α_s extraction from radiative quarkonium decays

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(work done with Nora Brambilla, Joan Soto and Antonio Vairo)
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Outline of the talk

- Reminder: Current α_{s} from PDG

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- The photon spectrum ($\Upsilon \rightarrow X\gamma$)

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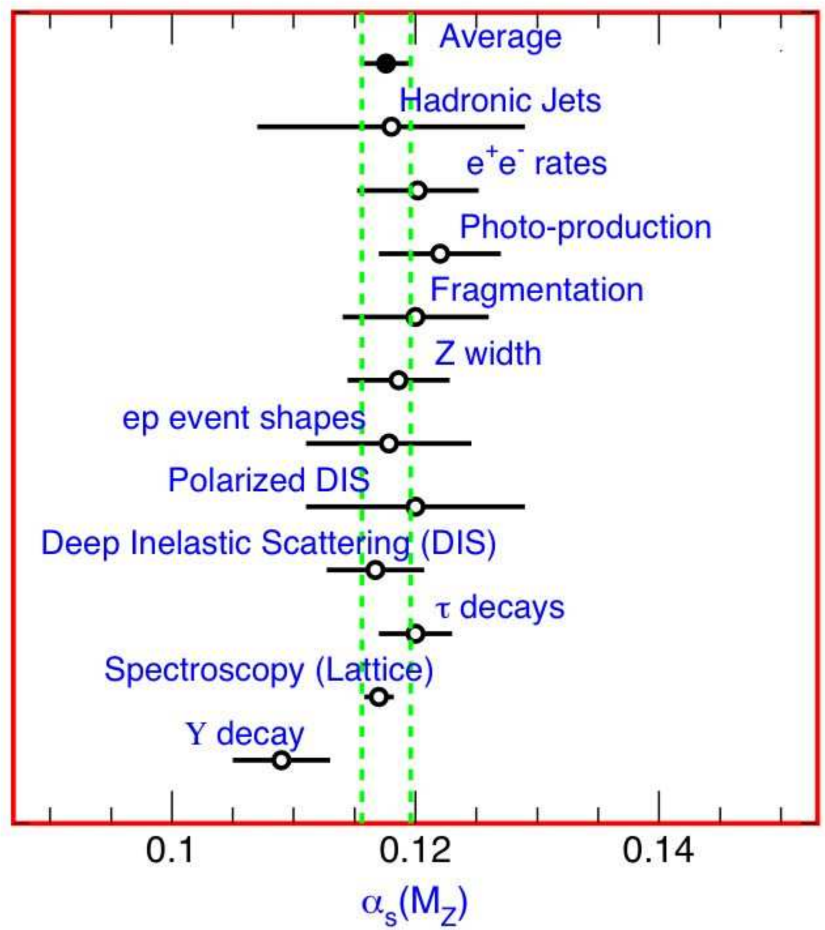
- Conclusions

α_s from PDG06



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

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

- Recent CLEO measurement of the photon spectrum

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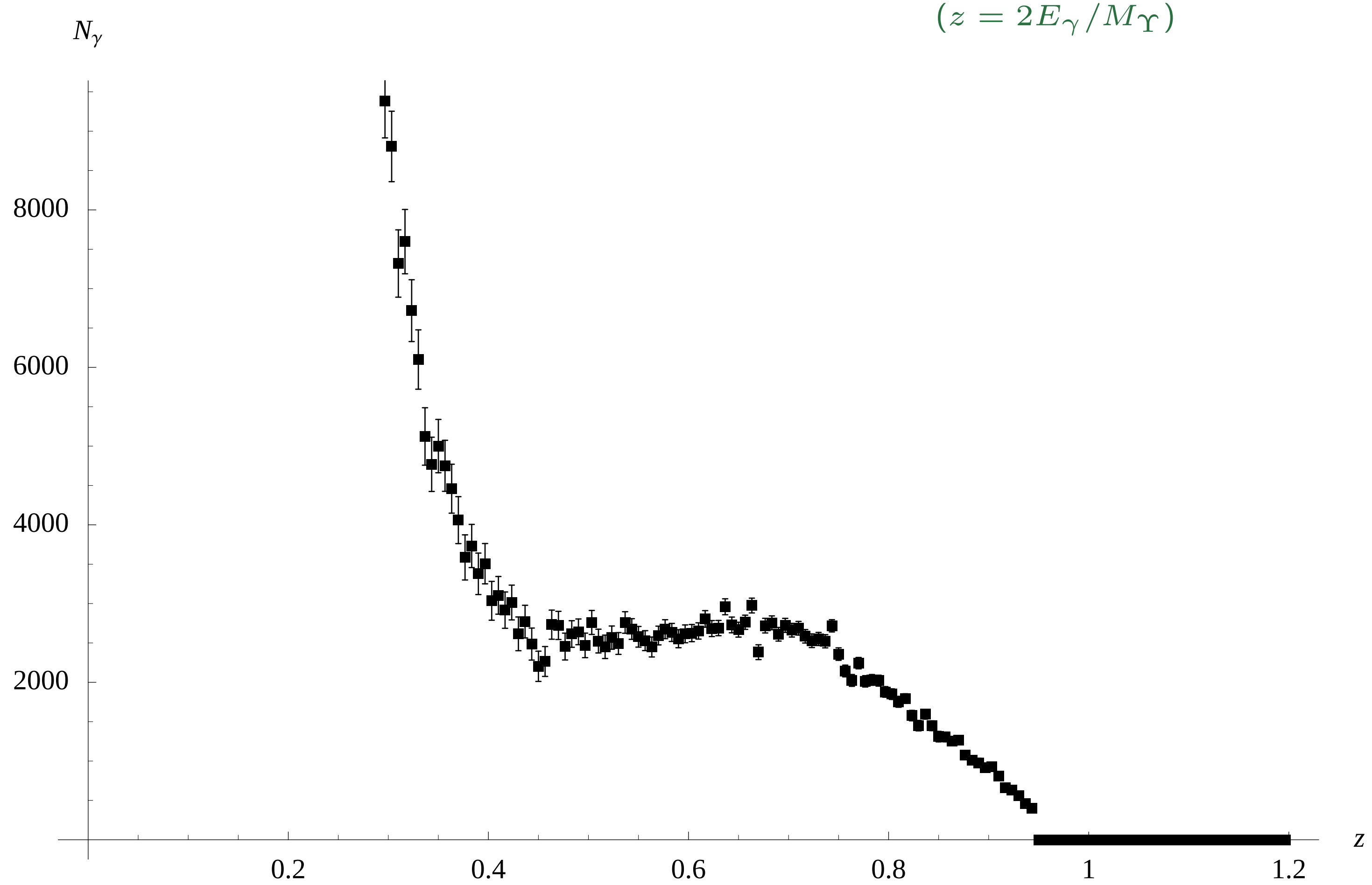
$(z = 2E_\gamma/M_\Upsilon)$



Data from CLEO III, 2005

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

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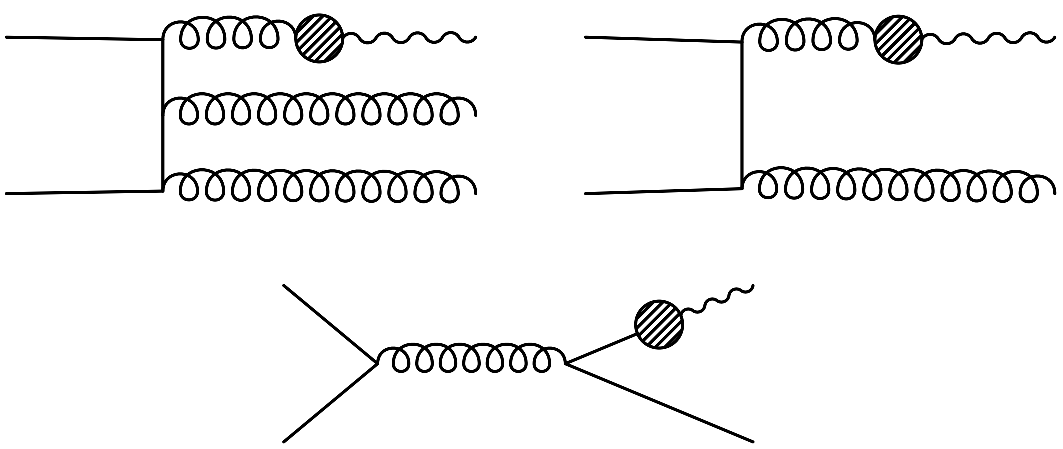
  - Direct contributions

Fragmentation contributions

Electromagnetic couplings to light quarks

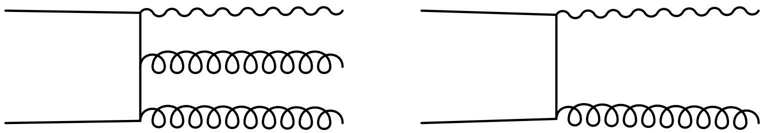
$$\frac{d\Gamma^{frag}}{dz} = \sum_a C_a \otimes D_{a\to\gamma}$$



This type of contributions become important in the low z region of the spectrum

Direct contributions

Electromagnetic couplings to heavy quarks



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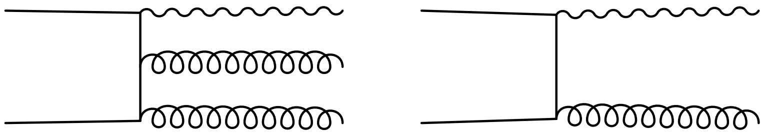

NRQCD factorization formalism

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

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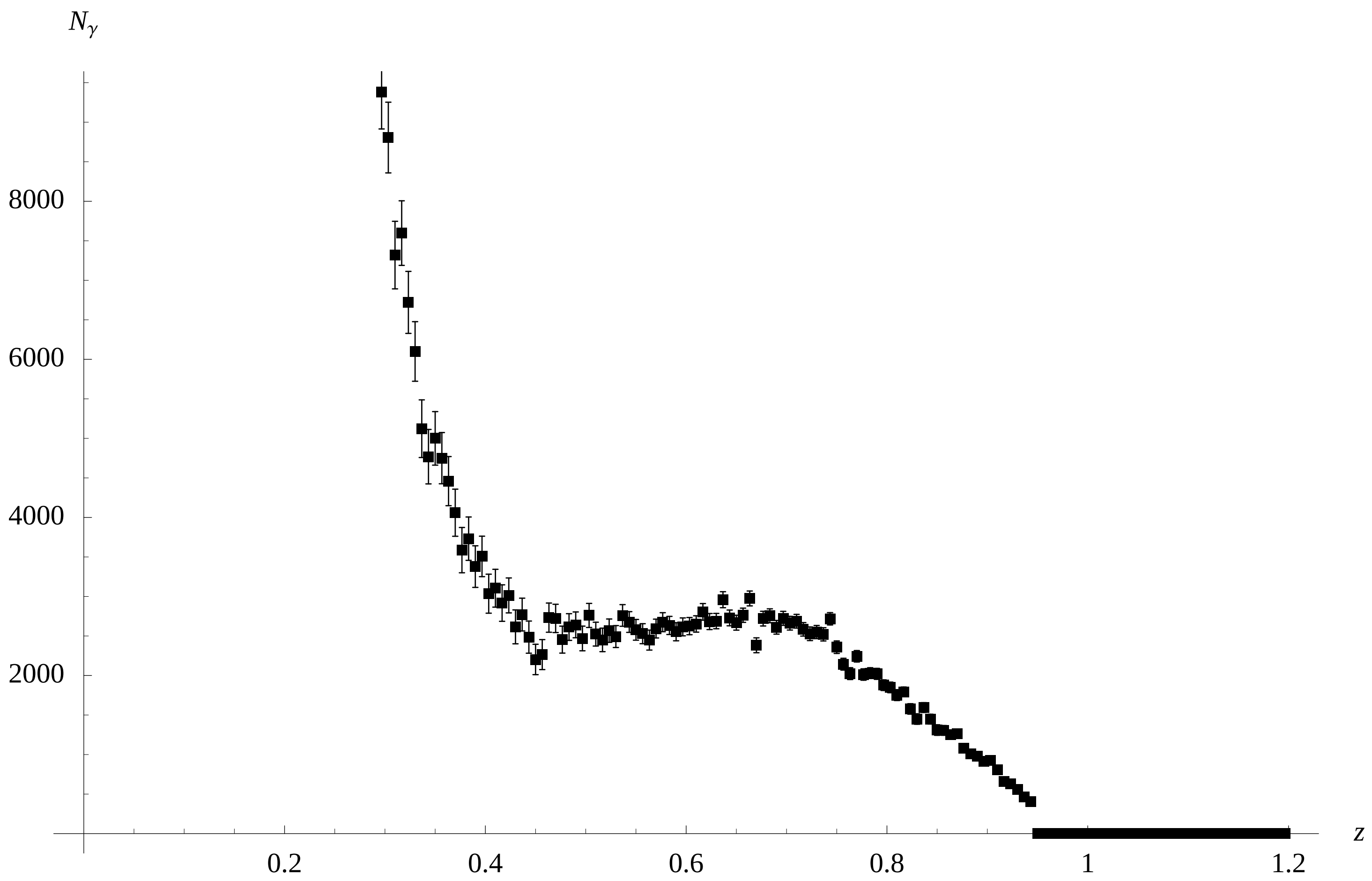
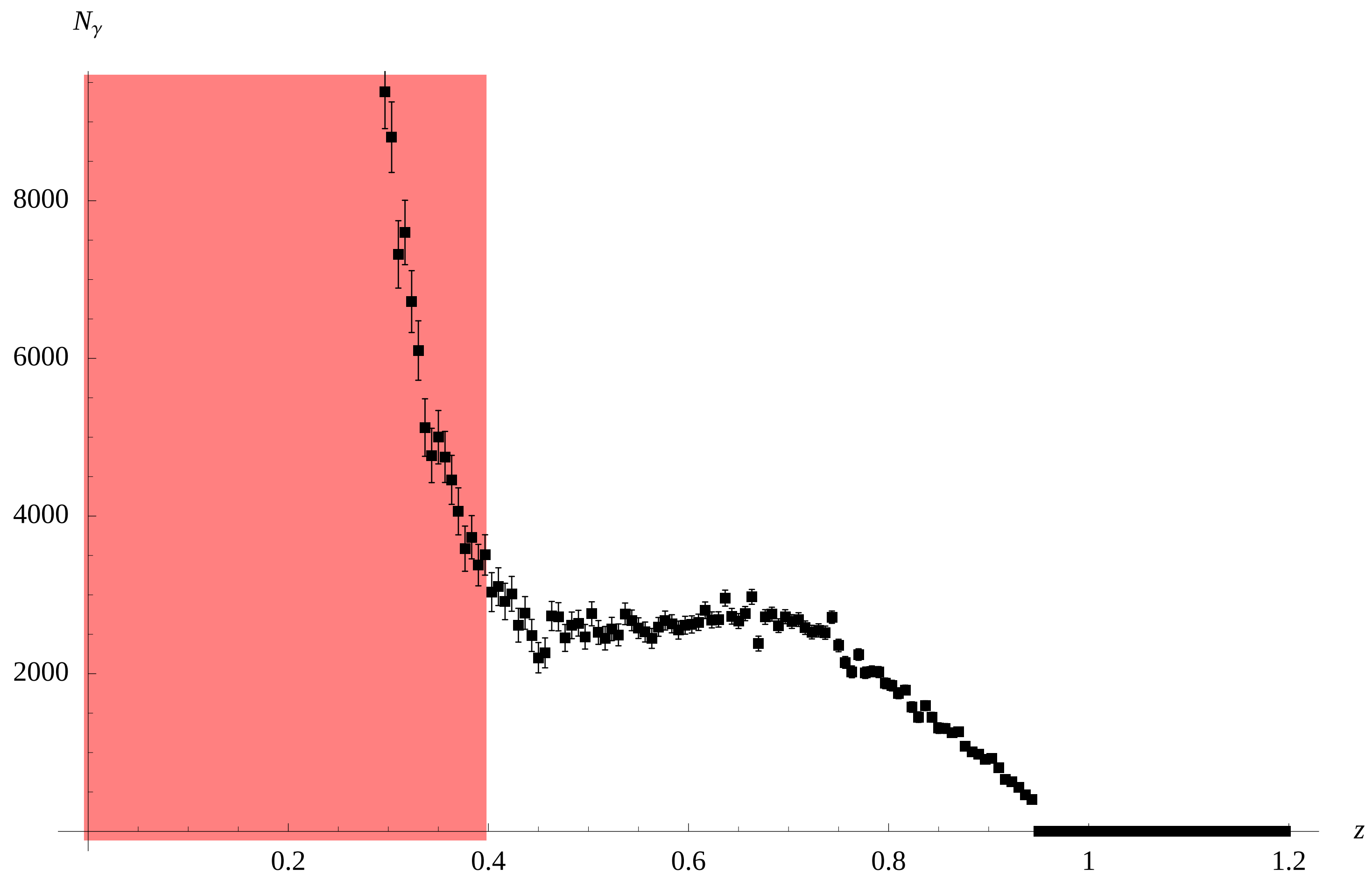
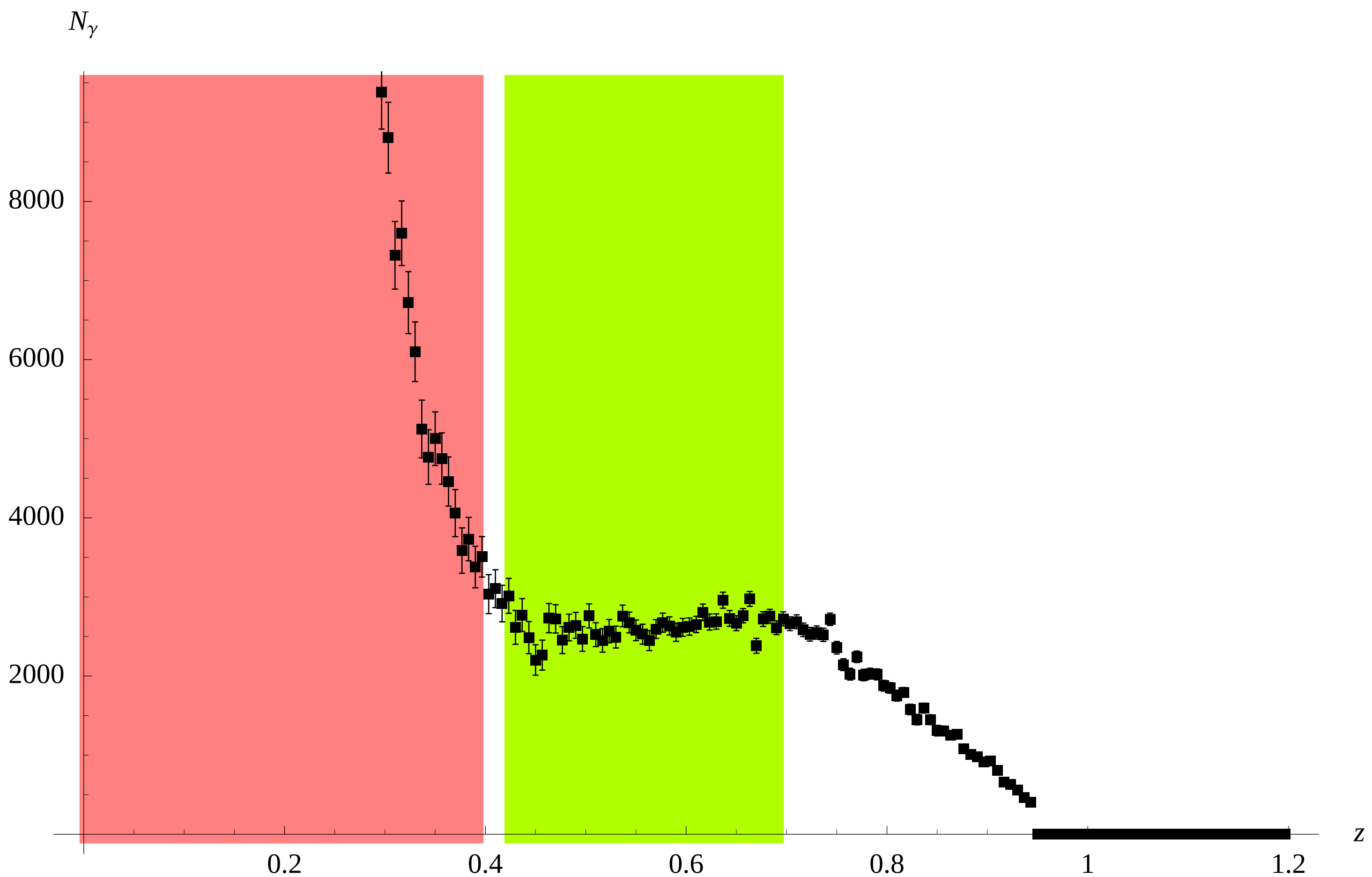
- For $z \to 1$ NRQCD expansion breaks down. Collinear degrees of freedom become relevant
  - Large $\log(1-z)$ need to be resummed

    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

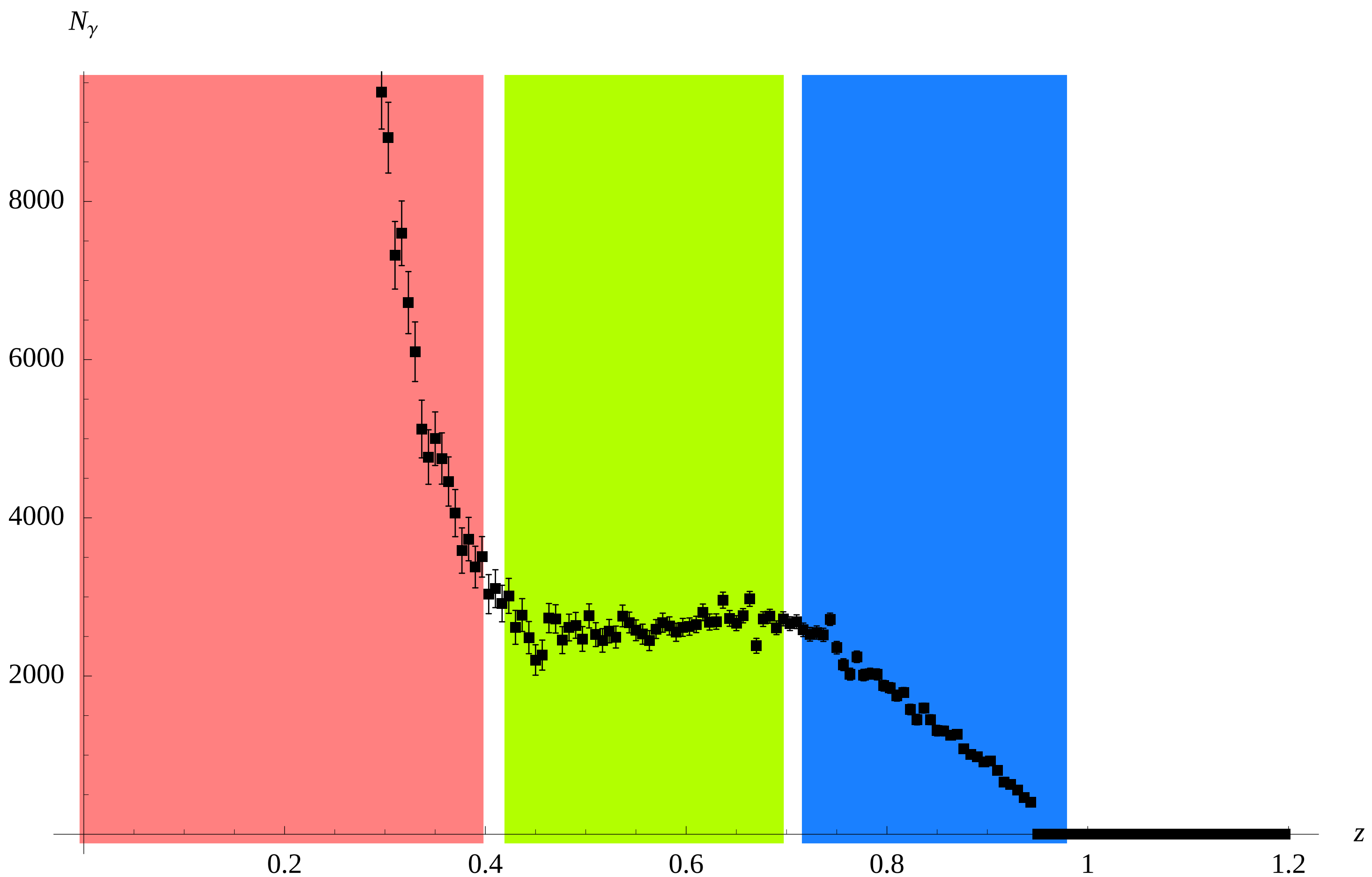

N_γ
8000
6000
4000
2000
0.2
0.4
0.6
0.8
1
1.2
z



Fragmentation region



NRQCD (central) region



upper end-point region

After taking into account all those contributions, the complete spectrum can be well described X.G.T. and Soto '05

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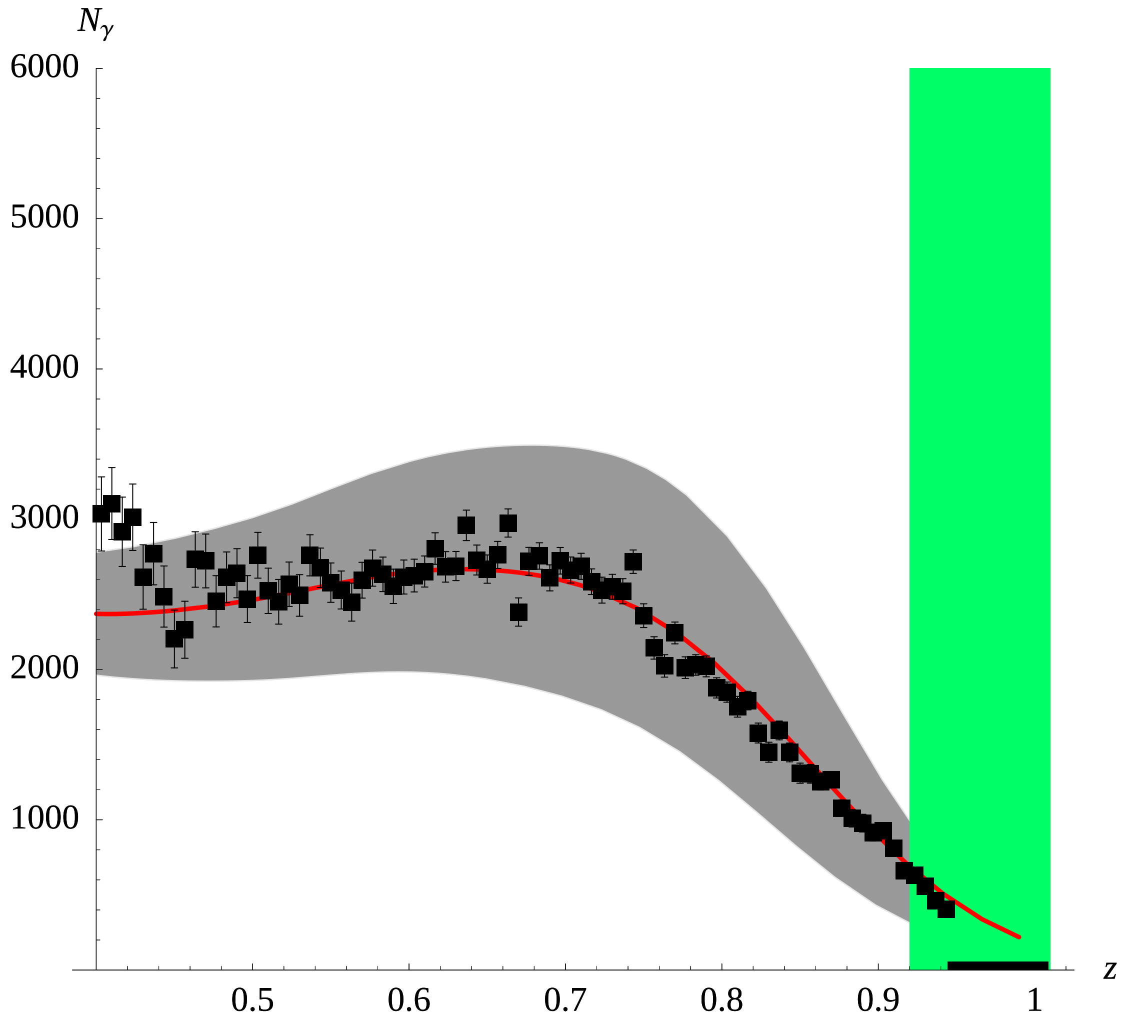

The extraction

- Extract α_s from the ratio

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- Compare then with a theoretical expression for R_γ to extract α_s

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We will use the same counting employed for the calculation of the spectrum to extract α_s

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- Inclusion of all those terms well known to be potentially important
- Data is now very precise and we have all the necessary theoretical ingredients to include all the pieces

Schematically

$$\frac{\Gamma gg\gamma}{\Gamma ggg} = \frac{C_{\gamma O_1(^3S_1)} O_1(^3S_1) + C_{\mathcal{P}_1(^3S_1)} \mathcal{P}_1(^3S_1) + C_{\gamma O_8(^1S_0,^3P_0)} O_8(^1S_0,^3P_0)}{C_{O_1(^3S_1)} O_1(^3S_1) + C_{\mathcal{P}_1(^3S_1)} \mathcal{P}_1(^3S_1) + C_{O_8(^1S_0,^3P_0,^3S_1)} O_8(^1S_0,^3P_0,^3S_1)}$$

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Octet matrix elements:

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Octet matrix elements:

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

  X.G.T. and Soto '04

- $\mathcal{O}_8({}^3S_1)$ and $\mathcal{O}_8({}^1S_0)$ have been calculated on the lattice

  Bodwin, Lee and Sinclair '05

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- C (for continuum)

- L (for lattice)

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  - Uses all the weak-coupling expressions available and lattice calculation for $\mathcal{O}_8(^3S_1)$
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The two procedures give very similar results. We take the average as the final value

Error estimation

- C (for continuum)

- L (for lattice)

Error estimation $\left(\mathcal{R}_O = \frac{\langle O \rangle}{m^{\Delta d} \left\langle O_1(^3S_1) \right\rangle}\right)$

- C (for continuum)

$$\begin{aligned} 0.18 \le & \quad \alpha_s(m_b v) & \le 0.38 \\ 0.32 \le & \quad \alpha_s(m_b v^2) & \le 1.3 \\ 0 \le & \quad \mathcal{R}_{O_8(^3S_1)} & \le 1.6 \times 10^{-4} \end{aligned}$$

- L (for lattice)

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

Plus errors associated to higher order terms (v^3) and experimental errors

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- The error in the final result is taken as the full range of the two determinations

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N.Brambilla, X.G.T., J.Soto, A.Vairo '07

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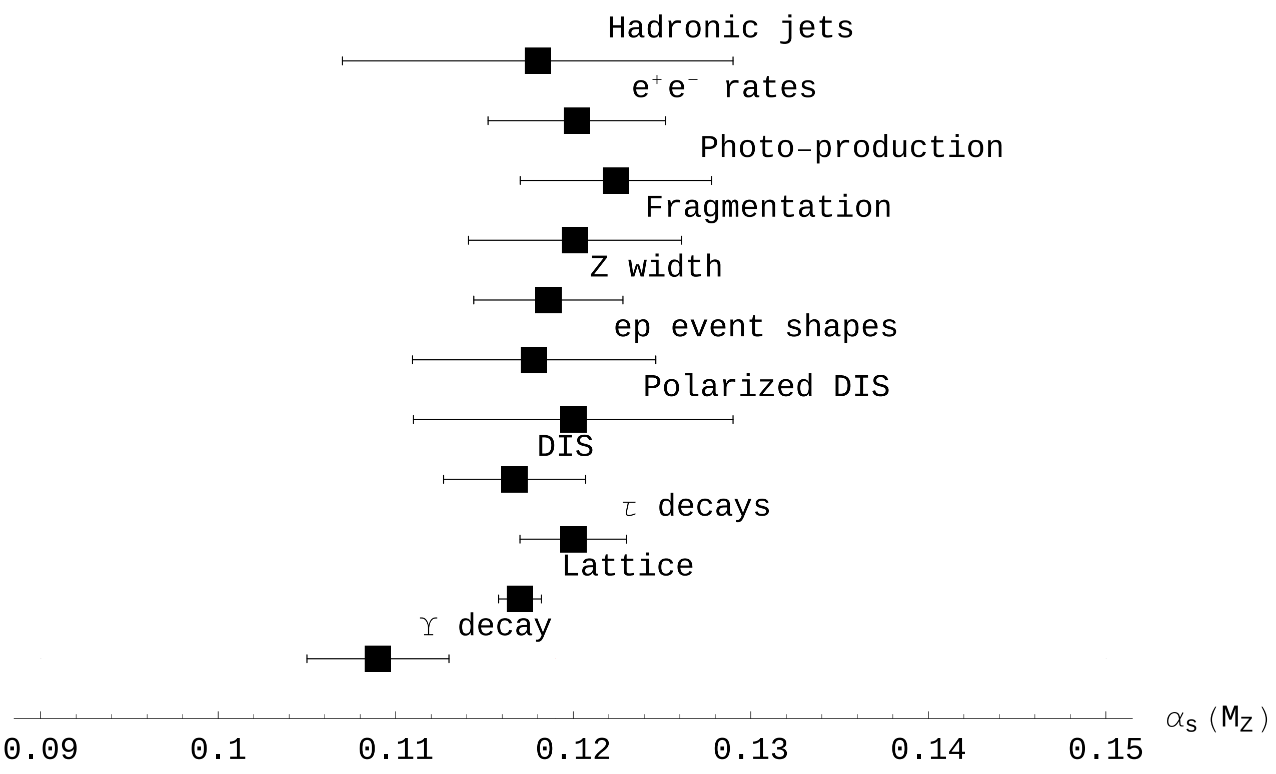
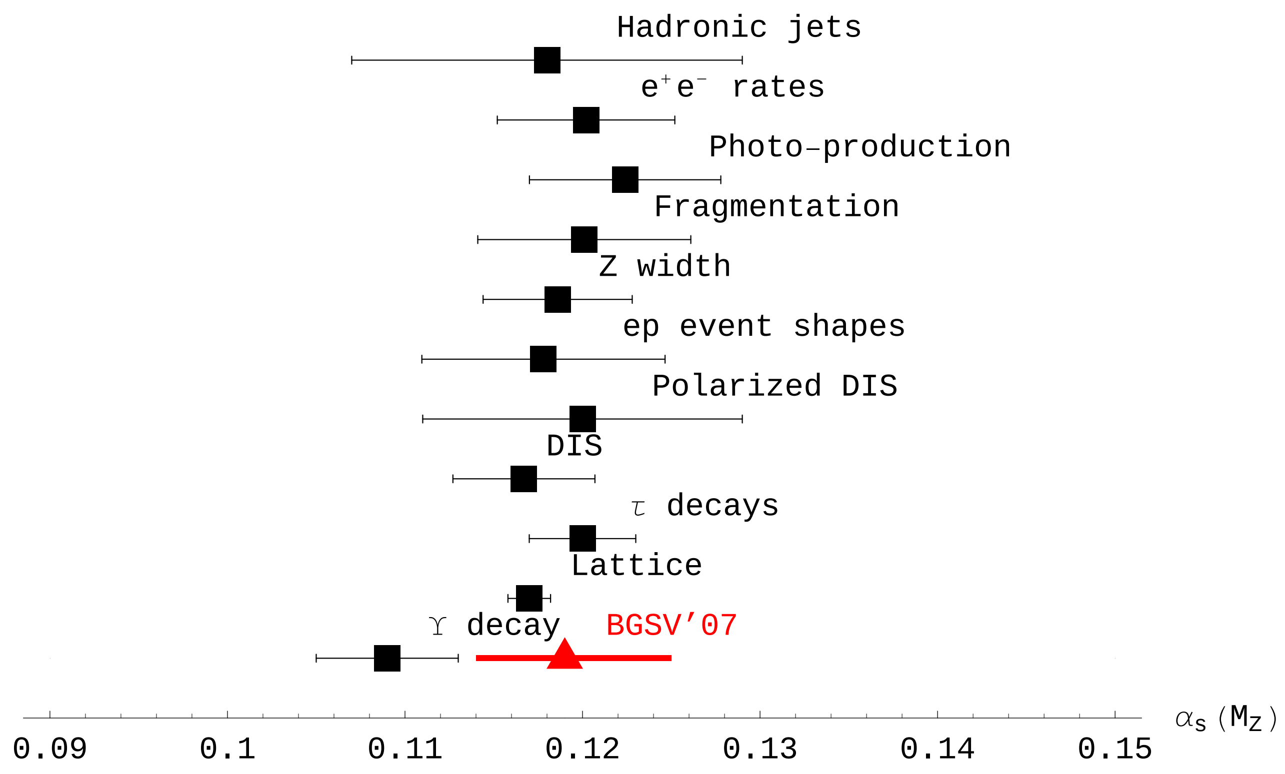
Recall, PDG average $\quad \longrightarrow \quad \alpha_s(M_Z) = 0.1176 \pm 0.0020$


Hadronic jets
e⁺e⁻ rates
Photo-production
Fragmentation
Z width
ep event shapes
Polarized DIS
DIS
τ decays
Lattice
Υ decay
0.09
0.1
0.11
0.12
0.13
0.14
0.15
αs (MZ)



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0.09
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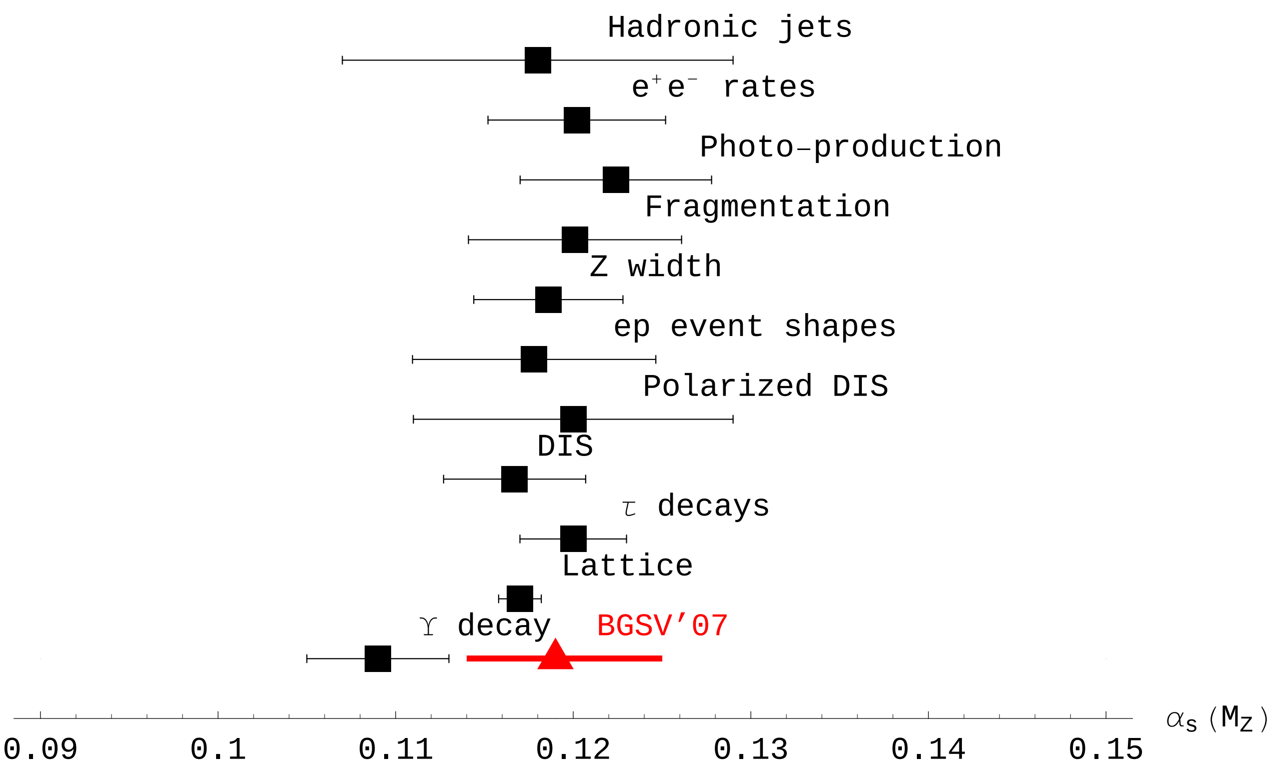
$\alpha_s(M_Z)$



Of course, if the new value is used in the average, the average will move up

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- The new extracted value of α_s shows better agreement with the other determinations