Charm in China: BEPCII/BESIII

University of Michigan
HEP Seminar
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University of Hawaii
OUTLINE

• Introduction: physics of tau charm region
• BEPCII
• BESIII
• $\psi(2S)$ (very) preliminary results
• Beam energy measurement
• BESIII physics
• Summary

Thanks to Yifang Wang (LP09 talk)
The Beijing Electron Positron Collider (BEPC)

BESII

CM Energy ranges from 2 to 5 GeV
Luminosity at J/ψ ~ 5 x 10^{30} cm^{-2} s^{-1}

Beijing, China

BESII detector removed in 2004.
Revival of Interest in Charm Physics

- Evidence for unexpectedly large $D^0 \bar{D}^0$-bar mixing in B factory experiments.
  - {BaBar, PRL98, 211802 (2007); Belle, PRL98, 211803 (2007)}

- A $2.3\sigma$ discrepancy between the world average $f_{D_s} = 259.5 \pm 7.3$ MeV and the precision lattice QCD $f_{D_s} = 241 \pm 3$ MeV from the HPQCD-HISQ Collaboration.
  - {see CLEOc: PRD79, 052001 & 052002 (2009)}

- Many new charmonium-like states, the XYZ mesons, that do not fit into the traditional quark model.
• Light hadron spectroscopy.
• Charmonium: $J/\psi$, $\psi(2S)$, $\eta_c(1S)$, $\chi_c(0,1,2)$, $\eta_c(2S)$, $h_c(1P_1)$, $\psi(1D)$, etc.
• New Charmonium states above open charm threshold ($X$, $Y$, $Z$).
• Exotics: hybrids, glueballs, and other exotics in $J/\psi$ and $\psi(2S)$ radiative decays.
• Baryons and excited baryons in $J/\psi$ and $\psi(2S)$ hadronic decays.
• Mesons and mixing of quarks and gluons in $J/\psi$ and $\psi(2S)$ decays.
• Electromagnetic form factors and QCD cross section ($R$ values).
• Tau and charm physics near the threshold. High precision measurements.
• Flavor physics complementary to LHC.

Tremendous variety:
Physics of tau – charm region

- Open charm factory:
  - Absolute BR measurements of D and Ds decays
  - Rare D decay
  - D⁰ - D⁰bar mixing
  - Quantum correlations ($\psi''$)
  - CP violation, strong phase.
  - $f_{D+}, f_{Ds}$, form factors in leptonic D decays
  - Can provide calibrations and tests of lattice QCD.
  - Precise measurement (~1.6%) of CKM (Vcd, Vcs)
  - Light meson spectroscopy in D⁰ and D⁺ Dalitz plot analyses.
  - Search for new physics.

Very rich and interesting energy region.
BES Highlights:

- BESI tau mass measurement:

\[ m_\tau = 1776.96^{+0.18}_{-0.21} \pm 0.25 \text{ MeV}/c^2 \]


- 10X better precision
BESI -- Tau mass measurement

- Lifetime, leptonic branching ratio, and mass are related in Standard Model:

\[ \Gamma(\tau \rightarrow e\nu_\tau\bar{\nu}_e) = \frac{B(\tau \rightarrow e\nu_\tau\bar{\nu}_e)}{\tau(\tau \rightarrow e\nu_\tau\bar{\nu}_e)} = \frac{G_F^2 m_\tau^5}{192\pi^3} F_{\text{cor}}(m_\tau, m_e) \]

Status 1992 (2.4 \(\sigma\)) and 1994 (1.3 \(\sigma\))

Status 2006

A. Pich, Charm06 talk

1992

1994
BESII: R

BES reduces R errors from 15 - 20 % to an average of 6% in the 2 - 5 GeV region. Important region!

\[ R = \frac{\sigma(e^+e^- \rightarrow \text{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} \]

Before BES R Scan

PRL 84, 594 (2000).
PRL 88, 101802 (2002).
83 + 189 citations

After BES R Scan

PRL 84, 594 (2000).
PRL 88, 101802 (2002).
83 + 189 citations
**R measurement**

- Needed to improve precision of $\alpha(M_Z^2)$:
  - Uncertainties in $\alpha$ introduced when it is extrapolated to the Z-pole:
    
    $$\alpha(q^2) = \frac{\alpha_0}{1 - \Delta\alpha(q^2)}$$
    
    $$\Delta\alpha(q^2) = \Delta\alpha_l(q^2) + \Delta_{\text{had}}^{(5)}\alpha(q^2) + \Delta_{\text{top}}\alpha(q^2)$$
  
  - Dominant uncertainty due to hadronic vacuum polarization.
  - This is determined from R values using a dispersion relation.

- The Higgs mass determined from radiative corrections in the SM is very sensitive to $\alpha(M_Z^2)$.
SM Fit to $m_H$

Data from tau-charm mass region important for standard model fits.

$m_H = 62^{+53}_{-30}$ GeV

$m_H < 170$ GeV (95% C.L.)

$m_H = 98^{+58}_{-38}$ GeV

$m_H < 212$ GeV (95% C.L.)

Latest R result:

BES, PLB 677, 239 (2009).

error ~ 4%
Threshold enhancement in $J/\psi \rightarrow \gamma p \overline{p}$

- **BESII**: enhancement seen near threshold in $M_{pp}$ in $J/\psi \rightarrow \gamma p \overline{p}$.

- If fitted with an $S$-wave resonance:
  
  $M = 1859^{+3}_{-10}^{+5}_{-25}$ MeV/c²
  
  $\Gamma < 30$ MeV/c² (90% CL)


156 citations

“The BES Particle”

Klempt: Glueballs, Hybrids, and Pentaquarks
pp bound state (baryonium)?

There is lots & lots of literature about this possibility:

E. Fermi, C.N. Yang, Phys. Rev. 76, 1739 (1949)


M.L. Yan et al., hep-ph/0405087

B. Loiseau et al., hep-ph/0411218

loosely bound 3-q 3-q color singlets with $M_d = 2m_p - \varepsilon$

loosely bound 3-q 3-q color singlets with $M_b = 2m_p - \delta$?
Observation of a new 1−− resonance $Y(2175)$ at BaBar

- A structure at 2175 MeV was observed in
  \[ e^+e^- \rightarrow \gamma_{\text{ISR}} f_0(980), \]
  \[ e^+e^- \rightarrow \gamma_{\text{ISR}} K^+K^- f_0(980) \]

\[ M = 2175 \pm 10 \pm 15 \text{ MeV} \]
\[ \Gamma = 58 \pm 16 \pm 20 \text{ MeV} \]

Speculation: may be $s\bar{s}$-bar version of $Y(4260)$ since 1−− and similar decay. [BaBar PRL95, 142001 (2005).]
BESII

$J/\psi \rightarrow \eta \phi f_0(980)$

$\Upsilon(2175)$

58 $M$ $J/\psi$

Final states:

$\eta \rightarrow \gamma \gamma$, $\phi \rightarrow K^+K^-$, $f_0(980) \rightarrow \pi^+\pi^-$

Simultaneous fit to signal and sideband events with single BW + p3

$B(J/\psi \rightarrow \eta \Upsilon(2175)) \cdot B(\Upsilon(2175) \rightarrow \phi f_0(980)) \cdot B(f_0(980) \rightarrow \pi^+\pi^-) = (3.23 \pm 0.75 \pm 0.73) \times 10^{-4}$

$M(\phi f_0(980))$ GeV/c$^2$

<table>
<thead>
<tr>
<th></th>
<th>Mass (GeV/c$^2$)</th>
<th>Width (GeV/c$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BES</td>
<td>2.186$\pm$0.010$\pm$0.006</td>
<td>0.065$\pm$0.023$\pm$0.017</td>
</tr>
<tr>
<td>BABAR</td>
<td>2.175$\pm$0.010$\pm$0.015</td>
<td>0.058$\pm$0.016$\pm$0.020</td>
</tr>
</tbody>
</table>

BES, PRL 100, 102003 (2008).
The future of BEPC

• Decision to build BEPC in the early 1980s was a great success:
  - Rich physics results:
    • A total of ~120 papers in PRL, PRD, PLB, etc.
    • A total of ~300 entries in the Particle Data Book.
    • Several highlights well known to the community.
  - Established foundation of particle physics and its related technology in China.
  - Started the era of synchrotron radiation studies in China.
  - Technology transfer.

• In the 1990s, there was discussion of the future. The conclusion was to continue tau-charm physics with a major upgrade of the accelerator and detector (BEPCII/BESIII).

• The physics window is precision charm physics and the search for new physics.
  - High statistics: high luminosity machine + high quality detector.
  - Small systematic error: high quality detector.
History

1979  First US/PRC HEP meeting
1984  BEPC approved
1988  first electron positron collisions
1991  US/China BESI Collaboration formed
1992  tau mass measurement published
1995/96 BESII Upgrade
1998/99 R Scan (91 energy points)
2000/01 J/psi data (58 M)
2002  psi’ data (14M)
2003  BEPCII/BESIII approved
2006  BESIII collaboration formed
2008  First event in BESIII
BESIII collaboration

US (6)
- Univ. of Hawaii
- Univ. of Washington
- Carnegie Mellon Univ.
- Univ. of Minnesota
- Univ. of Rochester
- Univ. of Indiana

EUROPE (8)
- Germany: Univ. of Bochum, Univ. of Giessen, GSI
- Russia: JINR, Dubna; BINP, Novosibirsk
- Italy: Univ. of Torino, Frascati Lab
- Netherland: KVI/Univ. of Groningen

Korea (1)
- Seoul Nat. Univ.

Japan (1)
- Tokyo Univ.

Pakistan (1)
- Univ. of Punjab

China (26)
- IHEP, CCAST, Shandong Univ., Univ. of Sci. and Tech. of China
- Zhejiang Univ., Huangshan Coll.
- Huazhong Normal Univ., Wuhan Univ.
- Zhengzhou Univ., Henan Normal Univ.
- Peking Univ., Tsinghua Univ.
- Zhongshan Univ., Nankai Univ.
- Shanxi Univ., Sichuan Univ.
- Hunan Univ., Liaoning Univ.
- Nanjing Univ., Nanjing Normal Univ.
- Guangxi Normal Univ., Guangxi Univ.
- Hong Univ., Hong Kong Chinese Univ.

~ 300 collaborators
BEPCII: a high luminosity double-ring collider

- 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: 0.25 A @ 2.5 GeV

Use many bunches and SC mini-beta.

22 mrad crossing angle
BEPCII/BESIII Commissioning

Mar. 2008: Collisions at 500 mA × 500 mA, Lumi.: 1 ×10^{32} cm^{-2}s^{-1}
Apr. 30, 2008: Move BESIII to IP
July 18, 2008: First e^+e^- collision event in BESIII
Nov. 2008: Lumi. ~ 1.2 × 10^{32}cm^{-2}s^{-1}, BESIII ~ 10M ψ(2S) events
Apr. 14, 2009 BESIII ~100M ψ(2S) events
May 14, 2009 BEPCII Lumi. ~ 3 × 10^{32}cm^{-2}s^{-1}
July 28, 2009 ~200 M J/ψ events

May 15, 2008: detector at IP; installing SC quads and beam pipe.
Peak Luminosity of $3.0 \times 10^{32}$ achieved on May 13 with $\sim 2 \times 500\text{mA}$ and 71 bunches
Parameters achieved in collision mode

| parameters                  | design | Achieved |
|                            |       | BER | BPR  |
| Energy (GeV)                | 1.89  | 1.89| 1.89 |
| Beam curr. (mA)             | 910   | 650 | 700  |
| Bunch curr. (mA)            | 9.8   | >10 | >10  |
| Bunch number                | 93    | 93  | 93   |
| RF voltage                  | 1.5   | 1.5 | 1.5  |
| $\nu_s$ @1.5MV              | 0.033 | 0.032| 0.032|
| $\beta_x^*/\beta_y^*$ (m)  | 1.0/0.015| ~1.0/0.016| ~1.0/0.016|
| Inj. Rate (mA/min)          | 200 e⁻/ 50 e⁺ | >200 | >50  |
| Lum. (10³³ cm⁻² s⁻¹)        | 1     | 0.30|
MDC

Parameters

R inner: 63mm ; R outer: 810mm
Length (out.): 2582 mm
Inner cylinder: 1.2 mm Carbon fiber
Outer cylinder: 11.5 mm CF with 8 windows
Sense wire: 25 micron gold-plated tungsten (plus 3% Rhenium) -- 6796
Layers (Sense wire): 43 (19 axial, 24 stereo)

Field wire: 110 micron gold-plated Aluminum --- 21884
Gas: He + C₃H₈ (60/40)
Cell: inner chamber --- 6 mm
    outer chamber --- 8.1 mm
Polar angle: |cos θ| < 0.83 (all layers) < 0.93 (20 layers)

Expected performance

\[ \sigma_x \sim 130 \, \mu m \]
\[ \frac{\sigma_P}{P} \sim 0.5 \% \text{ @1GeV/C} \]
\[ \frac{dE}{dx} \sim 6 \% \]
MDC construction
MDC wiring
$\Psi(2s)$ data

MDC calibration

Bhabhas

Resol. 136 mm

$\sigma_p = 14.6\text{MeV}/c$

$= 0.79\%$

Bhabhas

dE/dx resol. = 5.1\%

Bhabhas

HPCMS

$\pi$

$\eta$

K

P

Pulse Height versus Momentum

Entries

137691

Mean

1.827

RMS

0.4415

Constant

9767 ± 42.3

Mean

1.846 ± 0.000

Sigma

0.01463 ± 0.00005

Entries

133319

Mean

301.1

RMS

28.96

$\chi^2$/ndf

795.1 / 89

Constant

9906 ± 34.2

Mean

650.9 ± 0.1

Sigma

20.04 ± 0.08
CsI(Tl) crystal calorimeter

- Design goals:
  - Energy: 2.5% @ 1 GeV
  - Energy range: 20 MeV - 2 GeV
  - Spatial: 0.6 cm @ 1 GeV

- Crystals:
  - $L = 28 \text{ cm} (15 \ X_0)$
  - $A = (5.2 \times 5.2 - 6.4 \times 6.4) \text{ cm}^2$
  - Barrel: 5280 w: 21564 kg
  - Endcaps: 960 w: 4051 kg
  - Total: 6240 w: 25.6 T

BaBar: 2.2% @ 1 GeV
BELLE: 2.2% @ 1 GeV
CLEO: 2.2% @ 1 GeV
CsI(Tl) crystal calorimeter

- **Readout:**
  - 2 PDs + 2 preamps + 1 amp
  - PD: Hamamatsu S2744-08
  - 12480 PDs total (1 cm × 2 cm)
  - Preamp noise: < 220 keV
Structure of EMC

Barrel EMC

Super module

Structure of endcap EMC

Endcap EMC
EMC calibration

- **Barrel energy resolution**
- **Energy deposit for $e^+e^- \rightarrow \gamma\gamma$**: 2.7%
- **Energy resolution for Bhabhas**
- **Position resolution for Bhabhas**: 4.4 mm
Crucial for particle ID and for fast trigger.

- **Barrel**
  - 50mm x 60mm x 2320 mm (inner layer).
  - BC408
  - 2 layers - 88 in each
  - Radius from 810 to 930 mm.
- **Endcap**
  - 48 fan shaped pieces - each end.
  - BC404
- **PMT:** Hamamatsu R5942
  - fine mesh
  - 2 on each barrel scintillator
  - 1 on each endcap counter
- **Resolution**
  - **Barrel:** $\sigma_T = 100$ ps (one layer)
  - **Endcap:** $\sigma_T = 110$ ps

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Length (cm)</th>
<th>Resolution</th>
</tr>
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<tbody>
<tr>
<td>BESIII</td>
<td>240</td>
<td>90 ps</td>
</tr>
<tr>
<td>BELLE</td>
<td>255</td>
<td>90~100 ps</td>
</tr>
<tr>
<td>CDFII</td>
<td>279</td>
<td>100 ps</td>
</tr>
</tbody>
</table>
Structure of TOF

Barrel TOF

Endcap TOF
TOF calibration - Bhabhas

Barrel time resol. (ps) vs. z (cm)

- TOF Barrel single layer: 98 ps
  - Design: 100 ps

Endcap time resol. vs R (cm)

- Endcap TOF: 125 ps
  - Design: 110 ps

Resol.: 100 ps

Dimu

Endcap Bhabha
TOF – MC Comparison

![Graph showing beta vs. P(GeV) with different particle markers: pi, K, p, e, mu.](image-url)
Monitor the amplitude and time performance of each channel including PMTs and electronics.

Concept:
- Use fiber cable bundles (2 cables) to distribute light to barrel and endcap TOF counters.
- Use light splitter to illuminate one bundle at a time.
BESIII TOF Monitoring System

- State-of-the-art TOF monitoring system built by Hawaii.
- Major improvements:
  - Diode Laser
  - High quality multi fiber – fiber optic cables

Use PicoQuant 440M Laser Diode.
- Simple to use and maintain.
- Long lifetime (6 k hours at full power).
- Peak power: ~1W
- Pulse width < 70 ps.
- Wavelength 440 ± 10 nm.
- Power stability 1% RMS.
TOF Monitoring

West Barrel TOF’s Tmean and Tsigma vs. PMT number.

10,000 laser pulses @ 1kHz


~75 ps
Barrel Time of Flight - last run.

Barrel TOF’s Qm and Qsigma vs. PMT number.

~5 % resolution

Liu Qian
History Database (BIE01)

Liu Qian
Superconducting Magnet

Coil: single layer solenoid
Cooling mode: two phase helium force flow
Superconductor: Al stabilized NbTi/Cu
Winding: inner winding
Cold mass support: tension rod
Thermal shield: LN$_2$ shield, MLI
Flux return: barrel/end yoke, pole tip

First of its kind built in China.

<table>
<thead>
<tr>
<th>Cryostat</th>
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<tbody>
<tr>
<td>Inner radius</td>
<td>1.375m</td>
</tr>
<tr>
<td>Outer radius</td>
<td>1.7m</td>
</tr>
<tr>
<td>Length</td>
<td>3.91m</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Coil</th>
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<tbody>
<tr>
<td>Mean radius</td>
<td>1.482m</td>
</tr>
<tr>
<td>Length</td>
<td>3.52m</td>
</tr>
<tr>
<td>Cable dimension</td>
<td>3.7mm*20mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical parameters</th>
<th></th>
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<tbody>
<tr>
<td>Central field</td>
<td>1.0T</td>
</tr>
<tr>
<td>Nominal current</td>
<td>3650A</td>
</tr>
<tr>
<td>Inductance</td>
<td>2H</td>
</tr>
<tr>
<td>Stored energy</td>
<td>10MJ</td>
</tr>
<tr>
<td>Cold mass</td>
<td>3.6ton</td>
</tr>
<tr>
<td>Total Weight</td>
<td>15ton</td>
</tr>
<tr>
<td>Radiation thickness</td>
<td>44X$_0$</td>
</tr>
</tbody>
</table>
BESIII SC Magnet Progress

- wiring
- thermal insulation
- assembly
- installation
- field mapping
Muon Detector

Barrel + EndCap;
RPCs as $\mu$ detector;
Barrel: 9 layers - 72 modules
EndCap: 8 layers - 64 modules
Muon Detector

Barrel

Endcap
RPCs

- Electrodes made from a special type of phenolic paper laminate on bakelite.
- Have good surface quality (~200nm).
- Extensive testing and long term reliability testing done.
- Have high efficiency, low counting rate and dark current, and good long-term stability.
- One dimension read-out strips (4 cm wide) - 10,000 channels.
MUON Counter

**Efficiency**

- **Data**
- **MC**

**Spatial resolution**

- $\sigma_x = 15 \text{ mm}$

**Single counting rate**

- Entries: 264523
- Mean: -0.001771
- RMS: 17.62
- $\chi^2 / \text{ndf}$: 1.283e+04 / 197
- Constant: 6759 ± 17.5
- Mean: 0.1058 ± 0.0295
April 2008 - Installation complete
May 2008 - At IR
First collision event on July 19, 2008

13 M $\psi'$ events collected in 2008; 100 M in 2009
(Very) preliminary results from 110 M $\psi'$ events
Integrated luminosity - $\psi(2S)$ run

One month running.
EM transitions: inclusive photon spectrum

$\chi_{c_2}$ $\chi_{c_1}$ $\chi_{c_0}$ $\chi_{c_1,2} \rightarrow \gamma J/\psi$

$\eta_c (2^3S_1)$ $\psi (2^3S_1)$ $\chi_{c_2} (1^3P_2)$ $h_c (1^1P_1)$ $\chi_{c_1} (1^3P_1)$ $\chi_{c_0} (1^3P_0)$ $\eta_c (1^1S_0)$ $J/\psi (1^3S_1)$

BESIII preliminary
\( \psi' \rightarrow \gamma \gamma \, 1^{+}1^{-} : \text{signals} \)
\[ \psi(2S) \rightarrow \gamma \chi_{cJ} \]

\( \chi_{cJ} \) Hadronic Decays

Clean signals will allow detailed analyses of decays

BESIII preliminary
Observation of $h_c$: E1-tagged $\psi(2S) \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$

- Select E1-photon to tag $h_c$
- A fit of Double-Gaussian signal + sideband bkg. yield:
  
  $M(h_c)_{\text{Inc}} = 3525.16 \pm 0.16 \pm 0.10$ MeV
  
  $\Gamma(h_c)_{\text{Inc}} = 0.89 \pm 0.57 \pm 0.23$ MeV (First measurement)
  
  $\text{Br}(\psi' \rightarrow \pi^0 h_c) \times \text{Br}(h_c \rightarrow \gamma h_c)_{\text{Inc}} = (4.69 \pm 0.48(\text{stat})) \times 10^{-4}$ (\(\Gamma(h_c)\) floated)
  
  $= (4.69 \pm 0.29(\text{stat})) \times 10^{-4}$ (\(\Gamma(h_c)\) fixed at \(\Gamma(\chi_{c1})\))

CLEOc: 25 M $\psi(2S)$ events:

E1-photon-tagged:

$M(h_c)_{\text{Inc}} = 3525.35 \pm 0.23 \pm 0.15$ MeV

$\text{Br}(\psi' \rightarrow \pi^0 h_c) \times \text{Br}(h_c \rightarrow \gamma h_c)_{\text{Inc}} = (4.22 \pm 0.44 \pm 0.52) \times 10^{-4}$ with $\Gamma(h_c)$ fixed at $\Gamma(\chi_{c1})$
Observation of $h_c$ : Inclusive $\psi(2S) \rightarrow \pi^0 h_c$

- Select inclusive $\pi^0$
- A fit of Double-Gaussian signal + 4th Poly. bkg yield
  $$N(h_c) = 9233 \pm 935, \quad \chi^2/d.o.f = 38.8/38.0$$
- Combined inclusive and E1-photon-tagged spectrum
  $$\text{Br}(\psi' \rightarrow \pi^0 h_c) = (8.42 \pm 1.29 \text{ (stat)}) \times 10^{-4} \text{ (First measurement)}$$
  $$\text{Br}(h_c \rightarrow \gamma \eta_c) = (55.7 \pm 6.3 \text{ (stat)}) \% \quad \text{(First measurement)}$$

Systematic errors under study
Study of $\psi(2S) \to \gamma \pi^0 \pi^0$, $\gamma \eta \eta (\eta \to \gamma \gamma$, $\pi^0 \to \gamma \gamma$)

- Interesting channels for glueball searches
- Color octet mechanism important for $\chi_c$ decays.
  Help in understanding $\eta$.
- Based on 110M $\psi(2S)$

<table>
<thead>
<tr>
<th>BR ($10^{-3}$)</th>
<th>$\chi_{c0}$</th>
<th>$\chi_{c2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^0 \pi^0$</td>
<td><strong>BESIII</strong> 3.25±0.03 (stat)</td>
<td>0.86±0.02 (stat)</td>
</tr>
<tr>
<td></td>
<td>PDG08      2.43±0.20</td>
<td>0.71±0.08</td>
</tr>
<tr>
<td></td>
<td>CLEO-c     2.94±0.07±0.35</td>
<td>0.68±0.03±0.08</td>
</tr>
<tr>
<td>$\eta\eta$</td>
<td><strong>BESIII</strong> 3.1±0.1 (stat)</td>
<td>0.59±0.05 (stat)</td>
</tr>
<tr>
<td></td>
<td>PDG08      2.4±0.4</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td></td>
<td>CLEO-c     3.18±0.13±0.35</td>
<td>0.51±0.05±0.06</td>
</tr>
</tbody>
</table>

CLEO-c arxiv:0811.0586
Study of $\chi_{cJ} \rightarrow VV, V = \omega, \phi$

Important laboratory to test QCD:

<table>
<thead>
<tr>
<th>PDG09 (BESII results)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR($10^{-3}$)</td>
</tr>
<tr>
<td>$\rightarrow \phi\phi$</td>
</tr>
<tr>
<td>$\rightarrow \omega\omega$</td>
</tr>
</tbody>
</table>

BESIII sees clear $\chi_{c1} \rightarrow \phi\phi \rightarrow 4K$ signal
First observation of $\chi_{cJ} \rightarrow \omega \phi$

- $\chi_{cJ} \rightarrow \phi \omega$ doubly OZI suppressed
- Background from sideband & 100M MC events
- Clear signal from $\chi_{c0}/\chi_{c1} \rightarrow \omega(\pi^+\pi^-\pi^0)\phi(K^+K^-)$
Confirmation of the BESII observation: pp threshold enhancement

\[ J / \psi \rightarrow \gamma p \bar{p} \]

**BES II**

\[ M = 1859 \pm 3^{+5}_{-10}^{+10}_{-25} \text{ MeV/c}^2 \]
\[ \Gamma < 30 \text{ MeV/c}^2 (90\% \text{ CL}) \]

**BES III preliminary**

\[ \psi(2S) \rightarrow \pi \pi J / \psi \]
\[ J / \psi \rightarrow \gamma p \bar{p} \]

\[ M = 1865 \pm 5 \text{ MeV/c}^2 \]
\[ \Gamma < 33 \text{ MeV/c}^2 (90\% \text{ CL}) \]

*PRL 91 (2003) 022001*
Beam Energy Measurement
Tau mass measurements

- **Tau Mass status:**
  - **KEDR:** Most precise:
    \[ M_{\tau}^{\text{KEDR}} = 1776.69^{+0.17}_{-0.19} \pm 0.15 \text{ MeV} \]
  - Consistent with **BES 1996**:
    \[ M_{\tau} = 1776.96^{+0.18 + 0.25}_{-0.21 - 0.17} \text{ MeV} \]
  - **PDG (2008):**
    \[ 1776.84 \pm 0.17 \text{ MeV} \]

- **KEDR used two methods to calibrate beam energies:**
  - Resonant spin depolarization technique (\(<\sim 30 \text{ KeV}\))
  - Compton back scattering (\(<\sim 60 \text{ KeV}\)) \(\Rightarrow\) to be used by BESIII
  - Also measured masses of \(J/\psi, \psi(2S), \psi(3770)\)

Importance of $\tau$ Mass Measurement

- $M(\tau)$ is fundamental parameter of SM.
- $M(e)$ and $M(\mu)$ are known to $\delta M/M \sim 10^{-8}$ while $M(\tau)$ is only known $\sim 10^{-4}$.
- Improved precision important to test universality:
  \[
  \left( \frac{g_\tau}{g_\mu} \right)^2 = \frac{\tau_\mu}{\tau_\tau} \left( \frac{m_\mu}{m_\tau} \right)^5 \frac{B(\tau \to e\nu\bar{\nu})}{B(\mu \to e\nu\bar{\nu})} \frac{F(m_e, m_\mu)}{F(m_e, m_\tau)} (1 + \delta_W)(1 + \delta_\gamma)
  \]
- At present:
  \[
  \frac{g_\tau}{g_\mu} = 1.0006 \pm 0.0022
  \]


Tests universality at 0.2% level.
BESIII Beam Energy Measurement

- BESIII can improve $\tau$ mass measurement but precision is limited by knowledge of beam energy.
- Use BINP method: measure energies of back scattered Compton photons produced by a CO$_2$ laser beams on both the $e^+$ and $e^-$ beams:
  1. Beam energy $\varepsilon$ determined by max energy ($\omega_{\text{max}}$) of back scattered photons:

$$\varepsilon = \frac{\omega_{\text{max}}}{2} \left[ 1 + \sqrt{1 + \frac{m_e^2}{\omega_0 \omega_{\text{max}}}} \right]$$

where $\omega_0$ is laser photon energy.
  2. Back scattered photons measured with High Purity Ge (HPGe) detectors with precision of $\delta\varepsilon/\varepsilon \sim 1 \times 10^{-5}$.
BESIII Beam Energy Measurement

3. Absolute calibration of energy scale done using $\gamma$-active radionuclides.

4. Expected resolution at BESIII $\Delta \varepsilon = 40$ keV.

$\Delta m_\tau \approx 0.13 \text{ MeV/c}^2$; PDG08, $\Delta m_\tau \approx 0.17 \text{ MeV/c}^2$
BESIII Beam Energy Measurement

• First BESIII upgrade.
• Collaboration by IHEP, BINP, and U. of Hawaii.
• Scheme:

Continue installation in fall 2009
BESIII Beam Energy Measurement
$e^+ e^- \text{ physics at BESIII}$
Production

Average Lum: $\mathcal{L} = 0.5 \times \text{Peak Lum.}$; One year data taking time: $T = 10^7s$

$$N_{\text{event/year}} = \sigma_{\text{exp}} \times \mathcal{L} \times T$$

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass (GeV) CMS</th>
<th>Peak Lum. ($10^{33}\text{cm}^{-2}\text{s}^{-1}$)</th>
<th>Physics Cross Section (nb)</th>
<th>Nevents/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>$J/\psi$</td>
<td>3.097</td>
<td>0.6</td>
<td>3400</td>
<td>$10 \times 10^9$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>3.670</td>
<td>1.0</td>
<td>2.4</td>
<td>$12 \times 10^6$</td>
</tr>
<tr>
<td>$\psi(2S)$</td>
<td>3.686</td>
<td>1.0</td>
<td>640</td>
<td>$3.2 \times 10^9$</td>
</tr>
<tr>
<td>$D^0\bar{D}^0$</td>
<td>3.770</td>
<td>1.0</td>
<td>3.6</td>
<td>$18 \times 10^6$</td>
</tr>
<tr>
<td>$D^+D^-$</td>
<td>3.770</td>
<td>1.0</td>
<td>2.8</td>
<td>$14 \times 10^6$</td>
</tr>
<tr>
<td>$D_s\bar{D}_s$</td>
<td>4.030</td>
<td>0.6</td>
<td>0.32</td>
<td>$1.0 \times 10^6$</td>
</tr>
<tr>
<td>$D_s\bar{D}_s$</td>
<td>4.140</td>
<td>0.6</td>
<td>0.67</td>
<td>$2.0 \times 10^6$</td>
</tr>
</tbody>
</table>

Huge $J/\psi$ and $\psi(2S)$ samples at BES3.
Charm physics will be high priority when luminosity improves.

Testing LQCD: $f_{DS}$

$V_{td}$ and $V_{ts}$ determined from $B_0 - \bar{B}_0$ and $B_S - \bar{B}_S$ mixing results plus decay constants from LQCD. Charm decay BRs provide a test of LQCD.

$$\Gamma(D^+ \to l^+ \nu) = \frac{G_F^2}{8\pi} f_{D^+}^2 m_{l}^2 M_{D^+} (1 - \frac{m_{l}^2}{M^2_{D^+}}) |V_{cd}|^2$$

CLEOc uses tagged D’s from $e^+e^- \to \psi(3770) \to D^+D^-$ and tagged $D_S$’s from $e^+e^- \to D_S^+D_S^- + c.c.$ at $E = 4170$ MeV to measure $f_D$ and $f_{DS}$.

<table>
<thead>
<tr>
<th></th>
<th>LQCD* (MeV)</th>
<th>Experiment (MeV)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_D$</td>
<td>207 ± 4</td>
<td>205.8 ± 8.5 ± 2.5$</td>
<td>-</td>
</tr>
<tr>
<td>$f_{DS}$</td>
<td>241 ± 3</td>
<td>259.5 ± 7.3$^+$</td>
<td>2.3σ</td>
</tr>
</tbody>
</table>

$^*$ HPQCD & UKQCD, PRL 100, 062002 (2008).
$^\dagger$ CLEOc, PRD 78, 052003 (2008).
$^+$ Belle, PRL 100, 241801 (2008); CLEOc, PRD79, 052001 & 052002 (2009).

New physics?

How well can BESIII do with 20 fb$^{-1}$ of data? About 2 years.

$\text{f}_{DS} = 269.6 \pm 3.0$

**CKM matrix elements**

- **Leptonic decays**
  \[
  \Gamma(D_{(s)} \rightarrow \ell \nu) = f_{D_{(s)}}^2 |V_{cq}|^2 \frac{G_F^2}{8\pi} m_{D_{(s)}} m_\ell \left( 1 - \frac{m_\ell^2}{m_{D_{(s)}^2}} \right)^2
  \]
  - Direct measurement of $V_{cd}$ & $V_{cs}$
  - $f_D$ and $(f_B/f_D)_{LQCD} \Rightarrow f_B \Rightarrow |V_{td}|$
  - $f_D/f_{Ds}$ checks $(f_B/f_{Bs})_{LQCD} \Rightarrow |V_{td}| / |V_{ts}|$

- **Semi-leptonic decays**
  \[
  \frac{d\Gamma(X \rightarrow X' \ell \nu)}{dq^2} = \left[ f_{X \rightarrow X'}^X (q^2) |V_{Qq}| \right]^2 \frac{G_F^2}{24\pi^3} p_X^3
  \]

- **BESIII will improve the precision:**

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>BESIII</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{cd}$</td>
<td>$\sim 4.8%$</td>
<td>$\sim 1%$</td>
</tr>
<tr>
<td>$V_{cs}$</td>
<td>$\sim 5.8%$</td>
<td>$\sim 1%$</td>
</tr>
</tbody>
</table>

*with 20 fb$^{-1}$ data*

**$D\bar{D}$ mixing and CPV**

- The only mixing system via **down-type** quarks
- Very small mixing: $m_b^2 / m_W^2 \sim O(10^{-3})$, $|V_{ub}V_{cb}|^2 / |V_{us}V_{cs}|^2 \sim O(10^{-6})$
- The only mixing system whose parameters ($x$ and $y$) are notoriously hard to be calculated in the SM
  - $m_c$ is neither $<< \Lambda_{QCD}$ nor $>> \Lambda_{QCD}$ – non-PQCD
- A sensitive probe to **CP-violating** new physics, as the SM CPV in neutral-D decays $\leq 0.1\%$
- $D\bar{D}$ mixing at $\psi(3770)$: Doubly produced at threshold (at rest):
  - Almost background free
  - Quantum correlation
  - Double-tag $\Rightarrow$ reduce systematics

\[
\begin{align*}
\psi(3770) + e^- &\rightarrow D^- \bar{D}^0 \\
&\text{or } D^0 \bar{D}^0
\end{align*}
\]
First determination of $\cos \delta$

**DDbar mixing described by:**

\[
x = \frac{(m_1 - m_2)}{\Gamma}, \quad y = \frac{(\Gamma_1 - \Gamma_2)}{2\Gamma}
\]

where $D_{1,2}$ are the mass eigenstates:

\[
D_{1,2} = p|D^0> \pm q|\bar{D}^0>
\]

and $m_1, m_2, \Gamma_1, \text{ and } \Gamma_2$ are their masses and decay rates. $\Gamma$ is average decay rate.

Actually measured in $D$ decays to two body hadronic states:

\[
x' = x \cos \delta + y \sin \delta
\]
\[
y' = -x \sin \delta + y \cos \delta
\]

$\delta$ is the strong phase difference between DCS and CF decays:

- $D^0 \rightarrow D^0 \rightarrow K^+ \pi^-$ (mixing followed by CF decay)
- $D^0 \rightarrow K^+ \pi^-$ (DCS decay)

**CLEOc** can measure $\delta$ and relate $x, y$ and $x', y'$.
D₀ – D₀ mixing

Mixing in the D sector has turned out to be much more interesting than expected:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>x (%)</td>
<td>0.89 ± 0.26</td>
</tr>
<tr>
<td>y (%)</td>
<td>0.75 ± 0.17</td>
</tr>
<tr>
<td>δ (°)</td>
<td>21.9 ± 11.3</td>
</tr>
<tr>
<td>R_D (%)</td>
<td>0.3348 ± 0.0086</td>
</tr>
<tr>
<td>A_D (%)</td>
<td>-2.0 ± 2.4</td>
</tr>
<tr>
<td></td>
<td>q/p</td>
</tr>
<tr>
<td>φ (°)</td>
<td>-9.1 ± 8.1</td>
</tr>
<tr>
<td>δ_{Kππ} (°)</td>
<td>33.0 ± 25.9</td>
</tr>
</tbody>
</table>

Strong phase δ is important for extracting the CKM angle γ.

|q/p| and φ are consistent with no CPV.

CLEOc: δ = (22_{-12}^{+11+9}_{-12-11})°

Phys. Rev. Lett. 100, 221801 ('08)
Phys. Rev. D78, 012001 ('08)

BESIII:
For δ = 19°, Δ(δ) = ± 9°.
Will set strong limits on CPV

Fit to Belle, BaBar, CDF, and CLEOc results.


Summary

• BES has had a long productive history. Future is BEPCII/BESIII.

• Commissioning of BEPCII/BESIII completed successfully:
  - Peak Luminosity of $3.0 \times 10^{32}$ achieved.
  - 100 M $\psi(2S)$ and 200 M $J/\psi$ events obtained.

• Rich physics after CLEOc: 10 billion $J/\psi$ events per year.

• BES is unique.
Extra Slides
Electroweak Fits - Limits on $M_H$

$M_t = (172.5 \pm 1.2)$ GeV

$\alpha_s(M_Z) = 0.1185 \pm 0.0026$

$\Delta \alpha^{(5)}_{\text{had}} = 0.02758 \pm 0.00035$

$M_H = 84^{+34}_{-26}$

$\chi^2 = 17.3/13$, prob = 18%

$M_H < 154$ GeV @ 95% CL

with theory driven value of

$\Delta \alpha^{(5)}_{\text{had}} = 0.02749 \pm 0.00012$

$M_H = 93^{+31}_{-24}$

<table>
<thead>
<tr>
<th>Impact of uncertainties on $M_H$:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta M_t = \pm 1.2$ GeV</td>
</tr>
<tr>
<td>$\Delta M_W = \pm 25$ MeV</td>
</tr>
<tr>
<td>$\Delta \alpha^{(5)}_{\text{had}} = \pm 0.00035$</td>
</tr>
</tbody>
</table>