HARP Collaboration

HARP Memo 08-102
5 October 2008
http://cern.ch/harp-cdp/T9beamelectrons.pdf

Fraction of electrons in the T9 pion beams

CERN-HARP-CDP-2008-002
05/10/2008

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Abstract

In the T9 beam line, the beam instrumentation does not permit the separation of electrons from pions, except for the 1.5, 3 and 5 GeV/c beam momenta. For beam momenta of 8 GeV/c or higher, the flux of beam electrons must be subtracted from the flux of pion-like particles incident on the target in order to obtain correct pion interaction cross-sections. In this memo, data from the beam instrumentation and the electron-identifier in 'empty-target' runs are analysed in order to determine the fraction of electrons incident on the target, in the pion beams from 1.5 to 15 GeV/c.

Contents

1 Introduction

In the T9 beam line, the nitrogen pressure of one beam Cherenkov counter was set such that for beam momenta up to 5 GeV/c electrons[1] were separated from pions and thus could be directly identified. At these beam momenta it is in principle not necessary to know the fraction of electrons in the pion beam: events produced by incoming electrons are simply rejected.

For beam momenta above 5 GeV/c, no separation of electrons from pions is possible from the beam instrumentation. The fraction of beam electrons must be determined in other ways and subtracted from the flux of pion-like particles incident on the target in order to obtain correct pion interaction cross-sections. The electron fraction can be estimated either using the HARP electron-identifier (ECAL) or by extrapolation of the electron fractions measured at lower beam momenta.

In this memo, we (the HARP–CDP Group[2]) give our results on the fraction of electrons incident on the target, in the pion beams from 1.5 to 15 GeV/c. At occasions, we compare our results with results published by 'Official' HARP.

2 Electron identification in a beam Cherenkov counter

Generally, beam particle identification was provided for by two threshold Cherenkov counters, BCA and BCB, filled with nitrogen, and by time of flight over a flight path of 24.3 m. Table 1 lists the beam instrumentation that was used at different beam momenta for p/π^+ and for π/e separation.

Table 1: Beam instrumentation for p/π^+ and π/e separation

Beam momentum [GeV/c]	p/π^+ separation	π/e separation
± 3.0	TOF	BCB (1.05 bar)
± 5.0	TOF BCB (2.50 bar)	BCA (0.60 bar)
-8.0 and $+8.9$	BCA (1.25 bar) BCB (1.50 bar)	
± 12.0 and ± 15.0	BCA (3.50 bar) BCB (3.50 bar)	

The fraction of electrons was measured for +1.5, +3.0 and +5.0 GeV/c beam momenta. Only beam particles with a 'downscale trigger bit' were used to measure this fraction.

Figure 1 shows the pulseheight distribution of the Cherenkov counter BCB for +3 GeV/c pions and electrons (protons were rejected by TOF). The signals from pions and electrons are

[1] In this memo, the term 'electron' is generic and comprises both the electron and the positron.

[2] *http://cern.ch/harp-cdp*

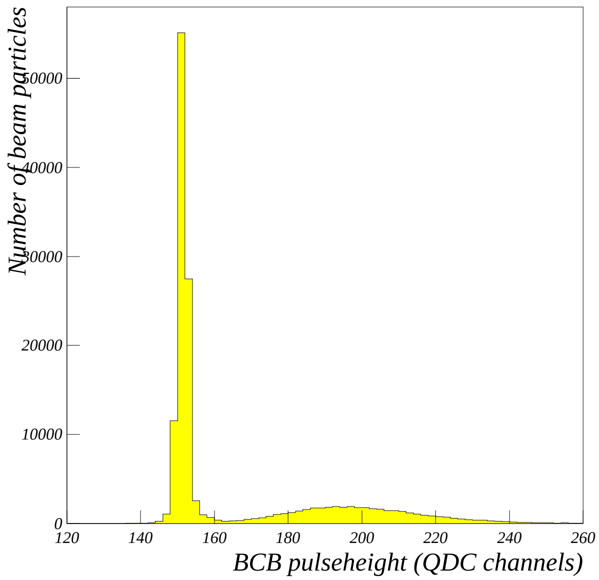

Figure 1: Pulseheight distribution of the Cherenkov counter BCB in the +3.0 GeV/c beam.

clearly separated. Figure 2 shows the distributions of inverse velocity of the beam particles, as measured by the TOF counters. The distributions are shown separately for pions and electrons according to the identification by Cherenkov counter BCB. Pions and electrons cannot be separated by TOF, however on the average the difference in the TOF is clearly visible and consistent with the expectation for the beam momentum of 3 GeV/c.

Figure 3 shows the pulseheight of the Cherenkov counter BCA for +5 GeV/c pions and electrons. The separation is good. We note that the fraction of electrons is considerably smaller than at +3 GeV/c beam momentum.

Our measurements of the electron fraction with the Cherenkov counters are summarized in Table 2. For comparison we also give the published [1] results of 'Official' HARP[3].

Beam momentum	e/π	'Official' HARP's e/π
1.5 GeV/c	3.9	
3 GeV/c	0.40	0.01
5 GeV/c	0.063	0.001

Table 2: Fraction of electrons to pions, for different beam momenta.

[3]Their numbers are wrong.

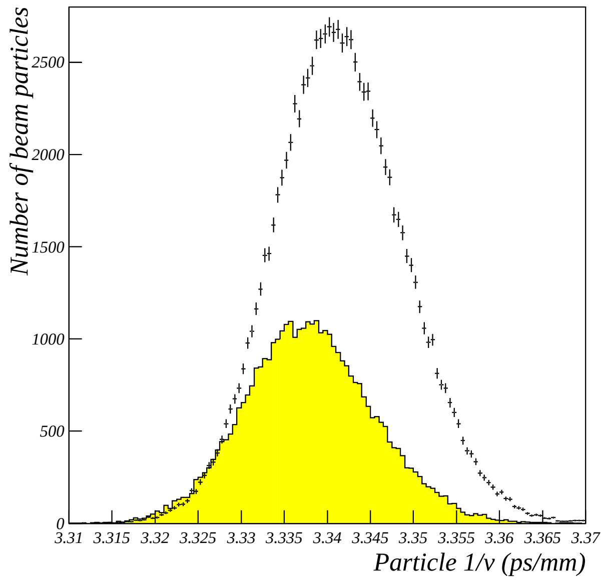

Figure 2: Inverse velocity $1/v$ of the beam particles as measured by the TOF counters; the shaded (empty) histogram shows the distribution for electrons (pions) as identified by the Cherenkov counter BCB.

3 Extrapolation of measurements to larger momenta

In order to extrapolate the measurements in the beam momentum range from 1.5 to 5 GeV/c to higher momenta, input is needed on the energy dependence of the e/π ratio. This input came from a Geant4 simulation of the T9 beam line from the primary proton target down to the HARP target. The results of this simulation are shown in Fig. 4 together with the experimental measurements.

The Geant4-inspired extrapolation of the fraction of electrons to pions to 8 GeV/c beam momentum gives $(1.1 \pm 0.5)\%$. The rather large uncertainty of the extrapolation reflects the apparent difference in the energy dependence between data and simulation.

4 Electron identification in ECAL

The HARP electron identifier (ECAL) has quite some potential to separate electrons from pions. Electrons deposit all their energy in the two layers of the calorimeter, while hadrons typically deposit only a small fraction of their energy. The difficulty of this approach to measure the fraction of beam electrons to beam pions arises from the small number of electrons on top of a large number of pions.

We have used two different approaches which are described in the following.

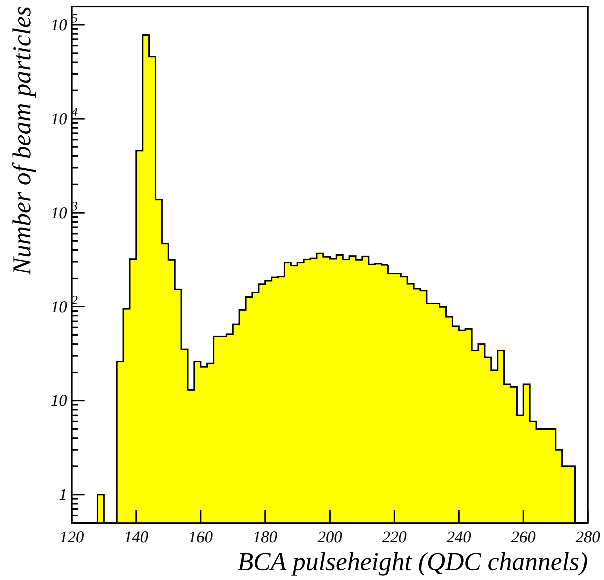

Figure 3: Pulseheight distribution of the Cherenkov counter BCA in the +5.0 GeV/c beam.

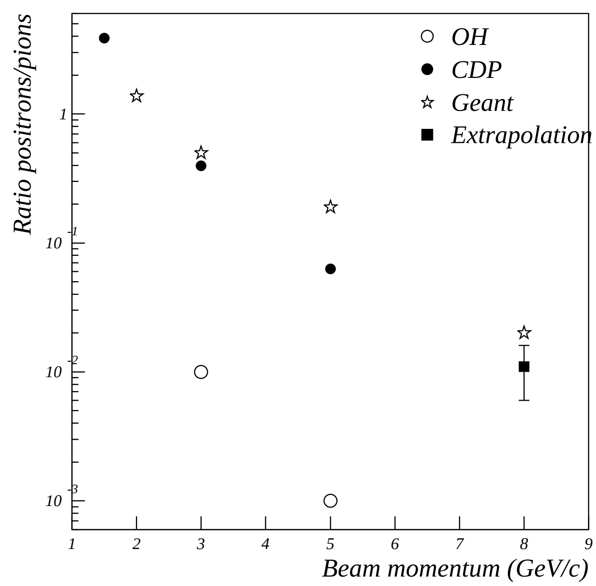

Figure 4: Ratio of electrons to pions, as a function of beam momentum; our measurements are shown as black dots, 'official' HARP's measurements as open circles, and our Geant4 simulation as asterisks; the black square shows the Geant4-inspired extrapolation of our measurements to 8 GeV/c beam momentum.

4.1 Fit of the ECAL energy spectrum

Figure 5 shows the energy deposition by +5 GeV/c beam particles in ECAL. This beam momentum is chosen because the ECAL response of electrons and pions can be studied separately because of their identification by the Cherenkov counter BCA. The energy deposition of electrons concentrates in a peak that reflects the beam momentum. However, the high-energy tail from pions gives a comparable contribution.

The ECAL deposition by +8.9 GeV/c beam particles is shown in Fig. 6. The electron peak is expected at about 4700 QDC counts (extrapolated from the lower energies). A fit of the electron contribution strongly depends on the shape of the pion contribution. We used two approaches. In the first, the shape of the pion contribution was assumed to be the same as the one at 5 GeV/c beam momentum, yet scaled linearly to 8.9 GeV/c. In the second, the shape of the pion contribution was rather arbitrarily described by a Gaussian distribution (the parameters of the Gaussian were free fit parameters).

The fraction of electrons to pions was found to be 0.9% in the first approach and 2.1% in the second. From the difference of the results we conclude that the systematic uncertainty of this method is at the level of a factor of two. Still, these results exclude a fraction of electrons to pions larger than a few per cent.

4.2 Determination from bremsstrahlung photons

Here, we determine the fraction of electrons to pions through bremsstrahlung photons that are radiated in materials in the straight section of the beam line just upstream of the HARP detector[4]. The point is that the amount of photon radiation is determined by the amount of material—*nota bene*, with the target removed—in the beam line and thus is largely independent of the beam momentum.

We first study the ECAL response at the beam momenta of +3 and +5 GeV/c because of the identification of electrons by the Cherenkov counters BCB and BCA, respectively.

Figure 7 shows the hit distribution from +3 GeV/c beam electrons in the scintillation counters of the first ECAL layer. One can clearly see the main peak from the electrons bent in the magnetic field and the second peak in the centre of the HARP detector (counters 60–65). This second peak is the signal from photons radiated by electrons in materials in the straight section of the beam line just upstream of the HARP detector.

Figure 8 shows the energy deposition by +5 GeV/c beam electrons and beam pions in the scintillation counters of the first ECAL layer. Notice that no photon peak is present for beam pions.

Only events with an energy deposition in the ECAL above 70% of the beam energy are considered.

The energy sharing between electrons and photons at +5 GeV/c beam momentum is the

[4]In Ref. [2] 'Official' HARP say wrongly that these photons are radiated in the HARP dipole spectrometer magnet.

basic parameter that will also be used at higher beam momenta.

In order to make the photon peak visible amidst an overwhelming number of pions, further cuts are applied at +8.9 GeV/c beam momentum with a view to improving signal over (pion) background: the total energy deposition in both ECAL layers had to be above 82% of the beam energy, and the deposition in the second ECAL layer had to be less than 80% of the deposition in the first layer. The resulting energy distribution across the scintillation counters in the first ECAL layer is shown in Fig. 9. The photon peak, albeit small, is clearly visible. The distribution was fitted by a sum of two Gaussians and the shape of the photon peak from +5 GeV/c beam electrons[5]. We obtained the fraction of electrons to pions of (1.2 ± 0.5)%.

5 Synopsis

For the beam momentum of +8.9 GeV/c we have estimated the fraction of electrons to pions with four different methods. The results are summarized in Table 3. Although each result has a relatively large uncertainty, they are in a reasonable agreement with each other. Our best estimate of the fraction of electrons to pions at the beam momentum of +8.9 GeV/c is (1.2 ± 0.5)%.

Table 3: Fraction of electrons to pions, at +8.9 GeV/c beam momentum, resulting from four different methods.

Method	e/π ratio
Extrapolation from lower momenta	(1.1 ± 0.5)%
Energy spectrum (pion shape from +5 GeV/c)	0.9%
Energy spectrum (Gaussian pion shape)	2.1%
Bremsstrahlung photons	(1.2 ± 0.5)%

[5]We ignored the small shrinkage of the relative width of the photon peak due to the higher average energy of the radiated photons.

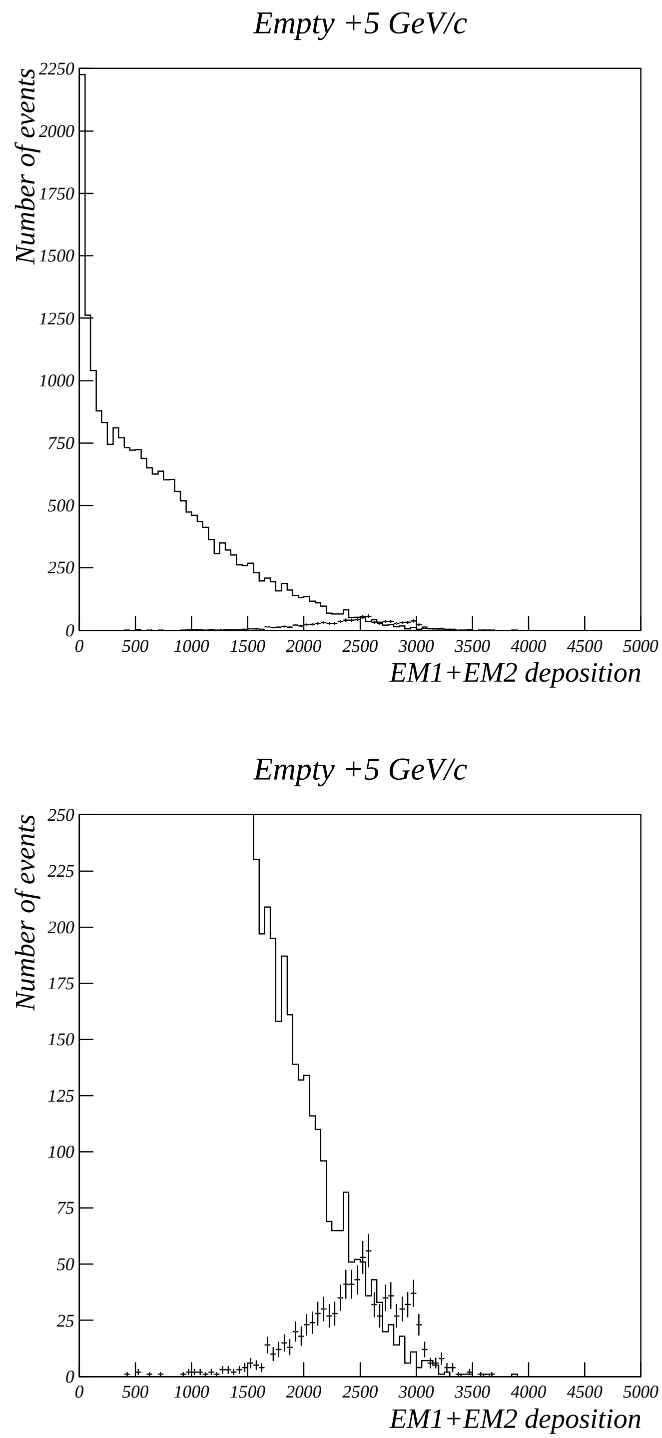

Figure 5: Energy deposition (in units of QDC counts) in ECAL by 5 GeV/c pions (histogram) and electrons (crosses); the upper and the lower panel show the same distributions but on different scales.

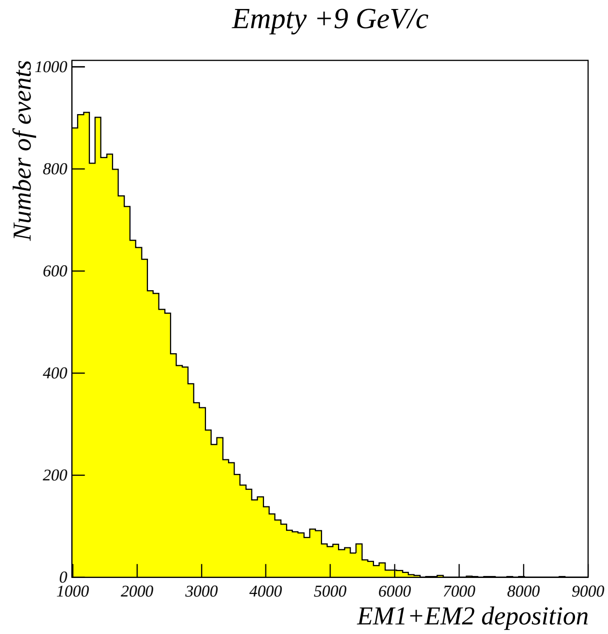

Figure 6: Energy deposition (in units of QDC counts) in ECAL by +8.9 GeV/c beam particles; the peak at very small energy deposition is suppressed.

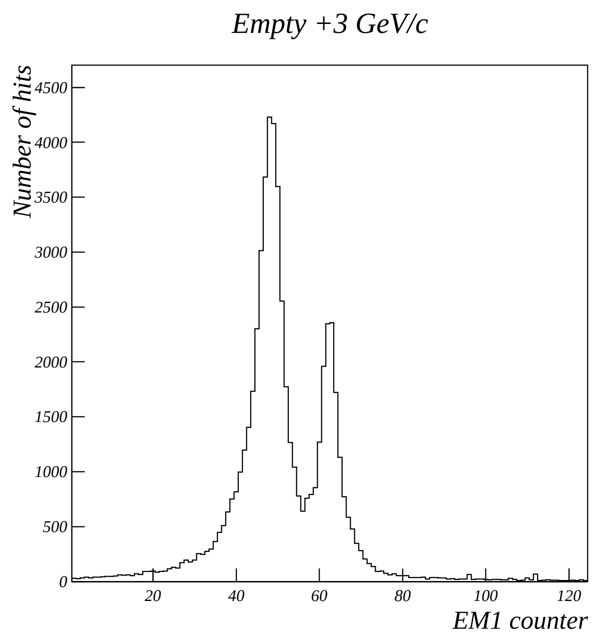

Figure 7: Hit distribution from +3 GeV/c beam electrons in the scintillation counters of the first ECAL layer.

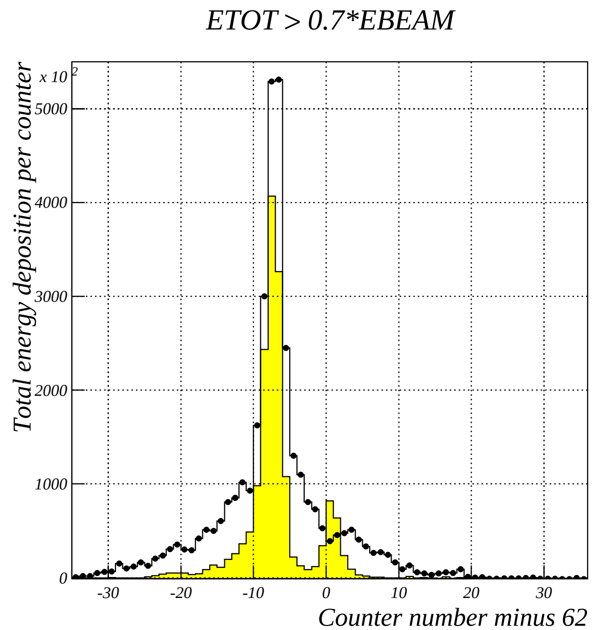

Figure 8: Energy deposition in the scintillation counters of the first ECAL layer for identified beam electrons (shaded histogram) and beam pions (open histogram) with +5 GeV/c momentum; the constant 62 is subtracted with a view to moving the centre of the HARP ECAL to 'zero'.

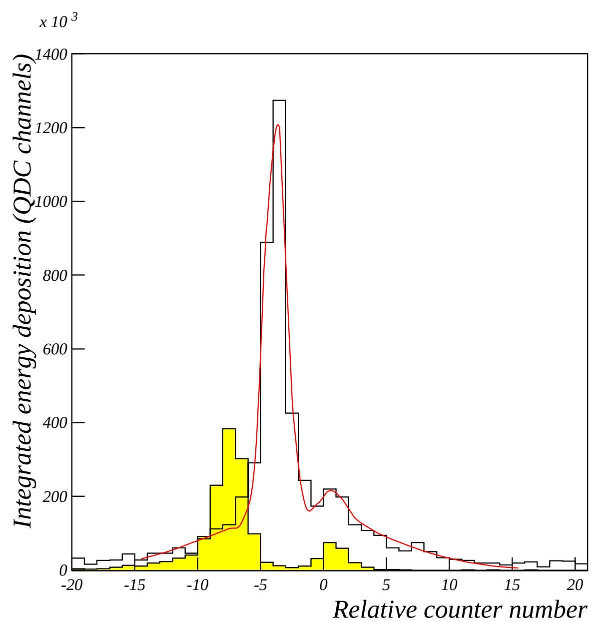

Figure 9: Open histogram: energy distribution across the scintillation counters in the first ECAL layer, for +8.9 GeV/c beam momentum; shaded histogram: energy distribution for +5 GeV/c beam electrons, scaled and normalized to fit the photon peak in the open histogram.

At the beam momenta of +12 and +15 GeV/c no signal from electrons is seen. This is not surprising because the electron fraction drops by about a factor of five for every increase of beam momentum by 3 GeV/c. So, we expect to see something like $(0.3 \pm 0.5)\%$, which is consistent with what is seen in the data.

There is a safe upper limit of 1% for the fraction of electrons to pions at the beam momentum of +12 GeV/c. We use the numerical result of $(0.5\pm0.5)\%$ in the cross-section normalization. Along the same line of reasoning, we use $(0.0\pm0.5)\%$ for the beam momentum of +15 GeV/c.

There is a final consideration concerning whether the beam is a π^+ or a π^- beam. The origin of the beam electrons are converted photons from the decay of π^0's that are generated at the primary proton target. Since the incident proton momentum is with 24 GeV/c rather high, the number of secondary π^+ and π^- are comparable, especially at low momenta of the secondary pion beam—which is the region where the contamination of the pion beams by electrons is non-zero. Therefore, we take the same fraction of electrons to pions for π^+ and for π^- beams.

Table 4 summarizes our results for the beam momenta used in the HARP experiment.

Table 4: Contaminations of the pion beams by electrons

Beam momentum [GeV/c]	Electron fraction
±3.0	rejected
±5.0	rejected
-8.0	$(1.2 \pm 0.5)\%$
$+8.9$	$(1.2 \pm 0.5)\%$
±12	$(0.5 \pm 0.5)\%$
±15	$(0.0 \pm 0.5)\%$

References

[1] M.G. Catanesi *et al.*, Astropart. Phys. **29** (2008) 257

[2] M. G. Catanesi *et al.*, Nucl. Instrum. Methods Phys. Res. **A571** (2007) 527