Future prospects for charm physics at BESIII and beyond

Yangheng Zheng
on behalf of BESIII collaboration
University of Chinese Academy of Sciences
May. 22, 2015
Outline

- Current BEPCII/BESIII
  - Operations and data taking plans
- Detector upgrade
  - Endcap TOF
  - Inner tracking detector
- Prospects for charm physics
  - BESIII
  - Super Tau-charm factory
- Summary
Current status of BEPCII

BEPCII: A double ring $e^+e^-$ collider

- A record $L_{\text{peak}} = 8.5 \times 10^{32}$ cm$^{-2}$s$^{-1}$ @ 3.773 GeV reached in Nov. 20, 2014
- Weekly record luminosity: 169 pb$^{-1}$, Average of daily lumi: $>17$ pb$^{-1}$
- 500 pb$^{-1}$ data collected @4.6 GeV: the limit of BEPCII energy region
- Bunch crossing time: 8ns $\rightarrow$ 6ns
Data samples available

- 1.3x10^9
- 5x10^8
- 2.9 fb^{-1}

20 points for R & QCD Scan: 500 pb^{-1} finished in May 1st, 2015

Currently: at Y(2175) resonance, plan: 100 pb^{-1}
Data samples \( \@ \) charm threshold

- CLEO-c: 818 pb\(^{-1} \@ \psi(3770)\)
- BESIII: 2.9 fb\(^{-1}\) (~3.5 x CLEO-c data) \@\psi(3770)\)

- BESIII: 0.5 fb\(^{-1}\) \@ \psi(4040)\)
- In 2015-2016 run period: 3 fb\(^{-1}\) \@4.17 \text{ GeV}
Data taking plan

Approved plan for 2015/2016 run period

- 4170 data taking 3 fb⁻¹, 5 months
- Data taking at around $\chi_{c1}$ mass 25 days
  - $e^+e^- \rightarrow \chi_{c1}$, Collins fragmentation function
  - 2-3 points, 3.5136 (3 MeV below, 20 pb⁻¹)
    - 3.5106 (180 pb⁻¹)
    - 3.5100 (0.5 MeV below) or $\chi_{c1}$ mass for 180 pb⁻¹
- Psi’ scan 500 pb⁻¹ 25 days

Final goal for data set at threshold: ~20 fb⁻¹
BESIII detector upgrade

- **Inner Drift Chamber appeared aging effect**
  - Cathode aging → Malter discharge
    - Adding ~2000ppm water vapor into the gases
  - Anode aging → gain drop 14% - 26%
  - Short-term upgrade plan: a new inner drift chamber
  - Long-term upgrade plan: a 3-layer CGEMs inner tracker

- **Endcap TOF (ETOF: scintillator + PMT)**
  - To improve PID
  - Upgrade with MRPC
    - Less affected by scattering
    - Tracking with more readout pads
    - Total resolution: ~140ps → <80ps
Upgrade for inner tracking detector

✧ New inner drift chamber
  ✧ Chamber wiring finished in January, 2015
  ✧ Ready for installation

✧ CGEM inner tracker
  ✧ Proposed by the Italy group;
  ✧ 3-Layer CGEM foils (KLOE2-like);
  ✧ The design is coming to a conclusion;
  ✧ construction of the layer 2 has started;
  ✧ beam test of the prototype is ongoing;
  ✧ software: progress in simulation and reconstruction.

CGEM inner tracker

3-Layer CGEM foils (KLOE2-like)

The design is coming to a conclusion;

construction of the layer 2 has started;

beam test of the prototype is ongoing;

software: progress in simulation and reconstruction.
Two MRPCs has been installed.
- Testing with real data
- A VERY preliminary calibration \(\Rightarrow\) time resolution \(\sim 70\) ps
- The production of the whole ETOF system: finished
- Performance and stability test is carrying
  - on \(\sim 4\) months cosmic-ray test
- Simulation: new GDML and Digitization is developed.
Physics at tau-charm Energy Region

- Hadron form factors
- $\Upsilon(2175)$ 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
Charm facilities

- Hadron colliders (huge cross-section, energy boost)
  - Tevatron (CDF, D0)
  - LHC (LHCb, CMS, ATLAS)
- $e^+e^-$ Colliders (more kinematic constrains, clean environment, ~100% trigger efficiency)
  - B-factories (Belle, BaBar)
- Threshold production (CLEOc, BESIII)
  - Can not compete in statistics with Hadron colliders & B-factories !!!
  - Quantum Correlations (QC) and CP-tagging are unique
  - Only D meson pairs, no extra CM Energy for pions
  - Systematic uncertainties cancellations while applying double tag technique
Physics at Charm threshold

- Decay constants & form factors for Charm meson
- Quantum correlations at $\psi(3770)$
  - CPV measurements
  - Strong phase measurements
- Rare decays
- Charm baryons
  - $D^0$-$\bar{D}^0$ mixing & CPV @$\psi(4040)$

Many new BESIII results have been released!
Selected results will be shown!
Double Tag (DT) techniques

✧ 100% of beam energy converted to $D$ pair (Clean environment, kinematic constrains $\nu$ Recon.)
✧ $D$ generated in pair $\Rightarrow$ absolute Branching fractions
✧ At $\psi(3770)$ charm production is $D^0\bar{D}^0$ and $D^+D^-$
✧ Fully reconstruct about 15% of $D$ decays

Double tag techniques: Hadronic tag on one side, on the other side for leptonic/semileptonic studies. Neutrino is reconstructed from missing energy and momentum (Double tag efficiency is high.)

\[ \Delta E = E_D - E_{\text{Beam}} \]
\[ M_{BC} = \sqrt{E_{\text{Beam}}^2 - p_D^2} \]
$f_D(s)^+ : \text{Leptonic decays}$

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

- Extract decay constant $f_{D(s)}$ incorporates the strong interaction effects (wave function at the origin)
  - Multiple tests with charm: $f_D$, $f_{Ds}$ and $f_D/f_{Ds}$
  - To validate Lattice QCD calculation of $f_{B(s)}$ and provide constrain of CKM-unitarity
  - Sensitive to New Physics (Charged Higgs contribution, …)
$f_{D^+}$ Results ($D^+ \rightarrow \mu^+\nu$)

\[ N(D^+ \rightarrow \mu^+\nu) = 409.0 \pm 21.2 \pm 2.3 \]
\[ B(D^+ \rightarrow \mu^+\nu) = (3.71 \pm 0.19 \pm 0.06) \times 10^{-4} \]
\[ f_{D^+} = (203.2 \pm 5.3 \pm 1.8) \iff |V_{cd}| \text{ of CKM-Fitter Input} \]
\[ |V_{cd}| = 0.221 \pm 0.006 \pm 0.005 \]

\[ \iff \text{LQCD calculated } f_D = 207 \pm 4 \text{ MeV[PRL100(2008)062002]} \]

The error is still dominated by statistics! More data is needed.
**f_{D(s)}^+** Comparison

**f_{D+} (MeV)**

- **CLEO-c**: 206.1 ± 8.6 ± 2.6
- **BESIII**: 203.2 ± 5.3 ± 1.8
- **Average**: 203.9 ± 4.6 ± 0.9

**BESIII**: 2.7% with 2.92 fb^{-1}
**BESIII final**: 1.5% with 10 fb^{-1}

**f_{D_s^+} (MeV)**

- **CLEO-c**: 257.6 ± 10.3 ± 4.3
- **Belle**: 249.7 ± 6.6 ± 5.0
- **BaBar**: 265.9 ± 8.4 ± 7.7
- **Average**: 255.6 ± 5.6 ± 1.8

**CLEO-c**: 2.5% with 0.68 fb^{-1}
**BESIII final**: 1.25% with 5 fb^{-1}
Form Factors: Semileptonic decays

\[ \frac{d\Gamma(D \rightarrow K(\pi)e\nu)}{dq^2} = \frac{G_F^2 |V_{cs(d)}|^2 P_{K(\pi)}^3}{24\pi^3} \left| f_+(q^2) \right|^2 \]

\[ q^2 = (p_1 + p_\nu)^2 \Rightarrow M_{inv}^2 \text{ of lepton pair} \]

- ★ \( D_{(s)} \rightarrow P l \nu \) (Theoretically clean)
- ★ Measure \(|V_{cx}| \times \text{FF}\)
- ★ Charm physics:
  - ★ CKM-unitarity \(\Rightarrow |V_{cx}|\), extract FF, test LQCD
  - ★ Input LQCD FF to test CKM-unitarity
- ★ B physics: Validate LQCD for form factor, extract \(|V_{ub}|\) to test CKM-unitarity
  - ★ Example: \( B \rightarrow \pi l \nu \Rightarrow |V_{ub}| = 3.92 \pm 0.09 \pm 0.45\) (Theory) rely on LQCD Form Factor calculations (provide perfect calibration)
Form Factors fit results ($D^0 \rightarrow K/\pi\ e^+\nu$)

### Decay rate

2.92$\text{fb}^{-1}$ @ 3.773 GeV

### Table of Results

<table>
<thead>
<tr>
<th></th>
<th>$D^0 \rightarrow K e^+\nu$</th>
<th>$D^0 \rightarrow \pi e^+\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Pole</td>
<td>$f_K^+(0)</td>
<td>V_{cs}</td>
</tr>
<tr>
<td></td>
<td>$M_{\text{pole}}$</td>
<td>1.9207±0.0103±0.0069</td>
</tr>
<tr>
<td>Mod. Pole</td>
<td>$f_K^+(0)</td>
<td>V_{cs}</td>
</tr>
<tr>
<td></td>
<td>$\alpha$</td>
<td>0.3088±0.0195±0.0129</td>
</tr>
<tr>
<td>ISGW2</td>
<td>$f_K^+(0)</td>
<td>V_{cs}</td>
</tr>
<tr>
<td></td>
<td>$r_{\text{ISGW2}}$</td>
<td>1.6000±0.0141±0.0091</td>
</tr>
<tr>
<td>Series.2.Par</td>
<td>$f_K^+(0)</td>
<td>V_{cs}</td>
</tr>
<tr>
<td></td>
<td>$r_1$</td>
<td>-2.2278±0.0864±0.0575</td>
</tr>
<tr>
<td>Series.3.Par</td>
<td>$f_K^+(0)</td>
<td>V_{cs}</td>
</tr>
<tr>
<td></td>
<td>$r_1$</td>
<td>-2.3331±0.1587±0.0804</td>
</tr>
<tr>
<td></td>
<td>$r_2$</td>
<td>3.4223±3.9090±2.4092</td>
</tr>
</tbody>
</table>
Comparison of Form Factors

**Theory:**
- HPQCD (2010) \(0.747 \pm 0.011 \pm 0.015\)
- Fermilab/MILC (2005) \(0.73 \pm 0.03 \pm 0.07\)
- Sum Rules (2009) \(0.75^{+0.11}_{-0.08}\)

**Experiment:**
- CLEO-c (2009) \(0.739 \pm 0.007 \pm 0.005 \pm 0.000\)
- Belle (2006) \(0.695 \pm 0.007 \pm 0.022\)
- BaBar (2007) \(0.727 \pm 0.007 \pm 0.005 \pm 0.007\)
- BESIII (2014) \(0.7368 \pm 0.0026 \pm 0.0036\)

\[ f^D_{+ \rightarrow K}(q^2 = 0) \]
\[ f^D_{+ \rightarrow \pi}(q^2 = 0) \]

**BESIII:** the most precise measurements

The error of \(f^D_{+ \rightarrow \pi}\) is still dominated by statistics.
CKM matrix elements $|V_{cd(s)}|$  

**BESIII: the most precise measurements**
Reaches for rare charm decays?

SM predictions and experimental reaches

- Cabibbo favor
- Single Cabibbo suppressed
- Doubly Cabibbo suppressed

Radiative decays

<table>
<thead>
<tr>
<th>$10^{-15}$</th>
<th>$10^{-14}$</th>
<th>$10^{-13}$</th>
<th>$10^{-12}$</th>
<th>$10^{-11}$</th>
<th>$10^{-10}$</th>
<th>$10^{-9}$</th>
<th>$10^{-8}$</th>
<th>$10^{-7}$</th>
<th>$10^{-6}$</th>
<th>$10^{-5}$</th>
<th>$10^{-4}$</th>
<th>$10^{-3}$</th>
<th>$10^{-2}$</th>
<th>$10^{-1}$</th>
<th>$10^{0}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^{*0} \gamma / \phi \gamma / \rho \gamma / \omega \gamma$</td>
<td>$D^+ \rightarrow K^{*+} \gamma / \rho^+ \gamma$</td>
<td>$D_S^+ \rightarrow K^{*+} \gamma / \rho^+ \gamma$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Long distance:

Vector meson Dominance

$D^0 \rightarrow \gamma \gamma / VV'(\rightarrow ll) / hV(\rightarrow ll) / hh'V(\rightarrow ll)$

Short distance FCNC

$D^0 / D^+ \rightarrow \gamma \gamma / Vl^+l^- / hl^+l^- / hh'l^+l^-$

Forbidden decays: LNV, LFV, BNV

$D \rightarrow (h)\mu^+ \mu^-$

$D \rightarrow (hh)e^+e^- / (hh)\mu^+\mu^+$

CLEO-c

BESIII

BESIII final/B factory

LHCb

Super-B

Super-\(\tau\)-charm
Rare decays \((D^0 \rightarrow \gamma\gamma)\)

Double tag method

Tag modes
\[ \bar{D}^0 \rightarrow K\pi \]
\[ \bar{D}^0 \rightarrow K\pi\pi^0 \]
\[ \bar{D}^0 \rightarrow K3\pi \]
\[ \bar{D}^0 \rightarrow K3\pi\pi^0 \]
\[ \bar{D}^0 \rightarrow K\pi2\pi^0 \]

\[ D^0 \rightarrow \gamma\gamma \]

\[ \mathcal{B}(D^0 \rightarrow \gamma\gamma) = 10 \times 10^{-6} \]

\[ \mathcal{B}(D^0 \rightarrow \pi^0\pi^0) = (8.24 \pm 0.21\text{(stat.)} \pm 0.30\text{(syst.)}) \times 10^{-4} \]

BESIII 2.92fb\(^{-1}@3770\):
\[ \mathcal{B}(D^0 \rightarrow \gamma\gamma) < 3.8 \times 10^{-6} @ 90\% C.L. \]

BESIII 10fb\(^{-1}@3770\):
\[ B_{D^0 \rightarrow \gamma\gamma} < 1.0 \times 10^{-6} \]

BESIII has much smaller background than that at B factory, peaking background from \(D^0 \rightarrow \pi^0\pi^0\) is under control.
$D^0 \rightarrow \gamma\gamma$ reach at super $\tau$-charm

1 ab$^{-1}$ at threshold at super $\tau$-charm factory will reach Long Distance contribution: about 60 events are expected per year.

SM beyond the experimental" reach, however NP parameter " space is already being probed

Up to 200x ! enhancement !

over SM in MSSM
δ and γ/ϕ₃ input

- **D** hadronic parameters for a final state

\[
f : \frac{A(\bar{D}^0 \rightarrow f)}{A(D^0 \rightarrow f)} \equiv -r_D e^{-i\delta_D}
\]

- Charm mixing parameters:

\[
x = \frac{\Delta M}{\Gamma}, \quad y = \frac{\Delta \Gamma}{2\Gamma}
\]

- Time-dependent WS \( D^0 \rightarrow K^+\pi^- \) rate implies:

\[
y' = y \cos \delta_{K\pi} - x \sin \delta_{K\pi} = (0.72 \pm 0.24)\% \quad \text{(LHCb 2012)}
\]

- \( \delta_{K\pi} \): QC measurements from Charm factory

- \( \gamma/\phi_3 \) measurements from \( B \rightarrow D^0 K \):

- \( b \rightarrow u : \gamma/\phi_3 = \text{arg} V^{*}_{ub} \)

- most sensitive method to constrain \( \gamma/\phi_3 \) at present

- GLW, ADS method

- \( r_D, \delta_D \): QC measurements from Charm factory

- GGSZ method

- \( c_i, s_i \): QC measurements from Charm factory
## Time-integrated decay rates

- **No time dependent information at Charm threshold**

\[ \psi(3770) \rightarrow [D^0 \bar{D}^0 - \bar{D}^0 D^0]/\sqrt{2} \]

\[ = -[D_{CP+}D_{CP-} - D_{CP-}D_{CP+}]/\sqrt{2} \]

\[ D_{CP\pm} = [D^0 \pm \bar{D}^0]/\sqrt{2} \]

- **Anti-symmetric wavefunction:**

\[ \Gamma_{ij} = \left| \langle i|D^0\rangle\langle j|\bar{D}^0 \rangle - \langle j|D^0\rangle\langle i|\bar{D}^0 \rangle \right|^2 \]

- **Double tag rates:**

\[ A_i^2 A_j^2 [1 + r_i^2 r_j^2 - 2 r_i r_j \cos(\delta_i + \delta_j)] \]

- **CP tag:** \( r=1, \delta=0 \) or \( \pi \); \( l^\pm \) tag: \( r=0 \)

- **Single and Double tag rates**

\[ z_f \equiv 2 \cos \delta, \ r_f \equiv \frac{A_{DCS}}{A_{CF}}, R_M \approx \frac{x^2 + y^2}{2} \]

<table>
<thead>
<tr>
<th>C-odd</th>
<th>( f )</th>
<th>( \bar{f} )</th>
<th>( l^+ )</th>
<th>( l )</th>
<th>( CP+ )</th>
<th>( CP- )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f )</td>
<td>( R_M[1 + r_f^2(2 - z_f^2) + r_f^4] )</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \bar{f} )</td>
<td>( 1 + r_f^2(2 - z_f^2) + r_f^4 )</td>
<td>( R_M[1 + r_f^2(2 - z_f^2) + r_f^4] )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( l^+ )</td>
<td>( r_f^2 )</td>
<td>( 1 )</td>
<td>( R_M )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( l )</td>
<td>( 1 )</td>
<td>( r_f^2 )</td>
<td>( 1 )</td>
<td>( R_M )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( CP+ )</td>
<td>( 1 + r_f(r_f + z_f) )</td>
<td>( 1 + r_f(r_f + z_f) )</td>
<td>( 1 )</td>
<td>( 1 )</td>
<td>( 0 )</td>
<td></td>
</tr>
<tr>
<td>( CP- )</td>
<td>( 1 + r_f(r_f - z_f) )</td>
<td>( 1 + r_f(r_f - z_f) )</td>
<td>( 1 )</td>
<td>( 1 )</td>
<td>( 4 )</td>
<td>( 0 )</td>
</tr>
<tr>
<td>Single Tag</td>
<td>( 1 + r_f^2 - r_f z_f (A - y) )</td>
<td>( 1 )</td>
<td>( 2[1 \pm (A - y)] )</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
\[ \delta_{K\pi} \text{ in } D \to K\pi \text{ (BESIII: 2.9 fb}^{-1} \text{)} \]

A simple picture: \[
\frac{\langle K\pi|D^0 \rangle}{\langle K\pi|D^0 \rangle} \equiv \frac{A_{K\pi}}{A_{K\pi}} \equiv r_{K\pi} e^{i \delta_{K\pi}}
\]

\[
\langle K\pi|D_{CP\pm} \rangle = (\langle K\pi|D^0 \rangle \pm \langle K\pi|D^0 \rangle) / \sqrt{2} \Rightarrow \sqrt{2} A_{CP\pm} = A_{K\pi} \pm \overline{A_{K\pi}}
\]

\[ 2r_{K\pi} \cdot \cos \delta_{K\pi} \approx A_{CP\to K\pi} \equiv \frac{|A_{CP-}|^2 - |A_{CP+}|^2}{|A_{CP-}|^2 + |A_{CP+}|^2} \]

\[ = \frac{Br(D_{CP-}\to K\pi) - Br(D_{CP+}\to K\pi)}{Br(D_{CP-}\to K\pi) + Br(D_{CP+}\to K\pi)} \]

\[ \Rightarrow \]

- Measuring \( \delta_{K\pi} \) from rate differences if using external \( r_{K\pi} \)
- Reconstructed modes:
  - Flavor tags: \( K^-\pi^+, K^+\pi^- \)
  - CP+ tags (5 modes): \( K^-K^+, \pi^+\pi^-, K_S^0\pi^0\pi^0, \pi^0\pi^0, \rho^0\pi^0 \)
  - CP- tags (3 modes): \( K_S^0\pi^0, K_S^0\eta, K_S^0\omega \)
$\delta_{K\pi}$ in $D \to K\pi$ (BESIII: 2.9 fb$^{-1}$)

Direct result:

$$A_{CP\to K\pi} = (12.7 \pm 1.3 \text{(Stat.)}) \pm 0.7 \text{(sys.)})\%$$

$$2r_{K\pi}\cos \delta_{K\pi} + y = (1 + R_{WS}) \cdot A_{CP\to K\pi}$$

Using external input for $r_{K\pi}^2$, $y$, $R_{WS}$ we extract:

$$\cos \delta_{K\pi} = 1.02 \pm 0.11 \pm 0.06 \pm 0.01$$

If BESIII accumulate 10 fb$^{-1}$ on threshold $D$ data:

sensitivity of $\cos \delta_{K\pi} \sim 0.06$
**$y_{CP}$ measurement (BESIII: 2.9 fb$^{-1}$)**

**PLB 744, 339(2015)**

We measure the $y_{CP}$ using $CP$-tagged semi-leptonic $D$ decays, which allows to access $CP$ asymmetry in mixing and decays.

### Single Tag decay rate (CP tags)

- $\Gamma_{CP^\pm} \propto 2 |A_{CP^\pm}|^2 (1 \mp y)$

### Double Tag decay rate (Flavor tags + CP tags)

- $\Gamma_{l;CP^\pm} \propto |A_l|^2 |A_{CP^\pm}|^2$

### Neglect term $y^2$ or higher order

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

### Reconstructed modes:

- **Flavor tags:** $Ke\nu_e$, $K\mu\nu_\mu$
- **CP+ tags (3 modes):** $K^-K^+$, $\pi^+\pi^-$, $K_S^0\pi^0\pi^0$
- **CP- tags (3 modes):** $K_S^0\pi^0$, $K_S^0\eta$, $K_S^0\omega$
**BESIII results:**

\[ y_{CP} = (-2.0 \pm 1.3 \pm 0.7)\% \]

- Result is statistically limited
- Systematic uncertainty is relatively small
- Most precise measurement with QC charm mesons
- In the limit of no CP violation:
  \[ y_{CP} = y \]
- Super \( \tau \)-C: \( \Delta(y_{CP}) \sim 0.1\% \)
$K_s \pi^+ \pi^-$ (BESIII preliminary: $2.9 \text{ fb}^{-1}$)

- Extract $c_i$, $s_i$ for "$\gamma/\phi_3$ GGSZ method"
- Preliminary results presented @ APS meeting, Apr. 2014

### BESIII Preliminary

<table>
<thead>
<tr>
<th>Bins</th>
<th>BES-III $c_i$</th>
<th>CLEO-c $c_i$</th>
<th>BES-III $s_i$</th>
<th>CLEO-c $s_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.066 ± 0.066</td>
<td>-0.009 ± 0.088</td>
<td>-0.843 ± 0.119</td>
<td>-0.438 ± 0.184</td>
</tr>
<tr>
<td>2</td>
<td>0.796 ± 0.061</td>
<td>0.900 ± 0.106</td>
<td>-0.357 ± 0.148</td>
<td>-0.490 ± 0.295</td>
</tr>
<tr>
<td>3</td>
<td>0.361 ± 0.125</td>
<td>0.292 ± 0.168</td>
<td>-0.962 ± 0.258</td>
<td>-1.243 ± 0.341</td>
</tr>
<tr>
<td>4</td>
<td>-0.985 ± 0.017</td>
<td>-0.890 ± 0.041</td>
<td>-0.090 ± 0.093</td>
<td>-0.119 ± 0.141</td>
</tr>
<tr>
<td>5</td>
<td>-0.278 ± 0.056</td>
<td>-0.208 ± 0.085</td>
<td>0.778 ± 0.092</td>
<td>0.853 ± 0.123</td>
</tr>
<tr>
<td>6</td>
<td>0.267 ± 0.119</td>
<td>0.258 ± 0.155</td>
<td>0.635 ± 0.293</td>
<td>0.984 ± 0.357</td>
</tr>
<tr>
<td>7</td>
<td>0.902 ± 0.017</td>
<td>0.869 ± 0.034</td>
<td>-0.018 ± 0.103</td>
<td>-0.041 ± 0.132</td>
</tr>
<tr>
<td>8</td>
<td>0.888 ± 0.036</td>
<td>0.798 ± 0.070</td>
<td>-0.301 ± 0.140</td>
<td>-0.107 ± 0.240</td>
</tr>
</tbody>
</table>

***Only statistical uncertainty is listed


- Improved errors w.r.t. CLEO-c

Model prediction
- BESIII
- CLEO-c

Consistent agreement with CLEO-c measurements.

Slide from Dan Ambrose, APS 2014
Charm baryon $\Lambda_c^{\pm}$ decays

- **BESIII**: $\Lambda_c^{\pm}$ Pair production at threshold (4.6 GeV)
- **Largest data set @4.6 GeV**
- **Double Tag $\Rightarrow$ Model-independent absolute $\Lambda_c^{\pm}$ decay Branching fractions**

### Preliminary results: statistical error only!

<table>
<thead>
<tr>
<th>Decay modes</th>
<th>global fit $B$</th>
<th>PDG $B$</th>
<th>Belle $B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$pK^-\pi^+$</td>
<td>$5.77 \pm 0.27$</td>
<td>$5.0 \pm 1.3$</td>
<td>$6.84 \pm 0.24^{+0.21}_{-0.27}$</td>
</tr>
<tr>
<td>$pK_S\pi^0$</td>
<td>$1.77 \pm 0.12$</td>
<td>$1.65 \pm 0.50$</td>
<td></td>
</tr>
<tr>
<td>$pK_S\pi^+\pi^-$</td>
<td>$1.43 \pm 0.10$</td>
<td>$1.30 \pm 0.35$</td>
<td></td>
</tr>
<tr>
<td>$pK^-\pi^+\pi^0$</td>
<td>$4.25 \pm 0.22$</td>
<td>$3.4 \pm 1.0$</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\pi^+$</td>
<td>$1.20 \pm 0.07$</td>
<td>$1.07 \pm 0.28$</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\pi^+\pi^0$</td>
<td>$6.70 \pm 0.35$</td>
<td>$3.6 \pm 1.3$</td>
<td></td>
</tr>
<tr>
<td>$\Lambda\pi^+\pi^-\pi^+$</td>
<td>$3.67 \pm 0.23$</td>
<td>$2.6 \pm 0.7$</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^0\pi^+$</td>
<td>$1.28 \pm 0.08$</td>
<td>$1.05 \pm 0.28$</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^+\pi^0$</td>
<td>$1.18 \pm 0.11$</td>
<td>$1.00 \pm 0.34$</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^+\pi^+\pi^0$</td>
<td>$3.58 \pm 0.22$</td>
<td>$3.6 \pm 1.0$</td>
<td></td>
</tr>
<tr>
<td>$\Sigma^+\omega$</td>
<td>$1.47 \pm 0.18$</td>
<td>$2.7 \pm 1.0$</td>
<td></td>
</tr>
</tbody>
</table>
Absolute BR for $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$

✧ Dominated process: $\Lambda_c^+ \rightarrow \Lambda e^+\nu_e$
✧ Input for LQCD calculations
✧ First direct absolute BF measurement
✧ Theoretical predictions: 1.4% ~ 9.2%

![Graph showing $B(\Lambda_c^+ \rightarrow \Lambda e^+\nu_e)$]

$B(\Lambda_c^+ \rightarrow \Lambda e^+\nu_e) = (3.63 \pm 0.38 \pm 0.??)\%$

Statistical error only!
Statistical limited measurement!
Prospects for $\Lambda_c$ decays

Can BEPCII challenge the CM energy limit at 4.6 GeV?

With larger $\Lambda_c$ data sample

- PWA $\Rightarrow$ intermediate structures in 3-body decays
- More semileptonic decays: $n\nu$, $\Lambda^*\nu$, $\Sigma\pi\nu$ ...
- Decay asymmetry parameters $\alpha$ $\Leftarrow \Lambda_c^+ \rightarrow BP/BV$
- $\Lambda_c^+$ Rare decays search
  - Weak radiative decay $\Lambda_c^+ \rightarrow \gamma \Sigma^+$
  - FCNC $\Lambda_c^+ \rightarrow p l^+ l^-$
  - LNV $\Lambda_c^+ \rightarrow p e\mu$

Current dataset @4.6GeV

How about @peak 4.63Gev?

PRL101 (2008) 172001

BELLE
Future charm facilities (CHARM 2013)

Future charm facilities

Marcello A. Giorgi
INFN and Università di Pisa

The Italian Tau-Charm

Novosibirsk machine

CHARM 2013- Manchester 31 August-4 September, 2013
Another proposed Machine

- In China
- $e^+e^-$ collider
- Wide c.m. energy coverage: 2 – 7 GeV
- Collider + 4th generation SR source
  - Symmetric two ring collision
  - Collision & SR: sharing mode feasible
- Peak luminosity: $1 \times 10^{35}$ cm$^{-2}$s$^{-1}$ (Optimized @ $E_{cm} = 4$ GeV)
- Data set: 1 ab$^{-1}$ at Charm threshold
- Polarized beam
  - Polarized electron beam source
  - Siberian Snake curing depolarization
High Intensity Electron Positron Accelerator

HIEPA project

$E_{cm} = 2 - 7 \text{ GeV}, \, L = 1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1}$ at 4 GeV

4$^{th}$ generation SRF

~1000M double ring

Crabbed Waist

• For tau-charm physics
A potential location: Hefei

- University of Science and Technology of China (USTC)
- National Synchrotron Radiation Lab and Hefei Light Source, operated by USTC
- The only National Lab operated by University in China. (Totally Four National Labs in China)
Detector

- Superconducting magnet (0.7-1 T)
- MUD:
  - $\mu/\pi$ suppression power >10/30
- EMC:
  - Energy range: 0.02-2.5 GeV
  - At 1 GeV $\sigma_E (%)$
    - Barrel (Cs(I)): 2
    - Endcap (Cs): 4
- PID:
  - $\pi/K$ (and $K/p$) 3-4$\sigma$ separation up to 2GeV/c
- MDC:
  - $\sigma_{xy}$=130 mm
  - $dE/dx$<7%, $\sigma_p/p$=0.5% at 1 GeV
- PXD:
  - Material budget ~0.15%$X_0$/layer
  - $\sigma_{xy}$=50 mm

York/Muon

- IP
- PXD/SSD
- MD C
- PID-endcap
- PID-barrel

Dimensions:
- 245 cm
- 185 cm
- 135 cm
- 105 cm
- 85 cm
- 15 cm
- 3-6 cm
Expected Key features

- **Vertex** – very low material budget \( \sim 0.15-0.3\%X_0/\text{layer} \), \( <50\mu\text{m} \) position resolution;
- **MDC** – \( \pT \) resolution @1GeV/c \( 0.5-0.7\% \), \( \text{dE/dx} \) resolution \( <7\% \), low material budget;
- **PID** – \( \pi/K \) (and \( K/p \)) 3-4\( \sigma \) separation up to 2GeV/c, low material \( (<0.5X_0) \);
- **EMC** – stochastic term \( <2\%/\sqrt{E} \), constant term \( <0.75\% \);
- **MUD** - \( \mu/\pi \) suppression power \( >10 \).
Some sensitivities at HIEPA

✧ With 1 ab\(^{-1}\) data at threshold
  ✧ Direct CP violation in \(D^+\rightarrow hh\) sensitivity: \(10^{-3}\)
    \~ 10^{-4}
  ✧ Probe \(y\): \(\Delta(y_{\text{CP}}) \sim 0.1\%\)
  ✧ \(RM = (x^2 + y^2)/2 \sim 10^{-5}\) in \(K\pi\) and \(K\nu\) channels
  ✧ \(\Delta(\cos\delta_{K\pi}) \sim 0.007; \Delta(\delta_{K\pi}) \sim 2^\circ\)

✧ Clean background and better systematic control in threshold production
  (complementary to the future B factory results)
Several domestic workshops

Jan 13-16, 2015, HIEPA International Workshop on Physics at Future High Intensity Collider @ 2 – 7 GeV in Hefei, China

June 3 – 4, 2015, Domestic workshop on “Physics, applications and Key technologies on 2 – 7 GeV HIEPA”,

more “official” discussions within HEP community in China

CDR for accelerator & detector in progress (Will be ready by 2016)
Summary

✦ Many BESIII Charm results are released in this conference! It’s just the beginning!
✦ Charm at threshold provides opportunities for both QCD and New Physics
  ✦ Very active on XYZ analyses
  ✦ Will provide best measurements: $f_{D(s)}$ & FF
  ✦ Unique access to strong phases & ability to extract model-independent results with charm at threshold
  ✦ Charm baryon results
✦ BESIII team has learned and developed technology with charm at threshold.
✦ BESIII will continue to run 6 – 8 years.
✦ It is natural to propose the $e^+e^-$ intensity frontier for the $\tau$-charm energy region in China ⇒ High Intensity Electron Positron Accelerator (HIEPA)
Thank you
Backup slides