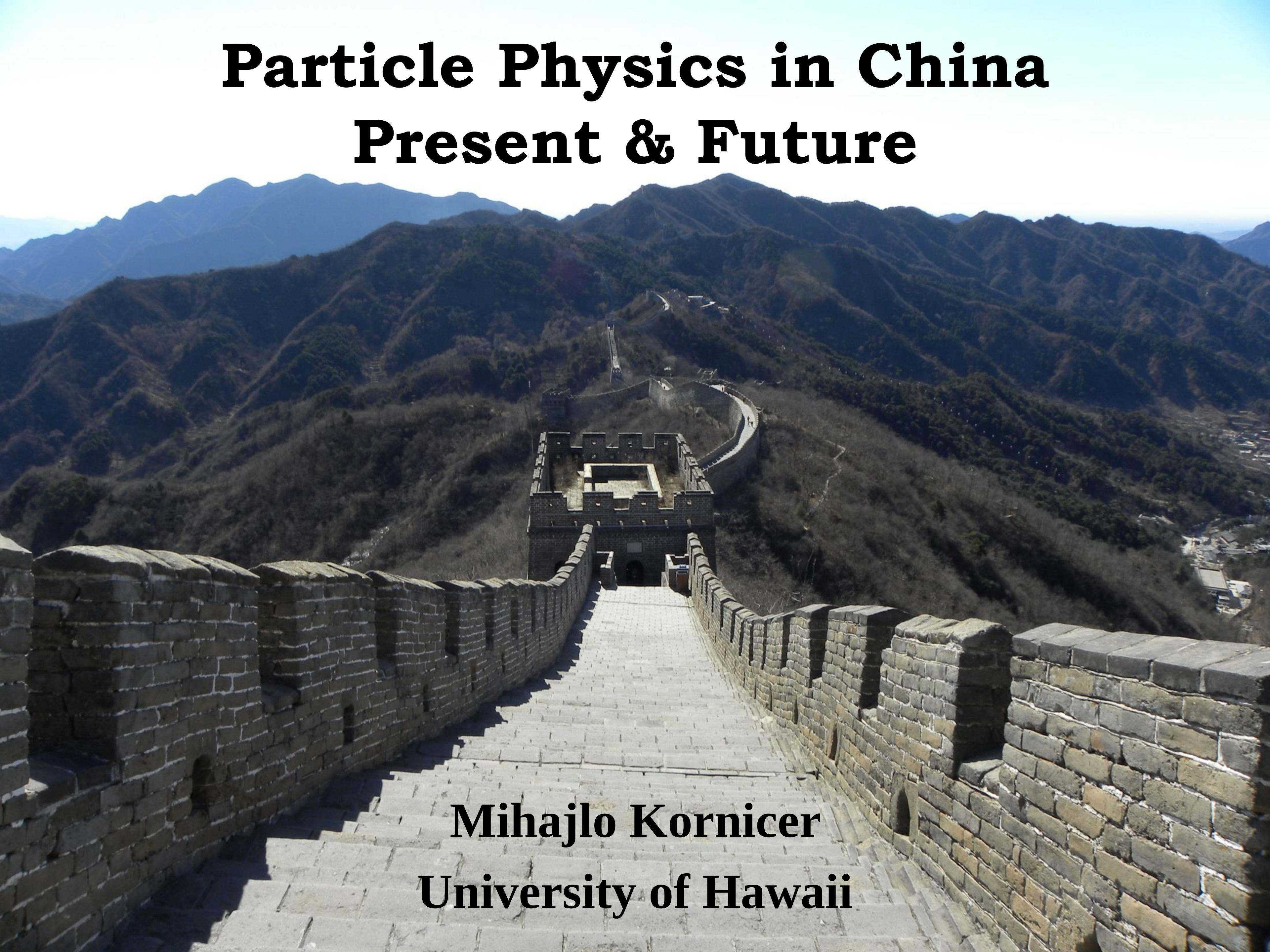
Particle Physics in China
Present & Future

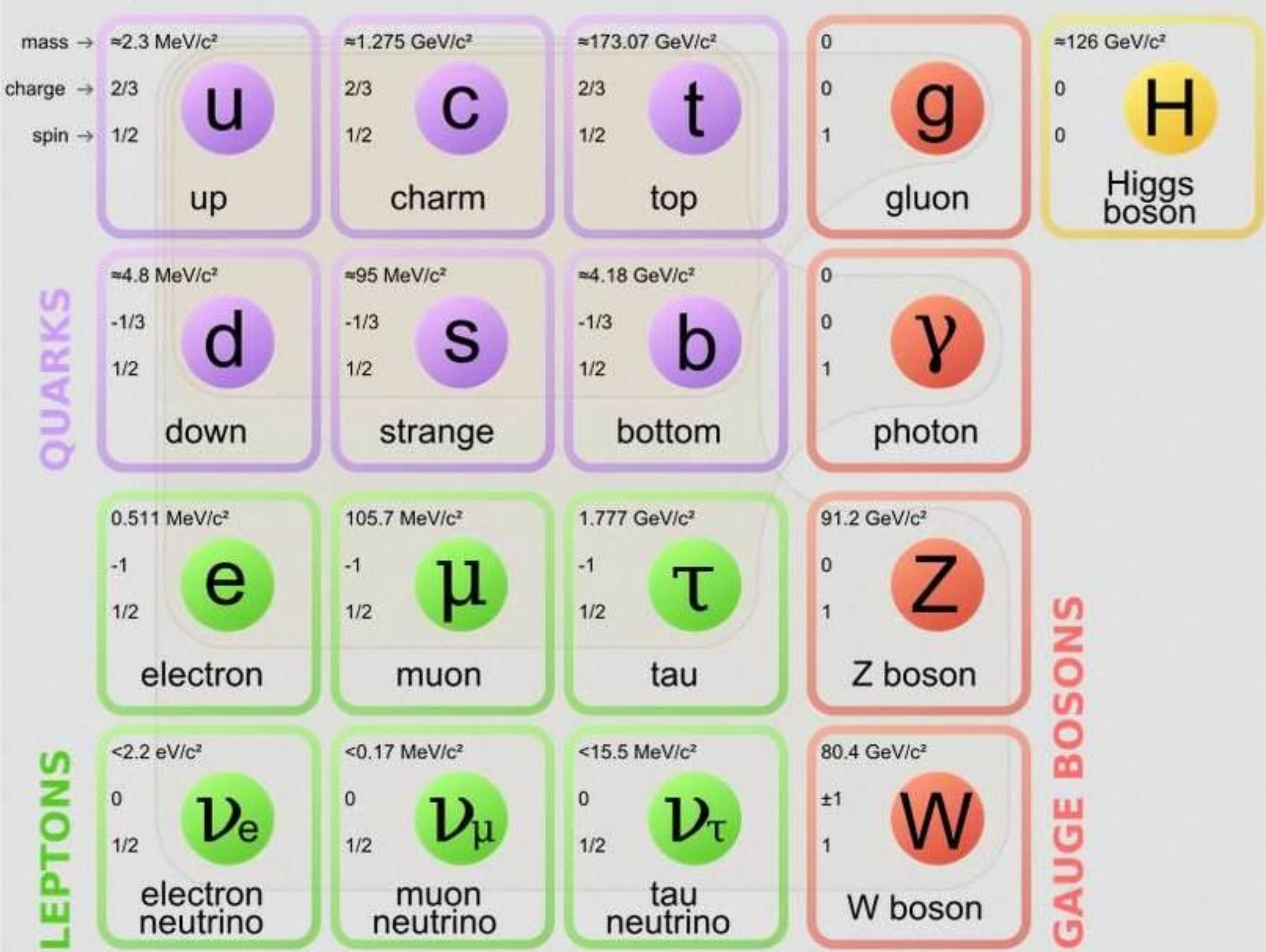


Mihajlo Kornicer
University of Hawaii

Outline

- **Introduction**
- **Physics program @ BESIII**
  - **modern exotic mesons (XYZ) @ BESIII**
  - **Charm physics, Λ_c, light hadron X(1835)**
- **UH contribution:**
  - **τ – mass**
  - **old-fashion exotic mesons π_1(1400), π_1(1600) …**
- **BESIII future … and beyond**

Story of Stuff (SM)

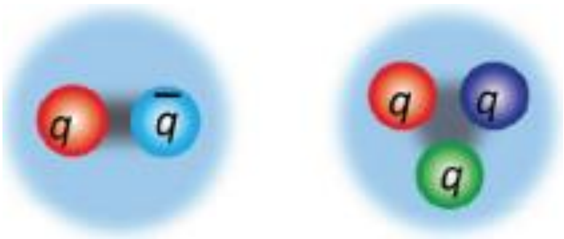


Ordinary QCD

All 'ordinary' hadrons are made of 2 or 3 quarks!

More precisely (QM): $q\bar{q}$ **or qqq**

Standard hadrons



What we observe:

- **nucleons** → **p = uud** **n = udd**
- **light mesons** → $\pi^+ = u\bar{d}$ $\pi^- = \bar{u}d$
- **charm meson** → $D^+ = c\bar{d}$ $D^- = \bar{c}d$
- **charmonium** → $J/\psi = c\bar{c}$

Extraordinary QCD

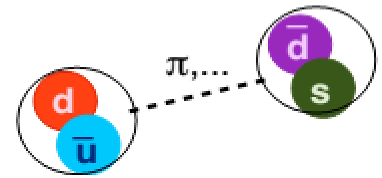
QCD allowed but unusual == exotic:

- multi-quark states

Tetraquark

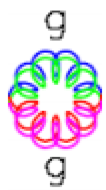
Pentaquark

Molecule



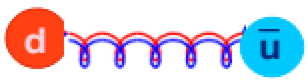
- glueballs

Glueball



- hybrids …

Hybrid



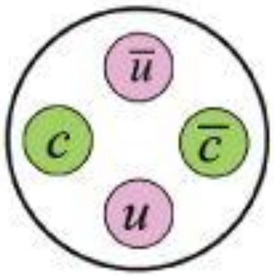
- any meson with $J^{PC} = 0^{--}, 0^{-+}, 1^{-+}, 2^{+-} \ldots$

$$J = L + S$$
$$P = (-1)^{L+1}$$
$$C = (-1)^{L+S}$$

We learn from hadron spectroscopy!

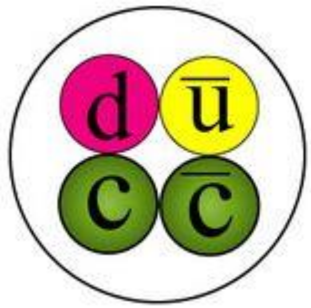
Heavy Flavor QCD: exotics popping out!

X(3872)

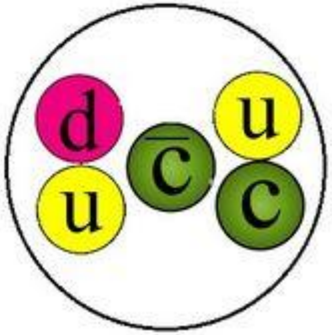


Z(4430)

Z(3900)



P_c



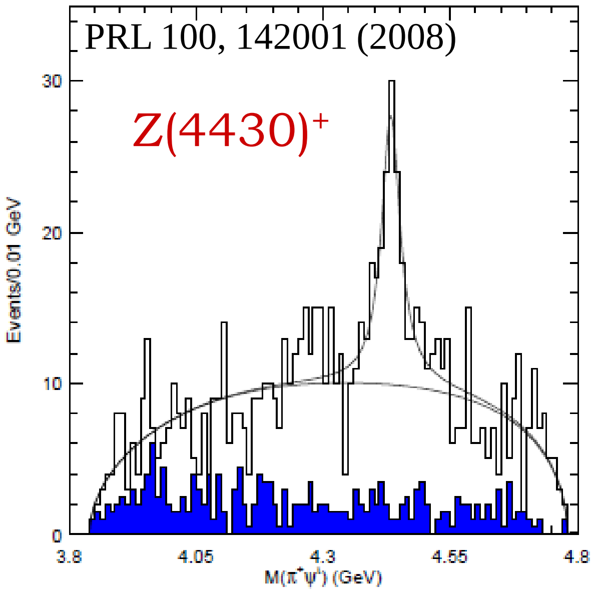
Why do we care?

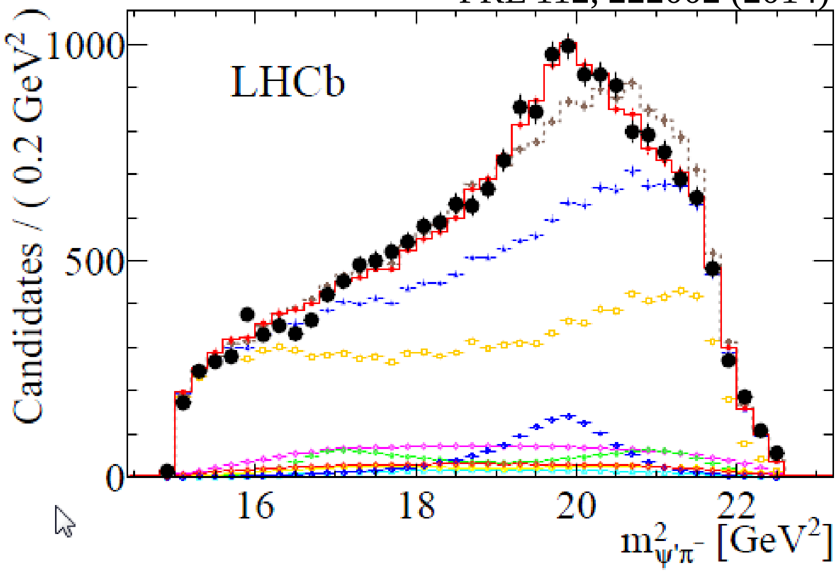
N. Brambilla, et. al.: …. understanding QCD background was instrumental to the Higgs discovery …!

Understanding QCD excitations in low-energy region might be instrumental for discovering NP in precision frontier?

$Z_c(4430)$ in $B \to \psi' \pi^{+(-)} K$

Belle 2008

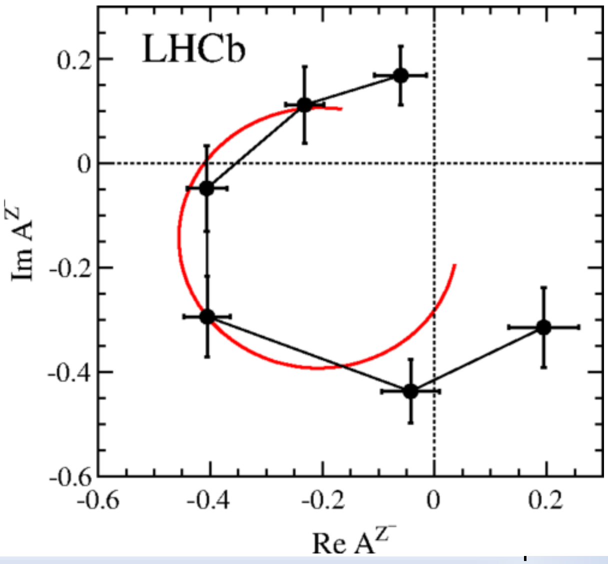




Z(4430)$^-$

$J^P = 1^+$

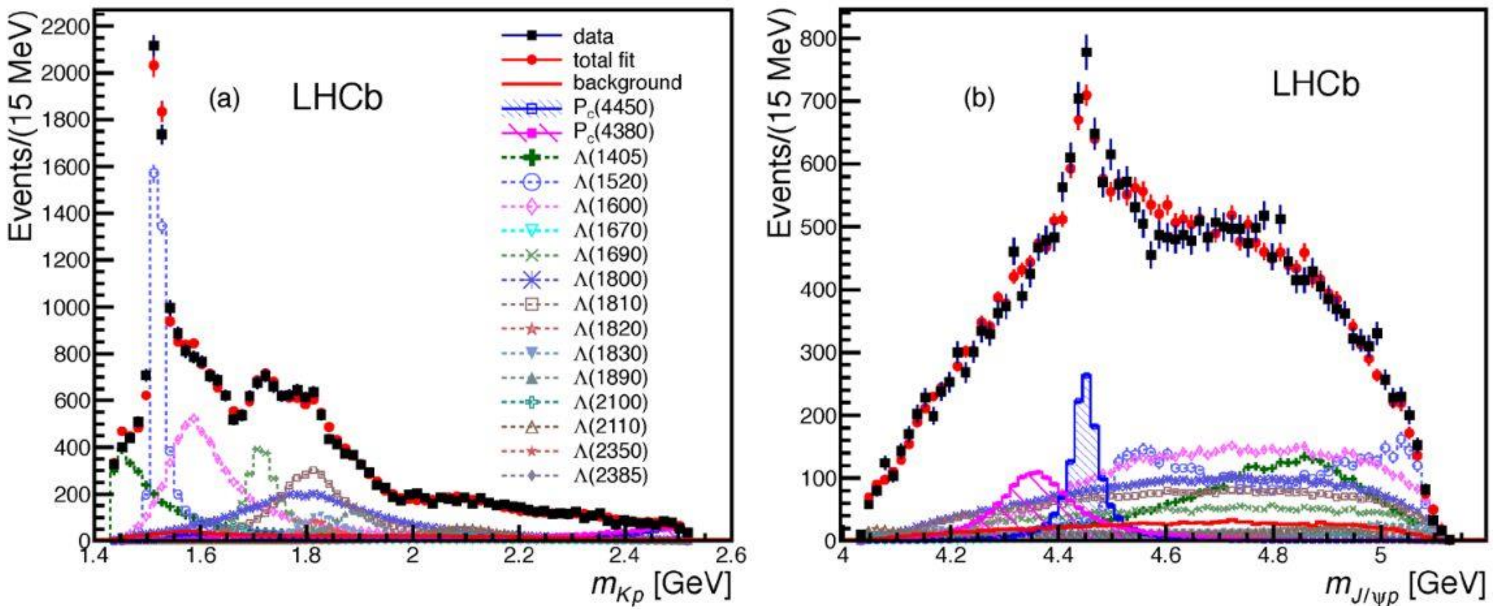
Rapid phase transition at the peak of the amplitude: points to resonance!

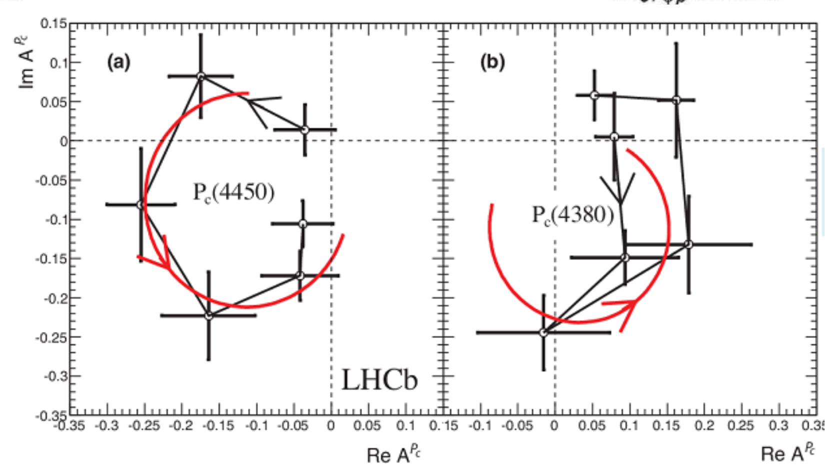


Pentaquark @ LHCb

$$\Lambda_b^0 \rightarrow J/\psi\, p K^-$$

PRL 115 (2015) 072001

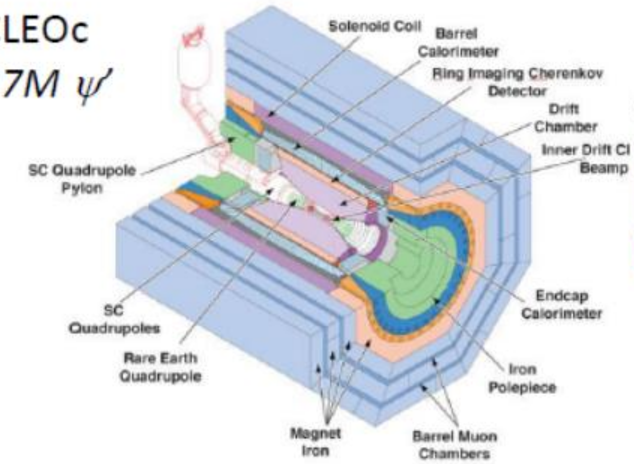




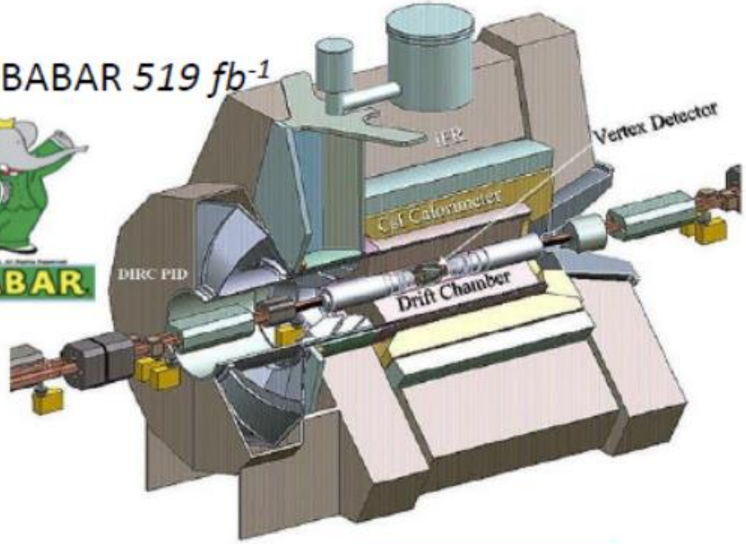
Two Pc, one exhibits phase transition consistent with resonance!

Experiments

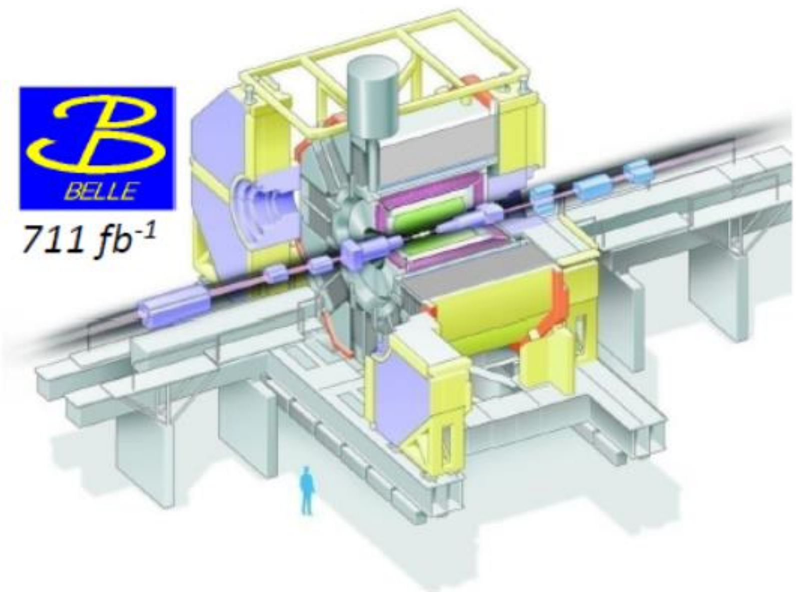
CLEOc
$27M\ \psi'$



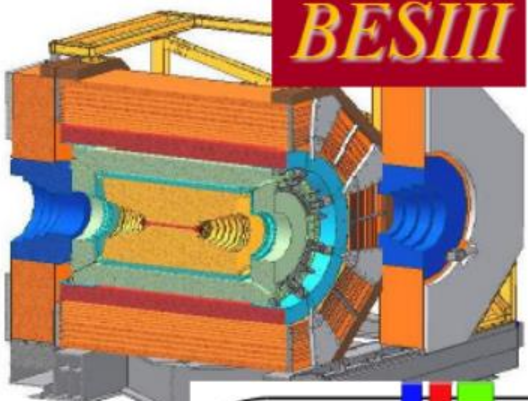
BABAR $519\ fb^{-1}$



BELLE
$711\ fb^{-1}$



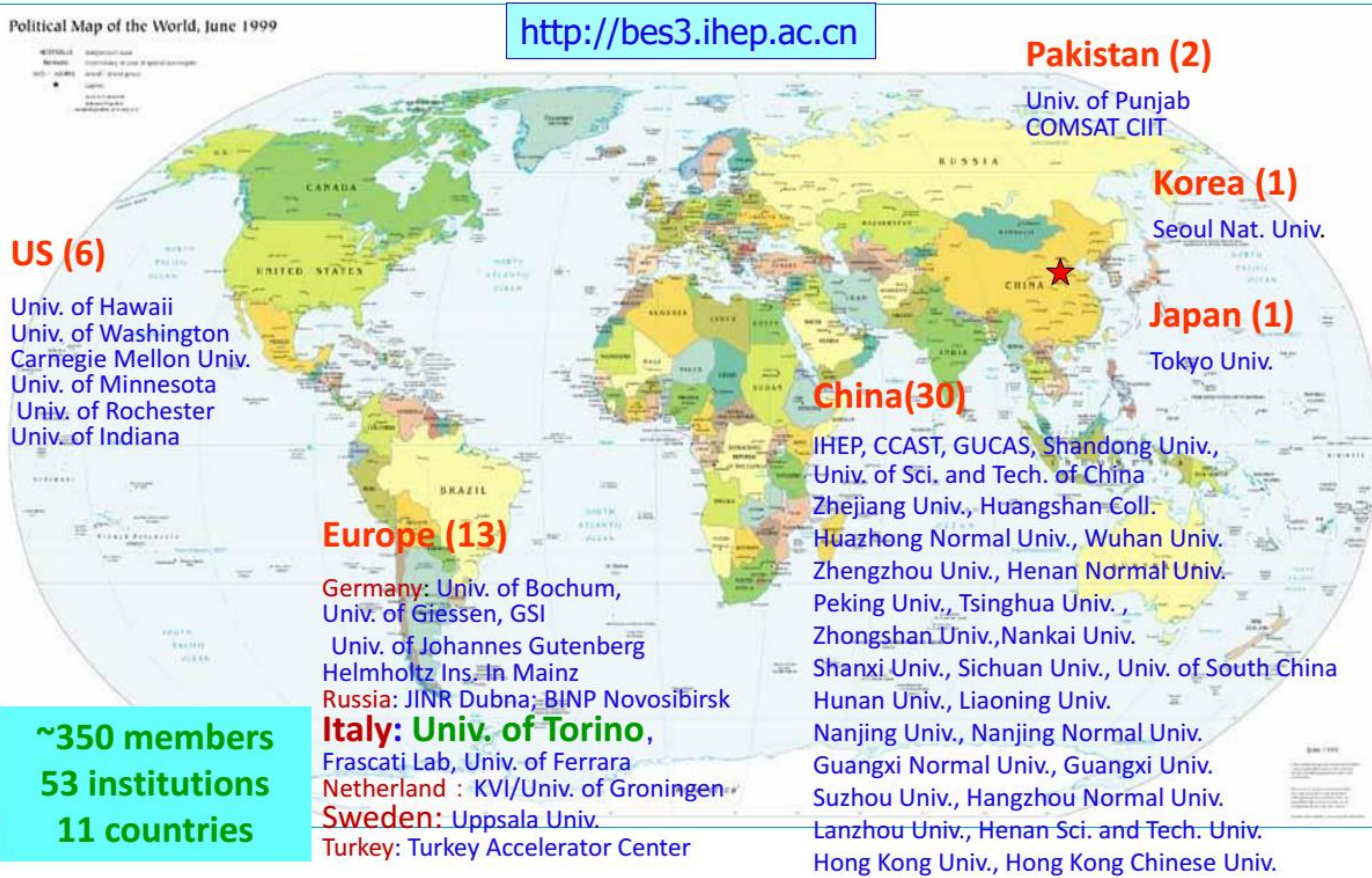
BESIII



LHCb

panda

BESIII Collaboration



http://bes3.ihep.ac.cn

US (6)

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

Pakistan (2)

Univ. of Punjab
COMSAT CIIT

Korea (1)

Seoul Nat. Univ.

Japan (1)

Tokyo Univ.

China(30)

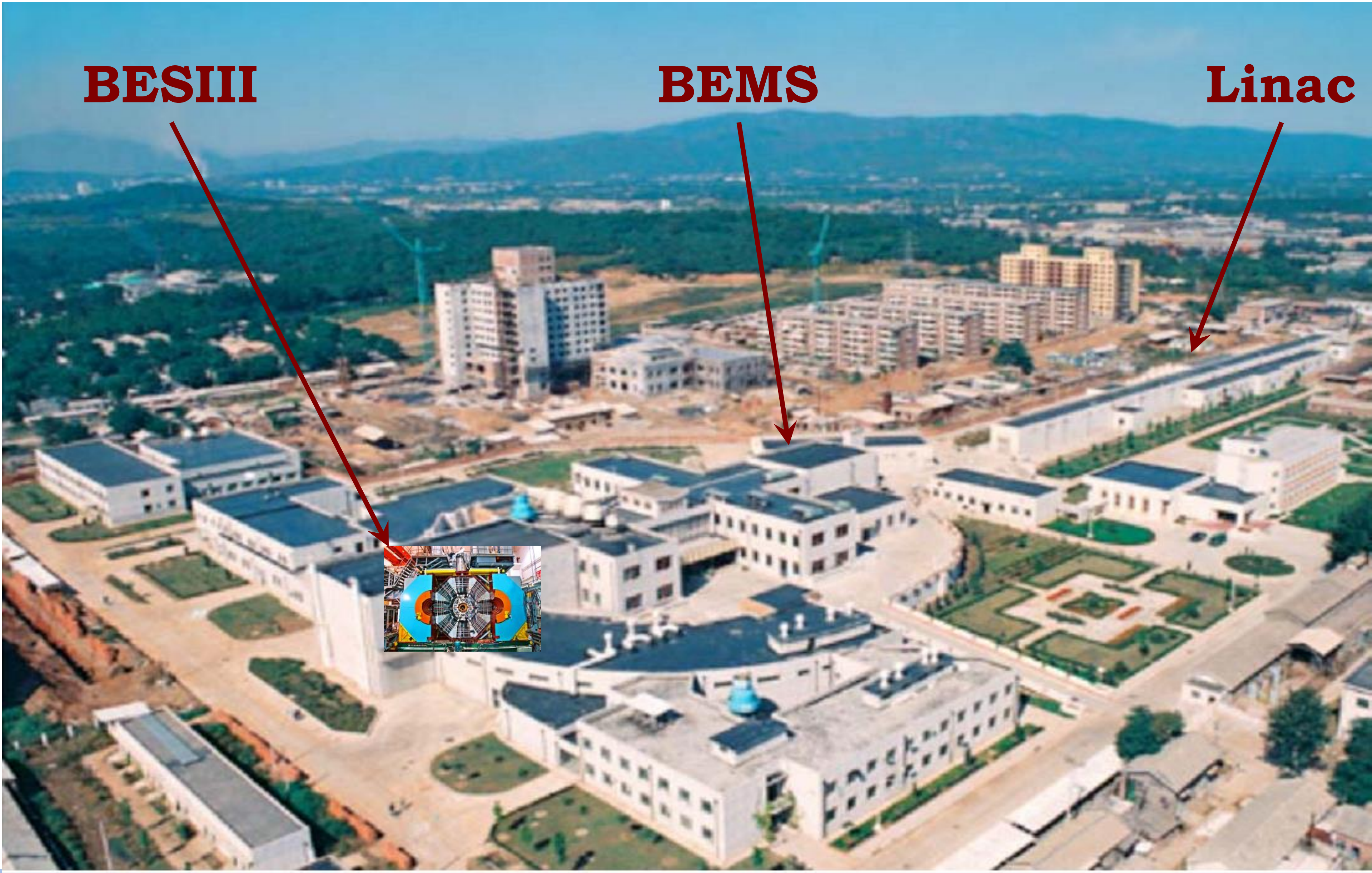
IHEP, CCAST, GUCAS, Shandong Univ.,
Univ. of Sci. and Tech. of China
Zhejiang Univ., Huangshan Coll.
Huazhong Normal Univ., Wuhan Univ.
Zhengzhou Univ., Henan Normal Univ.
Peking Univ., Tsinghua Univ. ,
Zhongshan Univ.,Nankai Univ.
Shanxi Univ., Sichuan Univ., Univ. of South China
Hunan Univ., Liaoning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

Europe (13)

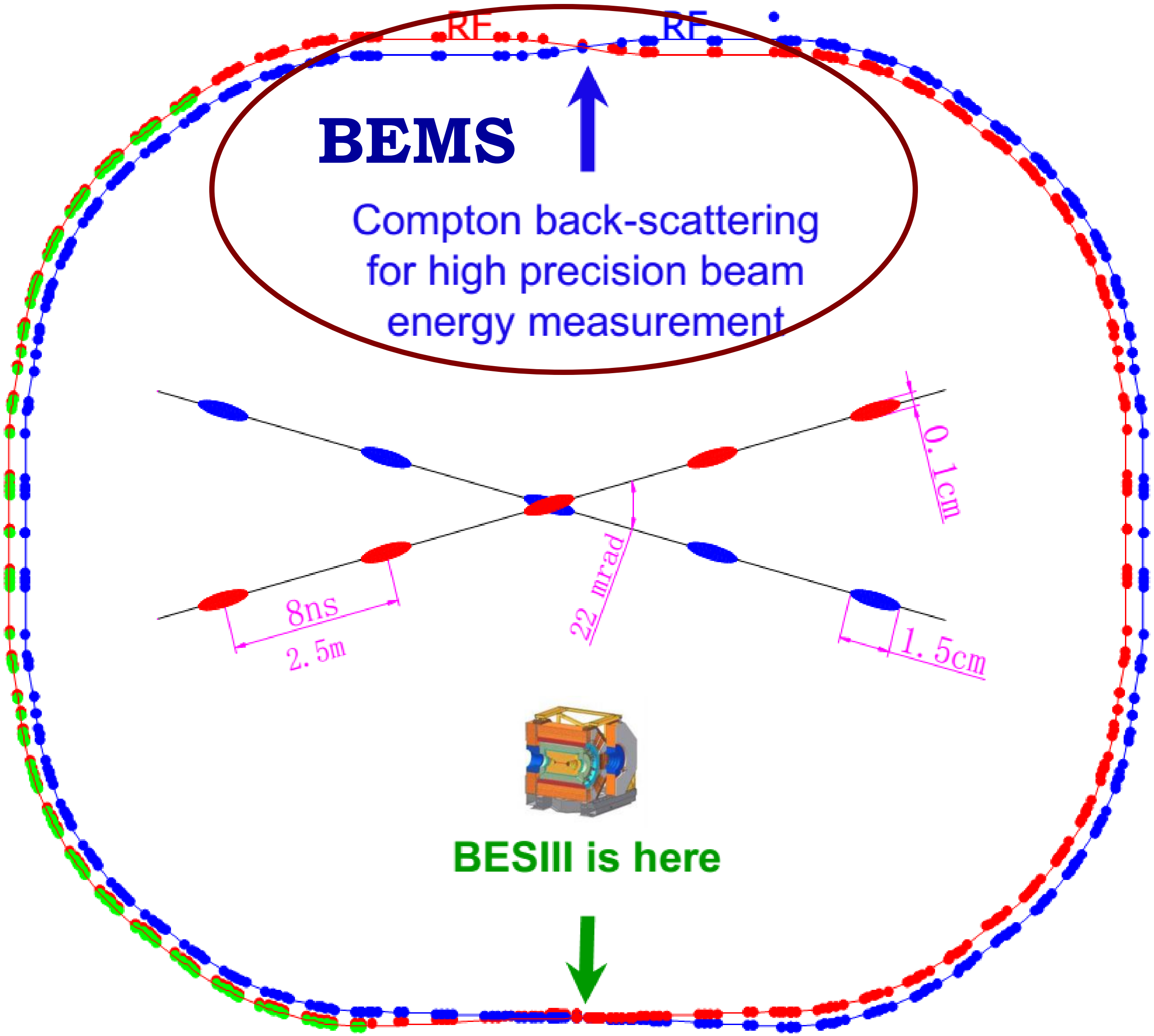
Germany: Univ. of Bochum,
Univ. of Giessen, GSI
Univ. of Johannes Gutenberg
Helmholtz Ins. In Mainz
Russia: JINR Dubna; BINP Novosibirsk
Italy: Univ. of Torino,
Frascati Lab, Univ. of Ferrara
Netherland : KVI/Univ. of Groningen
Sweden: Uppsala Univ.
Turkey: Turkey Accelerator Center

~350 members
53 institutions
11 countries

Beijing Electron Positron Collider II



BEPCII



Beam energy:
1-2.3 GeV

Crossing angle:
22 mrad

Design Luminosity:
1×10^{33} $cm^{-2}s^{-1}$

Optimum energy:
1.89 GeV

Energy spread:
5.16×10^{-4}

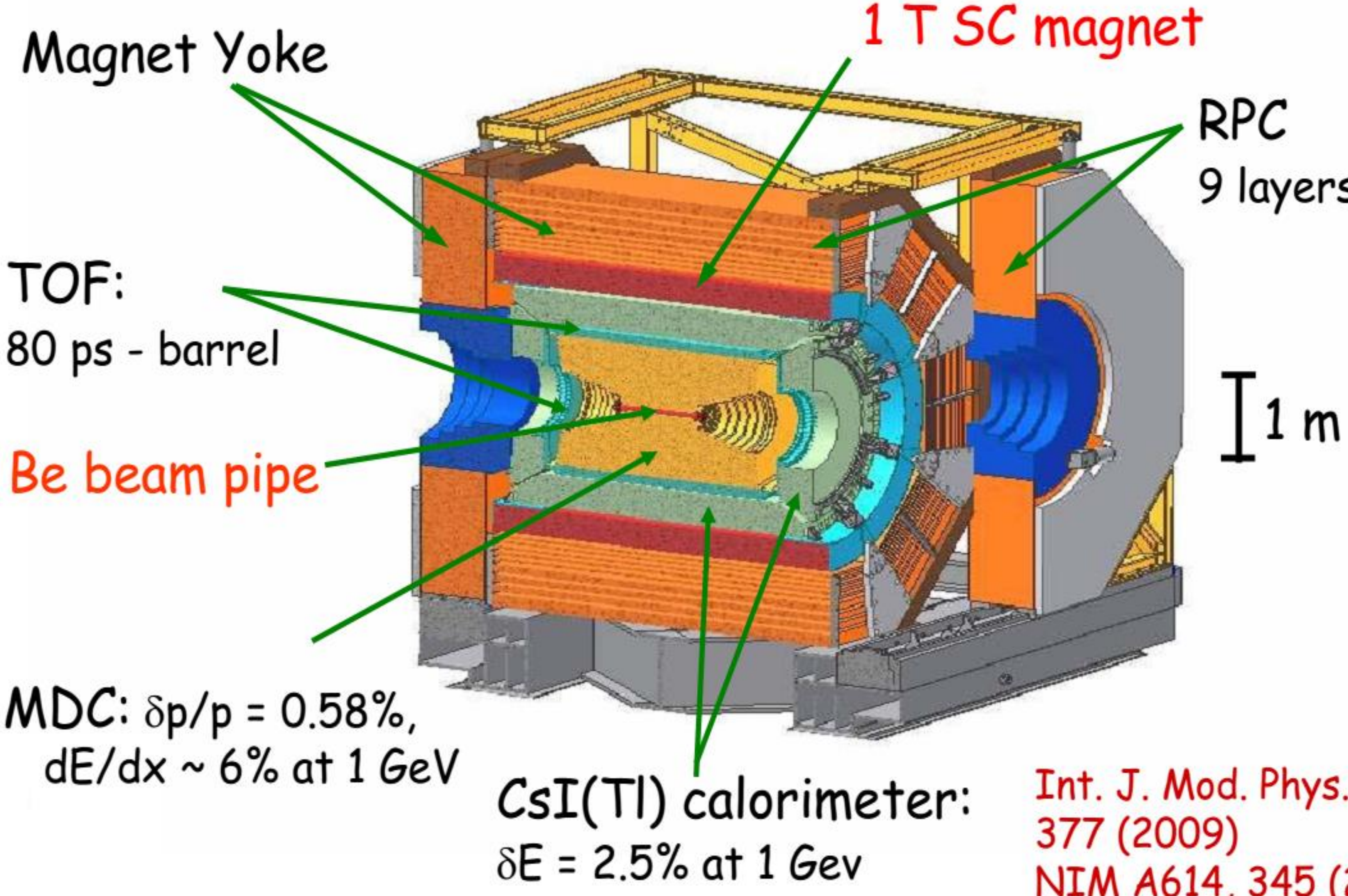
No. of bunches:
93

Bunch length:
1.5 cm

Total current:
0.91 A

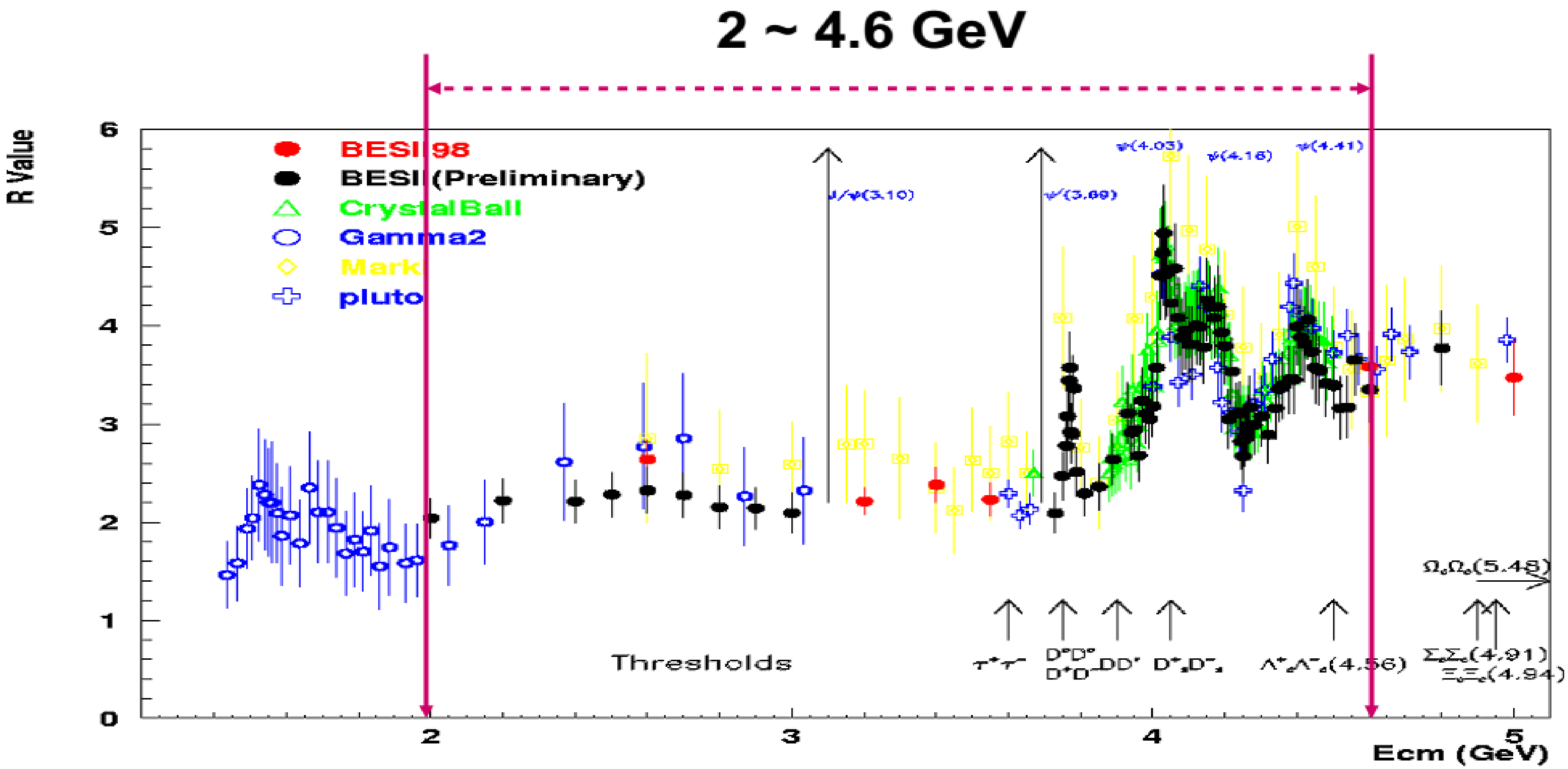
SR mode:
0.25A @ 2.5 GeV

BESIII detector

Int. J. Mod. Phys. A24, 377 (2009)
NIM A614, 345 (2010)

Energy range @ BEPCII



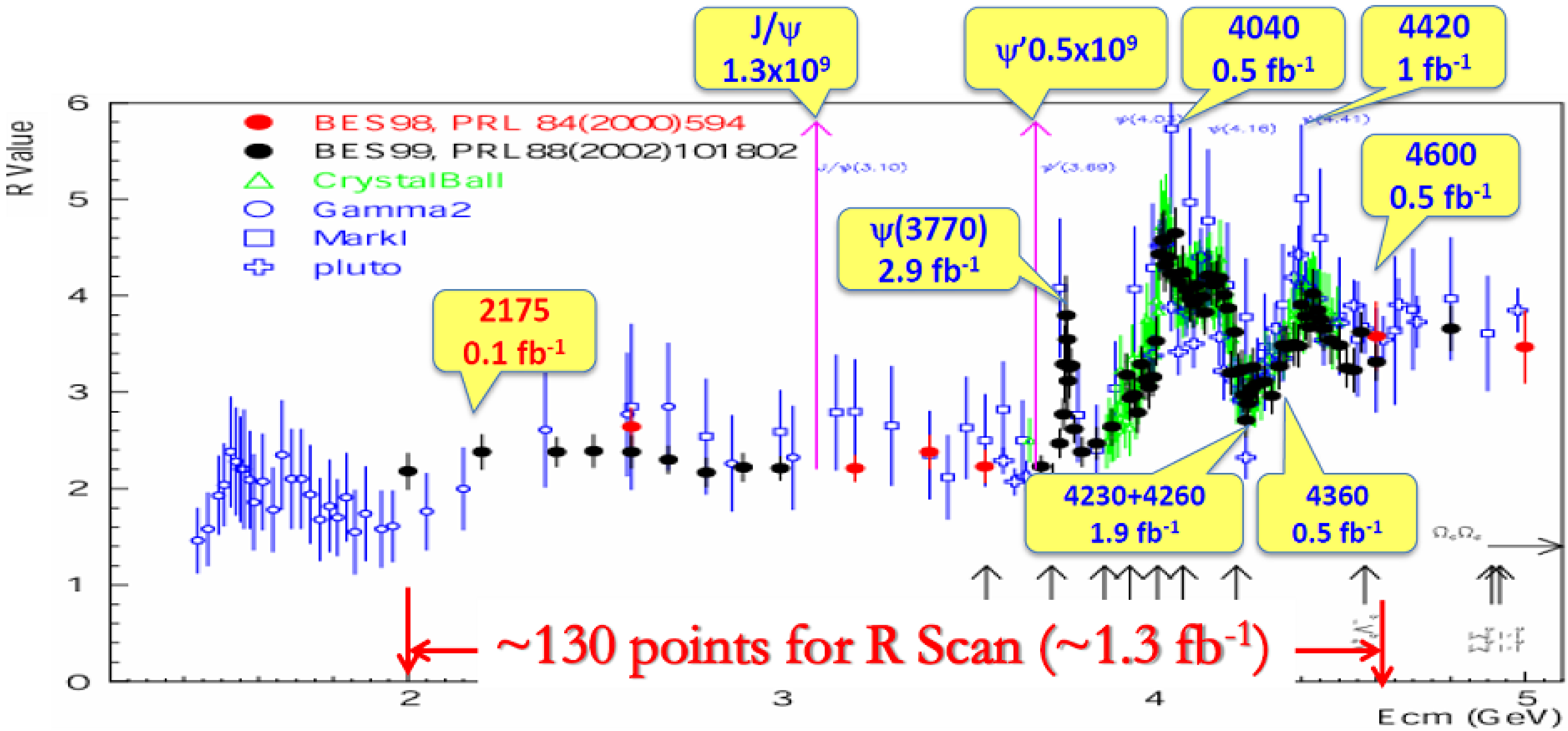
Transition between perturbative and non-perturbative QCD

Resonance rich: charmonia and charmed mesons

Interesting thresholds: ττ, DD, D*D*, $\Lambda_c\Lambda_c$ …

Multi-quark states found, possible gluonic excitations…

Data collected by BESIII



World largest: J/ψ, $\psi(2S)$, $\psi(3770)$, $Y(4260)$ …
from direct e^+e^- collisions!

BESIII: "τ-charm" factory

Charmonium physics:
- Spectroscopy
- transitions and decays

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

Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, from factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

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

…and many more.

- ❖ X(3780), Y(4260), Z(3900), Λ_c …
- ❖ X(1835), X(2120) X(2370), Y(2175), Zs?, $\pi_1(1600)$, $f_0(980)$-$a_0(980)$…
- ❖ matrix elements for η,η'
- ❖ f_D, f_{Ds}, EM FFs nucleon, hyperon, pion FF …
- ❖ precision τ-mass

$\psi(2S) \rightarrow \tau\tau$ …

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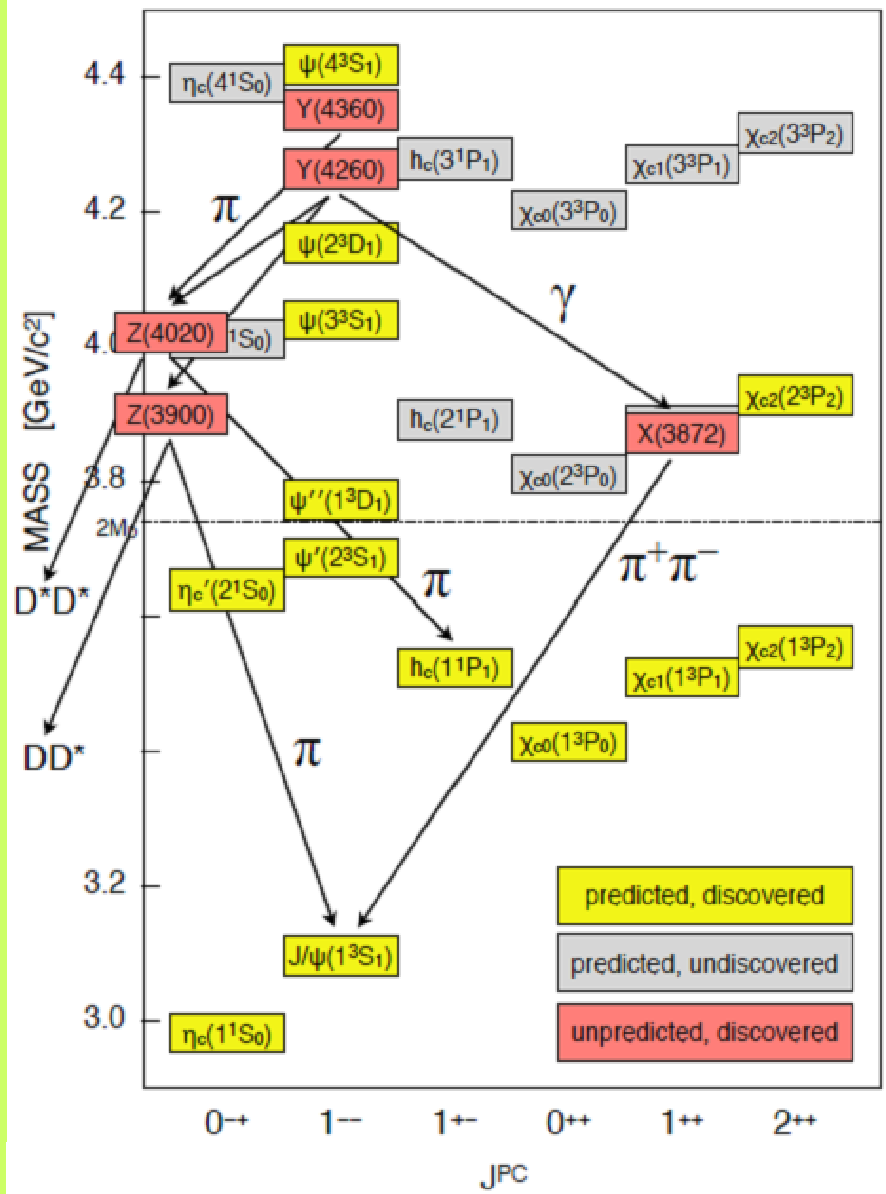
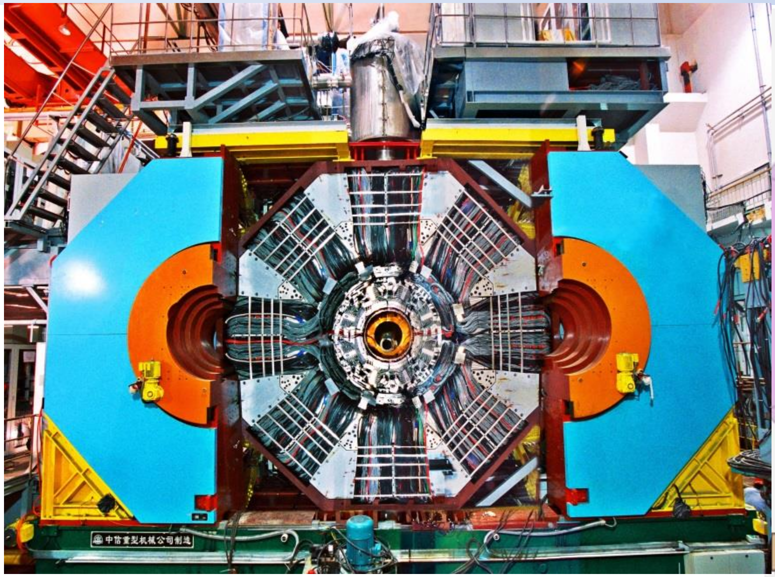
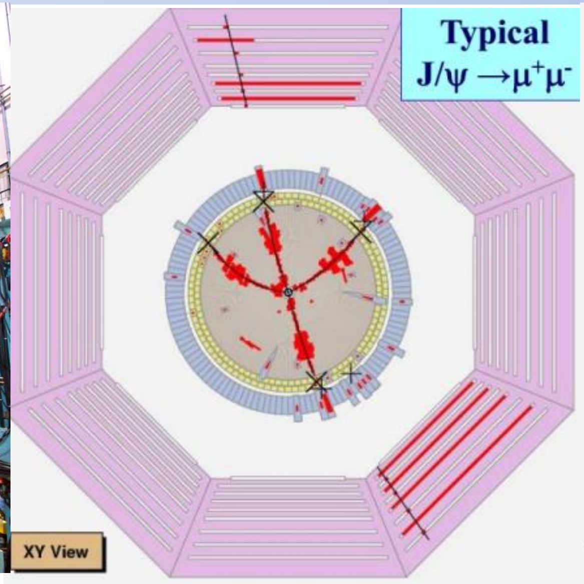
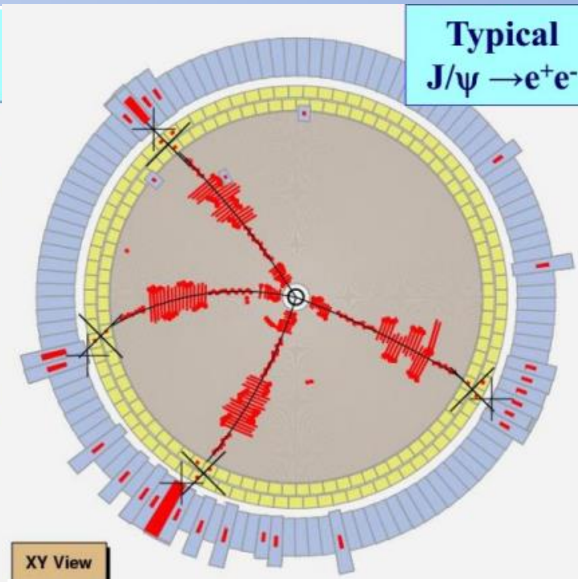


What do we see in the detector ?

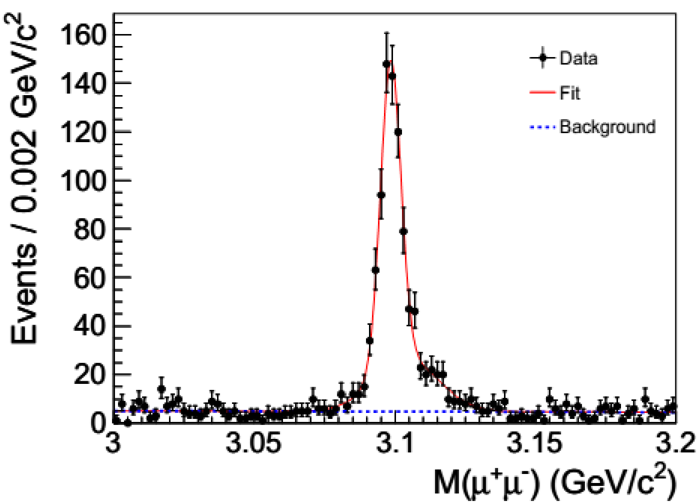




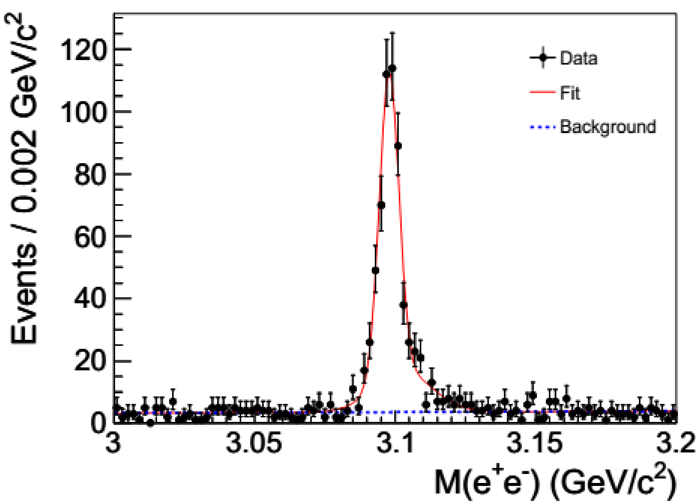


Signal purity 90%

$e^+e^- \rightarrow J/\psi \rightarrow \mu^+\mu^-$



$e^+e^- \rightarrow J/\psi \rightarrow e^+e^-$

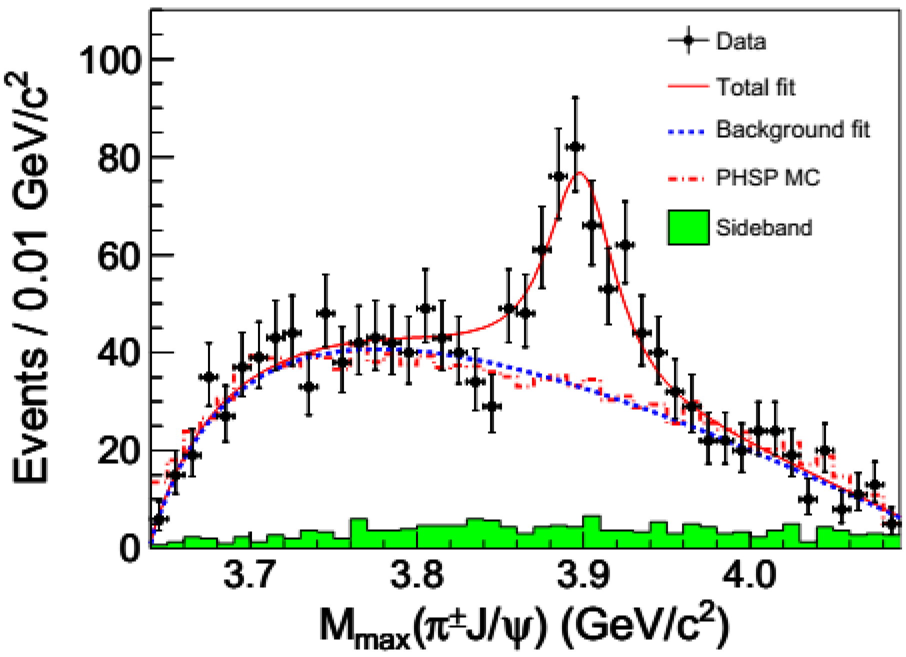


$Z_c(3900) \to \pi^{\pm} J/\psi$

- **Charged** charmonium-like structure: $e^+e^- \to \pi^{\mp}(\pi^{\pm} J/\psi)$
  manifestly exotic:

Significance > 8 σ

- couples to $c\bar{c}$
- has charge
- at least 4 quarks
- what is it ?

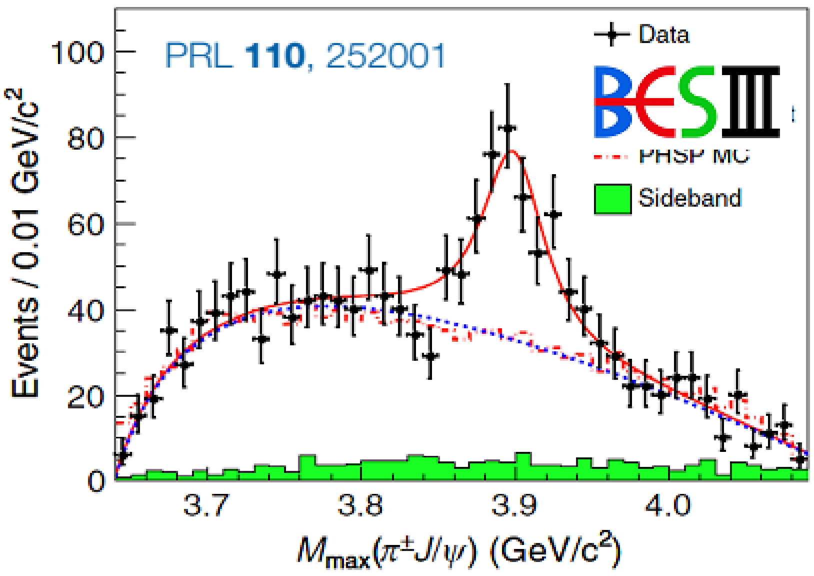


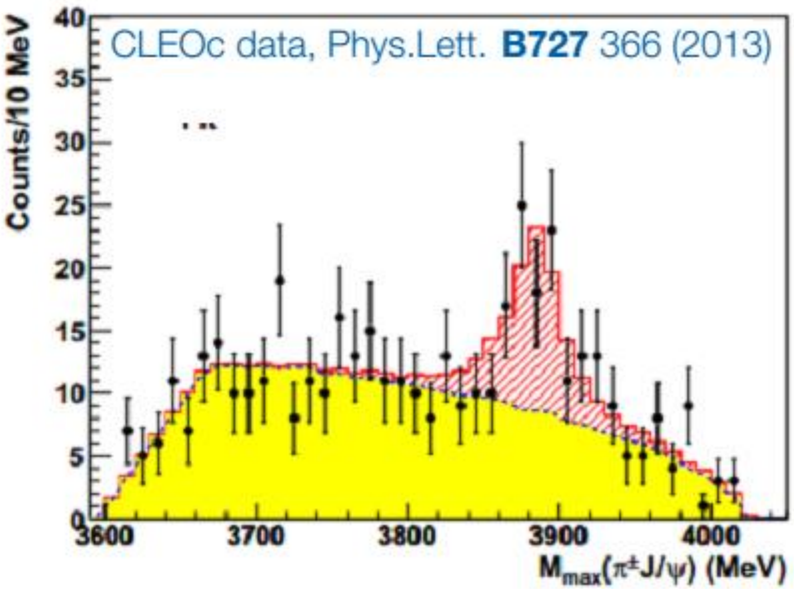
M: (3899.0 ± 3.6 ± 4.9) MeV/c^2
Γ: (46 ± 10 ± 20) MeV
R: (21.5 ± 3.3 ± 7.8)%

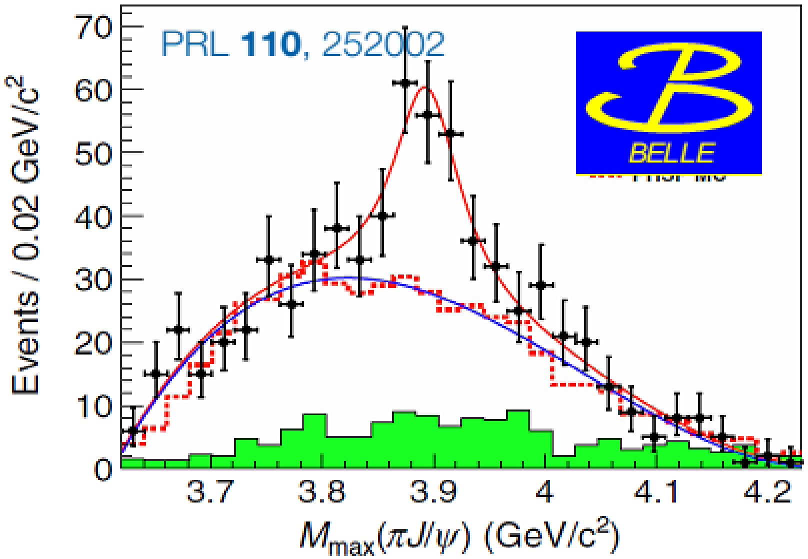
PRL 110, 252001 (2013)

The first Z_c confirmed

by data from three experiments!





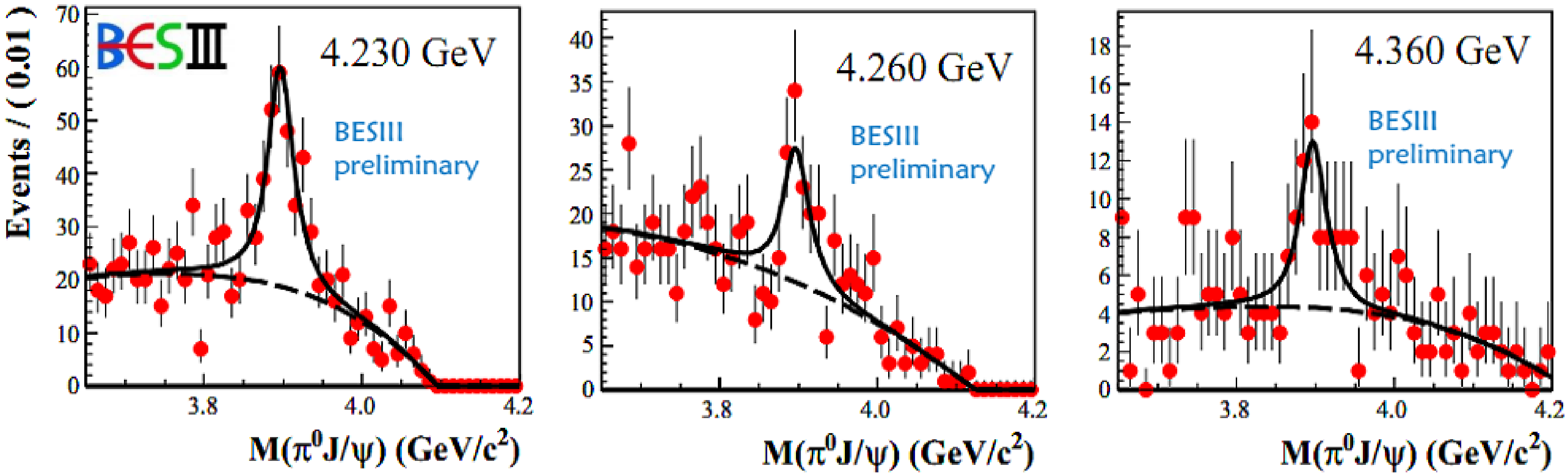


	m / MeV	Γ / MeV
BESIII	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$
Belle	$3894.5 \pm 6.6 \pm 4.5$	$63 \pm 24 \pm 26$
CLEOc	$3885 \pm 5 \pm 1$	$34 \pm 12 \pm 4$

Belle: $e^+e^- \to \gamma_{ISR} J/\psi\, \pi^+\pi^-$,
in $Y(4260)$ region
CLEOc data: $\sqrt{s} = 4.170\,\mathrm{GeV}$

Neutral partner!

Studying $e^+e^- \rightarrow \pi^0\pi^0 J/\psi$ at different $\sqrt{s}$



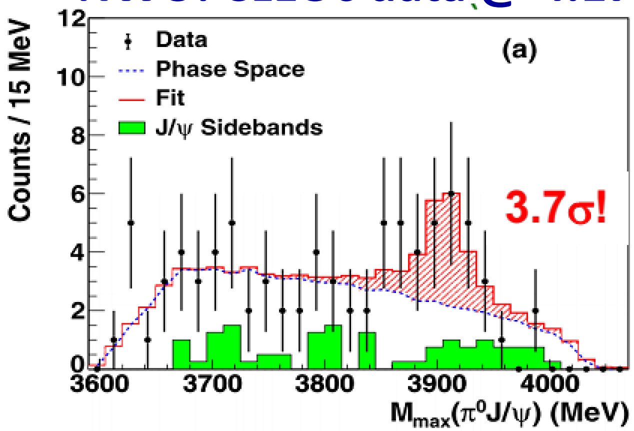
Isospin triplet **established!**

M: (3894.8 ± 2.3 ± 2.7) MeV/c^2

Γ: (29.6 ± 8.2 ± 8.2) MeV

Significance = 10σ

NWU: CLEOc data @ 4.17 GeV



PLB 727, 366

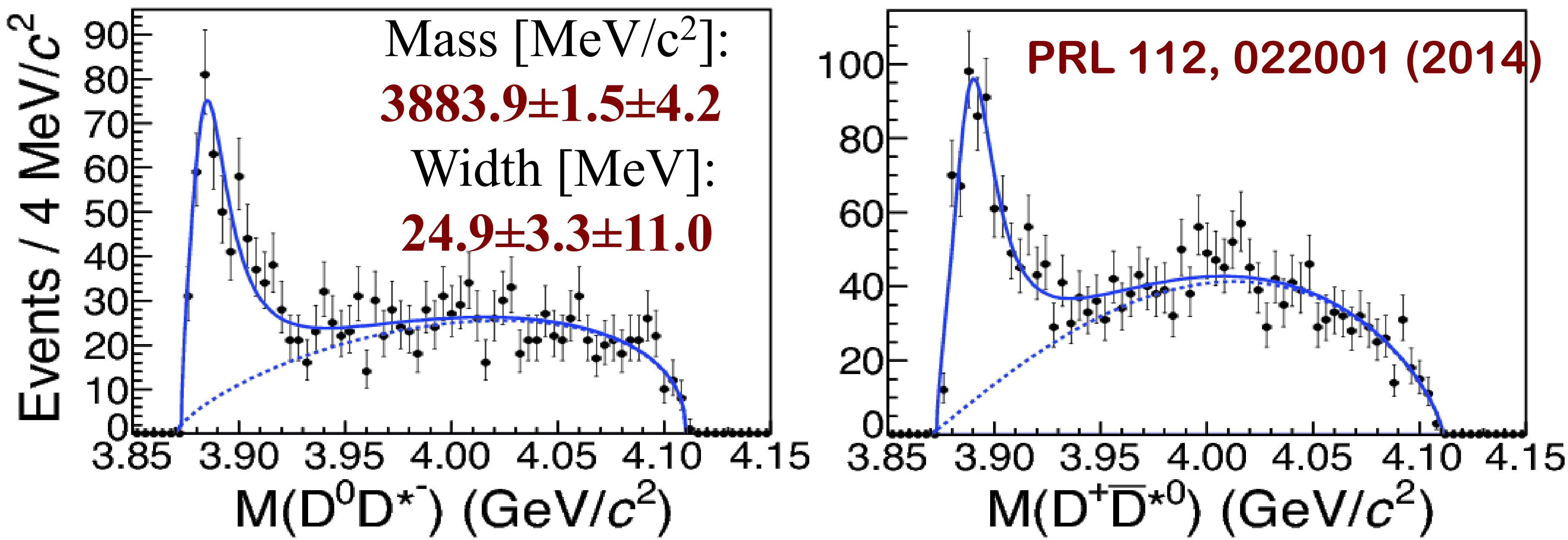
$Z_c(3900)$: close to D^*D threshold

$$e^+e^- \to \pi^+ D^0 D^{*-} + c.c. \quad (D^0 \to K^-\pi^+)$$

$$e^+e^- \to \pi^+ D^- D^{*0} + c.c. \quad (D^- \to K^-\pi^+\pi^+)$$

$\sqrt{s} = 4.26\ GeV$

Single D-tag: reconstruct π^+ and $D^0 \to K^-\pi^+$ and require that missing mass is consistent with D^*; (do the same for $\pi^+D^-D^{*0}$)



Enhancement in both $D\overline{D^*}$ modes, labeled $Z_c(3883)$

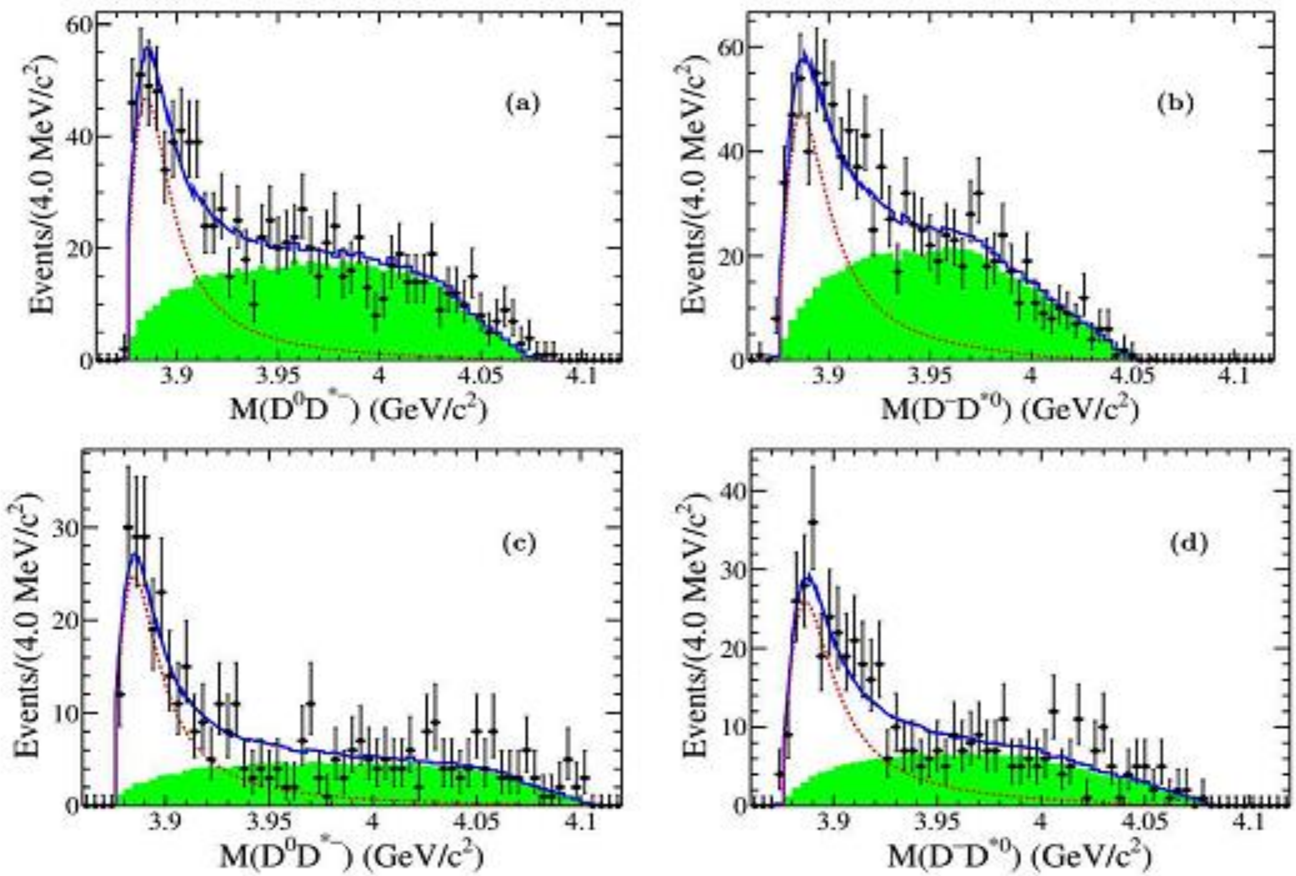
$Z_c(3883)$: double tag D^*D analysis

Reconstruct π^+ and D^0, D^-, in 4 or 6 decay modes, plus require π in missing D^* mass:

PRD accepted

$e^+e^- \rightarrow \pi^+ D^0 D^{*-}$

$e^+e^- \rightarrow \pi^+ D^- D^{*0}$



Mass [MeV/c^2]:
3884.3±1.2±1.5
Width [MeV]:
23.8±2.1±2.6

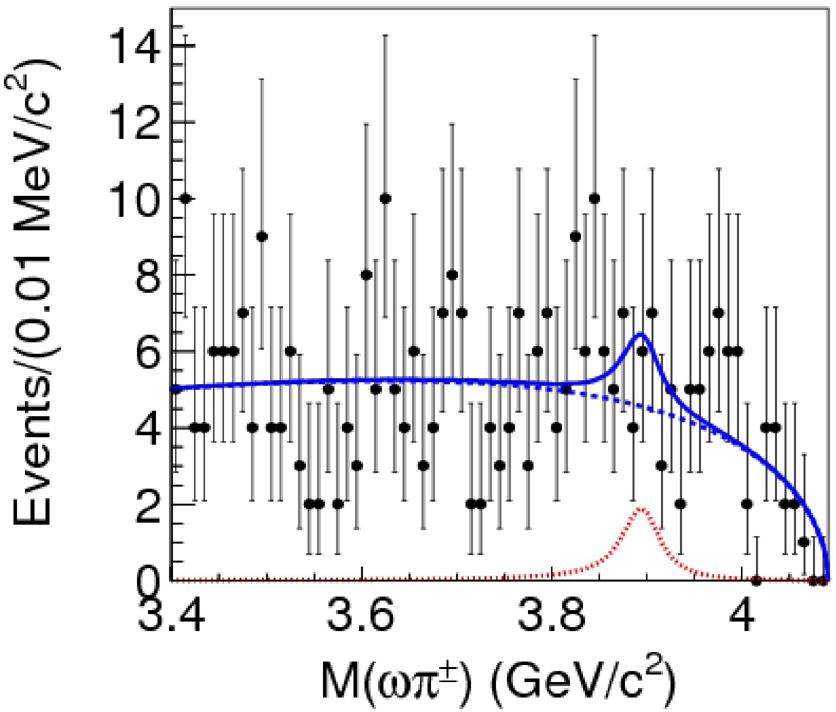
Compatible with single D-tag result, but much more precise!

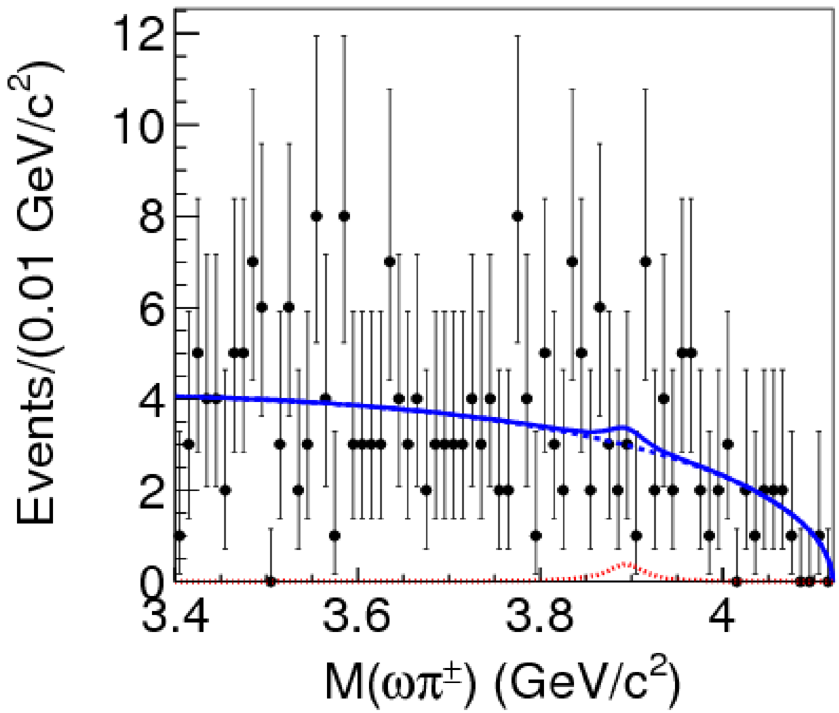
Angular analysis:
$J^{PC} = 1^+$
from ST & DT!

$e^+e^- \to \pi^+\pi^- \omega$ @ 4.23-4.26 GeV

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

PRD 92, 032009 (2015)





No significant **Z_c(3900)→πω** signal!

$\Gamma(Z_c(3900)\to\pi\omega)$ < **0.2 %** $\Gamma_{tot}(Z_c(3900))$

Indicates that $c\bar{c}$ annihilation **is suppressed!**

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

$h_c \to \gamma\eta_c$; η_c in 16 decay channels @ 13 different energies!

$\pi^{\pm}h_c$ structure observed: $Z_c(4020)$

M = **4022.9±0.8±2.7** MeV/c^2

Γ = **7.9±2.7±2.6** MeV

$e^-e^+ \to \pi^0\pi^0 h_c(1P)$:

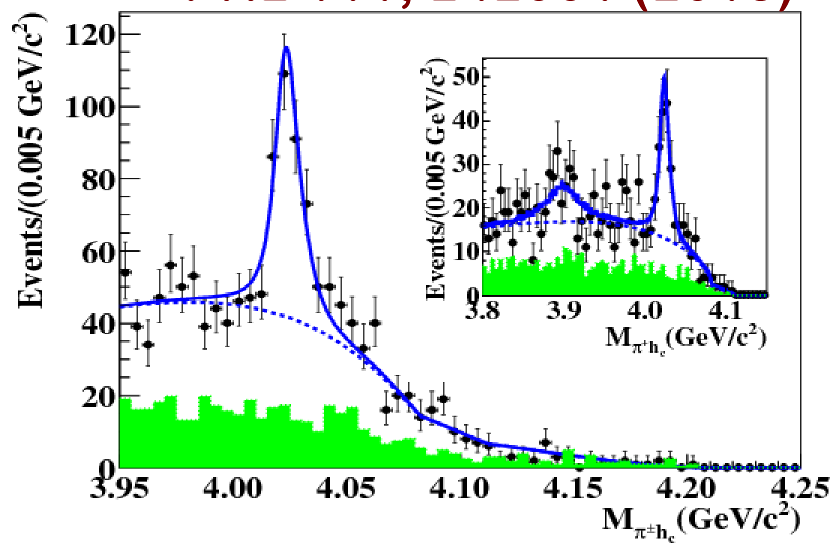
M = **4023.9 ± 2.2 ± 3.8** MeV/c^2

Γ – fixed

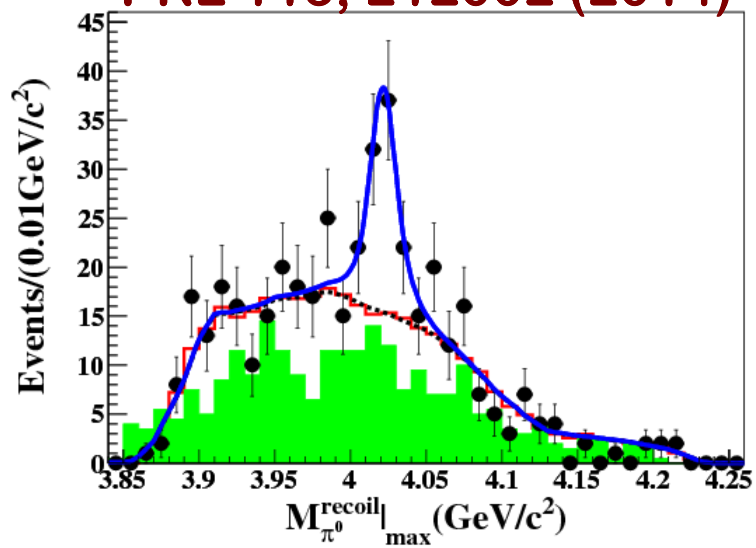
Another isospin triplet

established!

PRL 111, 242001 (2013)



PRL 113, 212002 (2014)

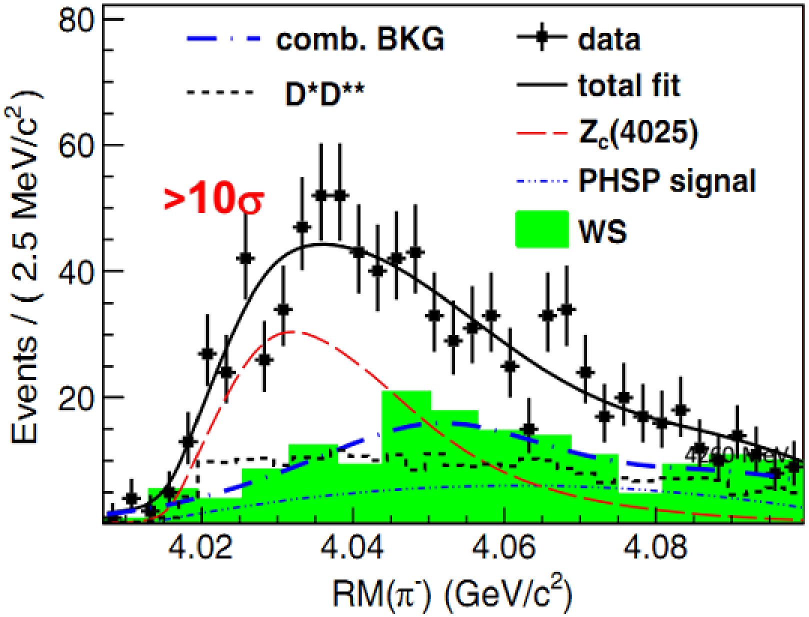


$Z_c(4020)$ close to D^*D^* threshold

$e^+e^- \rightarrow \pi^- (D^*\overline{D^*})^+ + c.c.$ at $\sqrt{s} = 4.26\ GeV$

PRL 112, 132001 (2014)

Tag a D* and `bachelor` π^- :
look for recoil mass against π^-
after reconstructing π^0 to suppress
the background.



$D^*\overline{D^*}$ structure observed $Z_c(4025)$:

M = **4026.3 ± 2.6 ± 3.7** MeV/c²

Γ = **24.8 ± 5.6 ± 7.7** MeV

If $Z_c(4020)$ and $Z_c(4025)$ are the same, coupling to $D^*\overline{D^*}$ much stronger compared to πh_c:

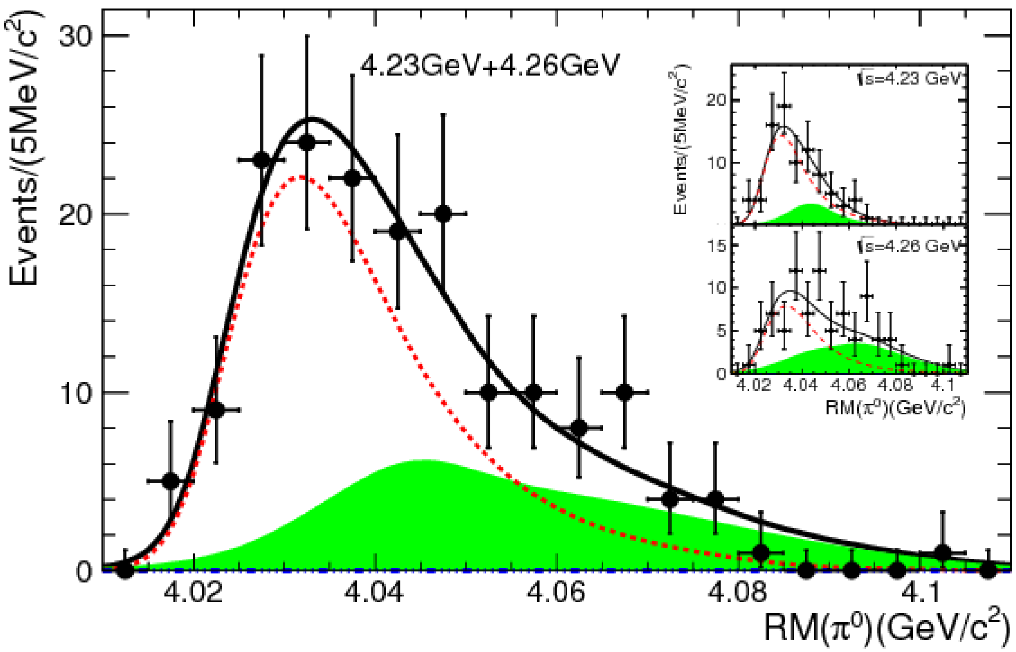
$$\sigma[e^+e^- \rightarrow (D^*\bar{D}^*)^\pm\pi^\mp] = 137 \pm 9 \pm 15 \text{ pb at } 4.26 \text{ GeV}$$

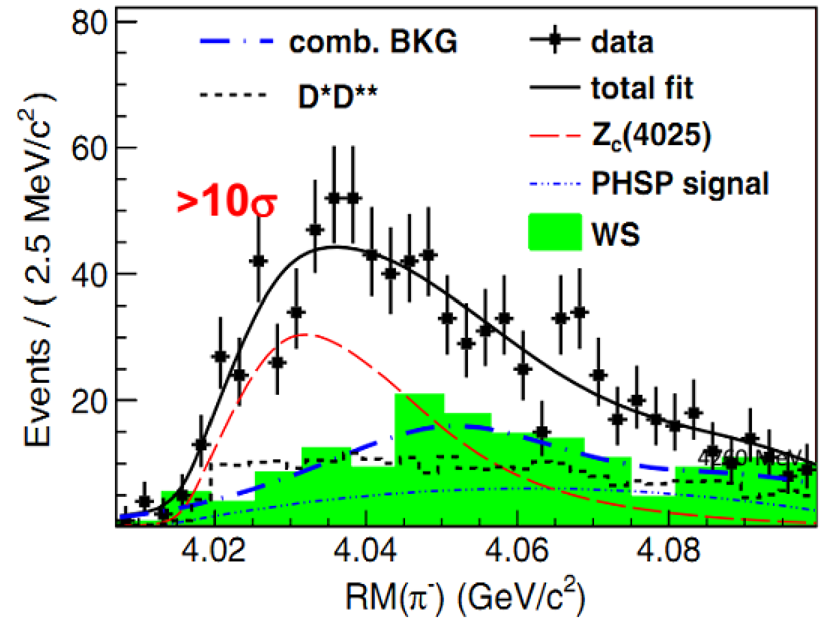
$$\frac{\sigma[e^+e^- \rightarrow \pi^\pm Z_c(4025)^\mp \rightarrow (D^*\bar{D}^*)^\pm\pi^\mp]}{\sigma[e^+e^- \rightarrow (D^*\bar{D}^*)^\pm\pi^\mp]} = 0.65 \pm 0.09 \pm 0.06$$

$Z_c(4020)$ close to D^*D^* threshold

PRL 112, 132001 (2014)

Neutral partner: arXive: 1507.02404



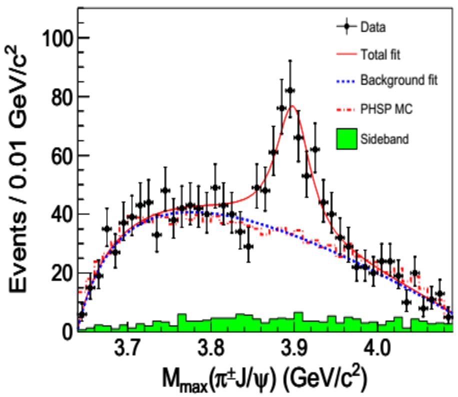


If $Z_c(4020)$ and $Z_c(4025)$ are the same, coupling to $D^*\overline{D^*}$ much stronger compared to πh_c:

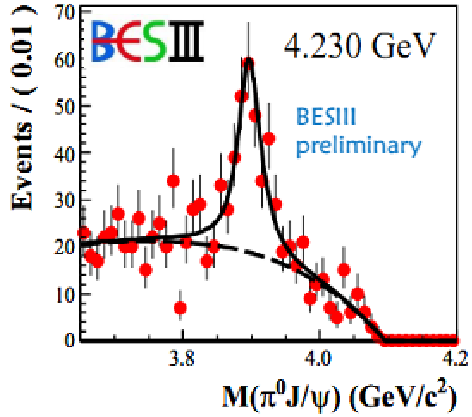
$$\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}] = 137 \pm 9 \pm 15 \text{ pb at } 4.26 \text{ GeV}$$

$$\frac{\sigma[e^+e^- \to \pi^{\pm} Z_c(4025)^{\mp} \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]}{\sigma[e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}]} = 0.65 \pm 0.09 \pm 0.06$$

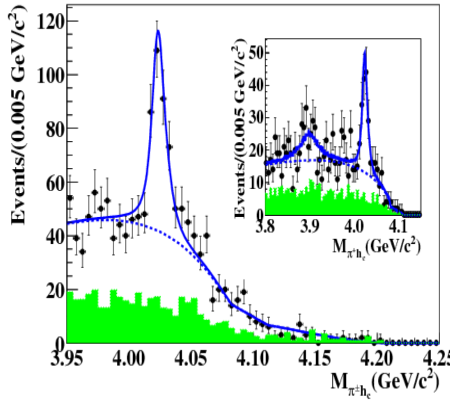
What we know so far!



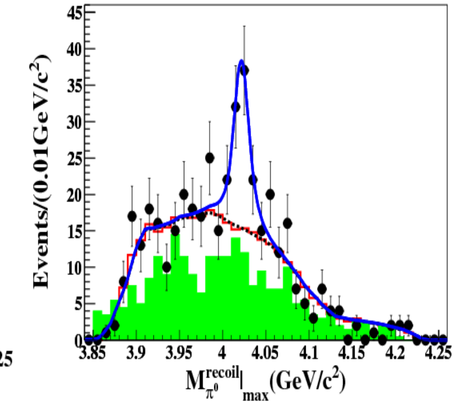
$e^+e^- \to \pi^-\pi^+J/\psi$



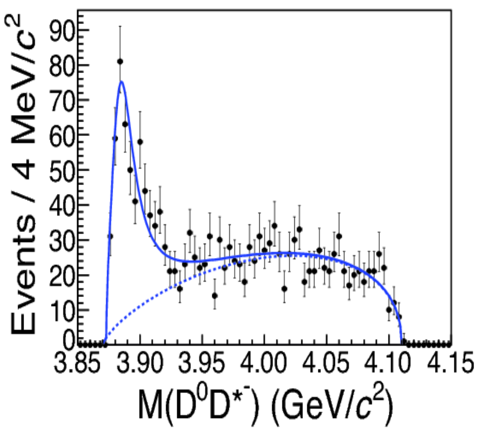
$e^+e^- \to \pi^0\pi^0J/\psi$



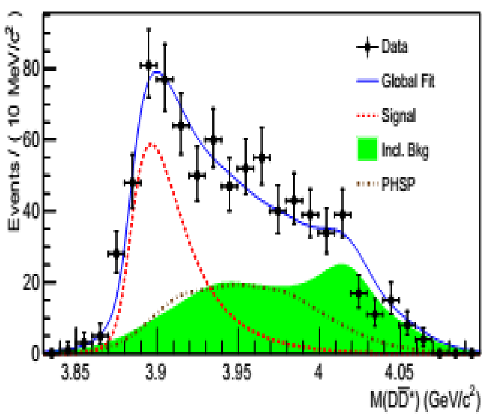
$e^+e^- \to \pi^-\pi^+h_c$



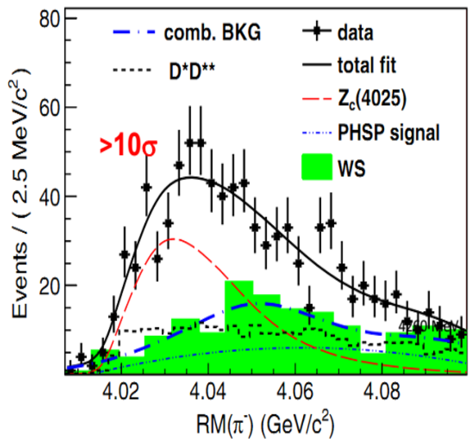
$e^+e^- \to \pi^0\pi^0h_c$



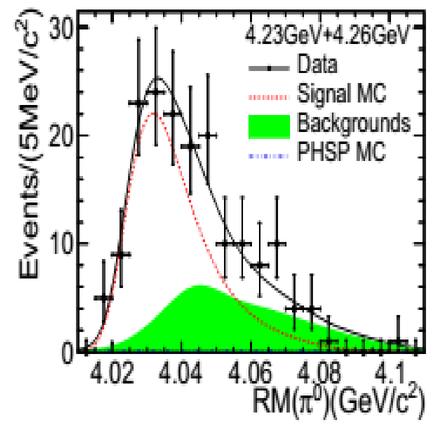
$e^+e^- \to \pi^- (D\overline{D^*})^+$



$e^+e^- \to \pi^0 (D\overline{D^*})^0$



$e^+e^- \to \pi^- (D^*\overline{D^*})^+$



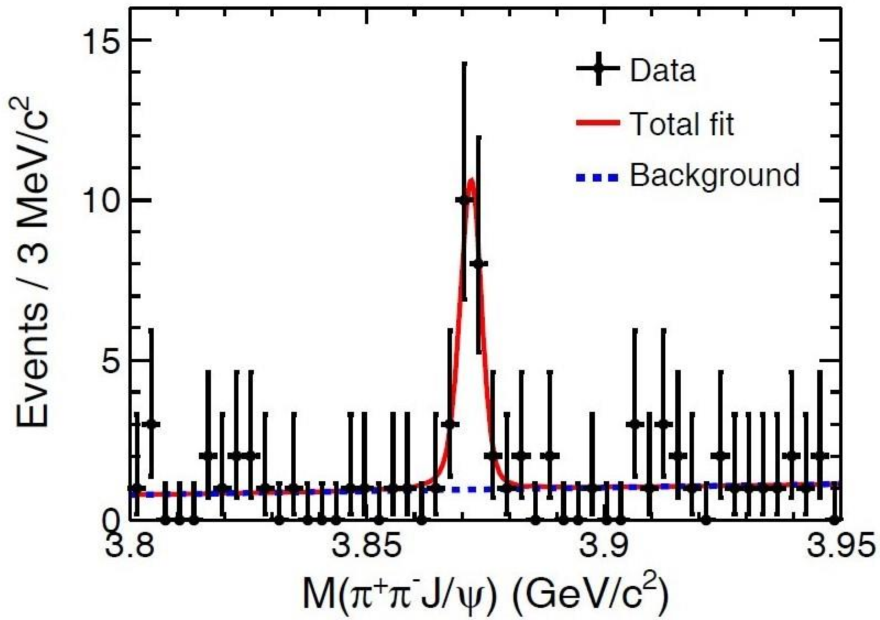
$e^+e^- \to \pi^0 (D^*\overline{D^*})^0$

$Z_c(3900)^+$? **$Z_c(3900)^0$?** **$Z_c(4020)^+$?** **$Z_c(4020)^0$?**

X(3872) @ BESIII

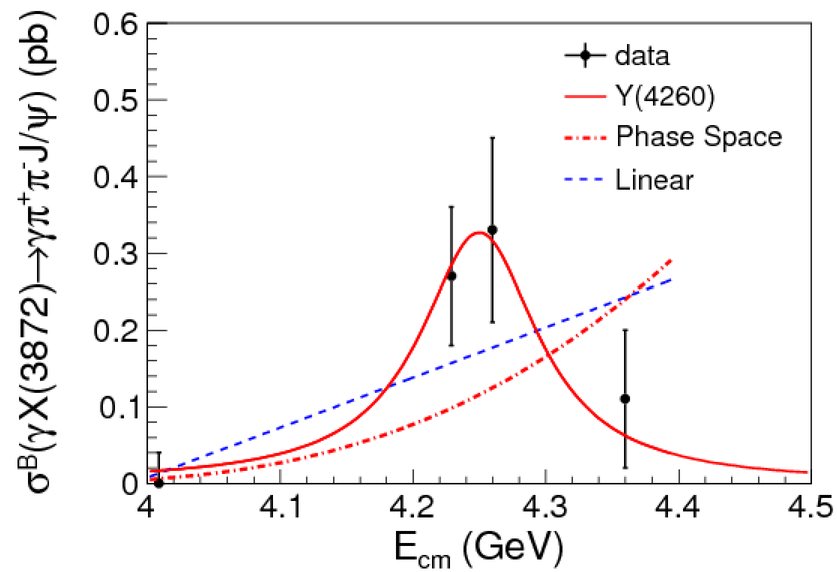
Strong evidence for
X(3872) → ππ J/ψ

M = 3871.9 ± 0.7 ± 0.2 MeV/c²



PRL 112, 092001 (2014)

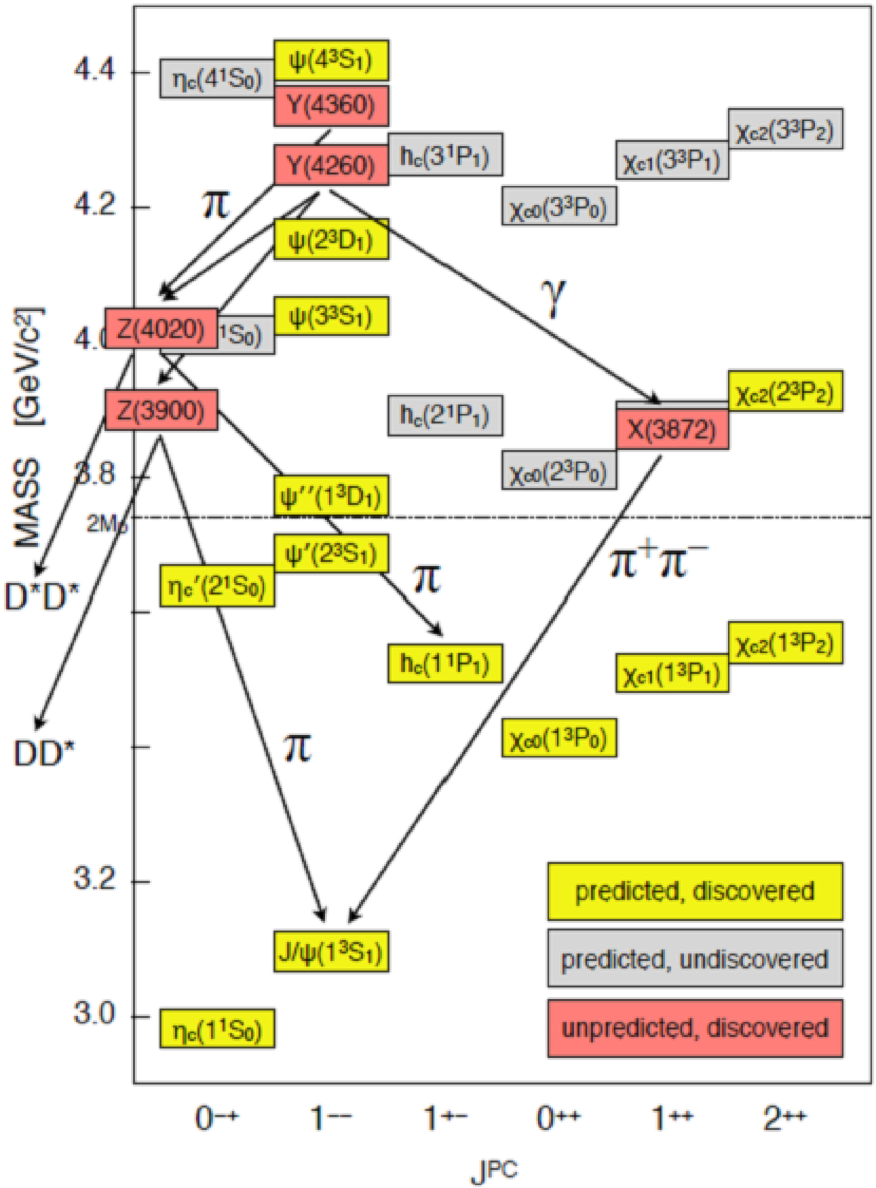
Suggestive of
Y(4260) → γ X(3872)



- ❖ **New mode of production of X(3872) and Y(4260) decay?**

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

$\frac{\sigma(e^+e^-\to\gamma X(3872))}{\sigma(e^+e^-\to\pi^+\pi^- J/\psi)} \sim$ 10% Large transition ratio !



Cross section measurements completed or ongoing (not a comprehensive list):

- $e^-e^+ \to \omega\chi_0$

  no $\omega\chi_1$ or $\omega\chi_2$
- $e^-e^+ \to \eta J/\psi$ & $\eta' J/\psi$
- $e^-e^+ \to \eta\pi^0 J/\psi$
- $e^-e^+ \to \gamma\phi J/\psi$
- $e^-e^+ \to \gamma\chi_{cJ}$
- …

What is the nature of multi-q objects?

E. Swanson: HADRON 2015

$\boxed{Q\bar{Q}}$ Loop Corrections Instantons

$\boxed{Q\bar{Q}g}$

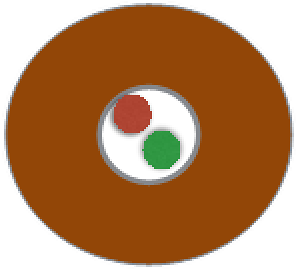
$\boxed{o\pi e}$?

chiral solitons

chiral doublers ?

hadrocharmonium

?

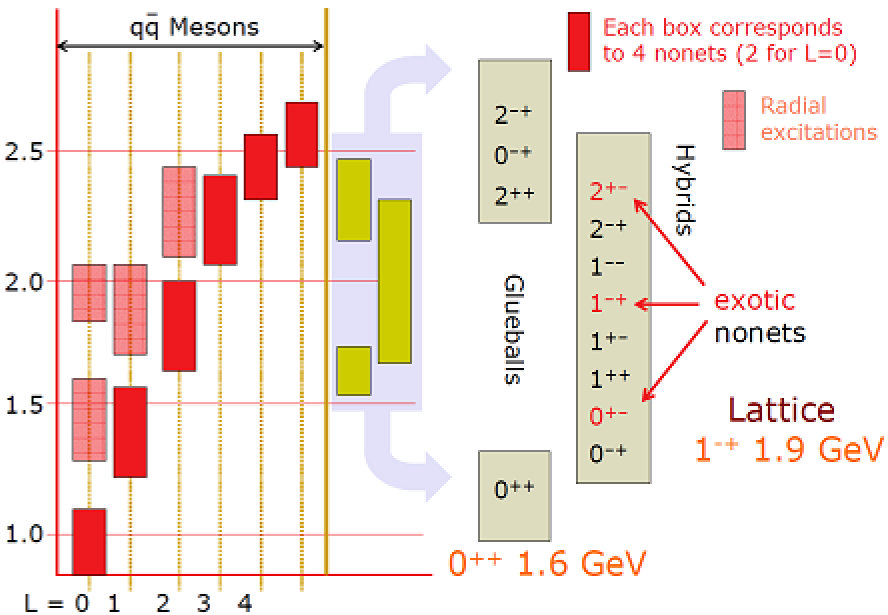


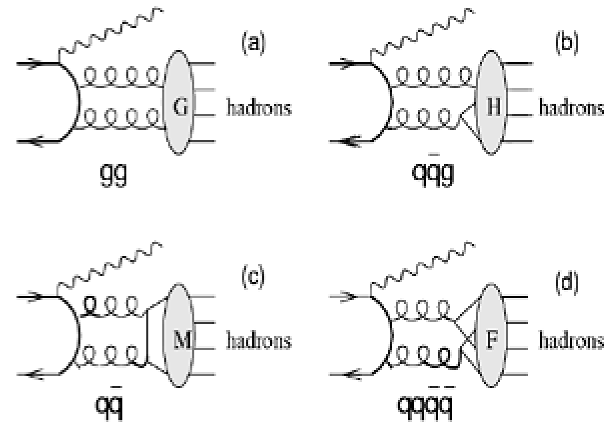
diquarks

cusps

"Modern Exotic Hadrons" INT workshop starts in a couple of weeks!

LH charmonium decays - hunting ground for light glueballs and hybrids





$\Gamma(J/\psi \to \gamma G) \sim O(\alpha\alpha_s^2), \Gamma(J/\psi \to \gamma H) \sim O(\alpha\alpha_s^3),$

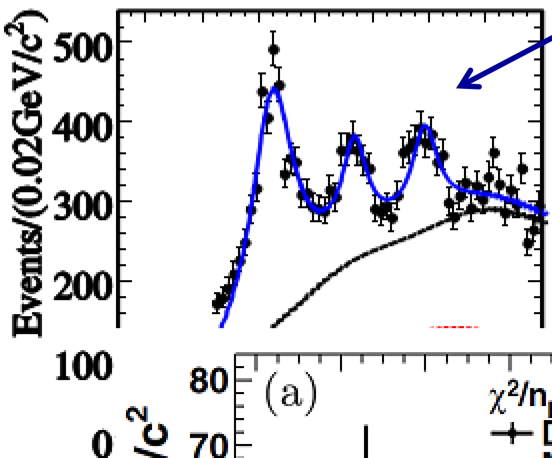
$\Gamma(J/\psi \to \gamma M) \sim O(\alpha\alpha_s^4), \Gamma(J/\psi \to \gamma F) \sim O(\alpha\alpha_s^4)$

- **"Gluon-rich" process**
- **Clean high statistics data samples from e+e- production**
- **I(J^{PC}) filter in strong decays of charmonium**

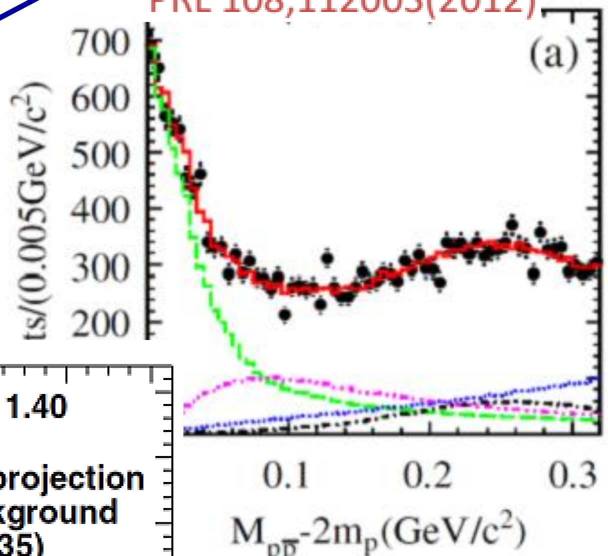
Light-hadrons: X(???) $J^P = ?^?$

X(1835), X(2120), X(2370)

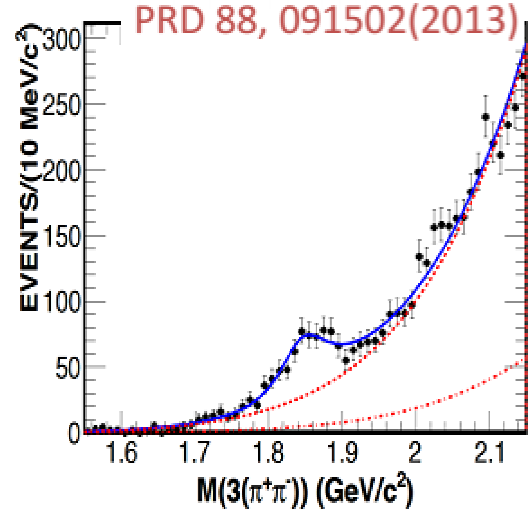
PRL 106, 072002(2011)

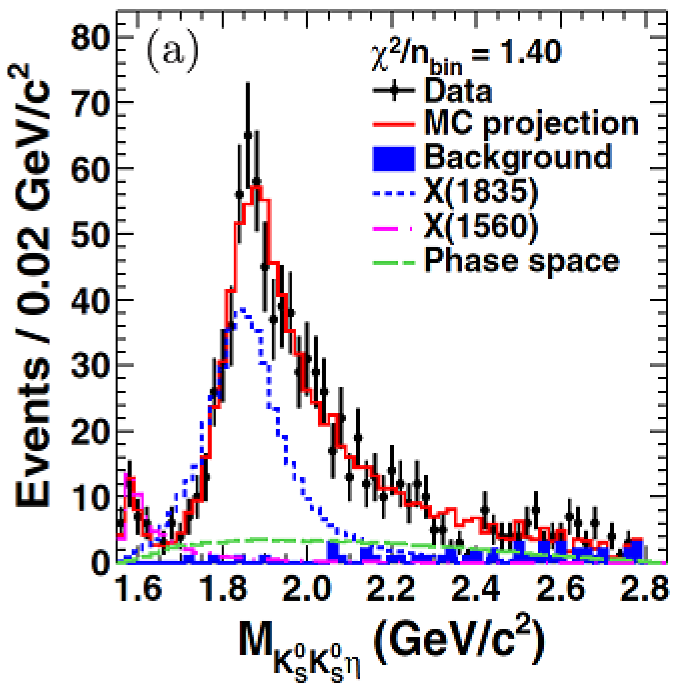


PRL 108,112003(2012)



PRD 88, 091502(2013)





X(1835)→$K_S K_S \eta$ $J^{PC}=0^{-+}$, (> 12.9 σ)

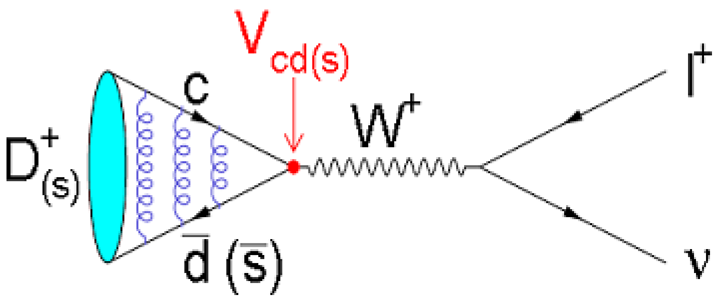
X(1560) → $f_0(980)\eta$: $J^{PC}=0^{-+}$, (> 8.9 σ)

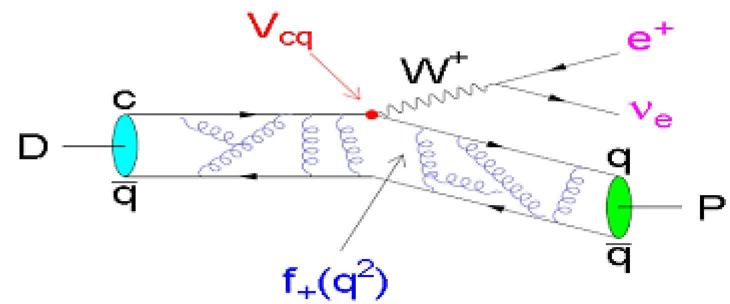
Mass and width consistent with those of $\eta(1405)$ / $\eta(1475)$ within 2.0 σ

This just an example, a lot of important analyses ongoing …

Charm physics @ BESIII

Leptonic and semi-leptonic D decays are ideal window to probe for weak and strong effects





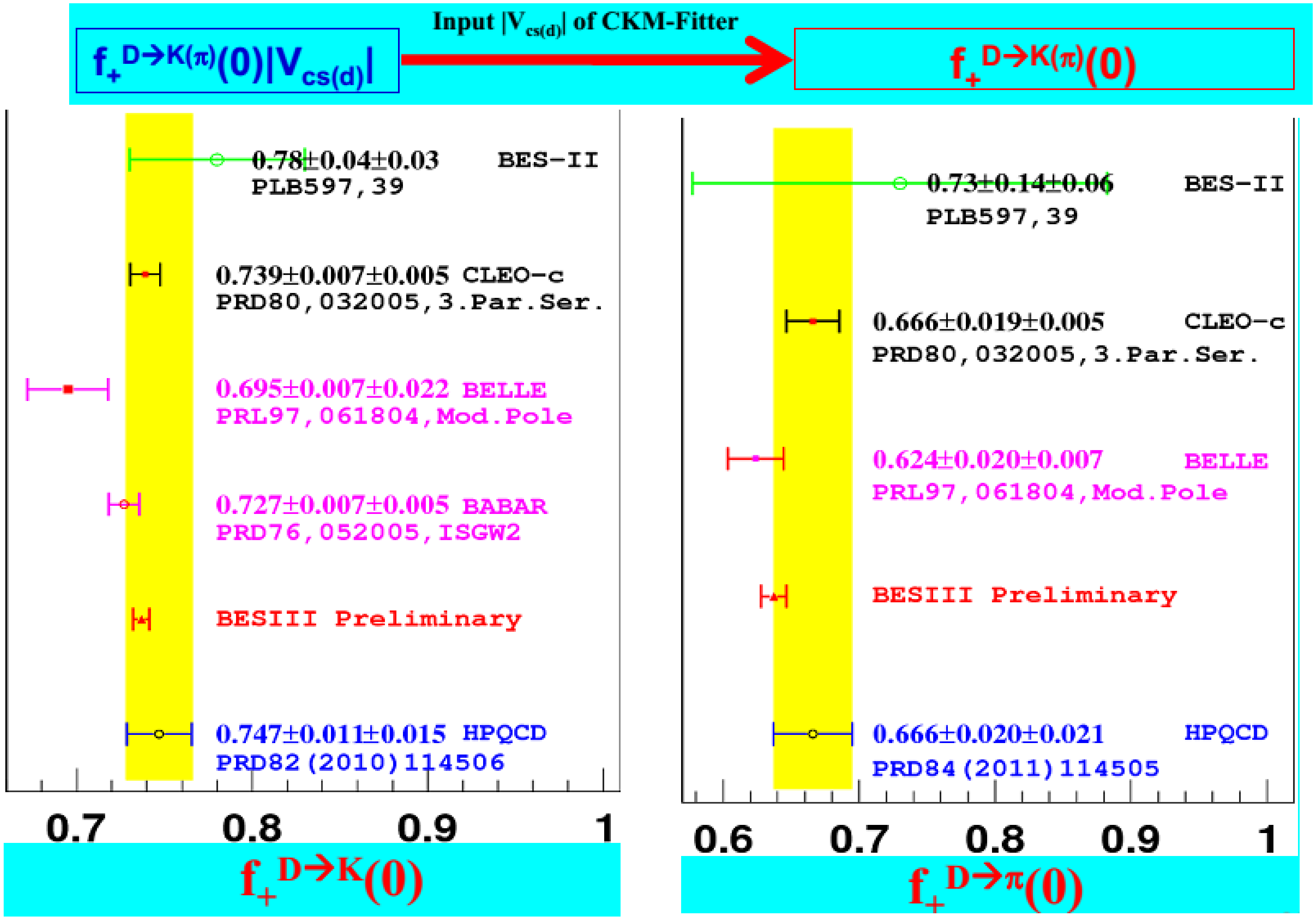
$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

$$\frac{d\Gamma}{dq^2} = X\frac{G_F^2|V_{cd(s)}|^2}{24\pi^3}p^3|f_+(q^2)|^2$$

- **Precision measurements of decay constants f_{D+}, f_{Ds+}, form factors $f_+^{D\to K(\pi)}(q^2)$ of semi-leptonic decays of $D_{(s)}$ mesons will calibrate LQCD calculations at higher accuracy.**

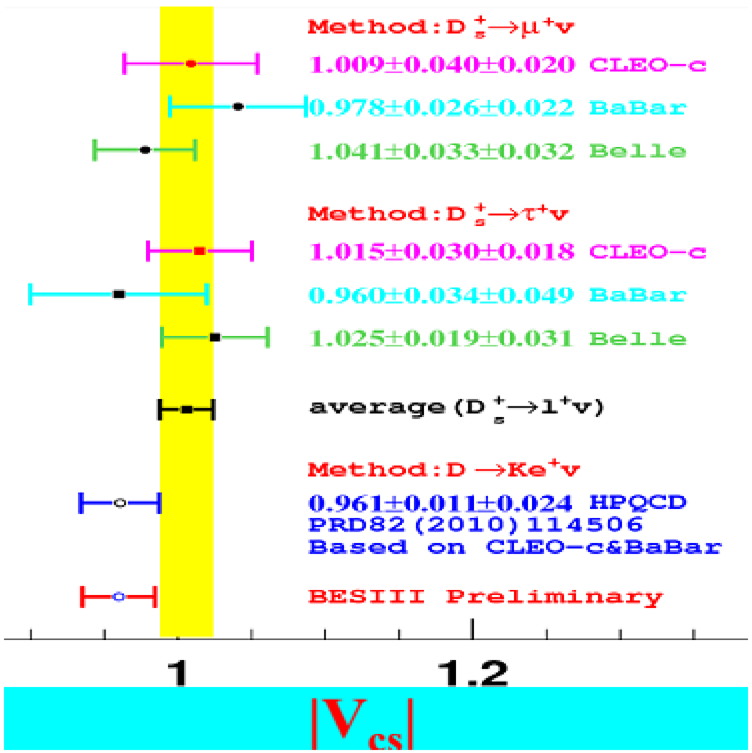
- **Recently improved LQCD calculations on $f_{D(s)+}$[0.5(0.5)%], $f_+^{D\to K(\pi)}(0)$ [2.4(4.4)%] provide good chance to precisely measure the CKM matrix element $|V_{cs(d)}|$, which are important for the unitarity test of the CKM matrix and search for NP beyond the SM**

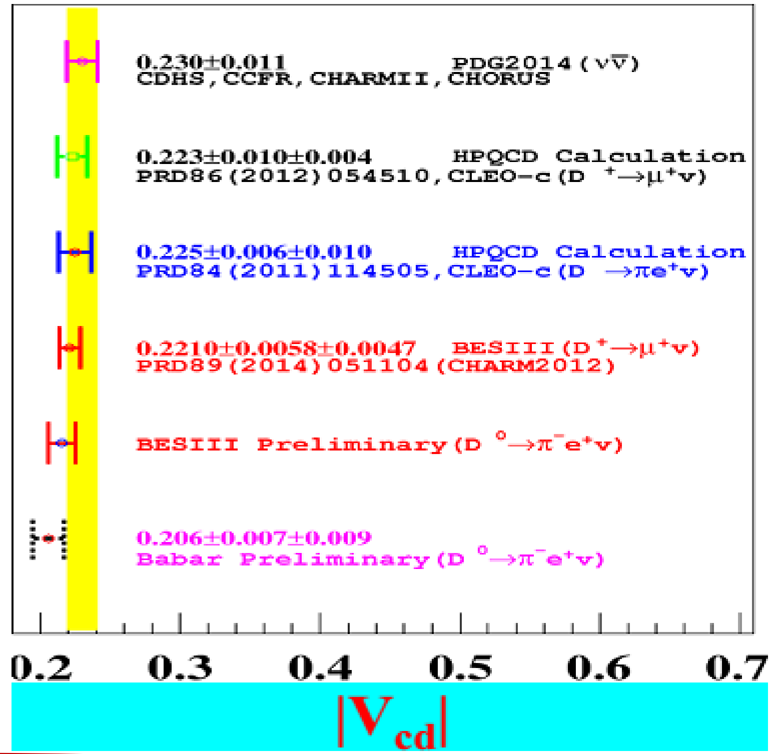
Improved form factor $f_+ \rightarrow D^{K(\pi)}(0)$ @ BESIII



Improved $|V_{cs(d)}|$ @ BESIII

- **Method 1** $B[D_{(s)}^{+} \rightarrow l^{+}\nu]$ — Input t_{D+}, m_{D+}, $m_{\mu+}$ on PDG and LQCD calculated $f_{D(s)+}$ → $|V_{cd(s)}|$
- **Method 2** $f_{+}^{D\rightarrow K(\pi)}(0)|V_{cs(d)}|$ — Input $f^{D\rightarrow K(\pi)}_{+}(0)$ of LQCD → $|V_{cs(d)}|$

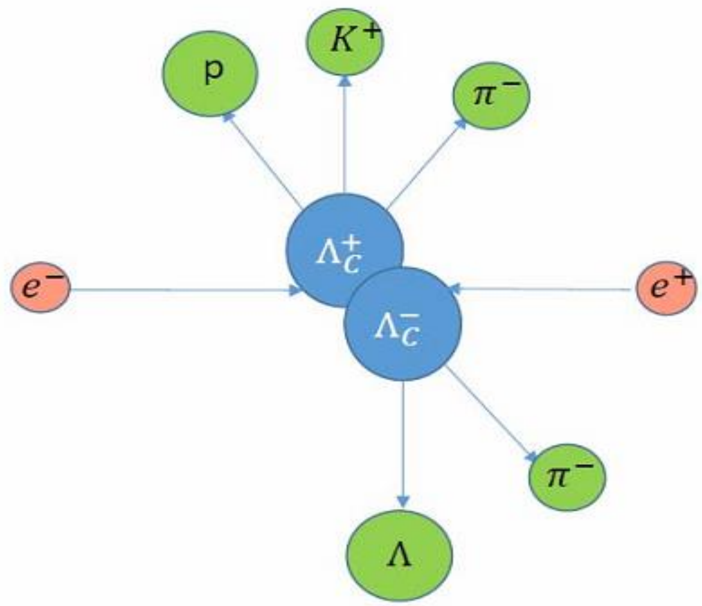




- **BESIII will take 3 fb^{-1} data at 4.17 GeV in 2016, improved measurement of f_{Ds+} and $|V_{cs}|$ by $D_s^{+} \rightarrow l^{+}\nu$ is expected in the near future**

Λ_c @ BESIII

mode
$\Lambda_c \to pK_s$
$\Lambda_c \to pk^-\pi^+$
$\Lambda_c \to pK_S\pi^0$
$\Lambda_c \to pK_S\pi^+\pi^-$
$\Lambda_c \to pk^-\pi^+\pi^0$
$\Lambda_c \to \Lambda\pi^+$
$\Lambda_c \to \Lambda\pi^+\pi^0$
$\Lambda_c \to \Lambda\pi^+\pi^-\pi^+$
$\Lambda_c \to \Sigma^0\pi^+$
$\Lambda_c \to \Sigma^-\pi^0$
$\Lambda_c \to \Sigma^-\pi^+\pi^-$
$\Lambda_c \to \Sigma^-\omega$



12 modes used in reconstruction of Λ_c covers ~1/3 of the total decays.

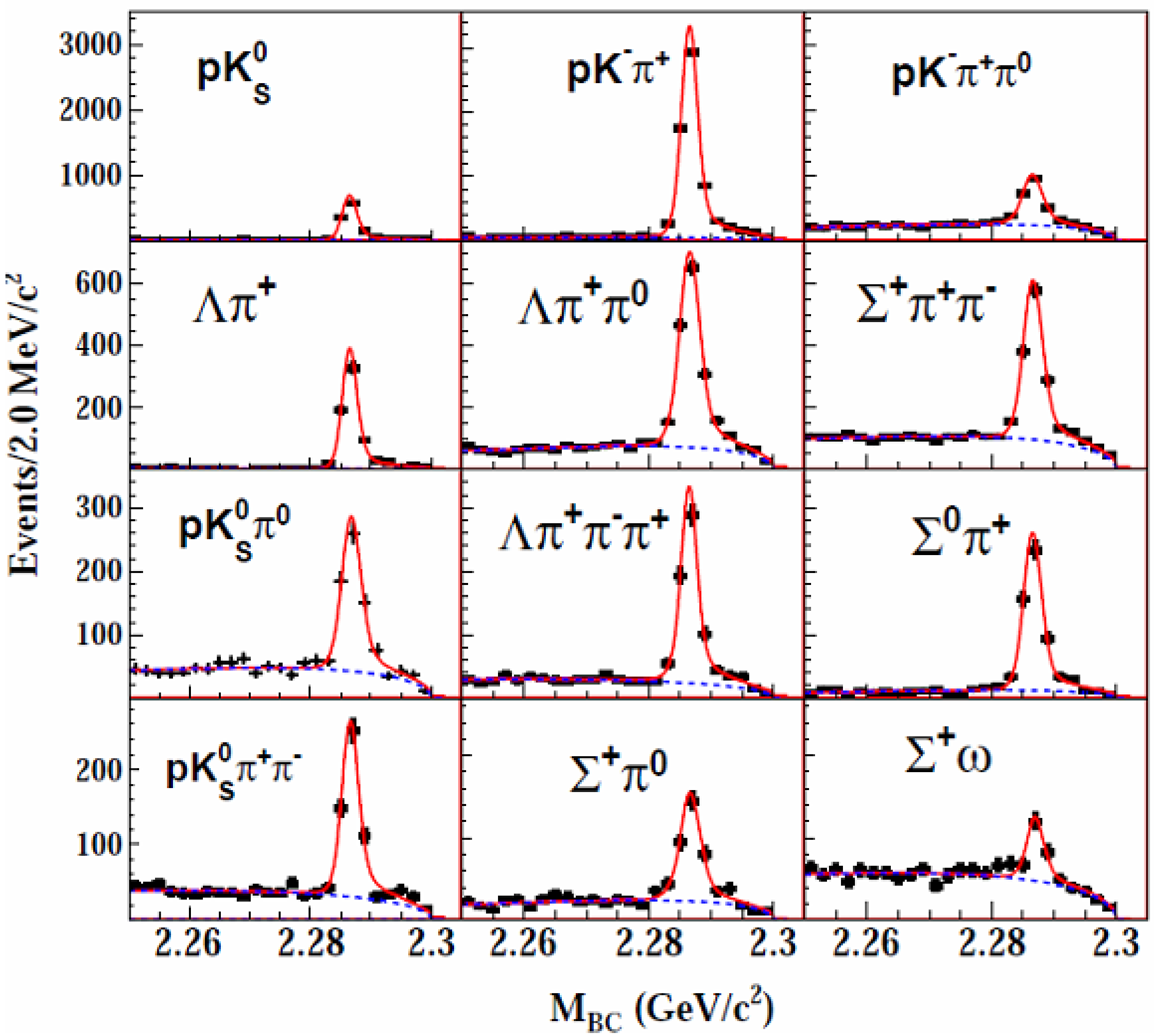
Constructing particles from final state particles:

- $K_S \to \pi^+\pi^-$
- $\pi^0 \to \gamma\gamma$
- $\Lambda \to p\pi^-$
- $\Sigma^0 \to \Lambda\gamma$
- $\Sigma^+ \to p\pi^0$
- $\omega \to \pi^+\pi^-\pi^0$

$\Lambda^+{}_c \to \Lambda e^+\nu_e$ is c→ slν dominated, provides important info for:

- testing theoretical predictions for B($\Lambda^+{}_c \to \Lambda e^+\nu_e$)
- LQCD calibration
- additional information for determining CKM elements

Single Tag (ST)

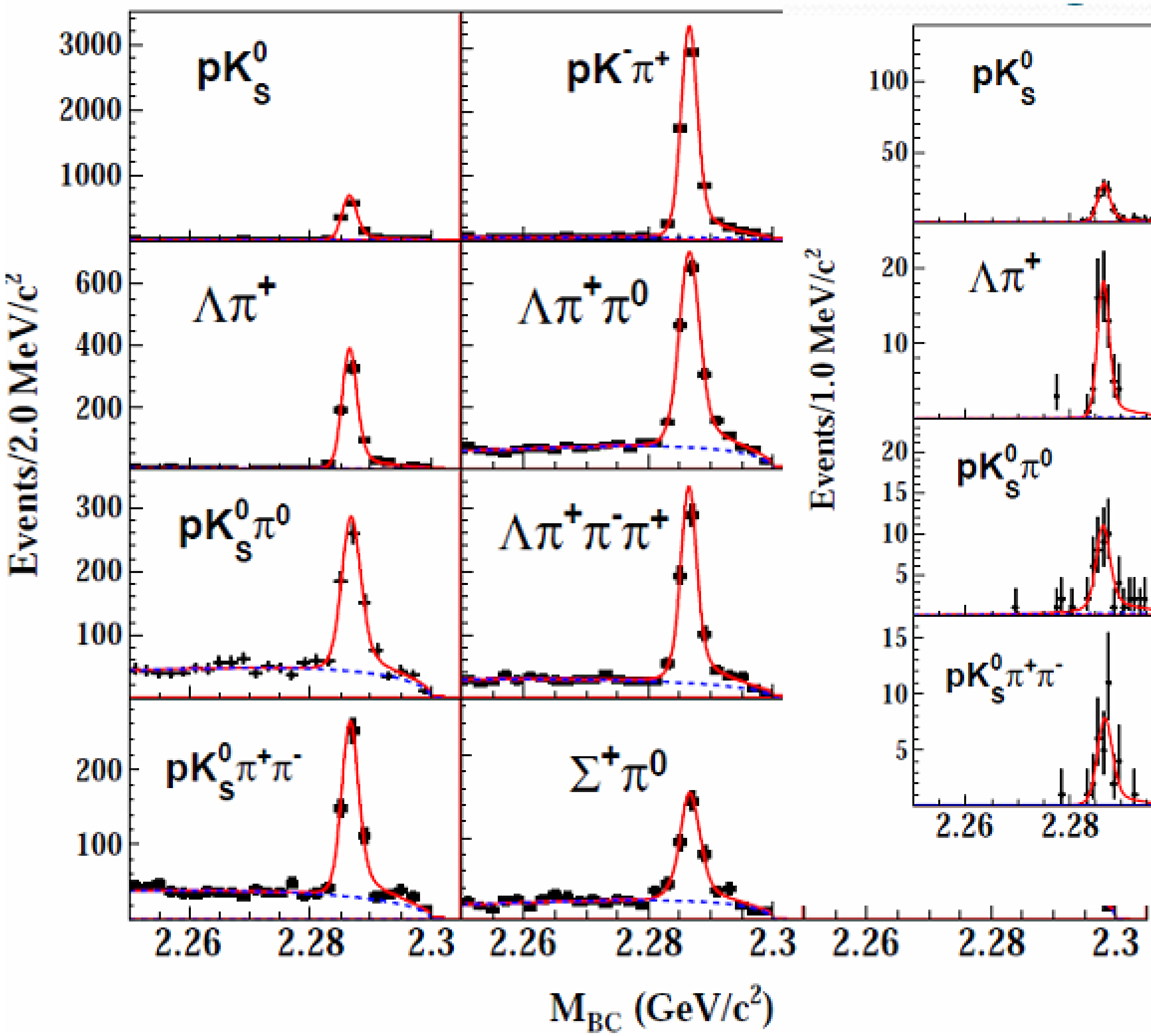


Mode	N_j^{ST}
pK^0_S	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK^0_S\pi^0$	558 ± 33
$pK^0_S\pi^+\pi^-$	485 ± 29
$pK^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	522 ± 27
$\Sigma^+\pi^0$	309 ± 24
$\Sigma^+\pi^+\pi^-$	1156 ± 49
$\Sigma^+\omega$	157 ± 22

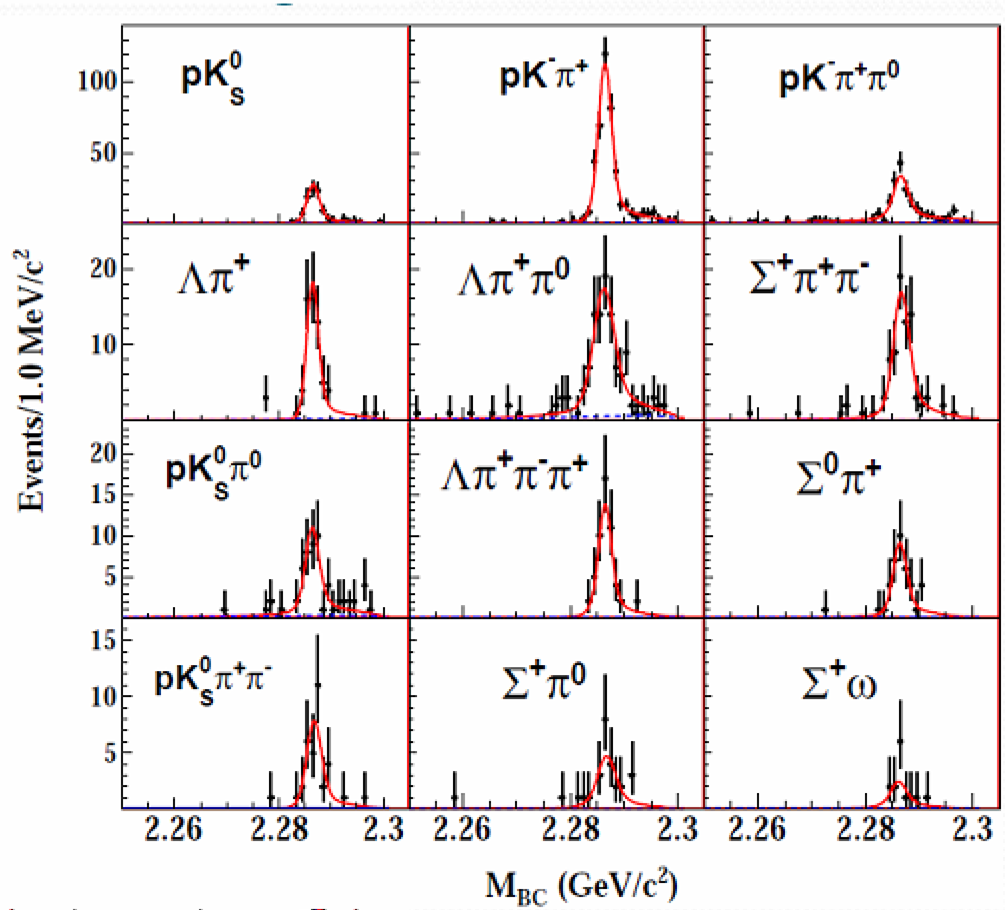
ST sum:~1.5K

Λ_c @ BESIII

Single Tag (ST)



Double Tag (DT)



ST sum:~1.5K

We perform a simultaneousfit to all tag modes, taking into account the correlations.

BESIII ***preliminary***

Decay modes	global fit $\mathcal{B}$	PDG $\mathcal{B}$ [1]	Belle $\mathcal{B}$ [6]
pK_S	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

stat. and sys. err

- ✓ **$\mathcal{B}(pK^-\pi^+)$: BESIII precision comparable with Belle's result**
- ✓ **BESIII rate $\mathcal{B}(pK^-\pi^+)$ is smaller**
- ✓ **Improved precision of the other 11 modes significantly**

Dark photon & light Higgs

arXiv.org > hep-ex > arXiv:1510.01641

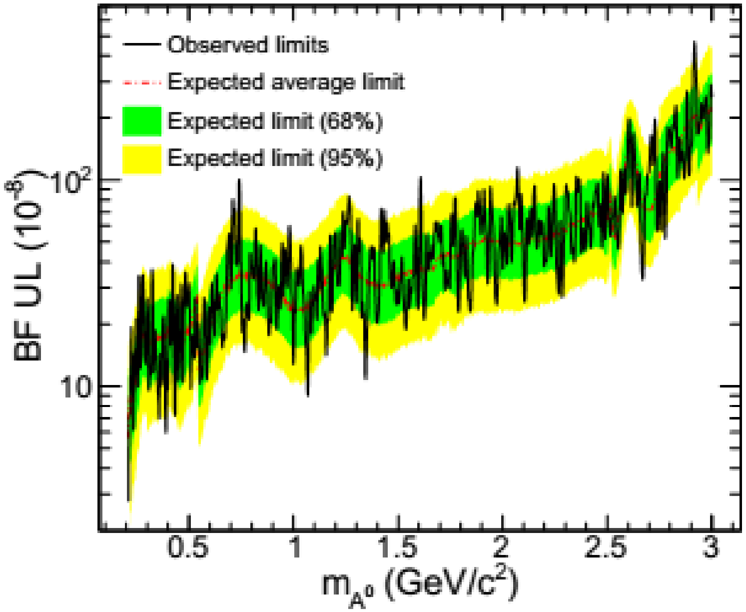
High Energy Physics - Experiment

Search for a light CP-odd Higgs boson in the radiative decays of J/psi

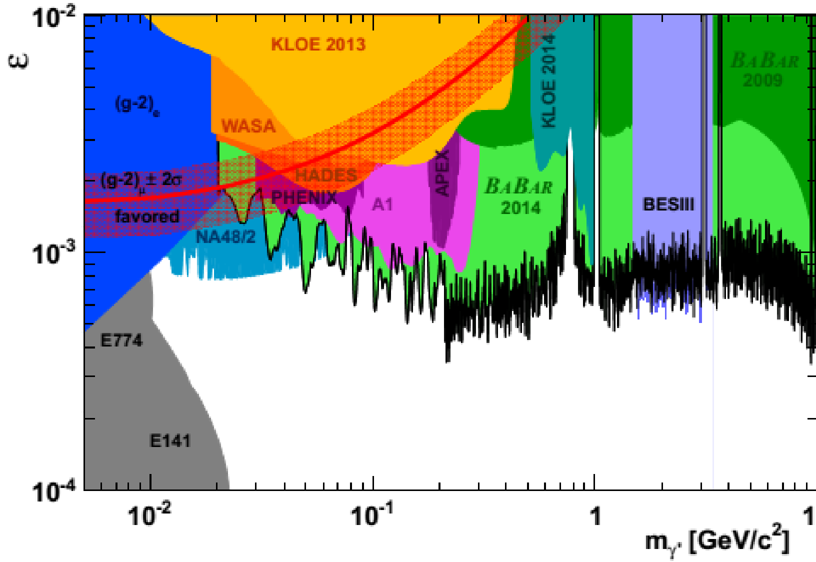
The BESIII Collaboration, M. Ablikim

(Submitted on 6 Oct 2015 (v1), last revised 10 Oct 2015 (this version, v2))

We search for a light Higgs boson A^0 in the fully reconstructed decay chain of $J/\psi \to \gamma A^0$, $A^0 \to \mu^+\mu^-$ using $(225.0 \pm 2.8) \times 10^6$ J/ψ events collected by the BESIII experiment. The A^0 is a hypothetical CP-odd light Higgs boson predicted by many extensions of the Standard Model including the Next-to-Minimal Supersymmetric Standard Model. We find no evidence for A^0 production and set 90% confidence-level upper limits on the product branching fraction $\mathcal{B}(J/\psi \to \gamma A^0) \times \mathcal{B}(A^0 \to \mu^+\mu^-)$ in the range of $(2.8 - 471.4) \times 10^{-8}$ for $0.212 \le m_{A^0} \le 3.0$ GeV/c^2. The new limits are an order of magnitude below our previous results and can exclude a large portion of the parameter space of the new physics models.



Dark photon exclusion @ BESIII



What else can we do @ BESIII?

UH contribution!

Leptonic world: τ-mass

m_τ is a fundamental parameter in SM:

$$\frac{B(\tau \to e\nu\bar{\nu})}{\tau_\tau} = \frac{g_\tau^2 m_\tau^5}{192\pi^3}$$

$$Q = \frac{m_e + m_\mu + m_\tau}{(\sqrt{m_e} + \sqrt{m_\mu} + \sqrt{m_\tau})^2} \approx \frac{2}{3}$$

Test lepton universality: $g_e = g_\mu = g_\tau$

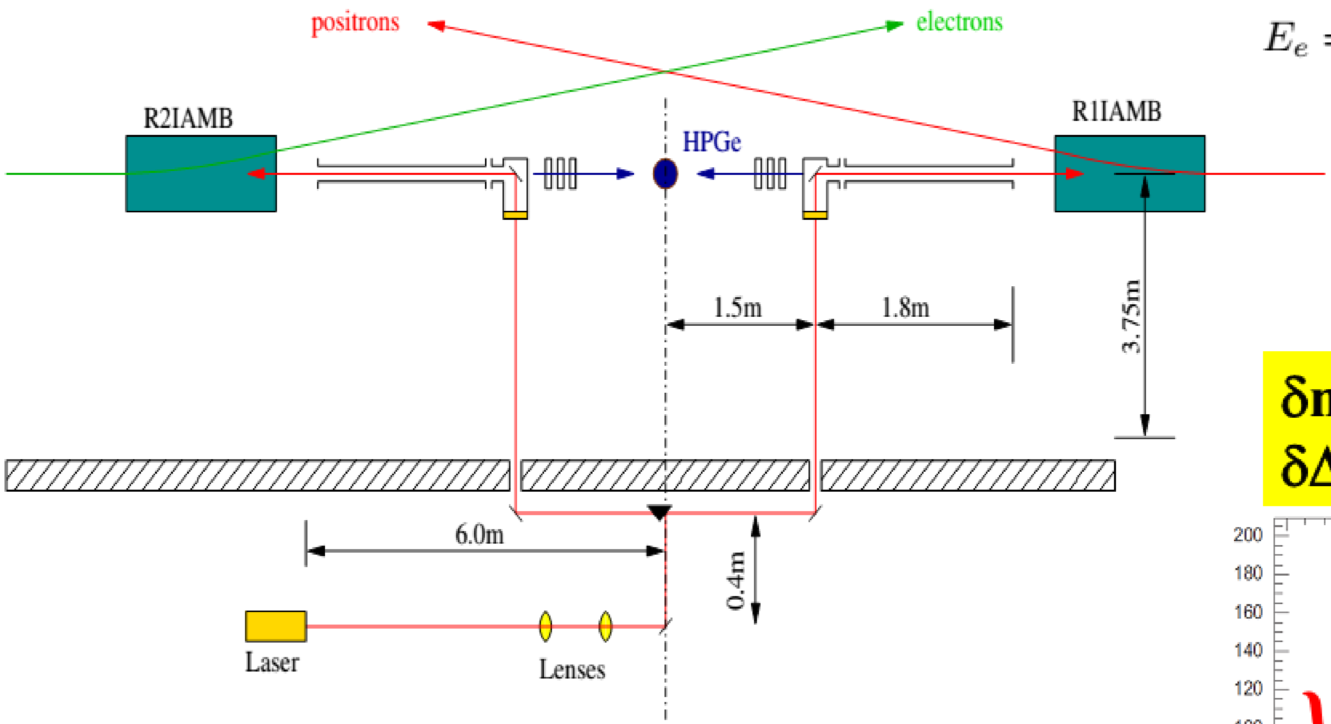
$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{B(\tau \to e\nu\bar{\nu})}{B(\mu \to e\nu\bar{\nu})}(1+F_W)(1+F_\gamma)$$

Heaviest lepton, known with least precision:

- **M_e=0.510998910±0.000000013 (2.6×10^{-8})**
- **M_μ=105.658367±0.000004 (3.8×10^{-8})**
- **M_τ=1776.82 ±0.16 (9.0×10^{-5})**

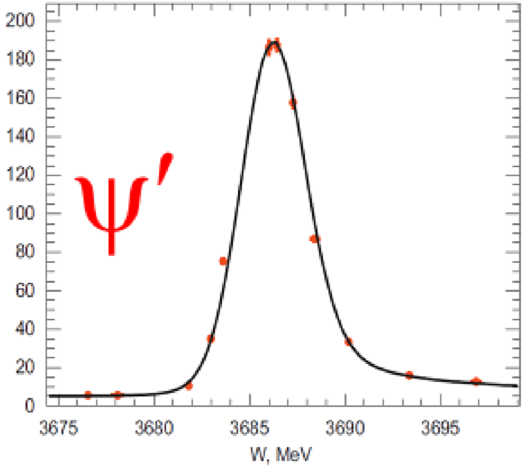
Threshold scan: need BEMS!

Measure Compton scattered photon energy with high precision!



$$E_e = \frac{E_\gamma}{2}\left[1 + \sqrt{1 + \frac{m_e^2}{\mathcal{E}_\gamma E_\gamma}}\right]$$

$\delta m_{\psi'}/m_{\psi'} = 2 \times 10^{-5}$
$\delta\Delta / \Delta = 6\%$.



NIM A659, 21 (2011)

Analysis: 18 scan points

7 @ J/ψ **4 @ τ** **7 @ ψ(2S)**

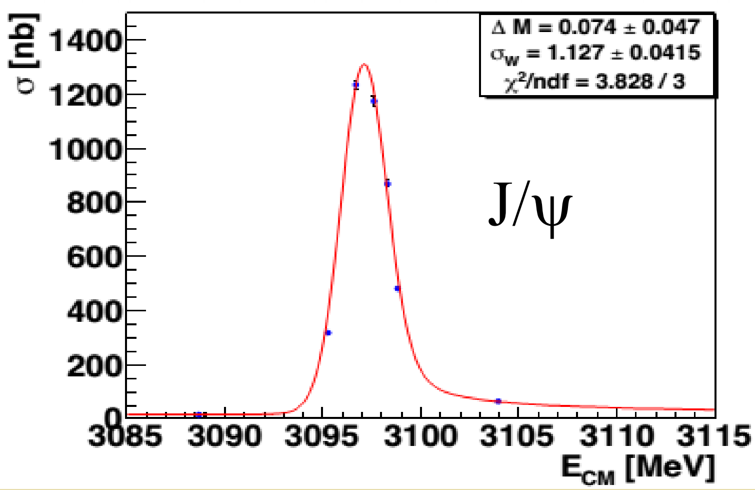
using only 1/5 of proposed data = 24pb^{-1}

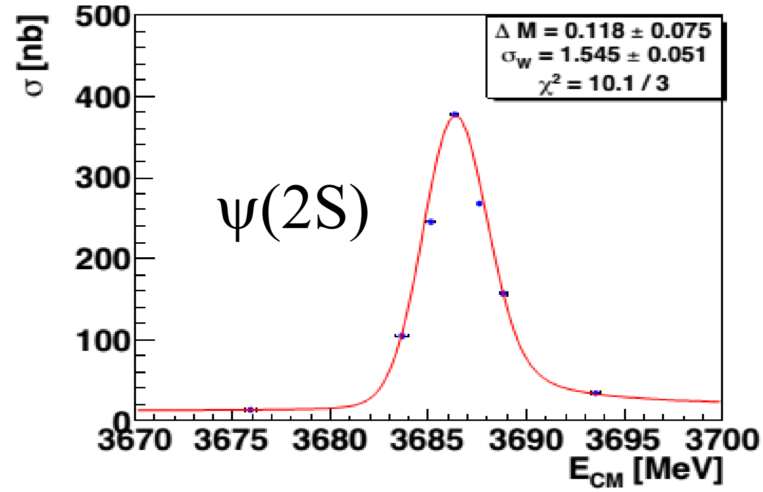
Ingredients:

$\Delta\mathcal{L}/\mathcal{L}<2\%$

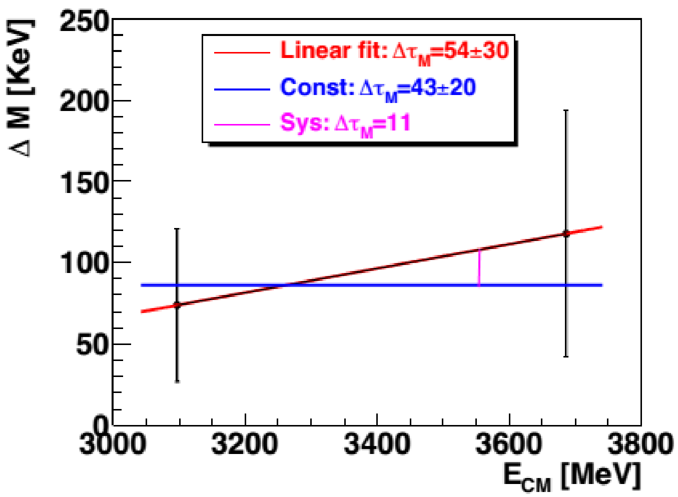
- **Luminosity** from **γγ** and **Bhabha** events (Fred)
- **Hadronic cross-section**: **energy scale** and **energy spread** from resonance line shapes (Mihajlo)
- **τ cross-section**: **13 two-prong** decay modes, **ee, eμ, eπ, eK, μμ, μK, πK, KK, eρ, μρ and πρ** (with accompanying neutrinos implied) (Tao)

Hadronic cross section

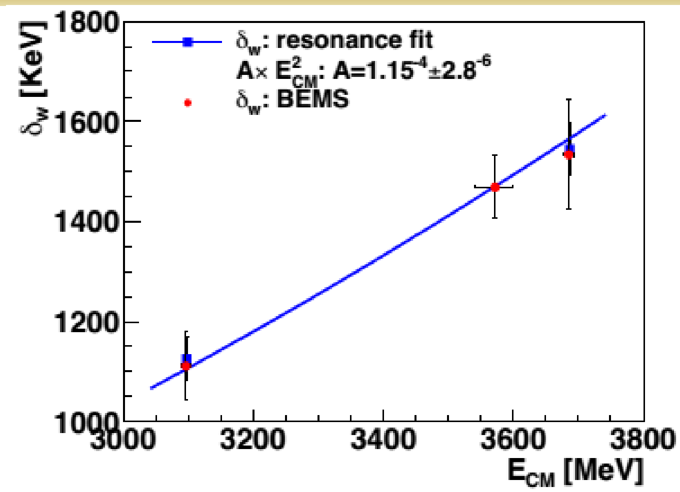




Extrapolate mass correction, ΔM and energy spread $\delta\omega$ to τ region:



PRD 90, 012001

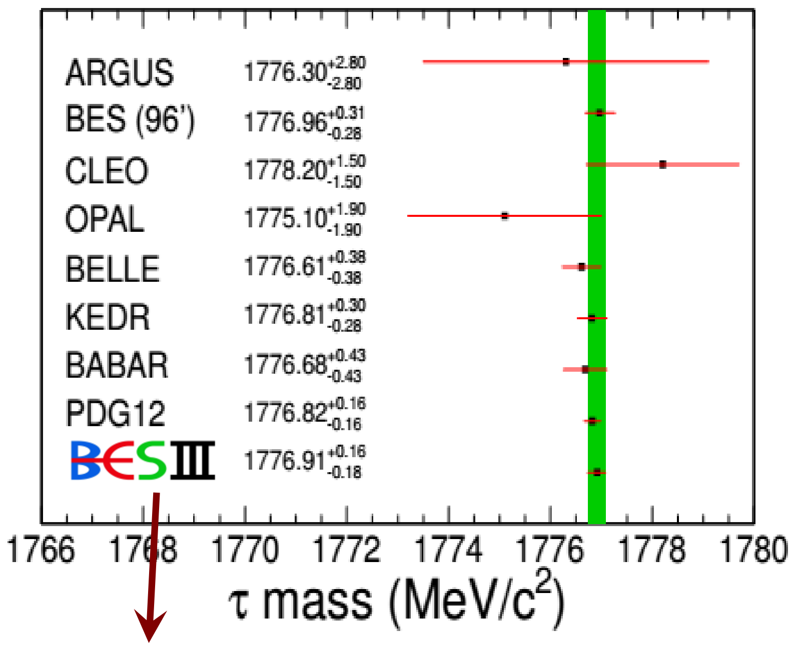


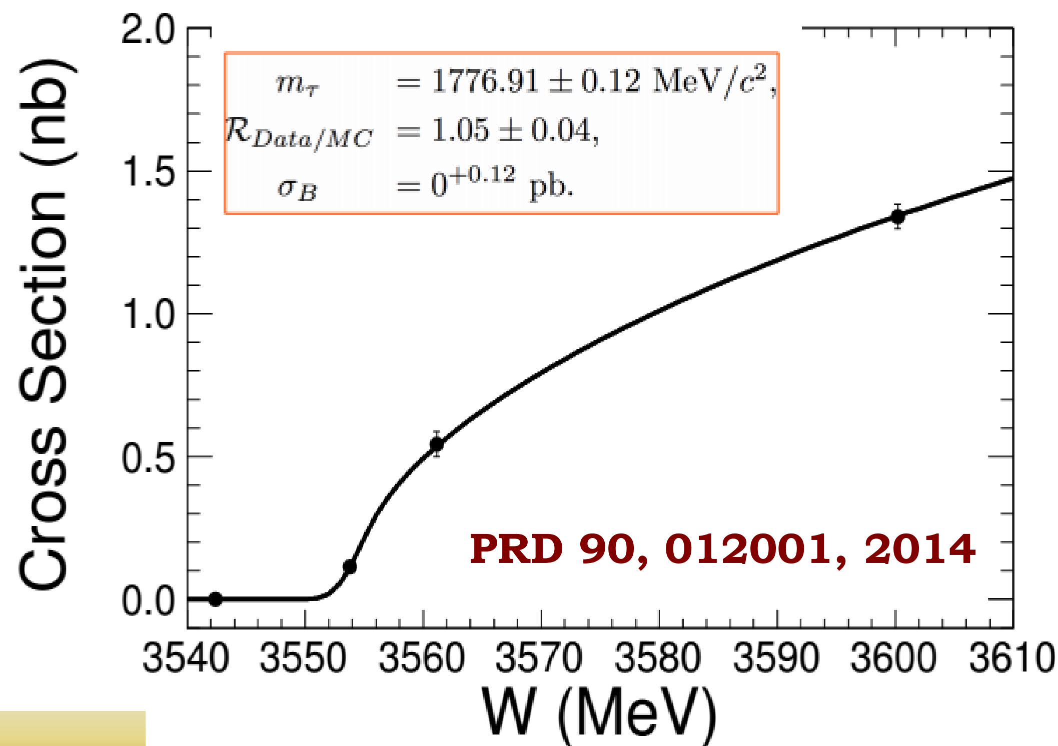
$\Delta M = 54 \pm 32$ KeV/c^2

$\delta w = 1.469 \pm 85$ MeV/c^2

τ- cross section

$$\sigma(E_{\rm CM}, m_\tau, \delta_w^{\rm BEMS}) = \frac{1}{\sqrt{2\pi}\delta_w^{\rm BEMS}} \int_{2m_\tau}^{\infty} dE'_{\rm CM} e^{\frac{-(E_{\rm CM}-E'_{\rm CM})^2}{2(\delta_w^{\rm BEMS})^2}} \int_0^{1-\frac{4m^2}{E'^2_{\rm CM}}} dx F(x, E'_{\rm CM}) \frac{\sigma_1(E'_{\rm CM}\sqrt{1-x}, m_\tau)}{|1-\prod(E_{\rm CM})|^2}$$





The most precise measurement so far, tests lepton universality @ **0.4 σ level**:

$$(g_\tau / g_\mu)^2 = 1.0016 \pm 0.0042$$

$\chi_{c1} \to$ hhh $(0^-0^-0^-)$

Assume two-body processes: $1^{++} \to (0^-0^-)0^-$ $(\eta\pi\pi)$

I=0: $\chi_{c1} \to R_J\eta$; $R_J \to \pi\pi$

I=1: $\chi_{c1} \to R_J\pi$; $R_J \to \eta\pi$

J^{PC}	L	Decay sequence
0^{++}	P	$f_0(980)\eta$, $a_0(980)\pi$
1^{-+}	S, D	$\pi_1(1600)\pi$
2^{++}	P, F	$f_2(1270)\eta$, $a_2(1320)\pi$
4^{++}	F, H	$f_4(2020)\eta$, $a_4(2040)\pi$

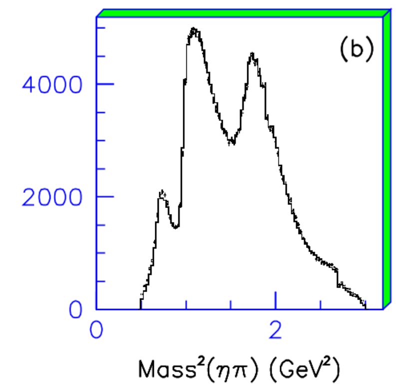
S-wave: the lowest orbital two-body excitation, **manifestly exotic**

$\pi_1(1400)$ $\to \eta\pi$: GAMS, KEK, C. Barrel, E852

$\pi_1(1600)$ $\to f_1\pi$; $\eta'\pi$; $b_1\pi$: VES, E852, COMPASS, CLEO-c

Old 4q candidates: $a_0(980) \to \eta\pi$, $f_0(980) \to \pi\pi$:

PRD 78 74023 (2008)

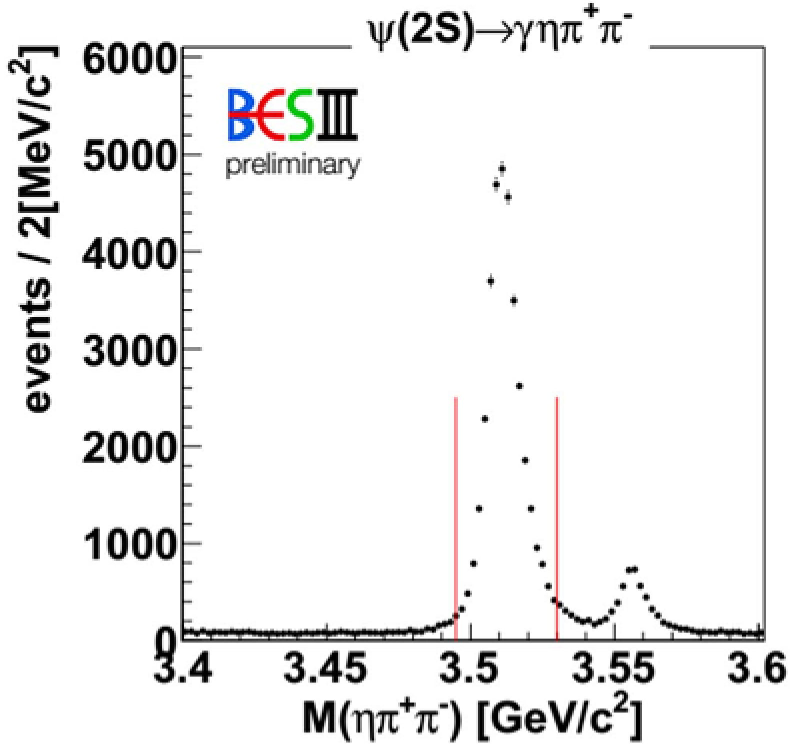


Crystal Barrel data

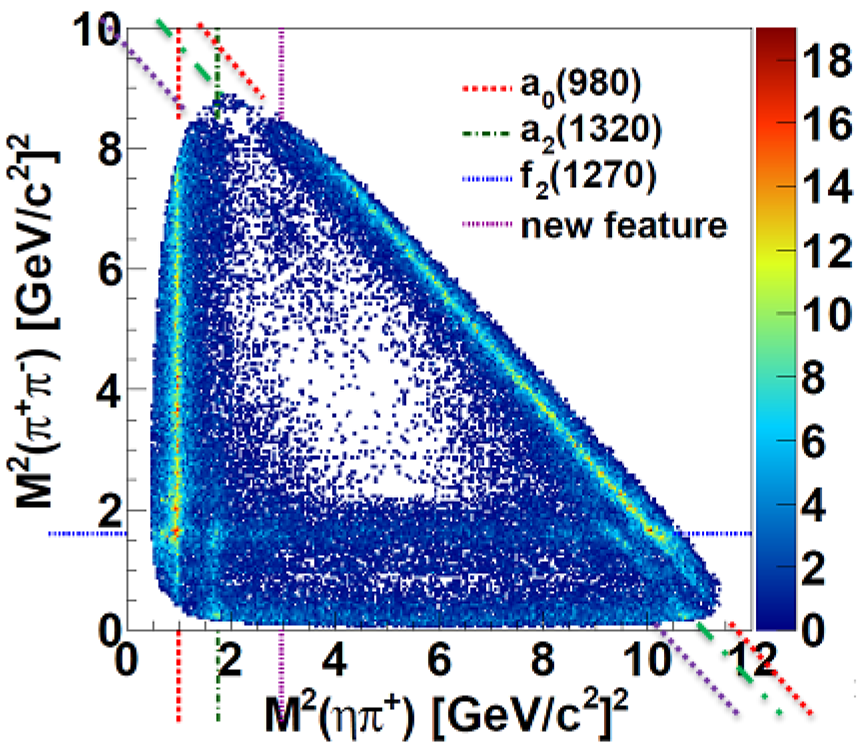
450M $\psi(2S) \to \gamma\chi_{c1}$; $\chi_{c1} \to \eta\pi\pi$

HADRON 2015

$N(\chi_{c1}) \sim 35000$

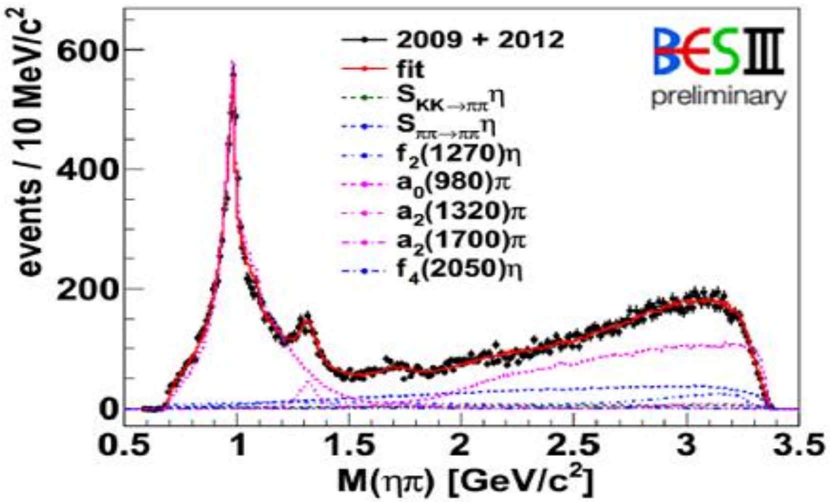


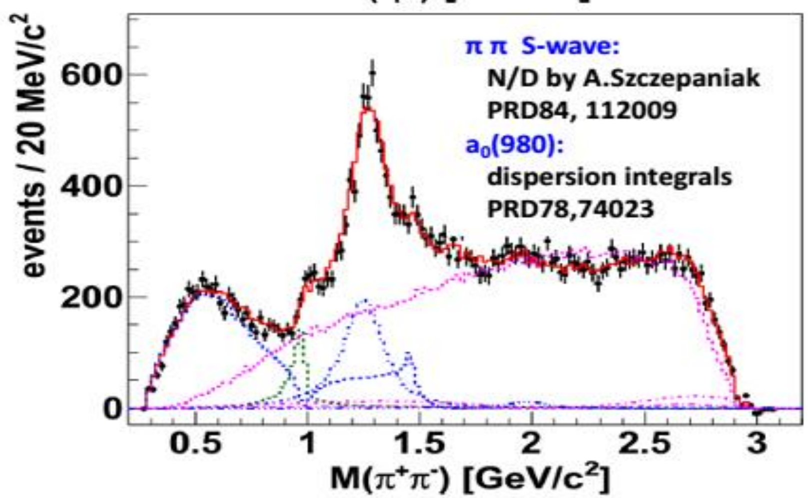
compatible with $a_2(1700)$ hypothesis



Purity after background subtraction: 98.5 ± 0.3%

450M $\psi(2S) \rightarrow \gamma\chi_{c1}$; $\chi_{c1} \rightarrow \eta\pi\pi$





Decay mode	$\mathcal{B}(\chi_{c1} \to \eta\pi^+\pi^-) \times 10^{-3}$
$\eta\pi^+\pi^-$	$4.819 \pm 0.031 \pm 0.088 \pm 0.210$
$a_0(980)^{\pm}\pi^{\mp}$	$3.506 \pm 0.034 \pm 0.182 \pm 0.153$
$a_2(1320)^{\pm}\pi^{\mp}$	$0.185 \pm 0.009 \pm 0.038 \pm 0.008$
$a_2(1700)^{\pm}\pi^{\mp}$	$0.048 \pm 0.005 \pm 0.014 \pm 0.002$
$S_{kk}\eta$	$0.123 \pm 0.007 \pm 0.018 \pm 0.005$
$S_{pp}\eta$	$0.791 \pm 0.019 \pm 0.037 \pm 0.035$
$\pi\pi_S\eta$	$0.859 \pm 0.021 \pm 0.031 \pm 0.037$
$f_2(1270)\eta$	$0.371 \pm 0.012 \pm 0.054 \pm 0.016$
$f_4(2050)\eta$	$0.027 \pm 0.004 \pm 0.009 \pm 0.001$

BESIII Preliminary		U.L. [90% c.l.]
$\pi_1(1400)^{\pm}\pi^{\mp}$	0.028 ± 0.010	< 0.048
$\pi_1(1600)^{\pm}\pi^{\mp}$	0.005 ± 0.005	< 0.016
$\pi_1(2015)^{\pm}\pi^{\mp}$	0.003 ± 0.002	< 0.008

- **Clear evidence for $a_2(1700)$ in χ_{c1}decays.**
- **First measurement of $g'_{\eta\pi} \neq 0$ using $a_0(980) \rightarrow \eta\pi$ line shape.**
- **Measured upper limits for $\pi_1(1^{-+})$ in 1.4 - 2.0 GeV/c² region.**

BESIII summary and future

Very rich and fruitful program:

- $3fb^{-1}$ @ 4.17 GeV expected in 2016
- Lots of proposals, including high precision τ-mass
- Plans to continue next 6-8 years, partially in XYZ

	BESIII	Goal
J/ψ	$1.3*10^9$ 21x BESII	$10*10^9$
ψ'	$0.6*10^9$ 24x CLEO-c	$3*10^9$
$\psi(3770)$	2.9 fb^{-1} 21x CLEO-c	20 fb^{-1}
Above open charm threshold	0.5 fb^{-1}@ψ(4040), 1.9 fb^{-1} @~4260, 0.5 fb^{-1}@4360, 1.0 fb^{-1} @4420, 0.5 fb^{-1} @4600	5-10 fb^{-1}
R scan and tau	3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points	
Y(2175)	100 pb^{-1} (2015)	
ψ(4170)	3 fb^{-1} (next run)	

What's next

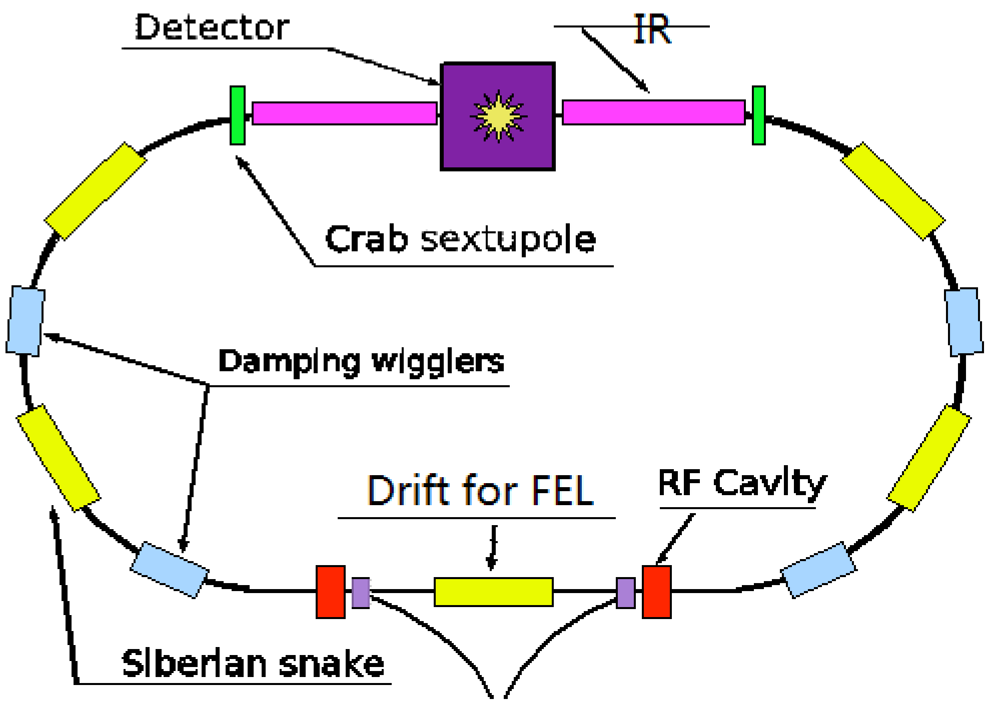
High Intensity Electron Positron Accelerator (HIEPA)

Collaborative Innovation Center for Particle Physics and Interaction

University of Science and Technology of China
Institute of High Energy Physics, CAS
Institute of Theoretical Physics, CAS
Tsinghua University
University of Chinese Academy of Sciences
Shangdong University
Shanghai Jiaotong University
Peking University
Nanjing University
Nankai University
Wuhan University
Hua Zhong Normal University

HIEPA: super τ-charm factory!

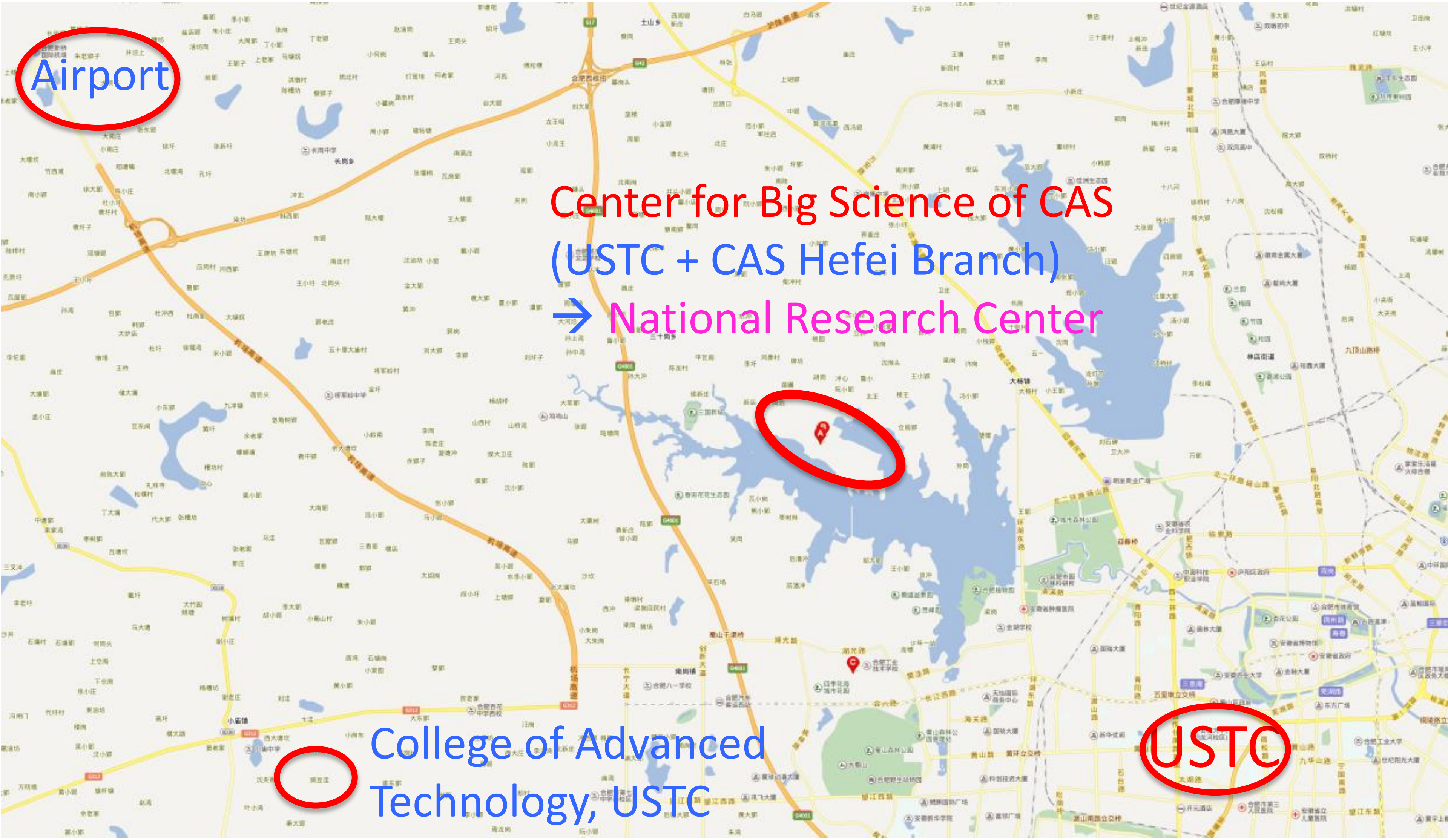
- provide unique opportunities in the energy region that bridges the perturbative and non-perturbative QCD
- search for new forms of hadrons and explore the structure of hadrons
- search for possible NP at high intensity and high precision frontier.



Key features:

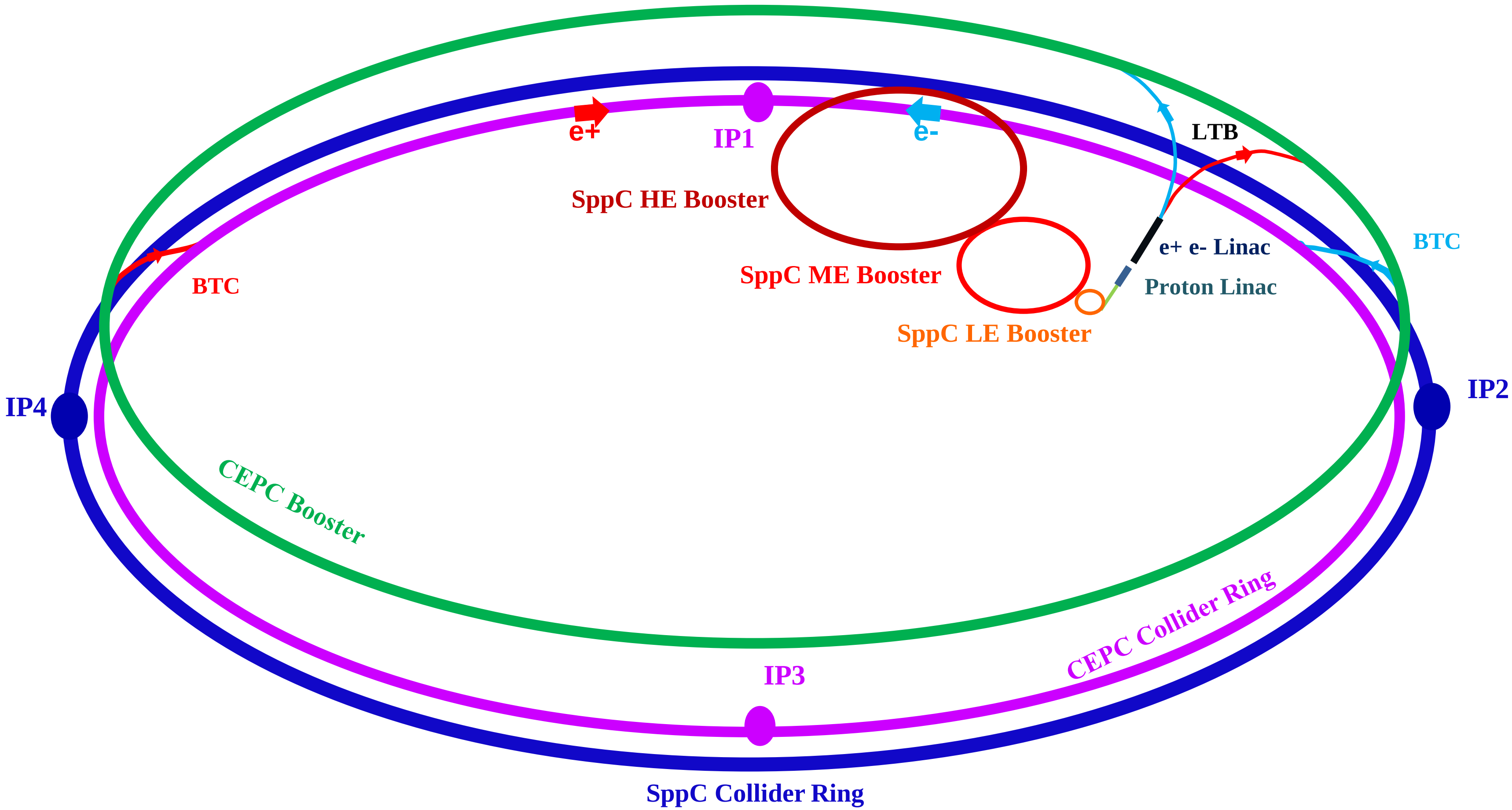
- HIEPA covers the CM energy of 2-7 GeV
- peak luminosity L = 10^{35} $cm^{-2}s^{-1}$
- possible polarized beam
- serve as a 3rd/4th generation SRF
- do FEL studies ..

HIEPA location



CEPC & SppC

CEPC is an 240 GeV Circular Electron Positron Collider, proposed to carry out high precision study on Higgs bosons, which can be upgraded to a 70 TeV or higher pp collider SppC, to study the new physics beyond the Standard Model.



CEPC & SppC

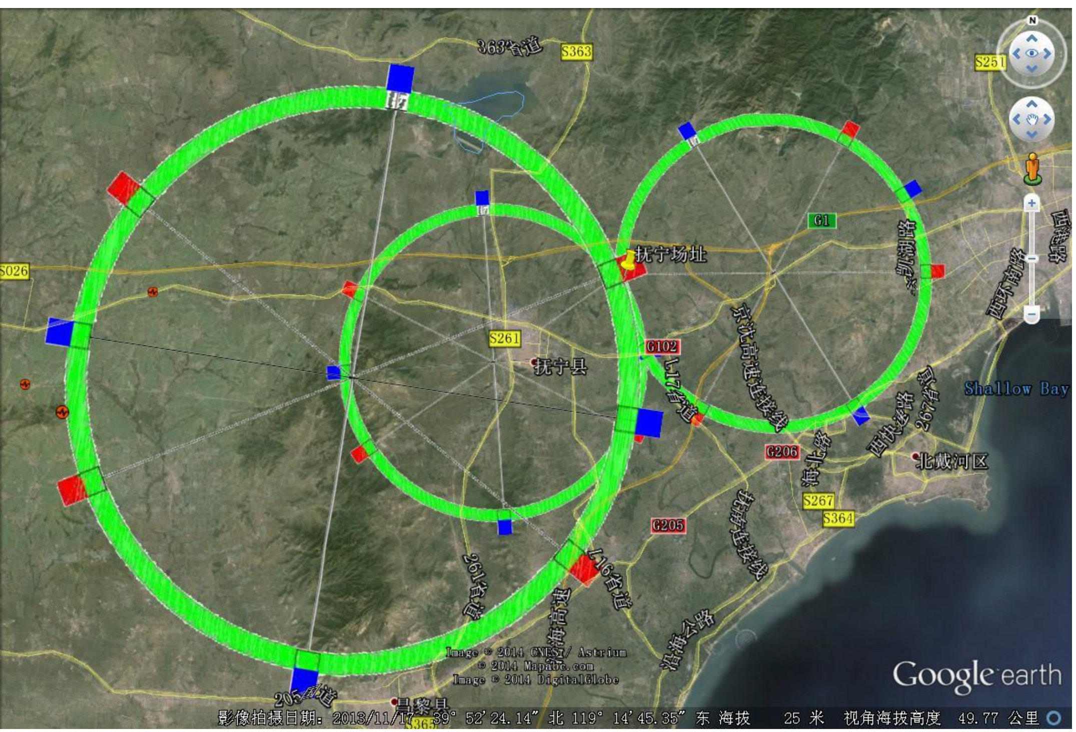
Phase 1: **e⁺e⁻ Higgs (Z) factory** **two detectors, 1M ZH events in 10yrs**

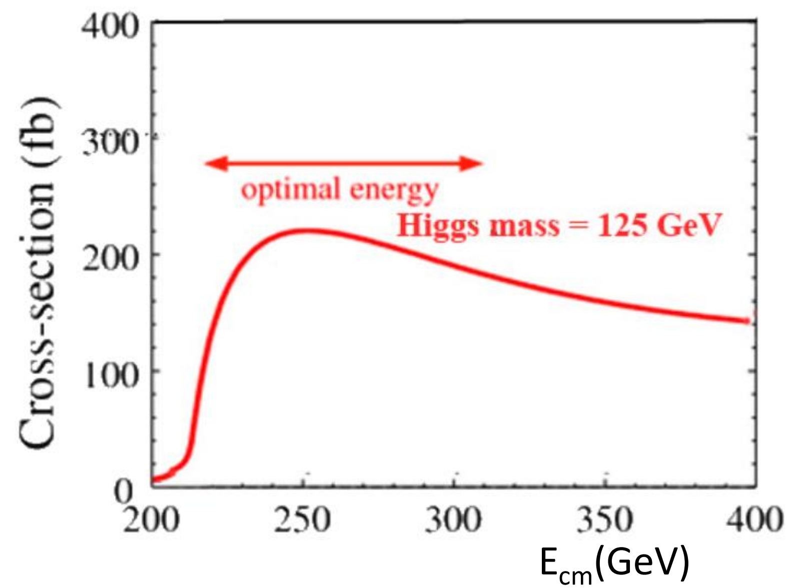
$E_{cm} \approx 240$GeV, luminosity $\sim 2\times10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$, can also run at the Z-pole

Precision measurement of the Higgs boson (and the Z boson)

Phase 2: **a discovery machine**; pp collision with $E_{cm} \approx$ 50-100 TeV; ep,HI options

Discovery machine for BSM





QingHuangDao site
300km from Beijing

CEPC & SppC: preCDR review

"The committee considers the CEPC-SPPC to be well aligned with the future of China's HEP program, and in fact the future of the global HEP program."

"The committee strongly endorses the physics case of the CEPC, as outlined in the preCDR, recognizing it as an essential step in the understanding of Nature"

"The Committee has been very impressed with the progress during such a short period of time, as well as the work and presentations shown, mostly done by the young generation, who are the ones that can devote their carriers to this project through the coming decades"

- Physics goals and precision reachable（preliminary）
- No technological obstacles that cannot be overcome
- Specification of R&D items
- Initial cost estimate
- Complete preCDR (implement reviewers comments),

CEPC & SppC: Pre. R&D and funding

1. IHEP internal investment ~10M RMB

   organize teams, initialize preliminary R&D

2. Seek funding from Chinese Ministry of Sci. & Tech.

   kick-off R&D

In May 2015, the CEPC Study Group decided to begin the CDR process, with a preliminary target date of completion: end of 2016

An International Advisory Committee has been formed to advise the CEPC SG on int’l collaboration, organizational structures, governance, Science & Technology issues, etc.

Future in China seems bright!

R&D plan of the 20 T accelerator magnets

(Very Preliminary)

- **2015-2020**: Development of a 12 T operational field Nb_3Sn twin-aperture dipole with common coil configuration and 10^{-4} field quality; Fabrication and test of 2~3 T HTS (Bi-2212 or YBCO) coils in a 12 T background field and basic research on tape superconductors for accelerator magnets (field quality, fabrication method, quench protection).
- **2020-2025**: Development of a 15 T Nb_3Sn twin-aperture dipole and quadrupole with 10^{-4} field uniformity; Fabrication and test of 4~5 T HTS (Bi-2212 or YBCO) coils in a 15 T background field.
- **2025-2030**: 15 T Nb_3Sn coils + HTS coils (or all-HTS) to realize the 20 T dipole and quadrupole with 10^{-4} field uniformity; Development of the prototype SppC dipoles and quadrupoles and infrastructure build-up.

a long term plan for SC 20T magnets is being developed

will be a world wide effort

Multi-quark objects

$\pi\pi J/\psi$
$\pi D\bar{D}^*$

$Z_c(3900)$

$\pi\pi h_c$
$\pi D^*\bar{D}^*$

$Z_c(4025)$

$K\pi\chi_{cJ}$

$Z_1(4050)$
$Z_2(4250)$

$K\pi J/\psi$

$Z_c(4200)$

R. L. Jaffe

No fundamental distinction between "tetraquarks" and "meson-meson bound states".

$\pi K\psi'$

$Z_c(4475)$

$\pi\pi\Upsilon(nS)$
$\pi\pi h_b(nP)$
$\pi B\bar{B}^*$

$Z_b(10610)$
$Z_b(10650)$

pJ/ψ

$P_c(4380)$
$P_c(4450)$

$Z_c(3883)$: angular analysis

PRL 112, 022001 (2014)

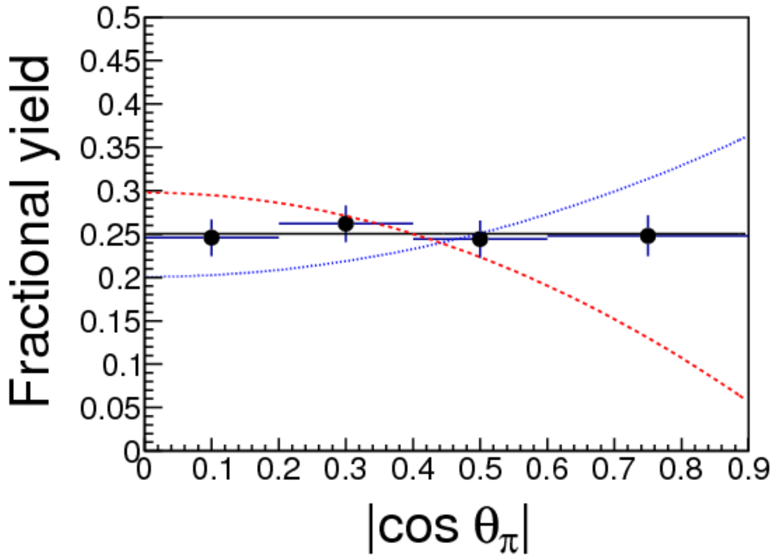
0^-, π in P-wave: $dN/\, d\, cos\theta_\pi \propto 1 - cos^2\theta_\pi$

1^-, π in P-wave: $dN/\, d\, cos\theta_\pi \propto 1 - cos^2\theta_\pi$

1^+, π in S-wave : $dN/\, d\, cos\theta_\pi \propto$ flat

(assuming D-wave small near threshold)

0^+: excluded by parity conservation



Data clearly favor $J^{PC} = 1^+$

If $Z_c(3900)$ and $Z_c(3883)$ are the same:

$$\frac{\mathcal{B}(Z_c \to D^*\bar{D})}{\mathcal{B}(Z_c \to J/\psi\,\pi)} = 6.2 \pm 1.1 \pm 2.7$$

Compare to:

$$\frac{\mathcal{B}(\psi(4040) \to D^{(*)}\bar{D}^{(*)})}{\mathcal{B}(\psi(4040) \to J/\psi\,\eta)} = 192 \pm 27$$

Open charm decays clearly suppressed: different dynamics in Y(4260) – $Z_c(3900)$ system!

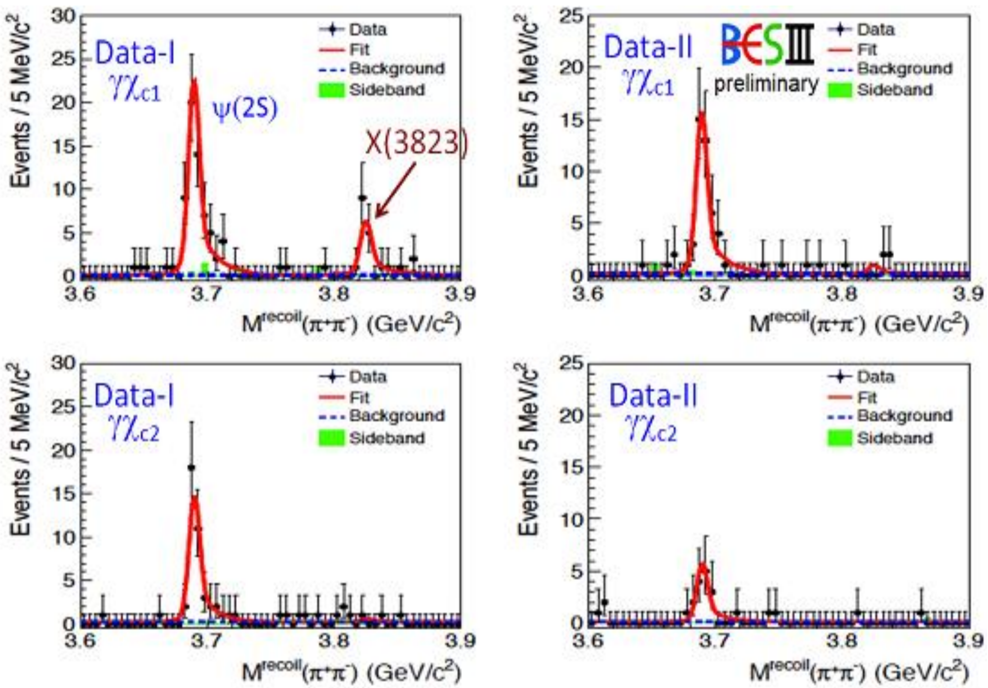
What do we know so far!

State	Mass(MeV)	Width(MeV)	Decay mode	Process
$Z_c(3900)^{\pm}$	$3899.0 \pm 3.6 \pm 4.9$	$46 \pm 10 \pm 20$	$\pi^{\pm} J/\psi$	$e^+e^- \to \pi^+\pi^- J/\psi$
$Z_c(3900)^0$	$3894.8 \pm 2.3 \pm 2.7$	$29.6 \pm 8.2 \pm 8.2$	$\pi^0 J/\psi$	$e^+e^- \to \pi^0\pi^0 J/\psi$
$Z_c(3885)^{\pm}$	$3883.9 \pm 1.5 \pm 4.2$ [single D tag] $3884.3 \pm 1.2 \pm 1.5$ [double D tag]	$24.8 \pm 3.3 \pm 11.0$ [single D tag] $23.8 \pm 2.1 \pm 2.6$ [double D tag]	$D^0 D^{*-}$ $D^- D^{*0}$	$e^+e^- \to \pi^+ D^0 D^{*-}$ $e^+e^- \to \pi^+ D^- D^{*0}$
$Z_c(3885)^0$	$3885.7^{+4.3}_{-5.7} \pm 8.4$	$35.0^{+11}_{-12} \pm 15$	$(DD^*)^0$	$e^+e^- \to \pi^0(D^0 D^{*0})$ $e^+e^- \to \pi^0(D^{\pm} D^{*\mp})$
$Z_c(4020)^{\pm}$	$4022.9 \pm 0.8 \pm 2.7$	$7.9 \pm 2.7 \pm 2.6$	$\pi^{\pm} h_c$	$e^+e^- \to \pi^+\pi^- h_c$
$Z_c(4020)^0$	$4023.9 \pm 2.2 \pm 3.8$	fixed	$\pi^0 h_c$	$e^+e^- \to \pi^0\pi^0 h_c$
$Z_c(4025)^{\pm}$	$4026.3 \pm 2.6 \pm 3.7$	$24.8 \pm 5.6 \pm 7.7$	$D^{*0} D^{*-}$	$e^+e^- \to \pi^+(D^* \bar{D}^*)^-$
$Z_c(4025)^0$	$4025.5^{+2.0}_{-4.7} \pm 3.1$	$23.0 \pm 6.0 \pm 1.0$	$(D^*D^*)^0$	$e^+e^- \to \pi^0(D^*D^*)^0$

$e^+e^- \to \gamma\pi^+\pi^-\chi_c$ @ 4.2-4.6 GeV

preliminary
arXiv:1503.08203

Reconstruct $\chi_c \to \gamma\, J/\psi \to \gamma\, l^+l^-$
look for $\pi\pi$ recoil



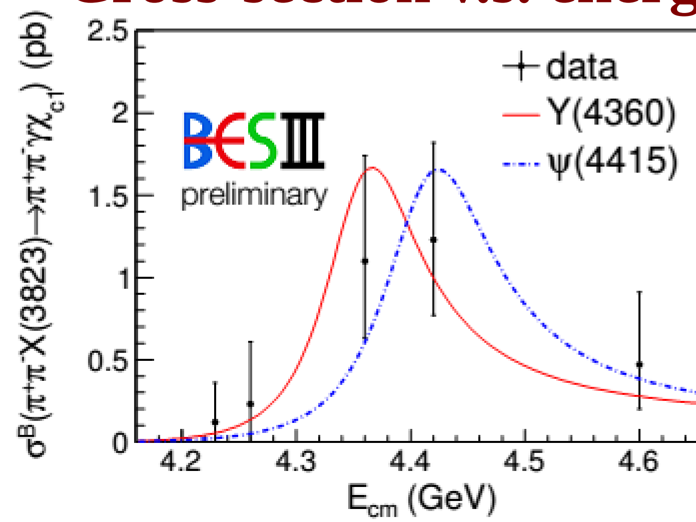
$M = 3821.7 \pm 1.3 \pm 0.7$ MeV, significance 6.7σ

$\Gamma < 16$ MeV at 90% C.L.

X(3823) candidate
consistent with
$\psi(1^3D_2) \to \gamma\, \chi_c$

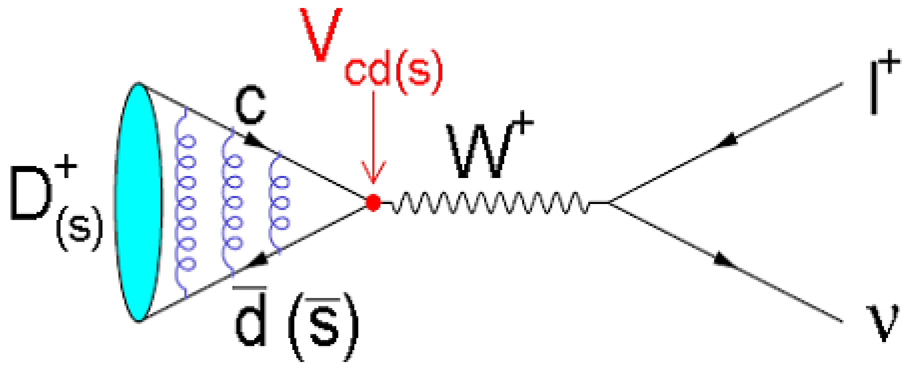
$e^+e^- \to \pi^+\pi^- X(3823) \to \pi^+\pi^-\gamma\chi_c$

Cross-section v.s. energy



Line shape consistent with both Y(4260) & Y4360

D^+ Leptonic Decays



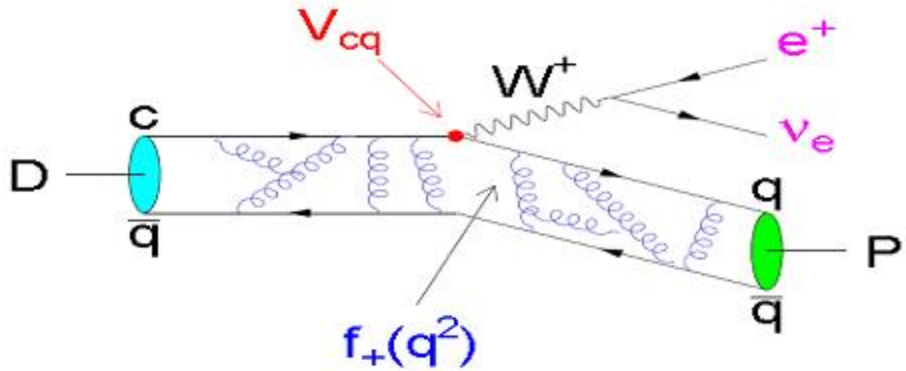
In the SM:

$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi} |V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}} \left(1 - \frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

Bridge to precisely measure

- **Decay constant $f_{D(s)+}$ with input $|V_{cd(s)}|^{CKMfitter}$**
- **CKM matrix element $|V_{cd(s)}|$ with input $f^{LQCD}{}_{D(s)+}$**

Semi-leptonic Decay $D^0 \to K(\pi)^- e^+ \nu$



Differential rates: $$\frac{d\Gamma}{dq^2} = X \frac{G_F^2 |V_{cd(s)}|^2}{24\pi^3} p^3 |f_+(q^2)|^2$$

Bridge to precisely measure:

- **Form factors $f_+^{D \to K(\pi)}(0)$ with input $|V_{cd(s)}|^{CKMfitter}$**

  – **Single pole form**
  $$f_+(q^2) = \frac{f_+(0)}{1 - \frac{q^2}{M_{\rm pole}^2}}$$

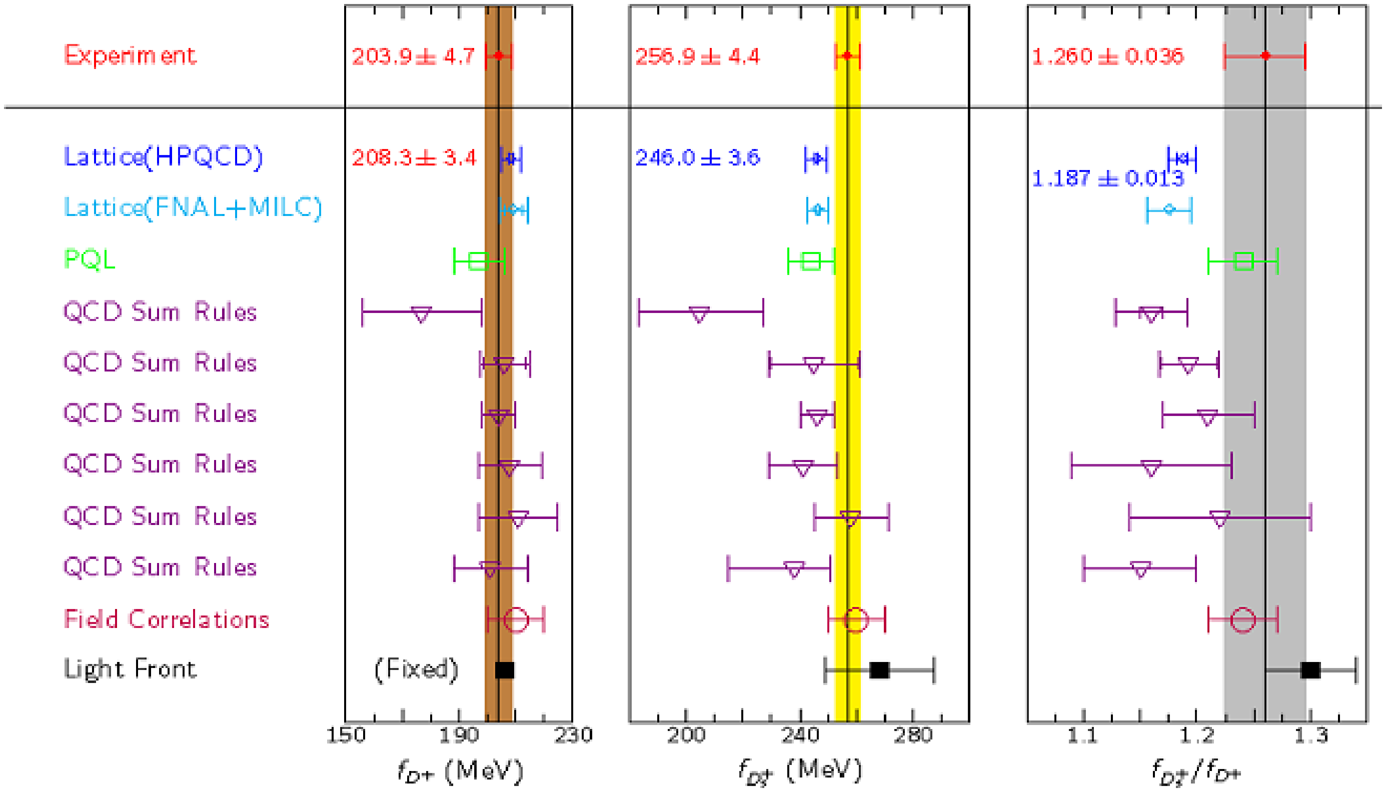
  – **Modified pole model**
  $$f_+(q^2) = \frac{f_+(0)}{(1 - \frac{q^2}{M_{\rm pole}^2})(1 - \alpha \frac{q^2}{M_{\rm pole}^2})}$$

  – **ISGW2 model**
  $$f_+(q^2) = f_+(q^2_{\rm max}) \left(1 + \frac{r^2_{\rm ISGW2}}{12}(q^2_{\rm max} - q^2)\right)^{-2}$$

  – **Series expansion model**
  $$f_+(t) = \frac{1}{P(t)\Phi(t,t_0)} a_0(t_0) \left(1 + \sum_{k=1}^{\infty} r_k(t_0)[z(t,t_0)]^k\right)$$

- **CKM matrix element $|V_{cs(d)}|$ with input $f_+^{LQCD, D \to K(\pi)}(0)$**

Comparing existing f_D , f_{Ds}



- **Precisions of the LQCD calculations of f_{D+}, f_{Ds+}, f_{D+}:f_{Ds} reach 0.5%, 0.5% and 0.3%, which are challenging the experiments**
- **The experimentally measured and the theoretically calculated f_{D+}, f_{Ds+}, f_{D+}:f_{Ds+} differ by about 2σ**

	Experiments	Femilab Lattice+MILC (2014)		HPQCD (2012)	
	Averaged	Expected	Δ	Expected	Δ
f_{D+}(MeV)	203.9±4.7	$212.6\pm0.4^{+1.0}_{-1.2}$	1.8σ	208.3±3.4	0.8σ
f_{Ds+}(MeV)	256.9±4.4	$249.0\pm0.3^{+1.1}_{-1.5}$	1.7σ	246.0±3.6	1.4σ
f_{D+}:f_{Ds+}	1.260±0.036	$1.1712\pm0.0010^{+0.0029}_{-0.0032}$	2.5σ	1.187±0.013	1.9σ

- **Improving measurement with larger data sample is necessary!**

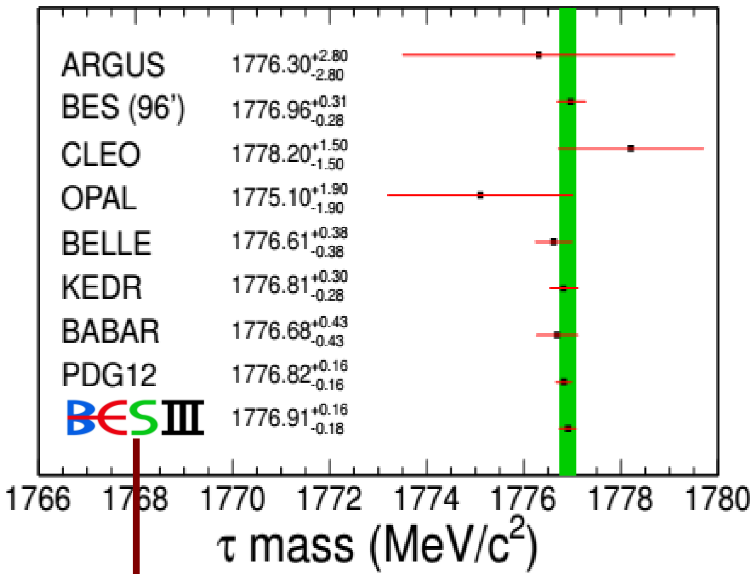
τ- cross section

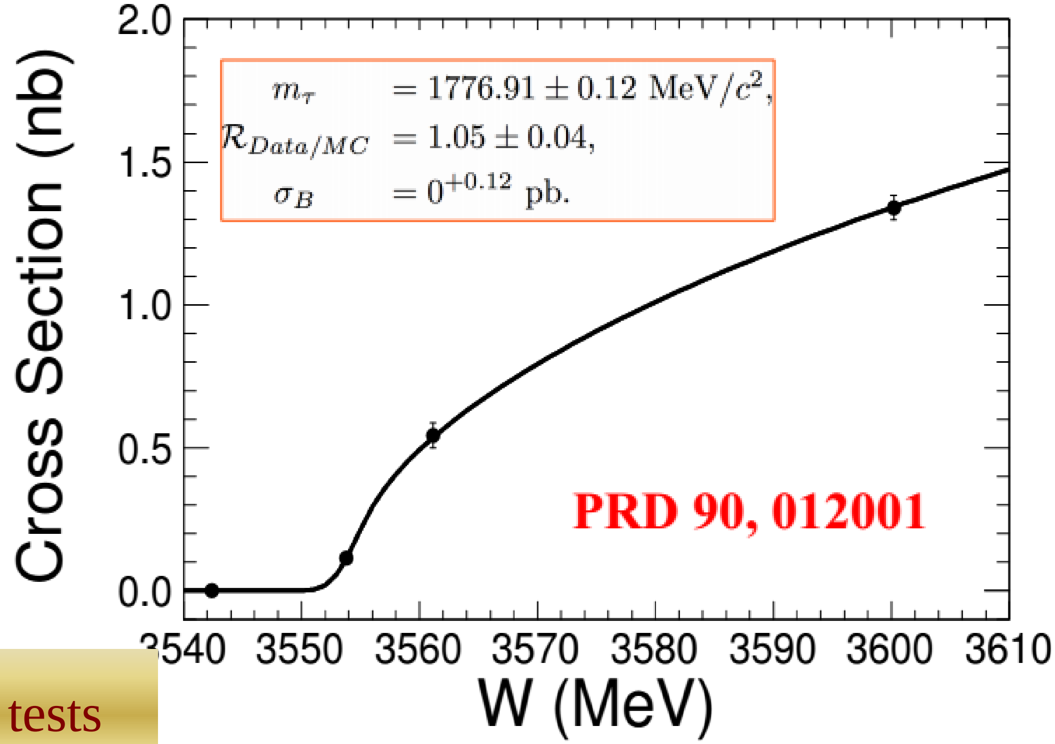
$$\sigma(E_{\mathrm{CM}}, m_\tau, \delta_w^{\mathrm{BEMS}}) = \frac{1}{\sqrt{2\pi}\delta_w^{\mathrm{BEMS}}} \int_{2m_\tau}^{\infty} dE'_{\mathrm{CM}} e^{\frac{-(E_{\mathrm{CM}}-E'_{\mathrm{CM}})^2}{2(\delta_w^{\mathrm{BEMS}})^2}} \int_0^{1-\frac{4m^2}{E'^2_{\mathrm{CM}}}} dx F(x, E'_{\mathrm{CM}}) \frac{\sigma_1(E'_{\mathrm{CM}}\sqrt{1-x}, m_\tau)}{|1-\prod(E_{\mathrm{CM}})|^2}$$

$$L(m_\tau, \mathcal{R}_{Data/MC}, \sigma_B) = \prod_{i=1}^{4} \frac{\mu_i^{N_i} e^{-\mu_i}}{N_i!} \qquad \mu_i = [\mathcal{R}_{Data/MC} \times \epsilon_i \times \sigma(E^i_{\mathrm{CM}}, m_\tau) + \sigma_B] \times \mathcal{L}_i \quad \epsilon_i = \sum_i Br_j \epsilon_{ij}$$

i - scan point; j – decay mode

Plan for 30 days : 100 pb^{-1}





The most precise measurement so far, tests lepton universality @ **0.4 σ level**:

$$\left(g_\tau / g_\mu\right)^2 = 1.0016 \pm 0.0042$$

τ - selection: data vs. MC

MC normalized by the luminosity and ratio of efficiencies for τ-pair identification in data and MC

	1		2		3		4		Total	
Final state	Data	MC	Data	MC	Data	MC	Data	MC	Data	MC
ee	0	0	4	3.7	13	12.2	84	76.1	101	92.0
$e\mu$	0	0	8	9.1	35	31.4	168	192.6	211	233.1
$e\pi$	0	0	8	8.6	33	29.7	202	184.4	243	222.6
eK	0	0	0	0.5	2	1.8	16	16.9	18	19.3
$\mu\mu$	0	0	2	2.9	8	9.2	49	56.3	59	68.4
$\mu\pi$	0	0	4	3.9	11	14.1	89	86.7	104	104.7
μK	0	0	0	0.2	3	0.8	7	9.0	10	10.1
$\pi\pi$	0	0	1	2.0	5	7.7	57	54.0	63	63.8
πK	0	0	1	0.3	0	0.8	10	8.2	11	9.3
KK	0	0	0	0.0	1	0.1	1	0.3	2	0.4
$e\rho$	0	0	3	6.1	19	20.6	142	132.0	164	158.7
$\mu\rho$	0	0	8	3.3	8	11.8	52	63.3	68	78.5
$\pi\rho$	0	0	5	3.4	15	10.8	97	96.0	117	110.2
Total	0	0	44	44.2	153	151.2	974	975.7	1171	1171.0

Agree well

τ – mass: systematic uncertainties

Source	Δm_τ (MeV/c^2)
Theoretical accuracy	0.010
Energy scale	$^{+0.022}_{-0.086}$
Energy spread	0.016
Luminosity	0.006
Cut on number of good photons	0.002
Cuts on PTEM and acoplanarity angle	0.05
mis-ID efficiency	0.048
Background shape	0.04
Fitted efficiency parameter	$^{+0.038}_{-0.034}$
Total	$^{+0.094}_{-0.124}$

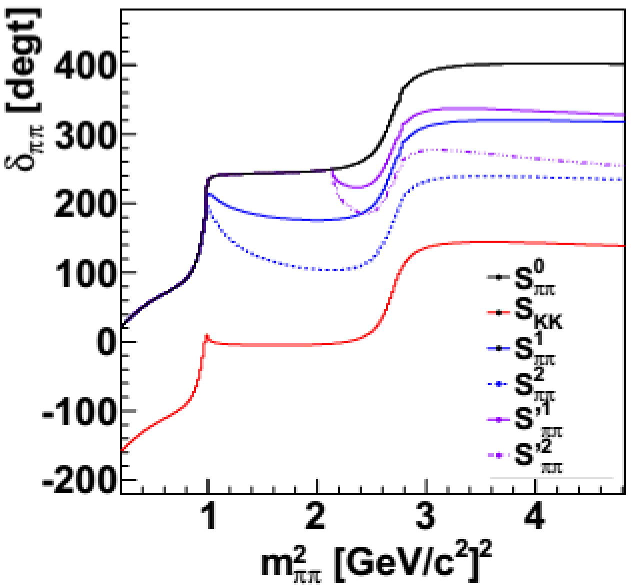
ππ S-wave

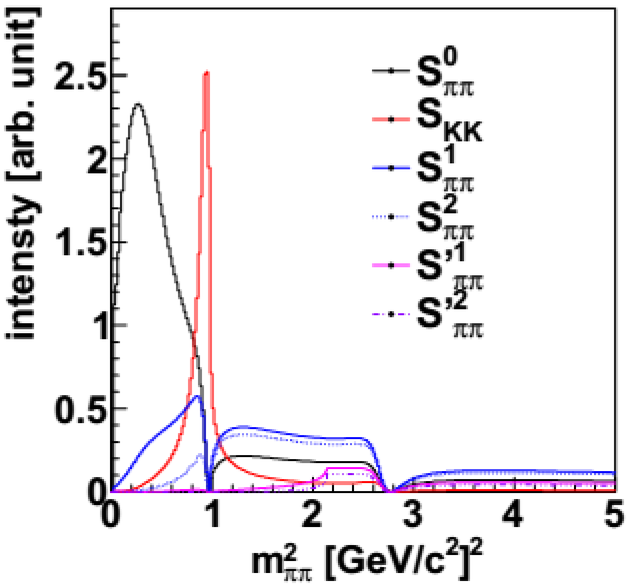
Adapted by A. Szczepaniak from

Eur.Phys.J.C9,141 (1999)
PRD50,3145 (1994)

1. S_{KK} : for **KK→ππ**
2. $S_{\pi\pi}$: for **ππ→ππ, expanded using $z_{th}(s)$**

$$S(s)_{\pi\pi} = c_0 S^0_{\pi\pi} + c_1 z_{KK} S^0_{\pi\pi} + c'_1 z_{s\prime} S^0_{\pi\pi} + c'_2 z^2_{s\prime} S^0_{\pi\pi}$$





$$z_{KK}(s) = \frac{\sqrt{s+s_0} - \sqrt{4m_K^2 - s}}{\sqrt{s+s_0} + \sqrt{4m_K^2 - s}}$$

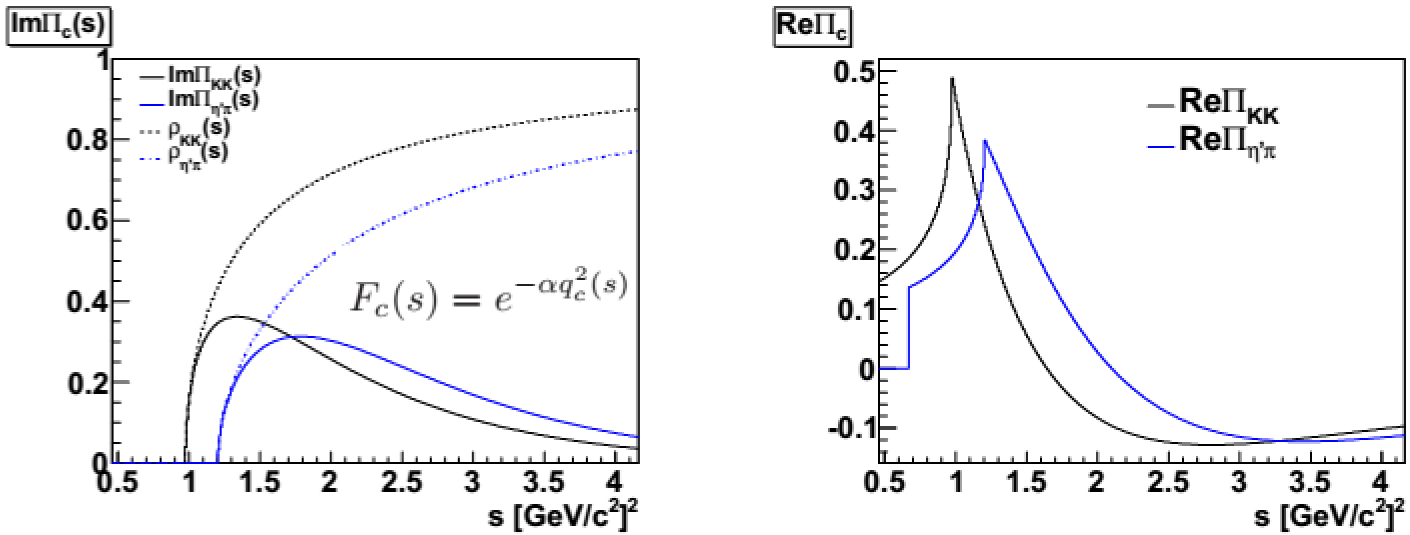
$$z_{s\prime}(s) = \frac{\sqrt{s+s_0} - \sqrt{s\prime - s}}{\sqrt{s+s_0} + \sqrt{s\prime - s}}$$

BESIII $a_0(980)$: dispersion integrals

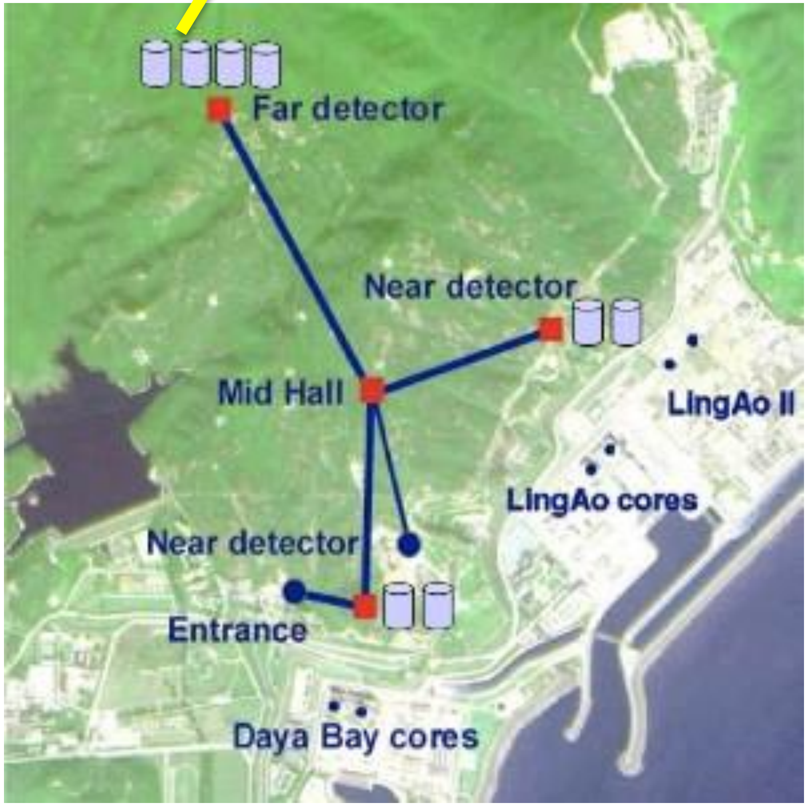
Using dispersion relation; instead of Flatte parametrization, based on **PRD 78 74023 (2008)**

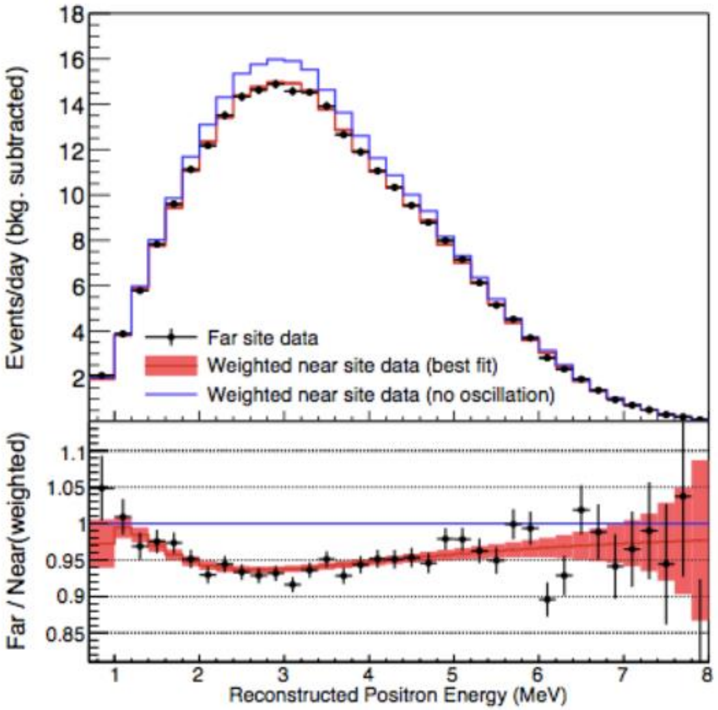
$$D_\alpha(s) = m_0^2 - s - \sum \Pi_c(s) \qquad Im\Pi_c(s) = g_c^2 \rho_c(s) \qquad Re\Pi_c(s) = \frac{1}{\pi} P \int_{s_{th}}^{\inf} \frac{Im\Pi_c(s')ds'}{(s'-s)}$$

$$D_\alpha(s) = m_0^2 - s - \left[\sum_c Re\Pi_c(s) - Re\Pi_c(m_0)\right] - i \sum_c Im\Pi_c.$$



Daya Bay result





$$\sin^2 2\theta_{13} = 0.084^{+0.005}_{-0.005}$$

From the last non-measured to
Mostly precisely measured neutrino
Mixing angle in a few years!