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Search for Massive Neutral Particles

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Summary

We propose to search for new massive neutral particles in the M-3 and M-4 beams of the Meson Laboratory. The search would be sensitive to neutral particles with mass ⩾ 2 GeV with strong or electromagnetic interactions and proper lifetimes ⩾ 10^{-7} sec. The masses of the particles would be determined by measuring their time-of-flight relative to the r.f. and their energy with a total absorption calorimeter.

The apparatus would be principally the Michigan calorimeter which is presently at the end of the M-3 beam line. Tuneup would be done on a parasitic basis in the M-3 line. Afterwards the calorimeter would be lowered into the M-4 line where a more sensitive search can be made (because of the reduced background from high-energy neutrons.)

We request approx. 2 months in the M-3 line for setup and tuning. This should include several short periods of parasitic running with modest beam intensities (⩽10^5 pulse). The calorimeter would then be moved to the M-4 line for 2 or 3 runs, each about one week long. If necessary, the calorimeter can be removed between these runs.

Physics Justification

Theorists are excited by the possible existence of new quantum numbers, such as charm or color. Most guesses suggest that the masses of charmed particles would be of order several GeV and their lifetimes $\sim 10^{-13}$ sec. However, as Bjorken has emphasized[1], it is quite possible that new particles exist with a combination of quantum numbers (color, charm, strangeness, etc.) and mass such that they would have much longer lifetimes, or perhaps be absolutely stable.

Searches using missing mass techniques are not sensitive to charmed particles which can only be produced in pairs. Furthermore, particles with lifetimes $\gtrsim 10^{-9}$ sec. are unlikely to be found by observing their decays. We know of no previous experiment which would have been sensitive to neutral particles with masses >2 GeV, lifetimes $>10^{-8}$ sec., and production cross sections appreciably smaller than those for neutrons. (Indeed, no other technique seems feasible for searching for such particles if their lifetime is $\lesssim 10^{-3}$ sec.).

Technique

The basic technique is to measure the energy and time-of-flight of particles in a neutral beam. This is somewhat similar to the method used by Appel _et al_.[2] for charged particles. Time-of-flight (relative to gammas) would be determined by measuring the time difference between the calorimeter pulses and the r.f. bunches in the machine. The energy of the particles would be determined from the energy deposited in the calorimeter, as measured from the pulse height.

Thus the flight time and pulse height would be recorded for each event. From these the mass can be calculated. The ultimate mass resolution depends on the timing and energy resolution, and it is difficult to predict it accurately. The main experimental problem is to distinguish new massive particles from the dominant neutrons. Limits on their production will therefore be mass dependent and improve with increasing mass.

As an illustration, let us consider a particle of mass 2 GeV produced with γ=13, approx. that of the c.m. in 300 GeV p-p collisions. At 200 GeV, the energy resolution of the calorimeter has been measured to be ±6% (std. deviation). We expect poorer resolution at lower energies. On the basis of experience with a similar calorimeter at the AGS we anticipate an energy resolution of about 25% at 26 GeV. For a particle with mass 2 GeV this gives a mass resolution of about ±0.5 GeV*. This should be sufficient to give fairly good separation for 2 GeV masses and very good separation for masses >3 GeV.

We have already investigated the timing resolution obtainable with the calorimeter by measuring the timing of fast neutrons with respect to the machine r.f. These studies were made without the benefit of special r.f. bunching, and we did not have the sufficient time to optimize the resolution. Nevertheless the results were quite encouraging. Some results are shown in Figure 1.

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*This assumes that the calorimeter is 1700' from the production target. A timing resolution $\sim$ ±1.4 ns is assumed as discussed later. For this particular choice of parameters the mass resolution is not especially sensitive to the timing resolution.

The dashed curve shows the time distribution found when a minimum energy of approx. 50 GeV was required in the calorimeter (i.e. - neutrons with $\gamma \geqslant 50$). The overall timing spread is $\approx$1.2 ns FWHM. When particles with E $\leqslant$50 GeV are selected (the solid curve), an obvious tail at long delays is seen. Pulse heights from the calorimeter were not recorded.

It should be possible to improve the time resolution significantly with modest effort and more suitable electronics. The tails can be reduced by appropriate tuning of the r.f.; studies of what can be done to improve the bunching will be carried out in conjunction with the r.f. group.

Note that the maximum flux that can be handled will be limited by accidental rates. The high-energy neutrons in the M-3 beam are a background to the interesting events with longer delays. The M-4 beam with its larger takeoff angle has a much reduced flux of high-energy neutrons while the production of lower energy particles is less dependent on takeoff angle. We therefore propose to use the M-3 beam for tuneup and do most of the data taking in the M-4 beam.

Apparatus Required

The calorimeter and much of the electronics are already available from E-4/E-248. No special magnets or targets are required. A very modest amount of rigging help will be needed to lower the calorimeter into the M-4 line. Hard lines to bring the calorimeter signals from the M-4 line to the E-248 portacamp will be needed (6 cables, approx. 200' long).

We also request Fermilab to purchase 3 constant-fraction discriminators for calorimeter timing. We shall also need a few standard modules from PREP.

Scope of the Experiment

We have in mind a very modest effort which will not significantly affect progress on E-248. The calorimeter is being set up in the M-3 line for E-248. The massive particle search mainly entails optimizing the timing resolution and setting up the electronics to record flight times. Some help from the r.f. group will be needed in the bunching studies.

The tuneup of the calorimeter can be done on a parasitic basis in the M-3 line in a period ~2 months.* After this we would like one or two one-week runs with beam control to take preliminary data. The calorimeter would then be installed in the M-4 line. There we would like two or three one-week runs with beam control. The calorimeter can be installed in the decay space of E-82 without disturbing their apparatus.[3] Moving it out of the way to enable them to run would be a simple matter.

We would be able to start work on this experiment as soon as it is approved.

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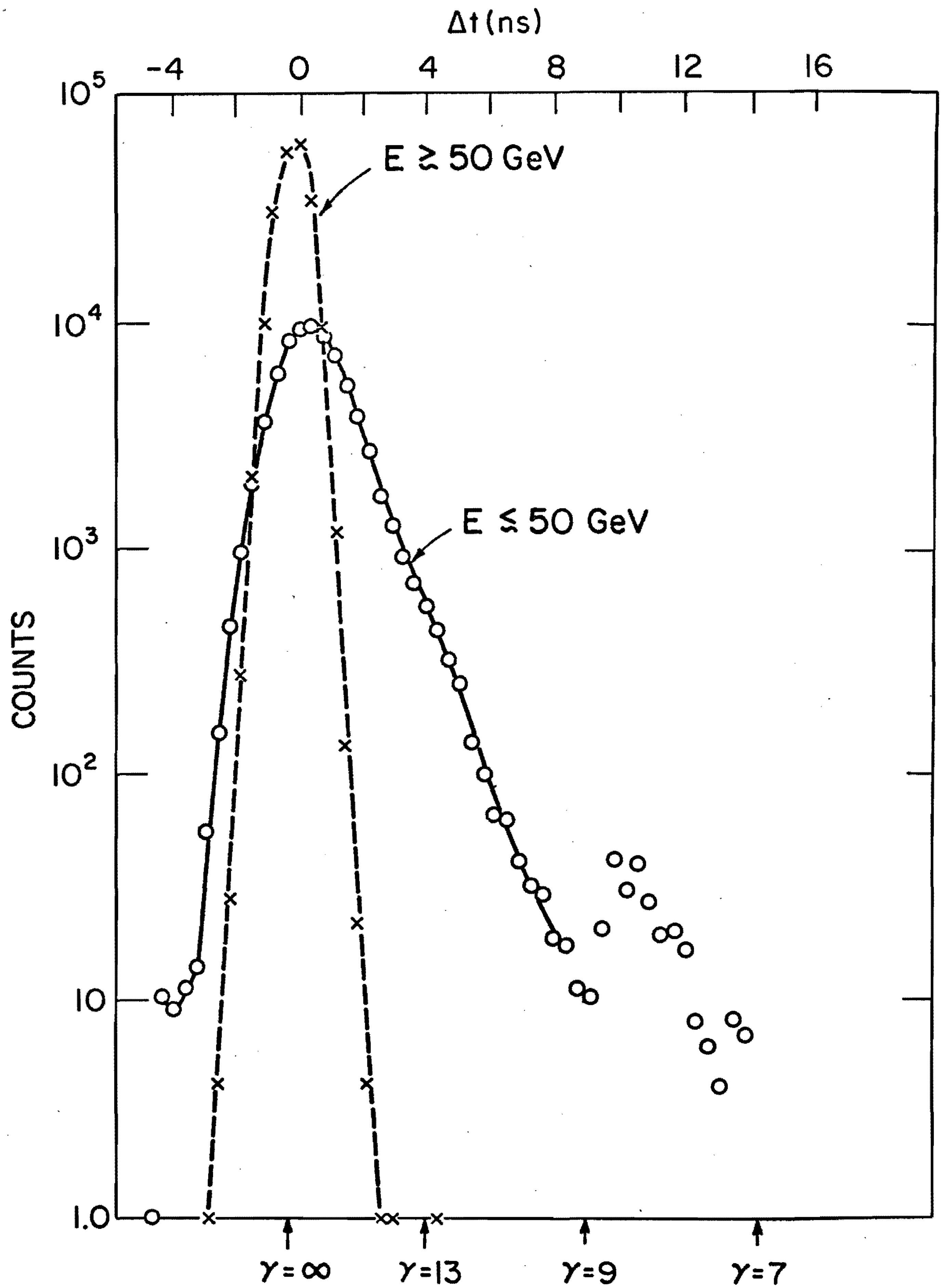
*Tuning can most conveniently be done when E-305 is running. Neutron fluxes required by E-12 are too high for serious tuning.

References

1. J.D. Bjorken, private communication.
2. J.A. Appel, *et al*., Phys. Rev. Letters **32**, 428 (1974).
3. This places the calorimeter about 1700' from the target. A longer flight path would be desirable; however making it much longer would require extending the M-4 line.

Figure Caption

Flight time distribution measured with the calorimeter in the M-3 neutral beam in conjunction with E-4. The dashed curve shows the distribution if high-energy neutrons are selected. The solid curve is that obtained when low energies ($E \leq 50$ GeV) are selected.



Δt (ns)
-4
0
4
8
12
16
10^5
10^4
10^3
10^2
10
1.0
COUNTS
E ≳ 50 GeV
E ≲ 50 GeV
γ=∞
γ=13
γ=9
γ=7