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Time-of-Flight Measurements at the
LAMPF Low-Energy Pion Channel

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TIME-OF-FLIGHT MEASUREMENTS AT THE LAMPF LOW-ENERGY PION CHANNEL

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ABSTRACT

Particle identification by time-of flight techniques was carried out using flight paths between two scintillation counters and between one such counter and the 200-MHz rf structure of the primary proton beam striking the meson production target. With the low-energy pion channel at 103 MeV/c, the two-counter technique yielded clean separation of pions, muons, and electrons. At 195 MeV/c, the rf technique measured the energy resolution of the primary proton beam to be as good as 0.14% FWHM.

I. INTRODUCTION

The measurement of pion-nucleus total cross sections (LAMPF Expt #2) requires the individual identification of incident particles as pions, and time-of-flight measurements with scintillation counters have been proposed as an aid in this objective. The purpose of this report is to inform interested parties of the progress made during the October 1973 beam tests in achieving particle identification by this technique.

The time-of-flight information will be used in an overlap coincidence mode capable of giving 1/2 nanosecond resolution at high count rates and some of the methods employed here reflect this future application. However, during the beam line tuneup the low particle fluxes allowed testing via the more conventional time to amplitude converter (TAC). The spectra acquired were of two types; there were those representing the differing flight times between two counters and those showing the differing flight times from the pion production target to the counter.

In Secs. 2-3, the counters are described and the experimental setup is explained. Clear separation of pions, muons, and electrons is obtained at low energy by timing between two counters and these results are given in Sec. 4. Section 5 deals with the electronics and discusses problems involved

with using the 200-MHz signal in a way which is insensitive to instabilities in the signal. The last section deals with time spectra measured relative to the rf signal. Included are a discussion of the neutron and gamma backgrounds, the contributions to the time resolution, and the measurement of the proton beam's energy resolution using time of flight.

II. DESCRIPTION OF COUNTERS

The detectors were 25.4-mm diameter discs (5-mm and 10-mm thick) of Pilot M whose cylindrical edges were bonded to 150-mm-long light pipes which illuminated the central 25 mm of the photocathode of 56 AVP phototubes. In order to accommodate the anticipated instantaneous rates of 10^6 particles/sec, the phototube resistor string had some modifications made from the usual saddle design. Time resolution was optimized with large amplification and the following steps were undertaken to prevent loading of the tubes. 1) The first stage and last four amplification stages have their voltages set with zener diodes. 2) The last four stages are powered from a separate supply and run at 5-mA current. The use of two power supplies prevents slight loading effects from being fed back to the first part of the string as well as reducing the total heat load of the base. 3) In addition to bypass capacitors, the last four stages have capacitors across them to supply ample

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current for slight overload recovery during the beam off part of the LAMPF macropulse.

III. EXPERIMENTAL ARRANGEMENT

In order to get the two types of spectra mentioned above while working in cooperation with concurrent measurements by others, the experimental arrangement was as shown in Fig. 1 and involved counters not necessary to this measurement. A copper screen house at the end of the Low-Energy Pion (LEP) channel contained all such counters. The multi-wire proportional counters and the two thin plastic (3 mm) ΔE counters always remained in place, but the thick E counters and Al absorber were removable. When they were all present only electrons would reach the timing counters downstream from them.

As noted in Fig. 1 there were three configurations for the two timing counters. Position one was useful to check intrinsic resolution of the counters and for measurements which referenced the rf. Position two served to check that the particles observed in position one had the proper delay corresponding to an extra meter of flight path. The location of timing counter one in position one and timing counter two in position three was used to measure time spectra corresponding to the differences in flight times between two counters separated by about a meter.

IV. TIMING BETWEEN TWO COUNTERS

With LEP set to select particles of momentum equal to 103 MeV/c, the velocities of pions, muons,

Fig. 1. The experimental arrangement beyond the end of the LEP vacuum system. The different positions of the three timing counters correspond to different measurements and are described in the text. The other counters shown are for an unrelated measurement.

and electrons are sufficiently different to allow particle identification by time of flight between two counters about one meter apart.

The resolution of the counters was determined from electrons passing through the E_1 counter (E_2 and Al removed) with the timing counters in position one. The pions and muons stopped in E_1 . The timing resolution was 400 psec. Dividing by the $\sqrt{2}$, the resolution in a single counter is found to be 280 psec.

Moving timing counter two to position three and removing E_1 , the spectrum shown in Fig. 2 was obtained. The calibration is 170 psec/channel. The momentum bite of LEP was 0.2% so that an essentially central trajectory was selected. With the momentum bite at 1%, the peaks were 1/2 channel broader which is what should be expected for the spread in velocities due to larger momentum acceptance.

The ratio of pions to muons to electrons seen in Fig. 2 is roughly the same as seen by measuring the channel contamination for a central trajectory with the multi-wire chambers and the $\Delta E - E$ counters. The small part of the beam phase space selected by these small timing counters makes them detect only central trajectory particles.

The directions of muons from the decay of pions peak near the maximum lab angle allowed by the center of mass to lab transformation:

Fig. 2. The two counter time-of-flight spectrum at 103 MeV/c momentum. Clean separation of electrons, muons, and pions is obtained with few muons observed due to pion decay within the channel. (That is, most muons are from the production target.)

$$(\tan \theta_{\max} = [\gamma_{\pi} \sqrt{13.68^2 - 1}]^{-1})$$

$$\text{for } T_{\pi} > 5.4 \text{ MeV, } \theta_{\max} \approx 37.9/P_{\pi}.$$

Since the maximum angle a particle can be off axis and pass both timing counters when they are 1 m apart is 3° , these counters are quite insensitive to decay muons. The muon peak has a velocity corresponding to muons with the momenta selected by LEP which probably originate near the production target. Muons formed in the last quadrupoles would appear between the electron and muon peaks shown. Muons formed from decays after passing timing counter two will be a continuum from this point to the pion peak. The observed spectrums show little evidence for decay muons produced within the channel which will satisfy the geometric restrictions of the counters.

V. ELECTRONICS AND THE RF TIME PICK-OFF

A block diagram for the electronics used to time against the 200-MHz rf is shown in Fig. 3. For the timing between two counters described in Sec. 4 the start and stop signals were from the outputs of the zero crossing discriminators.

The derivation of the timing signal used in these measurements is somewhat unconventional and will be briefly described here. Ordinary zero-crossing timing is limited by noise on the signal which

broadens the time of the pulse crossing zero. The slope of the pulse at the zero crossing point if derived from a clipped phototube anode signal is equal to the slope of the trailing edge of the anode pulse minus the slope of the leading edge of the pulse. The slow fall time of the anode pulse can make this zero crossing point spread over considerable time.

A circuit called a "differentiator" had been developed for shaping the 200-MHz signal and doing the overlap coincidence mentioned above which approximately took the derivative of the input signal and outputted the negative part of the result. The circuit is shown in Fig. 4. For this application inputs B and A' are terminated in 50Ω and the output signal has a clipping transmission line attached. It is not a true differentiator in that the rise and fall times of the output pulse are 1 nsec. Additionally, the zero level may be shifted by the bias control.

When the anode pulse is put into the differentiator the clipped output crosses zero with a rise time of about 1/2 nsec and a zero crossing point approximately related to the inflection point of the rise of the anode signal. The fast rise through zero reduces the time spread. The circuit has not been checked over a dynamic range of amplitudes greater than 5:1, but in this range it appears to work as well as constant fraction techniques.

Fig. 3. A block diagram of the electronics which shows the time pick-off circuitry for both the counters and the 200-MHz signal.

Fig. 4. A circuit diagram for the module referred to in the text as a "differentiator." It takes an approximate derivative of the inputs A and B and sums the outputs. Only one input is necessary and the output may be clipped with a shorted transmission line. The rise time of the output is less than 1 nsec.

A disadvantage of this circuit is that pulses just above the threshold of the tunnel diode in the zero-crossing discriminator may be mistimed because the tunnel diode does not have time to recover. Also, the circuit must be built with very short wiring paths in order to achieve the fast rise (this may make future repair difficult).

At the time these measurements were made the amplitude of the 200-MHz signal received in the LEP counting house was stable. However, the eventual plan is that this signal will be amplified and divided at least four ways in experimental area A. The dividers will have isolators, but the stability cannot be guaranteed to better than 10%. An attempt was therefore made to standardize the 200-MHz signal by passing the large sine wave through a fast trigger (EGG-T200) which would trigger at a low threshold and give an output phase locked to the input and independent of amplitude to better than 100 psec. Unfortunately, the large positive part of the signal combined with the high duty factor caused the EGG-T200 input limiting circuit to fail and the module worked improperly. It was found that the desired effect could be achieved by placing a differentiator module before the trigger.

To obtain a usable timing signal from the 200 MHz, it is necessary to work with a subset of the pulses to prevent any device such as the TAC from being required to stop only 5 nsec after it starts.

This was accomplished here by a fast coincidence with the timing counters. The coincidence is such that the output has its leading edge determined by the rf signal. To minimize the non-linearities due to the rounded edges of the pulses, one must have as fast rising pulses as possible, and in this case that was accomplished through the use of a differentiator. This pulse, which has less than 1-nsec rise and fall times produces a coincidence output which is linear over nearly 4 nsec out of the 5-nsec repetitive period of the signal.

Since any phototube output is in coincidence with some rf pulse, the random events from neutrons and gamma rays produce a large background under the particle peaks. This background is greatly reduced relative to the particle events by using the fact that small detectors are inefficient for neutrons and gammas. By requiring the logical coincidence with a second counter, this background is nearly eliminated.

Figure 3 does not show that a light-emitting diode was imbedded in the light pipe of each timing counter. The time jitter of the diodes in each counter was small compared to the time resolution of the counters. By adjusting the variable delay between the diodes to match the actual time that particles passed the detectors, a high rate of properly timed coincidences was obtained which made setting the above coincidences much easier than with beam pulses.

VI. RESULTS OF TIMING USING THE 200-MHz SIGNAL

The actual measurements were done with the timing counters in position one, and position two was used to verify that the particle spectra varied appropriately for the extra flight path. Figure 5 shows the best time resolution spectrum obtained for the channel set to accept 100-MeV pions with a momentum bite of 1%.

Particle identification done with the E detectors showed the beam consisted almost solely of pions with some muons and very few electrons. The time spectrum shows no evidence for an electron peak and unfortunately the flight time for 195-MeV/c muons over a 15-m path is shorter than that for pions of the same momentum by almost exactly 1-rf period (5 nsec). Because of the repetitive nature of the rf signal, the pion and muon peaks are therefore degenerate.

Fig. 5. A time spectrum of the single counter versus the rf. The meaningful spectrum is only 5 nsec wide since the rf repeats at 200 MHz. The peak resolution of 600 psec measures mainly the energy resolution of the primary proton beam. Pion and muon peaks are degenerate because at this momentum their times of flight from the production target differ by 5 nsec.

There are three major contributors to the time spread measured in this way. They are the counter time resolution, channel isochronism, and the time spread of the proton bunch at the production target. The overall time spread of the peak in Fig. 5 is 600 psec.

A single counter's resolution was shown to be about 300 psec and estimates of the isochronism of the channel at 195 MeV/c predict a similarly small contribution to the time resolution. Reducing the momentum acceptance to 0.2% did not affect the resolution. This means that the dominant contribution comes from the primary proton beam. The time spread in the proton bunch is due to the energy resolution of the beam and the length of the flight path from the last rf cavity to the production target. Although at 700- to 800-MeV proton energy this spread may be expected to be small, the operating conditions during these measurements were 497 MeV with a flight path of around 375 m. For a beam energy spread of 0.2% FWHM one expects an 840 psec time spread at the production target. This is sufficiently greater than the other sources of time spread to make the width of the peak in Fig. 5 largely a measure of beam time spread. The time width of the peak in Fig. 5 corresponds to a proton

beam energy spread of 0.14% FWHM. Under the usual operating conditions the resolution was closer to 800 psec, but Fig. 5 represents a particularly stable period of accelerator conditions.

The outstanding problem remaining to be solved in doing timing against the 200-MHz signal is due to the non-smooth background under the peak. The background comes from random coincidences in the timing counters which, of course, also have an rf signal associated with them. The background has a spectrum which oscillates and makes the detection of weak groups such as electrons difficult. In the linear central 4 nsec of the spectrum, the oscillations were found to have a separation corresponding to an 800-MHz signal. It is believed that this is due to non-linear response of the EGC-C304 trigger circuit to higher frequency components of its input signals, although this is uncertain. It is not believed to be due to 800-MHz feedthrough from the machine rf because it could be seen with an independent 200-MHz oscillator.

As a last point, it should be noted that the counters and rf signal remained remarkably stable over a period of several days with no discernable changes in peak locations or resolution. Unfortunately, the counters were never tested at their maximum design rates, but it is known from tests with sources that at 10^5 counts per second the stability is preserved.

It can be said in summary that particle identification both with two counters and with one counter and rf signal will be a practical technique at LAMPF.

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