Recent highlights at BESIII

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(for the BESIII Collaboration)

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Jan., 30–Feb., 4, 2016, High1 resort, Korea
Bird view of BEPCII

- Linac
- Storage ring

**BEPCII at BEPCII**

- $\tau$-charm physics
  - Charmonium(-like) physics
  - Light hadron spectroscopy
  - Charm physics
  - $\tau$-QCD physics
The BES-III detector

NIM A614, 345(2010)

Super conducting magnet: 1 T

EMC: CsI cristal
  - Energy resolution: 2.5% @1GeV
  - Spatial resolution: 6mm

MDC:
  - Spatial resolution: $\sigma_{xy} = 120\mu m$
  - Momentum resolution: 0.5% @ 1GeV
  - dE/dx resolution: 6%

TOF:
  Time resolution: 100ps (barrel)
  110ps (endcaps)

Muon ID:
  9 layers RPC, 8 for endcaps
The BESIII Collaboration

11 countries
58 institutes
~450 members
Outline

- Hadron spectroscopy
- Charmonium (charmonium-like) physics
- Charm physics
- R-QCD
- Summary
Hadron spectroscopy

• $X(1835)$ observation
• $J/\psi \rightarrow \eta \phi \pi^+ \pi^-$
• Dalitz decay of $\eta' \rightarrow \gamma e^+ e^-$
• $\psi' \rightarrow K^- \Lambda \Xi^+ \ + \text{c.c.} \quad \& \quad \psi' \rightarrow \gamma K^- \Lambda \Xi^+ \ + \text{c.c.}$
Overview of X(1835) observation

- First observation in $J/\psi \rightarrow \gamma \pi \pi \eta'$ at BESII, later confirmed at BESIII
- Second observation in $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta$

- Interpretations include glueball, $pp$ bound state, excited $\eta$ meson
- Two additional structures above 2 GeV/$c^2$ are observed

- Structure at $\sim 1.85$ GeV
- Strong correlation with enhancement at $KsKs$ mass threshold (interpreted as $f_0(980)$)
- Two resonance pseudoscalar components (BW parameterization) required in best fit hypothesis

$X(1835) \rightarrow f_0(980)\eta$ (>12.9$\sigma$)
$m = 1844 \pm 19_{-25}^{+16}$ MeV/$c^2$
$\Gamma = 192_{-17}^{+20}_{-43}$ MeV

$X(1560) \rightarrow f_0(980)\eta$ (>8.9$\sigma$)
$m = 1565 \pm 8_{-63}^{+0}$ MeV/$c^2$
$\Gamma = 45_{-13}^{+14+21}_{-28}$ MeV

• Confirm the observed Y(2175) and clarify its nature
• Investigate the properties of f(1285), \(\eta(1295)\), and \(\eta(1405)/\eta(1475)\) resonances
• Search for the observed X(1835) and X(1870) in different decay modes.

- Y(2175) is clearly observed with a significance of \(>10\sigma\)
- f1(1285) is observed significantly
- No evidence of X(1835) and X(1870) is found.

Dalitz decay of $\eta' \rightarrow \gamma e^+ e^-$

- Reveal the inner structure of the meson
- Study the transition form factor $\rightarrow$ providing information for the muon anomalous magnetic moment.

\[
\frac{d\Gamma(\eta' \rightarrow \gamma l^+ l^-)}{dq^2 \Gamma(\eta' \rightarrow \gamma \gamma)} = \frac{2\alpha}{3\pi q^2} \frac{1}{q^2} \left(1 - 4m_i^2 q^2\right)^{\frac{1}{2}} \left(1 + \frac{2m_i^2}{q^2}\right) \left(1 - \frac{q^2}{m_{\eta'}^2}\right)^3 |F(q^2)|^2 = [\text{QED}(q^2)] \times |F(q^2)|^2
\]

$|\text{QED}(q^2)|$ represents the calculable QED part for a point-like meson

\[
\frac{\Gamma(\eta' \rightarrow \gamma e^+ e^-)}{\Gamma(\eta' \rightarrow \gamma \gamma)} = (2.13 \pm 0.09(\text{stat}) \pm 0.07(\text{sys})) \times 10^{-2}
\]

\[
\mathcal{B}(\eta' \rightarrow \gamma e^+ e^-) = (4.69 \pm 0.20(\text{stat}) \pm 0.23(\text{sys})) \times 10^{-4}
\]

*Phys. Rev. D92,012001 (2015)*
For $\psi' \rightarrow K^- \Lambda \Xi^+$ + c.c., two structures around 1690 and 1820 MeV/c^2 are observed in M(K\Lambda) mass spectrum.

For $\psi' \rightarrow \gamma K^- \Lambda \Xi^+$ + c.c., $\psi' \rightarrow \Sigma^0 K^- \Xi^+$ + c.c. and $\chi_{cJ} \rightarrow K^- \Lambda \Xi^+$ + c.c. are observed for the first time.
Charmonium (like) physics

- $\psi(3770) \to \gamma \chi_{cJ}$
- DOZI decay: $J/\psi \to \phi \pi^0$
- XYZ study
• Search for the evidence of $\psi(3770)$ non-DD decay mode if it contains additional light quarks or gluons except $c\bar{c}$

• Test the $S$-$D$ mixing model: $\psi=1^3D_1$ (dominant) + $2^3S_1$ (small)

\[ \psi(3770) \rightarrow \gamma \chi_{cJ} \quad (\chi_{cJ} \rightarrow \gamma J/\psi) \]

The long-dashed (green) line is from the $\psi'$ radiative return

<table>
<thead>
<tr>
<th>Experiment/theory</th>
<th>$\Gamma(\psi(3770) \rightarrow \gamma \chi_{cJ})$ (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$J = 1$</td>
</tr>
<tr>
<td>This work</td>
<td>$67.5 \pm 4.1 \pm 6.7$</td>
</tr>
<tr>
<td>Ding-Qin-Chao [12]</td>
<td>95</td>
</tr>
<tr>
<td>Nonrelativistic</td>
<td>72</td>
</tr>
<tr>
<td>Relativistic</td>
<td>133</td>
</tr>
<tr>
<td>Rosner $S$-$D$ mixing [13]</td>
<td>73 $\pm$ 9</td>
</tr>
<tr>
<td>$\phi = 12^\circ$ [13]</td>
<td>79 $\pm$ 6</td>
</tr>
<tr>
<td>$\phi = (10.6 \pm 1.3)^\circ$ [32]</td>
<td>133</td>
</tr>
<tr>
<td>$\phi = 0^\circ$ (pure $1^3D_1$ state) [32]</td>
<td>183</td>
</tr>
<tr>
<td>Eichten-Lane-Quigg [14]</td>
<td>183</td>
</tr>
<tr>
<td>Nonrelativistic</td>
<td>125</td>
</tr>
<tr>
<td>With coupled-channel corr.</td>
<td>125</td>
</tr>
<tr>
<td>Barnes-Godfrey-Swanson [15]</td>
<td>77</td>
</tr>
</tbody>
</table>

\[ \mathcal{B}(\psi(3770) \rightarrow \gamma \chi_{cJ}) = (2.8 \pm 0.5 \pm 0.4) \times 10^{-3} \]

\[ \mathcal{B}(\psi(3770) \rightarrow \gamma \chi_{c2}) < 0.64 \times 10^{-3} \]
\( J/\psi \rightarrow \phi \pi^0 \)

- This decay mode is highly suppressed due to the DOZI rule.
- Such a search is helpful to understand the \( \omega - \phi \) mixing and SU(3) flavor symmetry breaking.

### Table

<table>
<thead>
<tr>
<th>Solution</th>
<th>( N^{\text{sig}} )</th>
<th>( \delta )</th>
<th>( 2\Delta \log L/N_f )</th>
<th>( Z )</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (a)</td>
<td>838.5 ± 45.8</td>
<td>-95.9° ± 1.5°</td>
<td>45.8/2</td>
<td>6.4σ</td>
</tr>
<tr>
<td>II (b)</td>
<td>35.3 ± 9.3</td>
<td>-152.1° ± 7.7°</td>
<td>45.8/2</td>
<td>6.4σ</td>
</tr>
</tbody>
</table>

Branching fraction:

I: \[ 2.94 \pm 0.16(\text{stat.}) \pm 0.16(\text{syst.}) \times 10^{-6} \]

II: \[ 1.24 \pm 0.33(\text{stat.}) \pm 0.30(\text{syst.}) \times 10^{-7} \]

**Theory prediction (Phys. Rev. 32, 2961 (1985))**

\[
\frac{B(\phi \pi^0)}{B(\omega \pi^0)} = \left( \frac{p_\phi}{p_\omega} \right)^3 \frac{(r_\epsilon \tan \theta_\nu - 1/\sqrt{2})^2}{(r_\epsilon + \tan \theta_\nu/\sqrt{2})^2} \quad r_\epsilon = 1 \text{ (Nonet symmetry)}
\]

\[
\theta_\nu = \arctan(1/\sqrt{2}) \text{ (ideal } \omega - \phi \text{ mixing)}
\]

**Nonet symmetry breaking strength** \( \delta = r_\epsilon - 1 \text{ (a)} \)

(21.0 ± 1.6)% or (-16.4 ± 1.0)% (solution I)

(3.9 ± 0.8)% or (-3.7 ± 0.7)% (solution II)

Nonet symmetry: \( \phi_\nu = |\theta_\nu - \theta_\nu^{\text{ideal}}| = 4.97^\circ \pm 0.33^\circ \) (solution I)

=1.03° ± 0.19° (solution II)

In fact, \( \phi_\nu = 3.84^\circ \text{ (PDG)} \), or 3.34°±0.09°, disagree with either

**Nonet symmetry is first indication**
• Below the open charm threshold the spectrums well understood
  – very good agreement between predicted and discovered states
• Above the threshold the situation in more complex
  – only few of the predicted states have been found
  – in the last decades many new states have been observed with properties that are not consistent with expectations for charmonium: X, Y, Z

X states:
• charmonium-like states with $J^{PC} \neq 1^{--}$
• Observed in B decays, pp and pp collisions

Y states:
• charmonium-like states with $J^{PC} = 1^{--}$
• Observed in direct $e^+ e^-$ annihilation or in ISR

Z states:
• Must contain at least a $cc$ and a light $qq$ pair
Z sates search at BESIII
\[ e^+ e^- \rightarrow \pi^\pm Z_c(3900) \rightarrow \pi^+ \pi^- J/\psi \]

- Requiring \( J/\psi \) mass window: \([3.08,3.12]\) GeV, we have 1595 signal events, with purity \( \sim 90\% \).

1. New charged resonance, exotic 4 quark hadron?!
2. Fit \( M_{\text{max}}(\pi^\pm J/\psi) \) mass distribution; avoid cross counting
3. S-Wave Breit Wigner; phase space factor; efficiency corrected.
4. \( M=(3899.0\pm3.6\pm4.9)\text{MeV}; \Gamma=(46\pm10\pm20)\text{MeV}. \)
5. Statistical significance: \( >8\sigma \), discovery!
$e^+e^- \rightarrow \pi^0 Z_c(3900)^0 \rightarrow \pi^0 \pi^0 J/\psi$

**CLEO-c data at 4.17GeV**

( PLB,727, 366)

- $M = 3894.7 \pm 2.3\,(\text{stat.}) \pm 3.2\,(\text{sys.})$ MeV/c$^2$
- $\Gamma = 29.6 \pm 8.2\,(\text{stat.}) \pm 8.0\,(\text{syst.})$ MeV
- statistical significance: $10.4\,\sigma$

The mass and width for $Z_c(3900)^0$ are consistent with its charged partner. Therefore, an isospin triplet for $Z_c(3900)$ has been established.

PRL 115 112003 (2015)
$e^+e^- \rightarrow \pi^\pm Zc(3885)^\mp \rightarrow \pi^\pm (D\overline{D}^*)^\mp$

\[ M = 3882.2 \pm 1.5 \text{ MeV} \]
\[ \Gamma = 24.6 \pm 3.3 \text{ MeV} \]
\[ N(Zc) = 502 \pm 41 \]

\[ M = 3885.5 \pm 1.5 \text{ MeV} \]
\[ \Gamma = 24.9 \pm 3.2 \text{ MeV} \]
\[ N(Zc) = 710 \pm 54 \]

\[ M = 3883.9 \pm 1.5 \pm 4.2 \text{ MeV} \]
\[ \Gamma = 24.8 \pm 3.3 \pm 11.0 \text{ MeV} \]
Two decay modes, $\pi^0 D^+ D^* - c.c., \pi^0 D^0 D^*0 + c.c.$

Tagged D* by $M_{\text{recoil}}(D\pi)$

Two energies are included, 4.226 & 4.257 GeV

$e^+e^- \rightarrow \pi^0 Z_c(3885)^0 \rightarrow \pi^0 D\overline{D}^*$

$M = 3885.7^{+4.3}_{-5.7} \text{(stat.)} \pm 8.4 \text{(sys.)} \text{ MeV}/c^2$

$\Gamma = 35^{+11}_{-12} \text{ (stat.)} \pm 15 \text{ (syst.)} \text{ MeV}$

statistical significance $>12 \sigma$

No isospin violation is found between charged and neutral mode

PRL 115 222002 (2015)
\[ e^+e^- \rightarrow \pi^\pm Z_c(4020)^\mp \rightarrow \pi^+\pi^- h_c \]

- 1D projection of \( M(\pi^\pm h_c) \) invariant mass distribution.
- \[ M[Z_c(4020)] = (4022.9 \pm 0.8 \pm 2.7) \text{MeV}; \]
  \[ \Gamma[Z_c(4020)] = (7.9 \pm 2.7 \pm 2.6) \text{MeV}. \]
  Significance: \( >8.9\sigma \)
- No significant signal for \( Z_c(3900)^\pm \rightarrow \pi^\pm h_c \) (<2.1\( \sigma \))

PRL111 242001 (2014)
\[ e^+e^- \rightarrow \pi^0 Z_c(4020)^0 \rightarrow \pi^0 \pi^0 h_c \]

- Observe \( Z_c(4020)^0 \) structure in \( \pi^0 h_c \) mass distribution.
- \( M[Z_c(4020)^0] = 4023.6 \pm 4.5 \) MeV with a fixed width
- It is the neutral isospin partner of the \( Z_c(4020)^\pm \).

Cross sections for \( e^+e^- \rightarrow \pi^+\pi^- h_c \)
and \( e^+e^- \rightarrow \pi^0\pi^0 h_c \)
are in agreement with isospin conservation within 2\( \sigma \): \( R_{\pi\pi h_c} = 0.63 \pm 0.09 \)

An isospin triplet for \( Z_c(4020) \) has also been established.
\[ e^+e^- \rightarrow \pi^- Z_c(4025)^+ \rightarrow \pi^- (D^*\bar{D}^*)^+ \]

\[ M = 4026.3 \pm 2.6 \pm 3.7 \text{ MeV} \]
\[ \Gamma = 24.8 \pm 5.6 \pm 7.7 \text{ MeV} \]
\[ N = 401 \pm 47 \]
\[ \text{Significance} > 10\sigma \]

- if \( Z_c(4025)^\pm \) is the \( Z_c(4020)^\pm \) observed in the \( \pi^\pm h_c \) spectrum:

\[
\frac{\Gamma(Z_c(4020) \rightarrow D^*\bar{D}^*)}{\Gamma(Z_c(4020) \rightarrow \pi h_c)} = 12 \pm 5
\]
Two decay modes, $\pi^0D^{**}\overline{D}^{*-} + \text{c.c.}$, $\pi^0D^0\overline{D}^{*0} + \text{c.c.}$.

Two energies are included, 4.23 & 4.26 GeV

$M = 4025.5^{+2.0}_{-4.7} \text{ (stat.)} \pm 3.1 \text{ (sys.) \ MeV/c}^2$

$\Gamma = 23.0 \pm 6.0 \text{ (stat.)} \pm 1.0 \text{ (syst.) \ MeV}$

statistical significance: $\sim 6.0\sigma$
Summary $Z_c$ states at BESIII

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

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

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

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

$e^+e^- \rightarrow \pi^+ (D\bar{D}^*)^-$

$Z_c(3900)^\pm$?

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

$Z_c(3900)^0$?

$e^+e^- \rightarrow \pi^+ (D^*\bar{D}^-)$

$Z_c(4020)^\pm$?

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

$Z_c(4020)^0$?
X states search at BESIII
$$e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \pi^+\pi^- J/\psi$$

- $M = (3871.9 \pm 0.7 \pm 0.2)$ MeV, $\Gamma < 2.4$ MeV, Significance: $6.3 \sigma$
- production in $Y(4260)$ decay suggestive, but not conclusive

$$\frac{\mathcal{B}[Y(4260) \rightarrow \gamma X(3872)]}{\mathcal{B}(Y(4260) \rightarrow \pi^+\pi^- J/\psi)} = 0.1$$

_PRL 112 092001 (2014)_
\( e^+e^- \rightarrow \pi^+\pi^-X(3823) \rightarrow \pi^+\pi^-\gamma\chi_{c1} \)

**Fit:** \( M=3821.7 \pm 1.3 \pm 0.7 \text{ MeV} \)

**Significance:** 6.7\( \sigma \), observation

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**X(3823) as the \( \psi(1^3D_2) \)**

- Mass agrees with \( \psi(1^3D_2) \)
- Narrow width (<16 MeV @90\% C.L.)
- \( R=B[X(3823)\rightarrow gc_{c2}]/B[X(3823)\rightarrow gc_{c1}]<0.43 @ 90\% C.L. \)
  - Agree with predicted ~0.2
- \( 1^3D_2 \rightarrow gc_{c1} \) forbidden; \( 1^3D_3 \rightarrow gc_{c1} \) amplitude=0.
Y states search at BESIII
$e^+e^- \rightarrow \omega \chi_{c0} \ (\sqrt{s}=4.23, 4.26 \text{ GeV})$

$\omega \rightarrow \pi^+\pi^-\pi^0, \ \chi_{c0} \rightarrow \pi^+\pi^-, K^+K^-$

<table>
<thead>
<tr>
<th>$\sqrt{s} \ (\text{GeV})$</th>
<th>$\sigma^{\text{Born}} \ (\text{pb}^{-1})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.23</td>
<td>$55.4\pm6.0\pm5.9$</td>
</tr>
<tr>
<td>4.26</td>
<td>$23.7\pm5.3\pm3.5$</td>
</tr>
</tbody>
</table>

This is not consistent with the $Y(4260)$ (!?)

Assuming the $\omega \chi_{c0}$ signals come from a resonance, we extract the $\Gamma_{ee} \cdot B(\omega \chi_{c0})$, mass, and width of the resonance to be $(2.9\pm0.7\pm0.4)$ eV, $M=(4230\pm8\pm6)$ MeV/c$^2$, and $(38\pm12\pm2)$ MeV.

Clear $\chi_{c2}, \chi_{c1}$ are observed at $\sqrt{s}=4.42, 4.6$ GeV, respectively.

The Born cross section have been measured for $e^+e^- \rightarrow \omega \chi_{c1,2}$.

$\sigma(e^+e^- \rightarrow \omega \chi_{c2})$ is fitted with the coherent sum of the $\psi(4415)$ BW function and a phase-space term. Two solutions are obtained: constructive, destructive.
Observation of $e^+e^- \rightarrow \eta J/\psi$

- Agree with previous results with improved precision
- The cross section peaks around 4.2 GeV
- Analysis of high energy points underway

Observation of $e^+e^- \rightarrow \eta' J/\psi$

First observation, cannot tell the line shape due to statistics

- 4.23 GeV: $\sigma = 3.1 \pm 0.6 \pm 0.3$ pb
- 4.26 GeV: $\sigma = 3.9 \pm 0.8 \pm 0.4$ pb
No significant $e^+e^- \rightarrow \gamma Y(4140)$

Upper limit at the 90% C.L. for $\sigma^B \cdot \mathcal{B} = \sigma^B(e^+e^- \rightarrow \gamma Y(4140)) \cdot \mathcal{B}(Y(4140) \rightarrow \phi J/\psi)$

<table>
<thead>
<tr>
<th>(GeV/)</th>
<th>Luminosity (pb$^{-1}$)</th>
<th>()</th>
<th>prod</th>
<th>(pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.23</td>
<td>1094</td>
<td>0.840</td>
<td>&lt;339</td>
<td>&lt;0.35</td>
</tr>
<tr>
<td>4.26</td>
<td>827</td>
<td>0.847</td>
<td>&lt;207</td>
<td>&lt;0.28</td>
</tr>
<tr>
<td>4.36</td>
<td>545</td>
<td>0.944</td>
<td>&lt;179</td>
<td>&lt;0.33</td>
</tr>
</tbody>
</table>

Systematic uncertainty is considered.

Compared with $X(3872)$ production. PRL 112, 092001

$$\sigma^B(e^+e^- \rightarrow \gamma X(3872)) \cdot \mathcal{B}(X(3872) \rightarrow \pi^+\pi^-J/\psi) = 0.27\pm0.09\text{(stat)} \pm0.02\text{(syst)} \text{ pb at } \sqrt{s} = 4.23 \text{ GeV},$$

$$= 0.33\pm0.12\text{(stat)} \pm0.02\text{(syst)} \text{ pb at } \sqrt{s} = 4.26 \text{ GeV.}$$

Take $\mathcal{B}(X(3872) \rightarrow \pi^+\pi^-J/\psi) = 5\%$. arXiv: 0910.3138

And $\mathcal{B}(Y(4140) \rightarrow \phi J/\psi) = 30\%$, molecular calculation, PRD 80, 054019.

$$\frac{\sigma^B(e^+e^- \rightarrow \gamma Y(4140))}{\sigma(e^+e^- \rightarrow \gamma X(3872))} \leq 0.1 \text{ at } \sqrt{s}=4.23 \text{ and } 4.26 \text{ GeV.}$$

Charm physics

- Measurement of $B[D^0 \rightarrow K(\pi)^-e^+\nu] \& f_+^{K(\pi)}(0)$
- $D^+ \rightarrow K_L e^+\nu, \omega e^+\nu, \phi e^+\nu$
- DD mixing parameter $y_{CP}$
- Search for $D^0 \rightarrow \gamma\gamma$ and Measurement of $B[D^0 \rightarrow \pi^0\pi^0]$
- Absolute BF for $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$
- Absolute BFs for $\Lambda_c^+$ hadron decays
Measurement of $\mathbf{B[D^0 \rightarrow K(\pi)^-e^+\nu]}$

\[ e^+e^- \rightarrow \psi(3770) \rightarrow D^0D^0 \]

\[ N_{D^0} = (279.33 \pm 0.37) \times 10^4 \]

\[ B_j^{D^0 \rightarrow K^-\pi^+e^+\nu} = (3.505 \pm 0.014 \pm 0.033)\% \]

\[ B_j^{D^0 \rightarrow \pi^-e^+\nu} = (0.2950 \pm 0.0041 \pm 0.0026)\% \]
# Measurement of $f^+_K(\pi)(0)$

The diagram illustrates the measurement of $f^+_K(\pi)(0)$, with input $|V_{cs(d)}|$ from CKM-Fitter.

**Input $|V_{cs(d)}|$ of CKM-Fitter**

- **$f^+_D \rightarrow K(\pi)_+(0)$**
  - **BES-II**
    - 0.78$\pm$0.04$\pm$0.03
      - PLB597, 39
  - **CLEO-c**
    - 0.739$\pm$0.007$\pm$0.005
      - PRD80, 032005, 3. Par. Ser.
  - **BELLE**
    - 0.695$\pm$0.007$\pm$0.022
      - PRL97, 061804, Mod. Pole
  - **BABAR**
    - 0.727$\pm$0.007$\pm$0.005
      - PRD76, 052005, ISGW2
  - **PRD92 (2015) 072012**
    - BESIII, 2-Par. Ser.
  - **HPQCD**
    - 0.747$\pm$0.011$\pm$0.015
      - PRD82 (2010) 114506

**Output $f^+_K(\pi)(0)$**

- **BES-II**
  - 0.73$\pm$0.14$\pm$0.06
    - PLB597, 39
  - **CLEO-c**
    - 0.666$\pm$0.019$\pm$0.005
      - PRD80, 032005, 3. Par. Ser.
  - **BELLE**
    - 0.624$\pm$0.020$\pm$0.007
      - PRL97, 061804, Mod. Pole
  - **Babar**
    - 0.610$\pm$0.017$\pm$0.011
      - PRD91 (2015) 052022
      - Babar, 3-Par. Ser.
  - **PRD92 (2015) 072012**
    - BESIII, 2-Par. Ser.
  - **HPQCD**
    - 0.666$\pm$0.020$\pm$0.021
      - PRD84 (2011) 114505
Comparisons with previous results

<table>
<thead>
<tr>
<th>Mode</th>
<th>This work</th>
<th>Previous</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_L e^+\nu$</td>
<td>$(4.482\pm0.027\pm0.103)%$</td>
<td>---</td>
</tr>
<tr>
<td>$\omega e^+\nu$</td>
<td>$(1.63\pm0.11\pm0.08)\times10^{-3}$</td>
<td>$(1.82\pm0.18\pm0.07)\times10^{-3}$</td>
</tr>
<tr>
<td>$\phi e^+\nu$</td>
<td>$&lt;1.3\times10^{-5}$</td>
<td>$&lt;9.0\times10^{-5}$</td>
</tr>
</tbody>
</table>

$A_{CP}^{D\rightarrow K_{L}e^+\nu} = (-0.59\pm0.60 \pm 1.50)\%$

$ f_K^+(0)|V_{cs}| = 0.728\pm0.006\pm0.011$

Results of form factor ratios:

$r_V = V(0)/A_1(0) = 1.24 \pm 0.09 \pm 0.06$

$r_2 = A_2(0)/A_1(0) = 1.06 \pm 0.15 \pm 0.05$
We measure the $y_{CP}$ using CP-tagged semi-leptonic D decays, which allows to access CP asymmetry in mixing and decays.

$y_{CP} = (-2.1 \pm 1.3 \pm 0.7)\%$
Search for $D^0 \rightarrow \gamma \gamma$ and Measurement of $B[D^0 \rightarrow \pi^0 \pi^0]$

In SM, $D^0D^0$ mixing, CP violation and rare decay of charm are small. Searching for rare decays probes for New Physics beyond SM.

Search for flavor-changing neutral current (FCNC) decay $D^0 \rightarrow \gamma \gamma$ using DT method.

Consistent with Babar measurements and SM predication.

Improved measurement of $B[D^0 \rightarrow \pi^0 \pi^0]$ by using ST.

$B[D^0 \rightarrow \pi^0 \pi^0] = (8.24 \pm 0.21 \pm 0.30) \times 10^{-4}$
Absolute BF for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

Theoretical calculations on the BF ranges from 1.4% to 9.2% 

PDG2014: (2.1±0.6)%  
PDG2015: (2.9±0.5)%

14415±159 events with 11 ST modes 

Input $B[\Lambda_c^+ \rightarrow pK^-\pi^+]=(6.84^{+0.32}_{-0.40})\%$ by BELLE [PRL113,042002(2014)]

$B[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = (3.63\pm0.38\pm0.20)\%$ First absolute measurement 

Important for test and calibrate the LQCD calculations.
Absolute BFs for $\Lambda_c^+$ hadron decays

Measurement using the threshold pair-productions via $e^+e^-$ annihilation is unique: the most simple and straightforward

A global least-square global fitter is utilized to improve the measured precision for 12 $\Lambda_c^+$ hadronic decay channels.

$N_{DT}^{-} = \sum_{i+\neq i} N_{i+j}^{-} + \sum_{i-\neq i} N_{i-j}^{-} + N_{jj}^{-}$

✓ Absolute BFs are improved significantly.

✓ BESIII BF for $\Lambda_c^+ \rightarrow pK^-\pi^+$ is smaller.

✓ Improved absolute BF of $pK^-\pi^+$ together with BELLE’s result are key to calibrate other decays.
R-QCD

• Proton form factor measurement
• $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ and form factor
• Collins Asymmetry
Proton form factor measurement

- Radiative corrections from Phokhara8.0 (scan)
- Normalization to $e^+e^- \rightarrow e^+e^-, e^+e^- \rightarrow \gamma\gamma$ (BABAYAGA 3.5)
- Efficiencies from 60% (2.23 GeV) to 3.0% (~4 GeV)
- $|G_E/G_M|$ ratio obtained from 3 c.m. energies

$\sigma(e^+e^-\rightarrow\pi^+\pi^-)$ and form factor

ISR analysis using 2.9 fb$^{-1}$ data at $\psi(3770)$: $e^+e^-\rightarrow\pi^+\pi^-\gamma_{ISR}$

Exp. $a_{\mu}^{2\pi,LO}(600-900\text{ MeV})[10^{-10}]$

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Value $\pm$ Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar</td>
<td>$376.7 \pm 2.0_{stat} \pm 1.9_{sys}$</td>
</tr>
<tr>
<td>KLOE08</td>
<td>$368.9 \pm 0.4_{stat} \pm 2.3_{sys,exp} \pm 2.2_{sys,tho}$</td>
</tr>
<tr>
<td>KLOE10</td>
<td>$366.1 \pm 0.9_{stat} \pm 2.3_{sys,exp} \pm 2.2_{sys,tho}$</td>
</tr>
<tr>
<td>KLOE12</td>
<td>$366.7 \pm 1.2_{stat} \pm 2.4_{sys,exp} \pm 0.8_{sys,tho}$</td>
</tr>
<tr>
<td>BESIII</td>
<td>$371.9 \pm 2.6_{stat} \pm 5.2_{sys}$</td>
</tr>
</tbody>
</table>

Summary

- X(1835), Y(2175) and other new N* are either observed or confirmed.
- Some semi-leptonic decay for charm mesons are observed for the first time. DD mixing is searched.
- X,Y,Z states are searched. A lot of new neutral Z states are observed recently.
- The absolute BF for $\Lambda_c$ semi-leptonic and hadronic decay are measured. Some of them are the first time.
- The form factor for $e^+e^- \rightarrow pp, \pi^+\pi^-$ are measured.

Thank you!
Backup