PROPOSAL TO SEARCH FOR NEW LONG-LIVED PARTICLES

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Abstract

New "stable" particles with lifetimes in the 10^{-14} sec to 10^{-12} sec range have been hypothesized on theoretical grounds.[1] The recent discoveries of the J/ψ particles[2] have added a great measure of conviction to these theoretical arguments and have consequently made it all the more important to search for such long-lived objects. Although observation of long-lived particles has been reported in the literature,[3] the evidence is still far from compelling as it is based on only very few interesting events. We propose to perform a sensitive search for particles with lifetimes in the 10^{-13} sec region. The equipment for the experiment will consist of the E397 spectrometer system presently in the M-3 beam line at the Meson Detector Building of Fermilab. In addition to the present apparatus we will require 3 silicon surface barrier detectors and ancillary electronics to execute our proposal. We request 300 hours of beam time to establish whether particles with lifetimes in the 10^{-13} sec region can account for at least 10% of the prompt lepton production in hadron collisions at Fermilab energies.

Introduction

We are presently developing for E-397 a method for detecting muons which are produced directly in hadronic collisions (i.e., not derived from π or K decays); these muon signals will be used to trigger our spark chambers so as to study the hadronic as well as leptonic objects which are produced in association with "prompt" muons. Although the origin of the large direct-lepton production cross section in hadronic collisions ($\sim 10^{-4}$ of π production) is not understood, best recent estimates of the contribution from standard sources, e.g., vector meson decays, indicate that only a fraction of direct lepton production at large transverse

momenta can be attributed to fast decays of known particles.[4] It would appear, therefore, that the presence of a prompt lepton is likely to be a signal for new phenomena. In E-397 we hope to find a narrow mass peak (charm particle) in the hadron system which is produced in association with our μ-trigger; in the present proposal we wish to examine, also in association with the prompt muon, the spatial distribution of particles produced within 0.5 mm of the target.

Technique

Figure 1 provides a sketch of the technique envisioned for the measurement of life-times corresponding to typical mean free paths of ~0.5 mm. A 0.7 mm thick iridium target will be positioned within 0.1 mm of a 0.2 mm thick silicon surface-barrier detector; two additional Si detectors spaced by 7 mm will be placed 7 m downstream of the first. A neutron beam of 10^6 particles/spill will impinge on the iridium target; the multiplicity (ionization pulse height) will be measured concurrently in the three detectors and recorded if a prompt muon trigger is obtained in the interaction. If only strongly decaying particles are produced forward in the collision then the pulse heights in all the detectors should be the same (this can and will be calibrated continually during running conditions by periodically ignoring the prompt muon trigger). If on the other hand a particle is produced which decays into two or more additional charged particles after the first detector (typically 0.4 mm flight path) then the pulse height in the two downstream detectors should be greater than in the first one. (We expect that if associated charm production contributes to prompt lepton production then two such long-lived decays per event are likely to occur and consequently a four-unit change in charge between the first and second detector might not be infrequent.)Once a signal of the type we have described is observed we can obtain in a separate run an estimate of the life-times involved by moving the iridium target ~0.4 mm further back from the

detectors and then performing another set of measurements with the effective mean free path for detectable decay lengthened from 0.4 mm to 0.8 mm. For a particle having mass of 2 GeV, produced at rest in the centerof mass, an effective decay mean free path of 0.4 mm corresponds to a lifetime of $\sim 10^{-13}$ sec (for the typical incident neutron momentum of ~300 GeV/c).

Rates

A 0.7 mm thick iridium target corresponds to ~0.8% neutron absorption mean free path (inelastic). Consequently, in comparison to our envisioned rates for E397 we expect a factor of 10 reduction in the yield of prompt muons per spill. We, however, expect the background trigger level to deteriorate somewhat because of the relatively low yield from the target material. Thus, we expect 0.02 prompt μ and 1 background μ trigger per spill ($\simeq 10^6$ neutrons during a 1 sec spill). We wish to take data for $\sim 10^5$ pulses and thereby obtain 2000 prompt μ and $\sim 10^5$ background triggers. (The background trigger level corresponds to $\sim 5 \times 10^{-3}$ of the charged hadron yield at production.) We expect to reduce the false μ background by a factor of ~10 in the off-line analysis and thus achieve a (prompt-μ)/(background-μ) ratio of $\gtrsim 0.2$. If 10% of the 2000 true μ triggers are due t long-lived particles (10^{-13} sec lifetimes) produced in pairs, and each particle decays 50% of the time into two or more charged particles, then we would expect to observe $\gtrsim 15$ decays containing a four-unit increase in charge ($\Delta Q \gtrsim 4$) between the first and second silicon wafer; a two-unit increase in charge ($\Delta Q \gtrsim 2$) would occur in $\gtrsim 110$ events. (The third wafer is used to reduce background which simulates signal events.)

Background

We foresee several important sources of background. The first one is due to secondary interactions in the second silicon detector or in the effective "dead" layer of the first detector; such interactions cause an increase in the number of charged tracks observed in the second and third detector relative to the first and consequently simulate our sought-for signal. The second important source of background is due to Λ^0 or K_S^0 decays which occur between the first two silicon detectors. Another important background is due to conversion of γ-rays in the second detector. Finally, there is the background due to δ-ray production in the downstream detectors caused by the traversal of charged particles produced in the iridium target. (The third Si wafer is used mainly to reduce backgrounds expected from δ-rays.) All these backgrounds should be independent of target position (on a 0.4 mm scale) or of the presence of the muon trigger and can therefore be subtracted out.

The average inelastic charged-particle multiplicity in 300 GeV/c collisions is ~8. We will consequently have 10^4 background events, each having ~8 particles which can interact in the second silicon detector. We will use 0.2 mm Si wafers (0.06% and 0.04% interaction mean free paths for baryons and mesons respectively) and consequently we expect ~35 secondary interactions in the downstream detector which can simulate the signal. (We expect in addition $\lesssim$20 events of the kind wherein the incident neutron interacts in the second detector and a single pion backscatters into the upstream Si detector. These background events will be easy to eliminate becauseof the characteristically small pulse heights which they will present in the upstream detector.) Of the ~35 secondary interactions, about half should provide heavy nuclear spallation products with ionizations corresponding to pulse heights of 100 times minimum. Such events can be safely excluded from consideration (see later section).

Background from Λ^o and K_s^o particles produced in the target and decaying between the first two Si detectors can be estimated as follows. In the 10^4 background triggers we expect a Λ^o or K_s^o produced in the backward hemisphere of the center of mass ~5% and ~8% of the time respectively (we ignore forward produced particles since their mean free paths for decay will be greatly time dilated). From 400 GeV pp data we find that the effective $\gamma\beta$ for a Λ^o is ~1.1 while for K_s^o it is ~3.5. The Λ^o and K_s^o decay ~60% of the time into charged final states. Consequently, for a 7 mm decay region we expect ~ 25 Λ^o and 30 K_s^o decays simulating the signal.

At high energies the average number of π^o's produced per interaction is ~50% of that of the number of charged particles. Thus we expect ~$4\pi^o$ or 8 γ-rays per trigger. The Si wafers have thicknesses of 2×10^{-3} of a conversion length. Consequently, we expect ~160 e^+e^- pairs in the second wafer, half of which will simulate our signal corresponding to $\Delta Q \geq 2$.

Consequently, aside from the background due to fluctuations in ionization in the detectors (δ-rays), we expect $\lesssim 150$ events which can simulate our $\Delta Q \geq 2$ signal. (The background for the $\Delta Q \geq 4$ signal is expected to be $\lesssim 1$ event.)

Noise and Resolution of Detectors

Ultimately, the experiment is based on the reliability and resolution of the solid state detectors. We have checked into state of the art surface barrier detectors provided by ORTEC and believe that the quality of their totally depleted Si surface barrier devices will meet the requirements of the experiment.

When a charged particle enters a silicon detector it creates free electron-hole pairs at a rate of one pair per 3.6 eV of energy loss. For minimum ionizing particles the rate of energy loss is ≈0.35 keV per micron of silicon; which means that ≈70 keV per minimum ionizing track is deposited in a 0.2 mm thick wafer.

Because the quoted resolution for the ORTEC detectors is ±15 keV (standard deviation) we see that fluctuations in the number of pairs due to statistics can be ignored for collisions involving the production of $\lesssim$100 minimum charged particles. Using the standard B-series ORTEC detectors in "transmission" mounts of the Type T we expect, for example, about a 10 standard deviation increase in the pulse height of the downstream detector when a neutral object decays into two charged particles in the the 7 mm decay region between the two detectors.

The sensitivity of the Si detectors is limited, however, by the non-Gaussian fluctuations in energy deposition which occur when charged particles traverse matter.[5] Charged particles originating in the target can produce δ-rays in the Si detectors. If δ-rays are produced in the first detector, depositing $\gtrsim$120 keV, and do not reach the second detector (range out in the first wafer), the effect is to mask our $\Delta Q \geq 2$ signal. The δ-ray production probability for δ-ray energies in the range $0.12 < E < 0.20$ MeV is $\sim 1.2 \times 10^{-2}$; which means that ~10% of the $\Delta Q \geq 2$ signal events will be lost as a result of δ-ray production in the first wafer. (Essentially no loss occurs of the $\Delta Q \geq 4$ signal.)

Not only can δ-rays mask signal events but they can also, and far more importantly, simulate the signal. For example, if two δ-rays with $E \gtrsim 0.2$ MeV are produced in the second detector and both penetrate into the third wafer, the pulse height information will be essentially identical to that for a $\Delta Q \geq 2$ signal. We expect ~25 events of this kind. The most serious background to the $\Delta Q \geq 2$ signal would originate from single δ-rays of energy $0.22 > E \gtrsim 0.20$ MeV which deposit ~half their energy in each of the two downstream detectors. We expect this background to be $\lesssim$130 events and the total $\Delta Q \geq 2$ background from δ-rays to be $\lesssim$200 events. The background to the $\Delta Q \geq 4$ signal is expected to be ~1 event.

Operation of Detectors

The detectors and the iridium target will be held under vacuum to assure proper functioning of the silicon devices. (We plan to use the preamplifier/amplifier system provided by ORTEC.) The effective lifetime of the detectors is usually limited by the accumulated radiation damage caused to the silicon lattice; it is believed that no significant deterioration in the performance of the detector is observed before the equivalent dose of $\sim 2 \times 10^{11}$ minimum ionizing particles per cm^2 of area. It therefore appears that the expected dose of $\sim 10^{10}$ minimum ionizing particles in our 10^{11} neutron experiment is well matched to the lifetime of the detector. (Recall that we have 1% interactions in the target and that the average produced charged-particle multiplicity is ~8.) We wish to point out, however, that the upstream silicon detector may sustain more severe radiation damage than the downstream one because nuclear spallation products from interactions in the last 0.1 mm of the iridium target will have sufficient energy to reach the first silicon wafer. The low-momentum protons ($\lesssim$120 MeV/c) would be heavily ionizing, depositing an amount of energy equivalent to approximately 100 minimum ionizing tracks. The energy resolution in such events would be compromised, but more important is the damage these events would cause the detector. There is no information at present regarding the rate of occurrence of such events nor the energy distribution of the spallation proton products. Finally, there will be radiation damage in both detectors resulting from the expected $\sim 6 \times 10^7$ neutron interactions. We believe that doses of this size can be sustained. Nevertheless, we must perform a test experiment to determine the severity of these problems.

New Equipment for Experiment

5	B-025-450-200 ORTEC Detectors	$ 3050
3	#125 ORTEC Preamplifiers	1395
2	#428 ORTEC Power Supplies	970
	#471 ORTEC Amplifier	1635
	Total Expense	$ 7050

Summary

Making a small addition to the E397 experimental apparatus we can perform a search for new particles with lifetimes in the region of 10^{-13}sec. In particular, if more than 10% of the directly produced muons in hadronic collisions involve the production of such long-lived particles, we expect to observe at least a four standard-deviations effect in the pulse-height spectrum of events produced in association with a prompt muon for both the $\Delta Q \geq 2$ signal (~90 events over a background ~350), and for the $\Delta Q \geq 4$ signal (~15 events over a background of $\lesssim 2$).

References

1. See, for example, M. K. Gaillard et al, Rev Mod Phys 47, 277 (1975).
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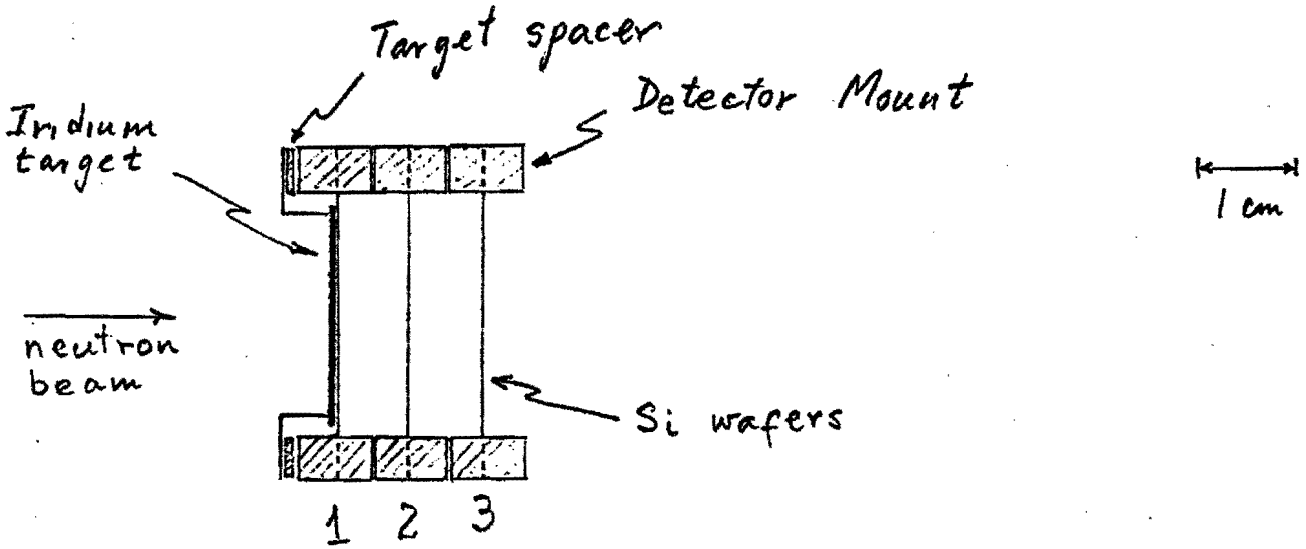
3. K. Niu et al, Prog. Theor Phys 46, 1644 (1971) and a recent Nagoya preprint; P. L. Jain and B. Girard Phys Rev Letters 34, 1238 (1975).
4. See, for example, J. Cronin, Lecture at Erice School (1975).
5. B. Rossi, High Energy Particles pp 14-35.



Target/Detector Replacement For Target/Hodoscope System in E397