



Status of ZEPLIN II and ZEPLIN IV Study

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We describe the construction status of ZEPLIN II detector, a 30-kg two-phase discriminating xenon detector to be installed in Boulby Mine, UK, for the direct detection of WIMP dark matter. Both scintillation and ionization will be measured in order to discriminate the radioactive background. ZEPLIN-II will have very high radioactive-background rejection efficiency. We will also discuss the study of ton scale ZEPLIN IV. The ZEPLIN program is a collaborative work of UCLA, TAMU, UKDMC, and CNR Torino, Italy.

1. Introduction

Since F. Zwicky [1] provided the first definitive evidence for non-luminescent matter (dark matter) in 1930's, much theoretical and experimental work has been undertaken. Especially during the past 10 years, technology advances have made it possible to probe with unprecedented sensitivity to detect low energy and low event-rate signals. During the last few years, some NaI detectors, especially those used in the DAMA experiment, have registered hints of event rate modulation from dark matter signals [2]. Advances in low temperature Si and Ge detectors developed by the CDMS [3] have reached an exclusion around the DAMA sensitivity. The sensitivity of these experiments will improve in the near future when

the detectors scale up and run for longer periods of time.

Because of the low-energy and low-event-rate nature of the dark matter signal, a detector must have a large mass, low energy threshold and, most importantly, the ability to discriminate low-energy radioactive background. Recently, UCLA, TAMU, CNR Torino, UKDMC formed a new collaboration for a direct search for WIMPs with ZEPLIN II. This experiment is based on liquid Xe R&R by UCLA & Torino [4], and on low background techniques and underground facilities developed by UKDMC and proven in the ZEPLIN I experiment [5]

The Xe nucleus provides a high event rate because of its high density and high atomic number. The low ionization potential and high scin-

tillation yield is especially suited for low-energy-threshold detectors with excellent potential background rejection, because the ionization and scintillation profile of background events is different from that of the recoil signal in general. Both non-zero-spin and zero-spin Xe nuclei exist in nature in large quantities, so the same design can be used for both spin-dependent and spin-independent searches for WIMPs events.

The ZEPLIN-II detector will have a 30-kg active target of liquid Xe and an Xe gaseous phase for ionization measurement by converting ionization electrons into luminescent photons. By measuring both ionization and scintillation simultaneously in the ZEPLIN-II detector, radioactive background signals can be rejected with very high efficiency. In late 2002, the ZEPLIN-II detector will be installed in Boulby Mine, a very low radioactive-background site. Because of its large mass, low energy threshold, and excellent background-rejection efficiency, the ZEPLIN-II detector will cover the current DAMA and CDMS sensitivity completely.

2. Background Discrimination

Xenon can be highly purified to the order of ~ 0.1 -ppb electron-negative impurities [6]. At this purity, both free electrons and hard-UV scintillation photons can travel much further (respectively, a few meters and ≈ 1 m) [7]. It is possible to achieve low energy threshold because xenon has high scintillation and ionization yield due to its low work function for ionization and for scintillation. Simulation show that energy threshold can be as low as 2-keV [8]. And the ionization charges can be drifted to a luminescence region where large amount of secondary luminescence photons will be produced, hence easily collected by PMT for background rejection.

In liquid Xe, the nuclear recoil signal is clearly different from the signal coming from the gamma interaction in the detector [9]. In the case of WIMP–nucleus interaction, the signal from WIMP–nucleus elastic scattering is similar to that of the neutron–nucleus elastic scattering. Using a neutron beam, we have measured the Xe recoil signals resulting from neutron–nucleus elas-

tic scattering [10]. The Xe recoil nuclei will produce mainly scintillation and almost no ionization under normal electric field. This result is similar to that of heavy ionizing particles, which produce a high density of electrons that quickly recombine and produce scintillation photons. Therefore, even with a high electric field present, very few electrons escape. In the case of gamma rays (minimum ionizing particles), both scintillation and ionization will be produced. When a normal electric field (\approx few 100 kV/cm) is present, recombination will be partially prevented, so some ionizing electrons will be extracted.

Because of the very high Xe purity, scintillation photons can be collected with high efficiency, and electrons can be drifted to an anode region for further readout. Since very few electrons escape from Xe recoil events due to the elastic scattering of WIMPs, the detection of electrons coming out of these gamma events will be the key for background differentiation. When the drifting electrons pass the interface between the liquid and gaseous Xe, most can be extracted without loss [11]. The number of electroluminescent photons produced per electron can be well approximated by the equation, $N_{ph} = 70 \cdot (E - 1.3P) \cdot d$, where the parameters E , P , and d are, respectively, the applied electric field in kV/cm, the pressure of Xe gas in atm, and the drift distance of the electrons in cm [11].

The direct (or primary) scintillation photons (which appear a few ns after the event) for both Xe recoil and gamma events will be detected by PMTs and the ionization electron will be drifted to the gas phase where electroluminescence takes place. The PMTs will also measure the ionization in terms of luminescent (or secondary) photons from the electroluminescent process at a later time, depending on the electron drift distance (few 10s of μ s).

Since electrons escape from recombination, every gamma event will have both primary and a large secondary scintillation signal, while recoil events will have very small (compare to those of gamma events) or no (depends on the strength of drift field for electron extraction) secondary signal. When plotted primary vs secondary, the background discrimination in two-phase xenon is

clearly seen in Fig. 1. This powerful discriminating technique will be used in the 30-kg two-phase ZEPLIN II detector.

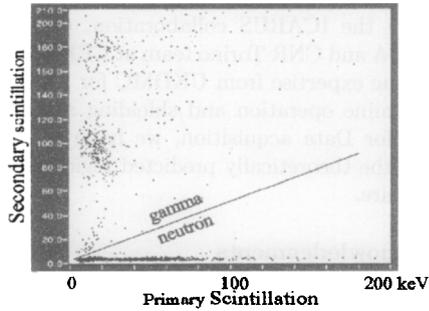


Figure 1. Secondary vs primary scintillation in two-phase Xe with mixed gamma and neutron sources. The secondary scintillation photons are produced by an electroluminescent process in gaseous Xe.

3. The ZEPLIN-II and IV Detector

The 30-kg of liquid Xe is confined in an upside down frustum by a Polytetrafluoroethylene (PTFE) cone. Ten copper rings outside the PTFE cone will provide the right potential configuration for the electron drift field. The cone also serves as an electric field modifier so that the final distribution of the electric field in the active liquid region will be uniform. The fringing field around the rings will be contained in the PTFE cone. Two fine meshes, one each in the liquid and gas phases, are placed face to face with a six-mm gap. The mesh will be welded on a stainless steel frame (pre-stressed) to maintain the flatness of the mesh. Seven similar small meshes will be used in front of the 7-PMTs to avoid field distortion on the PMT photo-cathode due to strong luminescence field near the PMT. Dead regions are kept to a minimum to avoid the loss of ion-

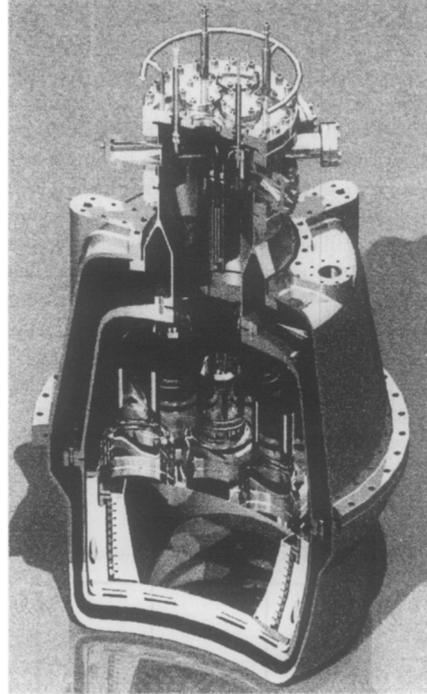


Figure 2. The cut-away 3D view of the ZEPLIN-II central detector.

ization electrons. The background discrimination power will rely on the efficiency of the ionization charge measurement.

Seven high-speed, five-inch PMT tubes are placed above the liquid with the photo cathode facing the liquid. Liquid Xe will be continuously purified, if purity can not be maintained long term in the system, with a recirculation system similar to that of ICARUS [12]. The expected energy threshold is < 10 keV. Future improvement on the primary scintillation readout will further lower the energy threshold [13] as well as increase the rejection power; the expected sensitivity is shown in Fig. 3. The entire detector is hosted by a pure copper cast and thermal-insulated by

vacuum in a stainless-steel cast vessel, which is then shielded by a Compton veto and lead shield (provided by the UKDMC). The stainless steel cast is already arrived in UCLA and under final machining.

The successful operation of ZEPLIN II will allow us to study the possibility of a ton scale design based on the same geometry. Additional R&Ds will be performed on ZEPLIN II to improve to primary scintillation readout, ionization readout and low activity readout devices, such as the use of CsI internal photo-cathode [13] to amplify the primary scintillation. The use of advanced photo readout device to replace PMT is important in order to probe completely the SUSY predicted region since the PMT induced neutron background will have comparable rate at lower SUSY region.

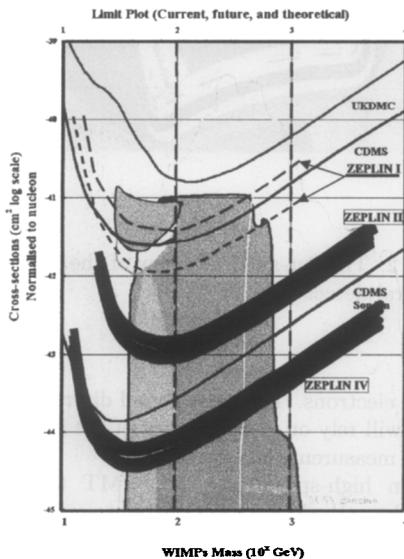


Figure 3. The expected sensitivity of the ZEPLIN-II detector.

4. Conclusion

The ZEPLIN-II detector has been designed and is under construction. It is expected to be installed under Boulby Mine in the UK during fall 2002. This detector will fully utilize the noble liquid technology developed over the past 10 years by the ICARUS collaboration, especially the UCLA and CNR Torino team at CERN. Combining the expertise from UKDMC for low background mine operation and shielding as well as TAMU for Data acquisition, we hope to probe most of the theoretically predicted regions in the near future.

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