α_s from Bottomonium

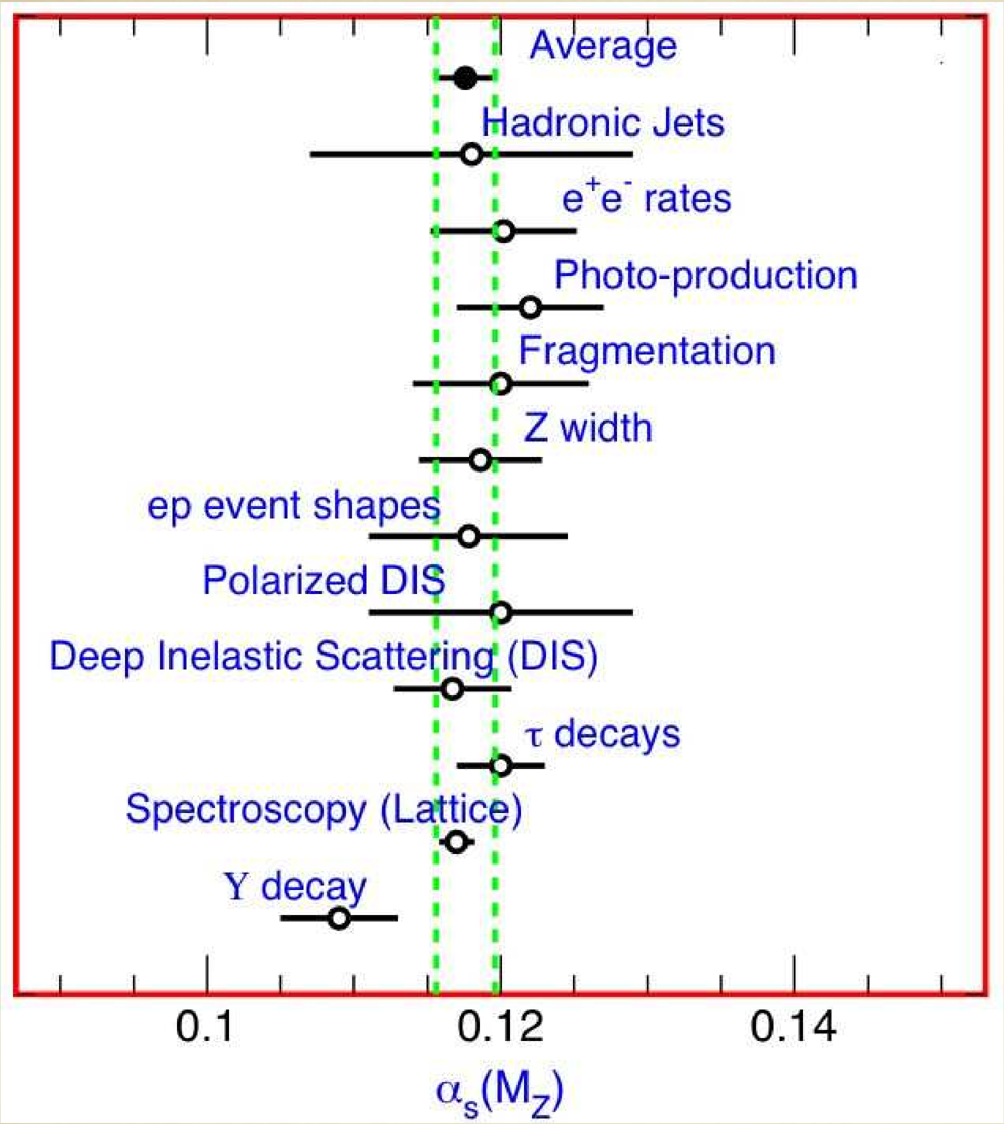
Nora Brambilla

α_s from Bottomonium

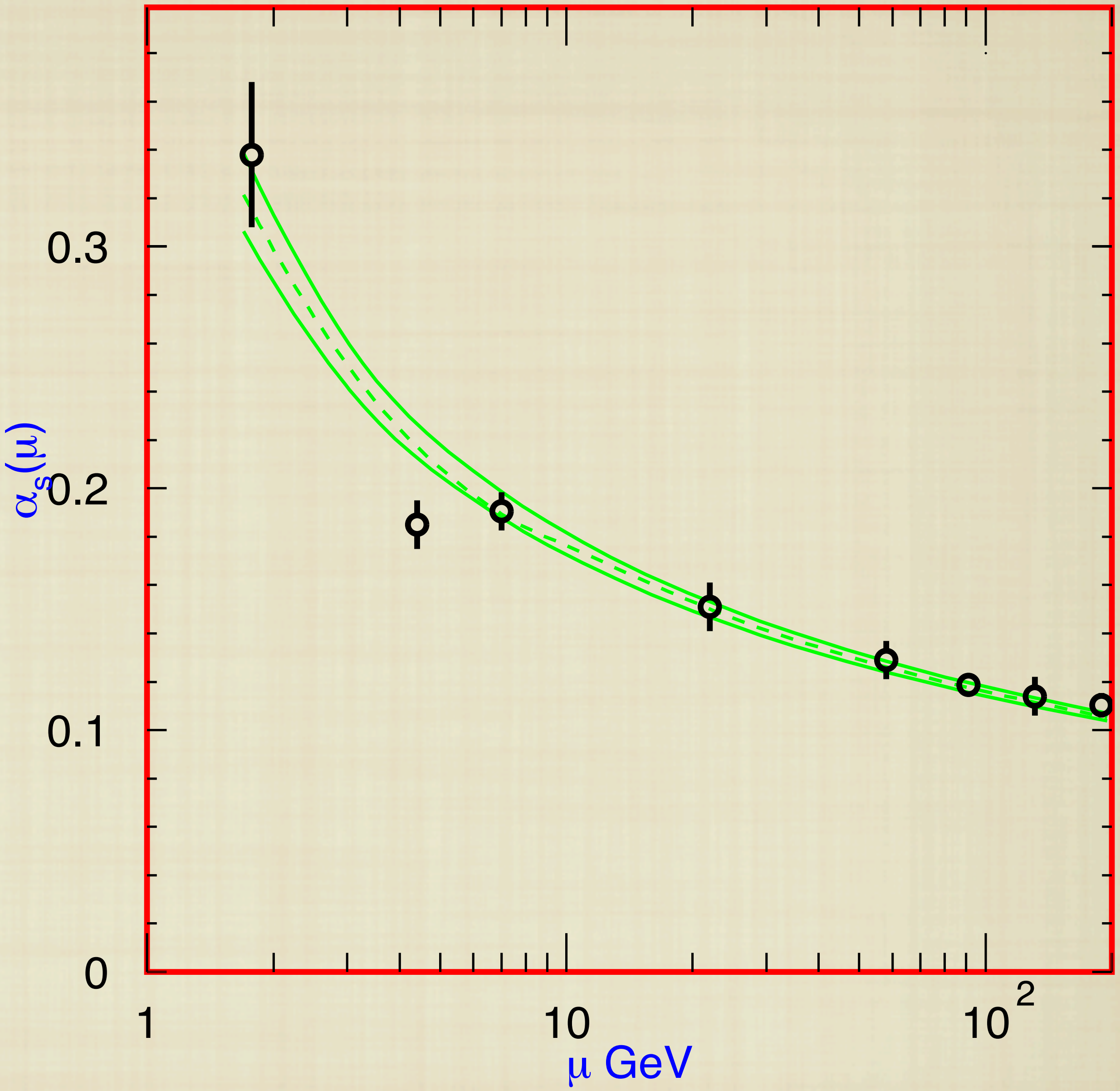
Nora Brambilla

N. B., Xavier Garcia, Joan Soto, Antonio Vairo
Phys. Rev. D75, 074014 (2007)

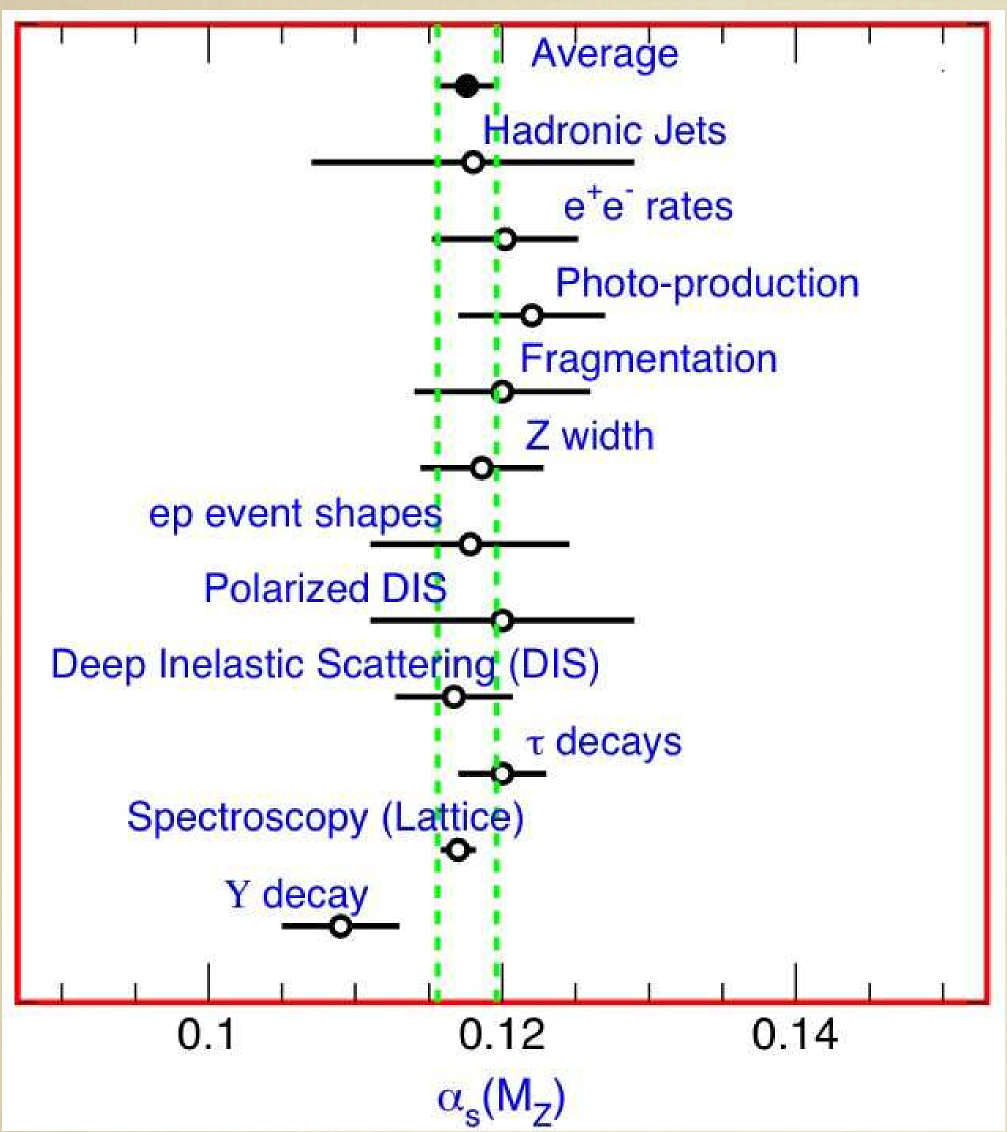
α_s from PDG06



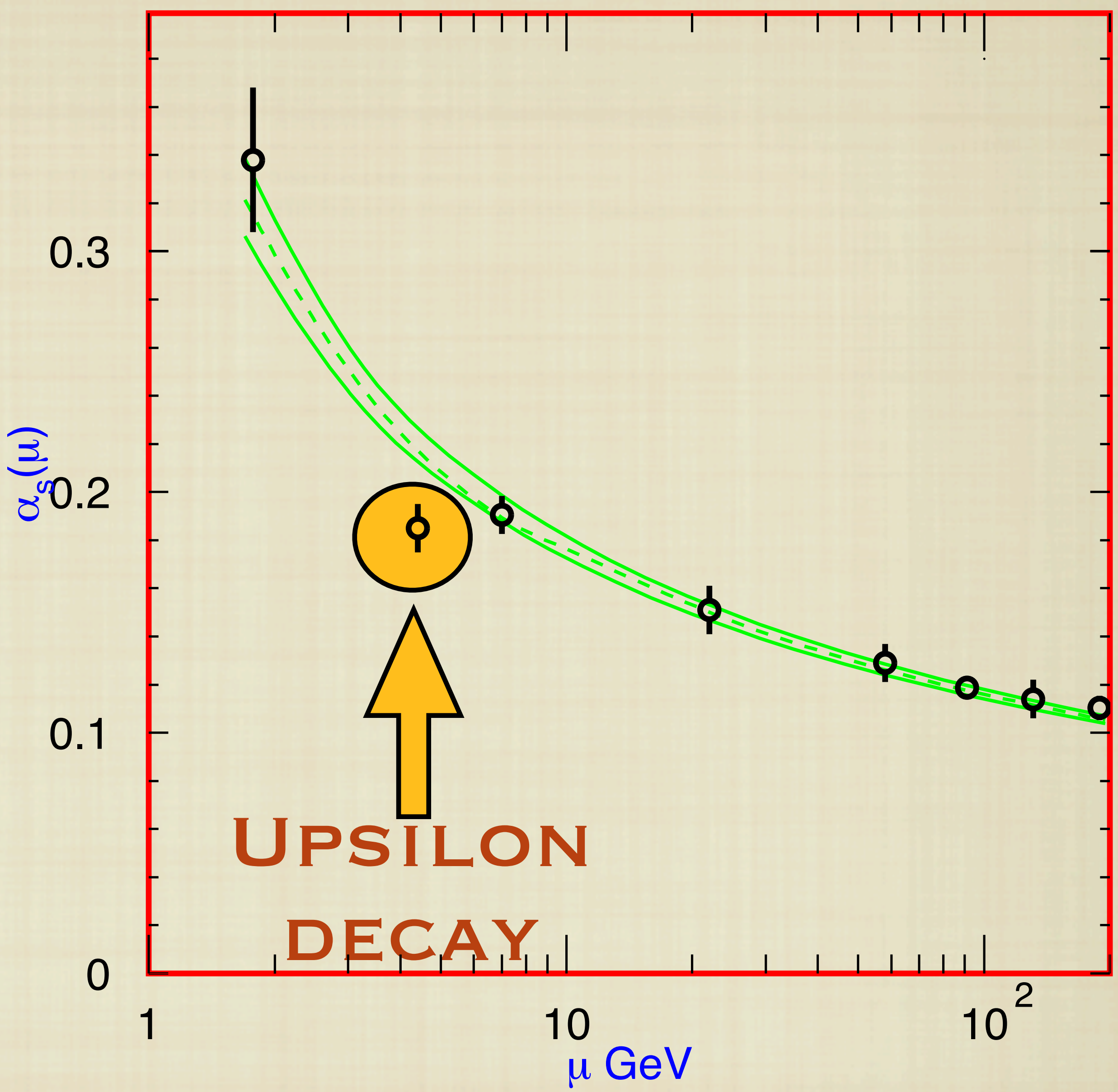
From W.-M. Yao et al., J. Phys. G 33, 1 (2006)



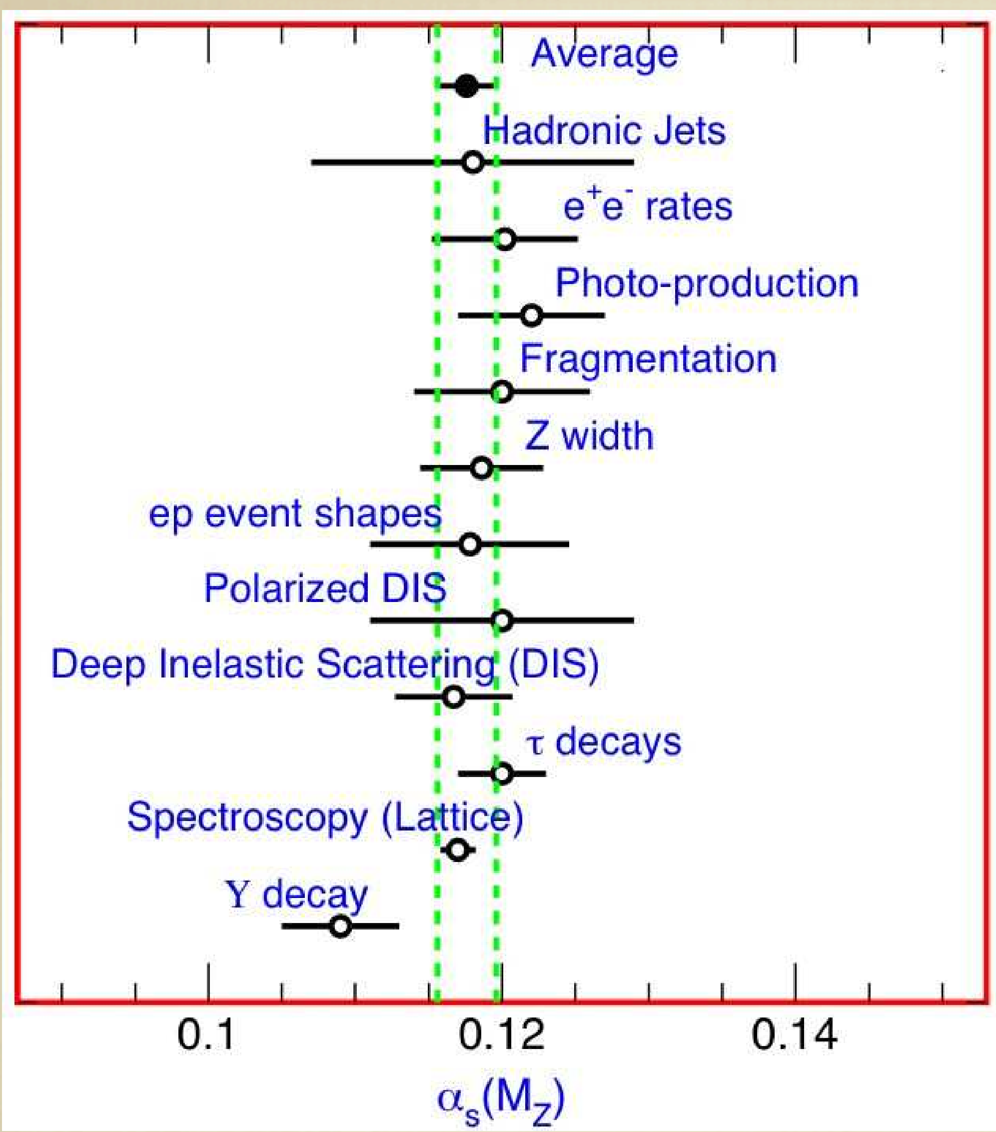
α_s from PDG06



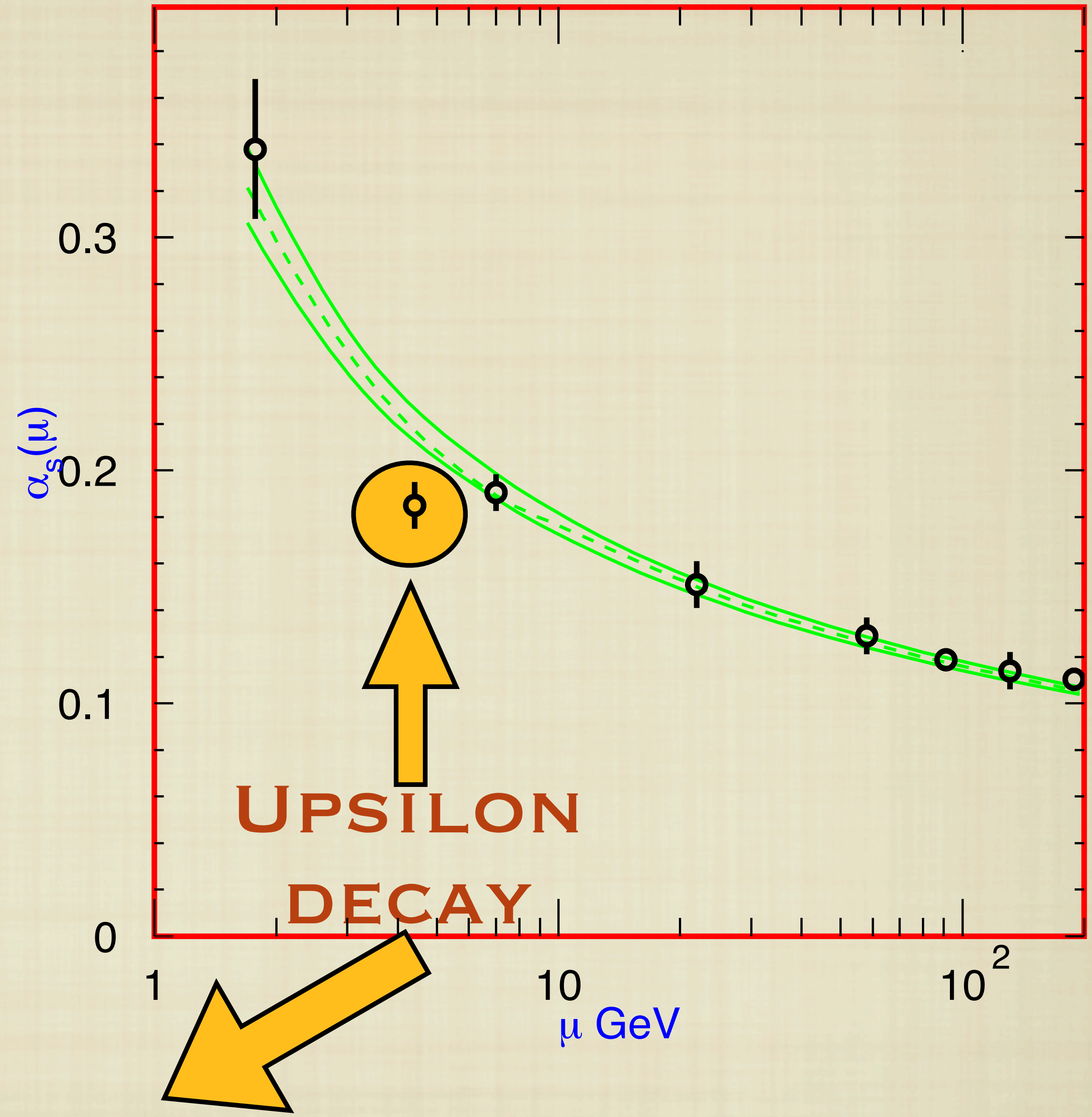
From W.-M. Yao et al., J. Phys. G 33, 1 (2006)



α_s from PDG06



From W.-M. Yao et al., J. Phys. G 33, 1 (2006)



Notice that this is an important determination: one of the few at relatively low energy with a relatively small error

We have obtained a new extraction of α_s from

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)}$$

based on

We have obtained a new extraction of α_s from

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)}$$

based on

- New data from CLEO (HEP-EX/0512061)

We have obtained a new extraction of α_s from

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)}$$

based on

- New data from CLEO (hep-ex/0512061)
- Combined use of NRQCD, pNRQCD and SCET

-> make possible a QCD description of the photon spectrum

X. Garcia, J. Soto 04, 05

We have obtained a new extraction of α_s from

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)}$$

based on

- New data from CLEO (HEP-EX/0512061)

- Combined use of NRQCD, pNRQCD and SCET

  -> make possible a QCD description of the photon spectrum

  X. GARCIA, J. SOTO 04, 05

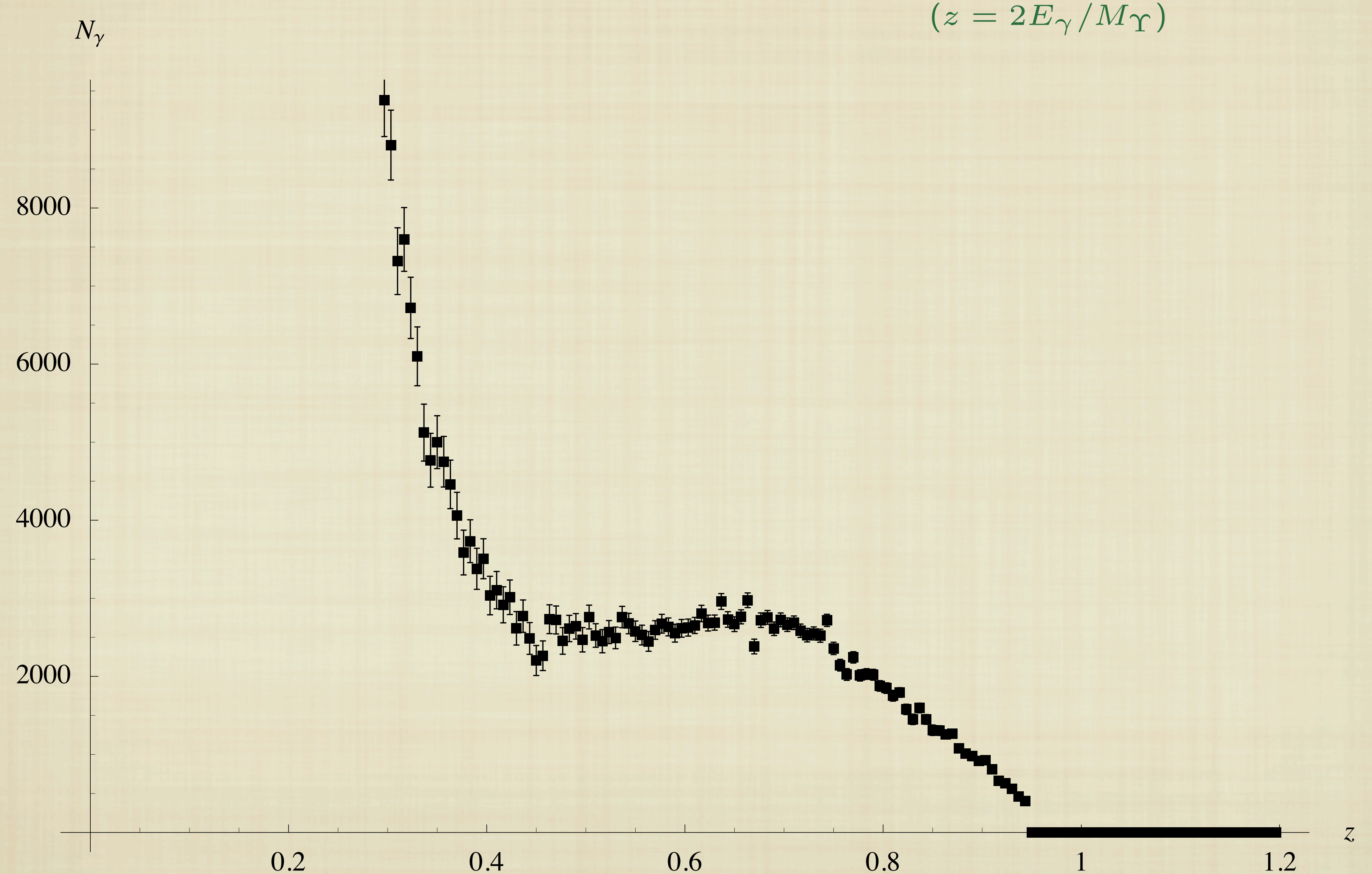
- Accurate estimates of the octet contributions from the lattice (BODWIN, LEE, SINCLAIR 05) and from continuum (GARCIA, SOTO 05)

• New data from CLEO

The photon spectrum ($\Upsilon \to X\gamma$)

- Recent CLEO measurement of the photon spectrum

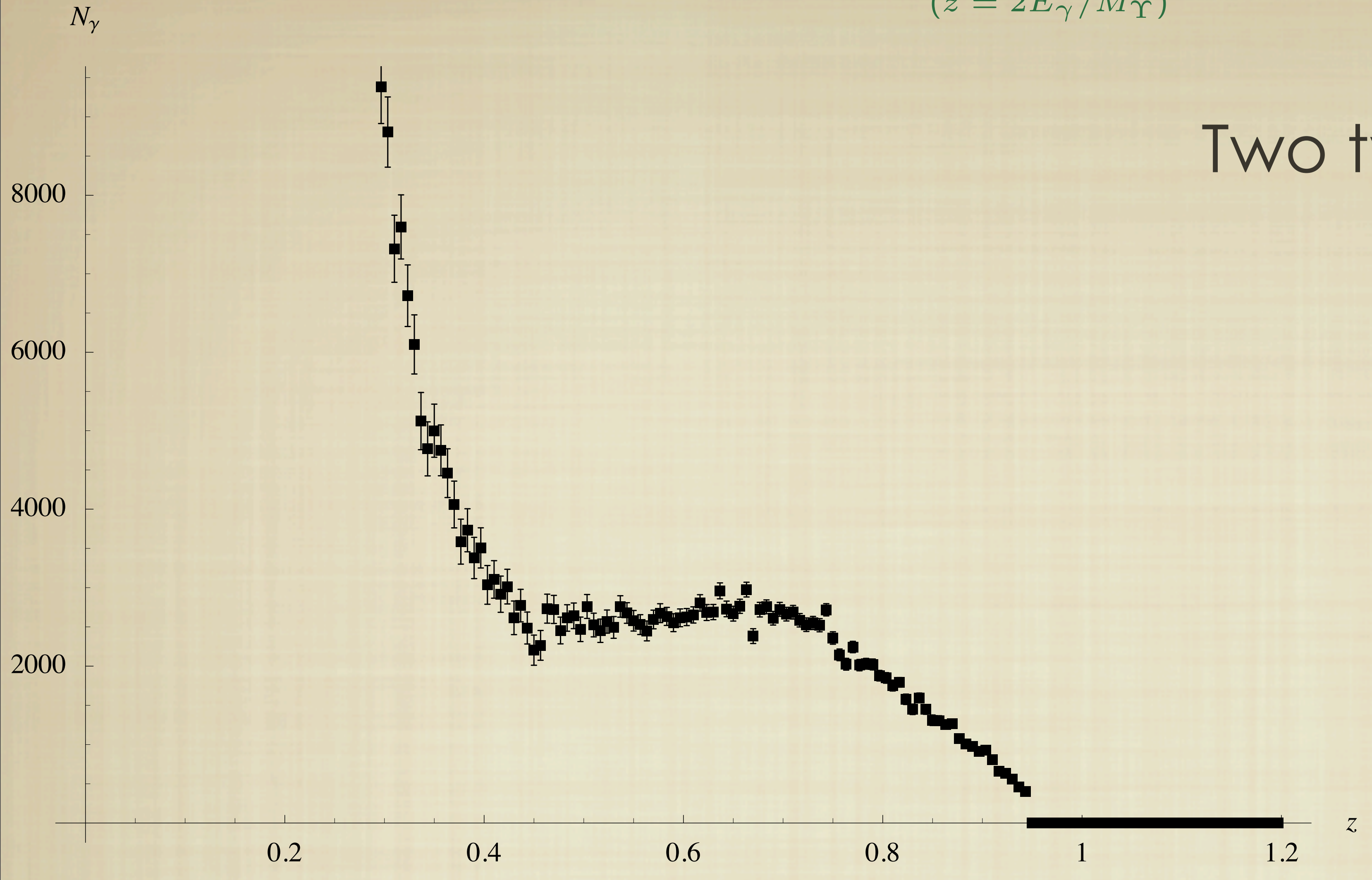
$(z = 2E_\gamma / M_\Upsilon)$



Data from CLEO III, 2005

[D. Besson *et al.* [CLEO Collaboration], Phys. Rev. D **74** (2006) 012003 (hep-ex/0512061)]

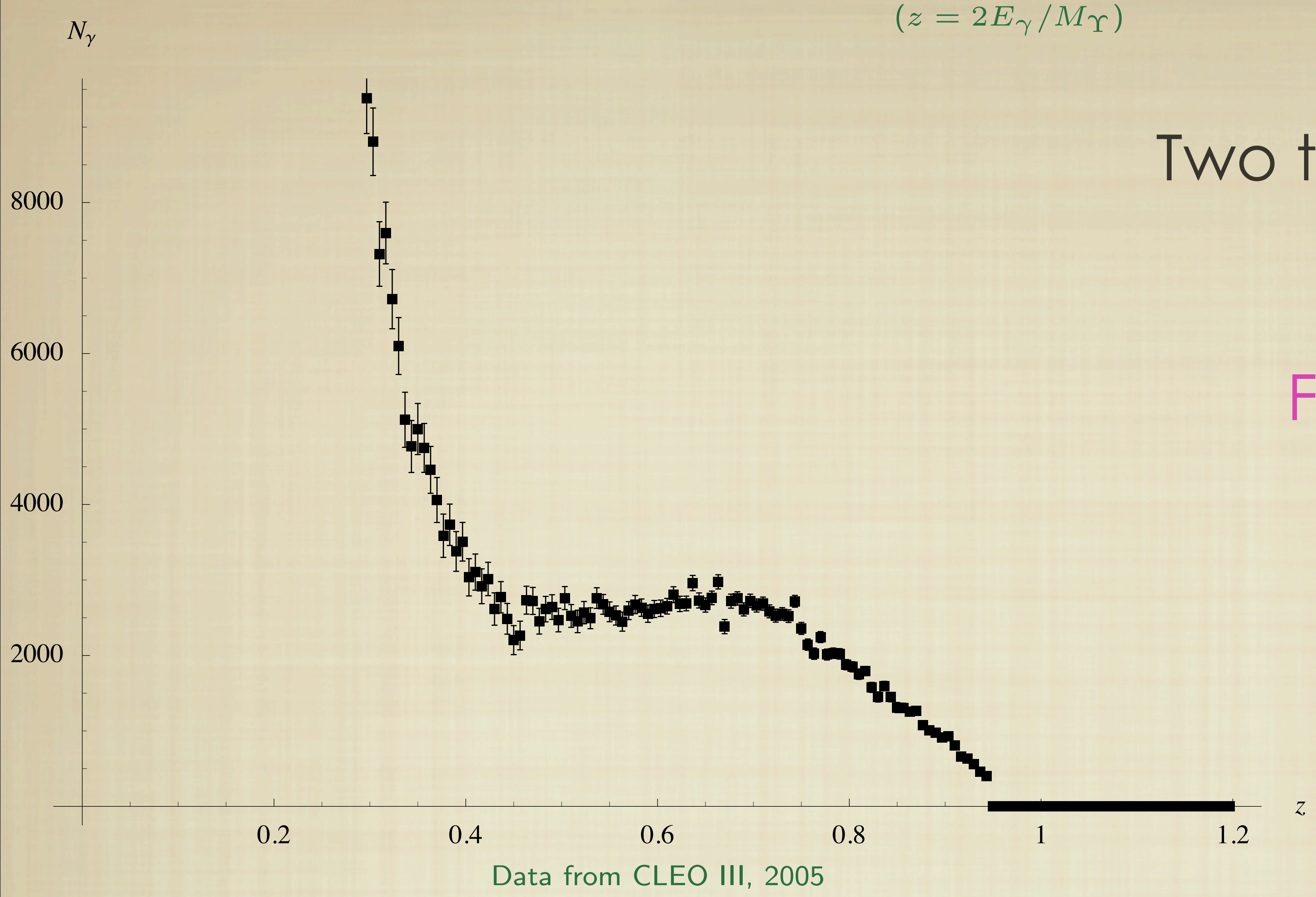
$(z = 2E_\gamma / M_\Upsilon)$



Data from CLEO III, 2005

Two types of contributions to the photon spectrum:

- Garcia, Soto 05

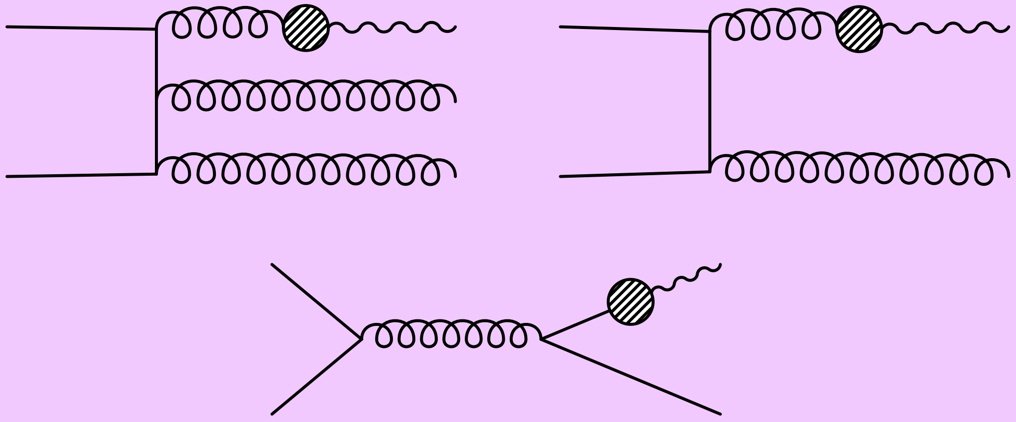


Data from CLEO III, 2005

Two types of contributions to the photon spectrum:

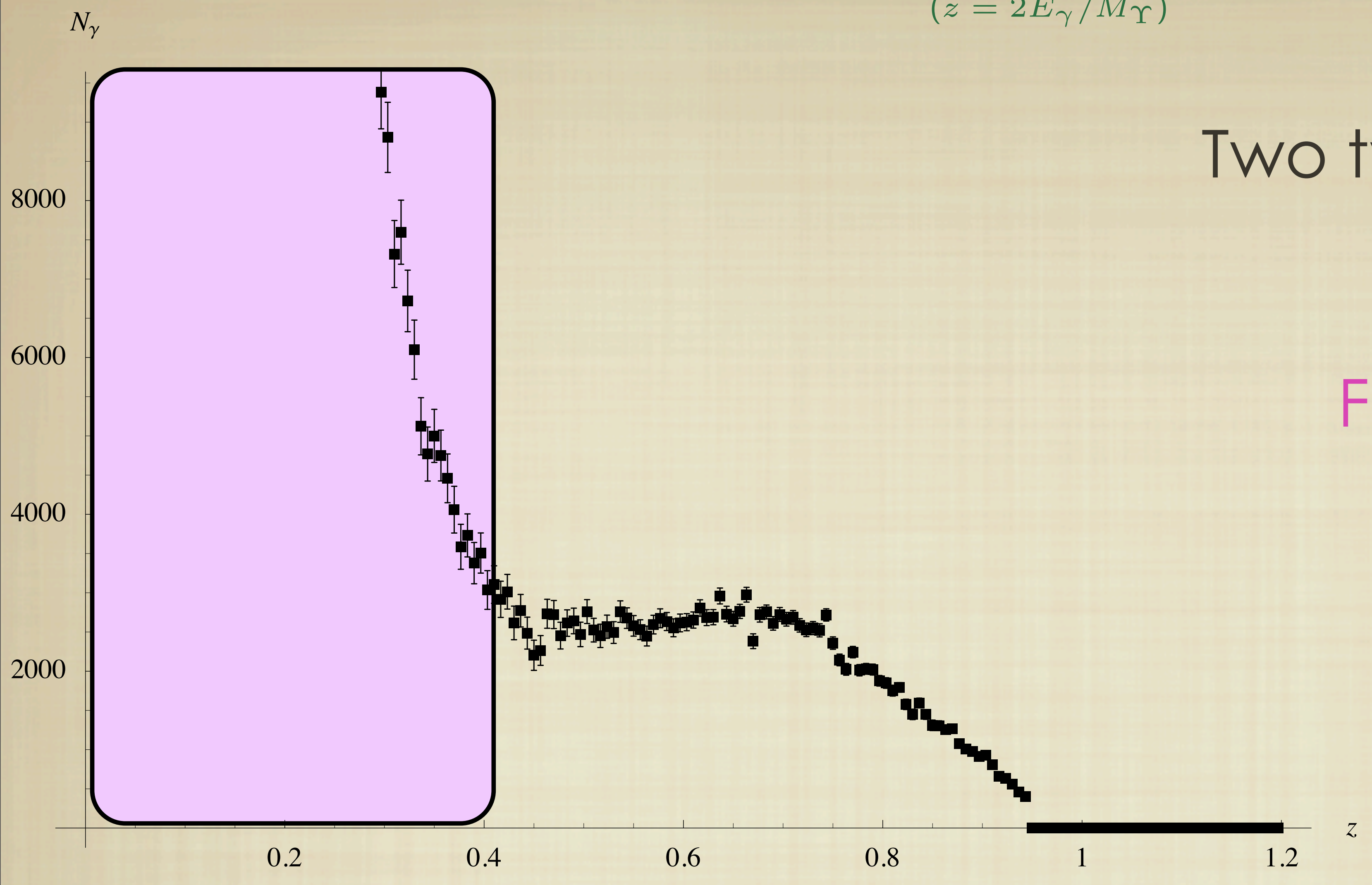
Fragmentation Contribution

$$\frac{d\Gamma^{frag}}{dz} = \sum_a C_a \otimes D_{a\to\gamma}$$



• Garcia, Soto 05

$(z = 2E_\gamma / M_\Upsilon)$



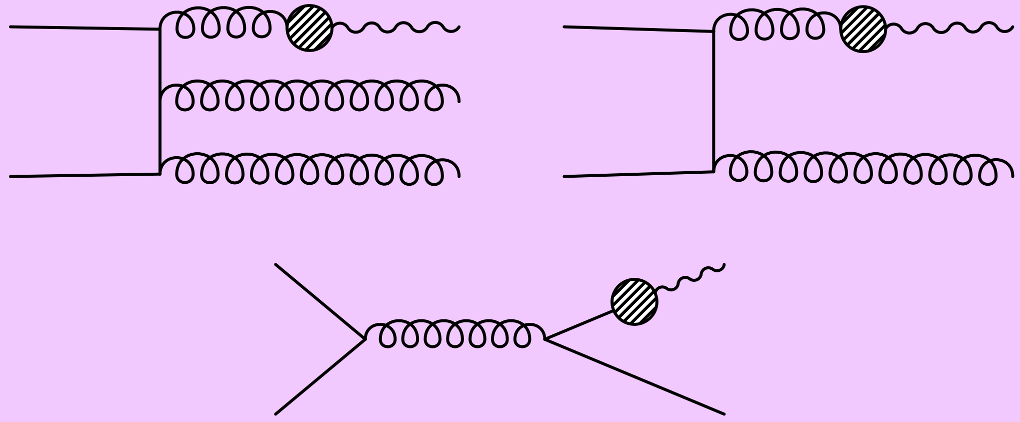
Data from CLEO III, 2005

Two types of contributions to the photon spectrum:

Fragmentation Contribution

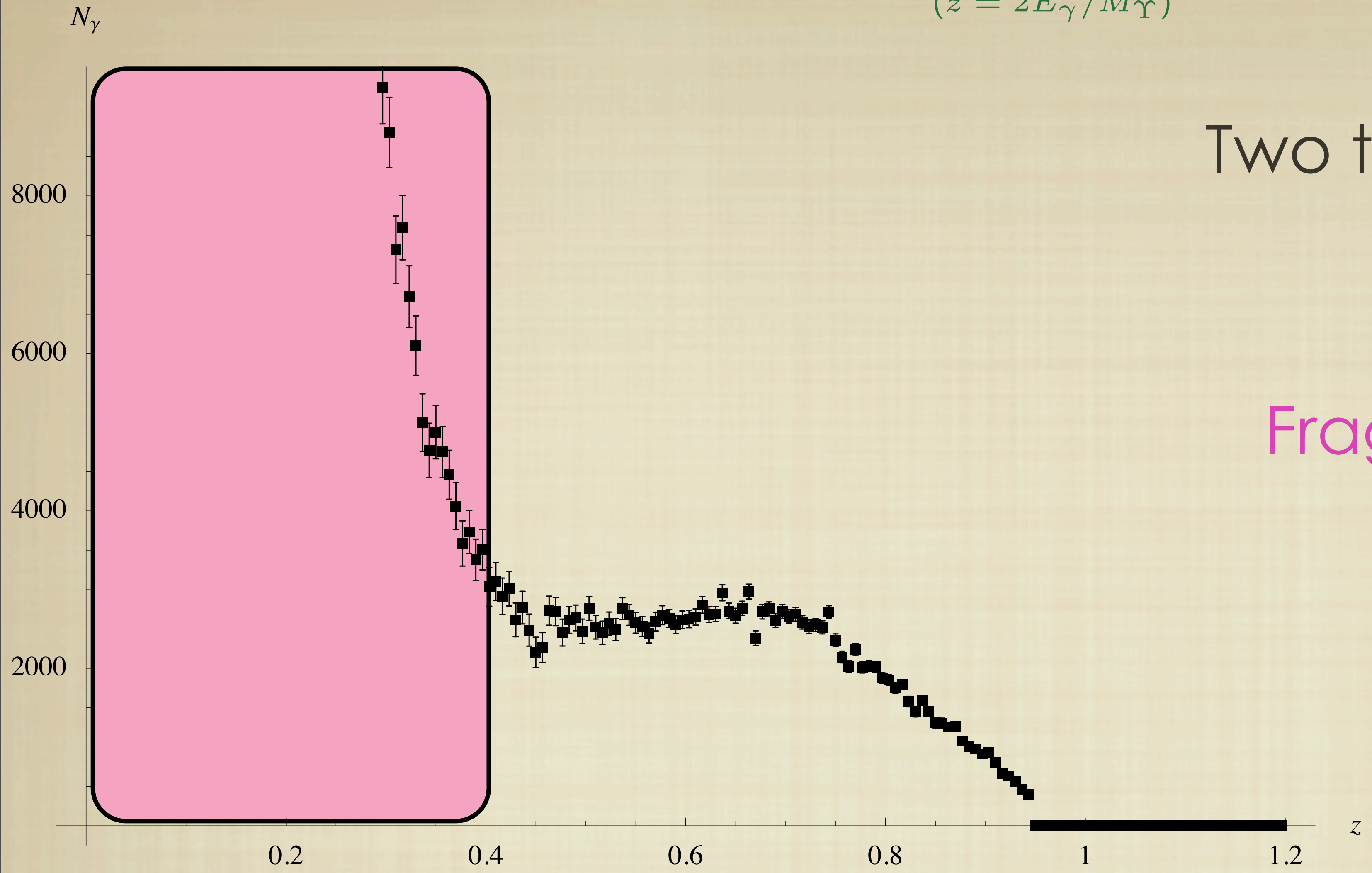
important in the low energy region of the spectrum

$$\frac{d\Gamma^{frag}}{dz} = \sum_a C_a \otimes D_{a\to\gamma}$$



• Garcia, Soto 05

$(z = 2E_\gamma / M_\Upsilon)$



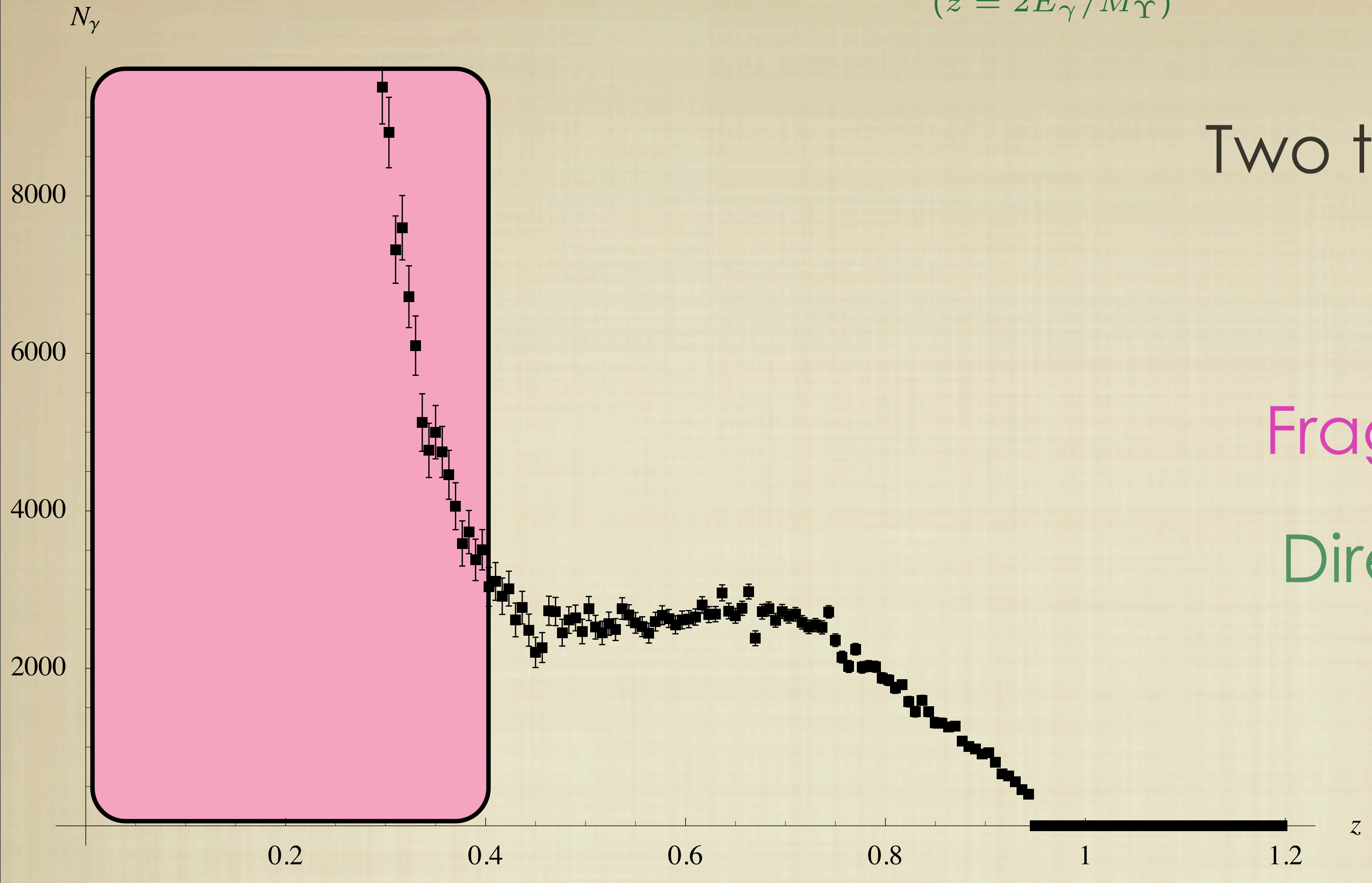
Data from CLEO III, 2005

Two types of contributions to the photon spectrum:

Fragmentation Contributions

- Garcia, Soto 05

$(z = 2E_\gamma / M_\Upsilon)$

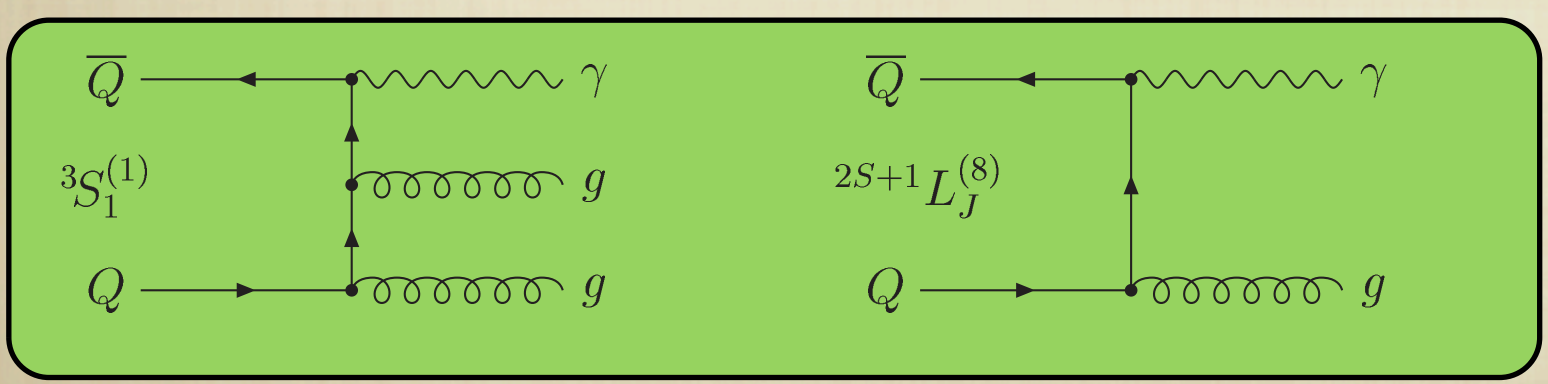


Data from CLEO III, 2005

Two types of contributions to the photon spectrum:

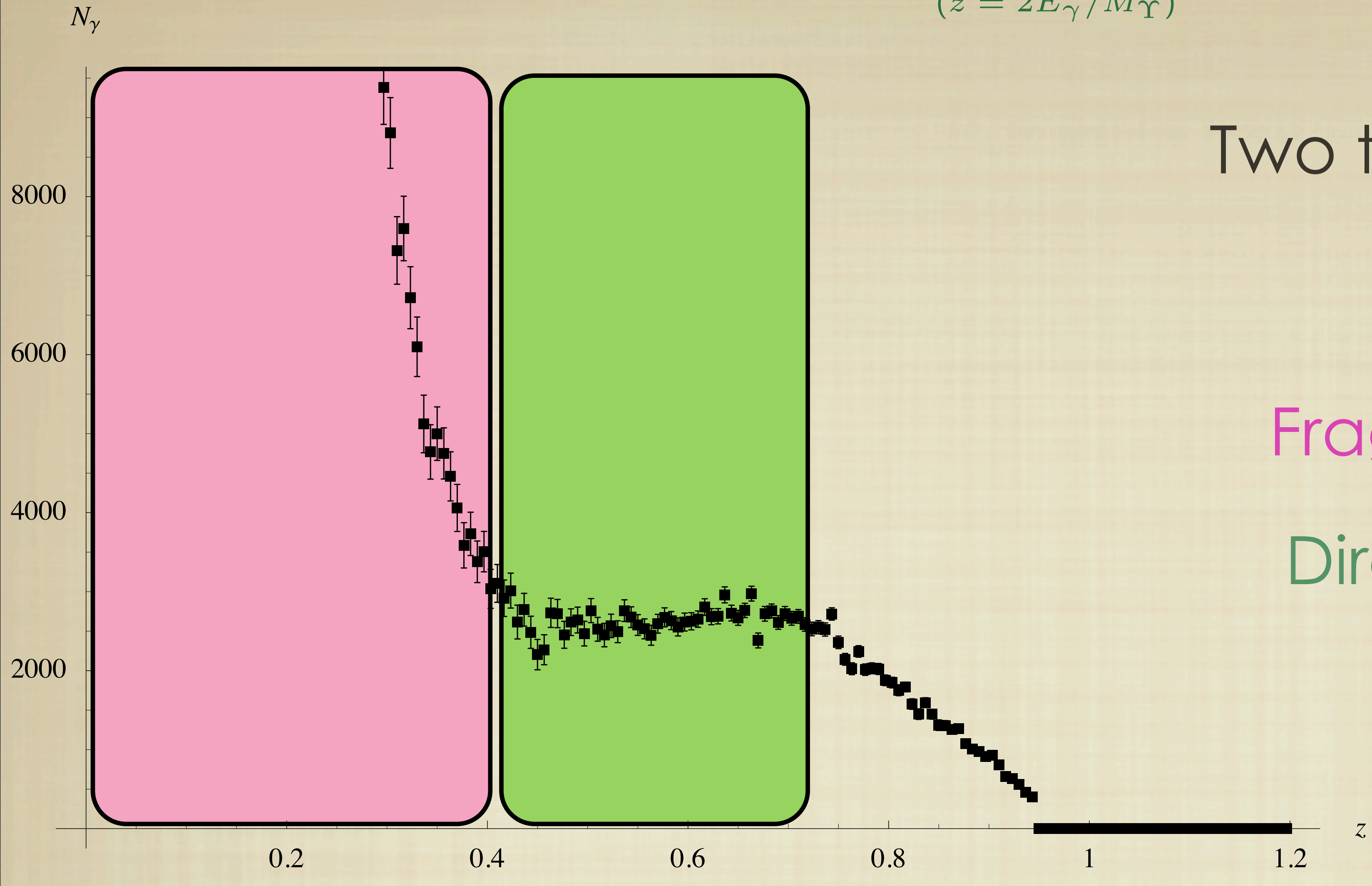
Fragmentation Contributions

Direct Contributions



- Garcia, Soto 05

$(z = 2E_\gamma / M_\Upsilon)$



Data from CLEO III, 2005

Two types of contributions to the photon spectrum:

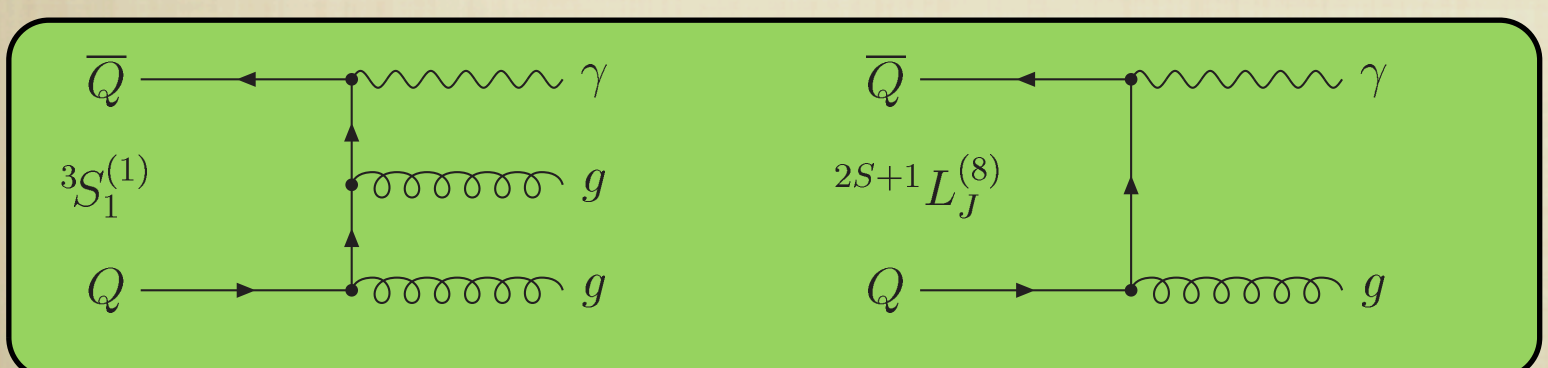
Fragmentation Contributions

Direct Contributions

it is described by NRQCD

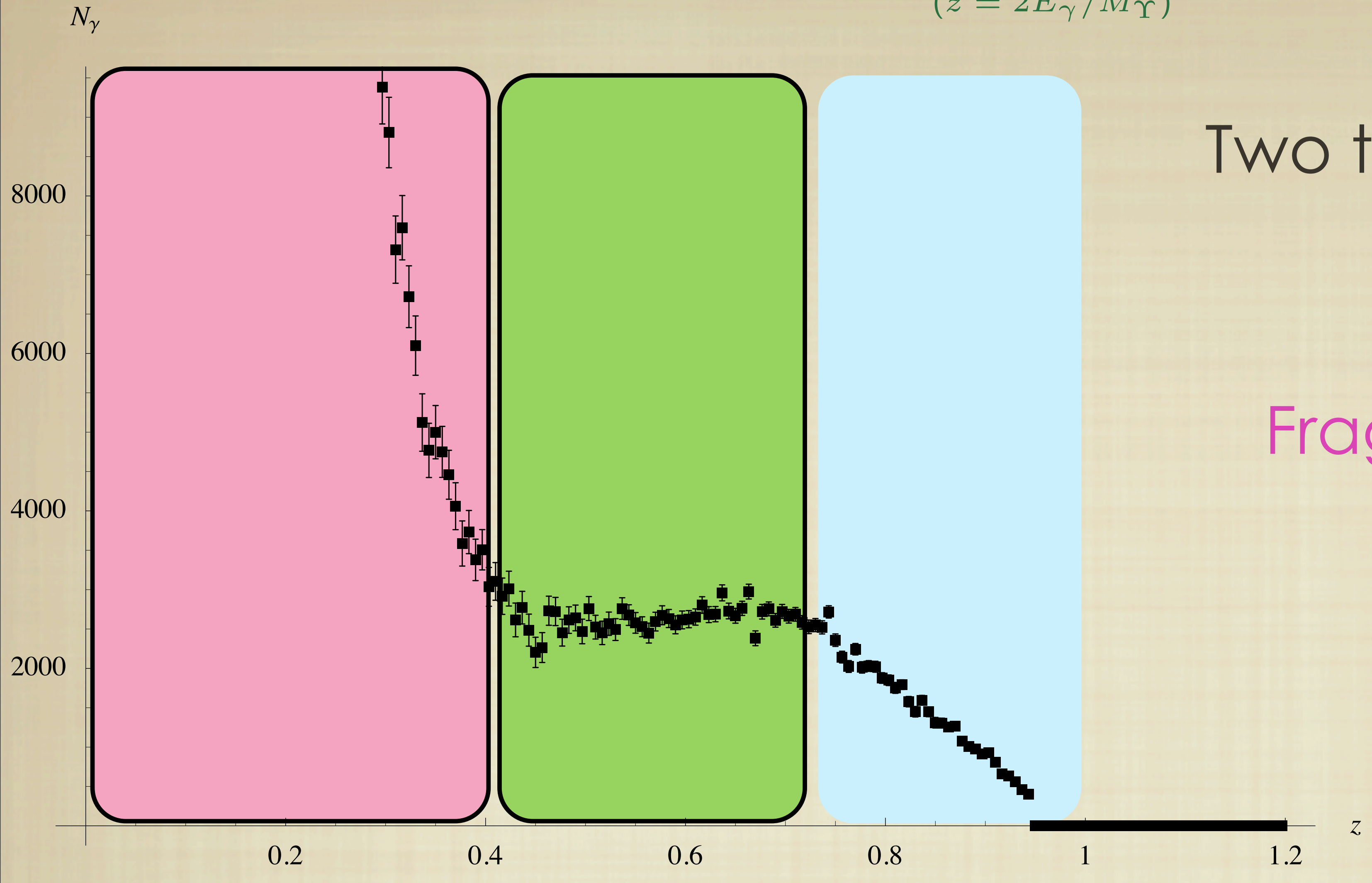
$$\frac{d\Gamma}{dz} = \sum_i C_i(M,z)\, \langle \Upsilon | \mathcal{O}_i | \Upsilon \rangle$$

and valid in the central region



- Garcia, Soto 05

$(z = 2E_\gamma / M_\Upsilon)$



Data from CLEO III, 2005

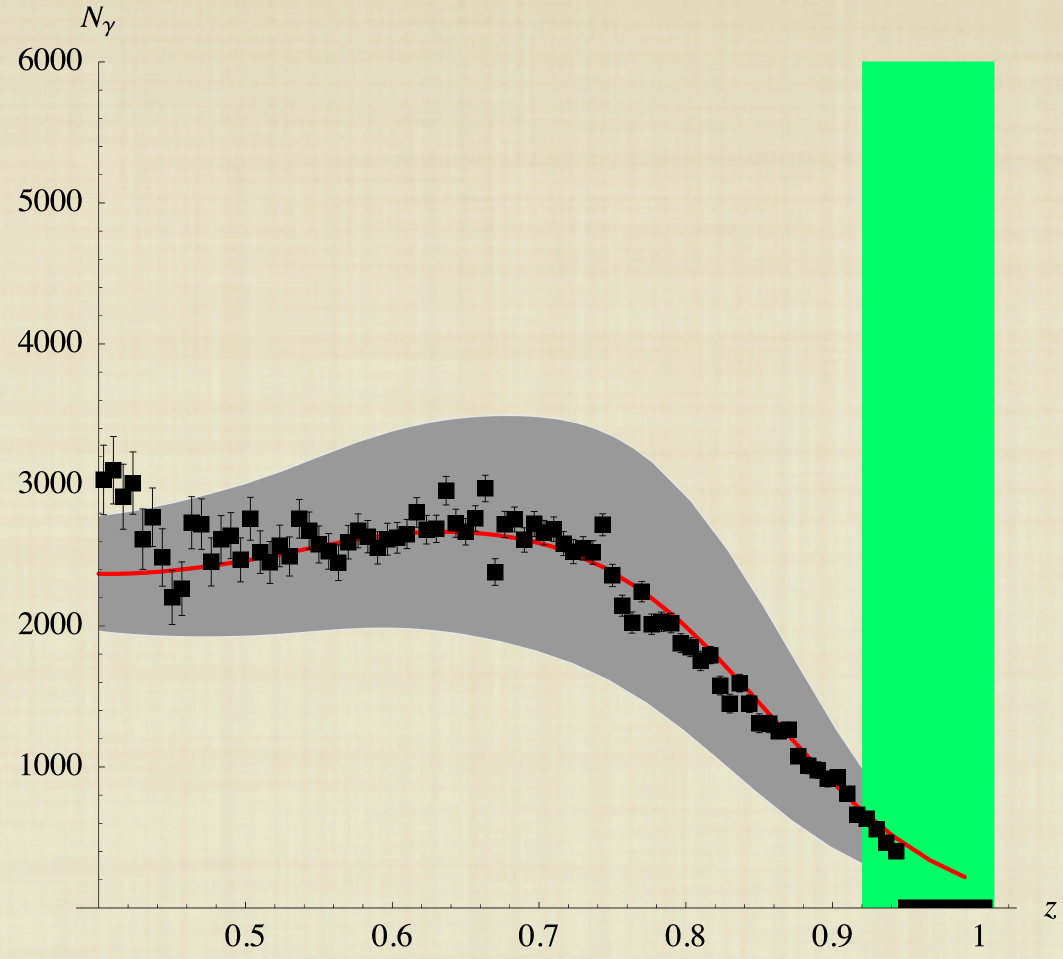
Two types of contributions to the photon spectrum:

Fragmentation Contributions

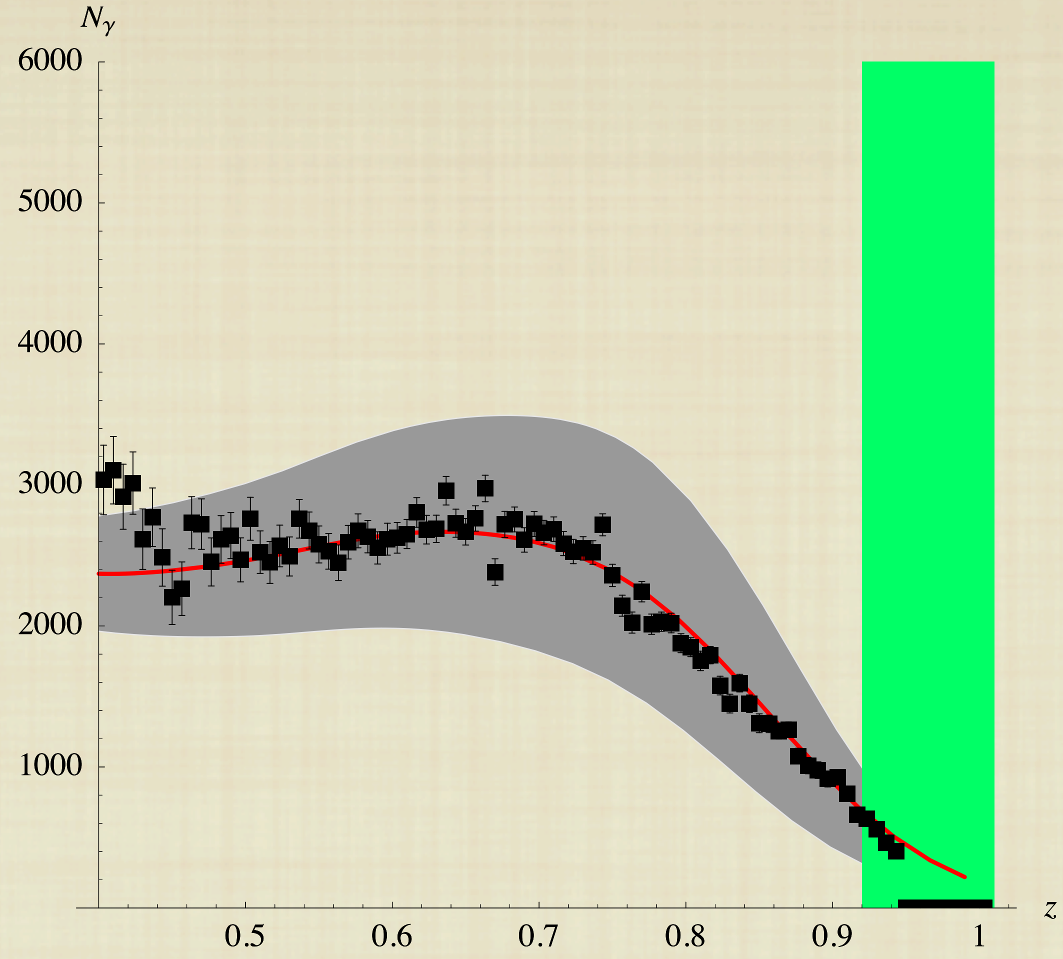
- For $z \to 1$ NRQCD expansion breaks down. Collinear degrees of freedom become relevant
  - Large $\log(1-z)$ need to be resummed

    Photiadis '85; Bauer et al. '01; Fleming and Leibovich '02 '04
  - Shape functions must be introduced. Rothstein and Wise '97
    Can be calculated assuming Coulombic state X.G.T. and Soto '04

Taking into account all these contributions the complete spectrum can be well described GARCIA, SOTO 05

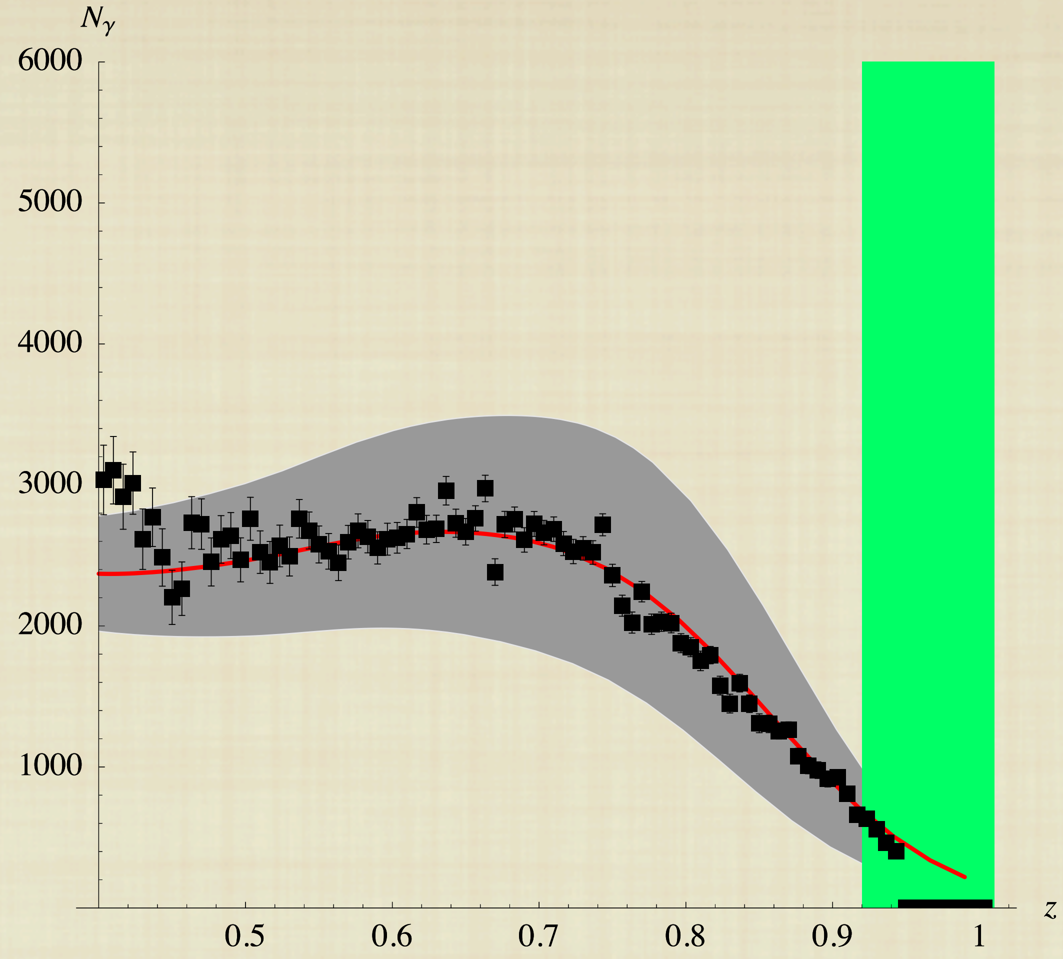


Taking into account all these contributions the complete spectrum can be well described Garcia, Soto 05



- from the data plus the theory description a value for $\Gamma_{\gamma gg}^{direct}$ can be obtained

Taking into account all these contributions the complete spectrum can be well described Garcia, Soto 05



- from the data plus the theory description a value for $\Gamma_{\gamma gg}^{direct}$ can be obtained

- Γ_{ggg} is determined experimentally

in this way $R_\gamma = \frac{\Gamma_{gg\gamma}^{direct}}{\Gamma_{ggg}} = \frac{N_{gg\gamma}^{direct}}{N_{ggg}}$ is measured

$$R_\gamma \sim \frac{\alpha}{\alpha_s}$$

$$R_\gamma^{exp} = 0.0245 \pm 0.0001 \pm 0.0013$$

in this way $R_\gamma = \frac{\Gamma_{gg\gamma}^{direct}}{\Gamma_{ggg}} = \frac{N_{gg\gamma}^{direct}}{N_{ggg}}$ is measured

$$R_\gamma \sim \frac{\alpha}{\alpha_s}$$

$$R_\gamma^{exp} = 0.0245 \pm 0.0001 \pm 0.0013$$

Statistical

Systematic

in this way $R_\gamma = \frac{\Gamma_{gg\gamma}^{direct}}{\Gamma_{ggg}} = \frac{N_{gg\gamma}^{direct}}{N_{ggg}}$ is measured

$$R_\gamma \sim \frac{\alpha}{\alpha_s}$$

$$R_\gamma^{exp} = 0.0245 \pm 0.0001 \pm 0.0013$$

Statistical

Systematic

Now we need to obtain a precise **theoretical** calculation of R_γ

in this way $R_\gamma = \frac{\Gamma^{direct}_{gg\gamma}}{\Gamma_{ggg}} = \frac{N^{direct}_{gg\gamma}}{N_{ggg}}$ is measured

$R_\gamma \sim \frac{\alpha}{\alpha_s}$

$$R^{exp}_\gamma = 0.0245 \pm 0.0001 \pm 0.0013$$

Statistical

Systematic

Now we need to obtain a precise theoretical calculation of R_γ

From the comparison of the two we get α_s

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n - 4}} \langle \Upsilon(1S) | O_n^{4-fermions} | \Upsilon(1S) \rangle$$

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n - 4}} \langle \Upsilon(1S) | O_n^{4-fermions} | \Upsilon(1S) \rangle$$

short distance matching coefficients

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n-4}} \langle \Upsilon(1S) | O_n^{4-fermions} | \Upsilon(1S) \rangle$$

short distance matching coefficients

nonperturbative matrix elements: contain singlet and octet operators

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n-4}} \langle \Upsilon(1S)|O_n^{4-fermions}|\Upsilon(1S)\rangle$$

short distance matching coefficients

nonperturbative matrix elements: contain singlet and octet operators

we assume the situation:

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n-4}} \langle \Upsilon(1S) | O_n^{4-fermions} | \Upsilon(1S) \rangle$$

short distance matching coefficients

nonperturbative matrix elements: contain singlet and octet operators

we assume the situation:

- $m_b v \gg \Lambda_{QCD}$

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n - 4}} \langle \Upsilon(1S) | O_n^{4-fermions} | \Upsilon(1S) \rangle$$

short distance matching coefficients

nonperturbative matrix elements: contain singlet and octet operators

we assume the situation:

- $m_b v \gg \Lambda_{QCD}$
- $\frac{\alpha_s(M_{\Upsilon(1S)})}{\pi} \sim v^2 \sim \alpha_s^2(m_b v)$

we use NRQCD to calculate the decay

$$\Gamma(\Upsilon(1S) \to X) = \sum_n \frac{C_n}{m^{d_n-4}} \langle \Upsilon(1S) | O_n^{4-fermions} | \Upsilon(1S) \rangle$$

short distance matching coefficients

nonperturbative matrix elements: contain singlet and octet operators

we assume the situation:

- $m_b v \gg \Lambda_{QCD}$
- $\frac{\alpha_s(M_{\Upsilon(1S)})}{\pi} \sim v^2 \sim \alpha_s^2(m_b v)$
- $v^2 = 0.08$

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5} \frac{e_b^2 \alpha}{\alpha_s} \frac{N}{D}$$

$$N = 1 + C_{gg\gamma} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s} C_{\gamma O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{\gamma O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2\alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1({}^3S_1)}\mathcal{R}_{\mathcal{P}_1({}^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8({}^1S_0)}\mathcal{R}_{O_8({}^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8({}^3P_0)}\mathcal{R}_{O_8({}^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1({}^3S_1)}\mathcal{R}_{\mathcal{P}_1({}^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8({}^3S_1)}\mathcal{R}_{O_8({}^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8({}^3S_1)}\mathcal{R}_{O_8({}^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8({}^1S_0)}\mathcal{R}_{O_8({}^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8({}^3P_0)}\mathcal{R}_{O_8({}^3P_0)} + \mathcal{O}_D(v^3)$$

WITH

$$\mathcal{R}_O = \frac{\langle \Upsilon(1S)|O|\Upsilon(1S)\rangle}{(m_b^{\Delta_d}\langle \Upsilon(1S)|O_1({}^3S_1)|\Upsilon(1S)\rangle)}$$

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2\alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

WITH

$$\mathcal{R}_O = \frac{\langle\Upsilon(1S)|O|\Upsilon(1S)\rangle}{(m_b^{\Delta_d}\langle\Upsilon(1S)|O_1(^3S_1)|\Upsilon(1S)\rangle)}$$

$$\mathcal{O}_1(^3S_1) = \psi^\dagger\boldsymbol{\sigma}\chi\cdot\chi^\dagger\boldsymbol{\sigma}\psi, \qquad \mathcal{O}_8(^1S_0) = \psi^\dagger T^a\chi\,\chi^\dagger T^a\psi,$$

$$\mathcal{O}_8(^3S_1) = \psi^\dagger\boldsymbol{\sigma}T^a\chi\cdot\chi^\dagger\boldsymbol{\sigma}T^a\psi. \qquad \mathcal{P}_1(^3S_1) = \frac{1}{2}\left[\psi^\dagger\boldsymbol{\sigma}\chi\cdot\chi^\dagger\boldsymbol{\sigma}(-\tfrac{i}{2}\overleftrightarrow{\mathbf{D}})^2\psi \;+\; \text{h.c.}\right],$$

$$\mathcal{O}_8(^3P_0) = \frac{1}{3}\psi^\dagger(-\frac{i}{2}\vec{\mathbf{D}}\cdot\sigma)T^a\chi\chi^\dagger(-\frac{i}{2}\vec{\mathbf{D}}\cdot\sigma)T^a\psi$$

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2 \alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{\gamma O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

The matching coefficients are known in the literature:

$$C_{O_8(^1S_0)} = 81/(8\pi^2 - 72)$$

$$C_{O_8(^3S_1)} = 81n_f/(20\pi^2 - 180)$$

$$C_{\gamma O_8(^1S_0)} = 27/(4\pi^2 - 36)$$

$$C_{gg\gamma} = -1.71 \text{ (for } n_f = 4)$$

$$C_{\mathcal{P}_1(^3S_1)} = -(19\pi^2 - 132)/(12\pi^2 - 108)$$

$$C_{O_8(^3P_0)} = 567/(8\pi^2 - 72)$$

$$C_{\gamma O_8(^3P_0)} = 189/(4\pi^2 - 36)$$

$$C_{ggg} = 3.79 \pm 0.54 \text{ (for } n_f = 4)$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

Octet matrix elements:

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2\alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

Octet matrix elements:

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5} \frac{e_b^2 \alpha}{\alpha_s} \frac{N}{D}$$

$$N = 1 + C_{gg\gamma} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s} C_{\gamma O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{\gamma O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

Octet matrix elements:

- $\mathcal{O}_8(^1S_0)$ and $\mathcal{O}_8(^3P_0)$ have been estimated in the continuum (weak coupling) GARCIA, SOTO 04

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5} \frac{e_b^2 \alpha}{\alpha_s} \frac{N}{D}$$

$$N = 1 + C_{gg\gamma} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s} C_{\gamma O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{\gamma O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

Octet matrix elements:

- $\mathcal{O}_8(^1S_0)$ and $\mathcal{O}_8(^3P_0)$ have been estimated in the continuum (weak coupling)
  GARCIA, SOTO 04
- $\mathcal{O}_8(^3S_1)$ and $\mathcal{O}_8(^1S_0)$ have been calculated on the lattice
  BODWIN, LEE, SINCLAIR 05

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2 \alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1({}^3S_1)}\mathcal{R}_{\mathcal{P}_1({}^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8({}^1S_0)}\mathcal{R}_{O_8({}^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8({}^3P_0)}\mathcal{R}_{O_8({}^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1({}^3S_1)}\mathcal{R}_{\mathcal{P}_1({}^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8({}^3S_1)}\mathcal{R}_{O_8({}^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8({}^3S_1)}\mathcal{R}_{O_8({}^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8({}^1S_0)}\mathcal{R}_{O_8({}^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8({}^3P_0)}\mathcal{R}_{O_8({}^3P_0)} + \mathcal{O}_D(v^3)$$

Octet matrix elements:

- $\mathcal{O}_8({}^1S_0)$ and $\mathcal{O}_8({}^3P_0)$ have been estimated in the continuum (weak coupling) GARCIA, SOTO 04
- $\mathcal{O}_8({}^3S_1)$ and $\mathcal{O}_8({}^1S_0)$ have been calculated on the lattice BODWIN, LEE, SINCLAIR 05

The continuum and lattice calculation of $\mathcal{O}_8({}^1S_0)$ are compatible

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5} \frac{e_b^2 \alpha}{\alpha_s} \frac{N}{D}$$

$$N = 1 + C_{gg\gamma} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s} C_{\gamma O_8(\,^1S_0)} \mathcal{R}_{O_8(\,^1S_0)} + \frac{\pi}{\alpha_s} C_{\gamma O_8(\,^3P_0)} \mathcal{R}_{O_8(\,^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s} C_{O_8(\,^3S_1)} \mathcal{R}_{O_8(\,^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(\,^1S_0)} \mathcal{R}_{O_8(\,^1S_0)} + \frac{\pi}{\alpha_s} C_{O_8(\,^3P_0)} \mathcal{R}_{O_8(\,^3P_0)} + \mathcal{O}_D(v^3)$$

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2 \alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)}\mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8(^3S_1)}\mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8(^1S_0)}\mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8(^3P_0)}\mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

- we include all contributions up to $O(v^2)$ in our counting: radiative, relativistic, octet

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5}\frac{e_b^2\alpha}{\alpha_s}\frac{N}{D}$$

$$N = 1 + C_{gg\gamma}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1({}^3S_1)}\mathcal{R}_{\mathcal{P}_1({}^3S_1)} + \\ + \frac{\pi}{\alpha_s}C_{\gamma O_8({}^1S_0)}\mathcal{R}_{O_8({}^1S_0)} + \frac{\pi}{\alpha_s}C_{\gamma O_8({}^3P_0)}\mathcal{R}_{O_8({}^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg}\frac{\alpha_s}{\pi} + C_{\mathcal{P}_1({}^3S_1)}\mathcal{R}_{\mathcal{P}_1({}^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8({}^3S_1)}\mathcal{R}_{O_8({}^3S_1)} \\ + \frac{\pi}{\alpha_s}C_{O_8({}^3S_1)}\mathcal{R}_{O_8({}^3S_1)} + \frac{\pi}{\alpha_s}C_{O_8({}^1S_0)}\mathcal{R}_{O_8({}^1S_0)} + \frac{\pi}{\alpha_s}C_{O_8({}^3P_0)}\mathcal{R}_{O_8({}^3P_0)} + \mathcal{O}_D(v^3)$$

- we include all contributions up to $O(v^2)$ in our counting: radiative, relativistic, octet

-->accurate at NLO in v^2 and α_s

$$R_\gamma \equiv \frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to X)} = \frac{36}{5} \frac{e_b^2 \alpha}{\alpha_s} \frac{N}{D}$$

$$N = 1 + C_{gg\gamma} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \\ + \frac{\pi}{\alpha_s} C_{\gamma O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{\gamma O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_N(v^3)$$

$$D = 1 + C_{ggg} \frac{\alpha_s}{\pi} + C_{\mathcal{P}_1(^3S_1)} \mathcal{R}_{\mathcal{P}_1(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} \\ + \frac{\pi}{\alpha_s} C_{O_8(^3S_1)} \mathcal{R}_{O_8(^3S_1)} + \frac{\pi}{\alpha_s} C_{O_8(^1S_0)} \mathcal{R}_{O_8(^1S_0)} + \frac{\pi}{\alpha_s} C_{O_8(^3P_0)} \mathcal{R}_{O_8(^3P_0)} + \mathcal{O}_D(v^3)$$

- we include all contributions up to $O(v^2)$ in our counting: radiative, relativistic, octet

-->accurate at NLO in v^2 and α_s

- the nonperturbative contributions are the same in N and D apart from $\mathcal{R}_{O_8(^3S_1)}$ that turns out to be small

The Analysis

Two different extractions

- C (for continuum)

- L (for lattice)

The Analysis

Two different extractions

- C (for continuum)
  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8(^3S_1)$
- L (for lattice)

The Analysis

Two different extractions

- **C (for continuum)**
  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8(^3S_1)$
- **L (for lattice)**
  - Uses all lattice calculations available and NRQCD v-scaling for $\mathcal{O}_8(^3P_0)$

The Analysis

Two different extractions

- **C (for continuum)**
  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8({}^3S_1)$
- **L (for lattice)**
  - Uses all lattice calculations available and NRQCD v-scaling for $\mathcal{O}_8({}^3P_0)$

The two procedures give very similar results. We take the average as the final value and as error the range of the two determinations

The Analysis

Two different extractions

- **C (for continuum)**
  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8(^3S_1)$
- **L (for lattice)**
  - Uses all lattice calculations available and NRQCD v-scaling for $\mathcal{O}_8(^3P_0)$

The two procedures give very similar results. We take the average as the final value and as error the range of the two determinations

Common features of C and L:

The Analysis

Two different extractions

- **C (for continuum)**
  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8(^3S_1)$
- **L (for lattice)**
  - Uses all lattice calculations available and NRQCD v-scaling for $\mathcal{O}_8(^3P_0)$

The two procedures give very similar results. We take the average as the final value and as error the range of the two determinations

Common features of C and L:

- We do not expand the O(v^2) terms in the denominator-
  > small terms add up to almost one

The Analysis

Two different extractions

- **C (for continuum)**
  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8(^3S_1)$
- **L (for lattice)**
  - Uses all lattice calculations available and NRQCD v-scaling for $\mathcal{O}_8(^3P_0)$

The two procedures give very similar results. We take the average as the final value and as error the range of the two determinations

Common features of C and L:

- We do not expand the O(v^2) terms in the denominator-
  > small terms add up to almost one
- Results are rather insensitive to the values of $O_8(^1S_0)$ $O_8(^3P_0)$

they would be sensitive to $O_8(^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

■ L (for lattice)

$$
\begin{aligned}
0 \leq\ & \mathcal{R}_{O_8({}^1S_0)} \leq 4.8 \times 10^{-3} \\
0 \leq\ & \mathcal{R}_{O_8({}^3S_1)} \leq 1.6 \times 10^{-4} \\
-2.4 \times 10^{-4} \leq\ & \mathcal{R}_{O_8({}^3P_0)} \leq 2.4 \times 10^{-4} \\
-0.052 \leq\ & \mathcal{R}_{\mathcal{P}_1({}^3S_1)} \leq -0.035
\end{aligned}
$$

L (for lattice)

$$0 \leq \quad \mathcal{R}_{O_8(^1S_0)} \quad \leq 4.8 \times 10^{-3}$$

$$0 \leq \quad \mathcal{R}_{O_8(^3S_1)} \quad \leq 1.6 \times 10^{-4}$$

maximum value
lattice data plus 100%
uncertainty

$$-2.4 \times 10^{-4} \leq \quad \mathcal{R}_{O_8(^3P_0)} \quad \leq 2.4 \times 10^{-4}$$

NRQCD power counting $\approx \frac{1}{9} \times \frac{v^4}{2N_c}$,
plus 100% uncertainty

$$-0.052 \leq \quad \mathcal{R}_{\mathcal{P}_1(^3S_1)} \quad \leq -0.035$$

Gremm Kapustin $\mathcal{R}_{\mathcal{P}_1(^3S_1)} = \frac{E_{\rm bin}}{m_b} = -\frac{(C_F\alpha_{\rm s})^2}{4}$,

■ L (for lattice)

$$0 \leq \mathcal{R}_{O_8(^1S_0)} \leq 4.8 \times 10^{-3}$$

$$0 \leq \mathcal{R}_{O_8(^3S_1)} \leq 1.6 \times 10^{-4}$$

maximum value
lattice data plus 100%
uncertainty

$$-2.4 \times 10^{-4} \leq \mathcal{R}_{O_8(^3P_0)} \leq 2.4 \times 10^{-4}$$

NRQCD power counting $\approx \frac{1}{9} \times \frac{v^4}{2N_c},$
plus 100% uncertainty

$$-0.052 \leq \mathcal{R}_{\mathcal{P}_1(^3S_1)} \leq -0.035$$

Gremm Kapustin $\mathcal{R}_{\mathcal{P}_1(^3S_1)} = \frac{E_{\rm bin}}{m_b} = -\frac{(C_F\alpha_{\rm s})^2}{4},$

$$\alpha_{\rm s}(M_{\Upsilon(1S)}) = 0.183\,,$$

L (for lattice)

$$0 \leq \mathcal{R}_{O_8(^1S_0)} \leq 4.8 \times 10^{-3}$$
$$0 \leq \mathcal{R}_{O_8(^3S_1)} \leq 1.6 \times 10^{-4}$$

maximum value
lattice data plus 100%
uncertainty

$$-2.4 \times 10^{-4} \leq \mathcal{R}_{O_8(^3P_0)} \leq 2.4 \times 10^{-4}$$

NRQCD power counting $\approx \frac{1}{9} \times \frac{v^4}{2N_c}$,
plus 100% uncertainty

$$-0.052 \leq \mathcal{R}_{\mathcal{P}_1(^3S_1)} \leq -0.035$$

Gremm Kapustin $\mathcal{R}_{\mathcal{P}_1(^3S_1)} = \frac{E_{\rm bin}}{m_b} = -\frac{(C_F\alpha_{\rm s})^2}{4}$,

The uncertainty on $\alpha_{\rm s}$ induced by a given parameter is evaluated by varying it in the range and keeping all other parameters at their central values. We obtain

$\delta_{C_{ggg}}\alpha_{\rm s} = 0.0026$,

$\delta_{\mathcal{R}_{O_8(^1S_0)}}\alpha_{\rm s} = 0.0040$,

$\delta_{\mathcal{R}_{O_8(^3S_1)}}\alpha_{\rm s} = 0.0026$,

$\delta_{\mathcal{R}_{O_8(^3P_0)}}\alpha_{\rm s} = 0.0027$,

$\delta_{\mathcal{R}_{\mathcal{P}_1(^3S_1)}}\alpha_{\rm s} = 0.0014$,

$\delta_{\mathcal{R}_{\mathcal{O}_N(v^3)}}\alpha_{\rm s} = 0.0044$,

$\delta_{\mathcal{R}_{\mathcal{O}_D(v^3)}}\alpha_{\rm s} = 0.0033$,

$\delta_{R_\gamma^{\rm exp}}\alpha_{\rm s} = 0.0085$.

estimate higher order corr $-0.04 \leq \mathcal{O}_N(v^3), \mathcal{O}_D(v^3) \leq 0.04$,

We sum up linearly the errors $\delta_{\mathcal{R}_{O_8(^1S_0)}}$ and $\delta_{\mathcal{R}_{O_8(^3S_1)}}$, which are correlated, a

sum the rest quadratically

$$\alpha_{\rm s}(M_{\Upsilon(1S)}) = 0.183 \pm 0.013\,.$$
$$\alpha_{\rm s}(M_Z) = 0.119 \pm 0.005\,.$$

■ L (for lattice)

$$0 \leq \mathcal{R}_{O_8(^1S_0)} \leq 4.8 \times 10^{-3}$$

$$0 \leq \mathcal{R}_{O_8(^3S_1)} \leq 1.6 \times 10^{-4}$$

maximum value lattice data plus 100% uncertainty

$$-2.4 \times 10^{-4} \leq \mathcal{R}_{O_8(^3P_0)} \leq 2.4 \times 10^{-4}$$

NRQCD power counting $\approx \frac{1}{9} \times \frac{v^4}{2N_c}$, plus 100% uncertainty

$$-0.052 \leq \mathcal{R}_{\mathcal{P}_1(^3S_1)} \leq -0.035$$

Gremm Kapustin $\mathcal{R}_{\mathcal{P}_1(^3S_1)} = \frac{E_{\rm bin}}{m_b} = -\frac{(C_F\alpha_s)^2}{4}$,

$$\alpha_s(M_{\Upsilon(1S)}) = 0.183\,,$$

The uncertainty on α_s induced by a given parameter is evaluated by varying it in the range and keeping all other parameters at their central values. We obtain

$\delta_{C_{ggg}}\alpha_s = 0.0026,$

$\delta_{\mathcal{R}_{O_8(^1S_0)}}\alpha_s = 0.0040,$

$\delta_{\mathcal{R}_{O_8(^3S_1)}}\alpha_s = 0.0026,$

$\delta_{\mathcal{R}_{O_8(^3P_0)}}\alpha_s = 0.0027,$

$\delta_{\mathcal{R}_{\mathcal{P}_1(^3S_1)}}\alpha_s = 0.0014,$

$\delta_{\mathcal{R}_{\mathcal{O}_N(v^3)}}\alpha_s = 0.0044,$

$\delta_{\mathcal{R}_{\mathcal{O}_D(v^3)}}\alpha_s = 0.0033,$

$\delta_{R_\gamma^{\rm exp}}\alpha_s = 0.0085.$

estimate higher order corr $-0.04 \leq \mathcal{O}_N(v^3), \mathcal{O}_D(v^3) \leq 0.04$,

We sum up linearly the errors $\delta_{\mathcal{R}_{O_8(^1S_0)}}$ and $\delta_{\mathcal{R}_{O_8(^3S_1)}}$, which are correlated,

sum the rest quadratically

$$\alpha_s(M_{\Upsilon(1S)}) = 0.183 \pm 0.013\,.$$

$$\alpha_s(M_Z) = 0.119 \pm 0.005\,.$$

C (for continuum)

In weak coupling the matrix elements can be calculated, the same central value used to fit the photon spectrum in Garcia-Soto 04 is used

$\langle \Upsilon(1S)|O_1(^3S_1)|\Upsilon(1S)\rangle$ is needed at NNLO

$$\mathcal{R}_{\mathcal{P}_1(^3S_1)} = -0.015\,,$$

$$\mathcal{R}_{O_8(^1S_0)} = 0.0012\,,$$

$$\mathcal{R}_{O_8(^3P_0)} = 0.0011\,.$$

$$\mathcal{R}_{O_8(^3S_1)} = 8\times 10^{-5}\,.$$

C (for continuum)

In weak coupling the matrix elements can be calculated, the same central value used to fit the photon spectrum in Garcia-Soto 04 is used

$\langle \Upsilon(1S)|O_1(^3S_1)|\Upsilon(1S)\rangle$ is needed at NNLO

$$\mathcal{R}_{\mathcal{P}_1(^3S_1)} = -0.015\,,$$

$$\mathcal{R}_{O_8(^1S_0)} = 0.0012\,,$$

$$\mathcal{R}_{O_8(^3P_0)} = 0.0011\,.$$

$$\mathcal{R}_{O_8(^3S_1)} = 8 \times 10^{-5}\,.$$

To get the errors we make the variation

$$0.18 \le \quad \alpha_s(m_b v) \quad \le 0.38$$

$$0.32 \le \quad \alpha_s(m_b v^2) \quad \le 1.3$$

$$0 \le \quad \mathcal{R}_{O_8(^3S_1)} \quad \le 1.6 \times 10^{-4}$$

C (for continuum)

In weak coupling the matrix elements can be calculated, the same central value used to fit the photon spectrum in Garcia-Soto 04 is used

$\langle \Upsilon(1S) | O_1(^3S_1) | \Upsilon(1S) \rangle$ is needed at NNLO

$$\mathcal{R}_{\mathcal{P}_1(^3S_1)} = -0.015\,,$$

$$\mathcal{R}_{O_8(^1S_0)} = 0.0012\,,$$

$$\mathcal{R}_{O_8(^3P_0)} = 0.0011\,.$$

$$\mathcal{R}_{O_8(^3S_1)} = 8 \times 10^{-5}\,.$$

To get the errors we make the variation

$$0.18 \leq \quad \alpha_s(m_b v) \quad \leq 0.38$$

$$0.32 \leq \quad \alpha_s(m_b v^2) \quad \leq 1.3$$

$$0 \leq \quad \mathcal{R}_{O_8(^3S_1)} \quad \leq 1.6 \times 10^{-4}$$

this large variation expected to account for uncertainties $O(\Lambda_{QCD})$ in the weak coupling estimate of the octets

■ C (for continuum)

In weak coupling the matrix elements can be calculated, the same central value used to fit the photon spectrum in Garcia-Soto 04 is used

$\langle \Upsilon(1S)|O_1(^3S_1)|\Upsilon(1S)\rangle$ is needed at NNLO

$$\mathcal{R}_{\mathcal{P}_1(^3S_1)} = -0.015\,,$$

$$\mathcal{R}_{O_8(^1S_0)} = 0.0012\,,$$

$$\mathcal{R}_{O_8(^3P_0)} = 0.0011\,.$$

$$\mathcal{R}_{O_8(^3S_1)} = 8 \times 10^{-5}\,.$$

To get the errors we make the variation

$$0.18 \leq \quad \alpha_s(m_b v) \quad \leq 0.38$$

$$0.32 \leq \quad \alpha_s(m_b v^2) \quad \leq 1.3$$

$$0 \leq \quad \mathcal{R}_{O_8(^3S_1)} \quad \leq 1.6 \times 10^{-4}$$

this large variation expected to account for uncertainties $O(\Lambda_{QCD})$ in the weak coupling estimate of the octets

the upper limit of $O_8(\,^3S_1)$ corresponds to twice the lattice value

C (for continuum)

The uncertainty on α_s induced by a given parameter is evaluated by varying it in the range and keeping all other parameters at their central values. We obtain

$$\delta_{C_{ggg}}\alpha_s = 0.0009,$$

$$\delta_{\alpha_s(m_b v)}\alpha_s =^{+0.0006}_{-0.0064},$$

$$\delta_{\alpha_s(m_b v^2)}\alpha_s =^{+0.0083}_{-0.0076},$$

$$\delta_{\mathcal{R}_{O_8(^3S_1)}}\alpha_s = 0.0016,$$

$$\delta_{\mathcal{R}_{\mathcal{O}_N(v^3)}}\alpha_s =^{+0.0035}_{-0.0034},$$

$$\delta_{\mathcal{R}_{\mathcal{O}_D(v^3)}}\alpha_s =^{+0.0026}_{-0.0025},$$

$$\delta_{R_\gamma^{\exp}}\alpha_s = 0.01.$$

We assume these errors to be independent and sum them up quadratically, obtaining

$$\alpha_s(M_{\Upsilon(1S)}) = 0.185^{+0.014}_{-0.015}.$$

$$\alpha_s(M_Z) = 0.120^{+0.005}_{-0.006}.$$

Errors Discussion

Errors Discussion

- Results are rather insensitive to the values of $O_8(^1S_0)$ $O_8(^3P_0)$

they would be sensitive to $O_8(^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

Errors Discussion

- Results are rather insensitive to the values of $O_8({}^1S_0)$ $O_8({}^3P_0)$

they would be sensitive to $O_8({}^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

How reliable is this extraction?

Errors Discussion

- Results are rather insensitive to the values of $O_8(^1S_0)$ $O_8(^3P_0)$

they would be sensitive to $O_8(^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

How reliable is this extraction?

It is an extraction at NLO in alpha_s(m_b) and v^2

Errors Discussion

- Results are rather insensitive to the values of $O_8(^1S_0)$ $O_8(^3P_0)$

they would be sensitive to $O_8(^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

How reliable is this extraction?

It is an extraction at NLO in alpha_s(m_b) and v^2

at this order terms corresponding to new feature (relativistic, radiative, octet) already appear

each of them is of natural size but the sum is of order 1

Errors Discussion

- Results are rather insensitive to the values of $O_8(^1S_0)$ $O_8(^3P_0)$

they would be sensitive to $O_8(^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

How reliable is this extraction?

It is an extraction at NLO in alpha_s(m_b) and v^2

at this order terms corresponding to new feature (relativistic, radiative, octet) already appear

each of them is of natural size but the sum is of order 1

What about the higher order corrections O_N and O_D?

Errors Discussion

- Results are rather insensitive to the values of $O_8({}^1S_0)$ $O_8({}^3P_0)$

they would be sensitive to $O_8({}^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

How reliable is this extraction?

It is an extraction at NLO in alpha_s(m_b) and v^2

at this order terms corresponding to new feature (relativistic, radiative, octet) already appear

each of them is of natural size but the sum is of order 1

What about the higher order corrections O_N and O_D?

They are expected to be small (no new qualitative feautures), they have been calculated partially (in v) for O_D (Bodwin, Petrelli 02) -> if we estimate them we get 0.02 compatible with $-0.04 \leq \mathcal{O}_N(v^3), \mathcal{O}_D(v^3) \leq 0.04\,,$

Errors Discussion

- Results are rather insensitive to the values of $O_8(^1S_0)$ $O_8(^3P_0)$

they would be sensitive to $O_8(^3S_1)$ that however is very small from the lattice evaluation (smaller than NRQCD power counting)

How reliable is this extraction?

It is an extraction at NLO in alpha_s(m_b) and v^2

at this order terms corresponding to new feature (relativistic, radiative, octet) already appear

each of them is of natural size but the sum is of order 1

What about the higher order corrections O_N and O_D?

They are expected to be small (no new qualitative feautures), they have been calculated partially (in v) for O_D (Bodwin, Petrelli 02) -> if we estimate them we get 0.02 compatible with $-0.04 \leq \mathcal{O}_N(v^3), \mathcal{O}_D(v^3) \leq 0.04\,,$

THE MAIN UNCERTAINTY OF OUR DETERMINATION COMES FROM THE SYSTEMATIC EXPERIMENTAL ERROR

Comparison with previous results

with respect to PDG06: Hinchcliffe, manohar

Comparison with previous results

with respect to PDG06: Hinchcliffe, Manohar

- The color octet matrix elements are ignored in $\Gamma(\Upsilon(1S) \to \gamma X)$ while we find that they contribute between 30% to 100%; in $\Gamma(\Upsilon(1S) \to X)$ they are underestimated

Comparison with previous results

with respect to PDG06: Hinchcliffe, Manohar

- The color octet matrix elements are ignored in $\Gamma(\Upsilon(1S) \to \gamma X)$ while we find that they contribute between 30% to 100%; in $\Gamma(\Upsilon(1S) \to X)$ they are underestimated
- Older less precise data are used and a model extrapolation to low z

Comparison with previous results

with respect to PDG06: HINCHCLIFFE, MANOHAR

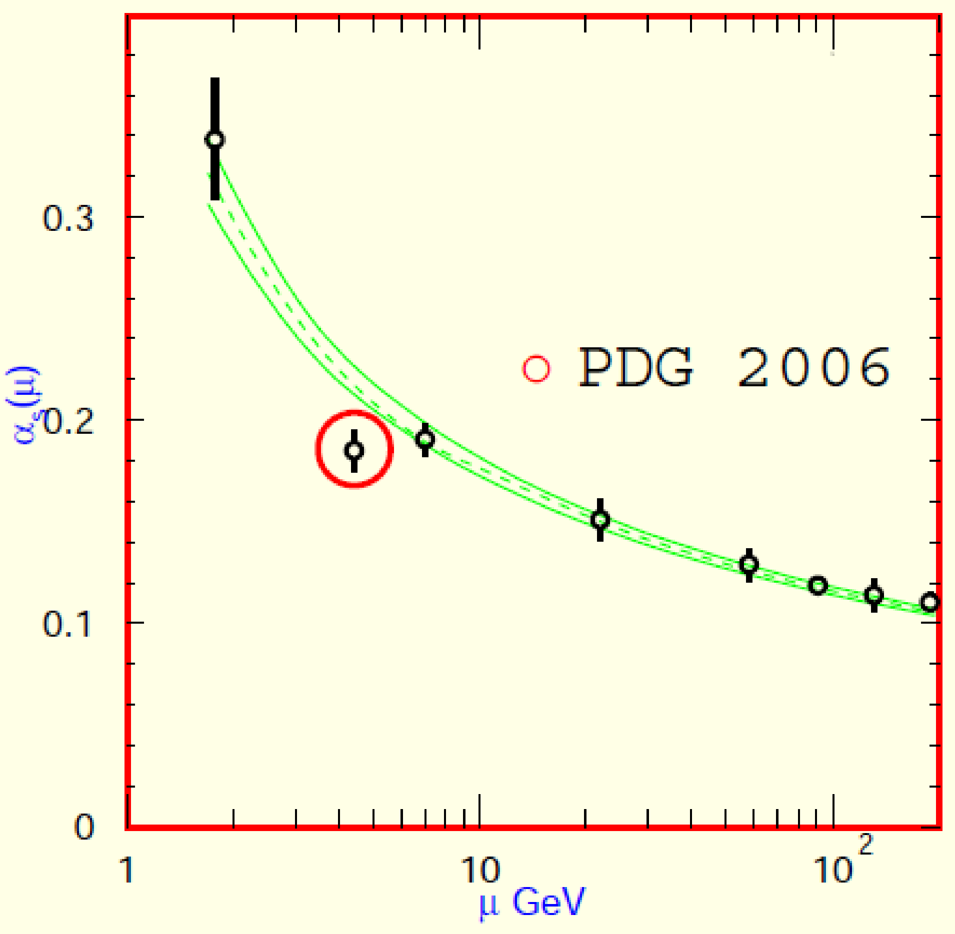
- The color octet matrix elements are ignored in $\Gamma(\Upsilon(1S) \to \gamma X)$ while we find that they contribute between 30% to 100%; in $\Gamma(\Upsilon(1S) \to X)$ they are underestimated
- Older less precise data are used and a model extrapolation to low z
- The extraction is done from $\frac{\Gamma(\Upsilon(1S) \to \gamma X)}{\Gamma(\Upsilon(1S) \to l^+ l^-)}$

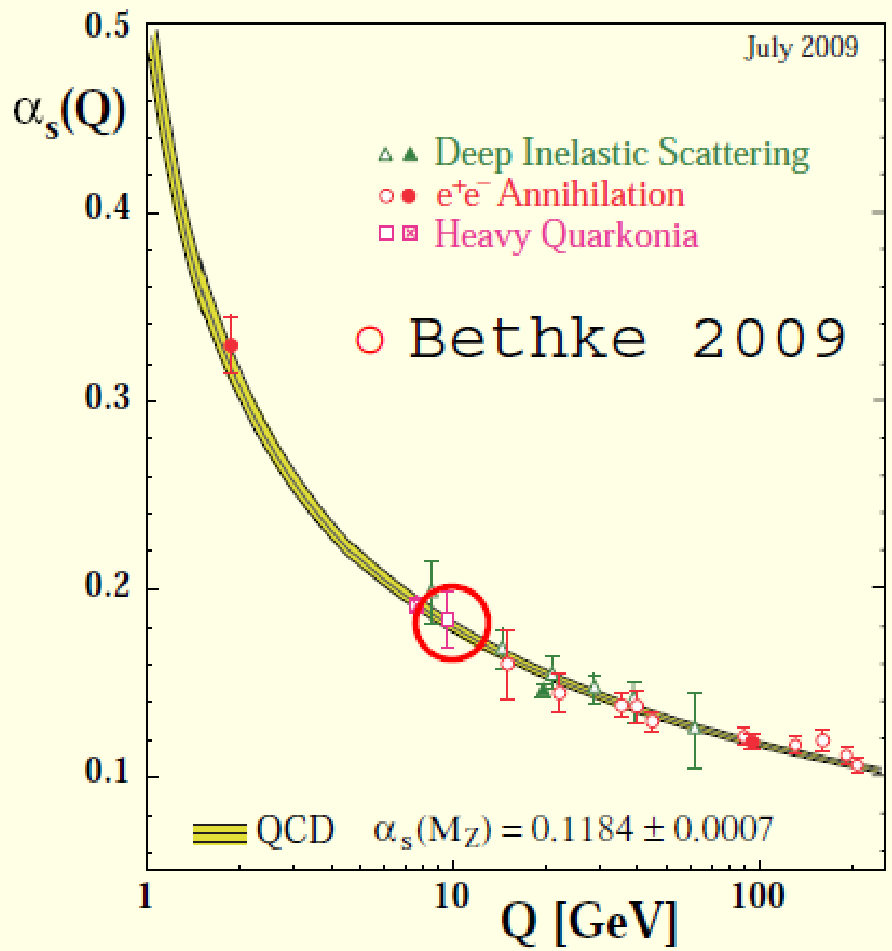
claiming it is cleaner. But the uncertainty increases due to the an increased sensibility to the octets. Moreover the leptonic width suffer from large corrections in alphas.

We obtain the final result

$$\alpha_s(M_{\Upsilon(1S)}) = 0.184^{+0.015}_{-0.014}$$

corresponding to



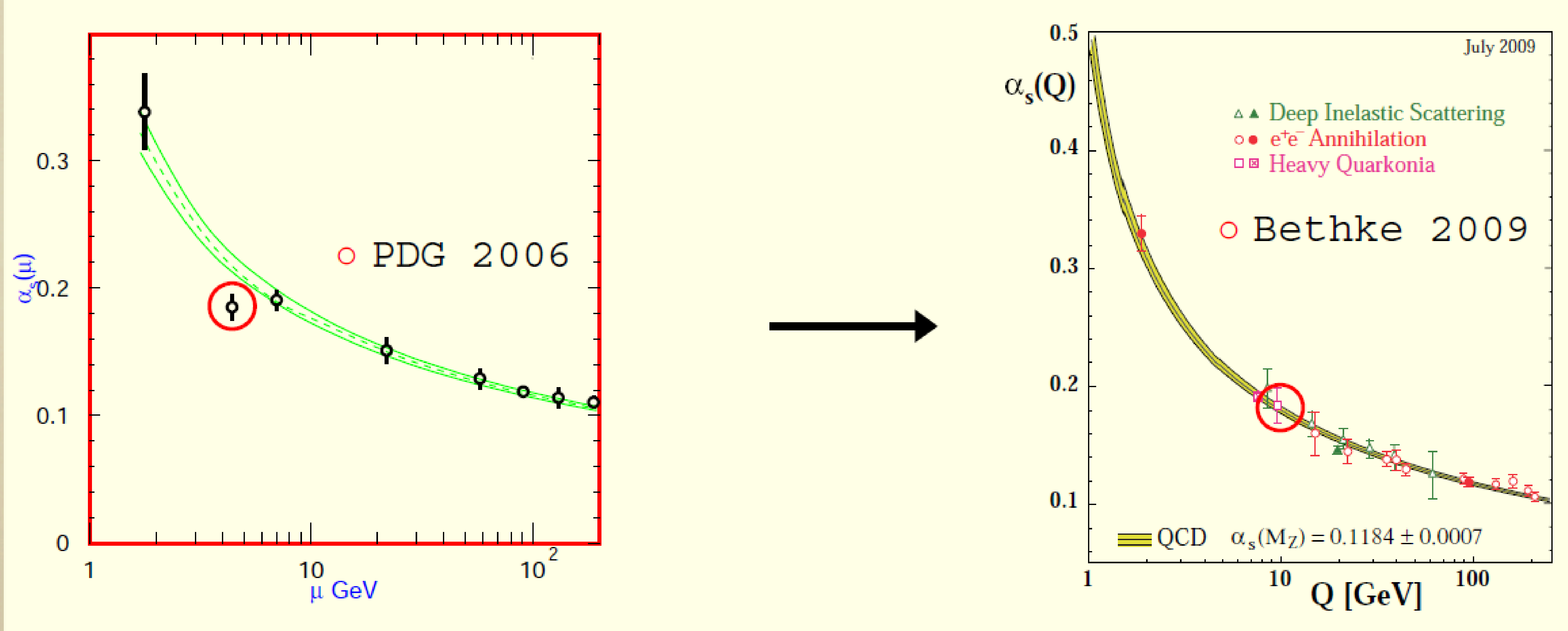


We obtain the final result

$$\alpha_s(M_{\Upsilon(1S)}) = 0.184^{+0.015}_{-0.014}$$

corresponding to

$$\alpha_s(M_Z) = 0.119^{+0.006}_{-0.005}$$



Future Prospects for α_s determinations from quarkonia

- More precise data for R_γ for $\Upsilon(1S)$ would allow a more precise extraction of $\alpha_s(M_{\Upsilon(1S)})$

- A new measurement of the inclusive photon spectrum at BESIII would provide the possibility to extract $\alpha_s(M_{J/\psi})$

  Garcia, soto 2007

- Previous to its discovery the η_b was indicated as the place where a very precise determination of α_s a could be obtained from the hyperfine separation

  kniehl, penin. pineda, smirnov, steinhauser 2007

BACKUP