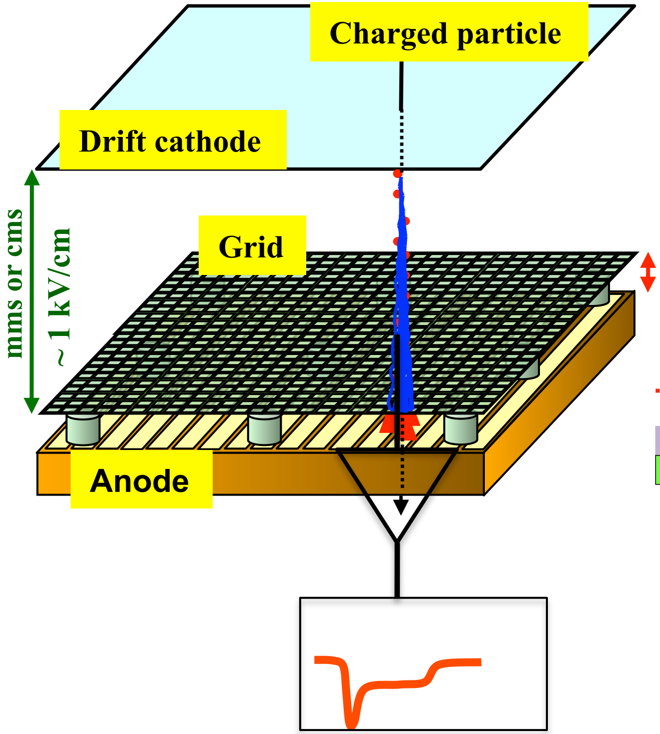
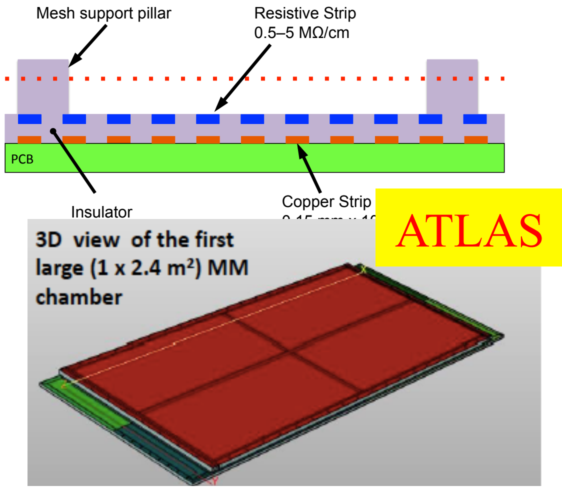
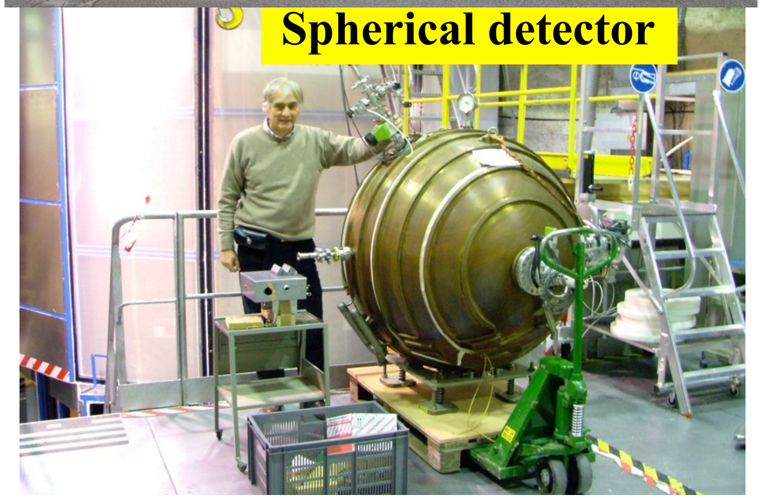
Trends in gaseous particle detectors and new physics *I. Giomataris CEA-Saclay*

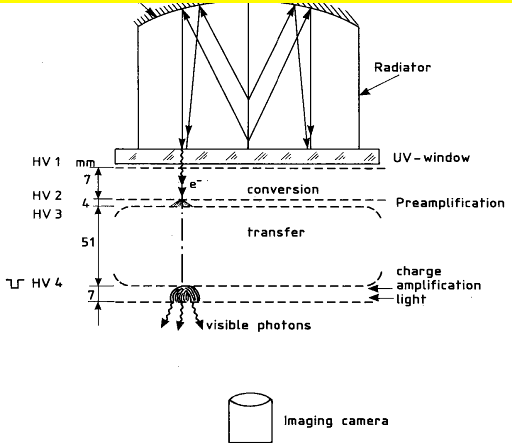






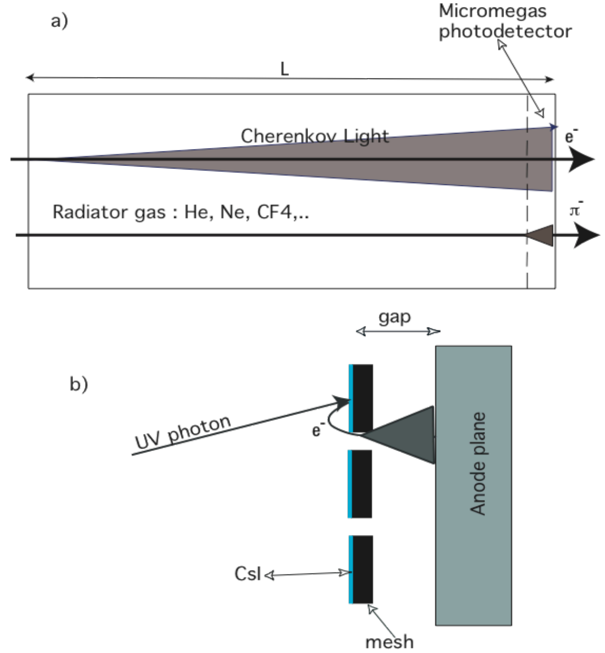
Previous developments

A high-energy gamma ray telescope
I. Giomataris; G. Charpak, CERN-EP-88-94

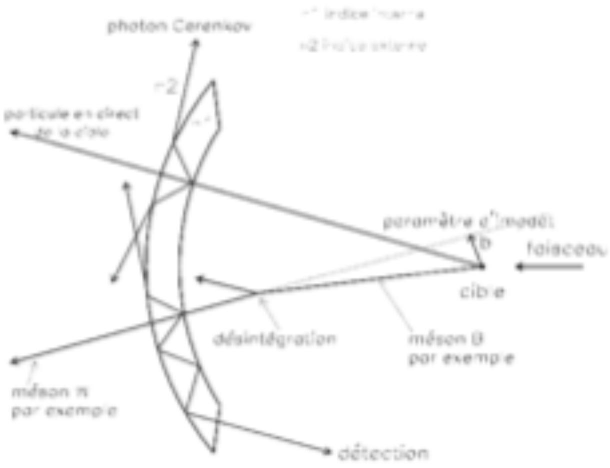


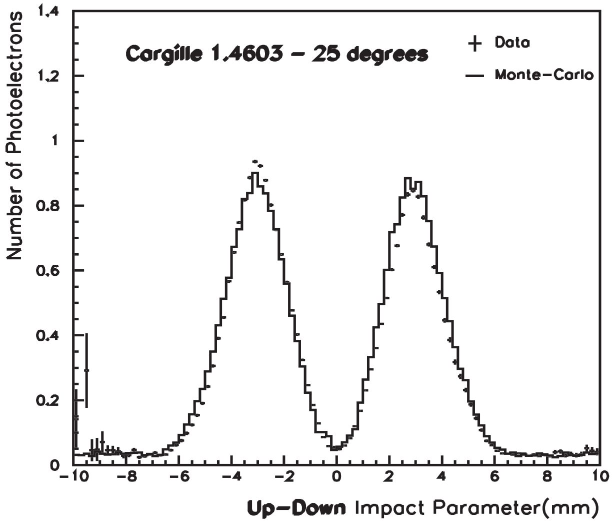
A single electron shower
G. Charpak, Y. Giomataris,, A. Gougas,NIM.A343:300,1994.

A Hadron Blind Detector (HBD)
I. Giomataris,G. Charpak, NIM A310(1991)589

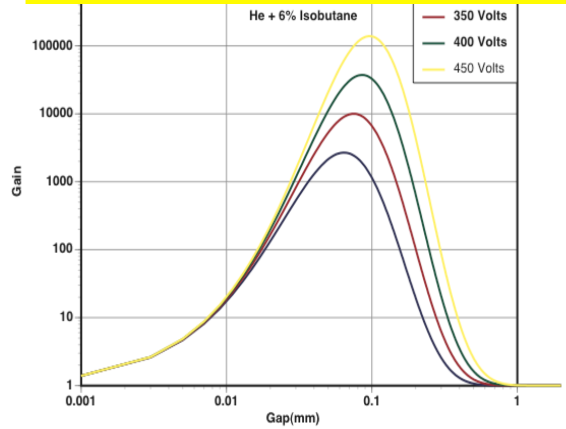


The trigger for Beauty
G. Charpak, I. Giomataris, L.Lederman, NIMA306(1991)439
Developed by Lausanne Uni, Saclay,CERN





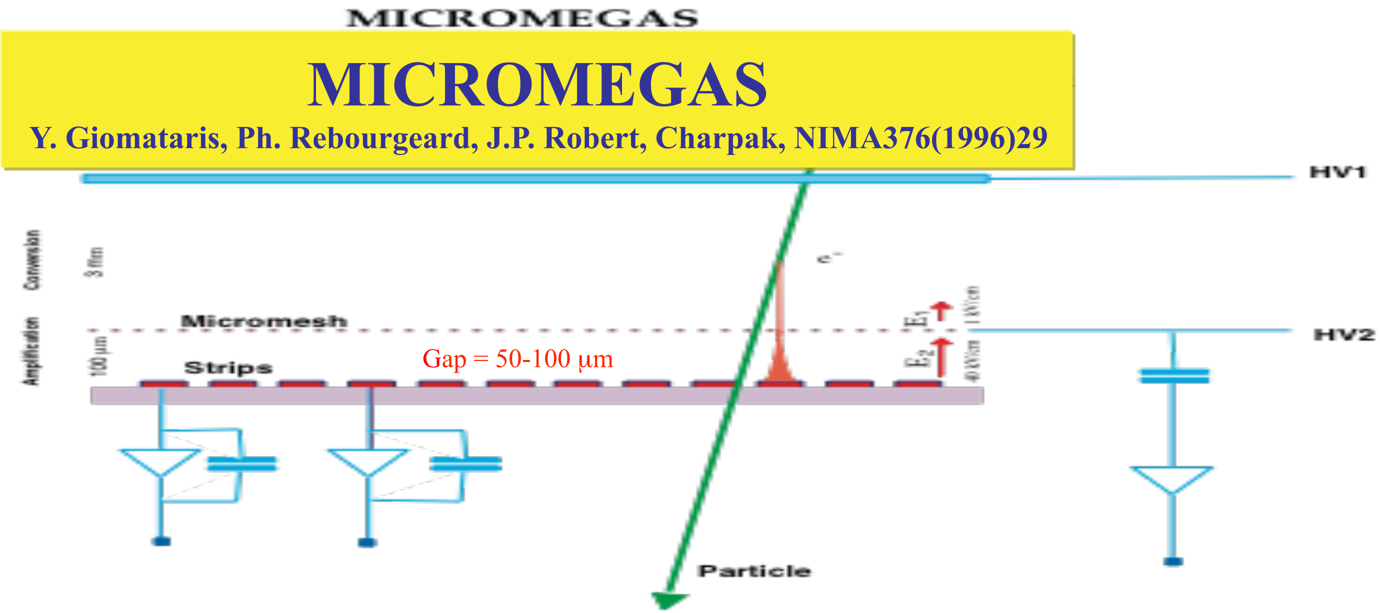
Virtue of the small gap
Y. Giomataris, NIM A419, p239 (1998)



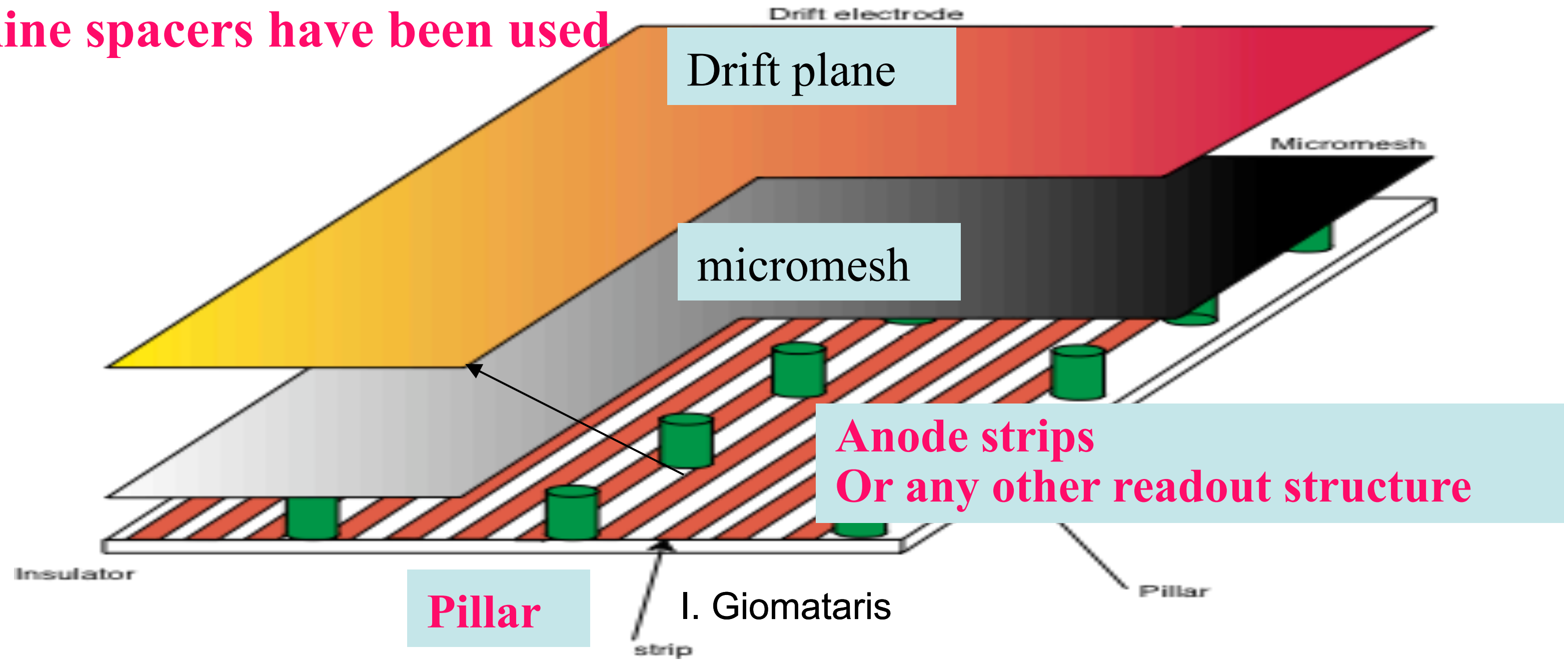
Optimum gap : 30 - 100 microns

MICROMEGAS

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



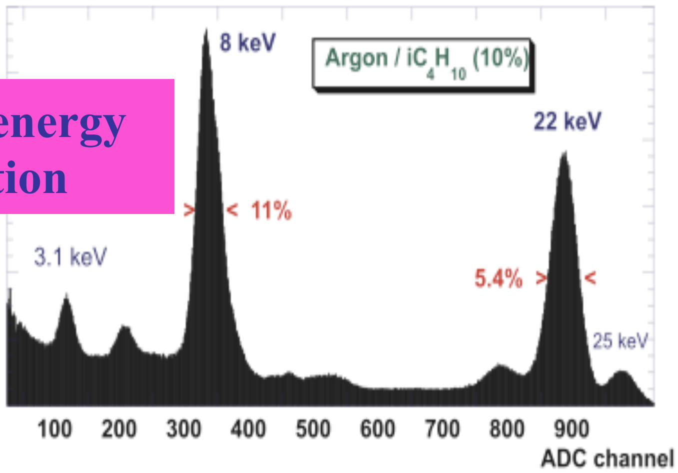
In 1st Micromegas
Fishing line spacers have been used



Earlier Micromegas performance

High radiation resistance : > 30 mC/mm2 > 25 LHC years
G. Puill, et al., IEEE Trans. Nucl. Sci. NS-46 (6) (1999)1894.

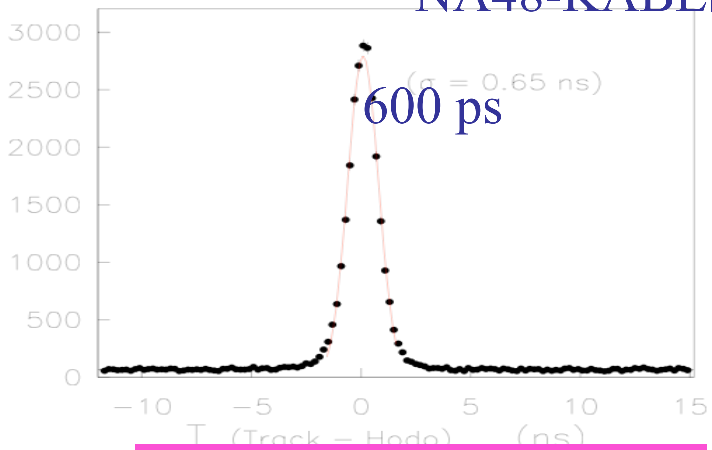
Good energy resolution



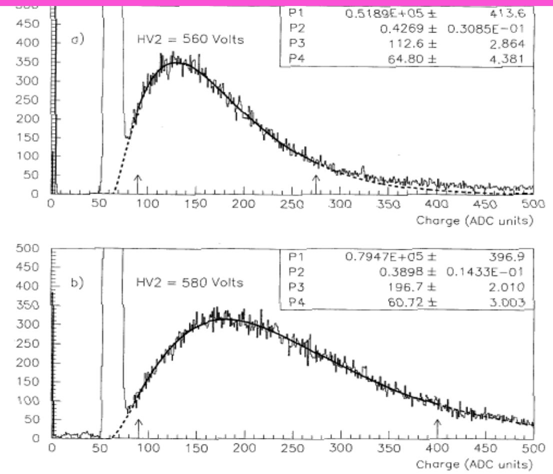
*A. Delbart, **Nucl.Instrum.Meth.A461:84-87,2001***

Sub-nanosecond time resolution

NA48-KABES



Excellent single electron resolution



High accuracy < 12 μm

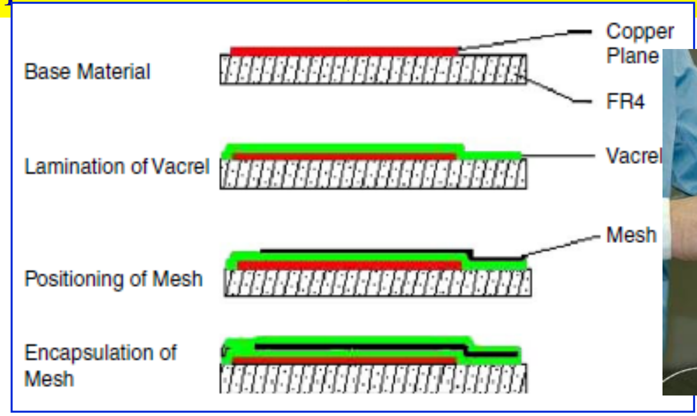
σ (μm)

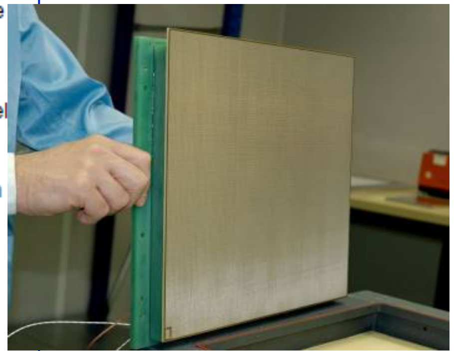
12	Pitch(μm)	Gas mixture	Institute
60	317	Ar + 10% DME	Saclay
45	200	Ar + 25% CO2	Subatech
50	200	Ne + 10% DME	Mulhouse
42	100	Ar + 10% Isobutane	Saclay
29	100	He+ 6% Isobutane + 10% CF_4	Saclay
25	50	He + 20% DME	Saclay
12	100	CF_4 + 20% Isobutane	Saclay

I. Giomataris

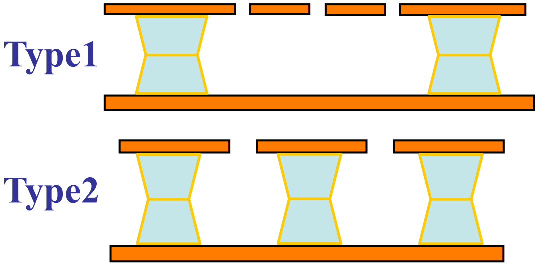
Micromegas fabrication technologies

Bulk micromegas : pre-stretched steel mesh laminated together with a PCB support and a photoresistive layer, later removed apart where pillars are formed, *I. Giomataris et al., NIMA 560 (2006) 405*



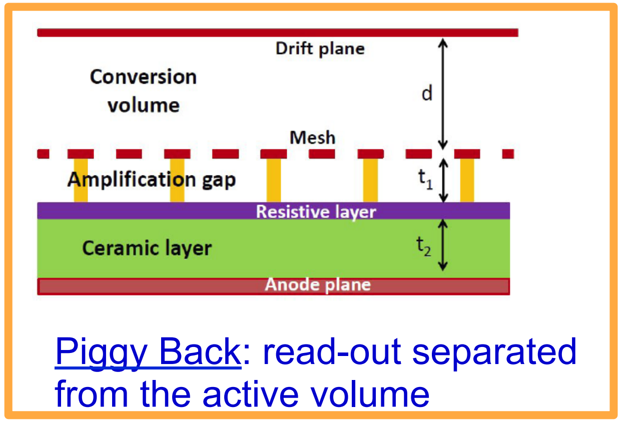


micro-Bulk,
50 µm, 25 and 12.5 µm gaps fabricated

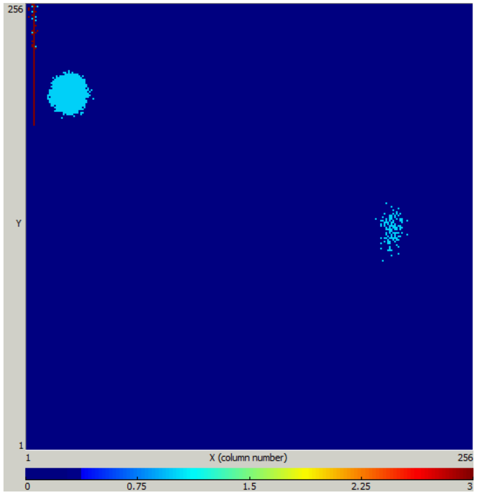


Very good energy resolution 11 % at 5.9 keV
- **Flexible structure (cylinder)**
- **Low material**
- **Low radioactivity**

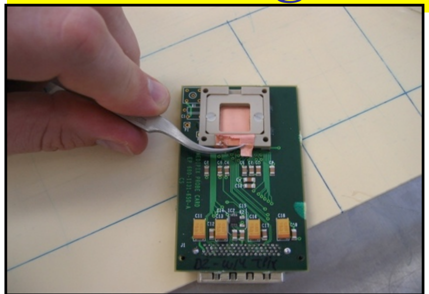
Piggy Back: read-out separated from the active volume

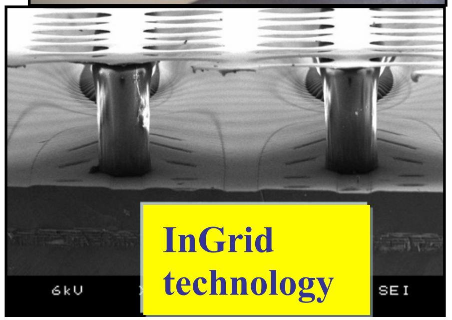


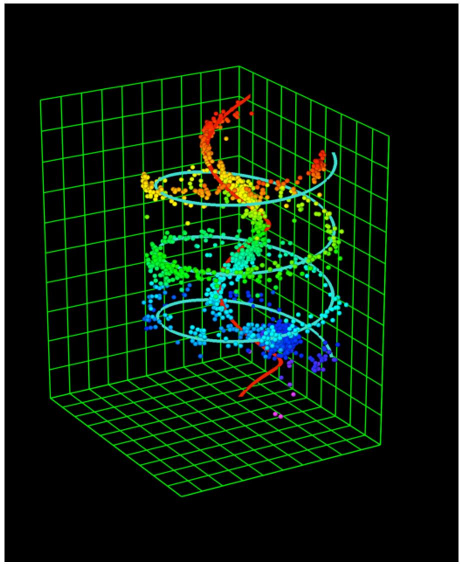
Piggy Back: read-out separated from the active volume



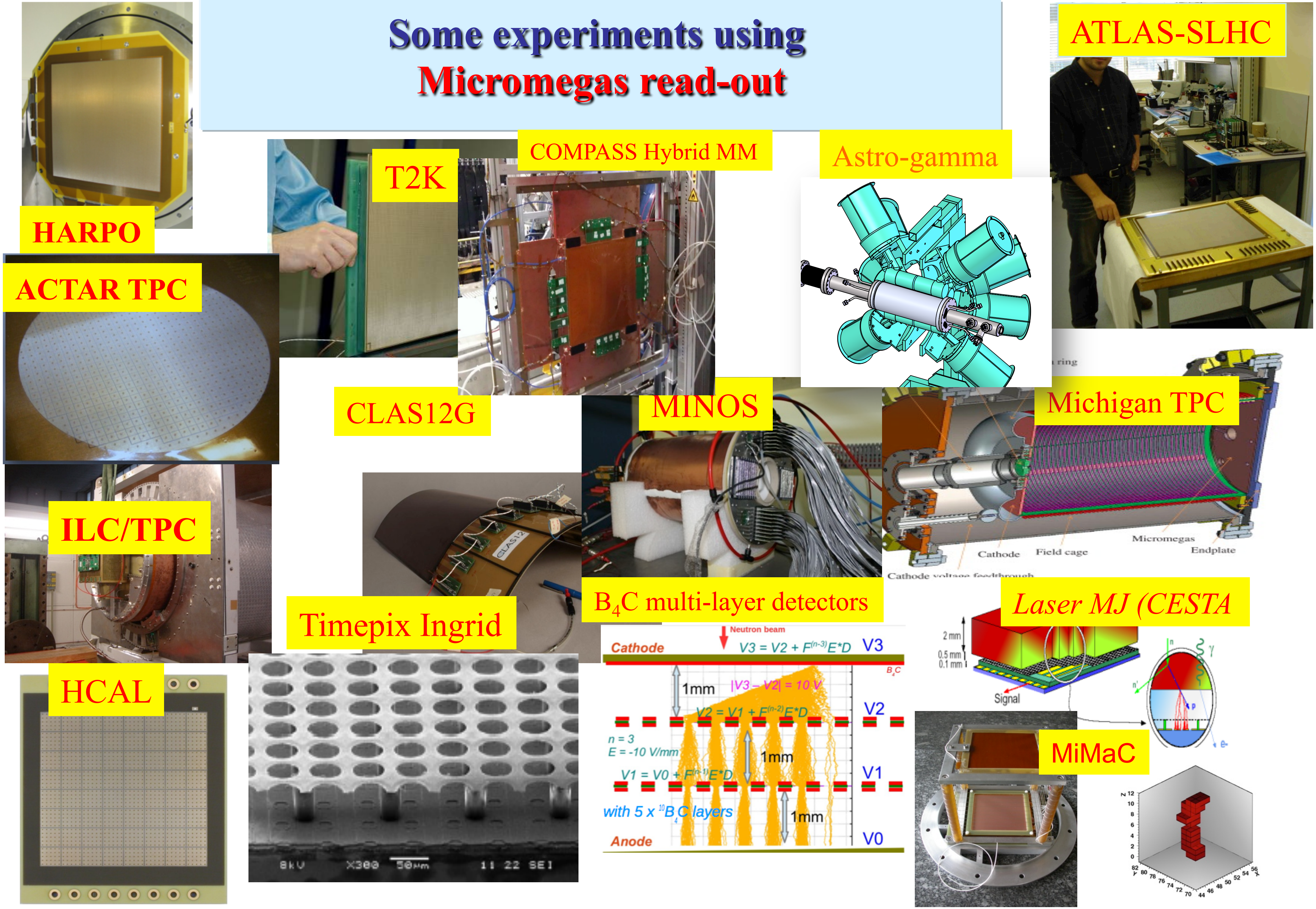
Micromegas + micro-pixels





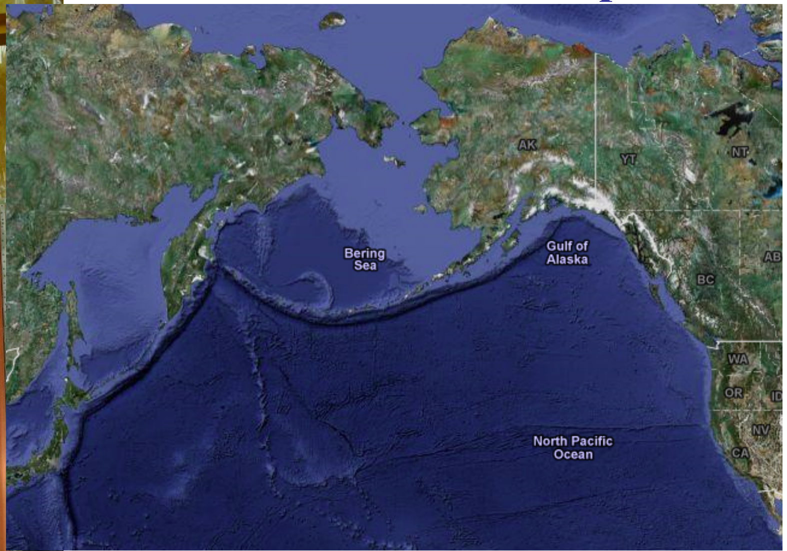


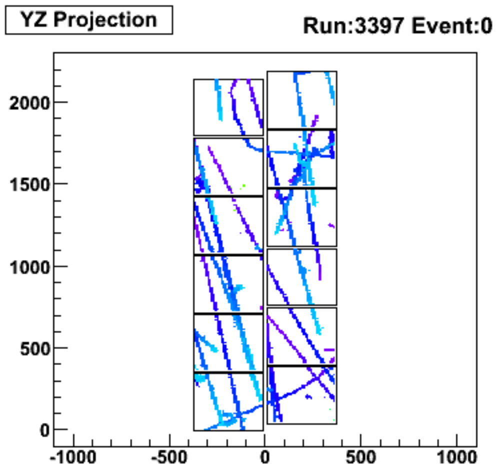
Some experiments using Micromegas read-out

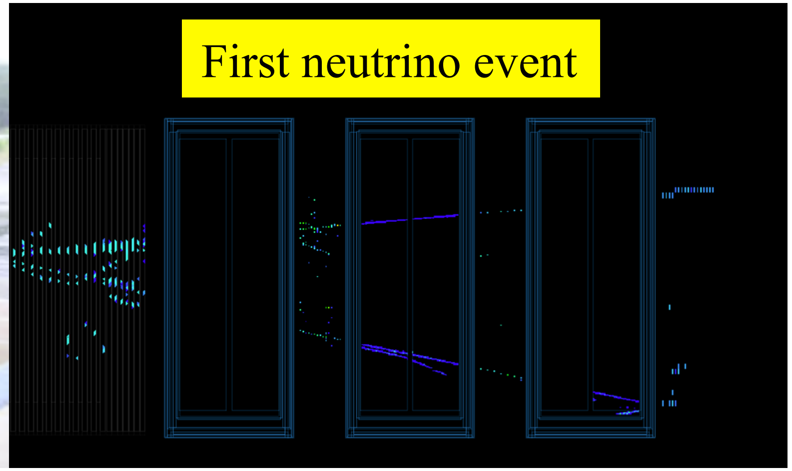


T2K Micromegas TPC – Bulk technology

3xTPCs, 6 end plates, 72 Micromegas







Next upgrade under under study:
A high pressure TPC

Construction of large chambers in ATLAS

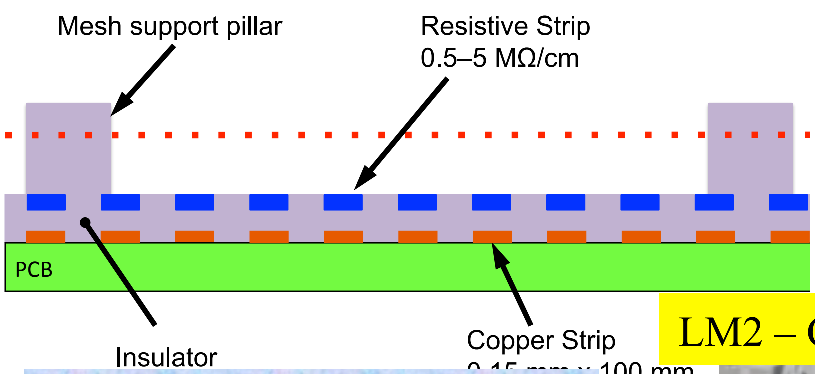
Goal : 1200 m2 total detector surface

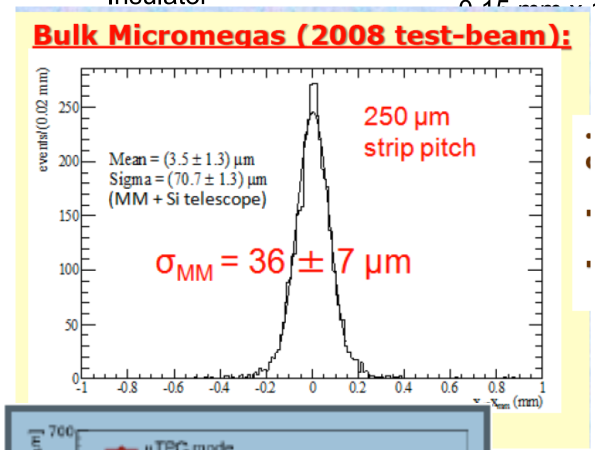
Industrialization is going on through ELVIA, ELTOS

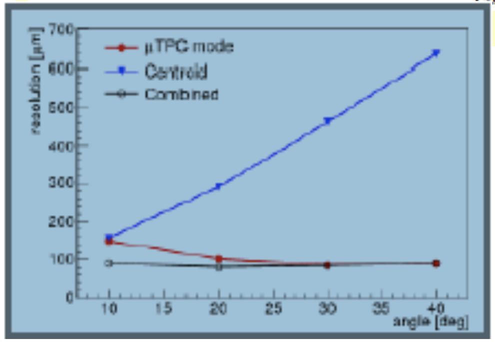
ATLAS Resistive strip technology

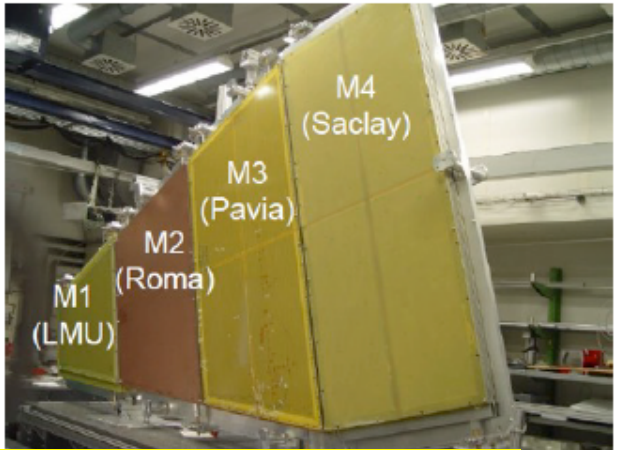
Joerg Wotschack, Mod.Phys.Lett. A28 (2013) 1340020

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

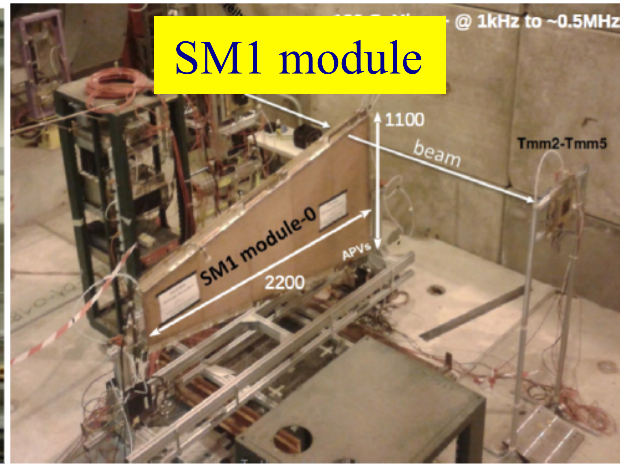




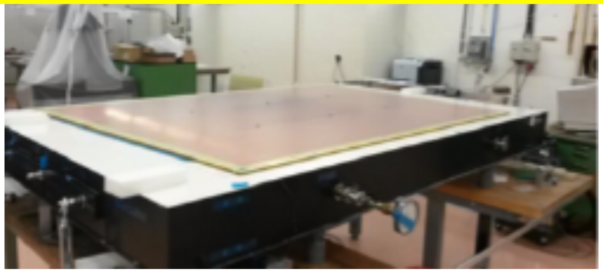




SM1 module

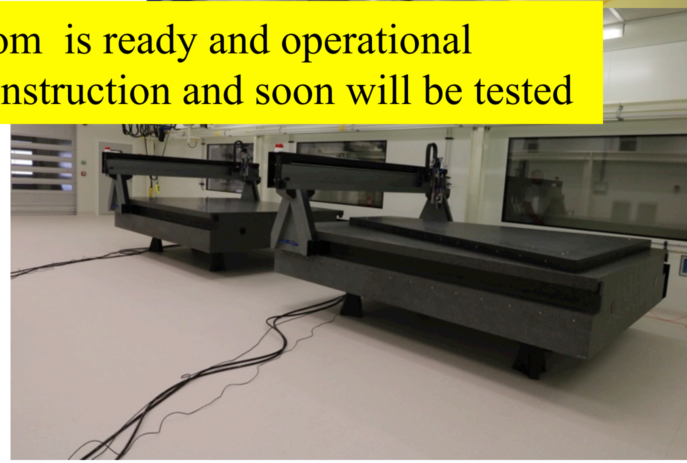


LM2 – CERN / Dubna -Thessaloniki

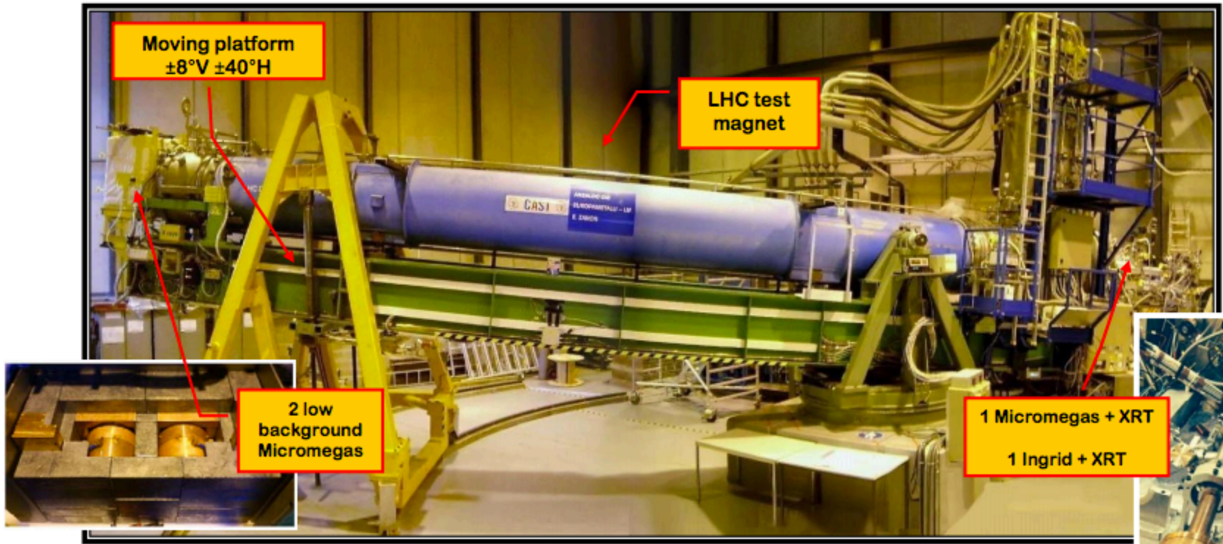


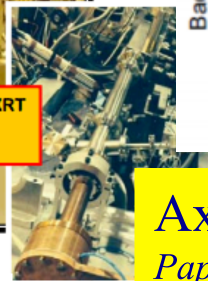
SM2 – Germany

At Saclay the large clean room is ready and operational
First M0 module is under construction and soon will be tested

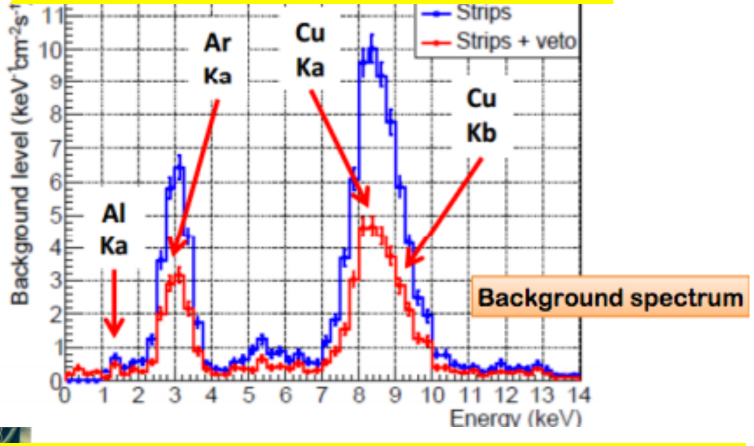


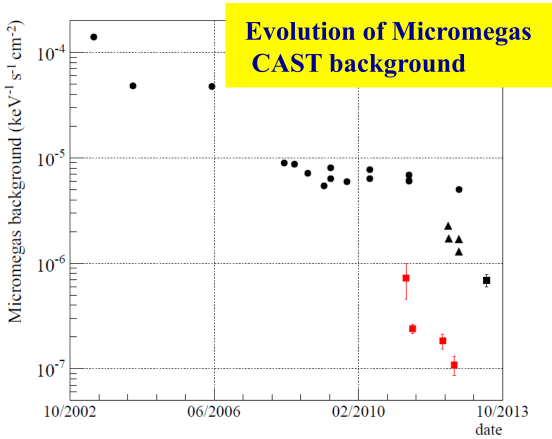
Micromegas micro-bulk in CAST

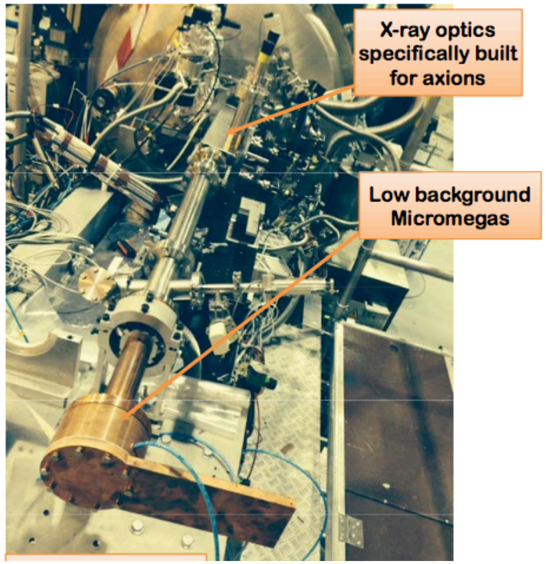




Lowest background than any other CAST detector

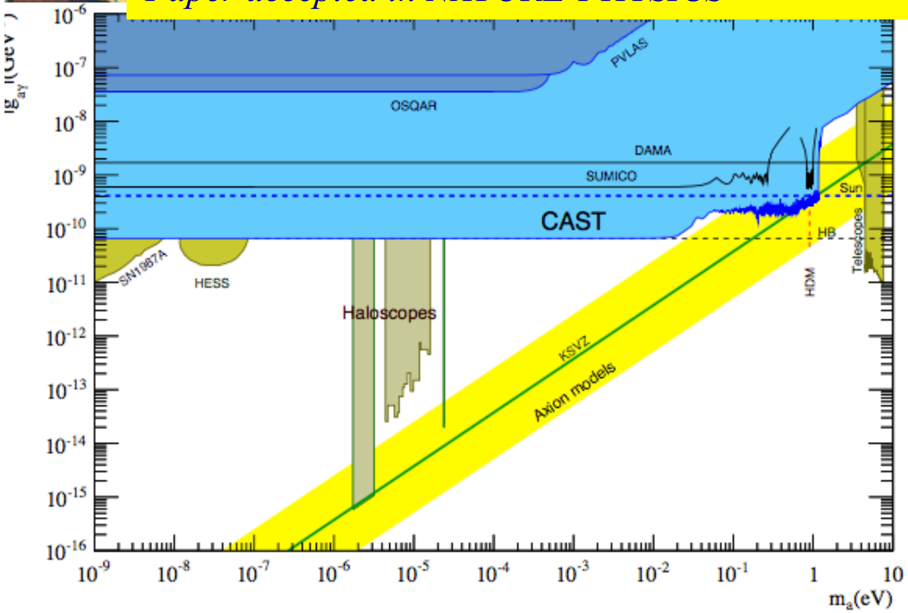






Axion search latest exclusion plots

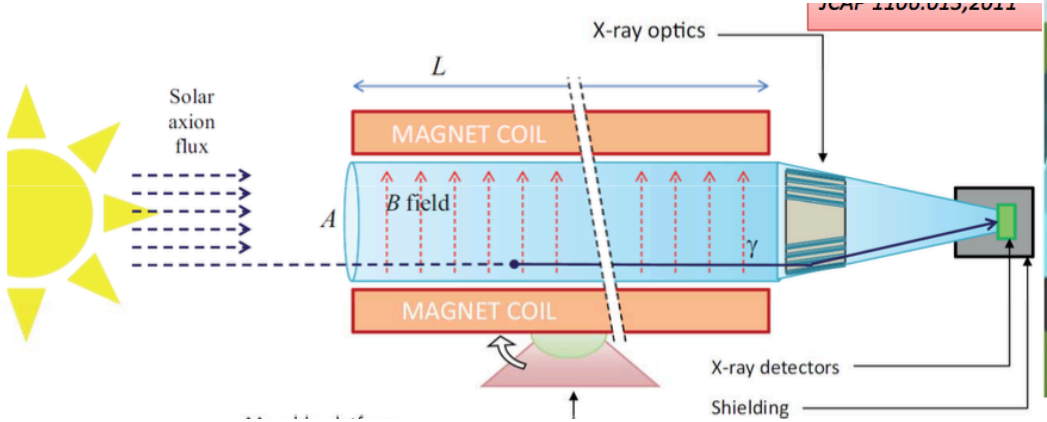
Paper accepted in NATURE-PHYSICS

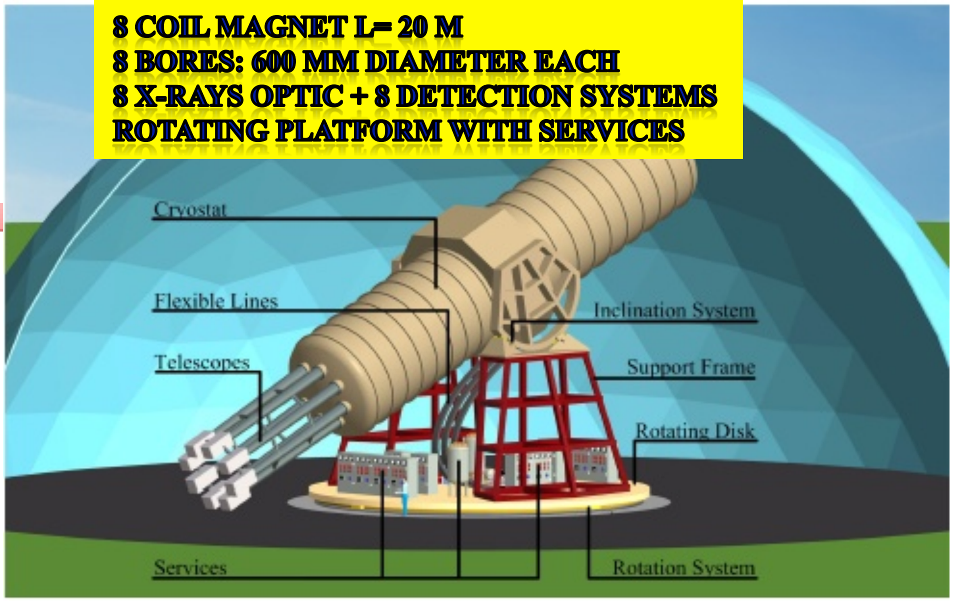


International Axion Observatory (IAXO)

A new proposed experiment

JCAP 1106:013,2011





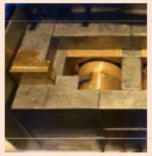
IAXO technologies – Baseline

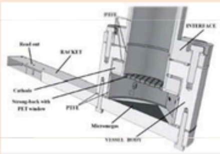
IAXO telescopes

- Slumped glass technology with multilayers
- Cost-effective to cover large areas
- Based on NuSTAR developments
- Focal length ~5 m
- 60-70% efficiency
- LLNL+UC+DTU+MIT expertise

IAXO detectors

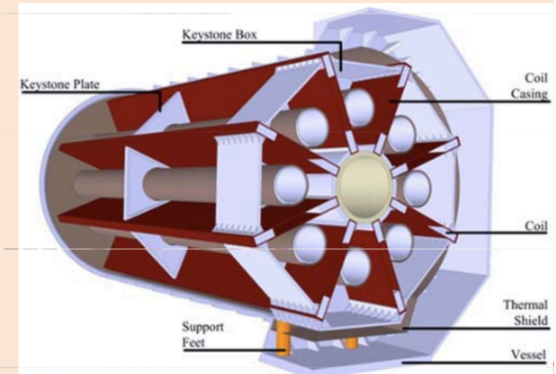
- Micromegas gaseous detectors
- Radiopure components + shielding
- Discrimination from event topology in gas
- Long trajectory in CAST
- Zaragoza + CEA (+ others) expertise
- Also considered: Ingrid, MMCs, CCDs



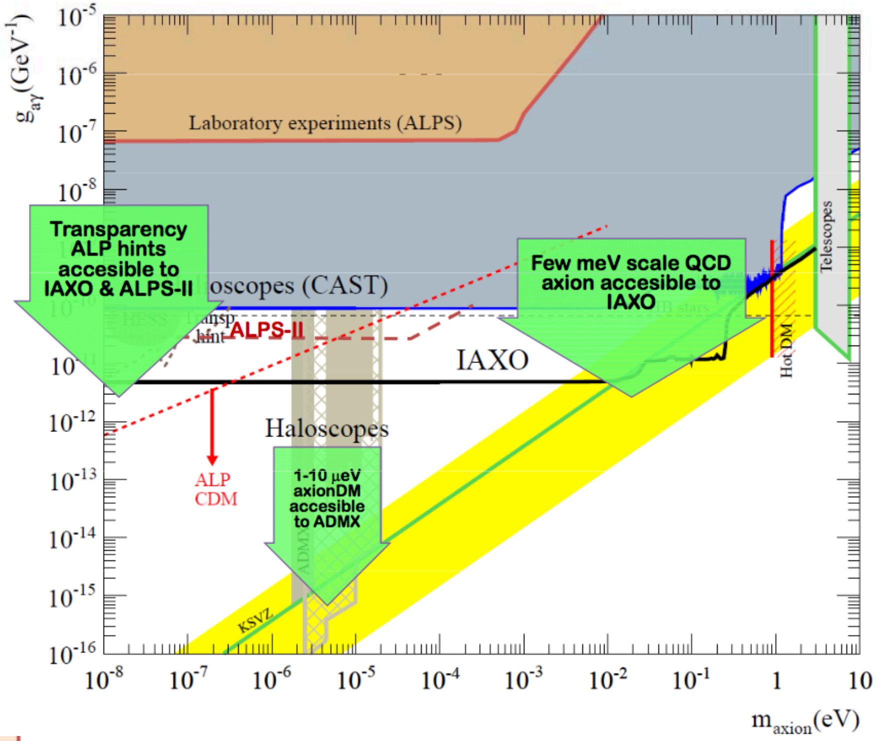


IAXO magnet

- Superconducting "detector" magnet.
- Toriodal geometry (8 coils)
- Based on ATLAS toroid technical solutions.
- CERN+CEA expertise
- 8 bores / 20 m long / 60 cm Ø per bore



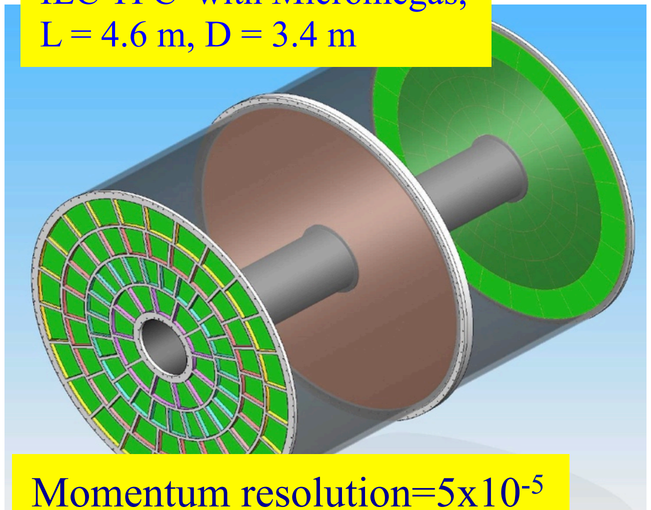
Baseline developed at:
IAXO Letter of Intent: CERN-SPSC-2013-022
IAXO Conceptual Design: JINST 9 (2014) T05002 (arXiv:1401.3233)



ILC TPC project - *Large International collaboration*

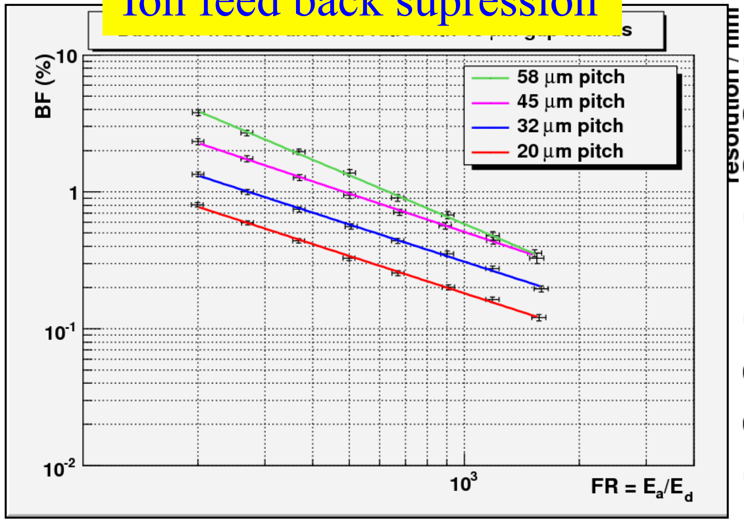
G. Aarons et al., arXiv:0709.1893, M. S. Dixit et al., NIMA 518 (2004) 521, M. Kobayashi et al.,NIMA581(2007)265,

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

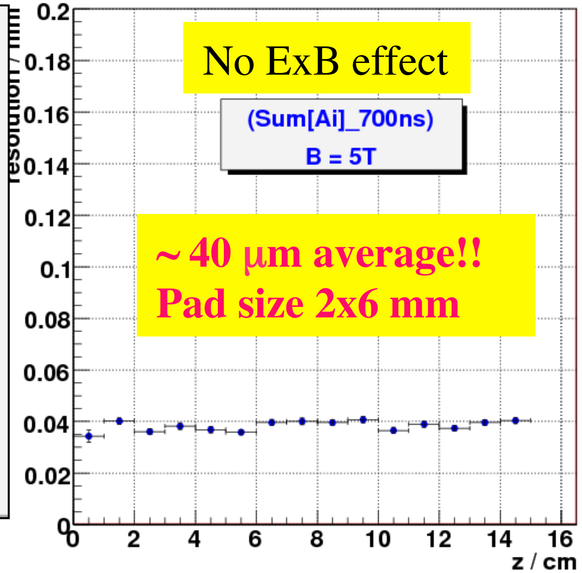


Momentum resolution=5x10^{-5}

Ion feed back supression



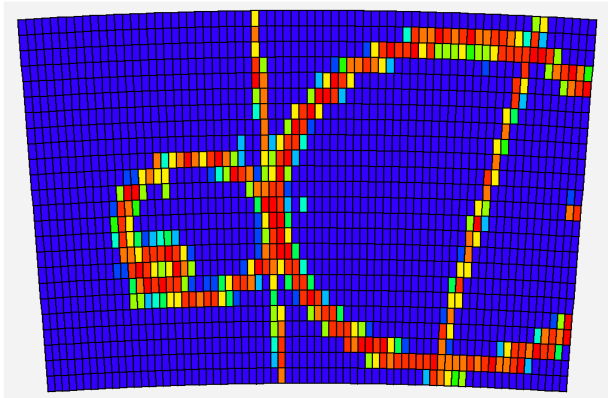
No ExB effect



~ 40 µm average!!
Pad size 2x6 mm

ILC TPC prototype
with Micromegas

Event in DESY test beam

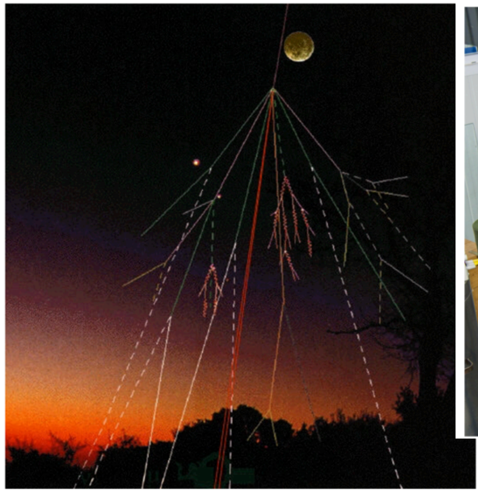


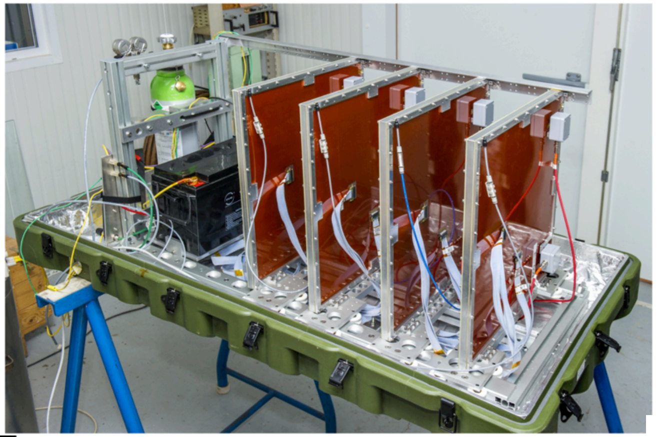
TPC Micromegas advantages

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

Muon tomography using Micromegas detector

D. Attie, S. Bouteille, S. Procureur et al.

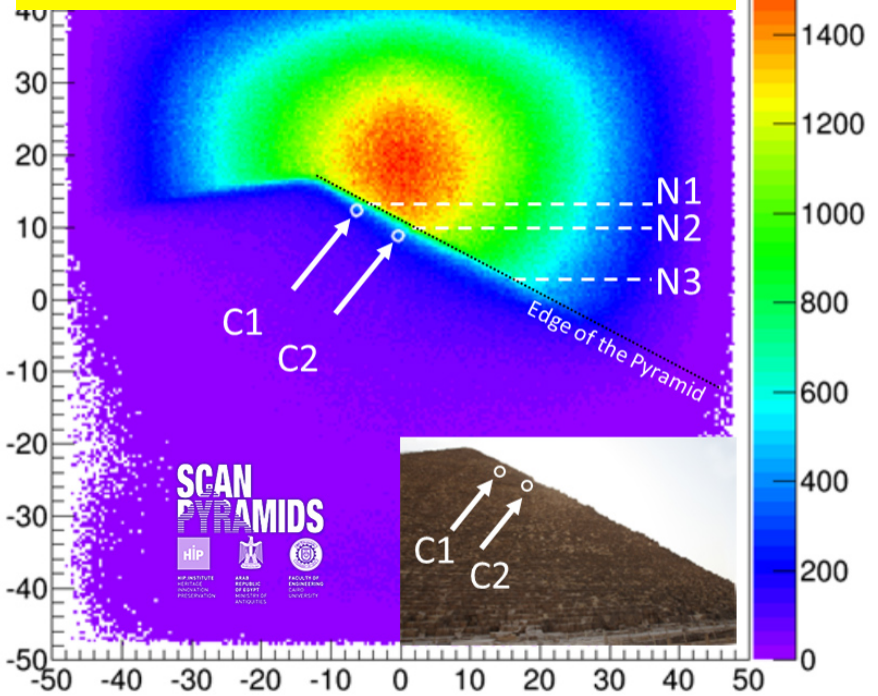




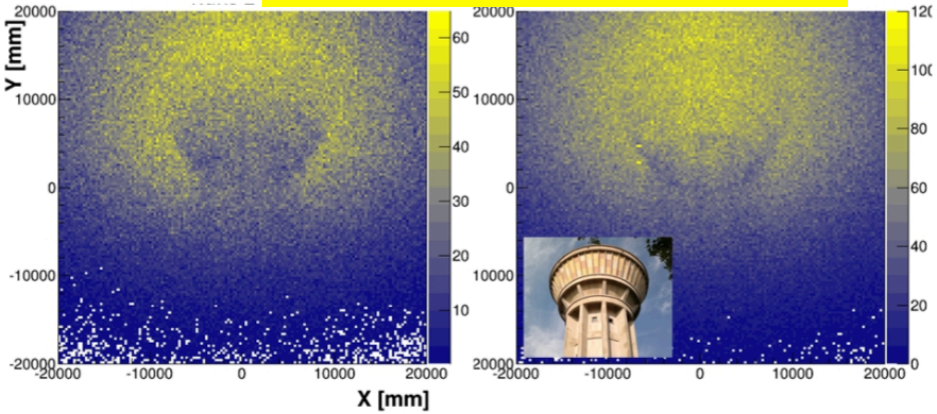
ScanPyramids Mission

Cheops: Discovery of a new cavity

Press released: October 15th, 2016



'Chateau d'eau' at Saclay



MIMAC-He3 MIcro-tpc Matrix of Chambers of He3

WIMP directional TPC, Micromegas read-out,

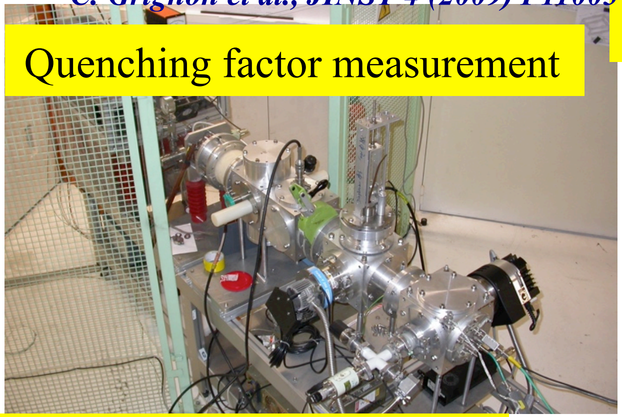
Grenoble – Saclay, Cadarache collaboration

C. Grignon et al., JINST 4 (2009) P11003

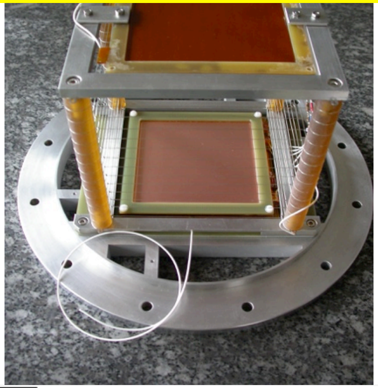
Direct QF evaluation

D. Santos et al., [arXiv:0810.1137]

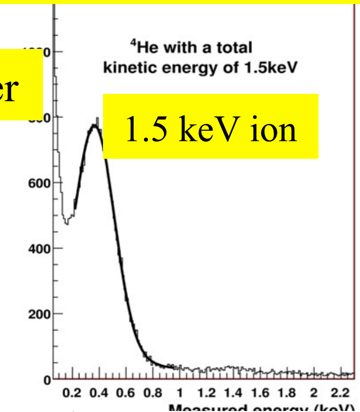
Quenching factor measurement



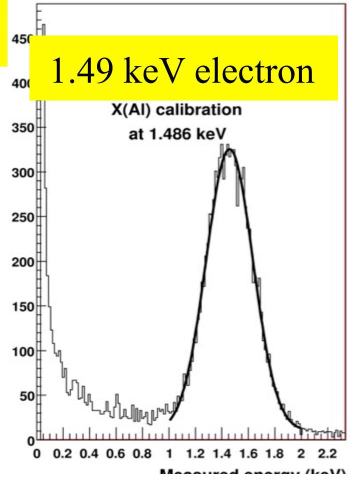
Micromegas:μTPC chamber



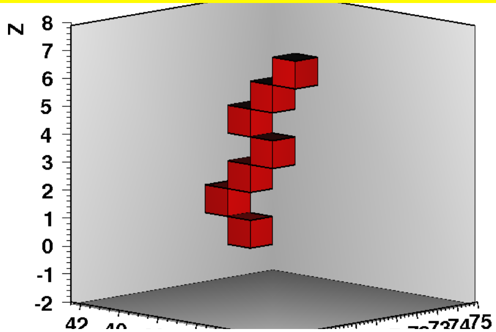
1.5 keV ion



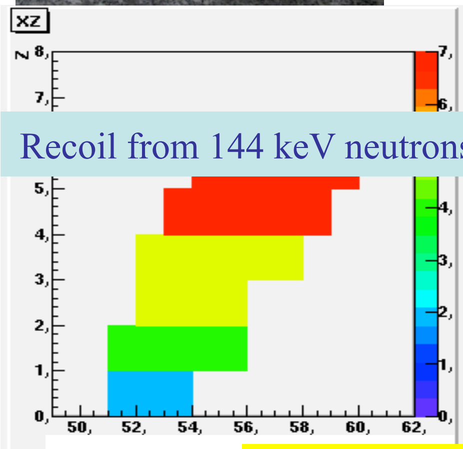
1.49 keV electron



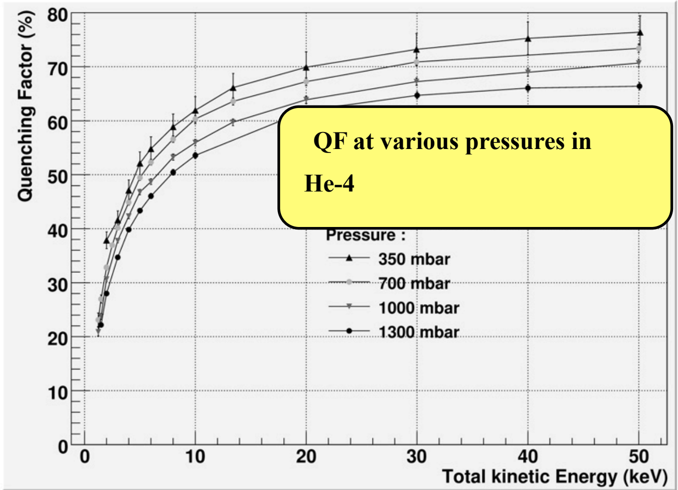
proton 8 keV, He + 5% iC_4H_{10}, 350 mbar



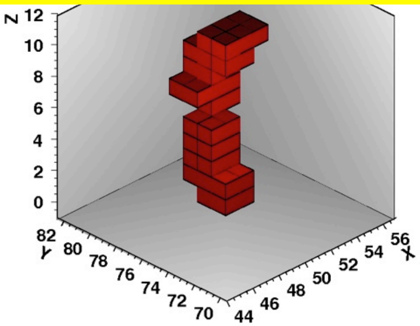
Recoil from 144 keV neutrons



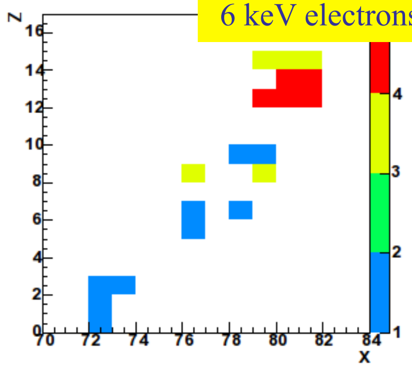
QF at various pressures in He-4

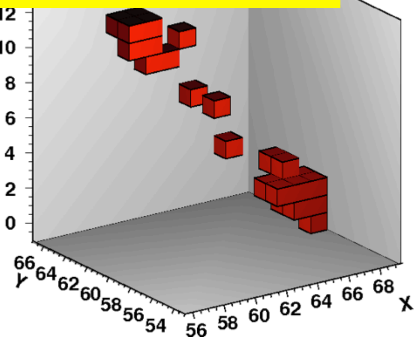


40 keV ^{19}F, 70 % CF_4 + 30% CHF_3 , 55 mbar



6 keV electrons in He + 5% iC_4H_{10} 350 mbar

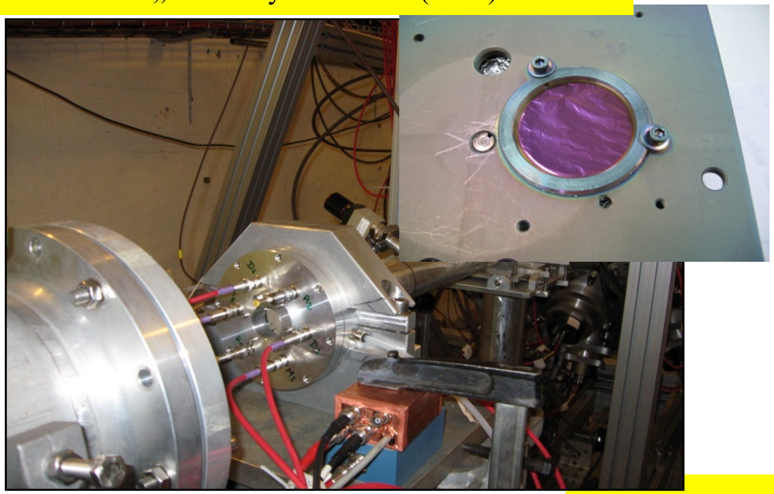




Applications in neutron detection

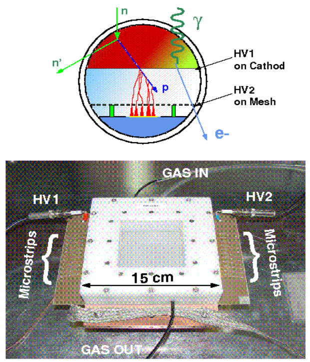
n-TOF MicroMegas-based neutron transparent flux monitor and profiler

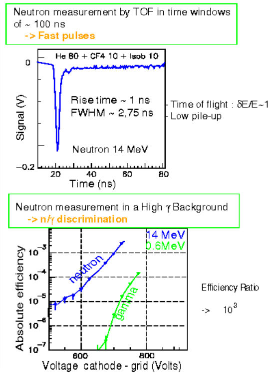
F. Belloni et al.,, Mod.Phys.Lett. A28 (2013) 1340023

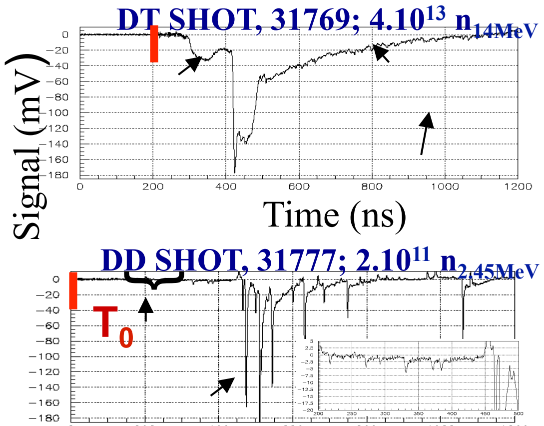


Micromégas Concept for Laser MégaJoule and ICF Facilities

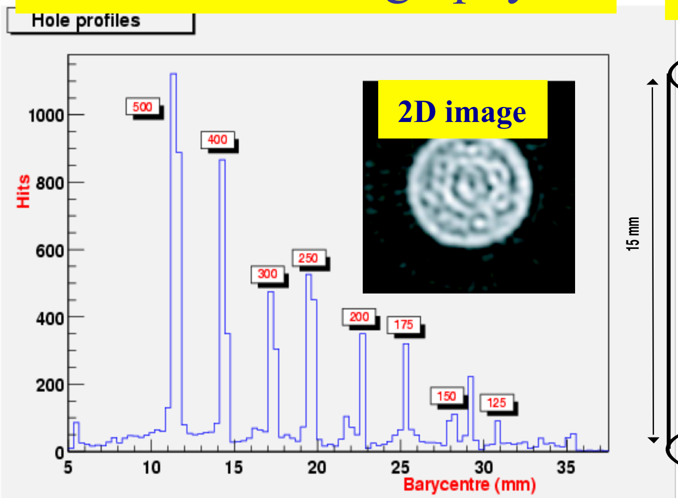
M. Houry et al., NIM,557(2006)648





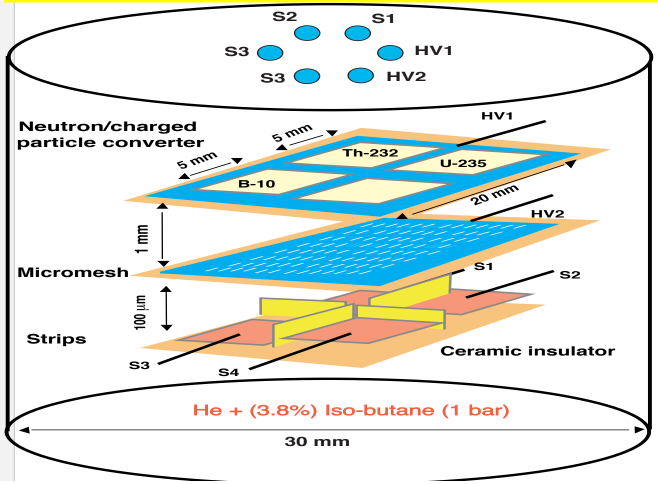


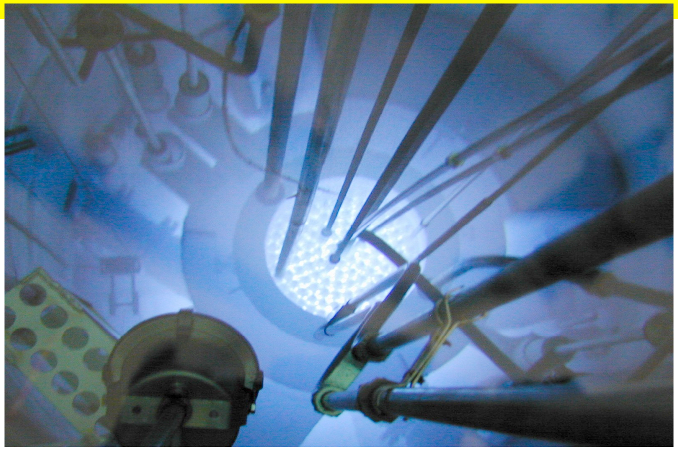
neutron tomography



Piccolo Micromegas, Nuclear reactor in-core neutron measurement

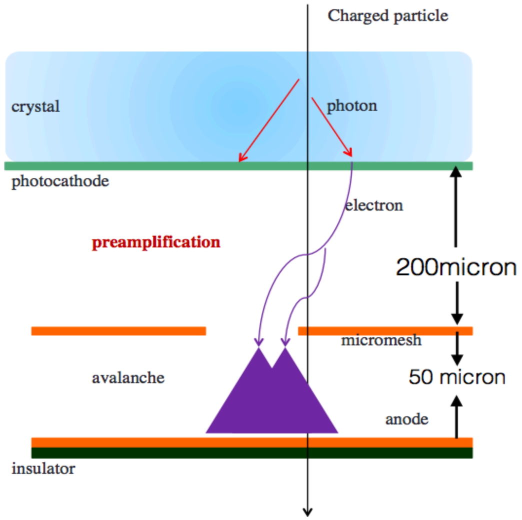
J. Pancin et al., NIMA, 592(2008)104





Fast timing Picosecond Micromegas

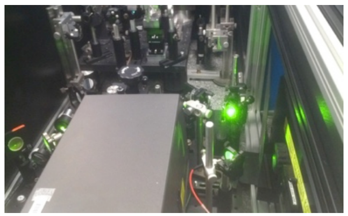
CEA-Saclay, CERN, Thessaloniki, Athens, Princeton, USTC

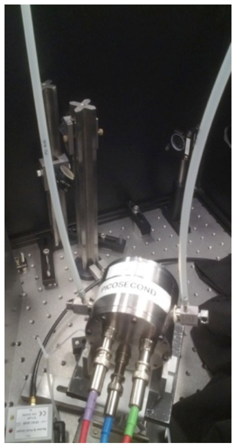


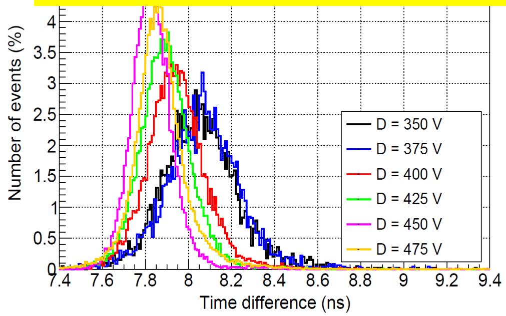
Test with UV fs laser @ IRAMIS-CEA

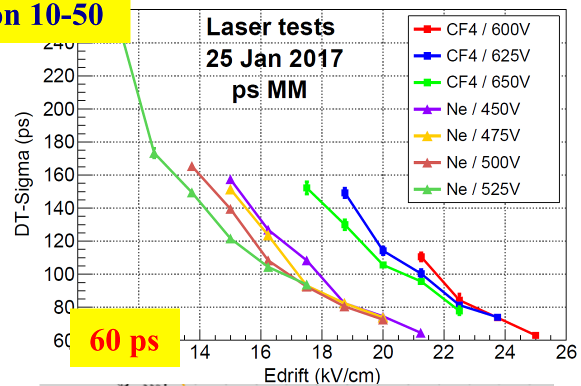
UV Photocathodes on MgF window:
CsI, Cr, Diamond (10-50nm thick)

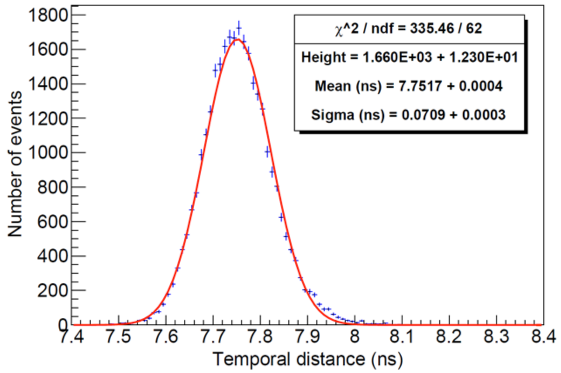
January 2017, Cr 18nm, single electrons/pulse
MM amplification 10^4, preamplification 10-50

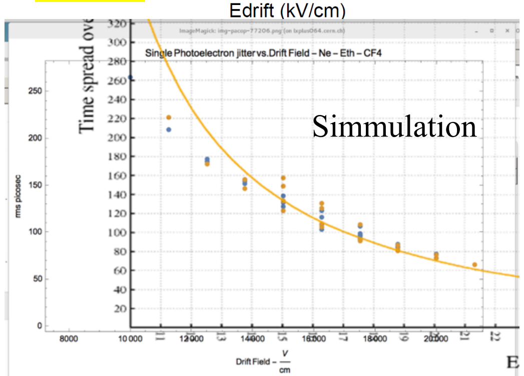








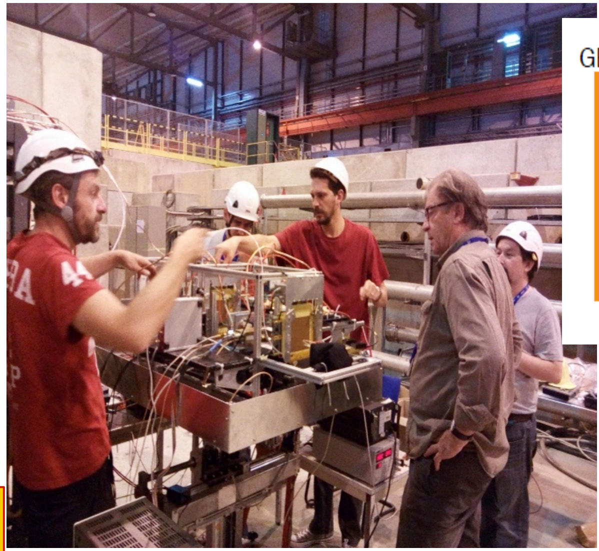


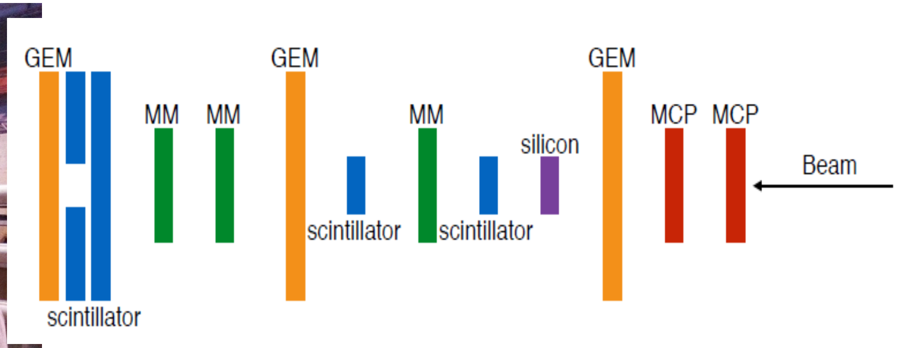


2016 beam tests with 150 GeV muons @ SPS H4

June 2016

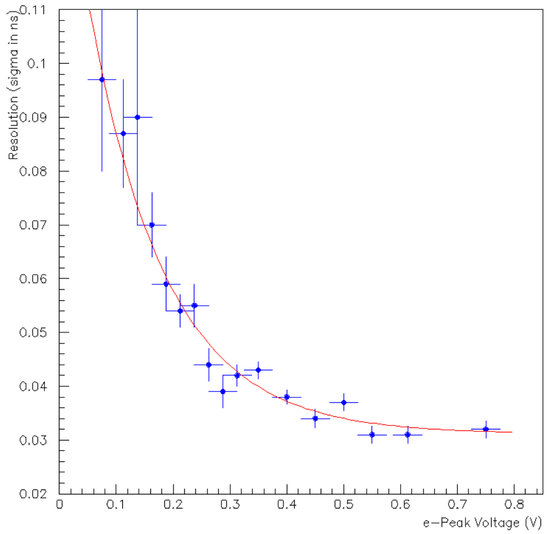
- Sensors: *Standard bulk Micromegas*
- *Photocathodes: 3,5mm* MgF_2
  CsI photocathodes : CsI, Cr, Diamond
  + 6 nm Al + 10.5 nm CsI
- Gas mixtures:
  $Ne/C_2H_6/CF_4$ (80/10/10)
  Ne/CH_4 (95/5)
  $CF4 / C_2H_6$ (sealed mode)

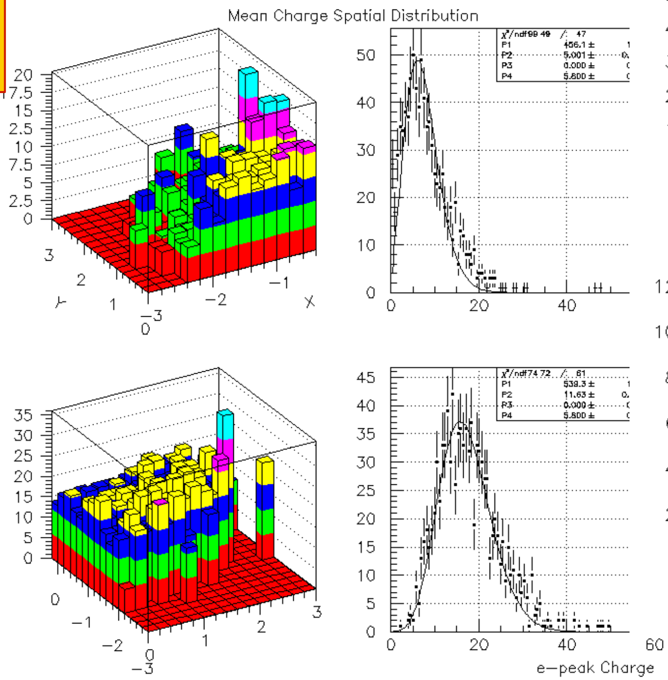


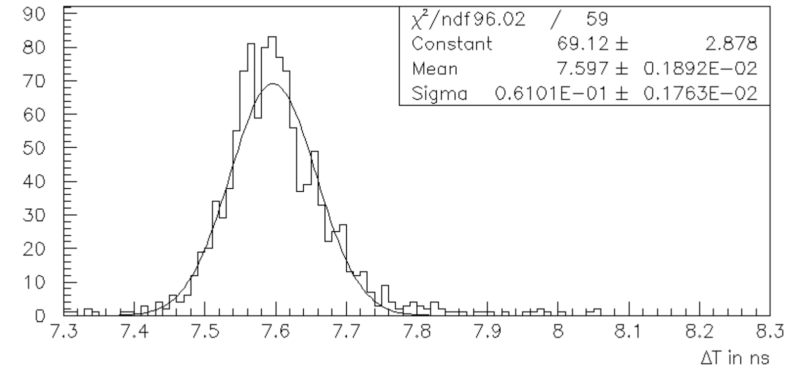


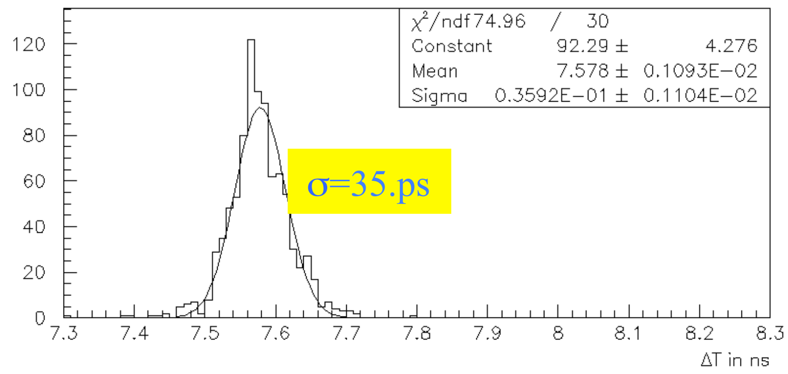
Data analysis in progress. Data from different detector configurations to be analyzed. Results for:

➢ $\sigma_t \approx 35$ ps, $\langle N_{p.e.}\rangle \approx 15$



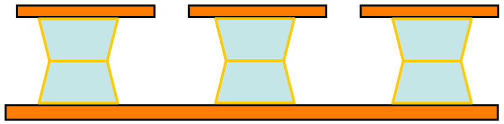


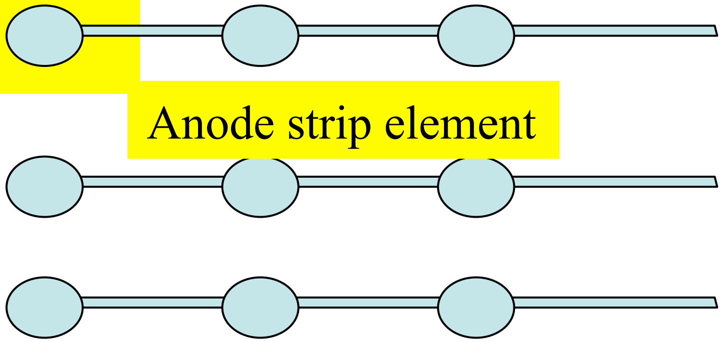




Towards ultra-low capacitance MM

- Spark protection
- Preserves fast electron signal



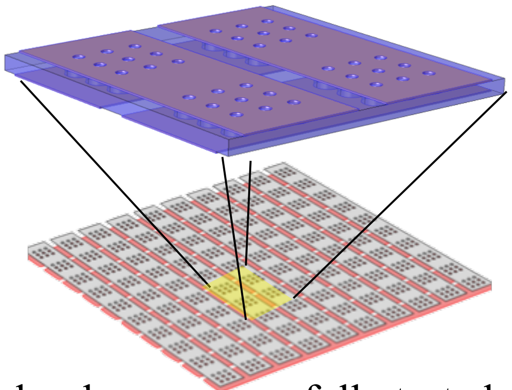


First protoype was fabricated using microbulk kapton etching

Results are encouraging: high gain, good energy resolution**, Capacitance x3 lower**

Future improvements

Combine with anode mesh segmentation to reduce capacitance



The idea has been successfully tested

Th. Geralis et al.,PoS TIPP2014 (2014) 055

- Pad read-out
- Move pad read-out back by 1-2 mm
- To further reduce capacitance

Ultimate goal

Read-out pad or strip capacitance <1 pF

Charge released by spark $< 10^9$ electrons

To reach the goal we need new high-precision fabrication technology

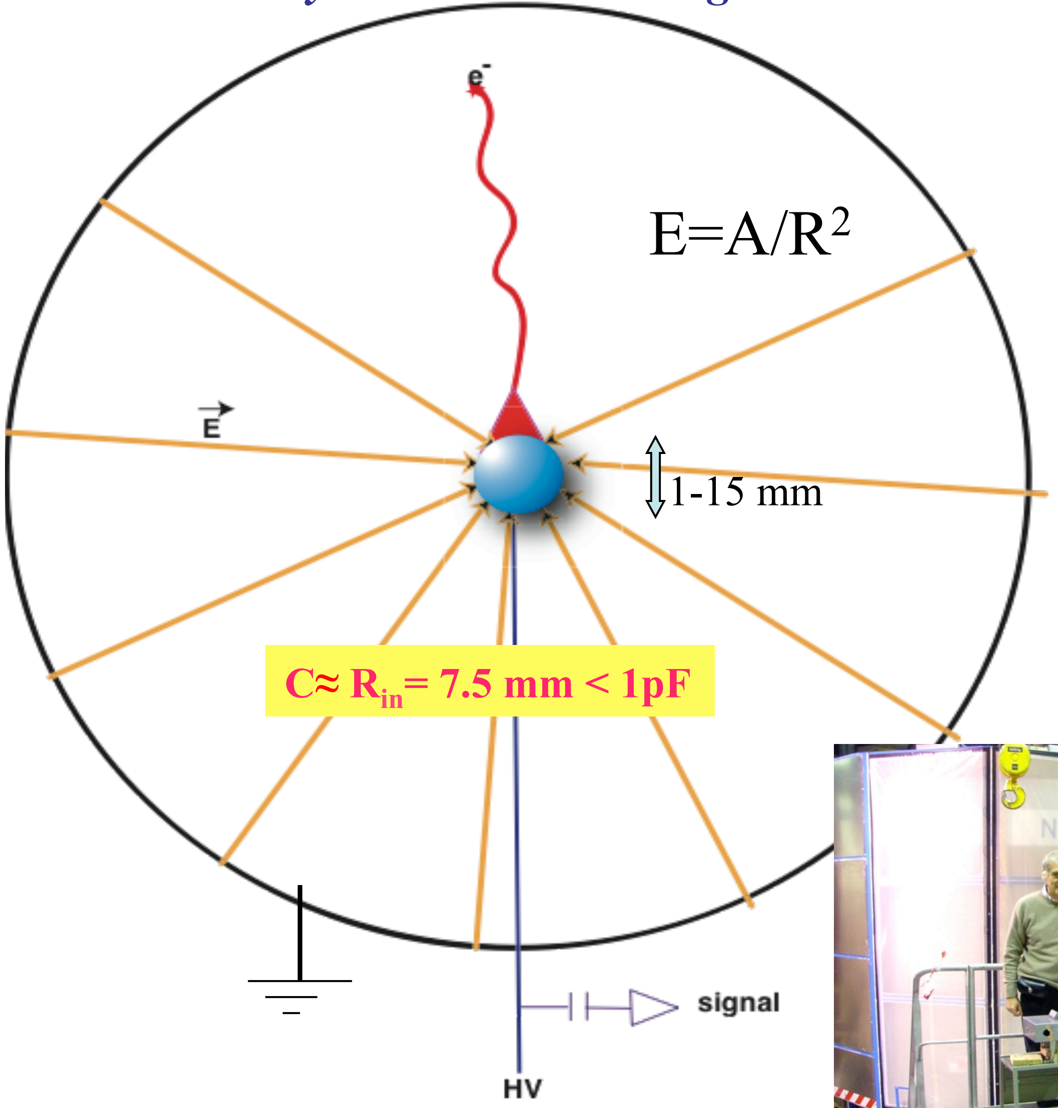
Second part

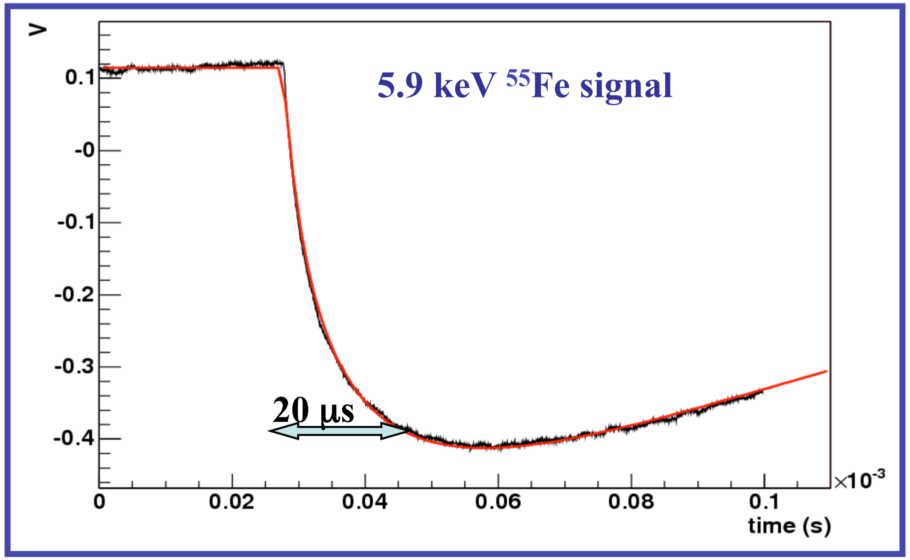
Spherical detector
Light-dark matter search
and low-energy neutrino physics

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

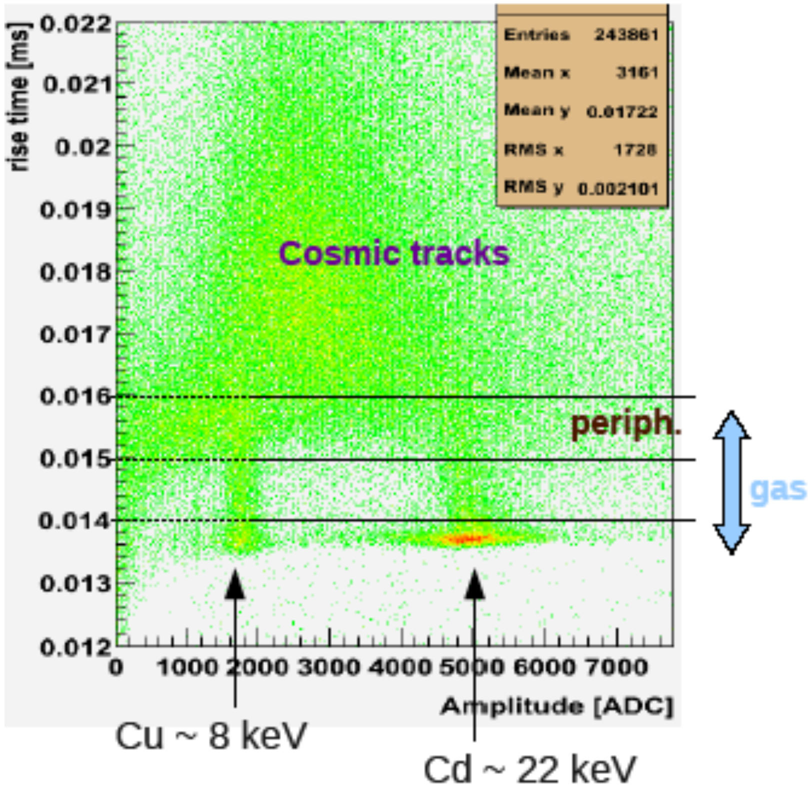


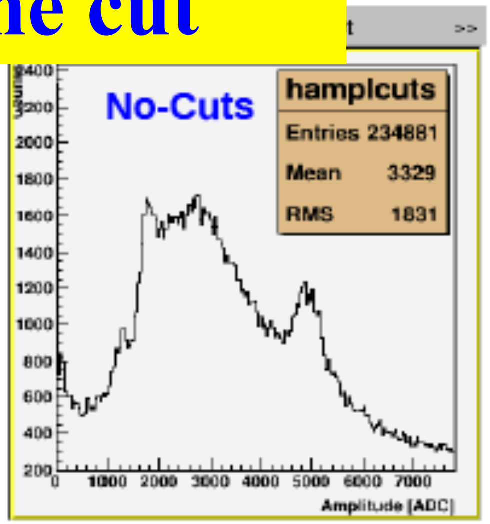


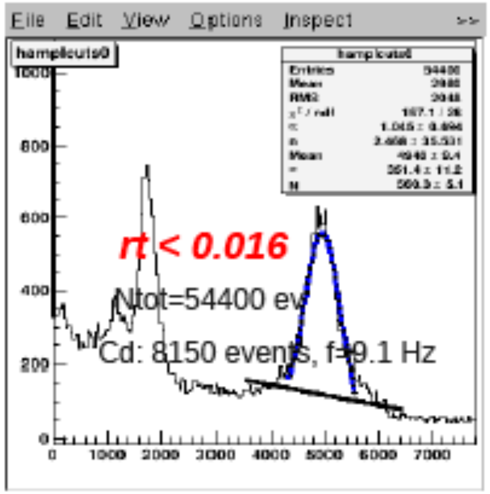
- Simple and cheap
- Large volume
- single read-out
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut
- Low background capability

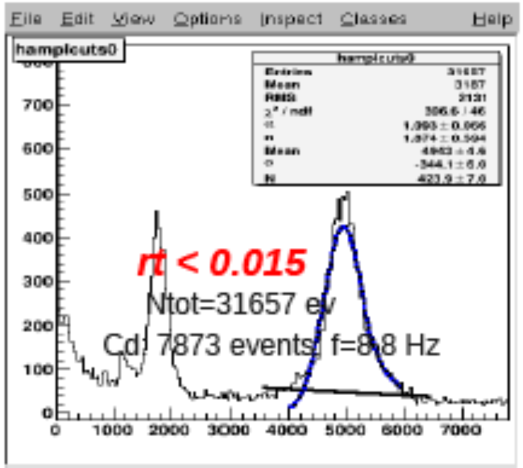
Rejection power
Rise time cut

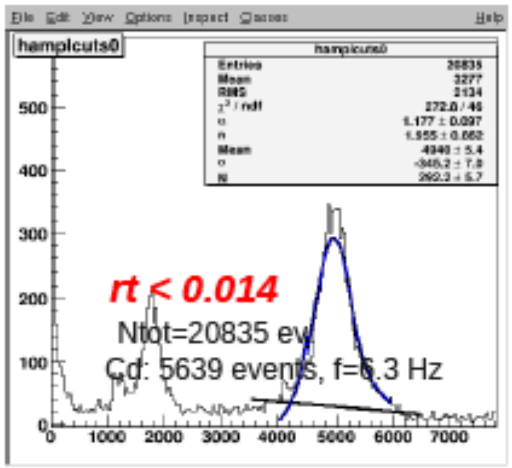
Using Cd-109 source – December 2009
Irradiate gas through 200µm Al window
P = 100 mb, Ar-CH_4 (2%)











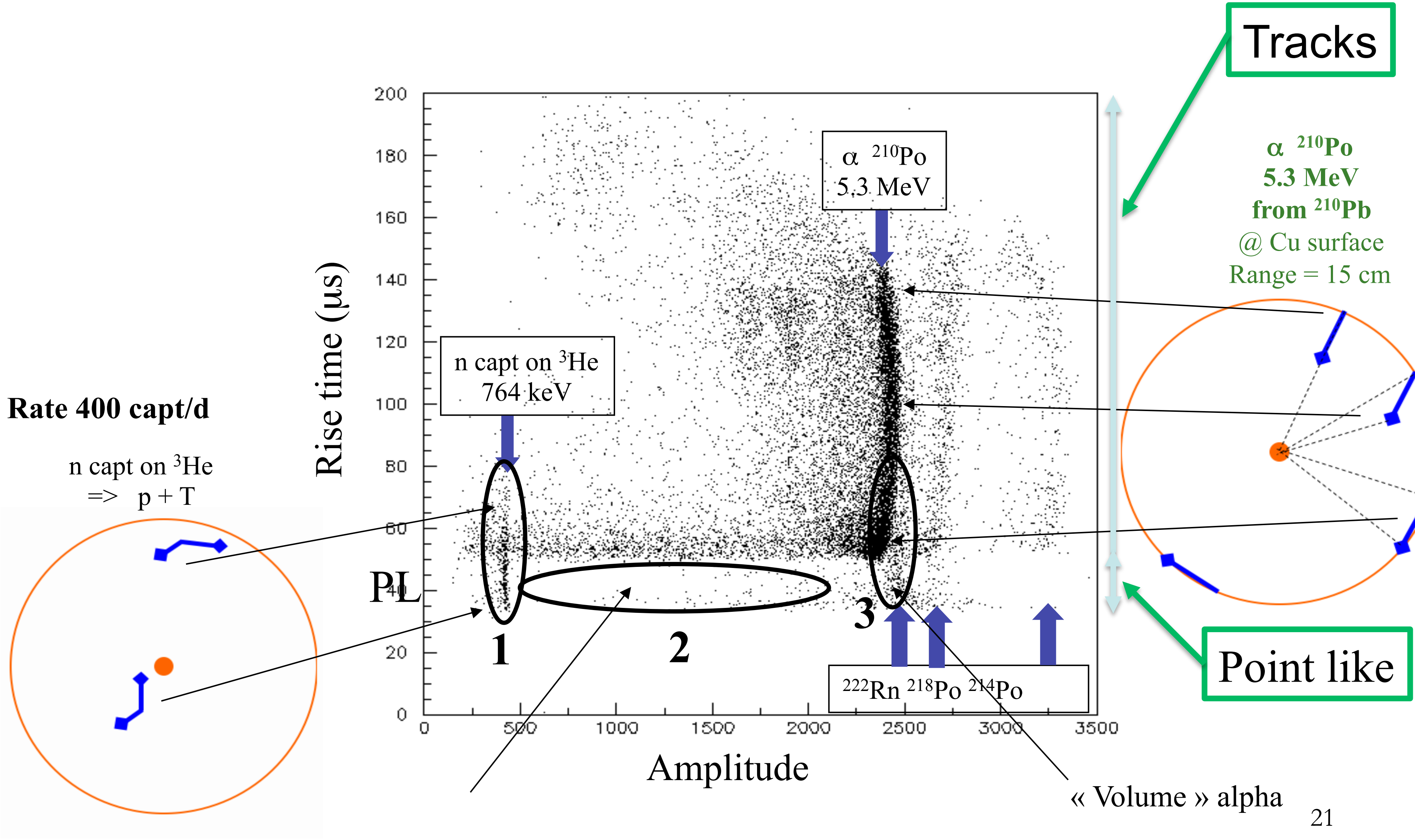
If rt ~ 0.0155 ms ==> R = 65 cm
0.014 ms ==> ~70% of signal

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

Severe background reduction

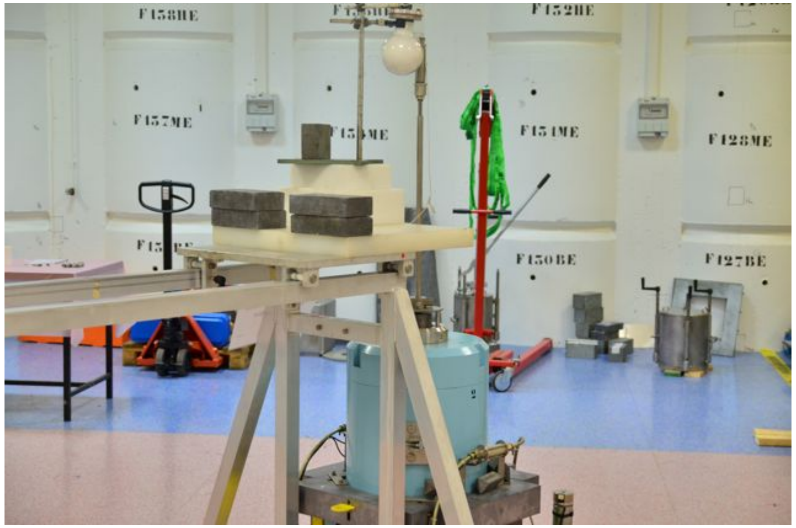
Energy resolution ~ 6 % and 9 % for Cu and Cd

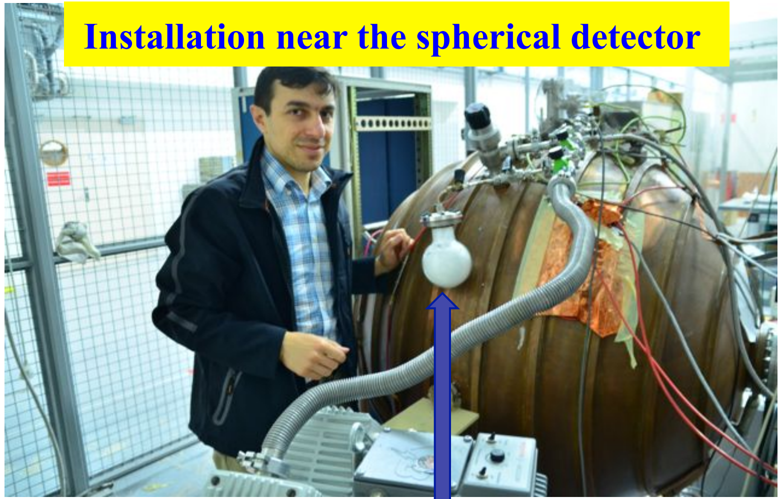
Particle identification capability at MeV energy
Ar/CH_4 + 3g ^{3}He @ 200 mb SPC 130cm Ø @ LSM



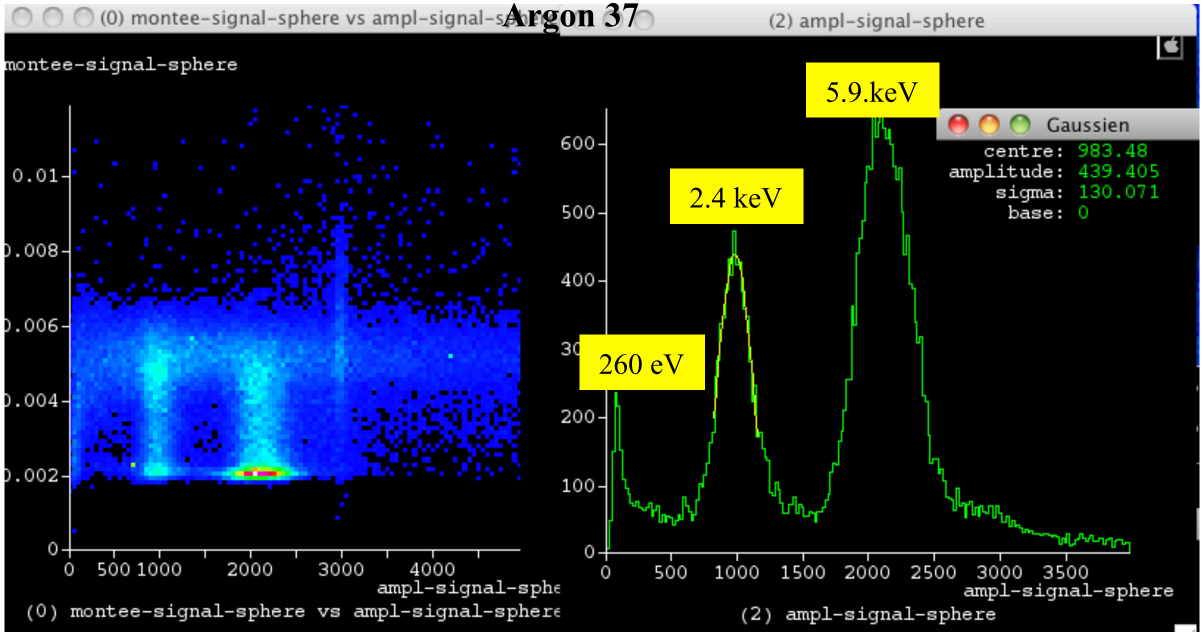
Low-energy calibration source *Argon-37*

Home made Ar-37 source: irradiating Ca-40 powder with fast neutrons 7x10^6neutrons/s
Irradiation time 14 days. Ar-37 emits K(2.6 keV) and L(260 eV) X-rays (35 d decay time)





Argon 37

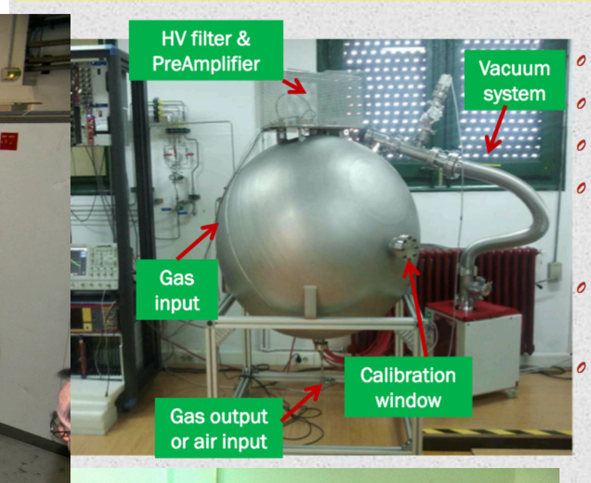


First measurement with Ar-37 source
Total rate 40 hz
in 250 mbar gas, 8 mm ball
240 eV peak clearly seen
A key result for light dark matter search

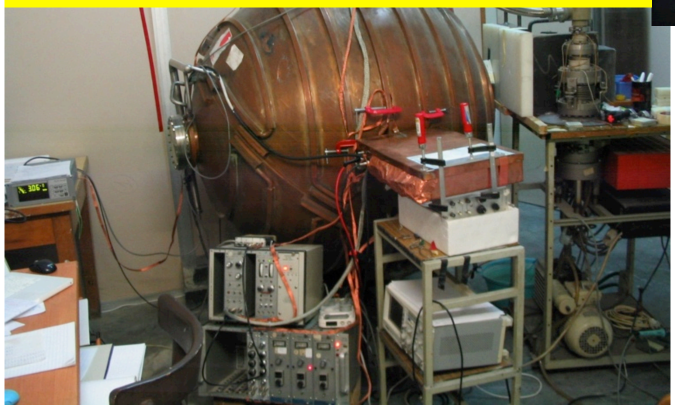
Low background detector d=60 cm p=10 bar

Basic R@D detector in Saclay

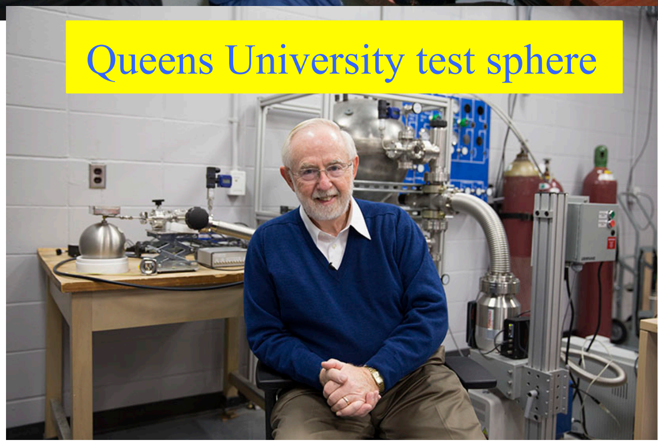
University of Saragoza detector



University of Thessaloniki detector



Queens University test sphere



University of Tsinghua - HEP detector

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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.

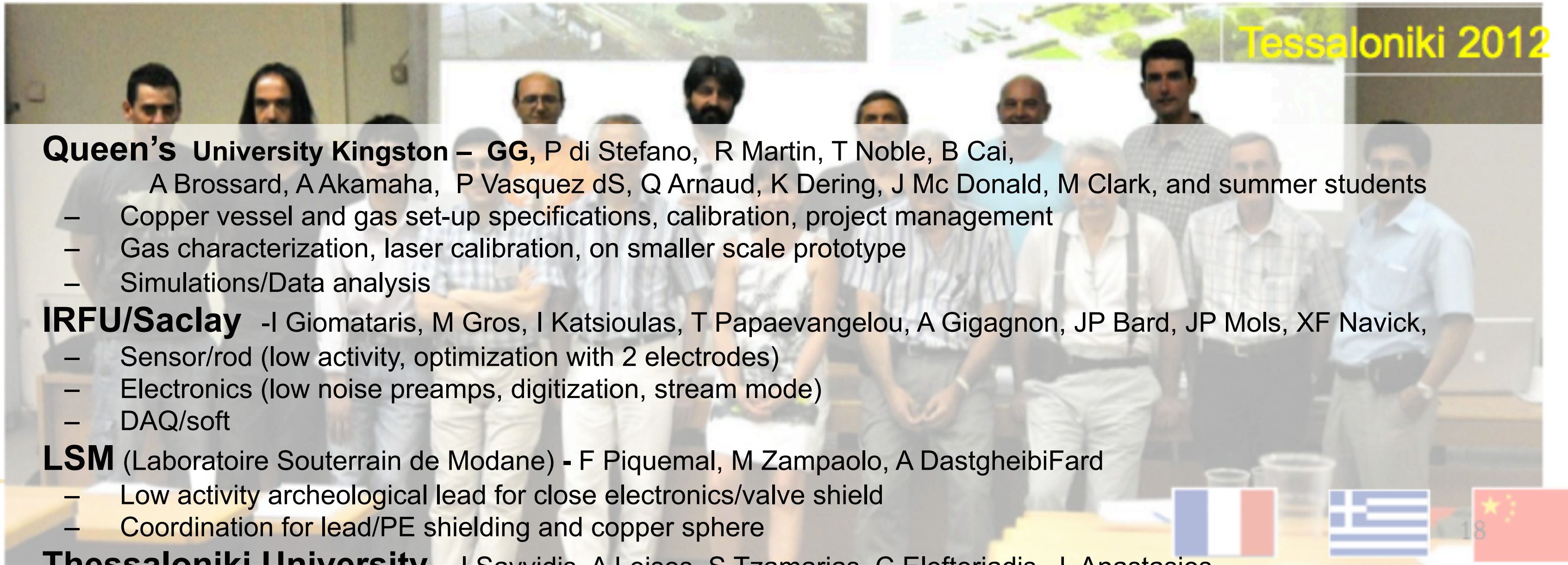
J. D. Vergados et al., Phys.Rev.D79:113001,2009.,

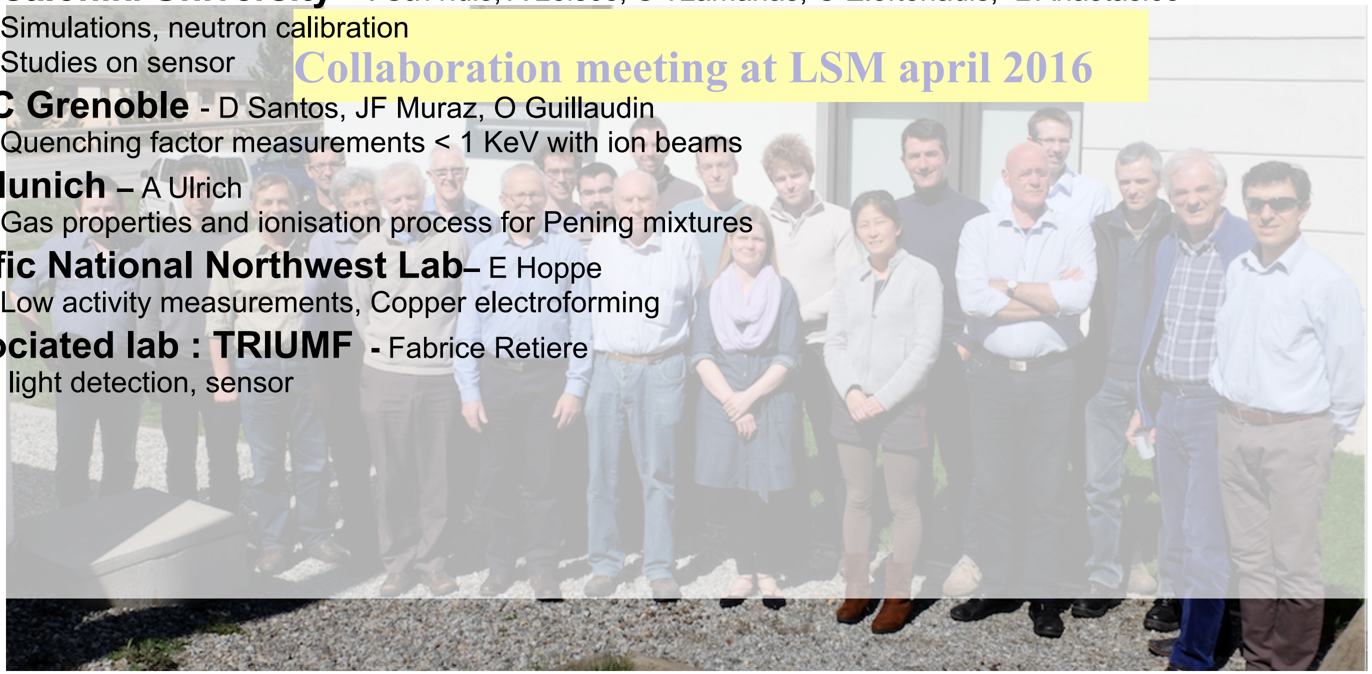
E Bougamont et al. arXiv:1010.4132 [physics.ins-det], 2010

G. Gerbier et al.,arXiv:1401.790v1

NEWS collaboration

Queen's University Kingston, IRFU/Saclay , LSM, Thessaloniki University, LPSC Grenoble, TU Munich,PNNLTRIUM



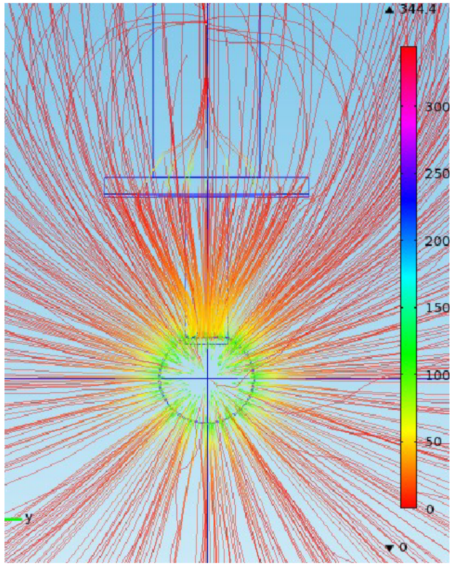


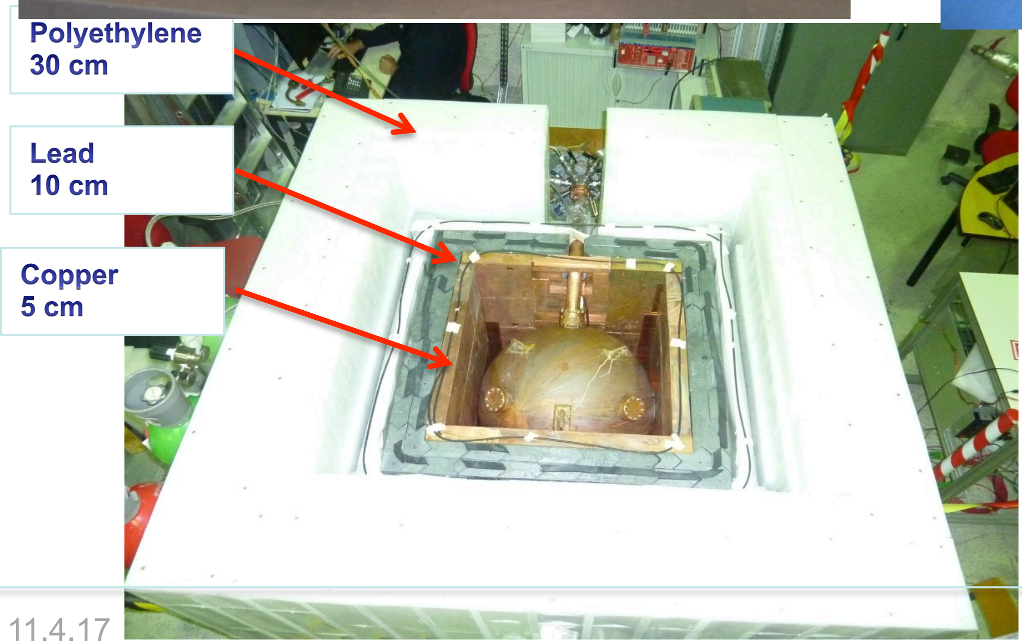
- **Queen's University Kingston – GG,** P di Stefano, R Martin, T Noble, B Cai,
  A Brossard, A Akamaha, P Vasquez dS, Q Arnaud, K Dering, J Mc Donald, M Clark, and summer students
  - Copper vessel and gas set-up specifications, calibration, project management
  - Gas characterization, laser calibration, on smaller scale prototype
  - Simulations/Data analysis
- **IRFU/Saclay** -I Giomataris, M Gros, I Katsioulas, T Papaevangelou, A Gigagnon, JP Bard, JP Mols, XF Navick,
  - Sensor/rod (low activity, optimization with 2 electrodes)
  - Electronics (low noise preamps, digitization, stream mode)
  - DAQ/soft
- **LSM** (Laboratoire Souterrain de Modane) **-** F Piquemal, M Zampaolo, A DastgheibiFard
  - Low activity archeological lead for close electronics/valve shield
  - Coordination for lead/PE shielding and copper sphere
- **Thessaloniki University –** I Savvidis, A Leisos, S Tzamarias, C Elefteriadis, L Anastasios
  - Simulations, neutron calibration
  - Studies on sensor
- **LPSC Grenoble** - D Santos, JF Muraz, O Guillaudin
  - Quenching factor measurements < 1 KeV with ion beams
- **TU Munich –** A Ulrich
  - Gas properties and ionisation process for Pening mixtures
- **Pacific National Northwest Lab–** E Hoppe
  - Low activity measurements, Copper electroforming
- **Associated lab : TRIUMF - **Fabrice Retiere
  - light detection, sensor

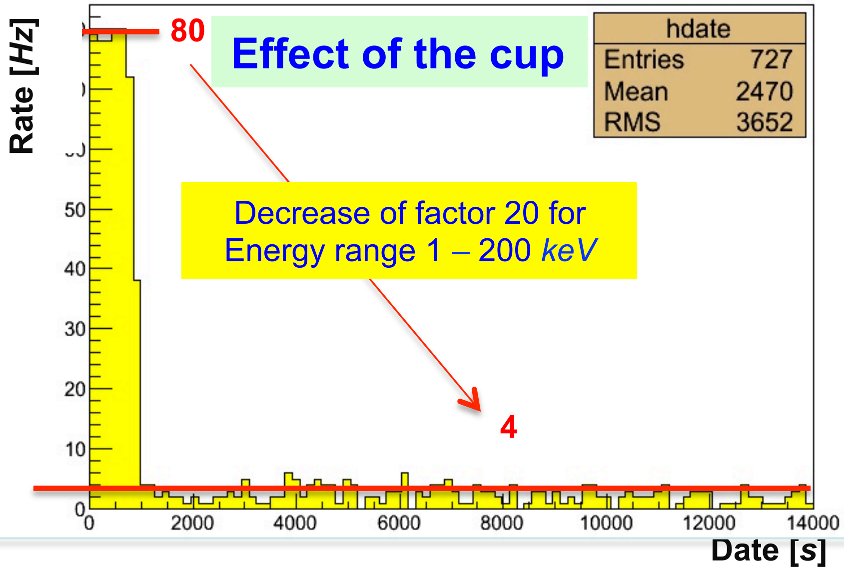
NEWS-LSM: Exploration of light dark matter search at LSM

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

Gas targets: Ne, He, CH4

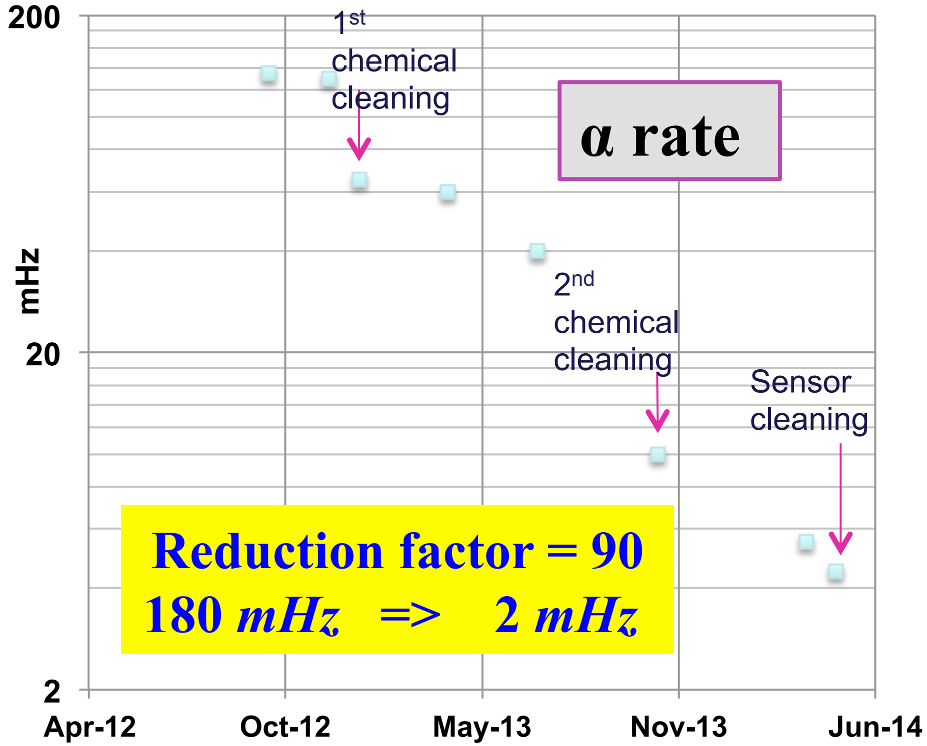




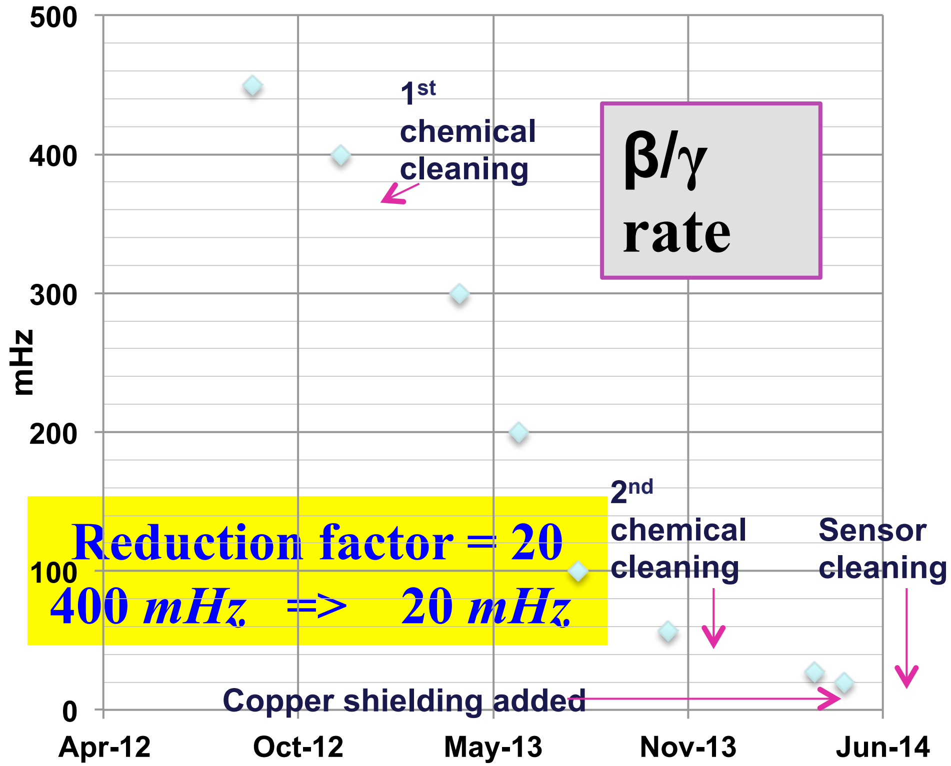


Backround evolution of the detector

Alpha rate evolution



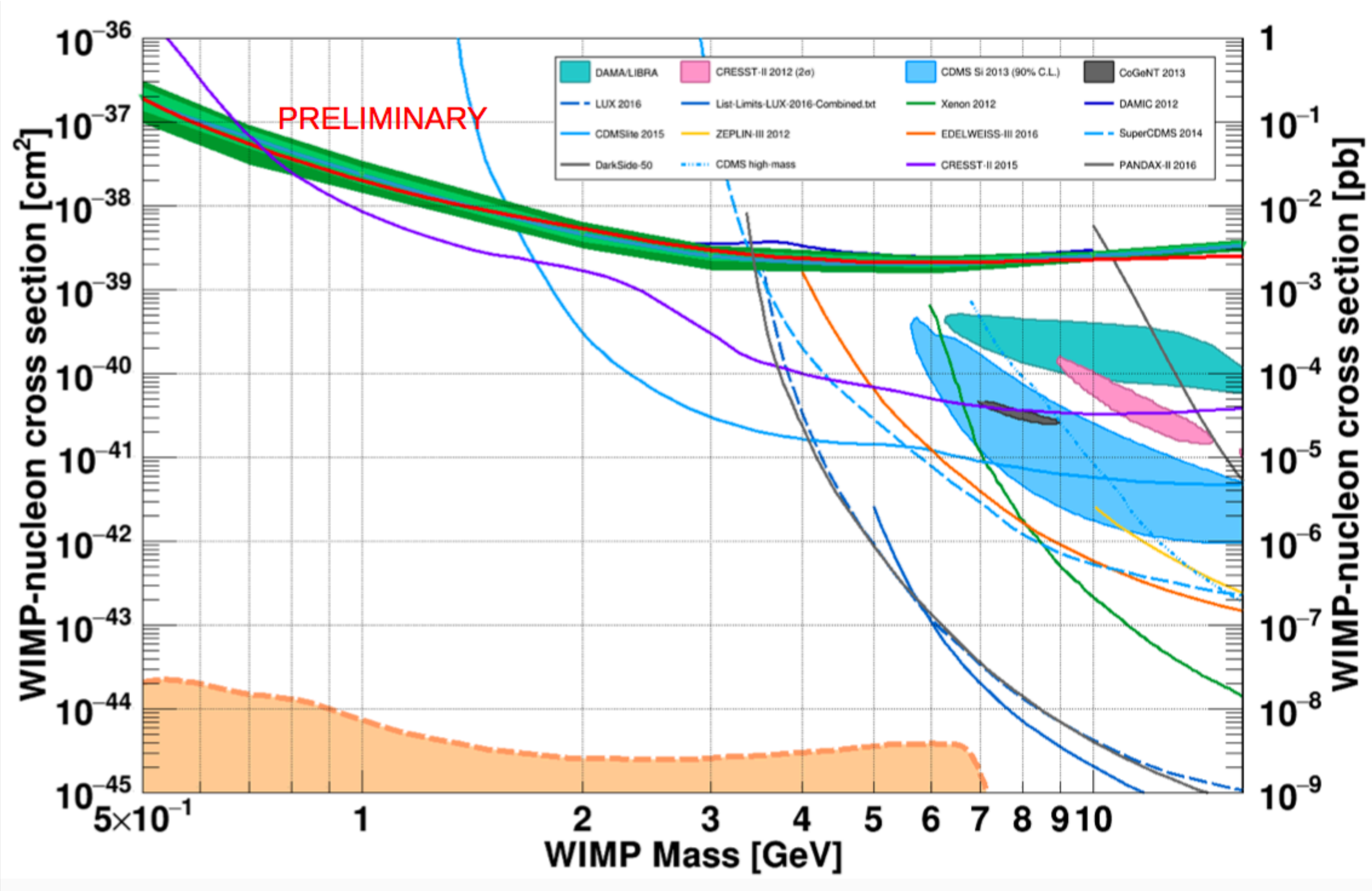
β/γ rate evolution



New development

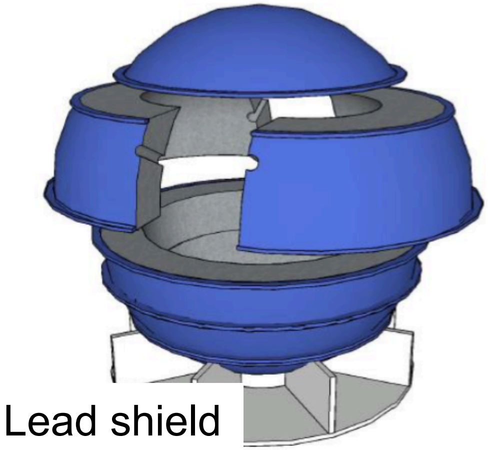
Removal of about 10mm copper using a high pressure jet is under study with a french compagny

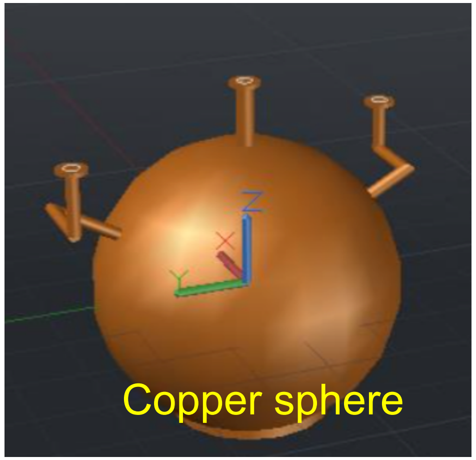
Current sensitivity with Neon at 3 bar
Data 40.5 days, threshold 30 eV

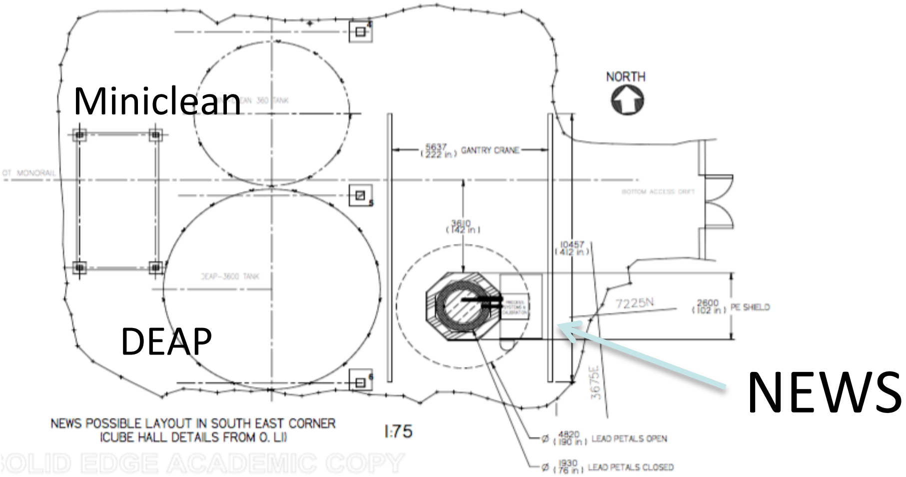


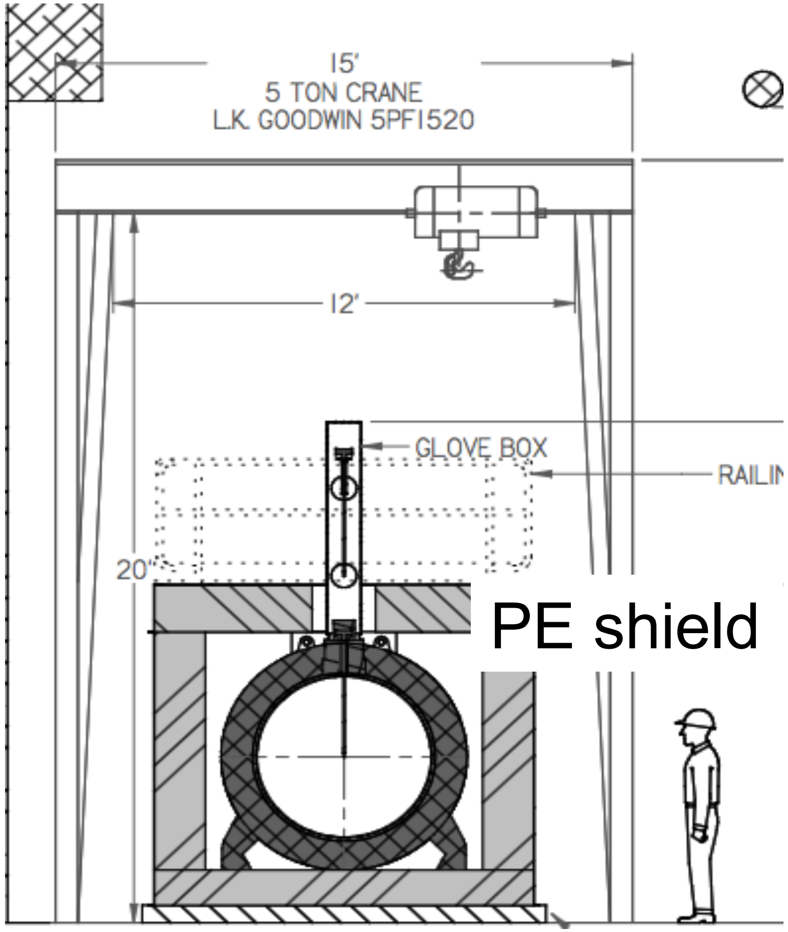
NEWS-SNO with compact shield : implementation at SNOLAB by fall 2017
Funded mainly by Canadian grant of excellence and ANR-France

140 cm Ø detector, 10 bars, Ne, He, CH_4
Copper 1 μBq/kg
Compact lead –ancient- & PE shield solution

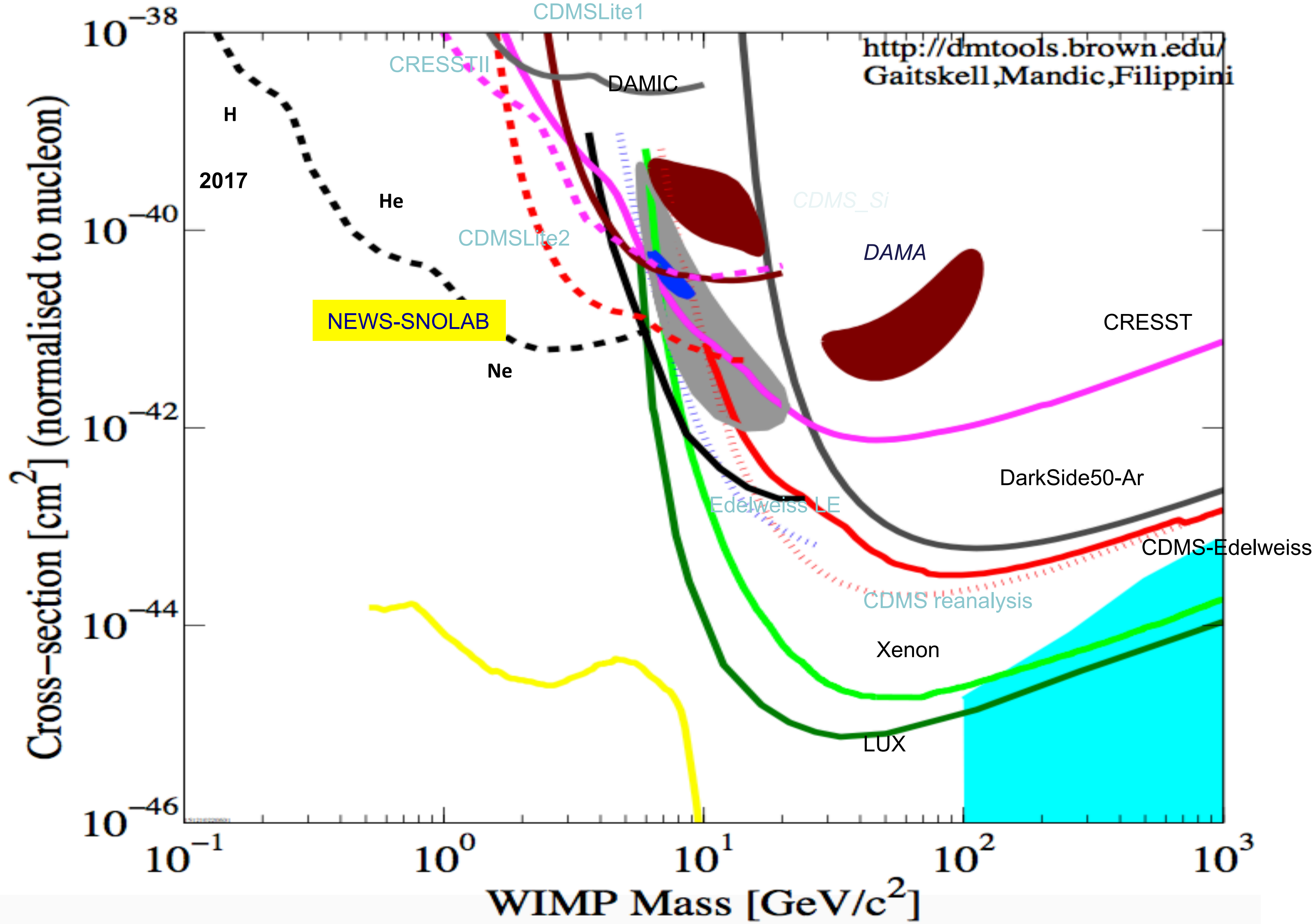






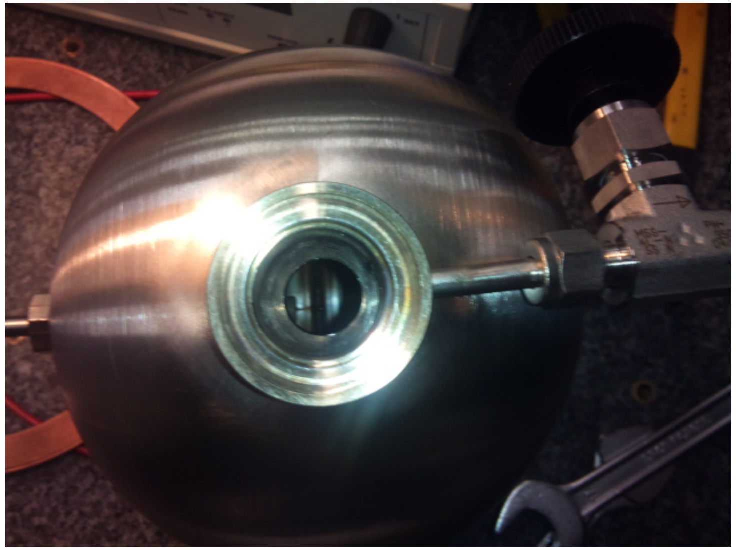


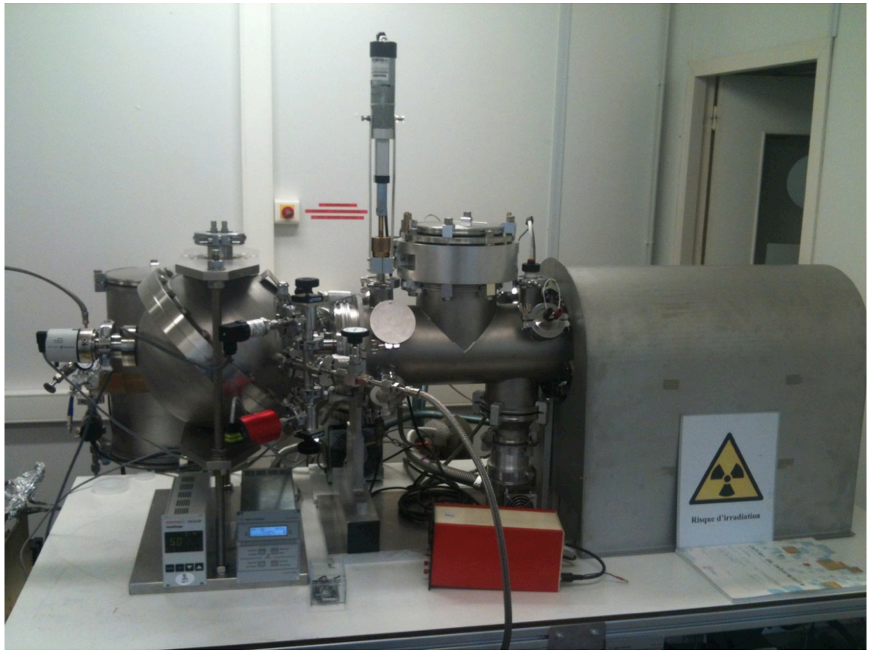
NEWS-SNOLAB project sensitivity



Quenching factor measurements

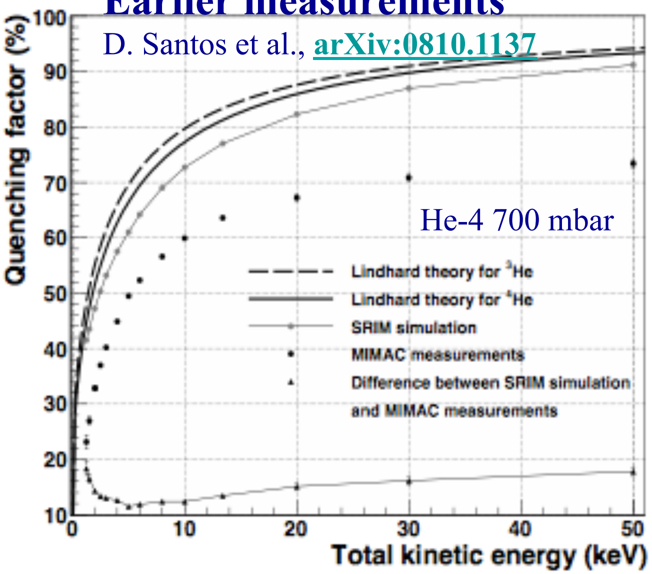
Goal: measure QF down to 500 eV ion energy using the Grenoble MIMAC facility for H, He, Ne, CF4, Ar, Xe at various pressures





Earlier measurements

D. Santos et al., **arXiv:0810.1137**



Previous 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

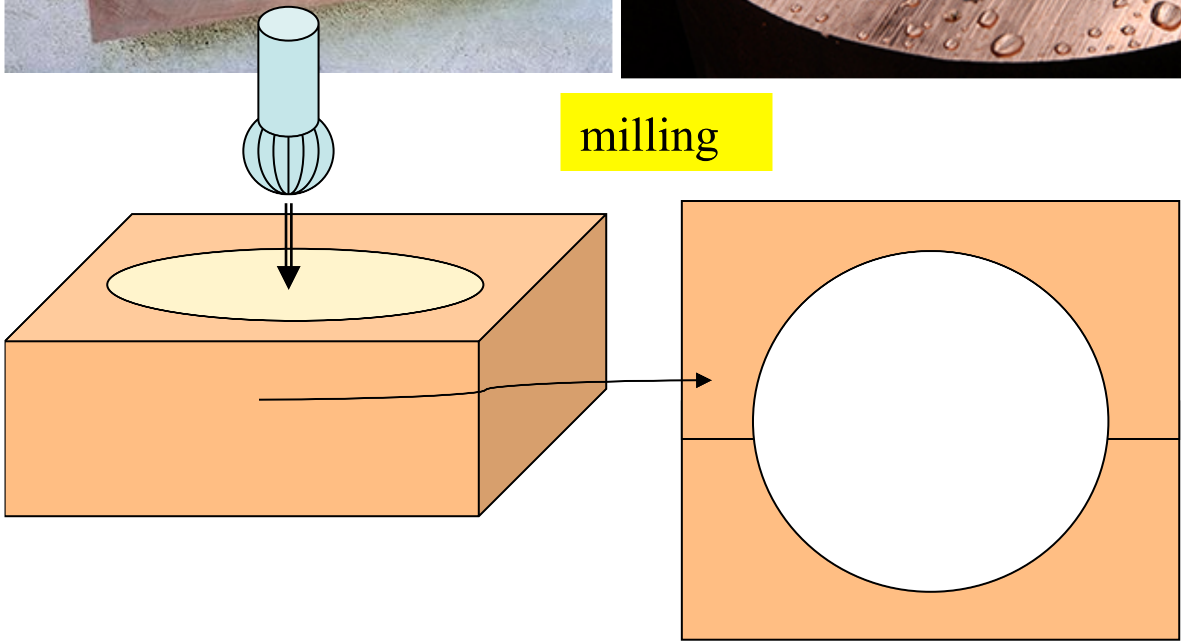
CUBIC: a new way of fabricating an ultra low-background spherical detector – under study

I. Giomataris, CEA-Irfu-France

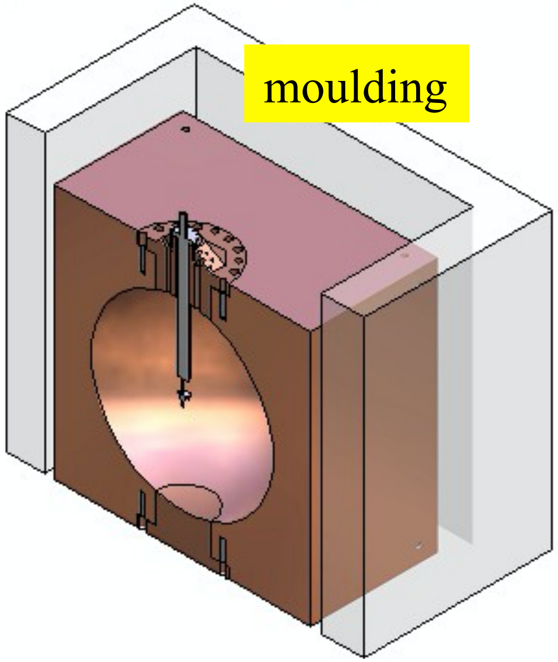
Aurubis pure copper
Tested in PNLL
μBq/kg : ^{232}Th= 1, ^{238}U= 1

Advantages

- Auto-shield
- Pressure up to 50 bar
- Low cost
- Faster process

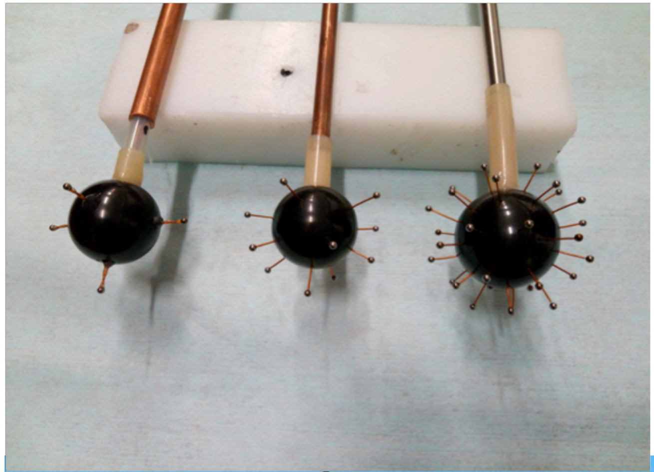


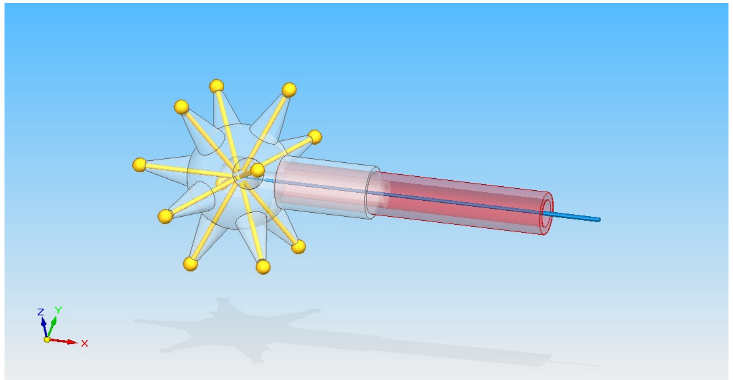
milling

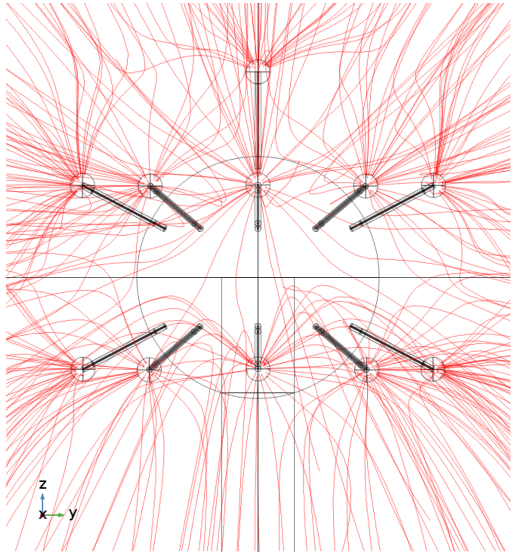


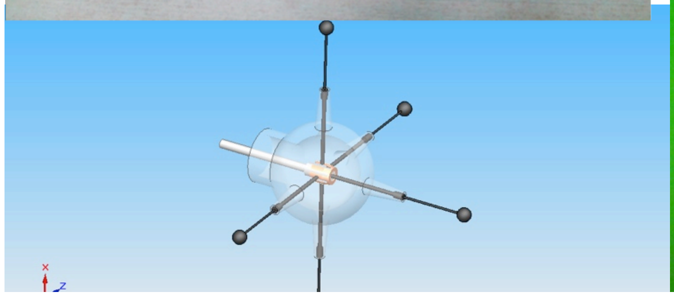
moulding

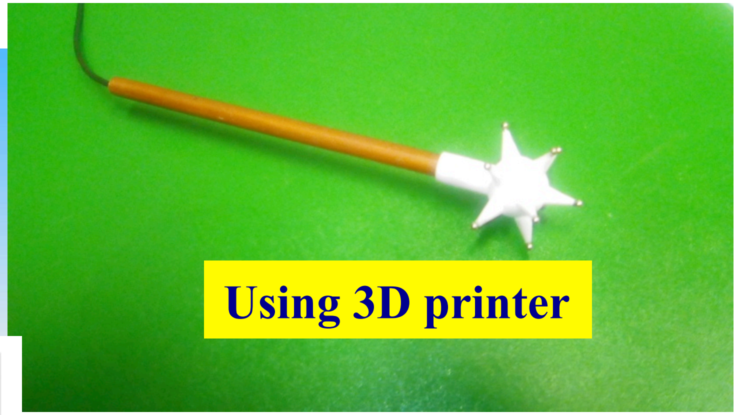
Multi-ball 'ACHINOS' structure
Developed in Saclay in collaboration with University of Thessaloniki

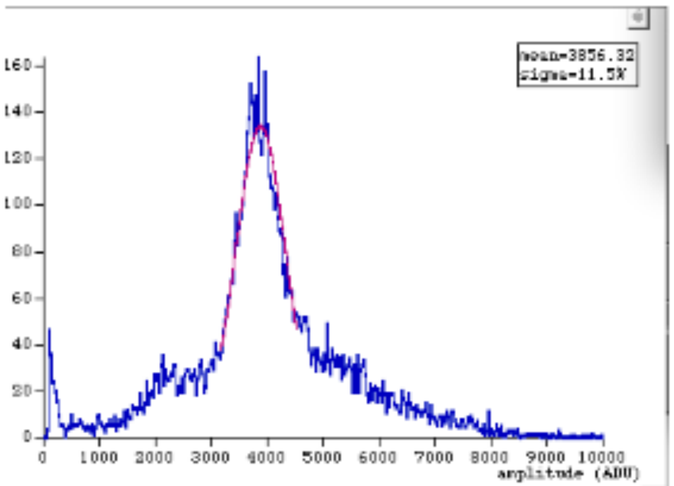




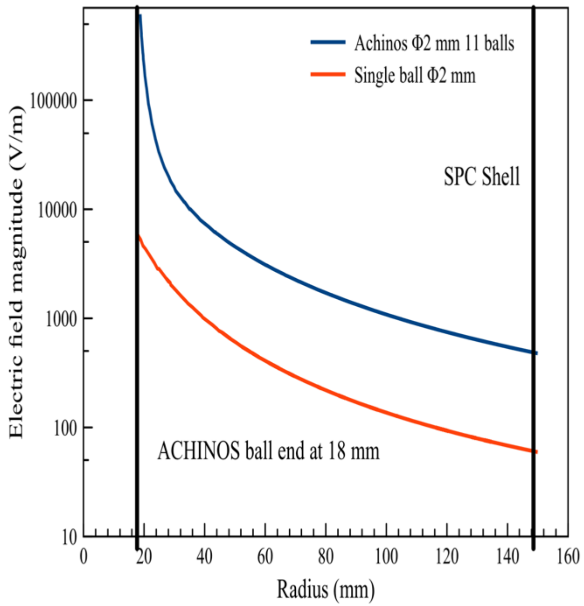








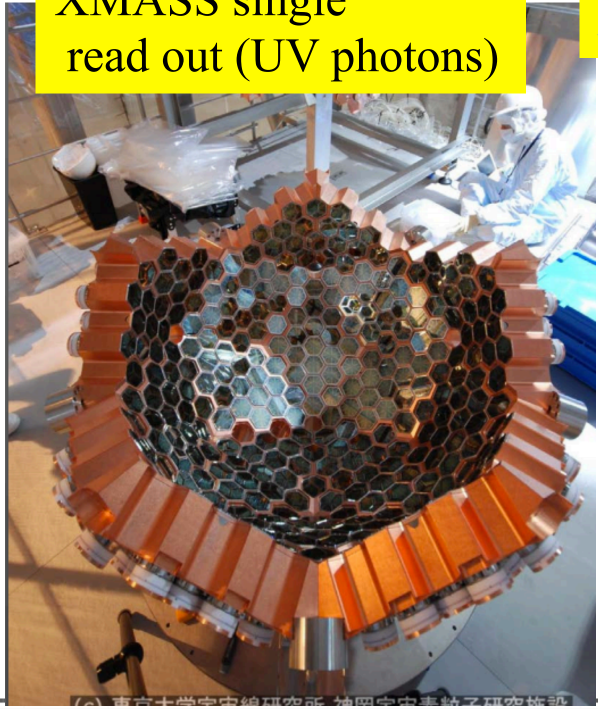
Advantages
- Amplification tuned by the ball size: 1mm diameter for high pressure
-Volume electric field tuned by the size of the ACHINOS structure
- Detector segmentation: 3D TPC like

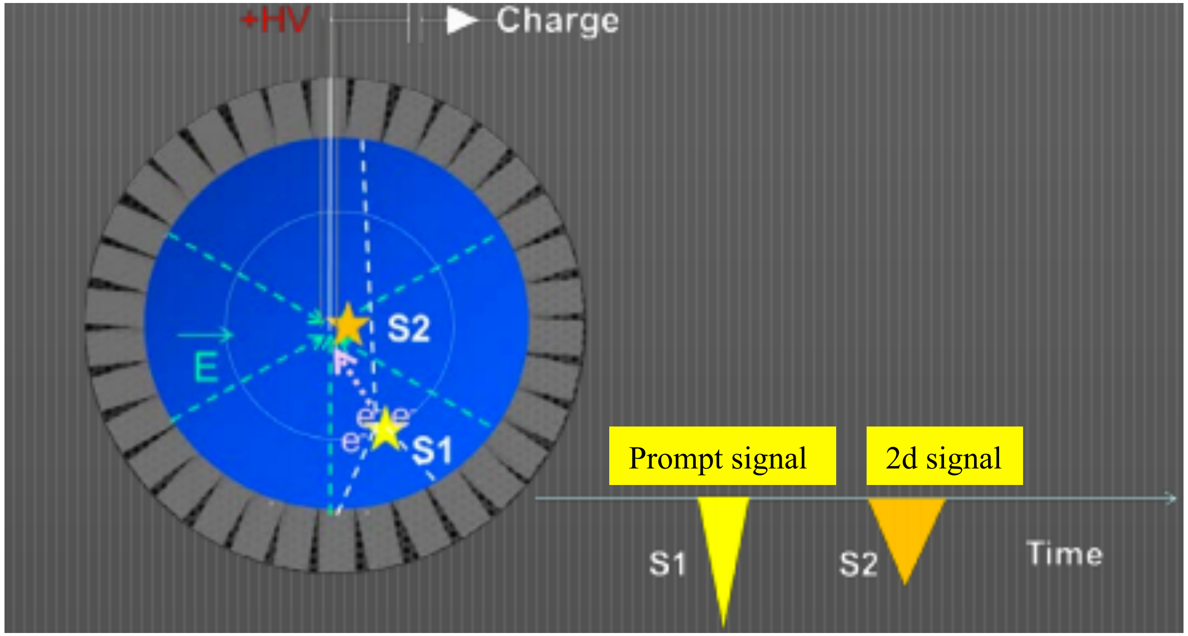


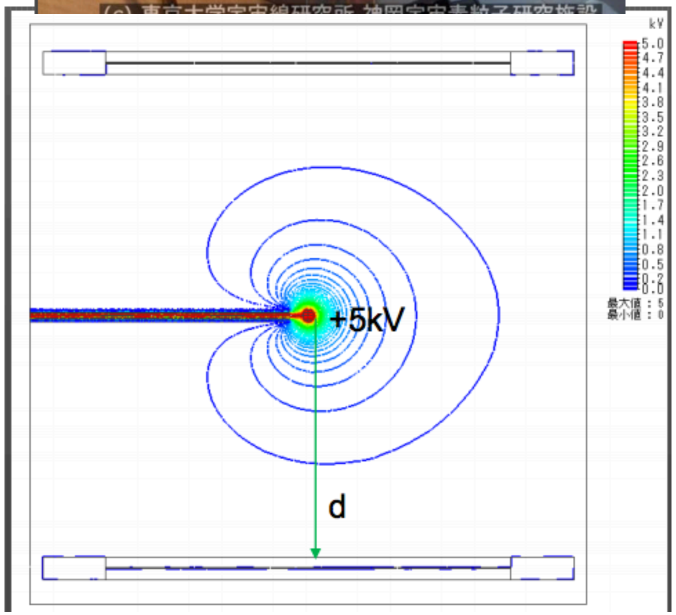
R@D towards a spherical liquid Xenon detector

In collaboration with H. Sekiya, K. Kanzawa, Y. Itow, K. Masuda

XMASS single
read out (UV photons)







The idea is to get a second signal (S_2) induced by charge collection in the ball and producing proportional scintillation under large electric field >200kV/cm

The ratio between S1 and S2 will be used to identify and reject electron-gamma background

To reach proportional scintillation we need a 500 mm ball.

First tests will be performed using a 150 mm ball because high-voltage feed through is limited to 5kV

Additional physics

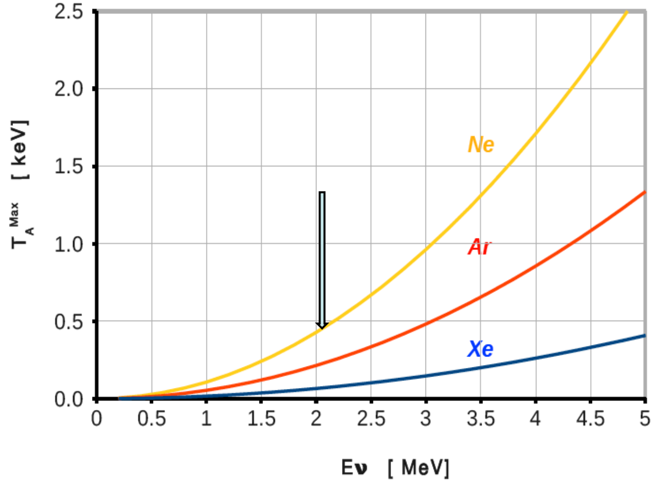
Neutrino-nucleus coherent elastic scattering

$\nu + N \rightarrow \nu + N \quad \sigma \approx N^2E^2$, *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

Competitive double beta decay experiment with Xe-136 at 50bar

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%

Simulation model

By J. Galan

Sphere diameter: 2 m

Shield 30 cm copper

Xenon gas at 50 bar (1272 Kg)

Vessel Copper activity μBq/kg :

Aurubis commercial ^{232}Th= 1, ^{238}U= 1

PNNL ^{232}Th=.034, ^{238}U=.13

Results are very encouraging:

Expected background rate in the region of Q_{bb} (2.46 MeV)

8.x10^{-5}/keV/Kg/ year Arubis copper

1.54x10^{-5}/keV/Kg/ year PNNL copper

(compared to 2x10^{-3}/keV/Kg/ year of running experiments)

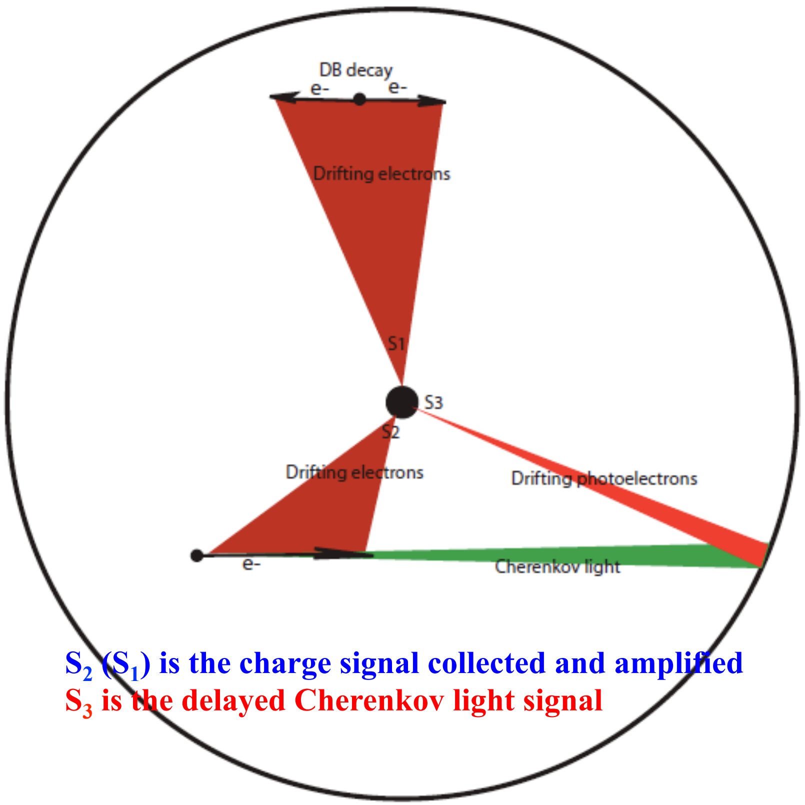
If additional rejection is required: a new idea

Background free double beta decay experiment, *I. Giomataris,* J.Phys.Conf.Ser. 309 (2011) 012010

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

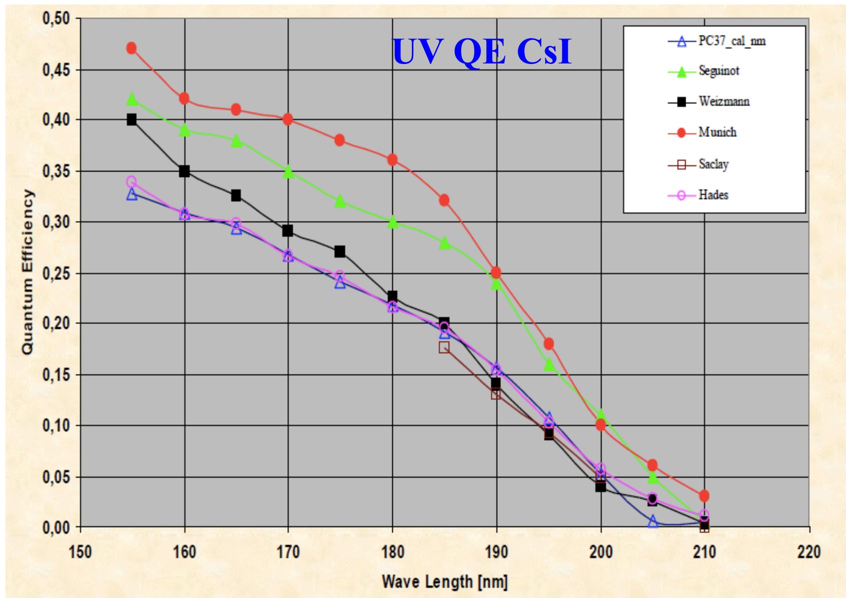
Xenon-136 at high pressure of about 25-40 bar is ideal to keep high efficiency for double electrons, Good enough electron path and reduce multiple scattering

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



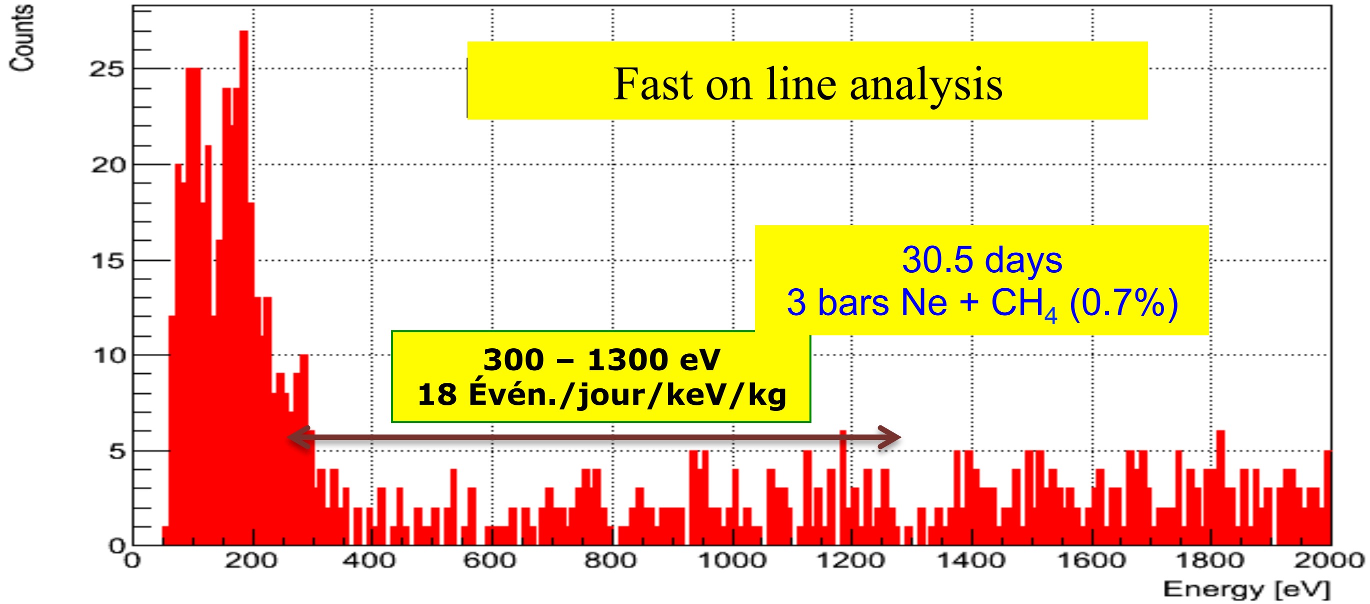
S_2 (S_1) is the charge signal collected and amplified
S_3 is the delayed Cherenkov light signal

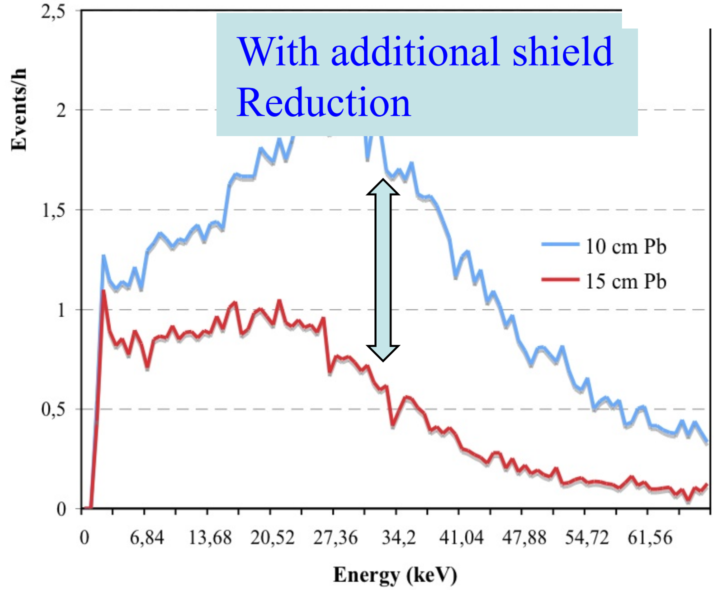
iomataris



THANK YOU

Light WIMP search results



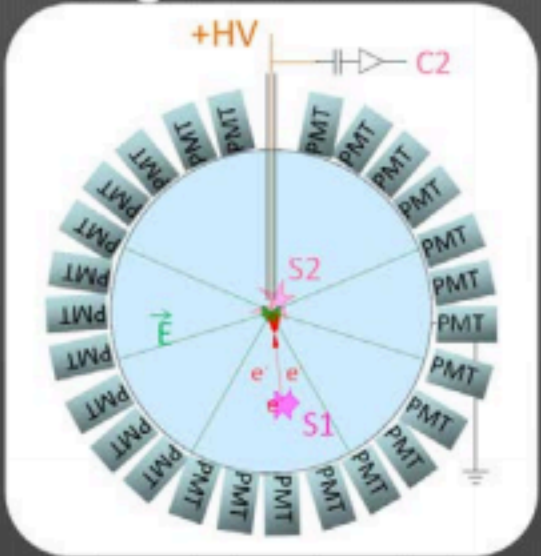


Summary:
background level among the best experiments
Achieved with modest budget and manpower
Combined with the low energy threshold and low-Z targets:
Competitive sensitivity for very-light WIMPs
Publication under preparation

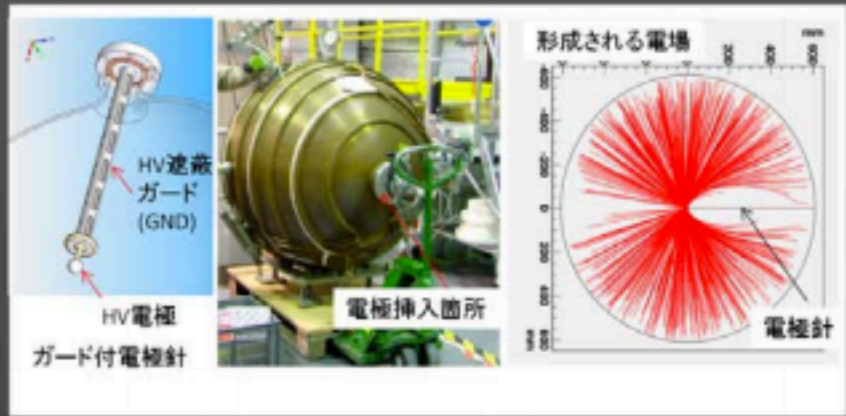
Another R&D: Spherical LXe TPC

- High electric field in XMASS (after XMASS-5t construction)

Inspired by I.Giomataris JINST 3:P09007(2008)



Now making small chamber and Cockcroft HV



Before two phase detector, many studies about the charge amplification and the proportional scintillation in single phase LXe

Nuclear Instruments and Methods in Physics Research A327 (1993) 203–206
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

NIMA 327 (1993) 203

Detection of energy deposition down to the keV region using liquid xenon scintillation

Using 4μm wire

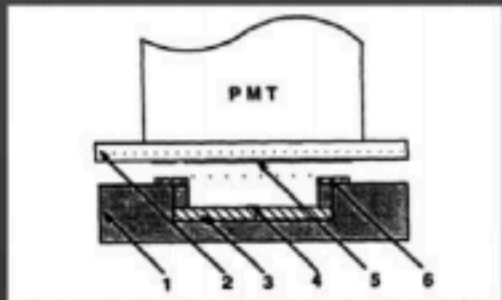


Fig. 1. Schematic drawing of the test chamber (1) HV insulator (Macor), (2) UV quartz window, (3) Cathode (stainless steel), (4) Source, (5) Grid (grounded), (6) Anode.

^{109}Cd 22keV was observed

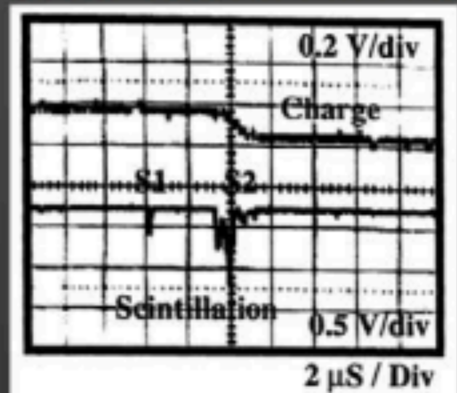
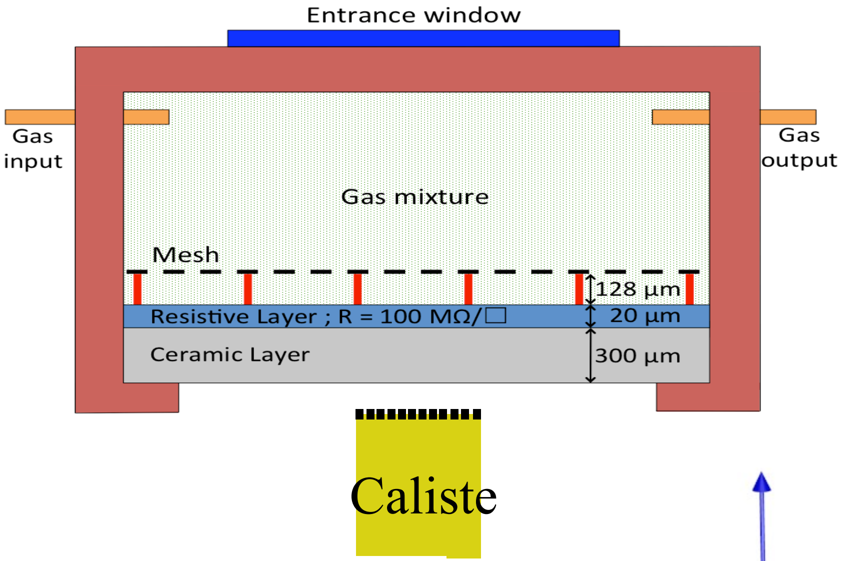
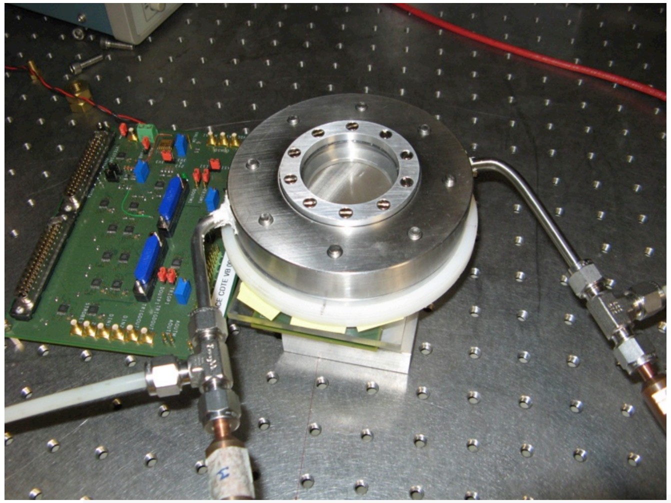


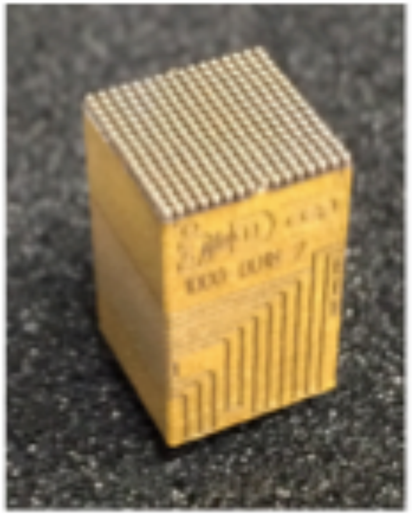
Fig. 5. Charge avalanche signal from preamplifier of 22 keV gamma rays from ^{109}Cd (top) together with the nonintegrated scintillation signal.

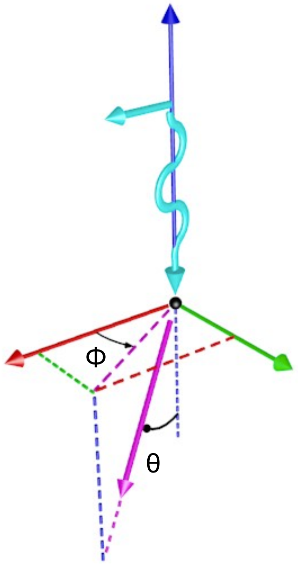
X-ray polarimeter using MM 'Piggyback' and Caliste

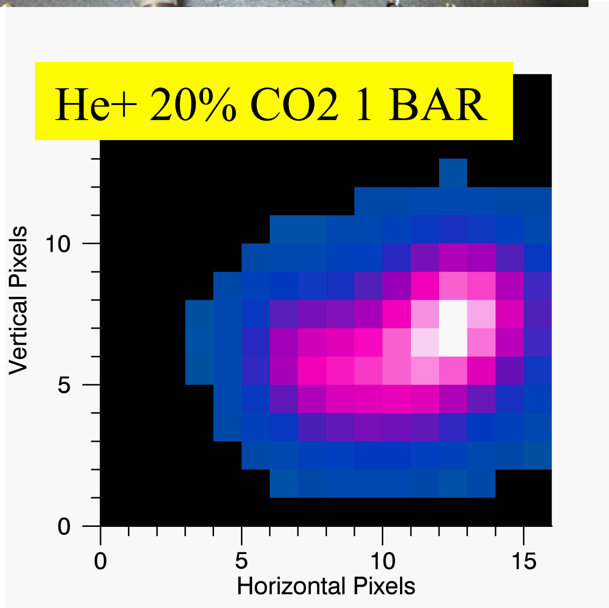
P. Serrano, E. Ferrer, O. Limousin











Promising prospects to measure X-rays polarisation