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Letter of Intent to Search for New Particles from the Prompt Beam Facility

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1) INTRODUCTION

This letter of intent describes an experiment to make a sensitive search for new particles emerging from the new beam dump facility which is being constructed at Fermilab. Presently approved experiments to use this facility will observe events which are due to the interaction and the decay of particles but will not be able to separately identify these two processes. Hence, in the event of an interesting and unexpected signal being observed, these experiments will be unable to conclude whether they are observing interactions or decays of new particles. We, therefore, propose a detector which can simultaneously identify decay processes and interactions of particles with similar experimental resolution functions and capabilities. In this way, maximum sensitivity and reliability can be achieved as will be described.

At CERN over the past six years there have been repeated indications that the flux rate of $(\nu_e+\bar{\nu}_e)/(\nu_\mu+\bar{\nu}_\mu)<1$. There may also be an excess of low energy muonless events. Neither of these phenomena can be explained within the Standard Model. It is therefore vitally important that the flux of particles from the Fermilab beam dump facility be analyzed for their interactions and decays separately.

Beyond these issues, the fundamental motivation for this experiment is to make a sensitive search for the decays and interactions of particles whose existence is beyond the scope of the "Standard Model". Because any evidence for the existence of these particles would profoundly influence the future direction of physics it is important to make a thorough search for them.

Neutrino-like objects which may decay include heavy spin one half neutrinos, scalar neutrinos, axions and photinos. In addition, the design of the new beam dump facility permits, for the first time, a search for neutral long lived hadronic states which have a strong interaction cross section in the mille barn range. The gluino states predicted by supersymmetry models may have these properties. An appreciable fraction of these particles come through the 9 meters of iron in the dump and their decays may be observed in the proposed detector.

Neutrino-like objects which will interact, besides ν_e, ν_μ and ν_τ, will include massive neutrinos, neutral long lived hadronic states, gluinos and photinos. It seems likely that for masses ≥10 GeV many of these particles are best searched for with the high luminosity of a beam dump rather than the high energy, low luminosity, of a colliding hadron facility.

To successfully address these physics objectives the characteristics of the detector must include a large decay volume with low density, good tracking capability for vertex determination followed by calorimetry for triggering purposes. The interactions of neutrino-like objects will be detected in the same calorimeter with identical experimental resolutions and capabilities.

The calorimeter must have good electron and photon discrimination and spatial resolution as well as measure hadronic and electromagnetic energies. In addition, muon identification and momentum analysis is required. We believe that these powerful capabilities will be essential to the discovery of the new physics which are likely to be revealed in this study. It seems possible to reach a sensitivity of about one event per 10^{17} protons on target. A sophisticated shielding and vetoing system is required to reach this level.

We propose installing the decay part of the detector in Lab C immediately upstream of the existing flash chamber detector. It is important to note that the calorimeter and the muon momentum analysis system exist and are in place. Tracking detectors and veto system are required as new items.

To provide space for the detector installation we require a modification of the front end of Lab C.

It is expected that the signal to background for new massive particle detection will improve with increasing production angle. Vital importance is therefore attached to good detector characteristics at the very low energies which will be encountered. The fine granularity (3.0cm longitudinal, 0.5 cm transverse) of the Lab C calorimeter provides good resolution and powerful pattern recognition properties at low energy. We therefore propose runs at 0, 15 and 30 milliradian production angle to explore with maximum sensitivity the existence of new particle production at the beam dump facility.

2) PHYSICS OBJECTIVES

2.1 Heavy Neutrinos

The new Fermilab prompt beam facility will be a copious source of third generation, ν_τ, neutrinos. Fourth generation neutrinos, if they exist, may also emerge if there is mixing between the third and fourth generation. The fourth generation, ν_4, flux will be reduced by a factor $|U_{\tau,4}|^2$ relative to the ν_τ flux. If the ν_4 are sufficiently massive then they will have dominant decays:

$$e^+e^-\nu_\tau,\ \mu^+\mu^-\nu_\tau,\ \pi^+\pi^-\nu_\tau,\ \ldots.$$

assuming as before that mixing to the first two generations will be small. These decays again involve a factor $|U_{\tau,4}|^2$. It appears that good sensitivity to the decays of massive fourth generation neutrinos can be obtained. These massive neutrinos, ν_4, would also interact in the calorimeter via neutral current interactions. Hence, the observed neutral current to charged current ratio in the calorimeter would be anomolous. The energy and angle dependence of the decay events and excess neutral current events should be related and this will provide an important confirmation of the existence of new physics.

2.2 Long Lived Strongly Interacting Massive Neutral Particles

The proposed experiment will be sensitive to the decay and interaction of long lived ($\gtrsim 10^{-9}$ sec) strongly interacting ($\lesssim 1$ mb) neutral massive (1-10 GeV) particles. An example of this kind of particle is the putative gluino. As the prompt beam facility will have only 9 meters of iron shielding, $\gtrsim 0.4\%$ of these particles will be transmitted through the dump without interacting.

It is believed that QCD calculations of gluino production cross sections are fairly reliable. Hence, the flux of gluino states through the detector can be calculated with an assumed decay lifetime and absorption cross section.

It appears that we will be sensitive to the decays of gluinos with mass up to at least 6 GeV. The decays may involve an imbalance of transverse momentum due to an undetected photino or goldstino. Hence good angle and energy resolution for the decay products are required.

In addition, we will detect the interaction of the strongly interacting (~1 mb) gluinos in the calorimeter. They will appear as neutral current events whose number decreases towards the back of the calorimeter.

We expect the signal to background for the detection of massive gluino states will be better at finite production angle. The angle and energy dependence of the decay and apparent neutral current events will be related. This will provide vital internal consistency to the claim of a new phenomenon and establish the strongly interacting nature of the particle involved.

2.3 Long Lived Weakly Interacting Massive Neutral Particles

J.D. Bjorken has described the phenomenology and experimental limits of searches for particles that carry no net quantum numbers and couple very weakly to ordinary quarks, leptons and gauge fields. While his primary interest was in the leptonic decay of particles whose mass was $\lesssim 1$ GeV we have extended the analysis to the hadronic decays of massive (>1 GeV) particles. We find that there is a unique range in the mass-coupling strength plane which cannot be accessed by any other known method.

2.4 Photino Decays and Interactions

If gluinos produced in the beam dump decay rapidly then there may be an appreciable photino flux through the detector. This is the complement to the situation described earlier. A massive photino can decay radiatively with the emission of a multi-GeV photon:

$$\tilde{\gamma} \longrightarrow \tilde{G} + \gamma$$

where $\tilde{G}$ is a goldstino.

A multi-Gev photon must therefore be detected at the exit of the decay volume. Both angle and energy of the photon is required to identify the imbalance in transverse momentum and reduce backgrounds from outside the decay volume. Photino interactions in the calorimeter would appear as neutral current events with a normal longitudinal spatial distribution. Once more, we would expect an enhancement in the signal to background at finite production angle from the beam dump facility. Once more, there will be a connection between the energy and angle dependence of the decay events and excess neutral current events which will help establish the existence and nature of the phenomenon.

2.5 Summary

We have discussed a variety of processes involving the decay and interaction of heavy neutrinos, strongly and weakly interacting massive particles and radiative decays. Existing limits for these processes will be substantially improved in the proposed experiment. Because of the profound implications of the existence of a signal for any particle of this type it is important to make a thorough search.

3. DETECTOR

3.1 Design

The major thrust of this proposal is to exploit the higher center of mass energy available at the Tevatron and search for large invariant mass particles. It appears that reasonable acceptance for the decay of massive particles into pairs of hadronic jets limits the decay length to less than about 10 meters. At the finite production angles where signal to background is expected to improve, the energy of these massive particles will be rather low in general. Hence, the optimal decay length in this case is less than 10 meters. We have approximately 6 meters available between the front of the existing flash chamber detector and the front of Lab C. This seems quite appropriate.

3.2 Detector Layout

The detection of rare events such as one decay per 10^{17} protons on target requires extreme attention to the detailed design of the detector. The proposed detector is shown in Fig.1. A 3.5 m thick iron shield 6m x 6m absorbs all hadrons and $\lesssim 5$ GeV muons incident on the detector. It is made as an "active" shield by the presence of ten proportional planes (P1...P10) within the last 1.7 meters. These planes detect interactions in the steel of neutrinos and muons. This is for off-line background rejection. The back of the steel shield has a two inch thick layer of lead to absorb photons which otherwise could create lepton pairs in the decay volume, thereby simulating decays or the radiative decays of particles.

An anticoincidence scintillation counter, (VI), 6m x 6m, provides a veto for an event with an incoming charged particle. This is followed by a 6 m long decay space, with transverse dimensions 6m x 6m and filled with helium. Downstream of the decay space there are 4m x 4m tracking chambers to establish the trajectories of all charged particles emerging from the decay volume. These detectors are proportional wire chambers operated in the drift mode with 1" wire spacing and are physically identical to the units which we have already built and installed between the 12' iron toroids in Lab C. New drift electronics is being added to the toroid planes in the fall of 1983. The identical system is proposed for these tracking chambers. There are six X chambers and six Y chambers deployed in the form XX,YY; 15 cm gap; XX,YY; 15 cm gap; XX,YY. These counters occupy a distance of 60 cm and are identified as TC1, TC2 and TC3. Each pair of chambers XX and YY has its two elements relatively displaced by 1.27 cm transverse to the beam axis. Each drift chamber provides a track reconstruction accuracy $\sim$1 mm. The short drift distance, 1.27 cm, of these tracking chambers will maintain a short sensitive time which will be useful due to background of low energy muons from the beam dump. The total material thickness of the tracking chambers is equivalent to 9.0 cm aluminium corresponding to 1 radiation length and about 23% of an interaction length. Particles emerging from the tracking region enter the existing flash chamber calorimeter in Lab C.

The first 12 planes of calorimeter proportional tubes (C12...C12) corresponding to 6 absorption lengths or 42 radiation lengths will be used in the trigger for decay processes. This is sufficient to absorb >95% of a 300 GeV hadronic cascade and more than adequate for electromagnetic showers. When a trigger from the proportional chambers is satisfied, high voltage will be applied to the flash chambers between the proportional tubes in the usual way. Thus, the search for decays will use the front part (~100 tons) of the Lab C detector in a dedicated fashion. The remaining 240 ton detector will be operated during the same run in a compatible but independent fashion in a search for interaction of new particles. The powerful properties of the calorimeter such as its excellent pattern recognition, high spatial resolution, electron hadron discrimination, gamma ray detection and good angle and energy resolution functions will be vital in exploring for the rare processes involving the new particles.

Muon momentum analysis will be performed with the 12' and 24' toroids up to a maximum angle of about 150 mrad. For muon momenta $\gtrsim 20$ GeV/c this maximum angle corresponds to transverse momenta $\gtrsim 3$ GeV/c. Because typical transverse momenta are expected to be $\lesssim M_x/2 \lesssim 3$ GeV/c, the muon angular coverage is adequate. The toroid proportional planes (TP 1...4) will be read out in the usual way when an event trigger occurs. These chambers are the only common elements of the decay and interaction experiments. Because the toroid chambers can be made to read out in about 5 microseconds, little dead time is expected to be introduced into either experiment from this commonality.

3.3 Trigger

Various analog and trigger signals are generated with fast logic in each of the calorimeter proportional planes. These signals can be combined to provide triggers on shower energy (maximum or minimum), shower width, shower length, the absence of any muon, or the presence of one or more than one muon. We have used all of these technqiues in the past and they can be used in this experiment. In addition, the track chambers, TC1, TC2 and TC3 may be incorporated in the trigger.

VI.

4) BACKGROUND

In this experiment any signal of decays of particles after appropriate background subtraction will indicate a physical process beyond the scope of the "Standard Model". Therefore, the minimization and understanding of the backgrounds is of prime importance.

Although it is very difficult to predict the background processes and rates that will ultimately be limiting, it is possible to design the detector to minimize the more obvious background possibilities. These are:

a) Inefficiencies of the veto counter, VI.

b) Large angle particles coming around the veto counter into the fiducial decay volume.

c) Neutrino interactions in the material within the decay volume.

d) Neutrino interactions in the 3.5 m thick steel shield producing neutral hadrons which decay or interact in the decay volume.

There are several techniques that will minimize the effect of these processes.

i) Veto inefficiencies. It is useful to have a second veto counter V2 adjacent to VI. In the off-line analysis V2 can be interrogated to ensure that the vertex originated downstream of the veto system.

ii) Large Angle Particles. Several techniques help to reduce this effect.

- A 3.5 m thick 6m x 6m iron wall in front of Lab C will absorb all hadrons and soft ($\lesssim$5 GeV) muons coming down in the general beam direction. This helps to eliminate the effects of upstream muon and neutrino interactions producing particles at all angles.

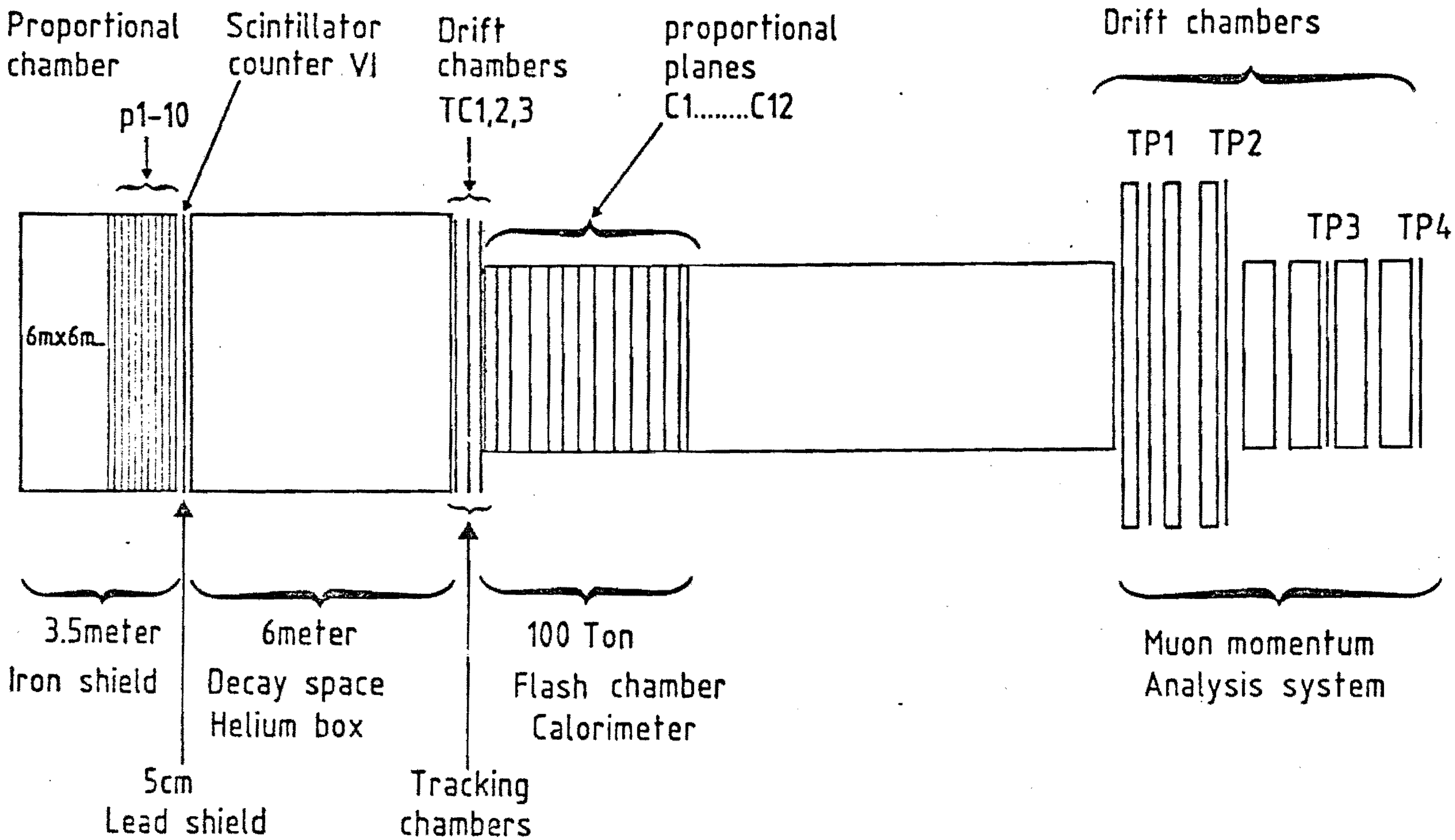
- It is important that the iron wall has a vertical slot of about 0.5 m width starting 2.5 m above the beam line. In this way, $\gtrsim$300 GeV muons at low P_T which are produced in the dump will not have a target to produce secondary hadrons at large angle into the decay volume.
- The transverse dimensions of the veto counter system P1-10, V_1, V_2 are made 6m x 6m, i.e. 1 m larger on all sides, than the downstream tracking and calorimetry.
- Material around the decay volume, which can act as a target for neutrinos or muons and in which hadrons can interact, should be kept to a minimum. We therefore plan to make the transverse dimensions of the low density region 1 m larger on all sides than the area of the downstream tracking and calorimetry. Hence, this volume is 6m x 6mx 6m.

iii) Neutrino Interactions Within the Decay Volume. We can minimize this effect by filling the volume of 6m x 6mx 6m with helium gas at atmospheric pressure. The containing vessel can be very thin thereby satisfying ii) above.

iv) Neutrino Interactions in the 3.5m Steel Shield. The neutrino beam can interact in the steel shield producing a neutral particle (K^o,Σ^o...) which could penetrate the veto counter, decay and activate the trigger. This type of neutral "punch through" can be measured and subtracted experimentally. Apparent events from this background source will normally be associated with an energy deposition in the last 1.7 m of iron shield. A correlation can therefore be made between apparent decays and the pulse height recorded in the proportional planes in the steel shield. Extrapolation of the number of apparent decays as a function of pulse height down to zero response from the proportional planes will give the limiting background from this source.

5) SCHEDULE

We assume first operation of the prompt beam facility in late 1986. Hence, there are more than two years to prepare the proposed experiment. If the modification of Lab C takes place in the spring of 1985 it will provide adequate time to install the 1000 tons of iron, the 6m x 6m planes of proportional chambers, the drift planes and scintillation counters and permit their check-out with cosmic rays. Our experience with the construction of this size of proportional chambers and the planes of drift chambers and associated electronics indicates that it will take one and a half years, June 1984 to December 1985, to meet this schedule. Cosmic ray tests can then begin in January 1986. Fortunately, there is no development work involved, however, production and testing will fully occupy this time. We therefore intend submitting a full proposal in the spring of 1984 for approval in June 1984.



LAYOUT OF DETECTOR

FIG. 1