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Scattering of thermal photons by a 46 GeV positron beam at LEP.

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Abstract

The scattering of the thermal photons present in the vacuum pipe of LEP against the high energy positron beam has been detected. The spectrum of the back-scattered photons is presented for a positron beam energy of 46.1 GeV. Measurements have been performed in the interaction region 1 with the LEP-5 experiment calorimeter.

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1- INTRODUCTION

The aim of the LEP-5 experiment is to measure the luminosity and other parameters of the electron beams circulating in the Large Electron Positron collider (LEP) at CERN, by detecting the single bremsstrahlung in the $e^+ e^-$ bunch crossings [1].

The data taking, performed during the 1990 LEP run, lead to an interesting experimental result showing the energy distribution of the black body thermal photons scattered off by the 46.1 GeV positron beam. LEP is the first accelerator in which such kind of measurement has been possible. A similar result obtained in the same run by another group has been already published [2]. The physics concerning this effect can be understood as follows.

The LEP vacuum pipe can be considered as a black body at about 300°K, hence an electromagnetic radiation in thermal equilibrium is present in its internal volume with an energy distribution following the Planck law with a maximum at an energy $K_{\max} = 0.07$ eV, as can be easily deduced from the Wien law. In the rest frame of the LEP electrons (positrons) such a photon, if incident at an angle of 180° , will appear to have an energy $K^* \approx K_{\max} 2\gamma = 13.7$ KeV. After a Compton back-scattering the photon energy in the laboratory frame will be $K \approx K_{\max} 4\gamma^2 = 2.8$ GeV ($\gamma = E_b/m$, where $E_b \approx 50$ GeV is the electron beam energy and m the electron rest mass). Therefore, a calorimeter may be able to detect the photons emitted along the electron direction and possibly to show the thermal photon distribution added to the 50 GeV photon energy spectrum due to the beam- residual gas bremsstrahlung (BGB). The latter in LEP is very low due to an existing vacuum pressure of the order of 10^{-10} torr along the 600 meter long straight section. This fact, and the possibility to keep under control the synchrotron radiation, made the detection of the Compton scattered thermal photon possible for the first time in a particle accelerator.

2- EXPERIMENTAL SET UP

The LEP-5 experimental apparatus has been designed to detect and analyse the single bremsstrahlung photons from the interaction point 1 (IP-1) of LEP. It consists essentially of a low-Z absorber (2 meters of LiH) to stop the synchrotron radiation background and of an e.m. calorimeter made of lead and scintillating fibres. This set-up is able to measure the energy K of the single bremsstrahlung photons with an overall resolution of $40\%/\sqrt{K}$, and their space distribution with an accuracy of the order of 1 mm. The high energy photons emitted at an angle of the order of $1/\gamma$, travel along the straight section almost in the direction of the positron bunch (Fig.1), and escape from the ring through a window of $2 \times 5 \text{ cm}^2$ area. The detector is positioned at about 50 m downstream the window.

The main features of the calorimeter can be summarized as follows.

It consists of 42 modules of $2.5 \times 2.5 \text{ cm}^2$ cross section and 35 cm long. Each module is made of lead and scintillating fibres of 1 mm diameter, parallel to the module axis, which is oriented almost parallel to the incident photons. Each module contains 144 fibres tight in a bundle and connected to a PMT through a light pipe. In order to improve the space resolution in the central region the fibres of the six central modules are separated in 4 bundles of 36 fibres each, connected to four PMTs by light pipes. The total number of read-out channels is therefore 60.

Details on the performances of this calorimeter and the calibration procedure, can be found elsewhere [3].

3- DATA TAKING AND EXPERIMENTAL RESULTS

The data taking aiming to measure thermal photons, was performed when the bunches were circulating in LEP without crossing in IP-1. A gate signal allowed to read-out signals from the calorimeter in synchronism with the positron bunch passing along the straight section 1.

In such a condition we were able to detect photons of the beam-gas bremsstrahlung and the Compton scattered thermal photons (TP) at the frequency of few tens of Hz. The average total energy E (in GeV per gate) deposited in the calorimeter at each bunch passage as a function of the positron current I^+ is shown in Fig.2. It can be

seen that the data are well fitted by a parabolic curve of the type $E = a(I^+)^2 + bI^+$. This behaviour can be easily obtained by considering that $E = E_{BGB} + E_{TP}$, where $E_{BGB} = nI^+$ is the BGB energy per gate and $E_{TP} = cI^+$ is the TP energy per gate; $n = fI^+ + g$ is the density of the residual gas, proportional to the synchrotron radiation hence to the circulating positron current I^+ ; a, b, c, f and g are constants.

From our data the photon energy spectrum can be obtained and the contribution of the thermal photons can eventually be single out.

In order to compare the experimental spectrum with the expected one, a complete Monte Carlo simulation has been carried out.

The TP theoretical energy distribution has been evaluated as follows. The basic expression of the laboratory energy K of the Compton scattered thermal photons is given by [4]:

$$K = \frac{\gamma^2 K' (1 - \beta \cos \psi) [1 + \beta (\cos \theta \cos \zeta + \sin \theta \cos \phi \sin \zeta)]}{1 + \gamma K' / m (1 - \beta \cos \psi) (1 - \cos \theta)}$$

where γ and β (positron velocity) are related to the positron beam; K' is the energy in the laboratory system of the photon before scattering; ψ and ζ are the incidence angles in the laboratory system and the e^+ rest frame system respectively; θ and ϕ are the polar and azimuthal scattering angles in the e^+ rest frame. The photon energy distribution in the laboratory system was obtained taking into account the Compton differential cross section, the TP Planck distribution, and averaging over all the angles.

The BGB spectrum has been evaluated using the cross section given in Ref.5, and assuming CO molecules as residual gas. The energy resolution of the experimental apparatus has been taken into account.

The spectrum of the energy per gate has been reproduced in terms of three parameters: μ_{BGB} (average number of BGB photons per gate), μ_{TP} (average number of TP per gate) and E_{th} (calorimeter energy threshold, assumed to be sharp).

The best agreement to the spectrum is obtained for the following values: $\mu_{BGB} = 0.44$, $\mu_{TP} = 1.47$ and $E_{th} = 200$ MeV.

The values of μ_{BGB} and μ_{TP} depend on E_{th} and on our geometrical acceptance, which is around 0.7.

With these values we can compute P (residual pressure in the pipe) and T (pipe temperature). They turn out to be $P \approx 2.2 \times 10^{-10}$ torr and $T \approx 291^\circ\text{K}$.

In Fig.3 the experimental spectrum is shown with data taken at beam currents I^+ in the range 1.0-1.7 mA. Data are compared with the Monte Carlo simulated BGB and BGB+TP energy spectra. The long tail at energies higher than 46 GeV is due not only to our resolution but mainly to the fact that more than one photon ($\mu = \mu_{\text{BGB}} + \mu_{\text{TP}} \approx 1.9$) is in the average detected for each bunch.

The same results are presented in Fig.4 in an expanded energy scale up to 20 GeV and by using a linear scale. A remarkable agreement is seen, except at photon energy lower than 1 GeV. This low energy effect is understandable as a loss of detection efficiency in the absorber+calorimeter system, which is approximated only by a sharp threshold cut.

4 - CONCLUSIONS

A clear evidence of Compton back-scattering of the thermal photons by the positron beam has been found at LEP for the first time in a particle accelerator. This is mainly due to the very low pressure existing in the vacuum pipe. The LEP-5 experiment has detected this effect in the straight section 1, during the 1990 run by operating in separate beams condition. The photon energy spectrum measured with the LEP-5 apparatus turns out to be in quite good agreement with the theoretical prediction.

The back-scattering of the thermal photons could in principle decrease the lifetime of the stored beams. However this reduction is too small to degrade significantly the LEP performance.

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FIGURE CAPTIONS

- 1 - A sketch of the LEP half straight-section from IP-1 to the LEP-5 detector.
- 2 - The average total energy per gate E deposited in the calorimeter as a function of the positrons current I^+ in LEP fill 409. Data were collected in "separate beams" condition.
- 3 - The number of gates (dN/dE) with total energy E is plotted versus E (0.5 GeV binning). The experimental data (histogram) were taken at I^+ values between 1.0 and 1.7 mA (see also Fig.2). They are compared to the Monte Carlo simulation of beam-gas bremsstrahlung (black circles) and beam-gas bremsstrahlung plus Compton scattered thermal photons (crosses).
- 4 - The same results of Fig.3 are shown in an expanded scale (up to 20 GeV). The energy spectrum dN/dE is plotted in a linear scale with a 0.1 GeV binning (same symbols as in Fig.3).

Fig. 1

Fig. 2

Fig. 3

Fig. 4