Abstract

We describe the research and development program carried out by the UCLA – Torino group leading to the ZEPLIN II detector under construction for the Boulby Laboratory. Knowledge of ZEPLIN II performance will help in the design and construction of ZEPLIN IV. This detector could be located at a U.S. underground laboratory (WIPP site or others) or elsewhere. We show that a detector of this size is required to observe SUSY WIMPS.

Introduction

The search for dark matter particles is among the most fundamental of all astroparticle physics goals. We know that at least 30% of the matter in the universe is due to this source. An excellent guide to the search is given by the SUSY-WIMP model. As new collider physics results have appeared the calculations for the rate of such WIMPs in dark matter detectors has gone down. Currently the expected value is less than $10^{-2}$ events/kg/day.

The detection of SUSY WIMPs at this level will require a massive (one ton) powerful discriminating (ZEPLIN II) detector that we call ZEPLIN IV. The ZEPLIN II detector is under construction at UCLA and elsewhere for operation at Boulby in 2002. We consider this a prototype for ZEPLIN IV.

1. Recent SUSY-WIMP predictions: the need for a one ton detector

The current status of the search for WIMPs is confused; a recent summary can be found in Ref. 1:

1. The level is about $1/2$ event/kg/d;
2. The DAMA group is making strong claims for a discovery;
3. The CDMS group has shown that their data and those of DAMA are incompatible to 99.5% confidence level against the observation of WIMPs.

* With H. Wang and Y. Seo from Astro-PH 0108147.
† Talk given at the 2001 COSMO Meeting, Finland.
Figure 1. Recent calculations for SUSY WIMP rates by Roszkowski presented at the COSMO Meeting (2001).

Theory, which allows WIMP rates from about $10^{-1}$ to $10^{-4}$ events/kg/d, gives poor guidance. We believe that it is essential that our method (a) resolve the CDMS/DAMA claims, and (b) cover the entire region of $10^{-1}$ to $10^{-4}$ events/kg/d. Fig. 1 shows a recent calculation for SUSY WIMPs. These predictions require a detector larger than CDMS IV or even ZEPLIN II if correct.

2. The UCLA – Torino research and development program

The key properties of liquid Xe are given in Table 1, and Fig. 2 shows the key method of discrimination. Starting in the early 1990s, the UCLA/Torino ICARUS group initiated the study of liquid Xe as a WIMP detector with powerful discrimination. Our most recent effort is the development of
the two-phase detector. Figure 3 shows our 1-kg, two-phase detector and the principle of its operation. WIMP interactions are clearly discriminated from all important background by the amount of free electrons that are drifted out of the detector into the gas phase where amplification occurs. In Fig. 4, we show the resulting separation between backgrounds and simulated WIMP interactions (by neutron interaction). It is obvious from this plot that the discrimination is very powerful.

3. ZEPLIN II construction at UCLA and other places

Construction of a large two-phase detector to search for WIMPs. The UCLA/Torino group has formed a collaboration with the UK Dark Matter team to construct a 40-kg detector (ZEPLIN II) for the Boulby Mine underground laboratory (Fig. 4).

Continuation of the R&D effort with liquid Xe to attempt to amplify the very weak WIMP signal. The second idea to test is inserting a CsI internal photo cathode to convert UV photons to electrons that are subsequently amplified by the gas phase of the detector. In Fig. 4b we show the latest design of the ZEPLIN II detector. The expected sensitivity of ZEPLIN II is shown in Figure 6.

| TABLE I. Liquid Xenon as a WIMP Detector |
|------------------------------------------|

1. Large mass available - up to tons.
   - Atomic mass: 131.29
   - Density: 3.057 gm/cm$^3$
   - W$_i$ value (eV/pair) 15.6 eV
   - No long-lived isotopes of xenon
2. Drift velocity: 1.7 mm/µs @ 250V/cm field
   - Decay time: 2 ns → 27 ns
3. Light yield > NaI, but intrinsic scintillator (no doping)
   ⇒ Excimer process very well understood
   ⇒ First excimer laser was liquid xenon in 1970!

The ZEPLIN II detector construction is started at UCLA and it will be completed by this fall. The central detector consists of:

1. PTFE cone which shapes the active liquid xenon zone,
2. Three liquid level meter to monitor the liquid level,
3. Ten copper rings to shape the static electric field for free ionization electrons to drift up to the gas phase,
4. Two wire frames to form an electron extraction field at the liquid and gas phase surface and to form an electro-luminescence field just above the surface,
5. Seven PMTs above the liquid to collect scintillation and luminescence photons.
6. Copper cast vessel to hold all the above in liquid xenon temperature,
7. Copper cast vacuum vessel to thermally insulate all the above,
8. Three 25kV HV feed-through to provide the power for the drift and luminescence field,
9. other signal, temperature sensing, level meter signal feed-throughs

Item 5 (PMTs) will be provided by Torino and everything else will be made at UCLA. The manufacturing is expected to finish this fall, and an initial assembly at UCLA is expected at the end of the fall and the RAL members will be present at the time to see the whole procedure so to ease the testing at RAL and installation at Boulby mine.

The copper casting is used because:

1) there will be no welding needed for the entire vessel system. This will guarantee the vacuum, and an extremely clean system since there are no dead surfaces on the inner vessel;

2) it is extremely cheap.

4. Design of ZEPLIN IV and the research and development program

To consider a 1-ton detector (ZEPLIN IV) we adopt the design principle of the ZEPLIN II detector under construction now. As we complete and operate ZEPLIN II, adjustments to the
The design of ZEPLIN IV will be carried out by this team. The basic concept of ZEPLIN IV is shown in Figure 6.

a) The PMTs are placed above the liquid and gas (two phase) system.

b) Great care is taken to reduce any dead regions in the detector (just like ZEPLIN II).

c) The engineering design principles will be the same as for ZEPLIN II.

d) The H.V. system will be raised to the level to detect ionization if needed (from the primary).

e) A possible CsI insert will be considered for a possible signal amplification.

Figure 5a. System setup for Xe target (40 kg total): overall setup.

Figure 6. 1-ton scaled up (ZEPLIN IV) detector.

Figure 5b. ZEPLIN II central detector.

Figure 7. Limit plot (current, future and theoretical).
5. Summary

We attempt to estimate the sensitivity of ZEPLIN IV in Figure 7. If correct, this would make ZEPLIN IV the most sensitive WIMP detector currently being studied. The dark matter signal levels expected in References 5 and 6 for example could ultimately require the sensitivity in Figure 6 and the construction of ZEPLIN IV.

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