Theoretical determination of η_b's electromagnetic decay width

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Outline

- Experimental evidence for η_b

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- Relation to other Bottomonium Mesons Width

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More recently – end of 2002 – CDF in Run 1 has done a search for η_b in the process

$$\eta_b \to J/\psi J/\psi$$

with 7 events where 1.8 events are expected from background.

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Singlet picture decay width factorises into:

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First order QCD correction:

$$\Gamma(\eta_b \to \gamma\gamma) = \Gamma_B^P \left[1 + \frac{\alpha_s}{\pi} \left(\frac{\pi^2 - 20}{3} \right) \right] \approx \Gamma_B^P \left(1 - \alpha_s\right)$$

Relation to Υ width

Compare to the Υ state: *Born level*

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Using these relations we extract η_b width from Υ width.

Assuming the wavefunctions are the same in both cases $\Rightarrow \mathcal{O}(\alpha_s/m_b^2)$ error.

Relation to Υ width

Expanding in α_s:

$$\frac{\Gamma(\eta_c \to \gamma\gamma)}{\Gamma(\Upsilon \to e^+e^-)} \approx \frac{1}{3}\frac{(1 - 3.38\alpha_s/\pi)}{(1 - 5.34\alpha_s/\pi)} = \frac{1}{3}\left[1 + 1.96\frac{\alpha_s}{\pi} + \mathcal{O}(\alpha_s^2)\right]$$

Need to compute the correction.

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Two–loop expression for α_s :

$$\alpha_s^{(2)}(Q) = \frac{4\pi}{b_0 f(Q)}\left\{1 - \frac{b_1}{b_0^2}\frac{\log[f(Q)]}{f(Q)}\right\}$$

$b_0 = (33-2N_f)/3, b_1 = (306-38N_f)/3$,

$f(Q) = \log\left[(Q/\Lambda_{\overline{MS}})^2\right]$.

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Combining the formulæ $\Rightarrow$

$$\Gamma(\eta_b \to \gamma\gamma) \pm \Delta\Gamma(\eta_b \to \gamma\gamma) = 489 \underbrace{\pm 19}_{\Upsilon\ \text{error}} \overbrace{\pm 2}^{\alpha_s\ \text{error}}\ \text{eV}$$

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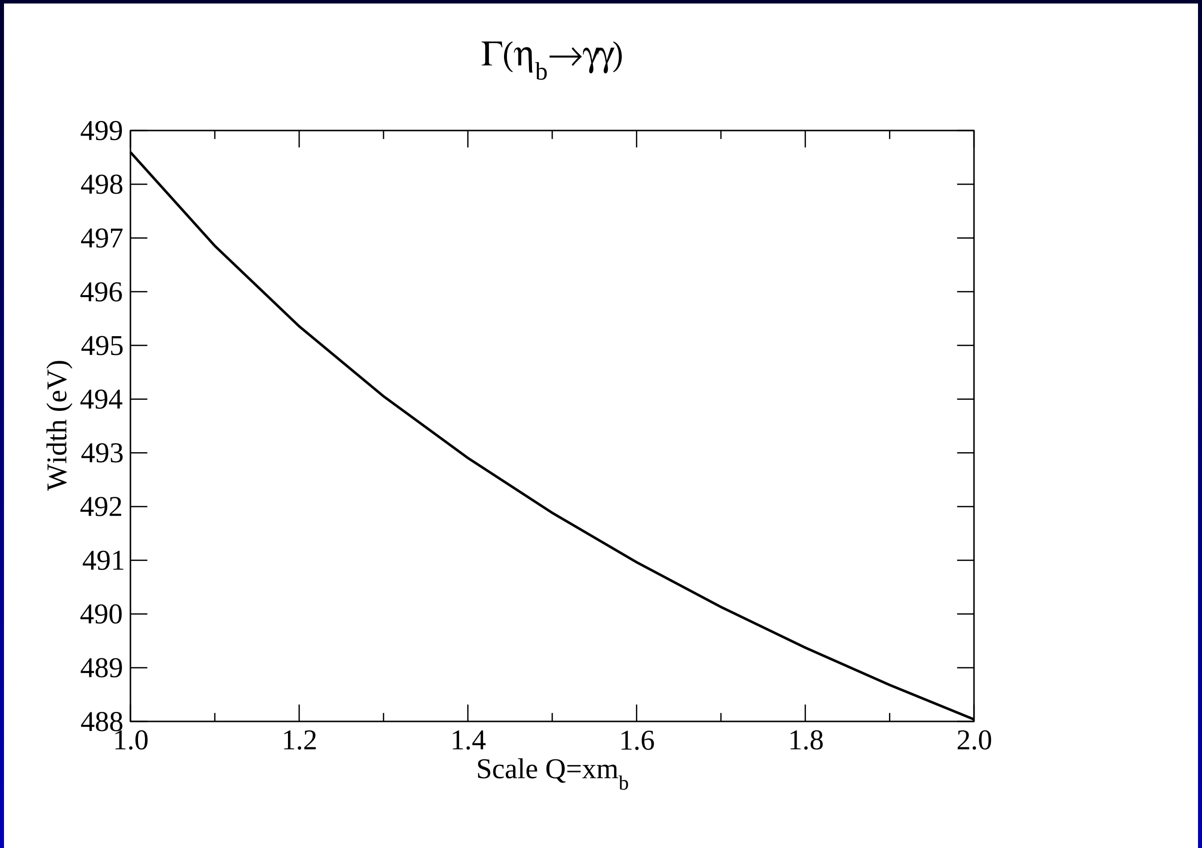
Here we assumed the α_s scale to be $Q = 2m_b = 10.0$ GeV. In the following plot we shall see the effect of a different choice for the α_s scale.

$\eta_b \to \gamma\gamma$ width



η_b decay width to $\gamma\gamma$ in eV, *with respect to the scale chosen for α_s . The fluctuation is of order 2%.*

Potential Models

We present now results for $\eta_b \to \gamma\gamma$ from the potential models. We have used:

- Cornell type potential:

$$V(r) = -\frac{k}{r} + \frac{r}{a^2}$$

with parameters $a = 2.43$, $k = 0.52$

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with parameters $a = 2.43$, $k = 0.52$

- Rosner's group potential:

$$V(r) = \frac{\lambda}{\alpha}\left[\left(\frac{r}{r_0}\right)^{\alpha} - 1\right] + C\,.$$

with $\alpha = -0.14$, $\lambda = 0.808$, $C = -1.305$ GeV, $r_0 = 1$ GeV^{-1}

Potential Models

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$$V_J(r) = V_{AR}(r) + dre^{-gr} + ar, \quad V_{AR}(r) = -\frac{4}{3}\frac{\alpha_s^{(2)}(r)}{r}$$

$\Lambda_{\overline{MS}} = 0.5$ GeV and $\Lambda_{\overline{MS}} = 0.3$ GeV

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- Coulomb potential

$$V(r) = -\frac{4}{3}\frac{\alpha_s}{r}$$

where α_s has been computed at a fixed scale.

Potential Models

The potential of the Coulombic model can be written as:

$$V(r) = -\frac{16\pi}{3\beta_0 r \log 1/(\Lambda_{\overline{MS}} r)^2} \times$$
$$\left[1 - \frac{\beta_1}{\beta_0^2}\frac{\log\log 1/(\Lambda_{\overline{MS}} r)^2}{\log 1/(\Lambda_{\overline{MS}} r)^2} + \frac{\left(\frac{31}{3} - \frac{10}{9}n_f\right)/\beta_0 + 2\gamma_E}{\log 1/(\Lambda_{\overline{MS}} r)^2}\right]$$

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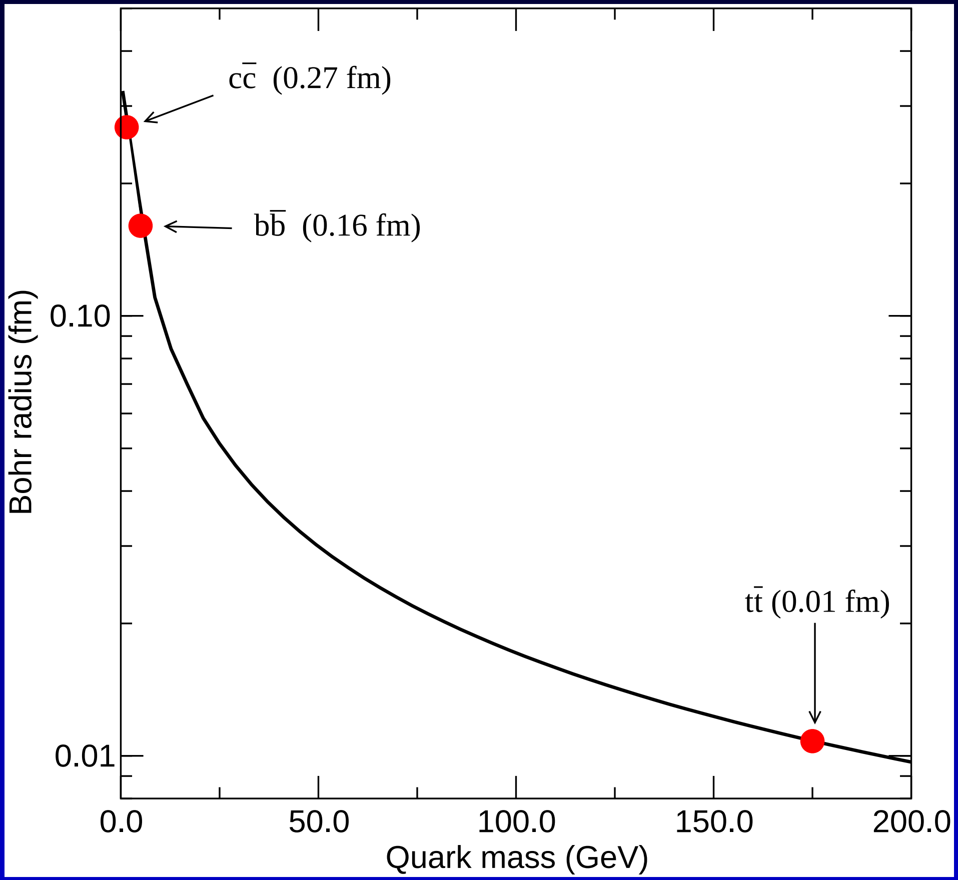
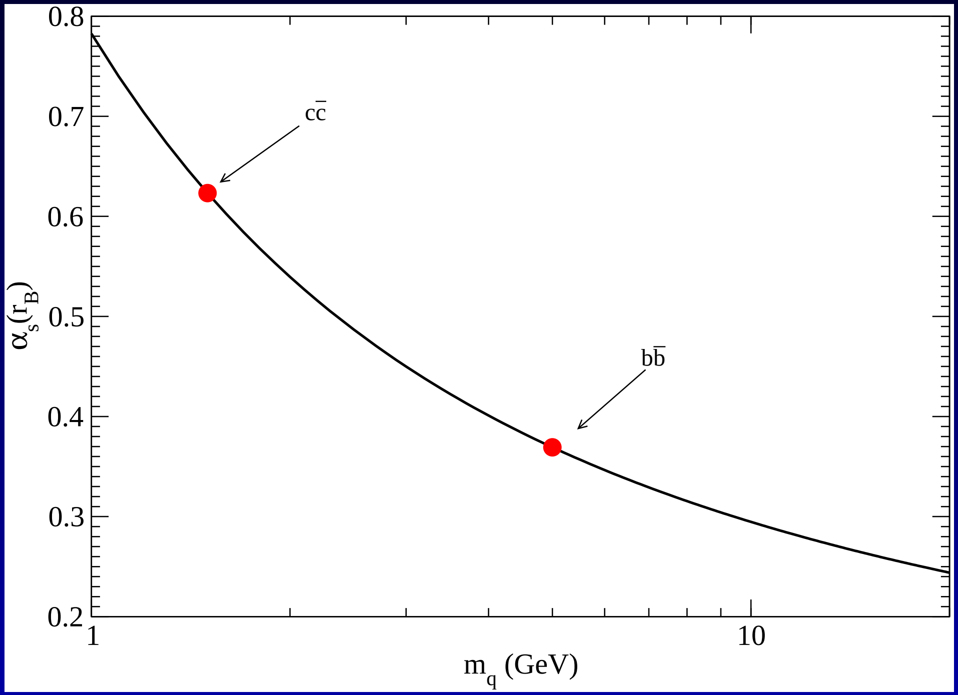
This model proved to be very effective for heavy quark systems, where r_B is small.

r_B as a function of m_q



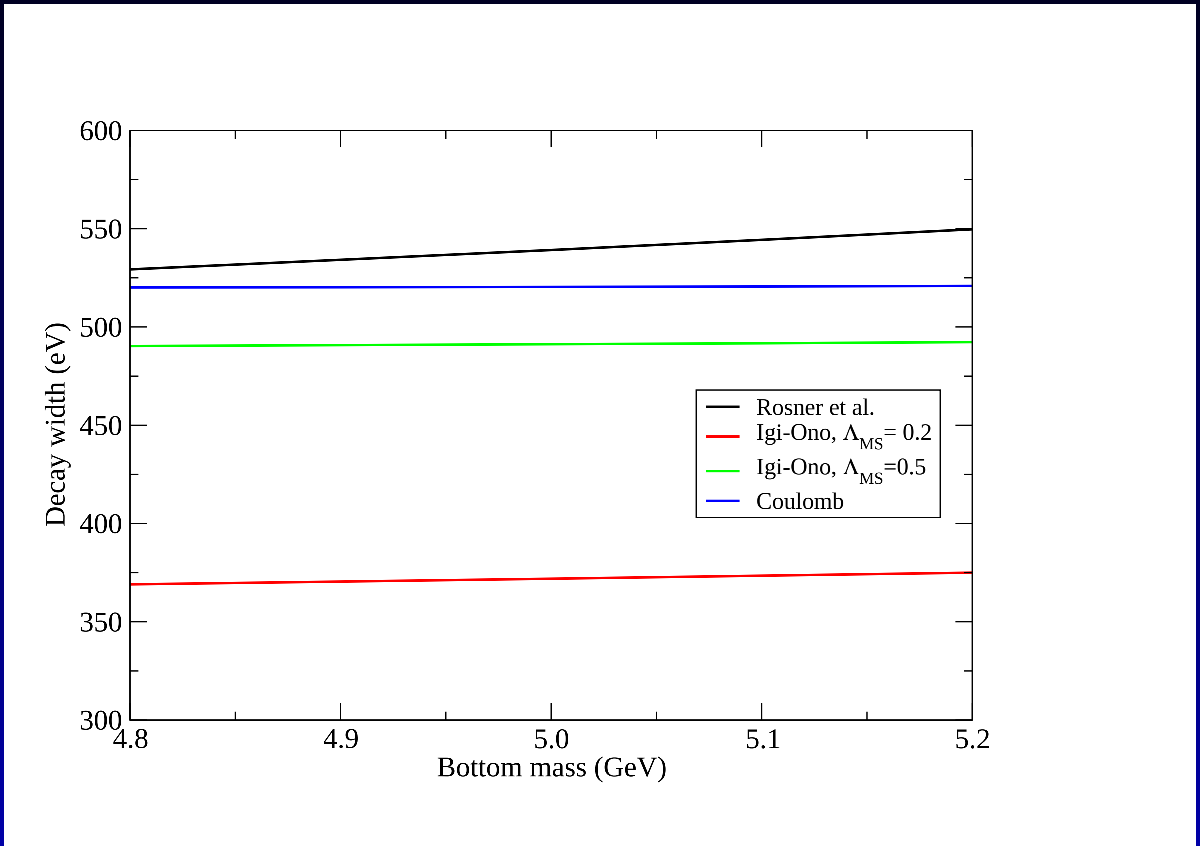
Bohr radius as a function of the quark mass. The radii of the mesonic bound states are enhanced.

$\alpha_s(r_B)$ as a function of m_q



Coulombic model potential with α_s evaluated at Bohr radius as a function of the quark mass. We have enhanced the α_s values of the mesonic bound states.

$\eta_b \longrightarrow \gamma\gamma$ from different potential models



η_b decay width to $\gamma\gamma$ in eV*, evaluated from potential models, as a function of the bottom mass. First order radiative correction in α_s has been evaluated at* $Q = 2m_b$

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$\eta_b \to \gamma\gamma$ potential models prediction gives a range of values:

$$\Gamma(\eta_b \to \gamma\gamma) = 466 \pm 101 \text{ eV}$$

The BBL Procedure

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NRQCD has been used to separate the short distance scale of annihilation from the nonperturbative contributions of long distance scale.

This approach has been successfully used to explain the larger than expected J/ψ production at the Tevatron.

According to BBL, in the octet model for quarkonium, the decay widths of bottomonium states are given by:

The BBL Procedure

$$\Gamma(\Upsilon \to LH) = \frac{2\langle\Upsilon|O_1({}^3S_1)|\Upsilon\rangle}{m_b^2}\left(\frac{10}{243}\pi^2 - \frac{10}{27}\right)\alpha_s^3 \times [1 - (1.161 n_f$$

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$$F_1 \equiv \langle \Upsilon | P_1(^3S_1) | \Upsilon \rangle = \langle \eta_b | P_1(^1S_0) | \eta_b \rangle$$

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$\Longrightarrow$ Only two unknown factors, G_1 and F_1 .
We obtain a system for the Υ decay widths:

$$\begin{cases} \Gamma(\Upsilon \to LH) &= G_1 h_1(\alpha_s, m_b) + F_1 h_2(\alpha_s, m_b) \\ \Gamma(\Upsilon \to e^+e^-) &= G_1 h_3(\alpha_s, m_b) + F_1 h_4(\alpha_s, m_b) \end{cases}$$

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This result is used to compute the η_b decay widths.

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$$\Gamma(\eta_b \to \gamma\gamma) = 364 \underbrace{\pm 13}_{\Upsilon \text{ error}} \overbrace{\pm 8}^{\alpha_s \text{ error}} \text{ eV}$$

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and

$$\Gamma(\eta_b \to LH) = 57.9 \underbrace{\pm 2.8}_{\Upsilon \text{ error}} \overbrace{\pm 4.6}^{\alpha_s \text{ error}} \text{ keV}$$

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We present also results from the lattice calculation of the long distance terms for the BBL approach:

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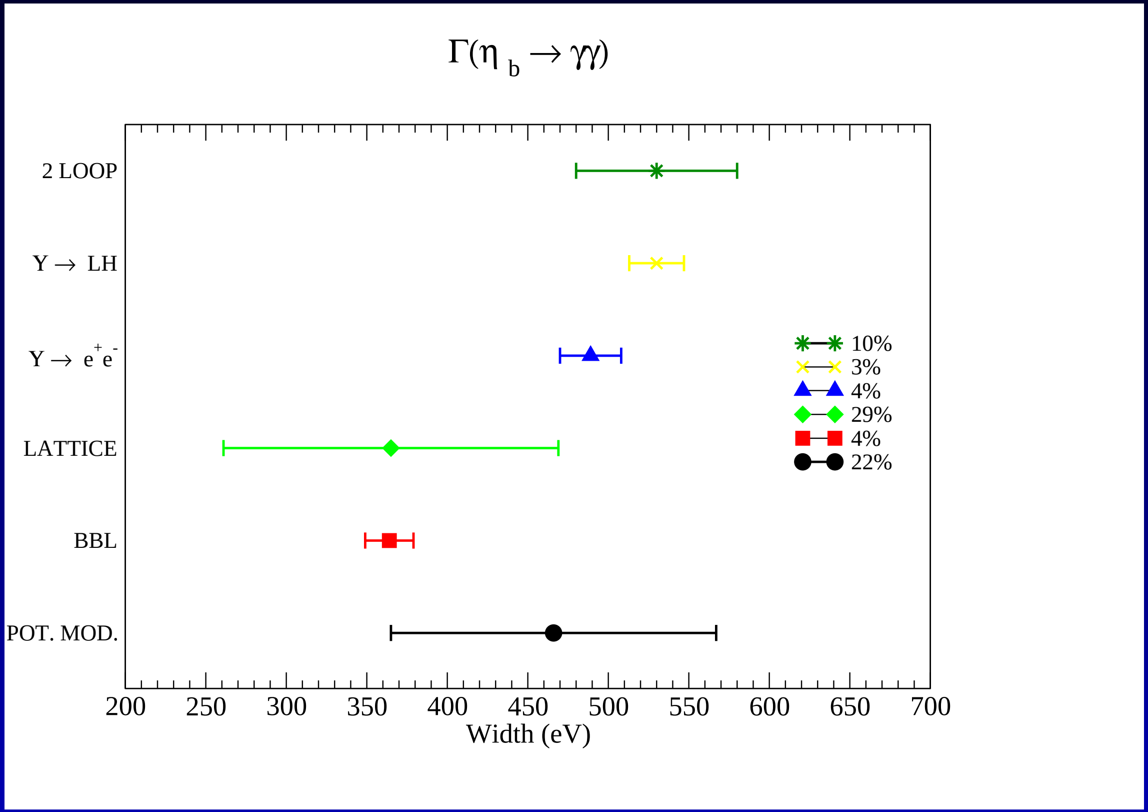
$\eta_b \longrightarrow \gamma\gamma$ Decay Width



Potential Models result; BBL approach with input from Υ decay data; Lattice evaluation of G_1 and F_1 factors; Singlet picture with G_1 obtained from $\Upsilon \to e^+e^-$ and $\Upsilon \to LH$ processes respectively. The last point refers to a $\mathcal{O}(\alpha_s^2)$ correction to the decay rate.

Conclusions

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- The results from the singlet picture are also consistent with the potential model results.