ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Nuovo Esperimento	Gruppo
WARP	2

Struttura
PAVIA

Ricercatore responsabile locale: E.Calligarich

Rappresentante Nazionale: C.Rubbia

Struttura di appartenenza: PAVIA

Posizione nell'I.N.F.N.: Inc.di ric.

PROGRAMMA DI RICERCA

A) INFORMAZIONI GENERALI

Linea di ricerca	ricerca di WIMPs - DARK MATTER
Laboratorio ove si raccolgono i dati	L.N.G.S.
Acceleratore usato	
Fascio (sigla e caratteristiche)	
Processo fisico studiato	interazione WIMPs - nuclei di Argon
Apparato strumentale utilizzato	TPC ad Argon liquido del tipo ICARUS attrezzata con PM's
Sezioni partecipanti all'esperimento	PV,PD,LNGS,L'AQUILA, LNF,MI
Istituzioni esterne all'Ente partecipanti	NCSR'DEMOCRITOS - Univ. of Ioannina - Univ.of Cyprus - CERN - IHEP PECHINO - UCLA - ETH Zurich
Durata esperimento	

B) SCALA DEI TEMPI: piano di svolgimento

PERIODO	ATTIVITA' PREVISTA
2001	messa a punto tecnologia di lettura ionizzazione nella transizione fase liquidagassosa e contemporanea lettura della luce di scintillazione. test del prototipo ICARUS da 30 lt su fascio monocromatico di neutroni per simulazione interazioni di WIMPs
2002	disegno e ingegnerizzazione rivelatore interno del 10 m3 (T14) e inizio allestimento rivelatore interno
2003	completamento allestimento rivelatore interno e inizio presa dati.
	2004 e seguenti presa dati

Mod. EN. 1

(a cura del rappresentante nazionale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Nuovo Esperimento	Gruppo
WARP	2

Struttura
PAVIA

PREVENTIVO LOCALE DI SPESA PER L'ANNO 2001

In ML

VOCI DI SPESA		DESCRIZIONE DELLA SPESA	IMPORTI Parziali	IMPORTI Totale Compet.	A cura della Comm.ne Scientifica Nazionale
Viaggi e missioni	Interno	contatti con collaboratori e meetings	8	8	
	Estero	contatti con collaboratori e meetings test con fascio monocromatico di neutroni	10 25	35	
Materiale Consumo		LAr e LN2 per test criogenici aggiornamento TPC da 30 lt	20 20	40	
Trasp.e facch.					
Spese Calcolo		Consorzio / Ore CPU / Spazio Disco / Cassette / Altro			
Affitti e manutenz. apparecchiat.					
Materiale Inventariabile		dewar per TCP da 30 lt strumentazione criogenica	15 25	40	
Costruzione Apparati					
			Totale	123	

Note:

Mod. EN. 2 (a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Nuovo Esperimento	Gruppo
WARP	2

Struttura
PAVIA

PREVISIONE DI SPESA: PIANO FINANZIARIO LOCALE

PER GLI ANNI DELLA DURATA DEL PROGETTO

In ML

ANNI FINANZIARI	Miss. interno	Miss. estero	Mater. di cons.	Trasp.e Facch.	Spese Calcolo	Affitti e manut. appar.	Mat. inventar.	Costruz. apparati	TOTALE Competenza
2001	8	35	40				40		**123**
2002	10	10	20					300	**340**
2003	10	10	10					70	**100**
2004	15	8							**23**
TOTALI	**43**	**63**	**70**				**40**	**370**	**586**

Note:

Osservazioni del Direttore della Struttura in merito alla disponibilità di personale e di attrezzature:

proposta preliminare
Normale assistenza dei Servizi Tecnici

Mod. EN. 3

(a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Nuovo Esperimento	Gruppo
WARP	2

Struttura
PAVIA

PREVISIONE DI SPESA

Piano finanziario globale di spesa

In ML

ANNI FINANZIARI	Miss. interno	Miss. estero	Materiale di cons.	Trasp.e Facch.	Spese Calcolo	Affitti e manut. appar.	Mat. inventar.	Costruz. apparati	TOTALE Competenza
2001	20	60	60				50		**190**
2002	20	20	30					400	**470**
2003	25	20	100					100	**245**
2004	30	15	200						**245**
TOTALI	**95**	**115**	**390**				**50**	**500**	**1150**

Note:

Mod. EN. 4

(a cura del rappresentante nazionale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Nuovo Esperimento	Gruppo
WARP	2

Struttura
PAVIA

PROPOSTA DI NUOVO ESPERIMENTO

VEDI LETTER OF INTENT ALLEGATA

A PROGRAMME TO SEARCH FOR WIMP PARTICLES IN LIQUID ARGON AT THE LNGS

WARP (***W****imp***AR***gon***P***rogramme*)

LETTER OF INTENT

ICARUS COLLABORATION

and

G.Fanourakis and S.Tzamarias,
Inst. of Nuclear Physics, NCSR “Democritos”, Greece

P.Assimakopoulos, I.Papadopoulos, P.Pavlopoulos and V.Vlachoudis,
Univ. of Ioannina, Greece

P.Razis and A.Vorvolakos,
Univ. of Cyprus, Cyprus

and

Additional people & Institutes:

July 1, 1999

TABLE OF CONTENTS.

1.—FROM ICARUS TO WARP.

The ICARUS Collaboration has been working for more than ten years on the development of a large cryogenic detector based on liquid Argon. In such a detector, ionisation electrons are used to create an "image" of the event; scintillation light may be used to trigger the event. The Collaboration has realised a series of several modules of different sizes in which all the basic features of ionisation, long electron drift and scintillation in liquid Argon and Xenon have been systematically studied for a variety of incident particles. At present, an industrial module with 14 tons of ultra-pure Argon (T14) is operational in Pavia (Figure 1) and it will be transported to LNGS the next Fall. An even larger module, called T600, with about 600 ton of Argon, is under construction in Pavia and it should become operational by the year 2000. The T600 module will be finally installed in the Hall C of LNGS to study cosmic ray neutrinos and solar neutrino events.

The proposed programme for a WIMP search, which we would like to call **WARP** (***W****imp***AR***gon***P***rogramme*) is a natural spin-off of such an extensive programme. In particular the module T14 (when no longer used for the ICARUS programme) can be outfitted as to become the basis of a WIMP search experiment, coupling an unusually large sensitive mass (≈ 1 ton of fiducial mass surrounded by ≈ 13 ton of an active anti-coincidence shield) to a very effective background rejection. The initial investments on the Cryogenics and Argon purification have already been made and all the basic "know-how" exists within the ICARUS Collaboration on the detection technology. The main fallout's of the R&D work already performed by the ICARUS Collaboration and relevant to the WARP programme are briefly recalled:

(1) Since 1993, a new method has been perfected [1] (P. Benetti et al.) in order to separate heavy ionising ion recoils (from WIMP) from lightly ionising tracks (from background radioactivity) produced by electrons in a ultra-pure, noble element (Xenon or Argon). This method is based on the simultaneous measurement of ionisation and direct scintillation light from the noble element in the liquid form. While minimum ionising particles produce roughly the same number of ionisation electrons and scintillation photons, in the case of heavy recoils, while scintillation persists, — though at somewhat lower level — ionisation is strongly suppressed by columnar recombination. *Therefore recoil events will be characterised by scintillation with essentially no associated primary ionisation*.

(2) The scintillation light from noble gases has been extensively studied and in particular an absorption length in excess of 1.5 m has been measured in Argon, either pure or slightly doped with Xenon to shift the light to a longer wavelength (175 nm).

(3) Ionisation electrons have been actually extracted from liquid into gas with the help of an appropriate electric field (≥ 1 kVolt/cm) and multiplied in the gas by a wire. In this way, even a

few electrons, produced in the liquid, once extracted in the gas, they can be detected unambiguously. In particular the luminescence light produced by the electron multiplication process near the wire is detected with scintillation as additional light, but arriving after a delay because of the drift time in the liquid and in the gas. *The single versus the double pulse signature recorded by the PM's constitute the signature for a WIMP.*

(4) A primary background to WIMP's detection are neutrons which induce nuclear recoils in the fiducial volume, thus effectively acting as "strongly interacting WIMPS". The neutron background in Hall C has been carefully measured by the ICARUS Collaboration [2], on which direct estimates can be made. As we shall see, this background can be mastered with an appropriate layout.

(5) Materials used for the construction of the T14 have been carefully chosen in order to minimise natural radioactivity. The Aluminium of the container has a measured radio-activity of less than 1 Bq/kg and similar limits have been measured for the NOMEX thermal insulation. The target material is ultra-pure Argon and the fractional content of additional (radio-active) impurities is expected to be very small. Notwithstanding, though expected to be low, the actual activity of the ultra pure Argon used for the experiment has to be directly measured. This is an important step in the WARP proposed programme.

(6) Hypothetical WIMP events can be closely simulated by neutron scattering. This is a useful feature since the WIMP signature and corresponding detection efficiency can be carefully studied with such artificial events. The ICARUS Collaboration has performed measurements both with a neutron source and with neutrons from an accelerator in Legnaro, using a small Xenon counter, in which both ionisation and scintillation have been detected in the energy domain appropriate to a WIMP signal. *However such a measurement must be further extended to Argon and to the actual geometry of a more massive detector.* It will be an integral part of the WARP proposal. The possibility of an appropriate neutron source "on-line" during the WIMP search in LNGS is also considered.

(7) The search for the WIMP, which interacts only weakly with ordinary matter, requires a substantial fiducial mass. The ICARUS Collaboration has developed, in collaboration with industry, the technology for massive, cryogenic Argon detectors. *A mass of several tons constitutes therefore for us no significant technological barrier and it can be achieved at reasonable cost.* In particular, the test module T14 m, once it has fulfilled its initial motivations related to the ICARUS programme, can constitute a valid building block for a WIMP detector of an adequate mass. Basic cryogenic facilities will soon exist at the LNGS and whatever necessary to operate the WARP experiment can be parasitically attached to the T600 programme.

To conclude, we believe that the ICARUS Collaboration, enlarged with additional physicists with similar scientific interests and experience, is ideally poised for an extension of their long and elaborate R&D programmes to the fundamental task of searching for a possible source of the fascinating problem of the non-baryonic Dark Matter in the Universe.

Incidentally, we would like also to point out that the method (1) of separating γ/e from nuclear recoils could constitute a valid method to measure simultaneously γ (by total absorption) and neutrons (by elastic recoils and TOF with respect to the γ's) in a complex detector, for instance in association with cross section determination in nuclear physics, like for instance the now approved TOF programme at CERN.

Figure 1. *Picture of T14 in the Hall in Pavia.*

2.—PHYSICS CONSIDERATIONS.

WIMPS are hypothetical, very long lived or stable particles in equilibrium at the early stages of the Universe from which they have de-coupled at an early freezing out temperature. They are expected to have an annihilation cross section of the order of $\left\langle \sigma_{anh} v \right\rangle \approx 10^{-26} / \Omega_W h^2 \;\; cm^3 s^{-1}$. The cross section on ordinary matter is typical of weak interactions. Their expected flux is $\Phi \approx 10^7 \left(1 \;\; GeV / M_{wimp}\right)$ cm^{-2} s^{-1}, corresponding to an energy density of the order of $0.2 \;\; GeV/cm^3 < \rho < 0.6 \;\; GeV/cm^3$. WIMPS form a dissipation-less gas trapped in the

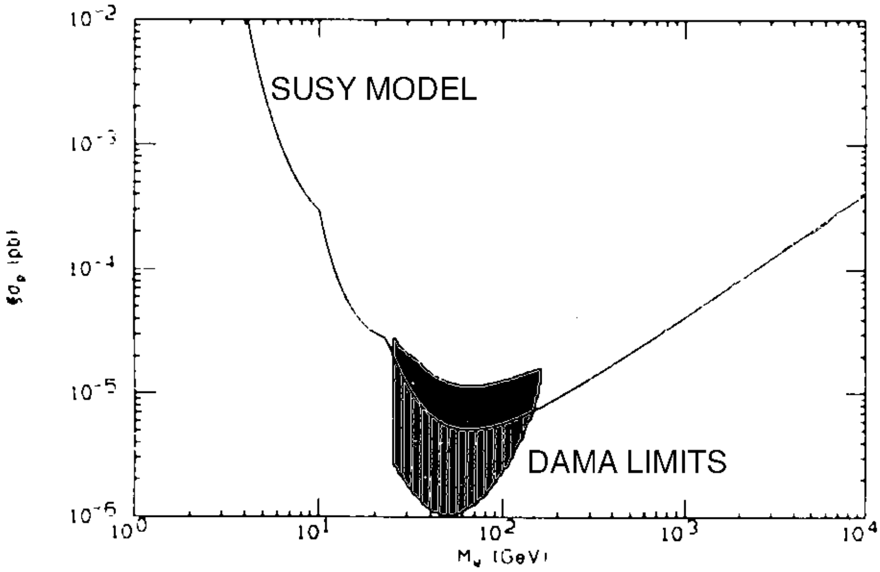

Figure 2. *Cross section versus WIMPS mass according to DAMA [3]: the region allowed at 90% C. L. is shown, superimposed to a theoretical model for neutralino candidate.*

gravitational field of the Galaxy with an approximate maxwellian distribution and a typical speed of the order of $\approx 10^{-3}c$. The most favoured candidate for these particles, which should be the main contributors to the non-baryonic Dark Matter are the lightest SUSY particle and in particular the neutralino.

An enormous scientific effort is being made with Colliders (LEP, Tevatron, LHC, etc.) in order to discover SUSY particles with masses of up to several hundred GeV[1]. If such SUSY particles indeed exist, they must have been produced as well at the time of the Big Bang. In this eventuality, *the presence today as some form of cosmic WIMPS seems to us as extremely likely* since their lowest mass state should be (1) stable by R-conservation[2] and (2) only weakly interacting with ordinary matter. One of the main hopes of SUSY is the one of be the key to the Dark matter problem: this cannot be achieved unless WIMPS exist. *Therefore the a priori chance of detecting SUSY at the LNGS first should not be underestimated.* We remark that the underground searches are less dependent on the actual WIMPS mass, (provided smaller than a few TeV). Mass values which are hard or impossible to reach with Colliders, may still give a significant signal in cosmic detectors, provided of sufficient sensitivity. We also remark that SUSY is only one of the many candidates for WIMPS: other kinds of massive relic particles may exist, which may have weak-like interaction properties and therefore detectable by our method.

The detection of a WIMPS in the >> 1 GeV mass range is related to potential scattering and recoils of target nuclei, typically of the order 1 ÷ 100 KeV. The size of the WIMPS signal is therefore quite elusive. In addition, the very small interaction cross section makes WIMP-nucleus

---

[1] The present upper limit to the lightest neutralino given by LEP is only of the order of 15 GeV/c^2.

[2] The existence of neutrino oscillations may hint at an R-violation, which however could be mild enough as to ensure the survival of the WIMPS particles of SUSY.

scattering a very rare event. Such a rate is not easily predicted, since it depends on many variables which are poorly defined, like for instance the halo model, the nature of the WIMPS (cross section), their survival probability from the Big Bang related to R-violation, the features of the nuclear target (atomic number, spin, form factors) and the type of detector used (energy threshold, resolution, signal discrimination). In practice, these uncertainties may encompass many orders of magnitude. Any new experiment must therefore reach a sensitivity which is several orders of magnitudes higher than the most naïve predictions of SUSY. And in order to reach such a goal, both sensitive mass and background discrimination should be as large as possible.

A recent claim for a positive effect[3] has been put forward by the DAMA experiment [3] which, based on an exposure of 19511 kg day of NaI has given the result $M_{wimp} = 59^{+17}_{-14} GeV/c^2$ and a scattering cross section $\sigma\xi_p = 7^{+0.4}_{-1.2}\ 10^{-6}\ \ pb$, based on the yearly variation of the rate for the WIMP signal due to the velocity changes of the Earth's motion with respect to the Galaxy. The parameter ξ_o is a measure of the WIMP mass density, $\xi_o = \rho_{WIMP} / \left(0.3\ \ GeV\ \ cm^{-3}\right)$. The seasonal change of recoil events as a function of the recoil energy, has been given in terms of counts for 1 keV bin and for kilogram of target. The integrated rate in the interval 2 ÷ 12 keV, over which the seasonal variation is expected to be significant, is claimed to be as large as 0.374 c/day/kg. Note also that the seasonal variation is only a few percent of the main signal, depending on the speed distribution of the WIMPS. *The time averaged event rate should therefore be of the order of several counts/day/kg.*

One of the many theoretical predictions [4] of minimal SUSY is shown in Figure 2. It is in good agreement with the level of sensitivity of the DAMA experiment [3].

The DAMA result is tentative and it should be taken conservatively as the possible level or as an upper limit for the kind of signal to be searched for. The DAMA analysis indicates that future detectors should have both a substantially larger mass and a better rejection of local background.

We consider here a sensitive mass of the order of 1 ton, i.e. about 10 times the mass of the NaI of DAMA. In our case the target will be pure Argon. If the mass of the WIMPS is actually the value given by the DAMA result, the choice of Argon, for instance compared to Xenon or Iodine, is optimal, since it is well known that the largest energy recoils are produced when the mass of the WIMP and of the recoiling nucleus are equal. In addition, a low A nucleus has a more favourable elastic form factor, since the nuclear radius, proportional to $A^{1/3}$, is smaller and $T_{rec} = q^2 / 2M_{target}$.

---

[3] The CDMS experiment has now nearly eliminated the region (< 1event/kg/d) with 35 days of data. They have 100 days more to analyse. In addition the DAMA results seem inconsistent with SUSY-GUT and the current limit on proton decay $p \to K + \nu_\mu$.

3.—THE METHOD OF DETECTION.

The recoil spectrum, dn/dT_{rec} has been calculated with a Montecarlo method, starting from a Maxwellian distribution of WIMPS galactic particles scattering on Argon, Iodine and Sodium. The result is shown in Figure 3 and, as expected, it is the hardest for Argon. For Argon and T_{rec} >10 keV, it has a roughly exponential fallout of the form: $dn/dT_{rec} = A\exp(-T_{rec}/15.5\ keV)$. Note that the seasonal variation changes sign for very small and very large recoil energies, with a null point at about 12 keV. At larger recoil energies, the seasonal effect is re-established, but with the opposite sign. The parameters used in the simulation are listed in Table 1.

Table 1. *List of parameters used for calculating WIMP spectra.*

Parameter	***value***	
WIMP velocity distribution	Maxwell + escape	
Characteristic velocity	220	km/s
Escape velocity	580	km/s
Earth velocity (respect to galaxy)	245	km/s
WIMP local density	0.3	GeV/cm^3

The main problem associated with the WIMPS search by recoil detection, as evidenced for instance by the DAMA result, is the presence of substantial local backgrounds in the energy range relevant for recoils (1÷100 keV). This background can be generally classified as spurious events with energy losses due either to

(1) *electron recoils,* due to γ or β emission or to

(2) *nuclear recoils*, where the target nucleus recoils after a scattering with a (neutral) particle

The best detector is the one which provides the highest rejection against (1) with a good efficiency for (2). Ideally, the detector should be able to detect both (i) the presence of an unambiguous recoil signal above background with the expected features and (ii) its much smaller seasonal variation.

Several of the first generation detectors, which rely only on the seasonal variation, including DAMA, make no distinction between electron and nuclear tracks and therefore both backgrounds must be minimal. More advanced detectors use a variety of methods to discriminate on energy losses (2) against (1), but with a variable degree of potential success. The main problem associated to classic methods of identifying ionisation density from scintillation light (either by pulse shape or the difference in spectrum of the emitted light) is the very small number of collected photoelectrons. Therefore, in these methods, the rejection power against events of type (1) vs. events of type (2) is plagued by statistical fluctuations, which are important in view of the small energy of the recoils. Other methods, like for instance cryogenic detectors, cannot be easily constructed with a sufficiently large mass (see however the CUORE Proposal).

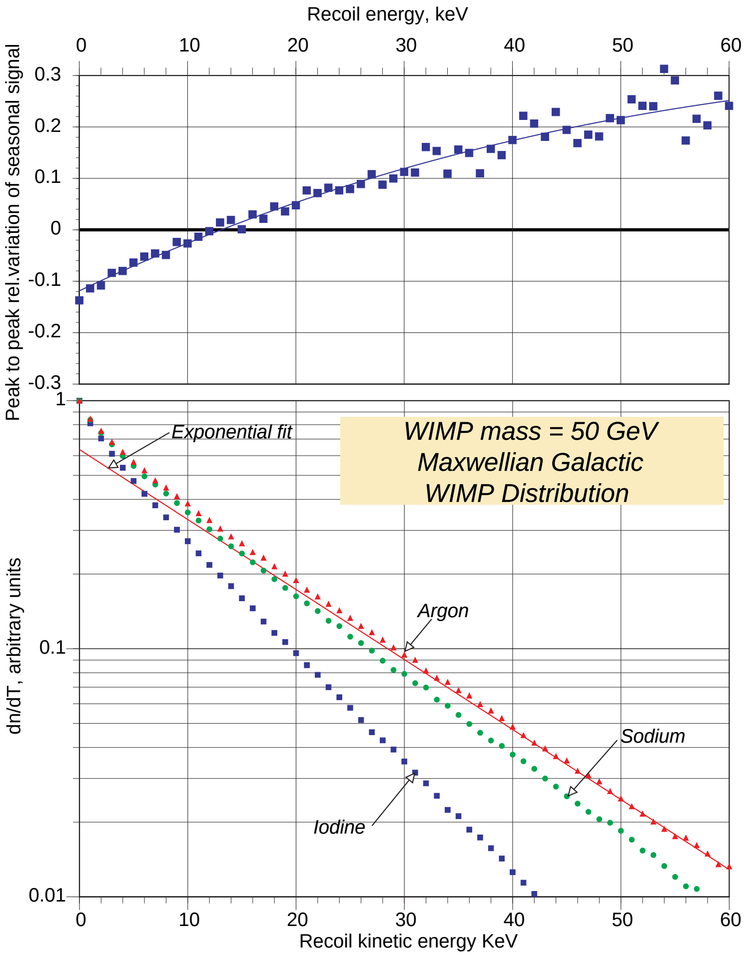

Figure 3. *Montecarlo prediction for WIMPS recoil spectrum in three different target elements. The WIMPS kinematical model is based on a truncated Maxwellian distribution in the galactic rest frame with a characteristic velocity of 220 km/s. For other parameters, see Table 1.*

As already pointed out, the ICARUS collaboration has developed since many years [1] an almost perfect method of discriminating (2) from (1) based on the simultaneous detection of the scintillation and ionisation from liquid Xenon or Argon. While scintillation has been shown to be substantial even for very heavy ionising recoils of a few keV *[5], the very strong columnar recombination essentially cancels the ionisation signal.* In the case of events of type (1), about the same amount of photons and electrons are emitted. In contrast with other methods based on light frequency differences or pulse discriminations, the practically total absence of ionisation accompanying events (2) is a powerful and highly efficient veto in suppressing entirely the background (1), mostly due to radioactivity.

Even if the e/γ background would be completely eliminated, nuclear recoil signal of type (2) can be simulated by an elastic neutron scattering, the neutron behaving effectively as a “strongly

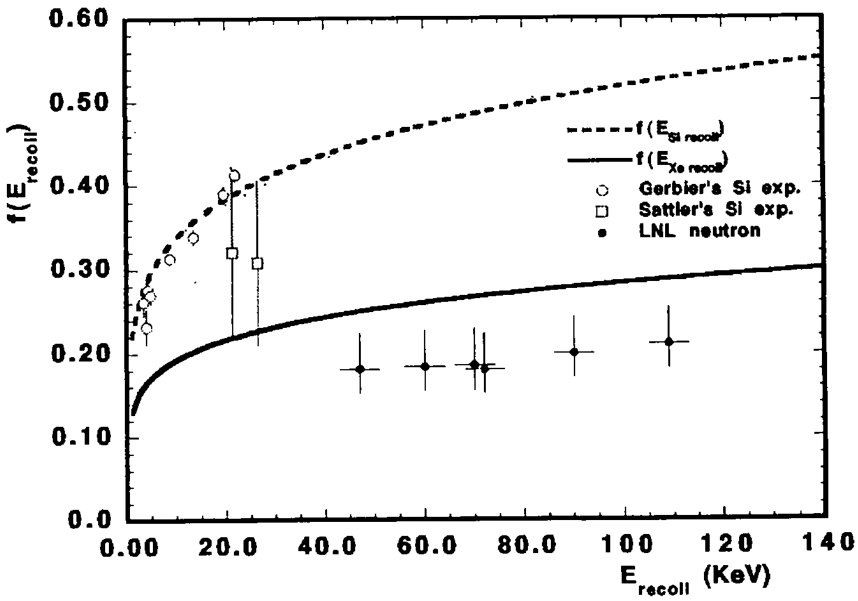

Figure 4. *Relative scintillation efficiency in liquid Xenon as a function of the Xenon recoil energy. Full circles are ICARUS data [5], open circles and squares are data points on Silicon from ref. [6] and [7] respectively. The curve represents the theory of Lindhard et al [8] for Xenon and Silicon respectively.*

interacting WIMP". The ICARUS Collaboration has carefully measured the neutron background in Hall C and this potential background can be estimated in the case of WARP. Neutrons are strongly rejected by an active shielding volume surrounding the detection volume. Neutrons recoiling both in the sensitive volume and in the anti-coincidence shield are identified and rejected.

Finally some background may be produced by α-particles produced for instance by residual natural radio-activity and for which a substantial ionisation suppression has been observed, though not as strong as in the case of ion recoils. These events however correspond to much higher energies and should generally fall outside the window of detection of the WIMPS.

An effective background elimination should permit to search for evidence of the main WIMPS signal, rather than relying only on its relatively modest time variation. For instance with the DAMA predicted flux and 1 ton detector the bare WIMPS signal should be of the order of several thousand counts/day before detection cuts and it could hardly be missed !

The elastic scattering of a WIMP produces a moving Argon recoil which produces both ionisation and atomic de-excitation (scintillation light). The scintillation yield has been measured by the ICARUS Collaboration[5] both for electrons and ion recoils from elastic neutron scattering in Xenon. Neutrons were produced by a source and by an accelerator (Legnaro). It turns out that the amount of light emitted by a heavy ion is about 20% of the one of an electron with the same initial kinetic energy (Figure 4).

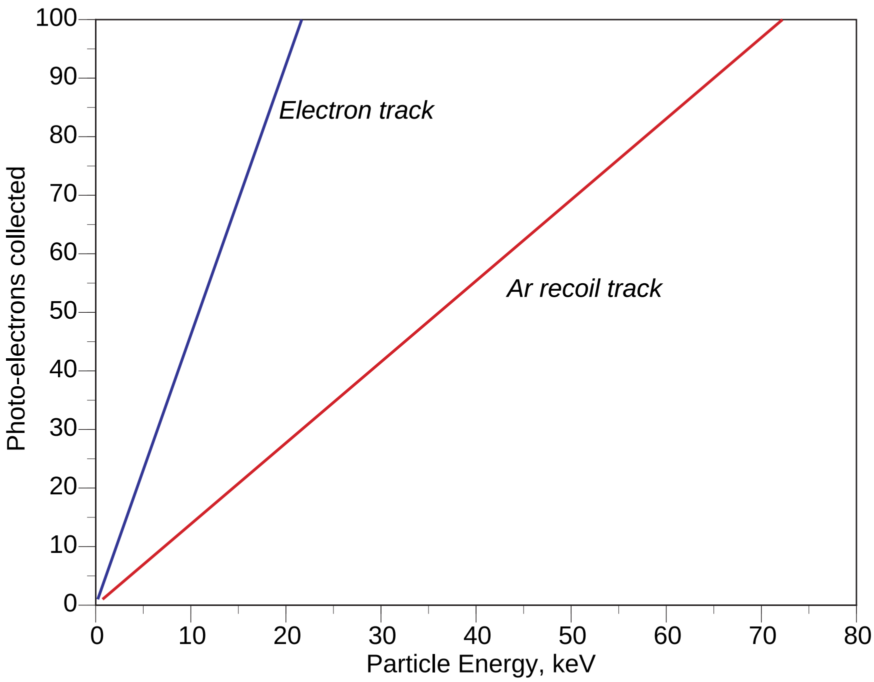

Figure 5. *Expected number of collected scintillation photo-electrons for a γ/e background event and a Argon recoil from WIMP as a function of the initial particle energy.*

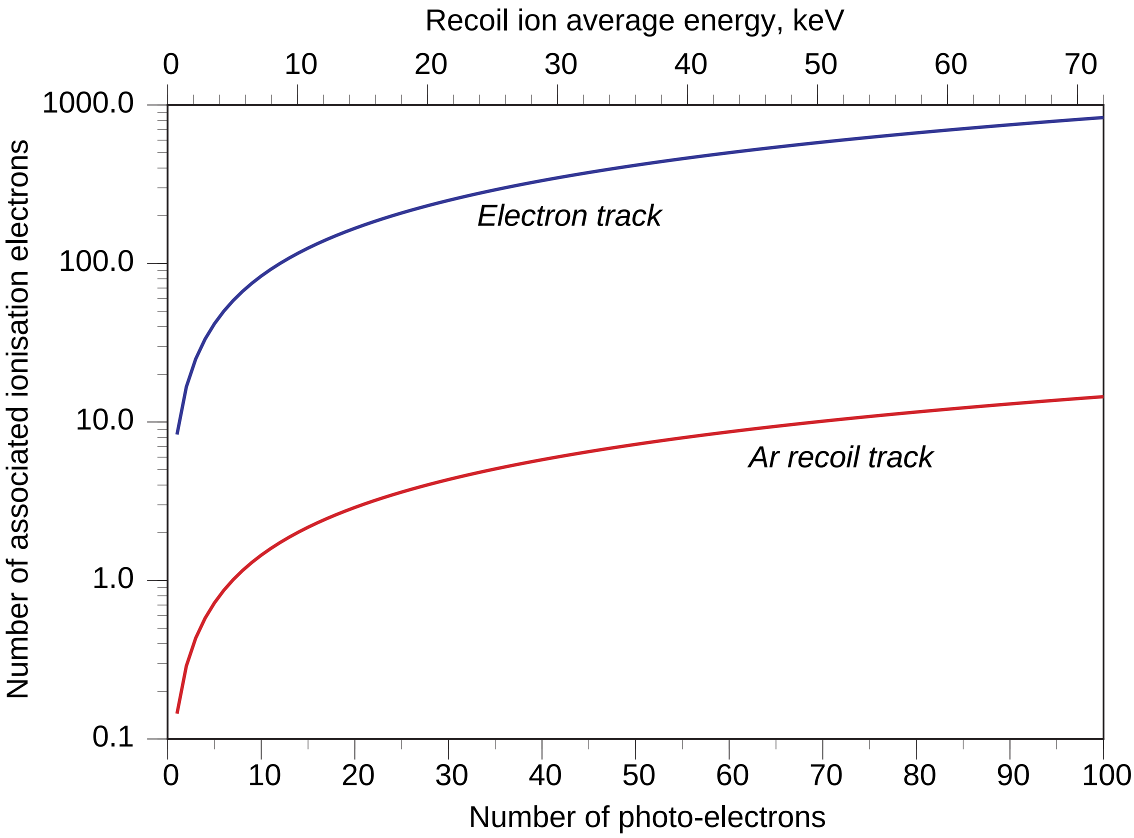

Figure 6. *Calculated number of associated ionisation electrons as a function of the number of scintillation photo-electrons collected in Argon for recoil tracks and for (background) γ/e events with the same average scintillation light collected.*

This result, in agreement with the Lindhard theory [8], could be reasonably extrapolated to an estimated value of order 0.25 for liquid Argon, since it is expected to improve for lighter ions. However as a part of the WARP programme, we intend to repeat this measurement directly with Argon in the near future.

The direct ionisation of recoiling ions was too small to be directly measured in the previously mentioned test. However, based on data existing in the literature, we can estimate a ionisation yield of the order of 1 electron for each 5 keV of ion energy lost[4]. Also this figure will be measured in the near future with the help of neutron scattering.

We assume at this point and for indicative purposes a scintillation light collection efficiency for the detector of 0.6 and a photo-cathode efficiency of 0.2. These figures have to be verified by more precise tests. The resulting number of photoelectrons collected as a function of the energy for an ionising electron and Argon recoil are shown in Figure 5. For an average recoil energy of 15 keV we expect to collect as many as 20 photoelectrons. The detection recoil threshold, if set to 3 photoelectrons, corresponds to a kinetic energy of about 2.5 keV.

For Argon recoils, the primary ionisation signal is strongly depressed. In Figure 6 we show the number of collected ionisation electrons for a γ/e event and an Argon recoil as a function of the number of photo-electrons of the scintillation signal. It is evident that the discrimination is complete even at the lowest number of collected photo-electrons. For instance at the average recoil energy of 15 keV, corresponding to an average of about 20 collected scintillation photoelectrons, in the case of a good recoil event we expect on average 2.9 ionisation electrons, while an equivalent background event, due to an electron of 4 keV, will be associated with as many as 165 ionisation electrons. It is evident that Poisson statistics considerations if applied literally will give in all instances an immense rejection factor, probably masked by instrumental effects, like dead times, geometrical factors and so on. It is clear that the ultimate separation will have to be measured experimentally, though it is expected to be extremely good. In the rest of the paper we assume an indicative rejection power of 10^4.

[4] This precise number, as long as it is very small, is not critical to the estimate of the separation.

4.—DETECTOR LAYOUT.

The ICARUS test module T14 which as been used to test the cryogenics of the ICARUS detector offers an interesting possibility for a WIMPS detector. The internal, cold dimensions of the dewar are 3.89 m height and 2.58 x 1.0 m^2 cross section, corresponding to a gross volume of 10.26 m^3 or about 14 tons of ultra high purity liquid Argon, if fully filled. The Argon is likely to be doped with a few % of Xenon in order to wave-shift the scintillation light. The volume (see Figure 7) can be ideally divided into two separate parts, a *central detection region* surrounded by the rest of the liquid as an *anti-coincidence shield*.

(1) The *central part* is equipped both with (1) photo-tubes to detect the WIMPS recoils and with (2) a charge collecting drift field, followed by a transfer to gas and wire multiplication to detect (in anti-coincidence). A gas pocket is maintained at the top of the central detecting region. The drift field and the wire multiplication is used to separate signals of type (1), namely electron ionisation from the (good) events of type (2) due to the potential WIMPS signal. The structure used to define and support such a structure should be as thin as possible and made of low activity materials.

(2) The *anti-coincidence volume* is simply seen by an adequate number of photo-tubes and it rejects the events due to neutrons or other particles penetrating from outside or travelling out from the central part. As already pointed out only events in which no signal is recorded by this component are potential candidates for the signal. Evidently the central part and the anti-coincidence volume must be optically separate in order to avoid cross-talk.

(3) The neutron simulated background is mainly due to elastic scattering on Argon nuclei. The maximum energy lost $\Delta T = T_{in} - T_{out}$ by a neutron of kinetic energy T_{in} in a head-on collision to a nucleus of atomic number A ≈ 40 is determined by the relation $T_{in} / T_{out} = (A-1)^2 / (A+1)^2$ = 1 – 0.095, namely the maximum recoil has about 9.5%of the incoming neutron energy. Therefore for a detection threshold of say, 10 keV, the minimum energy of the background neutrons is 105 keV. Therefore it is advantageous to add an *external neutron shield* to adsorb or at least to thermalise the environmental neutron background. A specific design for such a shield has already been carried out by the ICARUS Collaboration and it must surround the whole cryostat.

The design of the detector is relatively straightforward and it does not need to be further detailed at this stage, except for the requirement of extracting electrons from liquid Argon into gas. As already pointed out, this is already current practice in the ICARUS Collaboration for liquid Xenon.

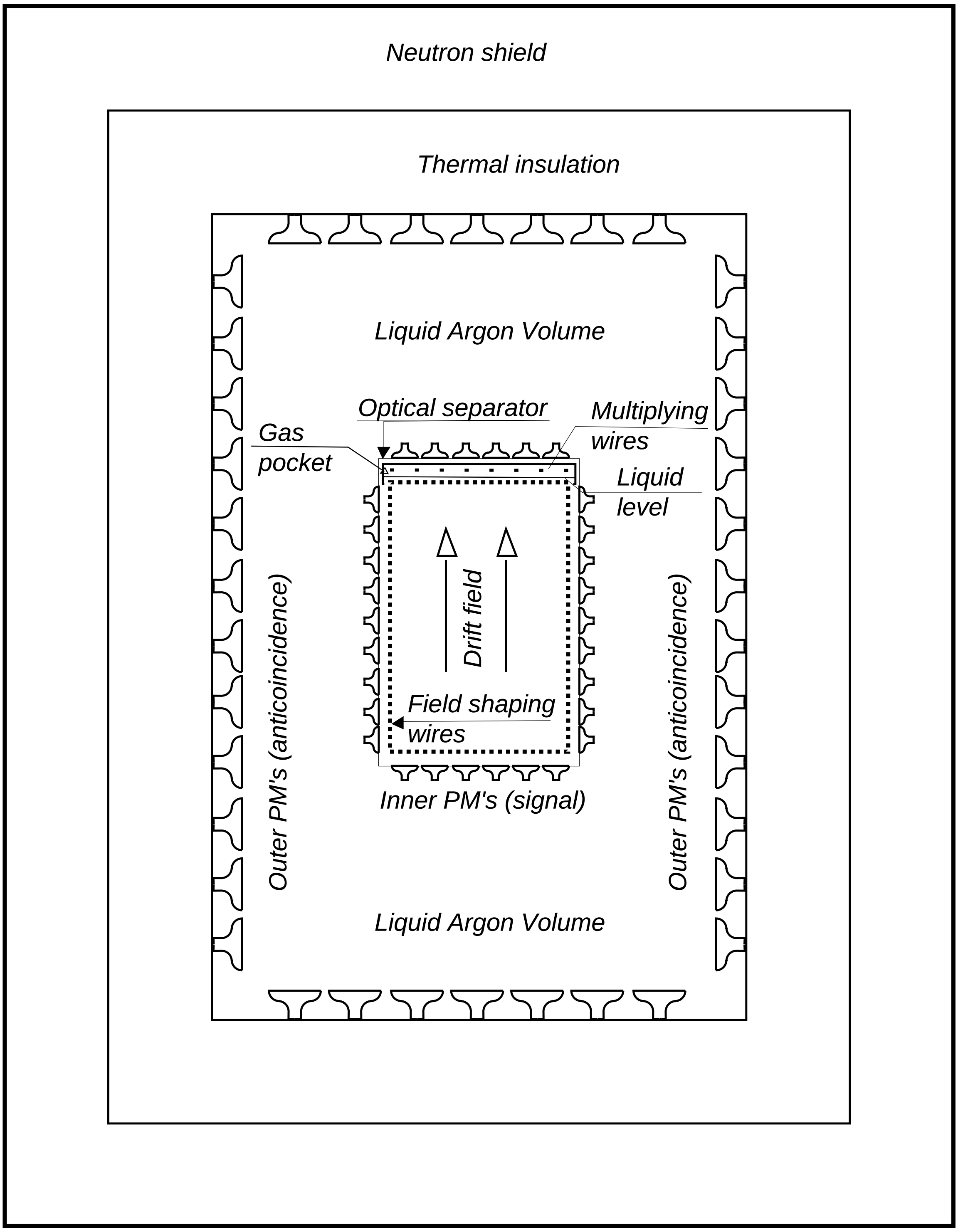

Figure 7. *Conceptual layout of the WIMPS detector housed in the 10 m3 ICARUS Test Module T14. The Liquid Argon volume is divided in two region, the target (central part) with both ionisation and scintillation detection and the outer anti-coincidence volume in which only scintillation is recorded. The whole module is surrounded by an neutron shield, mad of water, which absorbs and degrades the energy of the neutrons below recoil energy threshold in the central region. The multiplication of the ionisation signal is performed inside a gas pocket, dynamically stabilised by a feed-back loop operating on the gas pressure in order to maintain the level of the liquid constant in the pocket.*

The extraction of electrons both from liquid Argon and liquid Xenon is extensively reported in the literature [9], following the original work of Dolgoshein [10] in 1973. This extraction process depends from an emission coefficient, function of the temperature and local electric field. Classically, this is related to the work required to extract a negative charge from a dielectric material. In the case of liquid Argon and Xenon, this potential barrier is large compared to the electron temperature kT. Hence the spontaneous rate of emission is very small. However an applied, local accelerating electric field is capable of increasing the electron temperature to a sufficient level as to permit the quick extraction[5] of the electrons. The emission probability as a function of the locally applied electric field is shown in Figure 8, taken from ref. [9].

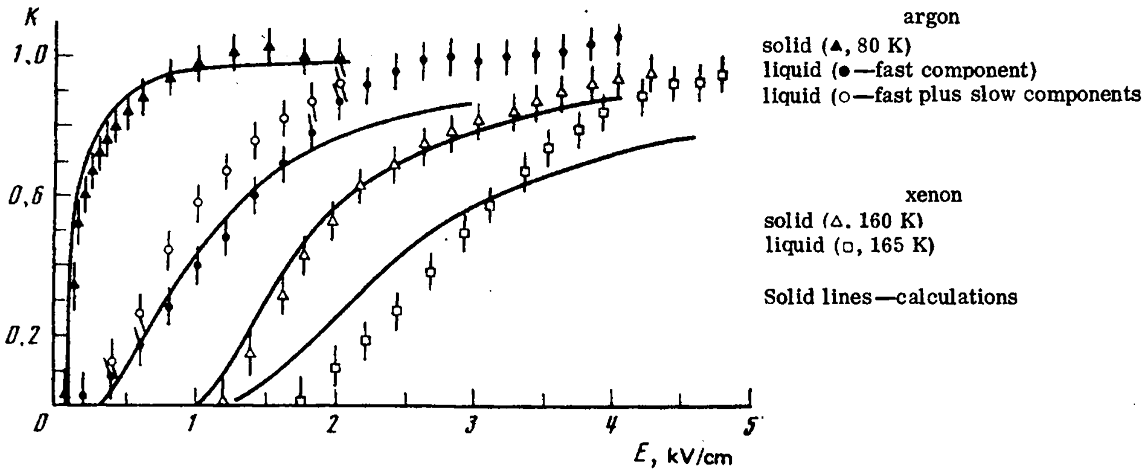

Figure 8. *Dependence of the coefficient of electron emission from solid and liquid Argon and Xenon (from ref. [9])*

It is apparent that extraction of electron from Argon is substantially complete already at values of the field of 3 ÷ 5 kV/cm. At sufficiently high field values the fast component is dominant. Therefore a grid must be inserted, still in the liquid phase, before the transition to the gas, in order to increase the field in the last bit of liquid and also in the gas region to this required value, to ensure that the role of the “heater” is assumed by the increased electric field. The higher field in the gas region is useful in the subsequent multiplication of the electrons, once extracted.

Ion recoils, though at a rate far smaller than electrons, produce also a few ionisation electrons. The exact number is known in Xenon and it must be measured in Argon as a part of the WARP programme. In view of the lighter mass of Argon ions when compared to Xenon, it is likely that the yield may be a bit larger, thus permitting a rough localisation of the recoil event by the drift time and the location of the multiplying cascade along the wire. Therefore the read-out in the gas phase could be made with an orthogonal arrangement of multiplying wires and read-out pads.

---

[5] An estimate [] of the emission time has shown that in suitable conditions, the electron remains in the interface not more than 0.1 µs.

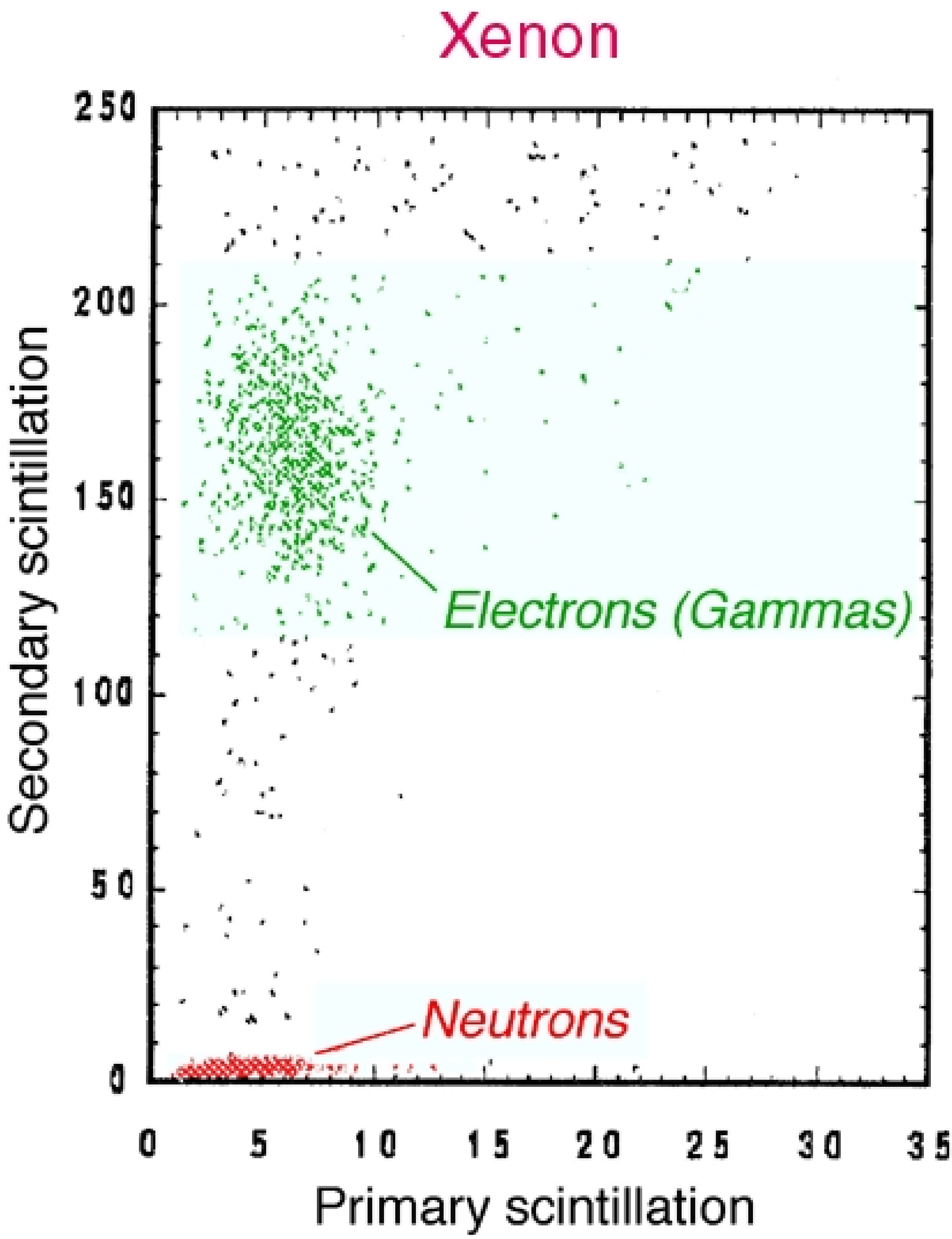

Figure 9 *First experimental evidence of electron recoils and nuclear recoils in liquid Xenon, as measured by the ICARUS Collaboration (ref. [1] and further work of P. Picchi et al.) The primary scintillation is measured with a photo-multiplier immersed in the liquid Xenon. The secondary scintillation is due to the delayed light emission during multiplication along a wire of the ionisation electrons extracted from the liquid into gas. Neutrons are produced by a radioactive source. The background is therefore substantial.*

5.—PRELIMINARY BACKGROUND ESTIMATES.

The neutron background is considered first. The bare neutron flux measured by the ICARUS Collaboration inside Hall C is shown in Figure 10. The integrated flux is about 4.33 x 10^{-6} n/cm^2/s, which corresponds to about 0.5 n/sec incident on the outer walls of the T14. An elaborate Montecarlo calculation has been set up [11] in order to estimate the residual background of neutron induced recoils in the fiducial volume. This Montecarlo takes into account all possible reactions and the detailed matter composition of the detector.

The neutron cross sections on Argon are shown in Figure 11. There is considerable disagreement between databases on the cross sections and the one we have chosen is the Japanese compilation JENDL. The elastic cross section is rich of many resonances and it is dominant over capture. At higher energies (≥ 1 MeV) the inelastic neutron cross section (n, n') and later on the (n, 2n) and (n,3n) start to play a role. Other cross sections are important in this region, like (n, p) , (n, d) and so on. It is evident that only a detailed, Montecarlo calculation can predict the expected neutron background of a WIMPS search.

We remark that the Argon elastic cross section, which can mimic WIMPS events in the region of interest for the recoils (≥ 10 keV) is relatively small, of the order of a few barns. The elastic mean free path is given by $L_{coll} = \sigma_{ela}(barn)/47.6\ cm$ and therefore, in view of the dimensions of the dewar, almost all neutrons penetrating or exiting the volume will undergo one or more scattering. Evidently those events in which at least one scattering occurs in the anti-coincidence volume will be rejected.

We select Montecarlo events with the following pattern:

(1) a single recoil is produced inside the fiducial volume;

(2) the final neutron capture does not occur inside the Argon. Clearly these events can be rejected because the capture is very energetic (many γ's);

(3) the (recoil) energy deposited inside the anti-coincidence shield is larger than 10 keV.

Starting from 26.3 x 10^6 incident neutrons, corresponding to an exposure time of 4.8 x 10^7 s (556 days), we find only 12 surviving events above an energy threshold of 5 keV, corresponding to a rate of 1 event every 46 days. Hence this background can be considered as entirely negligible. If the threshold is lowered to 2 keV, 8 more events are added. We note that this is an upper limit to the background, since neutrons, after having scattered, thermalise inside the detector and are eventually captured, with abundant γ-emission. These γ's may be easily detected by the anti-coincidence shield, vetoing the event.

.

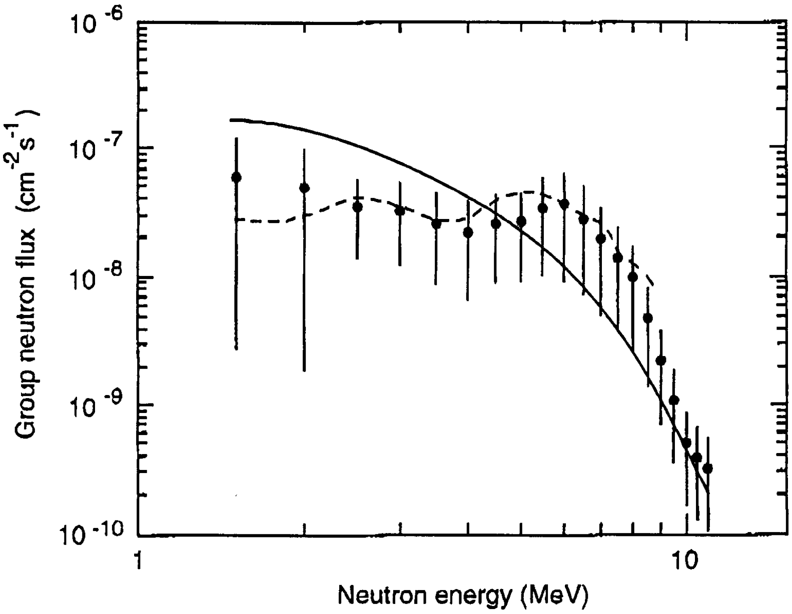

Figure 10. *Bare neutron flux in the LNGS Hall C, as measured by the ICARUS Collaboration.*

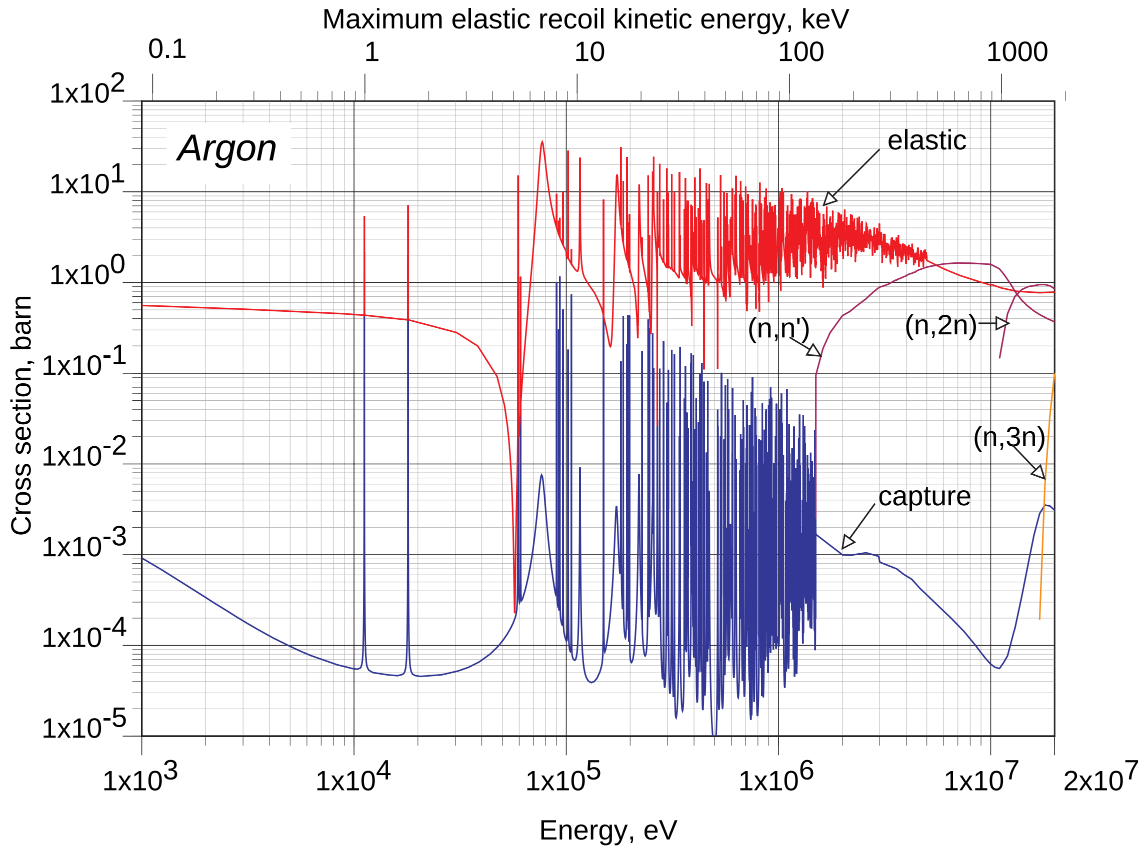

Figure 11. *Neutron cross sections in natural Argon. The maximum energy of the elastic recoil is also shown. We note the complex cross section behaviour in the region of recoils of interest (10 ÷ 100 keV).*

Another possible neutron source is represented by neutrons produced inside the detector, for instance because of spontaneous fission of Thorium or Uranium impurities. The activity of the materials used for the construction of the T14 have a conservative, measured upper limit of 1 Bq/kg of material. It is generally assumed that the ratio n/γ for these components is of the order of 10^{-6}.

Assuming a total weight of the container of 2 ton, this corresponds to a source of $2x10^3$ x $10^{-6} \leq 2$ x 10^{-3} n/s. In the Montecarlo we have therefore located a fission neutron source in the bulk of the walls of the T14. Therefore the internal neutron source is about 1/1000 of the general neutron flux coming from the environment. However now there is no shielding from the water surrounding the detector.

Events are selected according to the previous criteria (1)-(3). Starting from 2.62 x 10^6 incident neutrons, corresponding to an exposure time of 4.8 x 10^9 s (55600 days), we find only 17 surviving events in the interval 5 ÷ 25 keV, corresponding to a rate of 1 event/year. Hence this background can be considered as entirely negligible, even if the uncertainties of the flux estimate are taken into account. If the threshold is lowered to 2 keV, 20 more events are added. The number of events with a single recoil above 25 keV is 40. The effect of the anti-coincidence shield is very spectacular, as shown in Figure 12, in which events with and without veto have been displayed.

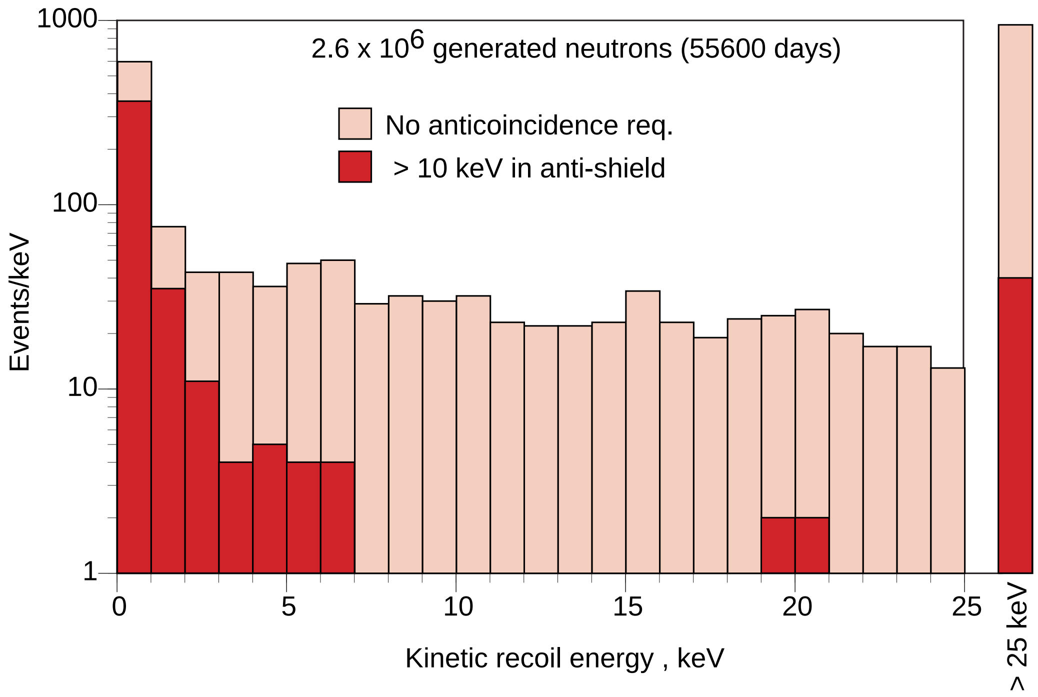

Figure 12. *Recoil energy spectrum for a fission neutron source and 2 x 10^{-3} n/s in the walls of the cryostat, presumably due to Th and U contamination. The effect of the anti-coincidence shield, in which a an energy deposition > 10 keV has been imposed is evident.*

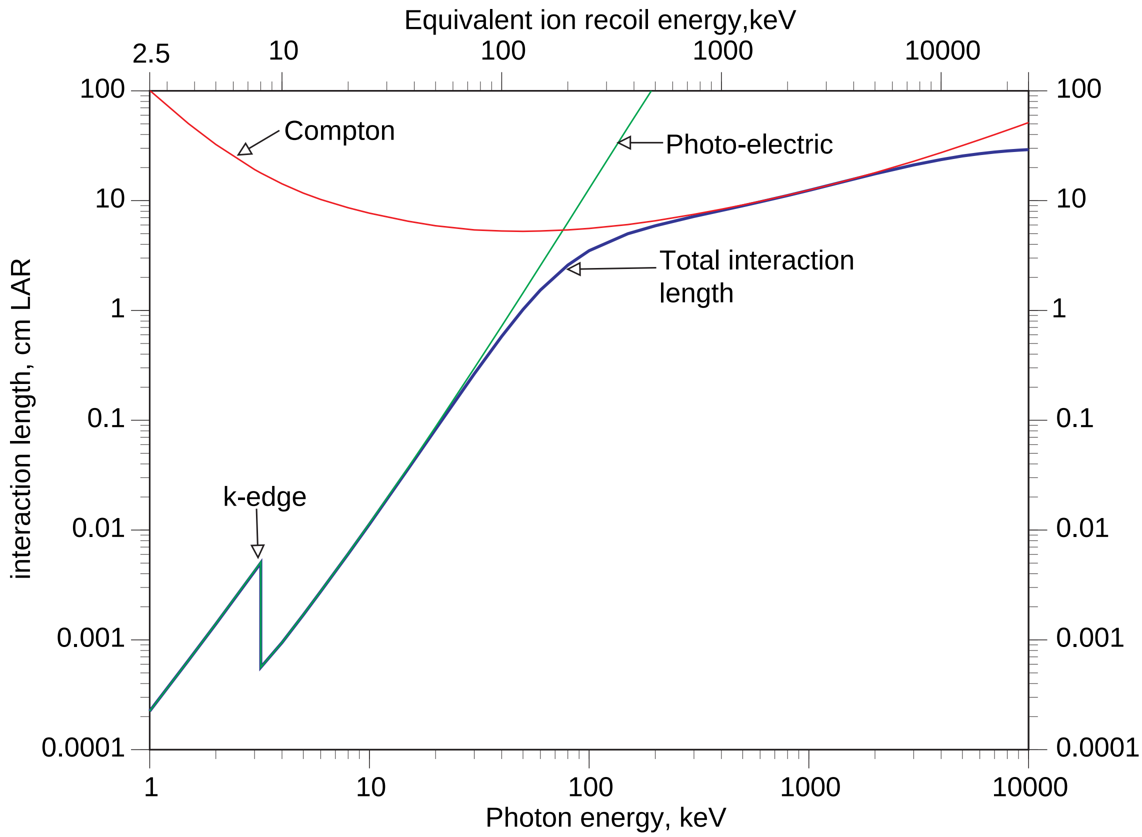

Figure 13. *Interaction length in cm of liquid Argon as a function of the photon energy. The equivalent energy of a WIMP recoil (scintillation light) is also shown. At low energies, the photo-effect dominates, while at high energies Compton effect takes over. Above a few MeV, pair production (not shown) becomes relevant.*

Next we consider the γ/e associated background. These events, as already pointed out, are rejected by the presence of a strong ionisation signal. However its rate must not be too large, in order not to rely too much from this single criterion. The actual rate of these events is hard to calculate with precision and its measurement is a part of the initial WARP programme. However qualitative considerations which follow indicate that they should be manageable.

Let us first consider direct electron production in the sensitive volume. This is presumably due to radio-active β-decay of unstable nuclei within the ultra pure Argon. The purification procedure does not reject other noble gases eventually present, which may end up dissolved in the liquid. Pure β-emitters are the most pernicious, since decays with associated γ's produce more than one signal "kernel", either in the sensitive volume or in the anti-coincidence and they can be rejected. Note that the mean interaction/absorption path of a nuclear photon of energies up to few MeV is short (see Figure 13) and hence, as discussed later on, the detector acts as a "calorimeter" accumulating a major fraction of the energy of the γ-cascade.

(1) There are two Argon isotopes which are radioactive with a long lifetime, A^{42} with $\tau_{1/2}$= 32.9 years and namely Ar^{39}, with $\tau_{1/2}$= 269 years. Ar^{42} is a pure β-emitter with an

average energy $\langle \beta^- \rangle$ = 233 keV and a specific activity of 259 Ci/g. For A^{39}, also a pure β-emitter, we have $\langle \beta^- \rangle$ = 218 keV and a specific activity of 34.1 Ci/g. While Ar^{39} contamination is expected to be minimal[6], Ar^{42} present in atmospheric Argon has been questioned, due to the thermonuclear tests in the atmosphere, (double neutron capture from natural Ar^{40}). Calculations by the ICARUS collaboration [13] have given a theoretical prediction of the order of $10^{-22} \div 10^{-23}$ in atomic concentration with respect to Ar^{40}. The ICARUS Collaboration has also searched it in liquid Argon sometime ago in the LNGS tunnel and found the upper limit ≥ 1.2 x 10^{-18} in atomic concentration [14]. A more stringent limit has been given recently by Ashitkov et al. [15]. also in LNGS, which find that the Ar^{42} content in the Earth's atmosphere is less than 6 x 10^{-21} parts of Ar^{42} per part of Ar^{40} at 90 % confidence level. One ton of Argon (10^6 g) has therefore an activity of less than 259 x 3.7 10^{10} x 6 10^{-21} x 10^6 = 0.057 c/s (one count every 17.4 s), which is small, but not negligible. The (allowed) β-spectrum $dn/dp_e \approx p_e^2 (T_o - T_e)^2$ — where (p_e, T_e) relate to the electron and T_o is the end point — has a significant part of the spectrum in the recoil energy interval ≤ 80 keV, corresponding to the actual electron energies ≤ 20 keV, because of the different scintillation efficiencies for ions and electrons. The probability of an electron $P(\leq T_{\max}) \propto T_{\max}^2$ is 0.0188[7] for $T_{\max}$ = 20 keV, corresponding to 1 count every 925 s (93.3 counts per day). Evidently the discrimination between e/γ and recoils must be powerful. For instance to reduce this background to the negligible level of ≥ 0.01 event/day, it must be of the order of 10^{-4}, which incidentally is not unreasonable. We note furthermore that the WIMP spectrum has the roughly exponential distribution as shown in Figure 3, while the Ar^{42} background spectrum is quadratic for low energies. Hence a residual background signal, if at all there, can be easily identified and subtracted out. Clearly the actual content of Ar^{42} in the Argon to be used must be carefully measured and it is a part of the tests of the WARP programme.

(2) The daughter element of Ar^{42} is K^{42}, with $\tau_{1/2}$ = 12.36 hours, a β-emitter with an average energy $\langle \beta^- \rangle$ = 1425 keV. At equilibrium we have therefore the same number of decays as Ar^{42}, but the probability for T_e ≤ 20 keV is only 1.36 x 10^{-3}. The decays is associated also to γ-emission with a prominent line of 1.542 MeV (18.8 %) and therefore some of the events can be rejected topologically.

(3) The liquid Argon contains also traces of other noble gases. The long lived Kr^{85} with $\tau_{1/2}$ = 10.7 years — maybe also related to nuclear applications (bombs and reactors) — may also be present to some extent. Kr^{85} is a pure β-emitter with an average energy $\langle \beta^- \rangle$ = 251 keV and a specific activity of 392 Ci/g. The same rejection criteria as for

---

[6] The production process in the thermonuclear tests is Ar^{38} (n.γ). The Ar^{38} natural isotopic fraction is 0.063%.

[7] The IB probability for the same energy threshold is 0.076 %.

Ar^{42} therefore apply, though its residual content is probably much smaller, although, as yet, to be checked. Xenon does not have medium or long lived radio isotopes and therefore it is intrinsically clean. Also Radon is a noble gas and it will not be rejected by the purification. However its longest living isotope is Rn^{222} with a $\tau_{1/2}$ =3.82 days. In addition it is a pure a-emitter with an energy of 5.489 MeV and therefore completely outside the energy range of interest.

(4) Other elements may creep in the liquid Argon because of an insufficient purification of the noble gas, resulting in some spurious radioactivity. These can only be identified experimentally, though the expectation for a measurable background due to these impurities is very remote, in view of the high level of purification attained, $<10^{-9}$.

(5) Neutrons inside the cryostat may end up in captures in Argon with production of Ar^{41}. About 40% of the neutrons emitted by the inner materials of the cryostat are indeed captured by Argon. Ar^{41} ($\tau_{1/2}$ = 1.27 hours) is a β-emitter with an average energy $\langle \beta^- \rangle$ = 464 keV and with an associated γ–line of 1.283 MeV (probability 99.16 %). The probability for $T_e \leq 20$ keV is 6.7 x 10^{-3}. Therefore the combined (very small) probability of a single electron signature $T_e \leq 20$ keV and with no γ is 6.7 x 10^{-3} x (1-0. 9916)=5.62 x 10^{-5}. To this small level, the discrimination against e/γ , estimated about 10-4 must be added, leading to a negligible background level.

(6) Cosmic ray muons traversing the volume may produce unstable elements and eventually some neutrons. These background are generally eliminated because of the anti-coincidence, generally triggered by the passing muon.

Let us consider now residual beta and gamma activity in the walls and other parts of the detector. The activity of the materials used for the construction of the T14 have a conservative, measured upper limit of 1 Bq/kg of material. Assuming a total weight of the container of 2 ton, this limit corresponds to a source of $\leq 2 \times 10^3$ γ/s. Only a fraction of these photons will penetrate the Argon and they will be powerfully shielded by the active Argon of the anti-coincidence shield.

The interaction path for photons as a function of the energy, or rather the equivalent scintillation light as ion recoil, is shown in Figure 13. In the WIMP recoil energy interval (2.5 ÷100 keV) the interaction length is very short, << 1 cm and dominated by the photo-effect. Therefore photons of these energies have an extremely short path and only local sources inside the Argon (already considered) may contribute. Higher energy photons, up to several MeV, have longer path lengths and the Compton effect becomes gradually relevant. Compton scattering generates a continuum of electron recoils and hence a Compton scattered electron may fall in the WIMP recoil energy window. However the Argon (sensitive volume + anti-coincidence) is “thick” and several scattering events generally occur (cascade), with a progressive degradation of the initial photon energy. The total energy collected in the whole Argon volume from higher energy photons is therefore generally close to the photon energy and much larger than the one of the WIMP recoils.

An elaborate Montecarlo has been performed in order to determine with precision the effects of the photon background in the sensitive volume. Since the mean free path for the most offending photons is not very dissimilar to the one for neutrons, we expect also in this case a very large suppression factor for the events with the correct signature.

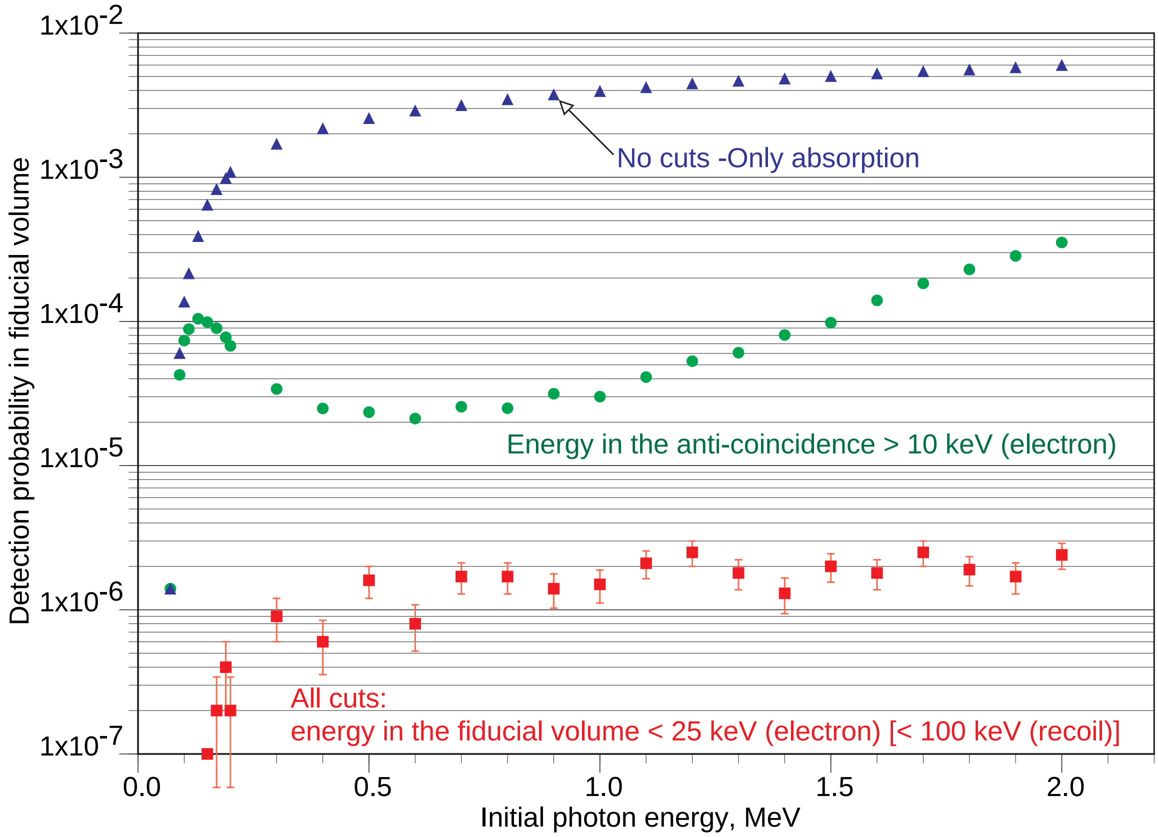

Figure 14. *Detection probability for a single hit in the sensitive volume of a photon emitted by the cryostat walls, as a function of its energy. The effect of the cuts is displayed*

The source of photons has been located in the cryostat walls, for which we know that the residual activity does not exceed 1 Bq/kg . Assuming a total weight of the container of 2 ton, this limit corresponds to a source of $\leq 2 \times 10^3$ γ/s. Only a fraction of these photons will penetrate the Argon and they will be powerfully shielded by the active Argon of the anti-coincidence shield. Therefore the Montecarlo is generating an isotropic source of photons of different energies and these are followed inside the detector volume. All relevant cross sections are considered, according to the data of Figure 13. The correct kinematics including the angular distribution for the Compton effect has been used. We require a number of different signatures, progressively leading to the simulation of a WIMP event:

10^7 *initial photons emitted by the cryostat walls*

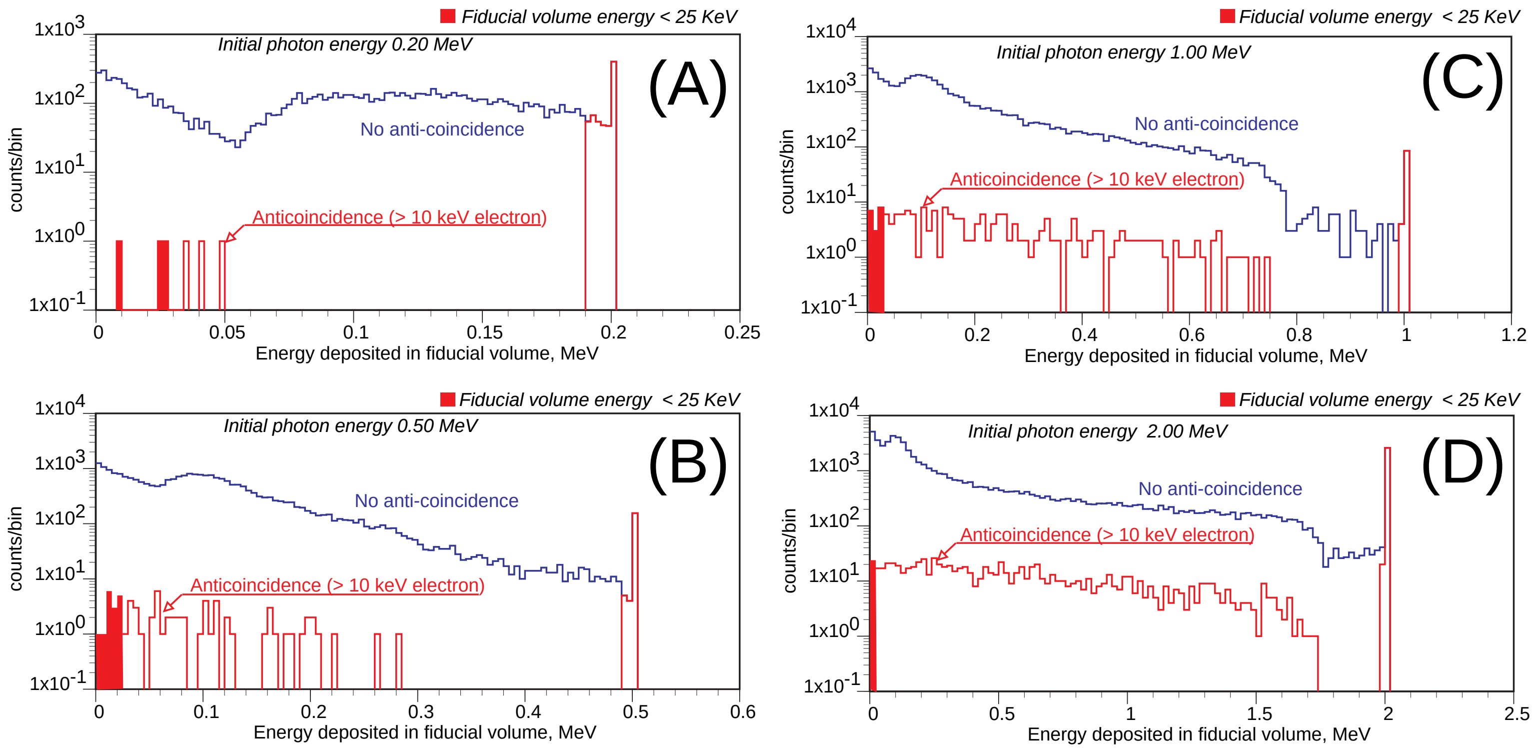

Figure 15. *Spectra of energy deposited by a single hit in the sensitive volume for different energies of initial photons emitted by the walls of the cryostat. The surviving spectrum with and without the anti-coincidence action of the surrounding Argon is shown. In addition the energy of the recoil must be compatible with the energy deposition of a potential WIMP recoil . Assuming conservatively that this is* $T_{rec} < 100\ keV$ *, it corresponds to an equivalent electron energy* $T_e \leq 25$ *keV. Curves (A) through (D) are for photon energies of 200 KeV, 500 keV, 1 MeV and 2 MeV respectively*

(1) There should be one and only one recoil event in the sensitive volume. This can be either produced by a photo-effect, by a Compton scattering or a pair production. At this level the signal is reduced only because of absorption or solid angle.

(2) The active anti-coincidence must not register a count, which has been set above a threshold of 10 keV.

(3) The energy deposited in the sensitive volume must be in the range of the potential WIMP recoils. Assuming conservatively that this is $T_{rec} < 100\ keV$, it corresponds to an equivalent electron energy $T_e \leq 25$ keV.

We show in Figure 14 the progressive effect of these cuts, as a function of the initial photon energy. At very low energies the absorption coefficient is very important and it reduces dramatically the photon flux arriving at the sensitive volume. At this level, the anti-coincidence is not very efficient, since the energy deposition required is of the order of the photon initial energy. When the initial photon energy is progressively increased, the Argon becomes more transparent, but the veto action is catching up. There is fortunately cancellation between these effect and the probability for a photon to meet above requirement (1) to (3) is almost independent of energy and flattens out at a value of about 2×10^{-6}. Therefore, widely independently of the actual spectrum of these background γ 's, which at this moment is unknown, we can say that the background rate will be of the order of $\leq 2 \times 10^{3} \times 2 \times 10^{-6} = 4 \times 10^{-3}\ s^{-1}$. Introducing the standard factor 10^{-4} for the scintillation-ionisation criterion, we get a rate of $4 \times 10^{-7}\ s^{-1}$, namely 1 event every 30 days.

We display in Figure 15 the effect of the several cuts in the spectral distribution of the energy deposited in the sensitive volume for four typical photon energies. One can see that the action of the anti-coincidence is such as not to eliminate those photons which deliver most of the energy in the sensitive volume. Fortunately only very few events have the small recoil energy exhibited by the WIMP recoils. When the initial photon energy is small, as already pointed out, the absorption of the Argon is taking over.

To conclude, there are two major sources of background which are to be compared to the potential WIMP signal level. We remind that according to the DAMA result [3], the event rate should be in excess of 1000 events/day/ton. These backgrounds are essentially :

(1) Neutrons which produce recoils faking the WIMP recoils. These events are mostly due to the inner sources in the materials, essentially Thorium and Uranium cycles. The external neutrons in the Hall are effectively shielded by the water surrounding the detector. Since these events are due to an elastic scattering, the neutron survives the

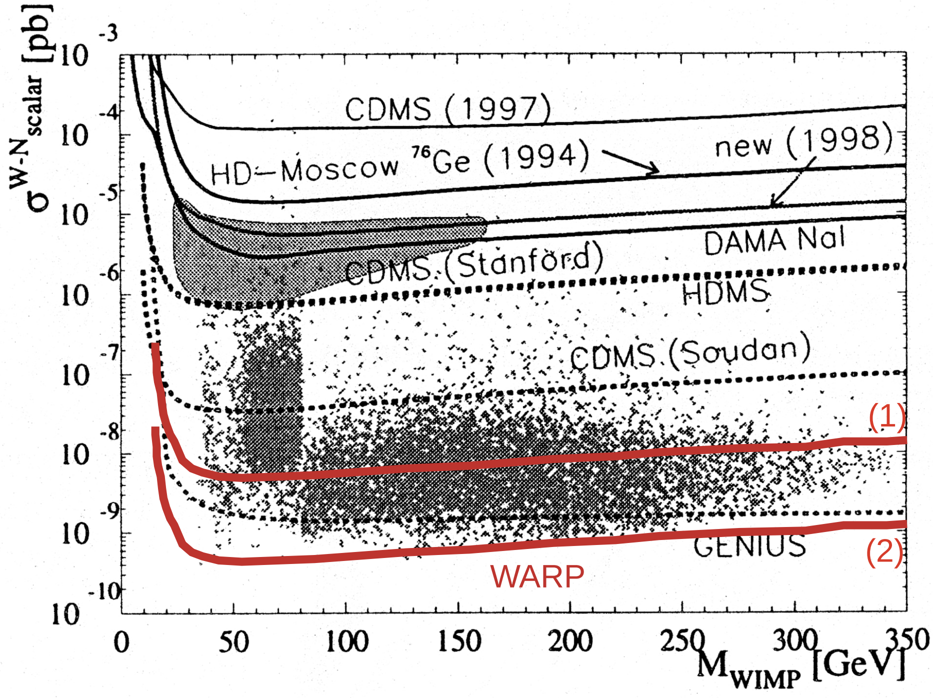

Figure 16. *Compared sensitivity of running WIMP direct detection experiments (continuous line) and proposals or upcoming experiments (dashed lines). The boundaries for WARP signal according to DAMA [3] are also indicated. The ultimate sensitivity interval for the present proposal are (1) for 1 ev/day and (2) 1 event every 10 days respectively. In light grey a scatter plot calculated in the MSSM framework with non-universal scalar mass unification from Heidelberg-Moscow collaboration[]. Graph from ref. [12].*

event and therefore has a large probability to give a count also in the anti-coincidence, either in its way in or in its way out. Many of these neutrons, once thermalised, are captured with prolific γ-emission[8]. Capture or multiple elastic scattering (elsewhere) can be used as signatures for background subtraction. The surviving background is estimated to be very small, << 1 event/day, assuming the measured upper limit to the activity of the T14 materials and with the assumption that $\gamma/n \approx 10^{-6}$.

(2) Beta decays with small energies and γ-conversions, either Compton or photo-effect. In all these events the ionisation vs. scintillation criterion must be grossly wrong (assumed rejection power $\geq 10^4$) and the topology of a single recoil with no other activity must be fulfilled. These events being more effective in producing scintillation light than nuclear recoils, they must be also of very low energy, since for instance an average WIMP recoil energy of 12.5 keV corresponds to electrons of about 2 ÷ 3 keV. Such isolated electron events can either be due to:

---

8 This signature could be enhanced introducing a thin foil (or alternative configuration) of a material with huge capture cross section.

(i) the low energy tail of the β-spectrum. These energies are very improbable, for all considered processes . Also the shape of the residual spectrum is quadratic in the electron energy. Hence shape dependent subtraction of background is possible, if at all necessary.

(ii) Compton events with unfavourable kinematics. However the photon survives the Compton effect and it is very likely to interact elsewhere either in the sensitive volume or in the anti-coincidence.

(iii) Photo-effect of a low energy photon. However in the photo-effect, the full energy minus the electron binding is transmitted to the electron, and hence only very low energy γ's may contribute. However they are very strongly absorbed by the Argon, with millimetric path lengths, as visible in Figure 13.

The very low background level, estimated approximately and conservatively at this stage to be less then 1 event/day permits the detection of the primary signal, rather than solely relying on it seasonal variation. The ultimate sensitivity is therefore about three/four orders of magnitude better than the DAMA experiment.

In Figure 16 we give the roughly estimated limits of sensitivity of the WARP experiment with the estimated background levels. Curve (2) represents the ultimate sensitivity for 1/10 events/day. The sensitivity of the WARP experiment is comparable to the one of GENIUS, one of the most sensitive, second generation experiments. It is therefore worth while pointing out some of the differences between the two proposals.

(1) The sensitive masses are comparable, of the order of 1 ton in both cases.

(2) The target material is Germanium in the case of GENIUS and Argon (or eventually Xenon if deemed necessary by the WARP R&D programmes (see next paragraph). The Germanium is ultra-pure but in our case we use the scintillation/ionisation criterion to lower the background by about 4 orders of magnitude. Therefore backgrounds are very low in both cases.

(3) The shielding around the sensitive volume is much larger in the case of GENIUS, since it is not active. In our case, as shown previously the active condition reduces by about 4 orders of magnitude the penetrating background

Therefore the fact that the two experiments have a comparable ultimate sensitivity is by no mean surprising.

6.—THE WARP PROGRAMME.

The WARP programme is a graded strategy intended to arrive at a WIMP search of unprecedented sensitivity, and aimed at the detection of both the “signal” and of its seasonal variation. These signals should be sufficiently clear as to be able to determine eventually both the mass and the (flux) x (cross section) of the WIMPS.

The signature of the events is made unambiguous (1) separating e/γ events from recoils and (2) reducing sufficiently the neutron background by an active anti-coincidence. This can be realised only with an active volume of Argon of many tons, in order to allow for a significant interaction probability of the offending particles, while of course completely transparent to WIMPS. The localisation of the events, possible by simultaneous measurements of drift time and position of the recoil events in the sensitive volume of about 1 ton, can be used to further ensure the uniformity of the signal as expected from the “weak” nature of the WIMP events.

If the DAMA claim is confirmed, the WIMP event rate should be very large, of the order of 1000 events/day. However the backgrounds, mainly determined by the residual β-activity of the ultra-pure Argon and by the ultimate rejection power of the e/g signal, should permit observable rates at the level of a fraction of event/day, thus improving roughly 1000 times the sensitivity of DAMA. In many respects our detector resembles to the proposed GENIUS with 1 ton of Germanium, for which a similar improvement over DAMA is expected, except that (1) our surrounding volume may be smaller, since fully active and (2) the low counting rate intrinsic to Germanium is replaced by the rejecting power of the double (lack of) ionisation and scintillation signature.

The WARP programme is considered as a technological spin-off of the ICARUS programme. Therefore it is very reasonable that the T14 module, once made available, should be the basic building block of the WARP programme. We remark incidentally that the cost of the actual cryostat body is modest, when compared to the rest, namely cryogenic pumps, purifier, controls etc. and therefore the WARP programme is not rigidly blocked by the dimension of the cryostat presently available (T14), though it is for us a perfectly sensible choice, on the basis of the previous considerations. There is at this stage a vast amount of flexibility in the design of the final unit.

- If the volume or the shape of the T14 would turn out to be inappropriate, it could be modified accordingly, since the structure is modular, made of panels of honeycomb.

- If the use of Argon in the sensitive volume would turn out to be inappropriate because for instance of an excessive residual radio-activity, it could be replaced with liquid Xenon contained inside a thin thermal shield and operated at a higher temperature, with the help of a heater. This is a remote possibility since Ar^{42} residual from thermonuclear tests — the worst potential offender — has an experimentally measured [15] upper limit of <10^{-2} faked WIMP events/day. Probably and according to calculations [13] the background is actually one order of magnitude lower. Hence Argon is already clean enough and — incidentally — much cheaper.

The WARP programme is therefore intended as a series of separate steps, leading to the realisation of a low background, largely redundant WIMP detector of about 1 ton. It may be spelled out in the following R&D phases, based on a small liquid Argon counter, of which most of the components already exist:

(1) An elaborate test in which both the scintillation and ionisation signals are detected, extending the measurements already done by the ICARUS Collaboration in Legnaro with liquid Xenon. In these tests, neutrons are used to mimic the WIMP signal and the technology of rejection of γ/e is fully tested and optimised.

(2) Presumably the same counter or a similar scale device is brought inside the LNGS tunnel to measure the residual activity of the actual Argon to be used, and in particular the one due to Ar^{42}.

(3) The extraction of electrons from liquid to gas, their multiplication and readout and the dynamics of the gas-pocket are further studied in the laboratory in order to design the full scale unit.

(4) The appropriate type of photo-multiplier is chosen, in co-operation with the similar activity already on going in the ICARUS Collaboration.

It is only when such a preliminary programme will be completed that the WARP Collaboration will submit a final technical proposal for the full scale experiment. We estimate that the R&D programme could be completed in about one year.

7.—REFERENCES.

[1] P. Benetti et al. , Nucl. Instr. and Meth. A329 (1993), 361-364

[2] ICARUS-TM in preparation

[3] R. Bernabei et al. "WIMPs search by scintillators: a possible strategy for annual modulation search with large-mass highly radiopure NaI(Tl), Proceedings of TAUP97 Conference

R. Bernabei, "Dark matter searches", Proceedings of the 8th International Symposium on Neutrino Telescopes, Venice, Feb20-22,19999

R. Bernabei et al. Phys. Lett. B389 (1996), 757

[4] D. Reusser et al. Phys. Lett., B255 (1991), 143

[5] "Scintillation efficiency of nuclear recoil in Liquid Xenon", ICARUS-TM 99/14

[6] G. Gerbier et al. Phys Rev, D42 (1990), 3211

[7] A.R. Sattler, Phys. Rev. 138, A1815 (1965)

[8] J. Lindhard et al., Mat. Fyz. Medd> Dan. Vid. Selsk. 33, no10(1963)

[9] E.M. Gushchin et al. Sov. Phys. JETP, 55 (5) 1982

[10] B. A. Dolgoshein et al. , Fiz. Element. Chastits at. Yadra 4, (1973) 167

[11] C. Rubbia, to be published

[12] H.V. Klapdor-Kleingrothaus, Proceeding of PASCOS'98

[13] M. Terrani et al. unpublished

[14] C. Arpella et al. Preprint LNGS 92/27, 1992

[15] V. D. Ashitkov et al., Nucl. Instr. and Meth. A416 (1998), 179-181

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
	WARP	2

Struttura
PAVIA

COMPOSIZIONE DEL GRUPPO DI RICERCA

RICERCATORI

N	Cognome e Nome	Qualifica: Dipendenti – Ruolo	Dipendenti – Art. 23	Incarichi – Ricerca	Incarichi – Assoc.	Affer. al Gruppo	Percentuale
1	BENETTI Pietro			P.A.		5	20
2	CALLIGARICH Elio	D.R.				2	20
3	MAURI Fulvio	I Ric				2	20
4	MONTANARI Claudio S.	Ric				2	20
5	RONCADELLI Marco	I Ric				4	20
6	RUBBIA Carlo			P.O.		2	20

Numero totale dei Ricercatori **6,0**

Ricercatori Full Time Equivalent **1,2**

TECNOLOGI

N	Cognome e Nome	Qualifica: Dipendenti – Ruolo	Dipendenti – Art. 23	Incarichi – Ass. Tecnol.	Percentuale

Numero totale dei Tecnologi

Tecnologi Full Time Equivalent

TECNICI

N	Cognome e Nome	Qualifica: Dipendenti – Ruolo	Dipendenti – Art. 15	Incarichi – Collab. tecnica	Incarichi – Assoc. tecnica	Percentuale

Numero totale dei Tecnici

Tecnici Full Time Equivalent

Mod. EC/EN 7

(a cura del responsabile locale)

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
	WARP	2

Struttura
PAVIA

COMPOSIZIONE DEL GRUPPO DI RICERCA (cont.)

LAUREANDI Cognome e Nome	Associazione SI	Associazione NO	Titolo della Tesi
Grandi Luca Relatore Rubbia Carlo	O SI	O NO	studio di un rivelatore ad argon liquido per l ricerca di WIMPs
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	
Relatore	O SI	O NO	

SERVIZI TECNICI

	Denominazione	mesi-uomo

Annotazioni

INTERAZIONI CON LE INDUSTRIE (COMMESSE HIGH TECH)

DENOMINAZIONE	DESCRIZIONE PRODOTTO O COMMESSA

ISTITUTO NAZIONALE DI FISICA NUCLEARE

Preventivo per l'anno **2001**

Codice	Esperimento	Gruppo
	WARP	2

Struttura
PAVIA

REFEREES DEL PROGETTO

Cognome e Nome	Argomento

MILESTONES PROPOSTE PER IL 2001

Data completamento	Descrizione
31/3/2001	completamento tests su piccolo prototipo
30/6/2001	progetto esecutivo modulo da $10m^3$
31/12/2001	ordini materiali

COMPETITIVITA' INTERNAZIONALE

Il progetto è in competizione con gli alti programmi di ricerca della materia oscura. Punti di forza del progetto sono l'elevata sensitività, dovuta alla grande massa sensibile e la capacità di rigettare gran parte del fondo dovuto alla radioattività mbientale grazie alla particolare segnatura degli eventi.

LEADERSHIPS NEL PROGETTO

Cognome e Nome	Funzioni svolte
Rubbia Carlo	spokesman della collaborazione

(a cura del responsabile nazionale)

Esperimento	gruppo	Rappresentante nazionale	Struttura res_naz	nuovo_continua
WARP	2	C.Rubbia	PAVIA	nuovo

STR.	ESPERIM.	Missioni interno	Inviti ospiti stran.	Missioni estero	Mater. di Cons.	Spes Sem	Tras. e Fac.	Pub. Scien.	Spese Calc	Aff. e Manut. App.	Mater. invent.	Costruz. apparati	TOTALE
PAVIA	Personale												
	Ricercatori 6,0 / FTE 1,2		Tecnologi / FTE			Tecnici / FTE				Servizi mesi uomo			
	Rapporti (FTE/numero) Ricercatori				0,20	**Ricercatori+Tecnologi**						0,20	
	WARP	8		35	40						40		123
	di cui sj												
	Totali	8		35	40						40		123
	di cui sj												
	Richieste/(FTE ricercatori+tecnologi)					102,50							

TOTALI

Totali	8		35	40						40		123
di cui sj												

Confronto con il modello EC4

Mod. EC4 dati												
Totali-Dati EC4	8,0		35,0	40,0						40,0		123,0

Personale

Ricercatori 6,0	Tecnologi	Tecnici	Servizi mesi uomo
FTE 1,2	FTE	FTE	

Rapporti (FTE/numero) Ricercatori 0,20 **Ricercatori+Tecnologi** 0,20

Richieste/(FTE ricercatori+tecnologi) 102,50