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PARTICLE IDENTIFICATION USING THE ANGULAR DISTRIBUTION OF TRANSITION RADIATION

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ABSTRACT

An electronic detector has been built which measures the angle of emission of transition radiation photons, as well as the energy deposit. A significant gain in the efficiency of particle identification is obtained for $\gamma \simeq 10^3$.

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1. INTRODUCTION

The technique of particle identification by transition radiation (TR) is well established for electron-hadron separation for threshold values of about 1.5 GeV, or in terms of the Lorentz factor $\gamma = E/m$, $\gamma \gtrsim 3000$ 1). For the lower values of γ of interest for π/K separation, $\gamma \simeq 1000$, the number of TR photons emerging from the radiator is necessarily smaller, and further improvements in the experimental technique are most desirable. One limitation of the standard technique is that the photon detector is sensitive also to the ionization on the track of the charged particle. If the number of photons is small, the energy of this ionization is comparable to that due to TR photons, and must be separated statistically by using an undesirably large number of successive radiator/detector sets.

In this paper we describe the performance of an electronic detector which separates the track ionization from the ionization due to the photon by detecting the finite angle between the track and the TR photon. Previously, such a measurement has been performed in a streamer chamber 2). It is difficult to use the angular characteristics of transition radiation because the emission angles are very small,

$$\theta \simeq \left[\gamma^{-2} + \left(\frac{\omega_\rho}{\omega}\right)^2\right]^{\frac{1}{2}} ,$$

where $\gamma = E/mc^2$, ω_ρ is the plasma frequency of the gas between the layers of radiator matter, and ω is the frequency of the TR quantum. Multifoil interference effects have been ignored in this formula, but the average effect is less than a factor of 2. For air, with $\omega_\rho \simeq 0.7$ eV and $\omega\hbar = 10$ keV, θ varies as $1/\gamma$ up to $\gamma \simeq 10^4$. In the region of low γ ($\simeq 10^3$), θ is $\simeq 10^{-3}$ rad, and spatial separation between the charged track ionization signal and the TR photon is possible if the distance between radiator and detector is $\simeq 1$ m.

For $\gamma \gtrsim 10^4$ the TR emission angle is very small, and spatial separation dE/dx from TR is in general very difficult. For electrons, however, the multiple scattering in the radiator matter gives a much wider angular distribution,

$$\frac{\theta_{\text{m.scatt.}}}{\theta_{\text{TR}}} = \frac{21 \text{ MeV} \sqrt{x/x_0}}{\rho \cdot \beta} \cdot \frac{E}{m_e c^2} \simeq 40 \sqrt{x/x_0} \simeq 10 ,$$

for $x/x_0 = 0.05$. In this case, for $\gamma \gtrsim 10^{-4}$, spatial resolution of track ionization from TR is also possible for π/e separation.

The use of the additional information from the angle of the TR quanta for particle separation has been demonstrated elsewhere[3]. A scintillation drift chamber with very high space resolution (∿ 20 μm in xenon at a pressure of 10 atm) was used. However, this method is not practical for the construction of large-aperture detectors.

In the present experiment a drift chamber at normal pressure was used for hadron identification at $\gamma \sim 10^3$ and π/e separation at $\gamma \gtrsim 10^4$.

2. EXPERIMENTAL SET-UP

Figure 1 shows the experimental set-up exposed in the hadron beam at the CERN Super Proton Synchrotron (SPS) at the following momenta: 15 GeV/c (∿ 50% π^-, 50% e^-), 40 GeV/c, and 140 GeV/c ($\gtrsim$ 98% π^-). A gas Čerenkov counter (22 m long, with 0.3 atm Xe) and a lead/scintillator shower detector were used for electron separation. A two-layer drift chamber was placed at a distance L from the TR radiator, with a helium-filled tube in the intervening space. The chambers, filled with a gas mixture of 60% Xe + 40% CO_2, had a maximum drift distance of 30 mm. The thickness of each chamber along the beam was 8 mm. The chambers were separated from the radiator by 30 μm mylar windows on the helium tube and the chamber, and by a radiator window of 50 μm of beryllium. The gas mixture, purified by a Cr-Ni catalyser, was continuously circulated through the chamber. The gas pressure in the chamber was maintained with the accuracy of ±1 mm of H_2O as to avoid insensitive zones between the window and the drift wires. The electron drift velocity at 650 V/cm was $1/v = (116 \pm 10)$ ns/mm, and the gas gain was $\sim 10^4$. After amplification, the current signals were analysed by 16 analog-to-digital converters triggered by 16 successive gates of 30 ns each. The total drift time of 16 × 30 = 480 ns allows measurements of the charge in the 4 mm centred transversely on the particle track. By this means the total charge Q and the total pulse width W above a fixed level of the signal amplitude were measured. Two kinds of radiator were used: lithium foils[4] and mylar foils[5]. The parameters of these radiators are shown in Table 1.

3. EXPERIMENTAL RESULTS. PARTICLE IDENTIFICATION

Figure 2 shows the total charge distribution in the first and second chambers for pions and electrons (E = 15 GeV/c, Li-foil radiator). Figure 3 shows the distribution of signal widths for the same case. One can see that the difference between pion and electron distributions for both Q and W spectra in the second chamber is less than in the first one, owing to absorbtion of TR quanta in the gas of the first chamber. We will use below only the data from the first chamber. The distributions of Figs. 2 and 3 are the projections of bidimensional distribution of charge Q and width W, represented in Fig. 4. The same distributions were obtained also for pions at 140 GeV/c and 40 GeV/c. In the last case the value of $\gamma = E/cm^2$ for pions corresponds to that for kaons at 140 GeV/c. We use the data obtained for π (40 GeV/c) to simulate π/K separation at (140 GeV/c).

The comparison of the methods of particle identification using Q only, and Q and W, was carried out for systems consisting of three successive radiator/detector sets for π/e separation at 15 GeV/c and of fifteen sets for π/K separation at 140 GeV/c. A group of 3 (or 15) particles traversing one detector were taken from the experimental data, which should represent one particle traversing 3 (or 15) detectors. The method (Q + W) is based on the identification function distribution, by the maximum likelihood principle:

$$F(Q + W) = \prod \frac{F^{\pi}(Q,W)}{F^{K}(Q,W)} ,$$

where $F^{\pi(K)}(Q,W)$ is the probability that a pion (or K meson) will produce an event with Q and W, and similarly for electron and pion separation. Figures 5 to 7 show that the measurement of signal width gives a five times increase of efficiency to identify π/K and slightly improves the efficiency of π/e separation. The difference in results in the two cases is due to the smaller value of the angle between the particle and TR quantum at $\gamma = 3 \times 10^4$ for 15 GeV e^-.

4. CONCLUSIONS

Joint use of the total energy deposit and of its transverse dimension gives a significant gain in the efficiency of particle identification at $\gamma \simeq 10^3$. However, even in this region, and still more at $\gamma \gtrsim 10^4$, the use of the emission angle of the TR quanta results in increasing the total length and consequently in decreasing the aperture of the TR identifier.

* * *

REFERENCES

1) J. Cobb et al., Nucl. Instrum. Methods 140 (1977) 413.
2) A. Alikhanian et al., Phys. Rev. Lett. 25 (1970) 635.
3) A. Alikhanian, Nucl. Instrum. Methods 158 (1979) 137.
4) J. Fischer et al., Nucl. Instrum. Methods 127 (1975) 525.
5) C. Camps et al., Nucl. Instrum. Methods 131 (1975) 411.

Table 1

Radiator	a (µm)	b (µm)	N	L_r (cm)
Li	30	200	1500	50
Mylar	5	140	1000	70

a = foil thickness; b = gap,
N = number of foils; L_r = length of radiator

Figure captions

Fig. 1 : Experimental set-up. The picture at lower right illustrates the transverse drift method of the detection TR quantum.

Fig. 2 : Total charge spectra for first (a) and second (b) chambers with lithium-foil radiator.

Fig. 3 : The width distribution for first (a) and second (b) chambers.

Fig. 4 : Two-dimensional plot of charge versus width, for beam energy 15 GeV.

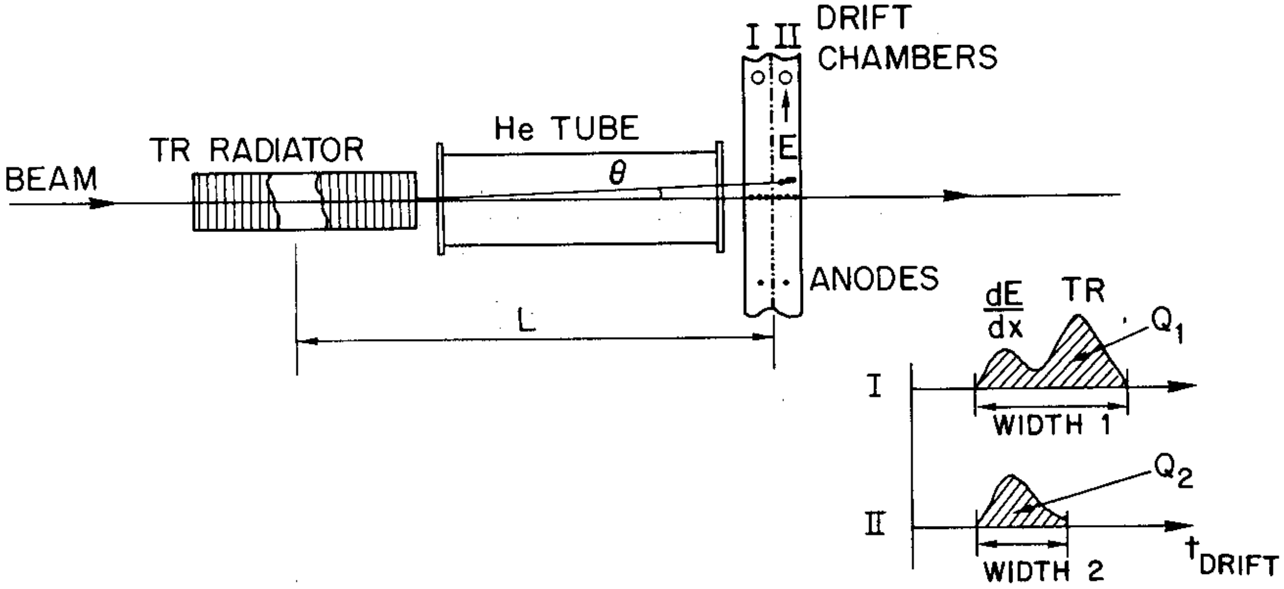
Fig. 5 : Pion-kaon separation by two methods:

a) total energy (charge) measurement, Q;

b) identification function method, Q + W.

Fig. 6 : Pion-kaon separation by two methods (Q, and Q + W).

Fig. 7 : Electron-pion separation by methods Q, and Q + W.



BEAM
TR RADIATOR
He TUBE
θ
I II DRIFT CHAMBERS
E
ANODES
L
dE/dx
TR
Q1
I
WIDTH 1
Q2
II
WIDTH 2
t DRIFT

Fig. 1

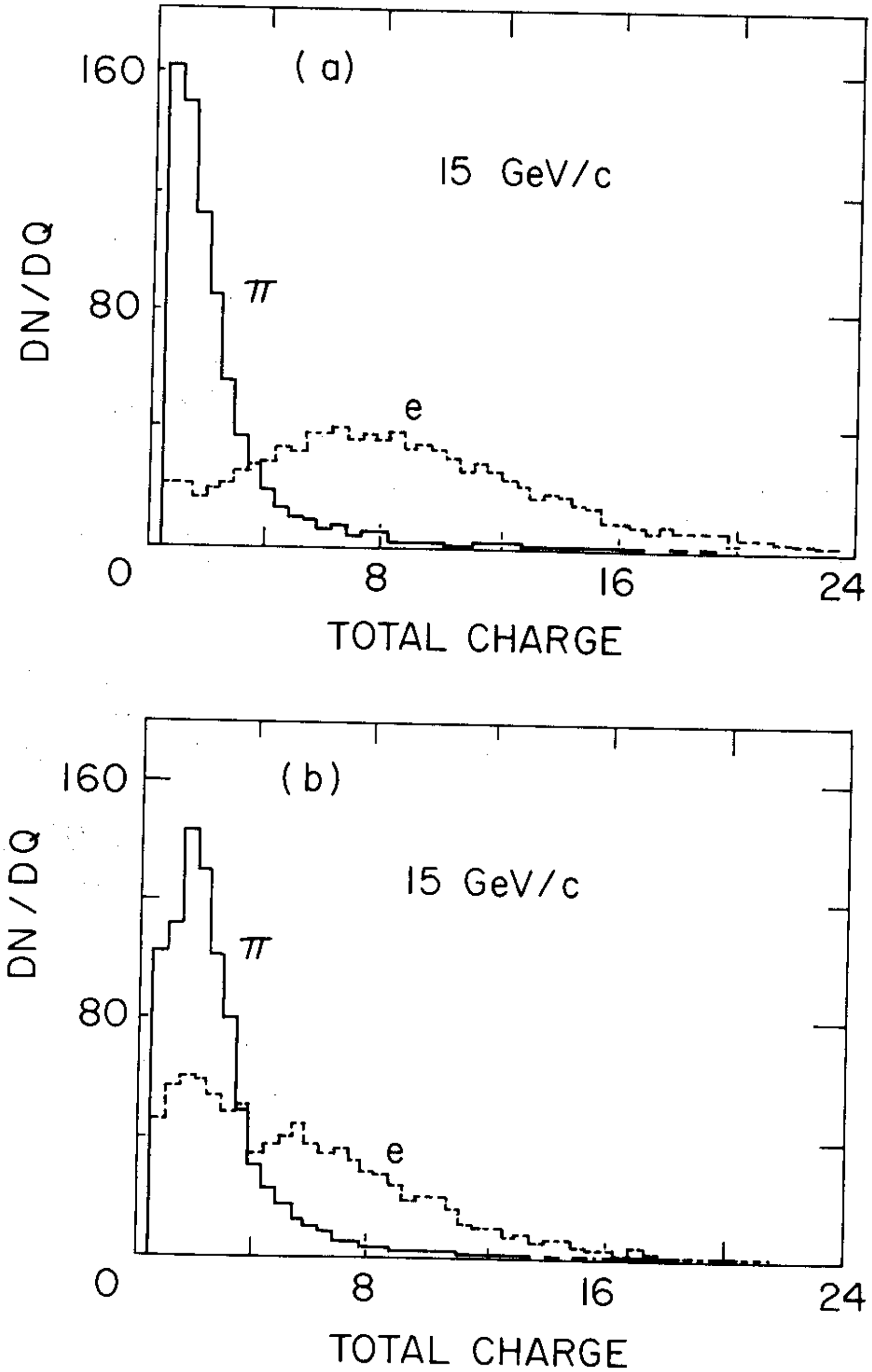

(a)
160
80
0
DN/DQ
15 GeV/c
π
e
8
16
24
TOTAL CHARGE
(b)
160
80
0
DN/DQ
15 GeV/c
π
e
8
16
24
TOTAL CHARGE

Fig. 2

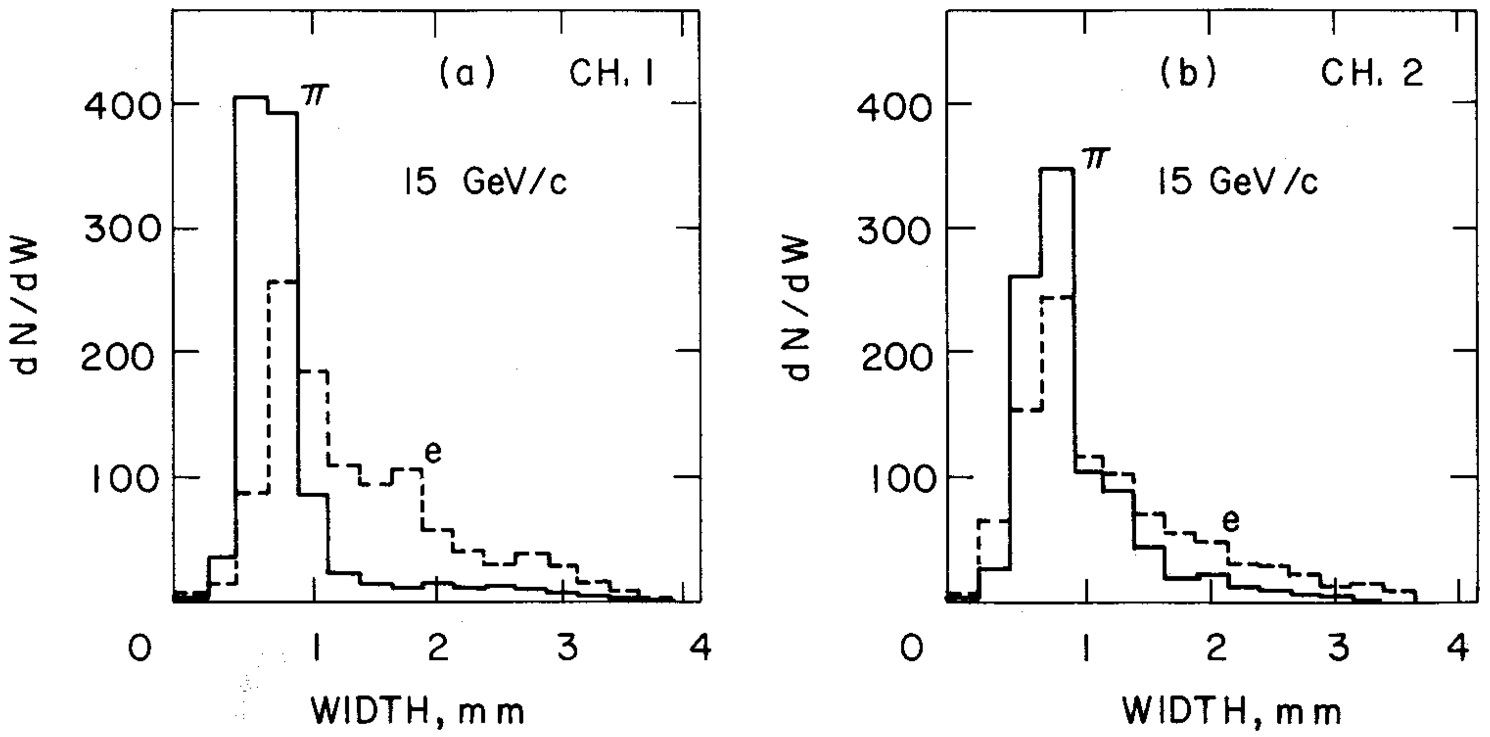

(a) CH. 1
15 GeV/c
π
e
dN/dW
400
300
200
100
0
1
2
3
4
WIDTH, mm
(b) CH. 2
15 GeV/c
π
e
dN/dW
400
300
200
100
0
1
2
3
4
WIDTH, mm

Fig. 3

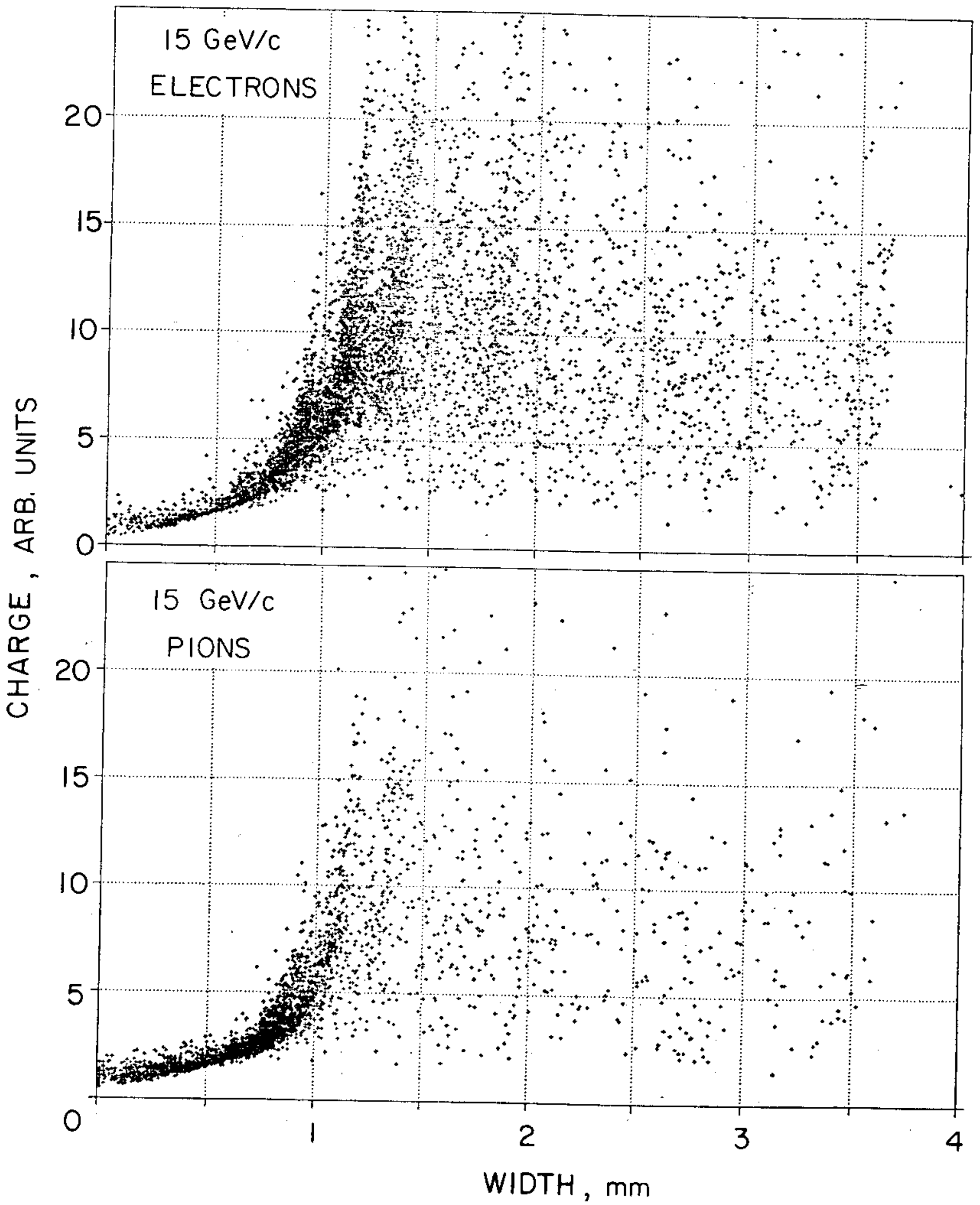

15 GeV/c
ELECTRONS
15 GeV/c
PIONS
CHARGE , ARB. UNITS
0
5
10
15
20
0
5
10
15
20
0
1
2
3
4
WIDTH , mm

Fig. 4

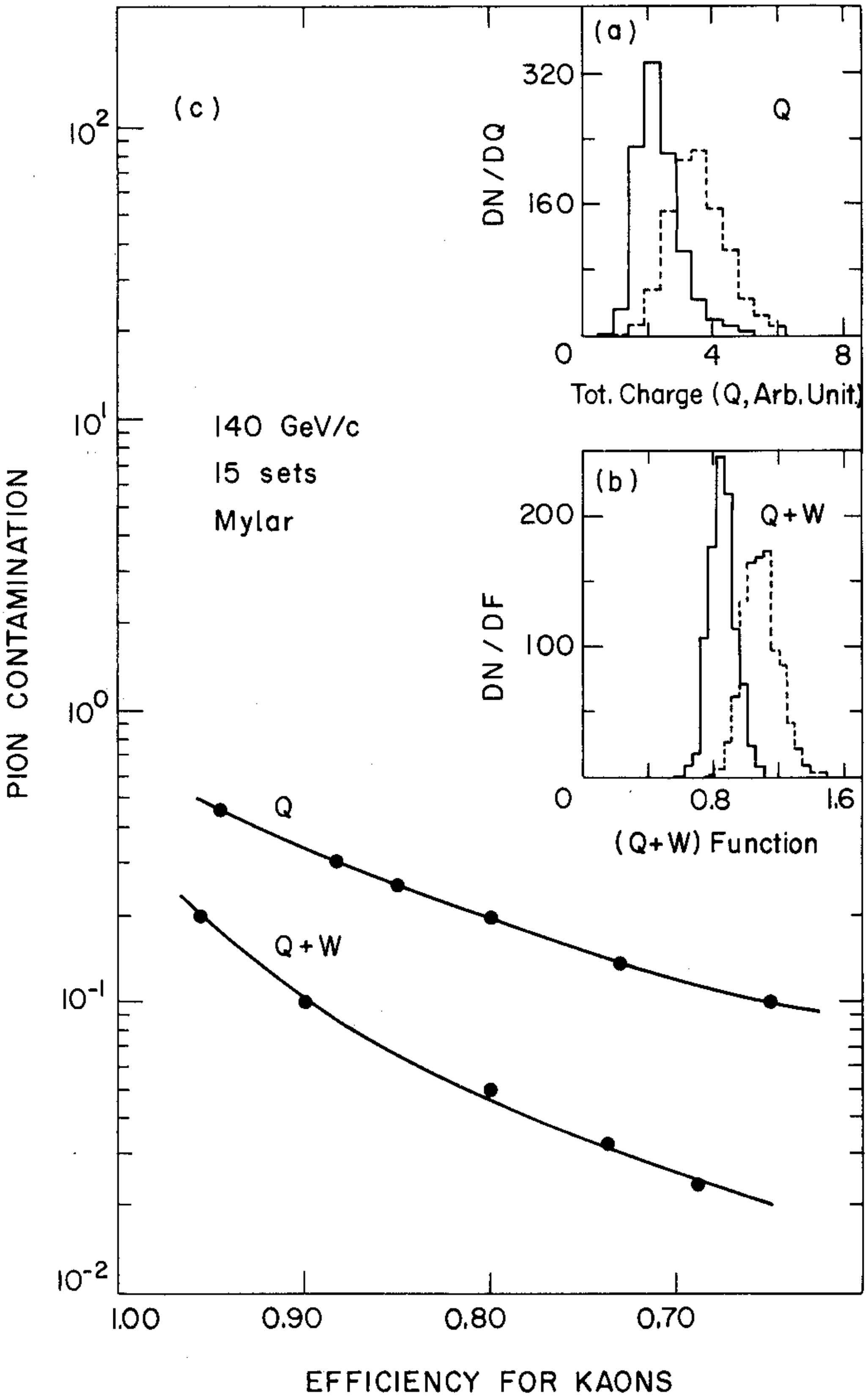

(c)
140 GeV/c
15 sets
Mylar
Q
Q + W
PION CONTAMINATION
EFFICIENCY FOR KAONS
10^2
10^1
10^0
10^-1
10^-2
1.00
0.90
0.80
0.70
(a)
Q
DN / DQ
320
160
0
4
8
Tot. Charge (Q, Arb. Unit)
(b)
Q+W
DN / DF
200
100
0
0.8
1.6
(Q+W) Function

Fig. 5

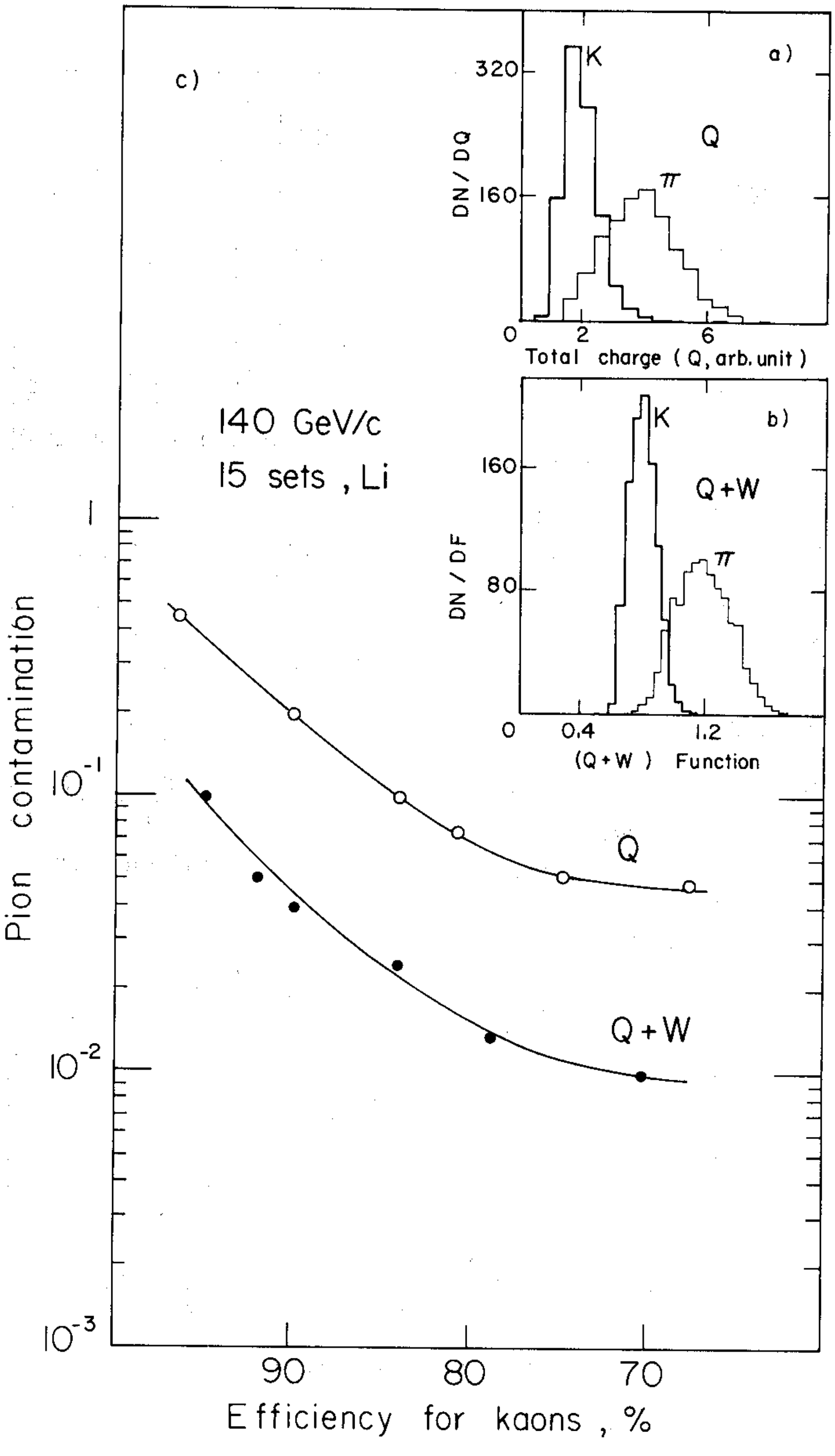

c)
140 GeV/c
15 sets , Li
Pion contamination
1
10^-1
10^-2
10^-3
Q
Q + W
90
80
70
Efficiency for kaons , %
a)
DN / DQ
320
160
0
K
Q
π
2
6
Total charge (Q, arb. unit)
b)
DN / DF
160
80
0
K
Q + W
π
0.4
1.2
(Q + W) Function

Fig. 6

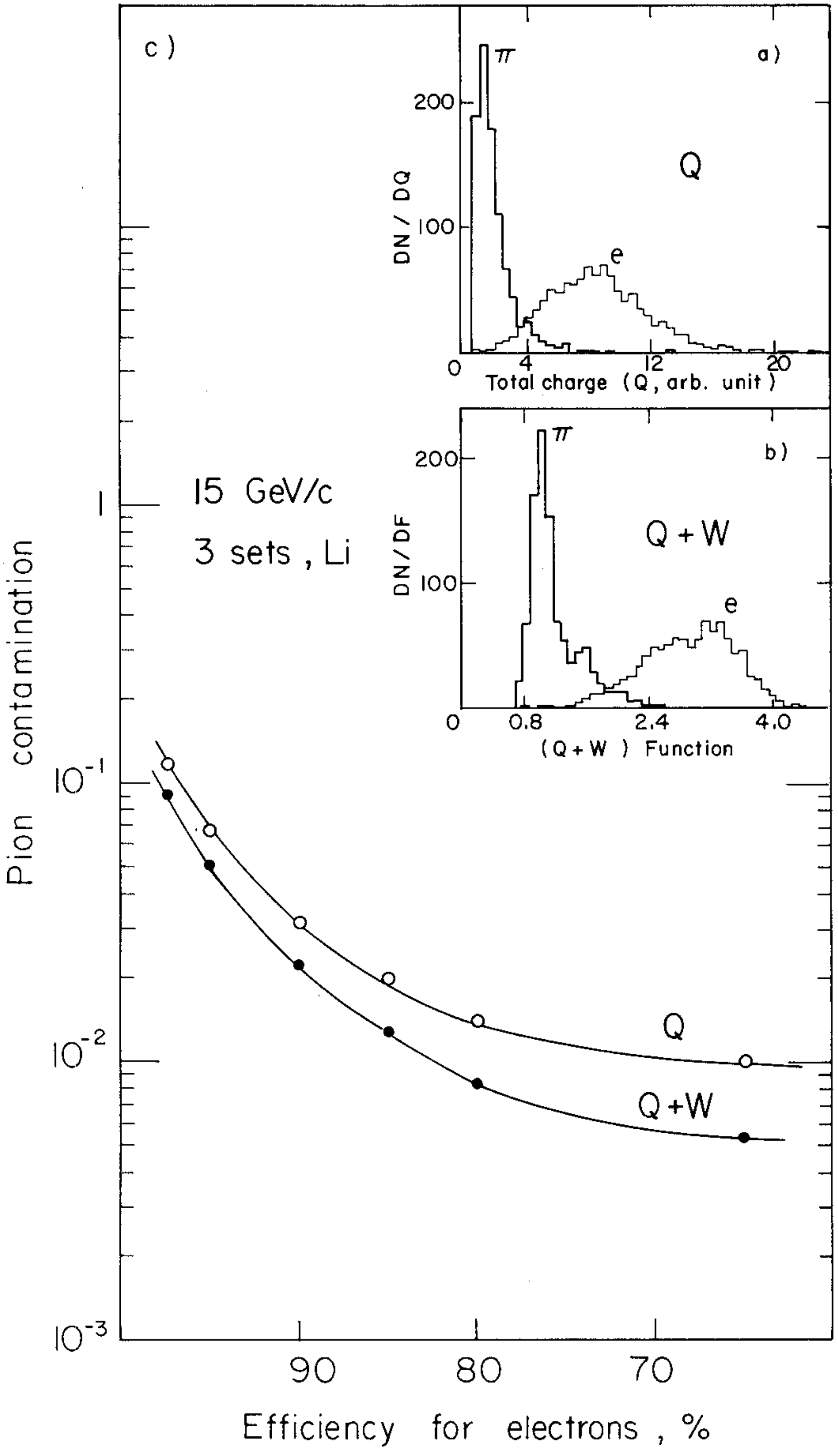

c)
a)
π
e
Q
200
100
DN / DQ
0
4
12
20
Total charge (Q, arb. unit)
b)
π
e
Q + W
200
100
DN/DF
0
0.8
2.4
4.0
(Q + W) Function
15 GeV/c
3 sets, Li
Pion contamination
1
10^{-1}
10^{-2}
10^{-3}
Q
Q + W
90
80
70
Efficiency for electrons, %

Fig. 7