

Νέες εξελίξεις στην τεχνολογία ανιχνευτών ακτινοβολιών και η χρησιμότητα τους στην βασική έρευνα και στην κοινωνία

I. Giomataris, CEA-Irfu-France

- Ιστορικο των ανιχνευτων
- Ο ανιχνευτής Μικρομεγας
- Σφαιρικός ανιχνευτής



MPGD2009, 12-15 June 2009,
Kolympari, Crete, Greece



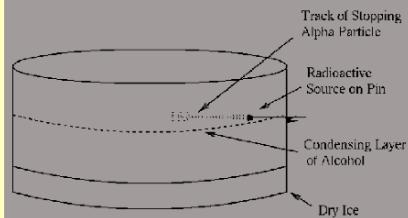
I. Giomataris

Θάλαμος νέφωσης του Wilson

Cloud chamber

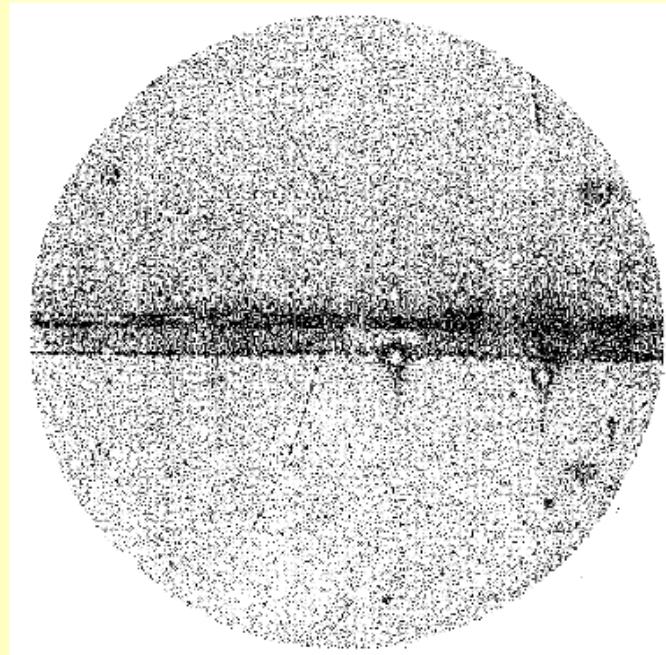
- Container filled with gas (e.g. air), plus vapor close to its dew point (saturated)
- Passage of charged particle \Rightarrow ionization;
- Ions form seeds for condensation \Rightarrow condensation takes place along path of particle \Rightarrow path of particle becomes visible as chain of droplets

Cloud Chamber Reveals Tracks of Charged Particles

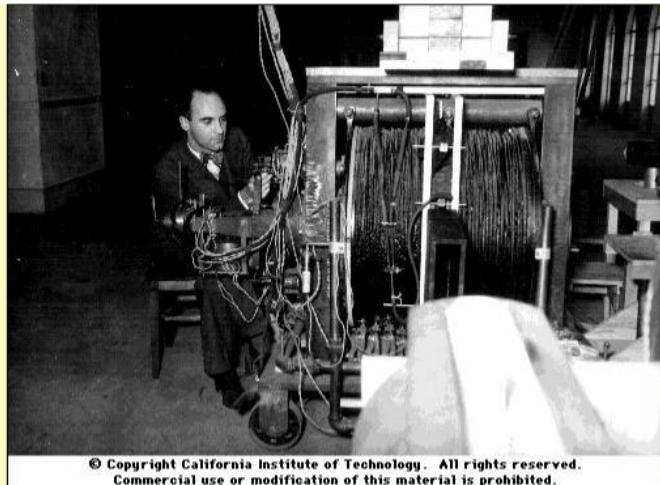


Positron discovery

- Positron (anti-electron)
 - predicted by Dirac (1928) -- needed for relativistic quantum mechanics
 - existence of antiparticles doubled the number of known particles!!!



- positron track going upward through lead plate
 - ◆ photographed by Carl Anderson (August 2, 1932), while photographing cosmic-ray tracks in a cloud chamber
 - ◆ particle moving upward, as determined by the increase in curvature of the top half of the track after it passed through the lead plate,
 - ◆ and curving to the left, meaning its charge is positive.



NEUTRON DISCOVERY

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Nuclear Chemistry
 Discovery of the Neutron (1932)
 Dr. Frank Settle

Study Index | Concept Map | Developing Knowledge | Comprehension | Applications | Evaluation | Instructor Guide | Links

Return to Start

Discovery of the Neutron

Playing with Neutrons(1934-38)

Discovery of Fission(1938)

Discovery of Pu-239(1941)

Controlled Chain Reaction(1942)

Chemistry and Metallurgy of uranium

Uranium-235 Enrichment

Plutonium-239 Production

Atomic Bombs(1945)

Nuclear Reactors

Nuclear and Chemical Waste

Proliferation

Recycling Spent Fuel

Effects of Radiation

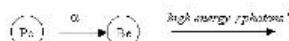
Case Study



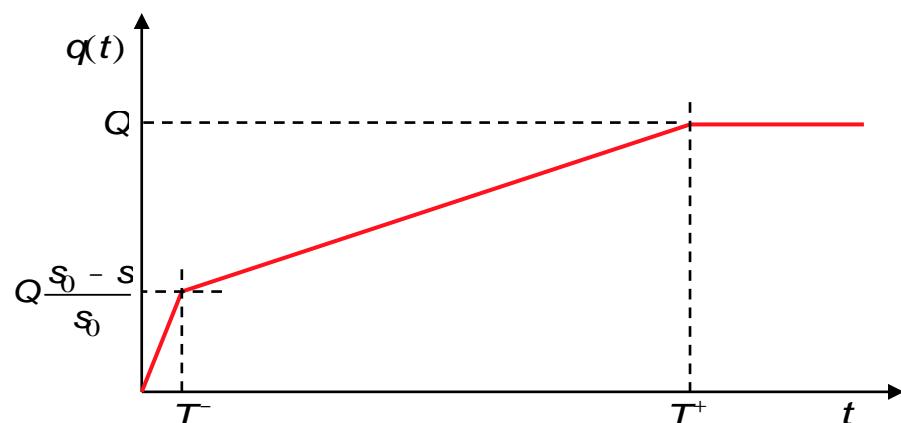
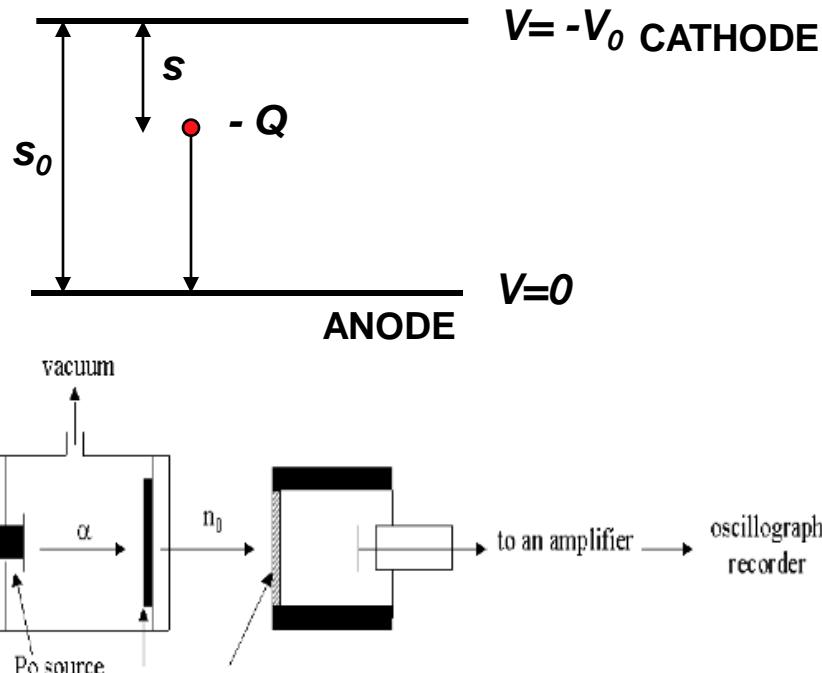
Sir James Chadwick (Courtesy of the American Institute of Physics) (left), Lord Rutherford at Cambridge (right)

Twelve years earlier, Lord Ernest Rutherford, a pioneer in atomic structure, had postulated the existence of a neutral particle, with the approximate mass of a proton, that could result from the capture of an electron by a proton. This postulation stimulated a search for the particle. However, its electrical neutrality complicated the search because almost all experimental techniques of this period measured charged particles.

In 1928, a German physicist, Walter Bothe, and his student, Herbert Becker, took the initial step in the search. They bombarded beryllium with alpha particles emitted from polonium and found that it gave off a penetrating, electrically neutral radiation, which they interpreted to be high-energy gamma photons.

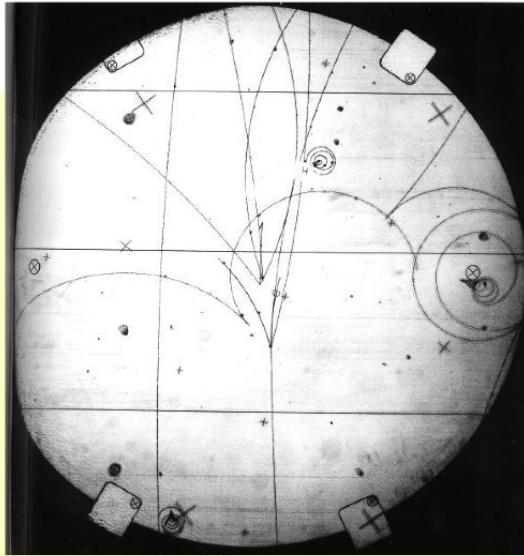


Ανιχνευτής Ιονισμού Παράλληλων Πλακών
 Σήμα πολύ μικρό για ανίχνευση, χρειάζεται ενίσχυση



Bubble chamber

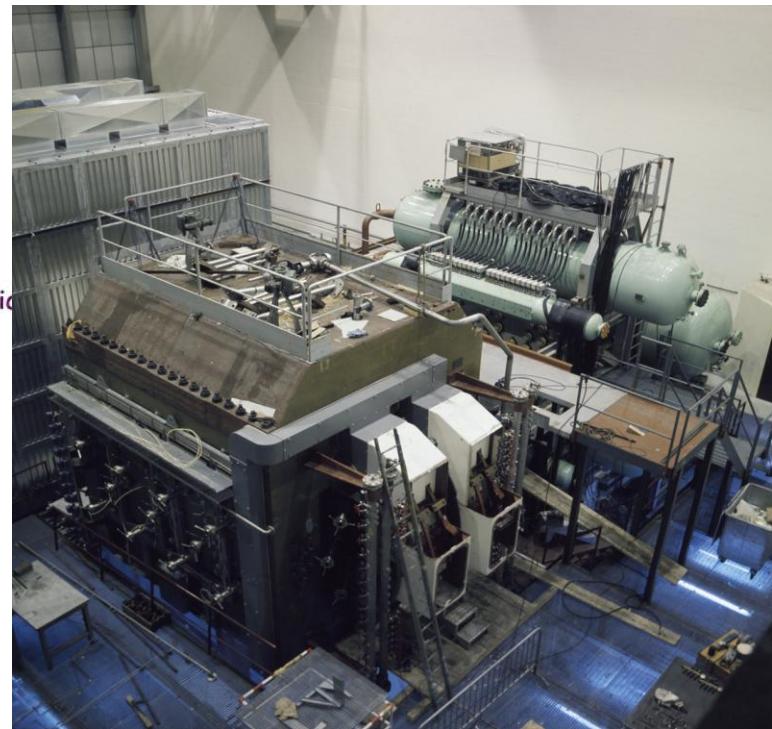
- bubble chamber
 - Vessel, filled (e.g.) with liquid hydrogen at a temperature above the normal boiling point but held under a pressure of about 10 atmospheres by a large piston to prevent boiling.
 - When particles have passed, and possibly interacted in the chamber, the piston is moved to reduce the pressure, allowing bubbles to develop along particle tracks.
 - After about 3 milliseconds have elapsed for bubbles to grow, tracks are photographed using flash photography. Several cameras provide stereo view of the tracks.
 - The piston is then moved back to recompress the liquid and collapse the bubbles before boiling can occur.
- Invented by Glaser in 1952 (when he was drinking beer)



- $p\bar{p} \rightarrow p\bar{n} K^0 K^- \pi^+ \pi^- \pi^0$
- $n\bar{n} + p \rightarrow 3 \text{ pions}$
- $\pi^0 \rightarrow \gamma\gamma, \gamma \rightarrow e^+ e^-$
- $K^0 \rightarrow \pi^+ \pi^-$

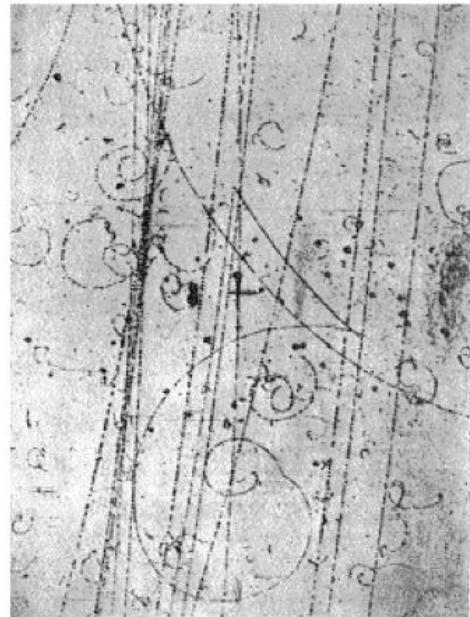
Gargamelle: Neutral current discovery

A.Lagarrigue, A. Rousset, P. Musset et al. in 1973

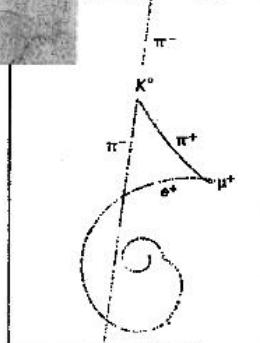


"Strange particles"

- Kaon: discovered 1947; first called "V" particle

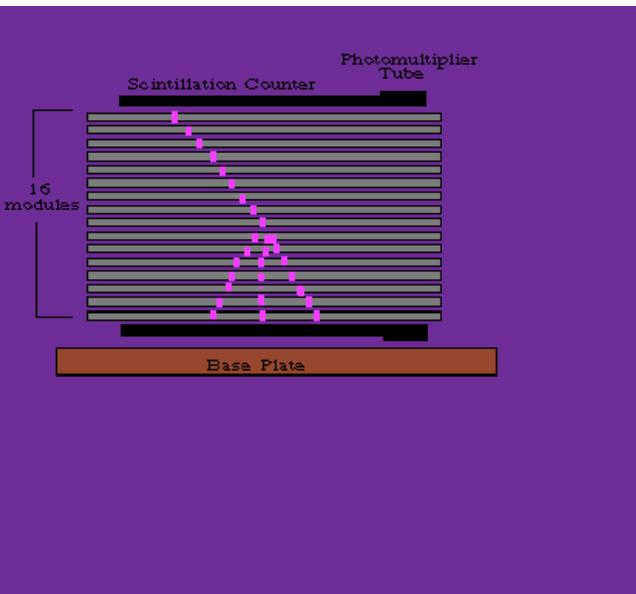


K^0 production and decay
in a bubble chamber



Θάλαμος Σπινθήρων Spark chamber

- gas volume with metal plates (electrodes); filled with gas (noble gas, e.g. argon)
- charged particle in gas \Rightarrow ionization \Rightarrow electrons liberated; passage of particle through “trigger counters” HV between electrodes \Rightarrow strong electric field;
- electrons accelerated in electric field \Rightarrow can liberate other electrons \Rightarrow “avalanche of electrons”,
 \Rightarrow of plasma between electrodes along particle path; \Rightarrow electric breakdown \Rightarrow discharge \Rightarrow spark
- HV turned off to avoid discharge in whole gas volume



13/04/2011

1962 Neutrino muon discovery

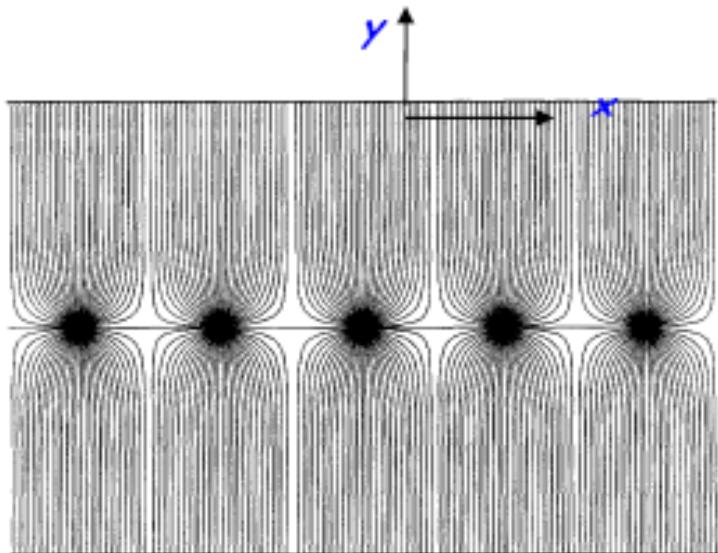
OBSERVATION OF HIGH-ENERGY NEUTRINO REACTIONS AND THE EXISTENCE OF TWO KINDS OF NEUTRINOS.

By G. Danby, J.M. Gaillard, Konstantin Goulianov, L.M. Lederman, N. Mistry, M. Schwartz, J. Steinberger (Columbia U. & Brookhaven),, 1962.
Phys.Rev.Lett.9:36-44,1962



MWPC – 1968 by G. Charpak

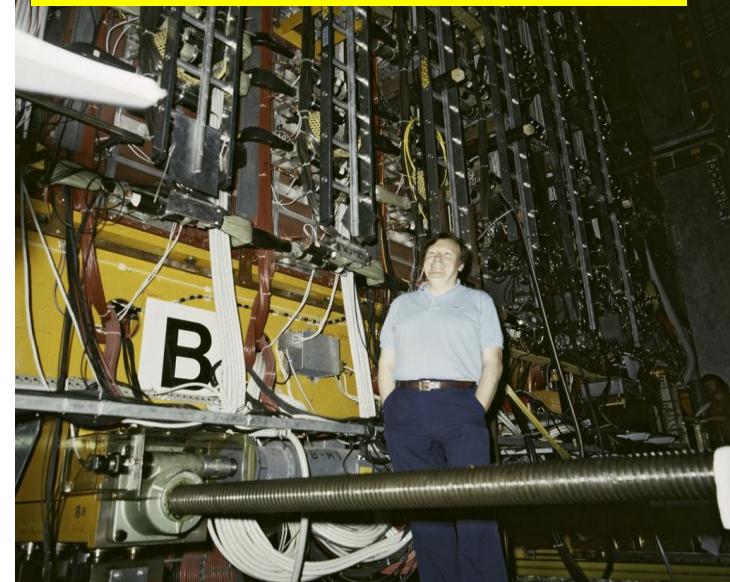
(πολυσυρματικός αναλογικός θάλαμος)



13/04/2011

UA1

Discovery of W and Z



Golden event in UA1



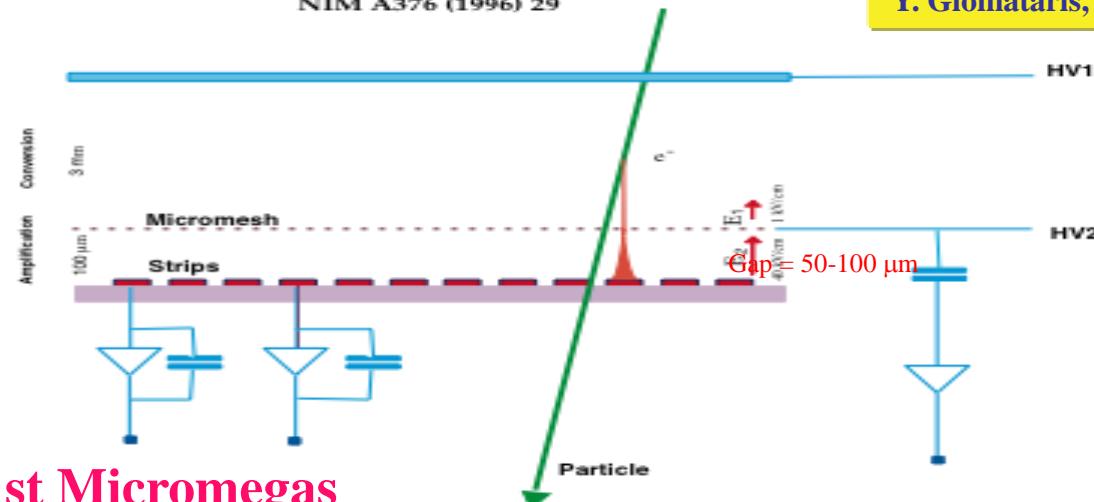
I. Gio

MICROMEGAS

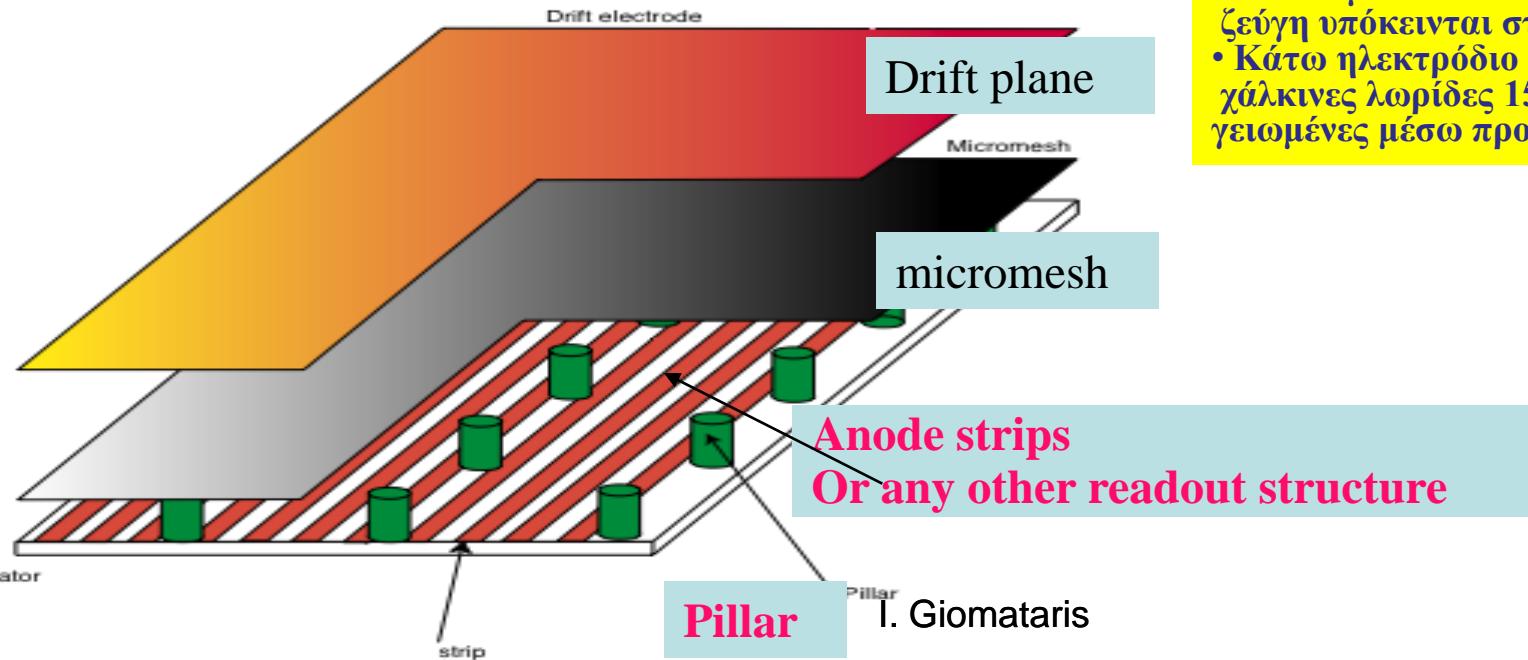
Y. Giomataris, Ph. Rebougeard, J.P. Robert and G. Charpak
NIM A376 (1996) 29

MICROMEGAS

Y. Giomataris, Ph. Rebougeard, J.P. Robert, Charpak, NIMA376(1996)29



In 1st Micromegas
Fishing line spacers have been used



- Ανω πλάκα: Ηλεκτρόδιο ολίσθισης
Περιοχή μετατροπής (conversion gap) ~mm:
 1°C ιονισμός $E \sim 500 \text{ V/cm}$
- Μικροπλέγμα, πάχους $\sim 5 \mu\text{m}$,
όπου εφαρμόζεται $V < 500 \text{ V}$
Περιοχή ενίσχυσης (amplification gap)
 $\sim 50-100 \mu\text{m}$: $E \sim 50 \text{ kV/cm}$,
ζεύγη υπόκεινται στο φαινόμενο χιονοστιβάδας
- Κάτω ηλεκτρόδιο ανόδου:
χάλκινες λωρίδες $150 \mu\text{m} \times 200 \mu\text{m}$,
γειωμένες μέσω προενισχυτών

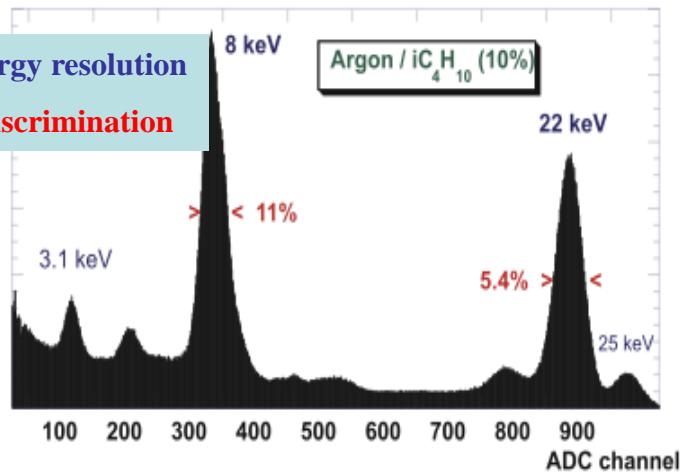
Micromegas performance

High radiation resistance : > 30 mC/mm² > 25 LHC years

G. Puill, et al., IEEE Trans. Nucl. Sci. NS-46 (6) (1999)1894.

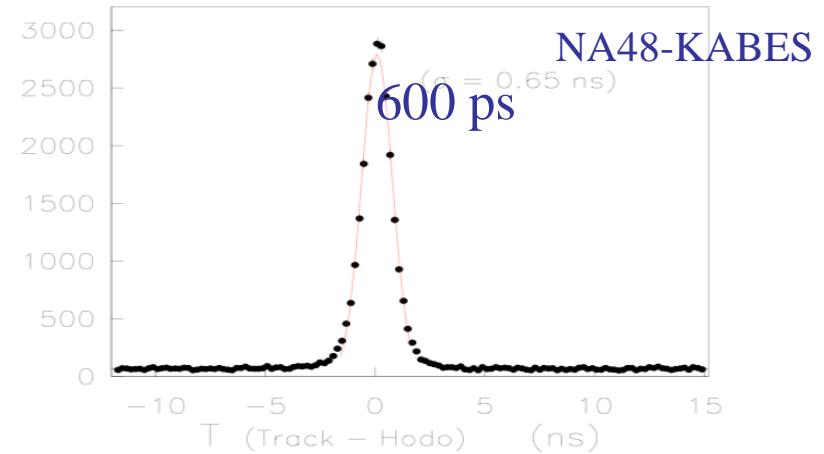
Good energy resolution

Signal discrimination



Sub-nanosecond time resolution

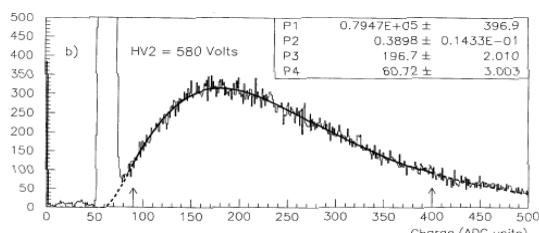
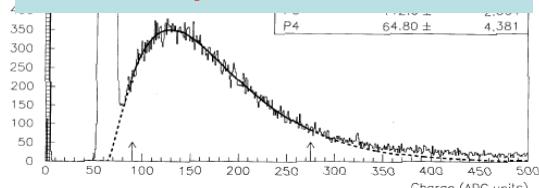
Time of flight, fast TPC



A. Delbart, Nucl.Instrum.Meth.A461:84-87,2001

Excellent single electron resolution

UV photodetector



Χωρική διακριτική ικανότητα

<12 μm

Χρονική Διακριτική ικανότητα

<0.2ns

Ενεργειακή Διακρ. Ικανοτητα
(FWHM)

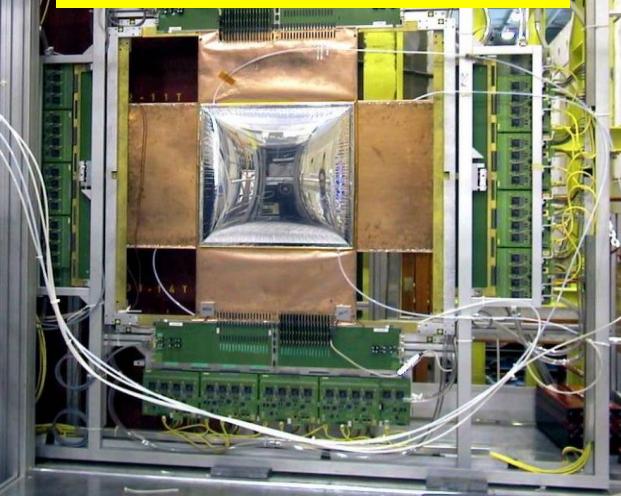
11% (στα 5.9 keV)

Rise time of the fast signal (για e)

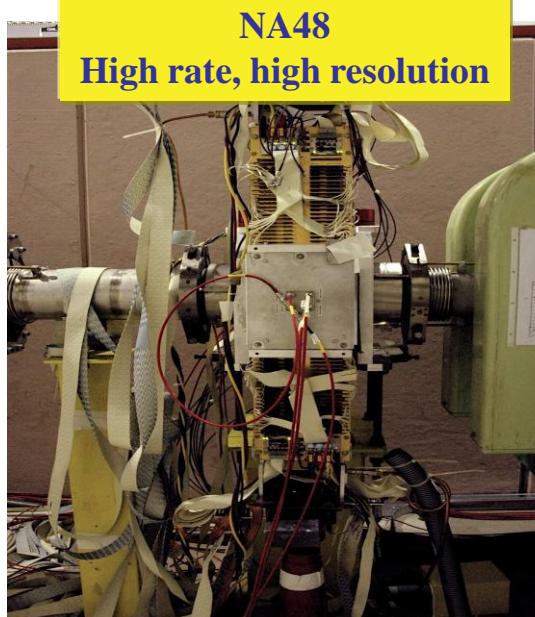
<1ns

Micromegas detectors using conventional technology

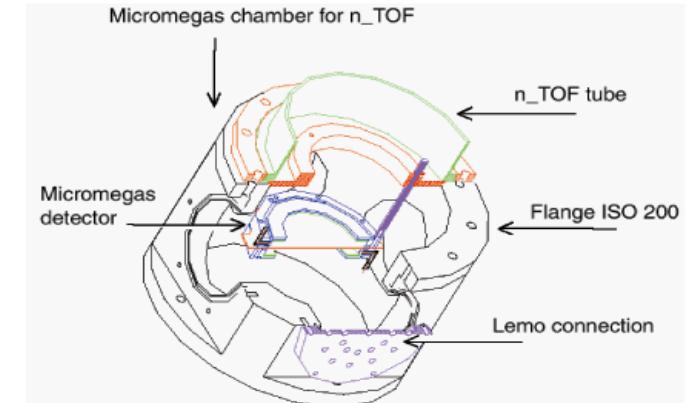
COMPASS
40x40 cm² Micromegas



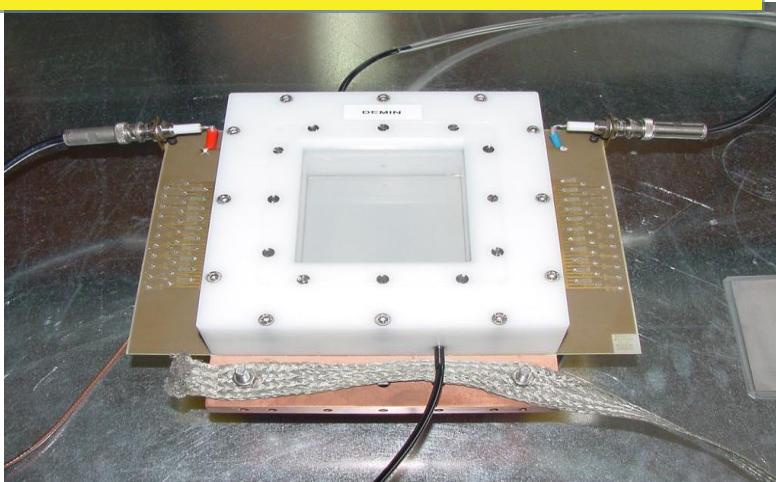
NA48
High rate, high resolution



N-TOF



Micromégas Concept for Laser MégaJoule



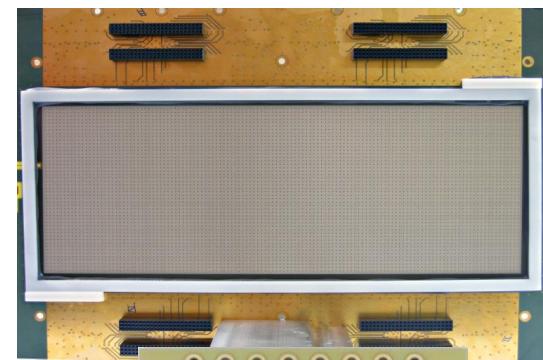
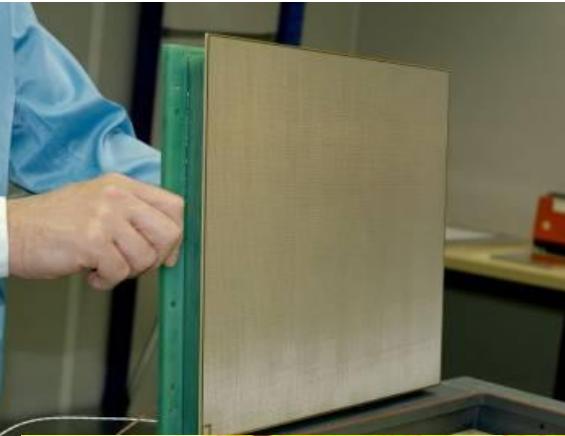
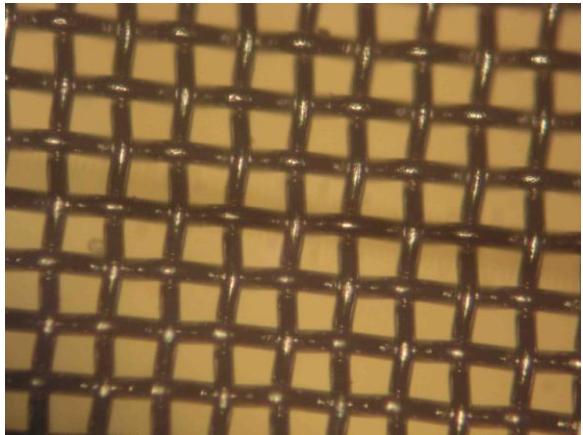
Piccolo in Casaccia reactor



New technology Bulk Micromegas

I. Giomataris et al., Nucl.Instrum.Meth.A560: 405-408,2006

ATLAS-SLHC



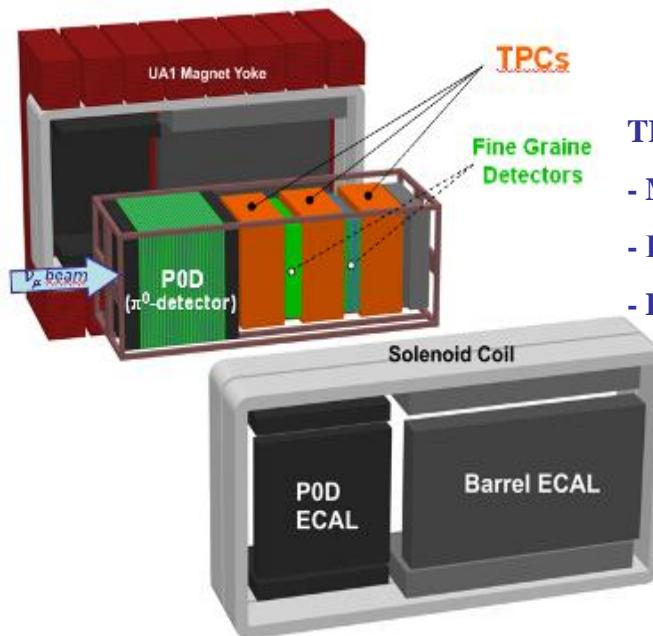
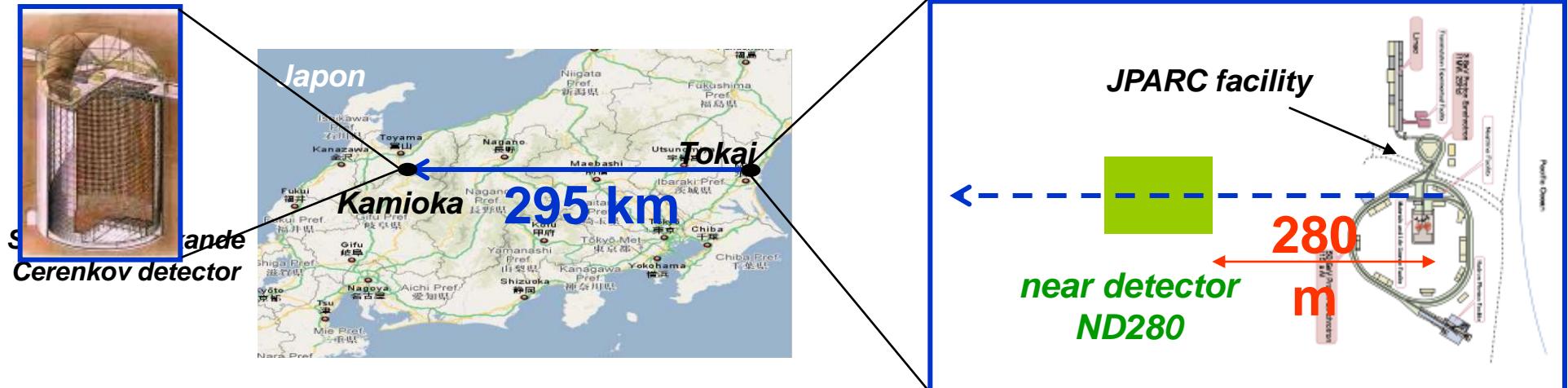
HCAL

A large TPC for T2K experiment

T2K: a long baseline neutrino oscillation experiment

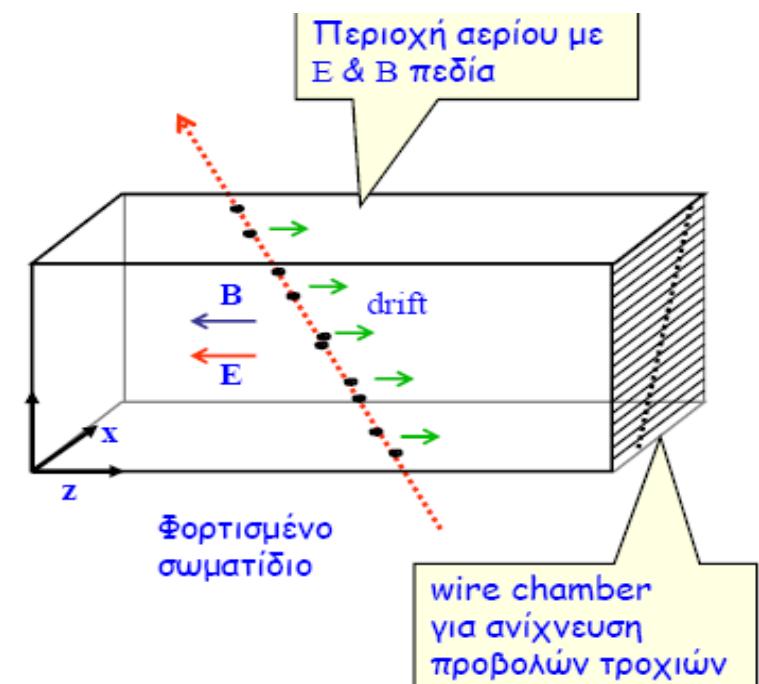
Intense ν_μ beam with 650 MeV/c energy mean for neutrino oscillation study

Main goal : Direct search for $\nu_\mu \rightarrow \nu_e$ appearance (θ_{13})

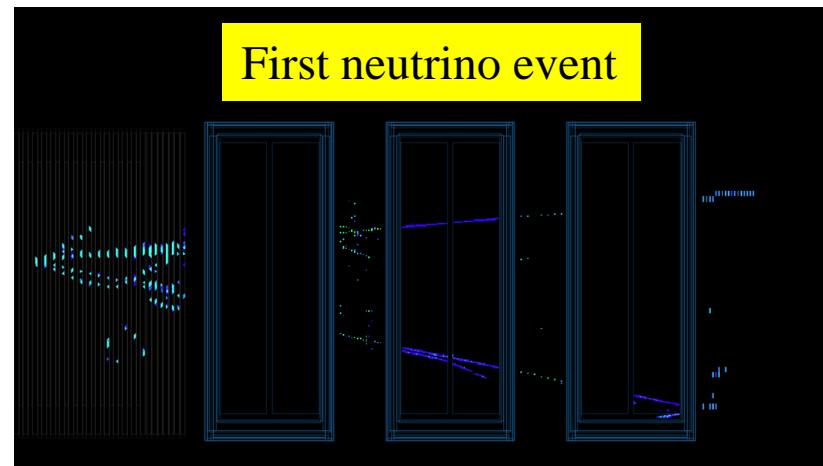
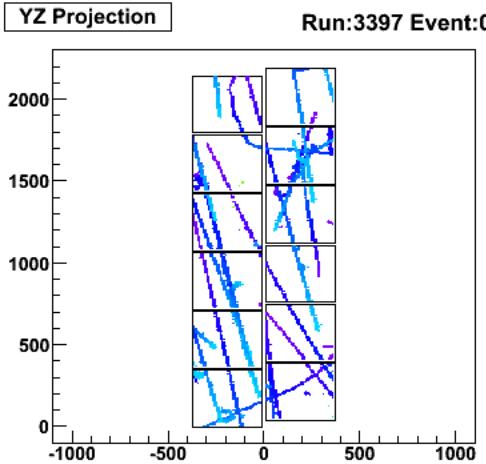
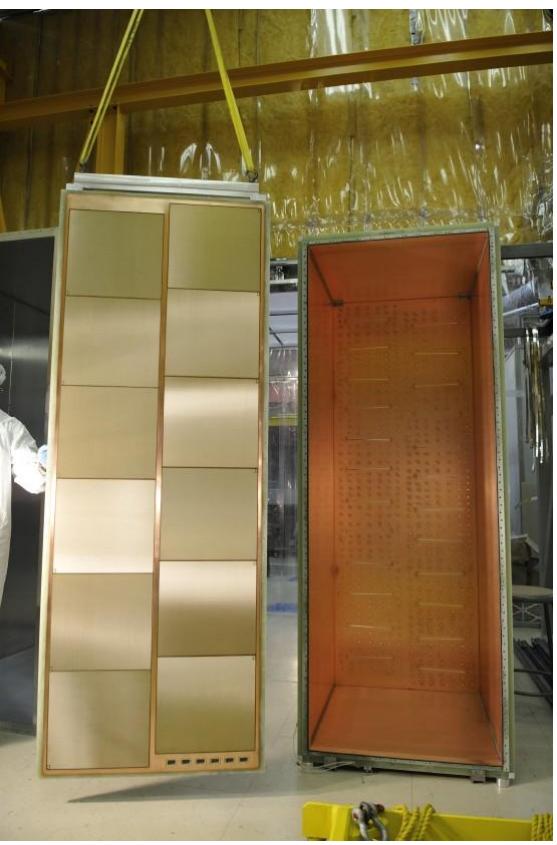


TPC :

- Measure charge and momentum of charged
- Particle identification to distinguish e, μ , π a
- Excellent pattern recognition



T2K TPC

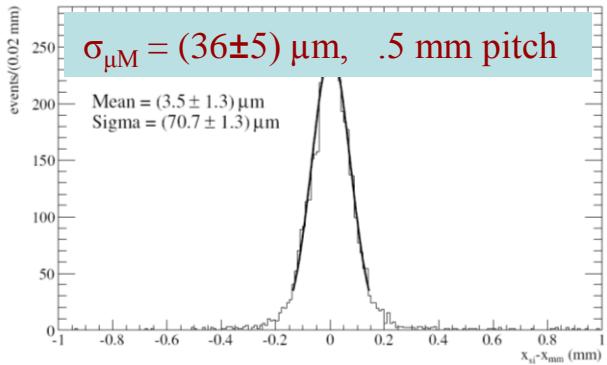
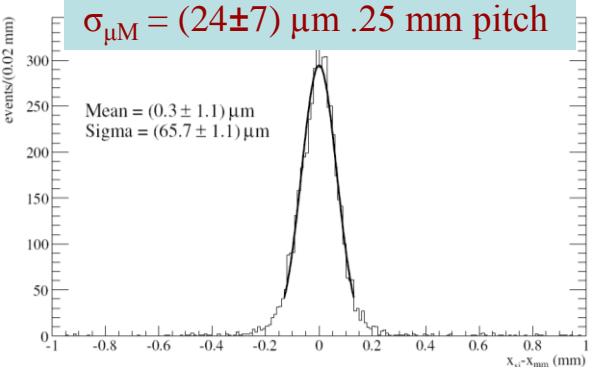


On the road to large detectors

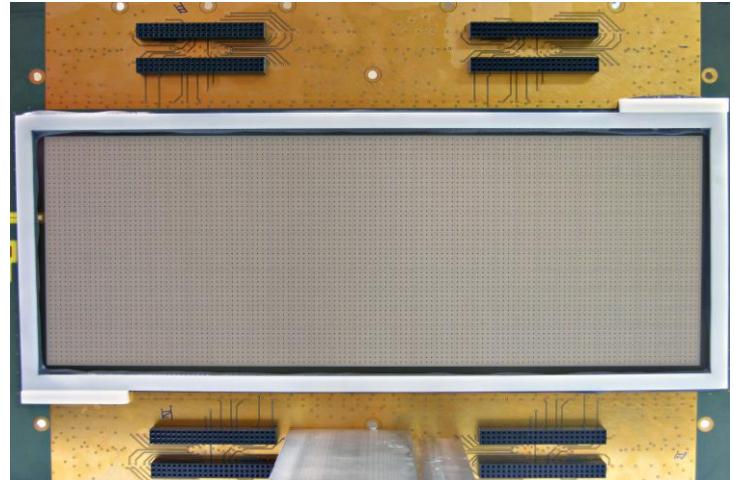
ATLAS sLHC Micromegas, R@D project



$\sigma_{\mu M} = (24 \pm 7) \mu\text{m}$.25 mm pitch

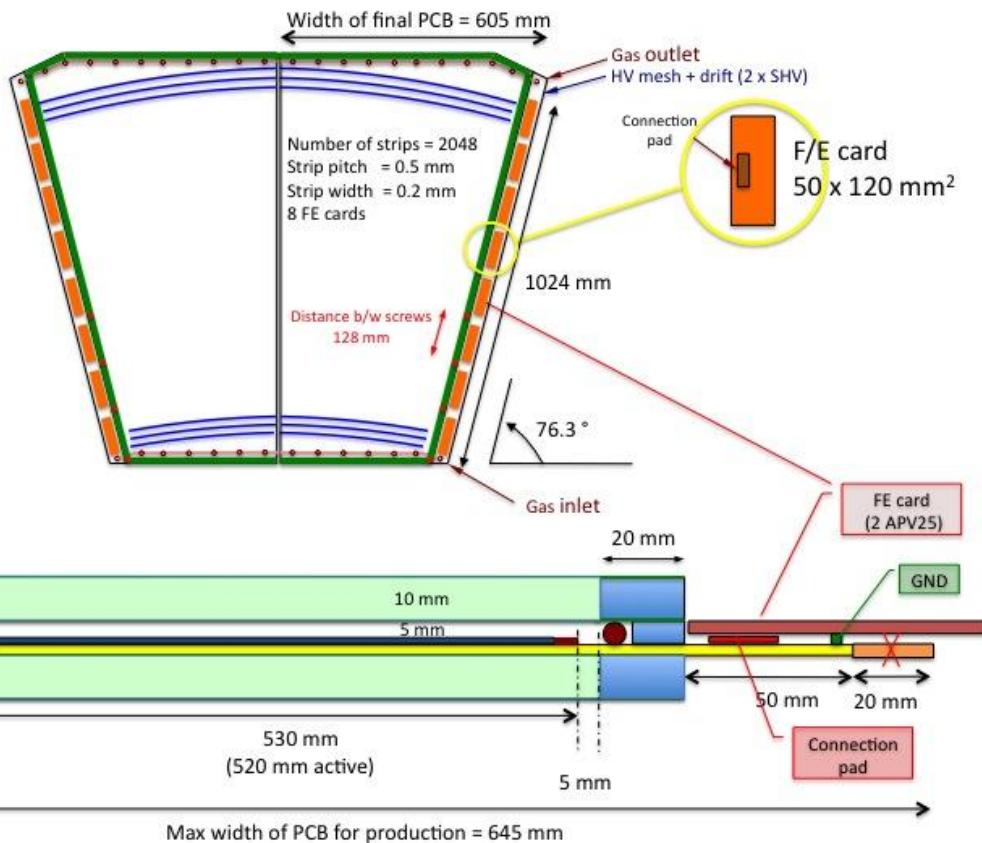


Micromegas DHCAL ILC , LAPP R@D



Other application
of large area detectors
Muon tomography

Large Atlas muon detector Half-size Chamber



Transfer to industry under way



Micromegas + micro-pixels

H. Van der Graaf, J. Timermans et al.

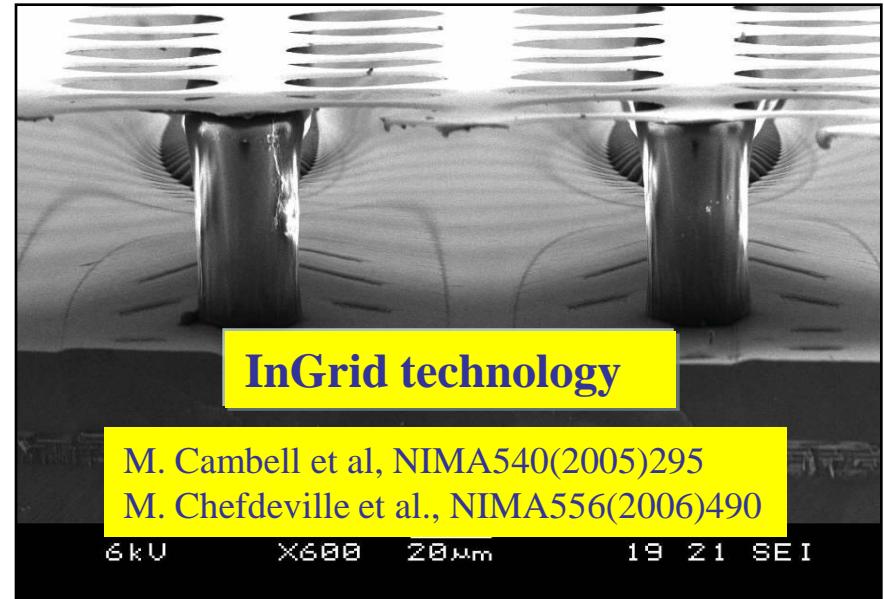
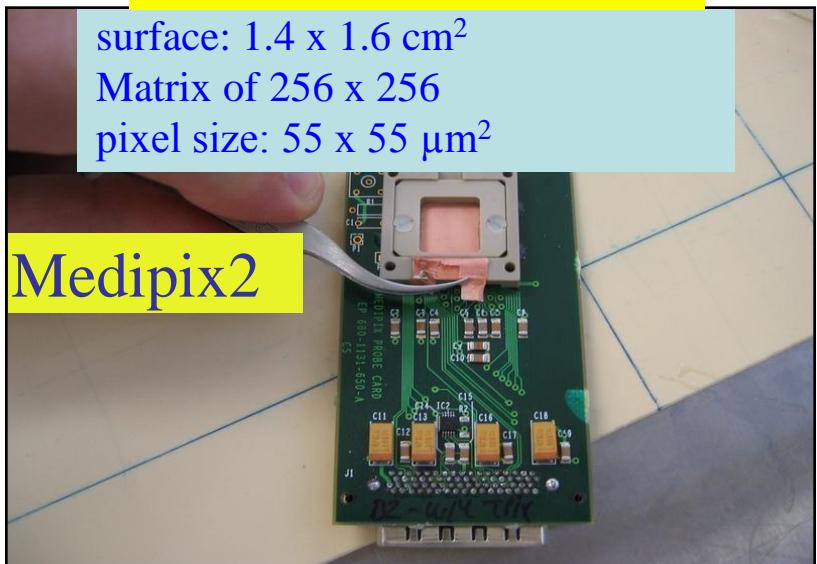
P. Colas et al., NIMA535(2004)506

surface: 1.4 x 1.6 cm²

Matrix of 256 x 256

pixel size: 55 x 55 µm²

Medipix2

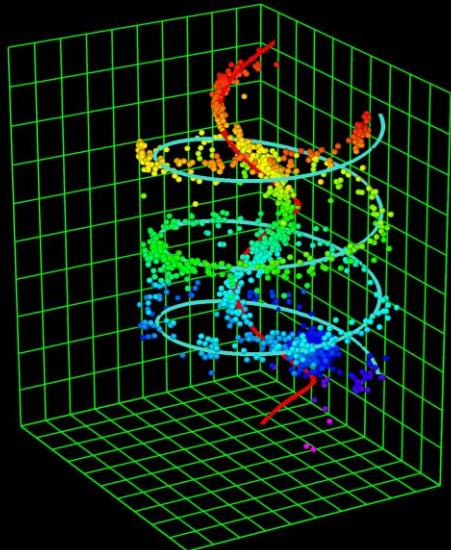


InGrid technology

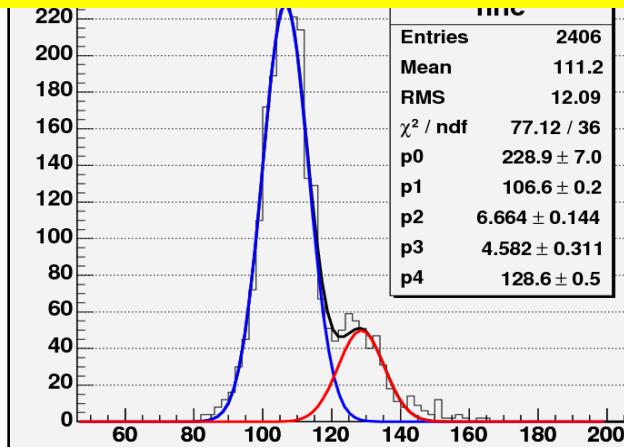
M. Cambell et al, NIMA540(2005)295

M. Chefdeville et al., NIMA556(2006)490

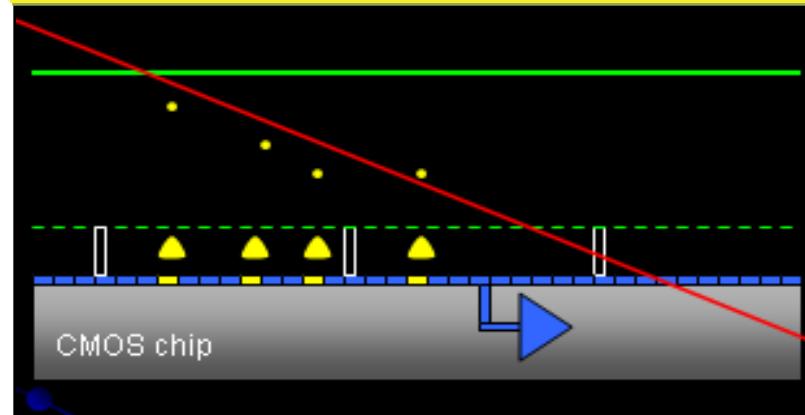
6 kV ×600 20 µm 19 21 SEI



Great resolution
Single electron counting!!



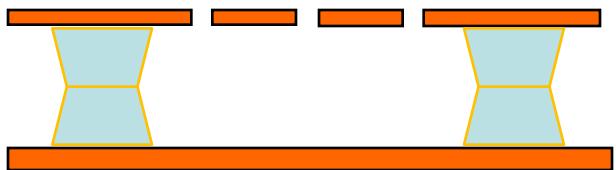
Gas On Slimmed Silicon Pixels (GOSSIP)
Under study for ATLAS SLHC tracker



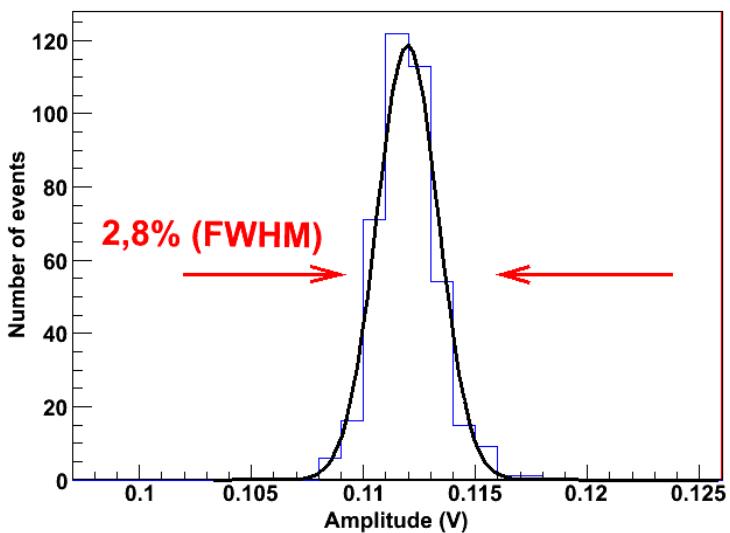
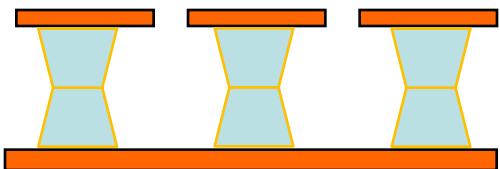
New fabrication technology

Micro-Bulk

Type1



Type2



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

I. Giomataris



50 μm and 25 μm gaps fabricated

Very good energy resolution

- 11% at 5.9 keV
- 5.5% at 22 keV
- <1.5% with Am alpha source

Other advantages

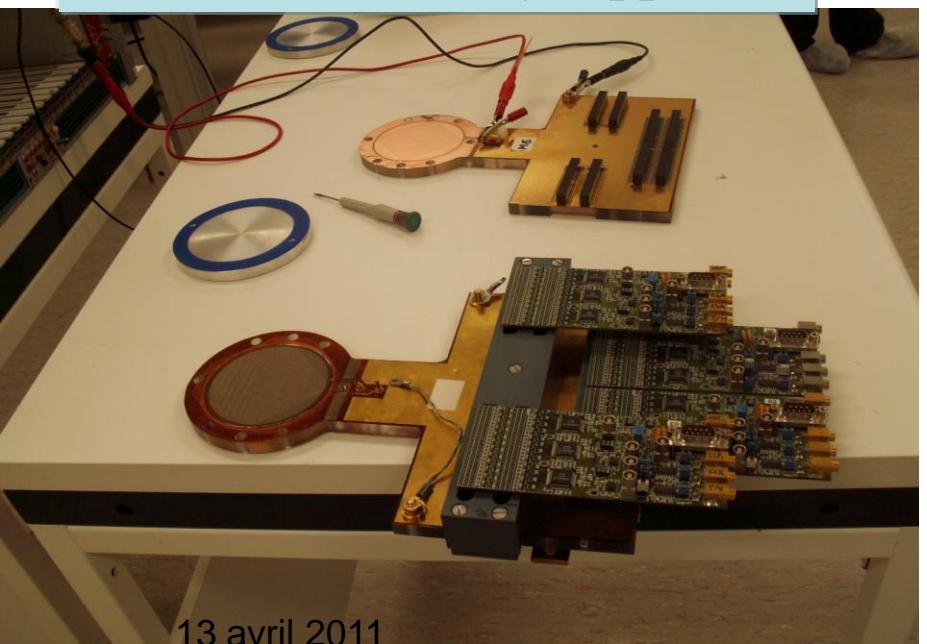
- Flexible structure (cylinder)
- Good uniformity
- Low material
- Low radioactivity

Long term stability ?

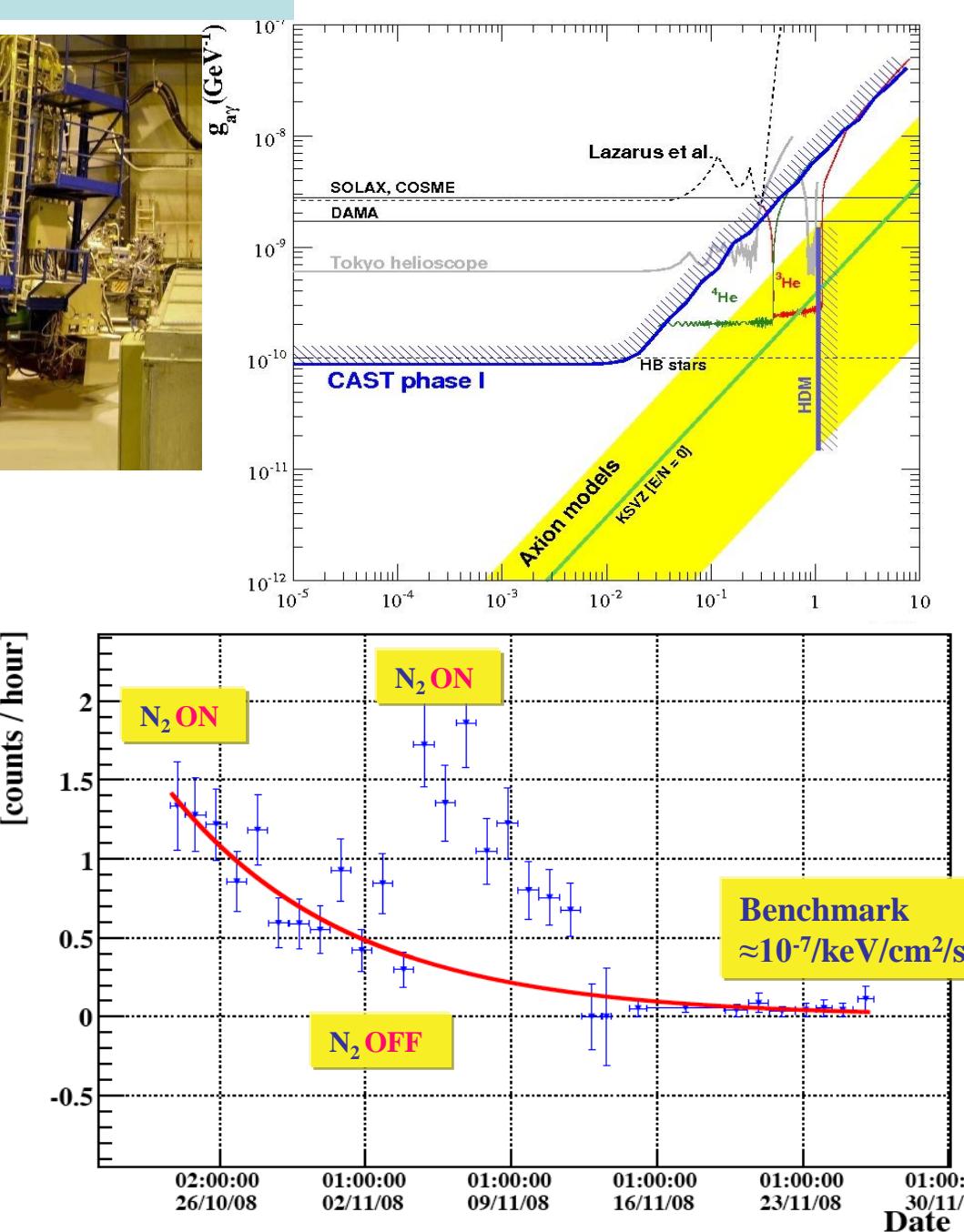
Micro-bulk in CAST - high performance



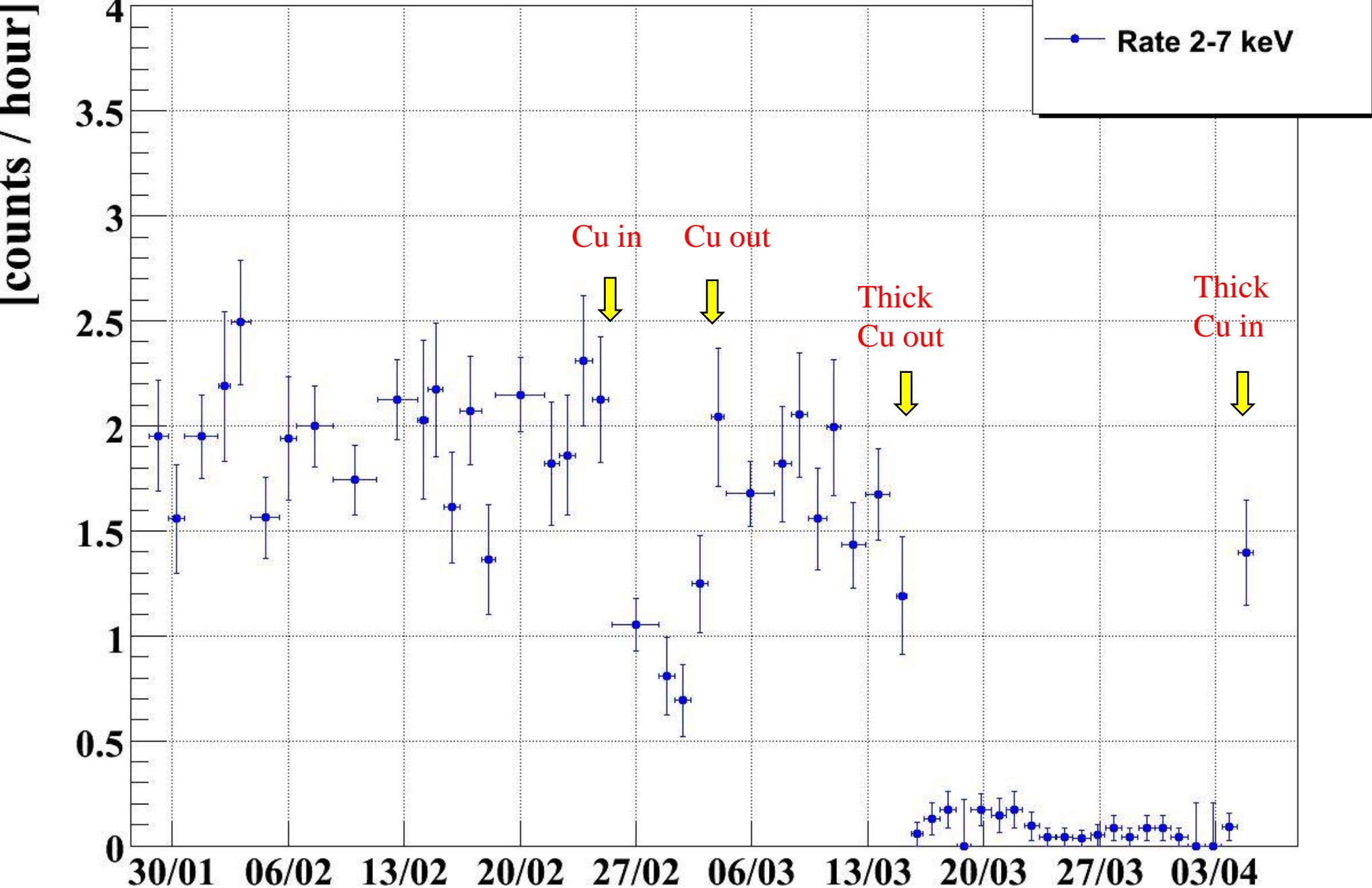
On low radioactivity support



13 avril 2011

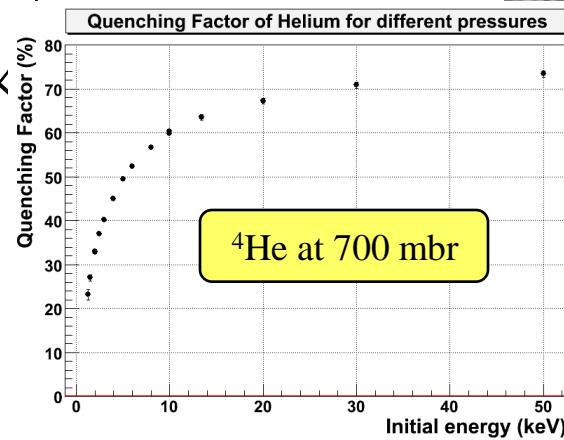
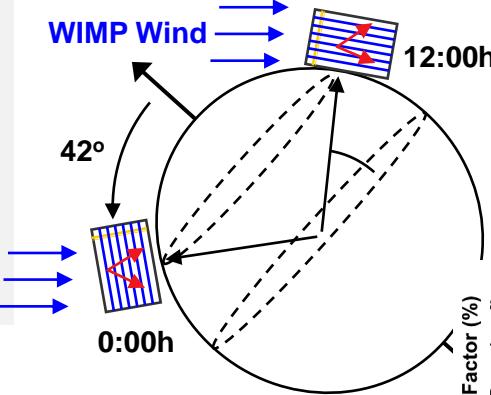
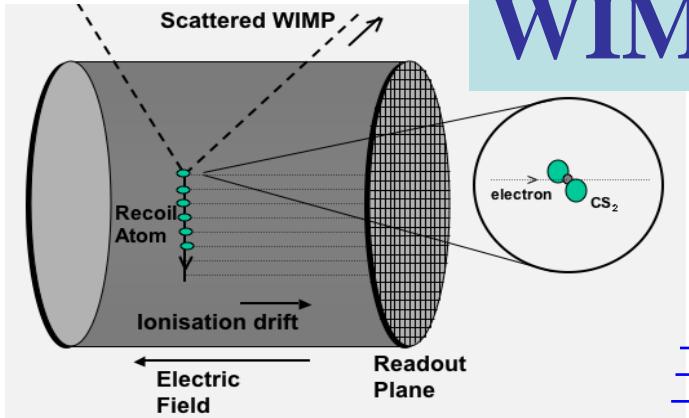


Rate 2-7 keV



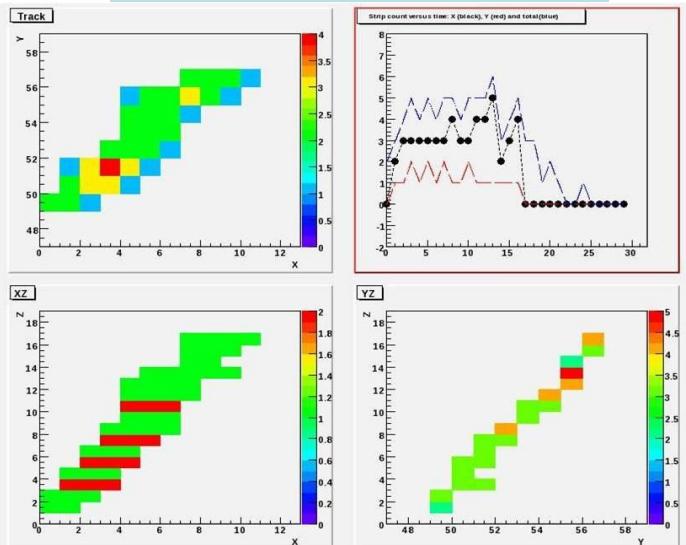
WIMP directional TPCs

Micromegas:μTPC chamber

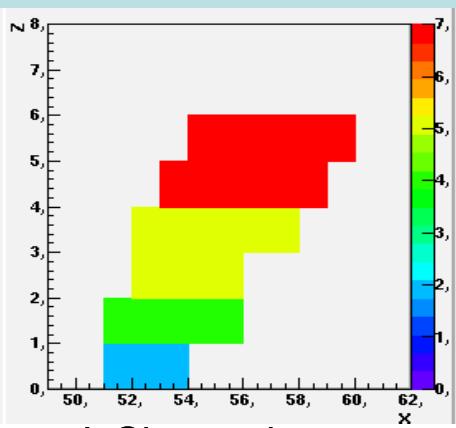


MIMAC-He3 MIcro-tpc Matrix of Chambers of He3
On-baryonic dark matter search, Micromegas read-out,
Grenoble – Saclay, Cadarache collaboration

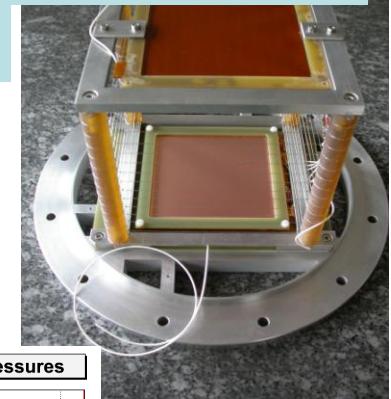
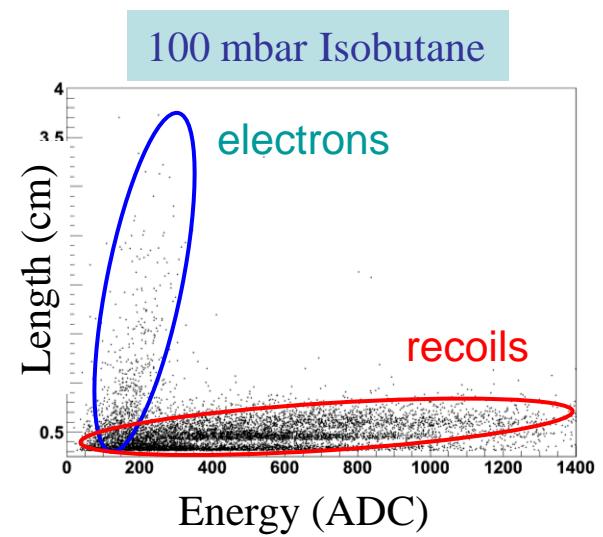
Electrons by 5.9 keV ${}^{55}\text{Fe}$



Recoil from 144 keV neutrons



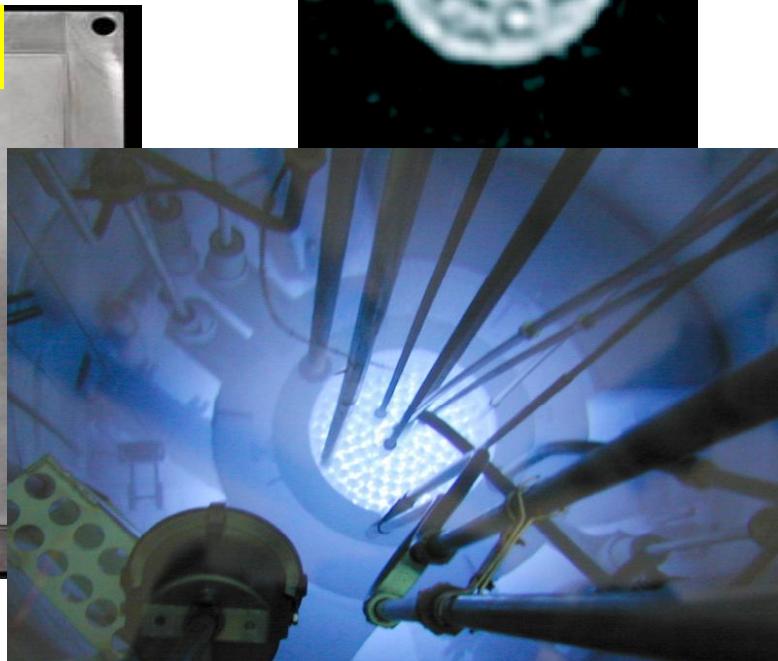
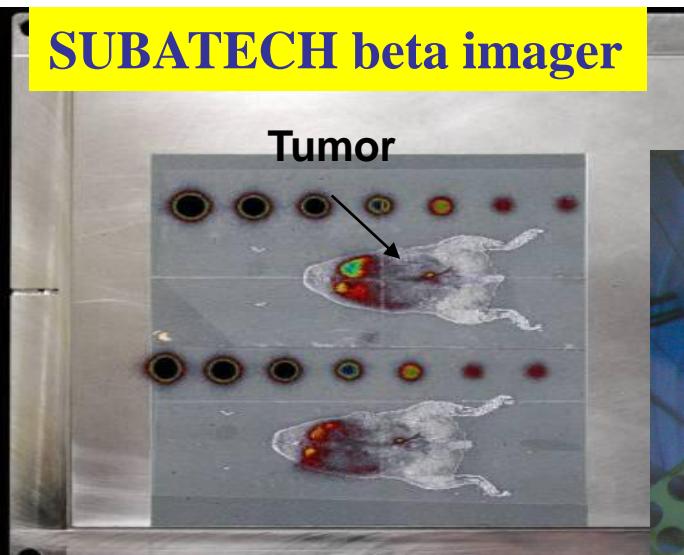
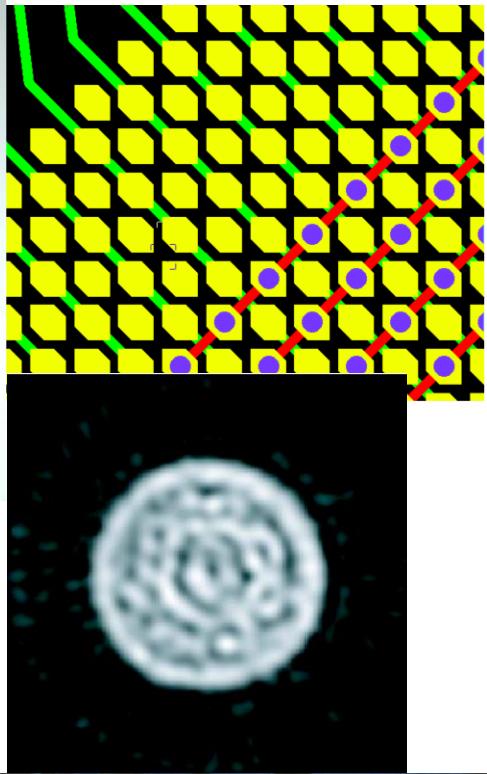
I. Giomataris



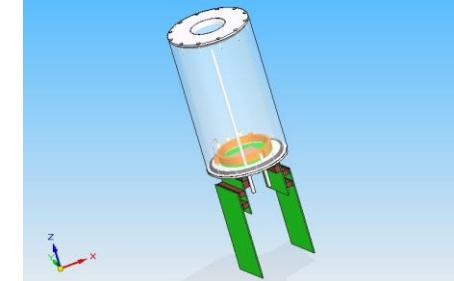
Radiography



Neutron imaging



Detecting Forest fires with Micromegas FORFIRE project – EU FP7

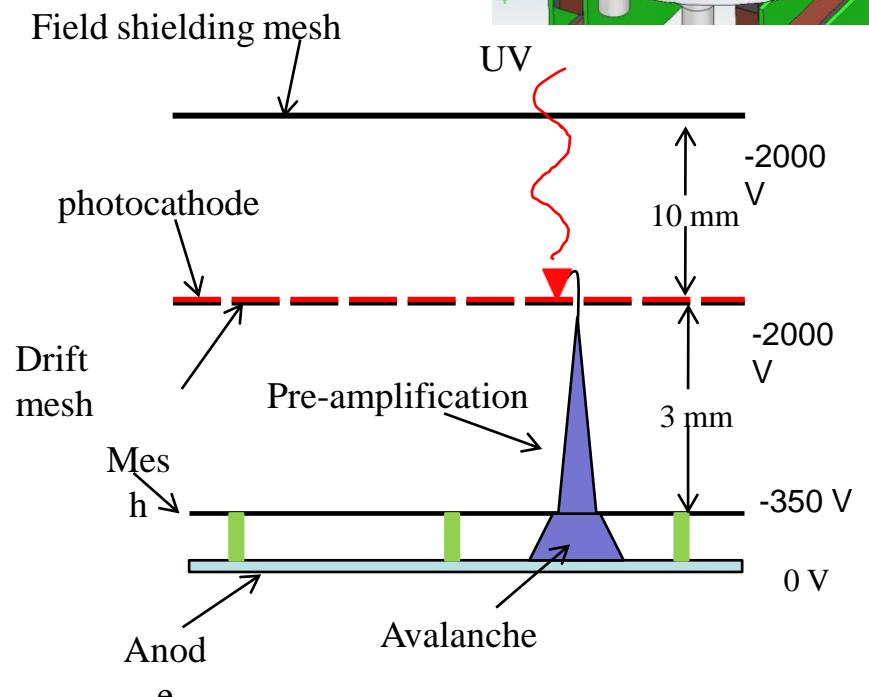


SOLAR Blind
Micromegas photodetector

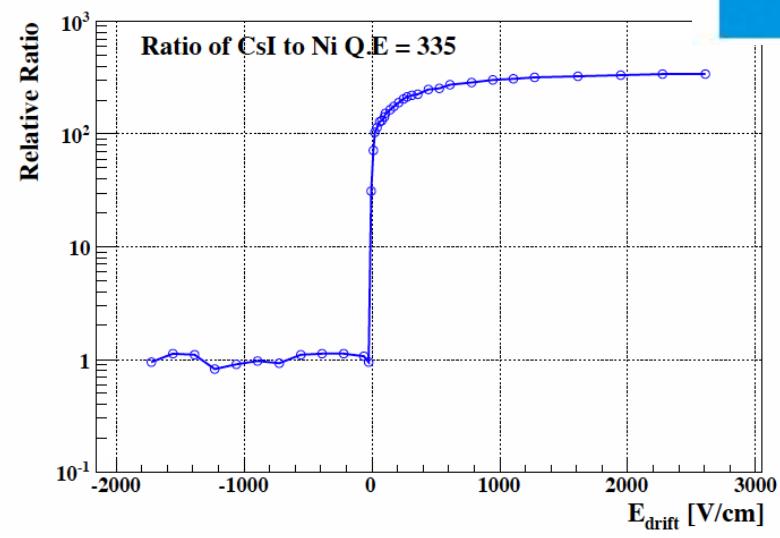
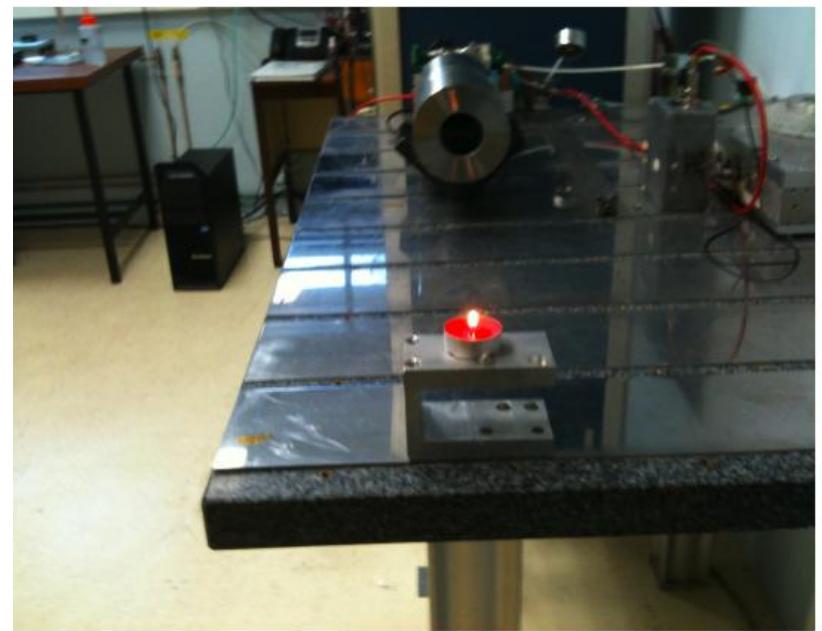
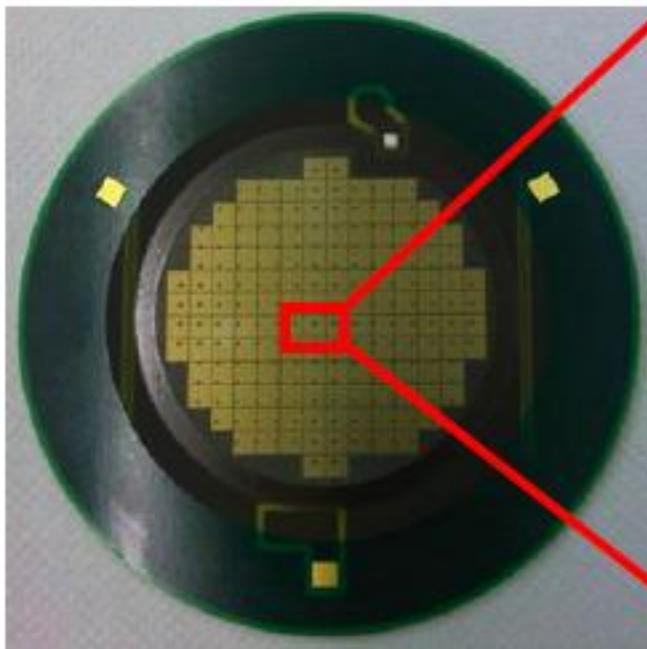


Beneficiary Number	Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project
1 – SME coordinator	Irish Precision Optics	IPO	Ireland	Month 1	Month 24
2 – SME	HERON Technologies	HERON	France	Month 1	Month 24
3 – SME	OPTOEL	OPTOEL	Rumania	Month 1	Month 24
4 – SME	PINDIATEC	PINDIATEC	Spain	Month 1	Month 24
5 – End User	Forest Research Institute	FRI	Poland	Month 1	Month 24
6 – RTD	CEA	CEA	France	Month 1	Month 24
7 – RTD	ITAV	ITAV	Spain	Month 1	Month 24
8 – RTD	University of Athens	UOA	Greece	Month 1	Month 24

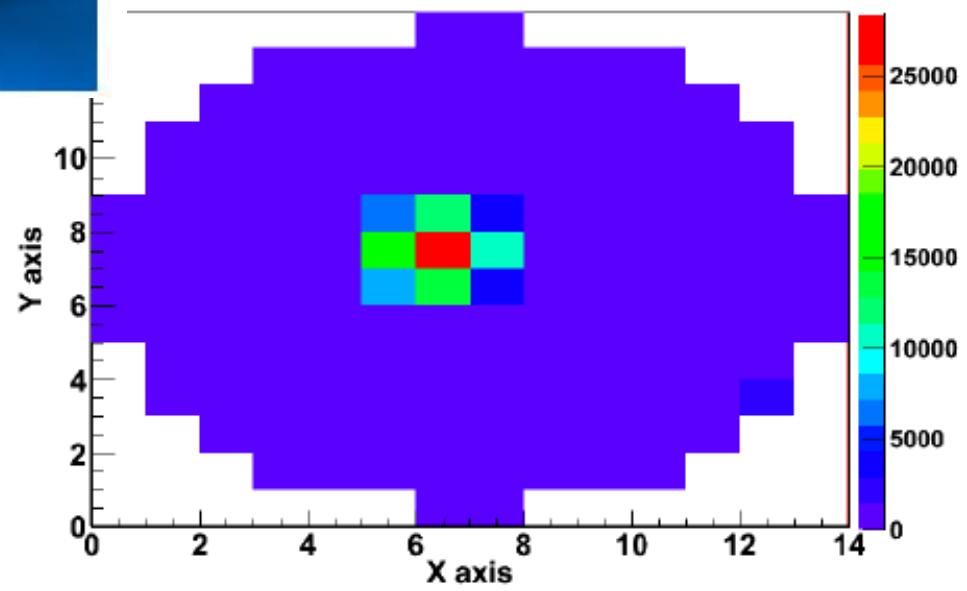
Project coordinator: Panagiotis Pavlopoulos,
president of HERON Technologies



Results



I. Giomat



New spherical TPC concept and its applications in rare event search physics

I. Giomataris, CEA-Saclay

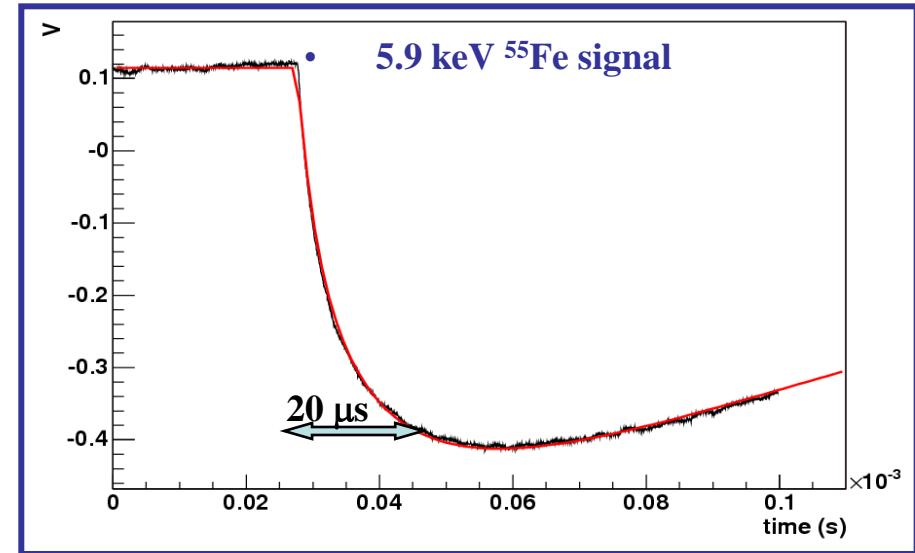
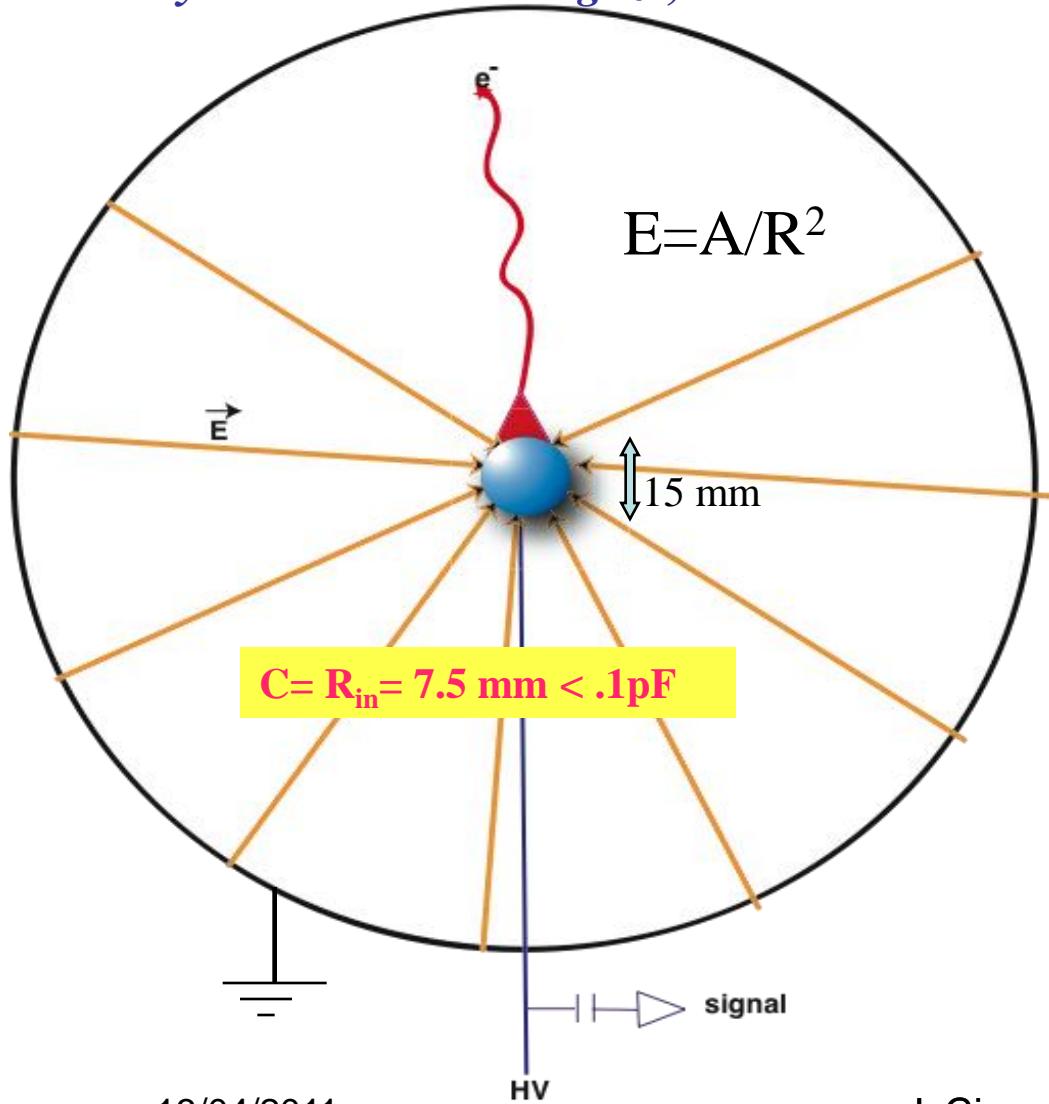


E. Bougamont, P. Colas, J. Derrière, G. Gerbier, I. Giomataris,
M. Gros, D. Jourde, P. Mangier, Ph. Mols, X.F. Navick, G. Tsiledakis **CEA-Saclay**,
I. Savvidis , University of Thessaloniki
P. Piquemal, M. Zampalo, P. Loaiza LSM
I. Irastorza, University of Saragoza
J. D. Vergados, University of Ioannina

Radial TPC with spherical proportional counter read-out

Saclay-Thessaloniki-Saragoza, Ioannina

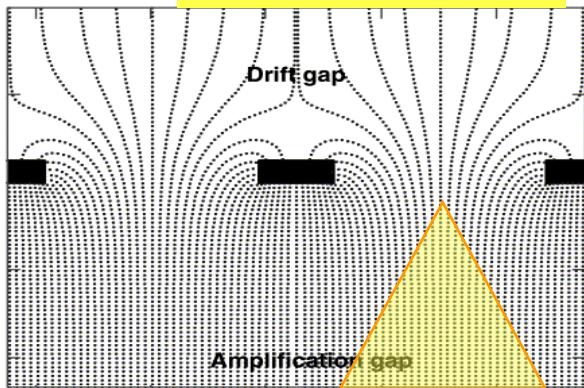
A Novel large-volume Spherical Detector with Proportional Amplification read-out, I. Giomataris *et al.*, JINST 3:P09007,2008



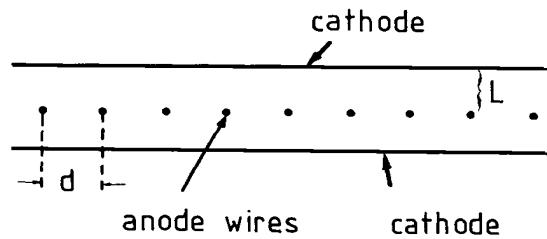
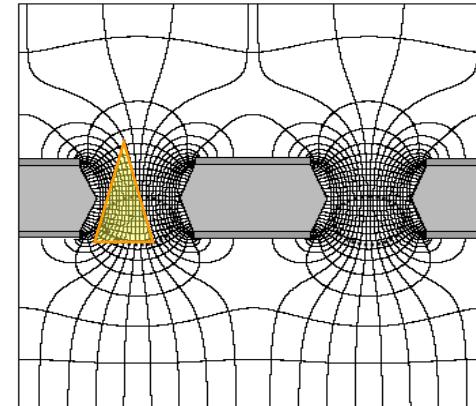
- Simple and cheap
- single read-out
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut

Parallel Plate Detector

Micromegas

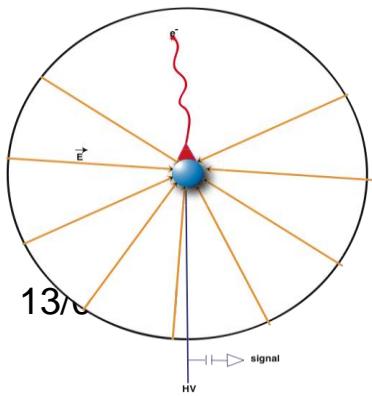
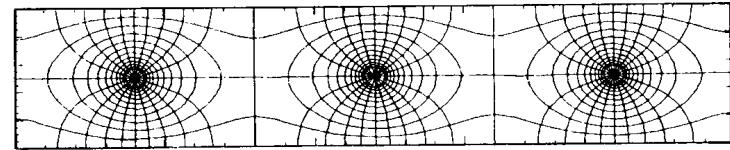


GEM



MPWC

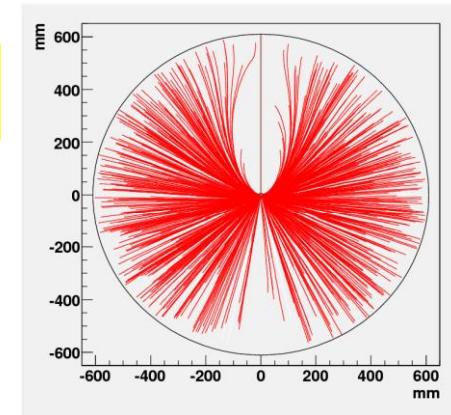
$E=1/r$
 $C \approx L > 10 \text{ pF}$



Spherical Proportional Counter

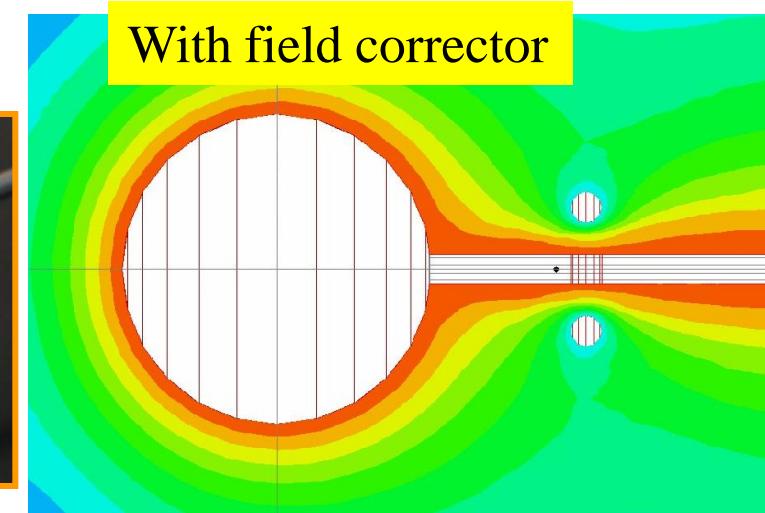
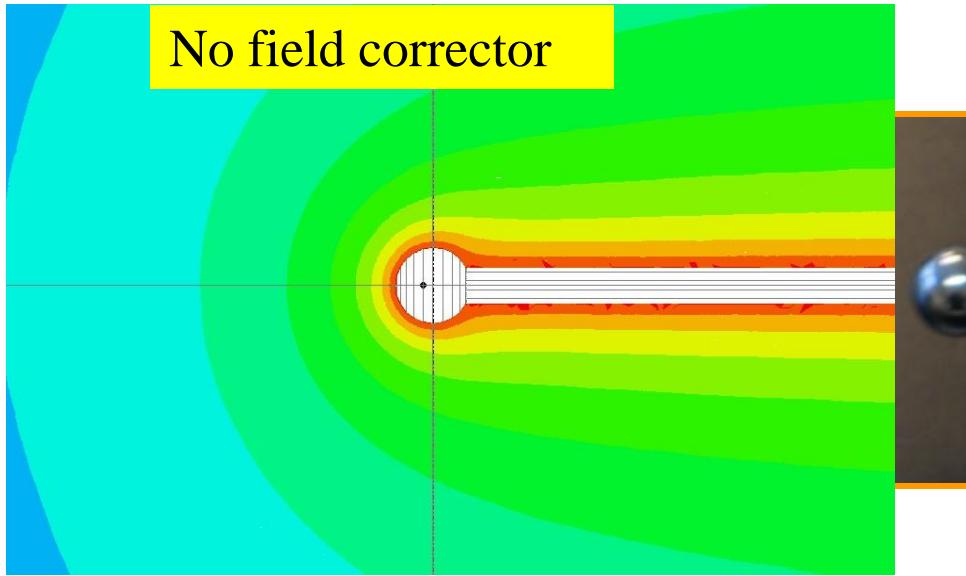
$E=1/r^2$
 $C \approx R_{in} < .1 \text{ pF}$

I. Giomataris

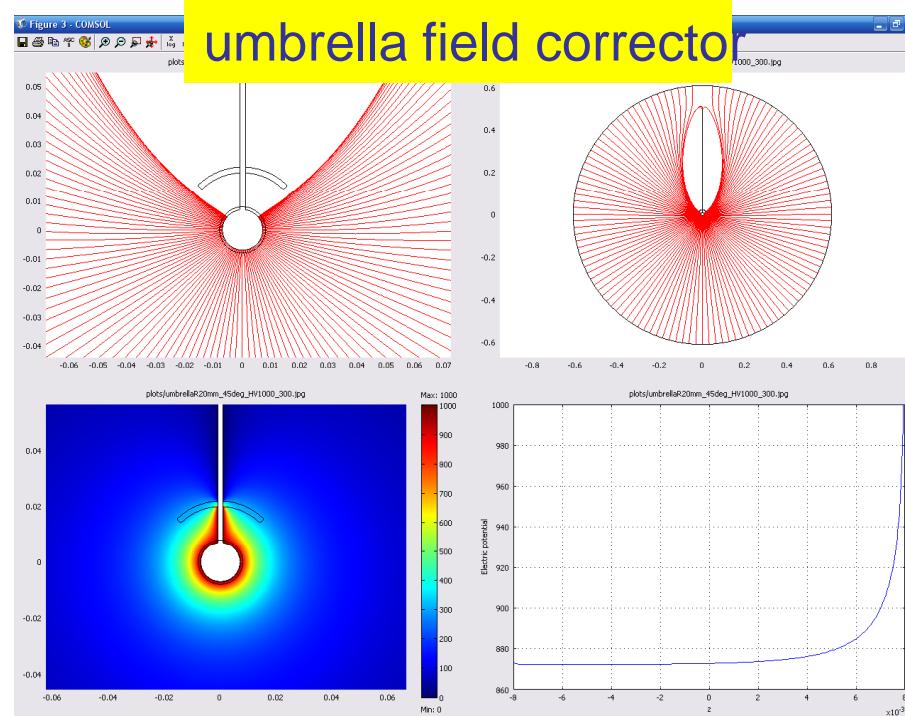
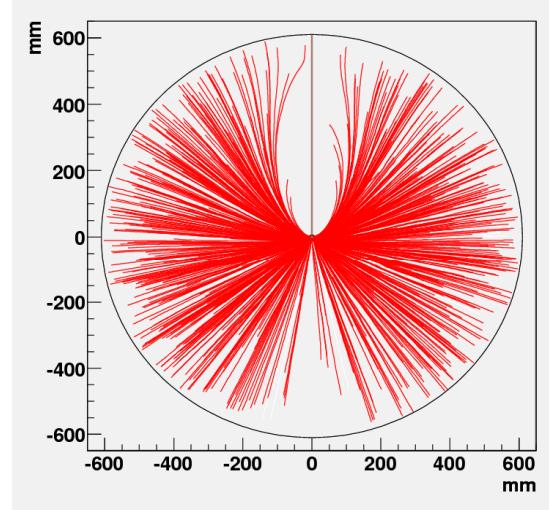
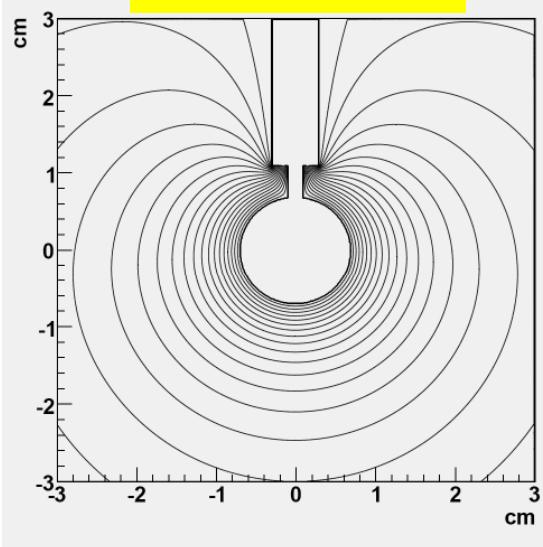


Electrostatics deal, How to keep radial field

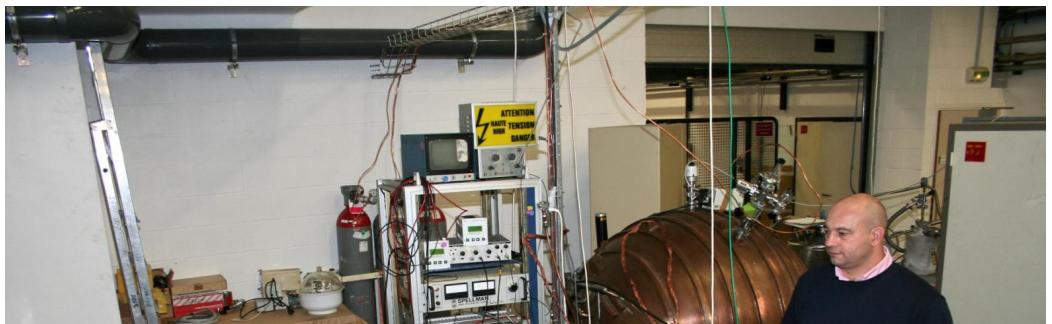
Ideal solution: field $1/R^2$ degrador around the wire



I. Savvidis idea



First prototype: “How to get large detector out of a LEP cavity?”



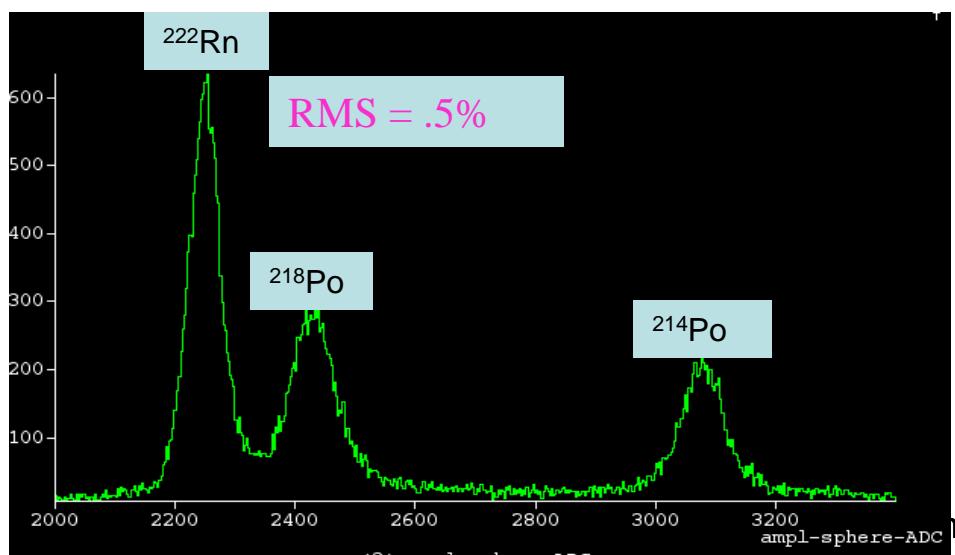
Visit on
December 2008



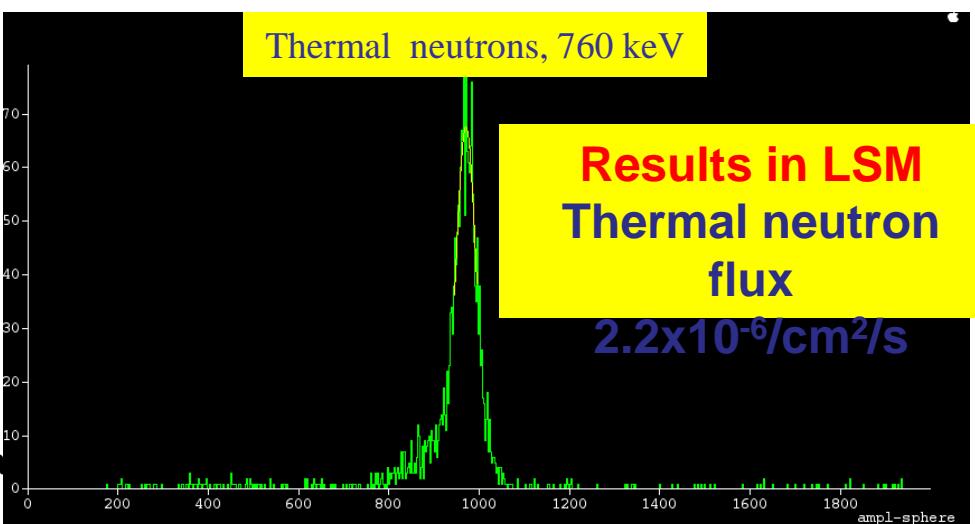
In 2008: Detector installed in LSM laboratory
Goal: measure thermal neutron background
and estimate fast neutron flux



Neutron energy and flux measurement
 $^3\text{He} + \text{n} \longrightarrow ^1\text{H} + ^3\text{H}$ ($Q = 760 \text{ keV}$)



Energy resolution under amplification: a world record !!



Under study

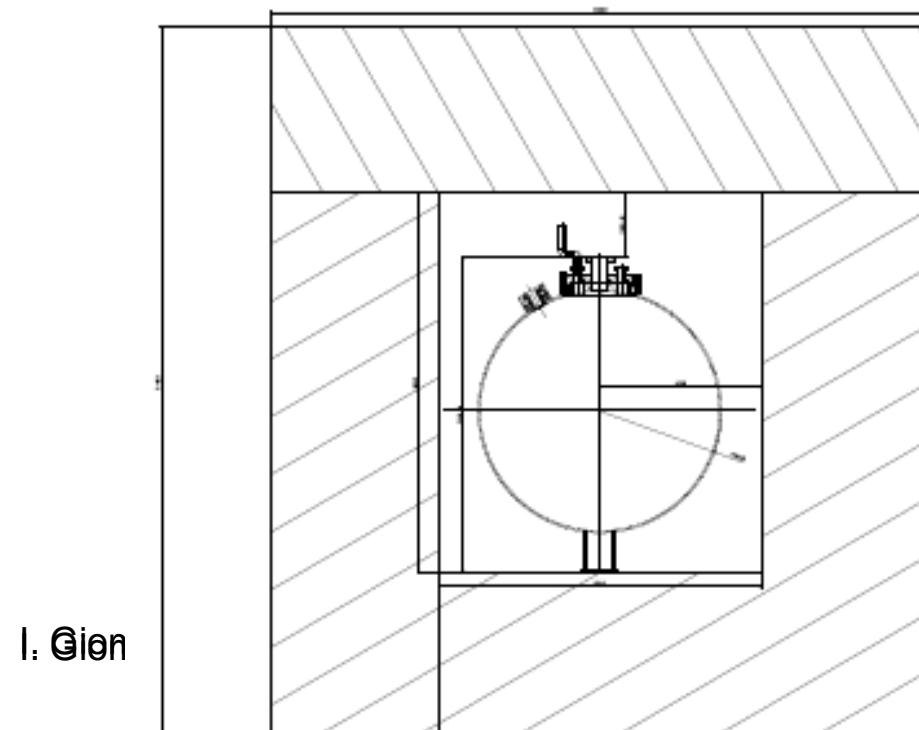
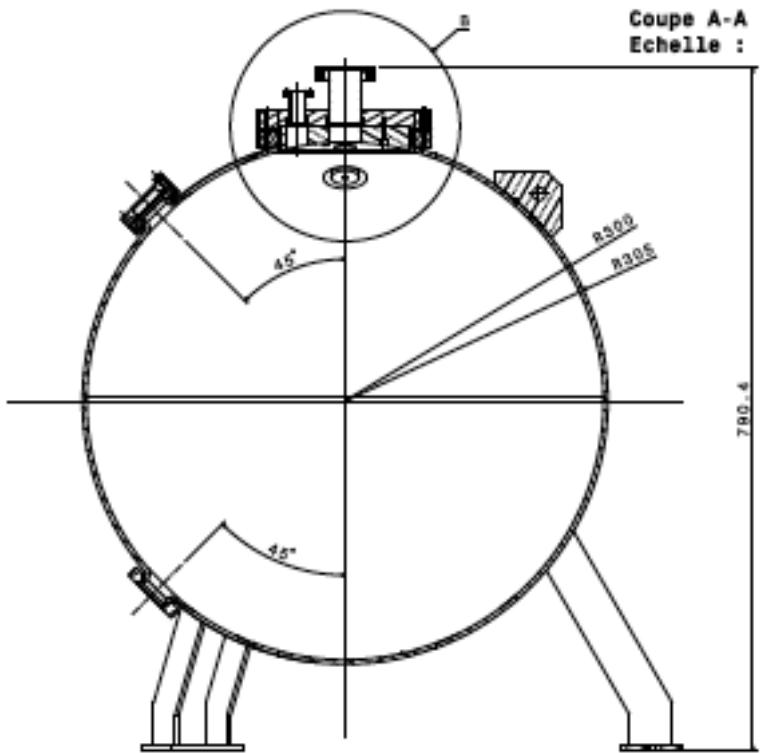
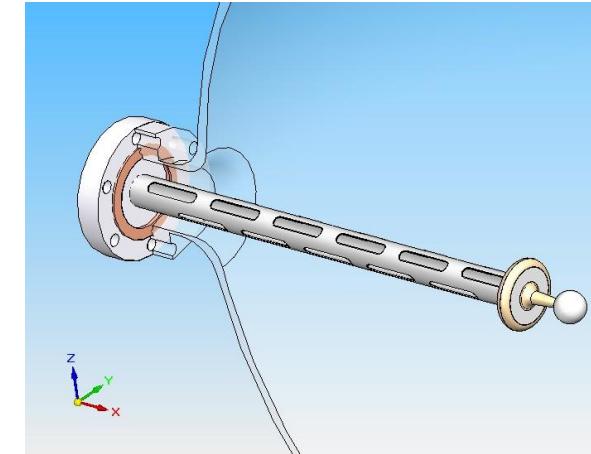
New detector made out of radiopure Cu vessel

- Diameter = 60 cm
- Pressure = up to 10 bar

Appropriate shield will be provided by LSM

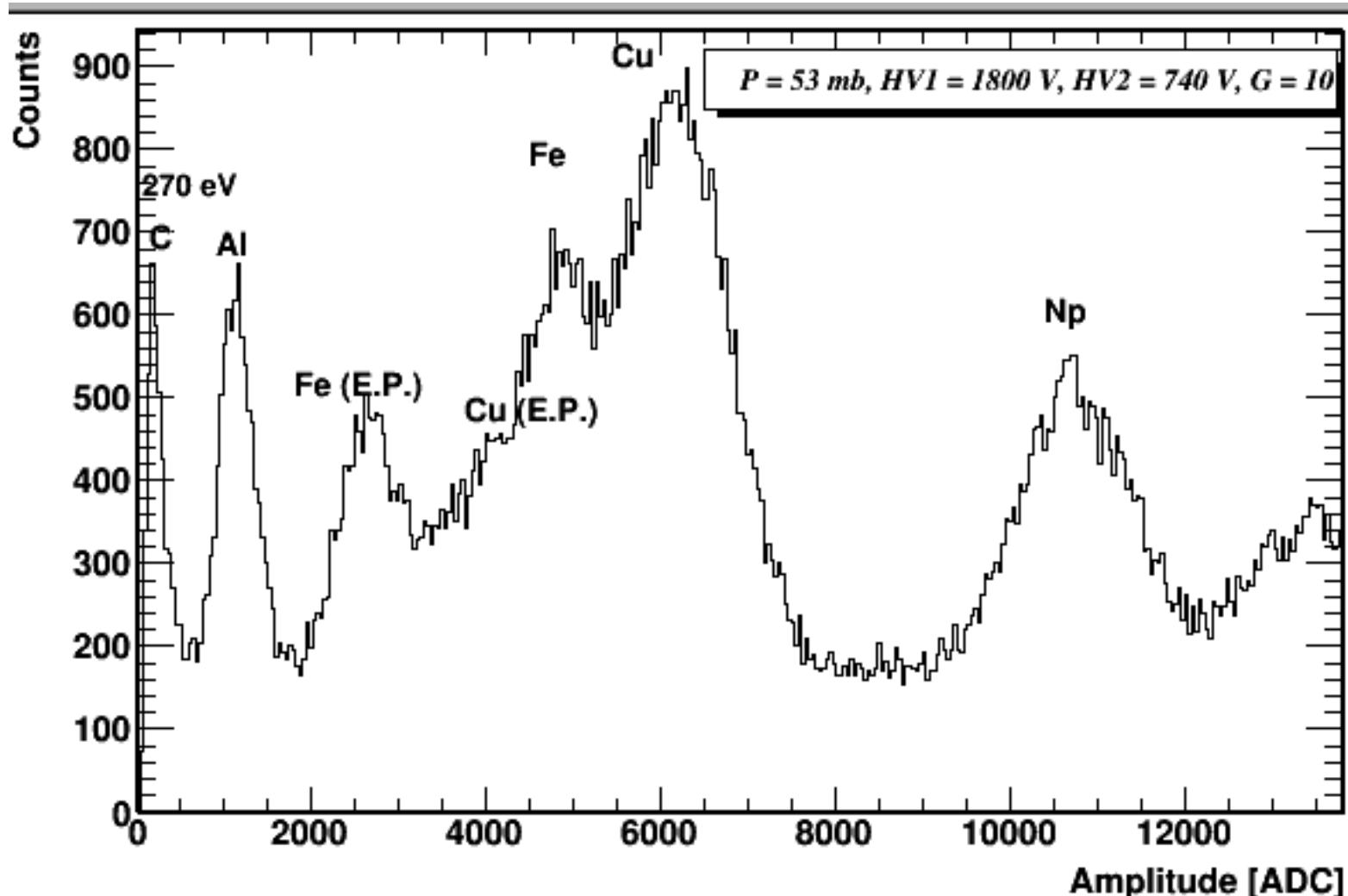
Goal

- Measure fast neutron energy distribution at LSM
- Explore ultra low energy with low background detector



Ultra low energy threshold observed

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



Neutrino-nucleus coherent elastic scattering

$$\nu + N \rightarrow \nu + N \quad \sigma \approx N^2 E^2, \text{ D. Z. Freedman, Phys. Rev.D, 9(1389)1974}$$

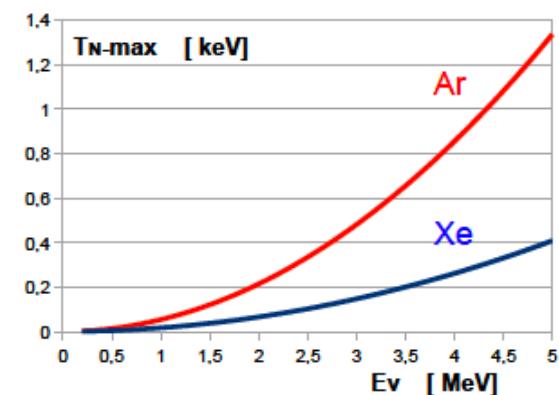
A. Druikier, L. Stodolsky, Phys. Rev. D30:2295, 1984, JI Collar, Y Giomataris - NIMA471:254-259, 2000, H. T. Wong, arXiv:0803.0033-2008, PS Barbeau, JI Collar, O Tench - Arxiv preprint nucl-ex/0701012, 2007

High cross section but very-low nuclear recoil

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

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

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



Argon is a good candidate

Challenge : Very low energy threshold

We need to calculate and measure the quenching factor

Application : Remote control of nuclear reactor

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



Destruction of massive star initiated by
the Fe core collapse

- 10^{53} ergs of energy released
- 99% carried by neutrinos
- A few happen every century in our Galaxy,
but the last one observed was over 300 years ago

Sensitivity for galactic explosion

For $p=10$ Atm, $R=2$ m, $D=10$ kpc, $U_v=0.5 \times 10^{53}$ ergs

# Number of events (no quenching, zero threshold)						
He	Ne	Ar	Kr	Xe	Xe (with Nuc. F.F.)	
.16	3.95	19.1	76.8	235	179	

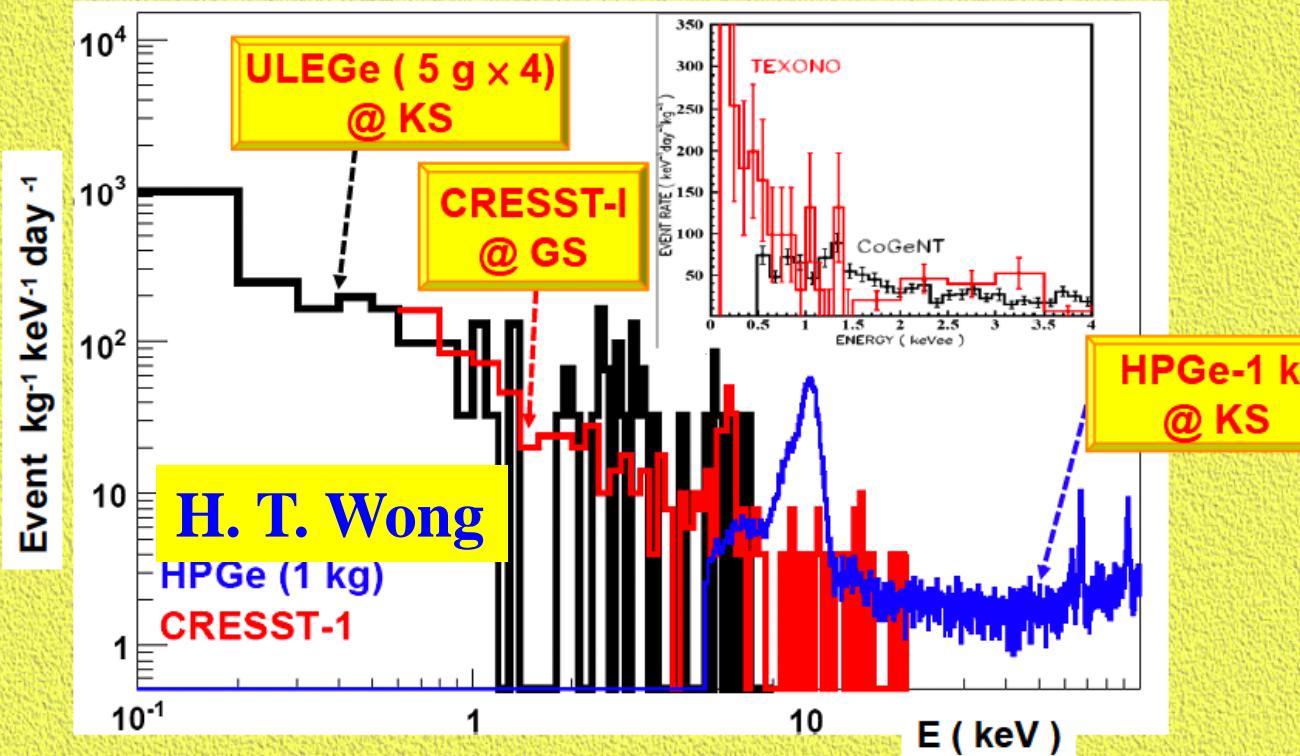
# Number of events (after quenching, $E_{th}=0.25$ keV)						
He	Ne	Ar	Kr	Xe	Xe (with Nuc. F.F.)	
0.08	1.5	6.7	23.8	68.1	51.8	

Idea : A world wide network of several (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

Dark matter search through very low energy threshold < 100 eV

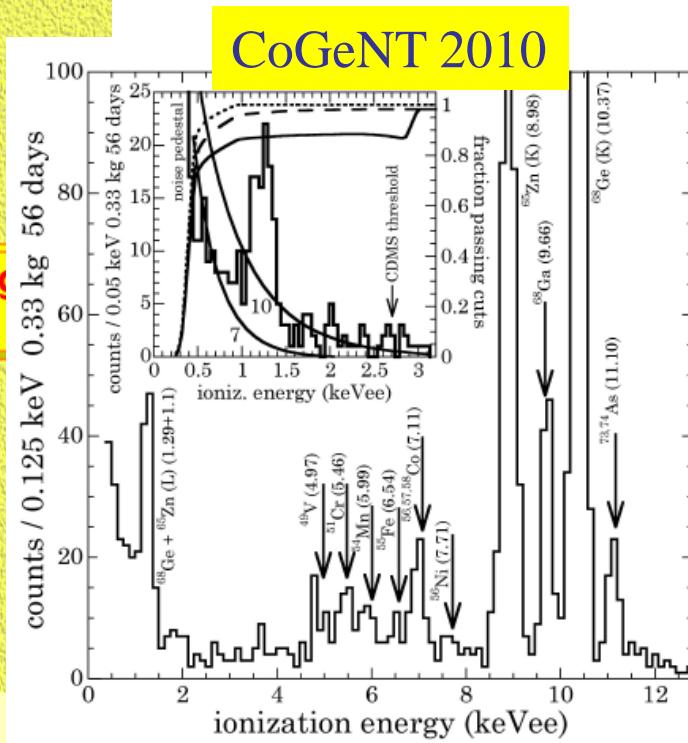
Sub-keV Background Measurements & Comparisons



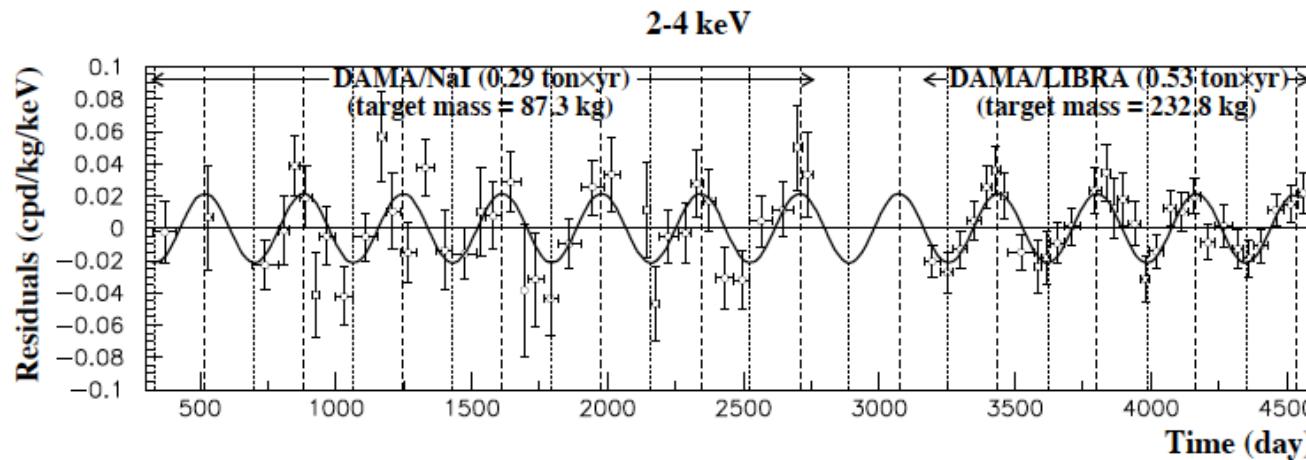
- Bkg $\sim O(1)$ cpd/kg/keV > 10 keV, \sim to underground expts.
- ULEGe bkg @ KS \sim CRESST-1 @ GranSasso
- Intensive studies on sub-keV background understanding

WIMP at 7 GeV?

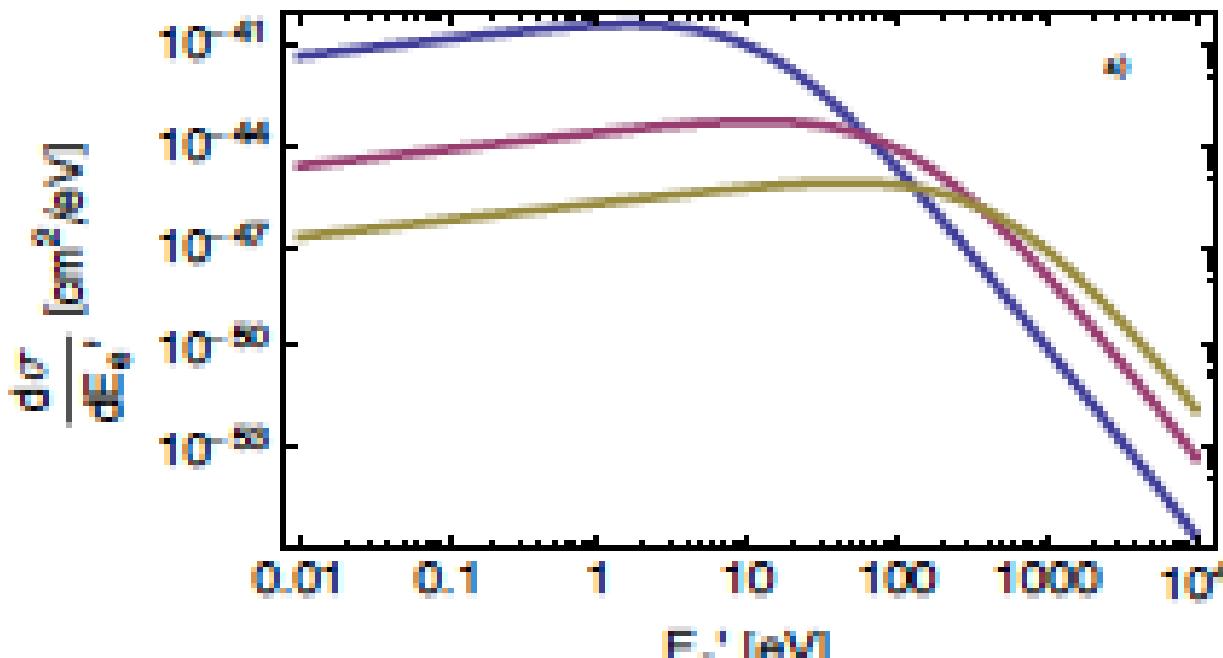
J. Collar, arXiv:1103.4132, 2011



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

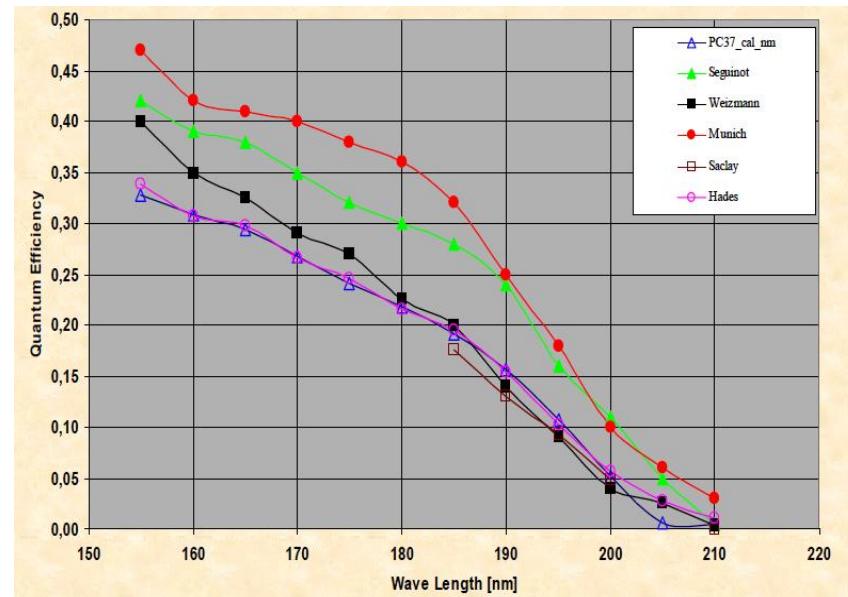
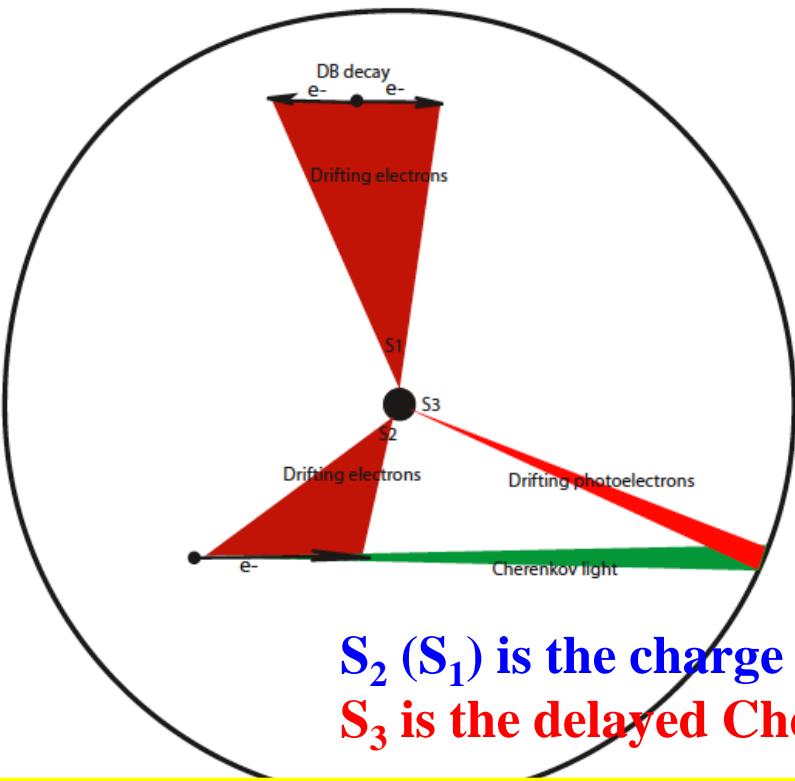


- Secluded WIMP dark matter (Pospelov, Ritz, Voloshin, Arkani-Hamed)
- Generally: Electron-Interacting dark matter



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

Spherical detector with Xenon-136 at high pressure
and CsI photocathode layer deposited at the internal vessel surface



S₂ (S₁) is the charge signal collected and amplified
S₃ is the delayed Cherenkov light signal

Advantages: Simple and cost effective

Provides full light collection system

Scaling up :

- 121 Kg with present prototype at p=20 bars
- 3200 Kg with a 3 m radius detector at p=20 bars

CONCLUSIONS

- New detectors – New discoveries
- Micromegas is a good world-wide reference
- Industrial fabrication process
- Multiples applications
- A new promising counter on spherical geometry
- Ultra low energy exciting results
- Reactor or SuperNova neutrino detection