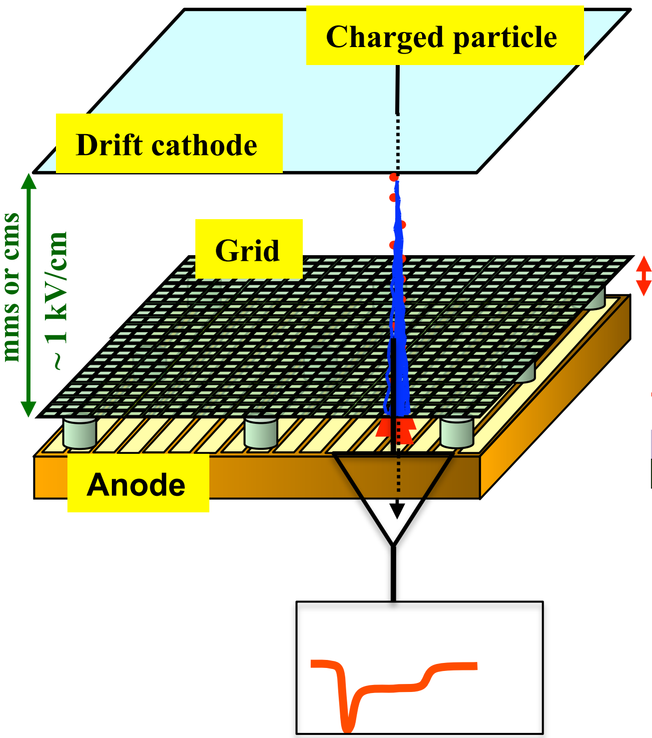
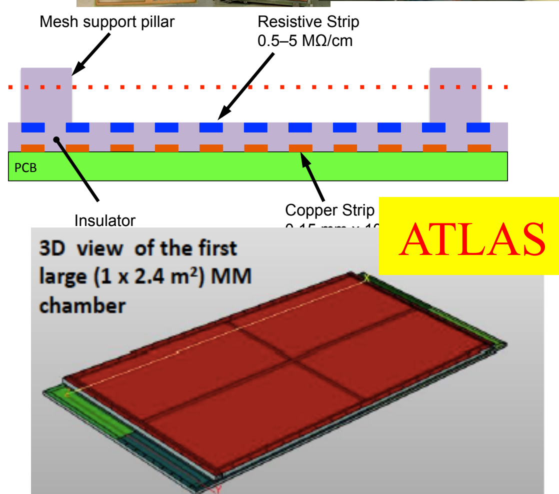
# Advance in particle detectors and new physics

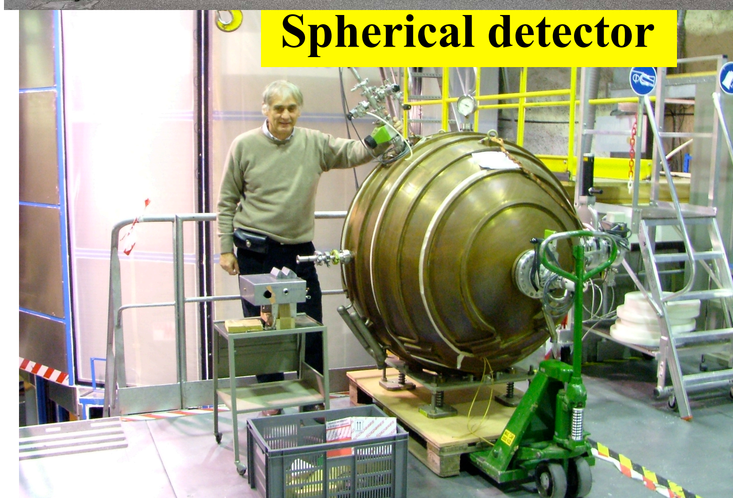
*I. Giomataris CEA-Saclay*



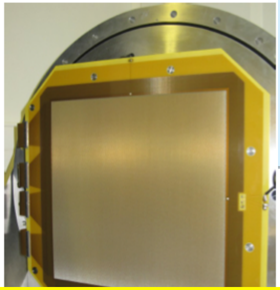





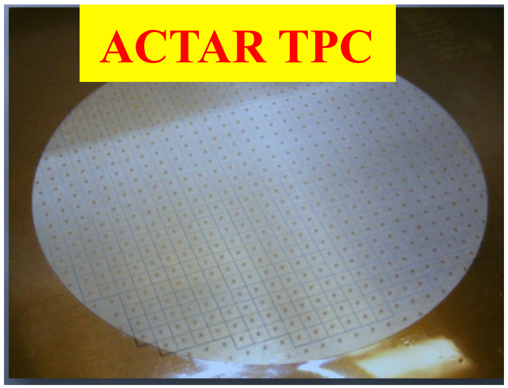
# Some experiments using **Bulk Micromegas**



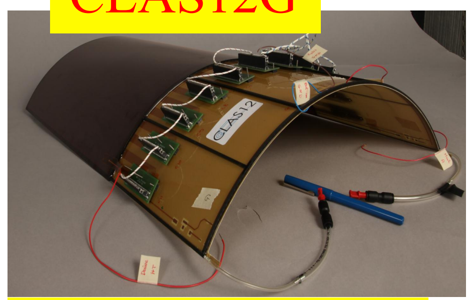
HARPO polarimeter

T2K

ATLAS-SLHC



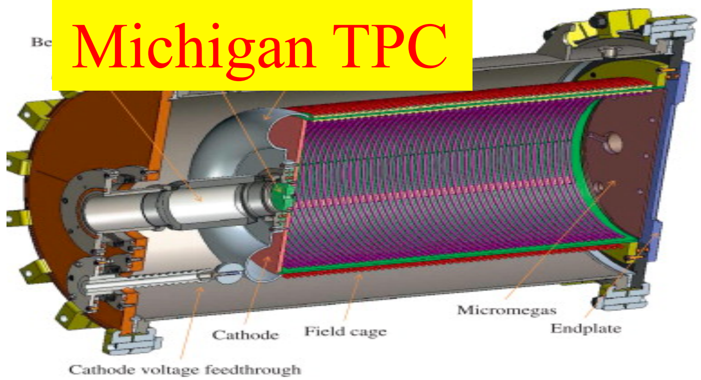
ACTAR TPC




CLAS12G

HCAL

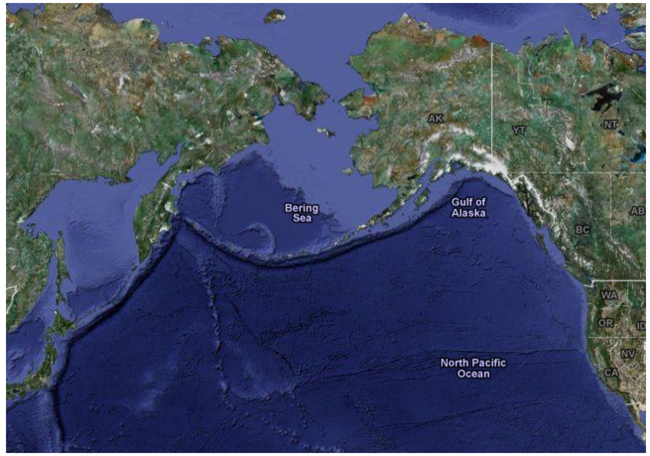
ILC/TPC

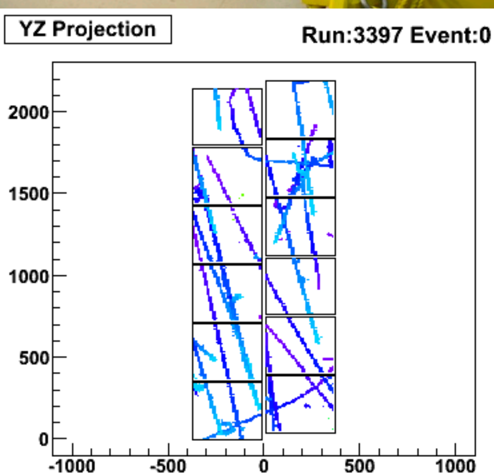


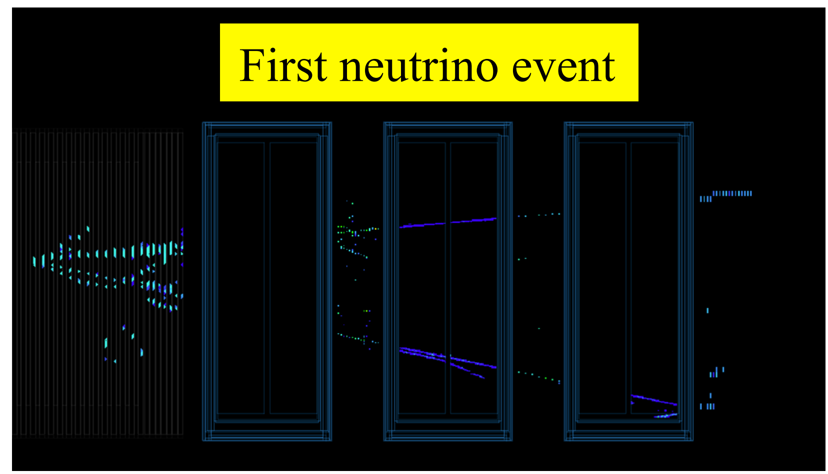

Michigan TPC

# T2K Micromegas TPC

## 3xTPCs, 6 end plates, 72 Micromegas



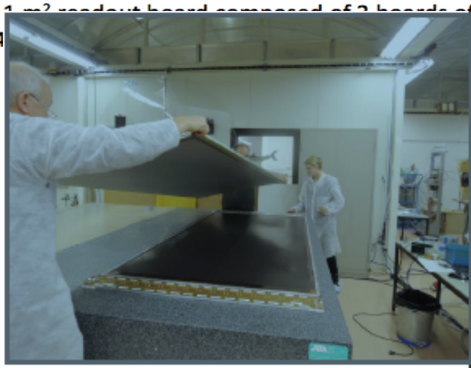



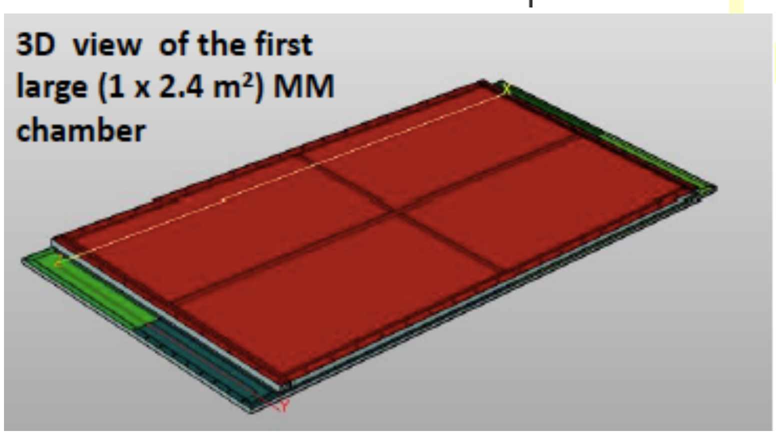
# Construction of large chambers in ATLAS

## Goal : 1200 m2 total detector surface

### 1 x 1 m² micromegas

1 x … f 0.5 x 1 m²
204 … mm
… l (top) and
… as gas seal

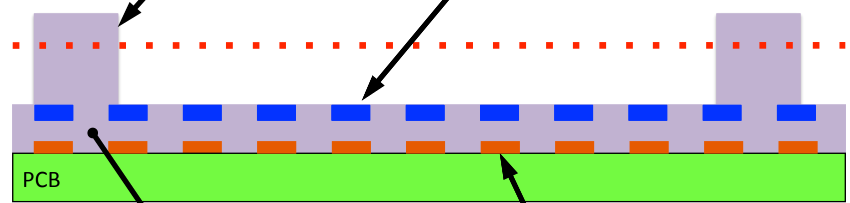


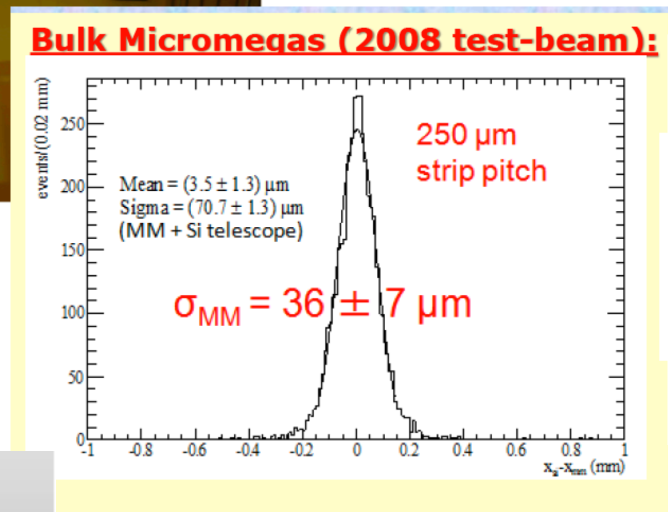


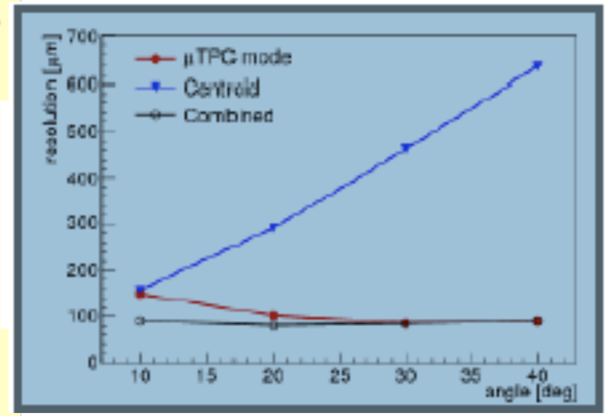

## ATLAS Resistive strip technology

*Joerg Wotschack, Mod.Phys.Lett. A28 (2013) 1340020*

*T. Alexopoulos, et al. Nucl. Instrum. Meth. A 640, 110-118, (2011).*



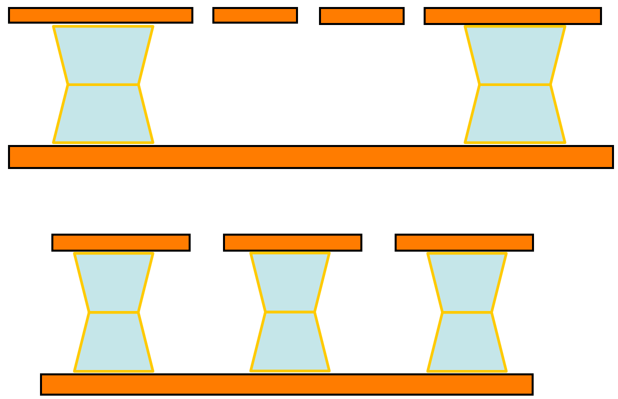




**Industrialization is going on through ELVIA, ELTOS**

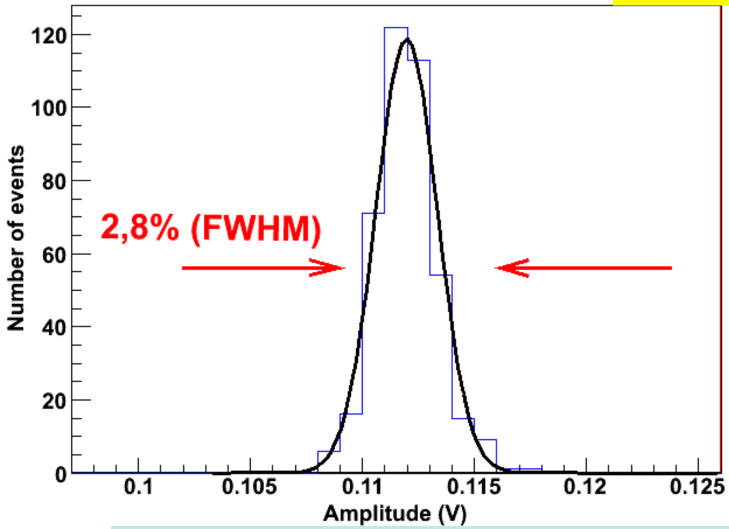
# $2^{nd}$ fabrication technology
## Micro-Bulk

Type1

Type2



***CEA-CERN patent***




Xe @ 2 bar
Neutrinoless Double Beta (0nbb) using $^{136}$Xe target


50 µm and 25 µm gaps fabricated

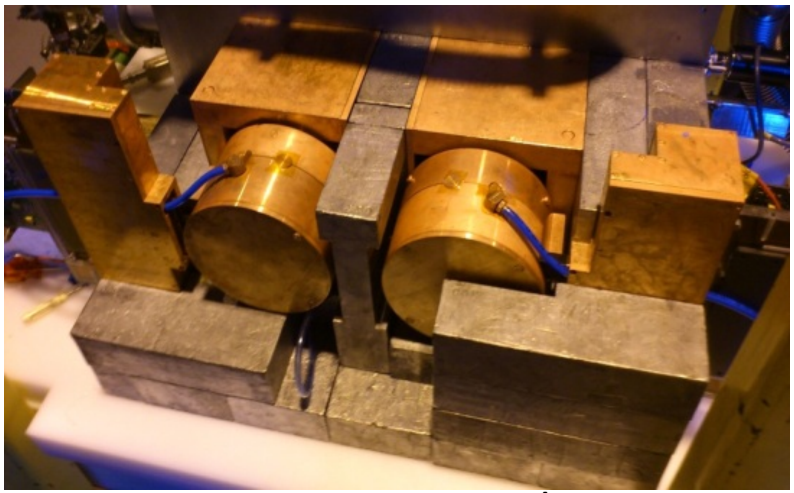
**Very good energy resolution**
- 11% at 5.9 keV
- 5.5% at 22 keV
- < 1% with Am alpha source

## Other advantages
- Flexible structure (cylinder)
- Good uniformity
- Low material
- Low radioactivity

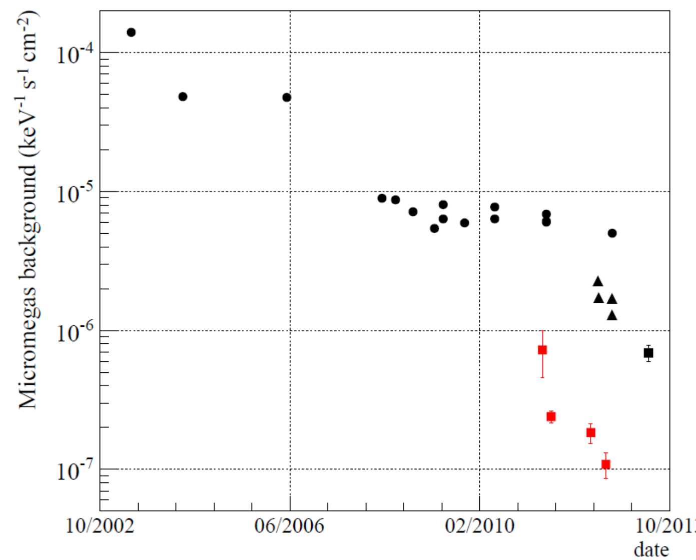
# Micromegas micro-bulk in CAST

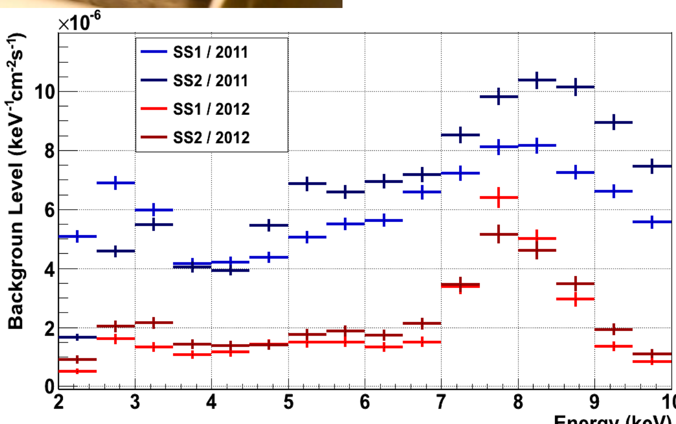
## Greek Institutes in CAST

- NCR "Demokritos", Athens, Greece
- Aristotle University of Thessaloniki, Greece
- University of Patras, Greece
- NTU Athens, Greece

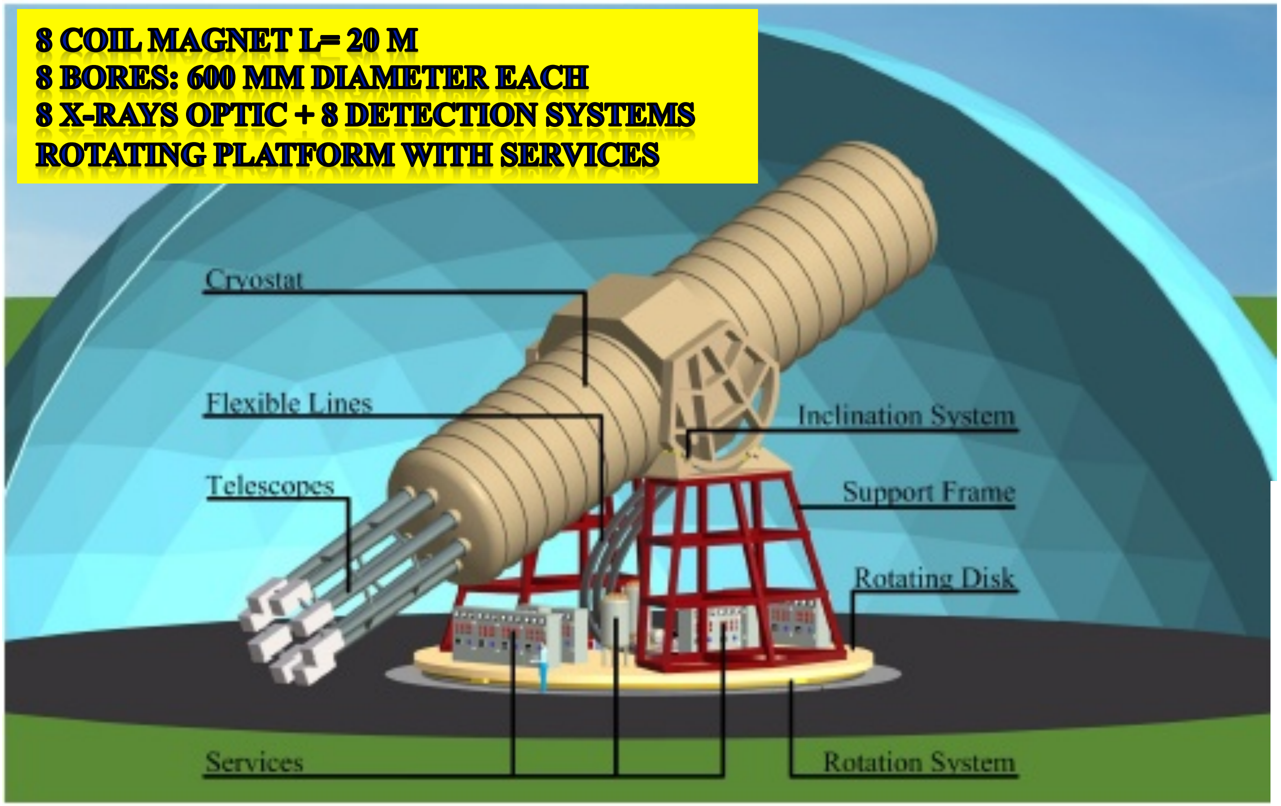
**Evolution of Micromegas CAST background**

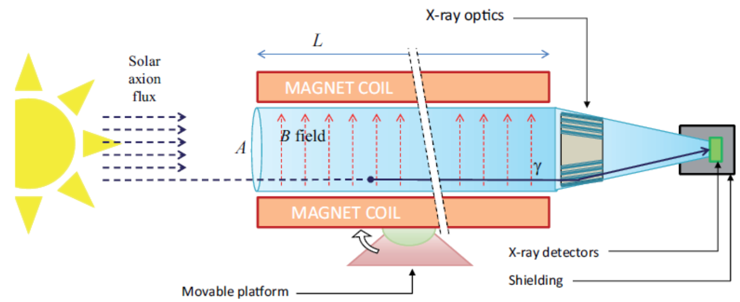


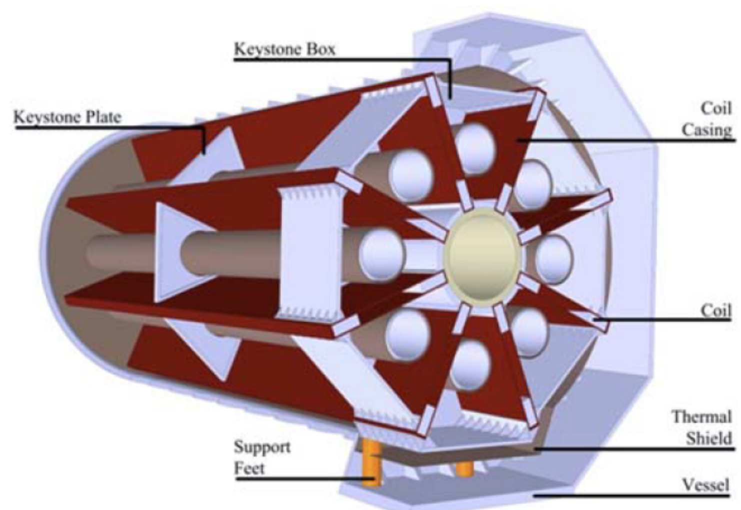
# International Axion Observatory (IAXO)

- Towards a new generation axion helioscope
- Conceptual Design Report and **Letter of Intent** to CERN in preparation.
- **Goal**: 1-1.5 orders of magnitude in sensitivity to $g_{ag}$ better than CAST

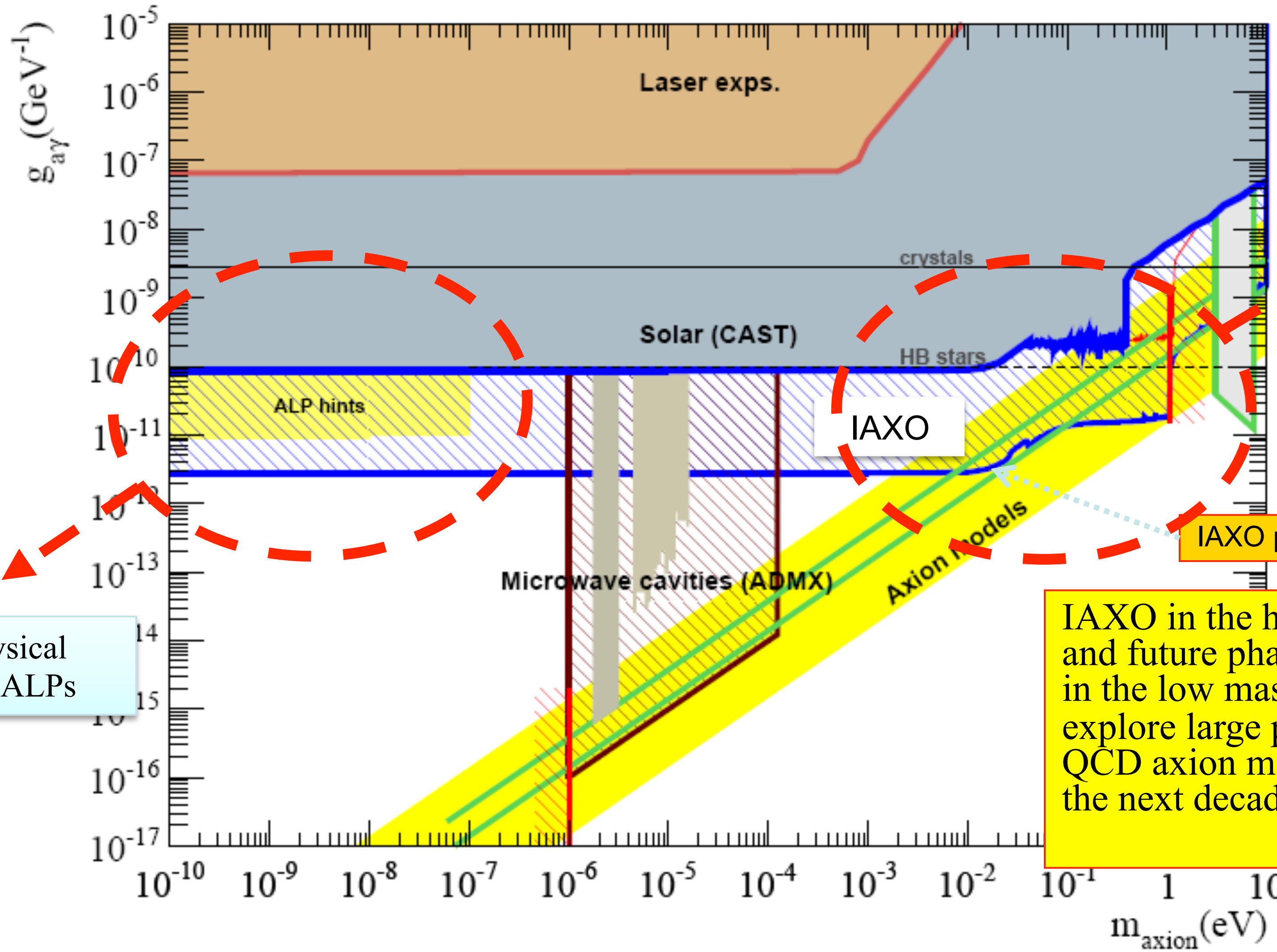



Optimised configuration: TOROIDAL with 8 bores
25 m long, 5 m diameter and a peak field of 6 T



# Axion search exclusion plots




Much larger QCD axion region explored

Astrophysical hints for ALPs

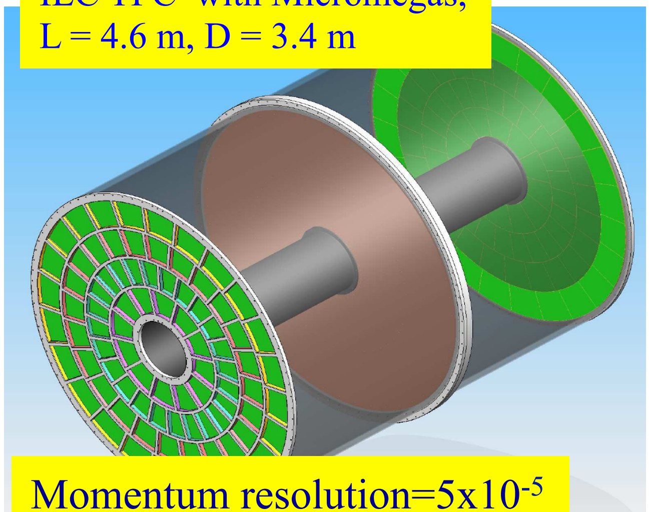
IAXO prospects

IAXO in the high mass end, and future phases of ADMX in the low mass end will explore large part of the QCD axion model region in the next decade.

# ILC TPC project - *Large International collaboration*

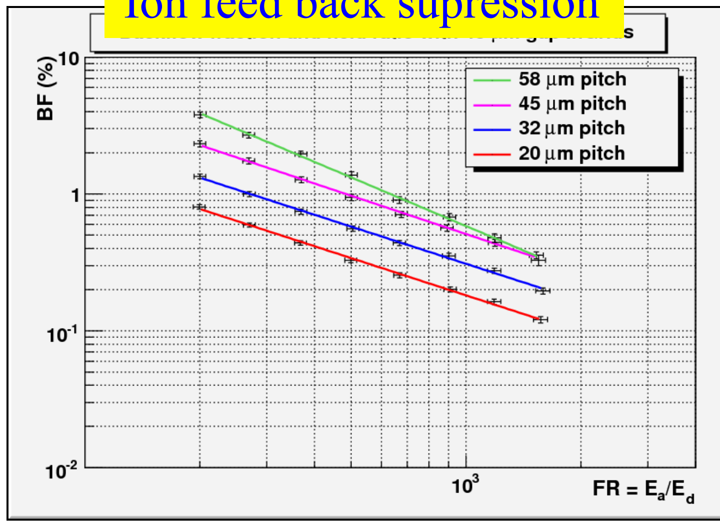
*G. Aarons et al., arXiv:0709.1893, M. S. Dixit et al., NIMA 518 (2004) 521, M. Kobayashi et al.,NIMA581(2007)265,*

ILC TPC with Micromegas,
L = 4.6 m, D = 3.4 m

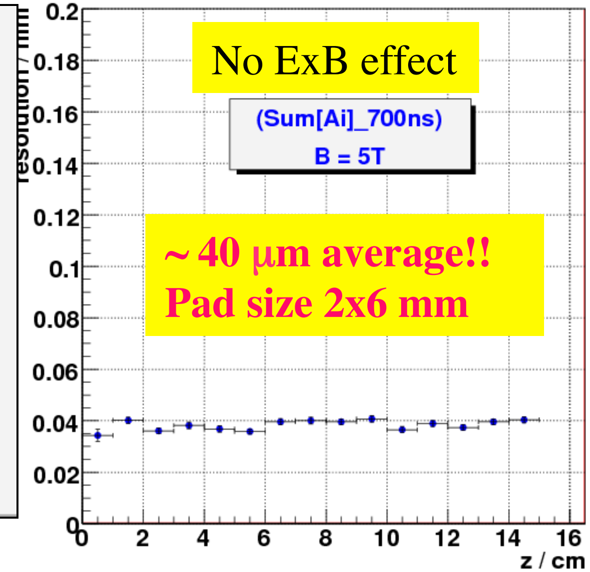


Momentum resolution=$5x10^{-5}$

Ion feed back supression

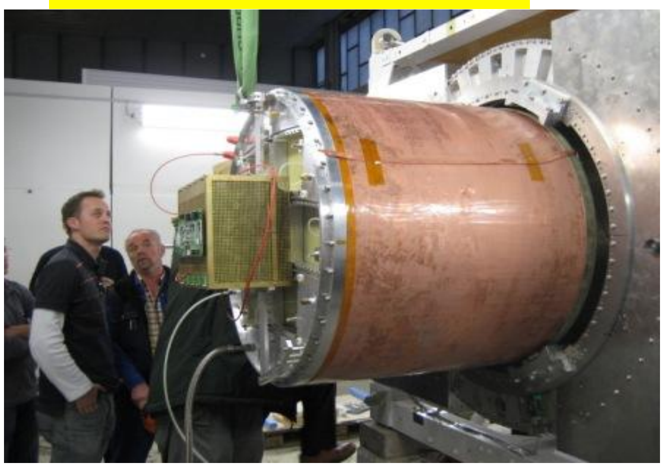



No ExB effect

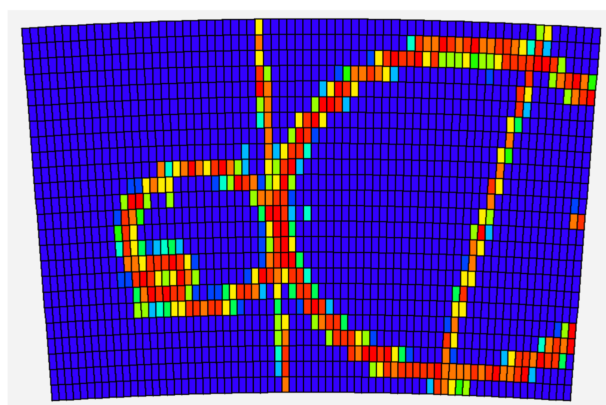



**~ 40 µm average!!**
**Pad size 2x6 mm**

ILC TPC prototype
with Micromegas



Event in DESY test beam



## TPC Micromegas advantages

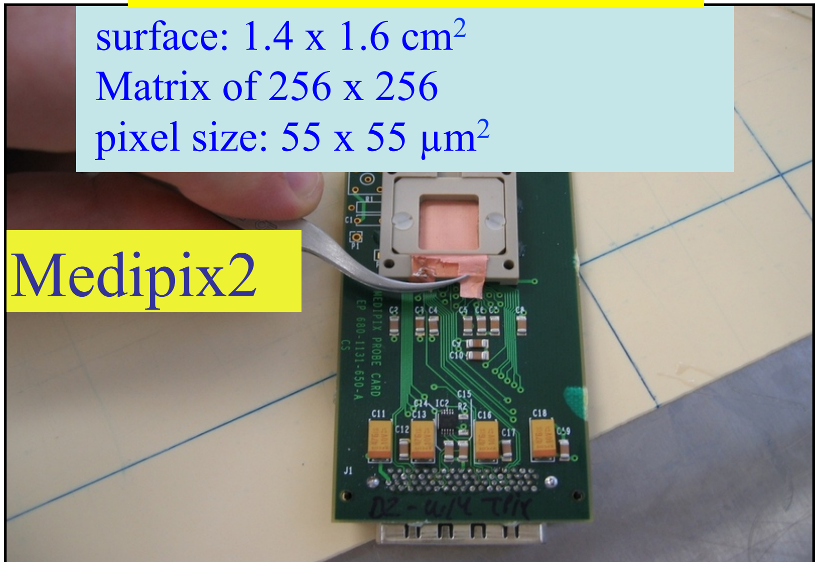
- Ion suppression .1%
- No ExB effect
- Great resolution ~ 40 µm
- Good energy resolution

# Micromegas + micro-pixels

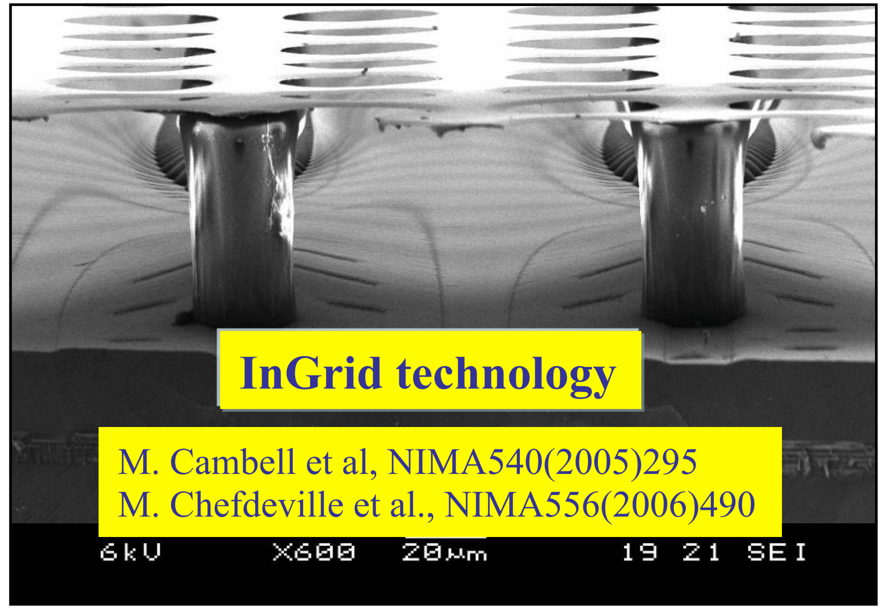
P. Colas et al., NIMA535(2004)506

surface: 1.4 x 1.6 cm$^2$
Matrix of 256 x 256
pixel size: 55 x 55 μm$^2$

Medipix2

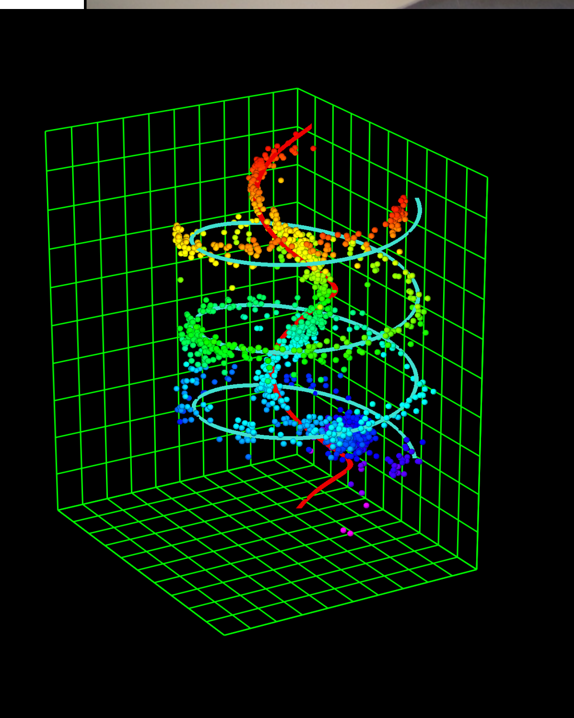


Nikhef, Saclay, Bonn collaboration
Industrialization by Bonn is going on

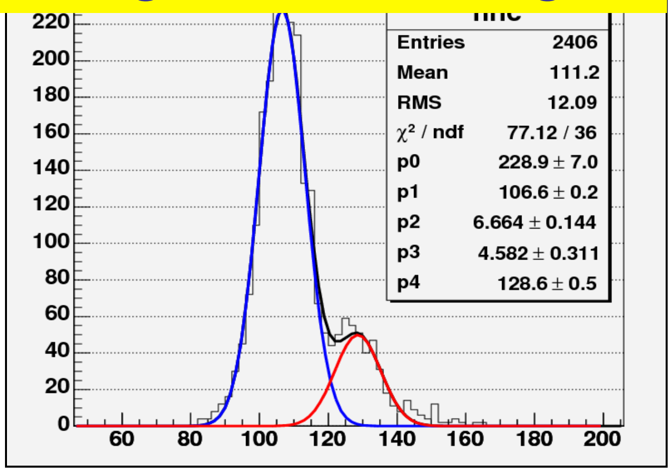



**InGrid technology**

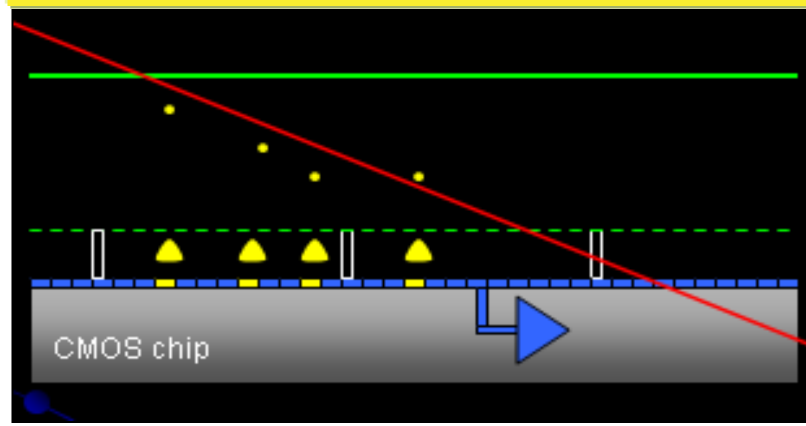
M. Cambell et al, NIMA540(2005)295
M. Chefdeville et al., NIMA556(2006)490



**Great resolution**
**Single electron counting!!**



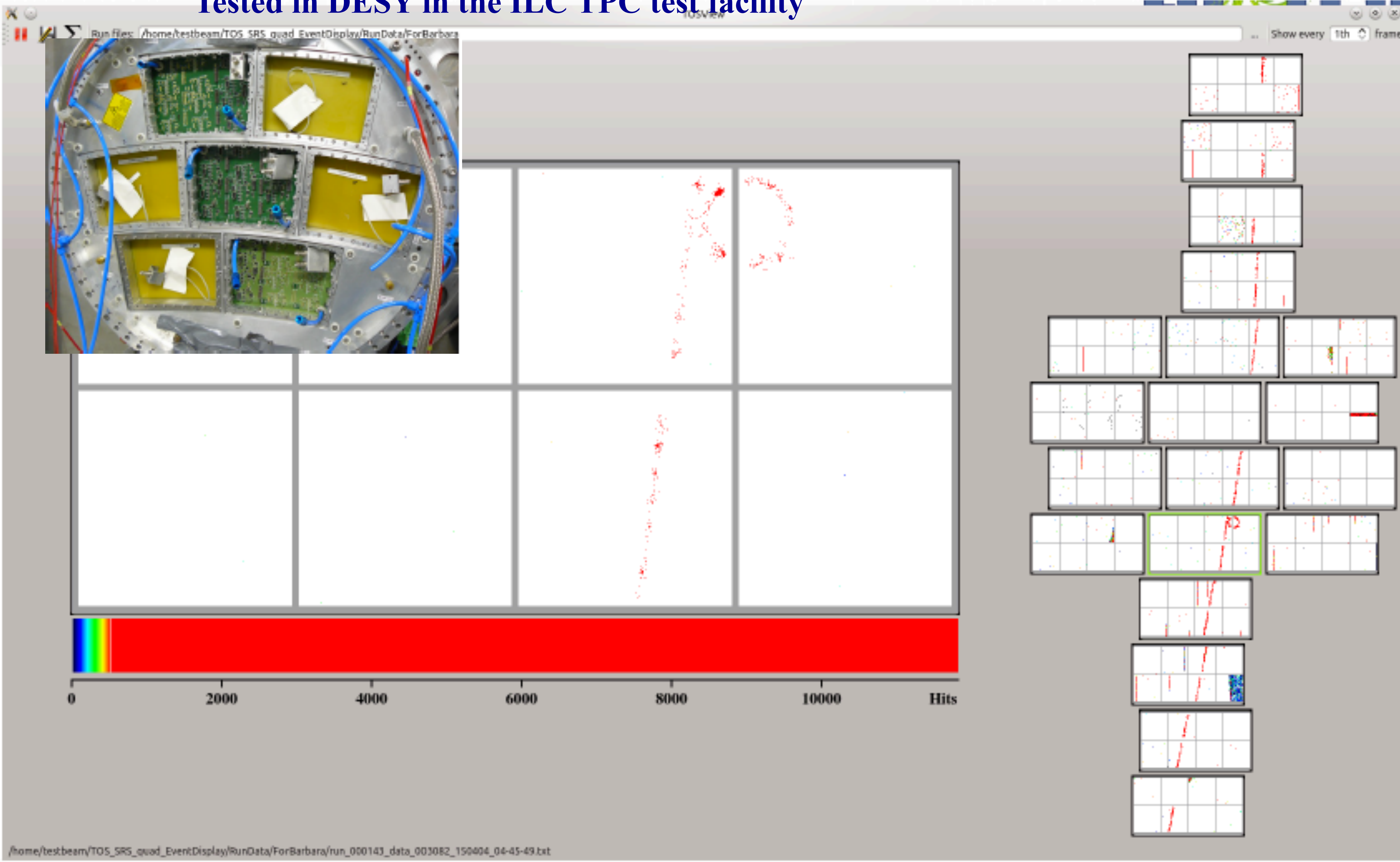

Gas On Slimmed SIlicon Pixels (GOSSIP)
Under study for ATLAS SLHC tracker



# InGrid Industrial production assured by Bohn University

**2015 successful test beam: large TPC read-out with 160 InGrid detectors (320cm$^2$)**

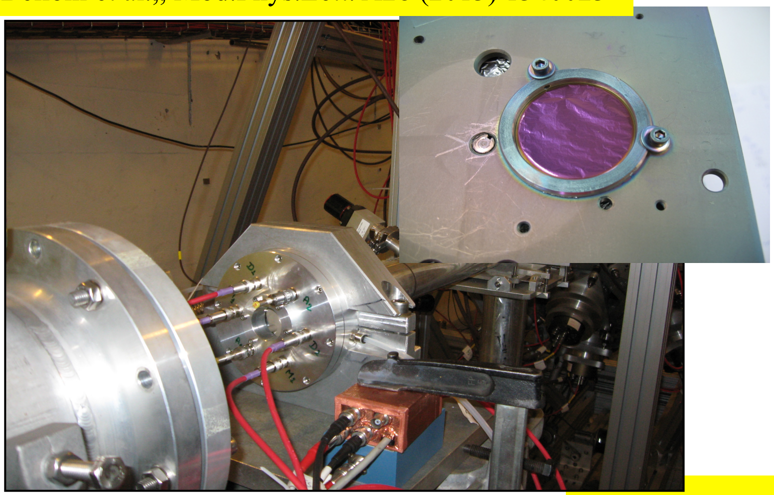
**Tested in DESY in the ILC TPC test facility**



# Applications in neutron detection

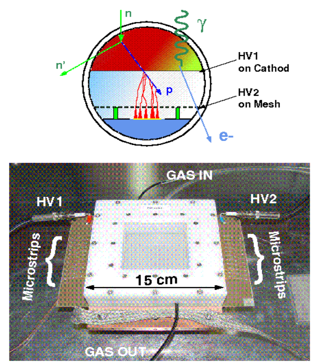
## n-TOF MicroMegas-based neutron transparent flux monitor and profiler

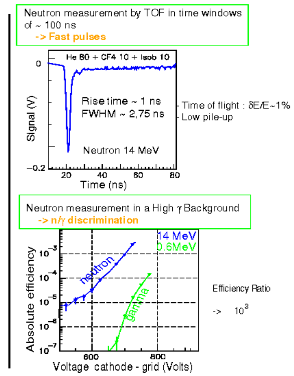
F. Belloni et al.,, Mod.Phys.Lett. A28 (2013) 1340023

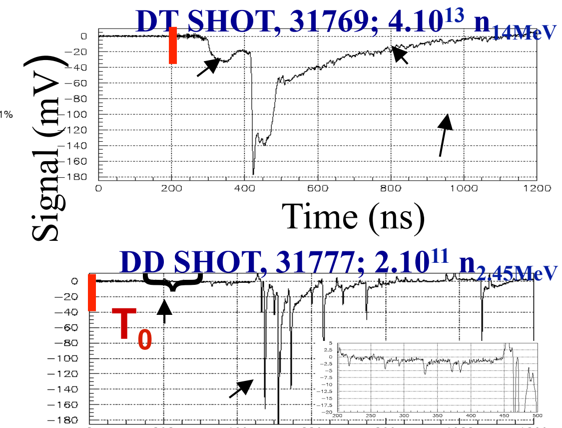


## Micromégas Concept for Laser MégaJoule and ICF Facilities

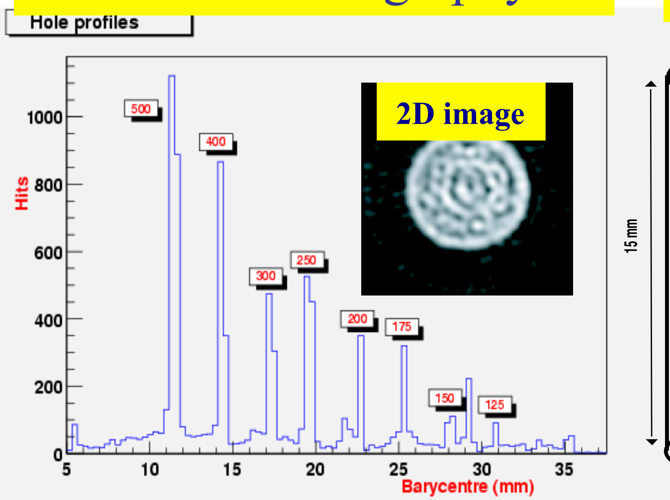
M. Houry et al., NIM,557(2006)648



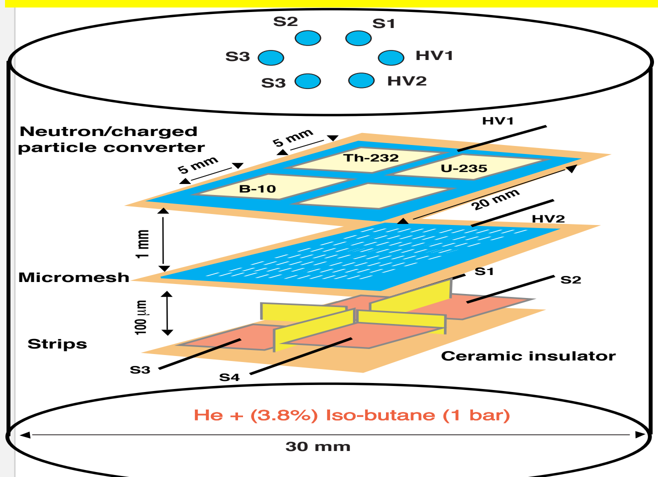



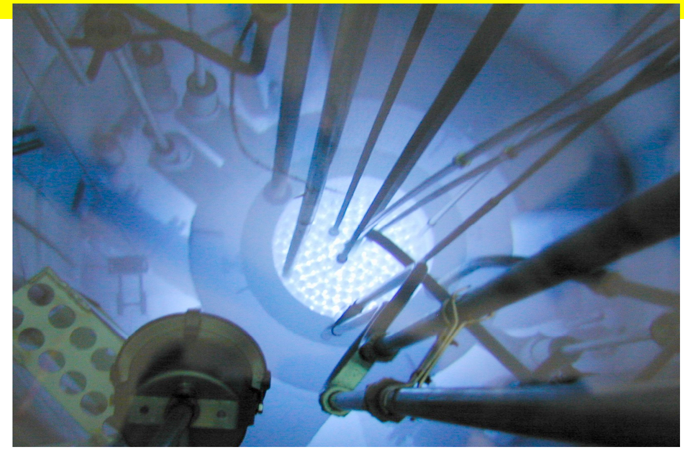

## neutron tomography




## Piccolo Micromegas, Nuclear reactor in-core neutron measurement

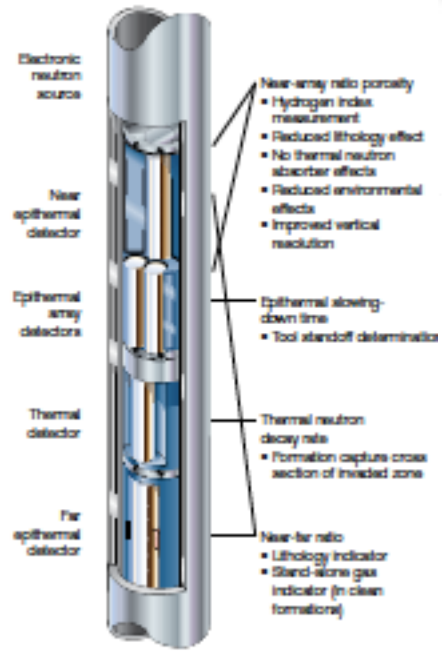
*J. Pancin et al., NIMA, 592(2008)104*



# Petroleum search using neutron detectors

*Neutron Logging idea by B. Pontecorvo*




**The idea is to build a multilayer Micromegas with thin Bo-10**

**Goal:**

- **thermal neutron efficiency >>30%**
- **much bigger surface detection than He-3 detector**

# MICROMEGAS PHOTODETECTOR
## Reflective mode

J. Derre et al, NIM, vol. 449, (2000) p. 314–321

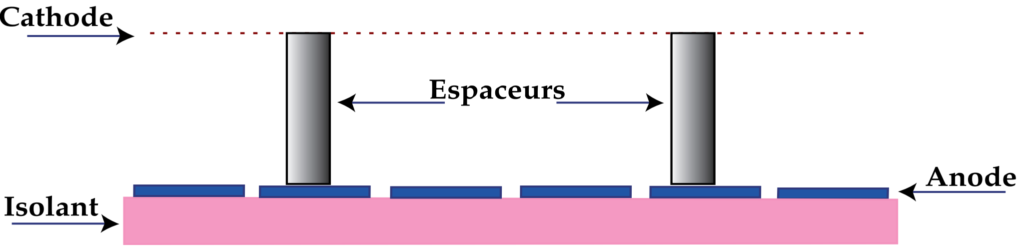



Figure 1

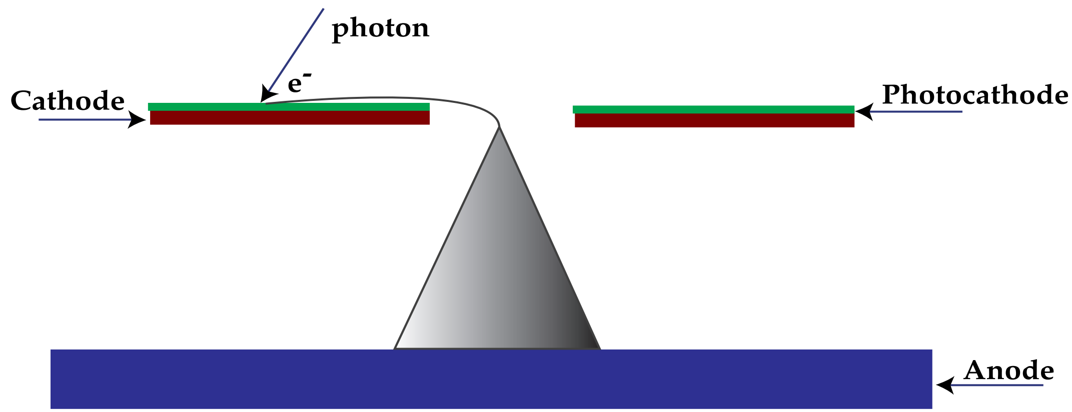
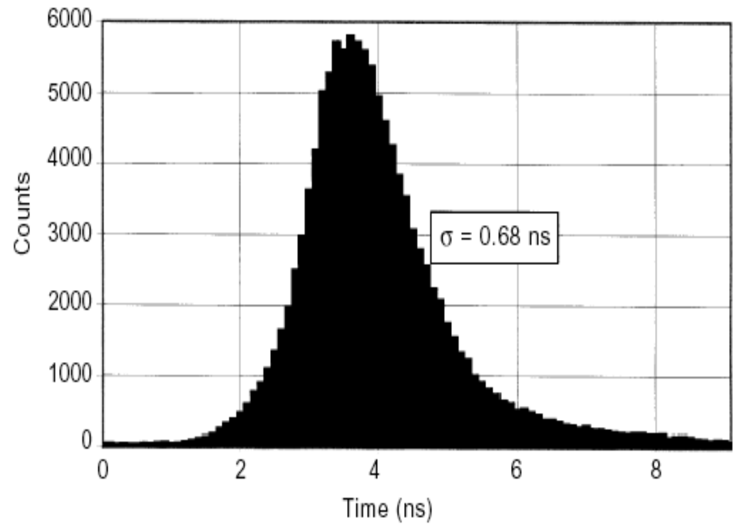



Figure 2

Sub-nanosecond time resolution

With single electrons from a UV hydrogen flash lamp



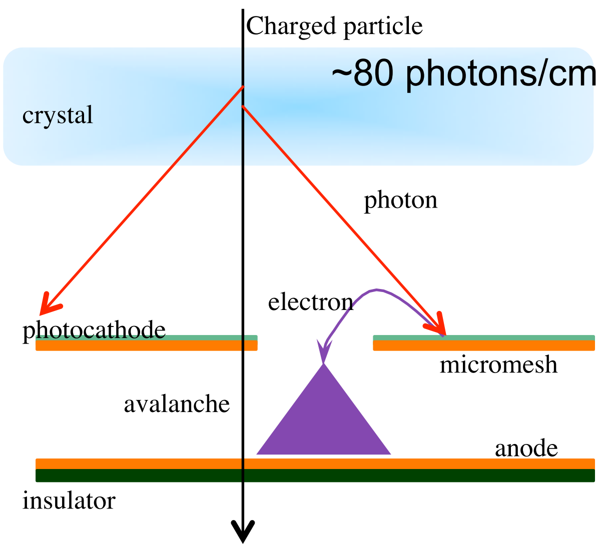

**With N2 fast laser we got a better resolution of 400 ps with single electrons**

# Towards pico-second timing

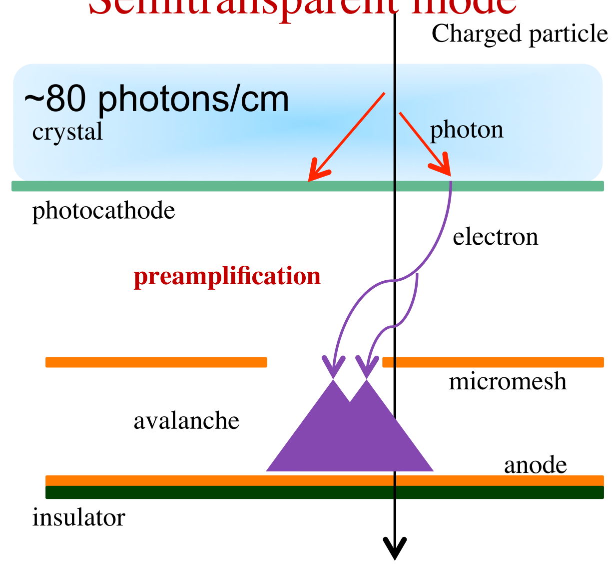
***Collaboration: Saclay-CERN-Princeton aprooved by RD51***

E. Delagnes, G. Fanourakis, E. Ferrer Ribas, I. Giomataris, C. Godinot, D. González Díaz, U. Joshi, Changguo Lu, M. Kebbiri, K.T. McDonald, H. Muller, E. Olivieri, T. Papaevangelou, A. Peyaud, F. Resnati, L. Ropelewsky, R. Veenhof, S. White

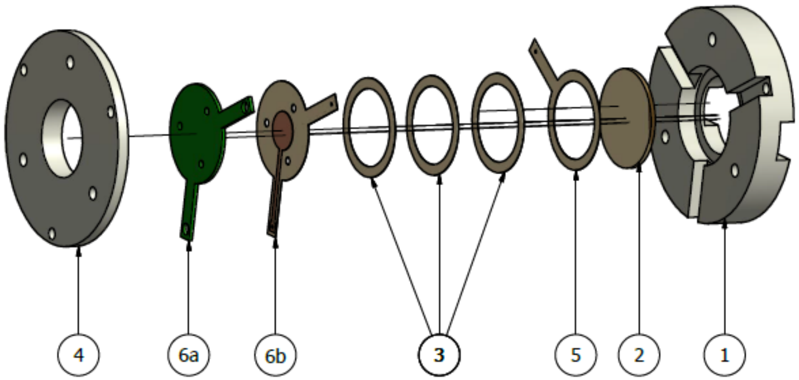
## Reflective mode

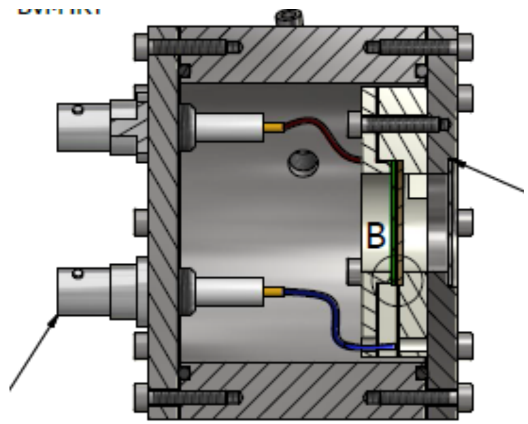


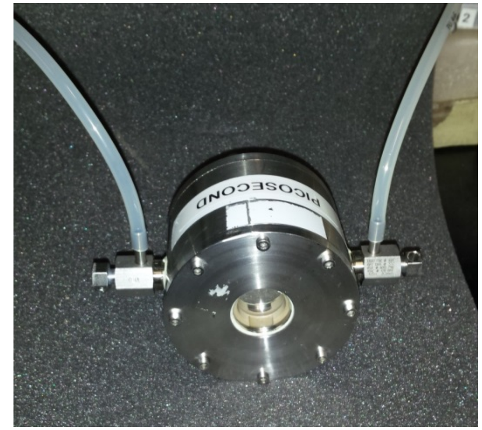

## Semitransparent mode



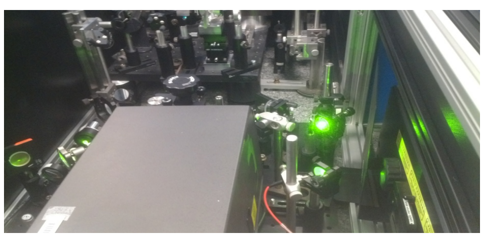
# Detector prototype

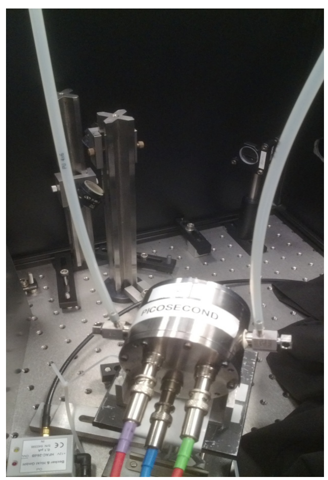


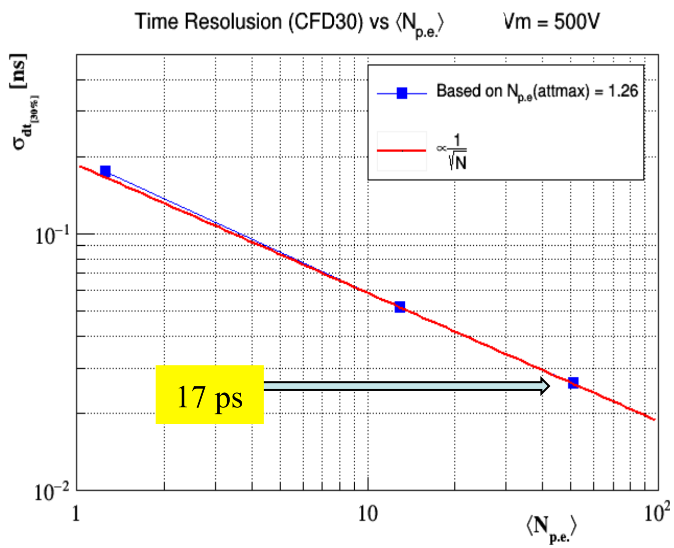



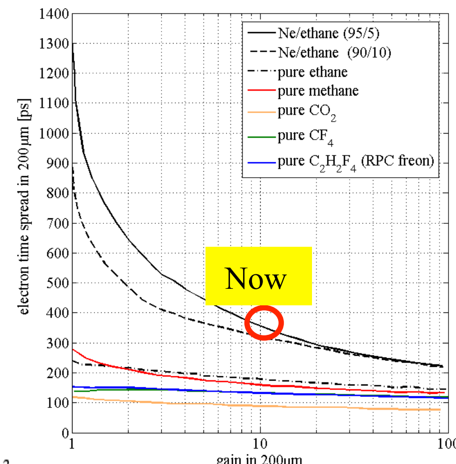




## Measurements @ IRAMIS laser








Encouraging results (17 ps) + growing interest!

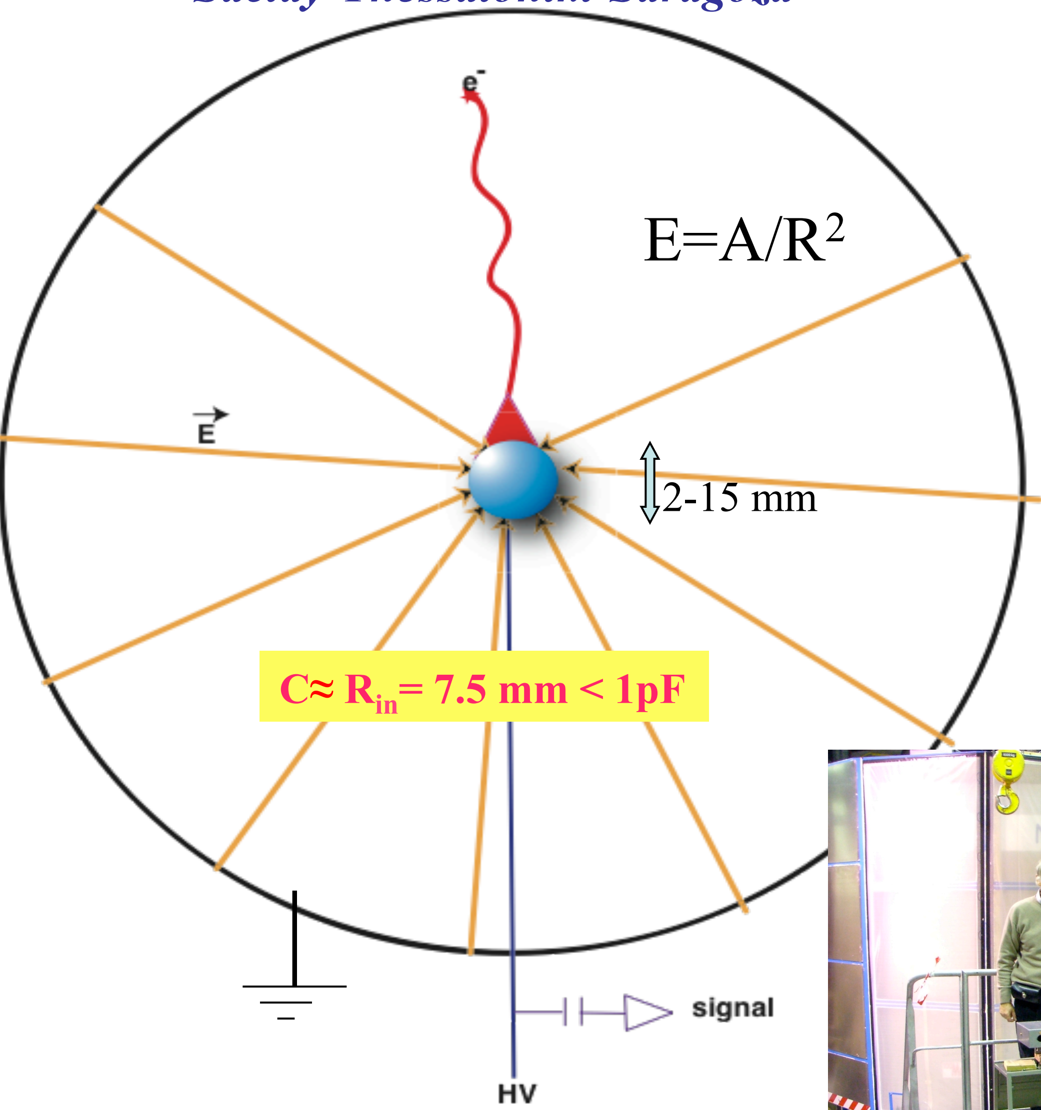
# Second part

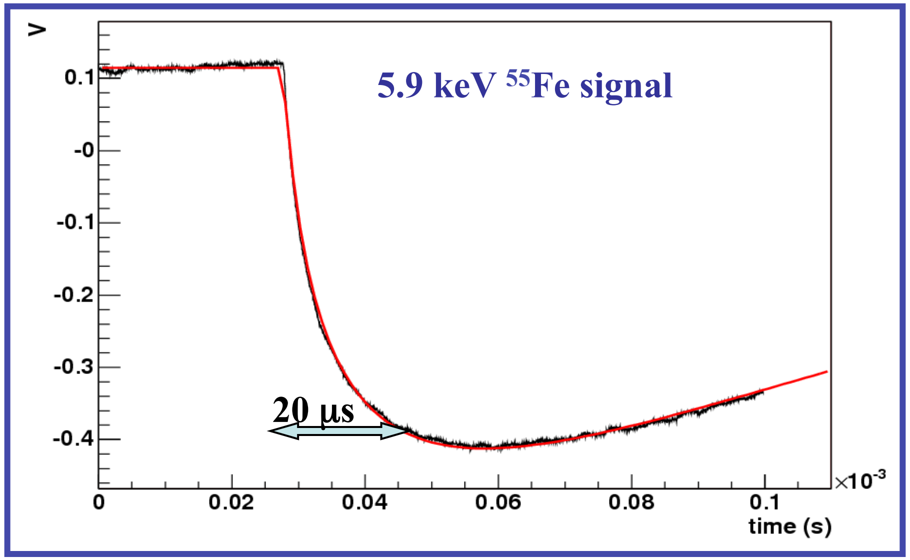
# Spherical detector, light-dark matter search and neutrino physics

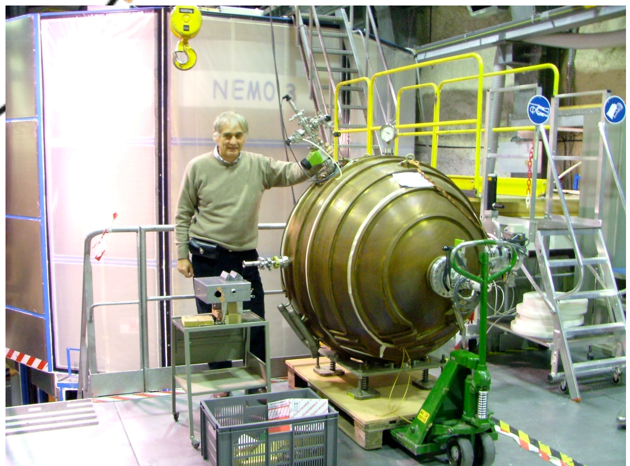
# Radial TPC with spherical proportional counter read-out

*Saclay-Thessaloniki-Saragoza*

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




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

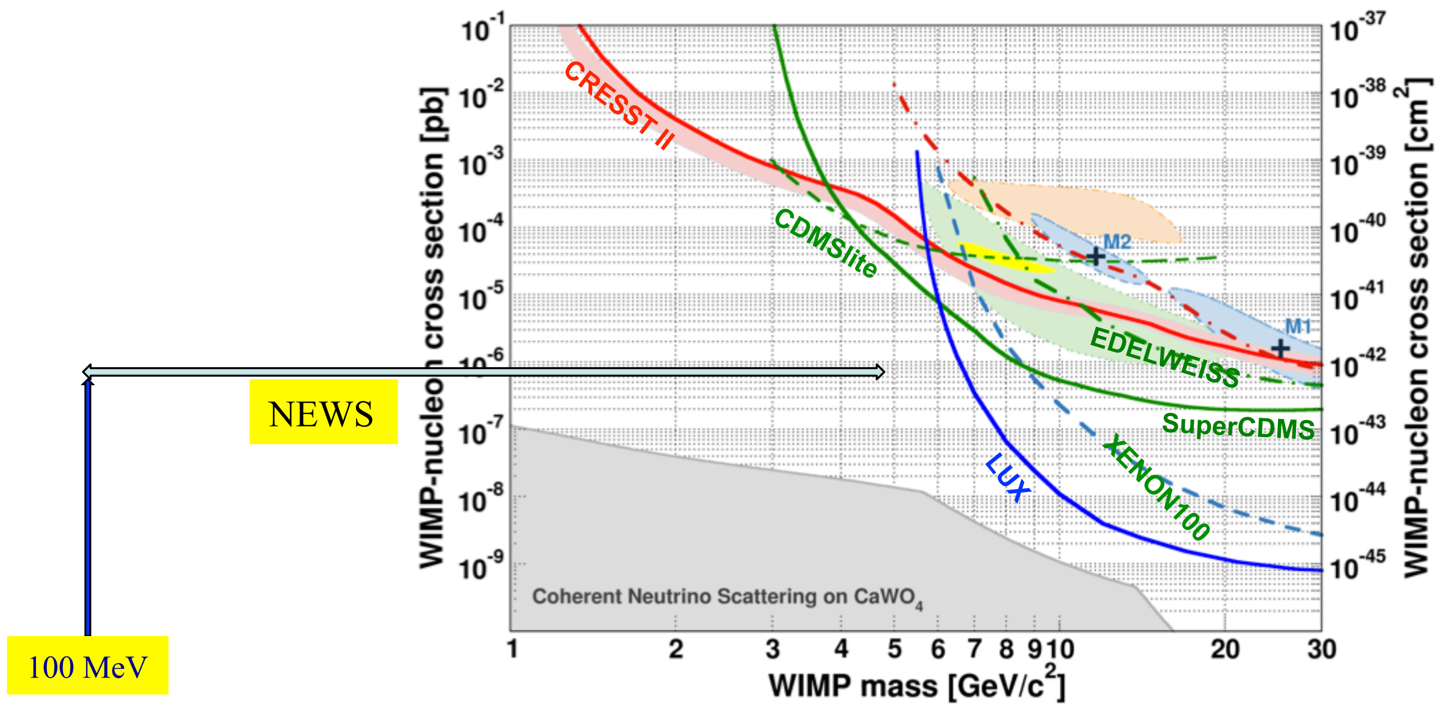
# NEWS

# Light dark matter search using the spherical detector

## GOAL: EXPLORE DM MASSES DOWN TO 100 MEV

**Motivated by:**

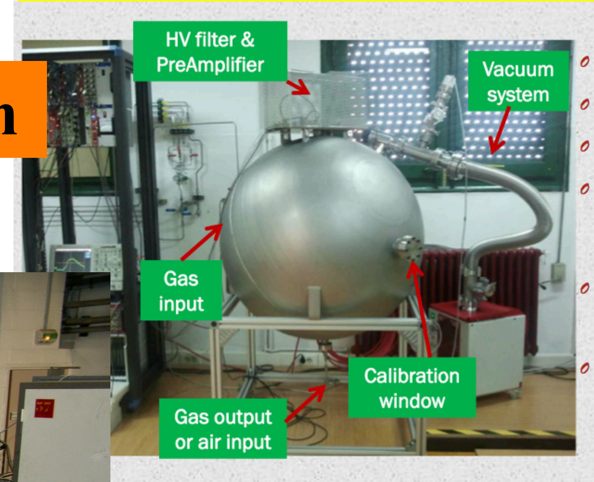
- **Sub-keV energy threshold of the detector**
- **Versatility of the low-Z target (H, He, Ne)**
- **Low background capability of this design**



# Spherical detector propagation

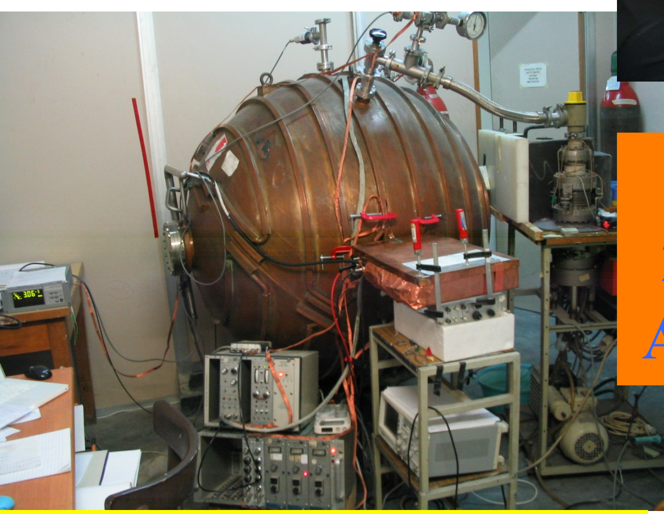
Low background detector d=60 cm p=10 bar

University of Saragoza detector




Basic R@D  detector in Saclay

**Future project**
**2m detector will be developed**
**At SNOLAB (G. Gerbier et al.)**



University of Thessaloniki detector

University of Tsinghua - HEP detector

**NEWS collaborating Institutes and people - Spherical detector project**

**IRFU Saclay**, *E. Bougamont1, J. Derre, A. Dastgheibi-Fard, J. Galan, I. Giomataris, G. Gerbier, M. Gros, P. Magnier, J. P. Mols, X.F. Navick, B. Paul, P. Salin, G. Tsiledakis*

**LSM MODANE**, *P. Loiza, F. Piquemal,* **Univ. of Thessaloniki**, *I. Savvidis*

**NCR Dimokritos Athens**, *G. Fanourakis,* **Univ. of Ioannina**, *J. D. Vergados*

**Univ. of Saragoza,** *P. Iguaz, I. Irastorza,* **IHEP**, *Zhimin Wang, Ruiguang Wang*

**Univ. of Tsighua,** *C. Tao,* **Univ. of *Shanghai Jiao Tong,*** *K. Giboni, K. Ni*




**Bibliography**

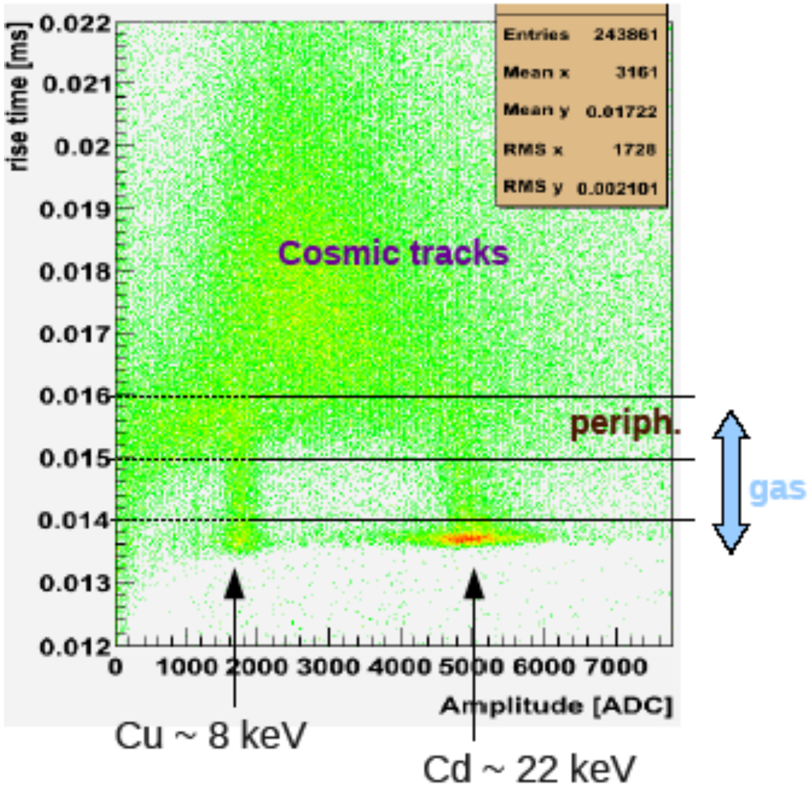
I Giomataris et al., JINST 3:P09007,2008., I Giomataris and J.D. Vergados, Nucl.Instrum.Meth.A530:330-358,2004, I. Giomataris and J.D. Vergados, Phys.Lett.B634:23-29,2006.

I. Giomataris *et al.* Nucl.Phys.Proc.Suppl.150:208-213,2006., S. Aune *et al.*, AIP Conf.Proc.785:110-118,2005.

J. D. Vergados et al., Phys.Rev.D79:113001,2009., E Bougamont et al. *arXiv:1010.4132 [physics.ins-det], 2010*

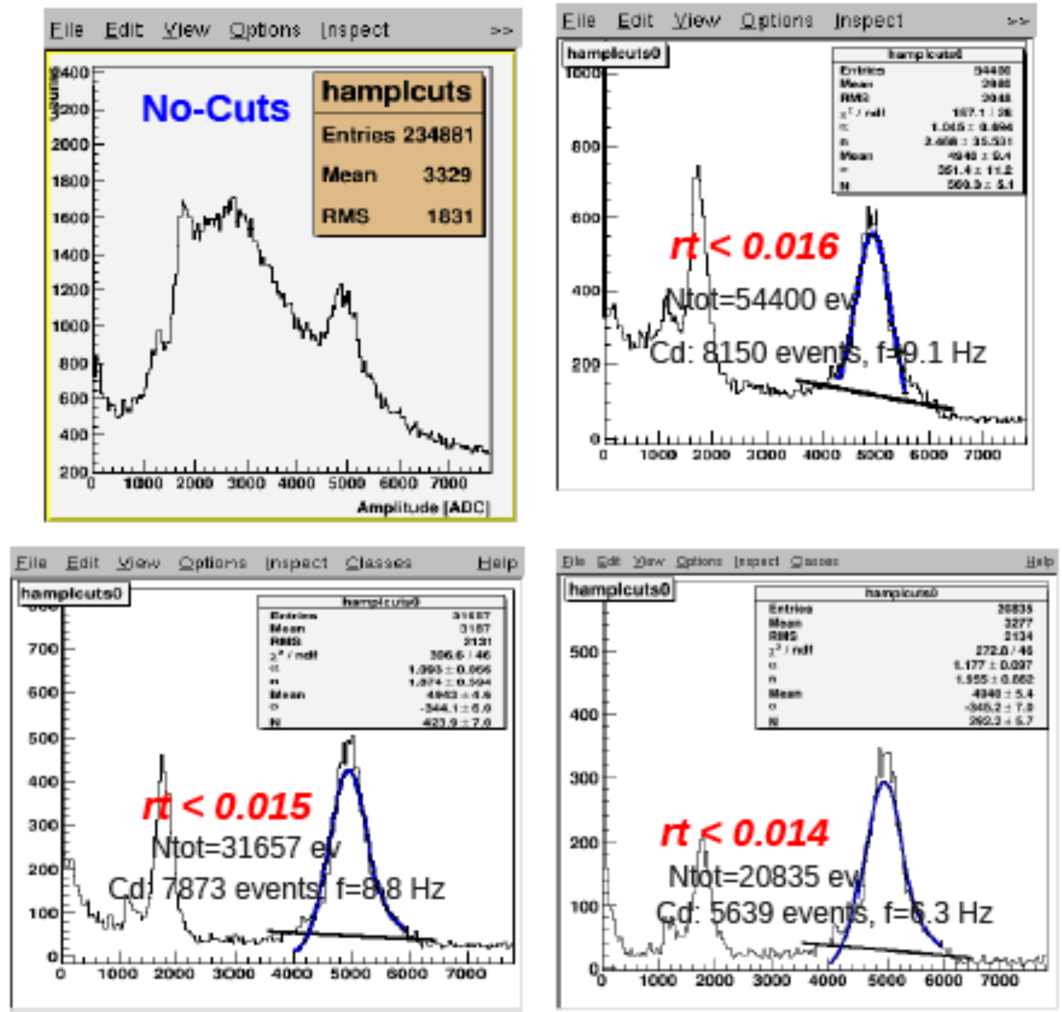
# Rejection power

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

## Rise time cut



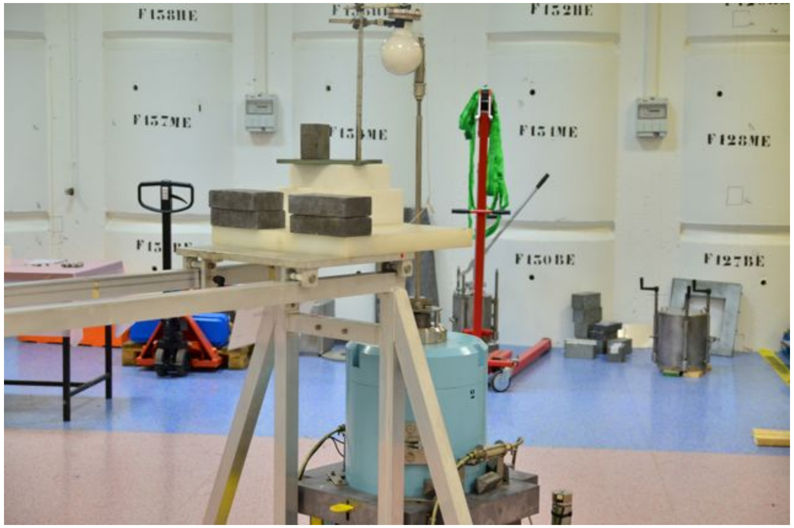

Efficiency of the cut in rt ==> ~ 70% signal (Cd peak)

Severe background reduction

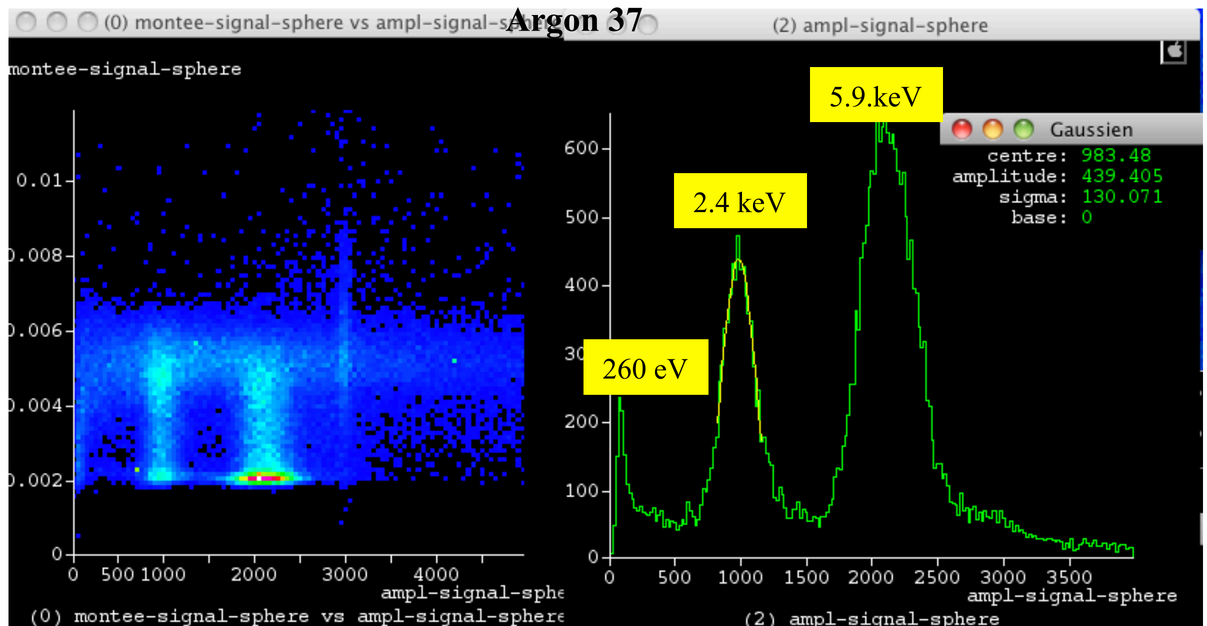
Energy resolution ~ 6 % and 9 % for Cu and Cd

# New low-energy calibration source *Argon-37*

Home made Ar-37 source: irradiating Ca-40 powder with fast neutrons $7 \times 10^6$ neutrons/s
Irradiation time 14 days. Ar-37 emits K(2.6 keV) and L(260 eV) X-rays (35 d decay time)




Argon 37

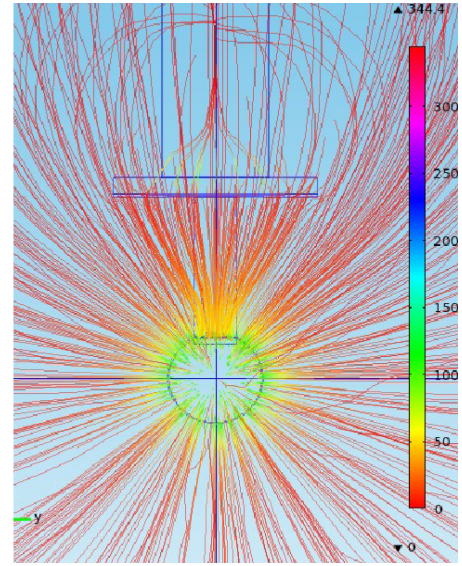


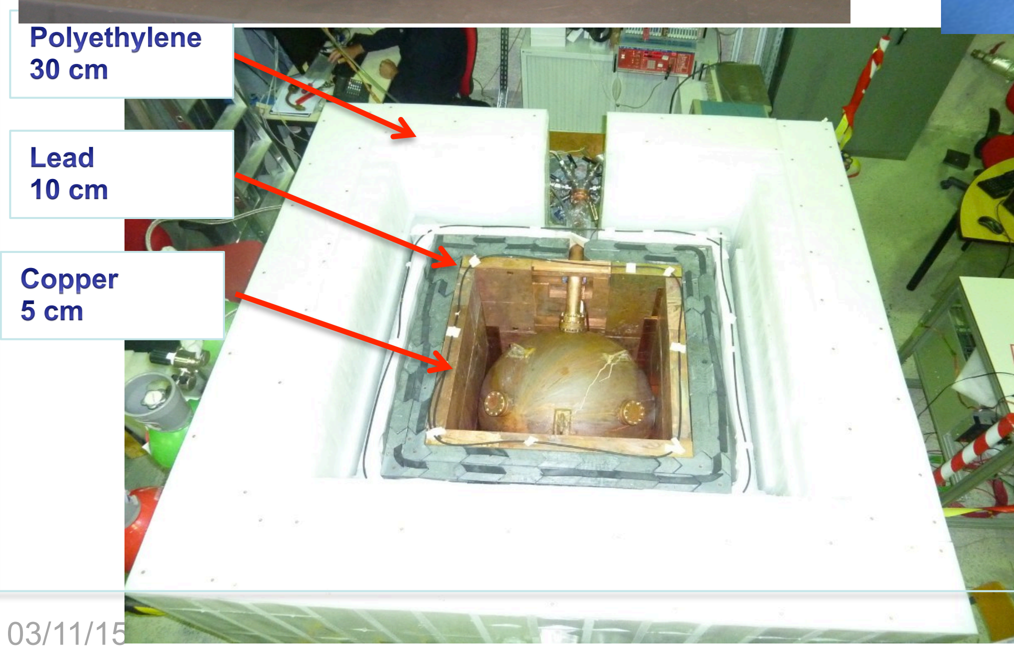

**First measurement with Ar-37 source**
**Total rate 40 hz**
**in 250 mbar gas, 8 mm ball**
**240 eV peak clearly seen**
**A key result for light dark matter search**

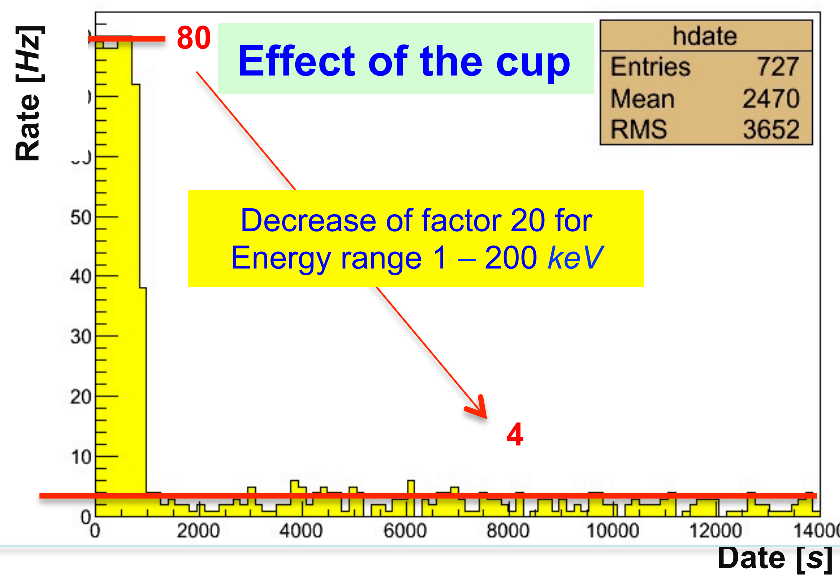
# Search for light dark matter

## Detector installed at LSM end 2012: 60 cm, Pressure = up to 10 bar

## Gas targets: Ar, Ne, He, CH4





# Internal contamination cleaning

# Goal: remove Po-210, Pb-210

## 1st chemical cleaning of sphere

**Conditions :**

- Nitric acid (17 %)
- Temperature 10° C
- Cleaning by filling the spherical cavity
- Washing by pure water
- Drying by hot nitrogen

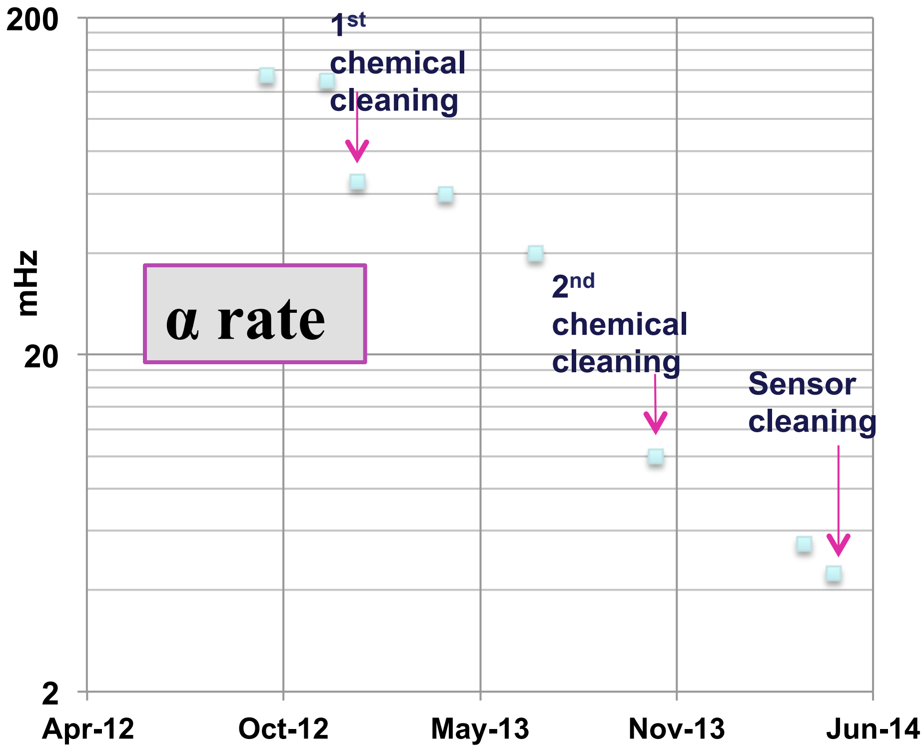
## 2nd chemical cleaning of sphere

**Conditions :**

- Nitric acid (30 %)
- Temperature 30° C
- Cleaning by spray
- Washing by pure water
- Drying by hot nitrogen

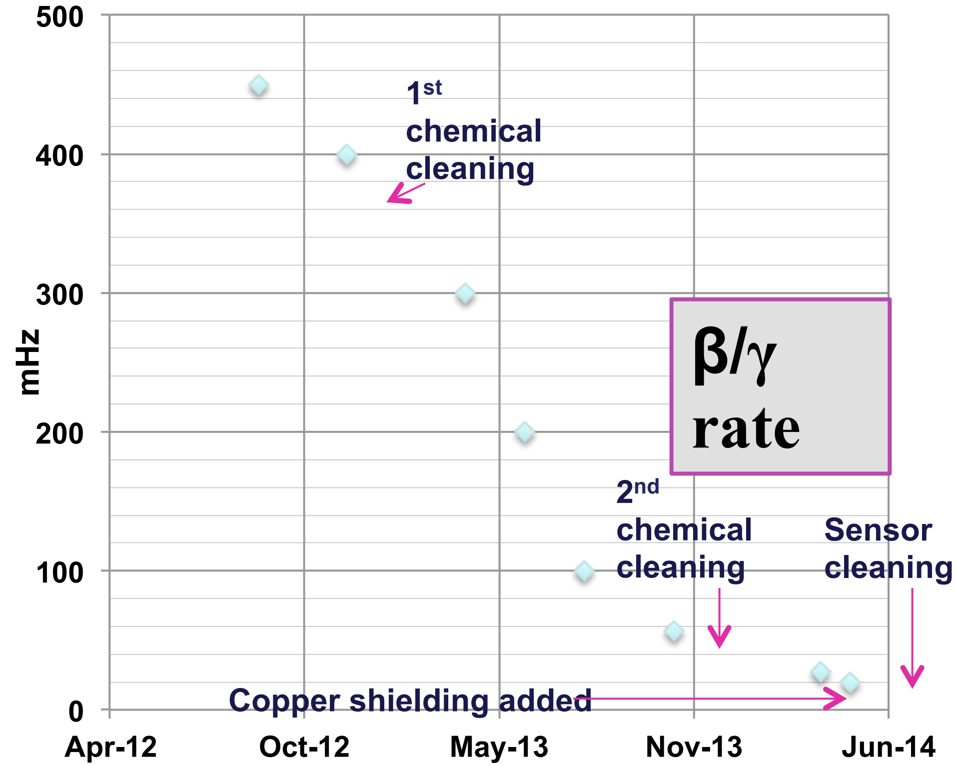
# Backround evolution of the detector

Alpha rate evolution




Decreasing factor = 45
180 *mHz* => 4 *mHz*

β/γ rate evolution

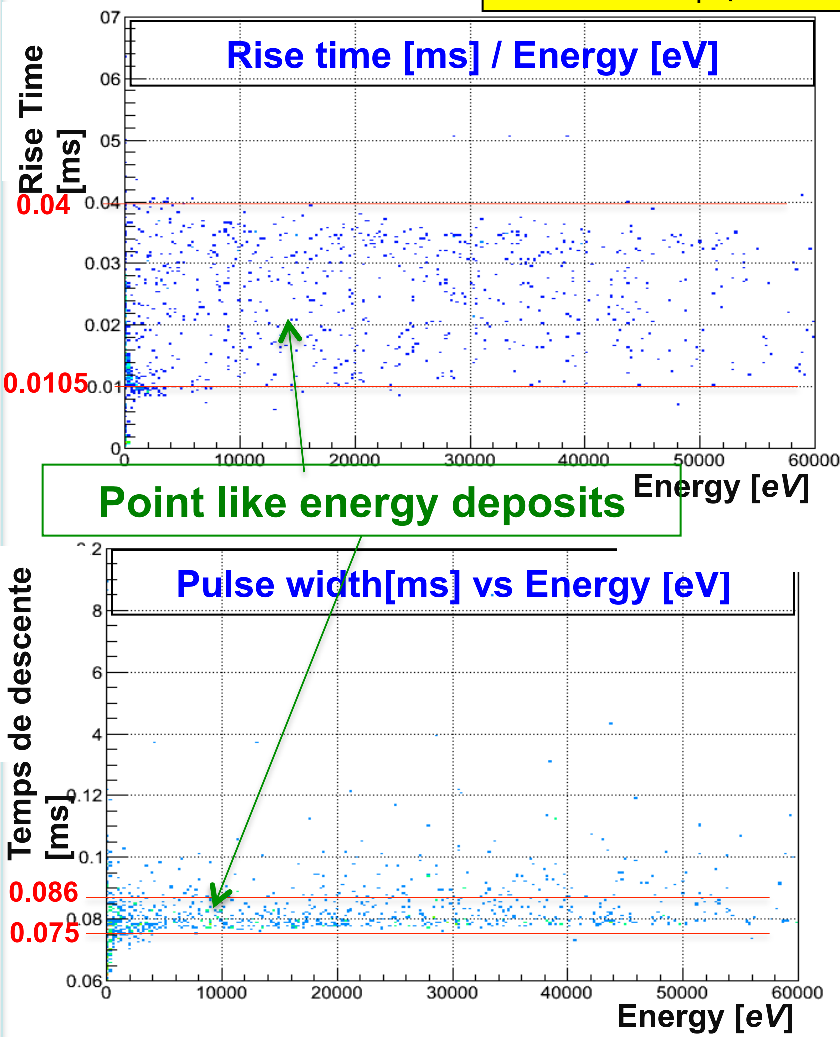


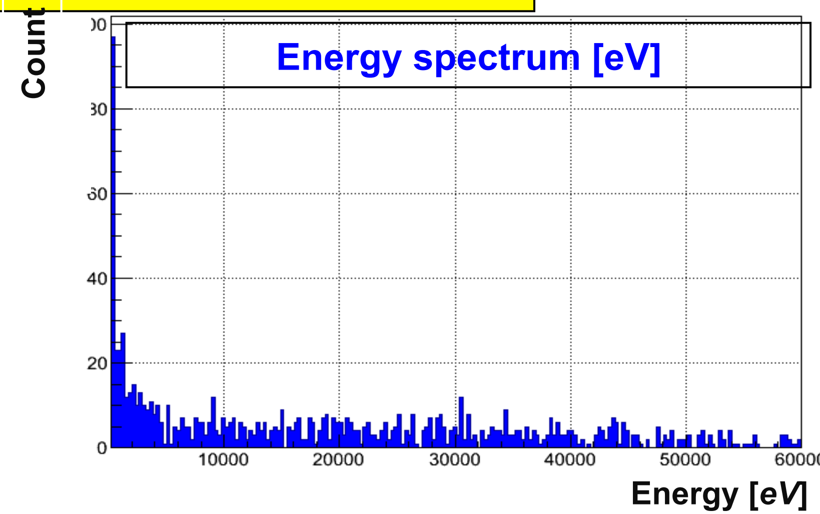

Decreasing factor = 20
400 *mHz* => 20 *mHz*

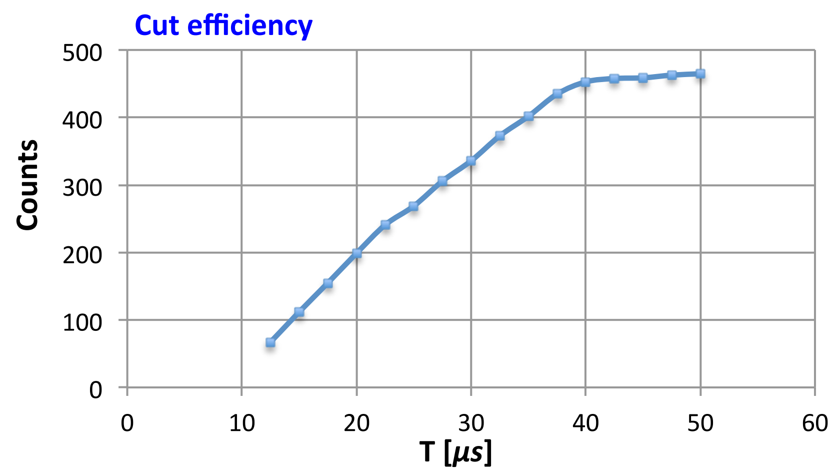
# Analysis – optimization of cuts

## Calibration with neutrons ($^{241}Am$-Be) source

Ne + $CH_4$ (0.7 %) P = 3 bar T = 4455 s

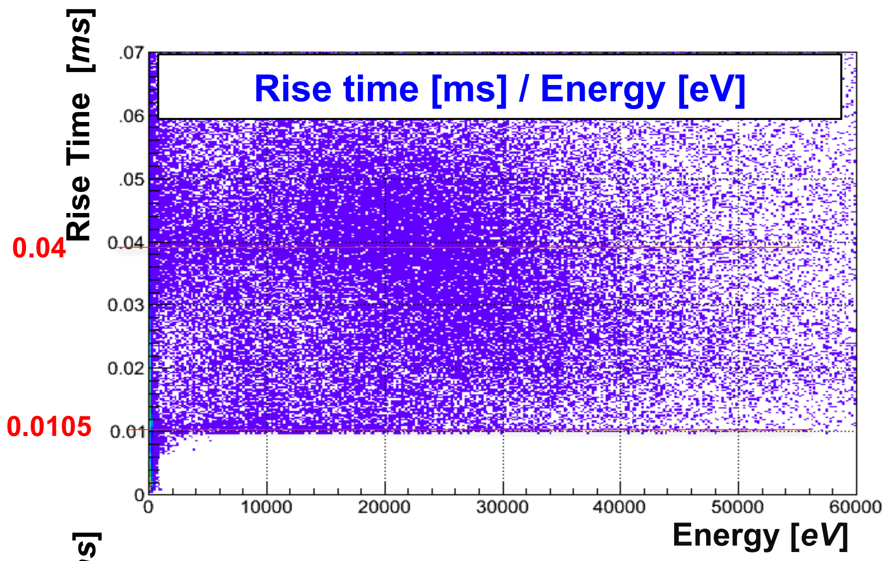


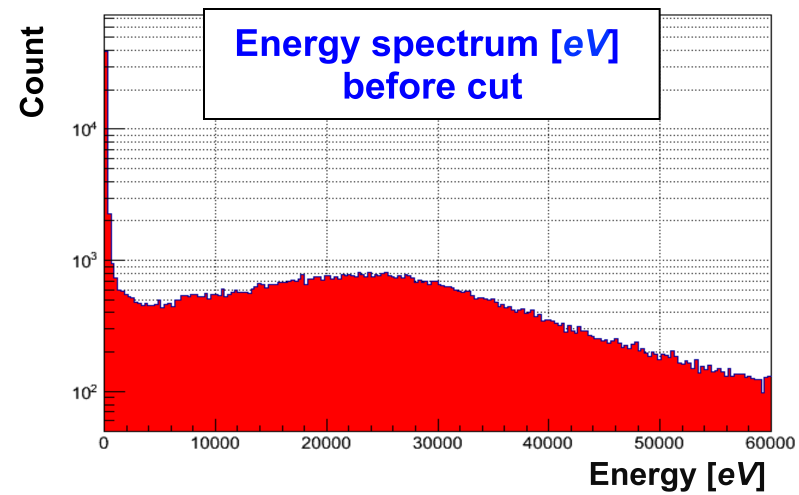



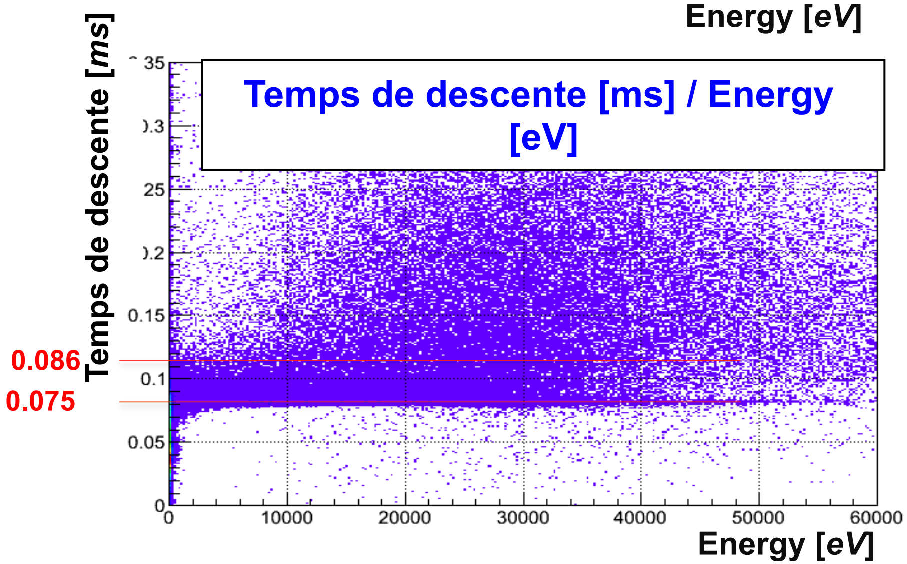



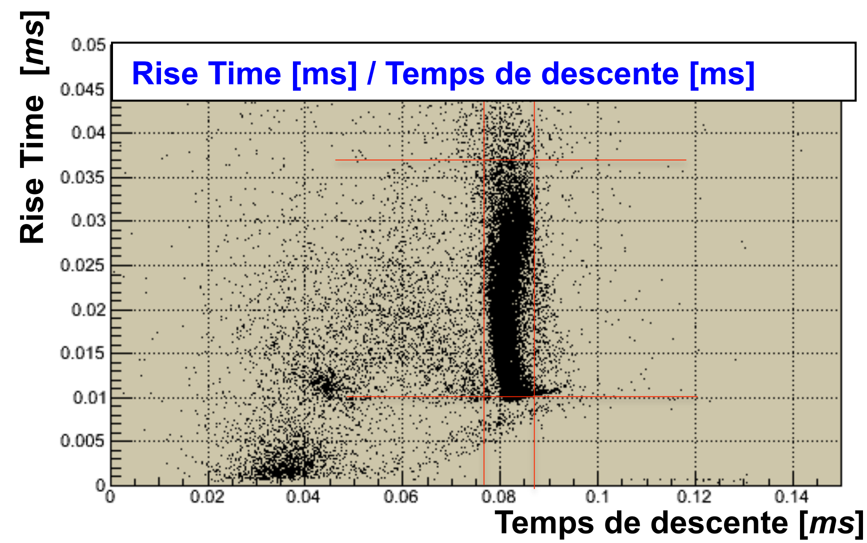
# Physic run (light-WIMPs research)

## Ne + $CH_4$ (0.7 %)  P = 3 bar  T = 30.5 jours



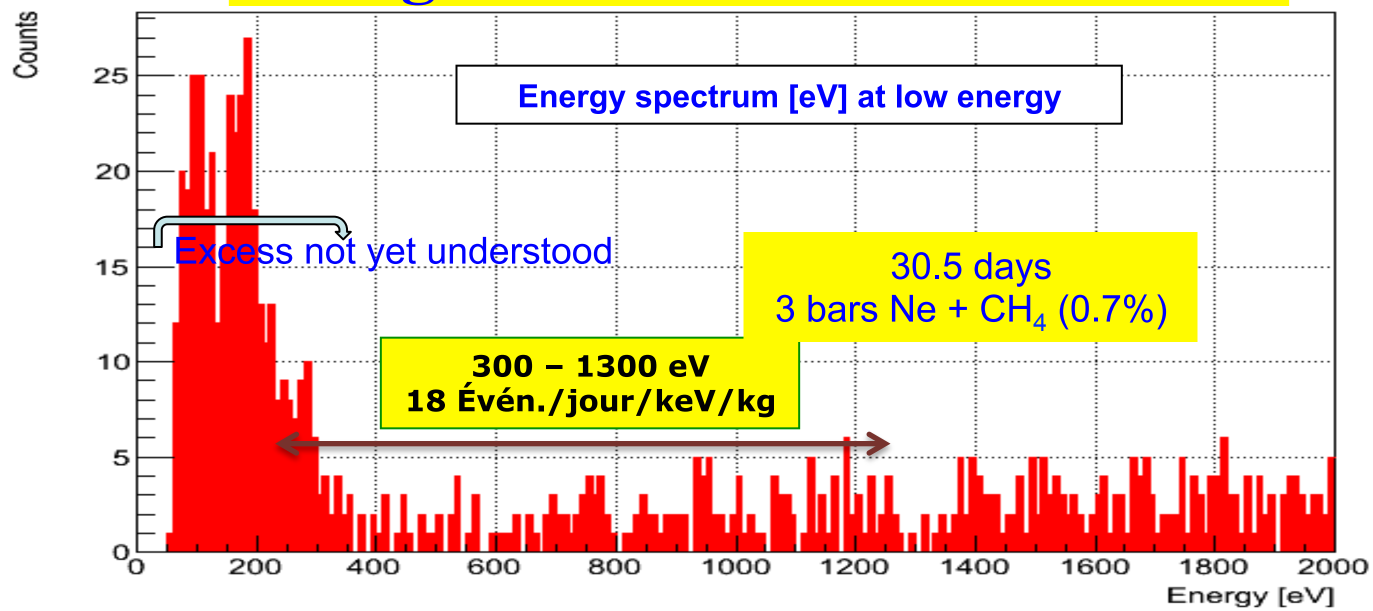



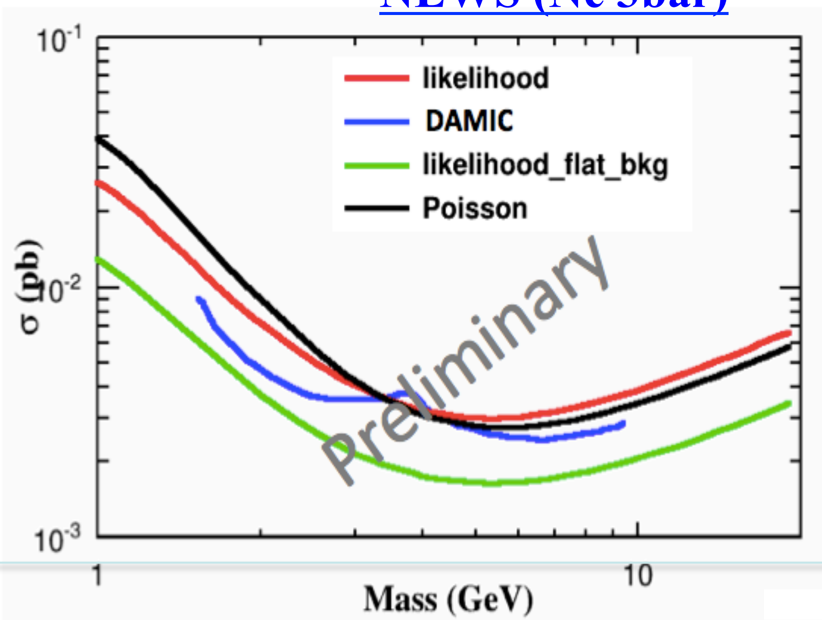



# Light WIMP search results

Count



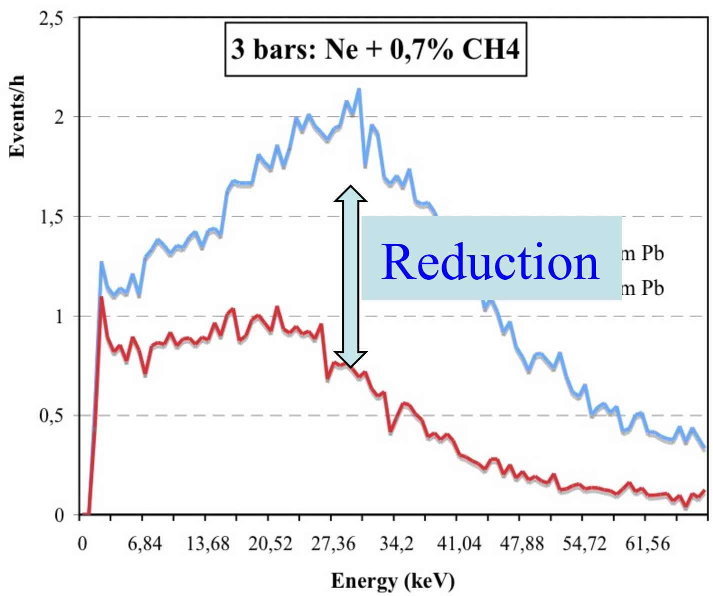

NEWS (Ne 3bar)



# Shield improvement

During last month intervention (May 2015)

- New platform fabricated and installed to carry detector and shield
- Chemical cleaning of internal copper shield plates
- Total lead thickness = 15 cm (from 10cm)
- Total copper thickness= 7 cm (from 5 cm)
- Improved anti-radon tent




**Summary**:

background level among the best experiments

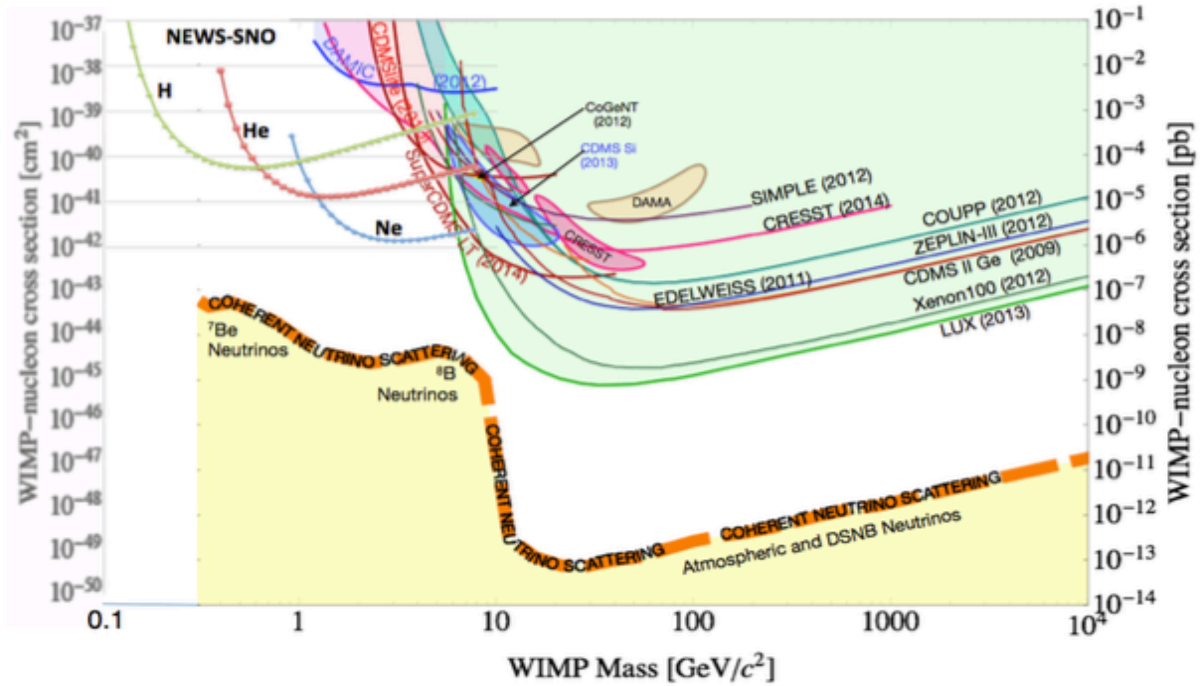
Achieved with modest budget and manpower

Combined with the low energy threshold and low-Z targets:

Sensitivity for very-light WIMPs of this experiment is out of competition

# NEWS-SNOLAB project

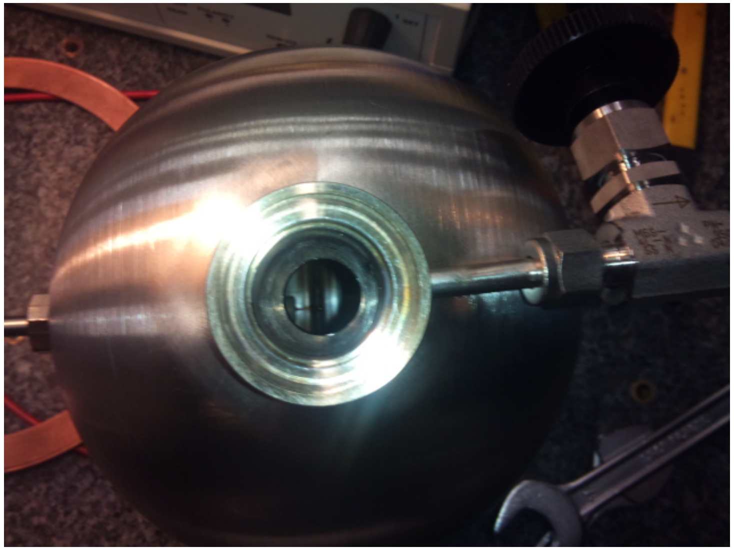
Kingston, Saclay, Grenoble, LSM, Thessaloniki…..
2 m detector at 10 bar
Pure water shield
Funded by Canadian grant of excellence
LOI recently approved by SNOLAB committee

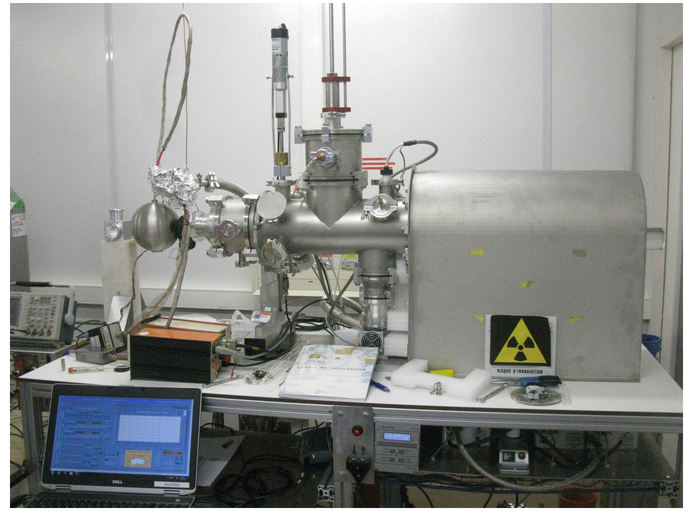



I. Giomataris

# Quenching factor measurements

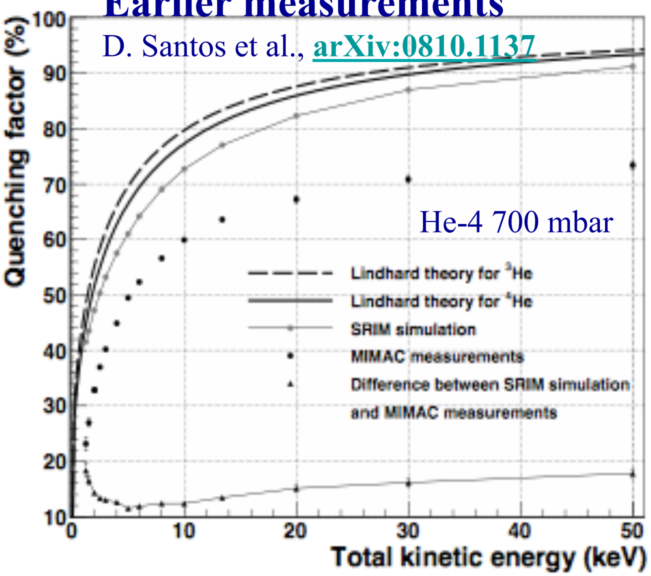
Goal: measure QF down to 500 eV ion energy using the Grenoble MIMAC facility for H, He, Ne, CF4, Ar, Xe at various pressures





**Earlier measurements**

D. Santos et al., arXiv:0810.1137




**Recent investigations with a 15 cm sphere show the capability to measure 500 eV He-4 ions with an estimated QF of about 25%**

***Saclay, Grenoble, Thessaloniki, Queen's-Kingston***

# Additional physics

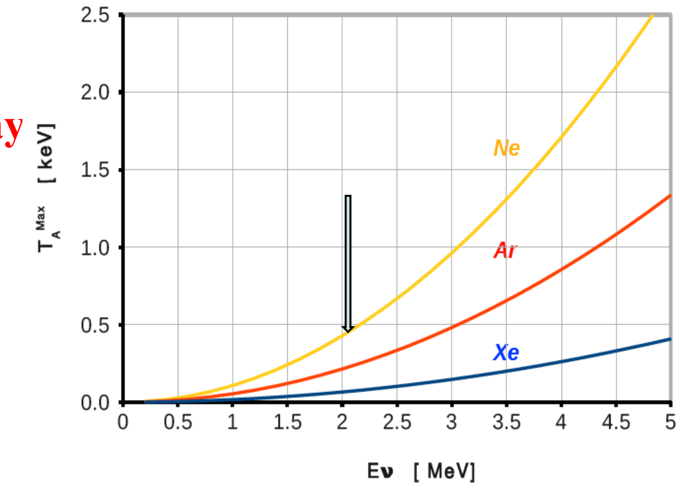
## Neutrino-nucleus coherent elastic scattering

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

### High cross section but very-low nuclear recoil

**Illustration: using the present prototype at 10 m from the reactor, after 1 day**

| Detector threshold (electrons) | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Xe | 105 | 32 | 3 | 0 |
| Ar | 42 | 24 | 9 | 4 |
| Ne | 18 | 12 | 7 | 4 |




## A dedicated Supernova detector

**Simple and cost effective - Life time >> 1 century**

**Through neutrino-nucleus coherent elastic scattering**

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

Sensitivity for galactic explosion

For p=10 Atm, R=2m, D=10 kpc, $U_\nu = 0.5\times10^{53}$ ergs

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

| He | Ne | Ar | Kr | Xe | Xe (with Nuc. F.F) |
|---|---|---|---|---|---|
| 0.08 | 1.5 | 6.7 | 23.8 | 68.1 | 51.8 |

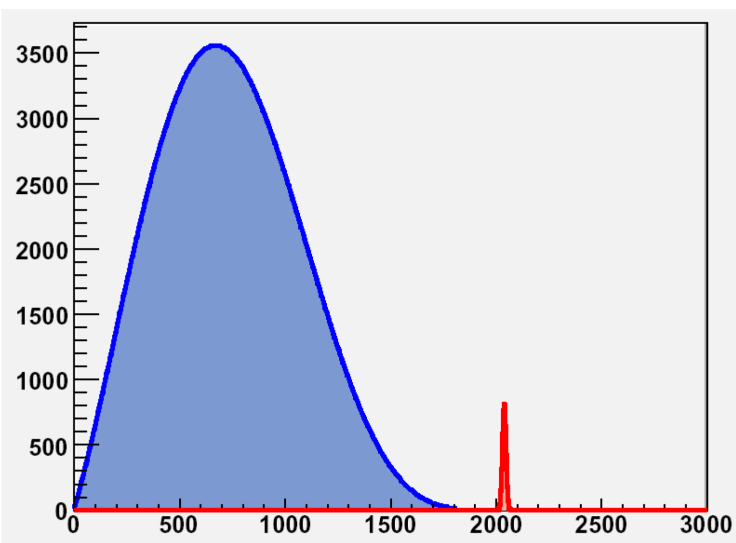
Idea : A world wide network of several of such dedicated Supernova detectors

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

# 0-$\nu$ ββ Decay

- If 0-$\nu$ decays occur, then:
  - Neutrino mass ≠0
  - Decay rate measures effective mass $\langle m_\nu \rangle$
  - Neutrinos are Majorana particles
  - Lepton number is not conserved
- Physics impact is great.

**Target >> 1000 Kgr and zero background**




- Xenon is relatively safe and easy to enrich
- Natural abundance of $^{136}$Xe is ~ 8%
- EXO and NEXT have 200 kg highly enriched in $^{136}$Xe
- Low cost
- Pressure variation

High density is desirable to contain event
But there is an upper limit! $\rho < 0.55$ g/cm$^3$
Beyond this density, $\delta E/E$ deteriorates rapidly!

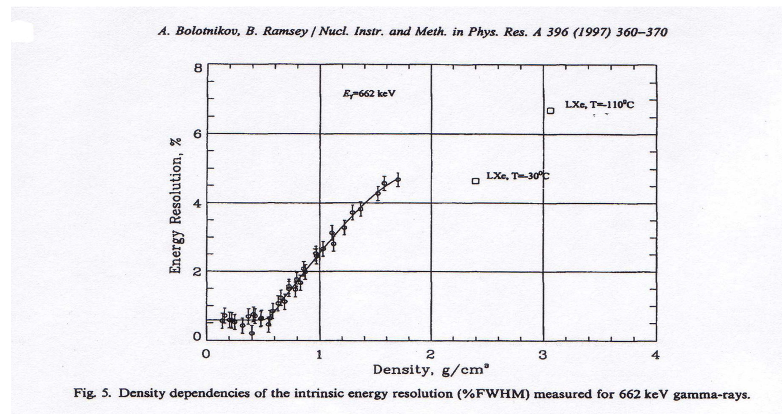
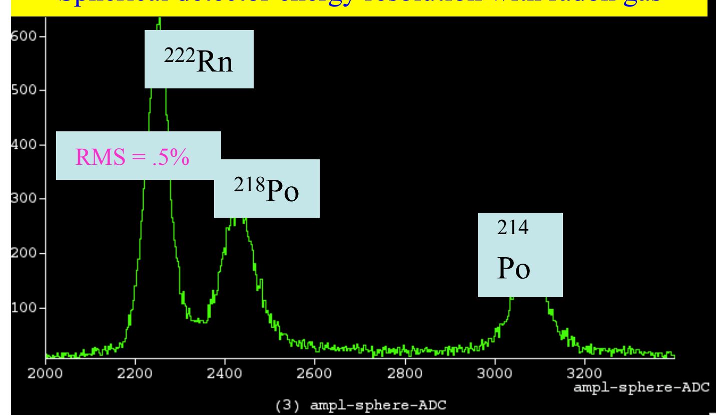


Fig. 5. Density dependencies of the intrinsic energy resolution (%FWHM) measured for 662 keV gamma-rays.

Spherical detector energy resolution with radon gas



# Current and future projects

| Experiment | Isotope | Method | Resolution (% at $Q_{\beta\beta}$) | Efficiency | Background ($10^{-3}$ c/keV/kg/y) | Isotope Mass (kg) | $m_{\beta\beta}$ (eV) |
|---|---|---|---|---|---|---|---|
| GERDA | $^{76}Ge$ | ionization | 0.16 | 0.8 | 10-1 | 15-35 | 100-200 |
| EXO | $^{136}Xe$ | liquid TPC | 3.3 | 0.7 | 1-0.5 | 160 | 100-200 |
| KamLAND-Zen | $^{136}Xe$ | scintillation | 9.5 | 0.8 | 0.5-0.1 | 360-1000 | 90-190 |
| CUORE | $^{130}Te$ | bolometer | 0.19 | 0.9 | 10-1 | 206 | 60-160 |
| NEXT | $^{136}Xe$ | gas TPC | 0.7 | 0.3 | 0.2-0.06 | 90-1000 | 90-190 |
| SNO+ | $^{150}Nd$ | scintillation | 6.5 | 0.5 | 10-1 | 40-500 | 40-140 |
| SuperNEMO | $^{82}Se$ | tracko-calo | 4.0 | 0.3 | 0.4-0.06 | 7-100 | 200-300 |

**ANEMOS project: Development of a high-pressure spherical detector demonstrator for neutrino less double beta decay search**

**In collaboration with CNBG ( F. Piquemal et al.,), CPPM (J. Busto et al.,)**

The goal is to reach a record low background level << $10^{-4}$/keV/Kg/y and an energy resolution of .3%

We target a sensitivity of $m_{bb}$ <50 meV better than other experiments

## ANEMOS strategy

- Demonstrate the ultra-low background capability with a small size 60 cm detector at a pressure of 50 bar
- The 2 m dark matter detector at SNOLAB will demonstrate the scaling (2 m detector ) needed for the double beta decay experiment (1 ton scale Xe-136)
- The combination of the two detectors and the good energy resolution to be reached in the R@D phase, will give the proof of principle of an optimized DBD experiment as required for the next generation projects

**A main idea is to take advantage of the detector simplicity to severely reduce backgrounds emitted from surrounding materials**

**ANEMOS demonstrator**

Identical size to SEDINE (60cm)
Made of ultra-pure copper
Transported with special castle to avoid
Radon contamination and activation
Installation inside the current LSM shield (improved)

I. Giomataris

# ANEMOS Sensitivity

**Simulation model**

Sphere diameter: 2 m

Xenon gas at 50 bar (1272 Kg)

Vessel: Copper PNNL μBq/kg $^{232}$Th=.034, $^{238}$U=.13

Shield 30 cm copper PNNL

GEANT simulation by J. Galan

- We assume complete suppression of external backgrounds
- Backgrounds are generated by $^{232}$Th and $^{238}$U contamination

of detector and shield

Results

Background rate in the region of $Q_{bb}$ (2.46 MeV)

$1.54 \times 10^{-5}$/keV/Kg/ year

$8. \times 10^{-5}$/keV/Kg/ year

(compared to $2 \times 10^{-3}$/keV/Kg/ year of running experiments)

# Double beta decay experiment with the spherical detector

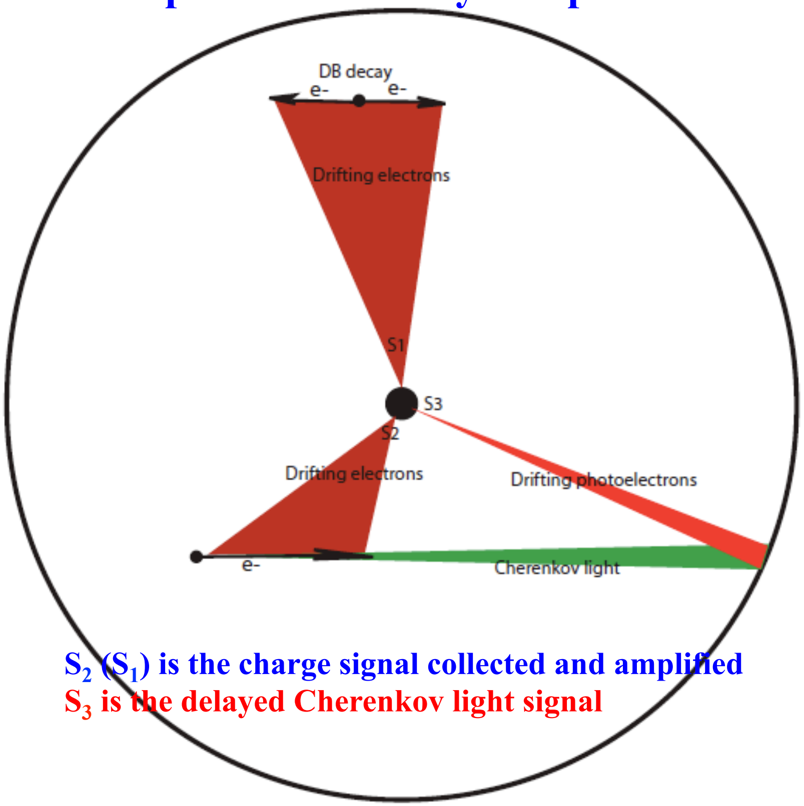
**If additional rejection is required: new idea**

**Background free double beta decay experiment**, *I. Giomataris, arXiv:1012.4289*

**The idea is to detect Cherenkov light emitted by two electrons and then reject background from single electrons (Compton scattering etc..)**

**Xenon-136 at high pressure of about 25-40 bar is ideal to keep high efficiency for double electrons, Good enough electron path and reduce multiple scattering**

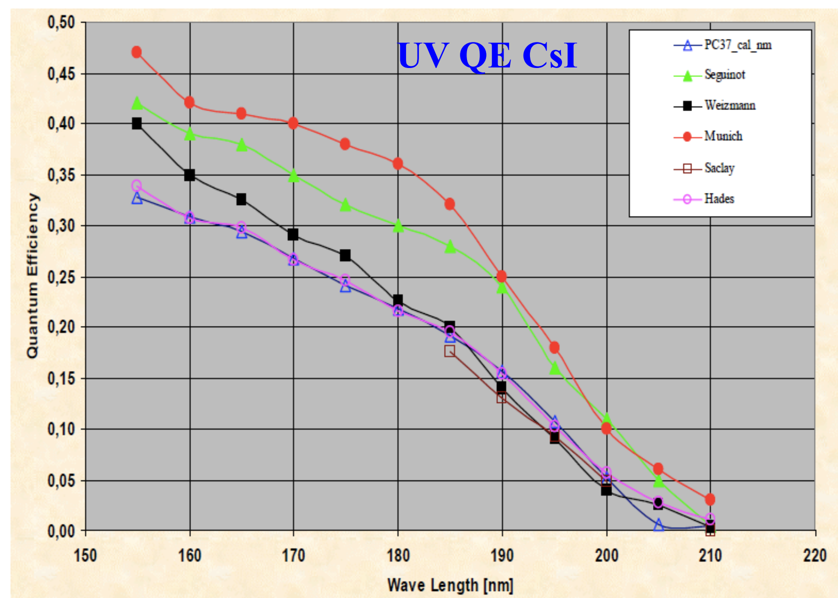
**A simple read-out is the standard spherical detector signal combined with CsI photocathode layer deposited at the internal vessel surface, inducing a delayed signal**




**$S_2$ ($S_1$) is the charge signal collected and amplified**

**$S_3$ is the delayed Cherenkov light signal**

iomataris



## CONCLUSIONS

- **Micromegas detector is widely used in particle physics**
- **Industrial applications are under development**
- **A promising low background detector**
- **Light dark matter search down to 100 MeV**