Open Charm Physics at BESIII

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Outline

• Introduction to the BESIII experiment
• Major Charm Physics at BESIII
• Physics Analysis being done
• Summary
Satellite view of BEPCII /BESIII

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

Design Luminosity: $1 \times 10^{33}$ cm$^{-2}$s$^{-1}$
Achieved Luminosity: $0.65 \times 10^{33}$ cm$^{-2}$s$^{-1}$
 Beam energy: 1.0-2.3 GeV
Design Luminosity: $1 \times 10^{33}$ cm$^{-2}$s$^{-1}$
Optimum energy: 1.89 GeV
Energy spread: $5.16 \times 10^{-4}$
No. of bunches: 93
Bunch length: 1.5 cm
Total current: 0.91 A
Circumference: 237m
EMC Csl(Tl) \[ \sigma_{E/E} \approx 2.5\% @ 1\text{ GeV} \]

Drift chamber:
small sell & He-based gas
\[ \sigma_{p/p} = 0.5\% @ 1\text{ GeV} \]
\[ \sigma_{(dE/dx)/dE/dx} \approx 6\% @ 1\text{GeV} \]

Time-of-flight (TOF)
\[ \sigma_{T(\text{barrel})} : 90\text{ ps} \]
\[ \sigma_{T(\text{endcap})} : 100\text{ ps} \]

RPC Muon Counter
Barrel : 9 layers
Encaps: 8 layers

SC magnet (1T)
So far BESIII has collected:

<table>
<thead>
<tr>
<th>Type</th>
<th>BES-III (×10^6)</th>
<th>BES-II (×10^6)</th>
<th>CLEO-c (×10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/ψ</td>
<td>225</td>
<td>58</td>
<td>—</td>
</tr>
<tr>
<td>ψ(3686)</td>
<td>106</td>
<td>14</td>
<td>27</td>
</tr>
<tr>
<td>DDbar</td>
<td>~18.3(2.9 fb⁻¹)</td>
<td>0.2(0.03 fb⁻¹)</td>
<td>5.4(0.8fb⁻¹)</td>
</tr>
<tr>
<td>D_sD_s</td>
<td>~0.5fb⁻¹@4.01</td>
<td>—</td>
<td>Scan</td>
</tr>
<tr>
<td>D_sD_s*</td>
<td>—</td>
<td>—</td>
<td>0.55(0.6fb⁻¹)</td>
</tr>
</tbody>
</table>

BESIII will collect:

- more J/ψ, ψ’, ψ(3770)
  
  Approved: 1 billion for J/ψ and (0.7-1.0) billion for ψ’ & off peak
- data at higher energies (for XYZ searches, R scan and D_s physics)
Charm plays important role in understanding the Standard Model in two respects.

- Precision Measurements
  - Leptonic decay of $D^+$ and $D_s^+$
    - decay constant $f_D$ and $f_{D_s}$
  - Semileptonic decay of $D$ mesons
    - $|V_{cs}|$, $|V_{cd}|$ and form factors
  - Absolute hadronic branching fractions
    - To normalize the B and D decays

Can be used to improve measurements in $|V_{ub}|$ and $\Delta m_d$ & $\Delta m_s$. 

Major Charm Physics
Major Charm Physics

Measurement of $|V_{cs(d)}|$ plays an important role in understanding the dynamics of quark mixing.

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

$$
V \approx \begin{pmatrix}
  1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\
  -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\
  A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1
\end{pmatrix} + O(\lambda^4)
$$

Weak CKM mass eigenstates

Four quark mixing parameters ($\lambda$, $A$, $\rho$, $\eta$) reside in CKM matrix

To understand quark mixing and CP violation in SM, and detect new physics in flavor change sector, one must determine the CKM elements as precisely as possible.
Major Charm Physics

The constraints in the \(( \bar{\rho}, \bar{\eta} )\) plan of Bd UT including the most recent inputs in the global CKM fit.

Charm can be used to calibrate the QCD calculations. If the QCD passed the test with the charm data, the theoretical uncertainties in calculating the B form factors and decay constants can be reduced, which in turn help to reduce the width of band for \(|V_{ub}|, \Delta m_d & \Delta m_s\).
Major Charm Physics

- Probe for New Physics
  - $D^0\bar{D}^0$ mixing
  - Searching for CP violation decays of D mesons
  - Searching for rare decays of D mesons

Precision measurements on charm decays can be served as precisely test of the SM.
Advantage of Open Charm at Threshold

e^+e^- colliders at threshold: CLEO-c, BESIII

e^+e^- → \psi(3770) → DDbar

Benefits for charm physics at threshold

• Clean
• Initial energy and quantum number
• D and Dbar can be fully reconstructed
• Absolute measurement
Singly Tagged $\bar{D}^0/D^-$ events

Beam constraint mass distribution

$M_{BC} = \sqrt{E_{beam}^2 - |P_D|^2}$

Resolution:
- 1.3 MeV for pure charged modes;
- 1.9 MeV for modes with one $\pi^0$.

By analyzing part of data taken at 3.773 GeV
Singly Tagged $D_s$ events

- Beam constraint mass distribution

$M_{BC} = \sqrt{E_{beam}^2 - |p_D|^2}$

By analyzing part of data taken @ 4.01 GeV
Leptonic Decay

- **Leptonic Analysis**
  - $D^+ \rightarrow \mu^+ \nu_\mu, e^+ \nu_e$ and $\tau^+ \nu_\tau$
  - $D_s^+ \rightarrow \mu^+ \nu_\mu, e^+ \nu_e$ and $\tau^+ \nu_\tau$

- **Motivations**
  - Extract out $f_D$ & $f_{Ds}$, which in turn be used to calibrate LQCD.
  - $R = (f_{Bs}/f_B)/(f_{Ds}/f_D) \sim 1$. $f_{Ds}/f_D$ can be used to estimate $f_{Bs}/f_B$.

All strong interaction effects between the two quarks within the $D^+$ meson is simply factorized into one parameter, the decay constant $f_{D^+}$.

The decay constant of $f_D$ is related to the decay rate by

$$\Gamma(D^+ \rightarrow l^+ \nu_l) = \frac{G_F^2}{8\pi} \left| V_{cd} \right|^2 \frac{f_{D^+}^2 m_l^2 m_{D^+}}{m_{D^+}^2} \left(1 - \frac{m_l^2}{m_{D^+}^2}\right)^2$$
Leptonic Decay

✓ Candidate events for \( D^+ \rightarrow \mu^+ \nu_\mu \)

With 4 fb\(^{-1}\) data at BESIII

\[
\frac{\Delta f_{D^+}}{f_{D^+}} = \sqrt{\left( \frac{\Delta B}{2B} \right)_{\text{sta}}^2 + \left( \frac{\Delta \tau_D}{2 \tau_D} \right)^2 + \left( \frac{\Delta |V_{cd}|}{|V_{cd}|} \right)^2}
\]

- \( \frac{\Delta \tau_D}{\tau_D} \sim 0.7\% \) \hspace{1cm} [PDG10]
- \( \frac{\Delta B}{B_{\text{sta}}} \sim 4.9\% \) \hspace{1cm} [4 fb\(^{-1}\) data]
- \( |V_{cd}| = 0.2252 \pm 0.0007 \) \hspace{1cm} [HPQCD]

\[
M_{\text{miss}}^2 = E_{\text{miss}}^2 - |\vec{p}_{\text{miss}}|^2
\]

\[
\Delta f_{D^+} / f_{D^+} \sim 2.5\%
\]
Semileptonic Decay

- **Semileptonic Analysis**
  - $D^0 \rightarrow K^- l^+ \nu_l, \pi^- l^+ \nu_l$ ($l=e, \mu$)
  - $D^+ \rightarrow \omega/\phi e^+ \nu_e$
  - $D^+ \rightarrow \pi^0 e^+ \nu_e, \eta e^+ \nu_e$

- **Motivations**
  - extract out the form factor, which in turn be used to calibrate LQCD calculations.
  - extract the $|V_{cs}|$ and $|V_{cd}|$, can be used to test the sides $B_d$ unitary triangles and provide indication for new physics.

For pseudo-scalar decays, the decay rate $\Gamma$ relates to form factor and CKM elements by

$$
\frac{d\Gamma(D \rightarrow Pl\nu)}{dq^2} = \frac{G_F^2}{24\pi^3} \left| V_{cs(d)} \right|^2 p_P^3 \left| f_+(q^2) \right|^2
$$
Semileptonic Decay

✓ Candidate events for \( D^0 \rightarrow K(\pi)^{-}e^{+}\nu_{e} \)

\( U_{\text{miss}} = E_{\text{miss}} - p_{\text{miss}} \cdot \)

\[ E_{\text{miss}} = E_{cm} - \sum_{i=1}^{N} \sqrt{p_{i}^{2} + m_{i}^{2}} \quad \text{and} \quad p_{\text{miss}} = \left| - \sum_{i=1}^{N} p_{i} \right| \]

By analyzing part of data taken @ 3.773 GeV
Prospect for measurements at BESIII

\[ d\Gamma(D \to Pl\nu) / dq^2 = \frac{G_F^2}{24\pi^3} p_p^3 |V_{cq}|^2 |f_+ (q^2)|^2 \]

\[ \Gamma(D \to K e^-) = \frac{B(D \to K e^-)}{\tau_D} = 1.53 |V_{cs}|^2 |f_+^K(0)|^2 \times 10^{11} s^{-1} \]

\[ \Gamma(D \to \pi e^-) = \frac{B(D \to \pi e^-)}{\tau_D} = 3.01 |V_{cd}|^2 |f_+^\pi(0)|^2 \times 10^{11} s^{-1} \]

To extract \( V_{cs} \) & \( V_{cd} \) need form factor from theory.

\( |V_{cs}| \) and \( |V_{cd}| \) at BESIII

\[ \frac{\Delta |V_{cq}|}{|V_{cq}|} = \sqrt{\left( \frac{\Delta B}{2B} \right)^2_{\text{sta}} + \left( \frac{\Delta B}{2B} \right)^2_{\text{sys}} + \left( \frac{\Delta \tau_D}{2\tau_D} \right)^2 + \left( \frac{\Delta f}{f} \right)^2} \]

- \( \frac{\Delta \tau_D}{\tau_D} \sim 0.4\% \) [PDG10]
- \( \frac{\Delta B}{B} \) \[\text{sta}\] \sim 0.6\%, 1.6\% [4 fb\(^{-1}\) data]
- \( \frac{\Delta B}{B} \) \[\text{sys}\] \sim 1.0\% [expected]
- \( \frac{\Delta f}{f} \sim 2.5 \) [HPQCD]

\( \Delta V_{cs}/V_{cs} \sim 2.6\% \)
\( \Delta V_{cd}/V_{cd} \sim 2.7\% \)

PDG10: \( \Delta V_{cs}/V_{cs} \sim 3.5\% \)
\( \Delta V_{cd}/V_{cd} \sim 4.8\% \)
**Absolute Branching fraction Measurement**

- Br[$D^0 \rightarrow K^-\pi^+$] and Br[$D^+ \rightarrow K^-\pi^+\pi^+$]

- **Normalize decay branching fractions for D and B decays**

- **single tag D$^0$**
  - single tag D$^0$ bar
  - double tag D$^0$

- **single tag events**
  
  \[ N_i^s = N_{D D} B_i \varepsilon_i - \sum_{j=1}^{N} (N_{D D} \varepsilon_{i,j} B_i B_j) \]

- **double tag events**
  
  \[ N_i^d = N_{D D} B_i B_j \varepsilon_{i,j} \]

- **branching fraction for hadronic decays**

- **MARK-III method**
  - single tag D$^-$
Other topics going on

- Dalitz plot analysis
  - $D^0 \rightarrow K^-\pi^+\pi^0$
  - $D^+ \rightarrow K_S^0\pi^+\pi^0$

- Search for CP violation through T-violation
  - $D^+ \rightarrow K^+K^-\pi^+\pi^0$
  - $D^+ \rightarrow K_S^0K^+\pi^+\pi^-$
Summary

- BESIII is accumulating data at a record speed.
- More precisely measurements will come out soon at BESIII.
  - Precise measurement on decay constant $f_{D^+}$ & $f_{D_s}$
  - Precise measurement on form factors and CKM matrix
  - Precise measurement on absolute branching fractions
  - Search for CP or T violation in D-meson decays
  - ......
THANKS!!