The BESIII Experiment at BEPCII

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(for the BESIII Collaboration)
IHEP, Beijing

KEK, Mar. 8-10, 2012
Where is the experiment

2 days + 2 hour if one follows the google recommended travel plan.
Where is the experiment

IHEP, Beijing

45 kilometers = 1 hour by taxi, or 1.5 hours by subway
The Beijing Electron Positron Collider

Satellite view of IHEP, Beijing

- **LINAC**
- **BEPC** (Beijing electron-positron collider)
- **BESIII detector**
- **My office**
- **Main entrance to IHEP**

**Founded:** 1984, Ecm=2-5 GeV

- **1989-2005 (BEPC):**
  - $L_{\text{peak}} = 1.0 \times 10^{31} \text{ /cm}^2\text{s}$

- **2008-now (BEPCII):**
  - $L_{\text{peak}} = 6.5 \times 10^{32} / \text{cm}^2\text{s}$
The Beijing Electron Positron Collider

Founded: 1984, Ecm=2-5 GeV
1989-2005 (BEPC): $L_{\text{peak}}=1.0 \times 10^{31} \text{ /cm}^2\text{s at Ecm}=3.77 \text{ GeV}$
2008-now (BEPCII): $L_{\text{peak}}=6.5 \times 10^{32} \text{ /cm}^2\text{s at Ecm}=3.77 \text{ GeV}$
**BEPC II**: Large crossing angle, double-ring

- **Beam energy**: 1.0-2.3 GeV
- **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
- **SR mode**: 0.25A @ 2.5 GeV
BESIII Detector

Magnet yoke

TOF, 90ps

Be beam pipe

SC magnet, 1T

RPC

MDC, 130 µm
0.5% at 1 GeV/c

CsI(Tl) calorimeter, 2.5% @ 1 GeV

Total weight 730 ton,
~40,000 readout chnls,
Data rate: 5kHz, 50Mb/s
Luminosity since startup

Note that luminosity is lower at $J/\psi$, and machine is optimal near $\psi''$ peak.

about 4.0 fb$^{-1}$ @ different energies
Note increase in slopes!

2009: $\psi'$ & $J/\psi$

2010: $\psi''$

2011: $\psi''$ & $\psi(4040)$

2012: $\psi'$ & $J/\psi$
### BESIII [and BESII, CLEO-c] data

<table>
<thead>
<tr>
<th>Data</th>
<th>BESII</th>
<th>CLEOc</th>
<th>BESIII (2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/$\psi$</td>
<td>58 M</td>
<td>--</td>
<td>225 M (+1.0 B)</td>
</tr>
<tr>
<td>$\psi'$</td>
<td>14 M</td>
<td>26 M</td>
<td>106 M (+0.7B~1.0 B)</td>
</tr>
<tr>
<td>$\psi''$</td>
<td>0.033 fb$^{-1}$</td>
<td>0.818 fb$^{-1}$</td>
<td>2.9 fb$^{-1}$</td>
</tr>
<tr>
<td>$\psi(4040)$</td>
<td>-</td>
<td>0.006 fb$^{-1}$</td>
<td>0.5 fb$^{-1}$</td>
</tr>
<tr>
<td>Continuum</td>
<td>6.4 pb$^{-1}$ ($\sqrt{s}=3.65$ GeV)</td>
<td>21 pb$^{-1}$ ($\sqrt{s}=3.67$ GeV)</td>
<td>44 pb$^{-1}$ (+120 pb$^{-1}$) ($\sqrt{s}=3.65$ GeV)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>BESII</th>
<th>CLEOc</th>
<th>BESIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{p/p}$</td>
<td>1.7%/$\sqrt{1+p^2}$</td>
<td>0.6%@p=1GeV</td>
<td>0.5%@p=1GeV</td>
</tr>
<tr>
<td>$\sigma_{E/E}$</td>
<td>22%/$\sqrt{E}$</td>
<td>2.2%@E=1GeV</td>
<td>2.5%@E=1GeV</td>
</tr>
<tr>
<td>PartID</td>
<td>dE/dx+TOF</td>
<td>dE/dx+RICH</td>
<td>dE/dx+TOF</td>
</tr>
<tr>
<td>Coverage</td>
<td>80%</td>
<td>93%</td>
<td>93%</td>
</tr>
</tbody>
</table>
BESIII Physics Programs

- B (looks like DD for D or charm physics)
- E (looks like cc for charmonium physics)
- S (for light hadron Spectroscopy [+exotics])
- T (for tau physics, looks like a Roman number “III”)
Charm physics

- Decay constants
- Form factors and CKM matrix elements
- Strong phase and impact on $\phi_3$ measurements
- D mixing & CPV
- Rare decays

Charm cross section at $\psi''$ peak

- $D^+D^-$: ~2.8 nb; $\bar{D}^0D^0$: ~3.6 nb
- $N^{\text{prod}}$ in 2.9 fb$^{-1}$
- $N(D^+D^-):$ ~8 M; $N(\bar{D}^0D^0):$ ~10 M

No results yet!
Clean tagged charms

In 2.9 fb\(^{-1}\) data, we tagged 1.6M D\(^{+}\) and 2.7M D\(^{0}\)

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

Resolution:
- 1.3 MeV for pure charged modes;
- 1.9 MeV for modes with one \(\pi^0\).
Pure leptonic decays of $D^+$

$N_{\text{obs}}(D^+\rightarrow \mu^+\nu)\sim 400 \Rightarrow \sigma B/B\sim 5\%; \; \sigma f_D/f_D \sim 2.5\%

Statistical error limited, systematic error on $B \sim 1.5\%$ level

In $20 \text{ fb}^{-1}$ data, errors can be scaled by $1/2.6$

$N_{\text{obs}}(D^+\rightarrow \mu^+\nu)\sim 2700 \Rightarrow \sigma B/B\sim 2\%\pm 1.5\%; \; \sigma f_D/f_D \sim 1\%\pm 0.8\%

[f_D: \text{PDG: } \pm 4\%; \; \text{LQCD: } \pm 2\%]
Semi-leptonic decays of $D^0$

CLEOc with 818 pb$^{-1}$ data, ~ 1400 events  \( D^0 \rightarrow \pi^- e^+ \nu \)

BESIII with 2.9 fb$^{-1}$ data, ~ 6000 events
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 $|V_{cs}|$, $\sigma(|V_{cs}|)/|V_{cs}| \sim 1.1\% (\text{expt}) \oplus 2.5\% (\text{theory})$.

**CLEO-c**

(818 pb$^{-1}$) $0.963 \pm 0.009 \pm 0.006 \pm 0.024$

stat syst theory

CLEO-c: $\sigma(|V_{cd}|)/|V_{cd}| \sim 3.1\% (\text{expt}) \oplus 10\% (\text{theory})$.

\(\nu N\) remains most precise determination.

**CLEO-c**

(818 pb$^{-1}$) $0.234 \pm 0.007 \pm 0.002 \pm 0.025$

stat syst theory

Vcd will be improved at BESIII by a factor of 2 with 2.9 fb$^{-1}$. 
Semi-leptonic decays of $D^0$

- In 2.9 fb$^{-1}$ data, with 2.7M tagged $D^0$ events
  
  $N_{\text{obs}}(D^0 \rightarrow K^- e^+\nu) \sim 60k$
  
  $N_{\text{obs}}(D^0 \rightarrow \pi^- e^+\nu) \sim 6k$

Statistical error limited, systematic error on $B \sim 2\%$ level [CLEOc$\sim 1\%$]

- In 20 fb$^{-1}$ data, statistical errors negligible, systematic errors dominant, need to investigate how to reduce them
  
  (tracking, PID, bkg subtraction, $q^2$ smearing, FSR, …)

- Form factor measurement depends on parameterization.

- $V_{cs}$, $V_{cd}$ extraction limited by FF uncertainty from LQCD.

[Kaneko, this workshop]
4.17 GeV vs. 4.01 GeV:

\[
\sigma(\bar{D}_s D_s) = 0.27 \text{ nb} \quad @ \quad 4.01 \\
\sigma(\bar{D}_s D_s^*) = 0.92 \text{ nb} \quad @ \quad 4.17
\]

[Need to detect one additional low energy photon at 4.17 GeV]

Data taking in May 2011 for XYZ particle search & for \( D_s \) study!

BESIII took 0.5/fb data at 4.01 GeV!
Ds tag at BESIII

@ 4.01 GeV with ~0.5 fb⁻¹ data, single-tag sample:

- About 11k tagged Ds (44k at CLEOc at 4.17 GeV)
- f_{Ds} (both μ and τ modes) measurement underway
- Uncertainty dominated by statistics of the signal events
Decay constant of $D_s$

$$
\Gamma(D_{(s)} \rightarrow \ell \nu) = f_{D(s)}^2 |V_{cq}|^2 \frac{G_F^2}{8\pi} m_{D(s)} m_{\ell}^2 \left(1 - \frac{m_{\ell}^2}{m_{D(s)}^2}\right)^2
$$

There is less fun in $f_D$ since data agree with LQCD 😊

Will the ~1.6σ difference between data and LQCD persists?

Table 3. Expected errors on the branching fractions for leptonic decays and decay constants at the BES-III with 20 fb$^{-1}$ at ψ(3770) peak and $E_{CM} = 4170$ MeV, respectively.

<table>
<thead>
<tr>
<th>Observable</th>
<th>Error</th>
<th>Measurement</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$BR(D^+ \rightarrow \mu^+ \nu)$</td>
<td>2.0%</td>
<td>$f_D</td>
<td>V_{cd}</td>
</tr>
<tr>
<td>$BR(D^+_s \rightarrow \mu^+ \nu)$</td>
<td>2.0%</td>
<td>$f_{Ds}</td>
<td>V_{cs}</td>
</tr>
<tr>
<td>$BR(D^0 \rightarrow \mu^+ \nu)$</td>
<td>2.6%</td>
<td>$\frac{V_{cs} f_{Ds}}{V_{cd} f_D}$</td>
<td>1.3%</td>
</tr>
</tbody>
</table>

Decay constant of $D_s$

$\Delta f_{Ds}$ (MeV)

Will the ~10 MeV difference between data and LQCD persists?

1% in experiment $\oplus$ 1% in LQCD $\sim$ 3.5 MeV ($\sim3\sigma$ effect!)

$\bar{D}^0 D^0$ quantum correlation @ $\psi''$

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

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

The quantum number of $\psi''$ is $JPC=1-$ - -

∴ For a correlated state $C=-1$:

\[ \psi_- = \frac{1}{\sqrt{2}} \left( |D^0\rangle |\bar{D}^0\rangle - |\bar{D}^0\rangle |D^0\rangle \right) \]

The correlated decay rate is

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

By investigating the correlation between the $\bar{D}^0 D^0$ decays, the strong phase between Cabibbo Suppressed / Favored decays and $\bar{D}^0 D^0$ mixing/CPV information can be extracted.
• 20 fb\(^{-1}\) data at $\psi''$ peak [72M produced $\bar{D}^0D^0$]

• $D^0$ mixing: $R_M = (x^2+y^2)/2 \sim 10^{-4}$; $y \sim 0.003$

• CP violation in $D$ sector: $O(10^{-3})$

• Uncertainty of $\phi_3/\gamma$ due to unknown relative phase on Dalitz decay $\bar{D}^0/D^0 \rightarrow K_s h^+h^-$ will be reduced to less than 1 degree.
Without mixing in $D^0$, the following process is forbidden due to Boson-Einstein statistics, with mixing happened, it is allowed.

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

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

$$= \frac{N[D^0\bar{D}^0 \rightarrow (K^-e^+/\mu^+\nu)(K^-e^+/\mu^+\nu)]}{N[D^0\bar{D}^0 \rightarrow (K^-e^+/\mu^+\nu)(K^+e^-/\mu^-\nu)]}$$

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Events RS ($\times 10^4$)</th>
<th>Sensitivity $R_M$ ($\times 10^{-4}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\psi(3770) \rightarrow (K^-\pi^+)(K^-\pi^+)$</td>
<td>10.4</td>
<td>1.0</td>
</tr>
<tr>
<td>$\psi(3770) \rightarrow (K^-e^+\nu)(K^-e^+\nu)$</td>
<td>8.9</td>
<td></td>
</tr>
<tr>
<td>$\psi(3770) \rightarrow (K^-e^+\nu)(K^-\mu^+\nu)$</td>
<td>8.1</td>
<td>3.7</td>
</tr>
<tr>
<td>$\psi(3770) \rightarrow (K^-\mu^+\nu)(K^-\mu^+\nu)$</td>
<td>7.3</td>
<td></td>
</tr>
</tbody>
</table>

X.D. Cheng et al., PRD75, 094019 (2007)
For C=-1 initial $D^0\bar{D}^0$ state, $y$ can be expressed as function of double tag rates to lepton and CP eigenstate and single tag rate to CP eigenstate:

$$y = \frac{1}{4} \left( \frac{\Gamma_{l;f_+} \Gamma_{f_-}}{\Gamma_{l;f_-} \Gamma_{f_+}} - \frac{\Gamma_{l;f_-} \Gamma_{f_+}}{\Gamma_{l;f_+} \Gamma_{f_-}} \right)$$

$$\Delta(y) = \frac{\pm 26}{\sqrt{N(D^0\bar{D}^0)}} = \pm 0.003$$

Depends on assumed CP-tagging efficiency and BRs, but the uncertainty should not change much.
CP violation in mixing can be measured with:

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

With $10^8 \bar{D}D$ pairs in $(K^+\nu)(\bar{K}^+\nu)$ mode, $|q/p|$ can be measured with (20-30)% accuracy. Current world averaged value is $0.89 \pm 0.16$.
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: $D^\pm \rightarrow K_{S,L} \pi^\pm$ with $A_{CP} = -3.3 \times 10^{-3}$.

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

$$A_{CP} = \frac{\Gamma(D \rightarrow f) - \Gamma(\bar{D} \rightarrow \bar{f})}{\Gamma(D \rightarrow f) + \Gamma(\bar{D} \rightarrow \bar{f})}$$

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

Y. Grossman et al
PRD75, 036008(2007)
The weak phase $\phi_{3/\gamma}$

Interference between tree-level decays; theoretically clean

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 $D^{(*)0}$ decay, e.g. $D^0 \to K_s\pi^0$, $D^0 \to \pi^+\pi^-$

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

- Giri, Grossman, Soffer, Zupan (GGSZ) / Belle: Use Dalitz plot analysis of 3-body $D^0$ decays, e.g. $K_s\pi^+\pi^-$
B⁻→D(K⁺h⁻)K⁻ Dalitz plot for \( \phi_3/\gamma \) 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 \( \phi_3/\gamma \) extracted in unbinned fit. However, need to understand different amplitudes from \( D^0 \) and \( \bar{D}^0 \) decay modes across Dalitz space, esp. variation in strong phase.

B⁻\( \rightarrow (D \rightarrow K^0_S \pi^+ \pi^-)K^- \)

B⁺\( \rightarrow (D \rightarrow K^0_S \pi^+ \pi^-)K^+ \)

B factories: construct Dalitz plot model of D with flavor-tagged decays, estimated model uncertainty of 3-9 degrees, which is \( \ll \) statistical error. But super-B and LHCb will start to be limited by this model uncertainty – Highly desirable to have precision model independent approach!
CP-tagged Dalitz plots of $D^0 \rightarrow K^0_S \pi^+ \pi^-$

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

818 pb$^{-1}$

$\psi''$ data at CLEOc
CLEOc: PRD82, 112006 (2010)

- Different binning causes different results!
- Projected uncertainty on $\phi_3/\gamma$ varies from 1.7 to 3.9°!
- Bias at O(1°) level is observed!

→ Low statistics in each bin!

BESIII will reduce this error to less than 1°!
Sensitivities for rare charm decay

- $D \rightarrow V\gamma$ will be reached at $10^{-6}$
- $D^0 \rightarrow \phi\gamma$, $K^*\gamma$ will be confirmed and improved
- $D^0 \rightarrow \rho\gamma$, $\omega\gamma$ will be improved or found
- $D^0 \rightarrow \gamma\gamma$ can be measured with tag or without tag
  - the sensitivity will be $10^{-6}$
- $D \rightarrow X l^+ l^-$ can be reached at $10^{-6}$
  - BESIII will reach contribution from long distance
- $D^0 \rightarrow l^+ l^-$ will be reached at $10^{-6}$  \[<10^{-8} \; @\text{LHCb: this workshop}\]
- $D^+ \rightarrow e^+\nu : 10^{-6}$ (SM: $10^{-8}$)

We really donot have that much compared with LHCb (LHCc?).
Charmonium physics
Charmonium + XYZ states

What are they?

- Charmonium?
- Hybrid?
- Tetraquark?
- Molecule?

• Below \( \bar{D}D \) threshold: spin-singlets, decay properties
• Above \( \bar{D}D \) threshold: excited \( \psi \)s, XYZ states, decay properties

\( Z(4430) \)
\( Z(4250) \)
\( Z(4050) \)
\( X(3872) \)
\( XYZ(3940) \)
\( X(3915) \)
\( X(4160) \)
\( Y(4008) \)
\( Y(4140) \)
\( Y(4260) \)
\( Y(4360) \)
\( X(4350) \)
\( Y(4660) \)
\[ \psi(2S) \rightarrow \pi^0 h_c \] transition

Combined inclusive and E1-photon-tagged spectrum

\[ B(\psi' \rightarrow \pi^0 h_c) = [8.4 \pm 1.3 \text{ (stat.)} \pm 1.0 \text{ (syst.)}] \times 10^{-4} \]

\[ B(h_c \rightarrow \gamma \eta_c) = [54.3 \pm 6.7 \text{ (stat.)} \pm 5.2 \text{ (syst.)}] \% \]

BESIII: PRL 104, 132002 (2010)
Mass: 3525.40 ± 0.13 ± 0.18 MeV
Width: 0.73 ± 0.45 ± 0.28 MeV
(<1.44 MeV @ 90% C.L.)

Mass: 3525.28 ± 0.19 ± 0.12 MeV
Width: fixed to 0.9 MeV

\[ \Delta M_{hf} = <M(^3P_J)> - M(^1P_J) \]
Agrees with zero within ~0.5 MeV

Information on spin-spin interaction.

Agree with predictions of Kuang, Godfrey, Dudek, et al.
$\psi(2S) \rightarrow \pi^0 h_c$, 16 $\eta_c$ exclusive decays

Simultaneous fit to $\pi^0$ recoiling mass

$M(h_c) = 3525.31 \pm 0.11 \pm 0.15$ MeV/c$^2$

$\Gamma(h_c) = 0.70 \pm 0.28 \pm 0.25$ MeV

$N = 832 \pm 35$

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

Consistent with CLEO-c exclusive

$M(h_c) = 3525.21 \pm 0.27 \pm 0.14$ MeV

$N = 136 \pm 14$

PRL101, 182003(2008)

BESIII preliminary
\( \eta_c \), the lightest charmonium state

**PDG (2010)**

**Weighted Average**

- **Mass**
  - \( \chi^2 = 1.3 \)
  - Entries: 10 BABR, 8 BELL, 8 BES, 3 BAI
  - Confidence Level: 0.99 (8)

- **Width**
  - \( \chi^2 = 4.6 \)
  - Entries: 10 BABR, 8 BELL, 6 BES, 5 BAI
  - Confidence Level: 0.99 (8)

**Lineshape**

- **Asymmetric**
  - \( \eta_c \rightarrow J/\psi(1S) \rightarrow \gamma\eta_c(1S) \)

- **Symmetric**
  - \( \gamma\gamma \rightarrow \eta_c(1S); \eta_c(1S) \rightarrow K\bar{K}\pi \)
Simultaneous fit with modified Breit-Wigner (hindered M1) with considering interference between $\eta_c$ and non-$\eta_c$ decays.

arXiv:1111.0398, submitted to PRL
Mass and Width of $\eta_c$

Mass = $2984.3 \pm 0.6_{\text{stat}} \pm 0.6_{\text{syst}}$ MeV/c$^2$

Width = $32.0 \pm 1.2_{\text{stat}} \pm 1.0_{\text{syst}}$ MeV

$\phi = 2.40 \pm 0.07_{\text{stat}} \pm 0.08_{\text{syst}}$ rad or $4.19 \pm 0.03_{\text{stat}} \pm 0.09_{\text{syst}}$ rad

World average in PDG2010 uses earlier measurements.

arXiv:1111.0398, submitted to PRL
Observation of $\psi' \rightarrow \gamma \eta'_c$

- $N(\eta_c(2S)) = 50.6 \pm 9.7$
- Pure statistical significance more than 6$\sigma$
- Significance with systematic variations not less than 5$\sigma$
- $\chi^2$/ndf=0.9

- $\eta_c(2S)$ signal: modified BW (M1) with fixed width (Resolution extrapolated from $\chi_{cJ}$)
- $\chi_{cJ}$ signal: MC shape smeared with Gaussian
- BG from $e^+ e^- \rightarrow K_s K\pi$ (ISR), $\psi' \rightarrow K_s K\pi$ (FSR), $\psi' \rightarrow \pi^0 K_s K\pi$: are measured from data

BESIII preliminary
Preliminary results on $\psi' \rightarrow \gamma \eta_c' \rightarrow \gamma KsK\pi$

$\mathcal{M}(\eta_c') = 3638.5 \pm 2.3 \text{stat} \pm 1.0 \text{sys} \text{ (MeV/c}^2\text{)}$

$\mathcal{B}(\psi' \rightarrow \gamma \eta_c' \rightarrow \gamma KsK\pi) = (2.98 \pm 0.57 \text{stat} \pm 0.48 \text{sys}) \times 10^{-6}$

$\mathcal{B}(\eta_c(2S) \rightarrow KK\pi) = (1.9 \pm 0.4 \pm 1.1)\% \text{ from BaBar}$

$\mathcal{B}(\psi' \rightarrow \gamma \eta_c') = (4.7 \pm 0.9 \text{stat} \pm 3.0 \text{sys}) \times 10^{-4}$

CLEO-c: $<7.6 \times 10^{-4}$ \hspace{1cm} (PRD81,052002(2010))

Potential model: $(0.1-6.2) \times 10^{-4}$ \hspace{1cm} (PRL89,162002(2002))

BESIII preliminary
Production Rates of XYZ at BESIII

- No theoretical calculation on $\psi(3S) \rightarrow \gamma + XYZ$ if they are exotic states [neither on $\psi(2D)$, $\psi(4S)$]

- Assuming $M(\chi_{cJ}(2P)) \sim 3930$ MeV
  - $B(\psi(3S) \rightarrow \gamma \chi'_{cJ}) = (7, 3, 1) \times 10^{-4}$ for $J=2,1,0$

  E. Eichten et al., Rev. Mod. Phys. 80, 1161 (2008)]

- As masses of the $\chi_{cJ}(2P)$ states are very different from the expectation of the potential models. S-D mixing will also affect the predictions. BRs could be very different.

- Can we observe the $X(3872)$ if it is the $\chi'_{c1}$ and the production rate is $3 \times 10^{-4}$?
BESIII took 0.5/fb data at 4010 MeV!

4.04 GeV vs. 4.01 GeV:
- No D*D*
- bkg for X3872 → DD*
- More Ds!
- Chance for f_{Ds} meas.
- Data taking in May 2011!
Light hadrons: normal & exotic

- Hadrons are composed from 2 (meson) or 3 (baryon) quarks

Quark model

- QCD allows hadrons with $N_{\text{quarks}} \neq 2, 3$
  - glueball: $N_{\text{quarks}} = 0$ (gg, ggg, …)
  - hybrid: $N_{\text{quarks}} = 2$ or more + excited gluon
  - Multiquark state: $N_{\text{quarks}} > 3$
  - molecule: bound state of more than 2 hadrons
Enhancement at ppbar threshold

- Observed at BESII in 2003
  - PRL91, 022001
  - $M=1861^{+3}_{-10}^{+5}_{-25}$ MeV
  - Width < 38 MeV (90% CL)
  - Agree with spin zero expectation
- Confirmed at BESIII (& CLEOc)
  - $M=1861.6^{±0.8}$ (stat.) MeV
  - Width<8 MeV @ 90% C.L.
  - $M=1859^{+6}_{-13}^{+7}_{-26}$ MeV
  - Width < 30 MeV (90% CL)
- Many possibilities:
  - Normal meson?
  - ppbar bound state/ multiquark/ glueball/ …
Partial wave analysis of $J/\psi \rightarrow \gamma p \bar{p}$

$J^{PC} = 0^{-+}$  

FSI correction from A. Sirbirtsen et al., PRD 71, 054010 (2005)

\[
M = 1832^{+19}_{-5} \text{ (stat.)}^{+18}_{-17} \text{ (syst.)} \pm 19 \text{ (model) MeV/c}^2
\]

\[
\Gamma = 13 \pm 39 \text{ (stat.)}^{+10}_{-13} \text{ (syst.)} \pm 4 \text{ (model) MeV/c}^2, \ (\lesssim 76 \text{ MeV/c}^2)
\]

\[
BB = (9.0^{+0.4}_{-1.1} \text{ (stat.)}^{+1.5}_{-5.0} \text{ (syst.)} \pm 2.3 \text{ (model)}) \times 10^{-5}
\]

FSI changes mass from 1861 MeV to 1832 MeV!
More states decay into $\eta'\pi^+\pi^-$

- $X(1835)$ at BESII
- Confirmed at BESIII, width much larger
- Two more peaks!!
- JP unknown, need PWA
- Nature?
  - $X_{1835}=X_{1859}=\bar{pp}$ bound state?
  - Pseudoscalar glueballs?
  - Excited $\eta$ or $\eta'$ states?
  - ...

<table>
<thead>
<tr>
<th>State</th>
<th>$X(1835)$</th>
<th>$X(2120)$</th>
<th>$X(2370)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (MeV)</td>
<td>$1836.5^{+3.0}_{-2.1}$</td>
<td>$2122.4^{+6.7}_{-2.7}$</td>
<td>$2376.3^{+8.7}_{-4.3}$</td>
</tr>
<tr>
<td>Width (MeV)</td>
<td>$190^{+38}_{-36}$</td>
<td>$83^{+16}_{-11}$</td>
<td>$83^{+17}_{-6}$</td>
</tr>
</tbody>
</table>

BESII $X(1835)$: $M = 1833.7 \pm 6.1 \pm 2.7$ MeV/c$^2$
$\Gamma = 67.7 \pm 20.3 \pm 7.7$ MeV/c$^2$

PRL106, 072002 (2011)
States in $J/\psi \rightarrow \omega \eta \pi^+ \pi^-$

- Fitting with three resonances (acceptance weighted BWxGaussian)
- Background component described by Polynomial function

$\eta(1405)$  $f_1(1285)$  $X(1870): 7.2\sigma$

1. Contribution from non-$\omega$ and/or non-$a_0(980)$ BG events
2. Contribution from $J/\psi \rightarrow b_1(1235)a_0(980)$
3. Contribution from “PS” process of $J/\psi \rightarrow \omega a_0(980)\pi$

<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>$1285.1 \pm 1.0^{+1.6}_{-0.3}$</td>
<td>$22.0 \pm 3.1^{+2.0}_{-1.5}$</td>
<td>$1.25 \pm 0.10^{+0.19}_{-0.20}$</td>
</tr>
<tr>
<td>$\eta(1405)$</td>
<td>$1399.8 \pm 2.2^{+2.8}_{-0.1}$</td>
<td>$52.8 \pm 7.6^{+0.1}_{-7.6}$</td>
<td>$1.89 \pm 0.21^{+0.21}_{-0.23}$</td>
</tr>
<tr>
<td>$X(1870)$</td>
<td>$1877.3 \pm 6.3^{+3.4}_{-7.4}$</td>
<td>$57 \pm 12^{+19}_{-4}$</td>
<td>$1.50 \pm 0.26^{+0.72}_{-0.36}$</td>
</tr>
</tbody>
</table>

arXiv: 1107.1806
PRL107, 182001 (2011)
$\eta(1405) \to f_0(980)\pi^0$ in $J/\psi \to \gamma\pi\pi\pi$

- Observed in two modes, $\eta(1405)$ mass and width agree with PDG
- Large Isospin-violating decay rate, $B(f_0\pi^0)/B(a_0\pi^0) \sim 18\%$
- A possible explanation is KK*(K) loop, triangle singularity (Wu, Liu, Zhao, Zou, PRL 2012)

$f_1(1285)/\eta(1295)$  \hspace{2cm} $\eta(1405)$

$\Gamma \sim 10\text{ MeV}!$
\( \tau \) mass

\begin{align*}
M_\tau &= 1776.96^{+0.18+0.25}_{-0.21-0.17} \text{ MeV} \\
\sigma M_\tau / M_\tau &= 1.7 \times 10^{-4} \\
\text{PDG10: } &1776.82\pm0.16 \text{ MeV}
\end{align*}

BESI results: stat. err. \( (0.18 / 0.21) \) is compatible with syst. \( (0.25 / 0.17) \)
Compton backscattering technique, accuracy up to $5 \times 10^{-5}$

Total systematic uncertainty on beam energy measurement can reach 90 keV
Relative error:

Meas.: $4.6 \times 10^{-5}$

Design: $5 \times 10^{-5}$

$^{137}$Cs: $E_\gamma = 661.657$ keV, $\sigma E_\gamma = 4.54 \times 10^{-6}$

$^{60}$Co: $E_\gamma = 1332.492$ keV, $\sigma E_\gamma = 3.01 \times 10^{-6}$

$^{232}$Th: $E_\gamma = 2614.533$ keV, $\sigma E_\gamma = 4.98 \times 10^{-6}$

Pu-C: $E_\gamma = 6128.63$ keV, $\sigma E_\gamma = 6.53 \times 10^{-6}$

$E_{edge} = 6217.137 \pm 0.568$ keV

$\sigma_{E_{edge}} = 6.97 \pm 0.93$ keV

$E_{beam} = 1886.478 \pm 0.086$ MeV

$\sigma_{E_{beam}} = 1058.0 \pm 140.6$ keV
$\Delta m = 17 \pm 50$ keV
Accuracy: $2 \times 10^{-5}$
Beam spread: $1.65 \pm 0.04$ MeV

- No efficiency correction
- Cross section in arbitrary unit

Published in NIMA 659, 21 (2011)
τ Mass measurement in 2012

Data at 4 energy points were taken, ~5 pb\(^{-1}\) at the τ threshold

Expect statistical precision is ±0.3 MeV, systematic error <0.1 MeV

More data expected in 2012 to reduce statistical precision to 0.1 MeV
Summary

- BEPCII has reached 2/3 of its designed luminosity goal of $10^{33}$/cm$^2$/s.
- BESIII was running very well and has accumulated world largest data samples at $J/\psi$, $\psi'$, $\psi''$, and $\psi(4040)$ peaks.
- Lots of results have been published and more to come soon (esp. on charm)!

Thanks a lot!
backup
BEPC Energy Measurement System

\[ 5 \times 10^{-5} \]

- **Income laser**
- **Backscattering laser**

North
Charm Physics: CKM matrix

20 fb\(^{-1}\) \( \bar{D}D \) pairs at \( \psi(3770) \) and 20 fb\(^{-1}\) \( D_s(\ast)^+D_s(\ast)^- \) pairs at \( \psi(4040) \) or \( \psi(4160) \) for high precision charm physics.

The Goal: Measure all CKM matrix elements and associated phases in order to over-constrain the unitary triangles.