The NOSTOS experiment

2005 Workshop on Recent Advances in Particle Physics and CosmologyARISTOTLE UNIVERSITY OF THESSALONIKI
Physics Department NUCLEAR Physics And Elementary Particle Physics Division 21-24 April 2005

- **Highlights from the Paris TPC workshop**
- **Spherical TPC prototype**
- **Tritium experiment**
- **Neutrino nucleus coherent scattering detection and applications**
- **Supernova world wide Network**

I. Giomataris

SECOND WORKSHOP ON LARGE TPC FOR LOW ENERGY RARE EVENT DETECTION

LPNHE - Paris VI and VII Universities

Place JussieuTour 33 Rdc PARIS, France 20 - 21 December 2004

Gaseous TPCs :

1) **Low energy neutrino detection** (neutrino oscillations, solar neutrinos, double beta decay, magnetic moment, supernova), I. Vergados, G. Gounaris, I. Irastorza, Ph. Gorodetzky,G. Bonvicini, Z. Daraktchieva, M. Green, M. Zito

2) **Axion search,** Th. Dafni, B. Beltran

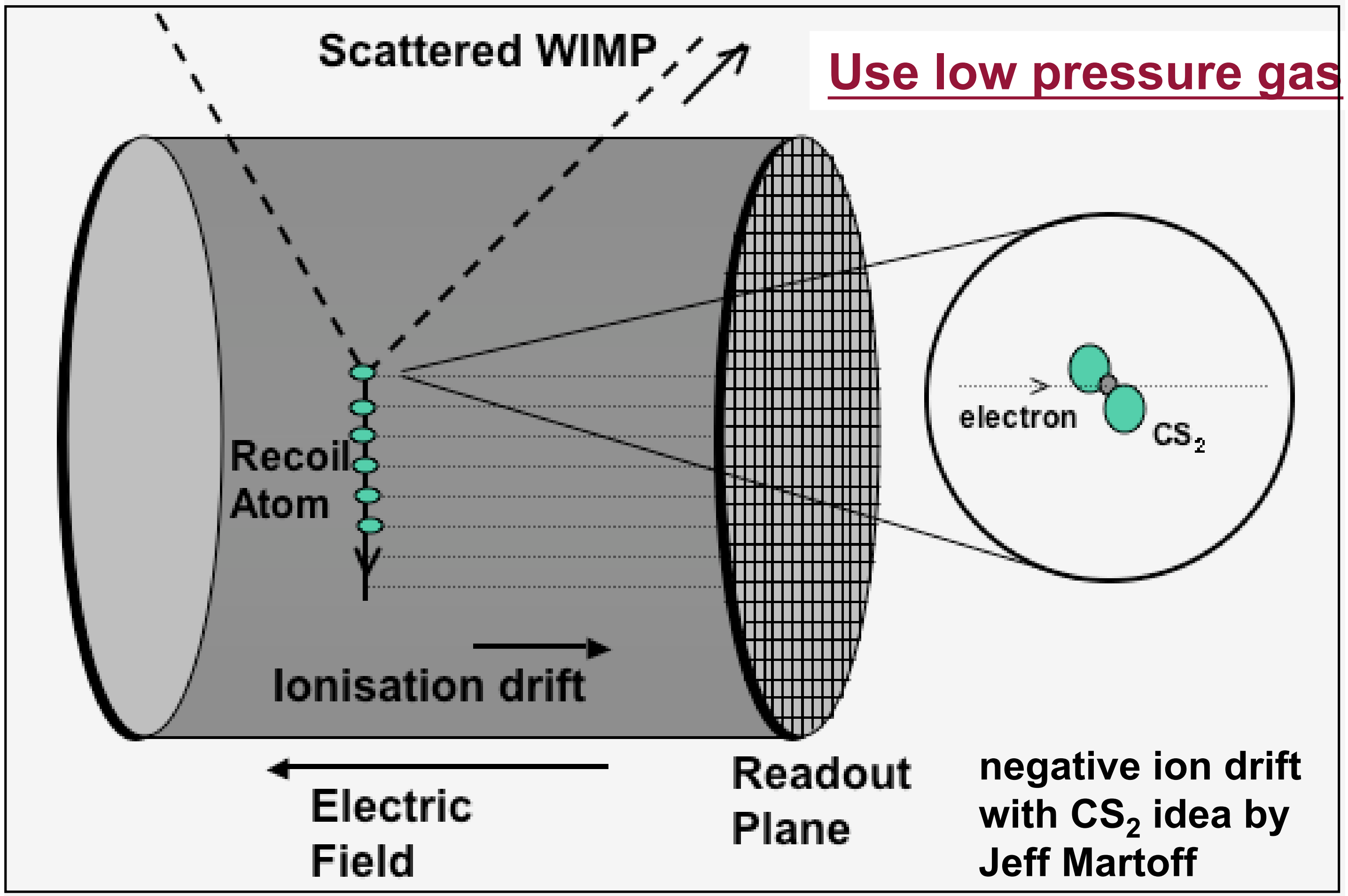
3) **WIMP search with recoil direction**, B. Sadoulet, N. Spooner, D. Santos

Liquid TPCs,

A. Rubbia, E. Aprile, N-J-T. Smith, Ph. Lightfoot, V. Peskov

DRIFT and Prospects for a Large Scale Directional WIMP TPC

N. Spooner



Main motivation : drifting ions instead of electrons reduces the diffusion effect

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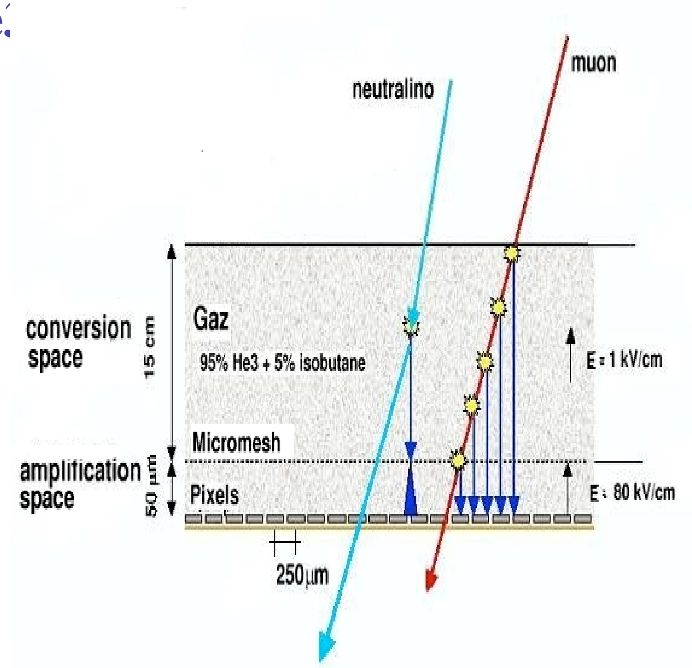
MIMAC-He3 :MIcro-tpc Matrix of Chambers of He
(D. Santos)

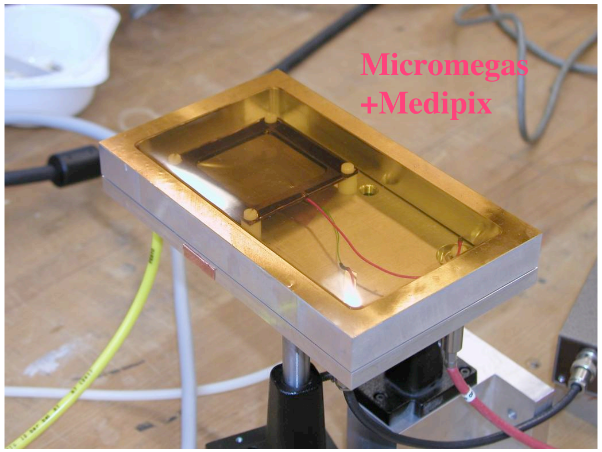
^{3}He for axial detection of non-baryonic dark matter

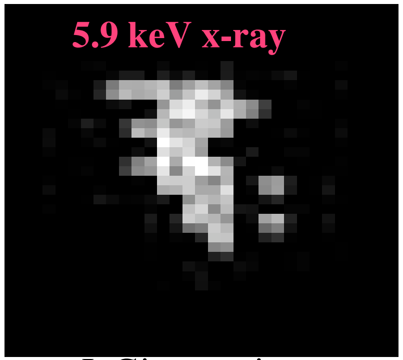
High   spatial temporal   resolution
recoil track projection
$\Rightarrow$ energy threshold < 1 keV
$\Rightarrow$ electron/recoil discrimination



Last refinement: CMOS integrated pixel anodes (H. Van der Graaf)

Idea : Combine micro-pad CMOS with high accuracy MPGD like Micromegas





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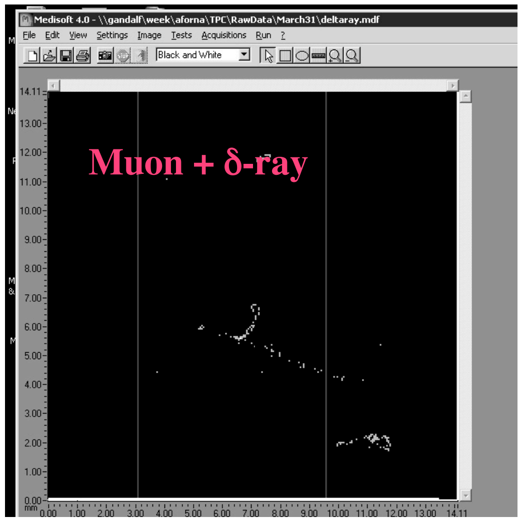
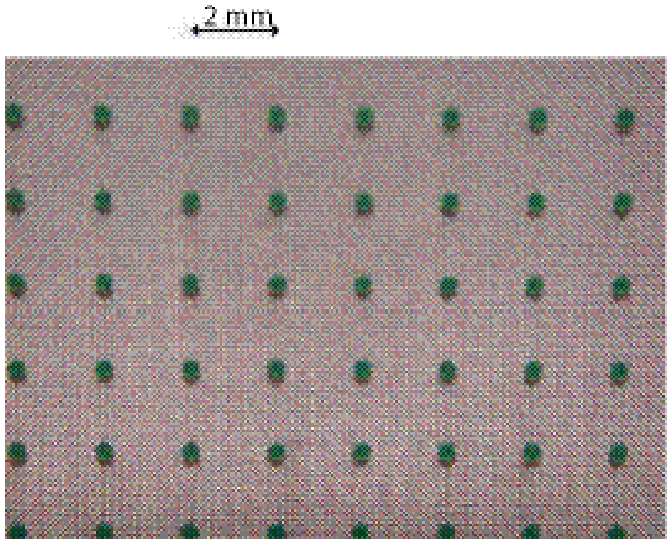
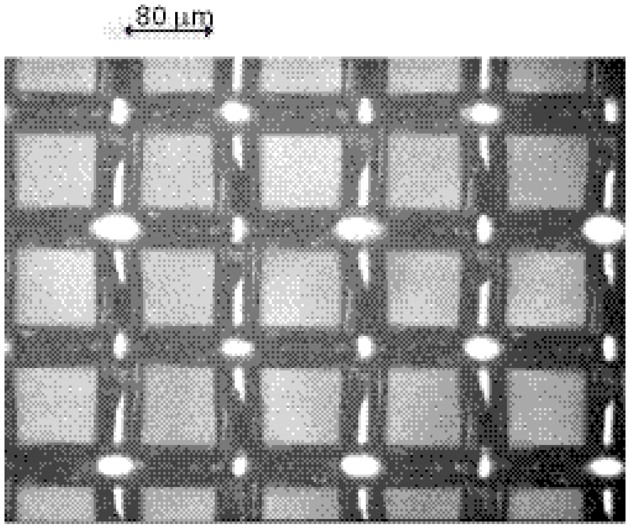


Micromegas Bulk

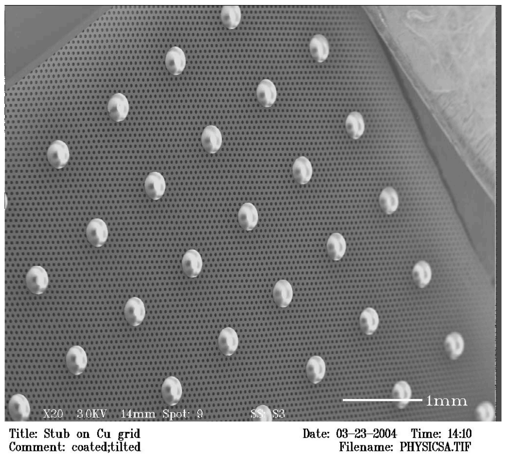
In one single process using traditional PCB technology

Large surfaces, simple, robust and low cost





3M 1st Mass Production of Micromegas



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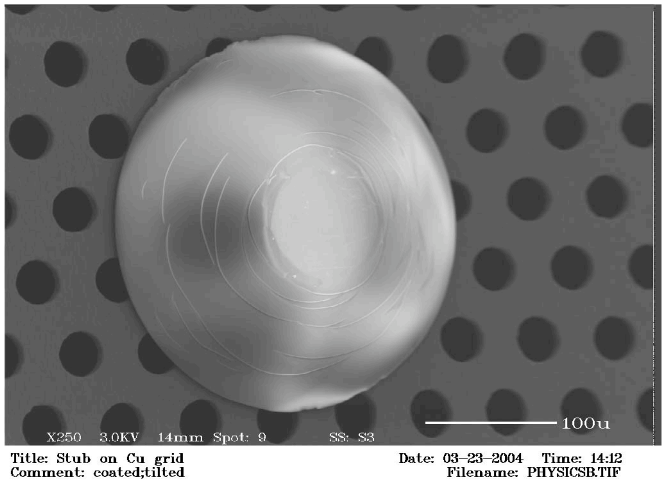
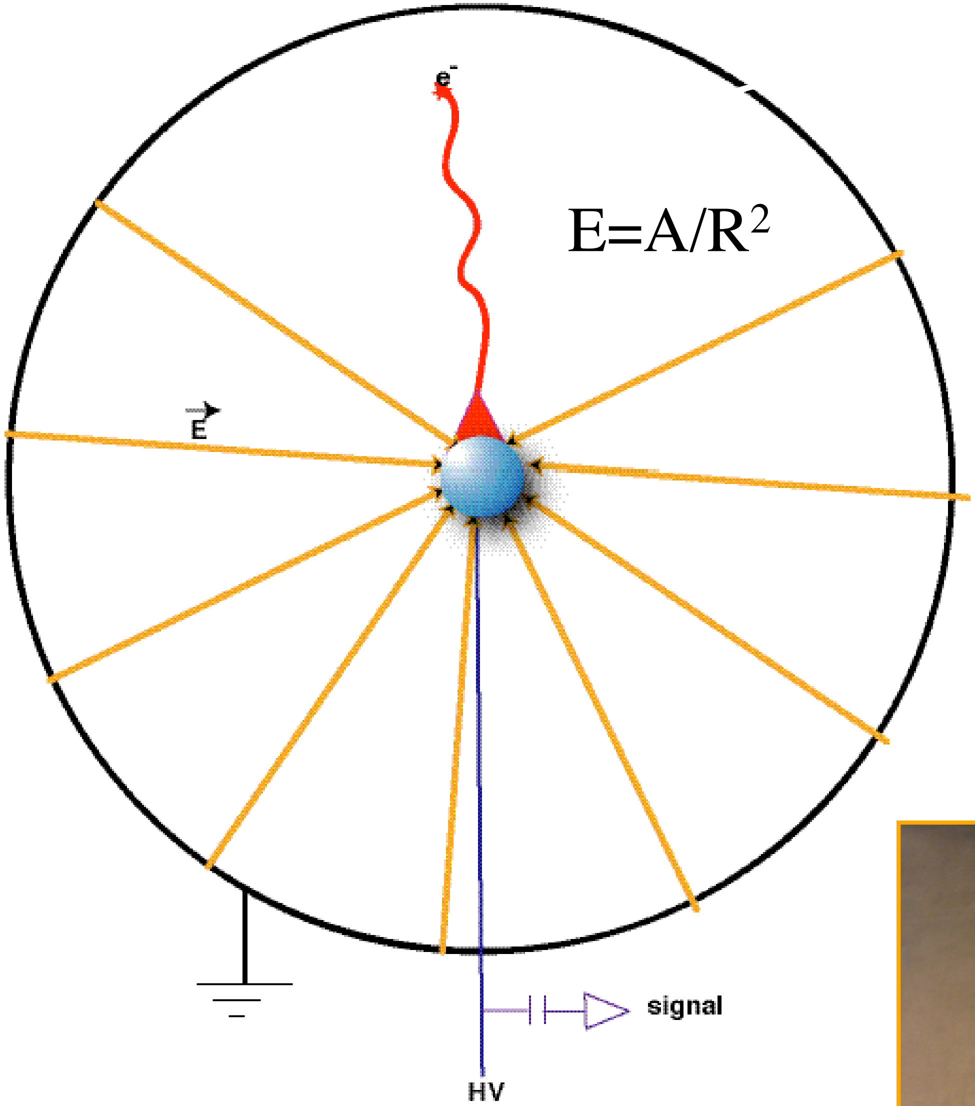
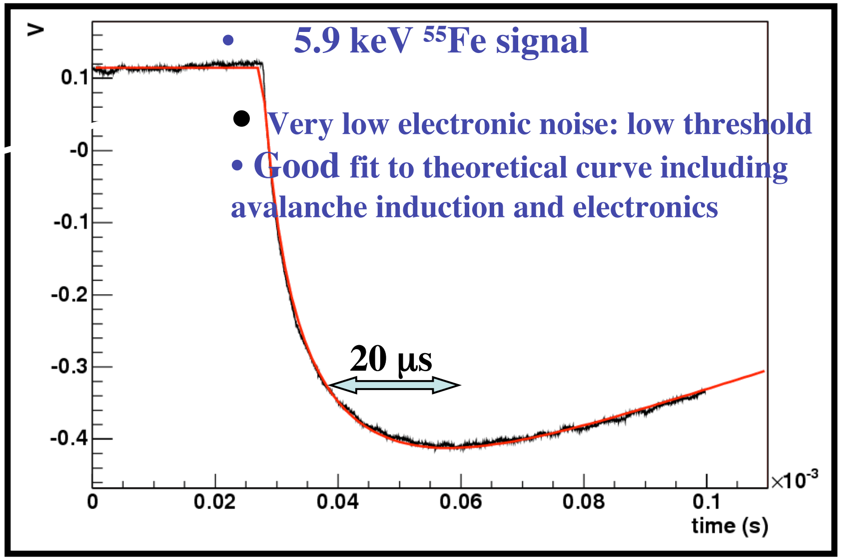
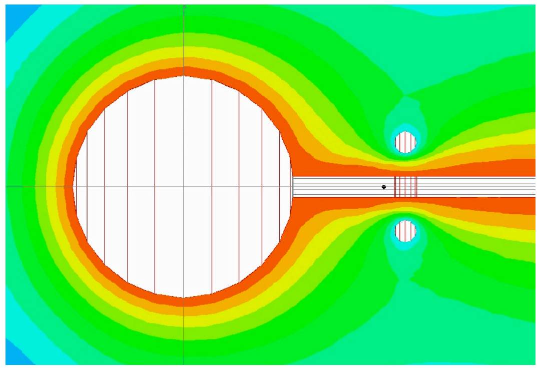
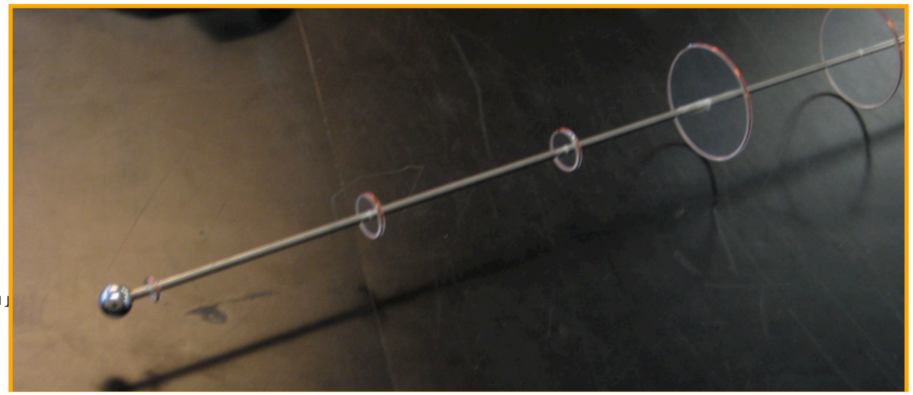


Spherical TPC with spherical proportional counter read-out









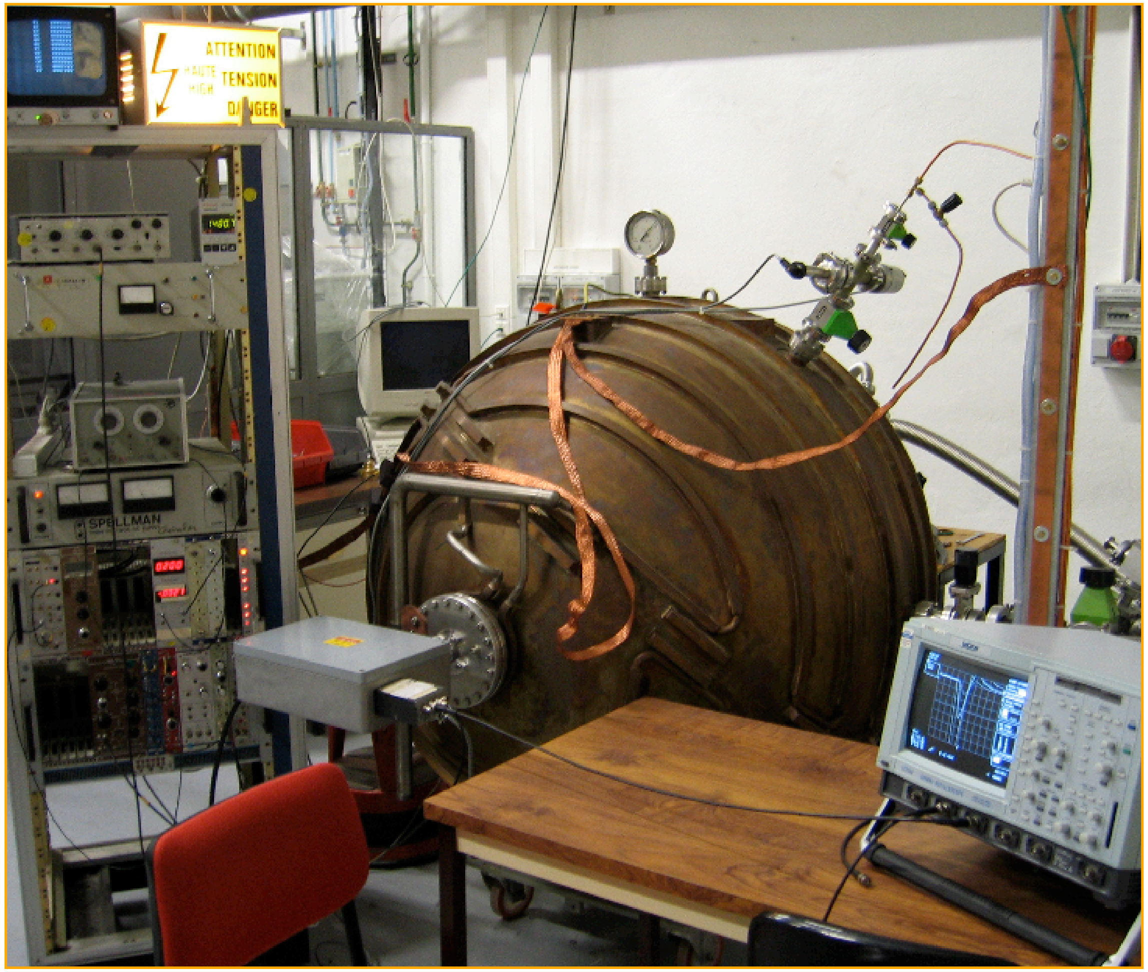
The spherical TPC concept: Advantages

- Natural focusing:
  - large volumes can be instrumented with a small readout surface and few (or even one) readout lines
- 4π coverage: better signal
- Still some spatial information achievable:
  - Signal time dispersion
- Other practical advantages:
  - Low capacity
  - lower noise and threshold
  - No field cage
- Simplicity: few materials. They can be optimized for low radioactivity.
- High pressure tanc
- Low cost

The way to obtain large detector volumes keeping low background and threshold

First prototype: the Saclay sphere

- D=1.3 m
- V=1 m^3
- Spherical vessel made of Cu (6 mm thick)
- P up to 5 bar possible (up to 1.5 tested up to now)
- Vacuum tight: ~10^{-6} mbar (outgassing: ~10^{-9} mbar/s)



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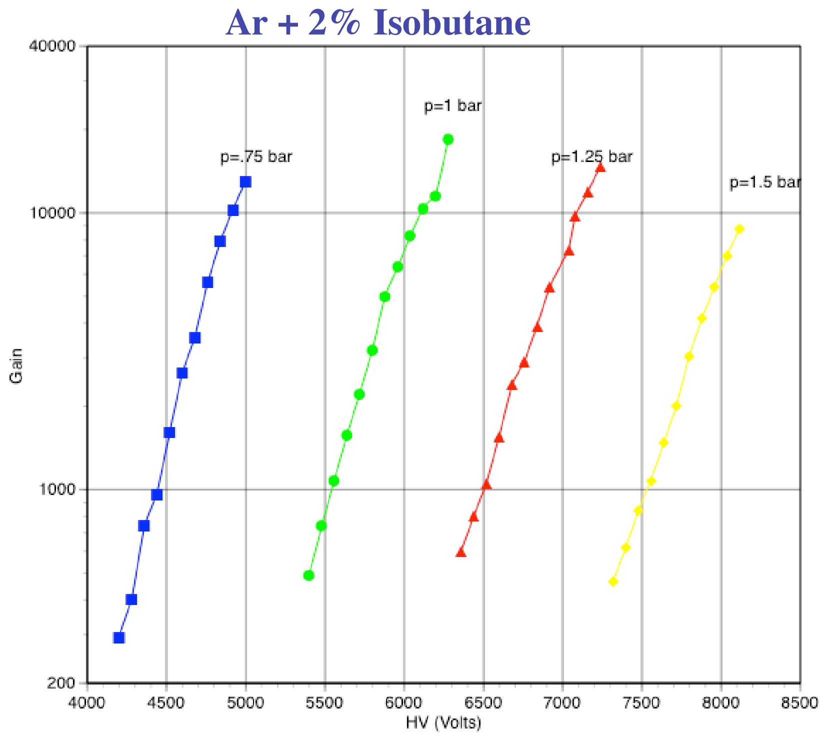
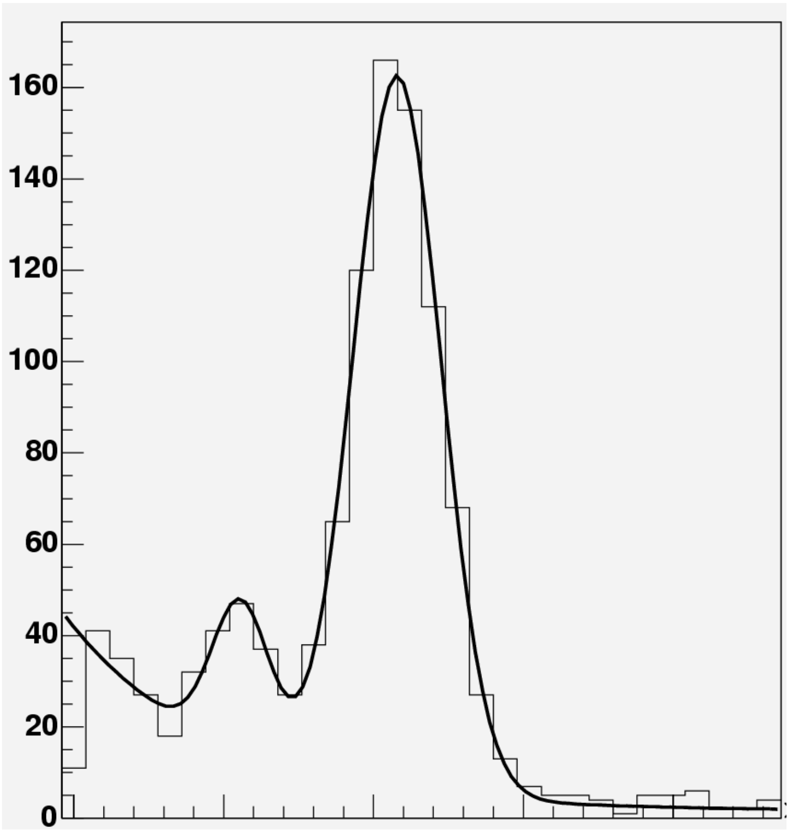


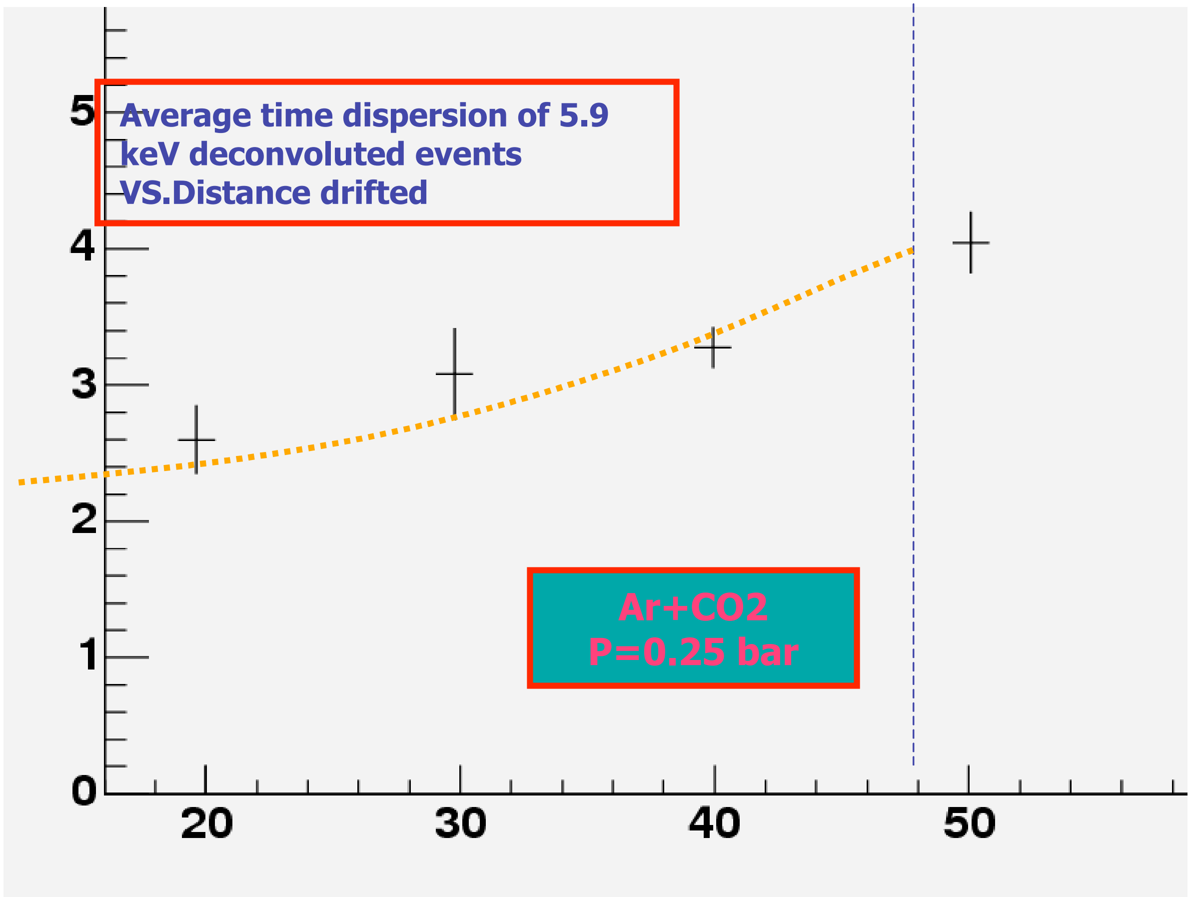


- **Stability:**
  - tested up to ~3 months.
  - No circulation of gas. Detector working in sealed mode. (1 pass through an oxysorb filter)
- **No absorption observed**
  - Signal integrity preserved after 60 cm drift.
  - Not high E needed to achieve high gain.

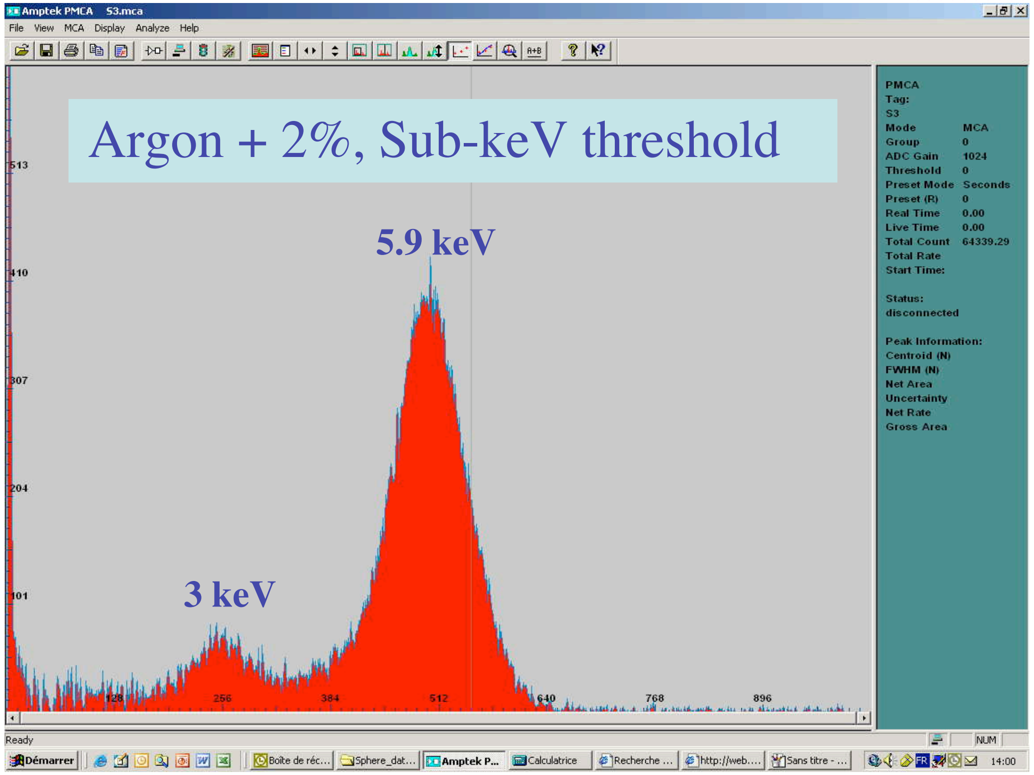
Measuring the radial depth

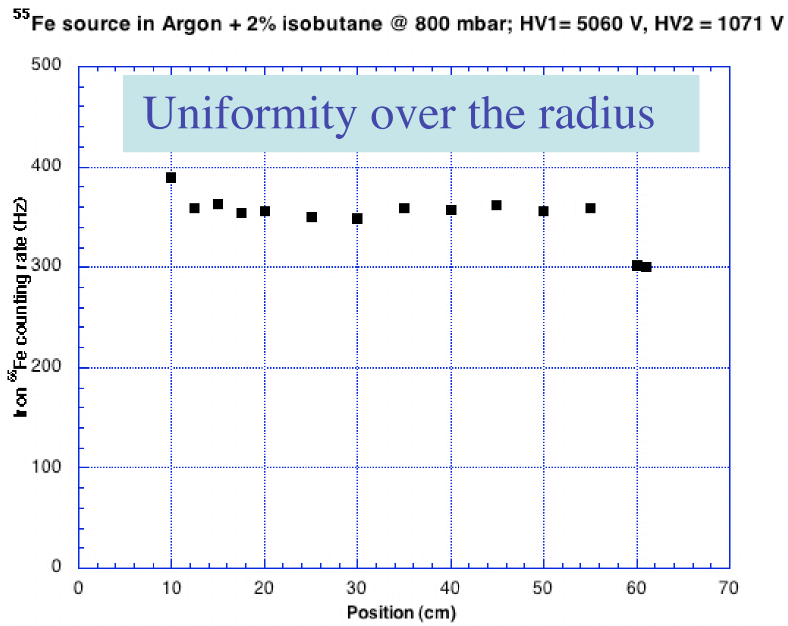
Fiducial cuts, estimate the radial depth of the interation

- Even with a very simple (and slow) readout, we have proved the use of dispersion effects to estimate the position of the interaction (at least at ~10 cm level).
- Further test are under preparation to better calibrate (external trigger from Am source)



First underground tests in LSM 5-4-2004





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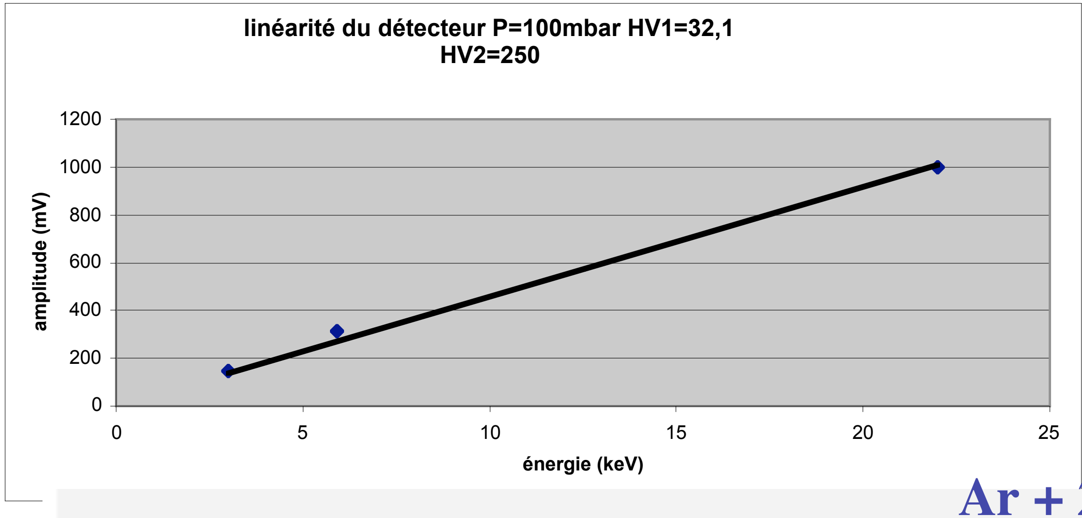
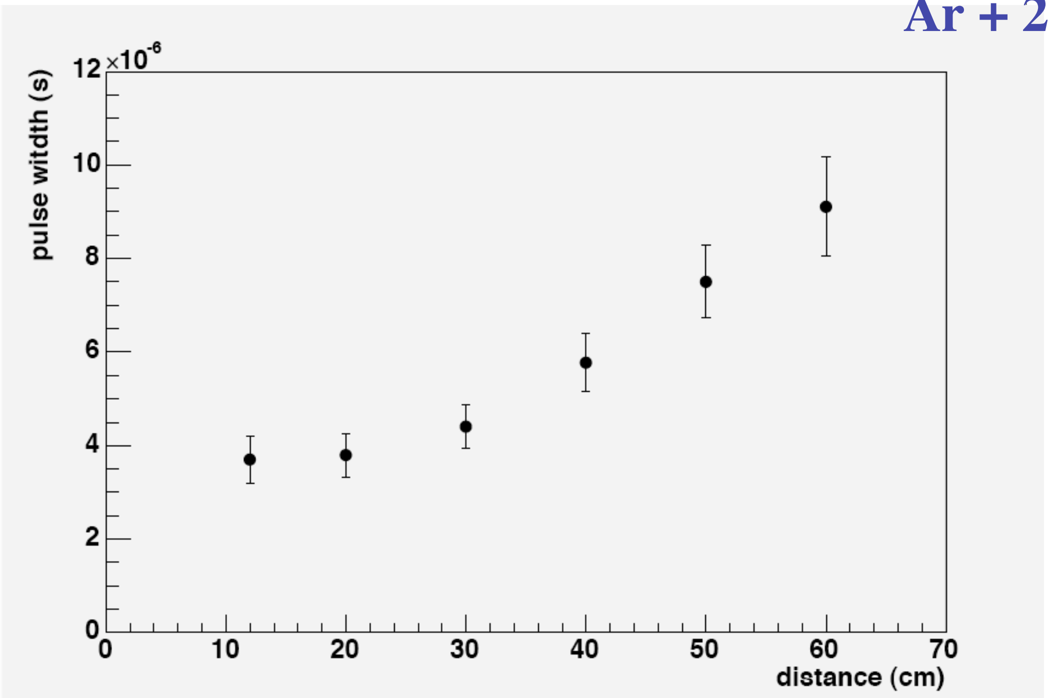
LSM 5-4-2004



Ar + 2% Isobutane



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Long term program

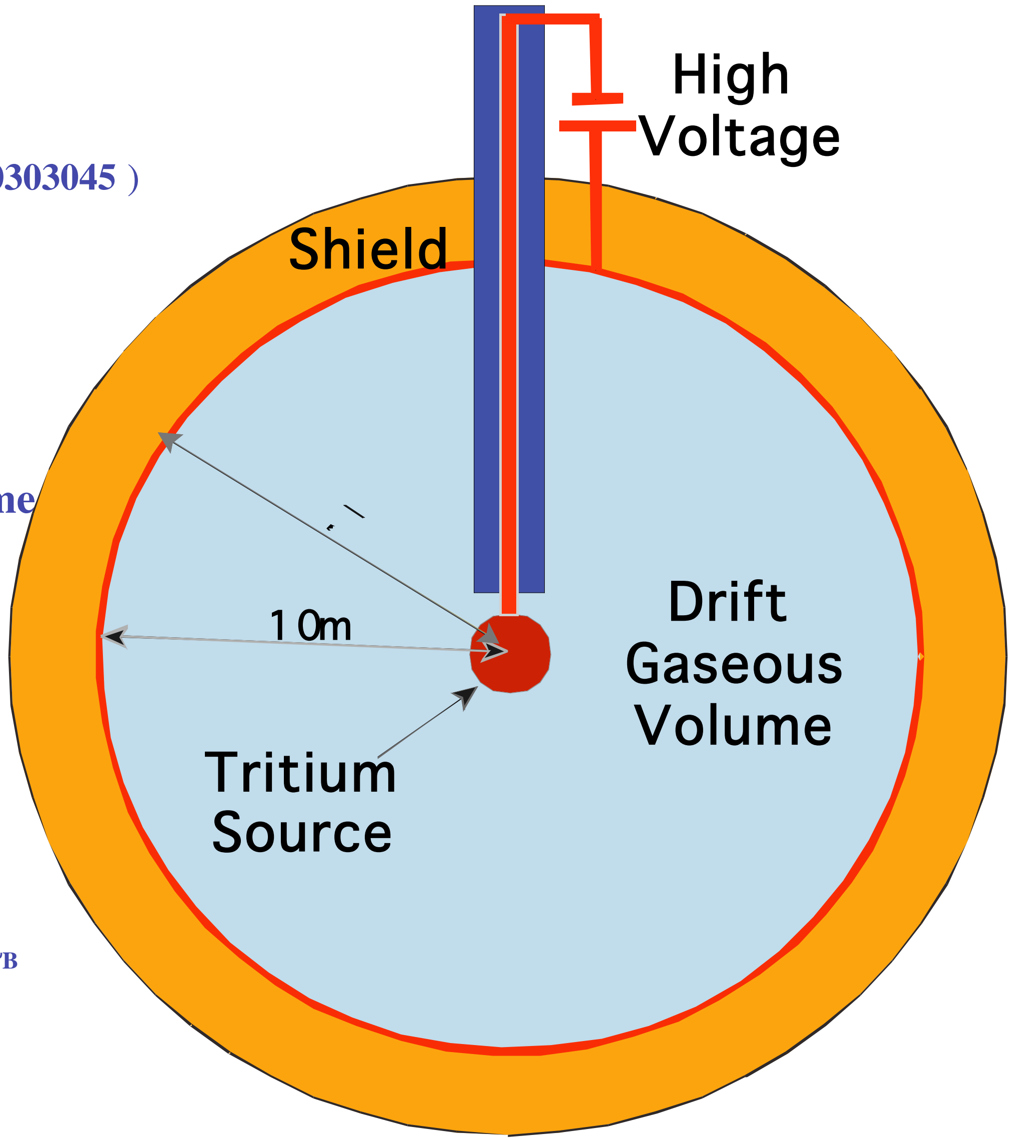
NOSTOS I. Giomataris, J. Vergados, hep-ex/0303045)

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

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

Objectives

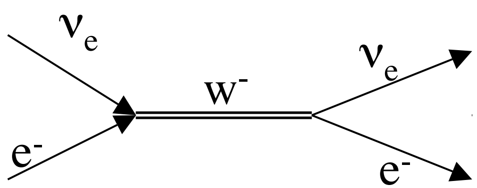
- Measure θ_{13} (systematic free)
- Neutrino magnetic moment studies << 10^{-12} μ_B
- Measurement of the Weinberg angle at low energy

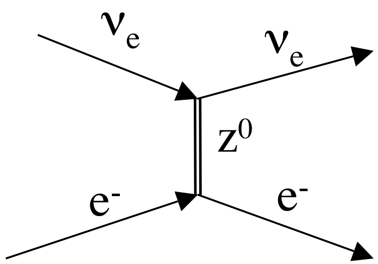


Challenge : detect electron recoils down to T=100 eV (Tmax=1.27 eV)
Low background level (to be measured and subtracted)
Measure the radial depth of the interaction

Neutrino-electron elastic scattering cross section

$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$ G.'t Hooft, Phys. Lett. B37,195(1971)





$$d\sigma/dT = 1.7\,10^{-47}(g_L^2 + g_R^2(1-T/E_\nu)^2 - g_L g_R m_e T/E_\nu{}^2)$$

$$g_L = \sin^2\theta_W, g_R = \sin^2\theta_W + 1/2, T \approx 2(E_\nu\cos\theta)^2/m_e, T_{\max} = 1.27\,keV$$

For T<<1 keV $d\sigma/dT = a(2\sin^4\theta_w + \sin^2\theta_w + 1/4)$

High accuracy measurement of the Weinberg angle at very-low energy!!

Test the weak interaction at long distances

Needs corrections due to atomic effects

G. Gounaris, E. Paschos, P. Porfyriadis, *Phys.Lett.B525:63-70,2002, Phys.Rev.D70:113008,2004*

Accuracy : from 10% for Xenon to 2% for lighter atoms

Target properties with 5×10^{30} electrons, 1000 events/year

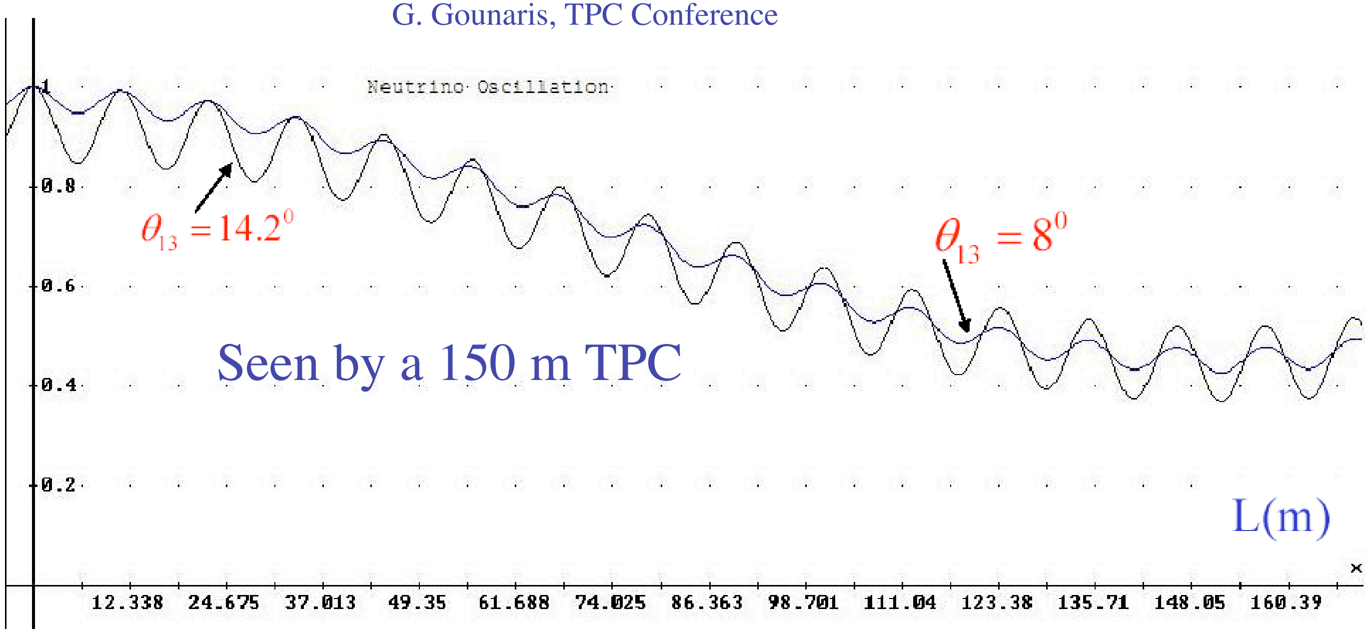
Noble gas	Pressure (bar)	W(eV)	Radioactivity	Comments
Xe	1	16	^{85}Kr	*It needs high purification* *Expensive*
Ar	3	26	^{42}Ar $T=33y, E_{max}=565keV$	*Low cost* *^{42}Ar activity: <1000/y below 1keV*
Ne	5.4	36	None	*Moderate cost*
He	27	41	None	*Low cost* *Very high pressure*

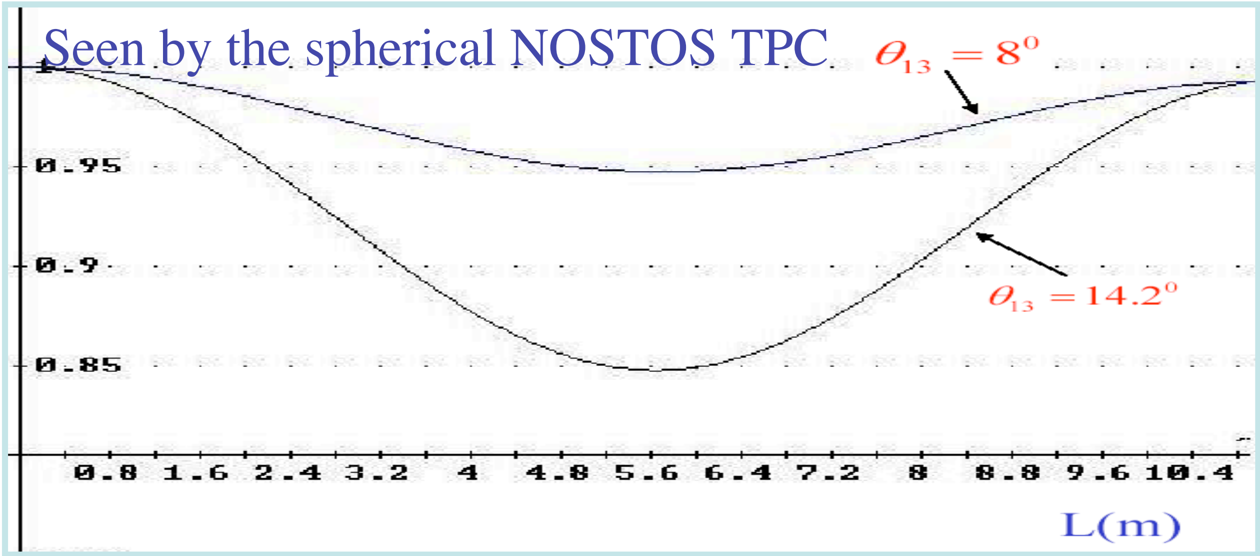
Reasonable goal: operate with Ar or Ne at pressures >10 bars

→ **>10^4 *events/year* to tackle a total number of events of 10^5**

Room size oscillations

G. Gounaris, TPC Conference

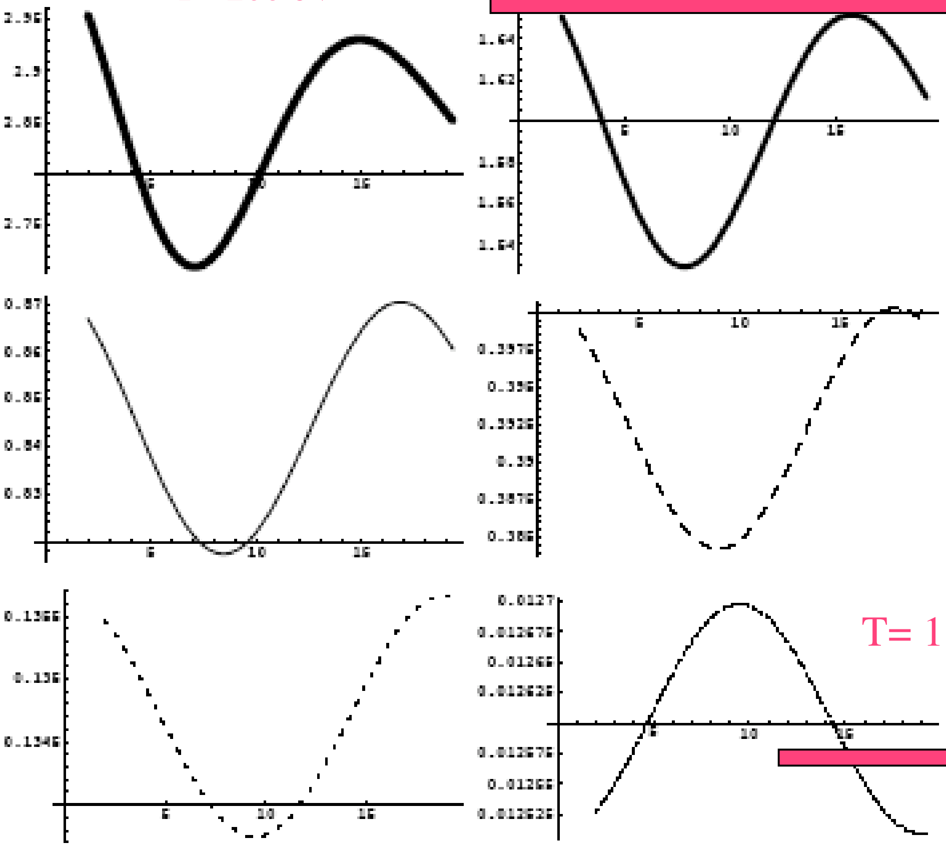




I. Giomataris, J. Vergados, hep-ph/0504149

Electron neutrino disappearance

T= 200 eV



T= 1.2 keV

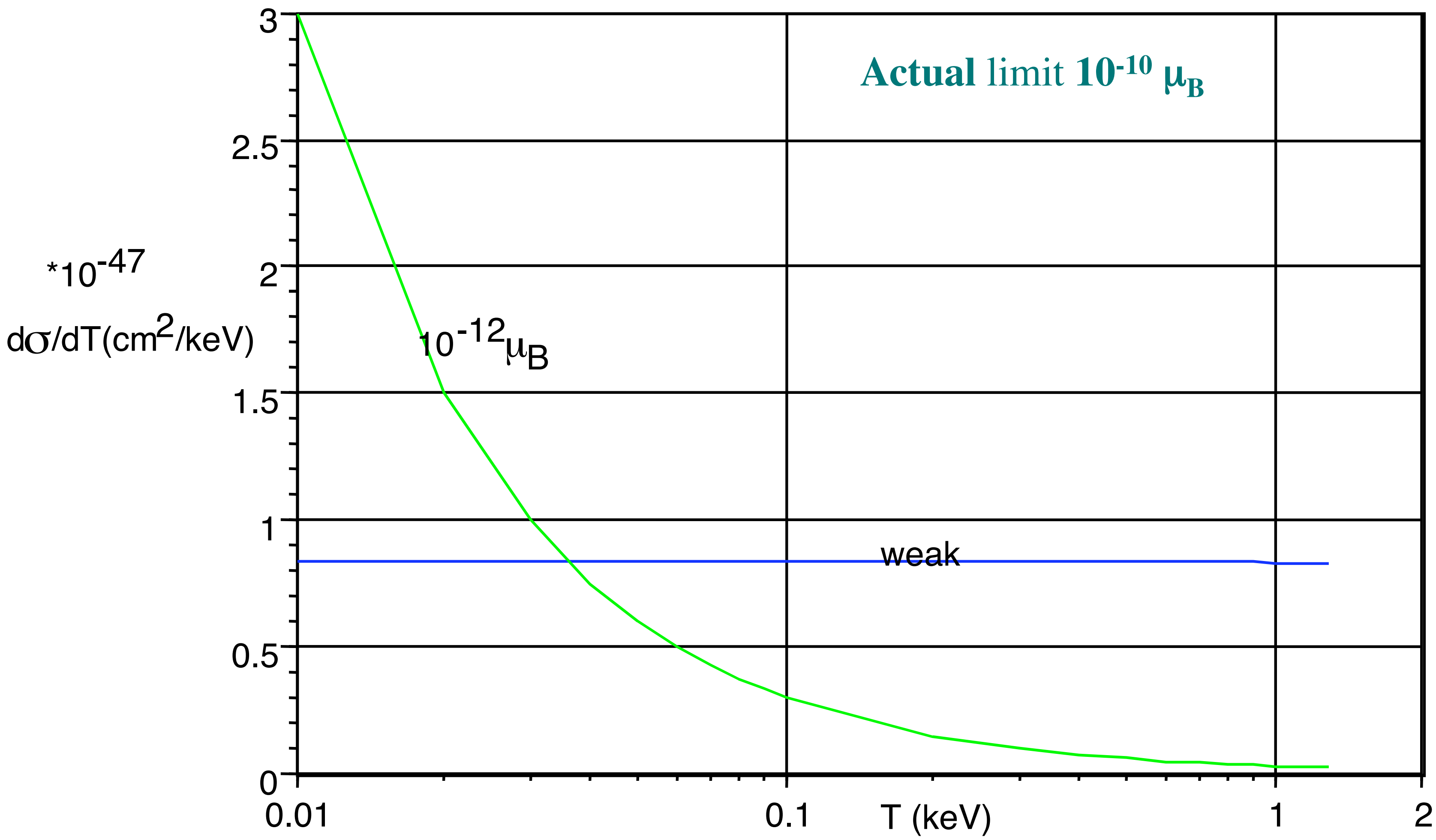
Neutrino muon or tau appearance!!!!

Fig. 6.19. The differential cross (ν_e, e^-) section, $\prec \frac{d\sigma}{dT} \succ$, in units of $\frac{G_F^2 m_e}{2\pi} = 4.5 \times 10^{-52} \frac{m^2}{keV}$, as a function of the source-detector distance averaged over the neutrino energy for electron energies from top to bottom and left to right 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 keV. The results shown correspond to $sin^2 2\theta_{13} = 0.170$

Neutrino magnetic moment sensitivity

$\ll 10^{-12}\ \mu_B$

$d\sigma/dT = cons(\mu_\nu)^2(1-T/E\nu)/T$



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Short term (3 year program)

Develop the spherical detector and study Neutrino-nucleus coherent elastic scattering

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

1. **Nuclear reactor measurement sensitivity with present prototype**

after 1 year run (2×10^7s), assuming full detector efficiency:

- Xe ($\sigma \approx 2.16\times10^{-40}$ cm^2), 2.2×10^6 neutrinos detected, E_{max}=146 eV
- Ar ($\sigma \approx 1.7\times10^{-41}$ cm^2), 9×10^4 neutrinos detected, E_{max}=480 eV
- Ne ($\sigma \approx 7.8\times10^{-42}$ cm^2), 1.87×10^4 neutrinos detected, E_{max}=960 eV

Challenge : Very low energy threshold
We need to calculate and measure the quenching factor
Application : Remote control of nuclear reactors

Neutron spallation source measurement with present prototype

F. Avignone, Yu Efremenko, Phys. G: Nucl. Part. Phys. 29 (2003) 2665–2675

Oak Ridge project

Total flux about $6x10^8/cm^2/s$ at 5 m

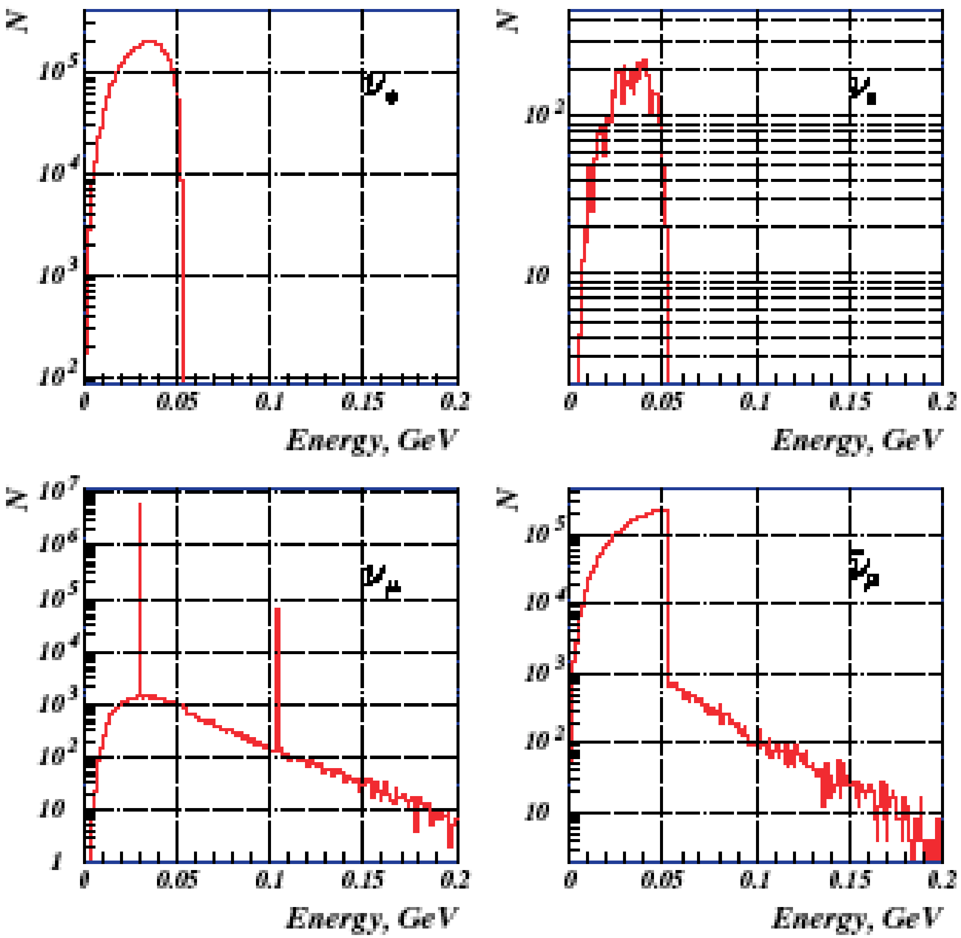


Figure 1. Energy spectra of the four neutrino flavours from a spallation source similar to the SNS.

Advantages

- Higher neutrino energies
- Reasonable nuclear recoil energy
- Pulsed beam

Supernova neutrino detection with a 2nd demonstrator (4 m)

Y. Giomataris, J. D. Vergados, **hep-ex/0503029**

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

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

Expected signal : 100 events (Xenon at p=10 bar) per galactic explosion (including detector threshold and quenching factor)

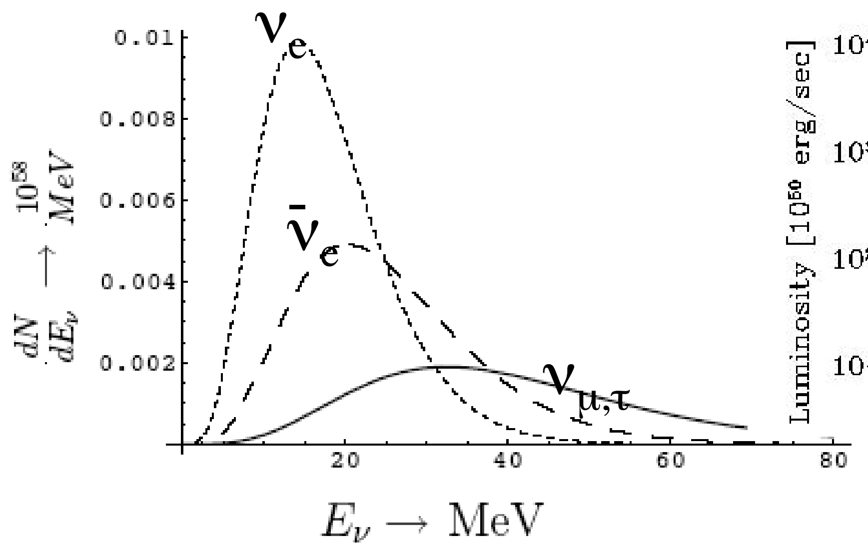
Idea : A European or world wide network of several (tenths or hundreds) of such dedicated Supernova detectors

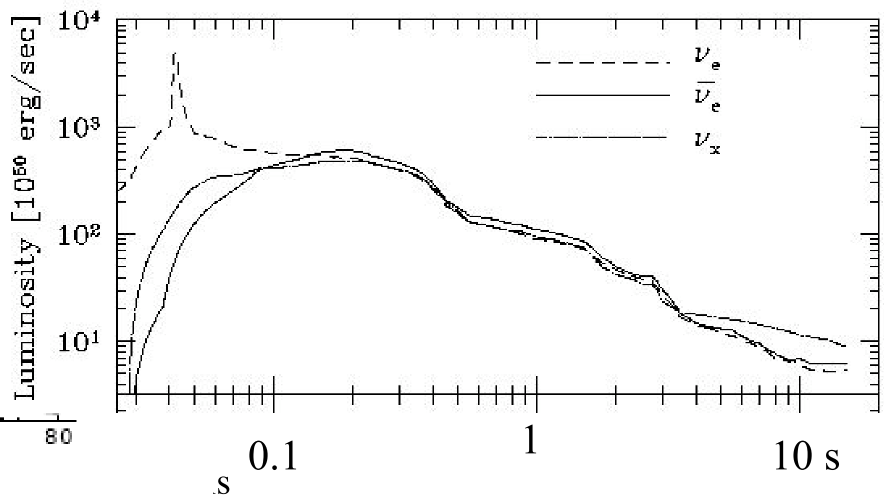
In coincidence with gamma ray bursts GRB (UPB)?

robust, low cost, simple (one channel), (Detector $\mathbf{T_{life\ time}}$ **>> 1 century**)

To be managed by an international scientific consortium

and operated by students





European bid

Proposal NEST: FP6-028699-1

Colaboration: Saclay, APC-Paris, Saragoza, Ioannina, Thessaloniki, Dimokritos, Dortmund, Sheffield

Main objectives (3 years):

- **Study the neutrino-nucleus coherent scattering (Theory, experiment and measure the quenching factor at low energy)**
- **Deliver a 4 m galactic Supernova detector**
- **Measure the neutron flux and energy at underground facilities (with 3He, see E. Savvidis)**

Conclusions

- Large volume TPCs are already used for rare event detection
- Combined with new MPGD precise detector can provide low energy threshold and recoil directionality
- A novel detector based in the spherical geometry with spherical proportional counter read-out has been successfully tested and it is under development.
- Many applications in low energy neutrino physics are open : oscillations, neutrino magnetic moment, Weinberg angle
- Study of the neutrino-nucleus coherent interaction
- Promising Super Nova detector