Bottomonium Decays at CLEO

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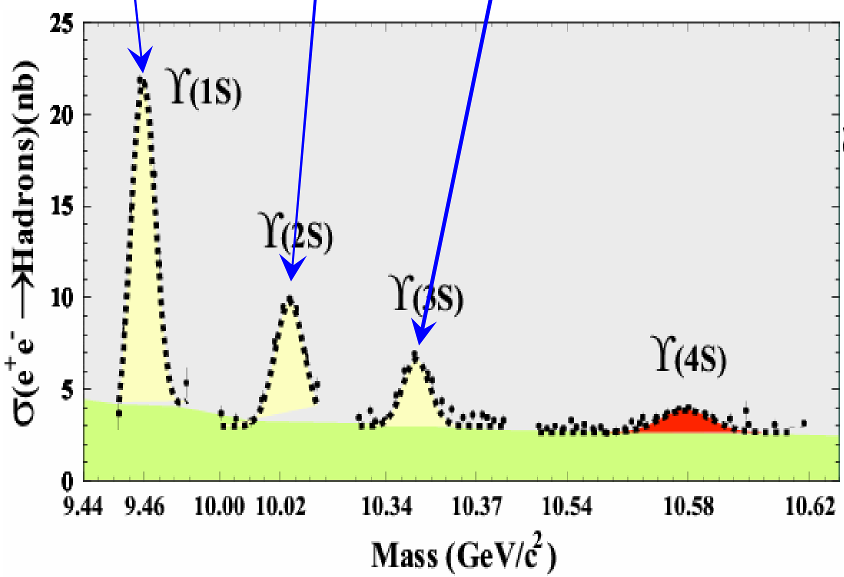
The Detector and Upsilon Data Sets

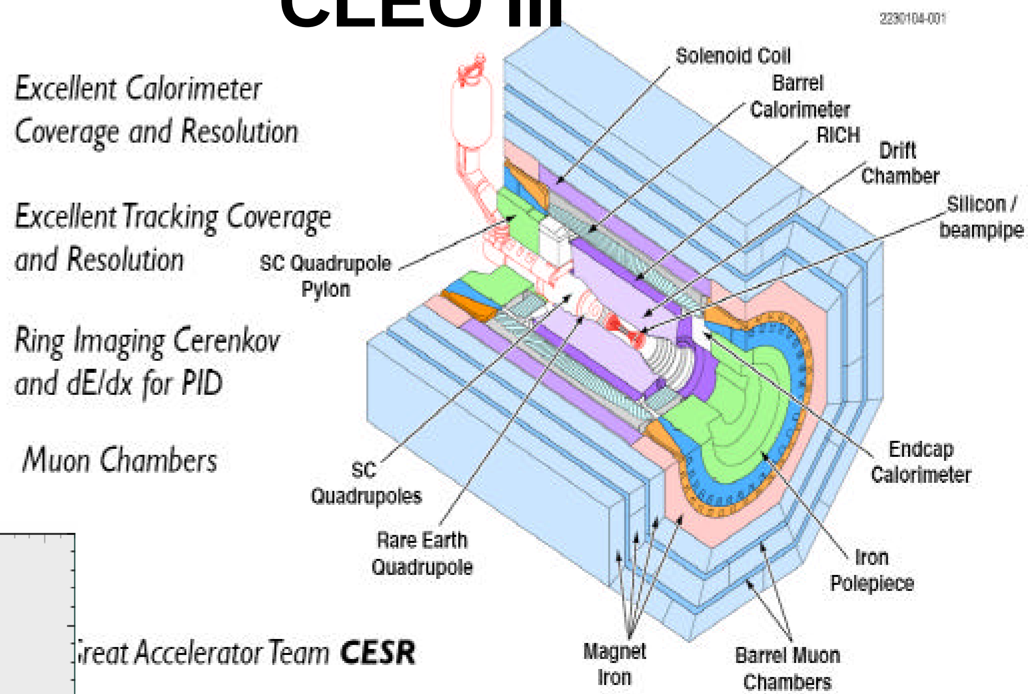
~21×10[6]

~9×10[6]

~6×10[6]



CLEO III



Dedicated ϒ(1S), ϒ(2S), ϒ(3S) runs (Nov 2001 – Dec 2002).

CLEO III Upsilon Topics

$\Upsilon(4S) \to B\bar{B}$

$\Upsilon(nS) \to ggg, gg\gamma, q\bar{q}$

$\Upsilon(nS) \to \Upsilon(mS)X, \chi_b X, \ldots$

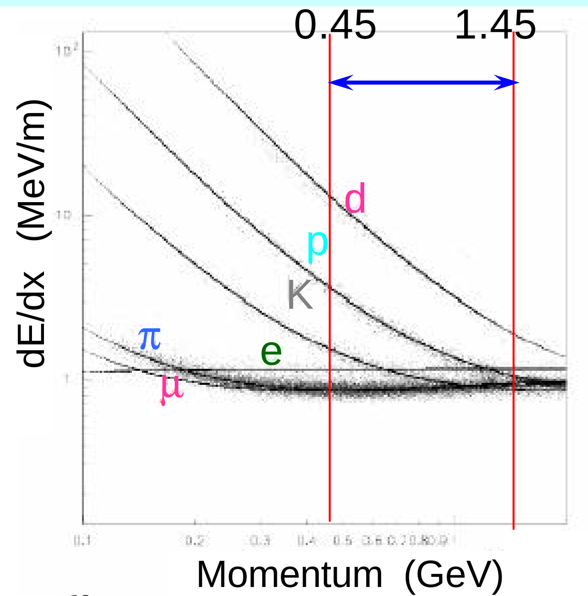
$e^+e^- \to q\bar{q}$

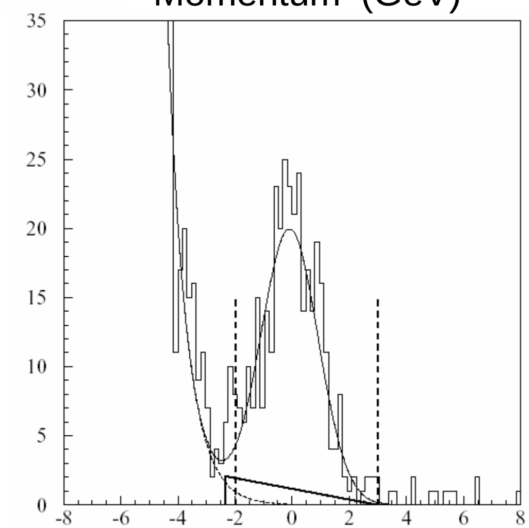
$\Upsilon(nS) \to ee, \mu\mu, \tau\tau$

- Anti-deuteron production in $\Upsilon(nS)$ decays and the nearby continuum.
- Inclusive production $\Upsilon(1S) \to \eta' X$.
- Upsilon radiative decays:
  - Observation of exclusive modes: $\gamma\pi\pi$, γKK.
  - Search for $\Upsilon(1S) \to \gamma\pi^0\pi^0$, $\gamma\eta\eta$, $\gamma\pi^0\eta$.
  - Search for $\Upsilon(1S) \to \gamma\eta$, $\gamma\eta'$.
  - UL on multi-body modes (≥4 charged tracks).
  - Comparison of inclusive hadron production in gluon-rich and quark environment.

Anti-Deuteron in Upsilon Decays

- Anti-deuteron production has been observed in many different kinds of hadronization processes.
- ARGUS observed anti-deuteron in $\Upsilon(1S)$ decays. OPAL set an upper limit in Z decays.
- The production can be explained by coalescence model and a model based on string calculation. The basic idea is that an anti-proton and an anti-neutron are produced nearby in phase space to form an anti-deuteron.
- CLEO has a factor ~40 more $\Upsilon(1S)$ than ARGUS to make a more precise measurement.
- The main PID tool is dE/dX with RICH info also used.
- CLEO measured production in momentum range (0.45 – 1.45) GeV/c and use a model dependent extrapolation for unmeasured region.





$$\chi_d \equiv \frac{(dE/dx)_{measured} - (dE/dx)_{expected,d}}{\sigma_{dE/dx}}$$

Anti-Deuteron Production

- The production BR per direct Υ(1S)→ggg,ggγ decays is

$$B^{dir}(\Upsilon(1S) \to \bar{d}X) = (3.36 \pm 0.23 \pm 0.25) \times 10^{-5}$$

The overall BR per Υ(1S) is

$$B(\Upsilon(1S) \to \bar{d}X) = (2.86 \pm 0.19 \pm 0.21) \times 10^{-5}$$

- The production in Υ(2S) is

$$B(\Upsilon(2S) \to \bar{d}X) = (3.37 \pm 0.50 \pm 0.25) \times 10^{-5}$$

Removing contribution of Υ(2S)→Υ(1S)X, and Υ(2S)→ggg,ggγ,$q\bar{q}$, CLEO set 90% CL limit

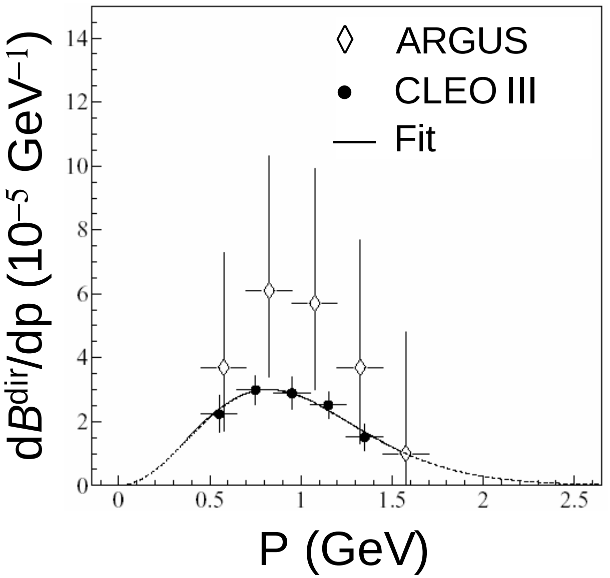
$$B(gc_{b1,2,0} \to \bar{d}X) < 1.09 \times 10^{-4}$$

- The production rate upper limit in Υ(4S) is

$$B(\Upsilon(4S) \to \bar{d}X) < 1.31 \times 10^{-5}$$

- Continuum production cross section at $\sqrt{s}$=10.5 GeV

$$B(e^+e^- \to \bar{d}X) < 0.031\ pb$$



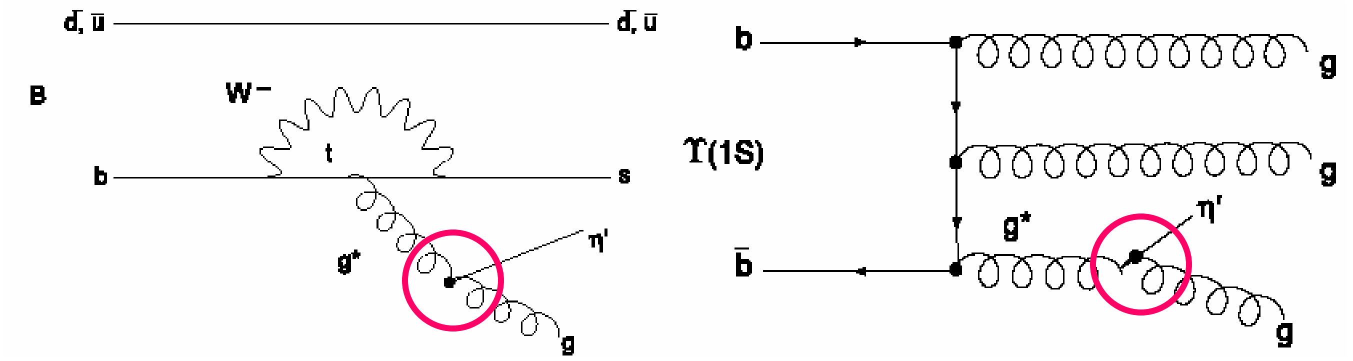
Deuteron production is enhanced in ggg, ggγ process.

Inclusive $\Upsilon(1S)\to\eta' X$

- The unexpectedly large $\mathcal{B}(B\to\eta' X_S)$ with $P_{\eta'} > 2$ GeV was observed by CLEO and confirmed by BaBar.

$$CLEO: (6.2 \pm 1.6 \pm 1.3^{+0.0}_{-1.5}) \times 10^{-4}$$
$$BaBar: (3.9 \pm 0.8 \pm 0.5 \pm 0.8) \times 10^{-4}$$

- Within SM, a possible explanation is the large $g^* \to g\eta'$ coupling in $b \to sg$ penguin diagram (*Atwood & Soni*).

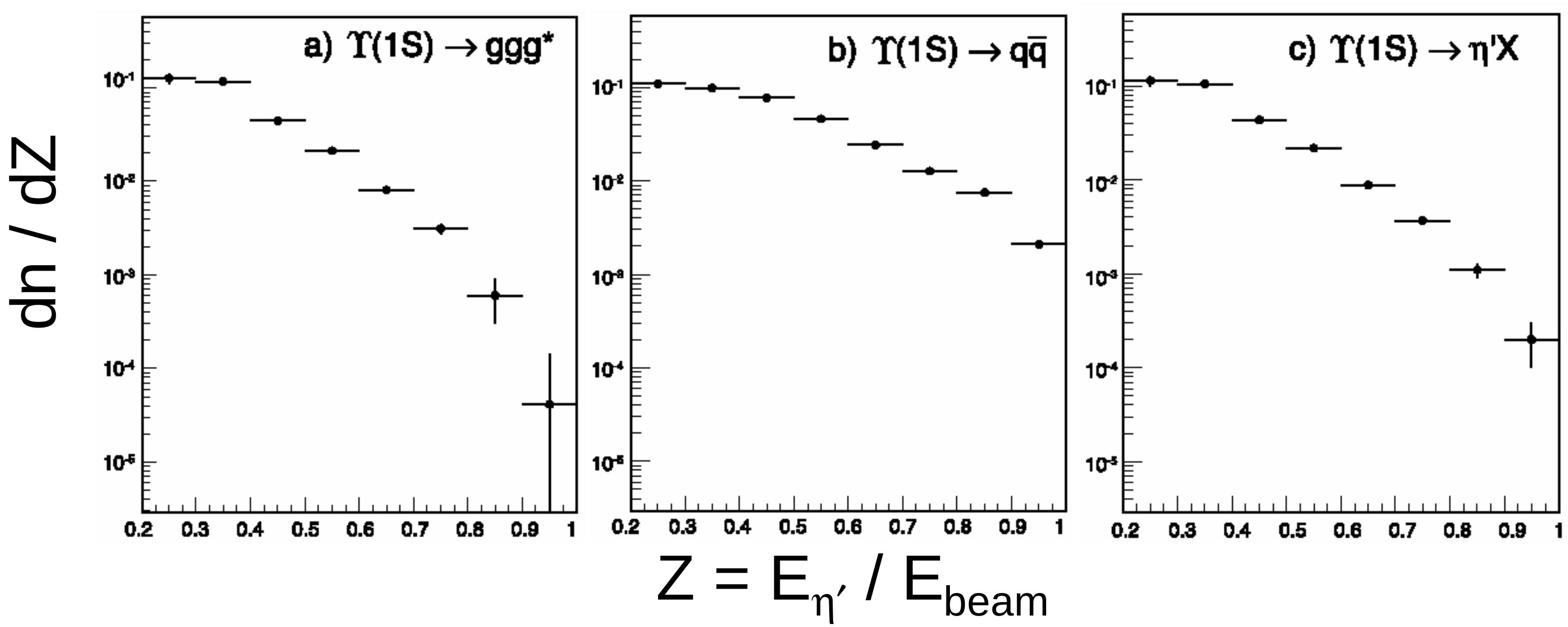


- Such enhancement should present in $\Upsilon(1S)$ decays (*Kagan, Atwood & Soni*).
- CLEO II measured $\mathcal{B}(\Upsilon(1S)\to ggg\to\eta' X)=(1.9\pm1.1\pm0.2)\times10^{-4}$ for $E_{\eta'}/E_{beam} > 0.7$, ruled out a class of form factors characterized by a weak q^2 dependence. Higher precision is needed for more model tests.

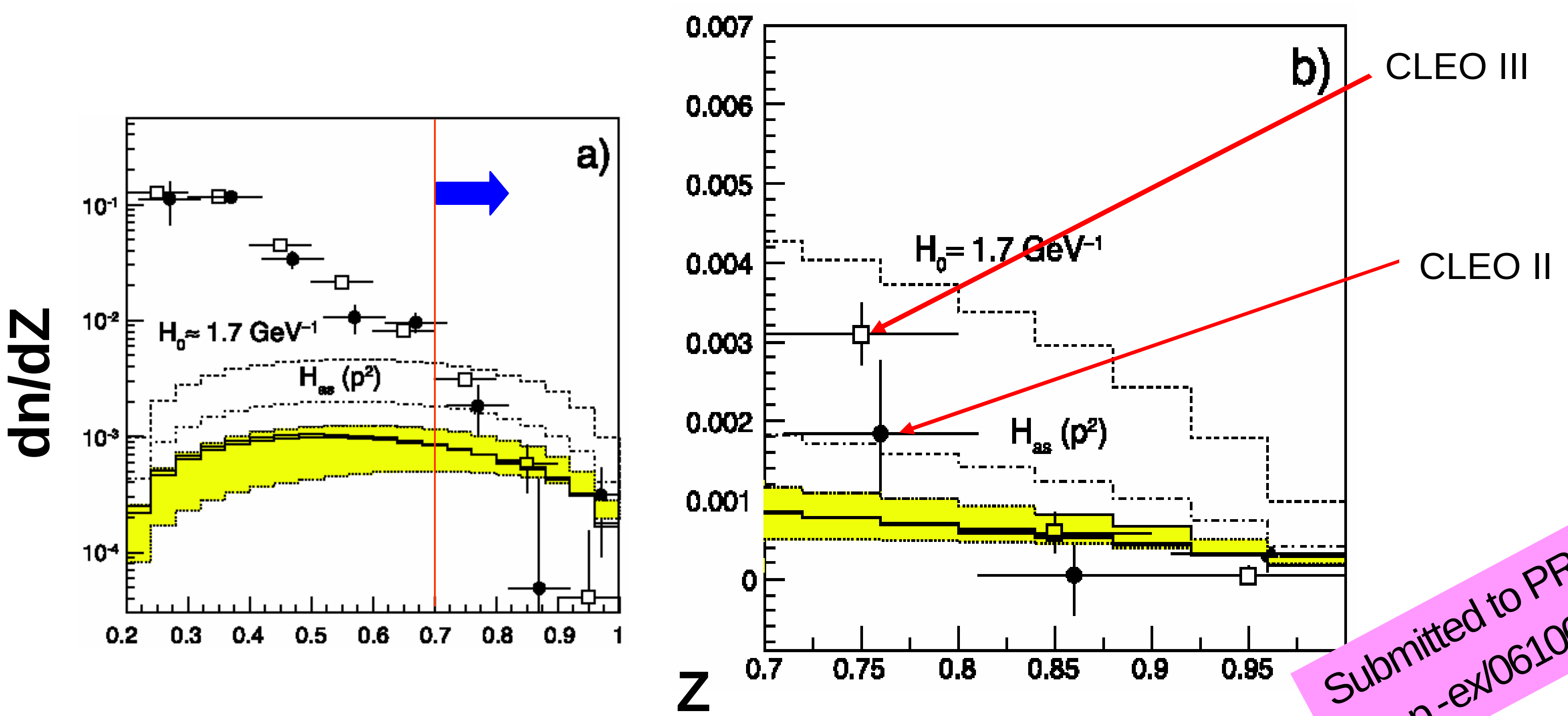
Inclusive η′ Production In ϒ(1S) Data

$\eta' \to \eta\pi^+\pi^-$, $\eta \to \gamma\gamma$

	All Z	Z > 0.7
a) $n \equiv \frac{N(\Upsilon(1S) \to ggg \to h'X)}{N(\Upsilon(1S) \to ggg)}$	$(3.2 \pm 0.2 \pm 0.2)\%$	$(3.7 \pm 0.5 \pm 0.3) \times 10^{-4}$
b) $n \equiv \frac{N(\Upsilon(1S) \to q\bar{q} \to h'X)}{N(\Upsilon(1S) \to q\bar{q})}$	$(3.8 \pm 0.2 \pm 0.3)\%$	$(22.5 \pm 1.2 \pm 1.8) \times 10^{-4}$
c) $n \equiv \frac{N(\Upsilon(1S) \to h'X)}{N(\Upsilon(1S))}$	$(3.0 \pm 0.2 \pm 0.2)\%$	$(5.1 \pm 0.4 \pm 0.4) \times 10^{-4}$



Inclusive η′ Production Compare with Theory



Submitted to PRD
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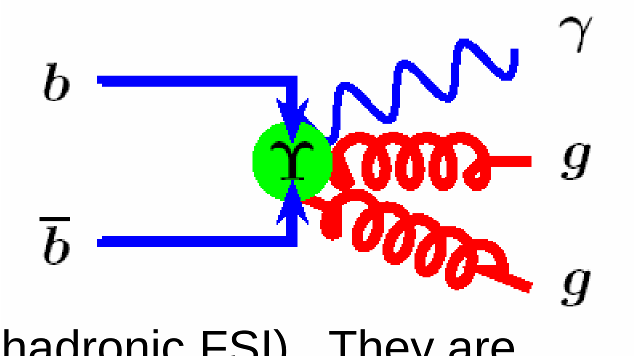
- Measured spectrum is not well described by existing models.
- The observed $B(B \to \eta' X_S)$ is unlikely to be explained by an enhanced $g^*g\eta'$ form factor. An explanation outside the realm of SM or an improved understanding of non-perturbative QCD effects may be needed.

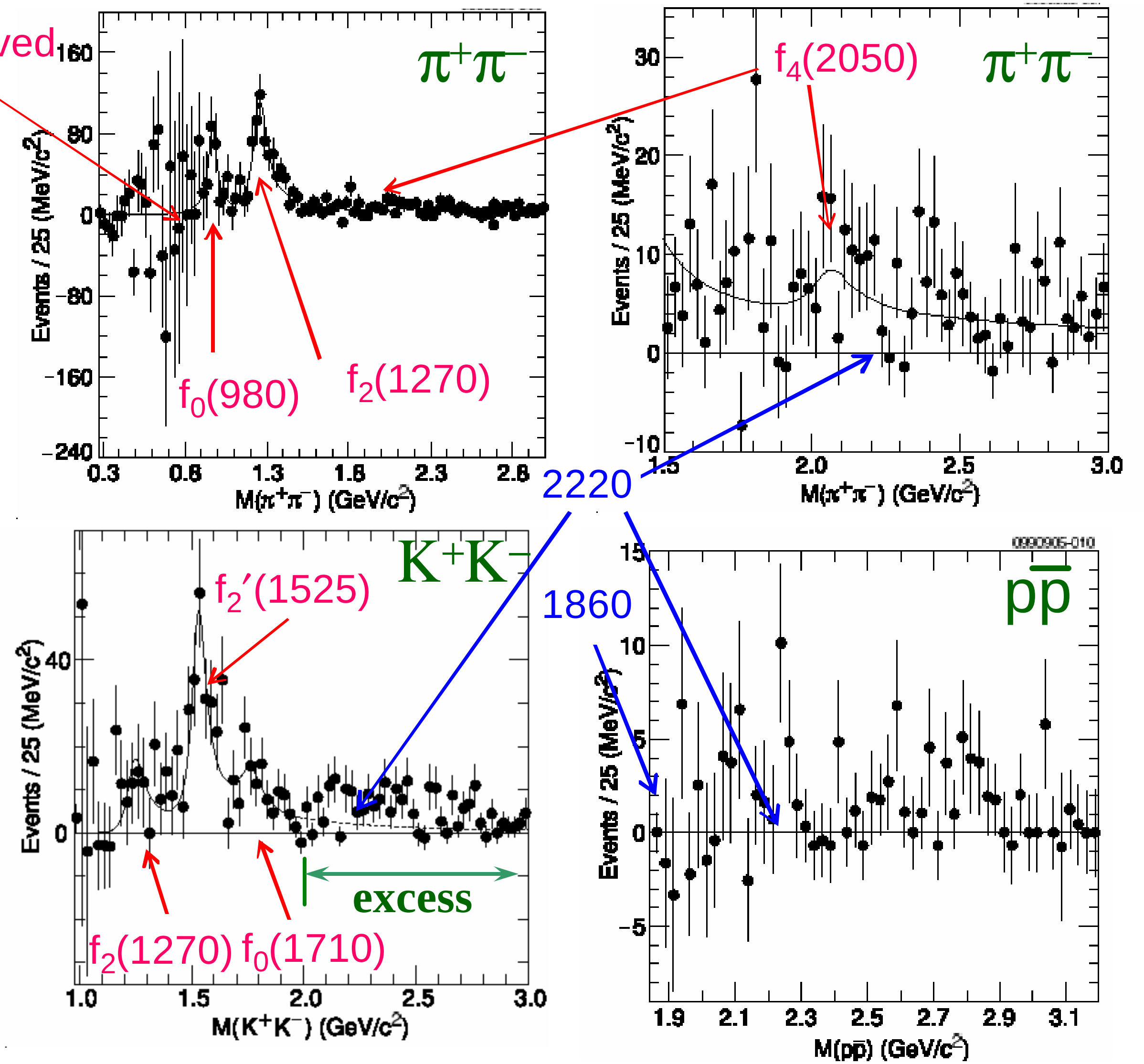
Upsilon Radiative Decays

- In Upsilon two-body radiative decays, The two gluons hadronize into a meson or form a glueball.



- These decays are theoretically simple (no hadronic FSI). They are useful in study of color-singlet two-gluon system.
- Many $J/\psi \to \gamma X$ ($X=\eta$, η', η_c, $f_2(1270)$, …) decay modes have been observed. A possible glueball state $f_J(2220)$ was reported by BES. Other candidates like X(1860) were also observed.
- Radiative decays $\Upsilon(1S) \to \gamma X$ are analogous to that of J/ψ. The decay branching fraction is scaled down by 1/25, due to the quark charges, masses and the total width of the quarkonia.
- CLEO II observed $\Upsilon(1S) \to \gamma f_2(1270)$, consistent with scaling down factor. CLEO also set an upper limit on $f_J(2220)$ production.

$\Upsilon(1S) \to \gamma h^+h^-$



CLEO III

No significant structure at 2220 or 1860.

$\Upsilon(1S) \to \gamma\, h^+h^-$

- Confirm $f_2(1270)$ in $\pi^+\pi^-$ mode and establish J=2 assignment.

  $$B(\Upsilon(1S) \to g\, f_2(1270)) = (10.2 \pm 0.8 \pm 0.7) \times 10^{-5}$$

- Observe $f_2'(1525)$ in K^+K^- mode and establish J=2 assignment.

  $$B(\Upsilon(1S) \to g\, f_2'(1525)) = (3.7^{+0.9}_{-0.7} \pm 0.8) \times 10^{-5}$$

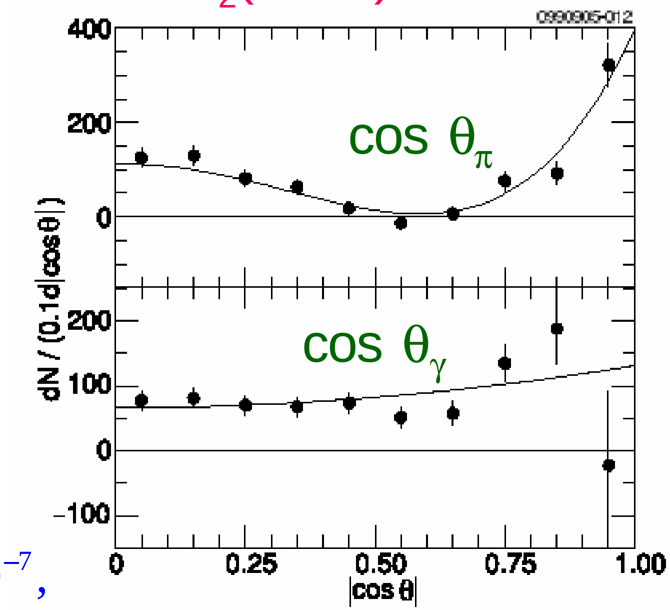
- Set 90% CL upper limit on product branching fraction for $f_J(2220)$:

  $$B(\Upsilon(1S) \to g\, f_J(2220)) \times B(f_J(2220) \to p^+p^-) < 8 \times 10^{-7},$$
  $$B(\Upsilon(1S) \to g\, f_J(2220)) \times B(f_J(2220) \to K^+K^-) < 6 \times 10^{-7},$$
  $$B(\Upsilon(1S) \to g\, f_J(2220)) \times B(f_J(2220) \to p\bar{p}) < 11 \times 10^{-7}.$$

- Set 90% CL upper limit on product branching fraction for X(1860):

  $$B(\Upsilon(1S) \to g\, X(1860)) \times B(X(1860) \to p\bar{p}) < 5 \times 10^{-7}.$$

$f_2(1270) \to \pi^+\pi^-$



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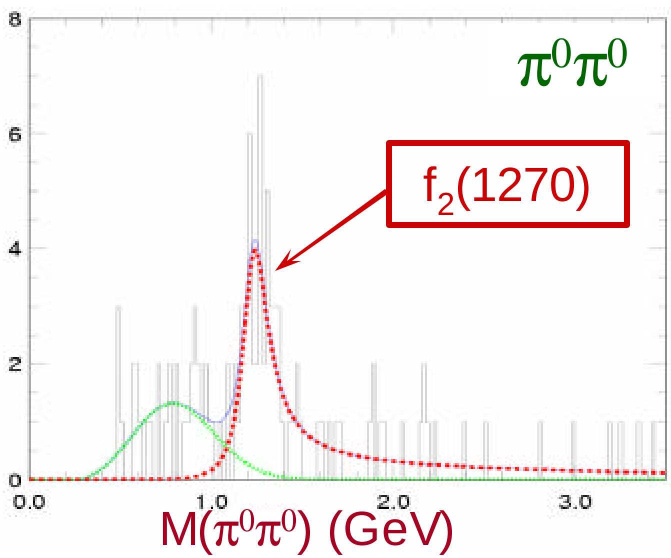
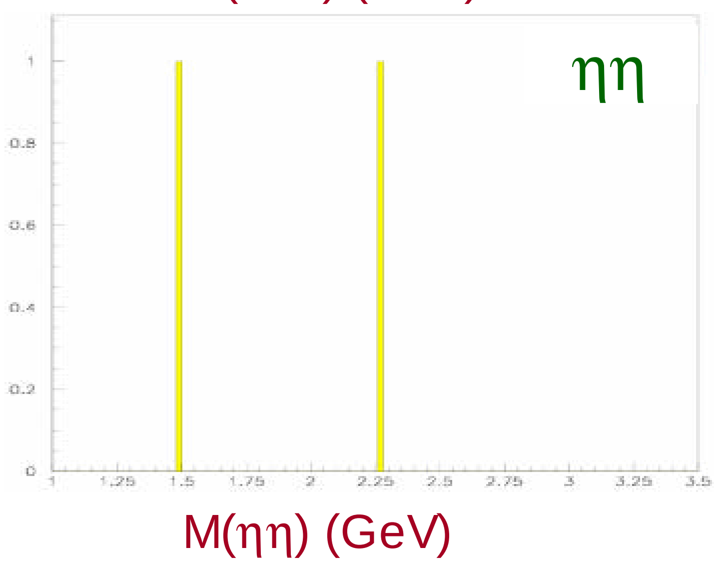
$\Upsilon(1S) \to \gamma\, h^0 h^0$





- Measured $f_2(1270)$ production rate in $\pi^0\pi^0$ mode, consistent with $\pi^+\pi^-$ mode.

  $$B(\Upsilon(1S) \to g\ f_2(1270)) = (10.5 \pm 1.6^{+1.9}_{-1.8}) \times 10^{-5}$$

- No resonance structure for $f_0(1500)$ and $f_0(1710)$ and 90% upper limits are set. The limits are order of magnitude lower than QCD factorization calculation (*PRD66, 074015*):

  $$B(\Upsilon(1S) \to g\ f_0(1500)) < 1.17 \times 10^{-5},$$

  $$B(\Upsilon(1S) \to g\ f_0(1710)) \times B(f_0(1710) \to p^0 p^0) < 1.2 \times 10^{-6}.$$

- See two candidates in $\eta\eta$ mode and no candidate in $\pi^0\eta$ mode. UL are:

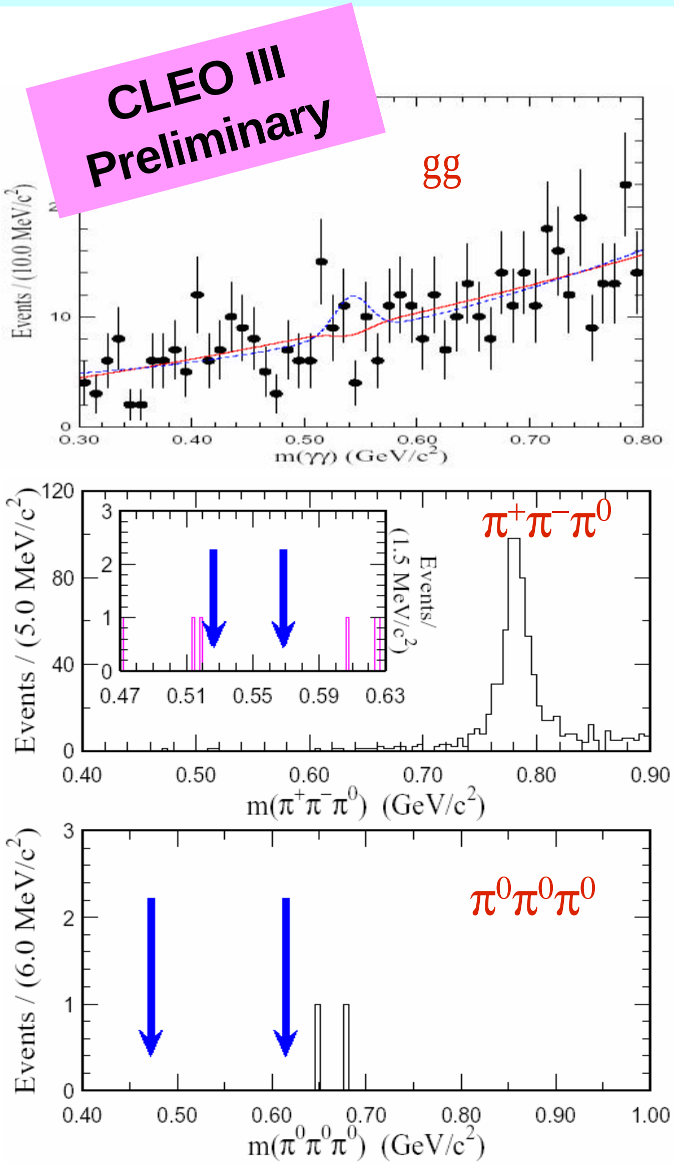
  $$B(\Upsilon(1S) \to g\ f_0(1500)) \times B(f_0(1500) \to hh) < 3.0 \times 10^{-6},$$

  $$B(\Upsilon(1S) \to g\ f_0(1710)) \times B(f_0(1710) \to hh) < 1.9 \times 10^{-6},$$

  $$B(\Upsilon(1S) \to gp^0 h) < 2.8 \times 10^{-6}.$$

Submitted to PRD
hep -ex/0512003

Search for ϒ(1S)→ γη, γη′ (I)



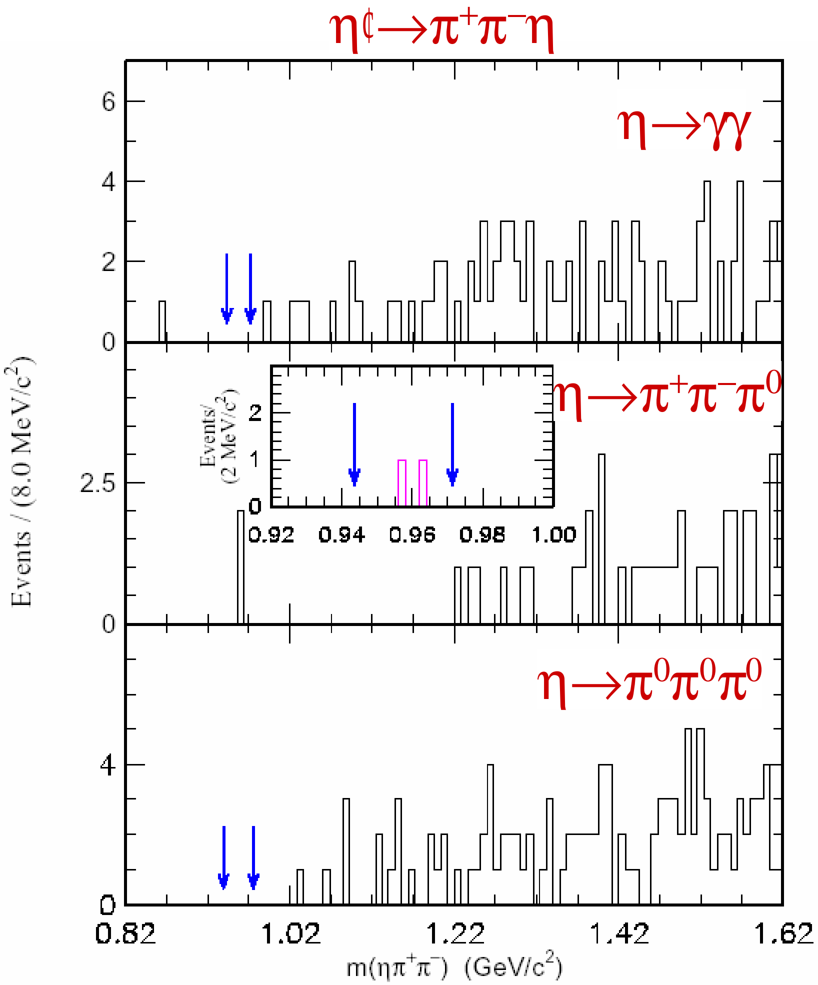
- Production rates of $J/\psi \to \gamma\eta$, $\gamma\eta'$, $\gamma f_2(1270)$ have been measured and

$$B(J/y \to gh')/B(J/y \to g f_2) \approx 3.4$$

$$B(J/y \to gh)/B(J/y \to g f_2) \approx 0.7$$

- $B(\Upsilon(1S) \to \gamma f_2(1270)) = 10.0\times10^{-5}$ by CLEO II and III.
- CLEO II set $B(\Upsilon(1S) \to \gamma\eta') < 1.6\times10^{-5}$ and $(\Upsilon(1S) \to \gamma\eta) < 2.1\times10^{-5}$, corresponding to the ratio limits of 0.16 and 0.21 respectively.
- Several models (VDM, NRQCD, mixing with η_b) try to explain the lower rates and need to be tested.
- Decay modes: $\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$, $\pi^0\pi^0\pi^0$ are searched. No candidate seen.

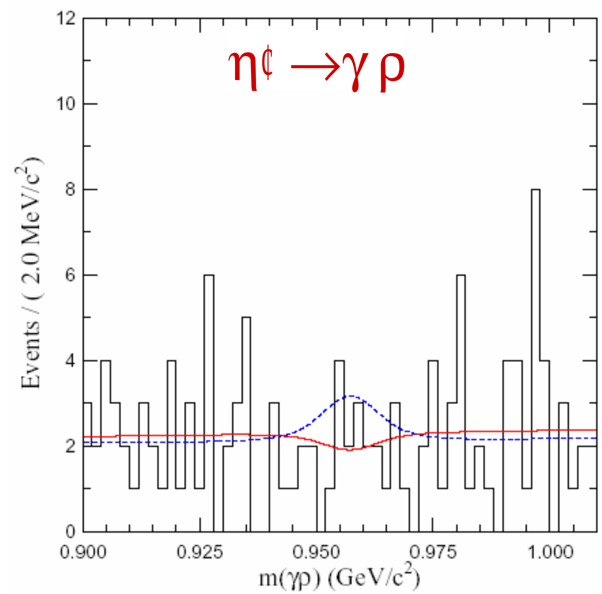
Search for $\Upsilon(1S) \to \gamma\eta, \gamma\eta'$ (II)



CLEO III

Preliminary

No Signal



$$\mathcal{B}(\Upsilon(1S) \to \gamma\eta) < 9.3 \times 10^{-7},$$

$$\mathcal{B}(\Upsilon(1S) \to \gamma\eta') < 1.77 \times 10^{-6}$$

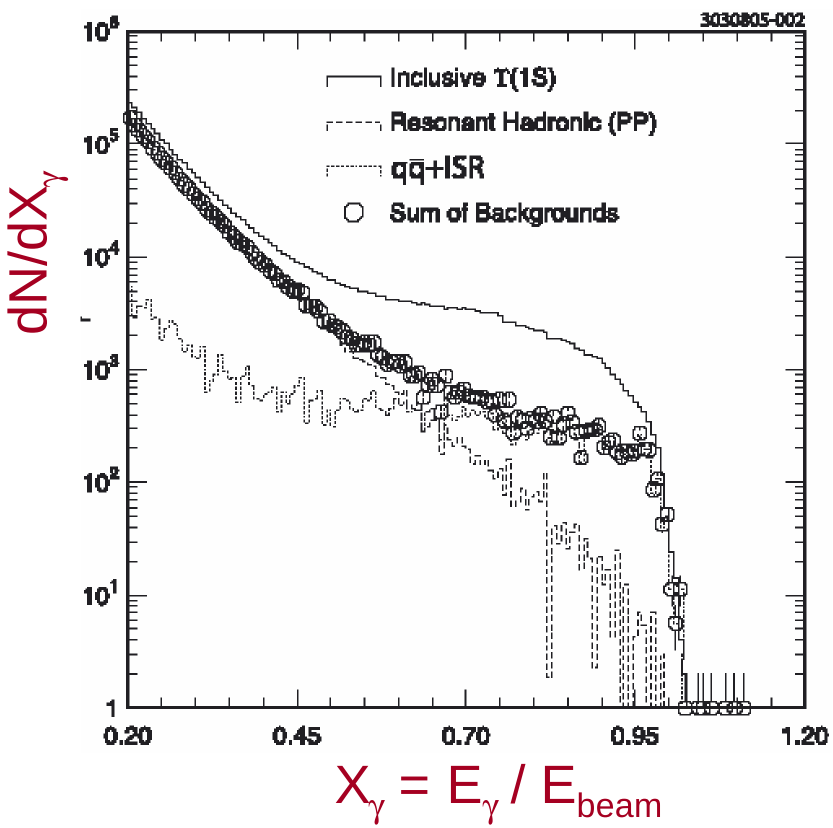
Strongly disfavors mixing with η_{b}.

Still consistent with VDM.

Barely consistent with NRQCD.

Search for $\Upsilon \to \gamma\mathfrak{R}$, $\mathfrak{R} \to (\geq 4\ h^{\pm})$

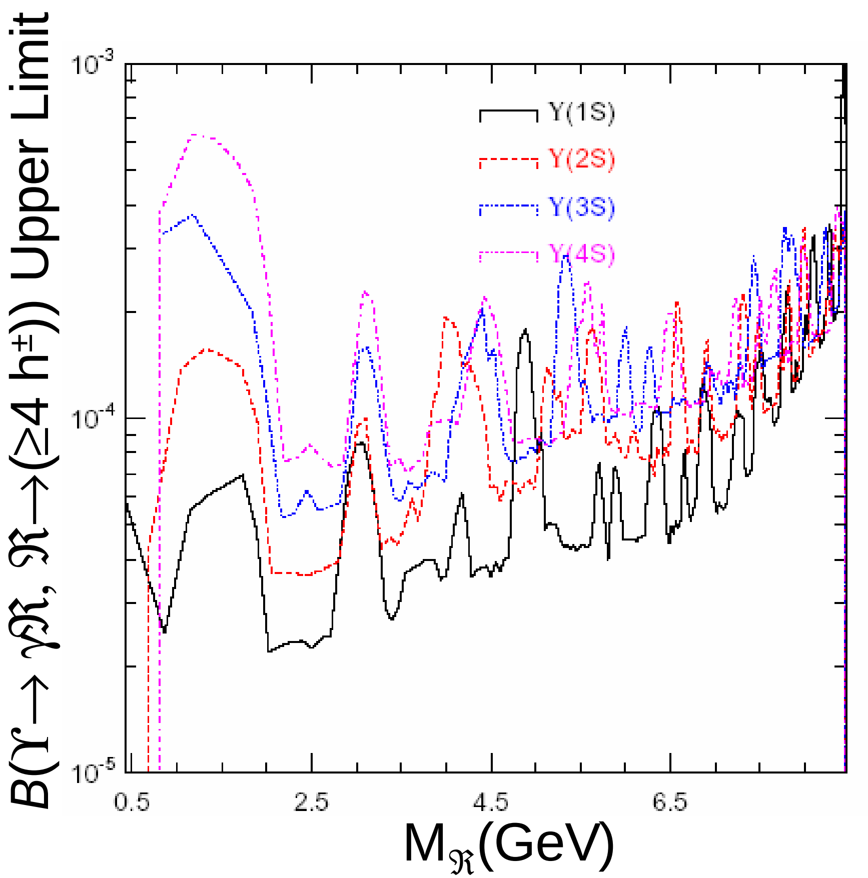
Plot borrowed from
PRD 74, 012003(2006)



- Two body decay with a narrow resonance $\mathfrak{R}$ results in monochromatic γ in the lab frame.
- A bump above the smooth background indicates a narrow resonance.
- A series of fit at each E_γ step to Chebyshyev polynomial function for background and Gaussian function for signal.
- The production upper limit at each E_γ is calculated from fit and map to $M_{\mathfrak{R}}$.

Search for $\Upsilon \to \gamma \mathfrak{R}$, $\mathfrak{R} \to (\geq 4\ h^{\pm})$

CLEO III Preliminary
hep-ex/0607054



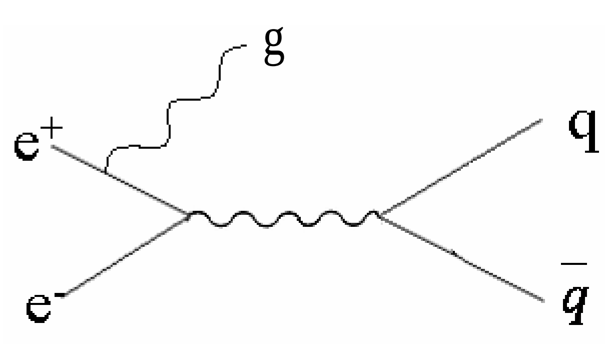
	$B(\Upsilon \to \gamma\mathfrak{R}, \mathfrak{R} \to (\geq 4\ h^{\pm}))$ 90%CL Upper Limit	
	All $M_{\mathfrak{R}}$	$1.45 < M_{\mathfrak{R}} < 5$ GeV
Υ(1S)	1.05×10^{-3}	1.82×10^{-4}
Υ(2S)	1.65×10^{-3}	1.69×10^{-4}
Υ(3S)	2.47×10^{-3}	3.00×10^{-4}

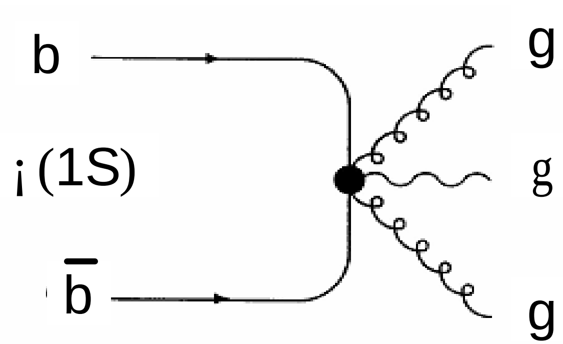
B.R upper limits are all $\sim 10^{-4}$.

No conflict with existing measurements

Hadron Production in Gluon vs Quark

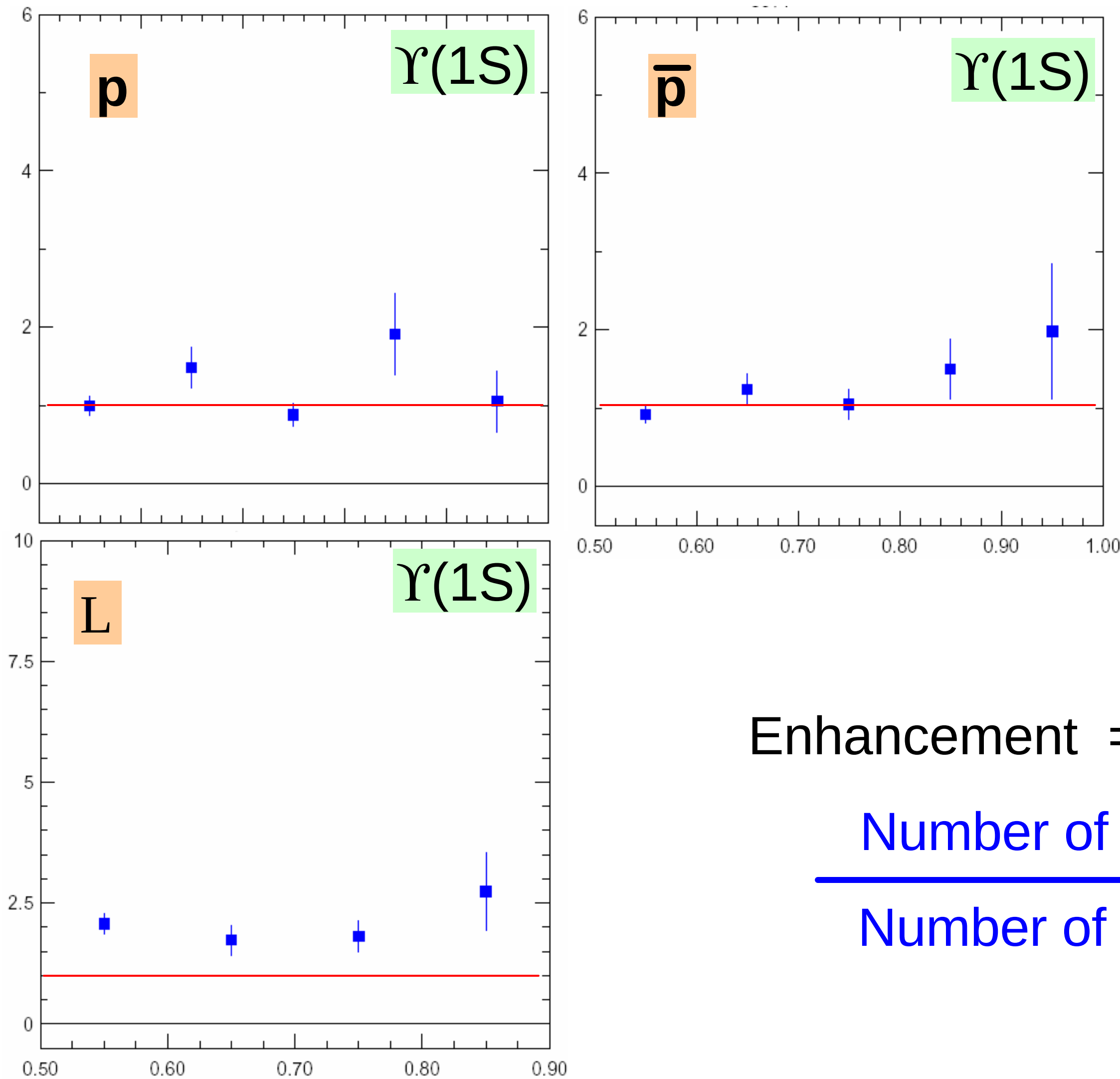
- Hadron productions in gluon rich and quark environment have been compared by many experiments.
- At LEP 3 jet ($q\bar{q}g$) and 2 jet ($q\bar{q}$) events were used for comparison.
- At CESR $\Upsilon(1S)\rightarrow ggg$ and $e^+e^-\rightarrow q\bar{q}$ were used. CLEO found that ϕ, Λ and p production rates are higher in ggg decays.
- Samples $\Upsilon(1S)\rightarrow gg\gamma$ and $e^+e^-\rightarrow q\bar{q}\gamma$ are better choices: Parton numbers are equal. Parton total energy can be equal.





Comparison Between $gg\gamma$ and $q\bar{q}\gamma$

Enhancement

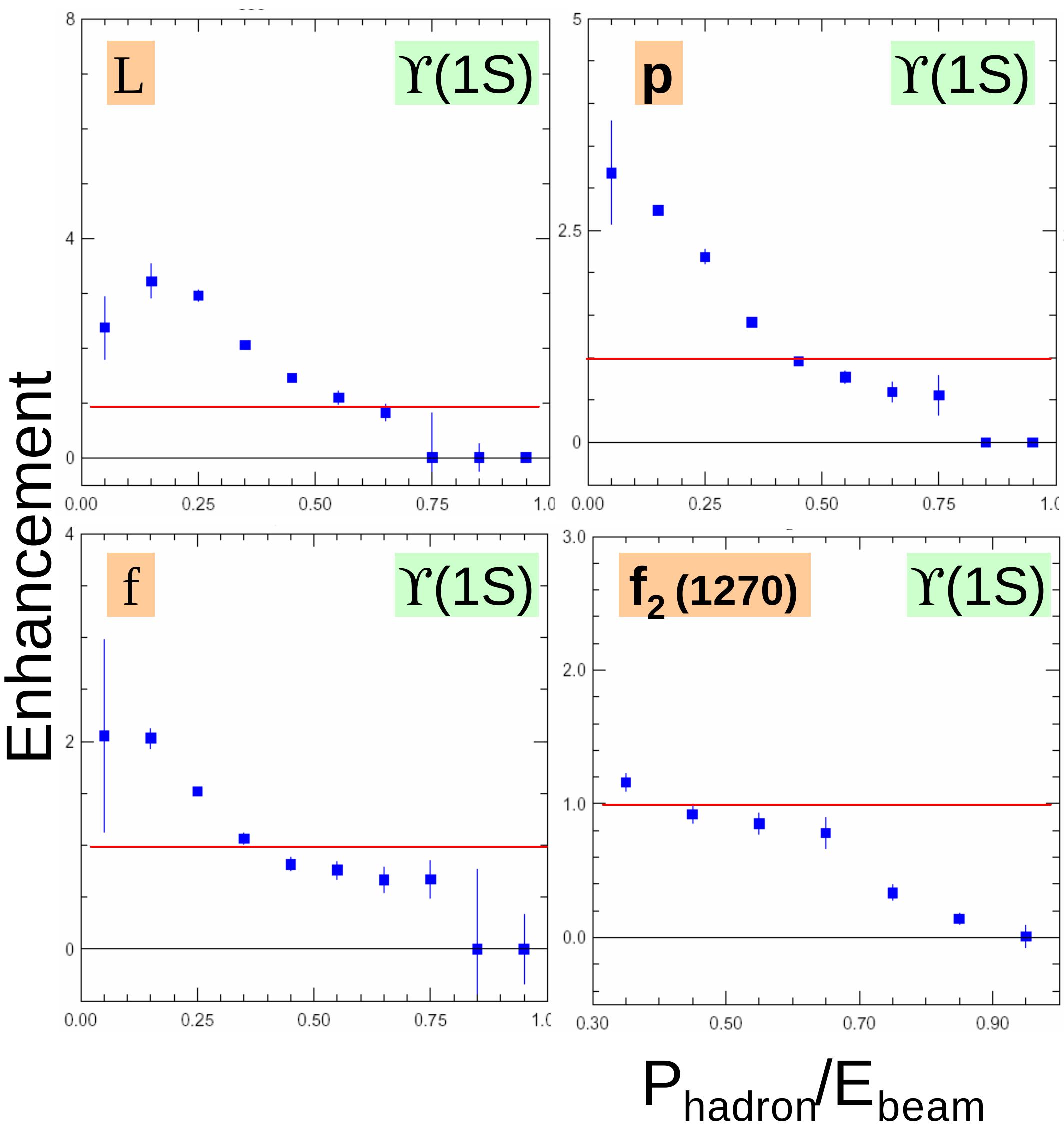


$E\gamma/E_{beam}$

CLEO III Preliminary

$$\text{Enhancement} = \frac{\text{Number of hadron per } gg\gamma \text{ event}}{\text{Number of hadron per } q\bar{q}\gamma \text{ event}}$$

Comparison Between ggg and $q\bar{q}$



CLEO III Preliminary

$$\text{Enhancement} = \frac{\text{Number of hadron per ggg event}}{\text{Number of hadron per } q\bar{q} \text{ event}}$$

Integrated Enhancement Comparison

1S		$gg\gamma$ vs. $q\bar{q}\gamma$	ggg vs. $q\bar{q}$	1984 Study
Data	Λ	1.86 ± 0.25 ± 0.03	2.668 ± 0.027 ± 0.051	~ 3 ± 0.3
MC		1.381 ± 0.039	1.440 ± 0.003	
Data	p	1.21 ± 0.11 ± 0.03	1.623 ± 0.014 ± 0.088	~ 1.5 ± 0.3
MC		1.582 ± 0.034	1.331 ± 0.005	
Data	$\bar{p}$	1.45 ± 0.14 ± 0.21	1.634 ± 0.014 ± 0.081	
MC		1.589 ± 0.034	1.333 ± 0.005	
Data	ϕ	0.48 ± 0.91 ± 0.05	1.423 ± 0.051 ± 0.065	~ 2 ± 0.6
MC		0.702 ± 0.027	0.836 ± 0.003	
Data	f_2	1.34 ± 0.84 ± 0.05	0.658 ± 0.029 ± 0.065	

CLEO III preliminary
hep-ex/0607052

- CLEO III measurement of ggg vs $q\bar{q}$ is consistent with CLEO II measurement.
- Enhancement effect is smaller in $gg\gamma$ vs $q\bar{q}\gamma$.
- Enhancement is smaller for meson than baryon.

Summary

- CLEO measured inclusive anti-deuteron and η' in Υ decays.
- CLEO studied a group of radiative modes of Υ decays.
- CLEO III dedicated Υ(1S), Υ(2S), Υ(3S) data samples have produced many interesting results.
- They are rich laboratories to study hadronization process from gluon.