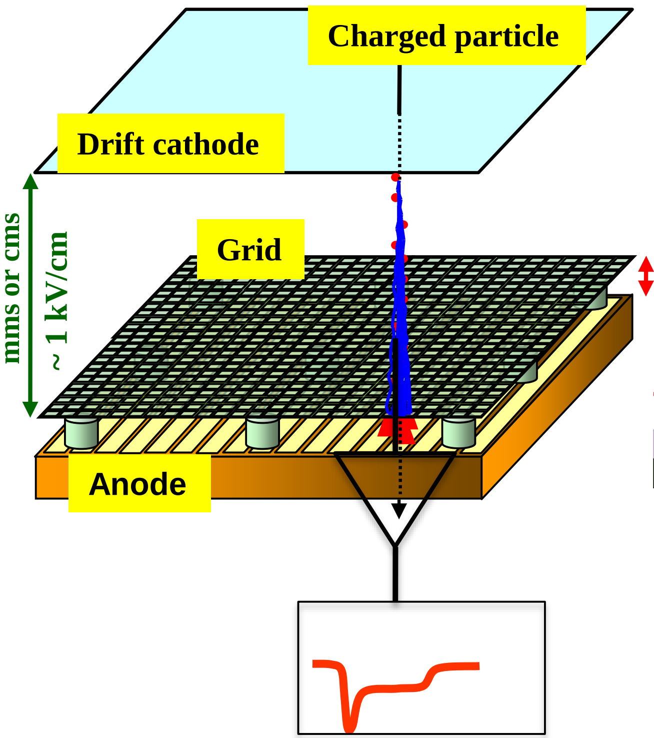
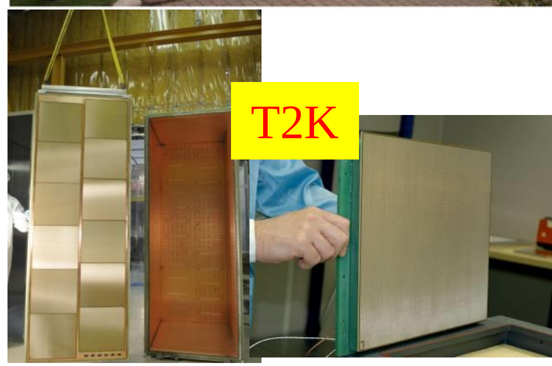
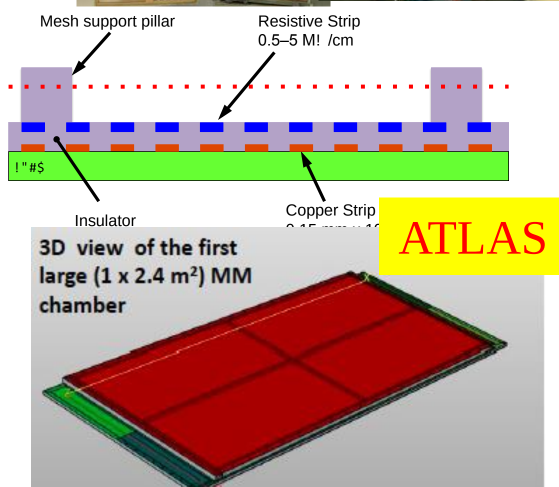
Gaseous detectors: current and future developments

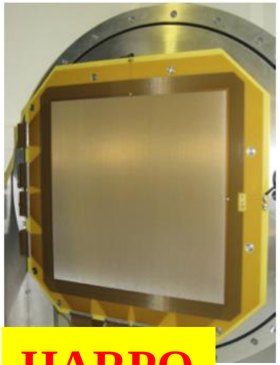
I. Giomataris CEA-Saclay

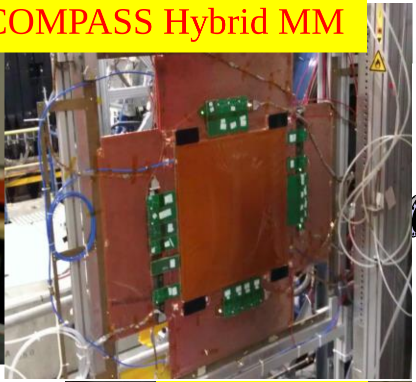


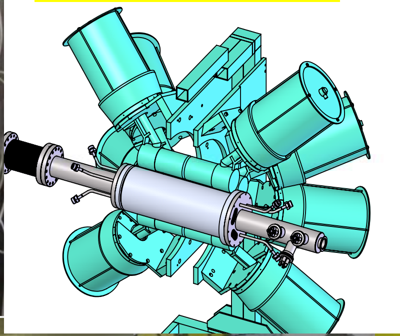


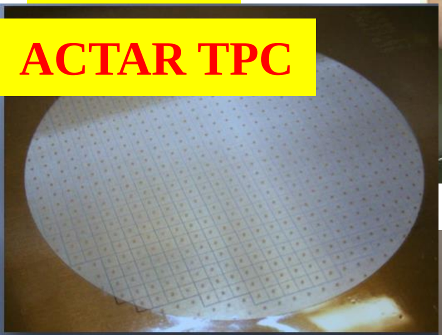


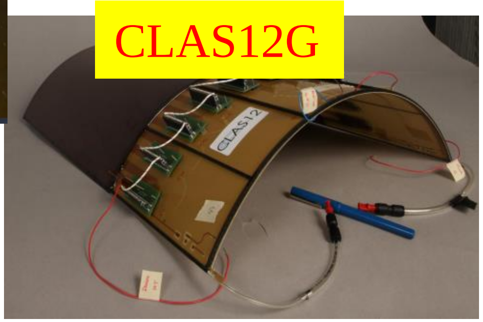
Some experiments using Micromegas read-out

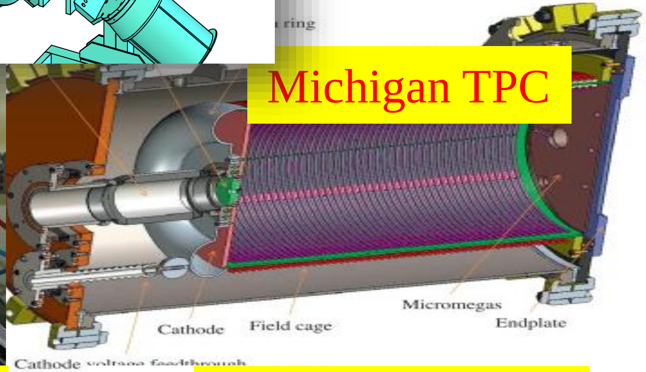


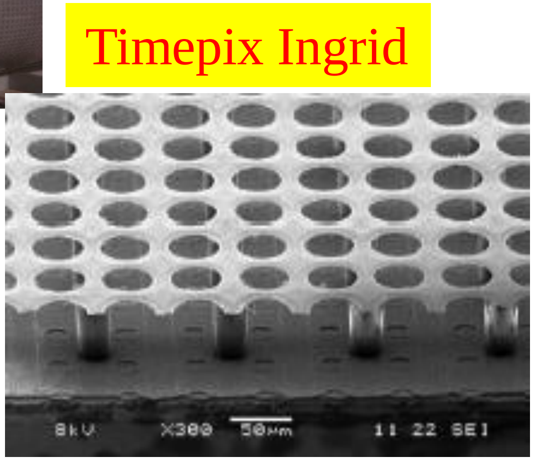


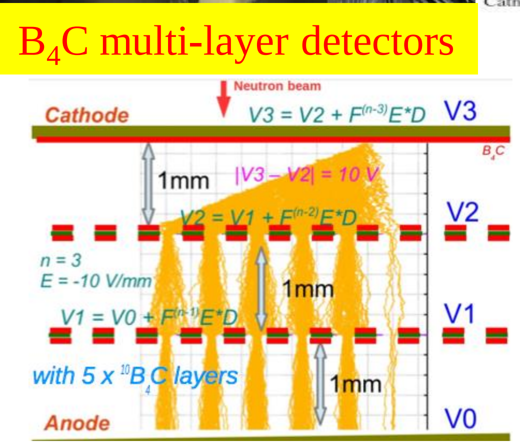


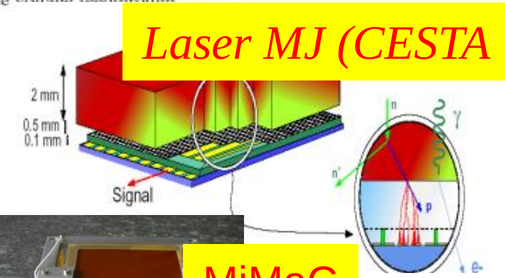


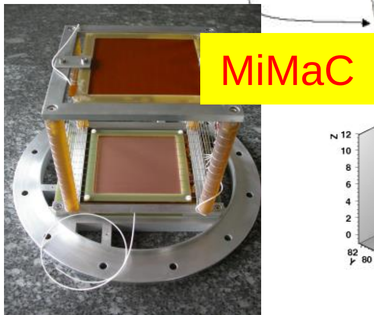


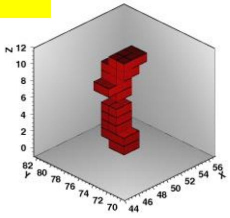






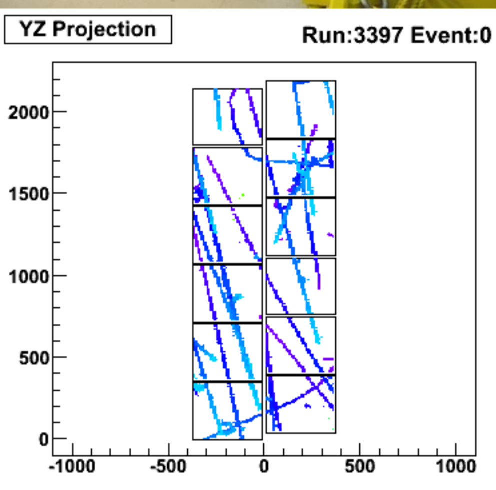


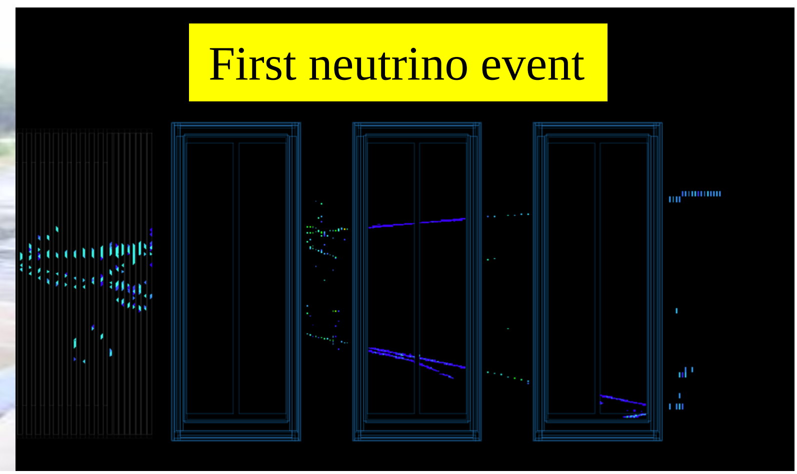




T2K Micromegas TPC – Bulk technology

3xTPCs, 6 end plates, 72 Micromegas





Next upgrade under under study:
A high pressure TPC

Construction of large chambers in ATLAS

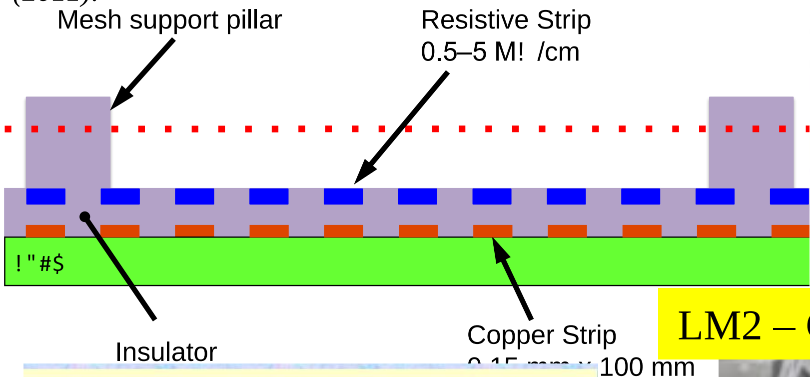
Goal : 1200 m2 total detector surface

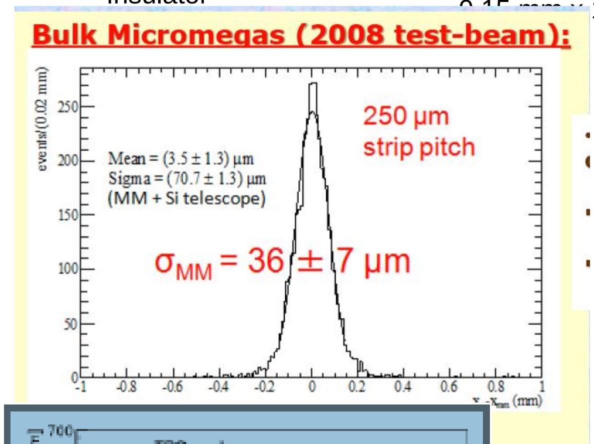
Industrialization is going on through ELVIA, ELTOS

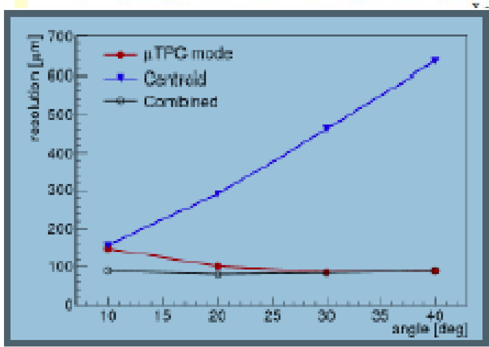
ATLAS Resistive strip technology

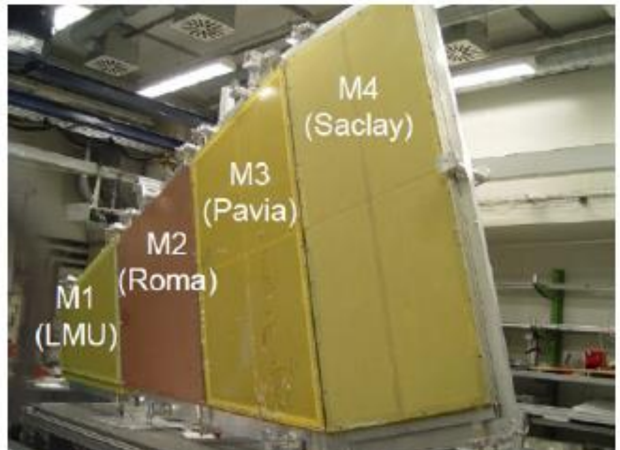
Joerg Wotschack, Mod.Phys.Lett. A28 (2013) 1340020

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

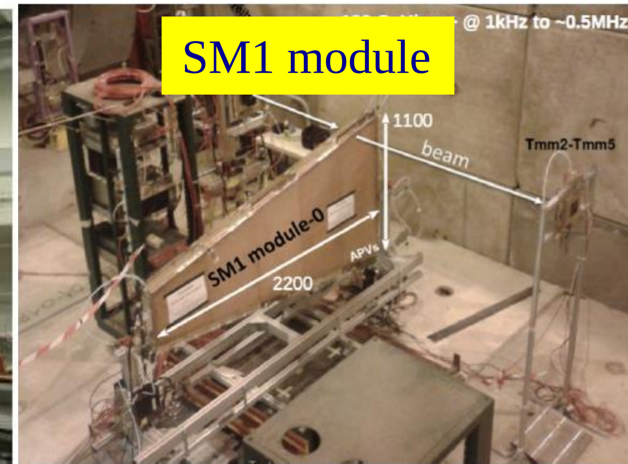








SM1 module



LM2 – CERN / Dubna -Thessaloniki

SM2 – Germany

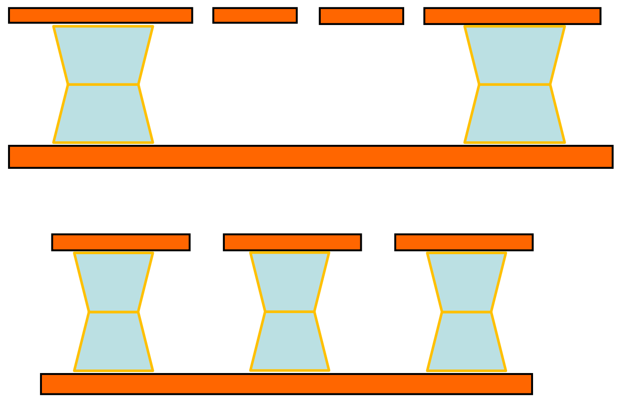
At Saclay the large clean room is ready and operational

First M0 module is under construction and soon will be tested

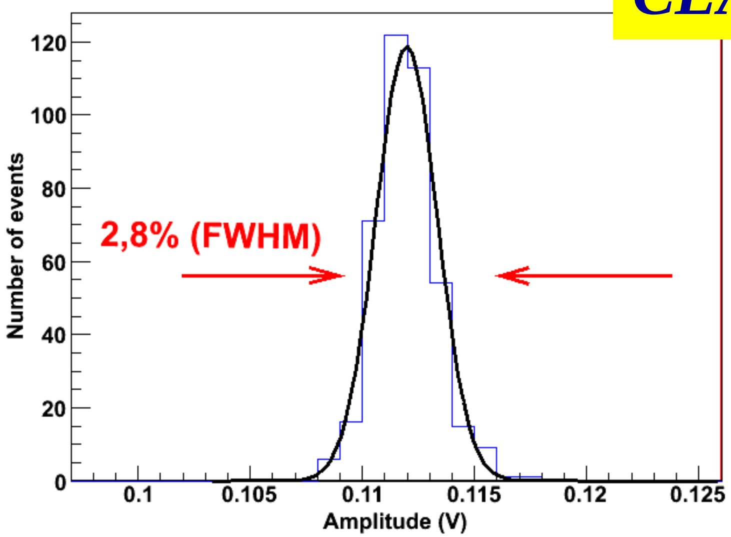
2^{nd} fabrication technology
Micro-Bulk

Type1

Type2



CEA-CERN patent



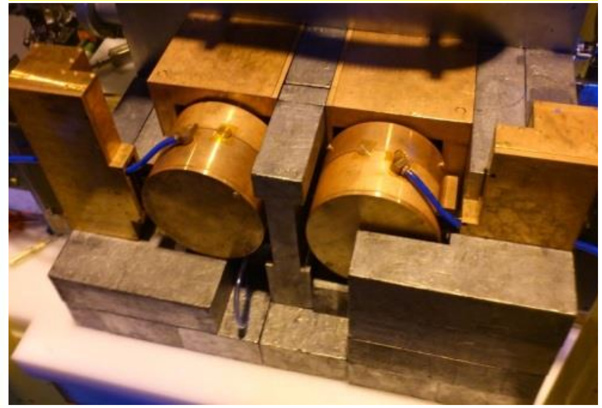
Xe @ 2 bar
Neutrinoless Double Beta (0nbb) using ^{136}Xe
Under study by PANDA-X DBD project

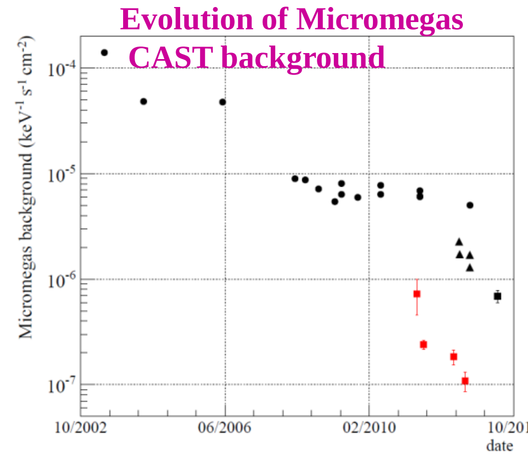
50 µm and 25 µm gaps fabricated

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

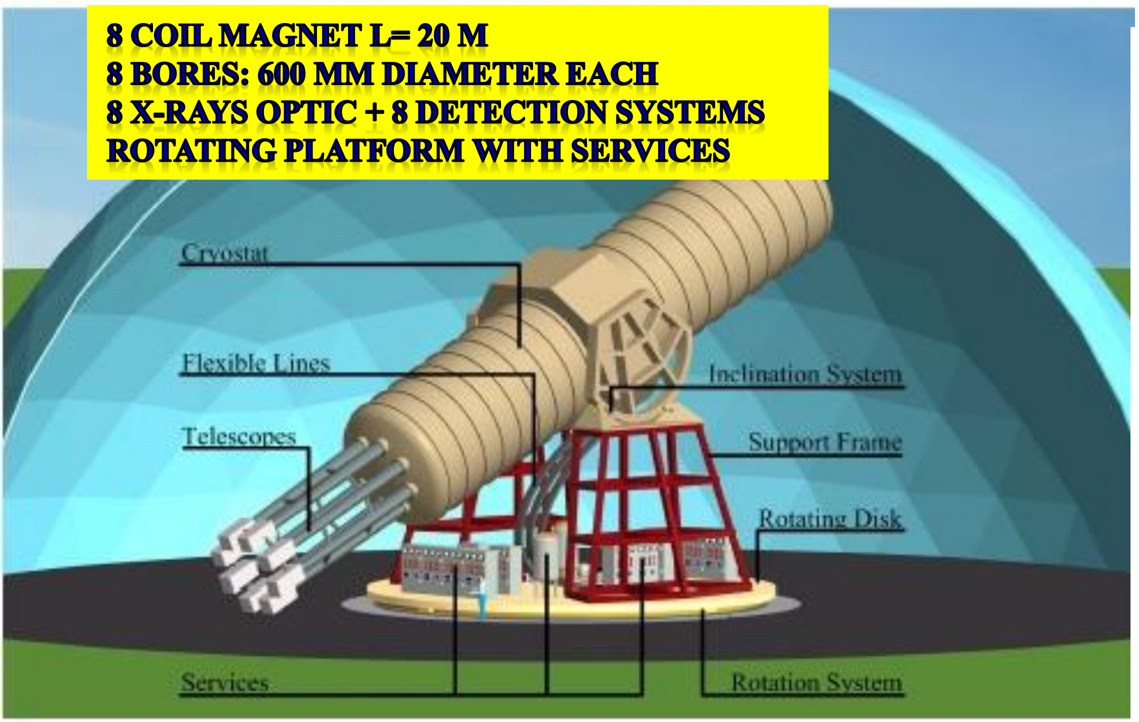
Other advantages
- Flexible structure (cylinder)
- Good uniformity
- Low material
- Low radioactivity

Micromegas micro-bulk in CAST

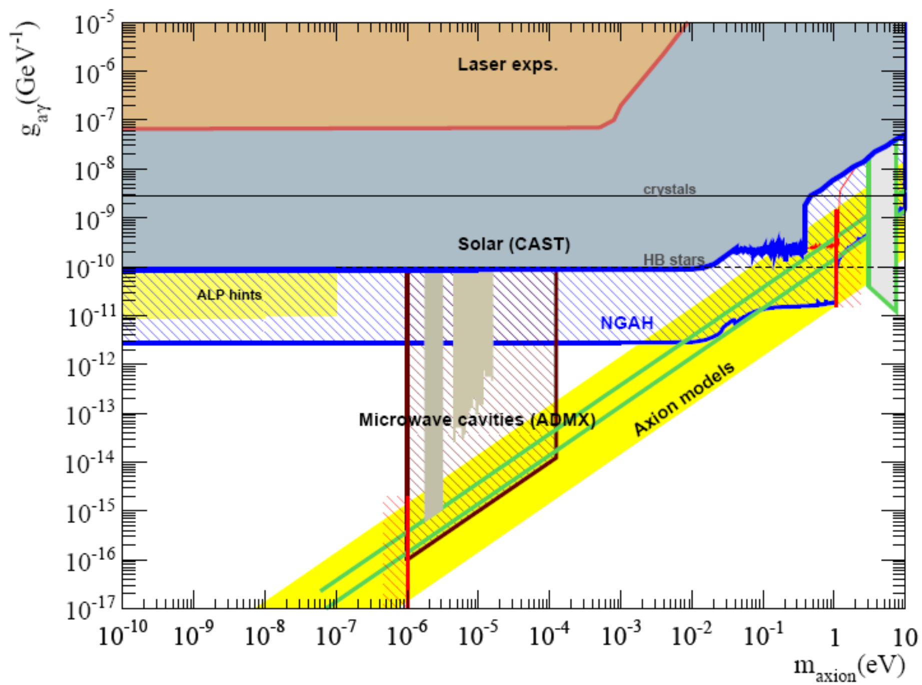




International Axion Observatory (IAXO)



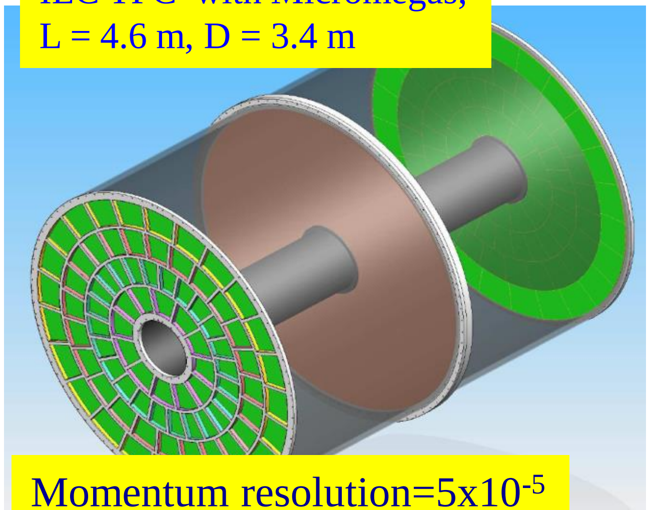
Axion search exclusion plots



ILC TPC project - *Large International collaboration*

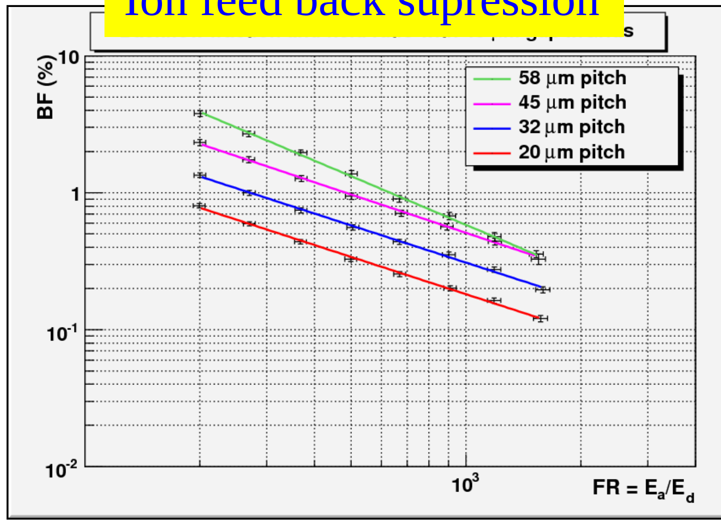
G. Aarons et al., arXiv:0709.1893, M. S. Dixit et al., NIMA 518 (2004) 521, M. Kobayashi et al.,NIMA581(2007)265,

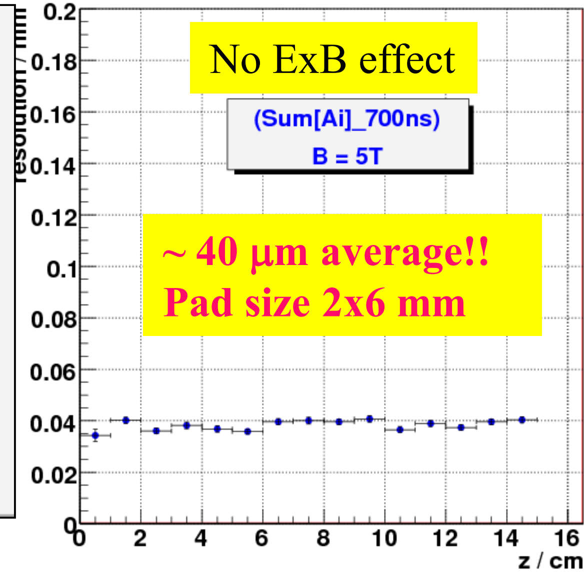
ILC TPC with Micromegas,
L = 4.6 m, D = 3.4 m



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

Ion feed back supression

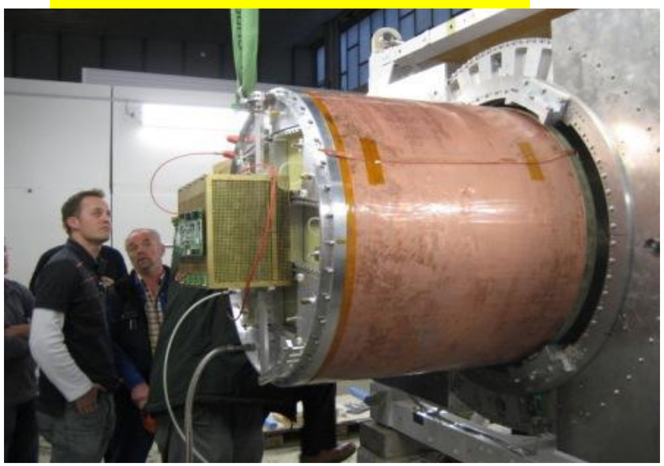




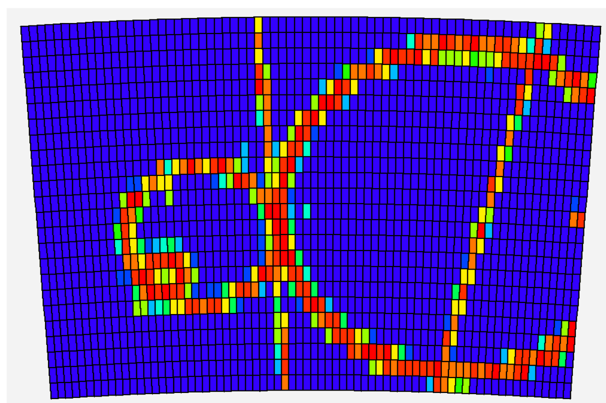
No ExB effect

~ 40 μm average!!
Pad size 2x6 mm

ILC TPC prototype
with Micromegas



Event in DESY test beam



TPC Micromegas advantages

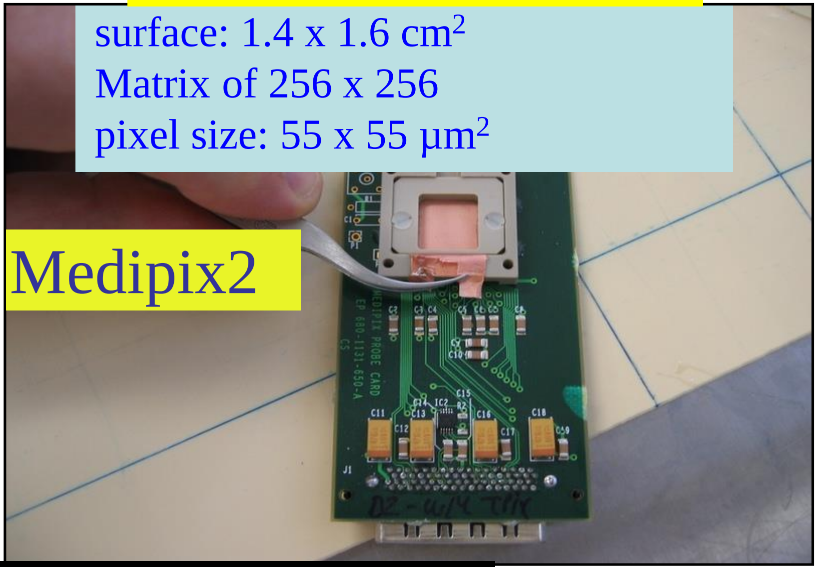
- Ion suppression .1%
- No ExB effect
- Great resolution ~ 40 μm
- Good energy resolution

Micromegas + micro-pixels

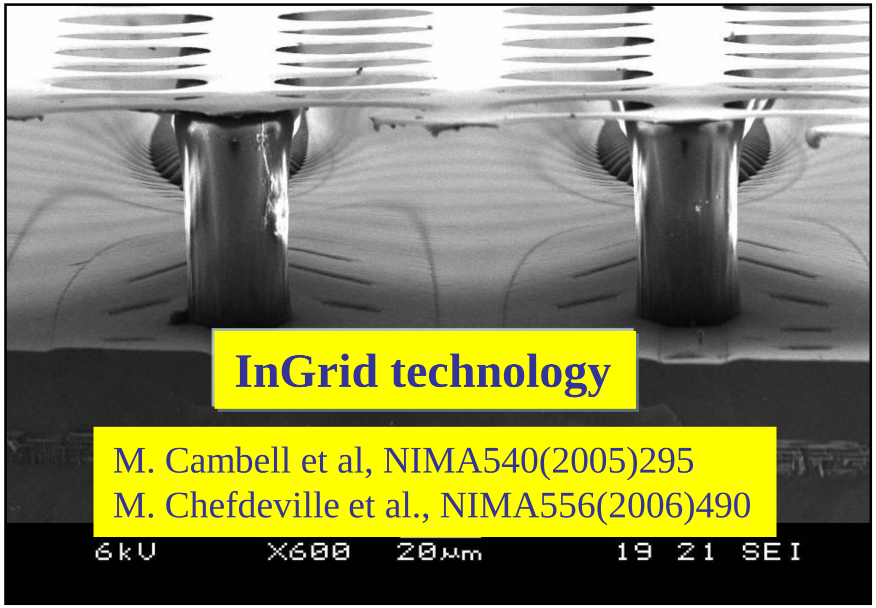
P. Colas et al., NIMA535(2004)506

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

Medipix2

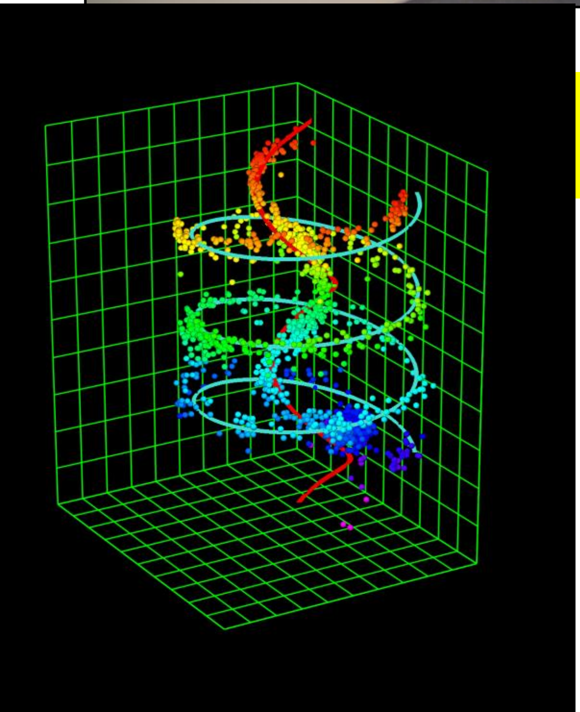


Nikhef, Saclay, Bonn collaboration
Industrialization by Bonn is going on

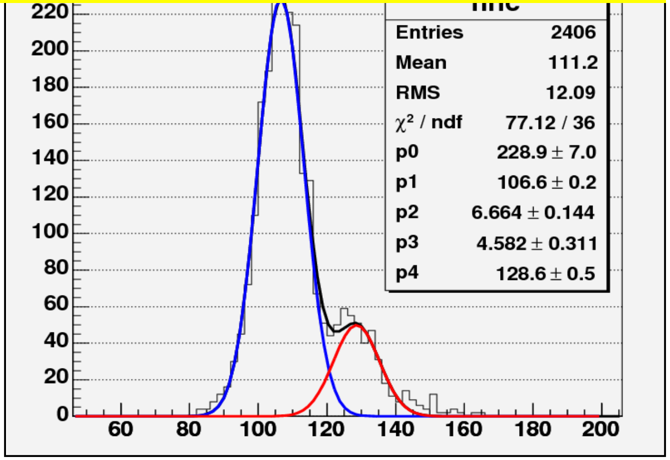


InGrid technology

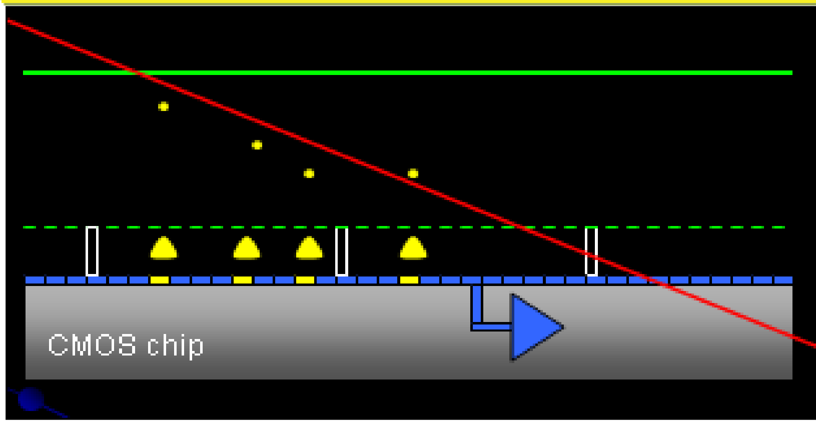
M. Cambell et al, NIMA540(2005)295
M. Chefdeville et al., NIMA556(2006)490



Great resolution
Single electron counting!!

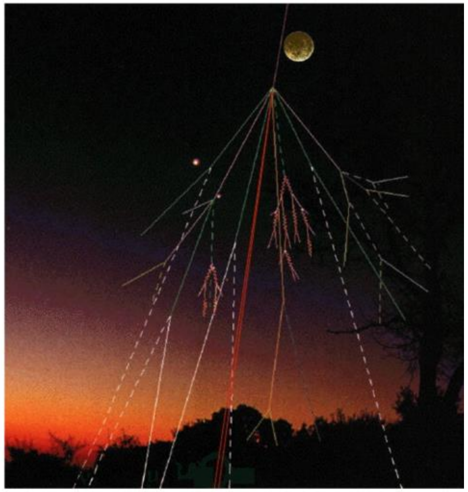


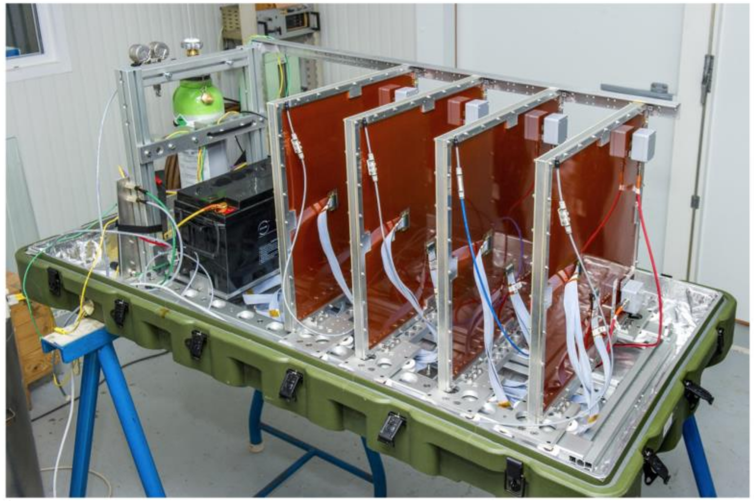
Gas On Slimmed SIlicon Pixels (GOSSIP)
Under study for ATLAS SLHC tracker



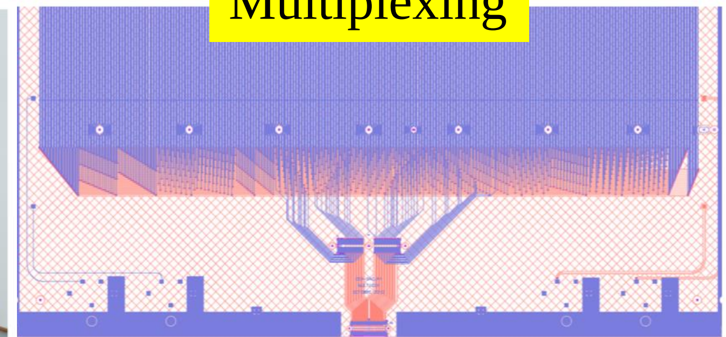
Muon tomography using Micromegas detector

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

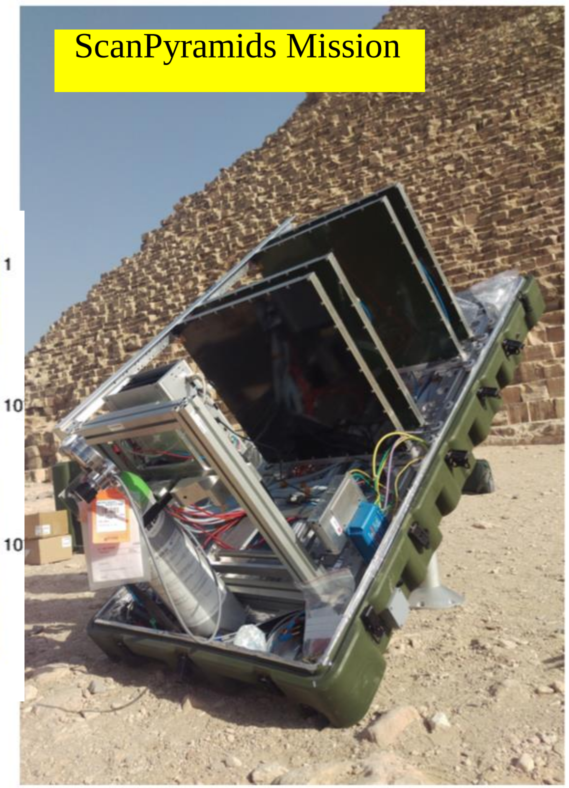




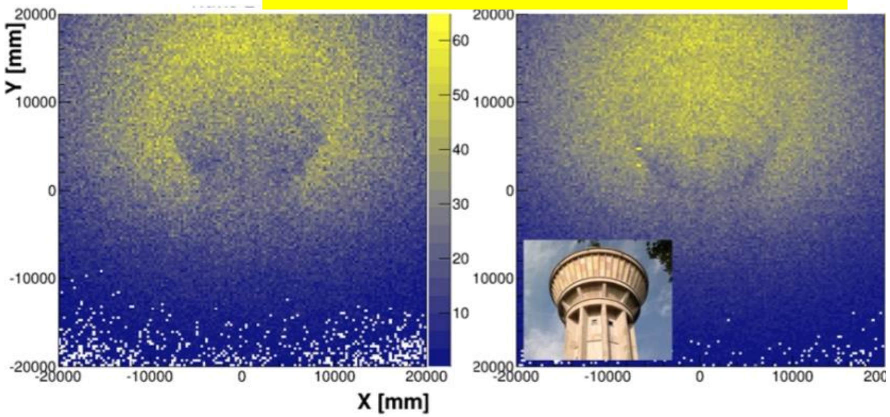
Multiplexing



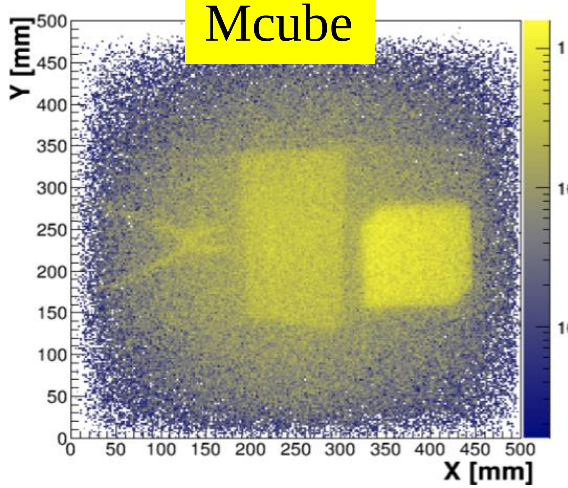
ScanPyramids Mission



‘Chateau d’eau’ at Saclay

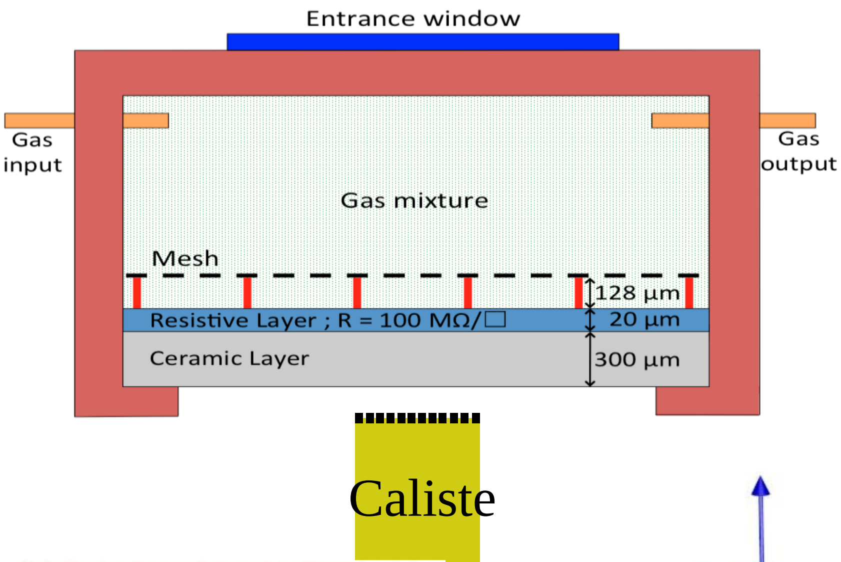


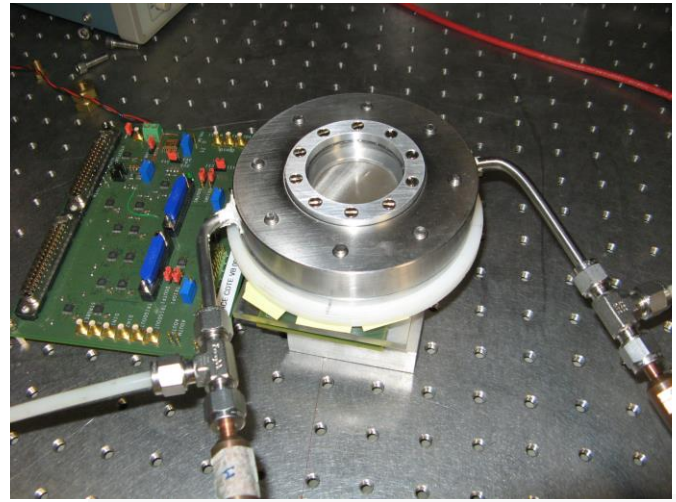
Mcube

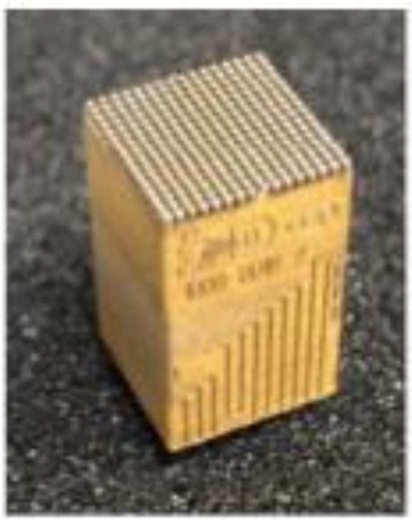


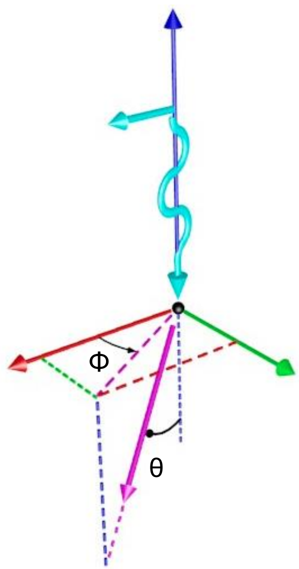
X-ray polarimeter using MM 'Piggyback' and Caliste

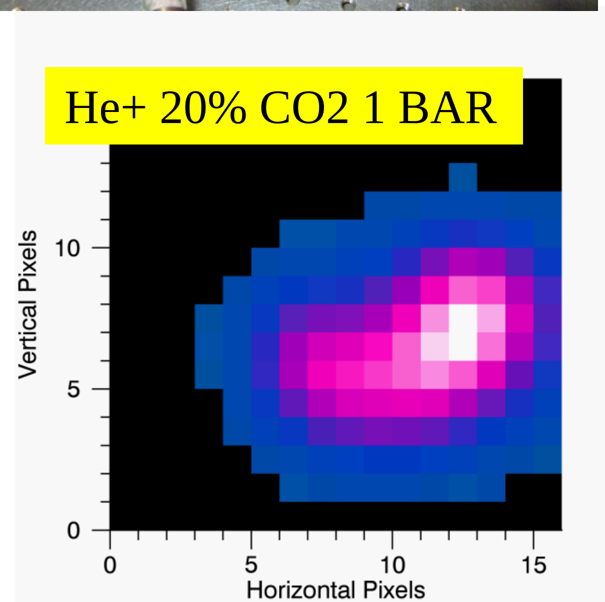
P. Serrano, E. Ferrer, O. Limousin









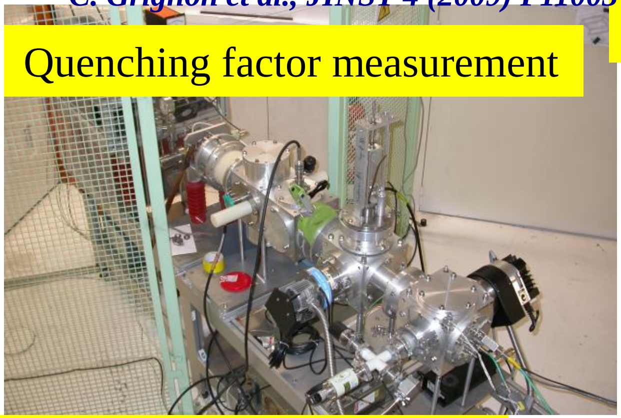


Promising prospects to measure X-rays polarisation

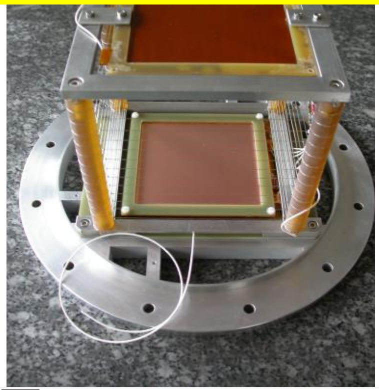
MIMAC-He3 MIcro-tpc Matrix of Chambers of He3
WIMP directional TPC, Micromegas read-out,
Grenoble – Saclay, Cadarache collaboration
C. Grignon et al., JINST 4 (2009) P11003

Direct QF evaluation
D. Santos et al., [arXiv:0810.1137]

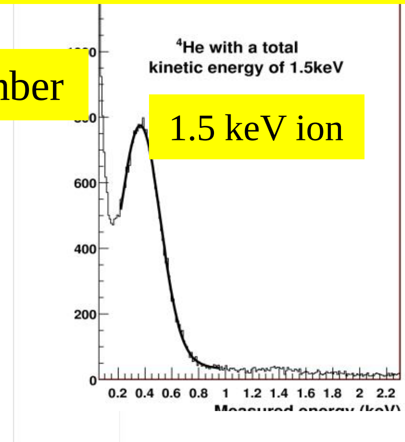
Quenching factor measurement



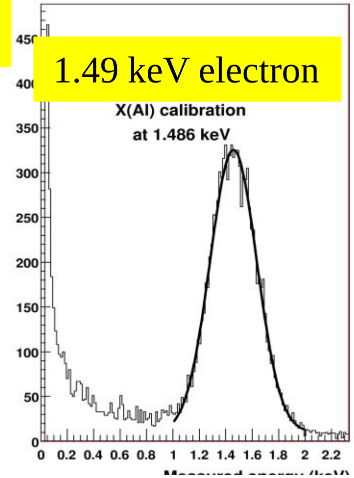
Micromegas:μTPC chamber



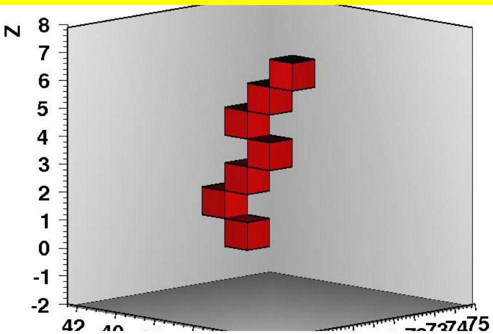
1.5 keV ion



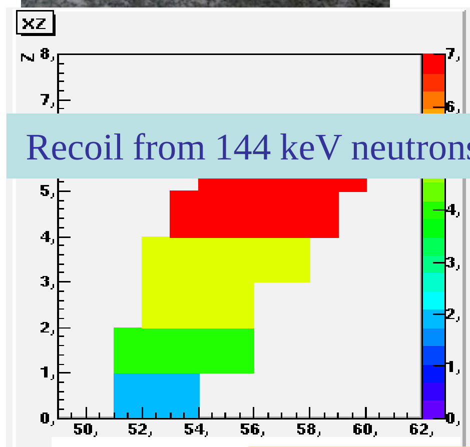
1.49 keV electron



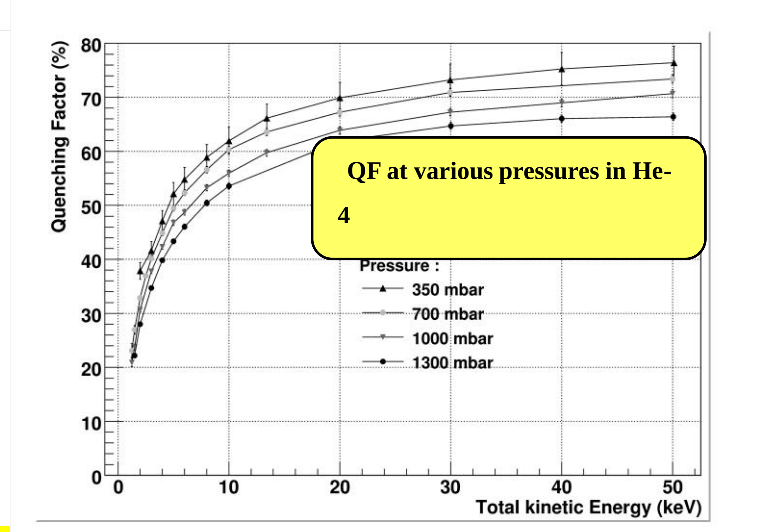
proton 8 keV, He + 5% iC_4H_{10}, 350 mbar



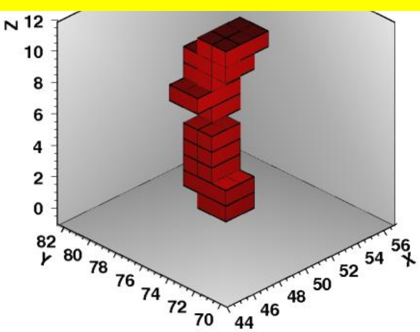
Recoil from 144 keV neutrons



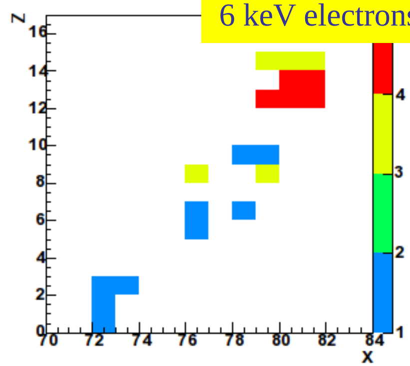
QF at various pressures in He-4

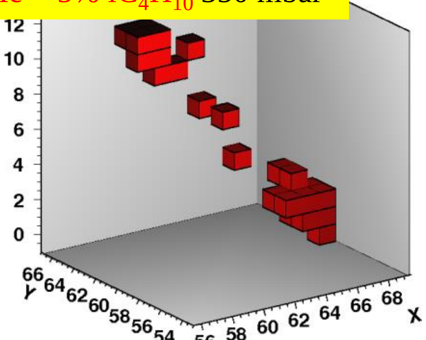


40 keV ^{19}F, 70 % CF_4 + 30% CHF_3 , 55 mbar



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

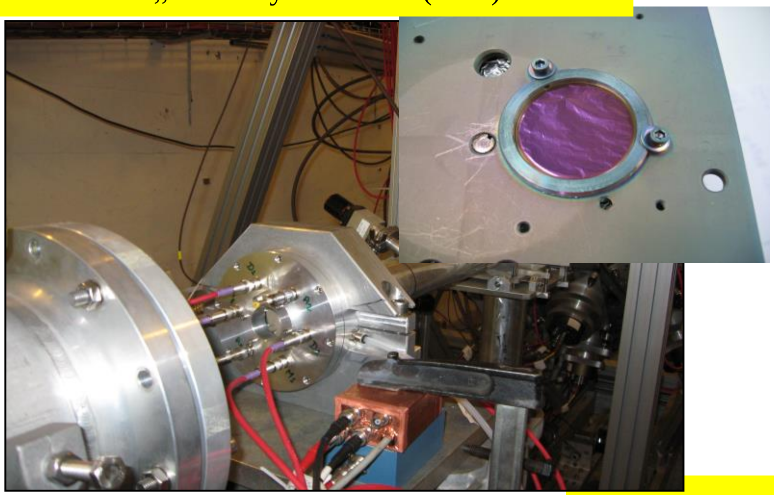




Applications in neutron detection

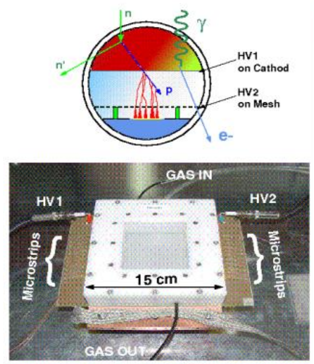
n-TOF MicroMegas-based neutron transparent flux monitor and profiler

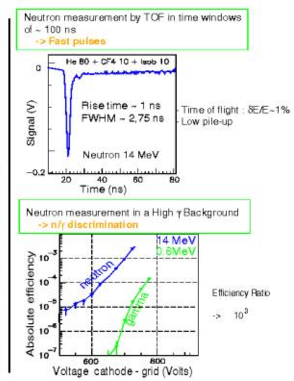
F. Belloni et al.,, Mod.Phys.Lett. A28 (2013) 1340023

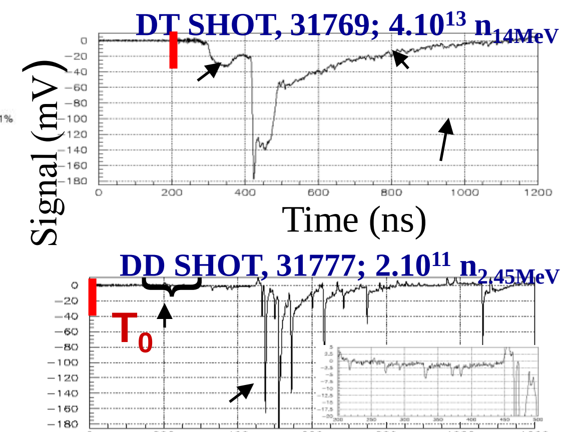


Micromégas Concept for Laser MégaJoule and ICF Facilities

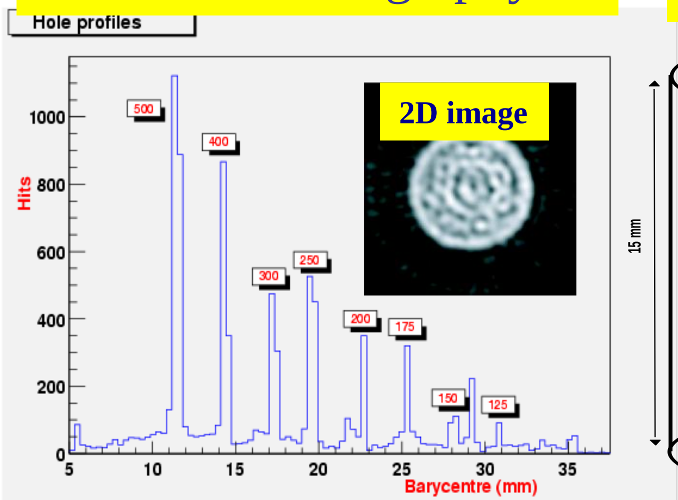
M. Houry et al., NIM,557(2006)648





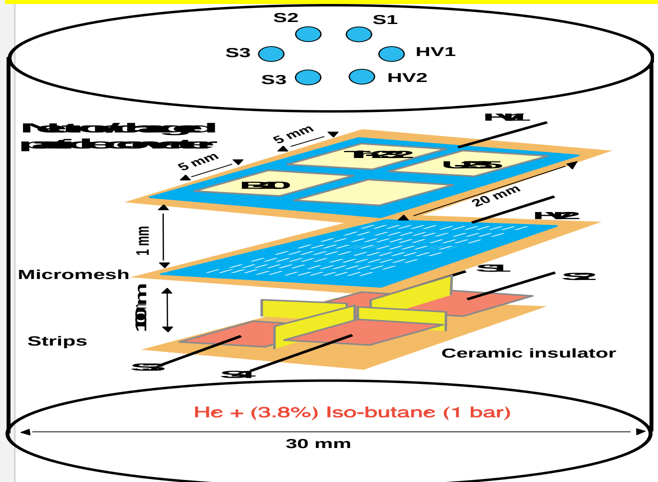


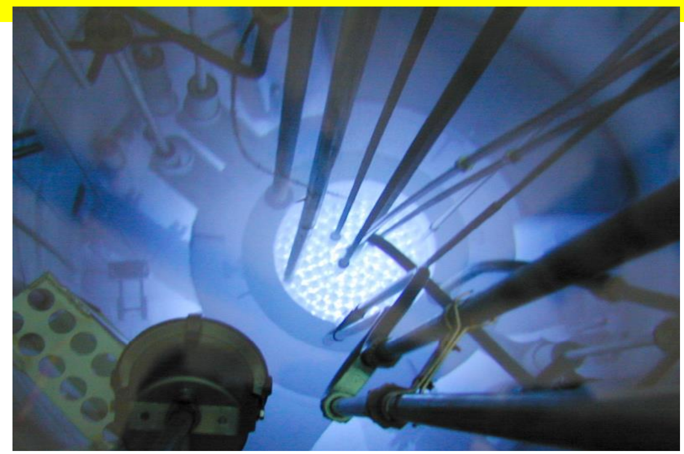
neutron tomography



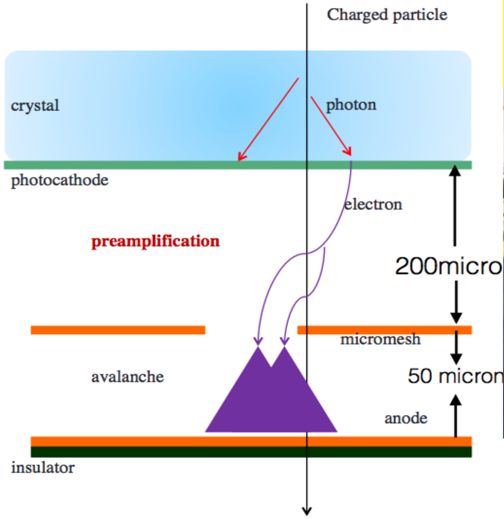
Piccolo Micromegas, Nuclear reactor in-core neutron measurement

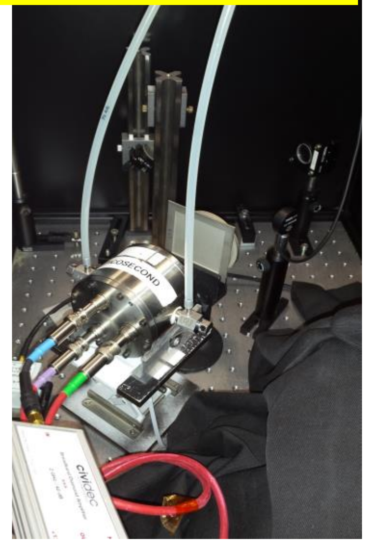
J. Pancin et al., NIMA, 592(2008)104



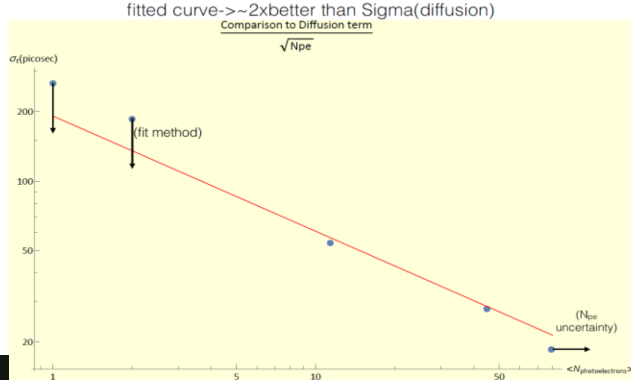


Fast timing Picosecond Micromegas
CEA-Saclay, CERN, Thessaloniki, Athens, Princeton





Summary of Ne-Ethane(10%): Efield=10kV/cm; Drift Gap =0.2 mm
1,2 pe data points consistent with 40% worse template method
fitted curve->~2xbetter than Sigma(diffusion)



First tets in

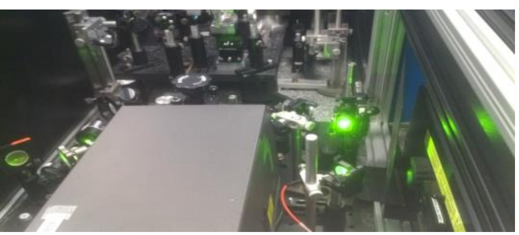
IRAMIS facility @ CEA Saclay
(***thanks to Thomas Gustavsson!***)

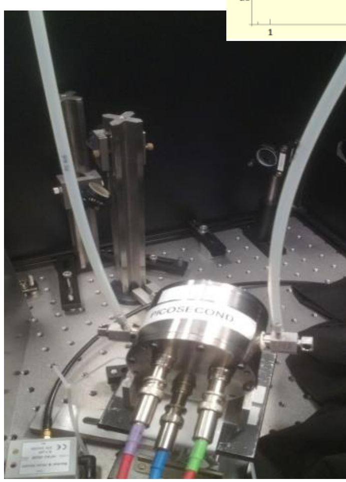
UV laser with σ_t ~ 100 fs

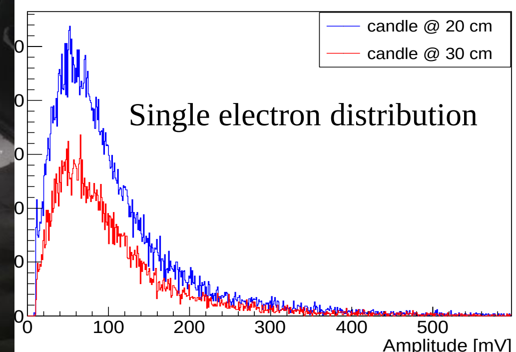
λ = 275-285 nm after doubling

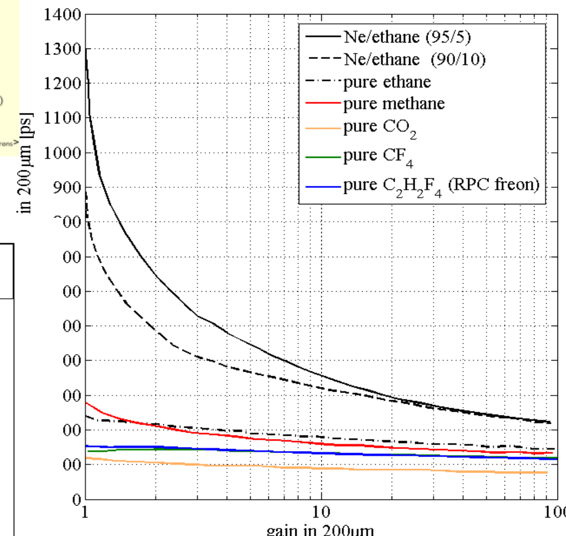
Cividec 2 GHz preamplifier

DAQ through Lecroy Osciloscope

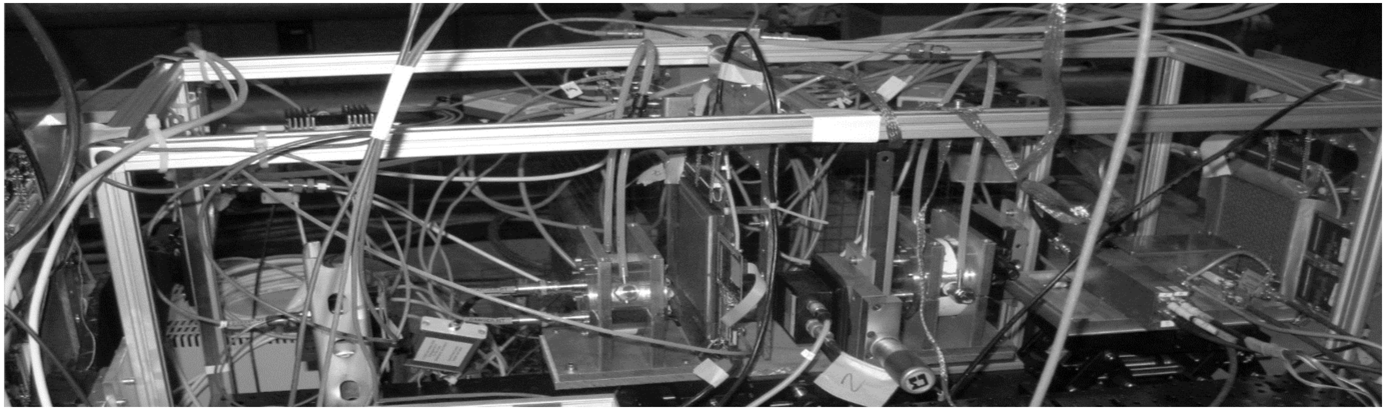


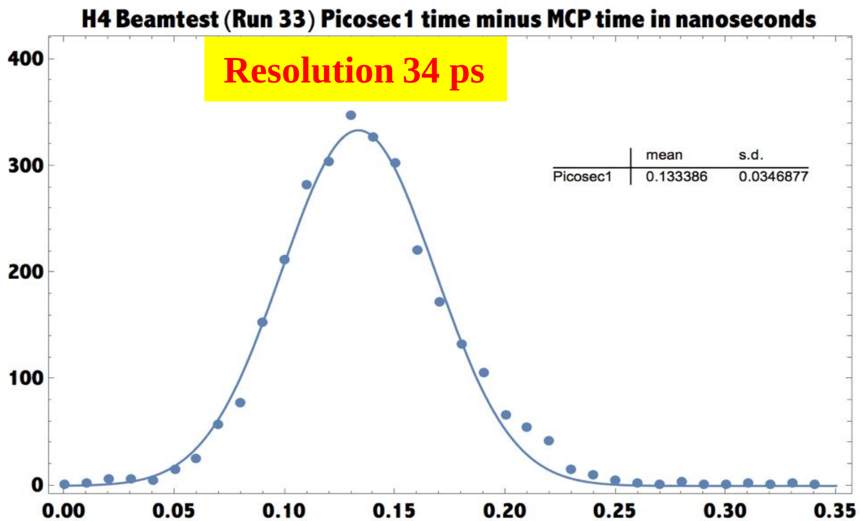


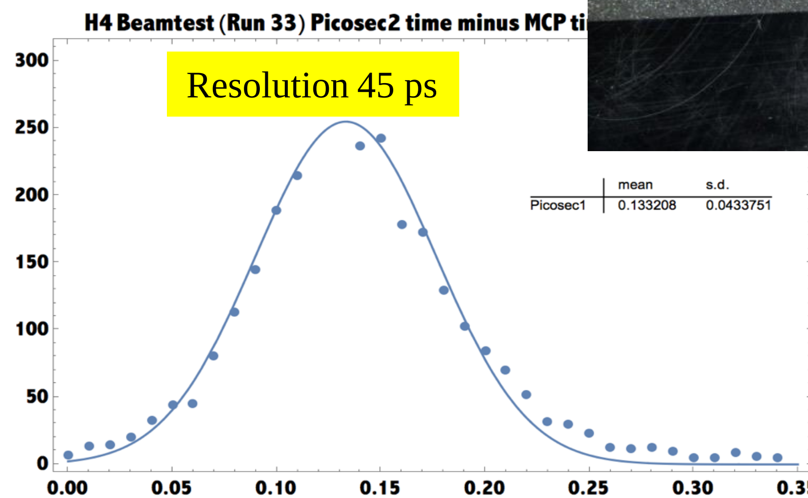


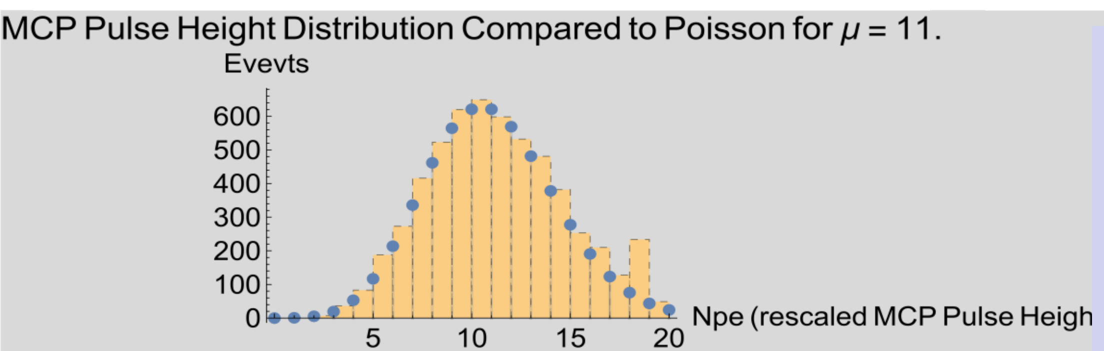


CERN-SPS recent measurements







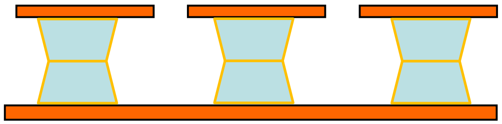


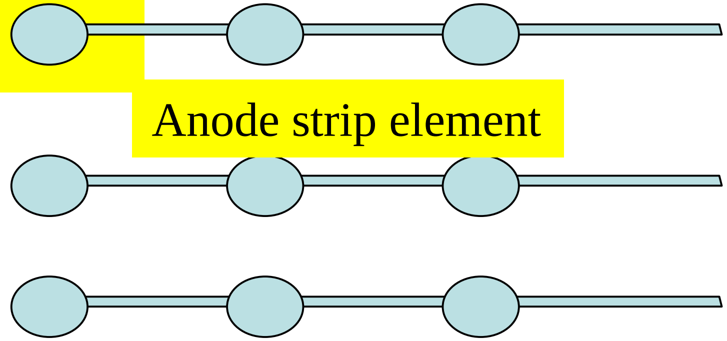
Future plans and improvements

- Improve analysis and include tracking information
- Improve photocathode quality
- Further improve detector, mesh and accuracy
- Optimize gas mixture
- Radiation hardness
- High rate protection

Towards ultra-low capacitance MM

- Spark protection
- Preserves fast electron signal



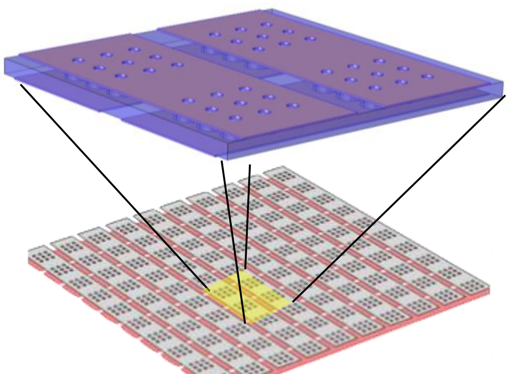


First protoype was fabricated using microbulk kapton etching

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

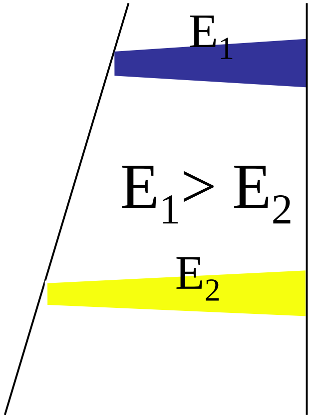
- Pad read-out
- Move pad read-out back by 1-2 mm
- To further reduce capacitance

Ultimate goal

Read-out pad or strip capacitance <1 pF

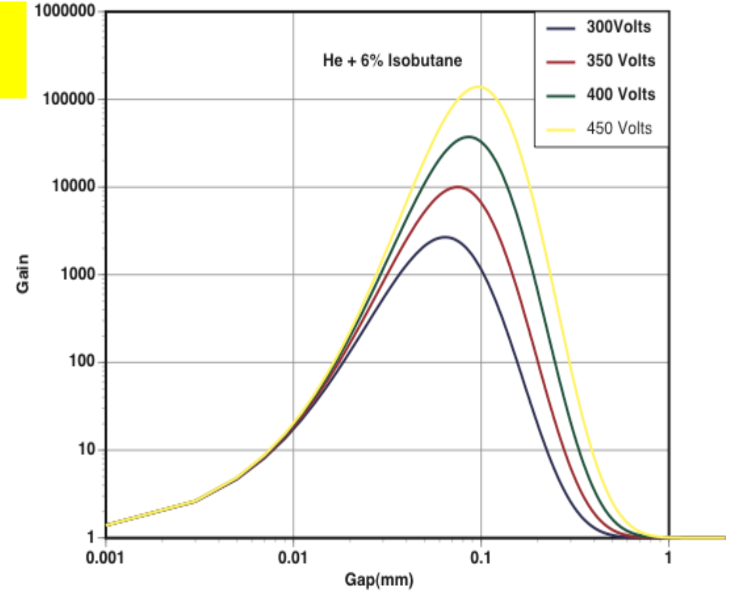
⇒ Charge released by spark < 10^9 electrons

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



High gas pressure detector deal

$$dG/G = apd(1 - Bpd/V) = apd(1 - Bp/E)$$



Ref: Y. Giomataris, NIM A419, p239 (1998)

Optimum gap : 30 - 100 microns

The gain variation exhibits a minimum for :

d = V/Bp

Ideal gap

Message

For high pressure operation up to 10 bar

We need a small 10-30 μm gap

The idea of small gap MM was tested *D. Attie et al., JINST 9 (2014) C04013*

Gaps of 12.5, 25, 50 μm have been fabricated and successfully tested

From this study we concluded that the highest achievable gain was lower with smaller gaps

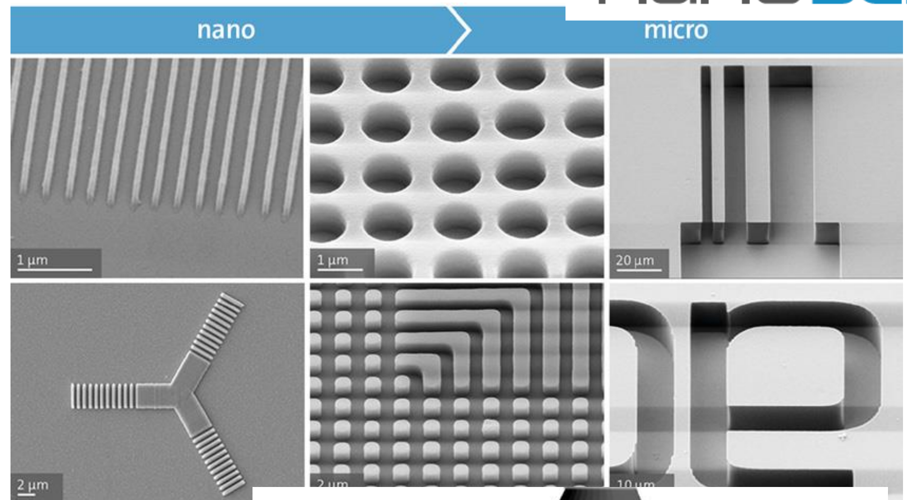
To improve gain we need to fabricate much smaller mesh holes, smaller than gap length of the order of 5- 10 μm

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

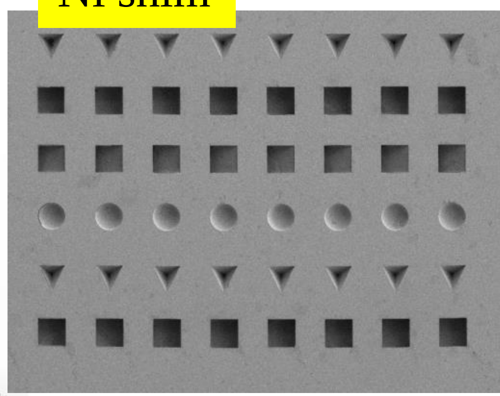
High precision 3D printer technology

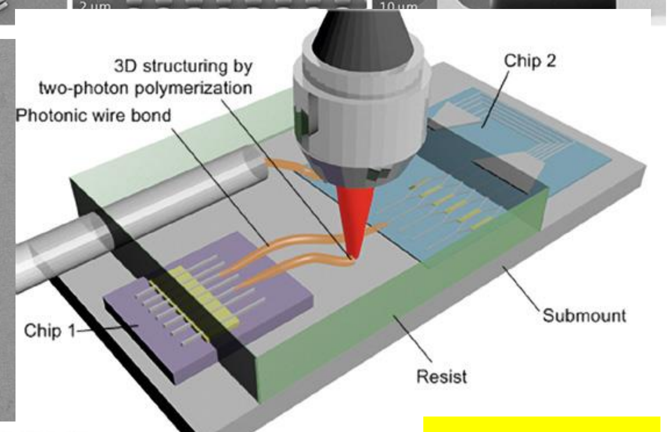
nanoscribe

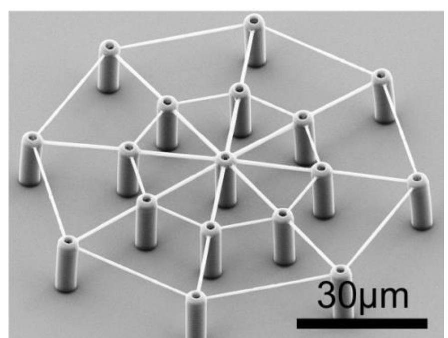
On our table



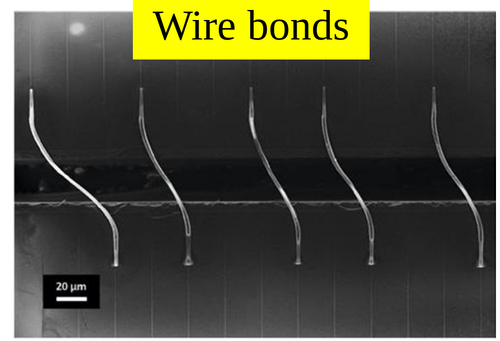
Ni shim







Wire bonds



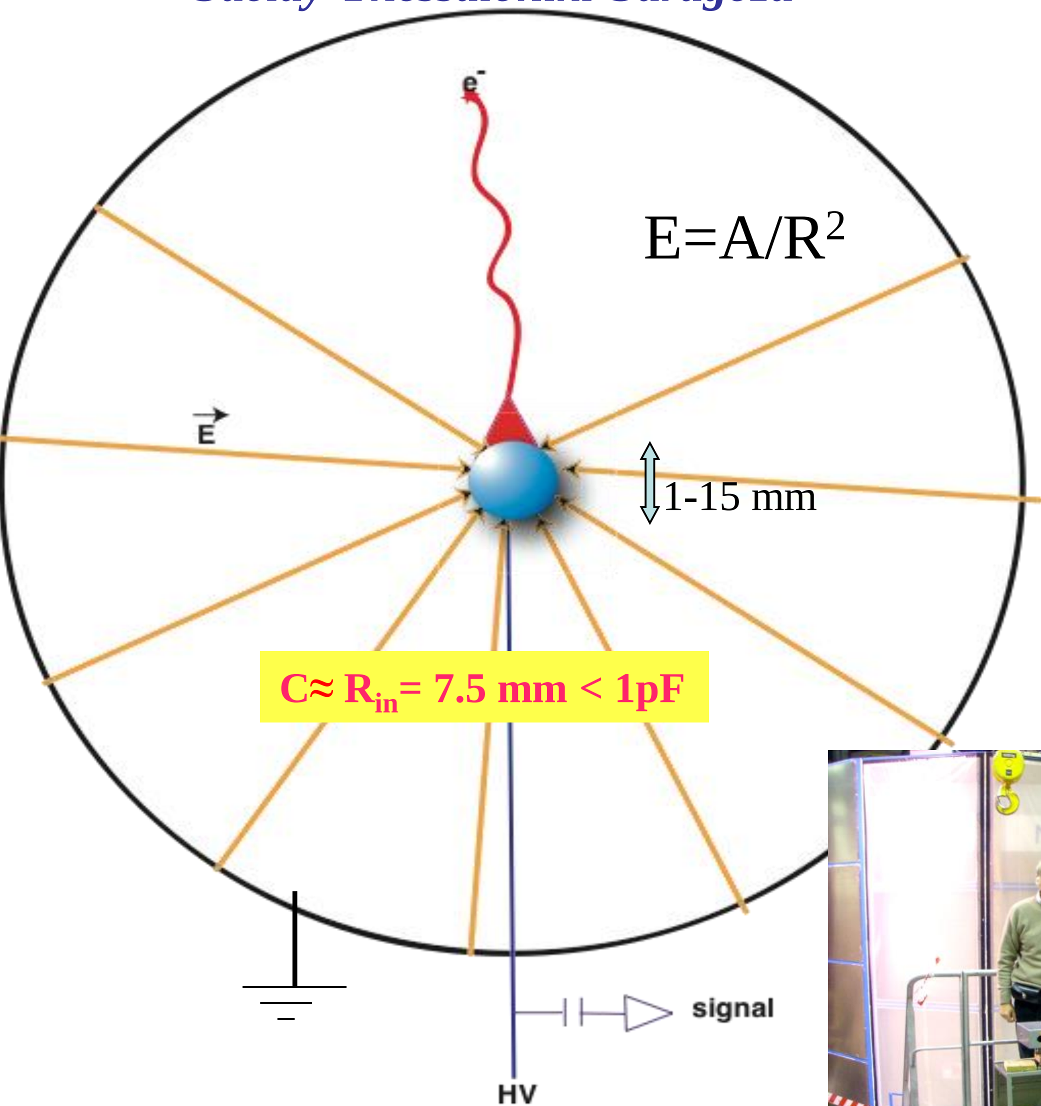
Second part

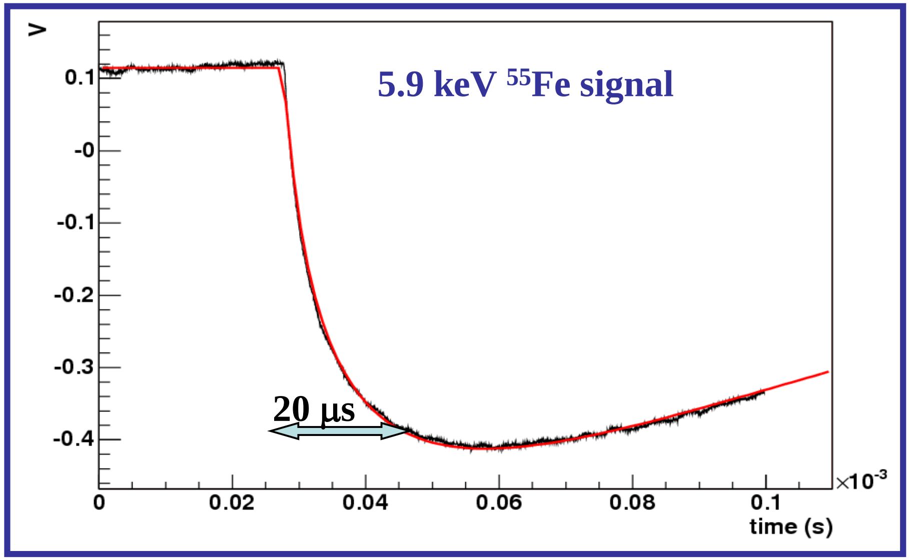
Spherical detector, light-dark matter search and neutrino physics

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



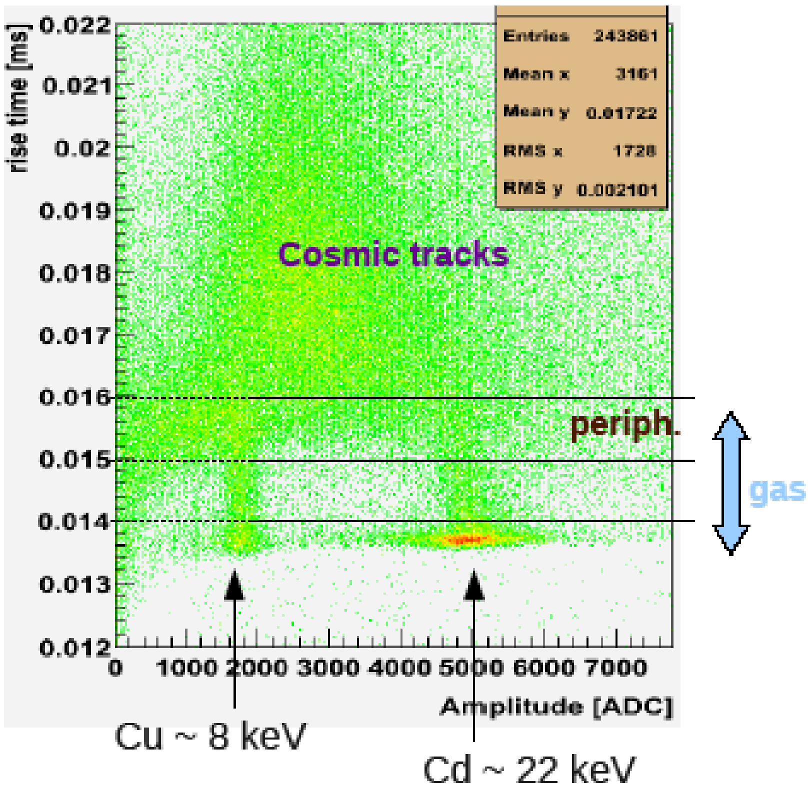


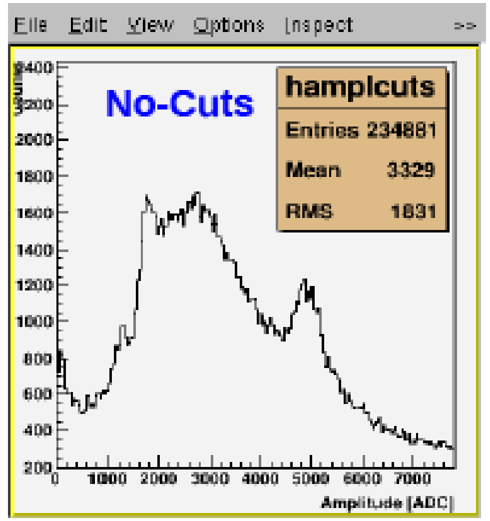
- Simple and cheap
- Large volume
- single read-out
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut
- Low background capability

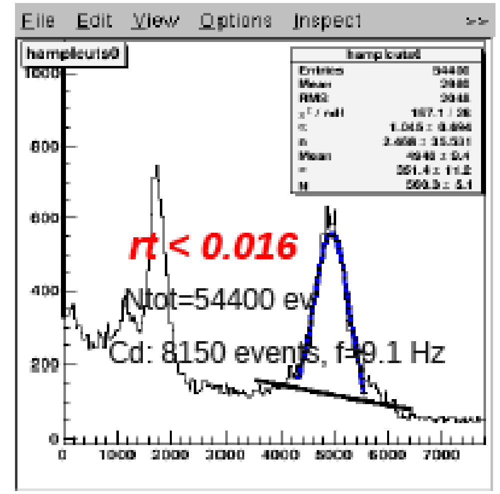
Rejection power

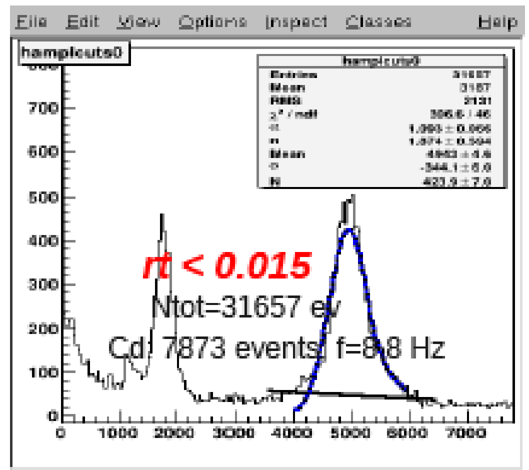
Rise time cut

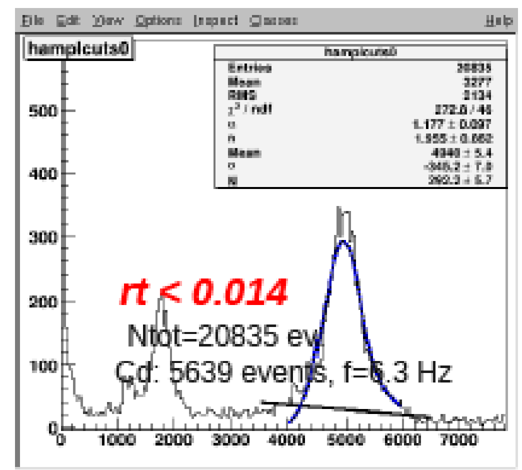
Using Cd-109 source – December 2009
Irradiate gas through 200µm Al window
P = 100 mb, Ar-CH_4 (2%)











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

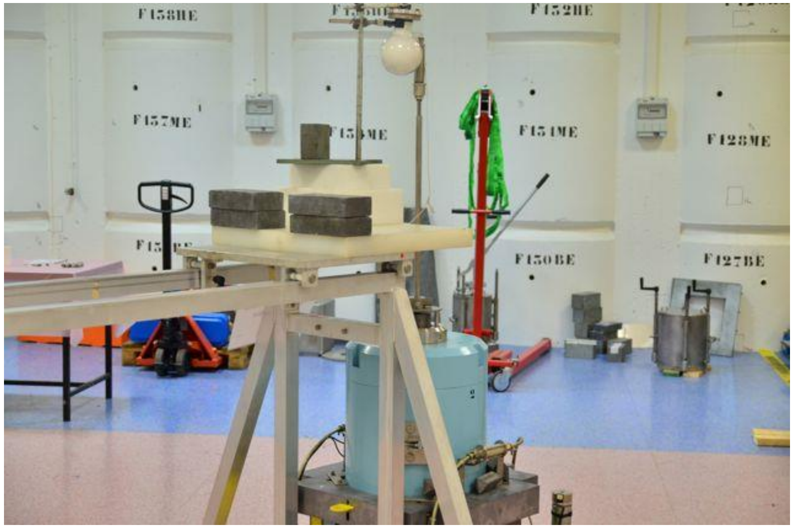
Efficiency of the cut in rt ==> ~ 70% signal (Cd peak)

Severe background reduction

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

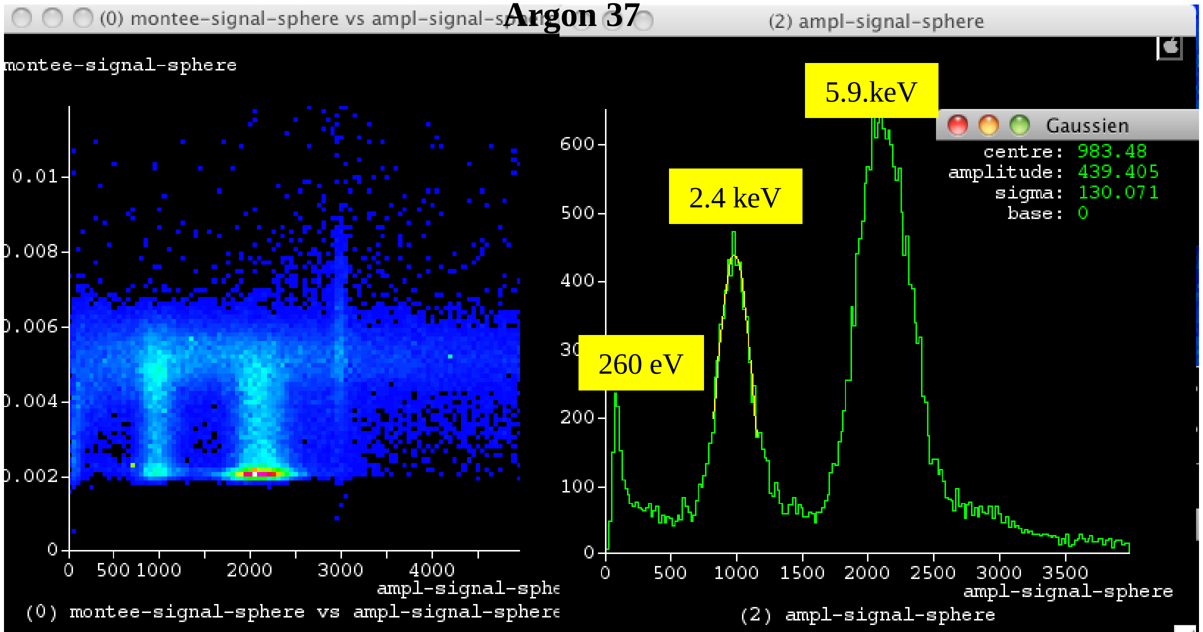
Low-energy calibration source *Argon-37*

Home made Ar-37 source: irradiating Ca-40 powder with fast neutrons $7x10^6$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

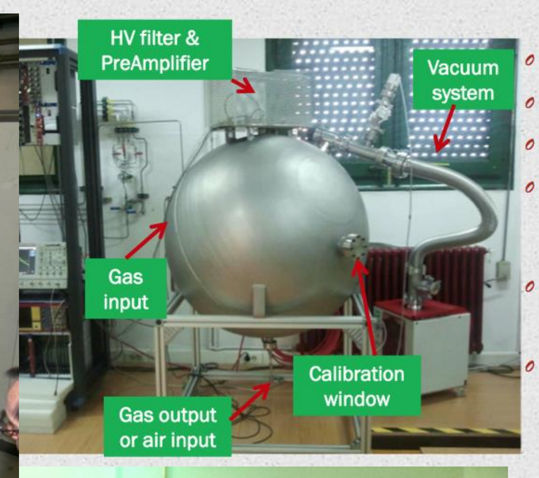
First measurement with Ar-37 source
Total rate 40 hz
in 250 mbar gas, 8 mm ball
240 eV peak clearly seen
A key result for light dark matter search



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, Nucl.Instrum.Meth.A530:330-358,2004,

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G. Gerbier et al.,arXiv:1401.790v1

NEWS collaboration

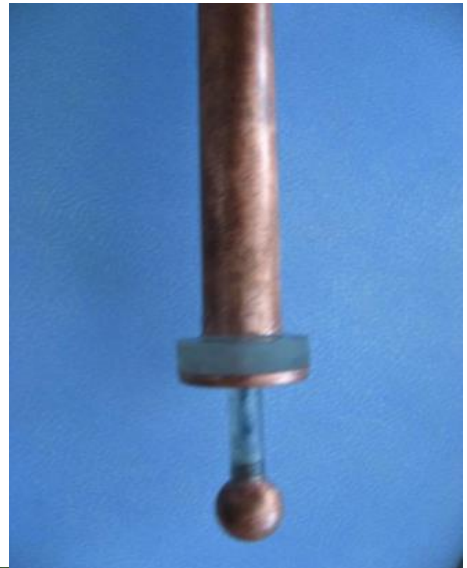
Queen's University Kingston, IRFU/Saclay , LSM, Thessaloniki University, LPSC Grenoble, TU Munich,PNNLTRIUM

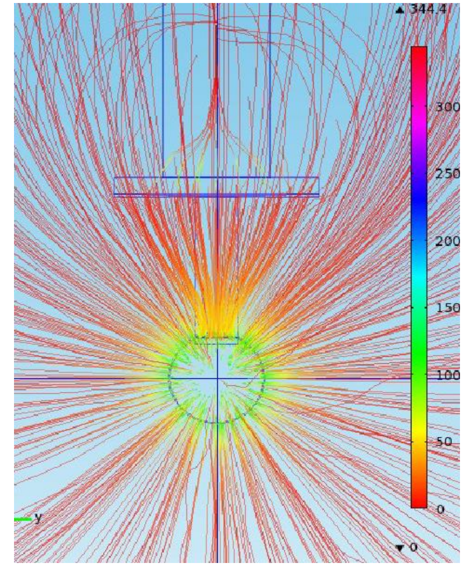
Collaboration meeting at LSM april 2016

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

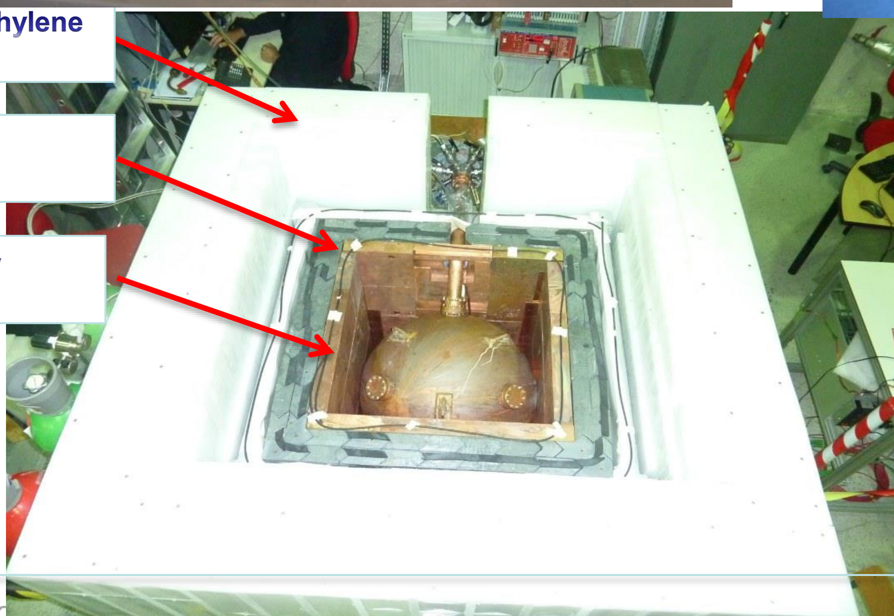


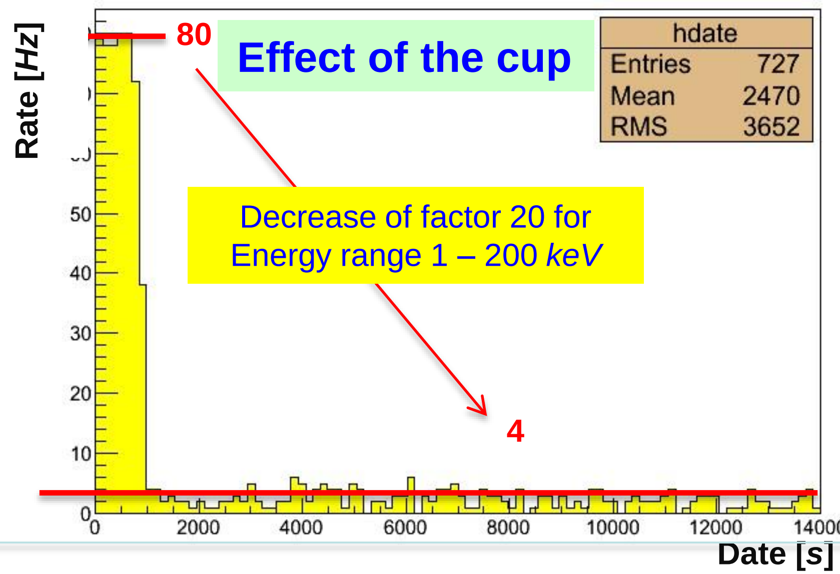


Polyethylene
30 cm

Lead
10 cm

Copper
5 cm





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

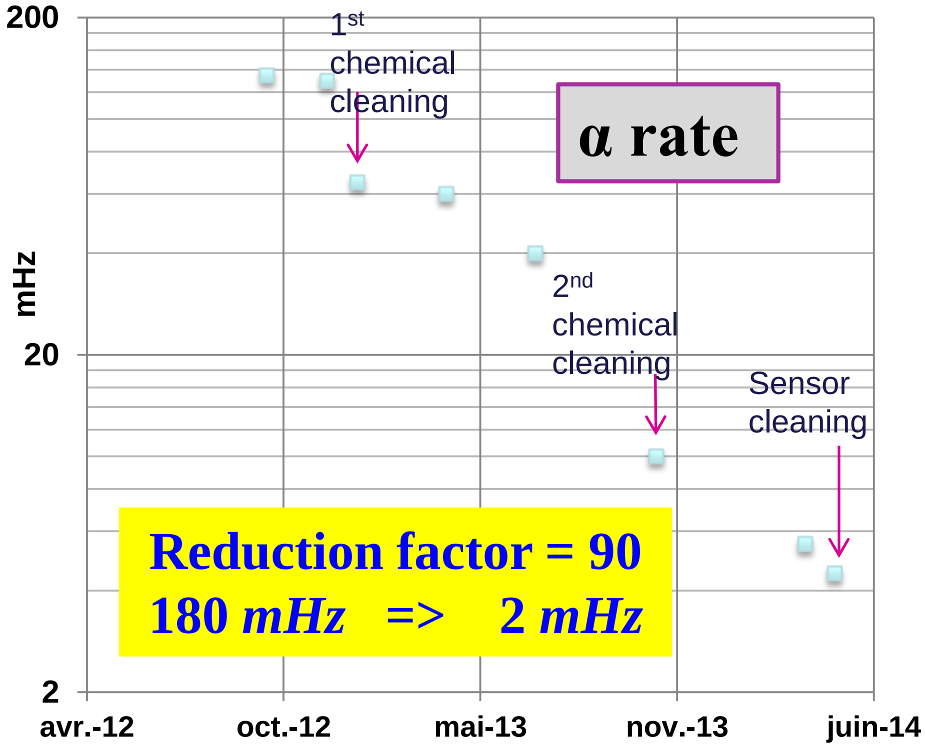
2nd chemical cleaning of sphere

Conditions :

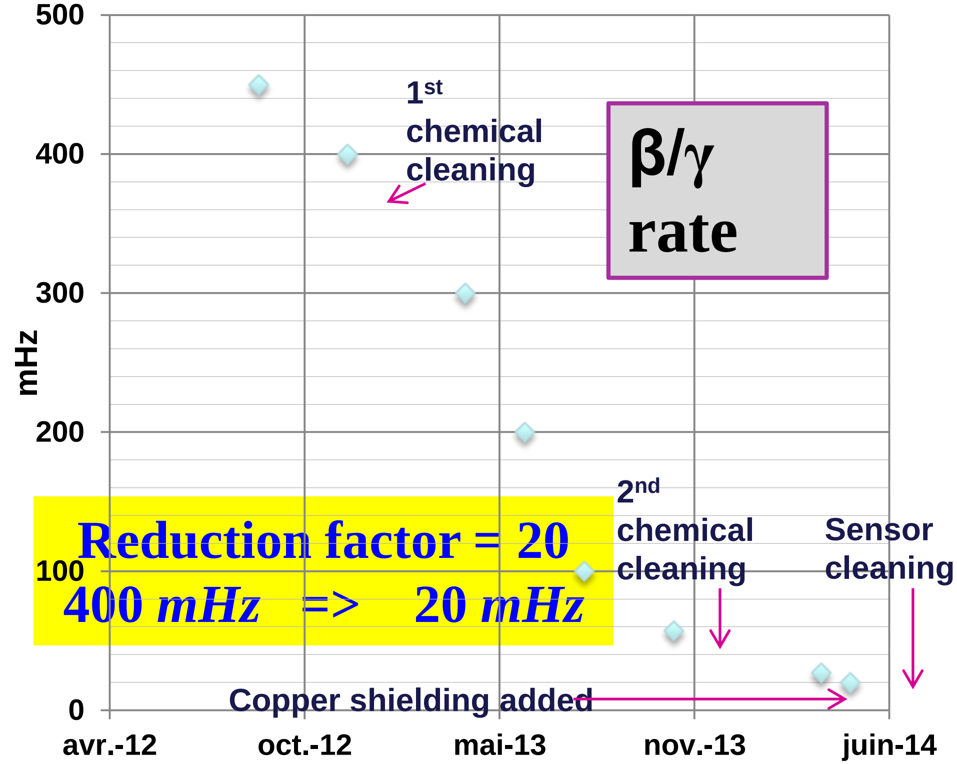
- Nitric acid (30 %)
- Temperature 30° *C*
- Cleaning by spray
- Washing by pure water
- Drying by hot nitrogen

Backround evolution of the detector

Alpha rate evolution

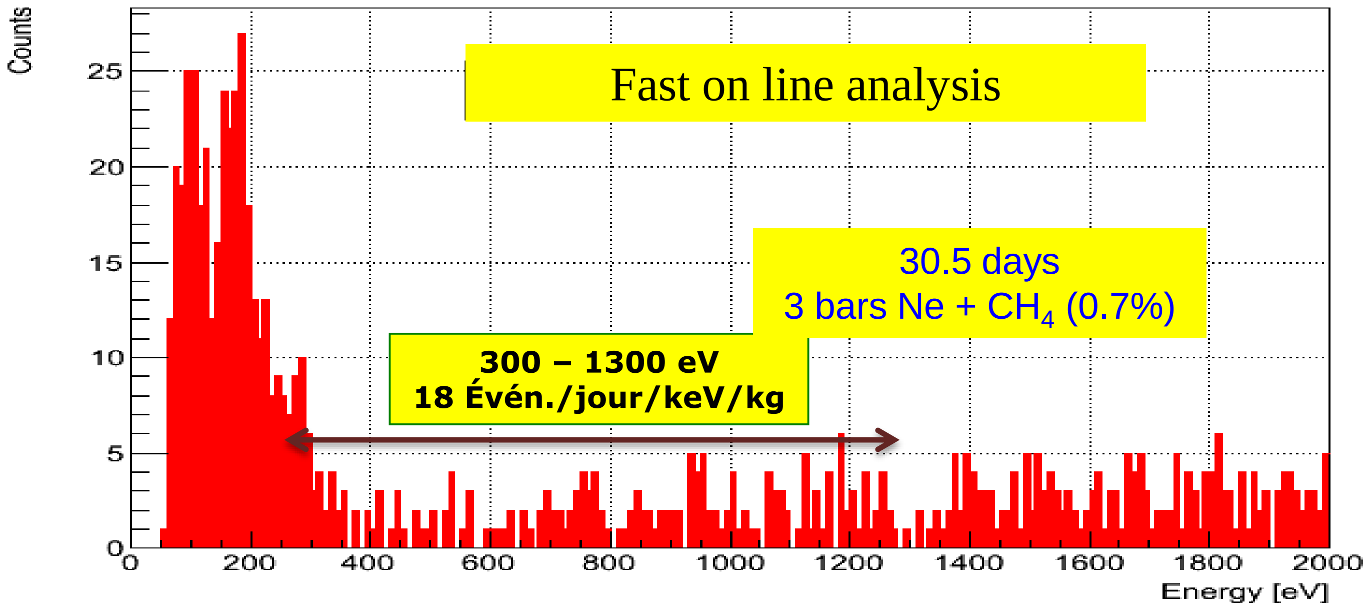


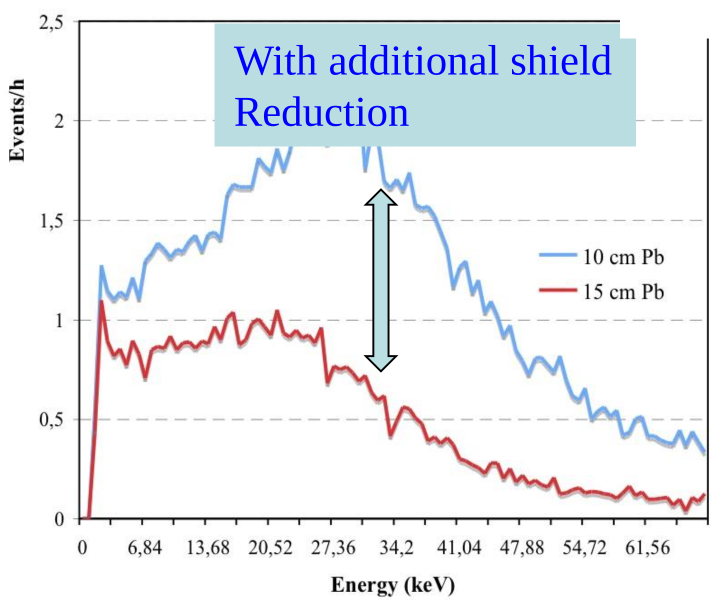
β/γ rate evolution



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

Light WIMP search results





Summary:

background level among the best experiments

Achieved with modest budget and manpower

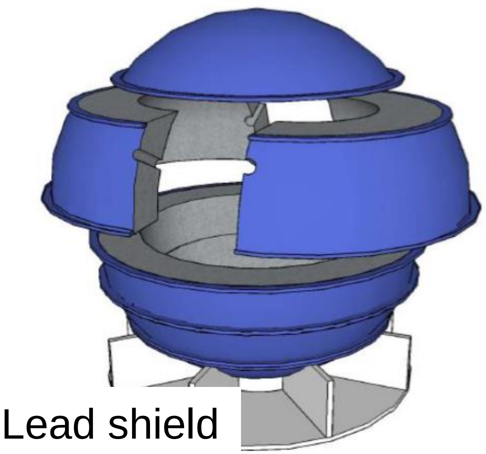
Combined with the low energy threshold and low-Z targets:

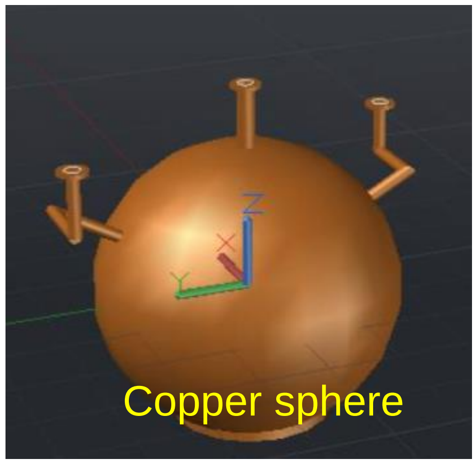
Competitive sensitivity for very-light WIMPs

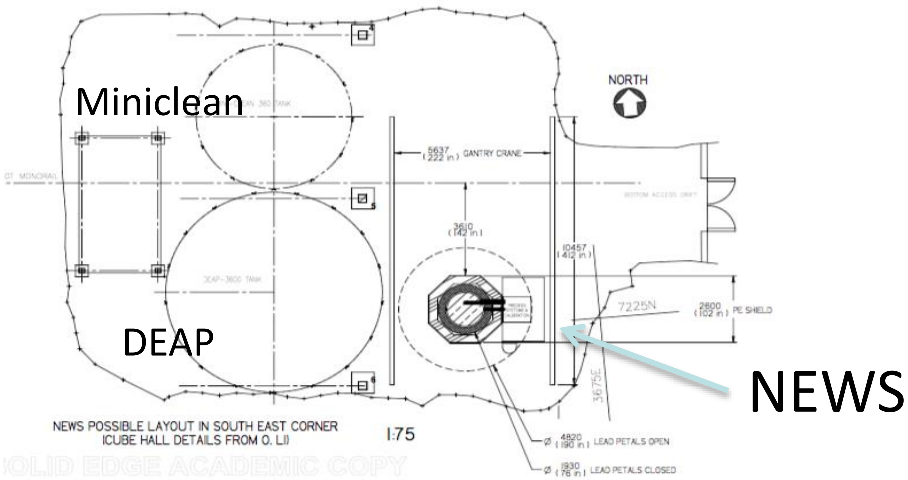
Publication under preparation

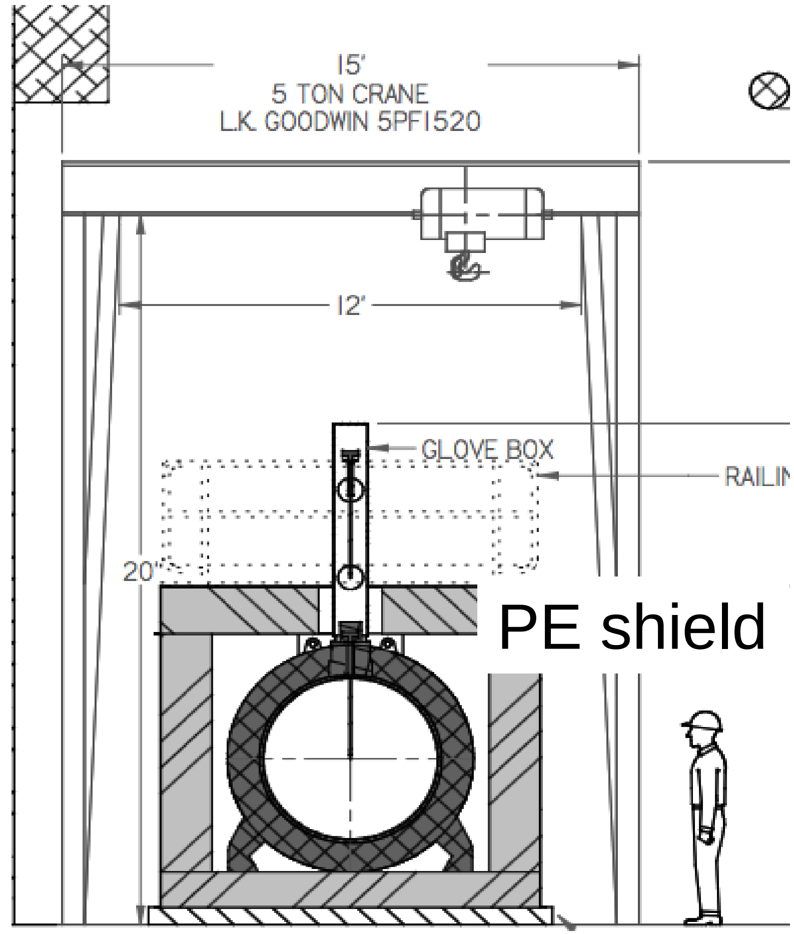
NEWS-SNO with compact shield : implementation at SNOLAB by fall 2017

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



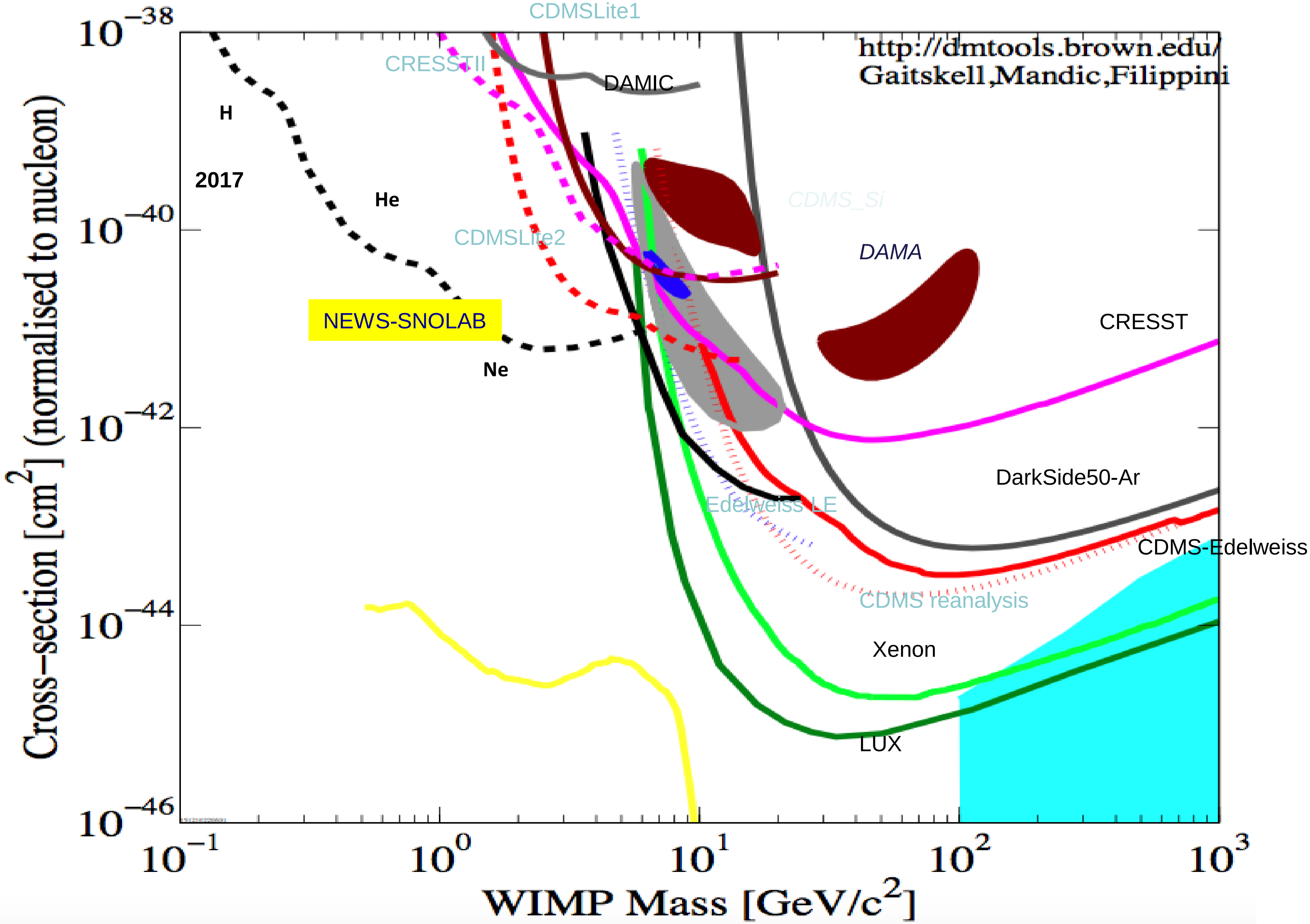






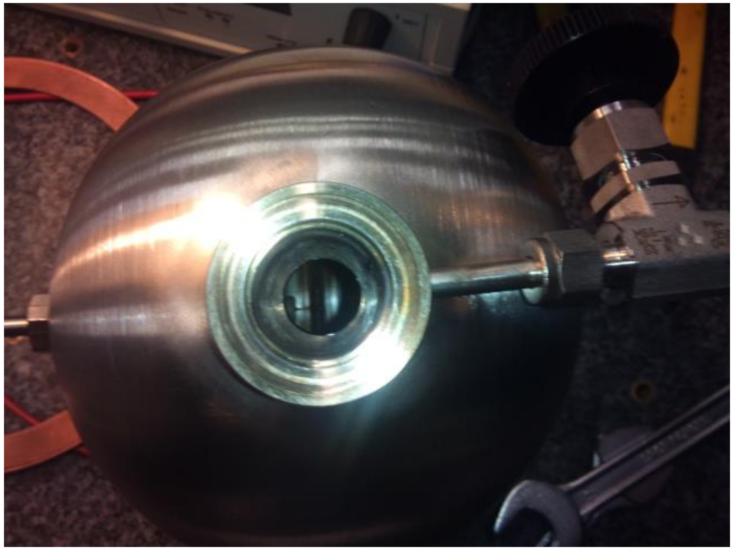
NEWS-SNOLAB project:

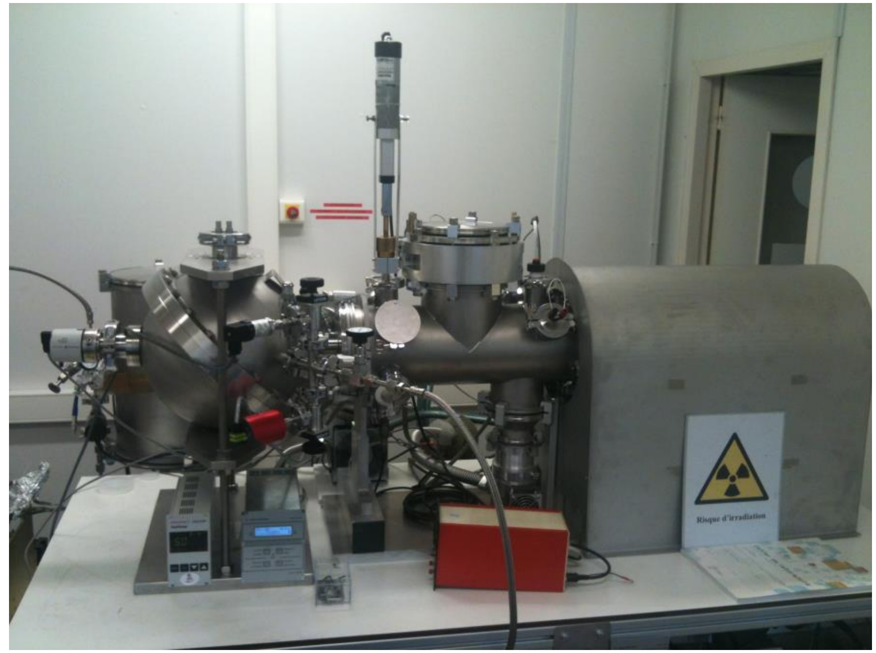
Funded by Canadian grant of excellence and ANR-France



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

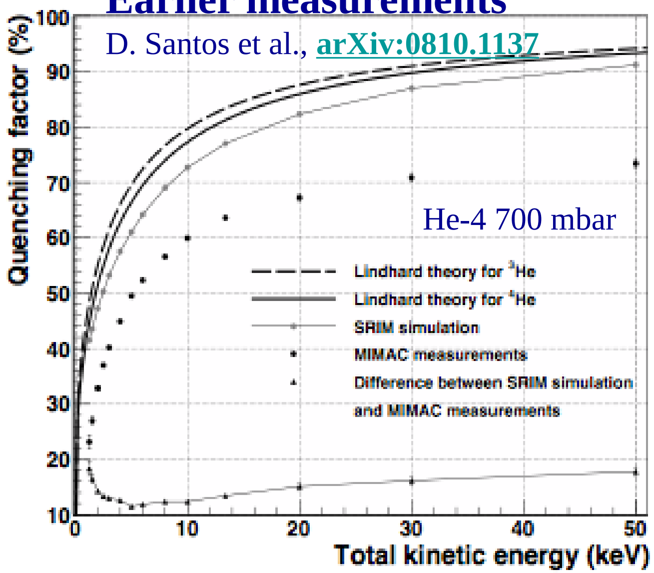




Earlier measurements

D. Santos et al., arXiv:0810.1137

He-4 700 mbar



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

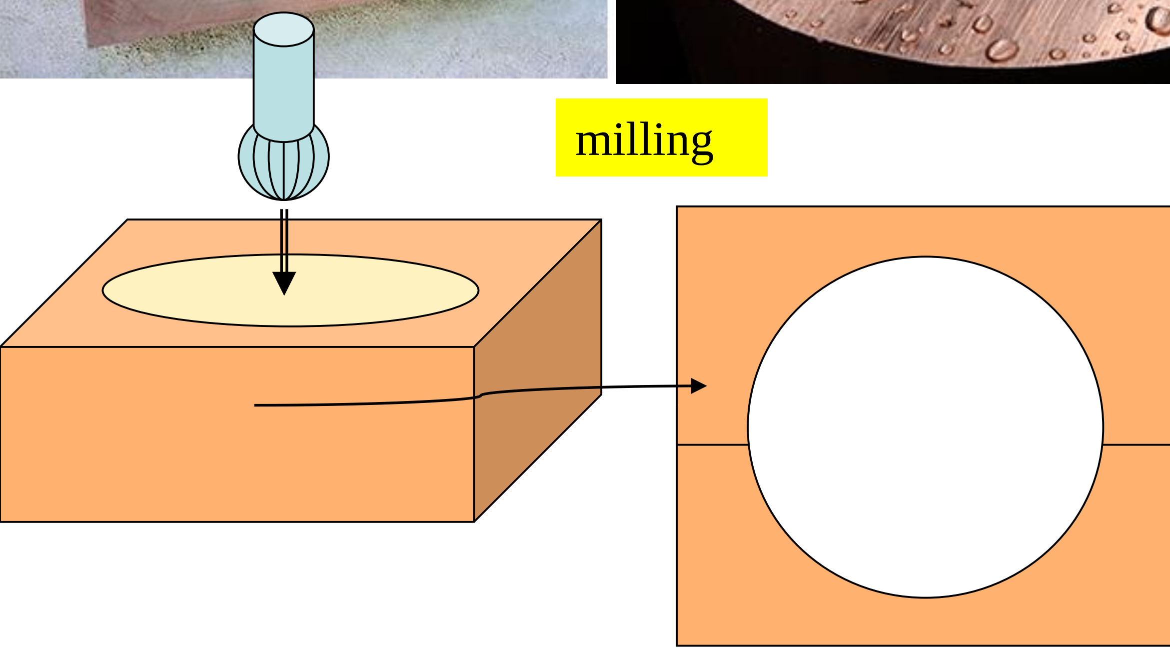
I. Giomataris, CEA-Irfu-France

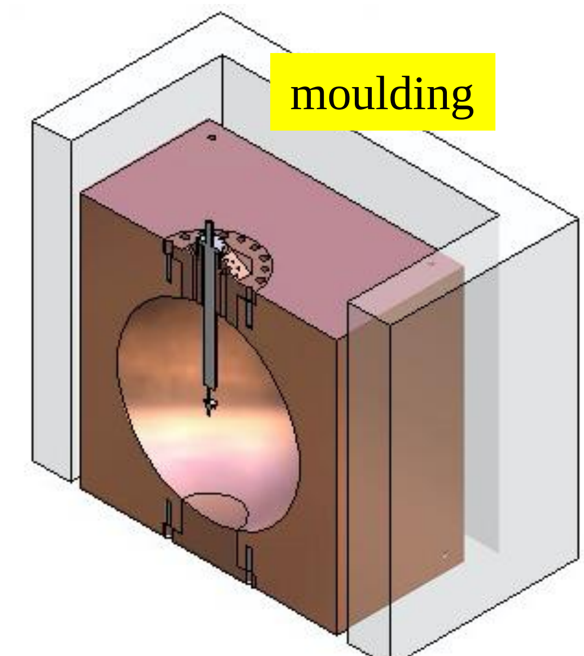
Aurubis pure copper
Tested in PNLL
μBq/kg : ^{232}Th= 1, ^{238}U= 1

Advantages

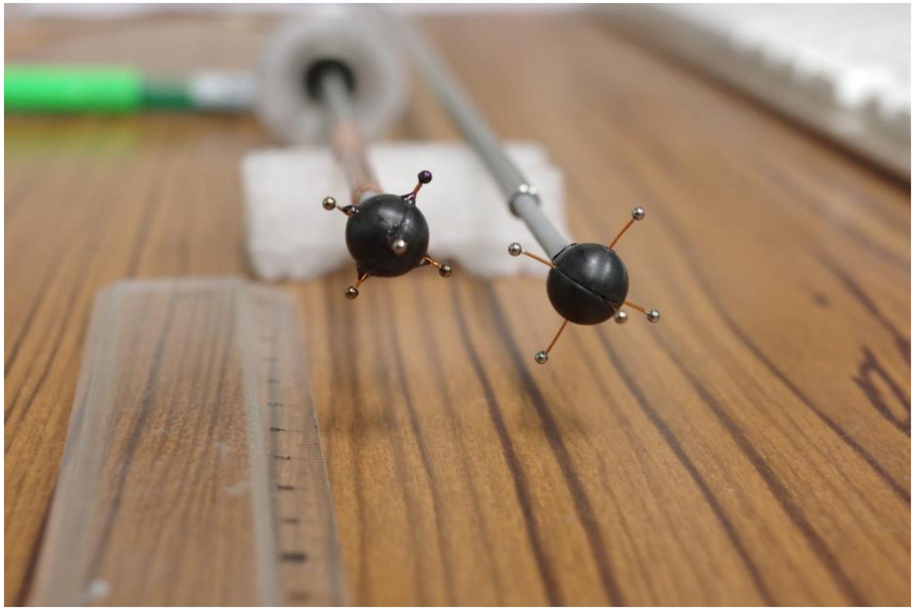
- Auto-shield
- Pressure up to 50 bar
- Low cost
- Faster process

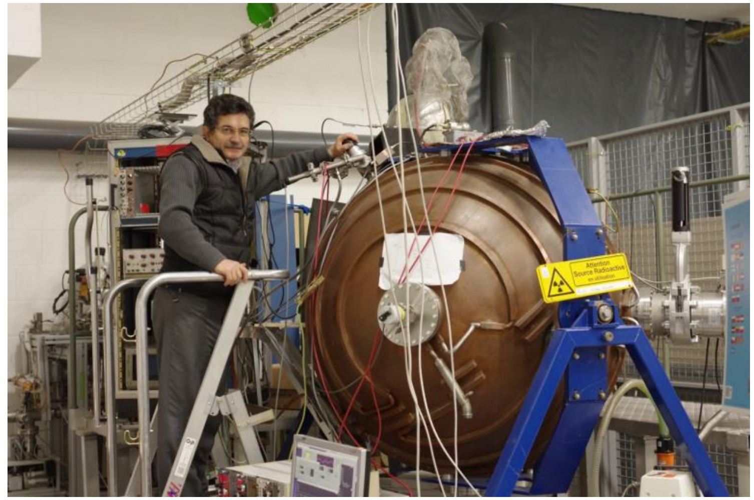
milling

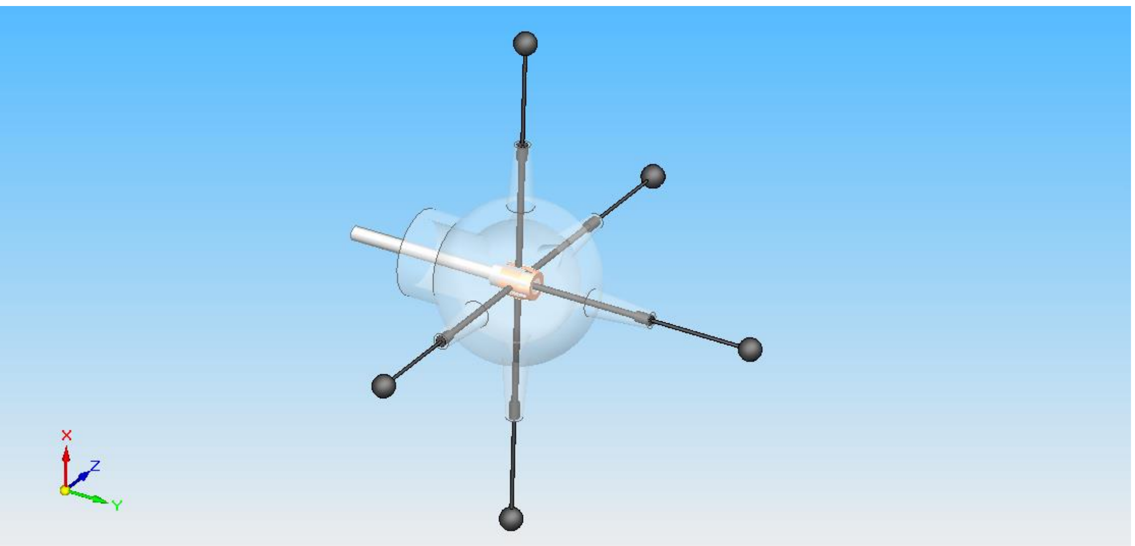




Multi-ball 'ACHINOS' structure
Developed in Saclay in collaboration with University of Thessaloniki







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**

Additional physics

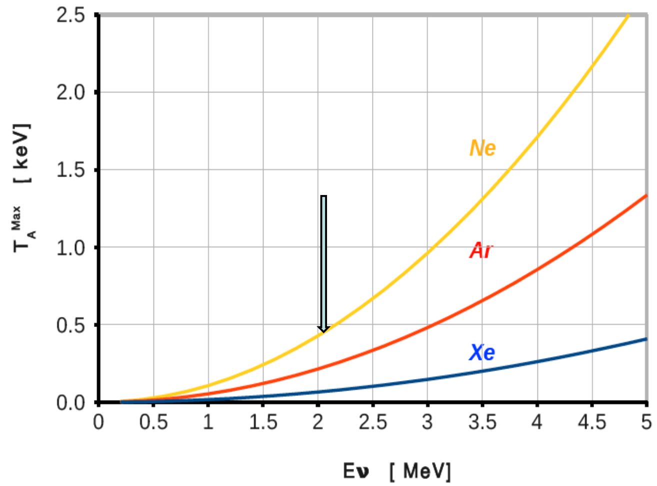
Neutrino-nucleus coherent elastic scattering

$\nu + N \dashrightarrow \nu + N \quad \sigma \approx N^2E^2$, *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_ν =0.5x10^{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)

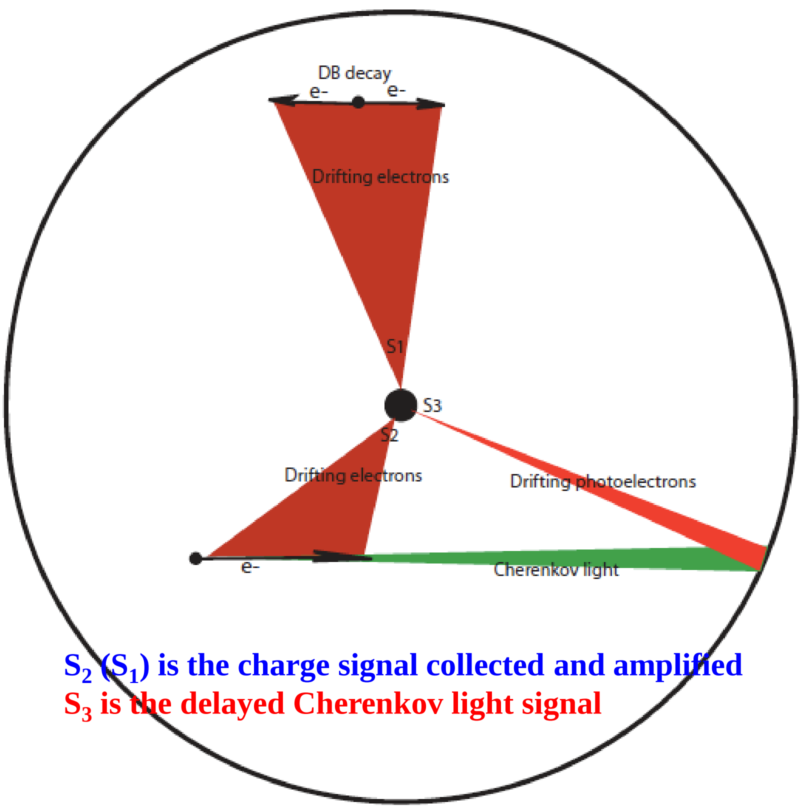
If additional rejection is required: a new idea

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

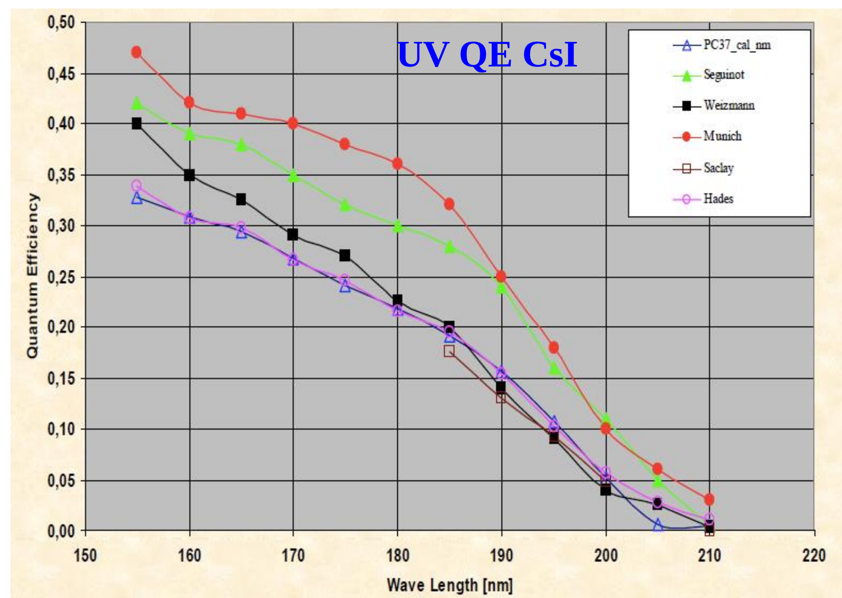
A simple read-out is the standard spherical detector signal combined with CsI photocathode layer deposited at the internal vessel surface, inducing a delayed signal



S_2 (S_1) is the charge signal collected and amplified

S_3 is the delayed Cherenkov light signal

iomataris



THANK YOU

8th SYMPOSIUM ON LARGE TPCs FOR LOW-ENERGY RARE EVENT DETECTION

The eighth international symposium on "large TPCs for low-energy rare event detection" will be held in Paris on the 5th-7th of December 2016.

The purpose of the meeting is an extensive discussion of present and future projects using a large TPC for low energy, low background detection of rare events (low-energy neutrinos, double beta decay, dark matter, solar axions).

In addition to the symposium, a half day workshop on neutrino from Supernova will complete this three-day symposium and will be the closing session just before the summary talk.