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THE AFS HADRON CALORIMETER AT THE CERN ISR

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Summary

The hadron calorimeter for the AFS experiment at CERN consists of a fine sampling uranium/copper scintillator sandwich. It is designed for high modularity and will provide azimuthal coverage over 8 sterad. We describe the optical readout system consisting of acrylic scintillator and wavelength shifter plates (WLS) and we present the performance of test modules with respect to the energy resolution for electrons ($\sigma = 0.16/\sqrt{E}$) and hadrons ($\sigma = 0.36/\sqrt{E}$), the linearity of response and the ratio of electron to hadron response ($e/\pi = 1.11$).

Introduction

The hadron calorimeter presently under construction at CERN will be part of the Axial Field Spectrometer (AFS) at the CERN Intersecting Storage Rings. The detector system (fig. 1) consists of a barrel shaped hodoscope, a cylindrical drift chamber immersed in a 0.5 T magnetic field coaxial with the ISR beams, a three layer Cerenkov arm and the hadron calorimeter to be described here covering 2π in azimuth in its final configuration. The experimental program aims at a general study of events characterized by a high transverse momentum flow (single particles, jets, multi-jets, etc.).

Fig. 1 Schematic view of the AFS calorimeter

Design

The configuration of the complete calorimeter can be seen in fig. 1. It consists of many identical units using more than 200 tons of metal - depleted uranium and copper - as absorber material. This paper will concentrate on the large "uranium units" (128 in total) containing a mixture of copper and uranium plates, whereas the so-called "copper catchers" (64 units placed in the corners) are smaller and made of copper plates only.

Uranium is used as passive absorber material to achieve optimum resolution and unbiased triggering [1]. In this material fluctuations in the energy deposit of the hadronic cascade are compensated in a correlated way by the energy gained from fission induced by the hadronic shower. The uranium plates are mixed with copper plates. This metal does not significantly degrade the performance of the calorimeter, but is more readily available.

Each unit - a layout is shown in fig. 2 - has a cross section of $\sim 20 \times 120 \text{ cm}^2$ facing the

Fig. 2 View of an uranium calorimeter stack

intersection region. The absorber volume (80 cm in depth) is segmented two-fold longitudinally: the "electromagnetic" front section of six radiation lengths and the "hadronic" rear section, giving a total of 3.79 absorption lengths. The detailed composition is listed in table 1. Pressure on the scintillator plates is minimized by maintaining the distance between consecutive metal plates with five brass spacers located in holes in the scintillator.

TABLE 1

Front section:	
Uranium plates, 2 mm	10
Scintillator plates, 2.5 mm	11
Rear section:	
Uranium plates, 3 mm	76
Copper plates, 5 mm	38
alternated in the ratio 2:1	
Scintillator plates, 2.5 mm	114

The readout of the scintillator is achieved with two layers of six WLS plates on each side of the stack. The two layers are optically decoupled, the outer one viewing only the front and the other only the back section. Thus, for the energy measurement of particles the calorimeter is subdivided into "towers" of 20 x 20 cm².

The I shaped aluminium profile at the back serves as a rigid structure for the calorimeter unit, provides the space for the light guides and supports the 1.5 inch photomultiplier (PM) tubes (Philips XP2008 UB). Each PM tube is housed in a three layer magnetic shielding designed to operate in the stray field of the AFS magnet (up to 0.1 T).

Optical readout system

The scintillator - The choice of the scintillator for this calorimeter was governed by the following considerations: because of the large quantity involved (18 t) an unexpensive scintillator must be used. The large number of plates requires that the material be mechanically rugged. The light yield of the scintillator must be adequate compared to the intrinsic energy resolution of a fine sampling calorimeter. We selected a scintillator^(*) based on polymethylmetacrylate (PMMA) with an addition of 10% naphthalene to improve the light yield. This matrix is doped with 1% butyl-PBD as the scintillating agent; there is no secondary chemical, as often used, to shift the light towards blue, because the emission spectrum of butyl-PBD matches well the absorption spectrum of BBQ used in the WLS plates. This scintillator has a rather short attenuation length (~ 30 cm), therefore it allows the localisation of the shower using the readout on both sides.

The wavelength-shifter plates - We selected BBQ with a concentration of 80 mg/l dissolved in acrylic plastic^(**) which contains in addition an ultra-violet absorbing chemical (UVA). The role of the latter is to absorb Cerenkov light produced by showers leaking into the WLS plate. Fig. 3 shows the absorption length as a function of wavelength for BBQ

Fig. 3 Absorption as a function of wavelength for acrylic doped with UVA or BBQ

and the UVA chemical. Light of wavelength shorter than the wavelength corresponding to the cross over point is absorbed by the UVA and is not converted by the fluorescence mechanism. The end face of the WLS bar opposite to the PM tube is painted with a white coating, acting as a diffuse reflector. The attenuation as measured along the WLS plate is shown in fig. 4 for both front and back sections.

Fig. 4 Attenuation along the WLS plates

The light in the WLS plate is directed via light guides of the lamella type, (made from UVA acrylic) towards the PM tube which is optically coupled by means of an elastic silicon rubber disc again doped with UVA. A more detailed discussion of the readout system can be found in ref. [2].

Experimental results of test units

Tests were made to study the performance of hybrid compositions of uranium and copper. Four stacks of different uranium and copper composition

(*) Manufactured by Altulor, Paris, France

(**) Manufactured by Röhm GmbH, Darmstadt, Germany

TABLE 2

No.	Configu- ration (U:Cu mix)	Uranium plates		Copper plates (5 mm)	Absorpt. lengths (a)	Radiation lengths (a)	Resolut. $\sigma_1 \cdot \sqrt{E}(\%)$		Ratio e/π
		(2 mm)	(3 mm)				Electrons	Hadrons	
1	1:0	10	125	-	3.81	124.4	$16.2 \pm .3$	33 ± 1	1.11
2	4:1	10	95	22	3.78	103.9	$15.8 \pm .7$	35 ± 1	1.09
3	2:1	10	76	37	3.79	91.3	$15.9 \pm .3$	36 ± 1	1.11
4	1:1	10	53	53	3.73	75.3	$15.1 \pm .3$	38 ± 1	1.22
5	2 mm	162	-	-	3.33	102.4	$13.9 \pm .3$	33 ± 1	1.12
6	copper catcher	-	-	100	3.77	35.7	$13.2 \pm .7(b)$	48 ± 1	1.48

(a) Using particle Data book values
(b) This resolution is better than stated in ref. [1], where the tests were made downstream of a large amount of material

have been tested in comparison to a unit made entirely of 2 mm uranium plates and a "copper catcher" unit. In table 2 the composition of the various test stacks is listed. Data were taken with a negative beam at incident momenta of 2, 5, 7 and 10 GeV/c with particle rates of typically 10^4 particles per burst (300 ms spill).

Calibration - The relative calibration of the PM tubes was performed using the signal created by the uranium radioactivity measured with a 10 μ s ADC gate. The balancing between the "electromagnetic" and the "hadronic" section of the calorimeter and the absolute calibration were achieved by comparing the muon signal with the calculated value of the most probable energy loss using ref. [3]. The ratio of the muon signal and the uranium radioactivity signal will be used later on to calibrate each channel.

Energy resolution - Table 2 summarizes the energy resolution for electrons and hadrons as well as the response for electrons and pions (e/π ratio) of the different stacks. Both, resolution and e/π ratio are averaged over the momentum range of 2-10 GeV/c. Note, that the best resolution for electrons is obtained with configurations 5 and 6, which are similar

for electromagnetic showers. For the hybrid stacks electron resolution improves with increasing admixture of copper. The two stacks of pure uranium (conf. 1 and 5) do not show a significant difference in hadron resolution, but the resolution is slowly degraded by increasing the copper fraction. Fig. 5 shows the resolution plotted against the copper fraction in terms of absorption lengths. It indicates a linear behaviour with perhaps a deviation in the case of pure copper, which might be associated with it being a shorter stack (in terms of absorption lengths).

Electron/pion ratio - The e/π ratio is practically the same for the 2 and 3 mm pure uranium stack and does not change significantly with the addition of copper until the mixture 1:1 is reached where this ratio increases by $\sim 10\%$.

The e/π ratio and the hadron resolution demonstrate in a clear way the advantage of a calorimeter of the fission compensated type compared to calorimeters using conventional absorber materials.

Linearity - The linearity was measured in the range of 2 - 10 GeV/c. All stacks are linear in this range and this is shown in fig. 6 for configuration 1. The non-linearity for electrons below 2 GeV/c is attributed to systematic uncertainties which increase with low momentum (beam settings, energy loss in the beam transport etc.).

Fig. 5 Hadronic resolution as a function of the copper fraction expressed in absorption lengths

Fig. 6 Linearity of response of configuration 1: E_{measured} = response of the calorimeter normalized to 5 GeV/c

The calorimeter in the trigger

Because of the electron hadron ratio being close to 1, the calorimeter will provide a means of unbiased triggering. Both for the electromagnetic and hadronic segments, the output of the last dynodes at constant azimuth, are summed up locally and brought to the counting room via aircore cables ($v/c = 0.95$) for further processing. There various sums are generated (electromagnetic single particle, hadronic single particle, jets and others) and encoded by multi-level discriminators. This information is then transmitted together with information from other detectors to the so-called "very fast bus" which is able to make decisions according to 50 different types of triggers and initiates the corresponding processing [4].

Conclusions

We are constructing a hadron calorimeter using depleted uranium 238 as absorber material. It will provide full azimuthal coverage over 8 sr with a cell size matched to the measurement of individual particles inside a jet of high transverse momentum. The energy resolution for electrons is $16\%/\sqrt{E}$ and the hadronic resolution is $36\%/\sqrt{E}$ where the contribution of sampling fluctuations is estimated to be $25\%/\sqrt{E}$. In this fission compensated calorimeter the ratio of signals from electromagnetic and hadronic cascades is close to 1, therefore providing a means of unbiased triggering on charged and neutral hadrons on a steeply falling high p_T spectrum.

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