SN neutrino detection via coherent scattering using the spherical proportional counter (SPC)

G. Tsiledakis

E. Bougamont[1], P. Colas[1], J. Derre[1], A. Dastgheibi-Fard, I. Giomataris[1], G. Gerbier[1], M. Gros[1], N. Grouas, P. Loiza, P. Magnier[1], J. P. Mols, X.F. Navick[1], P. Salin[3], I. Savvidis[2], G. Tsiledakis[1], J. D. Vergados[4]

1: IRFU Saclay, 2: Univ. of Thessaloniki, 3: APC Univ. of Paris, 4: Univ. of Ioannina

Friday 22/07/2011--Phenomenology and Detection Session

Contents

- Coherent Elastic Neutrino Nucleus Scattering
- Spherical Proportional Counter (SPC)
- Ultra low energy calibration results
- Applications
- SN detection
- Outlook / Summary

Coherent Elastic Neutrino – Nucleus Scattering

$\nu + A \rightarrow \nu + A$

Neutral current

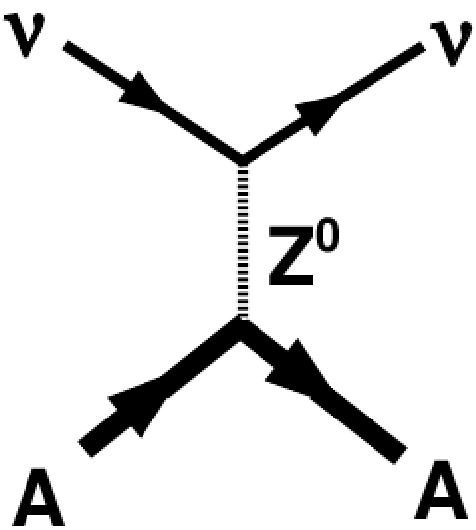
Coherent up to ~100 MeV

reactor, solar, spallation source, SN ν

$\sigma \sim 0.4 \times 10^{-44} N^2 (E\nu/MeV)^2 cm^2$

D. Z. Freedman, Phys. Rev.D,9(1389)1974

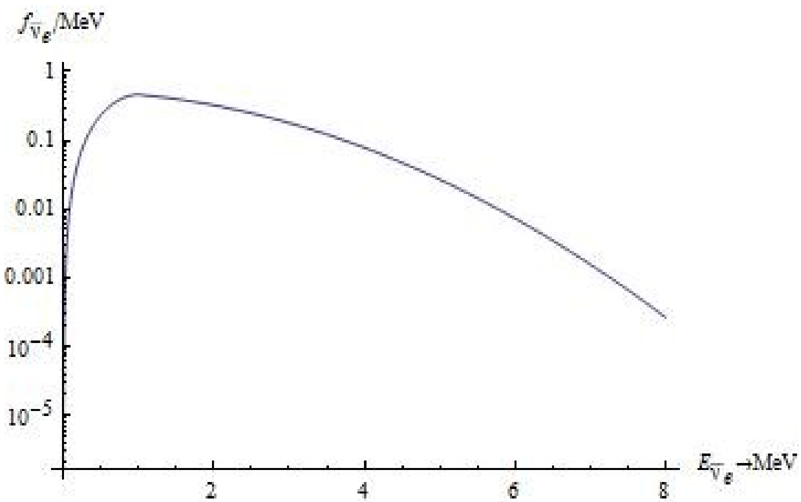
Large σ ↑as Eν↑and scales as N^2



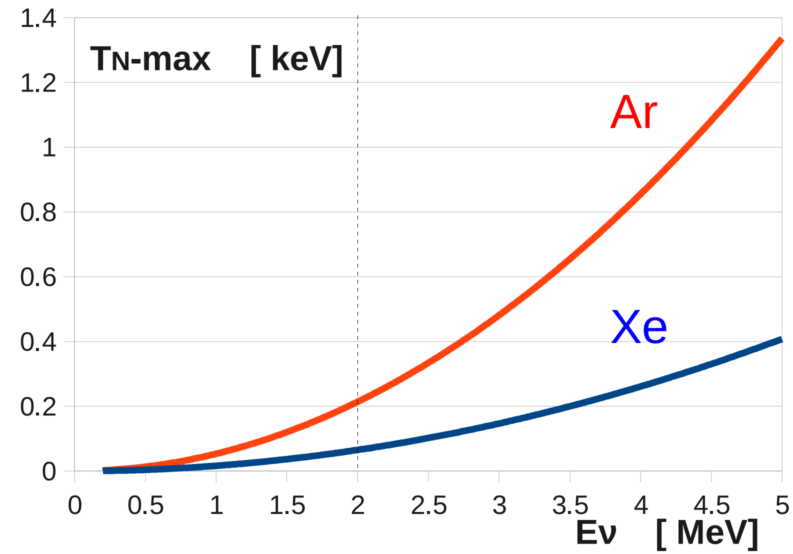
In the few-50 MeV range:

- Coherent ν-A elastic: ~10^{-39} cm²
- ν-A charged current: ~ 10^{-40} cm²
- ν-p charged current: ~10^{-41} cm²
- ν-e elastic: ~10^{-43} cm²

But this coherent ν - A elastic scattering has never been observed...



Typical reactor electron antineutrino spectrum



Recoil energies are tiny!

$$T_N = 2\, m_N (E_\nu \cos\theta)^2 / \{(m_N + E_\nu)^2 - (E_\nu \cos\theta)^2\}$$

Energy **ν = 2 MeV** ~ <Eν> at nuclear reactor

- Xe ==> T_{max}=66 eV
- Ar ==> T_{max}=215 eV

A. Druikier, L. Stodolsky, Phys.Rev.D30:2295,1984, JI Collar, Y Giomataris - NIMA471:254-259,2000, H. T. Wong, arXiv:0803.0033-2008, PS Barbeau, JI Collar, O Tench - Arxiv preprint nucl-ex/0701012, 2007

Advantages of a Neutral Current Detector

- All neutrinos contribute
- The event rate is not affected by neutrino oscillations
- Ideal probe for the neutrino source
- The target proton contribution is negligible, but all neutrons contribute
- The cross section is coherent, i.e. proportional to N^2

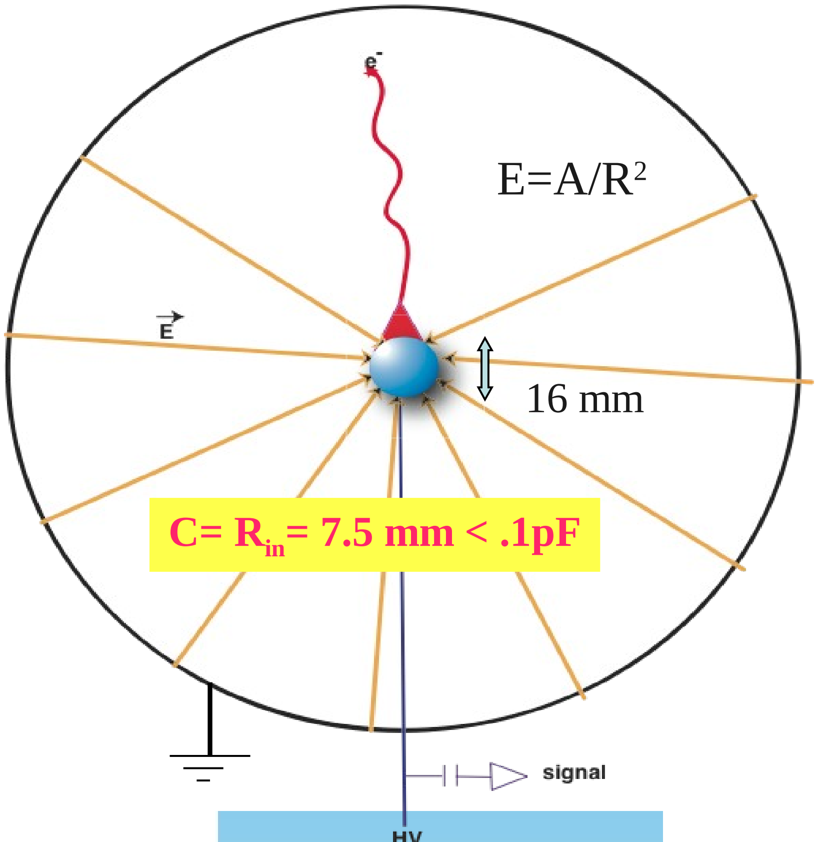
How to measure?

- The kinetic energy of the recoiling nuclei is very low (< 1 keV)
- Usual solid state detectors for DM search have thresholds of a few keV
- Detectors with large target mass, low energy threshold and low noise are needed
- What about the recently developed Spherical Proportional Counter?

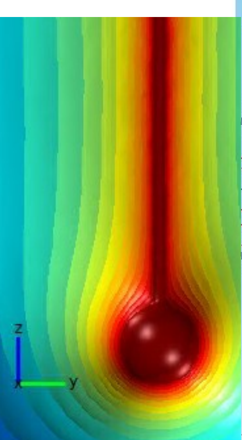
The Spherical Proportional Counter -Introduction

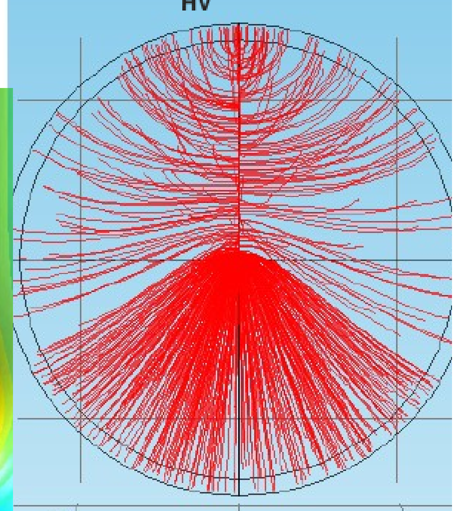
Radial TPC with spherical proportional counter read-out

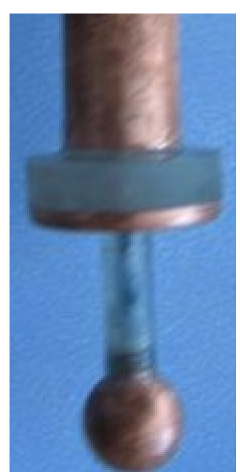
Saclay-Thessaloniki-Saragoza

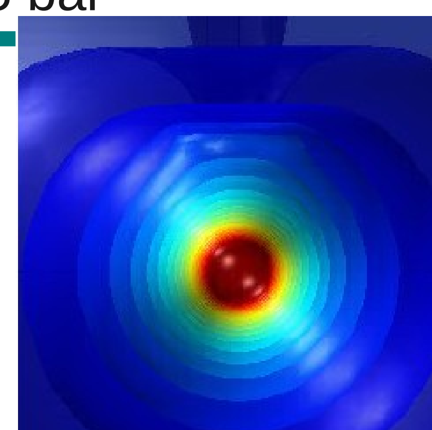


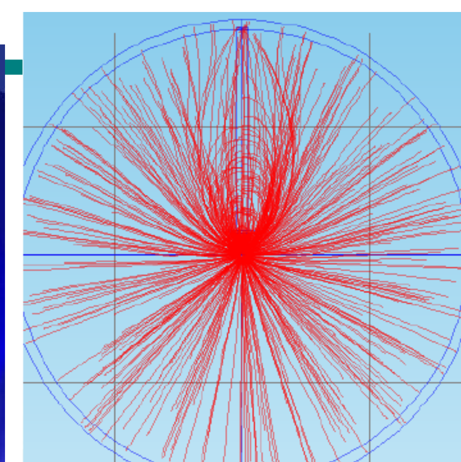
- A new detector was developed
- Spherical geometry
- Copper vessel with d ~ 1.3 m, 6 mm thick
- Proportional counter: small metallic ball with d ~ 16 mm in the centre ==> HV
- 2nd electrode (umbrella) 24 mm away from ball ==> electric field corrector
- Operation at seal mode
- Gas mbar - 5 bar







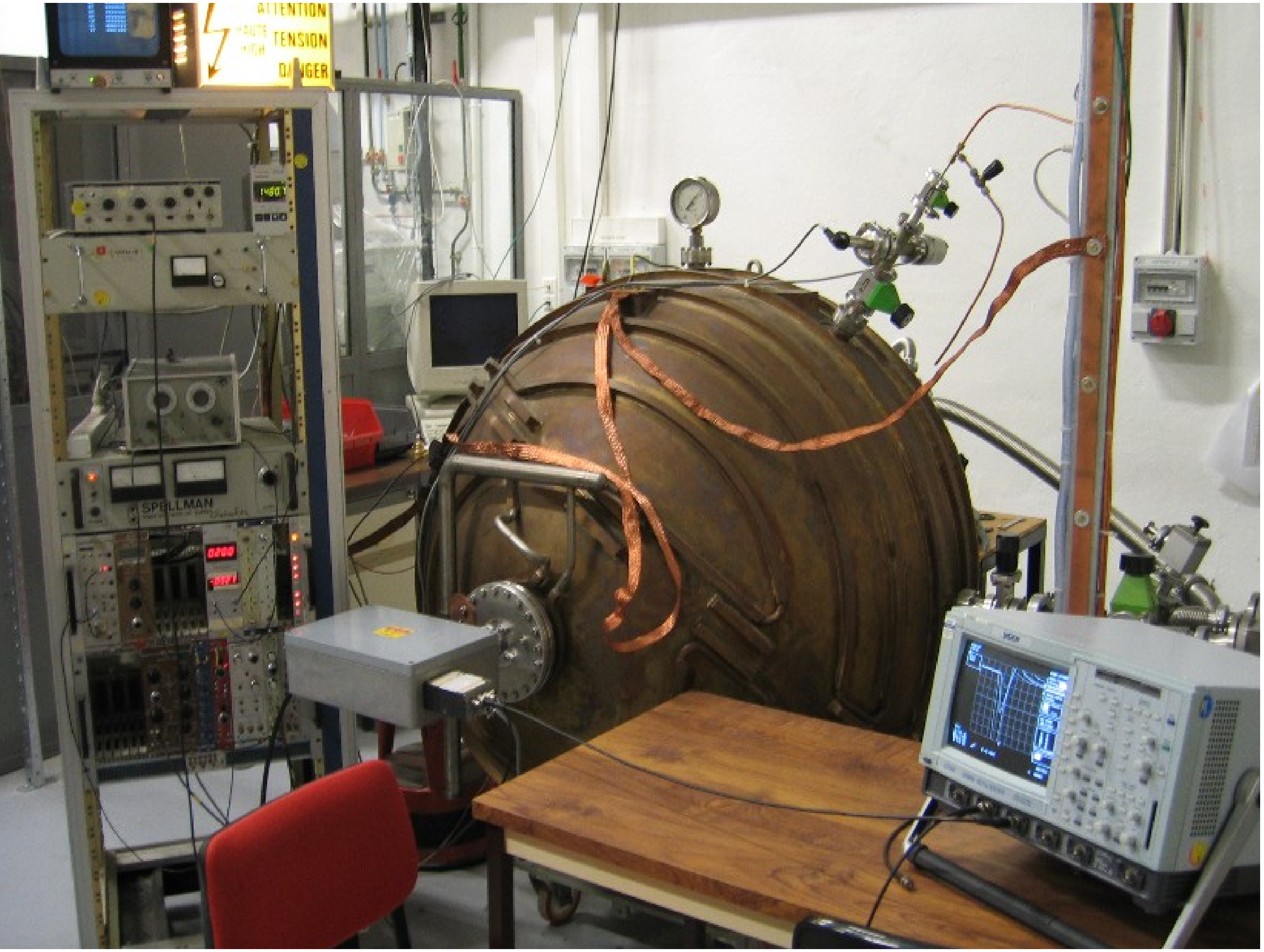




A Novel large-volume Sherical Detector with Proportional Amplification read-out, I. Giomataris et al., JINST 3:P09007,2008

Spherical Proportional Counter

- SPC at Saclay



→Simplicity of design

→Cheap

→ Single channel to read-out a large volume

→Low detector C < 0.1 pF ==> very-low electronic noise

→Large variety of gases – low to high p

→ Robustness

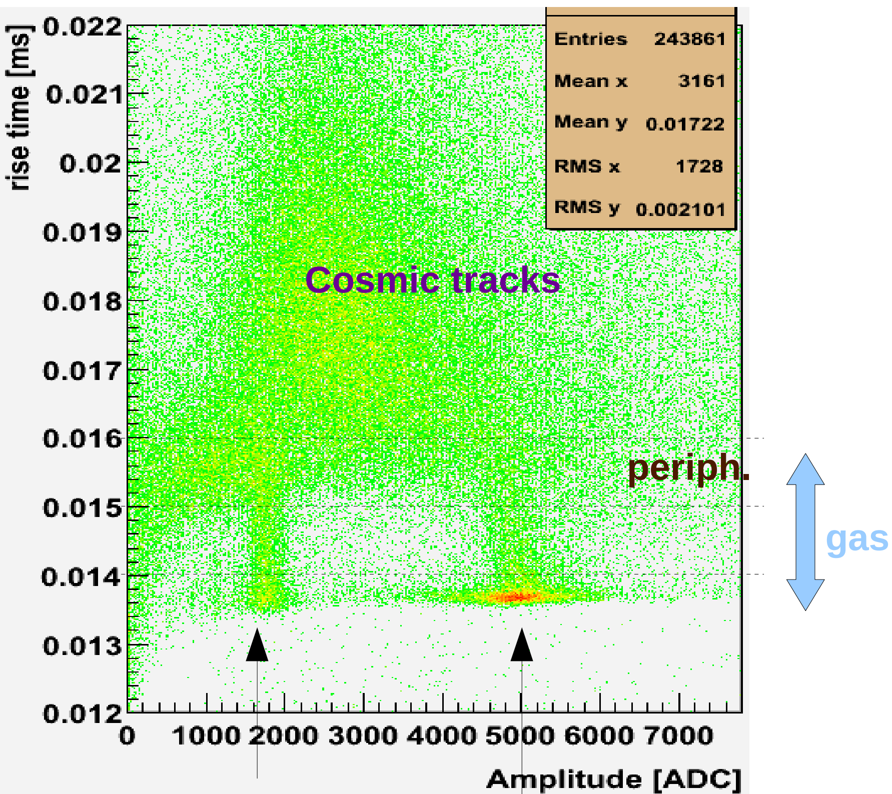
→ Good energy resolution

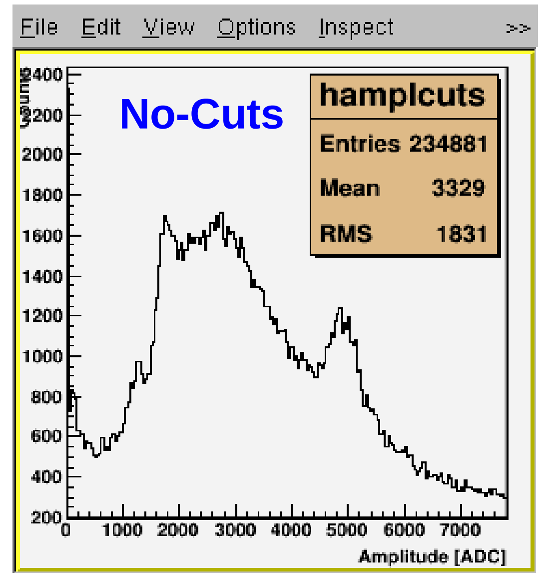
→ Low energy threshold

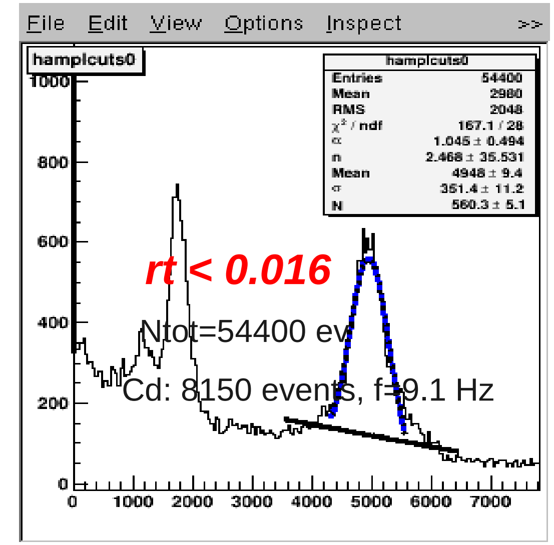
→ Efficient fiducial cut (rise time)

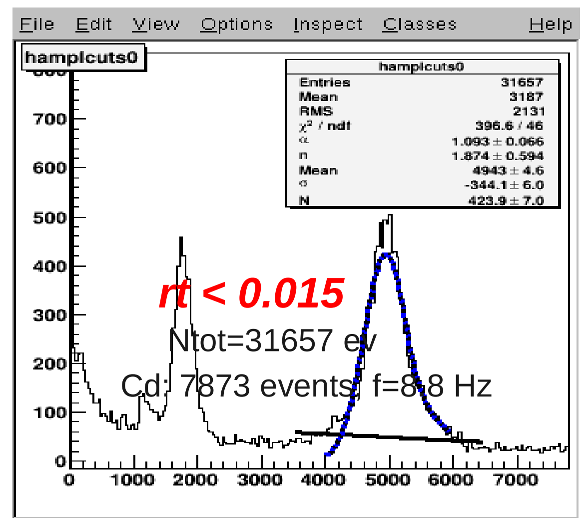
Rise time cut

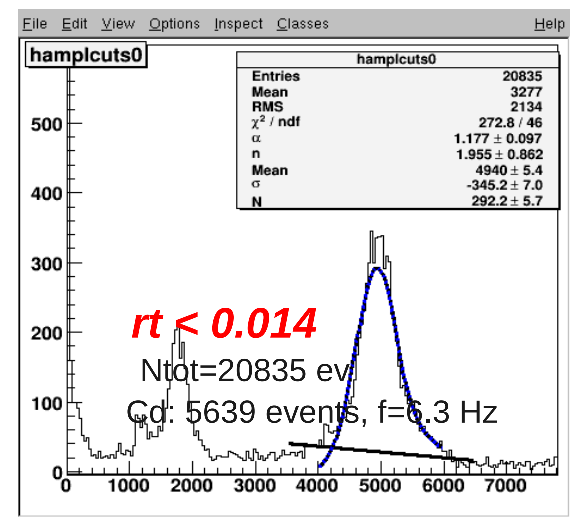
Using Cd-109 source – December 2009
Irradiate gas through 200µm Al window
P = 100 mb, Ar-CH_4 (2%)











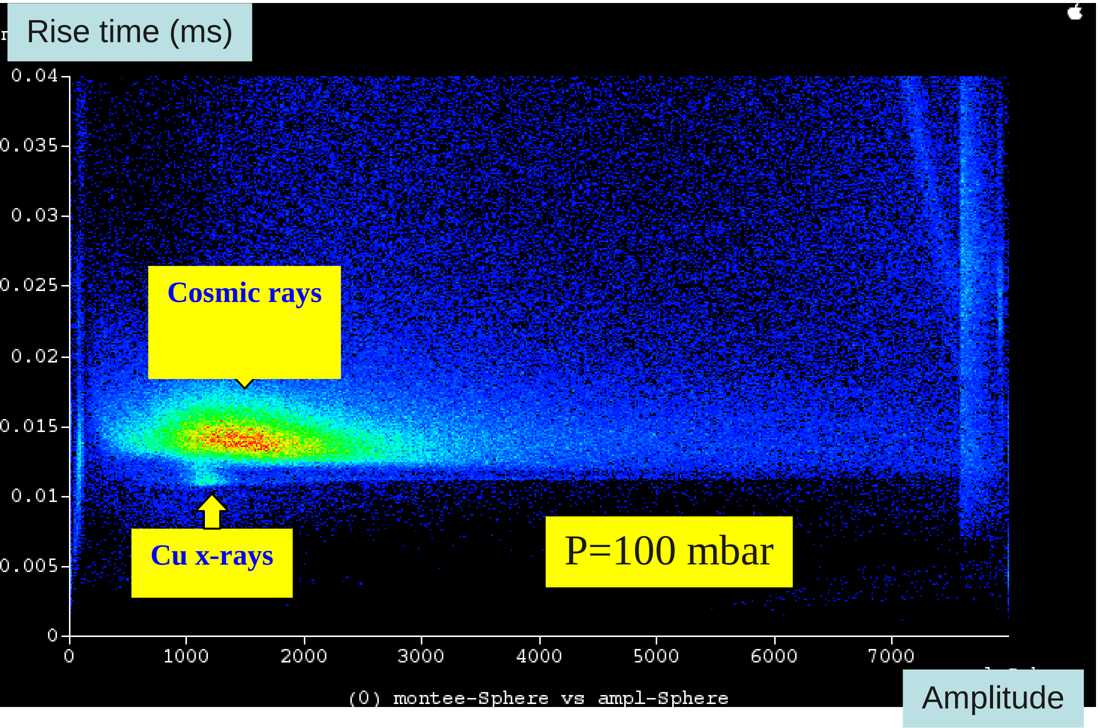
If rt ~ 0.0155 ms ==> R = 65 cm
0.014 ms ==> ~70% of signal

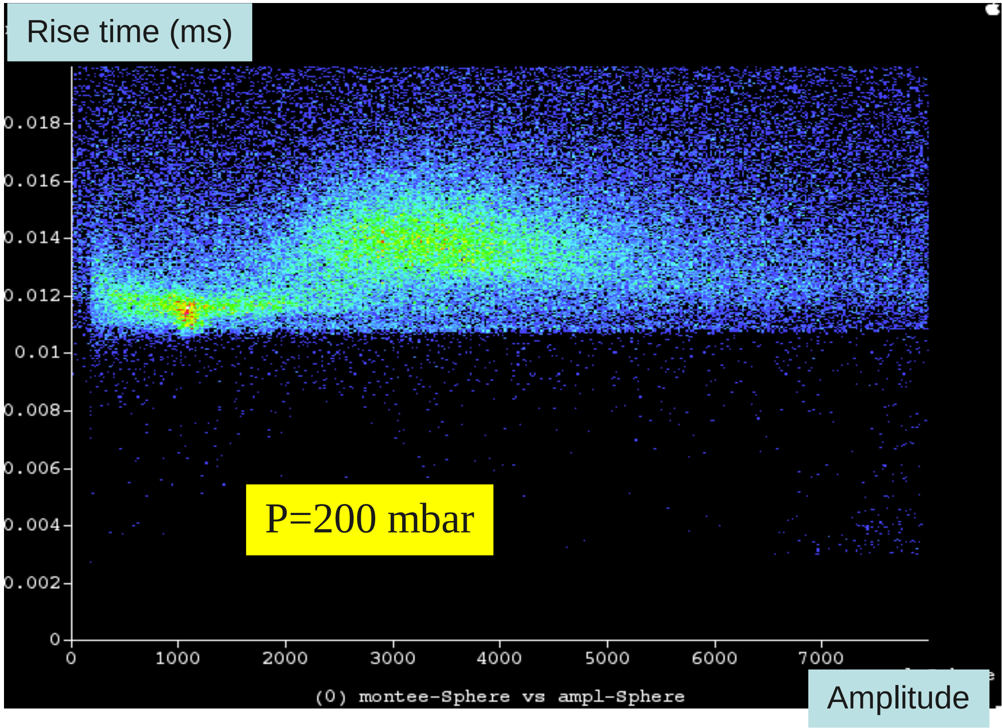
Efficiency of the cut in rt ==> ~ 70% signal (Cd peak)

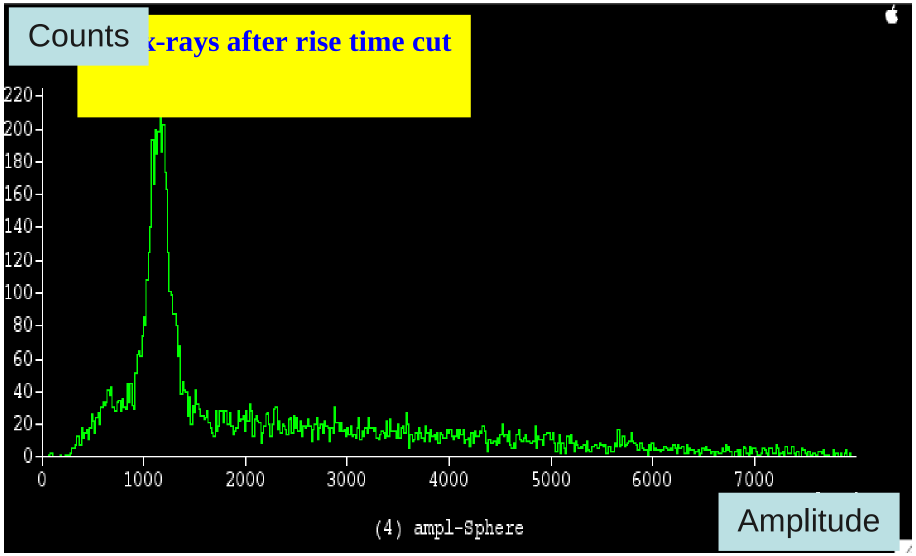
Severe background reduction

Energy resolution ~ 6 % and 9 % for Cu and Cd

Low energy investigations – No source







Sub-keV calibration sources (i)

Am-241 source – April 2010

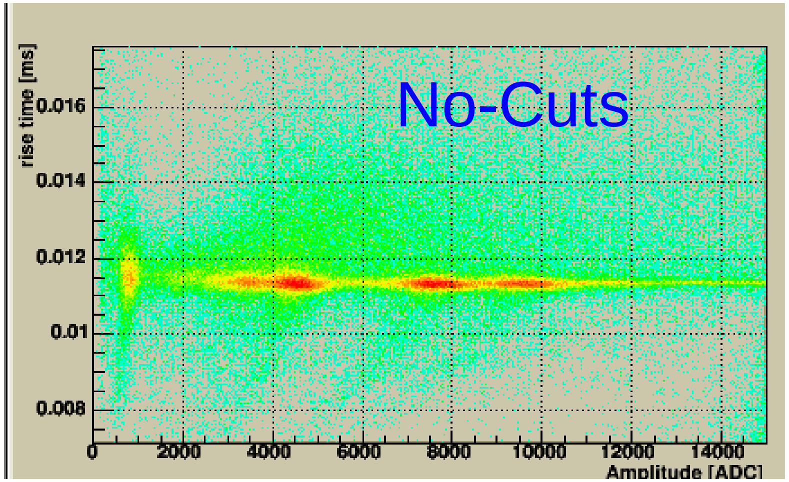
$$^{241}\text{Am} \rightarrow (\,^{237}\text{Np})^{*} + \,^{4}\text{He} + 5.6\ \text{MeV} \qquad \alpha$$

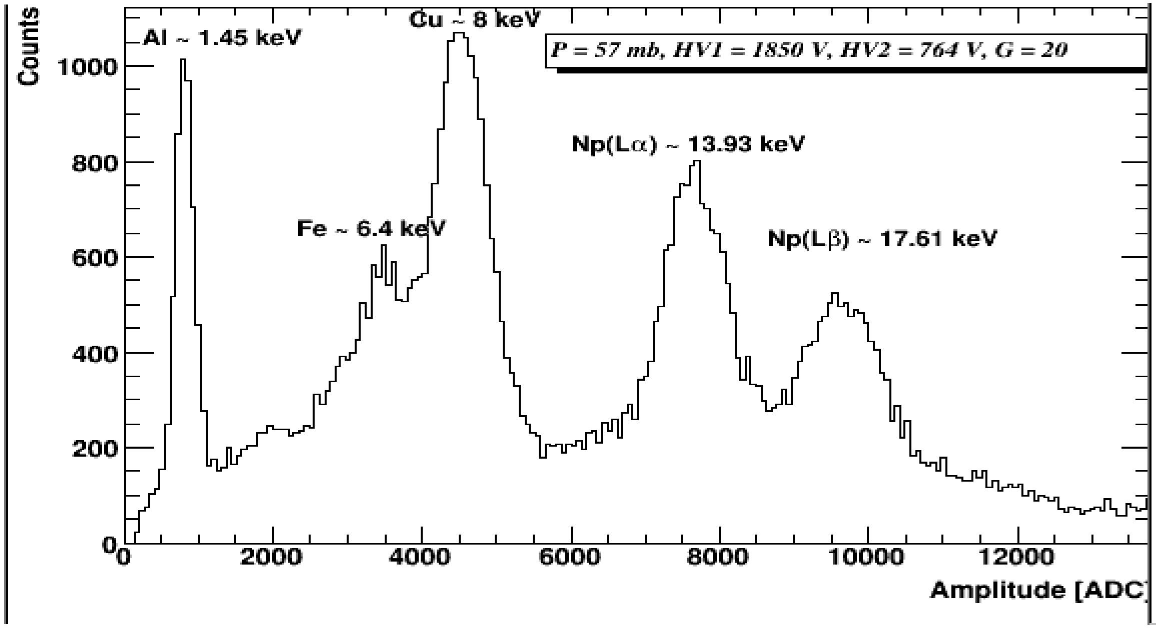
Np-237 decays with γ ~ 59.5 keV and L rays

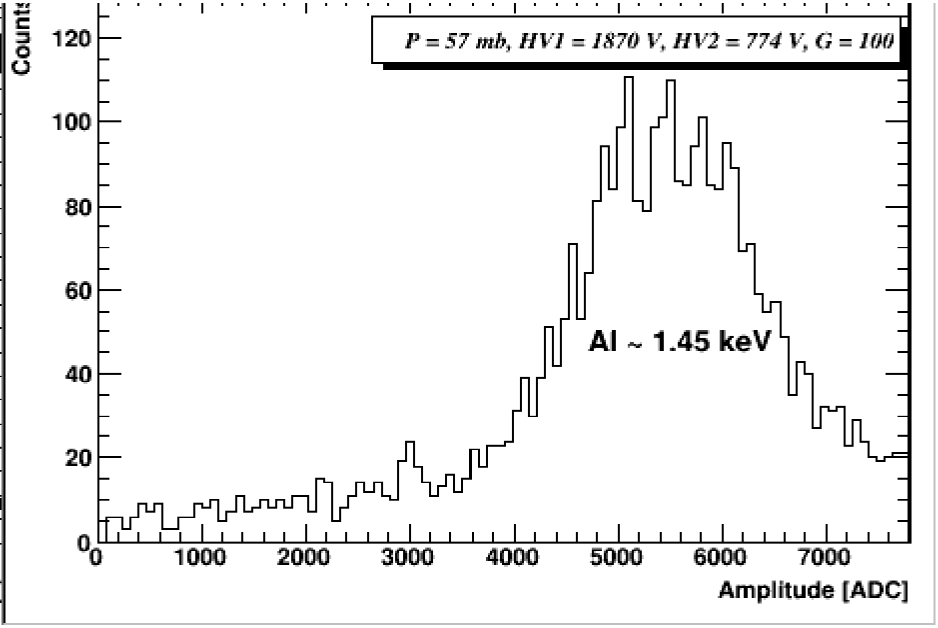
Source attached to sensor-rod

Source covered by thin foils

20µm Al foil ≈ α range







Flat background at low E

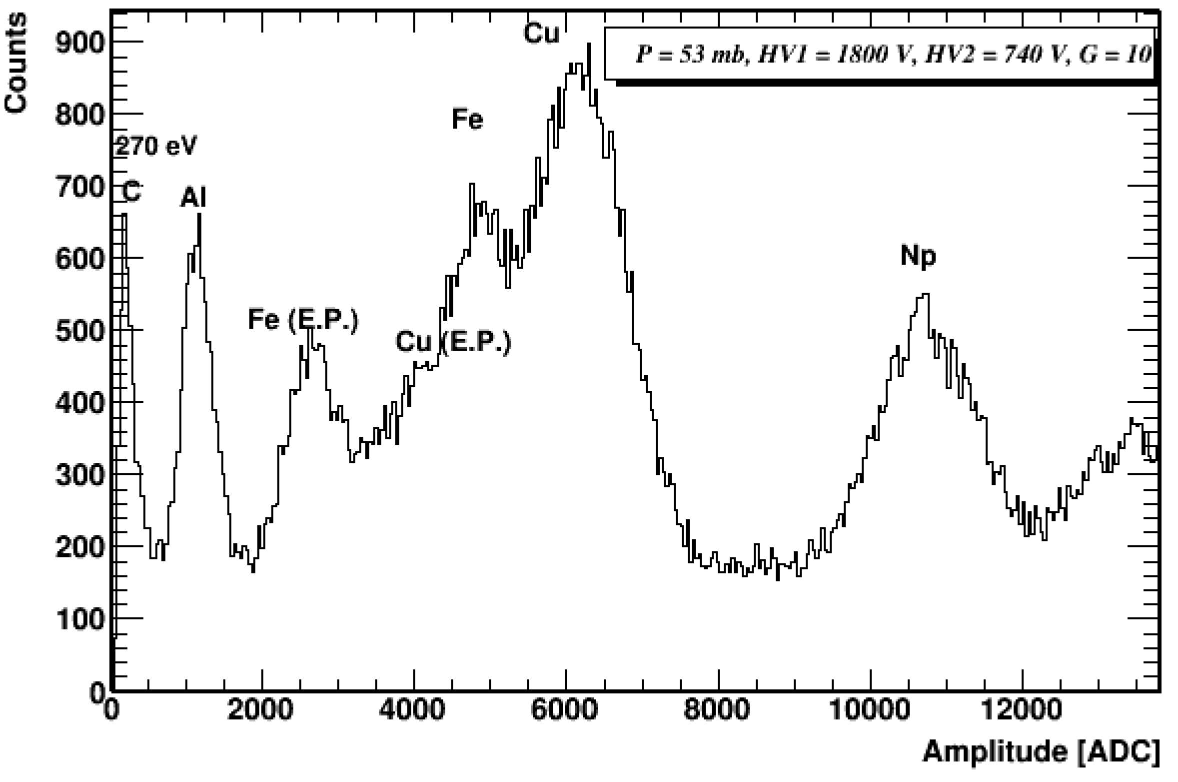
arXiv:1010.4132 [physics.ins-det], 2010

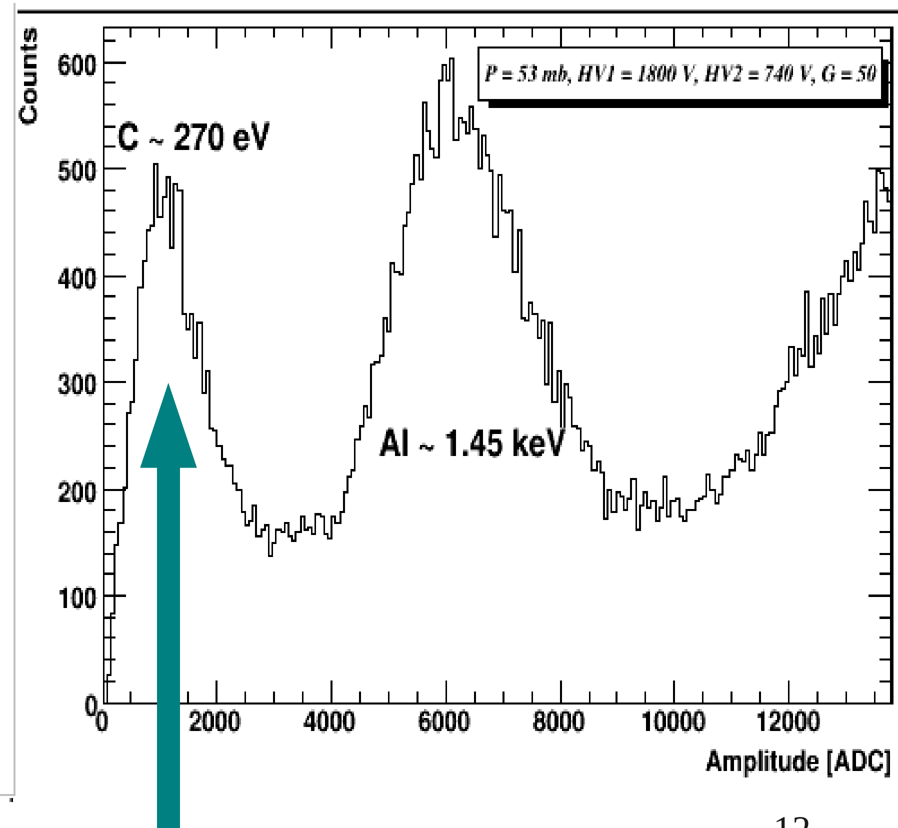
Sub-keV calibration sources (ii)

- **X-rays from Am-241 source**
- 10µm Al foil + 20µm polypropylene ≈ α range

➔α crosses Al and absorbed at polypropylene

➔==>Induced Al and C fluorescence



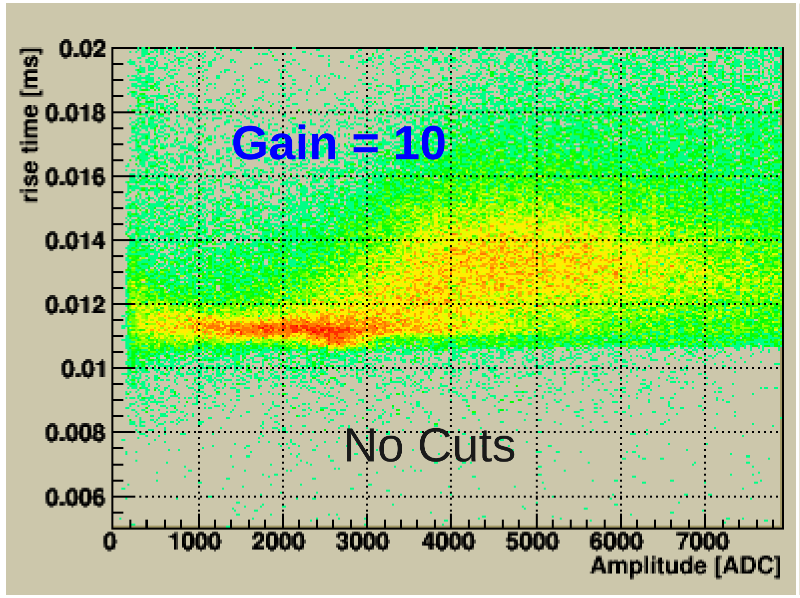


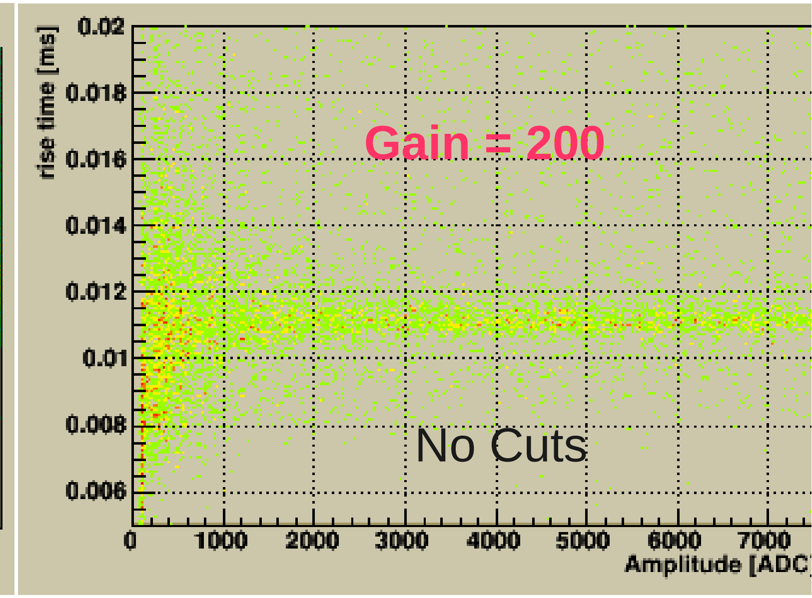
arXiv:1010.4132 [physics.ins-det], 2010

➔ **Carbon peak at 270 eV ==> WORLD RECORD**

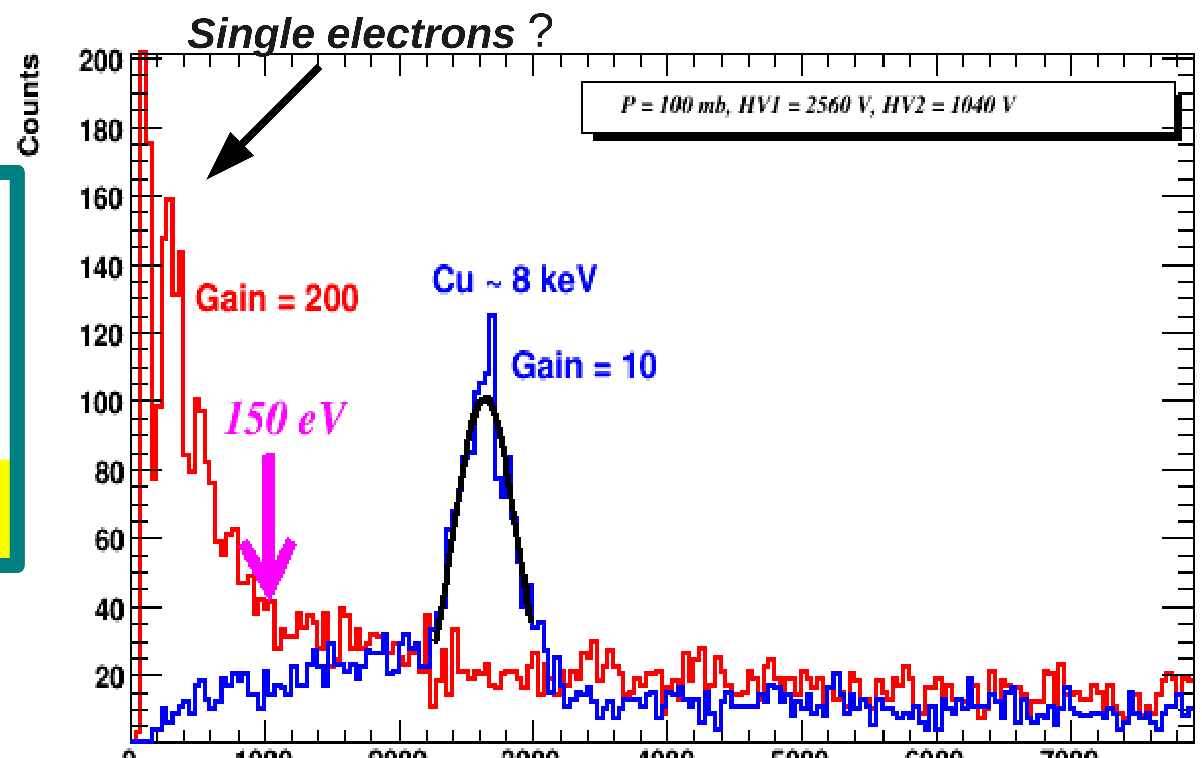
Ultra low energy data at ground – No source

P = 100 mb, Ar-CH_4 (2%)





- **High gain + low elec. noise**
- Reject cosmic rays (rt cut)
- Measure Cu peak (G=10)
- Increase gain of amplifier by 20 (G=200)
- **Very low detection threshold ≈ 30 eV**

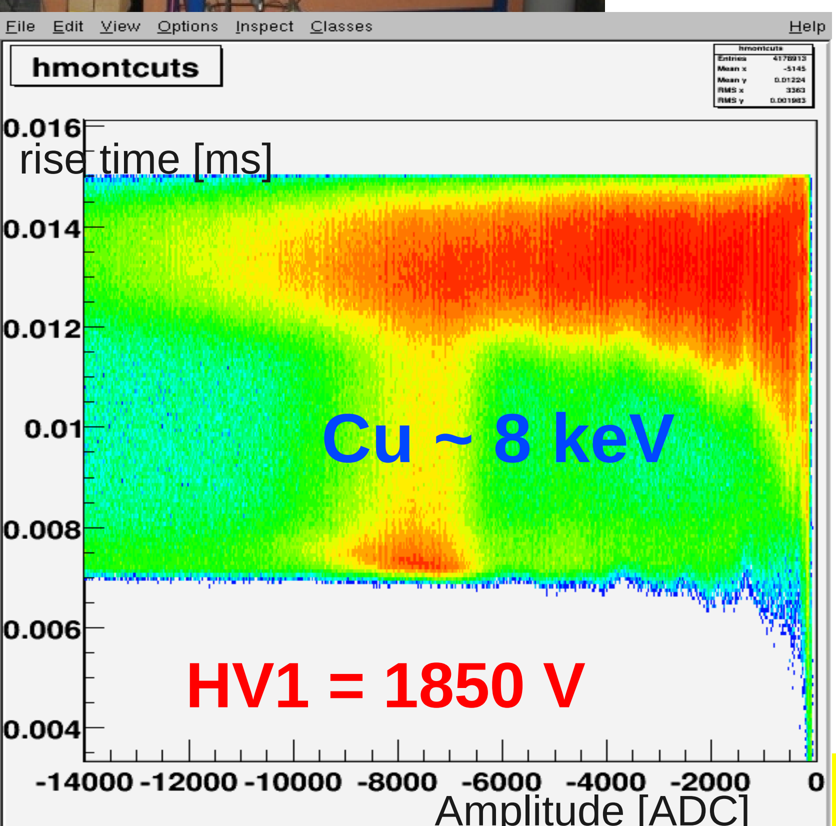


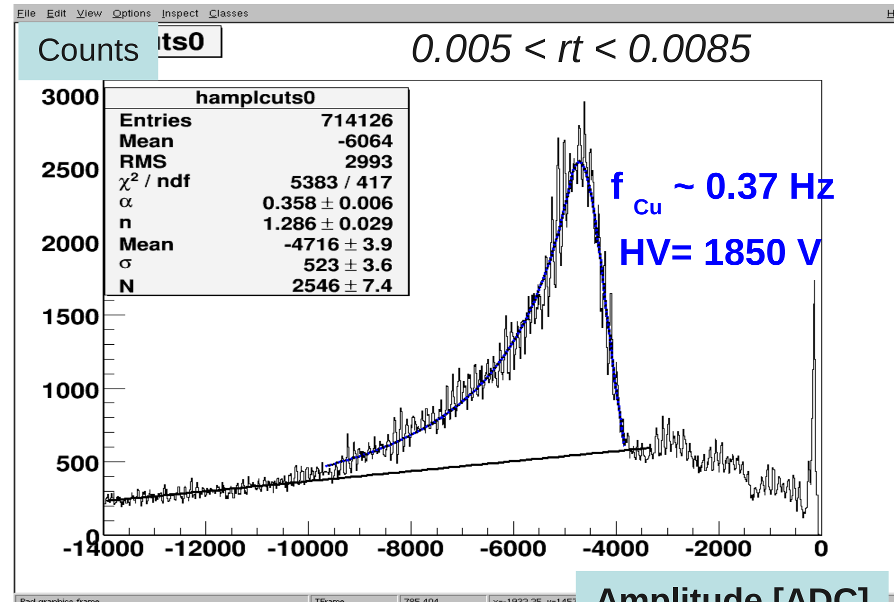
arXiv:1010.4132 [physics.ins-det], 2010

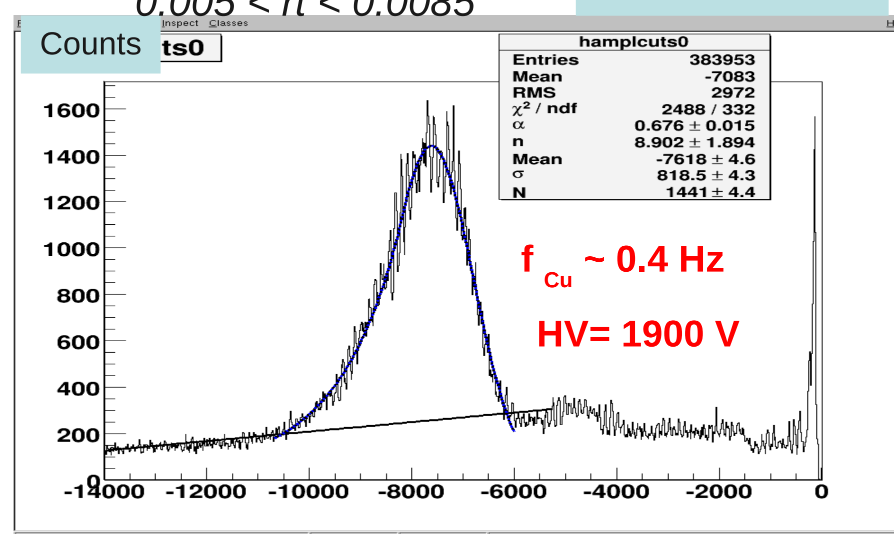
Low energy spectra at underground (LSM) – No source

- f_{Cu}^{total} ~ 1 Hz (~½ at ground)

p=57mb (Ar-CH_4 2%)

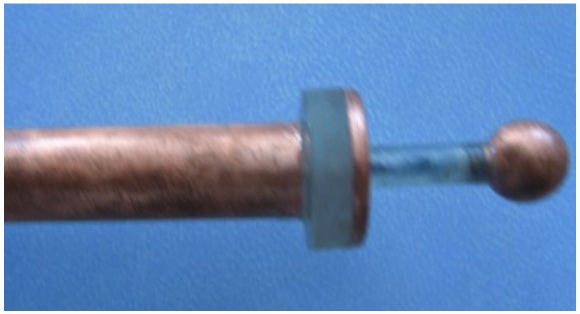


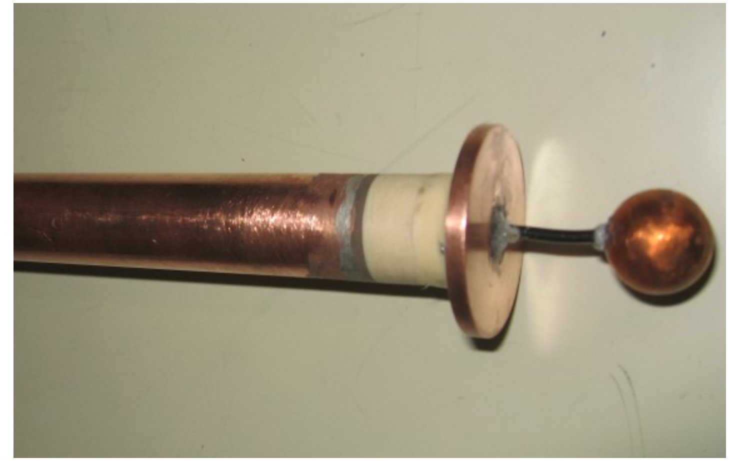


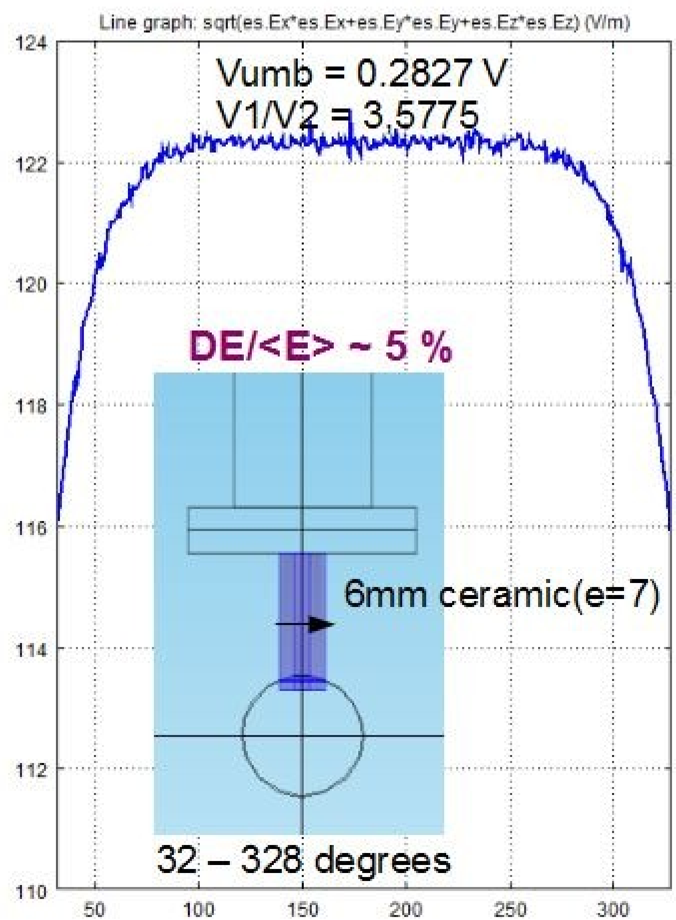


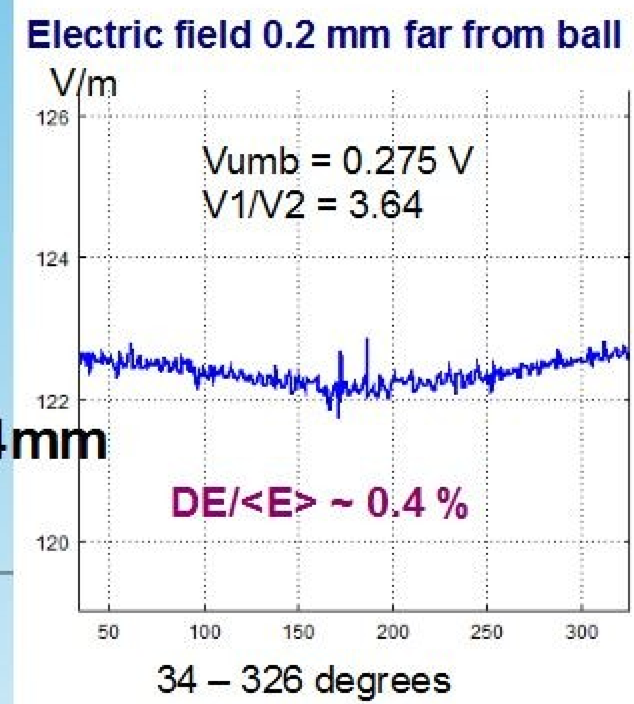
Preliminary results - october 2010

Optimization of sensor's sensitivity

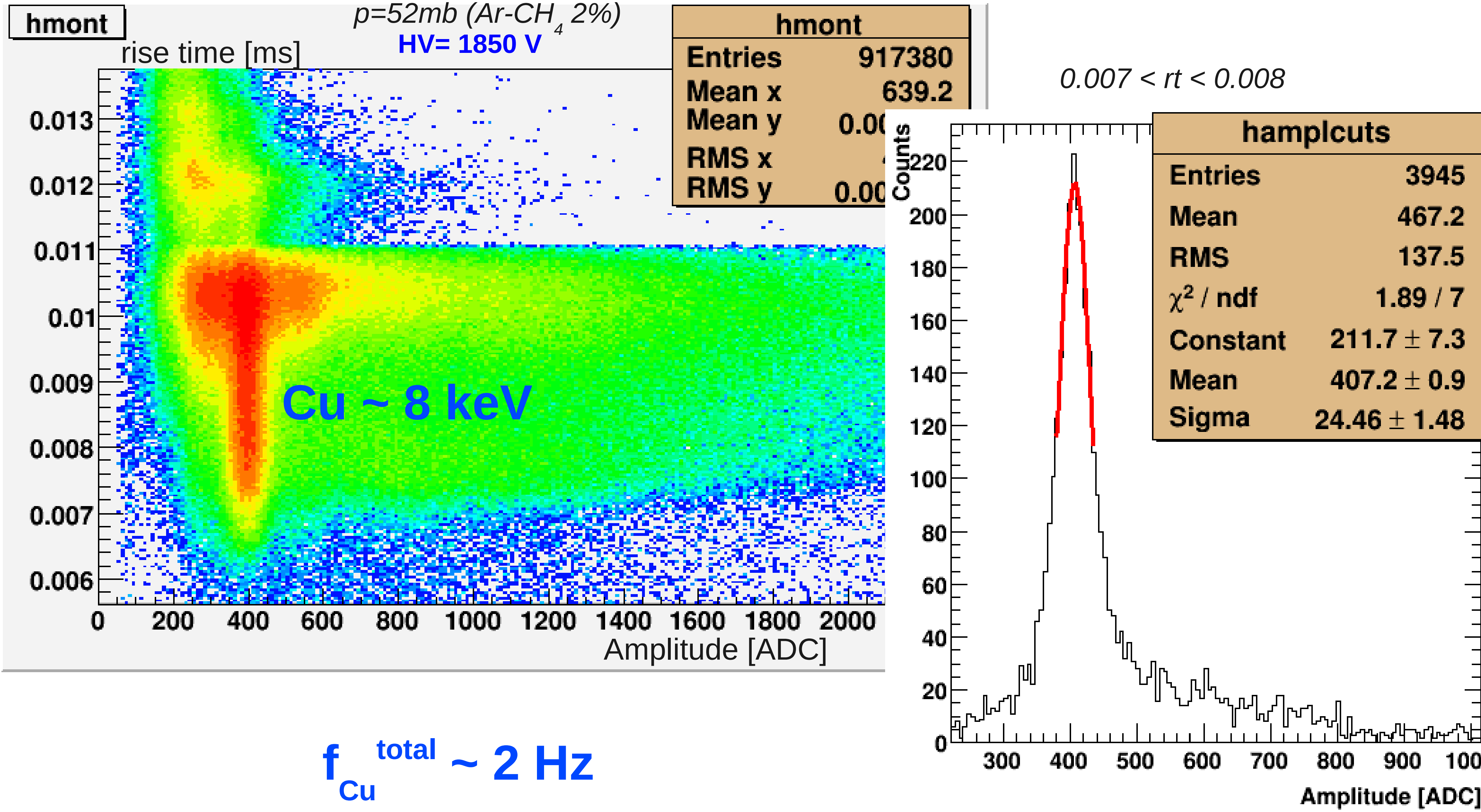








Latest tests at Saclay (10/7/2011)



f_{Cu}^{total} ~ 2 Hz

Sigma/Mean ~ 6 %

Preliminary results

Applications

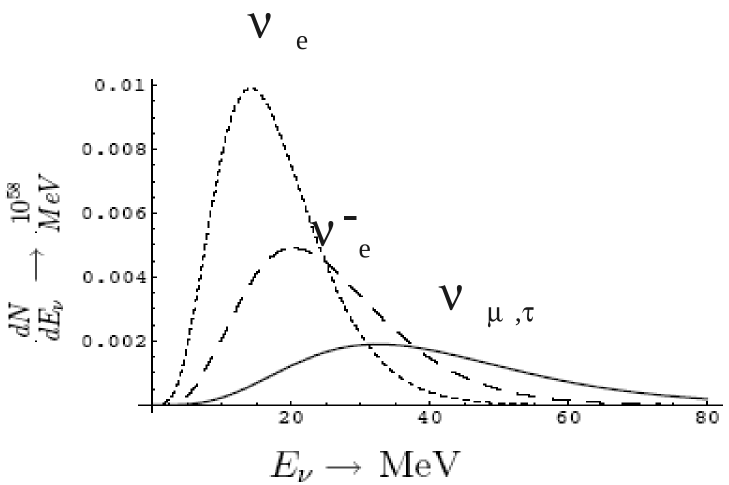
SPC detector has large mass and low sub-keV energy threshold

Several applications are open:

- ➔ **Supernova detection**
- ➔ **Coherent ν-A elastic scattering**
- ➔ Reactor ν detection
- ➔ Light DM search

etc...

SPC through ν-A coherent elastic scattering can be used for Supernova ν detection



The average nuclear recoil energy is:

	Ar	Xe
$\langle E_r \rangle$:	0.058	0.017 MeV

The threshold neutrino energy

(for nuclear recoil energy E_{th}=250 eV) is

	Ar	Xe
$(E_\nu)_{th}$	2.24	4.05 MeV

Sensitivity for galactic explosion

For p=10 Atm, R=2m, D=10 kpc, U_ν=0.5x10^{53} ergs

 # Number of events (no quenching, zero threshold)

Ar	Xe	Xe (with Nuc. F.F)
19.1	235	179

 # Number of events (after quenching, E_{th}=0.25 keV)

Ar	Xe	Xe (with Nuc. F.F)
6.7	68.1	**51.8**

Idea : A world wide network of several (tenths or hundreds) of such dedicated Supernova detectors robust, low cost, simple (one channel)

To be managed by an international scientific consortium and operated by students

Y. Giomataris, J. D. Vergados, Phys.Lett.B634:23-29,200

A dedicated SuperNova neutrino detector system

2nd LSM-EXTENSION WORKSHOP - OCTOBER 16th, 2009 - Modane, France

S. Aune[1], E. Bougamont[1], M. Chapellier[1], A. Dedes[5], P. Colas[1], J. Derre[1], G; Fanourakis[7], E. Ferrer[1], W. Fulgione[10], Th. Geralis[7], G. Gerbier[1], M. Gros[1], I. Irastorza[9], P. Kanti[5], Y. Lemiere[1], X.F. Navick[1], Th. Papaevangelou[1], P. Salin[4], I. Savvidis[3], N. Spooner[6], S. Tzamarias[8], J. D. Vergados[5]

The proposed Supernova demonstrator

- 4 m in diameter
- Vessel (seal) : radio pure Cu or stainless steel
- Gas Xe (10 bar) or Ar (50 bar)

Milestones of R@D phase

- Define the conditions for long term operation

Gas purification, gain stability, maintenance

- Design and build a low cost demonstrator

GOAL : **Life Time of such system about 1 century**

- Set up a European or worldwide collaboration

Summary

- A new spherical detector is developed with large mass and low sub-keV energy threshold
- Good energy resolution, robust, cheap and stable
- Very low detection threshold ~ 30 eV (single electrons sensitivity)
- ν – A coherent elastic scattering under reach
- Can be served as a low cost Supernova demonstrator
- A world wide network of several detectors is advertized

Back-up

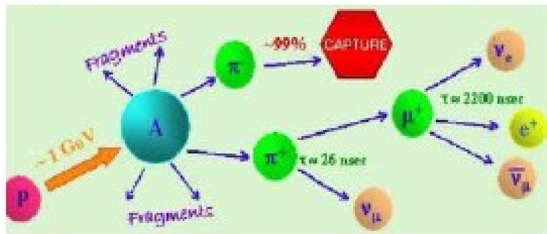
A possible test for the detector efficiency:

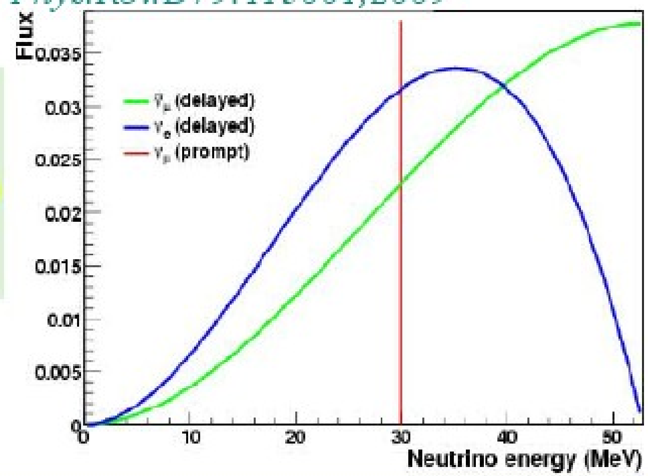
Measuring Neutrino-nucleus coherent elastic scattering

At the Oak Ridge Spallation Neutron Source (SNS).

J.D. Vergados, F.T. Avignone, I. Giomataris, Phys.Rev.D79:113001,2009

K. Scholberg, AIP Conf.Proc.1182:76-79,2009





$\Phi(\nu,r) = 6.14\times10^{14}\ s^{-1}/4\pi r^2$

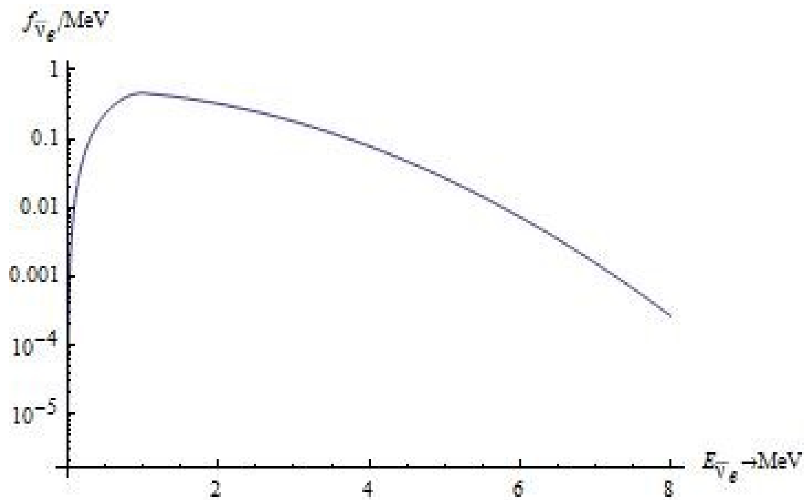
SENSITIVITY

The number of events in one year for the spherical TPC detector: P=10 Atm, R=5 m, T=300ºK, L=10 m

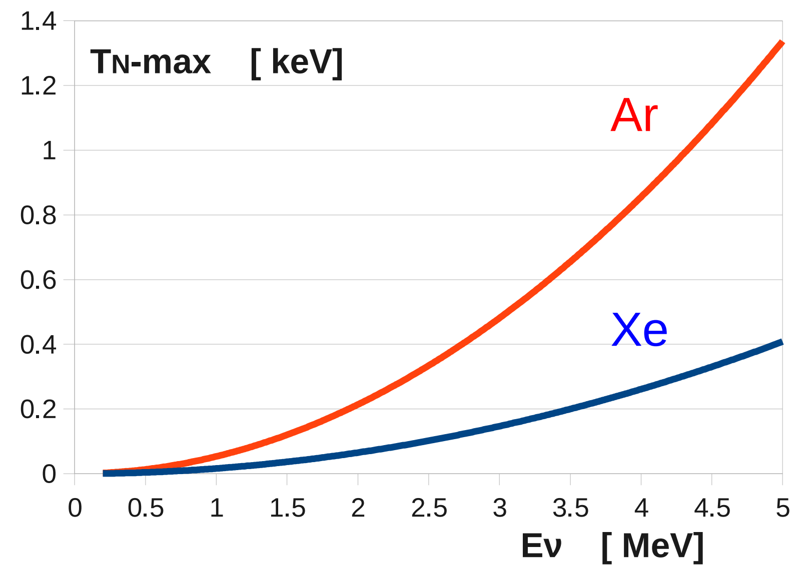
target	ν_e (no FF)	ν_e (FF)	anti ν_μ (no FF)	anti ν_μ (FF)	ν_μ (no FF)	ν_μ (FF)	all ν (no FF)	all ν (FF)
Xe	5115	3747	6840	4644	4179	3360	16137	**11751**
Ar	417	359	555	459	336	306	1311	**1126**

Low cost Argon gas could be used at higher pressure

Reactor neutrinos



Typical reactor electron antineutrino spectrum



With the present SPC prototype

At **10 m** from reactor, **1 y** run, and Energy **ν = 2 MeV** ~ <Eν> at nuclear reactor

Xe ($\sigma \approx 2.16\text{x}10^{-40}$ cm^2), $2.2\text{x}10^6$ neutrino interactions **but** T_{max}=66 eV

Ar ($\sigma \approx 1.7\text{x}10^{-41}$ cm^2), $9\text{x}10^4$ neutrino interactions, T_{max}=215 eV

Ne ($\sigma \approx 7.8\text{x}10^{-42}$ cm^2), $1.87\text{x}10^4$ neutrino interactions, T_{max}=429 eV

A. Druikier, L. Stodolsky, Phys.Rev.D30:2295,1984, JI Collar, Y Giomataris - NIMA471:254-259,2000,
H. T. Wong, arXiv:0803.0033-2008, PS Barbeau, JI Collar, O Tench - Arxiv preprint nucl-ex/0701012, 2007

Sensitivity for reactor neutrino detection

The number of events in one day for the present spherical TPC detector:

P=5 Atm, R=.65 m, T=300^{0}K, anti-neutrino flux= 10^{13}/cm^2/s

target	anti ν_e (QF, no Thr)	anti ν_e (QF) Thr = 1 electron	anti ν_e (QF) Thr = 2 electron
Xe	2325	**825**	**275**
Ar	430	**292**	**210**

This a considerable signal

Argon is a good candidate

Possible to measure with present prototype?

It needs a careful study but our first results look promising

Why neutrinos?

Neutrinos:

- Travel large distances with the speed of light -with light one cannot observe further than 50 Mpc (1 Mpc=$3.3x10^6$ light years)-
- They can pass through obstacles
- They do not get distorted on the way
- They are not affected by magnetic fields
- So they reveal information about the source interior

Prototype Supernova in our galaxy

- Distance: D=10 kpc=3.1×10^{22}cm
- Duration: 10 s
- Energy Output : Almost all gravitational energy goes into the neutrinos
- $E_\nu = 1.5 \times 10^{53}$ erg $(m_{SN}/m_{sun})^2$ $(10\text{km}/R_{SN})$
- Typical value: 3×10^{53}ergs
- A few SN per century expected

Assumptions about the Neutrino Content of Supernova explosion Dighe et al arXiv:10008.0380 [hep-ph]

SN explosion is a complex problem involving diverse physics. For our purposes we will assume:

- 6 (Neutrino & antineutrino) Flavors carry most of the gravitational energy, i.e. 0.5×10^{53} ergs each flavor
- The first stage neutrino distribution is taken to be of a Fermi-Dirac type (with non zero chemical potential $a=\mu/T=$ constant)

The characteristic temperatures of the F-D are:

T=8 MeV (for μ and τ neutrinos and antineutrinos)

T=3.5 MeV for ν_e and 5 MeV for anti-ν_e

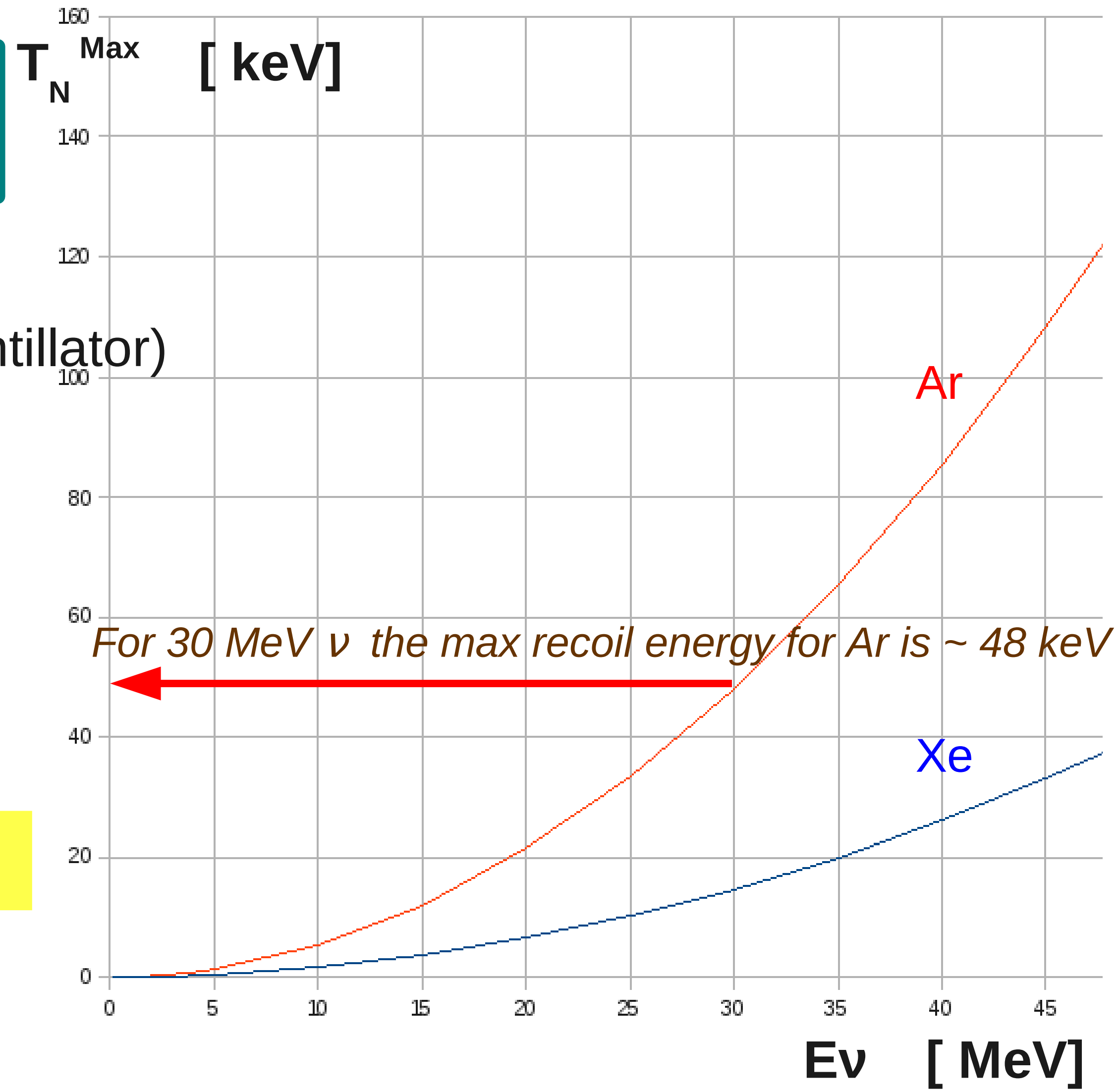
But this coherent ν - A elastic scattering has never been observed...

$$T_N = 2\, m_N (E_\nu \cos\theta)^2 / \{(m_N + E_\nu)^2 - (E_\nu \cos\theta)^2\}$$

- Most neutrino detectors (water, gas, scintillator) have thresholds ~ MeV

➢ so these interactions are hard to see...

• **Important for SN ν detection**



Recoil energies are tiny!

Pointing?

Neutral current detector has not pointing capability
In the case of a large number of such detectors direction could be provided by time triangulation

Synergy with other Supernova detectors?

(super-K, kamLAND, LVD, Borexino, Icarus, Baksan, Mini-BooNe)
(Hyper-K, MEMPHYS, DUSEL,LENA, CLEAN, NOvA, OMNIS, SNO+, HALO, MOON)

Yes,

- Neutral current is sensitive to all neutrino flavors – complementary
- In coincidence, they would improve extra galactic sensitivity

Extragalactic sensitivity ?

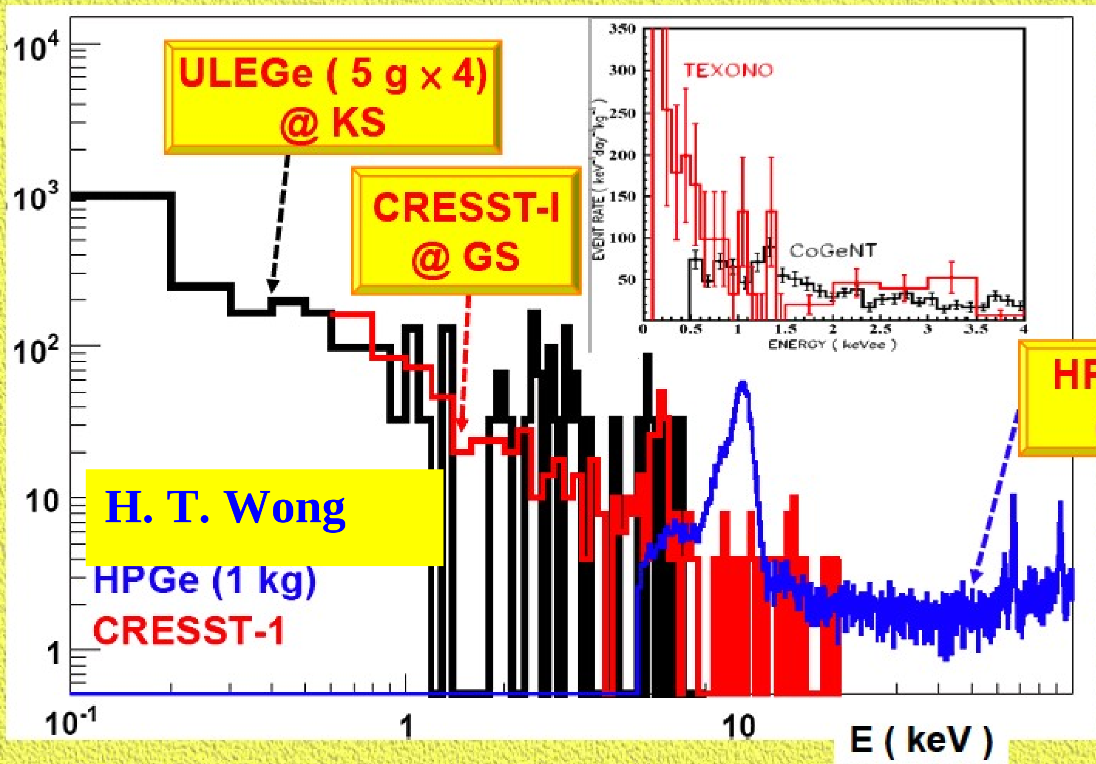
To tackle Andromeda neutrino bursts (700 kpc) we need:

- a world wide network of several hundreds such detectors
- background level of a few counts/hour below 1 keV

Additional physics,

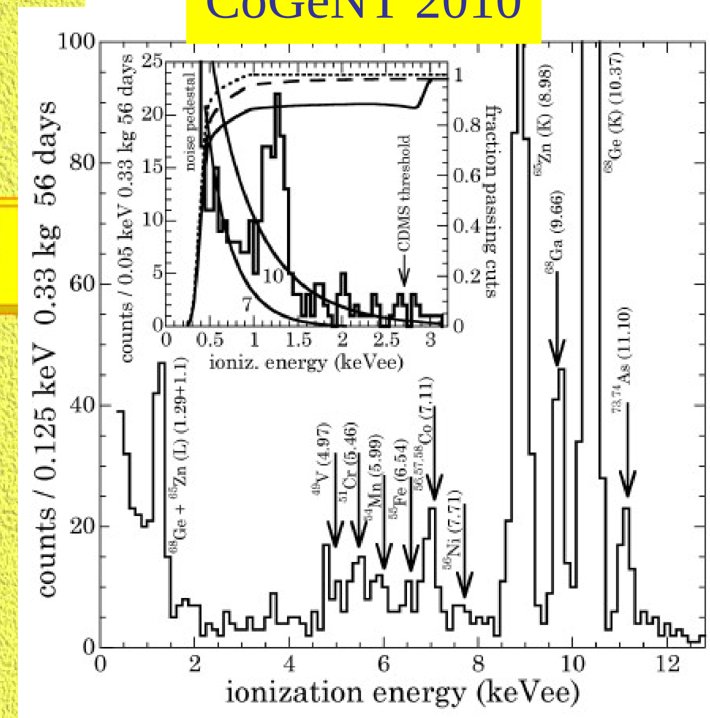
Dark matter search through very low energy threshold < 100 eV

Sub-keV Background Measurements & Comparisons



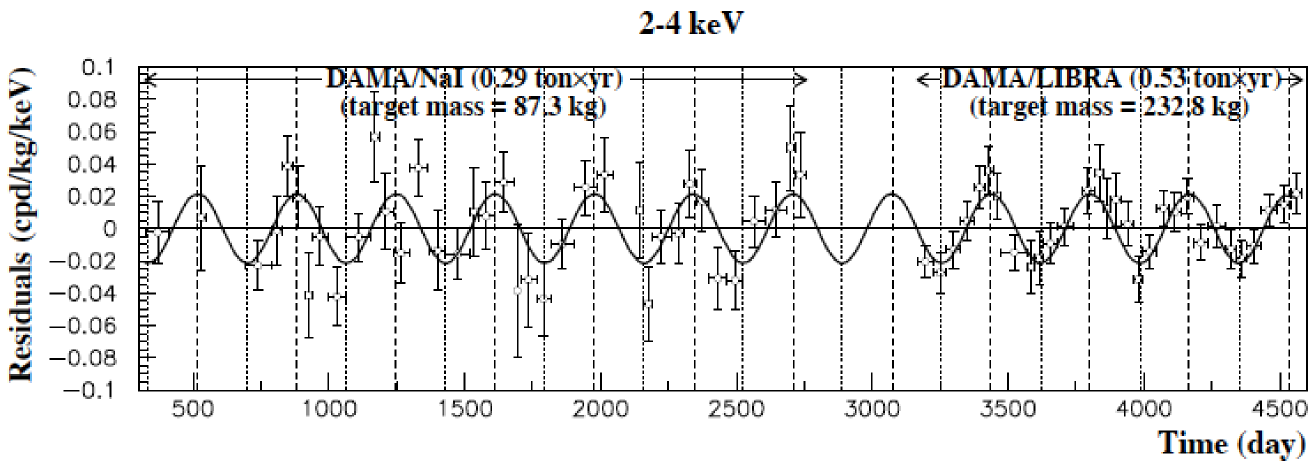
- Bkg ~ O(1) cpd/kg/keV >10 keV, ~ to underground expts.
- ULEGe bkg @ KS ~ CRESST-1 @ GranSasso
- Intensive studies on sub-keV background understanding

CoGeNT 2010



Needs to be clarified and verified by detectors having a lower energy threshold

DAMA+LIBRA 11 years, 0.83 ton × year, 8.2σ modulation signal.

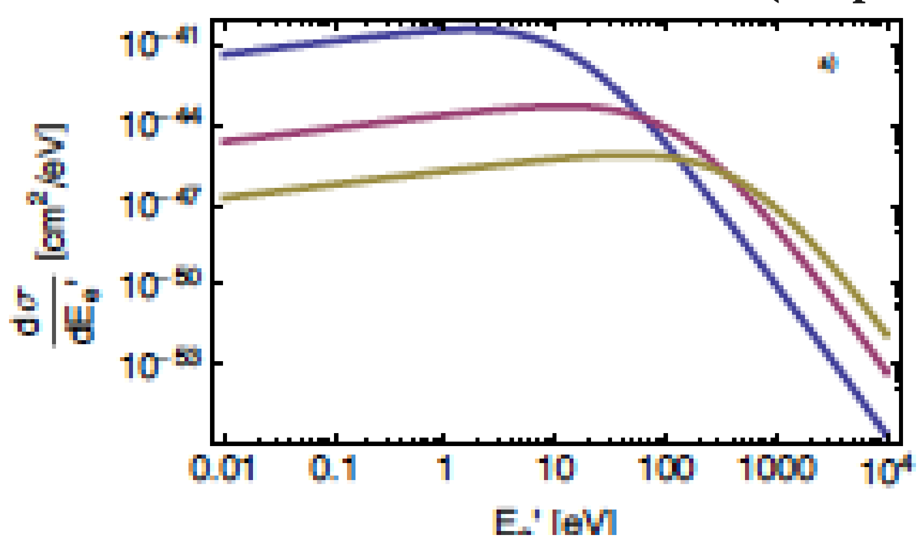


Light DM ==> low E recoils...

Light scalars or fermions (Fayet, Boehm&Fayet):

Kaluza-Klein Axion like Particle lighter than a few KeV.

Secluded WIMP dark matter (Pospelov, Ritz, Voloshin '07)

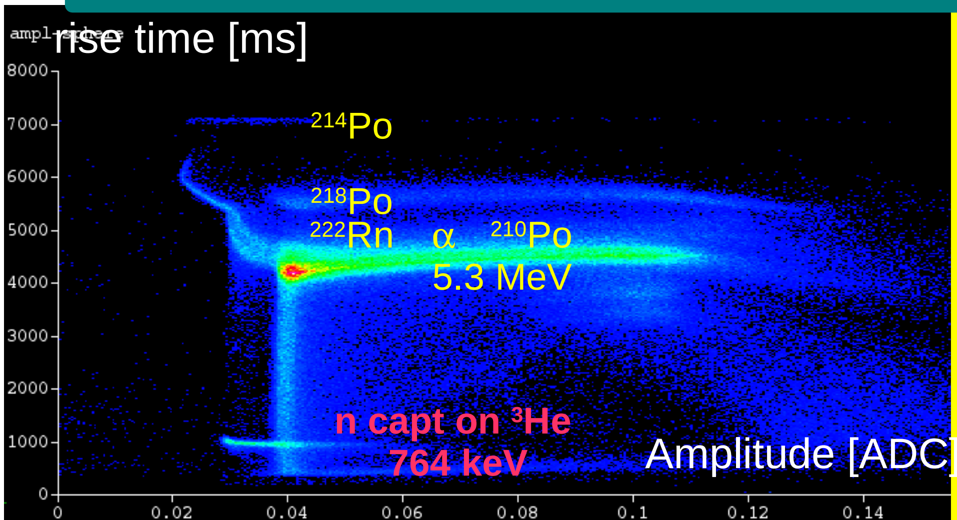


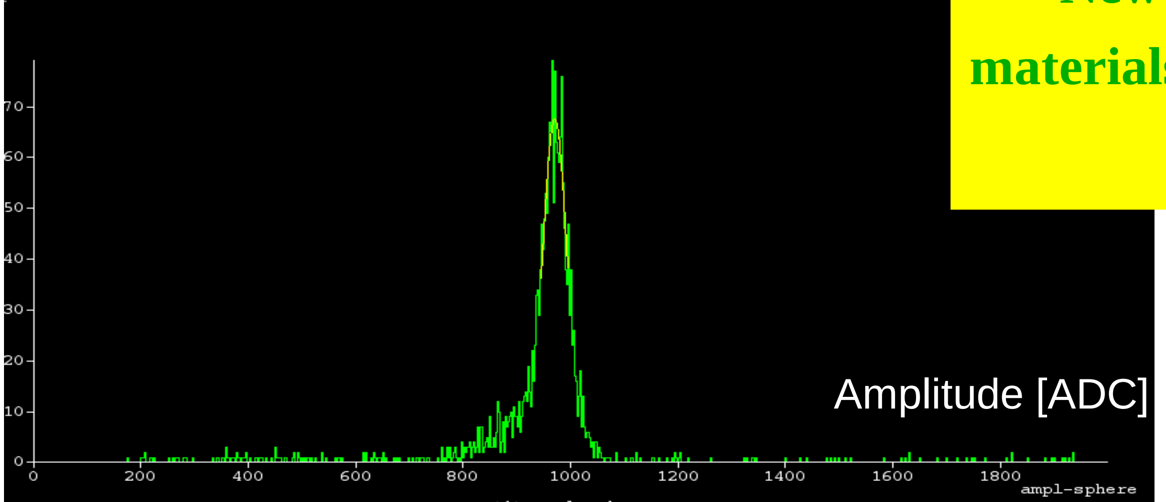
Link to previous low E excess?
The need to go to very low energies may become more crucial
Use of SPC

A. Dedes, I. Giomataris,, K. Suxho, J.D. Vergados, Nucl.Phys.B826:148-173,2010

Detection of thermal neutrons at LSM

- In 2008: SPC installed in LSM
- Goal: measure thermal n-background and estimate fast n-flux
- Filling with 3 g ^{3}He (Ar+2%CH4 at p=280mb)
- Detection of neutron through absorption on ^{3}He :
  - n + ^{3}He => p + ^{3}H + 764 keV





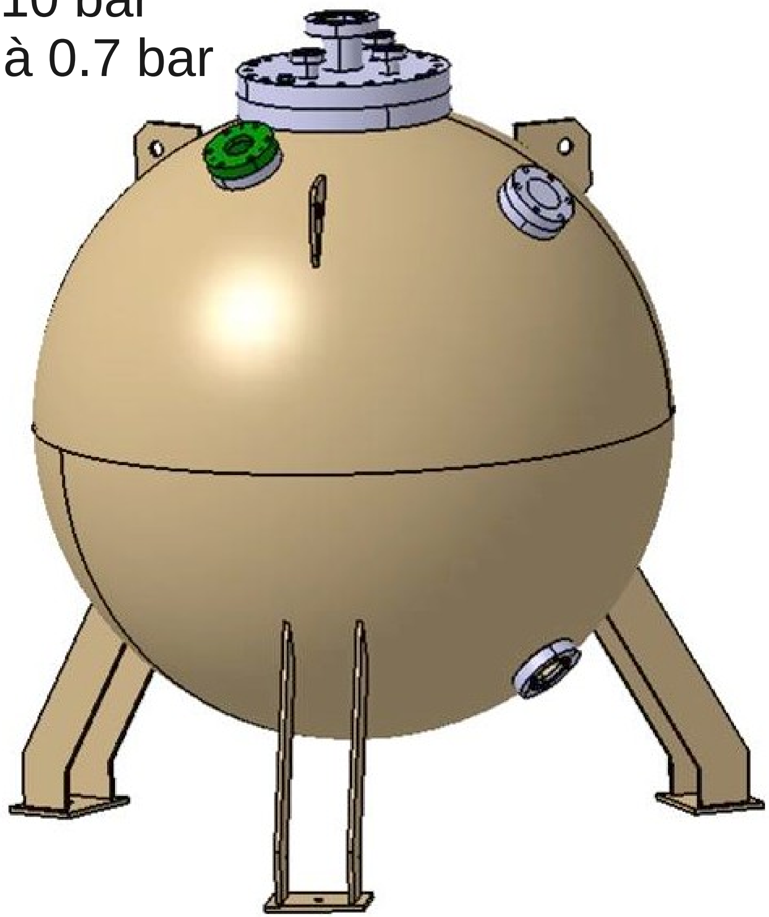
- Contamination due to ^{210}Po
- thermal neutron flux: $3 \times 10^{-6}/cm^{2}$
- With rise time cut (>0.04 ms) rejection of background and 60 % efficiency
- too difficult with present apparatus to measure fast neutrons

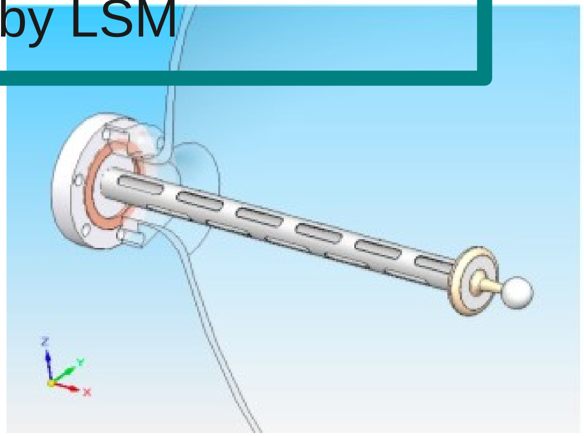
==>**New detector is needed from low background materials and higher 3He mass**

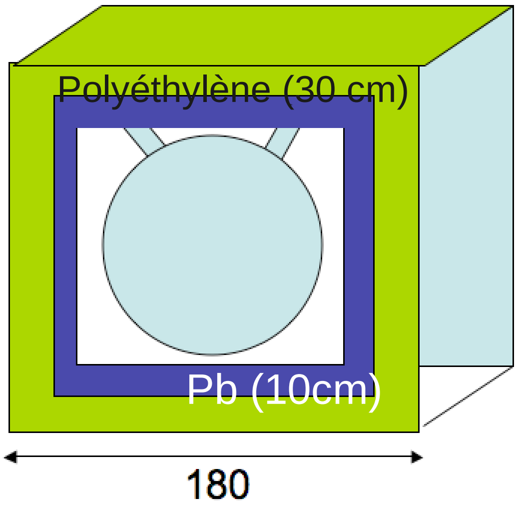
Low activity project SEDINE

- Sphere of 60 cm diameter in low activity Cu and steel
- Low activity material + low Rn emanation
- Appropriate shield will be provided by LSM

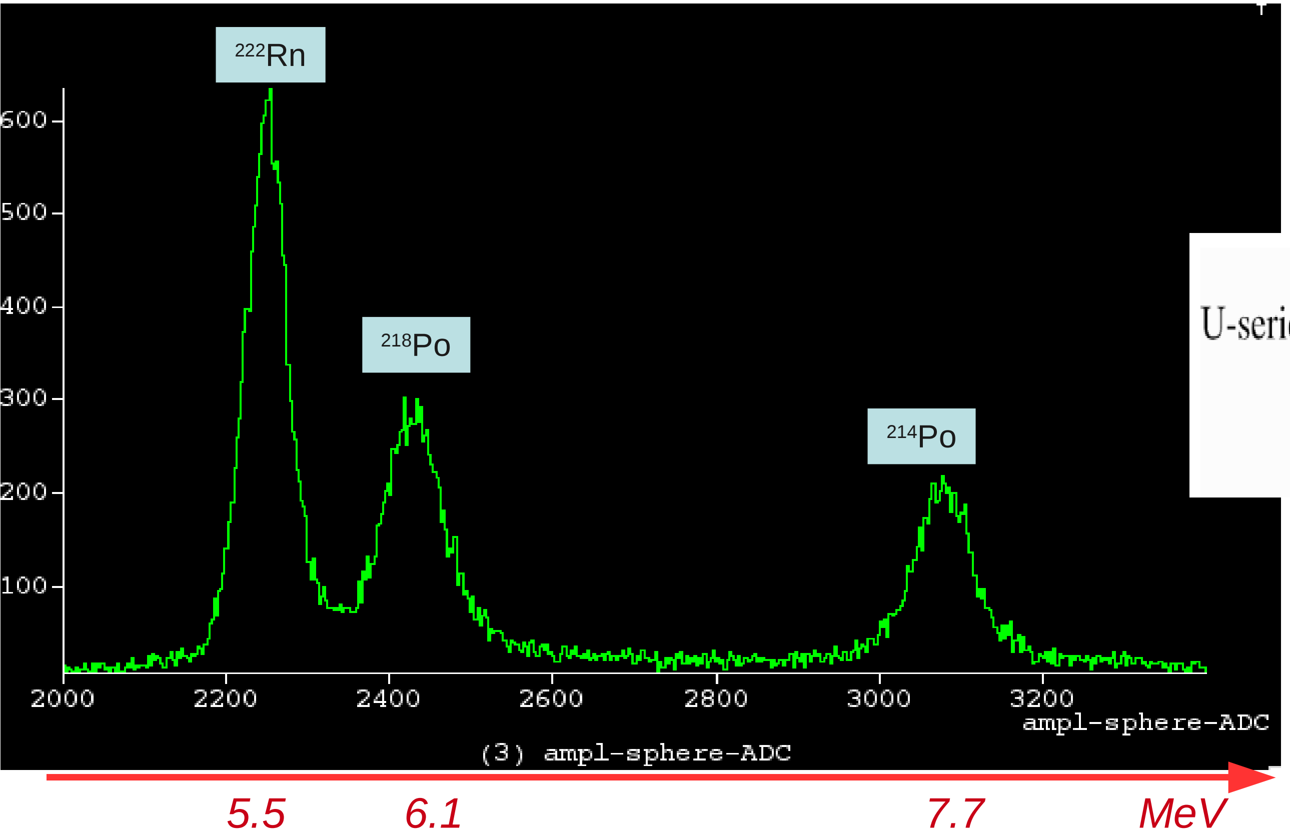
-2 kg Ar à 10 bar
-10 g He3 à 0.7 bar







Energy resolution at "high" energy



U-series: $^{222}\text{Rn} \xrightarrow{\alpha} {}^{\mathbf{218}}\mathbf{Po} \xrightarrow{\alpha} {}^{214}\text{Pb} \xrightarrow{\beta} {}^{214}\text{Bi} \xrightarrow{\beta} {}^{\mathbf{214}}\mathbf{Po} \xrightarrow{\alpha}$
$^{210}\text{Pb} \xrightarrow{\beta} {}^{210}\text{Bi} \xrightarrow{\beta} {}^{210}\text{Po} \xrightarrow{\alpha} {}^{206}\text{Pb},$

Measured Radon gas emission with SPC at Saclay (Ar-CH_4)

Excellent energy resolution

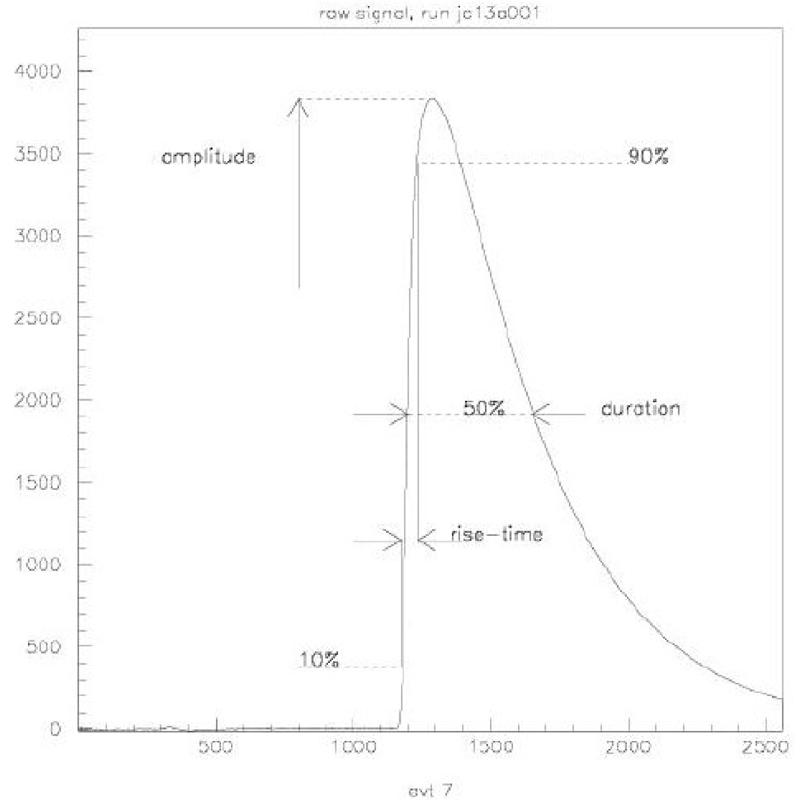
Symmetric peak

A Novel large-volume Sherical Detector with Proportional Amplification read-out,
I. Giomataris et al., JINST 3:P09007,2008

Signal

Signal analyzed by Tango program
(thanks to Michel Gros)
defined by 3 parameters:

- amplitude (adc units)
- rise-time (~30 μs)
- duration (~300 μs)



Jacques Derré
Thessaloniki_april_2009

4

Page 4 of 57 125% Quit

Signal parameters

Strong correlation between
Rise-time and Duration → Fall-time :

Fall-time = Duration – 0.5×Rise-time
≈ RC amplifier

→ all physics information into biparametric plot
Amplitude versus rise-time