Recent Results from CLEO

(selected topics among the most recent results)

Tomasz Skwarnicki
After 29 years CLEO program comes to an end

- CLEO-I (1979-89)
  - CsI calorimeter
- CLEO-II (1989-95)
  - Silicon Vertex Detector
- CLEO-II.V (1995-99)
  - Silicon Vertex Detector
- CLEO-III (2000-03)
  - RICH Particle ID
  - New IR & tracking: Silicon, Drift Chamber
- CLEO-c (2003-08)
  - Silicon replaced by ZD inner drift chamber

CESR-b (∼10.6 GeV): \( L = 1.2 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \)
CESR-c (∼4.0 GeV): \( L = 0.7 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \)

Last data taken: Run # 234607 Start: 07:38:06 End: 08:00:19 Date: 3/3/2008
## CLEO-III/CLEO-c data samples

<table>
<thead>
<tr>
<th>Detector</th>
<th>Energy or $\overline{Q}Q$ resonance (targeted $Q\overline{Q}$ meson)</th>
<th>Luminosity $fb^{-1}$</th>
<th>Narrow resonance statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO-III</td>
<td>11.227-11.383 GeV</td>
<td>0.71</td>
<td></td>
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<tr>
<td></td>
<td>Y(5S) ($B_s$)</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y(4S) ($B$) + cont</td>
<td>6.2 + 2.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y(3S) + cont</td>
<td>1.2 + 0.2</td>
<td>6M</td>
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<tr>
<td></td>
<td>Y(2S) + cont</td>
<td>1.2 + 0.4</td>
<td>9M</td>
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<tr>
<td></td>
<td>Y(1S) + cont</td>
<td>1.1 + 0.2</td>
<td>22M</td>
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<tr>
<td></td>
<td>$6.9 - 8.4$</td>
<td>0.02</td>
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<tr>
<td>CLEO-c</td>
<td>4.17 ($D_s$)</td>
<td>0.586</td>
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<tr>
<td></td>
<td>3.97-4.26</td>
<td>0.06</td>
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<tr>
<td></td>
<td>$\psi(3770)$ ($D$)</td>
<td>0.818</td>
<td></td>
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<tr>
<td></td>
<td>$\psi(2S)$</td>
<td>0.054</td>
<td>27M</td>
</tr>
<tr>
<td></td>
<td>3.673</td>
<td>0.021</td>
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</tbody>
</table>
Recent CLEO Results Meson08  T. Skwarnicki

Search for light CP-odd Higgs

- **SM Higgs**

\[
\tilde{H}_{SM} = \begin{pmatrix} \phi_+^0 \\ \phi_0 \end{pmatrix} \Rightarrow \text{Longitudinal components of } W^+, W^-, Z^0
\]

- Electroweak symmetry breaking
- Direct searches at LEP2: \( e^+ e^- \rightarrow Z^0 h^0, h^0 \rightarrow b\bar{b} \) \( m(h^0) > 114 \text{ GeV} \)
- Precision EW measurements: \( m(h^0) = 89^{+38}_{-28} \text{ GeV} \)

- **MSSM**

- Fixes hierarchy problem (stabilizes \( h^0 \) mass, \( m(h^0) \ll M_{\text{Planck}} \) natural)

\[
\tilde{H}_{up} = \begin{pmatrix} \phi_{up}^+ \\ \phi_{up}^0 \end{pmatrix}, \quad \tilde{H}_{dn} = \begin{pmatrix} \phi_{dn}^0 \\ \phi_{dn}^- \end{pmatrix} \Rightarrow \text{L.c. of } W^+, W^-, Z^0
\]

- \( h^0 \) SM-like. The LEP2 lower limit applies. \( h^0, H^0 \) heavy.
- \( m(A^0) > m(h^0) \). \( A^0 \) heavy.
- Coupling of \( A^0 \) to down(up-)type fermions \( \propto m_f \tan \beta \) (\( m_f / \tan \beta \))
- Theoretically expect \( h^0 \) to be light: \( m(h^0) < 100 \text{ GeV} \)
- \( \mu \)-problem: \( \mu \tilde{H}_{up} \tilde{H}_{dn} \) why \( \mu \ll M_{\text{Planck}} \)?
Search for light CP-odd Higgs

- NMSSM
  - Fixes $\mu$-problem: \[ \lambda \hat{S} \hat{H}_{up} \hat{H}_{dn}, \quad \mu_{\text{eff}} = \lambda \langle \hat{S} \rangle \quad (\mu << M_{\text{Planck}} \text{ natural}) \]

\[
\begin{align*}
\hat{H}_{up} &= \begin{pmatrix} \phi_{up}^0 \\ \phi_{up} \end{pmatrix}, \\
\hat{H}_{dn} &= \begin{pmatrix} \phi_{dn}^0 \\ \phi_{dn} \end{pmatrix}, \\
\hat{S} &= \begin{pmatrix} \phi_s^0 \\ \phi_s \end{pmatrix} \\
\end{align*}
\]

\[
L.c. \text{ of } W^+, W^-, Z^0 \quad H^+, H^- \quad h^0, H^0, h_s^0 \quad A^0, a_s^0
\]

- Lightest CP-odd Higgs is a mixture:
  \[ a_1^0 = A^0 \cos \theta_A - a_s^0 \sin \theta_A \]

- $m(a_1^0) < m(h^0)$ possible

- If $m(a_1^0) < 2 \, m_b$ then $a_1^0 \not\to b\bar{b}$ and $B(h^0 \to b\bar{b}) \ll B(h^0 \to a_1^0 a_1^0)$ i.e. both $h^0 & a_1^0$ evade the LEP2 lower mass limit based on $b\bar{b}$ final state:
  - Relieves “tension” between the direct LEP2 limit and precision EW measurements
  - Relieves “tension” between the direct LEP2 limit and SUSY preference for light $h^0$
  - Scenario advocated by Dermisek,Gunion,McElrath [PRD76,051105(R),2007]

- Coupling of $a_1^0$ to down(up)-type fermions
  \[ \propto \, m_i \cos \theta_A \tan \beta \quad (m_i \cos \theta_A / \tan \beta); \quad \cos \theta_A \text{ decreases with } \tan \beta \]
Search for light CP-odd Higgs

\[
\frac{B(\Upsilon(1S) \rightarrow \gamma a_1^0)}{B(\Upsilon(1S) \rightarrow \mu^+ \mu^-)} = \frac{G_F m_b^2}{\sqrt{2} \pi \alpha} g_d^2 \left( 1 - \left( \frac{m(a_1^0)}{m(\Upsilon(1S))} \right)^2 \right)
\]

\[
g_d^2 \propto \cos^2 \theta_A \tan^2 \beta
\]

- Good place to produce $a_1^0$ with mass $m(a_1^0) < 2 m_b$:
  - Favored over lighter mesons by:
    - $m_f$ dependence of the coupling
    - $\tan \beta$ dependence of the coupling (compared to charmonium)
    - phase-space

Dermisek, Gunion, McElrath [PRD76,051105(R),2007]
Search for light CP-odd Higgs

- We have searched for \( Y(1S) \rightarrow \gamma a_{1}^{0}, a_{1}^{0} \rightarrow \tau^{+}\tau^{-} \) 
  \( (a_{1}^{0} \rightarrow \mu^{+}\mu^{-} \text{ for } m(a_{1}^{0}) < 2 m_{\tau}) \)
  - \( B(a_{1}^{0} \rightarrow \tau^{+}\tau^{-}) \)
    - completely dominates for large \( \tan\beta \) (and \( m(a_{1}^{0}) > 2m_{\tau} \))
    - must compete with \( B(a_{1}^{0} \rightarrow c\bar{c}) \) for small \( \tan\beta \)
  - \( B(a_{1}^{0} \rightarrow \mu^{+}\mu^{-}) \)
    - large below \( ss \) threshold (\( \sim 1 \text{ GeV} \))
    - \( \sim 100\% \) for \( m(a_{1}^{0}) \) slightly above \( 2m_{\mu} \)

3 \( \Sigma^{+} \rightarrow \rho\mu^{+}\mu^{-} \) events observed by HyperCP
PRL 94, 021801 (2005)

He, Tandean, Valencia suggested it could be a \( a_{1}^{0} \)
PRL 98, 081802 (2007):
  - Fair amount of fine-tuning to reconcile with the limits from \( K \rightarrow \pi \mu^{+}\mu^{-} \)
  - \( g_{d} \sim O(1) \)
  - observable \( B(Y(1S) \rightarrow \gamma a_{1}^{0}) \) [Mangano, Nason
Mod.Phys.Lett.A22, 1373 (2007)]
Search for light CP-odd Higgs

2 oppositely charged tracks + at least 1 photon

\( \gamma^+ \tau^- \)

At least one \( \mu \) or \( e \) (no ee)

\( 2 < \text{missing energy} < 7 \text{ GeV} \)

\( \gamma^+ \mu^- \)

Two \( \mu \)'s

No missing energy

- No significant peaks found except for ISR J/\( \psi \)

Continuum background dominates
Search for light CP-odd Higgs

CLEO-III Preliminary!

- Our $\gamma\tau^+\tau^-$ limits significantly constrain NMSSM models
Search for light CP-odd Higgs

For $m(a_1^0) = 214.3$ MeV

$$B(\Upsilon(1S) \to \gamma a_1^0) B(a_1^0 \to \mu^+ \mu^-) < 2.3 \times 10^{-6}$$
(at 90% C.L.)

$g_d^2 < 0.026$

vs $g_d^2 = 0.12$ used in the
He, Tandean, Valencia paper explaining the HyperCP
events with the $a_1^0$ hypothesis

- Our $\gamma \mu^+ \mu^-$ limit makes $a_1^0$ interpretation of the
HyperCP events difficult
D, D_s decay constants

\[ \Gamma(D^+_q \rightarrow \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_{Dq}^2 m_\ell^2 M_{Dq} \left( 1 - \frac{m_\ell^2}{M_{Dq}^2} \right) |V_{cq}|^2 \]

Helicity suppression of D^+, D_s^+ → e^+\nu

Phase space suppression of D^+ → \tau^+\nu

- Take \( V_{cd} = V_{us} = 0.2256 \), determine \( f_{D,D_s} \) and compare to lattice QCD calculations:
  - “Calibration point” for lattice QCD calculations needed for B, Bs studies
  - Test of S.M. on \( f_D/f_{D_s} \)
Unquenched lattice QCD

- Precision of a few % possible with unquenched calculations
- New predictions of $f_{D^+} = 207 \pm 4$ MeV
  $f_{D_s} = 241 \pm 3$ MeV by Follana et al.
  HPQCD & UKQCD collaborations (PRL 100, 062002 (2008))
D$^+ \rightarrow \mu^+\nu$ with tagging technique

- $e^+e^- \rightarrow \psi(3770) \rightarrow D^+D^-$
  - No fragmentation particles produced

- Reconstruct one $D$ (tag) in several clean hadronic decay modes:
  - Cut on $\Delta E = E_D - E_{\text{beam}}$
  - Fit $M_{bc} = \sqrt{E_{\text{beam}}^2 - p_D^2}$ to determine $N_{\text{tag}}$
  - The tag determines momentum of the other $D$:
    $$p_{D \text{ signal}} = -p_{D \text{ tag}}$$

- Find subsample of events with only one additional oppositely charged track within $|\cos \theta|<0.9$ and no additional photons $>250$ MeV (to veto $D^+ \rightarrow \pi^+\pi^0$)

- Charged track must deposit only minimum ionization in calorimeter [$< 300$ MeV] (can’t use muon system at these low momenta)

- Compute Missing-Mass$^2$. If close to zero then almost certainly we have a $\mu^+\nu$ decay.

$$M^2_{\nu} = M_{\text{MM}}^2 = (E_{\text{beam}} - E_{\mu})^2 - (\vec{p}_{D \text{ signal}} - \vec{p}_{\mu})^2$$
Recent CLEO Results Meson08  T. Skwarnicki

818 pb$^{-1}$ of $\psi(3770)$ data
Entire CLEO-c sample.

- Very good signal/bkg ratio thanks to the threshold kinematics

$D^+ \rightarrow \mu^+\nu$ signal
• $\tau^+\nu/\mu^+\nu$ **fixed** to SM ratio
  – $149.7\pm12.0$ $\mu\nu$ events
  – $28.5\,\tau\nu$
  – $B(D^+\rightarrow\mu^+\nu) = (3.86\pm0.32\pm0.09)\times10^{-4}$
  – $f_{D^+}=(207\pm8.5\pm2.5)$ MeV

• $\tau^+\nu/\mu^+\nu$ is allowed to **float**
  – $153.9\pm13.5$ $\mu\nu$
  – $13.5\pm15.3\,\tau\nu$
  – $B(D^+\rightarrow\mu^+\nu) = (3.96\pm0.35\pm0.10)\times10^{-4}$
  – $f_{D^+}=(208.5\pm9.3\pm2.5)$ MeV

**CLEO-c Preliminary!**

*(small radiative corrections expected, not yet in)*
$D_s^+ \rightarrow \mu^+\nu$

- Reconstruction of tagging $D_s^-$

424 pb$^{-1}$ at $E_{CM}=4170$ MeV

$e^+e^- \rightarrow D_sD_s^*$

$2/3$ of full CLEO-c sample
$D_s^+ \rightarrow \mu^+\nu$

- Counting tagged $D_s^+$ events in $e^+e^- \rightarrow D_s D_s^*$: $30,848 \pm 695$

$$M_{D_s^+}^2 = MM^*^2 = (E_{CM} - E_{D_s^*} - E_\gamma)^2 - \left(\mathbf{p}_{D_s^*} - \mathbf{p}_\gamma\right)^2$$
$D_s^+ \rightarrow \mu^+\nu$ & $D_s^+ \rightarrow \tau^+\nu$

**CLEO-c Preliminary!**

- $\tau^+\nu/\mu^+\nu$ **fixed** to SM ratio
  - $171.1\pm11.5$ $\mu\nu$
  - $B(D_s^+\rightarrow\mu^+\nu)=(6.13\pm0.44\pm0.20)x10^{-3}$
  - $f_{D_s^+}=(268\pm10\pm4)$ MeV

- $\tau^+\nu/\mu^+\nu$ is allowed to **float**
  - $167.7\pm14.5$ $\mu\nu$
  - $43.7\pm10.1$ $\tau\nu$ (significant! $\tau\rightarrow\pi^+\nu$)
  - $B(D_s^+\rightarrow\mu^+\nu)=(6.00\pm0.54\pm0.20)x10^{-3}$
  - $f_{D_s^+}=(265\pm12\pm4)$ MeV
  - $B(D_s \rightarrow\tau\nu) = (61\pm9\pm2)x10^{-3}$
  - $f_{D_s^+}=(271\pm20\pm4)$ MeV
\[ D_s^+ \rightarrow \tau^+\nu, \tau^+ \rightarrow e^+\nu\nu \]

- No \( D_s^+ \rightarrow e^+\nu \) because of helicity suppression
- MM technique not very useful with 3 neutrinos
- Select events with a tag, electron and then look at extra energy in the calorimeter (includes \( \sim 150 \text{ MeV} \gamma \) from \( D_s^* \rightarrow \gamma D_s \))
- \( B(D_s^+ \rightarrow \tau^+\nu) = (6.17 \pm 0.71 \pm 0.36) \times 10^{-2} \)
- \( f_{D_s^+} = (273 \pm 16 \pm 8) \text{ MeV} \)
**CLEO-c $f_{Ds}$ results**

$$\Gamma(D_s^{+} \to \tau^{+}\nu)/\Gamma(D_s^{+} \to \mu^{+}\nu) = 10.3\pm1.1$$

vs SM (lepton universality) = 9.7

<table>
<thead>
<tr>
<th>Mode</th>
<th>$B(%)$</th>
<th>$f_{Ds}$ (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) $\mu\nu+\tau\nu$ (fix at SM ratio)</td>
<td>$B^{\text{eff}}(D_s \to \mu\nu) = 0.613\pm0.044\pm0.020$</td>
<td>$268\pm10\pm4$</td>
</tr>
<tr>
<td>(2) $\mu\nu$ only</td>
<td>$B(D_s \to \mu\nu) = 0.600\pm0.054\pm0.020$</td>
<td>$265\pm12\pm4$</td>
</tr>
<tr>
<td>(3) $\tau\nu$, $\tau\to\pi\nu$</td>
<td>$B(D_s \to \tau\nu) = 6.1\pm0.9\pm0.2$</td>
<td>$271\pm20\pm4$</td>
</tr>
<tr>
<td>(4) $\tau\nu$, $\tau\to e\nu\nu$</td>
<td>$B(D_s \to \tau\nu) = 6.17\pm0.71\pm0.36$</td>
<td>$273\pm16\pm8$</td>
</tr>
</tbody>
</table>

CLEO-c Average of (1) & (4) | $269.4\pm8.2\pm3.9$ |

*Preliminary!*
Conclusions on Decay Constants

- We are in close agreement with the Follana et al calculation for $f_{D^+}$. This gives credence to their calculations.
- The disagreement with $f_{D_s}$ is 3.3σ
Can we trust lattice QCD calculations?

- If theoretical predictions of $f_{D_s}/f_{D^+}$ do not agree with the data, why should we believe $f_{B_s}/f_B$ from theory? What does this do to the CKM fits?
If we can trust lattice QCD calculations...

- **New Physics possibilities:**
  - Dobrescu, Kronfeld, arXiv:0803.0512

A scalar lepto-quark with electric charge of -1/3

A charged Higgs from Two Higgs doublets model in which one doublet gives masses to u,c quarks and charged leptons, and the other doublet gives masses to down type quarks and top

- Kundu, Nandi, arXiv:0803.1898

  Supersymmetry with R-parity violating couplings
M1 Transitions in Charmonium

- Theory:

\[ \Gamma(i \rightarrow f + \gamma) = \frac{4\alpha e_Q^2}{3m_Q^2} (2J_f + 1)k^3 |M_{if}|^2 \]

\[ M_{if} = \int r^2 dr R_{n_i L_i}(r)j_0\left(\frac{rk}{2}\right)R_{n_f L_f}(r) \]

\[ j_0 = 1 - (kr)^2/24 + ..., \text{ so in NR limit} \]

\[ k = 0: \quad M_{if} = 1 \quad n_i = n_f; L_i = L_f \]

\[ = 0 \quad \text{otherwise} \]

\[ \Gamma(J/\psi \rightarrow \eta_c \gamma) = \frac{16}{3} \alpha e_c^2 \frac{k^3}{M_{J/\psi}^2} (1 + \kappa_c)[1 + o(v^2)] \]

LQCD 2.0±0.1±0.4 keV Dudek, Edwards, Richards PRD,73,074507(2007)
Not much different than the naïve calculation

- Experiment:

\[ B(J/\psi \rightarrow \eta_c \gamma) = (1.3\pm0.4)\% \quad \text{Gaiser et al. (Crystal Ball), PRD 34, 711 (1986)} \]

\[ \Gamma(J/\psi \rightarrow \eta_c \gamma) = B(J/\psi \rightarrow \eta_c \gamma) \times \Gamma_{\text{tot}} = (1.2\pm0.3) \text{ keV} \]

Significantly smaller than theoretically predicted!
CLEO-c method

- \(B(J/\psi \rightarrow \gamma \eta_c)\) difficult to measure from inclusive photon spectrum since \(\eta_c\) is broad (25 MeV) and the photon is relatively soft (large background of unknown shape).

- CLEO-c method:

\[
B(J/\psi \rightarrow \gamma \eta_c) = \frac{B(\psi' \rightarrow \gamma \eta_c) \times B(\eta_c \rightarrow X)}{B(\psi' \rightarrow \gamma \eta_c) \times B(\eta_c \rightarrow X)} \times \frac{A}{B}
\]

Measure from inclusive photon spectrum. The photon is hard, thus backgrounds are under control.

Use exclusive reconstruction of a large number of possible final states X (suppresses the backgrounds). Take the ratio to cancel unknown \(B(\eta_c \rightarrow X)\).
CLEO-c M1 transitions to $\eta_c$

- In exclusive approach use 13 signal-rich $\eta_c$ decay modes (some new)
  - Kinematic fitting of events to improve energy resolution
- Non-trivial line-shape in the hindered transition:
  - count signal events above bkg in exclusive sample
  - use exclusive signal shape to fit inclusive spectrum
CLEO-c M1 transitions to $\eta_c$

Branching Ratio | CLEO-c | PDG 2006
--- | --- | ---
$B(\psi(2S) \rightarrow \gamma \eta_c)$ | $(4.32 \pm 0.16 \pm 0.60) \times 10^{-3}$ | $(2.6 \pm 0.4) \times 10^{-3}$
$B(J/\psi \rightarrow \gamma \eta_c)$ | $(1.98 \pm 0.09 \pm 0.30) \times 10^{-2}$ | $(1.3 \pm 0.4) \times 10^{-2}$

• **The hindered M1 rate $B(\psi(2S) \rightarrow \gamma \eta_c)$:**
  - Previous measurements low since they neglected the high energy tail in the signal shape.
  - Theoretical predictions difficult because of the suppressed character of the matrix element.

• **The direct M1 rate $B(J/\psi \rightarrow \gamma \eta_c)$:**
  - Measured via exclusive event reconstruction. Significantly higher than previously measured by Crystal Ball from inclusive photons.
  - Agrees well with the theoretical expectations. Mystery solved.
New improved determination of $h_c$ mass

CLEO-c arXiv:0805.4599 [hep-ex]

- A factor of $\sim 6$ larger statistics than in the initial publication

$\eta_c$ reconstructed in one of 15 exclusive decay modes

Inclusive
- 1146±118 $h_c$ events
  - $10\sigma$
  - $3525.35\pm0.23\pm0.15$ MeV

Exclusive
- 136±14 $h_c$ events
  - $13\sigma$
  - $3525.21\pm0.27\pm0.14$ MeV
New improved determination of $h_c$ mass

- Averaging inclusive and exclusive results:
  - CLEO-c: $m(h_c(1^1P_1)) = 3525.28 \pm 0.19 \pm 0.12$ MeV
  - vs. spin-averaged $m(\chi_c(1^3P_J)) = 3525.30 \pm 0.11$ MeV

- Thus, hyperfine mass splitting of $1P$ states is $0.02 \pm 0.19 \pm 0.13$ MeV
  - vs. hyperfine splitting of $1S$ states of 115 MeV
  - consistent with naïve theoretical prejudice that spin-spin interactions are only short-range and, therefore, not present in $1P$ states
  - surprisingly small given that corrections to the naïve expectation may be several MeV (see J. M. Richard, Proc. 15th Int. Workshop, DIS 2007 (Munich), Ed. G. Grindhammer and K. Sachs, DESY-PROC-2007-01, p. 849.)
Other recent quarkonium measurements

- Measurement of $\mathbf{B}(\chi_{c0,2} \rightarrow \gamma \gamma) = (2.4 \pm 0.3 \pm 0.2) \times 10^{-4}$, $\mathbf{(3.1 \pm 0.3 \pm 0.2)} \times 10^{-4}$ arXiv:0803.2869 [hep-ex]

- First measurement of $\mathbf{B}(J/\psi \rightarrow \gamma \gamma \gamma) = (1.2 \pm 0.3 \pm 0.2) \times 10^{-5}$ arXiv:0806.0671 [hep-ex]

- Measurements of $\mathbf{B}(J/\psi \rightarrow \gamma gg) / \mathbf{B}(J/\psi \rightarrow \gamma ggg) = 0.137 \pm 0.001 \pm 0.016$ arXiv:0806.0315 [hep-ex]

- Update on $\mathbf{B}(\psi(2S) \rightarrow X J/\psi)$, $X=\pi^+\pi^-, \pi^0\pi^0, \eta, \pi^0, \gamma \gamma$ via $\chi_{cJ}$ arXiv:0804.4432 [hep-ex]

- First measurement of $\mathbf{B}(Y(2S) \rightarrow \eta Y(1S)) = (2.1 \pm 0.6 \pm 0.5) \times 10^{-5}$ (preliminary)

- Improved measurements of $\mathbf{B}(Y(2S) \rightarrow XY(1S))$, $X=\pi^+\pi^-, \pi^0\pi^0$ (preliminary)
Summary

- **Search for light CP-odd Higgs in radiative decays of $Y(1S)$:**
  - No evidence found
  - Limits in $\gamma\tau\tau$ channel 2 orders of magnitude more stringent than previously available.
  - Limit on $\gamma\mu\mu$ for $M(\mu\mu) = 214.3$ MeV makes the Higgs interpretation of HyperCP events unlikely
  - Both provide new constraints on NMSSM

- **Decay constants of $f_D, f_{Ds}$:**
  - Disagreement with HPQCD lattice QCD calculations on $f_{Ds}$
  - New physics or problems with HPQCD lattice calculations?

- **Measurement of M1 transition rates in charmonium:**
  - Significantly different than previously determined
  - Now good agreement with the theory

- **Precision measurement of $h_c$ mass:**
  - Hyperfine splitting in 1P state very small

- Many other results which I did not have time to describe