The Polarization of Prompt Muons Produced at P_t = 2.15 GeV/c by 400 GeV Proton Interactions*

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The polarization of prompt muons produced at a center-of-mass angle of 61° and a transverse momentum of 2.15 GeV/c by the interaction of 400 GeV protons was measured to be -0.135 ± 0.20. This value, consistent with zero, differs from the large value reported from similar measurements at 70 GeV and is inconsistent with the proposal that the prompt leptons observed at large transverse momenta are derived from weak decays of intermediate particles.

It has been proposed[1] that the anomalously large production of prompt leptons at large values of p_t by nucleon-nucleon interactions might be derived from the weak decays of intermediate particles. Most plausible descriptions of such decays would lead to a large polarization of the leptons so produced along their direction of flight. Recent communications by Anisimova et al.[2] and Abramov et al.[3] report measurements of the polarization of prompt muons produced by the interaction of 70 GeV protons with nuclei. They find a value of -0.85 ± 0.37 for the polarization of positive muons produced at an angle of 90° in the center-of-mass system with transverse momenta of 2.0 GeV/c and 2.8 GeV/c. Such a result, indeed any value of the longitudinal polarization other than zero, indicates that the production must be mediated by a non-parity-conserving interaction.

We have now made similar measurements, at Fermilab, of the longitudinal polarization of prompt muons produced with transverse momenta of 2.15 GeV/c by the interaction of 400 GeV protons with nuclei. Muons, produced through the interaction of protons with a vriable density copper target, passed through the target and through steel shielding near the target with trajectories defined by counters set 60 m from the target at an angle of 45 mr from the proton beam direction. The muons then passed through 60 m of earth to stop in a polarimeter designed to measure the polarization of the muons in the direction of their flight and the component of polarization perpendicular to the plane of production. The characteristics of the target and a more complete description of the beam have been presented previously.[4]

The energy of the muons was defined by their range as 54 ± 2 GeV. While the mean transverse momentum of the muons emerging from the target assembly was then about 2.40 GeV/c, the mean production transverse momenta was calculated to be 2.15 ± 0.10 GeV/c when the effects of the multiple scattering of the muons by the material of the target assembly was considered. The muon angle of production in the center-of-mass system of the nucleon-nucleon interaction was then 61°.

The polarimeter consisted, basically, of 24 layers of 5 cm thick aluminum plates backed by 6 mm sheets of scintillator each viewed by a phototube. The plates and scintillator sheets were 60 cm high and 90 cm wide aligned normal to the muon beam direction. A 30 gauss magnetic field, directed in the plane of production of the detected muons and perpendicular to the beam direction, served to precess the muons. The polarization was then measured by determining the direction of the positive muon decay (forwards or backwards) as a function of the precession time.

The polarimeter and the techniques used to determine muon polarizations have been described elsewhere.[5] These measurements have served to calibrate the polarimeter and in the configuration used here the asymmetry amplitude for the decay of positive muons which stop in the aluminum can be described by the relation:

$$A_+ = (F - B) / (F + B) = e_+ P \qquad (1)$$

where F and B represent the intensity of muons decaying forwards and backwards, P is the longitudinal polarization of the muons and e_+ is the calibration factor which has been determined to be 0.185 ± 0.01 for this polarimeter through analyses of other experiments.[5]

For the analysis of this experiment, where both positive and megative muons stop in the polarimeter and the muons precess about the direction of the magnetic field, the amplitude A(t) will be a function of time and F and B will vary with time in a complex, but well defined, manner:

$$F = [1 + e_+ P_+ \cos(\omega t) \exp(-\gamma t)] \exp(-t/\tau_+) + R[1 + e_- P_- \cos(\omega t) \exp(-\gamma t)] \exp(-t/\tau_-) \qquad (2)$$

$$B = [1 - e_+ P_+ \cos(\omega t) \exp(-\gamma t)] \exp(-t/\tau_+) + R[1 - e_- P_- \cos(\omega t) \exp(-\gamma t)] \exp(-t/\tau_-) + s(1 + R) \exp(-t/\tau_+)$$

Here we take the value of e_- as 0.01 for the analyzing effectiveness of negative muons: s, the proportion of decays from muons which stop in the scintillator was measured to be 0.13 in previous work[5]: γ, the measure of the decoherence induced by field inhomogeneities has been measured previously and is equal to 0.3: ω, the precession frequency is equal to $2.43 \cdot 10^6$/sec: τ_+, the lifetime of free muons, positive muons in aluminum and all muons in scintillator is 2.2 μ sec and τ_-, the lifetime of negative muons in aluminum, is 0.86 μ sec. The value of R, the ratio

of negative muons to positive muons, varies with the target density even as the ratio of muons from meson decays to prompt muons so varies. We use for the ratio, $R = (0.80\ I_m + I_p)/(I_m + I_p)$, where I_m and I_p are the intensities of muons from meson decay and from prompt production. Measurements of the total intensity $I = F + B$, as a function of time fitted to the forms defined in Eq. 2 are in accord with the choice of $R_m = 0.80$.

The results of the measurements which define the polarization of the prompt muons are shown in Fig. 1. From an analysis of the variation of the intensity of muons stopping in the polarimeter with respect to the target density, ρ, shown in the upper graph, we find that 51% of the muons generated by proton interactions with the solid copper target ($\rho = 1$) are derived from meson decays and 49% are prompt muons. Only 26% of the muons from the density 1/3 target are prompt muons while 74% come from meson decays. The lower two graphs show the results of the measurements of the asymmetry as a function of time for the two different target densities together with least square fits to the forms given in Eq. 2 which define the values of the polarizations. The polarization of the muons from the density one (solid copper) target is found to be $P(\rho = 1) = -0.52 \pm 0.095$ while $P(\rho = 1/3) = -0.72 \pm 0.125$.

For any meson production spectrum which falls off rapidly with increasing energy, the polarization of the muons from the meson decays is nearly equal to the polarization in the meson decay system. Explicit calculations of the meson spectrum using parameterizations which fit the known production spectra adequately, give a value of -0.90 ± 0.04 for the polarization of the muons. Using these numbers, we deduce a value of the polarization of the prompt muons from the density one

measurement of -0.123 ± 0.20 and a value of -0.205 ± 0.48 for the density one third measurements. Considering both measurements, we find a best value of -0.135 ± 0.20 for the polarization of the prompt muons. This value is consistent with zero, consistent with the null value of polarization found for prompt muons in the forward direction[5] and consistent with the hypothesis that the bulk of the prompt muon flux originates in electromagnetic processes. The result is quite different than a value near $+1.0$ expected from the more conventional models of prompt muon production through the weak decays of heavy intermediate particles and places a limit of about 10% on the portion of the muon flux derived from such sources. We also believe that our result is difficult to reconcile with the large negative values of polarization reported at 70 GeV.[2,3]

The transverse polarization of the muons in a direction normal to the plane of production was measured to be 0.108 ± 0.079 in the direction $(p_p \times p_\mu)$. Presuming no contribution from muons from meson decay, transverse polarization of the prompt muons was 0.22 ± 0.16, consistent with zero.

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Figure Caption

Fig. 1 The upper graph shows the variation of intensity of muons stopping in the polarimeter as a function of target density. The solid points show the raw data; the line shows the data corrected for the effects of material before the target. The intensity is presented in arbitrary units. The points on the two lower graphs show the measured muon decay asymmetry, $A = (F - B)/(F + B)$, for two different target densities while the solid curves show least square fits to Eq. 2 defining the value of the muon polarizations P.

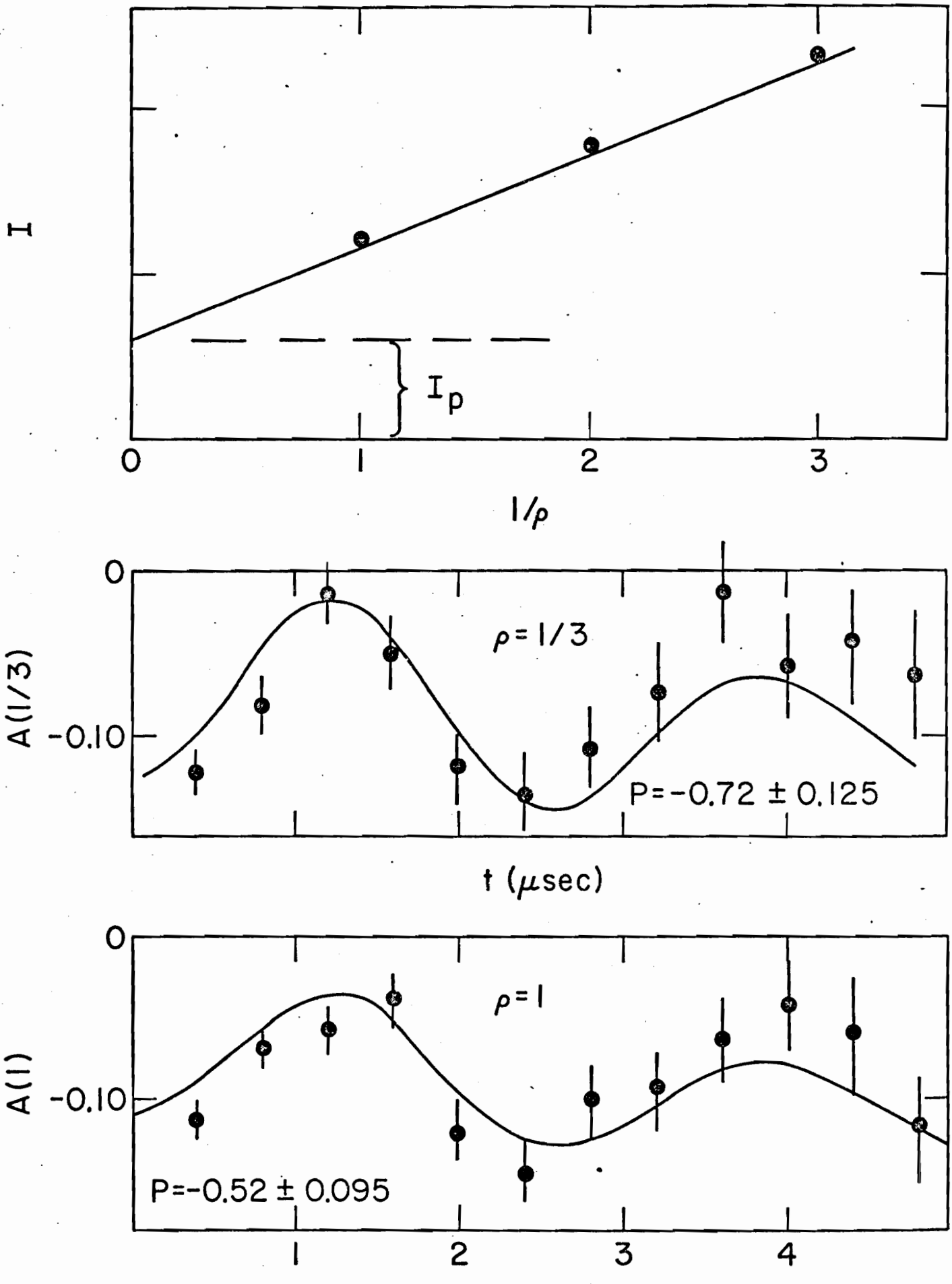
I
I_p
0
1
2
3
1/ρ
A(1/3)
0
-0.10
ρ=1/3
P=-0.72 ± 0.125
t (μsec)
A(1)
0
-0.10
ρ=1
P=-0.52 ± 0.095
1
2
3
4

Fig. 1.