Results from an Iron - Proportional Tube Calorimeter Prototype

Argonne National Laboratory

Yu. Gornushkin, A. Sadovska
JINR Dubna

J.L. Miller
University of Indiana

R. Schwienhorst
University of Minnesota

H. Gallagher
Oxford University

C. Arroyo
SLAC

W.A. Mann
Tufts University

W.L. Barrett
Western Washington University

Abstract:

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% CO₂, 9.5% isobutane and 2.5% argon which gave an operating range of 500V (limited by the electronics). We read out the wire signals on the tubes and in some configurations the cathode strips. We studied positrons, pions and muons over a momentum range of 2.5 - 30 GeV/c and achieved energy resolutions of about 45%/√E for EM and 75%/√E for hadronic showers.
MINOS-- Main Injector Neutrino Oscillation Search
Outline

I. APT design issues
II. Tests of 1 m (1/8 scale) prototype calorimeter at FNAL M-West test beam using 2.5-30 GeV $e^+$, $\pi^+$, $\mu^+$.
   1. Experimental configuration
   2. Efficiencies and response uniformity
   3. Electromagnetic energy resolution
   4. Hadronic energy resolution $e/h$
   5. Comparison of performance with other gas calorimeters
   6. Comments on data analysis
III. Cosmic ray tests of 8 m prototype chambers
IV. Conclusions and tragic denouement

Aluminum Proportional Tubes (APTs) as MINOS Active Detector Technology

- Limited streamer tubes were the initial choice (Proposal)
  ◦ Successful large scale fabrication
  ◦ Long term stability demonstrated
- Aluminum proportional tube technology was developed to overcome some of the less desirable features of LSTs
  ◦ Noncombustible gas is required for operation in the Soudan mine. While APTs suffer from afterpulsing when operated in limited streamer mode with low isobutane they can be operated in proportional mode.
  ◦ 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.
- Good spatial and energy resolution.
- Relatively easy to mass produce (10 kT detector requires $\approx$30,000 m$^2$ (7 Acre) of chambers). Can use commercially available aluminum and plastic extrusions.
- Cathode strips provide thin 2D readout.
Aluminum Proportional Tubes

Gas: 9.5% Isobutane
88% CO₂
2.5% Ar

“SLD gas”
non-flammable
Large Pulses
in prop. mode
APT Prototype Calorimeter

- Steel planes: 3.8 cm, hanging file configuration.
- 3 cm air gaps
- EM measurements: 9 active planes (19.4 X₀)
- Hadronic measurements: 25 active planes (5.7X₀), 3.5 X₀ Pb preshower radiator
- Cathode strip readout on first few planes

Data was taken June-August 1997 at FNAL M-West test beam:
- Positrons 2.5-25 GeV, Hadrons 5-25 GeV. (These represent nominal beamline energies-- correct energy scale determined later using CDF measurement system.)
- Muons: large scintillator paddles front and back in trigger provide full coverage of the calorimeter.
- Pulser trigger
- EM trigger: S₁ · S₂ · S₃ (veto on muons), preradiator removed from beamline
- Hadron trigger: S₁ · S₂ · S₂ > 1Mip (veto on EM showers in preradiator)

Data acquisition:
- Lecroy 2280/2285 12 bit charge adc systems (1200 channels) for chamber wires and strips.
- LRS 2249A adcs for scintillation counters
- CES 8210 VME-CAMAC interface
- MVME167 VME SBC
- SGI Indy workstation
- FNAL Dart software customized by us
Distribution of Response for all Tubes (Hadron Config)

Muons

Uncorrected For Gain Variations

<table>
<thead>
<tr>
<th>ID</th>
<th>Entries</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1152</td>
<td></td>
</tr>
</tbody>
</table>

| Mean | 72.46 |
| RMS  | 7.565 |

10.4%
Expect ≈ 90%
EM Resolution

Fit: $0.40/\sqrt{E} + 0.067$
Response vs. Energy

Hadron Beams

![Graph showing the relationship between Mean Pulse Charge and Energy (GeV)]
Hadronic Resolution

Fit: $0.71 / \sqrt{E} + 0.06$
Comments on the Data Analysis

The results presented here represent the first pass through the data using relatively unsophisticated algorithms (but the initial results were good enough to demonstrate APTs as a viable detector technology for MINOS).

- No attempts have been made to correct for temperature or pressure variations during data taking.
- Test beams were "dirty" and a number of cuts were required to produce clean showers.
- Events with longitudinal or transverse leakage were not removed from the analysis.
- Quoted resolutions use $\sigma$ obtained from fitting charge spectrum to a Gaussian. rms and hit counts (for hadron showers) were also used and gave similar results.
- The larger than expected constant terms in the resolution are due to the large momentum spread of the beam ($\Delta p/p \approx 5\%$ across S1).

8 m APT Prototype Tests

We have also constructed several full size chambers for cosmic ray tests. The goals here were to investigate potential problems in scaling up from 1 m to 8m.

- Movable scintillator telescope to sample wire and strip planes locally.
- No attenuation of signals was observed along wires and strips, i.e. the wires and strips behave as transmission lines.
- 8 m wire cells are uniform to within $\pm 10\%$ along their entire length.
- Charge sharing on strips as expected
8m APTs

Mean Pulse Charge

Distance along chamber (m)

-10\% 
+10\%

No Attenuation
No Attenuation - Strips-
Charge Sharing on Cathode Strips

Apt-8m, run_091806

<table>
<thead>
<tr>
<th>ID</th>
<th>4100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>12602</td>
</tr>
<tr>
<td>Mean</td>
<td>0.9121E-02</td>
</tr>
<tr>
<td>RMS</td>
<td>0.4336</td>
</tr>
</tbody>
</table>

\[ \langle Q \rangle \]

Strip with maximum charge
Conclusions

- APT prototype calorimeter worked very well:
  
  Resolution: $\sigma/E = 40\%/\sqrt{E} \oplus 7\% \quad \text{(EM)}$
  
  $71\%/\sqrt{E} \oplus 6\% \quad \text{(Hadron)}$

  Efficiencies: 87\% (Wires) 83\% (Strips)

- No apparent show stoppers in scaling up to 8 m production chambers.
- Very successful demonstration of APT technology in a prototype tracking calorimeter.

But...

In September the collaboration chose to proceed with extruded solid scintillator as the active detector technology.

- DRAC report cited APTs as being the most developed of the technologies under consideration but did not express a strong preference for any one technology. (All can be made to work.)
- APT disadvantages:
  - Gas system is an additional complication.
  - Perceived problems with relative calibration of near and far detectors and absolute calibration.
- Solid scintillator advantages:
  - Timing
  - Easier calibration
  - Thinner (1 cm vs $\approx 3$ cm for APTs)
  - More suitable for university group participation in fabrication.