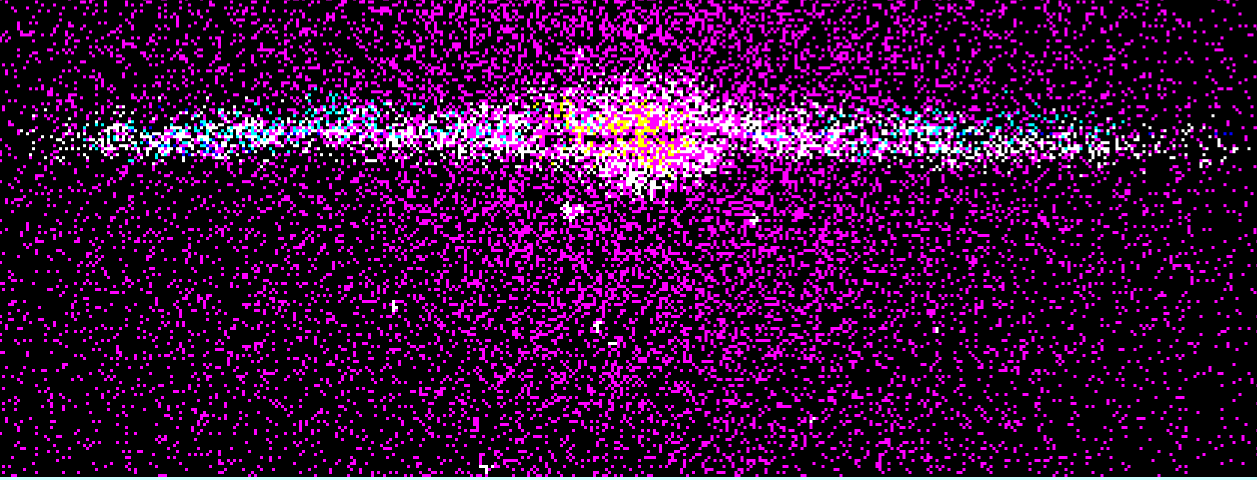
Ultra Low Temperature Instrumentation for Measurements in Astrophysics

ULTIMA

Yu. Bunkov, H. Godfrin, C.Winkelmann



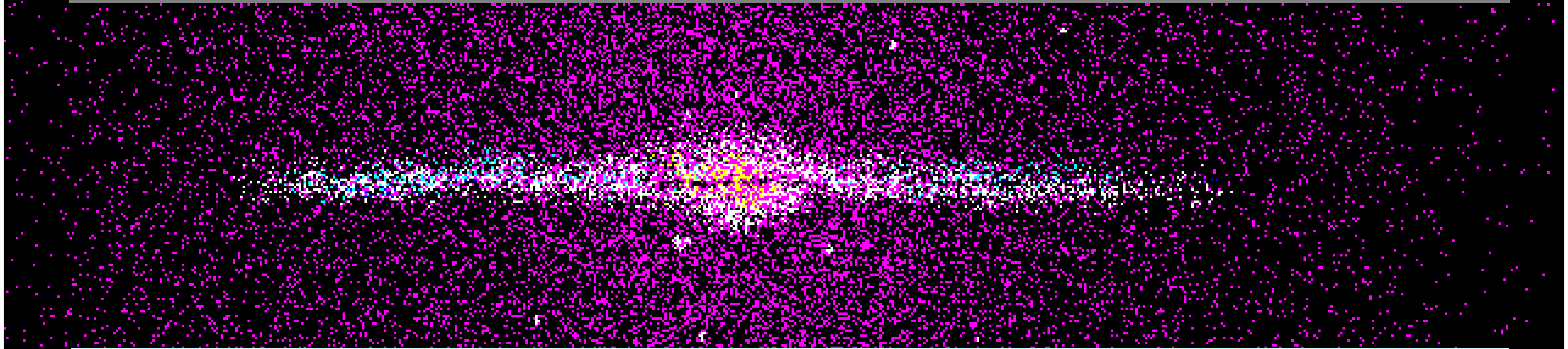
The idea :

Use the Bose –Einstein condensed coherent quantum state of superfluid ^{3}He at a limit of extremely low temperatures as a sensitive medium for the direct bolometric search of non-baryonic Dark Matter

First suggestion

G.R.Pickett in Proc. «Second european worshop on neutrinos and dark matters detectors», ed by L.Gonzales-Mestres and D.Perret-Gallix, Frontiers, 1988, p. 377.

Yu.Bunkov, S.Fisher, H.Godfrin, A.Guenault, G.Pickett. in Proc. « International Workshop Superconductivity and Particles Detection (Toledo, 1994)», ed. by T.Girard, A.Morales and G.Waysand. World Scientific, 1995, p. 21-26.



Neutron capture experiments

Lancaster

D.I.Bradley, Yu.M.Bunkov, D.J.Cousins, M.P.Enrico, S.N.Fisher, M.R.Follows, A.M.Guenault, W.M.Hayes, G.R.Pickett, T.Sloan, ***Phys. Rev. Lett.*** **75**, 1887 (1995)

Grenoble

C.Bauerle, Yu.M.Bunkov, S.N.Fisher, H.Godfrin, G.R.Pickett, ***Nature*** **382**, 332 (1996)

The main advantages of superfluid ^{3}He detector:

100μK (World record of cooling)

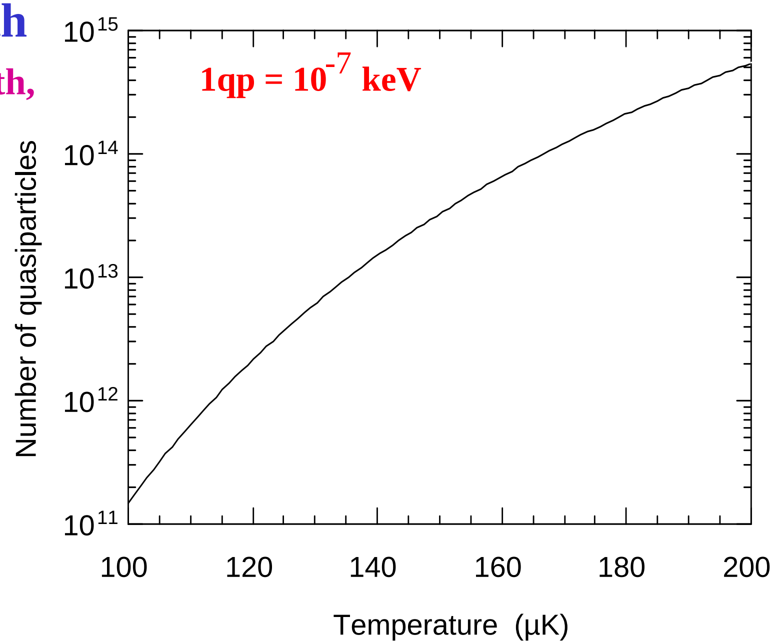
Bose – Einstein condensed coherent quantum state with rear gas of collective excitations, which density can be measured directly by micro-resonator.

At about 100 μK at 0.1 cm^3 remains only 10 keV from the level of absolute zero of temperature.

The deposited energy is intimately associated with the ^{3}He nuclear. **There is no isolated nuclear thermal bath, separated from electronic and phononic subsystems!**

Temperature is the density of quasiparticles, that measured directly by damping of mikro vibrating wire.

$$\frac{3\cdot 10^{10}}{T}\exp\left(-\frac{\Delta}{kT}\right)\left(\frac{\text{keV}}{\text{K cm}^3}\right)$$



Clear signature of neutrons!!! **(764 keV energy of capture)**

The nuclear momentum of ^{3}He makes the non-symmetric channel of interaction visible for dark matter.

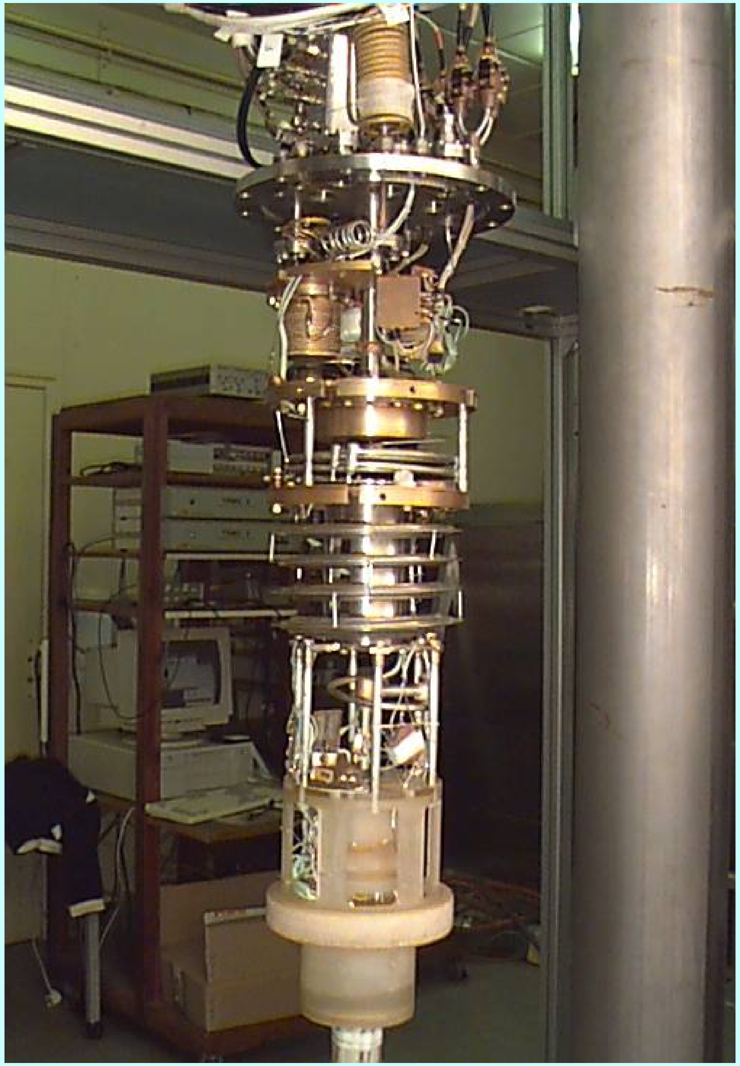
The absence of free electrons makes ^{3}He relatively insensitive to electromagnetic and gamma radiation background.

A the lowest temperatures superfluid ^{3}He is absolutely quantum pure matter.

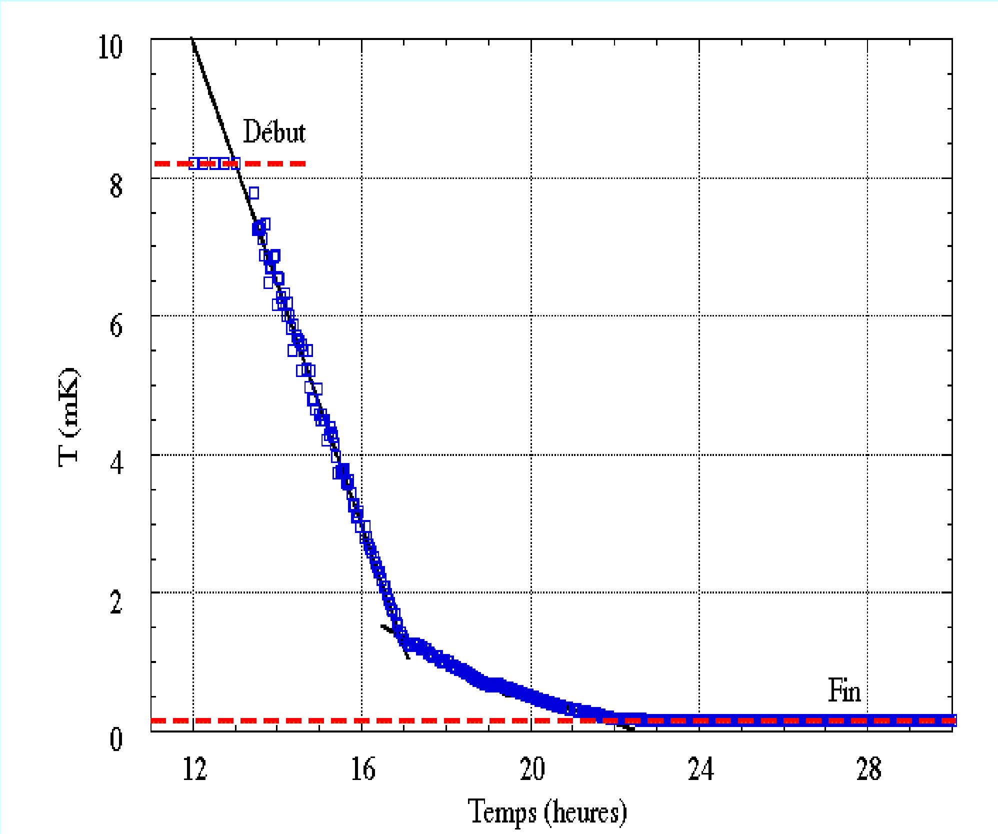
Since the ^{3}He pairs have a nuclear magnetic momentum but no electric charge, the superfluid ^{3}He is transparent to electromagnetic radiation, allowing to employ a very informative NMR methods. NMR can establish magnetically excited quantum state. The latter can be considered rather as metastable state, where instability can be triggered by a small deposit of energy. This variant of particle detector can be tested in future.

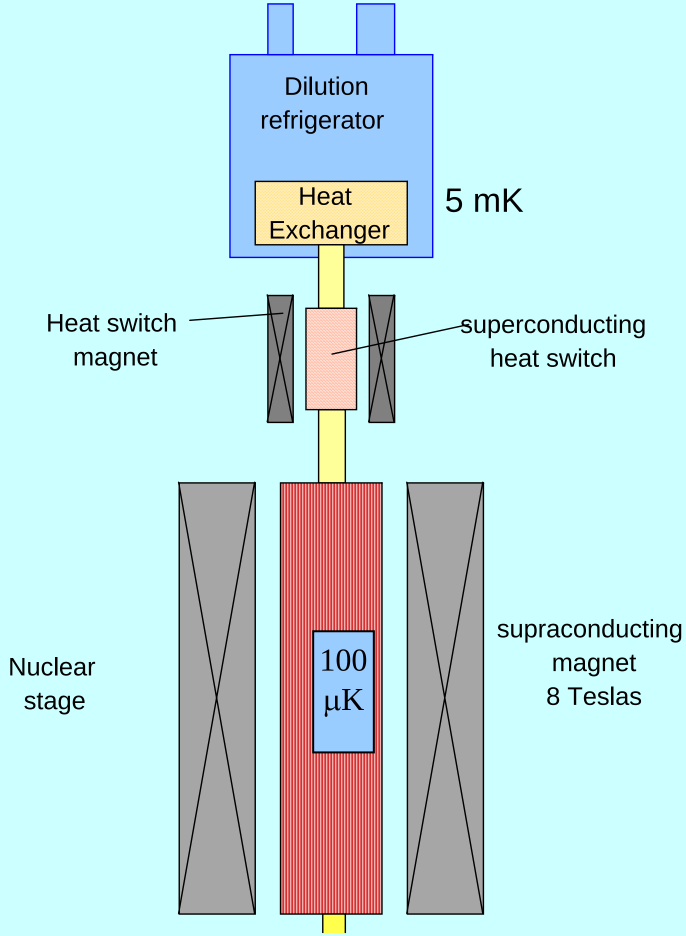
The small heat capacity, the absolute purity, the liquid state and the relative transparency to gamma radiation background make superfluid ^{3}He a very sensitive nuclear collision detector.

Cooling superfluid ^{3}He down to 100 µK

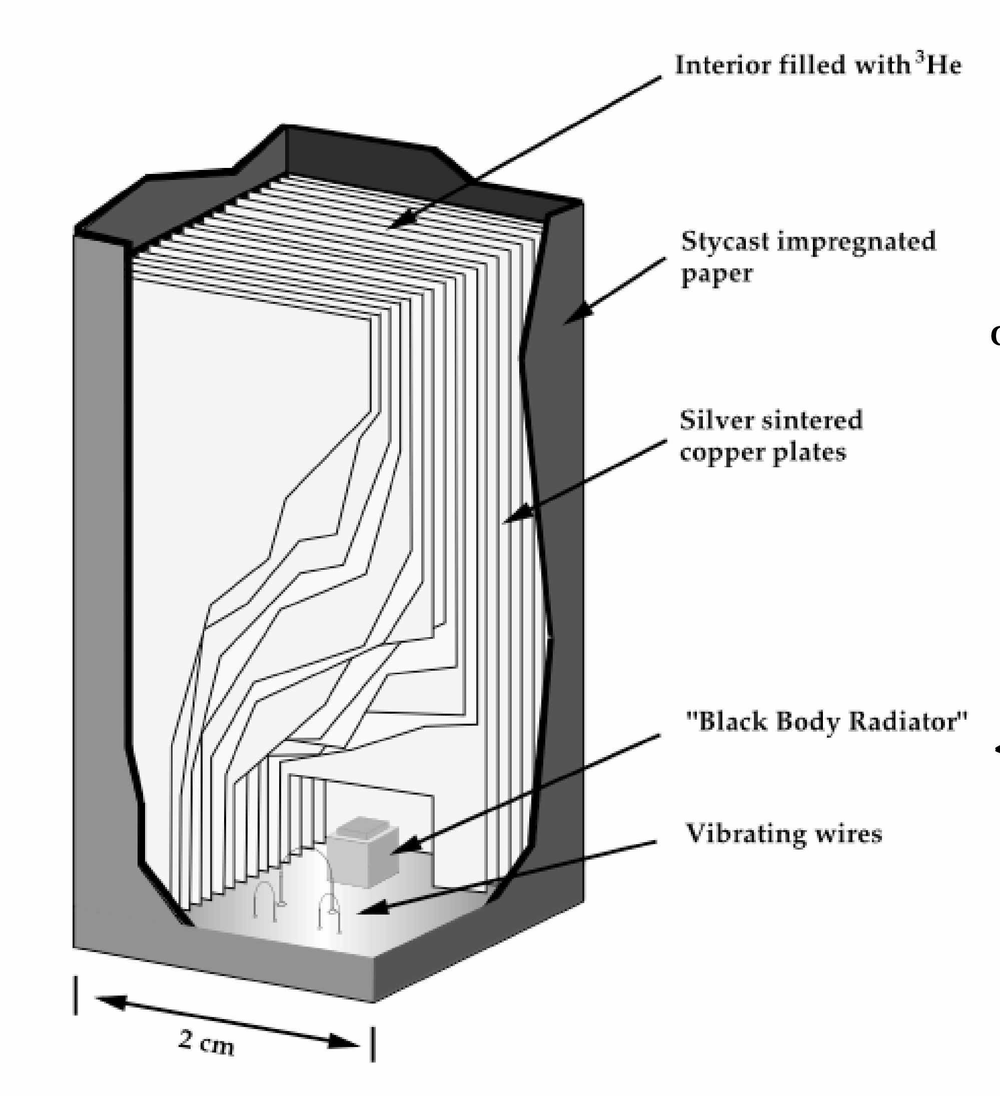


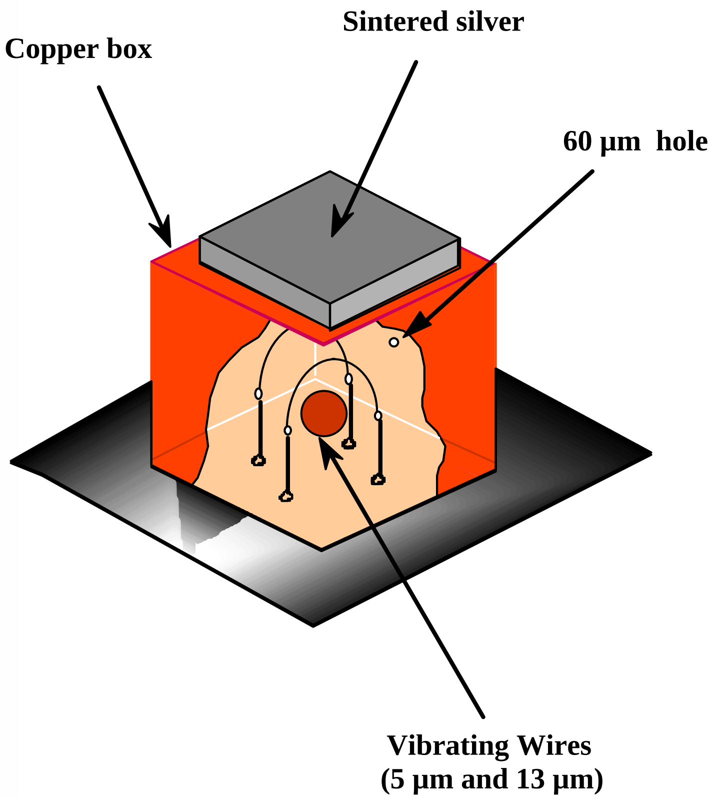
Nuclear demagnetization refrigerator





Superfluid ^{3}He bolometry





First experiments

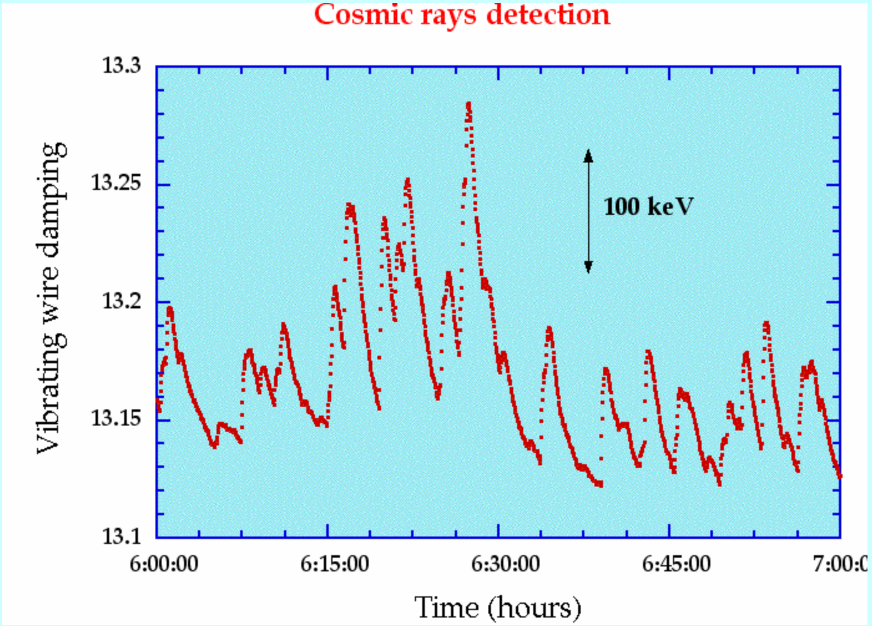
- Detection of particles radioactivity of environment (gammas) and cosmic particles

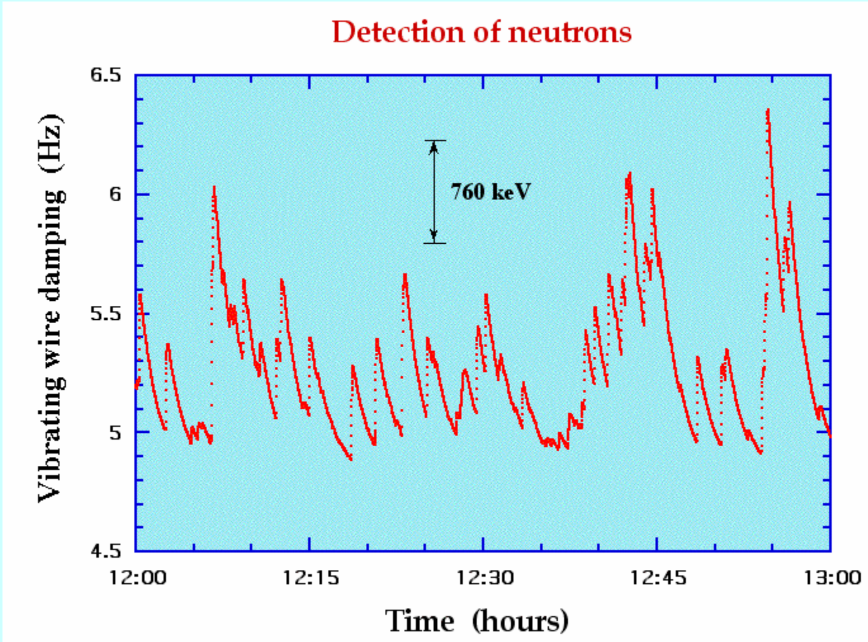
- Detection of neutrons (Am-Be source). Large neutron capture cross-section of ^{3}He

Local heating by nuclear reaction

$n + {}^{3}He = p + {}^{3}H + 764\ keV$

- "Missing energy" : shift due to creation of topological excitations (Big Bang analog, Nature 1996).

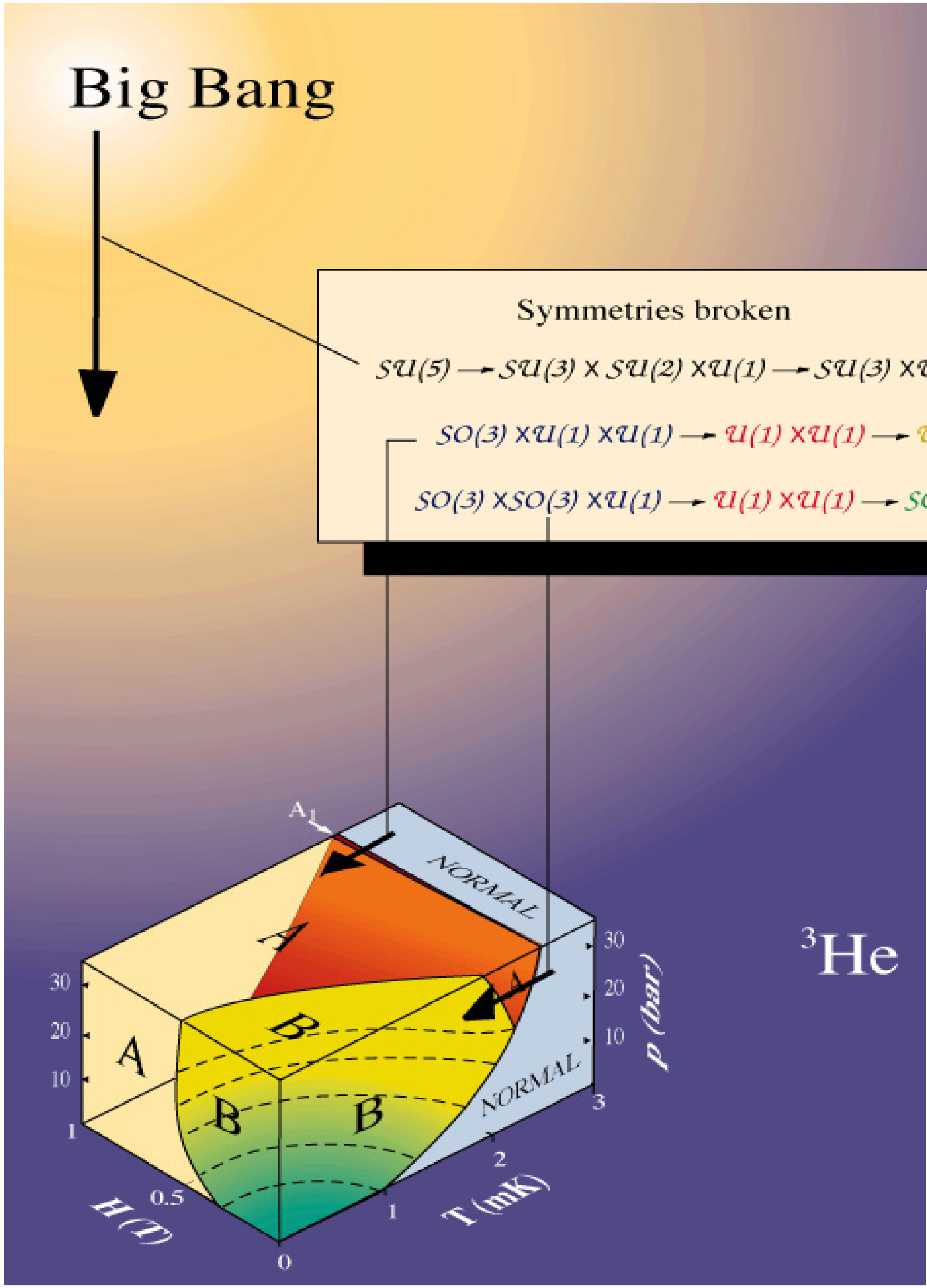


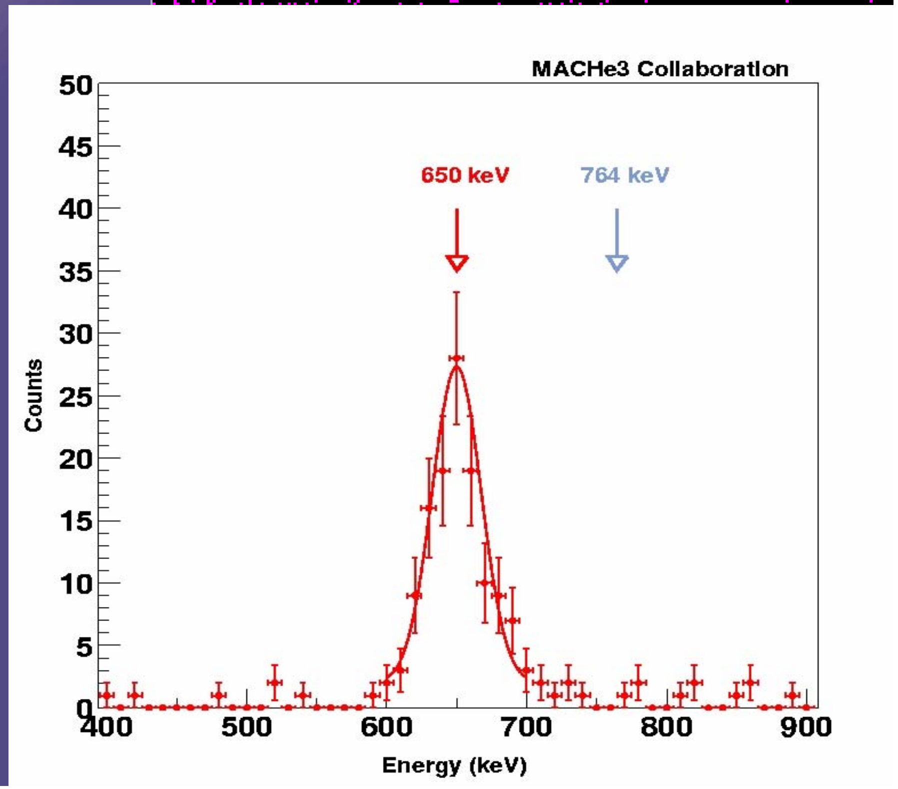


Annonce.

22.09.2004 IOP

G.Volovik: Simon prize

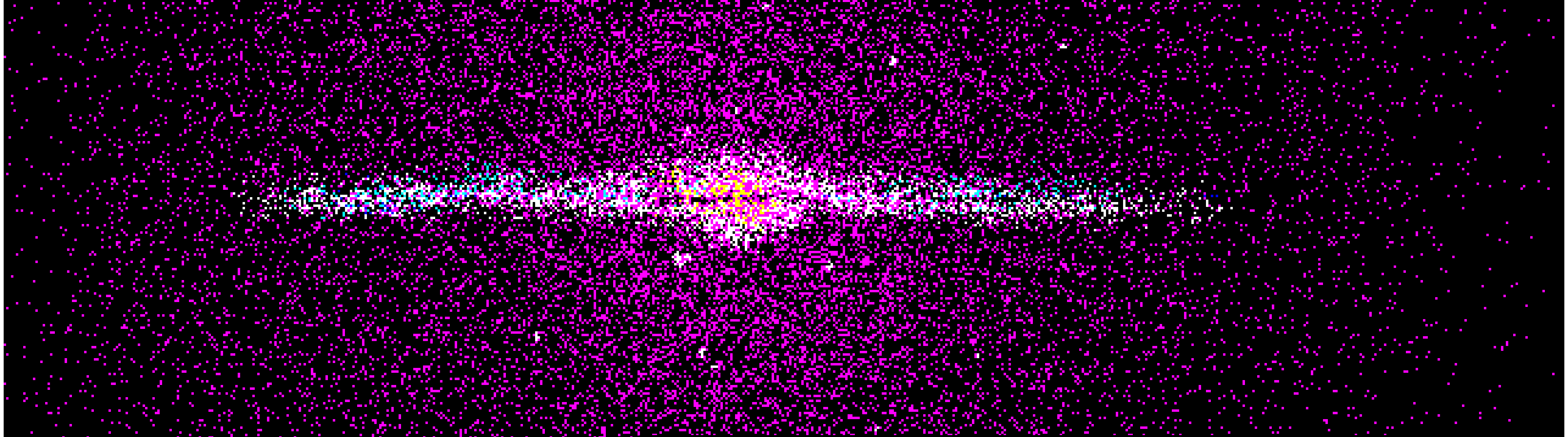




Results of the project - MACHe3 (2000-2004)

CRTBT (Grenoble) : **Yu. M. Bunkov, E. Collen, H. Godfrin, C.Winkelmann, M.Krusius**

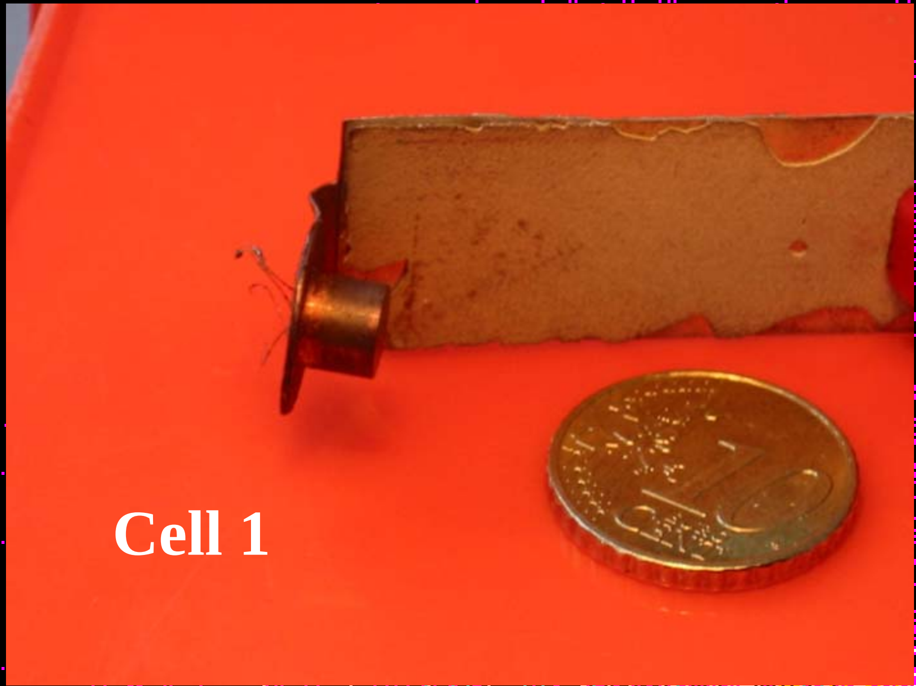
LPSC (Grenoble) : **J. Genevey, J. Macías-Pérez, E.Moulin J.A. Pinston, D. Santos**

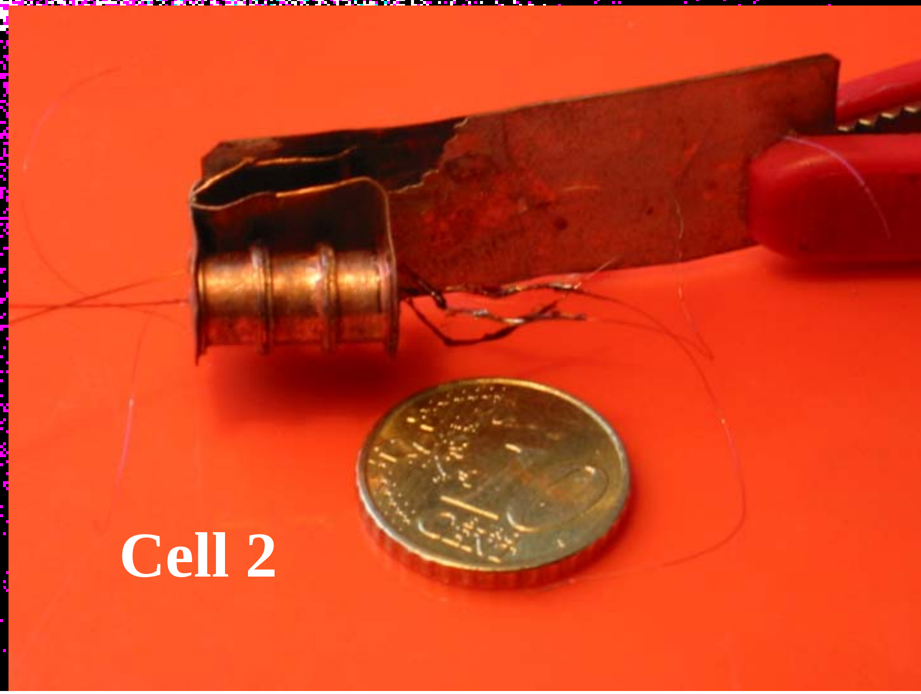


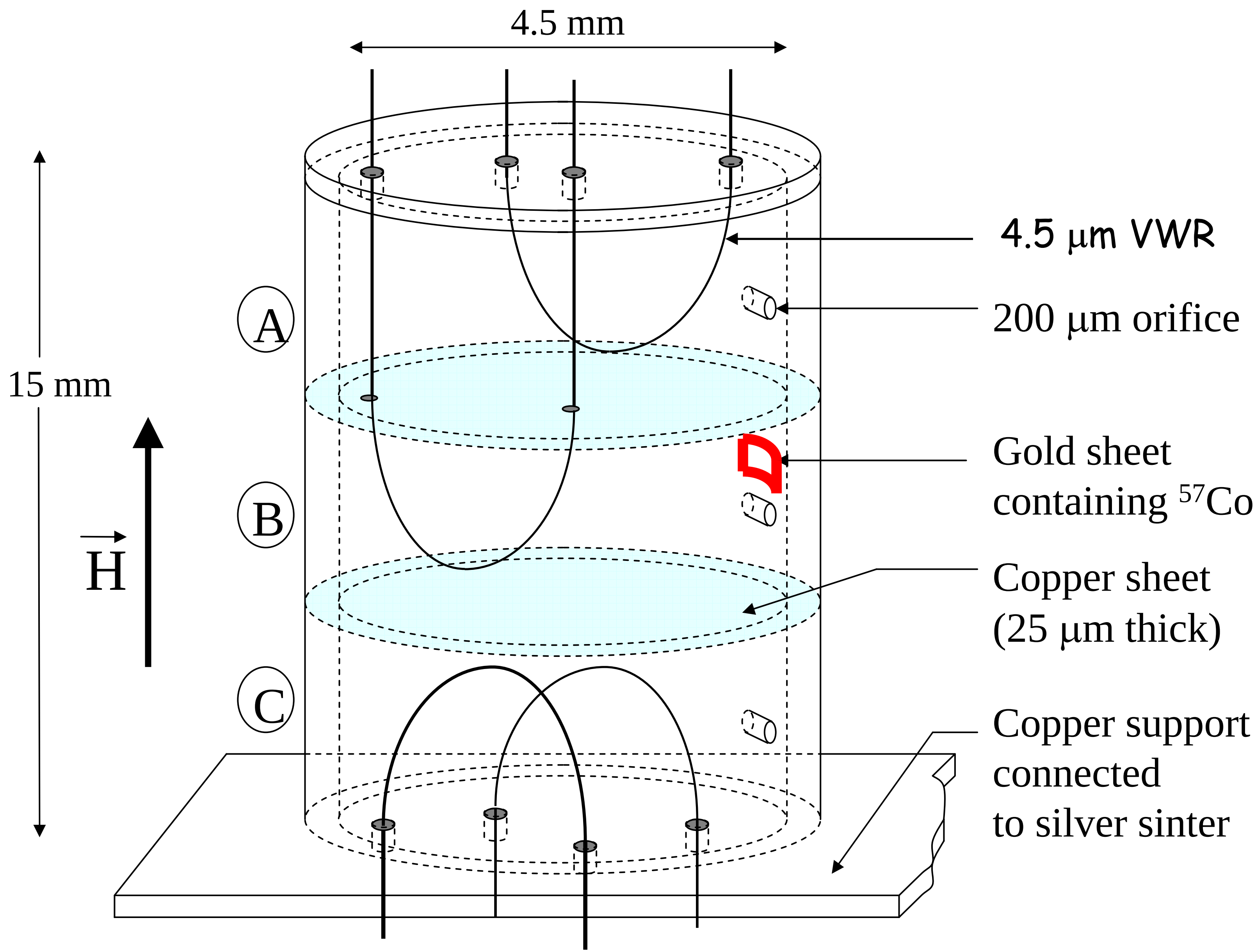
MACHe3: a prototype for non-baryonic dark matter search: keV event detection and multicell correlation

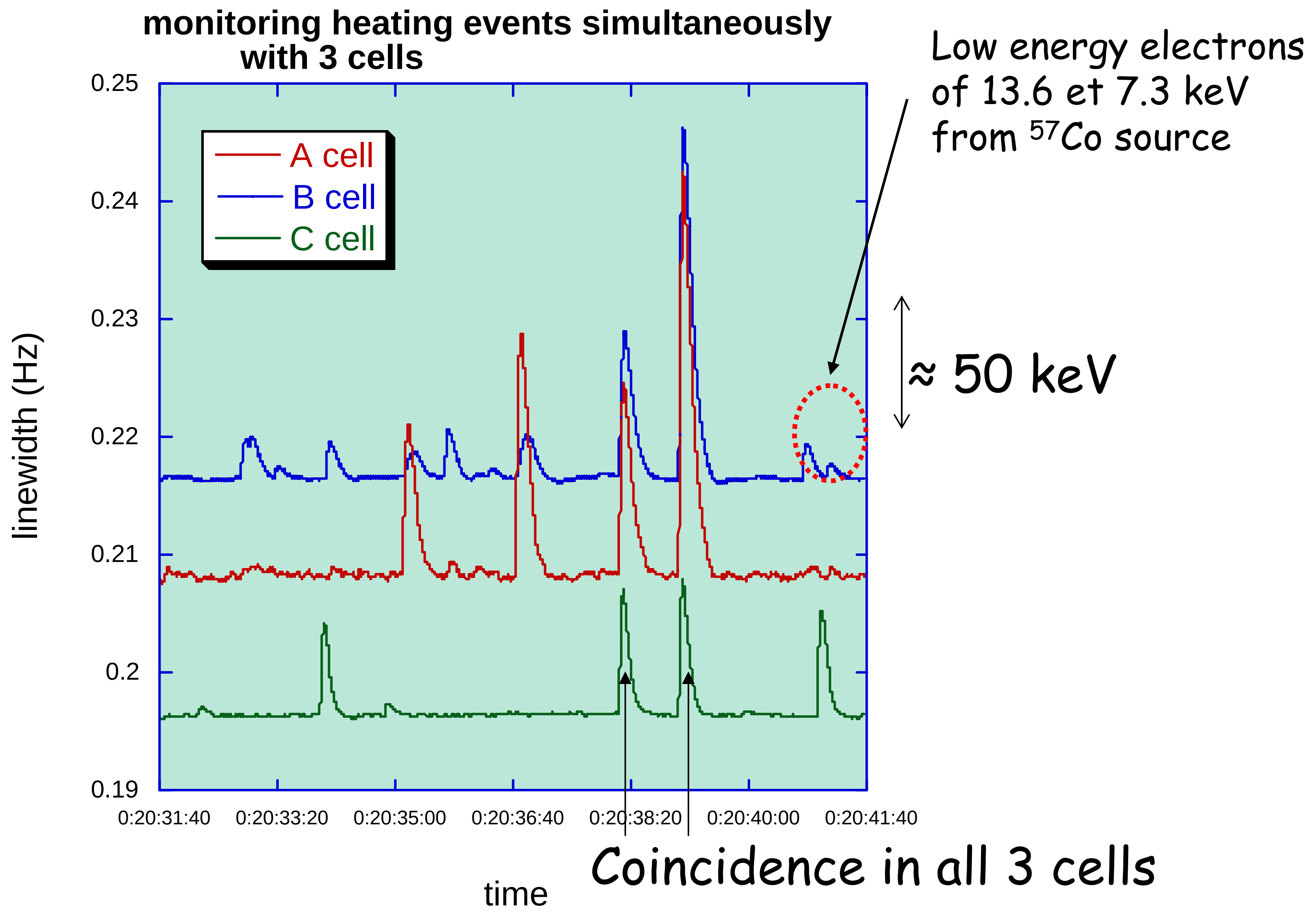
CRBT

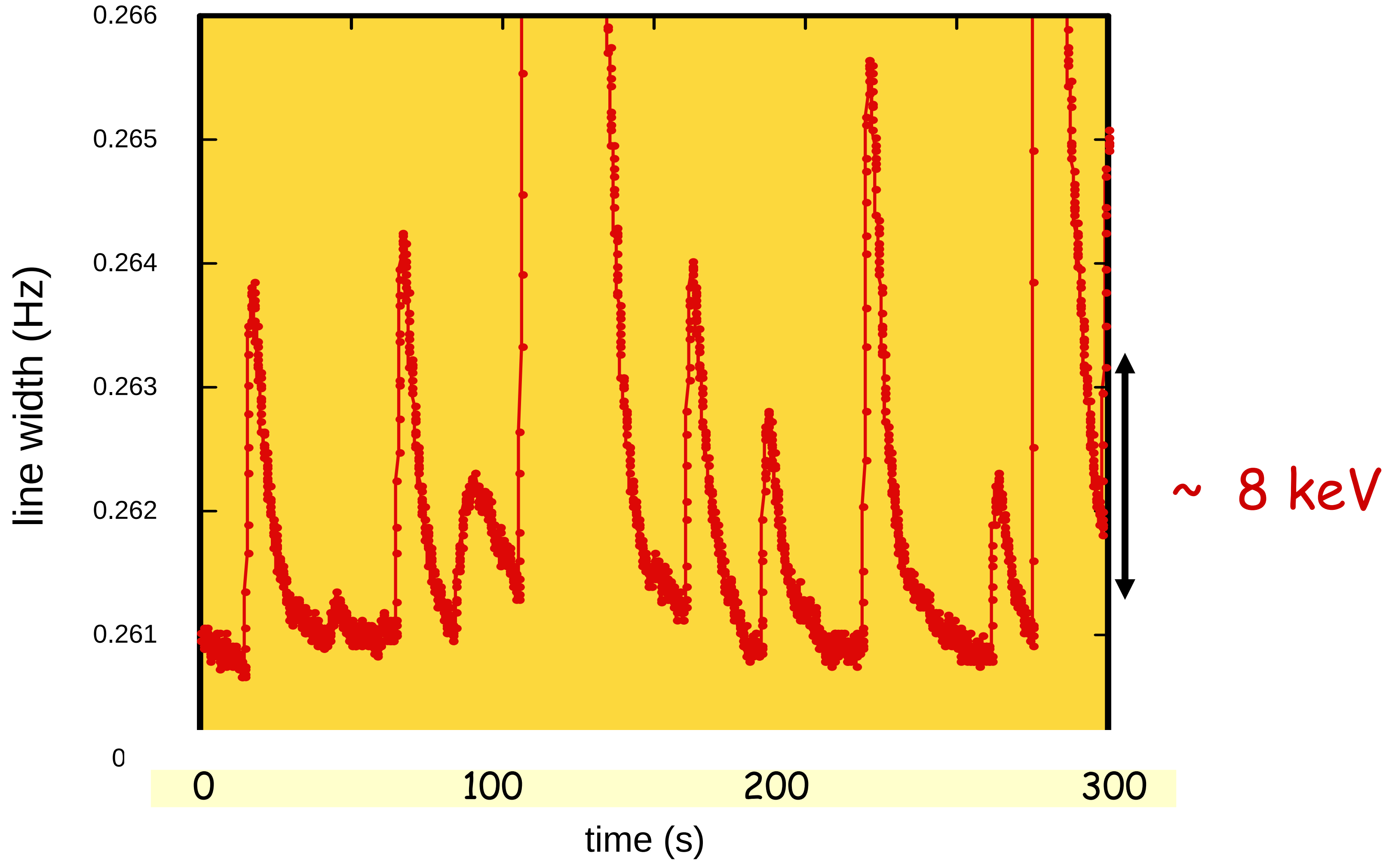
Centre de Recherches sur les Très Basses Températures

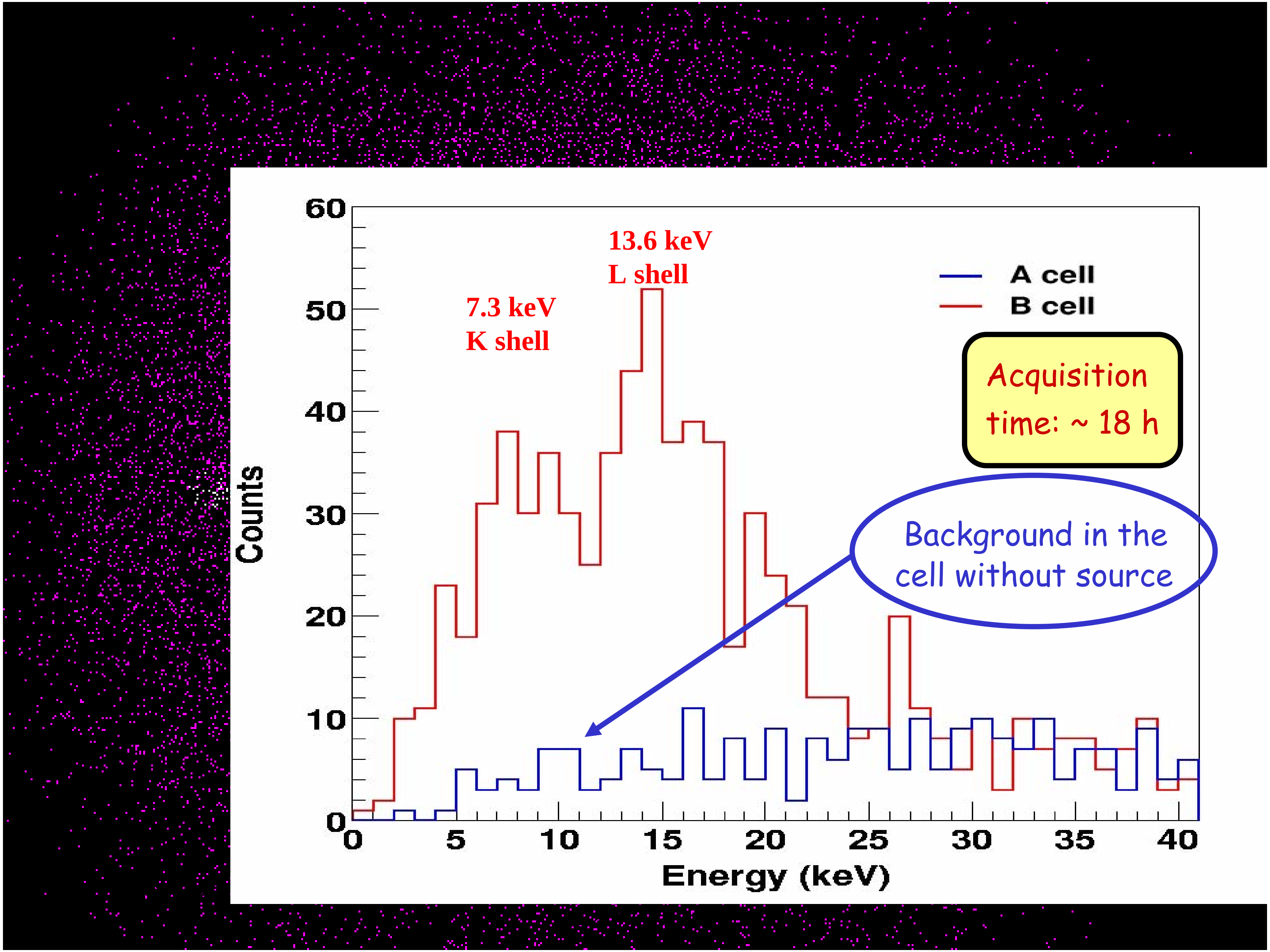

Cell 1


Cell 2


4.5 mm
15 mm
A
B
C
H
4.5 µm VWR
200 µm orifice
Gold sheet
containing 57Co
Copper sheet
(25 µm thick)
Copper support
connected
to silver sinter


monitoring heating events simultaneously with 3 cells
A cell
B cell
C cell
0.25
0.24
0.23
0.22
0.21
0.2
0.19
linewidth (Hz)
0:20:31:40
0:20:33:20
0:20:35:00
0:20:36:40
0:20:38:20
0:20:40:00
0:20:41:40
time
Low energy electrons of 13.6 et 7.3 keV from 57Co source
≈ 50 keV
Coincidence in all 3 cells


0.266
0.265
0.264
0.263
0.262
0.261
0
line width (Hz)
0
100
200
300
time (s)
~ 8 keV



13.6 keV
L shell
7.3 keV
K shell
A cell
B cell
Acquisition time: ~ 18 h
Background in the cell without source
Counts
Energy (keV)
0
10
20
30
40
50
60
5
15
25
35

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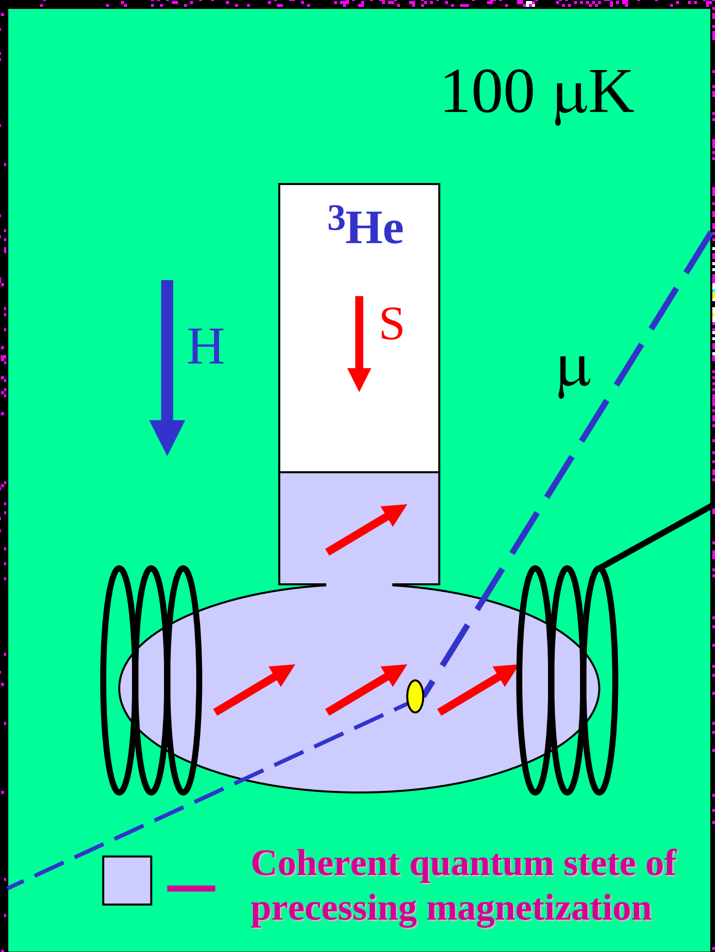

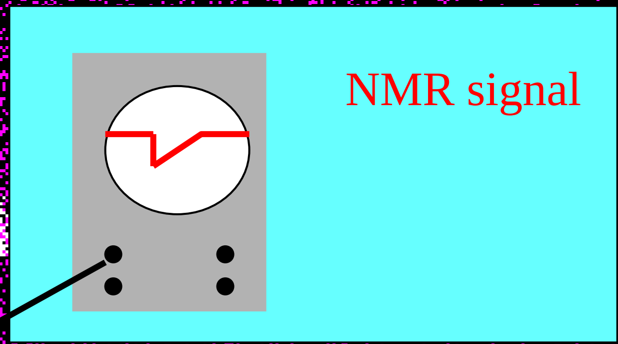

Future project.
One can use the timerate of relaxation
of Excited Coherent Quantum State of
Magnetization in ^{3}He as an
ULTIMATE
sensor of energy, deposited by cosmic particles.

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Collaboration: CRTBT – CNRS, Grenoble, France
LPNC – CNRS, Grenoble, France
University Fourie, Grenoble, France
Helsinki Technological University, Finland
Centre “Cosmion”, Moscow, Russia
Kyoto University, Japan

(2004-2006)

Stage 1: New refrigerator for cooling 100g of ^{3}He to 100 μK
Going to underground site.
Try to use NMR for thermometry.
Goal: Try to found axial interacted Dark matter.

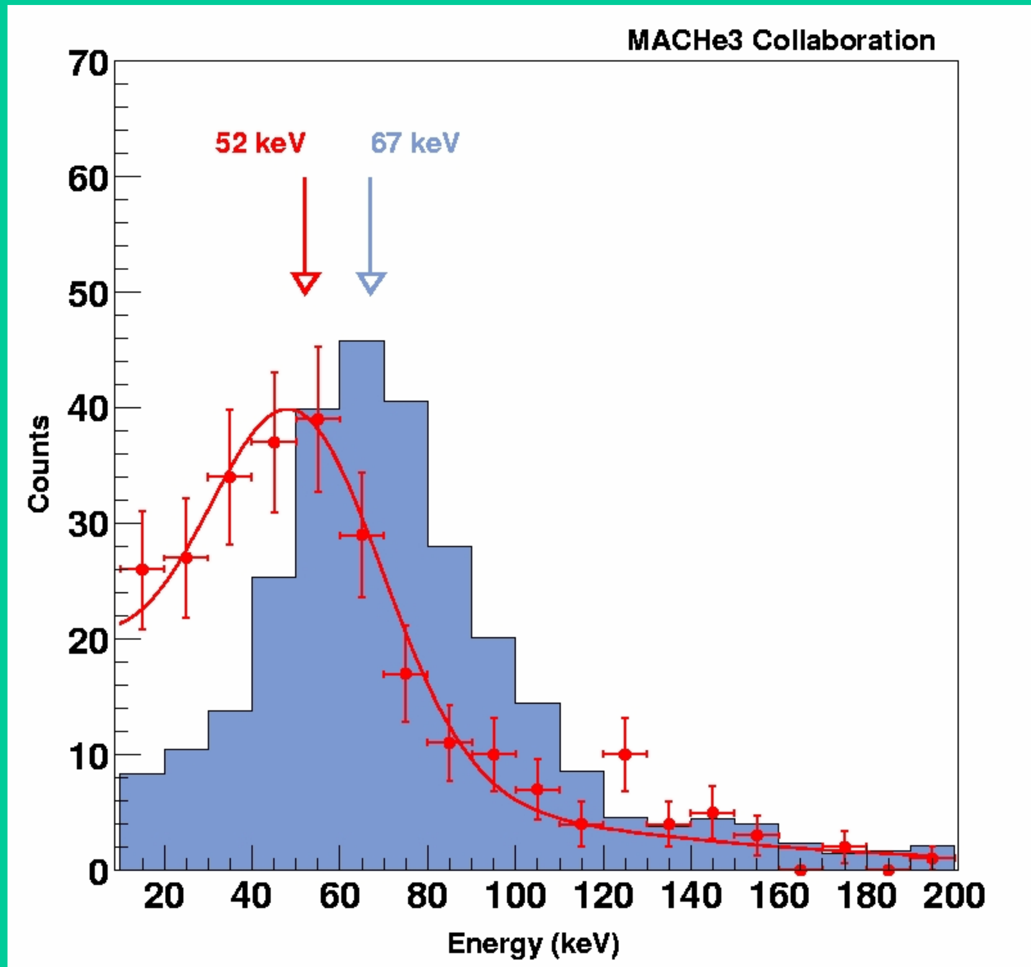
(2007-2009)

Stage 2: Detector with 1 kg of ^{3}He for ultimate search of dark matter

Muon detection (in first cell)

Experimental data :
⇒ peak at **52 keV**

Geant4 simulation
⇒ peak at **67 keV**



The 100 mK nuclear stage

Dilution refrigerator mixing chamber

Silver sintered heat exchangers

Filling capillary

Superconducting heat switch

Outer cell : ^{3}He and copper flakes

7T superconducting magnetic coil

Inner cell

Silver sintered copper plates

The 3-cell bolometer

Vibrating Wire thermometer in bath