Highlights from BESIII

Hai-Bo Li
for BESIII Collaboration
Institute of High Energy Physics
Beijing, China

XIV International Conference on Hadron Spectroscopy
June 13 – 17, 2011
Künstlerhaus, in München, Germany
Outline

• Status of BEPCII/BESIII
• Results from Charmonium data samples
• 2010-11: First open charm runs
• Charm Physics: advantage near threshold
• Conclusion
BESIII - physics using “charm”

Charmonium physics:
- Spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D\(^0\)–D\(\bar{0}\) mixing and CP violation
- rare/forbidden decays

Tau physics:
- Tau decays near threshold
- tau mass scan

...and many more.

June 15, 2011

Hai-Bo Li (IHEP)
Charmonium spectroscopy after the B-factories

Comprehensive study of charmonium decays
charm and charmonium spectroscopy

BESIII final goal
\[ J/\psi - 10^{10} \]
\[ \psi(2S) - 3 \times 10^9 \]
\[ \psi(3770) - 6 \times 10^8 \]
Higher \( \psi \)'s - \( 10^7 \)

In decays:
\[ \eta_c(1S) - 10^8 \]
\[ \chi_{cJ} - 10^8 \]
\[ h_c - 10^7 \]
(\( \psi(2S) \rightarrow h_c \pi^0 \))
\( 10^8 \eta/\eta' \) samples
Rare \( \eta/\eta' \) decays
2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking

Satellite view of BEPCII /BESIII

LINAC

BESIII detector

South
BEPCII storage rings

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: 237 m
BESIII Detector

Magnet: 1 T  Super conducting

MDC: small cell & Gas: He/C₃H₈ (60/40), 43 layers
σ_{xy} = 130 μm
σ_p/p = 0.5% @1 GeV
dE/dx = 6%

TOF:
σ_T = 100 ps  Barrel
110 ps  Endcap

EMC: CsI crystal, 28 cm
ΔE/E = 2.5% @1 GeV
σ_z = 0.6 cm/√E

Muon ID: 9 layers RPC
8 layers for endcap

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s
Data samples

• So far BESIII has collected:
  - 2009: 225 Million $J/\psi$
  - 2009: 106 Million $\psi'$
  - 2010-11: 2.9 fb$^{-1}$ $\psi(3770)$
    $(3.5 \times \text{CLEO-c} 0.818\text{fb}^{-1})$
  - May 2011: 0.5fb$^{-1}$ @4010 MeV (one month) for $D_s$ and XYZ spectroscopy
• BESIII will also collect:
  - more $J/\psi$, $\psi'$, $\psi(3770)$
  - data at higher energies
    (for XYZ searches, $R$ scan and $D_s$ physics)
June 15, 2011  Hai-Bo Li (IHEP) 9

Note that luminosity is lower at $J/\psi$, and machine is optimal near $\psi(3770)$

Integrated luminosity: Jan. 2009–June 3 2011 about 4.0 fb$^{-1}$@ different energies

Note increase in slopes!

2011: $\psi(3770)$ & $\psi(4040)$ for $D_s$

2010: $\psi(3770)$

2009: $\psi'$ & $J/\psi$
Recent $\psi(3770)$ running

Reference point: $\mathcal{L} = 0.5 \times 10^{33}$ /cm$^2$/s (maximum $0.65 \times 10^{33}$)
theoretically lumi: 43 pb$^{-1}$/day
But, filling beam, HV ramp, lumi. decay and down time loss 40%
Best week: 160.8 pb$^{-1}$
Best day: 29 pb$^{-1}$

Beam current: 700 mA x 700 mA

Luminosity curve (decay curve)

Peak luminosity $0.6 \times 10^{33}$/cm$^2$/s

Best day on April 7 2011
BESIII Collaboration

>300 physicists
49 institutions from 10 countries

June 15, 2011
Hai-Bo Li (IHEP)
Released results of BESIII

- **Charmonium Spectroscopy and Transitions**
  - Properties of the $h_c$ (PRL 104, 132002 (2010))
  - $\psi' \rightarrow \gamma \gamma J/\psi$ (submitted soon)

- **Charmonium Decays**
  - $\chi_{cJ} \rightarrow \pi^0\pi^0, \eta \eta$ (PRD 81, 052005 (2010))
  - $\chi_{cJ} \rightarrow \gamma \rho, \gamma \omega, \gamma \phi$ (PRD 83, 112005 (2011))
  - $\chi_{cJ} \rightarrow \omega \omega, \phi \phi, \omega \phi$ (submitted to PRL)
  - $\psi' \rightarrow \gamma \pi^0, \gamma \eta, \gamma \eta'$ (PRL 105, 261801 (2010))
  - $\chi_{cJ} \rightarrow 4\pi^0$ (PRD 83, 012006 (2011))
  - Observation of $\chi_{cJ} \rightarrow ppK^+K^-$ (accepted by PRD)

- **Light Quark States**
  - $a_0(980) - f_0(980)$ mixing (PRD 83, 032003 (2011))
  - $\eta' \rightarrow \eta \pi^+\pi^-$ matrix element (PRD 83, 012003 (2011))
  - $X(1860)$ in $J/\psi \rightarrow \gamma (p\bar{p})$ (Chinese Physics C 34, 4 (2010))
  - $X(1835)$ in $J/\psi \rightarrow \gamma (\eta' \pi^+\pi^-)$ (PRL 106, 072002 (2011))
  - $X(1870)$ in $J/\psi \rightarrow \omega (\eta \pi^+\pi^-)$ (submitted soon)

More than 20 analyses are under internal review!

June 15, 2011

Hai-Bo Li (IHEP)
Study isospin forbidden transition

\[ B(\Psi' \rightarrow \pi^0 h_c) \]

Measure as well the E1 transition

\[ B(h_c \rightarrow \gamma \eta_c) \]

Hyperfine splitting of the 1P states (spin-spin interaction term):

\[ M(h_c(1P)) - <M(\chi_cJ(1P))>_{(\text{spin-weighted})} \]
Observation of $h_c$ in inclusive reaction

Tag the E1 photon, yields:

$$\psi(2S) \rightarrow \pi^0 h_c \times B(h_c \rightarrow \gamma \eta_c)$$

$$= (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$$

(consistent with CLEO-c)

Inclusive analysis provides:

$$B(\psi(2S) \rightarrow \pi^0 h_c)$$

(first measurement)

$$= (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$$

Combining the two results:

$$B(h_c \rightarrow \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$$

(first measurement)

Natural width of $h_c$:

$$\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28 \text{ MeV}/c^2$$

(first measurement)

Hyperfine splitting:

$$\Delta M_{hf} = -0.10 \pm 0.13 \pm 0.18 \text{ MeV}/c^2$$

(consistent with zero)
h_c(1P1) in $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$, $\eta_c \rightarrow X_i$ (exclusive)

$\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma \eta_c$, $\eta_c$ is reconstructed exclusively with 16 decay modes

<table>
<thead>
<tr>
<th>16 Decays modes</th>
<th>BR($\eta_c \rightarrow X$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_c \rightarrow \pi^o \pi^-$</td>
<td>~0.13%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow \pi^+ \pi^- \pi^-$</td>
<td>~0.45%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow 2(\pi^+ \pi^-)$</td>
<td>~1.20%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow 2K^+2K^-$</td>
<td>~0.16%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow \pi^+ \pi^- k^+ k^-$</td>
<td>~1.50%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow 3(\pi^+ \pi^-)$</td>
<td>~1.50%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow K^+ K^- 2(\pi^+ \pi^-)$</td>
<td>~0.71%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow k^+ k^- \pi^0$</td>
<td>~1.17%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow pp \bar{p} \pi^0$</td>
<td>~0.18%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow k_s k p$</td>
<td>~2.33%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow k_s k 3\pi$</td>
<td>~2.40%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow \pi^+ \pi^- \eta; \eta \rightarrow \gamma \gamma$</td>
<td>~3.27%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow k^+ k^- \eta$</td>
<td>~0.57%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow 2(\pi^+ \pi^-) \eta$</td>
<td>~2.70%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow \pi^+ \pi^- \pi^0 \pi^0$</td>
<td>~2.40%</td>
</tr>
<tr>
<td>$\eta_c \rightarrow 2(\pi^+ \pi^-) \pi^0 \pi^0$</td>
<td>~11.0%</td>
</tr>
</tbody>
</table>

Black from PDG2010, blue from estimation of $\psi' \rightarrow \gamma \eta_c$

For detail see Quarkonia session: Liangliang Wang’s talk on June 13
Simultaneous fit to $\pi^0$ recoiling mass in 106M $\psi'$ sample (preliminary results):

$$M(h_c) = 3525.31 \pm 0.11_{(\text{stat})} \pm 0.15_{(\text{sys})} \text{ MeV/c}^2$$

$$\Gamma(h_c) = 0.70 \pm 0.28_{(\text{stat})} \pm 0.25_{(\text{sys})} \text{ MeV}$$

$$N = 832 \pm 35$$

$$\chi^2/\text{d.o.f.} = 32/46$$

Consistent with BESIII inclusive results PRL104, 132002(2010)
CLEOc exclusive results
$$M(h_c)=3525.21 \pm 0.27 \pm 0.14 \text{ MeV/c}^2$$

$$N = 136 \pm 14$$

PRL101, 182003(2008)
The $\eta_c$ lineshape is not distorted in the $h_c \rightarrow \gamma \eta_c$

Detail analysis of $\eta_c$ parameters is ongoing!

Symmetric lineshape in $\gamma \gamma$ production

Asymmetric lineshape in $\psi$ decay
$\eta_c$ resonance parameters from $\psi' \rightarrow \gamma \eta_c$

Simultaneous fit with r-BW by considering the interference between $\eta_c$ and non-$\eta_c$ decays, as well as the energy dependence of phase space:

**mass:** $2984.4 \pm 0.5_{\text{stat}} \pm 0.6_{\text{sys}}$ MeV/$c^2$

**width:** $30.5 \pm 1.0_{\text{stat}} \pm 0.9_{\text{sys}}$ MeV

$\phi$: $2.35 \pm 0.05_{\text{stat}} \pm 0.04_{\text{sys}}$ rad

June 15, 2011
Hai-Bo Li (IHEP)
Comparison of the mass and width for $\eta_c$

The world average in PDG2010 was using earlier results

BESIII results include both stat. and syst. errors, which is the most precision measurement, the interference between $\eta_c$ decay and non-resonance is important.

For detail see Quarkonia session on June 13:
Liangliang Wang

June 15, 2011  Hai-Bo Li (IHEP)
Observation of $\eta_c(2S)$ in $\psi' \to \gamma \eta_c(2S), \eta_c(2S) \to K_SK\pi$

With 106M $\psi'$ events:

- $M(\eta_c(2S)) = (3638.5 \pm 2.3 \pm 1.0) \text{ MeV}/c^2$
- $N(\eta_c(2S)) = 50.6 \pm 9.7$
- Statistical significance larger than $6.0\sigma$!

$$\text{Br}(\psi' \to \gamma \eta_c(2S) \to \gamma K_SK\pi) = (2.98 \pm 0.57_{\text{stat}} \pm 0.48_{\text{sys}}) \times 10^{-6}$$

+ $$\text{Br}(\eta_c(2S) \to KK\pi) = (1.9 \pm 0.4 \pm 1.1)\%$$

From BABAR (PRD78, 012006)

$$\text{Br}(\psi' \to \gamma \eta_c(2S)) = (4.7 \pm 0.9_{\text{stat}} \pm 3.0_{\text{sys}}) \times 10^{-4}$$

CLEO-c: $< 7.6 \times 10^{-4}$

PRD81, 052002(2010)

Potential model: $(0.1 - 6.2) \times 10^{-4}$

PRL89, 162002(2002)

For detail see Quarkonia session on June 13: Liangliang Wang
Measurement of $J/\psi \rightarrow p\bar{p}, n\bar{n}$

- $p\bar{p}$ amplitude $A^p_y$ from BABAR data
- $n\bar{n}$ amplitude $A^n_y$ from FENICE data
- $A^p_y - A^n_y$ relative phase from pQCD

$$B(J/\psi \rightarrow n\bar{n}) = \left| \frac{A_{3g} + A^n_y}{A_{3g} + A^p_y} \right|^2$$

$$B(J/\psi \rightarrow p\bar{p}) = (1.4 \pm 0.2) \times 10^{-3}$$

**BESII at BEPC [PLB591,42]:**
$$BR(J/\psi \rightarrow p\bar{p}) = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3}$$

**FENICE at ADONE [PLB444,111]:**
$$BR(J/\psi \rightarrow n\bar{n}) = (2.2 \pm 0.4) \times 10^{-3}$$

$$B(J/\psi \rightarrow p\bar{p}) \sim B(J/\psi \rightarrow n\bar{n}) \Rightarrow \text{large } A^N_{3g} - A^N_y \text{ relative phase?}$$

With 2.2 million $J/\psi$ at BESIII, with help of EMC, we can access neutron-anti-neutron final states
Preliminary results: $J/\psi \rightarrow p\bar{p}, n\bar{n}$

Anti-neutron identifications:

EMC energy deposit: $0.6 < E(\text{anti-neutron}) < 2.0 \text{ GeV}$

Comparison for anti-neutron in $J/\psi \rightarrow n\bar{n}$ and $p\bar{n}\pi^-$

Angle between $n$ and recoiling direction of $\bar{n}$

$\text{Br}(J/\psi \rightarrow p\bar{p}) = (2.112 \pm 0.004 \pm 0.027) \times 10^{-3}$

PDG: $\text{Br}(J/\psi \rightarrow p\bar{p}) = (2.17 \pm 0.07) \times 10^{-3}$

$\text{Br}(J/\psi \rightarrow n\bar{n}) = (2.07 \pm 0.01 \pm 0.14) \times 10^{-3}$

PDG: $\text{Br}(J/\psi \rightarrow n\bar{n}) = (2.2 \pm 0.4) \times 10^{-3}$

$\text{Br}(J/\psi \rightarrow p\bar{p}) \sim \text{Br}(J/\psi \rightarrow n\bar{n})$ suggests a large angle ($\sim 90^0$) between strong and EM amplitudes!
Preliminary results: $J/\psi \rightarrow p\bar{p}, n\bar{n}$

Anti-neutron identifications:

- **EMC energy deposit**: $0.6 < E(\text{anti-neutron}) < 2.0$ GeV

Comparison for anti-neutron in $J/\psi \rightarrow n\bar{n}$ and $p\bar{n}\pi^-$

- Angle between $n$ and recoiling direction of $\bar{n}$

**Br($J/\psi \rightarrow p\bar{p}$)** = $(2.112 \pm 0.004 \pm 0.027) \times 10^{-3}$

PDG: **Br($J/\psi \rightarrow p\bar{p}$)** = $(2.17 \pm 0.07) \times 10^{-3}$

**Br($J/\psi \rightarrow n\bar{n}$)** = $(2.07 \pm 0.01 \pm 0.14) \times 10^{-3}$

PDG: **Br($J/\psi \rightarrow n\bar{n}$)** = $(2.2 \pm 0.4) \times 10^{-3}$

This technique tells us that we can measure neutron-antineutron cross section between 2.0-4.0 GeV by using scan data, which is important. See MAGGIORA, Marco in Quarkonia session on June 13.

Suggests a large angle (~90°) between strong and EM amplitudes!
Evidence for $\psi'$ decays into $\gamma\pi$ and $\gamma\eta$

We are measuring BRs at $10^{-6}$

<table>
<thead>
<tr>
<th>BR $[10^{-6}]$</th>
<th>BESIII</th>
<th>Combined BESIII</th>
<th>PDG10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\psi' \rightarrow \gamma\pi^0$</td>
<td>$1.58 \pm 0.40 \pm 0.13$</td>
<td>$1.58 \pm 0.40 \pm 0.13$</td>
<td>$\leq 5$</td>
</tr>
<tr>
<td>$\psi' \rightarrow \gamma\eta(\pi^+\pi^+\pi^0)$</td>
<td>$1.78 \pm 0.72 \pm 0.17$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi' \rightarrow \gamma\eta(\pi^0\pi^0\pi^0)$</td>
<td>$1.07 \pm 0.65 \pm 0.08$</td>
<td>$1.38 \pm 0.48 \pm 0.09$</td>
<td>$\leq 2$</td>
</tr>
<tr>
<td>$\psi' \rightarrow \gamma\eta(958)(\pi^+\pi^+\eta)$</td>
<td>$120 \pm 5 \pm 8$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\psi' \rightarrow \gamma\eta(958)(\pi^+\pi^+\gamma)$</td>
<td>$129 \pm 3 \pm 8$</td>
<td>$126 \pm 3 \pm 8$</td>
<td></td>
</tr>
</tbody>
</table>

PRL105, 261801(2010)
Some surprises

PRL105, 261801(2010)

Theory

\[ R_{(c\bar{c})} = \frac{Br((c\bar{c}) \to \gamma \eta)}{Br((c\bar{c}) \to \gamma \eta')} \]

LO-pQCD

\[ \downarrow \]

\[ R_{\Psi'} \simeq R_{J/\Psi} \]


Experiment

CLEO-c

\[ R_{J/\Psi} = \frac{B(J/\Psi \to \gamma \eta)}{B(J/\Psi \to \gamma \eta')} = (21.1 \pm 0.9) \% \]

(consistent with other measurements of \( \eta-\eta' \) mixing angle and LO-pQCD)

BESIII

\[ R_{\Psi'} = \frac{B(\psi(2S) \to \gamma \eta)}{B(\psi(2S) \to \gamma \eta')} = (1.10 \pm 0.38 \pm 0.07) \% \]

(consistent with upper limit from CLEO-c)

\[ R_{\Psi'} \ll R_{J/\Psi} \]

Difference?: Other processes contributing? Related to \( p\pi \) puzzle, ... ??

June 15, 2011

Hai-Bo Li (IHEP) Q. Zhao, PLB697(2011)52
$\eta(1405)$ in $J/\psi \to \gamma f_0(980)\pi^0, f_0(980) \to \pi\pi$

**Preliminary results:**

\[
Br(J/\psi \to \gamma \eta(1405) \to \gamma f_0 \pi^0 \to \gamma \pi^0\pi^+\pi^-) = (1.48 \pm 0.13\,(\text{stat.}) \pm 0.17\,(\text{sys.})) \times 10^{-5}
\]

\[
Br(J/\psi \to \gamma \eta(1405) \to \gamma f_0 \pi^0 \to \gamma \pi^0\pi^0\pi^0) = (6.99 \pm 0.93\,(\text{stat.}) \pm 0.95\,(\text{sys.})) \times 10^{-6}
\]

Helicity analysis indicates that peak at 1400MeV is from $\eta(1405) \to f_0(980)\pi^0$ not from $f_1(1420)$:

**First observation of**

$\eta(1405) \to f_0(980)\pi^0$ (isospin violated decays) and $J/\psi \to \gamma f_0(980)\pi^0$

*June 15, 2011* Hai-Bo Li (IHEP)
New results on $\eta' \to 3\pi$ in $J/\psi \to \gamma\pi\pi\pi$.

Preliminary results:

$Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15\text{(stat.)} \pm 0.39\text{(sys.)}) \times 10^{-3}$

PDG2010: $(3.6^{+1.1}_{-0.9}) \times 10^{-3}$ (2009 CLEO-c)

$Br(\eta' \to 3\pi^0) = (3.56 \pm 0.22\text{(stat.)} \pm 0.34\text{(sys.)}) \times 10^{-3}$

PDG2010: $(1.68 \pm 0.22) \times 10^{-3}$ (1984: GAM2)
Confirmation of $X(1835)$ and two new structures

**BESII result (Stat. sig. ~ 7.7$\sigma$):**

$M = 1833.7 \pm 6.1\,(stat) \pm 2.7\,(syst)\,MeV$

$\Gamma = 67.7 \pm 20.3\,(stat) \pm 7.7\,(syst)\,MeV$

**BESIII fit results:**

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$M$ (MeV/c²)</th>
<th>$\Gamma$ (MeV/c²)</th>
<th>Stat. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X(1835)$</td>
<td>$1836.5 \pm 3.0^{+5.6}_{-2.1}$</td>
<td>$190.1 \pm 9.0^{+38}_{-36}$</td>
<td>$&gt;20,\sigma$</td>
</tr>
<tr>
<td>$X(2120)$</td>
<td>$2122.4 \pm 6.7^{+4.7}_{-2.7}$</td>
<td>$83 \pm 16^{+31}_{-11}$</td>
<td>$7.2,\sigma$</td>
</tr>
<tr>
<td>$X(2370)$</td>
<td>$2376.3 \pm 8.7^{+3.2}_{-4.3}$</td>
<td>$83 \pm 17^{+44}_{-6}$</td>
<td>$6.4,\sigma$</td>
</tr>
</tbody>
</table>

An amplitude analysis could help with interpretation for the additional new structures!

June 15, 2011

Hai-Bo Li (IHEP)
What's the nature of new structures?

It is the first time resonant structures are observed in the 2.3 GeV/c^2 region, it is interesting since:

- LQCD predicts that the lowest lying pseudoscalar glueball: around 2.3 GeV/c^2.
- \( J/\psi \rightarrow \gamma \pi \pi \eta \) decay is a good channel for finding 0^- glueballs.

Nature of \( X(2120)/X(2370) \) pseudoscalar glueball? \( \eta/\eta' \) excited states?

For detail see Light meson session: Hongwei Liu's talk on June 17.
**Identification of X(1870):**

**0−+(?)**

It is X(1835)?

Need PWA!

---

**BR(J/ψ→ωX, X→a_0^±(980)π^±)**

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass (MeV/c^2)</th>
<th>Width (MeV/c^2)</th>
<th>Branch ratio (10^-4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_1(1285)</td>
<td>1285.1 ± 1.0^{+1.6}_{-0.3}</td>
<td>22.0 ± 3.1^{+2.0}_{-1.5}</td>
<td>1.25 ± 0.10^{+0.19}_{-0.20}</td>
</tr>
<tr>
<td>η(1405)</td>
<td>1399.8 ± 2.2^{+2.8}_{-0.1}</td>
<td>52.8 ± 7.6^{+0.1}_{-7.6}</td>
<td>1.89 ± 0.21^{+0.21}_{-0.23}</td>
</tr>
<tr>
<td>X(1870)</td>
<td>1877.3 ± 6.3^{+3.4}_{-7.4}</td>
<td>57 ± 12^{+19}_{-4}</td>
<td>1.50 ± 0.26^{+0.72}_{-0.36}</td>
</tr>
</tbody>
</table>
Preliminary results on $N^*$ baryon in $\psi' \rightarrow \eta pp\bar{p}$ decay

A full PWA analysis performed selected in 106 $M\psi'$ events Background clean!

$N(1535)$ is $1/2^-$

**$M(p\eta)$**

$M(pp)$

$\text{Br}(\psi' \rightarrow pp\eta) = (6.6 \pm 0.2 \pm 0.6) \times 10^{-5}$

PDG2010: $(6 \pm 1.2) \times 10^{-5}$

$\text{Br}(\psi' \rightarrow N(1535)p) \times \text{Br}(N(1535) \rightarrow p\eta + \text{c.c.})$

$= 5.5_{-0.3-1.1}^{+0.3+7.4} \times 10^{-5}$

**Dalitz plot data**

**Dalitz plot MC fit**

Mass: $1.524^{+0.010} {_{-0.005}}$ GeV/C$^2$

Width: $0.130^{+0.061} {_{-0.014}}$ GeV

June 15, 2011

Hai-Bo Li (IHEP)
Running plan

- The luminosity of BEPCII is better than expected.
- Data taking for open charm:
  - $\psi(3770)$: 2.9 fb$^{-1}$ (2010 and 2011)
  - 4010 MeV: 0.5 fb$^{-1}$ in May 2011 for Ds physics and XYZ

<table>
<thead>
<tr>
<th>Year</th>
<th>Running</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>$J/\psi$: 1 billion / $\psi(2S)$: 0.5 billion (approved)</td>
</tr>
<tr>
<td>2013</td>
<td>4170 MeV: Ds decay + R scan (E &gt; 4 GeV)</td>
</tr>
<tr>
<td>2014</td>
<td>$\psi(2S)/\tau$ / R scan (E &gt; 4 GeV)</td>
</tr>
<tr>
<td>2015</td>
<td>$\psi(3770)$: 5-10 fb$^{-1}$ (our final goal)</td>
</tr>
</tbody>
</table>

Red: be approved by BESIII Collaboration
Prospect of charm physics at BESIII
Advantage of open charm at threshold

e^+e^- Colliders@threshold: CLEO-c, BESIII, Super-tau-charm

e^+e^- → ψ(3770) → D^0D^0 [C = -1] OR e^+e^- → γ* → D^0D^0γ [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
Charm role in flavor physics

Theoretical errors dominate width of bands

|IV_{ub}| from B → π ℓν:

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

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

Precision QCD calculations tested with precision charm data at threshold

- Theory errors of a few % on B system decay constants & semileptonic form factors

Charm decay measurements
- Decay constants
- Form factors
- \textit{V}_{CKM} clean extraction
- Validate QCD.

Over-constrain \textit{V}_{CKM}

Inconsistency → New Physics
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 \( \pi^0 \).
Prospects for Charm at BESIII

Look for the size of the statistics/systematic/FSR errors for precision measurements at BESIII after CLEO-c.

### CLEO-c errors for D⁰ /D⁺ physics with 818 pb⁻¹@3770 MeV

<table>
<thead>
<tr>
<th>Process</th>
<th>BESIII (5fb⁻¹)</th>
<th>CLEO-c (600fb⁻¹@4170 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{D⁺}(D⁺→μ⁺ν) ):</td>
<td>( ±4.1% \text{ (stat.)} ± 1.2% \text{ (sys.)} )</td>
<td>( ±2.0% \text{ (stat.)} ± 2.3% \text{ (sys.)} )</td>
</tr>
<tr>
<td>( f_{π⁺}(0)(D⁰→π⁺ν) ):</td>
<td>( ±5.3% \text{ (stat.)} ± 0.7% \text{ (sys.)} )</td>
<td>( ±2.3% \text{ (stat.)} ± 0.7% \text{ (sys.)} )</td>
</tr>
<tr>
<td>( \text{BR}(D⁰→Kπ) ):</td>
<td>( ±0.9% \text{ (stat.)} ± 1.8% \text{ (sys.)} )</td>
<td>( \text{limited by sys.} )</td>
</tr>
<tr>
<td>( \text{BR}(D⁺→Kππ) ):</td>
<td>( ±1.1% \text{ (stat.)} ± 2.0% \text{ (sys.)} )</td>
<td>( \text{limited by sys.} )</td>
</tr>
</tbody>
</table>

### CLEO-c errors for Ds physics with 600pb⁻¹@4170 MeV

<table>
<thead>
<tr>
<th>Process</th>
<th>BESIII (5fb⁻¹)</th>
<th>CLEO-c (600fb⁻¹@4170 MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{Ds}(Ds⁺→μ⁺ν,τν) ):</td>
<td>( ±2.5% \text{ (stat.)} ± 1.2% \text{ (sys.)} )</td>
<td>( ±0.8% \text{ (stat.)} ± 2.0% \text{ (stat.)} )</td>
</tr>
<tr>
<td>( \text{BR}(Ds⁺→KKπ) ):</td>
<td>( ±4.2% \text{ (stat.)} ± 2.9% \text{ (sys.)} )</td>
<td>( \text{limited by sys.} )</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) \( \rightarrow \) BESIII 0.5 fb⁻¹
- 4170 MeV (dirty single tag, maximum cross section 0.9 nb) \( \rightarrow \) CLEO-c 0.6 fb⁻¹

Significant gains will be made with increased luminosity at BESIII.
Coherence physics @ threshold

D^0

$e^+ e^- \rightarrow \psi'' \rightarrow D^0 \bar{D}^0$

The initial state $C = -1$

$\psi_- = \frac{1}{\sqrt{2}} (|D^0\rangle \langle \bar{D}^0| - |\bar{D}^0\rangle \langle D^0|)$

The coherent amplitude

$\Gamma_{ij}^2 = \langle i | D^0 \langle j | \bar{D}^0 \rangle \bar{D}^0 \rangle \bar{D}^0 \rangle = \langle i | D^0 \langle j | \bar{D}^0 \rangle \bar{D}^0 \rangle \bar{D}^0 \rangle = \langle i | D^0 \langle j | \bar{D}^0 \rangle \bar{D}^0 \rangle \bar{D}^0 \rangle$

$\langle K^- \pi^+ | \bar{D}^0 \rangle = r_{K\pi} e^{-i\delta_{K\pi}}$

$\delta_{K\pi}$ connects measurements of $y$ and $y'$

$\Gamma = \frac{\Gamma_1 + \Gamma_2}{2}$

$\Delta m \equiv \frac{m_2 - m_1}{\Gamma}$

$x \equiv \frac{\Delta \Gamma}{\Gamma} \frac{\Gamma_2 - \Gamma_1}{2 \Gamma}$

- $D^0$ mixing: $R_m = (x^2 + y^2)/2 \sim 10^{-4}$
- Strong phase can be accessed, will be helpful for mixing measurements at super-B factories:

Sensitivity on $x$ will be improved by a factor of 3

Uncertainty of $\gamma$ due to unknown relative phase on Dalitz decays $D^0 \rightarrow K_s h^+ h^-$ will be reduced to less than $10^\circ$.

$CP$ violation in $D$ sector: $10^{-3}$
Sensitivity of rare D decays at BESIII

- **Flavor Changing Neutral Current** (c→u l⁺l⁻)
  - \( D^0 \rightarrow \mu^+ \mu^- \) SM <10⁻¹², NP ~ 10⁻⁶
  - CDF \( \text{BR} < 4.3 \times 10^{-7} \)
  - \( D \rightarrow X_u l^+l^- \) SM <10⁻⁸, NP ~ 10⁻⁶
  - D0 \( \text{BR}(D^+ \rightarrow \pi^+ \mu^+ \mu^-) < 3.9 \times 10^{-6} \)
  - CLEO-c \( \text{BR}(D^+ \rightarrow \pi^+ e^+ e^-) < 7.4 \times 10^{-6} \)

- **Lepton Flavor Violation** NP ~ 10⁻⁶
  - BABAR \( \text{BR}(D^0 \rightarrow \mu^+ e^-) < 0.81 \times 10^{-6} \)
  - BABAR \( \text{BR}(D^+ \rightarrow \pi^+ e^+ \mu^-) < 1.1 \times 10^{-5} \)

With 5-10fb⁻¹ @\( \psi(3770) \), BESIII will provide 10⁻⁷ -10⁻⁸ sensitivity.
Conclusion

- Huge data samples collected for Charmonium decays at BESIII
- The first observation of $\eta_c(2S)$ in $\psi' \rightarrow \gamma \eta_c(2S)$ decay
- Precision measurements of $\eta_c(1S)$ parameters in $\psi' \rightarrow \gamma \eta_c(1S)$
- Confirmation of $X(1835)$ in $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$
- Observation of two new structures $X(2120)$ and $X(2370)$ in $J/\psi \rightarrow \gamma \pi \pi \eta'$ decays
- Observation of new structure $X(1870)$ in $J/\psi \rightarrow \omega \pi \pi \eta$
- Charm near threshold undertake complementary studies of $D$ mixing and CPV, and unique test of QCD techniques
- We expect rich physics results in the coming years from BESIII.
June 15, 2011 Hai-Bo Li (IHEP)

Thank you!

After 36 years of discovery, Charm is still charming!

Thanks!
Back up slides
Preliminary: relative phase between $\eta_c$ decays and non-$\eta_c$ background

<table>
<thead>
<tr>
<th>mode</th>
<th>yield</th>
<th>$\phi_i$ (stat.)</th>
<th>$\chi^2$/dof</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_SK\pi$</td>
<td>880.4</td>
<td>2.9±0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>$KK\pi^0$</td>
<td>948.4</td>
<td>2.4±0.4</td>
<td>0.9</td>
</tr>
<tr>
<td>$\pi\pi\eta$</td>
<td>573.4</td>
<td>2.2±0.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$K_SK3\pi$</td>
<td>432.3</td>
<td>2.3±0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>$2K2\pi\pi^0$</td>
<td>1033.6</td>
<td>2.6±0.2</td>
<td>1.2</td>
</tr>
<tr>
<td>$6\pi$</td>
<td>664.4</td>
<td>2.5±0.1</td>
<td>1.1</td>
</tr>
<tr>
<td>combined</td>
<td>4532.5</td>
<td>2.35±0.05</td>
<td>-</td>
</tr>
</tbody>
</table>

$\phi_i$ values from each mode are consistent within $3\sigma$: use a common phase in the simultaneous fit.
Vcs / Vcd from semileptonic D decays

The data determine \(|V_{cs(d)}| f_+ (0)\).
To extract \(|V_{cs(d)}|\), we combine the measured \(|V_{cs(d)}| f_+ (0)\) values using the Becher-Hill parameterization with (FNAL-MILC-HPQCD) for \(f_+ (0)\).

CLEO-c: the most precise direct determination of \(|V_{cs}|\): \(\sigma(|V_{cs}|)/|V_{cs}| \sim 1.1\% (\text{expt}) \oplus 2.5\% (\text{theory})\)

\(\text{CLEO-c} \quad |V_{cs}|
\)

\[(818 \text{ pb}^{-1}) \quad 0.963 \pm 0.009 \pm 0.006 \pm 0.024\]

\(\text{stat} \quad \text{syst} \quad \text{theory}\)

CLEO-c: \(\sigma(|V_{cd}|)/|V_{cd}| \sim 3.1\% (\text{expt}) \oplus 10\% (\text{theory})\)
\(\nu N\) remains most precise determination

\(\text{CLEO-c} \quad |V_{cd}|
\)

\[(818 \text{ pb}^{-1}) \quad 0.234 \pm 0.007 \pm 0.002 \pm 0.025\]

\(\text{stat} \quad \text{syst} \quad \text{theory}\)

Vcd will be improved at BESIII by a factor of 2.

June 15, 2011
Hai-Bo Li (IHEP)
$D^0D^0\bar{D}^0$ quantum correlation @ $\psi(3770)$

For a physical process producing $D^0\bar{D}^0$ such as

$$e^+e^- \rightarrow \psi'' \rightarrow D^0\bar{D}^0$$

The quantum number of $\psi''$ is $J^{PC} = 1^{--}$

∴ For a correlated state $C=-1$:

$$\hat{C}|D^0\rangle = |\bar{D}^0\rangle$$

$$\hat{C}|\bar{D}^0\rangle = |D^0\rangle$$

The correlated amplitude:

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

$D^0$ strong phase is necessary input for $D^0$ mixing and CKM measurements at B factories and LHCb

Z.Z. Xing, PRD55, 196(1997)
Measure $D^0$ mixing at threshold

Without mixing in $D^0$, the following process is forbidden due to Boson-Einstein statistics:

$$e^+e^- \rightarrow \psi(3770) \rightarrow D^0\bar{D}^0 \rightarrow (K^\pm\pi^\mp)(K^\pm\pi^\mp)$$

With mixing happened, it is allowed:

$$e^+e^- \rightarrow \psi(3770) \rightarrow D_H^0D_L^0 \rightarrow (K^\pm\pi^\mp)_H(K^\pm\pi^\mp)_L$$

At $\psi(3770)$ $R_M = (x^2 + y^2)/2$ can be measured using the ratios

$$R_M = \frac{N[D^0\bar{D}^0 \rightarrow (K^-\pi^+)(K^-\pi^+)]}{N[D^0\bar{D}^0 \rightarrow (K^-\pi^+)(K^-\pi^-)]}, \quad \frac{N[D^0\bar{D}^0 \rightarrow (K^-e^+\nu)(K^-e^+\nu)]}{N[D^0\bar{D}^0 \rightarrow (K^-e^+\nu)(K^+e^-\nu)]}$$

For $10^8$ D-pairs about 10 events will be detected. Sensitivity to $R_M$ is about $1 \times 10^{-4}$.

Expected sensitivity to mixing parameters:

1 $ab^{-1}$ at tau-charm factory = 10 $ab^{-1}$ at Super B-factory.
CPV in D decay at BESIII

Direct CP violation in D decays is expected to be small in SM.

For CF and DCS decays direct CP violation requires New Physics. Exception: \( D^\pm \to K_{S,L} \pi^\pm \) with \( A_{CP} = -3.3 \times 10^{-3} \).

For Singly Cabibbo Suppressed (SCS) decays SM CPV could reach \( 10^{-3} \).

\[ A_{CP} = \frac{\Gamma(D \to f) - \Gamma(\overline{D} \to \bar{f})}{\Gamma(D \to f) + \Gamma(\overline{D} \to \bar{f})} \]

At BESII, CP asymmetry can be tested with \( 10^{-3} \) sensitivity for many final states.

Belle: \( D^0 \to K^+K^-, \pi^+\pi^- \)
\[ A_{CP}(K^+K^-) = (0.43 \pm 0.30 \pm 0.11)\% \]
\[ A_{CP}(\pi^+\pi^-) = (0.43 \pm 0.52 \pm 0.12)\% \]

BABAR: \( D^+ \to K_S \pi^+ \)
\[ A_{CP}(K_S \pi^+) = (-0.44 \pm 0.13 \pm 0.10)\% \]

CLEO-c: \( K_S \pi^+\pi^0 \)
\[ A_{CP}(K_S \pi^+\pi^0) = (0.3 \pm 0.9 \pm 0.3)\% \]


Best limits:

June 15, 2011
Hai-Bo Li (IHEP)
CP violation near threshold

CP violating asymmetries can be measured by searching for events with two CP odd or two CP even final states:

\[ \pi^+\pi^-, K^+K^-, \pi^0\pi^0, \text{Ks}\pi^0, \]

for the decay of \( \psi'' \rightarrow D^0\bar{D}^0 \rightarrow f_1f_2 \)

\[ \text{CP}(f_1f_2) = \text{CP}(f_1) \cdot \text{CP}(f_2) \cdot (-1)^l = - \]

\[ \text{CP}(\psi'') = + \]

\[ A_{CP} \text{ sensitivity: } \Delta A \sim 10^{-3} \]

CP violation in mixing can be measured with:

\[ A_{SL} = \frac{\Gamma_{l^+l^+} - \Gamma_{l^-l^-}}{\Gamma_{l^+l^+} + \Gamma_{l^-l^-}} \approx \frac{1 - |q/p|^4}{1 + |q/p|^4} \]

With \( 10^8 \) D pairs in \((K^e^-\nu)(K^e^-\nu)\) mode, \(|q/p|\) can be measured with (15-20)% accuracy. Current world averaged value is \(0.86\pm0.16\).
**HFAG: new charm mixing with CLEO-c**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HFAG:FPCP2010</th>
<th>HFAG:CHARM2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y , (10^{-2})$</td>
<td>0.79 ± 0.13</td>
<td>0.83 ± 0.13</td>
</tr>
<tr>
<td>$x , (10^{-2})$</td>
<td>0.59 ± 0.20</td>
<td>0.55 ±0.12, -0.13</td>
</tr>
<tr>
<td>$r_{K\pi}^2 , (10^{-3})$</td>
<td>3.32 ± 0.08</td>
<td>3.32 ± 0.08</td>
</tr>
<tr>
<td>$\delta_{K\pi} , (^\circ)$</td>
<td>27.6 ±11.2, -12.2</td>
<td>31.0 ±10.7, -12.2</td>
</tr>
</tbody>
</table>

Consider CLEO-c results

**Surprising? Large impact on x uncertainty**
Project to $75 \text{ab}^{-1} \oplus Y(4S)$:

Golden channels

Uncertainties shrink: but are limited by the irreducible model uncertainty (biggest effect on $x_D$)

Strong phase measurement from $\psi(3770)$ can greatly reduce this.

$x_D = (5.5 \pm 1.3) \times 10^{-3}$

$y_D = (8.3 \pm 1.3) \times 10^{-3}$

$x_D = (xxx \pm 0.72) \times 10^{-3}$

$y_D = (xxx \pm 0.19) \times 10^{-3}$
The weak phase $\gamma (\Phi_3)$

Interference between tree-level decays; theoretically clean

Favored: $V_{cb} \ V_{us}^*$

$K(\star)$- Common final state

$D(\star)^0 \rightarrow f$ $\longleftrightarrow$ $\overline{D}(\star)^0$

$\frac{A(B^- \rightarrow \overline{D}^0 K^-)}{A(B^- \rightarrow D^0 K^-)} = r_B e^{i\delta} e^{-i\phi_3}$

Parameters: $\phi_3$, $(r_B, \delta)$ per mode

Three methods for exploiting interference (choice of $D^0$ decay modes):

- Gronau, London, Wyler (GLW): Use CP eigenstates of $D(\star)^0$ decay, e.g. $D^0 \rightarrow K_s \pi^0$, $D^0 \rightarrow \pi^+ \pi^-$

- Atwood, Dunietz, Soni (ADS): Use doubly Cabibbo-suppressed decays, e.g. $D^0 \rightarrow K^+ \pi^-$

- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body $D^0$ decays, e.g. $K_s \pi^+ \pi^-$
$B^{-} \rightarrow D(K_{s}h^{+}h^{-})K^{-}$ Dalitz plot for $\gamma$ at B factory

A powerful choice of common state $f(D)$ in $K_{s}h^{+}h^{-}$
Babar: PRL 105, 121801 (2010)
Belle: PRD 81, 112002 (2010)

Differents between $B^{-}$ and $B^{+}$ Dalitz plots allow $\gamma$ extracted in unbinned fit. However, need to understand different amplitudes from $D^{0}$ and $D^{0}$bar decay modes across Dalitz space, esp. variation in strong phase.

Approach of B factories: construct Dalitz plot model of D with flavor-tagged decays, estimated model uncertainty of 30-90, which is $\ll$ statistical error.

But super-B and LHC-b will start to be limited by this model uncertainty - Highly desirable to have precision model independent approach!

June 15, 2011
Hai-Bo Li (IHEP)
Binned Model-Independent Fit


\[ N_i^\pm = h(K_{\pm i}^+ + r_B^2 K_{\mp i}^- + 2\sqrt{K_{i}K_{-i}}(x_{\pm}c_i \pm y_{\pm} s_i)) \]

$\pm$: events in bin $i$ of Dalitz plot

Number of events for flavour-tagged D sample

$x_\pm = r_B \cos(\delta_B \pm \gamma)$

$y_\pm = r_B \sin(\delta_B \pm \gamma)$

$c_i, s_i$: average in bin of cosine, sine of strong phase $\delta_D$

Can be measured in quantum correlated decays at $\psi(3770)$!

Choosing bins of expected similar strong phase difference maximises statistical precision

Here take 8 bins of equal spacing in $\Delta\delta_D$ (using as reference model: BaBar, PRL 95 (2005) 121802)

Loss in statistical sensitivity w.r.t. unbinned result…(here ~20%) but no model error!

From Jim Libby CHARM2010


**CP-tagged Dalitz plots**

Clear difference between CP-even and CP-odd tagged Dalitz plots.

R. Briere et al., PRD 80 (2009) 032002
(model = BABAR PRL 95 (2005) 121802)

Projected uncertainty on $\gamma$ arising from uncertainty on $c_i$ & $s_i$ is $1.7^\circ$:
- Smaller than model error

**BESIII will reduce this error to less than 1^\circ**

June 15, 2011

Hai-Bo Li (IHEP)