Recent $\Upsilon(1S - 3S)$ Results
and Search for X(3872) at CLEO

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Representing the CLEO Collaboration

Introduction

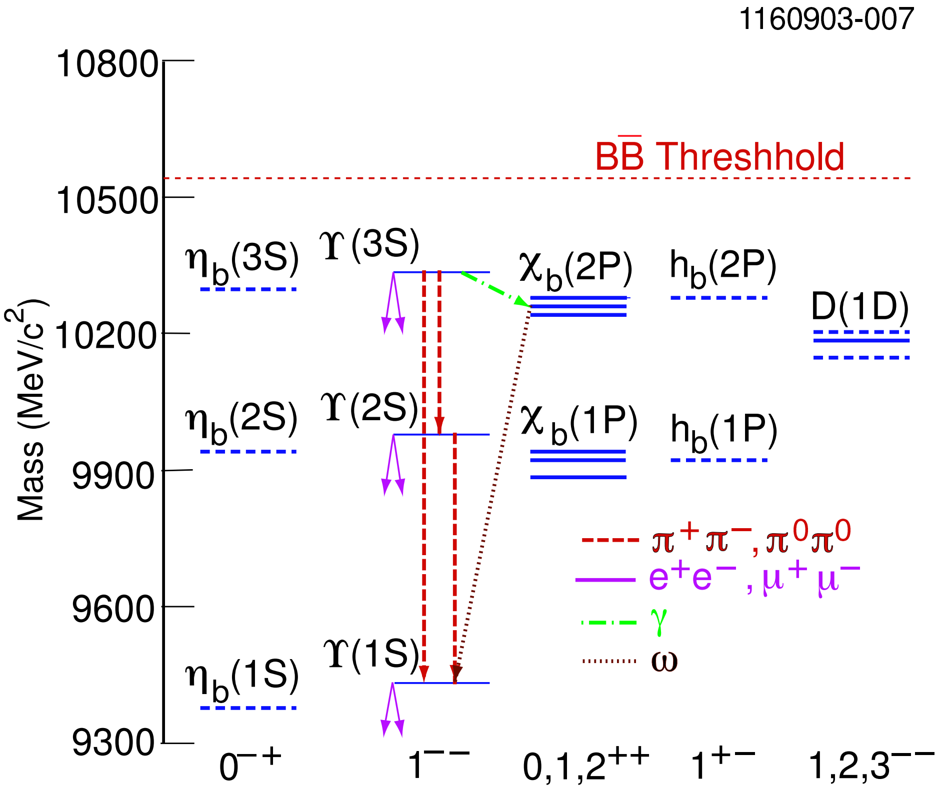
- Heavy quarkonia ($c\bar{c}$ charmonium, $b\bar{b}$ bottomonium) provide the best means of testing QCD, both

– the validity of perturbative QCD and potential models, and
– lattice QCD calculations.

- Bottomonium ($b\bar{b}$) is better then charmonium ($c\bar{c}$), both because it has smaller relativistic problems ($< v^2/c^2 > \approx 0.1$ versus ≈ 0.2) and smaller strong coupling constant ($\alpha_s \approx 0.2$ versus ≈ 0.35).

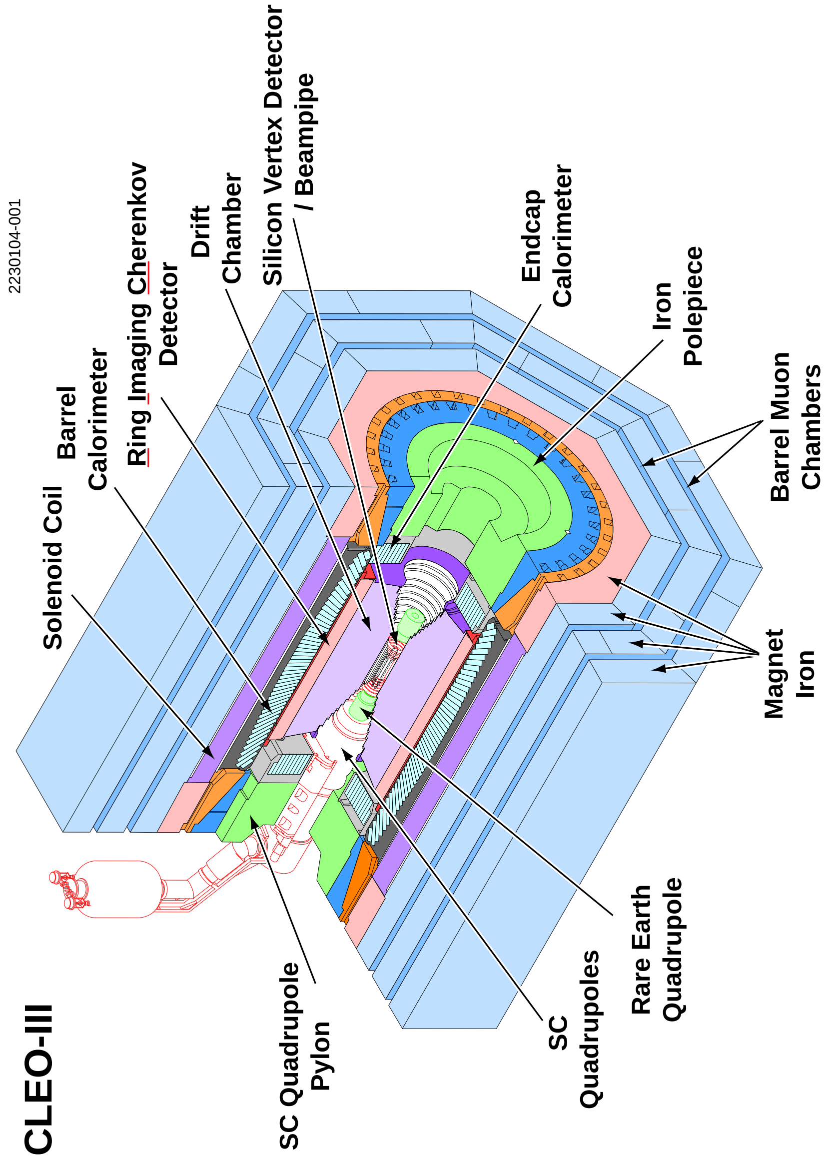
- There is much less high precision spectroscopic information available for bottomonium. No $b\bar{b}$ singlet states are known, and very few hadronic and radiative decays are known. Nevertheless, progress is being made through recently taken $\Upsilon(nS)$ data with CLEO III .

The Upsilon System - Bottomonium

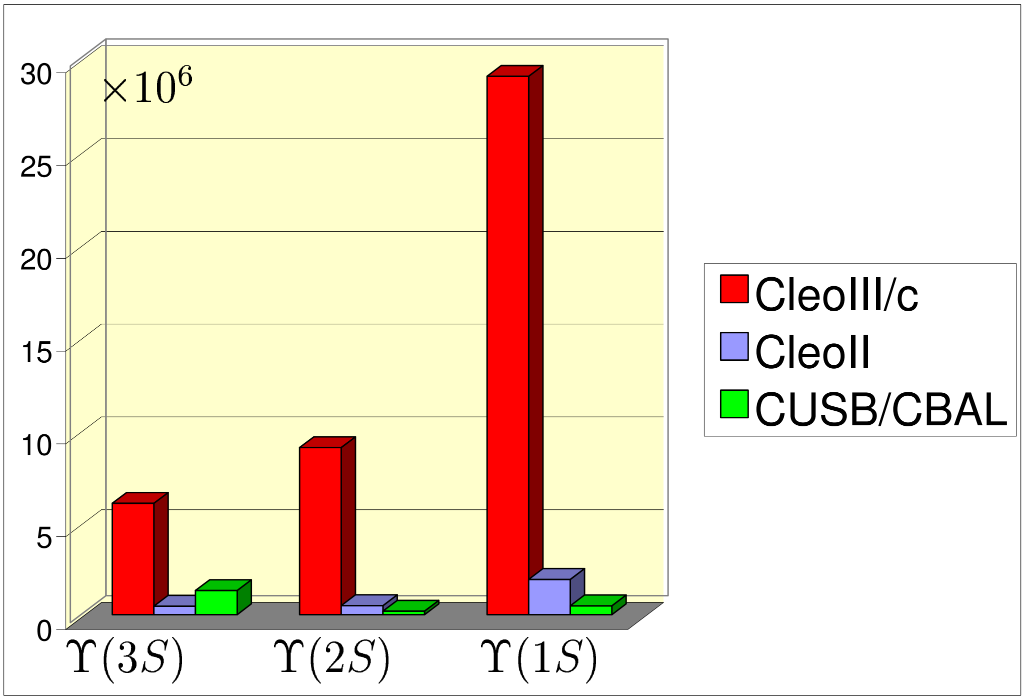


- Rich spectroscopy
- Many transitions - hadronic, radiative

CLEO III Detector



CLEO III Data



– Size of CLEO III data sets are shown by the red columns, in million of events, taken at $\Upsilon(3S)$, $\Upsilon(2S)$, $\Upsilon(1S)$ respectively, and compared to the data sets of other experiments.

Scope of Talk

- Measurement of the $B[Y(nS)] \to \mu^+\mu^-$
- Production of J/ψ from $\Upsilon(1S)$
- New narrow state X(3872)

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

- Leptonic (Γ_{ll}) and total widths (Γ) of $\Upsilon(n^3S_1)$ resonances are not very well established (4-16% relative errors).

- Γ and Γ_{ee} enter many PQCD calculations.

- Precise measurement of $B(l^+l^-)$ allows precise determination of $\Gamma(\Upsilon(nS))$ (also need precise Γ_{ee} measurement, expect from CLEO soon).

$$\Gamma = \Gamma_{ll}/B_{ll} = \Gamma_{ee}/B_{\mu\mu} \quad (assuming\ lepton\ universality)$$

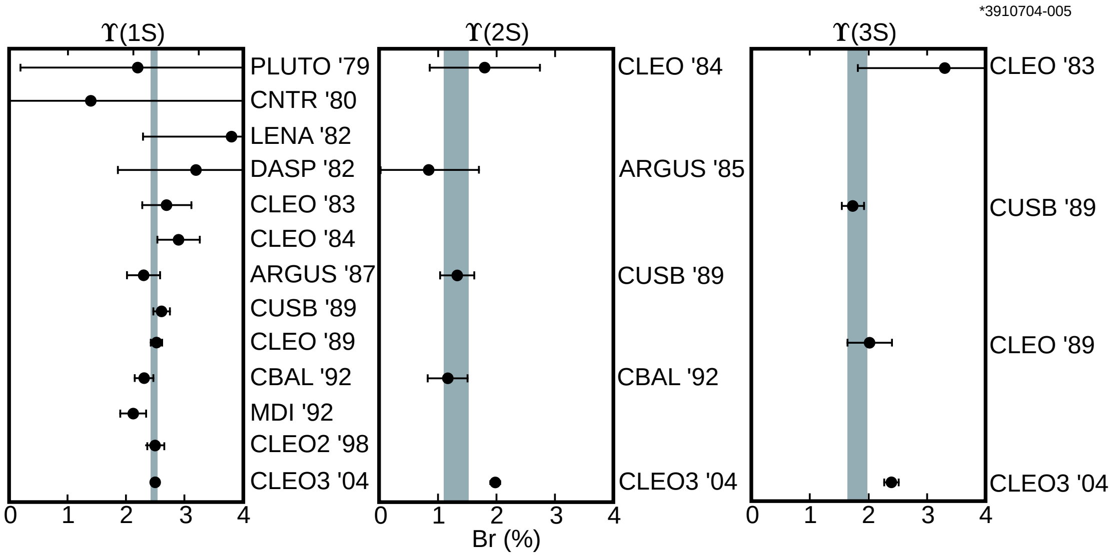
- Measure decay rate to muon pairs relative to hadronic decay rate:

$$\bar{B}_{\mu\mu} = \frac{\Gamma_{\mu\mu}}{\Gamma_{had}} = \frac{N(\Upsilon \to \mu^+\mu^-)/\epsilon_{\mu\mu}}{N(\Upsilon \to hadrons)/\epsilon_{had}}$$

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

Measurement of $B[\Upsilon(nS) \rightarrow \mu^+\mu^-]$

	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
$B_{\mu\mu}(\%)$ CLEO	2.49±0.02±0.07	2.03± 0.03±0.08	2.39±0.07± 0.10
$B_{\mu\mu}(\%)$ PDG	2.48 ± 0.06	1.31 ± 0.21	1.81 ± 0.17



- $\Upsilon(1S)$ branching fraction agrees with the PDG average. Significant discrepancy observed in case of $\Upsilon(2S)$ and $\Upsilon(3S)$.
- The new branching fractions combined with the PDG values of $\Gamma_{ee}\Gamma_{had}/\Gamma$ lead to the following values of the total widths $\Gamma[\Upsilon(nS)]$:

	PDG
$\Gamma(1S) = (52.8 \pm 1.8)$ keV	(53.0 ± 1.5) keV
$\Gamma(2S) = (29.0 \pm 1.6)$ keV	(43 ± 6) keV
$\Gamma(3S) = (20.3 \pm 2.1)$ keV	(26.3 ± 3.4) keV

Production of J/ψ in $\Upsilon(1S)$

- CDF (1992-1994) observes J/ψ production rates 10 times higher then the theoretical predictions.

- Braaten and Fleming (1995) propose the color octet mechanism as an explanation. The $c\bar{c}$ pair is produced in a color octet, and radiates a soft gluon to become a singlet.

- Calculations inconsistent with photoproduction of J/ψ at HERA (1996), with J/ψ polarization at CDF (2000), and $e^+e^- \to J/\psi + X$ at BaBar and Belle (2001).

- Fleming, Leibovitch and Mehen (2003) propose multiple gluon emission mechanism to fix some of these disagreements.

Production of J/ψ in $\Upsilon(1S)$

At the $\Upsilon(1S)$, J/ψ can be produced from:

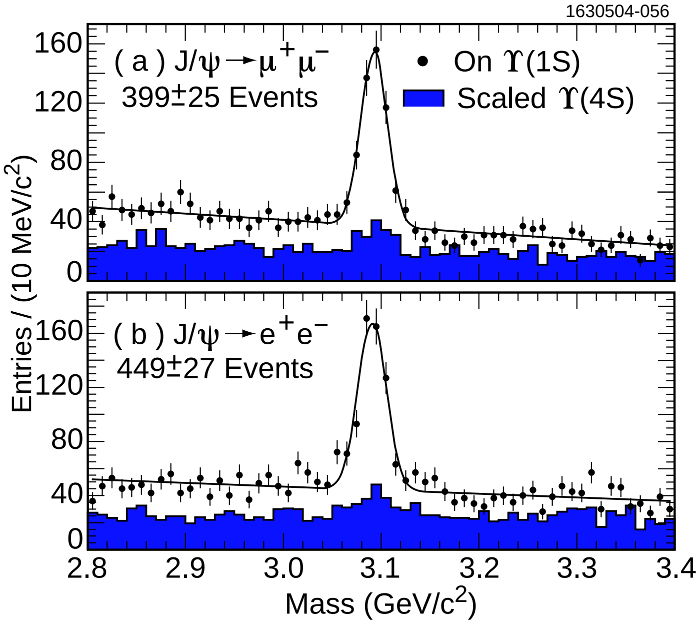
- $\Upsilon(1S) \to ggg$, $\Upsilon(1S) \to \gamma^* \to \bar{q}q$
- continuum production $e^+e^- \to J/\psi + X$.

$$B_{\mu\mu}[\Upsilon(1S) \to J/\psi + X] = (6.9 \pm 0.5 \pm 0.8) \times 10^{-4}$$

$$B_{ee}[\Upsilon(1S) \to J/\psi + X] = (6.1 \pm 0.5 \pm 0.7) \times 10^{-4}$$

$$B[\Upsilon(1S) \to J/\psi + X] = (6.4 \pm 0.4 \pm 0.6) \times 10^{-4}$$

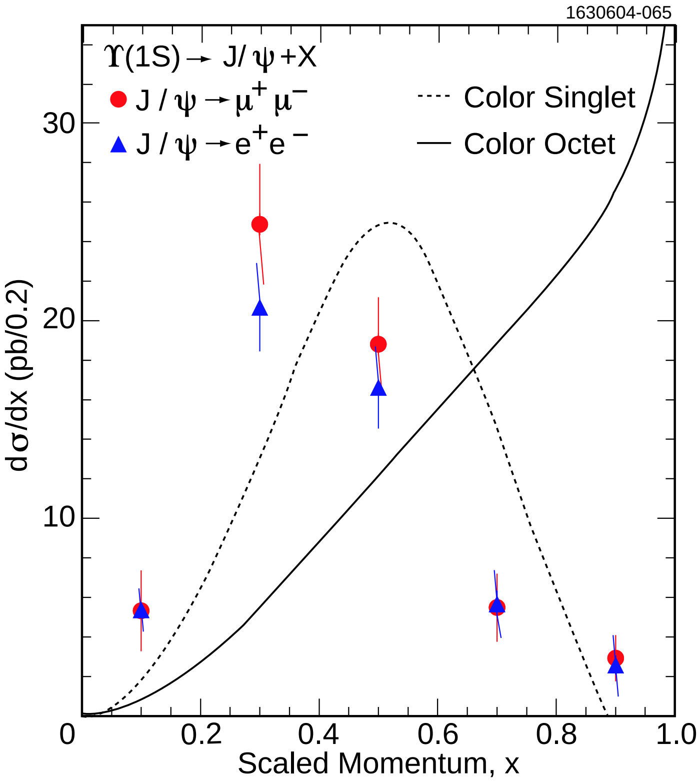
These branching fractions include feed-down from other charmonia.



Production of J/ψ in $\Upsilon(1S)$

- Color octet model predictions of branching fraction are in agreement with above measurements.

- Continuum subtracted J/ψ momentum spectra shows no indication of peaking at large x values, as predicted by color octet model.



New Narrow State X(3872)

- Belle Collaboration observed a narrow state in:

$B^{+-} \rightarrow K^{+-}X(3872)$, $X(3872) \rightarrow \pi^+\pi^-J/\psi$, $J/\psi \rightarrow l^+l^-$

$M = 3872.0 \pm 0.6 \pm 0.5$ (MeV), $\Gamma < 2.3$ MeV (90% CL) Belle (03)

$M = 3873.4 \pm 1.4$ (MeV), $\Gamma < 3.1 \pm 0.2$ (MeV), BaBar (04)

- CDF and D0 Collaborations confirmed in:

$\bar{p}p \rightarrow X(3872)...$, $X(3872) \rightarrow \pi^+\pi^-J/\psi$

$M = 3871.3 \pm 0.7 \pm 0.4$ (MeV), $\Gamma < 4.9 \pm 0.7$ (MeV) CDF (03)

$M = 3871.8 \pm 3.1 \pm 3.0$ (MeV), $\Gamma < 17 \pm 3$ (MeV) D0 (04)

- Identification of the quantum numbers is important to understand the structure:

– a conventional charmonium state? (Eichten, Lane, Quigg), (Barnes et al)

– a $D^0 - \bar{D}^{*0}$ molecule? (Tornqvist et al)

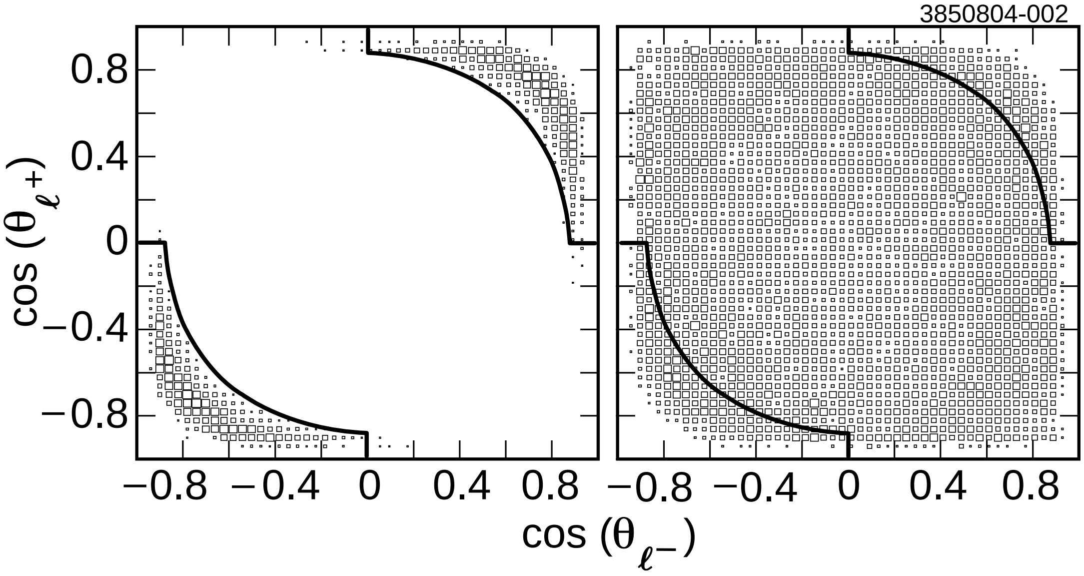
– a charmonium hybrid state? (Close et al)

New Narrow State X(3872)

- CLEO searched for X(3872) state with ∼15 fb^{-1} of CLEO III data in:

– untagged $\gamma\gamma$ fusion: +C parity, $J^{PC} = 0^{++}, 0^{-+}, 2^{++}, 2^{-+}, ..$

– ISR production: $J^{PC} = 1^{--}$



– $\gamma\gamma$ fusion selection: ∼86% $\gamma\gamma$ and <0.5% ISR events.

– ISR selection: >99.5% ISR and ∼14% $\gamma\gamma$ events.

New Narrow State X(3872)

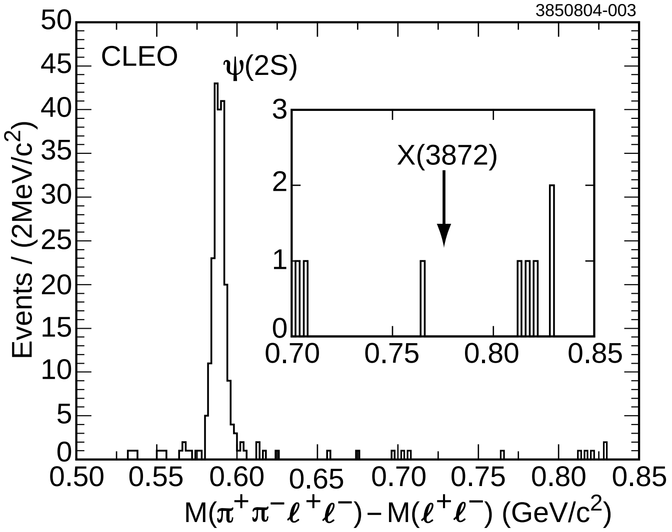
- Exclusive channels $X \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ were analysed.
- No signal was found.
- Following upper limits were set:

– Untagged $\gamma\gamma$ fusion (systematic errors are included):

$$(2J+1)\Gamma_{\gamma\gamma}B(X \to \pi^+\pi^- J/\psi) < 12.9 \text{ eV } (90\% \text{ CL})$$

– ISR production (systematic errors are included):

$$\Gamma_{ee}B(X \to \pi^+\pi^- J/\psi) < 8.3 \text{ eV } (90\% \text{ CL})$$



BES determined the following upper limit for ISR production:

$$\Gamma_{ee}B(X \to \pi^+\pi^- J/\psi) < 10 \text{ eV } (90\% \text{ CL})$$

(Phys. Lett. B579, 74 (2004)).

Summary

- Precision measurement of $B[\Upsilon(nS) \to \mu^+\mu^-]$ has been made for $\Upsilon(1,2,3S)$ narrow resonances. Evaluated $\Gamma(tot)$ of $\Upsilon(2,3S)$ resonances deviate from the PDG values.
(submitted to PRL)

- Measurement of $\Upsilon(1S) \to J/\psi + X$ has been made. The issue of color octet versus color singlet mechanism remains unresolved.
(PRD 70, 072001 (2004))

- X(3872) production has been searched for in untagged $\gamma\gamma$ fusion and ISR processes. No signals were found, and upper limits were set.