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A SEARCH FOR PROMPT PRODUCTION OF ELECTRONS

IN PROTON-Pt COLLISIONS AT 19 GeV/c

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ABSTRACT

Production of positrons in p-Pt collisions at 19 GeV/c has been observed in a previously reported experiment, performed to measure the mean life of the neutral pion, at $p_T = 0.54$ GeV/c, $x = 0.26$ and $\theta_{cm} = 73^\circ$; however, unlike to similar measurements at higher energies, 30 to 1500 GeV/c, the observed effects is demonstrated to be due to $K \rightarrow \pi e \nu$ decay and π^0 Dalitz decay. After subtraction a ratio $e^+/\pi^+ = -(0.2 \pm 0.29) \cdot 10^{-4}$ is obtained. This first observation of energy dependence of the e/π ratio is discussed.

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In a counter experiment¹ performed in 1962 to measure the mean life of neutral pions, evidence has been reported for production of prompt electrons in an internal target of the CERN Proton Synchrotron, exceeding the known coefficient of internal conversion (Dalitz-pairs) in π^0 decay. While an overall internal conversion coefficient for prompt electrons was determined, its excess over the well-known Dalitz-pair probability in π^0 decay was not taken as evidence for a new process, and the ratio of prompt electron to pion production was not calculated.

There is now considerable evidence²⁻⁶ for prompt lepton production in proton-nucleon collisions at high energies, 30-1500 GeV. It is observed that the lepton to pion ratio is 10^{-4} , nearly independent of transverse momentum in the range of $p_T = 2$ to 4 GeV/c and of the incident proton momentum in the range 300 to 1500 GeV/c. Recently, similar e/π ratios obtained at 28.5 GeV and $p_T = 0$ ⁷ and at $p_T = 1-2$ GeV⁸ have been reported.

It is the purpose of this note to call attention to our previous result, to calculate the electron to pion ratio, and to compare the value we obtain at low incident momentum (19 GeV/c) and small transverse momentum ($p_T = 0.54$ GeV/c) with the complementary high energy, large transverse momentum data.

The experiment was conducted, as described in reference 1, by exposing platinum foils of 3-60 micron thickness to the 19 GeV/c internal proton beam of the CERN Proton Synchrotron and measuring the production of positrons relative to other particles in a secondary beam of 5 GeV/c at an angle of 107 mrad.

Particles, and among them neutral pions, are produced uniformly throughout the depth of the target foil. Neutral pions have a mean decay length λ . For a foil of thickness t the probability per decay γ -ray to produce an e^+e^- pair in the foil is

$$(1) \quad P(\lambda, t) = D + \frac{1}{X_p} \left[\frac{1}{2} t - \lambda + \frac{\lambda^2}{t} (1 - e^{-t/\lambda}) \right]$$

where D is the internal conversion probability per γ -ray

$$D = (0.583 \pm 0.023) \cdot 10^{-2}$$

and X_p is the mean free path for pair production ($X_p = 0.3126$ cm for platinum).

The momentum spectrum of neutral pions, which are effective to produce 5 GeV/c positrons at an angle $\theta = 107$ mrad, is obtained by weighing the π^0 spectrum^{*)} $n_{\pi^0}(p, \theta)$ at the laboratory angle θ with the probability $f(p_e, p)$ that a neutral pion of momentum p produces a positron of $p_e = 5$ GeV/c.

The effective π^0 spectrum is narrow and characterized by an average momentum of $\bar{p}_{\pi^0} = 7.12$ GeV/c; the number of effective γ -rays per positive pion of 5 GeV/c is

$$(2) \quad A = \frac{2}{n_{\pi^+}(p_e, \theta)} \int_{p_e}^{p_{\max}} n_{\pi^0}(p, \theta) f(p_e, p) dp = 0.1289 \pm 0.0038.$$

The analysis of the experiment is much simplified by representing the effective π^0 spectrum at a single π^0 momentum, $\bar{p}_{\pi^0}$ ^{**)} by a flux $A(p_e, \theta)$ of effective γ -rays per π^+ . The measured ratio $R = N(e^+)/N(\pi^+)$ is related to the conversion probability $P(\lambda, t)$ of equation (1) by

$$(3) \quad R(\bar{\lambda}, t) = A[P(\bar{\lambda}, t) - C(t)],$$

where $C(t)$ is a correction term for the degradation of the positron spectrum by bremsstrahlung in the foil (see reference 1 for details).

*) The spectra of neutral and positive pions are assumed to be equal and the latter was measured during the experiment. Comparison of measurements of γ -ray spectra by M. Fidecaro et al¹⁰ and of π^+ spectra by D. Dekkers et al¹¹ support their equality within statistical uncertainties of $\pm 15\%$.

**) The error introduced by this is negligibly small, because

$$|\bar{p}_{\pi^0} - (\bar{p}_{\pi^0}^2)^{1/2}| / \bar{p}_{\pi^0} = 0.02.$$

Measurements with three different foil thicknesses are sufficient to determine the three parameters A , D and $\bar{\lambda}$; as a check for internal consistency (χ^2 test) we have used four platinum foils of accurately determined thicknesses.

Their thicknesses in micron and in units of X_p , and the measured e^+/π^+ ratios are given in table 1 and shown in figure 1.

The measured values are compared to the expected t dependence of equation (3) and an excellent fit is obtained with the following parameters:

$$\begin{aligned} A &= 0.1247 \pm 0.00028 && \text{(number of effective } \gamma\text{-rays per } \pi^+) \\ A.D &= (8.430 \pm 0.050) \cdot 10^{-4} && \text{(ratio of prompt } e^+ \text{ to } \pi^+ \text{ production)} \\ \lambda &= (1.50 \pm 0.25) && \text{(mean decay path of } \pi^0 \text{)***)} \end{aligned}$$

giving a $\chi^2 = 0.6$ for 1 degree of freedom.

In order to demonstrate whether there is an excess of prompt electrons a reliable way of determining the contribution of Dalitz-pairs from internal conversion in π^0 decay is needed. The number of effective γ -rays per π^+ , presumed to originate from π^0 decays, is determined experimentally by the slope of the conversion curve at $t \geq \lambda$. Consequently, the e^+/π^+ ratio due to Dalitz-pairs is monitored internally, with the result

$$\begin{aligned} \left(\frac{e^+}{\pi^+} \right)_{\text{Dalitz}} &= A \cdot (0.583 \pm 0.023) \cdot 10^{-2} = \\ &= (7.270 \pm 0.287) \cdot 10^{-4} . \end{aligned}$$

Comparing this value with the result of the total prompt positron to pion production ratio, we find an excess of

$$\left(\frac{e^+}{\pi^+} \right) = (1.16 \pm 0.29) \cdot 10^{-4} .$$

***) The corresponding π^0 mean life of $\tau = (0.95 \pm 0.16) \cdot 10^{-16}$ s is in excellent agreement with recent experiments¹².

The error is predominantly due to the internal conversion probability⁹.

Are there any known sources of electrons which could account for this excess? A summary of various positron yields which we have considered in detail is given in table 2. We have investigated the contribution of $K^+ \rightarrow \pi^0 e^+ \nu$ and $K_L^0 \rightarrow \pi^- e^+ \nu$ using a realistic Monte Carlo simulation¹³. A lay-out of the beam elements is shown in reference 1. There is a decay path of 15.69 m before the first aperture (quadrupole lens) and another drift space of 8.1 m before momentum selection. The beam accepts a phase space of $\Delta\theta_x \cdot \Delta X = 0.06$ rad. cm, $\Delta\theta_y \cdot \Delta y = 0.052$ rad. cm and a momentum bite of $\left(\frac{\Delta p}{p}\right)_{rms} = \pm 4\%$. As input we have used the K^+ spectrum and K^+/π^+ ratio in proton-Pb collisions at the same energy and angle¹¹. K_L^0 production is assumed¹⁴ to be represented by $\frac{1}{2}[N(K^+) + N(K^-)]$; there is good experimental evidence¹² for the validity of the relation $\Gamma(K_L^0 \rightarrow \pi^- e^+ \nu) = \Gamma(K^+ \rightarrow \pi^0 e^+ \nu)$ (due to $\Delta I = 1/2$) which we have assumed. We find a contribution of

$$\left(\frac{e^+}{\pi^+}\right)_{K_{e3}} = 1.14 \cdot 10^{-4}.$$

The contribution of η Dalitz decay is calculated from the value of

$$\frac{A_{calcul} - A_{meas}}{\bar{A}} = \frac{N(\pi^+) - N(\pi^0)}{N(\bar{\pi})} = 0.033 \pm 0.030,$$

assuming this charge asymmetry is due to $\eta \rightarrow 2\gamma$ decay.

After subtraction of all known positron yields the e/π ratio is compatible with zero,

$$\left(\frac{e^+}{\pi^+}\right)_{prompt} = -(0.2 \pm 0.29) \cdot 10^{-4}.$$

Comparing this result to similar measurements at higher energy and larger transverse momenta²⁻⁴, we have the choice to attribute the variation of the ratio e/π to the lower energy or the lower transverse momentum in this experiment. Figure 2 shows all published values as a function of the available total energy, $Q = \sqrt{s} - 2M_p$, irrespective of p_T . In either case the trend of the data is suggestive of a threshold behaviour of the process in which prompt leptons are produced. Comparison with the results of Leipuner et al.⁷ and S.C.C. Ting⁸ obtained at 28.5 GeV is suggesting a threshold in the range

$$4.0 < Q < 5.5 \text{ GeV} .$$

However, it should be noted that unpublished results of Nurushev et al.⁶ give a μ/π^+ ratio of $2.5 \cdot 10^{-5}$ at $\sqrt{s} = 11.5 \text{ GeV}$.

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target thickness t		$R(t) = N(e^+)/N(\pi^+)$
(microns)	(X_{pair})	(measured) $\times 10^4$
2.855 ± 0.02	$0.9133 \cdot 10^{-3}$	8.612 ± 0.026
4.379 ± 0.02	$1.401 \cdot 10^{-3}$	8.816 ± 0.028
18.326 ± 0.05	$5.862 \cdot 10^{-3}$	10.810 ± 0.017
58.569 ± 0.04	$18.736 \cdot 10^{-2}$	16.816 ± 0.049

TABLE 1

Observed e/π ratios for four target thicknesses

source	$N(e^+)/N(\pi^+)$
measurement at $t=0$	$(8.43 \pm 0.050) \cdot 10^{-4}$
external conversion on obstacles	$8.5 \cdot 10^{-7}$
hadron rejection	$< 10^{-5}$
$\pi^0 \rightarrow e^+e^- + \gamma$	$(7.270 \pm 0.287) \cdot 10^{-4}$
$\eta \rightarrow e^+e^- + \gamma$	$7.2 \cdot 10^{-6}$
$\pi^+ \rightarrow e\nu$	$< 10^{-6}$
$\pi^+ \rightarrow e\nu\bar{\nu}$	$< 10^{-7}$
$K^+ \rightarrow \pi^0 e^+ \nu$	$6.75 \cdot 10^{-5}$
$K_L^0 \rightarrow \pi^- e^+ \nu$	$4.67 \cdot 10^{-5}$
remaining prompt signal	$-(0.2 \pm 0.29) \cdot 10^{-4}$

TABLE 2

Positron yields from various sources,
normalized to the π^+ yield

1. G. von Dardel, D. Dekkers, R. Mermoud, J.D. van Putten, M. Vivargent, G. Weber and K. Winter, Physics Letters 4 (1963) 51.
2. J.P. Boymond et al., Phys. Rev. Letters 33 (1974) 112.
3. J.A. Appel et al., Phys. Rev. Letters 33 (1974) 722.
4. F.W. Büsser et al., Physics Letters 53B (1974) 212.
5. D. Bintinger et al., reported at the XVII International Conference on High Energy Physics, London, 1-10 July 1974, page V-50.
6. S. Nurushev et al., reported at the XVII International Conference on High Energy Physics, London, 1-10 July 1974, page V-53.
7. L.B. Leipuner et al., Phys. Rev. Letters 34 (1975) 103.
We refer here to data at $X = 0.45$.
8. S.C.C. Ting, private communication.
9. N.P. Samios, Phys. Rev. 121 (1961) 275.
10. M. Fidecaro et al., Nuovo Cim. 24 (1962) 73.
11. D. Dekkers et al., Phys. Rev. 137 (1965) 962.
12. Review of particle properties, Physics Letters 50B (1974) 41.
13. DECAY TURTLE, a computer programme for simulating charged particle beam transport systems, by K.L. Brown and Ch. Iselin (CERN Report 74-2) was used.

14. A comparison of K^0 , $\bar{K}^0$ and K^+ , K^- production in 24 GeV/c pN collisions shows good agreement, see e.g. Vera Lüth, NP Internal Report 74-4 (January 1974).

FIGURE CAPTION

Figure 1 - Measured e^+/π^+ ratios as a function of target thickness.

A correction is applied to account for energy loss by
Bremsstrahlung in the foils.

The expected Dalitz-ratio is determined by the asymptotic
slope of the conversion curve.

Figure 2 - Values of the lepton/pion ratio as a function of the
available energy Q . The numbers refer to the reference
list.

Figure 1

Figure 2