Low energy investigations and applications using the Spherical Proportional Counter (SPC) at ground/underground

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Wednesday 7/12/2011—Micromegas Workshop, Saclay

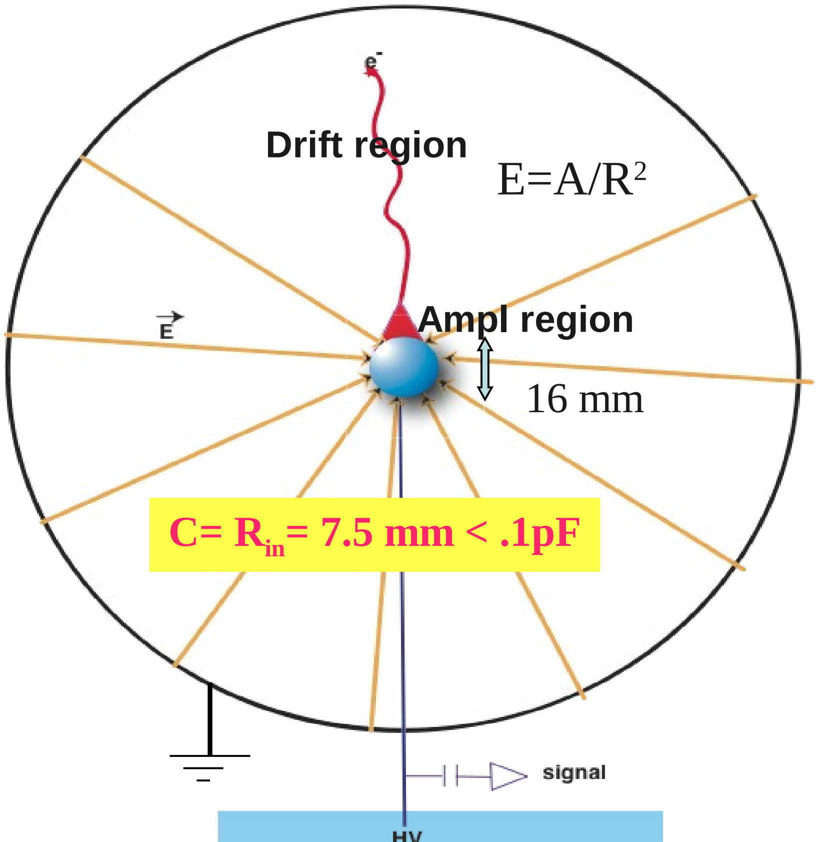
Contents

- The Spherical Proportional Counter (SPC) - Introduction
- Detector description and performance
- Ultra low energy calibration results
- Current developments configuring the electrostatics of the SPC
- Applications: (Low energy ν physics, SN detection, Light dark matter search...)
- SEDINE project (neutron detection)
- Outlook / Summary

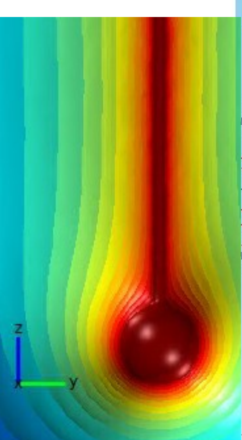
The Spherical Proportional Counter -Introduction

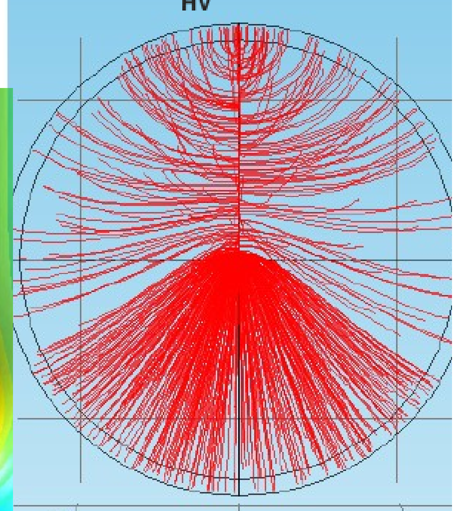
Radial TPC with spherical proportional counter read-out

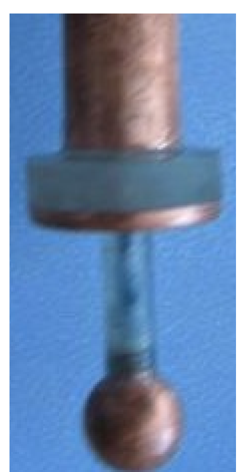
Saclay-Thessaloniki-Saragoza

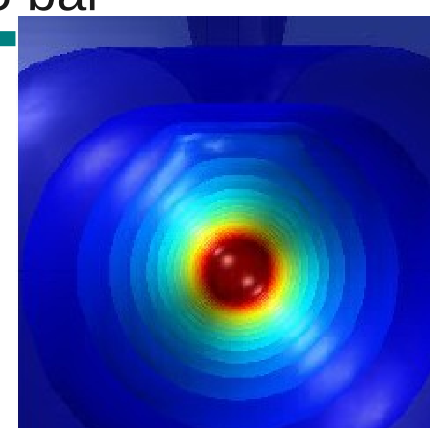


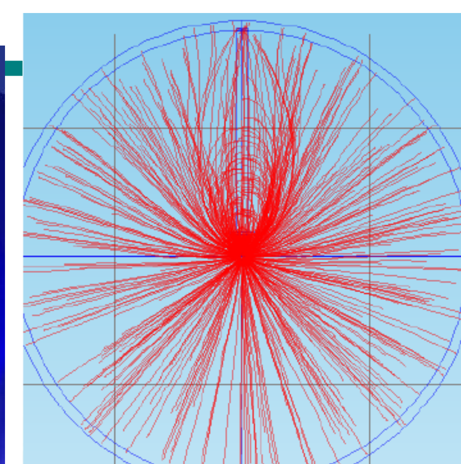
- A new detector was developed
- Spherical geometry
- Copper vessel with d ~ 1.3 m, 6 mm thick
- Proportional counter: small metallic ball with d ~ 16 mm in the centre ==> HV
- 2^{nd} electrode (umbrella) 24 mm away from ball ==> electric field corrector
- Operation at seal mode
- Gas mbar - 5 bar







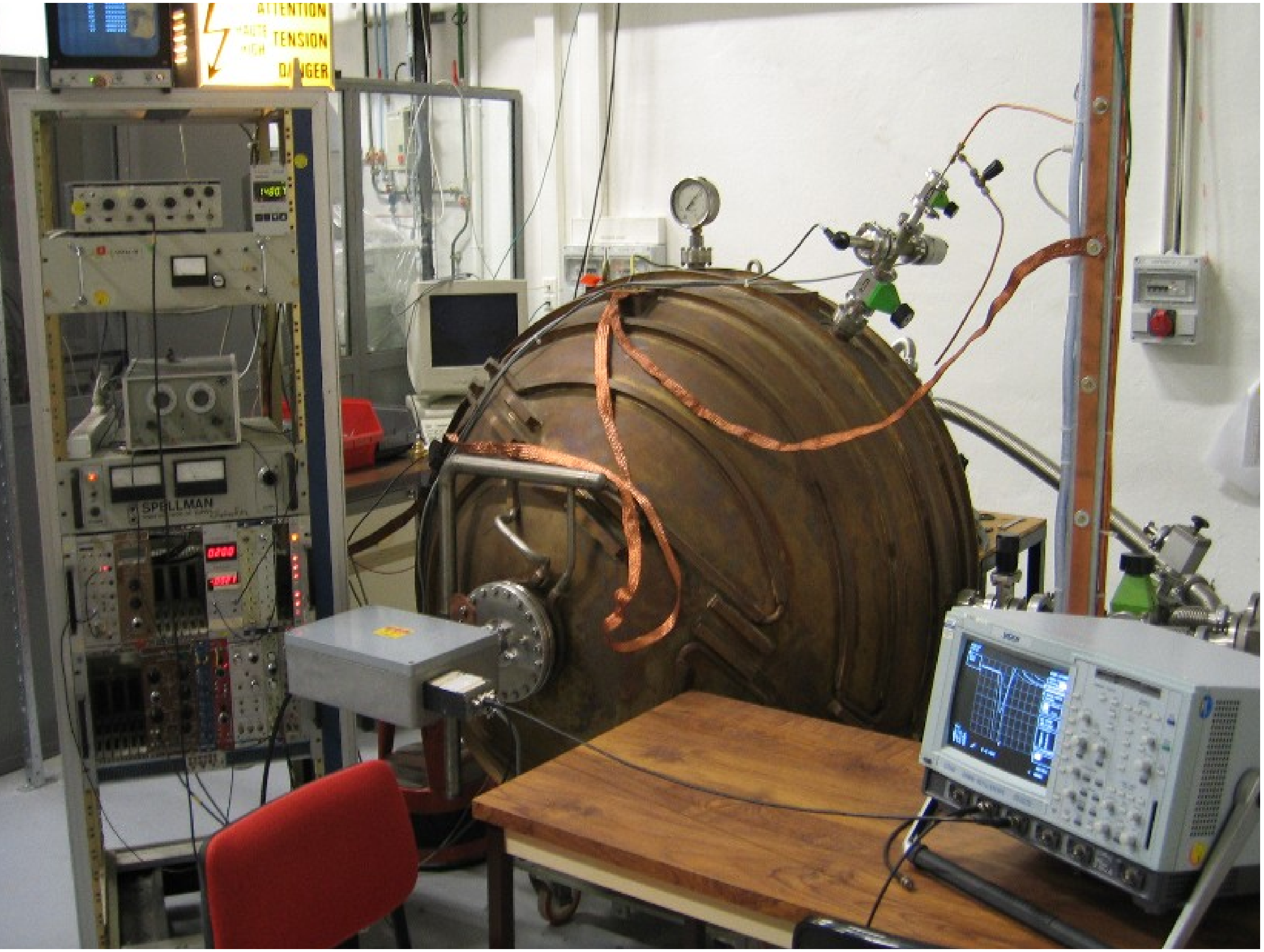




A Novel large-volume Sherical Detector with Proportional Amplification read-out, I. Giomataris et al., JINST 3:P09007,2008

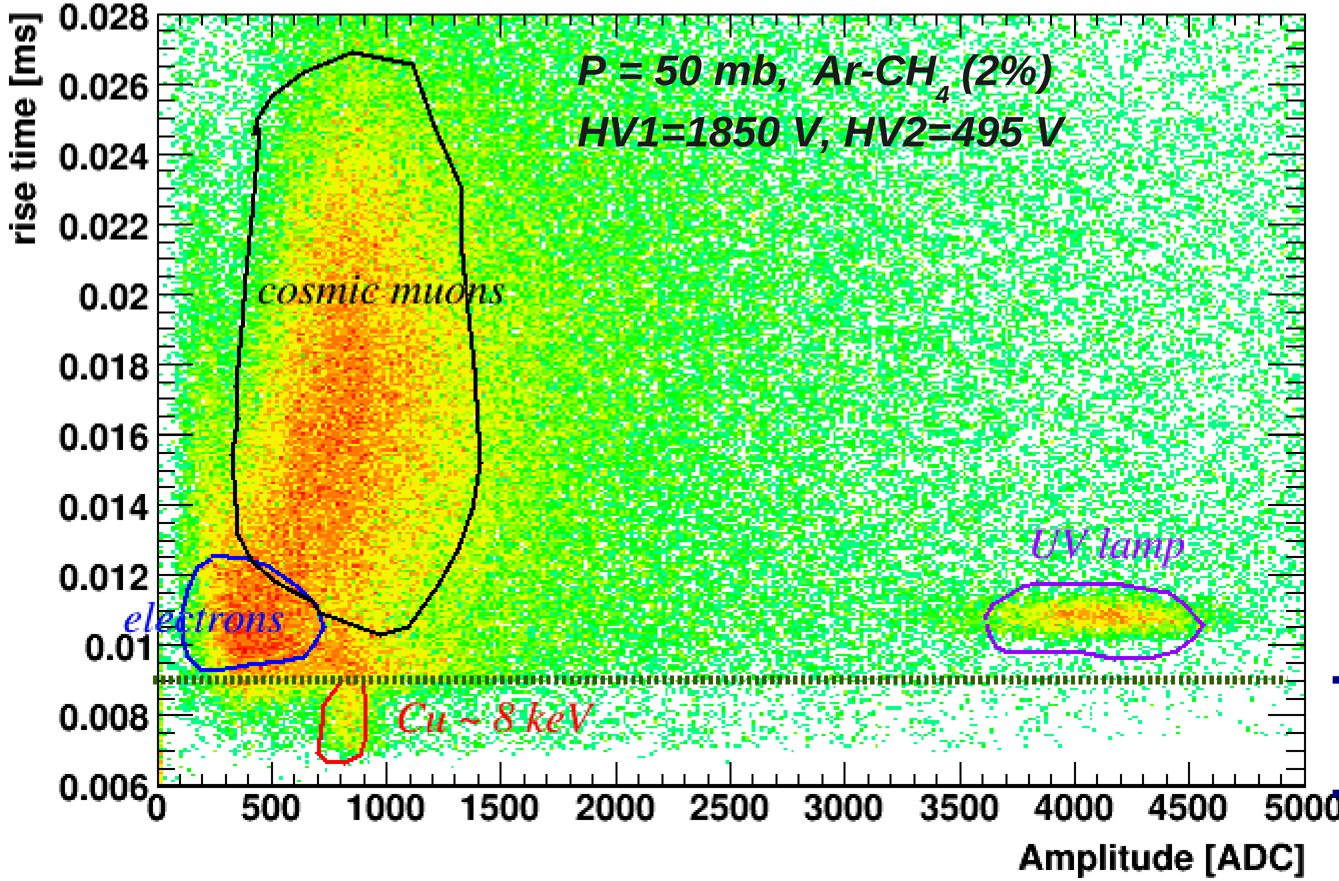
Spherical Proportional Counter

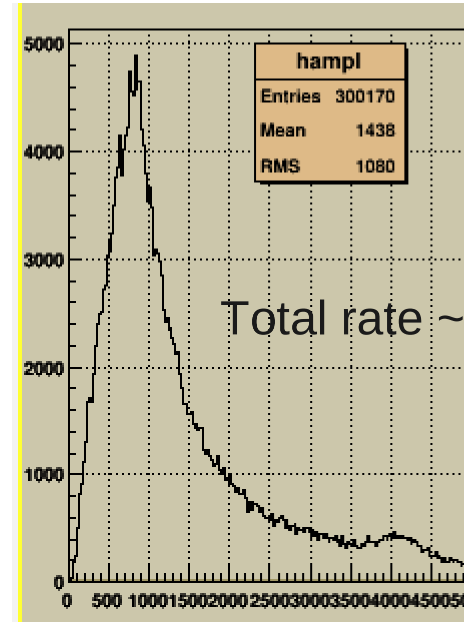
- SPC at Saclay

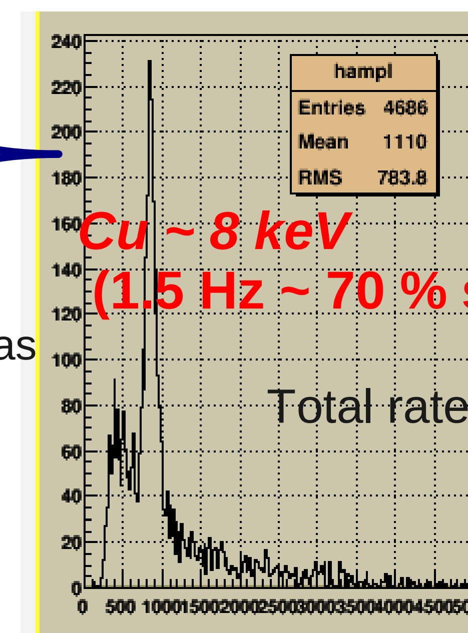


- Simplicity of design
- Cheap
- Single channel to read-out a large volume
- Low detector C < 0.1 pF ==> very-low electronic noise
- Large variety of gases – low to high p
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut (rise time)

Analysis method: Applying fiducial cuts for background rejection



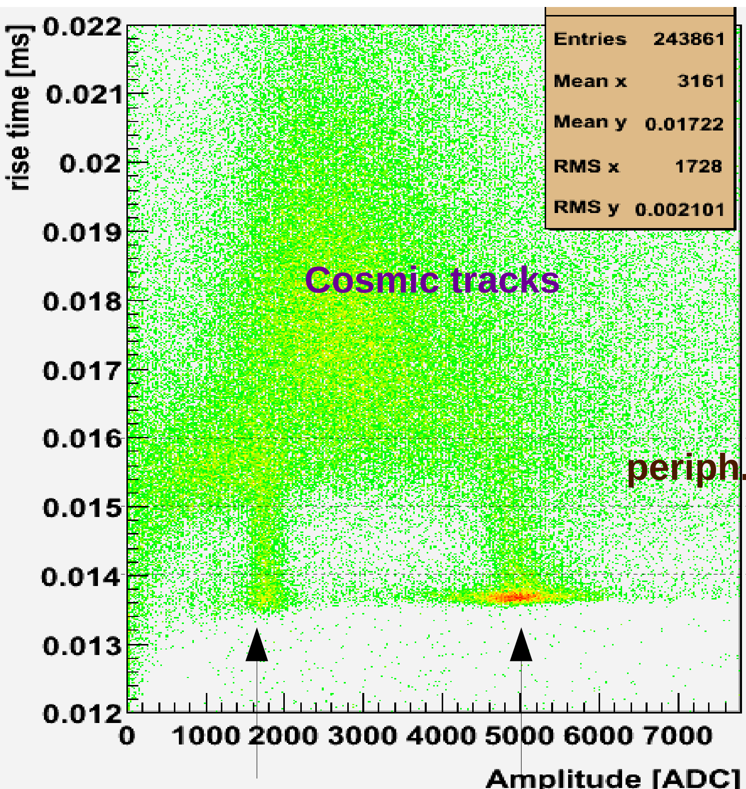




- The ***rise time (rt)*** of the signal==>depth of ionized e- produced in the gas
- Applying a cut rt<0.009 ms==>keeping volume effects
- Spectacular background reduction
- Observed background quite low at ground

Applying a rise time cut

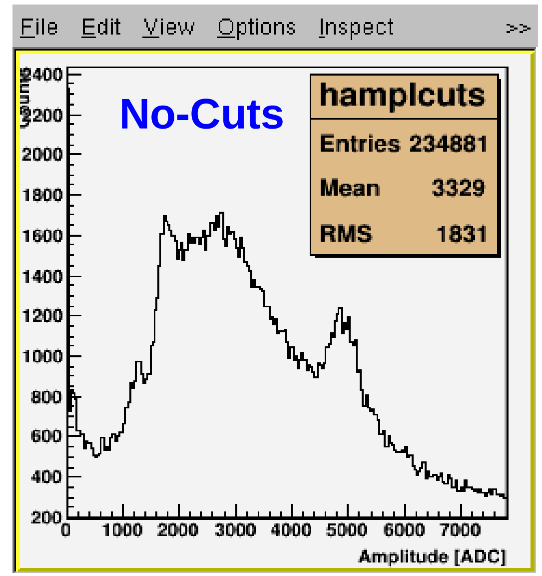
Using Cd-109 source – December 2009
Irradiate gas through 200µm Al window
P = 100 mb, Ar-CH_4 (2%)

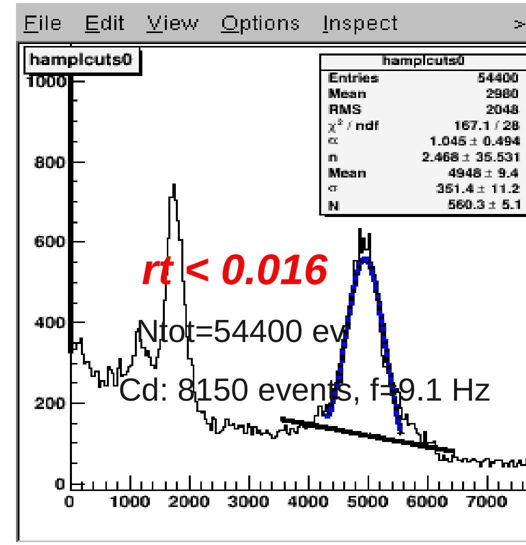


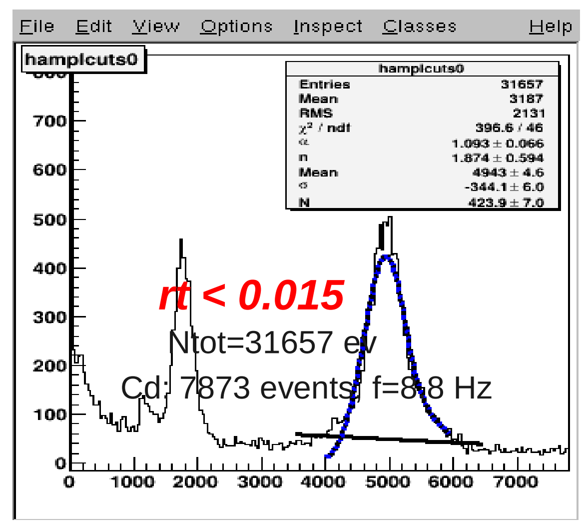
Cu ~ 8 keV

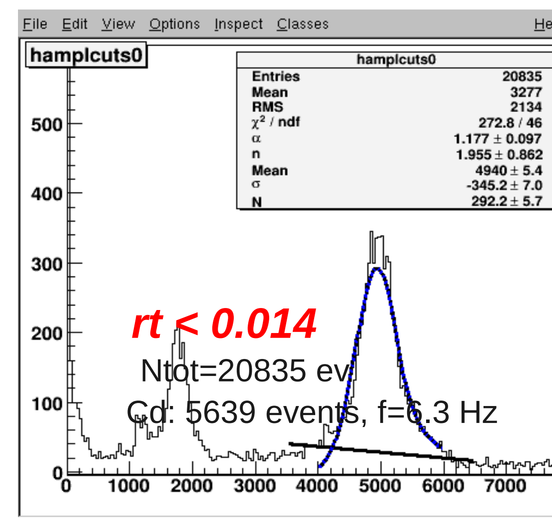
Cd ~ 22 keV

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







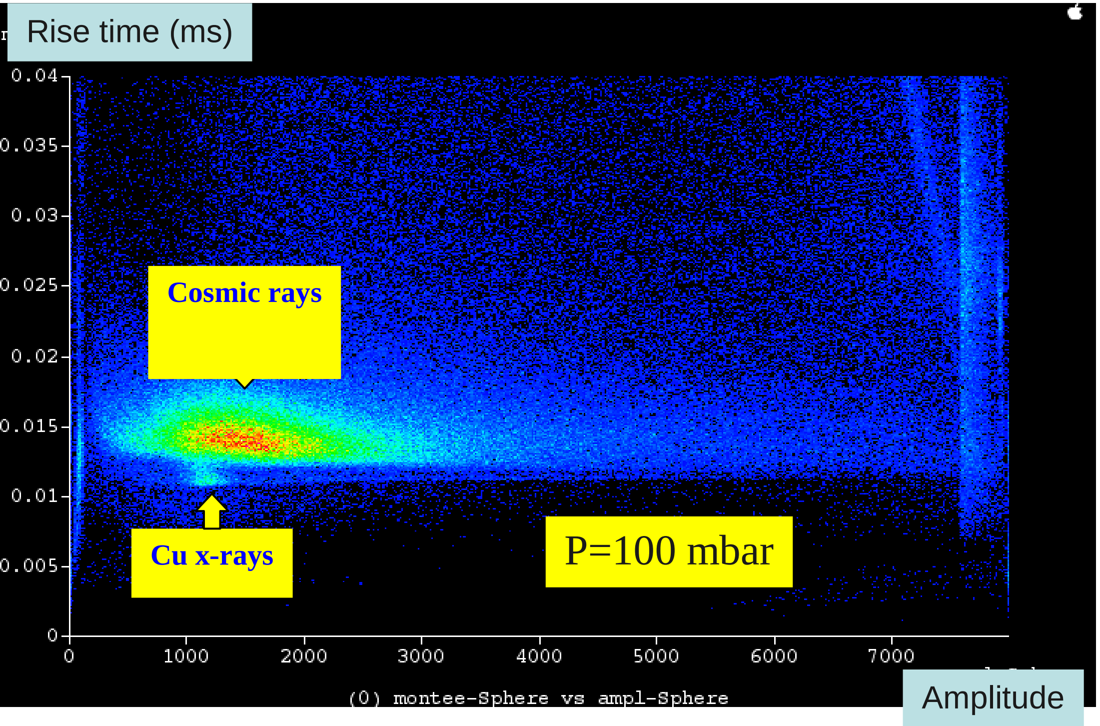


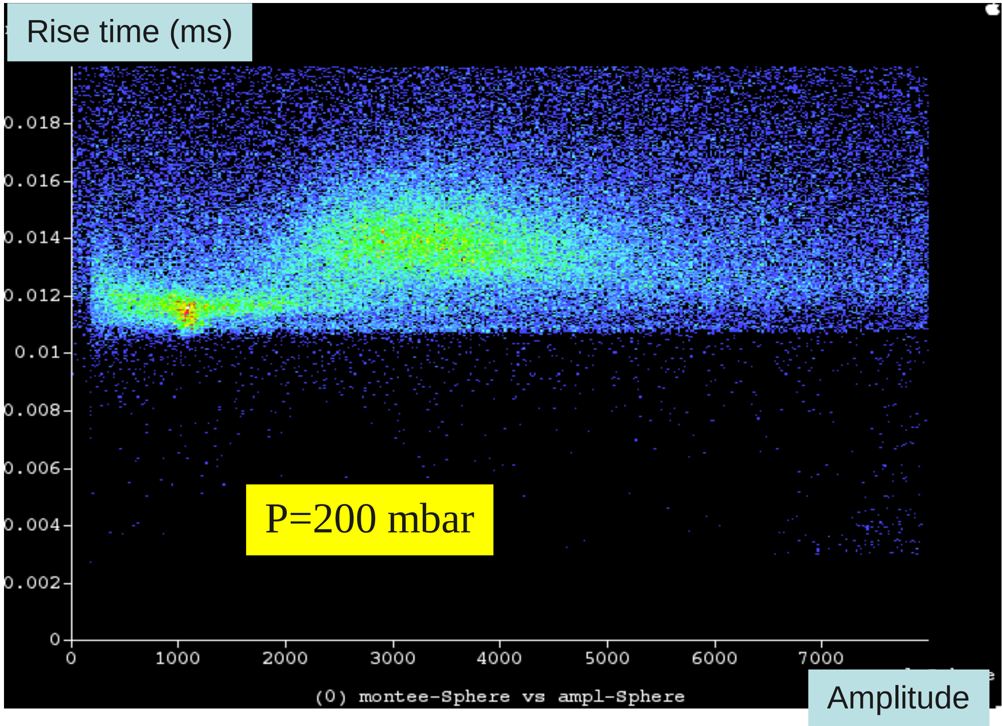
Efficiency of the cut in rt ==> ~ 70% signal (Cd peak)

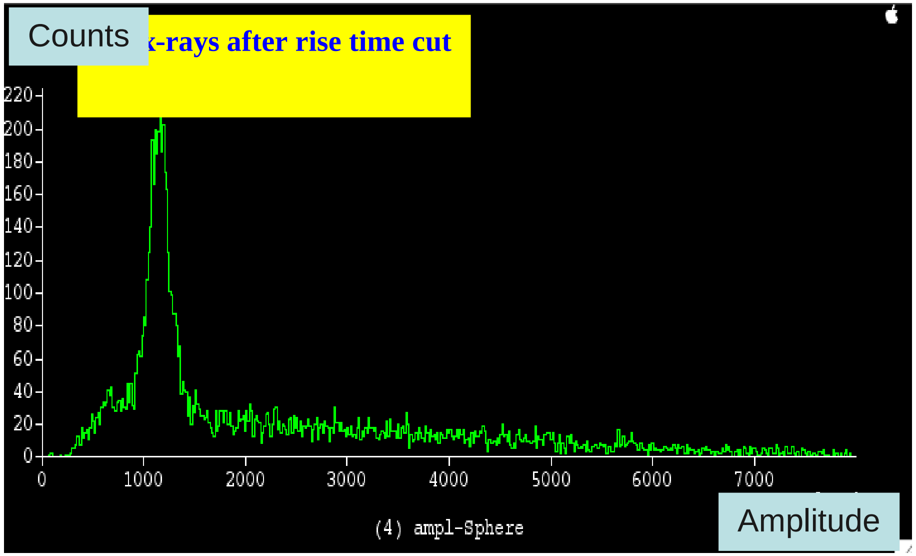
Severe background reduction

E. Bougamont et al 2011 J. Phys.: Conf. Ser. 309 012023

Detector's high versality

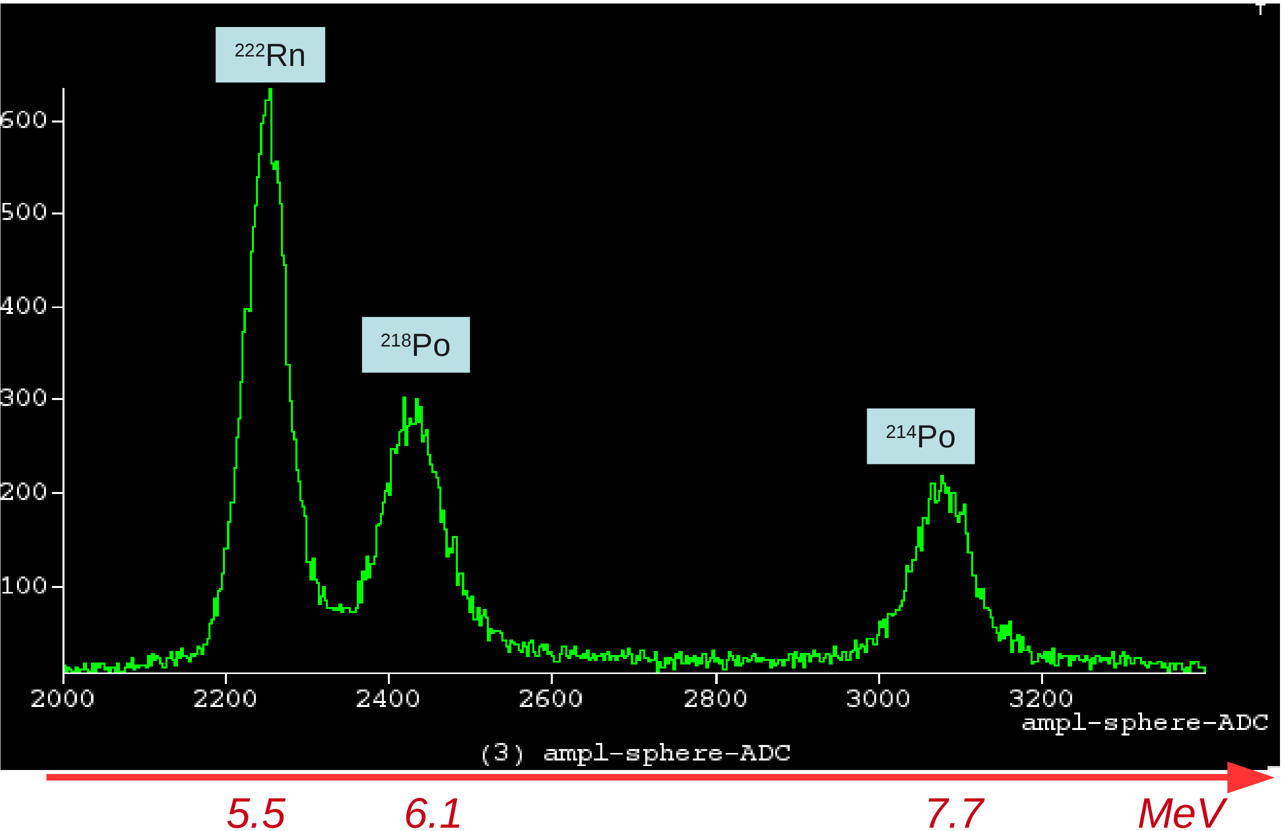






- Versality of the target material and density
- Compatible with large variety of gases (low to high p)
- Precious tool to identify signal out of backgrounds

Energy resolution at "high" energy



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

$^{210}\mathrm{Pb} \xrightarrow{\beta} {}^{210}\mathrm{Bi} \xrightarrow{\beta} {}^{210}\mathrm{Po} \xrightarrow{\alpha} {}^{206}\mathrm{Pb},$

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

Excellent energy resolution (< 1 % in sigma)

Symmetric peak

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

Sub-keV calibration sources (i)

Am-241 source – April 2010

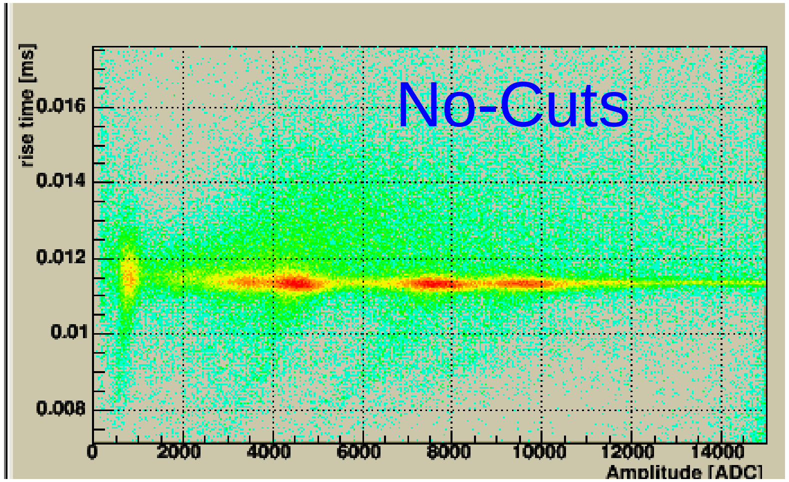
$$^{241}\mathrm{Am} \rightarrow (^{237}\mathrm{Np})^{*} + {}^{4}\mathrm{He} + 5.6\ \mathrm{MeV} \qquad \alpha$$

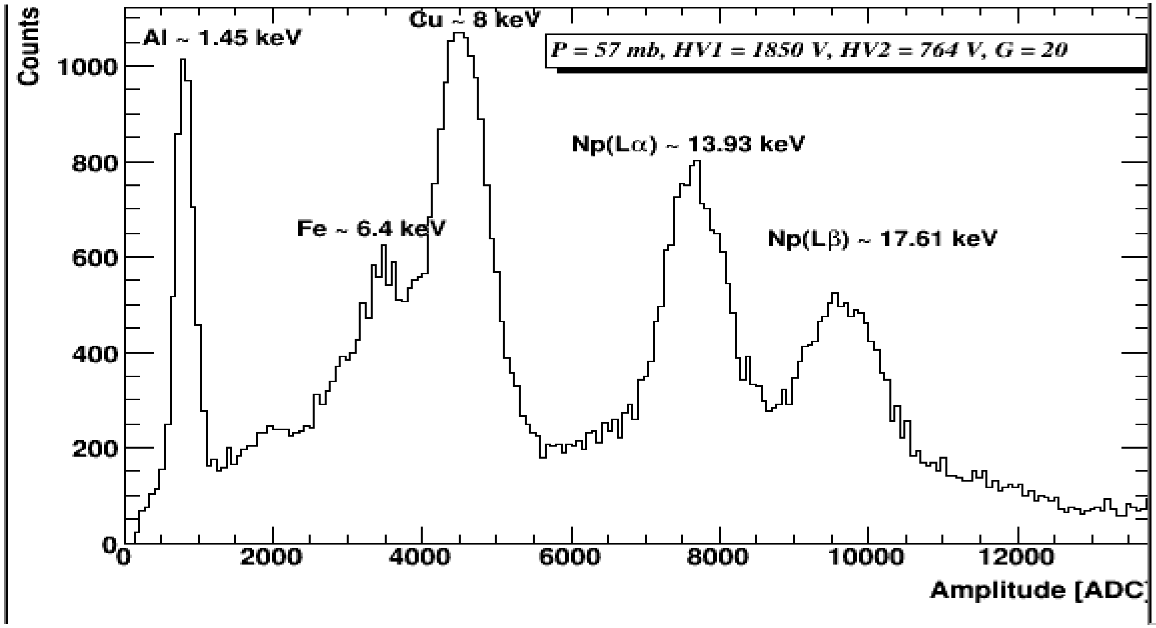
Np-237 decays with γ ~ 59.5 keV and L rays

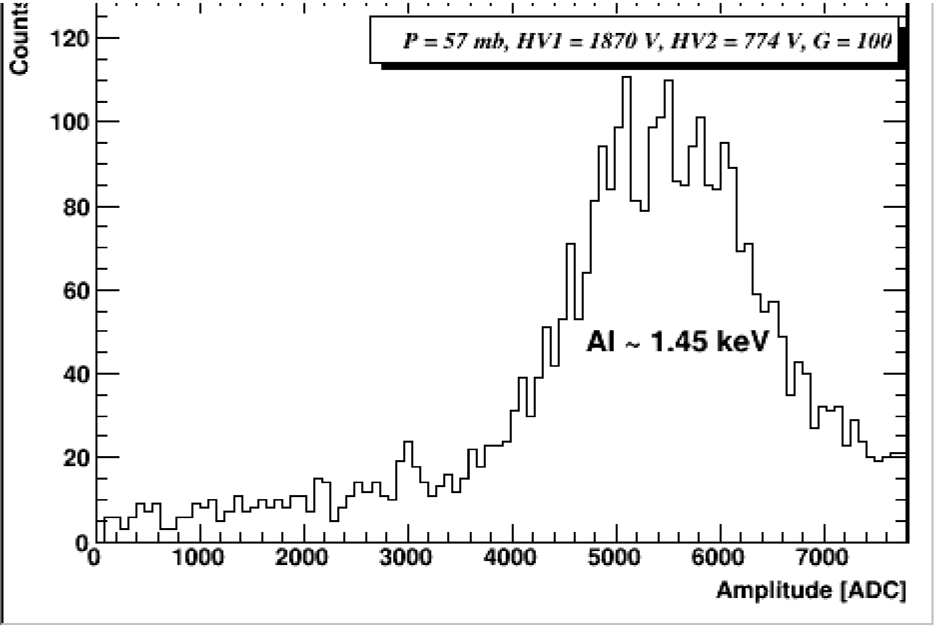
Source attached to sensor-rod

Source covered by thin foils

20µm Al foil ≈ α range







Flat background at low E

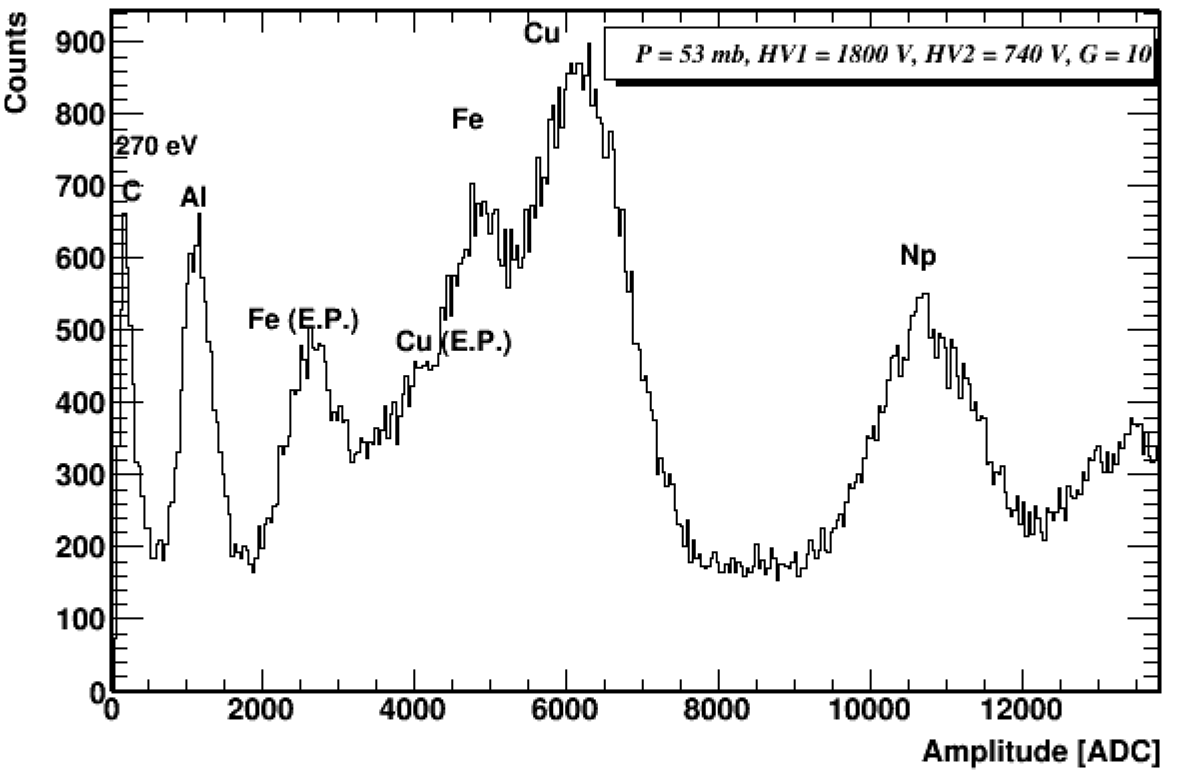
arXiv:1010.4132 [physics.ins-det], 2010

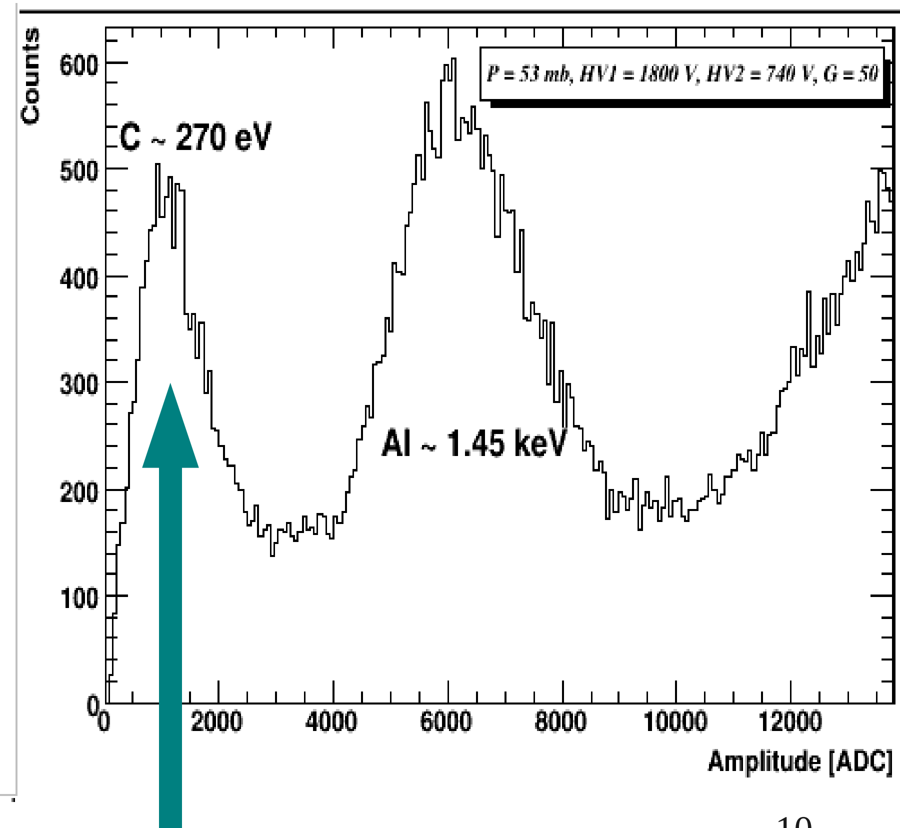
Sub-keV calibration sources (ii)

- **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



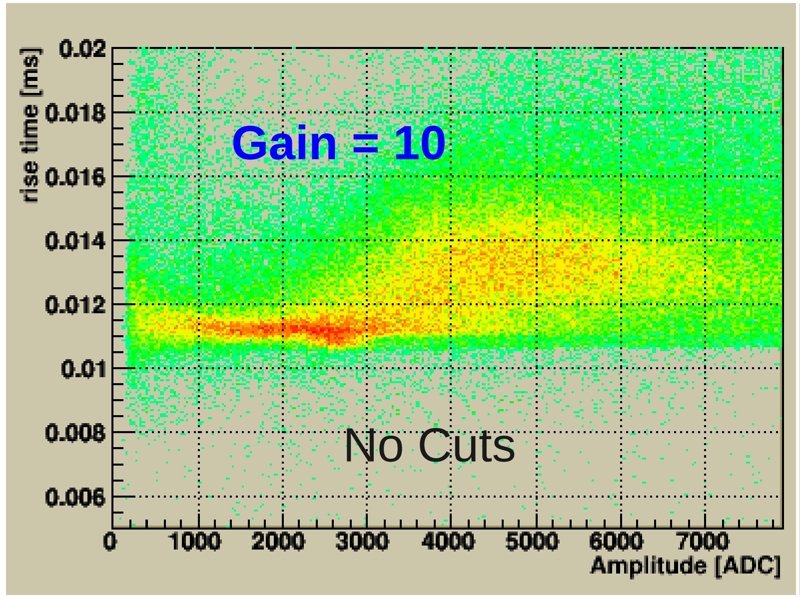


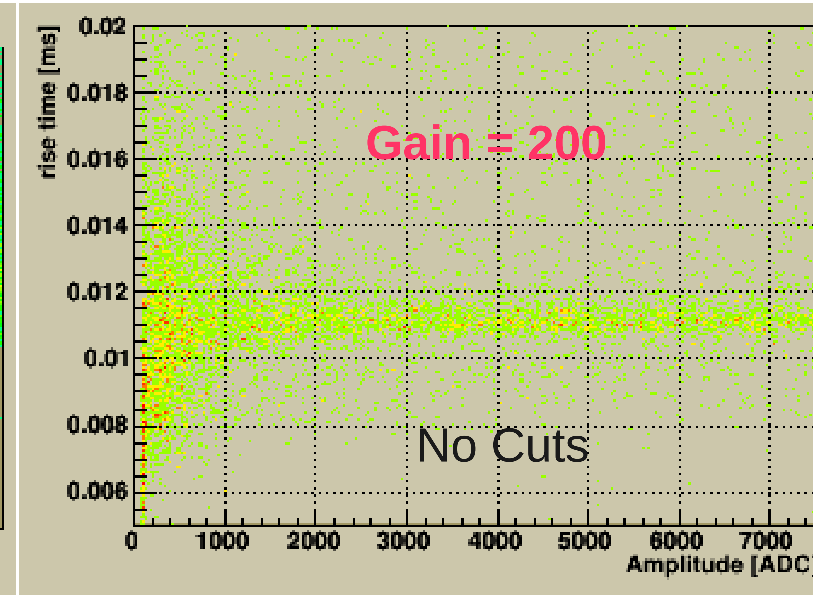
arXiv:1010.4132 [physics.ins-det], 2010

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

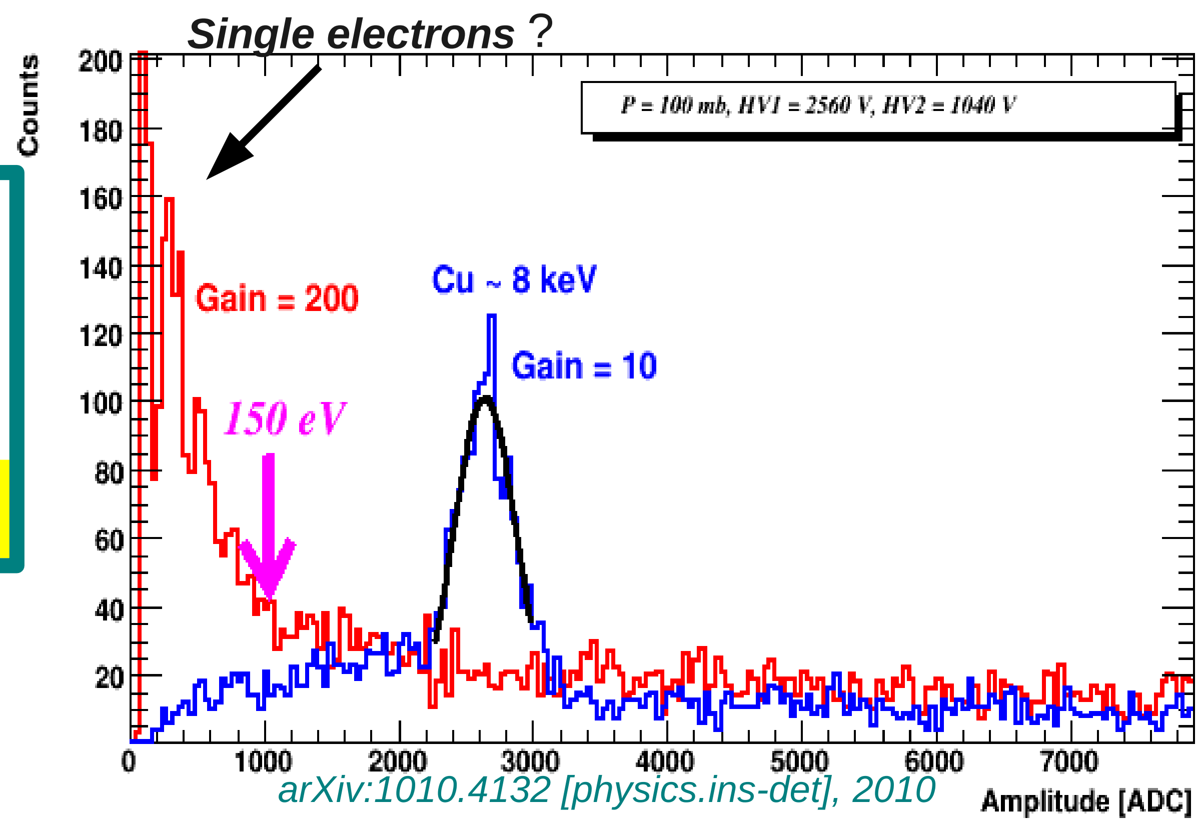
Ultra low energy data at ground – No source

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

Using a UV flash lamp for sub-keV calibration

5 attenuators

< 3 attenuators ==> Nev ~ stable

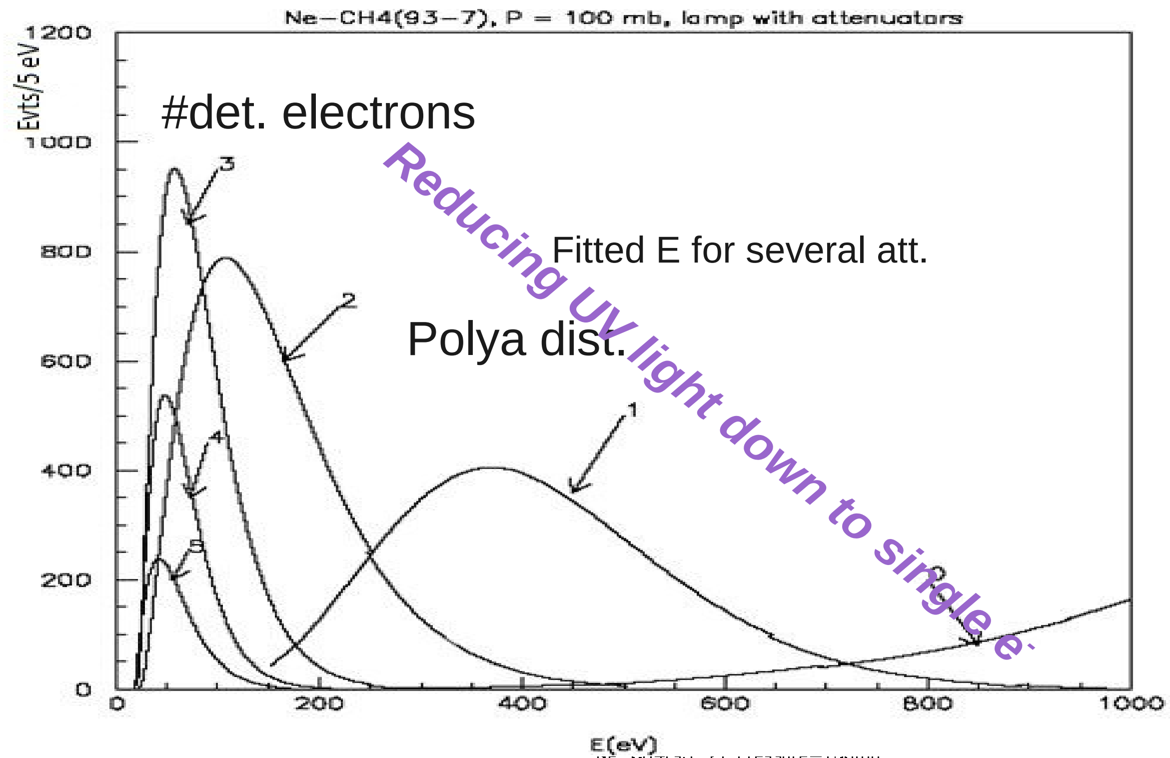
> 3 ==> P for 0 p.e. / flash ↑

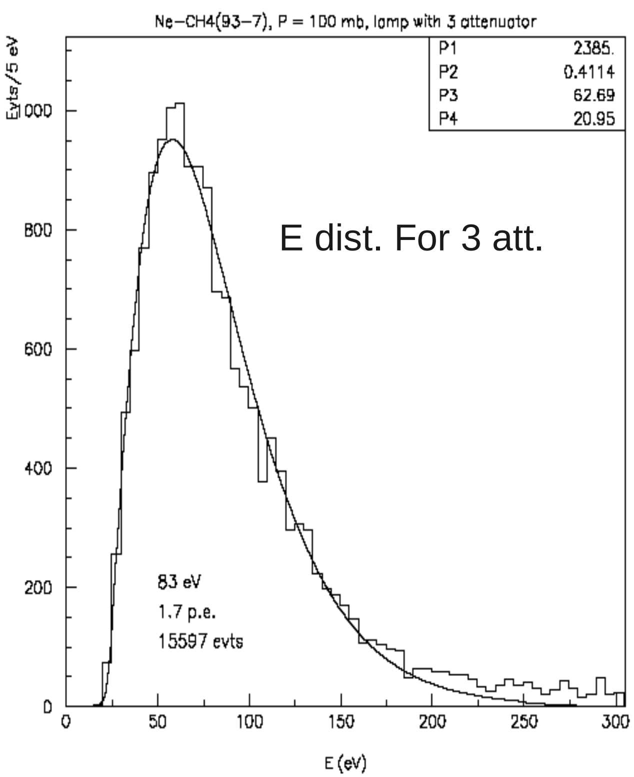
Reduction factor ~ 3

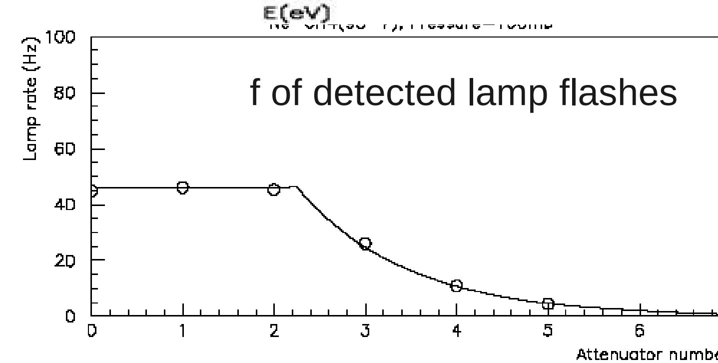
Natt >3 ==> Emean ~ const

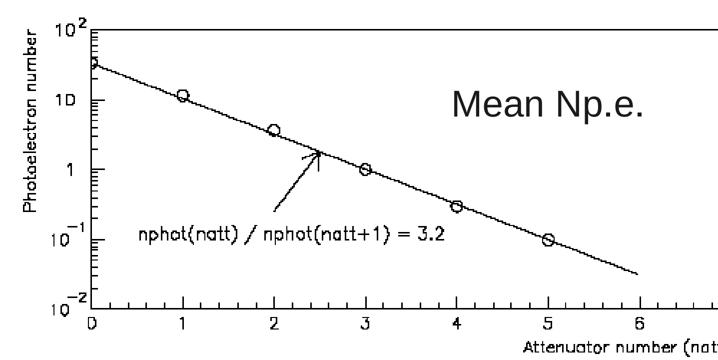
Single e- level

Thr ~ 30 eV







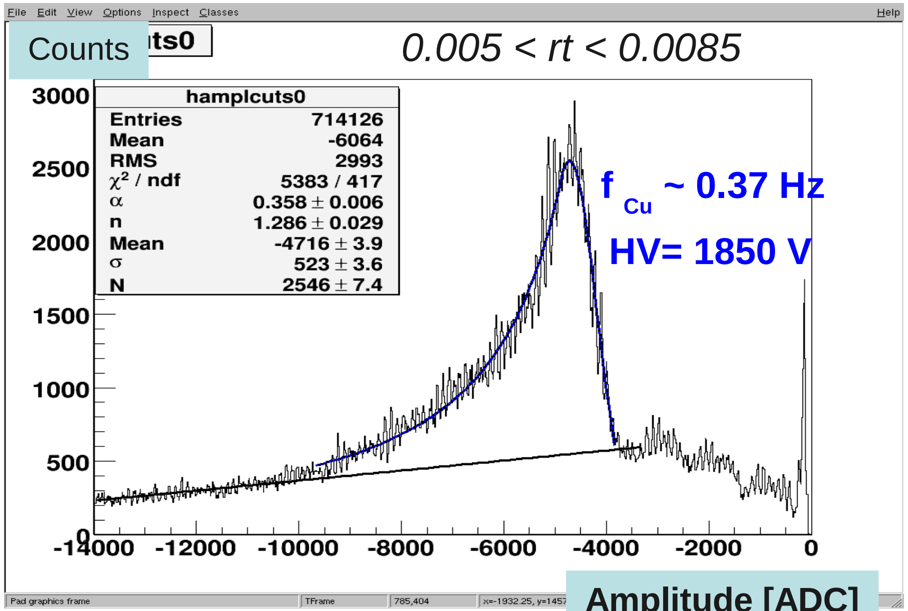


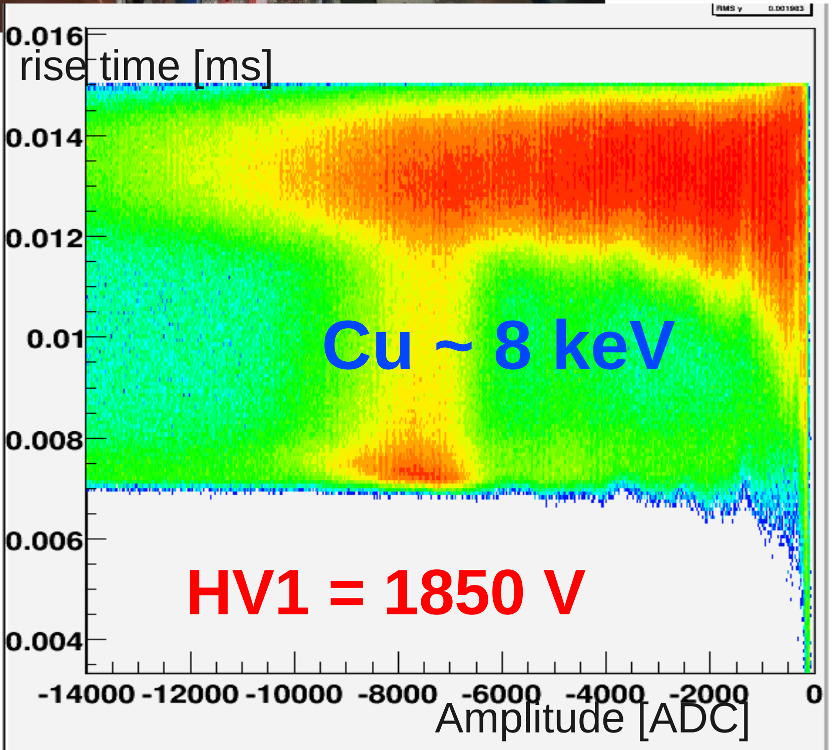
Jacques Derré *arXiv:1010.4132 [physics.ins-det], 2010*

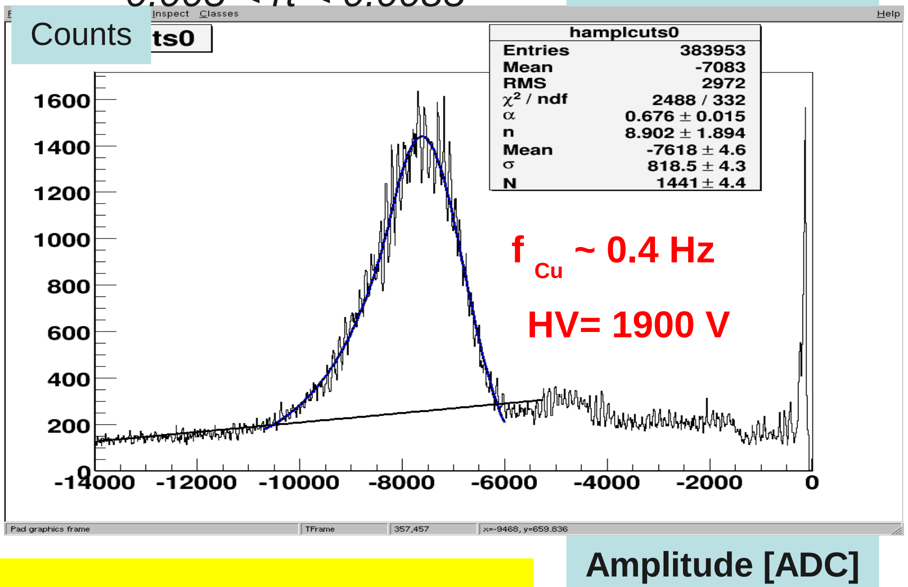
Low energy spectra at underground (LSM) – No source

- f_{Cu}^{total} ~ 1 Hz (~½ at ground)
- ~ 0.05 Hz/keV

p=57mb (Ar-CH_4 2%)

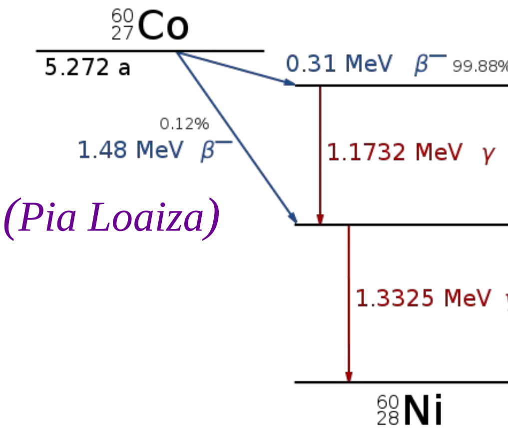




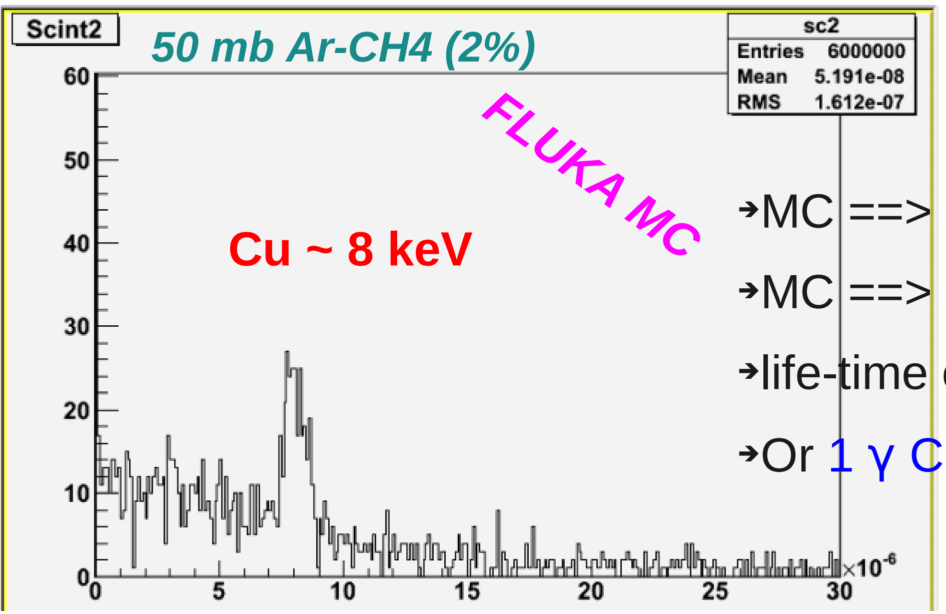


Preliminary results - october 2010

Cobalt inside Copper

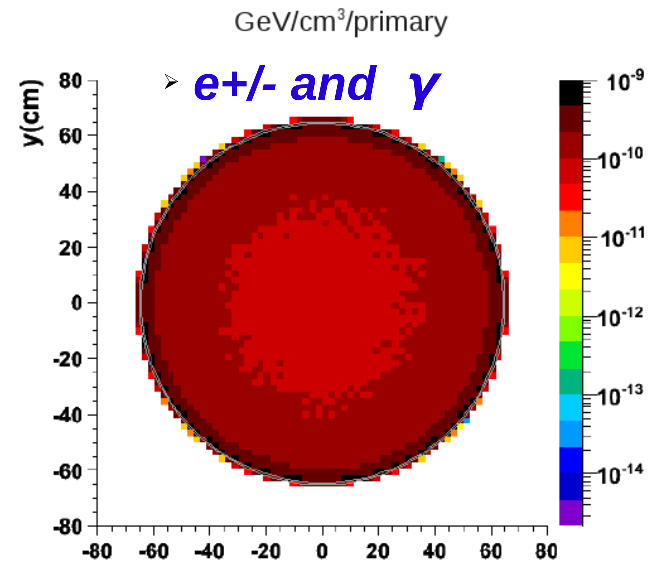


- Measured radioactivity at LSM (on SPC Copper): 60Co < 1.3 mBq/kg *(Pia Loaiza)*



Energy deposition in the gas from photons[GeV]

- MC ==> 190 hits in Cu
- MC ==> 3 M Co decays
- life-time of Co ~ 5 y ~ 1.67E8 s
- Or 1 γ Cu /16000 decays of Co



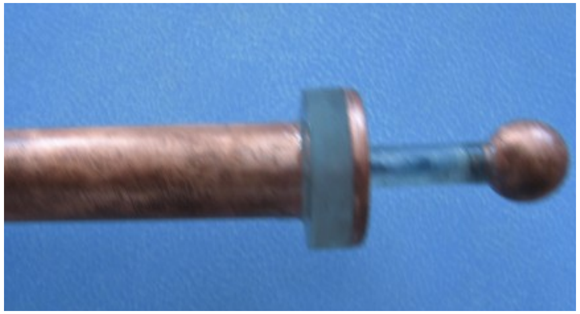
- Data (LSM) fCu ~ 1 Hz or 1γ Cu / s

or 1 x 16000 decays / 1 sec = 16000 decays / s ~ 16000 Bq

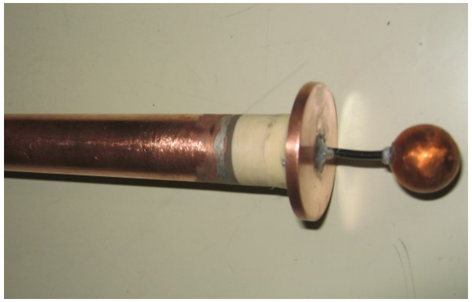
==> if measured A ~ 1.3 mBq * 200 kg = 0.26 Bq => fCu(data) ~ 1.6E-5 Hz

- **enviromental gammas induce the main signal on Cu at LSM**

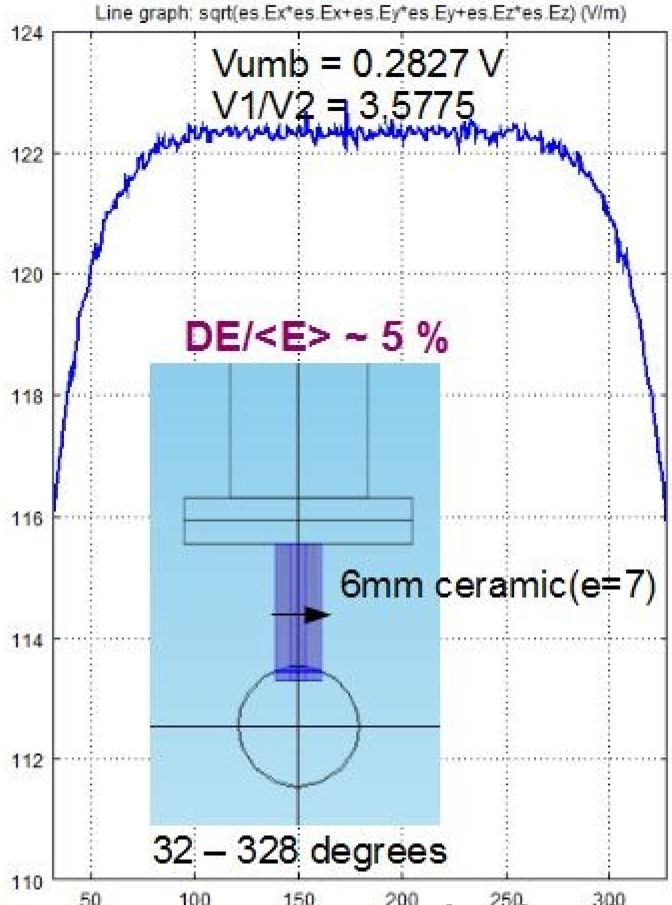
Optimization of sensor's sensitivity

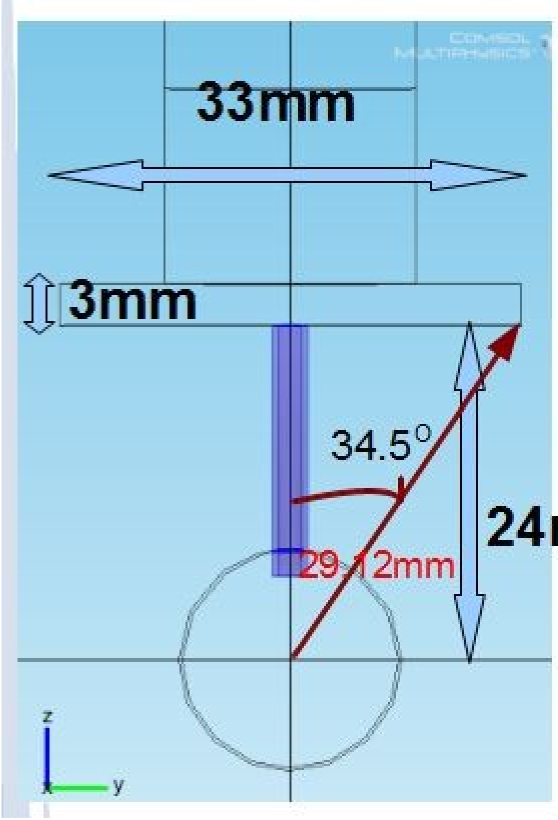


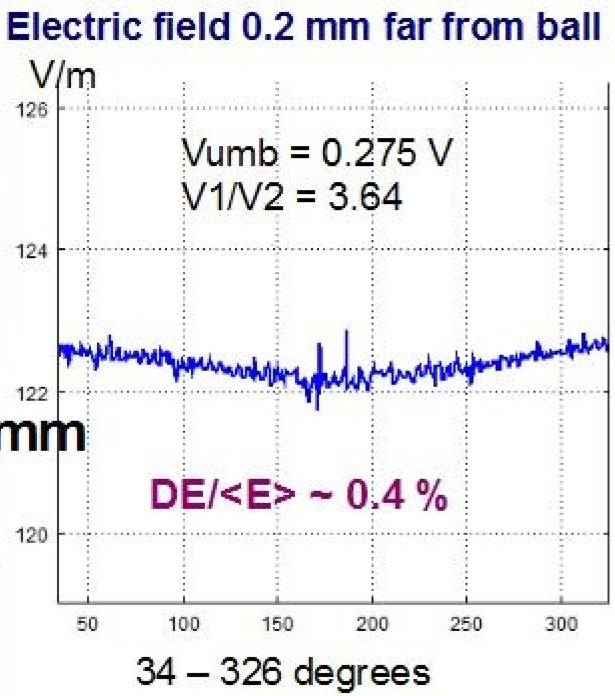
- Minimal distortion of the spherical field is needed
- Numerical simulation using ***COMSOL Multiphysics***
- Insulator with small thickness and dielectric constant



HavSE conf., DESY, Hamburg, GERMANY 19-23 july 2011

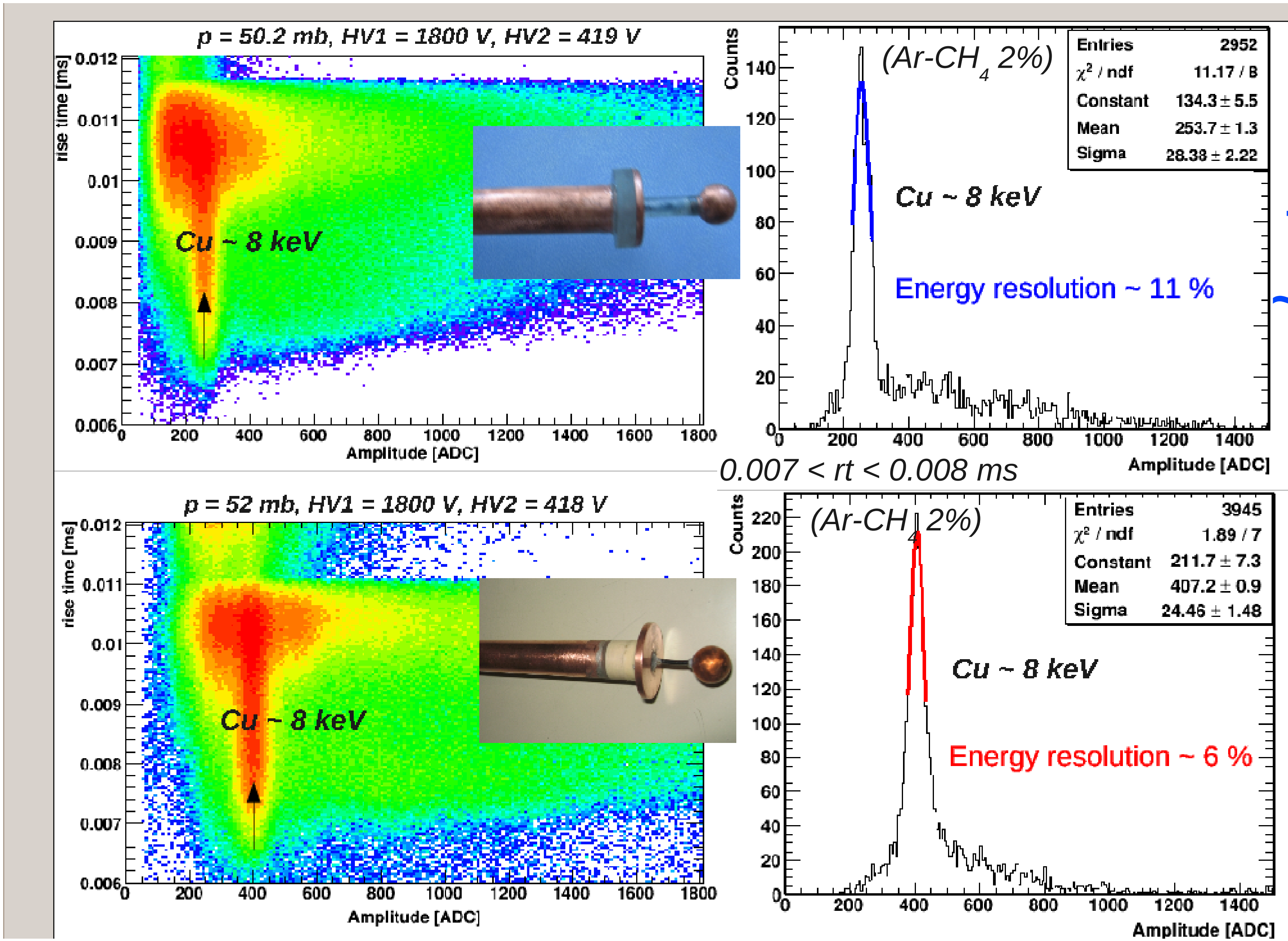






Simulated variation of the electric field 0.2 mm far from the ball for 2 diff. sensors

Best achieved resolution so far...



f_{Cu}^{total} ~ 2 Hz

~ 0.07 Hz/keV

Applications

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

Several applications are open:

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

etc...

Coherent Elastic Neutrino – Nucleus Scattering

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

Neutral current

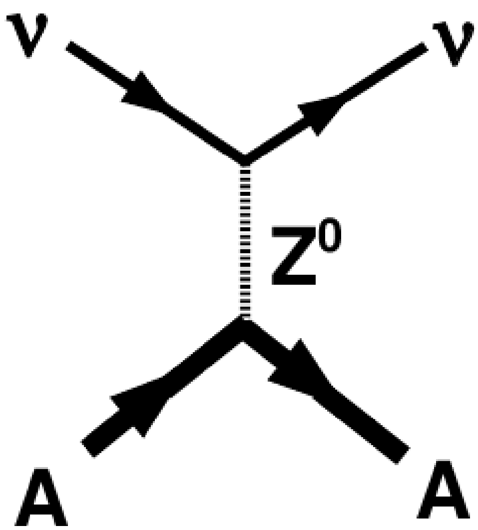
Coherent up to ~100 MeV

reactor, solar, spallation source, SN ν

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

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

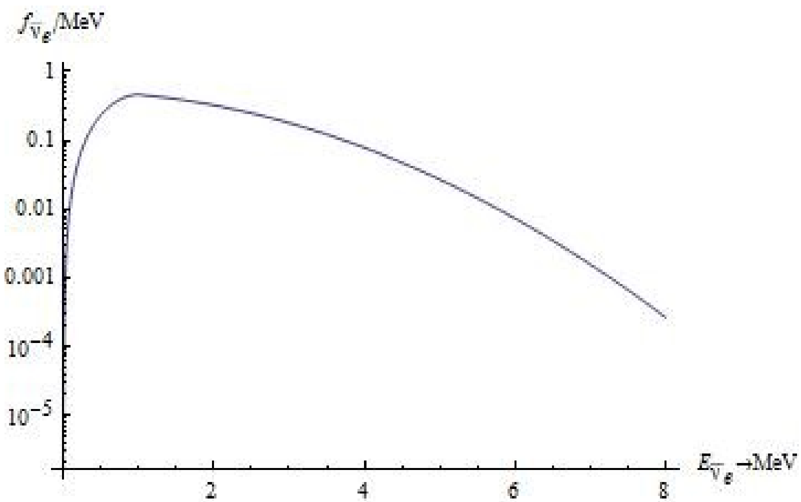
Large σ ↑as Eν↑and scales as N^2



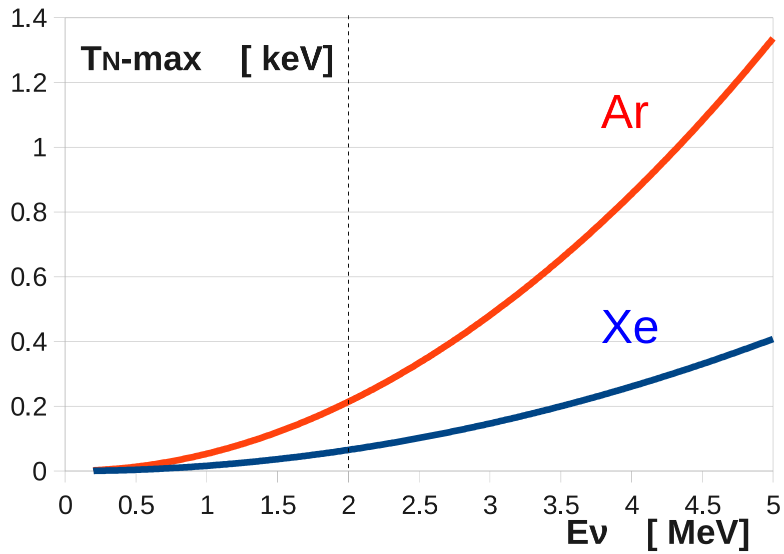
In the few-50 MeV range:

- 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!

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

With the present SPC prototype

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

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

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

Ne ($\sigma \approx 7.8 \times 10^{-42}$ cm^2), 1.87×10^4 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

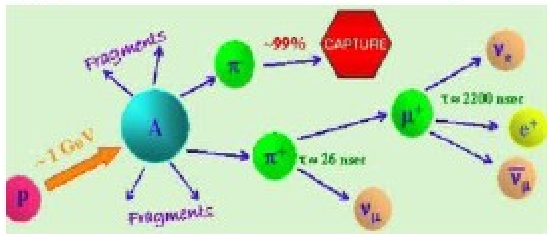
A possible test for the detector efficiency:

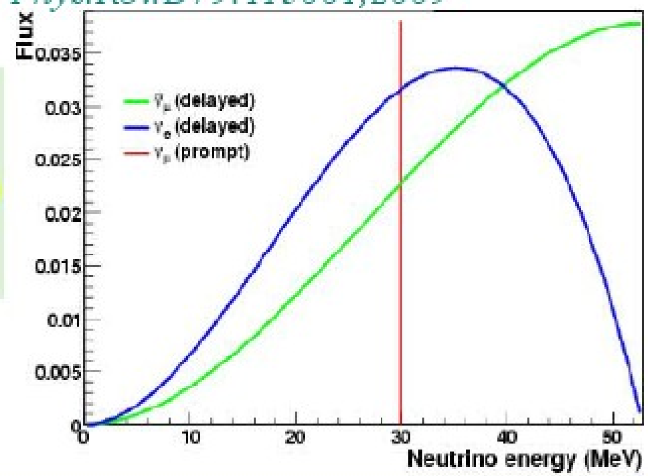
Measuring Neutrino-nucleus coherent elastic scattering

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





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

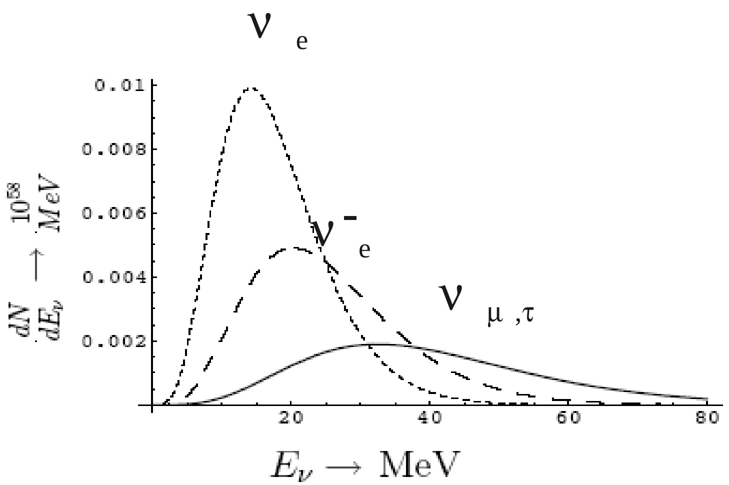
SENSITIVITY

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

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



The average nuclear recoil energy is:

	Ar	Xe
$<E_r>$:	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)

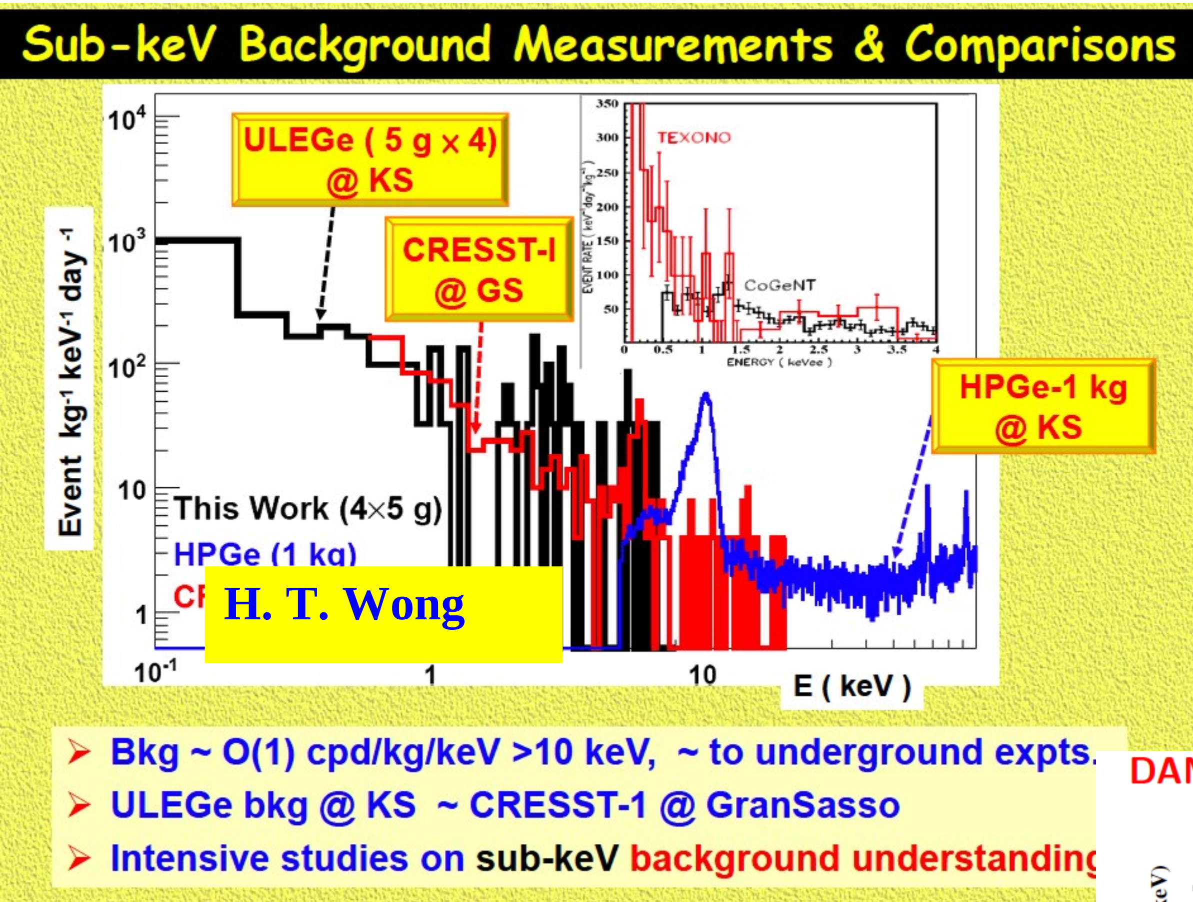
Milestones of R@D phase

- 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

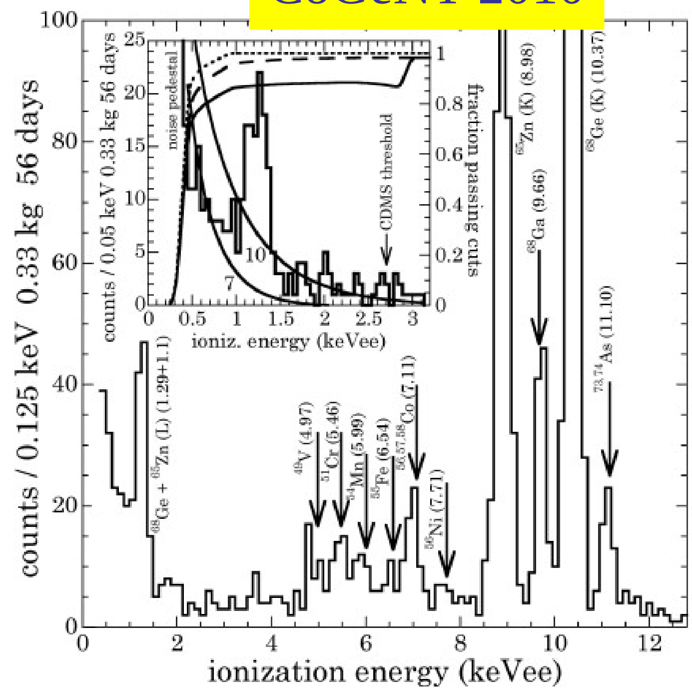
Additional physics,

Dark matter search through very low energy threshold < 100 eV

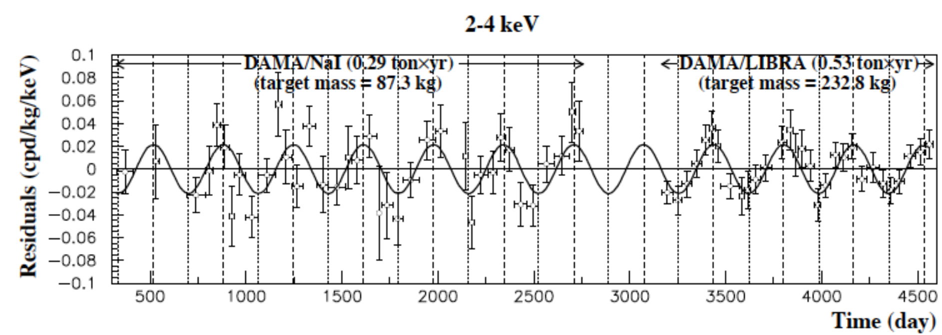


H. T. Wong

CoGeNT 2010



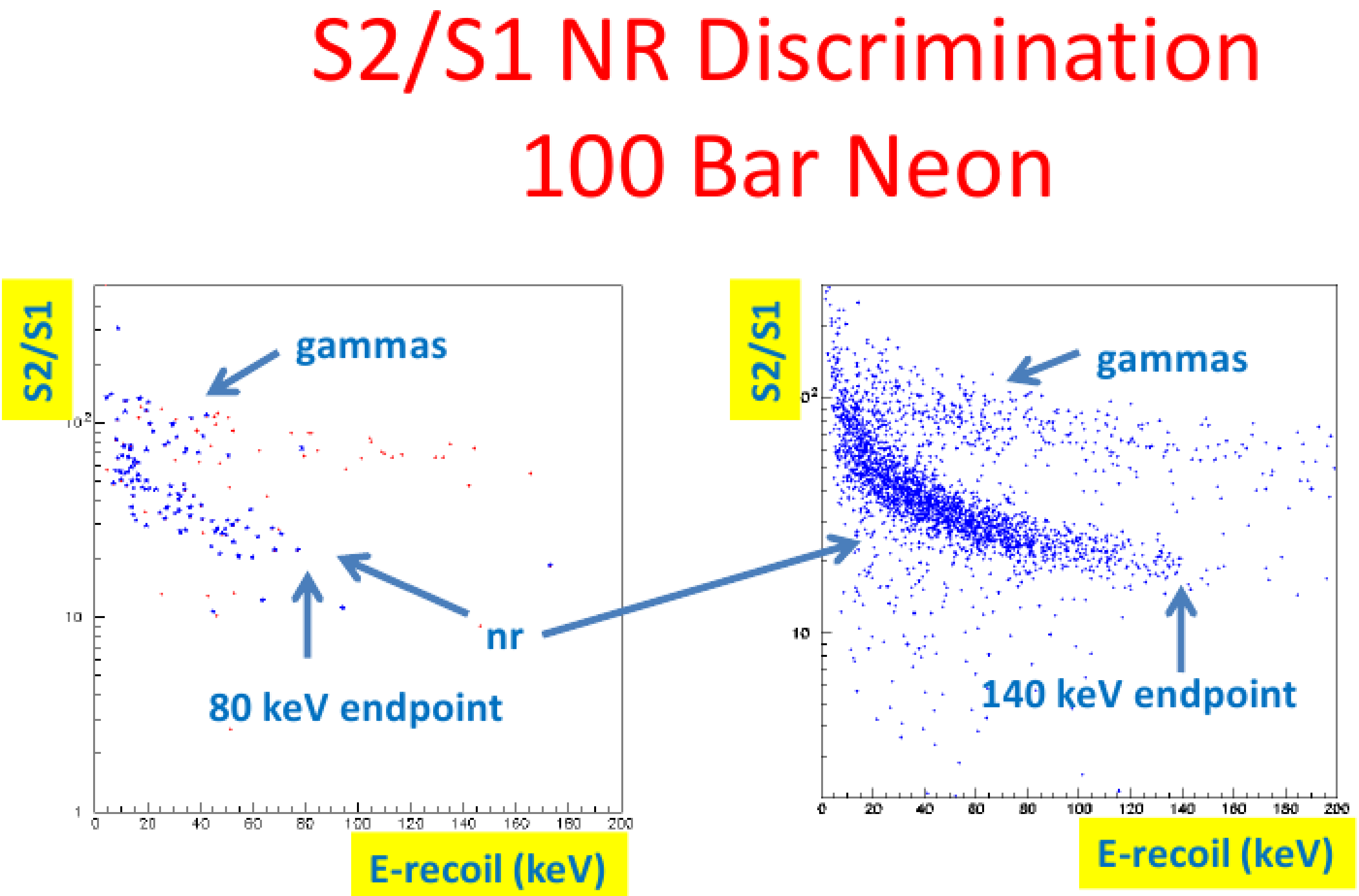
DAMA+LIBRA 11 years, 0.83 ton × year, 8.2σ modulation signal.



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

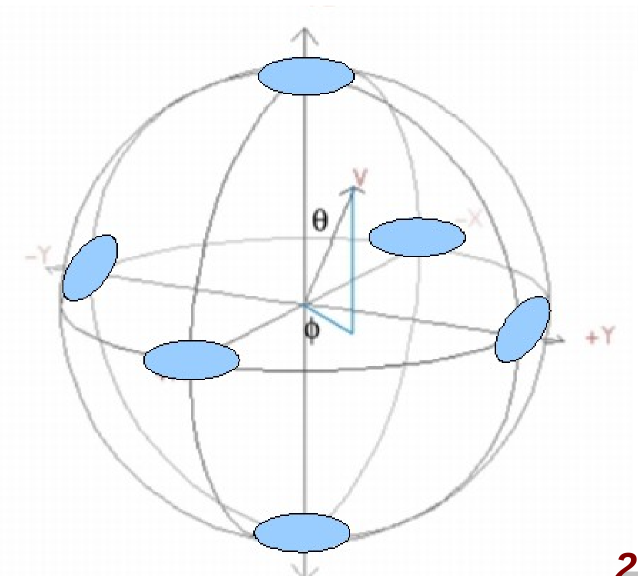
- **Link to previous low E excess?**
- **The need to go to very low energies may become more crucial==>Use of SPC**

Nuclear recoil response in high-pressure gases



- ***Discrimination***: electronic recoil and nuclear recoil interactions
- Crusial in the WIMP's search

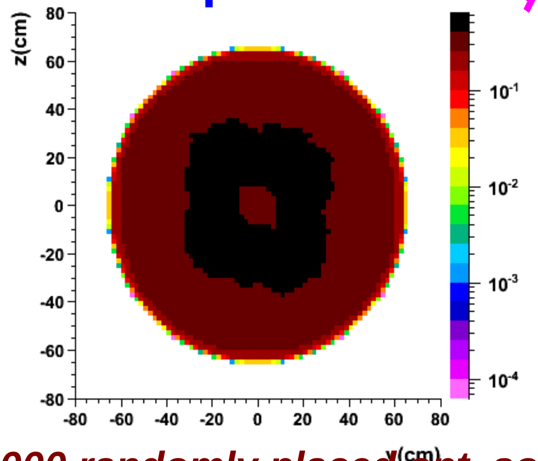
SPC as a UV detector



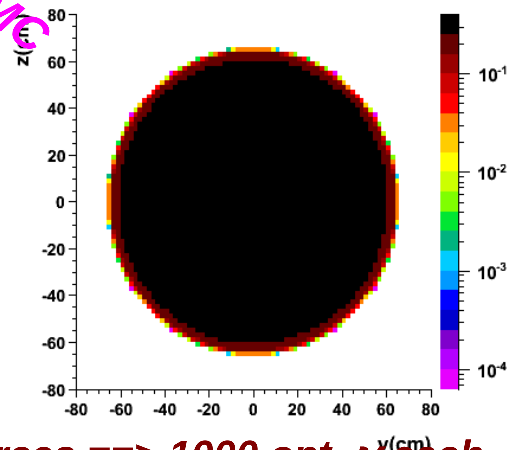
6 PMTs of d=12.5cm

FLUKA MC

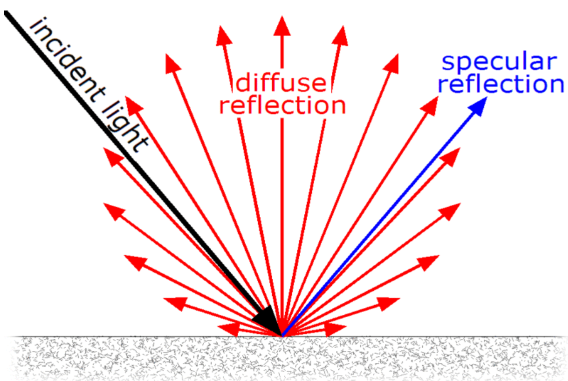
Specular

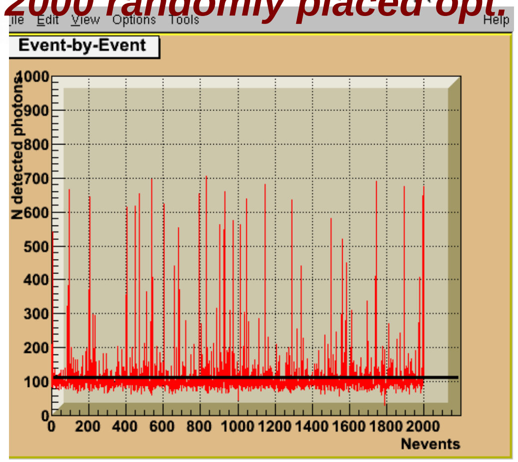


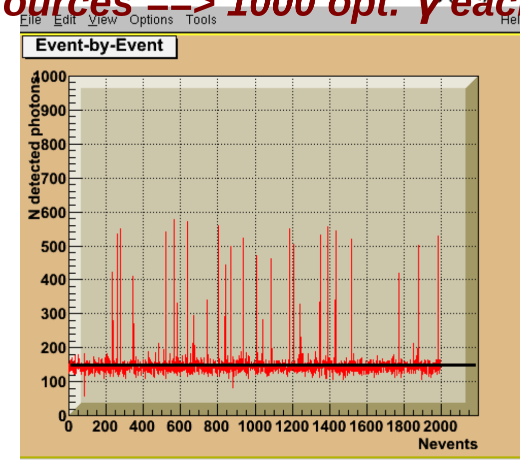
Diffuse



2000 randomly placed opt. sources ==> 1000 opt. γ each





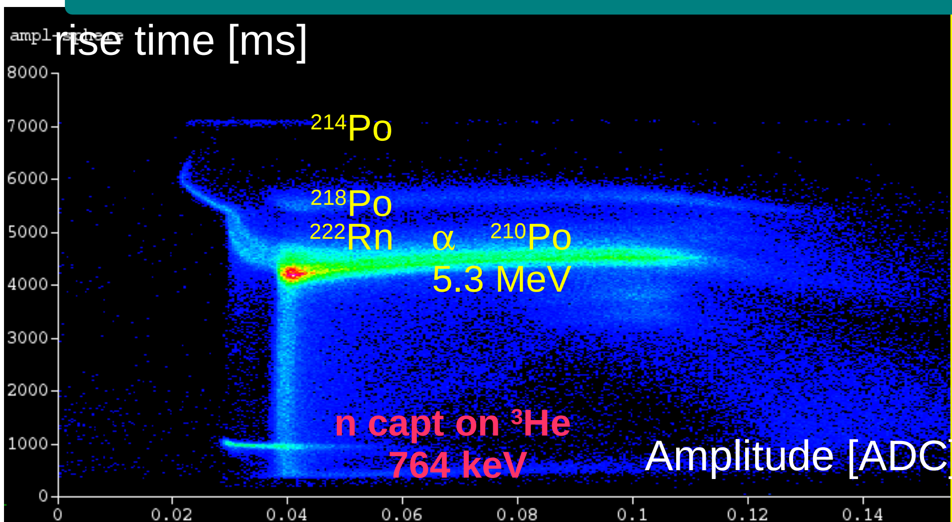


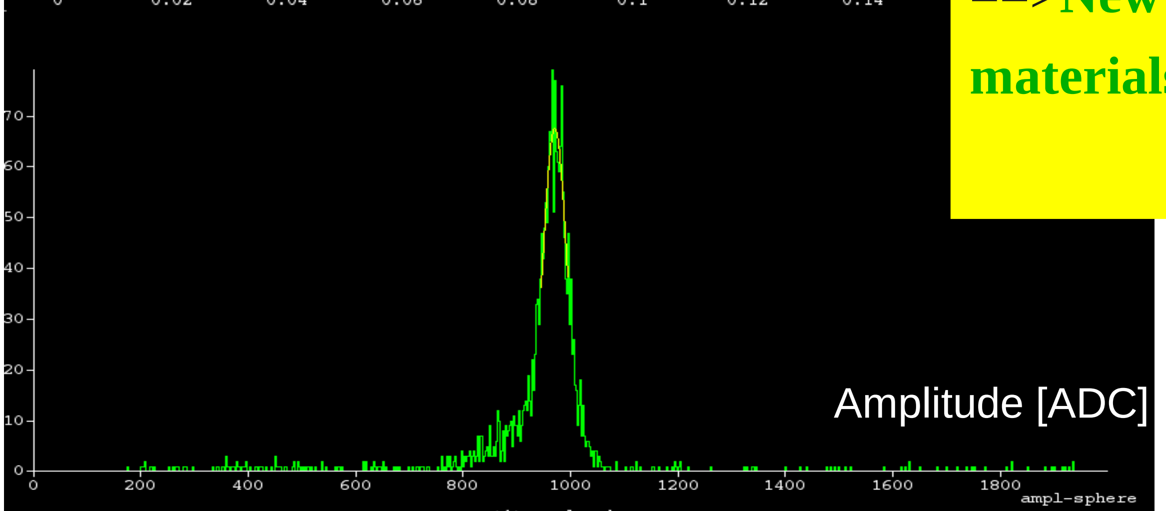
- **Specular** ~ 11.5 % 92 % reflectivity **Diffuse** ~ 15 %
- **Specular** ~ 23 % 99 % reflectivity **Diffuse** ~ 58 %

M. Schumann for XENON100 collab., 2011 J. Phys.: Conf. Ser. 309 012011

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





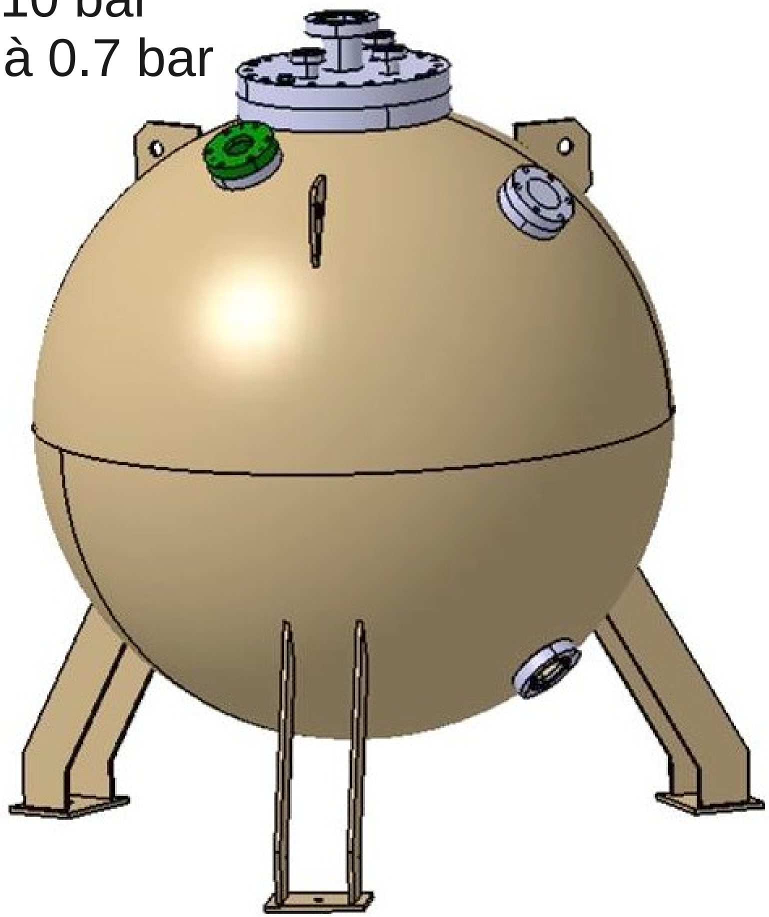
- Contamination due to ^{210}Po
- thermal neutron flux: $3\times10^{-6}/cm^2$
- With rise time cut (>0.04 ms) rejection of background and 60 % efficiency
- too difficult with present apparatus to measure fast neutrons

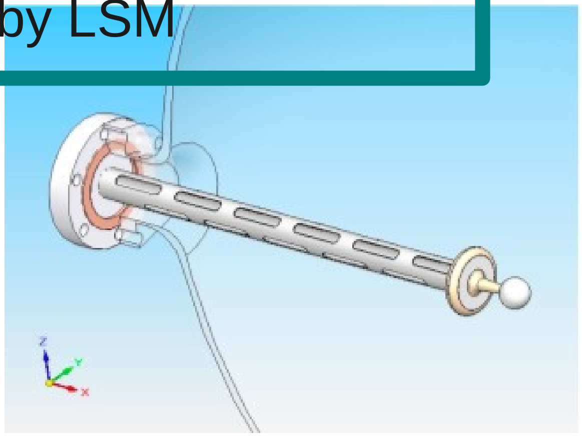
==>**New detector is needed from low background materials and higher 3He mass**

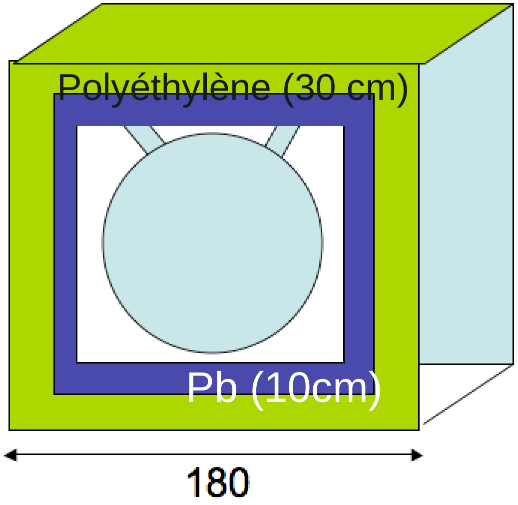
Low activity project SEDINE

- 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





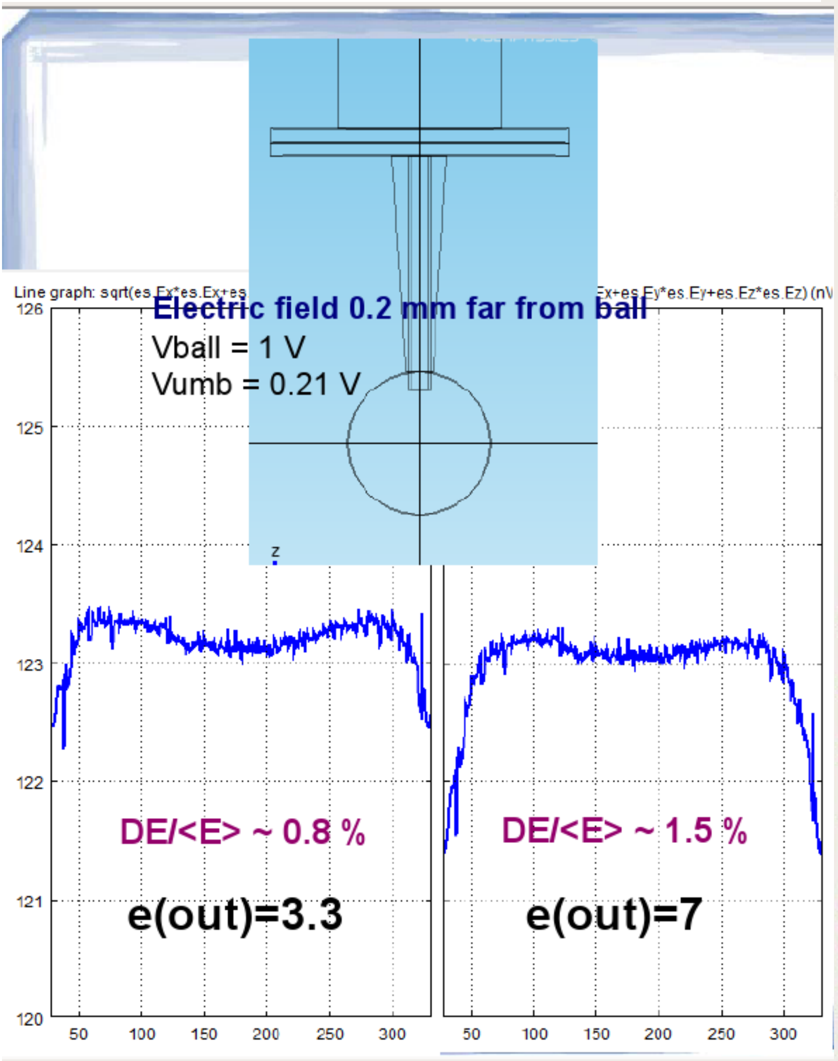


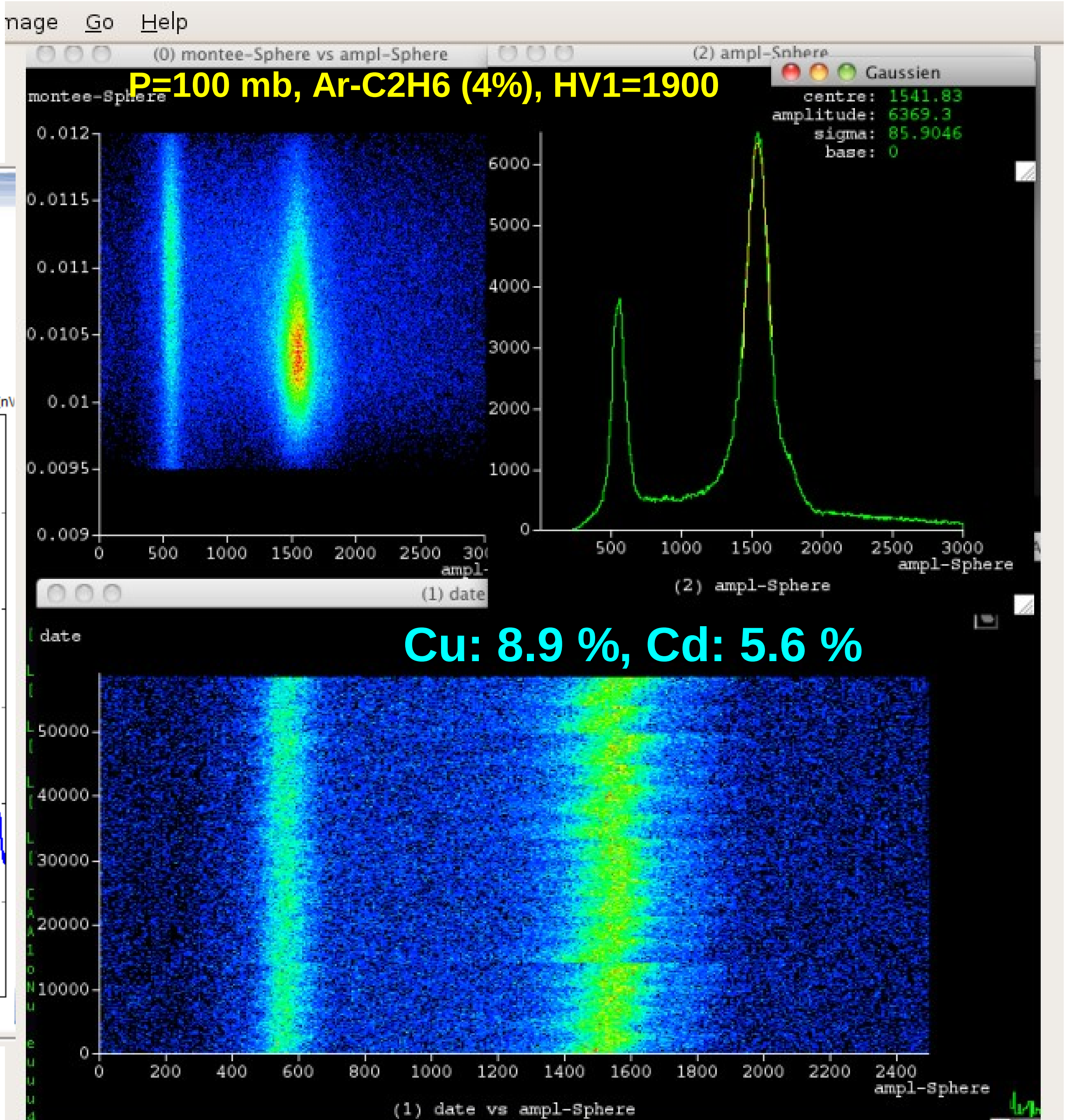
Summary

- 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
- Possible impact on Dark Matter

Back-up

Current design – preliminary tests





Using a UV flash lamp for sub-keV calibration (i)

A hydrogen flash lamp (~ 50 Hz)

MgF_2 entrance window

e^- are extracted by int. Cu vessel
$t_{drift}(R_{sphere}) = t_{signal} - t_{trigger}$

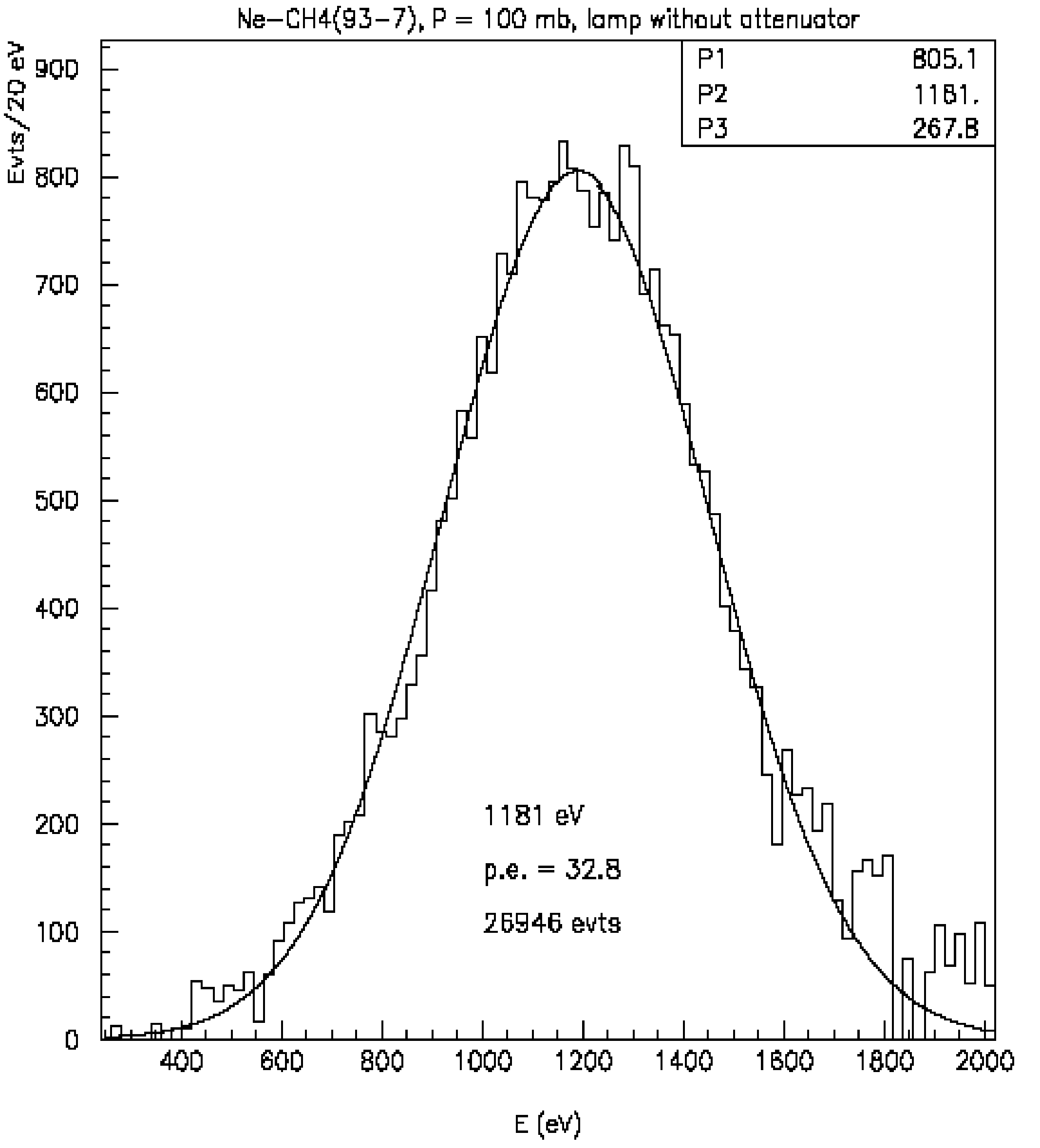
E calibration via 22 keV of Cd-109

and 8keV of Cu

Reducing UV light down to single e^-

Ne-CH_4 (7%) gas at p = 100 mbar

turnON-turnOFF==>suppress background



<u>E spectrum due to photoe⁻ extraction from Cu</u>
-No attenuator
<Nphotoe$^-$ >/ flash = 32.8

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

Using a UV flash lamp for sub-keV calibration (ii)

5 attenuators

< 3 attenuators ==> Nev ~ stable

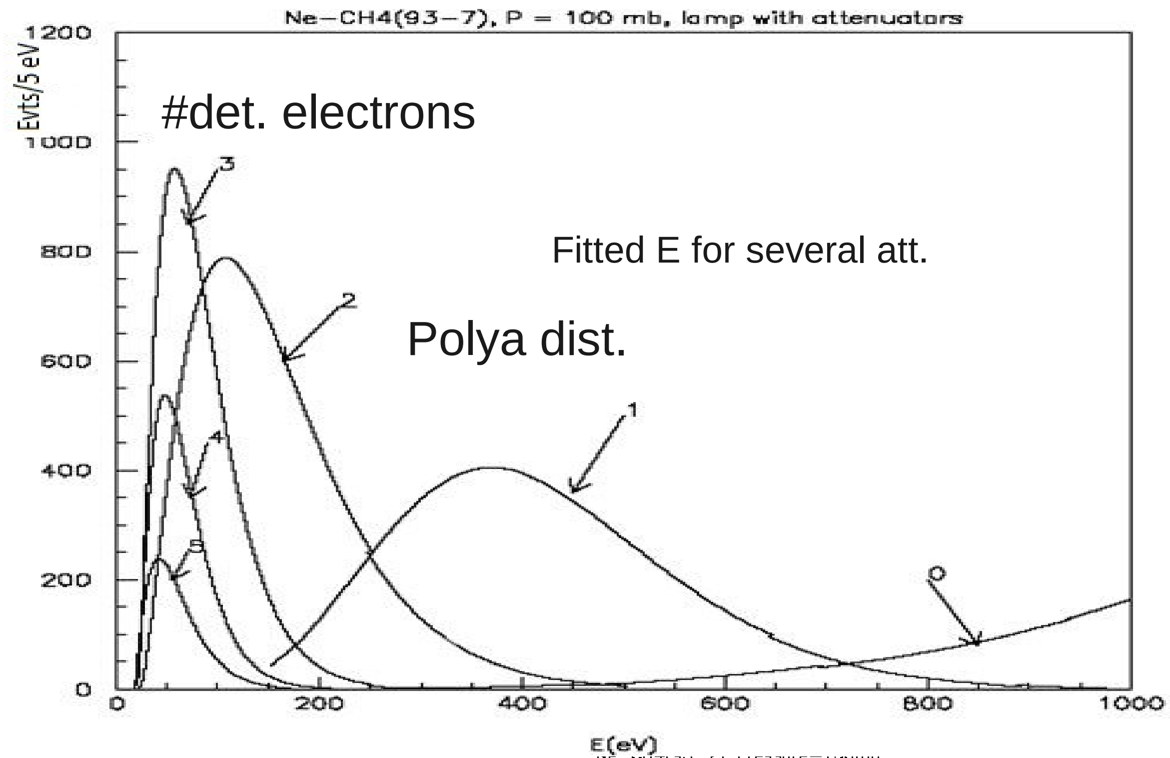
> 3 ==> P for 0 p.e. / flash ↑

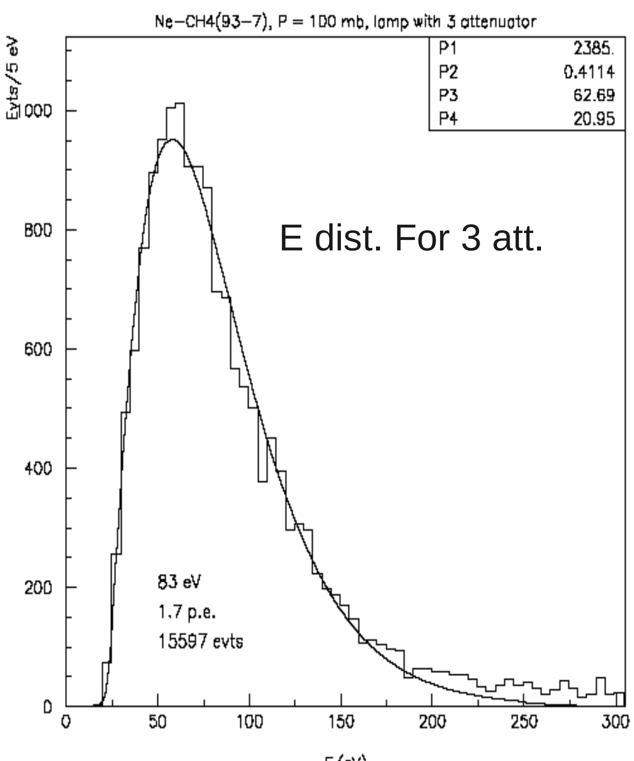
Reduction factor ~ 3

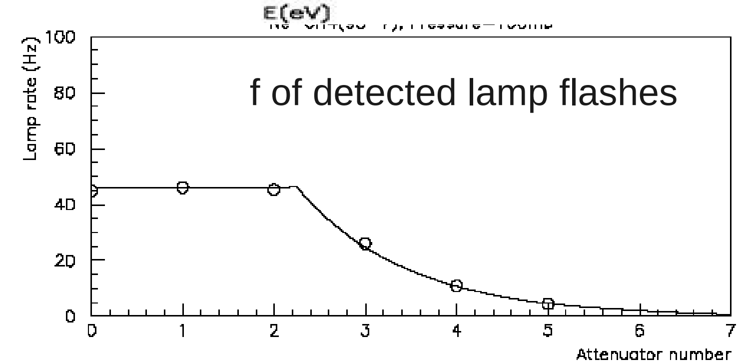
Natt >3 ==> Emean ~ const

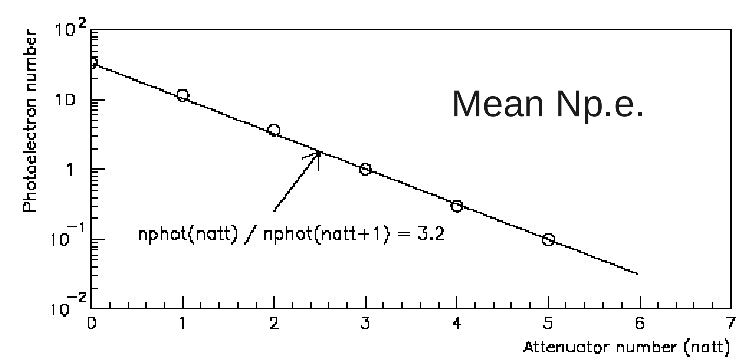
Single e- level

Thr ~ 30 eV









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

Why neutrinos?

Neutrinos:

- Travel large distances with the speed of light -with light one cannot observe further than 50 Mpc (1 Mpc=3.3×10^6 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

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?

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

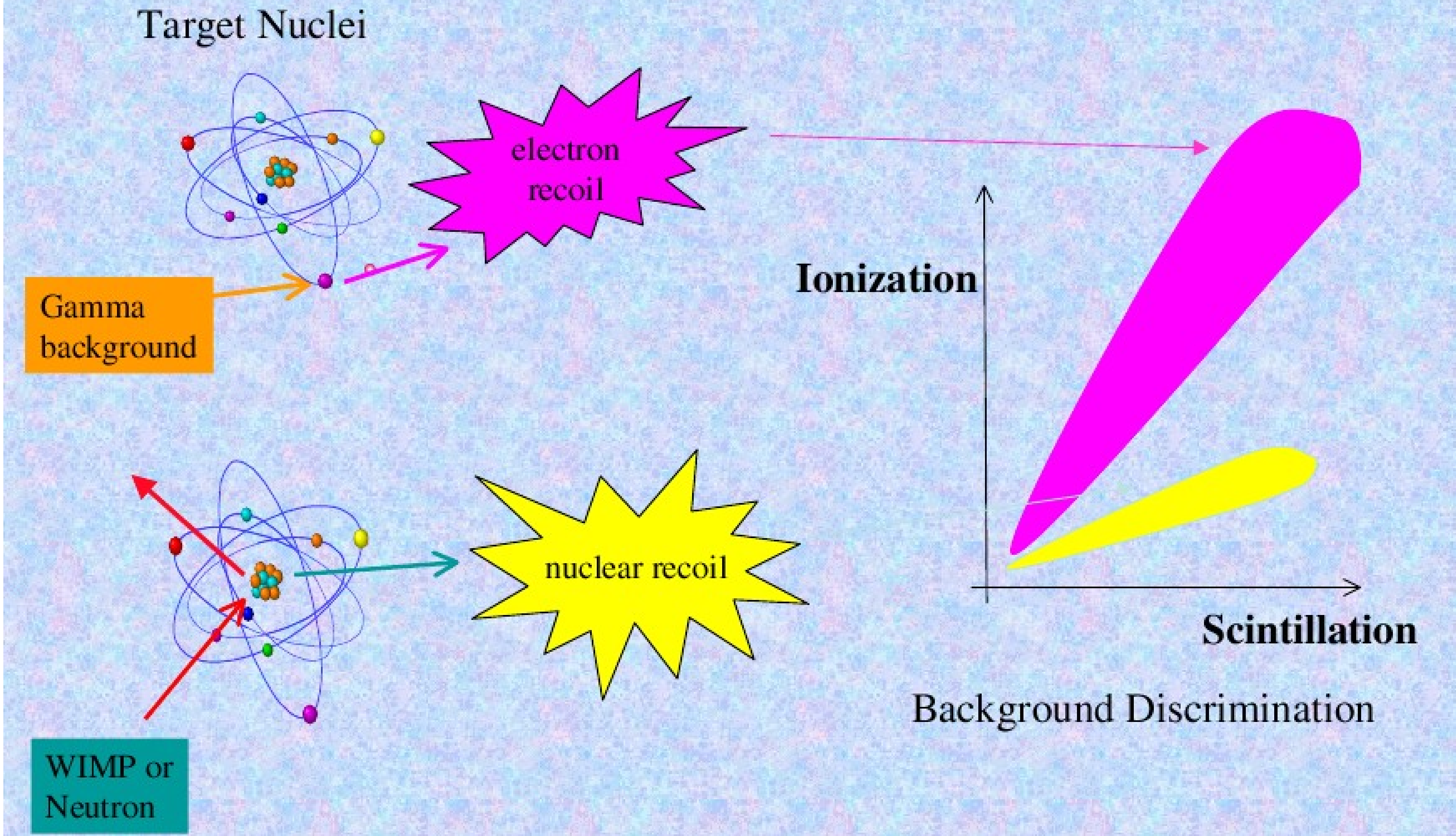
Extragalactic sensitivity ?

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

Direct Detection:

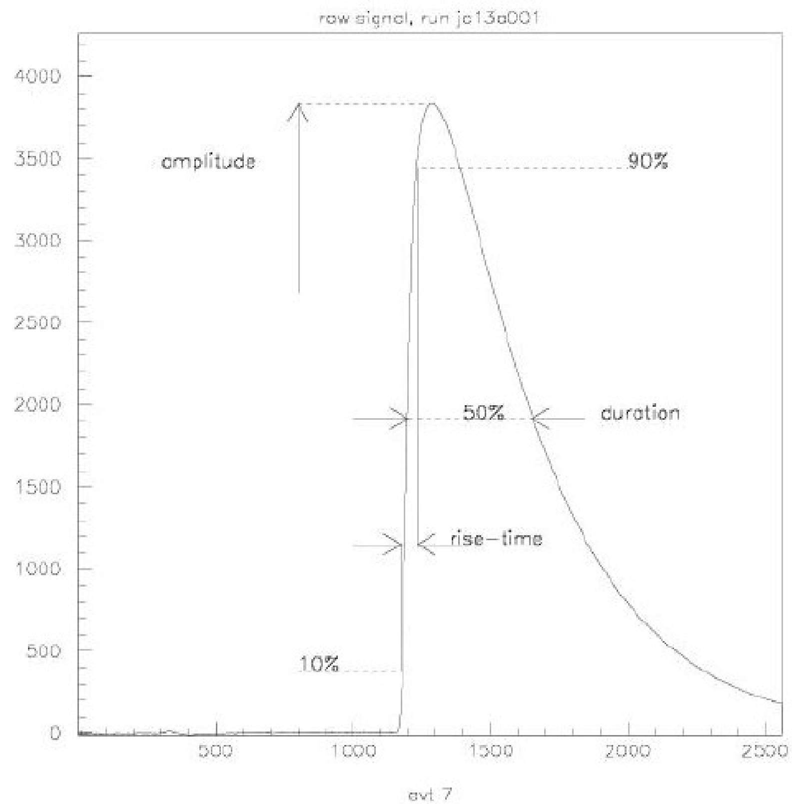
Expected Signal



Signal

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

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



Page 4 of 57 125% Quit

Signal parameters

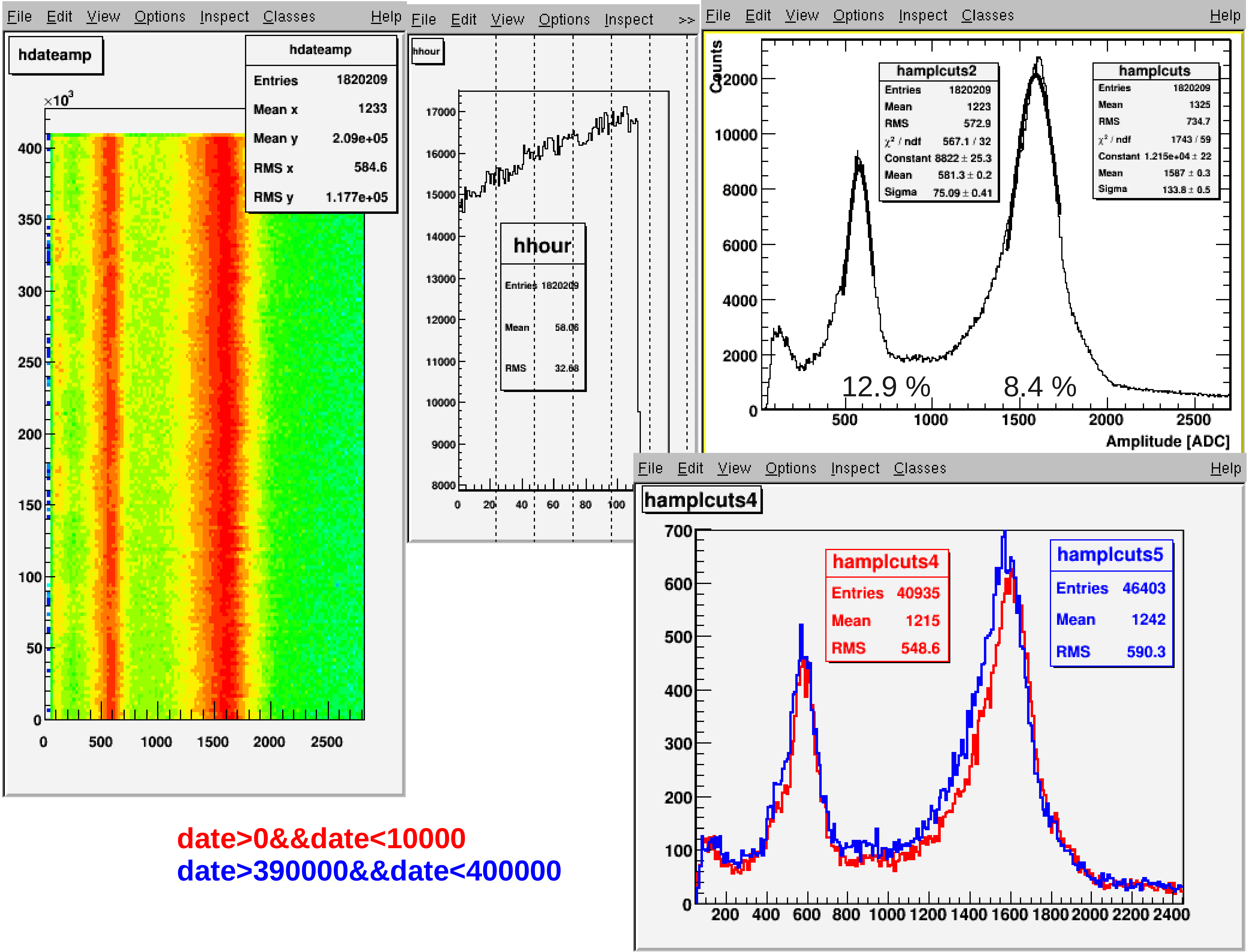
Strong correlation between
Rise-time and Duration → Fall-time :

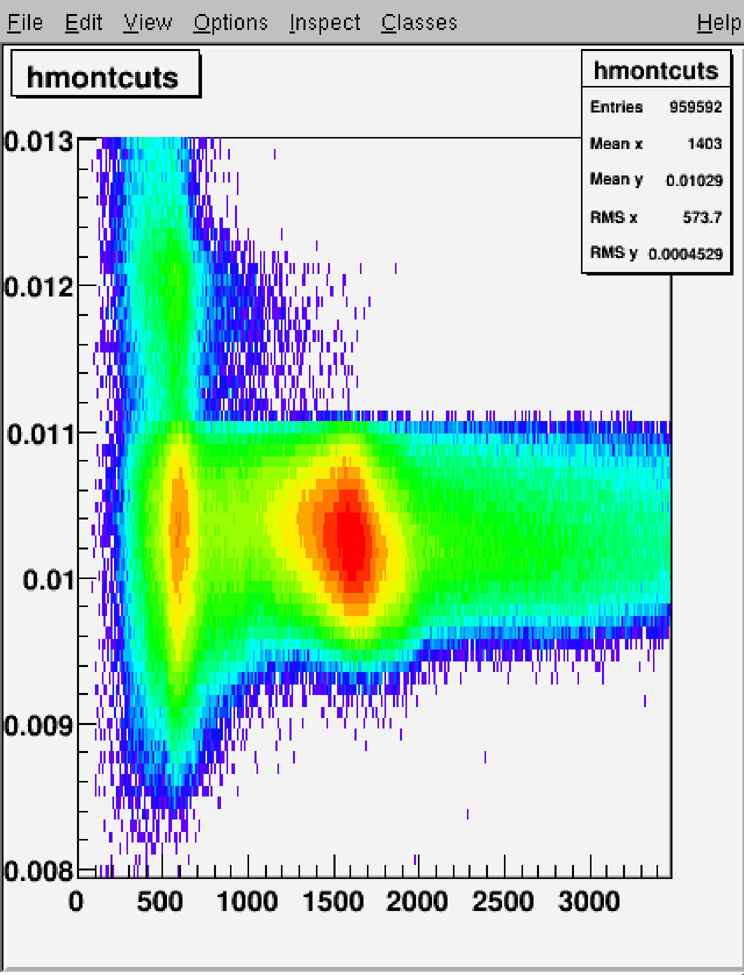
Fall-time = Duration – 0.5×Rise-time
≈ RC amplifier

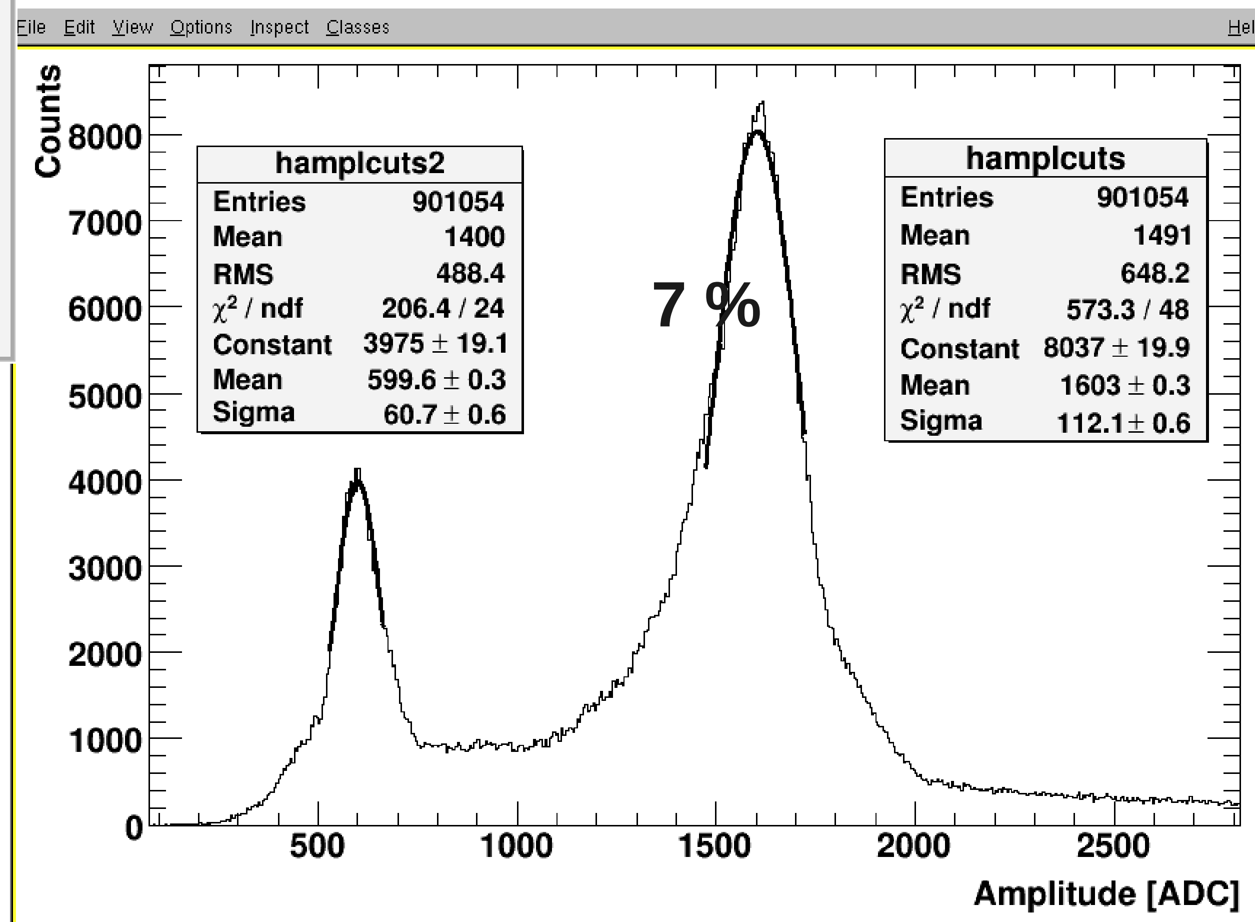
→ all physics information into biparametric plot
Amplitude versus rise-time

Run lj28_014

- p=5.7E-7 mb, Leak = 4E-8 mb/s
- P=102 mb Ar- C2H6 (~4.5%)
- HV1=1925 V,
- HV2=~100 - ~300 V ==>best resolution
- Ratio (HV1/HV2) ~ 9.6!!
- HV2=200
- Ampl=50 ADC, Tmax=0.011
- N=2039701, t=408840s ~ 4.7 days, f=5Hz


hdateamp
Entries 1820209
Mean x 1233
Mean y 2.09e+05
RMS x 584.6
RMS y 1.177e+05
hhour
Entries 1820209
Mean 58.06
RMS 32.68
hamplcuts2
Entries 1820209
Mean 1223
RMS 572.9
χ² / ndf 567.1 / 32
Constant 8822 ± 25.3
Mean 581.3 ± 0.2
Sigma 75.09 ± 0.41
hamplcuts
Entries 1820209
Mean 1325
RMS 734.7
χ² / ndf 1743 / 59
Constant 1.215e+04 ± 22
Mean 1587 ± 0.3
Sigma 133.8 ± 0.5
Counts
12.9 %
8.4 %
Amplitude [ADC]
hamplcuts4
Entries 40935
Mean 1215
RMS 548.6
hamplcuts5
Entries 46403
Mean 1242
RMS 590.3
date>0&&date<10000
date>390000&&date<400000


File Edit View Options Inspect Classes Help
hmontcuts
hmontcuts
Entries 959592
Mean x 1403
Mean y 0.01029
RMS x 573.7
RMS y 0.0004529
0.013
0.012
0.011
0.01
0.009
0.008
0 500 1000 1500 2000 2500 3000


File Edit View Options Inspect Classes Help
Counts
8000
7000
6000
5000
4000
3000
2000
1000
0
hamplcuts2
Entries 901054
Mean 1400
RMS 488.4
χ² / ndf 206.4 / 24
Constant 3975 ± 19.1
Mean 599.6 ± 0.3
Sigma 60.7 ± 0.6
7 %
hamplcuts
Entries 901054
Mean 1491
RMS 648.2
χ² / ndf 573.3 / 48
Constant 8037 ± 19.9
Mean 1603 ± 0.3
Sigma 112.1 ± 0.6
500 1000 1500 2000 2500
Amplitude [ADC]