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RESULTS FROM A TEST OF AN IRON STREAMER

TUBE CALORIMETER

by

H1 Collaboration

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Results from a Test of an Iron Streamer Tube Calorimeter

H1 Collaboration

December 22, 1987

Abstract

We have measured the response and energy resolution of an iron streamer tube calorimeter with 7.5 cm sampling for pions in the energy range from 10 to 100 GeV. For fully contained events, the energy resolution can be described by $\frac{\sigma_E}{E} \approx \frac{100\%}{\sqrt{E}}$.

Results from a Test of an Iron Streamer Tube Calorimeter

H1 Collaboration

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1 Introduction

The H1 experiment [1] foreseen at the e-p storage ring HERA will use limited streamer tubes for the instrumentation of the iron yoke. These tubes will serve as active elements of the muon detector and calorimeter for hadrons which penetrate through the central liquid argon (LAr) hadron calorimeter. We have measured the response of a prototype streamer tube calorimeter both in a stand alone mode and behind a LAr hadron calorimeter. The aim of the test was three-fold : (i) to gain experience with streamer tubes under beam conditions, (ii) to study the performance of the proposed detector scheme and (iii) to compare the Monte Carlo simulation parameters with the measurements. In this paper we report on the stand alone test of the streamer tube calorimeter. Results on the performance of the LAr calorimeter have been given in [2]. The results of the combined test will be given in a forthcoming paper [3].

2 Experimental Setup

2.1 Beam and Beam Detectors, Trigger and Data Acquisition

The test calorimeter was exposed to pions and muons (10 GeV/c $\leq p \leq$ 100 GeV/c) provided by the H6 beam [4] of the SPS at CERN. The beam was run in the tertiary mode [5]. For momenta $p \leq 50$ GeV/c, pions were separated from electrons by two Čerenkov counters with ring selection (CEDAR's) [6]. The typical momentum spread of the beam was $\frac{\Delta p}{p} = 0.8\%$. Further details are given in [2].

The layout of the experimental area is shown in figure 1. In front of the streamer tube calorimeter, two multiwire proportional chambers (MWPC's) with an active area of $25 * 25 \text{ cm}^2$ were installed. The distance between the two chambers was 19 cm. Each one consisted of a horizontal and a vertical anode plane. The wire spacing was 2 mm. The MWPC's were covered by scintillation counters on both sides (S1 and S2). The streamer tube calorimeter was installed in front of the LAr calorimeter [2] which was not read out. Behind the LAr calorimeter (depth about 10 nuclear interaction lengths (λ) and behind the beam dump (1.6 m iron), two scintillator hodoscopes for muon detection were installed (M1 and M2). Each consisted of 10 vertically oriented counters of 120 cm height and 20 cm width with an overlap of 0.5 cm between two adjacent counters.

The MWPC and the scintillators S1 and S2 were used for the trigger. The signals of the muon walls M1 and M2 were recorded for offline muon selection. The data acquisition system is described in [2].

2.2 The Test Detector

The test detector used iron as absorber (in total 75 cm, 4.47λ) and wire chambers which were operated in the limited streamer mode as active detector elements. Schematic side and front views of the detector are shown in figures 2 and 3.

The detector consisted of 10 iron plates of 5.0 cm thickness and 10 iron plates of 2.5 cm thickness. The actual sampling used was 7.5 cm, which is equal to the one foreseen for the H1 detector [1]. The gaps between the plates were 2.5 cm wide except after 30 cm of iron where the gap width was 5.0 cm. The lateral dimensions of the stack were $110 * 125 \text{ cm}^2$.

The detector was equipped with a total of 13 chamber planes. Each plane consisted of twelve PVC streamer tube elements of the Iarocci type [7] without cover [8], in total 156 elements. The details of the tube elements are shown in figure 4. The length of the elements was 120 cm. The surface resistivity of the cathode, R_s , was in the range of 100 k $\Omega/\Box \leq R_s \leq 1 \ M\Omega/\Box$. In total, 243 elements were fabricated at the INFN Frascati. Before installing them into the detector, a 24 hours high voltage test was performed. Tube elements which drew currents larger than 2 μ A at 4.7 kV after this test were rejected (in total 25 elements). The remainder were used to instrument the detector.

The readout was done with pick-up electrodes. On the coverless side, the tubes were equipped with strips parallel to the wire (all layers except 3 and 13), whereas the covered side was equipped either with orthogonal strips (layers 1 and 2) or pads (all other layers), as shown in figure 3 and table 1 (except for three missing muon chamber layers, this scheme is equal to the one originally foreseen for the H1 detector). The total active area was about 1 m². The wires were oriented horizontally. All layers were

aligned in the vertical direction except layer 2 which was shifted upwards by 0.5 cm to achieve full geometric acceptance for the double layer. The width of the strips was 4 mm with a pitch of 1 cm, in total 96 strips per layer. The readout of the strips was performed by the streamer tube operating system STOS of LeCroy Research Systems Corporation (LRS)⁷. The pad size was $16 * 16 \text{ cm}^2$ (6 * 6 pads per layer). The pads of layer 3 were read out seperately (presamplers), whereas the consecutive pads of layers 4, 5, 6, 7 and 8 (9, 10, 11, 12 and 13) were added to form the first (second) towers, as foreseen for H1. The pad signals were fed into a special electronic device where the towers were formed : the signals were summed up and inverted with a gain of 1.0 for the presamplers and 0.1 for the towers. A block diagram of the pad readout is shown in figure 5. The output signals were digitized using LRS 2249A ADC's (10 bit resolution, 0.25 pC per channel sensitivity). The integration time of the ADC's was 200 nsec. All electronics was located close to the detector. The total number of readout channels is listed in table 2.

The high voltage was fed into the tubes via a 1 M Ω resistor per tube and a 220 Ω resistor inside the tubes for each wire (see figure 4). The chambers were operated at high voltages of 4.7 and 4.6 kV. The gas mixture used was 25 % argon and 75 % isobutane.

3 Results

3.1 Results for Incident Muons

The muon analysis was done with data from three sources :

1. After the transportation to CERN, the detector was set up in a parking position behind the beam dump, where the status of the apparatus was checked and the high voltage efficiency plateau curve (see section 3.1.1) was measured. In this position, we used a special trigger and data acquisition system which allowed only an online analysis. The data consisted of a mixture of cosmic muons and beam muons. After these tests the detector was moved into the beam.

- 2. Before and after the running period, the data taken in special beam runs using M1 and M2 as trigger were written to tape. These data were mainly used for the intercalibration of the towers (see section 3.2.2).
- 3. From the data taken in normal hadronic beam runs, muons were selected offline. These data were used for the detailed studies of the detector response to muons (see section 3.1.2).

3.1.1 High Voltage Efficiency Plateau Curve

The dependence of the chamber efficiency for strip readout (averaged over all planes) on the high voltage (HV) and the readout threshold⁸ applied is shown in figure 6. It was measured online using the special muon trigger mentioned above. The algorithm for the online program was similar to the one described in section 3.1.2, except that a special treatment of dead channels in the digital electronics was not included. The absolute values of the efficiencies are different from the ones given below because of the different beam conditions and because of the dead channels in the digital electronics. From the data of figure 6, we decided to operate the detector at a high voltage of 4.7 kV and a nominal threshold of 50 mV.

For high muon rates (≥ 20 Hz / cm²), we observed dark currents of about 2 μ A in some of the chambers. This problem was less severe at lower high voltage. In order to study the performance of the detector if the high voltage has to be reduced due to large backgrounds, a part of the pion data was also taken at a high voltage of 4.6 kV and a nominal threshold of 50 mV.

3.1.2 Strip and Pad Response for Muons

During the pion runs, no special muon trigger was incorporated. The signals of the muon walls M1 and M2 were, however, recorded and could be used

⁷About 10% of the electronic STOS channels were broken As the STOS electronics is no longer supported by LRS, the broken channels could neither be repaired nor replaced. They were mainly placed at the edge of the detector. Within the region of \pm 10 cm around the beamline (in this region, for hadron showers, about 80% of the energy is deposited), only 3% of the channels were broken.

⁸The thresholds are defined by an external reference voltage between -30 and + 2000 mV, coresponding to a signal current threshold between 30 and 200 μ A

for offline muon selection. The following cuts were used :

- (i) Muon walls : one or two of the central counters of M1 and M2 fired
- (ii) MWPC : exactly one cluster in each of the four planes of the MWPC
- (iii) hit pattern in the calorimeter : exactly one cluster of arbitrary size in at least one of the layers of each of the following groups : (1,2,4), (5,6), (7,8), (9,10) and (11,12)

With these cuts, a sample of about 9300 muons at 4.7 kV and about 8600 muons at 4.6 kV remained.

The efficiency and clustersize in each plane was obtained by using all other planes as independant tracking system. In addition, no dead channels in the digital electronics were allowed in the region of the cluster. Efficiencies and mean cluster sizes for 4.7 and 4.6 kV are given in table 3. As the walls of all chamber layers except layer 2 were aligned within about 1 mm, the inefficiencies due to the chamber walls are not fully included in this measurement, such that the measured efficiency is somewhat higher than expected from the geometric inefficiency of about 10 %. The multiplicity distribution per cluster is shown in figure 7 for parallel and orthogonal strips at high voltages of 4.7 and 4.6 kV. At 4.7 kV, the mean multiplicity for the parallel strips is 1.3, whereas for the orthogonal strips the multiplicity is larger (2.4) and the efficiency is lower. This is due to the fact that (i) the signals on the parallel strips are larger than on the orthogonal strips because the parallel strips are on the coverless side of the tubes, whereas the orthogonal strips are on the graphited side and (ii) for the parallel strips, the streamer position is always close to the center of the strip, which is not generally true for the orthogonal strips. Thus a streamer generally illuminates one parallel strip, but more than one orthogonal strips. The total strip multiplicity for the parallel strips is given in figure 8. As expected from the mean clustersize, the total mean is close to the number of planes used (10).

The pad spectra were obtained from the selected muon events in the following way: After pedestal subtraction, a readout threshold of 2 $\sigma_{r.m.s.}$ of the noise distribution was applied to each tower. This corresponds to about 10 pC primary charge or half the charge of a single streamer (see

below). The signals of the central four pads of the first and second tower were added to get the total spectrum. Figure 9 shows these spectra for 4.7 and 4.6 kV. The peak value is 185 (145) pC at 4.7 (4.6) kV with a resolution of $\frac{\sigma_{\text{LM-L}}}{\text{peak}} \approx 43\%$. Assuming a mean value of 9 streamers for a penetrating muon (10 planes with 90 % efficiency each), this results in a measured charge of 20.6 (16.1) pC per streamer. Due to instabilities of the gas system and due to rate effects, the muon signal varied with time within $\pm 12\%$. This variation was permanently monitored and the pion data were corrected accordingly.

On those groups of pads which were located above the same tube element, we observed a negative crosstalk. Figure 10a shows the correlation between the signal on a pad hit by a muon versus the signal on the other pads located above the same tube element (i.e. with the same vertical coordinate). A correlation of about -9 % is seen. The same plot for pads perpendicular to the wire direction (i.e. with the same horizontal coordinate) is shown in figure 10b. No correlation is seen. In this case, the signal on the other pads is compatible with noise. Similar effects have been observed by other groups [9].

3.2 Results for Incident Pions

3.2.1 Event Selection

Beside the trigger condition, the following cuts were applied to select pion events :

- (i) CEDAR's : The beam particle must have been positively identified as a pion by at least one of the two Čerenkov counters
- (ii) Muon walls : No hits in M1 and M2
- (iii) MWPC : Exactly one cluster in each of the four planes of the MWPC
- (iv) First chamber layer : In layers 1 and 2 in front of the first iron section at most one cluster was allowed with at most 3 (6) parallel (orthogonal) strips

Cuts (i) and (ii) are used for particle identification, whereas cuts (iii) and (iv) ensure that exactly one beam particle enters the test detector. Table

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4 gives the total number of events obtained after these cuts. For beam energies of 10, 30 and 50 GeV the electron rejection of the CEDAR's (the probability to accept an electron as a pion is of the order of 10^{-4}) yields a clean pion sample. For 80 and 100 GeV, however, an electron contamination of about 3 % for both energies was observed. This was estimated from the different longitudinal shower profiles for electrons and pions.

To study the influence of longitudinal leakage, we selected events with no fired strip in the last chamber layer equipped with strips (layer 12). This cut implies full containment of the showers within 4.1 λ . Due to the electron contamination of the 80 and 100 GeV data, this cut was only used for the low energy runs. The numbers of events and the rejection factor obtained with this cut are also given in table 4.

Most of the results given in this section have been obtained at a high voltage of 4.7 kV (if not mentioned differently). Some results will also be given for 4.6 kV

3.2.2 Energy Measurement Using the Pads

After pedestal subtraction, a readout threshold of $2\sigma_{r.m.s.}$ of the noise distribution was applied to each tower (see section 3.1.2). The different towers were intercalibrated using muons. These muons were taken in special runs before and after the running period. For the central four pads of the first and second tower, the calibration values differ by \pm 5 %. The improvement on the energy resolution obtained by the intercalibration is, however, insignificant. A correction for the negative crosstalk mentioned in section 3.1.2 was not done for the following reasons: (i) the ADC's were unipolar and thus not able to measure the negative crosstalk for beam energies \geq 30 GeV properly and (ii) since the lateral shower width extends to only two towers and the crosstalk is about constant, it should not affect the energy resolution, but mainly the absolute calibration. This has been verified by Monte Carlo simulations. The total charge for each event was obtained by adding the measured charge in each channel above threshold in the first and second tower. Finally, to correct for variations in the gas amplification, the total measured charge was normalized to the mean muon signal for each run. Figure 11a shows the linearity curves both for all events and for the events fully contained in the calorimeter. For the contained events, good linearity is obtained up to 50 GeV. If one includes all events, a decrease of the signal is observed (~ 8% at 30 GeV, ~ 10% at 50 GeV). For the highest energies, the signal is further reduced due to ADC overflows. This effect was estimated to about -7 % at 100 GeV [10]. Using the contained events, an absolute calibration of (88.9 \pm 0.9) pC/GeV is obtained. Taking the mean charge per streamer as measured with muons (see section 3.1.2) and neglecting the influence of the negative crosstalk, this corresponds to 4.3 streamers per GeV incident energy.

Energy resolutions have been obtained from the charge spectra with a gaussian fit in the region

$$< Q > -2\sigma_{r.m.s.} \leq Q \leq < Q > +2\sigma_{r.m.s.}$$

where $\langle Q \rangle$ and $\sigma_{r.m.s.}$ are the mean value and the r.m.s. resolution of the charge spectrum after the rejection of the tails of the distribution. For the 10 GeV data, additionally the region

$$Q~\leq < Q^{\mu} > + 1.5 \sigma^{\mu}_{r.m.s}$$

was left out of the fit, where $\langle Q^{\mu} \rangle$ and $\sigma^{\mu}_{r.m.s.}$ are the mean value and the r.m.s. resolution of the charge spectrum for muons. Figure 12 shows the charge spectrum both for all events and for the contained events at 30 GeV together with a gaussian fit. The resolutions $\frac{\sigma_Q}{Q}$ obtained by this procedure both for all events and for the fully contained events (only for $E_{Beam} \leq 50$ GeV, see section 3.2.1) are shown in figure 13a. For the fully contained events, the resolution can be described by

$$rac{\sigma_E}{E} pprox rac{100\%}{\sqrt{E}}$$

(full line in figure 13a), whereas the decrease of the resolution is slower than $\sim 1/\sqrt{E}$ due to leakage when all events are included. In the case of H1, the effect of leakage will be much less severe, since in the H1 detector the streamer tube calorimeter will serve as 'tail catcher' for low energy particles leaking out of the central LAr hadron calorimeter.

The corresponding figures for the 4.6 kV data are shown in figure 11b (linearity) and 13b (energy resolution). The results are similar to the ones obtained at a high voltage of 4.7 kV. The absolute calibration is $(63.6\pm0.5)pC/GeV$ corresponding to 3.9 streamers per GeV.

3.2.3 Results Obtained with the Strip Readout

For low energies, the strip multiplicity provides the possibility to measure the energy. Figure 14 shows the strip multiplicity (i.e. the total number of parallel strips fired in layers 1, 4, 5, 6, 7, 8, 9, 10, 11 and 12) plotted versus the charge measured on the pads for each event for 10, 30 and 50 GeV pions. A non-linear correlation is seen. This non-linearity can also be seen when plotting the mean strip multiplicity versus the beam energy (see figure 15). Due to the digital readout of the strips, multiple hits on one wire are invisible (only a projection of the shower is seen). This leads to an early saturation. The measured multiplicity for the contained events (also shown in figure 15) is lower than for all events, because for contained events the track density inside a shower is higher, leading to a stronger saturation. The multiplicity distributions for 30 GeV pions for all events and for the contained events are shown in figure 16. Although the spectra are not quite gaussian, we have calculated the resolution using the same algorithm as for the pad signals (see section 3.2.2). The multiplicity resolutions obtained are shown in figure 17. They are about constant at $\sim 25\%$. Similar results have been shown in [11]. For the contained events, no improvement is seen. A possible improvement due to missing leakage is spoiled by the stronger saturation.

Since the calibration function is not linear (see figure 15), the resolution of the strip multiplicity is, however, not equal to an energy resolution. If one estimates the energy for each event from the strip multiplicity using the calibration function shown in figure 15, the energy resolution at 10 GeV amounts to $\frac{\sigma_E}{E} = 33\%$ (for the strip multiplicity distribution, the resolution is $\frac{\sigma}{Mean} = 24\%$). This value is comparable to the energy resolution obtained from the pads ($\frac{\sigma_E}{E} = 35\%$). For higher energies, $\frac{\sigma_E}{E}$ as calculated from the strip multiplicity increases.

3.2.4 Comparison with Monte Carlo Simulations

To understand the behaviour of the calorimeter, detailed Monte Carlo (MC) studies have been performed [12]. Hadronic showers were simulated by the GHEISHA code [13] version 7.04. All material except the chamber walls between the wires was included in the shower simulation. The simulation of the streamer mode was performed following an approach given in [14]:

In the plane perpendicular to the wire direction, for all tubes (active size $9 * 9 \text{ nm}^2$, wire distance 1 cm within one tube element and 1.4 cm between adjacent tube elements) which were hit by a charged particle at least one streamer was generated. Particles which only hit the inactive walls were not accepted. Particles which hit two or more adjacent tubes were only allowed to set more than one hit if their kinetic energy exceeded 100 MeV. Otherwise they were regarded as absorbed in the wall and streamers were generated only in the first hit tube (see figure 18a).

To calculate the number of streamers generated along the wire direction, each tube was divided into predefined cells of a given cellsize s. Each cell which was hit by at least one charged particle was regarded as one streamer. Double hits were only counted once. Thus the parameter s is a measure for the size of the dead region around one streamer. Figure 18b shows an example. This procedure was done for three different values of s: 2 mm, 3mm and 5 mm.

The pad signals were given by the total number of streamers within the volume of a tower multiplied by the mean charge per streamer taken from the measurements (see section 3.1.2). Then, a negative crosstalk of -9 % of the signal and a cutoff to simulate ADC overflows was applied. The absolute calibration value obtained for the MC was 4.8 (4.0, 2.9) streamers per GeV incident energy for s = 2mm (3 mm, 5 mm) compared to 4.3 streamers per GeV obtained for the data. This indicates a best value of s of about 2.6 mm (this is in good agreement with measurements of the dead zone around a streamer given in [15]). For the energy resolution, best agreement between data and MC is found for s = 3 mm. All further figures are shown for s = 3 mm. Linearity curve and energy resolution for the MC are shown in figures 11c and 13a. Both agree well with the data. To simulate the 4.6 kV data, only 91% of the generated streamers were accepted (as indicated by the reduced absolute calibration). The resolutions obtained are comparable to the ones obtained for the 4.7 kV simulation (see figure 13b).

For the simulation of the strip response, a variable number of strips according to the measured multiplicity distribution for muons (see section 3.1.2) was generated for each streamer. The efficiency for at least one fired strip per streamer was assumed to be 1.00 for the simulation of the 4.7 kV data (the geometric inefficiency has already been treated within the streamer simulation). The mean multiplicities and the resolutions are shown in figures 15 and 17, respectively. The data agree well with the MC both in multiplicity and resolution, except at 10 GeV where the MC multiplicity is 23% too low and the resolution is too bad. A possible explanation may be that the crosstalk on the strips within a hadronic shower is larger than for muons, as (i) the tracks within a shower are generally not perpendicular to the chamber plane and (ii) heavy ionizing particles may generate a larger strip multiplicity than minimum ionizing particles. At higher energies these effects become less important because they are partly compensated by saturation effects.

4 Conclusions

Calorimetric measurements with a 4.5 λ long iron streamer tube calorimeter with 7.5 cm iron sampling have been performed using pions in the energy range from 10 to 100 GeV for analogue pad readout and digital strip readout. For fully contained events, an absolute calibration of 4.3 streamers per GeV and an energy resolution of about $100\%/\sqrt{E}$ using pad readout has been obtained up to 50 GeV, whereas the resolution decreases slower than $\sim 1/\sqrt{E}$ if events with leakage are included. At low energies, it is possible to use the digital readout of the strips for energy measurement. At 10 GeV, the energy resolution obtained with the strips is compareable to the one obtained with the pads. The measurements are in good agreement with Monte Carlo calculations.

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Tables

layer	iron depth	equipped with			tower
number	(cm)	pads	parallel	orthogonal	number
			strips	strips	
1	0.0		*	*	
2	0.0		*	*	
3	0.0	*			presampler
4	7.5	*	*	-	1
5	15.0	*	*		1
6	22.5	*	*		1
7	30.0	*	*		1
8	37.5	*	*		1
9	45.0	*	*		2
10	52.5	*	*		. 2
11	60.0	*	*		2
12	67.5	*	*		2
13	75.0	*			2

Table 1: Location of the different layers in the test detector.

type	number of channels per layer	number of layers	total
analog (pads)	6*6	3	108
digital (parallel strips)	96	11	1056
digital (orthogonal strips)	96	2	192
digital (sum)	96	13	1248

Table 2: Number of electronic channels used.

13

14

high voltage	4.7 kV	4.6 kV	
parallel strips			
mean multiplicity/layer	1.292 ± 0.002	1.140 ± 0.002	
efficiency/layer	$(92.2 \pm 0.1)\%$	$(90.3 \pm 0.1)\%$	
orthogonal strips			
mean multiplicity/layer	2.385 ± 0.020	1.945 ± 0.018	
efficiency/layer	$(86.0 \pm 1.3)\%$	$(82.6 \pm 0.5)\%$	

Table 3: Mean multiplicities and efficiencies per layer for parallel and orthogonal strips for muon events at 4.7 and 4.6 kV.

beam energy	all events		contained events		reduction
(GeV)	4.7 kV	4.6 kV	4.7 kV	4.6 <u>k</u> V	factor
10	20239	20599	12452	13266	0.63
30	43121	33621	10122	8645	0.24
50	11552	9217	1368	1147	0.12
80	0	10691			
100	8437	9568	<u> </u>	<u> </u>	

Table 4: Total number of accepted pion events, number of events remaining after the containment cut and reduction factor of the containment cut for the different beam energies and high voltages.

Figure Captions

Figure 1: Schematic view of the test setup.

Figure 2: Front view of the test detector.

Figure 3: Side view of the test detector.

Figure 4: Basic structure of the streamertube elements.

Figure 5: Block diagram for pad readout.

- Figure 6: Chamber efficiency (from strip readout) for different readout thresholds versus high voltage.
- Figure 7: Strip multiplicity per cluster for muons. Shown are the distributions for parallel and orthogonal strips for 4.6 and 4.7 kV.
- Figure 8: Total strip multiplicity (parallel strips only) for muons at 4.6 and 4.7 kV.
- Figure 9: Charge spectra for muons obtained with pad readout at 4.6 and 4.7 kV.

Figure 10: Crosstalk observed on the pads :

a) in wire direction : signal on neighbouring pads located above the hit wire (Q_{\parallel}) versus signal on hit pad (Q_{hit}) , together with -9% line

b) perpendicular to the wire direction : signal on neighbouring pads perpendicular to the wire direction (Q_{\perp}) versus signal on hit pad (Q_{hit})

- Figure 11: Pad charge versus beam energy for pions (for all events and for the events fully contained in the calorimeter) together with a straight line fit to the contained event data for
 - a) 4.7 kV (data) b) 4.6 kV (data)
 - c) 4.7 kV (Monte Carlo)

- Figure 12: Charge spectrum for pions at 30 GeV and 4.7 kV obtained with pad readout, for all events and for the fully contained ones, together with a gaussian fit.
- Figure 13: Charge resolution (pad readout) for pions (data and Monte Carlo, for all events and for the fully contained ones). For the contained events, this corresponds directly to the energy resolution, as the calibration is linear.

b) 4.6 kV

- Figure 14: Pad charge versus multiplicity of parallel strips for pions of 10, 30 and 50 GeV at 4.7 kV (about 10000 events each).
- Figure 15: Strip multiplicity for parallel strips versus beam energy for pions at 4.7 kV (data and Monte Carlo, for all events and for the events fully contained in the calorimeter) together with a parametrization curve.
- Figure 16: Strip multiplicity for parallel strips for pions of 30 GeV at 4.7 kV (for all events and for the fully contained ones), together with a gaussian fit.
- Figure 17: Multiplicity resolution for pions at 4.7 kV (data and Monte Carlo, for all events and for the fully contained ones).

Figure 18: Simulation of the streamer mode

a) perpendicular to the wire

b) in wire direction



a) 4.7 kV







beam direction

Fig. 3











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Figure 13a

Figure 13b







Figure 14





Fig. 18a

Fig. 18 b