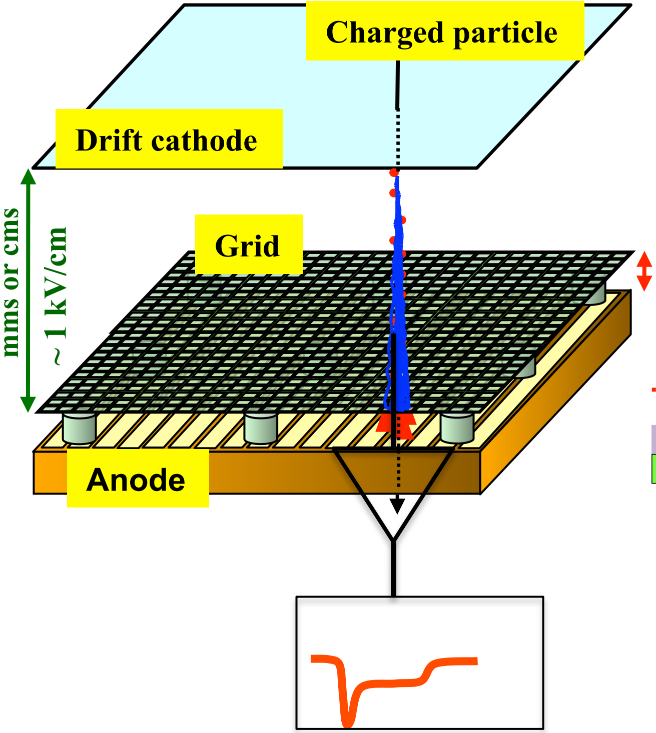
Gaseous detectors and search of new physics

I. Giomataris CEA-Saclay


MPGD2009, Kolymbari, Crete, Greece


MPGD2011, Kobe, Japan,


MPGD2013, Saragoza, Spain


Charged particle

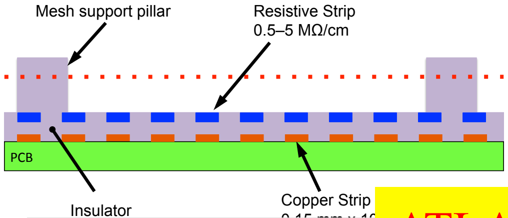
Drift cathode

Grid

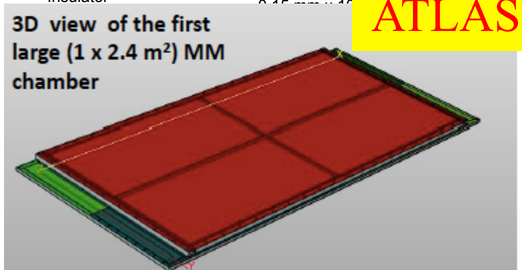
Anode

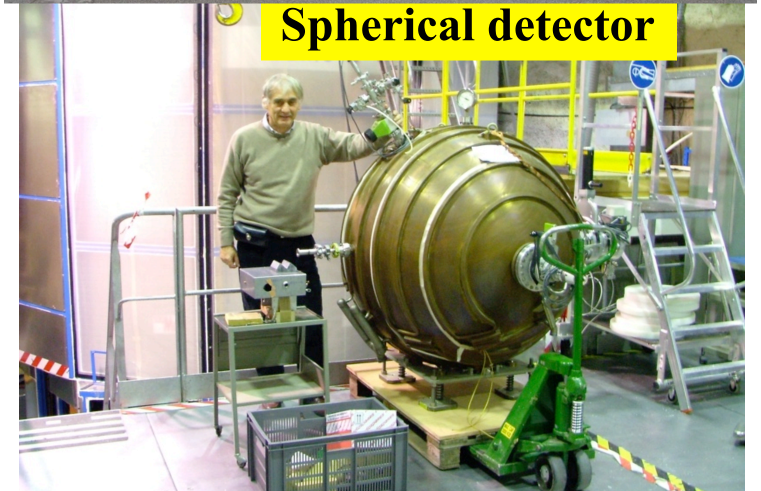

T2K


MPGD2015, Trieste, Italy



ATLAS

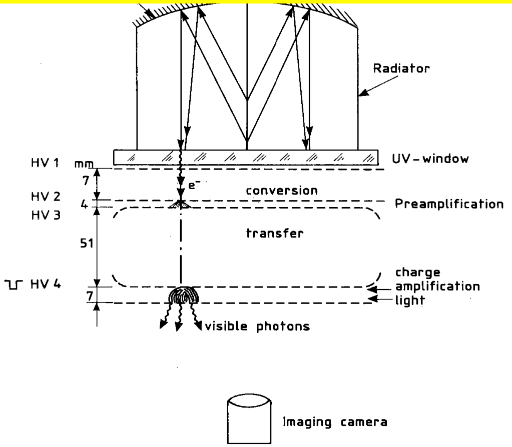

3D view of the first large (1 x 2.4 m^2) MM chamber


Spherical detector

Previous developments

A high-energy gamma ray telescope

I. Giomataris; G. Charpak, CERN-EP-88-94

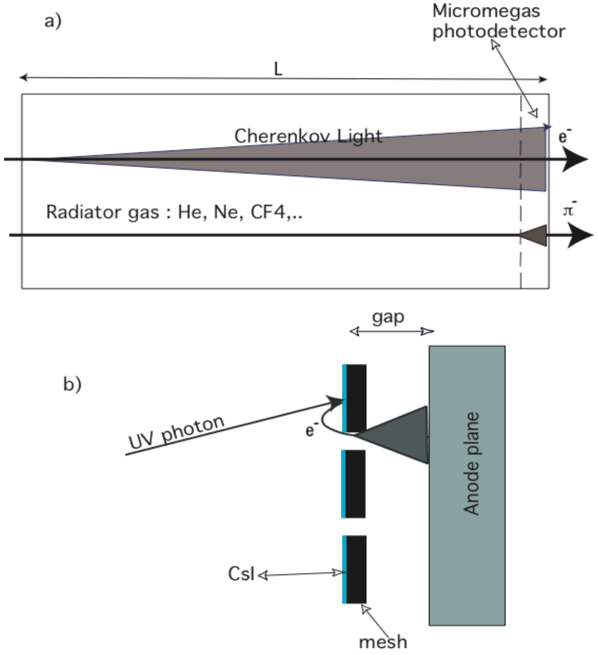


A single electron shower

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

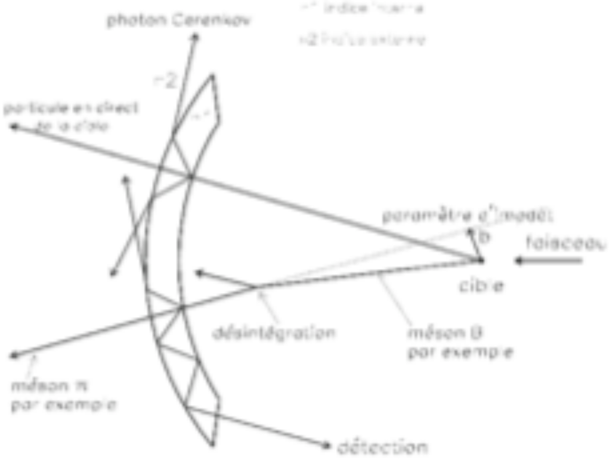
A Hadron Blind Detector (HBD)

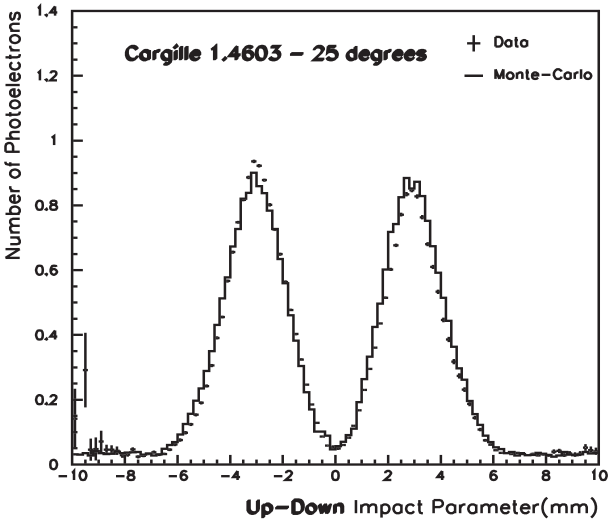
I. Giomataris,G. Charpak, NIM A310(1991)589



The trigger for Beauty

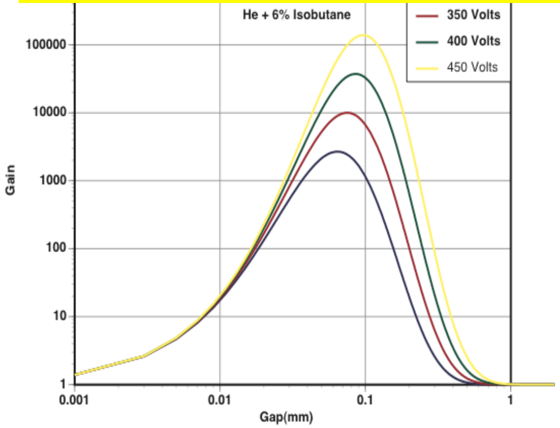
G. Charpak, I. Giomataris, L.Lederman, NIMA306(1991)439
Developed by Lausanne Uni, Saclay,CERN





Virtue of the small gap

Y. Giomataris, NIM A419, p239 (1998)

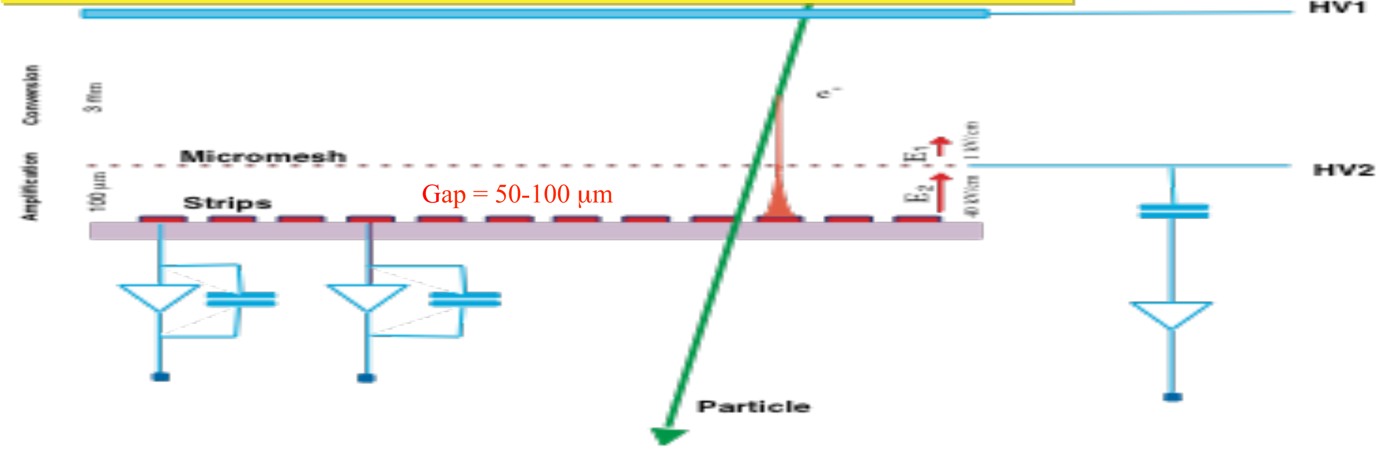


Optimum gap : 30 - 100 microns

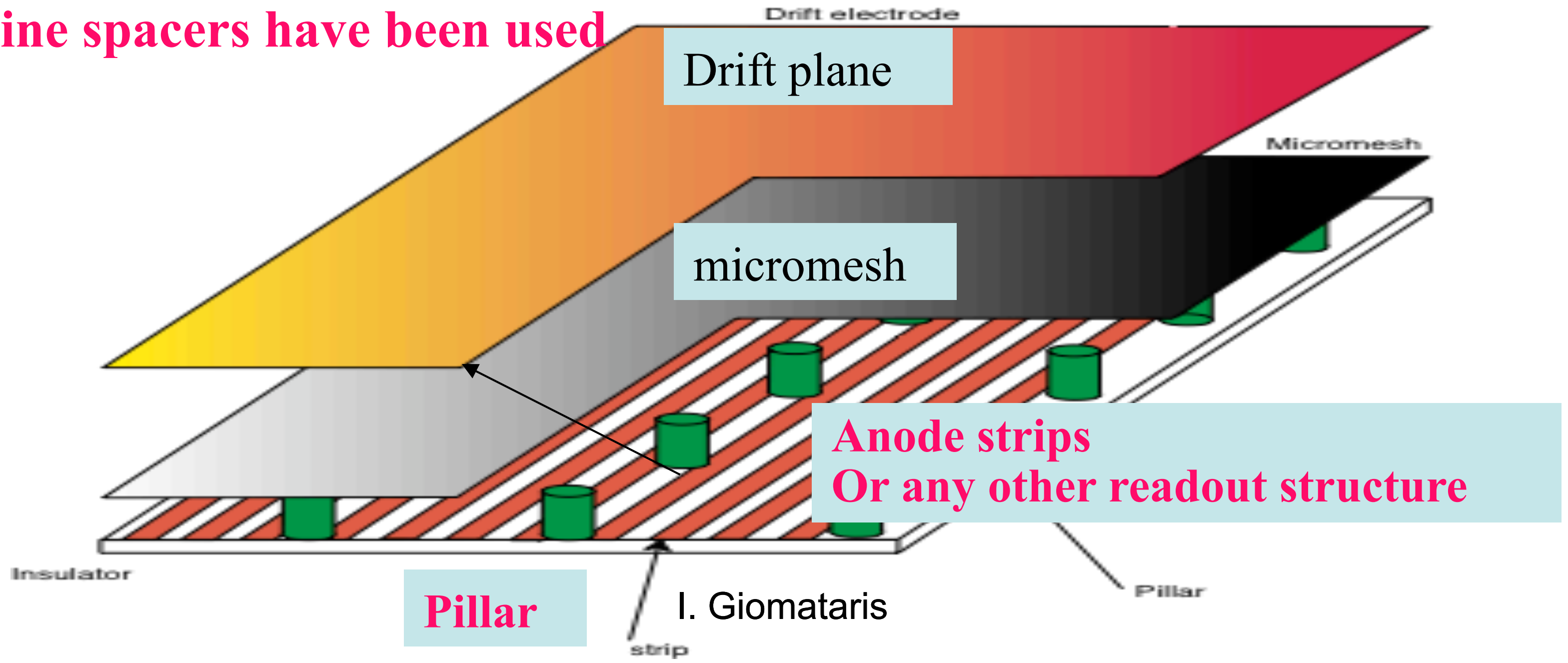
MICROMEGAS

MICROMEGAS

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



In 1st Micromegas
Fishing line spacers have been used



Drift plane

micromesh

Anode strips
Or any other readout structure

Pillar

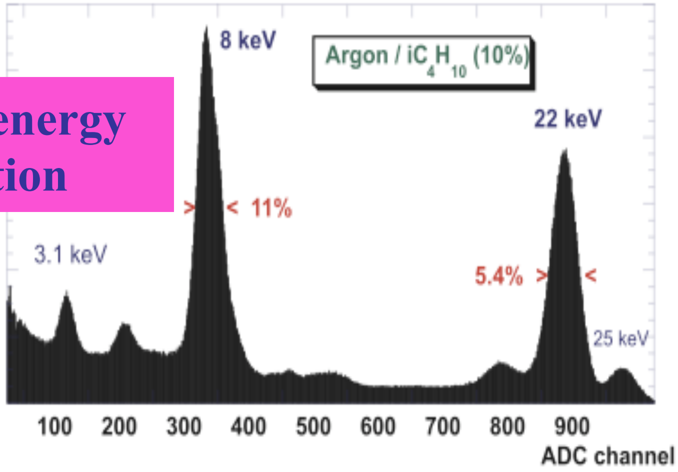
I. Giomataris

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.

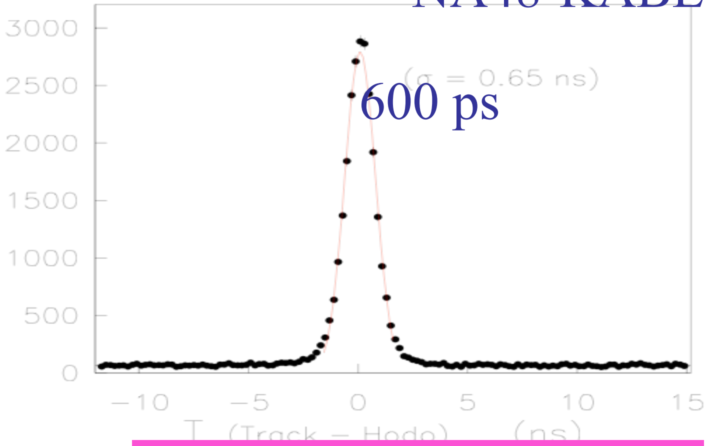
Good energy resolution



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

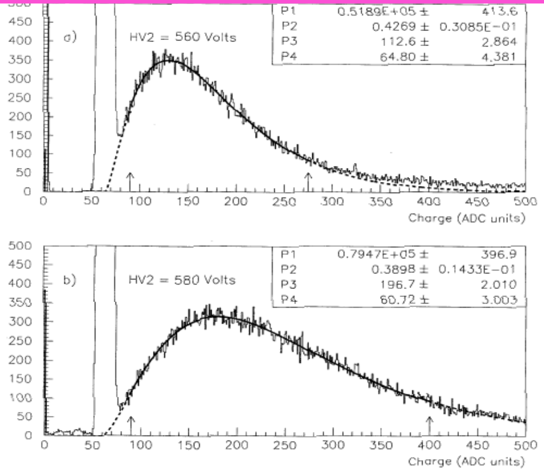
Sub-nanosecond time resolution

NA48-KABES



600 ps

Excellent single electron resolution



High accuracy < 12 μm

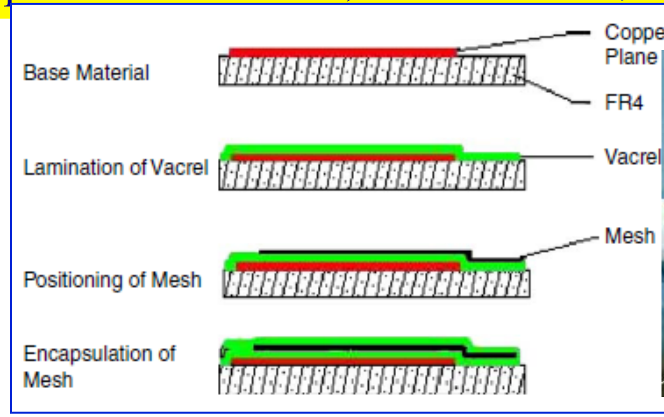
σ (μm)

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

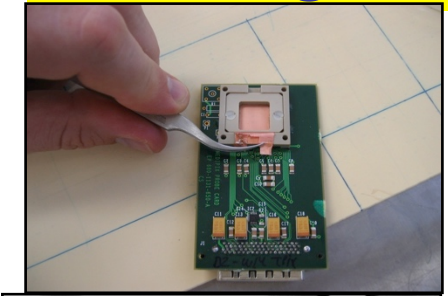
I. Giomataris

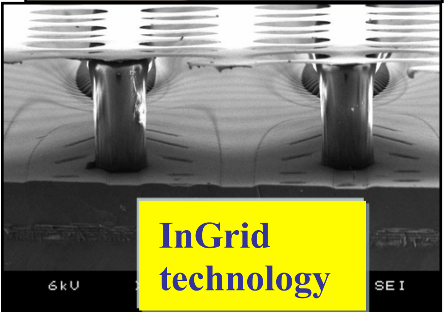
Micromegas fabrication technologies

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*

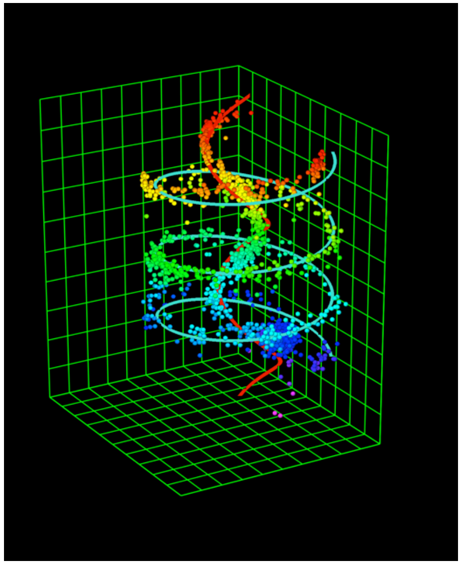


Micromegas + micro-pixels

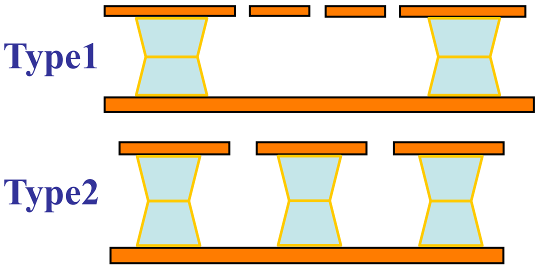




InGrid technology



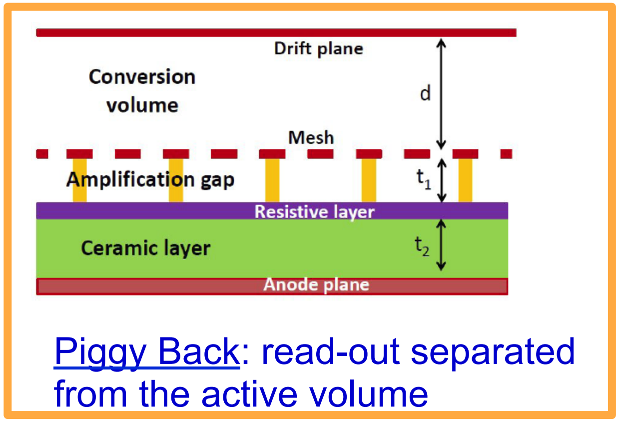
micro-Bulk,
50 μm, 25 and 12.5 μm gaps fabricated



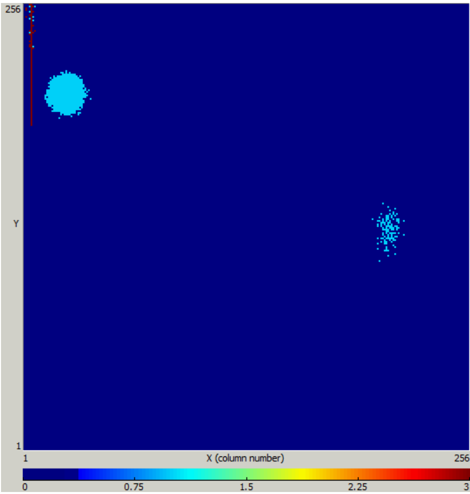
Very good energy resolution 11% at 5.9 keV

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

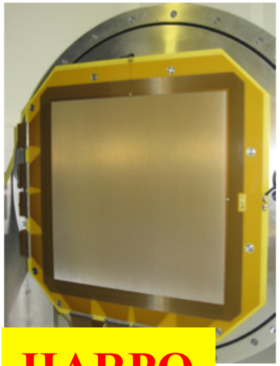
Piggy Back: read-out separated from the active volume



Piggy Back: read-out separated from the active volume

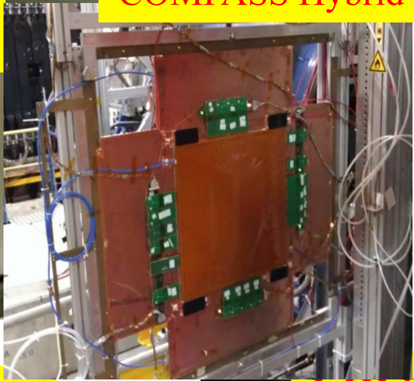


Some experiments using
Micromegas read-out

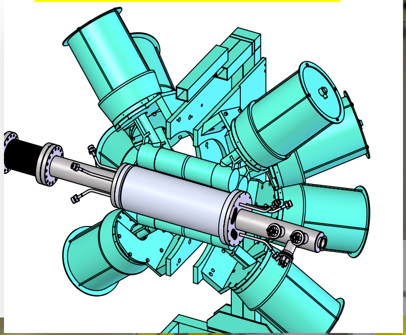


HARPO

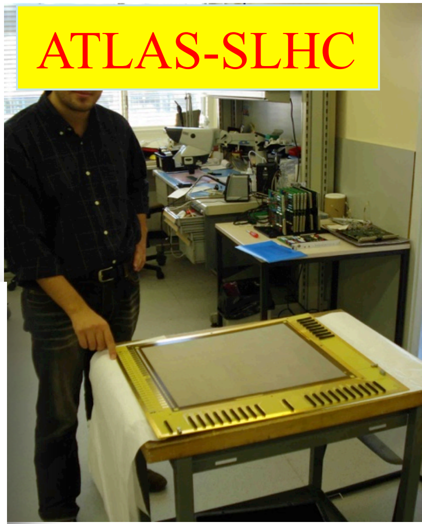
T2K



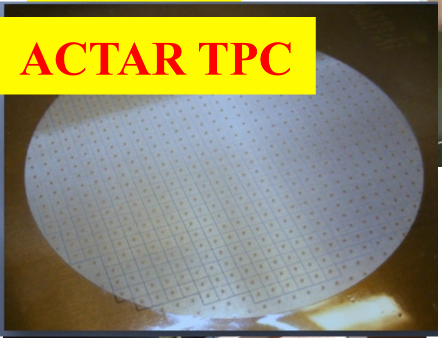
COMPASS Hybrid MM



Astro-gamma

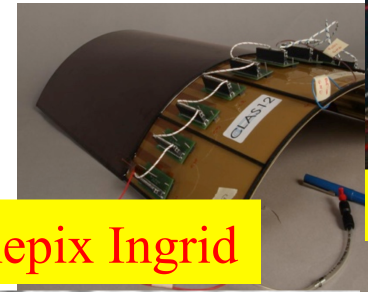


ATLAS-SLHC



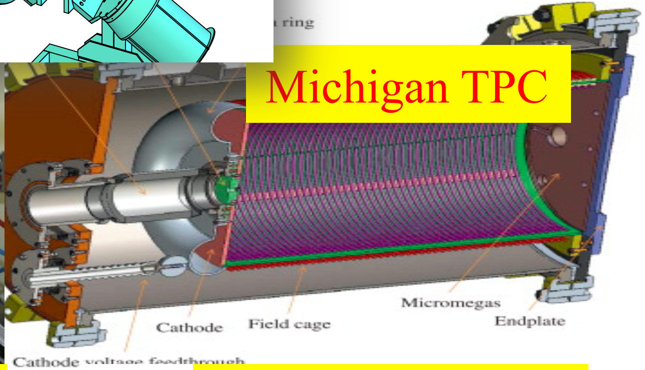
ACTAR TPC

ILC/TPC

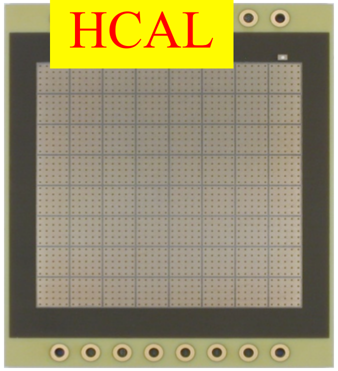


CLAS12G

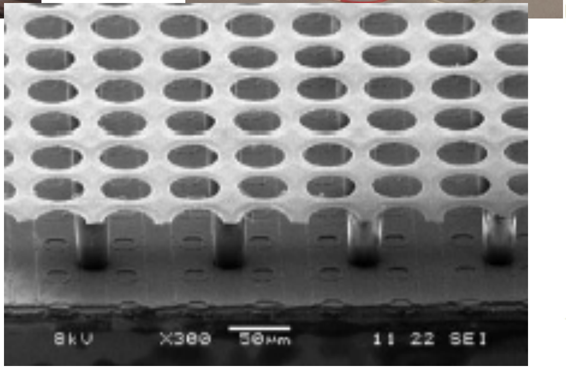
MINOS



Michigan TPC

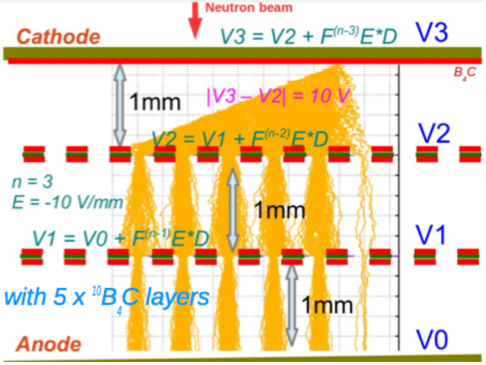


HCAL

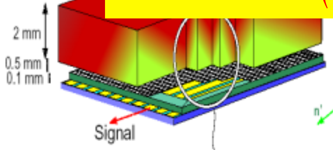


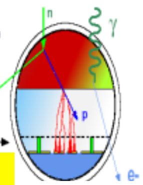
Timepix Ingrid

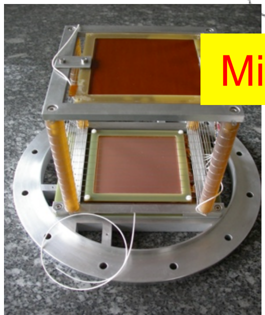
B$_4$C multi-layer detectors



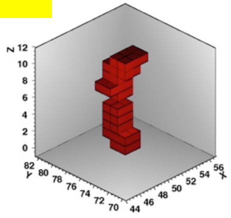
Laser MJ (CESTA





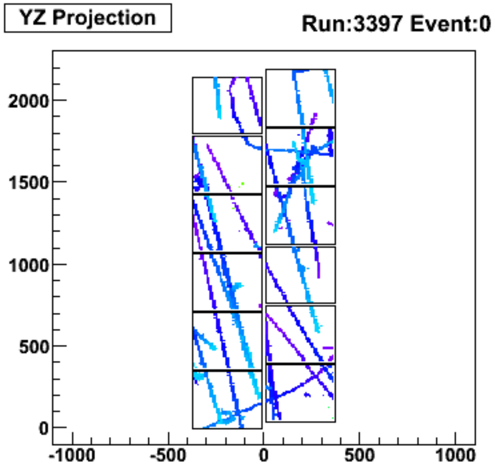


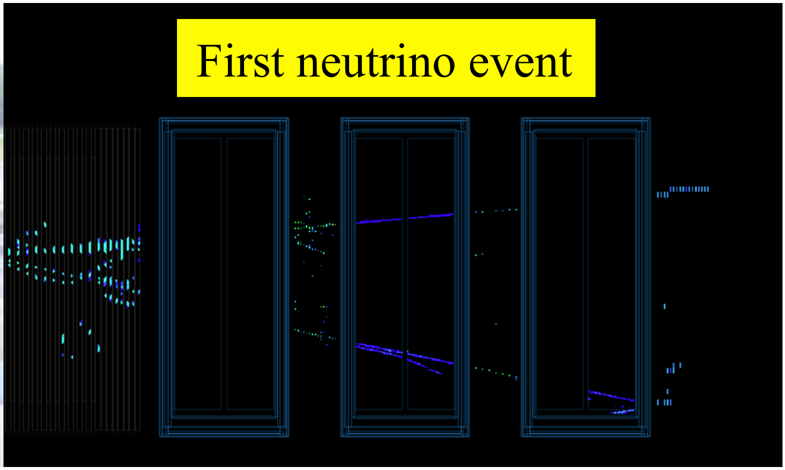
MiMaC



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

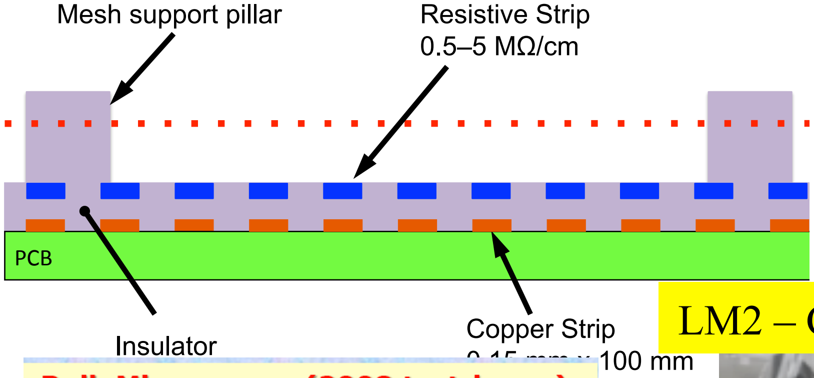
Goal : 1200 m2 total detector surface

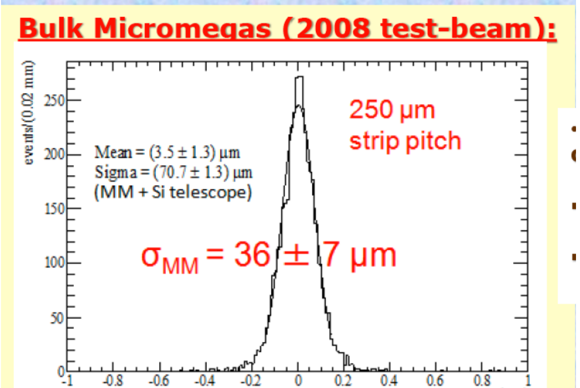
Industrialization is going on through ELVIA, ELTOS

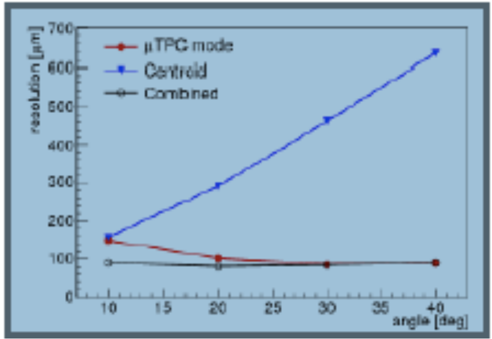
ATLAS Resistive strip technology

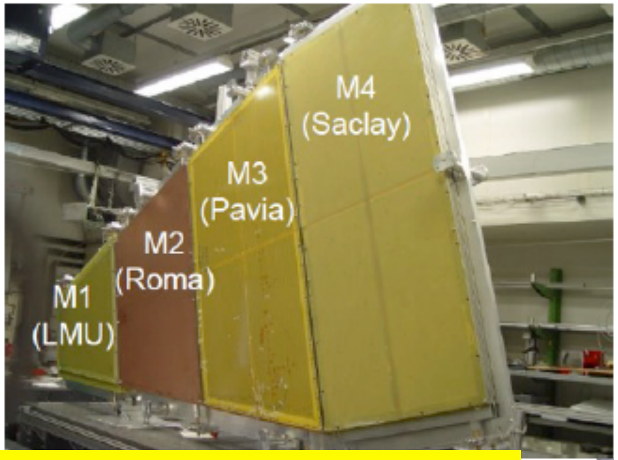
Joerg Wotschack, Mod.Phys.Lett. A28 (2013) 1340020

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

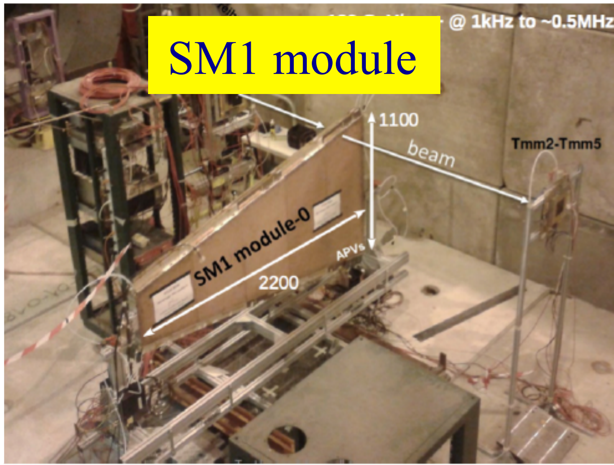




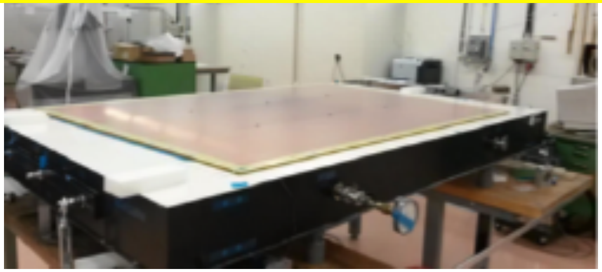




SM1 module



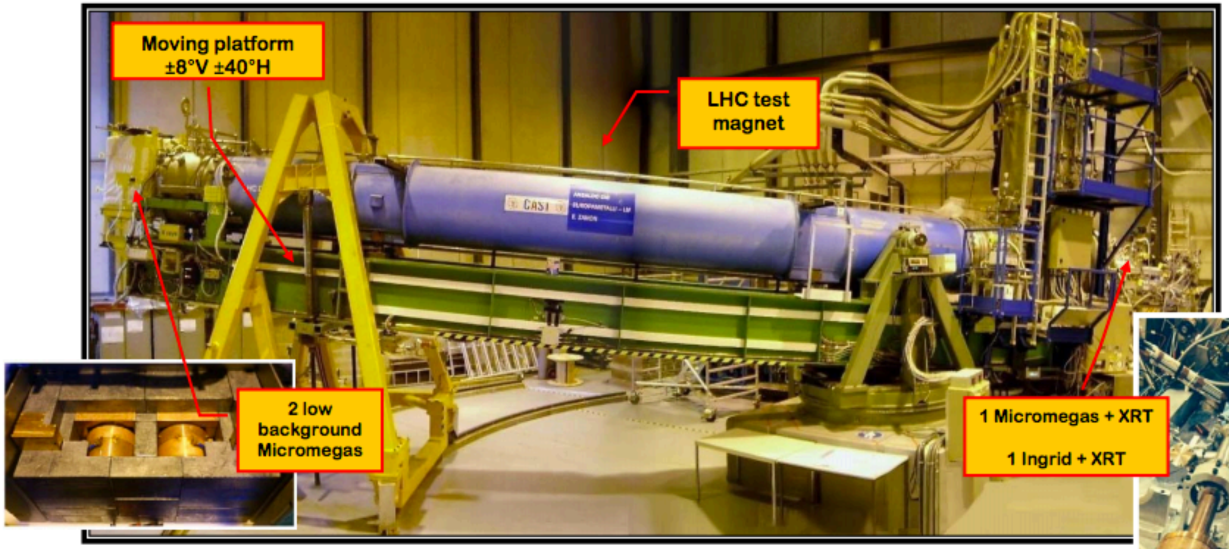
LM2 – CERN / Dubna -Thessaloniki



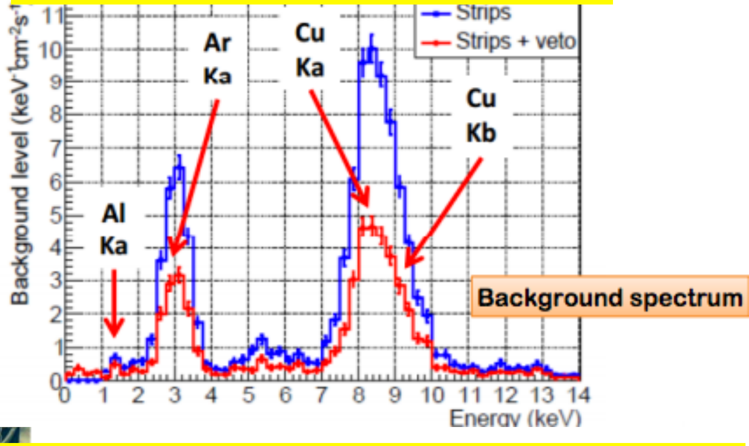
SM2 – Germany

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

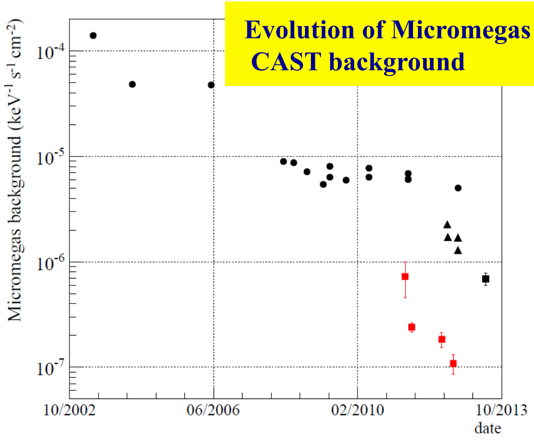


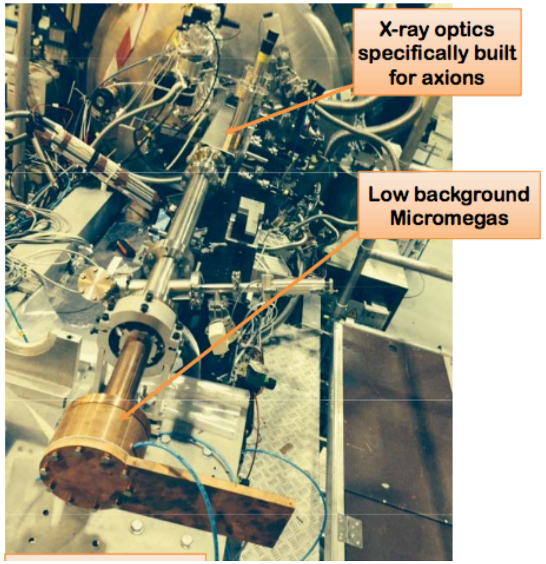
Lowest background than any other CAST detector

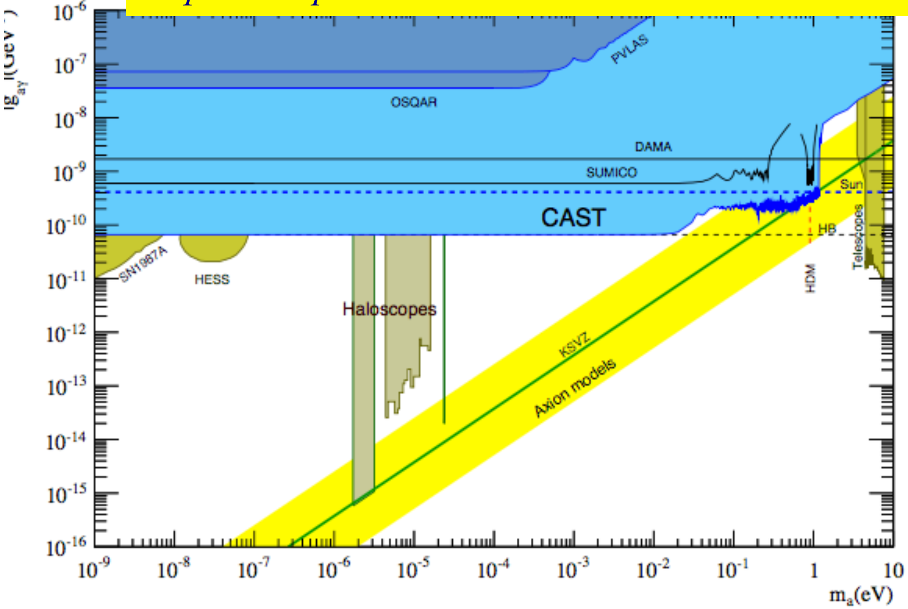


Axion search latest exclusion plots

Paper accepted in NATURE-PHYSICS



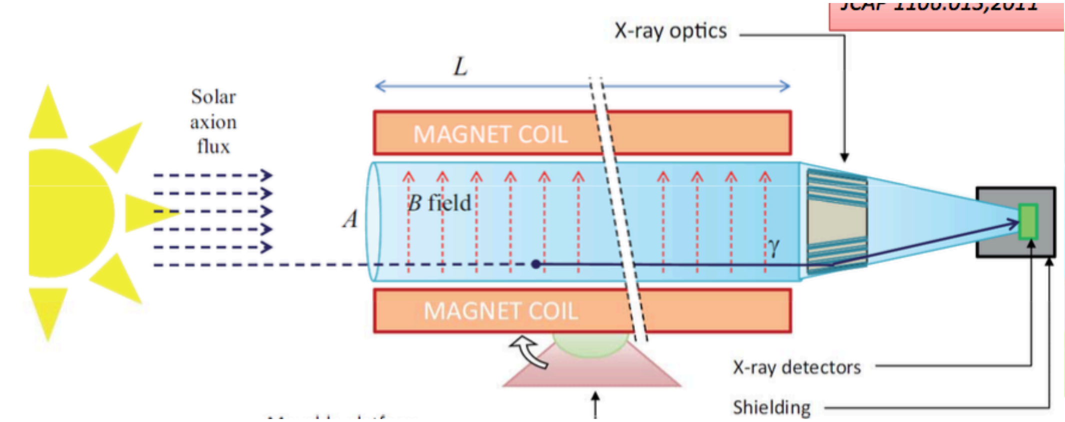




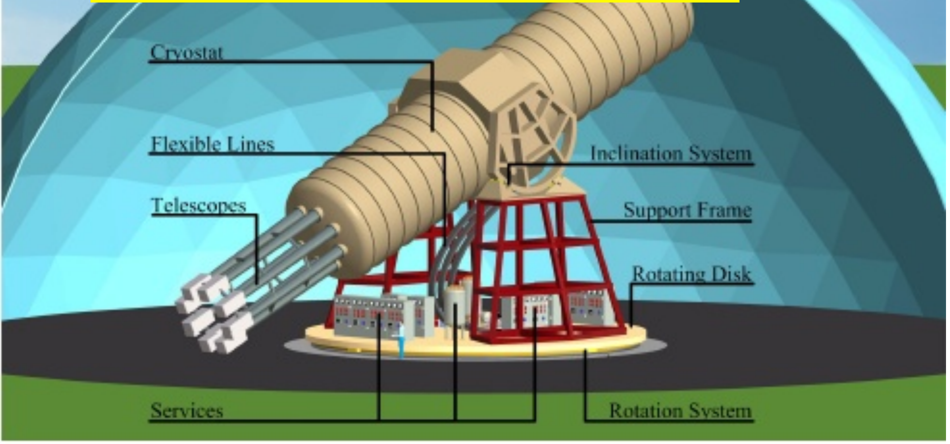
International Axion Observatory (IAXO)

A new proposed experiment

JCAP 1106:013,2011



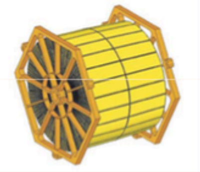
8 COIL MAGNET L= 20 M
8 BORES: 600 MM DIAMETER EACH
8 X-RAYS OPTIC + 8 DETECTION SYSTEMS
ROTATING PLATFORM WITH SERVICES



IAXO technologies – Baseline

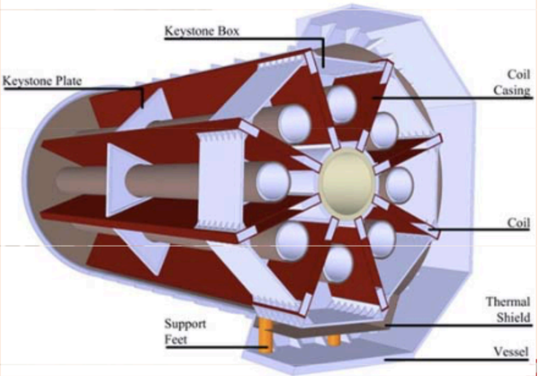
IAXO telescopes

- 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



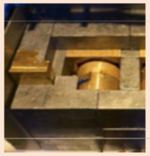
IAXO magnet

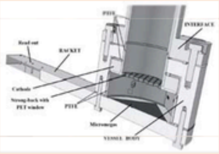
- Superconducting "detector" magnet.
- Toriodal geometry (8 coils)
- Based on ATLAS toroid technical solutions.
- CERN+CEA expertise
- 8 bores / 20 m long / 60 cm Ø per bore



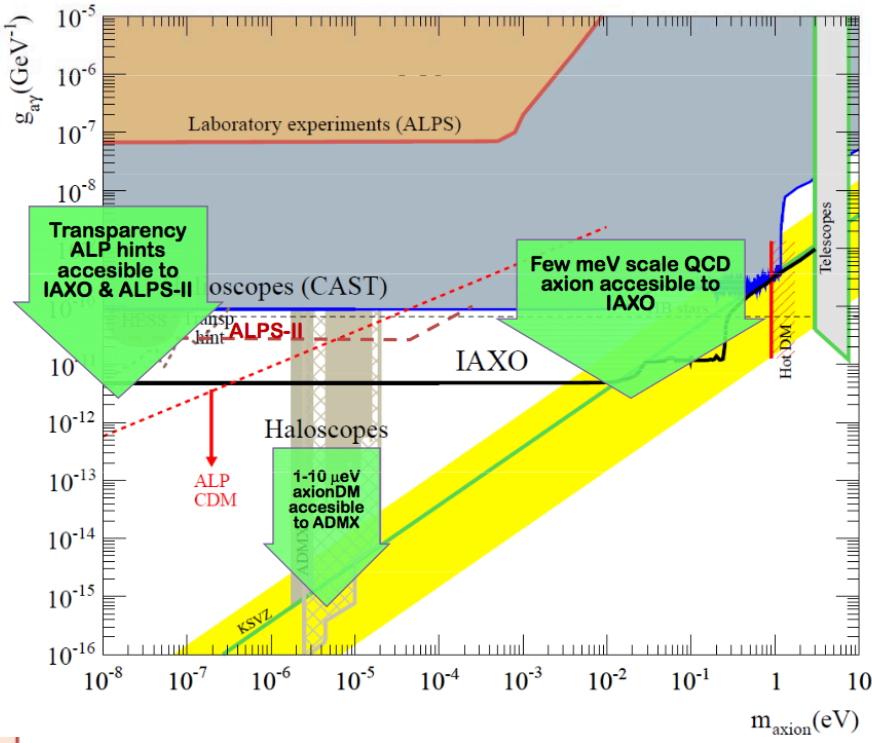
IAXO detectors

- 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





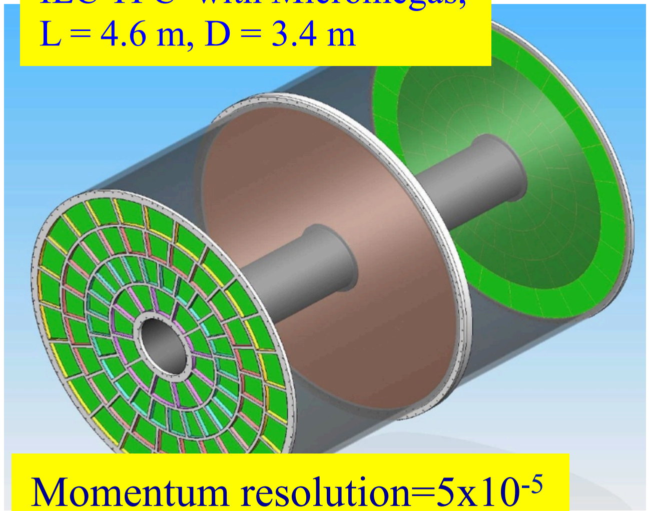
Baseline developed at:
IAXO Letter of Intent: CERN-SPSC-2013-022
IAXO Conceptual Design: JINST 9 (2014) T05002 (arXiv:1401.3233)



ILC TPC project - *Large International collaboration*

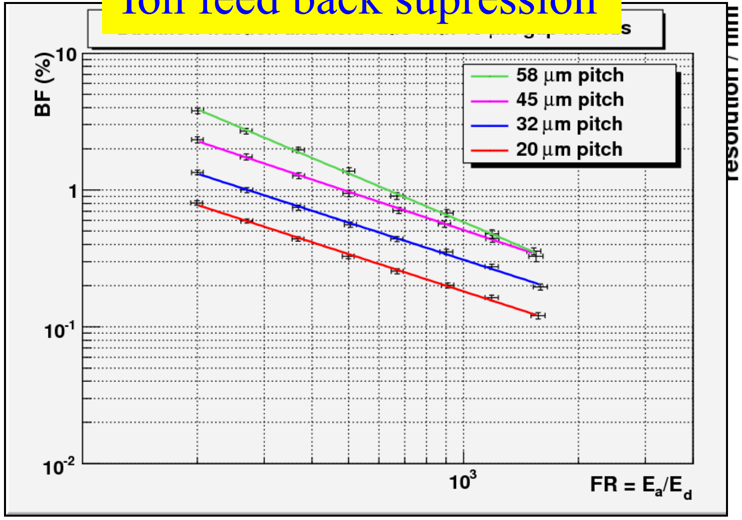
G. Aarons et al., arXiv:0709.1893, M. S. Dixit et al., NIMA 518 (2004) 521, M. Kobayashi et al.,NIMA581(2007)265,

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



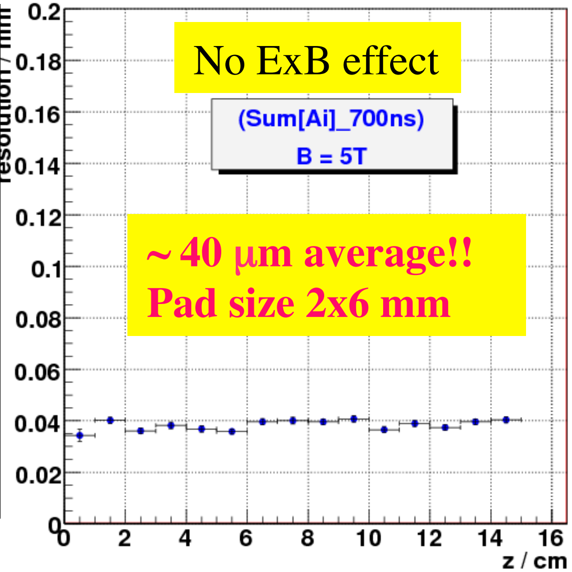
Momentum resolution=5x10^{-5}

Ion feed back supression



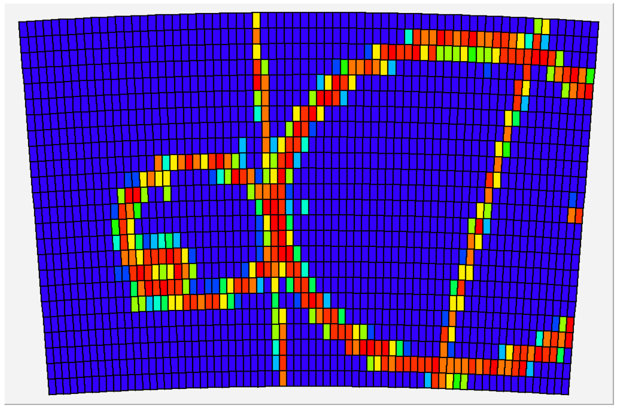
No ExB effect

~ 40 µm average!!
Pad size 2x6 mm



ILC TPC prototype
with Micromegas

Event in DESY test beam



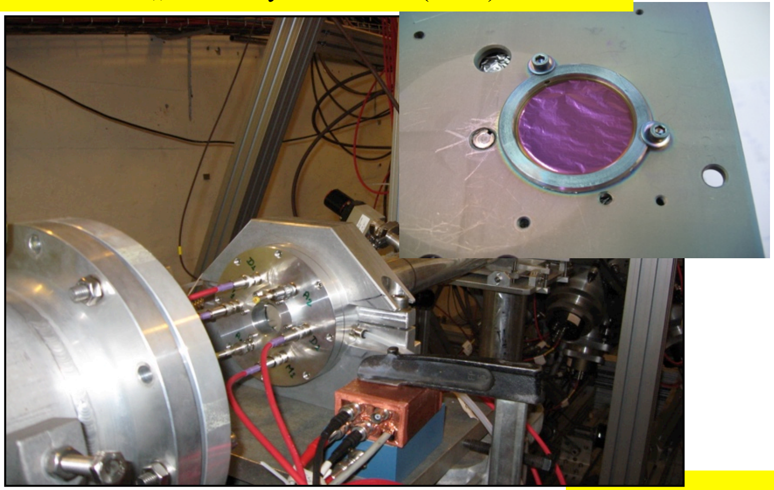
TPC Micromegas advantages

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

Applications in neutron detection

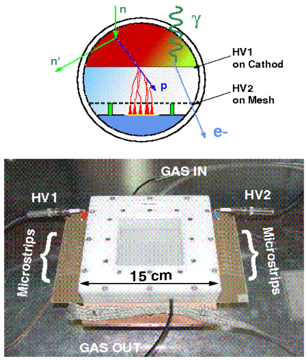
n-TOF MicroMegas-based neutron transparent flux monitor and profiler

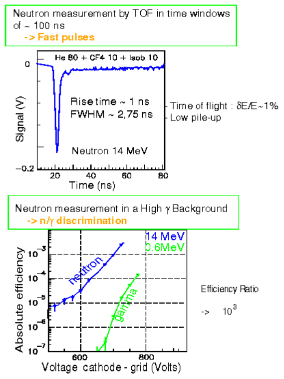
F. Belloni et al.,, Mod.Phys.Lett. A28 (2013) 1340023



Micromégas Concept for Laser MégaJoule and ICF Facilities

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





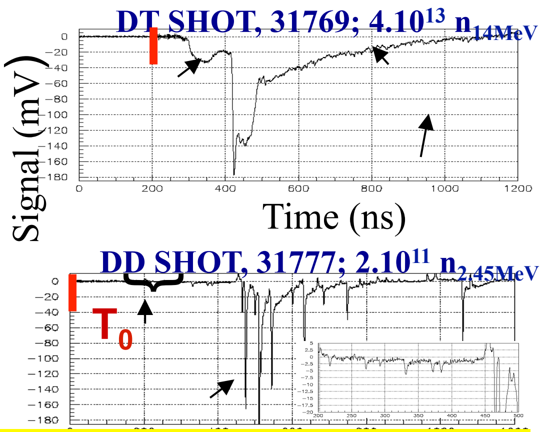
Neutron measurement by TOF in time windows of ~ 100 ns
-> Fast pulses

- Time of flight : δE/E~1%
- Low pile-up

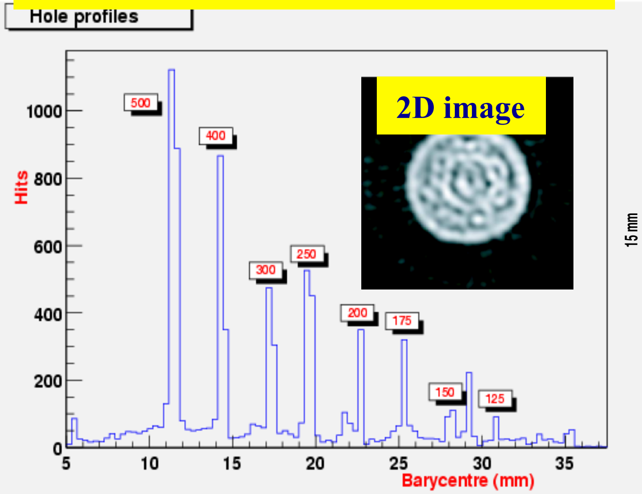
Neutron measurement in a High γ Background
-> n/γ discrimination

Efficiency Ratio

-> 10^3

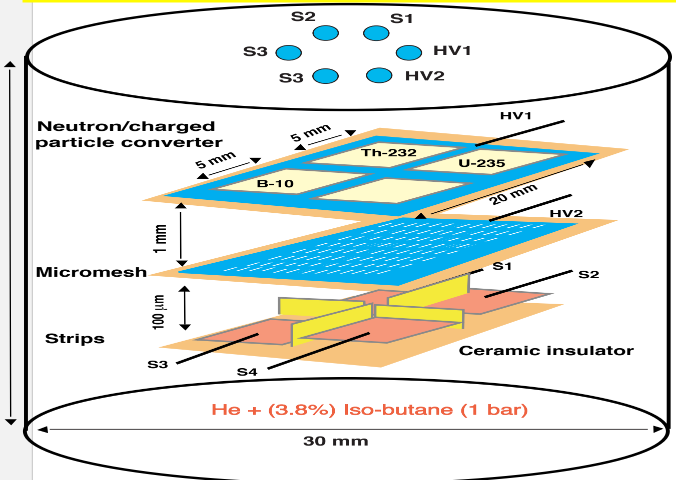


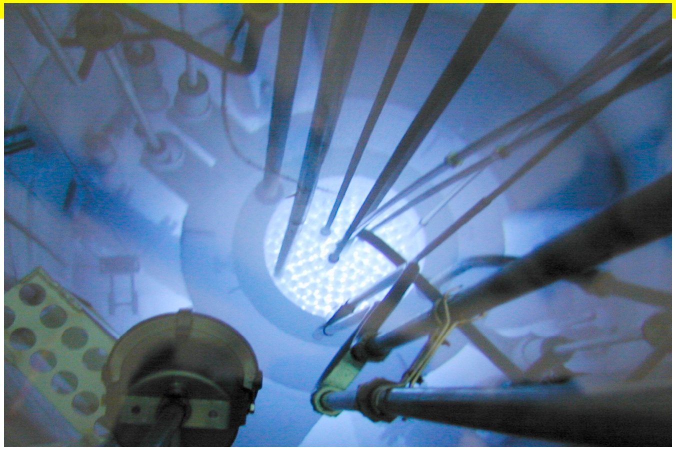
neutron tomography



Piccolo Micromegas, Nuclear reactor in-core neutron measurement

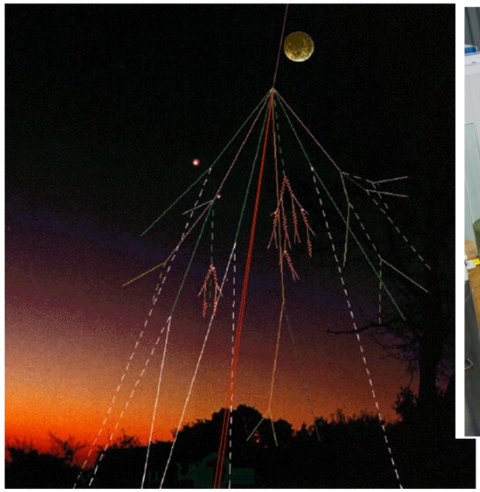
J. Pancin et al., NIMA, 592(2008)104

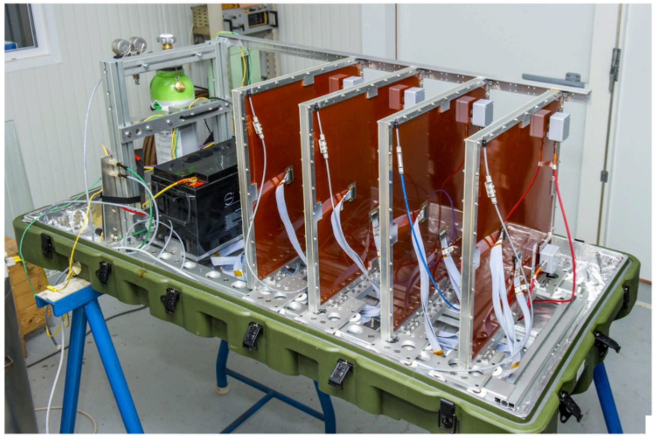




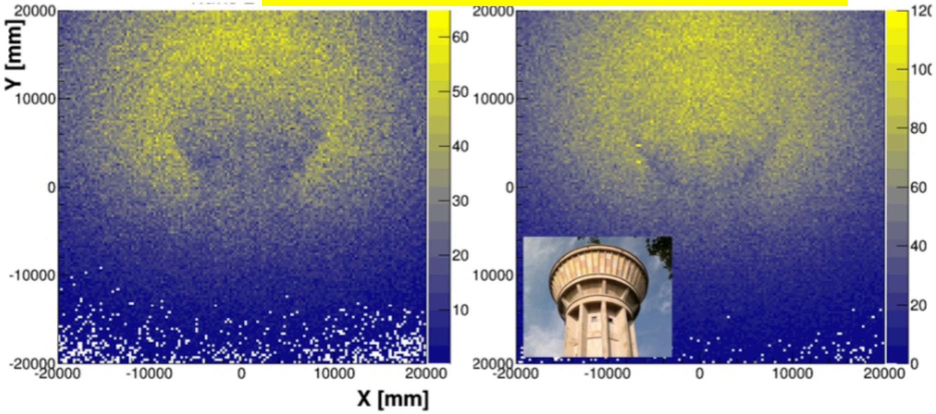
Muon tomography using Micromegas detector

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





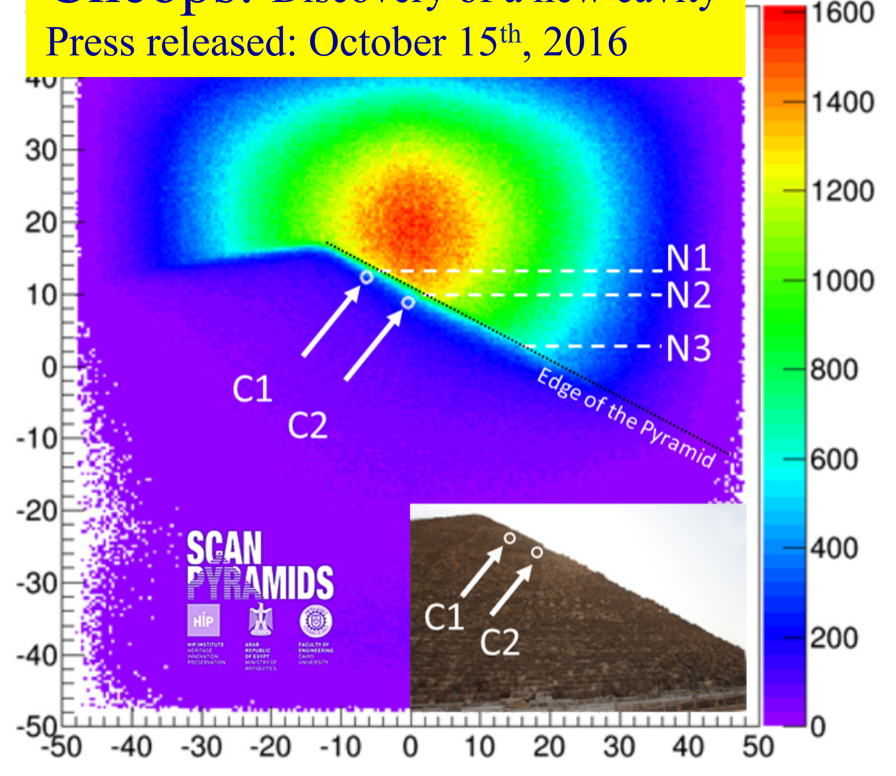
‘Chateau d’eau’ at Saclay



ScanPyramids Mission

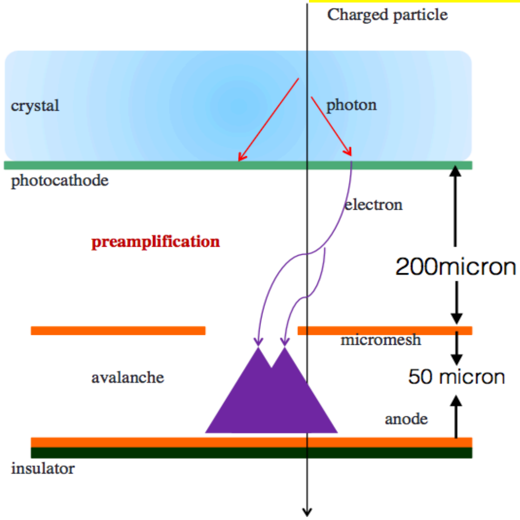
Cheops: Discovery of a new cavity

Press released: October 15th, 2016



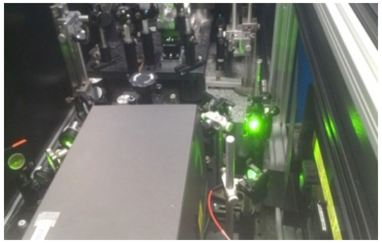
Fast timing Picosecond Micromegas

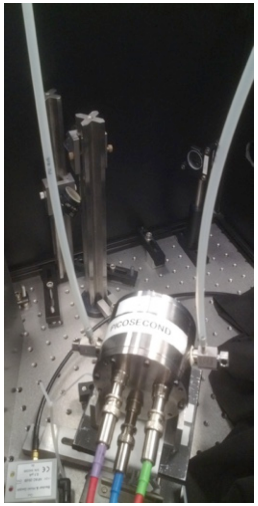
CEA-Saclay, CERN, Thessaloniki, Athens, Princeton, USTC, San Diego

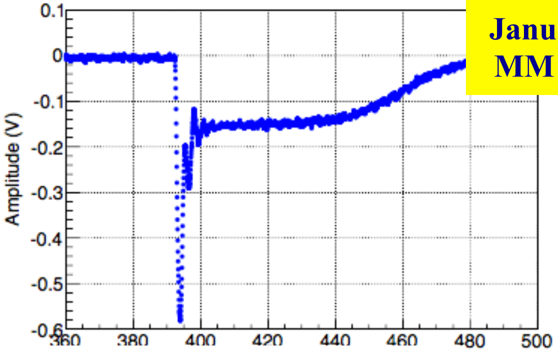


Test with UV fs laser @ IRAMIS-CEA

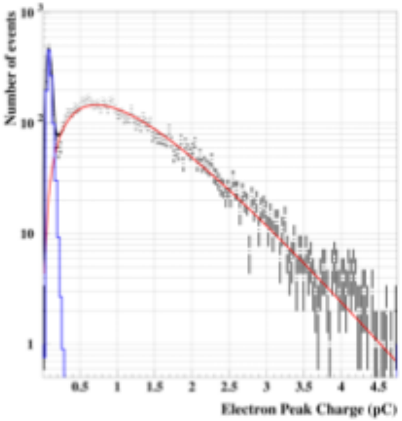
UV Photocathodes on MgF window:
CsI, Cr, Al, Diamond (10-50nm thick)

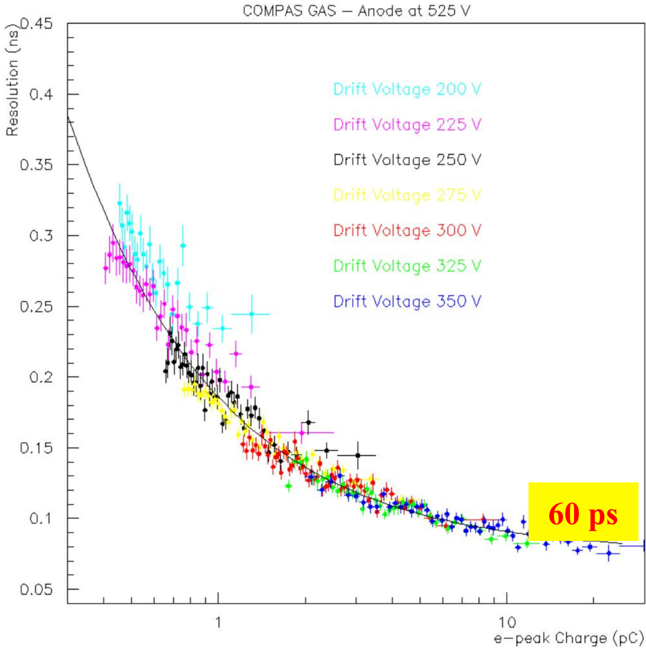






January 2017, Cr 18nm, single electrons/pulse
MM amplification 10^4, preamplification 10-50



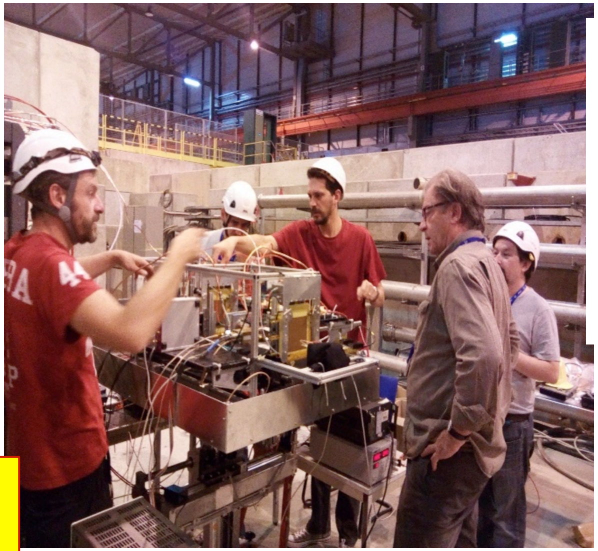


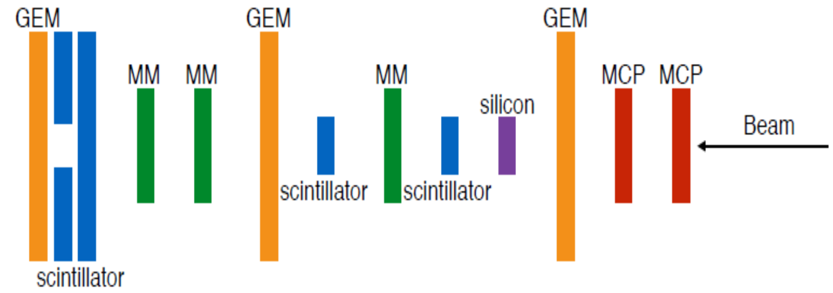
60 ps

2016-2017 beam tests with 150 GeV muons @ SPS H4

June 2016

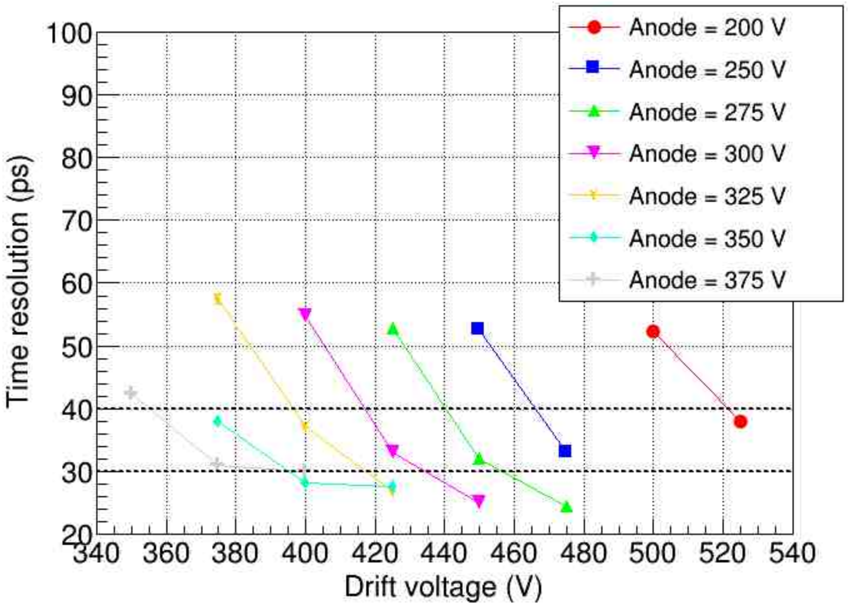
- **Sensors: *Standard bulk Micromegas***
- ***Photocathodes: 3,5mm* MgF$_2$**
  CsI photocathodes : CsI, Cr, Diamond
  + 6 nm Al + 10.5 nm CsI
- **Gas mixtures:**
  Ne/C$_2$H$_6$/CF$_4$ (80/10/10)
  Ne/CH$_4$ (95/5)
  CF4 / C$_2$H$_6$ (sealed mode)

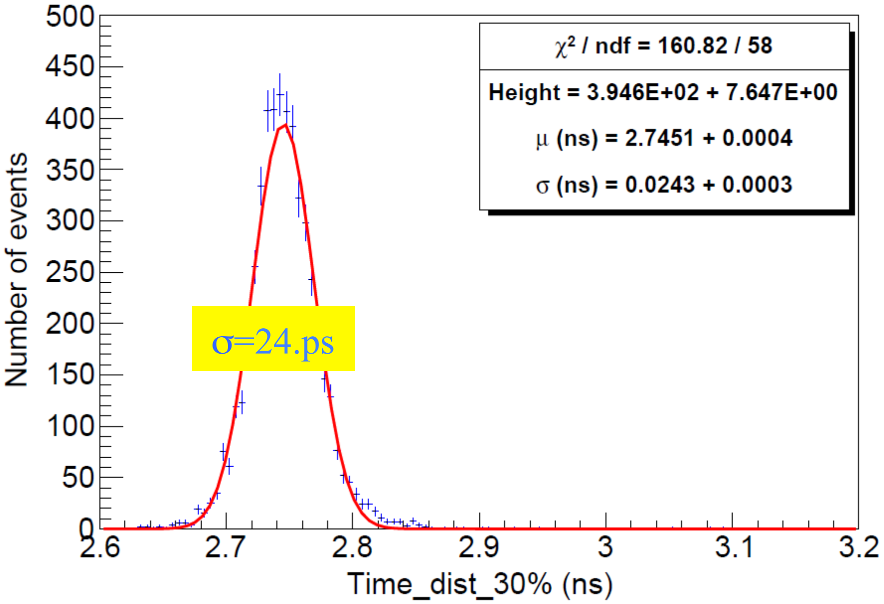




Data analysis in progress. Data from different detector configurations to be analyzed. Results for:

- **$\sigma_t \approx 24$ ps, $<N_{p.e.}> \approx 13$**

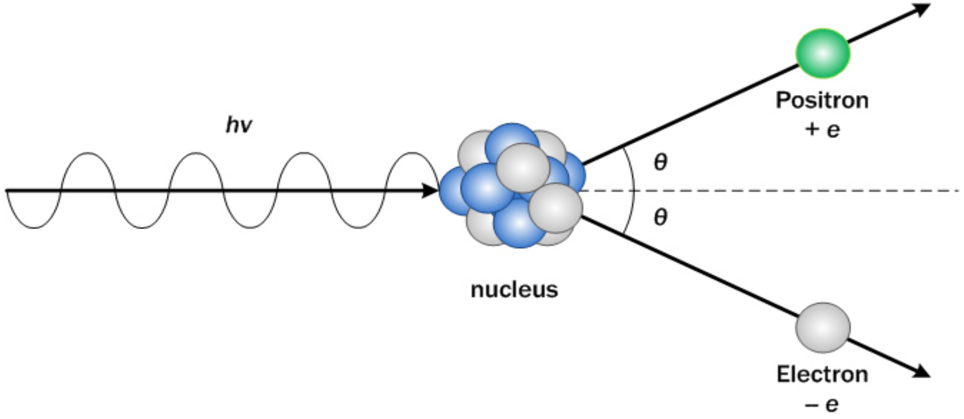




σ=24.ps

Gamma-ray polarimetry with TPC Micromegas + GEM: using the pair production

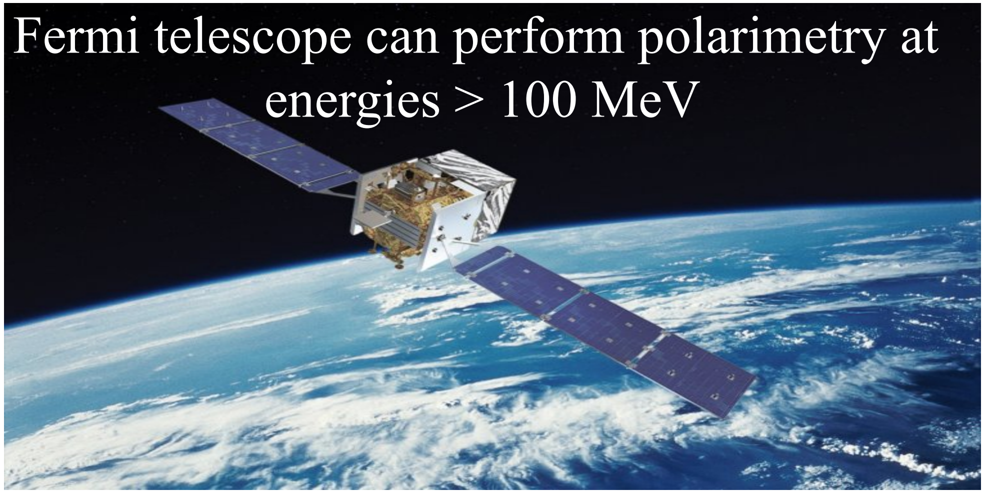
When the photon energy is above the pair creation threshold (>1.022 MeV)



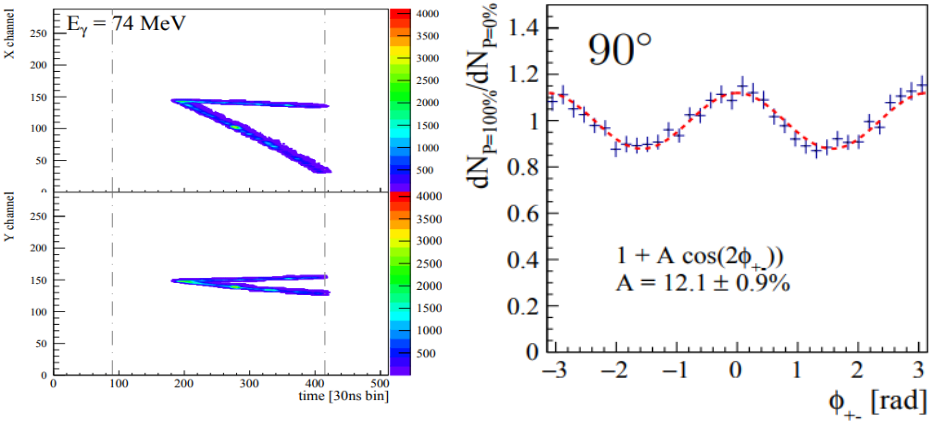
Azimuthal scattering anisotropy of the pair

Making a histogram of the azimuthal distribution gives polarized fraction and polarization direction

The HARPO detector can do it between 1 MeV and 100 MeV with high precision

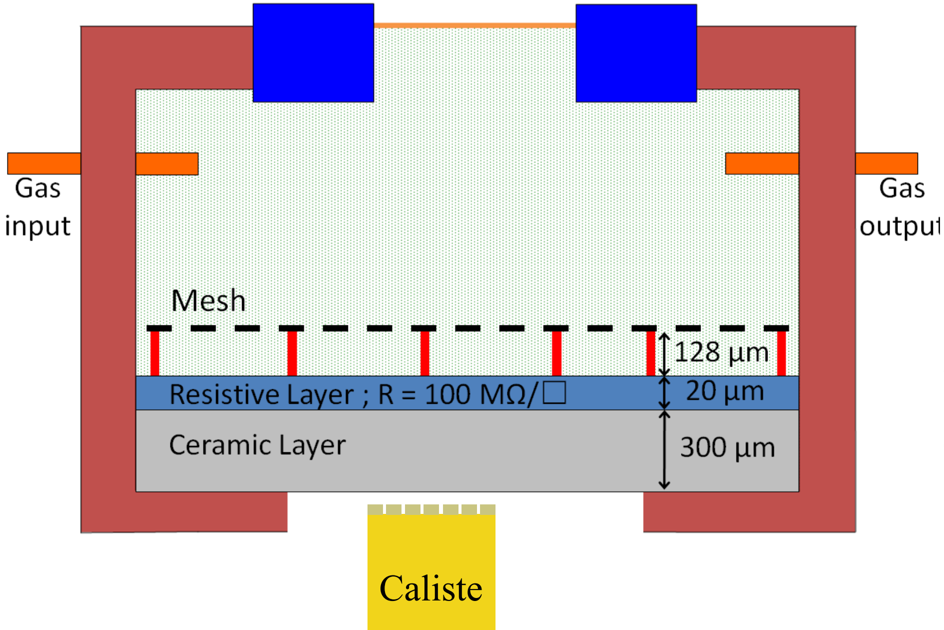


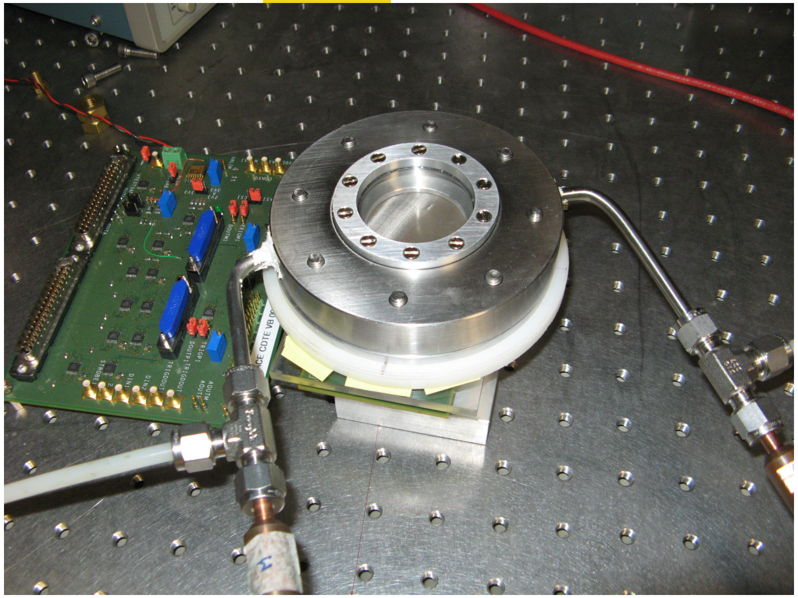
Fermi telescope can perform polarimetry at energies > 100 MeV



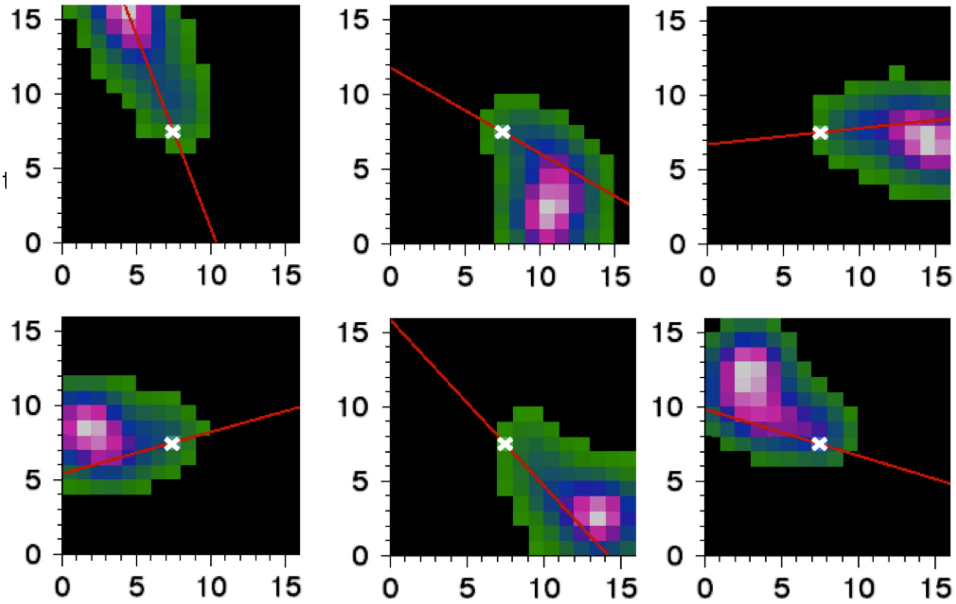
P. Gros et al. arXiv:1706.06483

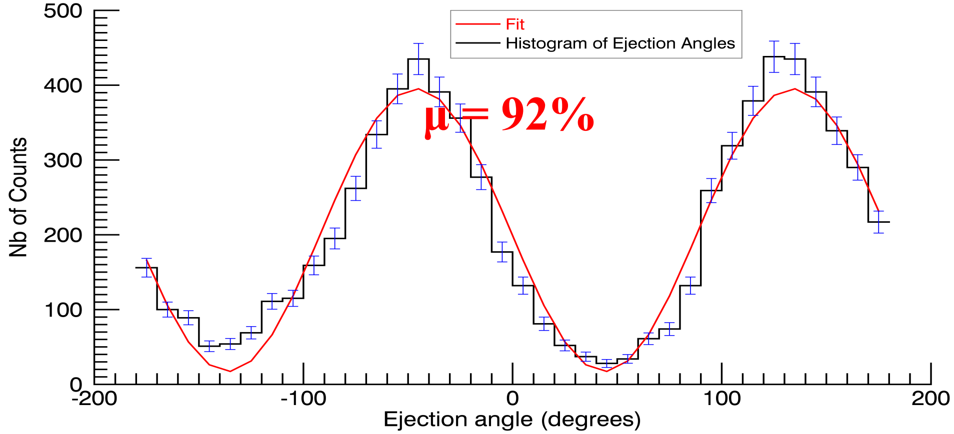
Soft X-ray polarimetry with ‘Piggy back’ Micromegas





Recorded events with 8 keV linerarly polarized in helium-isobutane





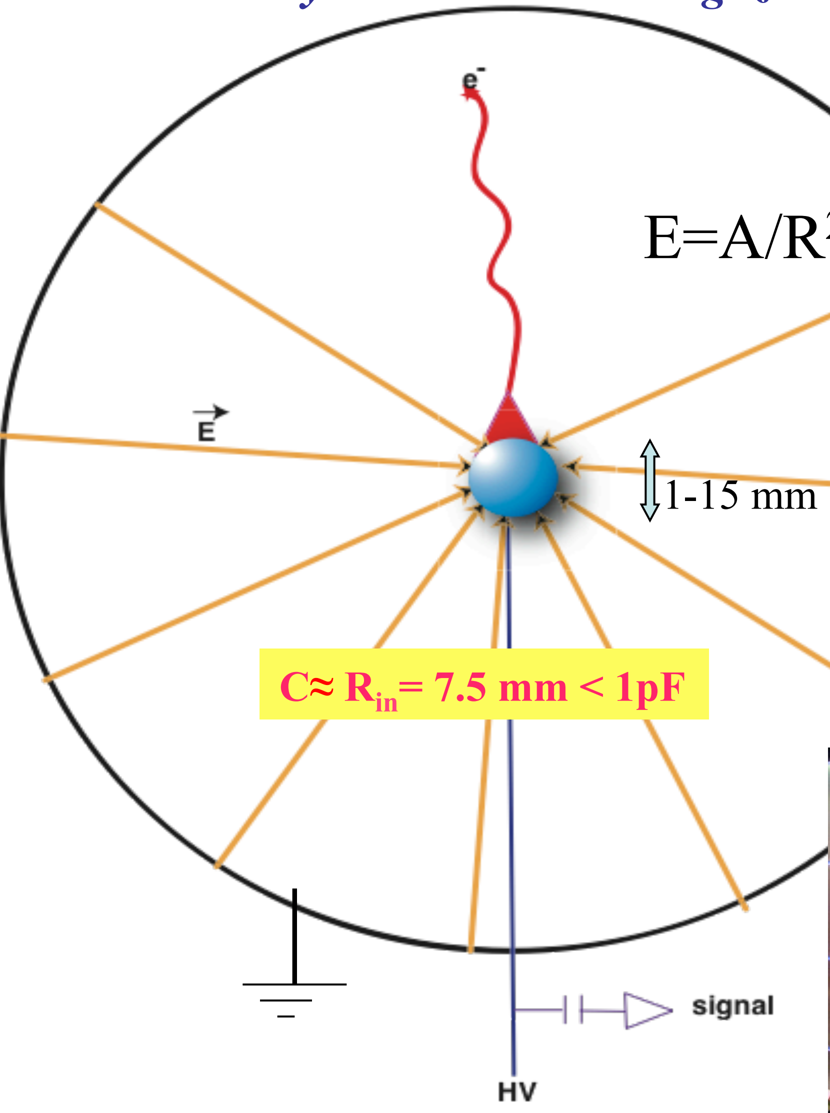
Second part

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

Radial TPC with spherical proportional counter read-out

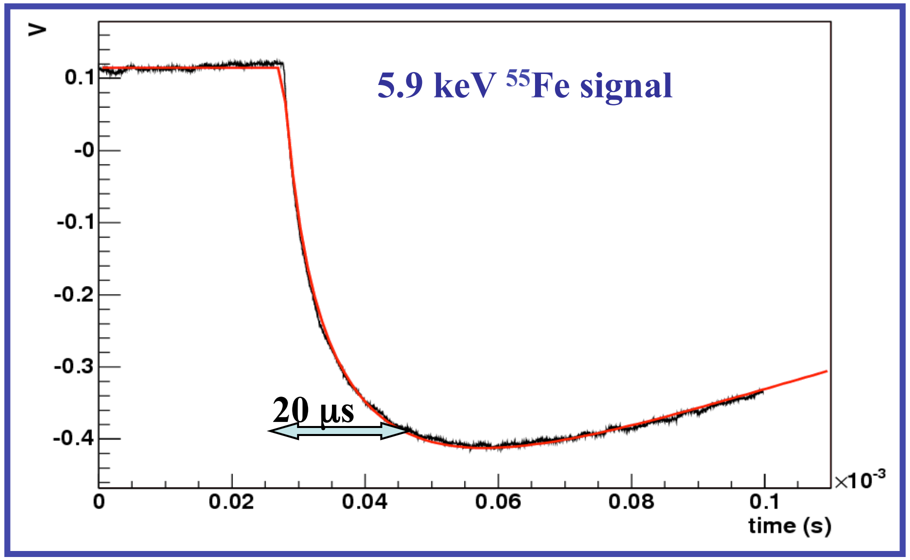
Saclay-Thessaloniki-Saragoza

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



$E=A/R^2$

$C \approx R_{in} = 7.5\ \text{mm} < 1\ \text{pF}$

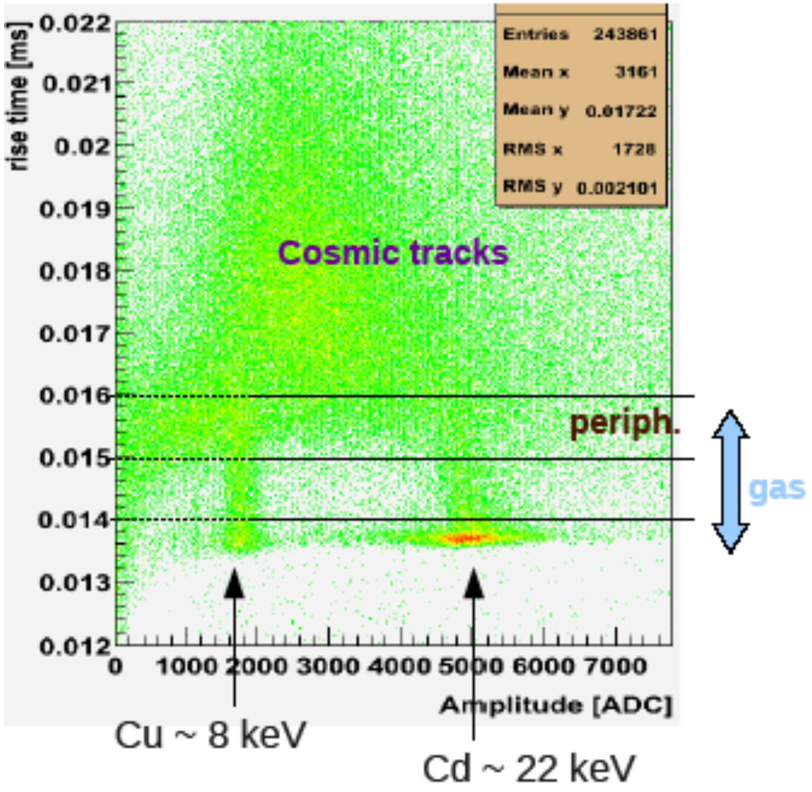


5.9 keV ^{55}Fe signal

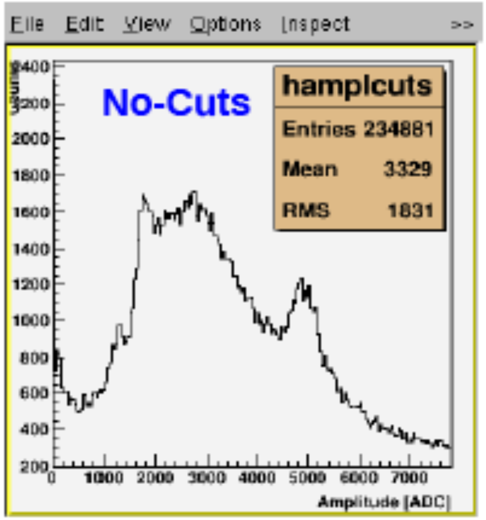
- Simple and cheap
- Large volume
- single read-out
- Robustness
- Good energy resolution
- Low energy threshold
- Efficient fiducial cut
- Low background capability

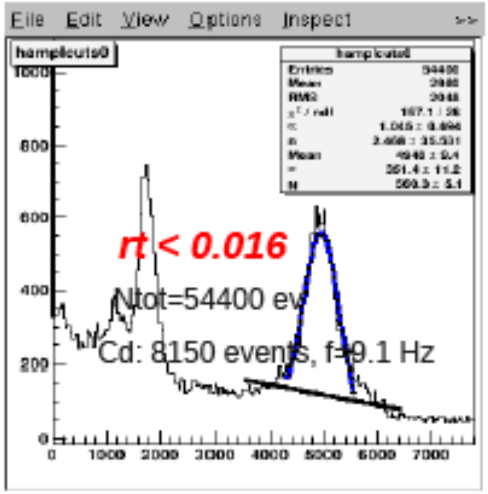
Rejection power- rise time cut

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

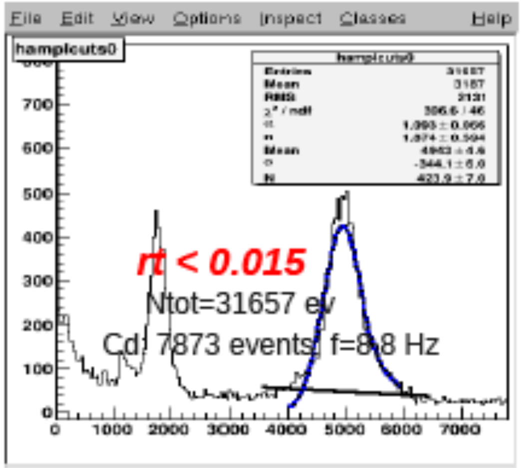


If rt ~ 0.0155 ms ==> R = 65 cm
0.014 ms ==> ~70% of signal

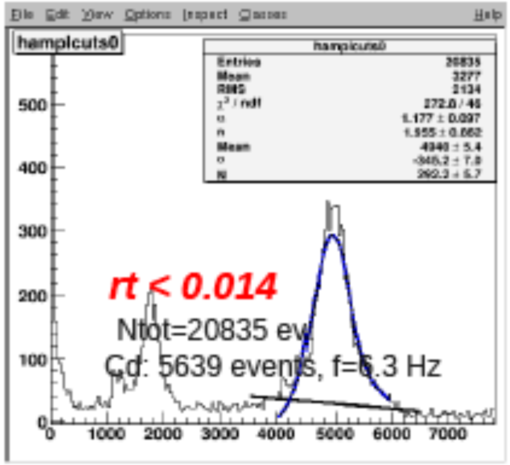




rt < 0.016
Ntot=54400 ev
Cd: 8150 events, f=9.1 Hz



rt < 0.015
Ntot=31657 ev
Cd: 7873 events, f=8.8 Hz



rt < 0.014
Ntot=20835 ev
Cd: 5639 events, f=6.3 Hz

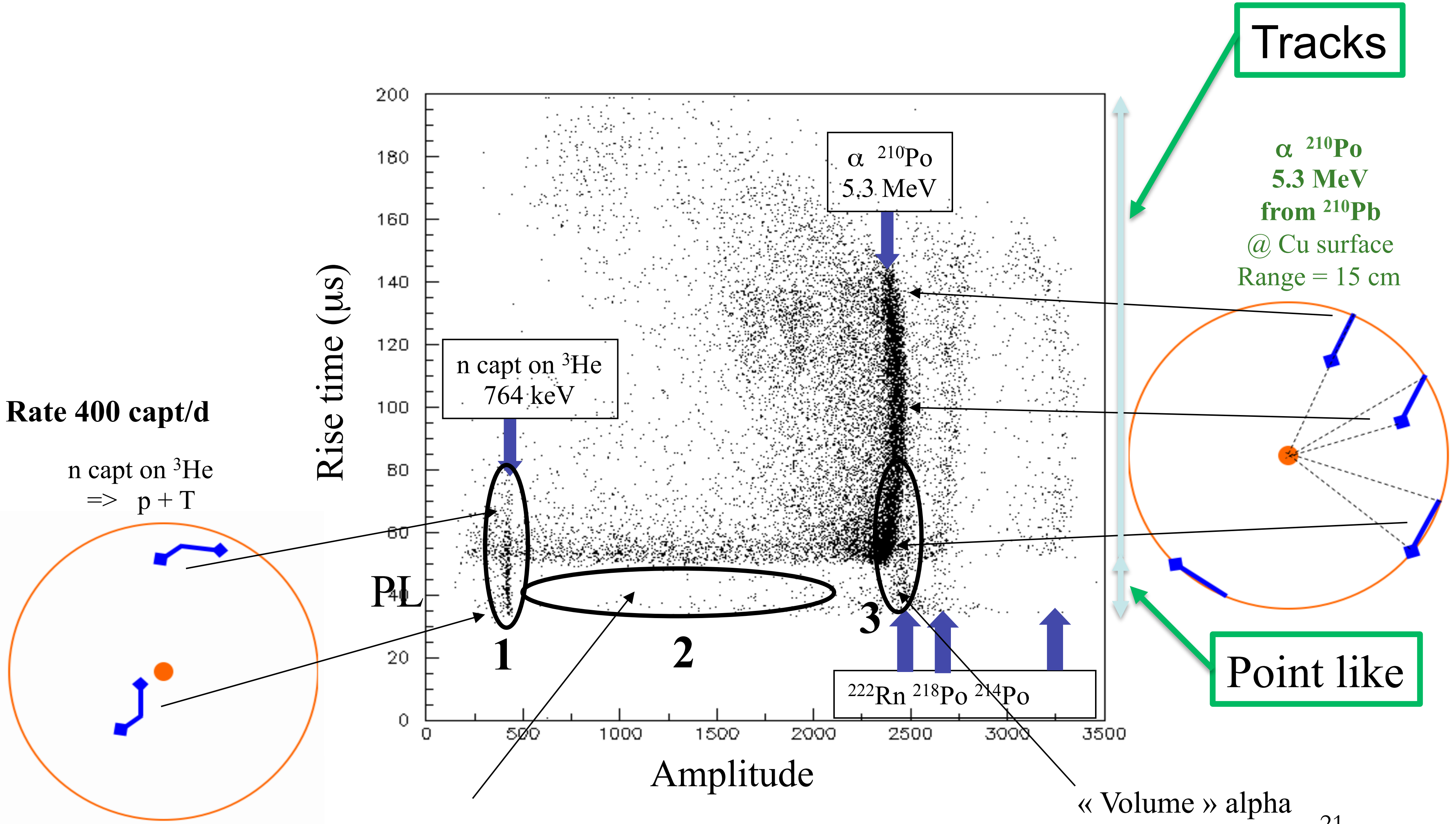
Efficiency of the cut in rt ==> ~ 70% signal (Cd peak)

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



Rate 400 capt/d

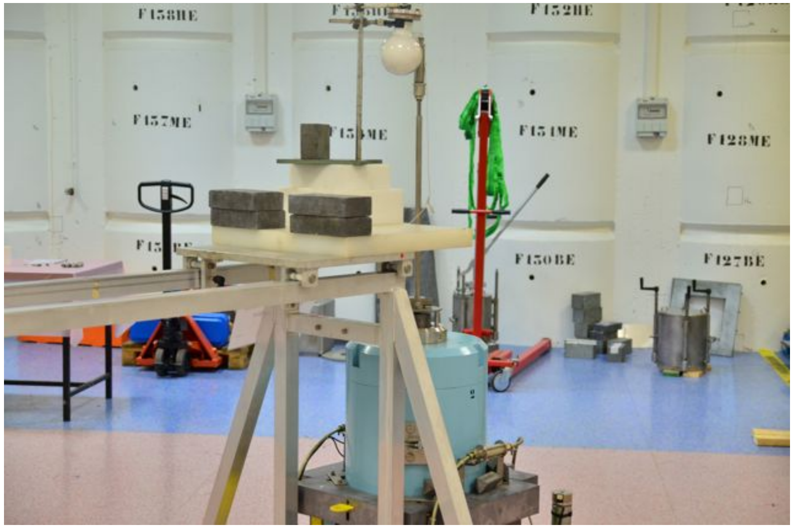
n capt on ^{3}He
=> p + T

α ^{210}Po
5.3 MeV
from ^{210}Pb
@ Cu surface
Range = 15 cm

« Volume » alpha

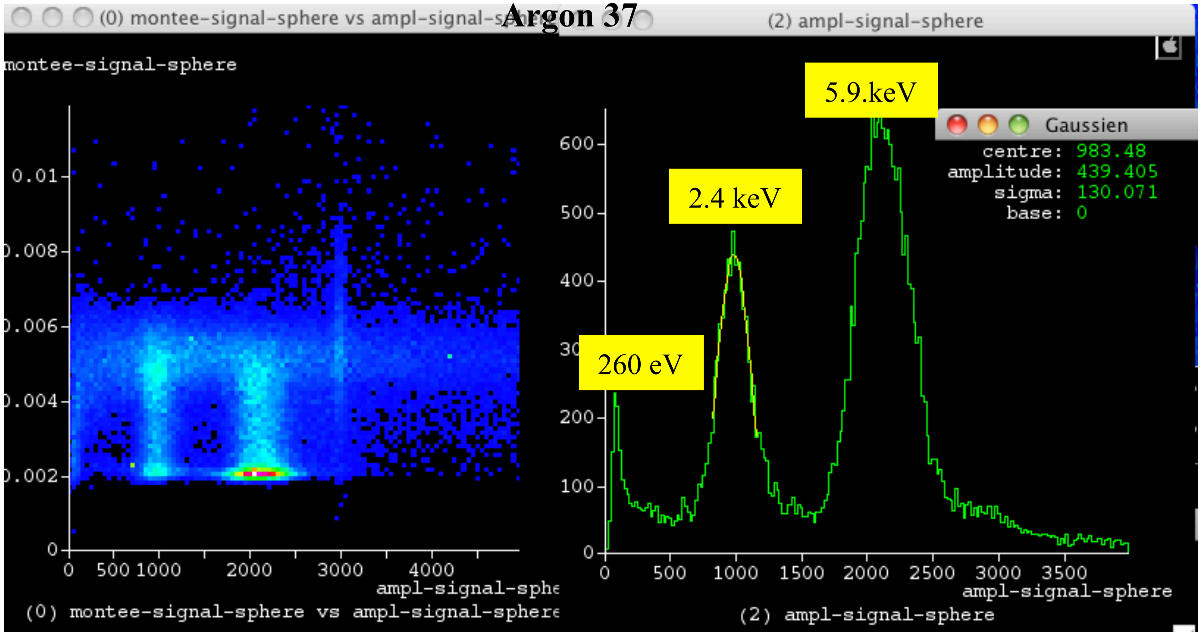
Low-energy calibration source *Argon-37*

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)




Installation near the spherical detector

Argon 37



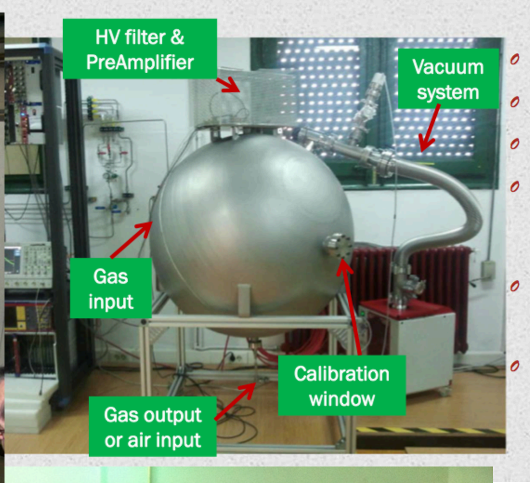
centre: 983.48
amplitude: 439.405
sigma: 130.071
base: 0

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

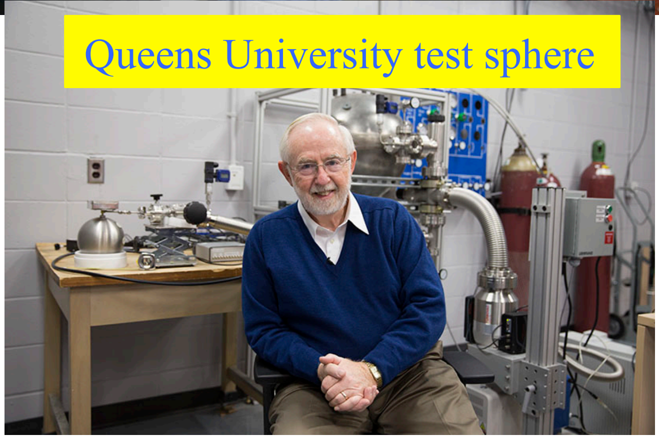
Basic R@D detector in Saclay

University of Saragoza detector



University of Thessaloniki detector

Queens University test sphere



University of Tsinghua - HEP detector

Bibliography

I Giomataris et al., JINST 3:P09007,2008.,

I Giomataris and J.D. Vergados, Nucl.Instrum.Meth.A530:330-358,2004,

I. Giomataris and J.D. Vergados, Phys.Lett.B634:23-29,2006.

I. Giomataris et al. Nucl.Phys.Proc.Suppl.150:208-213,2006.,

S. Aune et al., AIP Conf.Proc.785:110-118,2005.

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

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

G. Gerbier et al.,arXiv:1401.790v1

NEWS collaboration

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

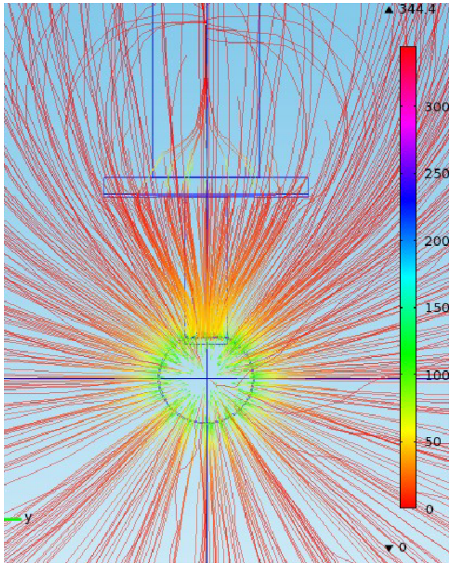
+ Birmingham University

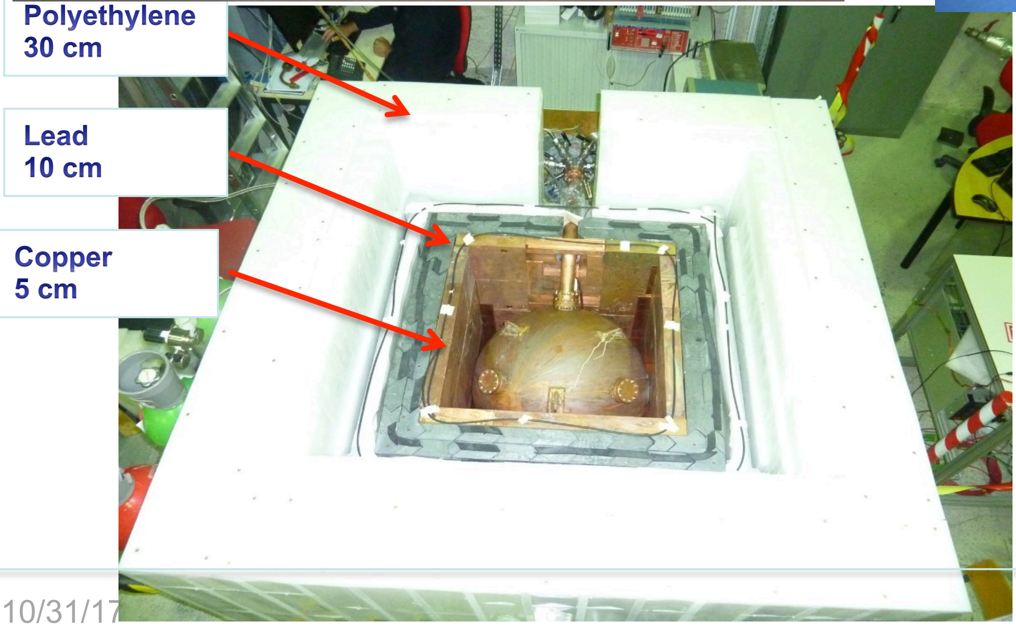
Collaboration meeting at LSM april 2016

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

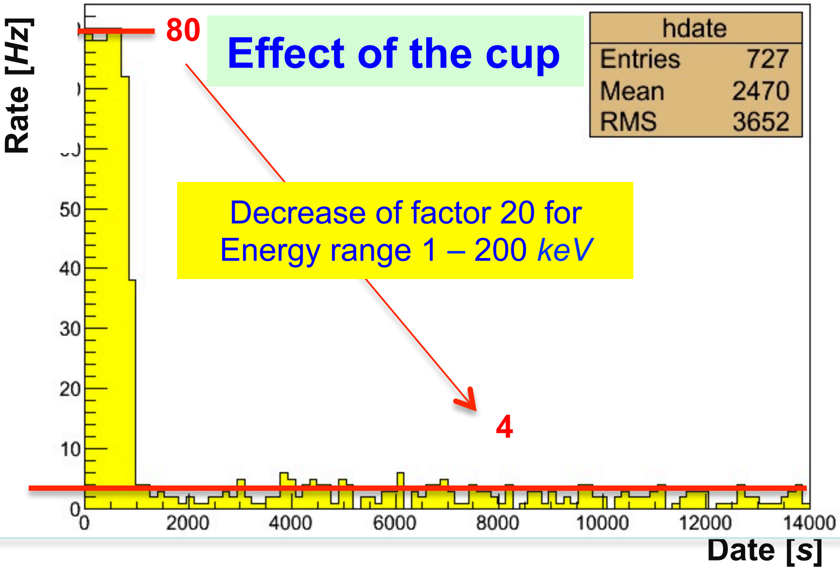




Polyethylene
30 cm

Lead
10 cm

Copper
5 cm

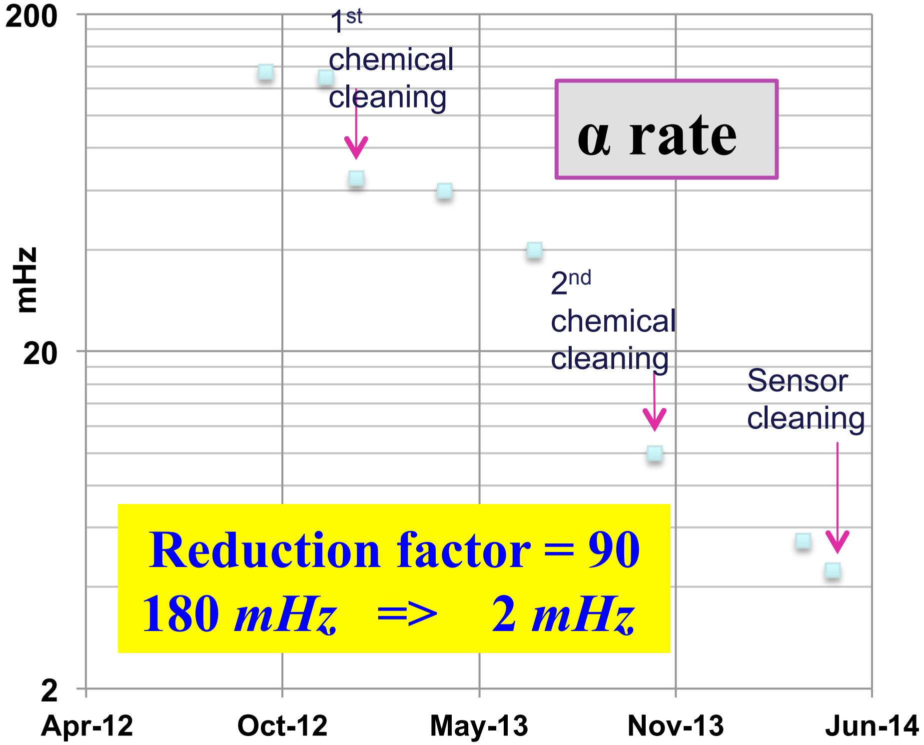


Effect of the cup

Decrease of factor 20 for
Energy range 1 – 200 *keV*

Backround evolution of the detector

Alpha rate evolution



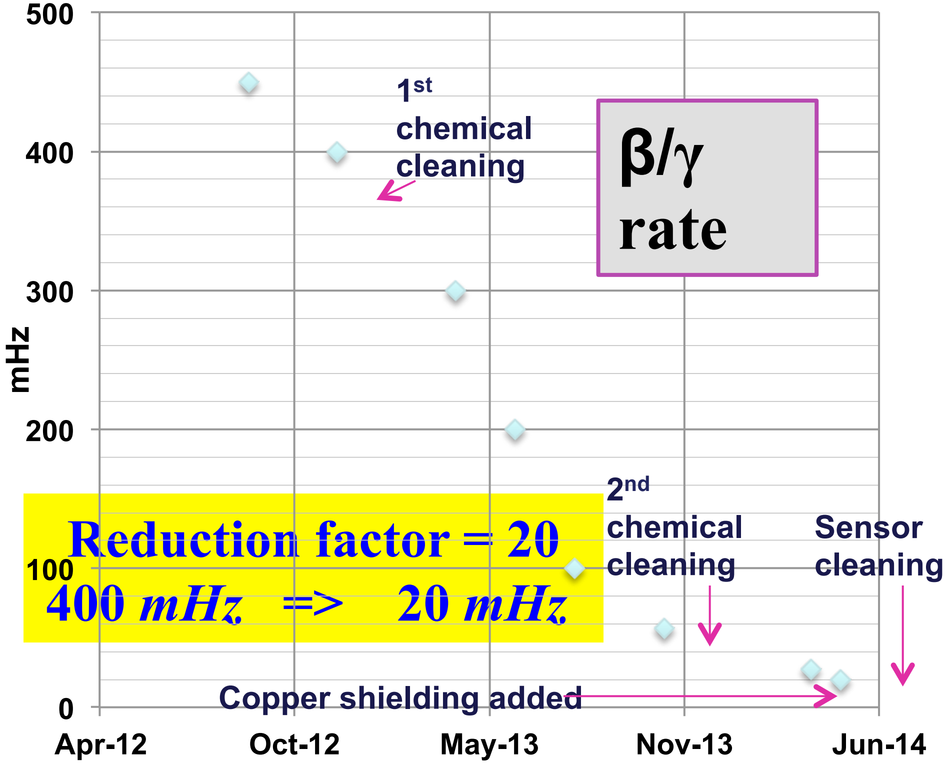
1st chemical cleaning

2nd chemical cleaning

Sensor cleaning

Reduction factor = 90
180 *mHz* => 2 *mHz*

β/γ rate evolution



1st chemical cleaning

2nd chemical cleaning

Sensor cleaning

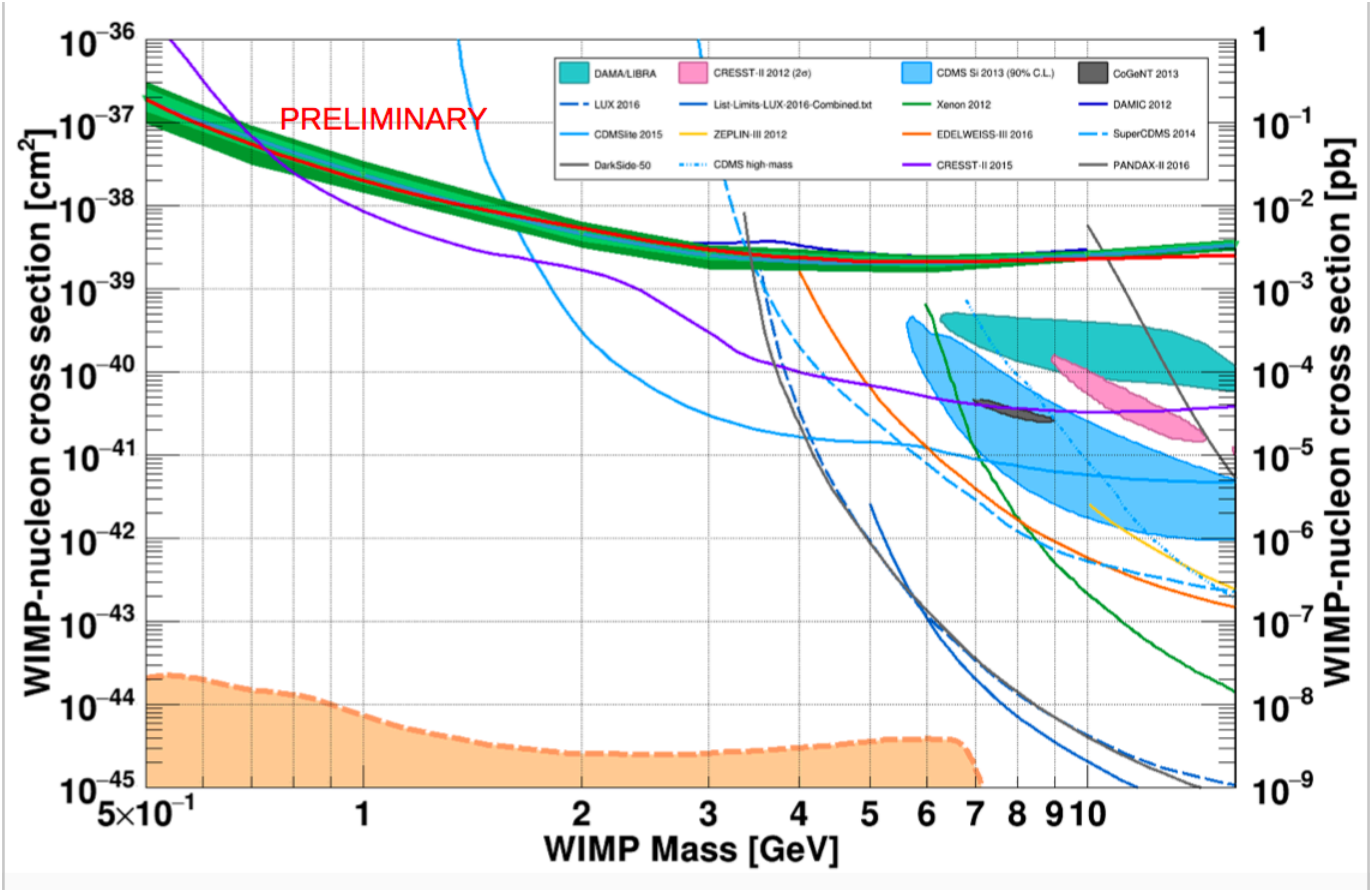
Copper shielding added

Reduction factor = 20
400 *mHz* => 20 *mHz*

New development with PPNL
Electropolishing of internal copper sphere +
Pure copper electroplating at LSM

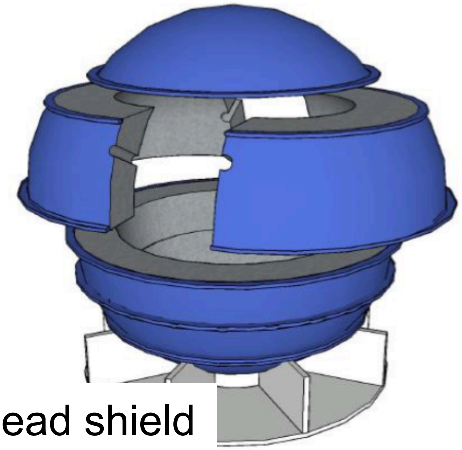
Current sensitivity with Neon at 3 bar
Data 40.5 days, threshold 30 eV

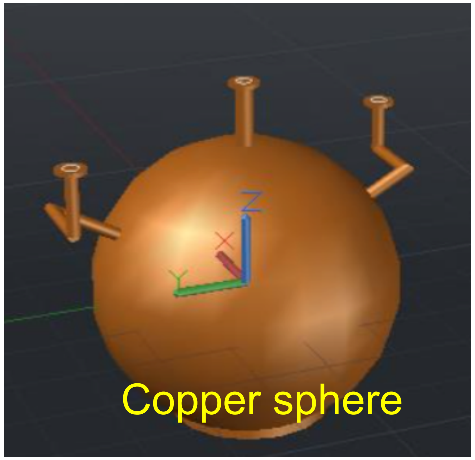
Q. Arnaud et al., Astroparticle Physics. 10.1016/j.astropartphys.2017.10.009.

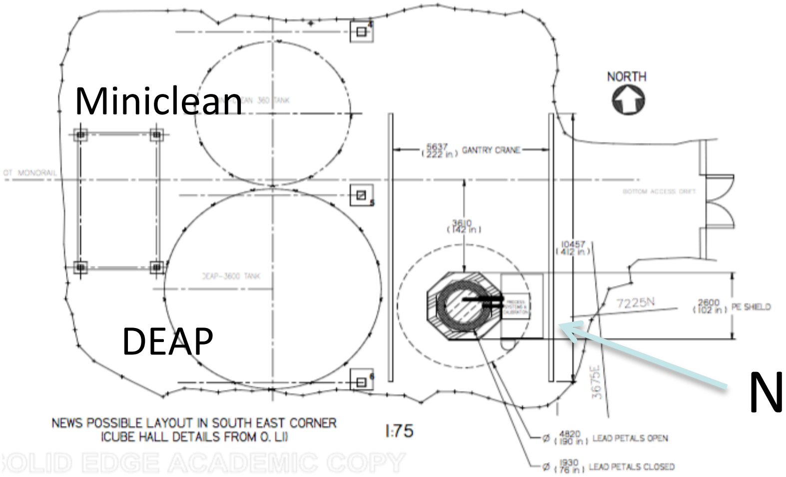


NEWS-SNO with compact shield : implementation at SNOLAB by fall 2017
Funded mainly by Canadian grant of excellence and ANR-France

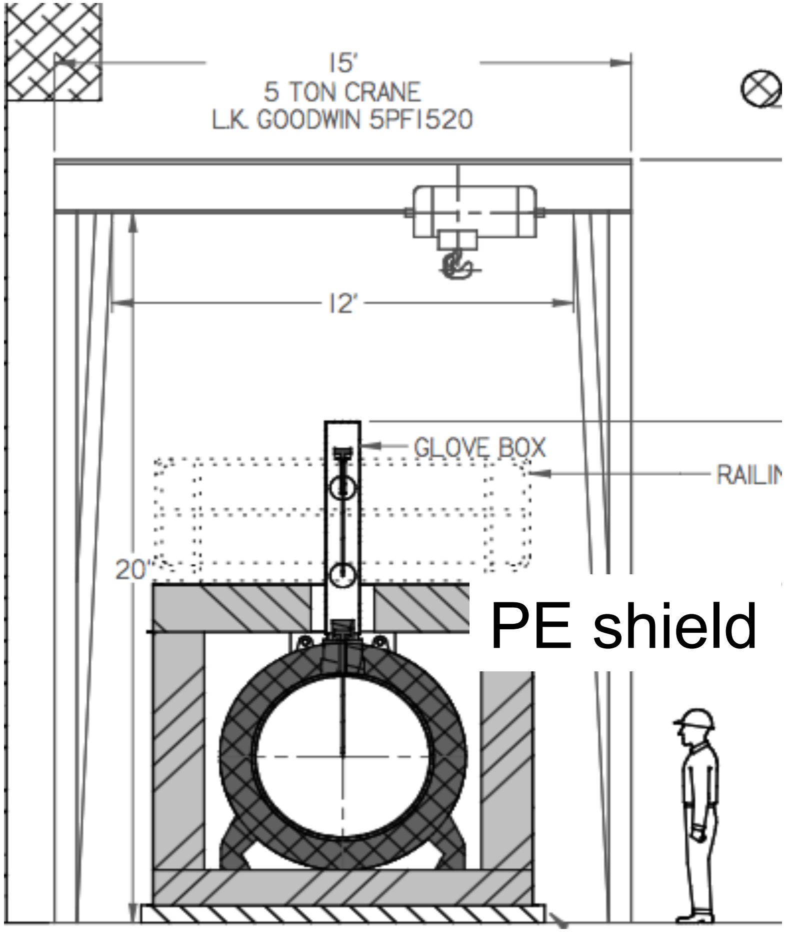
140 cm Ø detector, 10 bars, Ne, He, CH_4
Copper 1 mBq/kg
Compact lead –ancient- & PE shield solution



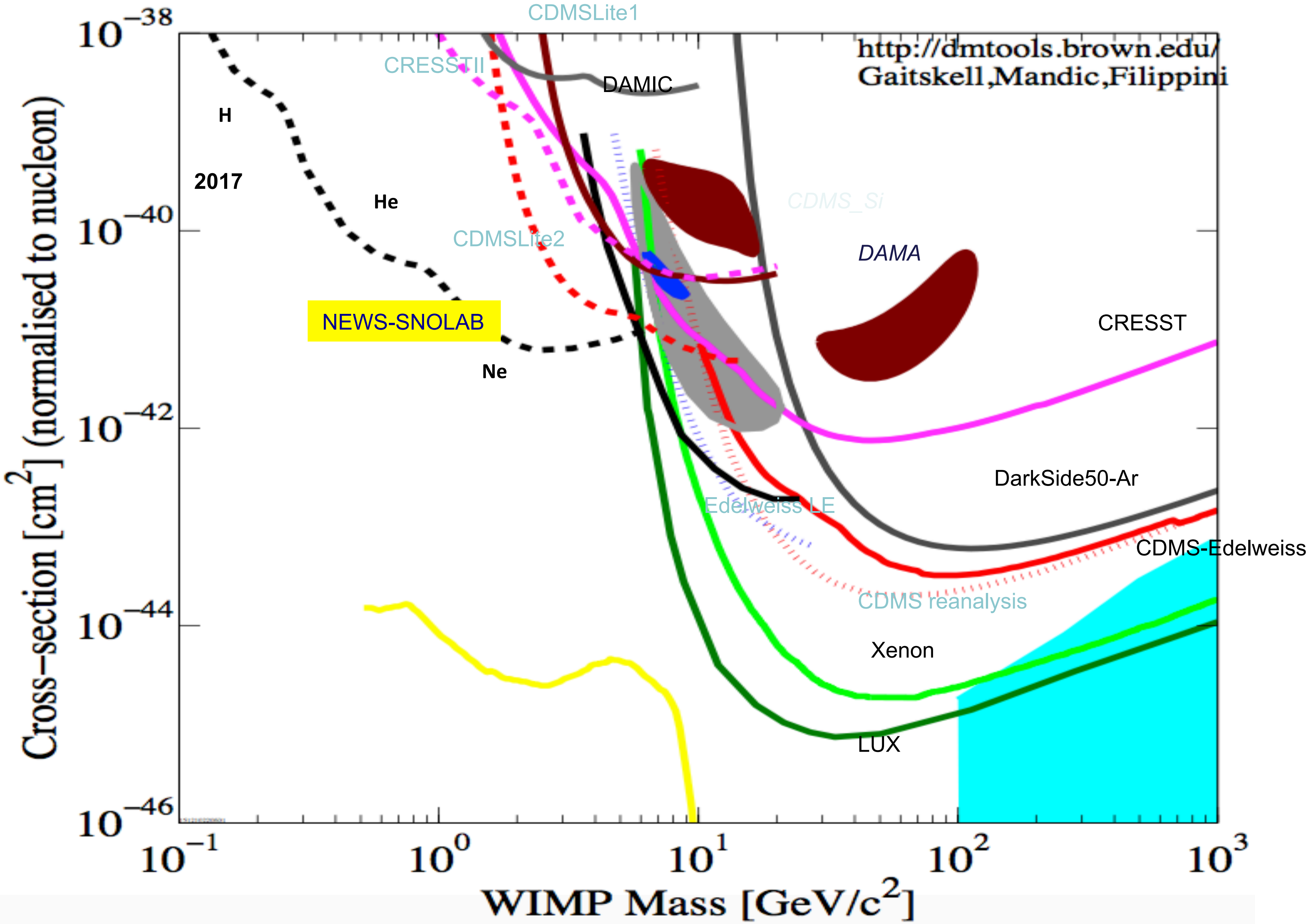




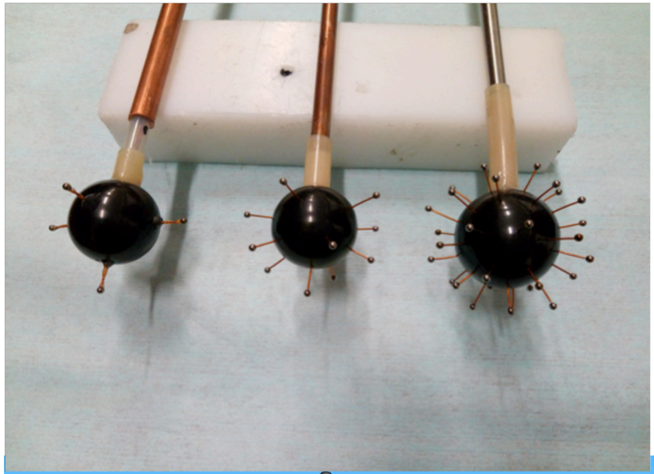
NEWS



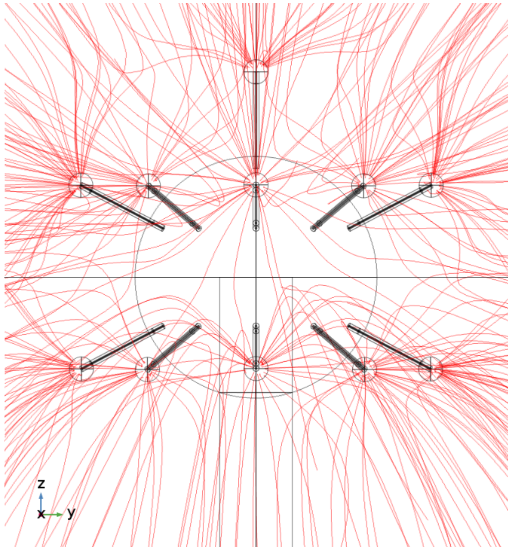
NEWS-SNOLAB project sensitivity

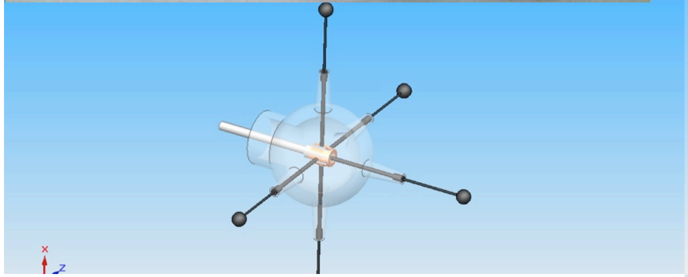


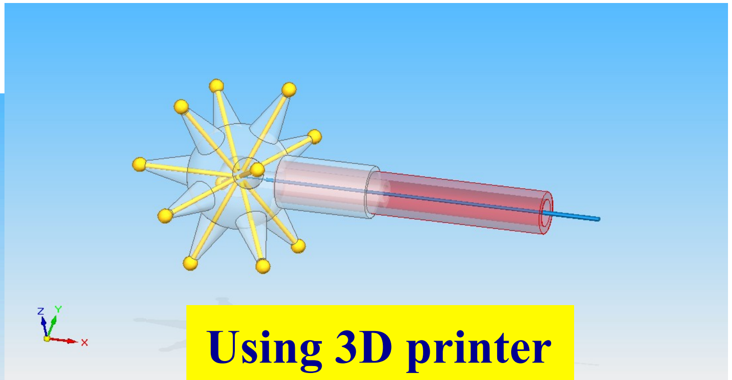
Multi-ball 'ACHINOS' structure
Developed in Saclay in collaboration with University of Thessaloniki



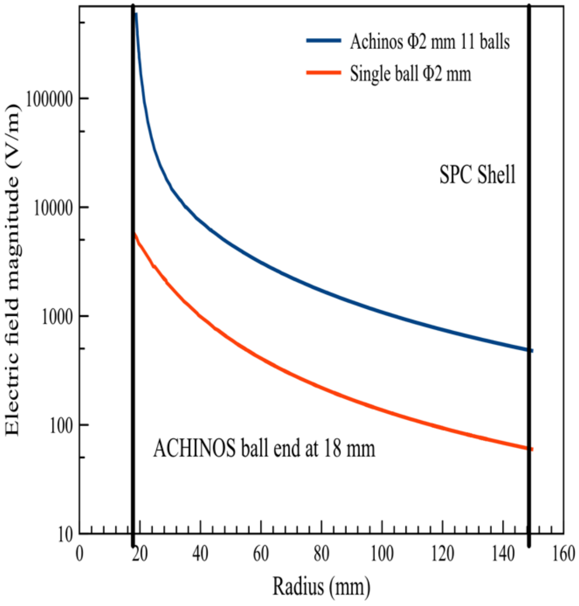
Advantages
- **Amplification tuned by the ball size: 1mm diameter for high pressure**
- **Volume electric field tuned by the size of the ACHINOS structure**
- **Detector segmentation: 3D TPC like**

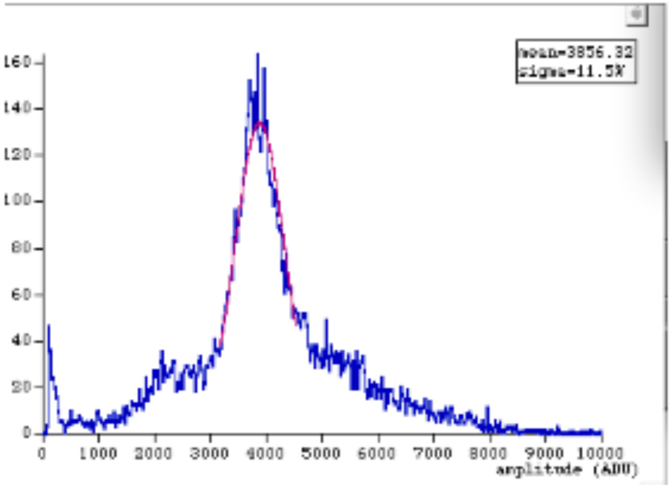






Using 3D printer





Additional physics

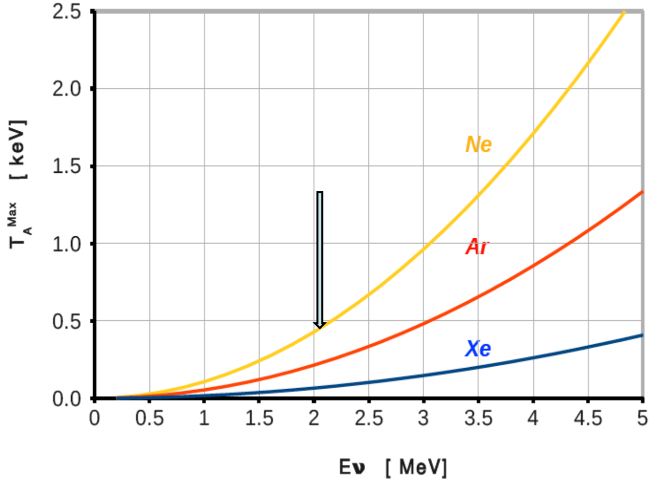
Neutrino-nucleus coherent elastic scattering

$\nu + N \dashrightarrow \nu + N$ $\sigma \approx N^2E^2$, *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, $U_\nu = 0.5 \times 10^{53}$ 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)

$8.\times10^{-5}$/keV/Kg/ year Arubis copper

1.54×10^{-5}/keV/Kg/ year PNNL copper

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

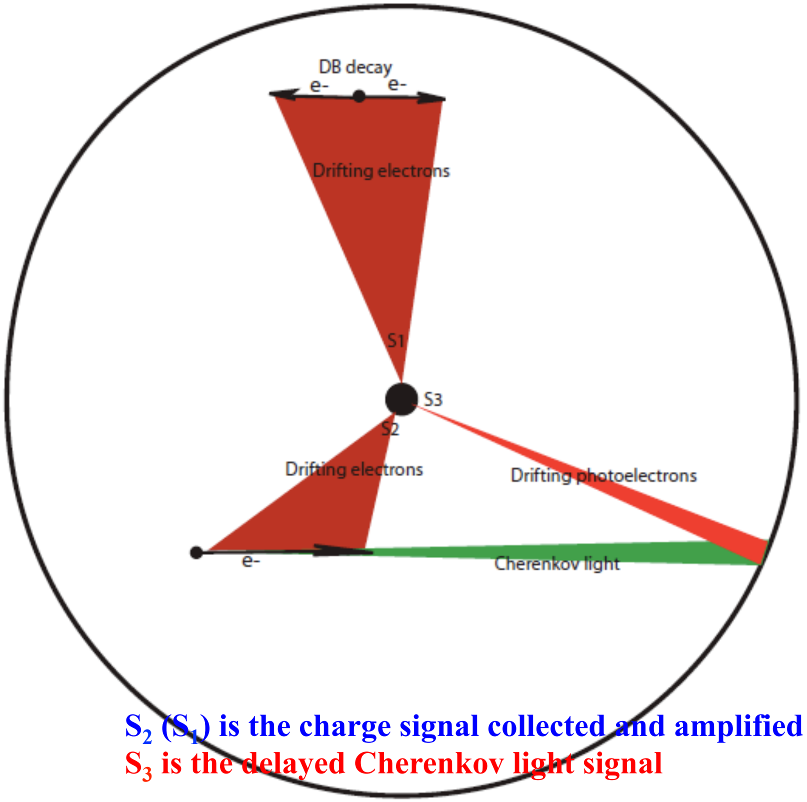
If additional rejection is required: a new idea

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..)

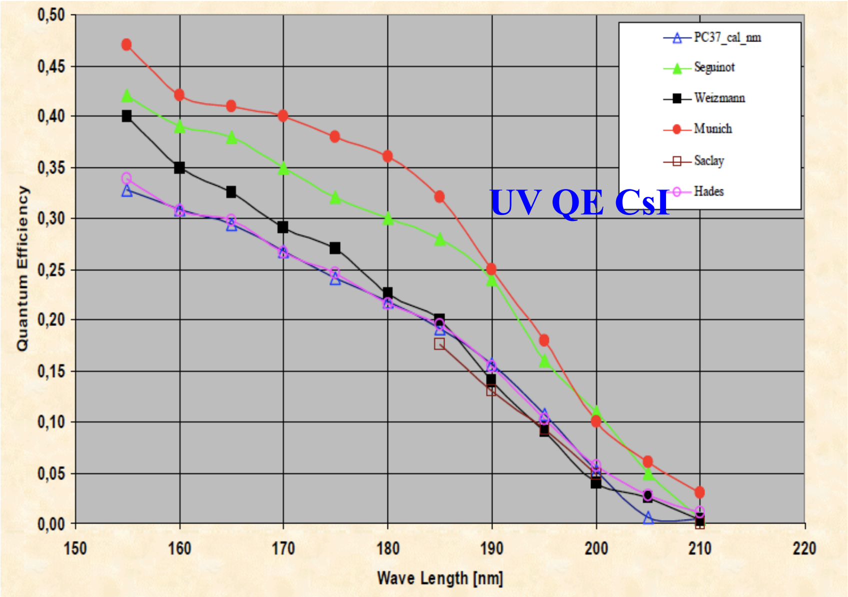
Xenon-136 at high pressure of about 25-40 bar is ideal to keep high efficiency for double electrons, Good enough electron path and reduce multiple scattering

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

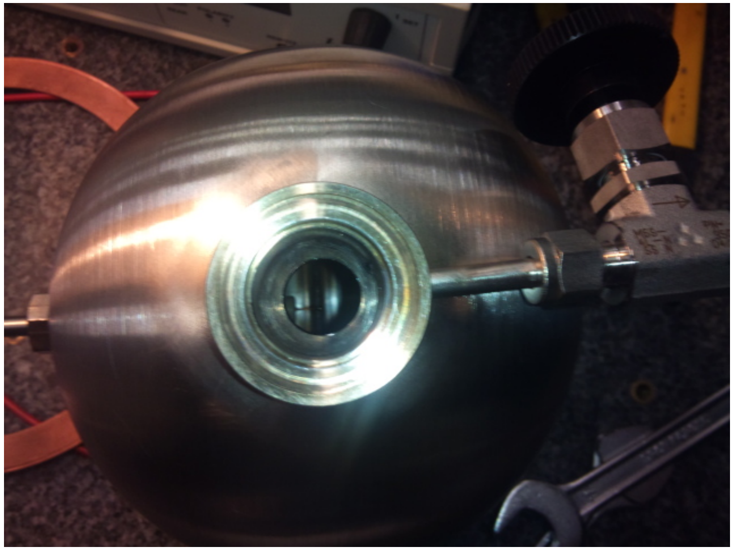


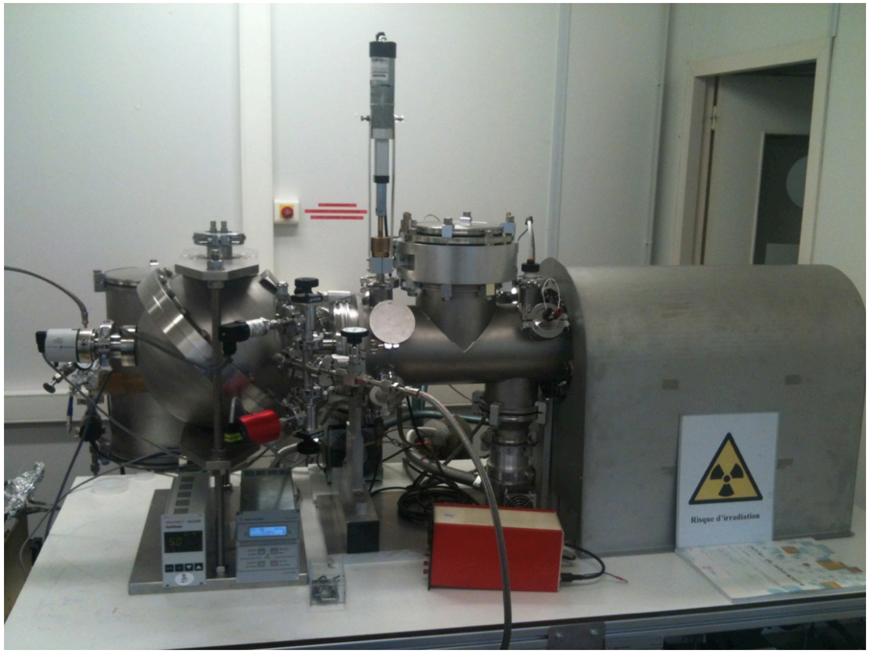
I. Giomataris

THANK YOU

Quenching factor measurements

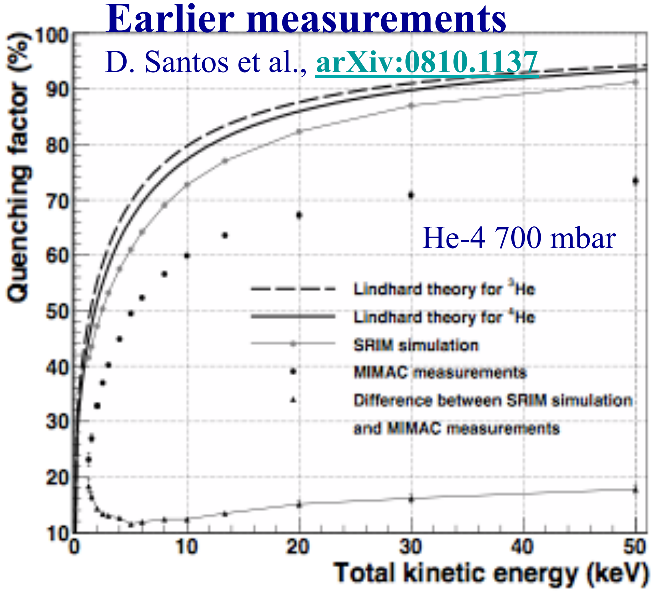
Goal: measure QF down to 500 eV ion energy using the Grenoble MIMAC facility for H, He, Ne, CF4, Ar, Xe at various pressures





Earlier measurements

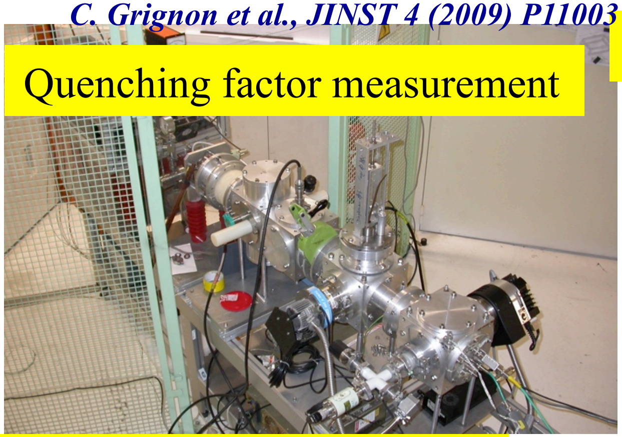
D. Santos et al., arXiv:0810.1137

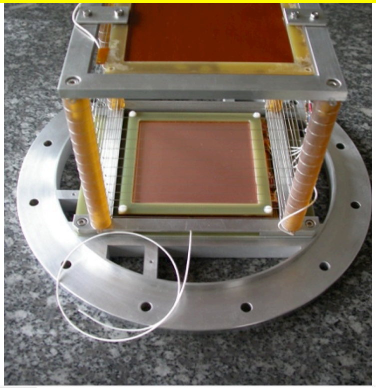


Previous investigations with a 15 cm sphere show the capability to measure 500 eV He-4 ions with an estimated QF of about 25%

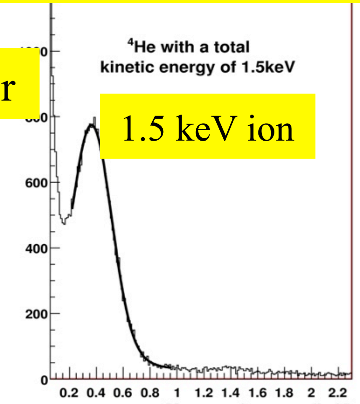
Saclay, Grenoble, Thessaloniki, Queen's-Kingston

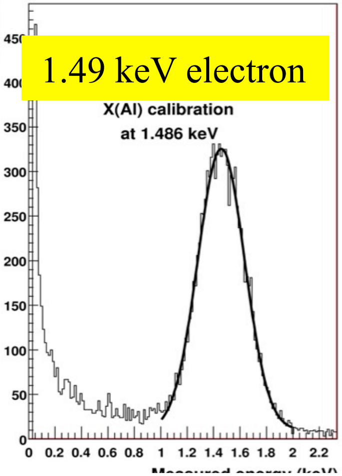
MIMAC-He3 MIcro-tpc Matrix of Chambers of He3
WIMP directional TPC, Micromegas read-out,
Grenoble – Saclay, Cadarache collaboration
C. Grignon et al., JINST 4 (2009) P11003


Quenching factor measurement

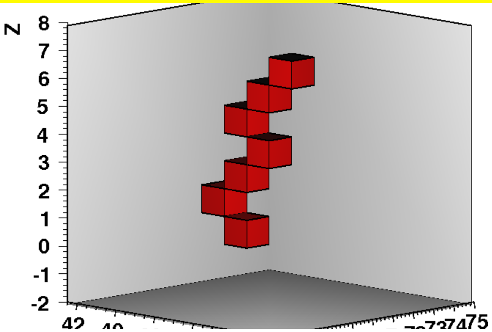

Micromegas:µTPC chamber

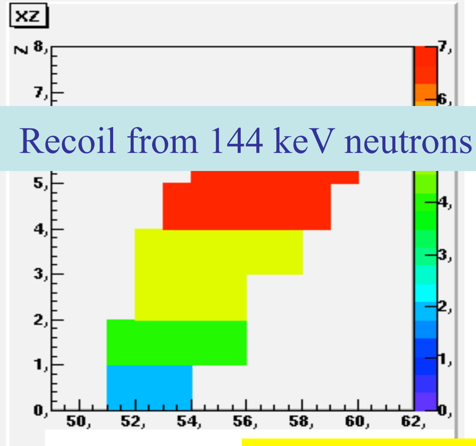
Direct QF evaluation
D. Santos et al., [arXiv:0810.1137]

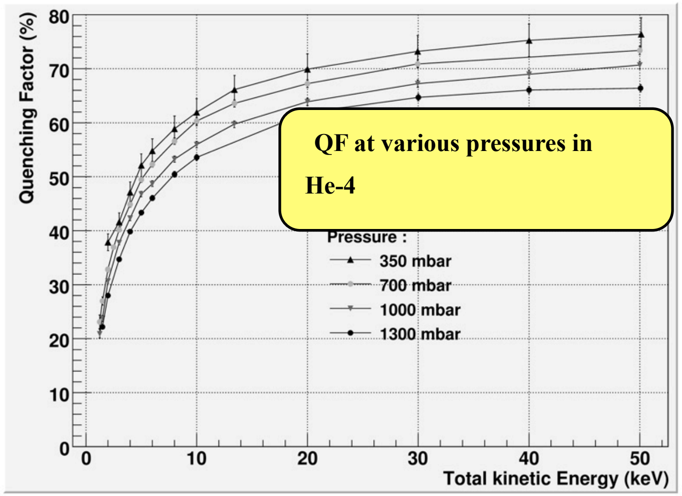

1.5 keV ion


1.49 keV electron

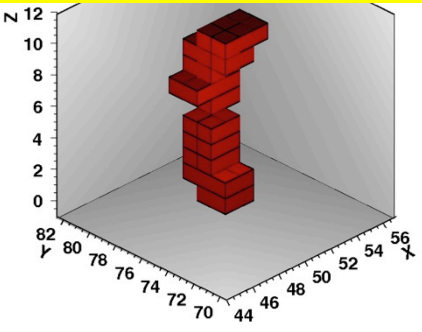
proton 8 keV, He + 5% iC$_4$H$_{10}$, 350 mbar




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$_4$H$_{10}$ 350 mbar