Charm Program at BESIII

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Outline

• BESIII introduction
• Charm prospects at BESIII
• Ongoing analyses
• Summary
BEPCII: $e^+e^-$ Double Ring Collider

Good news: already achieved 2/3 of the design luminosity 3 years into running
BESIII: General-Purpose Detector

A new detector, utilizing advanced detector technologies developed over the past two decades.
Data Taken

• Apr. 2009: 106 M ψ’ events (~150 pb⁻¹)
  (plus ~42 pb⁻¹ at 3.65 GeV)
• Jul. 2009: 225 M J/ψ events (~65 pb⁻¹)

• Jun. 2010: ~923 pb⁻¹ at ψ(3770)
  (plus ~70 pb⁻¹ scan data around ψ(3770))
• Apr. 2011: ~2 fb⁻¹ at ψ(3770)
  (~2.9 fb⁻¹ ψ(3770) together, 3.5 times of CLEO-c data)
• May. 2011: ~0.5 fb⁻¹ at 4010 MeV (for Dₛ and XYZ)
Charm Role in Flavor Physics

Theoretical errors dominate width of bands

$|V_{ub}|$ from $B \rightarrow \pi \ell \nu$:

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

Form factor $f(q^2)$:
- Hard to calculate
- Limits $|V_{ub}|$ precision
- Lattice QCD can do from first principles

Charm decay measurements
- decay constants
- form factors
- $V_{CKM}$ clean extraction
- validate QCD.

over-constrain $V_{CKM}$
Inconsistency $\rightarrow$ New Physics
Advantage of Open Charm at Threshold

• $e^+e^-$ colliders at threshold: CLEO-c, BESIII, super-tau-charm

  $e^+e^- \rightarrow \psi(3770) \rightarrow DD\bar{a}$

• Benefits for charm physics:
  – Threshold production is clean
  – Known initial energy and quantum number
  – Both D and DD$\bar{a}$r fully reconstructed
  – Absolute measurement
Clean single tag at BESIII

@ψ(3770) with 420pb⁻¹ first clean single tagging sample:

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

Resolution:
1.3 MeV for pure charged modes;
1.9 MeV for modes with one π⁰.
mBC of $D_s$ Single Tag
part of data @ 4010 MeV

$D_s \rightarrow K K \pi$

$D_s \rightarrow K_s K$

BESIII Preliminary

$\sigma \sim 1.6$ MeV

BESIII Preliminary

$\sigma \sim 1.4$ MeV
Prospects for Charm at BESIII

precision measurements at BESIII after CLEO-c.

<table>
<thead>
<tr>
<th>CLEO-c errors for D⁰/D⁺ physics with 818 pb⁻¹@3770</th>
<th>BESIII (5fb⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_D⁺ (D⁺→μ⁺ν)</td>
<td>±4.1% (stat.) ± 1.2% (sys.)</td>
</tr>
<tr>
<td>f_π(0) (D⁰→π⁺ν)</td>
<td>±5.3% (stat.) ± 0.7%(sys.)</td>
</tr>
<tr>
<td>BR(D⁰→Kπ)</td>
<td>±0.9% (stat.) ± 1.8%(sys.)</td>
</tr>
<tr>
<td>BR(D⁺→Kππ⁺)</td>
<td>±1.1% (stat.) ± 2.0%(sys.)</td>
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<th>CLEO-c errors for D_s physics with 600pb⁻¹@4170 MeV</th>
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<tr>
<td>f_D_s (D_s⁺→μ⁺ν,τν)</td>
</tr>
<tr>
<td>BR(D_s⁺→KKπ)</td>
</tr>
</tbody>
</table>

For Ds physics, BESIII are taking data at both 4010 and 4170 MeV:

4010 MeV (clean single tag, lower cross section 0.3 nb) → BESIII 0.5 fb⁻¹
4170 MeV (dirty single tag, maximum cross section 0.9 nb) → CLEO-c 0.6 fb⁻¹

Significant gains will be made with increased luminosity at BESIII.
Ongoing Analyses
(using data up to 2.9 fb\(^{-1}\))
Leptonic Analysis

• Two ongoing measurements:
  – $D^+ \rightarrow \mu^+ \nu$, 
  – $D_s \rightarrow \mu^+ \nu$

• Motivations:
  – Clean way to measure $f_{D^+}$ and $f_{D_s}$ (by Branch Fraction) in SM
  – Good agreement between expt. $f_{D^+}$ and LQCD calculations
  – $\sim 1.6 \sigma$ difference between expt. $f_{D_s}$ and LQCD calculations
  – Precise $f_{D^+}$ and $f_{D_s}$ measurements are important inputs for theory
D$^+ \rightarrow \mu^+ \nu$ Measurement

- Tag side: 9 D$^+$ hadronic modes (K$\pi\pi$, k$\pi\pi\pi^0$, K$\_s\pi$, etc)
- Signal side:
  1. one charged track only and muon PID satisfied
  2. no isolated EMC shower
- Key variable: $M^2_{miss} = E^2_{miss} - P^2_{miss}$

![Graph showing M$^2_{miss}$ Distribution (part of data)](image)
Semi-leptonic Analysis

• Three ongoing measurements:
  – $D^0 \rightarrow K^-/\pi^- e^+ \nu$
  – $D^+ \rightarrow \pi^0/\eta e^+ \nu$
  – $D^+ \rightarrow \omega/\phi e^+ \nu$, $\omega \rightarrow \pi^+\pi^-\pi^0$, $\phi \rightarrow KK$

• Motivations
  – Measure form factors and check theory
  – Test iso-spin symmetry in $D^0/D^+ \rightarrow \pi^-/\pi^0 e^+\nu$
  – Branch fraction measurements (large error for PDG value of $D^+ \rightarrow \omega e^+\nu$, and only upper limit for $D^+ \rightarrow \phi e^+\nu$. )
D^0 -> K^-/\pi^- e^+ \nu Measurement

• Tag side: Three D^0 modes (K\pi, K\pi\pi^0, K\pi\pi\pi)

• Signal side:
  1. two good tracks with opposite charges
  2. K/\pi PID and electron PID requirements
  3. electron has opposite charge as the tag side kaon

• Key variable: \( U_{\text{miss}} = E_{\text{miss}} - P_{\text{miss}} \)

U_{\text{miss}} Distribution of D^0 -> K e \nu mode
(part of data)

U_{\text{miss}} Distribution of D^0 -> \pi e \nu mode
(part of data)
$$d\Gamma(D \rightarrow Pe\nu)\over dq^2 = X{G_F^2 |V_{cd(s)}|^2 \over 24\pi^3} p^3 |f_+(q^2)|^2$$

Where $q^2$ is invariant mass of lepton-neutrino system

- To extract form factors, need to fit yields in $q^2$ bins.
- Less than 10 bins in $q^2$ from 0 to 3 GeV$^2$
- Excellent resolution according to MC: $\sigma \sim 0.015$ GeV$^2$

$$\Delta q^2 = q^2 - q^2_{\text{truth}}$$

From signal Monte Carlo
D Branch Fraction Measurement

• Motivation:
  (1) Important to normalize decay fractions of D and B mesons
  (2) Precise measurements of $B(D^0 \rightarrow K\pi)$ and $B(D^+ \rightarrow K\pi\pi)$ can directly improve precisions of CKM elements
  (3) Check CLEO-c measurements

• Current status:
  (1) Luminosity measurement
  (2) $K/\pi$ tracking, $\pi^0$, $K^0_s$ efficiency measurements
  (3) PID efficiency measurement

• All other analyses at BESIII would benefit from systematics studies
DDbar Cross Section Measurement

• Motivation
  – Measure ratio of $D^0$ and $D^+$ cross section to check theory calculation
  – To extract non-DDbar Brach Fraction
• previous results at $E_{cm} \sim 3773$ MeV:
  – BESII, $\sim 5.93 +/- 0.59$ nb (PRL, 97:121801, 2006)
  – CLEO-c, $\sim 6.51 +/- 0.08$ nb (xinshi, 2011 LLWI)
• Both single tag and double tag techniques are used to measure the DDbar cross sections at BESIII
Other Analyses at BESIII

- Dalitz plot analysis ( $D^0 \to K\pi\pi^0$, $D^+ \to K^0_s\pi\pi^0$, $D^0 \to K\pi\eta$, $D^+ \to KK\pi$):
  - Study the $K\pi$ system, search for the low mass scalar resonance $\kappa$
  - Develop the Dalitz plot analysis software for Charm physics at BESIII

- Search for CP violation through T-violation in modes: $D^+ \to K^0_sK^+\pi^+\pi^-$ and $D^+ \to K^+K^-\pi^+\pi^0$
Summary

• BESIII is accumulating data at record speed
• Charm prospects at BESIII is great
• Rich results are coming out soon
Back Up
Non-DDbar Brach Fraction

- $\psi(3770)$ (mixture of S and D waves) expected to decay to DDbar entirely
- However, long history of non-DDbar branch fraction measurements:
  - ~1988, Mark III/II, Lead-Glass Wall: ~50% non-DDbar
  - ~2006-2008, BESII: 14.7% +/- 3.2%
  - ~2010, CLEO-c: no evidence of non-DDbar, set upper limit <9% at 90%CL
Non-Ddbar Measurement at BESIII

• Use same p(3770) data as charm physics
• Inclusive measurement
• Exclusive measurement:
  – $\psi(3770)\rightarrow \gamma \chi_{cJ}$
  – $\psi (3770)\rightarrow J/\psi \pi \pi, J/\psi \pi^0, J/\psi \eta$
  – $\psi (3770)\rightarrow \text{VP}$
  – $\psi (3770)\rightarrow \text{light hadrons}$