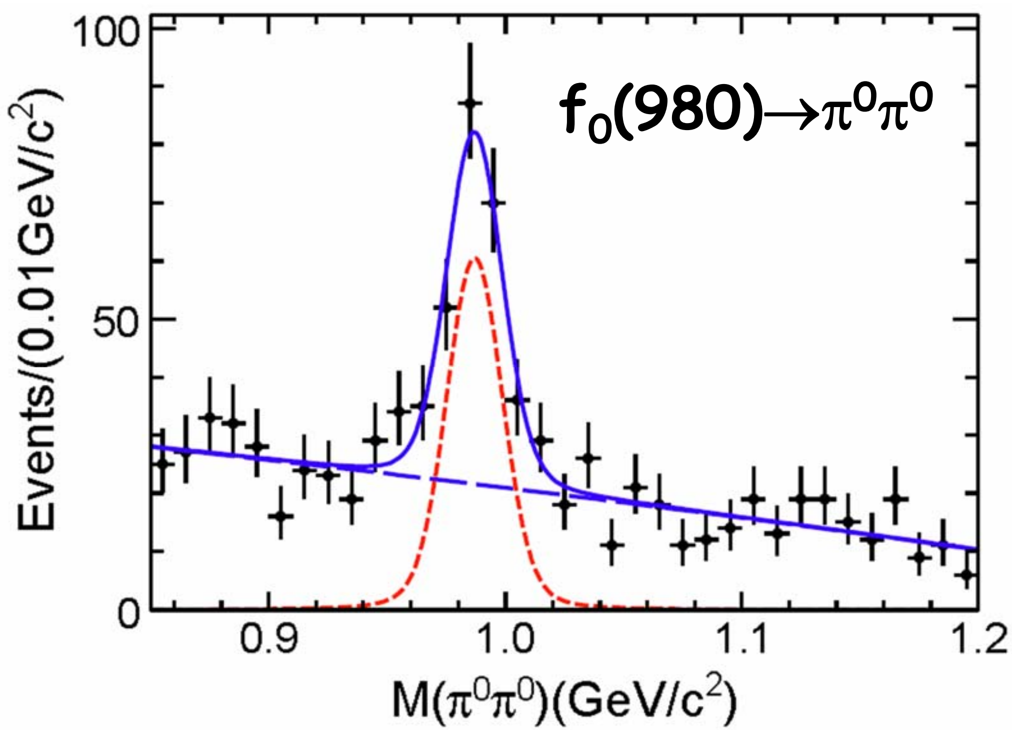
$$\frac{BR(\eta(1405) \to f_0(980)\pi^0 \to \pi^+\pi^-\pi^0)}{BR(\eta(1405) \to a_0(980)\pi^0 \to \pi^0\pi^0\eta)} \approx (17.9 \pm 4.2)\%$$

In general, magnitude of isospin violation in strong decay should be <1%.
$a_0 - f_0$ mixing alone can not explain the branching ratio of $\eta(1405) \to f_0(980)\pi^0$

Anomalous Lineshape of $f_0(980)$ in $J/\psi \to \gamma f_0(980)\pi^0$



$M = 989.9 \pm 0.4 \mathrm{MeV}/c^2$
$\Gamma = 9.5 \pm 1.1\ \mathrm{MeV}/c^2$



$M = 987.0 \pm 1.4 \mathrm{MeV}/c^2$
$\Gamma = 4.6 \pm 5.1\ \mathrm{MeV}/c^2$

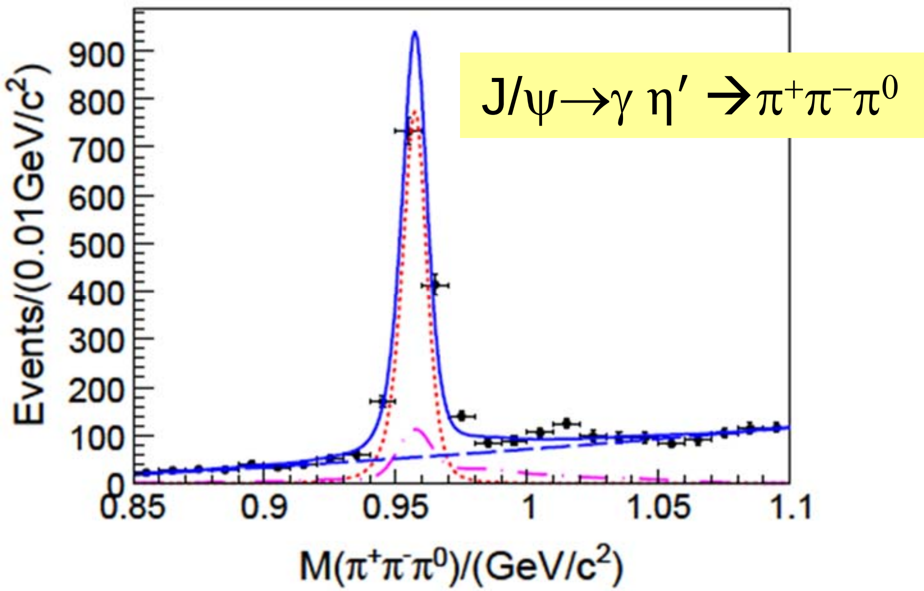
Surprising result:

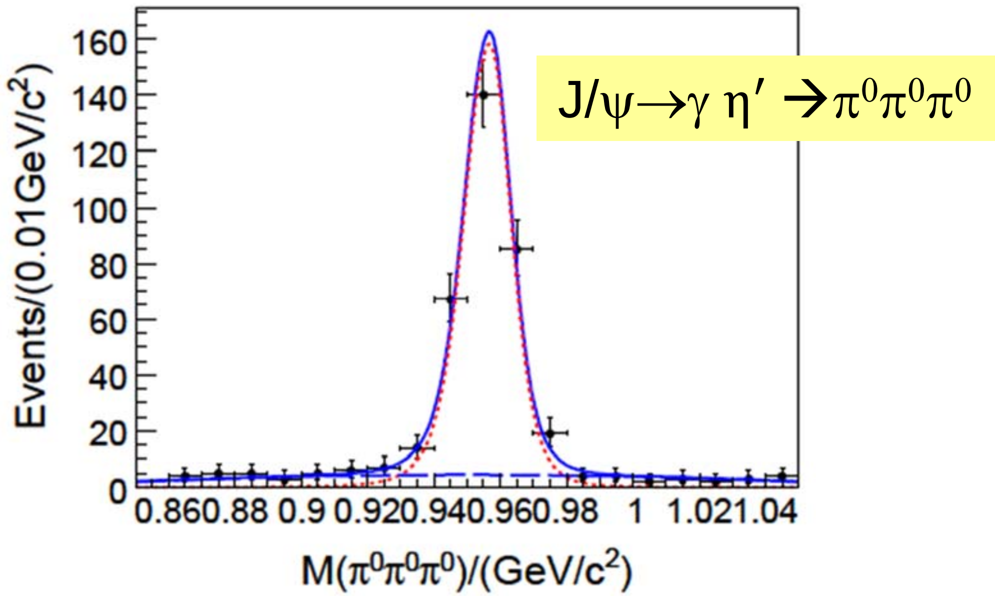
very narrow $f_0(980)$ width: <11.8 MeV/c^2 @90% C.L.

much narrower than the world average (PDG 2010: 40-100 MeV/c^2)

A possible explanation is KK^* loop, Triangle Singularity (TS) (J.J. Wu et al, PRL 108, 081803(2012))

New results on η'→πππ





New results:

$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ (PDG2010: $(3.6^{+1.1}_{-0.93}) \times 10^{-3}$)

$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$ (PDG2010: $(1.68 \pm 0.22) \times 10^{-3}$)

For the decay $\eta' \to \pi^0\pi^0\pi^0$, it is two times larger than the world average value.

Comparison: Isospin violations in η'→πππ :

$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%, \quad \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)} \approx 1.6\%$$

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- **3π Decays of J/ψ and $\psi(2S)$**

arXiv: 1202.2048 Accepted by PLB

3π Decays of J/ψ and ψ(2S)

$J/\psi \to \pi^+\pi^-\pi^0$ decays are dramatically different
From $\psi(2S) \to \pi^+\pi^-\pi^0$ decays:

- J/ψ is dominated by ρ
- ψ(2S) is strongly populated by higher mass state absent in J/ψ decay

Precision measurement of branching fractions:

$$Br(J/\psi \to \pi^+\pi^-\pi^0) = (2.137 \pm 0.004(stat)^{+0.058}_{-0.056}(syst)^{+0.027}_{-0.026}(norm)) \times 10^{-2}$$

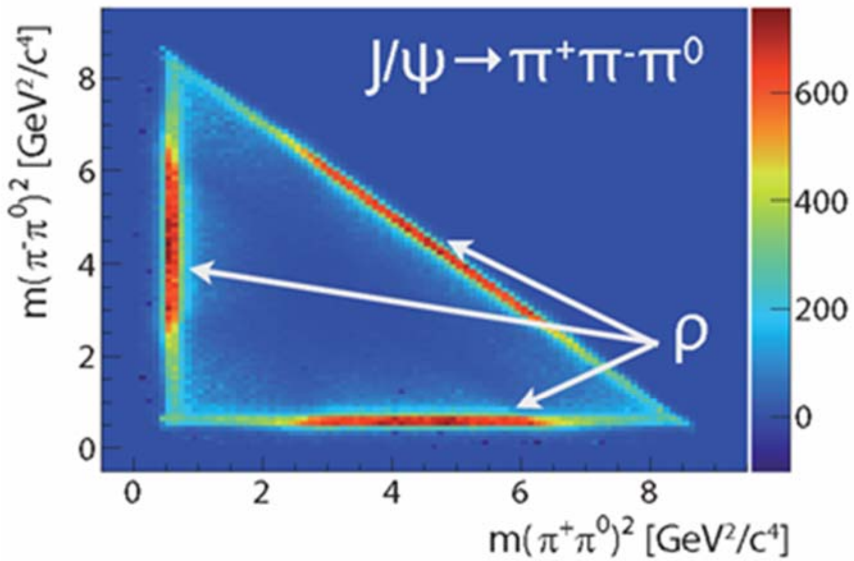
$$Br(\psi(2S) \to \pi^+\pi^-\pi^0) = (2.14 \pm 0.03(stat)^{+0.08}_{-0.07}(syst)^{+0.09}_{-0.08}(norm)) \times 10^{-4}$$

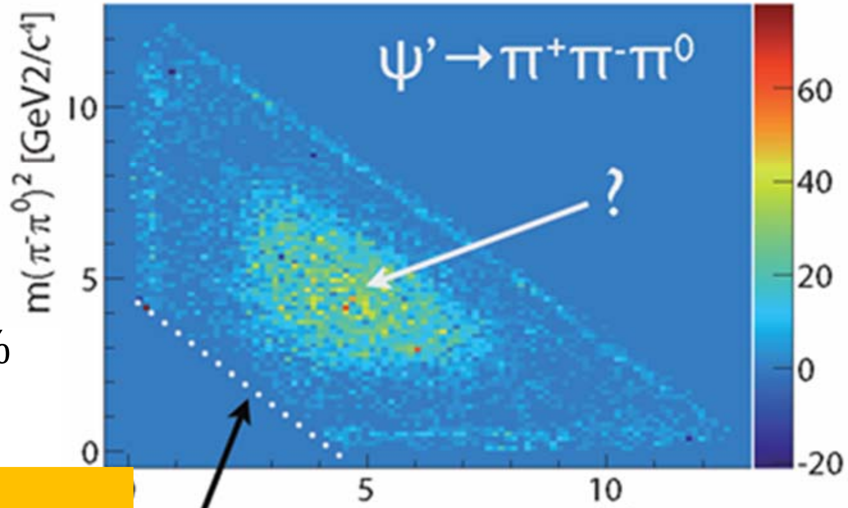
The ratio of these two branching fractions:

$$\frac{Br(\psi(2S) \to \pi^+\pi^-\pi^0)}{Br(J/\psi \to \pi^+\pi^-\pi^0)} = \left(1.00 \pm 0.01(\mathrm{stat})^{+0.06}_{-0.05}(\mathrm{syst})\right)\%$$

$\rho\pi$ puzzle: $Q_h = \frac{Br(\psi(2S)\to hadrons)}{Br(J/\psi \to hadrons)} \cong \frac{Br(\psi(2S)\to e^+e^-)}{Br(J/\psi\to e^+e^-)} \cong 12\%$

Dalitz plot with background subtracted and corrected for efficiency:





Recent Results on Charmonium Transitions

- **Properties of h_c**
- Mass and width of η_c
- Observation of $\psi' \to \gamma\eta_c(2S)$
- First evidence of $\psi' \to \gamma\gamma J/\psi$
- Multipole in $\psi' \to \gamma\chi_{c2}$

Property of h_c (1p1)

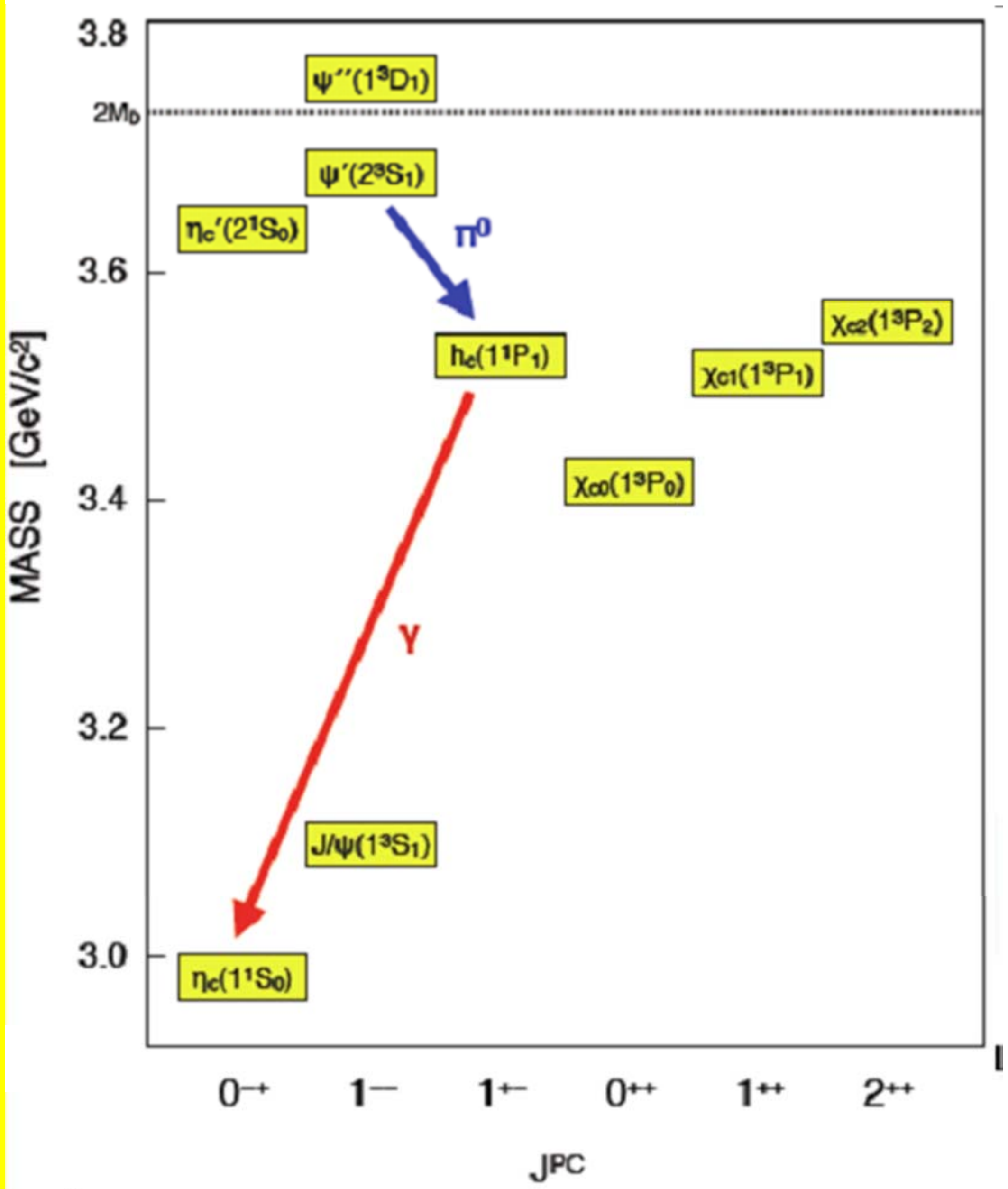
- First evidence:
  E835 in $pp \to h_c \to \gamma\eta_c$ (PRD72,092004(2005))

- CLEO-c observed h_c in $ee \to \psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$
  $\Delta M_{hf}(1P) = 0.08 \pm 0.18 \pm 0.12$ MeV/c^2
  (PRL104,132002(2010))

- Study isospin forbidden transition:
  $$B(\psi' \to \pi^0 h_c)$$

- Measure as well the E1 transition:
  $$B(h_c \to \gamma\eta_c)$$

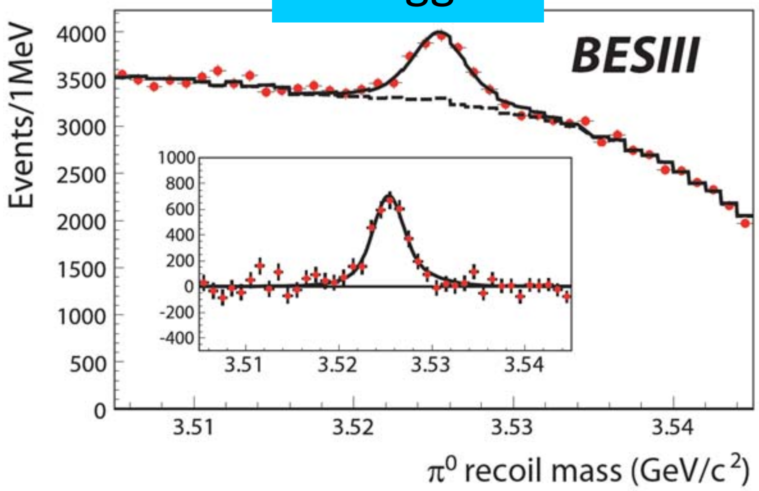
- M(h_c) gives access to hyperfine splitting of 1P states:
  $\Delta M_{hf}(1P) = M(h_c) - 1/9(M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2}))$



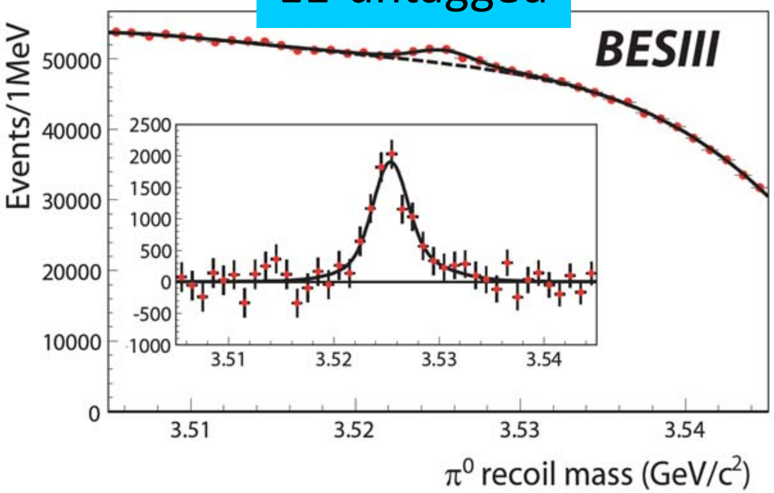
PRL104, 132002, (2010)

Observation of h_c at BESIII (inclusive)

E1-tagged



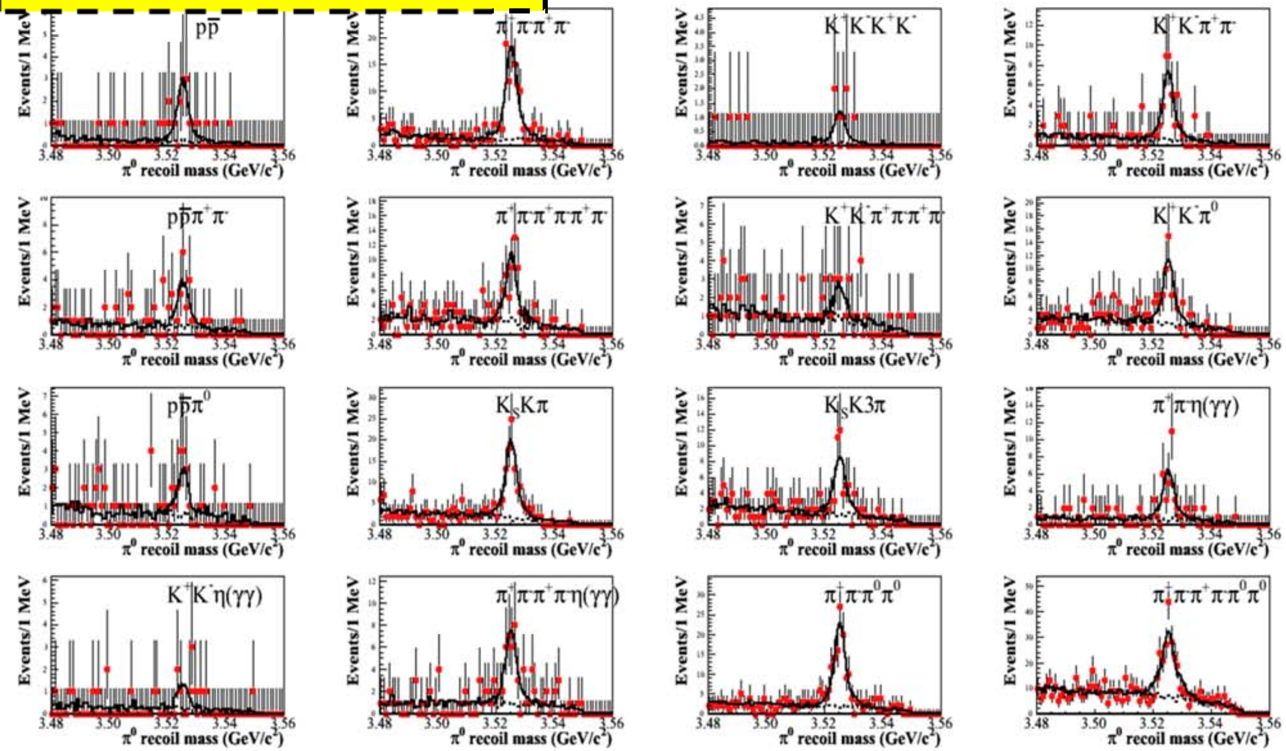
E1-untagged



- Select inclusive π^0 ($\psi' \to \pi^0 h_c$)
- Select E1-photon in $h_c \to \gamma\eta_c$ (E1 tagged) or not (E1 untagged)
- E1-tagged selection gives
  $M(h_c)$=3525.40±0.13 ±0.18MeV
  (ΔM_{hf}(1P)=0.10±0.13±0.18MeV/c^2)
  $\Gamma(h_c)$=0.73±0.45 ±0.28MeV (first measurement)
  (<1.44MeV at 90% CL)
  $Br(\psi' \to \pi^0 h_c) \times Br(h_c \to \gamma\eta_c)$= (4.58±0.40±0.50) $\times 10^{-4}$
- E1-untagged selection gives
  $Br(\psi' \to \pi^0 h_c)$ = (8.4±1.3±1.0) $\times 10^{-4}$
- Combining branching fractions leads to
  $Br(h_c \to \gamma\eta_c)$ = (54.3±6.7±5.2)%
  (first measurement)

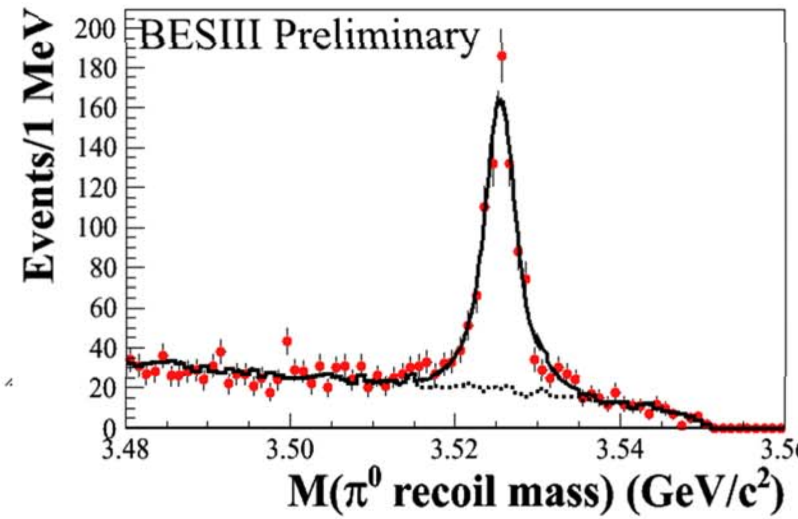
Measurements of the h_c properties at BESIII (exclusive)

BESIII preliminary



$\psi' \to \pi^0 h_C$, $h_C \to \gamma\eta_C$, η_C is reconstructed exclusively with 16 decay modes

Summed π^0 recoil mass



Simultaneous fit to π^0 recoiling mass:

$M(h_c)$ = 3525.31±0.11±0.15 MeV

$\Gamma(h_c)$ = 0.70±0.28±0.25 MeV

N = 832±35

χ^2/d.o.f. = 32/46

BESIII preliminary

Consistent with BESIII inclusive results PRL104,132002(2010)

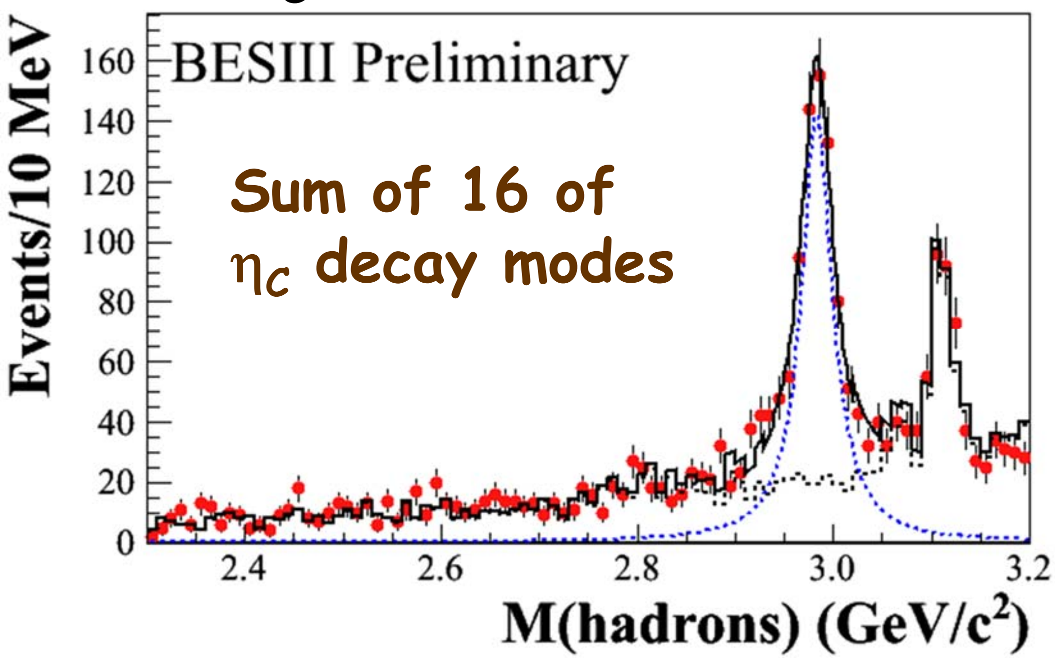
CLEOc exlusive results

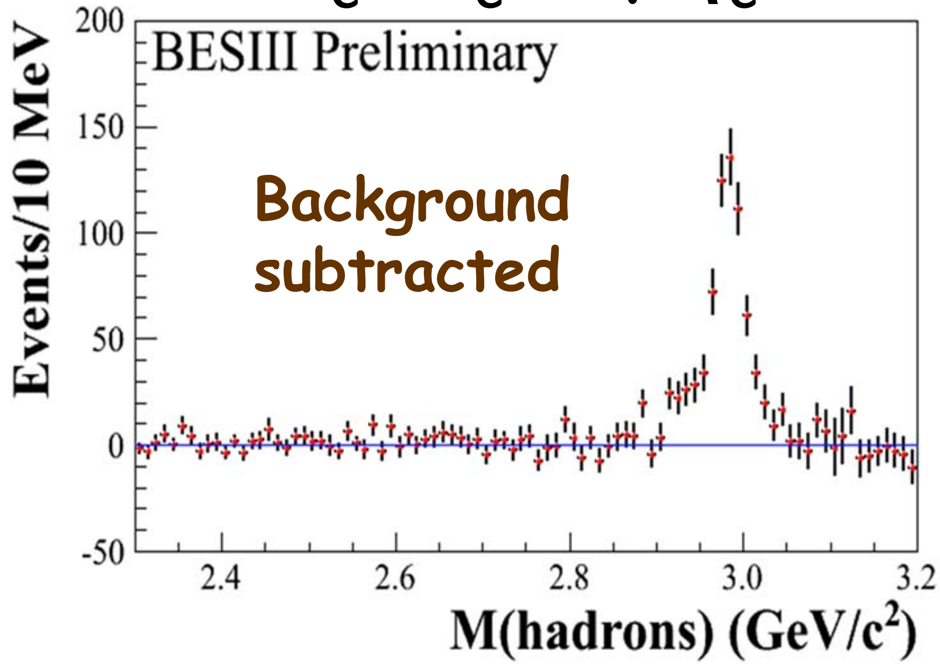
$M(h_c)$=3525.21±0.27±0.14 MeV/c^2

N = 136±14

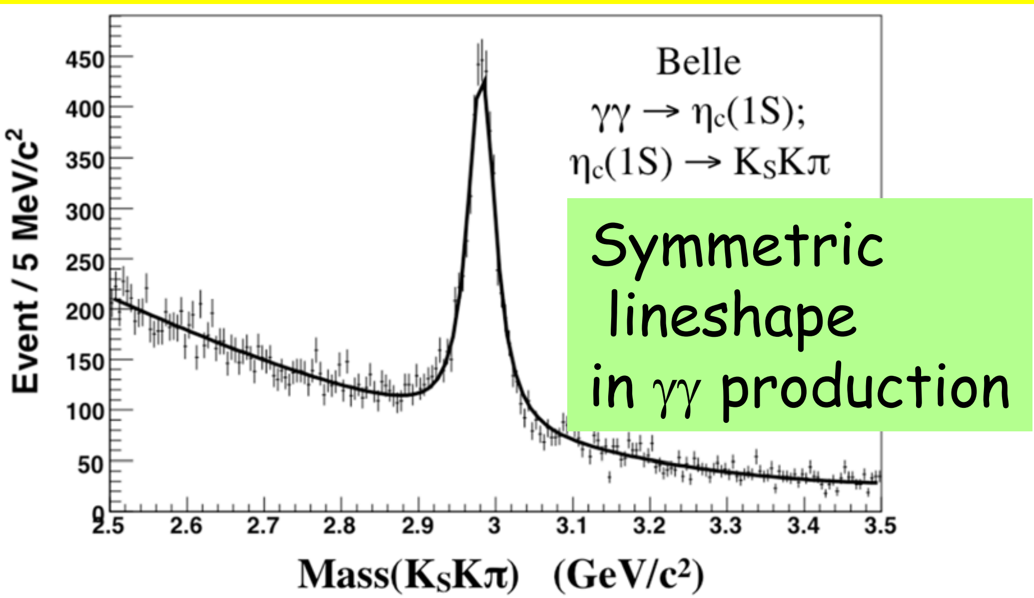
PRL101, 182003(2008)

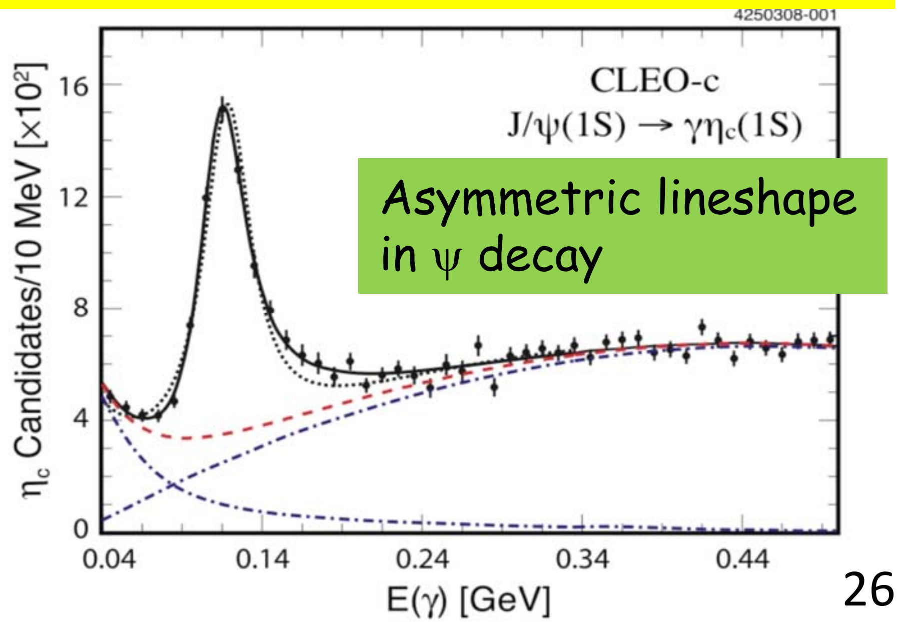
η_c lineshape from $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$





The η_c lineshape is not distorted in the $h_c \rightarrow \gamma\eta_c$, non-resonant bkg is small.
This channel will be best suited to determine the η_c resonance parameters.





Recent Results on Charmonium Transitions

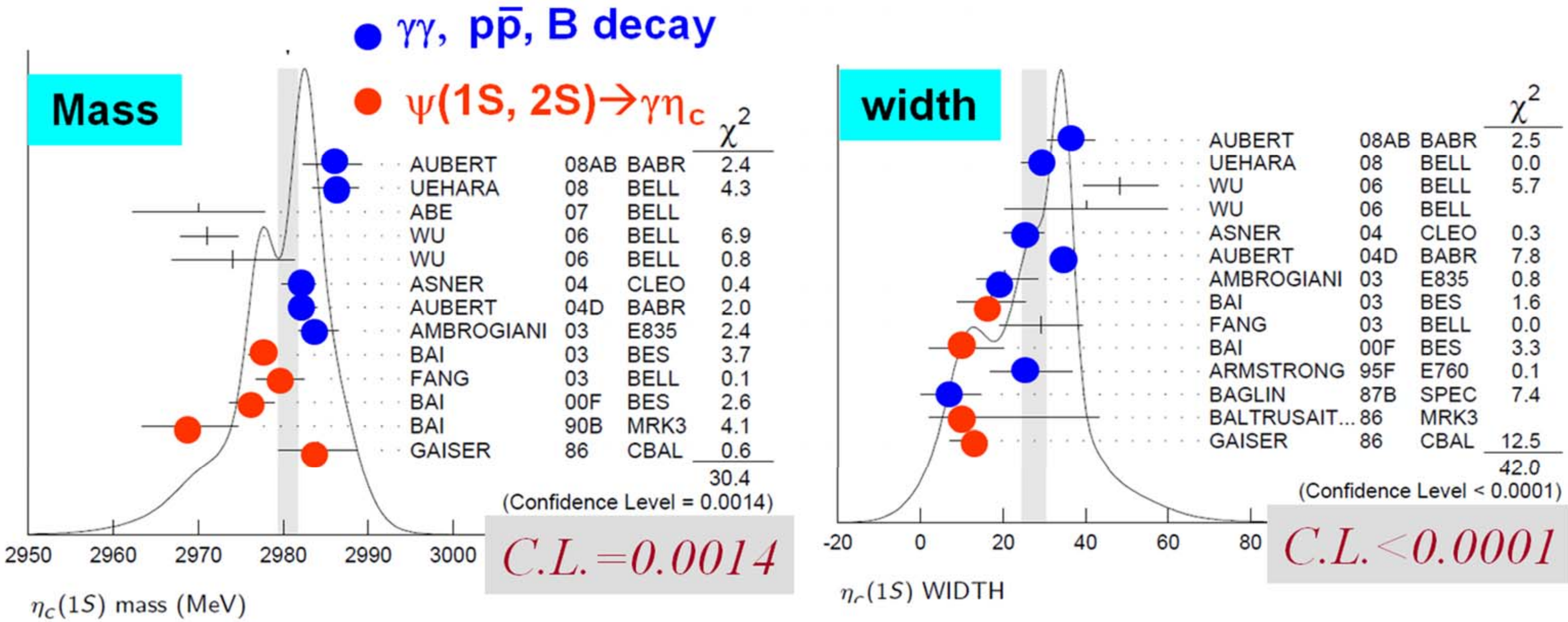
- Properties of h_c
- **Mass and width of η_c**
- Observation of $\psi' \rightarrow \gamma\eta_c(2S)$
- First evidence of $\psi' \rightarrow \gamma\gamma J/\psi$
- Multipole in $\psi' \rightarrow \gamma\chi_{c2}$

$\eta_c(1S)$

- Ground state of $c\bar{c}$ system, but its properties are not well known:

J/ψ radiative transition: $M \sim 2978.0 \text{MeV}/c^2$, $\Gamma \sim 10\text{MeV}$

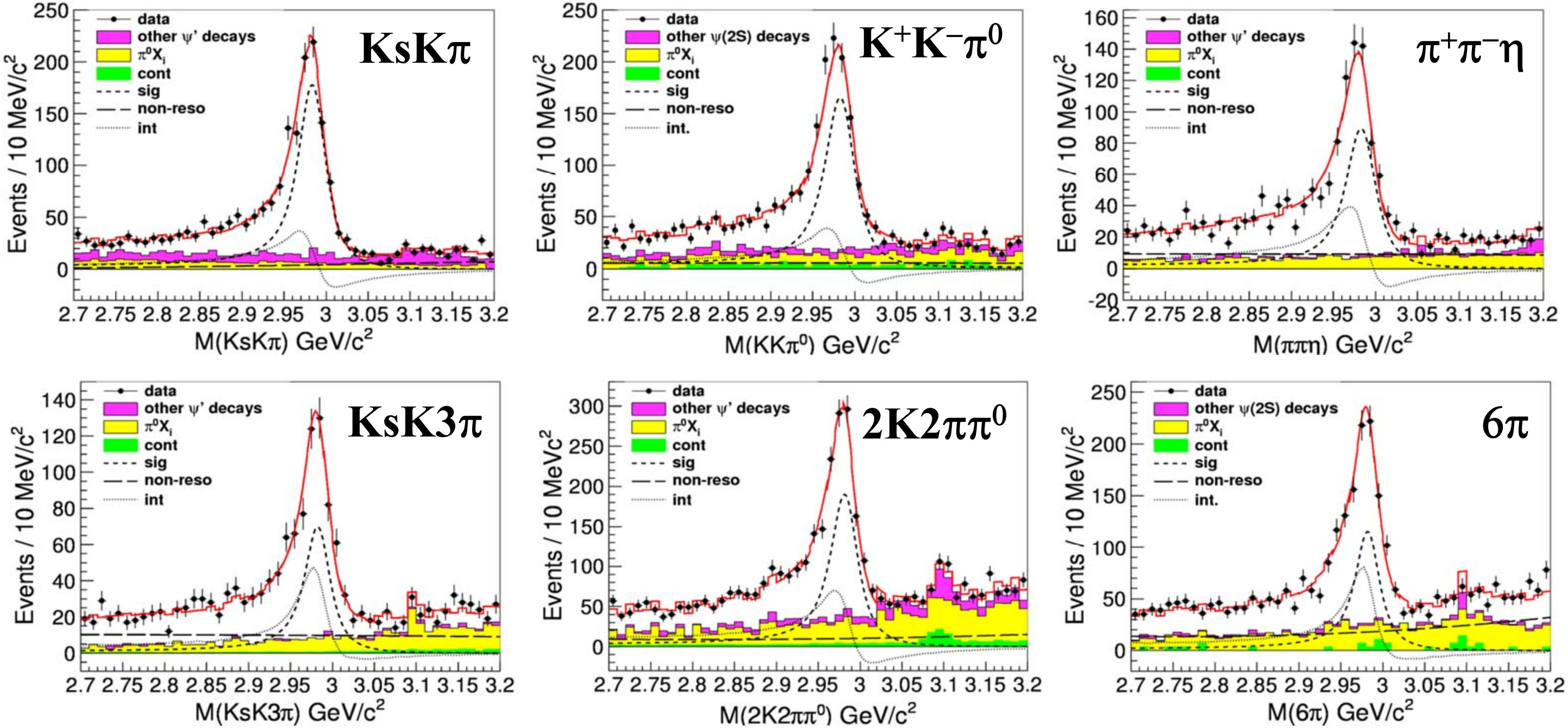
γγ process: $M = 2983.1 \pm 1.0 \text{ MeV}/c^2$, $\Gamma = 31.3 \pm 1.9 \text{ MeV}$



- CLEOc found the distortion of the η_c lineshape in ψ′ decays
- $c\bar{c}$ hyperfine splitting: $M(J/\psi)$- $M(\eta_c)$ is important experimental input to test the lattice QCD, but is dominated by error on $M(\eta_c)$

arXiv: 1111.0398 Accepted by PRL

$\psi' \rightarrow \gamma \eta_c$, η_c *exclusive decays*



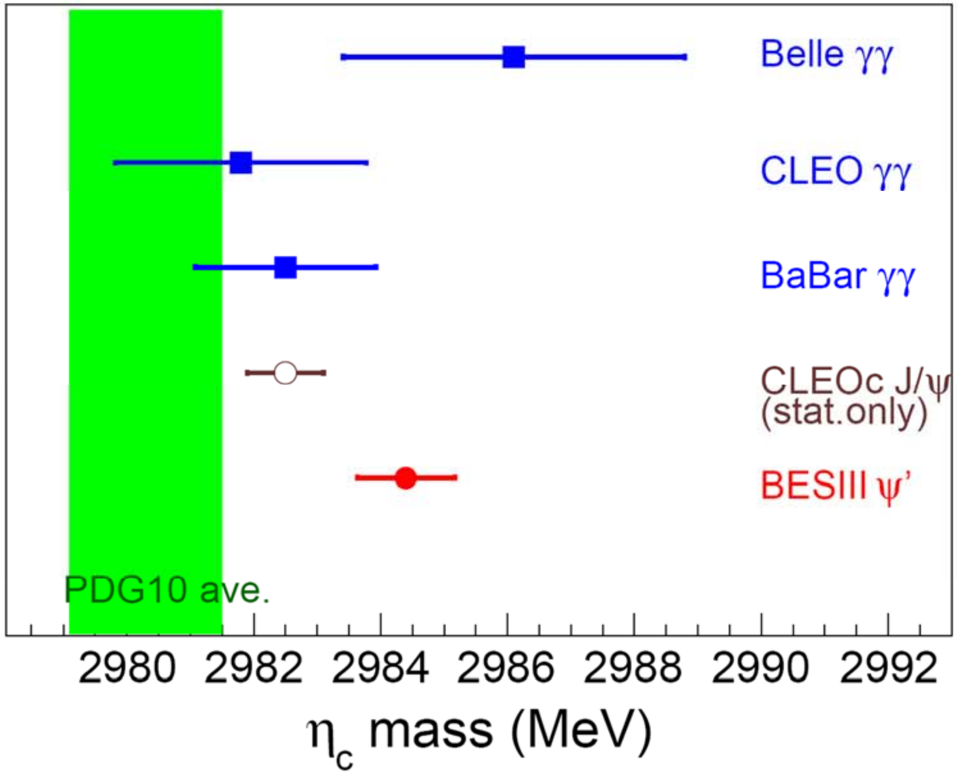
Interference with non-resonant is significant !

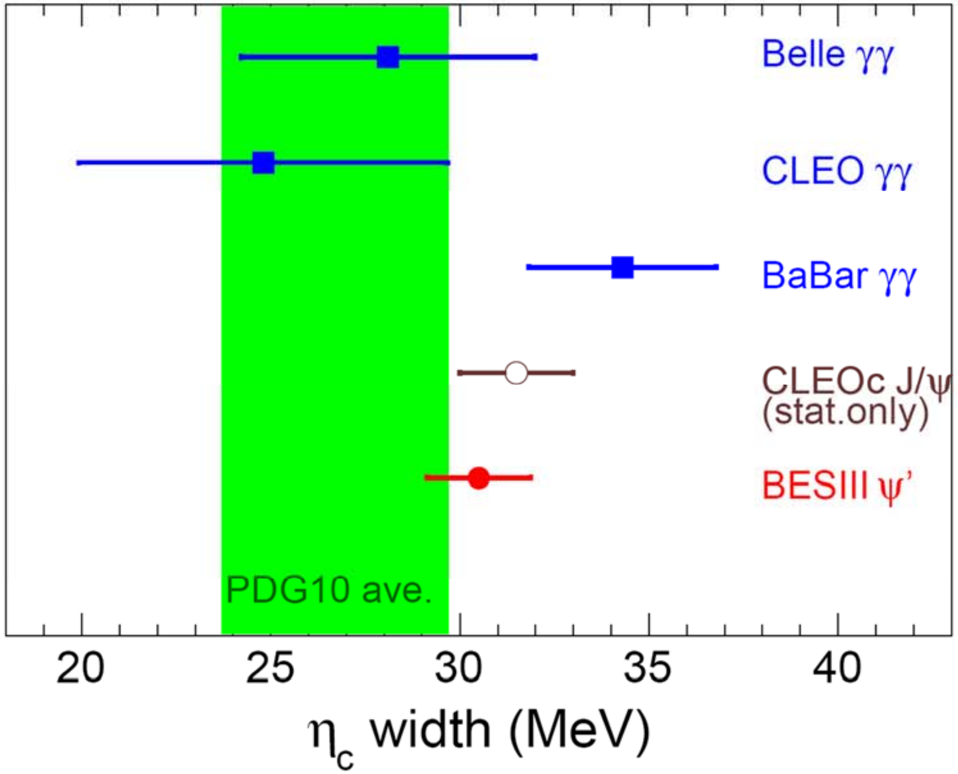
Relative phase ϕ values from each mode are consistent within 3σ,
➔ use a common phase value in the simultaneous fit.

Mass: **2984.3±0.6±0.6** MeV/c^2
width: **32.0±1.2±1.0** MeV
ϕ: **2.40±0.07±0.08** rad or
4.19 ±0.03±0.09 rad

Comparison of the mass and width for η_c

The world average in PDG2010 was using earlier measurements





Hyperfine splitting: $\Delta M(1S)$ = **112.6 ± 0.8** MeV

Consistent with B factory results in other production mechanisms.
Agree with lattice QCD calculations of the charmonium hyperfine splitting

Recent Results on Charmonium Transitions

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$\eta_c(2S)$

- First "observation" by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi' \to \gamma X$, never confirmed by other experiments.)

- Published results about $\eta_c(2S)$ observation:

Experiment	M [MeV]	Γ [MeV]	Process
Belle [1]	$3654 \pm 6 \pm 8$	—	$B^{\pm} \to K^{\pm} \eta_c(2S), \eta_c(2S) \to K_S K^{\pm} \pi^{\mp}$
CLEO [2]	$3642.9 \pm 3.1 \pm 1.5$	$6.3 \pm 12.4 \pm 4.0$	$\gamma\gamma \to \eta_c(2S) \to K_S K^{\pm} \pi^{\mp}$
BaBar [3]	$3630.8 \pm 3.4 \pm 1.0$	$17.0 \pm 8.3 \pm 2.5$	$\gamma\gamma \to \eta_c(2S) \to K_S K^{\pm} \pi^{\mp}$
BaBar [4]	$3645.0 + 5.5^{+4.9}_{-7.8}$	—	$e^+e^- \to J/\psi c\bar{c}$
PDG [5]	3638 ± 4	14 ± 7	—

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12 \pm 3$ MeV

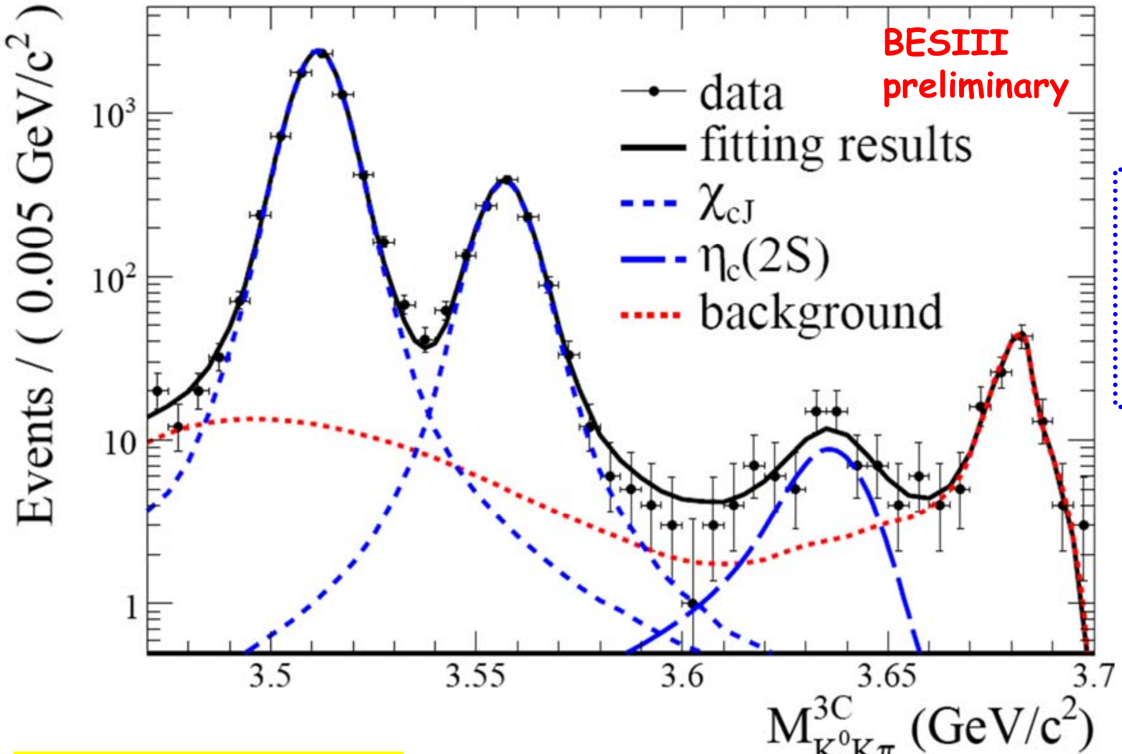
- The M1 transition $\psi' \to \gamma \eta_c(2S)$ has not been observed.

(experimental challenge : search for real photons ~50MeV,)

- Better chance to observe $\eta_c(2S)$ in ψ' radiative transition with ~106M ψ' data at BESIII.

- Decay mode studied: $\psi' \to \gamma \eta_c(2S) \to \gamma K_S K \pi$ ($K^+K^-\pi^0$ etc. in progress)

Observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S), \eta_c(2S) \to K_sK\pi$



With 106M ψ' events:

BESIII fit results:

$M(\eta_c(2S))$ = (3638.5 ± 2.3 ± 1.0) MeV/c^2

$N(\eta_c(2S))$ = 50.6 ± 9.7

Statistical significance larger than 6.0σ!

$Br(\psi' \to \gamma\eta_c(2S) \to \gamma KsK\pi)$
$= (2.98 \pm 0.57_{stat} \pm 0.48_{sys}) \times 10^{-6}$

+

$Br(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$
From BABAR(PRD78,012006)

⇩

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

CLEO-c: $<7.6\times10^{-4}$
PRD81,052002(2010)

Potential model: $(0.1\text{–}6.2)\times10^{-4}$
PRL89,162002(2002)

Mass fitting:

χ_{cJ}: MC shape ⊗ a Gaussian

$\eta_c(2S)$ signal:

$$(E_\gamma^3 \times BW(m) \times damping(E_\gamma)) \otimes Gauss(0, \sigma)$$

M1 transition

$$\frac{E_0^2}{E_\gamma E_0 + (E_\gamma - E_0)^2}$$

$\Gamma(\eta_c(2S))$ fixed to 12MeV (world average)

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- Multipole in $\psi' \to \gamma\chi_{c2}$

$\psi' \to \gamma\gamma\, J/\psi$

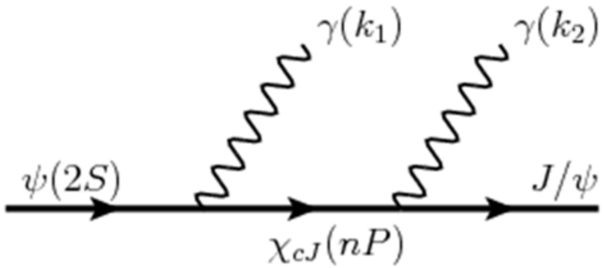
- Two photon transitions are well known in excitations of molecules, atomic hydrogen, and positronium.
  *[F. Bassani etal, PRL **39**, 1070 (1977);A. Quattropani etal, PRL **50**, 1258 (1983)]*

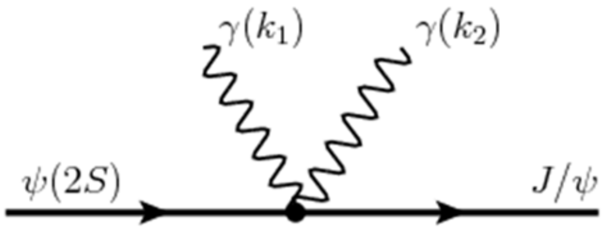
- Never been observed in the quarkonium system.
  CLEOc: upper limit of $Br(\psi' \to \gamma\gamma\, J/\psi)$ is 1×10^{-3} (PRD 78,011102(2008))

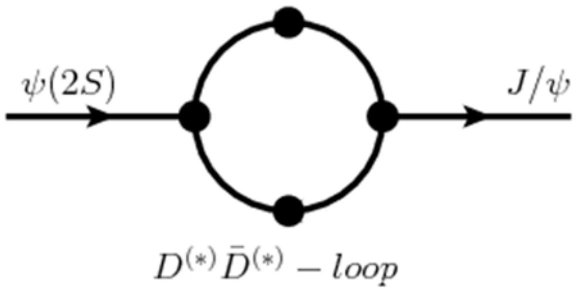
- Observation helpful to understand heavy quarkonium spectrum & strong interaction

Theoretically:

- Potential models give discrete spectra ($\psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$)
- Possibility of testing the hadron-loop effect
- Coupled channel: **the hadron-loop effect also may play a important role in the continuous spectra**





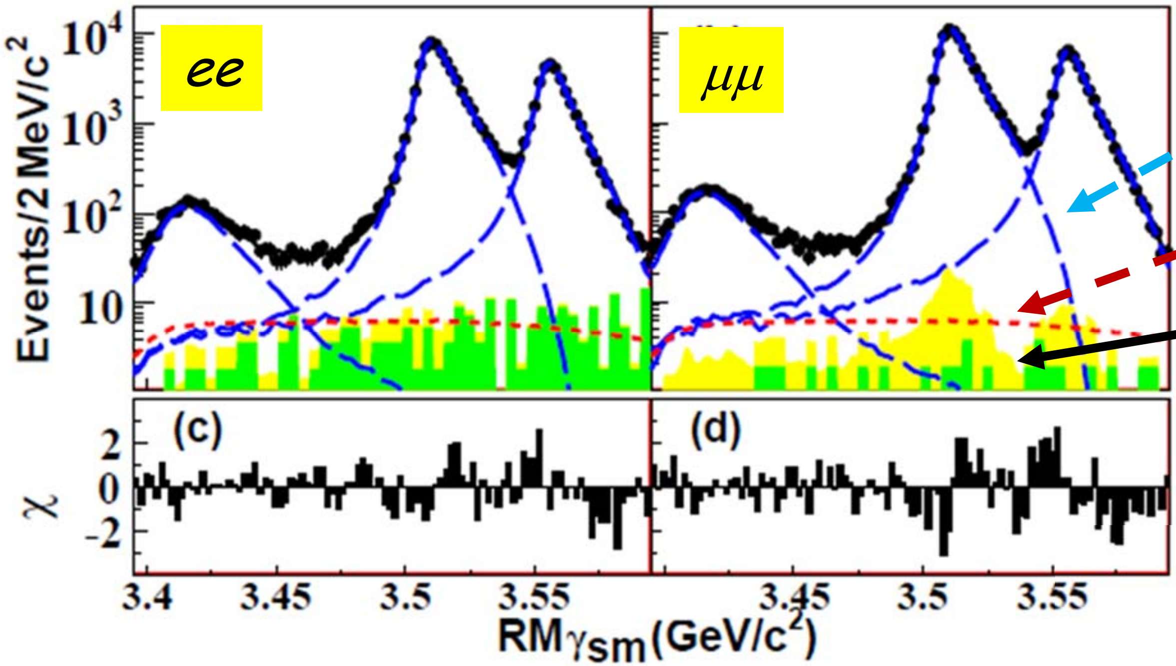


First evidence of $\psi' \to \gamma\gamma J/\psi$

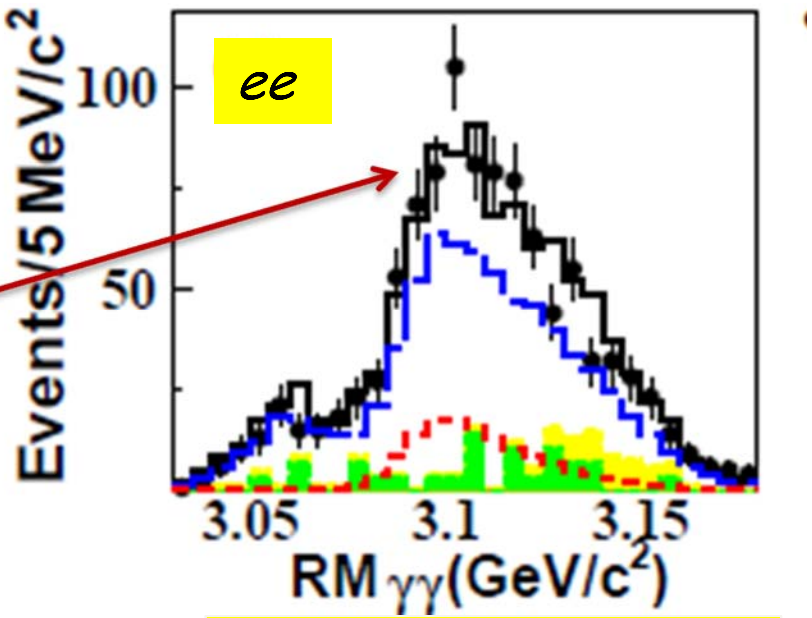
arXiv: 1112.0942 Submit to PRL

- Select $\psi(2S) \to \gamma\gamma J/\psi$, $J/\psi \to e^+e^-$ and $\mu^+\mu^-$ events

γ_{sm} - low energy gamma



- the χ_{cJ} components: double E1 scaling
- yields of the two-photon events
- continuum(green)+ ψ'-decay BG(yellow)



$3.44 < RM(\gamma_{sm}) < 3.48$GeV

- Global fit of the two-photon process and cascade χ_{cJ} processes
- See **clear excess** over BG + continuum

- $Br(\psi' \to \gamma\gamma J/\psi) = (3.3 \pm 0.6^{+0.8}_{-1.1}) \times 10^{-4}$ (both *ee* and $\mu\mu$)
- **Significance : 3.8σ including systematics**
- $Br(\psi' \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi)$ are also measured

Recent Results on Charmonium Transitions

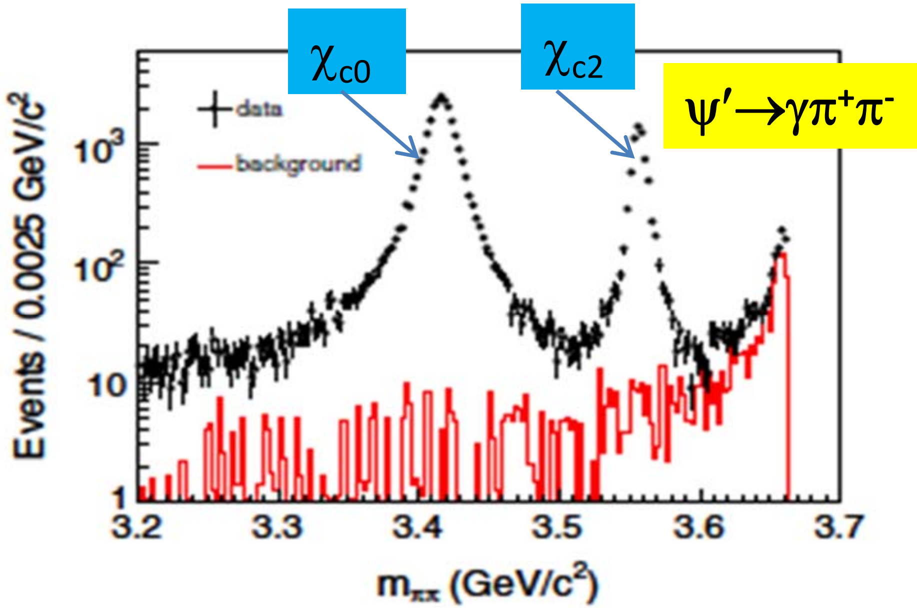
- Properties of h_c
- Mass and width of η_c
- Observation of $\psi' \to \gamma\eta_c(2S)$
- First evidence of $\psi' \to \gamma\gamma J/\psi$
- **Multipole in $\psi' \to \gamma\chi_{c2}$**

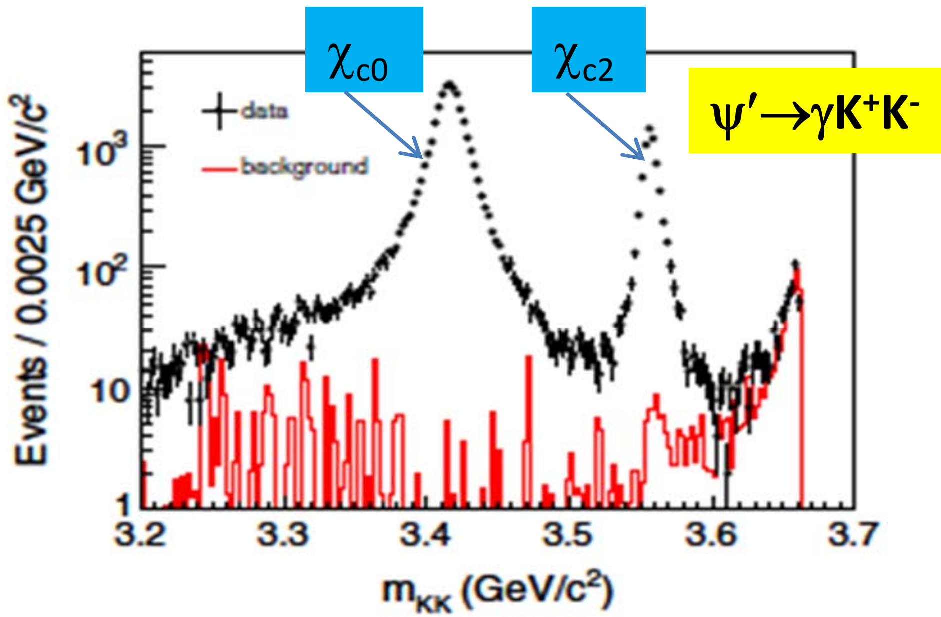
PRD84, 092006 (2011)

Higher-order Multipole in $\psi' \to \gamma\chi_{c2}$, $\chi_{c2} \to \pi^+\pi^-, K^+K^-$

Investigate the contribution from high-order multipole amplitudes

- $\psi' \to \gamma\chi_{c2}$ is dominated by electric dipole (E1) transition, but expect some magnetic quadrupole component (M2).
- M2 amplitude provides sensitivity to charm quark anomalous magnetic moment κ : $M2 = 0.029(1+\kappa)$
- Use large clean samples of $\chi_{c2} \to \pi^+\pi^-$ and $\chi_{c2} \to K^+K^-$; χ_{c0} samples used as control since M2 = 0.





PRD84, 092006 (2011)

Higher-order Multipole in $\psi' \to \gamma\chi_{c2}$, $\chi_{c2} \to \pi^+\pi^-, K^+K^-$

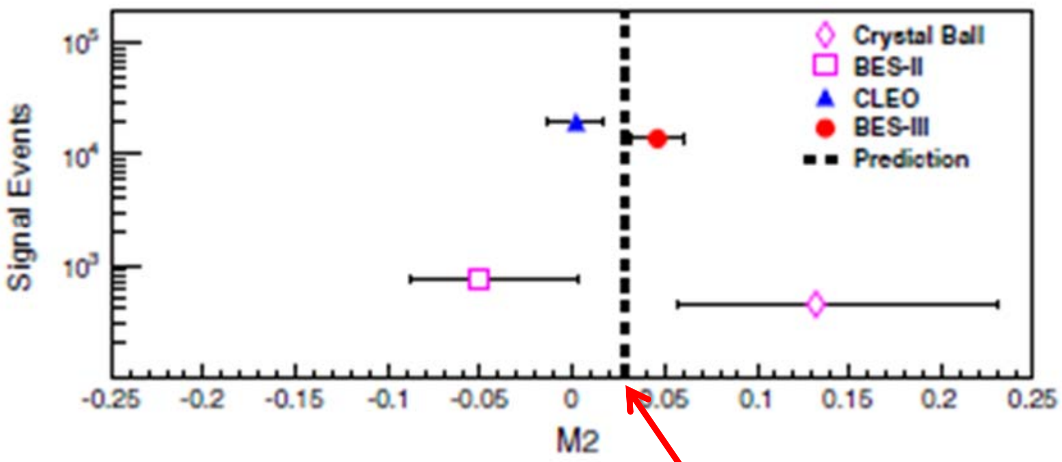
- Extract M2 using fit to full angular distribution

Evidence of M2 contribution:

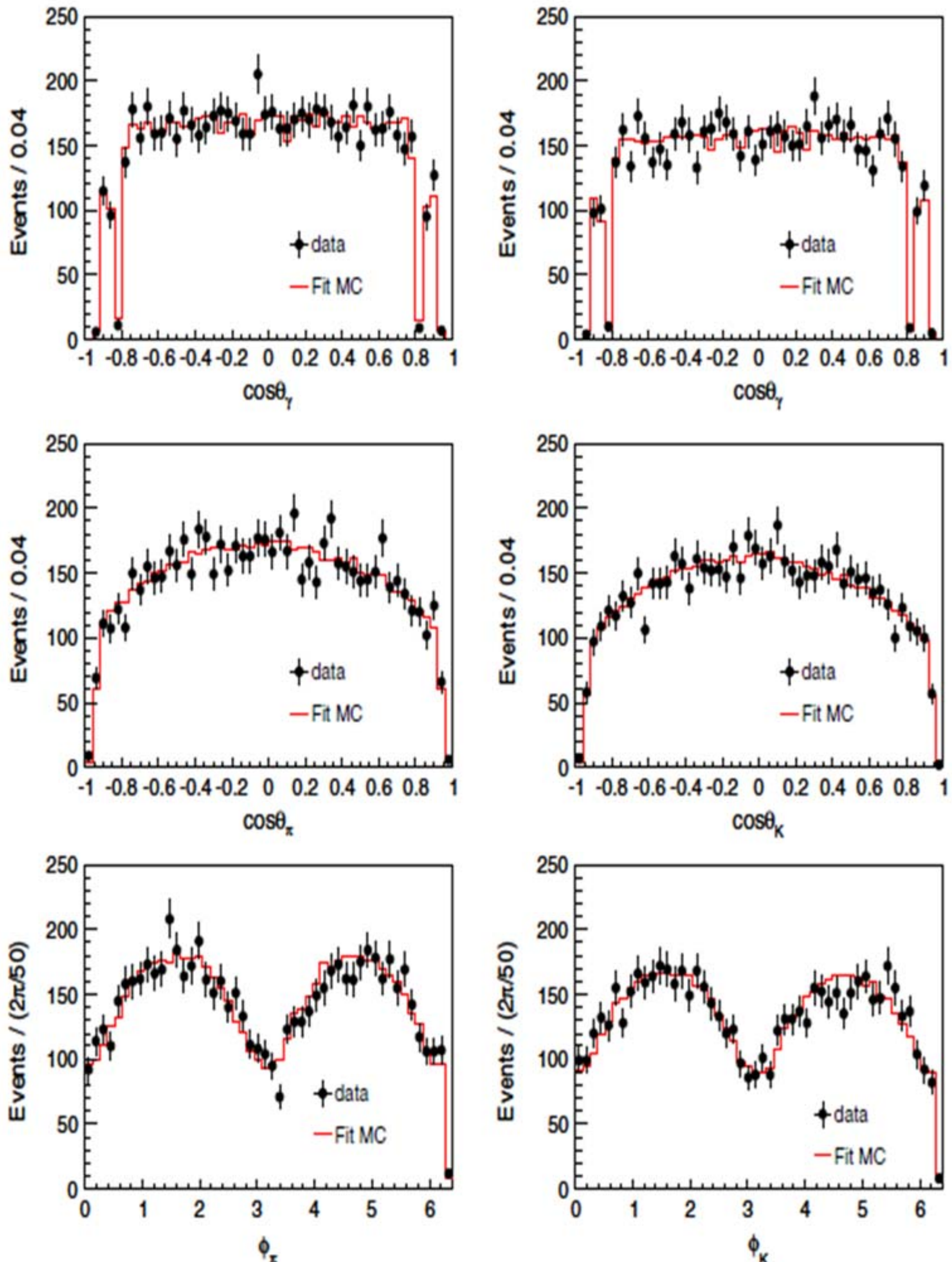
$$M2 = 0.046 \pm 0.010 \pm 0.013,$$
$$E3 = 0.015 \pm 0.008 \pm 0.018,$$

4.4σ

- Significant signal for M2 amplitude that is consistent with $\kappa = 0$



M(c) = 1.5 GeV and κ = 0



$\chi_{c2} \to \pi^+\pi^-$,

$\chi_{c2} \to K^+K^-$

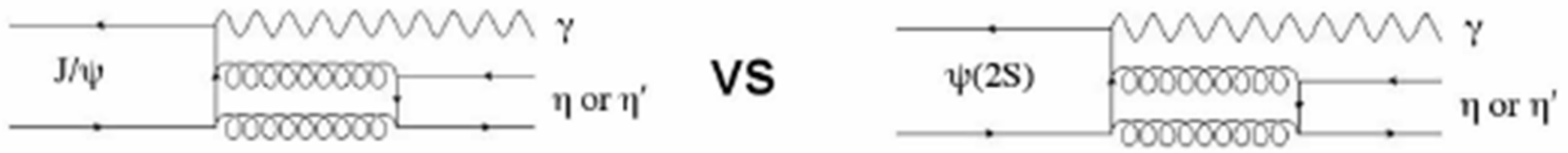
Recent Results on Charmonium Decays

- $\psi' \rightarrow \gamma\pi^0, \gamma\eta, \gamma\eta'$
- Search for $\eta_c(2S) \rightarrow VV$
- χ_{cJ} decays

$\psi' \to \gamma P(\pi^0, \eta, \eta')$, arise surprises

$V \to \gamma$ P are important tests for various mechanisms:

Vector meson Dominance Model (VDM); **Couplings & form factor;** Mixing of η-η'(η_c); **FSR by light quarks;** 12% rule and "$\rho\ \pi$ puzzle".



theory

$$R_{(c\bar{c})} = \frac{Br((c\bar{c}) \to \gamma\eta)}{Br((c\bar{c}) \to \gamma\eta')}$$

LO-pQCD

$\Downarrow$

$$R_{\psi'} \simeq R_{J/\psi}$$

PRP 112,173 (1984)

experiment

CLEO-c: $J/\psi, \psi', \psi'' \to \gamma$ P

$R_{J/\psi} = (21.1 \pm 0.9)\%$

No Evidence for $\psi' \to \gamma\ \pi^0$ or $\gamma\ \eta$

$Br(\psi' \to \gamma\eta') = (1.19 \pm 0.09)\%$

$R_{\psi'} < 1.8\%$ at 90% CL

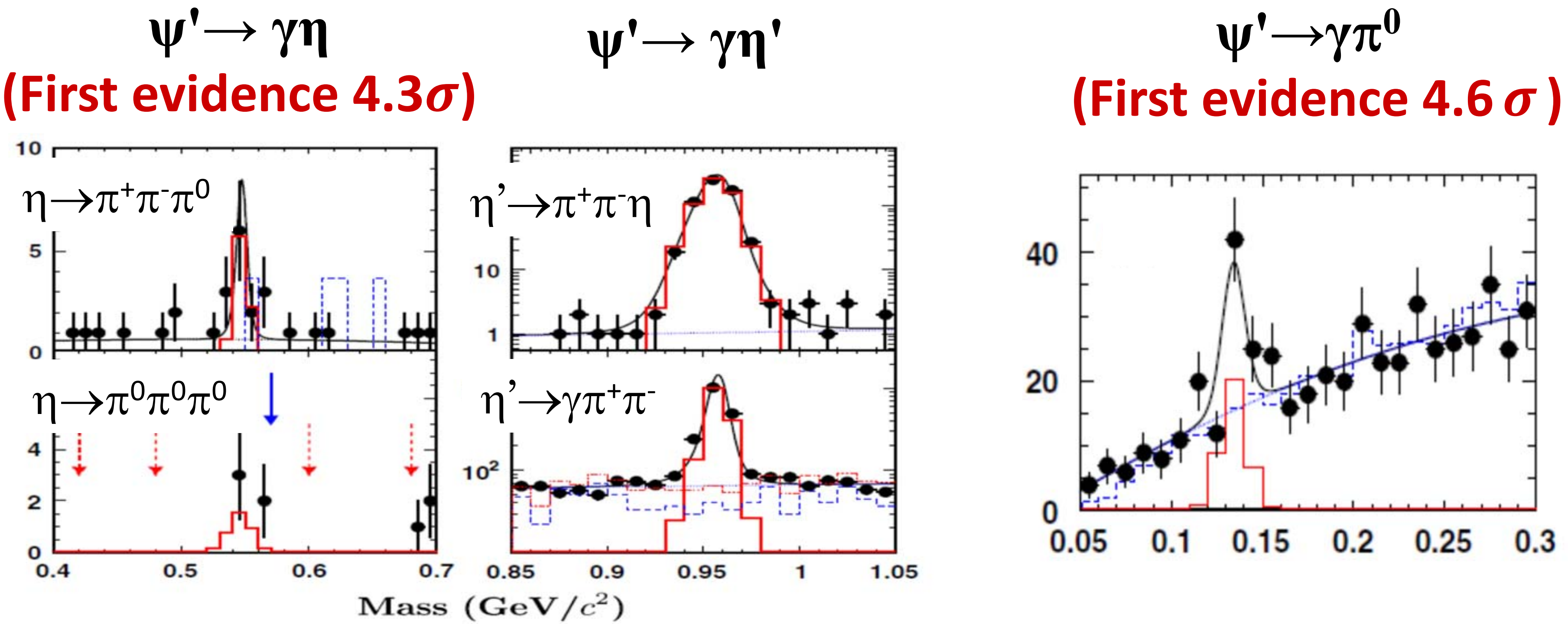
$\Downarrow$

$R_{\psi'} \ll R_{J/\psi}$

PRD 79, 111101 (2009)

PRL105, 261801, (2010)

$\psi' \to \gamma P(\pi^0, \eta, \eta')$



Mode	$B(\psi')$ [x10^{-6}]	$B(J/\psi)$ [x10^{-4}] (PDG)	Q (%)
$\gamma\pi^0$	1.58±0.42	0.35±0.03	4.5 ± 1.3
$\gamma\eta$	1.38±0.49	11.04±0.34	0.13 ± 0.04
$\gamma\eta'$	126±9	52.8±1.5	2.4 ± 0.2

$R_{\psi'}$= (1.10 ± 0.38 ± 0.07)% << $R_{J/\psi}$

Recent Results on Charmonium Decays

- $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$
- **Search for $\eta_c(2S) \to VV$**
- χ_{cJ} decays

PRD84, 091102R (2011)

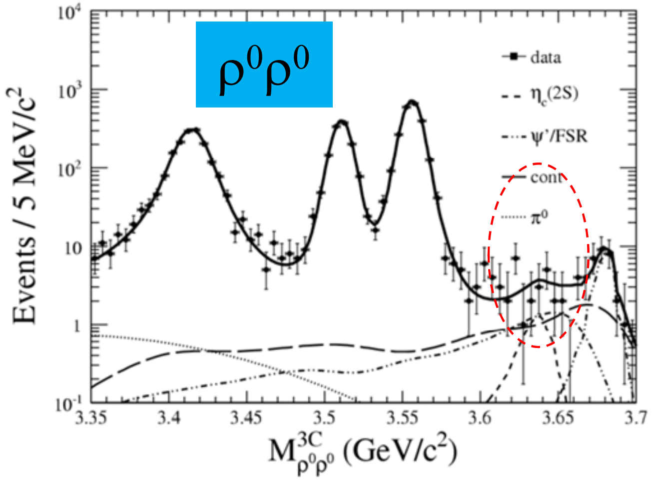
Search for $\eta_c(2S) \to VV$

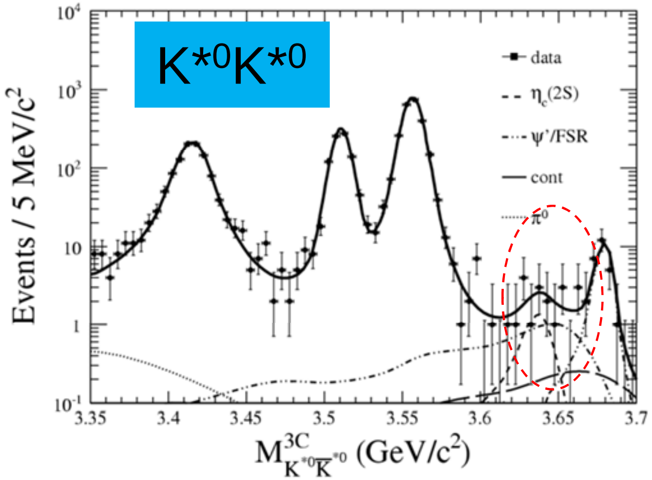
Test for the 'intermediate charmed meson loops':

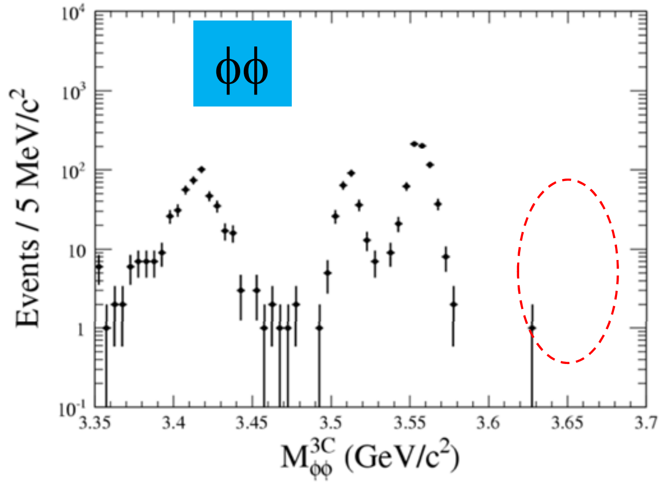
$\eta_c(2S) \to VV$ is highly suppressed by the helicity selection rule.

'intermediate charmed meson loops' can increase the production rate of $\eta_c(2S) \to VV$.

(PRD81, 014017 (2010))







	BF($\psi' \to \gamma\eta_c(2S) \to \gamma VV$) ($10^{-7}$)	BF($\eta_c' \to VV$) (10^{-3}) (using BESIII BF($\psi' \to \gamma\eta_c(2S)$))	BF($\eta_c' \to VV$) (10^{-3}) Theory: (arXiv:1010.1343)
$\rho^0\rho^0$	<12.7	<3.1	6.4 ~ 28.9
$K^{*0}K^{*0}$	<19.6	<5.4	7.9 ~ 35.8
$\phi\phi$	< 7.8	<2.0	2.1 ~ 9.8

No signals observed in $\eta_c(2S) \to \rho\rho$, $K^{*0}K^{*0}$, $\phi\phi$; more stringent UL's are set.

Recent Results on Charmonium Decays

- $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$
- Search for $\eta_c(2S) \to VV$
- **χ_{cJ} decays**

χ_{cJ} study at BESIII

The χ_{cJ} decays provide good place to:

- **Study gluonium: $\chi_c \rightarrow gg \rightarrow (q\bar{q})(q\bar{q})$**

  C. Amsler and F. E. Close,Phys. Rev. D 53, 295 (1996).

- **Test the Color Octet Mechanism(COM)**

  G. T. Bodwin *et al*., Phys Rev. Lett. D51, 1125 (1995).
  H.-W. Huang and K.-T. Chao, Phys. Rev. D54, 6850 (1996).
  J. Bolz *et al*., Eur. Phys. J. C 2, 705 (1998).

- **First measurement of $\chi_{cJ} \rightarrow \omega\phi$, $\omega\omega$, $\phi\phi$**
- **First measurement of $\chi_{cJ} \rightarrow \gamma\phi$**
- **First measurement of $\chi_{cJ} \rightarrow p\bar{p}K^+K^-$**

PRL107, 091803 (2011)

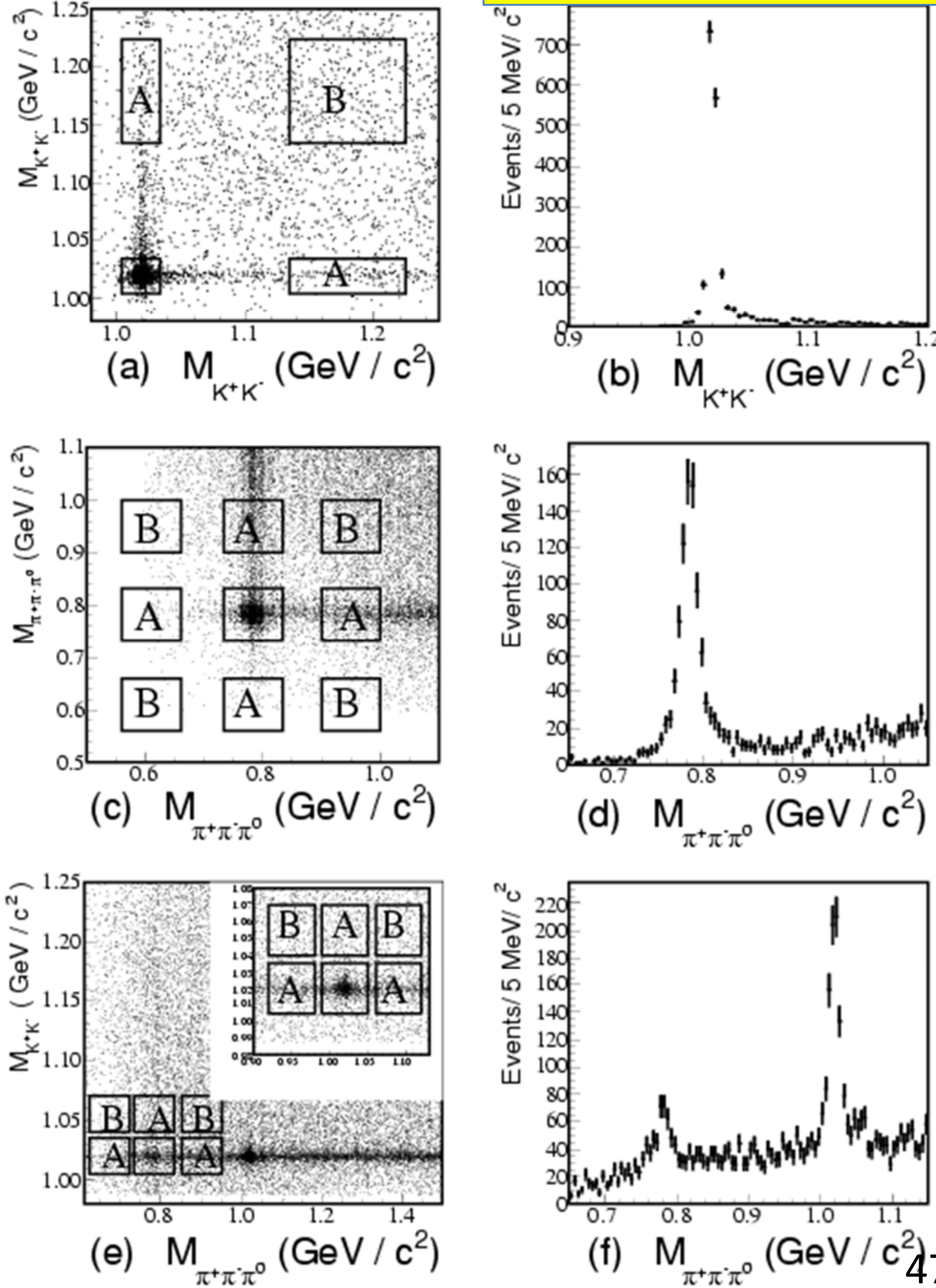
$\chi_{cJ} \rightarrow VV$ (V: ω, ϕ)

Reconstruct

$\phi \rightarrow K^+K^-$, $\pi^+\pi^-\pi^0$

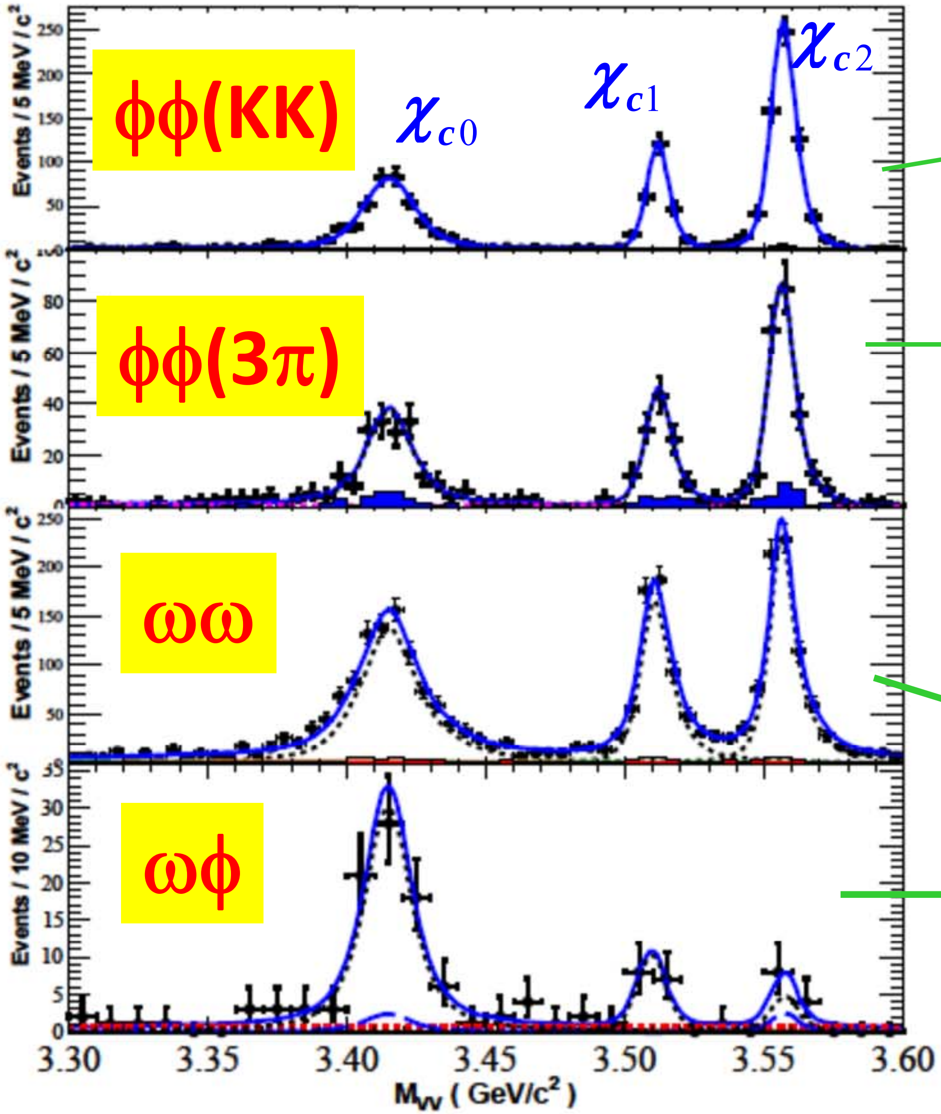
$\omega \rightarrow \pi^+\pi^-\pi^0$

- $\chi_{cJ} \rightarrow \phi\phi$ and $\chi_{cJ} \rightarrow \omega\omega$ are Singly OZI suppressed
- $\chi_{c1} \rightarrow \phi\phi$ and $\chi_{c1} \rightarrow \omega\omega$ is suppressed by helicity selection rule.
- $\chi_{cJ} \rightarrow \phi\omega$ is doubly OZI suppressed, not measured yet



PRL107, 091803 (2011)

$\chi_{cJ} \rightarrow VV$



Mode	$N_{\rm net}$	ϵ (%)	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \rightarrow \phi\phi$	433 ± 23	22.4	$7.8 \pm 0.4 \pm 0.8$
$\chi_{c1} \rightarrow \phi\phi$	254 ± 17	26.4	$4.1 \pm 0.3 \pm 0.4$
$\chi_{c2} \rightarrow \phi\phi$	630 ± 26	26.1	$10.7 \pm 0.4 \pm 1.1$
$\rightarrow 2(K^+K^-)$			
$\chi_{c0} \rightarrow \phi\phi$	179 ± 16	1.9	$9.2 \pm 0.7 \pm 1.0$
$\chi_{c1} \rightarrow \phi\phi$	112 ± 12	2.3	$5.0 \pm 0.5 \pm 0.6$
$\chi_{c2} \rightarrow \phi\phi$	219 ± 16	2.2	$10.7 \pm 0.7 \pm 1.2$
$\rightarrow K^+K^-\pi^+\pi^-\pi^0$			
Combined:			
$\chi_{c0} \rightarrow \phi\phi$	—	—	$8.0 \pm 0.3 \pm 0.8$
$\chi_{c1} \rightarrow \phi\phi$	—	—	$4.4 \pm 0.3 \pm 0.5$
$\chi_{c2} \rightarrow \phi\phi$	—	—	$10.7 \pm 0.3 \pm 1.2$
$\chi_{c0} \rightarrow \omega\omega$	991 ± 38	13.1	$9.5 \pm 0.3 \pm 1.1$
$\chi_{c1} \rightarrow \omega\omega$	597 ± 29	13.2	$6.0 \pm 0.3 \pm 0.7$
$\chi_{c2} \rightarrow \omega\omega$	762 ± 31	11.9	$8.9 \pm 0.3 \pm 1.1$
$\rightarrow 2(\pi^+\pi^-\pi^0)$			
$\chi_{c0} \rightarrow \omega\phi$	76 ± 11	14.7	$1.2 \pm 0.1 \pm 0.2$
$\chi_{c1} \rightarrow \omega\phi$	15 ± 4	16.2	$0.22 \pm 0.06 \pm 0.02$
$\chi_{c2} \rightarrow \omega\phi$	< 13	15.7	< 0.2
$\rightarrow K^+K^-\pi^+\pi^-\pi^0$			

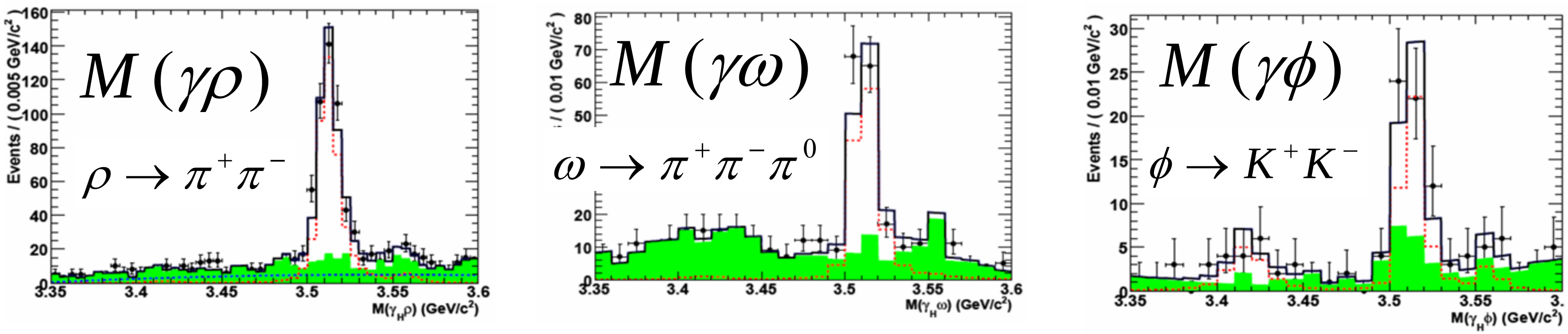
Evidence

First observation

Long distance transitions could contribute via the intermediate meson loops. PRD81 014017 (2010) , PRD81 074006 (2010)

PRD83, 112005, (2011)

$\chi_{cJ} \to \gamma$ V (V:ρ,ω,ϕ)



Branching fractions for χ_{cJ} radiative decays to a vector meson (In units of 10^{-6})

Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]	**BESIII**
$\chi_{c0} \to \gamma\rho^0$	< 9.6	1.2	3.2	2.0	**<10.5**
$\chi_{c1} \to \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42	**228±13±22**
$\chi_{c2} \to \gamma\rho^0$	< 50	4.4	13	38	**<20.8**
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22	**<12.9**
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7	**69.7±7.2±6.6**
$\chi_{c2} \to \gamma\omega$	< 7.0	0.5	1.5	4.2	**<6.1**
$\chi_{c0} \to \gamma\phi$	< 6.4	0.46	1.3	0.03	**<16.2**
$\chi_{c1} \to \gamma\phi$	< 26	3.6	11	11	**25.8±5.2±2.3**
$\chi_{c2} \to \gamma\phi$	< 13	1.1	3.3	6.5	**<8.1**

First observation

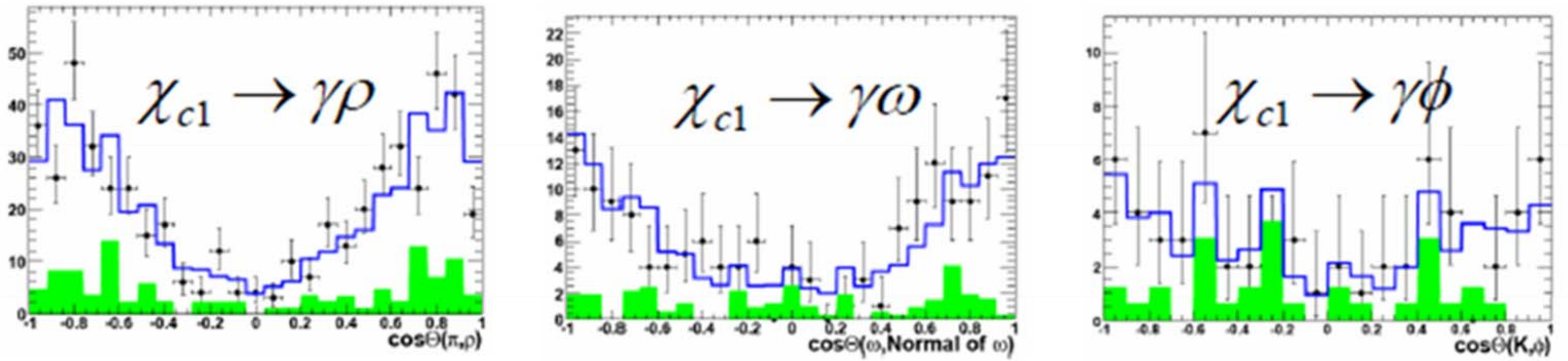
prediction by pQCD much lower than experiment

PRD83, 112005, (2011)

Polarization of $\chi_{cJ} \to \gamma$ V (V:ρ,ω,ϕ)

Longitudinal polarization (f_L); Transverse polarization (f_T); Helicity angle (θ)

$$\frac{d\Gamma}{\Gamma d\cos\theta} \propto (1-f_T)\cos^2\theta + \frac{1}{2} f_T \sin^2\theta \qquad f_T = \frac{|A_T|^2}{|A_T|^2 + |A_L|^2}$$



$f_T = 0.158 \pm 0.034^{+0.015}_{-0.014}$ $\quad f_T = 0.247^{+0.090+0.044}_{-0.087-0.026}$ $\quad f_T = 0.29^{+0.13+0.10}_{-0.12-0.09}$

Longitudinal polarization dominates, consistent with theoretical prediction

Z Phys. C 66, 71 (1995); Phys. Rev. 77, 242 (1950))

PRD 83, 112009 (2011)

$\chi_{cJ} \rightarrow p\bar{p}K^+K^-$

- Test Color Octet Mechinasim (COM) theory
- Search for new χ_{cJ} decay mode

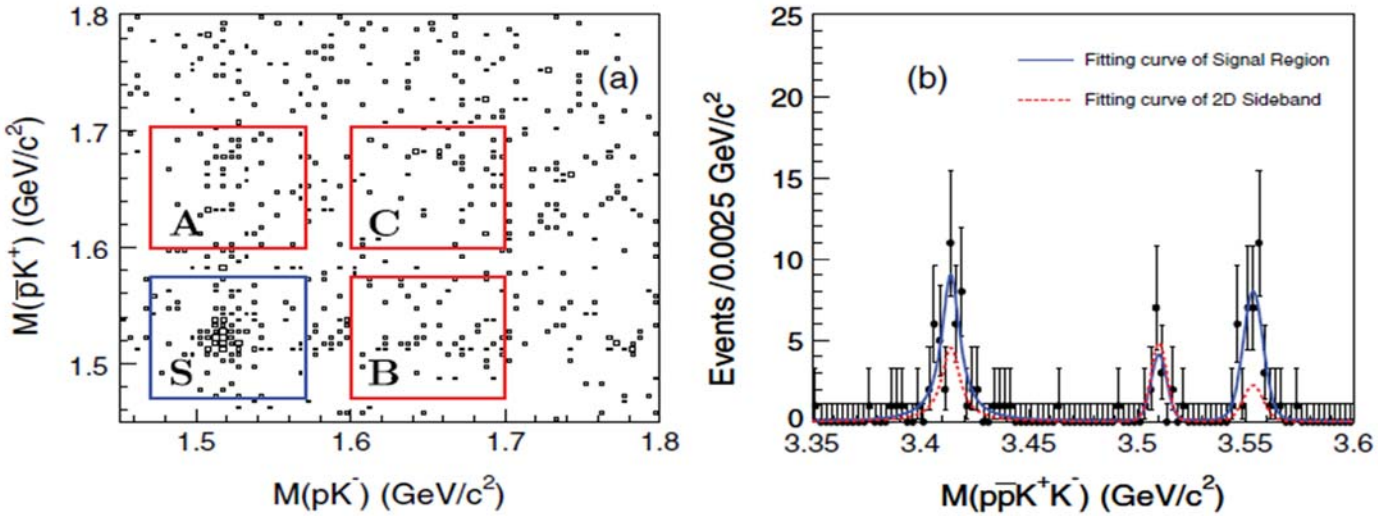


TABLE VII. Summary of branching fractions for 12 χ_{cJ} decay modes to $p\bar{p}K^+K^-$. The first errors are statistical, and the second ones are systematic. The upper limits are at the 90% C.L. including the systematic errors.

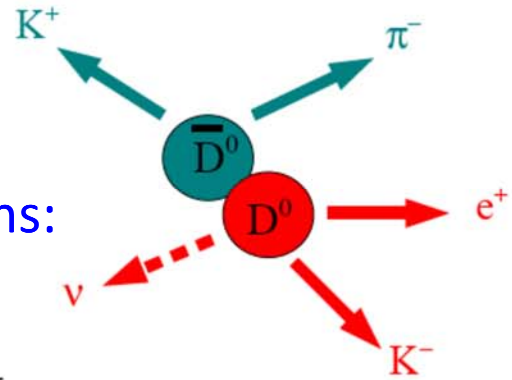
	χ_{c0}	χ_{c1}	χ_{c2}
$\mathcal{B}(\chi_{cJ} \to p\bar{p}K^+K^-)$ (10^{-4})	$1.24 \pm 0.20 \pm 0.18$	$1.35 \pm 0.15 \pm 0.19$	$2.08 \pm 0.19 \pm 0.30$
$\mathcal{B}(\chi_{cJ} \to \bar{p}K^+\Lambda(1520) + \text{c.c.})$ (10^{-4})	$3.00 \pm 0.58 \pm 0.50$	$1.81 \pm 0.38 \pm 0.28$	$3.06 \pm 0.50 \pm 0.54$
$\mathcal{B}(\chi_{cJ} \to \Lambda(1520)\bar{\Lambda}(1520))$ (10^{-4})	$3.18 \pm 1.11 \pm 0.53$	<1.00	$5.05 \pm 1.29 \pm 0.93$
$\mathcal{B}(\chi_{cJ} \to p\bar{p}\phi)$ (10^{-5})	$6.12 \pm 1.18 \pm 0.86$	<1.82	$3.04 \pm 0.85 \pm 0.43$

First measurement

D analyses currently in progress

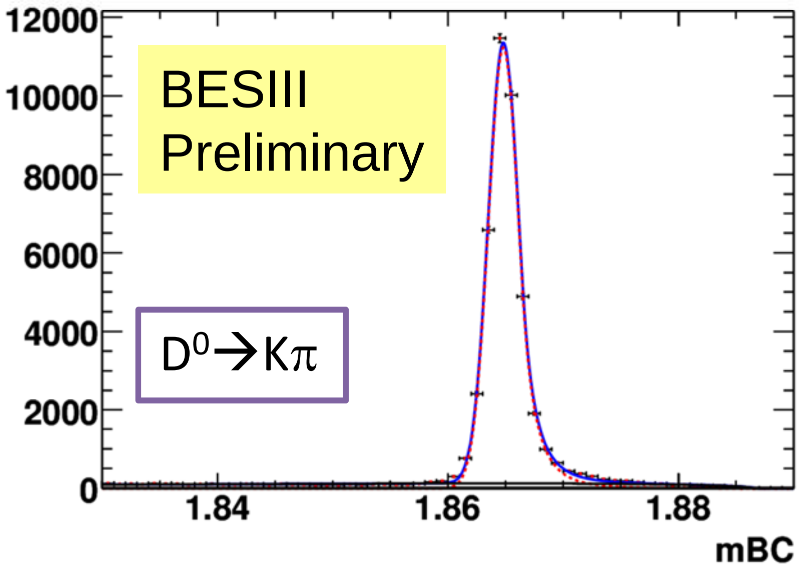
- D and Ds tagging
- $D^+ \rightarrow \mu^+ \nu$
- $D^0 \rightarrow K^- / \pi^- e^+ \nu$
- Search for $D^0 \rightarrow \gamma\gamma$

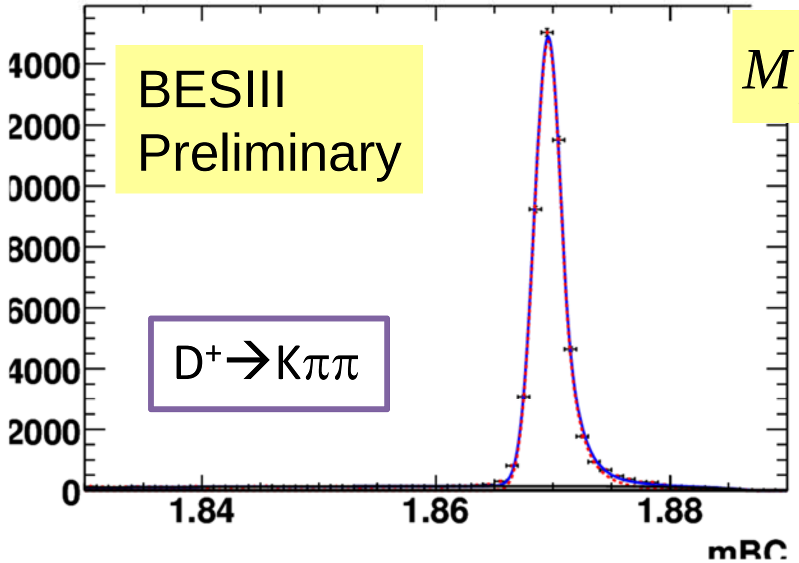
Open charm with BESIII – Stay tuned !



Use ψ(3770) →DD_{bar} to produce two quantum correlated D mesons:

@ψ(3770) with 420pb^{-1} first clean single tagging sample:

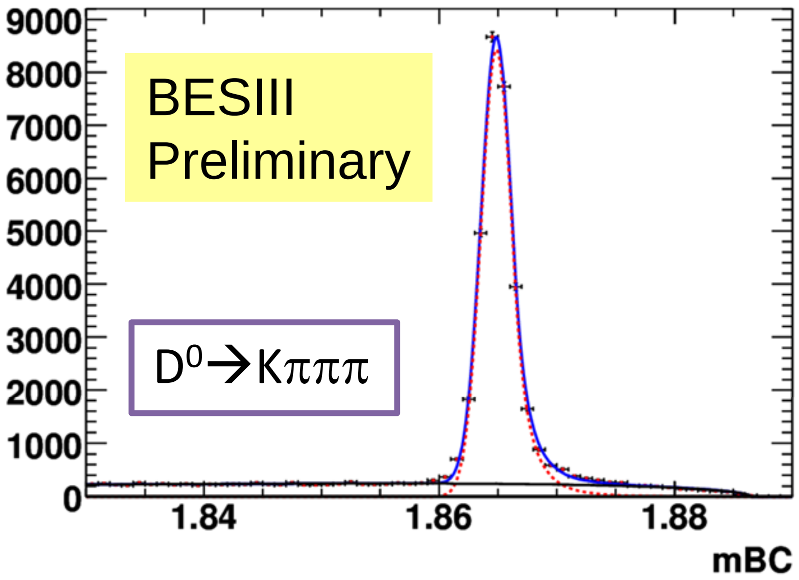


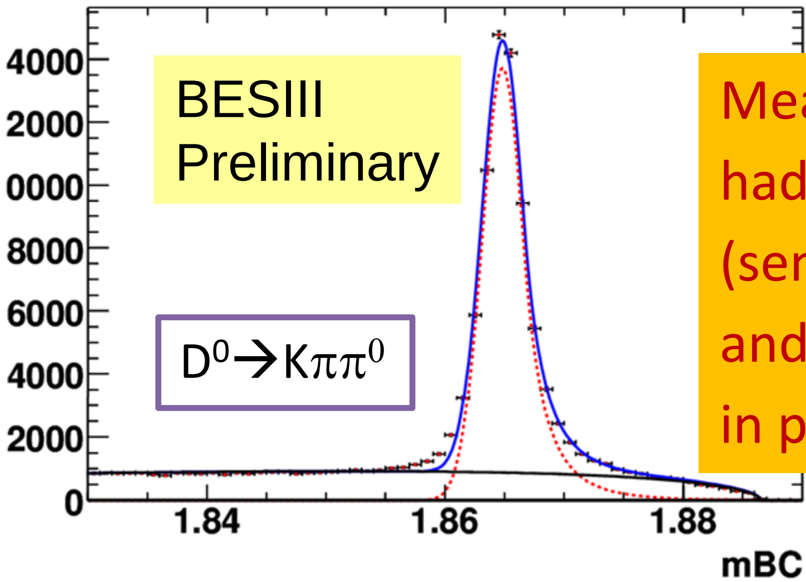


$$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$$

Resolution:
1.3 MeV
for pure charged modes;

1.9 MeV for modes with one π^0.

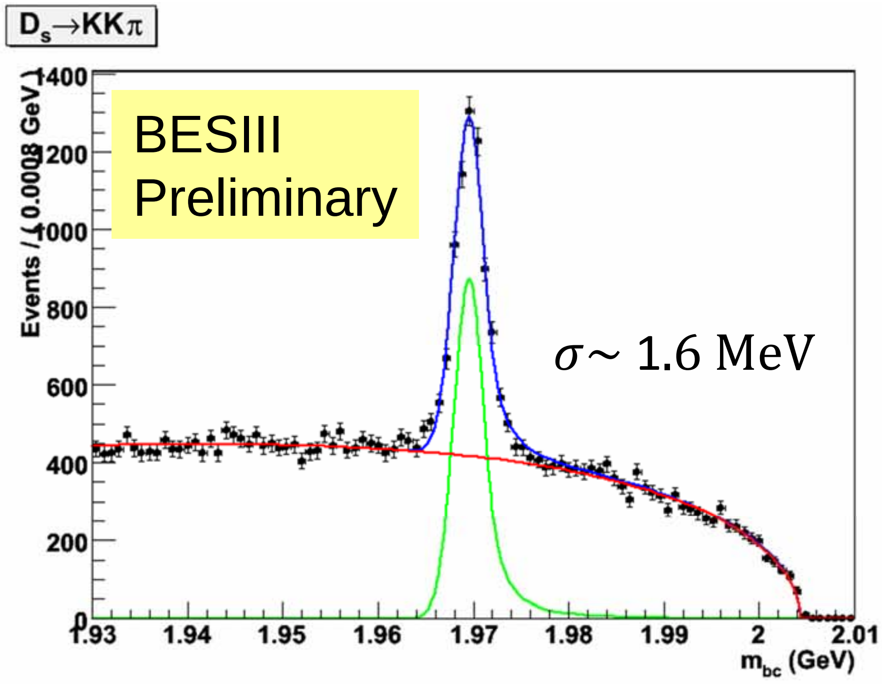


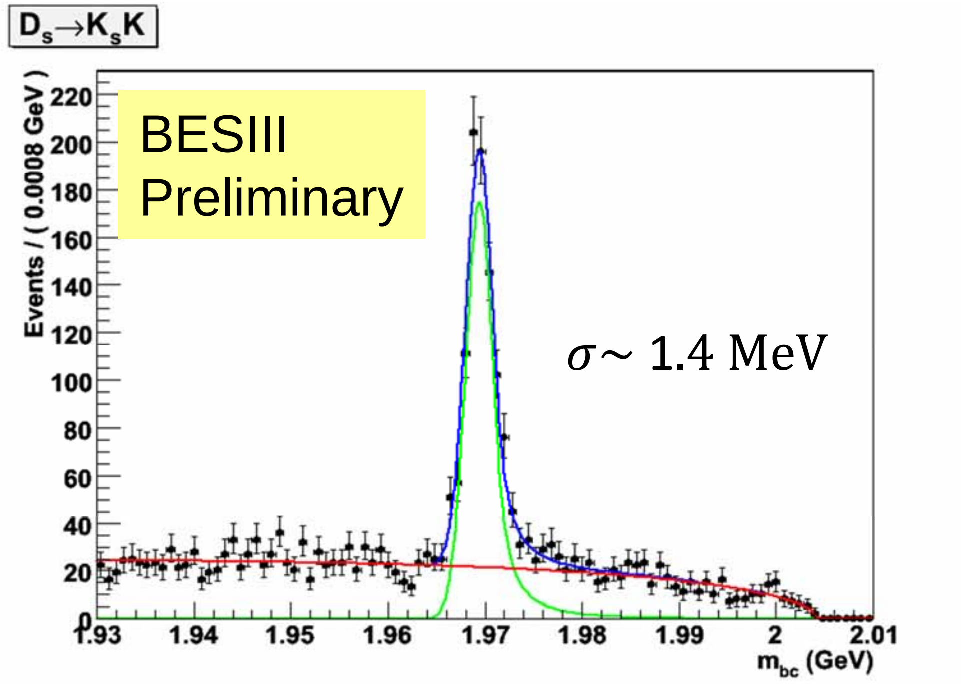


Measurements of hadronic decays, (semi)leptonic decays, and Strong phase in progress

m_{BC} of D_s Single Tags

(part of data @ 4010 MeV)





f_{Ds} (both μ and τ modes) measurement underway

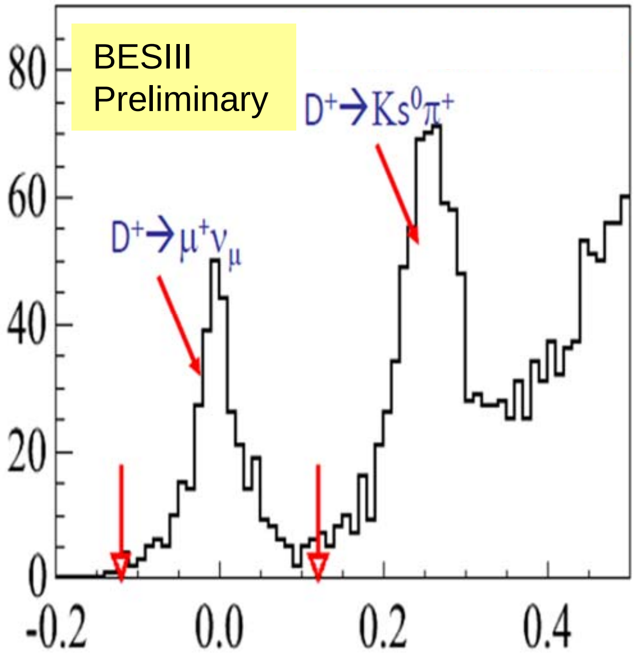
Note: this data is at 4010 MeV: ~0.3 nb of $D_S^+ D_S^-$

We plan to run at 4170 MeV: ~0.9 nb of $D_S^{*+} D_S^-$

pro: higher cross-section; **con**: need D_S^* transition photon ($D_S^{*+} \to \gamma D_S^+$)

D analyses currently in progress

1. $D^+ \to \mu^+ \nu$ Measurement

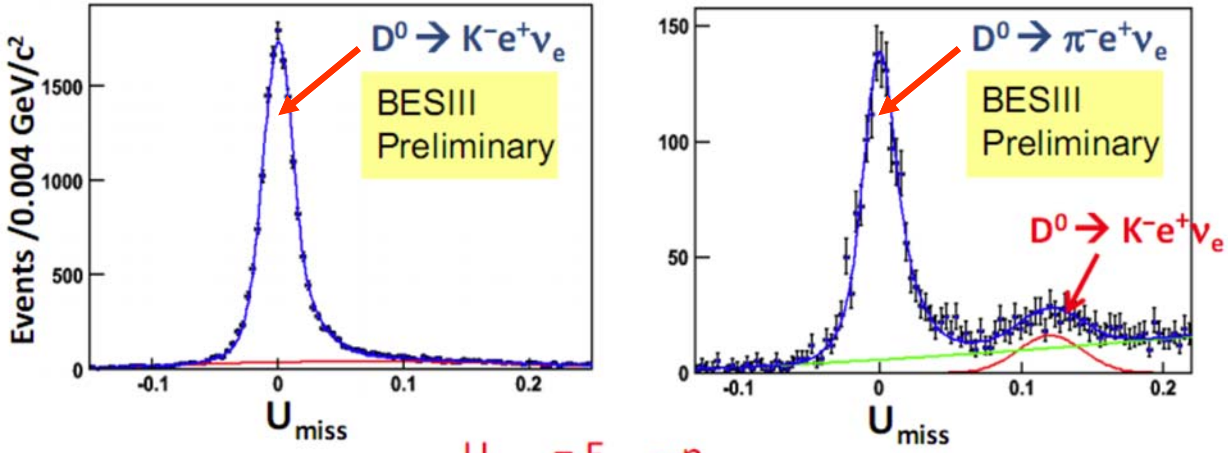


$M^2_{miss} = E^2_{miss} - p^2_{miss}$ (part of data)

2. $D^0 \to K^- / \pi^- e^+ \nu$ Measurement

Clean separation of signal from background

Candidate events for $D^0 \to K^- e^+ \nu_e$, $\pi^- e^+ \nu_e$



$U_{miss} = E_{miss} - p_{miss}$.

(part of data)

3. Search for $D^0 \to \gamma\gamma$: the sensitivity will be 10^{-6}

Target for CHARM2012 as preliminary results

Summary

- BESIII is successfully operating since 2008:
  - World largest data samples at J/ψ, ψ', $\psi(3770)$, $\psi(4040)$ already collected, more data in future ($D_S^{*+}D_S^-$ at 4170 MeV coming soon).
- Light quark states:
  - confirmation the enhancement at $p\bar{p}$ threshold in $J/\psi\to\gamma p\bar{p}$, $J^{PC}=0^{-+}$.
  - confirmation X(1835) with two new structures in $J/\psi\to\gamma\pi\pi\eta'$.
  - observation a new structure X(1870) in $J/\psi\to\omega\pi\pi\eta$.
  - First observation: $\eta(1405)\to f_0(980)\pi^0$ (isospin breaking).
- Charmonium transitions:
  - Precision measurements of h_c and $\eta_c(1S)$ properties.
  - first observation of $\eta_c(2S)$ in $\psi'\to\gamma\eta_c(2S)$ decay.
  - First evidence of $\psi'\to\gamma\gamma J/\psi$.
- Charmonium decays:
  - First measurement of $\psi'\to\gamma\eta$ and $\gamma\pi^0$, $\chi_{cJ}\to\omega\phi$, $\omega\omega$, $\phi\phi$, $\gamma\phi$ and $p\bar{p}K^+K^-$.
- Charm decays:
  - precision open-charm D physics to come soon.
- **Expect many more results from BESIII in the future!**

谢谢！