First Results from BESIII: Charmonium à la Carte

Roy A. Briere

Carnegie Mellon
(+ CLEO & BESIII)

LNS Journal Club
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Outline

Introduction: Collaborating in Beijing

Status: The BEPCII Accelerator & BESIII Detector

Charmonium Physics
1) $h_c$ studies: absolute BF
   
2) $\chi_{c0}, \chi_{c2} \rightarrow \pi^0\pi^0, \eta\eta$

3) Low-mass $p\overline{p}$ enhancement in tagged $J/\psi \rightarrow \gamma pp$

2010: First Open Charm Data Run

Conclusions [ more info: http://bes3.ihep.ac.cn/ ]
Introduction:
Collaborating in Beijing
BESIII Collaboration

25 Chinese groups  ( IHEP host lab + Universities )

8 European  ( 3 German, 2 Italian, 2 Russian, 1 Dutch )

6 US groups  ( see next page )

3 other Asian  ( Japan, Korea, Pakistan )

Still adding new groups...

First papers:  36 groups (of 42 listed above)
293 Authors;  148 from IHEP
CLEOns @ IHEP

Carnegie Mellon: Briere + postdoc Chunlei Liu
  dE/dx calibration (both); DTag software (Liu);
  (open) Charm co-convener (RAB)

U. Minn: Poling, Cronin-Hennessy + pdoc Zweber + grads
  MC Farm; DTag Coordinator (Zweber -> industry soon)

U. Rochester: Thorndike + many

Indiana U.: Shepherd, Mitchell, + ?

Past Interest from:
  RPI (no $$), Florida (Yelton settled on CMS)

Other US groups: Hawaii  (F. Harris only PI; S. Olsen now in Korea),
  U. Washington  (small: 1 author)
More on (sic) Working in Beijing

Collaboration meetings
> 2 per year; 1 @ IHEP, 1 @ Chinese university
  “typically” Jan & summer; in some flux
> 2 additional software workshops per year

Lots of “video” conference meetings (or just audio +pdf)
> Beijing is EDT+12 hrs (EST+13) easy to remember, hard to do!
> ~bi-weekly Physics/Software meeting
> ~bi-weekly “PTA” meetings (charm, charmonium, light hadrons)

I tried to take Chinese last fall, on sabbatical
> Characters and a tonal language: tough combination
> I did learn a lot more than I had picked up on the fly
> I can bargain while shopping with Chinese numbers now
> But... the single biggest thing I learned:
All teaching faculty should take a course every 10 years or so!  (It's my 11th year)

> It's hard to learn something you don't already know
> I suspect it's even harder to do 4-5 at once
> I kind of gave up 1/2 way through
  (ironically, when I missed some classes due to being in Beijing...)

But I can say things like:

Nihao! Wo jiao Roy; wo shi wu li laoshi.

(and I'm ever-so-slightly nicer to my students)
Large EVO-based Meeting...

Organization: *CLEO*-esque

- Officers
- Conveners ("PTA" chairs)
- Standing committees
- Paper committees
- Different: Executive Board, Institutional Board
Status:
The BEPCII Accelerator & BESIII Detector
BEPC II

Key features vs. CESR-c

- Two-Ring machine (BEPC → BEPCII)
- Smaller radius (built for low energy)

So equal stored current is fewer particles than CESR...
But, collision frequency is correspondingly higher

What I miss:

- Control room is not as close to counting room
- Can't read an online machine log

So... it's hard to get a good feeling of what's happening in real time!

Have lately been trying to have Chinese speakers in US groups translate Chinese minutes of weekly “runman” meetings...

But I can see currents, luminosity, etc. in real time (some plots a bit later on... and as a database, unlike CESR scoreboard)
BEPC II Storage ring:
Large crossing angle, double-ring

- Beam energy: 1 - 2 GeV
- Luminosity: 1 x 10^{33} cm^{-2}s^{-1}
- Optimum energy: 1.89 GeV
- Energy spread: 5.16 x 10^{-4}
- No. of bunches: 93
- Bunch length: 1.5 cm
- Total current: 0.91 A
- SR mode: 0.25A @ 2.5 GeV
BEPCII Peak Luminosity trend (2008-7-15 to 2009-5-13)

$3.01 \times 10^{32} \text{cm}^{-2} \text{s}^{-1}$

Removal of screen monitor

$\psi(2s)$ data

$v_x = 0.51$

$\psi(2s)$ data

Optimization, vacuum, …

SR
Peak Luminosity History

After less than one year, new BEPCII accelerator provided more than four times the best collision rate from CESR-c!
Main parameters achieved in collision mode

( may be a bit dated now… )

<table>
<thead>
<tr>
<th>parameters</th>
<th>design</th>
<th>Achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BER</td>
<td>BPR</td>
</tr>
<tr>
<td>Energy (GeV)</td>
<td>1.89</td>
<td>1.89</td>
</tr>
<tr>
<td>Beam curr. (mA)</td>
<td>910</td>
<td>650</td>
</tr>
<tr>
<td>Bunch curr. (mA)</td>
<td>9.8</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Bunch number</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>RF voltage</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>$\nu_s @1.5MV$</td>
<td>0.033</td>
<td>0.032</td>
</tr>
<tr>
<td>$\beta_x*/\beta_y*$ (m)</td>
<td>1.0 / 0.015</td>
<td>~1.0 / 0.016</td>
</tr>
<tr>
<td>Inj. Rate (mA/min)</td>
<td>200 e⁻ / 50 e⁺</td>
<td>&gt;200</td>
</tr>
<tr>
<td>Lum. ($10^{33}$cm⁻²s⁻¹)</td>
<td>1</td>
<td>0.30</td>
</tr>
</tbody>
</table>
BESIII detector

- Magnet yoke
- SC magnet, 1T
- RPC
- TOF, 90 ps
- Be beam pipe
- MDC, 120 µm
- CsI(Tl) calorimeter, 2.5% @ 1 GeV
Spokesperson Yifang Wang in front of BESIII (Jan’08)
BESIII Detector, vs. CLEO-c

Key features vs. CLEO-c

> All-in-one drift chamber
> TOF, not RICH, to aid dE/dx
> Gap between CsI barrel and endcap
> More ambitious muon system

Design and Construction of the BESIII Detector
NIM A614 (2010) 345-399

Chinese Physics C also has many (~20) articles on tests, software, calibration, MC studies, etc.
EMC: Projective Endcap, but w/ gap

A bit different than CLEO

CLEO-c

BESIII
BESIII Counting Room
First collision event on July 19, 2008

13 Million $\psi(2S)$ events collected in 2008 (engineering data)
**dE/dx Calibration**

**Manpower:**
- Chunlei & I from CMU  
  [see, Ed? I wrote “I”!]
- Student(s) from IHEP + (busy!) supervisor

Note: I look at J/ψ data with 2 undergrads; good practice for me...

\[ J/ψ \rightarrow pp\pi\pi, KK\pi\pi \]
Flies in the Ointment

Overall, a very smooth start-up, but...

Drift chamber noise limits currents; some reduced HV
Muon endcap has never really functioned properly
  (conveniently, the least important detector)

One bad experience w/ cooling water & electronics

Positron injection slow... improving
  limits turning peak lumi into integrated lumi

Equipment breakdowns:
  > quite rare overall
  > quenches mostly only early on
  > misc. magnet issues (only one serious recently)
Charmonium Physics
Charmonium Samples

2008:
Startup in July, engineering data

2009:
~105 $M \psi'$ (vs. 27 $M$ @ CLEO-c)
~225 $M$ J/$\psi$ (vs. 57 $M$ @ BESII: w/ poor EMC)

Beam-energy spread a bit smaller than CESR-c,
so effective cross-section is a bit higher... [~10% ?]

Synchrotron runs are separate; about 5 months
of HEP physics running per calendar year
(some things never change... )
$h_c$ Introduction

Last low-lying charmonium state; found by CLEO-c

**BES analysis:**
- Inclusive: $\psi' \rightarrow \pi^0 \ h_c$ using $\pi^0$ recoil mass
- E1-tagged: inclusive plus see $\gamma$ from $h_c \rightarrow \gamma \ \eta_c$

Use both to get separate absolute Branching Fractions

**Data Samples:**
- $(106 \pm 4)$ Million $\psi'$
- $42.6 \ \text{pb}^{-1} @ 3.65 \ \text{GeV}$
$h_c$ Analysis Cuts

Barrel $\gamma$: $E_\gamma > 25$ MeV $|$cos$\theta|$ < 0.80
Endcap $\gamma$: $E_\gamma > 50$ MeV $0.86 < |\cos{\theta}| < 0.92$
Isolation: $\geq 10^o$ from any track

$\pi^0$: 120 - 145 MeV (about -1.5 to +2.0 $\sigma$)

$1-C$ kinematic fit improves $E$ resolution
raise barrel cut to $E_\gamma > 40$ MeV
[ also “no other $\pi^0$ veto” for all transition $\gamma$, plus $\pi^0$ in incl. analysis ]

Candidate events:

a) at least two tracks, at least one passing:
   $|\cos{\theta}| < 0.93$ $|\Delta z| < 10$ cm $|\Delta r| < 1$ cm
b) $>0.6$ GeV in EMC

Background suppression:

$\pi^+\pi^- (\pi^0\pi^0)$ recoil mass $>7 (>15)$ MeV from $J/\psi$ mass
**h_c Recoil-Mass Plots**

**E1-tagged:**
- Events: $3679 \pm 319$ events
- Fit $\chi^2 = 33.5/36$
- Efficiency: $7.57\%$

Gives product BF

**Inclusive:**
- Events: $10353 \pm 1097$
- Fit $\chi^2 = 24.5/34$
- Efficiencies:
  - $12.89\%$ (E1 $h_c$)
  - $10.02\%$ (hadr. $h_c$)

Gives $h_c$ production BF, but efficiency weighting depends on $h_c$ decay BF!

**FIG. 1:** (a) The $\pi^0$ recoil mass spectrum and the fit for the E1-tagged analysis of $\psi' \rightarrow \pi^0 h_c, h_c \rightarrow \gamma \eta_c$; (b) The $\pi^0$ recoil mass spectrum and fit for the inclusive analysis of $\psi' \rightarrow \pi^0 h_c$. Fits are indicated by solid lines, background by dashed lines. The respective background-subtracted spectra are shown in the insets.
**h_c Systematics**

**Study Samples:**

\[ \pi^0 \text{ efficiency, resolution} \]

\[ \psi' \rightarrow \pi^0\pi^0 \ J/\psi, \ J/\psi \rightarrow ll \]

**E1 photon selection:**

\[ e^+ e^- \rightarrow e^+ e^- \gamma \]

(normalize with recoil mass)

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**TABLE I: Summary of systematic errors.**

<table>
<thead>
<tr>
<th>Source</th>
<th>(M(h_c)(\text{MeV}/c^2))</th>
<th>(\Gamma(h_c)(\text{MeV}/c^2))</th>
<th>(B_1(10^{-4}))</th>
<th>(B_1 \times B_2(10^{-4}))</th>
<th>(B_2(%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background shape and fit range</td>
<td>0.11</td>
<td>0.23</td>
<td>0.4</td>
<td>0.22</td>
<td>4.4</td>
</tr>
<tr>
<td>Energy scale, position reconstruction and 1-C fit</td>
<td>0.13</td>
<td>0.06</td>
<td>0.5</td>
<td>0.10</td>
<td>2.1</td>
</tr>
<tr>
<td>Energy resolution</td>
<td>0.00</td>
<td>0.15</td>
<td>0.2</td>
<td>0.03</td>
<td>1.0</td>
</tr>
<tr>
<td>Background veto</td>
<td>0.05</td>
<td>0.03</td>
<td>0.0</td>
<td>0.03</td>
<td>0.3</td>
</tr>
<tr>
<td>(\pi^0) efficiency</td>
<td>0.00</td>
<td>0.00</td>
<td>0.3</td>
<td>0.14</td>
<td>0.0</td>
</tr>
<tr>
<td>(E1) photon efficiency</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>0.10</td>
<td>1.2</td>
</tr>
<tr>
<td>Number of (\pi^0)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.6</td>
<td>0.35</td>
<td>0.6</td>
</tr>
<tr>
<td>Number of charged tracks</td>
<td>0.00</td>
<td>0.00</td>
<td>0.1</td>
<td>0.06</td>
<td>0.1</td>
</tr>
<tr>
<td>(N(\psi'))</td>
<td>0.00</td>
<td>0.00</td>
<td>0.4</td>
<td>\textbf{0.19}</td>
<td>0.0</td>
</tr>
<tr>
<td>(M(\psi'))</td>
<td>0.03</td>
<td>0.02</td>
<td>0.0</td>
<td>0.00</td>
<td>0.0</td>
</tr>
<tr>
<td>(M(\eta_c)) and (\Gamma(\eta_c))</td>
<td>0.00</td>
<td>0.00</td>
<td>0.0</td>
<td>0.01</td>
<td>0.3</td>
</tr>
<tr>
<td>Total systematic error</td>
<td>0.18</td>
<td>0.28</td>
<td>1.0</td>
<td>0.50</td>
<td>5.2</td>
</tr>
</tbody>
</table>
**h_c Results**

\[ B( \psi' \rightarrow \pi^0 h_c ) = (8.4 \pm 1.3 \pm 1.0) \times 10^{-4} \]
\[ B( h_c \rightarrow \gamma \eta_c ) = (54.3 \pm 6.7 \pm 5.2) \% \]

\[ M( h_c ) = (3525.40 \pm 0.13 \pm 0.18) \text{ MeV} \]
[CLEO: 3525.20 \pm 0.18 \pm 0.12]

**Hyperfine splitting:**
\[ <M^{3P_1}> - M^{(1P_1)} = -0.10 \pm 0.13 \pm 0.18 \]

\[ \Gamma( h_c ) < 1.44 \text{ MeV 90\% CL} \quad (0.73 \pm 0.45) \]

**Similar to values for \( B( \chi_{c1} \rightarrow \gamma J/\psi ) \) and \( \Gamma( \chi_{c1} ) \)**
\(\chi_{c0}, \chi_{c2} \rightarrow \pi^0\pi^0, \eta\eta: \) Analysis

\(\chi_{c1}\) modes forbidden by spin-parity

Cuts generally similar to \(h_c\) analysis...

Use decay angle cuts on \(\pi^0, \eta\)

5 or 6 photons, no charged tracks

efficiencies \(\sim 50\%\) (no need for isolation cuts!)

A "\(p_T^2\)" cut reduces missing particle background

( based on angle between \(\pi^0\pi^0\) recoil and radiative photon )
\( \chi_{c0}, \chi_{c2} \rightarrow \pi^0\pi^0, \eta\eta: \) Systematics

**TABLE II: Systematic uncertainties expressed in percent.**

<table>
<thead>
<tr>
<th>Mode</th>
<th>( \chi_{c0} \rightarrow \pi^0\pi^0 )</th>
<th>( \chi_{c2} \rightarrow \pi^0\pi^0 )</th>
<th>( \chi_{c0} \rightarrow \eta\eta )</th>
<th>( \chi_{c2} \rightarrow \eta\eta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>photon detection</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>( \pi^0(\eta) ) reconstruction</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>( p_T^2 \gamma )</td>
<td>0.9</td>
<td>1.2</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>( \chi_\eta \eta )</td>
<td>-</td>
<td>-</td>
<td>0.6</td>
<td>2.6</td>
</tr>
<tr>
<td>signal shape</td>
<td>1.6</td>
<td>1.2</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>background shape</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>fitting range</td>
<td>0.3</td>
<td>0.3</td>
<td>0.8</td>
<td>1.3</td>
</tr>
<tr>
<td>trigger</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>( N_{\psi'} )</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>7.0</td>
<td>6.9</td>
<td>6.9</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Study Samples:

- \( \pi^0, \eta \) selection:
  - \( J/\psi \rightarrow \pi^+\pi^-\pi^0 \)
  - \( J/\psi \rightarrow \eta \ p \bar{p} \)
    (recoil mass)

- Photon detection, conversion:
  - \( J/\psi \rightarrow \rho^0\pi^0 \)
  - \( e^+ e^- \rightarrow \gamma \gamma \)
χ_{c0}, χ_{c2} \rightarrow π^0π^0, ηη: Results

TABLE III: Branching fraction results (in units of 10^{-3}) for each decay mode. The uncertainties are statistical, systematic due to this measurement, and systematic due to the branching fractions of ψ' → γχ_{cJ}, respectively. CLEOc results are determined using their own branching fractions for ψ' → γχ_{cJ}, while ours are determined using branching fractions from the PDG. If we use the CLEOc branching fractions, we find Br(χ_{c0} → π^0π^0) = 3.29 \times 10^{-3}, Br(χ_{c0} → ηη) = 3.51 \times 10^{-3}, Br(χ_{c2} → π^0π^0) = 0.78 \times 10^{-3}, and Br(χ_{c2} → ηη) = 0.58 \times 10^{-3}.

<table>
<thead>
<tr>
<th>Mode</th>
<th>χ_{c0}</th>
<th>χ_{c2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>$π^0π^0$</td>
<td>This Work: 3.23 ± 0.03 ± 0.23 ± 0.14</td>
<td>0.88 ± 0.02 ± 0.06 ± 0.04</td>
</tr>
<tr>
<td></td>
<td>CLEOc [2]: 2.94 ± 0.07 ± 0.32 ± 0.15</td>
<td>0.68 ± 0.03 ± 0.07 ± 0.04</td>
</tr>
<tr>
<td></td>
<td>PDG [10]: 2.43 ± 0.20</td>
<td>0.71 ± 0.08</td>
</tr>
<tr>
<td>$ηη$</td>
<td>This Work: 3.44 ± 0.10 ± 0.24 ± 0.13</td>
<td>0.65 ± 0.04 ± 0.05 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>CLEOc [2]: 3.18 ± 0.13 ± 0.31 ± 0.16</td>
<td>0.51 ± 0.05 ± 0.05 ± 0.03</td>
</tr>
<tr>
<td></td>
<td>PDG [10]: 2.4 ± 0.4</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>

Bit higher than CLEO; closer when consistent ψ' → γχ_{c} BF used

BUT: we both agree old PDG is mostly too low... (3 of 4 cases)
$J/\psi \rightarrow \gamma p \bar{p}$: “Teaser Plots”
(shown at CHARM 2009, FPCP2009)

$M_{pp} - 2m_p$ (GeV)

**BESII**

**J/ψ**

Threshold resonance!

**ψ'**

NO threshold resonance!

**BESIII**

preliminary

~ 3x broader full-scale

**BESIII**

preliminary
\[ \frac{J}{\psi} \rightarrow \gamma \ p \ \bar{p} \]

Low-mass ppbar enhancement seen in BESII
But, NOT seen in \( \psi' \) decays

Ironically, we confirm with \( \psi' \)-tagged \( \frac{J}{\psi} \), with no mention of analogous \( \psi' \) decay in the paper...
( but it’s still absent! You saw “teaser plots” from ’09 confs )

Also NOT observed in other cases:
\( \bar{p}p \) cross-sections, B decays, \( \gamma \rightarrow \gamma \ p \ \bar{p} \) \( \frac{J}{\psi} \rightarrow \omega \ p \ \bar{p} \)
Dis-favors a pure final-state interaction (FSI) explanation

New BESIII data:
$J/\psi \rightarrow \gamma p \bar{p}$

**Control sample:**

$J/\psi \rightarrow \pi^0 p \bar{p}$

**S-wave B-W fit:**

$M = 1861^{+6}_{-13}^{+7}_{-26}$ MeV

$\Gamma < 38$ MeV

It's certainly fair to discuss the best way to fit this, but clearly something is happening.
2010:
First Open Charm Data Run
Current and Inst. Lumi. Cycles

600 mA

200 mA

$0.2 \times 10^{33}$

$0.0 \times 10^{33}$

2 hours between labels
**Best Week in Current Run**

**Instantaneous Luminosity**

- $0.2 \times 10^{33}$
- $0.0 \times 10^{33}$

**Integrated Luminosity**

- $65 \text{ pb}^{-1}$

Dates:
- 19 Mar
- 26 Mar
Integrated Luminosity

30 days with 200 pb$^{-1}$

Issues:

- Top-off + start/stop: can be 30 min. !!!
  Recent improvements, but still variable
- Consistency
- Peak lumi and lifetime
Reality...

A small lull...

Best rate ever... (10 \( pb^{-1} \)/day)

Kicker magnet fails !!! (almost 2 weeks)
Open Charm: Statistics

Run in progress now!

Data sample:

- 375 pb\(^{-1}\) from mid-Jan mid-April
  - [includes 2 weeks of kicker magnet downtime; 150/month for rest of time...]

  *Should* be able to take \(\sim 250\) pb\(^{-1}\) /month now
  - [all-out push at end of CLEO-c 3770: \(\sim 100\) /month
    - Have 3.5x peak, can get >2.5x integrated?]

Rest of run:

- Approved until about mid-June, perhaps more?
- Would like to exceed CLEO-c [it's doable]
- Possibly take a two-week (3770) scan...

(1 fb\(^{-1}\) now tough, w/o luck & extension & no scan)
Conclusions

Detector and accelerator successfully commissioned; a few teething pains, but no show-stoppers

World’s best Charmonium data samples; already publishing results

Open-charm physics data run in progress

Stay tuned for more! Should be a big wave of results for summer conferences...