**PRODUCTION OF PROMPT POSITRONS
AT LOW TRANSVERSE MOMENTUM IN 63 GeV pp COLLISIONS
AT THE CERN INTERSECTING STORAGE RINGS**

(The Axial Field Spectrometer Collaboration)

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ABSTRACT

The production of inclusive prompt positrons in pp collisions at $\sqrt{s} = 63$ GeV and $\theta_{\text{cm}} = 90^\circ$ has been measured over the p_T interval $0.08 < p_T < 1.0$ GeV/c. The e/π ratio rises from $\sim 2 \times 10^{-4}$ at $p_T = 0.9$ GeV/c to $\sim 1.2 \times 10^{-3}$ at $p_T = 0.1$ GeV/c. This is a factor of 6 higher than would be expected from the sum of hadronic bremsstrahlung and the semileptonic decay of charm.

1. INTRODUCTION

Inclusive lepton production in hadron-hadron collisions has been investigated extensively over the past decade. Following the initial observations of lepton-to-pion ratios at the level of $\sim 10^{-4}$ for large p_T at Serpukhov, Fermilab, and the CERN Intersecting Storage Rings (ISR) [1], subsequent studies [2,3] have been only partially successful in elucidating all contributions to the measured yields. For transverse momenta $p_T > 2$ GeV/c, the strongest contributions are due to lepton pairs from the decay of the J/ψ and from the Drell-Yan continuum. In the intermediate regime $0.5 < p_T < 2$ GeV/c the semileptonic decay of charmed particles (mostly D) presents a dominant source of single leptons, although large uncertainties still exist in the absolute charm cross-sections [3]. For p_T below 1 GeV/c down to 0.25 GeV/c, a rise in the e/π ratio with decreasing p_T has been reported in measurements from $\sqrt{s} = 4.5$ to 63 GeV [4]. Experimentally, the subject has remained somewhat controversial [5]. The interpretation of e/π values of up to 4×10^{-4} in this region is also still open, the alternatives being: charm decay [4c]; a dilepton continuum with masses $m < 0.6$ GeV/c², i.e. below the ρ^0 and ω as observed in $\mu^+\mu^-$ [6] and e^+e^- experiments [7] (in itself ill-understood); and, to some extent, internal conversion of bremsstrahlung radiated by charged hadrons [8]. It should be stressed that contributions from low-mass electron pairs (< 0.1 MeV/c²) and higher-mass Dalitz decays are eliminated or subtracted from the data.

In view of this situation, we have remeasured the e/π ratio in pp collisions at $\sqrt{s} = 63$ GeV and followed it down to values of p_T lower than previously achieved. Since the ratio depends crucially on the proper background elimination just mentioned, we have also performed an extensive Monte Carlo simulation of the known sources and checked for consistency via a simultaneous measurement of low-mass e^+e^- pairs. We not only confirm the rise in e/π , but find that it continues to a level of 1.2×10^{-3} at $p_T = 0.1$ GeV/c. At $p_T > 0.25$ GeV/c the results agree with previous experiments. The strong rise observed definitely rules out explanations in terms of semileptonic charm decays, other known hadronic decays, and hadronic bremsstrahlung. It may be related to the anomalous dilepton continuum [6,7], although a quantitative allowance remains to be verified.

2. APPARATUS

The experiment was performed at the Axial Field Spectrometer (AFS) [9] at the CERN ISR. For this study, the spectrometer was reconfigured as shown in fig. 1. To obtain efficient electron identification already at the trigger level, two gas Cherenkov counters, filled with CO₂ at atmospheric pressure, were added at $\theta_{cm} = 90^\circ$ in front of the segmented NaI-crystal wall. To allow for time-of-flight (TOF) identification, and in order to reduce the pile-up in the Cherenkov detector, the wall was moved back to a distance of 5 m from the intersection. Two scintillation counters positioned behind the Cherenkovs were used to define the π and e triggers. For the π triggers, a hit in the scintillators was used as a pretrigger for the spectrometer, whilst for the electrons an additional requirement of a signal in the corresponding Cherenkov counter was added. The final spectrometer trigger was defined as a coincidence between the pretrigger and the event time. The event time was defined by the beam-beam counters positioned around the beam pipes in front of the spectrometer, or by the inner hodoscope counters which surrounded the intersection region.

A high rejection efficiency of low-mass pairs from γ conversions and Dalitz decays was achieved by lowering the AFS magnetic field to 0.1 T. The charged tracks were recorded by the central vertex detector, a cylindrical drift chamber 1.40 m long with azimuthal segmentation of 4° sectors. Owing to the low magnetic field, the drift chamber was able to detect electrons accompanying the triggering track with momenta as low as 2 MeV/c. This was essential in the recognition of γ conversions.

This set-up was used in a single ISR run yielding an integrated luminosity of $3.9 \times 10^{34} \text{ cm}^{-2}$. About 850,000 events were recorded, mostly from Dalitz decays and photons converting in the beam pipe, the inner hodoscope, or the drift chamber walls. The material between the vertex and the drift chamber corresponded to 4.5% of a radiation length. Only events triggered by positrons were used in the e/π measurement owing to a large background from Compton scattering in the electron sample.

Because of the angular acceptance of the scintillator and Cherenkov detectors in the bending direction, the sensitivity of the experiment was limited to electrons or positrons in the p_T range above 0.07 GeV/c. The geometrical acceptance of each Cherenkov detector was about 6 msr.

3. DATA REDUCTION

The events were processed through the AFS track-finding and track-and-vertex-fitting programs. The reconstructed tracks were extrapolated, using the magnetic field, to the Cherenkov detectors and to the NaI-crystal and uranium calorimeter walls. Events with only one positive track extrapolating to the scintillation counters were selected for further analysis. At this stage, the events were processed through the shower reconstruction programs of the NaI detector. The triggering track was identified by matching both the coordinates measured with the plastic scintillator and the ones measured by the NaI detector with the extrapolated track position. This requirement removed a large fraction of accidental overlaps between pions and electrons from γ conversions. Identical requirements were imposed on the e and π triggers at this stage of the analysis.

The off-line rejection of pions in the electron sample is summarized in fig. 2. Pions were rejected by the Cherenkov pulse height and timing requirements, by the dE/dx measured in the drift chamber, by the time-of-flight obtained using the scintillators, and by measuring the energy deposited in the NaI. The requirements that the signal from the Cherenkov detectors should have a pulse height of > 2 photoelectrons and should occur within a certain time-window, made it possible to obtain a pion rejection factor of > 1000 from the Cherenkov alone. The combined probability of misidentifying a pion as an electron was measured to be less than 2×10^{-5} , whilst the detection efficiency was 75% over the whole p_T range studied.

To reject γ conversions and low-mass Dalitz decays, all the available information in the drift chamber was used. It consisted of identifying low-mass pairs using reconstructed tracks, of measuring dE/dx in order to recognize doubly ionizing pairs, and of using drift chamber hits which were not assigned to any reconstructed track. The invariant e^+e^- mass distribution in fig. 3a was calculated by combining the positive trigger track with all other reconstructed tracks of negative charge. In order to be able to make a comparison with other experiments, a mass cut of $m \geq 0.1 \text{ GeV}/c^2$ was imposed on unlike-sign pairs. Figure 3b gives the dE/dx distribution for this sample. Doubly ionizing events are clearly seen; visual inspection showed them to be mainly very close pairs undetected by the track recognition program. These pairs were removed by the dE/dx cut. Very asymmetric γ conversions, in which the second electron had a p_T less than $\sim 10 \text{ MeV}/c$ and consequently was not found by the track recognition program, were found and removed by counting the number of drift chamber hits which were not assigned to any track. Figure 3c gives the number of unassigned hits close to the trigger track for e and π triggers. A clear difference between the triggers is observed; this is due to unassigned hits originating from conversions. Finally, K_{e3} decays were rejected by requiring the triggering positron to be on the event vertex.

A subsample of the remaining electron events was scanned visually. A very small fraction ($< 2\%$) of the scanned events showed residual hits in the drift chamber which could be recognized as an accompanying low-momentum track. The visual scanning thus assured that the

remaining sample, with all cuts applied, included only a few asymmetric low-mass pairs where the second electron had reached the drift chamber.

4. BACKGROUND CALCULATIONS

The residual background from γ conversions and Dalitz decays was calculated using a drift-chamber Monte Carlo simulation program. The program simulated the π^0 p_T spectrum according to the measured π^+ and π^- spectra [10], assuming $\pi^0 = (\pi^+ + \pi^-)/2$. Isospin-breaking processes such as $\eta \rightarrow \pi^0\pi^0\pi^0$ had to be added separately. Because of the lack of experimental data at low p_T for η , η' , and ω , we assumed m_T scaling [11] with the parent-to- π^0 ratio fixed at high p_T according to experimental results ($\eta/\pi = 0.55$ and $\omega/\pi = \eta'/\pi = 0.9$) [2].

Bearing in mind the relative importance of the η background, we measured the integrated η/π ratio below $p_T = 1.5$ GeV using the decay $\eta \rightarrow \gamma\gamma$, where both γ 's have been converted before the drift chamber. From the (e^+e^-, e^+e^-) invariant mass distribution we obtained $\eta/\pi = -0.06 \pm 0.1$, to be compared with the m_T scaling prediction of $\eta/\pi = 0.14$. A similar result, $\eta/\pi = 0 \pm 0.16$, was obtained in a different data sample measuring $\gamma\gamma$ coincidences directly in the two NaI-crystal arrays of the detector. A total of fifteen different processes contributed to the calculated over-all background: Dalitz decays [12] and γ conversions of π^0 , η , ω , and η' ; the contribution from π 's created in $\eta \rightarrow \pi^0\pi^0\pi^0$ or $\omega \rightarrow \pi^0\gamma$; and finally, K_{e3} decay.

The results from the Monte Carlo were subjected to several tests. The difference between the measured e^-/π and e^+/π ratios was assumed to originate from Compton scattering, and the Monte Carlo prediction of this background agreed with the data within the statistical errors of the measured $(e^- - e^+)/\pi$ distribution. For another test of the Monte Carlo, a direct measurement of e^+e^- pairs was performed. For this study, the electron accompanying the triggering positron was identified by dE/dx for $p_T < 0.1$ GeV/c. The number of pairs with masses between 0.04 and 0.1 GeV/c² agreed with the Monte Carlo prediction of the π^0 Dalitz contribution within the statistical errors of $\pm 10\%$. At masses between 0.1 GeV/c² and 0.4 GeV/c² an excess of pairs was observed above the contribution expected from η Dalitz decay. However, the statistics were limited, and this measurement will be addressed in a subsequent publication when the pair data from later runs have been analysed. The systematic errors in the Monte Carlo calculation (illustrated with a shaded band in fig. 4) were estimated to be 15 to 20%.

5. RESULTS

The measured ratio of the inclusive positron-to-pion cross-section e^+/π at $y = 0$ is plotted in fig. 4. The $\pi \equiv (\pi^+ + \pi^-)/2$ distribution was corrected for lifetime losses and energy losses. Owing to strongly increasing energy losses and decay losses at low p_T , it was not possible to measure the pion yield accurately at $p_T < 0.2$ GeV/c. The three lowest data points in fig. 4 were therefore calculated using a parametrization of the pion spectrum given in ref. [10]; this parametrization showed good agreement with our measurements at $p_T > 0.2$ GeV/c. The e^+ spectrum was corrected for the inefficiency of the mass cut (which was not imposed on the π triggers). The calculated residual background from γ conversions, Dalitz decays, and K_{e3} decays is also included in fig. 4. Clearly, an excess of positrons exists above the systematic uncertainties in the Monte Carlo simulation of the residual background.

Figure 5 shows the e^+/π ratio from this experiment after background subtraction, and the results from other experiments which have measured e/π at higher p_T [13]. In the region of overlap, our results are consistent with other measurements. However, our data extend to lower p_T values than were previously achieved. The continuous rise of the e/π ratio is not only confirmed but is seen to continue to a level of $\sim 1.2 \times 10^{-3}$ at $p_T = 0.1$ GeV/c.

6. DISCUSSION AND CONCLUSIONS

The known sources which could contribute to the measured e/π ratio are also plotted in fig. 5. In the p_T region of 0.5–1 GeV/c, the semileptonic decay of charmed particles, in particular that of the D mesons, is the dominant source of the inclusive lepton yield. Owing to large systematic errors at low p_T in some previous experiments, the reported e/π ratio has been consistent with the expected contribution from open charm. The systematic errors in this experiment and the shape of the charm p_T spectrum now allow us to exclude charm as the dominant part of the low- p_T yield, in spite of the uncertainties in the absolute production cross-section. As seen in fig. 5, the contribution from vector meson decay and heavy quark production as well as Drell-Yan production is negligible at low p_T . One of the expected contributions at $p_T < 0.2$ GeV/c results from bremsstrahlung emitted from charged hadrons produced in the interaction. However, the magnitude of hadronic bremsstrahlung (which can be calculated quite reliably) cannot explain the data. After adding together all the known sources, there still exists an order of magnitude discrepancy between the possible yield from these sources and our measured e/π ratio at low p_T .

A number of experiments have reported observations of an excess of low-mass lepton pairs which cannot be explained by known pair sources, such as Dalitz decays and direct decays of the vector mesons ρ , ω , and ϕ . The first result on such a lepton pair continuum was reported from a $\mu^+\mu^-$ experiment at FNAL [6], followed by several others, both from $\mu^+\mu^-$ and e^+e^- pairs [7]. It is conceivable that such a low-mass dielectron continuum, which so far has not been identified at ISR energies, could account for the observed e/π ratio at low p_T . The production of quark bremsstrahlung or quark-antiquark annihilation could be one explanation of this excess of low-mass lepton pairs [14].

In summary, our data show that after the background from γ conversions and Dalitz decays have been subtracted, a residual signal is observed which rises from $e^+/\pi = 2.2 \times 10^{-4}$ at $p_T = 0.90$ GeV/c to $e^+/\pi = 1.2 \times 10^{-3}$ at $p_T = 0.10$ GeV/c. The strong increase in the e/π ratio below 0.3 GeV/c cannot be explained by the semileptonic decay of charmed particles, other known hadronic decays, or hadron bremsstrahlung. It may, however, be related to the low-mass lepton pair continuum previously seen by other experiments at lower energies.

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Figure captions

- Fig. 1 : The arrangement of the AFS spectrometer during this experiment. The time of flight was measured using the inner hodoscope and the scintillation counters.
- Fig. 2 : The probability of misidentifying a pion as an electron using different methods of identifying electrons. The curve for the Cherenkov detector is an upper limit. The dashed line gives the combined hadron rejection.
- Fig. 3 : a) The invariant mass distribution, combining the trigger track with all other reconstructed tracks of opposite and same charge in the drift chamber. b) The dE/dx distribution for positrons. c) The fraction of events as a function of the number of unassigned hits close to the trigger track.
- Fig. 4 : The measured e^+/π^0 ratio and the calculated residual background. The shaded band shows the systematic error in the MC calculation.
- A : $\pi^0 \gamma$ conversions
B : π^0 Dalitz decay
C : $\eta \gamma$ conversions
D : η Dalitz decay
E : $\eta \rightarrow \pi^0 \pi^0 \pi^0$ sum of Dalitz decay + γ conversions
F : η' sum of Dalitz decay + γ conversions
G : ω sum of Dalitz decay + γ conversions
H : K_{e3} decay
- Fig. 5 : The residual e/π ratio, after the background in fig. 4 was subtracted, together with the results from other experiments which have measured the e/π ratio at the ISR [13]. Both statistical and systematic errors are given for this experiment.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5