Dark matter detector, novel light counter and the ICARUS project

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ABSTRACT

We describe the current status of the development of imaging electron drift Liquid Argon Detectors (ICARUS) and the development of the Visible Light Photon Counter (VLPC) for scintillating fiber tracking for (SPC) SSC/LHC detectors. We then propose a detector that combines these two techniques to detect massive WIMPs through the possible identified Xe recoil in a liquid Xenon detector.

1. DARK MATTER DETECTION - MASSIVE WIMPS

While a search for Cold Dark Matter is underway in several places, there are many uncertainties in the expected flux and types of WIMPs[1]. Recent accelerator constraints imply that higher mass WIMPs are preferred. On the other hand, very low temperature detectors, while progressing, are still far from detector mass of 10 – 100 kilograms that is likely required. In this talk we first discuss the successful development of two new detector technologies: imaging in ultra-pure liquid argon (ICARUS) and the development of scintillating fiber technology.

There are several new developments in the issue of dark matter in the universe that are relevant to the current search

1) recent $\bar{p}p$ collider and LEP results suggest $M_{\rm WIMP} > 20\,{\rm GeV}$
2) the cross section for WIMP scattering falls rapidly with mass – 0.1 Ton or greater detectors are now required
3) no one knows how much of the dark matter in our galaxy is non baryonic
4) Cold Dark Matter models are in some trouble with the observed large scale structure of the universe

For these reasons we believe that an effort should be mounted to search for massive WIMPs with large detectors (> 0.1 Ton). In this report we discuss the possibility of a non ultra low temperature detector using liquid Xenon.

2. THE STATUS OF THE ICARUS DETECTOR DEVELOPMENT

The ICARUS detector was first proposed in 1983 and steady progress has been made over the recent period. Table 1 lists the possible physics goals of detectors that use this technique. The current technical effort is being directed by P. Picchi.

Table 1 lists some of the particle physics goals that can be carried out with detectors that use electron drift in ultrapure liquid argon, Krypton or Xenon. The ICARUS team is listed in Ref. 2. Recent progress in purification of liquid Argon and previous references are given in Ref. 3. Recently there has been a breakthrough in the ICARUS program with the successful operation of the 3 Ton prototype at CERN (Fig. 4)[4]. The detector has been triggered at 500 KeV (this is why a WIMP search may be possible for the solar neutrino physics simulation. Fig. 3 shows a stopping μ in the ICARUS detector at CERN. Pictures of this sort lead to the name ***an electronic bubble chamber***. The next step in the ICARUS program is to study the ^{42}Ar level in argon at the Gran Sasso this Fall (Fig. 4). We believe the initial goals of the ICARUS R & D program have been met and this technology is now available for physics studies as listed in Table 1. Some results have also been reported in liquid Xenon[5,6].

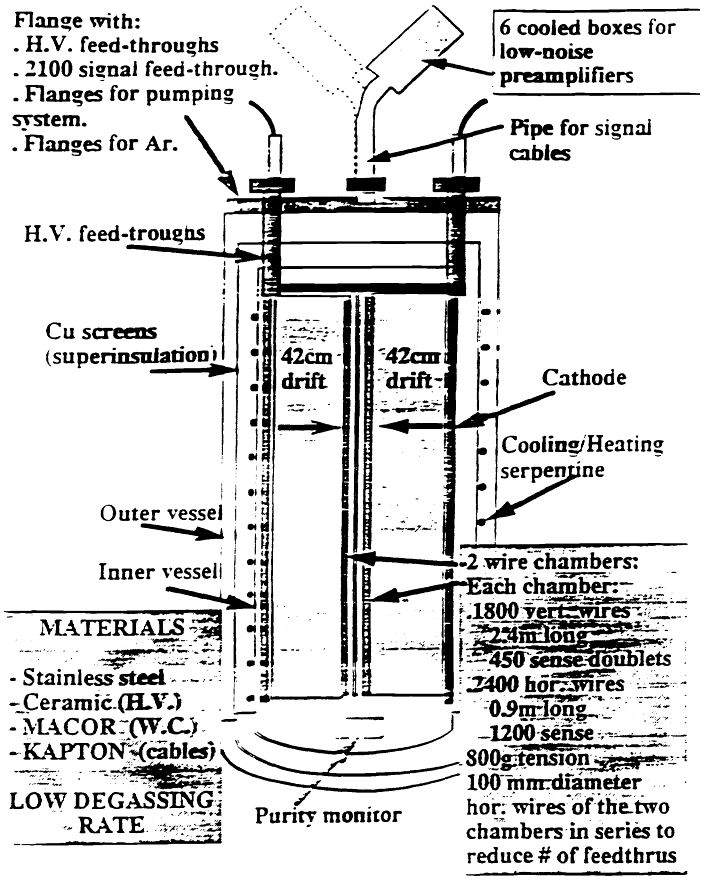

Fig. 2. The ICARUS Imaging R/O.

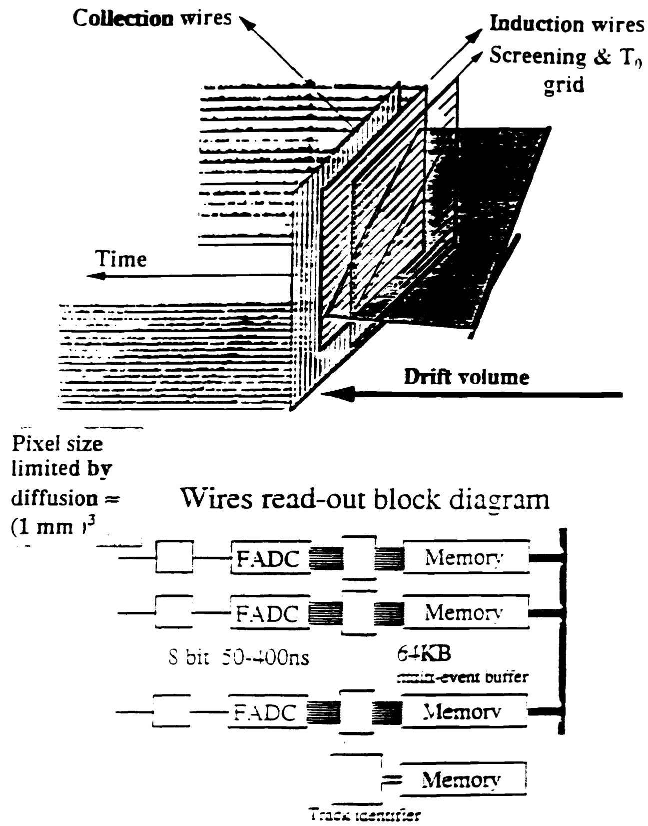

Fig. 1. The 3 Ton ICARUS Prototype.

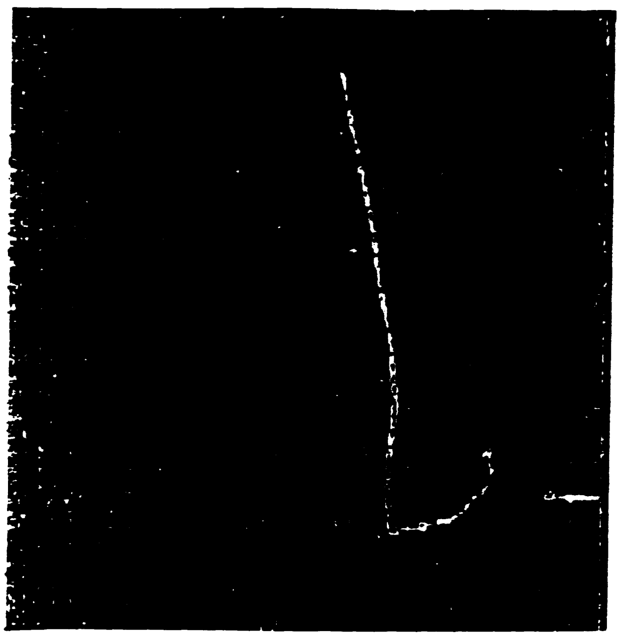

Fig. 3. Stopping μ in the ICARUS detector at CERN.

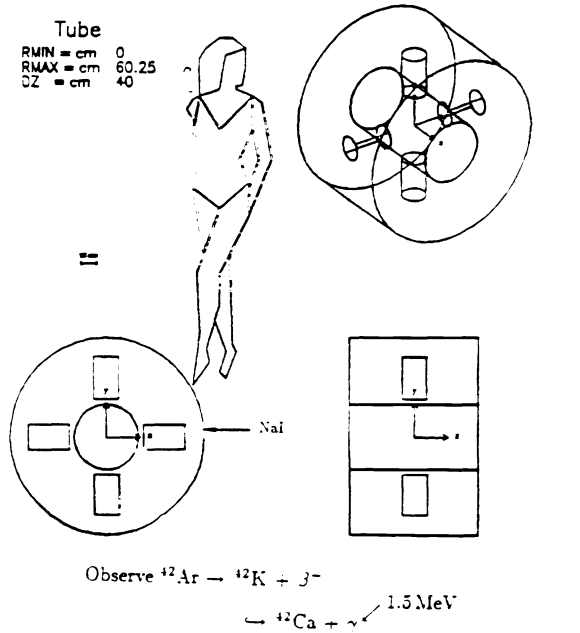

Fig. 4. ^{42}Ar Test Experiment (UCLA/L'Aquila/ Gran Sasso Exp.).

TABLE 1.

Physics Potential of Ultra Pure Liquid Drift Detectors Using Ar, Kr or Xe			
Energy Range	**Physics Study**	**Type of Detector**	**Size**
0.1 MeV	Massive WIMP Search	Liquid Xe with Ionization and Scintillation Detection	0.1 – 1 Ton
3 – 30 MeV	Double β Decay Solar Neutrino Study (ICARUS) γ Ray Telescope Neutrino Magnetic Moment	Liquid Ar or Xe (Kr too radioactive)	100 – 1000 Ton
100 – 1000 MeV	Atmospheric Neutrino Oscillation WIMPs in the Sun (ICARUS)	Ar	1000 – 10,000 Ton
1 GeV	Proton Decay ($p \rightarrow K^+\bar{\nu}$) (ICARUS)	Ar	1000 – 10,000 Ton
1 – 0.5 GeV	ϕ Factory Detector (Frascati, UCLA)	Ar or Kr (with Scintillation Light)	15 – 200 Ton
5 – 50 GeV	Search for $\nu_\mu \rightarrow \nu_\tau$ or $\nu_e \rightarrow \nu_\tau$	Ar	5 – 50 Ton

3. THE VLPC FOR SCINTILLATING FIBER TRACKING SYSTEMS

In order to use scintillating fibers for tracking in high energy high luminosity colliders, such as the SSC or LHC, a high quantum efficiency photon detector is required. Such a detector was invented by M. Petroff of Rockwell, Inc. and is being developed by a group that is being led by M. Atac. Much of the research is aimed for use in the SDC detector for the SSC. We now review the recent progress in this field.

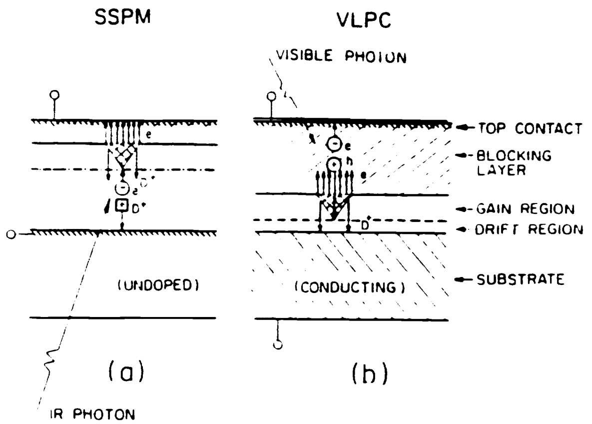

Fig. 5. Operation principles of the SSPM and VLPC are indicated.

The scintillating fiber tracking team in the SDC detector is listed in Ref. 7. A UCLA-Rockwell team is carrying out extensive studies at UCLA[8]. The idea of the VLPC is shown in Fig. 5[9]. In Fig. 6 we show the experimental arrangement for the UCLA-Rockwell tests. Fig. 7 shows the results of individual photon counting. This is the most efficient photon detector in the world. We believe this technology is now ready to be used in novel particle detectors, as well.

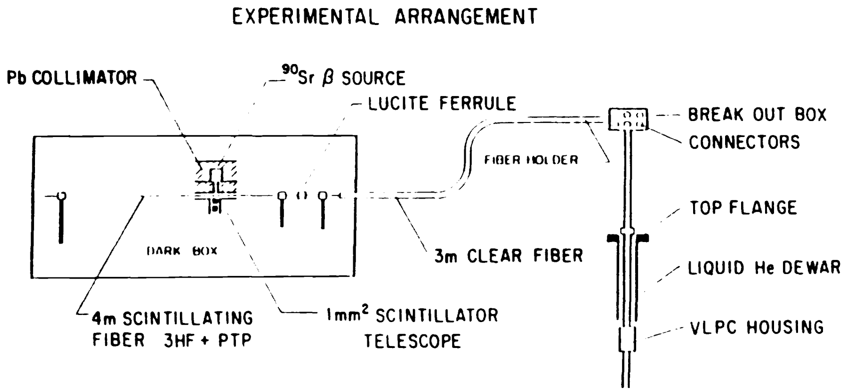

Fig. 6. Experimental arrangement for measuring detected photon by a VLPC using a 4 meter length of scintillating fiber of 0.8 mm core (3HF + PTP in polystyrene). The scintillating fiber is spliced to a 3 meter long optical clear fiber that carries the photons to the VLPC.

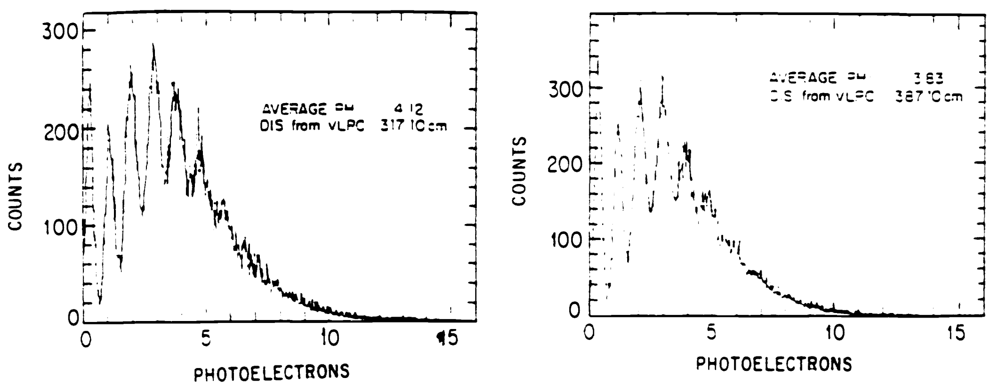

Fig. 7. Two samples of pulse height spectra obtained at the indicated sources positions. The weighted average number of detected photoelectrons.

4. A POSSIBLE DARK MATTER DETECTOR USING LIQUID XENON WITH AN EMBEDDED SCINTILLATING FIBER SYSTEM

The basic concept we propose is to attempt to detect individual recoiling Xe atom/nucleus created from the WIMP collision

$$W + Xe \rightarrow W + Xe \tag{1}$$

for the massive WIMPs. The concept is to use both ionization and scintillation light to identify the Xe recoil. The average energy given to the Xe is

$$\langle E\rangle = 2\,\mathrm{KeV}\ \frac{M_{\mathrm{Xe}}}{1\,\mathrm{GeV}} \left[\frac{M_{\mathrm{W}}}{M_{\mathrm{W}} + M_{\mathrm{Xe}}}\right]^2 \tag{2}$$

For $M_{\mathrm{W}} > M_{\mathrm{Xe}}$ $\langle E\rangle \rightarrow 270\,\mathrm{KeV}$.

Scintillation light from various particles has been recorded in Xe by T. Doke, et al[6]. Fig. 8 shows some of these results. Note that relativistic and non relativistic particles behave differently. We now propose a WIMP detector to record individual Xe recoil from massive WIMP interaction ($M > 250\,\mathrm{GeV}$). **The basic concept is to record ionization (and position) ICARUS style and to detect the Xe scintillation light using a large number of fibers in the liquid Xenon.** Detectors of $0.1 - 1$ Ton could result from this approach, allowing a definitive search for massive WIMPs. Fig. 9 shows a schematic view of such a detector. Tests are underway to put scintillating fibers in liquid argon at UCLA. These tests and further studies of ICARUS and the VLPC technology, as well as Monte Carlo simulations, will indicate the feasibility of this idea.

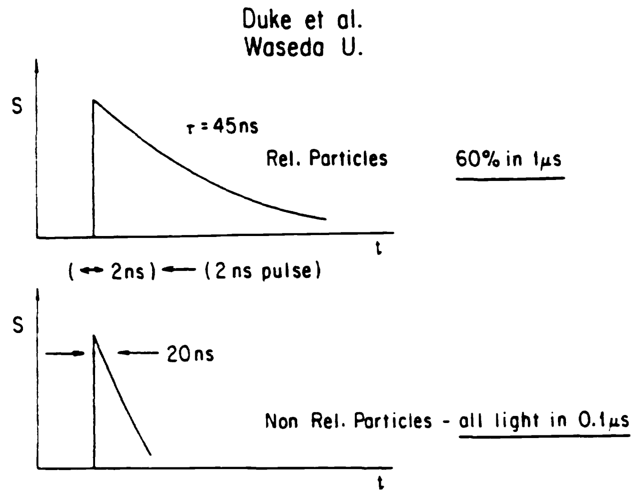

Fig. 8. Studies of Xe Scintillating Light (Waseda Univ.).

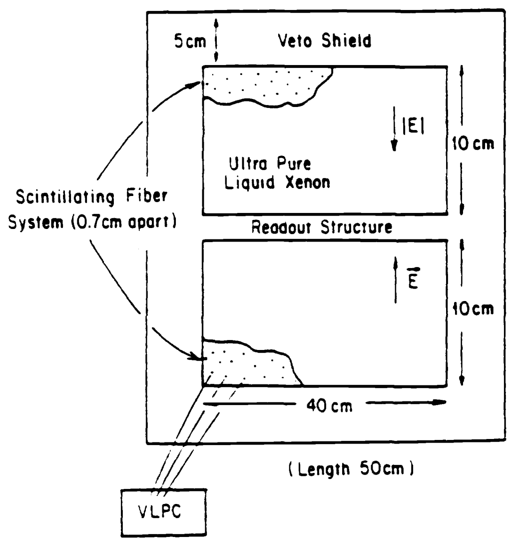

Fig. 9. Possible Massive WIMP Detector (0.1 Ton).

5. ACKNOWLEDGEMENTS

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