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**PRELIMINARY ANALYSIS OF THE PERFORMANCE OF A RICH COUNTER
FOR LOW- p_T ELECTRON IDENTIFICATION AT THE CERN $p\bar{p}$ COLLIDER**

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ABSTRACT

A ring-imaging Cherenkov (RICH) counter with a 60 cm long freon (C_2F_6) gas radiator has been used inside the UA2 detector at the CERN SPS $p\bar{p}$ Collider, the aim being to measure the amount of promptly produced electrons in the p_T region 1–3 GeV/c. About 800,000 events were recorded and the analysis is in progress. Results from a first analysis of a limited event-sample indicate that it will be possible to reach an e/π rejection power of at least 10^{-4} with the RICH counter.

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1. INTRODUCTION

The yield of prompt electrons in hadron-hadron collisions in the transverse momentum (p_T) region of one to several GeV/c has been extensively measured at ISR energies [1]. The magnitude of the measured yield is compatible with the origin of the prompt electrons being predominantly due to heavy-quark production. This fact is illustrated in Fig. 1, which shows results from measurements of the ratio of prompt electrons to charged pions as a function of p_T obtained in five different ISR experiments. The data are compared with the electron yields expected from different sources, including charm and beauty decays.

Here we report on an experiment designed to measure the prompt-electron yield at SPS $p\bar{p}$ energies in the p_T region 1–3 GeV/c. For the identification of the electrons we have used a gaseous-radiator ring-imaging Cherenkov (RICH) counter [2], developed by us. This is the first time that a RICH counter has been used in a collider experiment. The main data-taking run was carried out in November–December 1985, and the data analysis is in progress. In the present paper we give a short description of the experimental apparatus and a preliminary report on its performance, evaluated through a first analysis of a limited sample of the collected data.

2. EXPERIMENTAL SET-UP

The measurements were carried out using, in conjunction, the RICH counter and the UA2 detector [3] at the CERN $p\bar{p}$ Collider. Figure 2 shows a cross-section of the experimental layout, with the RICH counter installed in one of the 12 azimuthal sectors of the proton downstream end-cap in UA2. The outgoing line in the figure illustrates the trajectory of an electron produced at the beam collision centre. The electron traverses, in succession, a cylindrical vertex chamber (drift chambers and MWPCs), a silicon (Si) semiconductor array and two scintillator hodoscopes for dE/dx measurements, a toroidal magnetic field, the RICH counter, three planar drift chambers (three coordinates measured in each chamber), a lead converter, a MWPC (tubes), and finally hits an electromagnetic calorimeter.

A closer view of the RICH counter is shown in Fig. 3, which also illustrates how the photons radiated by the traversing electron are reflected from the spherical mirror to form a ring-image just behind the window of the TPC-type single-photon position detector. The radiator volume between the photon detector and the mirror is filled with a freon gas, C_2F_6 , at atmospheric pressure. The contamination of oxygen and water in this gas was continuously monitored and was found to be at most 20 ppm O_2 and 5 ppm H_2O . The refractive index of the radiator is $n = 1.0008$ in the VUV region, implying a π threshold momentum of 3.5 GeV/c and a Cherenkov angle of 40 mrad for fully relativistic particles. The spherical mirror, which has a radius of curvature of 1.2 m, is fabricated from 3 mm thick slumped and polished glass; this glass is coated, by vacuum evaporation, with 80 nm Al and 35 nm MgF_2 . The detector window is made of 5 mm thick CaF_2 . The TPC volume behind the window is 4 cm deep, and is filled with CH_4 containing an admixture of 0.6% TMAE $\{C_2[N(CH_3)_2]_4\}$.

Pure C_2F_6 , CaF_2 , and CH_4 are all transparent up to photon energies of 8.6 eV (cut-off set by CH_4), and the photoionization threshold of TMAE is at 5.4 eV. The counter is thus designed to be sensitive for photons in the range 5.4–8.6 eV, corresponding to the wavelength region 145–230 nm.

The essential features of the TPC single-photon position detector are illustrated in Fig. 4a. The UV photons enter through the 20×20 cm² CaF_2 window and ionize TMAE molecules in the detector gas (photon mean free path about 12 mm). Owing to an electric gradient of about 0.5 kV/cm generated in the TPC volume by a surrounding field-wire cage, the liberated photoelectrons drift parallel to the window, with a speed of about 9.2 cm/ μ s, up to a MWPC.

Figure 4b shows a schematic picture of the MWPC in two projections. The anode wires, which are directed perpendicularly to the CaF_2 , are surrounded by tubular cathodes that have 0.5 mm wide slits through which the electrons drift, guided by potential wires positioned on both sides of a slit. There are 80 anode wires of 20 μm diameter, mounted at 2.54 mm pitch. The block of tubular cathodes is sliced up into eight separate bars, each 5 mm wide, which are directed perpendicularly to the anode wires. Both the anode wires and the cathode bars are connected to a readout chain comprising a sensitive preamplifier (Philips NE 592 D) mounted directly on the MWPC, an amplifying-discriminating circuit, and a time-to-digital converter (CERN Drift Time Recorder). The two coordinates in the window plane, of the point at which the photoionization occurs, are obtained from the anode-wire address and from the measured drift time, respectively. The third coordinate is obtained from the cathode-bar address and is associated with the corresponding anode-wire coordinate by requiring the drift times on the anode and the cathode to be equal.

3. PERFORMANCE REQUIREMENTS

As the e/π ratio at SPS $p\bar{p}$ Collider energies might very well be as low as 10^{-4} (see Fig. 1), we need to achieve an e/π rejection power of the RICH counter such that the probability of mistaking a pion for an electron is less than 10^{-4} . As the absence of a signal in the RICH counter could only lead to an electron being mistaken for a pion, the requirement for the efficiency of the counter is a less critical parameter.

Most electrons detected by the RICH counter are not produced from the decay of heavy flavours but from conversion of π^0 -decay gammas or from Dalitz decay. Such electrons appear in electron-positron pairs, and will be suppressed in the off-line analysis using the dE/dx signals from the two scintillator hodoscopes and from the Si counter array upstream of the magnetic field, as well as by the observation of no hits in the first planes of the vertex detector and the detection of coplanar tracks in the drift chambers downstream from the magnetic field.

4. FIRST ANALYSIS OF A LIMITED DATA SAMPLE

Of the order of 800,000 events were collected with the UA2 RICH set-up using a trigger that required signals in both scintillator hodoscopes and in the RICH counter, and at least 1 GeV transverse energy deposited in the electromagnetic calorimeter. All signals from the RICH counter and from the whole of the UA2 detector were recorded for each event. A preliminary analysis of a limited event-sample has been performed as follows.

For each event the signals in the UA2 drift chambers were used to reconstruct the charged-particle trajectories going through the RICH counter. If any such trajectory was found to traverse the $20 \times 20 \text{ cm}^2$ active area of the RICH photon detector, all hits registered by this detector within an area of $8 \times 5.5 \text{ cm}^2$ around the track were considered as being caused by the charged-particle ionization in the photon detector gas. Such hits were disregarded in the subsequent analysis.

4.1 Cherenkov angular resolution

From the information on the direction of the charged-particle track through the RICH counter, an expected Cherenkov-ring centre was reconstructed in the photon detector image-plane. For each hit recorded in the photon detector, the distance r of the hit from the expected image centre was calculated.

A histogram of this distance r for about 12,000 tracks is shown in Fig. 5a. There is a broad (FWHM = 17 mm) peak at $r = 24 \text{ mm}$, corresponding to a Cherenkov angle of $\theta = 40 \text{ mrad}$

($\theta = r/f$; f = focal length of the mirror = 600 mm) as expected for electrons. This peak is caused by the relatively abundant conversion electrons, which were enhanced in the data by the trigger condition used. The detectors upstream of the RICH counter represent about 10% of a radiation length, and the amount of charged pions with momentum above the threshold of 3.5 GeV/c, i.e. above $p_T = 1.75$ GeV/c at 30° to the beam, is therefore negligible compared with the amount of conversion electrons.

The photon detector sits in the fringe field of the UA2 toroidal magnet, and the drift paths of the conversion electrons in the TPC are therefore distorted with regard to the electric drift-field, resulting, to first order, in a displacement of the Cherenkov ring by approximately 1 cm. Without including any information on the magnetic field, a first-order correction to this displacement was made in the following way. All hits in the photon detector within 5 to 40 mm distance from the expected image centre were used to fit a circle. The r -distribution was then replotted using, as the predicted image centre, the centre of the fitted circle. The resulting r -distribution, displayed in Fig. 5b, shows that the peak is still at 24 mm radius but is of significantly smaller width (FWHM = 8 mm). The distribution of radii from the circle fits is displayed in Fig. 6, showing a peak at 24 mm of 6 mm FWHM. However, a further decrease in this width can be expected, as a number of corrections still remain to be introduced in the analysis. These corrections include a precise alignment of all detectors, a detailed evaluation of distortions due to the magnetic field, using a measured field map, and compensation of parallax effect in the photon detector using the measured depth coordinate of the point at which the photoionization occurred.

4.2 Efficiency

For each circle-fit centre, the number N of hits inside a range $18 < r < 27$ mm was counted. Figure 7 shows a frequency distribution for N with normalized Poisson curves superimposed. The curve with a mean value of 4.5 seems to represent the data best. With a radiator length of 60 cm and a Cherenkov angle of $\theta = 40$ mrad, this implies an N_0 value of

$$N_0 = N/L \sin^2 \theta = 47 \text{ cm}^{-1}.$$

In view of the large wavelength region, 145–230 nm, over which the photon detector is expected to be sensitive, this N_0 value is lower than anticipated. It is also lower than N_0 values obtained in earlier measurements made in a test beam with the same RICH counter. One possible reason for the low N_0 value is that the surface of either the mirror or the window may have been contaminated, thereby reducing the wavelength region of detector sensitivity. In future we intend to verify this point by measuring the mirror reflectivity and the window transparency in the VUV, using a monochromator.

For an event sample having a Poisson-distributed hit frequency with a mean of 4.5, the probability of having two hits or less is 18%. Consequently, if three hits or more will be needed for reliable identification of an electron, this will imply a contribution of 18% to the detection inefficiency.

The above analysis was repeated for a sample of double tracks, which had been selected as being due to conversion electrons on the basis of the pulse-height information in the scintillator hodoscope and the criteria of track coplanarity downstream from the magnetic field. Because of this preselection, the statistics of this sample was greatly reduced. The results of the analysis of the preselected conversion-electron sample were, however, compatible with the results obtained with the non-preselected sample. In Fig. 8 are shown the accumulated photon-detector images in the window plane from 100 selected conversion-electrons. Each image has been shifted so that the expected image-centre falls on the mid-point of the plot.

4.3 Electron-to-pion rejection

A pion with momentum below threshold ($< 3.5 \text{ GeV}/c$) can be wrongly identified as an electron if background signals appear within the fiducial ring-area, around the expected image centre defined by the pion track.

It was observed in the data that a limited fraction of the events contained several random noise signals spread over the whole photon-detector area. The origin of this kind of background is not fully understood. However, in order to identify these disturbed events a check was made to see if all detected hits in an event could be assigned to either a charged particle or to a Cherenkov ring. If more than two hits were found unassigned, the event was rejected. This removed on the average 15% of the events.

In order to determine to what extent, in the remaining event sample, other spurious background signals could lead to a pion being wrongly identified as an electron, a large number of faked ‘image centres’ were Monte-Carlo-generated in real data, and fiducial ring-areas were constructed around these generated centres. Cherenkov photon signals originating from other tracks were excluded by disregarding all signals in overlapping fiducial areas. If three or more spurious background signals were found inside the remaining fiducial area, a circle-fit was performed. A fit radius inside $15 < r < 30 \text{ mm}$ was found in about one 1 out of 10,000 generated events, indicating, already at this preliminary stage of the data analysis, that an e/π rejection of the order 10^{-4} is achievable with the RICH counter.

5. SUMMARY AND OUTLOOK

We have reported on some indicative results obtained from a first analysis of a limited data sample. The results are: i) with the RICH counter the electron Cherenkov ring can be clearly observed with the expected ring radius of 24 mm and with a width not larger than 6 mm; ii) the N_0 of the RICH is found to be of the order of 47 cm^{-1} ; and iii) the e/π rejection of the RICH obtained so far is of the order of 10^{-4} . There are several additional steps to be taken in the analysis (alignment of detectors, use of magnetic field-map data, involvement of depth coordinate readout), from which a significant improvement in the Cherenkov angular resolution—and therefore in the rejection—can be expected. Measurements of the VUV transparency of the window and the VUV reflectivity of the mirror will be done in order to seek an explanation for the unexpectedly low N_0 value found. We are also planning to verify, by direct measurement, the e/π rejection of the RICH at very high statistics in a π^- beam from the CERN PS by independent identification of the π using two threshold Cherenkov counters, of about 5 m length each, in the incident beam.

From the results obtained we conclude that the goal of our experiment, which is to measure the e/π ratio at SPS $p\bar{p}$ energies, should be within reach.

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Figure captions

- Fig. 1 : Data on prompt electron production, normalized to the π yield, from five different ISR experiments (see Ref. 1). The curves represent estimates of the contribution of different sources to the prompt electron yield.
- Fig. 2 : Layout of the UA2 experiment at the CERN $p\bar{p}$ Collider showing the position of the RICH counter.
- Fig. 3 : a) Cross-section of the RICH counter in UA2 showing the photon detector, the spherical mirror, and the radiator-gas container.
b) A cross-section of the RICH aperture as viewed from the $p\bar{p}$ collision point with four photon hits indicated.
- Fig. 4 : a) Schematic drawing of the single-photon position detector showing the $200 \times 200 \text{ mm}^2$ CaF_2 window, the 40 mm deep photoionization and electron-drift volume, and the MWPC with the direction of the anode wires and cathode bars indicated.
b) Drawing of the structure of the MWPC in two projections.
- Fig. 5 : Plot of the distance r of a photon-detector hit from the expected image centre for 12,000 tracks. In Fig. 5a the image centre has been reconstructed, for each track, from the optics of the RICH counter, using the measurement of the particle direction in the external drift chambers. In Fig. 5b the image centre has been reconstructed as the centre obtained from a circle fit to the photon-detector hits inside the range $5 < r < 40$ in Fig. 5a.
- Fig. 6 : Distribution of circle radii R obtained from circle fits to the photon-detector hits inside the range $5 < r < 40$ mm in Fig. 5a for each track.
- Fig. 7 : Frequency distribution of photon-detector hits per fitted Cherenkov ring. The fit includes hits inside the range $18 < r < 27$ mm (see Fig. 5b) and excludes tracks with less than three photon-detector hits. The three dashed curves correspond to Poisson curves with mean values of 4, 4.5, and 5, respectively. All distributions are normalized so that the total number of events = 100%. Some representative error bars are shown.
- Fig. 8 : Accumulated x-y plot of photon-detector hits from 100 conversion-electrons. For each image the expected image-centre has been moved to the centre of the plot. Note the difference in scale of the two axes.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8