First physics results from WARP 2.3 liter prototype

G. Fiorillo

"Federico II" University and
INFN
Napoli
Italy

Dark Matter search with liquid Argon in the Gran Sasso Laboratory

http://warp.pv.infn.it

In memory of Nicola Ferrari, who gave a major contribution to this work

WArP Collaboration

P.Benetti, E.Calligarich, M.Cambiaghi, L.Grandi, C.Montanari, G.L.Raselli, M.Roncadelli, M.Rossella, C.Rubbia*, C.Vignoli
Dipartimento di Fisica Nucleare e Teorica, INFN and University of Pavia, Italy

F.Carbonara, A.G.Cocco, G.Fiorillo, G.Mangano
Dipartimento di Scienze Fisiche, INFN and University Federico II, Napoli, Italy

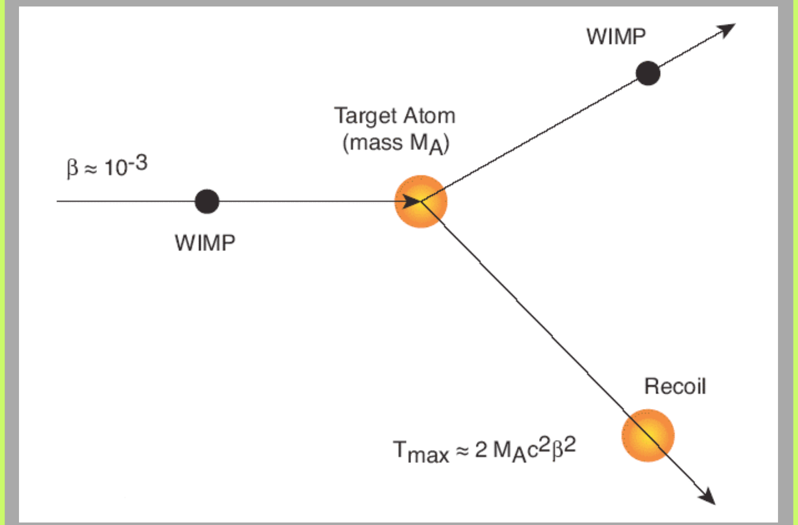
R.Acciarri, F.Cavanna, F.Di Pompeo, N.Ferrari, A.Ianni, O.Palamara, L.Pandola
Laboratori Nazionali del Gran Sasso dell'INFN, L'Aquila, Italy

F.Calaprice, C.Galbiati
Department of Physics, Princeton University, New Jersey, USA

A.M.Szelc
Instytut Fizyki Jadrowej PAN, Krakow, Poland

Detection of WIMP-Ar elastic scattering

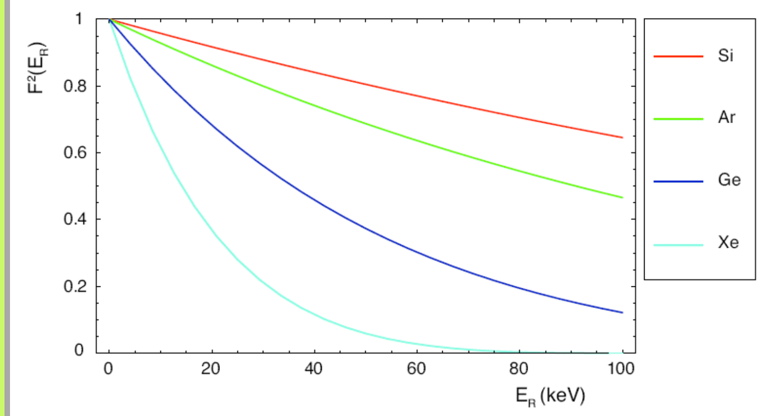
- Argon recoil energy is in the range $E_R \sim 10 \div 100$ keV
- Coherent cross section depends on A^2 (A=40 for Argon)
- Spin-independent form factor since natural Argon is composed by spinless isotopes



Interaction Rate

$$R(E_1, E_2) = \int_{E_1}^{E_2} c_1 \frac{R_0}{E_0 r} e^{-c_2 \frac{E_R}{E_0 r}} F_A^2(E_R)\, dE_R$$

E_0 kinetic energy of WIMP
$r=4m_\chi m_N/(m_\chi+m_N)^2$
c_1 and *c_2* constants depending on the time of the year

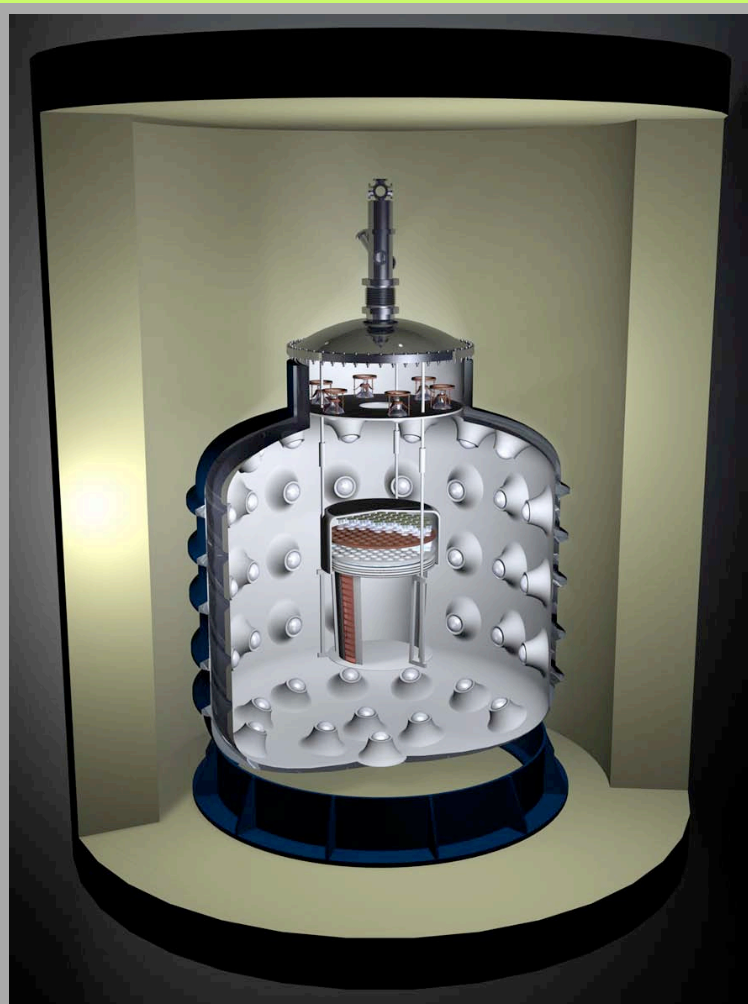


WIMP CANDIDATES IDENTIFICATION: Highest discrimination between nuclear recoils and beta/gamma-like background ^{39}Ar, 0.8 Bq/kg (*) → need 3 x 10^8 rejection against betas (for 140 kg detector)

*WARP Collaboration, Benetti et al., astro-ph/0603131

- The WArP experiment foresees a **100 liter LAr sensitive** fiducial volume (**140 kg**) and a detection **threshold** ≤ **20 keV$_R$**. The volume is fully contained in a **8000 kg 4π LAr** anti-coincidence to veto γ-like events and neutrons (together with passive shielding).

- A **2.3 liter prototype** (without active shielding) has been installed in **LNGS** to perfect the technology. To this purpose the background has been kept at a high level. Nevertheless a very **competitive limit** on WIMP search has been **obtained** with a total fiducial **exposure of 96.5 kg x day**.



Interactions Detection Technique

WArP

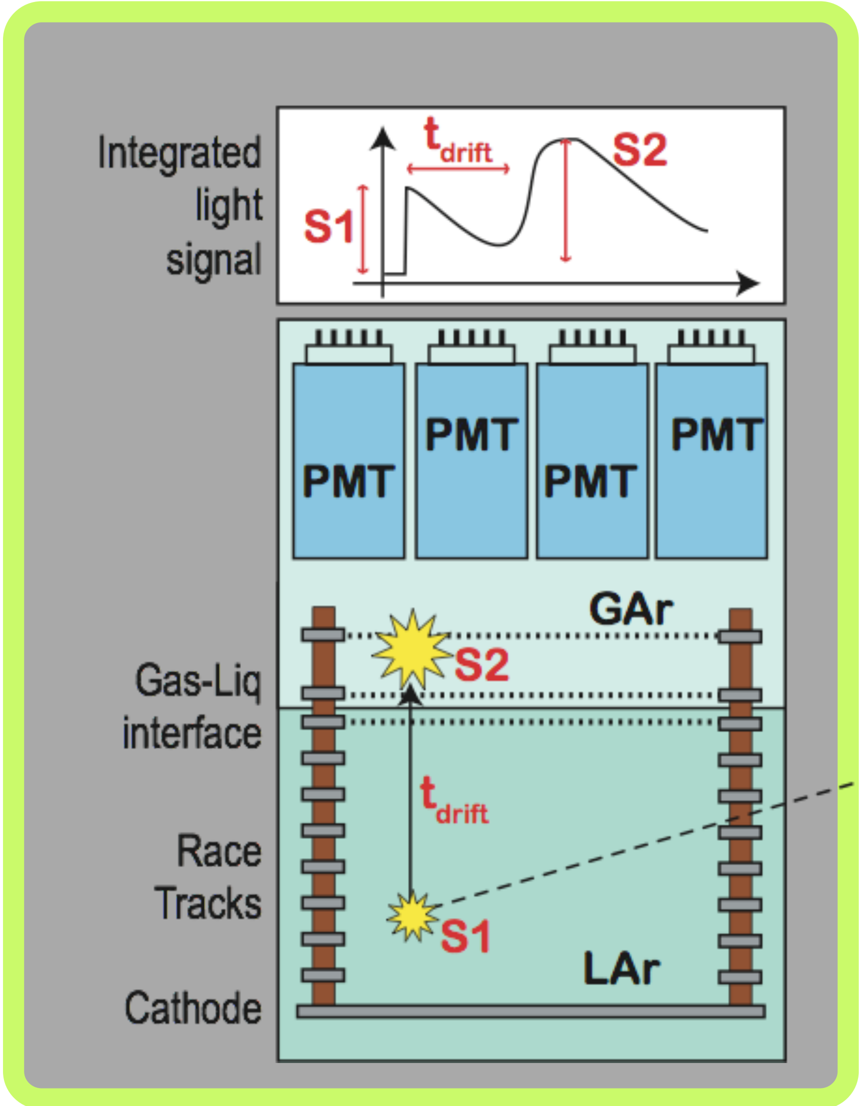
Double phase detector:

For each interaction in the sensitive volume a set of PMTs detects both

1) the prompt scintillation (**S1**)

and

2) the ionization through the proportional electroluminescence (**S2**) produced by the electrons drifted towards the gas phase, extracted and accelerated

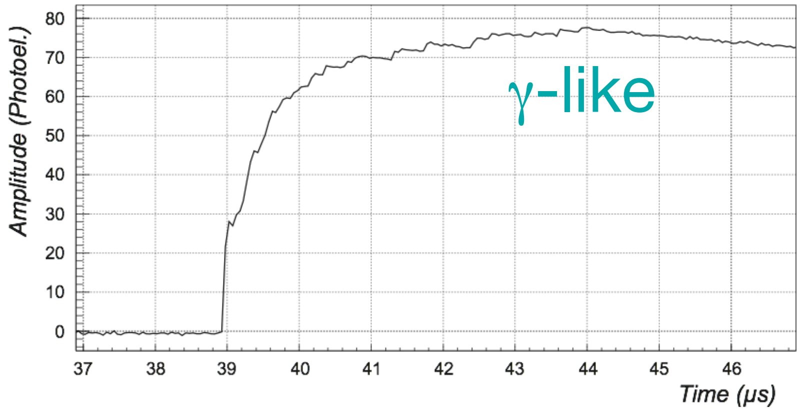


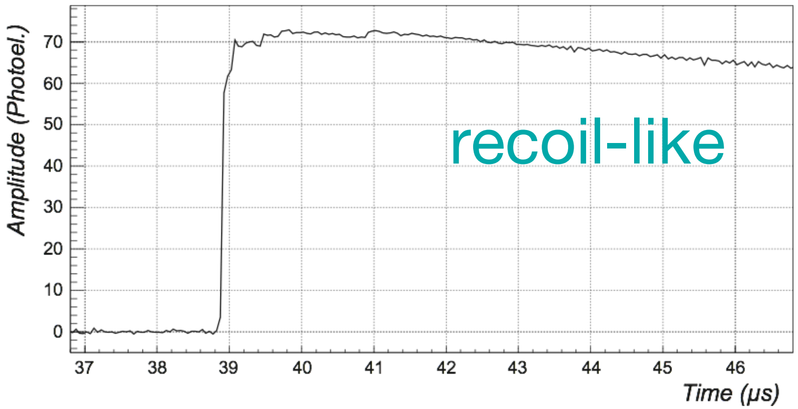
Particle Identification methods (1)

The highest discrimination of minimum ionizing events, in favour of potential WIMP recoils, is obtained with two simultaneous and independent criteria:

1) **Pulse shape discrimination of primary scintillation (S1)** based on the very large difference in decay times between fast (≈ 7 ns) and slow (1.6 μs) components of the emitted UV light

- Minimum ionizing: slow/fast ~ 3/1
- Nuclear recoils: slow/fast ~ 1/3





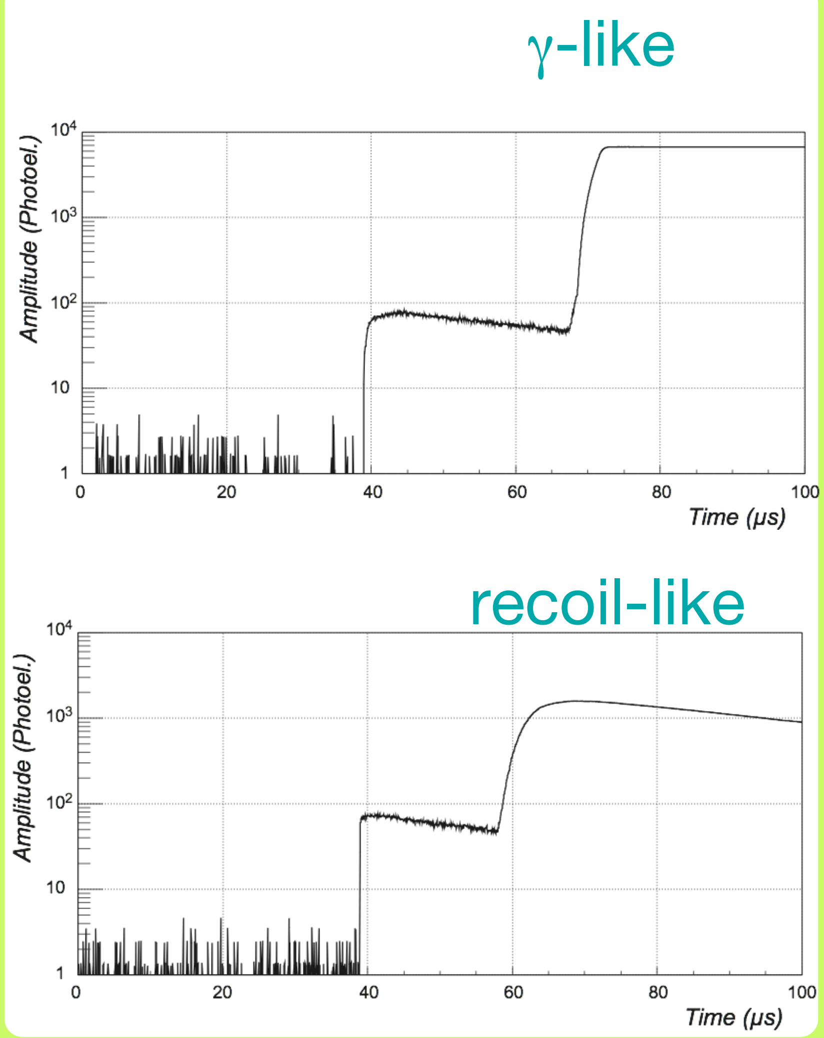
Particle Identification methods (2)

2) **Ratio of proportional light signal/ primary light signal (S2/S1)**

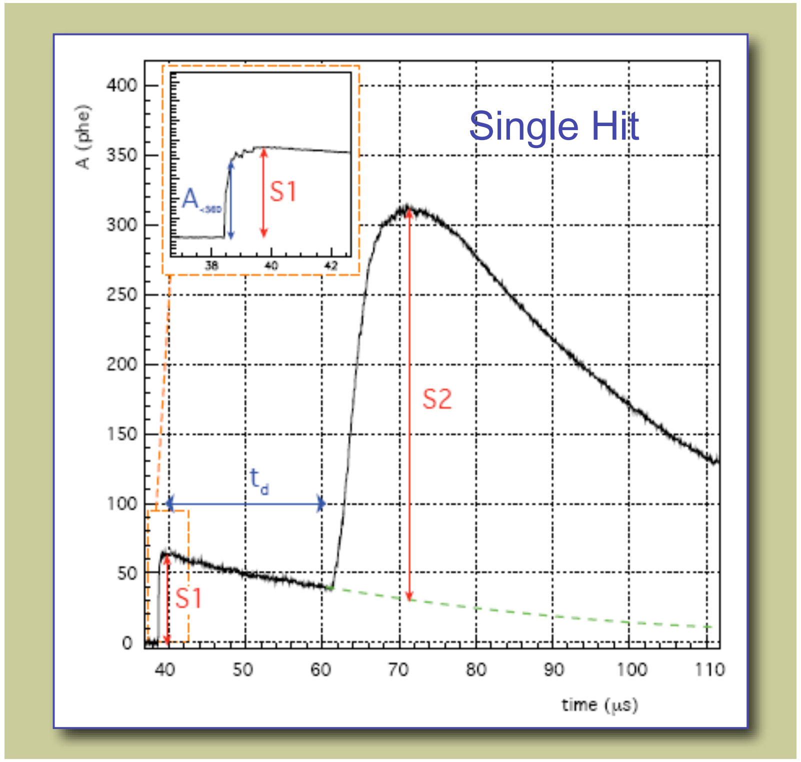
This ratio is of the order of 250 for minimum ionizing particles, 4 for α particles, and 10 for Ar-recoils.

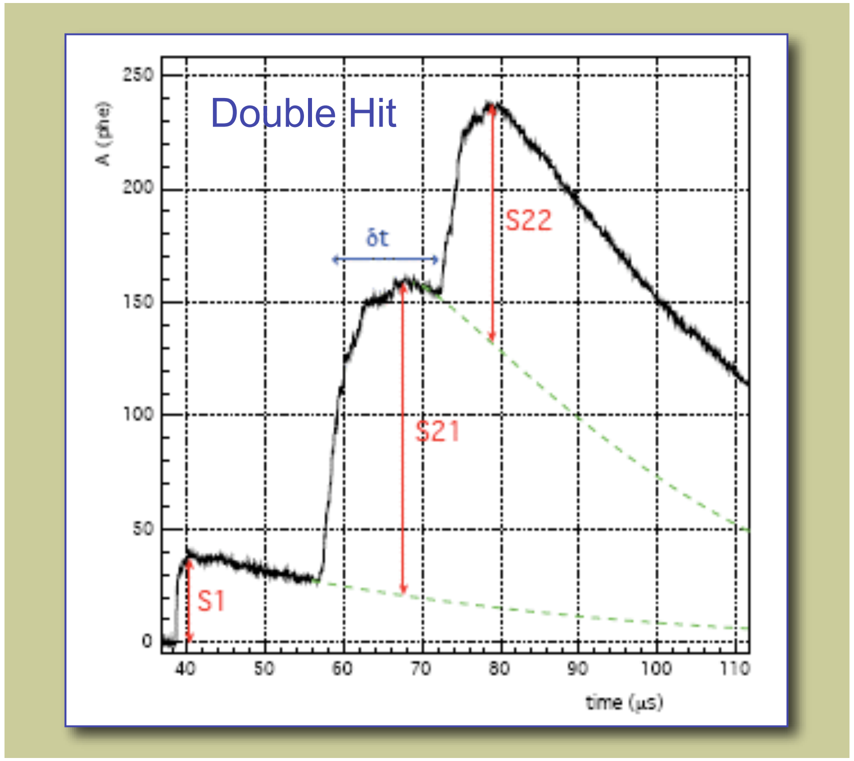
In addition S2 allows for

- Precise determination of events location in 3D: 5 mm x-y, 1 mm z
- Additional rejection for multiple neutron recoils and γ background

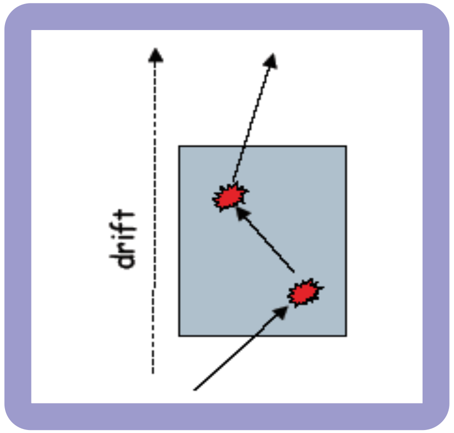


Multiple recoils





Multiple recoils can be identified and measured, if separated along the drift coordinate by a few mm (few μs drift).

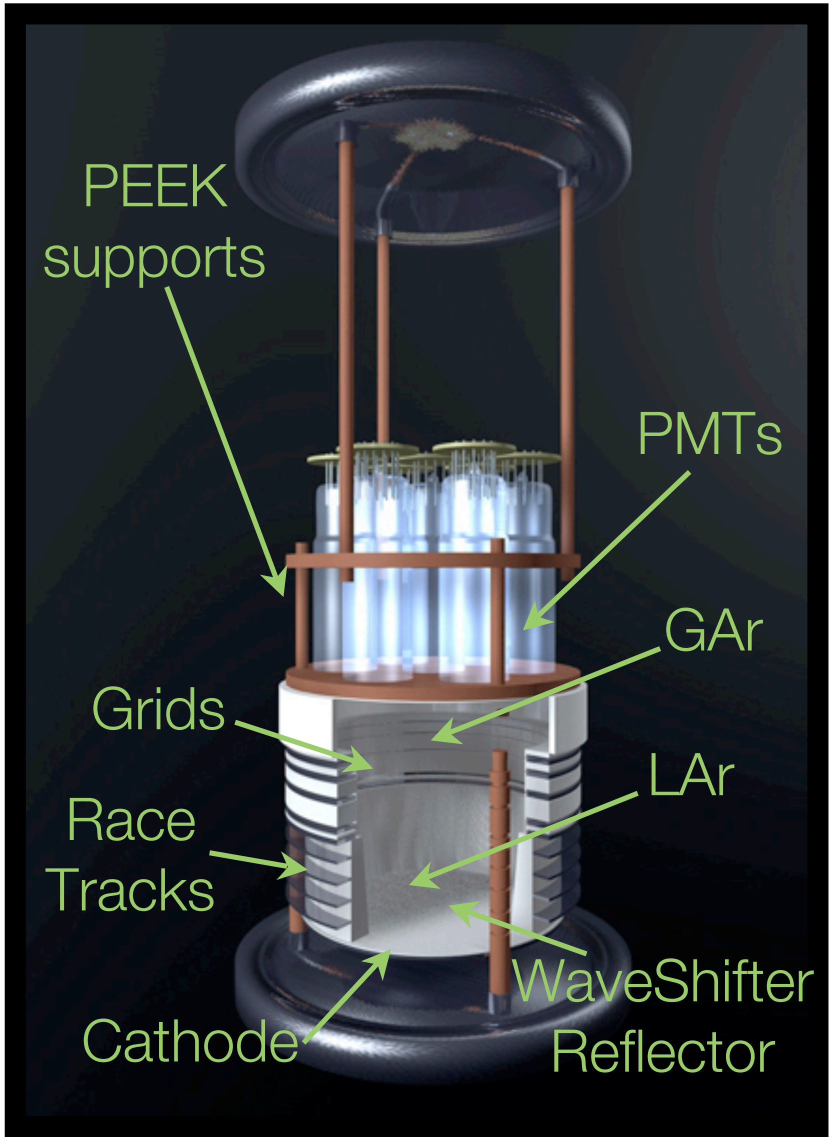


2.3 l prototype

2.3 liters

The prototype is a double phase Argon chamber. It reproduces the conceptual design of the 100 l sensitive volume:

- Equipped with seven 2” PMTs manufactured by ETL to work at 87K*.
- Field shaping electrodes and a set of grids to provide ionization electrons extraction and light multiplication in gaseous phase. To increase light collection, the sensitive volume is surrounded by a VM2000+TPB layer to shift the VUV wavelength to a visible one and then to reflect it.



*ICARUS Coll: P. Benetti et al., NIM A 505 (2003)

The detector is contained in a vacuum tight stainless steel container, equipped with a recirculation system to provide a high Ar purity (<1 ppb O_2 *equiv.*) and hence a stable electron lifetime*. It is completely immersed in a LAr bath.

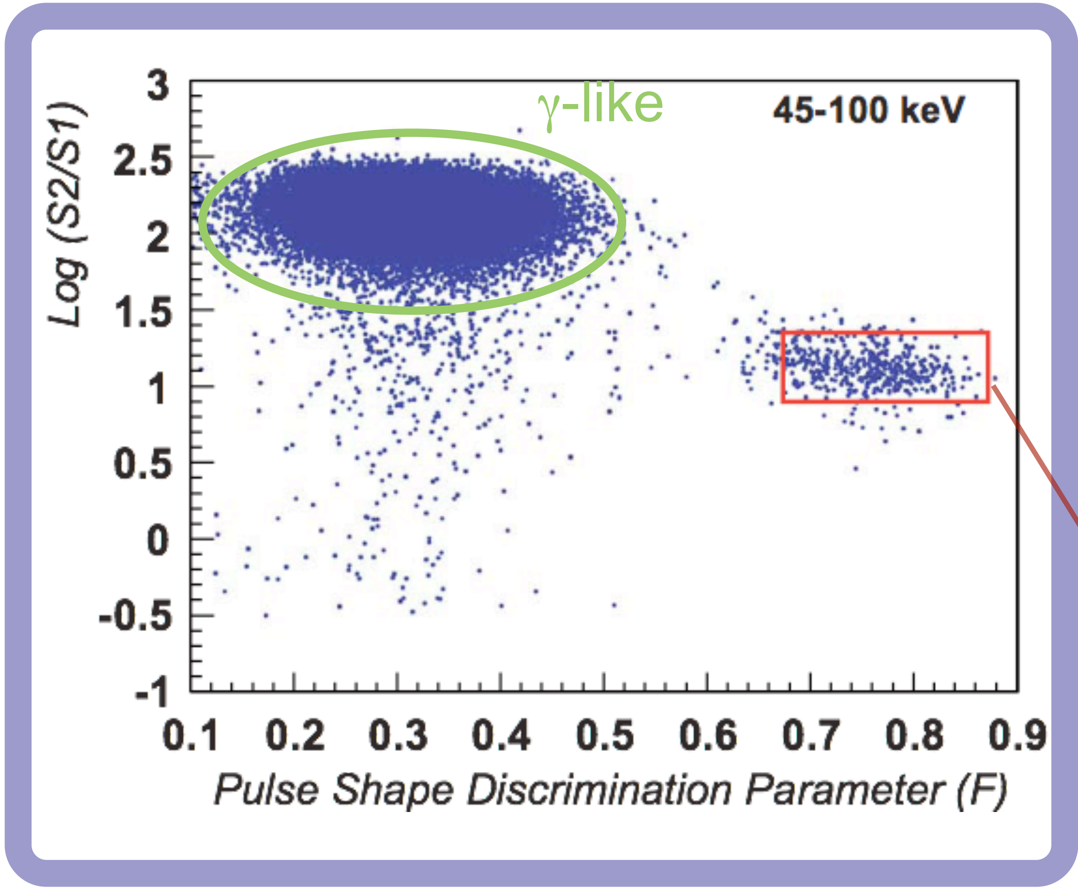
2.3 liters

A lead (10 cm) and polyethylene shielding (60 cm) surrounds the bath dewar.

The signal from each PMT is sent to a charge preamplifier (40 ms shaping time) and recorded when the trigger hits.

The trigger requires that ≥3 PMTs detect at least 1.5 photoelectrons (hardware threshold of about 5 keV_{ion}).

*Icarus Coll.: Icarus Proposal, LNF-89/005(R) (1989);
S. Amerio et al., NIM A 527 (2004);



The Ar-recoil events can be beautifully identified in the plane S2/S1 vs F (fast component fraction) by

- simple selection on F and
- energy dependent selection on S2/S1 (see next slide)

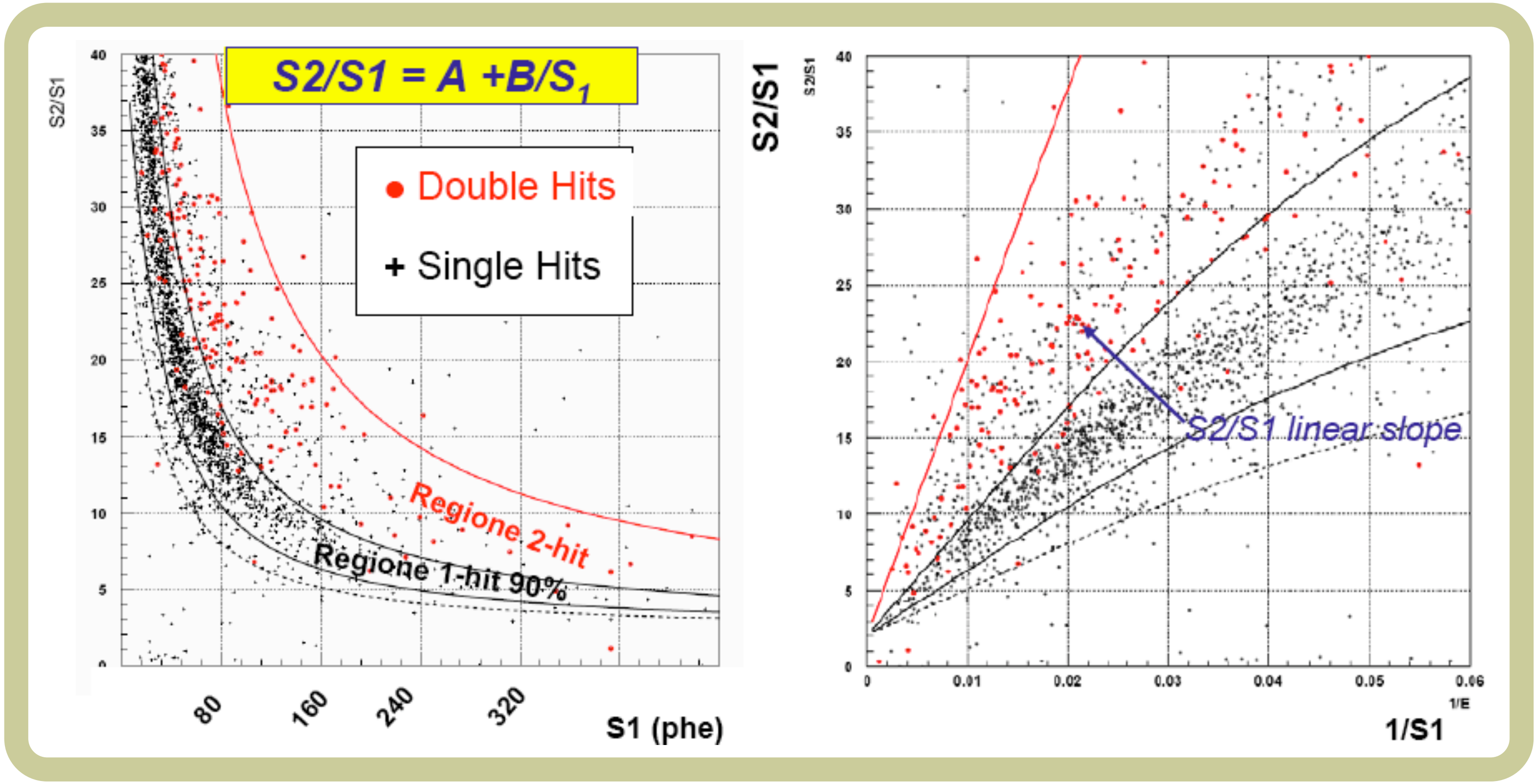
Ar-recoil indicative red box (energy dependent):

8<S2/S1<22

0.68<F<0.87

Neutron-induced Ar recoils
(Am-Be calibration source)

Ar-recoil selection region



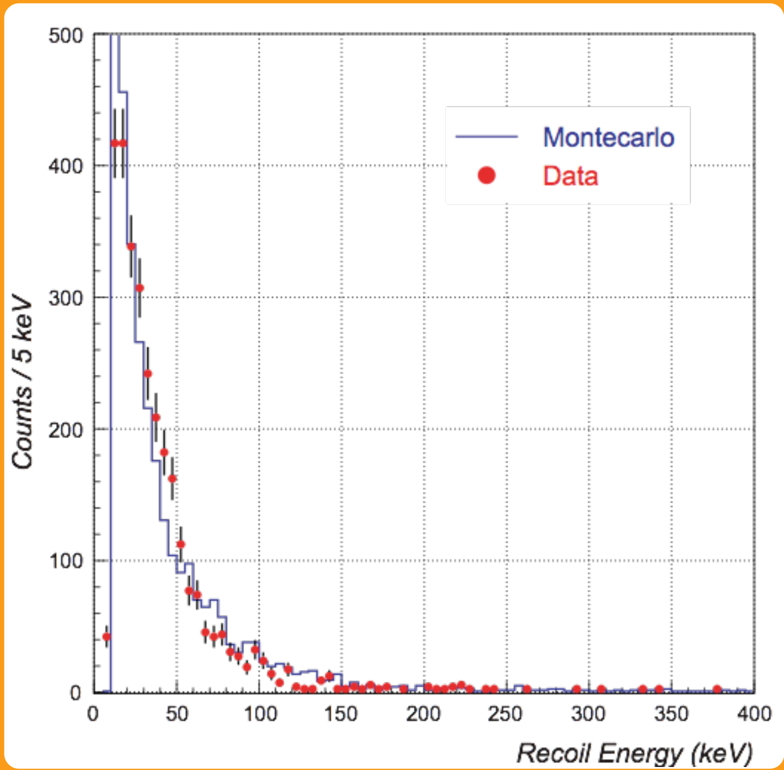
Defined a **single recoil identification band** (90%)

Experimental observations show that:

i) S2/S1 for Ar-recoils higher than for α (typ. $\approx$3)

ii) S2/S1 is inversely proportional to the recoil energy

Nuclear recoil photoelectron yield



Y_{Ar}=(1.65±0.25) phe/keV

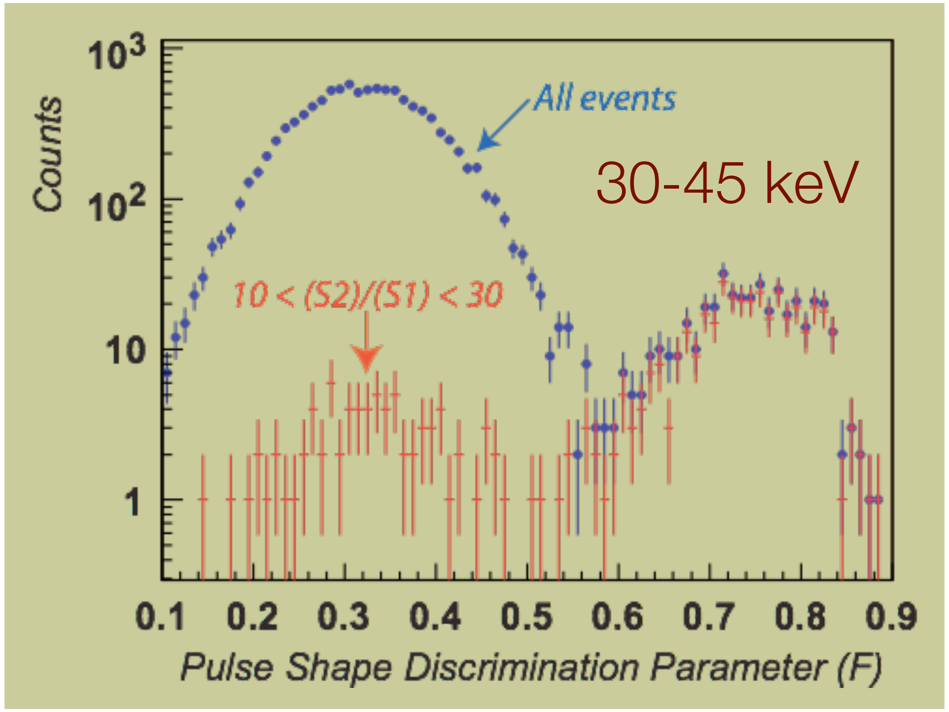
The Am-Be neutron-induced recoil spectrum is compared with MC predictions. We accept only events in the single recoil band.

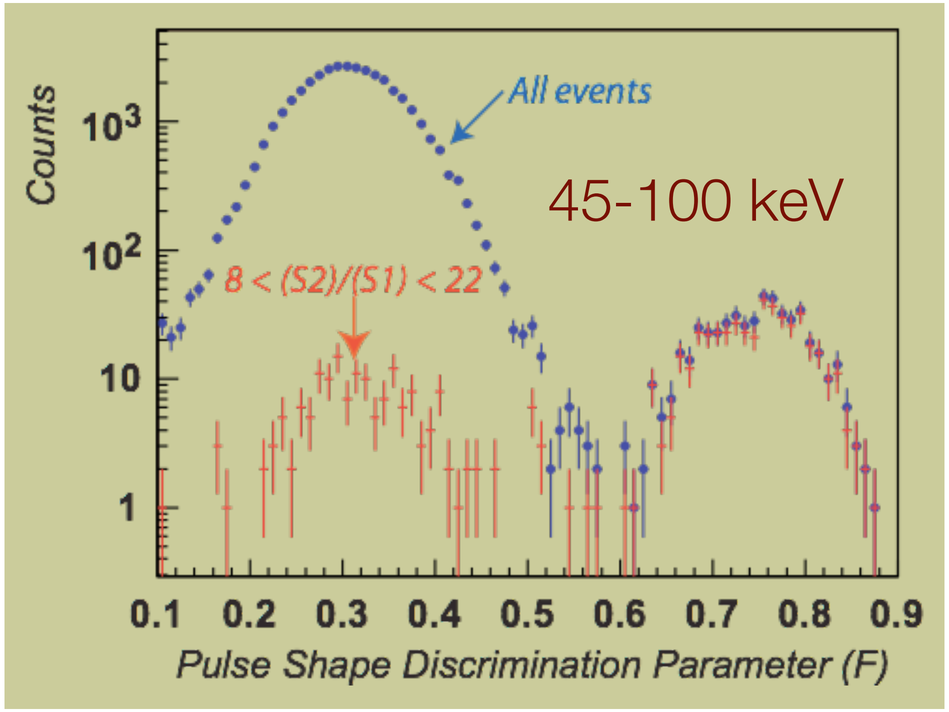
Checks are needed to verify the consistency with results claimed by other collaborations for the ratio of nuclear to electron yields (quenching).

Our estimate is being further verified.

Additional measurements with neutron sources underground, and a new measurement with monoenergetic neutron beam at an accelerator are foreseen to complete the job.

Effect of S2/S1 cut

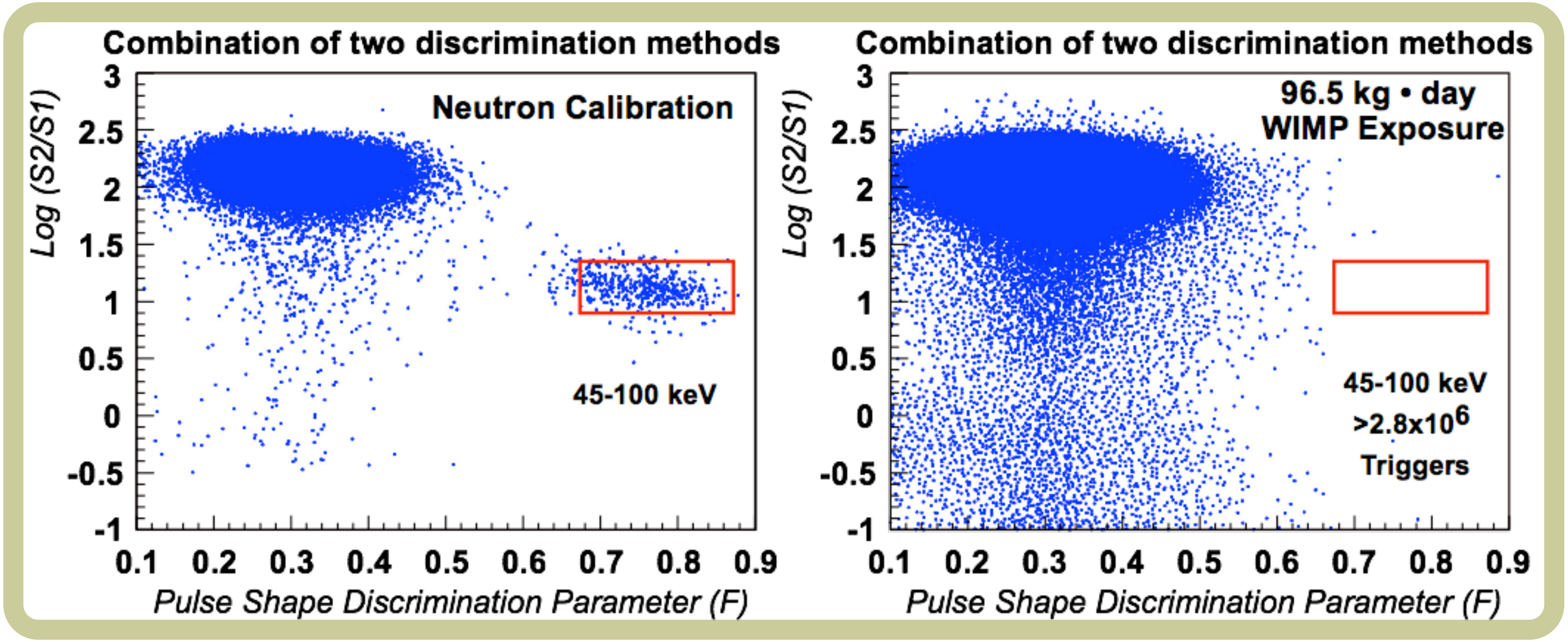




The effect of the S2/S1 ratio cut (energy dependent) is shown for neutron-calibration data.

- It strongly depletes the γ-like population (F<0.6);
- It leaves the Ar-recoil population unaffected (F>0.6)

exposure of 96.5 kg x day 45-100 keV



Selected events in the n-induced single recoils window:

None

The Need for both identification methods

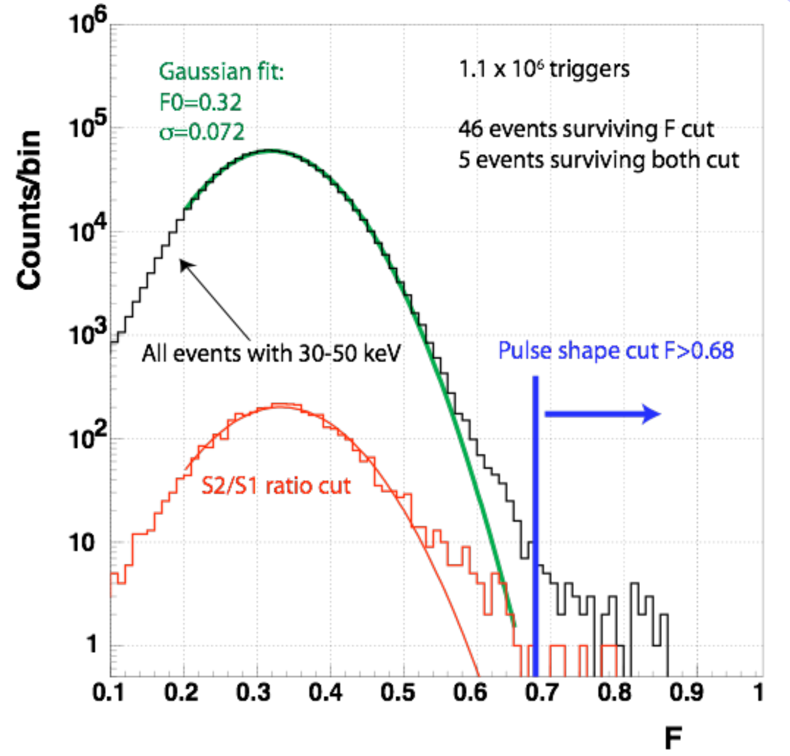
The effect of both discrimination techniques is summarized in the plot for all the events from a run with an exposure of 96.5 kg x day falling in the range 30-50 keV_{ion}.

The background to Ar-recoils surviving the F cut is constituted of spurious physical events whose rate is orders of magnitude higher than that expected from statistical fluctuations of the γ-like population*.

Measured S1 Shape Rejection Power F>0.68:

30-50 keV_{ion} = 3.7×10^{-5}

50-100 keV_{ion} = 1×10^{-6}



*Calculated for zero fields in
A. Hime and M.G.Boulay, Astrop. Phys. 25 (2006), 179

Results of WIMP search

Since the Form Factor for Argon is not too steep, gold-plated high energy recoils are not completely suppressed and even with an analysis threshold of about 40 keV_{ion} a sensitivity comparable with the most performing “milli-kelvin” experiments (CRESST, EDELWEISS, CDMS) can be reached.

For WIMP-induced recoils it is assumed that the selection cut efficiency is similar to the one measured for Am-Be calibration (90% above 40 keV_{ion}). The following cuts have been applied:

- Fiducial volume cut (10 $\mu s < t_{drift} < 35$ μs);
- Pulse shape discrimination $0.68 < F < 0.87$;
- S2/S1 ratio falling in the neutron-induced single recoil band;
- Visual scanning to reject mis-reconstructed events.

Results of WIMP search 90% C.L upper limit

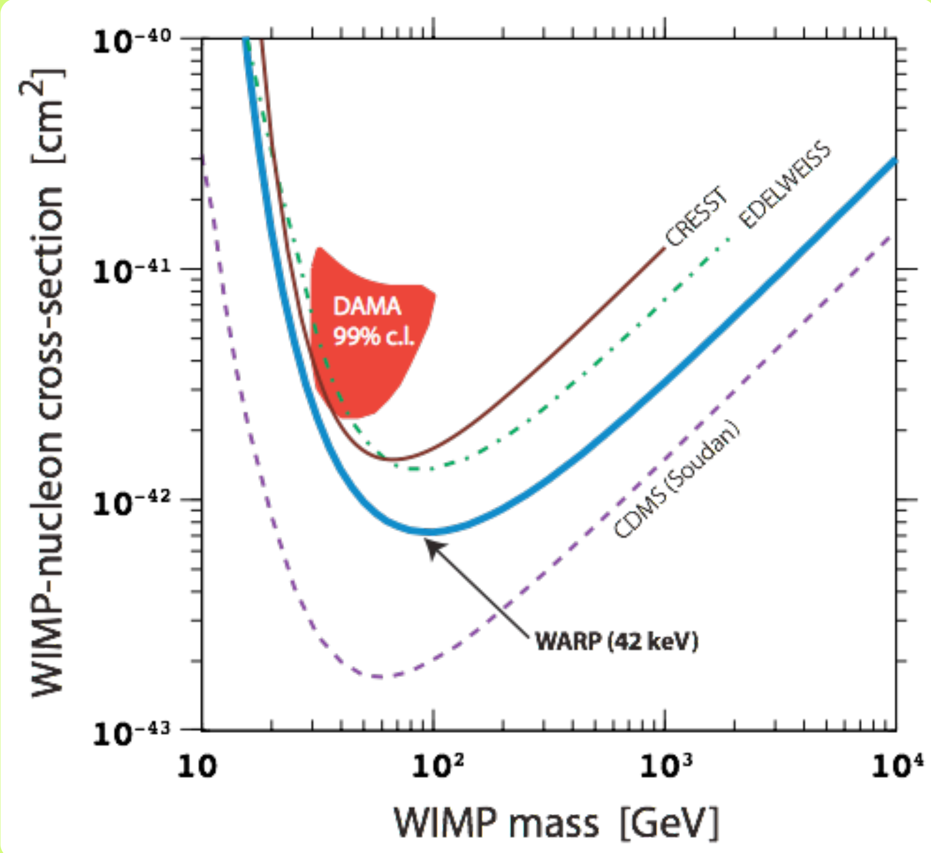
No recoil-like events are observed above 42 keV$_{ion}$ in a total fiducial exposure of 96.5 kg x day (2.8 x 10^7 triggers).

90% C.L. upper limit spin-independent interaction

(standard WIMP scenario)

Energy resolution due to statistical fluctuations and to a non uniform light collection has been taken into account.

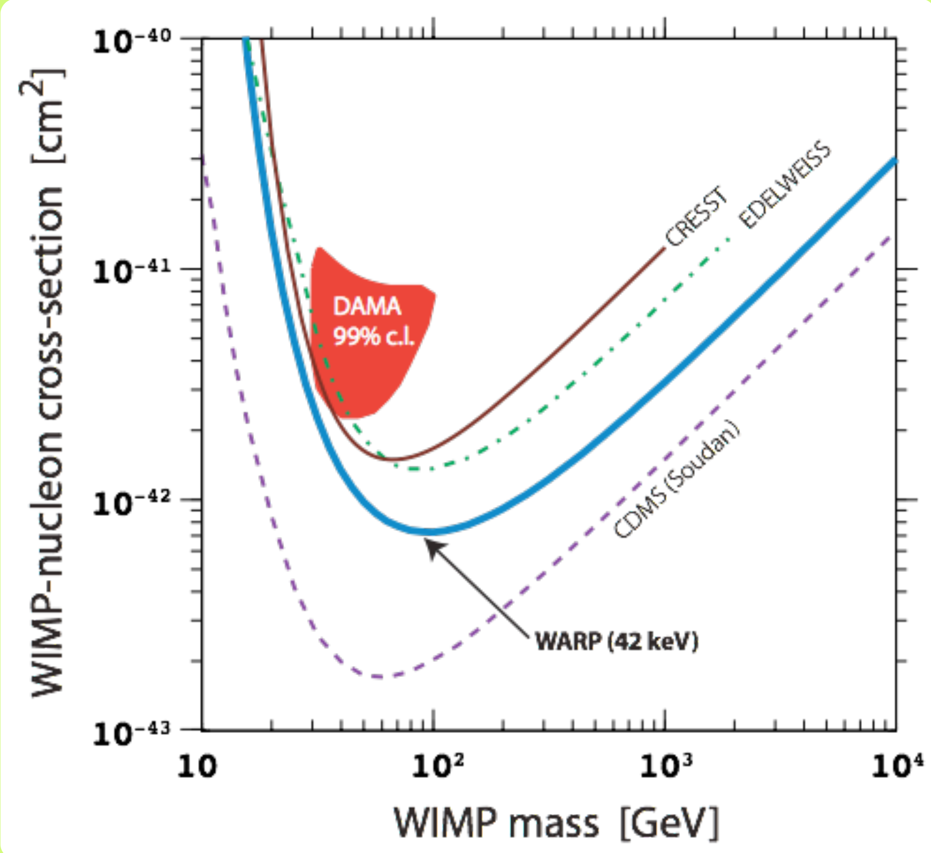
The dominant systematic effect is due to uncertainties on scintillation yield. An error of 15% on Y_{Ar} corresponds to a variation of 20% @ M_W=100 GeV /c^2 and of 30% @ M_W=50 GeV/c^2.



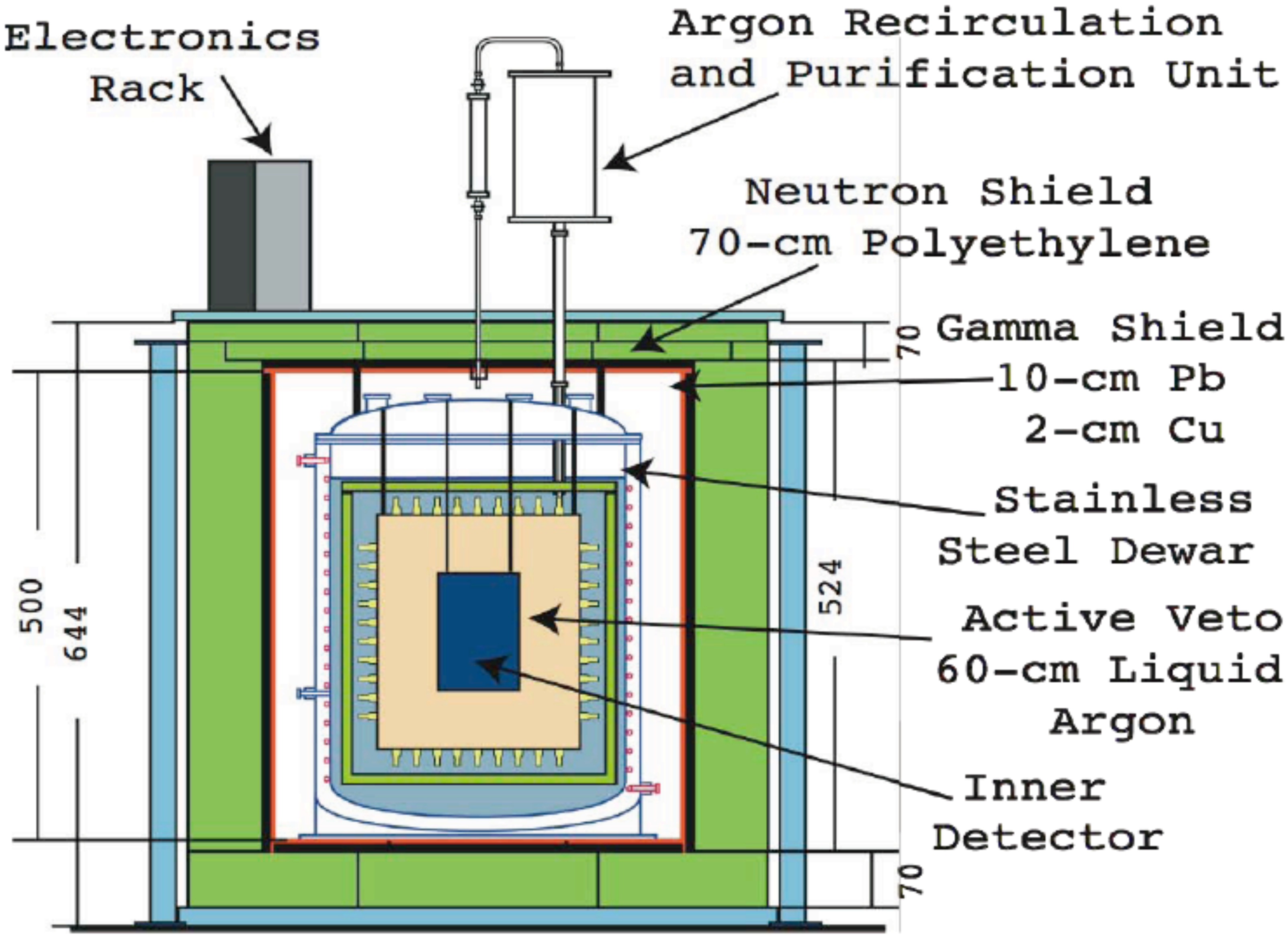
Results of WIMP search 90% C.L upper limit

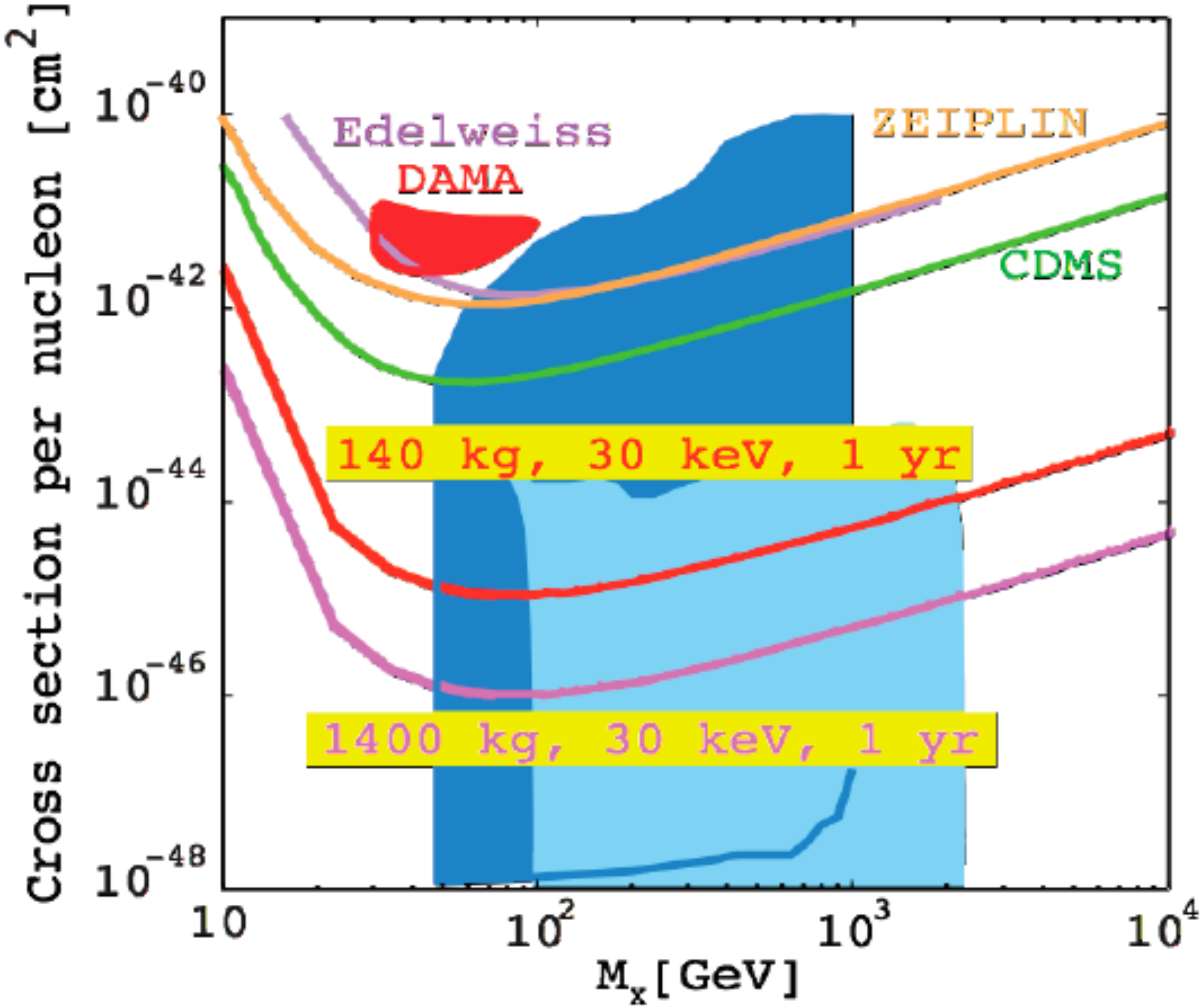
5 events are observed in the range 30-42 keV_{ion}

- To be ascribed either to residual neutrons or spurious events due to statistical fluctuations of the high level background
- Further improvement of the limit can be achieved using a lower analysis threshold and performing a background subtraction (presently under study)



WArP 100 liters





Expected Sensitivity

Thank you