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TEST RESULTS FROM A URANIUM HADRON CALORIMETER USING WIRE CHAMBER READOUT

B. BLEICHERT, F. LÜRKEN, K. LÜBELSMEYER, H.U. MARTYN, H.G. SANDER and W. WALLRAFF

I. Physikalisches Institut RWTH Aachen, FRG *

T. AZEMOON, R. BALL, I. LEEDOM and M. LONGO

Harrison M. Randall Laboratory of Physics, University of Michigan, Ann Arbor, USA **

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A uranium gas sampling calorimeter has been tested with electrons and pions between 1 and 50 GeV. A comparative evaluation of the response and the resolution for proportional and streamer mode operation of the gas wire chamber detectors is given for two different gas mixtures.

1. Introduction

The use of uranium as absorber material for hadron calorimeters has several advantages. Due to its high density it allows for very compact construction if a maximum amount of interaction lengths is required in a given geometrical space. In addition the fission products occurring in a nuclear cascade are supposed to compensate for binding energy losses thus leading to a relative response of electrons to hadrons closer to 1 than for ordinary materials [1]. These properties depend on the sampling layer thickness and the readout device. Compensation has been shown to work for scintillator [2] and liquid argon [3] calorimeters. Recently some results on a gas sampling calorimeter have been reported [4].

Here we report on a uranium calorimeter using wire chambers as readout. They were operated either in the proportional or in the limited streamer mode with Ar/CO_2 and Ar/C_4H_{10} gas mixtures. The main advantages in using wire chambers are the good spatial resolution, the ability to work in a magnetic field and the low costs for large scale detectors. In design this test setup is close to that for the hadron calorimeter of the L3 experiment currently under construction for operation at the LEP storage ring.

Results are given for the response and the energy resolution of electrons and hadrons up to 50 GeV. These data have been used in a detailed study of uranium gas detector calorimetry [5].

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2. Calorimeter, test beam and chamber performance

The calorimeter (see table 1) is longitudinally segmented into 100 layers of 4 mm uranium covered on both sides with 1 mm of copper followed by 13 copper plates of 20 mm. The copper shielding of the uranium plates turned out to be essential for the operation of the wire chambers, it reduces the noise due to the natural radioactivity [4] by a factor of approximately 10. The total depth of the calorimeter amounts to 6.87 interaction length λ_0, $5.14\lambda_0$ in the finer segmented uranium part and $1.73\lambda_0$ in the coarser copper part. The lateral dimensions of the absorber material are 50×50 cm^2.

The absorber layers are interleaved with two different types of wire chambers details of which are sum-

Table 1
Layout of the calorimeter absorber plates [a]

Layer no.	Material	Thickness [mm]	Radiation length ΔX_0	Absorption length $\Delta\lambda_0$
1–100	Cu U Cu	1 4 1	1.39	0.054
101–113	Cu	20	1.40	0.1328
Sum			167	6.864

[a] Material constants from ref. [6].

Table 2
Description of the wire chambers

	Type 1	Type 2
Layers	1–65	66–113
Outer dimensions	60×50 cm^2	65×50 cm^2
Material	brass	ABS (PVC)
Tube cross section	6×12 mm^2	4.5×6.5 mm^2
Wall thickness	0.5 mm	1 mm
No. of wires/plane	40	72
Wire length	50 cm	50 cm
Wire spacing	12 mm	6.5 mm
Wire diameter	54 μm	30 μm
Total thickness	9 mm	19 mm
Gas mixtures	argon/isobutane (Ar/C_4H_{10})	60/40
	argon/carbon dioxide (Ar/CO_2)	10/90

marized in table 2. The readout of the first 65 chambers is organized in the following way: In chamber no. 1 two neighbouring wires are fed together into one ADC, i.e. in total 20 ADCs were used. For chambers nos. 2–65 interleaved double layers are formed by combining 2×2 wires of two even-numbered or two odd-numbered chambers. Each of the 32 interleaved double layers again feeds 20 ADCs in the same fashion as in the single first layer. For chambers nos. 66–113 all wires in one chamber are fed into one ADC.

When working in the streamer mode identical electronics were used for both types of chambers [7]. The signals of all wires of one plane or one double layer are ganged into one ADC.

The gate width of the electronics is 2 μs (400 ns) for chambers of type 1 (type 2) in the proportional mode and 350 ns in the streamer mode. The two chamber systems were always operated with the same gas mixture (either Ar/C_4H_{10} or Ar/CO_2) and similar gas amplification. The dynamic range of each ADC channel when running in the proportional mode was set to 50 (80) minimum ionizing particles for Ar/CO_2 (Ar/C_4H_{10}).

The experiment was run in the CERN SPS X3 test beam at momenta between 1 and 50 GeV/c. The momentum resolution was 1.5% at 1 GeV/c and 0.5% above 4 GeV/c. It was possible to choose between hadron (mostly pions) and electron enriched beams. Electrons were identified by two Cherenkov counters. Penetrating particles were identified as muons by a scintillation counter behind the calorimeter and by additional software selection. The pion data contain less than 0.1% of electrons and less than 2% of muons. The contamination of the electron data by pions is less than 0.1%. No corrections for these small backgrounds have been applied.

3. Chamber calibration and analysis procedure

The pedestals for each group of wires or whole planes have been determined from the mean signal of random triggers. By this procedure the radioactivity noise is taken into account. The pedestals were stable within 3–5% of the minimum ionizing signal.

The calibration has been done with muons for every plane. In fig. 1 we show as an example the pulse height distribution of a typical plane for the pedestal and the muon signal. The muon distribution shows a long tail representative of Landau fluctuations of the energy deposit in the detector gas. The asymmetry of the pedestal distribution reflects the detection of signals from the radioactivity of the uranium absorber during the integration time of the ADC. The negative entries of the muon distribution are caused by fluctuations of the observed radioactivity.

We have defined the equivalent of a minimum ionizing particle (m.i.p.) response per plane as the average over the complete muon spectrum including negative values and overflows. For the streamer mode analysis the same procedure has been applied after cutting out 3% of the high end of the distribution in order to suppress multiple streamers. This method accounts for the geometrical chamber inefficiencies and the occurrence of δ-rays.

In order to compare different particles and chamber operating conditions all energy measurements are expressed in terms of m.i.p. The backward copper part of the calorimeter is thus scaled with respect to the uranium part in the ratio of the energy loss in the absorber plates as calculated for minimum ionizing particles. In addition a relative adjustment of at most 15% for the two calorimeter parts with the two different wire chamber types is applied accounting for their different sensitivity to slow wide angle tracks. The longitudinal shower profile is used for this purpose. No cuts or corrections

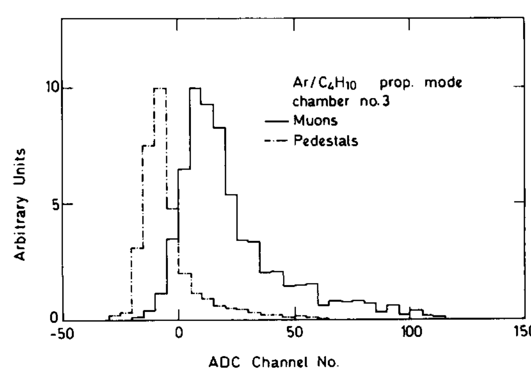

Fig. 1. Single muon spectrum (full line) and pedestal distribution (dashed–dotted line) for a typical detector plane; proportional mode operation.

have been applied for backscattering or sideward and backward leakage.

All values concerning the response and the energy resolution were taken from the means and the widths of Gaussian fits to the pulse height distributions. A systematic uncertainty in the calibration of 10% has been included.

4. Results

The wire chambers have been run in the proportional mode with Ar/CO_2 and Ar/C_4H_{10} gas mixtures. The properties of both mixtures concerning density and mean ionization loss are very similar. The latter contains, however, free protons which may raise the sensitivity to few-MeV neutrons from fission processes. In fig. 2 pulse height distribution for pions of different energies between 4 and 35 GeV are presented for the Ar/C_4H_{10} gas mixture. We do not observe long tails at the higher end as expected from protons or highly ionizing slow heavy particles like recoil protons, deuterons, tritons or alphas contributing $\approx 60\%$ to the energy deposited in the detector gas [5]. The effective compression in the fluctuations of the recorded ionization – mean and most probable values of the observed pulse height distributions never differ by more than 8% – is due to both the saturation in the gas amplification and the limited dynamic range of the electronic signal processing. A full discussion of this compression is given in ref. [5].

For proportional mode operation the calorimeter response – expressed in terms of m.i.p. – to electrons and pions is shown in figs. 3 and 4. The calorimeter behaves linearly for both electrons and pions. For electrons the response for both gas mixtures are identical within errors. This is expected since the ionization signal of an electromagnetic shower is exclusively produced by relativistic electrons (positrons). The proportional mode pion response from the Ar/C_4H_{10} gas mixture is barely higher than that from Ar/CO_2, the difference being about one standard deviation. In our measurements the additional signal from fission neutrons, which should be detectable in hydrogen containing gases, is small.

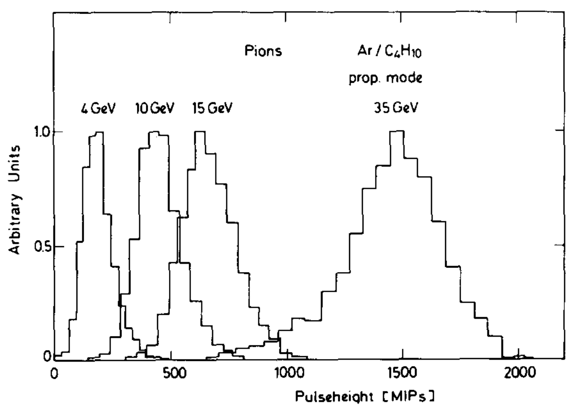

Fig. 2. Pulse height spectra for pions of different energies for the uranium gas calorimeter; proportional mode operation.

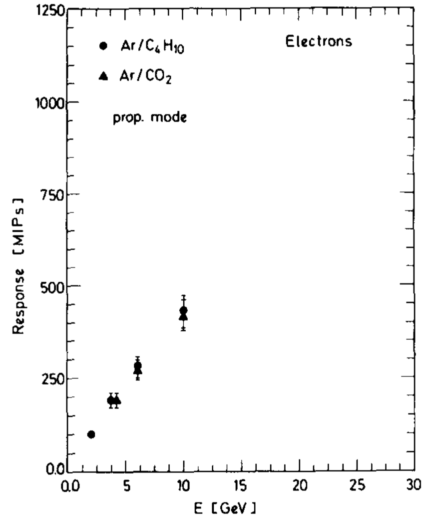

Fig. 3. Electron energy reponse function for the uranium gas calorimeter; proportional mode operation.

The electron/pion response ratio is displayed in fig. 5. In the energy region covered (4–10 GeV) this ratio is much closer to unity than that for the less dense absorbers investigated so far [7]. This situation is particularly favourable for the jet energy measurements in e^+e^- collider experiments. The errors are dominated by

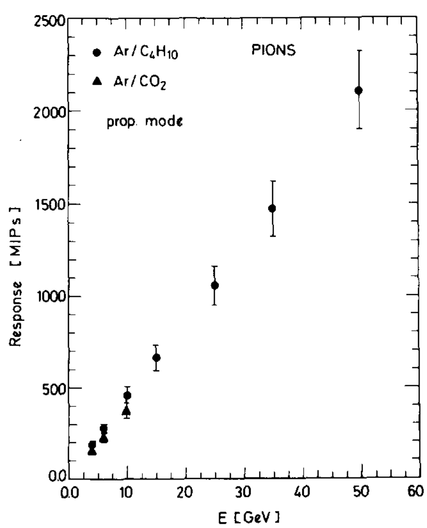

Fig. 4. Pion energy reponse function for the uranium gas calorimeter; proportional mode operation.

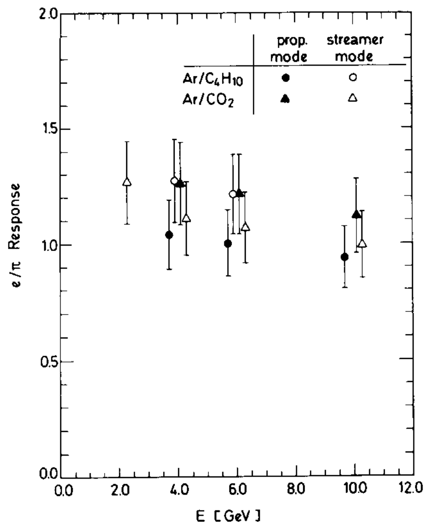

Fig. 5. Ratio of electron to pion response for the uranium gas calorimeter; closed symbols proportional mode operation, open symbols streamer mode operation.

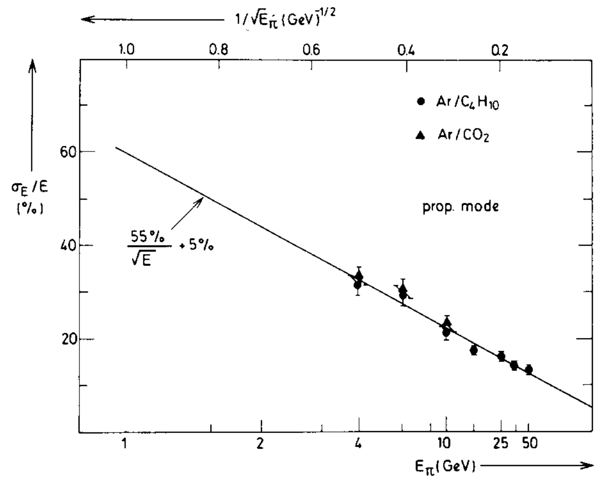

Fig. 7. Uranium gas calorimeter resolution for pions as a function of energy; proportional mode operation.

systematics for the responses ($\approx 10\%$) and the ratios ($\approx 15\%$). The energy resolution for electrons and pions is displayed in figs. 6 and 7. No apparent difference between the two gas mixtures is seen. The interpolating lines assume an $E^{-1/2}$ dependence of the resolutions. For pions a nonzero offset at very high energy is observed.

Working in streamer mode an improved resolution might be expected since – apart from oblique tracks causing multistreamers – fluctuations in the primary ionization are suppressed. On the other hand saturation effects of high density showers limit the linear response of a streamer tube detector. Furthermore the high gas amplification may cause operation problems in a uranium environment.

The streamer mode electron response is shown in fig. 8. A saturation effect causing a deviation from linear behaviour is observed for electron energies above 6 GeV. In the region where measurements with both gas mixtures are available no difference in response is observed. The streamer mode pion response is displayed in fig. 9. It shows a linear dependence up to the highest energies. The electron/pion response ratio is plotted in

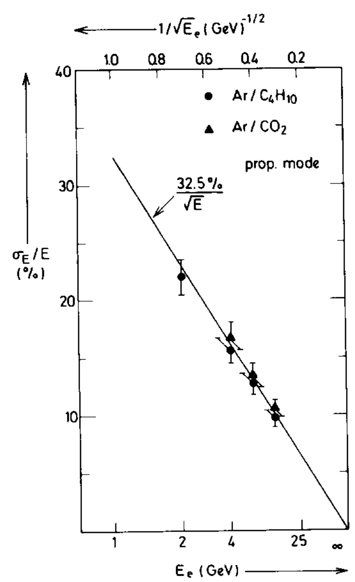

Fig. 6. Uranium gas calorimeter resolution for electrons as a function of energy; proportional mode operation.

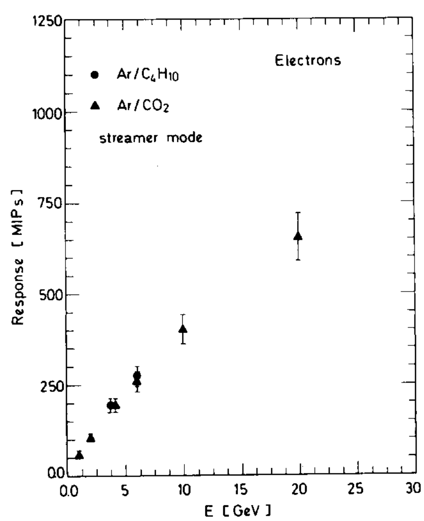

Fig. 8. Electron energy reponse function for the uranium gas calorimeter; streamer mode operation.

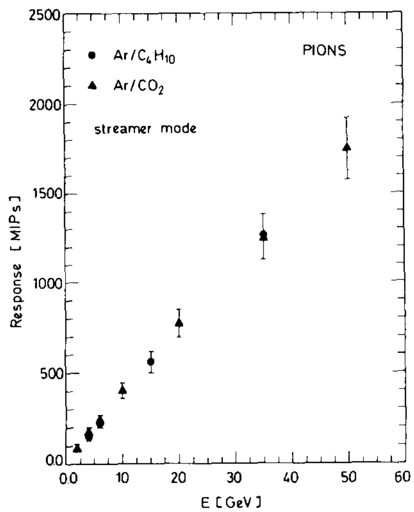

Fig. 9. Pion energy reponse function for the uranium gas calorimeter; streamer mode operation.

fig. 5. It is the same for both gas mixtures within errors with a value close to 1. We conclude that no apparent difference between the two gas mixtures has been observed. This applies also to the resolutions shown in figs. 10 and 11. Under our experimental conditions there is no improvement in resolution while operating in the streamer mode as is shown by comparing the interpolating lines in figs. 6 and 10 (figs. 7 and 11). The nonzero offset of the pion energy resolution at very high energy is smaller than in the proportional mode.

A good description of these results has been achieved

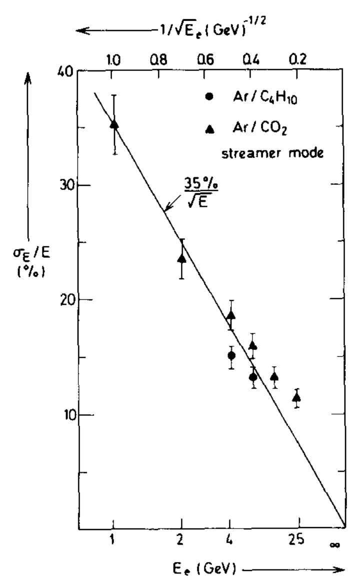

Fig. 10. Uranium gas calorimeter resolution for electrons as a function of energy; streamer mode operation.

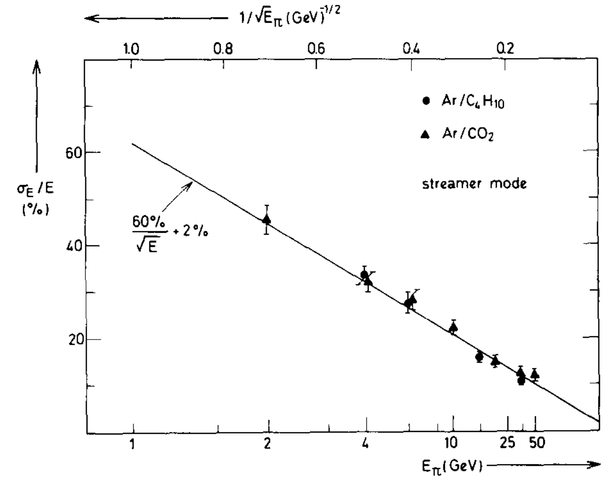

Fig. 11. Uranium gas calorimeter resolution for pions as a function of energy; streamer mode operation.

by Monte Carlo simulation [5,8] using the hadronic GEISHA [9] and the electromagnetic EGS [10] codes. The similar hadron response in the proportional mode for the Ar/CO_2 and Ar/C_4H_{10} gas mixtures can be explained by gas saturation effects, the geometrical layout of the chambers and the limited dynamic range of the ADC system.

5. Conclusions

We have tested a uranium calorimeter with wire chamber readout working in proportional or streamer mode with Ar/CO_2 and Ar/C_4H_{10} gas mixtures. Under the experimental conditions described we observe similar behaviour concerning responses and resolutions in all cases.

The relative response of electrons to pions is close to 1. Averaging over the energy range from 2 to 10 GeV an electron/pion response ratio of 1.15 ± 0.2 is obtained, the error being dominated by systematic uncertainties. This value is in agreement with other experiments having a similar uranium absorber thickness and using gas chamber [4], scintillator [2] or liquid argon [3] readout techniques.

As stated before, the energy resolutions clearly reflect the fluctuations in ionization characteristics for a gas detector. Working in the proportional mode for pions a parametrization of the form:

$$\sigma/E = 0.55/\sqrt{E(\mathrm{GeV})} + 0.05$$

is appropriate. The electron resolution of:

$$\sigma/E = 0.32/\sqrt{E(\mathrm{GeV})} = 0.26\sqrt{t/E(\mathrm{GeV})},$$

where t is the absorber thickness expressed in radiation lengths, is comparable to that obtained with other gaseous electromagnetic calorimeters.

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