Review of BESIII results

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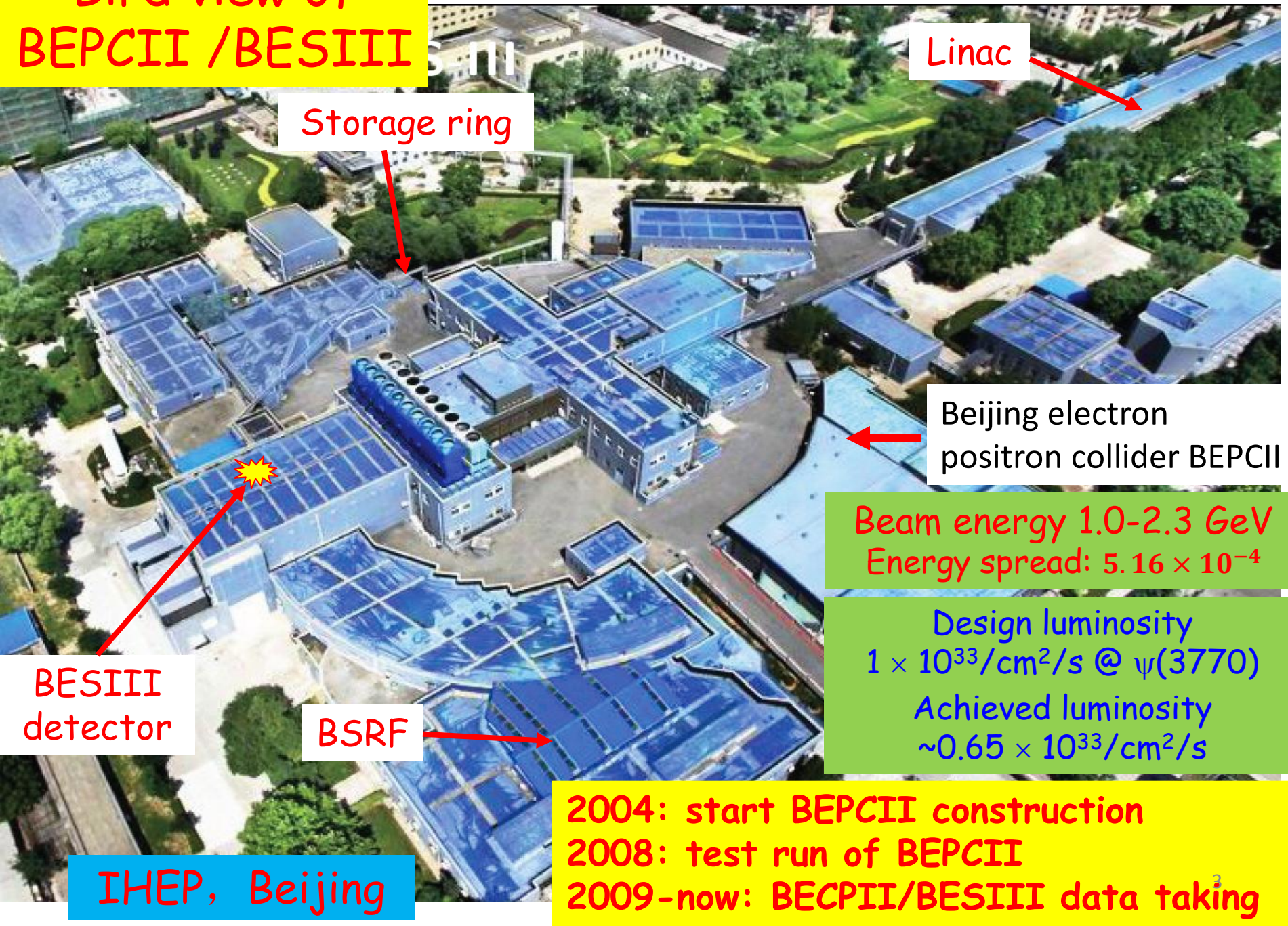
Outline

- Status of BEPCII/BESIII
- Selected Results from BESIII
  - Charmonium Spectroscopy

    (For light hadron spectroscopy, see Yang's talk at Light flavor session)
  - Charmonium Transitions
  - Charmonium Decays
  - Charm Decays
- 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

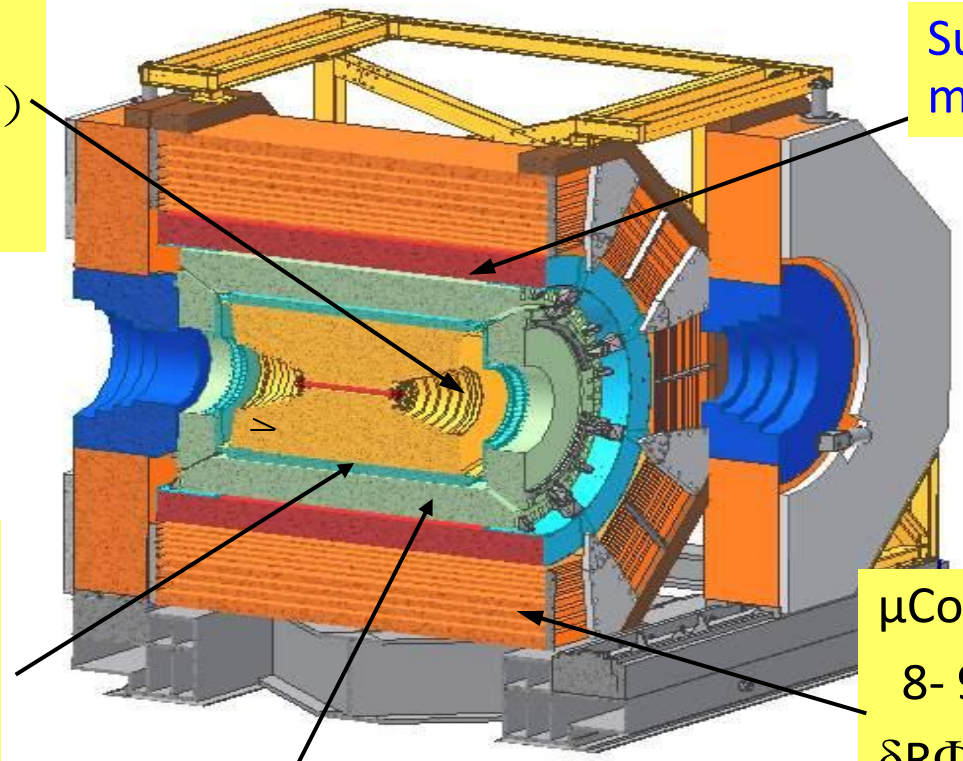
NIM A614, 345 (2010)

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

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**

$\psi(2S)$: 0.4 billion; J/ψ: 1 billion

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

Tentative future running plans:

E_{cm}=4.26 GeV, 4.36 GeV and R-scan

The BESIII Collaboration

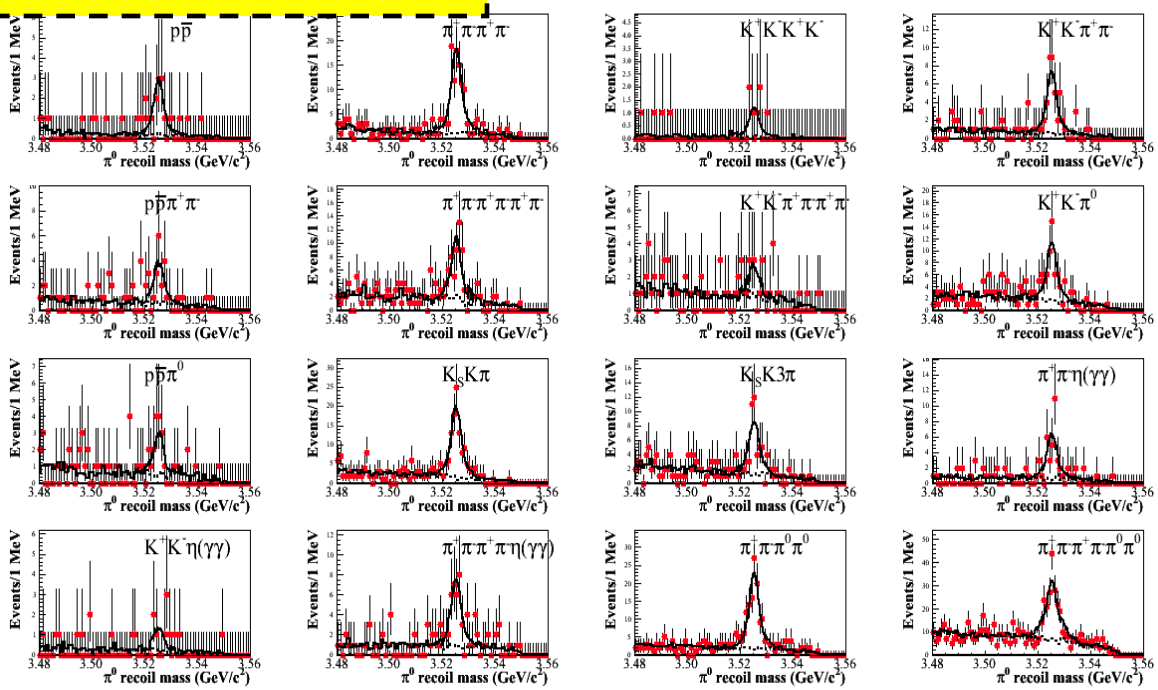
http://bes3.ihep.ac.cn

Charmonium spectroscopy

- Properties of h_c
- Mass and width of η_c
- Observation of $\psi' \rightarrow \gamma\eta_c(2S)$

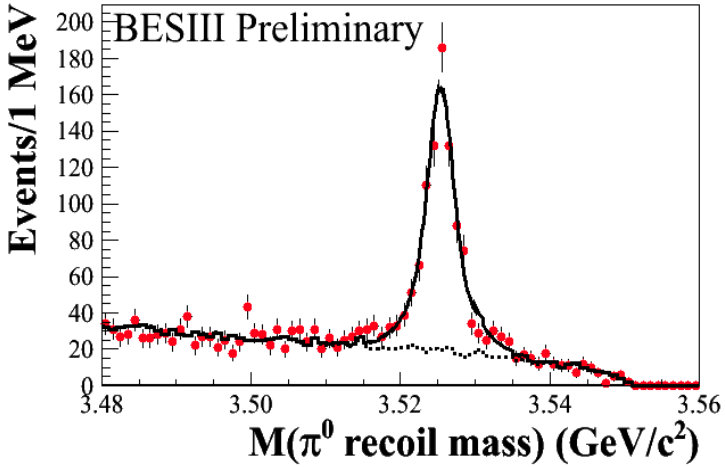
Measurements of the h_c properties at BESIII (exclusive)

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

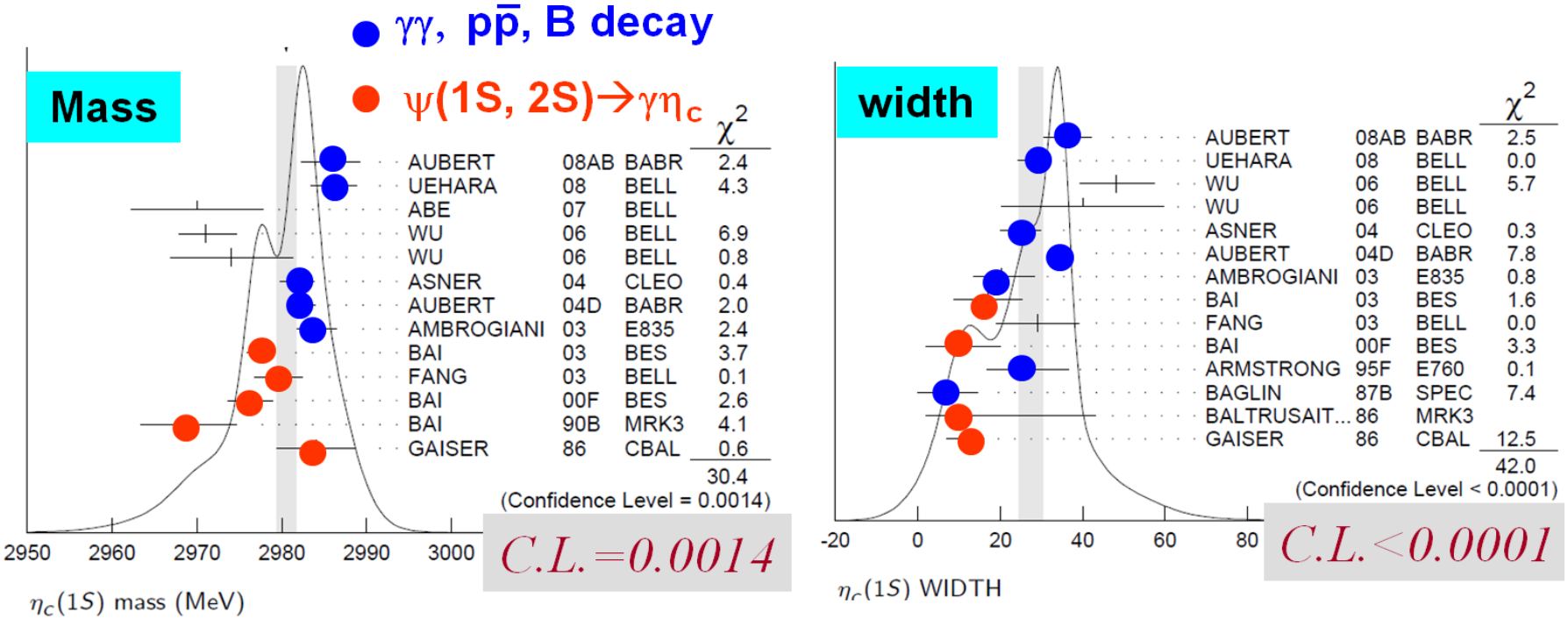
PRL101, 182003(2008)

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: $M \sim 2978.0 MeV/c^2$, $\Gamma \sim 10 MeV$

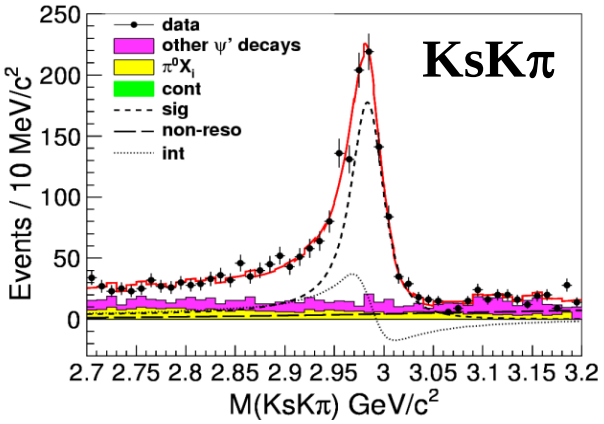
  $\gamma\gamma$ process: $M = 2983.1 \pm 1.0\ MeV/c^2$, $\Gamma = 31.3 \pm 1.9\ MeV$

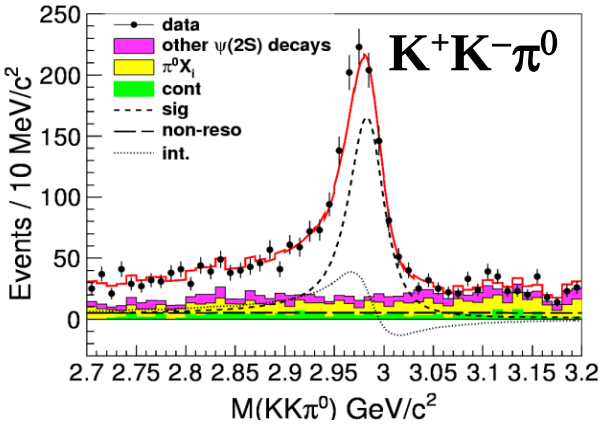


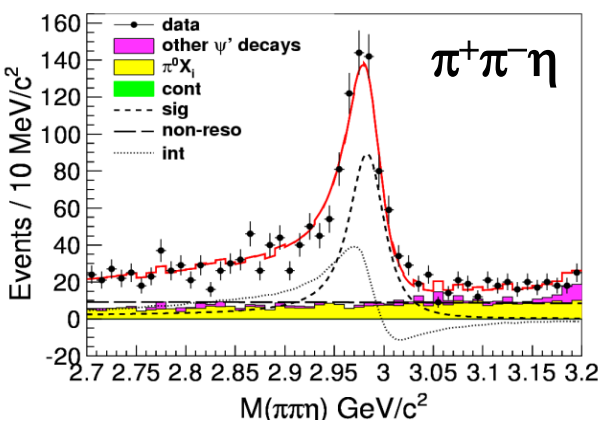
- CLEOc found the distortion of the η_c lineshape in ψ' decays
- $c\bar{c}$ hyperfine splitting: $M(J/\psi)$- $M(\eta_c)$ is important experimental input to test the lattice QCD, but is dominated by error on $M(\eta_c)$

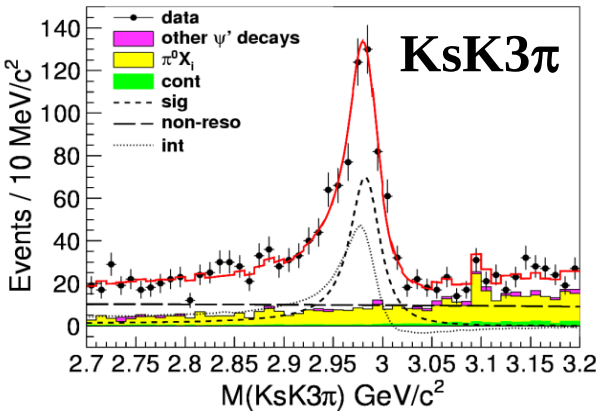
$\psi' \rightarrow \gamma\eta_c$, η_c exclusive decays

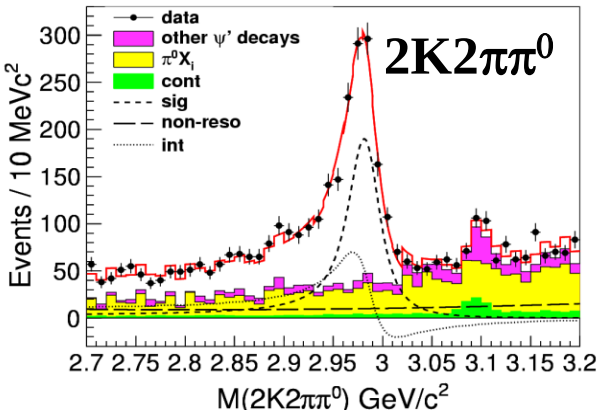
Phys.Rev.Lett. 108 (2012) 222002
arXiv: 1111.0398

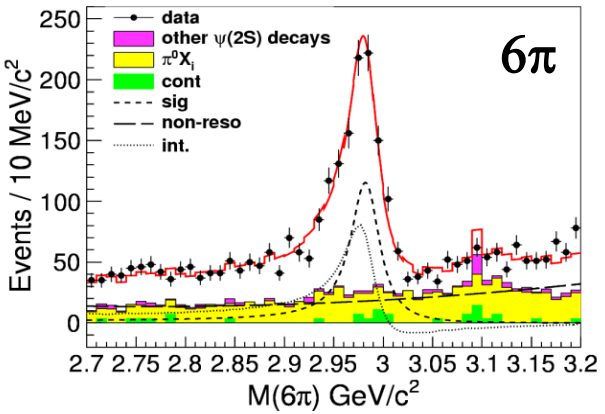












Interference with non-resonant is significant !

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

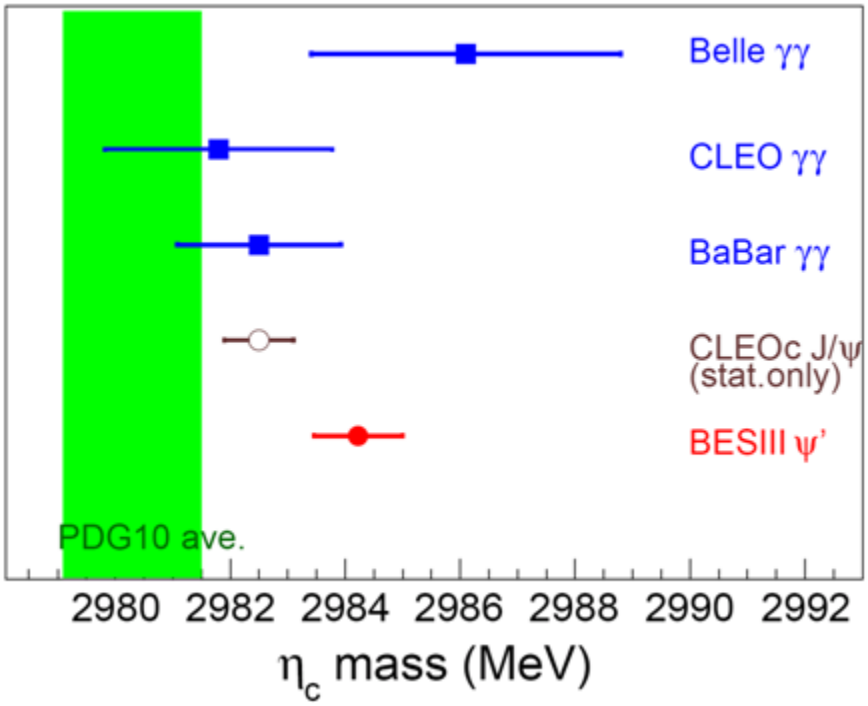
width: **32.0±1.2±1.0** MeV

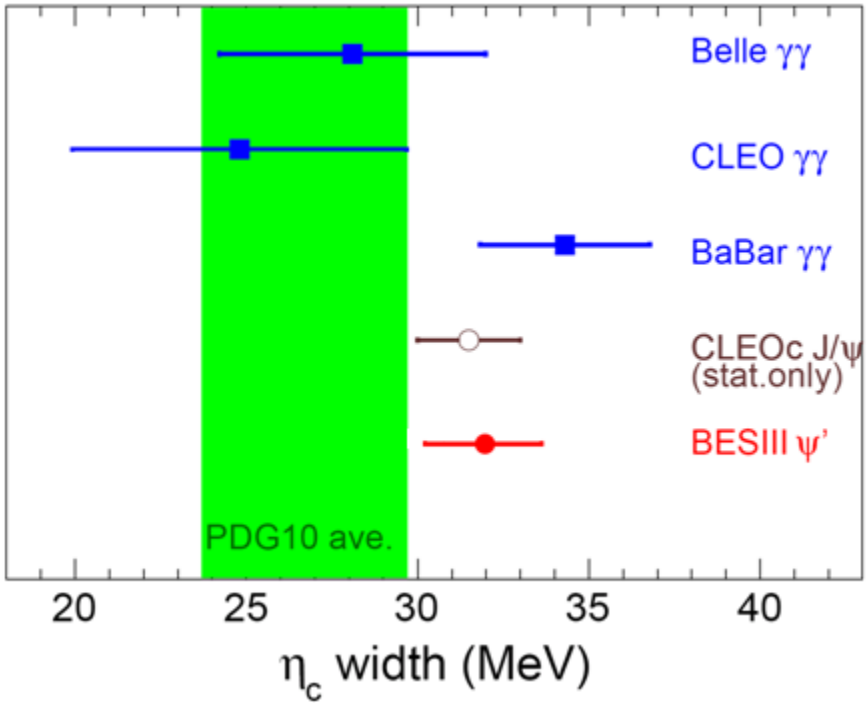
ϕ: **2.40±0.07±0.08** rad or

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

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.

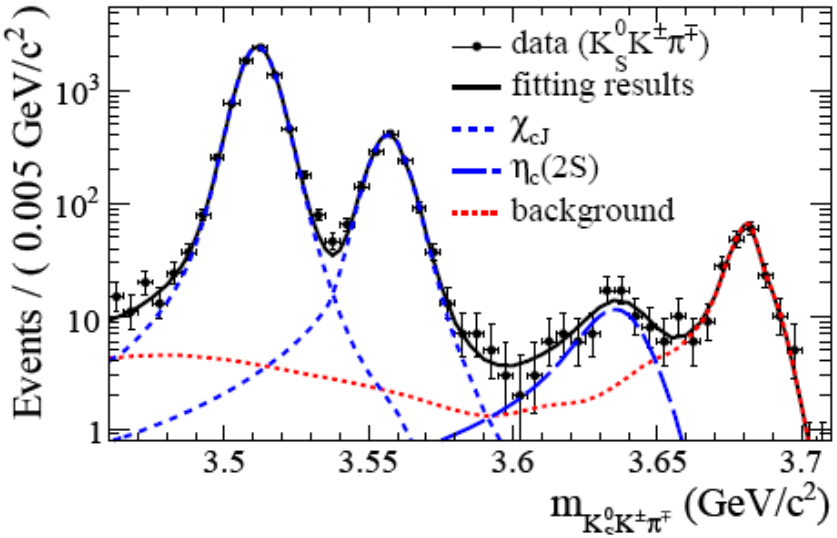
  (experimental challenge : search for real photons ~50MeV,)

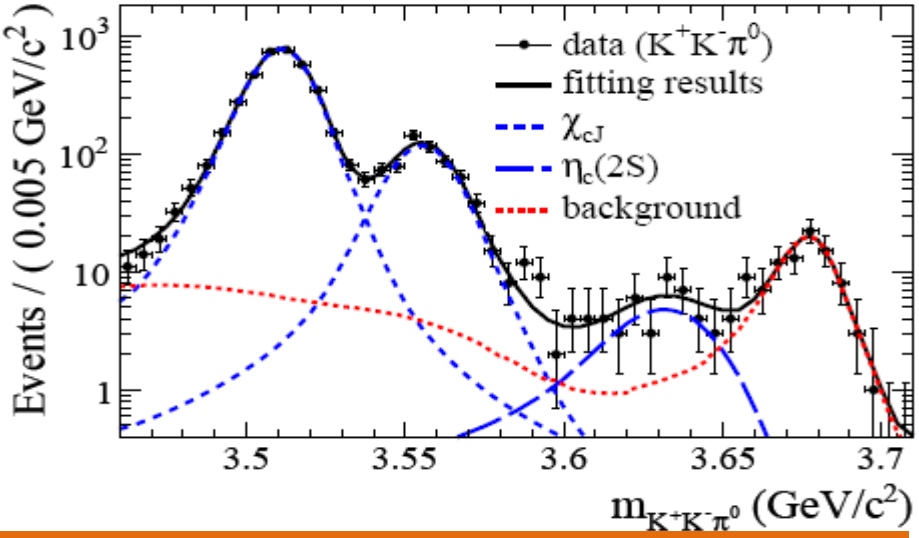
- Better chance to observe $\eta_c(2S)$ in ψ' radiative transition with ~106M ψ' data at BESIII.

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

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

With 106M ψ' events:





1205.5103v2[hep-exp], accepted by PRL

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!

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

+

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

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

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

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

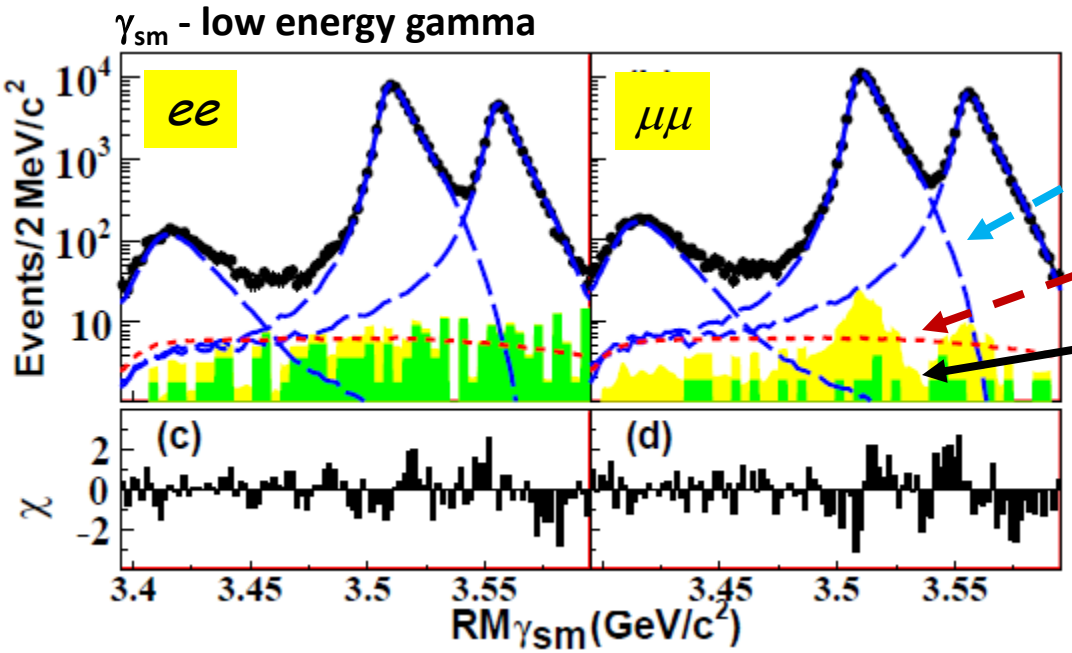
Charmonium Transitions

- **First evidence of $\psi' \rightarrow \gamma\gamma J/\psi$**
- **Multipole in $\psi' \rightarrow \gamma\chi_{c2}$**

arXiv: 1112.0942 Submit to PRL

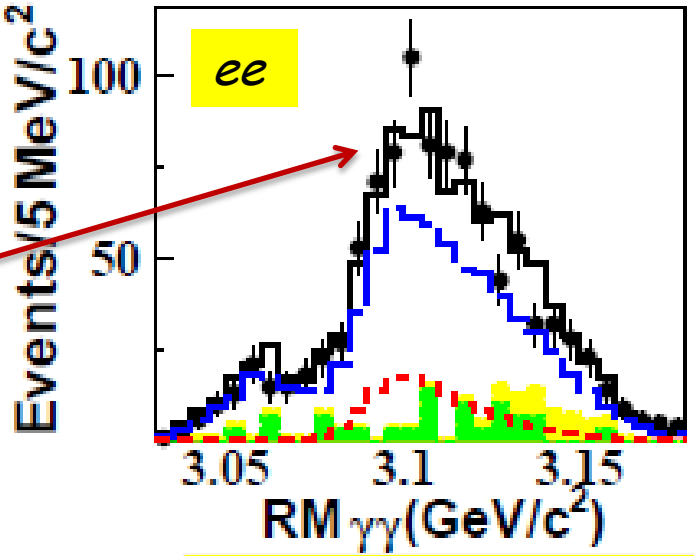
First evidence of $\psi' \to \gamma\gamma J/\psi$

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



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

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



3.44<RM(γ_{sm})<3.48GeV

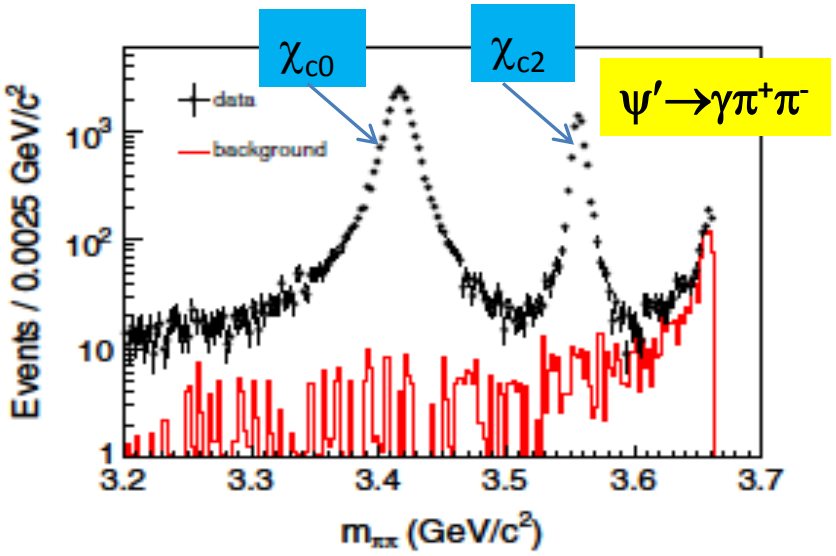
- $Br(\psi' \to \gamma\gamma J/\psi) = (3.3 \pm 0.6^{+0.8}_{-1.1}) \times 10^{-4}$ (both *ee* and $\mu\mu$)
- **Significance : 3.8σ including systematics**
- $Br(\psi' \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi)$ are also measured

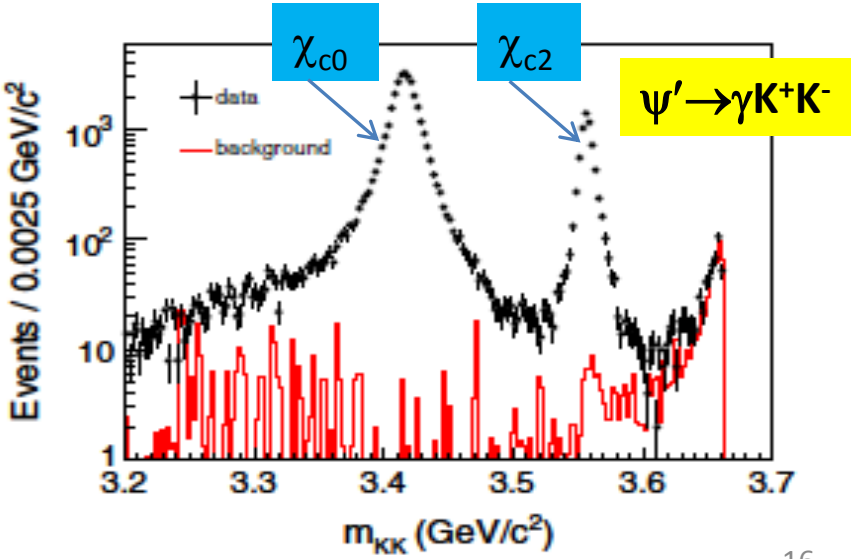
PRD84, 092006 (2011)

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 : $\mathrm{M2} = 0.029(1+\kappa)$
- 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 $\psi' \to \gamma\chi_{c2}$, $\chi_{c2} \to \pi^+\pi^-, K^+K^-$

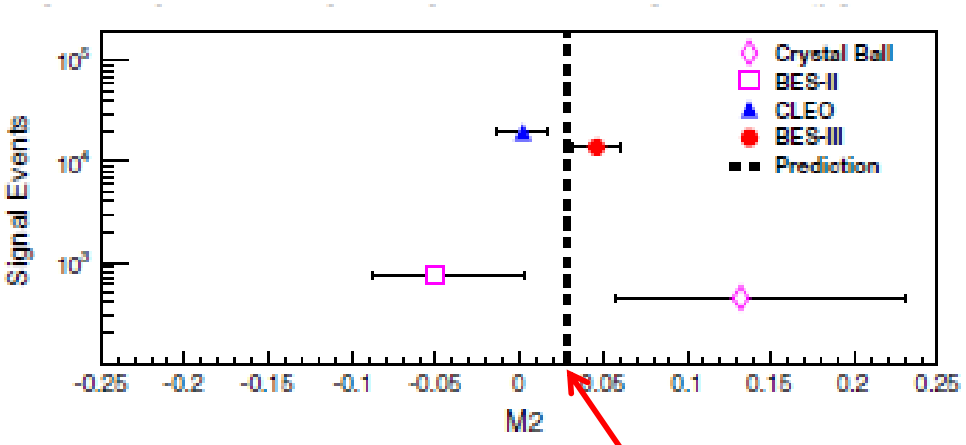
- Extract M2 using fit to full angular distribution

Evidence of M2 contribution:

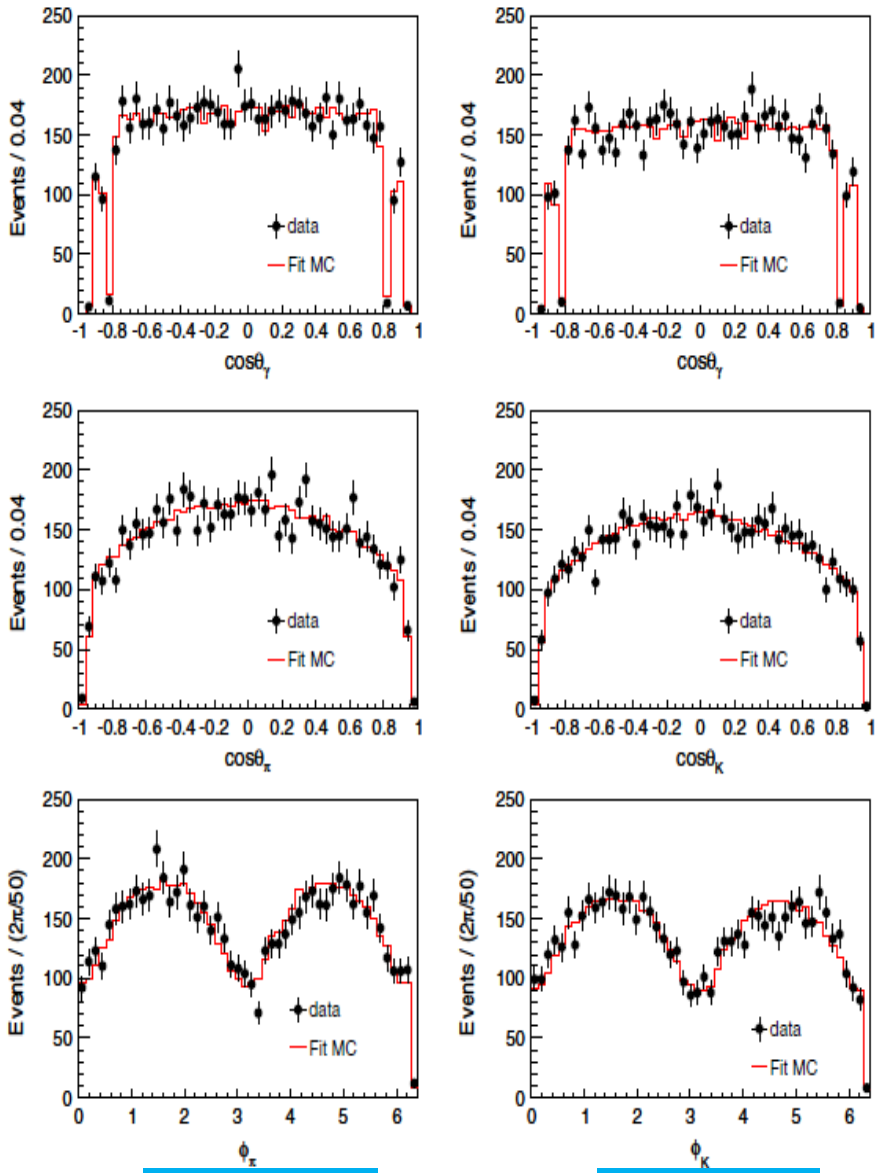
$$M2 = 0.046 \pm 0.010 \pm 0.013,$$
$$E3 = 0.015 \pm 0.008 \pm 0.018,$$

4.4σ

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



M(c) = 1.5 GeV and κ = 0



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

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

Charmonium Decays

- Search for $\eta_c(2S) \rightarrow VV$
- $\chi_{cJ} \rightarrow VV$
- $\chi_{c0/2} \rightarrow \gamma\gamma$

PRD84, 091102R (2011)

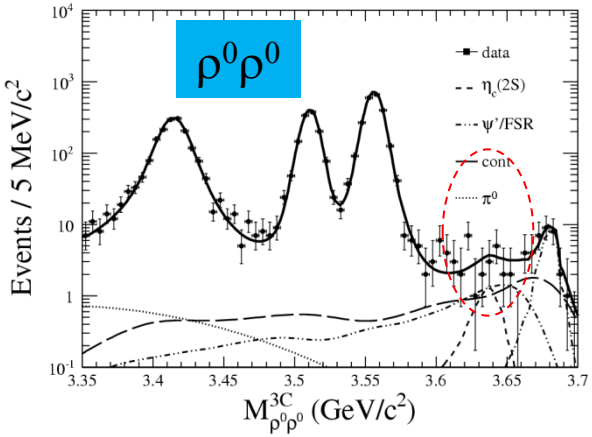
Search for $\eta_c(2S)\rightarrow VV$

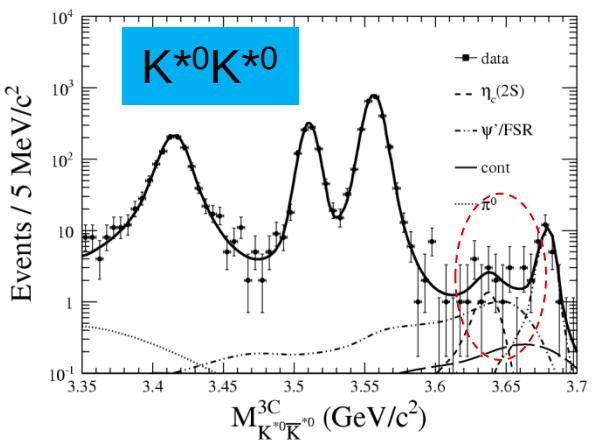
Test for the 'intermediate charmed meson loops':

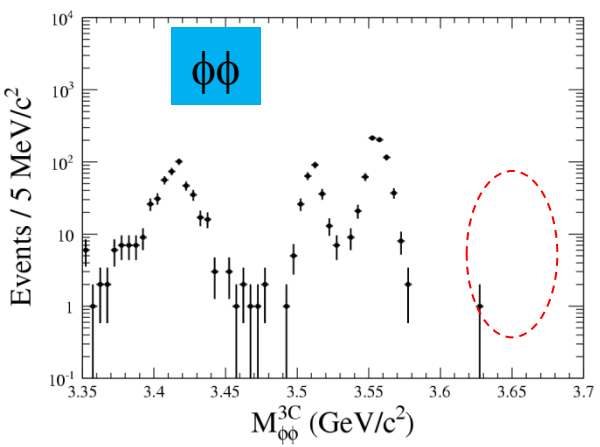
$\eta_c(2S)\rightarrow VV$ is highly suppressed by the helicity selection rule.

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

(PRD81, 014017 (2010))





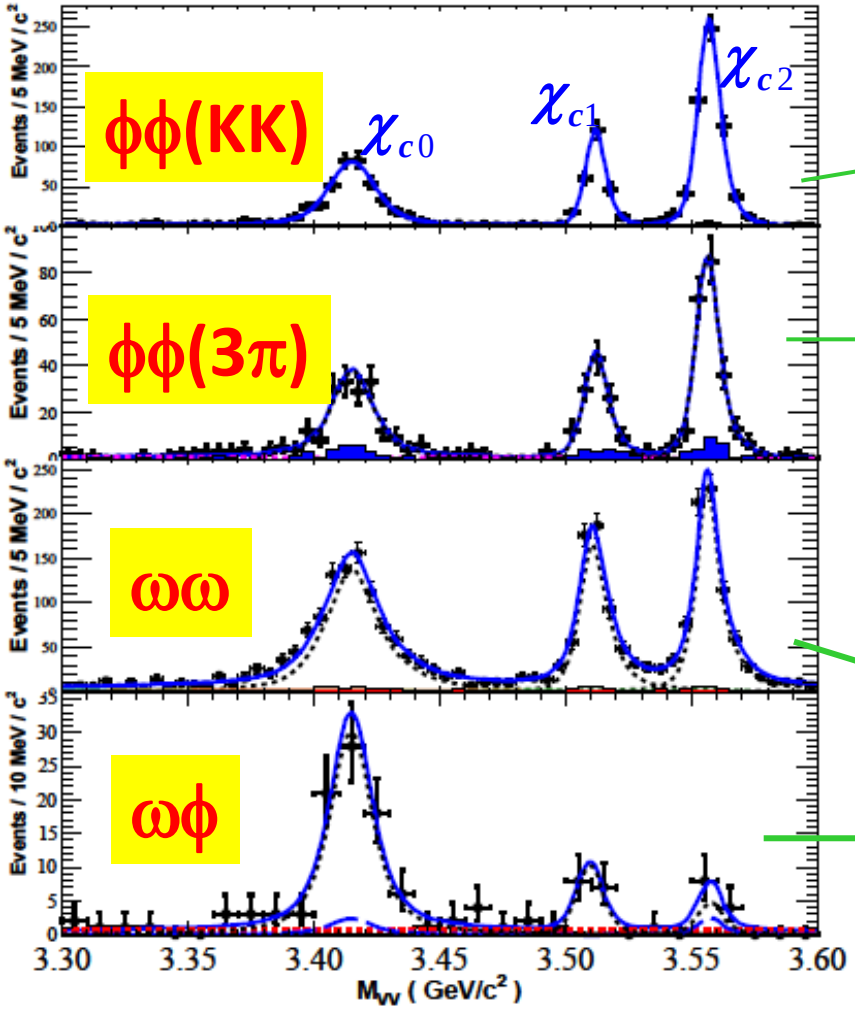


	Br($\psi'\rightarrow\gamma\eta_c(2S)\rightarrow\gamma VV$) ($10^{-7}$)	Br($\eta_c'\rightarrow VV$) (10^{-3}) (using BESIII BF($\psi'\rightarrow\gamma\eta_c(2S)$))	Br($\eta_c'\rightarrow VV$) (10^{-3}) Theory: (arXiv:1010.1343)
$\rho^0\rho^0$	<12.7	<3.1	6.4 ~ 28.9
$K^{*0}K^{*0}$	<19.6	<5.4	7.9 ~ 35.8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

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

$\chi_{cJ} \to VV$

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
$\to K^+K^-\pi^+\pi^-\pi^0$			

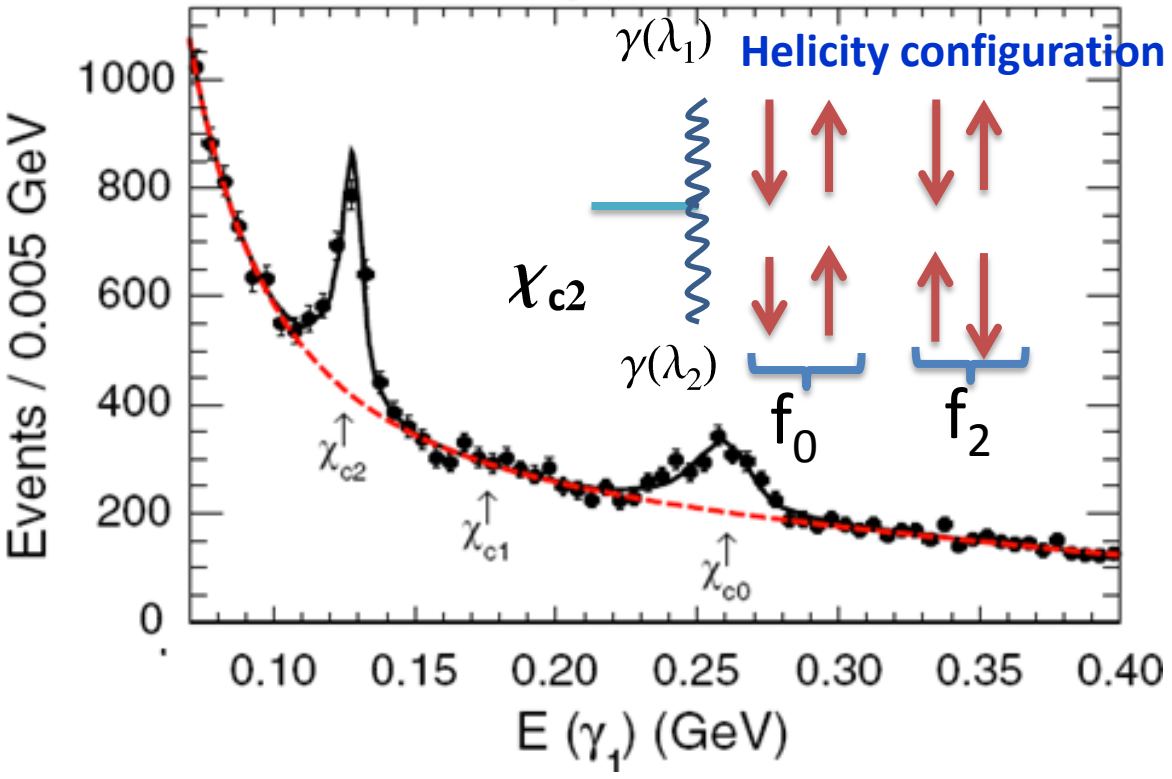
Evidence

First observation

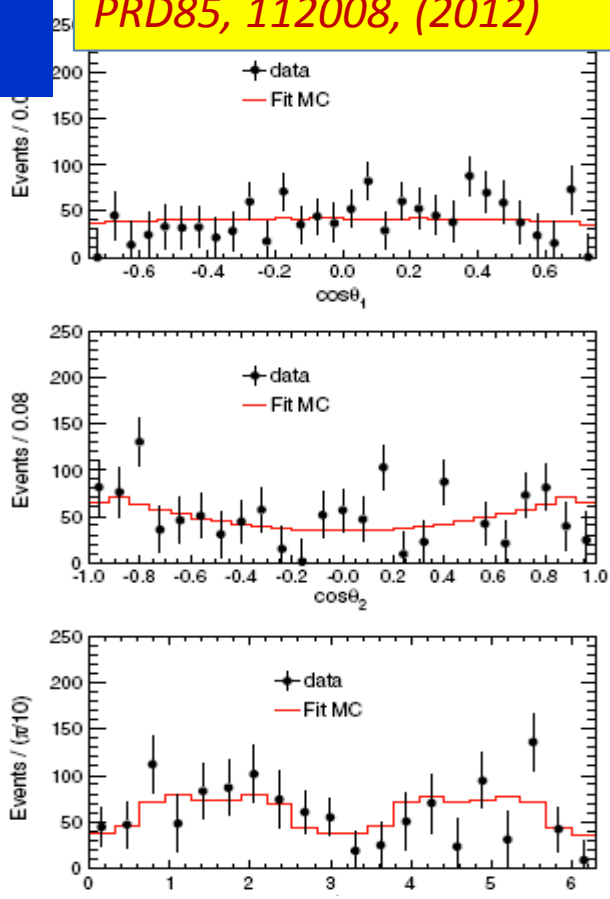
Long distance transitions could contribute via the intermediate meson loops. PRD81 014017 (2010) , PRD81 074006 (2010)

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

PRD85, 112008, (2012)



Helicity configuration



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

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	$0.28 \pm 0.05 \pm 0.04$	$0.27 \pm 0.03 \pm 0.03$
$f_{0/2} = \Gamma_{\gamma\gamma}^{\lambda=0}(\chi_{c2})/\Gamma_{\gamma\gamma}^{\lambda=2}(\chi_{c2})$	...	...	$0.00 \pm 0.02 \pm 0.02$

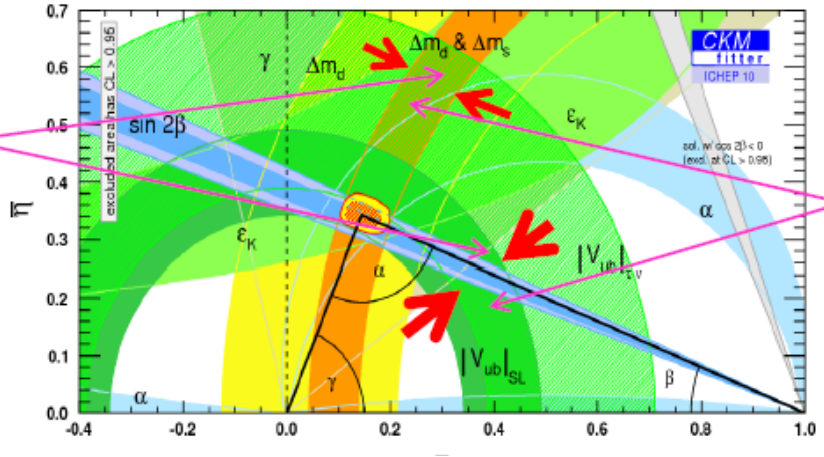
D decays

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

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

- D^+ leptonic decays play an important role in understanding of the SM of particle physics
- Unitary trianlge

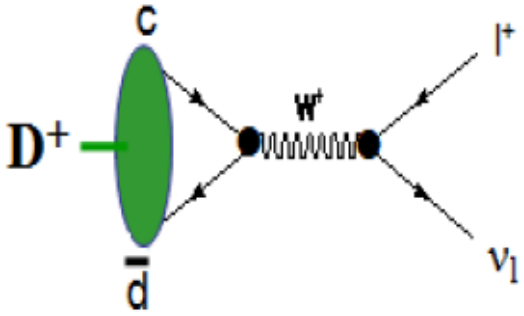
Widths of bands are dominated by errors of f_B and f_{Bs} from LQCD.



The widths of bands will be reduced if the LQCD pass the test with measured f_D, f_{Ds}.

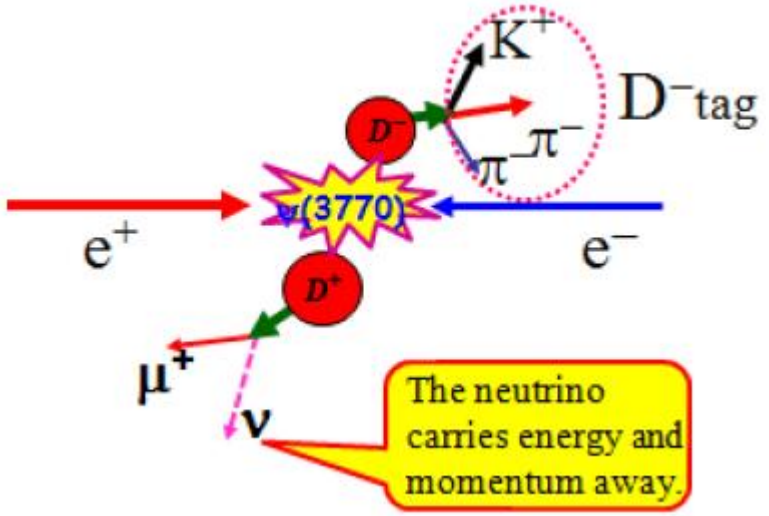
- **Test LQCD calculation of f_D**

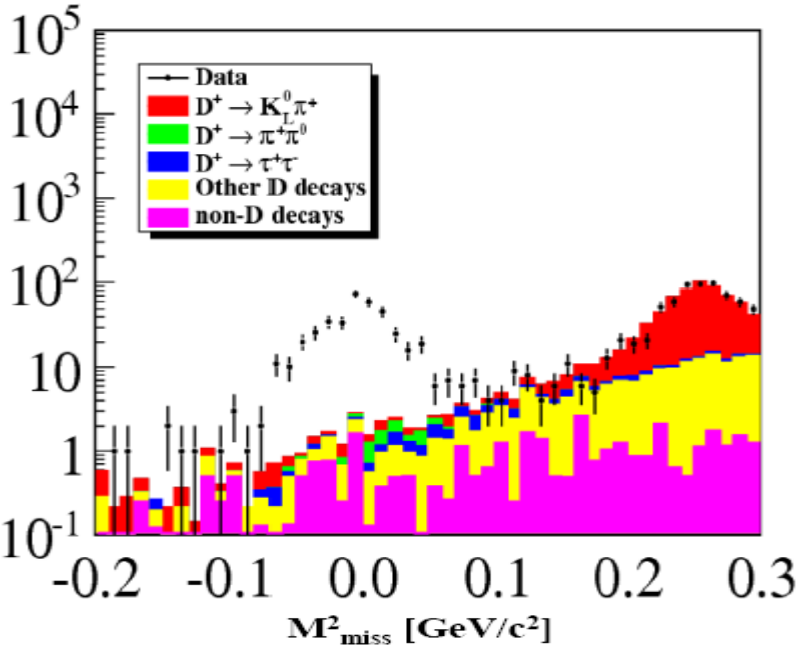
$$\Gamma_{SM}(D^+_{(s)} \to l^+\nu) = \frac{G_F^2}{8\pi} m_l^2 m_{D_{(s)}} \left(1 - \frac{m_l^2}{m^2_{D_{(s)}}}\right)^2 |V_{cd(s)}|^2 f^2_{D^+_{(s)}}$$



- **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 $D^+ \rightarrow \mu^+\nu$





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

Results:

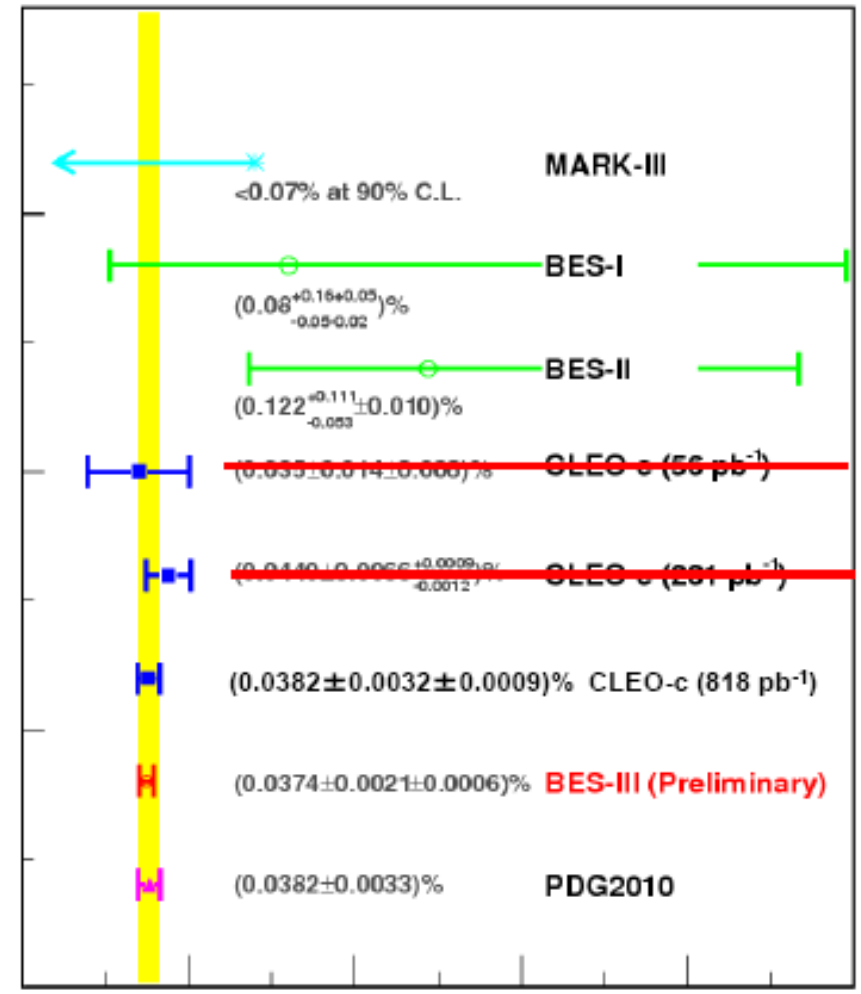
$N(D^+ \rightarrow \mu^+\nu) = 377.3 \pm 20.6$

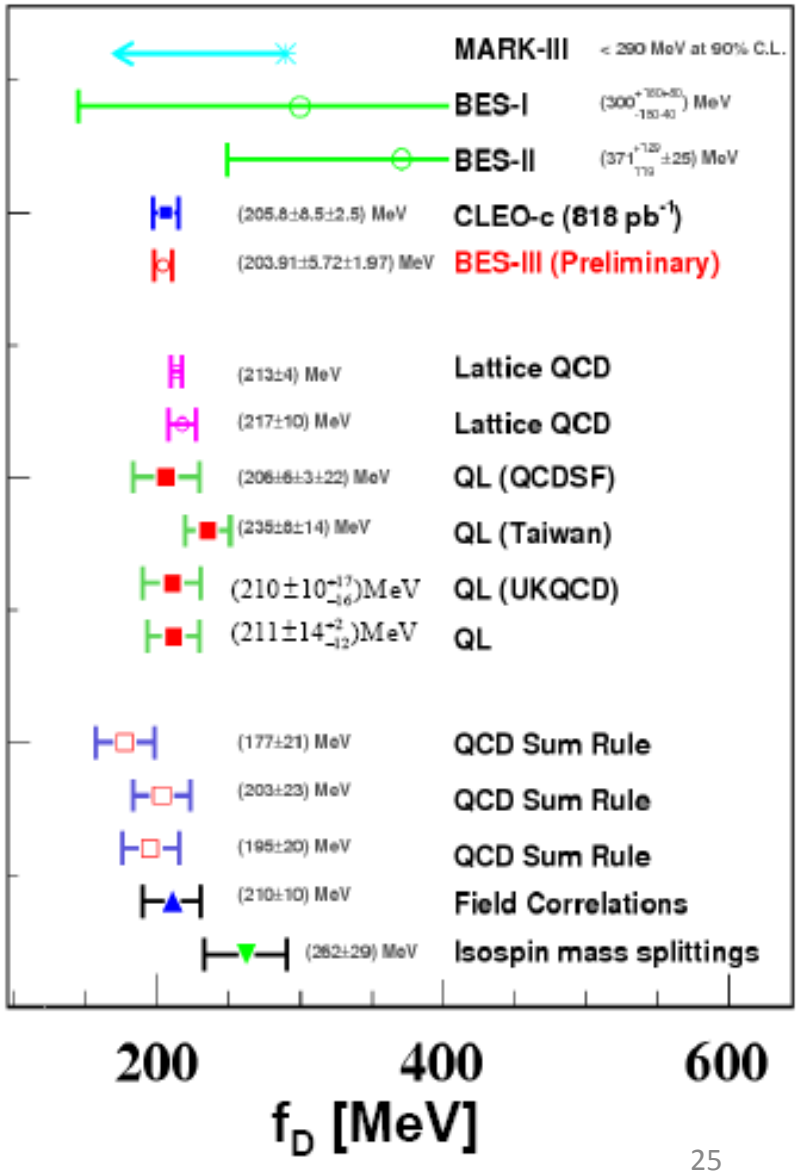
$BF(D^+ \rightarrow \mu^+\nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$

f_{D+} = (203.91±5.72±1.97) MeV

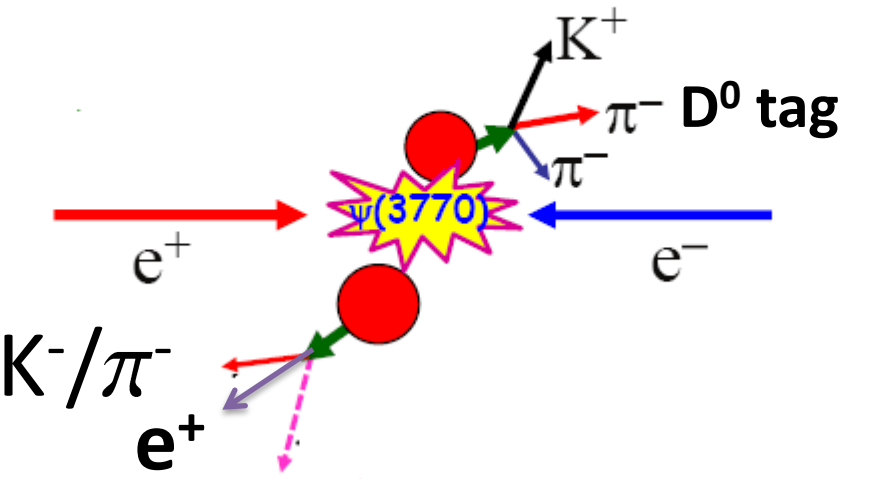
BESIII preliminary

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



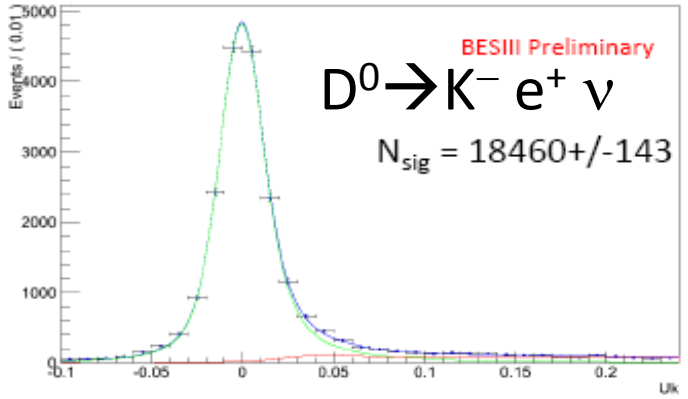


$D^0 \to K^-/\pi^- e^+ \nu$

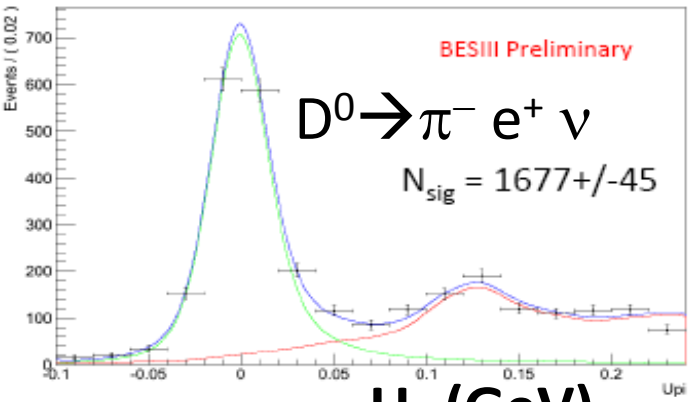


- **BESIII, ~2.93 fb-1 data taken at ψ(3770), ~923 pb-1 analyzed (by two groups, partially blind analysis)**
- **signal side: missing neutrino inferred**

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



U_k (GeV)

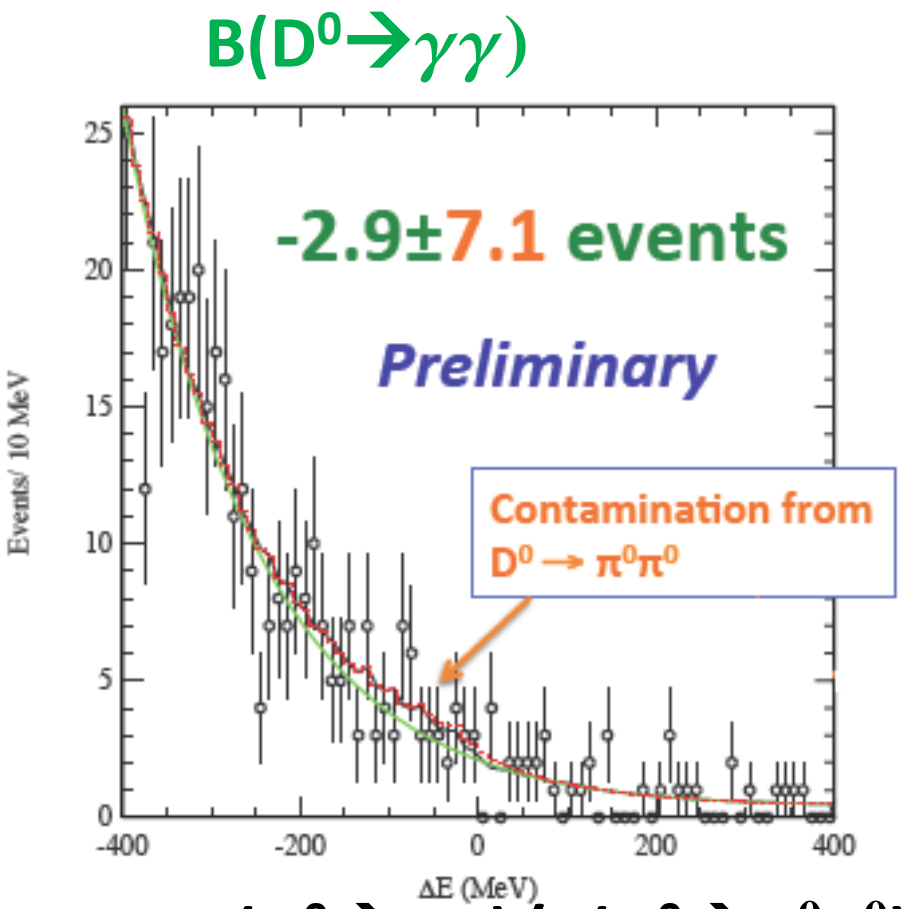


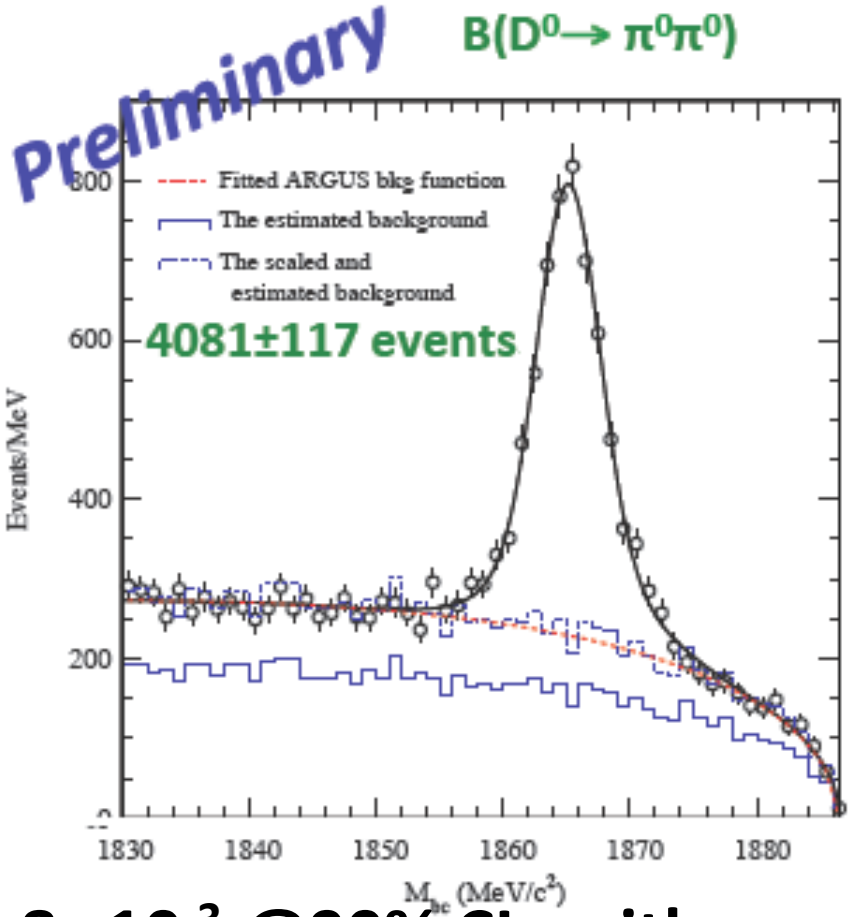
U_π (GeV)

BESIII Preliminary

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

$D^0 \to \gamma\gamma$





$B(D^0 \to \gamma\gamma)/B(D^0 \to \pi^0\pi^0) < 5.8\times10^{-3}$ @90% CL, with

PDG value: $B(D^0 \to \pi^0\pi^0) = 8\times10^{-4}$,

BESIII: $B(D^0 \to \gamma\gamma) < 4.6\times10^{-6}$ @90% CL.

BaBar: $B(D^0 \to \gamma\gamma) < 2.2\times10^{-6}$ @90% CL.

Summary

- BESIII is successfully operating since 2008:
  - World largest data samples at J/ψ, ψ′, ψ(3770), ψ(4040) already collected, more data in future ($D_S^{*+}D_S^-$ at 4170 MeV coming soon).
- Charmonium specscopy:
  - Precision measurements of h_c and $\eta_C(1S)$ and $\eta_C(2S)$ properties.
- Charmonium transitions
  - 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 $\chi_{c1} \to \omega\phi$, $\omega\omega$, $\phi\phi$ and $\eta_c(2S) \to VV$, $\chi_{c0/2} \to \gamma\gamma$.
- Charm decays:
  - precision open-charm D physics to come soon.
- **Expect many more results from BESIII in the future!**

谢谢！

Quarkonium 2013

The 9th International Workshop on Heavy Quarkonium
Organized by the Quarkonium Working Group

April 22-26, 2013, IHEP, Beijing, China

http://bes3.ihep.ac.cn/conference/QWG2013

Working Groups [with conveners: Theory / Experiment]

- Spectroscopy [G. Bali, N. Brambilla, J. Soto / R. Mizuk, R. Mitchell, R. Mussa]
- Decays [E. Eichten, A. Vairo / C. Patrignani, C.Z. Yuan]
- Production [G. Bodwin, E. Braaten, F. Maltoni / A. Meyer, V. Papadimitriou]
- Standard Model Measurements [A. Kronfeld, A. Pineda / S. Eidelman]
- Quarkonium in Media [P. Petreczky, R. Vogt / T. Frawley, E. Scomparin]
- Beyond the Standard Model [A.G. Mokhtar, A. Petrov, M.-A. Sanchis-Lozano]