q

NuMI-L-335
November, 1997
ANL-HEP-CP-98-02

ANL-HEP-CP-98-02

RESULTS FROM AN IRON-PROPORTIONAL TUBE CALORIMETER PROTOTYPE

P. SCHOESSOW, I. AMBATS, D. S. AYRES, J. W. DAWSON,
W. N. HABERICHTER, N. HILL, R. L. TALAGA, J. L. THRON

Argonne National Laboratory
9700 S. Cass Avenue, Argonne, IL 60439, USA

YU. GORNUSHKIN, A. SADOVSKI

Joint Institute for Nuclear Research
Joliot Curie 6, Dubna, Moscow Region, RU141980, Russia

J.L. MILLER

Indiana University, Physics Department, Swain West 302
Bloomington, IN 47405, USA

R. SCHWIENHORST

University of Minnesota, School of Physics and Astronomy
116 Church St. SE, Minneapolis, MN 55455, USA

H. GALLAGHER

Oxford University
Keble Road, Oxford OX1, 3RH, UK

C. ARROYO

SLAC, MS 63, PO Box 4349
Stanford, CA 94309, USA

W.A. MANN

Tufts University, Physics Department
Medford, MA 02155, USA

W.L. BARRETT

Western Washington University, Physics Department
Bellingham, WA 98225, USA

Submitted to the proceedings of the VII International Conference on Calorimetry in High Energy Physics, University of Arizona, Tucson, Arizona, Nov. 9-14, 1997.

C97-11-09

We have studied the energy resolution of a prototype gas tracking calorimeter in a test beam at Fermilab as part of the detector development program for the MINOS long baseline neutrino oscillation experiment. The calorimeter consisted of 25 layers of 1.5 inch thick steel plates interleaved with planes of aluminum proportional tubes. The tube cells are square, with 0.9 cm edges and open tops. Cathode strips were used for read out transverse to the wire cells. The tubes operated with a nonflammable gas mixture of 88% CO_2, 9.5% isobutane and 2.5% argon which gave an operating range of > 500 V (limited by the electronics). We read out the wire signals on the tubes and in some configurations the cathode strips as well. We studied positrons, pions and muons over a momentum range of 2.5 - 30 GeV/c and achieved energy resolutions of about $40\%/\sqrt{E}$ for EM and $71\%/\sqrt{E}$ for hadronic showers.

1 Introduction

The MINOS experiment is designed to search for neutrino oscillations over an unprecedented 730 km baseline.[1] The detector will be a toroidal magnetized iron tracking calorimeter, with a toroid diameter of 8 m. The active detector technology for this experiment needs to be rugged, reliable and relatively inexpensive, since the total area of detector planes required is about 30 000 m^2, or more than seven acres!

Limited streamer tubes (LSTs) were the initial choice[2] for the active detector technology. The experience of the MACRO experiment[3] demonstrated successful large scale fabrication of LSTs at a scale close to that required for the MINOS detector (20 000 m^2). In addition, LST technology has a proven track record of long term stability, especially important in the Soudan Mine environment, where replacement of defective chambers will be unfeasible. The use of wire chamber technology also permits the use of thin two-dimensional readout via cathode strips.

We have chosen to use aluminum proportional tube (APT) technology which is a modifications of the basic LST design, developed to overcome some of the less desirable features of LSTs. Noncombustible gas is required for operation in the Soudan mine, hence the fraction of isobutane in the chamber gas must be reduced significantly. At these low isobutane levels APTs suffer from afterpulsing when operated in limited streamer mode, but operation in proportional mode is possible. Better dimensional uniformity is available with aluminum extrusions than with the PVC extrusions used in LSTs, hence more uniform gas gain and better EM resolution can be obtained. Commercially available aluminum extrusions can be used to reduce fabrication costs.

2 Design of MINOS APTs

A single APT module (figure 1) consists of a 16 cell square channel aluminum extrusion through which 50 μm gold plated tungsten anode wires are strung under 250 g tension. The channel spacing is 1 cm; the wires are read out in pairs to provide a 2 cm pitch. The anode wires are supported with plastic spacers at each end. (In the 8 m configuration, spacers are located at 50 cm intervals.) The aluminum channel is enclosed in an extruded PVC gas sheath. Injection molded endcaps close the gas volume and provide feedthroughs for signal, high voltage and gas connections.

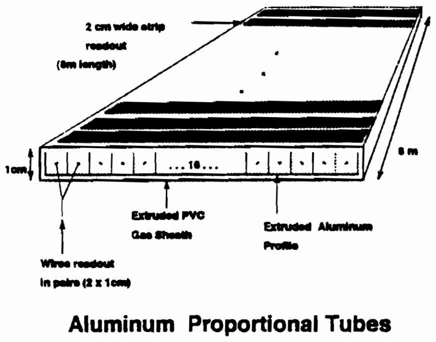

Figure 1: APT module (8 m configuration)

Cathode strip planes consist of double sided copper clad PC board. The strips are formed by scoring the copper on one side at 2 cm intervals. The strip planes are mounted on the PVC sheaths of the assembled wire planes.

The gas used is a nonflammable mixture of 9.5% isobutane, 88% CO_2, and 2.5% Argon. Operating the chambers at 3100 V gives a gas gain of 2×10^5 and anode signals of $\simeq$ 1 pC/MIP. The chambers were operable up to 3700 V without afterpulsing.

3 Prototype Calorimeter Configuration and Data Taking

The prototype calorimeter is shown in fig.2. 3.8 cm thick steel plates 1 m × 1 m square mounted in hanging file configuration were used as absorbers. 3 cm gaps were left between the plates to provide space for chamber mounting.

Positron measurements were taken with 9 active detector planes, corresponding to a total detector thickness of 19.4 X_0. Hadron and e/h measurements were taken with 25 active layers (5.7 λ_I). A 3.5 X_0 Pb preshower radiator was used to eliminate positron contamination in the beam for hadron data

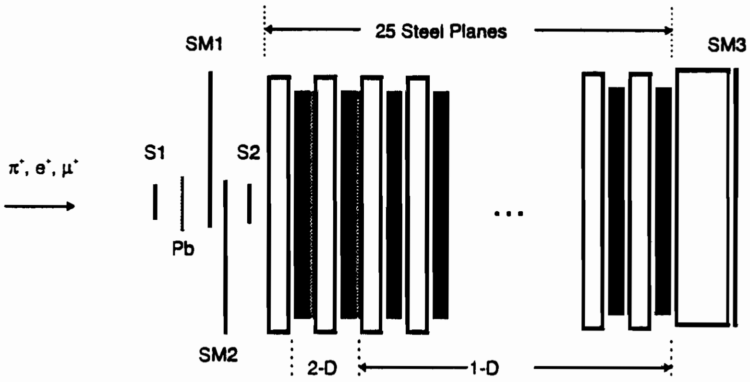

Figure 2: Prototype APT calorimeter. Open rectangles: Steel absorbers, Shaded rectangles: APTs, S1,S2: Trigger counters, SM1,SM2,SM3: Muon counters, Pb: Lead preradiator (hadron runs only).

taking. For the hadron configuration the cathode strips were instrumented on the first two planes only. Scintillation counters mounted on the calorimeter were used to form the various triggers used. The 1200 channels of APT wires and strips were read out using Lecroy 2280/2285 12 bit charge ADC systems.

Data were taken during June-August 1997 at the Fermilab M-West test beam. The various triggers used are described below.

- Muons: $((SM1 + SM2) \cdot SM3)$ The large scintillator paddles upstream and downstream provided full coverage of the calorimeter. Muon data were used for efficiency and response uniformity analysis.
- EM trigger: $(S1 \cdot S2 \cdot \overline{SM3})$ Data were taken with 2.5-25 GeV e^+, vetoing on muons, and with Pb preradiator removed from beamline.
- Hadron trigger: $(S1 \cdot S2 \cdot \overline{SM2 > 1MIP})$ 5-25 GeV π^+, Pb preradiator in, veto on EM showers in preradiator.

4 Results

The results presented here represent the first pass through the data using relatively simple algorithms; nevertheless the initial results obtained were good enough to validate APTs as a viable detector technology for MINOS. In particular, the energy resolutions given here should be viewed as upper bounds to the true detector resolution since

- No corrections have been made for atmospheric pressure variations during data taking, although the barometric pressure was recorded for each run.

- Events with longitudinal or transverse leakage have not been removed from the analysis.

- The large constant terms in the resolution are due to the large momentum dispersion of the beam at the detector ($\Delta p/p \simeq 5\%$ across trigger counter S1). While there were no beam chambers to measure the track momentum, in principle the shower position in the calorimeter could be used to refine the particle momentum and determine the constant terms more accurately.

Test beams were "dirty" and a number of cuts were required to produce clean showers. No particle identification (e.g. Cherenkov counters) was available in the the test beam other than that provided by the scintillators and calorimeter itself. Typical raw "positron" data which passed the hardware trigger consisted of wide angle muons which missed the SM3 veto counter, a true e^+ peak, and a low tail due to positrons which showered upstream of the detector. Offline analysis requiring hits in two beamline counters (C2, C3) upstream of the final bend magnet, and no preshower (S1 = 1 MIP, more charge deposited in layer 2 than in layer 1) isolated the real e^+ peak. The hadron analysis also required $C2 \cdot C3$, but the use of the preradiator in the trigger was sufficient to remove the e^+ contamination.

The quoted resolutions are based on σ obtained from fitting the charge spectrum to a Gaussian. RMS widths and hit count distributions (for hadron showers) were also fitted and gave similar results.

Muon data: The expected wire efficiency is 90%, based on the aluminum extrusion geometry (gas volume width 9 mm, wall width 1 mm). The measured efficiency is 87%, based on counts of missing hits on reconstructed muon tracks in the calorimeter. The measured strip efficiency was 83%, with the slightly smaller value consistent with the reduced signal amplitudes and wider pedestals observed for the strips.

The channel to channel uniformity was measured from the distribution of mean muon pulse heights for the detector. The RMS width of this distribution is 10.4%. When this is corrected for the gain of the individual electronics channels, the actual uniformity is 7.0%.

Electromagnetic energy resolution: After applying the cuts described in the previous section, the positron charge distributions are fitted to Gaussians and σ_E/E plotted as a function of beam energy in figure 3. The resolution function is found by fitting to be $\sigma_E/E = 40\%/\sqrt{E} \oplus 7\%$.

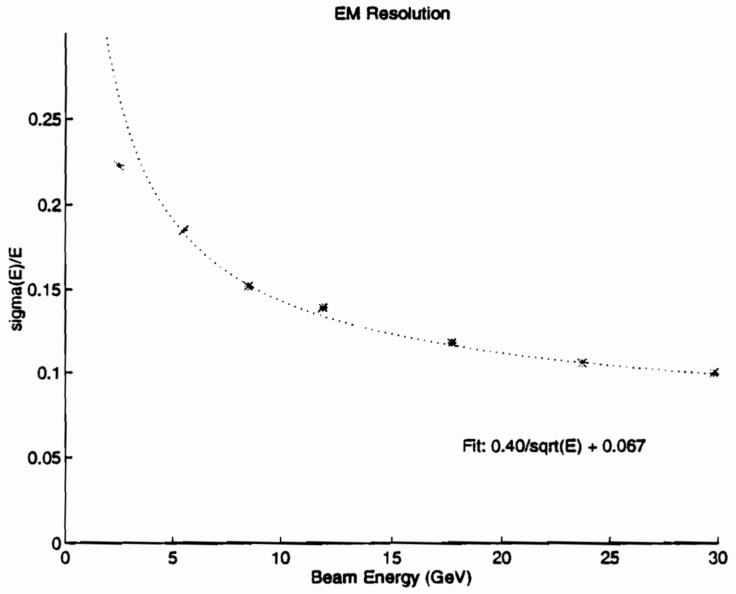

Figure 3: Measured electromagnetic energy resolution

Hadronic energy resolution: Figure 4 shows the measured hadronic energy resolution, with fitted resolution function $\sigma_E/E = 71\%/\sqrt{E} \oplus 6\%$. Use of the rms charge rather than the the fitted σ does not significantly change the resolution, giving $E_{rms}/E = 74\%/\sqrt{E} \oplus 8\%$. The obtained hadronic energy resolutions are well within the required resolution $(100\%/\sqrt{E})$ of the MINOS detector.[2]

A comparison of the resolution of the MINOS APT prototype with the published resolutions of various other gas hadron calorimeters is shown in figure 5. The curves plotted show the parametrization $\sigma_E/E = 0.5/\sqrt{E} \oplus R'\sqrt{(4t/3E)}$.[4] Here t is the absorber layer thickness in radiation lengths and $R' \simeq 0.3 - 0.4$ is an empirical parameter. (The solid and dashed curves correspond to $R' = 0.3$ and $R' = 0.4$ respectively.)

The performance of the prototype compares very well with that of other gas calorimeters, in large part due to the degree of compensation obtained.

e/h: This quantity was measured using the beamline tuned for hadrons and the preradiator removed. Positron and pion peaks were easily separated for each energy by looking at the number of hits in each event. e/h varies from $\simeq$ 1.3 at low energies to $\simeq$ 1.1 at the high energy end. The origin of the near-

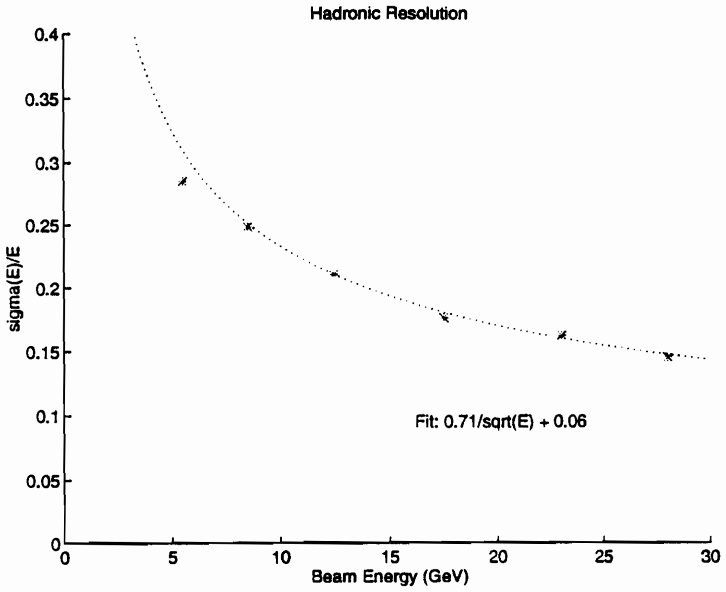

Figure 4: Measured hadronic energy resolution

compensation is not completely understood. In particular the contributions of the different interaction and absorption lengths of the materials comprising the detector do not seem to account for the effect.

5 Conclusions

These measurements represent a successful demonstration of APT technology in a prototype tracking calorimeter. The 1 m prototype calorimeter met MINOS requirements for energy and spatial resolution.

Aluminum proportional tubes emerged as one of several viable active detector technologies, but in September 1997 the collaboration chose to proceed with extruded solid scintillator as the technology of choice. It was felt that the possibility of obtaining even better energy resolution from a scintillator calorimeter would be an important physics advantage for the MINOS detector. The fast time response of scintillator (e.g. for distinguishing upward going from downward going cosmic ray muons) was also an important consideration.

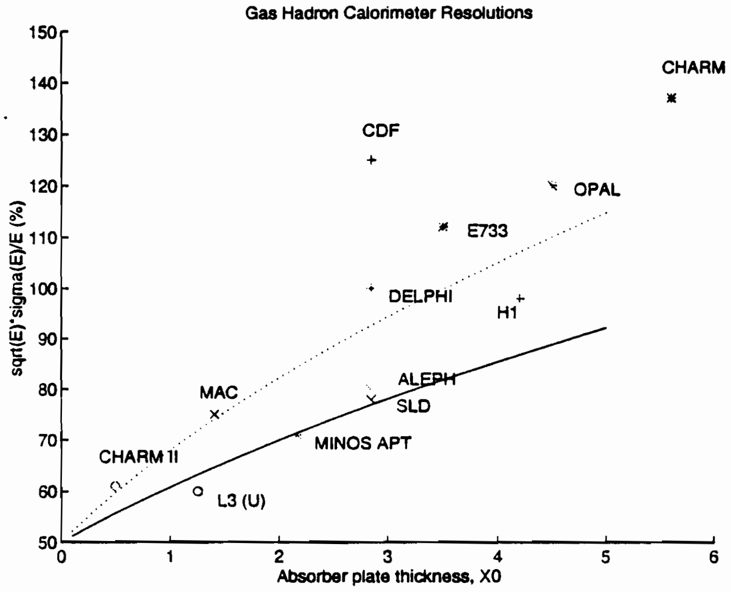

Figure 5: Comparison of APT prototype resolution with other gas calorimeters

Acknowledgments

This work was supported by the US Department of Energy, the US National Science Foundation, and JINR Dubna. The authors gratefully acknowledge the assistance of the technical staffs of of ANL, Tufts University, Fermilab, and Dubna.

References

1. D. Ayres in *Proceedings of the 4th KEK Topical Conference on Flavor Physics*, Nuclear Physics B (Proc. Suppl.) **59** 297 (1997)
2. "P-875: A Long-baseline Neutrino Oscillation Experiment at Fermilab", MINOS Collaboration, E. Ables et al., FERMILAB-PROPOSAL-P-875, Feb 1995
3. S.P.Ahlen et al., NIM **A324**, 337 (1993)
4. K. Kleinknecht, *Detectors for Particle Radiation* Cambridge 1986