Recent results at BESIII

H. L. Ma
(For BESIII Collaboration)

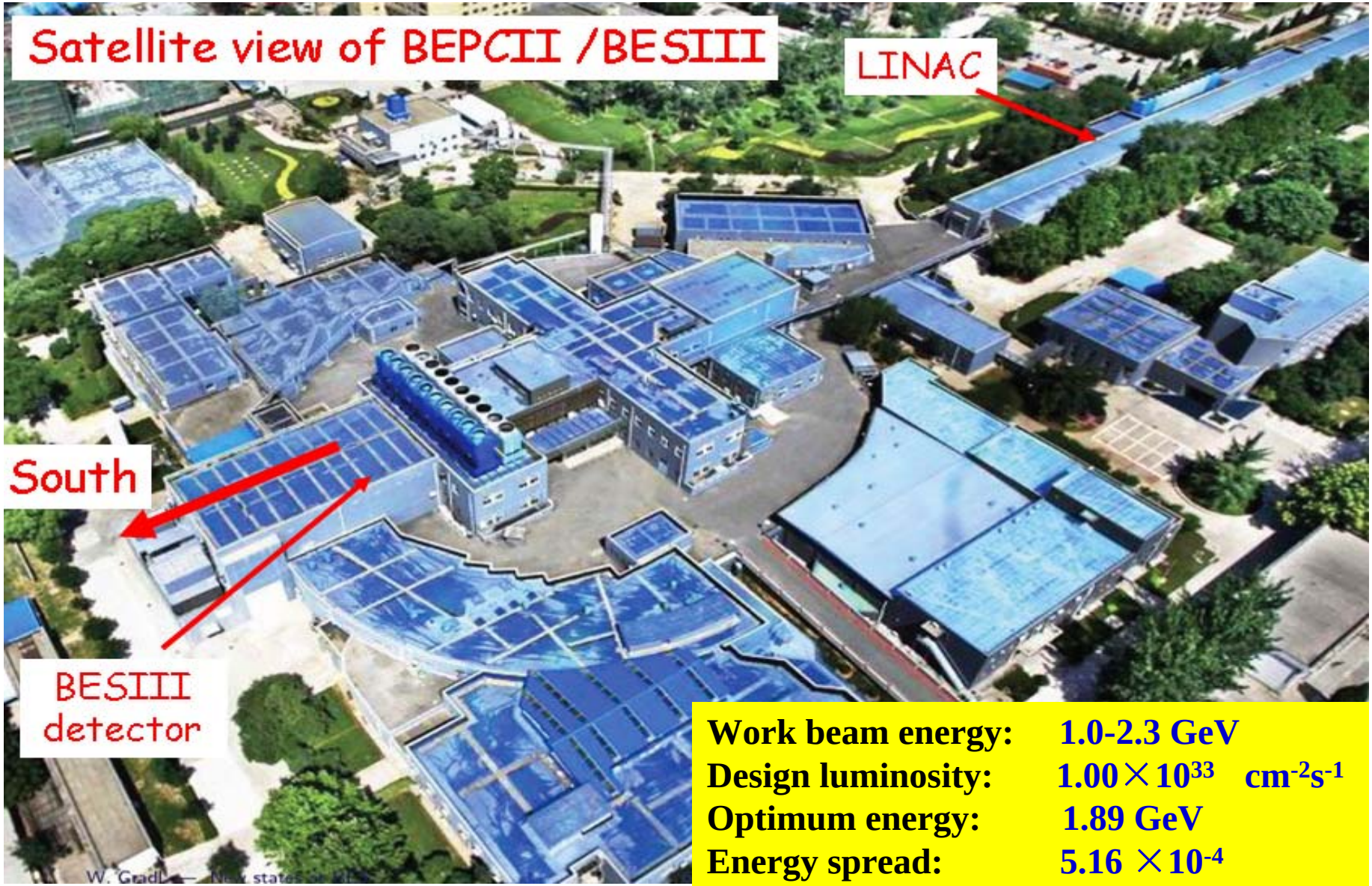
中國科學院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

The 20th International IUPAP Conference on Few-Body Problems in Physics (FB20), Aug. 19-25, 2012, Fukuoka, Japan

Contents

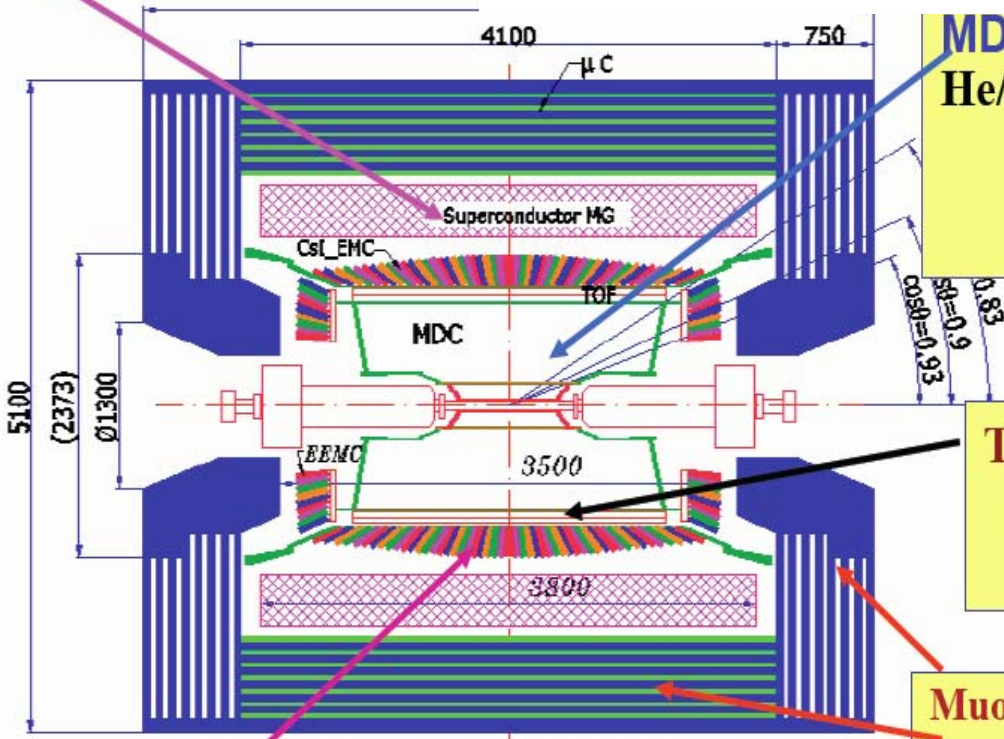
- **BEPCII/BESIII**
- **Recent results**
  - **New structures and phenomena**
  - **Charmonium parameters and decays**
  - **f_{D+}, V_{cd} and $f_{K/\pi}(q^2)$**
- **Summary**

BEPCII: high luminosity double-ring collider



Work beam energy:	**1.0-2.3 GeV**
Design luminosity:	**1.00×10^{33} $cm^{-2}s^{-1}$**
Optimum energy:	**1.89 GeV**
Energy spread:	**5.16×10^{-4}**

BESIII detector



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%

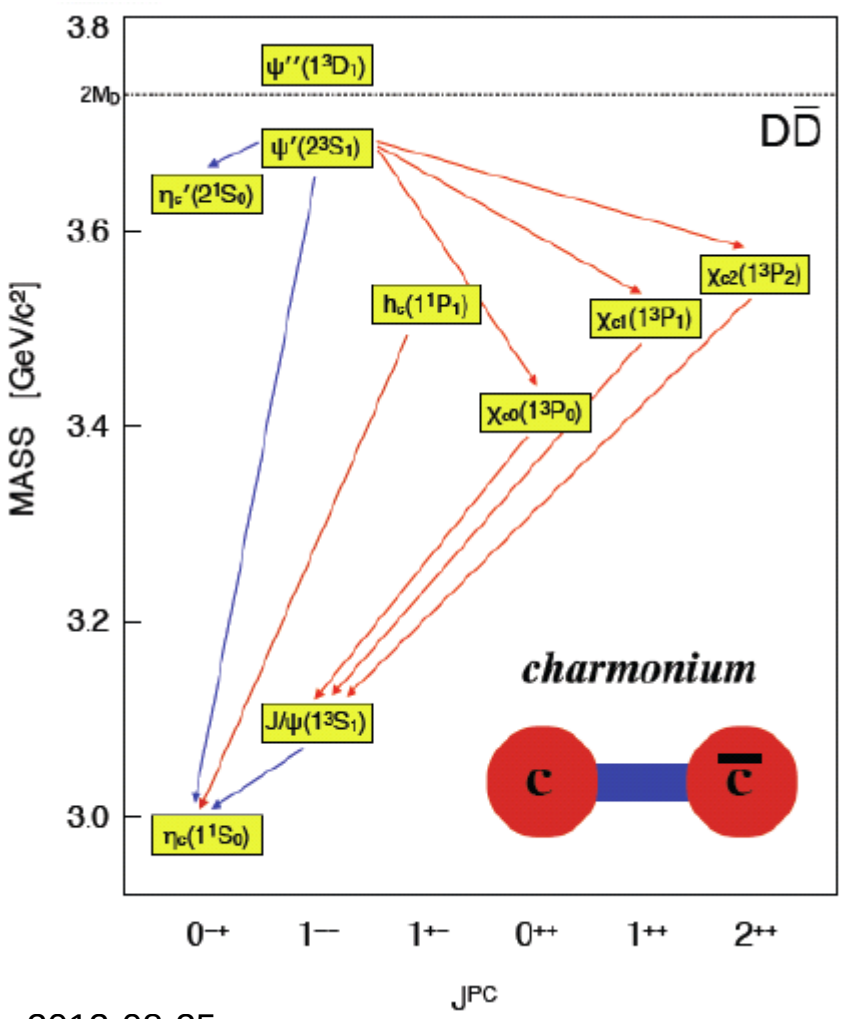
TOF:
σ_T = 100 ps Barrel
110 ps Endcap

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

Physics at BESIII



Light hadron physics:
- -Meson spectroscopy
- -Baryon spectroscopy
- -Threshold effects
- -Multi-quark states
- -Glueball & hybrid
- -Two-photon physics
- -Form factor of nucleon

Charmonium physics:
- -Spectroscopy
- -Transitions & decays

Charm physics:
- -Decay constant of D^+ / D_s^+
- -CKM matrix: V_{cd}, V_{cs}
- -Form factor of $f_{K/\pi}(q^2)$
- -$D^0\bar{D}^0$ mixing and CP violation
- -Rare decays

τ-QCD physics:
- -τ mass and decays
- -R values

Data taken at BESIII

Data taken from: 2009
Achieved luminosity: 0.65×10^{33} $cm^{-2}s^{-1}$

- **2009:** 106 M $\psi(3686)$ and 225 M J/ψ
- **2010-2011:** 2.9 fb^{-1} data at $\psi(3770)$
- **2011:** 477 pb^{-1} data at 4.01 GeV
- **2012:** τ mass scan, 0.4 B $\psi(3686)$ and 1 B J/ψ
- **2013:** 0.5 fb^{-1} @ each of 4.26 and 4.36 GeV (XYZ)
- **2014:** 2.4 fb^{-1} @ 4.17 GeV (D_s^+)
- **TBD:** More data @ $\psi(3770)$?

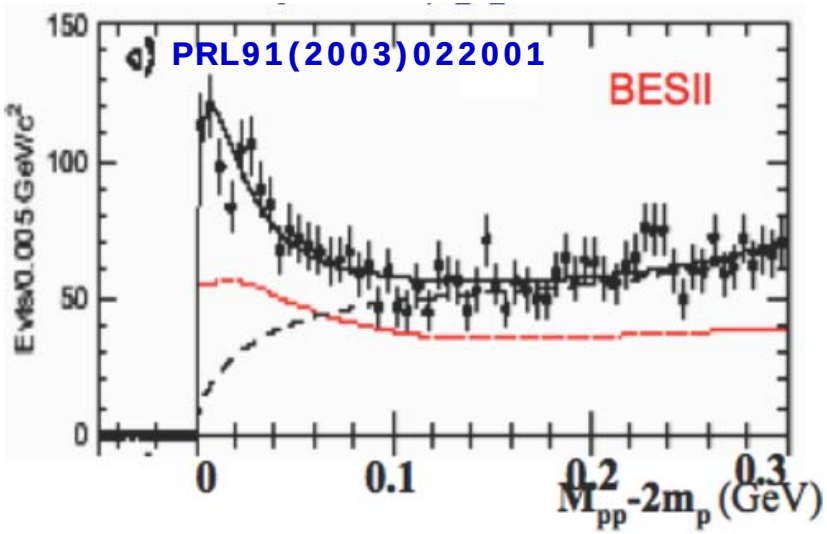
Reported results are based on 106 M $\psi(3686)$, 225 M J/ψ, 2.9 fb^{-1} data at $\psi(3770)$ and 477 pb^{-1} data at 4.01 GeV

Light hadron physics

- $p\bar{p}$ threshold enhancement in J/ψ and $\psi(3686)\rightarrow\gamma p\bar{p}$
- First observation of $\eta(1405)\rightarrow f_0(980)\pi^0$
- $\omega\phi$ threshold enhancement in $J/\psi\rightarrow\gamma\omega\phi$
- Structures in $\eta\eta$ system via $J/\psi\rightarrow\gamma\eta\eta$
- New N* structures in $\psi'\rightarrow p\bar{p}\pi^0$
- PWA of $\psi'\rightarrow p\bar{p}\eta$

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

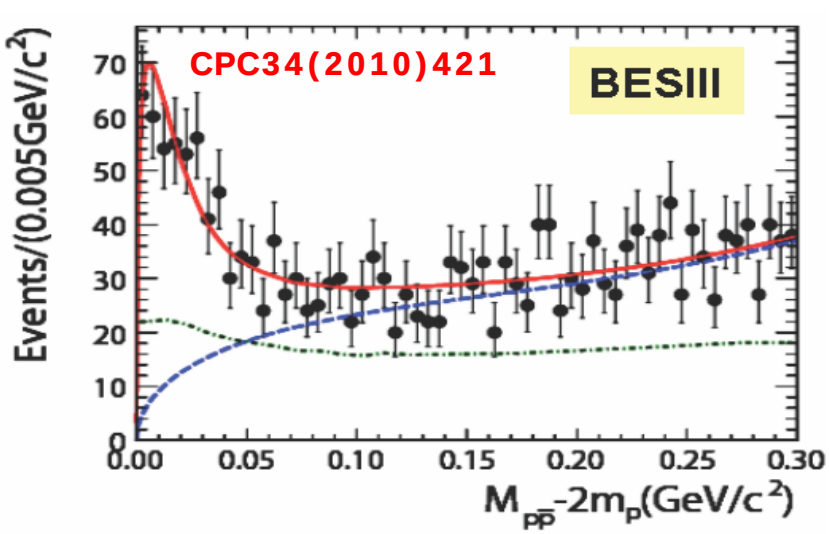
First observed in $J/\psi \to \gamma p\bar{p}$ at BESII



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

$\Gamma < 30\ \mathrm{MeV/c^2}$ @ 90%CL

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

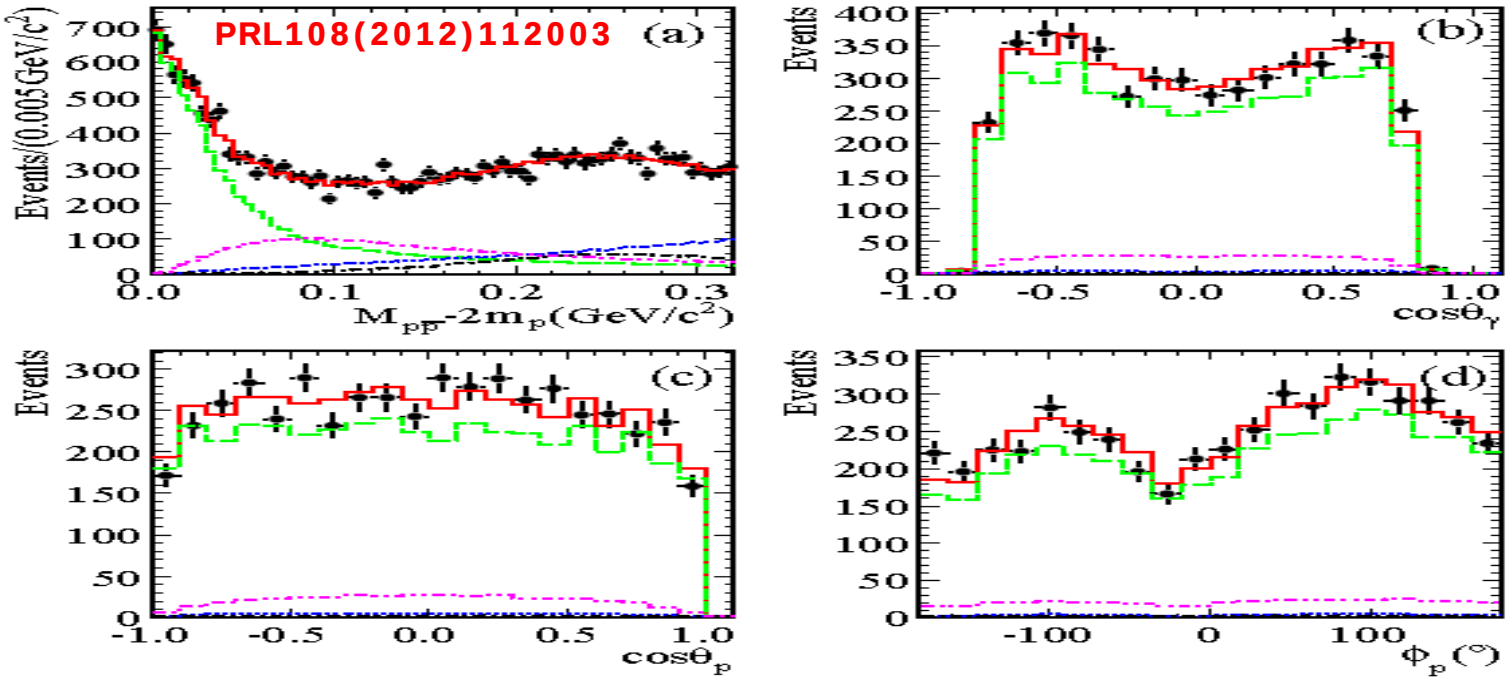


$M = 1861\,^{+6}_{-13}\,^{+7}_{-26}\ \mathrm{MeV/c^2}$

$\Gamma < 38\ \mathrm{MeV/c^2}$ @ 90%CL

- **Many possibilities: normal meson / $p\bar{p}$ bound state / multiquark / glueball / Final state interaction effect(FSI)…**
- **Spin-parity analysis is essential for probing for it's nature**

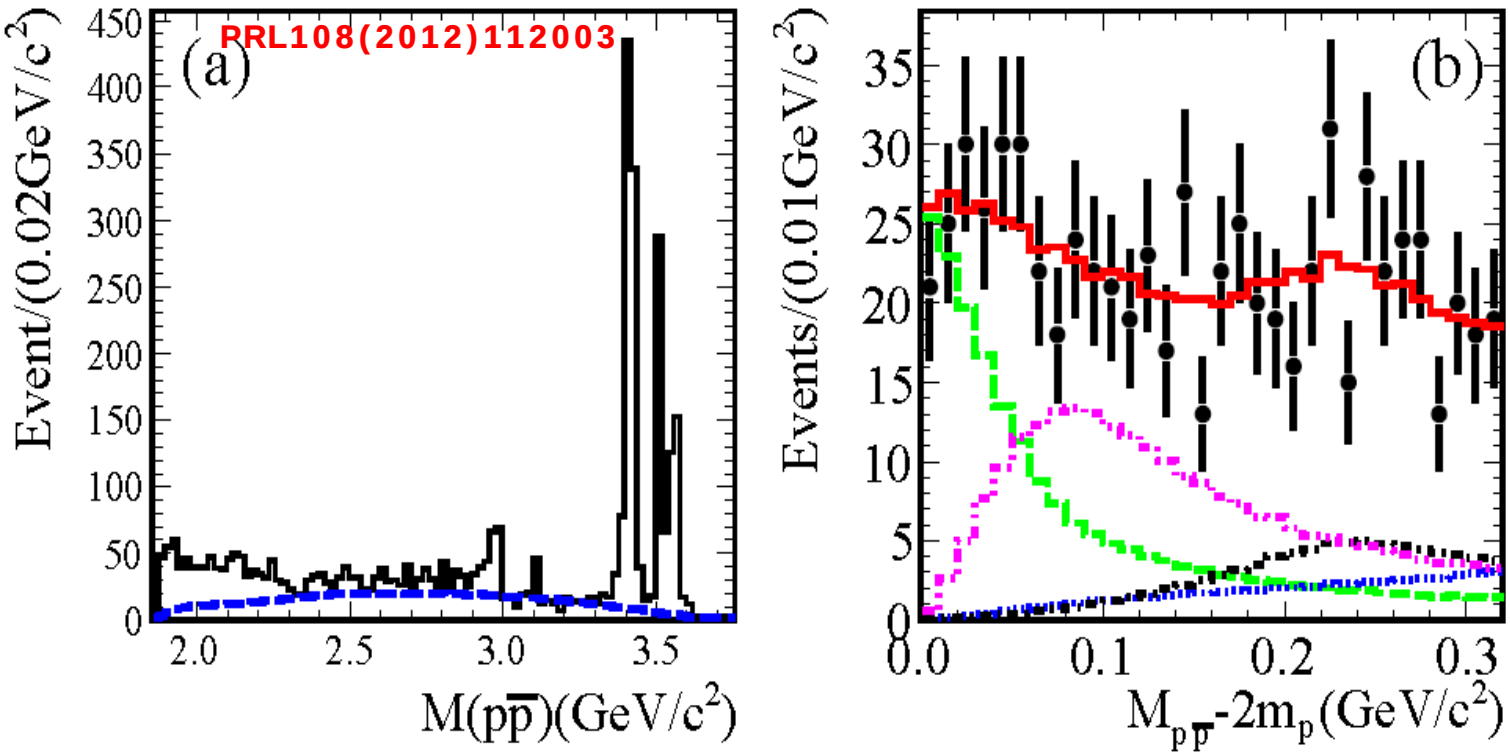
PWA of $J/\psi \to \gamma p\bar{p}$ at BESIII



The fit with a BW and S-wave FSI factor can well describe the structure. It is 7.1σ better than that without FSI.

- **Spin-Parity:** $J^{PC}=0^{-+}$ **>6.8σ better than other assignments**
- **Mass:** $M = 1832^{+19}_{-5}(\text{stat.})^{+18}_{-17}(\text{sys.}) \pm 19(\text{mod.})\ \text{MeV}/c^2$
- **Width:** $\Gamma = 13 \pm 20(\text{stat.})^{+11}_{-33}(\text{sys.}) \pm 4(\text{mod.})\ \text{MeV}/c^2$ $\quad \Gamma < 76\ \text{MeV}/c^2\ @90\%\text{CL}$
- **BF:** $B\left[J/\psi \to \gamma X(p\bar{p})\right] \times B\left[X(p\bar{p}) \to p\bar{p}\right] = \left[9.0^{+0.4}_{-1.1}(\text{stat.})^{+1.5}_{-5.0}(\text{sys.}) \pm 2.3(\text{mod.})\right] \times 10^{-5}$

$p\bar{p}$ threshold structure in $\psi' \rightarrow \gamma p\bar{p}$ at BESIII



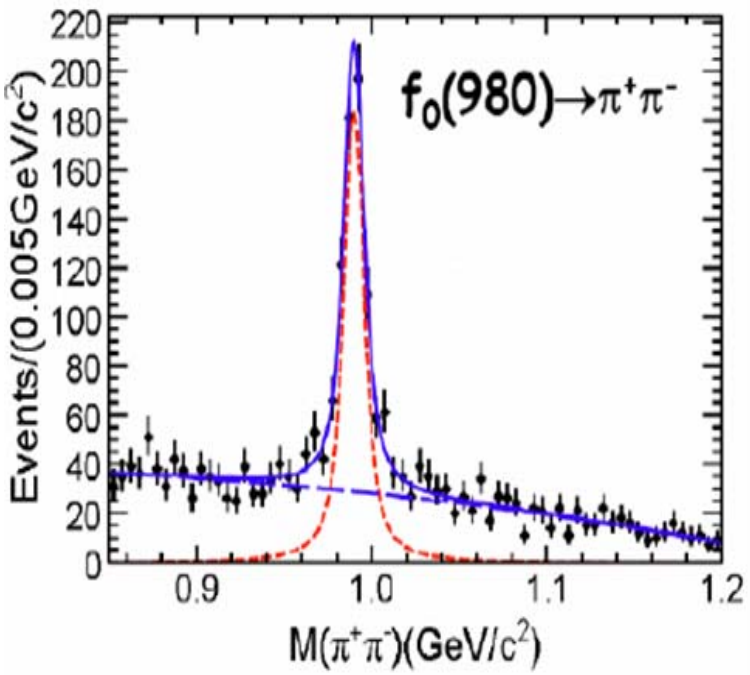
- **Different shape is observed**
- **Significance of X($p\bar{p}$) is >6.9σ**
- **Production ratio:**

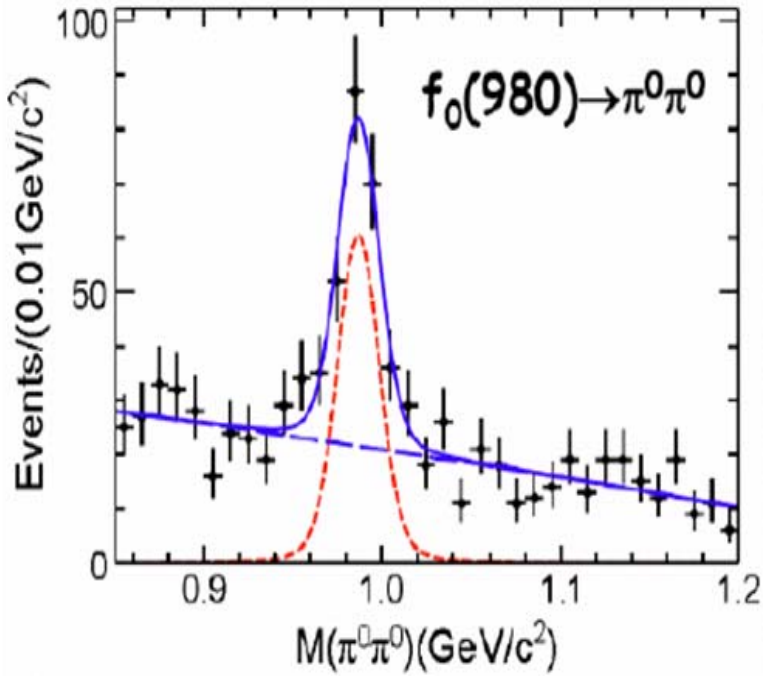
$$\frac{B[\psi' \to \gamma X(p\bar{p})]}{B[J/\psi \to \gamma X(p\bar{p})]} = [5.08^{+0.71}_{-0.45}(\text{stat.})^{+0.67}_{-3.58}(\text{sys.}) \pm 0.12(\text{mod.})]\%$$

It is suppressed compared to "12% rule"

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

PRL108(2012)182001





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

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

$\Gamma < 11.8\ \mathrm{MeV/c^2}$ @ 90%CL

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

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

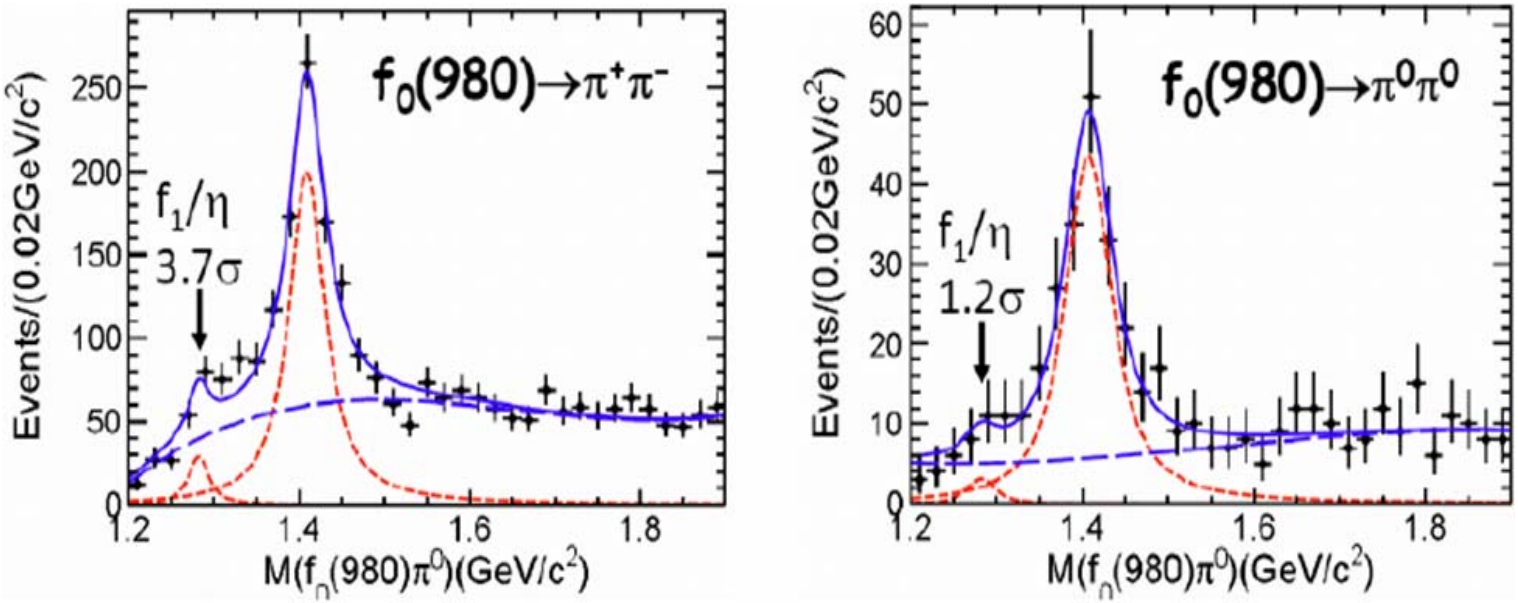
PDG10 : 40 – 100 MeV/c^2

A possible explanation is KK* loop. Triangle singularity (T5)

J.J.Wu, PRL108(2012)081803

First observation of $\eta(1405)\to f_0(980)\pi^0$

PRL108(2012)182001



- **BF for the isospin breaking decay**

$$B\left[J/\psi\to\gamma\eta(1405)\to\gamma f_0(980)\pi^0\to\gamma\pi^+\pi^-\pi^0\right]=\left[1.50\pm0.11(\text{stat.})\pm0.11(\text{sys.})\right]\times10^{-5}$$

$$B\left[J/\psi\to\gamma\eta(1405)\to\gamma f_0(980)\pi^0\to\gamma\pi^0\pi^0\pi^0\right]=\left[7.10\pm0.82(\text{stat.})\pm0.72(\text{sys.})\right]\times10^{-6}$$

$$\frac{B\left[\eta(1405)\to f_0(980)\pi^0\to\pi^+\pi^-\pi^0\right]}{B\left[\eta(1405)\to a_0(980)\pi^0\to\pi^0\pi^0\eta\right]}=(17.9\pm4.2)\%$$

Simple a_0-f_0 mixing can not explain B[$\eta(1405)$]

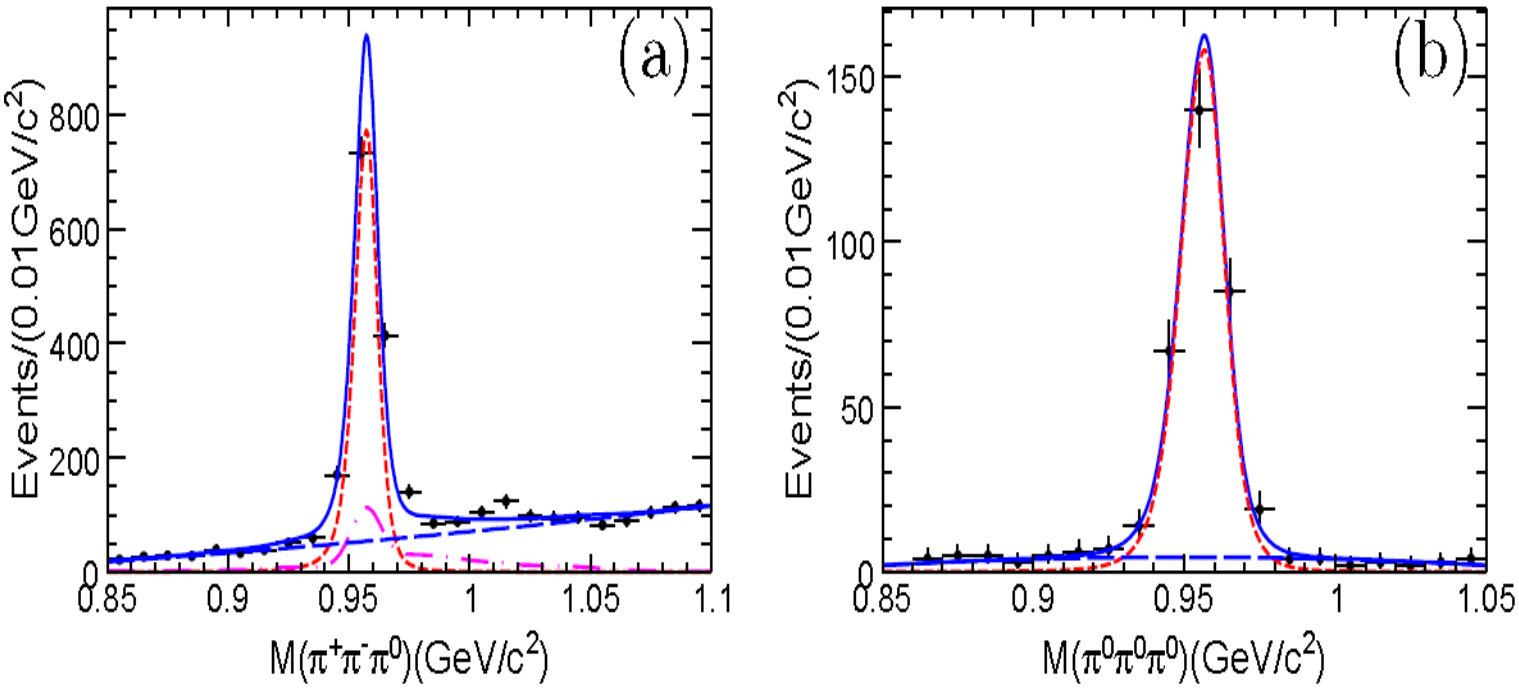
- **Compared to**

$$\frac{B\left[\chi_{c1}\to f_0(980)\pi^0\to\pi^+\pi^-\pi^0\right]}{B\left[\chi_{c1}\to a_0(980)\pi^0\to\pi^0\pi^0\eta\right]}<1\%\,(@90\%\text{CL})$$

BESIII, PRD83(2010)032003

Improved B[η'→3π] via J/ψ→γππ

PRL108(2012)182001



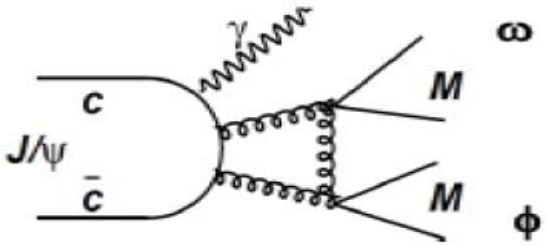
$$B(\eta\to\pi^+\pi^-\pi^0)=(3.83\pm0.15\pm0.39)\times10^{-3}$$
$$B(\eta\to\pi^0\pi^0\pi^0)=(3.56\pm0.22\pm0.34)\times10^{-3}$$

$$B^{PDG10}(\eta\to\pi^+\pi^-\pi^0)=(3.60^{+1.1}_{-0.93})\times10^{-3}$$
$$B^{PDG10}(\eta\to\pi^0\pi^0\pi^0)=(1.68\pm0.22)\times10^{-3}$$

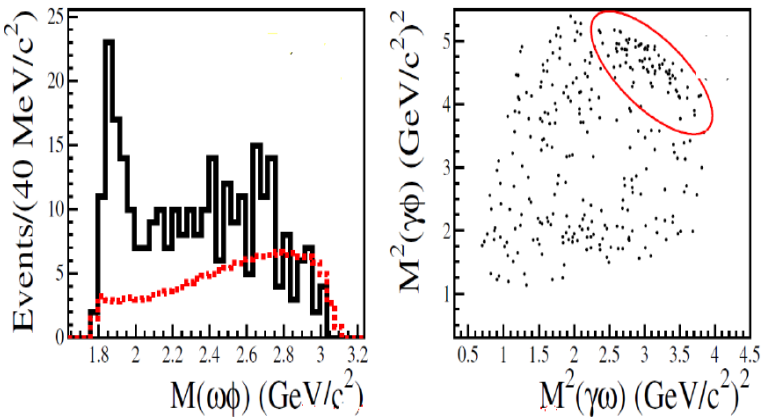
B[η'→π⁰π⁰π⁰] is two times larger than the world averaged value

ωϕ threshold enhancement in J/ψ→γωϕ

J/ψ→γωϕ:DOZI



BESII, PRL96(2006)162002

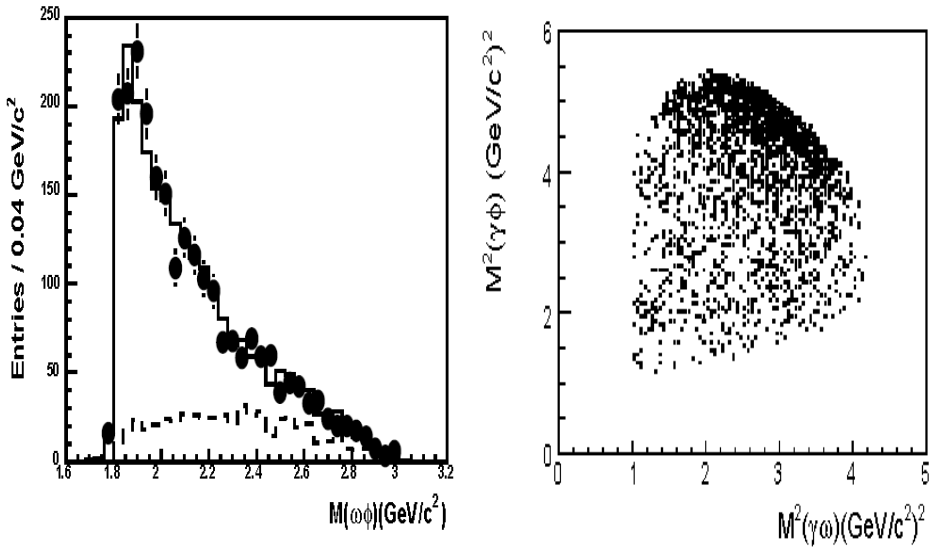


$M = 1812^{+19}_{-26} \pm 18\ \mathrm{MeV}/c^2$

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

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

PWA of J/ψ→γωϕ at BESIII Preliminary



BESIII preliminary results

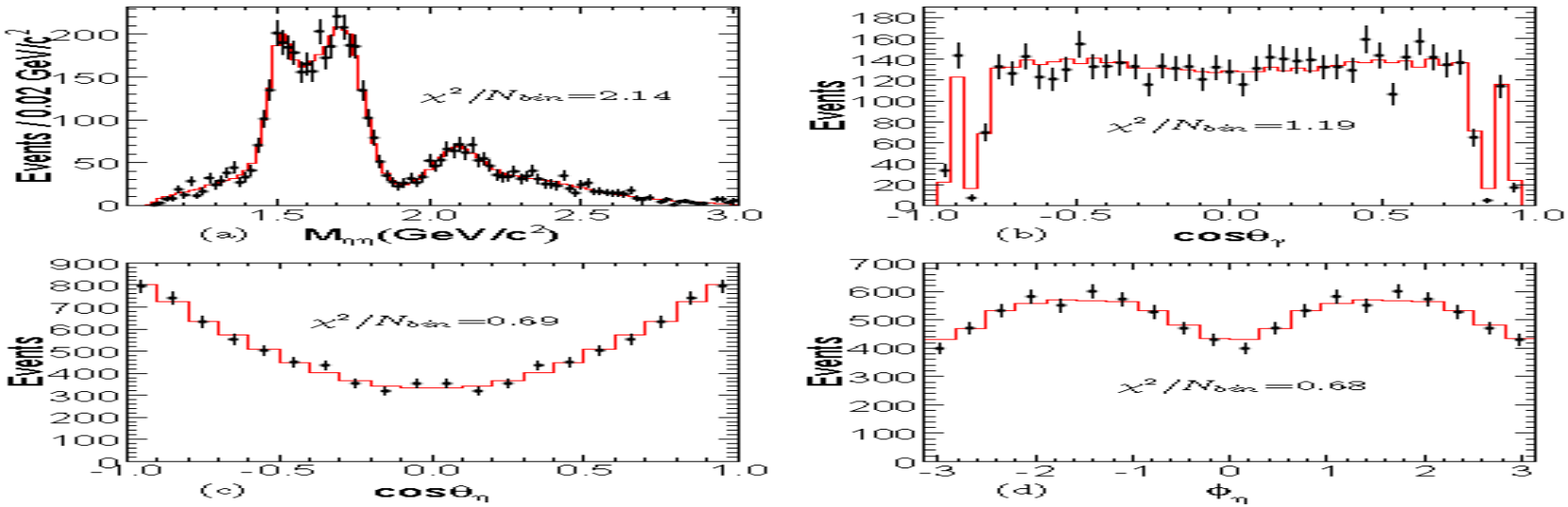
Resonance	J^{PC}	M(MeV/c^2)	Γ(MeV/c^2)	Events	$\Delta\mathcal{S}$	Δndf	Significance
$X(1810)$	0^{++}	1795 ± 7	95 ± 10	1319 ± 52	783	4	$> 30\sigma$
$f_2(1950)$	2^{++}	1944	472	665 ± 40	211	2	$> 10\sigma$
$f_0(2020)$	0^{++}	1992	442	715 ± 45	100	2	$> 10\sigma$
$\eta(2225)$	0^{-+}	2240	190	70 ± 30	23	2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

Is X(1810) the $f_0(1710)/f_0(1790)$ or new state?

Structures in ηη system via J/ψ→γηη

- $f_0(1710)$ first observed in ηη system via J/ψ→γηη by Crystal Ball (1982).
- LQCD predict: 0^{++}, 1710±50±80 MeV
- Crystal Barrel Collaboration (2002) found a 2^{++}(1870 MeV) but no $f_0(1710)$.
- E835 (2006) find $f_0(1500)$ and $f_0(1710)$ in $p\bar{p}$→πηη
- WA102 and GAMS all identify $f_0(1710)$ in ηη system

BESIII, preliminary of PWA of J/ψ→γηη



BESIII preliminary results

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}_{-24-18}	$(9.99^{+0.57+5.52}_{-0.52-2.21}) \times 10^{-5}$	13.9 σ
$f_2'(1525)$	1513^{+5+3}_{-5-10}	75^{+12+15}_{-10-9}	$(3.41^{+0.43+1.22}_{-0.50-1.23}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	1822^{+29+61}_{-24-54}	$229^{+52+64}_{-42-152}$	$(5.38^{+0.60+3.31}_{-0.67-2.24}) \times 10^{-5}$	6.4 σ
$f_2(2340)$	$2362^{+31+139}_{-30-59}$	$334^{+62+164}_{-54-99}$	$(5.58^{+0.61+1.93}_{-0.65-1.81}) \times 10^{-5}$	7.6 σ

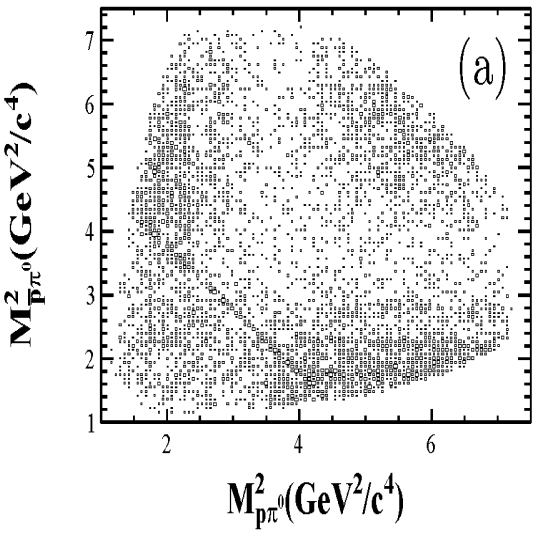
- $f_0(1500)$ exists (8.2σ)
- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f'_2(1525)$ is dominant tensor

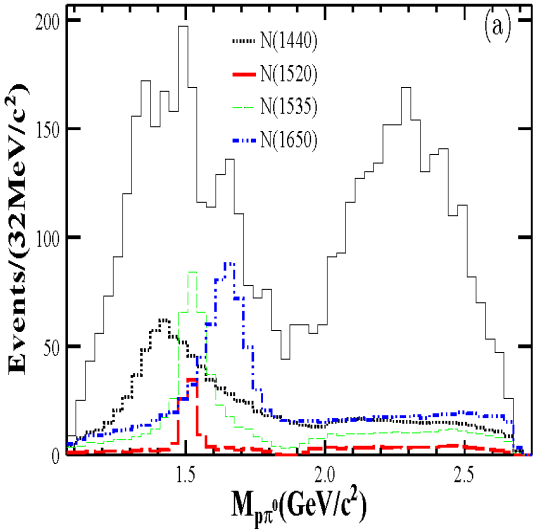
Two new N* structures from PWA of $\psi' \to \pi^0 p\bar{p}$

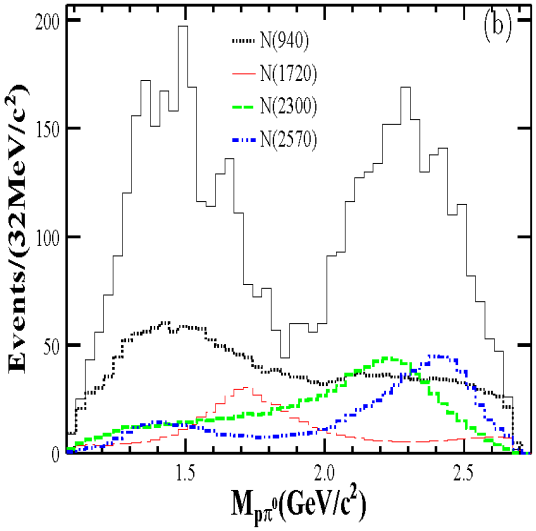
- **Non-relativeistic quark model is successful in interpreting the excited baryons**
- **Predicted more excited states**

  J/ψ and ψ' provide ideal channels to search for the "missing resonance"

arXiv:1207.0223, submitted to PRL







- **Two new N* structures are observed**

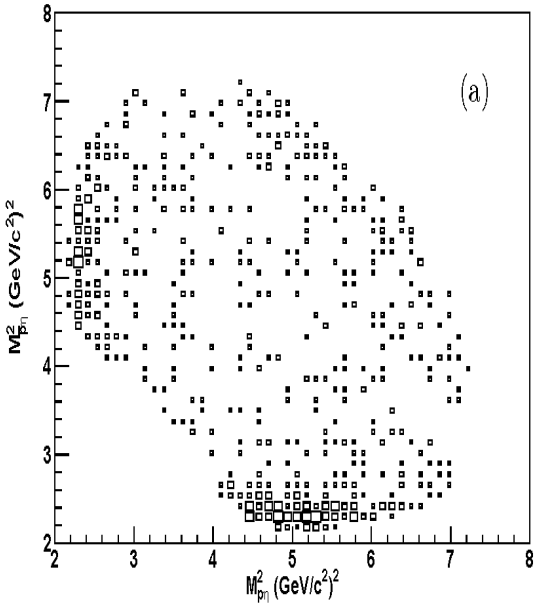
Resonance	M(MeV/c^2)	Γ(MeV/c^2)	ΔS	ΔN_{dof}	Sig.
$N(1440)$	1390^{+11+21}_{-21-30}	$340^{+46+70}_{-40-156}$	72.5	4	11.5σ
$N(1520)$	1510^{+3+11}_{-7-9}	115^{+20+0}_{-15-40}	19.8	6	5.0σ
$N(1535)$	1535^{+9+15}_{-8-22}	120^{+20+0}_{-20-42}	49.4	4	9.3σ
$N(1650)$	1650^{+5+11}_{-5-30}	150^{+21+14}_{-22-50}	82.1	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

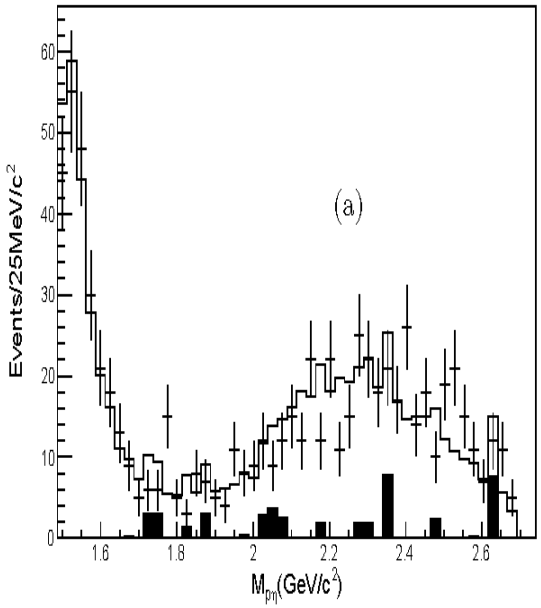
2012

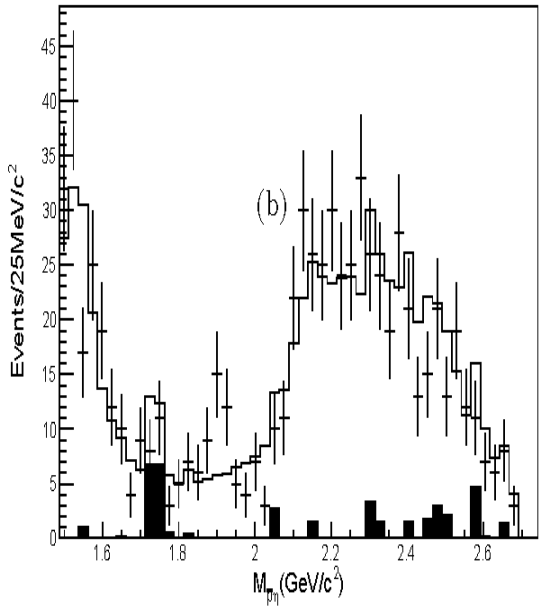
Resonance	N	$\epsilon(\%)$	B.F.($\times 10^{-5}$)
$N(940)$	$1870^{+90+487}_{-90-327}$	27.5 ± 0.4	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	27.9 ± 0.4	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	190^{+14+64}_{-14-48}	28.0 ± 0.4	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	25.8 ± 0.4	$2.47^{+0.28+0.99}_{-0.28-0.97}$
$N(1650)$	$1080^{+77+382}_{-77-467}$	27.2 ± 0.4	$3.76^{+0.28+1.37}_{-0.28-1.66}$
$N(1720)$	$510^{+27+50}_{-27-197}$	26.9 ± 0.4	$1.79^{+0.10+0.24}_{-0.10-0.71}$
$N(2300)$	$948^{+68+394}_{-68-213}$	34.2 ± 0.4	$2.62^{+0.28+1.12}_{-0.28-0.64}$
$N(2570)$	$795^{+45+127}_{-45-83}$	35.3 ± 0.4	$2.13^{+0.08+0.40}_{-0.08-0.30}$
Total	4515 ± 93	25.8 ± 0.4	$16.5 \pm 0.3 \pm 1.5$

N* structures from PWA of ψ'→ηp̄p

BESIII, preliminary







- **N(1525) dominant:** $M = 1524^{+5}_{-5}{}^{+10}_{-4}\,\mathrm{MeV}/c^2$ $\Gamma = 130^{+27}_{-24}{}^{+57}_{-10}\,\mathrm{MeV}/c^2$
- **Branching fraction:**

$$B[\psi' \to p\bar{p}\eta] = (6.6 \pm 0.2 \pm 0.6) \times 10^{-5}$$

$$B^{\mathrm{PDG10}}[\psi' \to p\bar{p}\eta] = (6.0 \pm 1.2) \times 10^{-5}$$

$$B[\psi' \to N(1535)\bar{p}] \times B[N(1535) \to p\eta + \mathrm{c.c.}] = (5.5^{+0.3}_{-0.3}{}^{+7.4}_{-1.1}) \times 10^{-5}$$

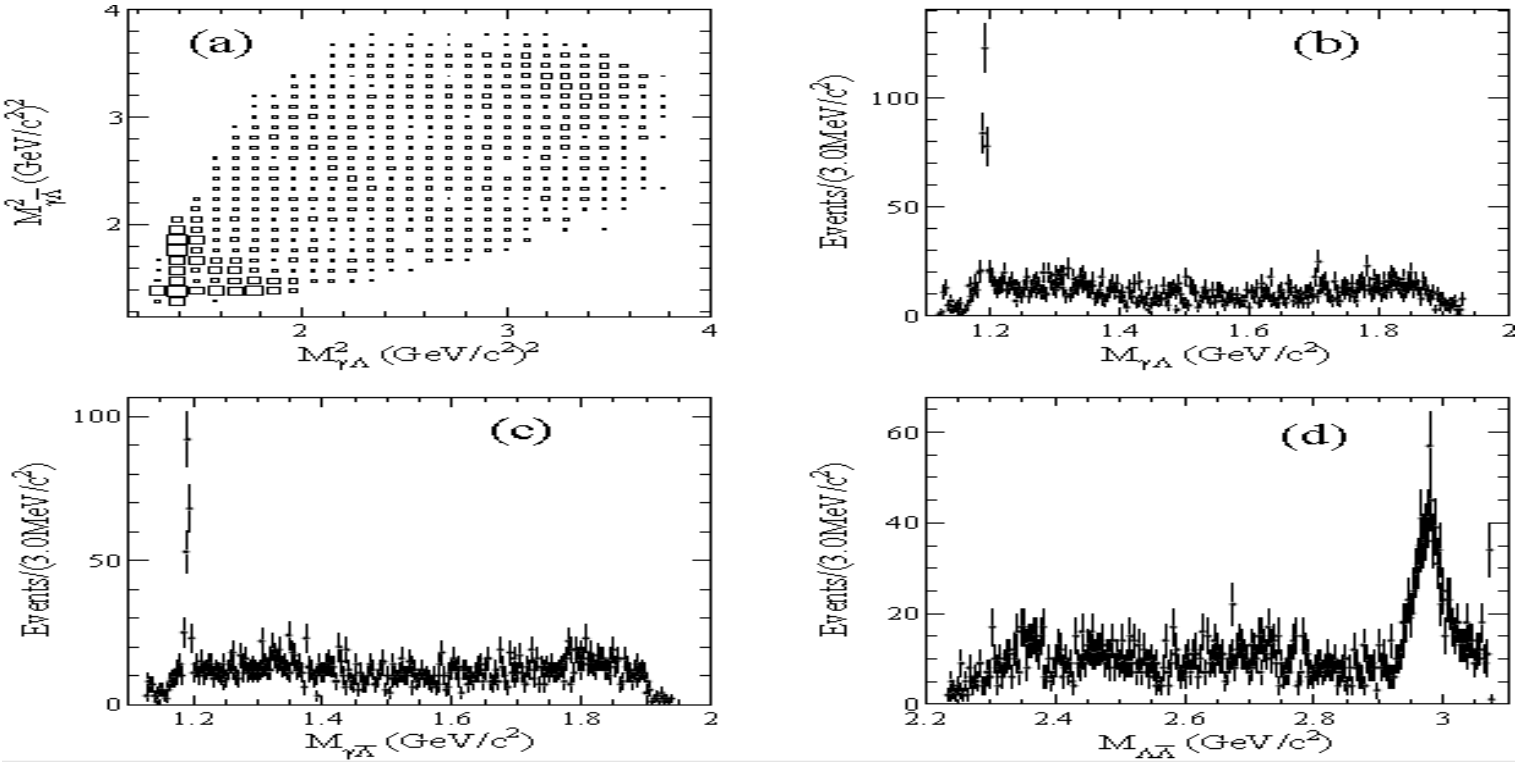
- **Production ratio:**

$$\frac{B[\psi' \to p\bar{p}\eta]}{B[J/\psi \to p\bar{p}\eta]} = (3.1 \pm 0.4)\%$$

It is suppressed compared to "12% rule"

First observe of isospin violating decay $J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.$

arXiv:1207.1201, submitted to PRD



[$\times 10^{-5}$]

J/ψ decay mode	BESIII	PDG
$\bar{\Lambda}\Sigma^0$	$1.46 \pm 0.11 \pm 0.12$	< 7.5
$\Lambda\bar{\Sigma}^0$	$1.37 \pm 0.12 \pm 0.11$	< 7.5
$\gamma\eta_c(\eta_c \to \Lambda\bar{\Lambda})$	$1.98 \pm 0.21 \pm 0.32$	-
$\Lambda\bar{\Lambda}(1520) + c.c.(\bar{\Lambda}(1520) \to \gamma\bar{\Lambda})$	< 0.41	-

90 % CL

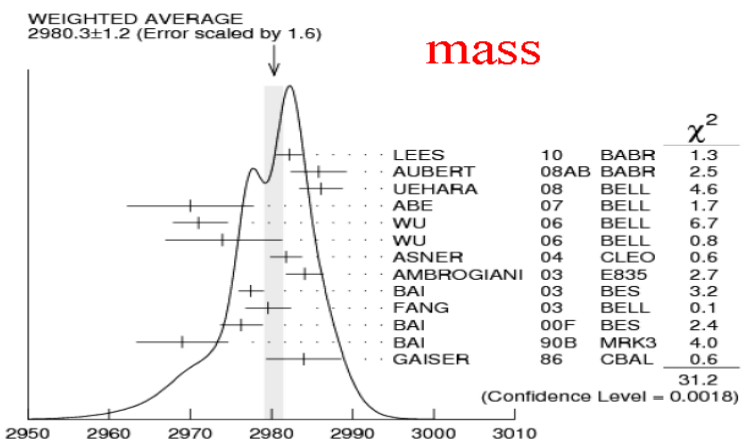
Charmonium physics

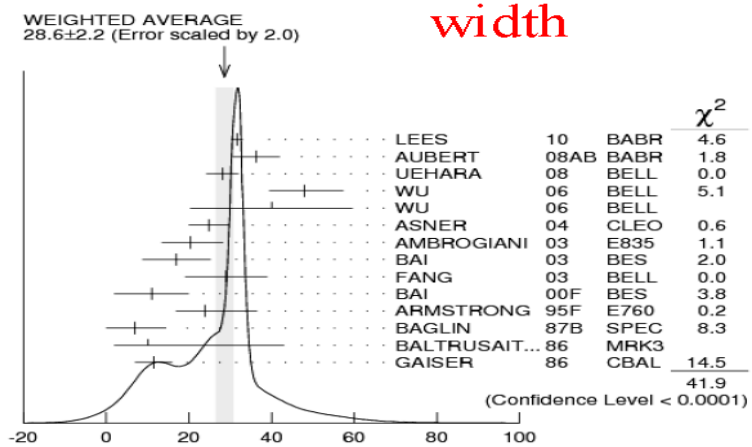
- $\eta_c(1S)$ parameters
- h_c parameters
- Observation of $\psi' \rightarrow \gamma\eta_c(2S)$
- First evidence for $\psi' \rightarrow \gamma\gamma J/\psi$
- First evidence for $\eta_c \rightarrow \gamma\gamma$
- Measurements of χ_{CJ} decays

Why $\eta_c(1S)$ parameters is important?

- **The lowest lying charmonium, discovered in 1980 by MARKII**

- **$\eta_c(1S)$ parameters**
  - **J/ψ radiative transition:** $M \sim 2978 0\,\mathrm{MeV}/c^2$ $\Gamma \sim 10\ \mathrm{MeV/c}^2$
  - **$\gamma\gamma$ process:** $M = 2983.1 \pm 1.0\,\mathrm{MeV}/c^2$ $\Gamma = 31.1 \pm 1.9\ \mathrm{MeV/c}^2$



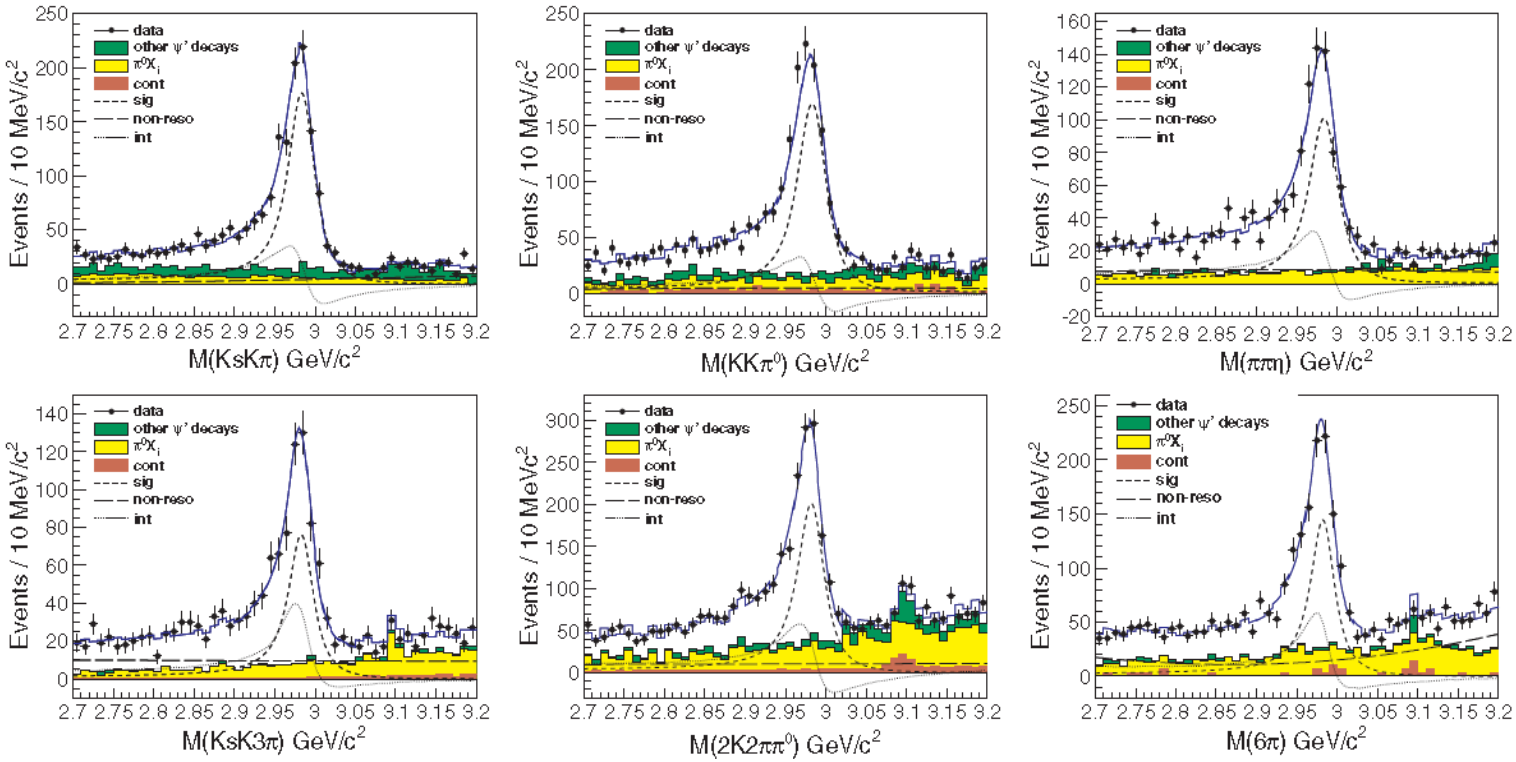


- **CLEOc found the distortion of $\eta_c(1S)$ lineshape in ψ' decays**
  PRL106(2011)159903

- **$c\bar{c}$ hyperfine splitting: M(J/ψ)-M(η_c) is important experimental input to test LQCD.**

Measurements of $\eta_c(1S)$ parameters

PRL108(2012)222002

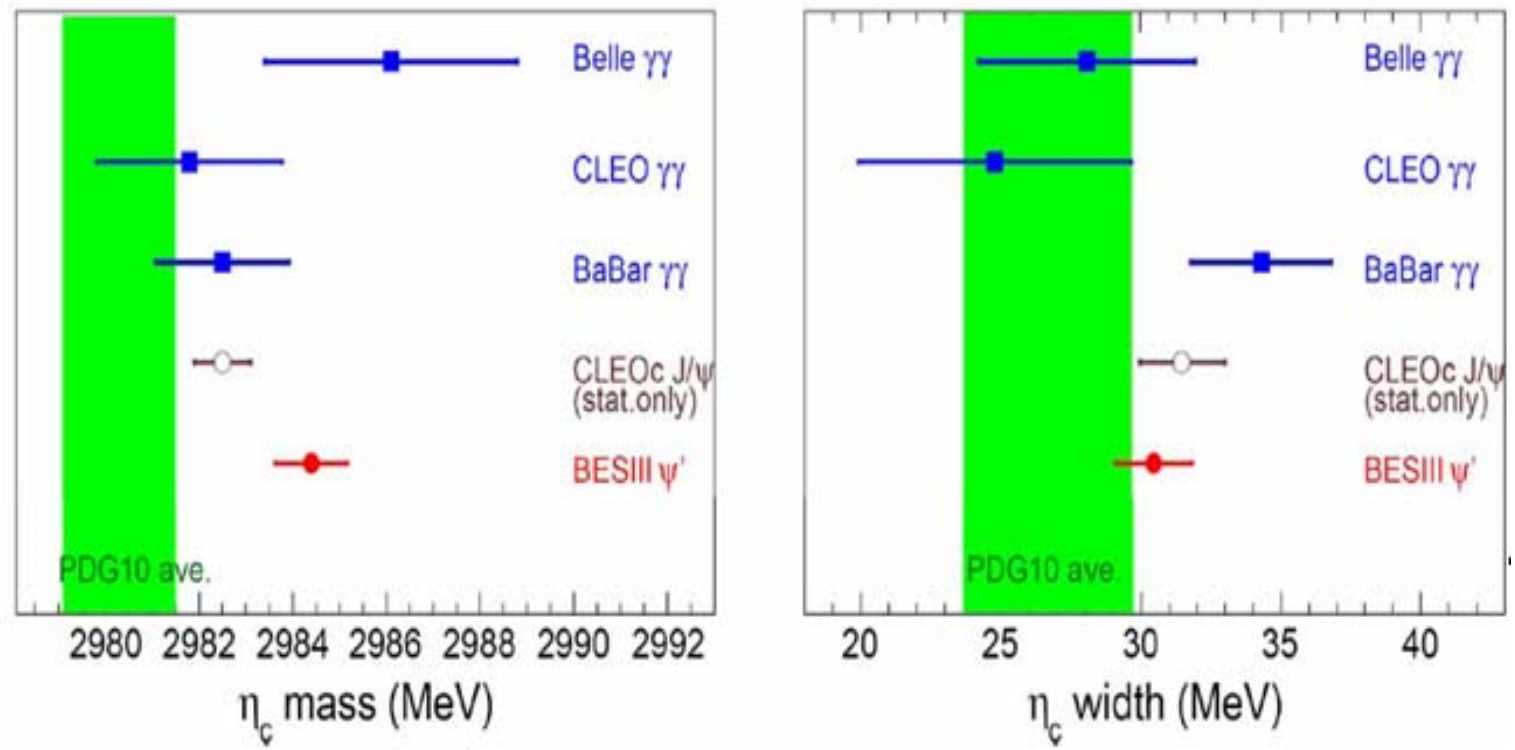


- **Interference with non-resonant is significant!**

- **Relative phase ϕ values from each mode are consistent within 3σ.**
  → use a common phase value in the simutanous fit.

$$M = 2894.3 \pm 0.6 \pm 0.6\ \mathrm{MeV/c^2}$$
$$\Gamma = 32.0 \pm 1.2 \pm 1.0\ \mathrm{MeV/c^2}$$
$$\phi = 2.40 \pm 0.07 \pm 0.08\ \mathrm{rad}$$
$$\mathrm{or} = 4.19 \pm 0.03 \pm 0.09\ \mathrm{rad}$$

Comparison of $\eta_c(1S)$ parameters



- **Hyperfine splitting:** $\Delta M(1S) = 112.6 \pm 0.8\ \mathrm{MeV}/c^2$
- **Consistent with B factory results in other production mechanisms**
- **Agree with the LQCD expectation of $\Delta M(1S)$**

Why $h_c(1P)$ is interesting?

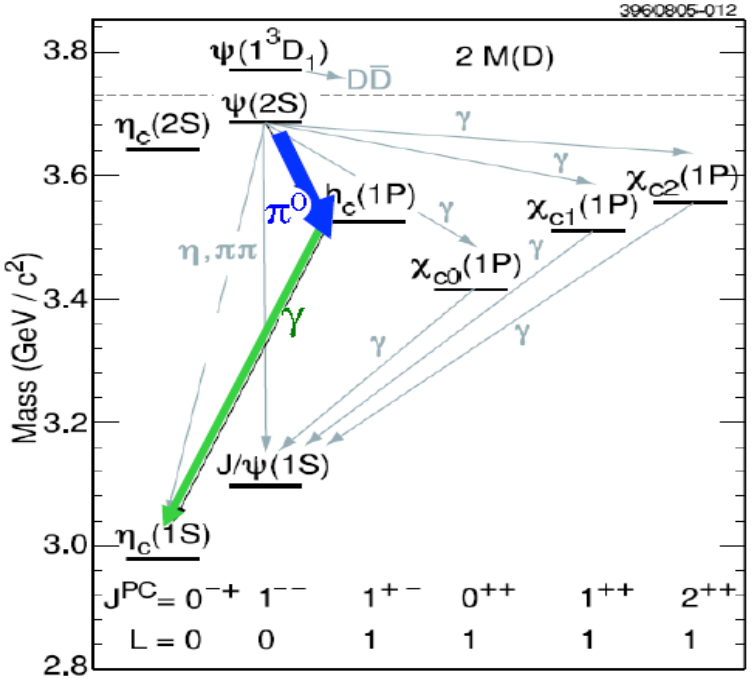
- **Isospin forbidden transition**

  $B(\psi' \to \pi^0 h_c)$

- **E1 transition of h_c**

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

- **Hyperfine splitting of the 1P states**



- **First evidence for h_c:**
  E835, $p\bar{p} \to h_c \to \gamma\eta_c$ E835, PRD72(2005)092004

- **CLEOc observed h_c in e^+e^-**
  $\to \psi' \to \pi^0 h_c, h_c \to \gamma\eta_c$ CLEO, PRL101(2008)182003

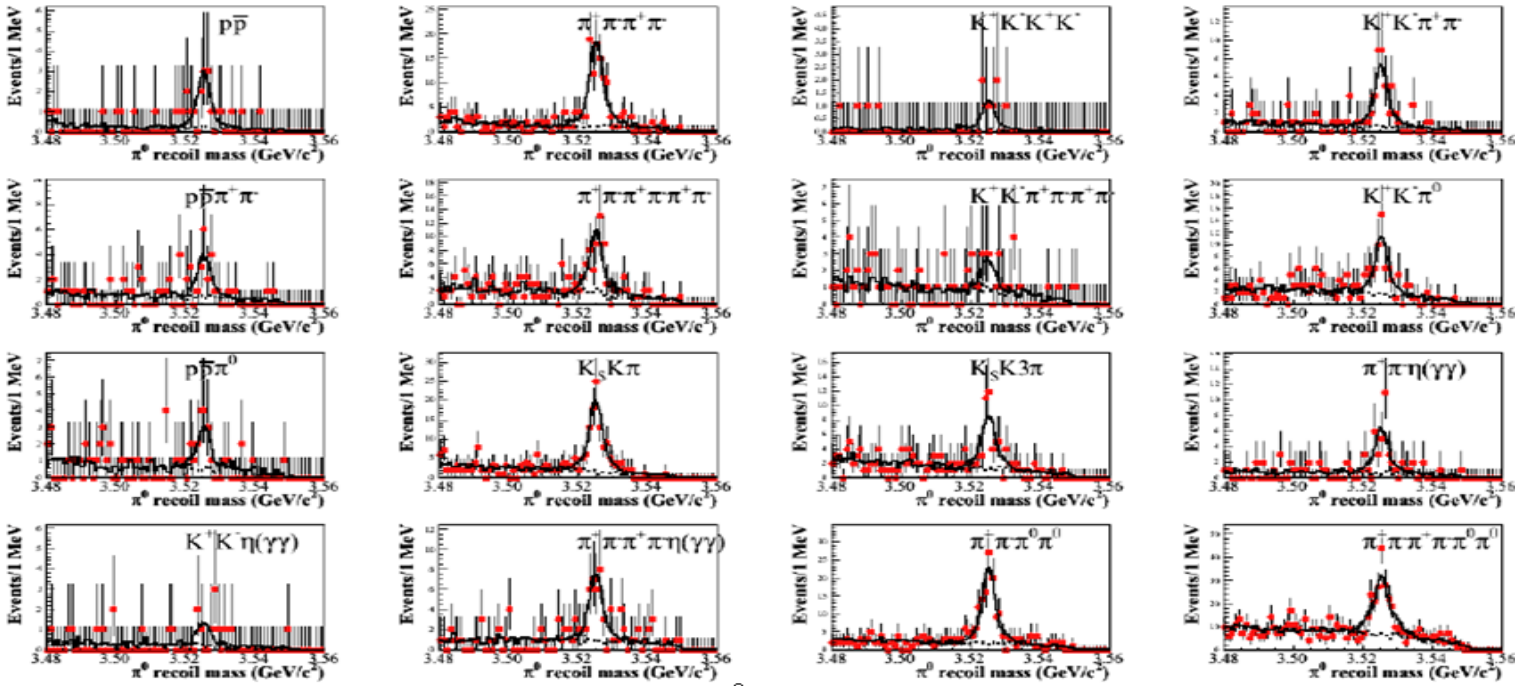
- **BESIII and CLEO performed more studies by inclusive method** BESIII, PRL104(2010)132002
  CLEO, PRD(2011)032008

More experiments will help to better understand h_c properties and calibrate the theoretical predictions

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

BESIII preliminary

Signal in very clear in exclusive channel



- **Simultaneous fit to π^0 recoil mass χ^2/d.o.f=32/46**

  $M = 3525.31 \pm 0.11 \pm 0.15\ \mathrm{MeV}/c^2$ $\quad\quad$ $\Gamma = 0.70 \pm 0.28 \pm 0.25\ \mathrm{MeV}/c^2$

- **Consistent with BESIII inclusive results PRL104(2010)132002**

  $M = 3525.40 \pm 0.13 \pm 0.18\ \mathrm{MeV}/c^2$ $\quad\quad$ $\Gamma = 0.73 \pm 0.45 \pm 0.28\ \mathrm{MeV}/c^2$

- **Consistent with CLEOc exclusive results PRL101(2008)182003.**

  $M = 3525.21 \pm 0.27 \pm 0.14\ \mathrm{MeV}/c^2$

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

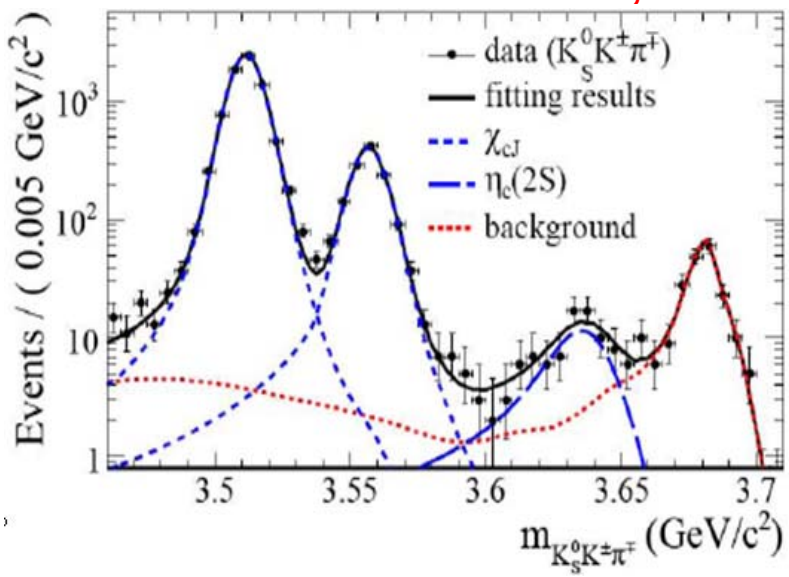
- **$\eta_c(2S)$ was observed in other decay mechanism**

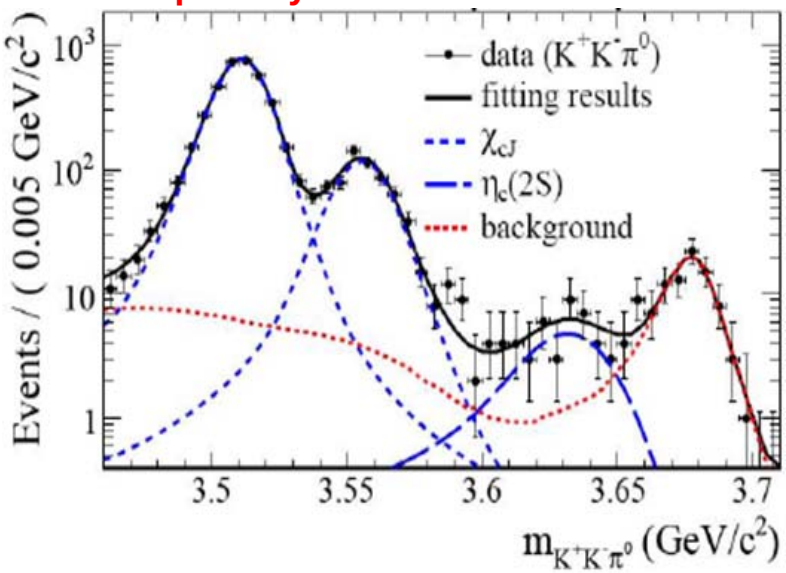
1. $B \to K\eta_c(2S)$ — Belle: PRL 89 102001 (2002)
2. $\gamma\gamma \to \eta_c(2S) \to KK\pi$ — CLEO-c: PRL 92 142001 (2004); Belle: NPPS 184 220 (2008); PRL 98 082001(2007); BaBar: PRL 92 142002 (2004); PR D72 031101(2005)
3. double charmonium production — BaBar: PR D84 012004 (2011)

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

Experimental challenge: radiation γ with ~50 MeV

BESIII, arXiv:1205.5103. accepted by PRL





- **Combined fit to the two channels [Significance > 10σ]**

$$M = 3637.6 \pm 2.9 \pm 1.6\ \mathrm{MeV}/c^2 \qquad \Gamma = 16.9 \pm 6.4 \pm 4.8\ \mathrm{MeV}/c^2$$

- **Branching fractions**

$$B[\psi' \to \gamma\eta_c(2S)] \times B[\eta_c(2S) \to K\bar{K}\pi] = (1.3 \pm 0.2 \pm 0.3) \times 10^{-3}$$

$$B[\psi' \to \gamma\eta_c(2S)] = (6.8 \pm 1.1 \pm 4.5) \times 10^{-4}$$

Input $B[\eta_c \to KK\pi]$ on PRD78(2008)012006

First evidence for ψ'→γγJ/ψ

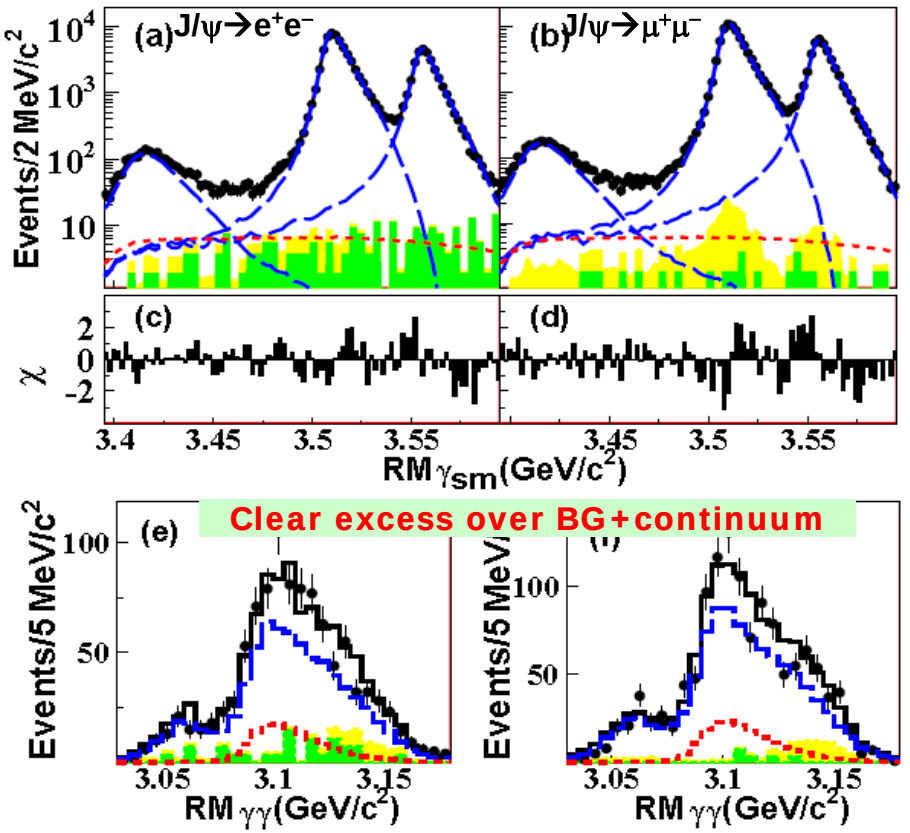
- Two photon transitions are well know in excitations of molecules, atomic hydrogen, and positronium.

  PRL39(1977)1070, PRL50(1983)1258

- Never been observed in quarkonium system.

- Help to better understand heavy quarkonium spectrum and strong interaction.

BESIII, arXiv:1112.0942. submitted to PRL



- Significance for ψ'→γγJ/ψ: 3.8σ
- B[ψ'→γγJ/ψ] and B[ψ'→γχ$_{cJ}$, χ$_{cJ}$→γJ/ψ]

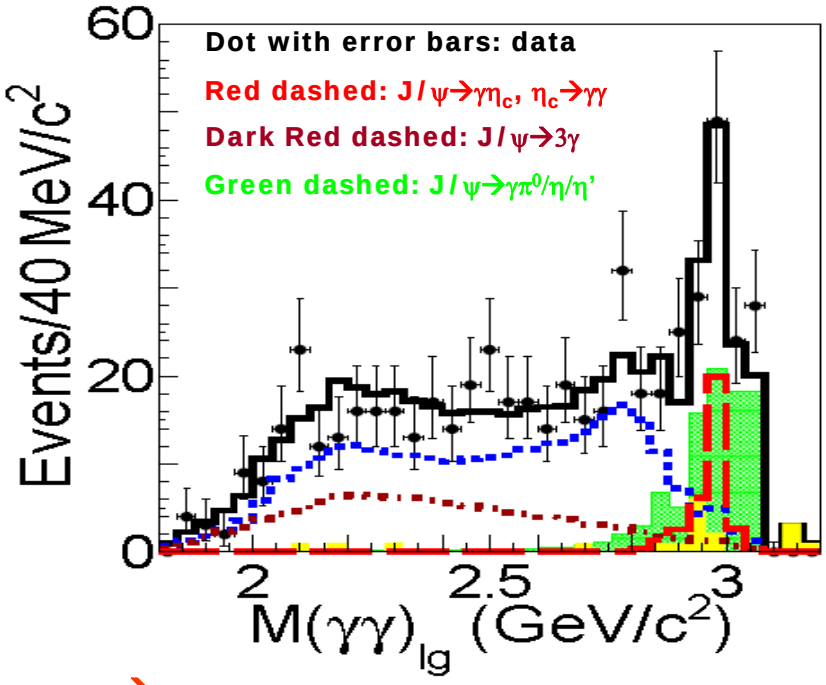
Channels	n_e	ϵ_e	n_μ	ϵ_μ	$\mathcal{B}(\times 10^{-4})$
$\gamma\gamma J/\psi$	564±116	22.4	536±128	30.0	$3.3 \pm 0.6^{+0.8}_{-1.1}$
$\gamma(\gamma J/\psi)_{\chi_{c0}}$	1801±60	19.3	2491±69	26.0	$15.1 \pm 0.3 \pm 1.0$
$\gamma(\gamma J/\psi)_{\chi_{c1}}$	59953±253	28.5	81922±295	38.2	$337.7 \pm 0.9 \pm 18.3$
$\gamma(\gamma J/\psi)_{\chi_{c2}}$	32171±187	27.5	44136±219	37.1	$187.4 \pm 0.7 \pm 10.2$
$R_{21} \equiv \frac{\mathcal{B}_{\chi_{c2}}}{\mathcal{B}_{\chi_{c1}}}(\%)$		$R_{01} \equiv \frac{\mathcal{B}_{\chi_{c0}}}{\mathcal{B}_{\chi_{c1}}}(\%)$		$R_{02} \equiv \frac{\mathcal{B}_{\chi_{c0}}}{\mathcal{B}_{\chi_{c2}}}(\%)$	
$55.47 \pm 0.26 \pm 0.11$		$4.45 \pm 0.09 \pm 0.18$		$8.03 \pm 0.17 \pm 0.33$	

First evidence for $\eta_c \to \gamma\gamma$

BESIII, arXiv:1208.1461. submitted to PRL

- $\eta_c \to \gamma\gamma$ and $J/\psi \to 3\gamma$ have relative theoretical description. Measurements of their BFs provide fundamental tests on non-PQCD theory.

- $B[J/\psi \to 3\gamma]/B[J/\psi \to e^+e^-]$ provide a clean way to extract running coupling constant, which influences the prediction of QCD models.



- **Via $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \gamma\eta_c$, $\eta_c \to \gamma\gamma$**

- **Significance for $\eta_c \to \gamma\gamma$ is 3.7 σ**

$$B[J/\psi \to \gamma\eta_C, \eta_C \to \gamma\gamma] = (4.5 \pm 1.2 \pm 0.6) \times 10^{-6}$$

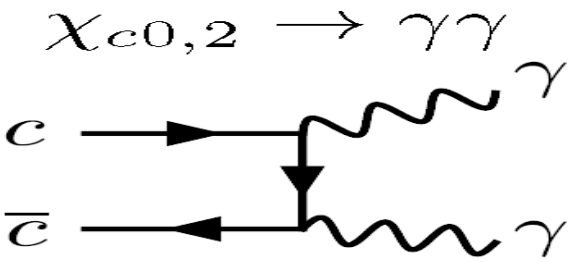
$$B[\eta_C \to \gamma\gamma] = (2.6 \pm 0.7 \pm 0.7) \times 10^{-4}$$

Input $B[J/\psi \to \gamma\eta_c]$ on PDG

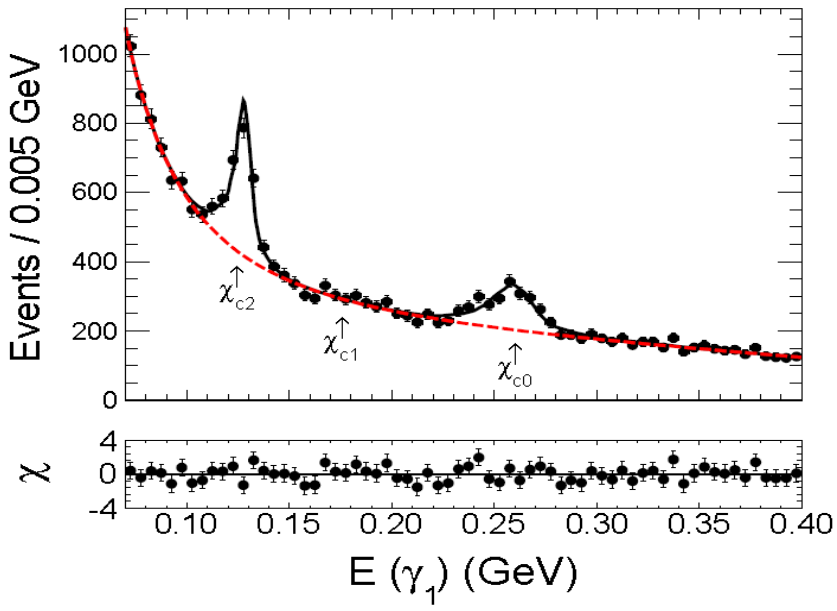
- **Improved $B[J/\psi \to 3\gamma]$**

$$B[J/\psi \to 3\gamma] = (11.3 \pm 1.8 \pm 2.0) \times 10^{-6}$$

Measurements of $\chi_{C0/2} \rightarrow \gamma\gamma$



PRD85(2012)112008



- **Lowest order (QED) predicts:**

  $R=\Gamma(\chi_{C2} \rightarrow \gamma\gamma)/\Gamma(\chi_{C0} \rightarrow \gamma\gamma)=4/15=0.27$

  R vary from 0.09-0.36 with high order corrections

- **Can also measure the ratio of two helicity amplitudes for $\chi_{C2} \rightarrow \gamma\gamma$**

$$B_1 = B[\psi[\rightarrow \chi_{C0/2}]]$$
$$B_2 = B[\chi_{C0/2} \rightarrow \gamma\gamma]$$
$$\Gamma_{\gamma\gamma}(\chi_{C0/2}) = \Gamma_{\gamma\gamma}(\chi_{C0/2} \rightarrow \gamma\gamma)$$
$$R = \Gamma_{\gamma\gamma}(\chi_{C2})/\Gamma_{\gamma\gamma}(\chi_{C0})$$
$$f_{0/2} = \Gamma^{\lambda=0}_{\gamma\gamma}(\chi_{C2})/\Gamma^{\lambda=2}_{\gamma\gamma}(\chi_{C2})$$

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	$3.23 \pm 0.34 \pm 0.24$	$3.21 \pm 0.18 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c0})(\mathrm{keV})$	2.32 ± 0.22	$2.36 \pm 0.35 \pm 0.22$	$2.33 \pm 0.20 \pm 0.22$
$\Gamma_{\gamma\gamma}(\chi_{c2})(\mathrm{keV})$	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	$0.28 \pm 0.05 \pm 0.04$	$0.27 \pm 0.03 \pm 0.03$
$f_{0/2}$	-	-	$0.00 \pm 0.02 \pm 0.02$

Measured Rs are consistent with the lowest order predictions

Measurements of $B[\chi_{cJ} \to B\bar{B}]$

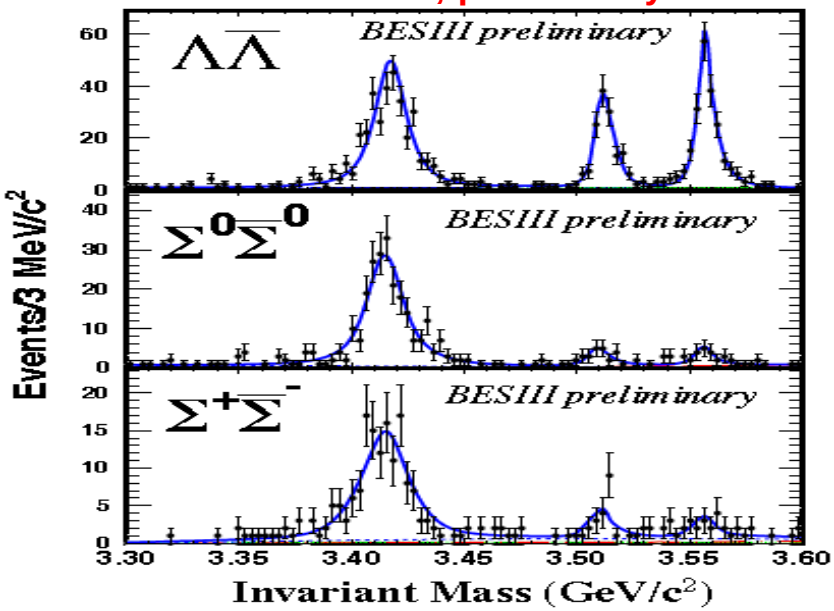
- **Only color singlet model predicts:**

$$\mathcal{B}(\chi_{c0} \to p\bar{p}) = 0.29 \times 10^{-5}$$
$$\mathcal{B}(\chi_{c2} \to p\bar{p}) = 0.84 \times 10^{-5}$$

which are far lower than experimental measurement

- **Color Octet Model is introduced. Other $B\bar{B}$ rates can also be predicted**

BESIII, preliminary



- **$B[\chi_{C1,2} \to \Lambda\bar{\Lambda}]$ are larger than the COM prediction**

- **$B^{up}[\chi_{C1,2} \to \Sigma\bar{\Sigma}]$ agree with the COM prediction**

- **$\chi_{C0} \to \Lambda\bar{\Lambda}$ and $\Sigma\bar{\Sigma}$ are large violation of the helicity selection rule**

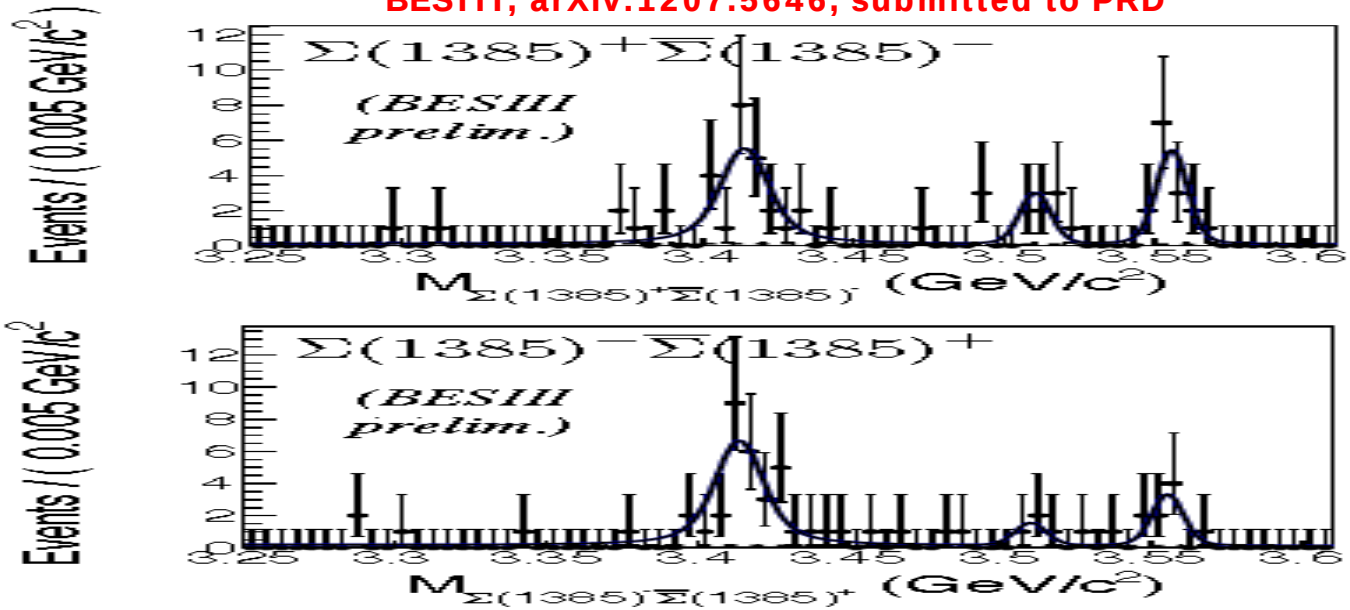
BESIII preliminary results [$\times 10^{-5}$]

Mode		χ_{c0}	χ_{c1}	χ_{c2}
$\Lambda\bar{\Lambda}$	This work	33.3±2.0±2.6	12.2±1.1±1.1	20.8±1.6±2.2
	PDG	33.0±4.0	11.8±1.9	18.6±2.7
	CLEO [18]	33.8± 3.6±2.2±1.7	11.6±1.8±0.7±0.7	17.0±2.2±1.1±1.1
	Theory [4, 19]	11.9∼15.1	3.9	3.5
$\Sigma^0\bar{\Sigma}^0$	This work	47.8±3.4±3.8	3.8±1.0±0.5 (< 6.1)	4.0±1.1±0.4 (< 6.4)
	PDG	42.0±7.0	<4.0	<8.0
	CLEO [18]	44.1±5.6±4.2±2.2	<4.4	<7.5
	Theory [4]	–	3.3	5.0
$\Sigma^+\bar{\Sigma}^-$	This work	45.4±4.2±2.5	5.4±1.5±0.4 (< 8.5)	4.9±1.9±0.6 (<8.6)
	PDG	31.0±7.0	<6.0	<7.0
	CLEO [18]	32.5±5.7±4.0±1.7	<6.5	<6.7
	Theory [4]	–	3.3	5.0

90% C.L.

Measurements of $B[\chi_{CJ} \to B\bar{B}]$

BESIII, arXiv:1207.5646, submitted to PRD



BF [$\times 10^{-5}$]

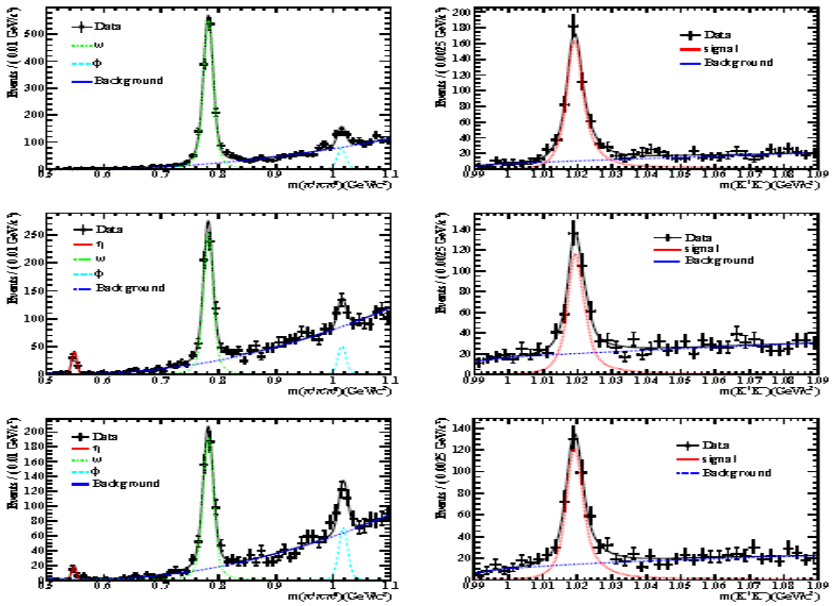
χ_{cJ} decay mode	χ_{c0}		χ_{c1}		χ_{c2}	
	$\mathcal{B}$	UL	$\mathcal{B}$	UL	$\mathcal{B}$	UL
$\chi_{cJ} \to \Lambda\bar{\Lambda}\pi^+\pi^-$ (w/o $\Sigma(1385)$)	29.9±13.6±7.4	< 57	27.4±8.5±2.7		75.9±14.9±6.9	
$\chi_{cJ} \to \Sigma(1385)^+\bar{\Lambda}\pi^- + c.c.$	35.4±14.7±7.0		1.4±7.3±9.0	< 12	23.9±13.6±4.1	< 43
$\chi_{cJ} \to \Sigma(1385)^-\bar{\Lambda}\pi^+ + c.c.$	25.0±14.3±5.9	< 45	0.0±7.2±0.0	< 11	38.8±14.4±4.3	
$\chi_{cJ} \to \Sigma(1385)^+\bar{\Sigma}(1385)^-$	17.0±6.0±2.0		4.6±2.7±1.0	< 9.3	8.1±4.4±1.8	< 16
$\chi_{cJ} \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$	24.0±6.3±3.1		1.7±2.0±0.3	< 5.4	0.1±3.7±0.3	< 7.2
$\chi_{cJ} \to \Lambda\bar{\Lambda}\pi^+\pi^-$(total)	129±7±12		32.5±3.6±4.1		163±9±19	

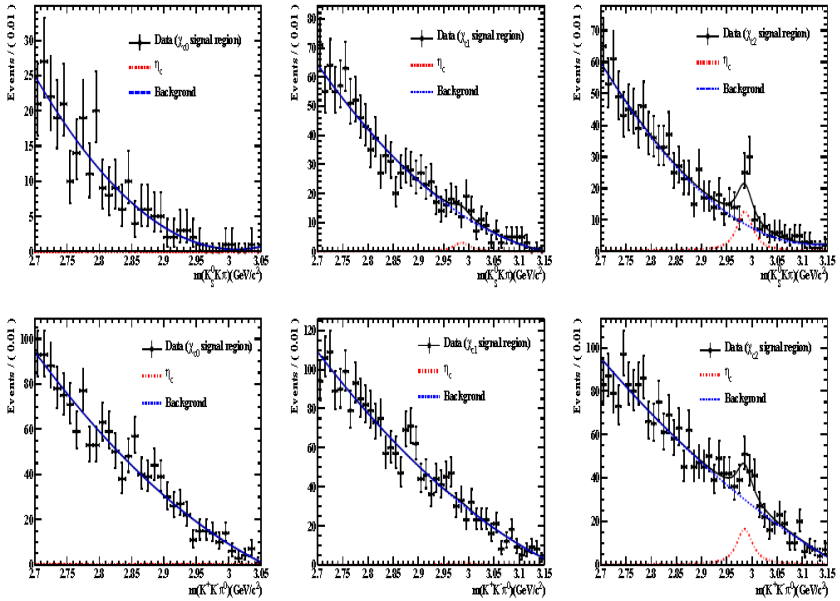
90 % CL

- $B^{up}[\chi_{C1,2} \to \Sigma(1385)\bar{\Sigma}(1385)]$ agree with the COM prediction
- $\chi_{C0} \to \Sigma(1385)\bar{\Sigma}(1385)$ are large violation of the helicity selection rule

Search for $\chi_{cJ} \to \pi^+\pi^-\eta_c$

BESIII, preliminary





Preliminary results on B[$\chi_{cJ} \to KK\pi\pi\pi$]

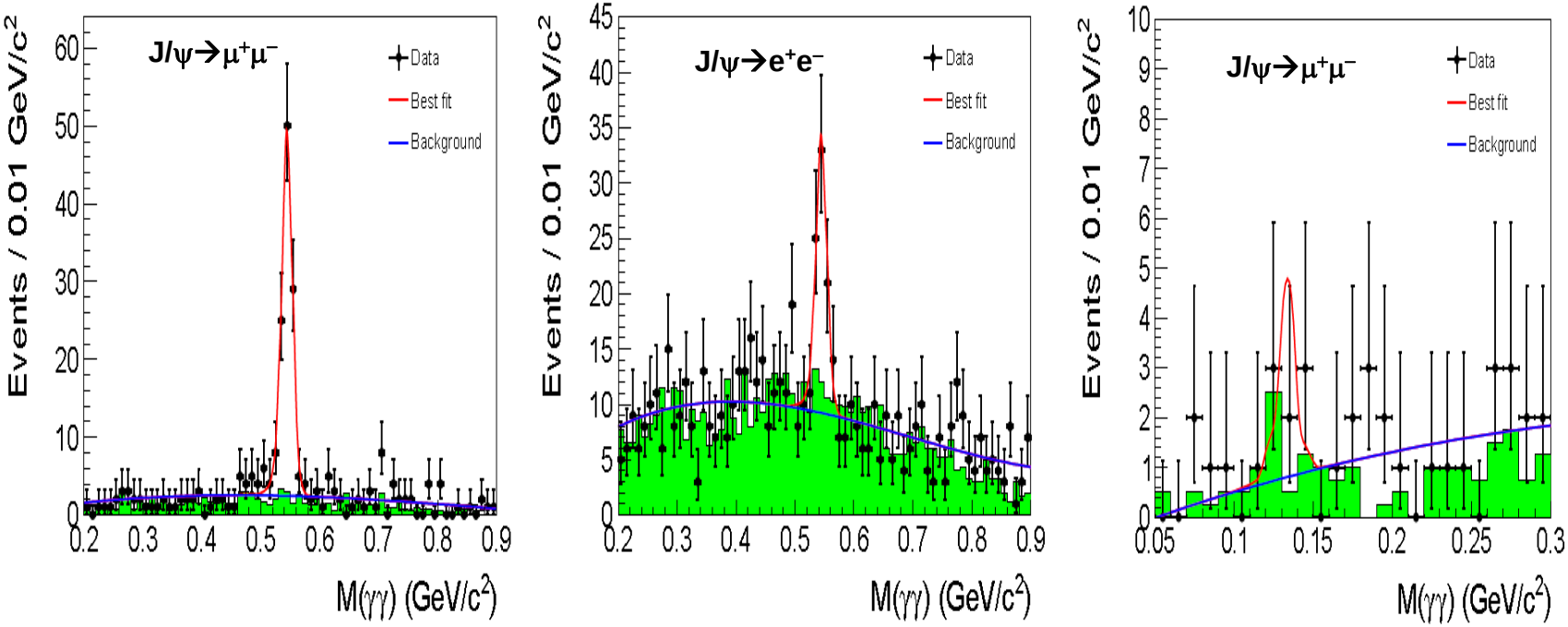
Decay mode	$N^{\rm signal}$	ϵ (%)	$\mathcal{B}$ ($\times 10^{-3}$)
$\chi_{c0} \to K^0_S K^\pm\pi^\mp\pi^+\pi^-$	2789 ± 66	9.30	$4.22 \pm 0.10 \pm 0.43$
$\chi_{c0} \to K^+K^-\pi^+\pi^-\pi^0$	9031 ± 132	10.34	$8.61 \pm 0.13 \pm 0.94$
$\chi_{c0} \to \omega K^+K^-$	1414 ± 42	8.04	$1.94 \pm 0.06 \pm 0.20$
$\chi_{c0} \to \phi\pi^+\pi^-\pi^0$	538 ± 29	9.16	$1.18 \pm 0.07 \pm 0.13$
$\chi_{c1} \to K^0_S K^\pm\pi^\mp\pi^+\pi^-$	5180 ± 75	10.21	$7.52 \pm 0.11 \pm 0.79$
$\chi_{c1} \to K^+K^-\pi^+\pi^-\pi^0$	12256 ± 127	11.10	$11.46 \pm 0.12 \pm 1.29$
$\chi_{c1} \to \omega K^+K^-$	628 ± 29	9.34	$0.78 \pm 0.04 \pm 0.08$
$\chi_{c1} \to \phi\pi^+\pi^-\pi^0$	373 ± 26	10.50	$0.75 \pm 0.06 \pm 0.08$
$\chi_{c2} \to K^0_S K^\pm\pi^\mp\pi^+\pi^-$	4559 ± 71	9.76	$7.30 \pm 0.11 \pm 0.75$
$\chi_{c2} \to K^+K^-\pi^+\pi^-\pi^0$	11189 ± 124	10.48	$11.69 \pm 0.13 \pm 1.31$
$\chi_{c2} \to \omega K^+K^-$	512 ± 27	8.58	$0.73 \pm 0.04 \pm 0.08$
$\chi_{c2} \to \phi\pi^+\pi^-\pi^0$	408 ± 28	9.88	$0.93 \pm 0.06 \pm 0.10$

No clear signal for $\chi_{cJ} \to \pi^+\pi^-\eta_c$ is observed. UL on BF is set at 90 % CL

Decay mode	$N^{\rm fit}$	$N^{\rm up}$	ϵ (%)	$\mathcal{B}^{\rm up}(\chi_{cJ} \to \eta_c\pi^+\pi^-)$ (%)	$\mathcal{B}^{\rm theory}(\chi_{cJ} \to \eta_c\pi^+\pi^-)$ (%)
$\chi_{c0} \to (K^0_S K^\pm\pi^\mp)\pi^+\pi^-$	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	-

Observation of $e^+e^-\to\eta J/\psi$ at 4.01 GeV

BESIII, arXiv:1208.1857



- **First observe $e^+e^-\to\eta J/\psi$ at 4.01 GeV**

$$\sigma^{\rm Born}[e^+e^-\to J/\psi\eta] = (32.1\pm2.8\pm1.3)\ {\rm pb}$$

- **Assuming it arises from $\psi(4040)$**

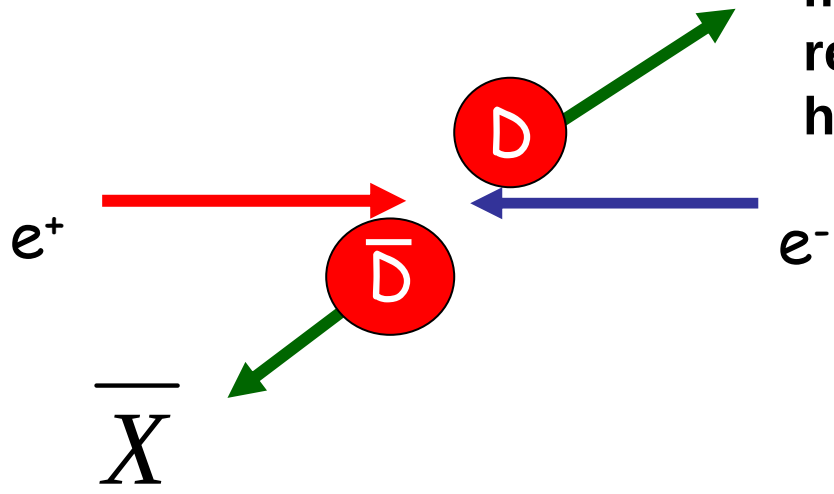
$$B[\psi(4040)\to J/\psi\eta] = (5.2\pm0.5\pm0.2\pm0.5)\times10^{-3}$$

$$B[\psi(4040)\to J/\psi\pi^0] < 2.8\times10^{-4}\ @\ 90\%{\rm CL}$$

Charm physics

- **Decay constant f_{D+} and V_{cd} from $D^+ \rightarrow \mu^+ \nu_\mu$**
- **Form factor of $f_{K/\pi}(q^2)$ from $D^0 \rightarrow K/\pi^- e^+ \nu_e$**
- **Search for FCNC decay of $D^0 \rightarrow \gamma\gamma$**

$D\bar{D}$ production at $\psi(3770)$

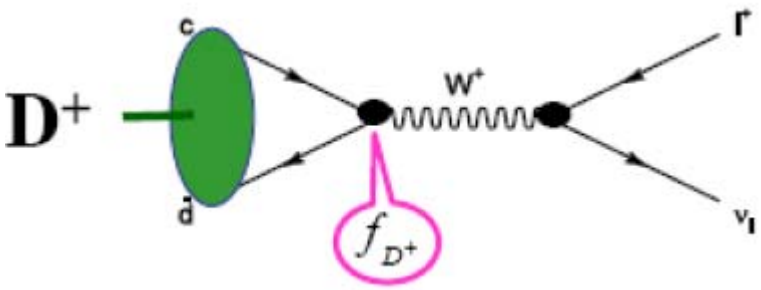


Singly tagged D mesons can be fully reconstructed by hadronic modes

X denotes purely leptonic decays, semi-leptonic decays ……

$$B(D \to X) = \frac{N(D \to X)}{N_{\overline{D}\,\mathrm{tag}} \times \varepsilon_{D \to X}}$$

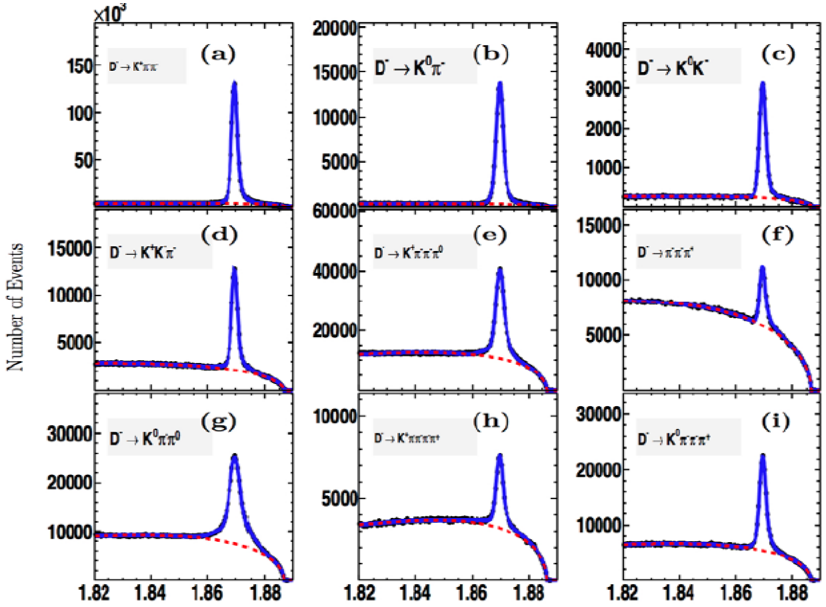
Purely leptonic decay of $D^+ \to \mu^+ \nu_\mu$



All strong interaction effects between the two quarks within the D^+ meson is simply factorized by a parameter, decay constant f_{D^+}.

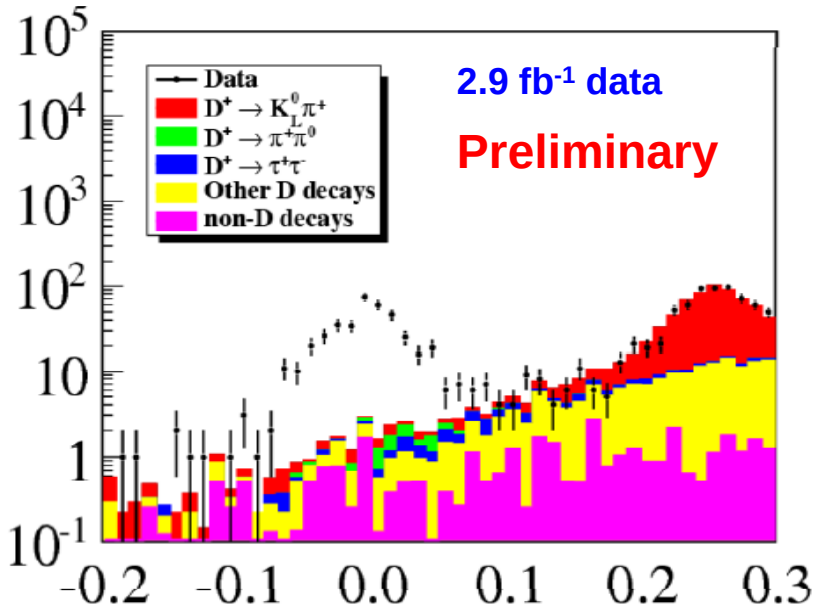
$$\Gamma(D^+ \to \mu^+ \upsilon_\mu) = \frac{G_F^2}{8\pi} f_{D^+}^2 \, |V_{cd}|^2 \, m_l^2 \left(1 - \frac{m_l^2}{m_{D^+}^2}\right) m_{D^+}$$

Preliminary



$M_{BC}(GeV/c^2)$

$$N_{D^-_{tag}} = (1.566 \pm 0.002) \times 10^6$$



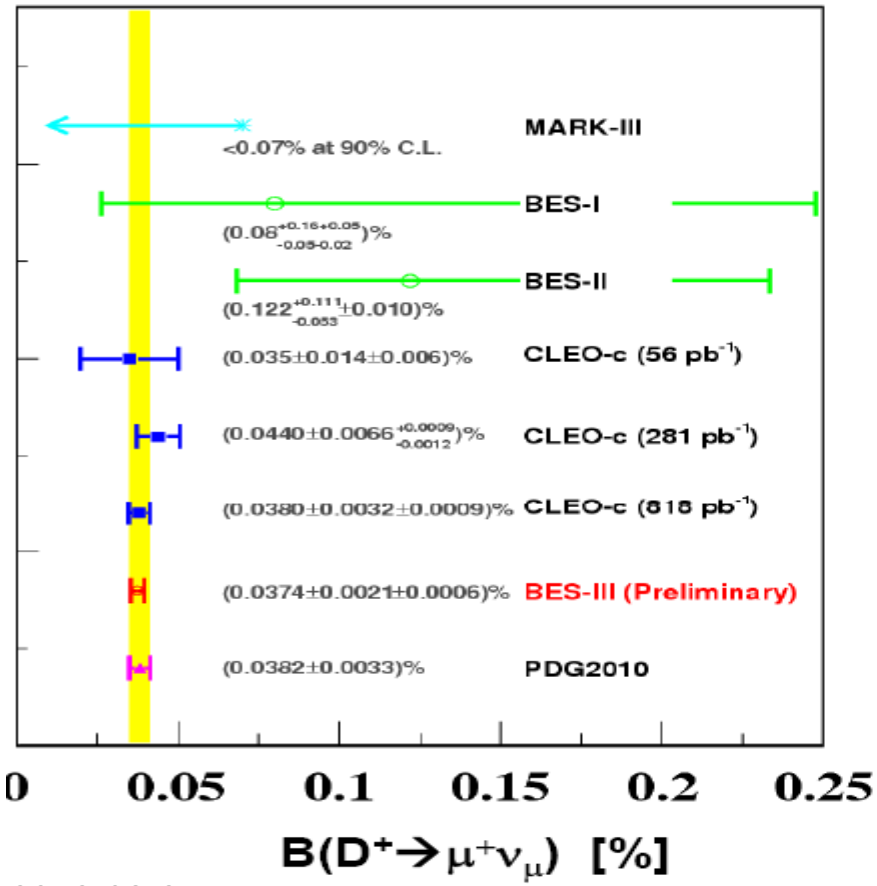
$M^2_{miss}(GeV^2)$

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

Preliminary results on $B[D^+ \to \mu^+ \nu_\mu]$ and f_{D+}

- **Branching Fraction**

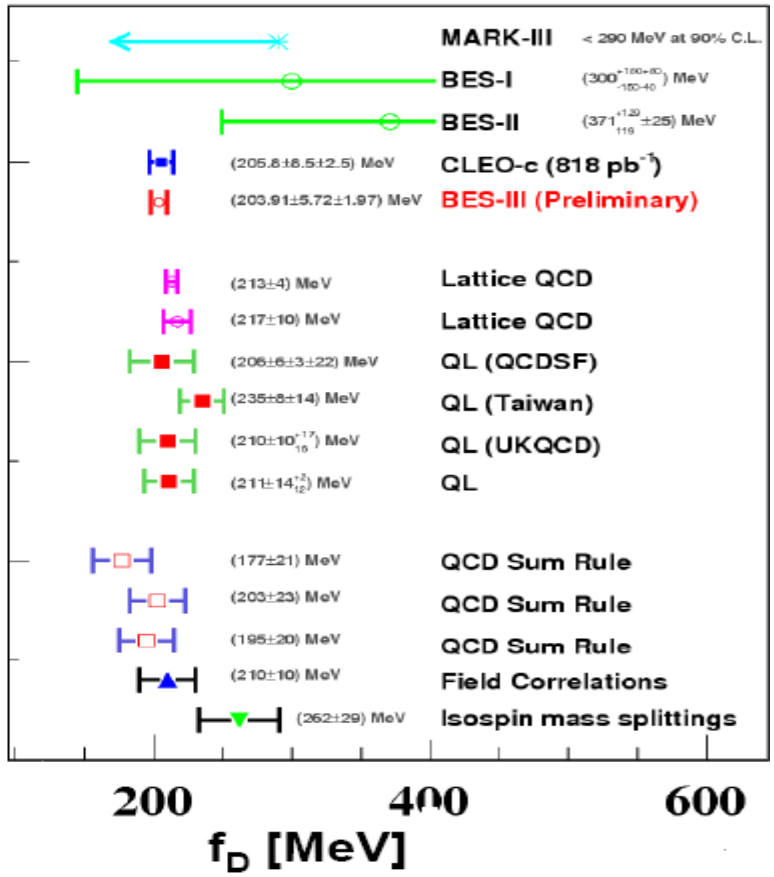
$$B(D^+ \to \mu^+ \upsilon_\mu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$$



- **Decay constant**

$$f_{D^+} = (203.91 \pm 5.72 \pm 1.97)\ \text{MeV}$$

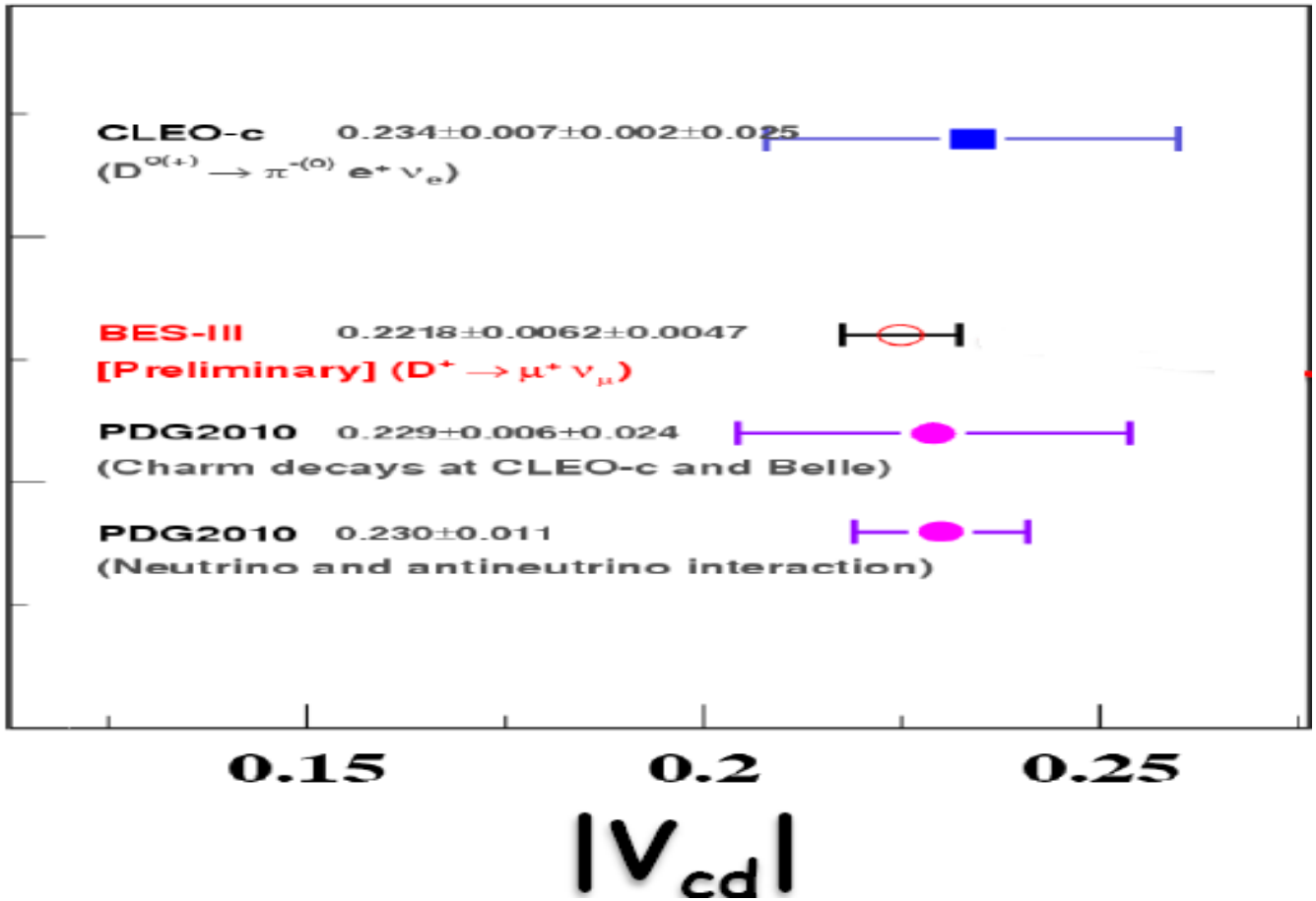
(Input τ_{D+}, m_{D+}, $m_{\mu+}$ of PDG10 and V_{cd} of CKM-Fitter)



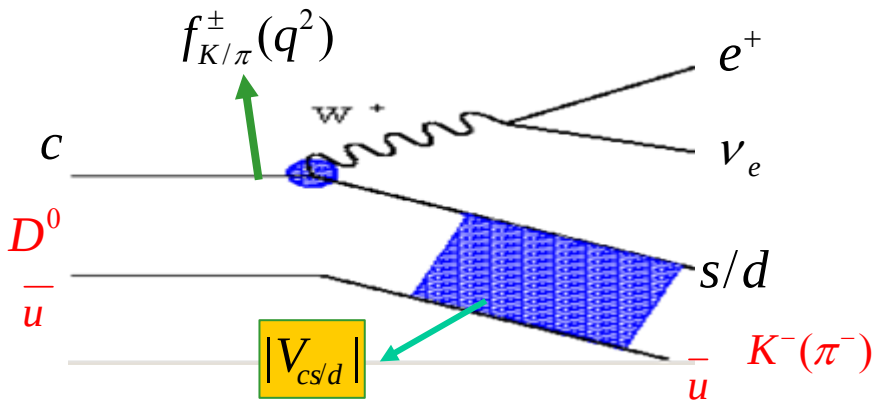
Preliminary results on $|V_{cd}|$

$$|V_{cd}| = 0.222 \pm 0.006 \pm 0.005$$

(Input τ_{D+}, m_{D+}, $m_{\mu+}$ of PDG10 and f_{D+}=207±4 MeV from LQCD [PRL100(2008)062002]



Semi-leptonic decay of $D^0 \to K/\pi^- e^+ \nu_e$

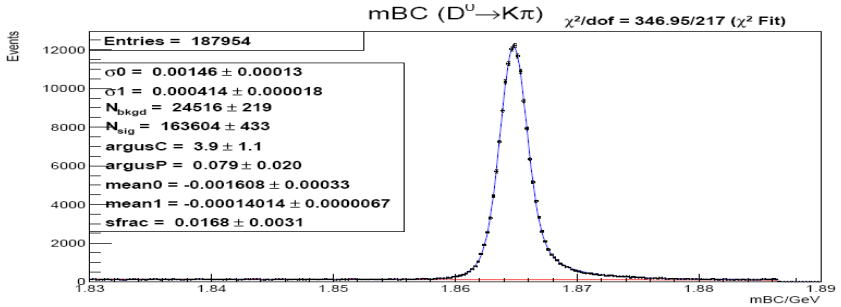


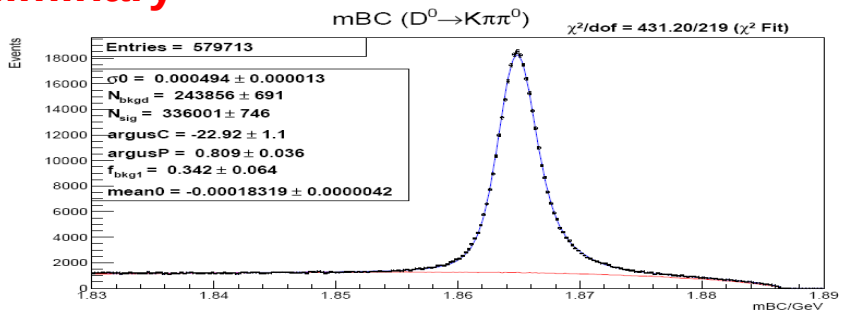
The strong interaction effects between the two quarks within the D^0 meson is simply factorized by a parameter, the form factor $f_{K/\pi}(q^2)$

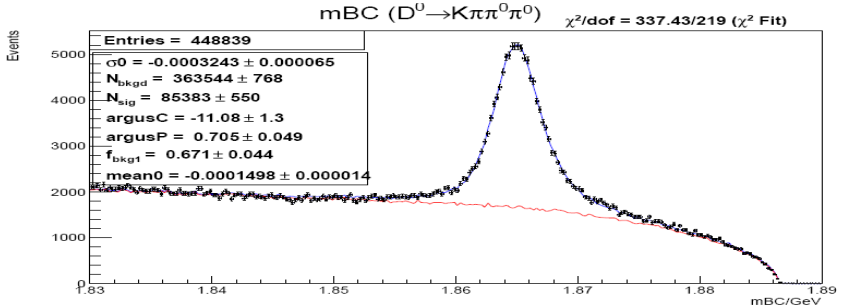
$$\frac{\Delta\Gamma(D^0 \to K/\pi^- e^+ \nu_e)}{dq^2} = \frac{G_F^2 |V_{cs(d)}|^2}{24\pi^3} p^3 \left| f_+^2(q^2) \right|^2$$

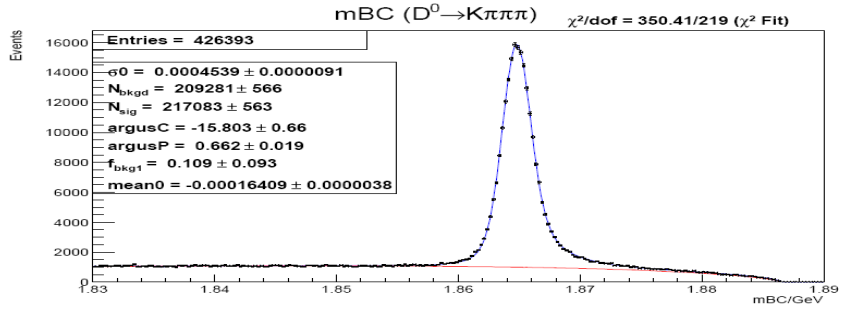
0.922 fb^{-1} data

Preliminary







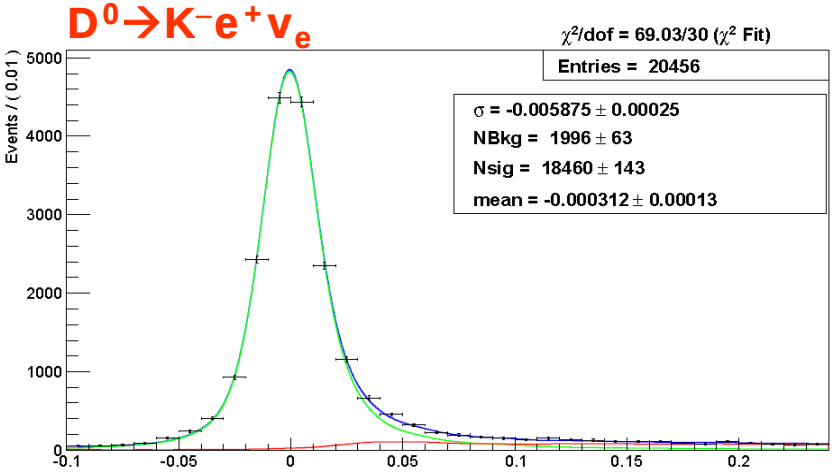


$$N_{\bar{D}^0_{tag}} = (0.774 \pm 0.001) \times 10^6$$

Preliminary results

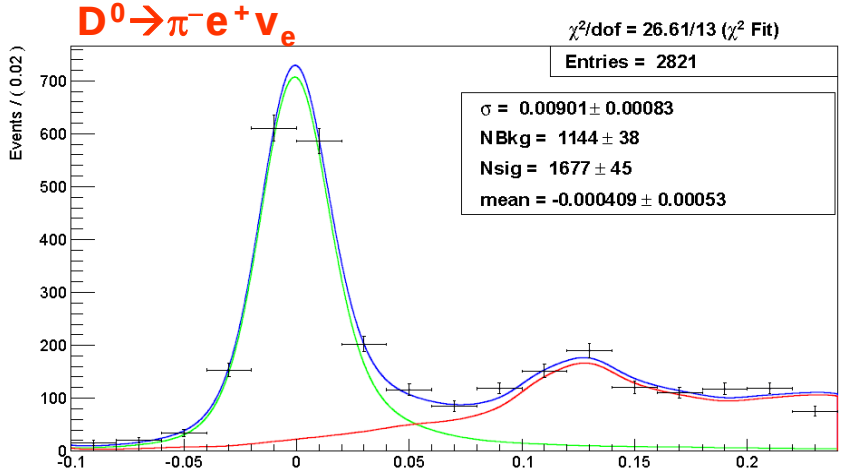
0.922 fb^{-1} data

$D^0 \to K^- e^+ \nu_e$



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

$D^0 \to \pi^- e^+ \nu_e$



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

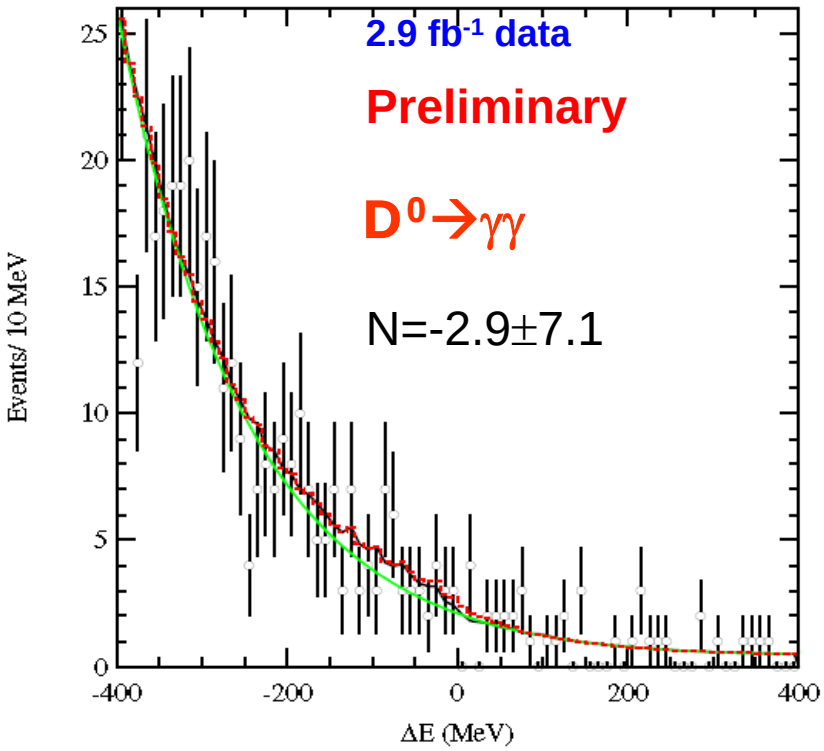
- **Branching fractions**

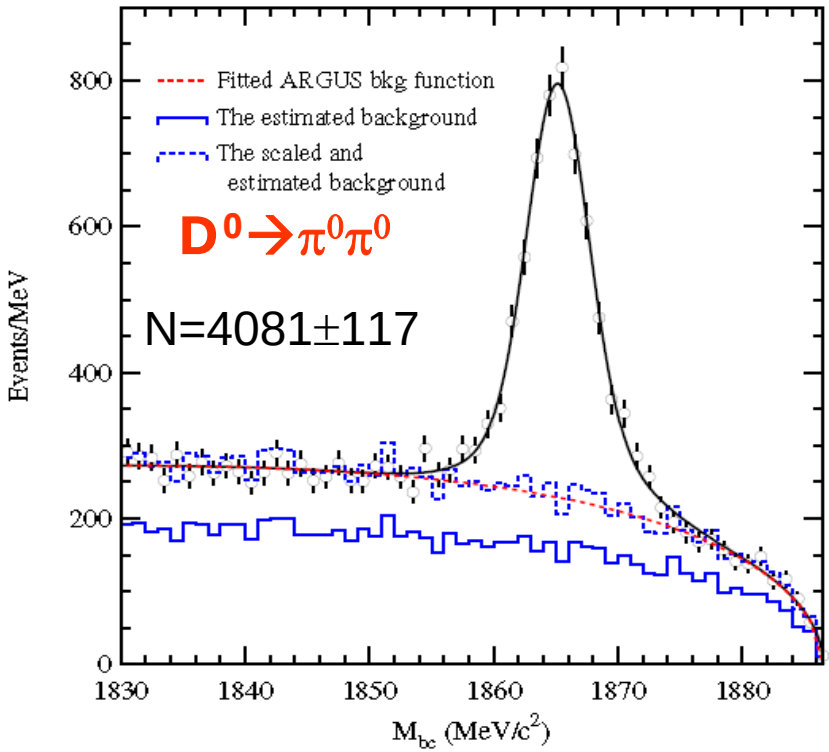
B [%]	BESIII (0.922 fb^{-1})	CLEOc (0.818 fb^{-1})	PDG10
$D^0 \to K^- e^+ \nu_e$	3.542±0.030±0.046	3.50±0.03±0.04	3.55±0.04
$D^0 \to \pi^- e^+ \nu_e$	0.288±0.008±0.004	0.288±0.008±0.003	0.289±0.008

- **Full data and fit to form factor $f_{K/\pi}(q^2)$**

Search for FCNC decay of $D^0 \to \gamma\gamma$

- SM predicts: $B[D^0 \to \gamma\gamma] \sim 10^{-8}$ or less





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

Experiments	BESIII	BABAR	CLEOc	PDG11
$B^{up}(D^0 \to \gamma\gamma)$ [$\times 10^{-6}$]	<4.6	<2.2	<8.63	<27

Summary

- **With world largest data of J/ψ, ψ(3686), ψ(3770) events…, many interesting results on light hadron spectroscopy, charmoinium spectroscopy, and charm physics have been obtained at BESIII**

  New structures, phenomena, observations

  Precision measurements of elementary parameters and decays

- **More data in hand, more interesting results in the future.**

Thank you!