DARK MATTER : A NEW DETECTOR, THE GEYSER

- Very short summary on Detectors based on Bubble Nucleations (Bubble Chambers, SDD, Geyser)
- The experiment MOSCAB (Materia OSCura A Bolle): The Prototype (0.6 kg)
- The first Module (40 kg)
- Background and sensitivity of the experiment
- Acoustics Trigger
- Collaboration

Detector based on 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 that 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

NUCLEATION OF A BUBBLE IN A SUPERHEATED LIQUID

–1952 **GLASER investigates the behaviour of a superheated liquid <u>(diethyl ether) -Basis for the Bubble Chamber</u>**

-Particles discovered with this technique : Σ Ξ Ω + **Neutral Current ,etc.**

-Liquids used : Hydrogen,Helium, Deuterium, Propane,Freon ,Xenon etc.

- The energy is:

$$\Delta E = 4\pi R^2 \sigma - \frac{4}{3}\pi R^3 (P_{svp} - P)$$

Surface contribution Volume contribution

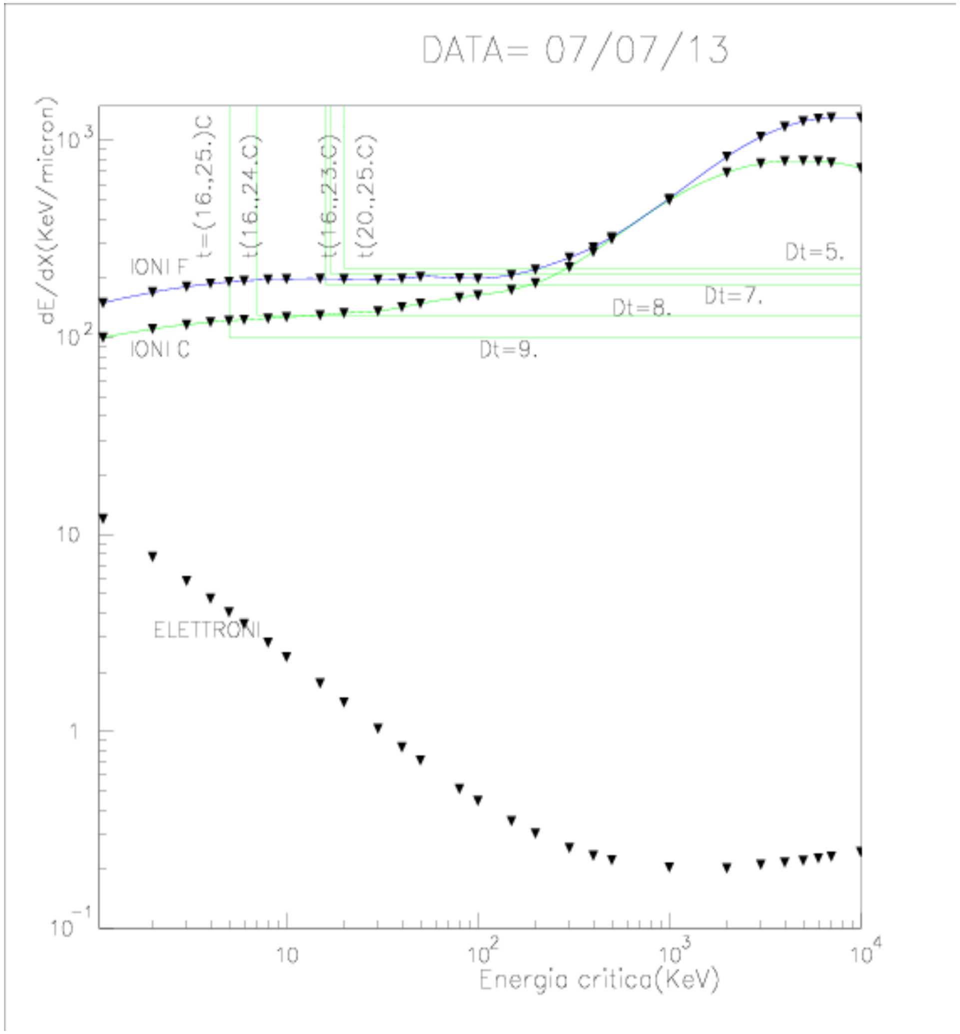
σ=liquid-gas surface tension ; P_{svp}=saturated vapor pressure

-For small R the Volume term is not important ($\sim R^3$) and the Energy decreases with deacreasing radius (the radius shrinks to zero)

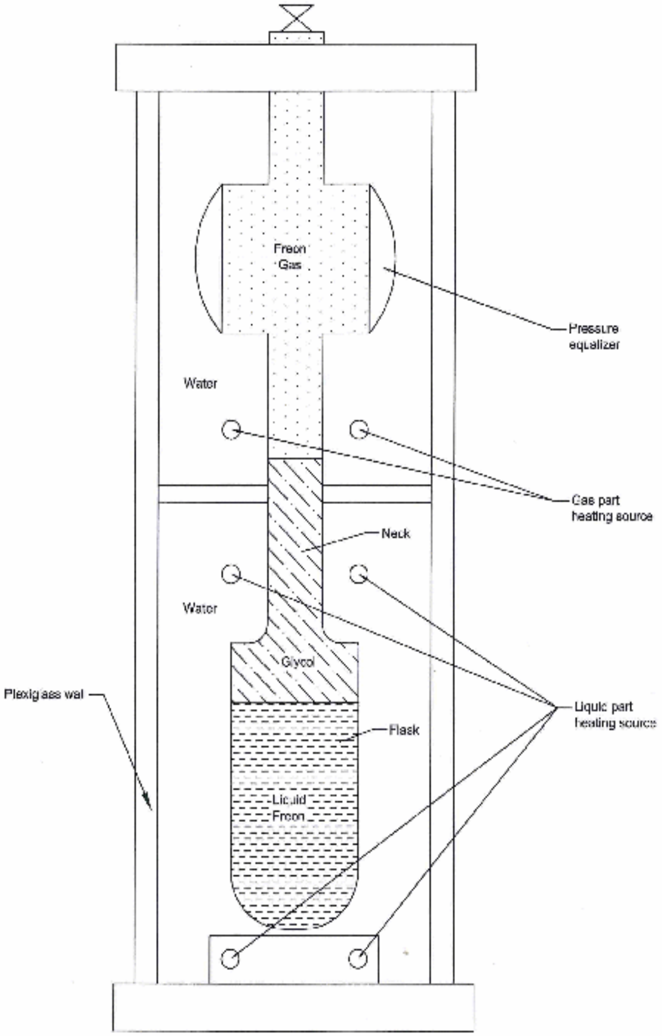
-For large R the surface term is not important ($\sim R^2$) and the energy decreases with inreasing radius (the bubble grows)

-OLD BUBBLE CHAMBER WORKED ON THE ACCELERATOR BEAMS AND WERE IN THE RIGHT CONDITION OF THE SUPERHEATED LIQUID ONLY WHEN THE BEAM PASSED THROUGH..

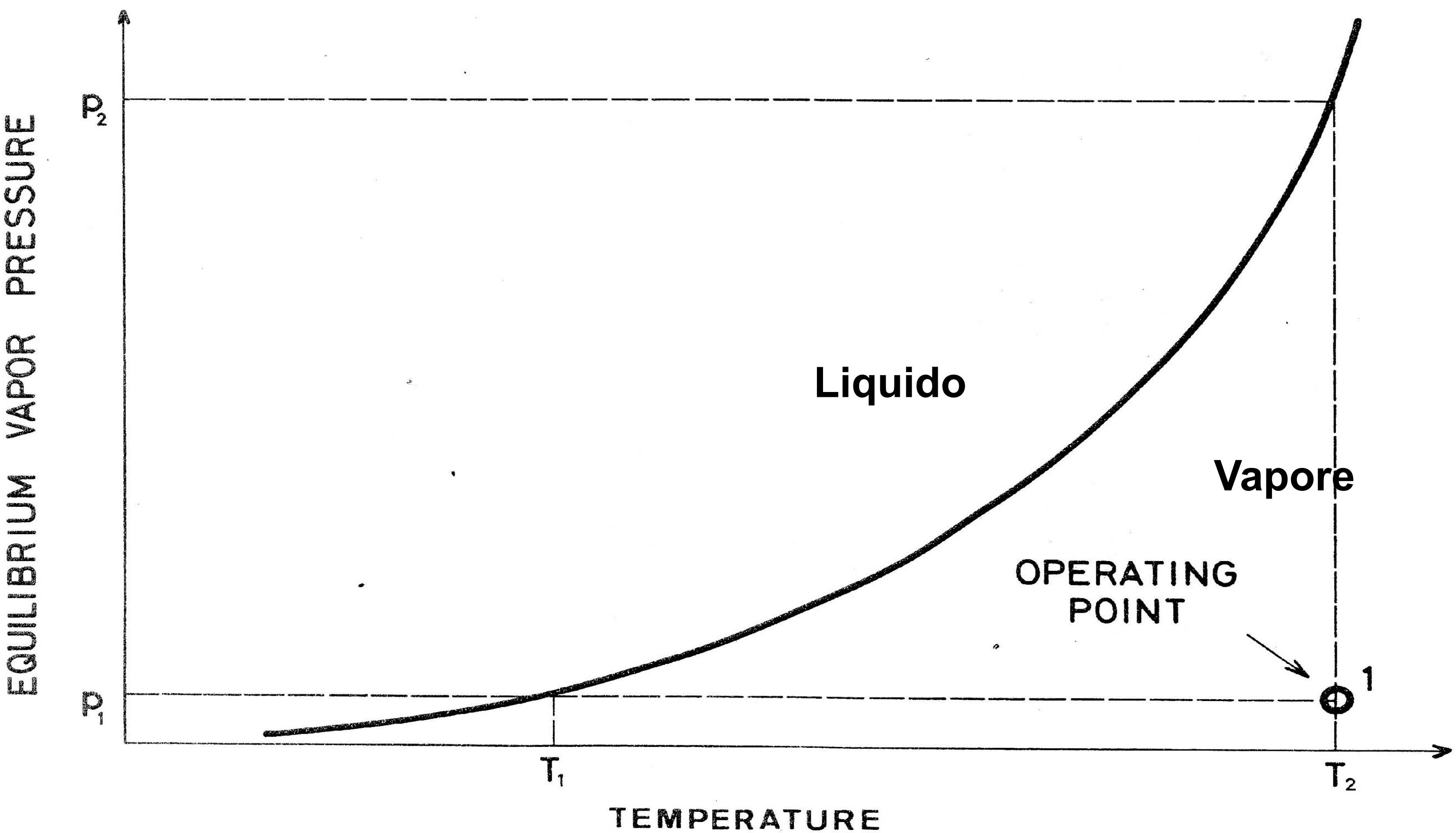
Working Region→



THE MOSCAB EXPERIMENT

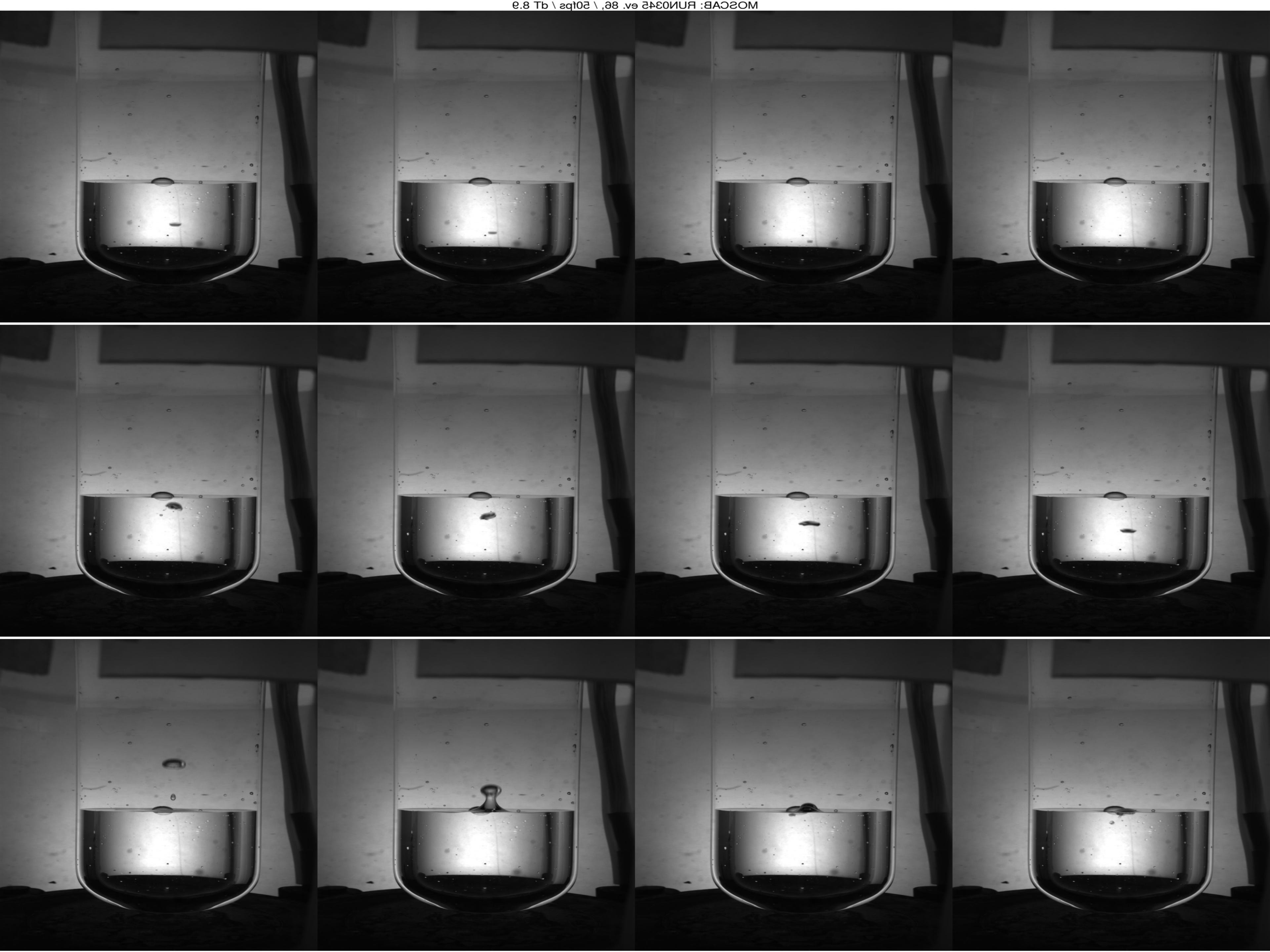


T1=10 C T2=65 C



A.Pullia

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

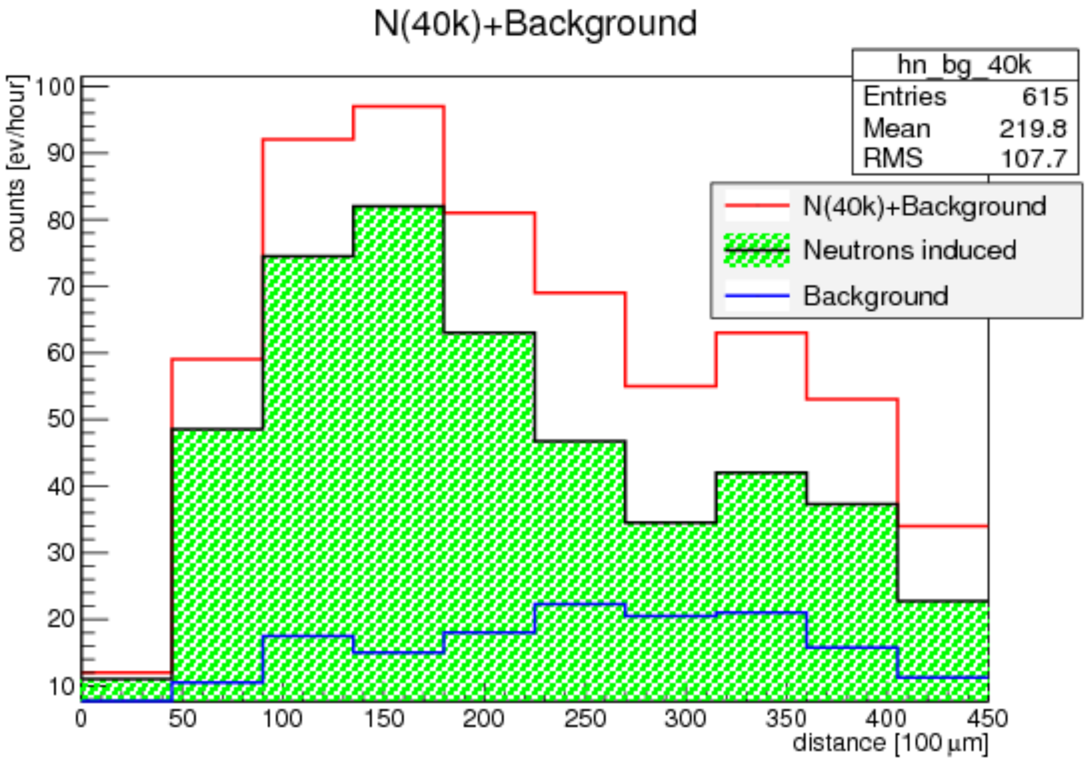


Performances of the prototype Geyser

INVESTIGATION OF THE GEYSER (0.5 L) constructed in Milano-Bicocca

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

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


N(40k)+Background
hn_bg_40k
Entries 615
Mean 219.8
RMS 107.7
N(40k)+Background
Neutrons induced
Background
counts [ev/hour]
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
450
distance [100 μm]

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 sensitivity for different particles:

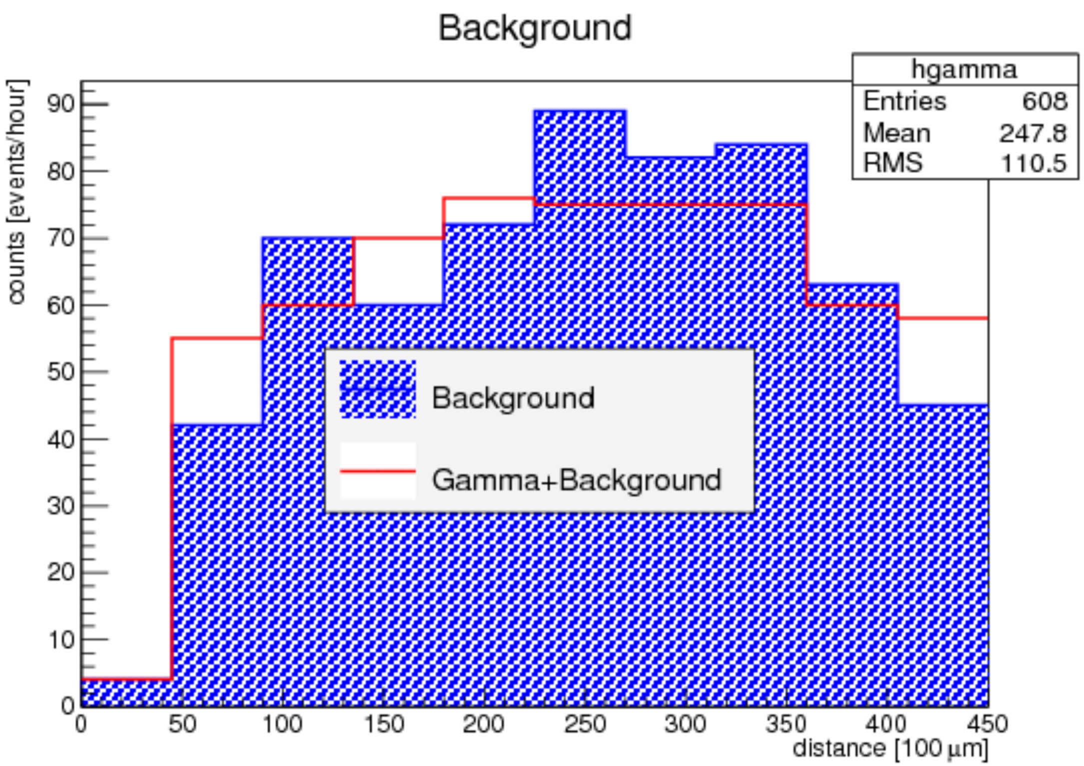
For weak degrees of superheat THE DETECTORS ARE INSENSITIVE TO THE ELECTROMAGNETIC SHOWERS and ARE WELL SENSITIVE TO HIGHLY IONIZING IONS.

These considerations bring to 3 different techniques for DARK MATTER SEARCH:

I)Bubble Chambers Continuosly Sensitive (See COUPP)

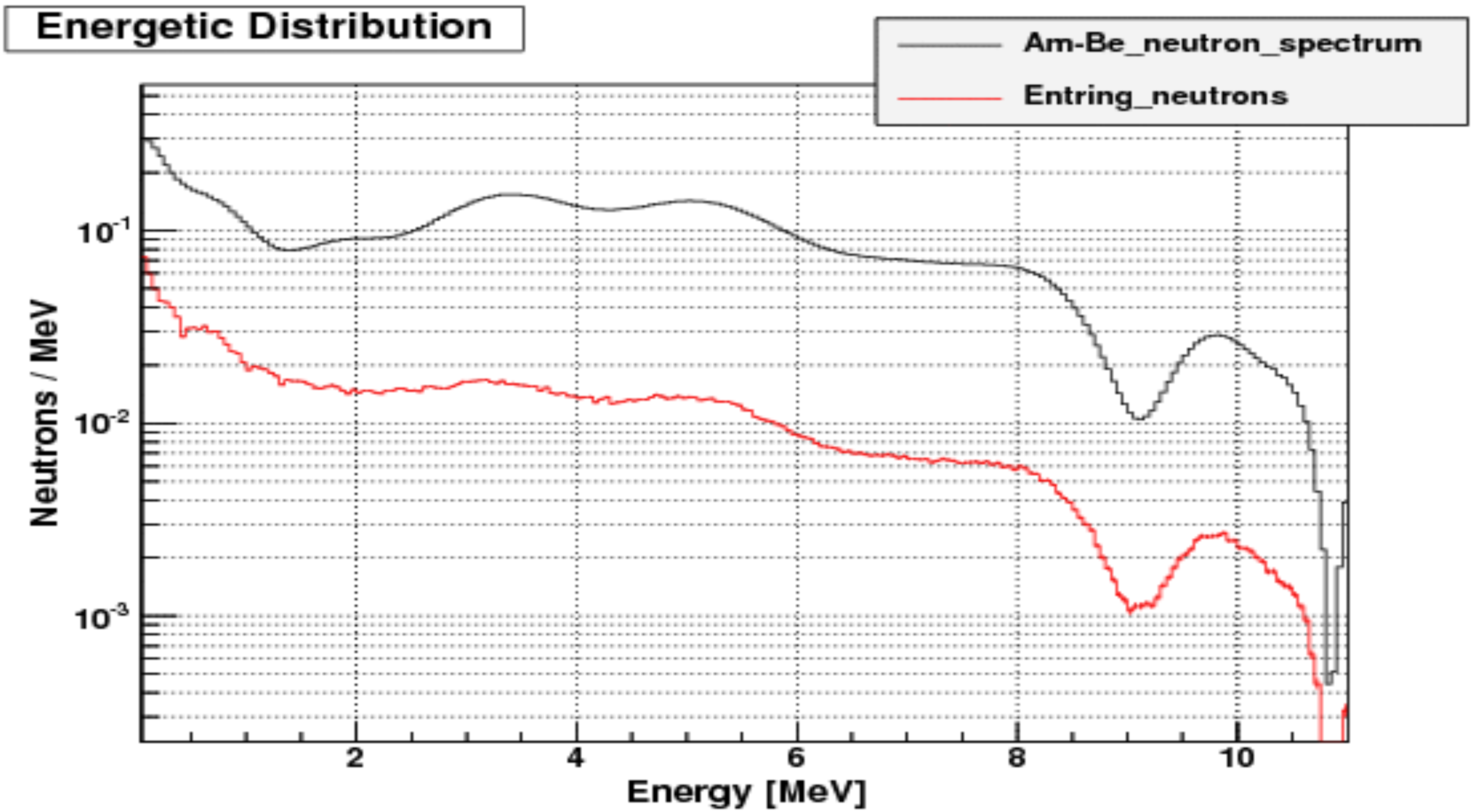
II)S.D.D. (Superheated Droplet Detectors) (PICASSO,SIMPLE)

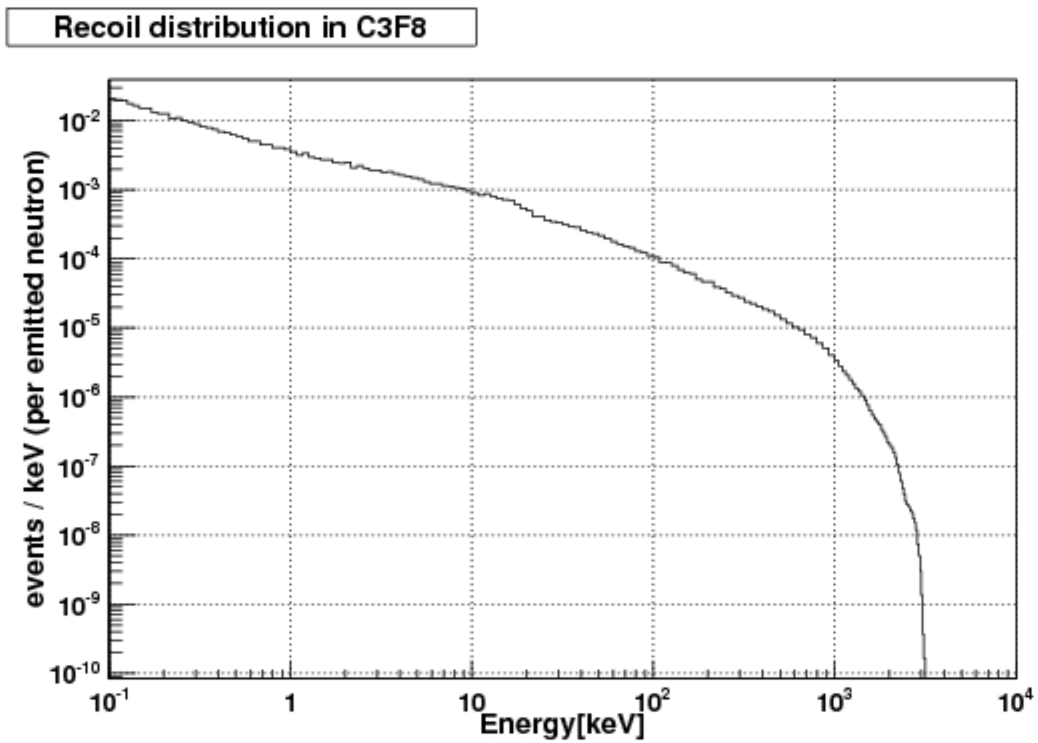
III)The "GEYSER" detector.(Milano-Bicocca and PICASSO+)

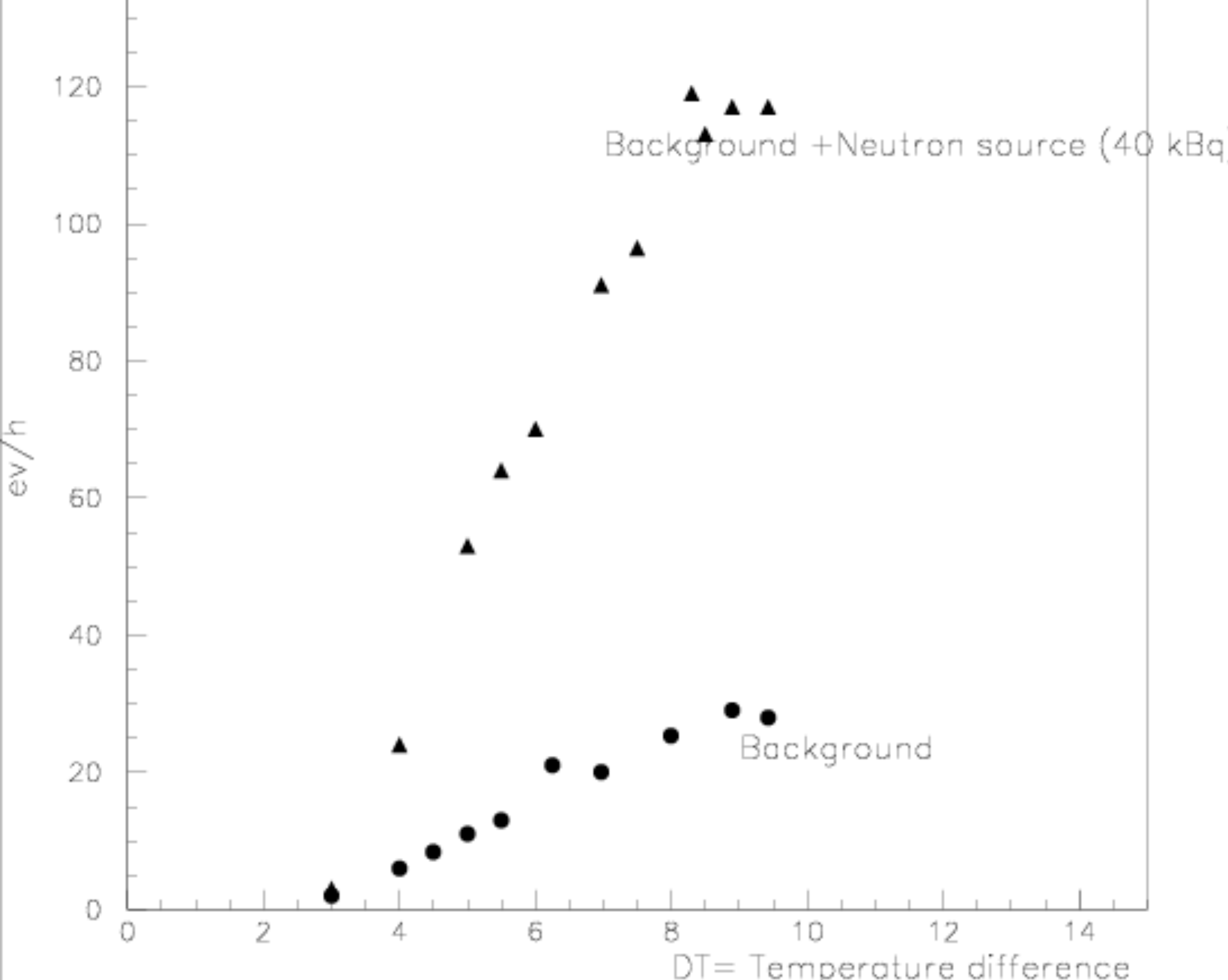


Background
hgamma
Entries 608
Mean 247.8
RMS 110.5
counts [events/hour]
distance [100 µm]
Background
Gamma+Background

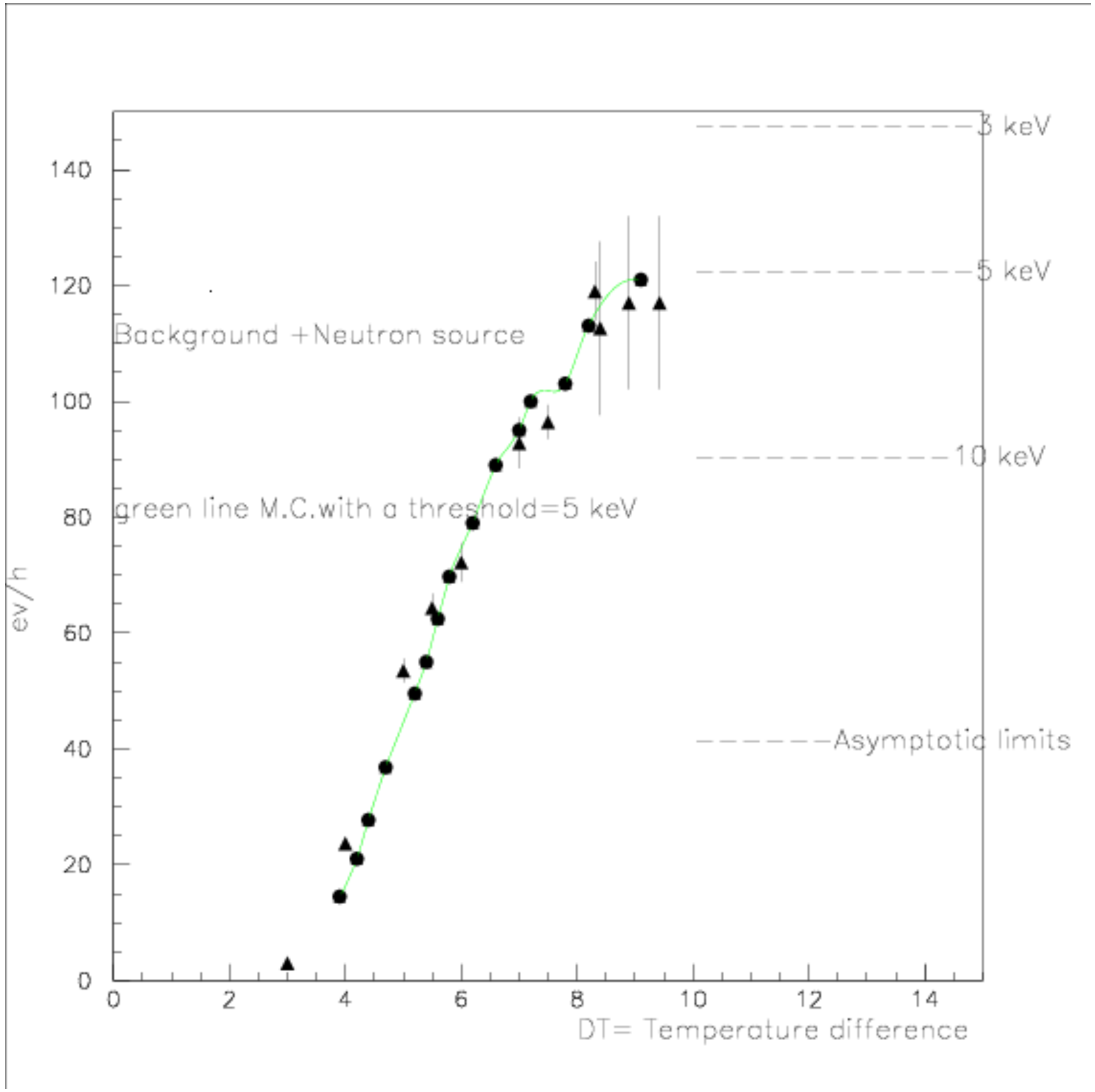
M.C. Calculation (MCNP from Los Alamos)

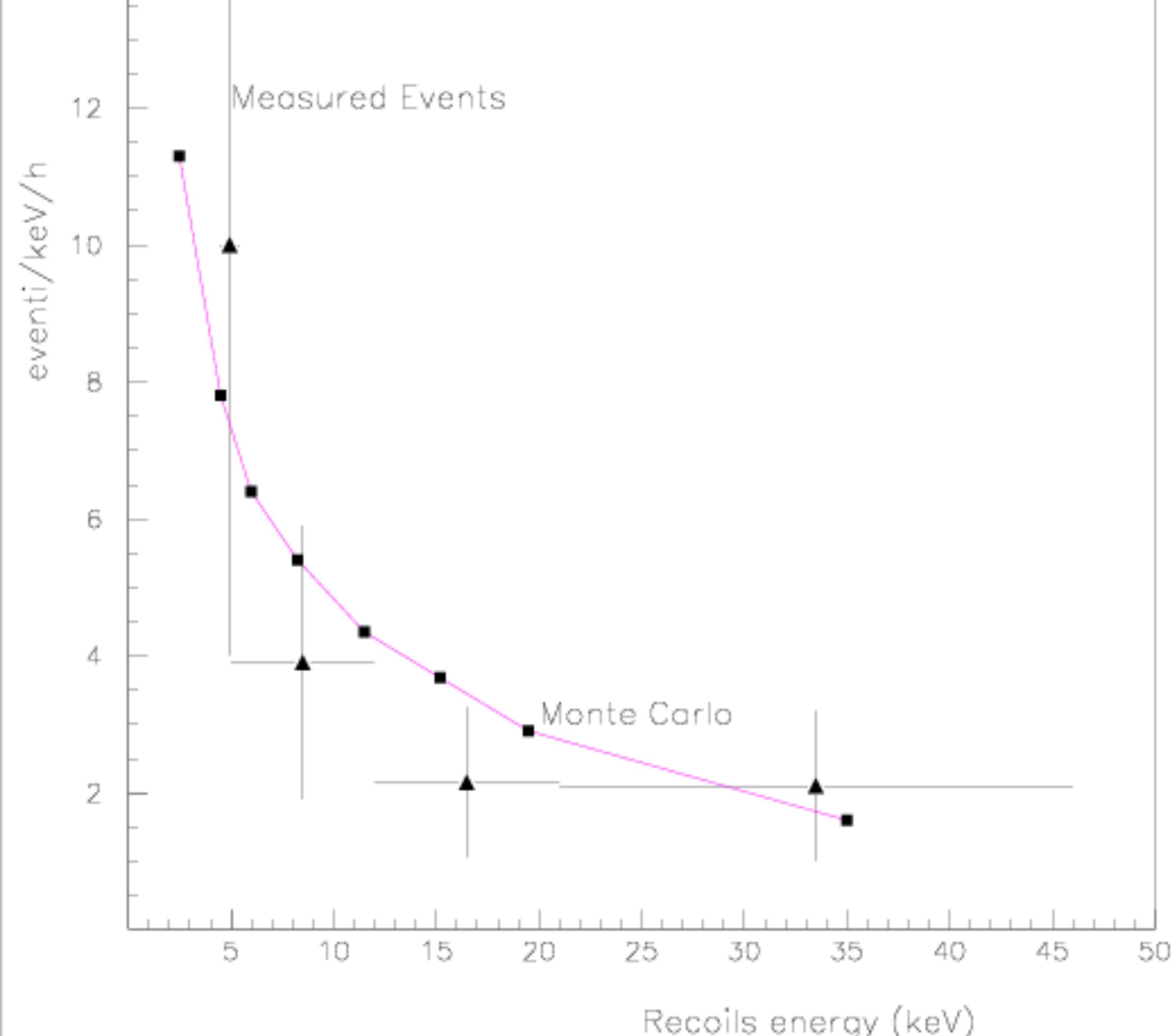



Recoil distribution in C3F8
events / keV (per emitted neutron)
Energy[keV]
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
10-10
10-1
1
10
102
103
104

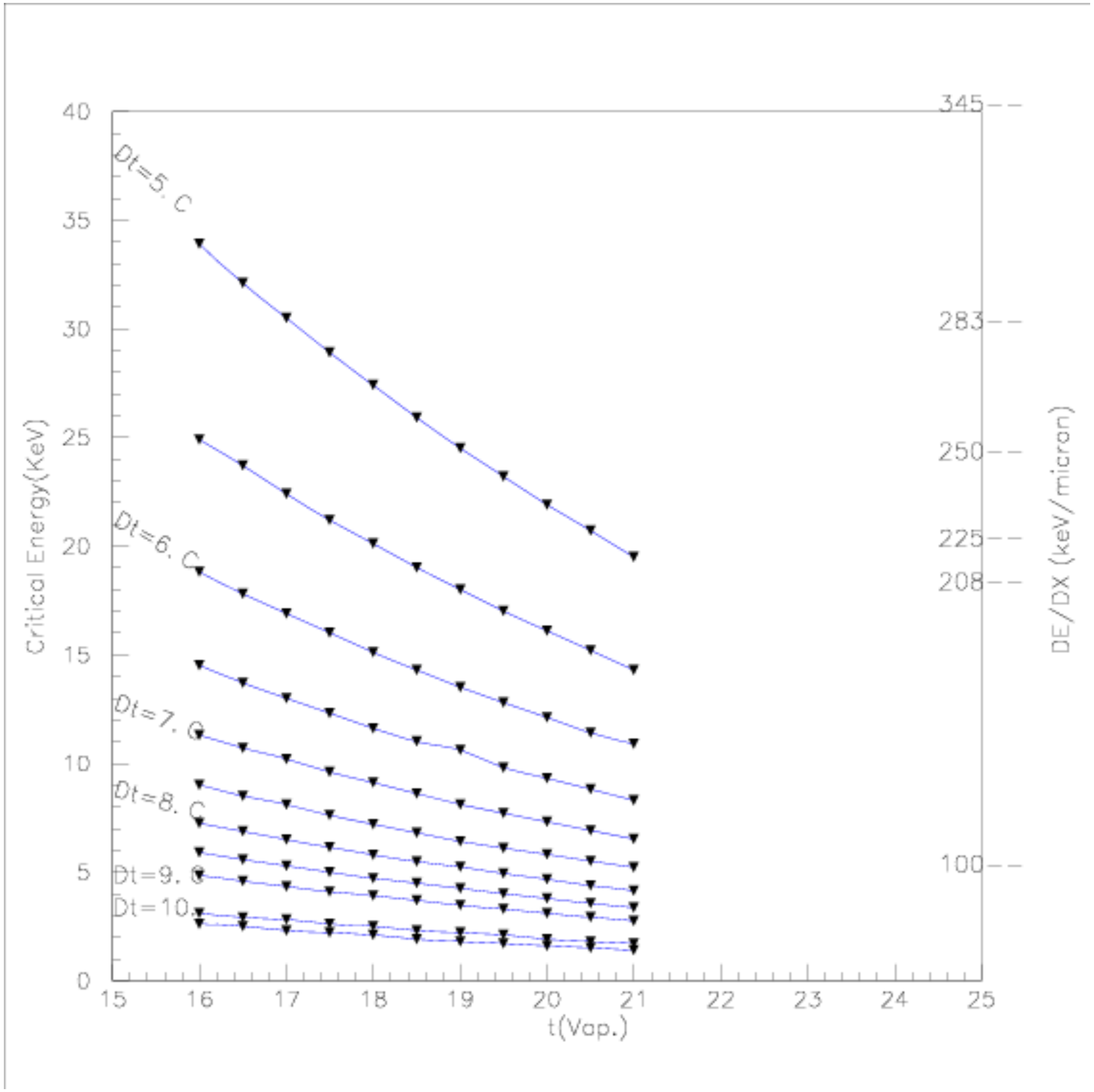

Background +Neutron source (40 kBq)
Background
ev/h
DT= Temperature difference
0
20
40
60
80
100
120
0
2
4
6
8
10
12
14

THRESHOLD IN ENERGY



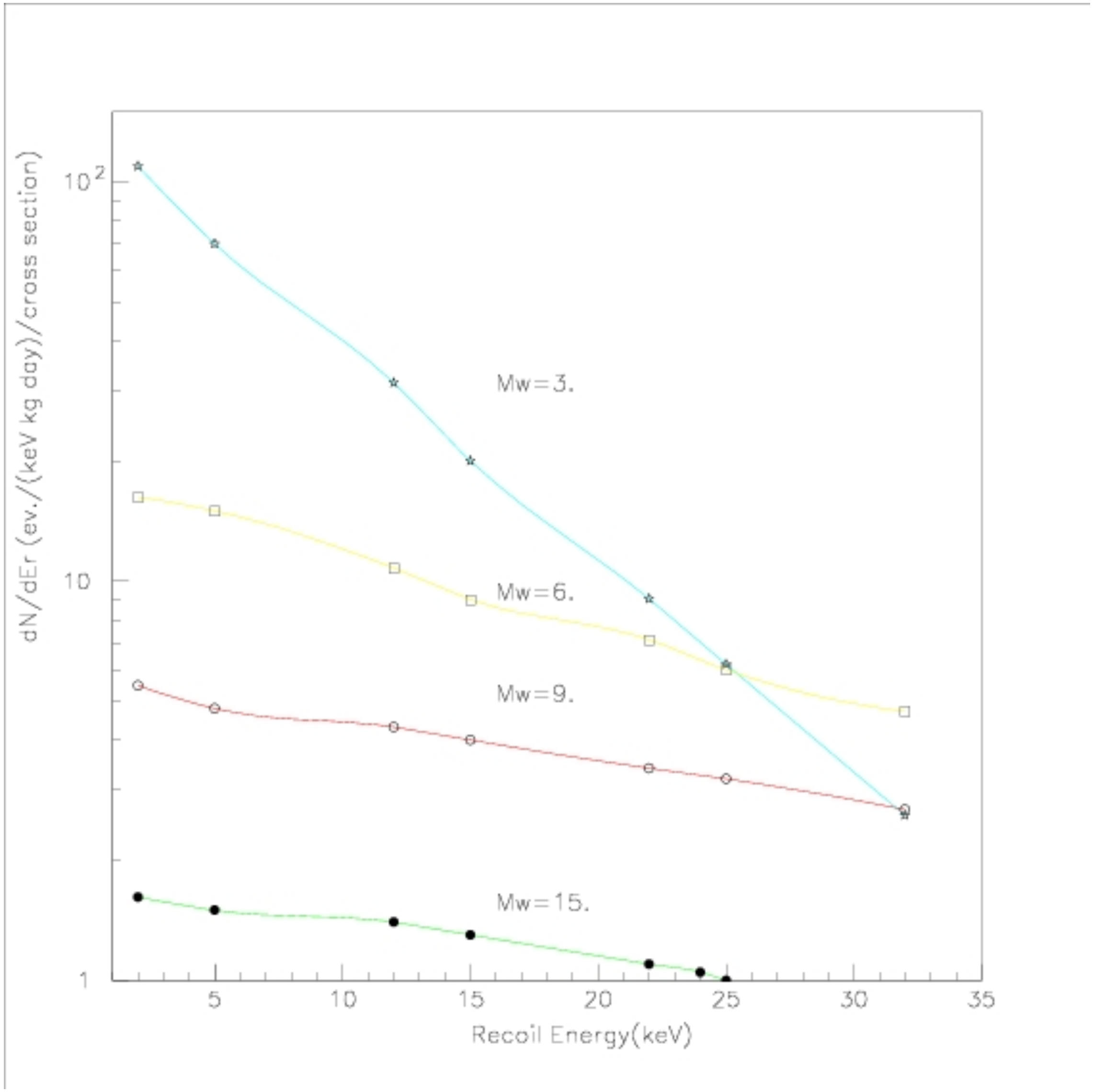


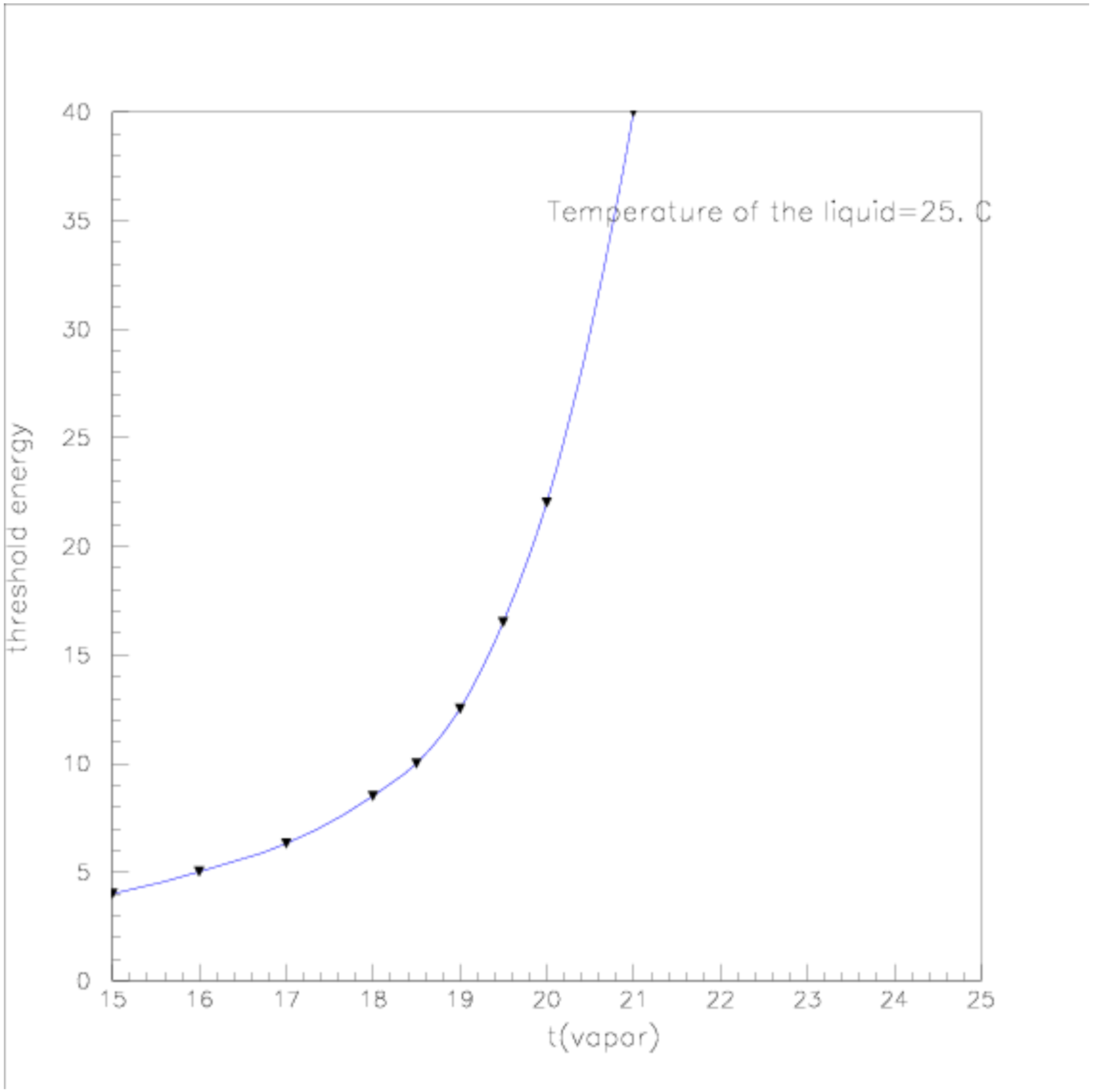
Measured Events
Monte Carlo
eventi/keV/h
Recoils energy (keV)
2
4
6
8
10
12
5
10
15
20
25
30
35
40
45
50



Critical Energy(KeV)
DE/DX (keV/micron)
t(Vap.)
Dt=5. C
Dt=6. C
Dt=7. C
Dt=8. C
Dt=9. C
Dt=10.
345
283
250
225
208
100

Levy and Smith Calculation




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

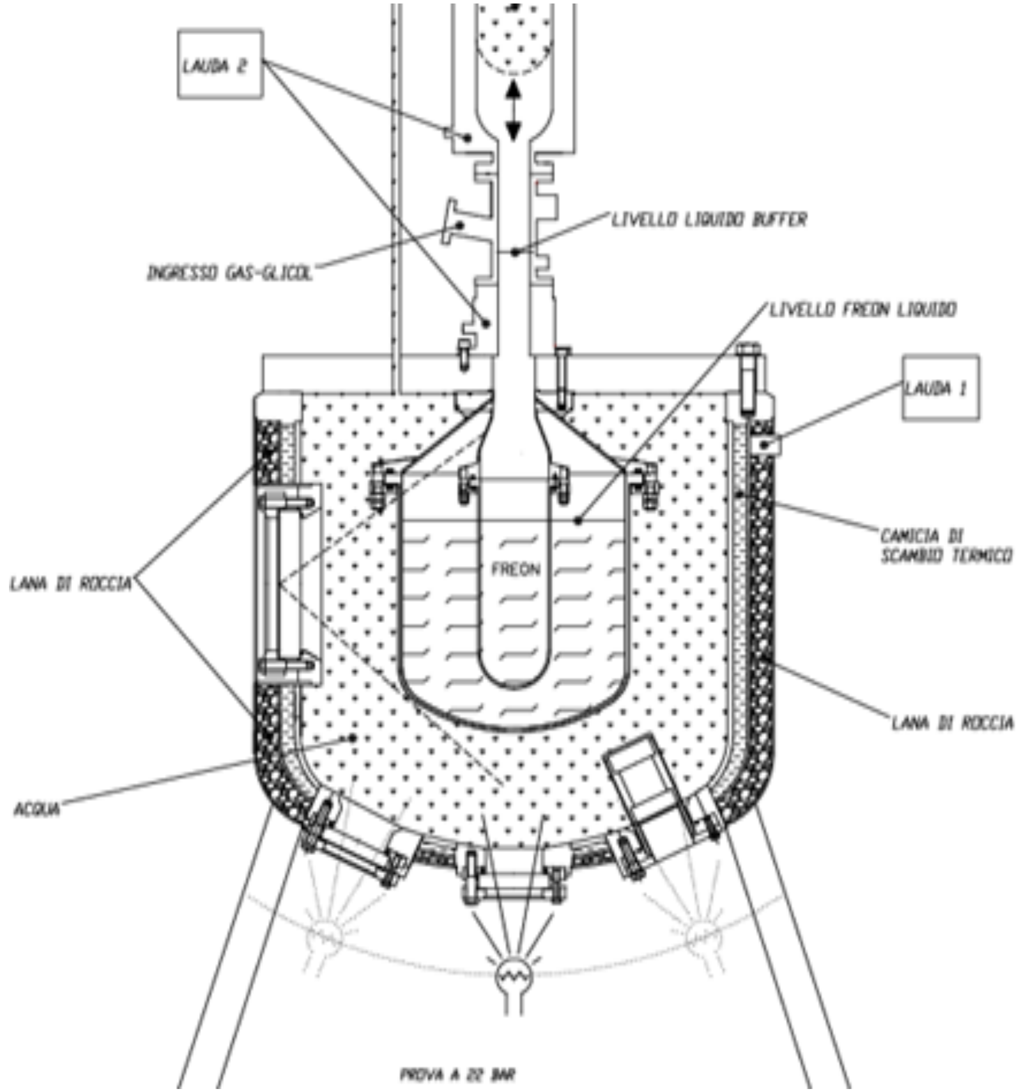
THE 40 kg DETECTOR (FIRST MODULE FOR A POSSIBLE EXPERIMENT IN THE L.N.G.S).

We have constructed a big detector (40 kg) that we will put in the Gran Sasso Laboratory;

We have preliminary estimate of Background and an expectation for the sensitivity on the SD (proton) cross section.

VESSEL OF 27 L :   now O.K.

Stability level
0.01 degree



The First Module (40 kg) is running→

BACKGROUND:

The main backgound in general is due:

1) to gamma rays , electrons , beta decays etc.

2)Neutrons

3) α decays

Preliminar estimate of Background:

(Exposure of 40 kg for 1 year at LNGS)

1)Background of γ and electrons: no sensitive Detector!

f.i. $^{14}C = {}^{14}N + \beta^- + \nu$: $<6\ 10^{-3}$. (40 kg /1 y at LNGS)

2)n from the rock $6x\ 10^{-2}$.

3)n from Cosmic Rays $4.8\ x10^{-2}$.

4)(α,n) from Radon <<0.005.

5)(α,n) from steel $<<4.x10^{-7}$.

6)(α,n) from the quartz vessel 0.01

7)(α,n) from acoustic hydrophones $4x10^{-3}$.

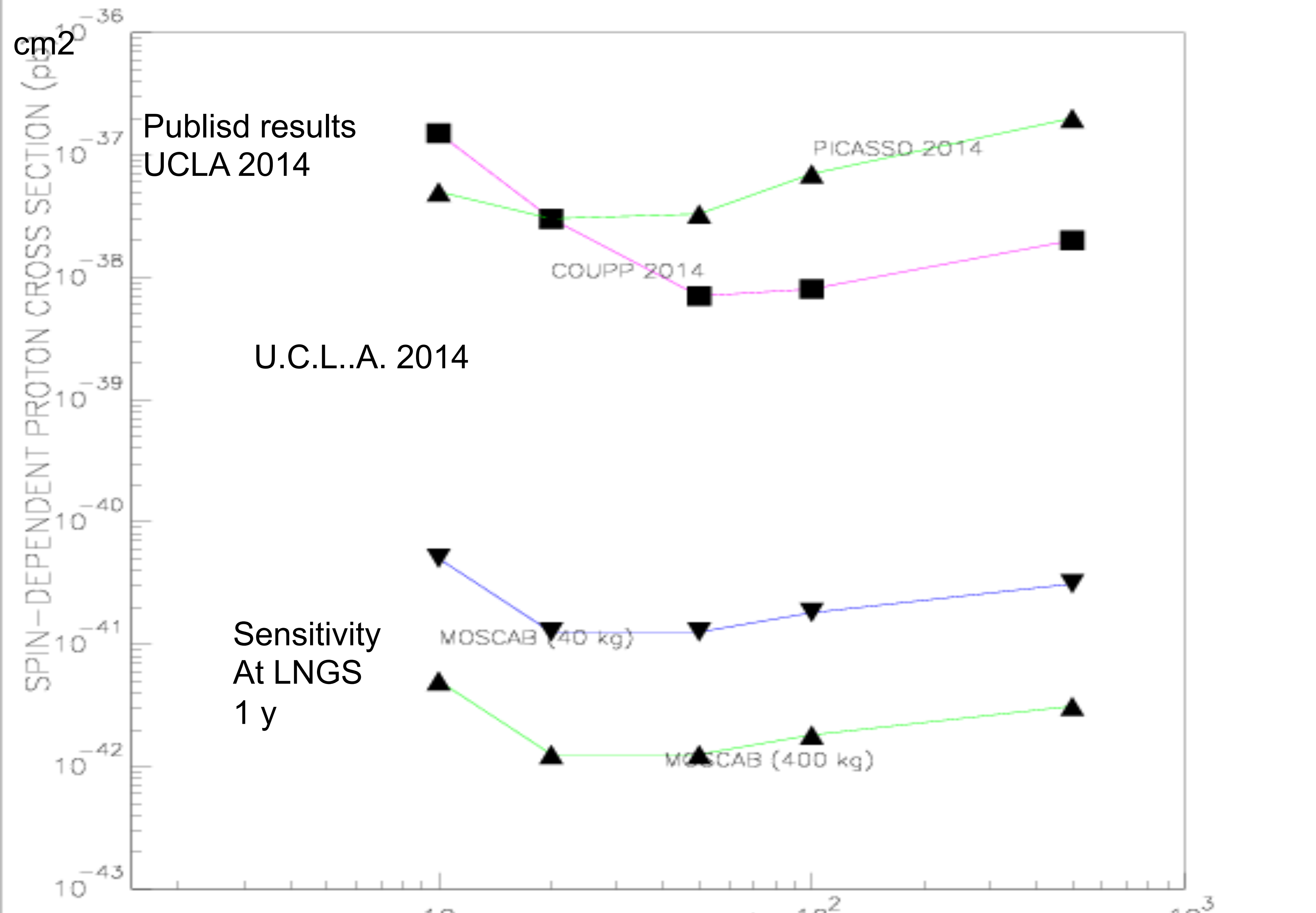
8) α from freon 0.02.

9)α from quartz 0.02

If neutrons multiple scattering
Are taken into account,the
dominant background become
the alpha

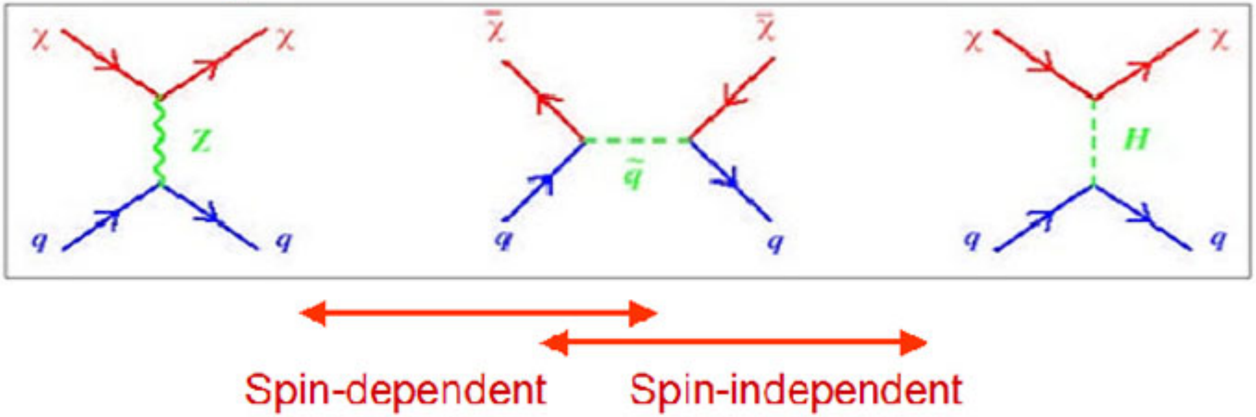
$\Sigma<0.2$ events/y (40 kg)

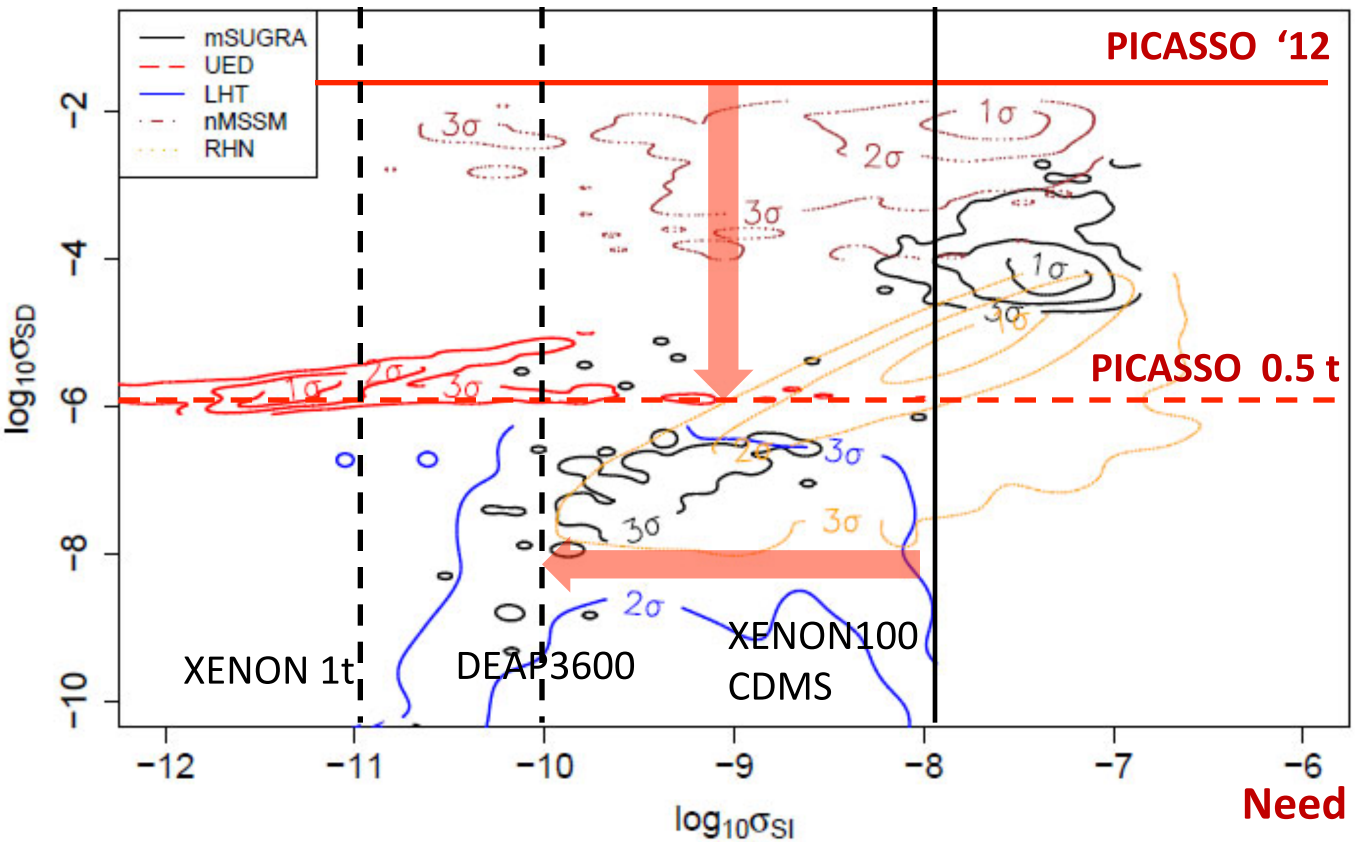
SENSITIVITY AND PUBLISHED RESULS



cm2
SPIN–DEPENDENT PROTON CROSS SECTION (p
10^-36
10^-37
10^-38
10^-39
10^-40
10^-41
10^-42
10^-43
10^2
10^3
Publisd results
UCLA 2014
PICASSO 2014
COUPP 2014
U.C.L..A. 2014
Sensitivity
At LNGS
1 y
MOSCAB (40 kg)
MOSCAB (400 kg)

Comparison SD and SI - searches

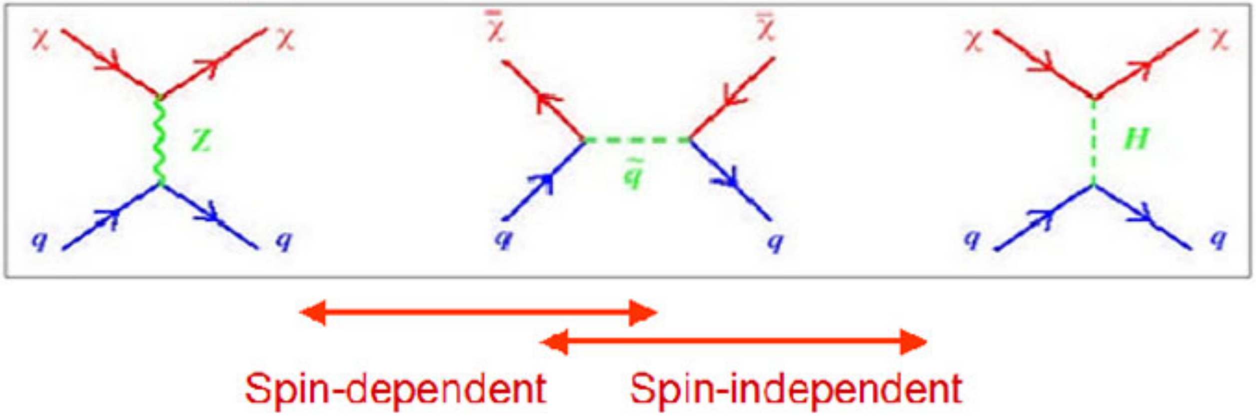


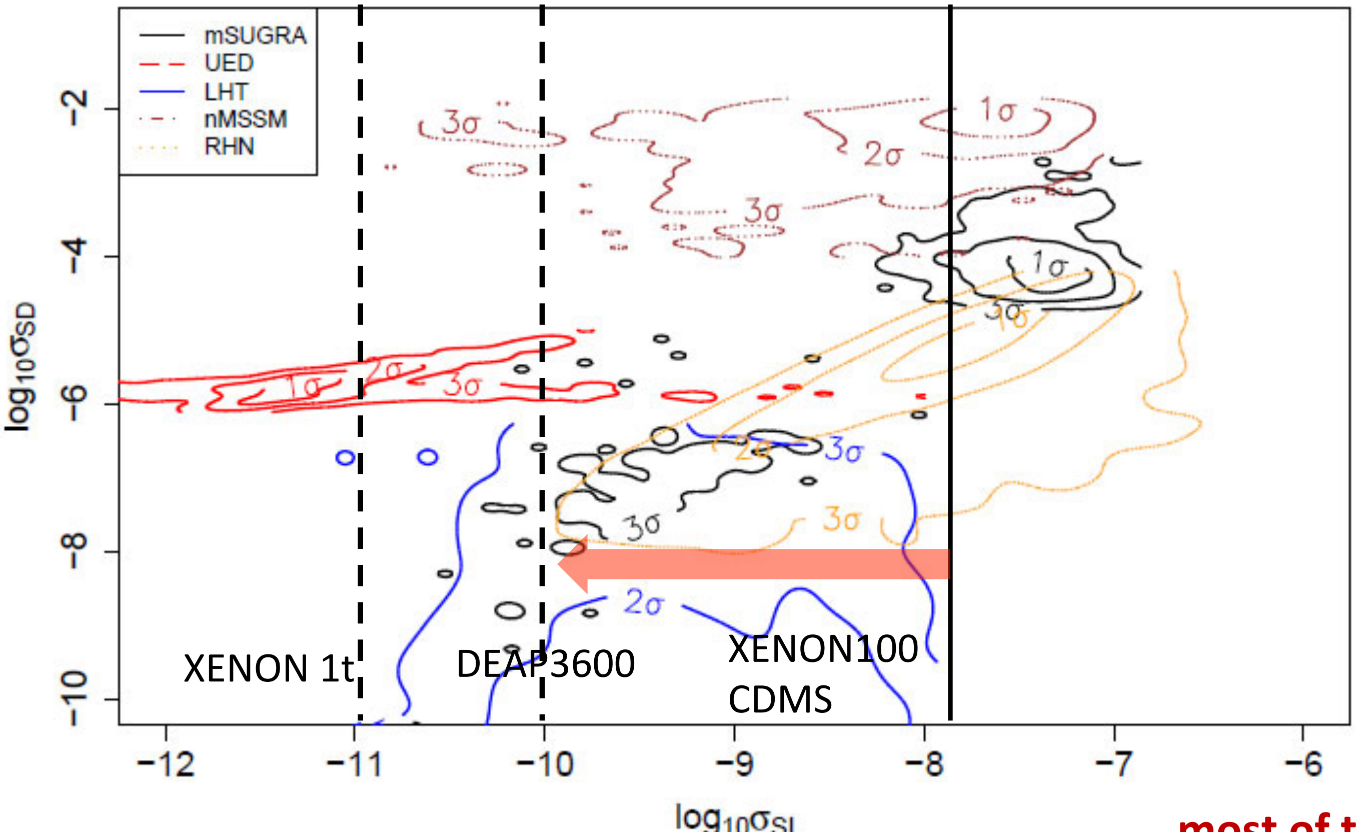


- no channel favored
- largely uncorrelated
- desctructive interference possible in SI sector

Need to explore both sectors!

Comparison SD and SI - searches





most of the activity in SI sector !

ACOUSTICS TRIGGER

We have two sensitive hydrophones -200 db; one of them is attached to the Detector's Vessel ando the second one is floating in the water.

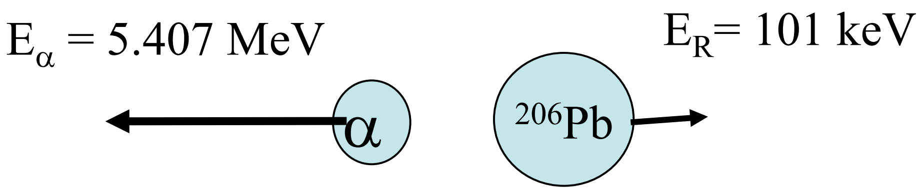
We will have soon the elettrical signal out of the Detector ; we plan to make a Fourier Analysis in Amplitude and frequencies to be optimized for the separation of alpha and recoils.

With more hydrophones we plan to have the coordinates of starting point the bubble and a trigger (as substitution of the actual visual trigger (2 Million of pixels of 5 μm ; 50 fps)

What Will the Dominant Background Be?

- Alpha decay produces monoenergetic, low energy nuclear recoils.

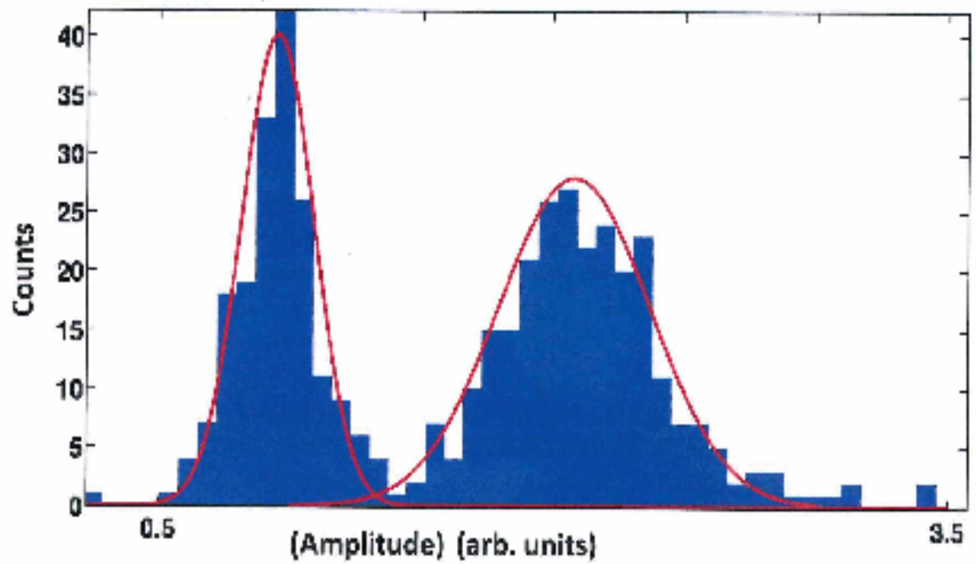
For example, consider ^{210}Po->^{206}Pb:



- The recoiling nucleus will nucleate a bubble in any chamber that is sensitive to the lower energy (~10 keV) recoils expected from WIMP scattering.
- The ^{238}U and ^{232}Th decay series include many alpha emitters, including radon (^{222}Rn) and its daughters.
- Radon is highly soluble in bubble chamber liquids.
- Solar neutrino experiments (Borexino, Kamland, SNO) have demonstrated feasibility of reduction to ~1 event per day in scintillator and water-- about 2 orders of magnitude lower rates than seen in current-generation dark matter experiments.

Separation between α decays and recoils of ions.

limits on the presence of alpha-emitters in the target liquids (C_4F_{10}). However, this problem is mitigated in superheated liquids by the possibility to discriminate acoustically alpha particle induced signals from nuclear recoil induced events. This new discrimination feature was first discovered with PICASSO droplet detectors and is described in [5,6]. It is because recoiling nuclei create only one bubble nucleation, whereas an alpha decay triggers at least two vaporizations: one from the recoiling daughter nucleus, and a second or more vaporizations along the track of the α-particle. Since the primary acoustic signal is proportional to the acceleration of the total expanding bubble volumes, alpha decay signals are at least twice as loud as nuclear recoil signals (Fig.7). By placing a cut between single and double nucleations, α- decays can be rejected at a level of 10^{-4}, still keeping an acceptance for recoiling nuclei of 90%. With some optimization of the acoustics system we expect that an α-recoil discrimination at the same level of 10^{-4} will be also possible when scaling up to a 0.5 ton experiment. This important discrimination effect was confirmed with the COUPP 4 kg bubble chamber [3].



Technical specifications

HYDROPHONE	Nominal capacitance: 3300pF Receiving sensitivity: -203 dB re 1V/uPa @10kHz
GAIN	30 dB Unbalanced out 36 dB Balanced outputs
CUTOFF FREQUENCY -3dB	700Hz – 170 kHz
POWER	5 Vdc – 24 Vdc
MAX. PP OUT	2,9Vpp @ 5 kHz (single output) 5,8Vpp @ 5 kHz (differential output)
NOISE	-160 dB re 1V / sqrt Hz @ 5 kHz (single output) -163 dB re 1V / sqrt Hz @ 5 kHz (differential output)
CALIBRATOR	CAL IN: 5Vpp @ 50 kHz SINGLE OUT: 776 mVpp (-16 dB re 1Vpp)
DIMENSIONS	75mm Lenght 20mm Diameter

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COLLABORATION:

1)MILANO-BICOCCA University and I.N.F.N.

2)L.N.G.S. (W. Fulgione et al.)

2)UNIVERSIDAD POLITECNICA de VALENCIA (M.ARDID et al.)

3)UNIVERSITY OF PRAGUE (I. STEKL et. al.)

END OF THE TALK

BACKGROUND

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

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

Even an unshielded detector (external source ≈10^{7} 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 ^{14}C 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 α mainly due to 222Rn → 218Po (101 keV)+ α (5.5 MeV)

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

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

With an acoustic trigger we will have a separation of α from recoil of ions at the level of 10^{-3}

NEW MECHANICAL SUPPORT

PART 1 DETECTOR

DESIGN of the DETECTOR

-The mechanical structure and the termal scheme were planned by our techecnicians with a firm of Bergamo (cost 40 kEuro) TECNOLOGIA MECCANICA

-The Quartz Vessel (Synthetic) was planned by us and a Germal firm (QSIL) (cost 5 kEuro)

-The assembling of the Geyser was done by us.

-Our line of work is that:

a) insert in the mech. struct. The 0.5 L vessel
b) “ “ a 2 L vessel
c) “ “ the 27 L vessel

-At the moment we are working on neutron measurements inside the water, and we have mounted the small vessel.

_With the big detector we cannot fully fill the vessel in MILANO; the foreseen background counting 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.

Future Program :

- Continue the test of the 40 kg In Milano (8-10) months.
-Start the work in LNGS at the end of the year.
-Collect DATA for 1 year.
(This point requires a small enlargement of the collaboration)
-If the results will be encouraging we will propose to make an experiment with 10 similar detectors
(This requires a large enlargement of the collaboration)

Comparison between MOSCAB and PICO (COUPP)

	MOSCAB	PICO (COUPP)
	27 L(Geyser)	30 L(Bubble Chamber)
	(Testing in Mi)	(Working iSNOLAB)
filling	$C_3 F_8$	C_2F_3I

Project 250 L Geyser (Small Prot. Working) (Not yet (Canada))

Composition of groups Weak Strong

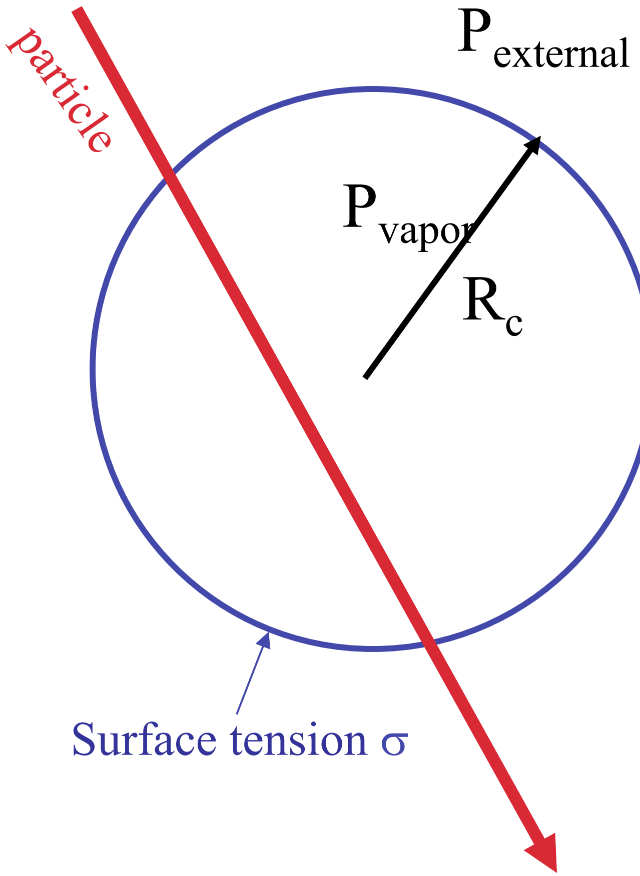
TO BE COMPETITIVE WE NEED AN ENLARGEMENT OF THE COLLABORATION MOSCAB!!

TO BE COMPETITIVE is not right : better PARALLEL: indeed we use:

a)Different LABORATORY b)Different liquids

Bubble Nucleation by Radiation

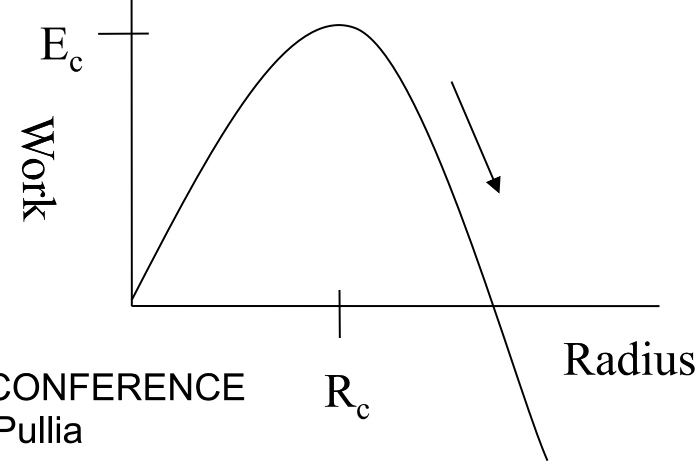
(Seitz, "Thermal Spike Model", 1957)



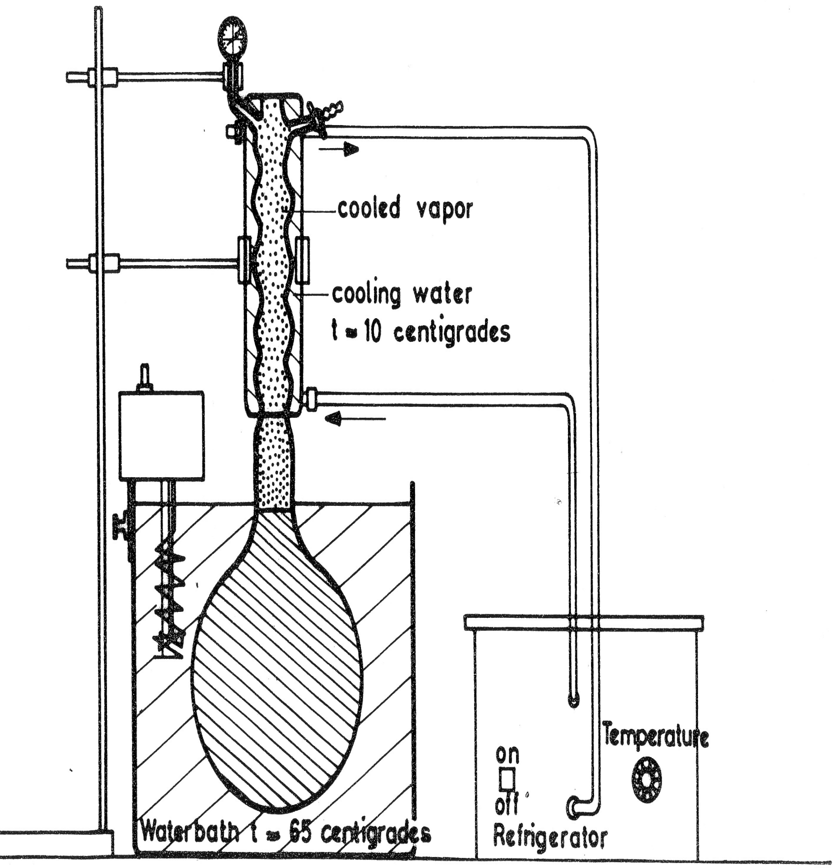
- **Pressure inside bubble in equilibrium with the vapor pressure.**
- **At critical radius R_c surface tension balances pressure.**

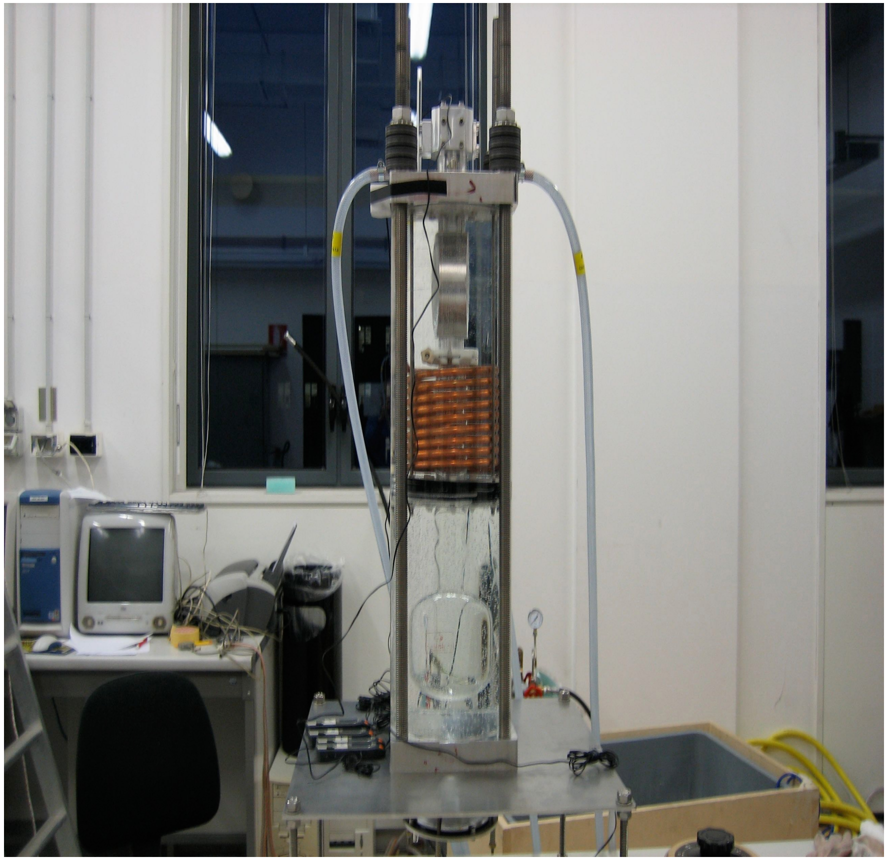
$$R_C = \frac{2\sigma}{P_{vapor} - P_{extern}}$$

- **Bubbles bigger than the critical radius R_c will grow, while smaller bubbles will shrink to zero.**
- **Boiling occurs when energy loss of through going particle is enough to produce a bubble with radius > R_c**



FIRST ATTEMPT(2009) Laura Baudis (General talk at CERN)





Old Geyser (Berne) (1973)

Geyser in Milano-Bicocca (2009)