Overview of BESIII Experiment

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Outline

• Introduction
• Status of BESIII
• Selected results from BESIII
• Upgrade plan
• Summary
Beijing Electron Positron Collider (BEPC)

beam energy: 1.0 – 2.3 GeV

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

- 1989-2004 (BEPC):
  \[ L_{\text{peak}} = 1 \times 10^{31} \text{ /cm}^2\text{s} \]
- 2009-now (BEPCII):
  \[ L_{\text{peak}} = 1 \times 10^{33} \text{ /cm}^2\text{s} \]
**BESIII Detector**

**MDC**
- R inner: 63mm
- R outer: 810mm
- Length: 2582 mm
- Layers: 43

**CsI(Tl) EMC**
- Crystals: 28 cm$(15 \times X_0)$
- Barrel: $|\cos \theta| < 0.83$
- Endcap: $0.85 < |\cos \theta| < 0.93$

**RPC MUC**
- BMUC: 9 layers – 72 modules
- EMUC: 8 layers – 64 modules

**TOF**
- BTOF: two layers
- ETOF: 48 scintillators for each
- MRPC --- new ETOF
Features of the BEPC Energy Region

- Rich of resonances: charmonia and charm mesons
- Threshold characteristics (pairs of $\tau$, $D$, $D_s$, ...)
- Transition between smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the new hadrons: glueballs, hybrids, multi-quark states
New forms of hadrons

- Conventional hadrons consist of 2 or 3 quarks:
  
  Naive Quark Model:
  - meson
  - baryon

- QCD predicts the new forms of hadrons:
  - Multi-quark states: Number of quarks \( \geq 4 \)
  - Hybrids: \( q\bar{q}g, \, qqqg \text{ ...} \)
  - Glueballs: \( gg, \, ggg \text{ ...} \)

None of the new forms of hadrons is settled!
Charmonium decays provide ideal hunting ground for light glueballs and hybrids

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

\[
\Gamma(J/\psi \rightarrow \gamma G) \sim O(\alpha_s^2), \quad \Gamma(J/\psi \rightarrow \gamma H) \sim O(\alpha_s^3), \\
\Gamma(J/\psi \rightarrow \gamma M) \sim O(\alpha_s^4), \quad \Gamma(J/\psi \rightarrow \gamma F) \sim O(\alpha_s^4)
\]
Charmonium spectroscopy

- Charmonium states below open charm threshold are all observed

Above open charm threshold:
- many expected states not observed
- many unexpected observed

from Ryan Mitchell

- X(3915)
- X(3872)
- X(4160)
- Y(4008)
- Y(4140)
- Y(4260)
- Y(4360)
- X(4350)
- Y(4660)
Precision measurement of CKM elements
-- Test EW theory

CKM matrix elements are fundamental SM parameters that describe the mixing of quark fields due to weak interaction.

\[
\begin{pmatrix}
  d' \\
  s' \\
  b'
\end{pmatrix}
= 
\begin{pmatrix}
  V_{ud} & V_{us} & V_{ub} \\
  V_{cd} & V_{cs} & V_{cb} \\
  V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
  d \\
  s \\
  b
\end{pmatrix}
\]

Three generations of quark?
Unitary matrix?

Expected precision < 2% at BESIII

BESIII + B factories + LQCD

Precision measurement of CKM matrix elements
-- a precise test of SM model
New physics beyond SM?
**Nucleon Form Factor**

- Fundamental properties of the nucleon
  - Connected to charge, magnetization distribution
  - Crucial testing ground for models of the nucleon internal structure
  - Necessary input for experiments probing nuclear structure, or trying to understand modification of nucleon structure in nuclear medium

- Can be measured from space-like processes ($eN$) (precision 1%) or time-like process ($e^+e^-$ annihilation) (precision 10%-30%)

\[ eN \rightarrow eN \]

**Space-like:**
- FF real

\[ e^+ e^- \leftrightarrow N \bar{N}, \Lambda \bar{\Lambda} \]

**Time-like:**
- FF complex
Physics at tau-charm Energy Region

- Hadron form factors
- \(Y(2175)\) resonance
- Multiquark states with s quark, Zs
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV
- Rare and forbidden decays
- Physics with \(\tau\) lepton

- XYZ particles
- D mesons
- \(f_D\) and \(f_{Ds}\)
- \(D_0\)-\(D_0\) mixing
- Charm baryons
BESIII Collaboration

Europe (14)
- Germany: Univ. of Bochum, Univ. of Giessen, GSI, Univ. of Johannes Gutenberg, Helmholtz Ins. In Mainz, Univ. of Munster
- Russia: JINR Dubna; BINP Novosibirsk
- Italy: Univ. of Torino, Frascati Lab, Ferrara Univ.
- Netherlands: KVI/Univ. of Groningen
- Sweden: Uppsala Univ.

China (34)
- IHEP, CCAST, UCAS, 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., Univ. of Sci. and Tech. Liaoning
- Nanjing Univ., Nanjing Normal Univ., Southeast Univ.
- Guangxi Normal Univ., Guangxi Univ.
- Suzhou Univ., Hangzhou Normal Univ.
- Lanzhou Univ., Henan Sci. and Tech. Univ.
- Jinan Univ., Hunan Normal Univ., Xinyang Normal Univ.

US (4)
- Univ. of Hawaii
- Carnegie Mellon Univ.
- Univ. of Minnesota
- Univ. of Indiana

Mongolia (1)
- Institute of Physics and Technology

Pakistan (2)
- Univ. of Punjab
- COMSAT CIIT

India (1)
- Indian Institute of Technology

Japan (1)
- Seoul Nat. Univ.

Korea (1)
- Tokyo Univ.

~ 450 members from 58 institutions in 13 countries
BESIII data samples

World largest $J/\psi$, $\psi(2S)$, $\psi(3770)$, $\psi(4170)$, $Y(4260)$, ... produced directly from $e^+e^-$ collision
Selected results

- XYZ studies
- Light hadron spectroscopy
- Charm physics
- $\Lambda_c$ absolute branching fractions
XYZ study at BESIII
Observation of $Z_c(3900)^\pm$

$Z_c(3900)^+$:

$m = (3899.0 \pm 3.6 \pm 4.9)$ MeV/c$^2$  
$\Gamma = (46 \pm 10 \pm 20)$ MeV  

Mass close to $D \overline{D}^*$ threshold

Decays to $J/\psi \rightarrow$ contains $c \overline{c}$  
Electric charge $\rightarrow$ contains $u \overline{d}$

\[
\sigma[e^+e^- \rightarrow \pi^+\pi^-J/\psi] = 62.9 \pm 1.9 \pm 3.7 \text{ pb at 4.26 GeV}
\]

\[
\frac{\sigma[e^+e^- \rightarrow \pi^\pm Z_c(3900)^\mp \rightarrow \pi^+\pi^-J/\psi]}{\sigma[e^+e^- \rightarrow \pi^+\pi^-J/\psi]} = (21.5 \pm 3.3 \pm 7.5)\% \text{ at 4.26 GeV}
\]

Belle with ISR data (PRL 110, 252002)

CLEOc data at 4.17 GeV (PLB 727, 366)
Summary of Zc’s at BESIII

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

\[Z_c(3900)^+?\]

\[Z_c(3900)^0?\]

\[Z_c(4020)^+?\]

\[Z_c(4020)^0?\]
### Summary of Zc’s at BESIII

<table>
<thead>
<tr>
<th>$Z_c^{\pm}$ (3900)</th>
<th>$Z_c^{\pm}$ (4020)</th>
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<tbody>
<tr>
<td>$e^+e^- \rightarrow \pi^+\pi^- J/\psi$</td>
<td>$e^+e^- \rightarrow \pi^+\pi^- h_c$</td>
</tr>
<tr>
<td>$M = 3899.0 \pm 3.6 \pm 4.9$ MeV</td>
<td>$M = 4022.9 \pm 0.8 \pm 2.7$ MeV</td>
</tr>
<tr>
<td>$\Gamma = 46 \pm 10 \pm 20$ MeV</td>
<td>$\Gamma = 7.9 \pm 2.7 \pm 2.6$ MeV</td>
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<th>$Z_c^0$ (3900)</th>
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<tr>
<td>$e^+e^- \rightarrow \pi^0\pi^0 J/\psi$</td>
<td>$e^+e^- \rightarrow \pi^0\pi^0 h_c$</td>
</tr>
<tr>
<td>$M = 3894.8 \pm 2.3$ MeV</td>
<td>$M = 4023.9 \pm 2.2 \pm 3.8$ MeV</td>
</tr>
<tr>
<td>$\Gamma = 29.6 \pm 8.2$ MeV</td>
<td>$\Gamma$ Fixed at $Z_c^{\pm}$ (4020)</td>
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<th>$Z_c^{\pm}$ (3885)</th>
<th>$Z_c^{\pm}$ (4025)</th>
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<tr>
<td>$e^+e^- \rightarrow \pi (D^*D)^{\pm}$</td>
<td>$e^+e^- \rightarrow \pi (D^<em>D^</em>)^{\pm}$</td>
</tr>
<tr>
<td>$M = 3882.2 \pm 1.1 \pm 1.5$ MeV</td>
<td>$M = 4026.3 \pm 2.6 \pm 3.7$ MeV</td>
</tr>
<tr>
<td>$\Gamma = 26.5 \pm 1.7 \pm 2.1$ MeV</td>
<td>$\Gamma = 24.8 \pm 5.6 \pm 7.7$ MeV</td>
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<th>$Z_c^0$ (3885)</th>
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<tr>
<td>$e^+e^- \rightarrow \pi^0(D^*D)^0$</td>
<td>$e^+e^- \rightarrow \pi^0(D^<em>D^</em>)^0$</td>
</tr>
<tr>
<td>$M = 3885.7 \pm 5.7 \pm 8.4$ MeV</td>
<td>$M = 4025.5 \pm 4.7 \pm 3.1$ MeV</td>
</tr>
<tr>
<td>$\Gamma = 35 \pm 12 \pm 15$ MeV</td>
<td>$\Gamma = 23.0 \pm 6.0 \pm 1.0$ MeV</td>
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Determination of $J^p$ of $Z_c(3900)$ from $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

- Amplitude analysis with helicity formalism
- Simultaneous fit to data samples at 4.23GeV and 4.26GeV
- $\pi^+\pi^-$ spectrum is parameterized by $\sigma$, $f_0(980)$, $f_2(1270)$ and $f_0(1370)$

$J^p$ of $Z_c$ favor $1^+$ with statistical significance larger than 7.3$\sigma$ over other quantum numbers.

arXiv:1706.04100 accepted by PRL
Determination of $J^p$ of $Z_c(3900)$ from $e^+e^- \rightarrow \pi^+\pi^- J/\psi$

<table>
<thead>
<tr>
<th>$Z_c$ : $J^P$</th>
<th>$M$ (MeV)</th>
<th>$g_1'$ (GeV$^2$)</th>
<th>$g_2'/g_1'$</th>
<th>$-\ln L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0$^-$</td>
<td>3906.3 ± 2.3</td>
<td>0.079 ± 0.007</td>
<td>25.8 ± 2.9</td>
<td>-1528.8</td>
</tr>
<tr>
<td>1$^-$</td>
<td>3903.1 ± 1.9</td>
<td>0.063 ± 0.005</td>
<td>26.5 ± 2.6</td>
<td>-1457.7</td>
</tr>
<tr>
<td>1$^+$</td>
<td>3900.2 ± 1.5</td>
<td>0.075 ± 0.006</td>
<td>21.8 ± 1.7</td>
<td>-1569.8</td>
</tr>
<tr>
<td>2$^-$</td>
<td>3905.2 ± 2.1</td>
<td>0.060 ± 0.004</td>
<td>28.7 ± 2.7</td>
<td>-1516.5</td>
</tr>
<tr>
<td>2$^+$</td>
<td>3894.3 ± 1.9</td>
<td>0.051 ± 0.005</td>
<td>23.4 ± 3.3</td>
<td>-1316.2</td>
</tr>
</tbody>
</table>

- $J^p$ of $Z_c$ favor $1^+$ with statistical significance larger than 7.3σ over other quantum numbers

- Significance for $e^+e^- \rightarrow Z_c^+(4020) \pi^- + c.c \rightarrow \pi^+\pi^- J/\psi$ is ~3σ.

Upper limits at 90% C.L.:

$$\frac{\sigma(e^+e^- \rightarrow Z_c^+(4020) \pi^- + c.c \rightarrow \pi^+\pi^- J/\psi)}{\sigma(e^+e^- \rightarrow Z_c^+(3900) \pi^- + c.c \rightarrow \pi^+\pi^- J/\psi)} < 3.3\% \text{ at 4.23 GeV}$$

$$< 25.1\% \text{ at 4.26 GeV}$$
Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$


- Coherent sum of two BW-like structures + one incoherent $\psi(3770)$
  - $M = (4222.0 \pm 3.1 \pm 1.4)\ MeV,$ $\Gamma = (44.1 \pm 4.3 \pm 2.0)\ MeV$
  - Lower and narrower than previous $Y(4260)$ PDG values
- $M = (4320.0 \pm 10.4 \pm 7 )\ MeV,$ $\Gamma = (101.4 \pm 25 \pm 10)\ MeV$
  - A little bit lower than $Y(4360)$ PDG value

- Compared with one BW fit, the sig. of the second BW is 7.6\sigma

- $Y(4260) + Y(4360)$? The first observation of $Y(4360) \rightarrow \pi^+\pi^-J/\psi$
Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^-\psi'$

- Cross section of $e^+e^- \rightarrow \pi^+\pi^-\psi(3686)$ has been measured at 16 energy points from 4.008 to 4.600 GeV.
- A clear peak around $Y(4360)$, consistent with the results from Belle and BaBar, but with much improved precision.
- The fit on the cross section is ongoing.
Cross section measurement of $e^+e^- \rightarrow \pi^+\pi^- h_c$

Fitted with coherent sum of two BW-like structures

- $M_1=4218.4^{+5.5}_{-4.5} \pm 0.9$ MeV/c$^2$, $\Gamma_1= 66.0^{+12.3}_{-8.3} \pm 0.4$ MeV $\rightarrow Y(4220)$
- $M_2=4391.5^{+6.3}_{-6.8} \pm 1.0$ MeV/c$^2$, $\Gamma_2=139.5^{+16.2}_{-20.6} \pm 0.6$ MeV $\rightarrow Y(4390)$

The $Y(4220)$ here is consistent with the state observed in $\pi^+\pi^-J/\psi$ around 4222MeV
Cross section measurement of $e^+e^- \rightarrow \omega \chi_{cJ}$

- Only $\omega \chi_{c0}$ has significant signal.
- The cross section is fitted with coherent sum of a BW and a phase space term.
- $M = 4230 \pm 8 \pm 6 \text{ MeV}$, $\Gamma = 38 \pm 12 \pm 2 \text{ MeV}$.
- The mass and width are compatible with the Y observed in $\pi^+\pi^- J/\psi$ and $e^+e^- \rightarrow \pi^+\pi^- h_c$.
Light meson spectroscopy at BESIII

(Joint efforts with GlueX in future)
- Any relations?
- What is the role of the ppbar threshold (and other thresholds)?
- Patterns in the production and decay modes
Anomalous line shape of $\eta'\pi^+\pi^-$ near $p\bar{p}$ mass threshold: connection between $X(1835)$ and $X(p\bar{p})$

$X(1835)$ observed in $J/\psi\to\gamma\eta'\pi^+\pi^-$


$X(1835)$ $J^P C=0^{-+}$

$M = 1844 \pm 9^{+16}_{-25}$ MeV/$c^2$

$\Gamma = 192^{+20+62}_{-17-43}$ MeV/$c^2$

$X(p\bar{p})$ observed in $J/\psi\to\gamma p\bar{p}$

PRL 108, 112003 (2012)
PRL 115, 091803 (2015)

$X(p\bar{p})$ $J^P C=0^{-+}$

$M = 1832^{+19+18}_{-5-17} \pm 19$ MeV/$c^2$

$\Gamma = 13 \pm 19$ MeV/$c^2$ ($< 76$ MeV/$c^2$ @ 90% C.L.)

Connection is emerging

PRL 117, 042002 (2016)

Model 1: Flat line shape with strong coupling to $p\bar{p}$ and one additional, narrow Breit-Wigner at $\sim 1920$ MeV/$c^2$

Model 2: Coherent sum of $X(1835)$ Breit-Wigner and one additional, narrow Breit-Wigner at $\sim 1870$ MeV/$c^2$

• Suggest the existence of a state, either a broad one with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass thresh.
• Support the existence of a $p\bar{p}$ molecule-like state or bound state.
Partial Wave Analysis of $J/\psi \rightarrow \gamma \phi \phi$

Besides $\eta(2225)$, very little was known in the sector of pseudoscalar above 2 GeV. The new experimental results are helpful for mapping out the pseudoscalar excitations and searching for $0^+$ glueball.

- Dominant contribution from pseudoscalars
  - $\eta(2225)$ is confirmed;
  - $\eta(2100)$ and $X(2500)$ are observed with large significance.
- Three tensors $f_2(2010)$, $f_2(2300)$ and $f_2(2340)$ stated in $\pi p$ reactions observed. A strong production of $f_2(2340)$.
- Model-dependent PWA results are well consistent with the results from MIPWA.
Amplitude analysis of $\chi_{c1} \to \eta\pi^+\pi^-$

- Clear evidence for $a_2(1700)$ in $\chi_{c1}$ decays.
- First measurement of $g'_{\eta/\pi} \neq 0$ using $a_0(980) \to \eta\pi$ line shape.
- Measured upper limits for $\pi_1(1^{--})$ in 1.4 - 2.0 GeV/c$^2$ region.
Charmonium decays provide novel insights into baryons --- complementary to other experiments

\( J/\psi (\psi') \rightarrow \overline{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^* \)

- Isospin 1/2 filter: \( \psi \rightarrow N\overline{N}\pi, \psi \rightarrow N\overline{N}\pi\pi \)
- Missing \( N^* \) with small couplings to \( \pi N \) & \( \gamma N \), but large coupling to \( gggN \): \( \psi \rightarrow N\overline{N}\pi/\eta/\eta'/\omega/\phi, \overline{p}\Sigma\pi, \overline{p}\Lambda K \ldots \)
- Not only \( N^* \), but also \( \Lambda^*, \Sigma^*, \Xi^* \)
- Gluon-rich environment: a favorable place for producing hybrid (qqqqg) baryons
- Interference between \( N^* \) and \( \overline{N}^* \) bands in \( \psi \rightarrow N\overline{N}\pi \) Dalitz plots may help to distinguish some ambiguities in PWA of \( \pi N \)
- High statistics of charmonium @ BES III
\( \Xi^{-}(1690) \) and \( \Xi^{-}(1820) \) are observed in \( \psi' \to K^- \Lambda \Xi^+ \) \( + \) c. c. Resonance parameters consistent with PDG values.

<table>
<thead>
<tr>
<th>Decay</th>
<th>Branching fraction</th>
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<tbody>
<tr>
<td>( \psi(3686) \to K^- \Lambda \Xi^+ )</td>
<td>((3.86 \pm 0.27 \pm 0.32) \times 10^{-5})</td>
</tr>
<tr>
<td>( \psi(3686) \to \Xi(1690)^- \Xi^+, \Xi(1690)^- \to K^- \Lambda )</td>
<td>((5.21 \pm 1.48 \pm 0.57) \times 10^{-6})</td>
</tr>
<tr>
<td>( \psi(3686) \to \Xi(1820)^- \Xi^+, \Xi(1820)^- \to K^- \Lambda )</td>
<td>((12.03 \pm 2.94 \pm 1.22) \times 10^{-6})</td>
</tr>
<tr>
<td>( \psi(3686) \to K^- \Sigma^0 \Xi^+ )</td>
<td>((3.67 \pm 0.33 \pm 0.28) \times 10^{-5})</td>
</tr>
<tr>
<td>( \psi(3686) \to \gamma \chi_{c0}, \chi_{c0} \to K^- \Lambda \Xi^+ )</td>
<td>((1.90 \pm 0.30 \pm 0.16) \times 10^{-5})</td>
</tr>
<tr>
<td>( \psi(3686) \to \gamma \chi_{c1}, \chi_{c1} \to K^- \Lambda \Xi^+ )</td>
<td>((1.32 \pm 0.20 \pm 0.12) \times 10^{-5})</td>
</tr>
<tr>
<td>( \psi(3686) \to \gamma \chi_{c2}, \chi_{c2} \to K^- \Lambda \Xi^+ )</td>
<td>((1.68 \pm 0.26 \pm 0.15) \times 10^{-5})</td>
</tr>
<tr>
<td>( \chi_{c0} \to K^- \Lambda \Xi^+ )</td>
<td>((1.96 \pm 0.31 \pm 0.16) \times 10^{-4})</td>
</tr>
<tr>
<td>( \chi_{c1} \to K^- \Lambda \Xi^+ )</td>
<td>((1.43 \pm 0.22 \pm 0.12) \times 10^{-4})</td>
</tr>
<tr>
<td>( \chi_{c2} \to K^- \Lambda \Xi^+ )</td>
<td>((1.93 \pm 0.30 \pm 0.15) \times 10^{-4})</td>
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</table>

In the study of \( \psi' \to \gamma K^- \Lambda \Xi^+ \) \( + \) c. c., the branching fraction of \( \psi' \to K^- \Sigma^0 \Xi^+ \) \( + \) c. c. and \( \chi_{cJ} \to K^- \Lambda \Xi^+ \) \( + \) c. c. are measured.
Charm physics at BESIII

Advantage of open charm at threshold

e^+e^- colliders@threshold:

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

Good for charm flavor physics:

- Threshold production: clean
- Known initial energy and quantum numbers
- Both D and Dbar fully reconstructed (double tag)
- Absolute measurements

A joint effort among BESIII, LHCb and Belle-II should be formed to understand the charm decay dynamics and insight of CPV in charm sector.
$f_{D(s)^+}: \text{Leptonic decays}$

\[
\Gamma(D^+ \rightarrow \ell^+ \nu_{\ell}) = f_D^2 |V_{cd}|^2 \frac{G_F^2}{8\pi} m_D m_{\ell} \left(1 - \frac{m_{\ell}^2}{m_D^2}\right)^2
\]

$B(D^+ \rightarrow \mu^+ \nu) = (3.72 \pm 0.19 \pm 0.06) \times 10^{-4}$

$f_{D^+} = (203.4 \pm 5.2 \pm 1.9) \text{ MeV}$

$|V_{cd}| = 0.2212 \pm 0.0056 \pm 0.0047$

$\iff$ LQCD calculated $f_D = 207 \pm 4 \text{ MeV}$

[PRL100(2008)062002]
\[ B(D^+ \rightarrow \mu^+\nu) \]

BES III: 2.7% with 2.92 fb\(^{-1}\)

BES III final: 1.5% with 10 fb\(^{-1}\)
Semi-leptonic decays

- Provide a good place to study the weak and strong interaction

\[
\frac{d\Gamma(D \to P e\nu)}{dq^2} = \frac{G_F^2 |V_{cs(d)}|^2}{24\pi^3} p^3 |f_+ (q^2)|^2
\]

- Measure hadronic form factors \( f_+^{D\to K}\) and \( f_+^{D\to \pi}\)

- Extract CKM matrix elements \(|V_{cs}|\) and \(|V_{cd}|\)
$D^0 \rightarrow K^- e^+ \nu_e$ and $\pi^- e^+ \nu_e$

$(279.33 \pm 0.37) \times 10^4$ single $D^0$ tags

$70727 \pm 278$ signals

$6297 \pm 87$ signals
Measure partial decay rates in $q^2$ bins:

$$\Delta \Gamma_i = \frac{N_{\text{prd}}^i}{\tau_D N_{\text{tag}}} = \frac{1}{\tau_D N_{\text{tag}}} \sum_j N_{\text{obs}}^j (\varepsilon^{-1})_{ij} N_{\text{obs}}^j$$

Extract $f_+(0) | V_{cs}(d) |$ and other form factor parameters from measured partial decay rates in $q^2$ bin

Form Factor Parameterizations:

1. Single Pole
   \[ f_+(q^2) = \frac{f_+(0)}{1 - q^2/M_{Pb}^2} \]

2. Modified Pole (BK)
   \[ r_s(q^2) = \frac{f_+(0)}{1 - q^2/M_{Pb}^2} \]  
   \[ f_+(q^2) = f_+(q_{\text{min}}^2) \left( 1 + \frac{r_{\text{ISGW2}}}{12} (q_{\text{max}}^2 - q^2)^2 \right)^{-1} \]

3. ISGW2
   \[ f_+(q^2) = f_+(q_{\text{min}}^2) \left( 1 + \frac{r_{\text{ISGW2}}}{12} (q_{\text{max}}^2 - q^2)^2 \right)^{-1} \]

4. Series Expansion
   \[ f_+(q^2) = \frac{1}{P(q^2) \phi(q^2, t_0)} \sum_{k=0}^{\infty} \frac{c_k(t_0)}{\varepsilon(q^2, t_0)^k} \]
To determine $f_{+}^{D\rightarrow K(\pi)}(0)$, use the measurements of $f_{+}^{D\rightarrow K(\pi)}(0)\,|\,V_{cs(d)}|$ and the PDG values for $|V_{cs(d)}|$ (assuming CKM unitarity).

- **BESIII** made the best precise determinations of these two form factors.
- The experimental accuracy is better than that of theoretical predictions.
**Λ_c** study at BESIII

**Λ_c^+**: a heavy quark \( (c) \) with a unexcited spin-zero diquark \( (u-d) \)

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<thead>
<tr>
<th>Charmed meson ( (D^+[c\bar{d}]) )</th>
<th>Strange baryons ( (Λ[uds]) )</th>
<th>Charmed baryon ( (Λ_c[udc]) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_d \ll m_c \rightarrow \text{quark + heavy quark} \ (q) )</td>
<td>( m_u, m_d \approx m_s \rightarrow (qqq) ) uniform</td>
<td>( m_u, m_d \ll m_c \rightarrow \text{diquark + quark} \ (qq) ) (Q)</td>
</tr>
</tbody>
</table>

**Λ_c^+** may provide complementary powerful test on internal dynamics to charmed meson.

- The **lightest** charmed baryon
- Most of the charmed baryons will **eventually decay** to **Λ_c^+**
- \( B(Λ_c^+ \rightarrow pK^-\pi^+) \): dominant error for \( V_{ub} \) via b-baryon decay
**Λ⁺ experimental status**

**Λ⁺ Measurements [PDG2015]**

<table>
<thead>
<tr>
<th>Hadronic modes with a μ: S = 1 final states</th>
<th>Scale factor/Confidence level (Mode)</th>
<th>ΔB/B</th>
</tr>
</thead>
<tbody>
<tr>
<td>pK⁰</td>
<td>(3.21 ± 0.30)%</td>
<td>9.3%</td>
</tr>
<tr>
<td>pK⁰(892)⁰</td>
<td>(6.84 ± 0.32)%</td>
<td>5.8%</td>
</tr>
<tr>
<td>Δ(1232)⁺⁺⁻⁻K⁻</td>
<td>(1.18 ± 0.22)%</td>
<td>14.1%</td>
</tr>
<tr>
<td>A(1520)⁺⁺</td>
<td>(2.4 ± 0.6)%</td>
<td>22.9%</td>
</tr>
<tr>
<td>pK⁺⁻π⁻ nonresonant</td>
<td>(3.8 ± 0.4)%</td>
<td>25.0%</td>
</tr>
<tr>
<td>pK⁺⁻π⁻ η</td>
<td>(4.5 ± 0.6)%</td>
<td>10.5%</td>
</tr>
<tr>
<td>pK⁺⁻π⁻</td>
<td>(1.7 ± 0.4)%</td>
<td>13.3%</td>
</tr>
<tr>
<td>pK⁺⁻π⁻</td>
<td>(3.5 ± 0.4)%</td>
<td>13.5%</td>
</tr>
<tr>
<td>pK⁺⁻π⁻</td>
<td>(4.6 ± 0.8)%</td>
<td>11.4%</td>
</tr>
<tr>
<td>seen</td>
<td>(5.0 ± 0.9)%</td>
<td>13.0%</td>
</tr>
<tr>
<td>Δ(1232)(K⁰(892))</td>
<td>(1.5 ± 0.5)%</td>
<td>33.3%</td>
</tr>
<tr>
<td>pK⁺⁻π⁺π⁻</td>
<td>(1.6 ± 1.0) × 10⁻³</td>
<td>18.0%</td>
</tr>
<tr>
<td>Hadronic modes with a μ: S = 0 final states</td>
<td>Scale factor/Confidence level (Mode)</td>
<td>ΔB/B</td>
</tr>
<tr>
<td>p⁺π⁻</td>
<td>(4.7 ± 0.5) × 10⁻³</td>
<td>45.4%</td>
</tr>
<tr>
<td>p⁺π⁻</td>
<td>(3.8 ± 0.5) × 10⁻³</td>
<td>45.4%</td>
</tr>
<tr>
<td>p⁺π⁻π⁻⁻⁻⁻</td>
<td>(2.5 ± 1.6) × 10⁻³</td>
<td>53.2%</td>
</tr>
<tr>
<td>k⁺⁻K⁻</td>
<td>(1.1 ± 0.4) × 10⁻³</td>
<td>64.0%</td>
</tr>
<tr>
<td>p⁺</td>
<td>(1.12 ± 0.22) × 10⁻⁴</td>
<td>36.4%</td>
</tr>
<tr>
<td>k⁺⁻K⁻ non-φ</td>
<td>(4.8 ± 1.0) × 10⁻⁴</td>
<td>36.4%</td>
</tr>
<tr>
<td>Hadronic modes with a hyperon: S = 1 final states</td>
<td>Scale factor/Confidence level (Mode)</td>
<td>ΔB/B</td>
</tr>
<tr>
<td>A⁺⁻</td>
<td>(1.46 ± 0.13)%</td>
<td>8.9%</td>
</tr>
<tr>
<td>A⁺⁻π⁻⁻⁻⁻</td>
<td>(5.0 ± 1.3)%</td>
<td>25.0%</td>
</tr>
<tr>
<td>A⁺⁻π⁺⁻⁻⁻⁻</td>
<td>&lt; 6%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Σ⁺(1385)⁺⁺⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻⁻ нарко modes</td>
<td>Scale factor/Confidence level (Mode)</td>
<td>ΔB/B</td>
</tr>
<tr>
<td>-suppressed modes</td>
<td>&lt; 3.1 × 10⁻⁴</td>
<td>20.3%</td>
</tr>
</tbody>
</table>

- Total BFs < 65%
- Large uncertainties, most larger than 20%
- Most BFs are measured relative to $\Lambda_c \rightarrow pK\pi$
Semi-Leptonic decay $\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$

- **ARGUS first measurement**:  
  \[ \sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot \text{BR}(\Lambda_c^+ \rightarrow \Lambda e^+ X) = 4.20 \pm 1.28 \pm 0.71 \text{ pb} \]  
  \[ \sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot \text{BR}(\Lambda_c^+ \rightarrow \Lambda \mu^+ X) = 3.91 \pm 2.02 \pm 0.90 \text{ pb} \]  
  
- **CLEO improved measurement**:  
  \[ \sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot \text{BR}(\Lambda_c^+ \rightarrow \Lambda e^+ X) = 4.87 \pm 0.28 \pm 0.69 \text{ pb} \]  
  \[ \sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot \text{BR}(\Lambda_c^+ \rightarrow \Lambda \mu^+ X) = 4.43 \pm 0.51 \pm 0.64 \text{ pb} \]  

- Combined with the $\tau(\Lambda_c^+)$ and the assumption of form factors

  \[ \begin{align*}
  \Lambda e^+ \nu_e & \quad \text{PDG 2015} \\
  \text{BR}[r] & = (2.8 \pm 0.4) \% \\
  \text{BR} & = (2.9 \pm 0.5) \% \\
  \Lambda \mu^+ \nu_\mu & \quad \text{(2.7 \pm 0.6) \%}
  \end{align*} \]

- Not a direct measurement!

  Theoretical calculations on the BF ranges from 1.4% to 9.2%
The measurement of $\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$

Double tag method  11 tag modes:

$$M_{BC} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_{\Lambda_c^-}|^2}$$

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\Delta E$ (GeV)</th>
<th>$N_{\Lambda_c^-}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{p}K_S^0$</td>
<td>$[-0.025, 0.028]$</td>
<td>$1066 \pm 33$</td>
</tr>
<tr>
<td>$\bar{p}K^+\pi^-$</td>
<td>$[-0.019, 0.023]$</td>
<td>$5692 \pm 88$</td>
</tr>
<tr>
<td>$\bar{p}K^0\pi^0$</td>
<td>$[-0.035, 0.049]$</td>
<td>$593 \pm 41$</td>
</tr>
<tr>
<td>$\bar{p}K^0\pi^-\pi^0$</td>
<td>$[-0.044, 0.052]$</td>
<td>$1547 \pm 61$</td>
</tr>
<tr>
<td>$\bar{p}K^0\pi^+\pi^-$</td>
<td>$[-0.029, 0.032]$</td>
<td>$516 \pm 34$</td>
</tr>
<tr>
<td>$\bar{\Lambda}\pi^-$</td>
<td>$[-0.033, 0.035]$</td>
<td>$593 \pm 25$</td>
</tr>
<tr>
<td>$\bar{\Lambda}\pi^-\pi^0$</td>
<td>$[-0.037, 0.052]$</td>
<td>$1864 \pm 56$</td>
</tr>
<tr>
<td>$\bar{\Lambda}\pi^-\pi^+\pi^-$</td>
<td>$[-0.028, 0.030]$</td>
<td>$674 \pm 36$</td>
</tr>
<tr>
<td>$\bar{\Sigma}^0\pi^-$</td>
<td>$[-0.029, 0.032]$</td>
<td>$532 \pm 30$</td>
</tr>
<tr>
<td>$\bar{\Sigma}^-\pi^0$</td>
<td>$[-0.038, 0.062]$</td>
<td>$329 \pm 28$</td>
</tr>
<tr>
<td>$\bar{\Sigma}^-\pi^+\pi^-$</td>
<td>$[-0.049, 0.054]$</td>
<td>$1009 \pm 57$</td>
</tr>
</tbody>
</table>

ST yields: $14415 \pm 159$ events with 11 ST modes
BFs of $\Lambda_c^+ \to \Lambda l^+ \nu_l$ decay

First direct measurement, optimized variables:

$$U_{\text{miss}} = E_{\text{miss}} - c|\vec{P}_{\text{miss}}|$$

$$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$

$$B[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$$

Important to test and calibrate LQCD and lepton universality.

$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$
Absolute BFs of $\Lambda_c^+$ Cabibbo-Favored hadronic decays

Signal Tag Variable: $M_{BC} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_{\Lambda^-_c}|^2}$

**ST yields**

<table>
<thead>
<tr>
<th>modes</th>
<th>$N_{ST}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pK_S$</td>
<td>1243 ± 37</td>
</tr>
<tr>
<td>$pK^-\pi^+$</td>
<td>6308 ± 88</td>
</tr>
<tr>
<td>$pK_S\pi^0$</td>
<td>558 ± 33</td>
</tr>
<tr>
<td>$pK_S\pi^+\pi^-$</td>
<td>454 ± 28</td>
</tr>
<tr>
<td>$pK^-\pi^+\pi^0$</td>
<td>1849 ± 71</td>
</tr>
<tr>
<td>$\Lambda\pi^+$</td>
<td>706 ± 27</td>
</tr>
<tr>
<td>$\Lambda\pi^+\pi^0$</td>
<td>1497 ± 52</td>
</tr>
<tr>
<td>$\Lambda\pi^+\pi^-\pi^+$</td>
<td>609 ± 31</td>
</tr>
<tr>
<td>$\Sigma^0\pi^+$</td>
<td>586 ± 32</td>
</tr>
<tr>
<td>$\Sigma^+\pi^0$</td>
<td>271 ± 25</td>
</tr>
<tr>
<td>$\Sigma^+\pi^+\pi^-$</td>
<td>836 ± 43</td>
</tr>
<tr>
<td>$\Sigma^+\omega$</td>
<td>157 ± 22</td>
</tr>
</tbody>
</table>

**DT yields**

<table>
<thead>
<tr>
<th>Decay modes</th>
<th>$N_{DT}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pK_S$</td>
<td>89 ± 10</td>
</tr>
<tr>
<td>$pK^-\pi^+$</td>
<td>390 ± 21</td>
</tr>
<tr>
<td>$pK_S\pi^0$</td>
<td>40 ± 7</td>
</tr>
<tr>
<td>$pK_S\pi^+\pi^-$</td>
<td>29 ± 6</td>
</tr>
<tr>
<td>$pK^-\pi^+\pi^0$</td>
<td>148 ± 14</td>
</tr>
<tr>
<td>$\Lambda\pi^+$</td>
<td>59 ± 8</td>
</tr>
<tr>
<td>$\Lambda\pi^+\pi^0$</td>
<td>89 ± 11</td>
</tr>
<tr>
<td>$\Lambda\pi^+\pi^-\pi^+$</td>
<td>53 ± 7</td>
</tr>
<tr>
<td>$\Sigma^0\pi^+$</td>
<td>39 ± 6</td>
</tr>
<tr>
<td>$\Sigma^+\pi^0$</td>
<td>20 ± 5</td>
</tr>
<tr>
<td>$\Sigma^+\pi^+\pi^-$</td>
<td>56 ± 8</td>
</tr>
<tr>
<td>$\Sigma^+\omega$</td>
<td>13 ± 3</td>
</tr>
</tbody>
</table>

Almost background free

**PRL 116, 052001 (2016)**
Results of 12 CF hadronic BFs

- Straightforward and model independent
- A least square global simultaneous fit:

\[ \text{BESIII precision comparable with Belle's} \]

\[ \text{BESIII } B(\Lambda_c^+ \rightarrow pK^- \pi^+) \text{ is compatible with BELLE's within } 2\sigma \]

Improved precisions of the other 11 modes significantly
Observation of $\Lambda_c^+ \rightarrow nK_S^0p^+$

First observation of $\Lambda_c^+$ decays involving the neutron in final states.

The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry and extract the strong phases of different final states.

$\text{B}[\Lambda_c^+ \rightarrow nK_S^0\pi^+] = (1.82\pm0.23\pm0.11)\%$

$\frac{\text{B}[\Lambda_c^+ \rightarrow nK_S^0\pi^+]}{\text{B}[\Lambda_c^+ \rightarrow pK^-\pi^+]} = 0.62\pm0.09$

$\frac{\text{B}[\Lambda_c^+ \rightarrow nK_S^0\pi^+]}{\text{B}[\Lambda_c^+ \rightarrow pK^0\pi^0]} = 0.97\pm0.16$

The phase difference between $I^{(0)}$ and $I^{(1)}$: $\cos\delta = -0.24 \pm 0.08$

and relative strength: $|I^{(1)}|/|I^{(0)}| = 1.14 \pm 0.11$
Upgrade plan and physics prospects
New ETOF (built by USTC & IHEP) was installed in 2015 to improve the time resolution.

MDC: Malter effect found in inner chamber in 2012, add water vapor to the chamber to cure the aging problem.
- New inner chamber, built by IHEP, is ready now.
- CGEM as the inner chamber ongoing: Italy group in collaboration with other groups.

New valve box for superconducting magnet

Other possible upgrade plan is under discussion
Installation of MRPC Endcap TOF

• Scintillator Endcap TOF: time resolution for $\pi$ is 138ps.

• New MRPC Endcap-TOF built

• The installation of MRPC ETOF completed in the Oct. of 2015
MRPC Endcap TOF

Time resolution vs Strip Number

Time resolution of 60ps achieved; Efficiency ~97%
New Inner Drift Chamber

- An aluminum outer cylinder was manufactured for the chamber cosmic-ray test
- The outer cylinder was assembled after wiring had been finished
The performance of the new chamber

In cosmic ray test, the efficiency > 99%

HV @2200V

Spatial res. 129μm

HV @2200V

dE/dx res. 7.8% 55 samplings

The chamber is stored in a clean room and is ready to be replaced.
BESIII is building a cylindrical GEM detector (CGEM-IT) to replace the BESIII Inner MDC to recover some efficiency loss due to aging and to improve the secondary vertex resolution.

- Low Material budget \( \leq 1.5\% \) of \( X_0 \) for all layers
- High Rate capability: \( \sim 10^4 \) Hz/cm\(^2\)
- Coverage: 93%
- Spatial resolution \( \sigma_{r\phi} \sim 130 \mu m \) in 1 T magnetic field
- Operation duration at least 5 years

Each layer composed by a triple cylindrical GEM

The CGEM is co-funded by the European Commission Research and Innovation Staff Exchange (RISE) project 2015-2018.

Formation of a consortium: INFN (Ferrara, Frascati, Perugia and Torino), Mainz, Uppsala, IHEP
Project timeline

2012
Initial proposal

2013
R&D and CDR preparation

2014
CDR approval
R&D and detector design

2015
Detector design
Begin construction
Start RISE project.

2016
Complete detector design
Continued detector construction
Electronics development

2017
Continue detector and electronics production
Full CGEM-IT test

2018
Installation and commissioning (summer 2018)
Expected performance of CGEM

Track fitting with Kalman Filter

Approaching point resolution

\[ \sigma_p \]

\[ \sigma_z \]

Momentum resolution

\[ \sigma_p \]

\[ p(\text{GeV/c}) \]
• Will challenge BEPCII CM energy limit
  from 2.30 → 2.35 → 2.45 GeV (4.6 → 4.7 → 4.9 GeV)
  Funding approved (~5 M RMB)

  ➢ Λc study

  ➢ XYZ study: Y(4660), ....

• BEPCII Top-up project
  funding approved (about 12M RMB)
  data taking efficiency: increased by 20-30%

With larger Λc data sample

✦ PWA ⇒ intermediate structures in 3-body decays

✦ More semileptonic decays: nlν, Λ*lν, ΣXlν ...

✦ Decay asymmetry parameters α
  \[ \Lambda_c^+ \rightarrow BP/BV \]

✦ Λc+ Rare decays search
  ✦ Weak radiative decay \[ \Lambda_c^+ \rightarrow \gamma \Sigma^+ \]
  ✦ FCNC \[ \Lambda_c^+ \rightarrow p l^+ \nu \]
  ✦ LNV \[ \Lambda_c^+ \rightarrow p e\mu \]
### BESIII data taking status & plan (run ~8-10 years)

<table>
<thead>
<tr>
<th></th>
<th>Previous data</th>
<th>BESIII present &amp; future</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>J/ψ</strong></td>
<td>BESII 58M</td>
<td>1.2 B 20* BESII</td>
<td>10 B</td>
</tr>
<tr>
<td><strong>ψ’</strong></td>
<td>CLEO: 28 M</td>
<td>0.5 B 20* CLEOc</td>
<td>3B</td>
</tr>
<tr>
<td><strong>ψ”</strong></td>
<td>CLEO: 0.8/fb</td>
<td>2.9/fb 3.5*CLEOc</td>
<td>20 /fb</td>
</tr>
<tr>
<td><strong>Above open charm threshold</strong></td>
<td>CLEO: 0.6/fb @ ψ(4160)</td>
<td>0.5/fb @ ψ(4040) 2.3/fb@~4260, 0.5/fb@4360 0.5/fb@4600, 1/fb@4420</td>
<td>5-10 /fb</td>
</tr>
<tr>
<td><strong>R scan &amp; Tau</strong></td>
<td>BESII</td>
<td>3.8-4.6 GeV at 105 energy points 2.0-3.1 GeV at 20 energy points</td>
<td></td>
</tr>
<tr>
<td><strong>Y(2175)</strong></td>
<td></td>
<td>100 pb⁻¹</td>
<td></td>
</tr>
<tr>
<td><strong>ψ(4170)</strong></td>
<td></td>
<td>3 fb⁻¹</td>
<td></td>
</tr>
</tbody>
</table>

Thank you
Backup slides
## BESIII Detector

<table>
<thead>
<tr>
<th>Exps.</th>
<th>MDC Wire resolution</th>
<th>MDC dE/dx resolution</th>
<th>EMC Energy resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO</td>
<td>110 μm</td>
<td>5%</td>
<td>2.2-2.4 %</td>
</tr>
<tr>
<td>Babar</td>
<td>125 μm</td>
<td>7%</td>
<td>2.67 %</td>
</tr>
<tr>
<td>Belle</td>
<td>130 μm</td>
<td>5.6%</td>
<td>2.2 %</td>
</tr>
<tr>
<td>BESIII</td>
<td>115 μm</td>
<td>&lt;5% (Bhabha)</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

- New ETOF (MRPC) installed
- New Inner MDC, being built

<table>
<thead>
<tr>
<th>Exps.</th>
<th>TOF time resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDFII</td>
<td>100 ps</td>
</tr>
<tr>
<td>Belle</td>
<td>90 ps</td>
</tr>
<tr>
<td>BESIII</td>
<td>68 ps (BTOF)</td>
</tr>
<tr>
<td></td>
<td>100 ps (ETOF)</td>
</tr>
<tr>
<td></td>
<td>60 ps (MRPC)</td>
</tr>
</tbody>
</table>
Data/Monte-Carlo Consistency

- For tracking efficiency, data/MC difference < 1%
- For particle identification efficiency, data/MC difference < 2%
$$e^+e^- \rightarrow \pi^+D^0D^{*-}$$

$$\sigma_{dress} = \frac{N^{obs}}{\mathcal{L}(1 + \delta r)B(D^0 \rightarrow K^-\pi^+)\epsilon}$$

$$\sigma_{dress}(m) = |c \cdot \sqrt{P(m)} + e^{i\phi_1}B_1(m)\sqrt{\frac{P(m)}{P(M_1)} + e^{i\phi_2}B_2(m)\sqrt{\frac{P(m)}{P(M_2)}}}|^2$$

Fit with a constant (pink dashed triple-dot line) and two constant width relativistic BW functions (green dashed double-dot line and aqua dashed line).

$$M(Y(4220)) = (4224.8 \pm 5.6 \pm 4.0)\text{ MeV}/c^2, \Gamma(Y(4220)) = (72.3 \pm 9.1 \pm 0.9)\text{ MeV}.$$  
$$M(Y(4390)) = (4400.1 \pm 9.3 \pm 2.1)\text{ MeV}/c^2, \Gamma(Y(4220)) = (181.7 \pm 16.9 \pm 7.4)\text{ MeV}.$$
The statistical significance of two resonances assumption over one resonance is greater than 10s.

The resonant parameters of $Y(4220)$ and $Y(4390)$ states are consistent with the structures observed in $e^+e^- \rightarrow \pi^+\pi^- h_c$. The resonant parameters of $Y(4220)$ are also consistent with those of the resonance observed in $e^+e^- \rightarrow \omega\chi_{c0}$ and $e^+e^- \rightarrow \pi^+\pi^- J/\psi$. 

$e^+e^- \rightarrow \pi^+D^0D^{*-}$
Model Independent PWA of $J/\psi \rightarrow \gamma \pi^0 \pi^0$

- Extracted Intensity
- Relative Phase

- Solution 1
- Solution 2

- Extract amplitudes in each $M(\pi^0 \pi^0)$ mass bin
- Significant features of the scalar spectrum includes structures near 1.5, 1.7 and 2.0 GeV/$c^2$
- Multi-solution problem in MIPWA is usually unavoidable.
- Model Dependent PWA of global PWA fit is still needed to extract resonance parameters

Measurements of $J/\psi \rightarrow \phi p \bar{p}$


No obvious threshold structure of $\bar{p}p$ or $\phi p$

$$B(J/\psi \rightarrow p\bar{p}\phi) = [5.23 \pm 0.06 \text{ (stat)} \pm 0.33 \text{ (syst)}] \times 10^{-5}$$
Study of $N^*$ and $\Xi^*$

$N^*$ in $\psi' \rightarrow \pi^0 p \bar{p}$

New $N^*$s: $N(2300)$ and $N(2570)$

$\Xi^*$ in $\psi' \rightarrow K \Lambda \Xi$

$\Xi(1690)$, $\Xi(1820)$

- PWA of
  - $J/\psi(\psi') \rightarrow \pi^0 p \bar{p}$
  - $J/\psi(\psi') \rightarrow \eta p \bar{p}$
  - $J/\psi(\psi') \rightarrow p K \Lambda$
  - $\cdots$

PRL. 110 (2013) 022001

arXiv:1504.02025
Measurement of $\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+ (\pi^0)$

- The total measured $\Lambda_c^+$ decay BFs is $\sim 65\%$, searching for more decay modes are important.
- Only one $\Lambda_c^+$ decay involved $\Sigma^-$ is observed, $B(\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^-) = (2.3 \pm 0.4)\%$, where $\Sigma^-$ dominantly decay to $n\pi^-$

11 ST modes, $11415 \pm 159$ $\Lambda_c^+$ tagged candidates

$B[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+] = (1.81 \pm 0.17)\%$ [Improved precision]

$B[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^0] = (2.11 \pm 0.33)\%$ [first observation]

Statistical only, totally uncertainty <5%
Single-Cabibbo-Suppressed decay of \( \Lambda_c^+ \to p \pi^+ \pi^- / K^+ K^- \)

Sensitive to non-factorizable contributions from \( W \)-exchanged process

<table>
<thead>
<tr>
<th>Decay modes</th>
<th>( \mathcal{B}<em>{\text{mode}} / \mathcal{B}</em>{\text{ref.}} ) (this work)</th>
<th>( \mathcal{B}<em>{\text{mode}} / \mathcal{B}</em>{\text{ref.}} ) ([28])</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Lambda_c^+ \to p \pi^+ \pi^- )</td>
<td>((6.70 \pm 0.48 \pm 0.25) \times 10^{-2})</td>
<td>( \sim )</td>
</tr>
<tr>
<td>( \Lambda_c^+ \to p \phi )</td>
<td>((1.81 \pm 0.33 \pm 0.13) \times 10^{-2})</td>
<td>(0.015 \pm 0.002 \pm 0.002)</td>
</tr>
<tr>
<td>( \Lambda_c^+ \to p K^+ K^- ) (non-( \phi ))</td>
<td>((9.36 \pm 2.22 \pm 0.71) \times 10^{-3})</td>
<td>(0.007 \pm 0.002 \pm 0.002)</td>
</tr>
</tbody>
</table>

\( \mathcal{B}_{\text{mode}} / \mathcal{B}(\text{PDG}) \)

| \( \Lambda_c^+ \to p \pi^+ \pi^- \) | \((3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}\) | \((3.5 \pm 2.0) \times 10^{-3}\) |
| \( \Lambda_c^+ \to p \phi \)       | \((1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}\) | \((8.2 \pm 2.7) \times 10^{-4}\) |
| \( \Lambda_c^+ \to p K^+ K^- \) (non-\( \phi \)) | \((5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}\) | \((3.5 \pm 1.7) \times 10^{-4}\) |

first observation

improved precision
Proton FF measurement at BESIII


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

<table>
<thead>
<tr>
<th>$E_{cm}$/GeV</th>
<th>$L_{int}$/ pb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.23</td>
<td>2.6</td>
</tr>
<tr>
<td>2.40</td>
<td>3.4</td>
</tr>
<tr>
<td>2.80</td>
<td>3.8</td>
</tr>
<tr>
<td>3.05, 3.06, 3.08</td>
<td>60.7</td>
</tr>
<tr>
<td>3.40, 3.50, 3.54, 3.56</td>
<td>23.3</td>
</tr>
<tr>
<td>3.60, 3.65, 3.67</td>
<td>63.0</td>
</tr>
</tbody>
</table>
Analysis Technique

$e^+e^- \rightarrow c\bar{c} \rightarrow \bar{D}_{tag} D_{sig}$: Double-tag technique, Absolute measurement

- Tag $\bar{D}_{tag}$ in hadronic decay modes
  \[
  \Delta E = E_{\bar{D}_{tag}} - E_{beam}
  \]
  \[
  M_{BC} = \sqrt{E_{beam}^2 - p_{\bar{D}_{tag}}^2}
  \]

- Reconstruct $D_{sig}$ using the remaining tracks not associated to $\bar{D}_{tag}$
  - $E_{D_{sig}} = E_{beam}$, $\vec{p}_{D_{sig}} = -\vec{p}_{\bar{D}_{tag}}$
  - no additional tracks/showers
  - (semi-)leptonic decay: missing neutrino, $U_{miss} \equiv E_{miss} - |\vec{p}_{miss}| \sim 0$

- $N_{tag} = 2N_{DD}B_{tag}\varepsilon_{tag}$
- $N_{tag,SL} = 2N_{D\bar{D}}B_{tag}B_{SL}\varepsilon_{tag,SL}$
- $B_{SL} = \frac{N_{tag,SL}}{N_{tag}} \frac{\varepsilon_{tag}}{\varepsilon_{tag,SL}} = \frac{N_{tag,SL}}{N_{tag}\varepsilon}$

- High tagging efficiency
- Extremely clean
- Systematic uncertainties associated to tag side are mostly canceled out
• BESIII superconducting magnet: funding approved for a new valve box (~5M RMB)