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PROPOSAL TO SEARCH FOR THE DECAY OF NEW LONG-LIVED NEUTRAL PARTICLES WITH A MASS AND LIFETIME EXCEEDING THAT OF THE K_L^0

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ABSTRACT

In this proposal we outline the capabilities that the spectrometer for experiment E533 ($\pi\mu$ atoms) has for detecting the decay products of any new long-lived particles. The "off to the side" geometry, intense neutral beam, and long decay region are ideally suited to such a search which, to our knowledge, has not been previously performed.

Our sensitivity to new particles is critically dependent upon the cleanliness of the neutral beam: neutral particles with a mass of 3 Gev/c^2 and a lifetime between 10^{-8} sec and 10^{-3} sec could be observed in a 300 hr run even if produced only as frequently as the ψ.

We propose to test the feasibility of the idea once the E533 spectrometer is set up in the M3 beam line. We would like to complete the test before the meso-pause so that necessary hardware modifications could be made during the meso-pause. The search proper would be performed in the post-pause period, after the completion of E533.

Motivation

The prime motivation for the proposed search comes from the opportunity that the E533 spectrometer presents for the detection of new long-lived, neutral particles coupled with a definite lack of experimental information on the possible existence of such particles.

To our knowledge, only one high energy search specific to neutral particles has been carried out previously[1]: there the experimenters attempted to observe the interaction of any new states (in their calorimeter) and while that search was sensitive even to absolutely stable new particles, the results are dependent upon assumptions about the particle's interaction probability. In the present proposal, we plan to observe any new states by their decay products and therefore our sensitivity depends essentially only on the conjectured lifetimes.

What are we looking for: it could be a long-lived Han-Nambu[2] neutral quark with fractional Baryon number, or a nearly stable neutral heavy lepton, or a combination of a quark from the $\Upsilon(9.4)$ with an ordinary quark to produce a meson which is very long-lived if the new (heavy) quark doesn't decay into old quarks[3], or more likely something unforeseen.

Method

Figure 1 shows a schematic of the layout for experiment E533 ($K_L \rightarrow (\pi\mu)_{atom}\nu$), soon to be installed in the M3 beam line.

The basic idea of the present proposal is to look at the transverse momentum (P_T) spectrum of single particles coming out of the decay region. The only long-lived particle in the beam should be the K_L: thus we expect that the maximum P_T of any single particle (from any K_L decay mode) will be less than about 230 Mev/c. Figure 2a shows the measured P_T spectrum of the pion for simulated $K_L \to \pi\mu\nu$ decays in the geometry of E533.

Thus in principle the detection of any particles with a $P_T \gtrsim 250$ Mev/c would indicate the presence of a new neutral particle in the beam. In practice, a peak at the maximum P_T would be more convincing: Figure 2b shows a simulation of the P_T spectrum from a (2-body) decay of a 1 Gev/c^2 neutral particle.

Thus we propose to trigger the spectrometer slightly reconfigured on single particles which point back to the decay region and have a P_T greater than about 300 Mev/c. We note that a "peak" in P_T is expected regardless of the multiplicity of the decay. We also note that we can identify (or trigger on) whether the decay products are μ's, e's, or hadrons.

The Beam

The M3 neutral beam is being considerably opened up for the purposes of E533: in the detector building (1300' from the target), it has a size of 5" x 10" and will contain about 5×10^9 neutrons and 5×10^7 K_L's (although the latter needs to be measured directly), with 4×10^{12} protons on target. About 1000 ψ's are created within our solid angle per pulse. The beam is removed of γ-rays, collimated, swept, and defined to be neutral at about 600' from the target where our decay region begins.

Acceptance

We have calculated by means of a monte-carlo program the acceptance of the present E533 spectrometer for the detection of single particles from the decay of new long-lived states. Table 1 shows the results for particles of mass 1 Gev/c^2, 5 Gev/c^2, and 10 Gev/c^2. The acceptance falls rapidly above 5 Gev/c^2 because the P_T of single particles is usually above the maximum detectable with the E533 geometry: $P_T^{max} \simeq 2.5$ Gev/c. The acceptance for higher mass states can be considerably boosted by collapsing the spectrometer with of course a loss of resolution.

Obtainable limits

The rate at which we would observe single large P_T tracks from the decay of a new particle depends upon the mass of the particle and its lifetime. In Figure 3 we show the number of events we would detect per 100 hours of running for 3 Gev/c^2 particles produced as copiously as the ψ, as a fraction of the particle lifetime. It is clear that we have a sensitivity in principle to the observation of particles with lifetimes as long as ≈1 msec and even longer depending upon the production rate. For this calculation we have assumed that the longitudinal momentum spectrum of the new state falls off sharply with increasing momentum, similarly to the K_L spectrum.

In comparison with the previously mentioned calorimeter search[1], a number of points must be made:

a) that search was sensitive to the interaction of any new particles in the detector, about 1800' from the primary target, so that the particle lifetime had to be greater than about 1 μsec. From an examination of figure 3, it is seen the present search is sensitive to lifetimes as short as 10^{-8} sec.

b) for particles which have normal strong interaction cross-sections, the limits of the previous search are quoted as being about 10^{-1} of the ψ production, whereas the presently proposed experiment can obtain limits between 10^{-2} and 10^{-4} of ψ production, depending upon the lifetime. The best limit of the previous search is 10^{-3} of ψ production and is obtained if they assume a total interaction cross-section of ≈1 mb.

c) the previous search was insensitive to any new particle (lepton-like for instance) which would not deposit all of its energy in their iron calorimeter.

d) the previous search was sensitive to particles which are absolutely stable whereas the proposed experiment is by nature not.

Backgrounds

In order to consider triggering the spectrometer on a single particle, we must ask what the backgrounds are expected to be considering the large intensity of the beam passing under the spectrometer.

The easiest to calculate is the background of single tracks from K_L decays within the 240 meter decay region. Here we find an intensity of just under 10^5 particles per pulse, an entirely manageable rate. All these particles (π's, μ's, and e's) will have p_T values less than 230 Mev/c and there are several ways in which they can be excluded from the trigger.

Another source of background comes from neutron interactions with the residual gas in the evacuated decay region. The trigger rate arising from particles from such interactions is negligably small; what will be a problem are the large p_T secondaries which simulate high mass particles, and in fact the ultimate sensitivity of the experiment is probably limited by how good a "vacuum" we can obtain. With a vacuum of 1 micron in the section of decay pipe within the detector building we retain our sensitivity to particles with lifetimes as long as 1 ms, and an even better vacuum is likely.[5]

Additionally we point out that this background will be about two orders of magnitude smaller were we to trigger on large p_T μ's or e's (the pion decay probability is a few percent on the average while in our electromagnetic shower counters we identify electrons with only 1 or 2% pion contamination).

A source of background that is not easy to estimate results from any neutron or muon halo. Here we must wait to see just what the conditions are. We anticipate that with the stringent trigger requirements described in the next section, we will not be bothered by halos.

Trigger Requirements

To avoid a great deal of dead-time and the recording of unwanted events, a stringent trigger must be employed to reject on-line low p_T particles, particularly those from K_L decays.

First, we would employ a "point-back" requirement: with the fast outputs of our MWPC's, we obtain $\frac{1}{2}$ inch spatial resolution on tracks. With a flight path of about 20 m we can effectively reject tracks not pointing back (in the side view) to the decay region.

Second, we will have to effectively eliminate the background from K_L decays at two stages: first, we must do a quick determination of the bending angle in the analyzing magnet (again using MWPC fast outputs) to find the momentum of each track. This momentum, when multiplied by the "point-back" angle already determined provides us with an estimate of the p_T of the secondary. Using standard ECL logic, we anticipate a lowering of the trigger rate by a factor of greater than 10 with a dead-time of less than 200 ns.

The second stage of reduction at the trigger level will involve an essentially "exact" calculation of the p_T of the triggering particle by means of a system of microprocessors operating in parallel on the data scanned from each MWPC wire plane. We are using the 2900 family of bi-polar microprocessors which can perform an arithmetic operation, shift the result and store in 100 ns.

The system also affords a high degree of programming flexibility. The microprocessing system proposed is to be employed in E533 to avoid the recording of unwanted events in the search for K_L decays to $\pi\mu$ atoms. We have built and tested a prototype which checks that the dissociated π and μ point back to the stripping foil, lie in a plane perpendicular to the direction of the magnetic fields, and are parallel in the rear of the spectrometer. We have timed the software for these checks, and they can all be done within about 10 μs of the event! Thus we plan, in E533, to abort the recording of events when any of the above tests (performed in parallel) fails. For the presently proposed work, a new algorithm will have to be coded which calculates p_T - again we expect to be able to abort within 10 μs.

Conclusions and Laboratory Requirements

We have examined the capabilities that our spectrometer for E533 has to detect the decay products from new long-lived neutral particles and found them to be substantial. We propose to examine the nature of single track triggers in the spectrometer once the magnets, beam pipe and apparatus are installed, in order to determine the feasibility of the search. This we would like to accomplish before the meso-pause so that the necessary modifications could be made during the pause: these center around the trigger requirement of reducing the low p_T background. The experiment would be run after the pause and after the completion of E533, and would require 300 hrs.

We anticipate that a study of background tracks will be necessary in the tune-up stage of E533 itself, so that it should not cost us any appreciable amount of additional beam time to determine the feasibility of the presently proposed idea.

We would like continued support from the laboratory in obtaining the best possible vacuum in the decay region.

References and Footnotes

1. H. R. Gustafson et al., PRL 37, 474 (1976)

2. M. Y. Han and Y. Nambu, Phys. Rev. B139, 1006 (1965)

3. R. Cahn, PRL 40, 80 (1978)

4. For an estimate of ψ production, we used the parameterization of J. G. Branson et al., PRL 38, 1331 (1977)

5. John O'Meara, meson laboratory engineer

Table 1

Acceptance for detection of a single particle from the decay (within the 240 m decay pipe) of a new neutral long-lived particle as a function of mass.

Mass (Gev/c^2)	Acceptance (%)
1	2.7
3	1.5
5	0.5
10	0.2

Figure Captions

Figure 1: Layout for E533 ($\pi\mu$ atoms). For the present experiment, the stripping foil would not be employed. The two sets of magnets (labeled "sweeping magnets") could be set to bend positive particles so that only positive particles with a p_T exceeding that possible in K_L decay would be rising through the spectrometer. This would be an effective way to reduce triggers from K_L decays with a loss of about a factor of two in sensitivity. For the present experiment the chambers and hodoscopes behind the analyzing magnet would be somewhat collapsed to increase the acceptance for large p_T particles.

Figure 2a: The detected p_T distribution for pions going through the spectrometer from $K_{\mu 3}$ decays.

Figure 2b: The detected p_T distribution for pions from the (2-body) decay of a 1 Gev/c^2 particle.

Figure 3: The number of detected events from the decay of a 3 Gev/c^2 neutral particle produced as copiously as the ψ as a function of lifetime in a 100 hr run.

Fig. 1

ES33 Spectrometer

side view

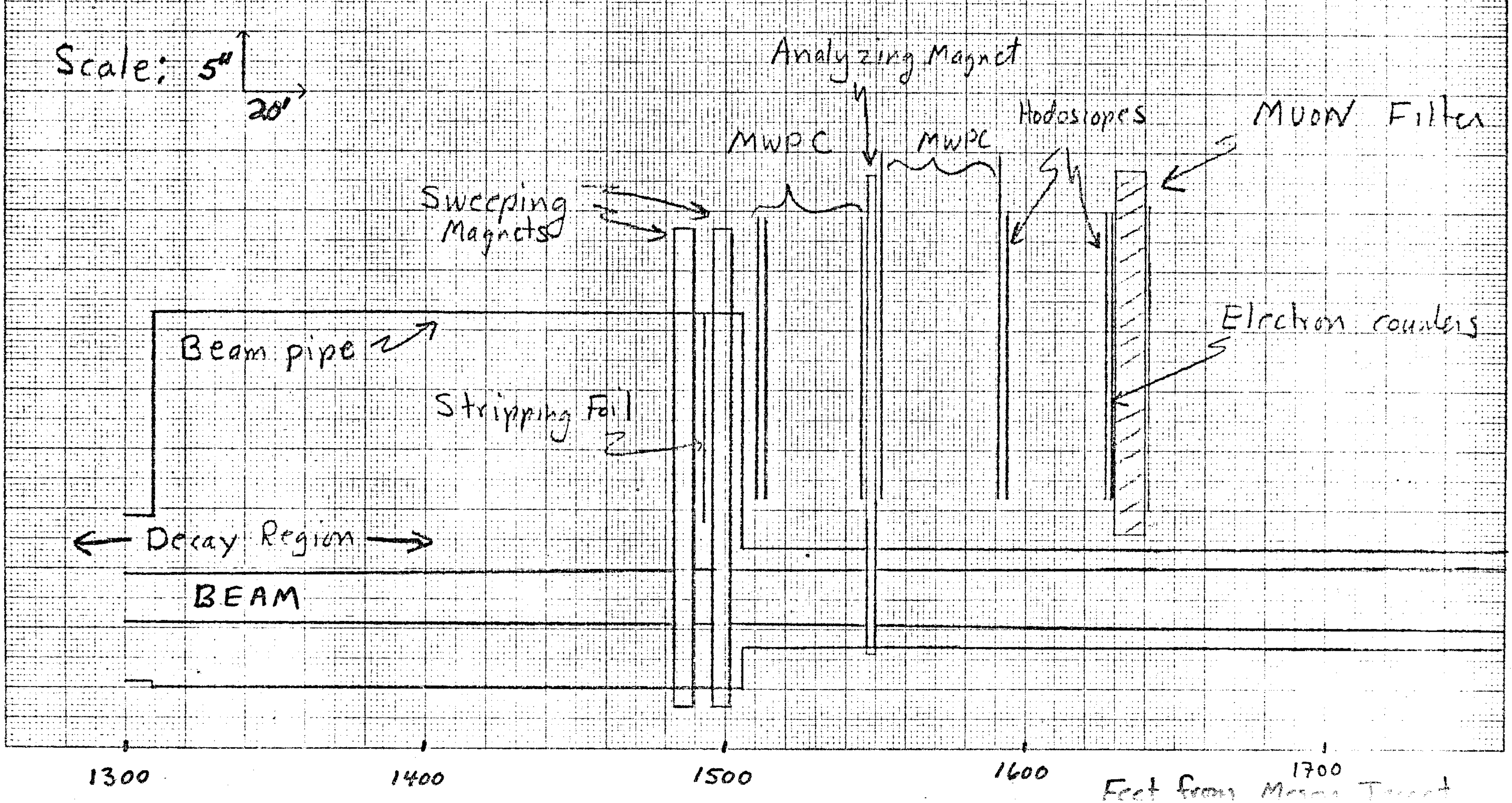


Figure 2b) MEASURED $P_\perp$ FOR PIS FROM $A \to \pi\pi$ $MASS_A = 1$ GEV

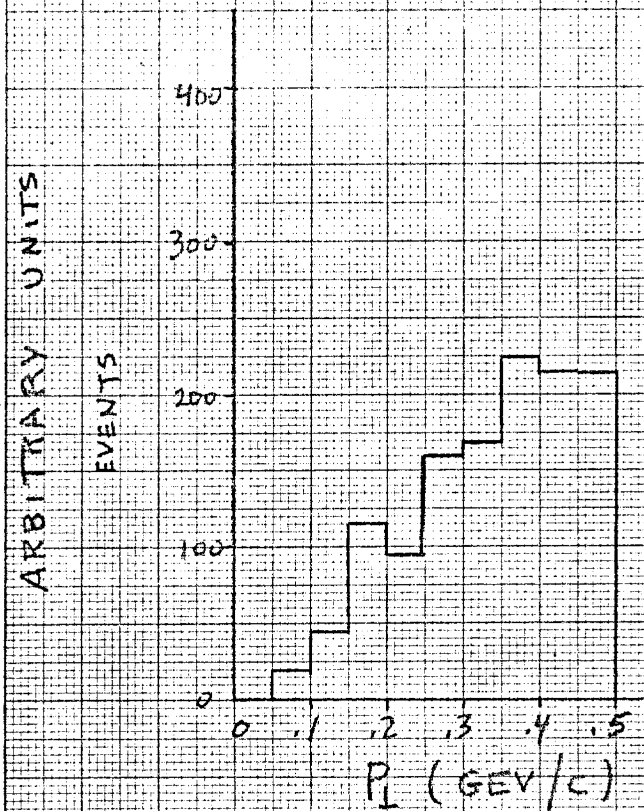
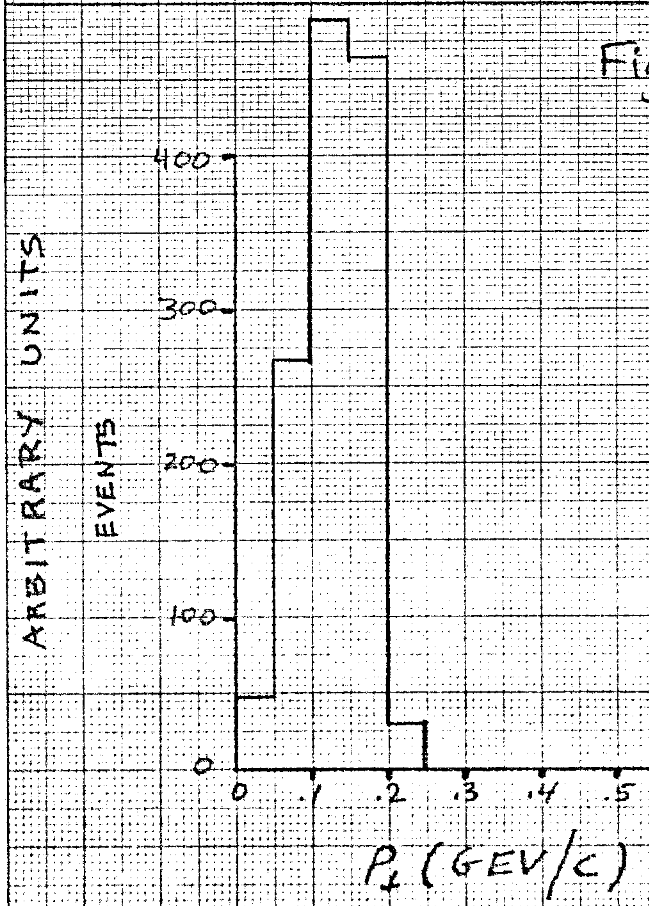


Figure 2a) MEASURED $P_\perp$ FOR PIS FROM $K_L \to \pi\mu\nu$



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