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A Search for New Metastable Particles Trapped in Matter

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Proposal Summary

Every few years we are reminded that whenever we look in an unexplored area of elementary-particle physics we are likely to find something new. The richness of our field seems to be bounded not by the laws of Nature, but by our imagination and perseverance in seeking them out.

Very little information now exists about the possible existence of particles, particularly neutrals, with lifetimes $10^{-9} \leqslant \tau \leqslant 10^{-2}$ sec and production cross sections $\ll$ 1 mb. At present good limits exist for charged particles and for neutral hadrons with lifetimes $\geqslant 10^{-7}$ sec. and masses $\geqslant$ 2.0 GeV/c; but new long-lived particles with unusual properties could well be found at lower masses where they are masked by copious production of "old" particles. Another possibility is that particles exist which have such strong binding forces to ordinary matter that they rarely (or never) leave the target in which they are produced, so that previous searches would have failed. Quasi-confined quarks would be an important and timely example of such particles.

We propose to use the M3 neutral beam line in a search for new particles which are trapped in matter and which might be produced by 300 GeV neutrons. The search would be sensitive to states with a lifetime $\geqslant 10^{-9}$ sec which decay with energy releases $\geqslant$ 10 MeV and which are produced with cross sections $\geqslant$ 0.1 nb/nucleon. A variety of signatures would be investigated. We request six calendar months of nonexclusive use of the M3 beam line.

Introduction

The discovery of the ψ/J and of heavy leptons in the past several years has forcefully reminded us that Nature has many surprises yet in store for us, even at comparatively modest energies. It is probably fair to say that the existence of most of the particles we now know was unanticipated except in cases where symmetry arguments (isospin, charge conjugation, SU_3) made it rather obvious where to look.

There is also an interesting correlation between the number of states that have been found and sensitivity of searches for them. This correlation is especially strong for neutral particles. The most sensitive search method is the missing mass technique which is suitable for lifetimes $\leqslant 10^{-10}$ sec where most neutral particles have been found. All the other neutral particles (ν, K°, n, Λ°, Ξ°) are produced with cross sections large enough to make it fairly easy to see them in bubble chambers, either through their interactions or their decays. To our knowledge the only sensitive searches for long-lived neutrals were E-330 carried out by our group,[1] which set cross section limits $\leqslant 10^{-34}$ $cm^2/(GeV^2\text{-nucleon})$ for neutral hadrons with $\tau \geqslant 10^{-7}$ sec and masses $\geqslant 2$ GeV/c^2, and a search for long-lived neutral leptons by the E-1A group[2].

This strong correlation between numbers of states found and the sensitivity of searches makes it imperative to carry out sensitive searches for long-lived neutral particles. The question is

not whether such searches should be done, but how to do them. B. Pontecorvo has proposed searching for them by looking for unusual kinds of radioactivity produced when such particles are trapped in matter.[3] This method has the advantage of being sensitive to charged as well as neutral particles. [It could, for example, be used to "rediscover" essentially all the known particles with lifetimes $\infty > \tau > 10^{-10}$ sec: neutrons through the β-decay of neutrons trapped in nuclei; muons, pions, and kaons through muonic, pionic and kaonic atoms; and hyperons through the decay of hypernuclei.]

Another very important motivation for such experiments is the possible existence of isolated quarks trapped within matter but not confined within hadrons as is usually assumed. Very stringent limits have been set on the possible existence of free quarks, both integrally or fractionally charged, in high-energy beams and for fractionally-charged quarks trapped in matter.[4] As a result it is generally believed that quarks are completely confined within hadrons. There is still the possibility, however, that they are only partially confined. D. Garelick,[5] has suggested that strong, long-range forces between quarks and hadrons cause quarks to be trapped in matter very quickly after production. (Presumably the quarks would then form some sort of quarked atom with the quark eventually dropping into the nucleus after emitting a cascade of high-energy photons.) M. Longo[6] has pointed out that present ideas of quark confinement by long-range color forces allow the possibility of metastable states consisting of two quarked

nuclei bound together by long-range color forces. Each of the two nuclei could be fractionally charged, but since the two nuclei remain bound together, previous quark searches would not have detected such states. They would, however, emit a series of high-energy photons as they de-excite, followed by some combination of photons, charged particles, and fission fragments when the displaced quarks eventually recombine.

Our proposal is to search for unusual kinds of delayed radioactivity from a nuclear target exposed to ~300 GeV neutrons. A variety of signatures would be investigated (e.g. - delayed emission of γ's with energy $\geqslant$ 10 MeV, delayed emission of electrons or muons, cascades of photons, ...) There is at present little experimental evidence bearing on the existence of such states. A search carried out by Frankel et al.[7] at Fermilab was sensitive only to states with lifetimes $\geqslant$ 2 hours which decayed into a charged particle with $\gamma \geqslant 10$. Searches at Serpukhov[8] were sensitive to states with lifetimes $\geqslant$ 5 millisec which decayed into an electron with > 30 MeV or a muon or pion with $\geqslant$ 140 MeV and no charged particle going off into the opposite hemisphere.

We believe these searches can and should be pushed to much shorter lifetimes. We propose to search in the lifetime range $10^{-9} \leqslant \tau \leqslant 10^{-2}$ sec for such states. This can be done by taking advantage of the rf bunching of the beam at Fermilab. The experiments can be done with very modest apparatus. However, the techniques are of a pioneering nature and need to

be developed. We also feel that a variety of signatures must be sought. Any promising leads will have to be followed by more detailed studies. The development of the necessary techniques and learning how to obtain high sensitivity will take considerable beam time. The use of a neutron beam has important practical advantages in such searches. We expect that for most of the work the target will have to serve as a detector (such as a lead glass counter or solid state detector). Neutrons which do not interact in the target will not be a source of background so that much higher fluxes can be tolerated than with a charged beam.

The M3 beam line which is currently under-utilized is ideal for our purposes. The beam costs very little to run, the intensity can be controlled over a wide range, and quick access to the apparatus is possible. Our use of the M3 beam would not preclude its use by other experiments.

Experimental Technique

Basically the technique is to pass a high-energy hadron beam through a nuclear target and look for unusual types of delayed radioactivity from the target. This vague prescription obviously covers a lot of territory. In fact the only real limitation is the imagination of the experimenters. The width of the rf bunches ($\approx 2\times10^{-9}$ sec) and the response time of detectors ($\approx 3\times10^{-9}$ sec) place a practical lower limit $\sim 3\times10^{-9}$ sec for the lifetime. "Unusual" types of delayed radioactivity might include high energy photons ($\geq$ 10 MeV), pions, leptons or lepton pairs, delayed nuclear fission, or combinations of

these (not necessarily simultaneous!). Obvious backgrounds include ordinary radioactive decays of nuclei and decay of known particles, in particular μ's, K's, and hyperons. These will limit the potential sensitivity for short lifetimes ($\lesssim 10^{-6}$ sec) and modest energy releases.

We propose to search for a variety of signatures over as large a range of lifetime as possible. This will require a variety of techniques which we expect to evolve online as we gain experience with backgrounds and limitations of detectors and electronics. One key element in this search is the rf bunching of the beam. In E-330 we made good use of this to do the most sensitive search to date for long-lived ($>10^{-7}$ sec) massive neutral particles, such as integrally charged quarks. That experiment was done with very minimal demands on the laboratory (several hours of rigging time, use of some PREP equipment, and several weeks of running in an underutilized beam line (M4).

It is difficult to predict where we will be led and what kind of search is most likely to be rewarding. As an example of the possibilities, let us consider the following scenario. We suppose $\bar{q}$'s (or other particles) can be trapped within nuclei or in a Bohr orbit just outside in states with lifetimes $>10^{-9}$ sec, some of which eventually decay into lepton pairs. In Fig. 1 is an experimental arrangement for searching for such states. Basically, the apparatus consists of two small scintillation counter telescopes on opposite sides of a lead glass counter which serves as the target. The telescopes are

in fast coincidence with each other, and a veto synchronized with the accelerator rf is used to gate out prompt particles which are in time with the rf bunches. Upon receipt of a trigger, pulse height information from the lead glass counter for the previous few rf buckets is read into ADC's. Pulse height data from the lead glass counter is also continuously fed into an analog shift register[9] clocked by the rf. The circulation of the data through the shift register is stopped upon receipt of a trigger. The data in it can then be read out sequentially into an ADC under computer control. This will allow us to look for lifetimes up to a few milliseconds. Pulse height data from the lead glass counter subsequent to the trigger can also be read in to search for γ's or electrons which might come from excited nuclear fragments.

Limits of sensitivity of the proposed search will depend very much on the uniqueness of the signature of the states and the lifetime. The optimum lifetime range for the technique shown in Figure 1 would be $2 \leqslant \tau \leqslant 10^4$ ns. where cross section limits $\sim$ 0.1 nb/nucleon might be anticipated. Better limits for lifetimes $>10^{-6}$ sec can be obtained by running with a fast spike at the end of the spill to the Meson Lab, but we prefer to wait until we have perfected the necessary techniques before we make such a request.

Equipment and Running Time Needs

We shall provide all necessary detectors. Online data acquistion will be handled by our HP-2100 computer used for

E-330 and E-248. This system now includes two discs and a fast line printer. Financial support for the University of Michigan contribution will come from a continuing NSF grant.

Our principal request of Fermilab is for use of the M3 beam line for 6 months of calendar time starting after E-438 is completed. This use need not be exclusive or continuous. (We would anticipate using the beam about 50 to 75% of the time it is available.) Since a large fraction of our time will be devoted to "learning" we feel that it makes more sense to phrase our request in terms of calendar time, rather than beam time. We note that our use of the beam generally requires turning on no additional magnets as most of the sweeping is done by magnets normally used in the M2 or M4 line. We may on occasion request the use of one of the downstream magnets in the M3 line for additional sweeping. Our space requirements in the beam line are modest. If necessary, we can work in the part of the M3 line upstream of the Detector Building. (This would not interfere with the use of the M3 line as a staging area for the riggers.)

We also request the continued use of most of the PREP electronics and the portacamps used for E-248 (or reasonably equivalent space). In addition, we may need some additional CAMAC modules, totalling not more than $5000 in cost. In order to assist us in the development of any special electronics we may need for our measurements we also request up to two man-weeks of electronic engineering help from the Research Services Department.

REFERENCES AND FOOTNOTES

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9. These are essentially clocked analog delay lines. Packets of charge are shifted sequentially from cell to cell under control of an external clock. Devices with 128 or more cells and aperture times of 25 ns are readily available commercially.

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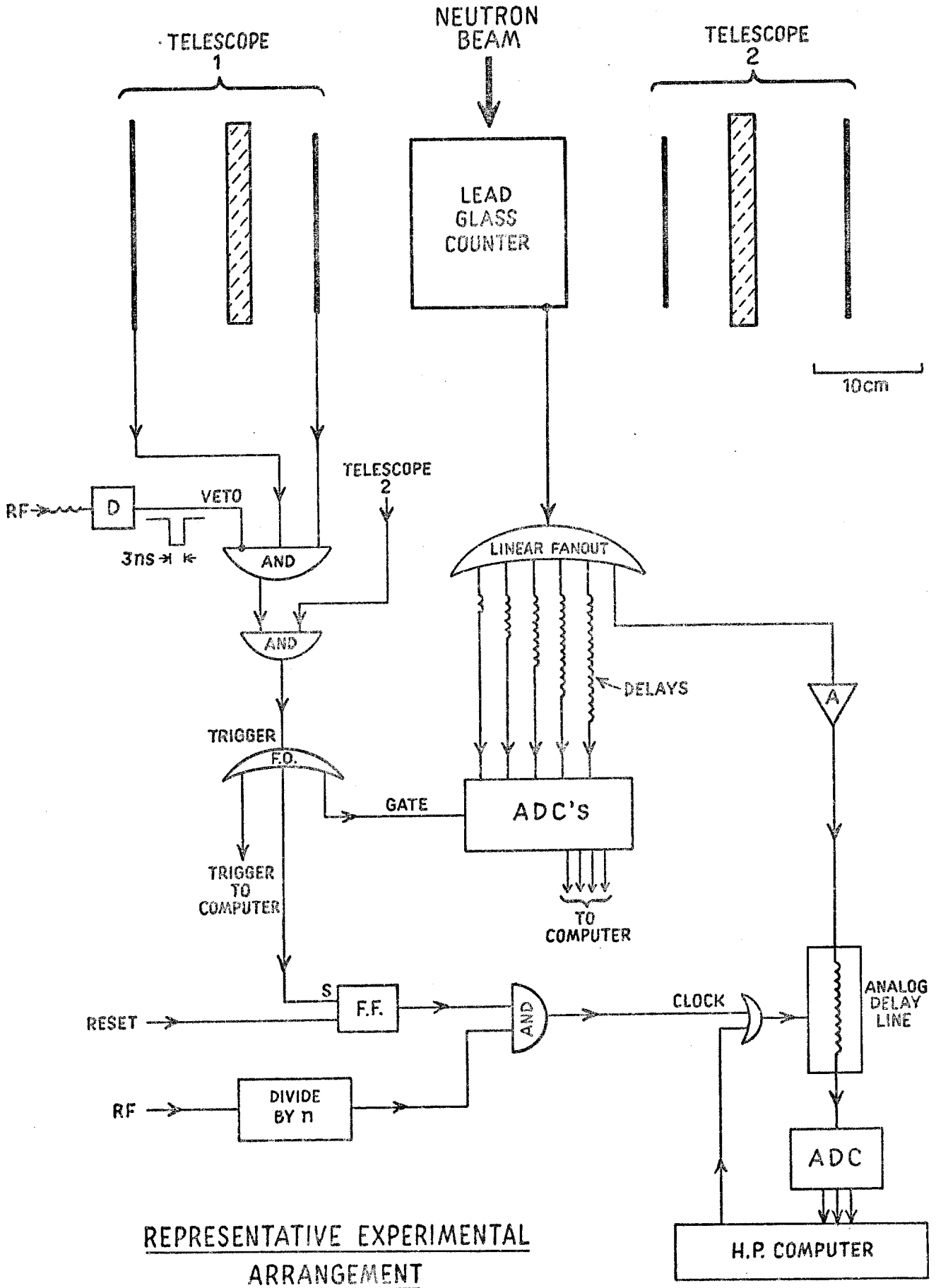

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