Recent Results from BESIII

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Outline

- Status of BEPCII/BESIII
- Selected Results from BESIII
  - Light Hadron Spectroscopy
  - Charmonium Transitions
  - Charm Decays
  - $\tau$ Mass Scan
- Summary
Bird View of BEPCII /BESIII

Linac

Storage ring

Beijing electron positron collider BEPCII

Beam energy 1.0-2.3 GeV
Energy spread: $5.16 \times 10^{-4}$

Design luminosity
$1 \times 10^{33}/\text{cm}^2/\text{s} @ \psi(3770)$

Achieved luminosity
$\sim 0.65 \times 10^{33}/\text{cm}^2/\text{s}$

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

IHEP, Beijing

BESIII detector

BSRF
BEPC II: Large Crossing Angle, Double-ring

Compton back-scattering for high precision beam energy measurement

Beam energy: 1-2.3 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@2.5GeV
The BESIII Detector

Drift Chamber (MDC)
\[ \sigma_{p/p}(0/0) = 0.5\% (1\text{GeV}) \]
\[ \sigma_{dE/dx}(0/0) = 6\% \]

Time Of Flight (TOF)
\[ \sigma_T : 90\text{ ps Barrel} \]
\[ 110\text{ ps endcap} \]

Super-conducting magnet (1.0 Tesla)

μ Counter
8- 9 layers RPC
\[ \delta R\Phi=1.4\text{ cm} \sim 1.7\text{ cm} \]

EMC:
\[ \sigma_E/E(0/0) = 2.5\% (1\text{ GeV}) \]
\[ (\text{CsI}) \sigma_{z,\phi}(cm) = 0.5 - 0.7\text{ cm}/\sqrt{E} \]
BESIII Commissioning

- July 19, 2008: first e^+e^- collision event in BESIII
- Nov. 2008: \( \sim 14 \text{M } \psi(2S) \) events for detector calibration
- 2009: \( 106 \text{M } \psi(2S) \) \( 4 \times \text{CLEO-c} \)
  \( 225 \text{M J/\psi} \) \( 4 \times \text{BESII} \)
- 2010: \( \sim 0.9 \text{ fb}^{-1} \psi(3770) \) \( 3.5 \times \text{CLEO-c} \)
- 2011: \( \sim 2.0 \text{ fb}^{-1} \psi(3770) \)
  \( \sim 0.5 \text{ fb}^{-1} @ 4.01 \text{ GeV} \)
- 2012: tau mass scan: \( \sim 5.0 \text{ pb}^{-1} \)
  \( \psi(2S): 0.4 \text{ billion}; J/\psi: 1 \text{ billion (May 22!)} \)

Tentative future running plans:

- 2013: \( D_s \) physics (\( E_{cm}=4170 \text{ MeV} \)) + R scan (\( E_{cm} > 4 \text{ GeV} \))
- 2014: \( \psi(2S) / \tau / \text{R scan} (E_{cm} > 4 \text{ GeV}) \)
- 2015: \( \psi(3770): 5-10 \text{ fb}^{-1} \) for DD physics
The BESIII Collaboration

http://bes3.ihep.ac.cn

>300 physicists
50 institutions from 10 countries
Physics Programs @ BESIII

**Light hardron physics**
- meson & baryon spectroscopy
- threshold effects
- multiquark states
- glueballs & hybrids
- two-photon physics
- form-factors

**Charmonium physics:**
- precision spectroscopy
- transitions and decays

**Charm physics:**
- (semi-)leptonic decays
- $f_D$ & $f_{Ds}$ decay constants
- CKM matrix: $V_{cd}$, $V_{cs}$
- $D^0$-$D^0$ mixing and CPV
- strong phases

**QCD & $\tau$-physics:**
- precision $R$-measurement
- $\tau$ mass / $\tau$ decays

**XYZ meson physics:**
- $Y(4260) \rightarrow \pi\pi\eta_c$ decays

...
Recent Results on Light Hadron Physics

- $p\bar{p}$ mass threshold structure in $J/\psi \rightarrow \gamma p\bar{p}$
- $\eta(1405)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$, $f_0(980) \rightarrow 2\pi$
- 3$\pi$ Decays of $J/\psi$ and $\psi(2S)$
- $\omega\phi$ threshold enhancement in $J/\psi \rightarrow \gamma \omega\phi$
- $\eta\eta$ system in $J/\psi \rightarrow \gamma \eta\eta$
Enhancement at $p\bar{p}$ threshold in $J/\psi \rightarrow \gamma p\bar{p}$

Observed at BESII in 2003 (PRL,022001) agree with spin zero expectation $M = 1860^{+3}_{-10}^{+5}_{-25}$ MeV, $\Gamma < 38$ MeV (90% CL)

Confirmed at BESIII in 2010 (CPC 34,421 (2010)) $M = 1859^{+6}_{-13}^{+6}_{-25}$ MeV, $\Gamma < 30$ MeV (90% CL)

Many possibilities:
normal meson/ $p\bar{p}$ bound state/multiquark/glueball/Final state interaction effect (FSI)......

Spin-parity analysis
is essential for determining place in the spectrum and possible nature.
Spin-Parity analysis of $J/\psi \rightarrow \gamma \eta \bar{p}p$ ($M_{\eta \bar{p}p} < 2.2\text{GeV}$)

**Four components:**
- $X(\eta \bar{p}p)$, $f_2(1910)$, $f_0(2100)$,
- and $0^{++}$ phase space

**Include the FSI effect**

**Fit features:**
- The fit with BW and S-wave FSI($I=0$) factor can well describe $\eta \bar{p}p$ mass threshold structure.
- It is much better than that Without FSI effect ($7.1\sigma$)

**Spin-parity, mass, width and Br. of $X(\eta \bar{p}p)$:**

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

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

$\Gamma = 13 \pm 39(\text{stat})^{+10}_{-13}(\text{syst}) \pm 4(\text{model}) \text{ MeV}/c^2$ or $\Gamma < 76 \text{ MeV}/c^2$ @ 90% C.L.

$Br(J/\psi \rightarrow \gamma X(\eta \bar{p}p))Br(X(\eta \bar{p}p) \rightarrow \eta \bar{p}p) = (9.0^{+0.4}_{-1.1}(\text{stat})^{+1.5}_{-5.0}(\text{syst}) \pm 2.3(\text{model})) \times 10^{-5}$

**model:** Model dependent uncertainty (Different FSI models)
$\psi(2S) \rightarrow \gamma p\bar{p}$ \hspace{1cm} (M_{p\bar{p}} < 2.2\text{GeV})

$\mathcal{M}, \Gamma$ and $\mathcal{J}^{PC}$ of $X(p\bar{p})$ are fixed to the results obtained from $J/\psi$ decays.

\[
Br(\psi(2S) \rightarrow \gamma X(p\bar{p})) Br(X(p\bar{p}) \rightarrow p\bar{p}) \\
= (4.57 \pm 0.36(\text{stat})^{+1.23}_{-4.07}(\text{syst}) \pm 1.28(\text{model})) \times 10^{-6}
\]

The production ratio $R$:

\[
R = \frac{Br(\psi(2S) \rightarrow \gamma X(p\bar{p}))}{Br(J/\psi \rightarrow \gamma X(p\bar{p})} = \left( 5.08^{+0.71}_{-0.45}(\text{stat})^{+0.67}_{-3.58}(\text{syst}) \pm 0.12(\text{model}) \right)\%
\]

It is suppressed compared with 12% rule.
Recent Results on Light Hadron Physics

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- $\eta(1405)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$, $f_0(980) \rightarrow 2\pi$
- $3\pi$ Decays of $J/\psi$ and $\psi(2S)$
- $\omega\phi$ threshold enhancement in $J/\psi \rightarrow \gamma\omega\phi$
- $\eta\eta$ system in $J/\psi \rightarrow \gamma\eta\eta$
$\eta(1405)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$, $f_0(980) \rightarrow 2\pi$

First observed: $\eta(1405) \rightarrow f_0(980)\pi^0$ (isospin breaking)

- Helicity analysis indicates the peak at 1400MeV is from $\eta(1405)$, not from $f_1(1420)$
  \[
  Br(J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma \pi^0 f_0 \rightarrow \gamma \pi^0 \pi^\pm \pi^\mp) = (1.50 \pm 0.11(stat.) \pm 0.11(syst.) \times 10^{-5}
  \]
  \[
  Br(J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma \pi^0 f_0 \rightarrow \gamma \pi^0 \pi^0 \pi^0) = (7.10 \pm 0.82(stat.) \pm 0.72(syst.) \times 10^{-6}
  \]

- Large Isospin-violating decay rate:
  \[
  \frac{BR(\eta(1405) \rightarrow f_0(980)\pi^0 \rightarrow \pi^+ \pi^- \pi^0)}{BR(\eta(1405) \rightarrow a_0(980)\pi^0 \rightarrow \pi^0 \pi^0 \eta)} \approx (17.9 \pm 4.2) \%
  \]

In general, magnitude of isospin violation in strong decay should be <1%.
$a_0 - f_0$ mixing alone can not explain the branching ratio of $\eta(1405) \rightarrow f_0(980)\pi^0$.
Anomalous Lineshape of $f_0(980)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$

Surprising result:
very narrow $f_0(980)$ width: $<11.8$ MeV/$c^2$ @90% C.L.
much narrower than the world average (PDG 2010: 40-100 MeV/$c^2$)

A possible explanation is $KK^*$ loop, Triangle Singularity (TS) (J.J. Wu et al, PRL 108, 081803(2012))
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• $\eta(1405)$ in $J/\psi \rightarrow \gamma f_0(980)\pi^0$, $f_0(980) \rightarrow 2\pi$
• $3\pi$ Decays of $J/\psi$ and $\psi(2S)$
• $\omega\phi$ threshold enhancement in $J/\psi \rightarrow \gamma \omega\phi$
• $\eta\eta$ system in $J/\psi \rightarrow \gamma \eta\eta$
3π Decays of $J/\psi$ and $\psi(2S)$

$J/\psi \rightarrow \pi^+\pi^-\pi^0$ decays are dramatically different from $\psi(2S) \rightarrow \pi^+\pi^-\pi^0$ decays:

- $J/\psi$ is dominated by $\rho$
- $\psi(2S)$ is strongly populated by higher mass state absent in $J/\psi$ decay

Precision measurement of branching fractions:

$$Br(J/\psi \rightarrow \pi^+\pi^-\pi^0) = (2.137 \pm 0.004_{stat}^{+0.058}(-0.056_{syst}^{+0.027}(-0.026_{norm})) \times 10^{-2}$$

$$Br(\psi(2S) \rightarrow \pi^+\pi^-\pi^0) = (2.14 \pm 0.03_{stat}^{+0.08}(-0.07_{syst}^{+0.09}(-0.08_{norm})) \times 10^{-4}$$

The ratio of these two branching fractions:

$$\frac{Br(\psi(2S) \rightarrow \pi^+\pi^-\pi^0)}{Br(J/\psi \rightarrow \pi^+\pi^-\pi^0)} = \left( 1.00 \pm 0.01_{stat}^{+0.06}(-0.05_{syst}) \right)\%$$

$\rho\pi$ puzzle: $Q_h = \frac{Br(\psi(2S) \rightarrow \text{hadrons})}{Br(J/\psi \rightarrow \text{hadrons})} \approx \frac{Br(\psi(2S) \rightarrow e^+e^-)}{Br(J/\psi \rightarrow e^+e^-)} \approx 12\%$
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- $3\pi$ Decays of $J/\psi$ and $\psi(2S)$
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ωφ threshold enhancement in J/ψ → γωφ

\[ J/ψ \rightarrow γφφ, \ φ \rightarrow K^+ K^- \quad (OZI) \quad J/ψ \rightarrow γωφ \quad (DOZI) \]

\[ M = 1812^{+19}_{-26} \pm 18 \text{ MeV}/c^2 \]
\[ Γ = 105 \pm 20 \pm 28 \text{ MeV}/c^2 \]

\( J^{PC} \) favors 0++ over 0− and 2++

G.S. Huang

FPCP2012, May 21-25

Phys. Rev. Lett. 96(2006)162002
$J/\psi \rightarrow \gamma \omega \phi$ at BESIII

Backgrounds estimated from $\omega$ and $\phi$ sidebands

Backgrounds estimated from inclusive MC -- mainly from $\omega K^*K$
Preliminary PWA Results at BESIII

Is $X(1810)$ the $f_0(1710)/f_0(1790)$ or new state?
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Study of $\eta\eta$ System

- First observed $f_0(1710)$ from $J/\psi$ radiative decays to $\eta\eta$ by Crystal Ball in 1982.

- Crystal Barrel Collaboration (2002) analyzed the three final states $\pi^0\pi^0\pi^0$, $\eta\pi^0\pi^0$ and $\pi^0\eta\eta$ with $K$ matrix formalism. Found a $2^{++}$ ($\sim 1870$), but no $f_0(1710)$.

- E835 (2006): $p\bar{p} \rightarrow \pi^0\eta\eta$, found $f_0(1500)$ and $f_0(1710)$.

- WA102 and GAMS all identified $f_0(1710)$ in $\eta\eta$. 

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**J/ψ → γηη at BESIII:** Preliminary PWA results

- $f_0(1710)$ and $f_0(2100)$ are dominant scalars
- $f_0(1500)$ exists ($8.2\sigma$)
- $f_2'(1525)$ is the dominant tensor

| Resonance | Mass (MeV/$c^2$) | Width (MeV/$c^2$) | $B(J/ψ \rightarrow γX \rightarrow γηη)$ | Significance |
|-----------|------------------|-------------------|----------------------------------------|--------------|
| $f_0(1500)$ | 1468$^{+14+20}_{-15-74}$ | 136$^{+41+8}_{-26-100}$ | (1.61$^{+0.29+0.41}_{-0.32-1.28}$) $\times 10^{-5}$ | 8.2 $\sigma$ |
| $f_0(1710)$ | 1759$^{+6+14}_{-6-25}$ | 172$^{+10+31}_{-10-15}$ | (2.35$^{+0.07+1.23}_{-0.07-0.72}$) $\times 10^{-4}$ | 25.0 $\sigma$ |
| $f_0(2100)$ | 2081$^{+13+23}_{-13-34}$ | 273$^{+27+65}_{-24-18}$ | (9.6$^{+0.57+5.52}_{-0.52-2.21}$) $\times 10^{-5}$ | 13.9 $\sigma$ |
| $f_2'(1525)$ | 1513$^{+5+3}_{-5-10}$ | 75$^{+12+15}_{-10-7}$ | (5.41$^{+0.43+1.22}_{-0.50-1.23}$) $\times 10^{-5}$ | 11.0 $\sigma$ |
| $f_2(1810)$ | 1822$^{+29+61}_{-24-54}$ | 229$^{+52+64}_{-42-26}$ | (5.38$^{+0.60+3.31}_{-0.67-2.24}$) $\times 10^{-5}$ | 6.4 $\sigma$ |
| $f_2(2340)$ | 2362$^{+31+139}_{-30-59}$ | 334$^{+63+140}_{-65-181}$ | (5.58$^{+0.61+1.93}_{-0.65-1.81}$) $\times 10^{-5}$ | 7.6 $\sigma$ |
Recent Results on Charmonium Physics

- Properties of $h_c$
- Mass and width of $\eta_c$
- Observation of $\psi(2S) \rightarrow \gamma \eta_c(2S)$
- First evidence of $\psi(2S) \rightarrow \gamma \gamma J/\psi$
Property of $h_c$ (1p1)

- First evidence: E835 in pp → $h_c$ → $\gamma_c$ (PRD72,092004(2005))

- CLEO-c observed $h_c$ in ee → $\psi(2S)$ → $\pi^0 h_c$, $h_c$ → $\gamma_c$
  $\Delta M_{hf}(1P) = 0.08 \pm 0.18 \pm 0.12$ MeV/c² (PRL104,132002(2010))

- Study isospin forbidden transition:
  $\psi(2S) \rightarrow \pi^0 h_c$

- Measure as well the E1 transition:
  $h_c \rightarrow \gamma_c$

- $M(h_c)$ gives access to hyperfine splitting of 1P states:
  $\Delta M_{hf}(1P) = M(h_c) - 1/9(M(\chi_{c0}) + 3M(\chi_{c1}) + 5M(\chi_{c2}))$
Observation of $h_c$ at BESIII (inclusive)

- Select inclusive $\pi^0(\psi(2S) \to \pi^0 h_c)$

- Select E1-photon in $h_c \to \gamma \eta_c$ (E1 tagged) or not (E1 untagged)

- E1-tagged selection gives
  $M(h_c) = 3525.40 \pm 0.13 \pm 0.18$ MeV
  ($\Delta M_{hf}(1P) = 0.10 \pm 0.13 \pm 0.18$ MeV/c$^2$)
  $\Gamma(h_c) = 0.73 \pm 0.45 \pm 0.28$ MeV (first measurement)
  (<1.44 MeV at 90% CL)
  $\text{Br}(\psi(2S) \to \pi^0 h_c) \times \text{Br}(h_c \to \gamma \eta_c) = (4.58 \pm 0.40 \pm 0.50) \times 10^{-4}$

- E1-untagged selection gives
  $\text{Br}(\psi(2S) \to \pi^0 h_c) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4}$

- Combining branching fractions leads to
  $\text{Br}(h_c \to \gamma \eta_c) = (54.3 \pm 6.7 \pm 5.2)\%$ (first measurement)
Measurements of the $h_c$ properties at BESIII (exclusive)

Simultaneous fit to $\pi^0$ recoiling mass:

$M(h_c) = 3525.31 \pm 0.11 \pm 0.15$ MeV

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

$N = 832 \pm 35$

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

Consistent with BESIII inclusive results

PRL104, 132002(2010)

CLEOc exclusive results

$M(h_c) = 3525.21 \pm 0.27 \pm 0.14$ MeV/c$^2$

$N = 136 \pm 14$

PRL101, 182003(2008)
The $\eta_c$ lineshape is not distorted in the $h_c \rightarrow \gamma \eta_c$, non-resonant bkg is small. This channel will be best suited to determine the $\eta_c$ resonance parameters.
Recent Results on Charmonium Physics

- Properties of \( h_c \)
- Mass and width of \( \eta_c \)
- Observation of \( \psi(2S) \rightarrow \gamma \eta_c(2S) \)
- First evidence of \( \psi(2S) \rightarrow \gamma \gamma J/\psi \)
\( \eta_c(1S) \)

- Ground state of \( c\bar{c} \) system, but its properties are not well known:
  - \( J/\psi \) radiative transition: \( M \sim 2978.0 \text{MeV}/c^2, \quad \Gamma \sim 10 \text{MeV} \)
  - \( \gamma\gamma \) process: \( M = 2983.1 \pm 1.0 \text{MeV}/c^2, \quad \Gamma = 31.3 \pm 1.9 \text{MeV} \)
  - CLEO-c found the distortion of the \( \eta_c \) lineshape in \( \psi(2S) \) decays
  - \( c\bar{c} \) hyperfine splitting: \( M(J/\psi) - M(\eta_c) \) is important experimental input to test the lattice QCD, but is dominated by error on \( M(\eta_c) \)
$\psi(2S) \rightarrow \gamma \eta_c, \eta_c$ exclusive decays

**Interference with non-resonant is significant!**

Relative phase $\phi$ values from each mode are consistent within $3\sigma$, 
$\Rightarrow$ use a common phase value in the simultaneous fit.

- **Mass:** $2984.3 \pm 0.6 \pm 0.6$ MeV/$c^2$
- **Width:** $32.0 \pm 1.2 \pm 1.0$ MeV
- **$\phi$:** $2.40 \pm 0.07 \pm 0.08$ rad or $4.19 \pm 0.03 \pm 0.09$ rad
Comparison of the mass and width for $\eta_c$

The world average in PDG2010 was using earlier measurements

Hyperfine splitting: $\Delta M(1S) = 112.6 \pm 0.8$ MeV

Consistent with B factory results in other production mechanisms. Agree with lattice QCD calculations of the charmonium hyperfine splitting.
Recently Results on Charmonium Physics

- Properties of $h_c$
- Mass and width of $\eta_c$
- **Observation of $\psi(2S) \rightarrow \gamma \eta_c(2S)$**
- First evidence of $\psi(2S) \rightarrow \gamma \gamma J/\psi$
First “observation” by Crystal Ball in 1982 (M=3.592, B=0.2%-1.3% from $\psi(2S)\rightarrow\gamma X$, never confirmed by other experiments.)

Published results about $\eta_c(2S)$ observation:

| Experiment | $M$ [MeV] | $\Gamma$ [MeV] | Process |
|------------|-----------|----------------|---------|
| Belle [1]  | 3654 ± 6 ± 8 | — | $B^\pm \rightarrow K^\pm \eta_c(2S), \eta_c(2S) \rightarrow K_s K^\pm \pi^\mp$ |
| CLEO [2]   | 3642.9 ± 3.1 ± 1.5 | 6.3 ± 12.4 ± 4.0 | $\gamma \gamma \rightarrow \eta_c(2S) \rightarrow K_s K^\pm \pi^\mp$ |
| BaBar [3]  | 3630.8 ± 3.4 ± 1.0 | 17.0 ± 8.3 ± 2.5 | $\gamma \gamma \rightarrow \eta_c(2S) \rightarrow K_s K^\pm \pi^\mp$ |
| BaBar [4]  | 3645.0 + 5.5 +4.9 | — | $e^+ e^- \rightarrow J/\psi \bar{e}e$ |
| PDG [5]    | 3638 ± 4 | 14 ± 7 | — |

Combined with the results based on two-photon processes from BaBar and Belle reported at ICHEP 2010, the world average $\Gamma(\eta_c(2S))=12 \pm 3$ MeV

The M1 transition $\psi(2S)\rightarrow\gamma \eta_c(2S)$ has not been observed.
(experimental challenge: search for real photons $\sim50$ MeV, )

Better chance to observe $\eta_c(2S)$ in $\psi(2S)$ radiative transition with $\sim106$M $\psi(2S)$ data at BESIII.

Decay mode studied: $\psi(2S) \rightarrow \gamma \eta_c(2S) \rightarrow \gamma Ks\pi / \gamma K^+K^-\pi^0$. 

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Observation of $\psi(2S) \rightarrow \gamma \eta_c(2S)$

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

BESIII preliminary

Statistical significance $> 10\sigma$
Preliminary results on $\psi(2S) \rightarrow \gamma \eta_c(2S) \rightarrow \gamma KK\pi$

BESIII preliminary

- $M(\eta_c(2S)) = 3637.6 \pm 2.9 \pm 1.6$ MeV/$c^2$
- $\Gamma(\eta_c(2S)) = 16.9 \pm 6.4 \pm 4.8$ MeV

- $\text{Br}(\psi(2S) \rightarrow \gamma \eta_c(2S) \rightarrow \gamma KK\pi) = (1.30 \pm 0.20 \pm 0.30) \times 10^{-5}$

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

$\text{Br}(\psi(2S) \rightarrow \gamma \eta_c(2S)) = (6.8 \pm 1.1_{\text{stat}} \pm 4.5_{\text{sys}}) \times 10^{-4}$

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

Potential model: $(0.1-6.2) \times 10^{-4}$  PRL89,162002(2002)
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\[ \psi(2S) \rightarrow \gamma\gamma J/\psi \]

- Two photon transitions are well known in excitations of molecules, atomic hydrogen, and positronium.

  \[ [F. Bassani et al, PRL 39, 1070 (1977); A. Quattropani et al, PRL 50, 1258 (1983)] \]

- Never been observed in the quarkonium system.

  CLEO-c: upper limit of \( Br(\psi(2S) \rightarrow \gamma\gamma J/\psi) \) is \( 1 \times 10^{-3} \) (PRD 78, 011102(2008))

- Observation helpful to understand heavy quarkonium spectrum & strong interaction

**Theoretically:**

- Potential models give discrete spectra

  \( (\psi(2S) \rightarrow \gamma \chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi) \)

- Possibility of testing the hadron-loop effect

- **Coupled channel:** the hadron-loop effect also may play an important role in the continuous spectra
First evidence of $\psi(2S) \to \gamma\gamma \ J/\psi$

- Select $\psi(2S) \to \gamma\gamma J/\psi$, $J/\psi \to e^+e^-$ and $\mu^+\mu^-$ events

- $\gamma_{sm}$ - low energy gamma

- The $\chi_{cl}$ components: double E1 scaling
- Yields of the two-photon events
- Continuum(green) + $\psi(2S)$ decay BG(yellow)

- Global fit of the two-photon process and cascade $\chi_{cl}$ processes
- See clear excess over BG + continuum

- $Br(\psi(2S) \to \gamma\gamma J/\psi) = (3.3 \pm 0.6^{+0.8}_{-1.1}) \times 10^{-4}$ (both $ee$ and $\mu\mu$)

- Significance: 3.8$\sigma$ including systematics

- $Br(\psi(2S) \to \gamma\chi_{cl}, \chi_{cl} \to \gamma J/\psi)$ are also measured

- $3.44 < \text{RM}(\gamma_{sm}) < 3.48 \text{ GeV}$
Charm Physics (all preliminary)

- $D^+ \rightarrow \mu^+ \nu$
- $D^0 \rightarrow K^-/\pi^- e^+ \nu$
- Search for $D^0 \rightarrow \gamma \gamma$
- $D_s$ tagging
D⁻ Tagging

Resolution: 1.3 MeV for pure charged modes; 1.9 MeV for modes with one π⁰.

9 singly tagged modes

\[ N_{D^-} = (1.57 \pm 0.2) \times 10^6 \]
$D^+ \rightarrow \mu^+ \nu$

- In the system recoiling against the tagged $D^-$, select leptonic decay for $D^+ \rightarrow \mu^+ \nu$

**Signal selection:**

- One charged track only
- Positively identified $\mu$
- No isolate photon
$D^+ \rightarrow \mu^+ \nu$ 

There are still some backgrounds 

The $K^0_L$ escape from the detector.
Backgrounds for $D^+ \to \mu^+ \nu$

Estimated with Monte Carlo events

| Source mode                  | Number of events |
|------------------------------|------------------|
| $D^+ \to K_L^0 \pi^+$        | $7.9 \pm 0.8$    |
| $D^+ \to \pi^+ \pi^0$       | $3.8 \pm 0.5$    |
| $D^+ \to \tau^+ \nu_\tau$   | $6.9 \pm 0.7$    |
| Other decays of $D$ mesons   | $17.9 \pm 1.1$   |
| $e^+ e^- \to \gamma \psi(3686)$ | $0.2 \pm 0.2$  |
| $e^+ e^- \to \gamma J/\psi$ | $0.0 \pm 0.0$   |
| $e^+ e^- \to \text{light hadron (continuum)}$ | $8.2 \pm 1.4$  |
| $e^+ e^- \to \tau^+ \tau^-$  | $1.9 \pm 0.5$   |
| $\psi(3770) \to \text{non-D} \bar{D}$ | $0.9 \pm 0.4$  |
| **Total**                    | **47.7 \pm 2.3** |

G.S. Huang

FPCP2012, May 21-25
**D^+ \rightarrow \mu^+ \nu**: Preliminary Results

\[ N(D^+ \rightarrow \mu^+ \nu) = 377.3 \pm 20.6 \]

\[ B(D^+ \rightarrow \mu^+ \nu) = (3.74 \pm 0.21^{\text{stat}} \pm 0.06^{\text{sys}}) \times 10^{-4} \]

\[ f_{D^+} = (203.91 \pm 5.72^{\text{stat}} \pm 1.97^{\text{sys}}) \text{ MeV} \]
Charm Physics (all preliminary)

- $D^+ \rightarrow \mu^+ \nu$
- $D^0 \rightarrow K^-/\pi^- e^+ \nu$
- Search for $D^0 \rightarrow \gamma\gamma$
- Ds tagging
D⁰ Tagging

| Mode                  | Data Yield       |
|-----------------------|------------------|
| \( D^0 \rightarrow K^-\pi^+ \) | 159,929 ± 413    |
| \( D^0 \rightarrow K^-\pi^+\pi^0 \) | 323,348 ± 667    |
| \( D^0 \rightarrow K^-\pi^+\pi^0\pi^0 \) | 78,467 ± 480    |
| \( D^0 \rightarrow K^-\pi^+\pi^-\pi^+ \) | 211,910 ± 550   |
D⁰ → K/π e ν

BESIII Preliminary

N_{sig} = 18460+/−143

D⁰ → K e ν

D⁰ → π e ν

| Mode               | measured branching fraction(%) | PDG         | CLEOc              |
|--------------------|--------------------------------|-------------|--------------------|
| $\bar{D}^0 \to K^+ e^- \bar{\nu}$ | 3.542 ±0.030±0.067 | 3.55 ±0.04 | 3.50 ±0.03 ±0.04  |
| $\bar{D}^0 \to \pi^+ e^- \bar{\nu}$ | 0.288 ±0.008±0.005 | 0.289 ±0.008 | 0.288 ±0.008±0.003 |

BESIII preliminary, with 0.92 fb⁻¹ data, will improve with full 2.9 fb⁻¹ soon. Form factor measurement ongoing.
Charm Physics (all preliminary)

- $D^+ \rightarrow \mu^+ \nu$
- $D^0 \rightarrow K^-/\pi^- e^+ \nu$
- **Search for $D^0 \rightarrow \gamma \gamma$**
- $D_s$ tagging
Search for $D^0 \rightarrow \gamma \gamma$

- Forbidden FCNC transition ($c \rightarrow u + \gamma$);
- SM prediction: $B(D^0 \rightarrow \gamma \gamma) \sim 10^{-8}$ or less;
- Results presented in $B(D^0 \rightarrow \gamma \gamma)/B(D^0 \rightarrow \pi^0 \pi^0) < 5.8 \times 10^{-3}$ UL @ 90% CL, or $B(D^0 \rightarrow \gamma \gamma) < 4.6 \times 10^{-6}$ UL @ 90% CL (preliminary, to be improved);
- PDG $2.7 \times 10^{-5}$, CLEO-c preli. $8.63 \times 10^{-6}$, BaBar $2.2 \times 10^{-6}$.

$D^0 \rightarrow \gamma \gamma$: $-2.9 \pm 7.1$ events

$D^0 \rightarrow \pi^0 \pi^0$: $4081 \pm 117$ events
Charm Physics (all preliminary)

- $D^+ \rightarrow \mu^+\nu$
- $D^0 \rightarrow K^-/\pi^- e^+\nu$
- Search for $D^0 \rightarrow \gamma\gamma$
- Ds tagging
D_s Tag
(part of data @ 4010 MeV)

f_{D_s} (both \mu and \tau modes ) measurement underway

Note: this data is at 4010 MeV: \sim 0.3 nb of D_s^+ D_s^-

We plan to run at 4170 MeV: \sim 0.9 nb of D_s^{*+} D_s^-

pro: higher cross-section; con: need D_s^* transition photon (D_s^{*+} \rightarrow \gamma D_s^+)
τ Mass Scan
$\tau$ Mass measurement

$M_\tau = 1776.96^{+0.18+0.25}_{-0.21-0.17}$ MeV

$\sigma M_\tau / M_\tau = 1.7 \times 10^{-4}$

BES results: stat. err. (0.18 / 0.21)
is compatible with syst. (0.25 / 0.17)

12 points, Lum.: 5 pb$^{-1}$
τ Mass measurement in 2012

New beam energy measurement system with a precision of $5 \times 10^{-5}$;
Data at 4 energy points were taken, $\sim 5 \text{ pb}^{-1}$ at the $\tau$ threshold;
Expect statistical precision is $\pm 0.3 \text{ MeV}$, systematic error $< 0.1 \text{ MeV}$;
More data expected later this year to reduce statistical precision to 0.1 MeV.
BESIII is successfully operating since 2008:
- World largest data samples at J/ψ, ψ(2S), ψ(3770), ψ(4040), still growing...

Light quark states:
- Confirmation the enhancement at p̅p threshold in J/ψ→γp̅p, J^{PC}=0^{-+}.
- First observation: η(1405)→f_0(980)π^0 (isospin breaking).
- ωφ threshold enhancement in J/ψ→γωφ.
- ηη system in J/ψ→γηη.

Charmonium transitions and decays:
- Precision measurements of h_c and η_c(1S) properties.
- First observation of η_c(2S) in ψ(2S)→γη_c(2S) decay.
- First evidence of ψ(2S)→γγJ/ψ.

Charm decays:
- D^+ → μ^+ν, D^0 → K/π e ν, D^0 → γγ.

τ mass measurement.

Lots of results published, more to come!