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Thin, High Gain Wire Chambers for Electromagnetic Presampling in OPAL

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Abstract

Thin multiwire chambers, operating in a high gain mode, are used for electromagnetic presampling in the endcaps of the OPAL detector at LEP. The design, setup and performance of these chambers with respect to energy and space resolution for electromagnetic showers as well as to pion/electron separation is described.

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1. Introduction

Today's storage ring experiments attempt to cover almost 100% of the solid angle with detection devices for tracking, particle identification, and calorimetry. Space restrictions, especially for calorimetry, are often a major concern for a detector design.

Thin multiwire chambers operating in a high gain mode have been developed [1] to cope with such space limitations. They are used for hadron calorimetry in the magnet pole tip of the OPAL experiment where only narrow slits in the pole tip iron are available for detector instrumentation. The operation and performance of the pole tip calorimeter has been described elsewhere [2],[3]. The same chamber design with modified geometry and readout is used for a presampler detector in the endcaps of OPAL. This paper describes the design of the OPAL endcap presampler and its performance in various test beam setups.

The OPAL experiment is a large magnetic 4π detector designed and built for the e^+e^- storage ring LEP at CERN [4]. Its main features are a large cylindrical drift chamber for the detection of charged particles covering 95% of the solid angle, an array of about 14000 lead glass blocks covering the barrel and endcap regions of the experiment (98% of 4π), and a hadron calorimeter covering barrel, endcap, and pole tip regions (95% of 4π). Presampling devices are introduced in both, barrel and endcap, regions, to improve energy and position resolution for particles producing electromagnetic showers in the material before the electromagnetic calorimeter. Material in front of the lead glass is introduced by the coil structure of the solenoid magnet and the side flanges of the central drift chamber together with a pressure vessel housing the central detector [4], for barrel and endcap regions, respectively. The material thickness lies between a minimum of 1.3 radiation lengths for most of the solid angle up to a maximum of about 4 radiation lengths depending on the detailed geometry of the experiment and the angle of incidence of a showering particle.

Lead glass shower counters with photomultiplier or phototriode readout at the end of the counter have no means of resolving the longitudinal shower profile. As such they cannot compensate for the loss of energy that occurs in any material in front. A second energy measuring device between the radiator material and the LG calorimeter allows to correct for the influence of the material by correlating both measurements with each other, thus introducing "presampling" into the electromagnetic energy measurement. Once the correlation function between the energy measured in the lead glass and the energy measured by the presampler is known, this function can be used to obtain a more accurate measurement of the shower energy, event by event.

Thin, high gain multiwire chambers operating in a saturated mode are ideally suited to match the constraints being imposed by the requirements of energy and position resolution as well as by severe space restrictions in the OPAL endcap regions.

2. Chamber description and geometry

The endcap presampler is an umbrella type arrangement of 32 chambers in 16 wedges (sectors) which covers the electromagnetic calorimeter between 18° and 35° . A three dimensional sketch is shown in Fig. 1(a). The chamber size is optimized to fit into the available space between the pressure bell and the endcap lead glass detector. At the outer radius, acceptance coverage is guaranteed for showers which traverse at least about half of the thickness of a lead glass block; at perpendicular incidence the blocks are $20-22 X_0$ long. No attempt has been made to cover the regions at the inner radius where the total material thickness including the pressure bell flange exceeds four radiation lengths.

Each sector has one large and one small trapezoidal chamber, the large one being inclined by 18° with respect to the plane perpendicular to the beam in order to follow the shape of the pressure bell and the lead glass. The small chamber is at 90° to the beam axis. A cross section of the detector is shown in Fig. 1(b). Neighbouring sectors overlap each other to ensure complete coverage of the endcap region. The front end readout electronics is directly mounted onto the chambers carried by an additional G10 printed circuit board. A schematic view of the cross section of an individual chamber is shown in Fig. 2.

The anode wire plane consists of 432 (69) gold plated tungsten wires of $50\text{ }\mu\text{m}$ diameter spaced by 2 mm. Here and in the following the numbers in parenthesis refer to the small chambers. The wires are strung with a tension of 350g and supported by spacers to avoid gravitational sagging and to provide mechanical strength for the chamber itself. The geometrical dimensions are given in Fig. 3. The cathode planes are thin ($200\text{ }\mu\text{m}$) G10 sheets coated with resistive carbon paint placed at a distance of 1.6 mm from the anode wire plane. G10 boards of 1.6 mm thickness provide mechanical strength and cathode readout by means of strips and pads etched on the side facing the cathode sheet. The layout of 32 (22) strips and 16 (10) pads is sketched in Fig. 3. The total thickness of the chamber is 6.8 mm, the distance between the two cathode planes (gap width) is only 3.2 mm.

The completed presampler detector mounted in front of the lead glass on the OPAL pole tips is shown in the photograph of Fig. 4.

3. Chamber operation characteristics

Detailed studies of the chamber operation are described in [2]. We summarize the main operation characteristics here.

The presampler chambers are operated at a voltage between 3.5 kV and 3.7 kV using a gas mixture of CO_2 and n-pentane. The mixture is obtained by bubbling CO_2 through the n-pentane liquid at a temperature of 17° to 18° corresponding to a mixture of about equal amounts of both gases. These characteristics ensure operation in a nearly saturated mode [2] such that the total pulse height observed is roughly proportional to the number of shower particles entering the chamber. The gas amplification reaches values of the order of 10^7 . The maximum input gas overpressure allowed is about 3 mbar to avoid inflating the chamber and breaking the glue joints.

The chamber operation is quite sensitive to any external forces or torques applied which might change the gap between the cathode and anode planes. Special care must thus be taken in the design of the support ring holding the chambers in the position between the lead glass and the pressure bell. The support structure is visible in the photograph of Fig. 4.

4. Readout electronics

Two space coordinates are provided by the simultaneous readout of wires and strips. The energy correction for showers (see section 5.3) is best obtained using the pad readout because the summation over a large number of electronic channels, which is necessary for wires and strips, is largely reduced. The additional pad readout also provides a reduction of ambiguities present on wires and strips to aid offline cluster finding. For the small chambers no wire readout is foreseen.

Multiple scattering of particles in the material before the presampler renders a position resolution, i.e. granularity, of much better than a few millimeters unnecessary. The anode wires of the large chamber are therefore grouped into groups of 4 wires serving one readout channel. Together with the cathode strips and pads this results in a total of 190 electronic channels per sector and 6080 channels total for both endcaps. During operation at LEP all channels have analog readout using a 24 x 32 fold multiplexing arrangement which is outlined in Fig. 5. No preamplification is needed.

The front end electronics consists of charge integrating multiplexers (MCI) which were developed at Saclay [5]. Each hybrid equips 8 channels. Four hybrids (32 channels) are multiplexed by a summing amplifier hybrid circuit (CN2125II) providing a 32-fold multiplexing at the front end. Switching signals with an appropriate timing tailored to the conditions during LEP operation must be provided by a sequencer VME module. The front end electronics is directly mounted onto the presampler chambers by means of an additional board carrying HV components and the multiplexing hybrids (c.f. Fig. 2.).

At the rear end additional 24-fold multiplexing is obtained in the ADC module. The entire readout system is realised in VME standard and connected to a local system crate via a VIP (VME Interface Processor) module. A local microprocessor (68020) running under the OS9 operating system allows communication with the Sequencer, ADC, and Fanout modules and reads out the digitized information from the ADC module. The digitization time for one channel is 5 μ s yielding a total of about 5 ms for the readout of 32 x 24 electronic channels into the ADC memory including delays when switching between groups of channels. During operation in LEP the time necessary to scan the ADC memory, to perform zero suppression, and to transfer the information to the local system crate processor must be added. A second event can be accepted before the ADC memory is read out provided that after charge collection in the front end capacitors the digitization sequence is halted while the first event is being transferred into the processor memory. This feature reduces the average readout time substantially, depending of course on the trigger rate. For an assumed trigger rate of 20 Hz the total time for digitisation and read out into the local system crate is about 7 ms per event on average for the entire detector.

5. Testbeam performance

In this section the performance of the chambers with respect to energy and position resolution of showers and with respect to π/e separation is described. Test beam studies have been carried out with two versions of prototype chambers and one final chamber in different test beam setups always together with an array of lead glass counters. Here we report only on the results of a setup using the final chamber design as it is used in OPAL.

One presampler sector, consisting of one large and one small chamber, was exposed to electrons from secondary beams of the CERN SPS up to energies of 50 GeV. The radiator material was represented by a stack of Al slabs, each 0.2 radiation lengths thick arranged similarly to the actual geometry in OPAL. The layout of anode wires, strips and pads was as described in chapter 2. The chambers were read out using the multiplexing electronics introduced in chapter 4. The performance of the multiplexing electronics was found comparable, if not superior, to conventional ADC's (LeCroy 2282B) which were used in a former test, due to the short distance achieved by mounting the front end multiplexing hybrids directly onto the chambers. Energy and position resolution as well as e/π discrimination studies were done using an arrangement of one half of the actual OPAL endcap lead glass calorimeter [6] behind, and a delay wire chamber in front of the presampler chamber. In most of the studies described below the beam was incident on a lead glass block of 16.4 radiation lengths. Most of the OPAL endcap lead glass assemblies are longer (20-22 X_0).

5.1 Response to minimum ionizing particles and to showers

In Fig. 6(a) an amplitude spectrum of an individual pad obtained from a charged pion beam at 20 GeV at an operating voltage of 3650 V is shown. This is compared in Fig. 6(b) with the response to a 20 GeV electron beam showering incident on a $1.6 X_0$ Al radiator block upstream of the presampler chamber. The pedestal peak in Fig. 6(a) is well separated from the minimum ionizing signal.

A minimum ionizing particle produces a pulse of typically 20 mV amplitude and 150 ns foot width into 50Ω . The dynamic range for charge collection ranges from 2 pC for the smallest signals of individual minimum ionizing particles to about 500 pC for a 50 GeV electron shower incident on a $1.6 X_0$ aluminium block in front of the chamber. No amplification is needed for the readout of the signals. The chamber response for minimum ionizing particles as well as for showers is shown in Fig. 7(a) as a function of beam energy for a fixed radiator thickness of $1.6 X_0$ and in Fig. 7(b) as a function of material thickness at a fixed beam energy of 10 GeV. The comparison with a Monte Carlo calculation (EGS) is also shown.

5.2 Cross talk

We have investigated four different possible sources of cross talk between electronic channels. They are best described considering for a moment only pad-pad cross talk correlations.

A first source of cross talk is caused by the direct capacitive coupling between neighbouring pads rendering a positive correlation the size of which is given by the pad-pad capacitance relative to the pad capacitance to ground. A second kind of cross talk is due to the potential drop of the anode wire group upon an avalanche arriving at the wire which causes a negative cross talk on the pads. The size of this effect is governed by the wire to pad capacitance relative to the HV decoupling capacitance (here 470 pF). As a third effect we considered the diffusion of charge on the graphite coated cathode during the charge collection time. That is, the charge deposited on the resistive surface ($\approx 50 \text{ k}\Omega$) will spread in all directions into areas covered by neighbouring pads. This effect appears as positive cross talk in the detector and is dependent on the actual geometry of the pads and the charge collection time of the electronics. The relevant diffusion constant for the ‘charge diffusion’ on the surface of the graphite is given by $(R_{\text{pad}} \cdot C_{\text{pad}})^{-1} \approx 1.3 \text{ cm}^2/\mu\text{s}$. As a last potential source of cross talk we considered the direct correlation between neighbouring electronic channels in the front end electronic circuits.

The different types of cross talk were measured directly in the test beam setup described above by steering the beam in a pad (‘signal’ pad) and analysing the response of the adjacent pads. Taking into account the orientation of the anode wires which run under the ‘signal’ pad one can disentangle the first three kinds of cross talk by comparing neighbouring pads which share the same anode wire groups, neighbouring pads which do *not* share the same wires, and diagonal pads.

Between two pads we find typically +1% direct pad to pad cross talk, -1.5% cross talk due to the anode wire voltage drop, and about +5% due to the effect of charge spreading with a collection time of $1 \mu\text{s}$. Depending on the position of the projectile particle relative to the pad geometry this can add up to a sizeable effect of up to 40%. A much smaller (300 ns) collection time, possible in IEP, will reduce the latter. The measurements agree with an estimation obtained by the ratio of capacitances involved. Cross talk in the front end electronics itself was not observed.

Cross talk on wires and strips was not studied in detail. On the wire groups, direct capacitive cross talk is reduced since only cross talk on wires of neighbouring groups will show an effect while cross talk on wires within the same group will not affect the charge collection. For strips the same types of cross talk need to be considered. Here the charge diffusion is seen to be much bigger than in the case for pads. This will in some clean cases allow a better position measurement using a weighted

mean but it will cause problems in resolving shower clusters in the presence of events with high multiplicities.

5.3 Presampler energy correction

When a showering particle is incident on passive material like aluminium before entering the electromagnetic calorimeter some fraction of its energy is rendered invisible to the calorimeter, mainly due to energy loss or absorption of the shower particles which are created in the passive material. This process is governed by large fluctuations in the amount of energy loss of the incident projectile particle. By exploiting the presampler information in correlation with the lead glass measurement an improvement in combined energy resolution can be obtained.

We have studied the effect of radiator material on the energy resolution in OPAL using electron beams from the CERN SPS between 2 and 50 GeV, using different radiator material thicknesses. Fig. 8(a) displays the correlation of presampler pulse height (ADC counts) and energy measurement of the lead glass counters for a 20 GeV electron beam. A clear anti-correlation between E/P , the measured lead glass energy divided by the measured beam momentum, and the total measured charge collected in the presampler is evident especially in Fig. 8(b) which shows the mean E/P as a function of presampler charge together with a cubic fit to the correlation. The energy dependence of the correlation can be taken from Fig. 9 where the mean E/P is shown as a function of presampler ADC counts for various energies.

In the following correction procedure fits to the mean E/P as described above are used to correct for the effect of energy loss in the radiator material. The correlation function used is of the form

$$f(Q) = a_0 + a_1Q + a_2Q^2 + a_3Q^3$$

where Q denotes the charge (ADC counts) measured in the presampler and the a_i are the energy and material dependent correlation coefficients.

Let E_{LG} be the energy measured by the lead glass calorimeter and $\tilde{E} = \beta_{shift} \cdot E_{LG}$ the best estimate for the actual electron energy obtained by multiplying by a calibration constant, β_{shift} ¹, taking into account the losses occurring in the radiator material. We then wish to perform a presampler correction to the measured E/P such that the corrected quantity is independent of Q , and also has the same mean value as $\tilde{E}$. Calling the correction function $g(Q)$, we then obtain

$$\langle \tilde{E} \cdot g(Q) \rangle = constant = \langle \tilde{E} \rangle$$

A reasonable choice for $g(Q)$, to ensure approximate Q independence of corrected energy, is $\alpha/f(Q)$ which yields

$$\alpha = \langle \tilde{E} \rangle / \langle \frac{\tilde{E}}{f(Q)} \rangle$$

Event by event we then obtain the presampler corrected energy

$$E_{corr} = E_{LG} \cdot \beta_{shift} \cdot \left(\frac{\alpha}{f(Q)} \right)$$

¹ Note that this correction can be applied without knowing the presampler information.

Clearly, in the above framework, the presampler correction can be easily decoupled if the presampler information should not be used or the association of a lead glass energy cluster with a presampler cluster is not possible. Applying the presampler correction an improvement of combined energy resolution of presampler and lead glass, as compared to the resolution obtained by the lead glass alone, is obtained. This is displayed in Table 1 and in Fig. 10(a) where we plot the energy resolution σ_E/E as a function of beam energy. Typically, at 10 GeV, about half of the deterioration in resolution suffered from the material is gained back applying the presampler correction. At lower energies the improvement is smaller, at higher energies larger.

Table 1

Energy resolutions obtained with a calorimeter consisting of a lead glass array and presampler chambers. Quoted are values measured without material and with $1.6 X_0$ of aluminium for various energies.

Energy (GeV)	σ_E/E (%) I.G with no material	σ_E/E (%) $1.6 X_0$, I.G only	σ_E/E (%) $1.6 X_0$, I.G + presampler
2	3.81 ± 0.06	9.36 ± 0.18	8.17 ± 0.17
3	3.08 ± 0.07	7.33 ± 0.08	6.12 ± 0.07
5	2.72 ± 0.04	5.43 ± 0.06	4.61 ± 0.05
10	2.29 ± 0.03	3.85 ± 0.04	3.05 ± 0.04
20	1.94 ± 0.04	3.07 ± 0.03	2.29 ± 0.03
35	1.79 ± 0.03	2.50 ± 0.03	1.87 ± 0.02
50	1.65 ± 0.05	2.18 ± 0.03	1.69 ± 0.02

To explicitly show the effect of the presampler correction, in Fig. 10(b) we have quadratically subtracted the intrinsic lead glass resolution (σ_E/E)_{no material} from the lead glass only result (black dots) as well as from the presampler corrected resolution (black squares), multiplied with $\sqrt{E}$ to show the approximate $1/\sqrt{E}$ scaling of the upper curve. The two measurements thus give an estimate of the material effect to the resolution if one does or does not apply the presampler correction. The functional dependence of the resolution on the thickness of the radiator material is shown in Fig. 11. Obviously, a presampler is no alternative for minimal material in the detector design. In particular, aluminium as a radiator material is a bad choice, compared for example to lead, due to its relatively large ionisation loss for a given radiation length.

5.4 Position resolution

In this section we report on some measurements of the position resolution of the presampler for both, single electrons with no radiator material in the beam line and for electron showers which have been initiated by $1.6 X_0$ of aluminium located 15 cm before the chamber. The position measurements are taken with respect to a delay wire chamber (DWC) with spatial resolution in both transverse coordinates of better than $200 \mu\text{m}$, located 4.5 m upstream of the presampler chamber. In the test beam setup the axis of the chamber had to be rotated azimuthally by 11.25° to the vertical, and the chamber was inclined by 18° . In this orientation the wires still measure essentially the vertical

coordinate and the strips measure the horizontal coordinate. It should be noted that the effective strip pitch varies as a function of the chamber radius as the strips run radially outwards (c.f. Fig. 3).

The contribution of the intrinsic beam divergence to the measured resolution can be neglected. The rms spread of the beam in the vertical plane is estimated to be $11 \mu\text{rad}$, and in the horizontal plane it is $90 \mu\text{rad}$. This corresponds to a 0.05 mm contribution to the resolution due to beam optics vertically and about 0.4 mm horizontally. However, the main contribution to the beam divergence is multiple coulomb scattering arising from scattering centres of about $6.3\% X_0$ well upstream of the DWC, and from $8\% X_0$ of material near the DWC. The trigger is tightly defined by some scintillator vetoes with a $3 \text{ cm} \times 2 \text{ cm}$ hole near the DWC. Therefore electrons which scatter in the upstream section may not be accepted. It can then be seen that the multiple scattering contribution at high energies will be caused by scatters in the material of both regions, whereas for lower energies the material near the DWC is the predominant effect.

Figs. 12 (a) and (b) display the resolutions obtained from wire and strip measurements, respectively. For single minimum ionising particles the expected intrinsic resolution of the chamber for wires and strips is simply the effective pitch divided by $\sqrt{12}$, which gives 2.17 mm and 4.62 mm , respectively. In the test beam setup, because of the inclination of the chamber, minimum ionising particles deposit charge on two wire groups in 15% of the cases. In these cases a better estimate of the position is the midpoint of the two wire groups. In the final experiment particles from an e^+e^- interaction will be incident at an even larger angle resulting in multiple wire clusters. Therefore the position resolution should be improved compared to the situation presented here.

For high energies the resolution approaches the intrinsic resolution fixed by the respective pitch values. The worse resolution at lower momenta is simply the effect of multiple scattering which leads to contributions to the resolution of order $15 \text{ mm} / E \text{ (GeV)}$. Position resolution measurements for minimum ionising particles using the strips are difficult because of the small pulse height per channel (caused mostly by cross-talk – see section 5.2) and are omitted in this study.

The results for the wires have been fitted to a constant presampler resolution plus a $1/E$ multiple scattering term. The result is

$$\sigma_{\text{wire group}}^2 = (2.48 \text{ mm})^2 + \left(\frac{17.3 \text{ mm}}{E(\text{GeV})} \right)^2.$$

This corresponds to $9.5\% X_0$ located 4.5 m upstream of the chamber in good agreement with the above expectations from multiple scattering. The constant term is observed to be close to that expected from the intrinsic resolution.

For showers the position estimate is determined using the pulse height weighted average for the three channels around and including the maximum pulse height channel. In order to account for divergence effects we have fitted the energy dependence with the same form as above, and then have subtracted the multiple scattering contribution term. As an upper limit on the contribution of multiple scattering we have also fitted the minimum ionising particle data fixing the constant term at 2.17 mm , the intrinsic resolution defined by the pitch. The resulting multiple scattering subtracted resolution is shown by the shaded band in Fig. 12.

We conclude that for energies above 10 GeV the position resolution for both, electromagnetic showers and minimum ionising particles, approaches the intrinsic resolution of 2.17 mm and 4.6 mm , respectively. This will provide a precise measurement of the polar angle (wires) of photons and, with lesser precision but still satisfactorily, of the azimuthal angle (strips).

The position measurement has been observed to be reasonably independent of the radiator thickness. This is much less true for the lead glass calorimeter alone whose information about the start of the shower is lost when there is a large amount of material in front. Therefore, with the presampler information a good position measurement can be achieved even for $3 X_0$. It should be noted that a precise position measurement for photons can improve the energy resolution. This is both because the distribution of the material is very position dependent and the lead glass response varies slightly from the block centre to the edge.

5.5 Electron/pion separation

In this section we report on studies on electron/pion separation by means of the combined setup of lead glass and presampler, comparing the different detector responses to 20 GeV pions and electrons, respectively. The material thickness was chosen to closely represent the geometry in OPAL. This was achieved by two plates of aluminium of $0.8 X_0$ each, separated by 22 cm, representing the drift chamber flange and the pressure bell, respectively.

Cuts on E/P measured by the lead glass and on the outputs of two beam Cerenkov counters provide good quality electron and pion data samples, respectively. The electron selection efficiency is 90% at a pion rejection efficiency of 97%. The event sample contains 1580 events. The pion sample (1331 events) is selected with 77% pion efficiency and an electron contamination consistent with zero which is very important for this study.

An electron incident on $1.6 X_0$ of aluminium has on average a probability in the order of 80% to lose all but a fraction of $1/c$ to bremsstrahlung. A pion which does not undergo a hadronic interaction will cause a minimum ionizing particle response in the lead glass as well as in the presampler. However, there is a relatively large probability ($\sim 60\%$) that a pion interacts in the lead glass and possibly fakes an electron signal. Clearly, the presampler is able to distinguish both shower types for those cases where an electron shower starts in the radiator material and the pion shower starts in the lead glass. This is so for the majority of events for which the lead glass signal is ambiguous.

Fig. 13 shows the correlation plots as well as the projections of the electron and pion events samples. We use appropriate cuts in these plots to determine the corresponding electron detection and pion misidentification probabilities. The four curves in Fig. 14 correspond to cuts on E/P as measured by the lead glass, on the total charge measured in the presampler, or on both simultaneously exploiting the existing correlation without and with an additional minimum presampler charge cut (see figure caption of Fig. 14). At 20 GeV, for an electron identification efficiency of 80% to 90% a pion rejection in the order of 10^{-3} can be achieved using the correlated information.

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Figure Captions

1. 3-D view and cross section of the OPAL endcap presampler chambers.
In (a) an artist's view of the endcap lead glass covered by the umbrella of presampler chambers is shown. The front end electronics is sketched by the shaded area. It is mounted on an extra PC board carried by the chamber itself.
The cross section in (b) shows the setup behind the pressure bell profile of the central detector which represents about 50% of the radiator material in front of the lead glass calorimeter.
2. Schematic view of the chamber cross section including the electronics board.
3. Layout and dimensions of the large and the small presampler chamber.
4. Photograph of the presampler detector mounted on the OPAL endcap lead glass.
5. Block diagram of the readout electronics showing front and rear end with R/O crate and detector system crate realized in VME standard.
6. Charge output for minimum ionizing particles and for showers.
Charge distribution obtained from (a) 20 GeV charged pions and (b) 20 GeV electrons showering in aluminium of 1.6 radiation lengths before entering the presampler chamber. In (a) the black histogram represents the pedestal peak, while in (b) the black area is the pion peak of (a).
7. Chamber response to electromagnetic showers.
The mean total charge is given as a function of the electron shower energy (a) and as a function of radiator material thickness (b). Expectations from Monte Carlo calculations (EGS) are displayed by the shaded area, the width of which represents systematic uncertainties in the simulation. The dashed-dotted line in (a) indicates the response to minimum ionizing particles with no material.
8. Correlation between E/P , the measured lead glass energy normalized to the electron beam momentum, and the total pulse height (charge) as measured in the presampler (pads) for a 35 GeV e^- beam entering 1.6 X_0 of aluminium upstream of the presampler chamber. The projections of both measurements are also shown in (a).
In (b) the mean E/P as a function of presampler output is shown. This plot is used to determine the correlation function between the two measurements as determined by a polynomial fit (solid line).
9. Correlation data of lead glass and presampler output for different energies. Shown is the mean lead glass response (E/P) versus the presampler charge output in arbitrary units. The E/P normalisation differs for different energies due to calibration reasons.
10. Energy resolution as a function of energy.
In (a) the obtained resolutions with and without presampling are shown. The open circles represent lead glass without radiator material, the open squares lead glass with 1.6 X_0 of aluminium, and the black circles represent the resolution after the presampler correction. The solid line indicates a $5\%/\sqrt{E}$ behaviour. In (b) the intrinsic resolution without material

has been quadratically subtracted to show the effect of the presampler correction. Note that $\sigma/\sqrt{E}$ is plotted in (b) to show the approximate scaling behaviour with $\sqrt{E}$ of the resolution deterioration without presampling.

11. Energy resolution as a function of radiator thickness, without (open circles) and with (black dots) presampler correction.
12. Position resolution for minimum ionizing particles and showers.
The black circles are the actual measurements using the wire (a) and strip (b) informations. The effective pitches of wires and strips are 7.5 mm and 16 mm, respectively. The contributions from multiple scattering (M.S.) and beam divergence were determined as described in the text, and the subtracted resolutions are shown by the shaded band. The insert in (a) displays the resolution for single non-showering electrons the asymptotic value of which is drawn as the dashed-dotted line in (a).
13. Scatterplots of E/P as measured by the lead glass and presampler charge output for (a) electrons and (b) pions, respectively. Below the projections are shown for both types of particles on lead glass E/P in (c) and on presampler charge output in (d), respectively. In (c) the pion response is multiplied by a factor 10.
14. Pion misidentification probability versus electron detection efficiency.
The curves represent various cuts in Fig. 12, cut on presampler output only (black squares), on lead glass E/P only (open circles), on E/P correlated with presampler (open squares), and finally on the correlated data together with an additional minimum presampler charge cut (black circles and shaded area).

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Fig.1

Fig.2

Small chamber

Large chamber

Fig.3

Fig.4

Fig.5

Fig. 6

Fig. 7

Fig.8

Fig.9

Fig.10

Fig.11

Fig.12

Fig.13

Fig.14