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A HIGH ENERGY ELECTRON/PHOTON DETECTOR WITH GOOD SPATIAL RESOLUTION
USING ANALOGUE READ-OUT MULTIWIRE PROPORTIONAL CHAMBERS

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ABSTRACT

An electron/photon detector has been developed for use at high energies. Two layers of lead glass plus Multiwire Proportional Chamber with analogue read-out provide positional information by measuring shower centroids. A spatial resolution of 6 mm (FWHM) has been obtained. Total energy is obtained by summing the front two layers and the main array of lead glass.

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Introduction

An electron/photon detector has been developed for use in a programme of physics using the CERN SPS high intensity muon beam¹⁾. As the detector was based upon an existing lead glass array²⁾ used previously at energies of a few GeV, it was necessary (a) to improve the spatial resolution, (b) to increase the thickness in an active way to contain high energy showers and (c) to improve pion/electron separation. These modifications were achieved by adding a double layer of lead glass plus multiwire proportional chamber (MWPC) in front of the existing array. The spatial coordinates of an incident photon or electron were obtained as the centroids of the electromagnetic showers produced in the lead glass converters and measured in the MWPCs using analogue read-out. The energy of the incident photon was obtained from the sum of the pulse heights measured in the 'pre-shower' and main lead glass arrays.

Photon position detectors employing scintillators³⁾, and MWPCs with digital read-out⁴⁾ are already in use. By using the narrow detector elements (wire spacings) of a MWPC rather than the minimum practicable scintillator widths, for a large detector, of ~ 10 mm, it was hoped to improve both the single particle resolution and the two shower identification and resolution. The disadvantage of digital read-out is that it is insensitive to the density of particles in the shower, i.e. the shower core, and therefore throws away information in a measurement already limited by statistical fluctuations. In the present detector a linear mode of operation was used, whereby the signal developed on a wire was proportional to the number of particles within its sensitive area. The signal was then recorded with analogue electronics. MWPCs with both anode and cathode read-out have been built and tested.

1. Preshower Detector Using Anode Read-out MWPCs

1.1 Construction and Operating Conditions

Two MWPCs of sensitive area $140 \times 160 \text{ mm}^2$, with conventional anode read-out, were used for the first series of preshower detector tests. Each chamber incorporated $20\mu\text{m}$ diameter Gold plated Tungsten anode wires, orthogonal $100\mu\text{m}$ diameter Copper/Beryllium cathode wires and had an anode-cathode spacing of 6.4 mm. A 2 mm anode wire pitch was used to provide good linearity for the analogue read-out although pairs of adjacent wires were ORed together. Computer simulation suggested that this would give adequate resolution and at the same time it reduced read-out costs. In order to obtain an output pulse proportional to the number of particles passing within the sensitive region of a wire, the chamber was run in the proportional mode. This condition was set up using the 3 and 6 keV X-rays of Fe^{55} which deposit all of their energy in the chamber. The distribution of gains of the separate channels was also measured with the source and found to have a spread of $\sim 30\%$ FWHM. All channels were normalised by connecting the data off-line. The variation in gain along a single wire was measured to be $<10\%$ FWHM.

A series of tests carried out with gas mixtures of Argon/ CO_2 , Argon/Methane and Argon/Isobutane showed little variation with mixture for the required mode of operation, and so mainly for reasons of convenience the latter mixture was used in the ratio 4:1.

The chamber was operated at a voltage of 3.3 kV, a value which satisfied the requirements of linearity and efficiency. Charge sensitive, high impedance amplifiers mounted on the chamber handled the small signals resulting from the lower gain operating conditions.

1.2 Test Beam Set-up

A pre-shower detector incorporating the above chambers was tested in a PS test beam at CERN. The apparatus is shown in Fig. 1. The beam contained pions with a few percent of electrons which were selected by means of two Čerenkov counters C_1 and C_2 . Beam energies between 2 and 4 GeV were used, and the maximum pion intensity was $\sim 10^4$ /pulse.

Two layers of pre-shower detector were installed, each made up of a transverse lead glass block measuring 2.7 radiation lengths (r.l.) along the beam direction, followed as closely as possible by a MWPC. The detector was completed by a 3 x 3 array of lead glass blocks, PG3, which measured the remainder of the shower energy. All blocks were of dimension $80 \times 80 \times 400 \text{ mm}^3$.

Two drift chamber modules D_1 , D_2 , each containing orthogonal y, z planes were located $\sim 1 \text{ m}$ and $\sim 2 \text{ m}$ upstream of the first MWPC. These measured incident trajectories which were projected onto the MWPCs with an accuracy of $< 1 \text{ mm}$ in the y and the z planes.

The trigger consisted of the coincidence $T_1 \cdot T_2 \cdot \bar{T}_3 \cdot C_1 \cdot C_2$ for electrons and $T_1 \cdot T_2 \cdot T_3 \cdot (C_1 \oplus C_2)$ for pions. Showers originating upstream were vetoed by T_3 which had a $20 \times 20 \text{ mm}^2$ hole.

After amplification, the MWPC pulse heights together with those of the lead glass were recorded by ADCs, the drift chamber times were recorded by TDCs, and all information was read-out into a computer and written to magnetic tape.

1.3 Results

Minimum ionizing pion pulses were attenuated to lie in as low an ADC channel as possible in order to obtain the maximum dynamic range for high multiplicity electron showers. The distribution of the mean pulse height/wire for 4 GeV pions in the first chamber had a resolution of $\sim 90\%$, and possessed a high energy tail. The mean pulse height/wire curve for

electrons was broader and peaked at approximately twice the minimum ionizing pion pulse height. Distributions of the number of hit wires/event in MWPC1 for pions and electrons are presented in Fig. 2. The mean numbers of wires/event were 1.5 and 8.3 respectively for MWPC1, and 1.5 and 10.7 respectively for MWPC2; the larger electron spread resulting from further shower development. Many of the high multiplicity large pulse height pion events were attributed to electron contamination of the pion trigger, and to knock-on electron showers created in the front lead glass block. A separate run without the first lead glass block removed the latter effect, producing a mean multiplicity of 1.35, and considerably reduced the high energy tail of the pulse height distribution. A study of the effects of low z absorbers positioned in front of the chambers to reduce knock-on showers produced inconclusive results.

Distributions of total pulse height/event for pions and electrons are presented in Fig. 3. Assuming a linear chamber behaviour, the ratio of the mean values of these distributions (mean electron pulse height/mean pion pulse height) gives the mean number of electrons in the shower. For 4 GeV events this figure was found to be 14.

The difference between the centroid of a shower measured by the MWPC and the intercept of the incident trajectory projected from the drift chambers gives a measure of the position resolution of the detector. The centroid can be defined in terms of the number of hit wires, $\sum_i N_i / N$ ($N_i = i^{\text{th}}$ wire, $N = \text{total hit wires}$), referred to here as the unweighted centroid, or in terms of the pulse heights, W_i , recorded on the wires, $\sum_i W_i N_i / \sum W_i$, referred to here as the weighted centroid. For pions, the distribution of the weighted centroids had a full width half maximum of $\sim 4\text{mm}$, essentially a measurement of the intrinsic resolution of the MWPC. Some resolution curves for electrons are shown in Fig. 4 which includes unweighted, weighted and fitted distributions. It is seen that the FWHM of the weighted curve is half that of the unweighted one with a value of 10mm . To obtain the fitted curve, the average 4 GeV simulated distribution was fitted to the experimental one, on an event by event basis using a χ^2 criterion for optimisation. The resultant curve showed an improvement in resolution attaining a FWHM of 7mm .

Two additional runs were made with 4 and 6 wires ORed together to a

single amplifier channel, to study spatial resolution as a function of detector element width. The FWHM values of the weighted distributions (see Fig. 5a) were respectively 12.5 and 14.0mm, compared with 10.0mm for the normal 2 wires/channel situation. The curve shown in the figure is the simulated result discussed in the following section.

1.4 Monte Carlo Simulation

A Monte Carlo programme was used to simulate and study the operation of the pre-shower detector. Electron and photon initiated showers were allowed to develop in a lead glass medium and the emergent charged particles were recorded in detector elements. The measured pion pulse height distribution corresponding to a minimum ionizing particle distribution was used to generate the final shower electron pulse heights recorded by the MWPC. Particles were followed down to 1 MeV although the present results were insensitive to this cut off.

The programme was first checked against the data. Calculated values of wire multiplicity and total pulse height/event for electrons are shown together with the experimental data in Figs 2b and 3b respectively. Good agreement was found from which it was concluded that the programme was able to give a reasonably good representation of the real situation, and that the linearity of the chamber was adequate, ie. the output pulse height was proportional to the number of particles per wire.

The simulated curve of weighted positional resolution was found to be in close agreement with the data. Since the minimum ionizing distribution used to weight the shower electrons was the measured one, the simulated curve was not expected to be significantly narrower than the experimental one.

Once the credibility of the programme had been established, it was used to study other features of the detector. The most important parameter was found to be the lead glass-MWPC separation. The variation of positional resolution with separation for incident energies of 4 and 10 GeV is shown in Fig. 5b. This decrease of resolution with separation results from the rapid increase in shower size in air produced by the low energy,

large angle scatters in the back region of the block. Minimisation of this parameter is clearly very important. A study of the variation of resolution with lead glass thickness found that there was little change within the range 2-4 r.l. for energies between 2 and 50 GeV. A further study of resolution as a function of detector element size yielded the curve shown in Fig. 5a. Simulation and experiment were found to be in agreement with errors, and the element width of 4mm was adopted as satisfactory.

1.5 Further Development

From the above tests and simulations it was concluded that a MWPC operating in a linear mode, behind 2.7 r.l. of lead glass, was able to give acceptable, predictable spatial resolution for incident electrons and photons, provided that the absorber-chamber separation was $\leq 30\text{mm}$.

The remaining issue was how to minimise the separation for both y and z coordinates. A possible solution was to use a thin gap thin framed chamber with analogue read-out of both cathode planes, the two planes having orthogonal wires. Such a technique had already been used for locating single particles⁵⁾, but not for showers. The same absorber - anode plane separation would be involved for each coordinate, since the cathode signals are induced from the anode plane. It was considered worthwhile to build such a chamber to investigate the method.

2. Pre-shower Detector Using a Cathode Read-out MWPC

2.1 Construction and Operating Conditions

A MWPC of sensitive area $150 \times 150 \text{ mm}^2$ was built using the same anode plane assembly as previously, but with strip cathode planes. The latter construction was used since it enabled the planes to be made as simple thin supporting structures. Simulation studies determined the optimum parameters to be a strip width of 3mm on a 4mm pitch, together with an anode-cathode separation of 3mm. The cathode planes were made from etched Copper-clad printed circuit board. An Aluminium plate plus thin outer frame was bolted to each side of the chamber, the plate providing a good grounded screen. Care was taken to maintain the anode-cathode gap

tolerance to $\leq 50\mu\text{m}$ in order to have uniform gain across the whole of the chamber. As before, a 4:1 Argon/Isobutane gas mixture was used. Charge sensitive high gain amplifiers⁶⁾ were mounted on the chamber, which was operated in a linear mode at a voltage of 2.1 kV.

Beam tests were carried out using the same experimental set-up as for the anode read-out tests.

2.2 Results

A single minimum ionizing pion passing through the chamber, produced a pulse height significantly above threshold on an average of 3 cathode strips/plane/event. This is shown in Fig. 6a for the plane with strips perpendicular to the anode wires, and the corresponding distribution for electrons is shown in Fig. 6b. As expected, the electron spectrum is slightly broader than the equivalent anode read-out plot, with a mean value of 9.3 strips/event. The minimum ionizing distributions/strip were of similar shape to the anode read-out curve, but somewhat broader with an average FWHM of $\sim 120\%$. The cathode plane with strips parallel to the anode wires gave similar results within errors for all of the measurements, and is not discussed separately.

Distributions of the total pulse height/event for pions and electrons are presented in Figs 7a and 7b respectively. Due to sharing between cathode strips the dynamic range of pulse height seen by a single strip was larger than that for a wire in the anode read-out. However the ratio of the mean values of the electron and pion total pulse height/event was 15, a similar value to the anode read-out ratio, confirming that the cathode read-out chamber was also linear up to high shower multiplicities.

The weighted positional resolution distribution is plotted in Fig. 8. It has a FWHM of $\sim 6\text{mm}$, a value significantly better than the weighted anode read-out result, which is attributed mainly to the smaller lead glass-anode separation of $\sim 20\text{mm}$. This value is also consistent with the simulated value as shown in Fig. 5b. Such a resolution was considered to be acceptable for the requirements of the final detector.

3. Two Shower Separation Using the MWPCs

At the proposed location of the final detector the minimum $\pi^0 \rightarrow 2\gamma$ separations up to 10 GeV and 100 GeV are ~ 35 cm and ~ 3.5 cm respectively. Hence two shower separations corresponding to at least these values are required for identification of π^0 s, whereas separations down to smaller distances will give more information on single photon shower overlaps.

Although double shower spectra were not measured, they were generated from single shower data by software. Simulated double showers were also studied over a wide range of energy between 1 and 50 GeV, incorporating the resultant changes in shower multiplicity and spread.

Identification of single and double showers was attempted using two criteria. Firstly, and simply, the ratio of the sum of the pulse heights on the central four wires of the distribution to the total pulse height was used, and secondly a theoretical averaged single shower spectrum corresponding to the measured total energy, was compared with the experimental spectrum. Both methods yielded similar results. Some curves for the simple ratio method are presented in Fig. 9a. For the simulated data, showers of random energy between 1 and 10 GeV were overlapped, whereas only 4 GeV measured data were used. It is seen that separations down to ~ 5 cm are achievable with up to 5% confusion of single and double events. This figure improves with energy as the pulse height distribution becomes more peaked, and for showers randomly generated in the 10-50 GeV energy range, a separation ~ 3 cm was achieved for $\sim 5\%$ confusion.

Finally, an estimate of the spatial resolution of two shower separation was made by fitting simulated distributions of half total energy to two overlapping spectra. Some results are presented in Fig. 9b, which shows the actual minus the calculated separation for overlapping showers with 5 cm separation and with random energy in the range 1-10 GeV. The resultant FWHM is 14mm and the mean of the distribution is consistent with zero. A similar curve for the measured data is also shown.

The resolution curve for 10-50 GeV overlapping showers with a separation of 3 cm was calculated to have a FWHM of 10 mm.

4. Electron-Pion Separation

4.1 Use of the MWPCs

Samples of 4 GeV electrons and pions defined by the standard trigger conditions were used. The data were first displayed in 2 dimensional (2D) plots of total pulse height/event for MWPC 1 versus MWPC2. From the electron distribution, it was immediately clear that there was a pion contamination in the sample and so a cut was made to exclude events lying within the minimum ionizing pulse height peak in both chambers. This removed 4.3% of the events and the remainder were accepted as electrons. Separation of pions and electrons was then carried out using cuts in the 4D phase space of total pulse height/event, and wire multiplicity/event for each chamber. Using the pulse height information alone, Fig. 10, 97.1% rejection of pions for 3.5% loss of electrons was achieved. Making cuts on both pulse height and multiplicity improved these figures to 98.2% rejection of pions for 2.0% loss of electrons.

Using the information from one chamber alone, electrons and pions were separated making cuts on the 2D distributions of total PH/event versus multiplicity/event. The first chamber gave the best result with a figure of 95% pion rejection for 8% loss of electrons.

As discussed later, the combined lead glass system was able to give a somewhat better result. Of the events not satisfying the lead glass cuts, 90% also failed the MWPC cuts, and so any additional separation provided by the chambers was not discernible within the statistics available. However, the similarity of the values achieved with the chambers and the lead glass was further confirmation that the chambers were operating satisfactorily.

Particle identification with the MWPCs was limited by the confusion between knock-on showers produced by pions in the lead glass, and electrons undergoing little or no interaction. The magnitude of the former process was measured in a separate run, without any lead glass present, to be $\sim 7\%$ per layer. This effect is seen in the pion pulse height distribution as tails extending along the axes. Although such events could not be identified by a single chamber, two chambers were able to resolve those events with a shower in the first chamber. Electrons which had little or no interaction

in the first layer of lead glass lay in the same region of the phase space as pions which produced knock-on showers in the second layer, and these unseparable types of events provided the final limitation in electron-pion separation for the chambers. In principle, the lead glass is able to resolve these events.

Finally, it was calculated that charge exchange reactions giving rise to π^0 s in the front 2 layers of lead glass were present at $\sim 1\%$.

4.2 Use of the Lead Glass System

The electron-pion separation efficiency of the lead glass system alone was investigated in a separated experiment in which pion and electron definition was provided by three Cerenkov counters. By this means the pion contamination of the electron sample, and the electron contamination of pions, were known to at least an order of magnitude better than the final rejection figures (see later). Data were taken at incident energies of 4 and 6 GeV. Three configurations of the lead glass were considered, the 3×3 array (PG3) alone, the first transverse block (PG1) plus PG3, and the complete system, PG1 + PG2 + PG3.

Using PG3 alone a single cut on the total pulse height distributions was made, yielding 95% pion rejection at 4 GeV and 6 GeV each for 1% loss of electrons.

With the information from PG1 and PG3 available, cuts were made on both total pulse height and on a 2D scatter plot of the total pulse heights in PG1 and PG3. Only the 6 GeV data were used giving a pion rejection of 98.3% for 1% loss of electrons.

Finally, the information from PG1, PG2 and PG3 was used. This enabled cuts to be made on total pulse height alone, on the 2D total pulse height scatter plots of the three PG combinations, and on the fractions of the total shower deposited in PG2, and PG1 plus PG2. The figures obtained for the total lead glass system were 98.2% pion rejection at 4 GeV and 99.2% rejection at 6 GeV, each for 1% loss of electrons.

Conclusions

An electron photon detector consisting of two layers of lead glass (2.7 r.l.) plus MWPC, the pre-shower counter, followed by a total absorption array of lead glass, has been studied and found to give good results up to an energy of 100 GeV. Monte Carlo simulation studies have been able to closely reproduce the experimental results, and have been used to predict others with some confidence.

A single layer of lead glass plus MWPC has achieved a positional resolution at 4 GeV of ≤ 6 mm FWHM. In addition two shower separations sufficient to resolve all $\pi^0 \rightarrow 2\gamma$ events up to 100 GeV appear possible, with separations varying from 50 mm at a few GeV to 30 mm in the region 10-50 GeV for 95% efficiency of separation.

Electron-pion separation using the MWPCs alone has achieved 98.2% rejection of pions for 2% loss of electrons at 4 GeV, whereas the total lead glass system has reached 98.2% rejection for 1% loss of electrons. Ninety per cent of events failing the lead glass cuts also failed the MWPC cuts implying that additional separation with the chambers was small, and in any case was not detectable with the statistics available.

The use of analogue read-out from orthogonal strip cathode planes of a MWPC has enabled an electron/photon detector to be built which is capable of giving good one and two particle resolution in a high energy, multi-particle environment.

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Figure Captions

- Fig. 1 Test Beam layout.
- Fig. 2 Number of wires/event for 4 GeV incident pions (a) and electrons (b) using anode read-out.
- Fig. 3 Total pulse height/event for 4 GeV incident pions (a) and electrons (b) using anode read-out.
- Fig. 4 Spatial resolution curves for 4 GeV incident electrons using anode read-out.
- Fig. 5 (a) Spatial resolution detector element width for 4 GeV incident electrons, simulated and measured data.
(b) Spatial resolution versus absorber detector separation for incident electrons of 4 and 10 GeV, simulated and measured data.
- Fig. 6 Number of strips/event for 4 GeV incident pions (a) and electrons (b) using cathode read-out.
- Fig. 7 Total pulse height/event for 4 GeV incident pions (a) and electrons (b) using cathode read-out.
- Fig. 8 Spatial resolution curve for 4 GeV incident electrons using cathode read-out.
- Fig. 9 (a) Two shower identification using anode read-out. Two shower separation efficiency for shower separations of 20, 30, 40 and 50 mm versus the ratio of pulse height on the central 4 wires to the total pulse height, for 4 GeV measured and 1-10 GeV simulated data.
(b) Two shower resolution at a separation of 50mm for 4 GeV measured and 1-10 GeV simulated data using anode read-out.
- Fig. 10 Total pulse height/event in MWPC1 versus MWPC2 for 4 GeV incident pions (a) and electrons (b), using anode read-out.

Fig. 1

- T_1-4 SCINTILLATORS
- $\check{C}_1, \check{C}_2$ ČERENKOV COUNTERS
- D_1, D_2 DRIFT CHAMBERS
- PG_1-3 LEAD GLASS
- P_1, P_2 MWPCs

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

(a)

Fig. 10

(b)