The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

**2047-7**

**Workshop Towards the Neutrino Technologies**

***13 - 17 July 2009***

# The spherical proportional counter for measuring coherent neutrino-nucleus scattering

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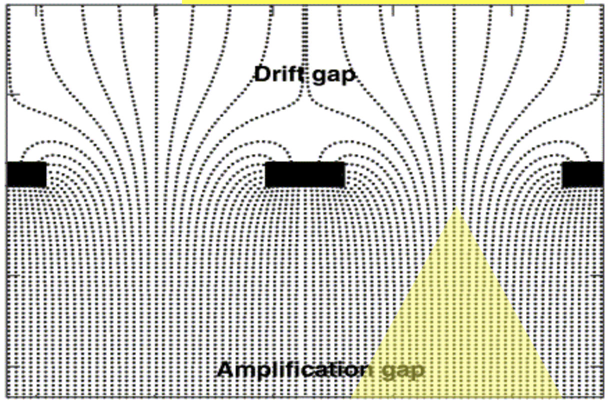
# Low energy neutrino physics with the Spherical Proportional Counter

I. Giomataris, NUTEX 2009, TRIESTE

- The new concept
- Initial motivation
- Performance
- Measuring neutrino coherent scattering
- Nuclear reactor monitoring
- Neutrinos from a spalation source
- Supernova detector

# Parallel Plate Detector

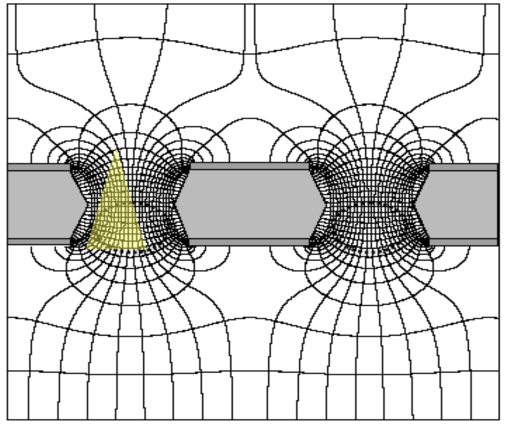
## Micromegas

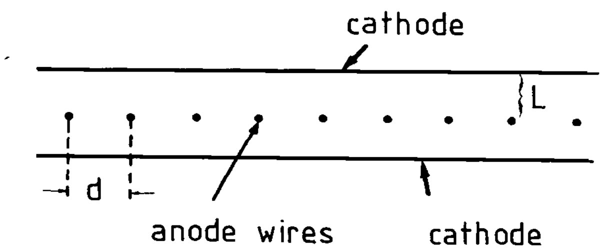



**E= constant**

**C ≈ S > 1nF**

## GEM

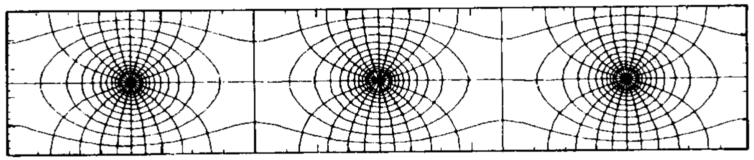


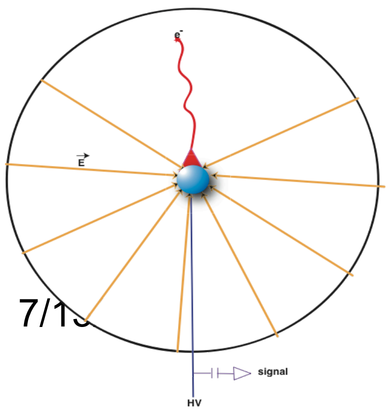



## MPWC

$E=1/r$

$C \approx$ **L>10 pF**

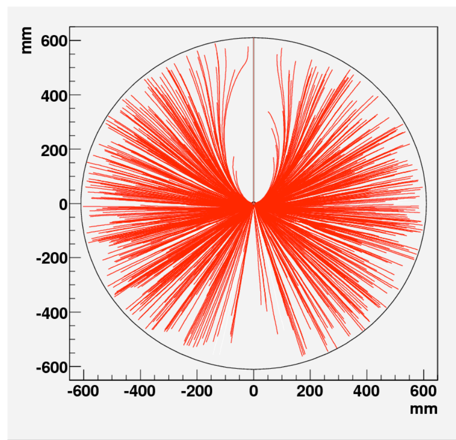





## Spherical Proportional Counter

$\mathbf{E=1/r^2}$

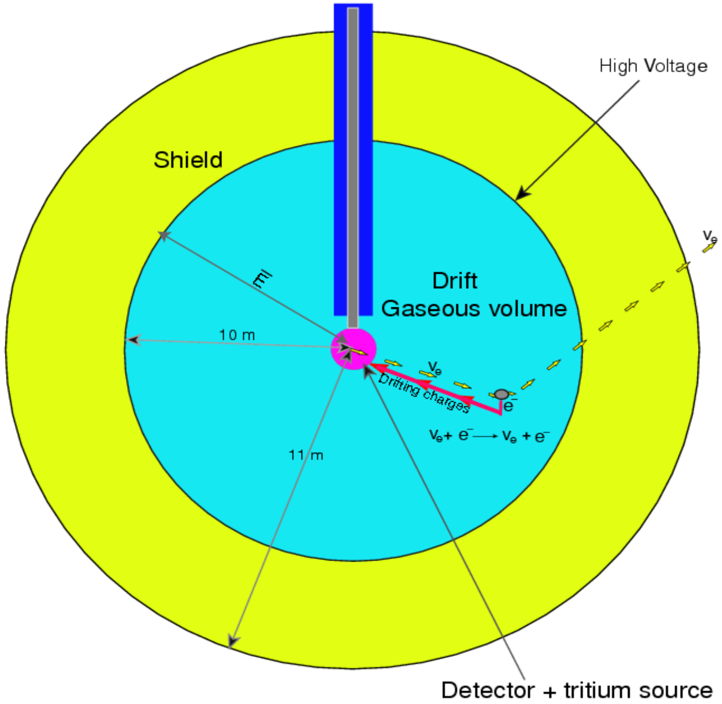
$\mathbf{C \approx R_{in} < .1pF}$



# Idea of a spherical detector

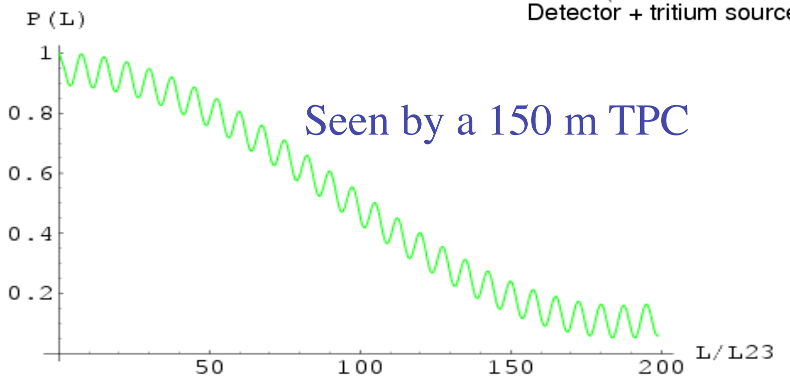
# Low energy neutrino search

I. Giomataris, J.D. Vergados, Nucl.Instrum.Meth.A530:330-358,2004,




- **Large Spherical TPC 10 m radius**
- **200 MCi tritium source in the center**
- **Neutrinos oscillate inside detector volume $L_{23}$=13 m**

$$P(\nu_e \rightarrow \nu_{\mu,\tau}) = \sin^2 2\theta_{13} \sin^2 \pi \frac{L}{L_{23}}$$

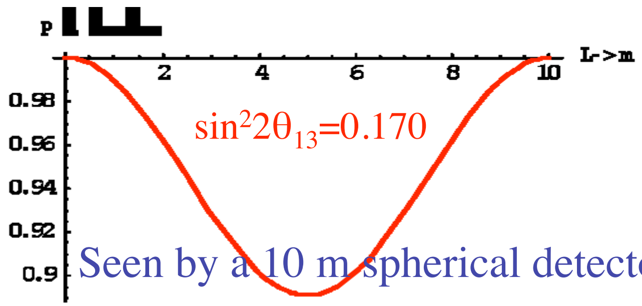



Seen by a 150 m TPC

**Objectives**

- **Measure $\theta_{13}$ (systematic free)**
- **Neutrino magnetic moment studies << $10^{-12}$ $\mu_B$**
- **Measurement of the Weinberg angle at low energy**

## Room size oscillations




Seen by a 10 m spherical detector

Challenge :

Detect electron recoils down to T=100 eV ($T_{max}$=1.27 eV)
Low background level (to be measured and subtracted)
Measure the radial depth of the interaction

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# Other low energy neutrino sources

- Difficult to accumulate 20 kg (220 MCurie) of triton.
- Other very low energy neutrino sources may have to be considered
- Electron capture monochromatic sources are preferred.

## Mono-energetic Neutrinos

*Y. Giomataris, N. Novikov, J.D. Vergados*

**Some candidates are:**

**A=157 (Tb), $T_{1/2}$ = 70 y, $E_\nu$=9.8 keV, $L_0$=4.9 m**

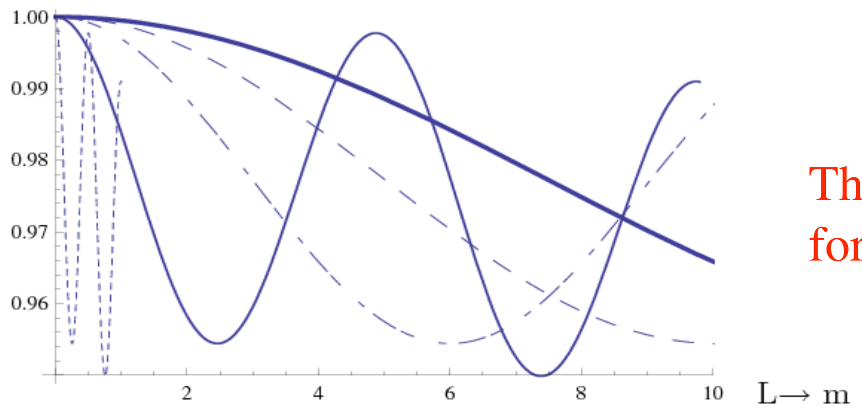
**A=163 (Ho), $T_{1/2}$ =4500, $E_\nu$ =0.5-2.6 keV, $L_0$=0.3-1.6 m**

**A=193 (Pt), $T_{1/2}$ =56.8y, $E_\nu$ =43.8 keV, $L_0$=21 m**

**A=178 (W), $T_{1/2}$=21.6d, $E_\nu$ =24 keV, $L_0$=12 m**

**A=194 (Hg), $T_{1/2}$ =440y, $E_\nu$ =55 keV, $L_0$=27 m**

**A=202 (Pb), $T_{1/2}$ =5x10$^4$ y, $E_\nu$ =35 keV, $L_0$=17 m**



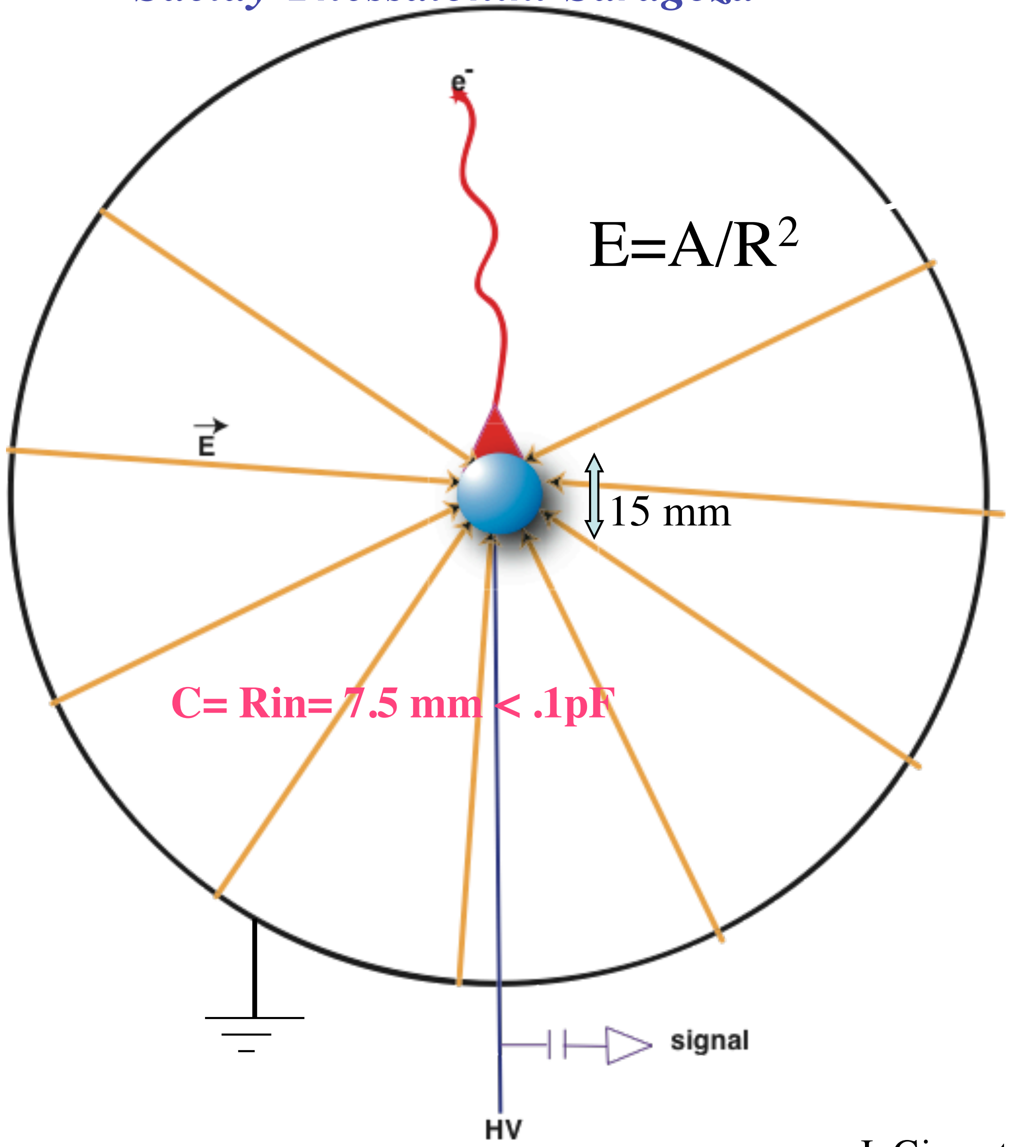

The oscillation profile for various targets

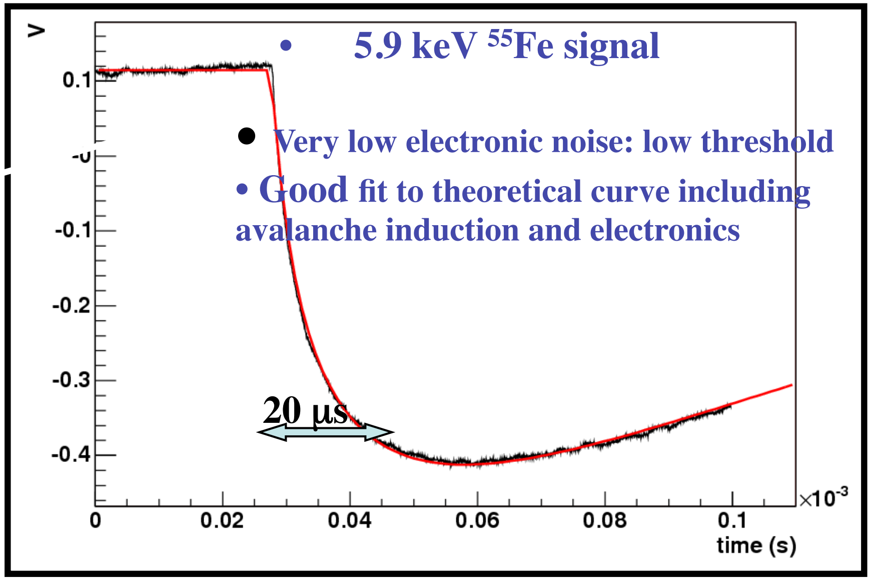
Fig. 3.4. The electron neutrino disappearance oscillation probabilities at short distances are plotted, assuming $\sin^2(2\theta_{13}) = 0.045$, for the sources considered in this work. The disappearance dip, is tiny, independently of the source, since $\sin^2(2\theta_{13})$ is small. We find $L_0 = L_{23} = 4.9, 0.4, 12, 22, 30, 20$ m associated with neutrino energies $E_{nu} = 9.8, 1.0, 23.9, 49, 60, 40$ MeV of the sources $^{157}$Tb, $^{163}$Ho, $^{178}$W, $^{193}$Pt, $^{194}$Hg, $^{202}$Pb respectively.

# Radial TPC with spherical proportional counter read-out

*Saclay-Thessaloniki-Saragoza*

**A Novel large-volume Spherical Detector with Proportional Amplification read-out,** I. Giomataris *et al. Jul 2008. 12pp, e-Print: arXiv:0807.2802 [physics.ins-det]*




- Simple and cheap
- single read-out
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut

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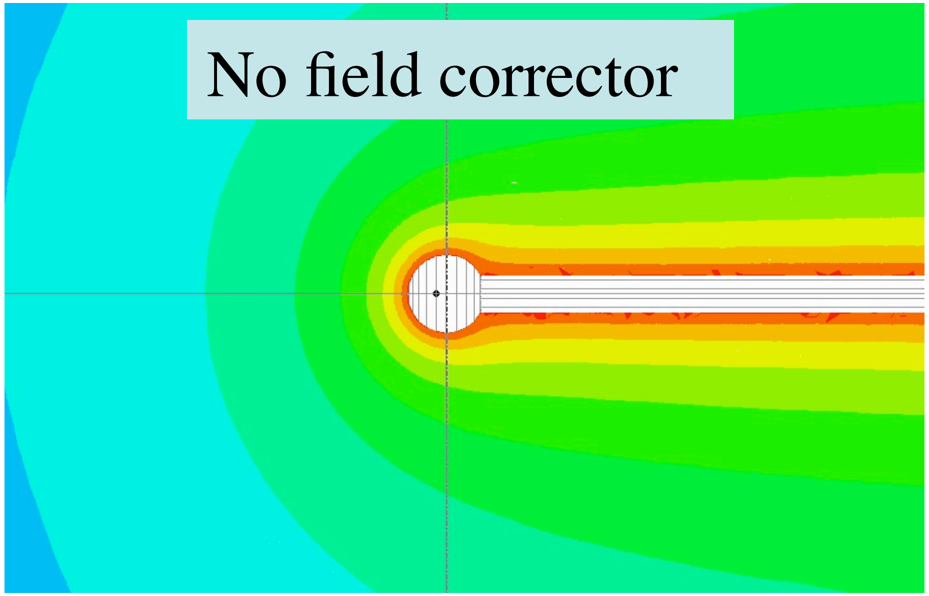
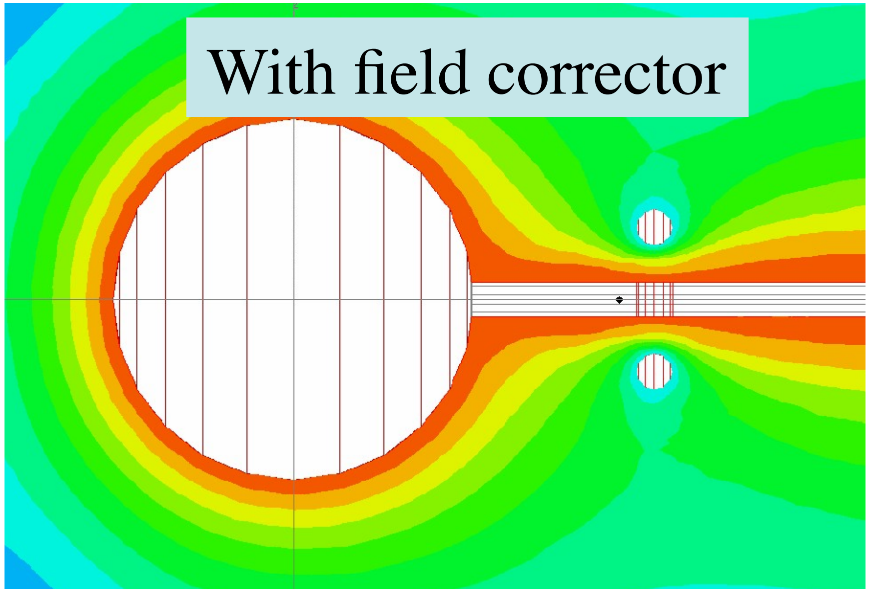
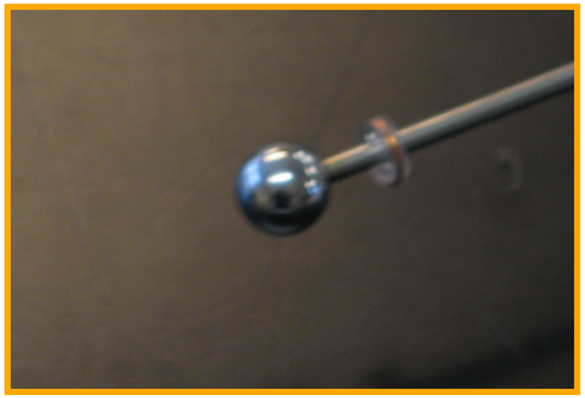
# Electrostatics deal

# How to keep radial field

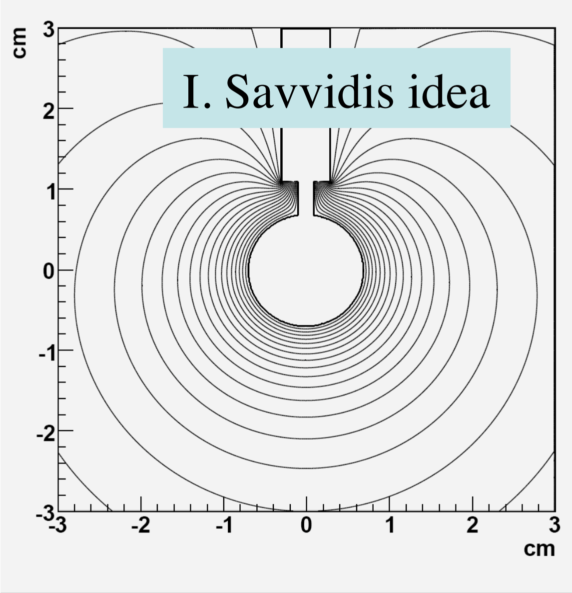
**Ideal solution: field $1/R^2$ degrador around the wire**

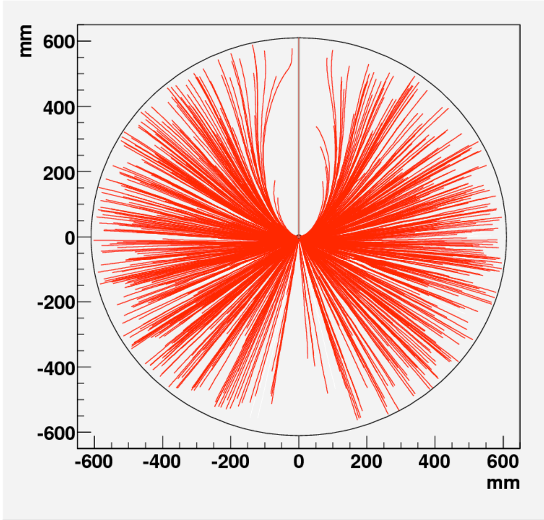


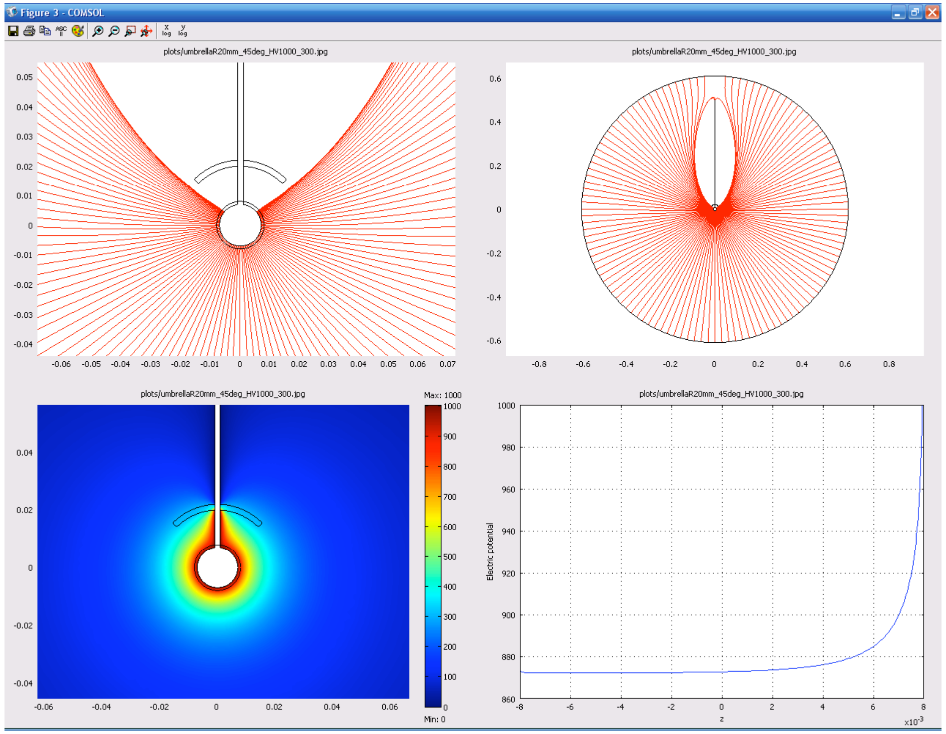



# A simple electrostatic solution





New idea by I. Giomataris and I. Irastorza, combines also second voltage corrector: "umbrella field corrector", big improvement in stability

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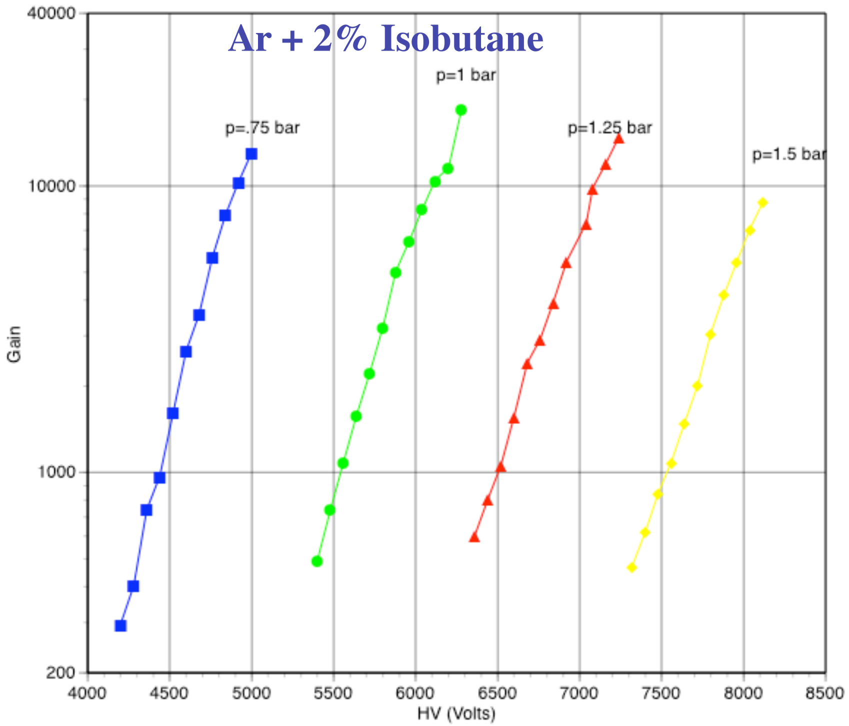
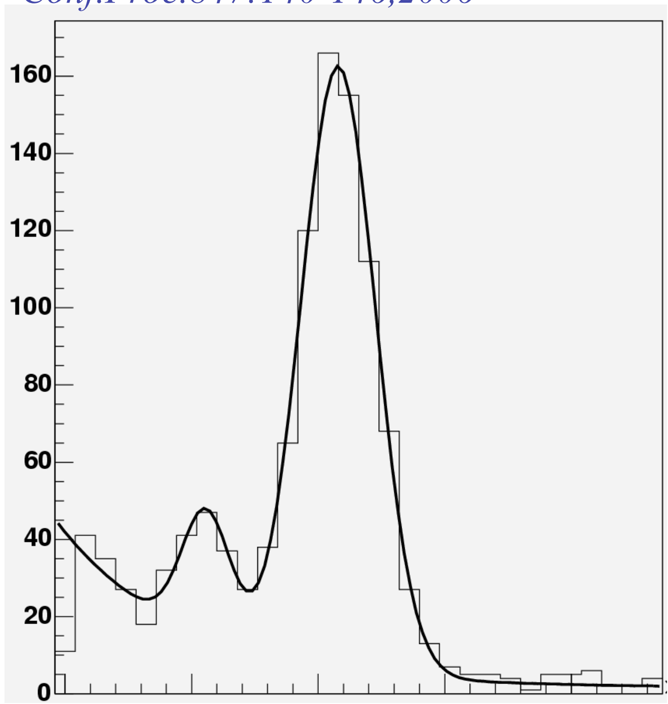
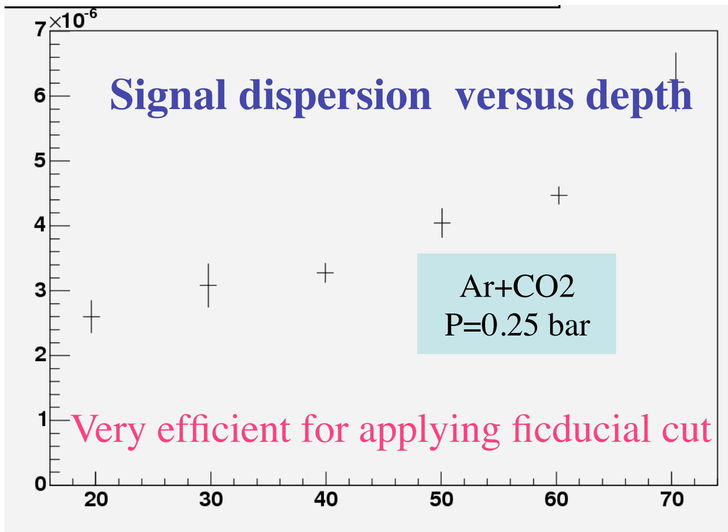
# Early experimental results

*S. Aune et al., AIP Conf.Proc.785:110-118,2005.*
*I. Giomataris et al.,Nucl.Phys.Proc.Suppl.150:208-213,2006.*
*I. Giomataris and J. D . Vergados, AIP Conf.Proc.847:140-146,2006*




- Good stability.
- Detector working in sealed mode
- No absorption observed
- Signal integrity preserved after 60 cm drift.
- Not high E needed to achieve high gain.

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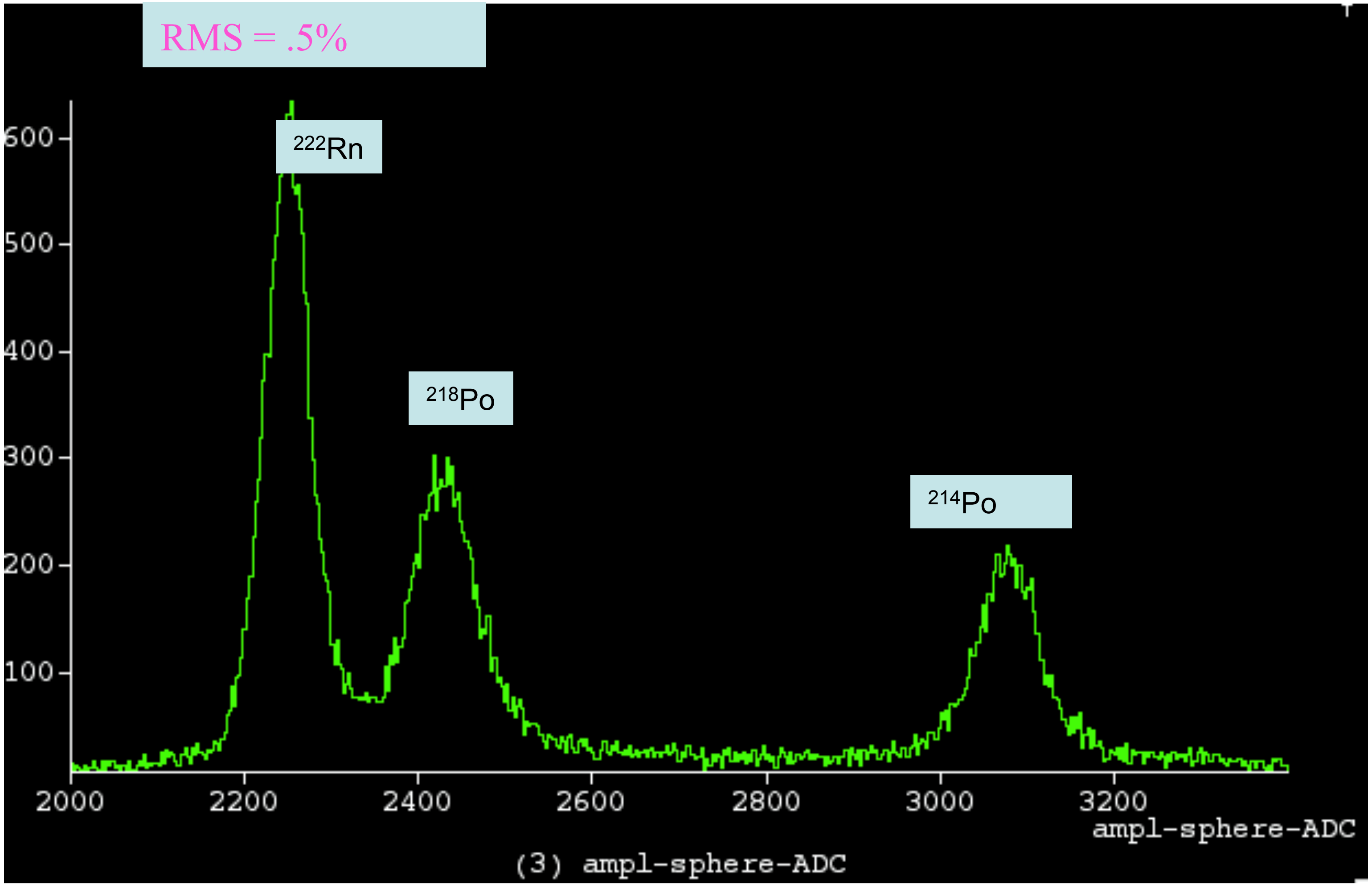
# At high energy : Excellent energy resolution

Measured Radon gas emission spectrum with spherical detector




**Energy resolution under amplification: a world record !!**

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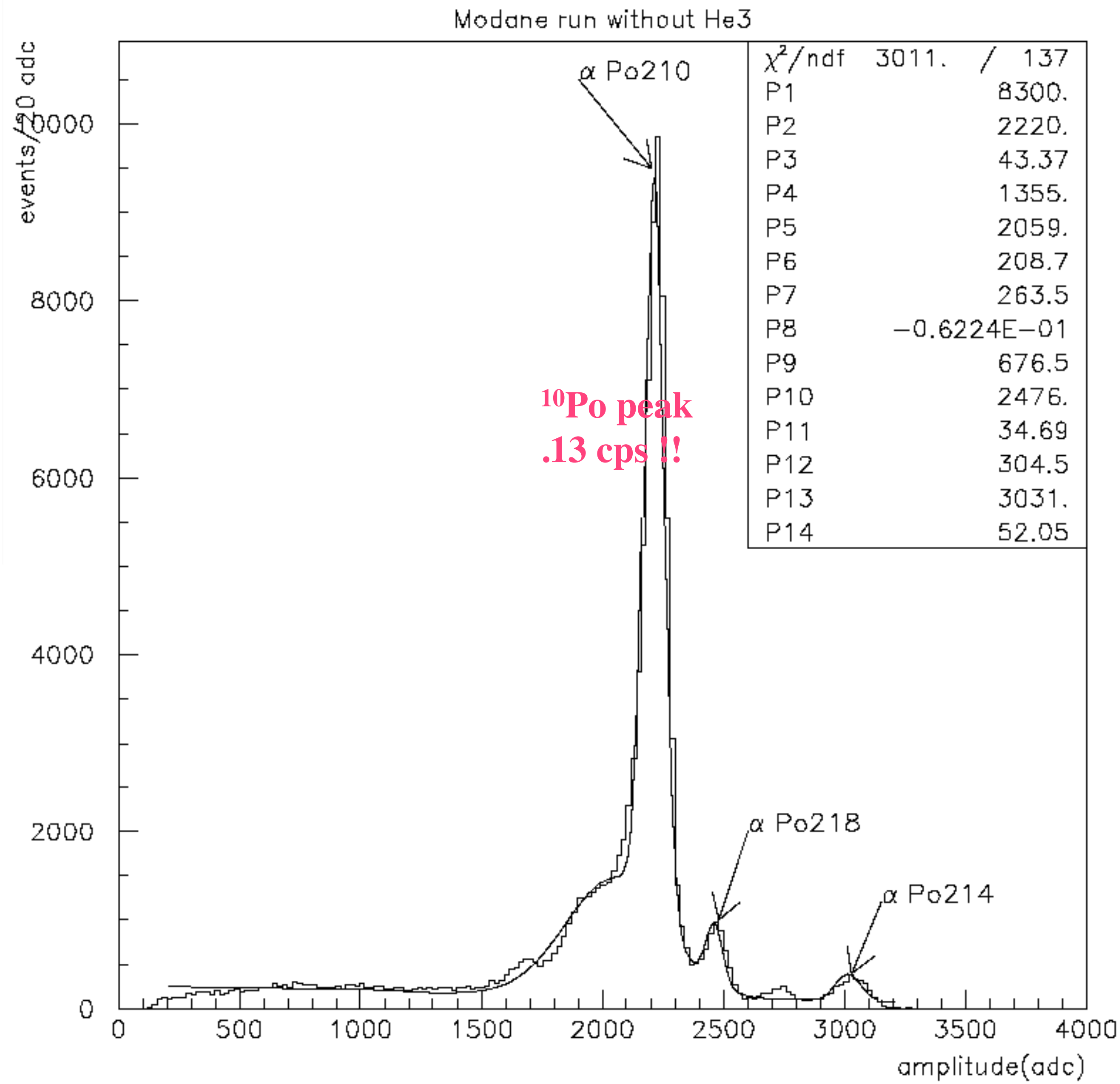
# LSM-Modane, same sphere, same gas, without He-3

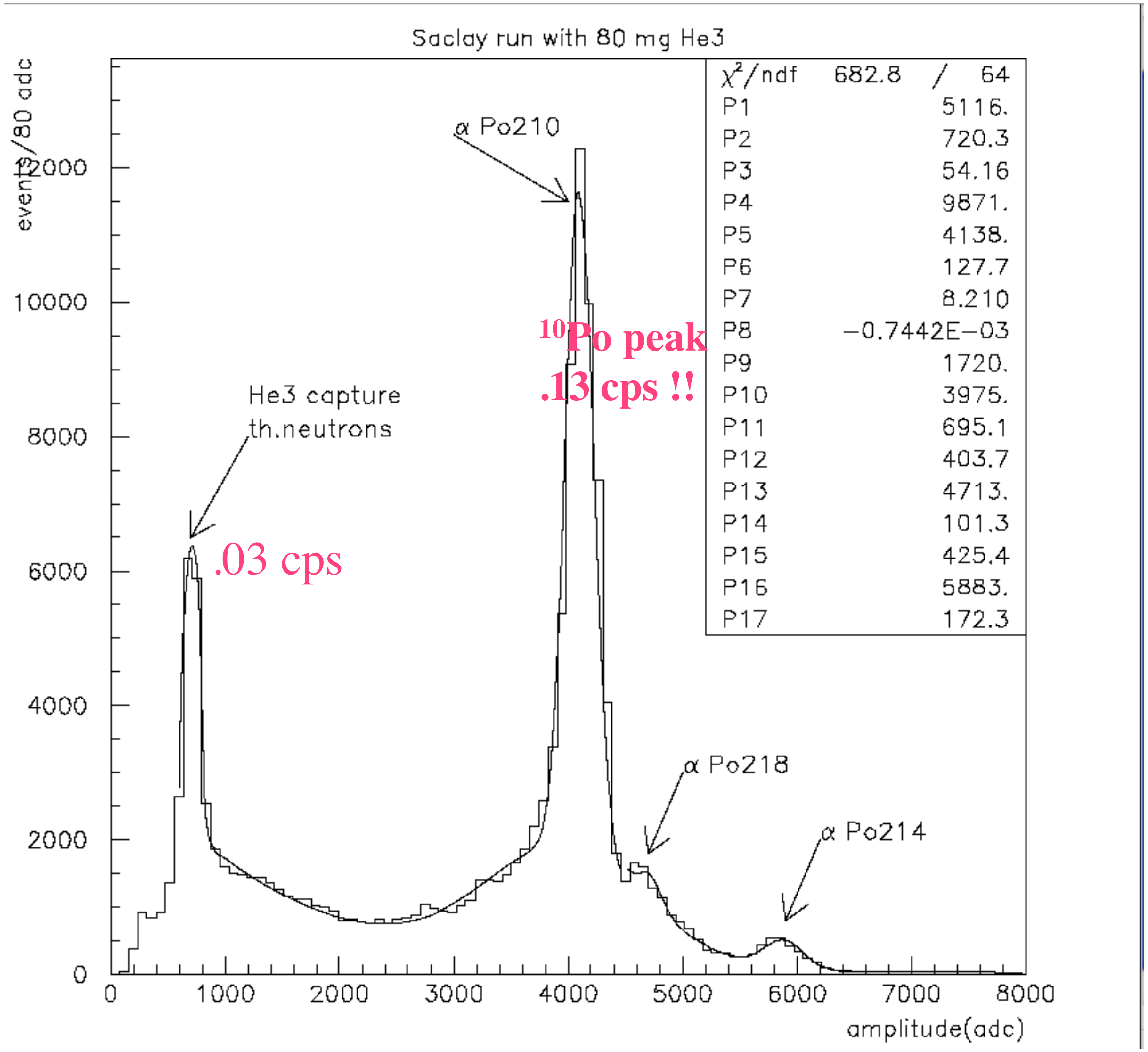


# Neutron energy and flux measurement

$^{3}He + n \longrightarrow {}^{1}H + {}^{3}H$ (Q= 765 keV)

## Results at ground

## Saclay Ar-CH4(98-2)+80mg He3



# In 2008
# Detector installed in LSM laboratory

*goal: measure thermal neutron background*
*and estimate fast neutron flux*

***with 10 gr $^{3}He$***

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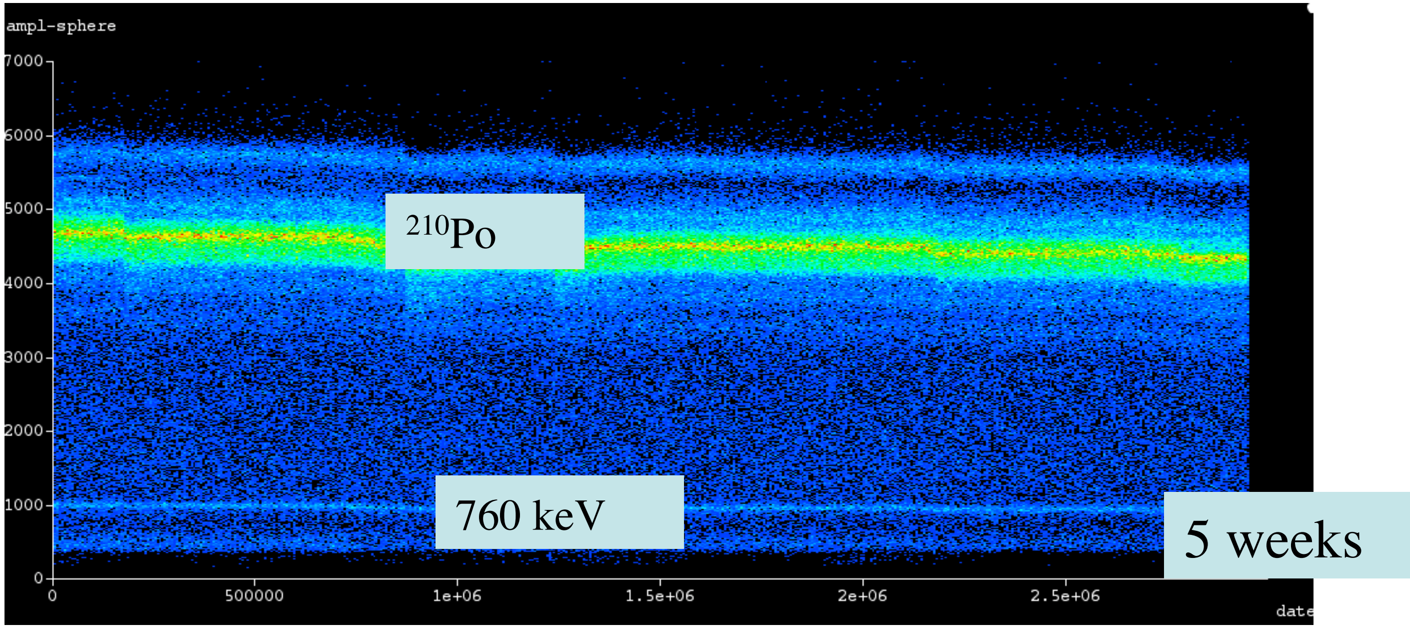
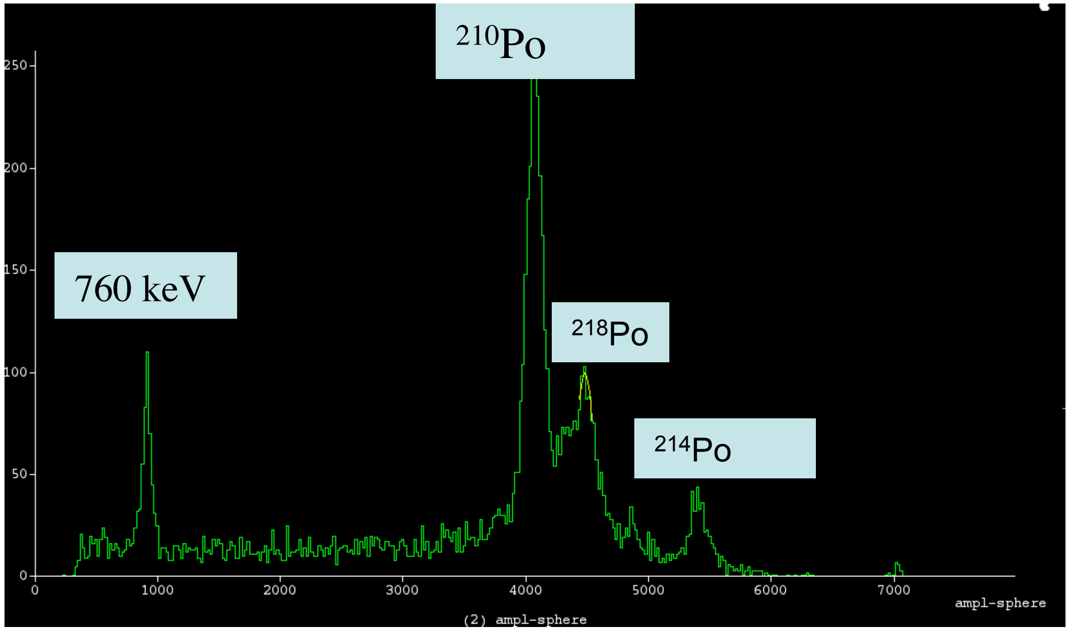
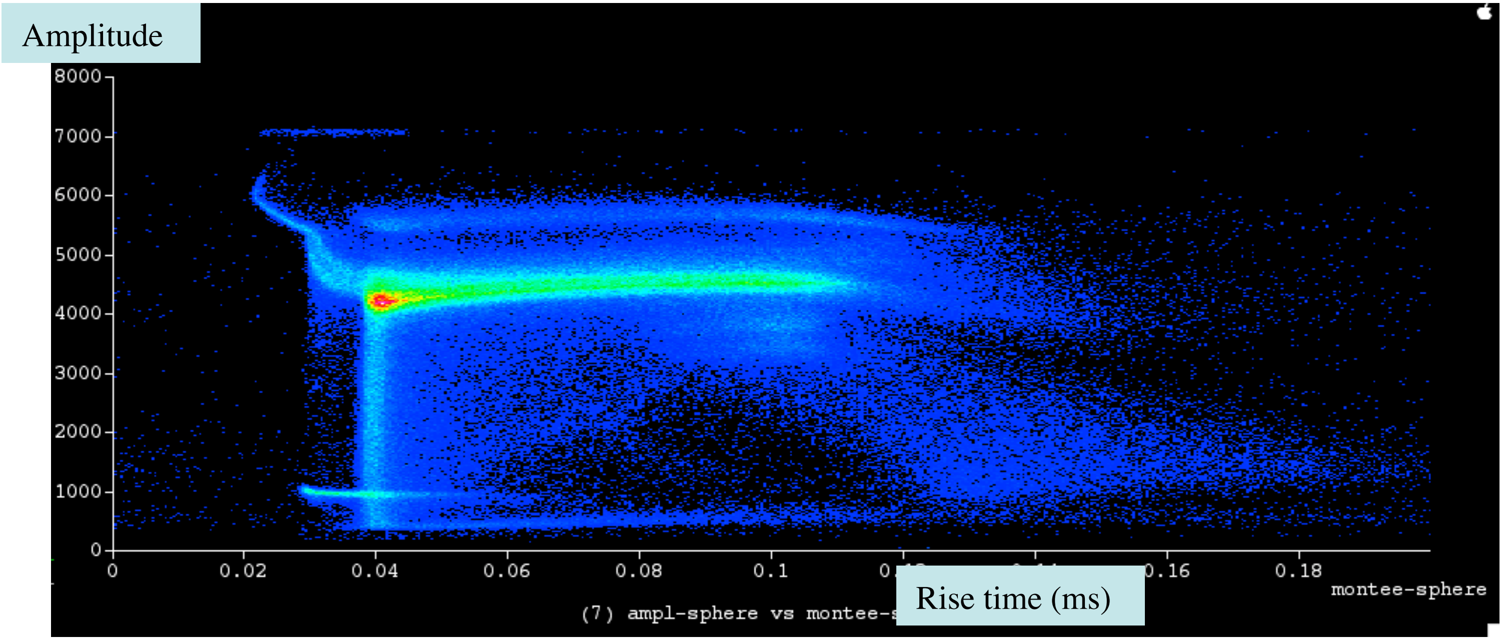
# 3 g of $^3$He have been introduced on June 30

**Detector is stable operating in seal mode**

**Gas Ar +2% CH4 at p=280 mbar**






**Thermal neutron peak after rise time cut**

**Great background rejection !!!**

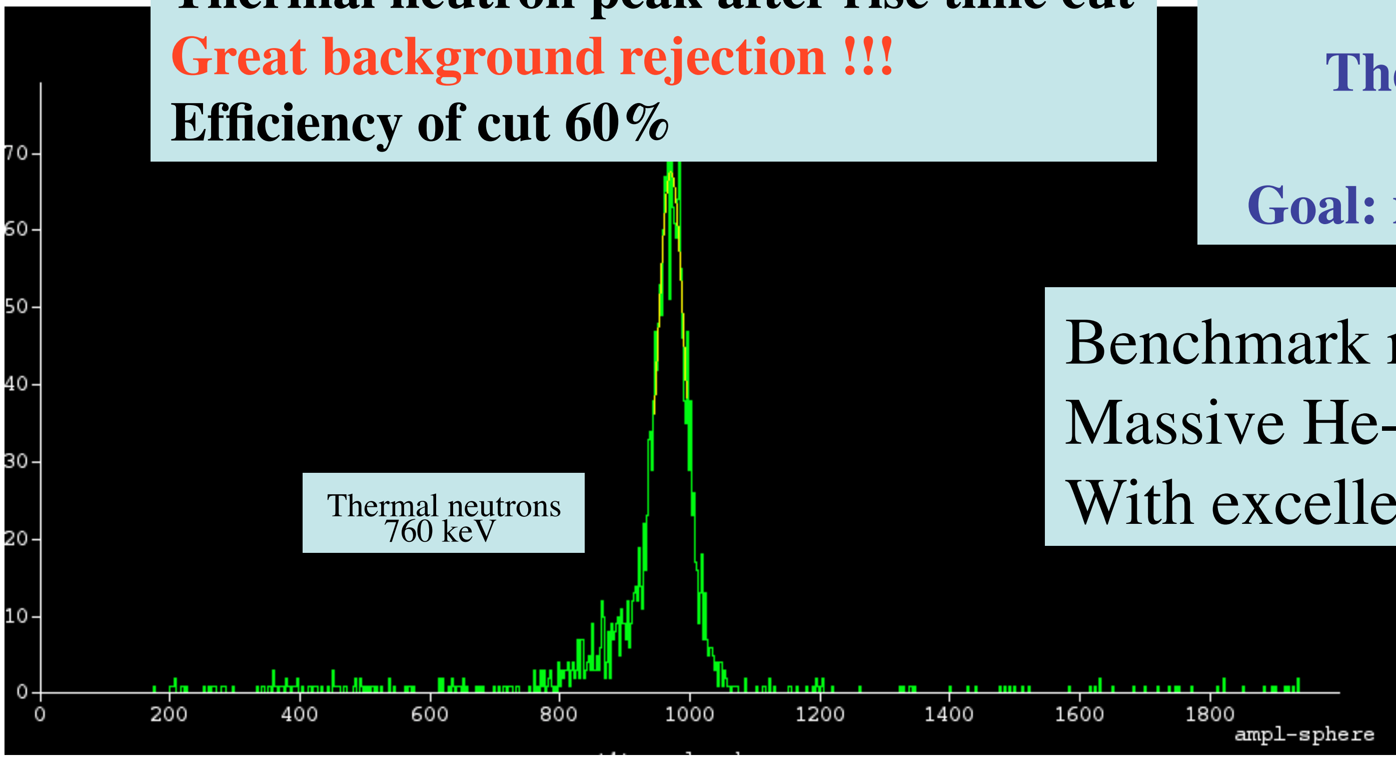
**Efficiency of cut 60%**

**Results in LSM**

**Thermal neutron flux**

**$2x10^{-6}/cm^2/s$**

**Goal: measure fast neutrons**




Benchmark result:

Massive He-3 detector,

With excellent background level

# Neutrino-nucleus coherent elastic scattering

$\nu + N \dashrightarrow \nu + N$

$\sigma \approx N^2 E^2$, *D. Z. Freedman, Phys. Rev.D,9(1389)1974*

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

*A. Druikier, L. Stodolsky, Phys.Rev.D30:2295,1984*

*JI Collar, Y Giomataris - NIMA*471:254-259,2000

*H. T. Wong, arXiv:0803.0033-2008*

*PS Barbeau, JI **Collar**, O Tench - Arxiv preprint nucl-ex/0701012, 2007*

# Nuclear reactor measurement with present prototype

**At 10 m from the reactor, after 1 year run ($2x10^7$s), assuming full detector efficiency:**

- Xe ($\sigma \approx 2.16x10^{-40}$ $cm^2$), $2.2x10^6$ neutrinos detected, $T_{max}$=146 eV
- Ar ($\sigma \approx 1.7x10^{-41}$ $cm^2$), $9x10^4$ neutrinos detected, $T_{max}$=480 eV
- Ne ($\sigma \approx 7.8x10^{-42}$ $cm^2$), $1.87x10^4$ neutrinos detected, $T_{max}$=960 eV

**Challenge : Very low energy threshold**

**We need to calculate and measure the quenching factor**
**Application : Remote control of nuclear reactors**
**Background must be kept as low as possible**

# 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 $\nu_e$ (QF, no Thr) | anti $\nu_e$ (QF ) Thr = 1 electron | anti $\nu_e$ (QF ) Thr = 2 electron |
|---|---|---|---|
| Xe | 2325 | **825** | **275** |
| Ar | 430 | **292** | **210** |

**This a considerable signal**
**Argon is a good candidate**
**But we need to build a new detector with appropriate shield**
**Background at 1 electron level?**

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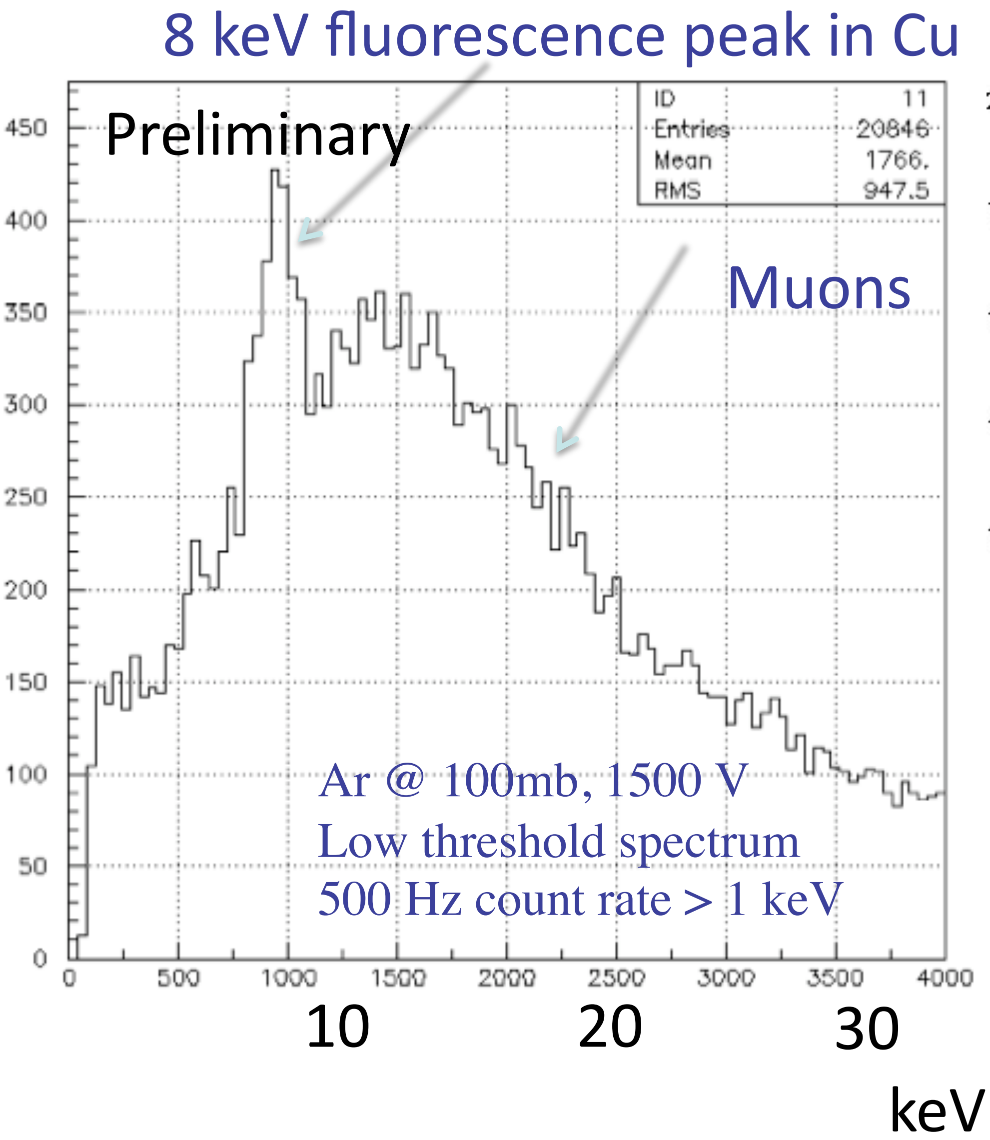
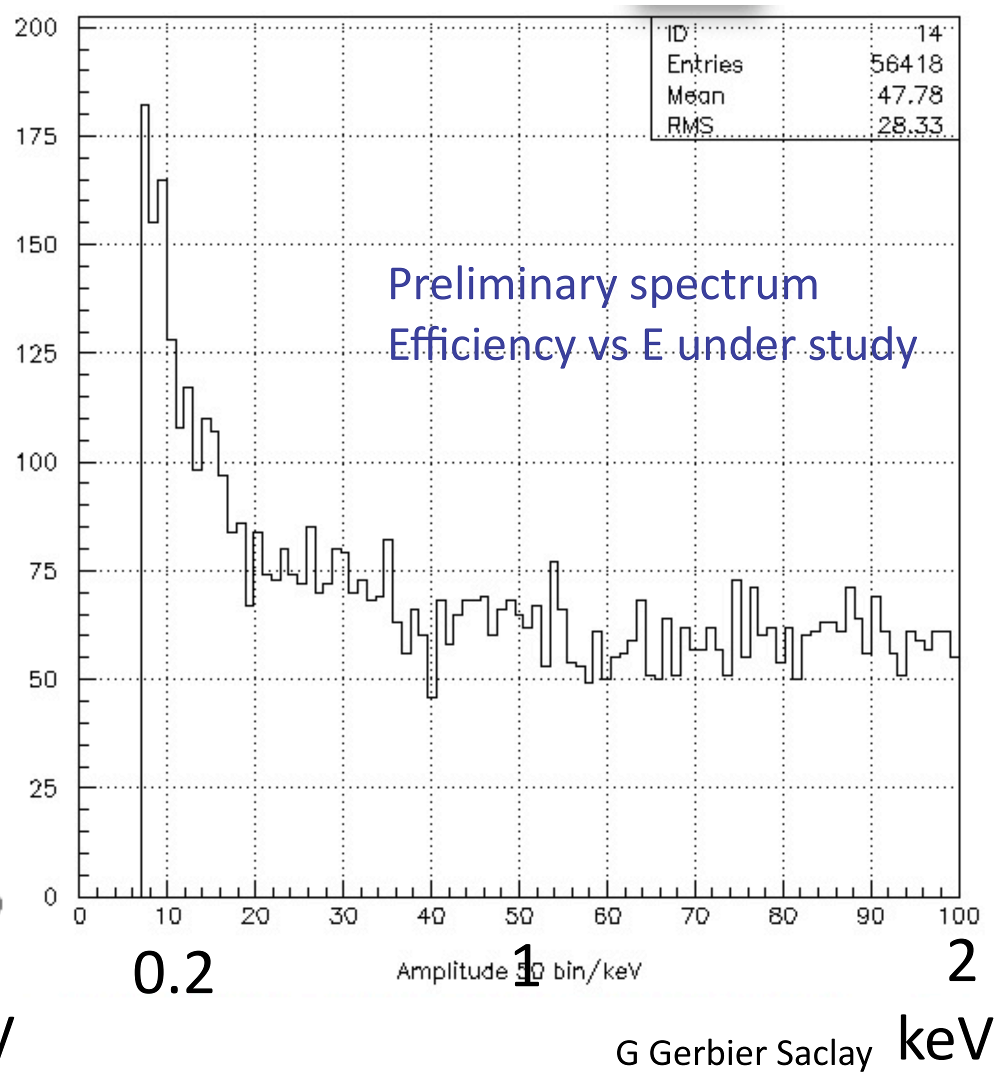
# Run at low threshold with Saclay SPC

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# How to get simple and cheap Supernova counter

## Neutrino-nucleus coherent elastic scattering

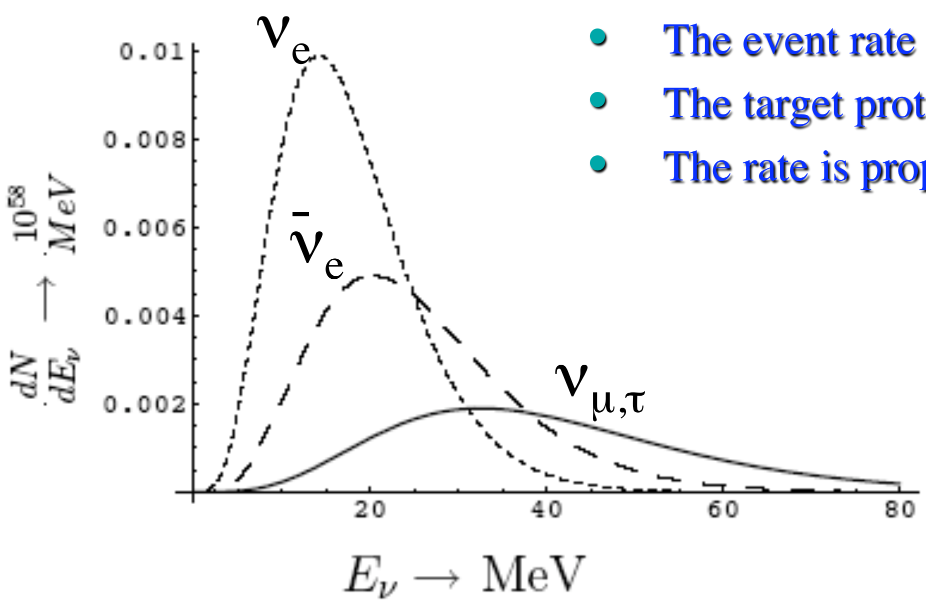
## Supernova neutrino detection with a 4 m spherical detector

*Y. Giomataris, J. D. Vergados, Phys.Lett.B634:23-29,2006*

For $E_\nu$ = 10 MeV $\sigma \approx N^2E^2 \approx 2.5\mathrm{x}10^{-39}$ cm$^2$, $T_{max}$ = 1.500 keV

For $E_\nu$ = 25 MeV $\sigma \approx 1.5\mathrm{x}10^{-38}$ cm$^2$, $T_{max}$ = 9 keV

Expected signal : about 500 events (Xenon at p=10 bar) per galactic explosion




## Advantages of a Neutral Current Detector

- All neutrinos contribute
- The event rate is not affected by neutrino oscillations
- The target proton contribution is negligible, but all neutrons contribute
- The rate is proportional to $N^2$

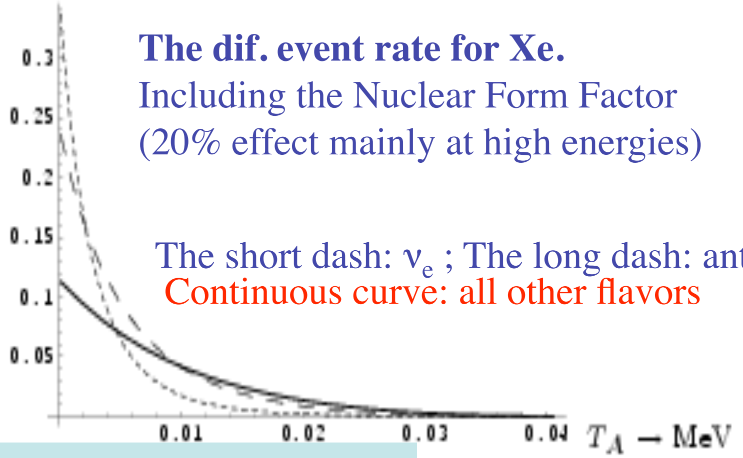
# Supernova detection sensitivity

The average nuclear recoil energy is:

| | He | Ne | Ar | Kr | Xe | |
|---|---|---|---|---|---|---|
| $<E_r>$: | 0.576 | 0.117 | 0.058 | 0.029 | 0.017 | MeV |

The threshold neutrino energy (for nuclear recoil energy $E_{th}$=250 eV) is

| | He | Ne | Ar | Kr | Xe | |
|---|---|---|---|---|---|---|
| $(E_\nu)_{th}$ | 0.70 | 1.58 | 2.24 | 3.16 | 4.05 | MeV |




**The dif. event rate for Xe.**
Including the Nuclear Form Factor
(20% effect mainly at high energies)

The short dash: $\nu_e$ ; The long dash: anti- $\nu_e$ ;
Continuous curve: all other flavors

## Sensitivity for galactic explosion

**For p=10 Atm, R=4m, D=10 kpc, $U_\nu$ =0.5x10$^{53}$ ergs**

**# Number of events** (no quenching, zero threshold)

| He | Ne | Ar | Kr | Xe | Xe (with Nuc. F.F) |
|---|---|---|---|---|---|
| 1.25 | 31.6 | 153 | 614 | 1880 | 1435 |

**# Number of events** (after quenching, $E_{th}$ =0.1 keV)

| He | Ne | Ar | Kr | Xe | Xe (with Nuc. F.F) |
|---|---|---|---|---|---|
| 0.61 | 12.0 | 53.5 | 190 | 545 | **415** |

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

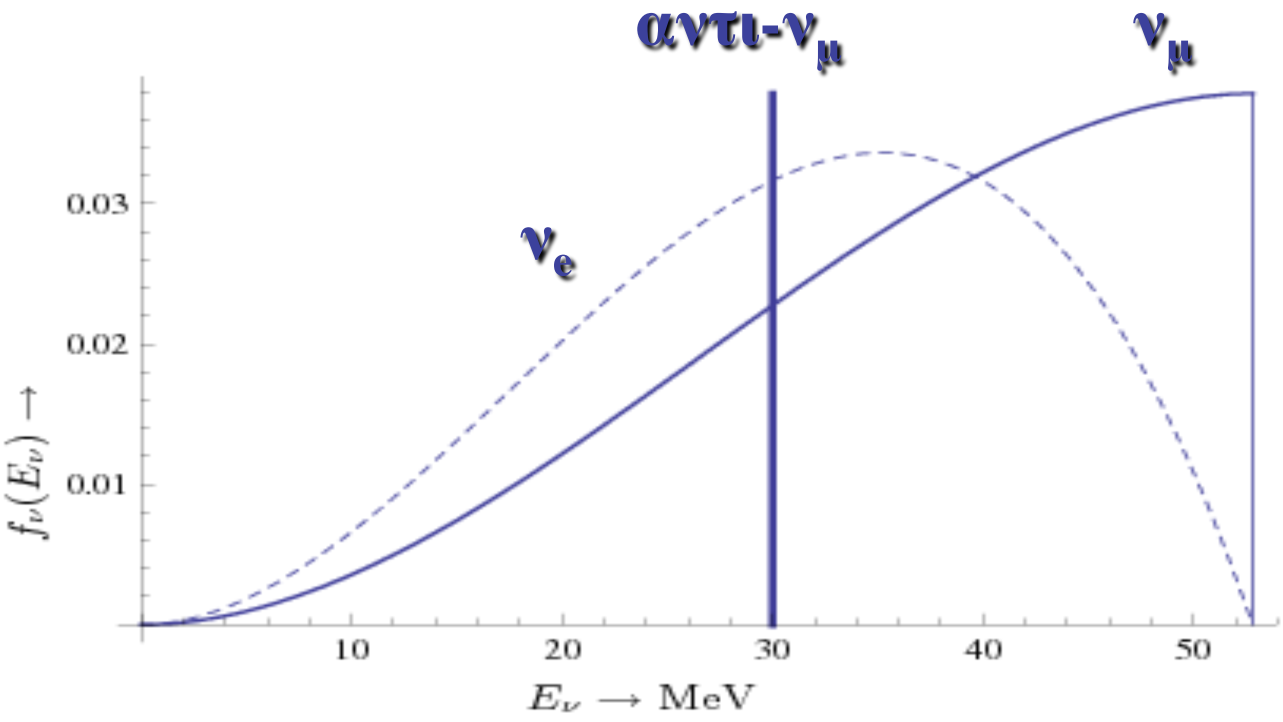
**To be managed by an international scientific consortium and operated by students**

**Extra galactic sensitivity**

# 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*




N($_{anti}\nu_e$) : 6 x$10^{14}$ per second

N($\nu_\mu$)=6 x$10^{14}$ per second (discreet)

N($\nu_e$)=N($\nu_{\mu\text{-bar}}$) =6 x$10^{14}$ per second (continuous)

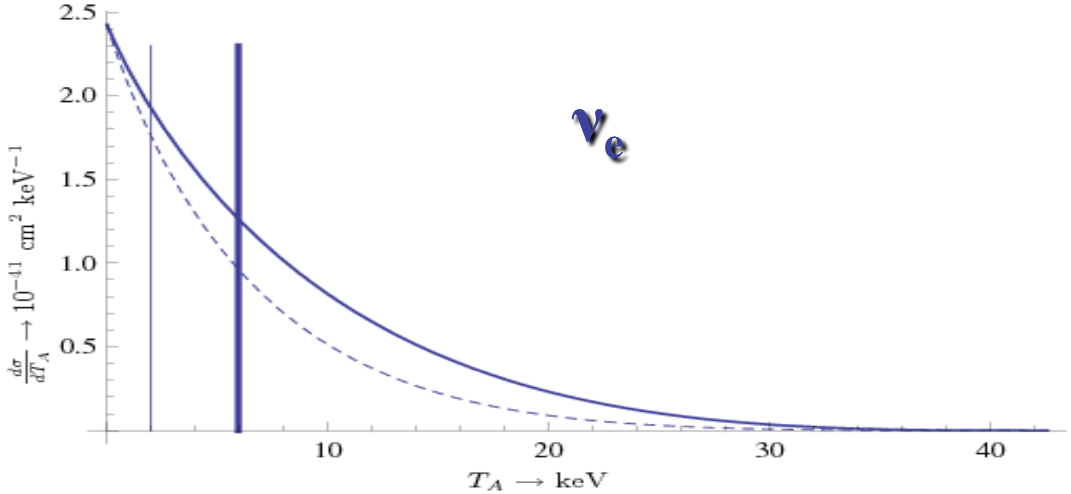
# The dif. event Rate $^{131}$Xe (solid<->No FF)

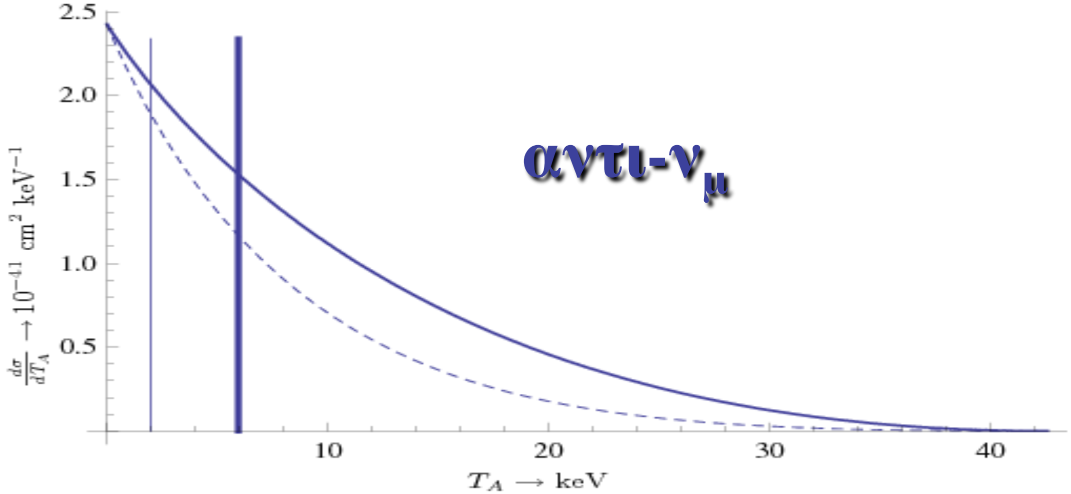
**Thick vertical bar <-> quenching**

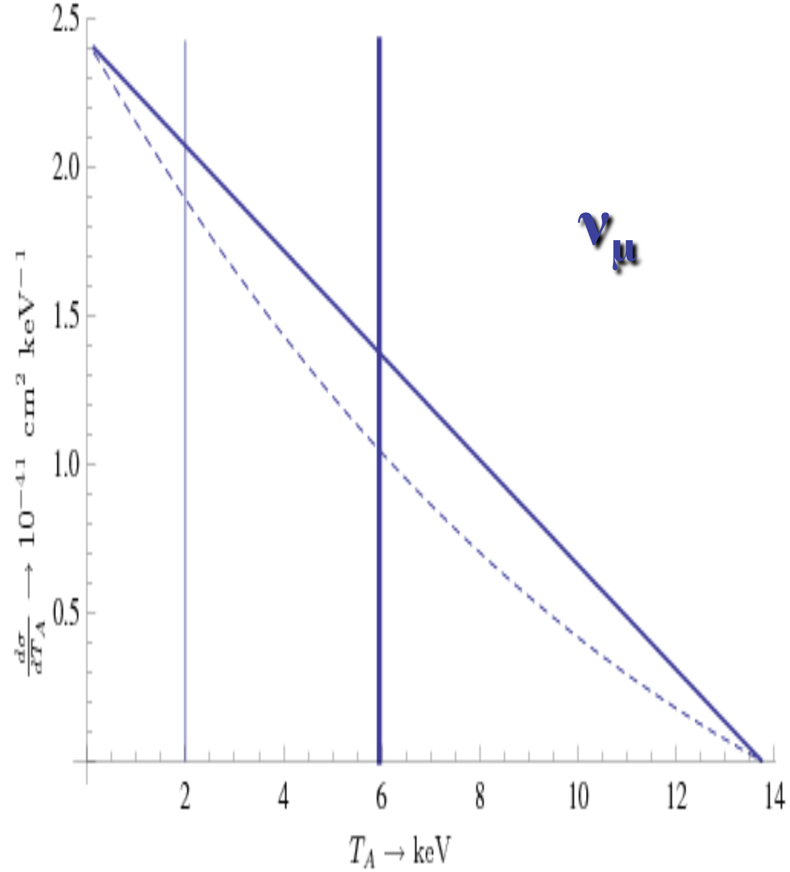
**$\nu_e$ (top) αντι-$\nu_\mu$ (bottom)**

**Discreet $\nu_\mu$**

**Thick vertical bar <->quenching**



# SENSITIVITY

## The number of events in one year for the spherical TPC detector: P=10 Atm, R=5 m, T=300$^0$K, L=10 m

| target | $\nu_e$ (no FF) | $\nu_e$ (FF) | anti $\nu_\mu$ (no FF) | anti $\nu_\mu$ (FF) | $\nu_\mu$ (no FF) | $\nu_\mu$ (FF) | all $\nu$ (no FF) | all $\nu$ (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**

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# Summary

- A new spherical detector is born and developed
- Good energy resolution, robust and stable
- Many applications in low energy neutrino physics are open
- Nuclear reactor monitoring through coherent neutrino scattering is challenging
- Measuring neutrino coherent scattering at a spalation source is promising but needs a bigger detector
- Low cost Supernova detector is proposed
- A world wide network of several detectors is proposed

**Life Time of such system > 1 century**