Recent Upsilonium Results from CLEO III

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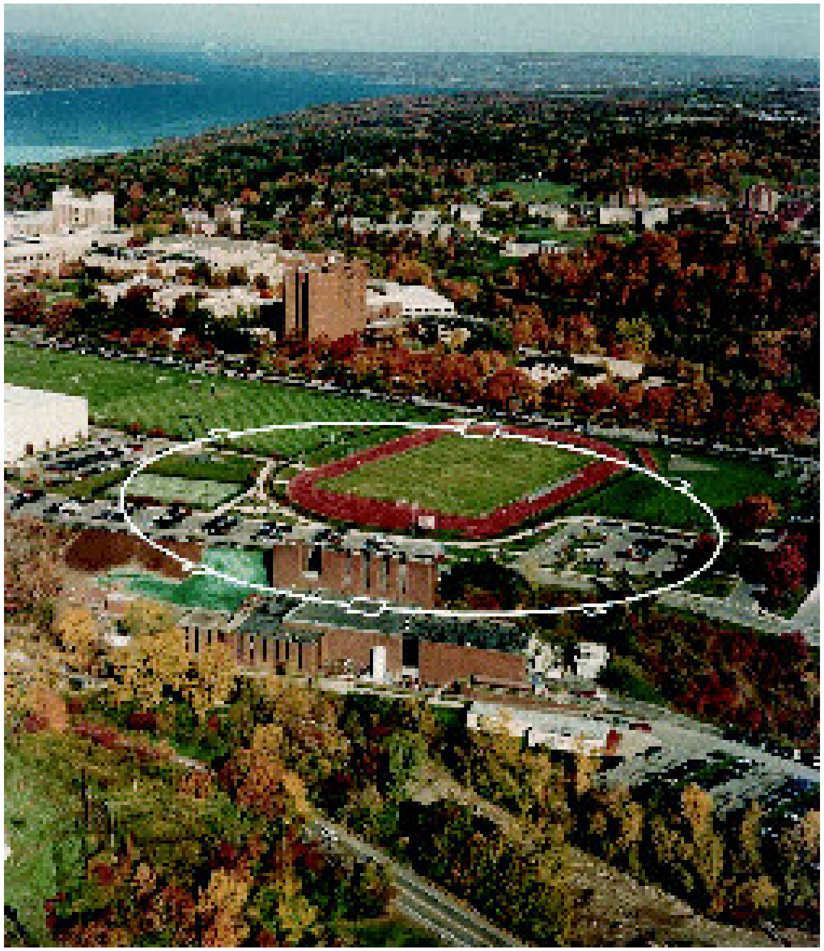
Outline

- The CLEO Detector
- Radiative Decays: $\Upsilon(1S) \to \gamma h^+h^-$, $\Upsilon(1S) \to \gamma\pi^0\pi^0, \gamma\eta\eta, \gamma\pi^0\eta$
- Hadronic Transitions within the Upsilon System
- Measurements of Resonance Parameters: $B_{\mu\mu}$, $B_{\tau\tau}$, Γ_{ee}, Γ_{tot}
- Summary

The CLEO/CESR Experiment

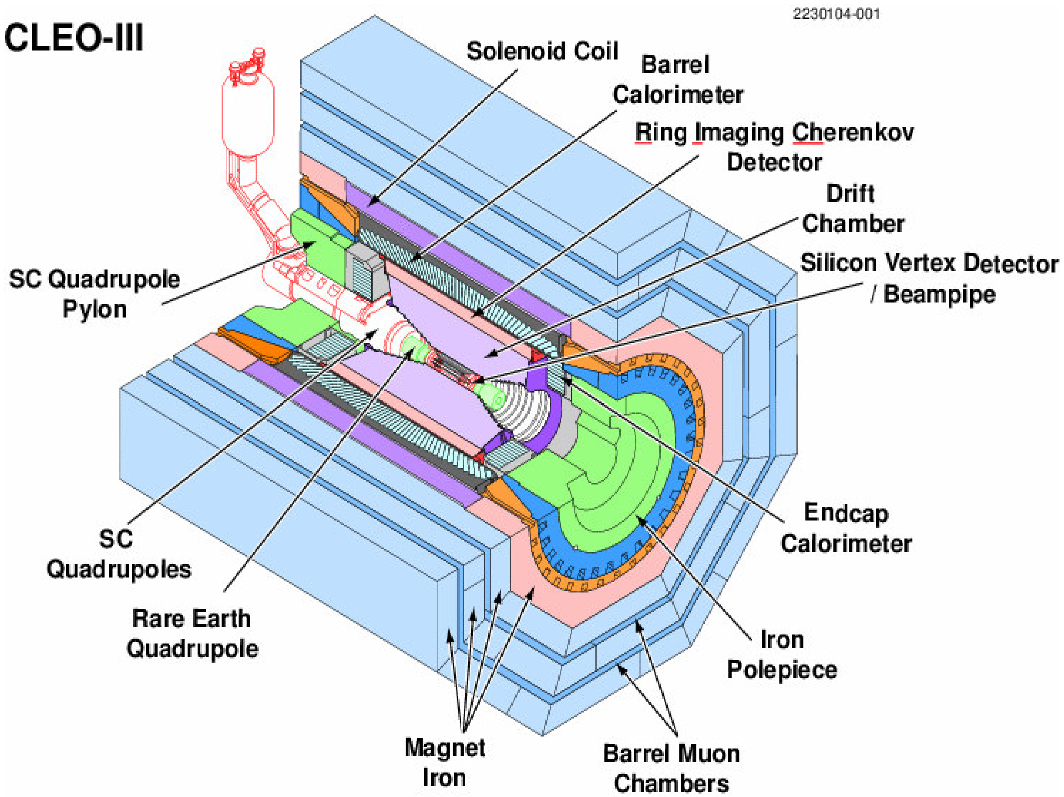


CESR (Cornell Electron Storage Ring) – Symmetric e^+e^- collider with capability of running at $\sqrt{s}$ = 3-11 GeV.

Located at Wilson Synchrotron Laboratory in Ithaca, NY.

CLEO and CESR have been producing results in B, Υ, τ, and 2-photon physics for over 25 years.

The CLEO III Detector



Drift Chamber:
- 47 layers
- 93% of 4π
- $\Delta p/p$ = 0.6% @ p=1.0 GeV.

CsI Calorimeter:
- 93% of 4π
- $\Delta E/E$ = 4% @ E=100 MeV.

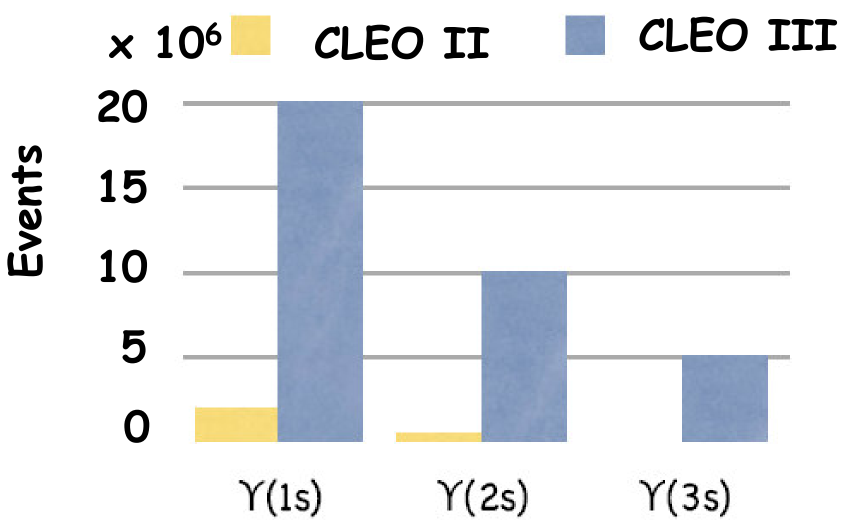
Muon Chambers:
- 85% of 4π
- Identify muons for p>1GeV

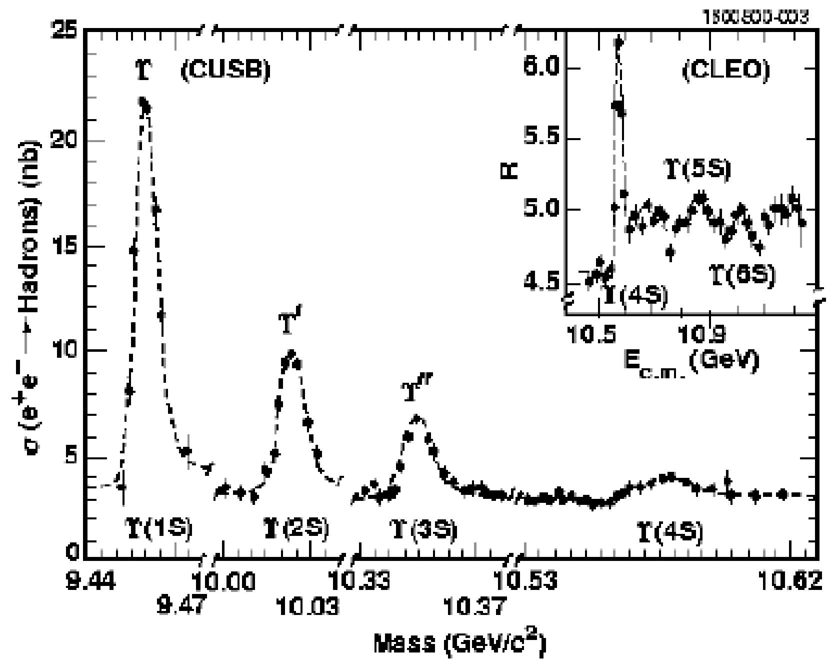
Particle Identification:
- RICH detector
- dE/dx in drift chamber
- Combined ε (π or K) > 90%.

CLEO III Data Sets

- Data taken Nov 2001 - Dec 2002.
- CLEO has the large sample of clean ϒ events below $b\bar{b}$ threshold.

ϒ(1S): ~ 1.1 fb^{-1}
ϒ(2S): ~ 1.2 fb^{-1}
ϒ(3S): ~ 1.2 fb^{-1}



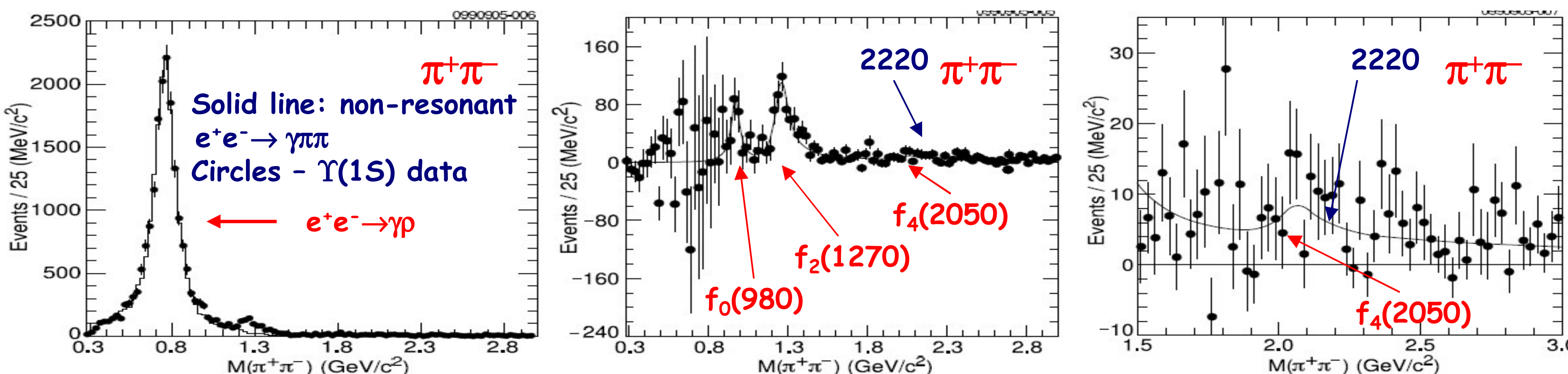


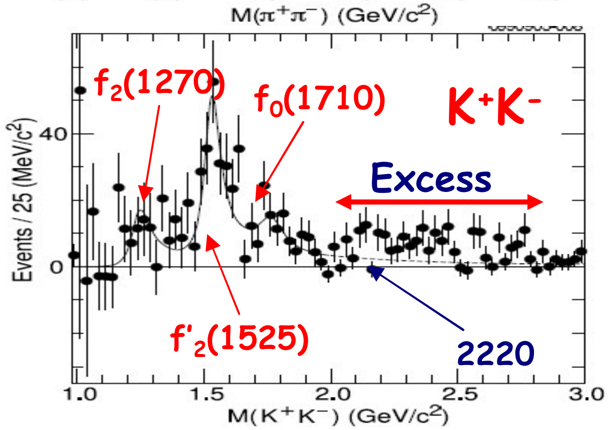
Radiative Decays of the $\Upsilon(1S) \rightarrow \gamma\, h^+h^-$ ($h=\pi$, K, p)

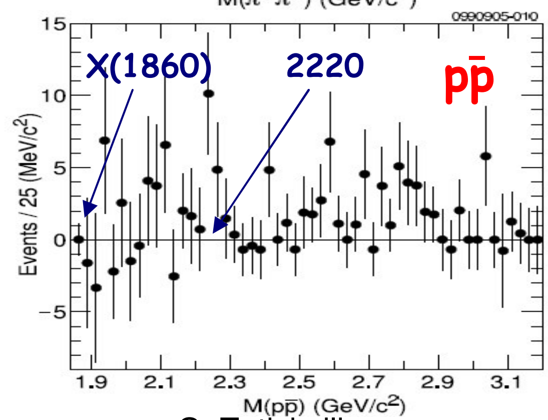
- BES'96: Observation of the $J/\psi \rightarrow \gamma f_J(2220)$
- MarkIII'86: similar to the $f_J(2220)$ in $K\bar{K}$ mode
- DM2'88: - not confirmed
- BES'03: new particle X(1860)
  $J/\psi \rightarrow \gamma X(1860) \rightarrow p\bar{p}$

The experimental observation of radiative $\Upsilon(1S)$ decays is challenging because their rate is suppressed to a level of ~0.04 of the corresponding rate of J/ψ radiative decays.

CLEO III $\Upsilon(1S)$ data

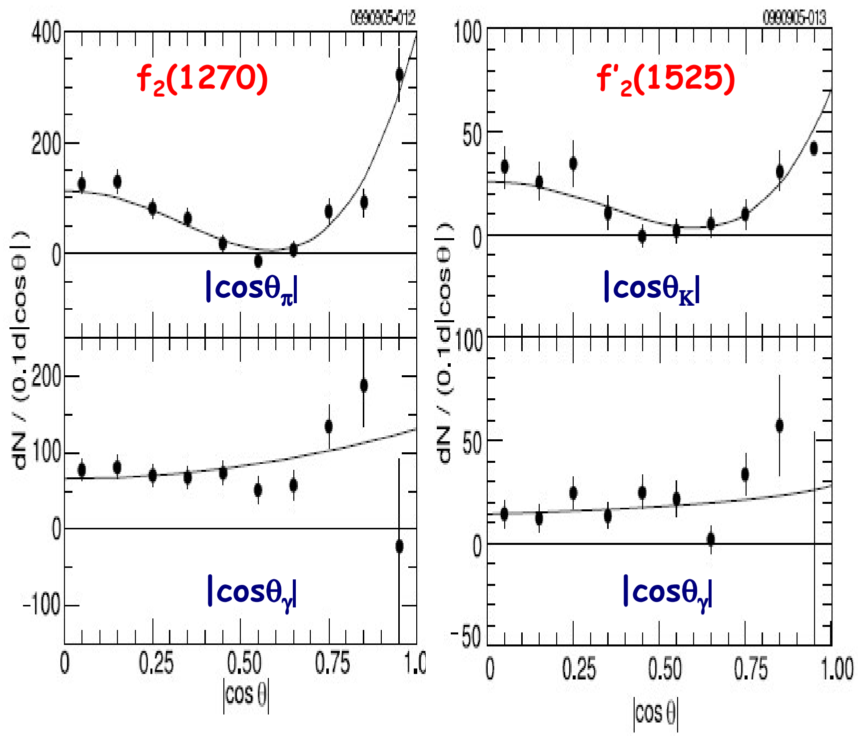






Possible signals are determined by fitting each spectrum to spin-dependent relativistic Breit-Wigner function.

Radiative Decays of the $\Upsilon(1S) \rightarrow \gamma\, h^+h^-$ (h=π, K, p)



To confirm the spins of our $f_2(1270)\rightarrow\pi\pi$ and $f'_2(1525)\rightarrow KK$ we examine:

- θ_γ - angle between γ and beam axis.
- θ_π - angle between 3-momentum vector of the hadron with the γ's direction.

Simultaneously fit of the angular distributions to the helicity formalism prediction strongly favour J=2 hypothesis.

- Confirm previous observation of $f_2(1270)$.
- New observation of $f'_2(1525)$ (both J=2).
- BR's consistent with scaling from J/ψ ratio.
- No signal of $f_J(2220)$, set UL at the 90% CL.

Radiative Decays of the $\Upsilon(1S) \rightarrow \gamma h^+h^-$ ($h=\pi$, K, p)

$B(\Upsilon(1S)\rightarrow\gamma f_2(1270))$	$(10.2\pm0.8\pm0.7) \times 10^{-5}$
$B(\Upsilon(1S)\rightarrow\gamma f'_2(1525))$	$(3.7^{+0.9}_{-0.7}\pm0.8) \times 10^{-5}$
$B(\Upsilon(1S)\rightarrow\gamma K^+K^-)$	$(1.14\pm0.08\pm0.1) \times 10^{-5}$
$B(\Upsilon(1S)\rightarrow\gamma f_0(980)\rightarrow\pi^+\pi^-)$	$(1.8^{+0.9}_{-0.7}\pm0.1) \times 10^{-5}$
$B(\Upsilon(1S)\rightarrow\gamma f_4(2050)\rightarrow\pi^+\pi^-)$	$(0.37\pm0.14\pm0.03) \times 10^{-5}$
$B(\Upsilon(1S)\rightarrow\gamma f_0(1710)\rightarrow K^+K^-)$	$(0.38\pm0.16\pm0.04) \times 10^{-5}$
$B(\Upsilon(1S)\rightarrow\gamma p\bar{p})$	$(0.41\pm0.08\pm0.1) \times 10^{-5}$

$B(\Upsilon(1S)\rightarrow\gamma f_J(2220)) \times B(f_J(2220)\rightarrow\pi^+\pi^-)$	$< 8 \times 10^{-7}$
$B(\Upsilon(1S)\rightarrow\gamma f_J(2220)) \times B(f_J(2220)\rightarrow K^+K^-)$	$< 6 \times 10^{-7}$
$B(\Upsilon(1S)\rightarrow\gamma f_J(2220)) \times B(f_J(2220)\rightarrow p\bar{p})$	$< 11 \times 10^{-7}$
$B(\Upsilon(1S)\rightarrow\gamma X(1860)) \times B(X(1860)\rightarrow p\bar{p})$	$< 5 \times 10^{-7}$

S.B. Athar et al., Phys.Rev.D73, 032001 (2006)

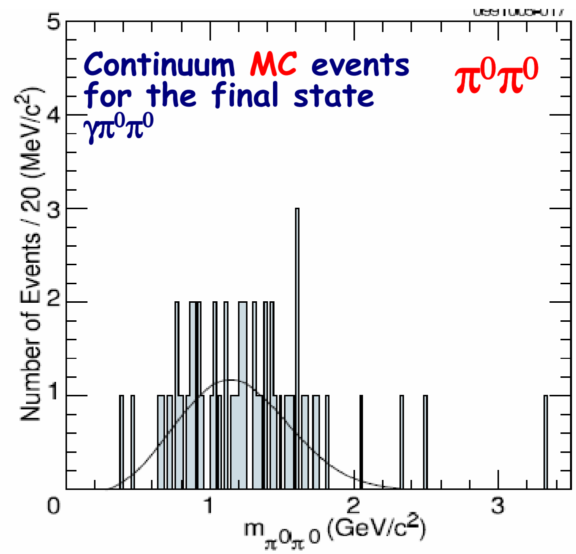
Radiative Decays. Search for $\Upsilon(1S) \to \gamma\pi^0\pi^0$, $\gamma\eta\eta$, $\gamma\pi^0\eta$

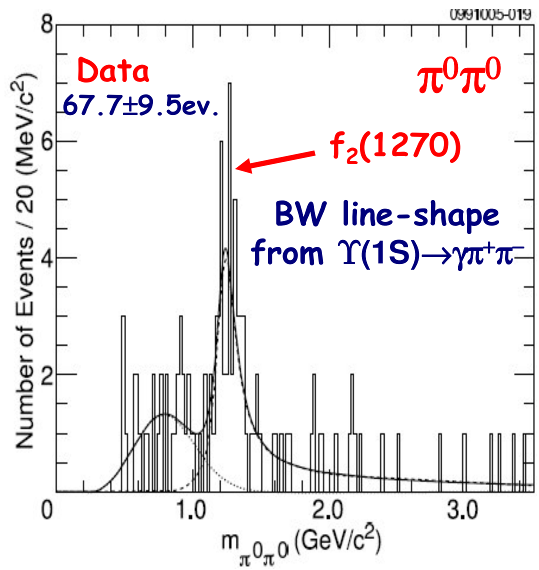
The identification of a scalar glueball is difficult for following reasons:

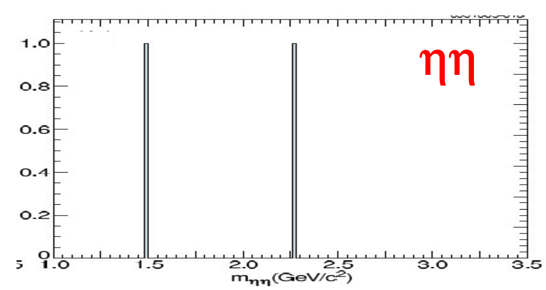
- Scalar glueball and scalar meson has the same quantum numbers ($J^{PC}=0^{++}$)
- Both prefer to decay into two pseudoscalar mesons ($\pi\pi$, $\eta\eta$, KK)
- The possible mixing of the glueball and nearby scalar meson.

Recently, the focus has been on the f_0 triplet: $f_0(1370)$, $f_0(1500)$, $f_0(1710)$ – could be a superposition of quark states and a glueball state.

$\Upsilon(1S)$ radiative decays were used for search for f_0 triplet states.







- No visible contributions of other resonances in the $m_{\pi^0\pi^0}$.
- Their influence is negligible for the $f_2(1270)$ result.

Threshold function: $F(x) = N \cdot (x-T) \cdot e^{c1(x-T)+c2(x-T)^2}$

Radiative Decays. Search for $\Upsilon(1S) \to \gamma\pi^0\pi^0$, $\gamma\eta\eta$, $\gamma\pi^0\eta$

- In the decay channel $\gamma\pi^0\pi^0$: $B_N(\Upsilon(1S)\to\gamma f_2(1270)) = (10.5\pm1.6^{+1.9}_{-1.8}) \times 10^{-5}$
- Excellent agreement with $\gamma\pi^+\pi^-$: $B_C(\Upsilon(1S)\to\gamma f_2(1270)) = (10.2\pm0.8\pm0.7) \times 10^{-5}$
- We determine the 90% C.L. upper limits of:

$B(\Upsilon(1S)\to\gamma f_0(1500))$	$< 1.17 \times 10^{-5}$
$B(\Upsilon(1S)\to\gamma f_0(1710))\times B(f_0(1710)\to\pi^0\pi^0)$	$< 1.20 \times 10^{-6}$
$B(\Upsilon(1S)\to\gamma f_0(1500))\times B(f_0(1500)\to\eta\eta)$	$< 3.00 \times 10^{-6}$
$B(\Upsilon(1S)\to\gamma f_0(1710))\times B(f_0(1710)\to\eta\eta)$	$< 1.90 \times 10^{-6}$
$B(\Upsilon(1S)\to\gamma\pi^0\eta)$	$< 2.80 \times 10^{-6}$

D. Besson et al., hep-ex/0512003

- Based on the scalar-glueball mixing matrix (F.E.Close, Eur.Phys.J. C21 (2001)) QCD factorization model (X.-G.He, Phys.Rev. D66 (2002)) predicts:

$B(\Upsilon(1S)\to\gamma f_0(1500))$	~ $42\text{-}84 \times 10^{-5}$
$B(\Upsilon(1S)\to\gamma f_0(1710))\times B(f_0(1710)\to\pi^0\pi^0)$	~ $6\text{-}12 \times 10^{-6}$

- Our measurement disagree with these predictions by an order of magnitude.

Di-pion Transition $\chi_b(2P) \to \pi\pi\chi_b(1P)$

The dominant hadronic transitions among the heavy quarkonia involve emission of two soft gluons which then hadronize as a di-pion system. (T.M.Yan, Phys. Rev. D22, 1652 (1980))

We have investigated hadronic transitions of $\chi'_b \to \pi^+\pi^-\chi_b$ and $\chi'_b \to \pi^0\pi^0\chi_b$.

Signal process:

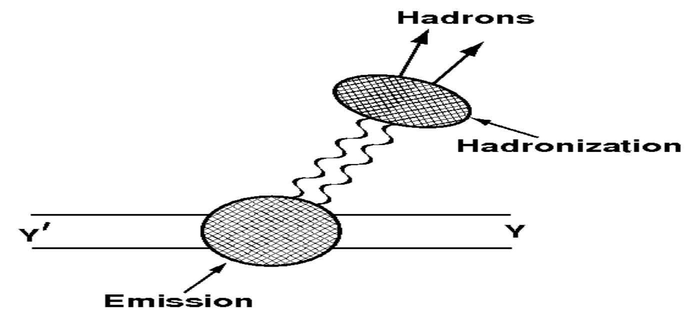
$\Upsilon(3S) \to \gamma_1\chi'_b$, $\chi'_b \to \pi\pi\chi_b$, $\chi_b \to \gamma_2\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$.

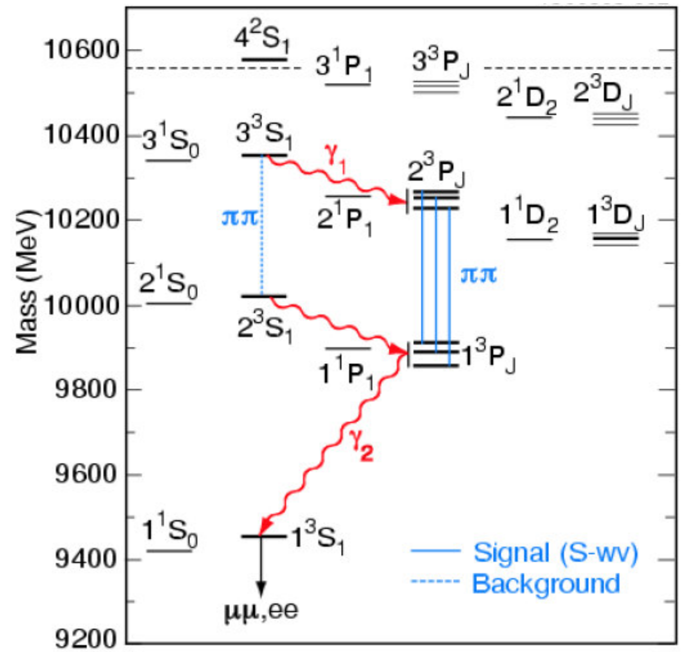
Background processes:

- $\Upsilon(3S) \to \pi\pi\Upsilon(2S)$, $\Upsilon(2S) \to \gamma\chi_b$, $\chi_b \to \gamma_2\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$
- $\Upsilon(3S) \to \pi\pi\Upsilon(2S)$, $\Upsilon(2S) \to \pi^0\pi^0\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$
- $\Upsilon(3S) \to \gamma_1\chi'_b$, $\chi'_b \to \omega\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$
- $\Upsilon(3S) \to \eta\Upsilon(1S)$, $\Upsilon(1S) \to l^+l^-$

Final state has: 2 photons, 2 low-momentum pions and 2 high-momentum leptons.
- "Fully reconstructed" and "one-pion analysis".

- Expected the J'=J=1 transition to dominate J'=J=2 by roughly a factor of 2.3.
- The E1 transition from χ_{b0} is unobserved, with a limit of 6% on its branching fraction at 90% C.L.





- We assumed that there were no D-wave contributions to the decays, only S-Wave, so that J'=J.

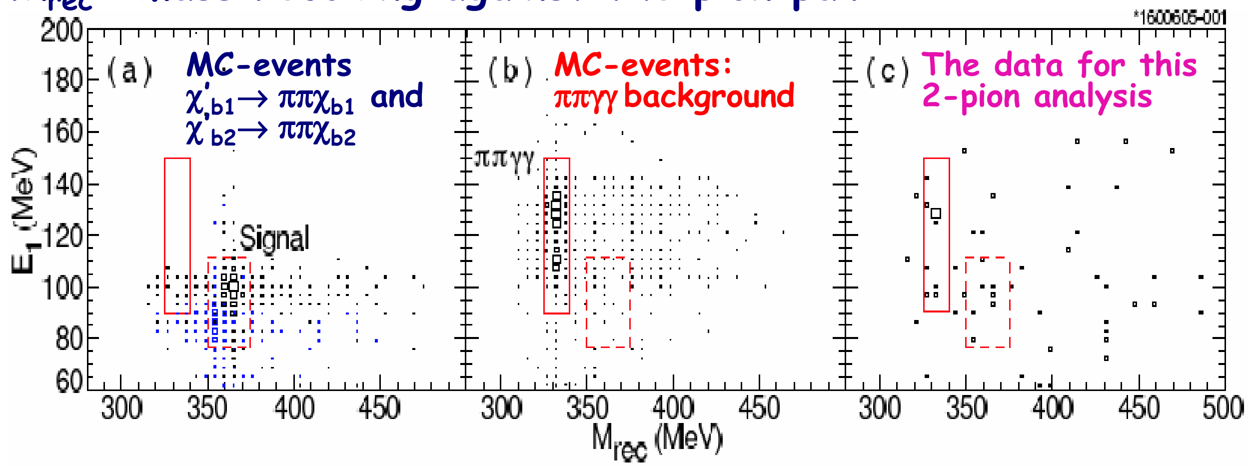
Di-pion Transition $\chi_b(2P) \rightarrow \pi\pi\chi_b(1P)$

Example: "Fully reconstructed" analysis. Observed both π^+ and π^-.

E_1 – Energy of photon in $\Upsilon(3S) \rightarrow \gamma_1\chi_b(2P)$,

M_{rec} – mass recoiling against the pion pair:

$$M_{rec} \equiv \sqrt{(P_{3S} - P_{\gamma 1})^2} - \sqrt{(P_{3S} - P_{\gamma 1} - P_{\pi 1} - P_{\pi 2})^2}$$



7 events observed.
1 event – expected background.

$\varepsilon(\chi'_{b1} \rightarrow \pi\pi\chi_{b1}) = 5.1\%$
$\varepsilon(\chi'_{b2} \rightarrow \pi\pi\chi_{b2}) = 4.3\%$

- First observation of a di-pion cascade between non-S states.
- Under the assumption of no D-wave contribution for $\chi'_b \rightarrow \pi^+\pi^-\chi_b$ and $\chi'_b \rightarrow \pi^0\pi^0\chi_b$:

$$\Gamma_{\pi\pi} = (0.83 \pm 0.22 \pm 0.08 \pm 0.19)\ \text{keV}$$

C. Cawlfield et al., Phys.Rev.D73,012003 (2006)

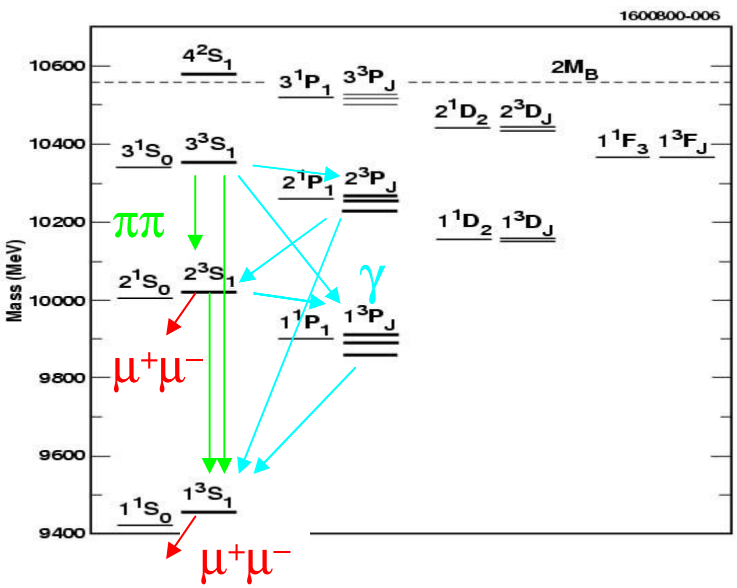
- PDG: $\Gamma(\Upsilon(3S) \rightarrow \pi\pi\Upsilon(2S))$ = (1.3 ± 0.2) keV (for a process with less Q)
  $\Gamma(\Upsilon(2S) \rightarrow \pi\pi\Upsilon(1S))$ = (12 ± 2) keV. (for a process with considerably more Q)
- Our $\Gamma_{\pi\pi}$ result is consistent with the theoretical expectations $\Gamma_{\pi\pi}$ = 0.4 keV.
  (Y.-P.Kuang and T.-M.Yan, Phys.Rev. D24, 2874 (1981))

Measurement of B(ϒ(nS) → $\mu^+\mu^-$)

The data collected by the CLEO detector enables to determine the $b\bar{b}$ resonance parameters with high precision.

- $B_{\mu\mu}$ is important to determine transition rates among the $b\bar{b}$ states ϒ(nS) → ππ/γγϒ(mS) (→ $e^+e^-/\mu^+\mu^-$).

$$B_{\mu\mu} = \frac{\Gamma_{\mu\mu}}{\Gamma} = \frac{\Gamma_{\mu\mu}}{\Gamma_{had}\,(1 + 3\Gamma_{\mu\mu}/\Gamma_{had})}$$



Comparing $B_{\mu\mu}/B_{ee}/B_{\tau\tau}$

- Check of lepton universality.
- Test the possible existence of new physics beyond the SM.

The major source of background

- Non-resonant (continuum) production of $\mu^+\mu^-$ and hadrons via $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to q\bar{q}$.

- We use continuum data collected at energies just below each resonance to subtract these backgrounds.

  Backgrounds from non-resonant $e^+e^- \to \tau^+\tau^-$, two-photon fusion ($e^+e^- \to e^+e^-\gamma^*\gamma^*$) < 0.2%.

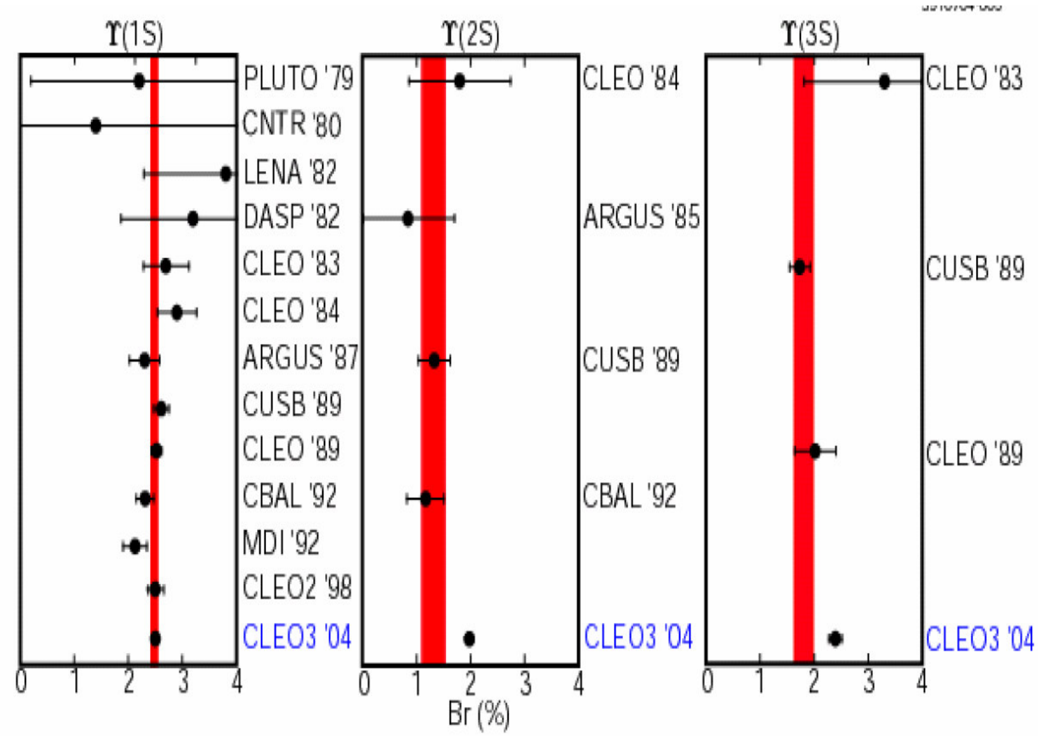
  The background from ϒ → $\tau^+\tau^-$ < 0.05%.

  The remaining backgrounds (to $\mu^+\mu^-$) are mainly from cosmic rays (0.3-0.6%).

Measurement of $B(\Upsilon(nS) \to \mu^+\mu^-)$

CLEO has measured $B_{\mu\mu}$ for $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$:

$\Upsilon(1S)$:	$(2.49 \pm 0.02 \pm 0.07)\%$	PDG: $(2.48 \pm 0.06)\%$
$\Upsilon(2S)$:	$(2.03 \pm 0.03 \pm 0.08)\%$	$(1.31 \pm 0.21)\%$
$\Upsilon(3S)$:	$(2.39 \pm 0.07 \pm 0.10)\%$	$(1.81 \pm 0.17)\%$



- $B(\Upsilon(1S))$ is consistent with PDG.
- $B(\Upsilon(2S))$ and $B(\Upsilon(3S))$ are significantly larger than the current world average value and much more precise.

G.S. Adams et al., Phys.Rev.Lett. 94, 012001 (2005)

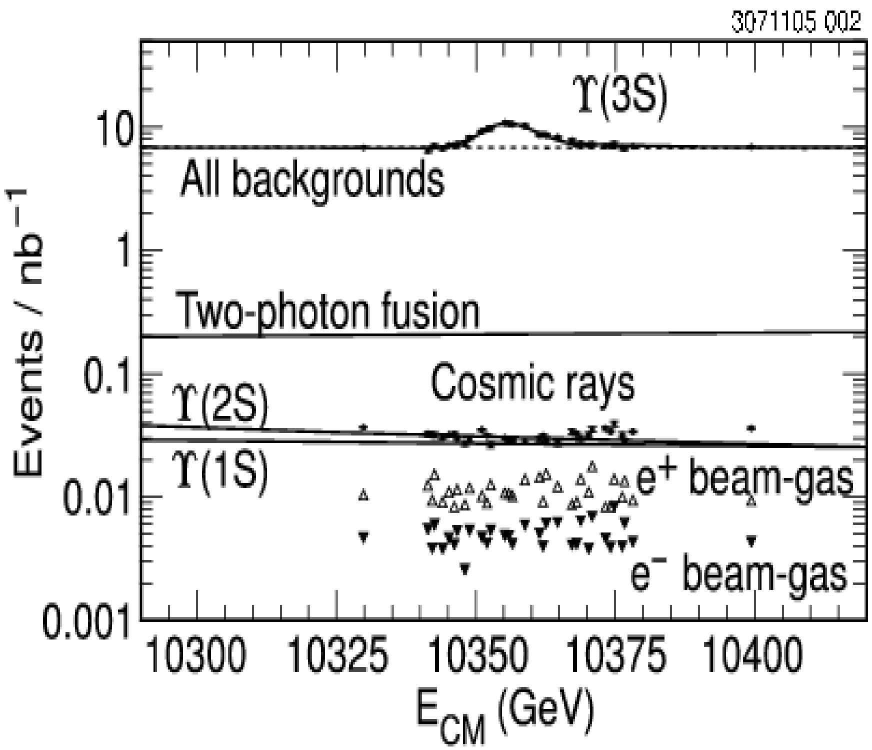
Di-electron Widths of $\Upsilon(1S,2S,3S)$ Resonances

Di-electron widths (Γ_{ee}) are basic parameters of any onium system. Their measurement can also test new unquenched lattice QCD calculations.

Basic Plan:

- Scan the three resonances and integrate the hadronic cross-section.
- Get $\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}$ without knowing of $B_{\mu\mu}$.
- Use $B_{\mu\mu}$ to get Γ_{ee} (assuming $B_{ee}=B_{\mu\mu}=B_{\tau\tau}$).
- Use $B_{\mu\mu}$ again to get $\Gamma_{tot} = \Gamma_{ee}/B_{\mu\mu}$.

$$\Gamma_{ee} = (\Gamma_{ee}\Gamma_{had} / \Gamma_{tot})/(1-3B_{\mu\mu})$$



The major sources of backgrounds:

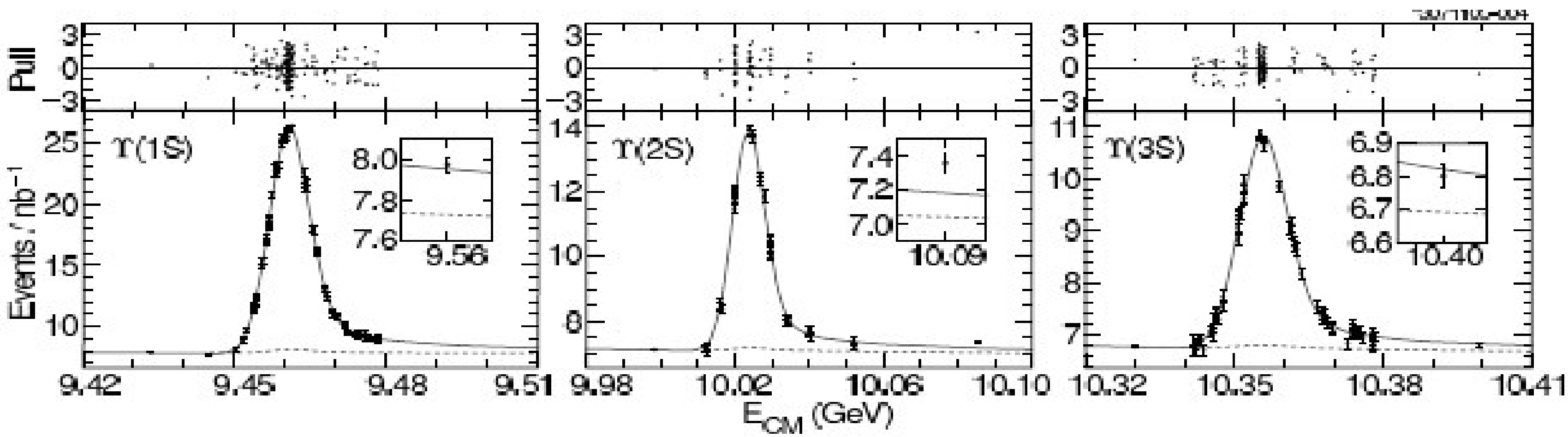
- Bhabha scattering ($e^+e^- \to e^+e^-$).
- Two-photon events ($e^+e^- \to e^+e^-\gamma^* \gamma^*$) ~ln s.
- Cosmic rays and beam gas interactions.
- Background from the high-energy tails of the $\Upsilon(1S)$ and $\Upsilon(2S)$.

Example: $\Upsilon(3S)$.

Points: data with fit superimposed.
Dashed curve: the sum of all backgrounds.

Di-electron Widths of Υ(1S,2S,3S) Resonances

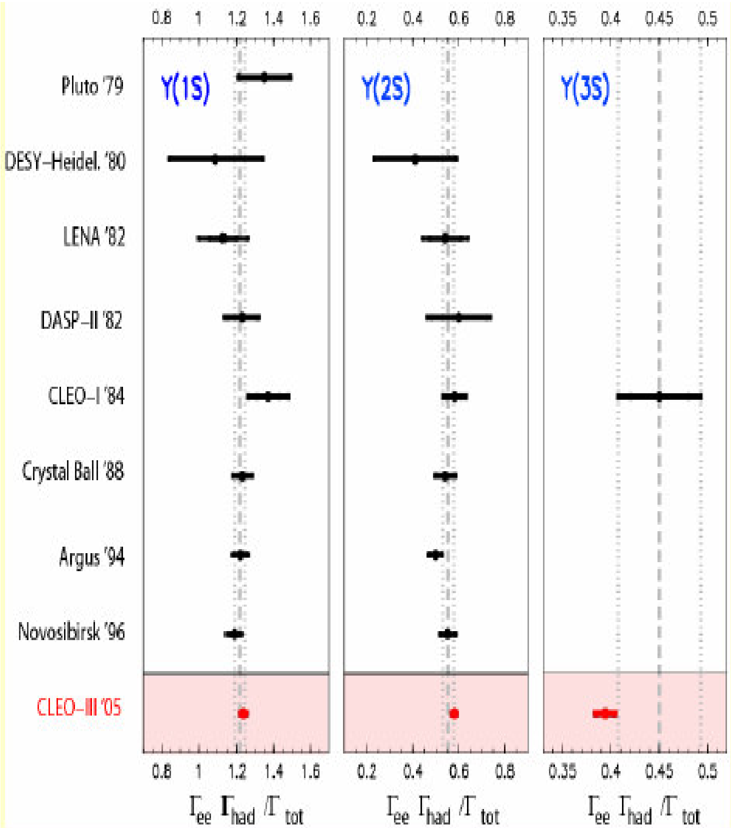
- Fit each resonance to convolution of:
  - Breit-Wigner resonance including interference between $\Upsilon \to q\bar{q}$ and $e^+e^- \to q\bar{q}$;
  - Initial-state radiation;
  - Gaussian spread in CESR beam energy of (4 MeV);
  - Background terms ~ 1/s and ln(s).



The hadronic yield versus E_{cm} in the vicinity of the three Υ resonances.

- Statistical errors: 0.3% (Υ(1S)), 0.7% (Υ(2S)), 1.0% (Υ(3S)).
- Main systematic errors: luminosity measurement (1.3%),
  hadronic efficiency (0.5%).

Di-electron Widths of Υ(1S,2S,3S) Resonances



		% Error	PDG % Error
$\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}(1S)$	$1.252 \pm 0.004 \pm 0.019$ keV		
$\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}(2S)$	$0.581 \pm 0.004 \pm 0.009$ keV		
$\Gamma_{ee}\Gamma_{had}/\Gamma_{tot}(3S)$	$0.413 \pm 0.004 \pm 0.006$ keV		
$\Gamma_{ee}(1S)$	$1.354 \pm 0.004 \pm 0.020$ keV	1.5	2.2
$\Gamma_{ee}(2S)$	$0.619 \pm 0.004 \pm 0.010$ keV	1.7	4.2
$\Gamma_{ee}(3S)$	$0.446 \pm 0.004 \pm 0.007$ keV	1.8	9.4
$\Gamma_{ee}(2S)/\Gamma_{ee}(1S)$	$0.457 \pm 0.004 \pm 0.004$		
$\Gamma_{ee}(3S)/\Gamma_{ee}(1S)$	$0.329 \pm 0.003 \pm 0.003$		
$\Gamma_{ee}(3S)/\Gamma_{ee}(2S)$	$0.720 \pm 0.009 \pm 0.007$		

Assuming $B_{ee} = B_{\mu\mu}$ gives:

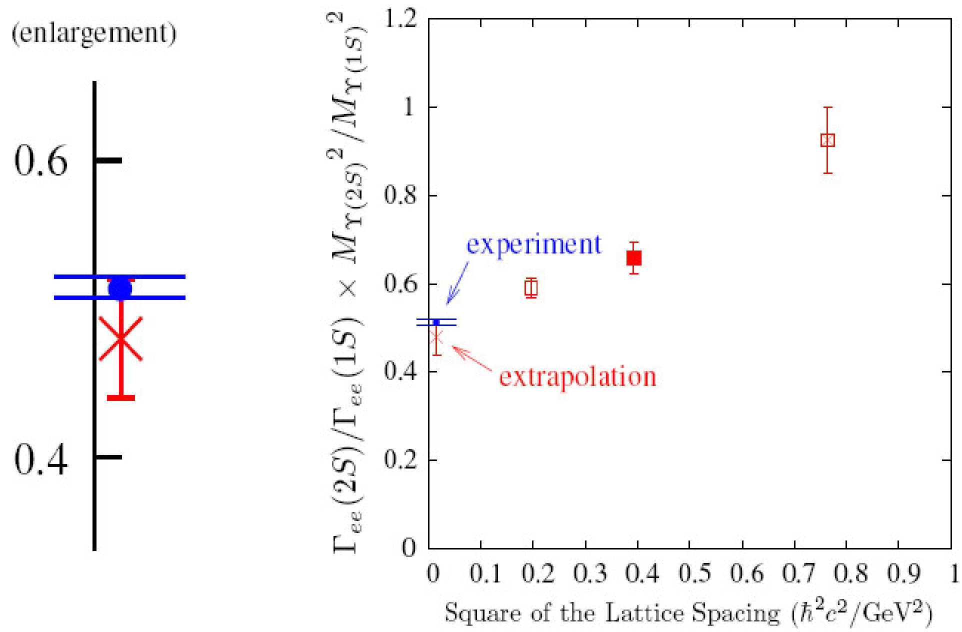
$\Gamma_{tot}[\Upsilon(1S)]$ = 54.4 ± 0.2 (stat.) ± 0.8 (syst.) ± 1.6 ($\sigma_{B\mu\mu}$) keV
$\Gamma_{tot}[\Upsilon(2S)]$ = 30.5 ± 0.2 (stat.) ± 0.5 (syst.) ± 1.3 ($\sigma_{B\mu\mu}$) keV
$\Gamma_{tot}[\Upsilon(3S)]$ = 18.6 ± 0.2 (stat.) ± 0.3 (syst.) ± 0.9 ($\sigma_{B\mu\mu}$) keV

Di-electron Widths of $\Upsilon(1S,2S,3S)$ Resonances

- To compare CLEO results to the latest unquenched lattice QCD calculations,

We use the combination
$$\frac{\Gamma_{ee}(2S)\cdot M^2(2S)}{\Gamma_{ee}(1S)\cdot M^2(1S)}$$

CLEO: 0.514 ± 0.007, J.L.Rosner et al., Phys. Rev. Lett. 96, 092003 (2006).
Lattice QCD (extrapolated to zero lattice spacing):
0.48 ± 0.05, A.Gray et al., Phys. Rev. D72, 094507 (2005).



The final lattice QCD results are expected to have a few percent precision in $\Gamma_{ee}(nS)/\Gamma_{ee}(mS)$ and ~10% in $\Gamma_{ee}(nS)$.

When this goal is achieved, the experimental measurements will now have the precision needed for a meaningful comparison.

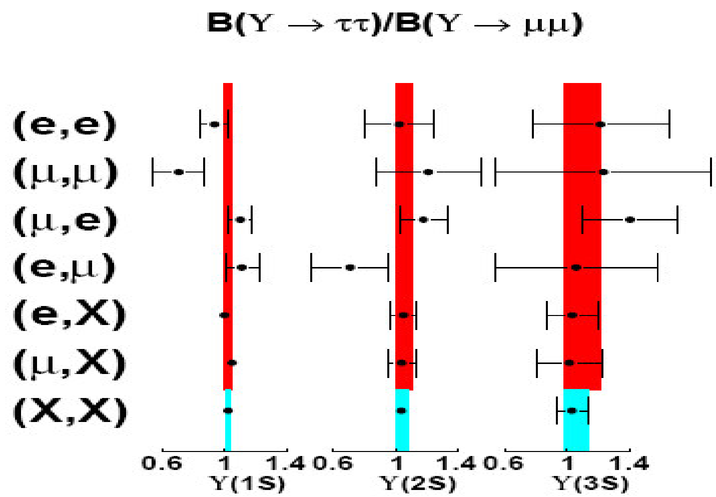
Measurement of $B(\Upsilon(nS) \to \tau^+\tau^-)$

Standard Model: the branching fractions for the decay $\Upsilon(nS) \to l^+l^-$ should be independent of the flavor of the lepton (except for negligible effects due to the lepton masses).

- Any deviation from unity for the $R_{\tau\tau}$ would indicate the presence of new physics.

$$R_{\tau\tau} = \frac{B(\Upsilon(nS) \to \tau\tau)}{B(\Upsilon(nS) \to \mu\mu)}$$

$\tau\tau$ final states are divided according to e-μ identification.
X – particles identified as neither e or μ.



Red band – average of all with at least one identified lepton.
Blue band – the average of all τ modes.

Errors shown are statistical.

- First observation of the decay $\Upsilon(3S) \to \tau\tau$.
- Most precise single measurement of $B(\Upsilon(1S) \to \tau\tau)$ and $B(\Upsilon(2S) \to \tau\tau)$.
- $R_{\tau\tau}$ is consistent with expectations from the standard model.

	$B(\Upsilon \to \tau\tau)/B(\Upsilon \to \mu\mu)$	$B(\Upsilon \to \tau\tau)$, %
$\Upsilon(1S)$	$1.02 \pm 0.02 \pm 0.05$	$2.54 \pm 0.04 \pm 0.12$
$\Upsilon(2S)$	$1.04 \pm 0.04 \pm 0.05$	$2.11 \pm 0.07 \pm 0.13$
$\Upsilon(3S)$	$1.07 \pm 0.08 \pm 0.05$	$2.55 \pm 0.19 \pm 0.15$

Summary

- A new study of exclusive radiative $\Upsilon(1S)$ decays into final states with charged and neutral hadrons.
- First observation of a di-pion cascade between non-S states $\chi_b(2P) \rightarrow \pi\pi\chi_b(1P)$.
- Precise measurement of $B_{\mu\mu}$, $B_{\tau\tau}$, Γ_{ee} and Γ_{tot}. First measurement of $B(\Upsilon(3S) \rightarrow \tau\tau)$.
- More exciting results from CLEO are expected.