PARTICLE IDENTIFICATION BY PLASTIC FLASH-CHAMBERS

M. Conversi and F. Lacava

CERN, Geneva - Switzerland

Abstract -

The possibility to utilize plastic flash-chamber systems for particle identification is investigated. It is first pointed out that a many-layer system of thin-wall extruded flash cells is suitable for ionization measurements, and might be applied e.g. to a search for e/3 quarks. The development of the cascade showers in a plastic flash calorimeter model containing 20 Pb plates 0.5 cm thick and 30 Fe plates 5 cm thick, alternated with flash chambers, is then simulated by Monte Carlo programs, for primary electrons and pions of various energies from 1 to 200 GeV. Analysis of the results of this simulation shows that the detector is capable to identify muons, γ's, electrons and charged hadrons with good confidence level.

(Submitted to Nuclear Instruments and Methods)

Geneva - 13 December 1978

(+*) Permanent address: Istituto di Fisica, Università di Roma, Rome, Italy.
1. - Introduction -

Flash chambers of honeycomb extruded sheets of polypropylene have been recently developed \(^1\) and utilized in total absorption particle detectors - called Plastic Flash Calorimeters \(^2\), PFC - which consist, in fact, of a large number of plates of dense inert material alternated with chambers of the same area. This new type of calorimeter, easy to realize in huge dimensions at a comparatively very low cost, provides track information, energy determination, fine-grain sampling and pattern recognition, at reasonable confidence levels. Hence, in spite of present limitations in speed of data acquisition (at most some 10 triggers per second) and in the maximum tolerable rate of background particles (at most some \(10^5\) traversals per second per chamber cell), the technique presents a number of appealing features which commend it for various applications, especially in neutrino physics. Among the proposals \(^3\text{-}6\) of experiments in this latter field one involves the construction of a large scale neutrino detector \(^3\), which according to the proposers should allow "exploration of a new range of physics inaccessible to present bubble chambers and electronic detectors". Extensive experimentation has been performed by J.Walker and his collaborators\(^3\text{-}6\) on a model of this neutrino detector (essentially a huge fine-grain sampling PFC) now being developed for use at the Fermilab "Energy Doubler".

Recently we have further investigated by Montecarlo simulation methods the response of a large PFC to different particles of energies up to 200 GeV, having in mind the possibility to apply the technique to the identification of unknown high energy particles. The results of this investigation are reported in the present paper, after pointing out (Sect. 2.2) that a many layer flash-chamber system can also be utilized for ionization measurements.
2. - **Methods of particle identification by plastic flash chambers**

The possibility to identify high energy particles by the flash-chamber technique relies on two different methods.

2.1 - **Identification by pattern recognition**

The first method is based on the different processes underwent by particles of different nature (\(\gamma\)-rays, electrons, muons, hadrons) in traversing dense matter. A large plastic flash calorimeter is well suited to observe directly these processes and thus provides a method of particle identification based essentially on pattern recognition as discussed later (Sect. 5).

2.2 - **Identification by ionization measurements**

The second method - which will be only briefly outlined here - is based on the fact that for a cell traversed by a particle of specific ionization \(j\), the flashing probability is a function of \(j\), \(p(j)\). Then in a many-layer flash-chamber traversed by a single ionizing particle the probability of observing \(n\) flashes is

\[
P(n,N) = \binom{N}{n} \cdot p^n \cdot (1 - p)^{N-n}
\]

where \(N\) is the number of layers. The standard deviation of this binomial distribution is \(\sigma = \sqrt{m(1-p)}\), if \(m = Np\) is the average number of cells flashed by a particle of specific ionization \(j\).
For another particle of specific ionization $j'$ and corresponding flashing probability $p'$, the average number of flashed cells, $m' = Np'$, differs from $m$ by $\Delta m = N(p' - p)$. This latter quantity is the distance between the peaks of the two distributions and has to be compared with the sum of the two standard deviations $\sigma$ and $\sigma'$ in order to estimate the sensitivity by which particles of different ionization can be distinguished by this method. Note that the sensitivity increases as $\sqrt{N}$ by increasing the number of layers.

The method just outlined was applied a few years ago to search for relativistic $e/3$ quarks in extensive cosmic ray air showers. Use was made, in that experiment, of $\sim 12,000$ glass neon-filled flash tubes disposed in nearly 200 layers. By using plastic flash chambers, where a much larger number of layers can be achieved easily, one should gain considerably in sensitivity.

For the applicability of this method to accurate ionization measurements, care should be taken, of course, to ensure that the flashing probability $p$ is the same all over the many cells of the flash-chamber system. Moreover, in order to avoid saturation effects, the value of $p$ should not be too close to 1 for either value of the specific ionization. The probability $p$ can be adjusted to the desired values by different methods, including the introduction of suitable delays on the instant of application of the sensitizing HV pulse.

The development of this method would require a detailed investigation of the relationship $p(j)$ between specific ionization and the flashing probability of the chamber cells.
3. - Choice and description of plastic-flash-calorimeter model

The response of a PFC to particles of different nature and energy, and therefore the PFC capacity to identify different particles of unknown energy, depends on the characteristics of the specific instrument, such as: transversal dimensions of the tubular cells, material and thickness of the inert plates, number and mutual distances of the PFC moduli, etc..

The choice of a model of PFC for the present investigation has been made taking into account that large extruded sheets of a type of polypropylene ("mopleen")¹, with tubular cells of transversal dimensions 3.5 mm x 5 mm, are commercially available at a very low cost (∼1.5 €/m²). Furthermore, for the number of chamber layers, the type of material (Pb and Fe) and the thickness of the inert plates, we have maintained the choices already made in projecting and realizing specific PFC's on which systematic direct experimentation was carried out already successfully² through exposures to electrons and pions in an energy range (1 to 4 GeV) smaller than that of the present investigation (1 to 200 GeV). The number of PFC moduli has been increased and the distance between any pair of contiguous PFC elements has been reduced to a minimum, corresponding to leaving 4 mm of free space on each side of the inert plates.

Fig. 1 shows the selected model. It consists indeed of two adjacent PFC's: The one up-stream - referred to as "electromagnetic" (em-)PFC in what follows - is a sandwich of 20 lead plates of 0.5 cm thickness (∼0.9 radiation length) alternated with 4-layer flash-chambers of the same effective area(+);

(+ In the Montecarlo simulation no limitation has been imposed to the chamber area, which in the drawing of Fig.1 is 120x120 cm² for the em-PFC and 180x180 cm² for the h-PFC. The total number of flash cells in the PFC of Fig.1 is then ∼60.000.
The one down-stream - referred to as "hadronic" (h-)PFC - is a sandwich of 30 iron plates of 5 cm thickness, alternated again with 4-layer flash-chambers of the same area. The chamber layers are the extruded mople sheet mentioned above, disposed as shown in Fig. 2. The chamber is contained in a thin-wall plexiglass box in which a noble gas mixture (e.g. 30% He, 70% Ne) is made to flow at the (slow) flowing speed \(^{(+)}\) required for a good detection efficiency \(^{1}\). Different layers in each chamber can be given, of course, different orientations, in order to achieve unambiguous space reconstruction of the tracks, when desired.

We recall that extraction of the information from the flash-chambers can be achieved by various optical, video-optical, or electrical read-out systems \(^{1,2}\).

The calorimeter illustrated by Fig. 1 and Fig. 2 is clearly suitable to identify - within certain confidence limits - different types of high energy particles, of unknown energy \(E (E > 1 \text{ GeV})\). For example a muon is promptly recognized, since it produces in nearly all instances a single long straight track. On the other hand, qualitatively speaking, a high energy electron, positron, or photon impinging onto the detector, has a \(\sim 100\%\) probability to develop the em-cascade in the first layers of the em-PFC, where a high energy hadron has but a small chance to initiate the hadronic cascade. Clearly this is, however, only a small fraction of the total information derivable through accurate inspection of the patterns of the two types of shower, as discussed later.

\(^{(+)}\) A flow through the chamber at a rate of 1-2% of the chamber volume per minute is usually required.
4. Montecarlo simulation

In order to make a detailed study of the PFC response over a wide energy range, events originated by primary electrons and pions, impinging with energies from 1 to 200 GeV onto the PFC model described above, were simulated by two Montecarlo programs. Confidence can be given to these programs, because when applied to PFC's similar, even through smaller than the em-PFC and h-PFC of the present detector model, they gave results in good agreement with those derived from direct measurements.

The program for the simulation of the em cascade takes into account all relevant effects, including the Landau-Pomeranchuk effect, which causes a reduction in the total electromagnetic cross section at very high energies (say $E_e > 10$ GeV). The rare electromagnetic processes involving muons or hadrons in the final states were nevertheless neglected. The cascade shower was followed up through PFC until the secondary-electron energy reached the value ($\approx 1.5$ MeV) corresponding to absorption in the plexiglass plate of the chamber modulus.

For the simulation of the hadronic cascade we used the Grant program, implemented with the previous em program.

By the Montecarlo simulation programs outlined above we can follow the development of the showers in our PFC model, for any given primary particle, of any given energy. Patterns are thus obtained, which are typical of the primary particle and energy chosen.

\[\text{(+)}\] It can be shown indeed that the em contribution to the total shower energy increases from 40\% at 10 GeV to 72\% at 300 GeV.
Examples of the generated patterns are shown in Fig. 3. These patterns have been obtained assuming that all flash-chamber layers are equally oriented in PFC, so that the patterns actually refer to the projections of the shower tracks onto a plane perpendicular to the axes of the tubular cells. Furthermore, the patterns in these examples have been printed assuming that charged particles are recorded by the chamber cells with 100% efficiency ($\varepsilon_c = 1$). Both assumptions do not affect appreciably, however, the validity of the general conclusions, derived from the analysis of the projected patterns, reported later. In all instances the primary particle ($e^-$ or $\pi^-$) is assumed to income in a direction perpendicular to the PFC layers. In the figures the patterns are represented without taking into account the detector geometry nor, in particular, the "dead space" of the inert Pb and Fe plates present in PFC. Two showers, as they would appear in reality, have been superimposed on Fig.1, as examples. One of them is an em-shower initiated in the 1st Pb plate of the em-PFC by a 50 GeV primary electron entering PFC at a position A; the other one is a h-shower initiated in the 4th Fe plate of the h-PFC by a 50 GeV primary $\pi^-$, entering PFC at a position B about 40 cm apart from A. These "actual patterns", derived from the two computer patterns reported in Fig. 3d), should help in getting a feeling on how they are related to their parent "computer patterns" on which our subsequent analysis is based.

Only part of the large amount of information which can be derived from these patterns has been considered in what follows for the purpose of identifying the nature and estimating the energy of the primary particles. Thus, for instance, since the shower lateral development was available unfortunately only in a small fraction of the computer outputs, we have not exploited at all this additional piece of information, which is certainly useful for that purpose.
5. - Results and discussion -

The results of the Montecarlo calculations for electrons and negative pions of various energies are illustrated in Figs. 3 to 9.

5.1 - Pattern characteristics of em- and h-showers -

In Fig. 3 we give examples of computed patterns for showers originated by electrons and negative pions of the same energy $E$. The difference in patterns for the two types of shower is significant at all considered values of $E$. After inspection of the many other patterns obtained by our Montecarlo simulation we conclude qualitatively that:

1. the pattern of an em-shower reproduces itself pretty well in all simulations made at a given primary energy, the shower being nearly all contained, even at the highest energy values, in the em-part of the PFC;

2. on the contrary, the pattern of a h-shower of a given energy fluctuates considerably from event to event (of course, the total number of flashed cells is greater, on the average, in the cases in which the shower is initiated in the thin Pb plates of the em-PFC);

3. the great majority (87%) of the h-showers initiate after the first five Pb plates, in which em-showers start to develop with a 99% probability. This provides a first criterion for the identification of the primary particle, even if its energy $E$ ($E > 1$ GeV) is unknown.

(+) About 150 patterns were made available on the computer outputs, corresponding to ~10 simulations, for primary electrons and pions, at each of the 8 energy values 1, 2, 5, 10, 20, 50, 100, 200 GeV.
Other criteria for particle identification may be found on the basis of differences that the patterns of the two types of shower exhibit in connection to the longitudinal and lateral shower developments, the presence of backward tracks, the "continuity" of the shower development, the level of uniformity of the flash distribution in space, etc.

5.2 - Detection efficiency -

We have to recall, now, that the efficiency $\varepsilon_C$ of the cells of a standard flash-chamber made of polypropylene sheets is known $^{1}$ to be about 85%. Nevertheless, the real number of flashed cells is smaller than that given by the Montecarlo program for $\varepsilon_C = 0.85$ because of "geometric inefficiency" (cell border effects and dimensions of the cell walls) not included in the program. Hence the value of the cell efficiency to use in the program has to be decreased by some 10% - 20%.

The dependence of the total number of flashes on $\varepsilon_C$ is shown in Fig. 4 for the simulated em-showers. Deviations from linearity, due to the finite dimensions of the cells, are seen to increase with the primary electron energy, as expected.

We note that in the chosen model of total absorption detector, both the electromagnetic and hadronic showers are in practice fully contained in the detector even at energies as large as 100 GeV. A small leakage is present at 200 GeV in the case of the hadronic showers.

5.3 - Calorimeter response: characteristic curves -

In Fig. 5 we report, on a double logarithmic scale, the energy dependence of the total number $N_T$ of flashed cells for
em-showers originated in em-PFC (curve a) and for h-showers originated in h-PFC\(^+\) (curve b), as well as the energy dependence of the standard deviation \(\sigma_{em}\) (curve c) relative to the data of curve a. Departure from linearity occurs here somewhat earlier than observed experimentally \(^2\) for a PFC quite similar to the present em-PFC but characterized by a larger amount of free space (12 mm rather than 4 mm between the 0.5 cm thick Pb plates and the contiguous flash chambers). Notwithstanding curve a can be utilized over the whole energy range to determine the unknown energy of an incoming single electron.

In Fig. 6 we report on an enlarged linear scale part of the results presented in Fig. 5, and compare them to those obtained from measurements carried out at Fermilab \(^3,6\) on a real calorimeter similar to the em-PFC of our model. It is seen from Fig. 6 that a unique calibration curve fits all simulated and measured points, once the latter are normalized to the former at a given energy (10 GeV in Fig. 6). This agreement provides further support to the validity of our Montecarlo simulation.

We show in Fig. 7 the longitudinal development in PFC of em-showers initiated by primary electrons of various energies. The curves are "hand best-fits" through the points derived by the Montecarlo simulation.

As an example, we report also in Fig. 8 the longitudinal development of the hadronic cascade (200 simulations) initiated by a primary \(\pi^-\) of 20 GeV in the h-PFC. The variation of the number of charged secondaries with PFC depth is shown separately for e\(^+\) originated from \(\pi^-\)'s, for charged hadrons (h) and for the total number of shower particles (e\(^+\) + h).

\(\textit{\textsuperscript{(+)}\text{ The h-shower data reported in Fig. 5 are based on 200 simulations made in a previous run of the M.C. program for primary pions of 5,10,20,60 GeV.\)\)
5.4 - Effect of finite cell size -

The relationship between number \( N_{\text{ch}} \) of charged secondaries at a given depth and number \( N_f \) of flashes of the corresponding chamber is

\[
N_f = 4 \epsilon_C \eta \cdot N_{\text{ch}}
\]

where \( \epsilon_C \) is the cell efficiency and \( \eta \) is the fraction of resolved particles (4 is the number of chamber plates). In general \( \eta < 1 \) due to cell finite size. The fraction \( \eta \), and therefore the ratio \( R = N_f / N_{\text{ch}} = 4 \eta \epsilon_C \), decreases of course with increasing the energy \( E \) of the primary particle. This causes a decrease in energy resolution at high energies (say \( E > 10 \text{ GeV} \)).

In Fig. 9 we report the variation of \( R \) with calorimeter depth, as derived from the simulation data of Fig. 8. The variation of \( R \) is on line with expectations based on the curves of the latter figure. Notice that at large depths \( R \) may become even larger than \( 4 \epsilon_C \) due to inclined shower particles which traverse more than one cell of the same chamber layer.

6. - Conclusions -

We have shown that systems of plastic flash chambers can be used not only for energy measurements, but also for particle identification over a wide energy range. High energy muons, \( \gamma \)-rays, electrons and hadrons can be identified with good confidence level by their patterns of flashes in a "plastic flash calorimeter" in which the chambers are alternated with thin plates of dense material: 20 Pb plates 0.5 cm thick and 30 Fe plates 5 cm thick, in the model considered in this paper.
In particular, when an observed shower starts after the fifth (Pb) plate of our calorimeter, the probability of it being originated by a primary electron is less than 1%; hence the primary particle is identified with less than 1% ambiguity as a hadron - if a pion, of the energy given by the "hadron curve" of Fig. 5 - even if the shower pattern is not taken into account. On the other hand, for the ~13% fraction of high energy pions which initiate the h-showers within the first five plates of the calorimeter, unambiguous identification can be achieved in general by exploiting all the information contained in the shower pattern.

We estimate that when utilized as a pion detector the calorimeter described in this article has a rejection factor greater than 1000 against electrons of the same energy (E > 1 GeV). Indeed, rejection factors of ~100 have been reported for similar but shorter calorimeters\(^2\) without taking into account the differences between the longitudinal developments of the hadronic and electromagnetic showers, nor the details of the shower patterns.

We have also pointed out the possibility to measure the specific ionization of charged particles, by counting, on single tracks, the number of flashes in the traversal of a many-layer system of thin-wall flash-cells, in each of which the flashing probability is adjusted at a suitable value for minimum ionization particles.
- References -

1) M.Conversi and L.Federici: Nucl. Instr. & Meth. 151, 93 (1978), also for previous references.


8) F.Lacava: Montecarlo program.


**Figure captions**

**Fig. 1** - Model of plastic flash calorimeter (PFC) utilized for particle identification in the present work. Two events originated by an $e^-$ and a $\pi^-$ of 50 GeV, as simulated by the Montecarlo programs outlined in Sect. 4, are superimposed on the PFC drawing (see also Fig. 3d). The number of flashed cells in $\sim 1900$ in the $e^-$ shower and $\sim 800$ in the case of the $\pi^-$ shower.

**Fig. 2** - Showing structure details of the "em-PFC" and "h-PFC" moduli of which the PFC of Fig. 1 is made.

**Fig. 3** - Examples of showers developing in PFC initiated by primary electrons and pions of energy:
- a) 2 GeV;
- b) 5 GeV;
- c) 20 GeV;
- d) 50 GeV;
- e) 200 GeV.

**Fig. 4** - Dependence of total member of PFC flashed cells (N_T) upon cell efficiency ($\epsilon_c$) for electromagnetic em-showers of various energies, $E$.

**Fig. 5** - Energy dependence of the total number N_T of flashed cells for showers originated by primary electrons (curve a) and for showers originated by primary $\pi^-$'s interacting in the Fe plates of h-PFC; curve c shows the energy dependence of the standard deviation $\sigma$(N_T), for em-showers developed in PFC. All data refer to an assumed cell efficiency $\epsilon_c = 0.8$. The percent standard deviation of the hadron shower developed in h-PFC, not reported in the figure, is about 20% over the energy range 5 to 60 GeV.

**Fig. 6** - Comparison between calibration points of similar PFC as obtained by our simulation and from measurements carried out at Fermilab.

**Fig. 7** - Longitudinal development of em-showers in PFC for primary electrons of various energies $E_e$ ($\epsilon_c = 0.8$).

**Fig. 8** - Longitudinal development of h-showers originated by a primary $\pi$ of 20 GeV, showing separately $e^\pm$ and secondary charged hadron contributions.

**Fig. 9** - Ratio $R$ between numbers of flashes and shower particles in each chamber of the h-PFC.
em-PFC modulus

HOT ELECTRODE

Pb
PLEXIGLASS
FLASH CHAMBER
PLEXIGLASS
Pb

(next modulus)

h-PFC modulus

HOT ELECTRODE

Fe
PLEXIGLASS
FLASH CHAMBER
PLEXIGLASS
Fe

(next modulus)

5cm

Fig. 2
Fig. 3a
Fig. 3b
Fig. 3c
20 GeV $\pi^-$

Nr. of Charged Secondaries vs. Chamber Nr.

- Total
- $e^\pm$
- Hadrons

Fig. 8
\[ \varepsilon_c = 0.80 \quad \pi^{-20 \text{ GeV/c}} \]