Abstract. PICASSO at SNOLAB searches primarily for spin-dependent WIMP interactions on $^{19}$F using the superheated droplet technique. This technique is based on the bubble chamber principle, where phase transitions in superheated liquid droplets can be triggered by WIMP induced nuclear recoils. The physics of the detection process allows a highly efficient suppression of backgrounds from cosmic muons, $\gamma$- and $\beta$-rays. We will discuss qualitatively recent progress in PICASSO and its sensitivity reach for spin-dependent and spin-independent WIMP searches.

1. Introduction
PICASSO (Project In Canada to Search for Super symmetric Objects) is an experiment searching for cold dark matter through the direct detection of WIMPs primarily via their spin-dependent interactions with nuclei. It uses a superheated liquid fluorocarbon, C$_4$F$_{10}$, as the target material and searches for WIMP interactions on $^{19}$F using a variant of the classic bubble chamber technique. $^{19}$F is, next to free protons and $^3$He, the most favorable nucleus for direct detection of spin-dependent interactions. The nuclear form factor of $^{19}$F enhances the signal by nearly an order of magnitude compared to other frequently used targets (Na, Si, Al, Cl). Also, the expectation values for the nucleon spin can be predicted with good precision in $^{19}$F. Moreover, the use of the light target nucleus $^{19}$F together with a low detection threshold of $\approx 1$ keV for recoil nuclei, renders PICASSO particularly sensitive to low mass WIMPs (below 20 GeV/c$^2$). This feature gives PICASSO some sensitivity in the region of the spin-independent sector where recently the CRESST, DAMA/LIBRA and CoGeNT collaborations reported an excess of events and annual count rate modulations, respectively [1,2,3].

2. The superheated droplet technique
The detector medium in PICASSO is a polymerized water saturated emulsion of C$_4$F$_{10}$ droplets about 200 $\mu$m in diameter. Since C$_4$F$_{10}$ has a boiling temperature $T_b = -1.7^\circ$C at a pressure of 1.013 bar these droplets are in a moderately metastable superheated state at ambient pressure and temperature. A heat
spike created by the energy deposition of a charged particle traversing a liquid droplet triggers a phase transition if the energy deposition occurs within a certain critical length (of the order of hundreds of nm) and the deposited energy exceeds a certain critical energy (in the keV range). Details of the detector principle are explained in [4]. The phase transition is of explosive nature, such that each bubble nucleation is accompanied by an acoustic signal in the audible and ultrasonic region, which is recorded by piezoelectric transducers.

Since this type of detector records phase transitions, it performs as a threshold device and the energy threshold can be controlled by setting the temperature and/or the pressure. The dependence of the threshold energy on temperature was studied with mono-energetic neutron beams and the resulting calibration curve, which is shown in Fig. 1 (left) allows a precise description of recoil threshold energies ranging from 0.8 keV up to 800 keV [4].

3. Detector response to different particle species
Since each temperature at a given constant pressure corresponds to a defined recoil energy threshold, the spectrum of the particle induced energy depositions can be reconstructed by varying the threshold temperature. A summary is shown in Fig.1 (right) . WIMP induced recoil energies of $^{19}\text{F}$ nuclei are expected to be smaller than 100 keV and therefore become detectable above 30°C. Particles which produce only low ionization densities, such as cosmic ray muons, $\gamma$- and $\beta$-rays, become detectable when they create sub-keV energy clusters within sub-nm sized regions and only become observable above 50°C. These particles are well separated from strongly ionizing neutron- or WIMP induced recoils, which allows an efficient suppression of such backgrounds at the level of $10^{-8}$ to $10^{-10}$.

$\alpha$-emitters produce a different response. In Fig. 1 (right) the $\alpha$-curve with the lower threshold temperature (i.e. higher threshold energy) was obtained with $^{226}\text{Ra}$ spiked detectors. In this case the $^{226}\text{Ra}$ daughter, $^{222}\text{Rn}$, diffuses into the droplets and the $^{210}\text{Pb}$ nucleus with the highest recoil energy in the decay chain ($E_{\text{rec}} = 146$ keV) defines the threshold (upper red circle in Fig.1 (left)). The $\alpha$-threshold at higher temperature was recorded after spiking the inactive detector matrix with $^{241}\text{Am}$ such that only

![Figure 1.](image-url)

Figure 1. Left: Calibration curve for the energy threshold for $^{19}\text{F}$ recoils as a function of temperature obtained from measurements with mono-energetic neutron beams; $\alpha$- data are shown as open (red) circles. Right: Response to different kinds of particles in superheated $\text{C}_4\text{F}_{10}$. From left to right: $^{210}\text{Pb}$ recoil nuclei from $^{226}\text{Ra}$ spikes; $\alpha$-particles at Bragg peak from $^{241}\text{Am}$ decays; poly-energetic neutrons from an AcBe source (dotted); $^{19}\text{F}$ recoils modeled assuming the scattering of a 50 GeV/c$^2$ WIMP; response to 1.75 MeV $\gamma$-rays and MIP’s (dot-dashed).
alpha particles entering the droplets from the bulk can induce nucleation. This threshold corresponds to a deposited energy of $E_{\text{dep}} = 66$ keV and only alpha particles with energy depositions at the Bragg peak are able to trigger nucleation (lower red circle in Fig. 1(left)).

With increasing temperature, in both cases the liquid becomes sensitive at threshold energies $E_{\text{th}} < 66$ keV to smaller $dE/dx$ on the alpha track, but since the detector is already fully sensitive, the response levels off into a flat plateau. A more detailed discussion can be found in [4]. With the detector fully sensitive to alpha particles over the entire range of WIMP sensitivity, $\alpha$-particles are the most important background for this kind of detector in dark matter searches. However the shapes of the WIMP response (essentially exponentially falling) and of the alpha response (constant) differ substantially, such that they can be separated by fitting the two contributions.

4. PICASSO at SNOLAB

The present PICASSO installation at SNOLAB accommodates 32 detector modules. A group of four detectors is installed in each of the 8 thermally and acoustically insulated boxes, serving as temperature control units, where the temperature can be controlled with a precision of $\pm 0.1^\circ \text{C}$ in the range from 20$^\circ$ to 50$^\circ$ C. The entire installation is surrounded by a 50 cm thick water shield which serves as a neutron moderator and absorber; a dedicated $^3\text{He}$ counter measurement established that the fast neutron flux from the surrounding rock is decreased by a factor 400.

The current detector generation consists of cylindrical modules of 14 cm diameter and 40 cm height as shown in Fig.2 (left). The containers are fabricated from acrylic and are closed on top by stainless steel lids sealed with polyurethane O-rings. Each detector is filled with 4.5 litres of polymerized emulsion loaded with 200 $\mu$m diameter droplets of $\text{C}_4\text{F}_{10}$. In the most recent detector generation the emulsion has glycerine and polyethylene glycol as its main ingredients. The best detectors have an $\alpha$-background at the level of 20 cts/kg/d (kg of $^{19}$F). The active mass of each detector is typically around 85 g of $\text{C}_4\text{F}_{10}$ corresponding to 65g of $^{19}$F. Each detector is read out by nine piezo-electric transducers. Details on detector operation and read-out are summarized in [5].

5. Data taking and analysis

Data have been taken with this set-up continuously from November 2008, with interspersed periods of maintenance, calibrations and a period of moving the experiment to a new location at SNOLAB in fall 2010. Roughly every three months neutron calibration data have been taken at several temperatures with a weak AmBe source (69 s$^{-1}$) to monitor the stability of the detectors and determine cut-efficiencies for discrimination variables. The count rates of all detectors show a flat plateau in the range from 1 to 60 keV 25$^\circ$ to 48$^\circ$ C (or between 60 down to 1 keV), consistent with the presence of
a pure alpha background (Fig.1(right)). An upper limit on the cross-section on $^{19}$F is obtained by fitting the WIMP response curve and the flat alpha background. By fall 2011 the still ongoing analysis reached a sensitivity at the level of a few cts/kg/d. Given this sensitivity and the low detection threshold of $\approx$ 1 keV for the light $^{19}$F recoil nuclei, PICASSO is particularly sensitive to low mass WIMPs below 15 GeV/c. This is interesting since it is in this mass region where the DAMA/LIBRA channeling results remained unchecked in the spin-dependent sector. Moreover for spin-independent interactions PICASSO is approaching the sensitivity to challenge or confirm the exciting recent claims of a positive effect by the CRESST, DAMA/LIBRA and CoGeNT collaborations [1,2,3].

6. Next: event by event $\alpha$-recoil discrimination

In previous studies the PICASSO collaboration showed that the acoustic signals contain information about the nature of the primary event: it was observed that the acoustic signals produced by $\alpha$- emitters are a factor four more intense than signals of neutron or WIMP induced events [6]. This result has been confirmed by COUPP [7] and a theoretical model proposed by us is discussed in [4]. An important next step in PICASSO is the full implementation of this discrimination technique. Fig. 3 (left) shows results obtained with n-calibration and WIMP data and 400 kHz sampling. Events were reconstructed with a localization algorithm, which allowed for gain and solid angle corrections. The obtained amplitude resolution is 30% FWHM and for a nuclear recoil acceptance of 80% an alpha particle rejection of 99.34% could be established. Fig.3 (right) displays the same two categories of events but recorded with modified preamplifiers, adjusted filtering and 800 kHz sampling. Assuming the present exposure and an $\alpha$-reduction by a factor 100 we expect an improvement of sensitivity to better than $\approx$3x$10^{-5}$ pb in the SD sector and $\approx$7 x $10^{-6}$ pb in the SI sector.

References
[1] G. Angloher et al., arXiv:1109.0702
[2] R. Bernabei et al., Eur. Phys.J.C67 (2010) 39
[3] C.E. Aalseth et al., Phys. Lett.106 (2011) 131301
[4] S. Archambault et al., New J. Of Physics 13 (2011) 043006
[5] S. Archambault et al., Phys. Lett. B 682 (2009) 185
[6] F. Aubin et al., New Journal of Physics 10 (2008) 103017
[7] E. Behnke et al., arXiv:1009.3518v2; W.H. Lippincott, these proceedings