Highlights from BESIII

Shuangshi Fang

(for the BESIII Collaboration)

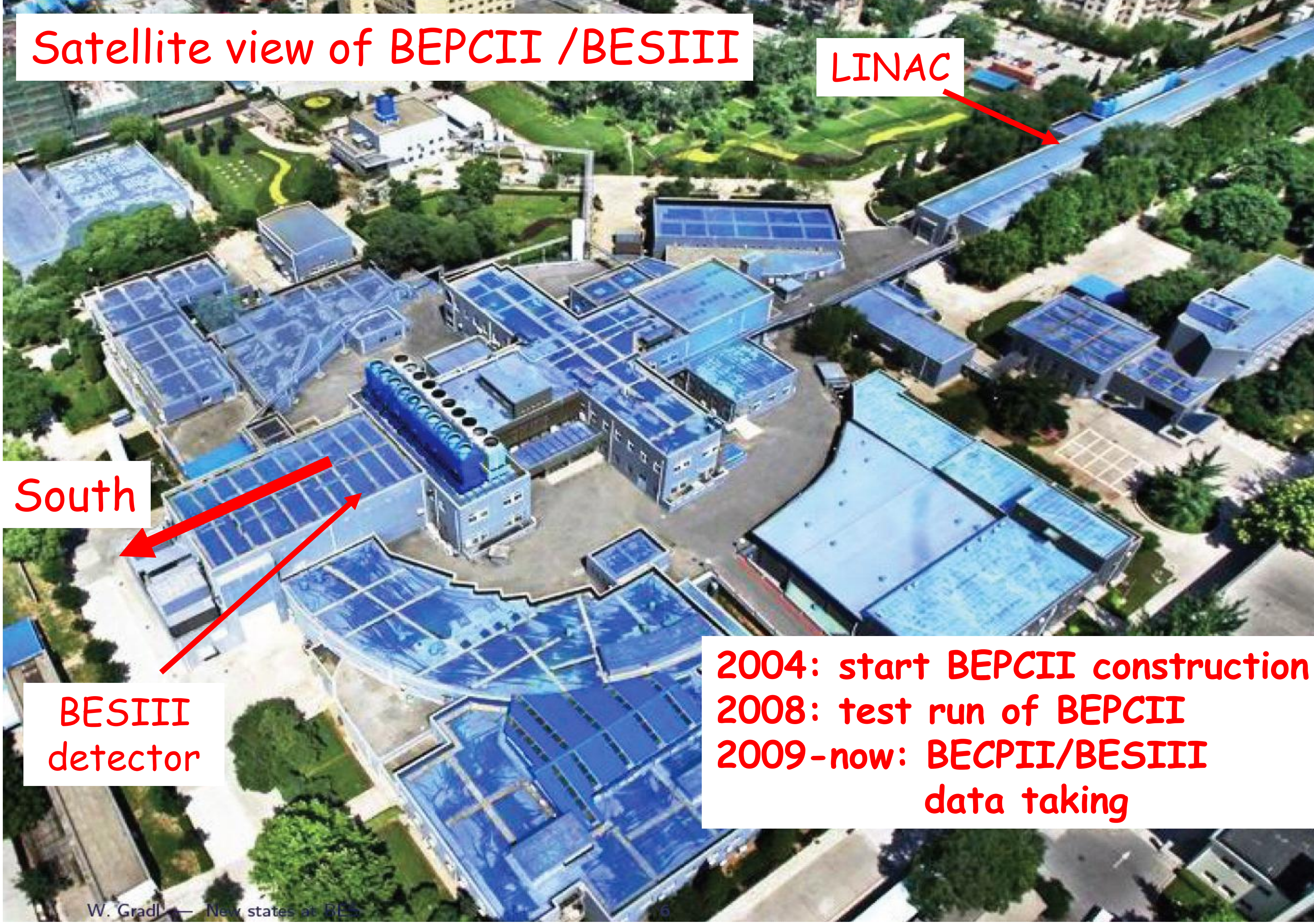
Institute of High Energy Physics

The 7th International Chiral Dynamics Workshop,

August 6-10, 2012, Jefferson Lab, USA

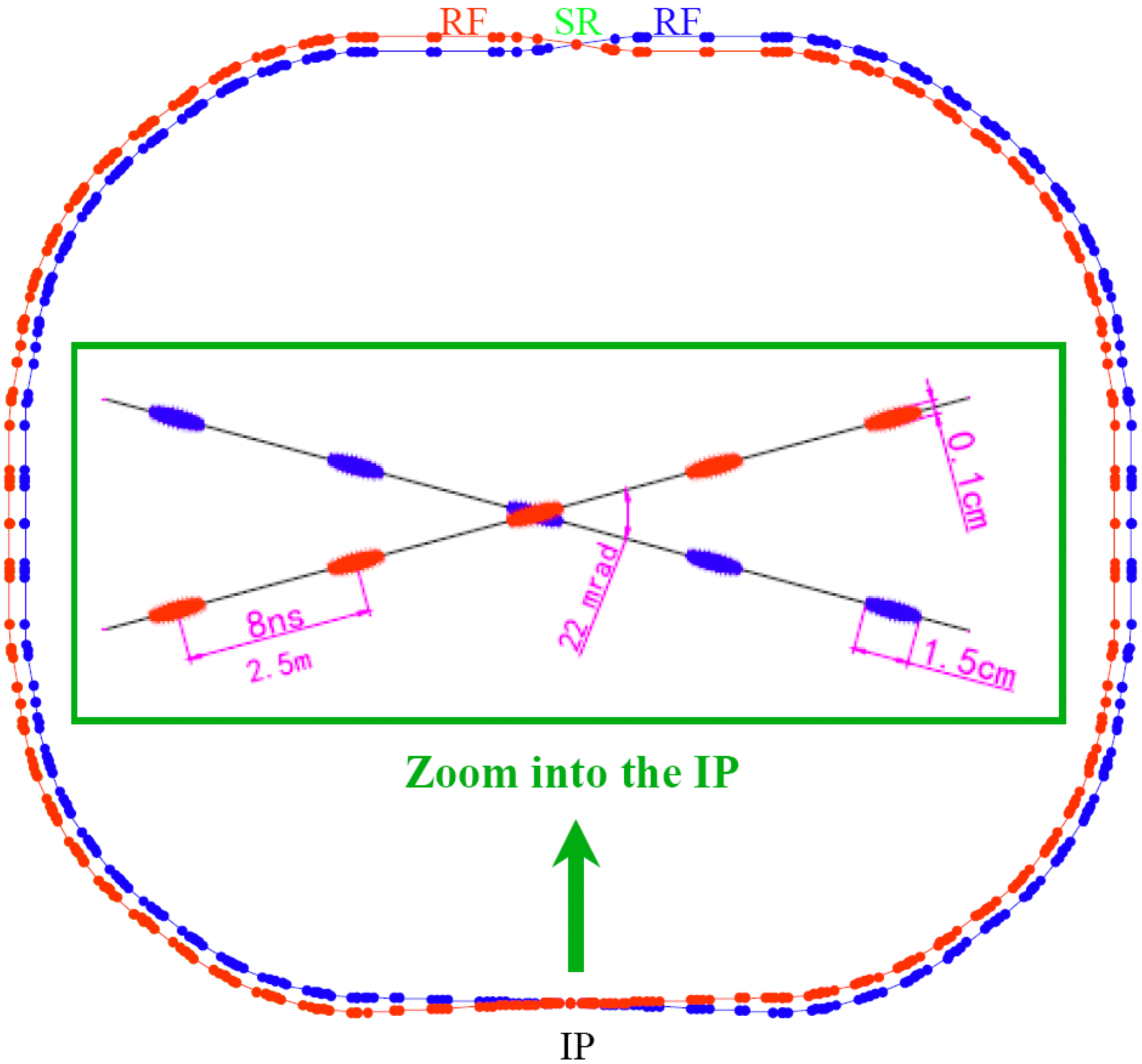
Outline

- Status of BEPCII/BESIII
- Charmonium transitions
- Charmonium decays
- Light hadron spectroscopy
- Charm physics
- Summary



Satellite view of BEPCII /BESIII
LINAC
South
BESIII detector
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

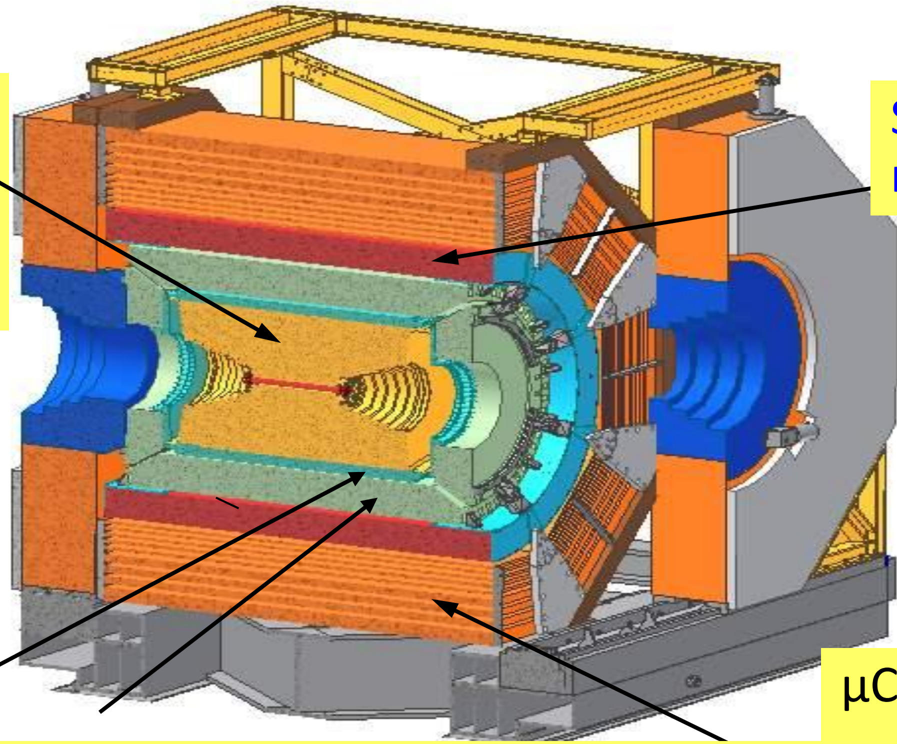
BEPCII storage rings



Beam energy:
1.0-2.3 GeV
Design Luminosity:
$1 \times 10^{33}\ cm^{-2}s^{-1}$
Optimum energy:
1.89 GeV
Energy spread:
5.16×10^{-4}
No. of bunches:
93
Bunch length:
1.5 cm
Total current:
0.91 A
Circumference：
237m

NIM A614, 345 (2010)

The BESIII Detector



- Comparable capabilities to CLEO-c, plus muon ID
- The big advantage: BEPCII is a double-ring machine designed for charm
  - Design (achieved) luminosity at $\psi(3770)$: 1 (0.65) x 10^{33}

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 (12)
Germany: Univ. [illegible]um,
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.

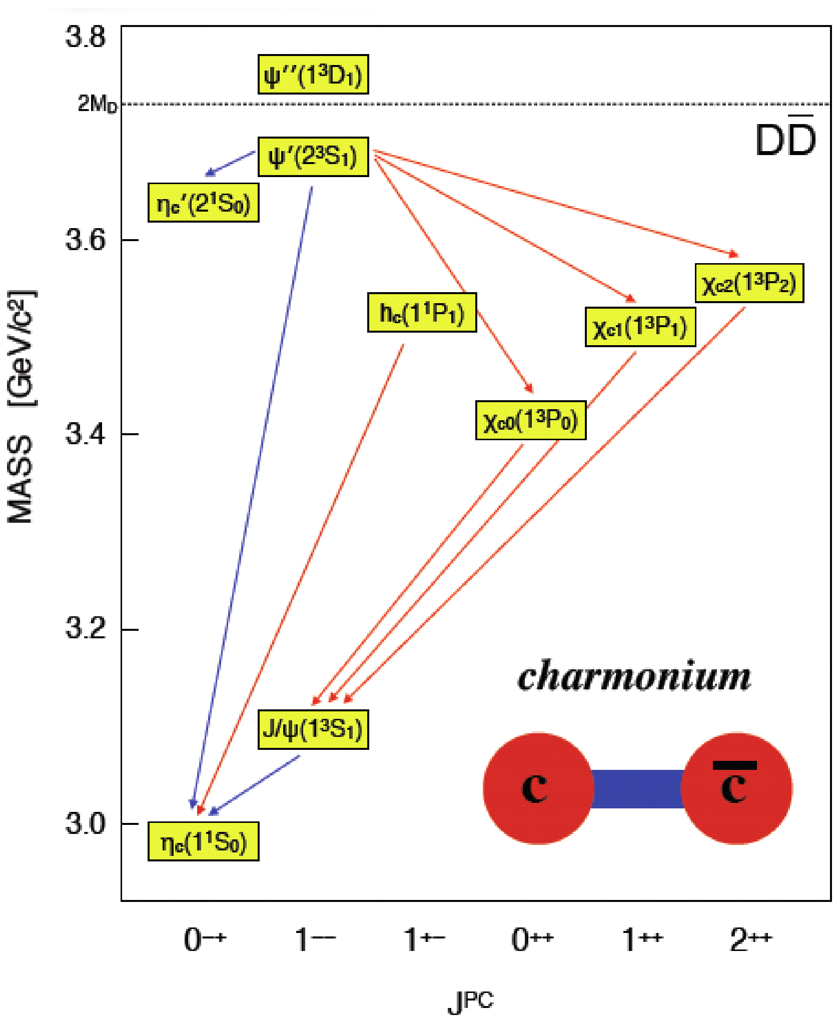
Japan (1)
Tokyo Univ.

Pakistan (2)
Univ. of Pu

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
52 institutes from 11 countries

BESIII - physics using "charm"



Charmonium physics:
- Spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

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.

BESIII data set and future plans

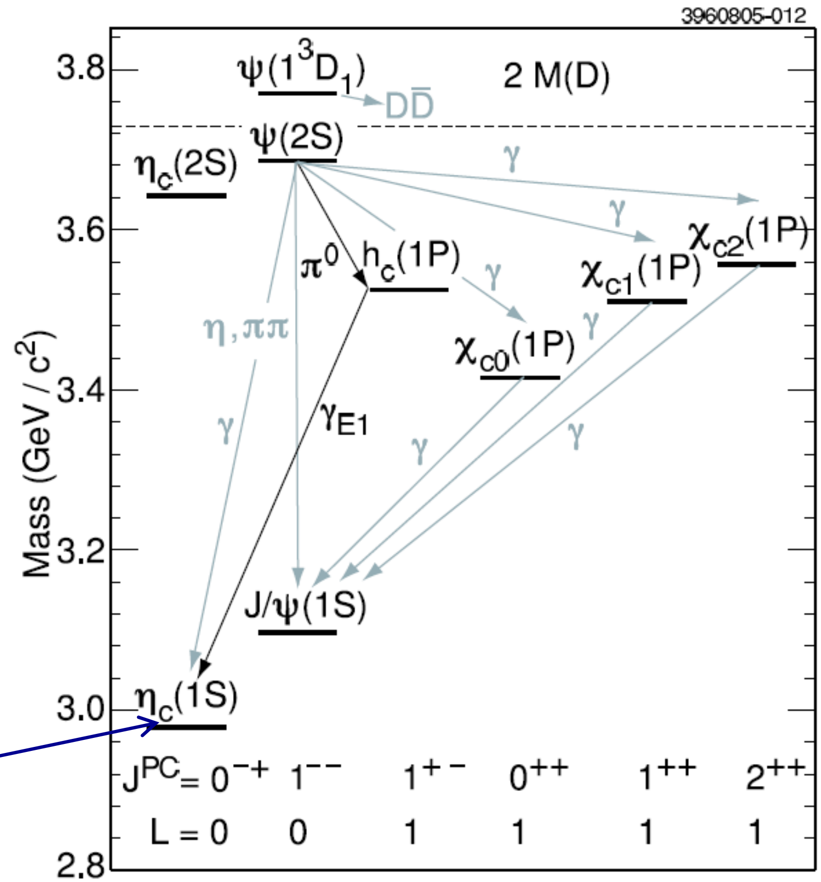
- July 19, 2008: first e^+e^- collision event in BESIII
- Nov. 2008: ~ 14M $\psi(2S)$ events for detector calibration
- 2009: **106M $\psi(2S)$ 4×CLEOc**
  225M J/ψ 4×BESII
- 2010: 900 pb^{-1} $\psi(3770)$
- 2011: 2000 pb^{-1} $\psi(3770)$ } **3.5×CLEOc** (2010 + 2011)
  470 pb^{-1} @ 4.01 GeV
- 2012: tau mass measurement
  $\psi(2S)$: 0.4 billion; J/ψ: 1 billion

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

Tentative future running plans:

2013 E_{CM}=4260 and 4360 MeV for "XYZ" studies (0.5 fb^{-1} each)
2014 E_{CM}=4170 MeV for Ds (~2.4 fb-1)
TBD Additional $\psi(3770)$ data

Below Threshold Charmonium



Properties not well known

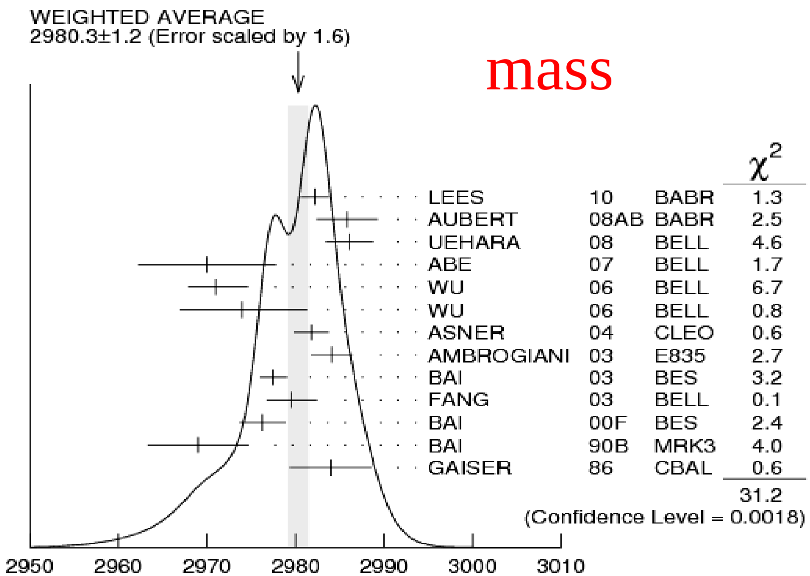
Problems with mass measurements

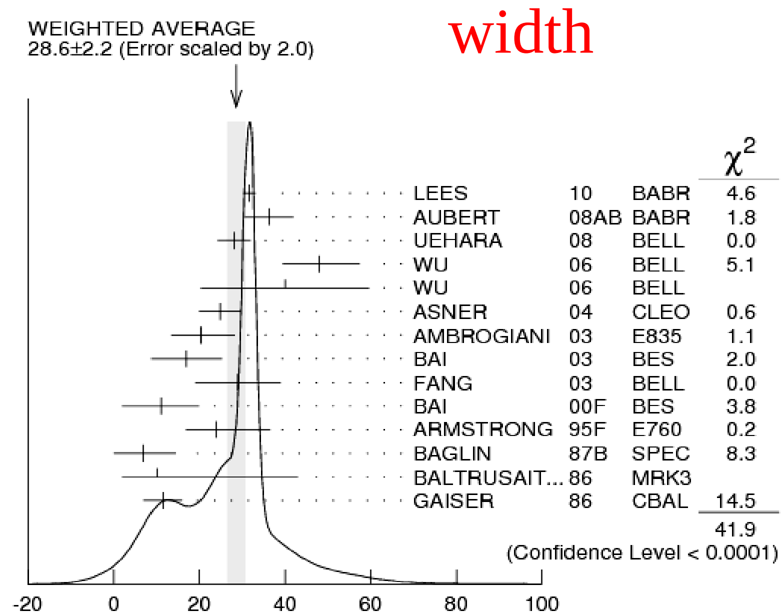
Mass and width of $\eta_c(1S)$

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

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

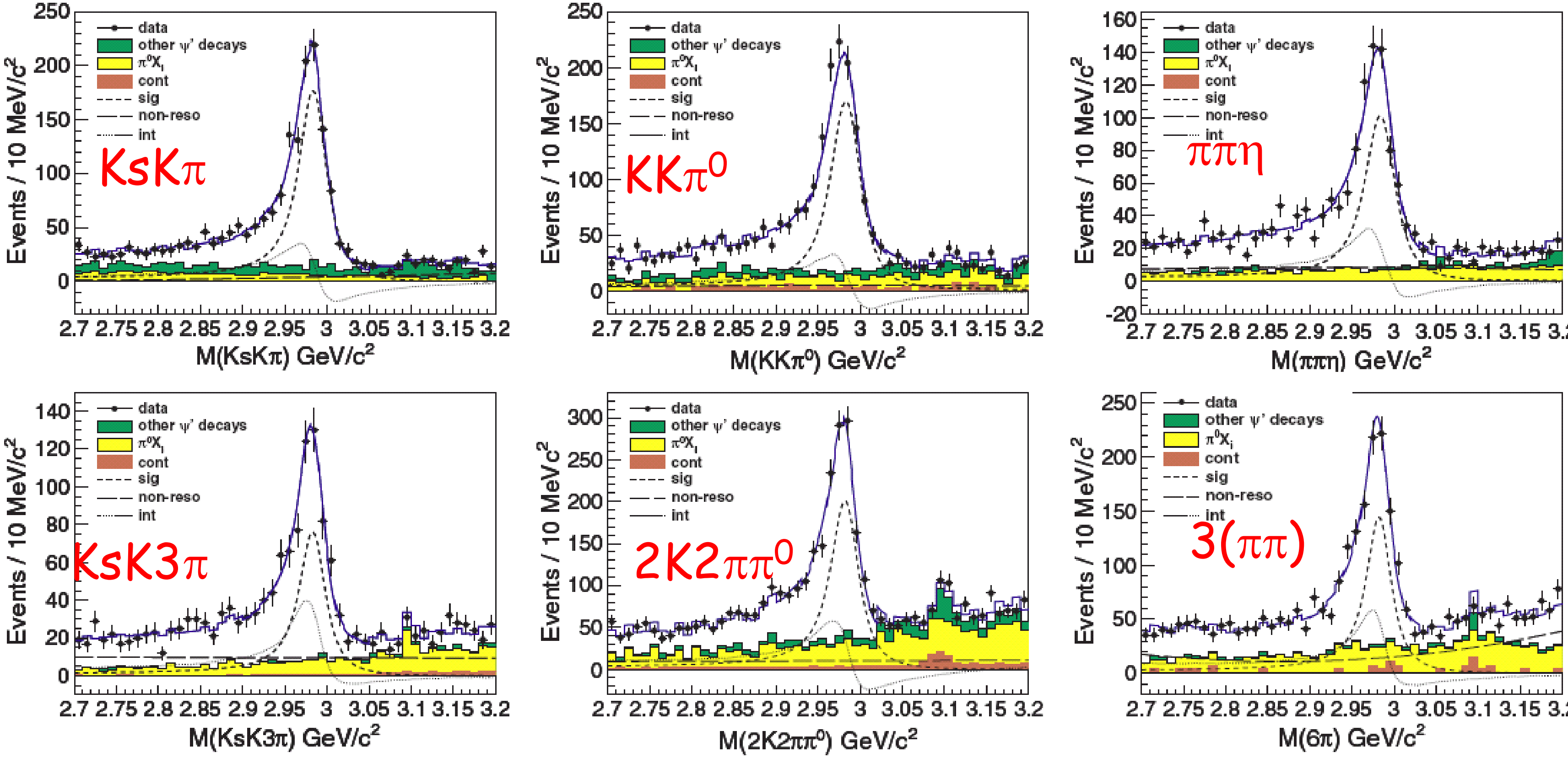
  $\gamma\gamma$ process: $M = 2983.1 \pm 1.0\ MeV/c^2$, $\Gamma = 31.3 \pm 1.9\ MeV$





- 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 $M(\eta_c)$

η_c resonance parameters from $\psi'\to\gamma\eta_c$



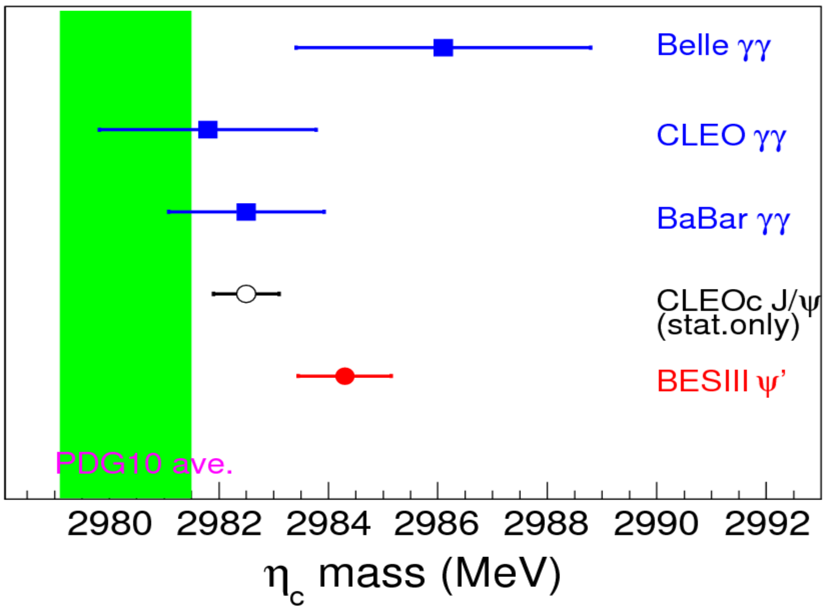
The interference between η_c and non-η_c decays:

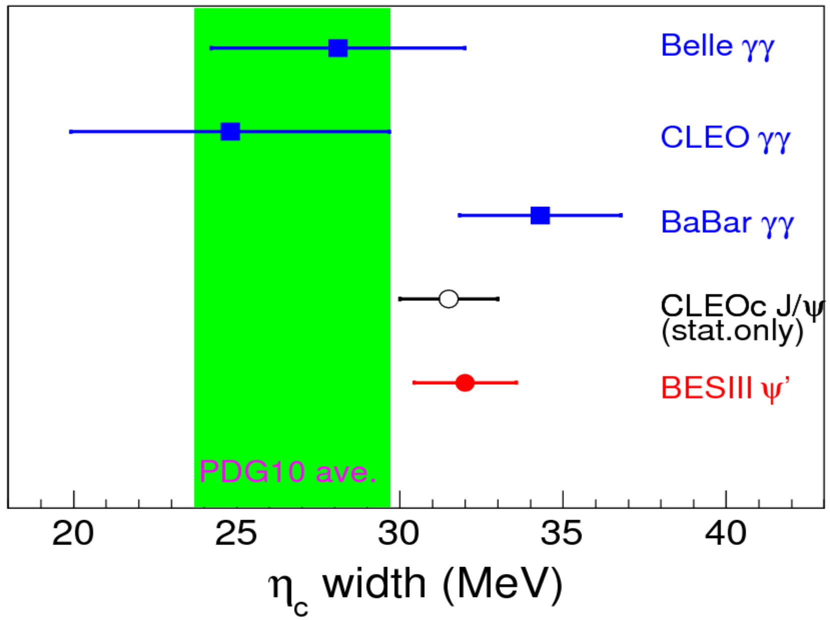
mass: $2984.3\pm0.6_{stat}\pm0.6_{sys}$ MeV/c^2
width: $32.0\pm1.2_{stat}\pm1.0_{sys}$ MeV
ϕ: $2.40\pm0.07_{stat}\pm0.08_{sys}$ rad (constructive)
or $4.19\pm0.03_{stat}\pm0.09_{sys}$ rad (desconstruct)

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

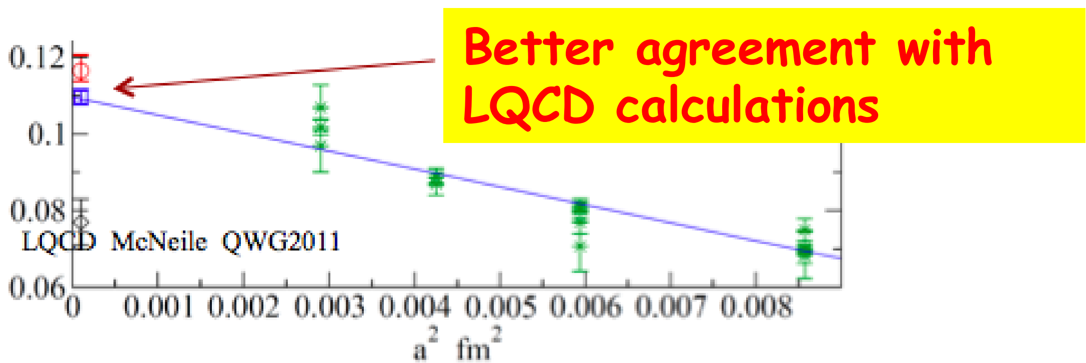
Phys.Rev.Lett. 108 (2012) 222002

Comparison of the mass and width for η_c





Hyperfine splitting: $\Delta M(1S) = 112.5 \pm 0.8$ MeV (earlyer results: ~117MeV)



Property of h_c (1p1)

PRL104, 132002 (2010)

Study isospin forbidden transition

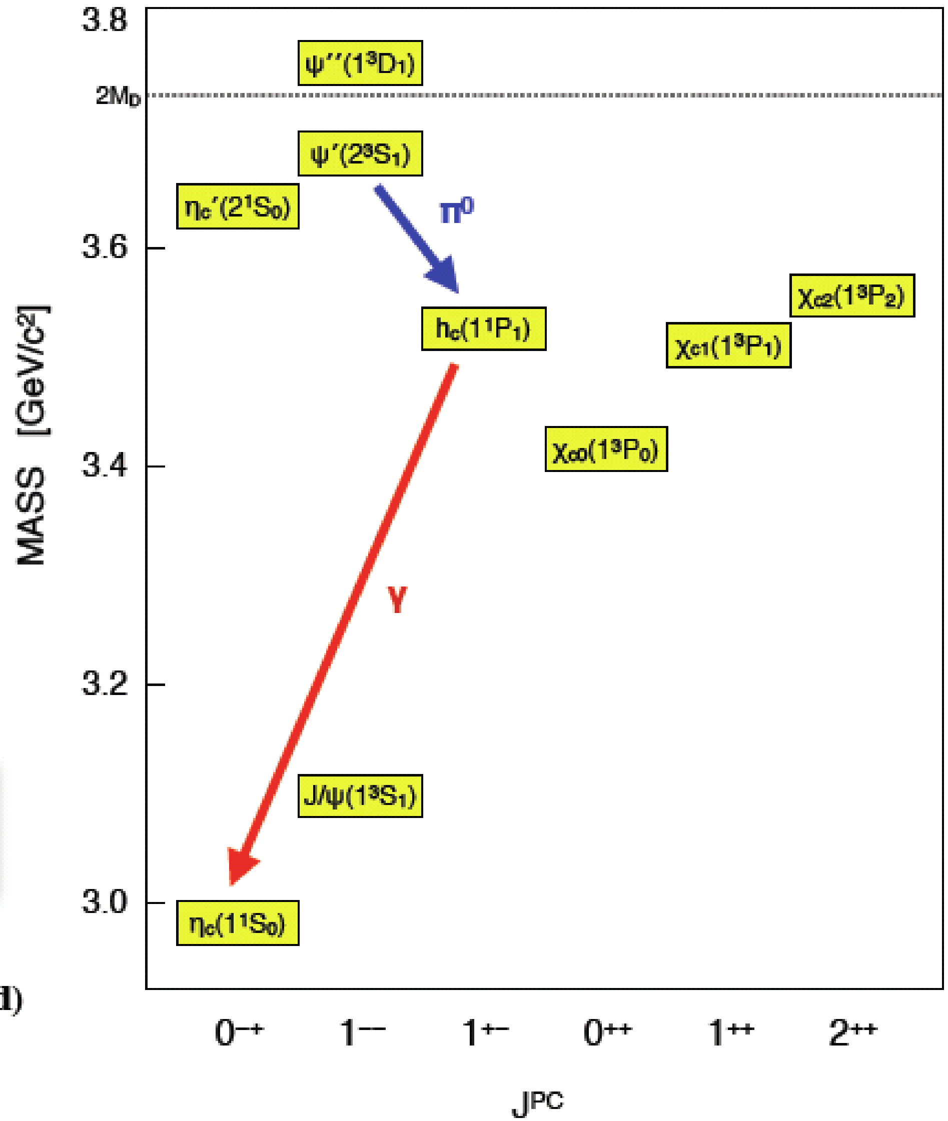
$$B(\Psi' \to \pi^\circ h_c)$$

Measure as well the E1 transition

$$B(h_c \to \gamma \eta_c)$$

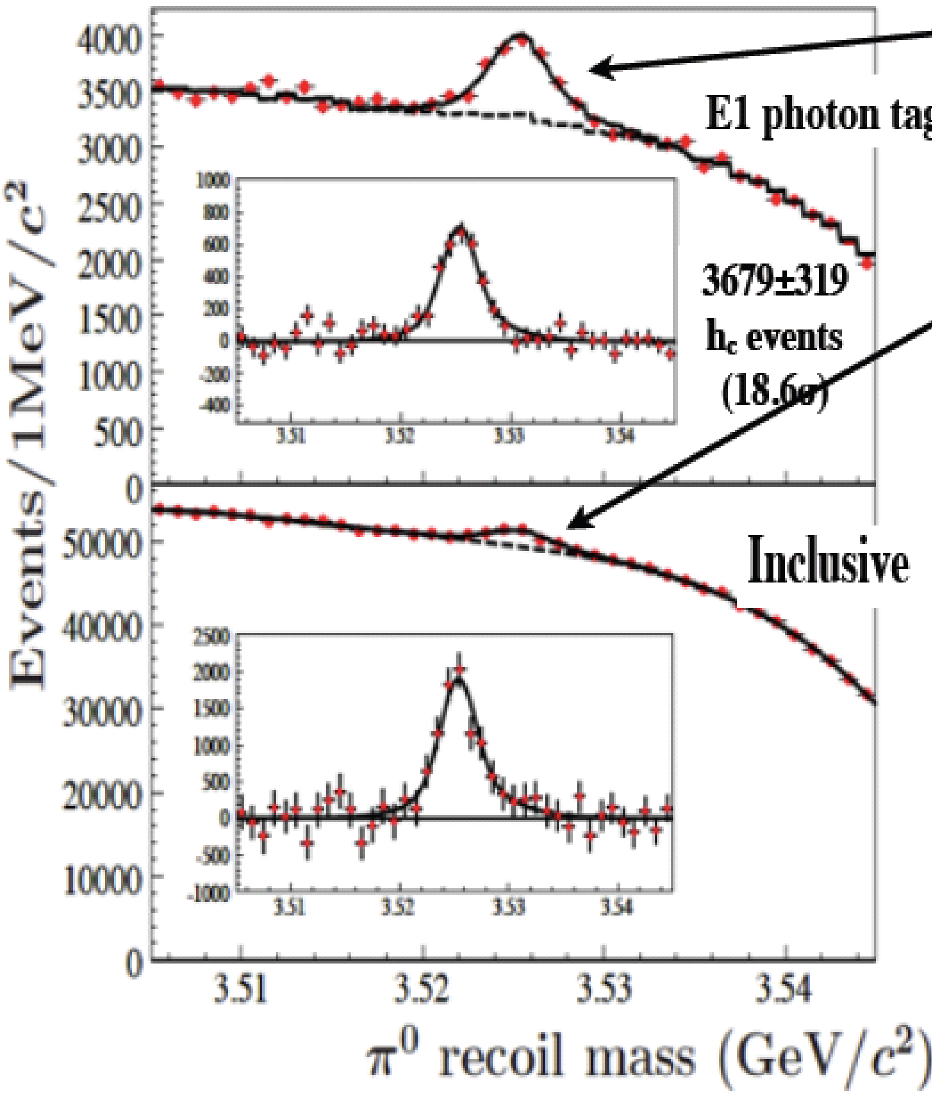
Hyperfine splitting of the 1P states (spin-spin interaction term):

M(h$_c$(1P)) – <M(χ_{cJ}(1P))>$_{\text{(spin-weighted)}}$



Observation of h_c in inclusive reaction

PRL104, 132002 (2010)



Tag the E1 photon, yields:

$\psi(2S) \to \pi^0 h_c) \times B(h_c \to \gamma\eta_c)$

$= (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$

(consistent with CLEO-c)

Inclusive analysis provides:

$B(\psi(2S) \to \pi^0 h_c)$ (first measurement)

$= (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

Combining the two results:

$B(h_c \to \gamma\eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$

(first measurement)

Natural width of h_c:

$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28\,\mathrm{MeV}/c^2$

(first measurement)

Hyperfine splitting:

$\Delta M_{hf} = -0.10 \pm 0.13 \pm 0.18\,\mathrm{MeV}/c^2$

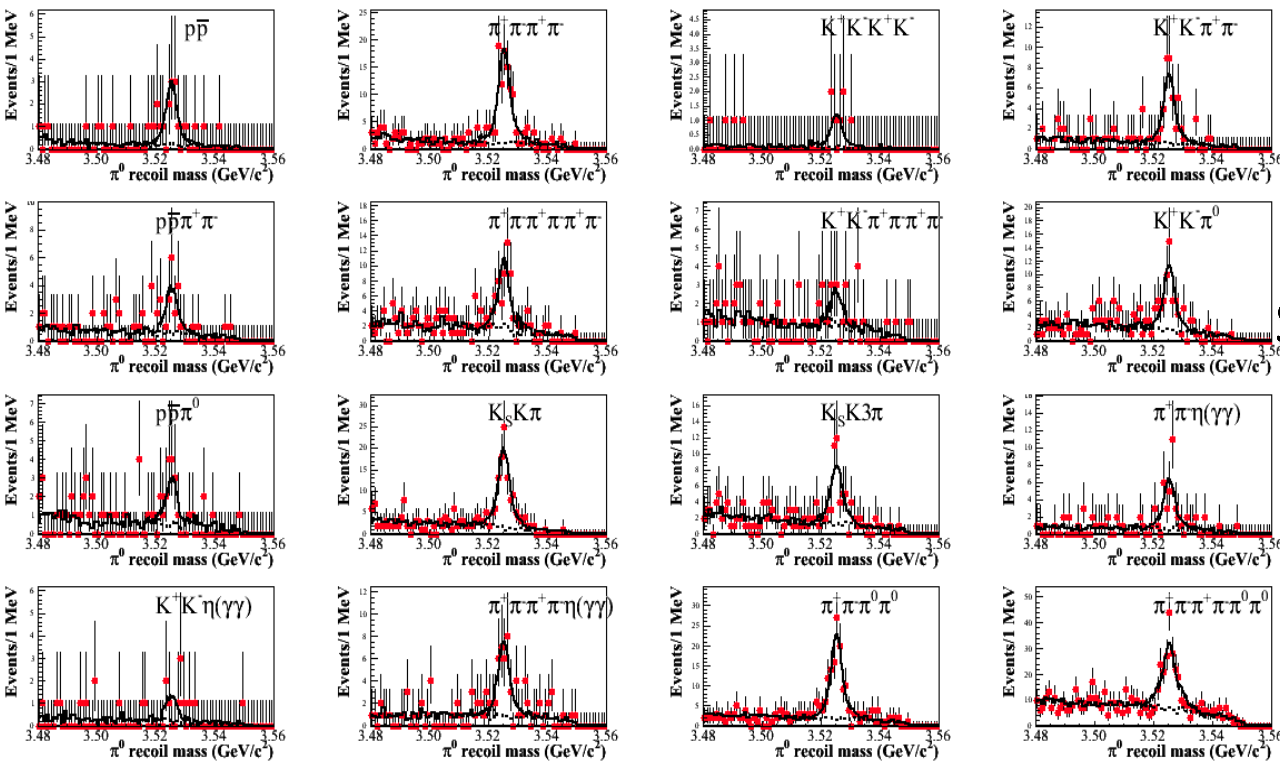
(consistent with zero)

$M(h_c) = 3525.40 \pm 0.13 \pm 0.18\ \mathrm{MeV}/c^2$

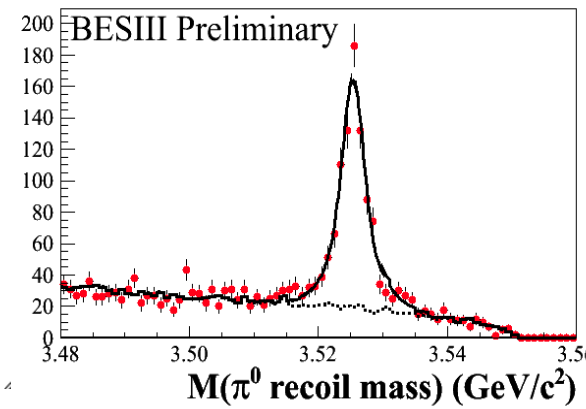
h_c(1P1) in $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$, $\eta_c \to X_i$ (exclusive)

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)

Observation of $\psi' \to \gamma\eta_c(2S)$

- 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

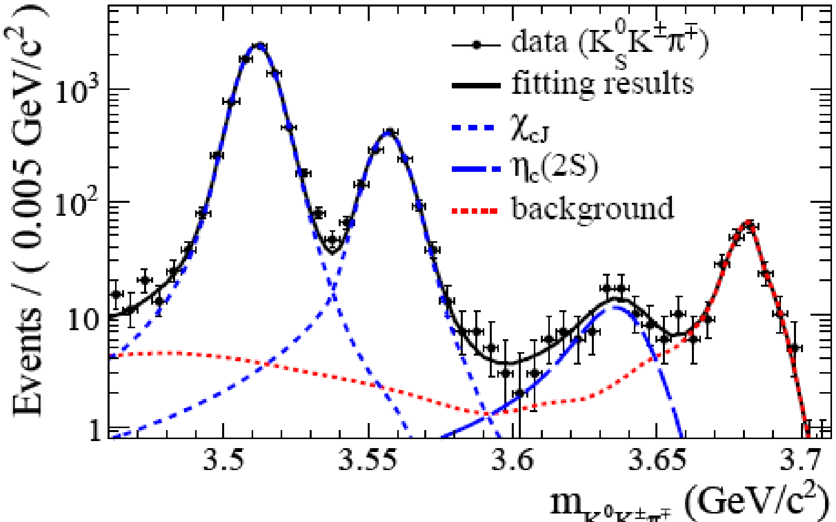
- The M1 transition $\psi' \to \gamma\eta_c(2S)$ has not been observed.

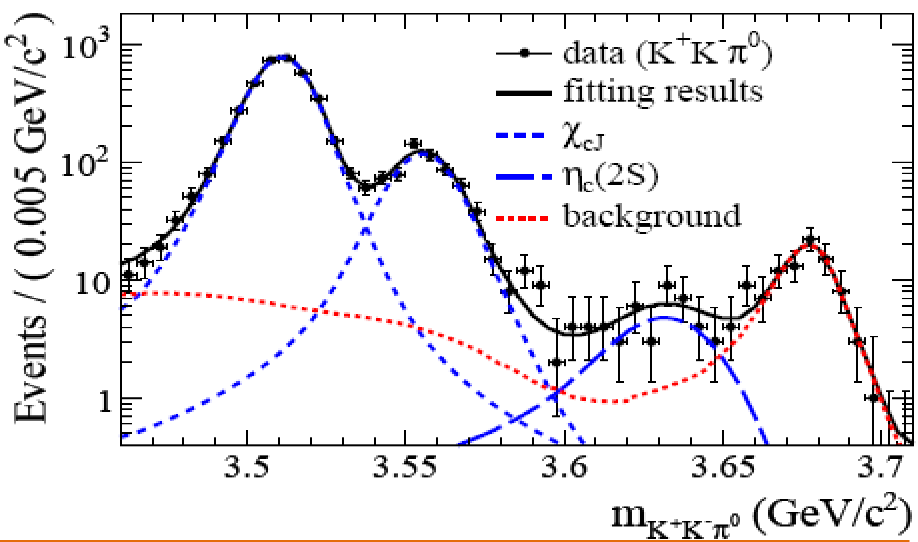
(experimental challenge : search for real photons ~50MeV,)

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

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

Observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S)$, $\eta_c(2S) \to K_s K\pi$, $K^+K^-\pi^0$





Phys. Rev. Lett. 109, 042003 (2012)

With 106M ψ' events:

simultaneous fit results:

$M(\eta_c(2S)) = (3637.6 \pm 2.9 \pm 1.6)$ MeV/c^2
$\Gamma(\eta_c(2S)) = 16.9 \pm 6.4 \pm 4.8$
Statistical significance larger than 10.2σ!

$Br(\psi' \to \gamma\eta_c(2S) \to \gamma K\bar{K}\pi)$
$=(1.30 \pm 0.20_{stat} \pm 0.30_{sys}) \times 10^{-5}$

+

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

$Br(\psi' \to \gamma\eta_c(2S))$
$=(6.8 \pm 1.1_{stat} \pm 4.5_{sys}) \times 10^{-4}$

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

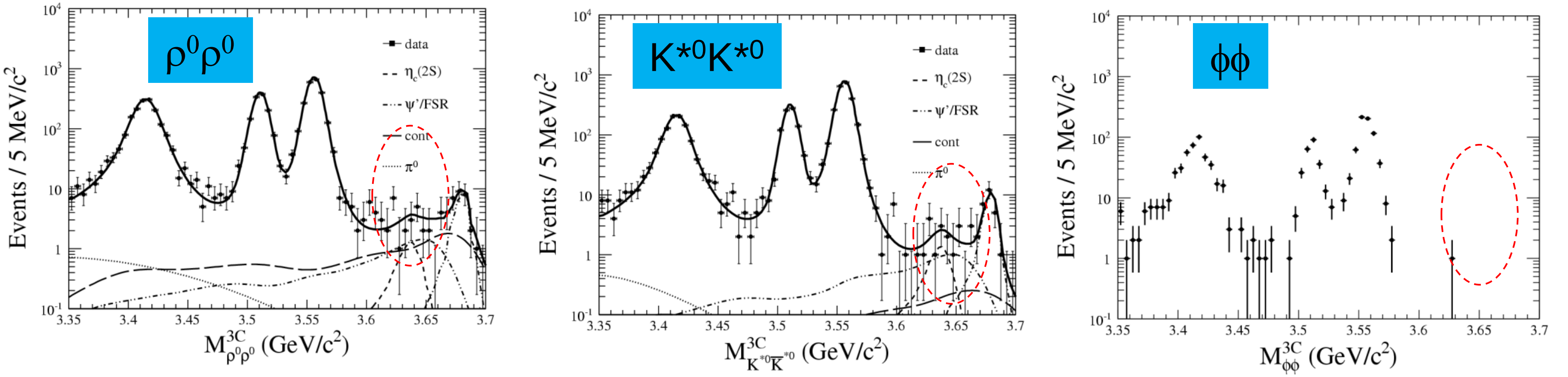
Potential model: $(0.1\text{–}6.2)\times10^{-4}$
PRL89,162002(2002)

PRD84, 091102R (2011)

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

Test for the 'intermediate charmed meson loops':

$\eta_c(2S)\rightarrow VV$ is highly suppressed by the helicity selection rule.
'intermediate charmed meson loops' can increase the production rate of $\eta_c(2S)\rightarrow VV$.
(PRD81, 014017 (2010))



	$Br(\psi'\rightarrow\gamma\eta_c(2S)\rightarrow\gamma VV)$ (10^{-7})	$Br(\eta_c'\rightarrow VV)$ (10^{-3}) (using BESIII BF($\psi'\rightarrow\gamma\eta_c(2S)$))	$Br(\eta_c'\rightarrow VV)$ (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 $\eta_c(2S)\rightarrow$ ρρ, $K^{*0}K^{*0}$, φφ; more stringent UL's are set.

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

- 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))

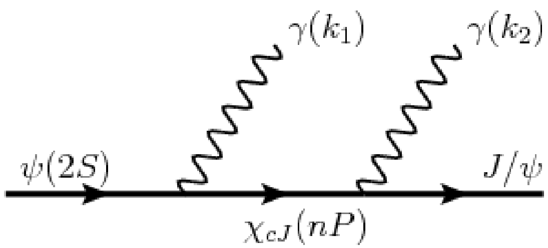
- Observation helpful to understand heavy quarkonium spectrum & strong interaction

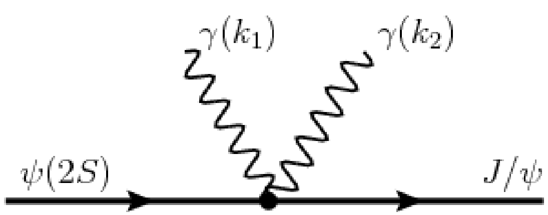
Theoretically:

- 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 an important in the continuous spectra



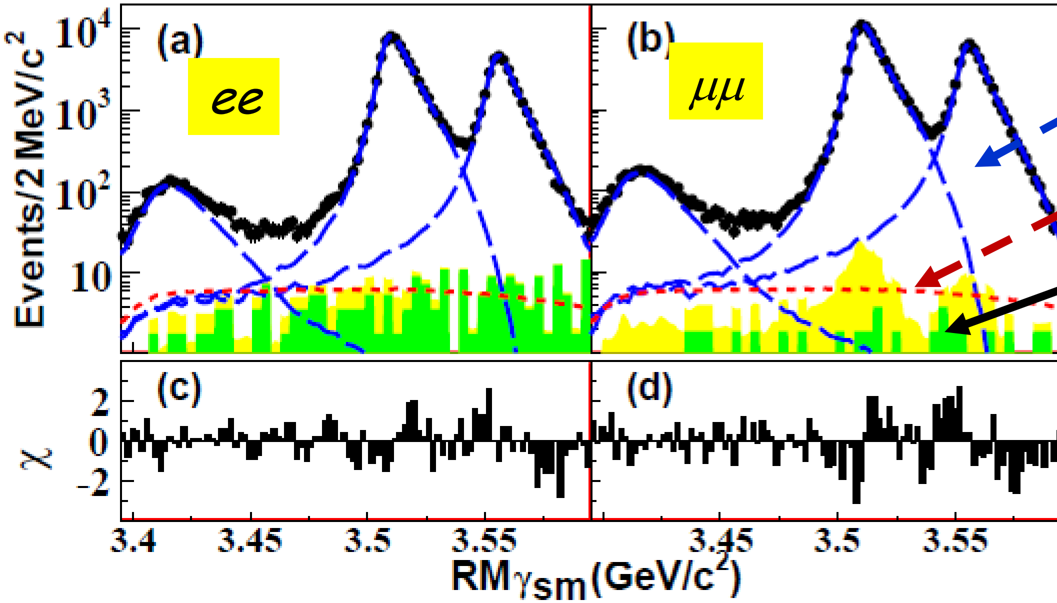


First evidence of $\psi' \to \gamma\gamma J/\psi$

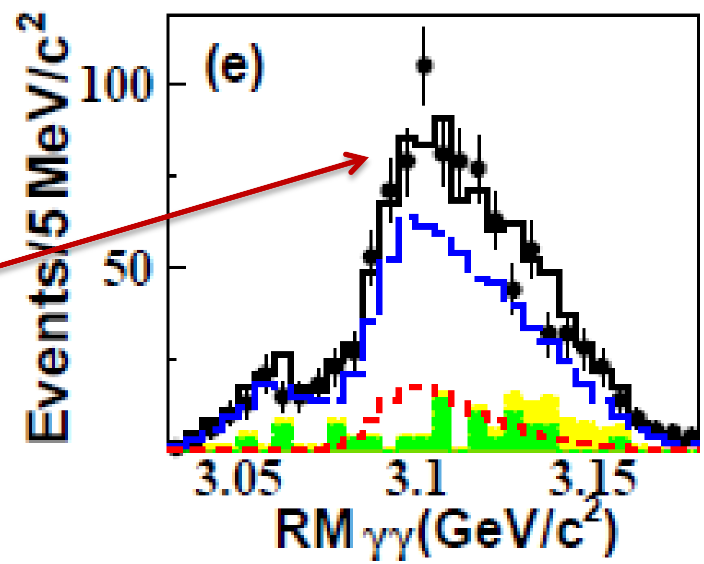
arXiv: 1112.0942 Submit to PRL

- 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(γ_{sm})<3.48GeV

- 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**

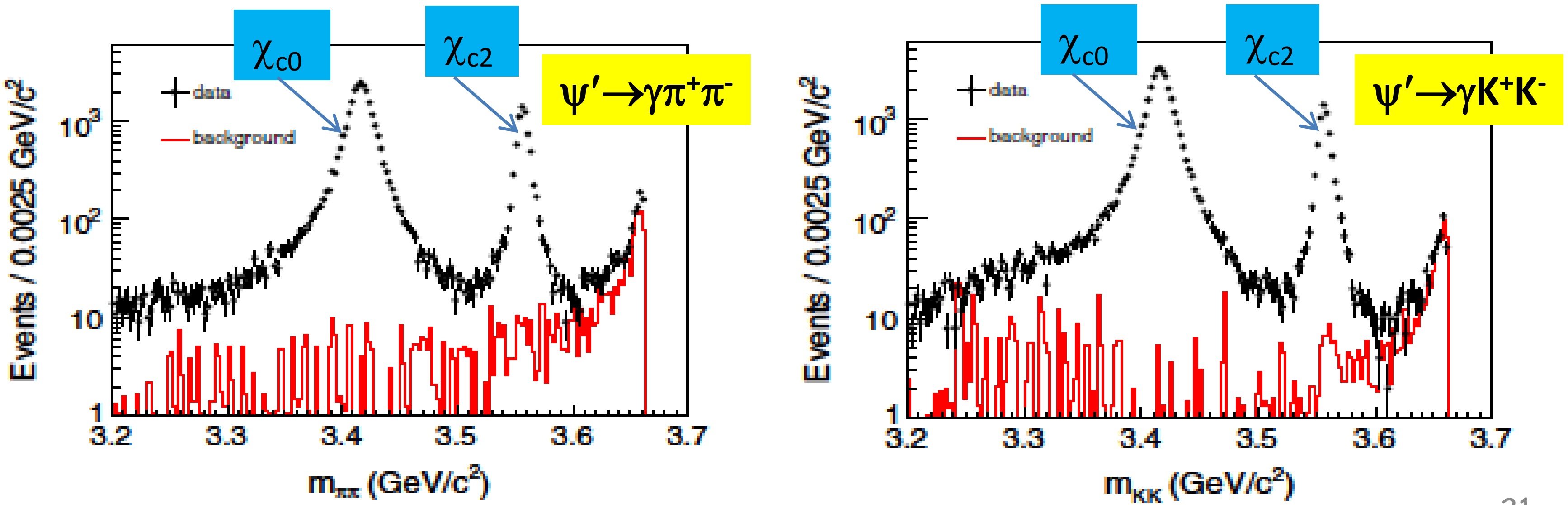
- $Br(\psi' \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi)$ are also measured

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

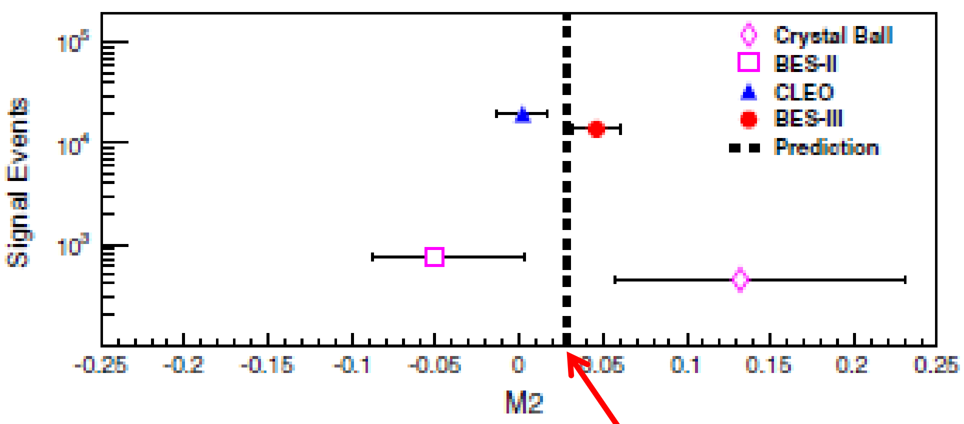
- Extract M2 using fit to full angular distribution

Evidence of M2 contribution:

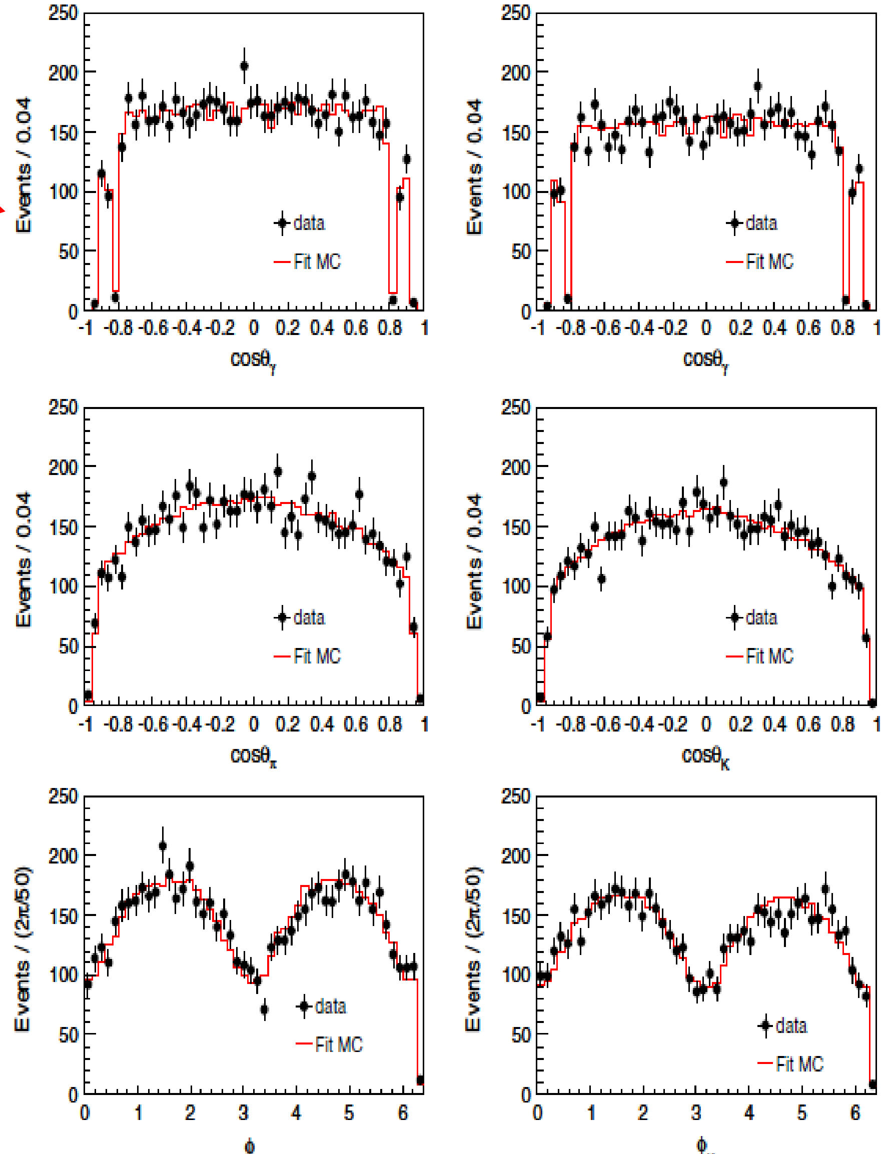
$$M2 = 0.046 \pm 0.010 \pm 0.013,$$
$$E3 = 0.015 \pm 0.008 \pm 0.018,$$

4.4σ

- Significant signal for M2 amplitude that is consistent with κ =0



M(c) = 1.5 GeV and κ = 0

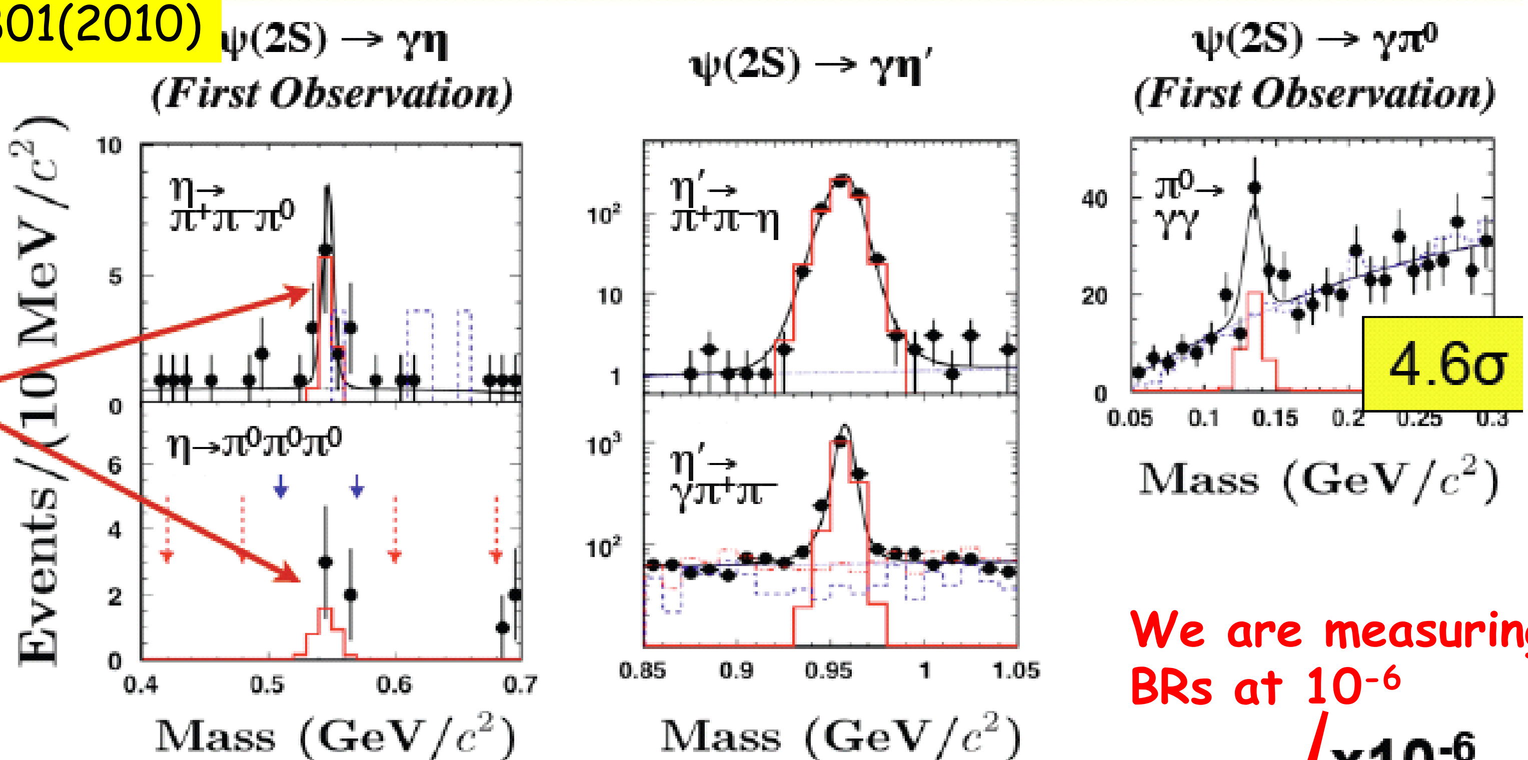


$\chi_{c2} \to \pi^+\pi^-$,

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

Evidence for ψ′ decays into γπ and γη

PRL105, 261801(2010)



strange depletion!

4.3σ

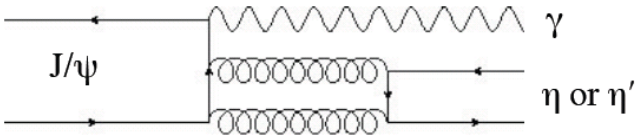
We are measuring BRs at 10^{-6}

$\times 10^{-6}$

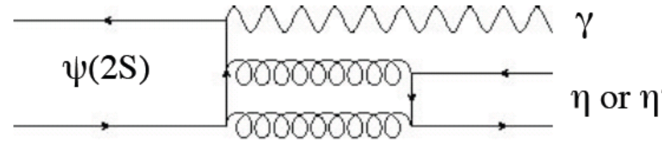
BR $[10^{-6}]$	BESIII	Combined BESIII	PDG10
$\psi' \to \gamma\pi^0$	$1.58 \pm 0.40 \pm 0.13$	$1.58 \pm 0.40 \pm 0.13$	≤ 5
$\psi' \to \gamma\eta(\pi^+\pi^+\pi^0)$	$1.78 \pm 0.72 \pm 0.17$		
$\psi' \to \gamma\eta(\pi^0\pi^0\pi^0)$	$1.07 \pm 0.65 \pm 0.08$	$1.38 \pm 0.48 \pm 0.09$	≤ 2
$\psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\eta)$	$120 \pm 5 \pm 8$		
$\psi' \to \gamma\eta'_{(958)}(\pi^+\pi^+\gamma)$	$129 \pm 3 \pm 8$	$126 \pm 3 \pm 8$	121 ± 8

Some surprises

PRL105, 261801(2010)



VS



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

PRD79, 111101 (2009)

$$R_{J/\Psi} = \frac{B(J/\psi \to \gamma\eta)}{B(J/\psi \to \gamma\eta')} = (21.1 \pm 0.9)\ \%$$

(consistent with other measurements of η-η′ mixing angle and LO-pQCD)

BESIII

$$R_{\Psi'} = \frac{B(\psi(2S) \to \gamma\eta)}{B(\psi(2S) \to \gamma\eta')} = (1.10 \pm 0.38 \pm 0.07)\ \%$$

(consistent with upper limit from CLEO-c)

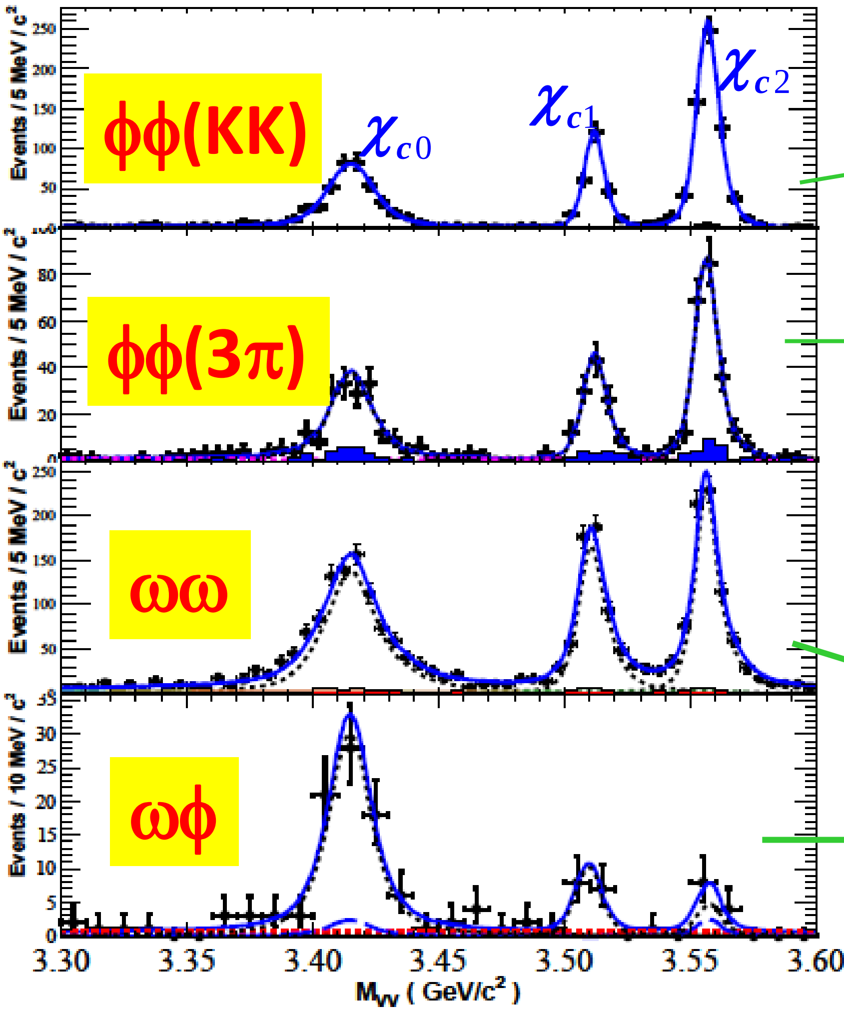
$$\Rightarrow \quad R_{\psi'} << R_{J/\psi}$$

Difference?: Other processes contributing? Related to ρπ puzzle, ... ??

Q. Zhao, PLB697(2011)52

$\chi_{cJ} \to VV$

PRL107, 091803 (2011)



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

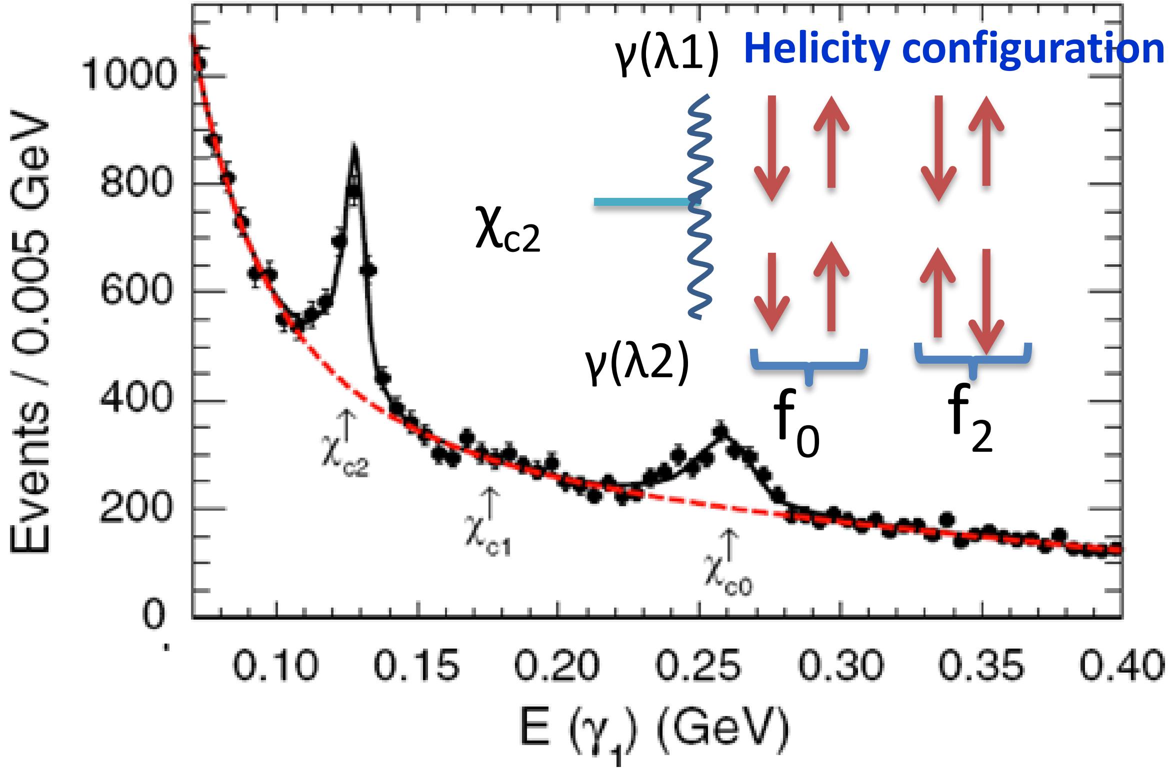
Evidence

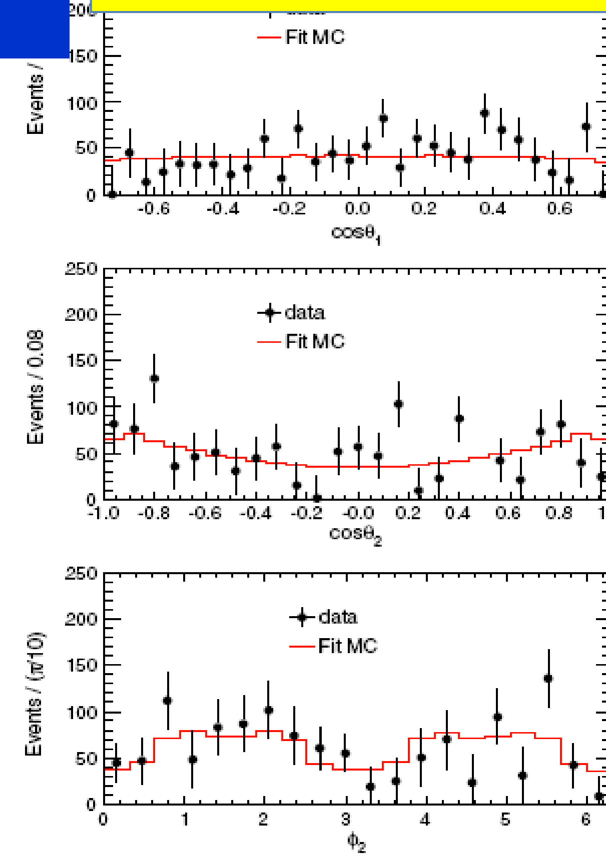
First observation

PRD81 014017 (2010) , PRD81 074006 (2010)

$\chi_{c0/2} \to \gamma\gamma$

PRD85, 112008, (2012)



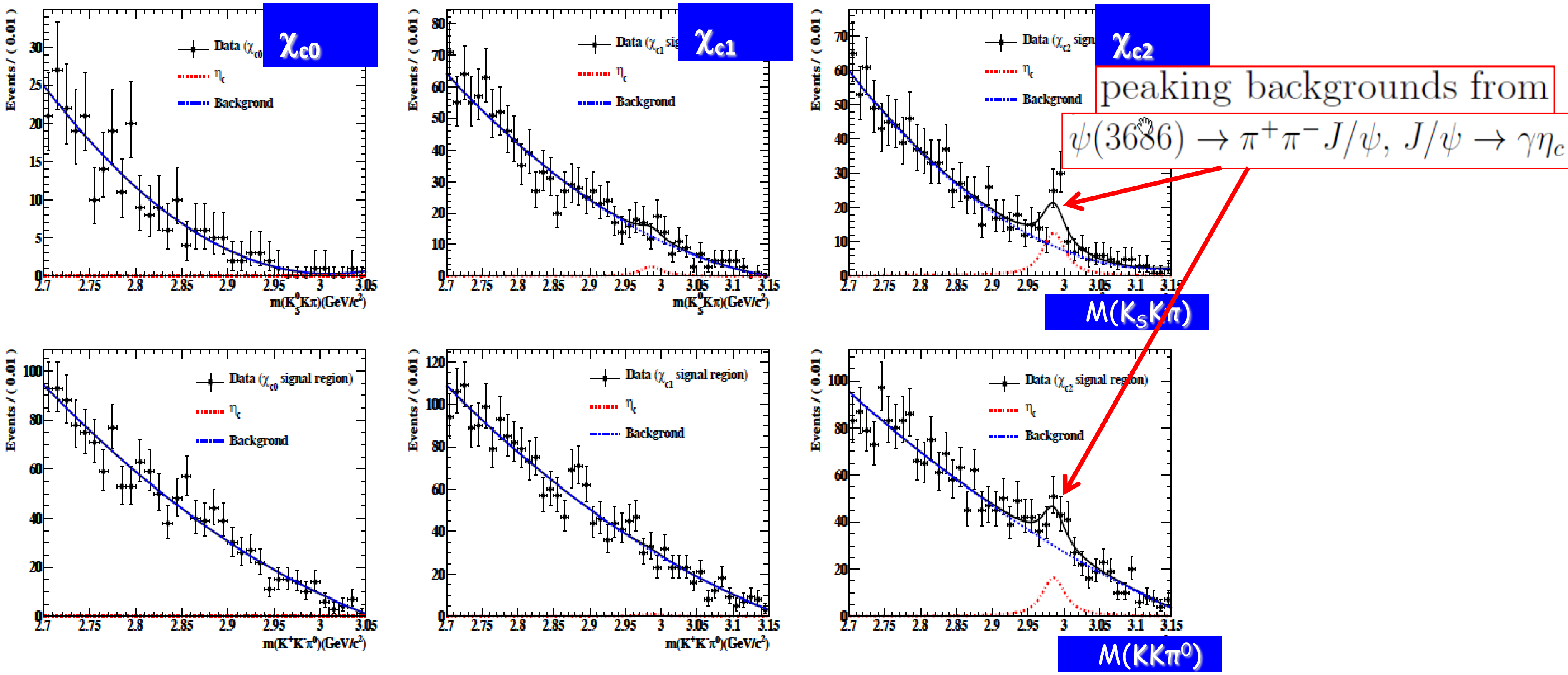


$\mathcal{B}_1 = \mathcal{B}(\psi(2s) \to \gamma\chi_{c0,c2})$, $\mathcal{B}_2 = \mathcal{B}(\chi_{c0,c2\to\gamma\gamma})$, and $\Gamma_{\gamma\gamma}(\chi_{c0,c2}) = \Gamma_{\gamma\gamma}(\chi_{c0,c2\to\gamma\gamma})$.

Quantity	PDG global fit results[a]	CLEO-c[b]	This measurement[b]
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5(\chi_{c0})$[c]	2.16 ± 0.18	$2.17 \pm 0.32 \pm 0.10$	$2.17 \pm 0.17 \pm 0.12$
$\mathcal{B}_1 \times \mathcal{B}_2 \times 10^5(\chi_{c2})$[c]	2.24 ± 0.17	$2.68 \pm 0.28 \pm 0.15$	$2.81 \pm 0.17 \pm 0.15$
$\mathcal{B}_2 \times 10^4(\chi_{c0})$[c]	2.23 ± 0.17	$2.31 \pm 0.34 \pm 0.15$	$2.24 \pm 0.19 \pm 0.15$
$\mathcal{B}_2 \times 10^4(\chi_{c2})$[c]	2.56 ± 0.16	$3.23 \pm 0.34 \pm 0.24$	$3.21 \pm 0.18 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c0})$ (keV)	2.32 ± 0.22	$2.36 \pm 0.35 \pm 0.22$	$2.33 \pm 0.20 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c2})$ (keV)	0.50 ± 0.05	$0.66 \pm 0.07 \pm 0.06$	$0.63 \pm 0.04 \pm 0.06$
$\mathcal{R}$	0.22 ± 0.03	$0.28 \pm 0.05 \pm 0.04$	$0.27 \pm 0.03 \pm 0.03$
$f_{0/2} = \Gamma^{\lambda=0}_{\gamma\gamma}(\chi_{c2})/\Gamma^{\lambda=2}_{\gamma\gamma}(\chi_{c2})$	...	...	$0.00 \pm 0.02 \pm 0.02$

Search for $\chi_{cJ} \to \pi^+\pi^+\eta_c$ ($\eta_c \to KK\pi$)

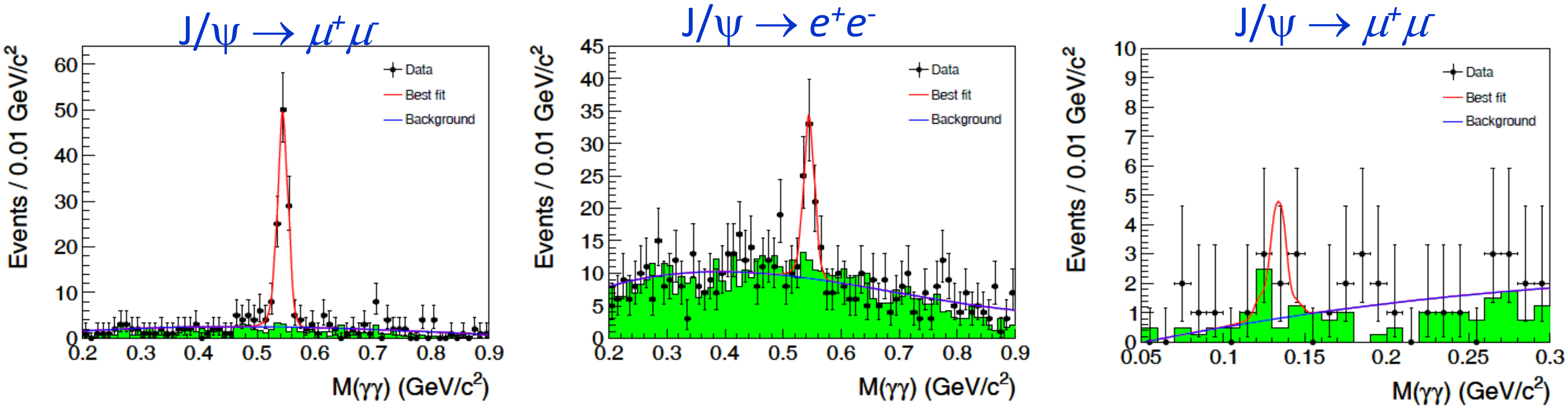
(Preliminary results)



Decay mode	N^{fit}	N^{up}	ϵ (%)	$\mathcal{B}^{up}(\chi_{cJ} \to \eta_c\pi^+\pi^-)$ (%)	$\mathcal{B}^{theory}(\chi_{cJ} \to \eta_c\pi^+\pi^-)$ (%)
$\chi_{c0} \to (K^0_S K^\pm\pi^\mp)\pi^+\pi^-$	0.0 ± 4.6	6.8	6.29	0.07	-
$\chi_{c0} \to (K^+K^-\pi^0)\pi^+\pi^-$	0 ± 15	33.6	6.82	0.41	-
$\chi_{c1} \to (K^0_S K^\pm\pi^\mp)\pi^+\pi^-$	18 ± 17	48.7	9.45	0.32	1.81 ± 0.26
$\chi_{c1} \to (K^+K^-\pi^0)\pi^+\pi^-$	6 ± 25	50.0	9.82	0.44	
$\chi_{c2} \to (K^0_S K^\pm\pi^\mp)\pi^+\pi^-$	77 ± 19	64.1	7.72	0.54	-
$\chi_{c2} \to (K^+K^-\pi^0)\pi^+\pi^-$	89 ± 26	105.4	7.83	1.23	-

@ 90% C.L.

Observation of $e^+e^- \to \eta\, J/\Psi$ @4.009 GeV
(Preliminary results)



- Data: $477 pb^{-1}$ @ 4.009 GeV
- First observation of e+e-→ ηJ/Ψ

$$\sigma^B(e^+e^- \to \eta J/\psi) = (32.1 \pm 2.8 \pm 1.3)\ \mathrm{pb}$$

- Assumption of ηJ/Ψ signal is from Ψ(4040)

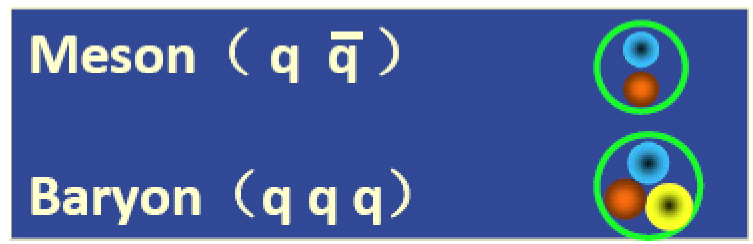
$$\mathcal{B}(\psi(4040) \to \eta J/\psi) = (5.2 \pm 0.5 \pm 0.2 \pm 0.5) \times 10^{-3}$$

$$\mathcal{B}(\psi(4040) \to \pi^0 J/\psi) < 2.8 \times 10^{-4}$$ @90% C.L.

Charm as a tool to study light hadron spectroscopy

- Hadrons consist of 2 or 3 quarks：

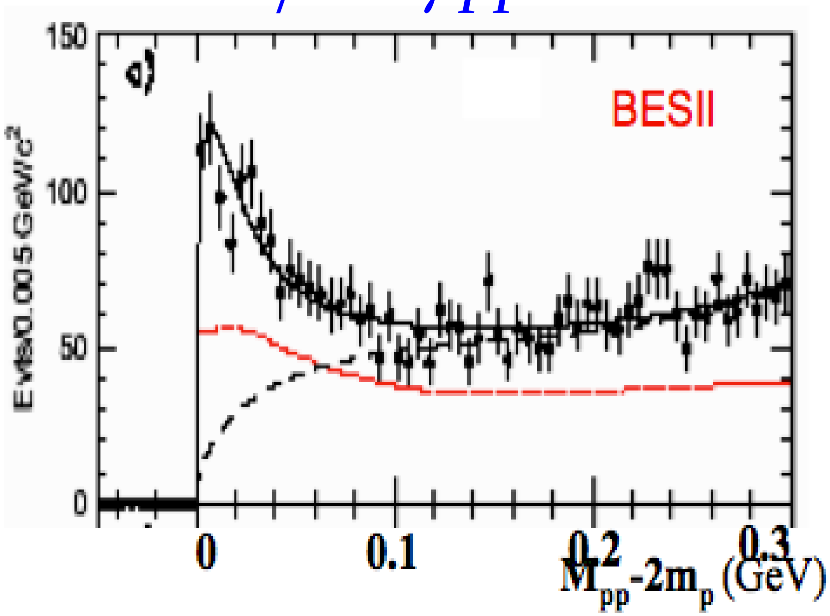
Naive Quark Model：



- QCD predicts the new forms of hadrons:
  - Multi-quark states： Number of quarks >= 4
  - Hybrids： $q\bar{q}g$， qqqg …
  - Glueballs： gg， ggg …

Observation of X(ppbar) @ BESII

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



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

Γ < 30 MeV/c^2 (90% CL)

PRL 91 (2003) 022001

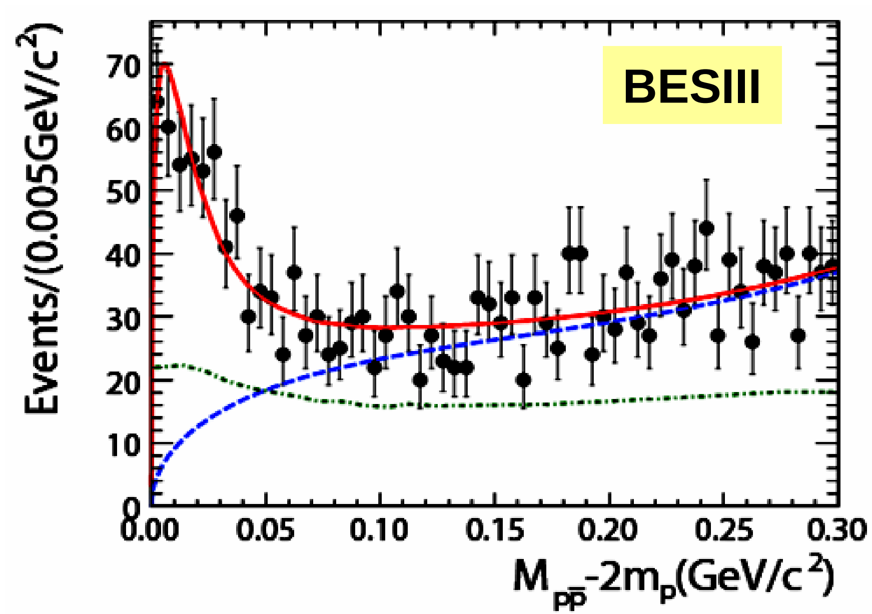
Theoretical interpretation:

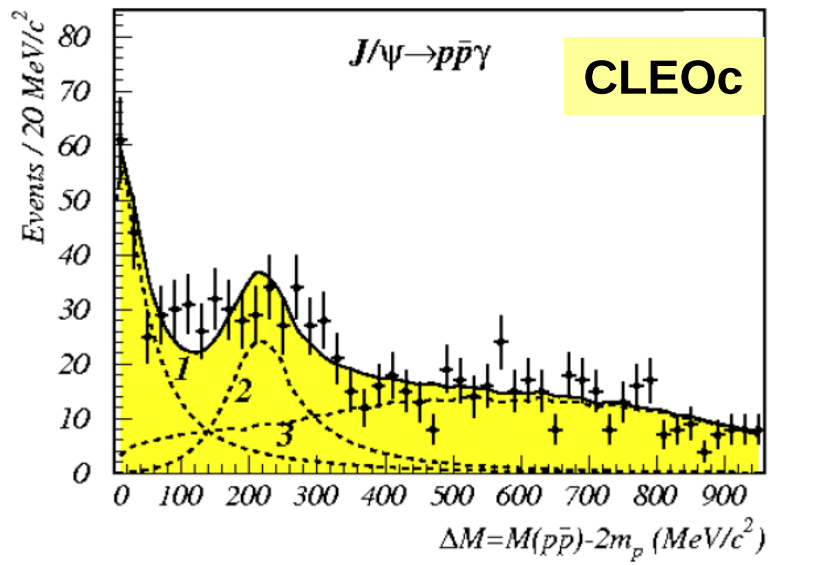
- conventional meson?
- ppbar bound state/multiquark
- glueball
- Final state interaction (FSI)
- ...

Confirmation @ BESIII and CLEOc

Fit with one resonance at BESII did:

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





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

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

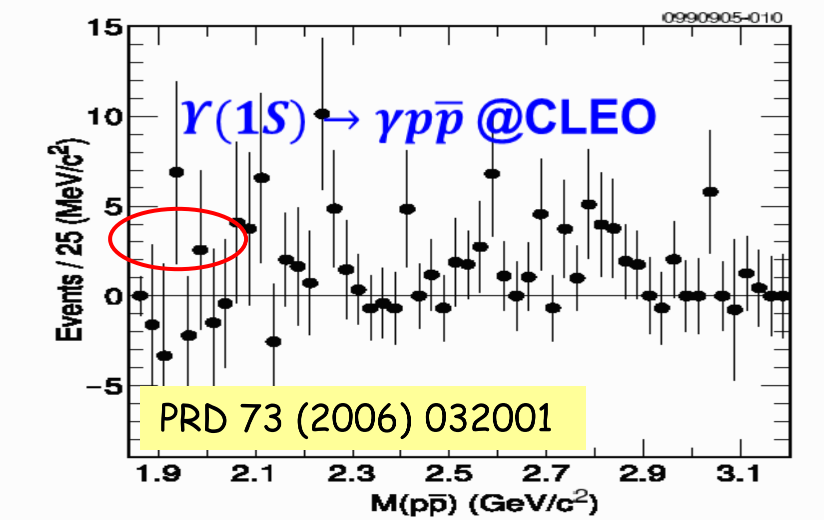
$M(R_{thr}) = 1861^{+6}_{-16}$ (MeV), $\Gamma(R_{thr}) = 0^{+32}_{-0}$ (MeV),

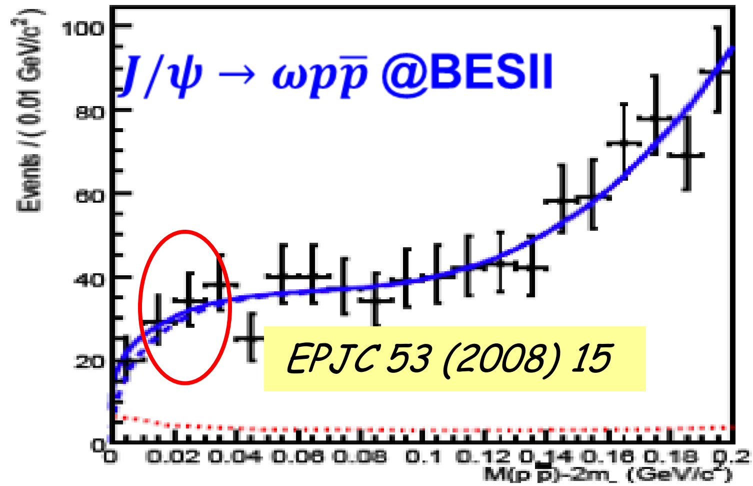
$B_1(J/\psi \to \gamma R_{thr}) \times B_2(R_{thr} \to p\bar{p}) = (5.9^{+2.8}_{-3.2}) \times 10^{-5}$

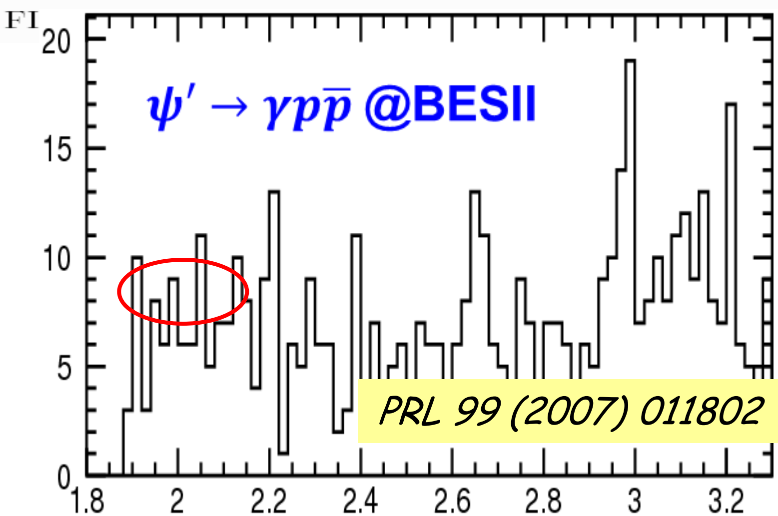
Chinese Physics C 34, 421 (2010)

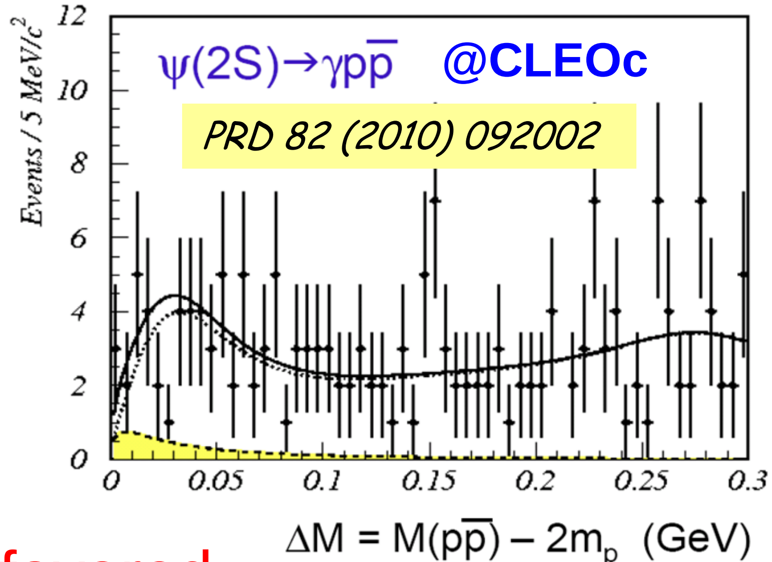
PRD 82, 092002(2010)

Several non-observations





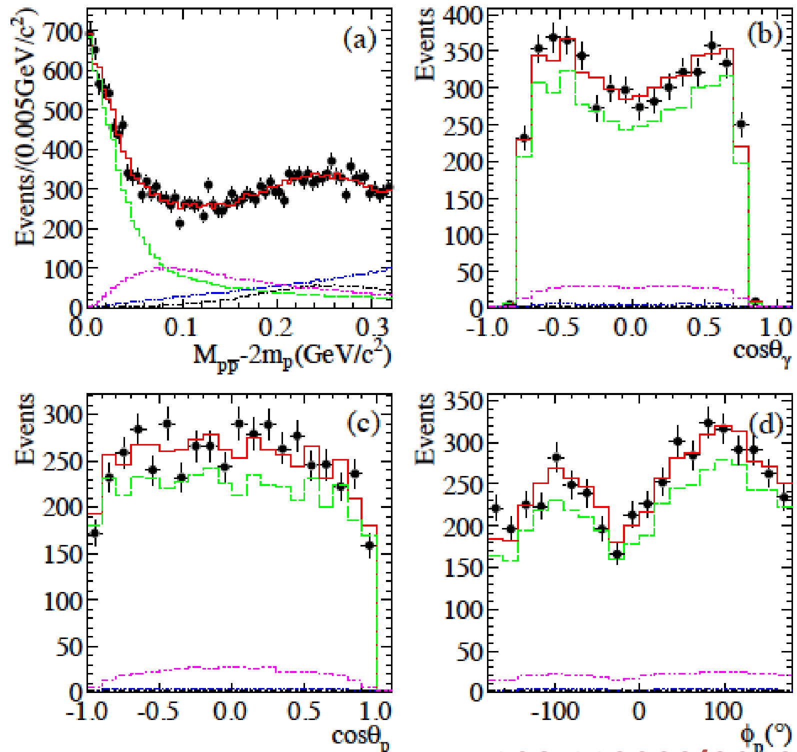




Pure FSI interpretation is disfavored

PWA of $J/\psi \to \gamma p\bar{p}$ @BESIII

- PWA of J/ψ→γppbar was first performed
- The fit with a BW and S-wave FSI(I=0) factor can well describe ppb mass threshold structure.
- It is much better than that without FSI effect, and Δ2lnL=51 (7.1σ)
- Different FSI models→Model dependent uncertainty



PRL 108,112003(2012)

- Spin-parity, mass, width and B.R. of X(ppbar):

$J^{pc} = 0^{-+}$ → **>6.8σ better than other J^{pc} assignments**

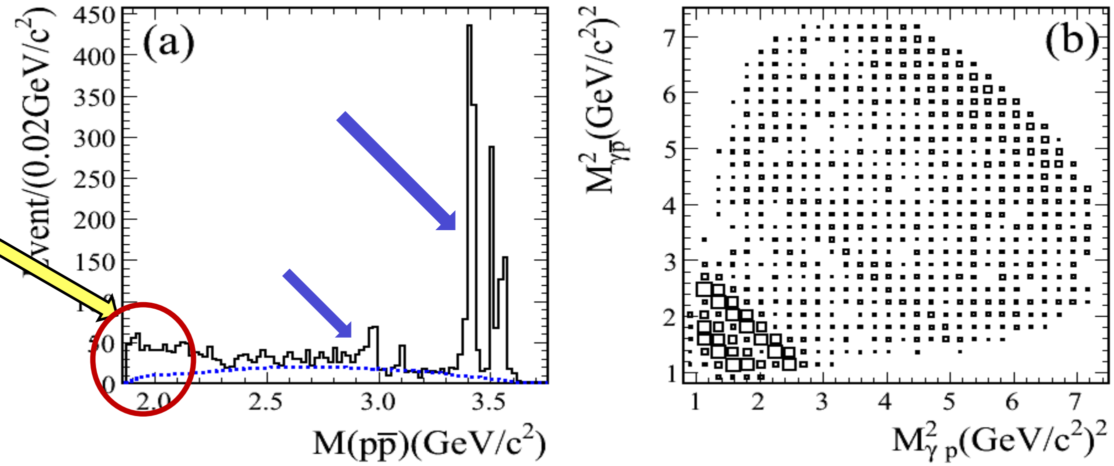
$$M = 1832^{+19}_{-5}(\text{stat})^{+18}_{-17}(\text{syst}) \pm 19(\text{mod})\text{MeV}/c^2$$

$$\Gamma = 13 \pm 20(\text{stat})^{+11}_{-33}(\text{syst}) \pm 4(\text{mod})\text{MeV}/c^2 \text{ or } \Gamma < 76\text{MeV}/c^2 \text{ @}90\% C.L.$$

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

M_{ppbar} threshold structure of $\psi' \rightarrow \gamma p\bar{p}$ @BESIII

Obviously different line shape of ppbar mass spectrum near threshold from that in J/ψ decays



PWA results:

- Significance of X(ppbar) is > 6.9σ.
- The production ratio R:

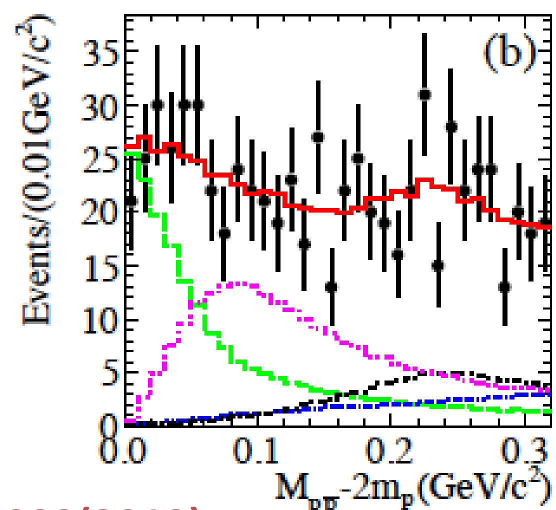
first measurement

$$R = \frac{B(\psi' \rightarrow \gamma X(p\bar{p}))}{B(J/\psi \rightarrow \gamma X(p\bar{p}))}$$

$$= (5.08^{+0.71}_{-0.45}(stat)^{+0.67}_{-3.58}(syst) \pm 0.12(mod))\%$$

- It is suppressed compared with "12% rule".

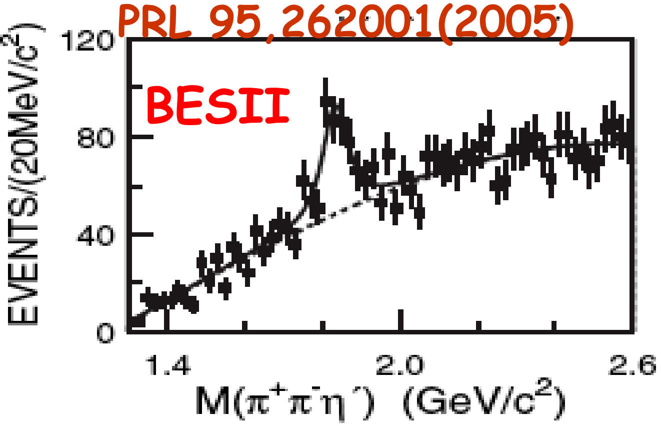
PWA Projection:



PRL 108,112003(2012)

Confirmation of X(1835) and two new structures

PRL 95,262001(2005)

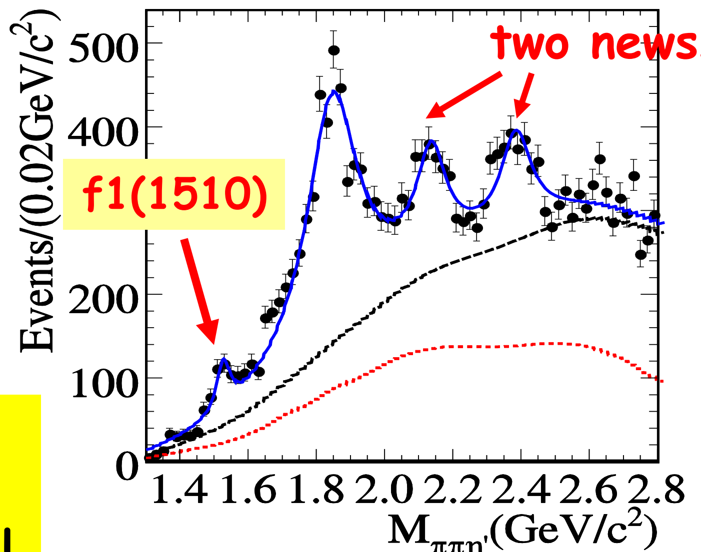


$J/\psi \to \gamma\eta'\pi^+\pi^-$
$\eta' \to \eta\pi^+\pi^-$
$\eta' \to \gamma\rho$

BESII result (Stat. sig. ~ 7.7σ):
$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst) MeV$
$\Gamma = 67.7 \pm 20.3(\text{stat}) \pm 7.7(\text{syst})\text{MeV}$

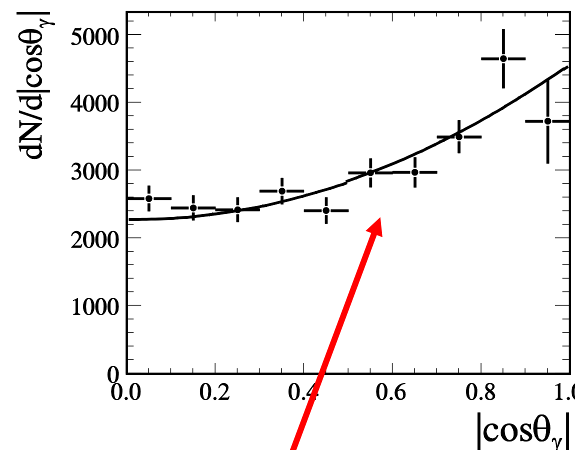
BESIII: 225M J/ψ events, new structures!

PRL 106, 072002(2011)



BESIII fit results:

Resonance	M(MeV/c²)	Γ(MeV/c²)	Stat.Sig.
X(1835)	$1836.5 \pm 3.0^{+5.6}_{-2.1}$	$190.1 \pm 9.0^{+38}_{-36}$	>20σ
X(2120)	$2122.4 \pm 6.7^{+4.7}_{-2.7}$	$83 \pm 16^{+31}_{-11}$	7.2σ
X(2370)	$2376.3 \pm 8.7^{+3.2}_{-4.3}$	$83 \pm 17^{+44}_{-6}$	6.4σ

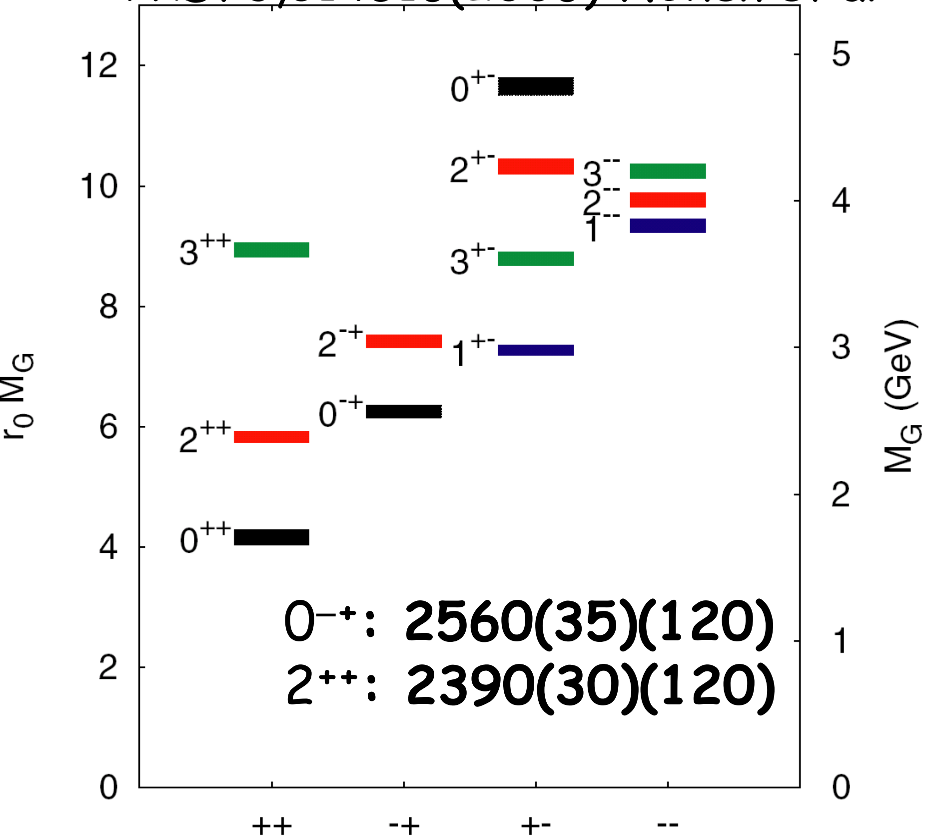


An amplitude analysis could help with interpretation for the additional new structures!

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

What's the nature of new structures?

PRD73,014516(2006) Y.Chen et al



✓It is the first time resonant structures are observed in the 2.3 GeV/c2 region, it is interesting since:

LQCD predicts that the lowest lying pseudoscalar glueball: around 2.3 GeV/c^2.

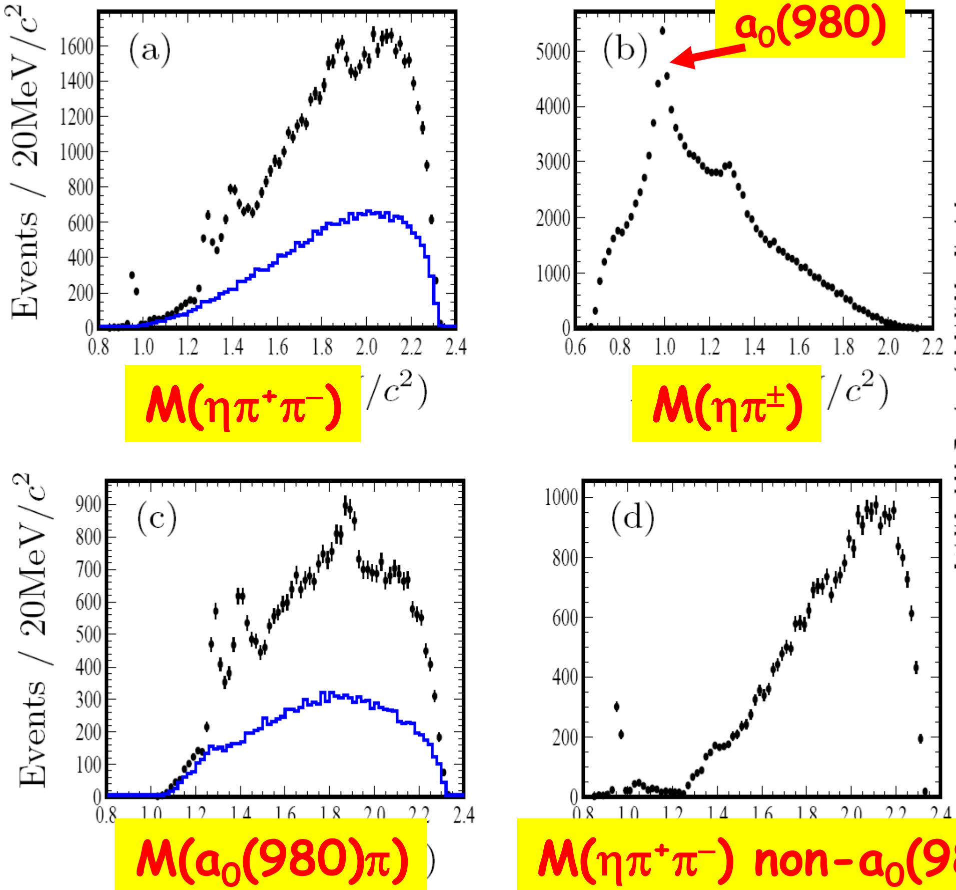
$J/\psi \to \gamma\pi\pi\eta'$ decay is a good channel for finding 0^{-+} glueballs.

✓Nature of X(2120)/X(2370)
pseudoscalar glueball ?
η/η' excited states?

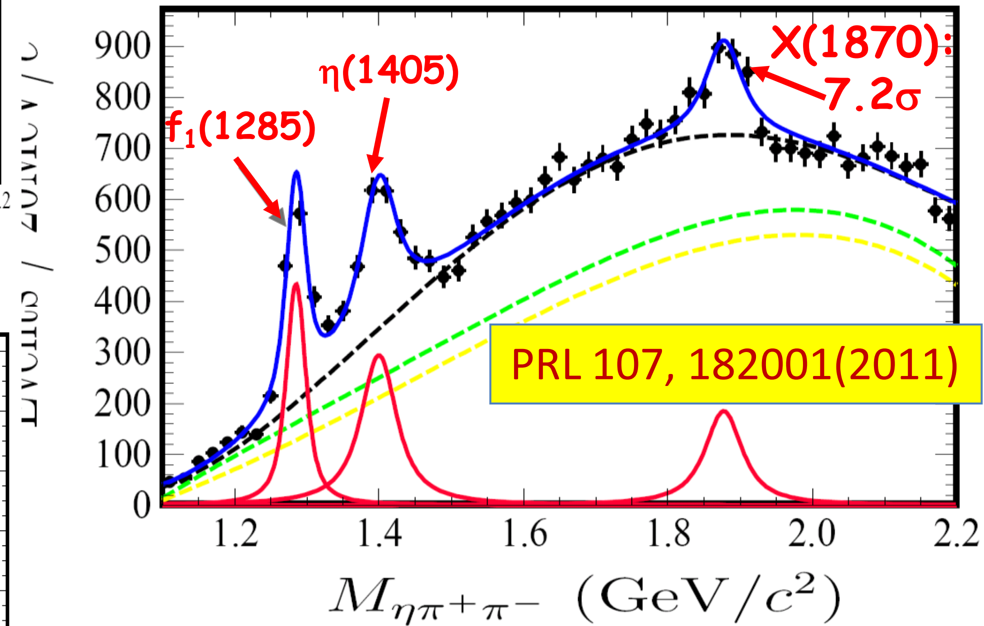
PRD82,074026,2010
J.F. Liu, G.J. Ding and M.L.Yan
PRD**83:114007,2011**
(J.S. Yu, Z.-F. Sun, X. Liu, Q. zhao),
and more…

For detail see Light meson session:
Hongwei Liu's talk on June 17

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



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

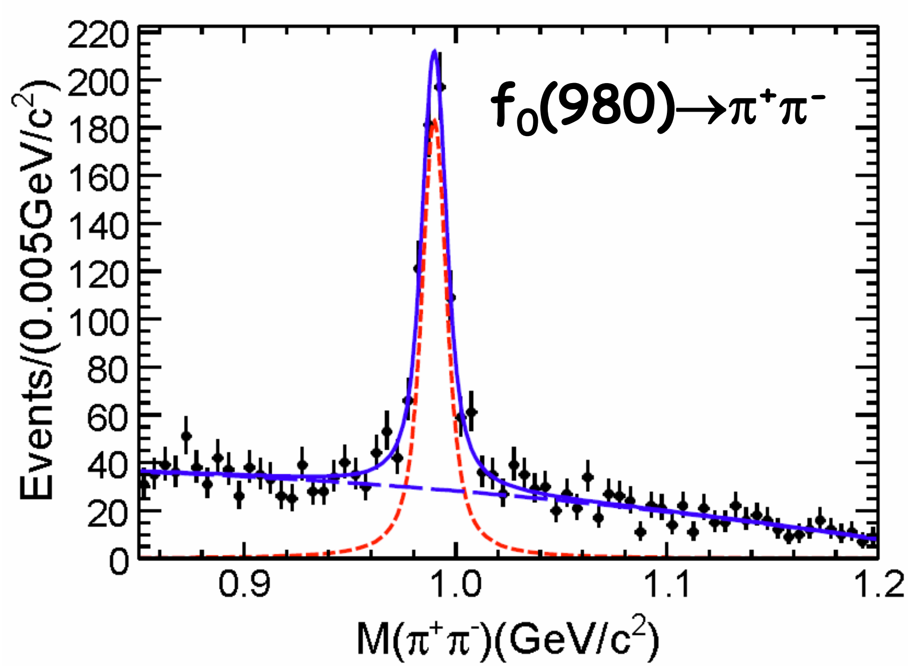


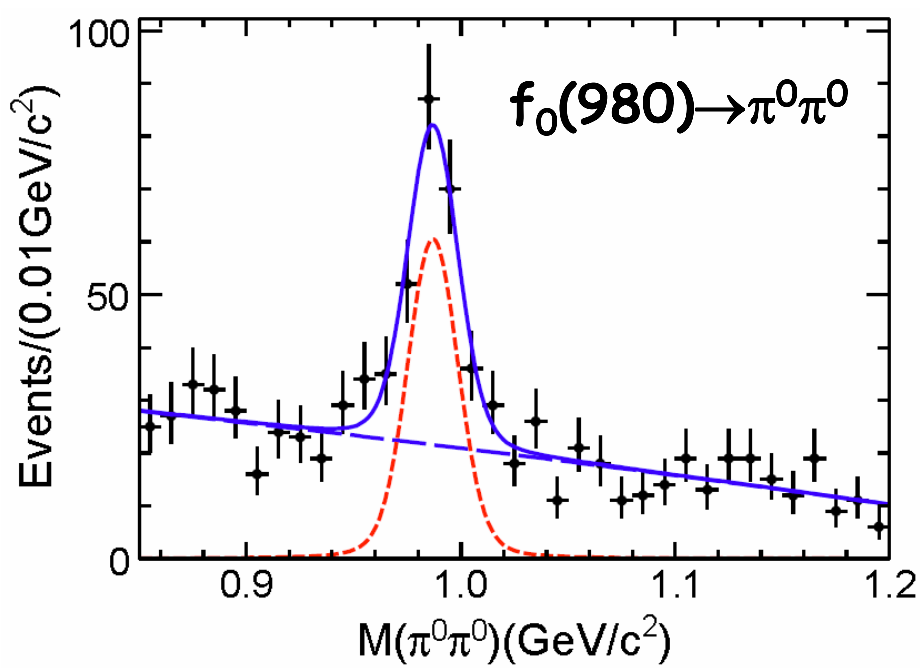
Identification of X(1870): 0^{-+}(?)
It is X(1835)?
Need PWA!

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

Anomalous line shape of $f_0(980)$ in $J/\psi \to \gamma 3\pi$





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

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

PRL 108, 182001 (2012)

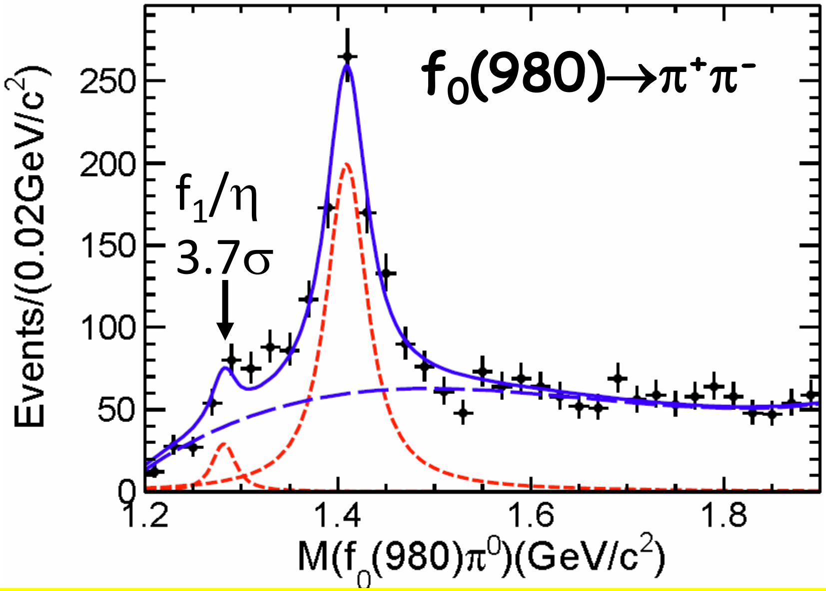
Surprising result:

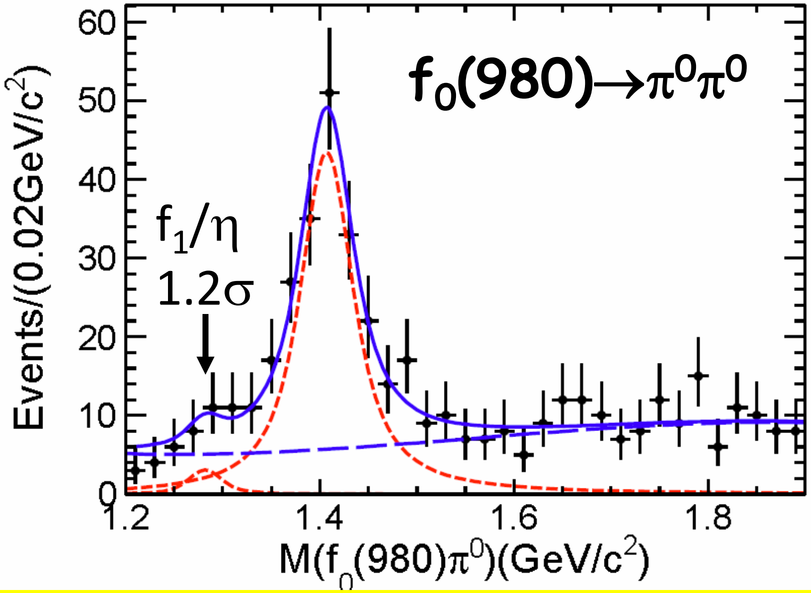
very narrow $f_0(980)$ width: <11.8 MeV/c^2 @90% C.L.

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))

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





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

$$\frac{BR(\eta(1405)\to f_0(980)\pi^0\to\pi^+\pi^-\pi^0)}{BR(\eta(1405)\to a_0(980)\pi^0\to\pi^0\pi^0\eta)}\approx(17.9\pm4.2)\%$$

PRL 108, 182001 (2012)

$\vee$

$$\xi_{af}=\frac{Br(\chi_{c1}\to f_0(980)\pi^0\to\pi^+\pi^-\pi^0)}{Br(\chi_{c1}\to a_0(980)\pi^0\to\eta\pi^0\pi^0)}<1\%(90\%\,C.L.)$$

PRD, 83(2100)032003

a_0-f_0 mixing alone can not explain the branching ratio of $\eta(1405)$

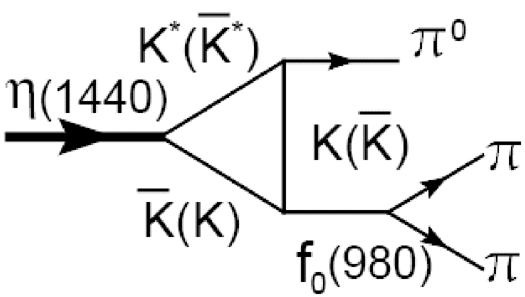
Large isospin violation in η(1405) decay

In general, magnitude of isospin violation in strong decay should be less than 1% or at 0.1% level. For example:

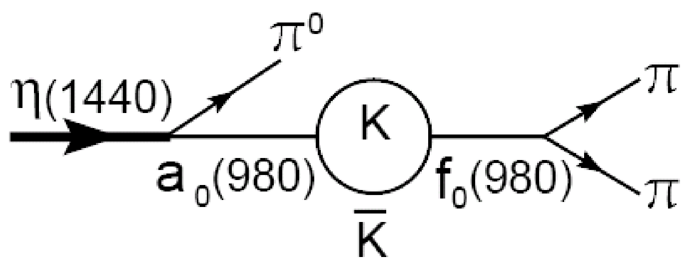
$$\frac{BR(\psi' \to \pi^0 J/\psi)}{BR(\psi' \to \eta J/\psi)} = 0.2 \times 10^{-2} \times \frac{|P_\pi|^3}{|P_\eta|^3}, \quad \frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} = 0.8 \times 10^{-2}$$

However:

$$\frac{BR(\eta(1405) \to f_0(980)\pi^0)}{BR(\eta(1405) \to a_0(980)\pi)} \approx 25\%$$



Triangle Singularity (TS)



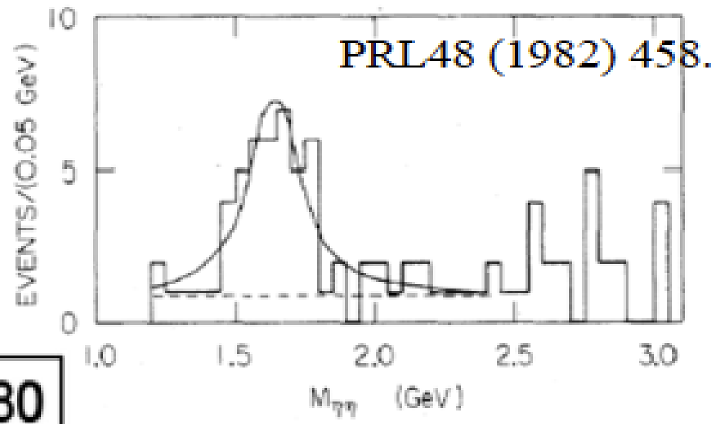
a_0—f_0 mixing

K*K pair in TS is almost on-shell, together with mixing explain the narrow $f_0(980)$, and large isospin violation.

J.J.Wu et al, PRL 108, 081803(2012)

Study of ηη system

- **First observed $f_0(1710)$ from J/ψ radiative decays to ηη by Crystal Ball in 1982.**
- **LQCD predicts:**



0^{++} : 1710 ± 50 ± 80

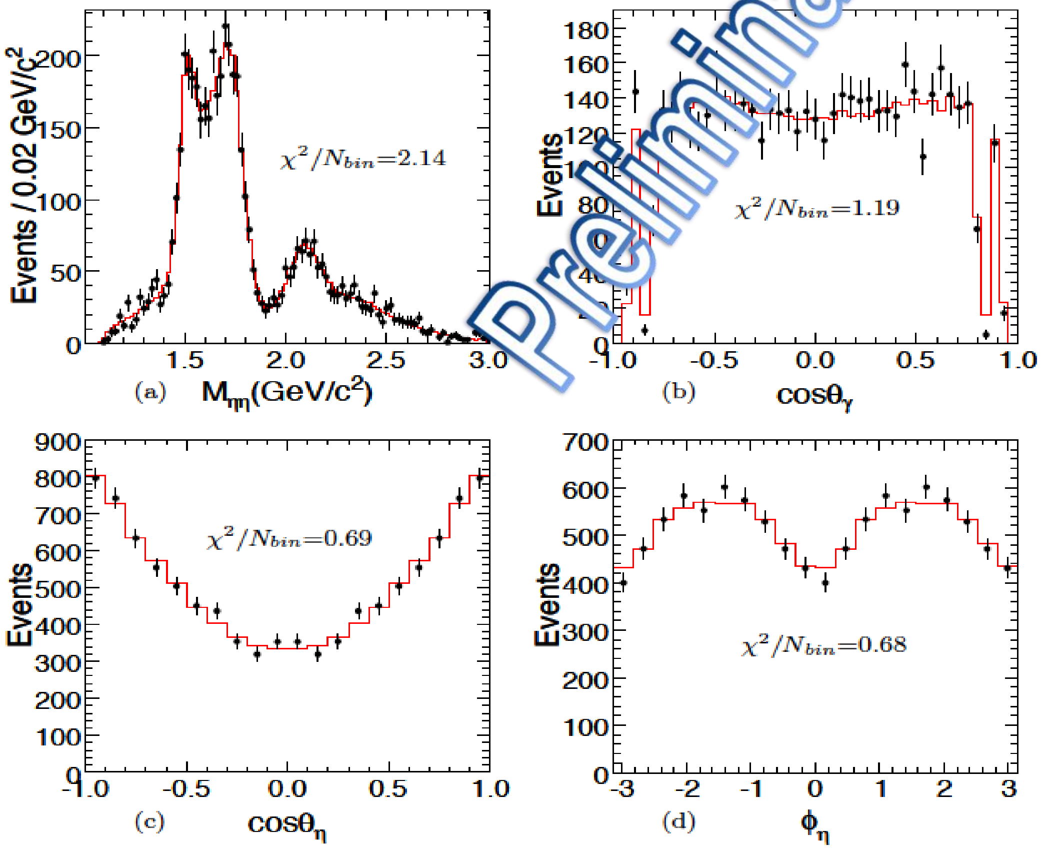
- **Crystal Barrel Collaboration (2002) analyzed the three final states $\pi^0\pi^0\pi^0$, $\eta\pi^0\pi^0$ and $\pi^0\eta\eta$ with K matrix formalism. Found a 2^{++} (~1870MeV), but no $f_0(1710)$.**

- **E835 (2006): ppbar → $\pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$.**

- **WA102 and GAMS all identified $f_0(1710)$ in ηη .**

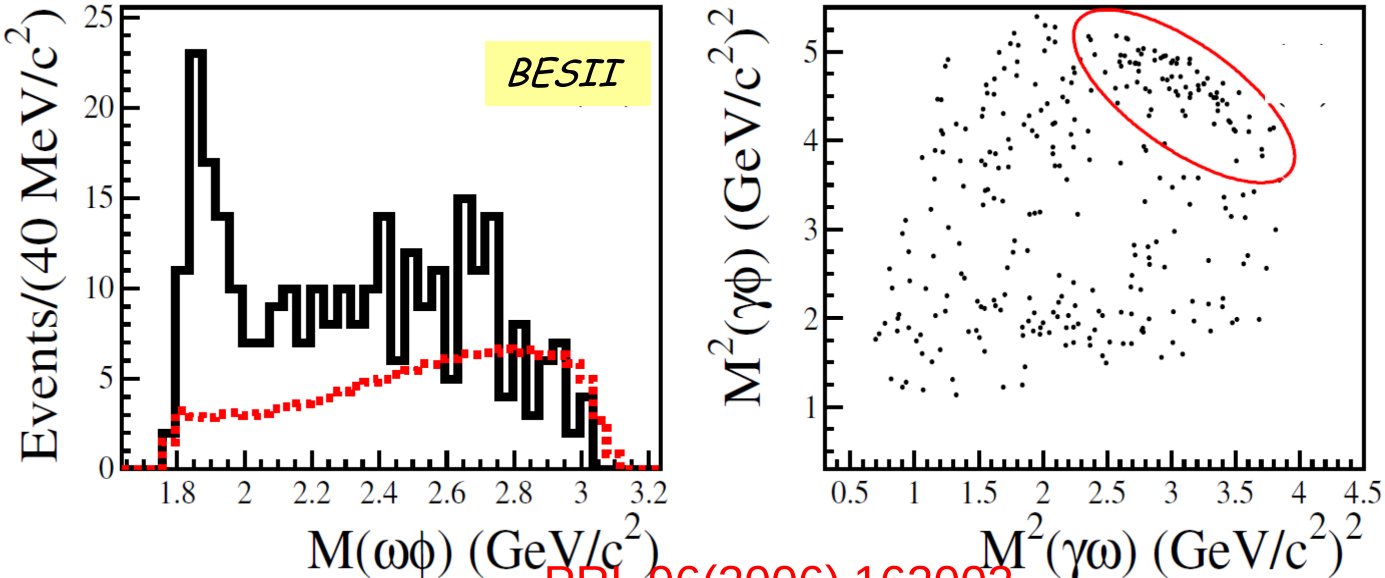
Preliminary PWA results of J/ψ→γηη @BESIII

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+20}_{-15-74}	$136^{+41+8}_{-26-100}$	$(1.61^{+0.29+0.41}_{-0.32-1.28}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	1759^{+6+14}_{-6-25}	172^{+10+31}_{-10-15}	$(2.35^{+0.07+1.23}_{-0.07-0.72}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	2081^{+13+23}_{-13-34}	$273^{+27+65}_{-2[illegible]-18}$	$(9.99^{+0.57+5.52}_{-0.52-2.21}) \times 10^{-5}$	13.9 σ
$f_2'(1525)$	1513^{+5+3}_{-5-10}	$75^{+12+[illegible]5}_{-[illegible]}$	$(3.41^{+0.43+1.22}_{-0.50-1.23}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+61}_{-24-54}	$229^{[illegible]2+[illegible]}_{-[illegible]-15}$	$(5.38^{+0.60+3.31}_{-0.67-2.24}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+139}_{-30-59}$	33[illegible]	$(5.58^{+0.61+1.93}_{-0.65-1.81}) \times 10^{-5}$	7.6 σ

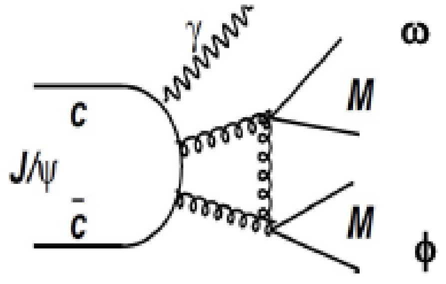


- $f_0(1710)$ and $f_0(2100)$ are dominant scalars.
- $f_0(1500)$ exists (8.2σ).
- $f_2'(1525)$ is the dominant tensor.

$M_{\omega\phi}$ threshold enhancement in J/ψ→γωφ



PRL 96(2006) 162002



$J/\psi \rightarrow \gamma\omega\phi$ **(DOZI)**

For X(1810):

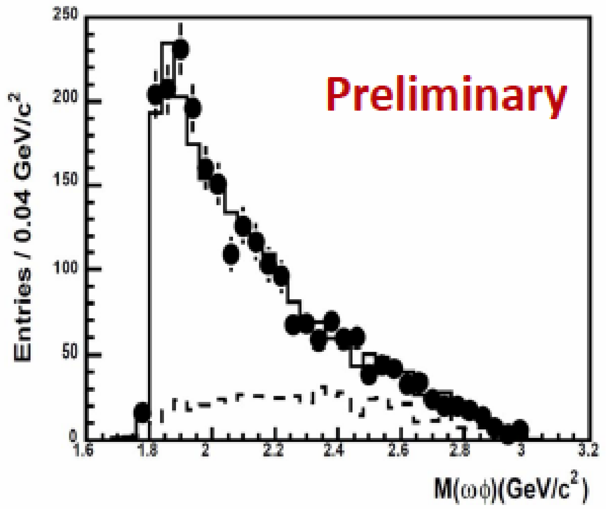
$$M = 1812^{+19}_{-26} \pm 18\ \mathrm{MeV/c^2}$$

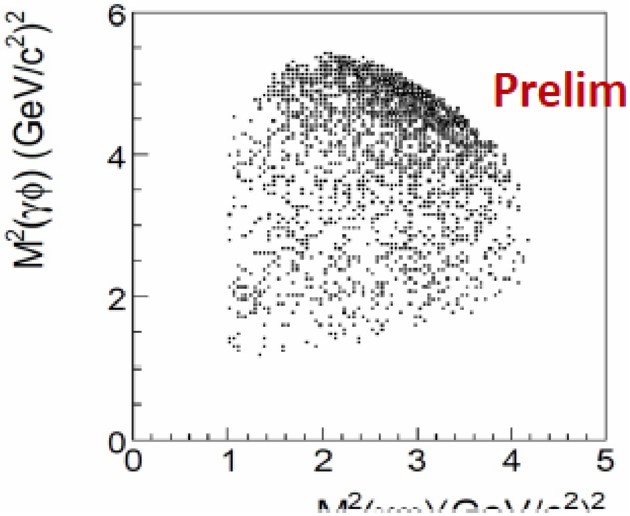
$$\Gamma = 105 \pm 20 \pm 28\ \mathrm{MeV/c^2}$$

J^{pc} favors 0^{++} over 0^{-+} and 2^{++}

Preliminary PWA results of J/ψ→γωϕ @BESIII

Resonance	J^{PC}	$M(MeV/c^2)$	$\Gamma(MeV/c^2)$	Events	ΔS	Δndf	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	665 ± 40	211	2	$> 10\sigma$
$f_0(2020)$	0^{++}	1992	442	715 ± 45	100	2	$> 10\sigma$
$\eta(2225)$	0^{-+}	2240	190	70 ± 30	23	2	6.4σ
phase space	0^{-+}	2400	5000	319 ± 24	45	2	$> 8\sigma$

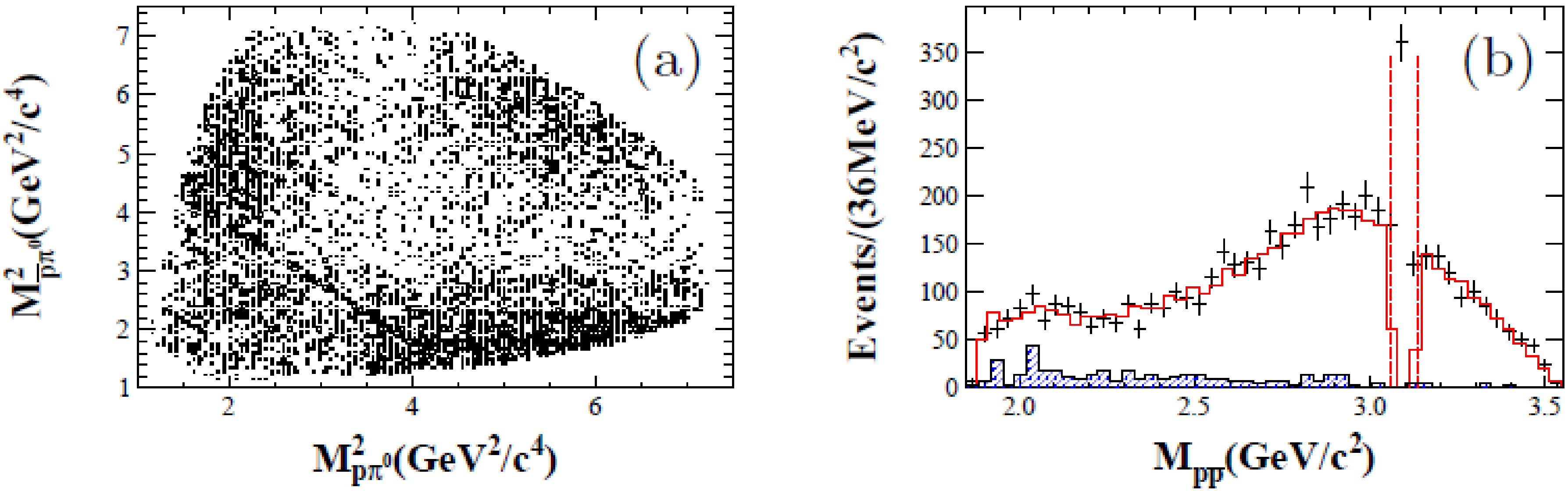




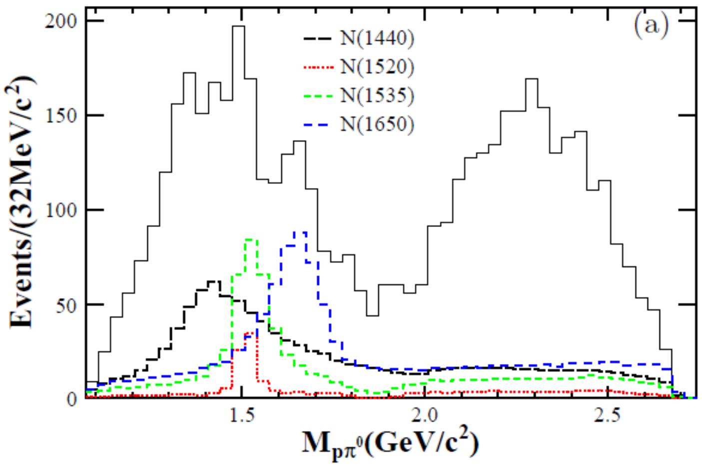
Is X(1810) the f0(1710)/f0(1790) or new state?

Observation of two N* baryons in $\psi' \to \pi^0 p \bar{p}$ decay
arXiv:1207.0223

- Non-relativistic quark model is successful in interpreting of the excited baryons
- Predicted more excited stated ("missing resonance problem")
- J/ψ (ψ′) decays offers an window to search for the missing resonance

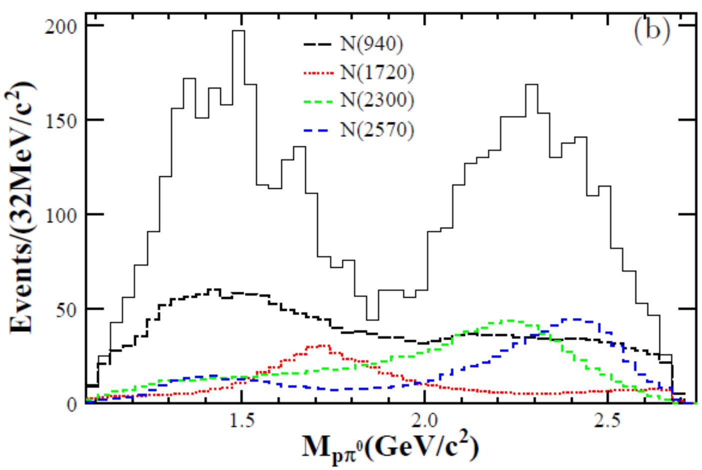


PWA results on N* baryons in $\psi' \to \pi^0 p \bar{p}$



Resonance	$M(MeV/c^2)$	$\Gamma(MeV/c^2)$	ΔS	ΔN_{dof}	C.L.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	4	12.2σ
$N(1720)$	1700^{+30+32}_{-28-35}	$450^{+109+149}_{-94-44}$	55.6	6	9.6σ
$N(2300)$	$2300^{+40+109}_{-30-0}$	$340^{+30+110}_{-30-58}$	120.7	4	15.0σ
$N(2570)$	2570^{+19+34}_{-10-10}	250^{+14+69}_{-24-21}	78.9	6	11.7σ

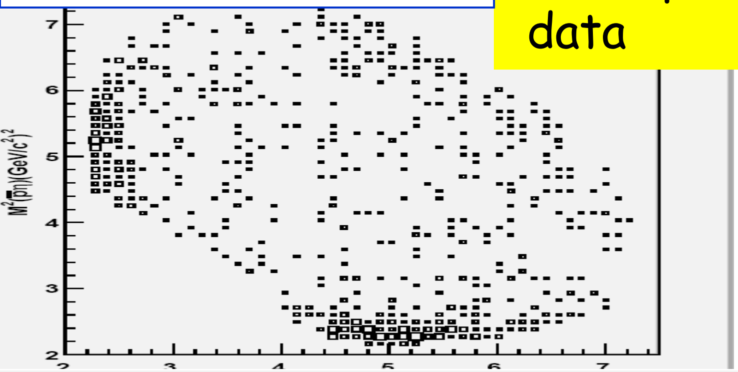
Two new baryonic excited states are observed !

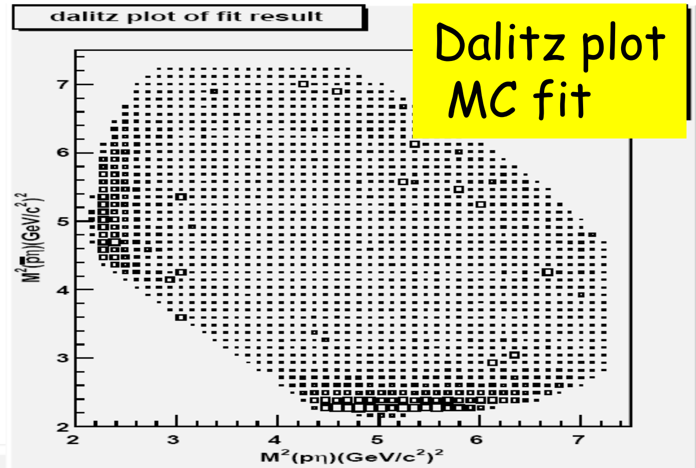


Resonance	N	$\epsilon(\%)$	B.F.$(\times 10^{-5})$
$N(940)$	$1870^{+90+487}_{-90-327}$	27.2 ± 0.4	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	27.6 ± 0.4	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	190^{+14+64}_{-14-48}	27.7 ± 0.4	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	25.5 ± 0.4	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1650)$	$1080^{+77+382}_{-77-467}$	26.9 ± 0.4	$3.76^{+0.28+1.37}_{-0.28-1.66}$
$N(1720)$	$510^{+27+50}_{-27-197}$	26.6 ± 0.4	$1.79^{+0.10+0.24}_{-0.10-0.71}$
$N(2300)$	$948^{+68+394}_{-68-213}$	33.8 ± 0.4	$2.62^{+0.28+1.12}_{-0.28-0.64}$
$N(2570)$	$795^{+45+127}_{-45-83}$	34.9 ± 0.4	$2.13^{+0.08+0.40}_{-0.08-0.30}$
Total	4515 ± 93	25.5 ± 0.4	$16.5 \pm 0.3 \pm 1.5$

Preliminary results on N* baryon in $\psi' \rightarrow \eta p \bar{p}$ decay

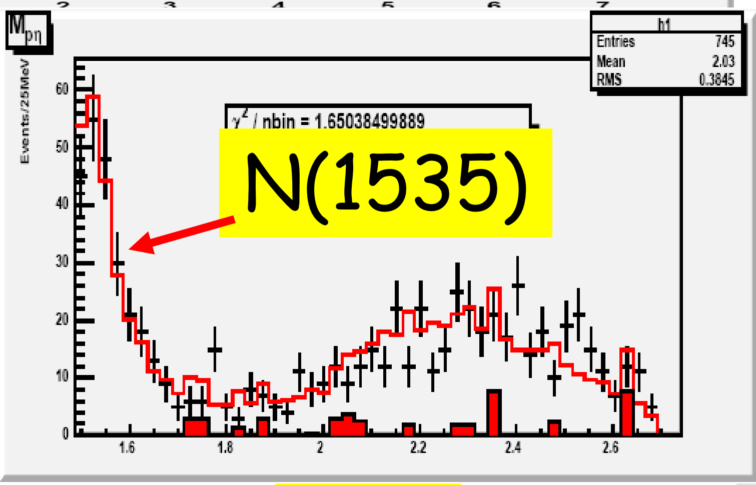
BESIII Preliminary



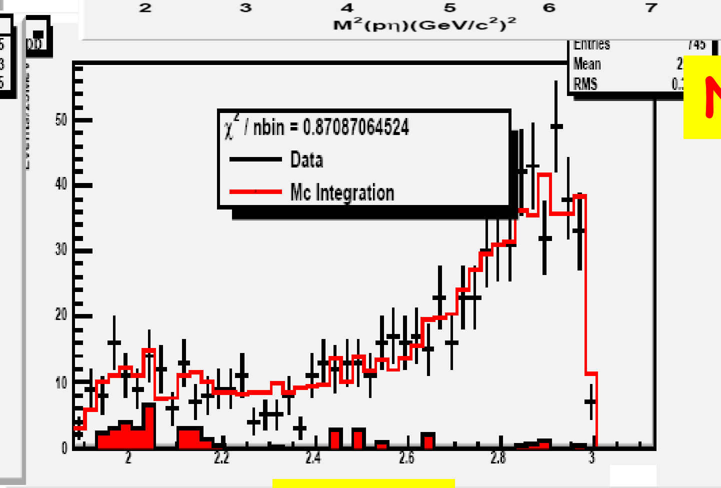


A full PWA is performed.

Background clean!



M(pη)



M($p\bar{p}$)

N(1535) is 1/2

Mass:

$1.524^{+0.005+0.010}_{-0.005-0.004}$ GeV/C²

Width:

$0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

$Br(\psi' \rightarrow pp\eta) = (6.6 \pm 0.2 \pm 0.6) \times 10^{5}$

PDG2010: $(6.0 \pm 1.2) \times 10^{5}$

$Br(\psi' \rightarrow N(1535)p) \times Br(N(1535) \rightarrow p\eta + c.c.)$

$= 5.5^{+0.3+7.4}_{-0.3-1.1} \times 10^{-5}$

Charm physics at BESIII

e^+e^- Colliders@threshold:

$$e^+e^- \to \psi(3770) \to D^0\bar{D}^0 \quad [C = -1] \qquad \text{OR} \qquad e^+e^- \to \gamma^* \to D^0\bar{D}^0\gamma \quad [C = +1]$$

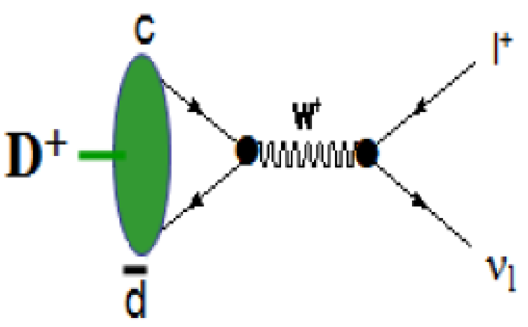
Good for charm flavor physics:

- Threshold production: clean
- Known initial energy and quantum numbers
- Both D and $\bar{D}$ fully reconstructed (double tag)
- Absolute measurements

$D^+ \to \mu^+ \nu$

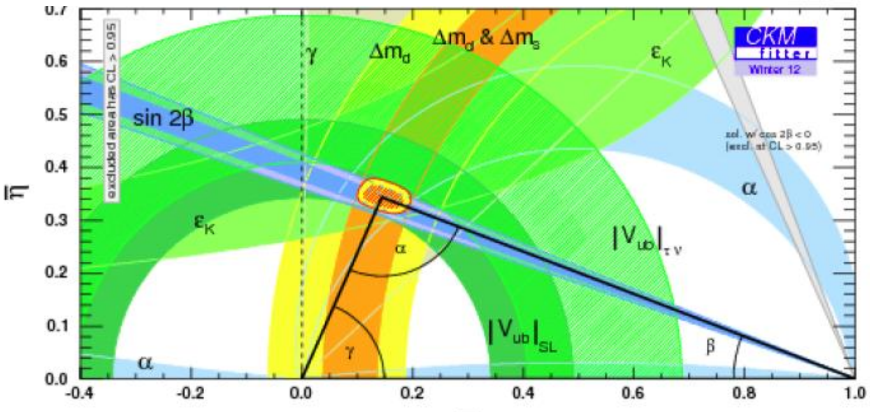
- D^+ leptonic decays play an important role in understanding of the SM

- Test LQCD calculation of f_D



$$\Gamma_{SM}(D^+_{(s)} \to l^+ \nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m_{D_{(s)}}^2}\right)^2 |V_{cd(s)}|^2 f_{D^+_{(s)}}$$

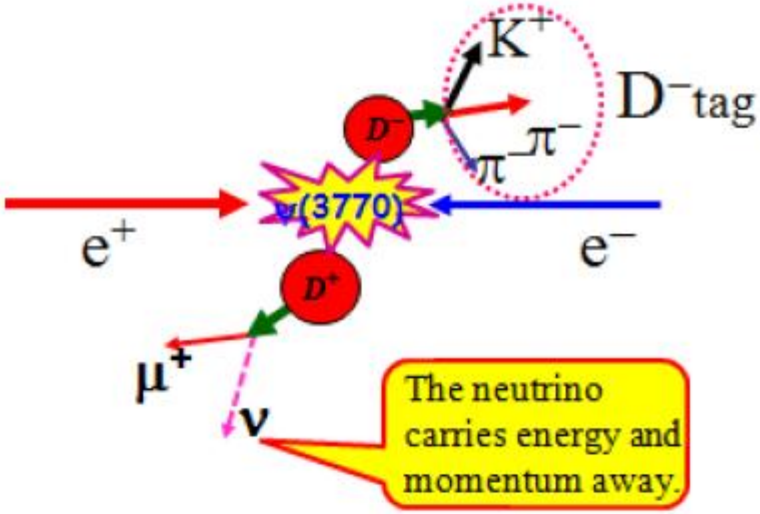
- Precise measurement of $|V_{cd}|$

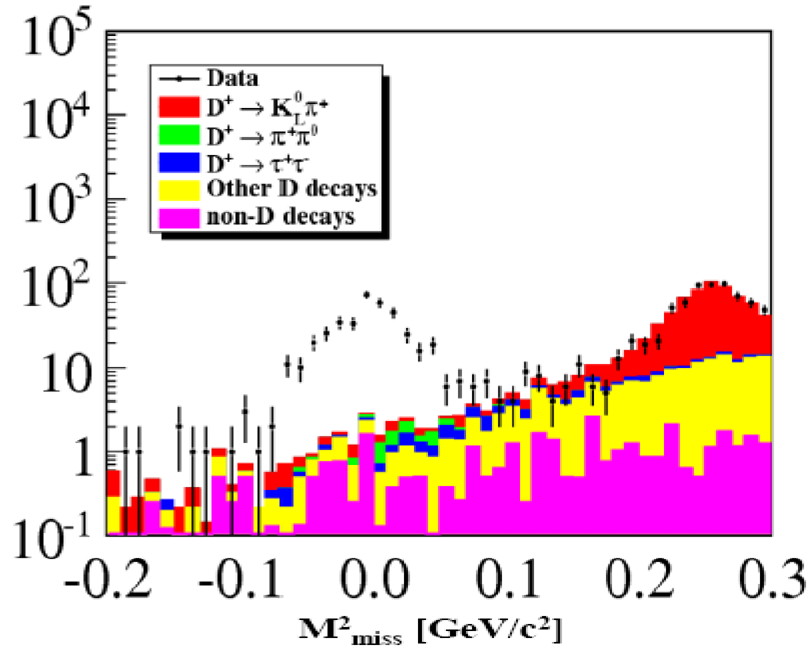


- Theoretical uncertainty will be reduced in determination of $|V_{ud}|$ If FF calculations can be validated with charm

- Reduced width of band in triangle would lead to precisely test the SM, and search for new physics beyond the SM

In the system recoiling against the singly tagged D^-, BES-III selected the purely leptonic decay events for $D^0 \to \mu^+ \nu$





Br. & f_{D+} at BES-III

Results:

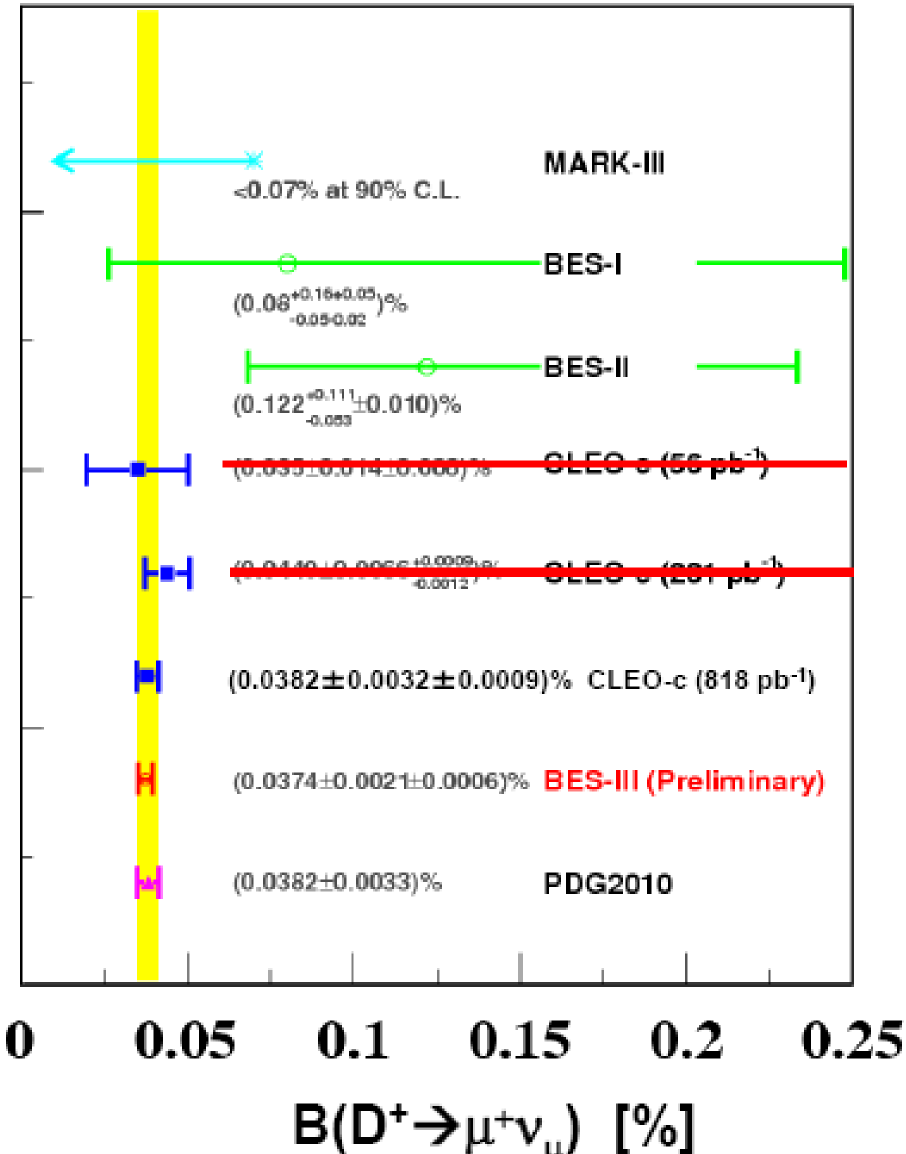
$N(D^+ \to \mu^+ \nu) = 377.3 \pm 20.6$

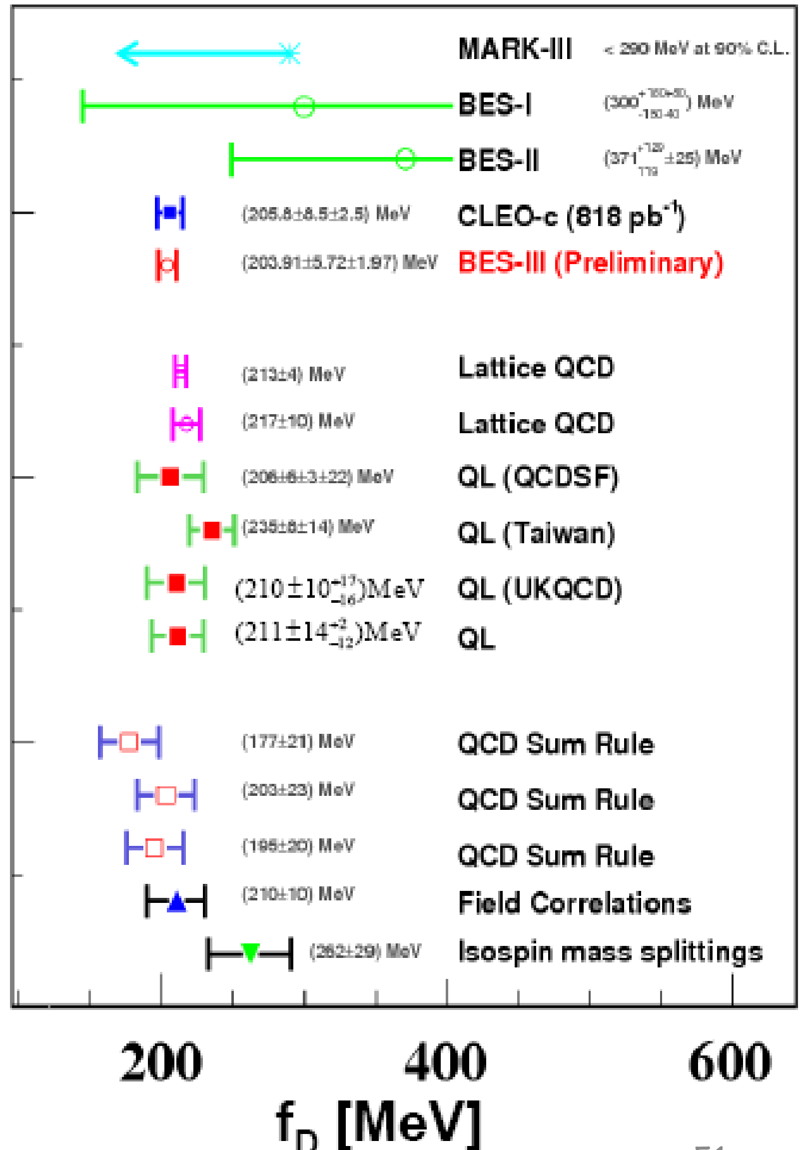
$BF(D^+ \to \mu^+ \nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$

f_{D+} = (203.91±5.72±1.97) MeV

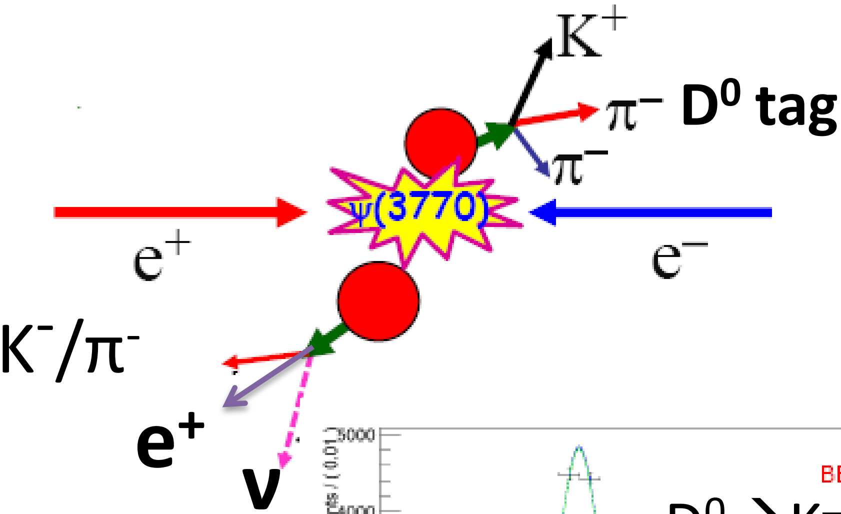
BESIII preliminary

Comparison of $B(D^+ \to \mu^+\nu)$ & f_D



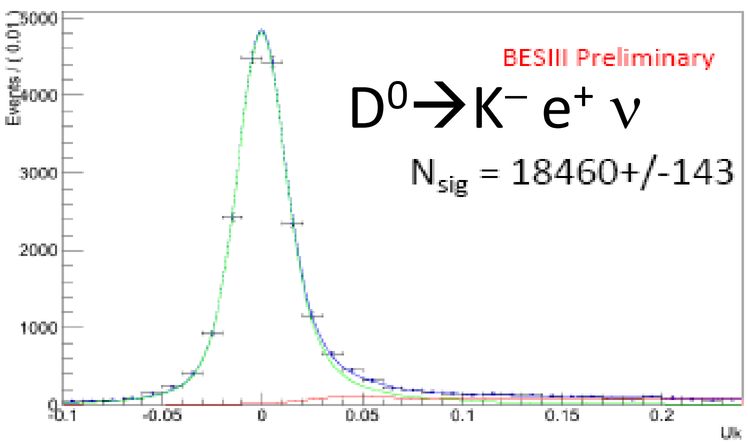


$D^0 \rightarrow K^-/\pi^- e^+ \nu$

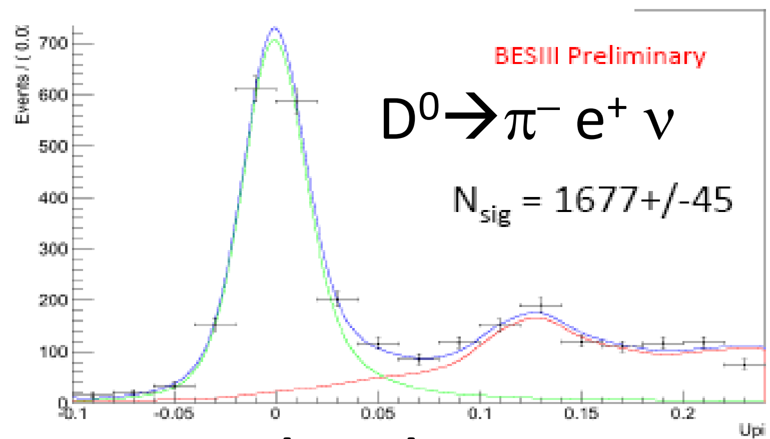


- **BESIII, ~2.93 fb-1 data taken at ψ(3770), ~923 pb-1 analyzed**
- **signal side: missing neutrino inferred**

$$U = E_{\text{miss}} - c\left|\vec{P}_{\text{miss}}\right| \approx 0$$



U_k(GeV)



U_π(GeV)

BESIII Preliminary

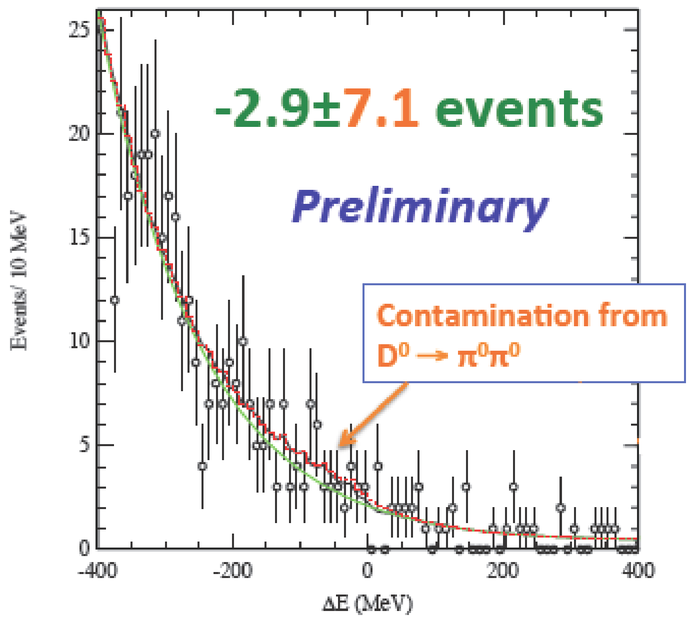
Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \rightarrow K^+ e^- \bar{\nu}$	3.542 ±0.030±0.067	3.55 ±0.04	3.50 ±0.03 ±0.04
$\bar{D}^0 \rightarrow \pi^+ e^- \bar{\nu}$	0.288 ±0.008±0.005	0.289 ±0.008	0.288 ±0.008±0.003

$D^0 \to \gamma\gamma$

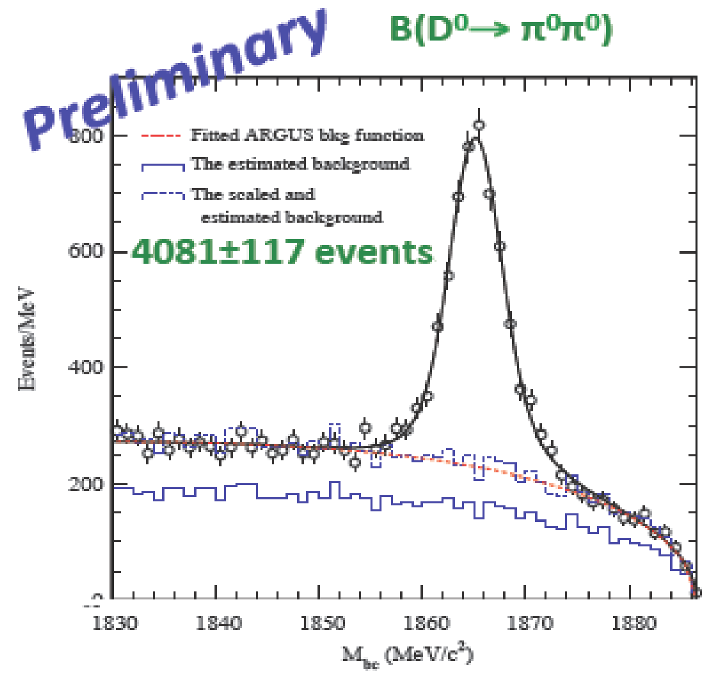
Theoretical predictions: SM (short distance)~ 10^{-11}

Long distance ~10^{-8}

$B(D^0 \to \gamma\gamma)$



$B(D^0 \to \pi^0\pi^0)$



$B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8 \times 10^{-3}$ @90% CL,

with PDG value: $B(D^0 \to \pi^0\pi^0) = 8 \times 10^{-4}$,

BESIII: $B(D^0 \to \gamma\gamma)) < 4.6 \times 10^{-6}$ @90% CL.

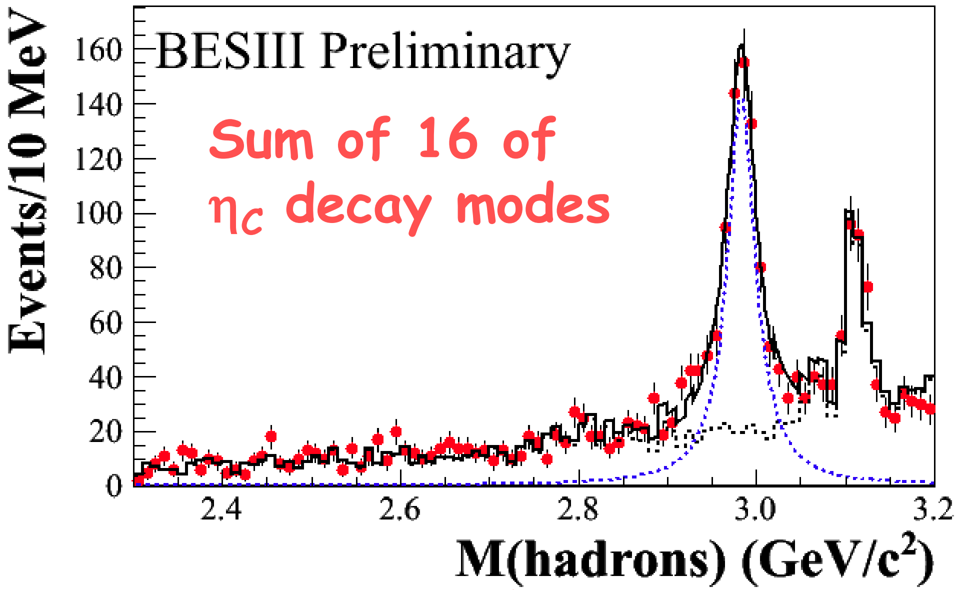
BaBar: $B(D^0 \to \gamma\gamma) < 2.2 \times 10^{-6}$ @90% CL.

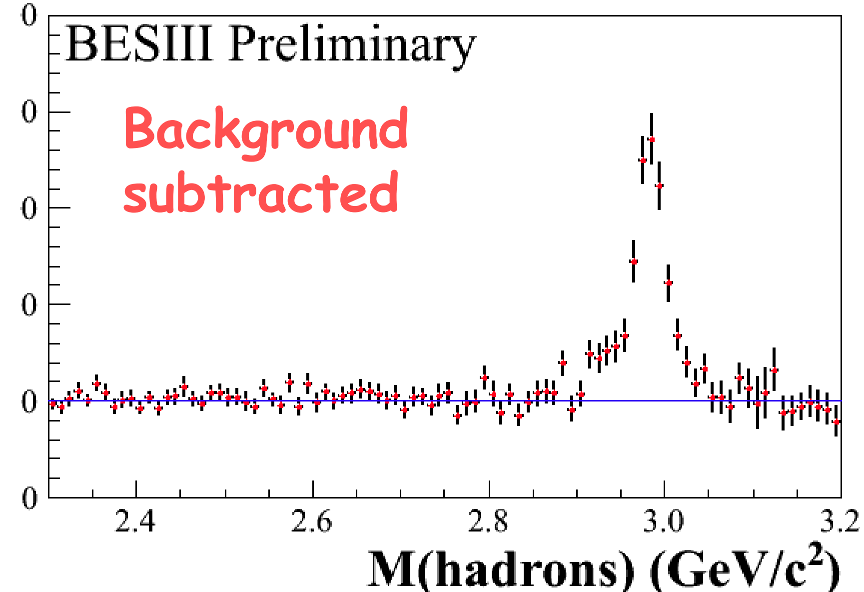
Summary

- 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).
- Charmonium decays
  - first observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S)$ decay.
  - Precision measurements of h_c and $\eta_c(1S)$ and $\eta_c(2S)$ properties
  - First evidence of $\psi' \to \gamma\gamma J/\psi$
  - First measurement of $\chi_{c1} \to \omega\phi$, $\omega\omega$, $\phi\phi$ and $\eta_c(2S) \to VV$, □$\chi_{c0/2} \to \gamma\gamma$
- Light hadron spectroscopy
  - Confirmation of ppbar threshold enhancement
  - Confirmation of X(1835) and observation of two new strucutures
  - Observation of a new structure X(1870)
  - First observation of $\eta(1405) \to f_0(980)\ \pi^0$
  - Observation of two new excited baryonic states
- Charm decays:
  - precision open-charm D physics to come soon.
- **Expect many more results from BESIII in the future!**

Thank you !

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





The η_c lineshape is not distorted in the $h_c \to \gamma\eta_c$

Detail analysis of η_c parameters is ongoing!