Recent results from BESIII

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(IHEP, Beijing)

Workshop on charm physics at threshold
Beijing, IHEP
(21- 23 October, 2011)

Physics activities @ BESIII

Charmonium physics:
- spectroscopy
- transitions and decays

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

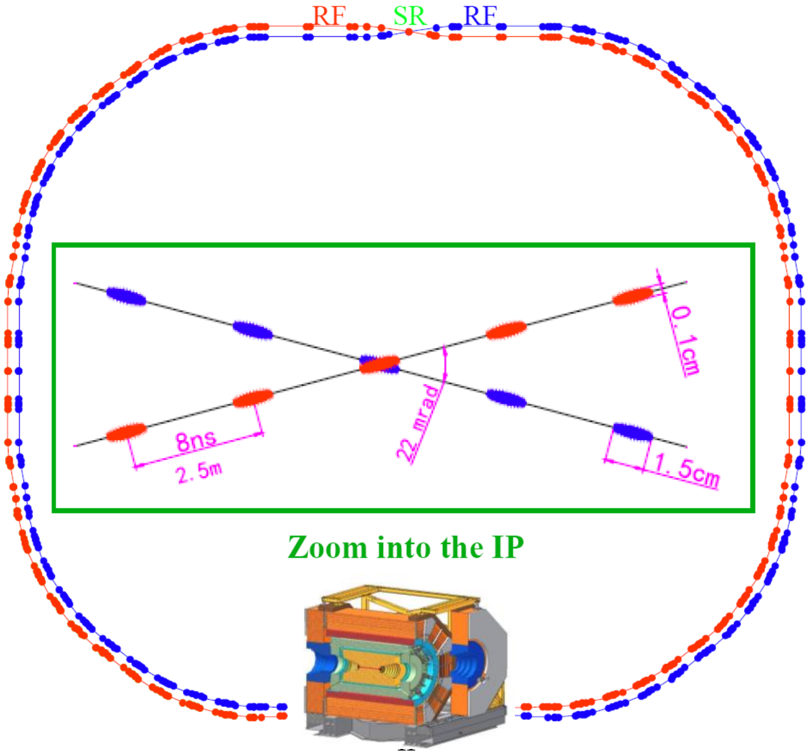
Charm physics:
- (semi)leptonic/ hadronic dec.
- decay const., form factors
- CKM matrix: V_{cd}, V_{cs}
- D^0-D^0bar mixing and *CPV*
- rare/forbidden decays

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

More…

Not in this talk

BEPCII storage rings



Beam energy: 1.0 – 2.3 GeV

Peak Luminosity:

Design: **1×10^{33} cm^{-2}s^{-1}**

Achieved: **0.65×10^{33} cm^{-2}s^{-1}**

Optimum energy: 1.89 GeV

Energy spread: 5.16×10^{-4}

Circumference: 237 m

Beam energy measurement: Using Compton backscattering technique. Accuracy up to **5×10^{-5}**

BESIII Detector

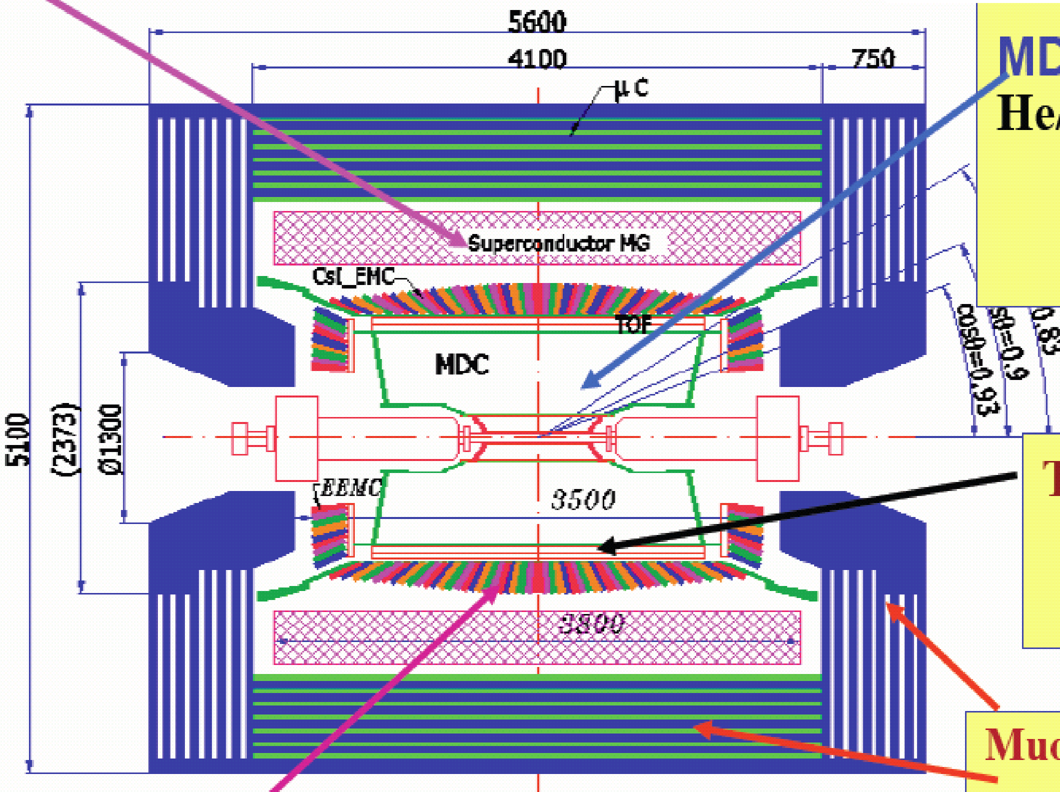
BESIII detector: all new !

CsI calorimeter

Precision tracking

Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σz = 0.6 cm/√E

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

Data Samples

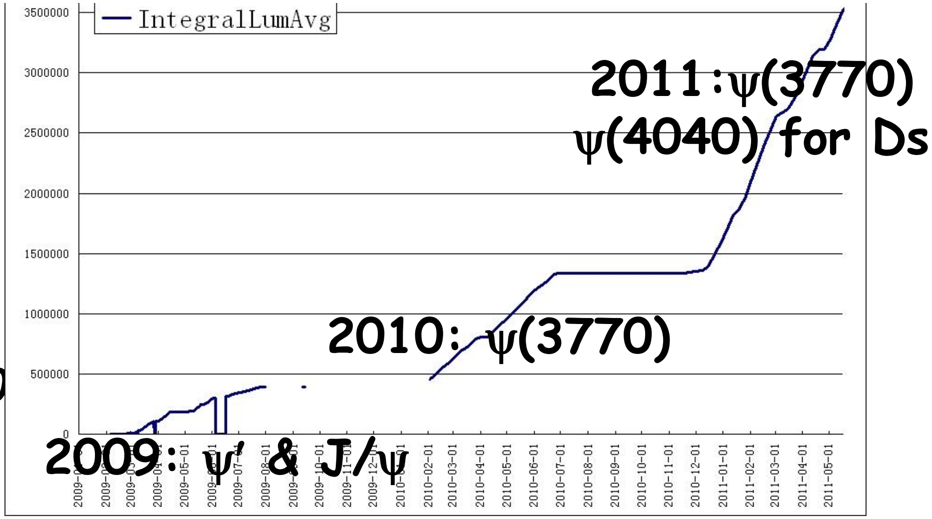
- ***<u>BESIII collected</u>***
  - 2009: **225 M** J/ψ
  - 2009: **106 M** ψ'
  - 2010-11: **2.9 fb^{-1}** ψ(3770)

    (3.5 × CLEOc 0.818 fb^{-1})
  - 2011-05:**477 pb^{-1}** @4010MeV

    (for D_S and XYZ spectroscop

Int. luminosity: 2009.01– 2011.06

~ 4.0 fb^{-1} @ all energies



- ***<u>BESIII data-taking plans</u>***
  - 2012: 1 billon J/ψ, 0.7~1 billon ψ'
  - 2013: @4170 MeV D_S physics; R scan
  - 2014: ψ'/T/ R scan
  - ψ(3770) 5-10 fb^{-1}

Publications

- Charmonium Spectroscopy and Transitions
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi' \to \gamma\gamma J/\psi$ *(to be submitted soon)*
- Charmonium Decays
  - $\psi' \to \gamma\pi^0$, $\gamma\eta$, $\gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to \pi^0\pi^0$, $\eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \to \gamma\rho$, $\gamma\omega$, $\gamma\phi$ *(PRD83,112005(2011))*
  - $\chi_{cJ} \to \omega\omega$, $\phi\phi$, $\omega\phi$ *(PRL 107, 092001(2011))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - $\chi_{cJ} \to ppK^+K^-$ (PRD 83, 112009(2011))
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(PRD 83, 012003 (2011))*
  - *Search for CP/P violation process pseudoscalar decays into pipi* (PRD 84, 032006(2011)).
- Light Quark States
  - $a_0(980)$ – $f_0(980)$ mixing *(PRD 83, 032003 (2011))*
  - X(1860) in $J/\psi \to \gamma pp$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$ *(PRL 106, 072002 (2011))*
  - X(1870) in $J/\psi \to \omega\eta\pi^+\pi^-$ *(accepted by PRL)*
  - *PWA on* $J/\psi \to \gamma pp$ *(to be submitted soon)*
  - *PWA on* $\psi' \to \eta pp$ *(to be submitted soon)*

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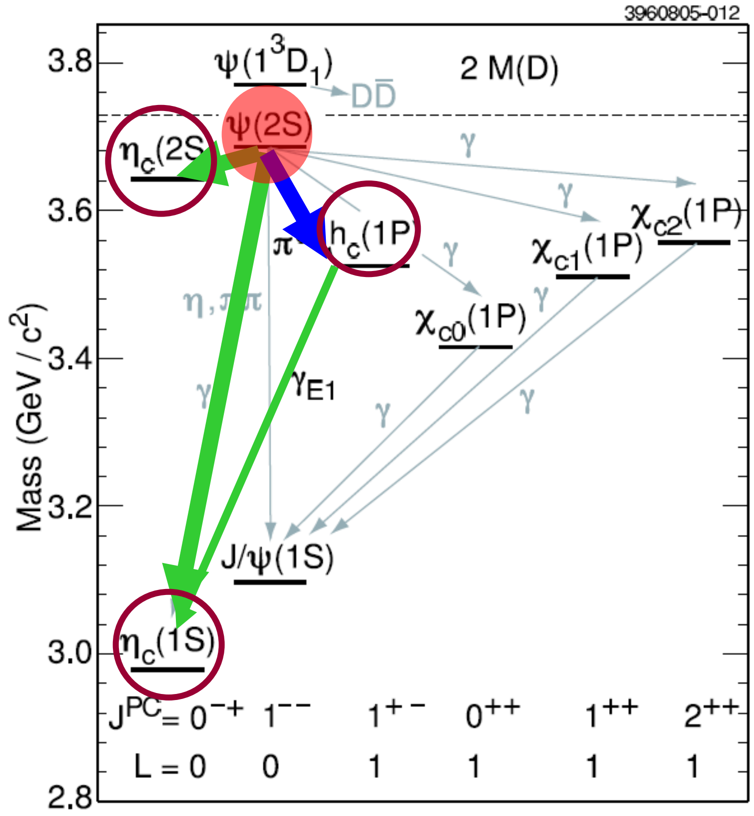
More…

Charmonium states
h_c , $\eta_c(1S)$, $\eta_c(2S)$



$h_c(^1P_1)$

- Spin singlet P wave (S=0, L=1)
- Potential model: if non-vanishing spin-spin interaction,

$\Delta M_{hf}(1P) = M(h_c) - \langle m(1\,^3P_J)\rangle \neq 0$

where $\langle m(1\,^3P_J)\rangle = [(M(\chi_{c0})+3M(\chi_{c1})+5M(\chi_{c2})]/9$,

- E835 found evidence for h_c in $p\bar{p} \rightarrow h_c \rightarrow \gamma\eta_c$
- CLEOc observed h_c in $ee \rightarrow \psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$ *PRL 101 182003 (2008)*

$\Delta M_{hf}(1P)=0.08\pm0.18\pm0.12$ MeV/c^2

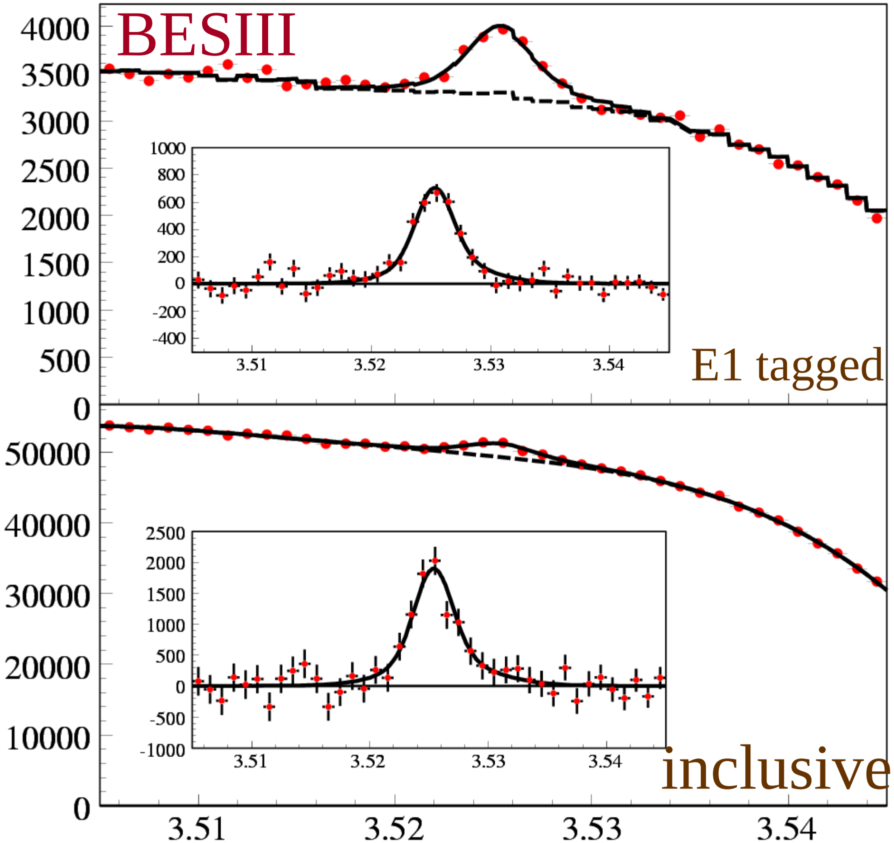
Consistent to 1P hyperfine splitting of 0.

__Theoretical prediction:__

$BF(\psi(2S) \rightarrow \pi^0 h_c) = (0.4\text{-}1.3) \times 10^{-4}$
$BF(h_c \rightarrow \gamma\eta_c)$ =48% (NRQCD)
$BF(h_c \rightarrow \gamma\eta_c)$ =88% (PQCD)
Kuang, PR D65 094024 (2002)

$BF(h_c \rightarrow \gamma\eta_c)$ =38%
Godfrey and Rosner, PR D66 014012(2002)

$\psi(2S) \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$



BESIII: PRL 104 132002 (2010)

Mass = **3525.40±0.13±0.18** MeV/c^2

Width = **0.73±0.45±0.28** MeV

<1.44 MeV @90%

CLEOc: PRL 101 182003 (2008)

Mass = **3525.28±0.19±0.12** MeV

Width: fixed at 0.9 MeV

Hyperfine mass splitting

$\Delta M_{hf}(1P) = M(h_c) - \langle m(1\ ^3P_J)\rangle$

BESIII: ***0.10±0.13±0.18*** MeV/c^2

CLEOc: ***0.02±0.19±0.13 MeV/c²***

By combining inclusive results with E1-photon tagged results

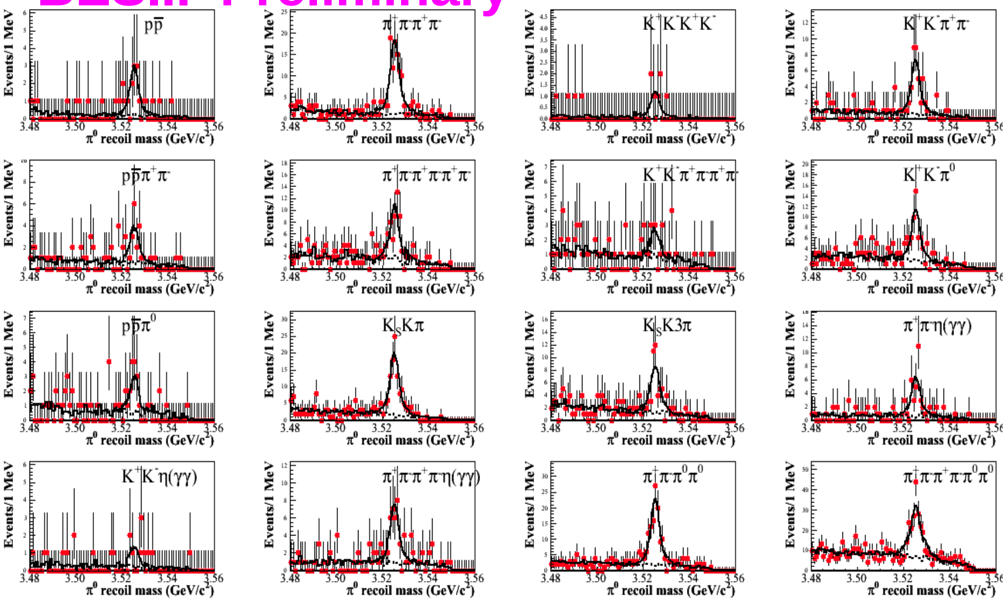
BF($\psi' \rightarrow \pi^0 h_c$) = **(8.4±1.3±1.0) ×10⁻⁴**

BF($h_c \rightarrow \gamma\, \eta_c$) = **(54.3±6.7±5.2)%**

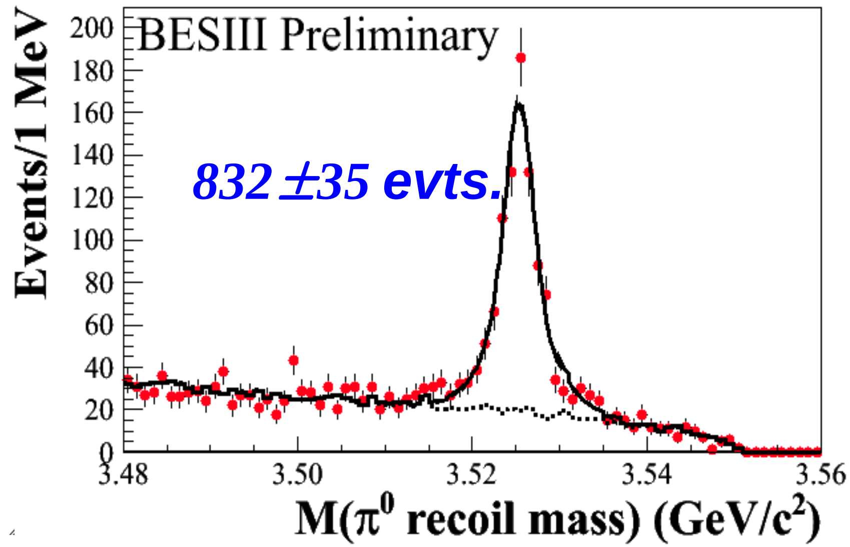
Agree with prediction from Kuang, Godgrey, Dude et al.

$\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$, η_c exclusive decays

BESIII Preliminary



Summed distribution



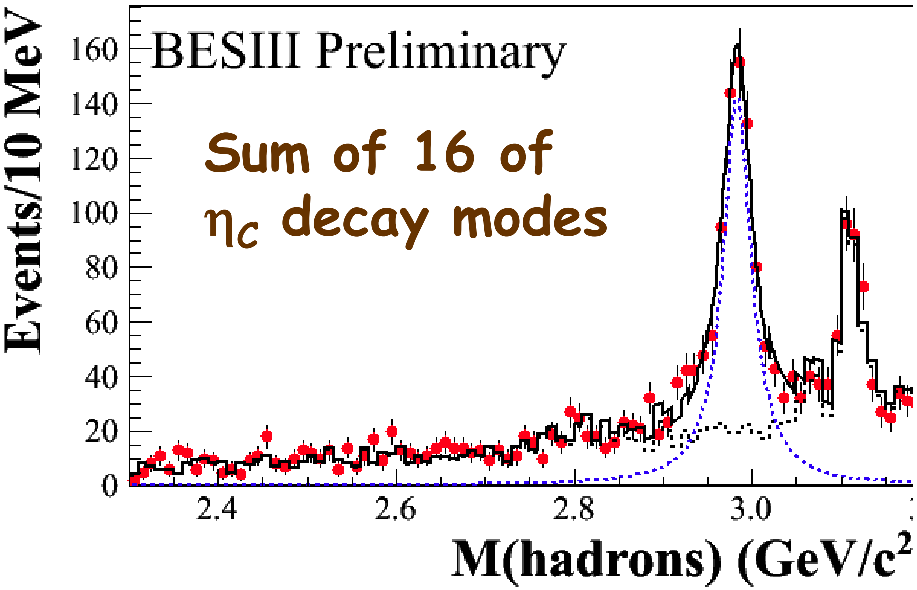
Simultaneous fit to π^0 recoiling mass
χ^2/d.o.f. = 32/46
Mass = **3525.31±0.11±0.15** MeV/c^2
Width = **0.70±0.28±0.25** MeV

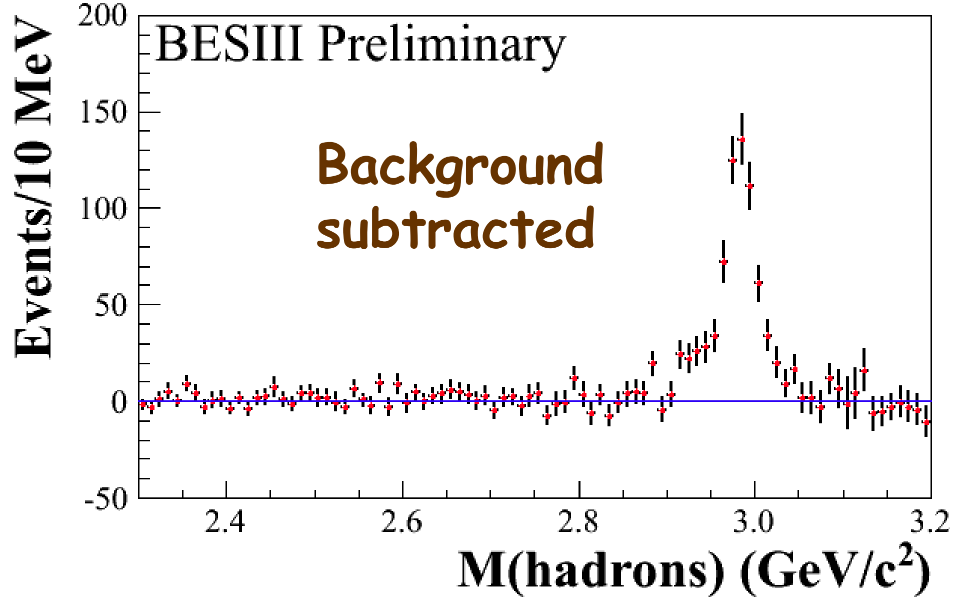
Consistent with BESIII inclusive results
Mass = **3525.40±0.13±0.18** MeV/c^2
Width = **0.73±0.45±0.28** MeV

CLEOc exclusive results
Mass =**3525.21±0.27±0.14** MeV/c^2
evts. =**136±14**

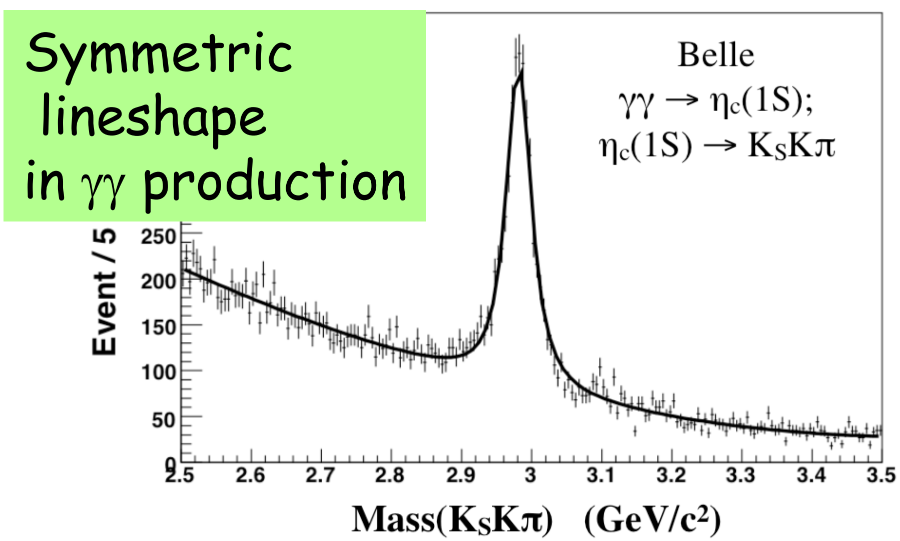
BESIII: PRL 104 132002 (2010)
CLEOc: PRL 101 182003 (2008)

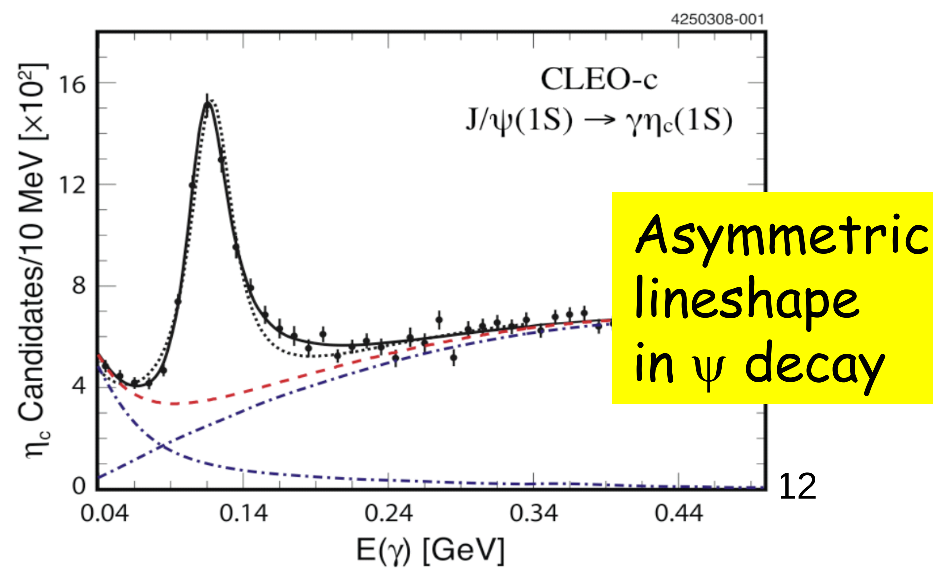
η_c lineshape from $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$





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



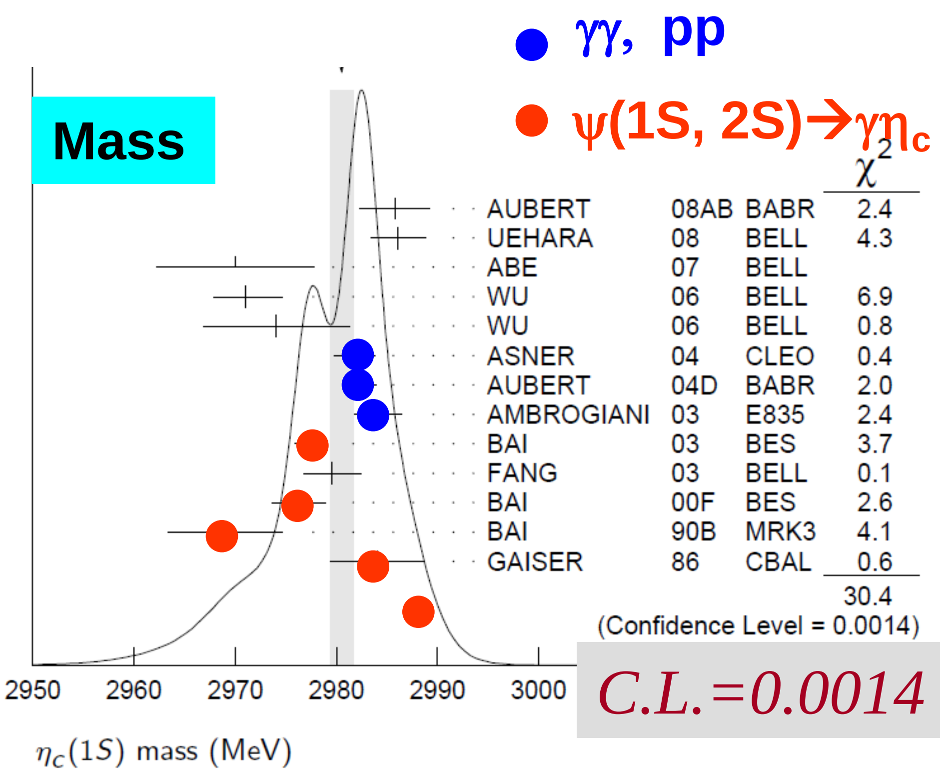


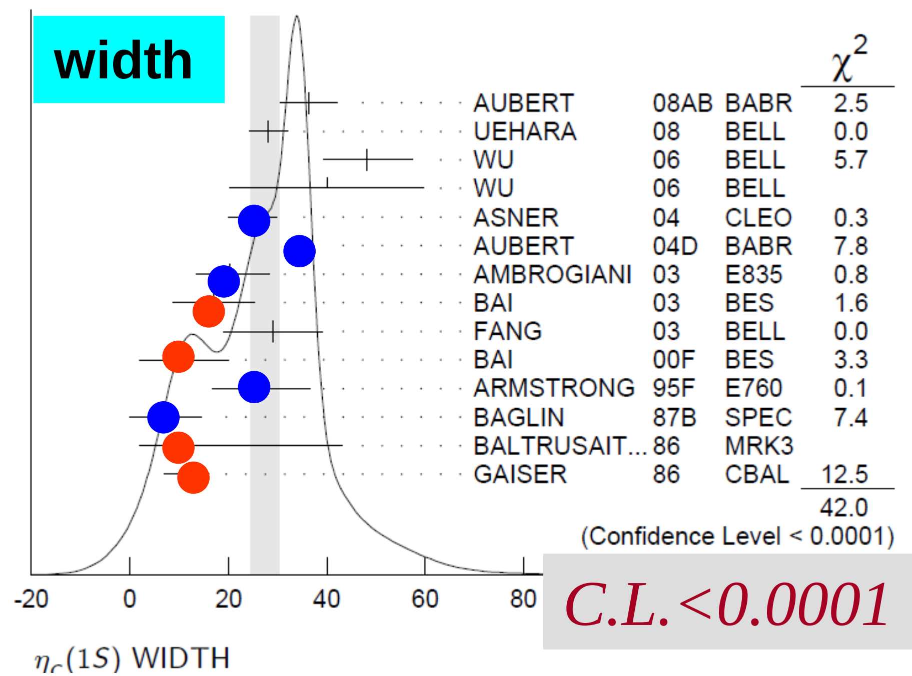
$\eta_c(1S)$

- The lowest lying S-wave spin singlet charmonium, discovered in 1980 by MarkII
- Parameters:

  J/ψ radiative transition: M ~ 2978.0MeV/c^2, Γ ~ 10MeV

  γγ process: M = 2983.1±1.0 MeV/c^2, Γ = 31.3±1.9 MeV
- CLEOc found the distortion of the η_c line shape in ψ' decays.

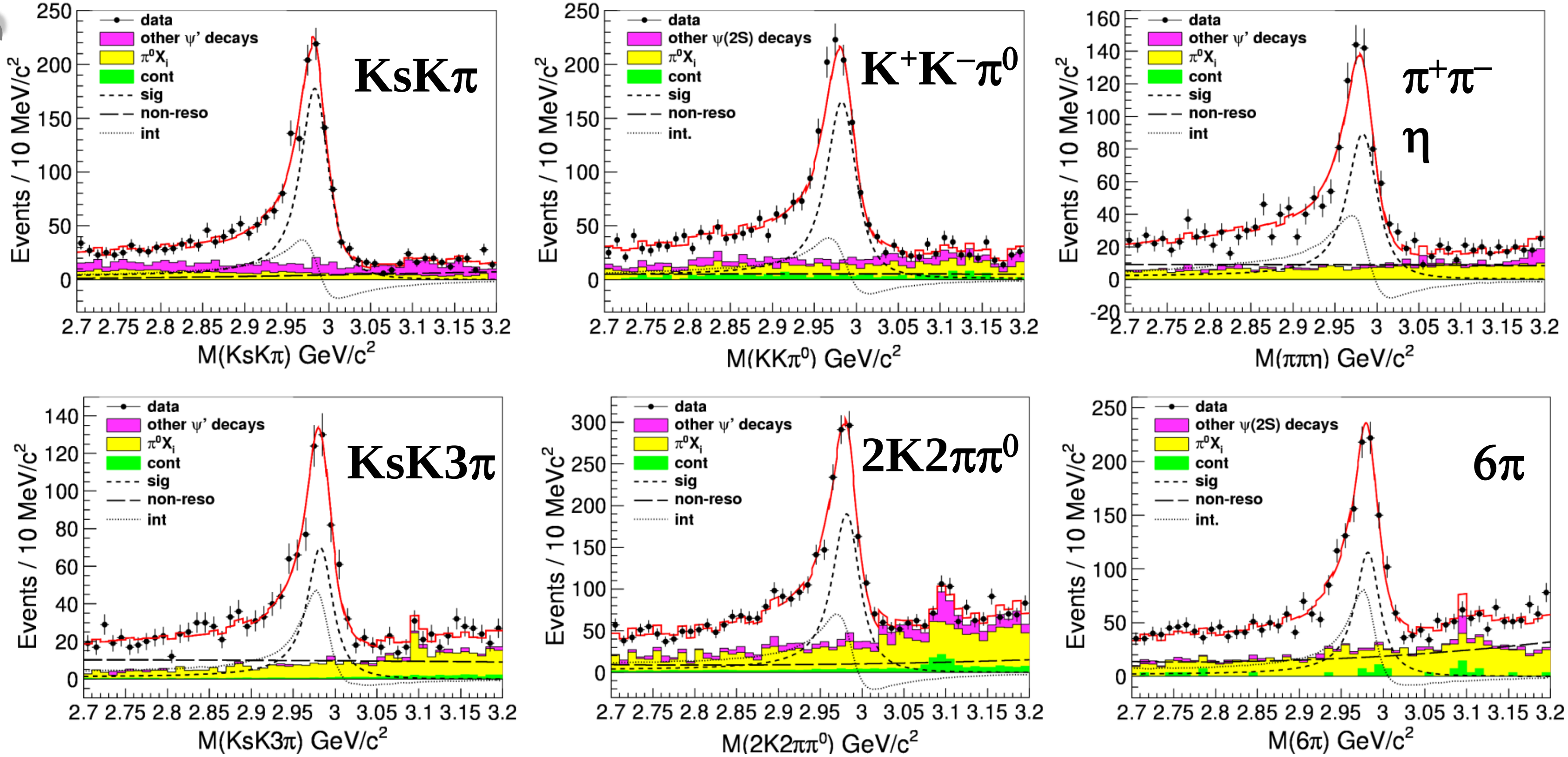




$\psi' \rightarrow \gamma\eta_c$, η_c exclusive decays

Possible interference has been take into account

BESIII Preliminary



Relative phase ϕ values from each mode are consistent within 3σ,

➔ use a common phase value in the simultaneous fit.

M: **2984.4±0.5±0.6** MeV/c^2

width: **30.5±1.0±0.9** MeV

ϕ: **2.35±0.05±0.04** rad

$\eta_c(2S)$

Crystal Ball's "first observation" of $\psi' \to \gamma X$ never been confirmed
PRL 48 70 (1982)

Observed in different production mechanisms,

1. $B \to K\eta_c(2S)$
2. $\gamma\gamma \to \eta_c(2S) \to KK\pi$
3. double charmonium production

Belle: PRL 89 102001 (2002)
CLEOc: PRL 92 142001 (2004)
Belle: NPPS.184 220 (2008); PRL 98 082001(2007)
BaBar: PRL 92 142002 (2004); PR D72 031101(2005)
BaBar: PR D84 012004 (2011)

M1 transition $\psi' \to \gamma\eta_c(2S)$

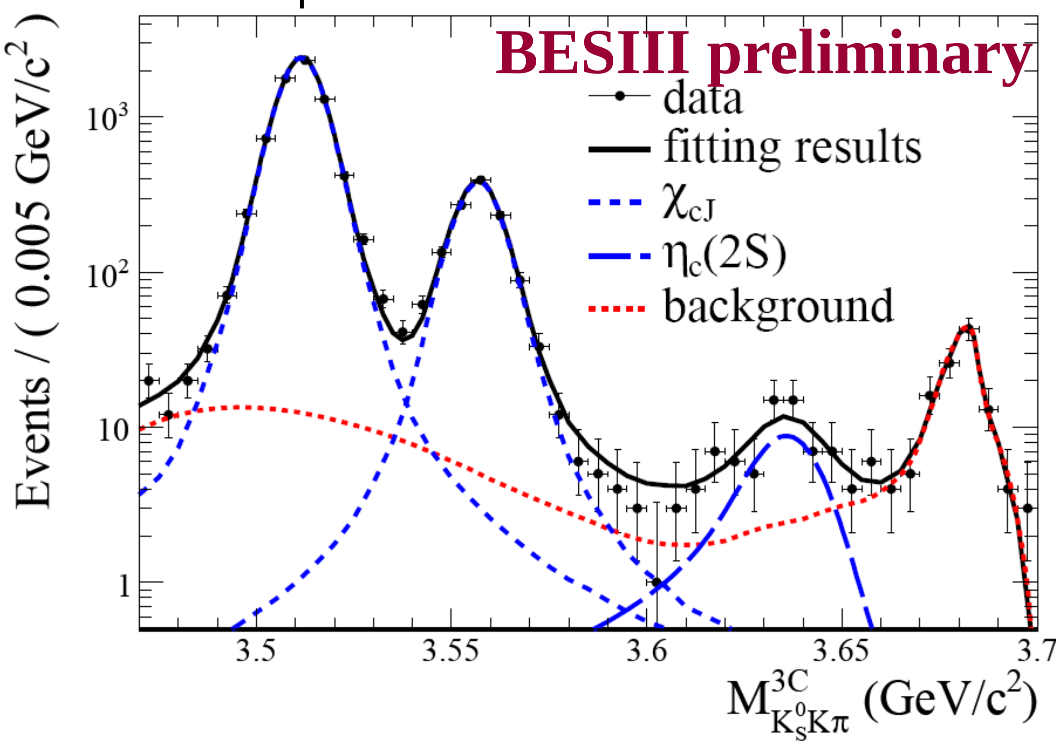
CLEO found no signals in 25M ψ'.

$BF(\psi' \to \gamma\eta_c(2S)) < 7.6 \times 10^{-4}$ CLEO: PRD 81 052002 (2010)

Experimental challenge : search for photons of 50 MeV

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

106M ψ′



Width fixed to 12 MeV (world ave.)

Events: **50.6±9.7**; Significance >6.0σ!

Mass = **3638.5±2.3±1.0** MeV/c^2

BF($\psi' \to \gamma\eta_c(2S) \to \gamma K_s K\pi$)

=(2.98±0.57±0.48)×10^{-6}

BF($\eta_c(2S) \to K\bar{K}\pi$)=(**1.9±0.4±1.1**)%

BaBar**:** PR D78 012006 (2008)

BF($\psi' \to \gamma\eta_c(2S)$)

= (4.7±0.9±3.0)×10^{-4}

CLEOc: <**7.6×10^{-4}**

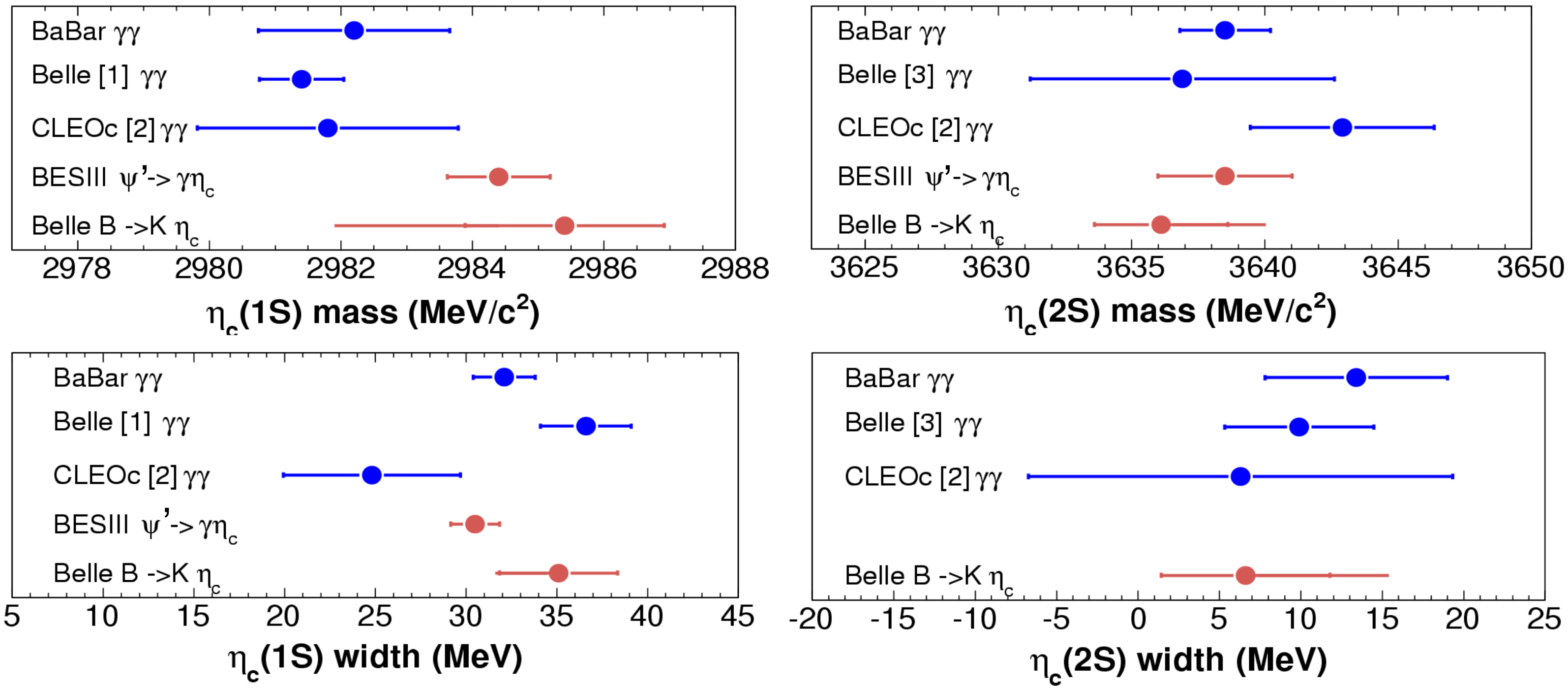
PR D81 052002 (2010)

Potential model predicts

(0.1” 6.2)×10^{-4}

PRL 89 162002 (2002)

Summary for $\eta_c / \eta_c(2S)$



[1] NPPS 184 220(2008); [2] PRL 92 142001; [3] PoS ICHEP2010:162, 2010

Hyperfine splitting: $\Delta M(1S)$ = **112.5 ± 0.8** MeV;

$\Delta M(2S)$ = **47.6 ± 1.7** MeV

$$\Delta M_{hf}(nS) = M(n^3S_1) - M(n^1S_0) = \frac{32\pi\alpha_s(m_q)}{9}(\psi(0)/m_q)^2 \quad , L=0 \rightarrow$$

$\Delta M(1S) \approx$ 118 MeV
$\Delta M(2S) \approx$ 68 MeV

$$\Delta M_{hf}(nL) = M(n^3L) - M(n^1L) = 0, \qquad L \neq 0 \rightarrow$$

$\Delta M(1P)$ = 0 MeV

K. Seth hadron11

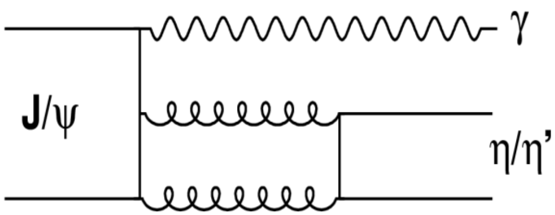
Study X(3872) at BESIII

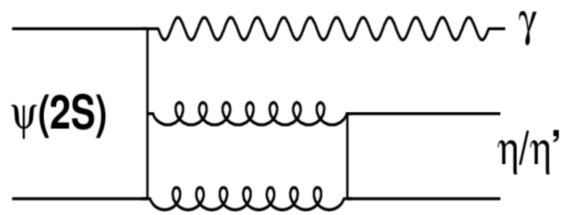
- 477 pb-1 data taken @ 4.01GeV
- $\psi(3S) \rightarrow \gamma X(3872)$
  - $E\gamma$~170 MeV, very narrow peak in photon spectrum (energy resolution ~ 4.5 MeV)
- $\psi(3S) \rightarrow \gamma$ + X/Y/Z(3940)/X(3915)
  - $E\gamma$=100~125 MeV, narrow peaks in photon spectrum (width ~ 30 MeV)
- Analysis is on going

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

$V \to \gamma P$ test various mechanisms:

Vector meson Dominance Model (VDM); Couplings & form factor;
Mixing of η-η' (-η_c);





LO-pQCD predicts R_1 🕓 R_2

PRP 112 173 (1984)

$$R_n \equiv \frac{BF(\psi(nS) \to \gamma\eta)}{BF(\psi(nS) \to \gamma\eta')}$$

CLEOc found R_2 surprisingly small !

PR D79 111101(2009)

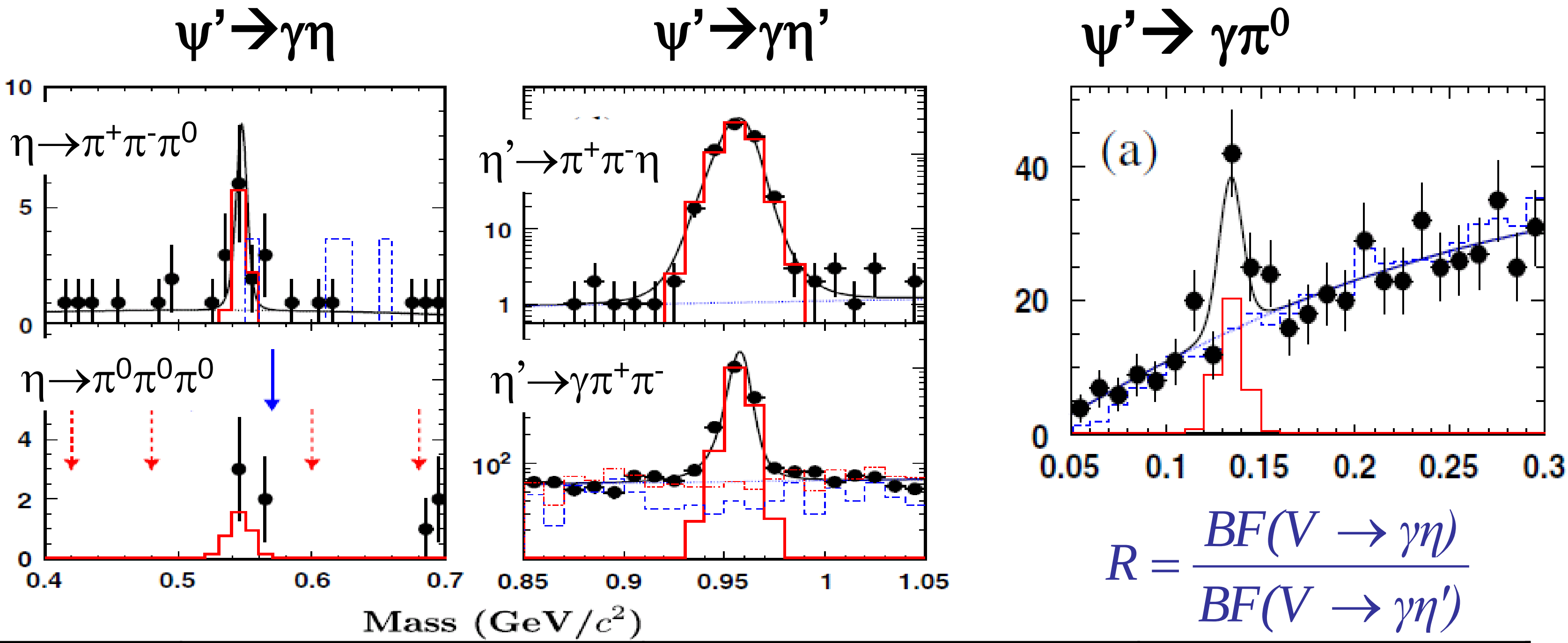
R_1 = (21.1 ± 0.9)% R_2 < 1.8% at 90% CL

Other processes contribute?
Or related to the "$\rho\pi$ puzzle"?

$$Q = \frac{BF(\psi' \to X)}{BF(J/\psi \to X)} \sim 12\%$$

Results from BESIII

BESIII PRL 105, 261801 (2010)



$$R = \frac{BF(V \to \gamma\eta)}{BF(V \to \gamma\eta')}$$

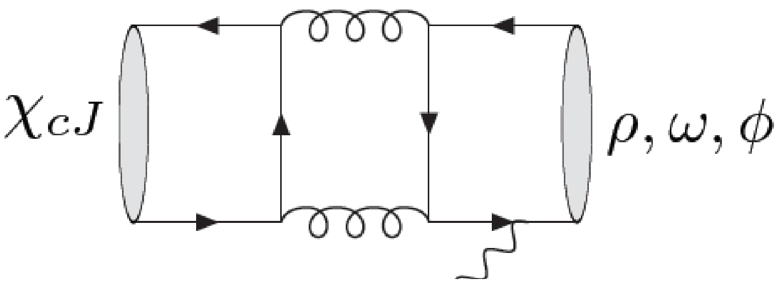
Mode	$BF(\psi')$ [x10^{-6}]	PDG $BF(J/\psi)$ [x10^{-4}]	Q (%)
$\gamma\pi^0$	1.58 ± 0.42	0.35 ± 0.03	4.5 ± 1.3
$\gamma\eta$	1.38 ± 0.49	11.04 ± 0.34	0.13 ± 0.04
$\gamma\eta'$	126 ± 9	52.8 ± 1.5	2.4 ± 0.2
$R_{1/2}$	$(1.10\pm0.39)\%$ <<	$(20.9 \pm 0.9)\%$	-

VDM associate with Mixing of η_c-$\eta(\eta')$?

Phys. Lett. B697, 52 (2011)

Large $\chi_{cJ} \to \gamma V(\rho, \omega, \phi)$

pQCD prediction much lower than experiment



- Information of C-even state
- Two gluon coupling
- Possible glue-ball or hybrid states
- Hadronization

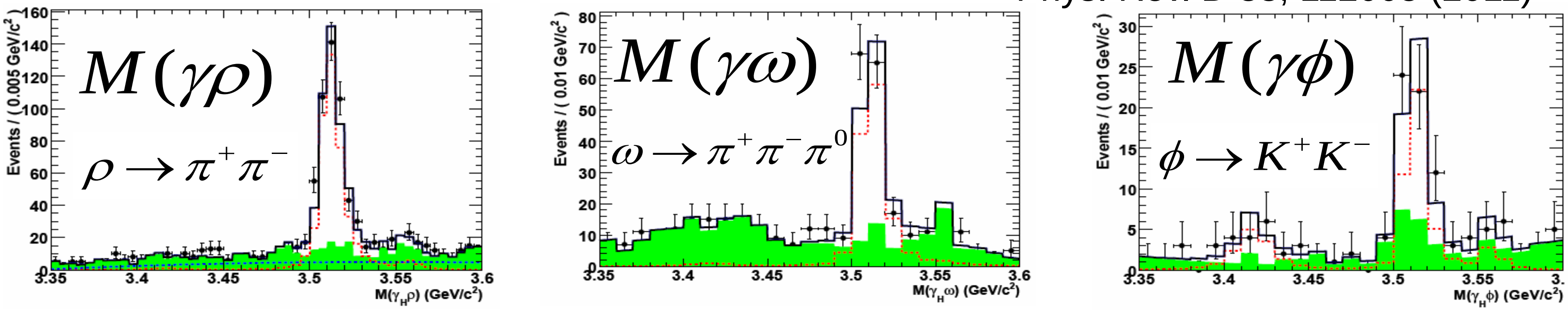
Mode	CLEO[1]	pQCD[2]	QCD[3]	QCD+QED[3]
$\chi_{c0} \to \gamma\rho^0$	< 9.6	1.2	3.2	2.0
$\chi_{c1} \to \gamma\rho^0$	$243 \pm 19 \pm 22$	14	41	42
$\chi_{c2} \to \gamma\rho^0$	< 50	4.4	13	38
$\chi_{c0} \to \gamma\omega$	< 8.8	0.13	0.35	0.22
$\chi_{c1} \to \gamma\omega$	$83 \pm 15 \pm 12$	1.6	4.6	4.7
$\chi_{c2}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

In unit of 10^{-6}

1. PRL 101,151801 (2008). 2. Chin. Phys. Lett. 23, 2376 (2006). 3. hep-ph/0701009

Results form BESIII

Phys. Rev. D 83, 112005 (2011)



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±16**
$\chi_{c2} \to \gamma\rho^0$	< 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±5.6**
$\chi_{c2} \to \gamma\omega$	< 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±2.0**
$\chi_{c2} \to \gamma\phi$	< 13	1.1	3.3	6.5	**<8.1**

First observation

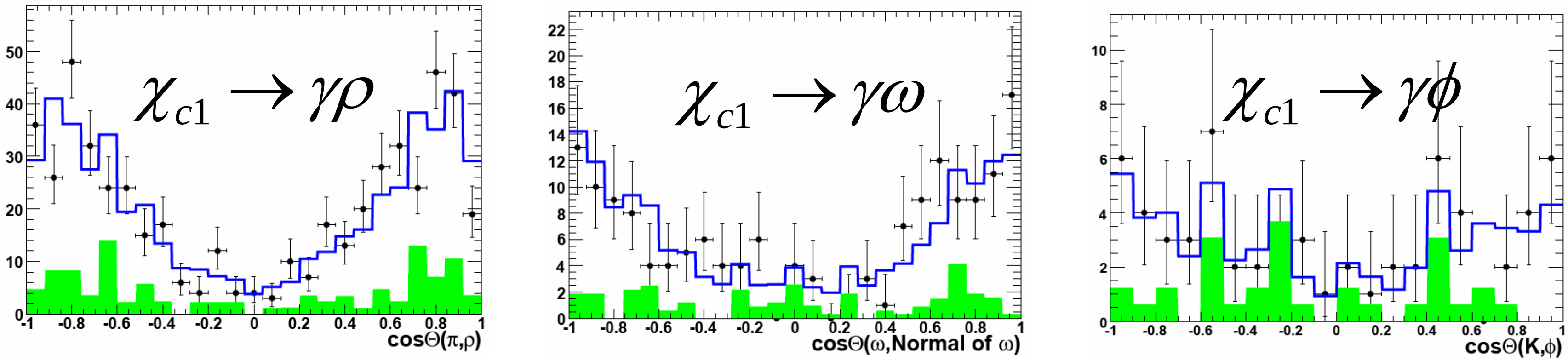
An non-pQCD explanation: "hadronic loop correction"

arXiv:1005.0066; EPJC70, 177-182 (2010);

Polarization of $\chi_{c1} \to \gamma V(\rho, \omega, \phi)$

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

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



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

Longitudinal polarization dominates, consistent with theoretical prediction

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

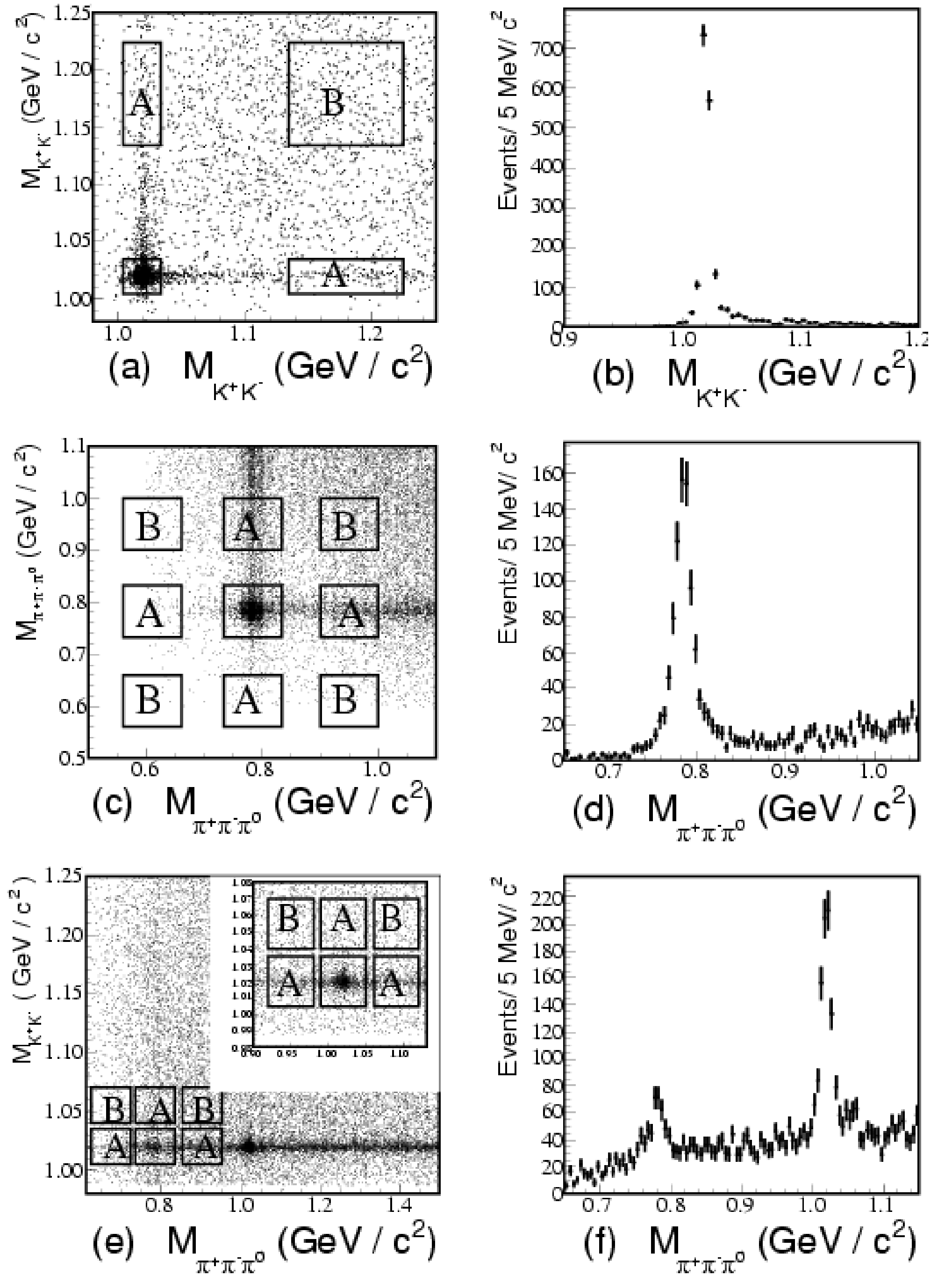
$\chi_{cJ}\rightarrow VV(V:\omega,\ \phi)$

- $\chi_{cJ}\rightarrow \phi\phi$ 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

Reconstruct

$\phi\rightarrow K^+K^-$

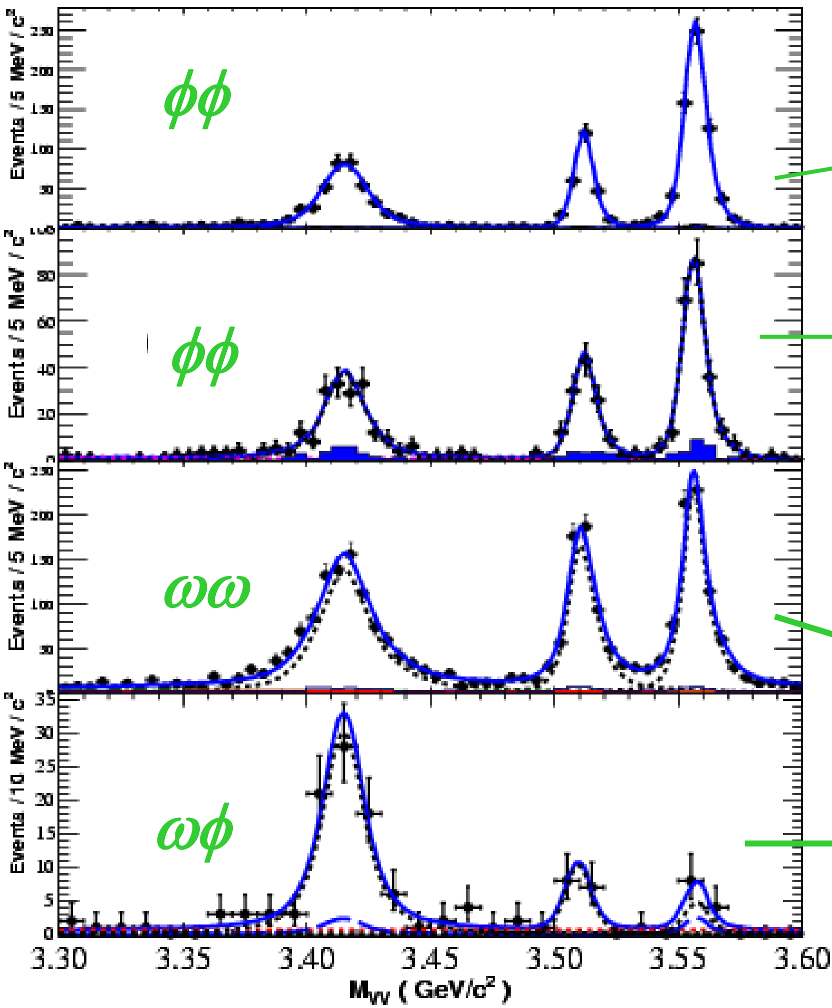
$\omega\rightarrow\pi^+\pi^-\pi^0$



BESIII PRL 107 091803(2011)

$\chi_{cJ} \rightarrow VV$ at BESIII

arXiv:1104.5068



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

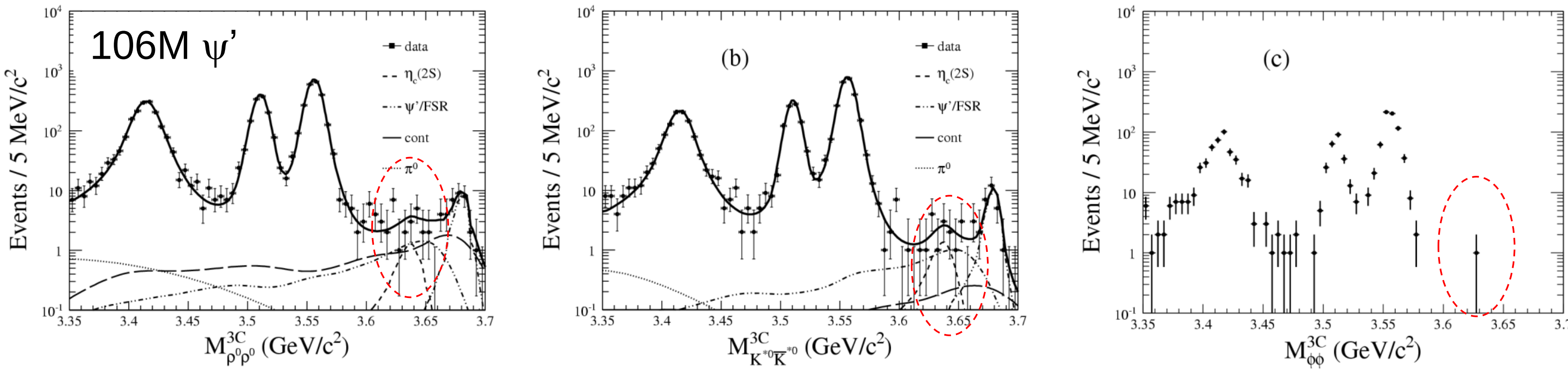
First observation

Long distance transitions could contribute via the intermediate meson loops.

PR D81 014017 (2010)
PR D81 074006 (2010)

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

Test for the "Intermediate charmed meson loops"



	$BF(\psi'\rightarrow\gamma\eta_c'\rightarrow\gamma VV)$ (10^{-7})	$BF(\eta_c'\rightarrow VV)$ (10^{-3})	Theory $BF(\eta_c'\rightarrow VV)$ (10^{-3})
$\rho^0\rho^0$	<11.4	<3.1	6.4 ” 28.9
$K^{*0}K^{*0}$	<19.4	<5.3	7.9 ” 35.8
$\phi\phi$	<7.8	<2.0	2.1 ” 9.8

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

arXiv: 1010.1343

Physics activities @ BESIII

Charmonium physics:
- spectroscopy
- transitions and decays

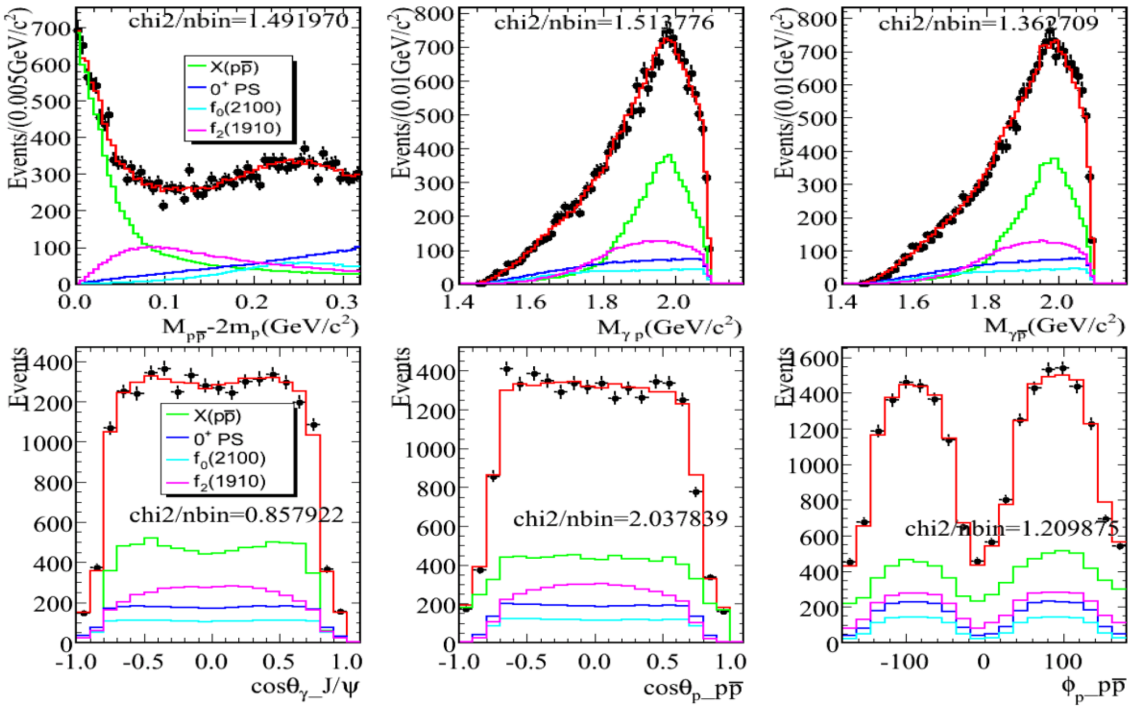
Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic/hadronic dec.
- decay const., form factors
- CKM matrix: V_{cd}, V_{cs}
- D^0-D^0bar mixing and *CPV*
- rare/forbidden decays

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

More…

PWA near $p\bar{p}$ threshold in $J/\psi \to \gamma p\bar{p}$



$f_0(2100)$ / $f_2(1910)$ fixed to PDG.
Signif. of X(1835) >>30σ

- 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.

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

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

$$M = 1832 \pm 5(\text{stat})^{+15}_{-17}(\text{syst}) \pm 19(\text{mod})\ \text{MeV}/c^2$$

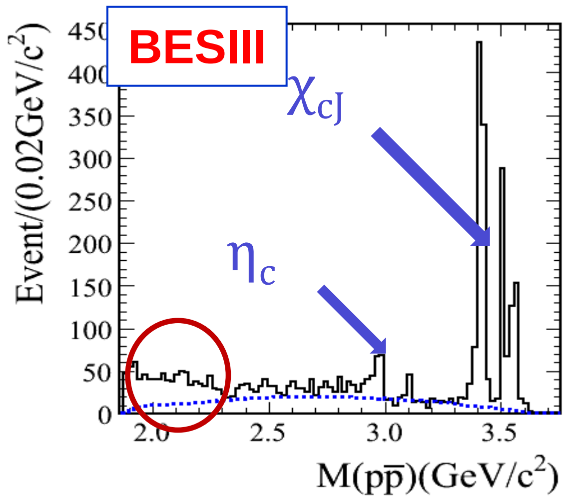
$$\Gamma = 13 \pm 20(\text{stat})^{+8}_{-26}(\text{syst}) \pm 4(\text{mod})\text{MeV}/c^2 \ \text{ or } \Gamma < 45\text{MeV}/c^2 \ @90\%\ C.L.$$

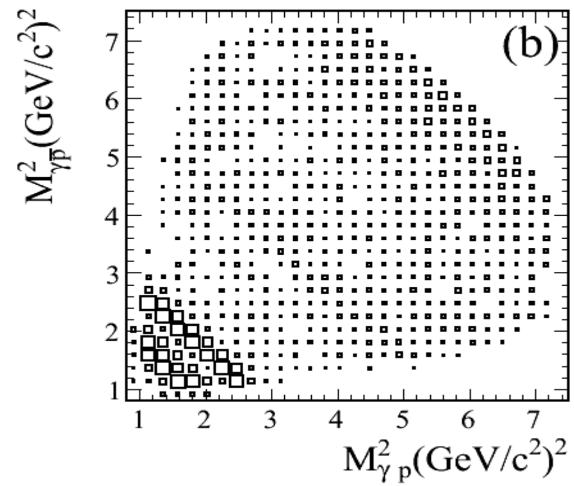
$$B(J/\psi \to \gamma X(p\bar{p}))B(X(p\bar{p}) \to p\bar{p}) = (9.0 \pm 0.7(\text{stat})^{+1.5}_{-4.8}(\text{syst}) \pm 2.3(\text{mod})) \times 10^{-5}$$

Different FSI models → Model dependent uncertainty

PWA on the $p\bar{p}$ mass threshold structure in $\psi' \to \gamma p\bar{p}$

Obviously different line shape of $p\bar{p}$ mass spectrum near threshold from that in J/ψ decays





Preliminary PWA results:

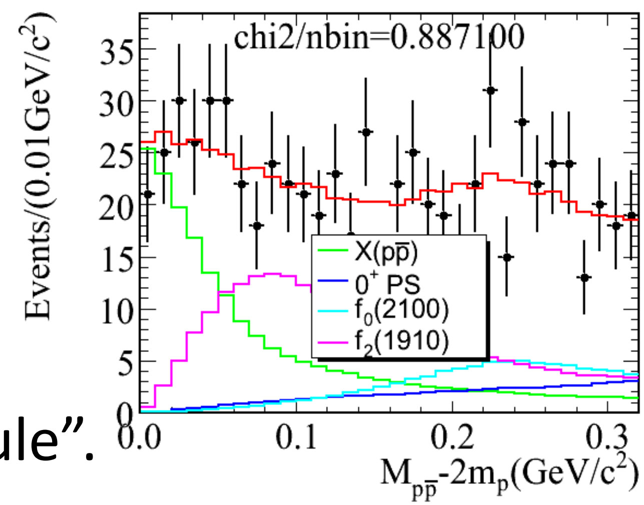
- Signif. of X($p\bar{p}$) is larger than 6.9σ.
- The production ratio R:

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

$$= (5.08 \pm 0.56(\text{stat})^{+0.72}_{-3.83}(\text{syst}) \pm 0.12(\text{mod}))\%$$

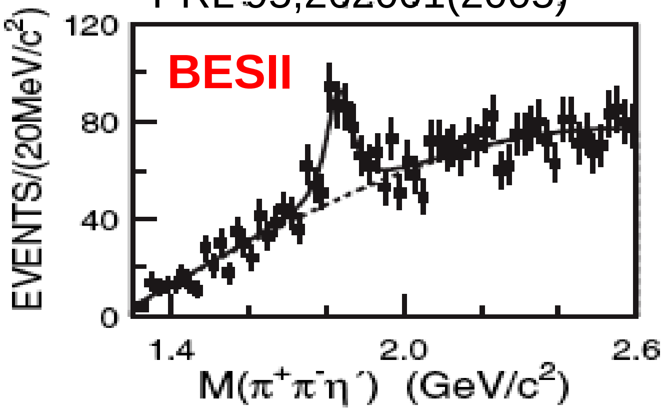
- It is suppressed compared with "12% rule".

PWA Projection:



X(1835) and two new structures

PRL 95,262001(2005)

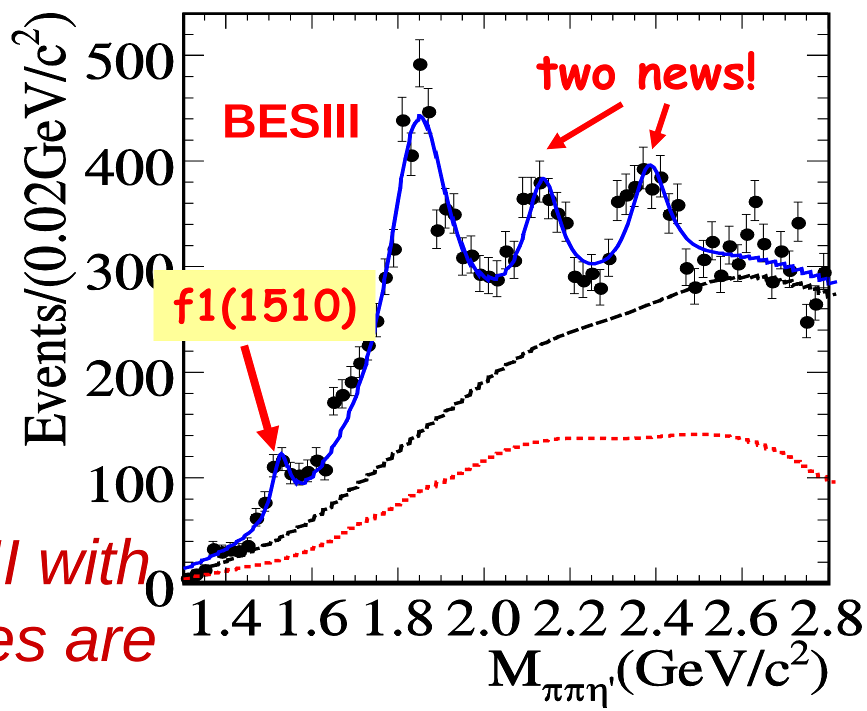


$BESII\ result$(Stat. sig. ~ 7.7σ):

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

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

PRL 106, 072002(2011)



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

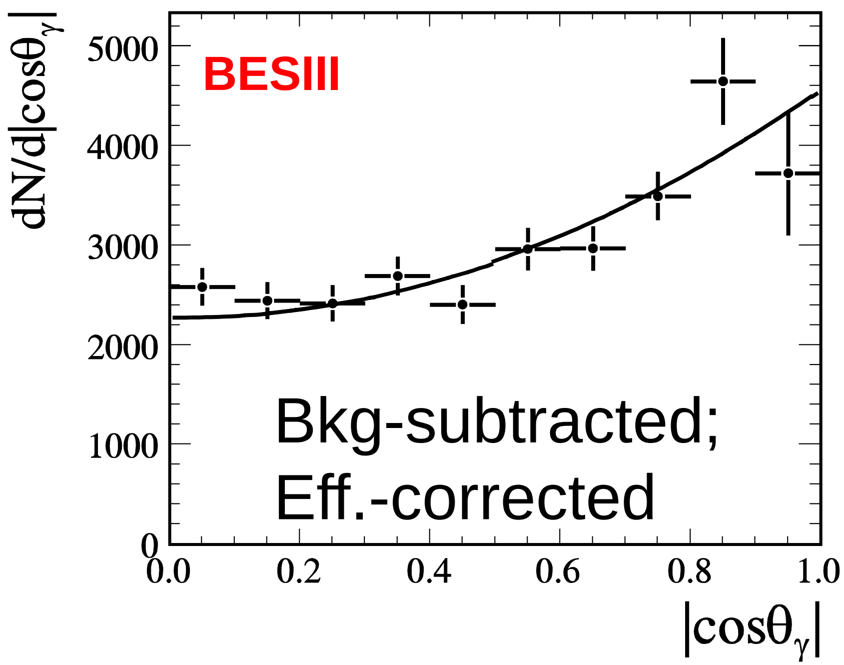
$\eta' \to \eta\pi^+\pi^-$

$\eta' \to \gamma\rho$

X(1835) is confirmed at BESIII with 225 M J/ψ. Two new structures are observed.

BESIII fit results (225 M J/ψ)

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

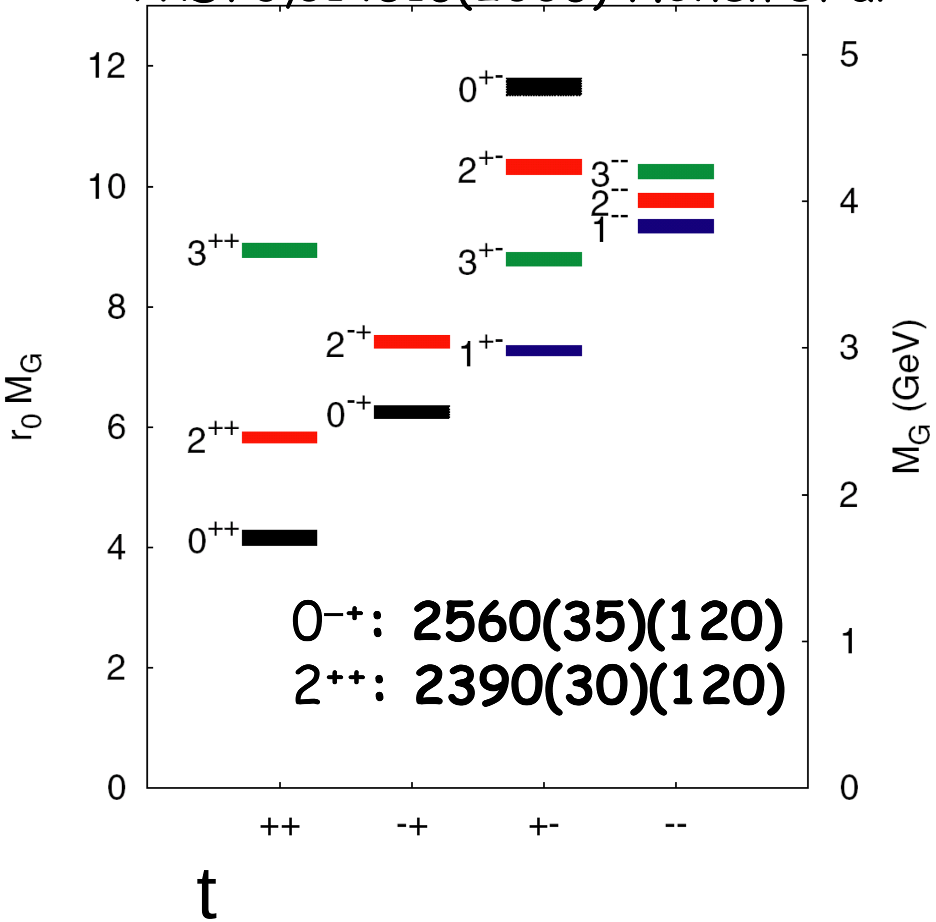


X(1835) consistent with 0^{-+}, but the others are not ruled out.

PWA is needed to understand these structures.

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/c^2 region, it is interesting since:

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

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

✓ Nature of X(2120)/X(2370)

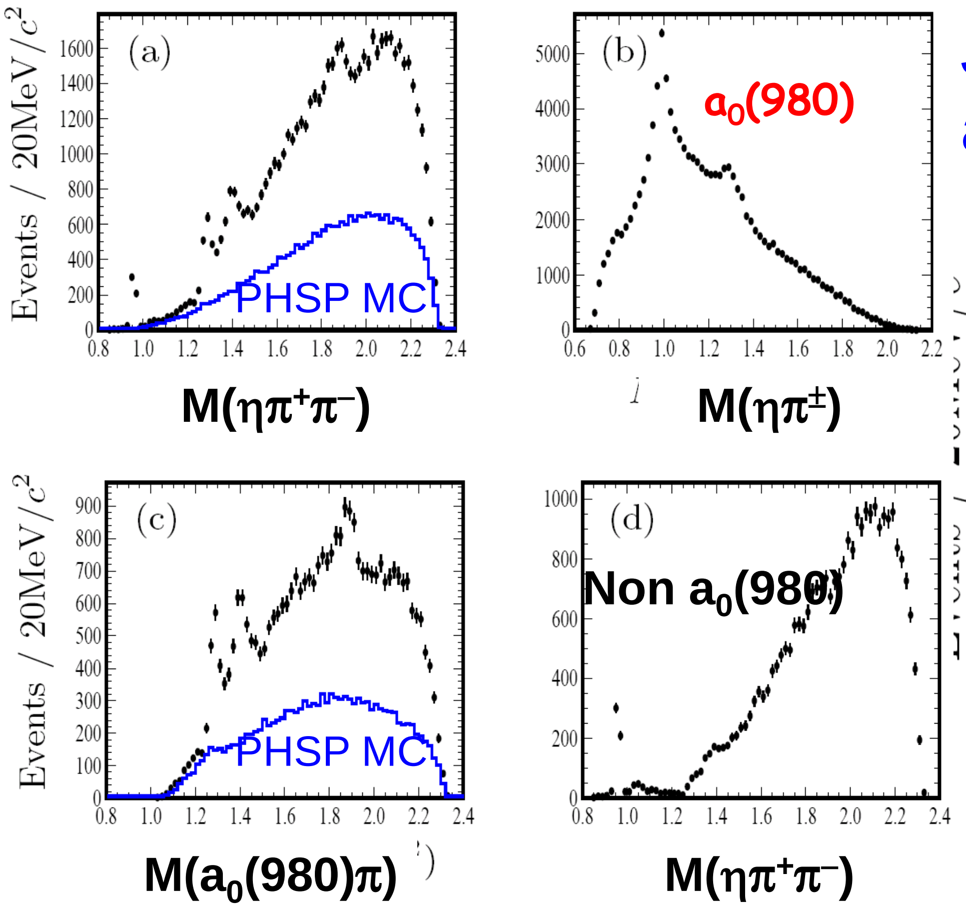
pseudoscalar glueball ?

η/η' excited states?

PRD82,074026,2010 J.F. Liu, G.J. Ding and M.L.Yan

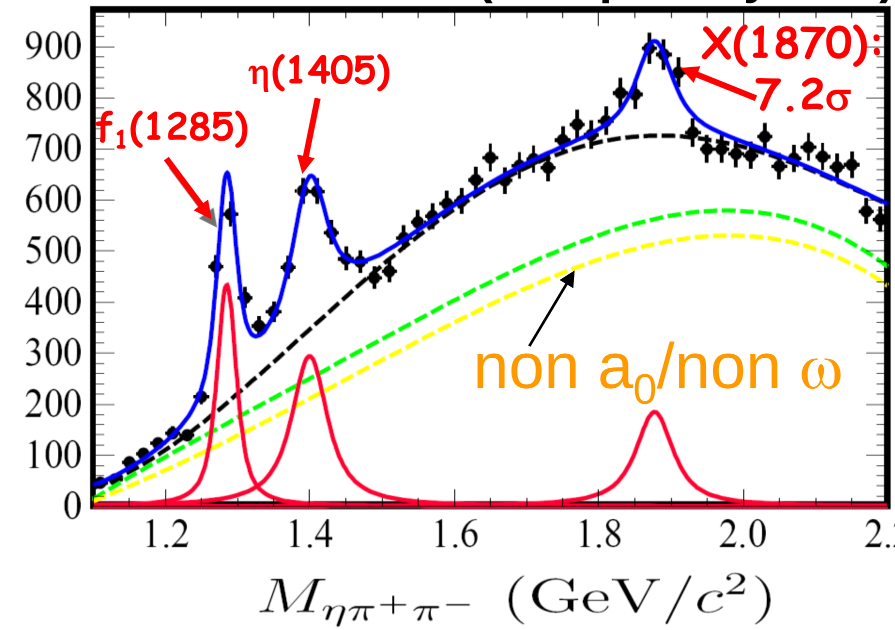
PRD83:114007,2011 (J.S. Yu, Z.-F. Sun, X. Liu, Q. zhao),

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 $\eta\pi^{\pm}$

arXiv: 1107.1806 (accepted by PRL)



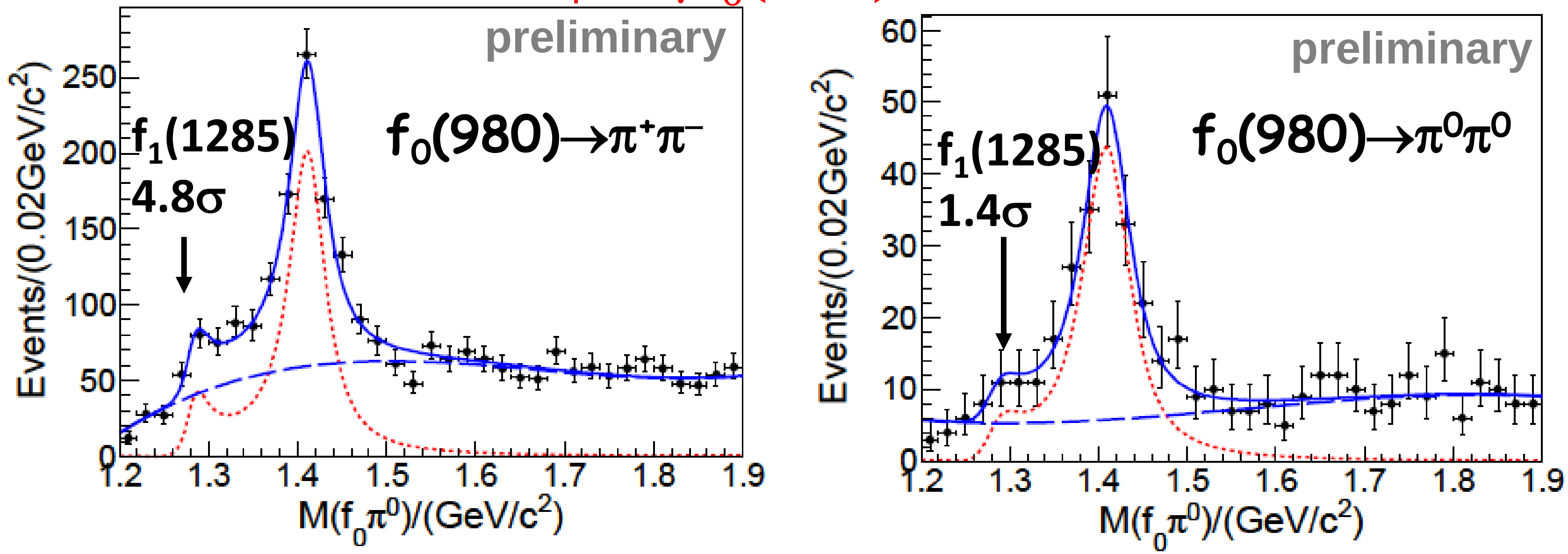
Resonance	Mass (MeV/c^2)	Width (MeV/c^2)	Branch ratio (10^{-4})
$f_1(1285)$	$1285.1 \pm 1.0^{+1.6}_{-0.3}$	$22.0 \pm 3.1^{+2.0}_{-1.5}$	$1.25 \pm 0.10^{+0.19}_{-0.20}$
$\eta(1405)$	$1399.8 \pm 2.2^{+2.8}_{-0.1}$	$52.8 \pm 7.6^{+0.1}_{-7.6}$	$1.89 \pm 0.21^{+0.21}_{-0.23}$
$X(1870)$	$1877.3 \pm 6.3^{+3.4}_{-7.4}$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

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

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

First observations: $\eta(1405) \to f_0(980)\pi^0$ (isospin violated)

$J/\psi \to \gamma f_0(980)\pi^0$



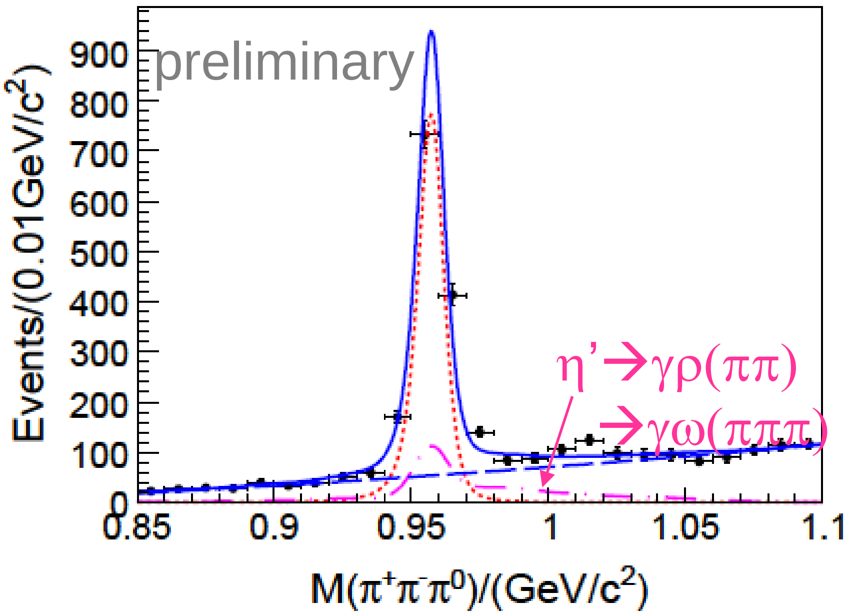
Helicity analysis indicates that peak ~1400MeV is from $\eta(1405) \to f_0(980)\pi^0$, not from $f_1(1420)$:

$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^+\pi^-)$$
$$= (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}$$

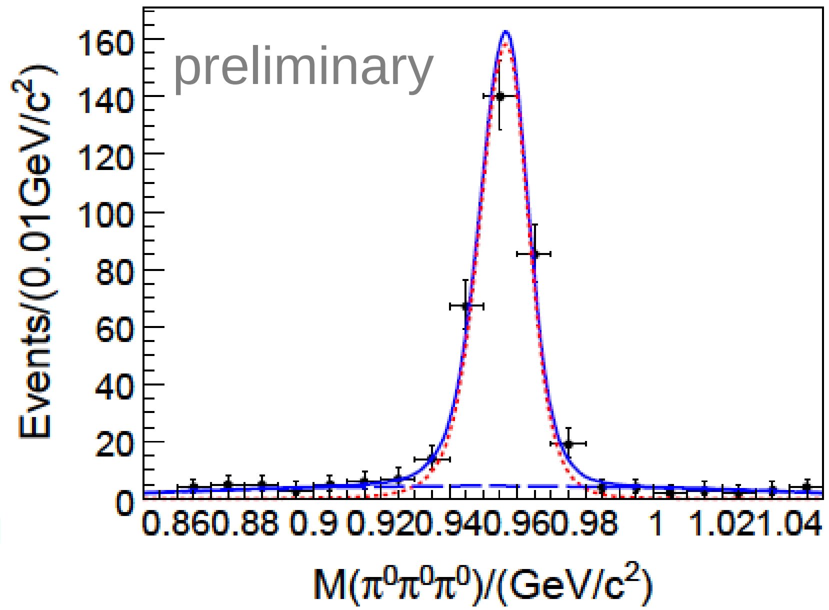
$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^0\pi^0)$$
$$= (6.99 \pm 0.93(stat.) \pm 0.95(sys.)) \times 10^{-6}$$

η′→3π in J/ψ→γπππ

J/ψ→γπ⁺π⁻π⁰



J/ψ→γπ⁰π⁰π⁰



$$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15(stat.) \pm 0.39(sys.)) \times 10^{-3}$$

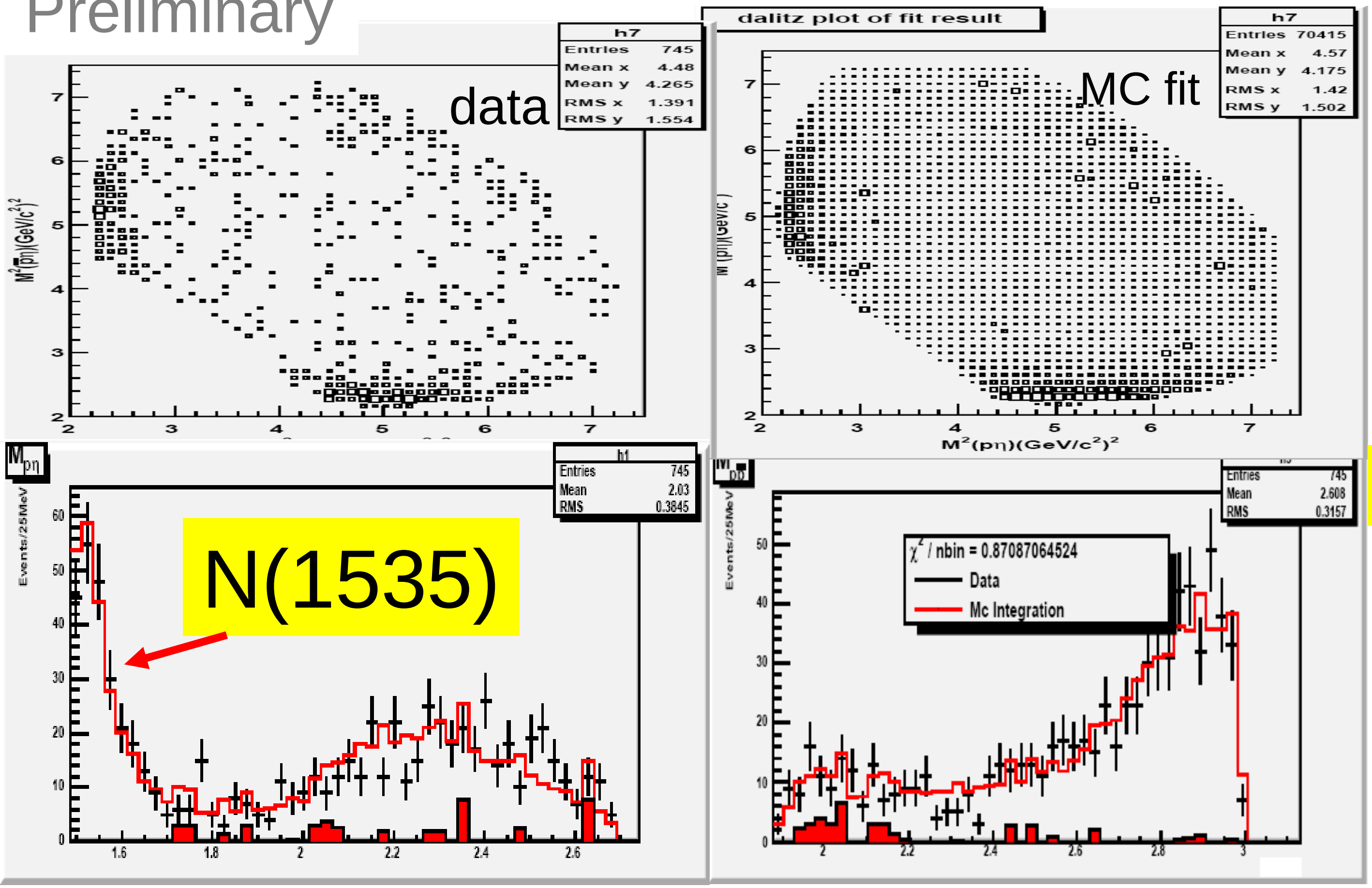
PDG2010: $(3.6^{+1.1}_{-0.9})\times10^{-3}$ **(2009 CLEO-c)**

$$Br(\eta' \to 3\pi^0) = (3.56 \pm 0.22(stat.) \pm 0.34(sys.)) \times 10^{-3}$$

PDG2010: $(1.68\pm0.22)\times10^{-3}$ (1984: GAM2)

Results on N* baryon in $\psi' \to \eta p \bar{p}$ decay

Preliminary



M(pη) **M(p$\bar{p}$)**

A full PWA ana. Is performed.

Based on 106M ψ' events

N(1535) is 1/2⁻

Mass (GeV/c²)

$$1.524^{+0.005+0.010}_{-0.005-0.004}$$

Width (GeV)

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

BF($\psi' \to pp\eta$)=**(6.6±0.2±0.6)×10^{-5}** PDG2010: **(6±1.2)×10^{-5}**

BF($\psi' \to$N(1535)p)×BF(N(1535)→pη+c.c.) = $5.5^{+0.3+7.4}_{-0.3-1.1} \times 10^{-5}$

Physics activities @ BESIII

Charmonium physics:
- spectroscopy
- transitions and decays

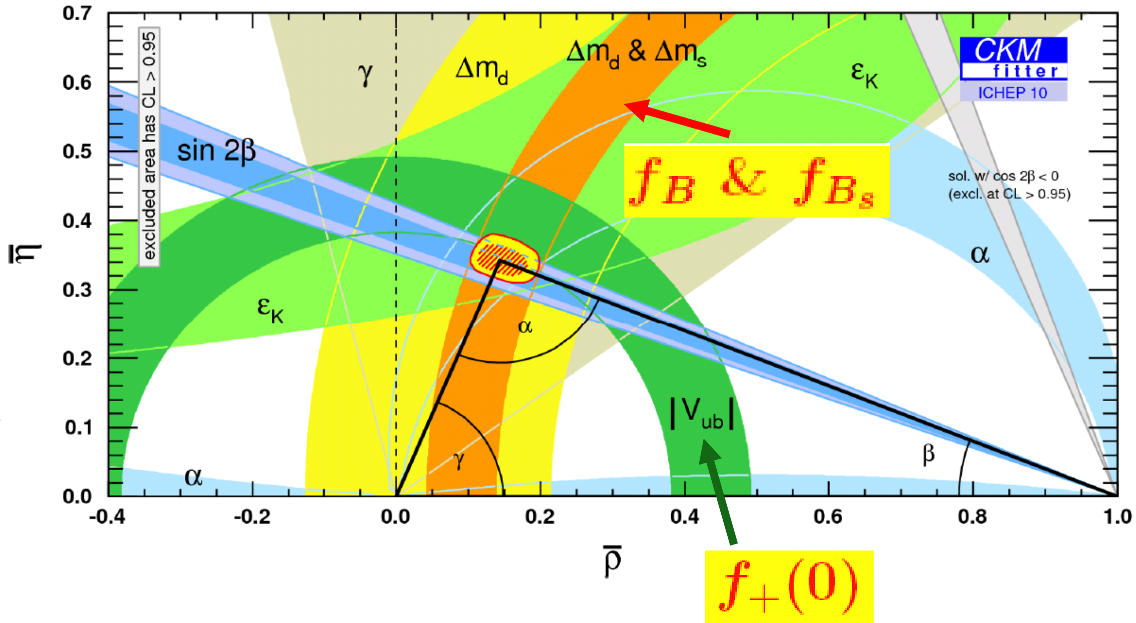
Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic/hadronic dec.
- decay const., form factors
- CKM matrix: V_{cd}, V_{cs}
- D^0-D^0bar mixing and *CPV*
- rare/forbidden decays

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

More…

Charm play an important role in flavor physics



$|V_{ub}|$ from $B \rightarrow \pi \ell \nu$:

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

Form factor $f(q^2)$:

- Hard to calculate
- Limits $|V_{ub}|$ precision
- Lattice QCD can do from first principles

Errors of $f(q^2)$ dominate!

QCD calculations can be tested in high *precision* with charm data at threshold

At BESIII, using charm decay we will <u>measure decay constants; form factors; V_{CKM}; validate QCD.</u>

B decay constant can not be measured (precisely), has to rely on theory calculation.

Advantage at threshold

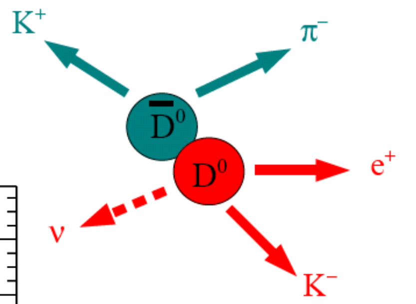
e^+e^- colliders at threshold: CLEOc, BESIII, Super-tau-charm

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

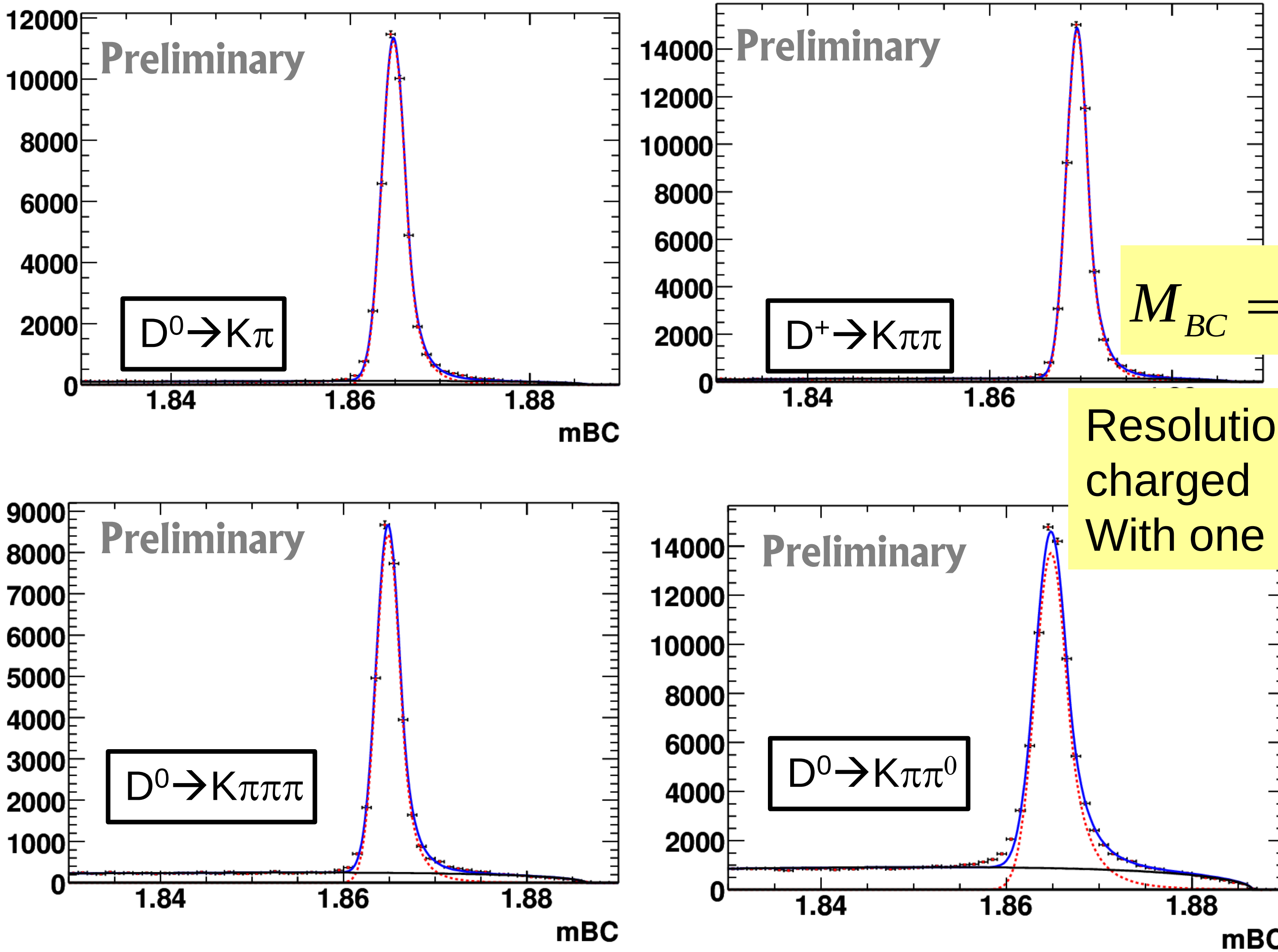
Good for charm flavor physics:

- Production: clean
- Known initial energy and quantum numbers
- Both D and $\bar{D}$ fully reconstructed (double tag), allows for absolute measurements

Clean single tag at BESIII



420pb^{-1} $\psi(3770)$, clean single tag



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

Resolution:
charged modes: 1.3 MeV
With one □^{0}: 1.9 MeV

Prospects for Charm at BESIII

With increased luminosity, BESIII will achieve high precision

CLEOc errors with 818 pb^{-1}@3770	BESIII (10fb^{-1})
f_{D+} ($D^+ \to \mu^+ \nu$): ±**4.1%** (stat.) ± **1.2%**(sys.)	±**1.2%** (stat.)
$f_{\pi}(0)$ ($D^0 \to \pi l \nu$): ±**5.3%** (stat.) ± **0.7%**(sys.)	±**1.5%** (stat.)
BF($D^0 \to K\pi$): ±**0.9%** (stat.) ± **1.8%**(sys.)	limited by syst.
BF($D^+ \to K\pi\pi$): ±**1.1%** (stat.) ± **2.0%**(sys.)	limited by syst.

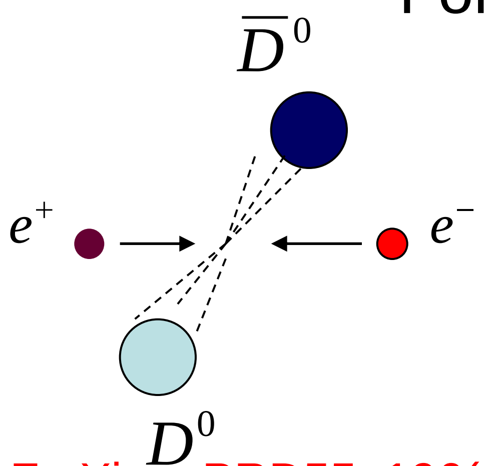
CLEOc errors with 600pb^{-1}@4170 MeV	BESIII(5fb^{-1})
f_{Ds}($Ds^+ \to \mu^+ \nu, \tau \nu$): ±**2.5%** (stat.) ± **1.2%** (sys.)	±**0.9%** (stat.)
BF($Ds^+ \to KK\pi$): ±**4.2%** (stat.) ± **2.9%**(sys.)	±**1.5%** (stat.)

For D_S study, data taken at 4010 MeV & 4170 MeV:

4010 MeV (clean, lower X-section, 0.3 nb) → BESIII 0.5 fb^{-1}

4170MeV (more BKG, higher X-section, 0.9 nb) → CLEOc 0.6 fb^{-1}

$D^0\,\overline{D}^0$ quantum correlation @ψ(3770)



For a physical process producing $D^0\,\overline{D}^0$ such as

$$e^+e^- \to \psi'' \to D^0\overline{D}^0$$

$$L=1; C=-1$$

for a correlated state *C*=-1

$$\psi'' = \frac{1}{\sqrt{2}}\left(\left|D^0\right\rangle\left|\overline{D}^0\right\rangle - \left|\overline{D}^0\right\rangle\left|D^0\right\rangle\right)$$

$$\hat{C}\left|D^0\right\rangle = \left|\overline{D}^0\right\rangle$$

$$\hat{C}\left|\overline{D}^0\right\rangle = \left|D^0\right\rangle$$

Z.Z . Xing, PRD55, 196(1997)
Cheng et al, PRD75, 094019(2007)

The correlated amplitude:

$$\Gamma_{ij}^2 = \left|\left\langle i\,|\,D^0\right\rangle\left\langle j\,|\,\overline{D^0}\right\rangle - \left\langle j\,|\,D^0\right\rangle\left\langle i\,|\,\overline{D^0}\right\rangle\right|^2$$

$$\frac{\left\langle K^-\pi^+ \,|\, \overline{D^0}\right\rangle^{\mathrm{DCS}}}{\left\langle K^-\pi^+ \,|\, D^0\right\rangle_{\mathrm{CF}}} = -r_{K\pi}\,e^{-i\delta_{K\pi}}$$

~0.06 ($r_{K\pi}$)

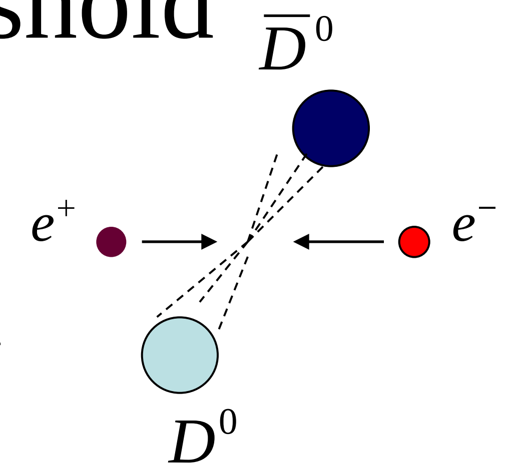
$\delta_{K\pi}$ connects measurements of *y* and *y'*

D^0 strong phase is necessary input for D^0 mixing and CKM measurements at B factories and LHCb .

For details

→see "strong phase measurement" by X.K.Zhou

Measure D^0 mixing at threshold



$$e^+e^- \to \psi(3770) \to D^0\overline{D}^0 \to (K^\pm\pi^\mp)(K^\pm\pi^\mp)$$

$(K^\pm\pi^\mp)(K^\pm\pi^\mp)$: P wave, C odd ← $\psi(3770)$ is 1^{--}

Bose-Einstein statistics does not allow the two D^0's decay into identical final states.

But if there is mixing,

Z.Z . Xing, PRD55, 196(1997)
H.B. Li and M.Z.Yang PRD74,094016(2006)

$$e^+e^- \to \psi(3770) \to D_H^0 D_L^0 \to (K^\pm\pi^\mp)_H (K^\pm\pi^\mp)_L$$

(D_H is not identical to D_L)

$$R_M \equiv \frac{X^2+Y^2}{2} = \frac{N[D^0\overline{D}^0 \to (K^-\pi^+)(K^-\pi^+)]}{N[D^0\overline{D}^0 \to (K^-\pi^+)(K^+\pi^-)]}, \quad \frac{N[D^0\overline{D}^0 \to (K^-e^+\nu)(K^-e^+\nu)]}{N[D^0\overline{D}^0 \to (K^-e^+\nu)(K^+e^-\nu)]}$$

For 10^7 D-pairs about 3-5 events will be detected.
Sensitivity to R_M is about 10^{-4}.

CPV in D decay at super-tau-charm

Direct CPV in D decays is expected to be small in SM.

For CF and DCS decays, direct CPV requires new physics.

Exception: $D^{\pm}\to K_{S,L}\pi^{\pm}$ with $A_{CP}=-3.3\times10^{-3}$.

Singly Cabibbo Suppressed (SCS) decays, SM CPV could reach 10^{-3}.

$$A_{CP}=\frac{\Gamma(D\to f)-\Gamma(\bar{D}\to\bar{f})}{\Gamma(D\to f)+\Gamma(\bar{D}\to\bar{f})}$$

D.S.Du , EPJC5,579(2007)
Y. Grossman et al
PRD75, 036008(2007)

Current Best limits:

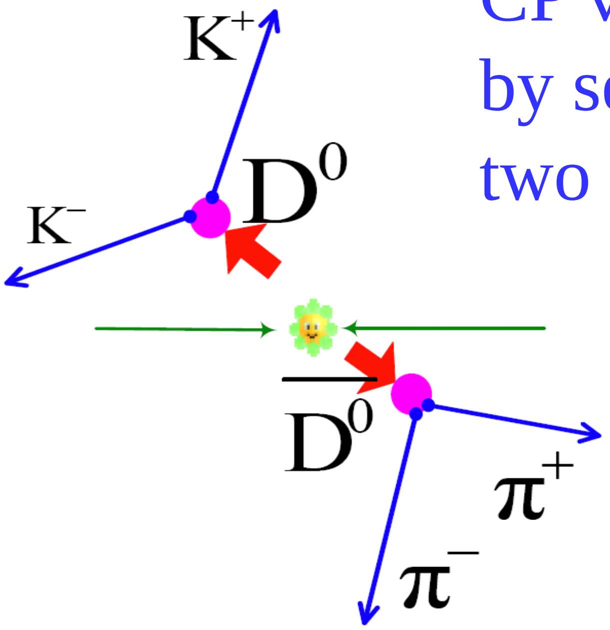
Belle: $D^0\to K^+K^-,\pi^+\pi^-$
$A_{CP}(K^+K^-)=(0.43\pm0.30\pm0.11)\%$
$A_{CP}(\pi^+\pi^-)=(0.43\pm0.52\pm0.12)\%$

BaBar: $D^+\to K_S\pi^+$
$A_{CP}(K_S\pi^+)=(-0.44\pm0.13\pm0.10)\%$

CLEOc : Ks $\pi^+\pi^0$
$A_{CP}(K_S\pi^+\pi^0)=(0.3\pm0.9\pm0.3)\%$

At BESIII (10fb^{-1}), CP asymmetry can be tested with 10^{-3} sensitivity for many final states.

CP violation near threshold



CP violating asymmetries can be measured by searching for events with two CP odd or two CP even final states:

$$\pi^+\pi^-,\ K^+K^-,\ \pi^0\pi^0,\ K_S\pi^0$$

$$\psi'' \rightarrow D^0\overline{D}^0 \rightarrow f_1 f_2$$

$$CP(f_1 f_2) = CP(f_1)\cdot CP(f_2)\cdot(-1)^L = -$$

$$CP(\psi'') = +$$

A_{CP} sensitivity : $\Delta A \sim 10^{-3}$

Sensitivity of rare *D* decays at BESIII

- Flavor Changing Neutral Current ($c \rightarrow u\, l^+ l^-$)
  - $D^0 \rightarrow \mu^+\mu^-$ SM $<10^{-12}$ NP $\sim 10^{-6}$
    - *CDF* *BR* $< 4.3\times10^{-7}$
  - $D \rightarrow X_u l^+ l^-$ SM $<10^{-8}$ NP $\sim 10^{-6}$
    - *D0* *BF*$(D^+\rightarrow\pi^+\mu^+\mu^-) < 3.9\times10^{-6}$
    - *CLEOc* *BF*$(D^+\rightarrow\pi^+e^+e^-) < 7.4\times10^{-6}$

- Lepton Flavor Violation NP $\sim 10^{-6}$
  - *BaBar* *BF*$(D^0 \rightarrow\mu^+e^-) < 0.81\times10^{-6}$
  - *BaBar* *BF*$(D^+\rightarrow\pi^+e^+\mu^-) < 1.1\times10^{-5}$

With $10 fb^{-1}$ $\psi(3770)$, BESIII will achieve 10^{-8} sensitivity.

Summary

- **Excellent BEPCII and BESIII performance. Large data samples have been collected.**
- **The first observation of $\eta_c(2S)$ in $\psi' \to \gamma\eta_c(2S)$ decay.**
- **Precision measurements of $\eta_C(1S)$ / h_c parameters in $\psi' \to \gamma\eta_c(1S)$ / $\psi' \to \pi^0 h_c$.**
- **Study charmonium various transition/decays to test theoretical prediction.**
- **Confirmation of X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$.**
- **Observation of two new structures X(2120) and X(2370) in $J/\psi \to \gamma\pi\pi\eta'$ decays.**
- **Observation of new structure X(1870) in $J/\psi \to \omega\pi\pi\eta$.**
- **Charm near threshold undertake complementary studies of D mixing and CPV, and unique test of QCD techniques.**
- **We expect rich physics results in the coming years from BESIII**

Thank Haibo for help with the talk