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MEASUREMENT OF THE DIRECT PHOTON SPECTRUM FROM THE $\Upsilon(1S)$

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Abstract

Using the Crystal Ball detector at the e^+e^- - storage ring DORIS II we have measured the direct photon spectrum from the $\Upsilon(1S)$. These photons result from the decay $\Upsilon \longrightarrow \gamma gg \longrightarrow \gamma + hadrons$. We determine the ratio $r = \Gamma(\Upsilon \longrightarrow \gamma gg)/\Gamma(\Upsilon \longrightarrow ggg) = (2.7\pm0.2\pm0.4)\%$. This ratio r is used to deduce the strong coupling constant in the $\overline{MS}$ scheme at $Q^2 = (1.5\ GeV)^2$ to be $\alpha_s = 0.25 \pm 0.02 \pm 0.04$. While the prediction of the shape of the spectrum by lowest order QCD can be ruled out, the prediction by R. D. Field fits our data well.

Talk given at the BNL Workshop on Glueballs, Hybrids and Exotic Hadrons, August 29-September 1, 1988

1. Introduction

According to QCD the $\Upsilon(1S)$ predominately decays via a 3 gluon intermediate state, but to a certain fraction it can decay also via one photon and 2 gluons [1,2]. The ratio of the partial decay widths has been calculated in perturbation theory to second order in α_s in the $\overline{MS}$ scheme at $Q^2 = (1.5\ GeV)^2$ [3]:

$$r = \frac{\Gamma(\Upsilon \longrightarrow \gamma gg)}{\Gamma(\Upsilon \longrightarrow ggg)} = \frac{36}{5}\frac{\alpha_{em}}{\alpha_s}\left(\frac{e_b}{e}\right)^2\left[1 + (2.2 \pm 0.6)\frac{\alpha_s}{\pi}\right] \tag{1}$$

where α_{em} and α_s are the electromagnetic and the strong coupling constants, respectively and $e_b = -\frac{1}{3}\cdot e$ is the electric charge of the b-quark. Thus, measuring the branching ratio of $\Upsilon(1S) \longrightarrow \gamma gg$, α_s can be determined.

In addition, the shape of the direct photon spectrum can provide a test of the applicability of perturbative QCD. While the lowest order QCD approximation predicts in analogy to the decay of the ortho-positronium [4] an almost linearly rising spectrum in $z = E_\gamma/E_{Beam}$, the more sophisticated model by R. D. Field [5] predicts a softer spectrum. This softening of the direct photon spectrum is due to the non-abelian character of QCD according to which the gluons themselves carry color and can therefore couple to each other. To include the effect of the gluon self coupling, R. D. Field uses a parton shower approximation to QCD perturbation theory. By radiating further bremsstrahlung gluons, the two gluons recoiling against the direct photon acquire an invariant mass $m_g \neq 0$. This leads to a suppression of direct photons with energies close to the beam energy E_{Beam} and thus to a softening of the photon spectrum; a maximum is predicted at $z \approx 0.7$.
By summing the leading logarithmic contributions to all orders in perturbation theory, Photiadis [6] obtains a slight softening of the lowest order QCD prediction. The spectrum predicted by [6], however, is still quite similar to the lowest order QCD prediction, peaking close to $z = 1$.

2. Detector

The Crystal Ball detector is well suited to measure precisely the energy and direction of electromagnetic showering particles [7,8]. The main part of this non-magnetic calorimeter consists of a spherical shell of 672 NaI(Tl) crystals which cover 93 % of 4 π. Each crystal projects a radial distance of 16 radiation lengths. For electromagnetic showering particles the energy resolution is $\sigma_E/E = (2.7 \pm 0.2)\%/\sqrt[4]{E/GeV}$, the polar angle resolution is about 2°. At the center of the main Ball a spherical cavity of radius $r = 25.4cm$ contains a set of proportional wire chambers, allowing the detection of charged particles.

3. Analysis

The dataset analyzed comprises 17.1 pb^{-1} taken on the $\Upsilon(1S)$ resonance and 7.8 pb^{-1} taken in the continuum nearby and yields about 150 000 $\Upsilon(1S)$ decays. In order

to suppress the backgrounds from QED, beam-gas and beam-wall events, a special γgg-event selection was performed.
For acceptance, we require a total energy deposited in the Ball, $E_{Ball} > 0.3 * E_{CMS}$ where $E_{CMS} = 9.46\ GeV$. Furthermore, the sum of energy deposited in the plane transverse to the beam E_{Trans} has to exceed a minimal value, $E_{Trans} \geq 0.25 * E_{CMS}$. Both cuts suppress the beam related backgrounds considerably, since the center of mass system of these background events is boosted strongly in the direction of the one interacting beam particle. This boost of particles leads to a deposition of energy preferentially in the crystals close to the beam axis, resulting in a considerable reduction of the transverse energy E_{Trans}. For e^+e^- annihilation events the energy is rather isotropically distributed, since their center of mass system coincides with the laboratory frame.

The suppression of the background from Bhabha scattering $e^+e^- \longrightarrow e^+e^-(\gamma)$ and from $e^+e^- \longrightarrow \gamma\gamma(\gamma)$ uses the fact, that these events generally contain two highly energetic particles in the Crystal Ball. Radiative QED events can have a multiplicity greater than two, but the sum of energy of the charged particles (electrons) usually exceeds E_{Beam}, while in γgg events only charged hadrons (mostly minimum ionizing) deposit energy clearly less than E_{Beam}. Moreover, while it happens both in radiative QED events and in γgg events that the most energetic particle has an energy close to E_{Beam}, it is very unlikely that a second particle deposits an energy larger than $E_{Beam}/2$ in γgg events. This, however, is the usual case in radiative QED events. Consequently, by requiring a multiplicity of $N_{Particles} \geq 3$ and not more than fixed fractions of the beam energy deposited either by charged particles or by the second most energetic particle, almost all QED background is rejected.
The small background still left after this event selection can be eliminated at a later stage by continuum subtraction.

In the remaining γgg event candidates, the photon candidate has to be neutral and has to have an energy $E_\gamma > 1.7 GeV$. This energy threshold takes into account the observation that in the energy region below $3 GeV$ the raw photon spectrum is dominated by background from π^o's; this background becomes overwhelming for $E_\gamma < 1.7 GeV$ ($z < 0.375$). Furthermore, the photon candidate must be well isolated from other particles and its lateral energy distribution must be consistent with those of photons. The efficiency of the event and photon selection is determined by using γgg Monte Carlo events generated with the LUND generator version 6.2 [9]. The efficiency is smooth and flat and ranges from about 50% at $z \approx 0.35$ to about 65% at $z \approx 0.7$ (Fig. 3).

After the photon selection, the remaining background stemming from continuum processes is eliminated by subtracting the raw photon spectrum derived from a dataset taken in the nearby continuum; this dataset is analyzed exactly like the on-resonance data and is scaled to the appropriate luminosity.

The main part of the background remaining after continuum subtraction comes from π^o's from $\Upsilon(1S) \rightarrow ggg$ and $\Upsilon(1S) \rightarrow q\bar{q}$ decays. The decay photons of these highly energetic π^o's are so close to each other that they appear as one energy cluster in our calorimeter. The background of these "merged" π^o's dominates the raw photon spectrum only for $z < 0.6$ and can be removed by using a special statistical subtraction procedure. This background subtraction method utilizes the different distributions of the mean angular width (*SMOMT*) of the lateral energy depositions of photons and merged π^o's [10,11].
In order to calculate *SMOMT*, the "center of gravity" $\vec{c}$ of the shower has to be determined first by $\vec{c} = 1/E \cdot \sum_i \vec{n_i} \cdot E_i$, where the sum goes over all crystals of the shower, E denotes the total energy of the shower, E_i is the energy in the i^{th} crystal and $\vec{n_i}$ is the unit vector pointing to the center of the i^{th} crystal. The value of the variable *SMOMT* is then calculated by $SMOMT = 1/E \cdot \sum_i (\vec{c} - \vec{n_i})^2 \cdot E_i$, where the sum goes over all crystals of the shower again.
Although the two decay photons of a highly energetic π^o come very close together and its electromagnetic shower looks therefore very much like the one caused by a single photon, the lateral shower extension (gauged by *SMOMT*) of the highly energetic π^o is on the average still clearly larger than the corresponding value for a single photon of the same energy.
The π^o background subtraction procedure consists of fitting the *SMOMT* distributions of photons and merged π^o's simultaneously to the *SMOMT* distributions of the photon candidates in the data for each z bin ($\Delta z = 0.05$). As an example, the fit result for the photon candidates with energies between $z = 0.60$ and $z = 0.65$ is shown in Fig. 1. In this example, the integral of the fitted *SMOMT* distribution from photons of this energy (dashed line) gives the number of direct photons for the energy bin $0.6 \leq z < 0.65$.
Fig. 2 shows the direct photon spectrum and the π^o background spectrum resulting from the *SMOMT* fits. The errors in Fig. 2 are the statistical errors resulting from the *SMOMT*-fitting procedure. Using the interpolated π^o background (shown as a full line in Fig. 2) and correcting for efficiency losses, the final direct photon spectrum is obtained (Fig. 4).

As an independent approach to the background subraction, the complete resonant background was modeled by the LUND generator and a Monte Carlo simulation of the full detector, scaled to the appropriate luminosity and analyzed exactly like the data. The resulting Monte Carlo background spectrum was directly subtracted from the raw photon spectrum from the data. Correcting the remaining spectrum for efficiency, this method yields the direct photon spectrum again [12].

Both direct photon spectra obtained by the procedures described above agree well within the statistical and systematic errors.

4. Results

Due to the large π^o background in the low energy region, large systematic uncertainties from background subtraction do not allow a reliable measurement of the direct photon spectrum below $z = 0.375$. In order to determine the number of direct photons from the spectrum, the part below $z = 0.375$ must be estimated by fitting theoretical models to our data above $z = 0.375$. While the Field model fits our spectrum quite well with a $\chi^2 = 10.6$ for $12 d.o.f.$, the lowest order QCD prediction does not with a $\chi^2 = 40.0$ for $12 d.o.f.$.

Using the Field prediction to extrapolate our spectra down to $z = 0$, we find a total number of $N_\gamma = (4000 \pm 300 \pm 560)$ photons, which corresponds to $r = (2.7 \pm 0.2 \pm 0.4)\%$. Using this ratio r in eq. 1, we obtain for the strong coupling α_s in the $\overline{MS}$ scheme at $Q^2 = (1.5\ GeV)^2$ the value $\alpha_s = 0.25 \pm 0.02 \pm 0.04$. Here, the first error is the statistical and the second one the systematic error, which is dominated by the uncertainties correlated to the π^o background subtraction. This value for α_s is in agreement with previous results of α_s measurements from the direct photon spectrum at the same Q^2 [13,14,15] and consistent with α_s determinations from other measurements at different Q^2 [16,17].

Concerning the shape of the spectrum, our result is in disagreement with the *CUSB* measurement [15] (which prefers a rather hard spectrum), while it confirms, with better energy resolution, the *ARGUS* observation [13] of a soft high energy photon spectrum. The *CLEO* result [14] is not conclusive on the shape of the spectrum.

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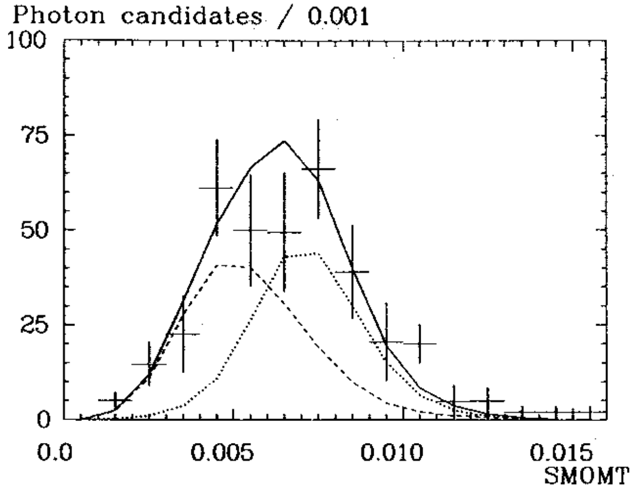

Figure 1: *Example of a simultaneous fit of the SMOMT distribution of photons (dashed line) and π^o's (dotted line) to the SMOMT distribution of the photon candidates with 0.6 $\leq z <$ 0.65 (crosses). The full line is the sum of the two fitted distributions.*

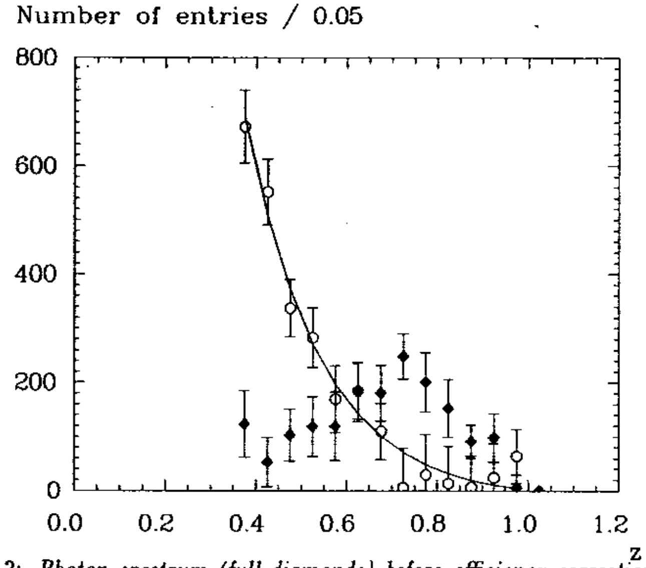

Figure 2: *Photon spectrum (full diamonds) before efficiency correction; π^o background (open circles). The full line indicates the interpolation of the π^o background.*

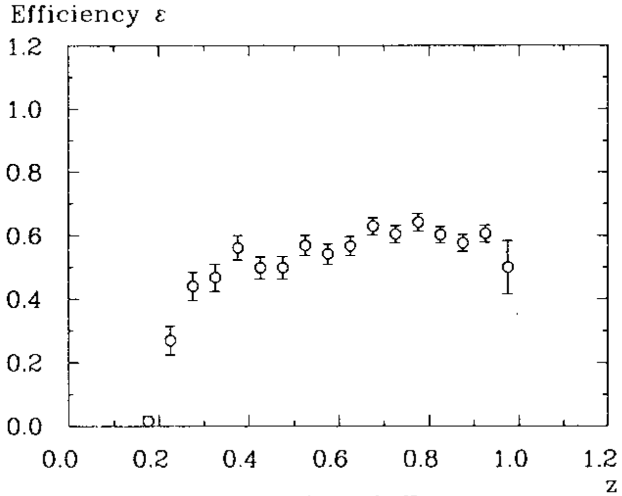

Figure 3: *The total efficiency.*

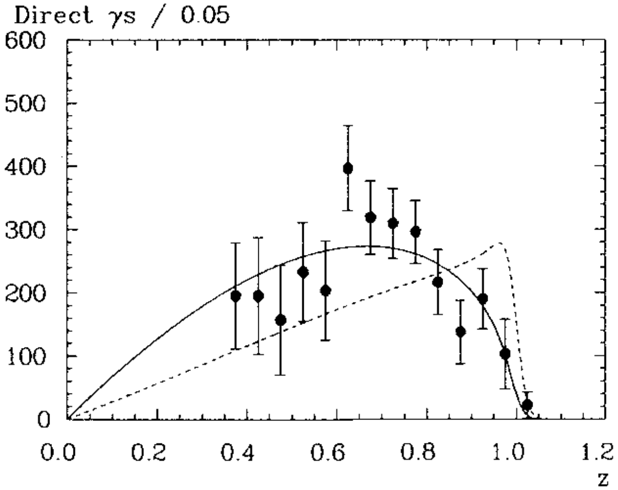

Figure 4: *The direct photon spectrum after efficiency correction using the interpolated π^o-background. The solid line is a fit of our data to the Field model, the dashed line corresponds to a fit to the lowest order QCD prediction.*