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Author(s): *S. Stanislaus, V. Armijo, J. K. Black, R. D. Bolton, S. Carius, M. D. Cooper, C. Espinoza, G. Hart, G. Hogan, A. Gonzales, R. E. Mischke, L. E. Piilonen, J. Sandoval, S. Schilling, J. Sena, G. Suazo, J. J. Szymanski, D. A. Whitehouse, C. A. Wilkinson, R. Fisk, D. D. Koetke, R. W. Manweiler, and C. C. Jui*

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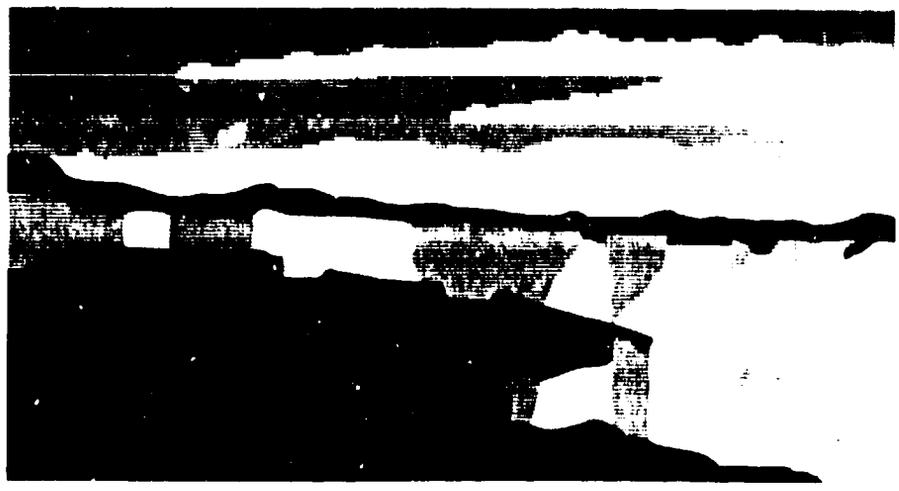

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Results from Beam Tests of MEGA's Low-Mass, High-Rate Cylindrical MWPCs*

S. Stanislaus, V. Armijo, J.K. Black, R.D. Bolton, S. Carius, M.D. Cooper, C. Espinoza, G. Hart, G. Hogan, A. Gonzales, R.E. Mischke, L.E. Piilonen, J. Sandoval, S. Schilling, J. Sena, G. Suazo, J.J. Szymanski, D.A. Whitehouse, C.A. Wilkinson(**Los Alamos National Laboratory**)

R. Fisk, D.D. Koetke, R.W. Manweiler **(Valparaiso University)**

C.C. Jui **(Stanford University)**

Abstract

One of the leading experimental projects at LAMPF has been the MEGA experiment. This is an experiment to search for the rare decay $\mu \rightarrow e\gamma$ with a sensitivity of 10^{-13} . A prime component of this project has been the design and construction of high-rate, low mass MWPCs for the tracking of positrons from muon decay. With rate capabilities of 2×10^4 $e^+/mm^2/s$ and a thickness of 3×10^{-4} radiation lengths, these chambers are state-of-the-art cylindrical MWPCs. Cylindrical chambers of this size (0.9 m^2) and thinness have never been previously constructed. The MEGA project at LAMPF has recently succeeded in building chambers with these necessary performance characteristics as demonstrated by data taken from muon decays, cosmic rays, and sources.

* Work supported by the U.S. Department of Energy.

1. Introduction

MEGA is the latest in a series of muon decay experiments at LAMPF. It is designed to search for the rare decay $\mu^+ \rightarrow e^+ + \gamma$ with a sensitivity of a few parts in 10^{13}. The MEGA detector is a magnetic spectrometer designed to detect in coincidence the back-to-back 52.8 MeV positron and the 52.8 MeV photon from the decay of the muon stopped in a thin target at the center of the spectrometer. The photon detector consists of three concentric, cylindrical pair spectrometers. The positron detector consists of eight state-of-the-art low-mass, high-rate cylindrical MWPCs for high precision tracking, and two cylindrical banks of 90 scintillators each to obtain precise timing. The photon detector surrounds the positron detector, and the entire apparatus is contained in a superconducting solenoid of 1.5 T. Details of the design of the experiment can be found in references [1-3]. This paper will discuss test results from the positron arm MWPCs [3]. Details of the chamber construction and electronics will be the subject of a later paper.

2. Design Considerations for Positron MWPCs

There were two dominant considerations in the design of the positron MWPCs. First, we needed low mass to minimize positron interactions producing γ-rays. This property also aids in achieving good positron energy resolution (0.6% at 52.8 MeV) by minimizing multiple scattering. Second, we needed stable and efficient operation in an instantaneous μ stopping rate of 500 MHz for more than 10^7 seconds.

The active chamber region consists of two concentric cylindrical cathode foils with the anode wires stretched axially between the two foils. Wires and foils are attached to two end pieces, that are in turn attached to a fixture (the tension shell) that holds all the chambers and maintains wire tension. The cylindrical foil shape is supported by differential gas pressure. The thickness of the chamber (two foils, gas

and wires) for normal incidence is 3×10^{-4} radiation lengths. A geometrical configuration that has been adopted to minimize the occupancy rate is shown in Fig. 1. In this configuration the chambers are named Snow White (SW, the larger chamber) and the seven dwarfs. The maximum flux in a chamber is expected to be 2×10^4 $e^+/mm^2/s$.

Some of the chamber parameters are: wire spacing 1mm, half-gap 1.75 mm, length 126 cm, dwarf radius 5.982 cm, SW radius 11.138 cm, wires 15 μm Au-W, cathode foil 200 nm Cu on 25 μm kapton, cathode stripe width 2.7 mm, gas CF_4(80%) + isobutane(20%), and four electro-mechanical supports. The supports each consist of a 0.1 mm diameter monofilament over the wires and a 0.66 mm diameter glass cane under the wires.

3. The Test Run

Engineering tests were conducted on the positron MWPCs during a 1990 beam run to demonstrate that the chambers would meet the needed requirements. Because the design work and code development relied heavily on the Monte Carlo code used to simulate the chamber response, we needed to compare the observed characteristics of the MWPCs with those of the simulation. The important features to be verified include the energy and position resolutions of the chambers as well as the degree of occupancy. The chamber tests were conducted with a limited prototype system consisting of a complete barrel of 90 positron scintillators, a fully instrumented dwarf chamber with 1mm wire spacing, a SW chamber with 2mm wire spacing, and one layer of scintillators in the photon arm.

4. Chamber Stability and Timing Test

During bench tests using a ^{90}Sr source producing the same current density as the beam, it was observed that at about 100 V below the operating voltage of 2450 V

the dwarf chambers produced a dark current of ~ 1-100 μA that was not self quenching when the source was removed. The purpose of the larger wire spacing used in the SW was to address this problem. The SW chamber did not produce dark currents during bench tests. The prototype chambers reproduced the same behavior when illuminated by positrons from muon decays as when exposed to the ^{90}Sr source. The dwarf chamber was unstable above 2350 V at rates above 1MHz whereas the SW chamber ran without trouble at full voltage (1850 V) even when the beam rate was 240 MHz. On the basis of this we concluded that the chamber dark current problem was not related to the gas gain.

The intrinsic drift time distribution had previously been measured for a prototype chamber that had short (20 cm) wires with the same wire spacing and half gap as the dwarf chambers. These tests showed that for a chamber using a mixture of 80% CF_4 + 20% isobutane the collection time was 12 ns (base width) [2]. During the 1990 run, timing measurements were made to study the characteristics of anode and cathode pulses. No difference was seen in the transmission properties between wires and stripes; there was no evidence of broadening in SW timing as the result of the wider spacing.

Figure 2 shows a typical cosmic ray time spectrum. It shows the time difference between the trigger scintillators and the first anode signal. In addition to the drift time, this spectrum contains contributions from jitter in the trigger box, track time-of-flight broadening, leading edge slewing from variations in pulse-height, and variation in propagation time due to location of the chamber hit. With these additional components, the resulting distribution of arrival times at the TDC should roughly double in width from that of the collection time. The spectrum shown in Fig. 2 with FWHM of 10 ns is therefore consistent with these expectations. It is important for the $\mu \rightarrow e\gamma$ search that the distribution of arrival times be made as

narrow as possible since a broader spectrum would result in increased accidental background in the chambers.

5. Comparison with Monte Carlo

We have developed a detailed Monte Carlo of the MWPCs including effects such as multiple scattering, variable energy deposition, pulse shape effects, etc. Using the parameters given in sections 2 and 3 the results of the simulation are compared with the 1990 data.

5.1 Hit Multiplicities

In addition to the rate of incident particles, the occupation fraction of the chambers depends on the number of wires or stripes activated by each particle. For the anodes, the multiplicity is determined mainly by geometry, i.e. the number of cells crossed by a given track. The situation is slightly more complicated for cathodes, where a realistic model of the image charge distribution is needed to make a correct simulation of hit multiplicities. The cathode multiplicity was one aspect of the Monte Carlo code that needed verification. In addition, the code does not include cross-talk between neighboring channels.

Figure 3 shows the histograms of anode and cathode hit multiplicity vs. incident angle of straight tracks (magnetic field off) on the chamber. The angle used here is that between the x-y projection (Fig. 1) of the track and a vector normal to the axis of the chamber; 0° represents a track incident along the normal. Events with angles up to 80° are included. Beyond this value, separate clusters in the chamber cannot be resolved. The anode distributions are in excellent agreement between the experiment and the Monte Carlo, where at very large angles the data exceed the simulation results by about 10%. The discrepancies were somewhat larger for the cathodes, where the data are ~20% higher over the wide

range of angles. This might indicate a significant contribution from cross-talk. The level of agreement is adequate for MEGA's needs. Similar data taken with the magnetic field on (curved tracks) show that the magnetic field does not affect the results.

5.2 Position Resolution

Straight track events (muon decays with magnet off) were used to make a comparison between the observed and expected position resolutions of the chambers. A straight track crosses SW at one point and the dwarf at two points. The dwarf chamber hits are used to predict the location of the crossings in SW. Histograms of the difference between the projected SW crossings in ϕ and z values (in a cylindrical coordinate system centered at SW), and those obtained from the SW chamber hits are shown in Fig. 4. For both $\Delta\phi$ and Δz, the simulation is in excellent agreement with experiment. Hence the position resolution of the chambers are reproduced accurately by the simulation program.

5.3 High Rate Tests

The onset of dark currents in the dwarf chamber restricted the high rate tests to SW and positron scintillators. Data were taken at various beam intensities up to an instantaneous rate of 240 MHz. Occupancy rates were studied by looking at the average number of anode and cathode clusters as a function of the beam rate. While the observed anode rate was slightly above the simulated rate, the experimental cathode rate was significantly below the Monte Carlo values. We attribute the larger discrepancy in the cathode rates to the absence of pulse-shaping in the cathode readout electronics [3]. The discrepancies in the results are within tolerable levels. We expect the level of agreement to improve with the installation of pulse-shaping on the amplifier-discriminator cards.

5.4 Energy Resolution and Track Reconstruction

During the latter part of the run sixteen hours were devoted to a trial search of $\mu \rightarrow e\gamma$. Approximately 4000 background positrons were reconstructed from this data. The energy spectrum of these events is shown in Fig. 5 along with a Monte Carlo Michel spectrum. The agreement is very good between the two spectra showing that the simulation reliably predicts the energy resolution of the detector. As another check of the simulation, Fig. 6 shows the fraction of events containing a reconstructed background track plotted against the instantaneous beam rate. The linear fit to the data points shows that as expected, at these rates the observations fit quite well to a linear model. Two Monte Carlo points are also shown in the plot, and are in very good agreement with the data points.

6. Progress Since The 1990 Run

At the end of the 1990 summer run the single outstanding technical issue remaining was the rate induced dark current. Tests revealed that the dark currents were usually drawn at the support posts of the glass garlands. The posts were replaced with glass beads. The wire spacing was also increased from 1 mm to 1.1 mm, bringing the operating voltage down to 2325 V. The above changes improved the stability of the chambers, but still they could not stand the full rate. The addition of 0.5% of isopropanol to the gas mixture made them stable and capable of handling the full rate of the experiment. But when the alcohol flow was stopped, the performance of the chambers was worse than before, and showed signs of degradation from the isopropanol. Subsequently, the wire spacing was increased to 1.3 mm. With the use of 0.2% water as the quenching agent instead of isopropanol, the chambers perform very reliably and show no signs of degradation. With the increased wire spacing the operating voltage is reduced to 2150 V. Monte

Carlo studies have shown that the larger wire spacing has negligible impact on tracking resolution, but will increase the occupancy fraction of the chambers making it necessary to lower the beam rate by about 10%.

7. Summary

After several years of detector development, prototypes of MEGA's high-rate, low-mass positron MWPCs were successfully tested with beam in 1990. Apart from the dark current problem (which was solved after the run), the behavior of the chambers were in good agreement with predictions of the simulation. In particular, the observed hit multiplicity and background cluster rates agree with simulated values at the 20% level. Within the limitations of the test, the observed chamber resolutions are identical to the Monte Carlo values.

The construction of all eight MWPCs is complete. The MEGA collaboration expects to search $\mu \rightarrow e\gamma$ to 6×10^{-12} level in the summer of 1992 and to reach 6×10^{-13} by the summer of 1994.

8. References

[1] M.D. Cooper, in: Intersection between Particle and Nuclear Physics, ed. G.E. Bunce (AIP, New York, 1988) p. 845; D.D. Koetke, in: Intersection between Particle and Nuclear Physics, ed.W.T.H. Van Oers (AIP, New York, 1991) p.397; LAMPF experiment 969, M.D. Cooper spokesman.

[2] V. Armijo et. al , Nucl. Instr. and Meth. A303 (1991) 298.

[3] C.C. Jui; Ph.D. thesis, Stanford University , 1992.

9. Figure Captions

1. Cross section of positron arm perpendicular to the spectrometer (B-field) axis.
2. Time spectrum for MWPC signals

3. Comparison of hit multiplicity vs. track incident angle for data and simulated events. The average multiplicities are shown in the profile on the right of each plot.
4. Comparison of experimental and Monte Carlo distributions for the difference between projected and actual ϕ (top) and z (bottom) coordinates of hits in SW from straight tracks.
5. Comparison of energy spectra of background Michel events from $e\gamma$ data set with Monte Carlo events.
6. Plot of number of reconstructed background tracks per 1000 triggers vs. instantaneous beam rate.

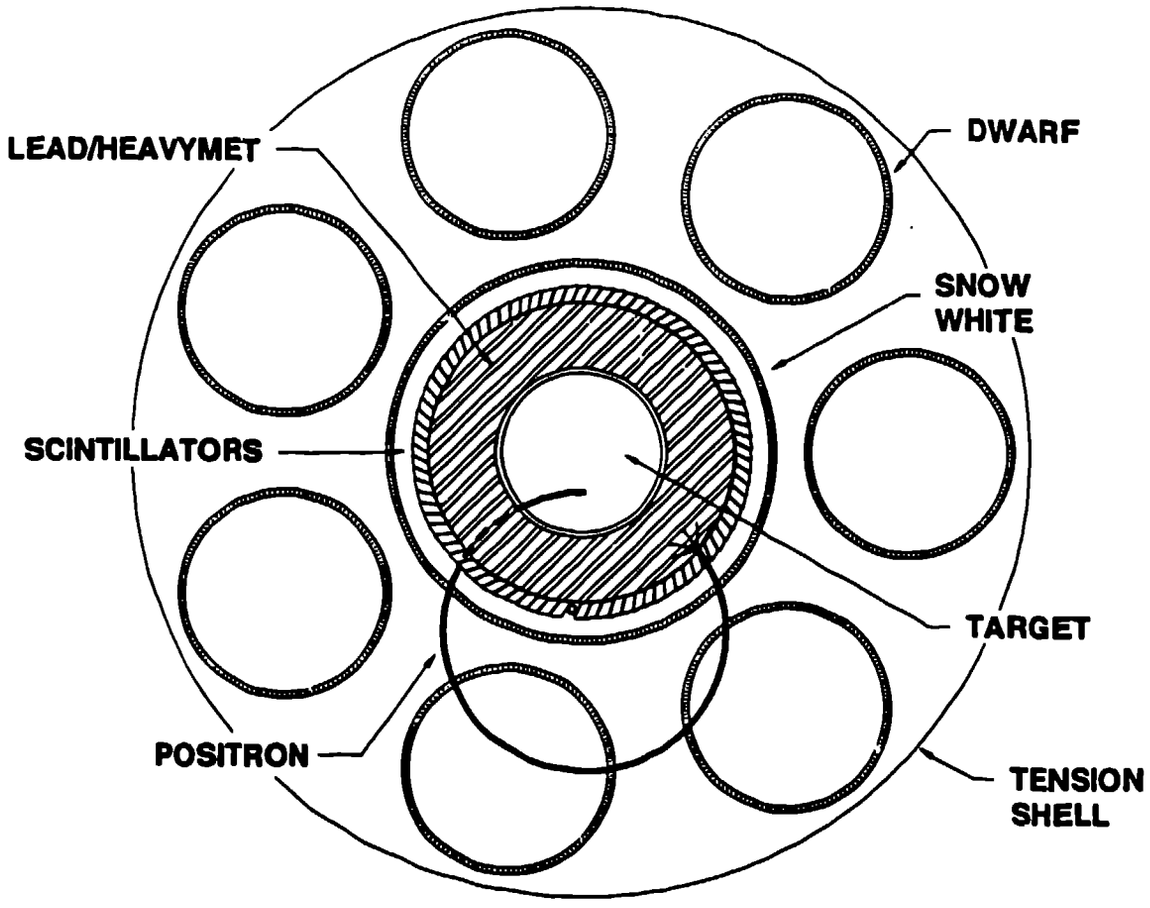
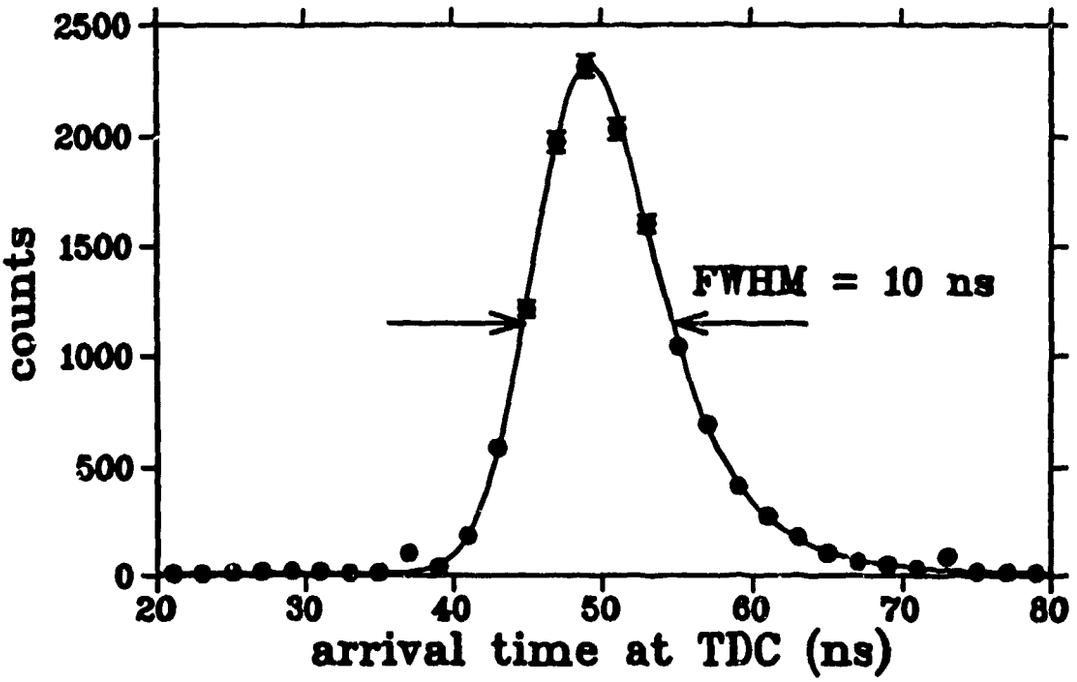

LEAD/HEAVYMET
DWARF
SNOW
WHITE
SCINTILLATORS
TARGET
POSITRON
TENSION
SHELL

Figure 1


2500
2000
1500
1000
500
0
counts
FWHM = 10 ns
20
30
40
50
60
70
80
arrival time at TDC (ns)

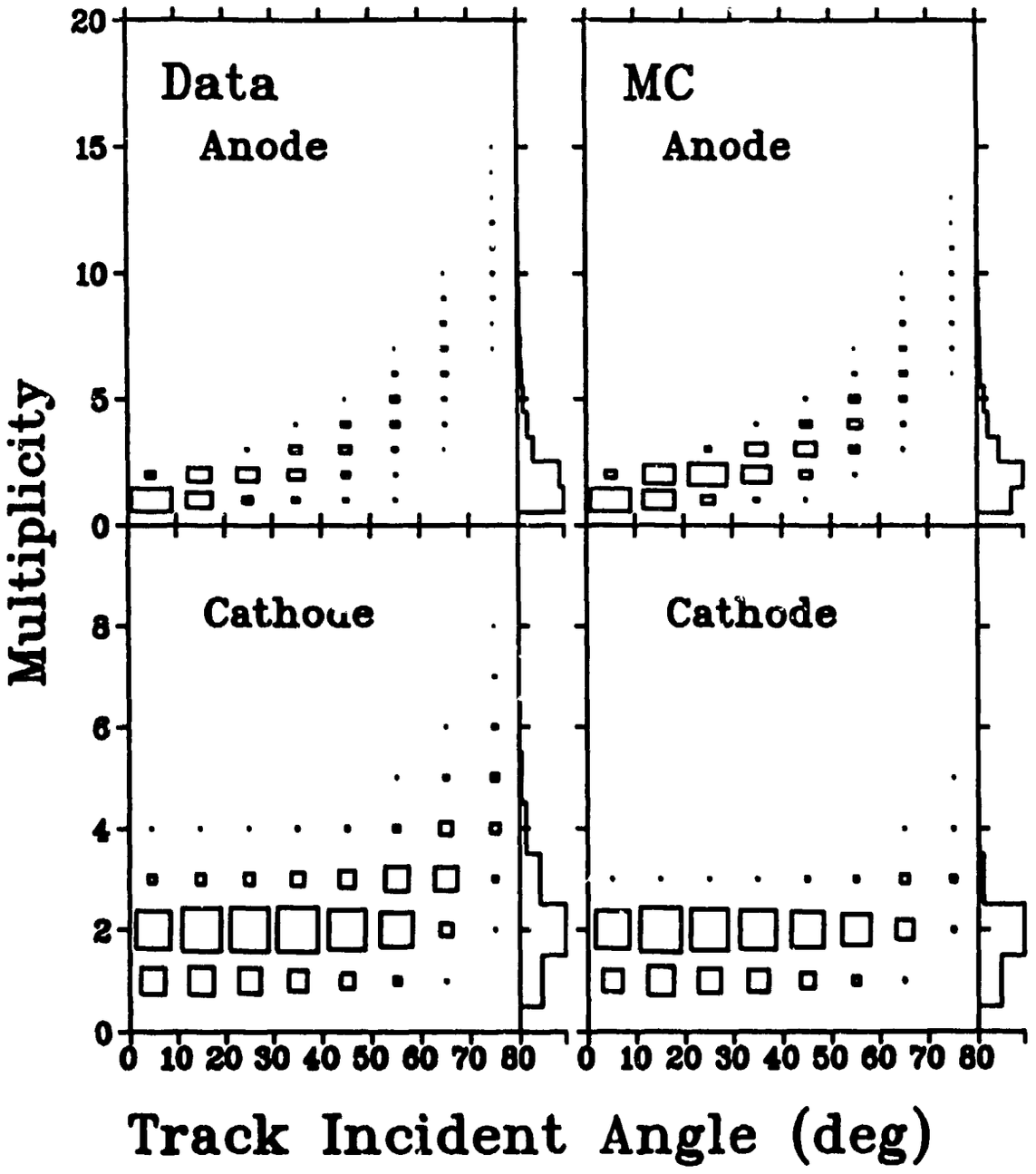
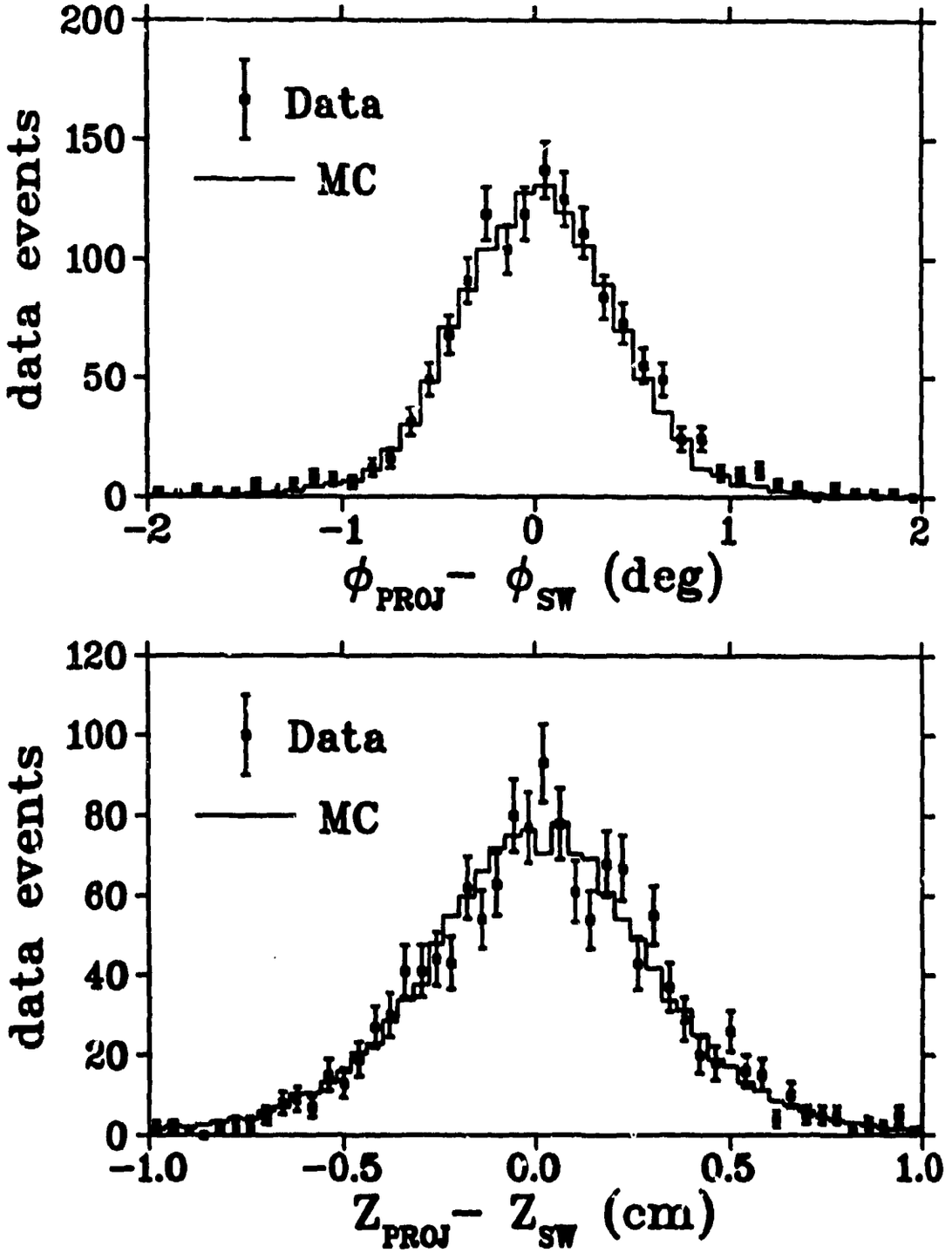
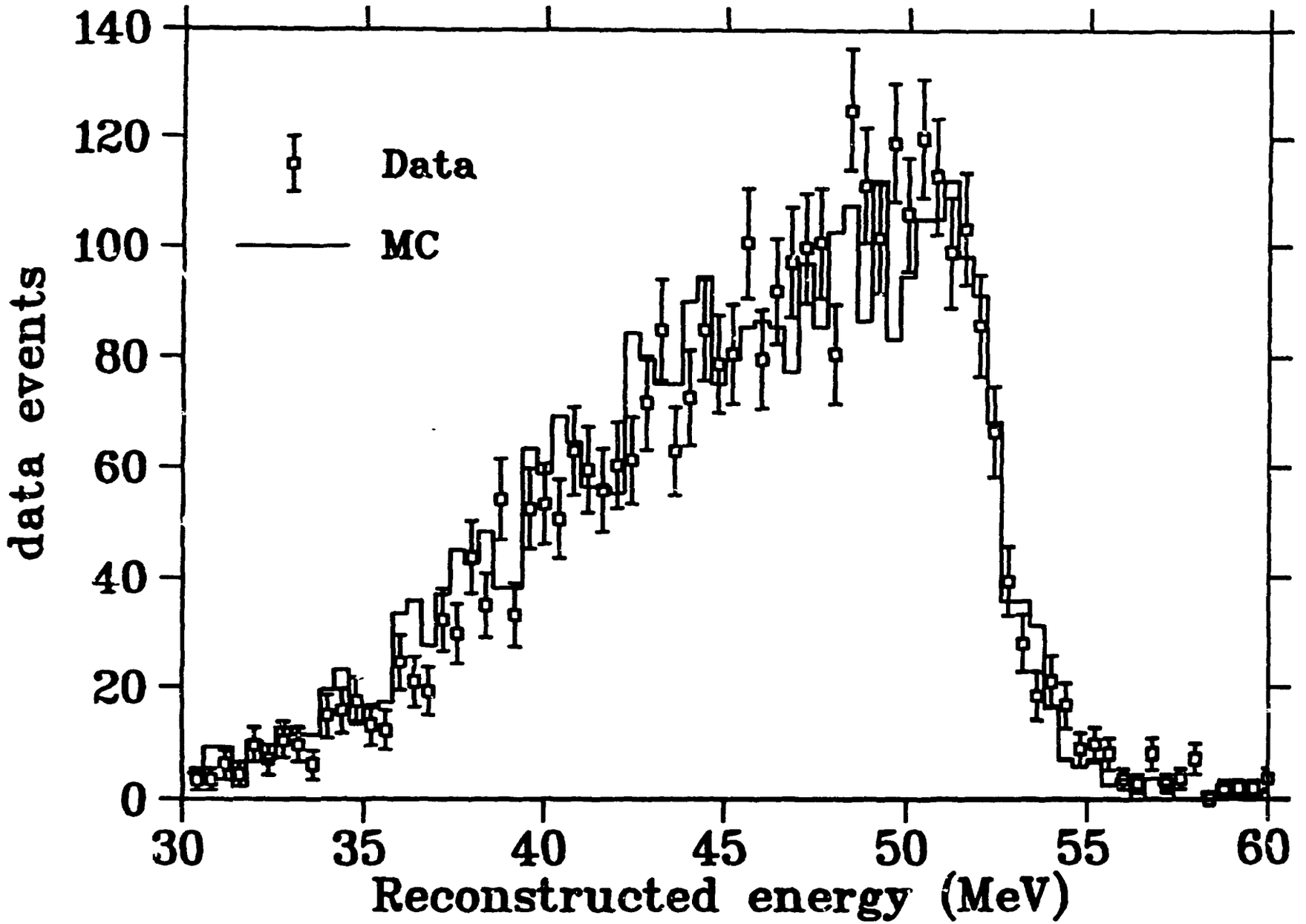

Data
Anode
MC
Anode
Cathode
Cathode
Multiplicity
Track Incident Angle (deg)
0
2
4
6
8
0
5
10
15
20
0 10 20 30 40 50 60 70 80

Figure 3


200
150
100
50
0
data events
Data
MC
−2
−1
0
1
2
$\phi_{PROJ} - \phi_{SW}$ (deg)
120
100
80
60
40
20
0
data events
Data
MC
−1.0
−0.5
0.0
0.5
1.0
$Z_{PROJ} - Z_{SW}$ (cm)


140
120
100
80
60
40
20
0
data events
Data
MC
30
35
40
45
50
55
60
Reconstructed energy (MeV)

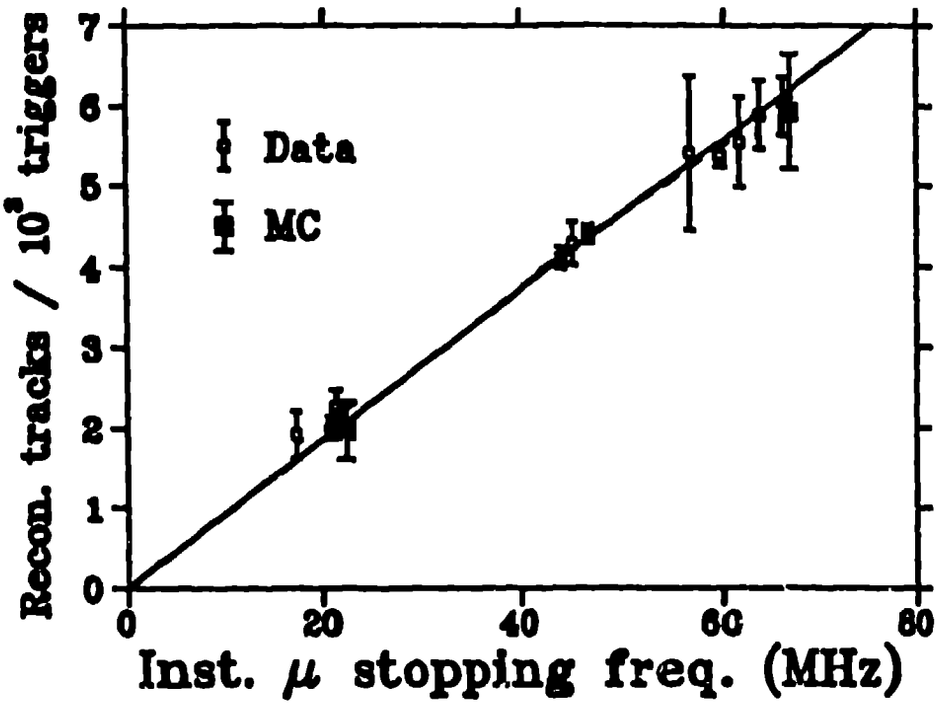

Recon. tracks / 10^3 triggers
Data
MC
0
1
2
3
4
5
6
7
0
20
40
60
80
Inst. μ stopping freq. (MHz)

FIG. 1