DARK MATTER: A NEW DETECTOR, THE GEYSER

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January 14, 2015

Abstract

The MOSCAB experiment (Materia OSCura A Bolle) uses a new technique for Dark Matter search. The Geyser technique is applied to the construction of a prototype detector with a mass of 0.5 kg and the encouraging results are reported here; an accent is placed on a big detector of 40 kg in construction at the Milano-Bicocca University and INFN.

1 INTRODUCTION

WIMPs (Weak Interacting Massive Particles) are one of the more suited hypothesis for the non-baryonic candidate of dark matter ; they indeed satisfy the required density compatible with the cosmological constraints; they form galactic halos with a Maxwellian velocity distribution around a mean value of about 230 km/s and with a matter density of about 0.3 GeV/cm^3 at the location of the solar system.
In this talk I will present a new experimental device to search for WIMPs: the Geyser.

Figure 1: Sketch of a Vertical section of the Geyser

2 DESCRIPTION OF A GEYSER

The "old" glorious Bubble Chambers(B.C.) worked following the phenomena described by Glaser [?] and Seitz [?]; these bubble chambers worked on beams from a accelerators and were ready to reach the right superheated condition when the beam passed through; the seen bubbles were destroyed by a succesive compression of the liquid.
Furtheremore the bubble chambers were used at very high superheated degree to see also the minimum ionizing particle (gamma and electrons).
This behaviour is not useful to search WIMPs; indeed it impossible to foreseen the passage of a Dark Matter Particle! Furtheremore gammas and electrons constitute an important background for WIMPS.
Two improvements were done now:
1)By using ONLY weak superheated states it is possible to keep a bubble chamber sensitive for long periods of time.
2)In such conditions the gammas and electrons are not seen by the bubble chamber(so eliminating an important background for Dark Matter).
The Geyser has these advantages and furthermore does not need a recompression for eliminate the residual bubbles; this is indeed automatic.

In Fig. 1 the sketch of the vertical section of our prototype Geyser is shown:
The Geyser is divided in two parts kept at different temperature:
1)The higher parts contains the vapour (f.i. in our case freon C3F8 at 18 C)
2)The lower part contains liquid freon superheated (f.i. at temperature of 25 C); between these 2 phases a "buffer" liquid (in our case Glycol) is inserted to take the temperatures different.
3)The vapour pressure is practically transmitted to the liquid freon.
The liquid is contained in a quartz vessel; everything is immersed in a plexiglass cilinder containing water; the water is kept by two

thermostats at the choosen temperatures(f.i. 18 C and 25 C) by cupper coils indicated in the figure by small circles; in the high region a pressure equalizer(an elastic rubber membrane) is also visible to take the pressure of the water similar to that of the vapour).
When a bubble is nucleated in the liquid the inner vapour corresponds to the temperature of the liquid (higher) and increases its volume; for the Archimede's law the bubble goes up, cross the Glycol and reach the freon vapour (where the temperature is lower); here the bubble recondenses and goes down for gravity reaching its original condition. Every thing happens without an external operation. It is AUTOMATIC!

The degree of superheat applied must exclude the detection of minimum ionizing particles (electrons and γ rays) and on the contrary it must allow the detection with high efficency of the recoiling ions.

The principal advantages of the Geyser (and of the Bubble techniques) are the following:

1)The strong rejection of the particles of minimum ionization (electrons and γ).

2)The simplicity of the mechanical construction, important for large size detectors and therefore low cost.

3)The very interesting possibility to count multiple neutron interactions and hence subtract the neutron background (the interaction length of a neutron is of the order of (6-9) cm in our liquid). The double or triple interaction in the same frame can be used statistically to evaluate the number of events with a single interaction due to neutrons.

4)The possibility to distinguish the spin dependent interaction of WIMP from spin independent by changing the liquid used.

5)For the Geyser (ONLY) the reset of the detector is automatic and has a very short time (few seconds).
A prototype of Geyser has been constructed with a mass of 0.5 kg in Milano-Bicocca [**?**].

Figure 2: Evolution of a bubble (starting from Lower-Right picture)

With reference to the Fig.1 the quartz vessel of 0.33 liters is immersed in a water bath and it is surrounded by Cu coils with an internal circulating water at the two fixed temperatures.
It contains freon C_3F_8 around 25^0C at a pressure of about 6 bar. The hot freon is separated from the cold freon vapour by the neck of the vessel filled by a buffer liquid (Glycol) with an high thermal capacity.

After an interaction with a neutral particle like a neutron or a WIMP the scattered ion deposits its energy in very small regions (size of the order 0.05-0.1 micron).
In these conditions a bubble can grow and reach a few mm of radius (well visible, see Fig. 2).

Two professional digital cameras monitor in a continuous way at 50 frames per second (fps) the volume in the freon vessel.
Some pixels undergo a change of luminosity when a bubble is generated.
At this point a trigger is launched and a stream of pictures is registered (between -50 and + 50 frames starting from the trigger). After that, the stream of data is stored and visually scanned to see the evolution of the bubbles.

3 RESULTS FROM THE PROTOTYPE

We are working in Milano-Bicocca at the IV floor in a Laboratory provided by the University and INFN.

Bubble formation is well understood [?] and depends on the critical radius $R_c = 2\sigma/\Delta p$, where σ is the surface tension of the

Figure 3: dE/dx for ions and electrons

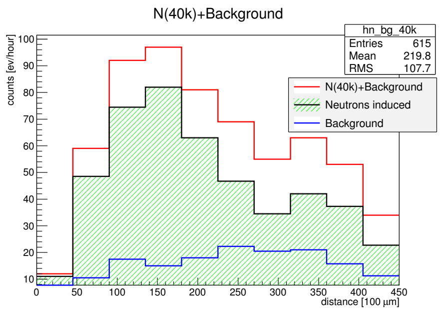

Figure 4: Background and a neutron source

liquid andΔ p the pressure difference between the vapour inside the bubble and the liquid.
Another important quantity is the critical energy E_c necessary for visible bubble formation.
E_c is a function of R_c, σ, Δp and the latent heat of evaporation of the liquid.
In Fig.3 is shown the energy loss dE/dx for C and F ions and also electrons.

Therefore if the energy of recoil is greater than E_c(the critical energy) and stopping power satisfises the relation $(dE/dx)2R_c > E_c$, then a bubble will form. In Fig.3 we show also several sensitivity zones for various vapour temperatures and liquid-vapour temperature differences DT; the experimental regions in which we must work are indicated by the boxes.

I said that the characteristic of a Geyser must be a high rejection

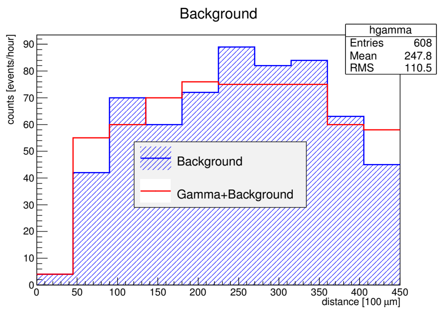

Figure 5: Background and a gamma source

Figure 6: Comparison with the events-Integrated Distribution and (green line) MC + Background

of electrons and γ accompanied by an easy detection of nuclear recoils(similar to the recoiling ions due to an interaction of a WIMP).
To test this point, we placed outside the detector (at a minimal distance from the freon) a neutron source ($Am-Be$ -40 kBq).The results are shown in Fig.4 and we can see that we are very sensitive to the detection of neutrons.
After that we put a gamma rays source (20 kBq ^{22}Na) near the detector and in Fig.5 are shown the background distributions and that obtained with a Gamma source (Na^{22}).
We can remark that in the latter case we obtained compatible results: no excess in events in presence of the radiative source!

In order to compare our data to what is expected from the neutron source we have performed Monte-Carlo calculations using the MCNP package coming from Los Alamos [?].

In Fig.6 we compare the distribution (M.C. results + the meaured background) with the corresponding experimental distribution and we can see a very good general agreement with a threshold of 5 keV; the reported errors are the statistical errors only.

We remark that in the SD case, our sensitivity could be much better (by 4 order of magnitude)than that obtained for the results pubblished by PICASSO,COUPP and Xenon100.

4 Conclusions

A new technique for the direct investigation of Dark Matter has been developed. The good results obtained with a Geyser prototype (with a low threshold= few keV) motivate the construction of larger detector of this type and the 40 kg detector will be ready as soon as possible to obtain very good physics results at the LNGS.
We also would like to claim that this kind of detector would be useful in a neutrino beam to investigate the interaction $\nu + C = \nu + C$.

References

[1] D. Glaser Some effect of Ionizing Radiation on the formation of Bubbles in Liquid. P.R. 87(4):665 (1952)

[2] F. Seitz On the theory of the Bubble Chamber Phys. Fluids 1,2 (1958)

[3] L. Baudis (Direct Dark Matter Searches-Rapporteur Talks) 'New Opportunities in the Physics Landscape at CERN', CERN May 11-13-2009 CERN.

[4] D.V. Bugg 'Progress in Nuclear Physics' Pergamon Press -London,1959 Vol.7,Pag.1.

[5] Manual (mcp) A general Monte Carlo N-Particle trasport Code, Version-5,2008.