Recent Results from BESIII

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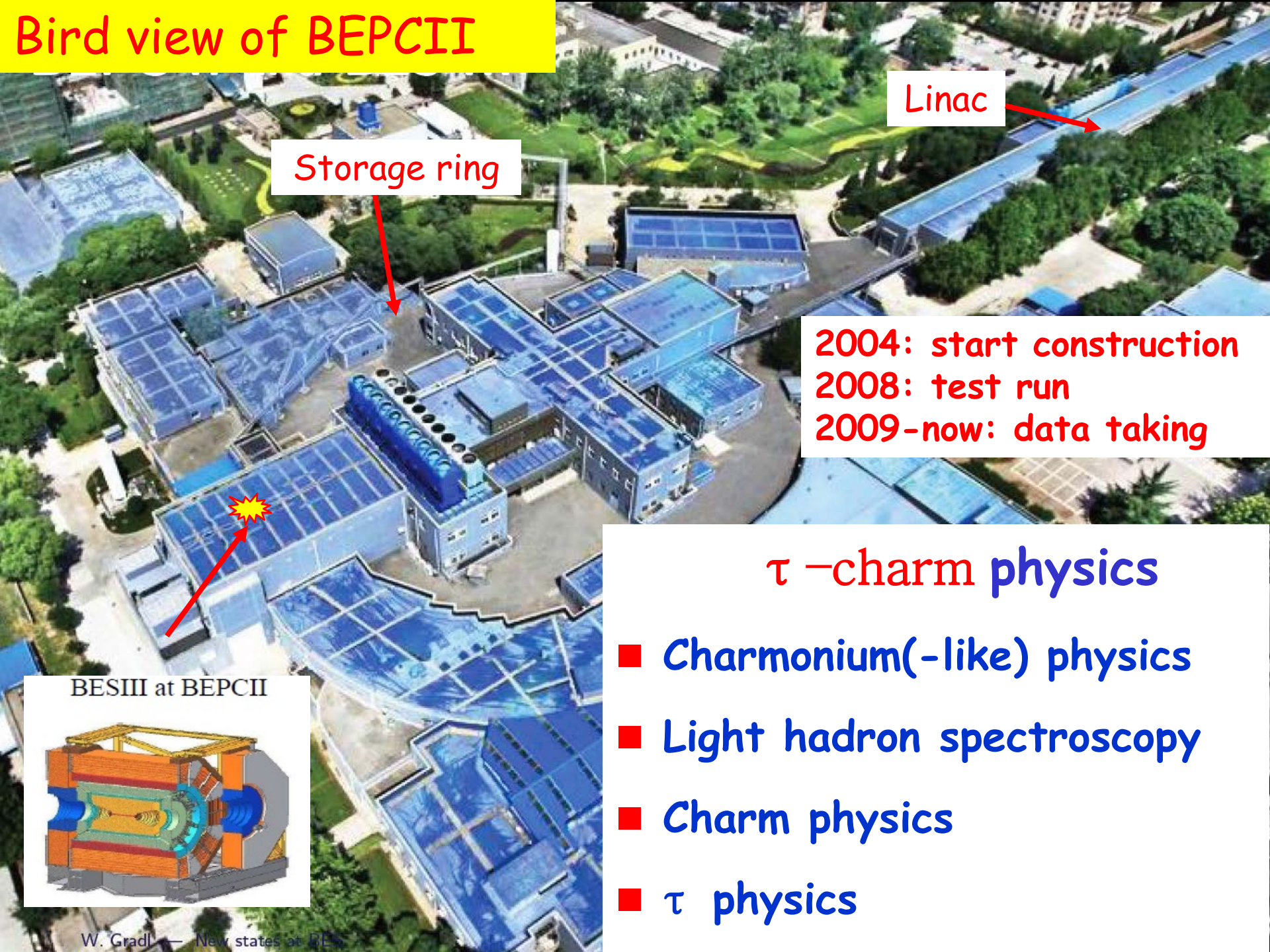
Outline

- Status of BEPCII/BESIII
- Hadron spectroscopy (XYZ,light hadrons)
- Charmonium physics
- Charm physics
- Summary

Bird view of BEPCII



2004: start construction
2008: test run
2009-now: data taking

τ –charm physics

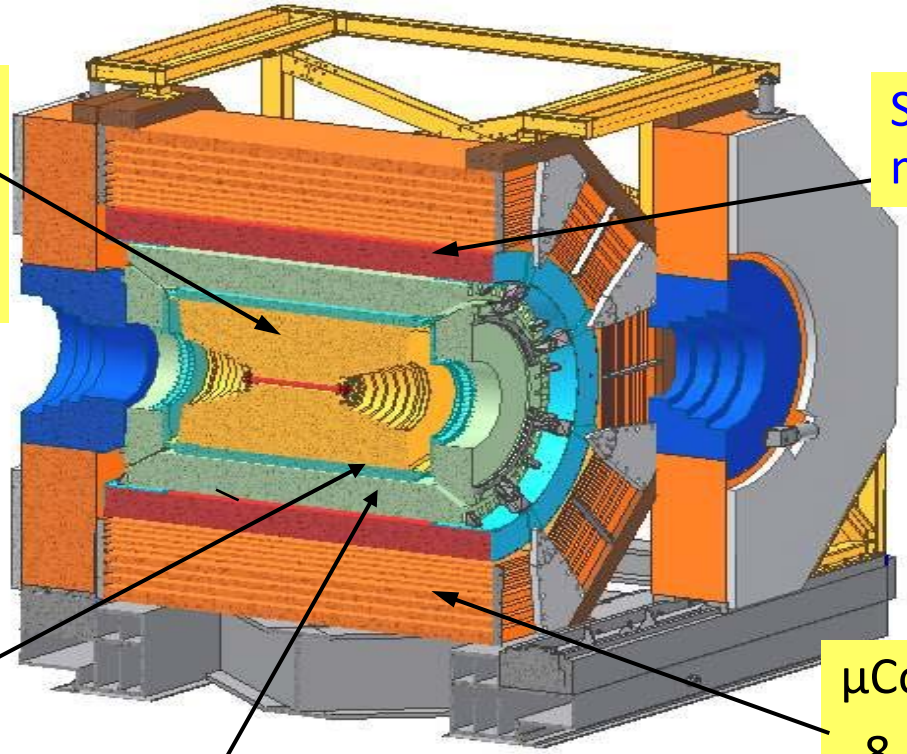
- Charmonium(-like) physics
- Light hadron spectroscopy
- Charm physics
- τ physics

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 Data Samples

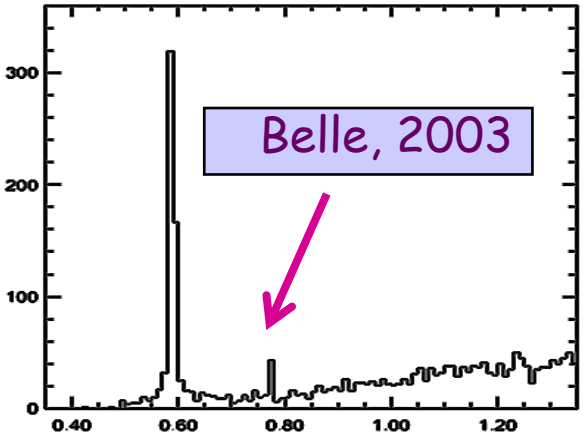
- 2009 : 106 M $\psi(2S)$ events (x4 CLEOc)
  225 M J/ψ events (x4 BESII)
- 2010 - 2011 : 2.9 fb^{-1} $\psi(3770)$
- 2011 : ~ 0.5 fb^{-1} @ 4.01 GeV
  ~ 30 pb^{-1} τ mass scan
- 2012 : ~ 0.4 billion $\psi(2S)$ events
  ~ 1 billion J/ψ events
  R scan [2.0, 3.65] GeV
- 2013: ~ 1.1, 0.8, 0.5 fb^{-1} @ 4.23, 4.26, 4.36 GeV
  and scan in vicinity

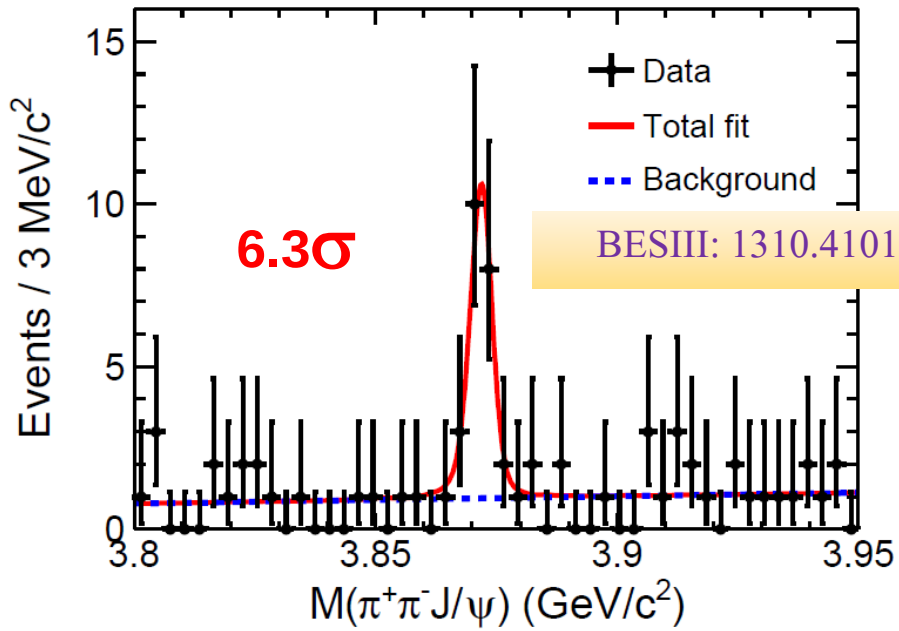
Hadron spectroscopy
(XYZ, light hadrons)

Please refer to the talks below for details

- Ryan Mitchell (Indiana U.): "Study of XYZ states at BESIII"
- Tianjue Min (IHEP): "J/Ψ radiative decays at BESIII"
- Beijiang Liu (IHEP): "Baryon spectroscopy at BESIII"
- Liqing Qin (Shandong U.): "η and η' physics at BESIII"

Observation of $e^+e^- \to \gamma X(3872)$





- $J^{PC}=1^{++}$ [LHCb: arXiv:1302.6269]
- Nature:
  - Loosely $\bar{D}^0D^{*0}$ bound state?
  - Mixture of excited χ_{c1} and $\bar{D}^0D^{*0}$ bound state?
  - Many other possibilities (if it is not χ'_{c1}, where is χ'_{c1}?)

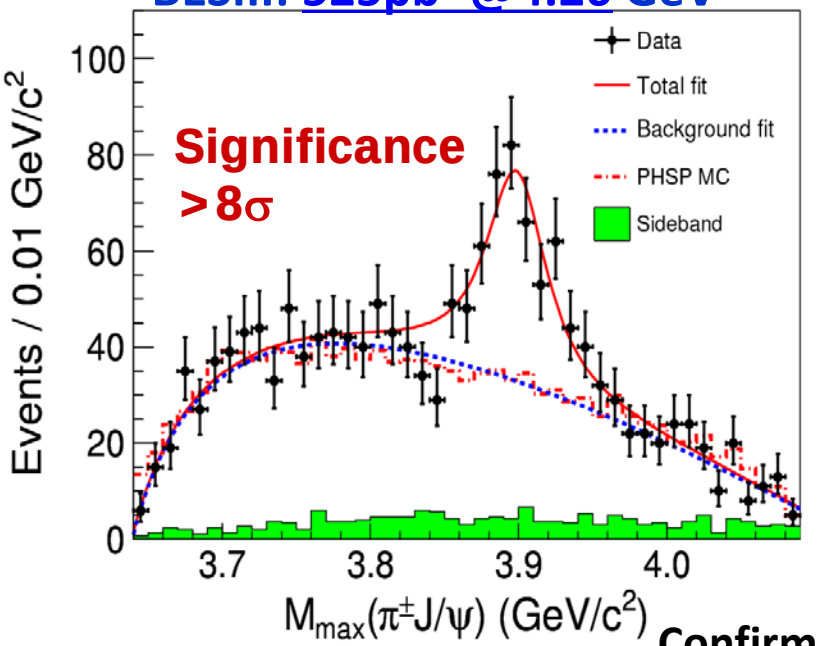
M= 3871.9±0.7±0.2 MeV
[PDG: 3871.68 ±0.17 MeV]

$\sqrt{s}$ (GeV)	$N^{\rm obs}$	ϵ (%)	$1+\delta$	$\sigma^B \cdot \mathcal{B}$ (pb)
4.009	< 1.4	25.5	0.861	< 0.12
4.229	9.6 ± 3.1	31.5	0.799	$0.29 \pm 0.10 \pm 0.02$
4.260	8.7 ± 3.0	30.5	0.814	$0.36 \pm 0.13 \pm 0.03$
4.360	< 5.1	21.1	1.023	< 0.39

seems it is from Y(4260) decays

Observation of Zc(3900) at BESIII

BESIII: 525pb^{-1}@4.26 GeV



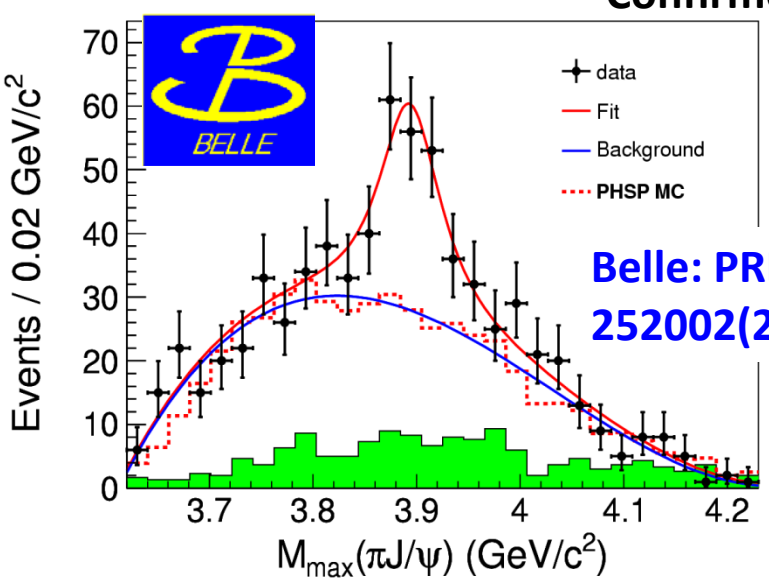
BESIII: PRL110, 252001 (2013)

- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events

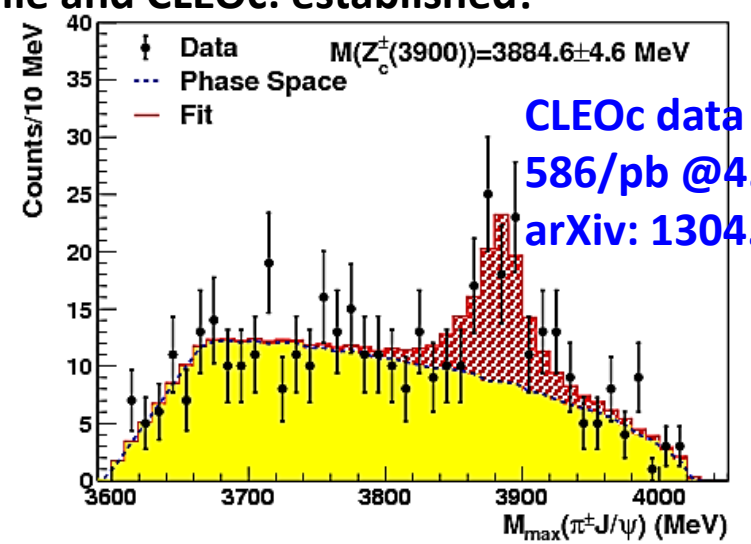
The mass position is 24 MeV away from DD* threshold!

A Partial wave analysis is on going!

Confirmed by Belle and CLEOc: established!



Belle: PRL 110, 252002(2013)

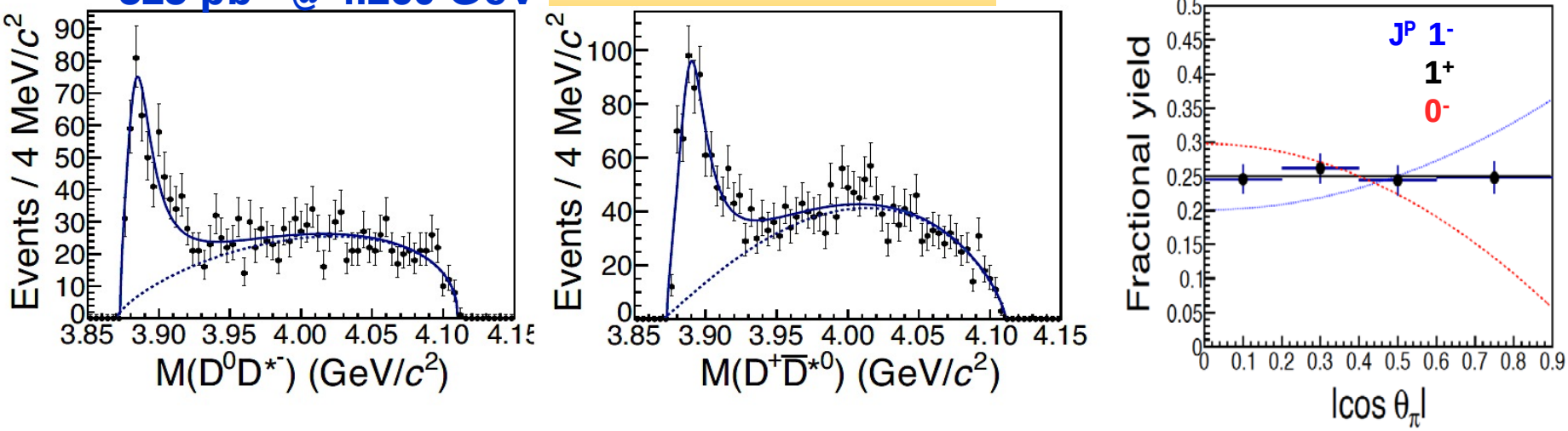


CLEOc data
586/pb @4.17GeV
arXiv: 1304.3036

Observation of Zc(3885) in $e^+e^- \to \pi^- (D^*D)^+$

BESIII: 1310.1163

525 pb^{-1} @ 4.260 GeV



- M = 3883.9±1.5±4.2 MeV; Γ = 24.8±3.3±11.0 MeV
- σ×B = 85.3±6.6±22.0 pb **[pole position]**
- **fits favor 1^+ distribution assumption**

fit with mass-dependent-width BW with phase space and efficiency correction

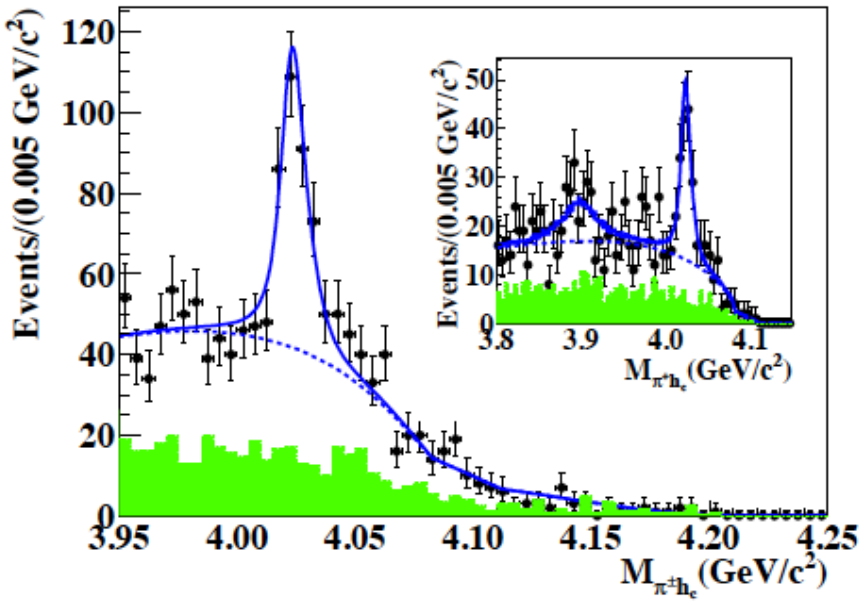
$$\frac{\Gamma(Z_c(3885)\to D\bar{D}^*)}{\Gamma(Z_c(3900)\to\pi J/\psi)} = 6.2 \pm 1.1 \pm 2.7$$

Assuming $Z_c(3885)$ due to $Z_c(3900)$

Large non-D $\bar{D}$ coupling

$e^+e^- \to \pi Z_c(4020) \to \pi^+\pi^- h_c$

BESIII: 1309.1896



Simultaneous fit to 4.23/4.26/4.36 GeV data, 16 η_c decay modes.

$M = 4022.9 \pm 0.8 \pm 2.7$ MeV/c^2

$\Gamma = 7.9 \pm 2.7 \pm 2.6$ MeV

Significance: 8.9σ ($Z_c(4020)$)
No significant $Z_c(3900)$ (2.1σ)

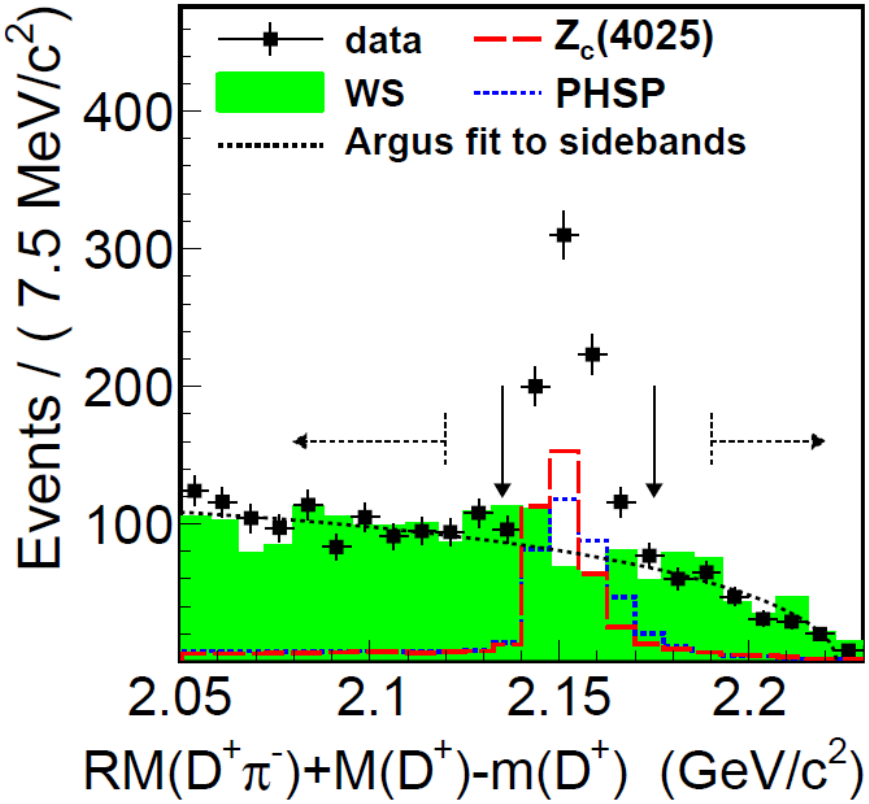
- $\sigma(e^+e^- \to \pi^+\pi^- h_c)$:

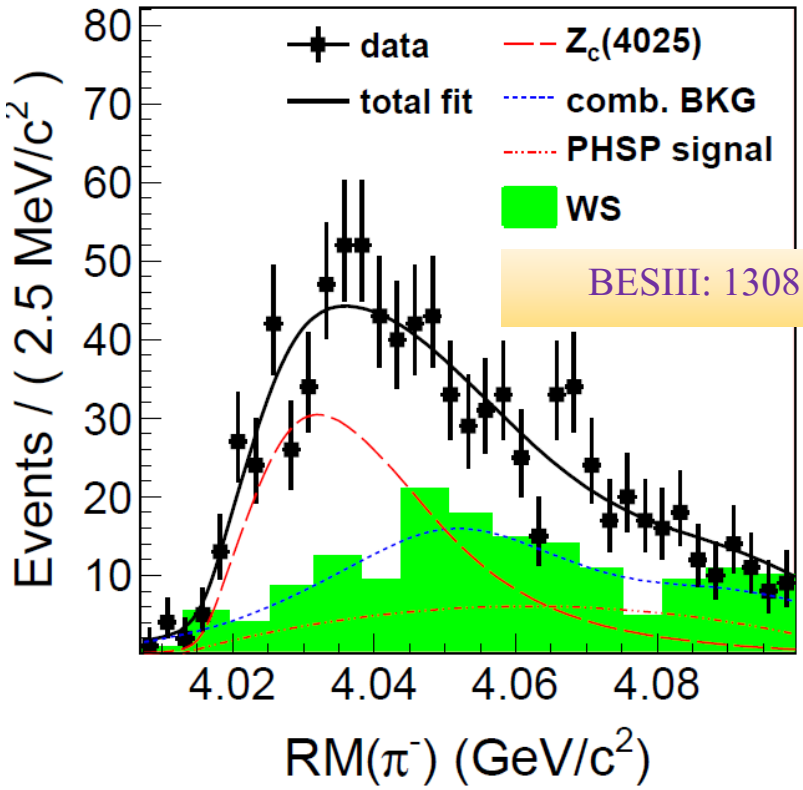
8.7±1.9±2.8±1.4 pb @ 4.230

7.4±1.7±2.1±1.2 pb @ 4.260

10.3±2.3±3.1±1.6 pb @ 4.360

$e^+e^- \to \pi Z_c(4025) \to \pi^- (D^* \bar{D}^*)^+$





BESIII: 1308.2760

Fit to $\pi^\pm$ recoil mass yields 401±47 $Z_c(4025)$ events. **>10σ**

$M(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7$ MeV; $\Gamma(Z_c(4025)) = 24.8 \pm 5.6 \pm 7.7$ MeV

$$\sigma(e^+e^- \to \pi^\pm (D^* \bar{D}^*)^\mp) = (137 \pm 9 \pm 15)\ \text{pb}$$

$$R = \frac{\sigma\ (e^+e^- \to \pi^\pm Z_c^\mp(4025) \to \pi^\pm (D^* \bar{D}^*)^\mp)}{\sigma\ (e^+e^- \to \pi^\pm (D^* \bar{D}^*)^\mp)} = (65 \pm 9 \pm 6)\%$$

Summary of the Zc states

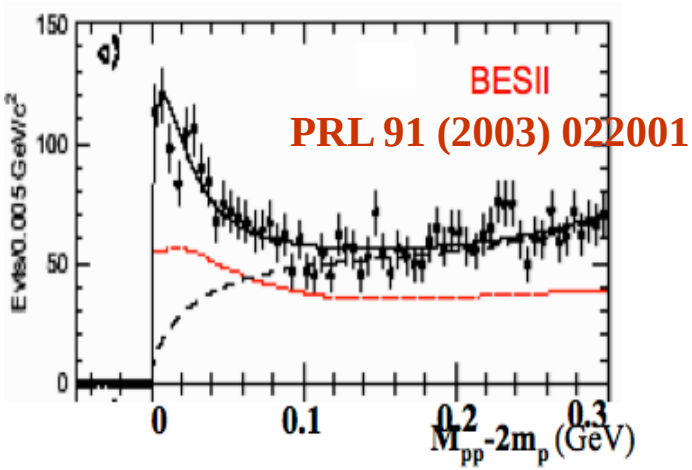
Channel	Mass (MeV/c^2)	Width (MeV)
$\pi^{\pm}J/\psi$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
$(D\bar{D}^*)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$
	2σ difference	1σ difference
$\pi^{\pm}h_c$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$
$(D^*\bar{D}^*)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$
	1σ difference	2σ difference

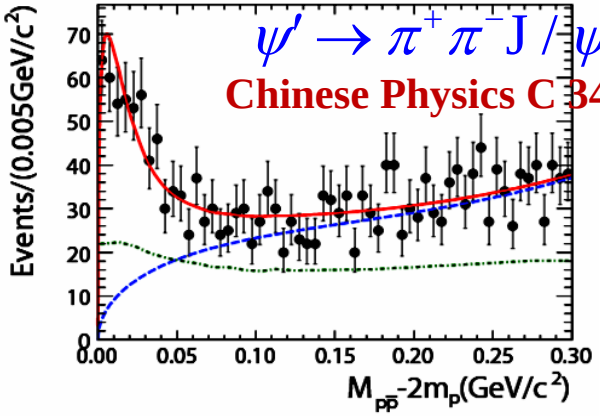
Close to $D\bar{D}^*$ threshold (3875 MeV)

Close to $D^*\bar{D}^*$ threshold (4017 MeV)

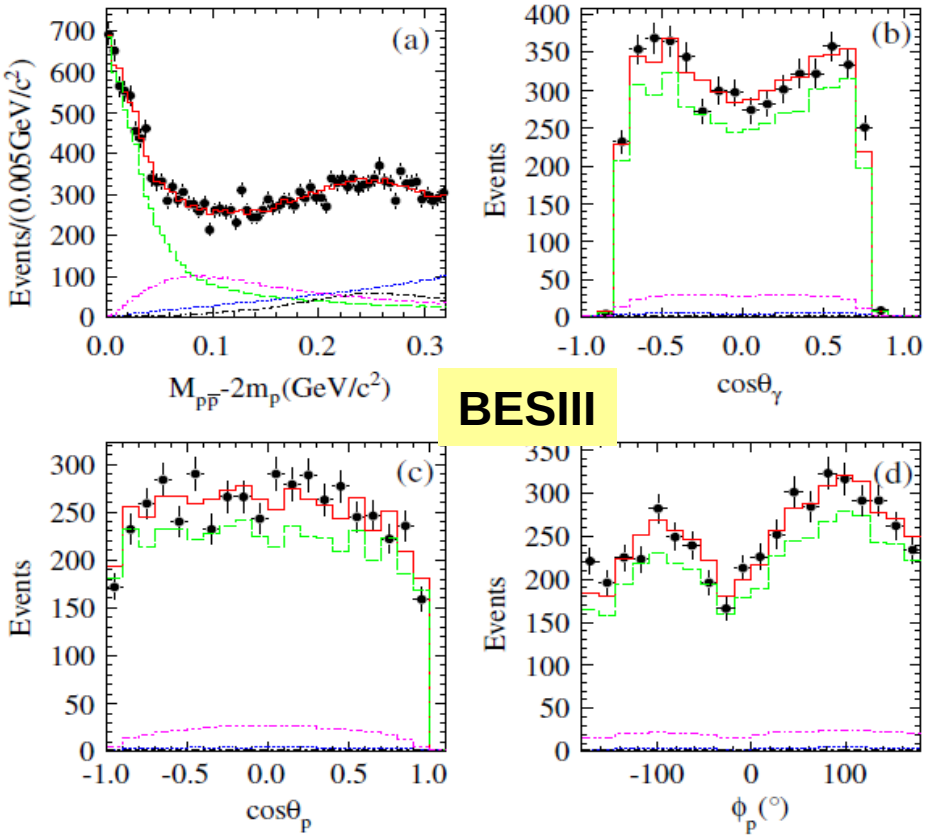
- At least 4-quarks; Charged; Near threshold;
- Couples to DD final states larger than charmonium final states;
- **Whether they are two states need further understanding (couple channel analysis? quantum number determination? interference?)**

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





BESIII

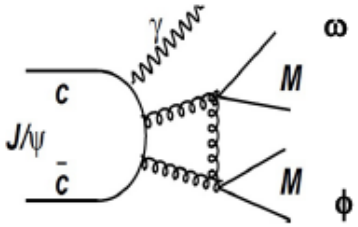


BESIII

- The fit with a BW and S-wave FSI (I=0) factor can well describe the $p\bar{p}$ mass threshold structure
- $J^{PC}=0^{-+}$ >6.8σ better than other J^{PC} assignments.
- $M = 1832^{+19}_{-5}{}^{+18}_{-17} \pm 19$ (model) MeV/c²
  $\Gamma = 13 \pm 39^{+10}_{-13} \pm 4$(model) MeV or
  $\Gamma < 76$ MeV/c² at 90% C.L.

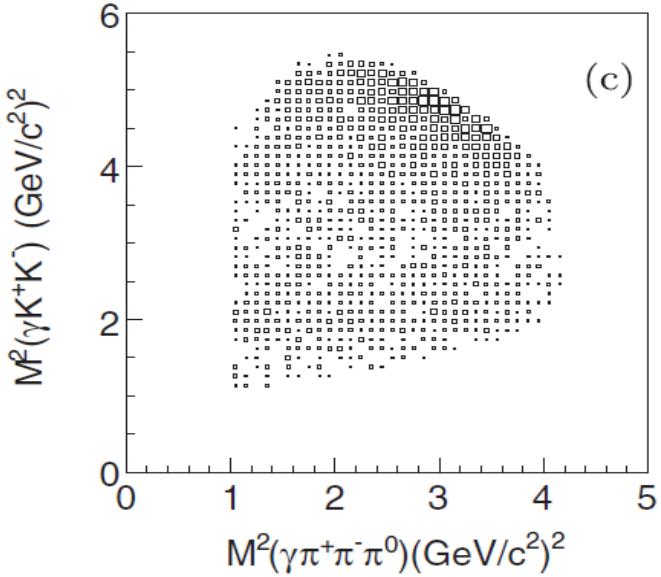
PRL 108, 112003 (2012)

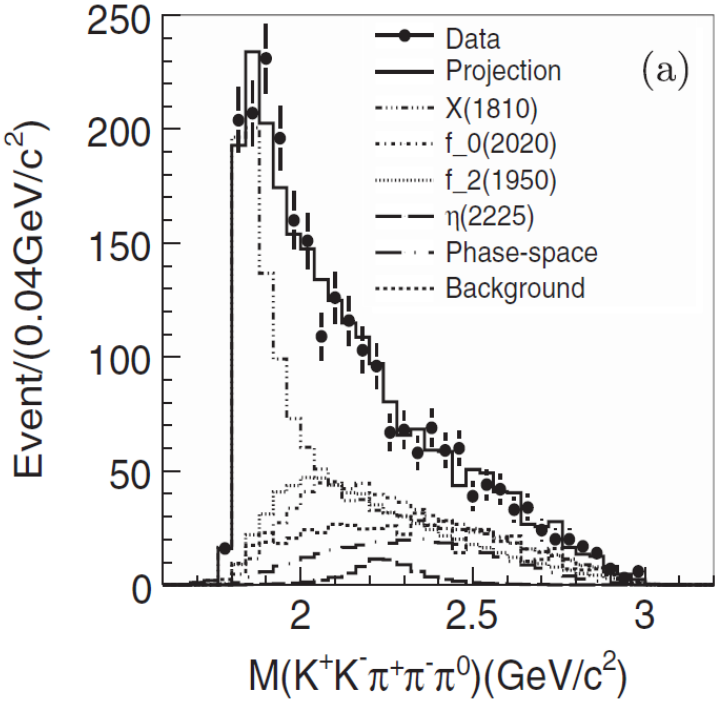
PWA of J/ψ→γωϕ



PRD 87, 032008(2013)

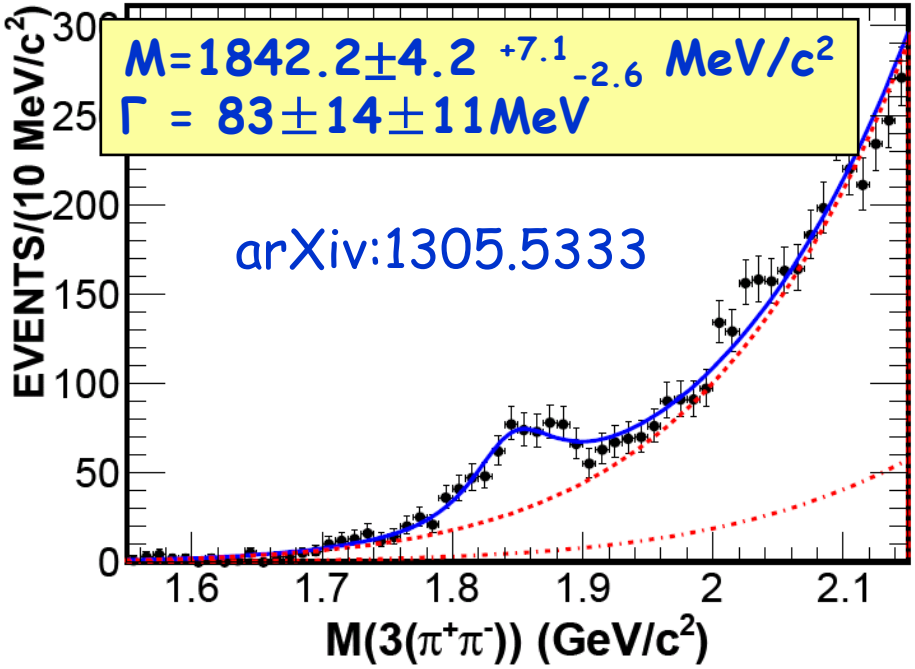
$J/\psi \to \gamma\omega\phi$ **(DOZI)**

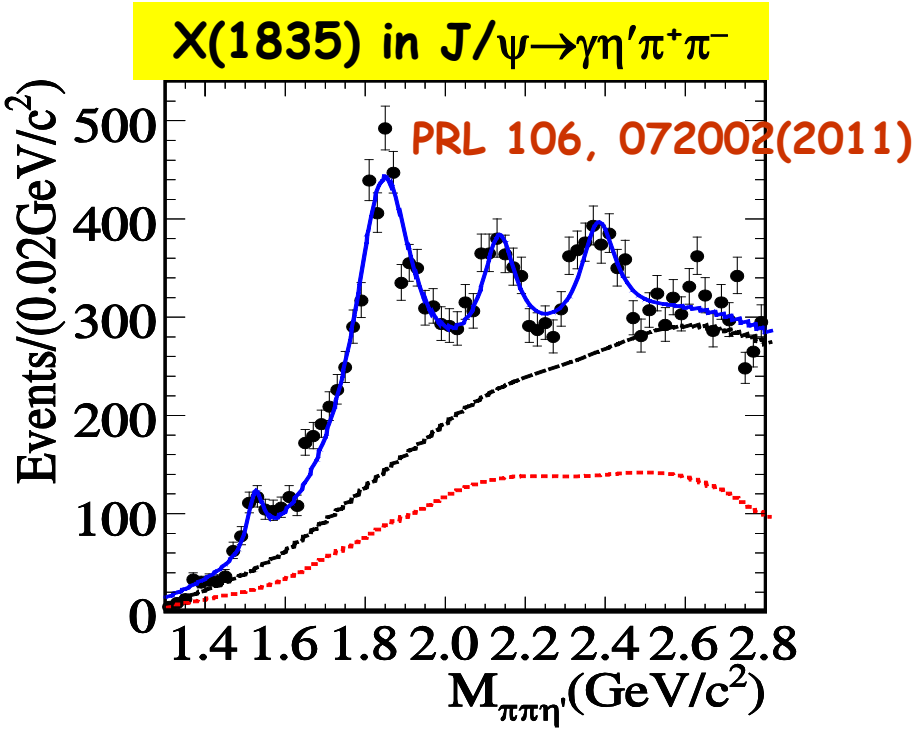




- Confirmed the enhancement observed at BESII
- $M = 1795 \pm 7^{+13}_{-5} \pm 19$(model) MeV/c2,
  $\Gamma = 95 \pm 10^{+21}_{-34} \pm 75$(model) MeV
- Spin-parity is determined to be 0^+
- the same as $f_0(1710)/f_0(1790)$, or a new state ?

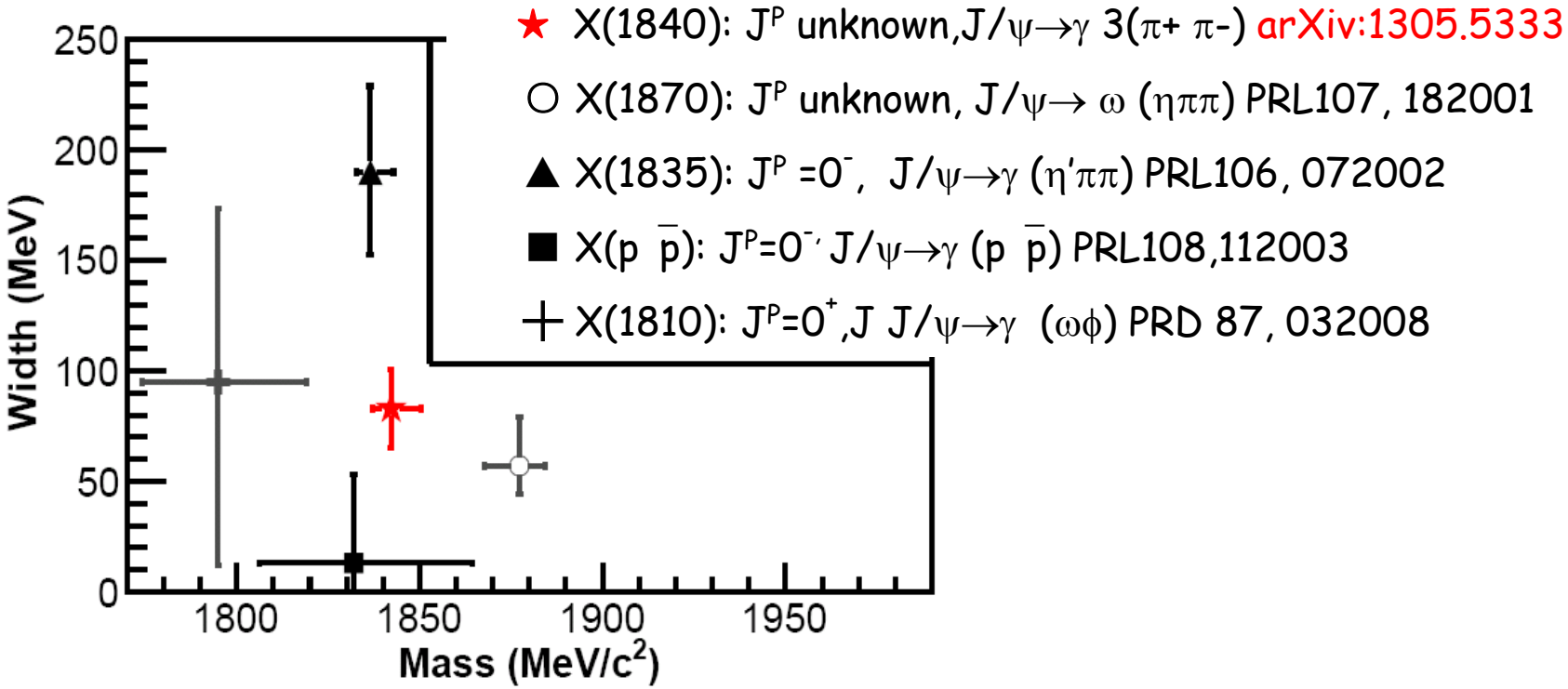
Observation of X(1840) in $J/\psi \to \gamma 3(\pi^+\pi^-)$





- Mass is consistent with that of X(1835), but the width is much smaller than $\Gamma_{x(1835)} = 190.1 \pm 9.0^{+38}_{-36}$ MeV
- A new decay modes of X(1835)?

Comparisons of the observations at BES

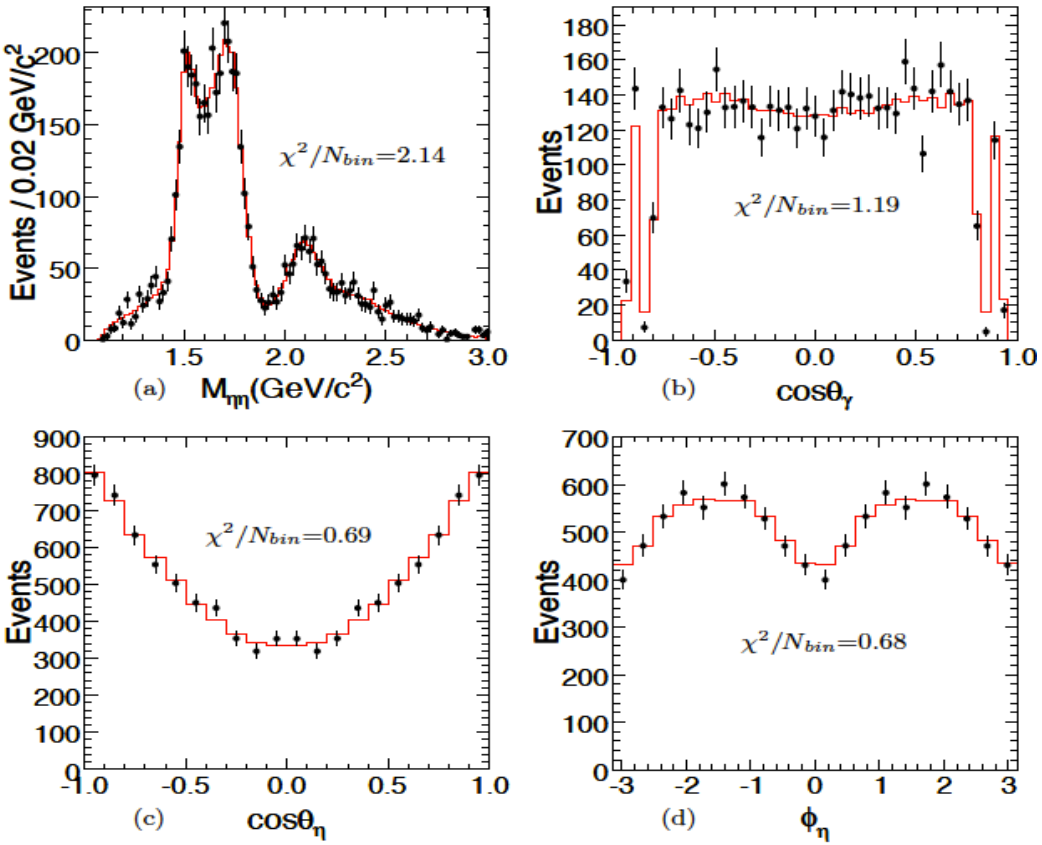


X(18??) near the threshold position of proton-antiproton

Are they the same particle? It is crucial to identify these observations.

PWA in $J/\psi \to \gamma\eta\eta$

Phys. Rev. D. 87, 092009 (2013)

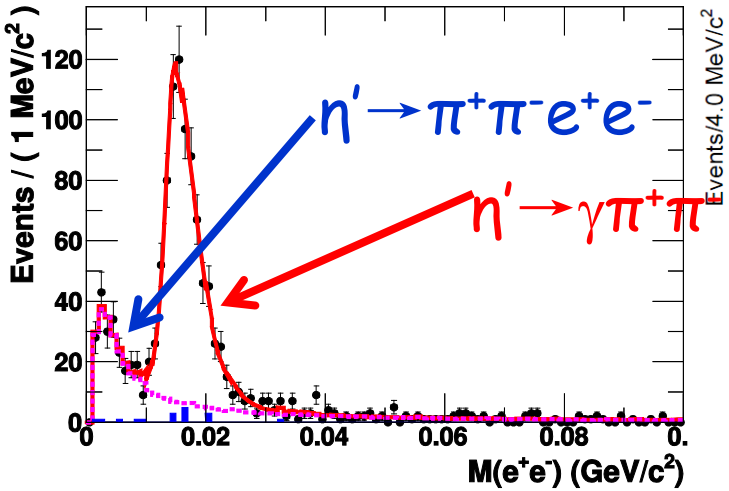


- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2σ)
- $f_2'(1525)$ is the dominant tensor
- $f_2(1810)$ and $f_2(2340)$ exist (6.4 and 7.6σ)
- No evidence for $f_J(2220)$

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+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0σ
$f_2(1810)$	1822^{+29+66}_{-24-57}	$229^{+52+88}_{-42-155}$	$(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$	6.4σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6σ

η and η′ physics at BESIII

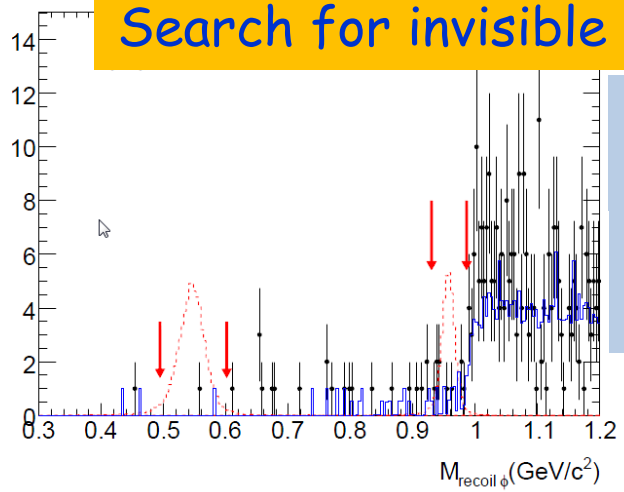
PRD87, 092011 (2013)



$B(\eta' \to \pi^+\pi^-e^+e^-)=(2.11\pm0.12\pm0.15)\times10^{-3}$

PRD87, 032006 (2013)

Search for invisible decays



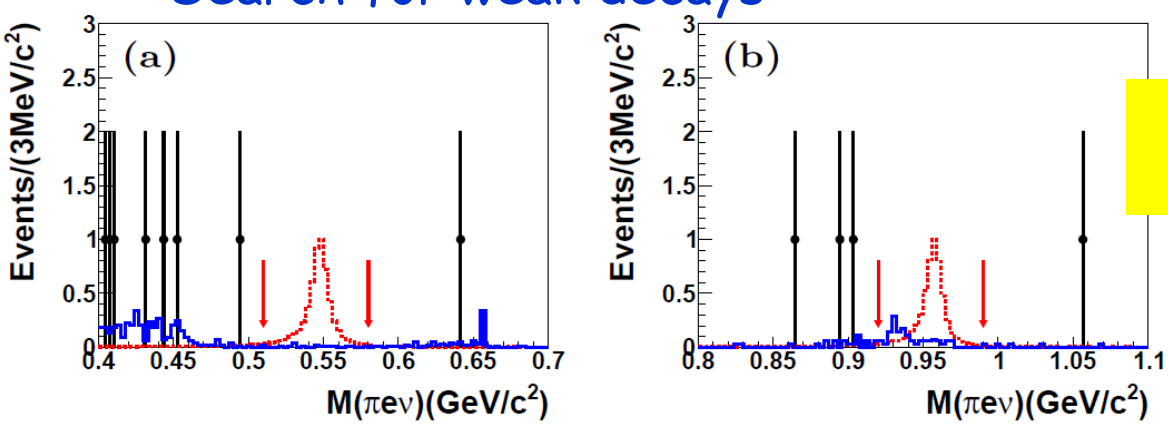
Theory:
PRD 72, 103508(2005)
$BR(\eta\to\chi\chi) \sim 7.4\times10^{-5}$
$BR(\eta'\to\chi\chi) \sim 8.1\times10^{-7}$

$B(\eta\to\text{invisible}) < 1.0\times10^{-4}$

$B(\eta'\to\text{invisible}) < 5.3\times10^{-4}$

@90%C.L.

Search for weak decays



$B(\eta\to\pi^-e^+\nu+c.c.)<1.7\times10^{-4}$
$B(\eta'\to\pi^-e^+\nu+c.c.)<2.2\times10^{-4}$

@90%C.L.

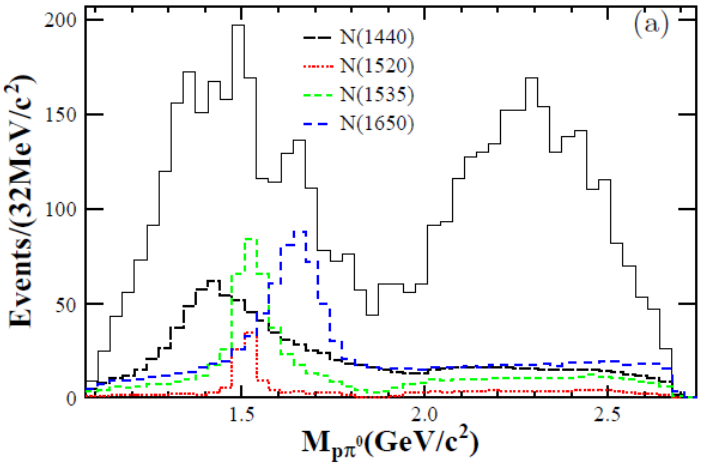
theory:$\sim10^{-8}$ -10^{-9}

PRD87, 032006 (2013)

Prog. Part. Nucl. Phys. 46, 413 (2001)

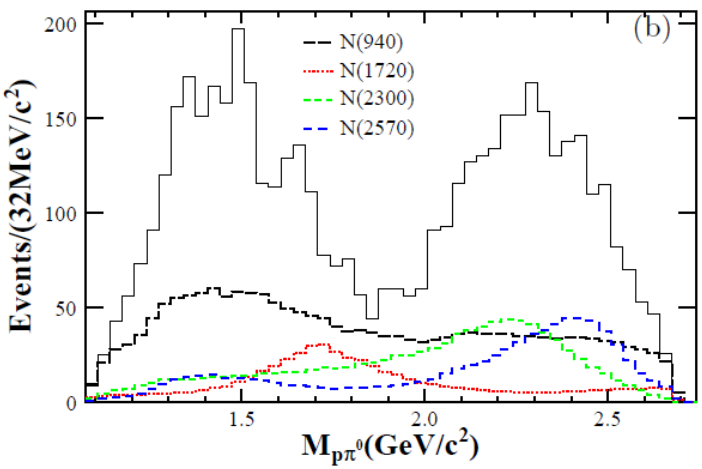
PWA results on N* baryons in $\psi' \to \pi^0 p \bar{p}$

Phys.Rev.Lett. 110 (2013) 022001



- 2-body decay:
  $\psi(2S) \to X\pi^0, X \to p\bar{p}$
  $\psi(2S) \to p\bar{N}^*, \bar{N}^* \to \bar{p}\pi^0$ + c.c.
- isospin conservation:
  Δ suppressed

Two new baryonic excited states are observed !



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

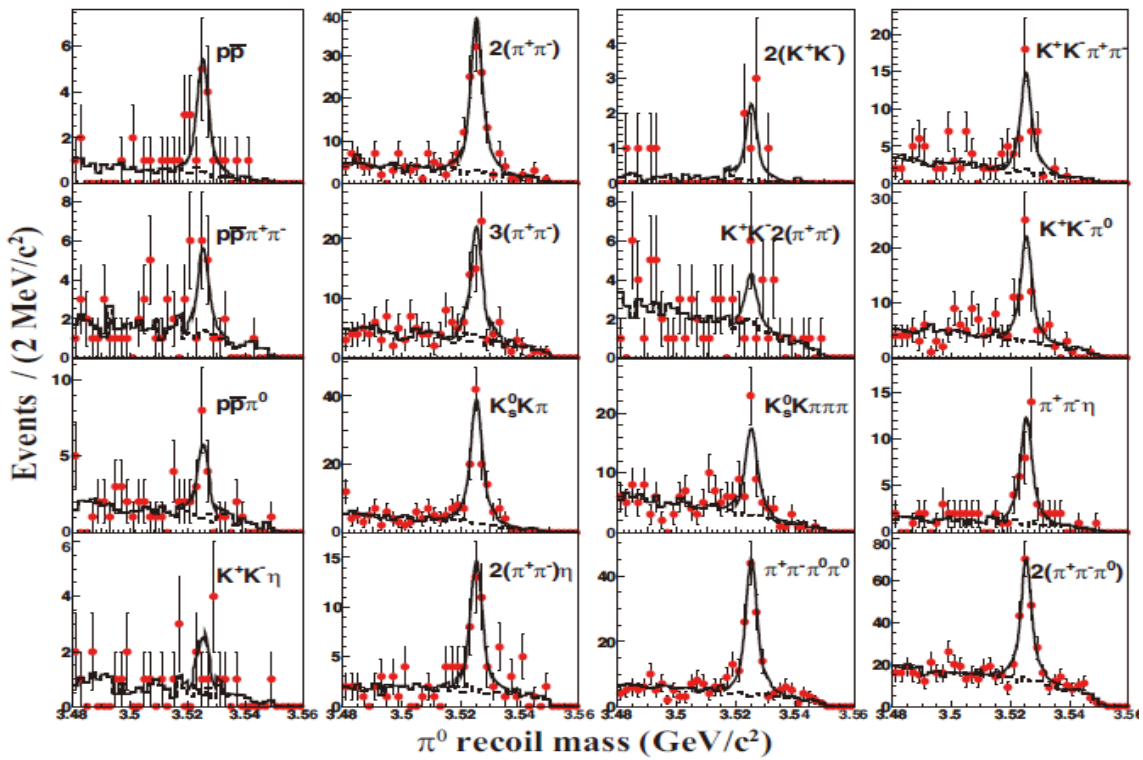
Charmonium physics

Please refer to the talks below for details

- Chi Zhang (Nanjing U.): "Charmonium spectroscopy from BESIII"

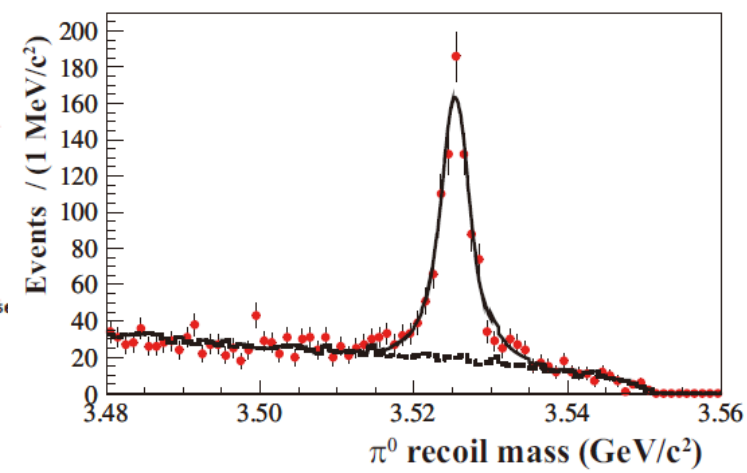
$h_c(^1P_1)$ in $\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$, η_c exclusive decays

BESIII: PRD 86, 092009 (2012)



$\psi' \to \pi^0 h_C$, $h_C \to \gamma\eta_C$, 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±0.14 MeV

$\Gamma(h_c)$ = 0.70±0.28±0.22 MeV

N = 832±35

χ^2/d.o.f. = 32/46

Consistent with BESIII inclusive results PRL104,132002(2010)

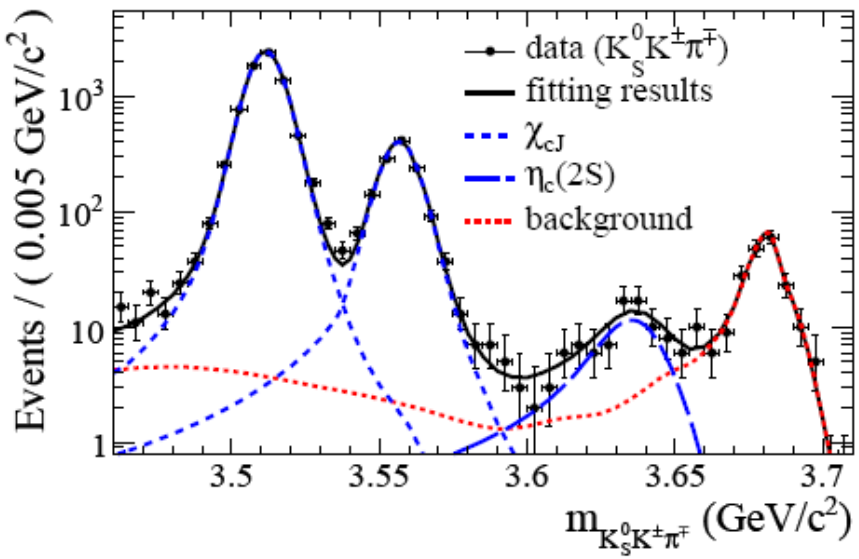
CLEOc exlusive results

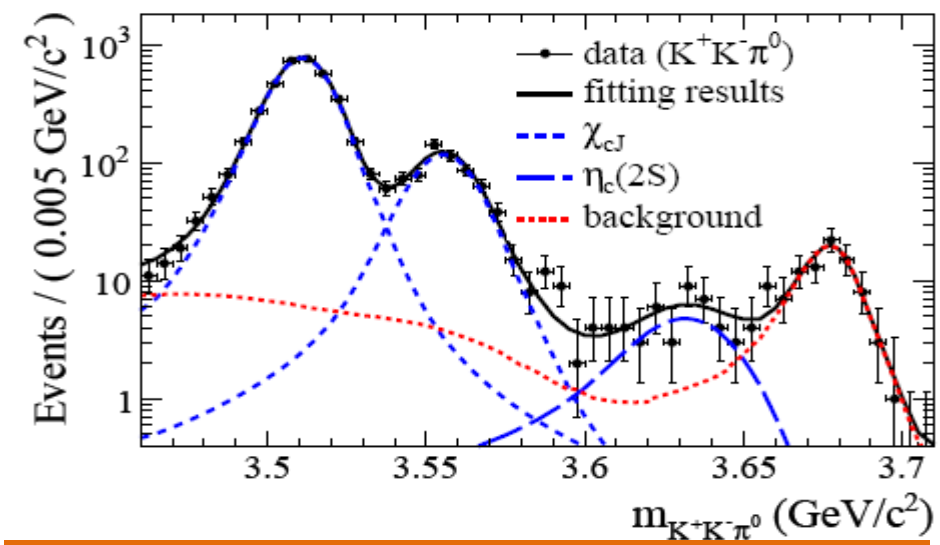
$M(h_c)$=3525.21±0.27±0.14 MeV/c^2

N = 136±14

PRL101, 182003(2008)

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





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

simultaneous fit results:

$M(\eta_c(2S)) = (3637.6 \pm 2.9 \pm 1.6)$ MeV/c^2
$\Gamma(\eta_c(2S)) = 16.9 \pm 6.4 \pm 4.8$ MeV
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)

$\Downarrow$

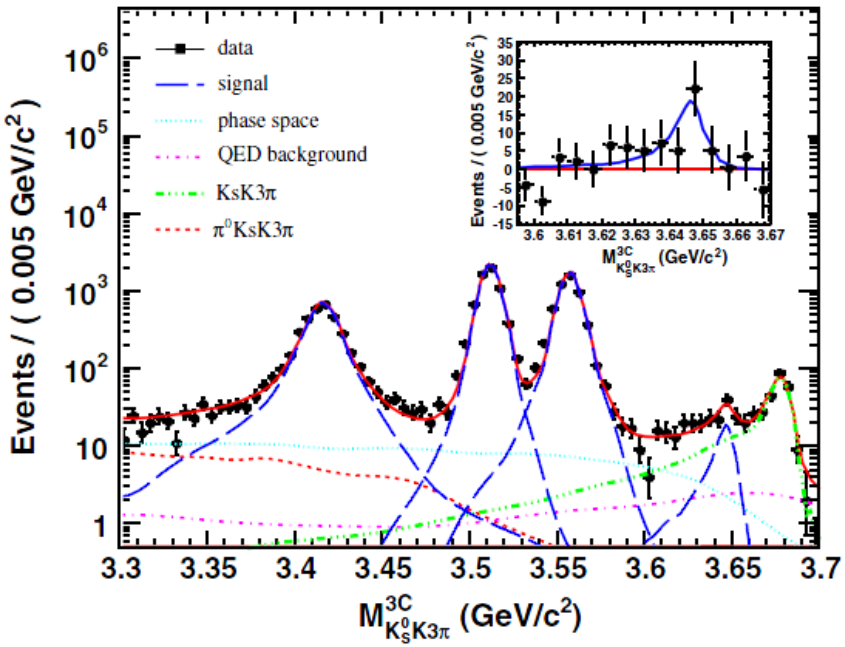
$Br(\psi' \to \gamma\eta_c(2S))$
$=(6.8 \pm 1.1_{stat} \pm 4.5_{sys}) \times 10^{-4}$

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

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

Evidence of $\eta_c(2S) \to K_s K 3\pi$

PRD87, 052005 (2013)



$M(\eta_c(2S)) = (3646.9 \pm 1.6 \pm 3.6)$ MeV/c^2

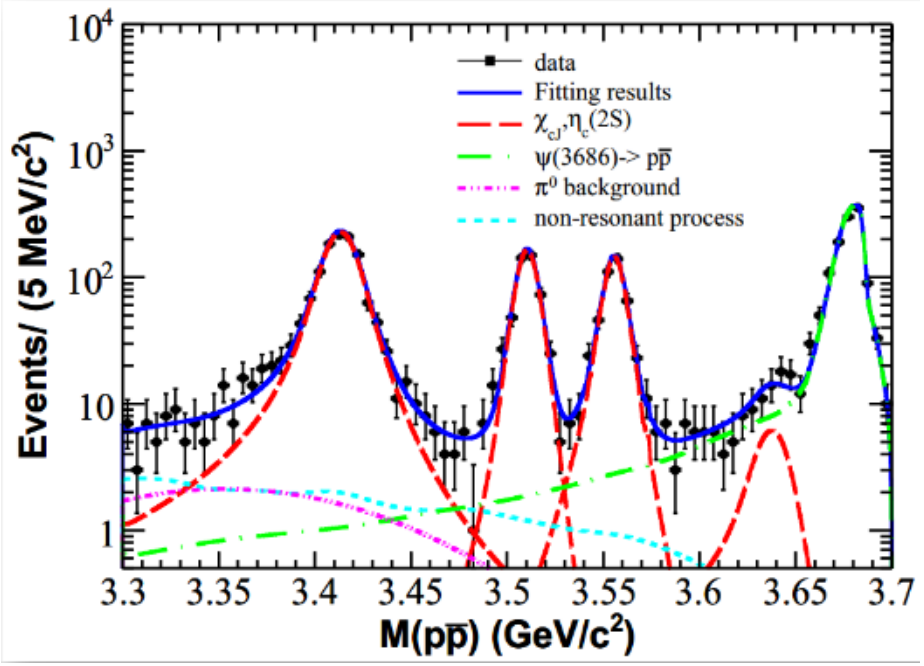
$\Gamma(\eta_c(2S)) = 9.2 \pm 4.8 \pm 2.9$ MeV

Statistical significance : 4.2σ

$B(\psi' \to \gamma\eta_c(2S) \to \gamma K_s \underline{K3}\pi)$
$= (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$

Search for $\eta_c(2S) \to p\bar{p}$

arXiv: 1310.6099



No evident signal was observed

$B(\psi' \to \gamma\eta_c(2S) \to \gamma p\bar{p})$
$< 1.4 \times 10^{-6}$ @90%C.L.

Charm physics

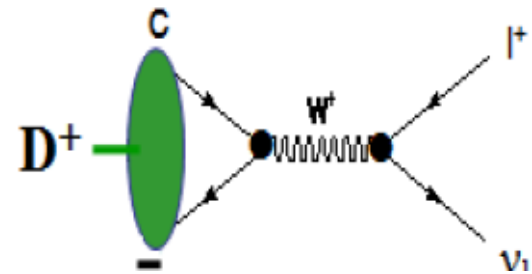
Please refer to the talks below for details

- Hailong Ma (IHEP): "D semi-leptonic and leptonic decays at BESIII"
- Shensheng Sun (IHEP): "Dalitz plot analysis of $D^+ \to K_S \pi^+\pi^0$ at BESIII"
- Yinghui Guan (IHEP): "Strong phase in $D^0 \to K\pi$ decay and y_{CP} measurements from CP-tagged D^0 semi-leptonic decays at BESIII"

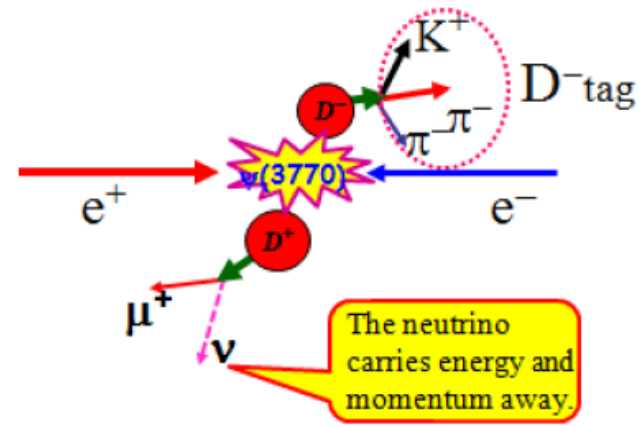
$D^+ \to \mu^+\nu$ and Decay constant f_{D+}

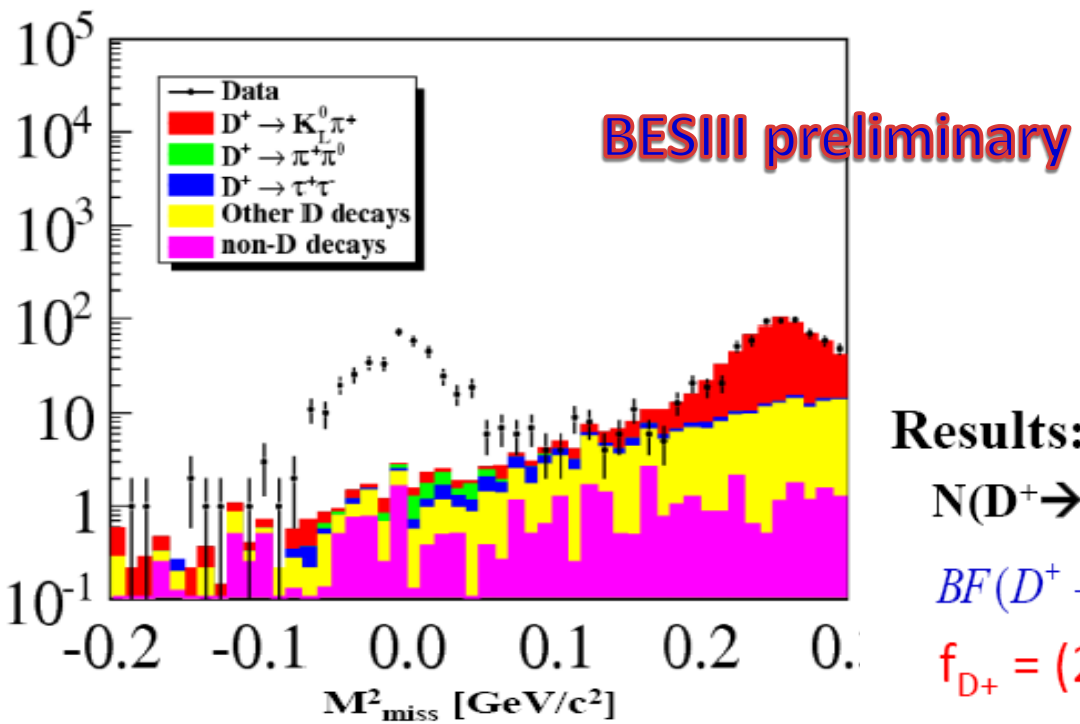
- **Test LQCD calculation of f_D**

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



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





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

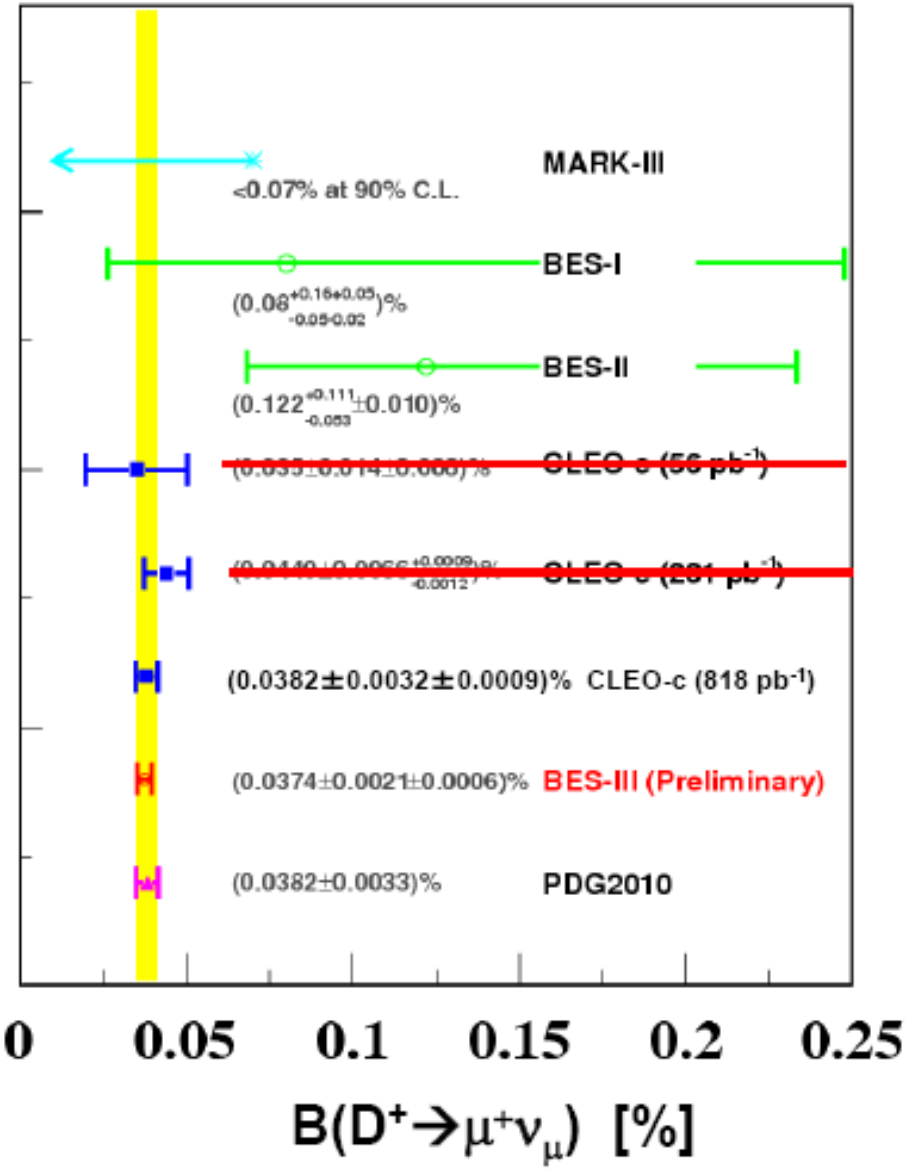
Results:

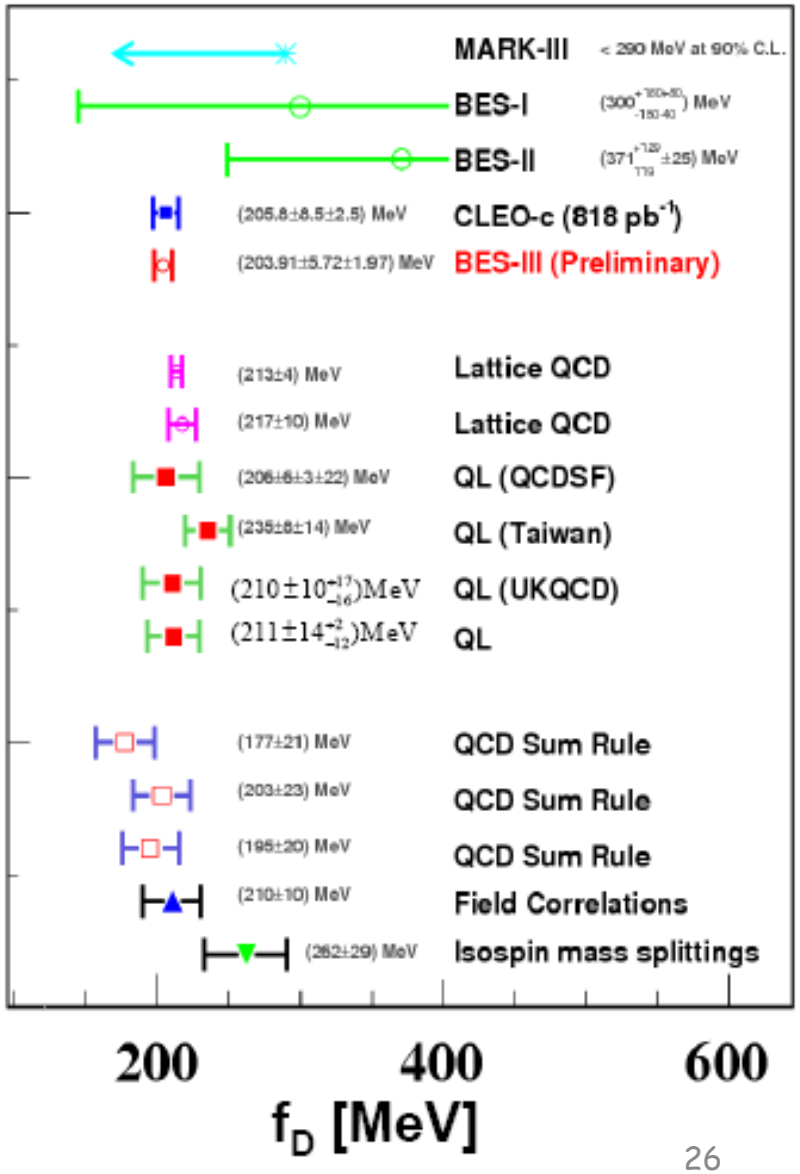
$N(D^+ \to \mu^+\nu) = 377.3 \pm 20.6$

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

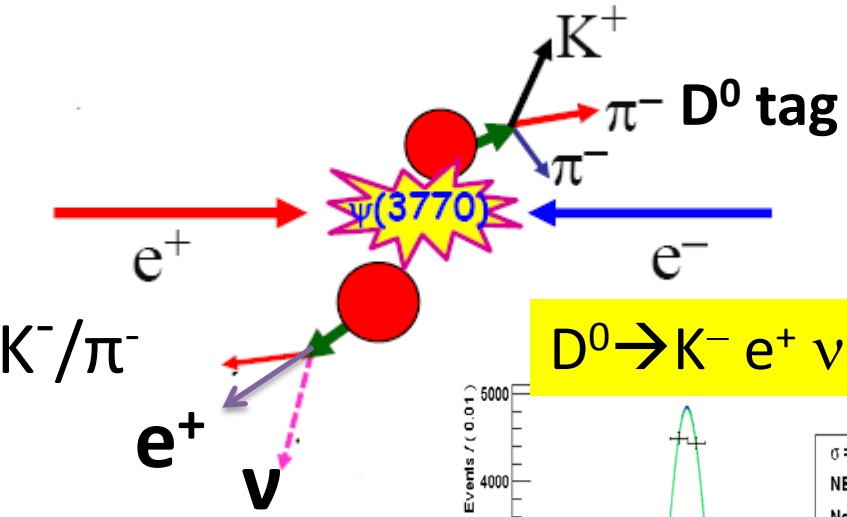
$f_{D+} = (203.91 \pm 5.72 \pm 1.97)$ MeV

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



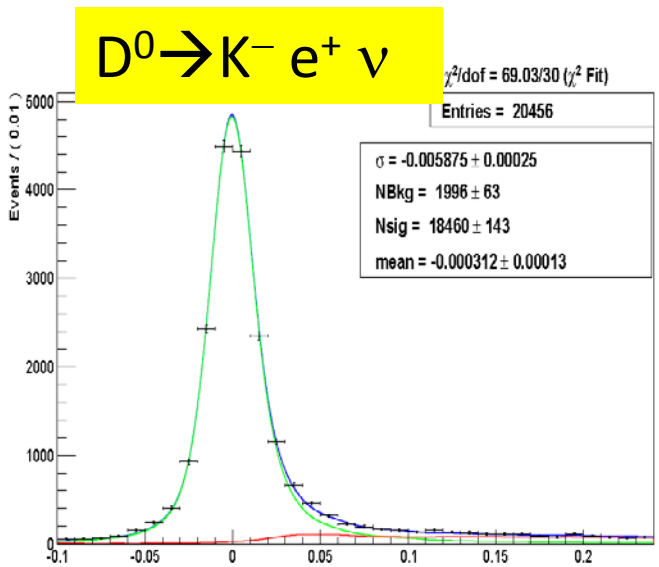


$D^0 \to K^-/\pi^- e^+ \nu$

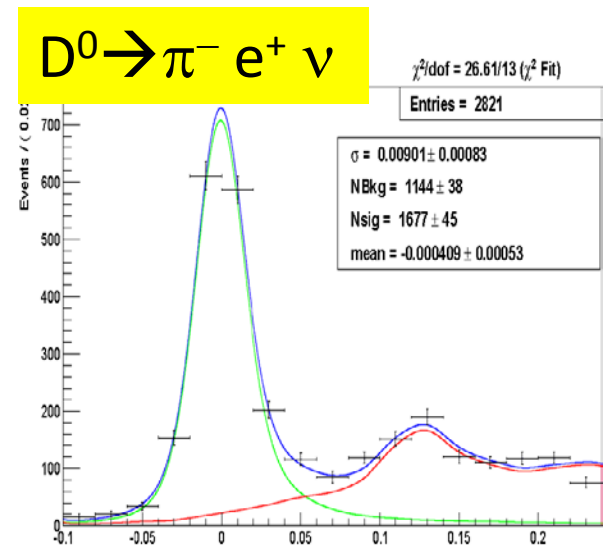


- **BESIII, ~2.93 fb-1 data taken at ψ(3770), ~923 pb-1 analyzed**
- **signal side: missing neutrino inferred**

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



U_k (GeV)

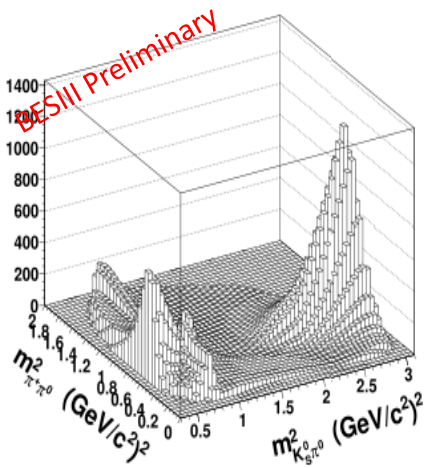


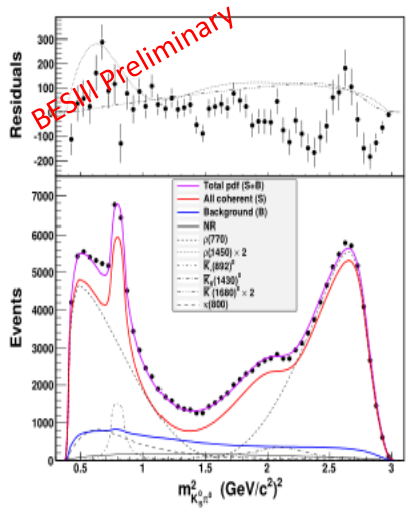
U_π (GeV)

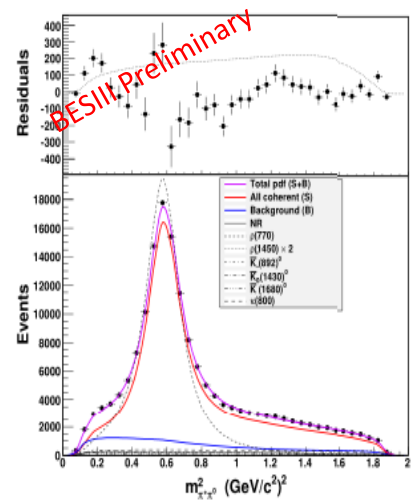
BESIII Preliminary

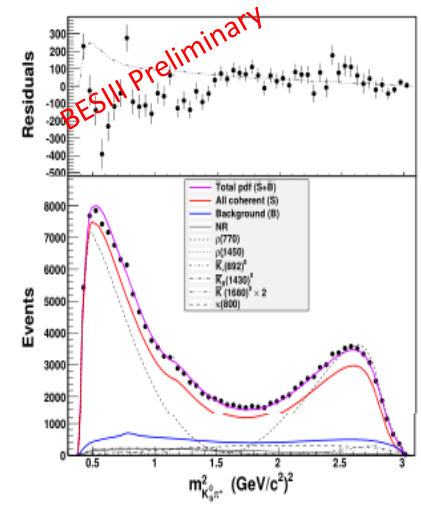
Mode	measured branching fraction(%)	PDG	CLEOc
$\bar{D}^0 \to K^+ e^- \bar{\nu}$	3.542 ±0.030±0.067	3.55 ±0.04	3.50 ±0.03 ±0.04
$\bar{D}^0 \to \pi^+ e^- \bar{\nu}$	0.288 ±0.008±0.005	0.289 ±0.008	0.288 ±0.008±0.003

Dalitz plot analysis of $D^+ \to K_S\pi^+\pi^0$









Resonance	Parameter (MeV)		BES-III	E791 Model C	CLEO-c Model C	CLEO-c Model I2
$\overline{K}^*_0(1430)$	BW	Mass	$1464 \pm 6 \pm 9^{+9}_{-28}$	1459 ± 14	$1463.0 \pm 0.7 \pm 2.4$	$1466.6 \pm 0.7 \pm 3.4$
		Width	$190 \pm 7 \pm 11^{+6}_{-26}$	175 ± 17	$163.8 \pm 2.7 \pm 3.1$	$174.2 \pm 1.9 \pm 3.2$
PDG	Flatt	Mass	1482 ± 10		1462.5 ± 3.9	1471.2 ± 0.8
1425 ± 50		$g_{K\pi}$	585 ± 14		532.9 ± 8.5	546.8 ± 4.2
270 ± 80		$g_{K\eta}$	0		0	0
		$g_{K\eta'}$	452 ± 85		197 ± 106	230 ± 32
κ	BW	Mass	860 ± 11	797 ± 47	809 ± 14	888 ± 2
		Width	446 ± 23	410 ± 97	470 ± 18	550 ± 12
	Pole	Re	$752 \pm 15 \pm 69^{+55}_{-73}$		769.9 ± 6.3	$706.0 \pm 1.8 \pm 22.8$
		Im	$-229 \pm 21 \pm 44^{+40}_{-55}$		-221.2 ± 8.4	$-319.4 \pm 2.2 \pm 20.2$

PRL 89, 121801(2002) PRD 78, 052001(2008)

Summary

- BESIII is successfully operating since 2008
  - World largest data samples at J/ψ, ψ', $\psi(3770)$, $\psi(4040)$, $Y(4260)$ already collected, more data in future coming soon
- Hadron spectroscopy
  - Observation of $X(3872)$, $Zc(3900)$, $Zc(4025)$
  - PWA of $J/\psi \rightarrow \gamma p \bar{p}$, $\gamma \eta\eta$, $\gamma\omega\phi$
  - Observation of $X(1840)$
  - η/η' physics
- Charmonium physics
  - Measurement of $\psi' \rightarrow \pi^0 h_c$ with η_c exclusive decays
  - Observation of $\psi' \rightarrow \gamma \eta_c(2S)$
- Charm physics
  - Precision open-charm D physics to come soon.
- **Expect more results from BESIII in the future !**

Thank you !