Overview of BESIII Experiment

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(Representing BESIII Collaboration)

Institute of High Energy Physics

Symposium on Lepton and Hadron Physics at Meson Factories,

Messina, October 13-15, Italy

Outline

- Introduction
- BESIII data sets
- Selected results from BESIII
  - Hadron spectroscopy (XYZ, light hadron spec.)
  - Charmonium physics
  - Charm physics
- Summary

τ-charm: Main physics goals

✓**Hadron spectroscopy and test of QCD at low energy:**
- **Light meson and baryon**
- **Glueball: direct test of QCD at low energy**
- **Hybrid/exotics states/multiquark states/molecular states…**
- **Charmonium(-like) spectroscopy and decays / Charmed baryon decays**

For XYZ, see Yuping Guo's talk

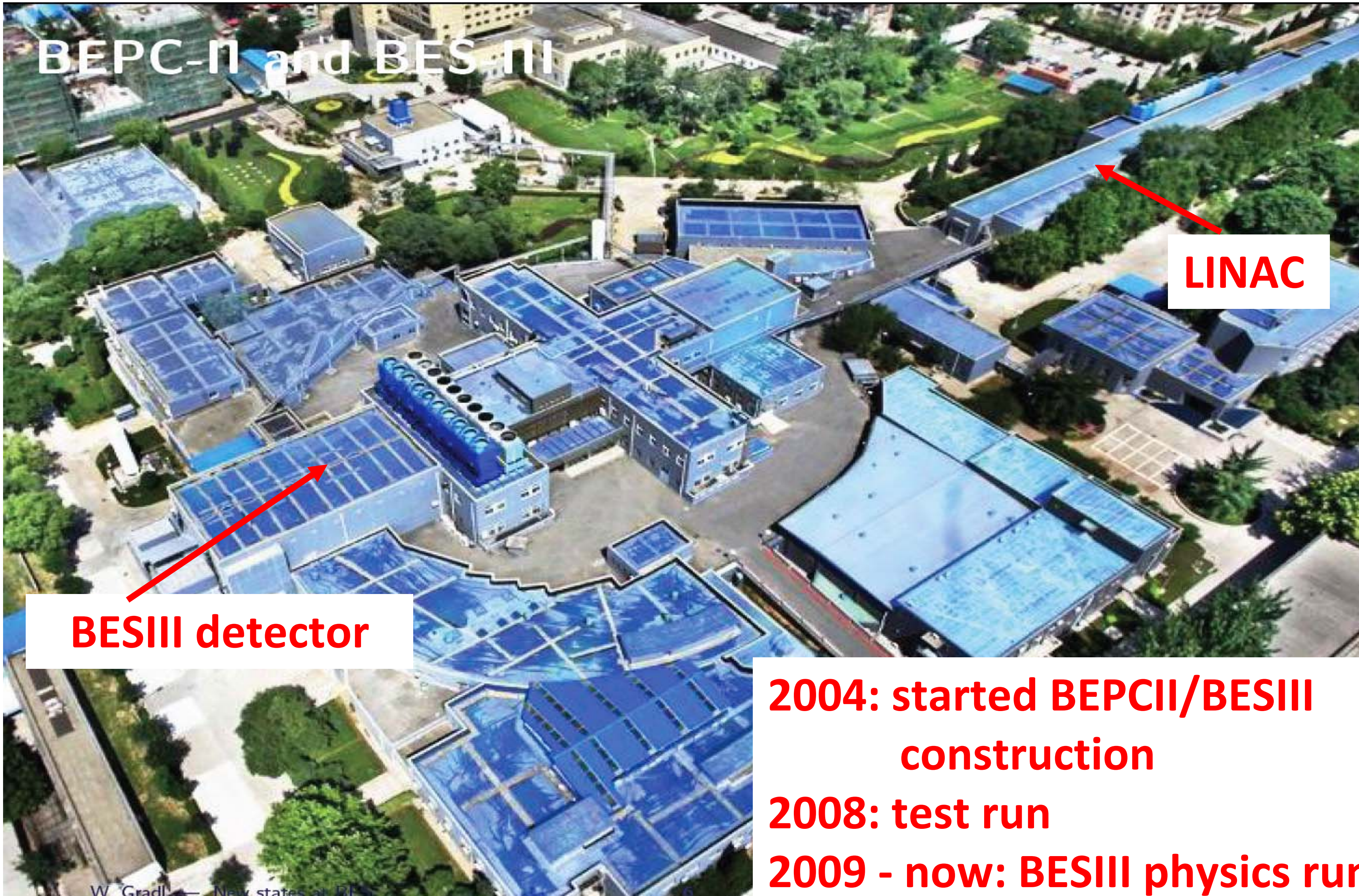
✓**Precise test of the Standard Model:**
- **R values, tau mass and tau decays, CKM matrix, lepton universality test…**
- **Decay constants, form factors (in D meson decays)**

✓ **New physics searches at low energy (tiny/forbidden in SM):**
- **Rare charmonium decays: weak decays, LFV, LNV, BNV …**
- **Rare charm and tau decays: FCNC, LFV, LNV, invisible decays**
- **Rare light meson decays: $\eta/\eta'/\omega/\phi$ rare decays**
- **Neutral D mixing**
- **CP violation in tau and charm: tiny in SM**
- **CP violation in baryon /charmed baryon weak decays**

For η/η' rare decays: Chritoph Redmer's talk

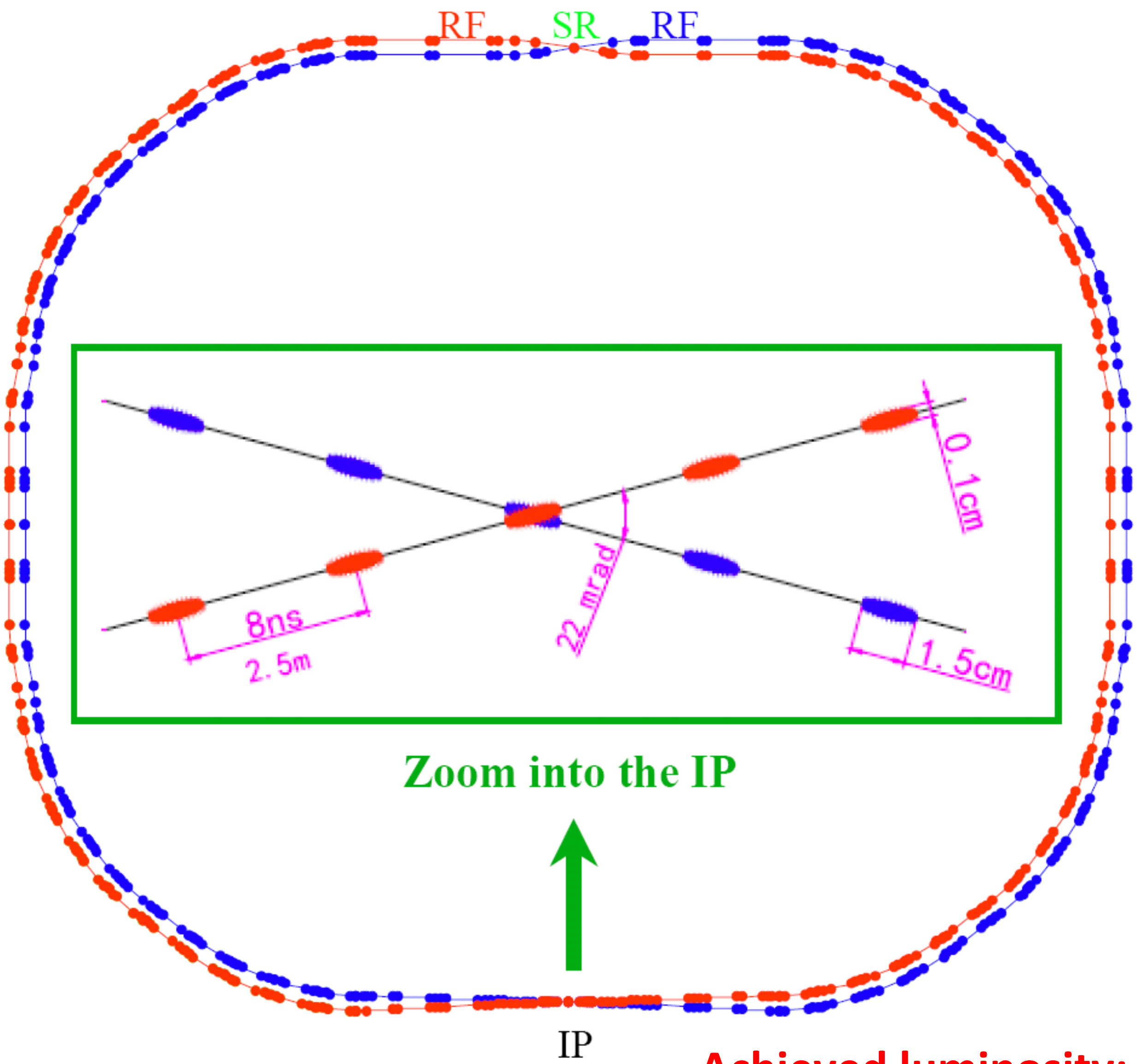
✓ **Exotic physics:**
- **Light dark matter candidates, Dark photon, light Higgs boson(a_0),**
- **New interactions…**

Beijing Electron Positron Collider-II (BEPCII)



2004: started BEPCII/BESIII construction
2008: test run
2009 - now: BESIII physics run

BEPCII storage rings



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

Achieved luminosity: 0.7×10^{33} $cm^{-2}s^{-}$

BESIII Detector

BESIII detector: all new !

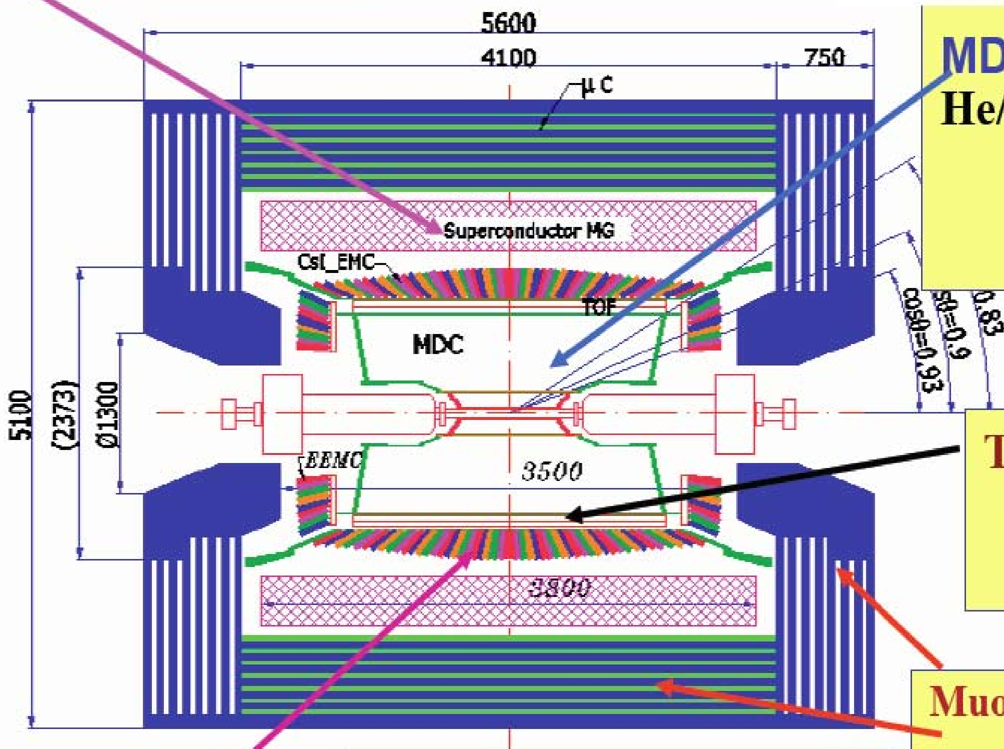
CsI calorimeter

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

The BESIII Collaboration

Europe (13)

Germany: Univ. of Bochum, Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
Univ. of Perugia, Univ. of Eastern Piedmont
Netherland: KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

US (6)

Univ. of Hawaii
Univ. of Washington
Carnegie Mellon Univ.
Univ. of Minnesota
Univ. of Rochester
Univ. of Indiana

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

China(29)

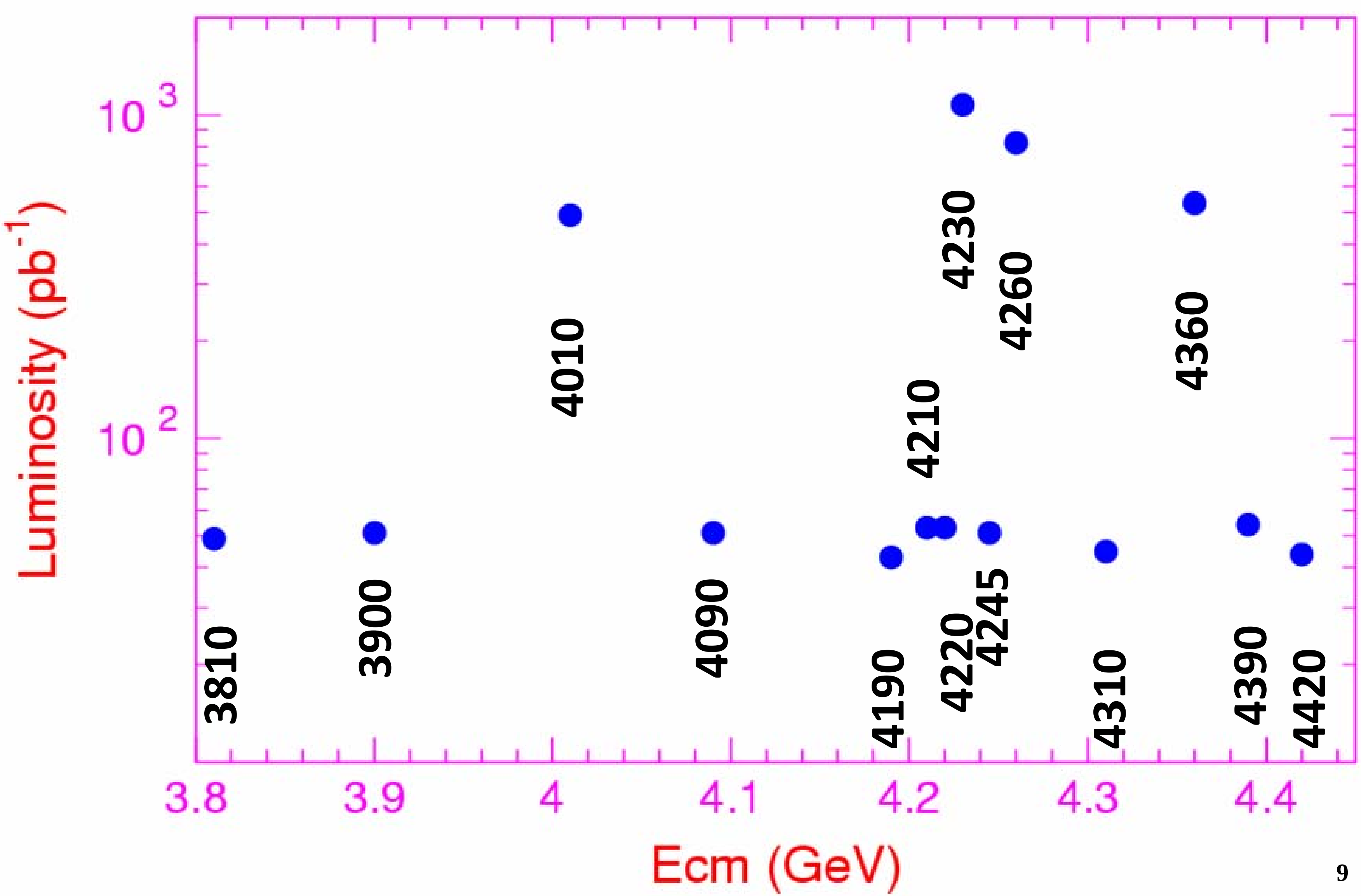
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ., Beihang Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning Univ.
Nanjing Univ., Nanjing Normal Univ.
Guangxi Normal Univ., Guangxi Univ.
Suzhou Univ., Hangzhou Normal Univ.
Lanzhou Univ., Henan Sci. and Tech. Univ.

~350 members
52 institutions from 11 countries

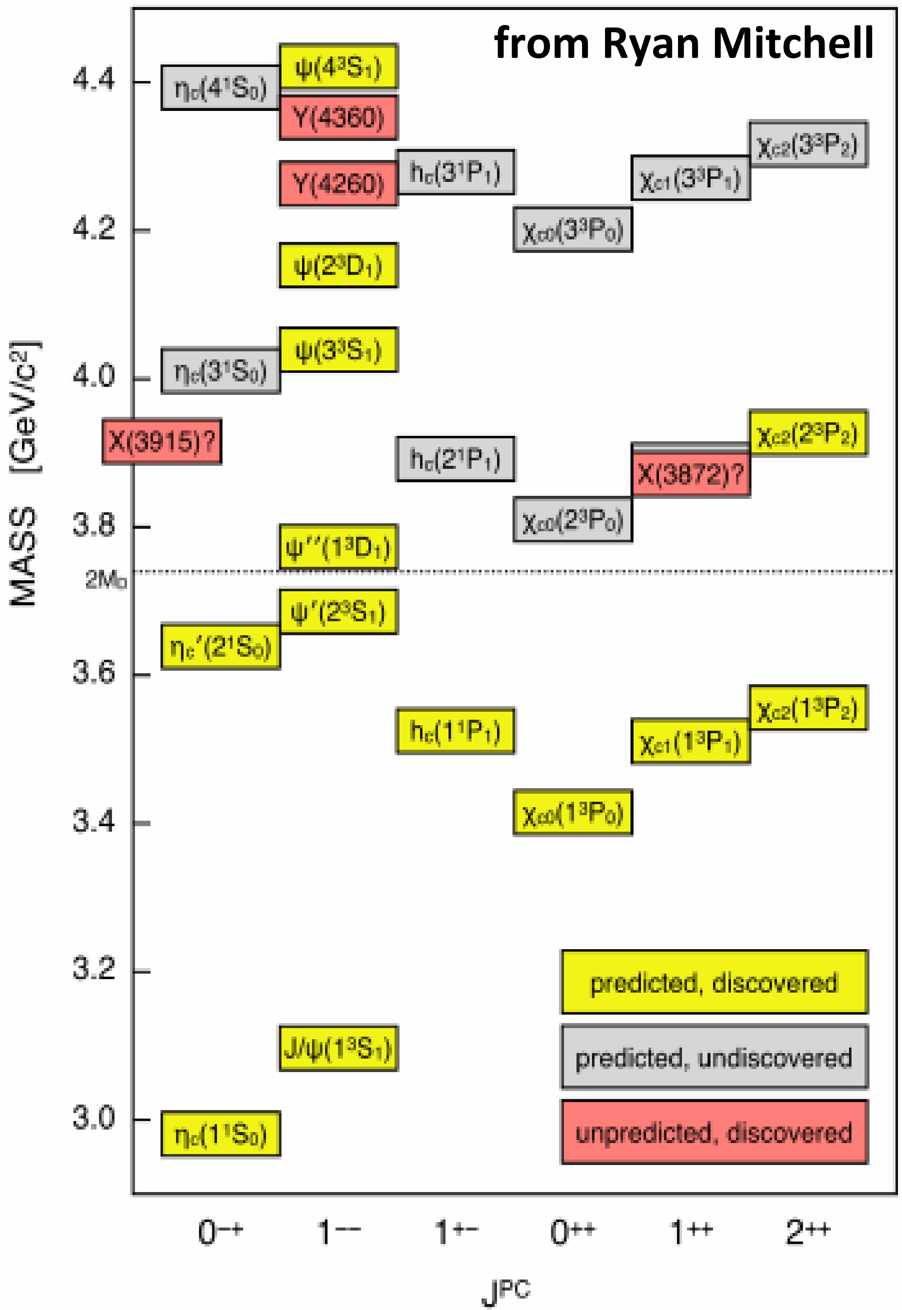
BESIII data taking status & plan

	Previous data	BESIII present & future	Goal
J/ψ	BESII: 58M	1.2 B 20* BESII	10 B
ψ'	CLEO: 28 M	0.5 B 20* CLEOc	3B
ψ''	CLEO: 0.8/fb	2.9/fb 3.5*CLEOc	20/fb
4040/4160/4260 /4360 MeV	CLEO: 0.6/fb @ ψ(4160)	2011: 0.5/fb @ ψ(4040) 2013： 2/fb@4260, 0.5/fb 4360 Data for lineshape	5-10/fb
R scan	BESII	2012: R @2.23,2.4,2.8,3.4GeV 25/pb tau 2013-2014: high mass resonances? R measurement ?	

BESIII collected 3.3/fb for XYZ study (2012-2013)



Charmonium spectroscopy



- Charmonium states below open charm threshold are all observed

Above open charm threshold:

- many expected states not observed
- many unexpected charmoniumlike states observed

Z(4430)	X(3872)	Y(4008)
Z(4250)	X(3915)	Y(4140)
Z(4050)	X(4160)	Y(4260)
Z(3900)	X(4350)	Y(4360)
Z(4020)		Y(4660)
Z(4025)	XYZ(3940)	

For detail, see Yuping Guo's talk

Cross section of $e^+e^- \to \pi^+\pi^- J/\psi$

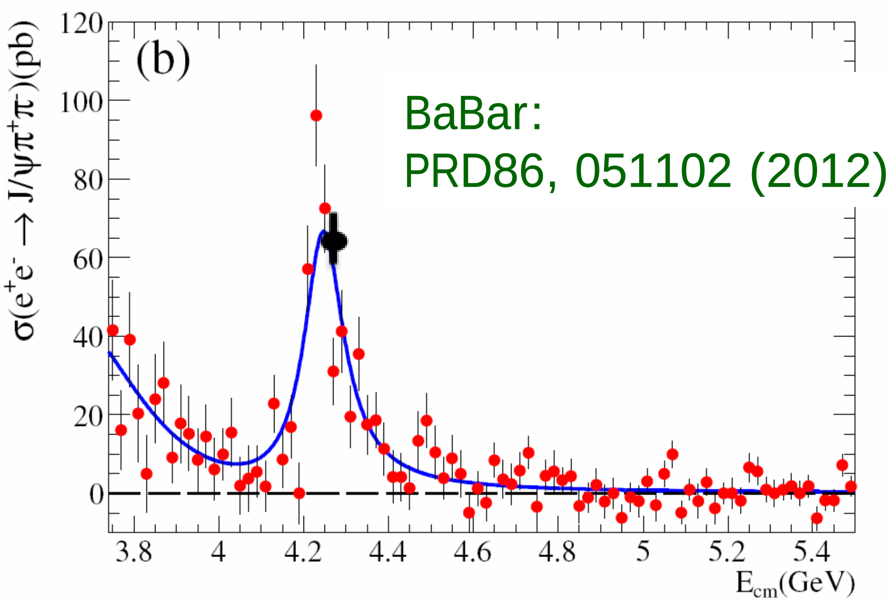
- 1^{--} resonance $Y(4260)$ seen in ISR production at e^+e^-

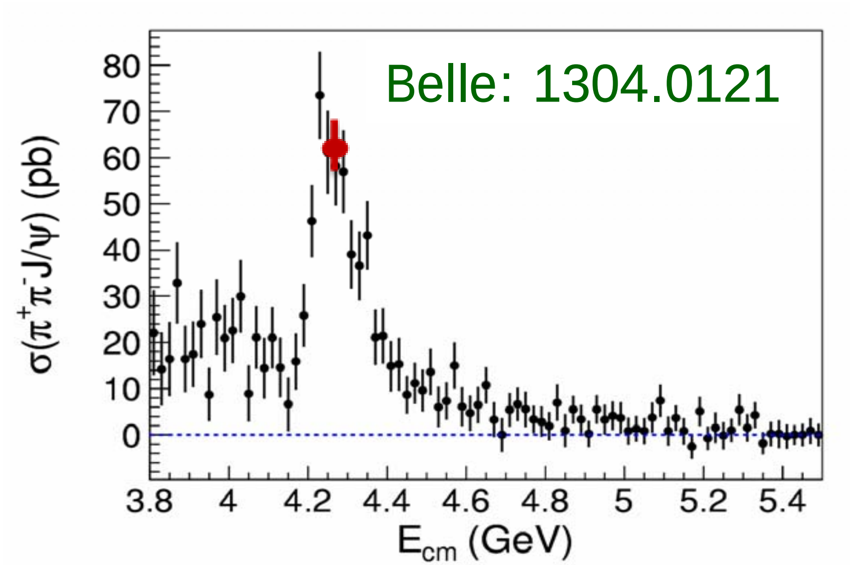
  BABAR, PRL **95**, 142001 (2005); CLEO, PRD **74**, 091104 (2006); Belle, PRL **99**, 182004 (2007)
- No obvious place in charmonium spectrum; unexpectedly large decay rate into $J/\psi\,\pi^+\pi^-$ for charmonium state

BESIII: $\sigma(e^+e^- \to \pi^+\pi^- J/\psi)$ = (62.9±1.9±3.7) pb @4.26 GeV

Agree with BaBar & Belle! Best precision!

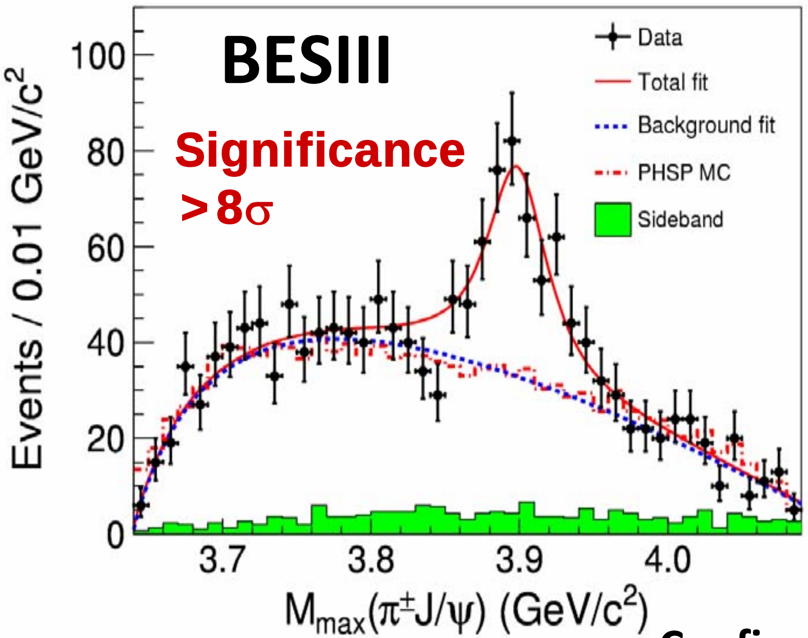
525/pb @4.26 GeV





BESIII: PRL110, 252001

Observation of Zc(3900) at BESIII



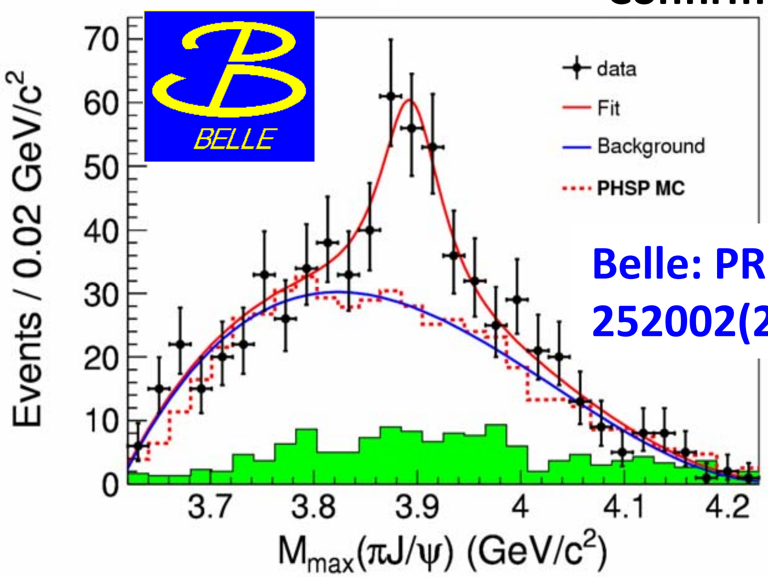
BESIII: PRL110, 252001 (2013)

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

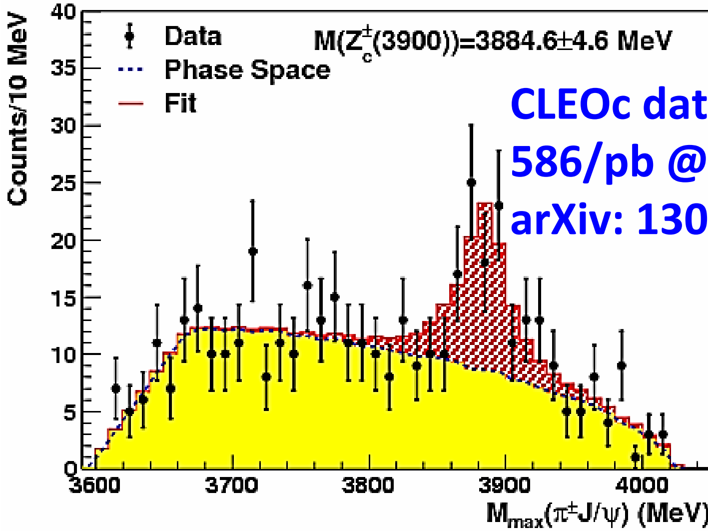
The mass position is 24 MeV away from DD* threshold!

A Partial wave analysis is on going!

Confirmed by Belle and CLEOc: established!



Belle: PRL 110, 252002(2013)

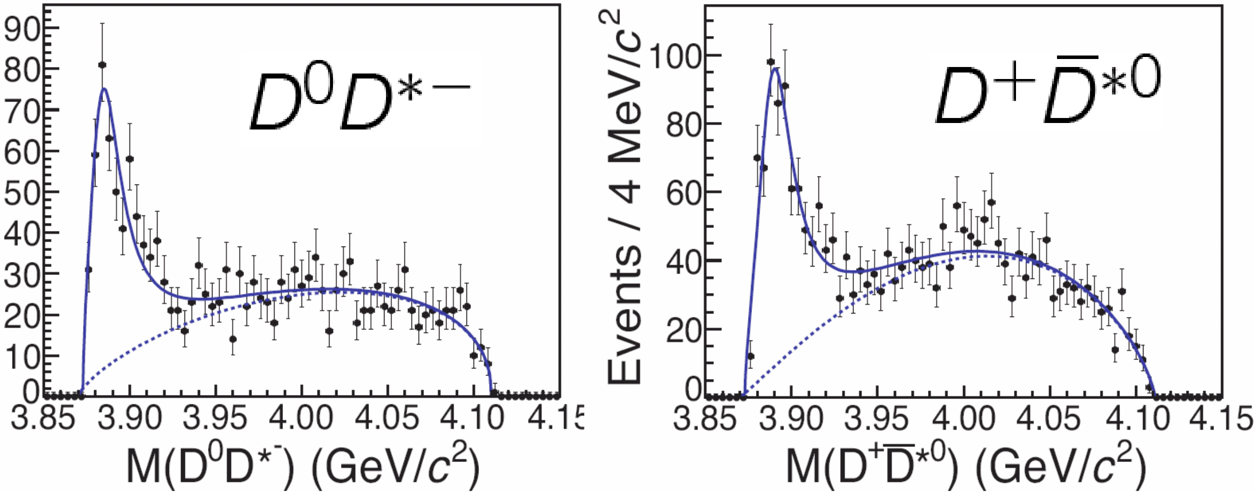


CLEOc data
586/pb @4.17GeV
arXiv: 1304.3036

$e^+e^- \to \pi^\pm(D\bar{D}^*)^\mp - Z_c(3885)$ with 525/pb @4.26 GeV

Partial reconstruct: reconstruct "bachelor" π
reconstruct $D^0 \to K\pi$ and $D^+ \to K\pi$
looking at the recoiling mass of π

BESIII: arXiv:1310.1163
Submitted to PRL



Fit with mass-dependent BW with phase space factor and efficiency correction.

	$Z_c(3885) \to D\bar{D}^*$	$Z_c(3900) \to \pi J/\psi$
Mass (MeV/c^2)	$3883.9 \pm 1.5 \pm 4.2$	$3899 \pm 3.6 \pm 4.9$
Γ (MeV)	$24.8 \pm 3.3 \pm 11.0$	$46 \pm 10 \pm 20$
$\sigma \times \mathcal{B}$ (pb)	$83.5 \pm 6.6 \pm 22.0$	$13.5 \pm 2.1 \pm 4.8$

The pole mass and width are reported for Zc(3885).

Assuming the Zc(3885) is due to Zc(3900):

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

Strange behavior of Y(4260)–Zc(3900)! Large non-DD coupling!

Quantum number of Zc(3885)

- $\cos\theta_\pi$: angle between bachelor pion and beam axis in CMS

0^+ excluded by parity conservation

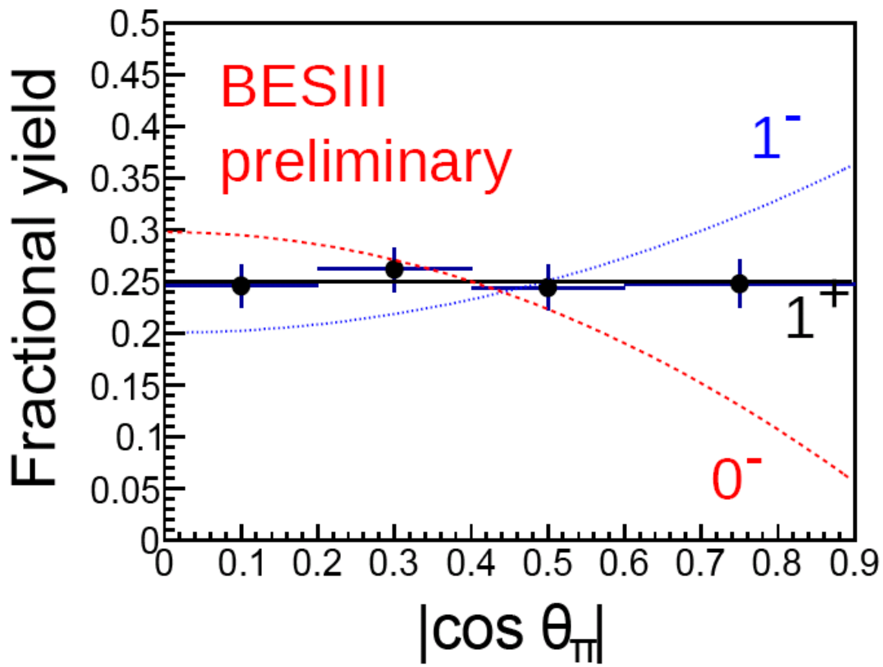
0^- π and $Z_c(3885)$ in P-wave, with $J_z = \pm 1$ ➡ $dN/d\cos\theta_\pi \propto \sin^2\theta_\pi$

1^- π and $Z_c(3885)$ in P-wave ➡ $dN/d\cos\theta_\pi \propto 1 + \cos^2\theta_\pi$

1^+ π and $Z_c(3885)$ in S or D wave. Assume D wave small near threshold: flat distribution in $\cos\theta_\pi$.

BESIII: arXiv:1310.1163
Submitted to PRL

Event yield in 4 bins in $|\cos\theta_\pi|$



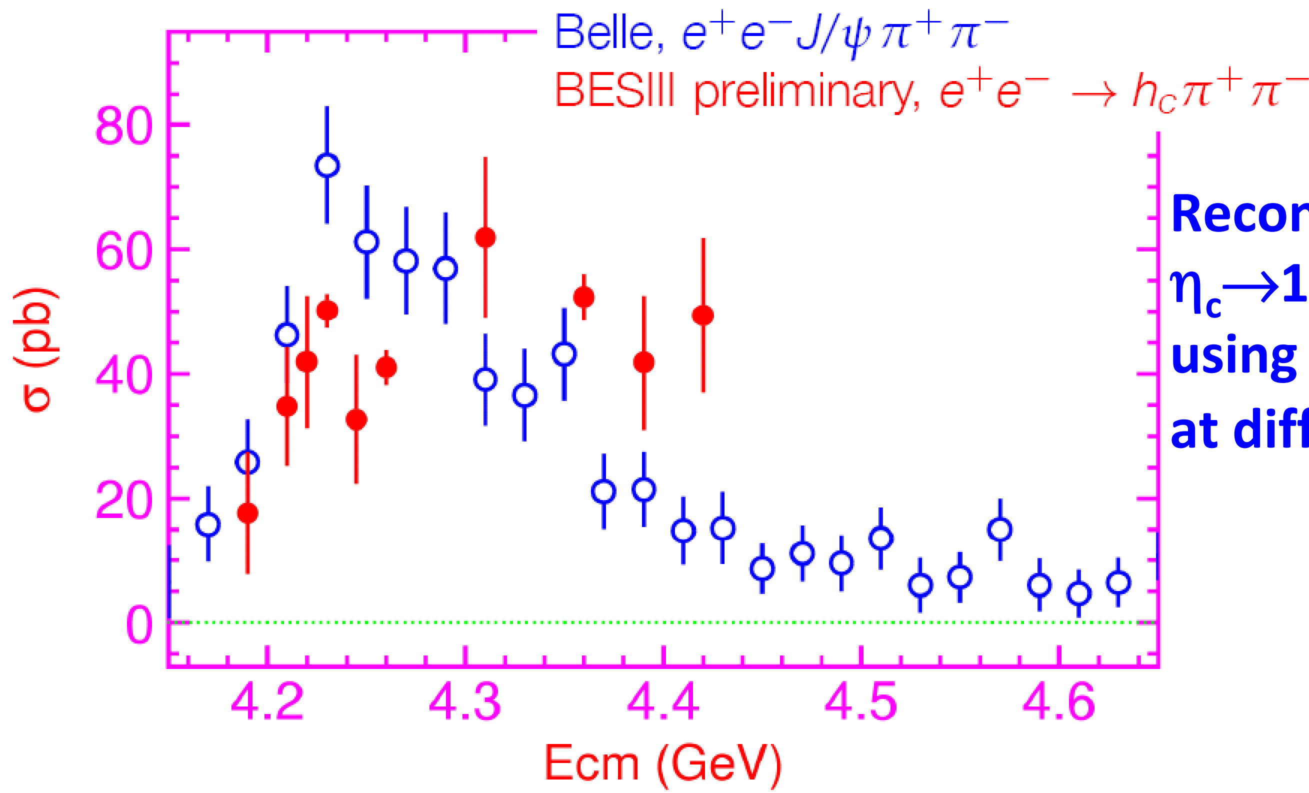
data clearly favour $J^P = 1^+$ for $D\bar{D}^*$ structure

first measurement of J^P for one of the Z_c

MENU2013 Walfgang Gradl

Cross-sections of $e^+e^- \to \pi^+\pi^- h_c(1P)$

arXiv:1309.1896
submitted to PRL



Reconstruct $h_c \to \gamma\eta_c$,
$\eta_c \to$16 exclusive modes
using data 2.4/fb
at different energy points.

- $\sigma(e^+e^- \to h_c\pi^+\pi^-) \approx \sigma(e^+e^- \to J/\psi\,\pi^+\pi^-)$, but different line shape
- Local maximum around 4.23 GeV?
- Broad structure around 4.4 GeV?

For detail, see Yuping Guo's talk
MENU2013 Walfgang Gradl

Puzzle of “Y(4260)”

Assuming the $\pi^+\pi^- h_c(1P)$ is from Y(4260) decay:

$$\frac{\Gamma(Y(4260)\to\pi^+\pi^- h_c(1P))}{\Gamma(Y(4260)\to\pi^+\pi^-\psi(1S))} = (66.0 \pm 7.6)\%$$

$S(h_c(1P)) = 0$
$S(J/\psi) = 1$

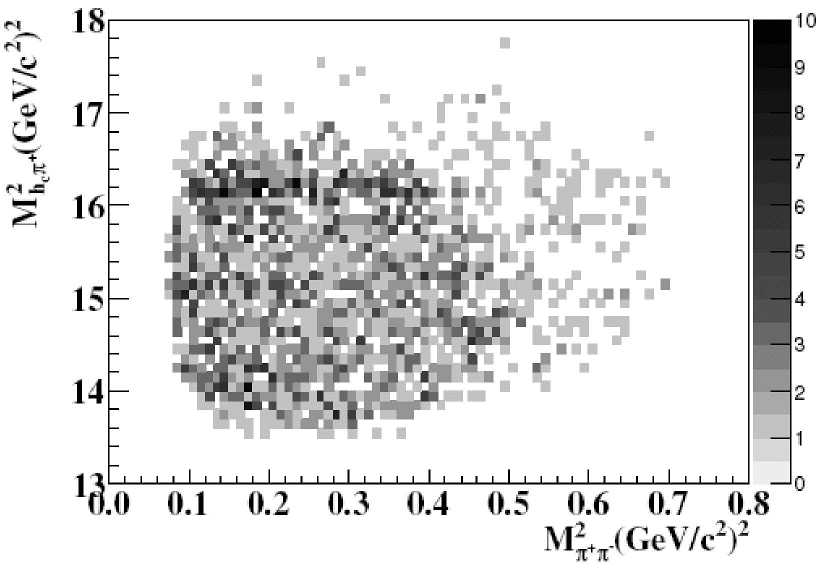
Spin-flip **No spin-flip**

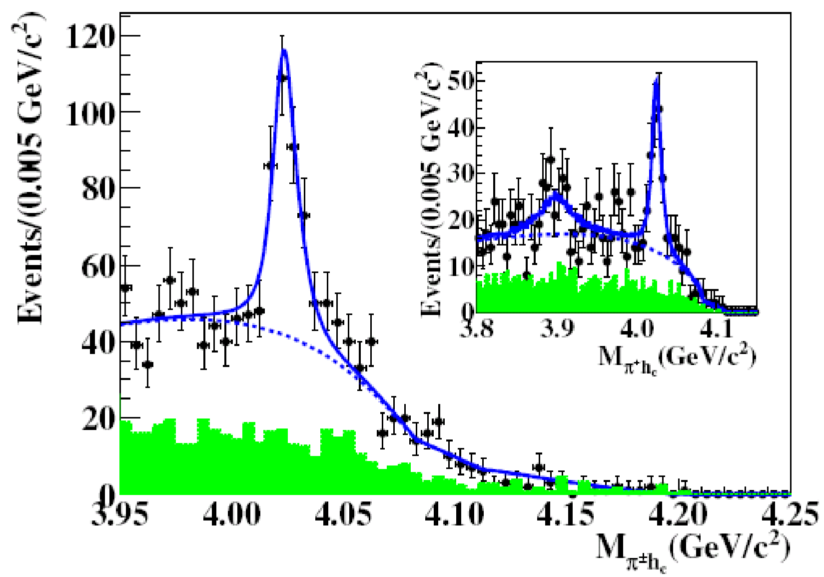
Process with spin-flip of heavy quark is not suppressed.

Mechanism of $\pi^+\pi^- h_c$ production is exotic!
Study of the substructure is motivated !

$Z^{\pm}_c(4020)$ in $e^+e^- \to \pi^+\pi^- h_c(1P)$

- Using data taken at 4.23 GeV, 4.26 GeV 4.36 GeV (total 2.4 fb^{-1})
- See structure in $h_c\pi^{\pm}$ spectrum, close to $D^*\bar{D}^*$ threshold :





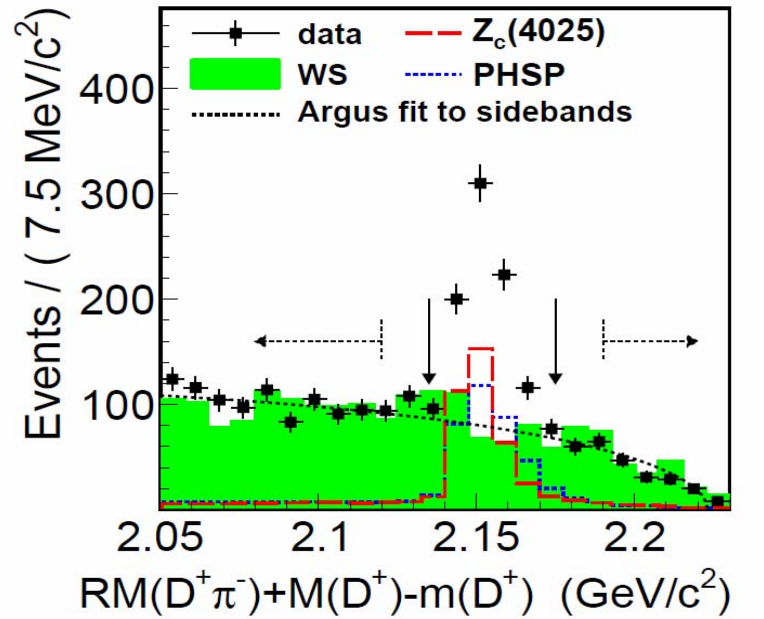
$$M(Z_c(4020)) = 4022.9 \pm 0.8 \pm 2.7\,\text{MeV}/c^2$$
$$\Gamma(Z_c(4020)) = 7.9 \pm 2.7 \pm 2.6\,\text{MeV}$$

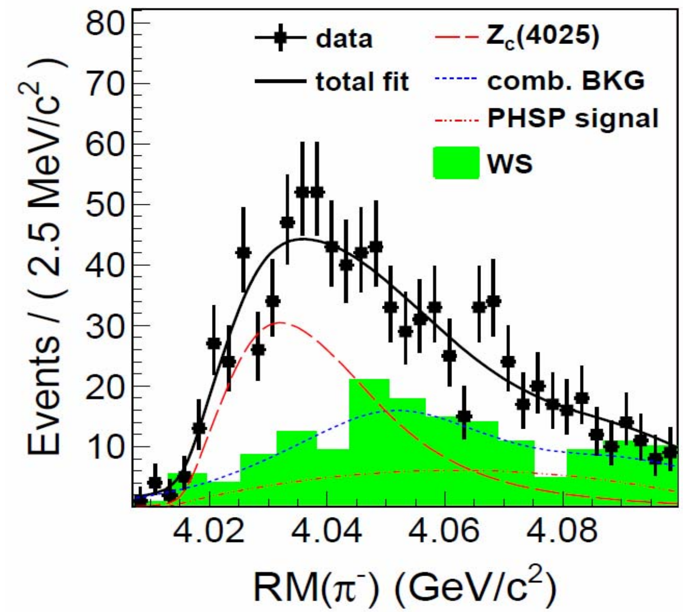
arXiv:1309.1896
submitted to PRL

No significant signal $Z_c(3900) \to h_c\pi^+$ seen **: less than 2.1 σ**

Zc(4025) in $e^+e^- \to \pi^- (D^*\underline{D}^*)^+$+c.c. @4.26 GeV

Partial reconstruction technique: reconstruct D^+ from D^{*+} decay, bachelor π^-, and at least one soft π0 from $D^* \to D^0 \pi$or $D^{*+} \to D^+\pi^0$ decays .





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

The pole mass and with:

$M(Z_c(4025)) = 4026.3 \pm 2.6 \pm 3.7$ MeV; $\Gamma(Z_c(4025)) = 24.8 \pm 5.7 \pm 7.7$ MeV

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

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

arXiv:1308.2760 submitted to PRL

Summary of Z states

Channel	Mass [MeV/c^2]	Width [MeV]	
$J/\psi\,\pi^+$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	**Close to**
$(D\bar{D}^*)^+$	$3883.9 \pm 1.5 \pm 4.2$	$24.8 \pm 3.3 \pm 11.0$	**D*D* threshold=3875 MeV**
$h_c\pi^+$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	**Close to**
$(D^*\bar{D}^*)^+$	$4026.3 \pm 2.6 \pm 3.7$	$24. \pm 5.6 \pm 7.7$	**D*D* threshold=4017 MeV**

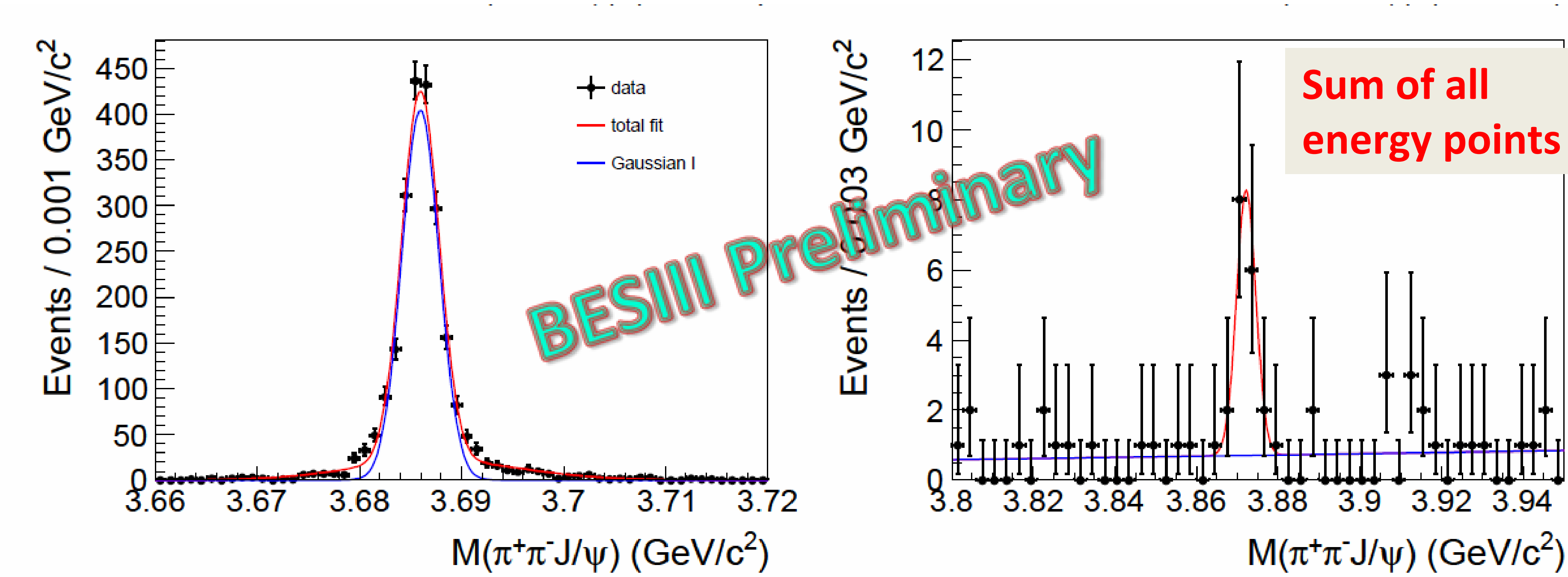
With electric charge thus has two more light quarks! ➔ Nquark $\geq$ 4 !
Clear **signature of exotic state**

Nature of these states?

- Tetraquark L. Maiani, A. Ali et al.
- Hadronic molecule U.-G. Meissner, F.K. Guo et al.
- Hadro-charmonium M. B. Voloshin
- Meson loop Q. Zhao et al.
- ISPE model X. Liu et al.
- ...

X(3872) at BESIII

Observation of $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$



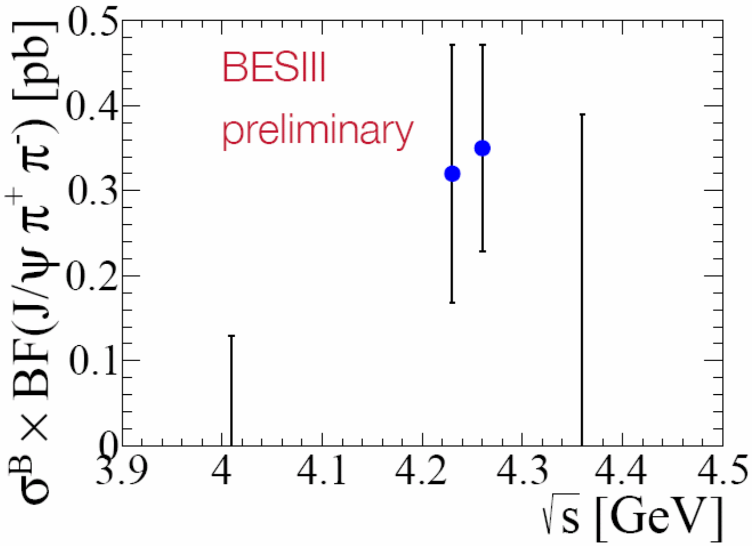
ISR ψ' signal is used for rate, mass, and mass resolution calibration.

$N(\psi')$=1242 ; Mass=3685.96±0.05 MeV; σ_M=1.84 ±0.06 MeV

N(X(3872))=15.0±3.9 **5.3σ**

M(X(3872)) = 3872.1±0.8±0.3 MeV [PDG: 3871.68 ±0.17 MeV]

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



$\sqrt{s}$ [GeV]	$\sigma^B \times \mathcal{B}$ [pb]
4.01	< 0.13
4.23	$0.32 \pm 0.15 \pm 0.02$
4.26	$0.35 \pm 0.12 \pm 0.02$
4.36	< 0.39

It seems X(3872) is from Y(4260) decays. At 4.26 GeV,
$\sigma^B(e^+e^- \to \pi^+\pi^- J/\psi) = (62.9 \pm 1.9 \pm 3.7)$ pb,

$$\frac{\sigma[e^+e^- \to \gamma X(3872)] \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} = (5.6 \pm 2.0) \times 10^{-3}$$

If we take $\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) \sim 5\%$, (>2.6% in PDG)

$\frac{\sigma(e^+e^- \to \gamma X(3872))}{\sigma(e^+e^- \to \pi^+\pi^- J/\psi)} \sim 11.2\%$ Large transition ratio !

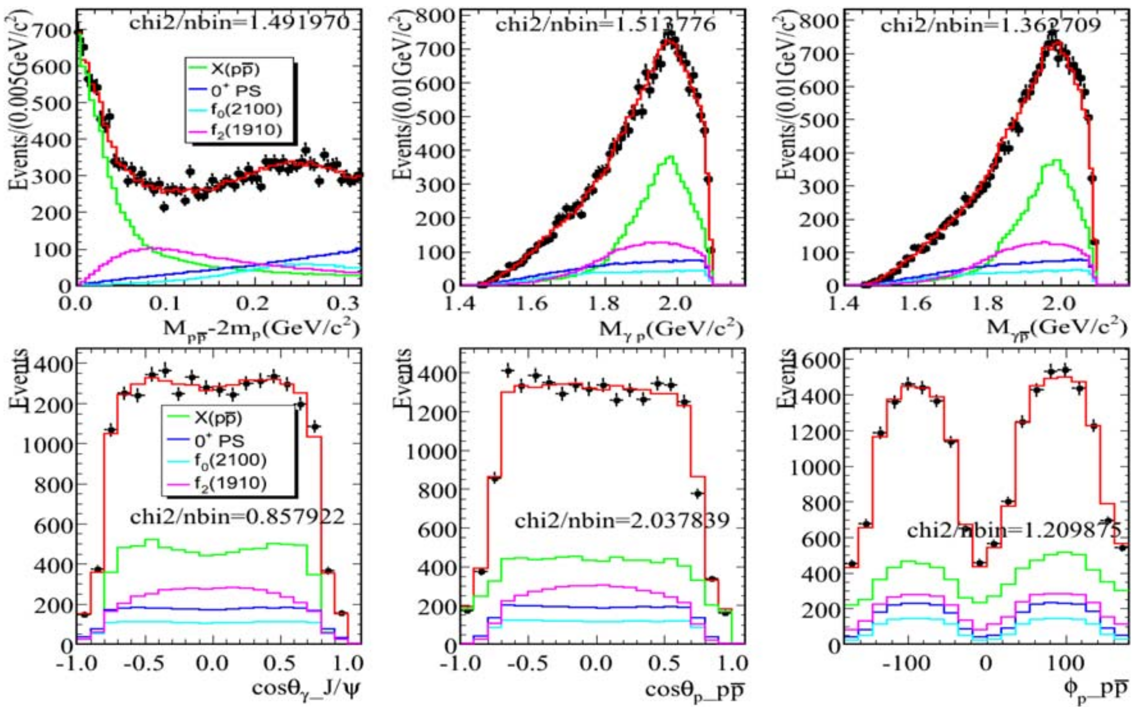
LP2013, C. Z. Yuan

Light hadron spectroscopy

-- from charmonium decays

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

BESIII: PRL 108, 112003 (2012)



$f_0(2100)$ / $f_2(1910)$ fixed to PDG.
Sig. of X(ppbar) >>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.

$$J^{PC} = 0^{-+}$$

$$M = 1832^{+10}_{-5}(\text{stat.})^{+18}_{-17}(\text{syst.}) \pm 19(\text{model})\ \text{MeV}/c^2$$

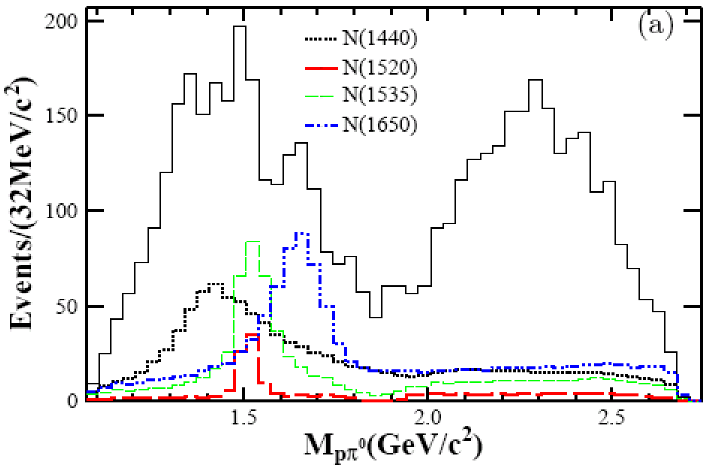
$$\Gamma = 13 \pm 39(\text{stat.})^{+10}_{-13}(\text{syst.}) \pm 4(\text{model})\ \text{MeV}/c^2 (\Gamma < 60\text{MeV}/c^2\ @\ 90\text{C.L.})$$

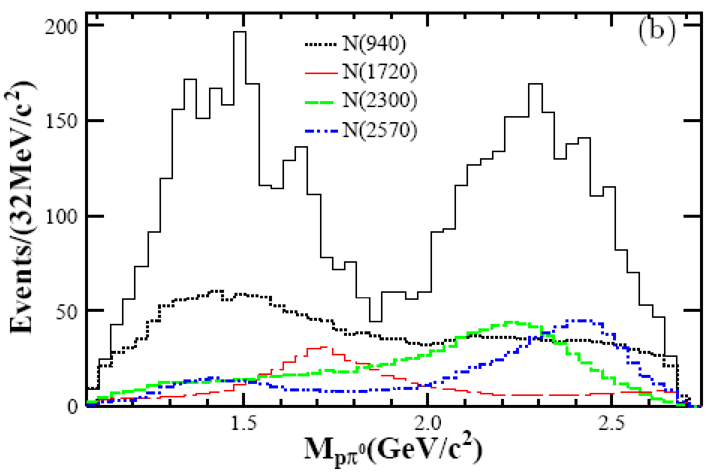
$$Br(J/\psi \to \gamma X)Br(X \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(\text{stat.})^{+1.5}_{-5.0}(\text{syst.}) \pm 2.3(\text{model})) \times 10^{-5}$$

Different FSI models → Model dependent uncertainty

N* resonances in ψ(2S)→$p\bar{p}\pi^0$ decays

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

Best solution:

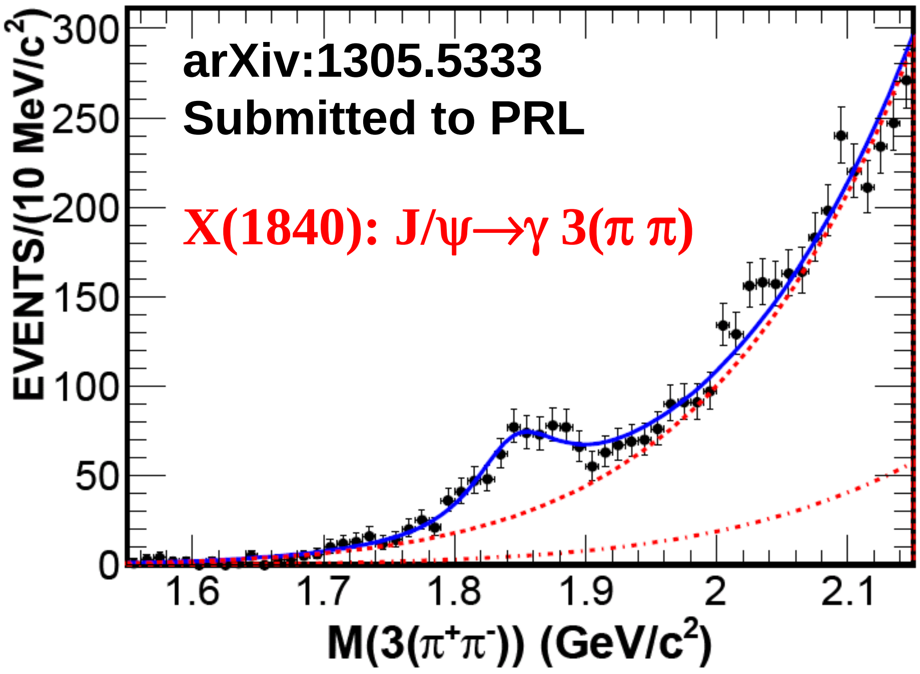
Resonance	N	$\epsilon(\%)$	B.F.$(\times 10^{-5})$
$N(940)$	$1870^{+90+487}_{-90-327}$	27.5 ± 0.4	$6.42^{+0.20+1.78}_{-0.20-1.28}$
$N(1440)$	$1060^{+90+459}_{-90-227}$	27.9 ± 0.4	$3.58^{+0.25+1.59}_{-0.25-0.84}$
$N(1520)$	190^{+14+64}_{-14-48}	28.0 ± 0.4	$0.64^{+0.05+0.22}_{-0.05-0.17}$
$N(1535)$	$673^{+45+263}_{-45-256}$	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	$16.5 \pm 0.3 \pm 1.5$

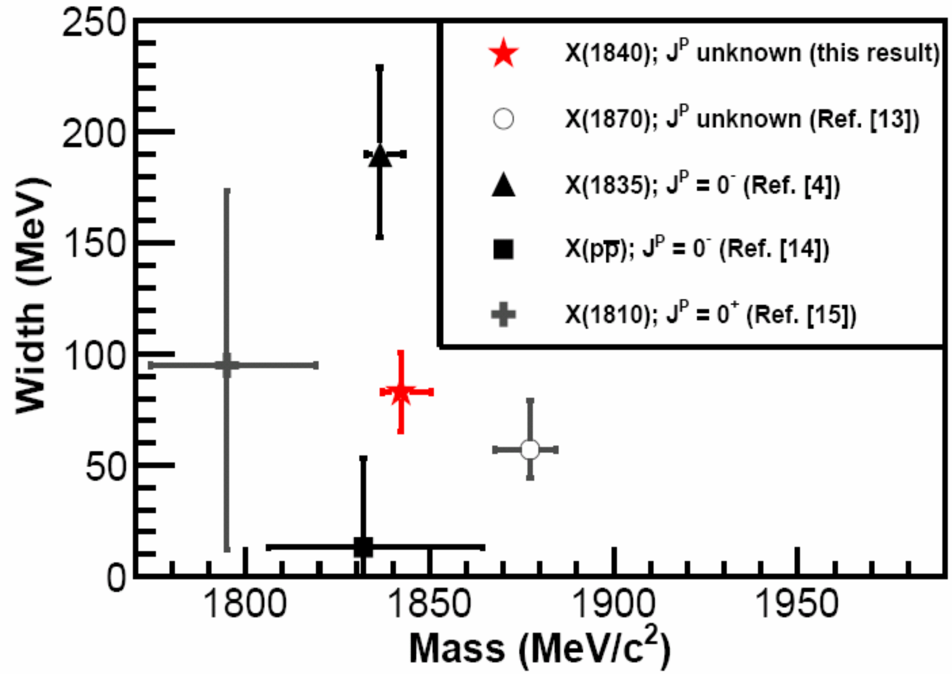
Two new baryonic excited states are observed !

$N(2300)\,[\frac{1}{2}^+]$

$N(2570)\,[\frac{5}{2}^-]$

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





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

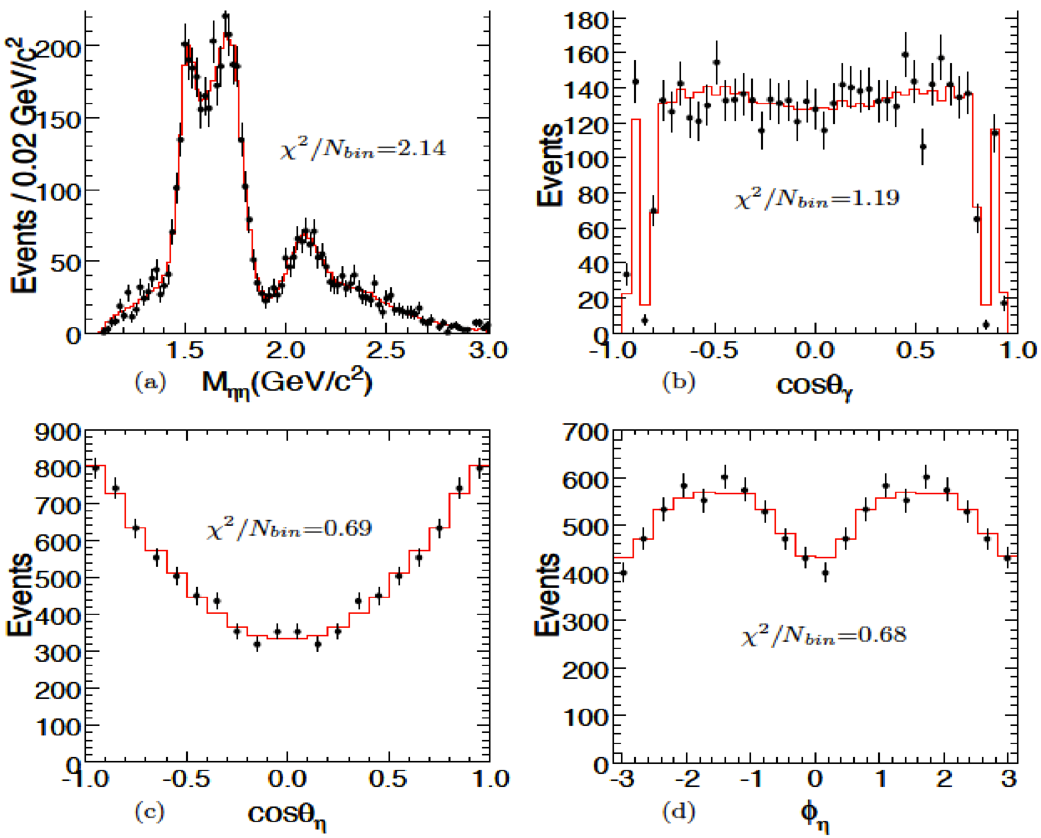
Observations at BESIII with 225M J/ψ decays:

- ★ $J/\psi \to \gamma\, (3(\pi\ \pi))$ X(1840) arXiV:1305.5333
- ○ $J/\psi \to \omega\, (\eta\pi\pi)$ X(1870) PRL107, 182001
- ▲ $J/\psi \to \gamma\, (\eta'\pi\pi)$ X(1835) PRL106, 072002
- ■ $J/\psi \to \gamma$ (ppbar) X($p\bar{p}$) PRL108,112003
- + $J/\psi \to \gamma\, (\omega\phi)$ X(1810) PRD 87, 032008

PWA in J/ψ→γηη

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

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



- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists (8.2 σ)
- $f_2'(1525)$ is the dominant tensor
- $f_2(1810)$ and f2(2340) exist (6.4 and 7.6σ)
- No evidence for $f_J(2220)$

Decay rate of pure glueball from LQCD

Pure scalar-glueball rate in J/ψ radiative decays:

$$BR(J/\psi \to \gamma\, G(0^{++})) = 3.8(9)\times 10^{-3}$$

Long-Cheng Gui et al.
PRL 110 (2013) 021601

Γ_{157}	$\gamma f_0(1710) \to \gamma K \overline{K}$	$(8.5\ ^{+1.2}_{-0.9}) \times 10^{-4}$	S=1.2
Γ_{158}	$\gamma f_0(1710) \to \gamma \pi \pi$	$(4.0\ \pm 1.0) \times 10^{-4}$	
Γ_{159}	$\gamma f_0(1710) \to \gamma \omega \omega$	$(3.1\ \pm 1.0) \times 10^{-4}$	
	$\gamma f_0(1710) \to \gamma \eta \eta$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	

Pure Tensor-glueball rate in J/ψ radiative decays:

$$BR(J/\psi \to \gamma\, G(2^{++})) = 1.1(2)\times 10^{-2}$$

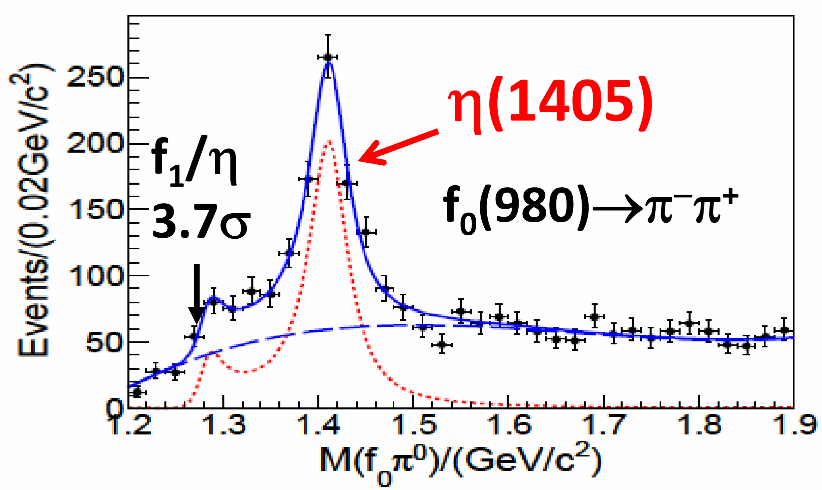
Large decay rate is predicted!

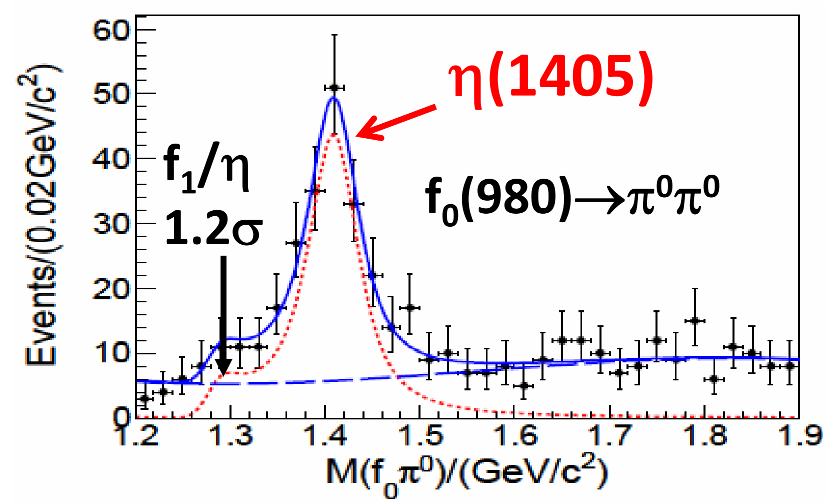
Yi-Bo Yang et al.
arXiv: 1304.3807
Submitted to PRL

Need more experimental information!

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

BESIII: PRL 108 (2012) 182001





First observation of $\eta(1405) \to f_0(980)\pi^0$ (isospin violated decays) and $J/\psi \to \gamma f_0(980)\pi^0$

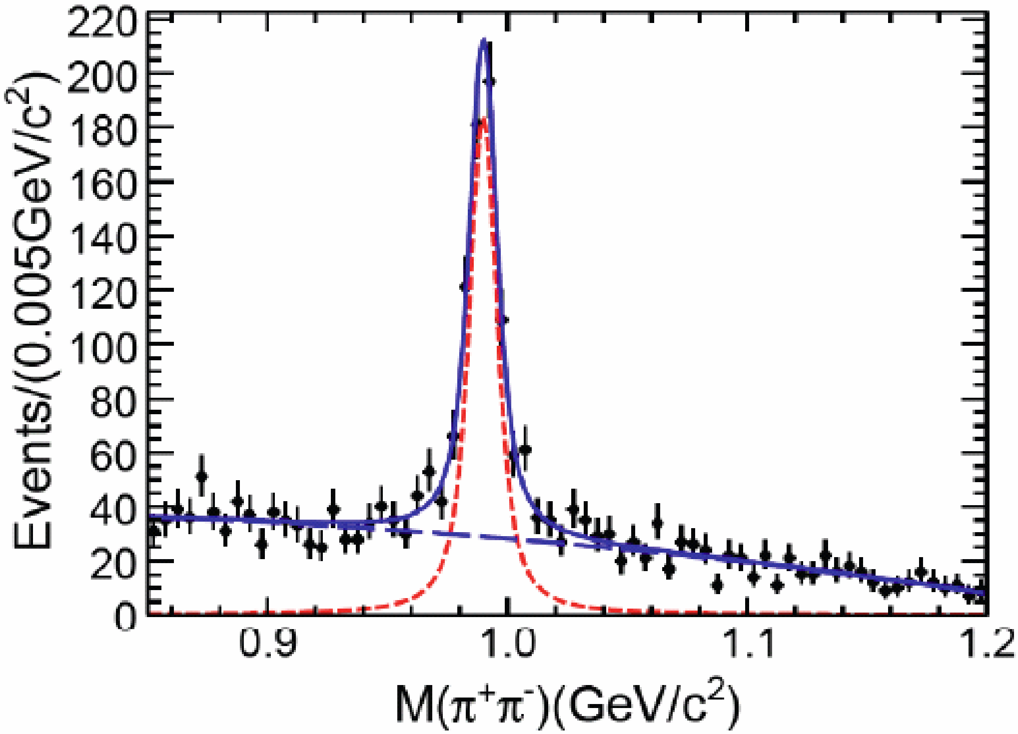
$$Br(J/\psi \to \gamma\eta(1405) \to \gamma f_0\pi^0 \to \gamma\pi^0\pi^+\pi^-) = (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}$$

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

Anomalous $f_0(980)$ lineshape in $\eta(1405) \rightarrow f_0(980)\pi^0$

Very narrow $f_0(980)$ – much narrower than PDG value!

BESIII arXiv:1201:2737



Fitted mass:

$M_{"f_0"}$ = 989.9 ± 0.4 MeV

$\Gamma_{"f_0"}$ = 9.5 ± 1.1 MeV

The peak is midway between $2m_{K^0}$ & $2m_{K^+}$ & width ≈ $2(m_{K^0} - m_{K^+})$

PDG2010:

M_{f_0}= 980 ± 10 MeV

Γ_{f_0}=40 ~ 100 MeV

Possible explanation: J.J.Wu et al, PRL 108, 081803(2012) effect of Triangle Singularity!

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

BESIII: PRL 108 (2012) 182001

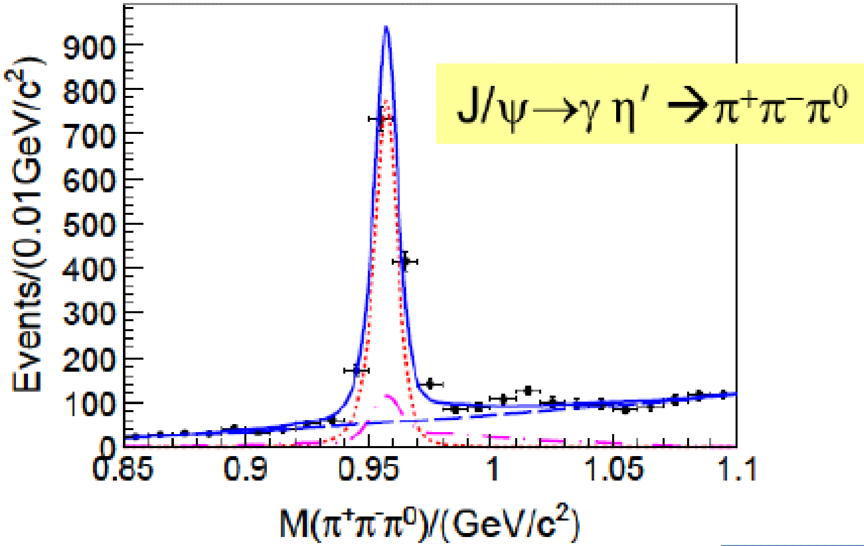
In general, magnitude of isospin violation in strong decay should be less than 1% or at 0.1% level. For example:

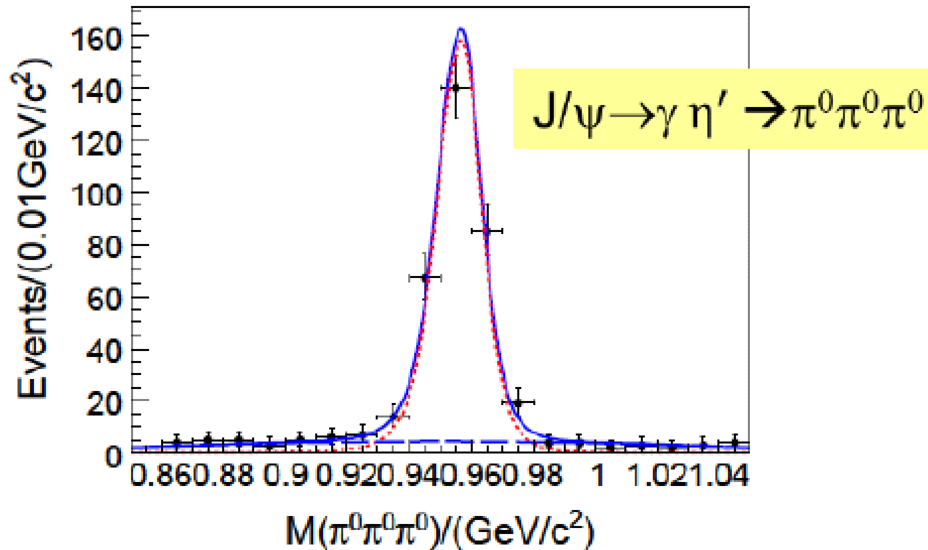
$$\frac{BR(\psi'\to\pi^0 J/\psi)}{BR(\psi'\to\eta J/\psi)} = 0.2\times10^{-2}\times\frac{|P_\pi|^3}{|P_\eta|^3},\quad \frac{BR(\eta'\to\pi^+\pi^-\pi^0)}{BR(\eta'\to\pi^+\pi^-\eta)} = 0.9\%$$

However:

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

$\eta' \to 3\pi$ in $J/\psi \to \gamma\pi\pi\pi$





PRL 108, 182001 (2012)

New results:

$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ (PDG2010: $(3.6^{+1.1}_{-0.93}) \times 10^{-3}$)

$Br(\eta' \to \pi^0\pi^0\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$ (PDG2010: $(1.68 \pm 0.22) \times 10^{-3}$)

For the decay $\eta' \to \pi^0\pi^0\pi^0$, it is two times larger than the world average value.

Comparison: Isospin violations in $\eta' \to \pi\pi\pi$:

$$\frac{BR(\eta' \to \pi^+\pi^-\pi^0)}{BR(\eta' \to \pi^+\pi^-\eta)} \approx 0.9\%, \quad \frac{BR(\eta' \to \pi^0\pi^0\pi^0)}{BR(\eta' \to \pi^0\pi^0\eta)} \approx 1.6\%$$

Results on η/η' physics

η and η' decays are the perfect lab to **See Chritoph Redmer's talk**

- test symmetries and symmetry breaking in QCD at low energies
- search for physics beyond the Standard Model

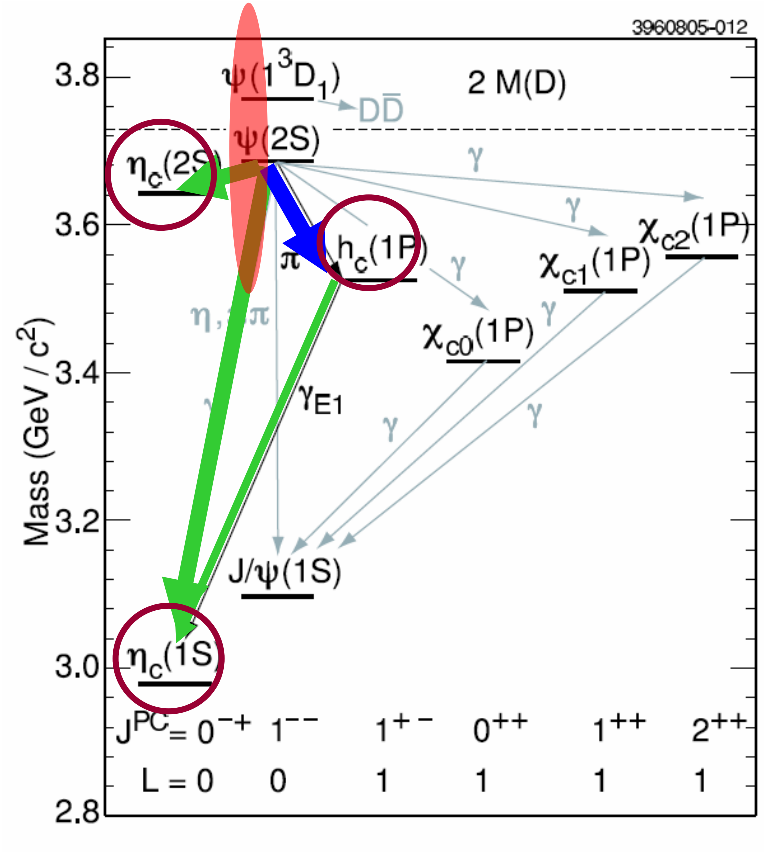
H.B. Li "η/η' physics at BESIII" *J. Phys. G: Nucl. Part. Phys.* 36 085009 (2009)

- Matrix element for $\eta'\to\pi^+\pi^-\eta$ — Phys. Rev. D83, 012003, (2011)
- Search for CP violation $\eta/\eta'\to\pi^+\pi^-,\pi^0\pi^0$ — Phys. Rev. D84, 032006, (2011)
- BF measurement of $\eta'\to\pi^+\pi^-\pi^0,\pi^0\pi^0\pi^0$ — Phys. Rev. Lett 108, 182001, (2011)
- BF measurement of $\eta'\to\pi^+\pi^-e^+e^-,\pi^+\pi^-\mu^+\mu^-$ — Phys. Rev. D87, 092001, (2013)
- Search for η/η' invisible decays — Phys. Rev. D87, 012009, (2013)
- Search for η/η' weak decays — Phys. Rev. D87, 032006, (2013)

On going analyses at BESIII :

Observation $\eta'\to\pi^+\pi^-\pi^+\pi^-$
Observation of $\eta'\to\gamma\gamma\pi^0$
Observation of $\eta'\to\gamma e^+e^-$, $\eta\to\pi^0$e+e-
Study of $\eta'\to\gamma\,\pi^+\pi^-$ …

Charmonium states
ψ’, $h_c(^1P_1)$, $\eta_c(1S)$, $\eta_c(2S)$



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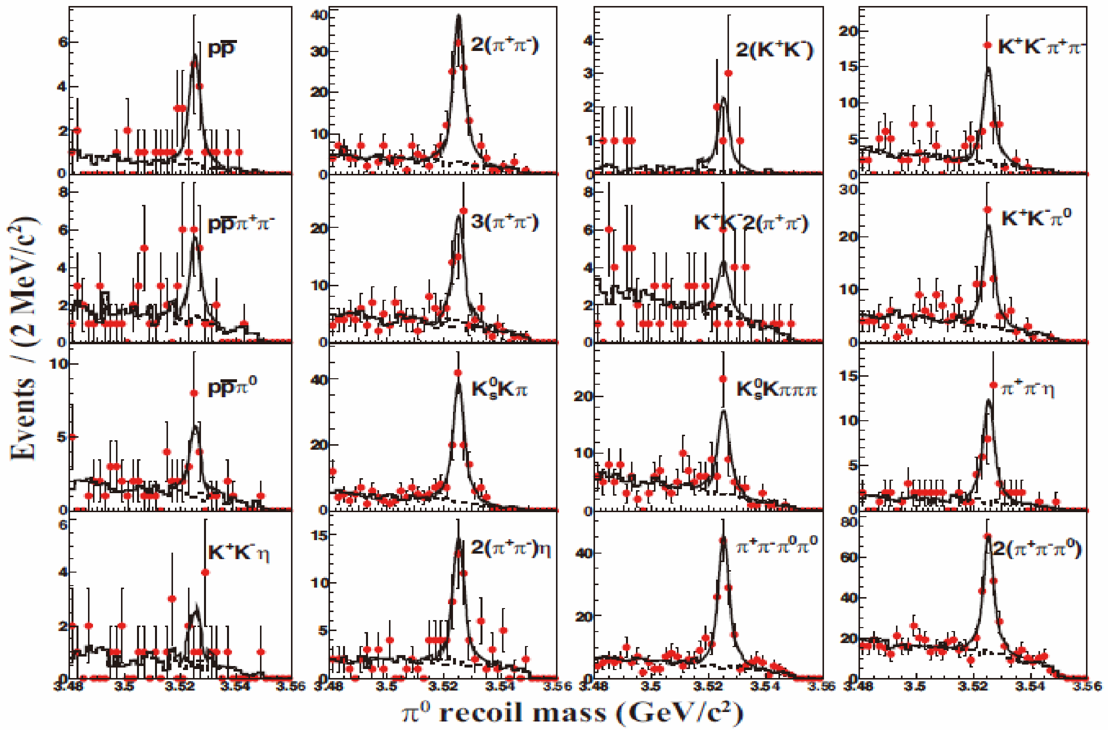
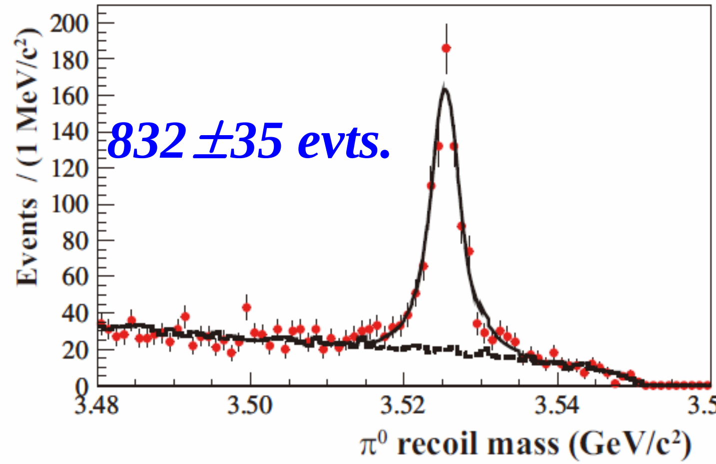
$\psi' \to \pi^0 h_c$, $h_c \to \gamma\eta_c$, η_c exclusive decays



BESIII: PRD 86, 092009 (2012)

Summed distribution



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

Mass = 3525.31±0.11±0.14 MeV/c^2

Width = 0.70±0.28±0.22 MeV/c^2

CLEOc exclusive results

Mass =3525.21±0.27±0.14 MeV/c^2

evts. =136±14 CLEOc: PRL 101 182003 (2008)

Hyperfine mass splitting :

DMhf(1P)= M(hc) - <m(1 ^3P_J)>

BESIII: 0.01±0.11±0.14 MeV/c^2

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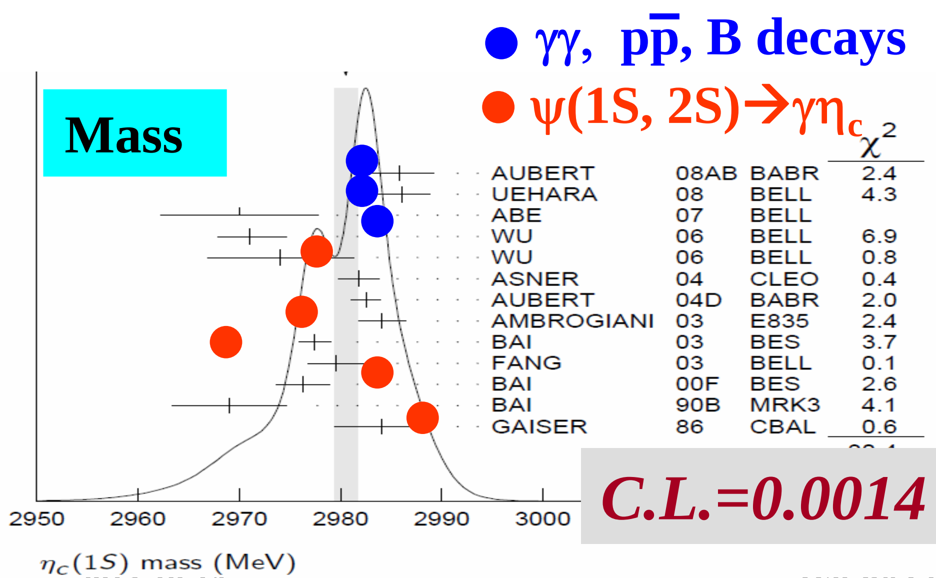
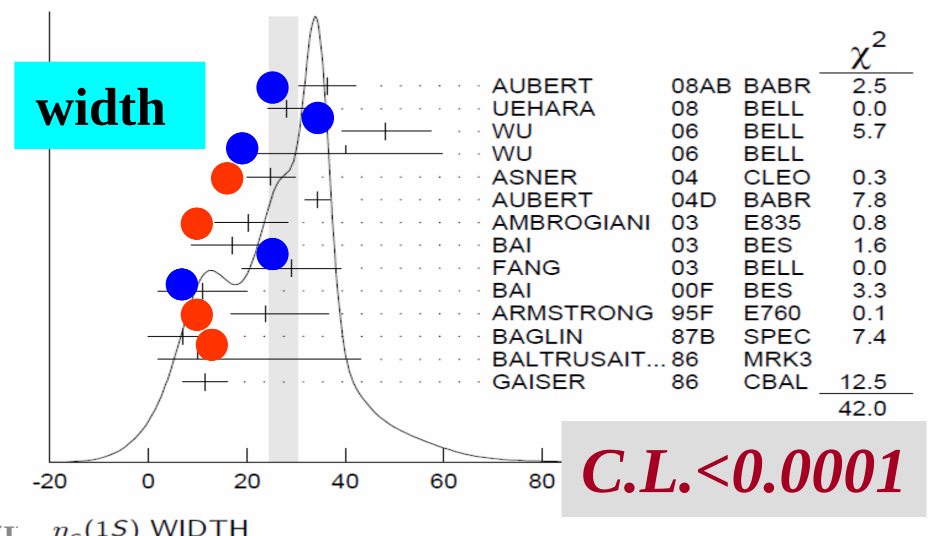
$\eta_c(1S)$

- **The lowest lying S-wave spin singlet charmonium, discovered in 1980 by MarkII. Properties not well known.**
- **J/ψ radiative transition: M ~ 2978.0MeV/c^2, Γ ~ 10MeV**
  $\gamma\gamma$ 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.**
- **$c\bar{c}$ hyperfine splitting M(J/ψ)-M(η_c(1S)) is the important exp. input to test LQCD, but is dominated by error on M(η_c(1S)).**

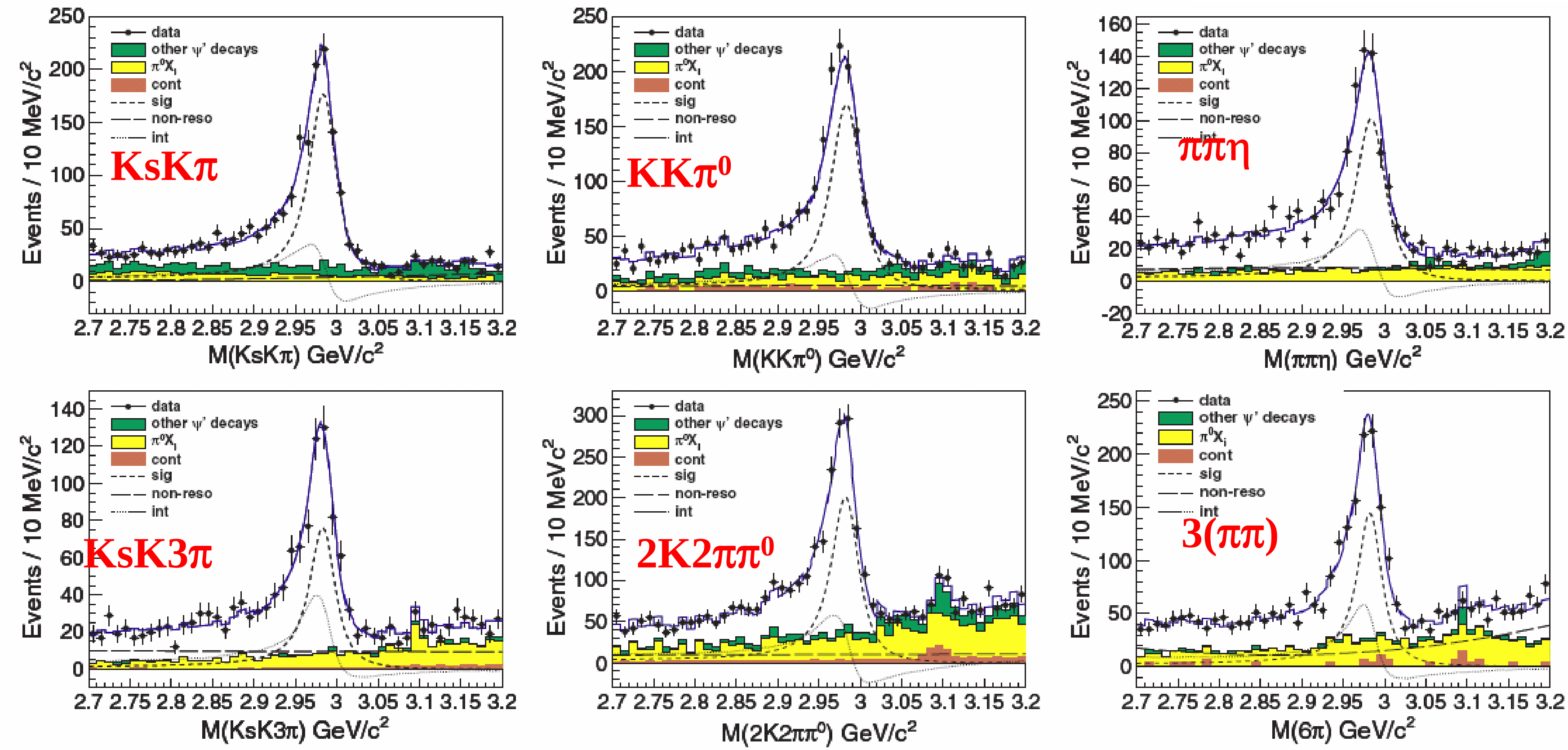




η_c resonance parameters from $\psi' \to \gamma\eta_c$ at BESIII

Possible interference has been taken into account

PRL 108 (2012) 222002



mass: $2984.3 \pm 0.6_{stat} \pm 0.6_{sys}$ MeV/c^2
width: $32.0 \pm 1.2_{stat} \pm 1.0_{sys}$ MeV

Phys.Rev.Lett. 108 (2012) 222002

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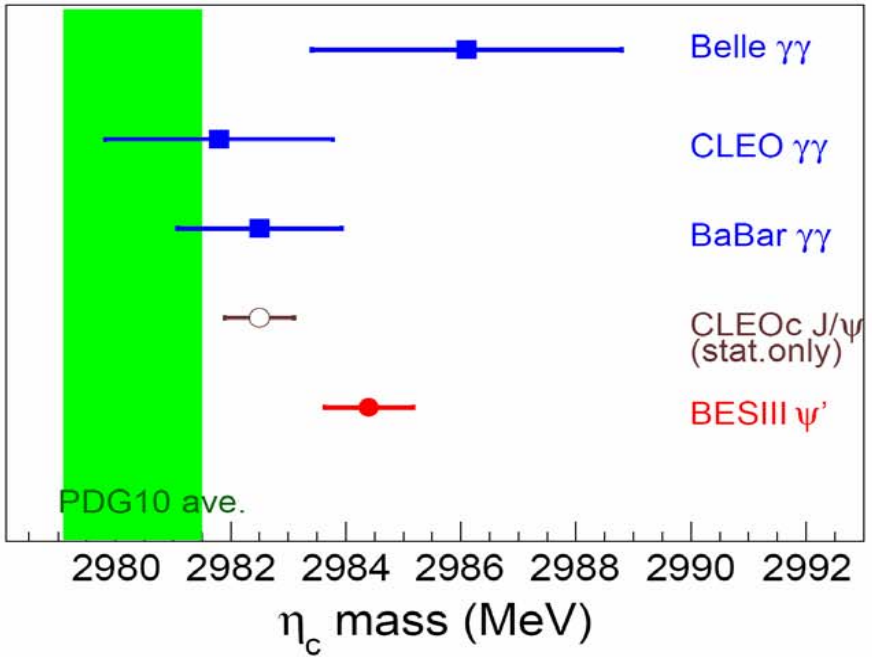
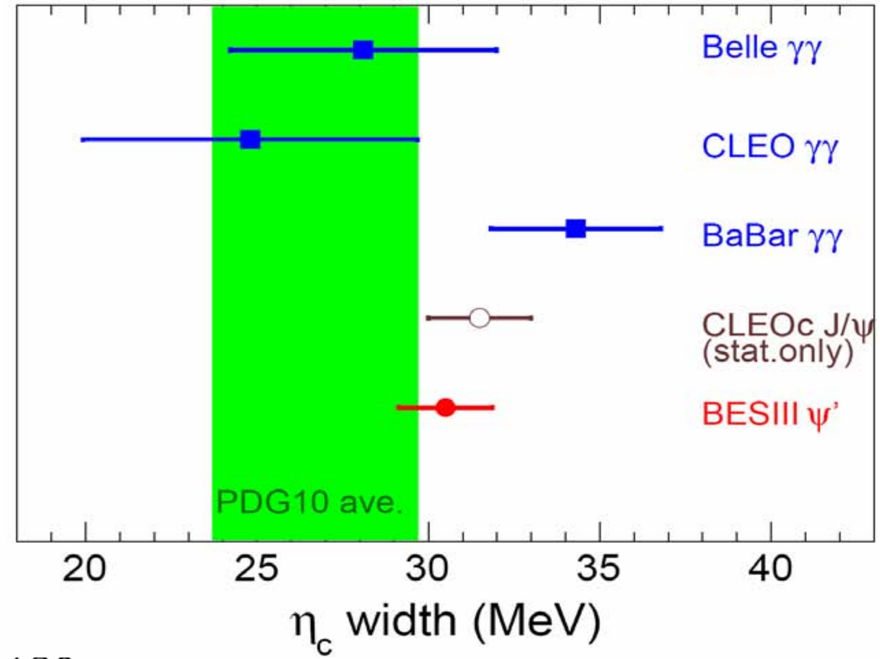
Comparison of the mass and width for $\eta_c(1S)$

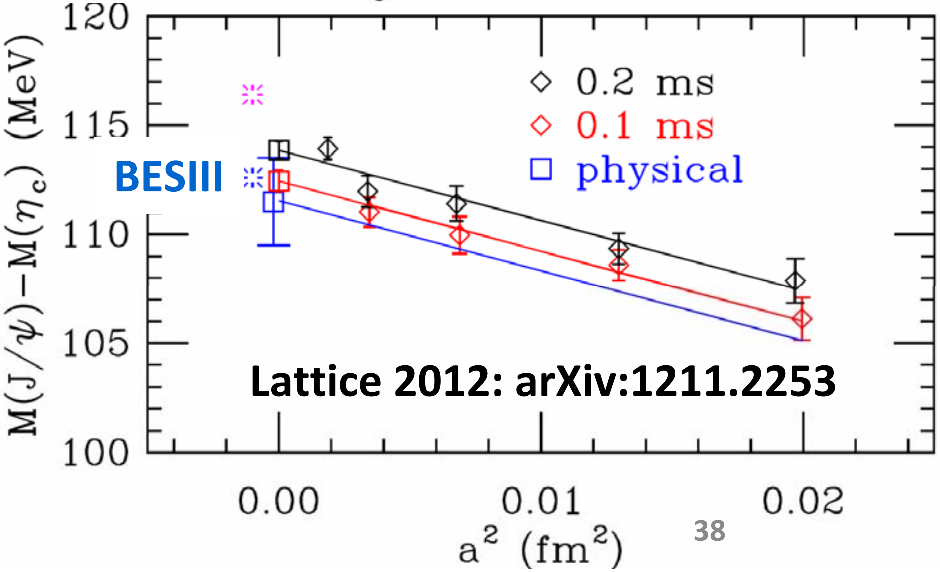




Hyperfine splitting:

$\Delta M(1S)$ = 112.6 ± 0.8 MeV

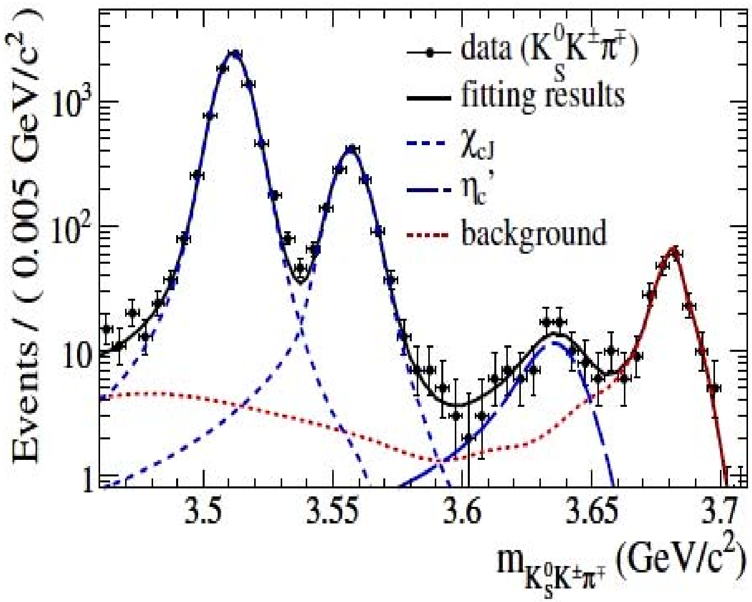
- **The most precise measurement**
- **Better agreement with LQCD calculation.**

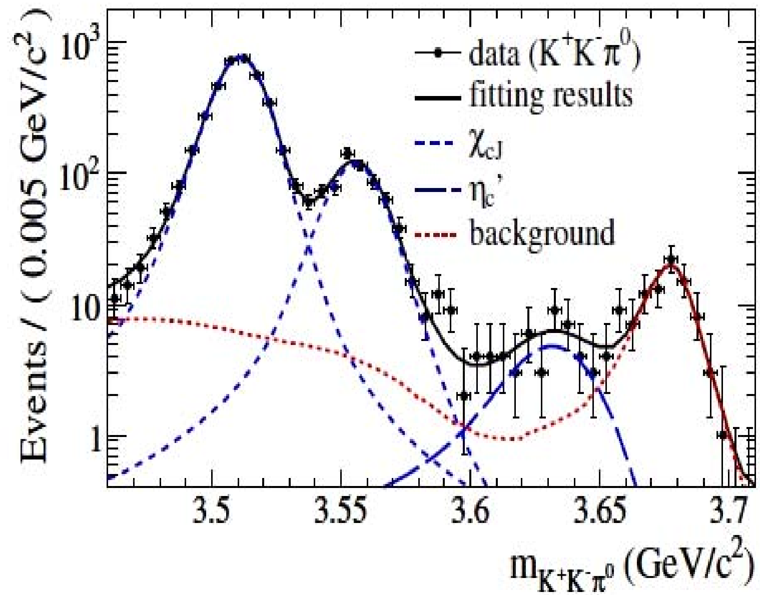


First observation of $\psi' \rightarrow \gamma\eta_c(2S)$@BESIII

Statistical significance >10 σ

BESIII: PRL109, 042003 (2012)





- **Observed signal in $K_sK^+\pi^-$+c.c.， found evidence in $K^+K^-\pi^0$**

Mass = 3638.5 ± 2.3 ± 1.0 MeV/c^2 $\Gamma(\eta_c') = 16.9 \pm 6.4 \pm 4.8$ MeV

- **First measured Br($\psi' \rightarrow \gamma\eta_c(2S)$)=(6.8 ± 1.1 ± 4.5) × 10^{-4}**

Potential model expectation: (0.1-6.2)×10^{-4} PRL 89 162002 (2002)

CLEOc: <7.6 × 10^{-4} PRD 81 052002 (2010)

Charm physics at BESIII

Advantage of open charm at threshold

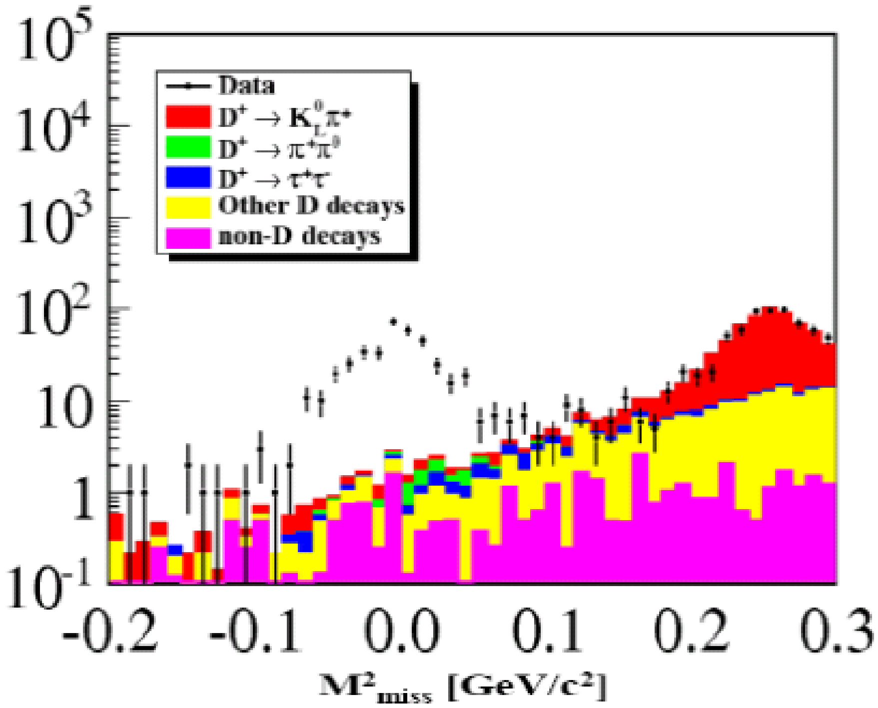
e^+e^- colliders@threshold:

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

Good for charm flavor physics:

- **Threshold production: clean**
- **Known initial energy and quantum numbers**
- **Both D and Dbar fully reconstructed (double tag)**
- **Absolute measurements**
- **Quantum correlation allow to determine the relative phase / CP violation in D decays/mixing parameters**

D^+ Leptonic Decays



BESIII Preliminary

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

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

$$f_{D^+} = (203.9 \pm 5.7 \pm 2.0)\ \text{MeV}$$

Consistent with CLEO-c

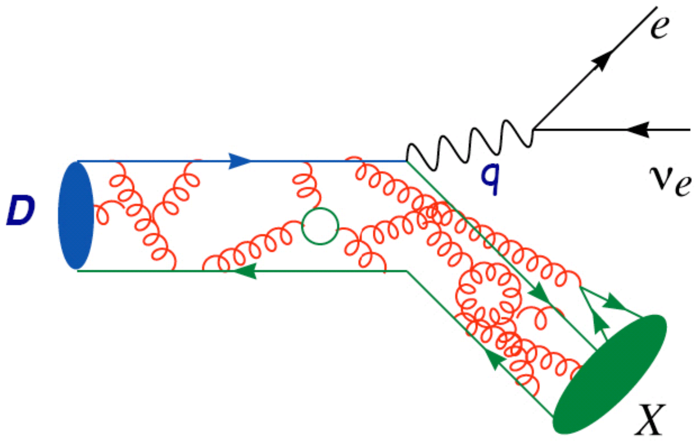
Still statistics limited – need more data!

Most precise measurement!

Experiment	$\mathcal{B}(D \to \mu\nu)$	f_d
BES III (preliminary)	$(3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$	$(203.91 \pm 5.72 \pm 1.97)$ MeV
CLEO-c	$(3.82 \pm 0.32 \pm 0.09) \times 10^{-4}$	$(205.8 \pm 8.5 \pm 2.5)$ MeV
Average	$(3.76 \pm 0.18) \times 10^{-4}$	(204.5 ± 5.0) MeV

The error is still dominated by statistics, more data at threshold is needed.

Semileptonic D decay



- Decay rate depends on kinematics and V_{CKM}
- Form factor encapsulates QCD bound-state effects
- Consider Pseudoscalar final states: K, π

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

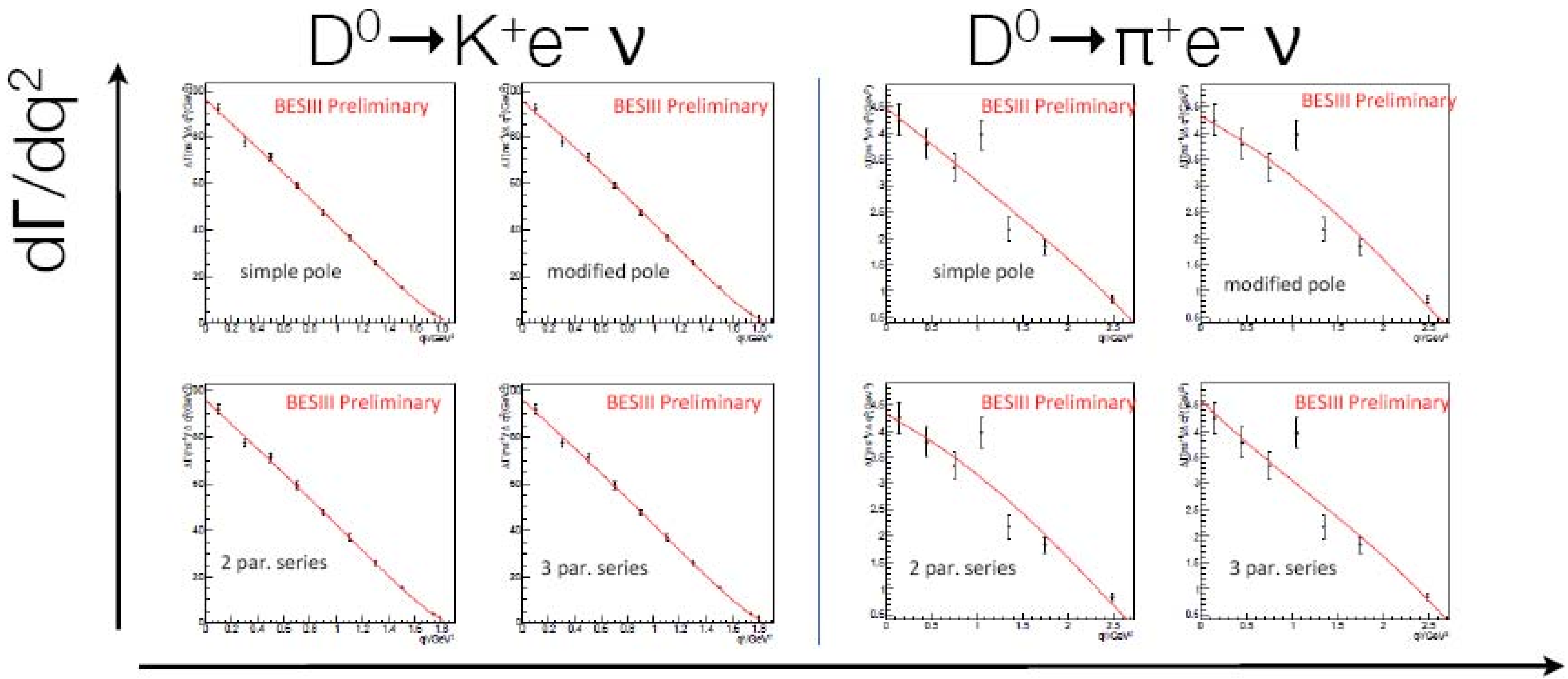
$$q^2 = (p_D - p_X)^2$$
$$= M_D^2 + M_X^2 - 2E_X M_D + 2\vec{p}_D \cdot \vec{p}_X$$

Precise measurement of $|V_{cx}|^2 \times f_+(q^2)$, get Vcx from CKM unitarity to extract form factor as test of Lattice QCD- or reverse the logic and test of CKM unitarity.

$D^0 \to \{K,\pi\}\, e^+ \nu$ fits to decay rates

BES III 2012 (prelim)

$d\Gamma/dq^2$: BES III data with fits using different form factor models



q^2/GeV^2

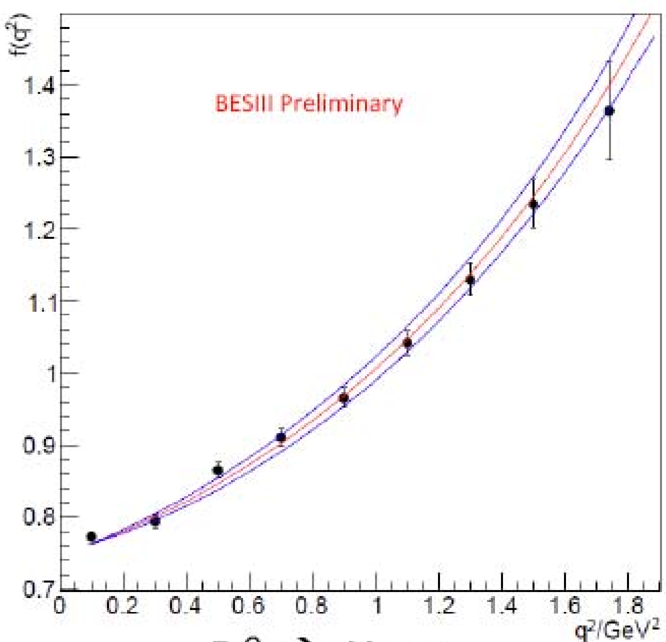
BES III: CHARM 2012 by Chunlei Liu

One third of total data@ψ(3770)

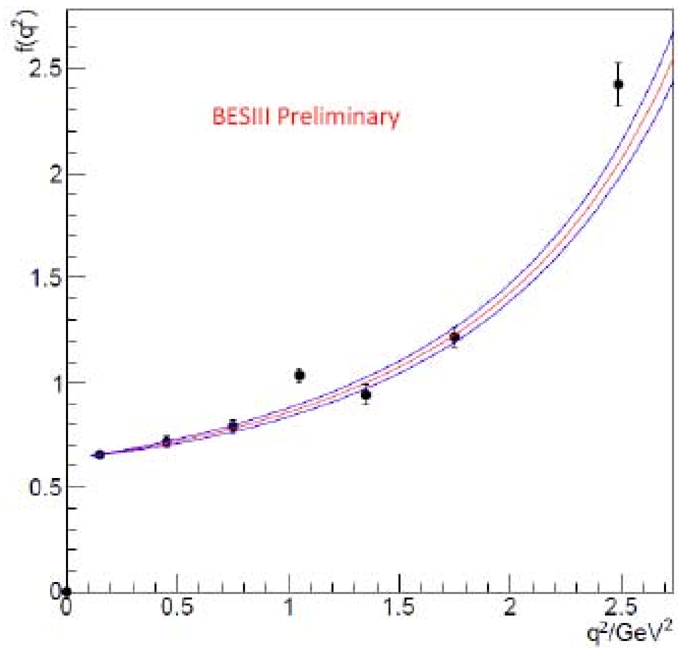
BES III 2012 (prelim)
Fermilab/The Lattice/MILC 2011

Form factor shapes: BES III / LQCD

note: these compare shape-only, no absolute scale.



$D^0 \rightarrow K e \nu$



$D^0 \rightarrow \pi e \nu$

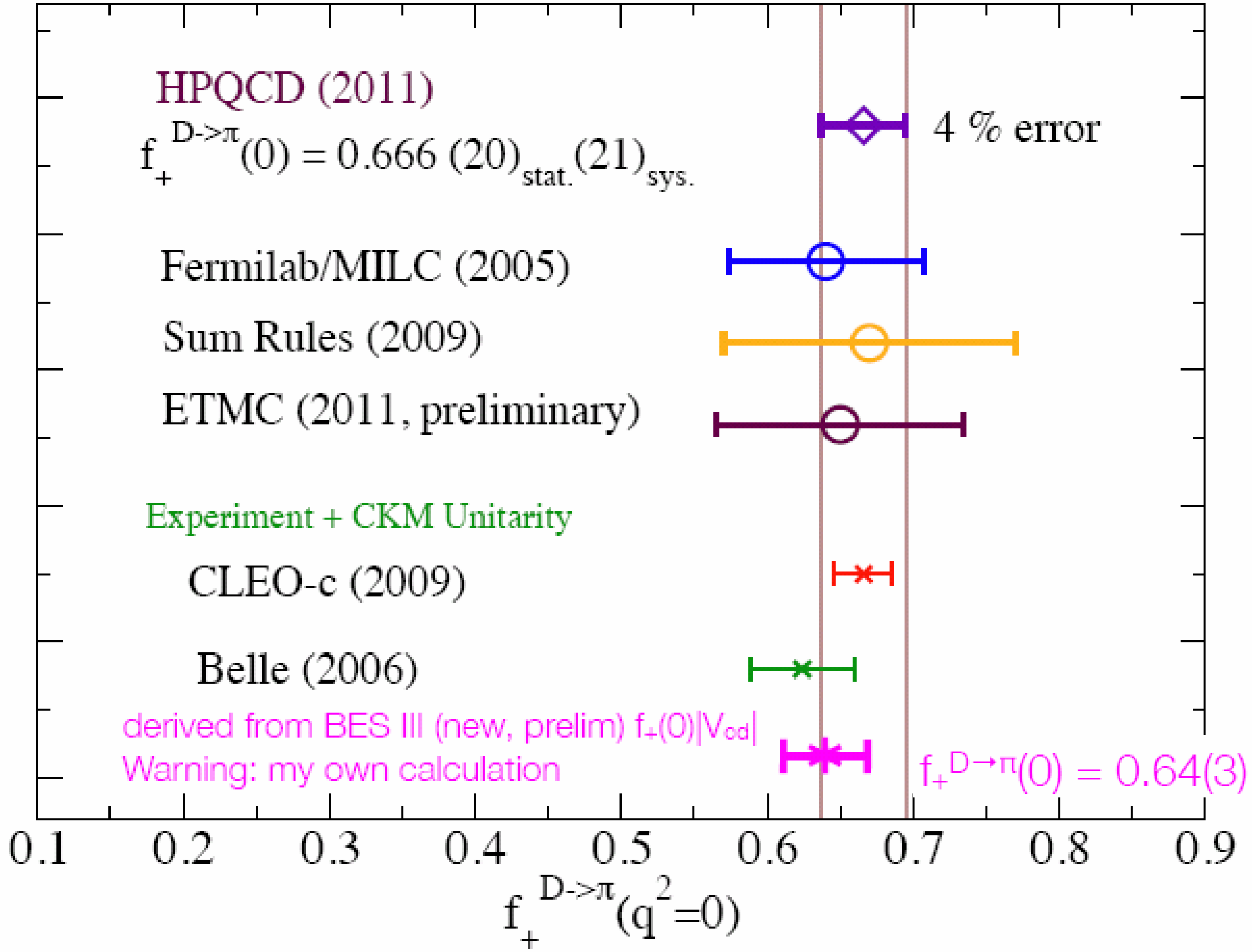
Points: BES III preliminary with stat errors
Curves: Fermilab/The Lattice/MILC with 1σ stat error band, arXiv:1111.5471 (Nov 2011)

BES III: CHARM 2012 by Chunlei Liu

One third of total data@ψ(3770)

$f_+^{D\to\pi}(0)$ from experiment and theory

Taken from Na, Davies, Follana, Koponen, Lepage and Shigemitsu, Phys.Rev. D84 (2011) 114505 and modified (added BES III)

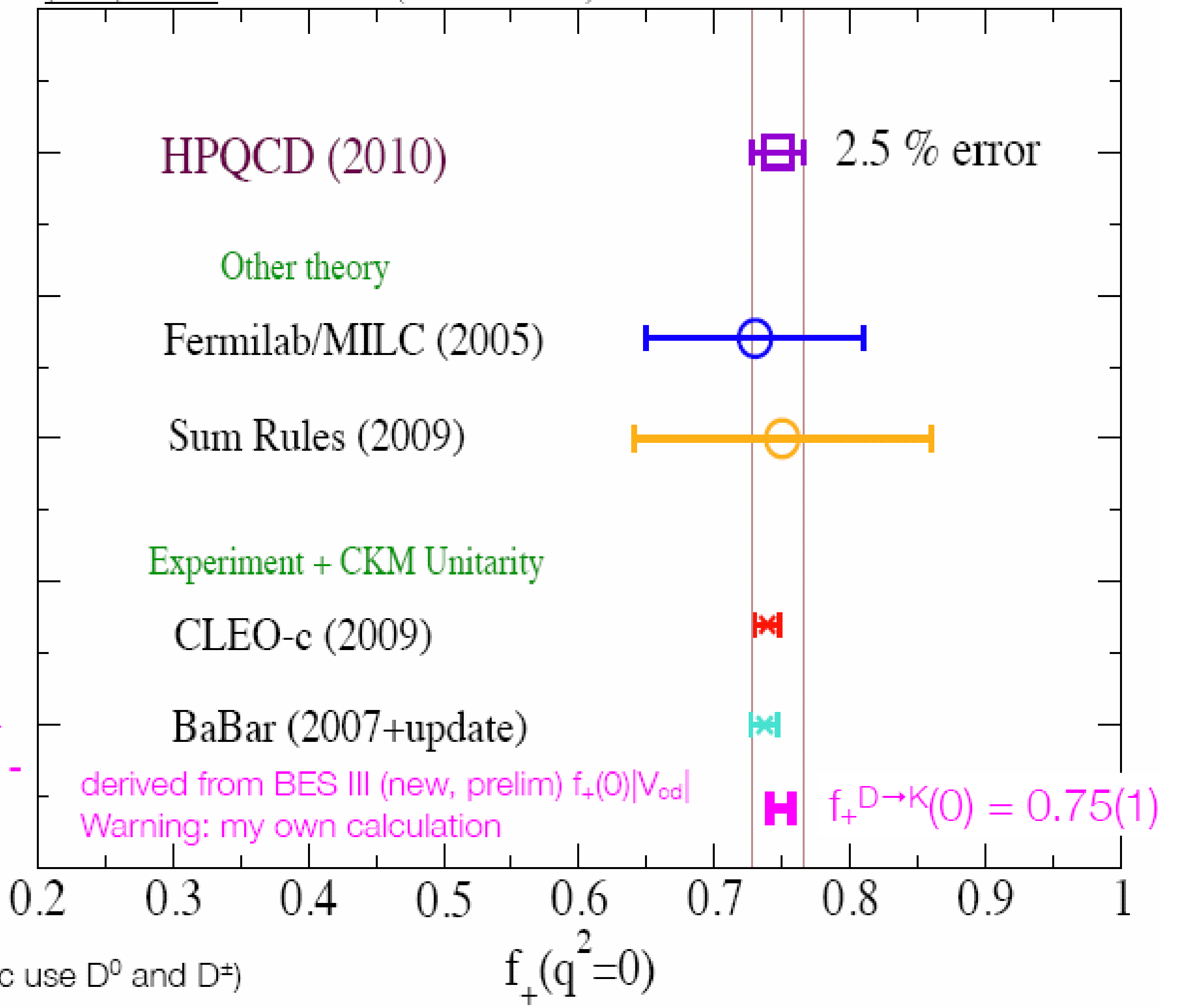


With $|V_{cd}| = 0.2252 \pm 0.0007$, I get from BES III new result (3 par series - as used by CLEO-c):

(note: BES III result from D^0 only, CLEO-c use D^0 and $D^\pm$)

$f_+^{D\to K}(0)$ from experiment and theory

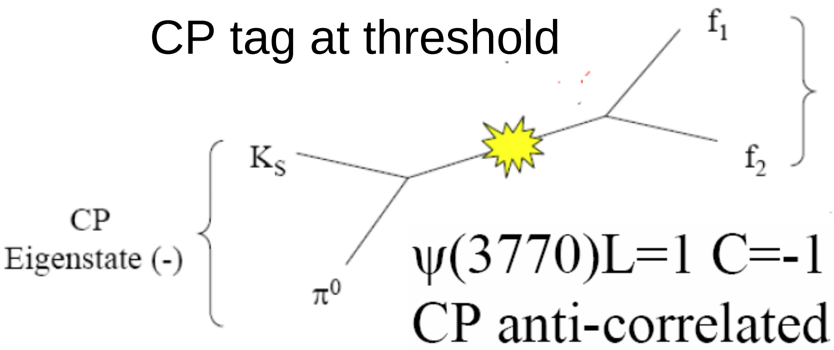
Taken from Na, Davies, Follana, Koponen, Lepage and Shigemitsu, Phys.Rev. D82 (2010) 114506 and modified (added BES III)

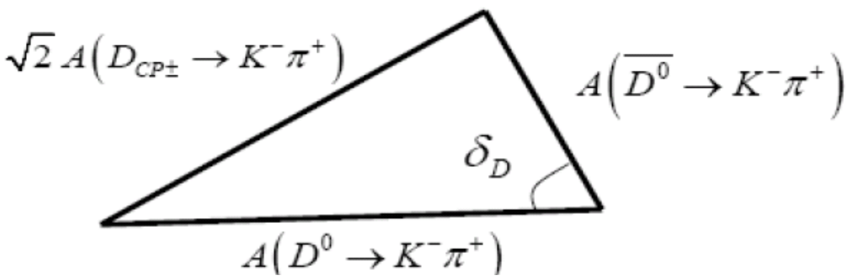


With $|V_{cs}| = 0.97345$, I get from BES III new result (3 par series - as used by CLEO-c):

(note: BES III result from D^0 only, CLEO-c use D^0 and $D^\pm$)

Access strong phase of D decay at threshold





$$\left|D_{CP\pm}\right\rangle = \frac{1}{\sqrt{2}}\left[\left|D^0\right\rangle \pm \left|\overline{D^0}\right\rangle\right]$$

The CP tagged amplitude is overlap of CF and DCS decays:

$$\sqrt{2}\,A(D_{CP\pm} \to K^-\pi^+) = A(D^0 \to K^-\pi^+) \pm A(\overline{D^0} \to K^-\pi^+)$$

Quantum correlation → Interference → access strong phase!

If CP violation in charm is neglected: mass eigenstates = CP eigenstates

$$\mathcal{A}_{CP\to K\pi} = \frac{\mathcal{B}_{D_2\to K^-\pi^+} - \mathcal{B}_{D_1\to K^-\pi^+}}{\mathcal{B}_{D_2\to K^-\pi^+} + \mathcal{B}_{D_1\to K^-\pi^+}}.$$

$$2r\boxed{\cos\delta_{K\pi}} + y = (1 + R_{\rm WS}) \cdot \mathcal{A}_{CP\to K\pi},$$

$$|D_1\rangle \equiv \frac{|D^0\rangle + |\overline{D}^0\rangle}{\sqrt{2}} \quad |D_2\rangle \equiv \frac{|D^0\rangle - |\overline{D}^0\rangle}{\sqrt{2}}.$$

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

$$A_{CP+} \equiv \langle f\,|D_1\rangle$$
$$A_{CP-} \equiv \langle f\,|D_2\rangle$$

Preliminary results of $\delta_{K\pi}$

Type	Mode
Flavored	$K^-\pi^+, K^+\pi^-$
$CP+$	$K^+K^-, \pi^+\pi^-, K_S^0\pi^0\pi^0, \pi^0\pi^0, \rho^0\pi^0$
$CP-$	$K_S^0\pi^0, K_S^0\eta, K_S^0\omega$

Based on 2.9 fb^{-1} ψ(3770) data

With external inputs of the parameters in HFAG2013 and PDG,

$$R_{\rm D} = 3.47 \pm 0.06‰,\ y = 6.6 \pm 0.9‰ \quad R_{\rm WS} = 3.80 \pm 0.05‰$$

we obtain $\cos\delta = 1.03 \pm 0.12 \pm 0.04 \pm 0.01$

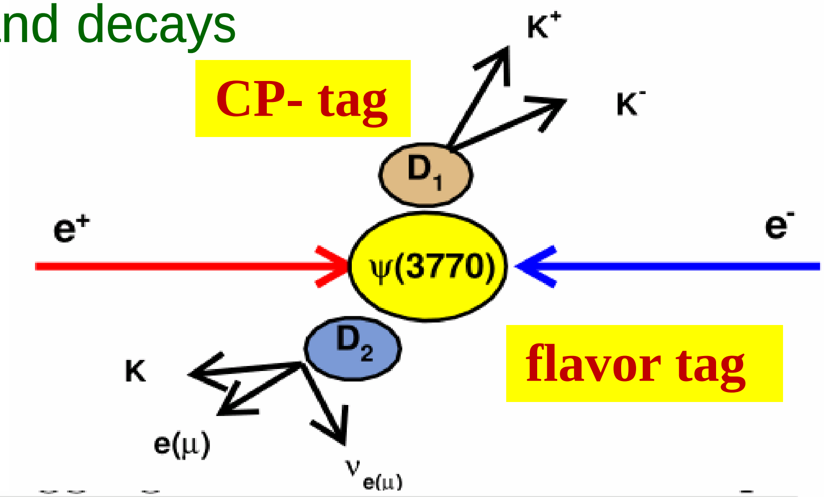
CLEO measurements of strong phase differences and coherence factors done with 0.8 fb^{-1} at ψ(3770). ***[CLEO, PRD 86 (2012) 112001]***

without external inputs: $\cos\delta = 0.81^{+0.22+0.07}_{-0.18-0.05}$,

with external inputs: $\cos\delta = 1.15^{+0.19+0.00}_{-0.17-0.08}$

Measurement of y_{CP}: CP tag and flavor tag

We measure the y_{CP} using CP-tagged semi-leptonic D decays allow to access CP asymmetry in mixing and decays



Type	Modes
CP^+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$
CP^-	$K^0_S\pi^0$, $K^0_S\omega$, $K^0_S\eta$
$l^\pm$	$Ke\nu$, $K\mu\nu$

For D decay to CP eigenstates:

$$R_{CP\pm} \propto |A_{CP\pm}|^2(1 \mp y_{CP})$$

$$y_{CP} = \frac{1}{2}[y\cos\phi(|\frac{q}{p}| + |\frac{p}{q}|) - x\sin\phi(|\frac{q}{p}| - |\frac{p}{q}|)]$$

For CP tagged semileptonic D decays:

$$R_{l,CP\pm} \propto |A_l|^2|A_{CP\pm}|^2$$

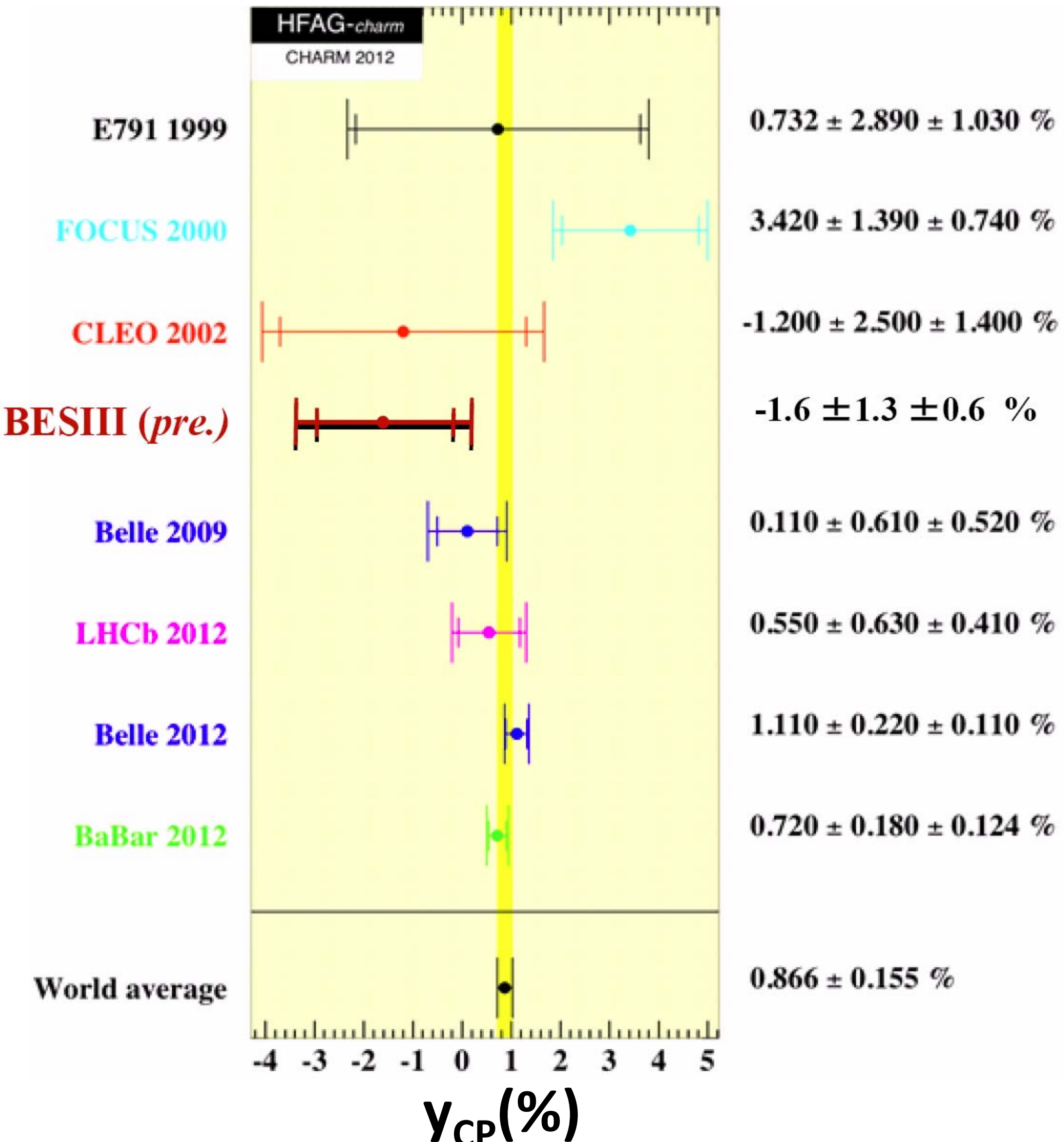
$$y_{CP} \approx \frac{1}{4}(\frac{R_{l;CP+}R_{CP-}}{R_{l;CP-}R_{CP+}} - \frac{R_{l;CP-}R_{CP+}}{R_{l;CP+}R_{CP-}})$$

Modes	N_{tag}	$N_{tag,Ke\nu}$	$N_{tag,K\mu\nu}$
K^+K^-	54307 ± 252	1216 ± 40	1093± 37
$\pi^+\pi^-$	19996 ± 177	427 ± 28	400 ± 23
$K^0_S\pi^0\pi^0$	24369 ± 231	560 ± 28	558 ± 28
$K^0_S\pi^0$	70419 ± 286	1699 ± 47	1475 ± 43
$K^0_S\omega$	21249 ± 157	473 ± 25	501 ± 26
$K^0_S\eta$	9843 ± 117	242 ± 17	237± 18

preliminary

$$y_{CP} = -1.6\% \pm 1.3\%(\text{stat.}) \pm 0.6\%(\text{syst.})$$

Comparison with world measurement



compatible with world average results

CLEOc 2012:
[PRD 86 (2012) 112001]
y_{CP}=(4.2±2.0 ±1.0)%

best precision in Charm factory

Tentative data-taking plan

- R scan data: from 3.8 to 4.6 GeV (108 energy points;
- 500/pb @ψ(4415) peak for XYZ and higher charmonium searches in E1/M1 and hadronic transitions of ψ(4415)
- Data @4.62 GeV for Λc baryon (absolute BR measurements
- More data (5/fb)@ 4170MeV for Ds physics
- More data (10/fb)@3770 MeV for D physics

Red: year: 2013-2014 (will be verified by the Collaboration meeting in Nov.)

Black: future plans need approve in the Collaboration

Summary

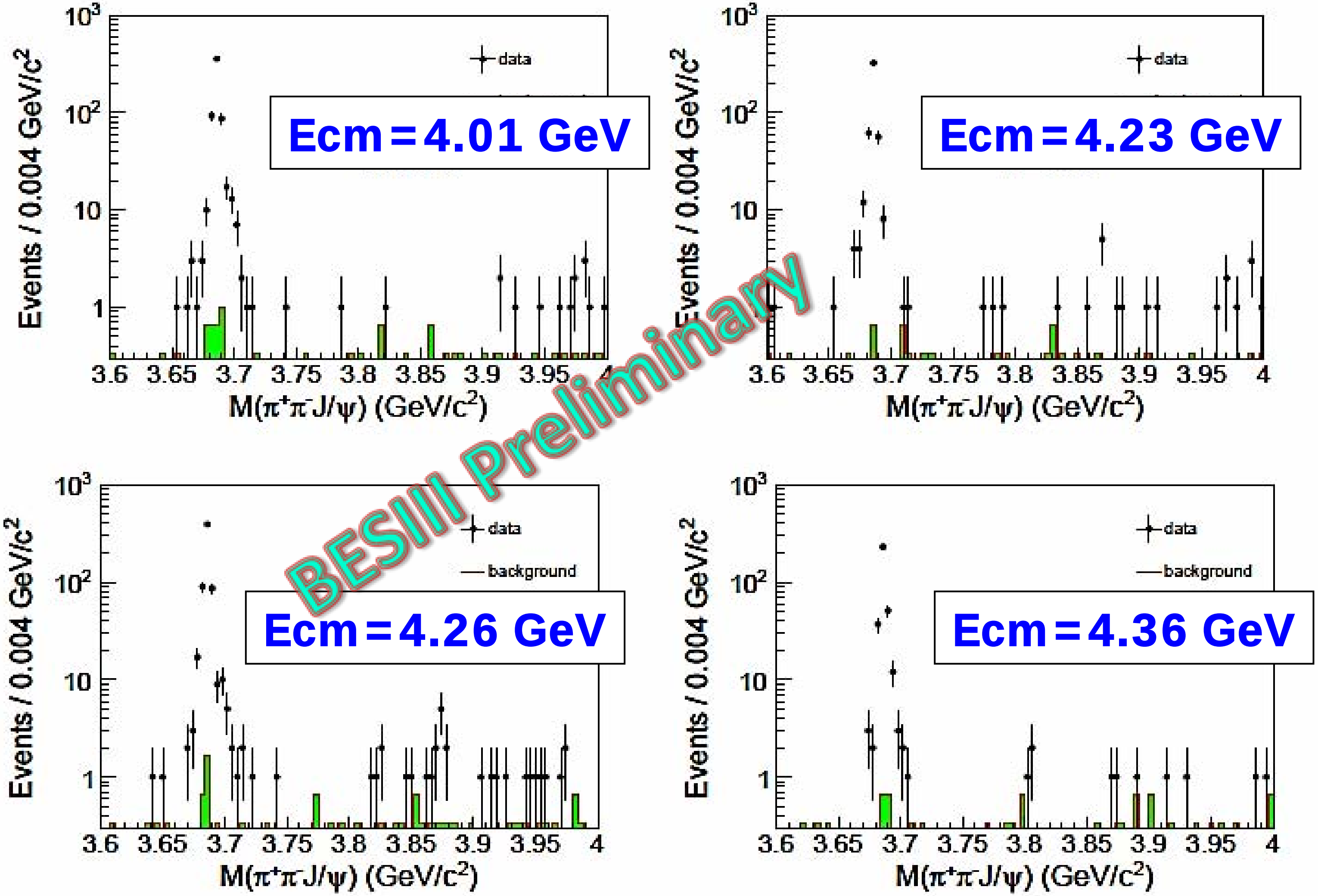
- BEPCII peak Luminosity of $0.7x10^{33}$ (Ecm=3.73GeV) achieved.
- BESIII is playing leading role on hadron spectroscopy
- BESIII starts study of XYZ particles
- Confirmed exotic state with at least four quarks Zc(3900)
- Observation of Zc(3885)/Zc'(4020) /Zc'(4025)
- BESIII is in her golden age, more results will appear: charm meson, form factors, tau physics, two-photon and ISR physics, rare processes … (I did not present here)
- More data will be collected near 4.420 GeV

Thank you!

Luminosity at each energy points

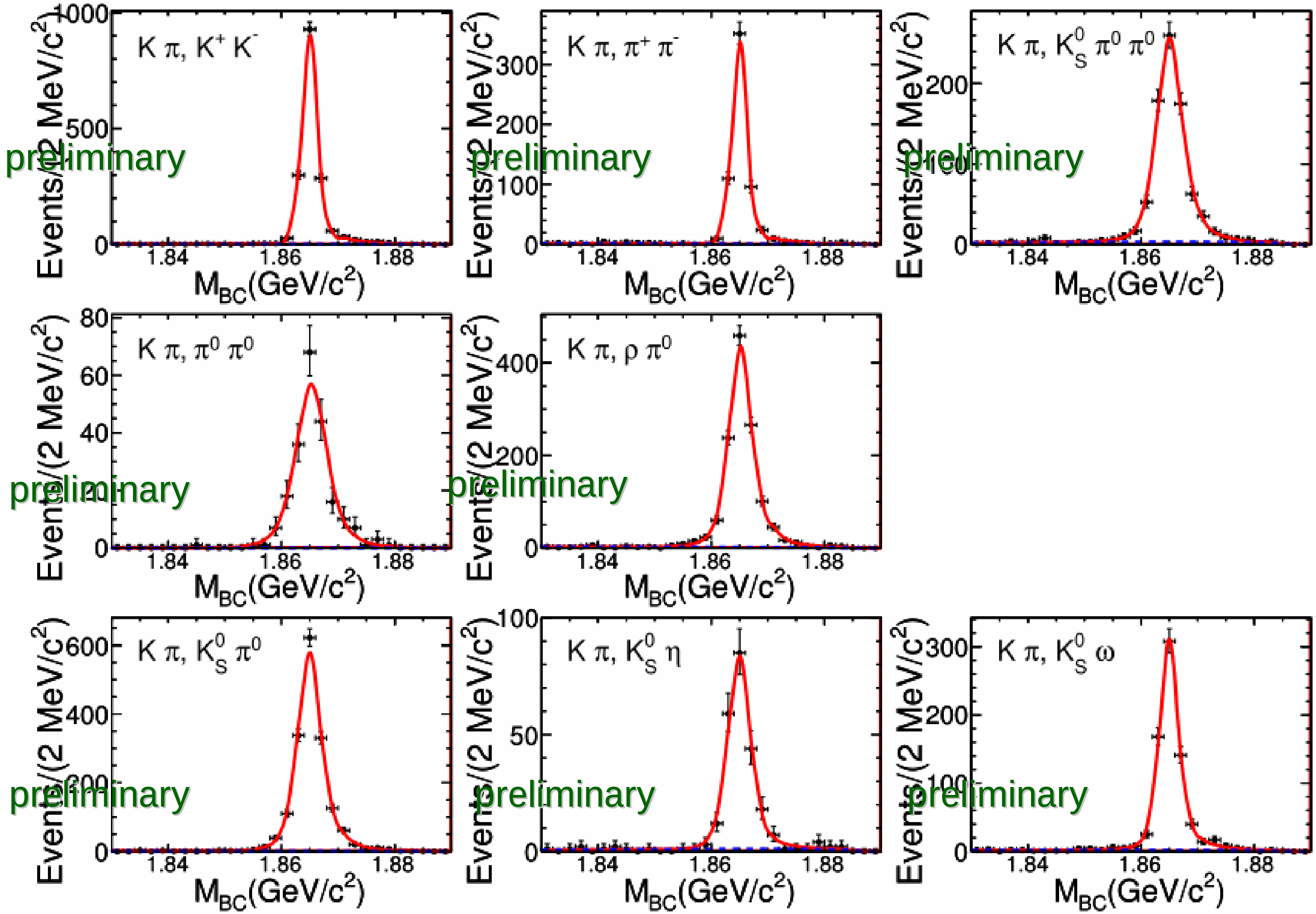
$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$n_{h_c}^{\rm obs}$	$\sigma(e^+e^- \to \pi^+\pi^- h_c)$ (pb)
3.900	52.8	< 2.3	< 8.3
4.009	482.0	< 13	< 5.0
4.090	51.0	< 6.0	< 13
4.190	43.0	8.8 ± 4.9	$17.7 \pm 9.8 \pm 1.6 \pm 2.8$
4.210	54.7	21.7 ± 5.9	$34.8 \pm 9.5 \pm 3.2 \pm 5.5$
4.220	54.6	26.6 ± 6.8	$41.9 \pm 10.7 \pm 3.8 \pm 6.6$
4.230	1090.0	646 ± 33	$50.2 \pm 2.7 \pm 4.6 \pm 7.9$
4.245	56.0	22.6 ± 7.1	$32.7 \pm 10.3 \pm 3.0 \pm 5.1$
4.260	826.8	416 ± 28	$41.0 \pm 2.8 \pm 3.7 \pm 6.4$
4.310	44.9	34.6 ± 7.2	$61.9 \pm 12.9 \pm 5.6 \pm 9.7$
4.360	544.5	357 ± 25	$52.3 \pm 3.7 \pm 4.8 \pm 8.2$
4.390	55.1	30.0 ± 7.8	$41.8 \pm 10.8 \pm 3.8 \pm 6.6$
4.420	44.7	29.1 ± 7.3	$49.4 \pm 12.4 \pm 4.5 \pm 7.6$

Observation of $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$



Clear ISR ψ' signal for data validation
X(3872) signal at around 4.23-4.26 GeV

Double tags of (*CP*, $K\pi$) modes



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arXiv:1304.6170

Sensitivity of the global fit at BESIII

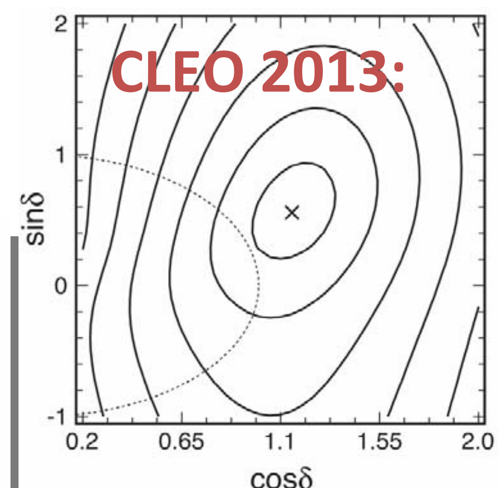
- MC study corresponds to 3.0 / fb data
- input of the central values of the world average in 2012:
- with the external constrains of :

$$\delta_{K\pi} = 22.1^{+9.7}_{-11.1}(^o),\ y_D = 0.75 \pm 0.12(\%)$$

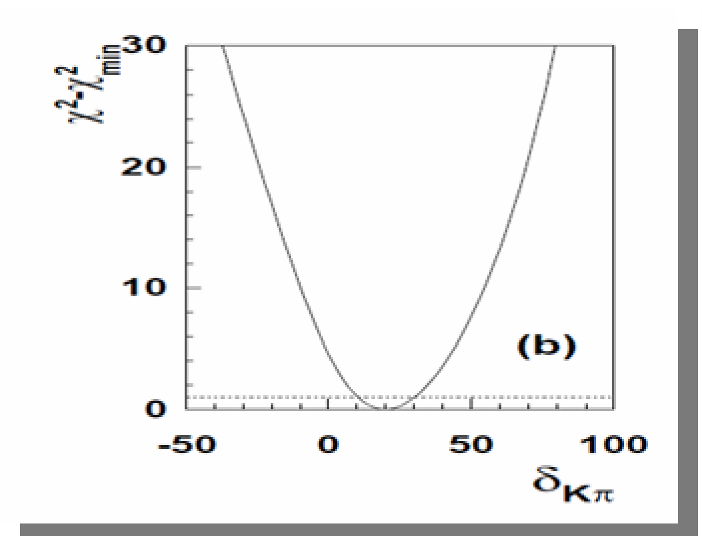
- output:

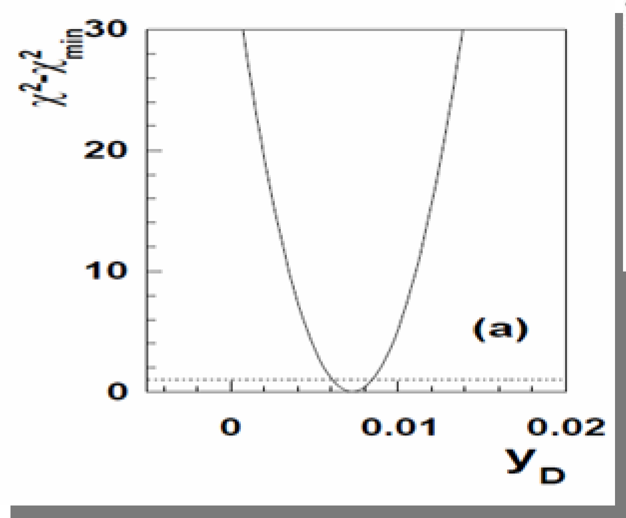
$$\delta_{K\pi}:\ \pm 8.3(^o),\ y_D:\ \pm 0.10(\%)$$

CLEO 2013:



$$\delta = (18^{+11}_{-17})^\circ$$





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