.

TAUP TORINO Settembre 2015

2015 8 April (Presented by A. Pullia)

INTRODUCTION

The general form of WIMPs interaction with ordinary matter is:

$\sigma(A) = 4G_F^2 ((M_W M_A)/(M_w+M_A))^2 C_A F(q^2)$ C_A=Coupl. Const. of Wimp to nucleus A

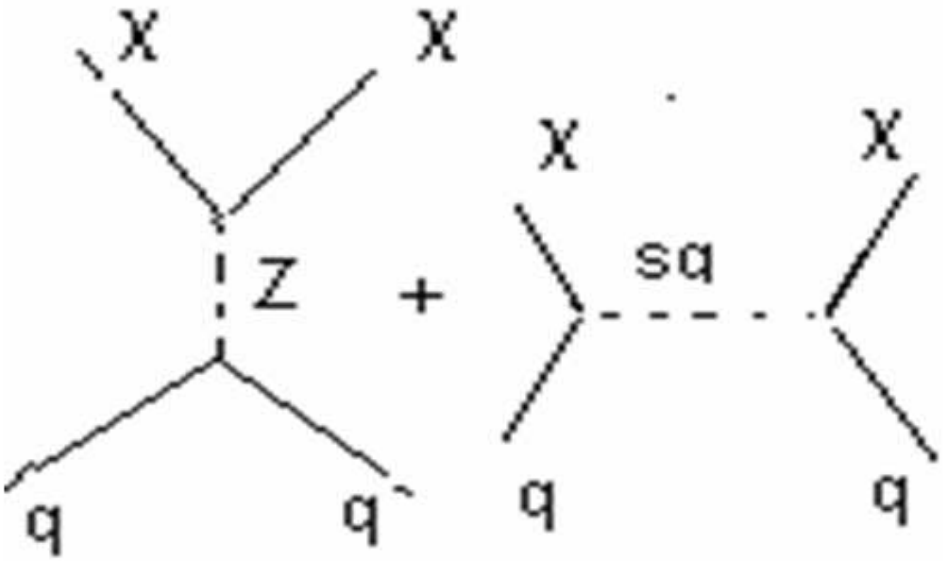
.In Supersymmetry the SPIN-INDEPENDENT (SI) or scalar interactions, proceeds via Higgs or squark exchange or both and C_A is given by:

$C_A(SI)= (1/(4\pi))[Z*fp + (A - Z)*fn]**2$ (Enhancement factor)

fn,p are the WIMP coupling strengths to nucleons.
On other hand SPIN DEPENDENT Interaction (SD) with axial-vector coupling, involve squarks and Z exchanges and the

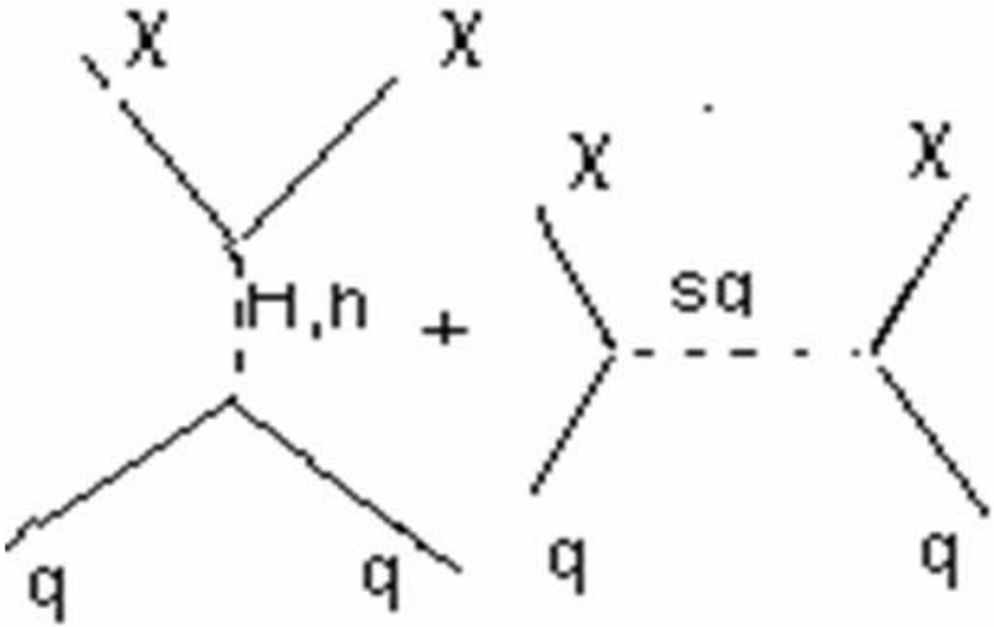
$C_A(SD) = (8/\pi)[Ap*Sp + An*Sn]**2 ((J + 1)/J)$

where Sp,n are the average spins over all protons and neutrons; Ap,n are the effective WIMP proton(neutron) coupling strengths and J is the total nuclear spin. THE ENHANCEMENT FACTOR FOR SD INTERACT. IS THE LARGEST for nuclei of F19!



axial-vector spin dependent

S.D.



Scalar scattering on q

Spin independent

S.I.

56

$$CA=(8/\pi)[Ap\ Sp + An\ Sn]^2\ (J+1)/J)=\lambda^{**}2(J+1)/J$$

Enhancement factor for SD reactions

Isotope	Spin	Unpaired	$\lambda^{**}2$
Li7	3/2	p	0.11
F19	1/2	p	0.863
Na23	3/2	p	0.011
Si29	1/2	n	0.084
Ge73	9/2	n	0.0026
I127	5/2	p	0.0026
Xe131	3/2	n	0.0147

DESCRIPTION OF THE EXPERIMENT

In the following I will describe:

- 1)The new technique we are using (The Geyser or the Superheated Technique)
- 2)The status of the experiment and results from the Prototype (0.5 L)
- 3)Background
- 4)The design and construction of a larger detector (40 kg)
- 5)The future of the experiment (in the INFN Laboratory at Gran Sasso)

VERY SHORT SUMMARY ABOUT the BUBBLE NUCLEATION

1)BUBBLE NUCLEATION

-In a superheated liquid a charged particle passing through, can produce a bubble nucleation with a thermal spike(due to the small electrons emitted).
-There are two opposite effects :
a) the pressure of the gas inside the bubble(at higher temperature) and outside; this effect try to increase the bubble size
b) the surface tension that try to close the bubble.
-When the two effects balance themself a critical radius is reached
-The old Bubble Chambers(GGM,BEBC etc.)were ready to make an expansion when the accelerated particle beam passed through; so the B.C. were not continuous detectors.

TWO IMPORTANT " NEWS"

1)It is NOW possible to reach indefinitely long stability in moderately superheated Bubble chamber J.Bolte NIM A577,569 (2007)

2)Different degree of the superheated state correspond to different sensitivities for different particles.

These considerations have brought to 3 different techniques for DARK MATTER SEARCH:

I)Bubble Chambers Continuosly Sensitive (See COUPP)

II)S.D.D. (**S**uperheated **D**roplet **D**etectors) (PICASSO)

III)The "GEYSER" detector (MOSCAB Milano-Bicocca and Montreal-PICASSO)

This kind of deterctor (Geyser) has never been realized for the Elementary Particle Physics (it was constructed once in BERNA in 1964 by Hahn and Reist to detect transuranic nuclei.

The Geyser is substantially a Vessel consisting of a "FLASK" containing a superheated liquid (f.i. some kind of freon) and a "NECK" (containing partially a separation liquid and partially the freon vapour).
The Geyser was realized in Milano by setting the two different parts of the detector (flask and neck, filled in our case by freon C3F8), **at different temperatures**.

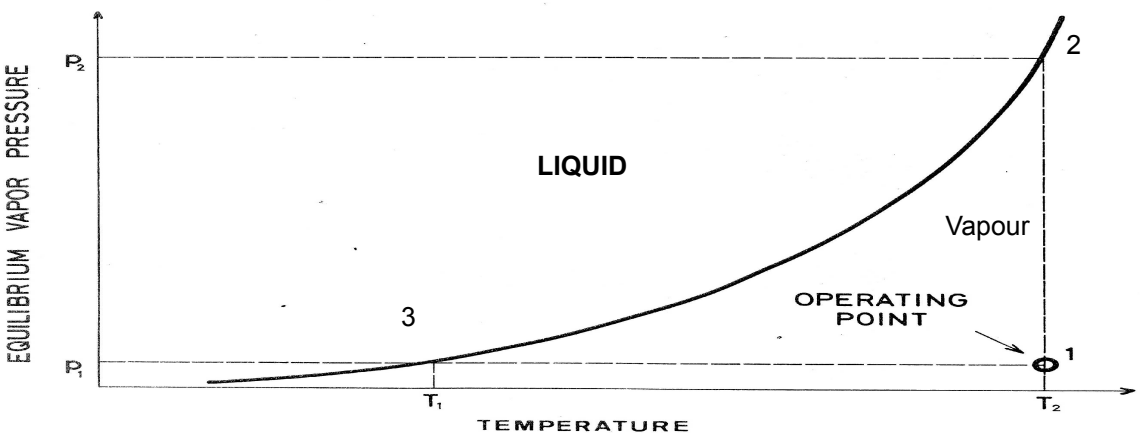
The part of the overheated liquid was kept at higher temperature (f.i. 25 degree) and the gaseous part was kept at lower temperature (f.i. 18 degrees).

The overheated liquid was in condition of **WEAK** superheat so that it was insensitive to the minimum ionizing particles like electrons, but well sensitive to the recoiling ow energy ions.

In these conditions the ions deposit their energy in a very small region (size of the order 0.05-0.1 micron); a bubble can grow and reach ~ 1 mm of radius (well visible).

Figure 3: Internal view of the Prototype of Geyser

A local energy release due, for instance, to a recoiling ion induced by a WIMP interaction, can produce a vapor bubble which can grow (if over a threshold in energy) to visible size.
This vapor bubble rises in the liquid and pushes up part of the liquid in the neck(this is the reason of the name Geyser).
When the equilibrium pressure is reached the hot vapor in the top of the vessel recondenses, and the liquid returns into the main volume. The original metastable state returns in a few seconds and the system is ready to record a new event. The system doesn't require external interventions or recompressions. This is Ideal Cycle of a Geyser.



Furthermore the degree of superheat must be adjusted in such a way to exlude the detection of MIP (like electrons and γ) and on the contrary to detect with high efficency recoilinng ions.

So the principal advantages of the Geyser and the B.C. are the following:

1)The strong rejection of the MIP particles.

2)The simplicity of the mechanical construction(for Geyser) also for for large size Detectors.

3)The very interesting possibility to count neutron's interactions and to subtract this background (the interaction length of a neutron is of the order of 6 cm in our liquid) and so the double or triple interactions in the same frame can help statistically to evaluate the number of events with a single interaction due to neutrons. Clearly a WIMP has at maximum only one interaction.

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

The property 1) mentioned before is already tested (Rejection of ≃ 10^{11} of mip particles (see COUPP work));

2)STATUS OF THE EXPERIMENT AND RESULTS FROM THE PROTOTYPE

The project is based on 5 phases:
1)Construction and tests of a small prototype (0.5 kg) (already done)
2)Design and construction of a larger detector (40 kg) (already done)
3)Assembling and testing in Milano of the 40 kg detector (≃ realized)
4)Use of this detector in LNGS (to be done in the future)

Two important RESULTS FROM THE PROTOTYPE:
a)Nuclear Recoils were well recognized(as for WIMPS) and electron recoils(background) were not OBSERVED.;
b)Comparison with MC Calculation and the thermal spikes theory is satisfactory.

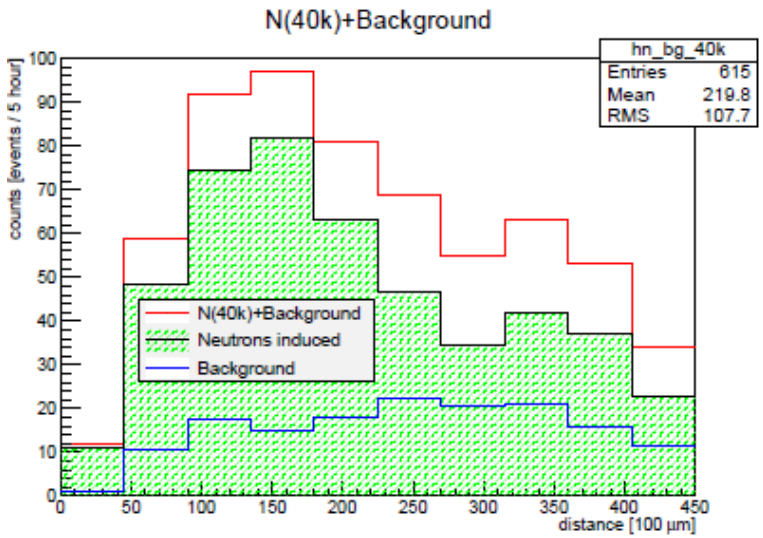
INVESTIGATION WITH THE GEYSER PROTOTYPE

1)Use of A NEUTRON SOURCE (Am-Be 40 kBq)

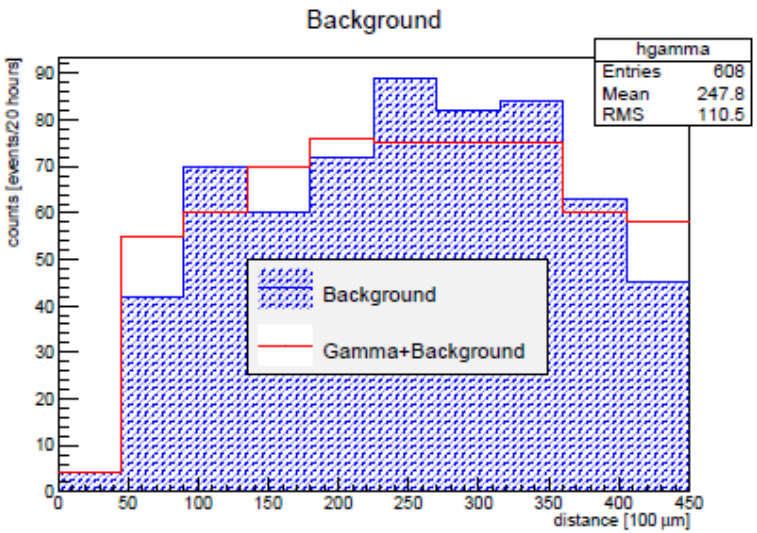
2)Use of a GAMMA SOURCE (^{22}Na)

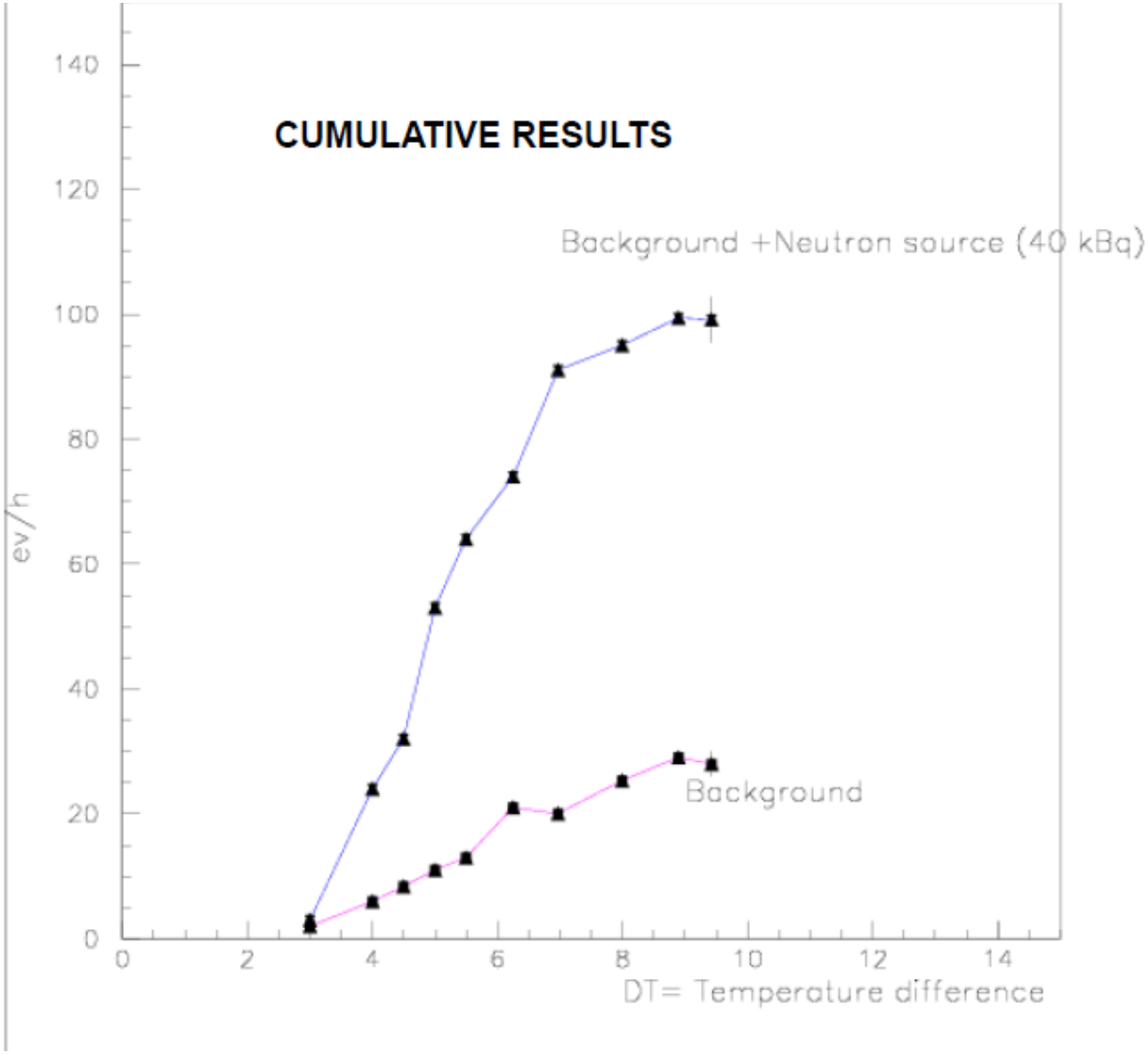
Two cameras were seeing in a continuous way (50 frames per second (fps)) the volume In the freon vessel.
Some pixels undergo a change of luminosity when a bubble is generated.
At this point a trigger was launched and a stream of pictures was registered (for Instance between -50 and + 50 frames starting from the trigger).
The evolution of a typical bubble observed in our prototype detector is shown in the following transparency.
After that, the stream of data was stored and visually scanned to check the bubbles.
The vessel (quartz or glass) was immersed in a water bath and it was surrounded by Cu coils with an internal circulating water at two fixed temperatures.
The temperature of the two regions of water were kept fixed by two thermostats with a precision of 0.1 degrees.
Everything was surrounded by a cylindrical vessel of plexiglass (thickness 1,5 cm).
The freon was illuminated by diffuse light, coming from LED.

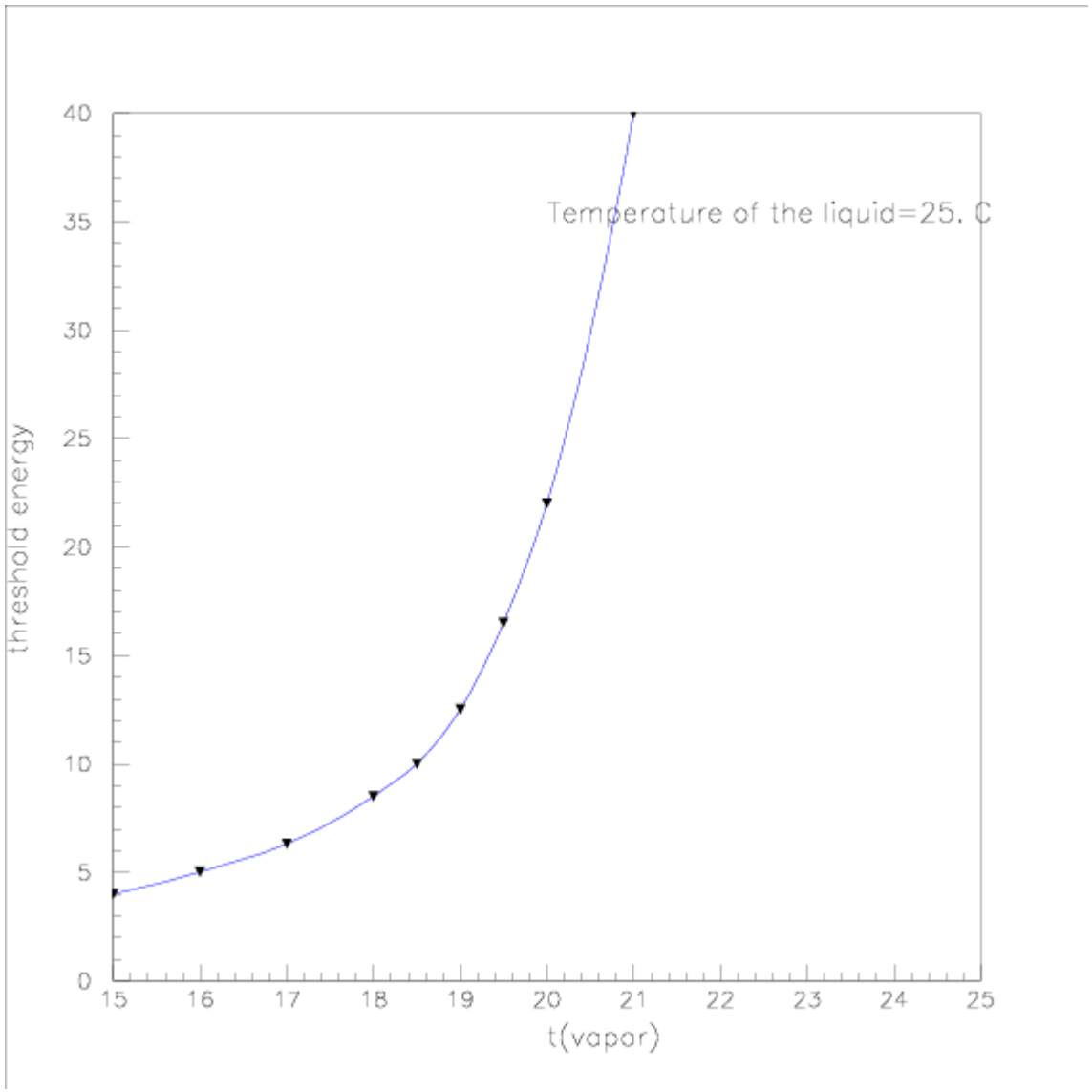
MOSCAB: RUN0345 ev. 86, \ 50fps \ dT 8.9



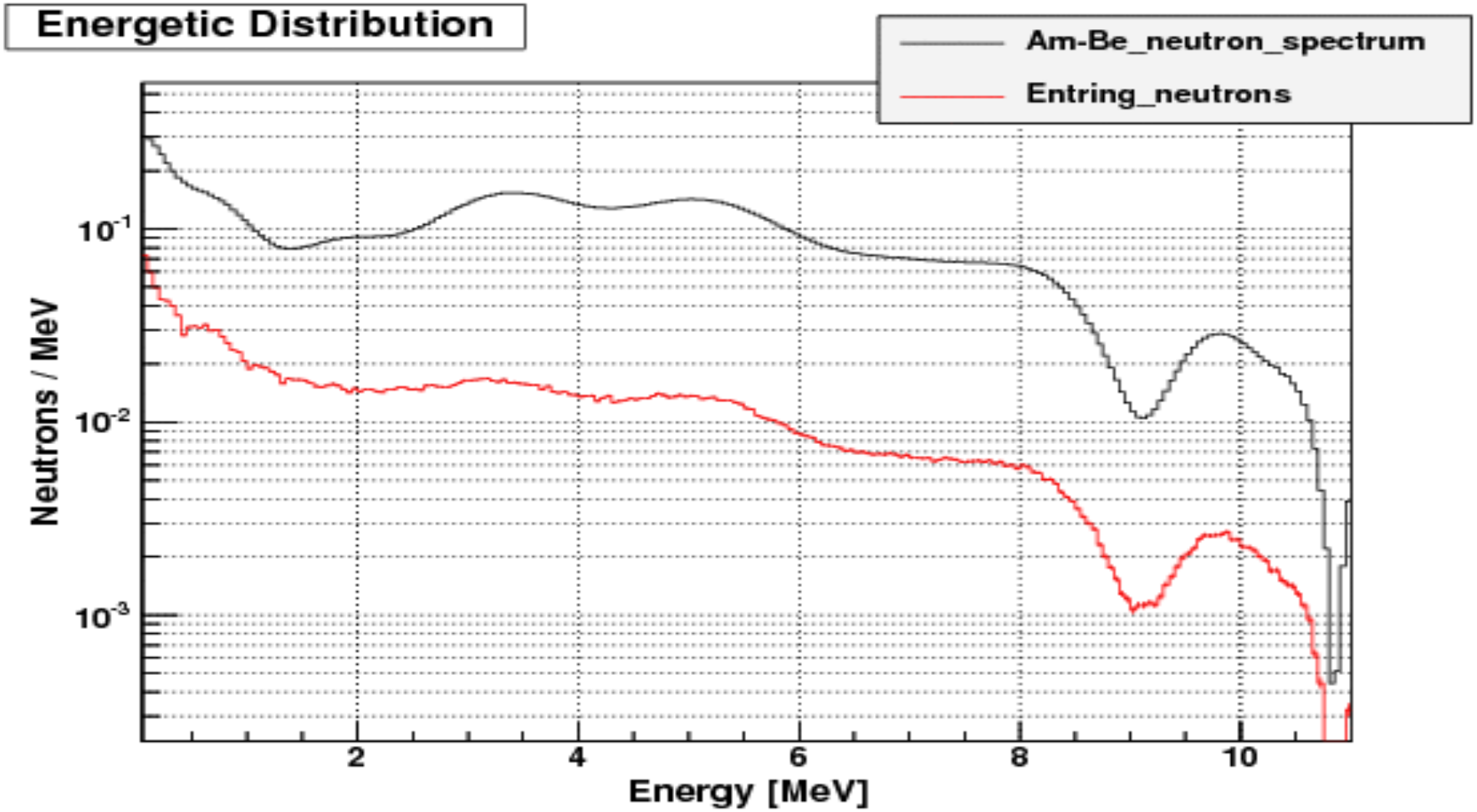
Background is due to the cosmic rays


Background
hgamma
Entries 608
Mean 247.8
RMS 110.5
counts [events/20 hours]
distance [100 μm]
Background
Gamma+Background


CUMULATIVE RESULTS
Background +Neutron source (40 kBq)
Background
ev/h
DT= Temperature difference
0
20
40
60
80
100
120
140
0
2
4
6
8
10
12
14


Temperature of the liquid=25. C
threshold energy
t(vapor)
0
5
10
15
20
25
30
35
40
15
16
17
18
19
20
21
22
23
24
25

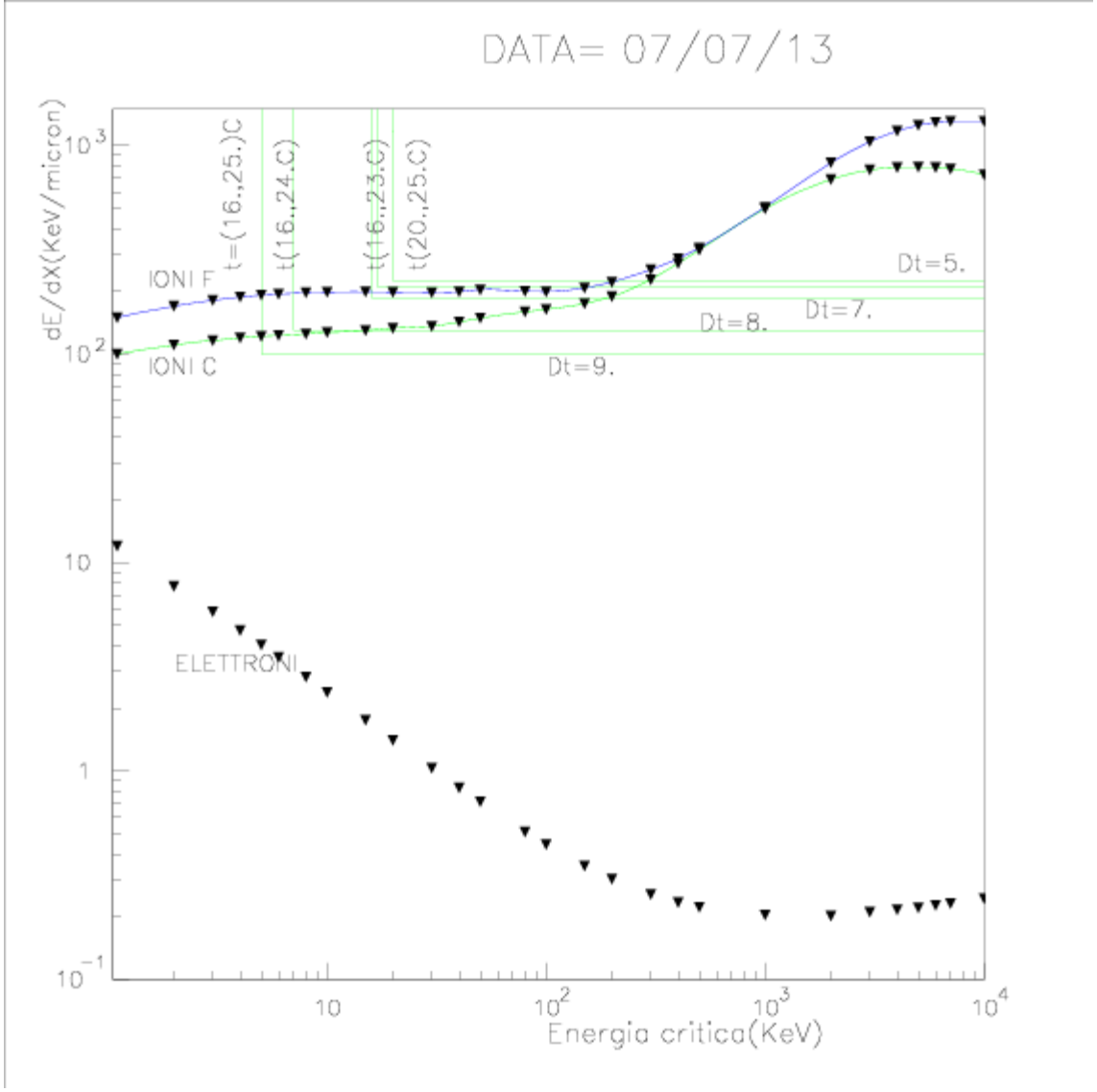
M.C. Calculation (MCNP from Los Alamos)

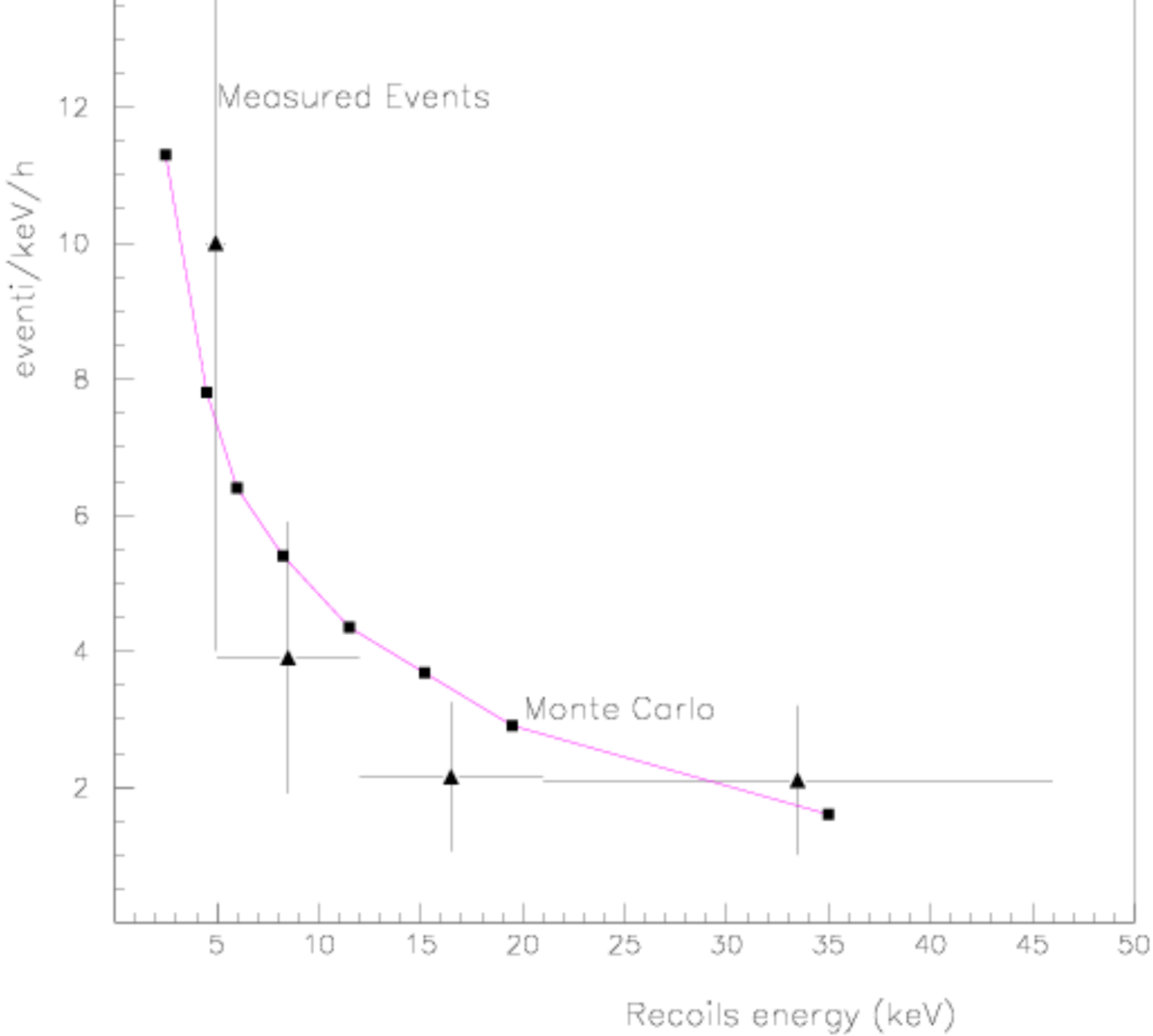


We have calculated the threshold in Energy and stopping Power for our conditions following the theory of Seitz corrected by Collar.
We can see that to reach a threshold of 10 keV for the recoiling Ions and a sensitivity of ~10 MeV on the WIMP Mass we must reach a Difference in Temperature (DT) between the liquid and vopour of Freon ≥7.5 K.
To reach a threshold of 3. keV to explore WIMP masses ≥3 GeV, we have to reach a DT=11 K.

We can see furthermore that that the electrons cannot be seen in these conditions.
The experimental used regions are the squared boxes in the Figure.

We have used a M.C. program ,coming from Los Alamos (MCMP) and we have found a good qualitative agreement with the observed events.


DATA= 07/07/13
dE/dX(KeV/micron)
Energia critica(KeV)
IONI F
IONI C
ELETTRONI
t=(16.,25.)C
t(16.,24.C)
t(16.,23.C)
t(20.,25.C)
Dt=5.
Dt=7.
Dt=8.
Dt=9.


Measured Events
Monte Carlo
eventi/keV/h
Recoils energy (keV)
2
4
6
8
10
12
5
10
15
20
25
30
35
40
45
50

3) B A C K G R O U N D

Misure a Milano di :

1)QUARZO con Si a barriera superficiale

2)QUARZO semicilidrico "

3)O-Ring NBR (Nitrile Butadiene Ring)

4)Lana di Roccia

5)Glicole (Liquido di Buffer termico)

6)Acqua bidistillata

7)Acciaio AISI316

ANALISI A PRAGA

The main Particle background in general is due:

1)gamma rays , electrons , beta decays etc.

2)Neutrons

3) α decays

1) e.m. particles are reduced by a factor 10^{-11} ; in any case we are trying to measure the contribution of C^{14} in the freon(very hard).

2) The multiple scattering of the neutrons in the large vessel(27 L) can reduce the already low background in the G.S. hall of a further 1%.

3) With the acoustic trigger we hope to reduce the α backgr. by a factor 10^{-4} .

IN ANY CASE WE HAVE MEASURED THE ACTIVITY OF SMALL PIECES of STAINLESS STEEL, of WOOL OF ROCK,etc.(with the sensible Ge and Si of the CUORE group); now we have to traslate these contaminants in term of neutron ev. rate.

BACKGROUND

-For the 2 kg Chamber (in the MINOS area) COUPP gives:

a) e.m. background (e± and γ) measured directly with a 137Cs source of 662 keV γ rays→ 2 10^{-10} probability of bubble nucleation.

Even an unshielded detector (external source ≈107 γ /kg day) has an expected count per day-kg of ≈ 0.001; with a shielding this background can be reduced by at least 3 order of magnitude.

Internal source of β decay (mainly 14C in Freon) is expected to be at the 10^{-12} level→0.0003 events/kg-day.

b)Neutrons : they are due to I)Cosmic rays muon interactions in material near the detector II) neutrons from natural radioactivity (Spontaneous fission AND α decay of U and Th followed by (α,n) reactions.

These kinds of background can be cured by:

OPERATION deep underground --- hydrogen rich shield to attenuate the neutrons which arise from local radioactivity---- understanding and subtraction of residual neutron background on statistical basis using the number of events with multiple scattering.

A Monte-Carlo simulation predicts backgrounds < 0.001 ev/kg-day

c) Contamination of alpha, mainly due to 222Rn → 218Po (101 keV)+ a (5.5 MeV)

and also alpha emitters of the chains of 238U and 232Th

Estimated sensitivity→ ≈0.005 events/kg-day (see Borexino measurements)

4)DESIGN AND CONSTRUCTION OF A DETECTOR OF 40 kg (First Module)

We have designed a bigger detector(40 kg) and the very challenging mechanica support.

We have mounted it in Milano Bicocca at the 4° floor and we made tests too,before

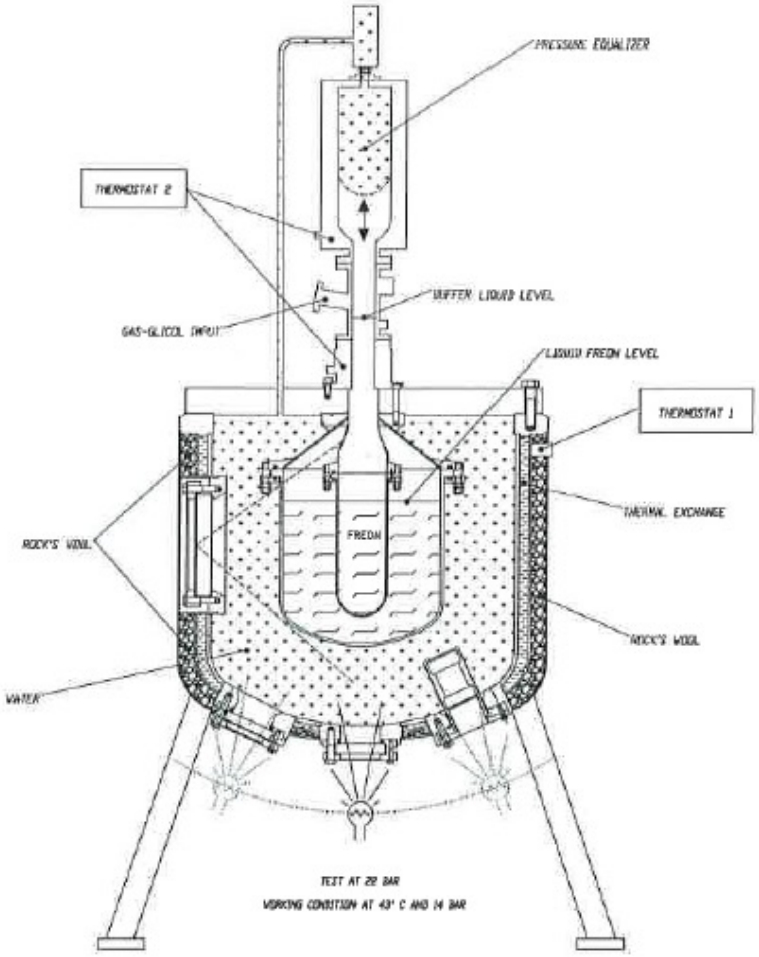
Going to the Gran Sasso. This detector contains a lot of change with respect to the

small one:

1)The 2 temperatures (Liquid and gas freon) are guaranteed at the level of 0.01 degrees

2)The cooling system is realized with special double walled technique.

3)The mechanical support is able to contain vessel of 2 L and also vessels of 25 L.


PRESSURE EQUALIZER
THERMOSTAT 2
BUFFER LIQUID LEVEL
GAS-GLICOL INPUT
LIQUID FREON LEVEL
THERMOSTAT 1
THERMAL EXCHANGE
ROCK'S WOOL
FREON
ROCK'S WOOL
WATER
TEST AT 28 BAR
WORKING CONDITION AT 43° C AND 14 BAR

Use of the BIG DETECTOR

-Our line of work is/was that:

a) insert in the mech. struct. The 0.5 L vessel (already done)

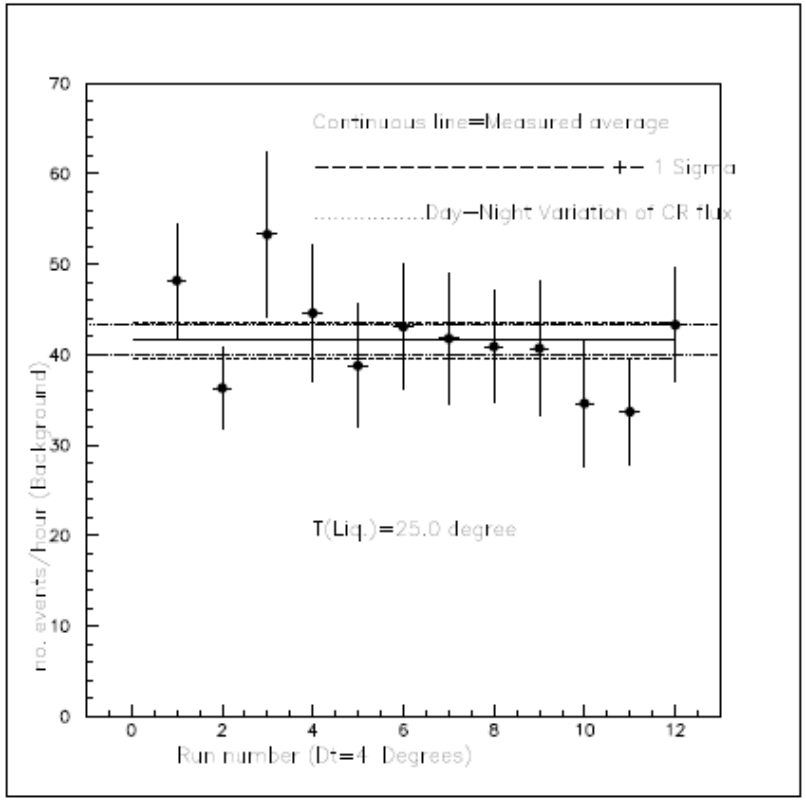
b) " " A 2 L vessel (~already done)

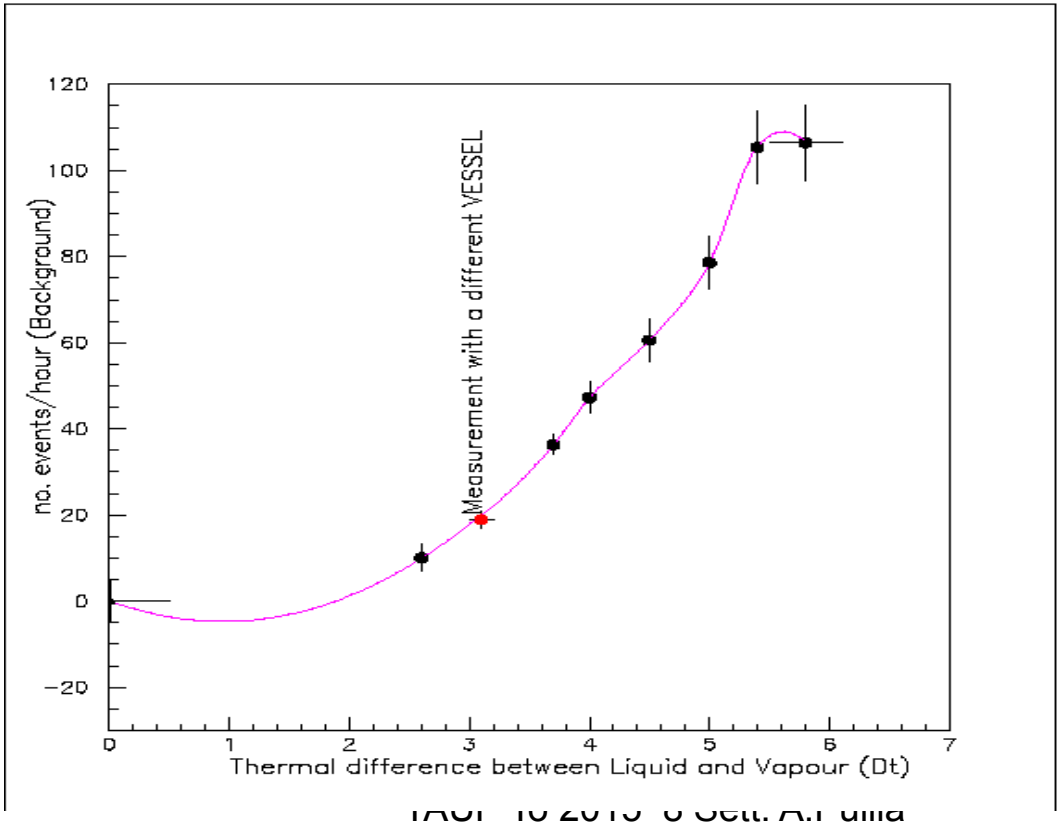
We have checked the REPRODUCIBILITY of the results.

c) " " the 27 L vessel

_With the big detector we cannot fully fill the vessel; the foreseen background counting rate is really to high to be stored.
So we will fill the big vessel only partially and the final test will be done in the LNGS.

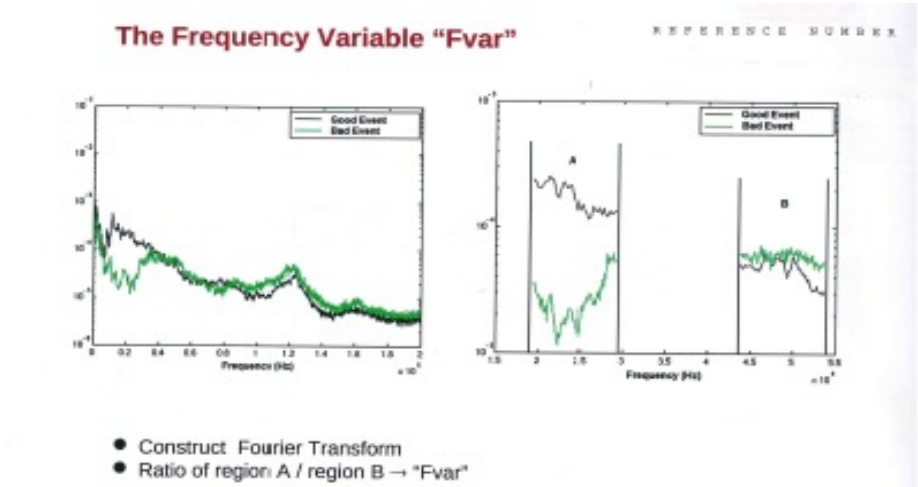
-We plan to move the detector to the LNGS at the end of February 2016.


Continuous line=Measured average
+- 1 Sigma
Day-Night Variation of CR flux
T(Liq.)=25.0 degree
no. events/hour (Background)
Run number (D*=4 Degrees)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12


120
100
80
60
40
20
0
−20
no. events/hour (Background)
Measurement with a different VESSEL
0
1
2
3
4
5
6
7
Thermal difference between Liquid and Vapour (Dt)

Acoustic Trigger

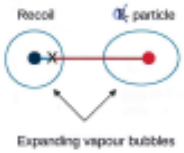
We have also turned our attention the design of the ACOUSTIC TRIGGER ; we have purchased two hydrophone sensors and one of them will be in the water of the detector. We plan to use the second one outside to study the signal.
The acoustic signal is very important,because it can be used to separate α particle (background) from recoiling ions (signal).
With more hydrophones we think to be able to reconstruct also the starting point of the bubbles.



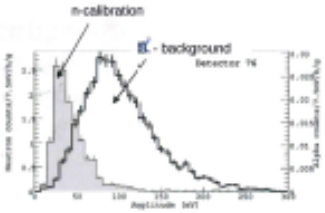
Discrimination of Nuclear Recoils from Alpha Particles

α - events are « louder » than recoil induced events...

region



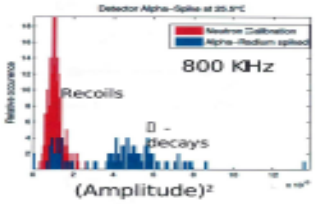
Signals carry information about very first instants of bubble formation



NJP 10(2008)103017 arXiv: 0807.1536

Alpha - Recoil Discrimination

- Required amplitude resolution < 30% FWHM @ 45° (2 keV)
- 3D localisation → fid.vol.; solid angle correction
- Increased sampling frequency 400kHz → 800 kHz



Confirmed by COUPP

99.34% rejection @ 80% WIMP acceptance

Works much better in bulk liquid than in droplets!

5) THE FUTURE OF THE EXPERIMENT; THE POSSIBLE RESULTS

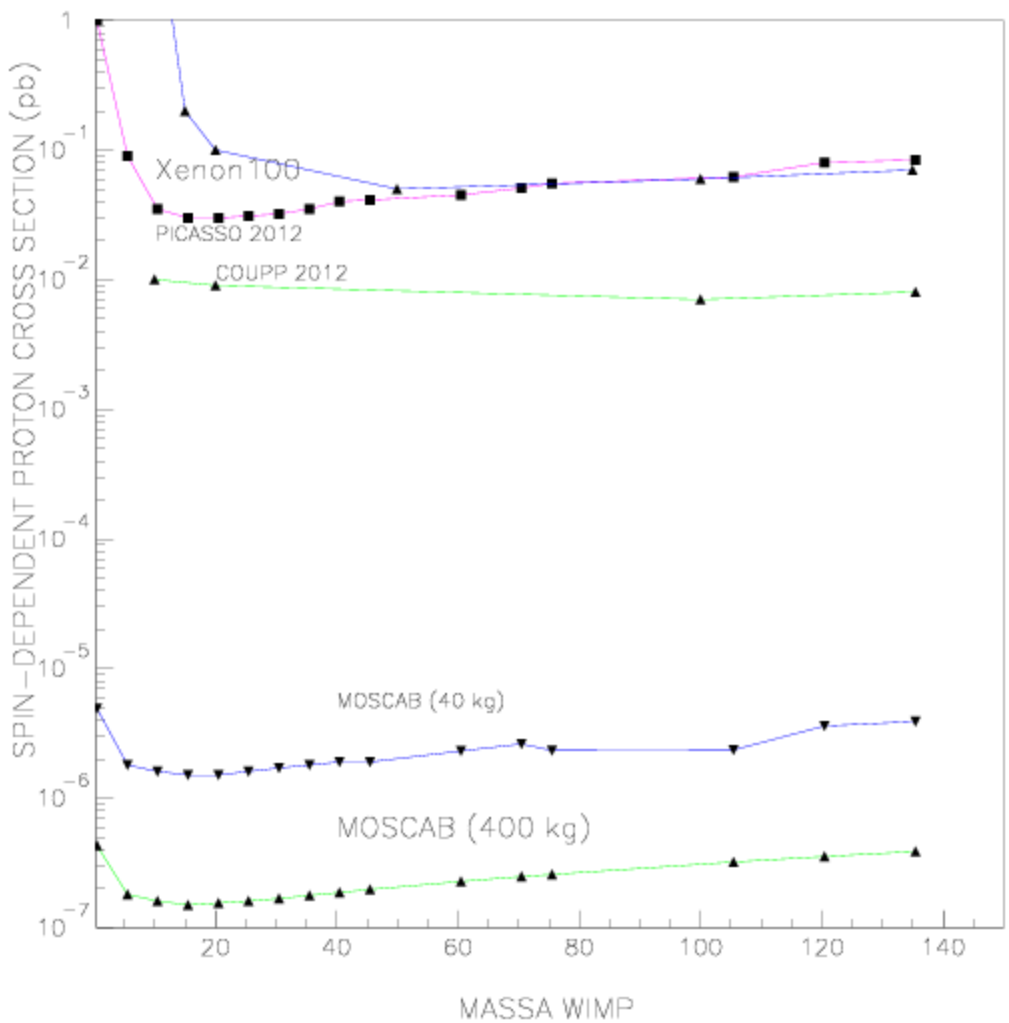
After the definitive tests of the 40 kg Detector in Milano we plan to bring it to

The LNGS and so becoming competitive with the PICO group, working at SNOLAB with a 4 kg bubble chamber (the same fluid) and becoming at the top in the world for the SD Wimp Interaction.

If these result will be reached we plan to construct 10 similar modules

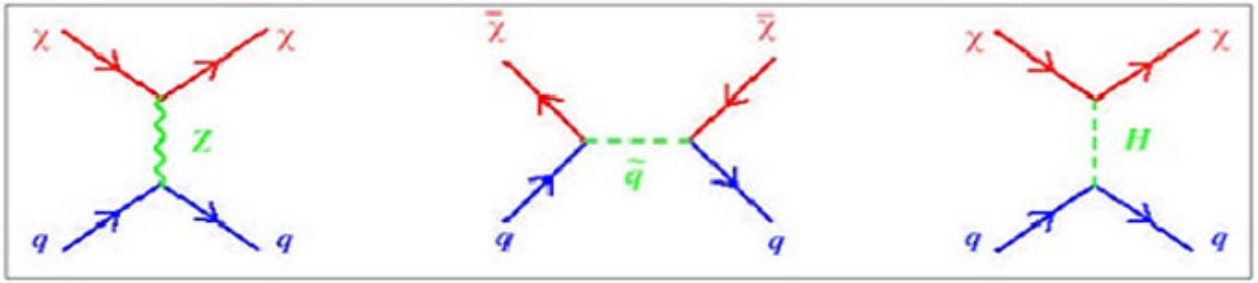
(Total mass 0.4 tons). In the “optimistic” hypothesis of 0 background (2.1 at

90% of c.l.) the sensitivity of our detector is reported in Figure.

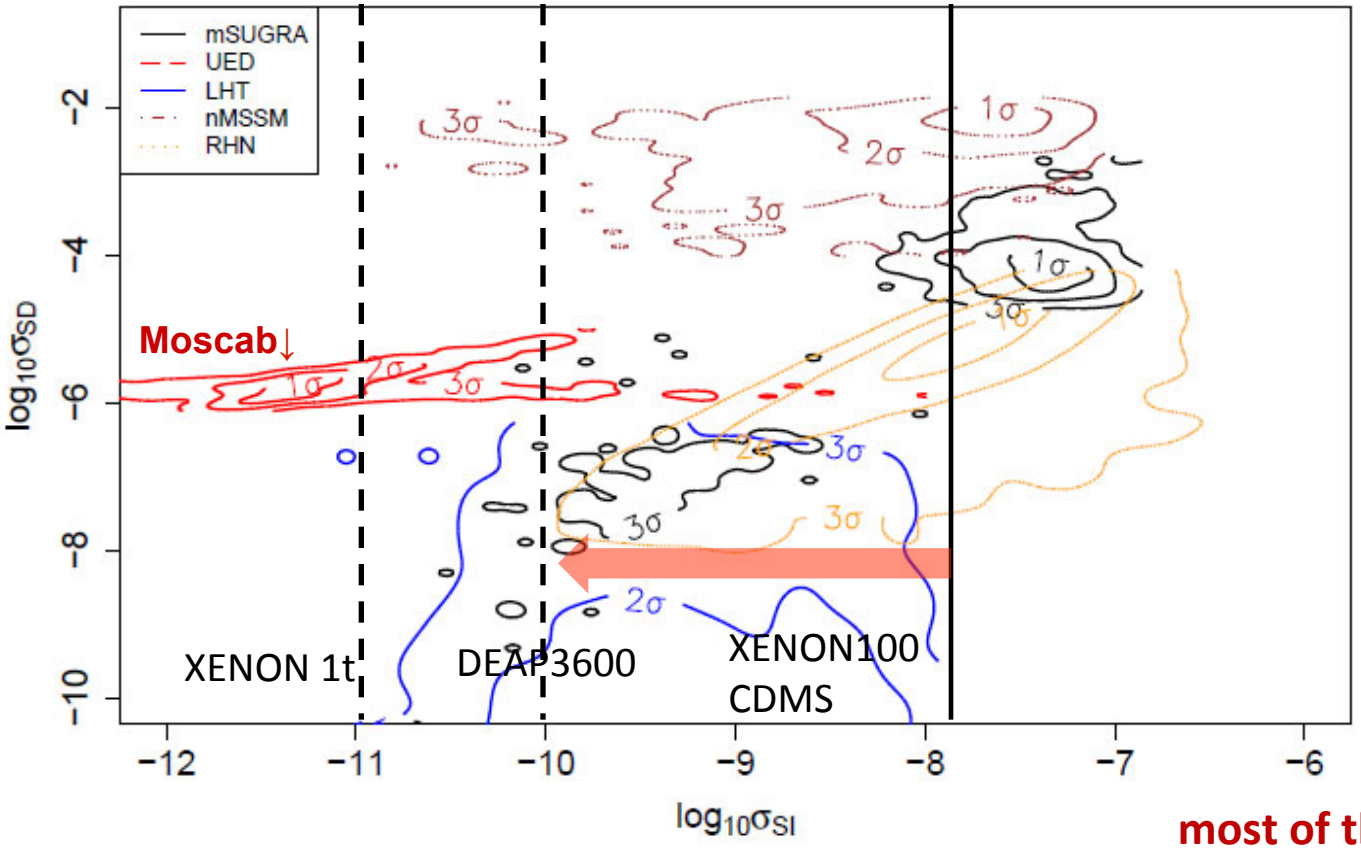

SPIN−DEPENDENT PROTON CROSS SECTION (pb)
1
10^−1
10^−2
10^−3
10^−4
10^−5
10^−6
10^−7
Xenon100
PICASSO 2012
COUPP 2012
MOSCAB (40 kg)
MOSCAB (400 kg)
20
40
60
80
100
120
140
MASSA WIMP

40 kg 1 anno

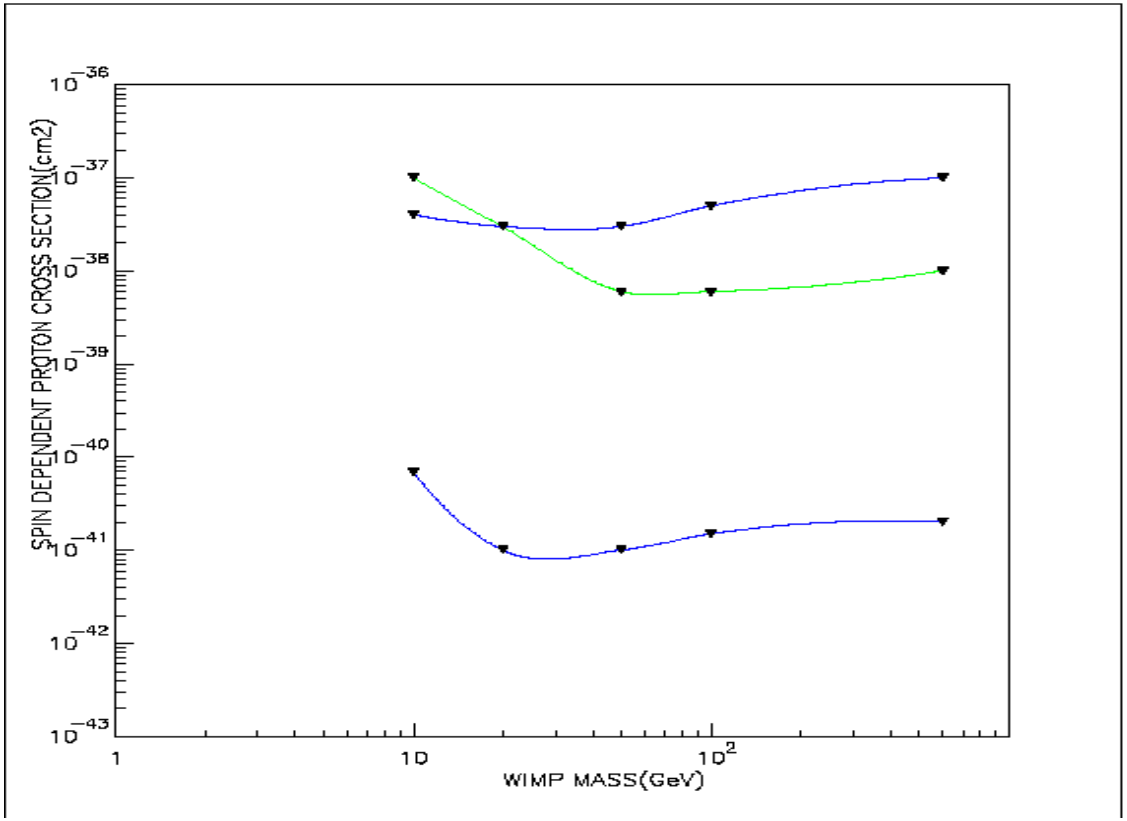
Comparison SD and SI - searches



Spin-dependent Spin-independent



most of the activity in SI sector !


SPIN DEPENDENT PROTON CROSS SECTION(cm2)
WIMP MASS(GeV)
10^{-36}
10^{-37}
10^{-38}
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
1
10
10^2