PARTICLE IDENTIFICATION WITH A COMBINED HODOSCOPE CALORIMETER

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(Joint CERN - IHEP experiment)

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Abstract

The differences in width and in deposited energy between electromagnetic and hadron showers developed by 18.5 GeV/c and 38 GeV/c pions and electrons in a combined hodoscope detector composed of a GAMS-type electromagnetic calorimeter and a modular hadron calorimeter allows to reject pions or electrons to a level $< < 0.1$ % keeping a detection efficiency larger than 90% when the other particle is selected. The hadron calorimeter helps to efficiently reject background in studies of multiphoton decays of neutral mesons with GAMS.

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It has been shown previously that the difference in transverse dimensions of showers allows to identify effectively electrons from hadrons in an electromagnetic calorimeter of the GAMS type [1]. Similar results have been obtained with a modular hadron calorimeter [2] $MHC-100$. In this case a hadron shower covers 3x3 cells in MHC (the transverse dimensions of a cell are 20 x 20 cm^2) while an electron develops a shower that is practically contained within a unique cell. The square root of the dispersion $D_{II} = D_{IIx} + D_{IIy}$ is used as a measure of the width of the shower in MHC, where $D_{IIx} = \sum_i x^2_i A_{IIi}/d^2\sum_i A_{IIi}$, x_i is the distance of the shower axis to the center of the i-th cell, d is the half-width of a cell (10 cm) and A_{IIi} is the amplitude of the signal in this cell. Distributions versus $\sqrt{D_{II}}$ are shown in fig. 1a for 18.5 GeV/c electrons and pions in MHC.

As the overlap of these distributions is small, it is possible to separate hadrons from electrons by imposing a suitable lower limit on D_{II} (fig. 1b). While the detection efficiency ε_π for 38 GeV/c pions still remains close to one (≈ 0.9) the ratio $\varepsilon_e/\varepsilon_\pi$ is reduced to 5 %. If instead an upper limit is put on the width of the shower ($\sqrt{D_{II}} \lesssim 0.4$, see fig. 1b) then MHC selectively detects electrons: for $\varepsilon_e = 0.9$, $\varepsilon_\pi/\varepsilon_e = 4\%$ and 5% at 38 GeV/c and 18.5 GeV/c, respectively.[1]

Thus, both the modular hadron calorimeter and GAMS may not only be used to measure the energy and coordinates of particles [2],[4], [5] but they also may be used to separate hadrons from electrons.

The rejection power of a combined hodoscope calorimeter [6], composed of $GAMS-2000$ [7], a fine granularity electromagnetic calorimeter, followed by the modular hadron calorimeter $MHC-100$, used in experiments performed at the IHEP accelerator in the framework of the GAMS programme[2] [10] has been measured with 18.5 GeV/c and 38 GeV/c negative particles.

Electron (photon) showers are practically totally absorbed in the lead glass of $GAMS-2000$. The energy leakage from GAMS into MHC (fig. 2a) does not exceed a few percent. On the other hand, GAMS is only a thin active converter for hadrons (one interaction length) in which 60 % of incident pions start a nuclear cascade while 40 % cross the glass without interacting. The combination of two hodoscope calorimeters, one for photons the other for hadrons, into a single detector allows to

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[1] With increasing energy the width of electromagnetic showers does practically not change, hadron showers slowly shrink and fluctuations in their width decrease [3], [4].

[2] A similar combined calorimeter, but of larger size, is in use at CERN (experiment $NA-12/2$) [5], [8], [9].

improve much the selectivity of single calorimeters while measuring the energy of either particles. [3]. The separation of electrons from pions is not only based on the difference between the widths of electromagnetic and hadron showers, but also on the difference between the energy released by these particles in both calorimeters (fig. 2a).

In order to select electrons in the presence of hadron background, cuts are applied on the width of the showers: $\sqrt{D_H} < 0.4$ and $0.1 < \sqrt{D_G} < 0.6$ [1], where D_G is the dispersion in GAMS, which suppress the detection of pions by one order of magnitude (fig. 2b); in this case $\varepsilon_e = 95$ %. If in addition one requires that the energy of the showers is mainly released in GAMS ($A_H/A_G < 0.1$), then a level $\varepsilon_\pi/\varepsilon_e < < 0.1$% can be achieved while maintaining a high detection efficiency for electrons ($\varepsilon_e \sim$ 90%). This result has been obtained in measurements with a pion beam containing a small electron component with the same momentum (the original electron contamination at 18 GeV/c is about 0.5%; it is reduced below 0.1% by a lead filter installed in the beam).

A similar rejection can be obtained when the energies of the electrons and of the hadrons are different: $\varepsilon_\pi/\varepsilon_e < 0.02$ % for $E_\pi = 18.5$ GeV and $E_e = 38$ GeV. Even in the case when the electrons have a lower energy ($E_\pi = 38$ GeV, $E_e = 18.5$ GeV) $\varepsilon_\pi/\varepsilon_e < 0.05$%. The combined hodoscope calorimeter is very efficient to identify electrons and photons in an intense hadron background.

Inversion of cuts on the widths (fig. 2c) and on the energy ($A_G < < A_H$) of the showers in GAMS and MHC allows to reject electrons down to a level of $\varepsilon_e/\varepsilon_\pi < 0.07$ % at 18.5 GeV and to less than 0.1 % at 38 GeV. These values are upper limits (the electron beam had a small hadron contamination), effective values of ε_e are significantly lower. With these cuts, $\varepsilon_\pi = 95$ %.

In the case of unequal electron and pion energies, a similar electron rejection $\varepsilon_e/\varepsilon_\pi < 0.07$ % is obtained for $E_\pi = 38$ GeV, $E_e = 18.5$ GeV and vice versa.

The combined calorimeter is particularly well suited for the detection of neutral mesons decaying into photons [9], [10]. In this case GAMS measures the coordinates and the energy of the photons and MHC allows to "cleanup" the hadron background. Fig. 3a shows, as an example, the invariant mass spectrum of 3γ events measured in GAMS $-$ 2000. Using the information of MHC $-$ 100 (with a cut $A_H < 1$ GeV), the background under the peaks, corresponding to the decays $\omega \to \pi^0 \gamma$ and

$\eta \rightarrow 2\gamma(+\gamma_f)$, where γ_f is a fake photon[3] may be reduced by a factor three (fig. 3b) [11].

A combined electromagnetic and hadron calorimeter of the type described here not only allows to measure the coordinates and energy of a large number of particles simultaneously, but it allows also to separate with high efficiency photons (electrons) from hadrons and vice versa without resorting to an additional detector. Essential is the fact that this information can be used in the trigger, before writing events on magnetic tape. This result (see also [6], [8]) is important for the conception of basic detectors for the future multi-TeV accelerators [12], [13].

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[3] The presence in the 3γ mass spectra of a peak in the region of the η is due to the fact that for a small fraction of $\eta \rightarrow 2\gamma$ decays the reconstruction program of events in GAMS interprets a fluctuation taking place at the periphery of one of the showers as an additional low energy photon γ (the decay $\eta \rightarrow 3\gamma$ is forbidden by C-parity conservation). The spurious η-peak is eliminated (fig. 3c) after introducing a cut on the mass of 2γ-systems: two nearby photons are considered to be a single photon if their invariant mass is less than 60 MeV.

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Figure captions

Fig.1   a) Distribution versus $\sqrt{\overline{D}_{II}}$ of events in the modular hadron calorimeter MHC − 100 irradiated with 18.5 GeV/c electrons and pions ($\sqrt{\overline{D}_{II}} = 1$ corresponds to 10 cm);

b) detection efficiency of pions (ε_π) and electrons (ε_e) versus the cut on $\sqrt{\overline{D}_{II}}$ at 18.5 GeV/c and 38 GeV/c momentum (present work) and 200 GeV/c (from the data in [5]).

Fig.2   Spectra of the signals in GAMS (Λ_G) and MHC (Λ_{II}) obtained with 38 GeV/c electrons (a_e) and pions (a_π) in the combined calorimeter. $\Lambda_{II} = \sum_i \Lambda_{IIi}$, $\Lambda_G = \sum_i \Lambda_{Gi}$. The black histogram in (a_e) shows the MHC spectrum with $\Lambda_G > 33$ GeV (bin width is 0.4 GeV). The dashed curve on (a_π) is the total energy released in the combined detector (the summation procedure of the signals in GAMS and MHC is described in [6]). (b_e) and (b_π) are the same as (a_e) and (a_π) but after selection of electrons with the cuts: $\sqrt{\overline{D}_{II}} < 0.4$, and $0.1 < \sqrt{\overline{D}_G} < 0.6$. ($c_e$) and ($c_\pi$) the same again but with cuts selecting hadrons: $\sqrt{\overline{D}_{II}} > 0.4$, $\sqrt{\overline{D}_G} < 0.1$ and $\sqrt{\overline{D}_G} > 0.6$.

Fig.3.   a) Invariant mass spectrum of 3γ events in GAMS obtained in the charge exchange reaction $\pi^- p \to M^0 n$, $M^0 \to 3\gamma$ at $E_\pi = 38$ GeV. The shaded peak corresponds to ω. The dashed curve is a polynomial background. Arrows point to the tabulated mass values of ω and η.

b) Same but after the cut $\Lambda_{II} > 1$ GeV is introduced.

c) Same as b) but after a cut on the mass of γ-pairs (see text). The width of the ω peak corresponds to the intrinsic resolution of GAMS.
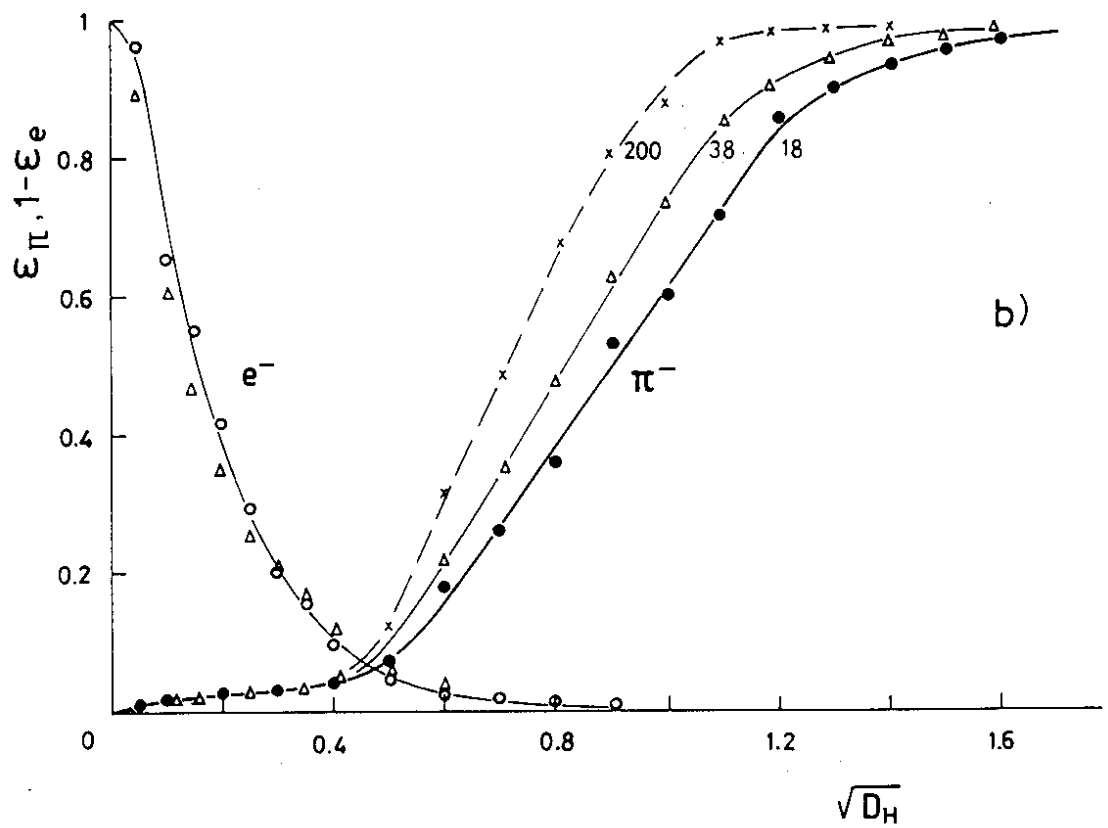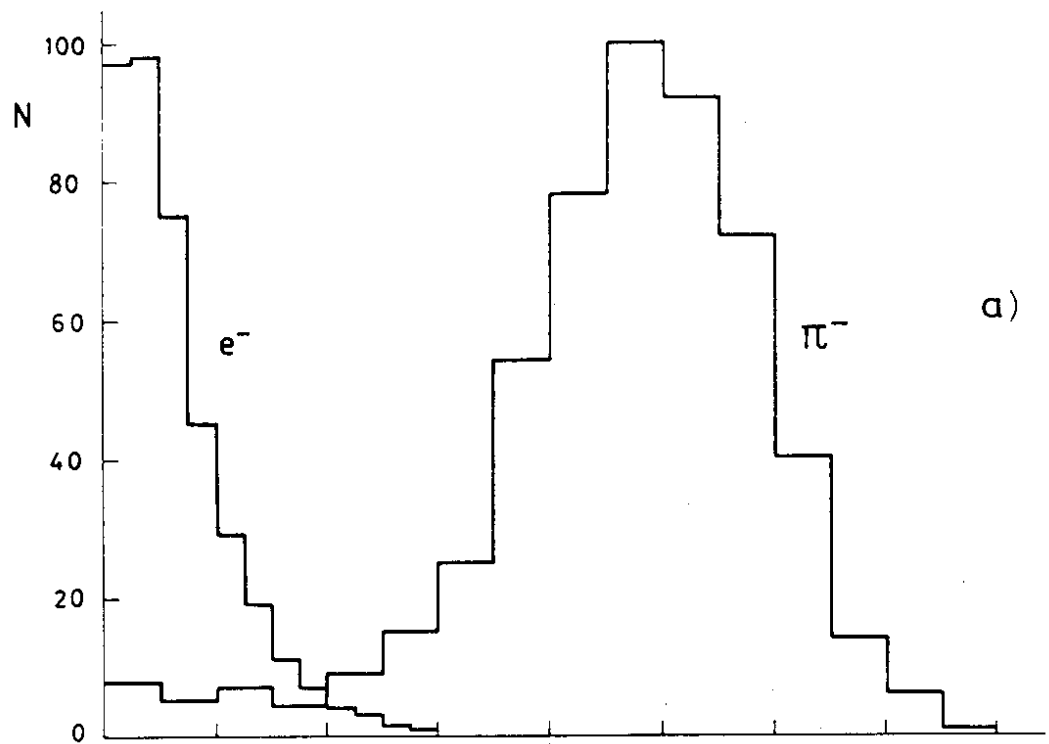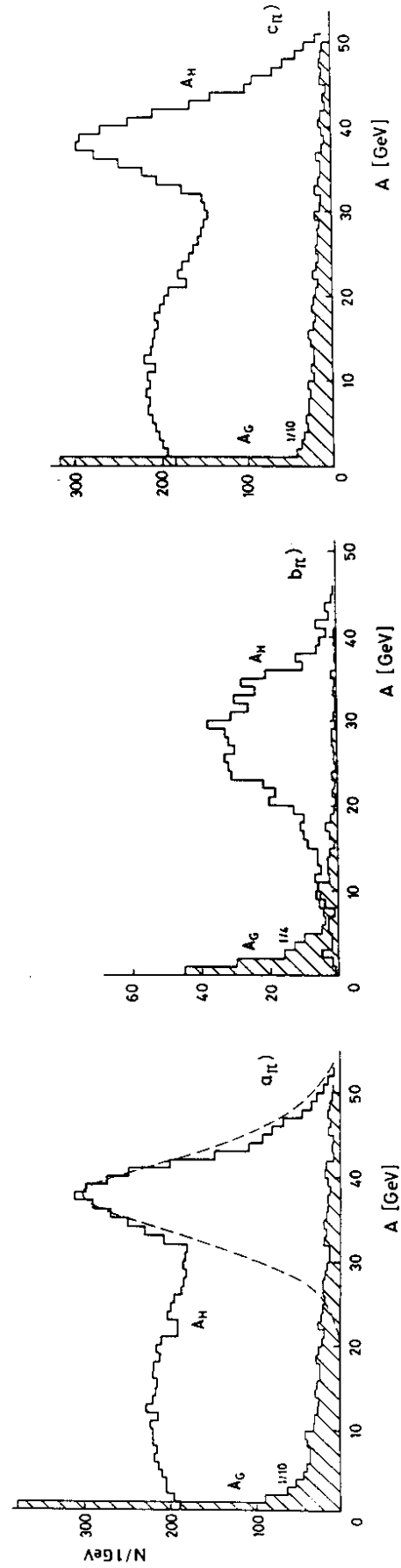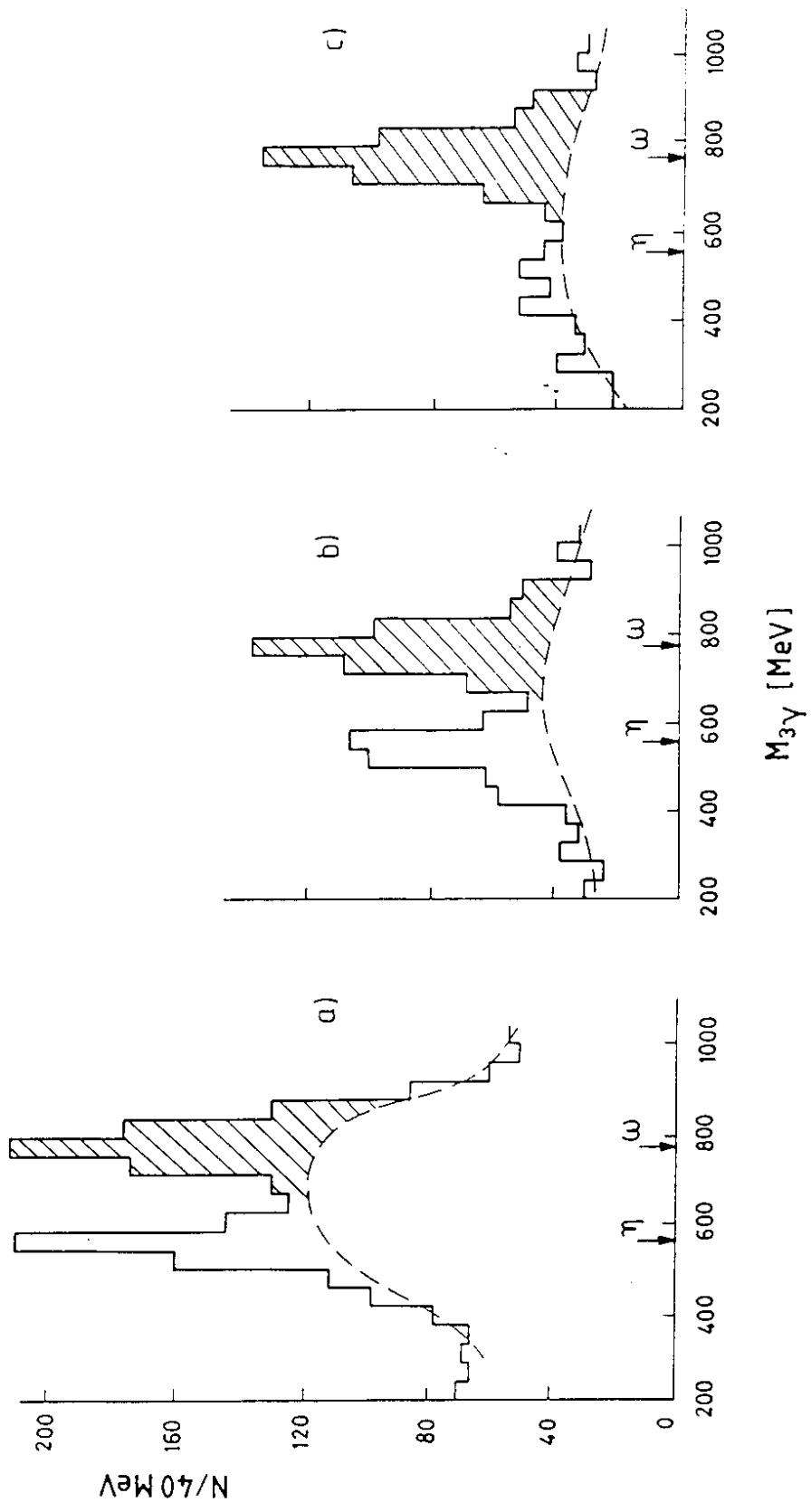
Fig. 1

Fig. 2

Fig. 3