TREX-DM:

a low background Micromegas-based TPC for low mass WIMP detection

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7th Symposium LTPCs for Rare Events – 15-17th December 2014

Many thanks to my colleagues F. Aznar, J.F. Castel, S. Cebrián, J.G. Garza, I.G. Irastorza, A.Lagraba & A. Peiró for their work all this years!!!

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Universidad Zaragoza 1542

erc European Research Council

StG-2009: T-REX

Outline

- Motivation for a low mass WIMPs Micromegas detector.
- TREX-DM: description & comissioning.
- A first background model of TREX-DM.
- Conclusions and prospects.

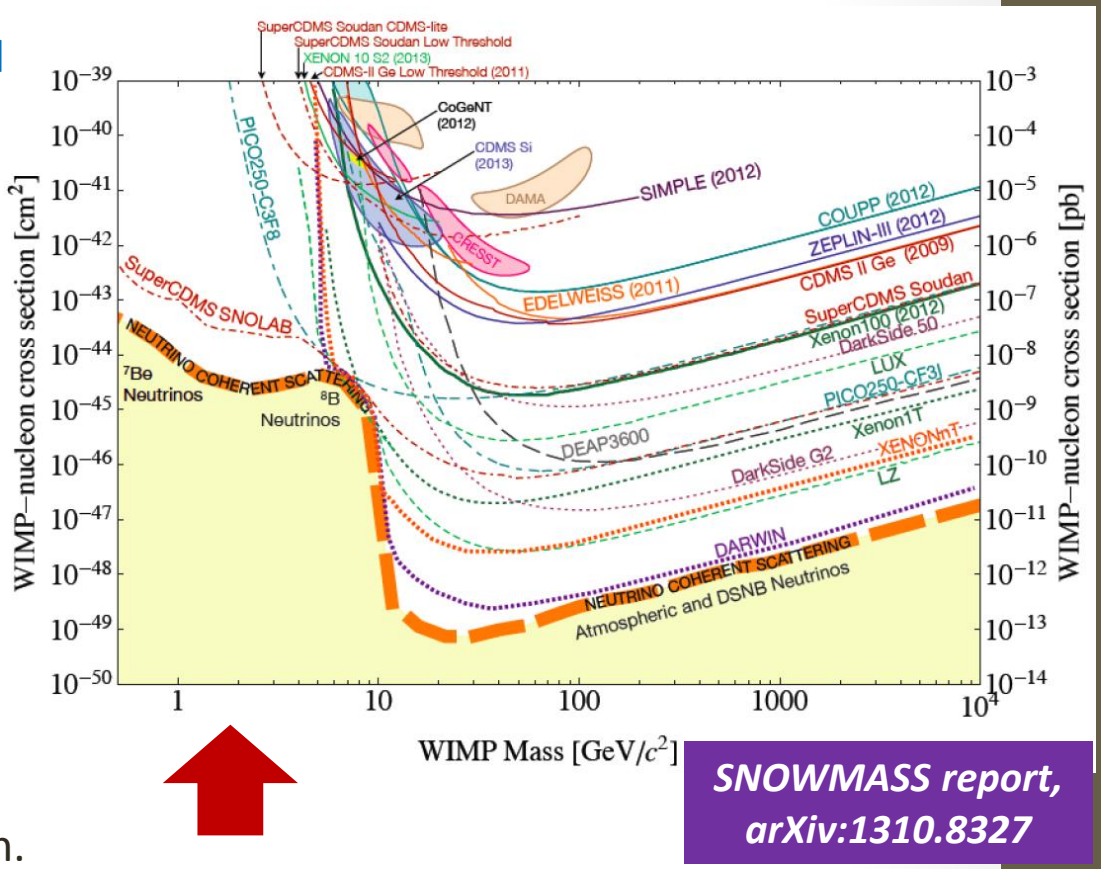
Motivation: low mass WIMP detection

Dark Matter experiments focused on ~50-200 GeV WIMPs

- Heavy nuclei target.
- Large target masses.
- Low background levels:
  - Radiopurity control
  - Electron/nuclear recoil discrimination -> high threshold -> less sensitive to low WIMP masses.

What happens if mass <10 GeV?

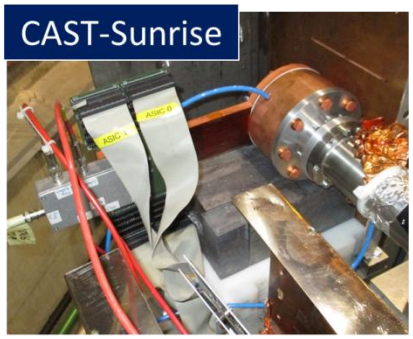
- Energy threshold < 1 keV.
- Electron/nuclear discrimination.
- Quenching factor at keV energies.
- DAMA/LIBRA signal is near these masses.

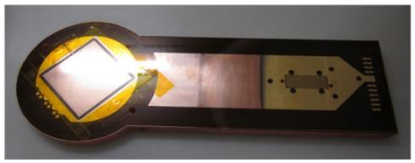


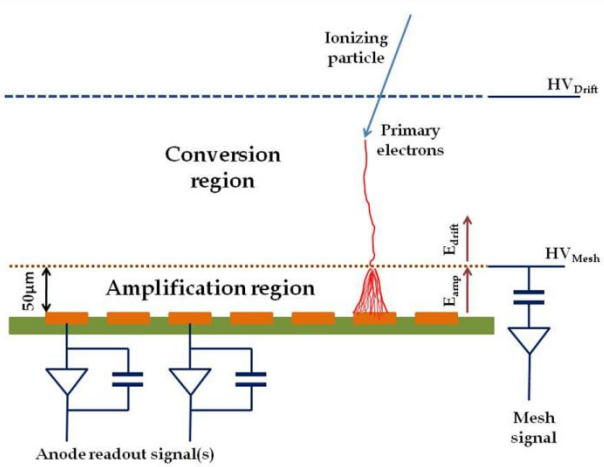
SNOWMASS report, arXiv:1310.8327

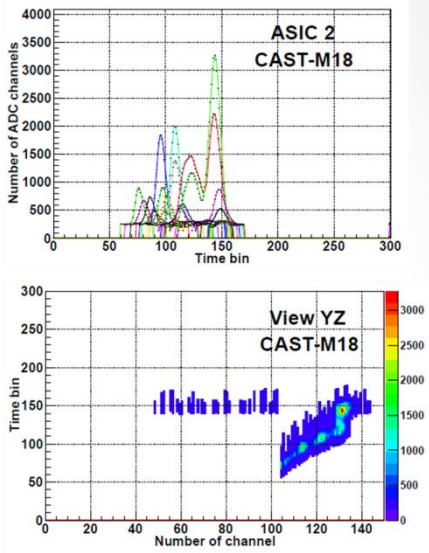
Micromegas: a reminder

I. Giomataris, NIMA 376 (1996) 29









It is an amplification structure used as readout in a Time Projection Chamber.

- **Conversion region:** radiation create electrons, which drift to the readout.
- **Amplification region**: electrons pass through mesh holes due to a high field difference & are amplified. Electron & ion movement induce signals in both mesh & strips.

Three technologies:

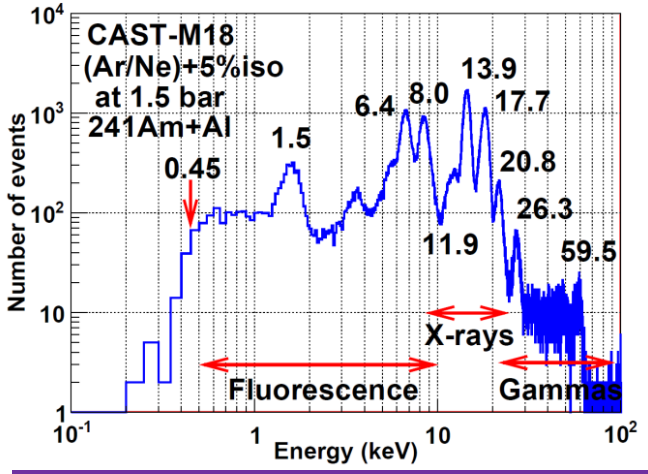
- **Classical:** first CAST detectors, ATLAS-MM (resistive).
- **Bulk:** COMPASS, T2K, CLAS-12, nTOF, AstroBoX, ForFire, MIMAC, FIDIAS...
- **Microbulk:** CAST, nTOF, NEXT-MM,…

Motivation: why a Micromegas TPC?

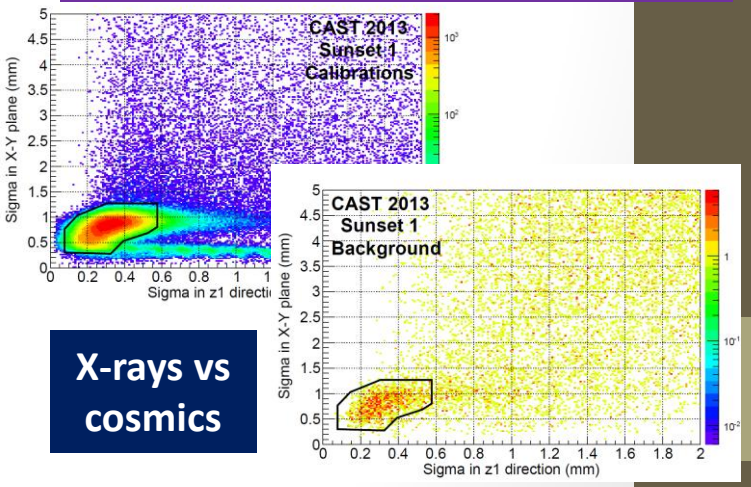
- A low energy threshold (**450 eV**) is feasible in gaseous detectors (***JINST 9 (2014) P01001***).
- Topology information available. Already proved for low energy x-rays (***JINST 8 (2013) C12042***).
- Kapton-copper detectors are intrinsic radiopure (***Astr . Part. 34 (2011) 354***).
- Consolidated manufacture (***JINST 5 (2010) P02001, JINST 7 (2012) P04007***).
- Assesment of material radiopurity for Rare Event Searches (***JINST 8 (2013) C11012***).
- Scaling up experience in NEXT-MM (***JINST 9 (2014) P03010***).

Challenges:

- Construction of **large radiopure** MM detectors.
- Background level: **systematic radiopurity control**.
- **Sub-keV energy threshold** for a large area.
- **Quenching factor** in gases: limited literature.



S. Aune et al, JINST 9 (2014) P01001



X-rays vs cosmics

TREX-DM: a MM-TPC for low mass WIMPs

Goals

- A large Micromegas detector with a mass x100 larger than CAST.
- Optimization of the design for **low energy threshold** and **low background level**.
- NOT focused in directionality like MIMAC & DRIFT -> operation at high pressure.

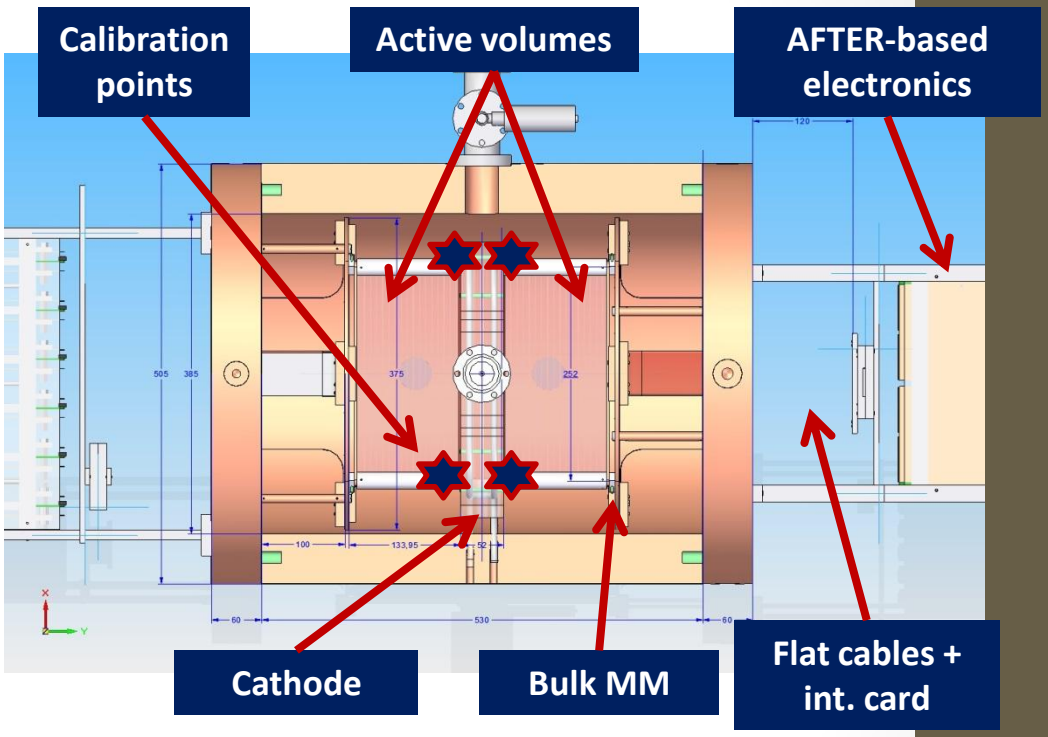
Commisioning timeline:

- **Surface at Zaragoza: 2012-15**
  - First setup: design, construction & comissioning.
  - Systematic measurement of the radiopurity of all components.
  - General characterization of bulk MM in Argon+2%iso 1-10 bar.
  - Dependence of energy threshold with electronics chain & pressure.
  - Discrimination of x-rays vs muons by the cluster width. Extension to neutrons?
  - Test of other interesting gases like neon.
- **Zaragoza -> Underground at LSC: 2015-16.**
  - Installation of radiopure components: Micromegas detectors, flat cables, ...
  - Cleaning of all components.
  - Installation of a 10 cm thick lead shielding.
  - Possible installation at LSC in 2016 for a physics run. Still in study.

TREXDM: general description.

Main features of the setup

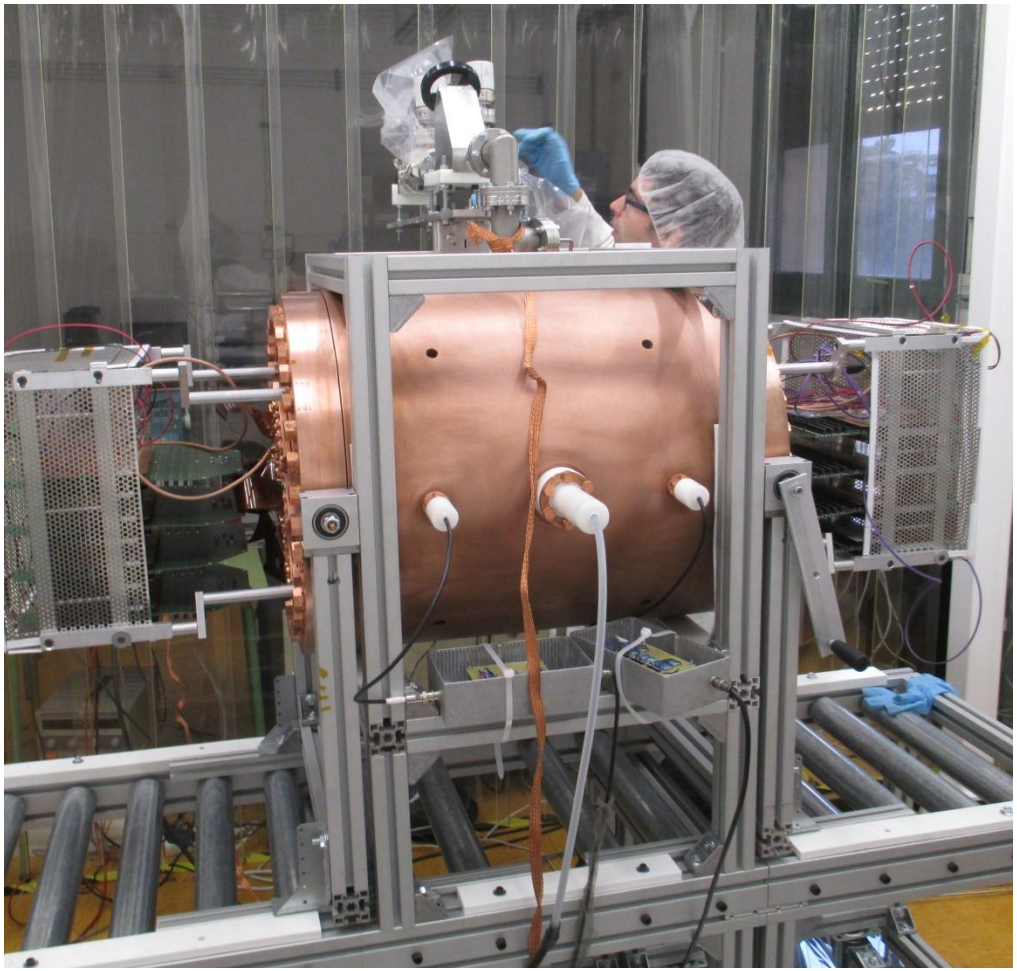
- Copper vessel: 6 cm thickness, 0.5 m diameter, 0.5 m length.
- Two volumes & a central cathode.
- Drift cage made of kapton&copper.
- 20 x 20 cm^2 bulk MM detectors. Bulked at IRFU/Saclay workshop.
- AFTER-based electronics. Possible update to AGET in next version.
- 4 points/side of calibration for a ^{109}Cd source inside a plastic tube.
- Base gas: Ar+2%iC_4H_{10}.



Other features

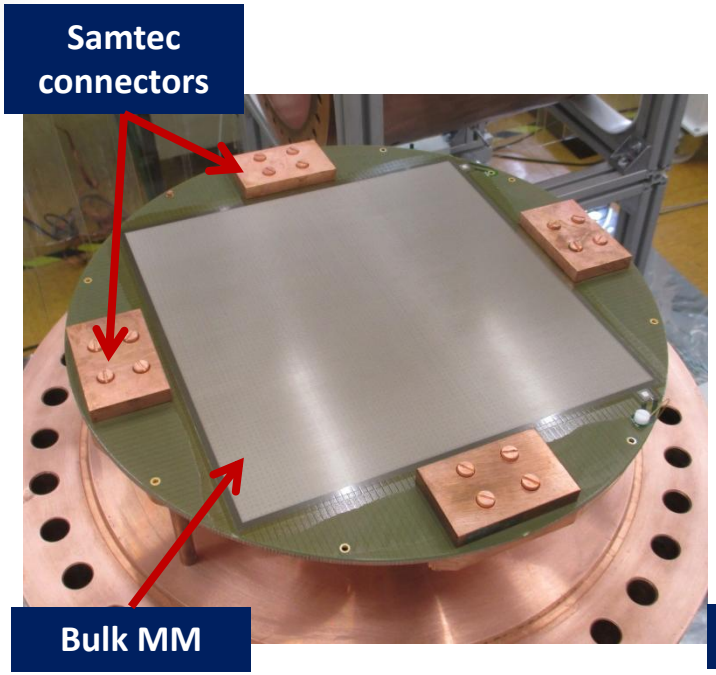
- Structure for an easy installation of any component at central cylinder & both caps.
- Gas & pumping system.
- Slow-control based on Arduino developped by A. Peiró: flow, temperature, pressure…

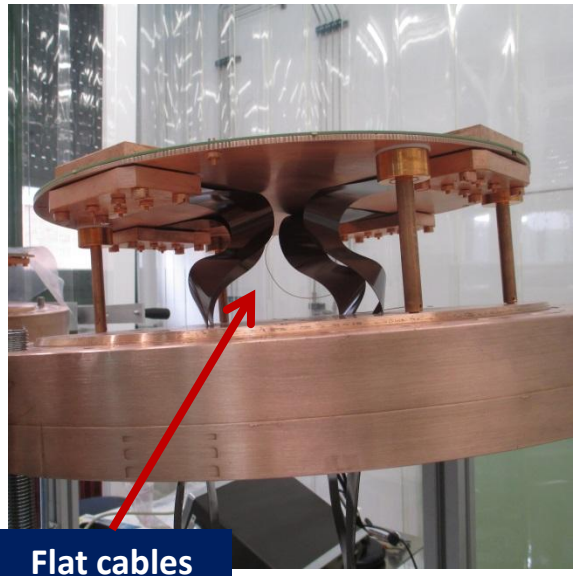
TREX-DM: a view of the experiment



TREX-DM: a MM-TPC for low mass WIMP detection, F.J. Iguaz et al.

TREXDM in detail: the Micromegas detector





- 20 x 20 cm^2 bulk Micromegas: 432 X-strips & 432 Y-strips, 0.5 mm pitch, 128 μm gap.
- Strips signals extracted by 4 flat cables using 300-Samtec connectors. A small shielding included too: **1 cm copper + 1 cm lead**.
- An interface card links a flat cable to the FEC. Any short-cut may be eliminated by a jumper.
- **AFTER**-based electronics. Possible update to **AGET** in next version, with **autotrigger capabilities** (lower energy threshold).

Many thanks to IRFU/SEDI-Micromegas workshop!!!

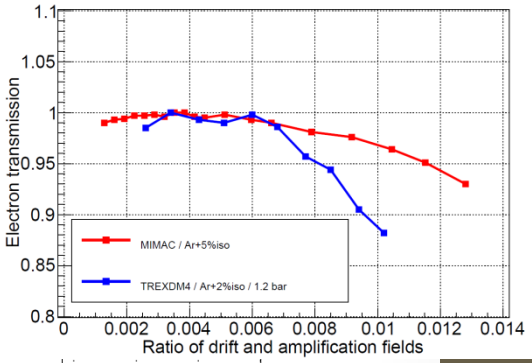
TREXDM: comissioning & first results

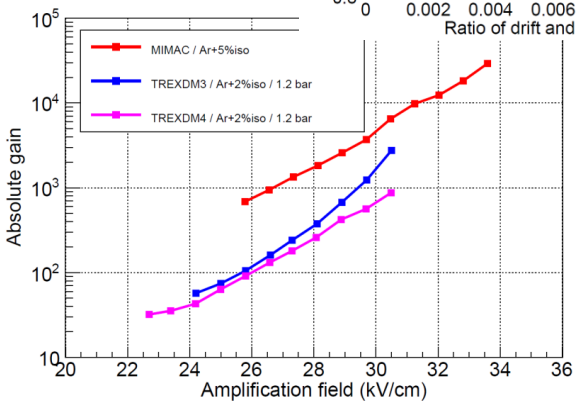
Comissioning

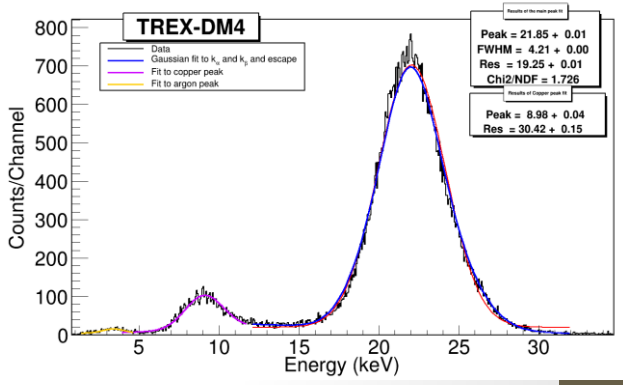
- Flat cables & high voltages feedthroughs validated before installation: leak < 10^{-5} mbar l /sec.
- Vessel tested in vacuum & at pressure < 10 bar.
- Drift cage successfully tested in argon-based mixtures for fields < 200 V/cm/bar up to 10 bar.
- Leak detection: at HV feedthrough and some flat cables. Values are the same as in test-bench.

First results

- First signals observed on 20th November 2014.
- The **general performance at 1.2 bar** was studied recording mesh pulses by an oscilloscope at different voltage settings:
  - **Electron transmission:** large operation range.
  - **Gain:** modest values (up to **10^3**).
  - **Energy resolution**: **19% FWHM** at **22 keV**.
- Some improvement expected at higher pressures due to the low quantity of quencher in gas.



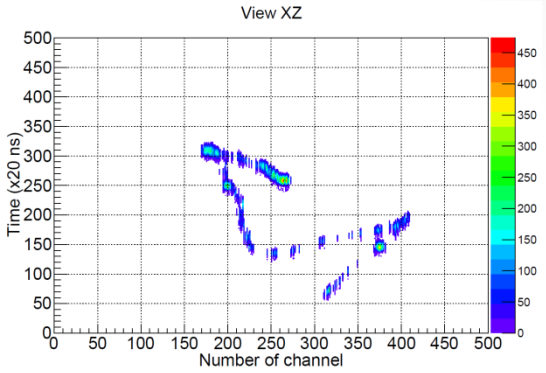


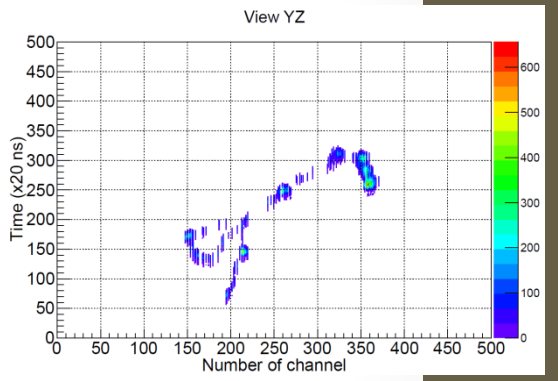


TREXDM: first results

First 2D events

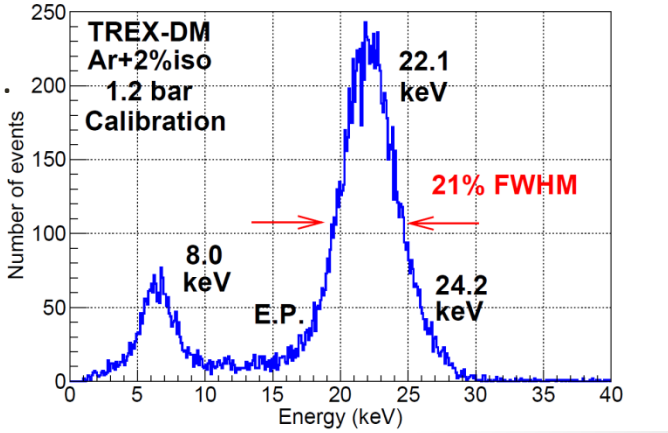
- AFTER-based electronics used to take some calibration and background data.
- TREX-DM decoding was successfully reconstructed.
- Energy spectrum of ^{109}Cd source was reconstructed. The energy resolution at 22.1 keV (**21% FWHM**) is similar to former values.
- **Energy threshold at 2 keV**, limited by a 1 MHz frequency noise, probably due to electronics.





NEXT steps:

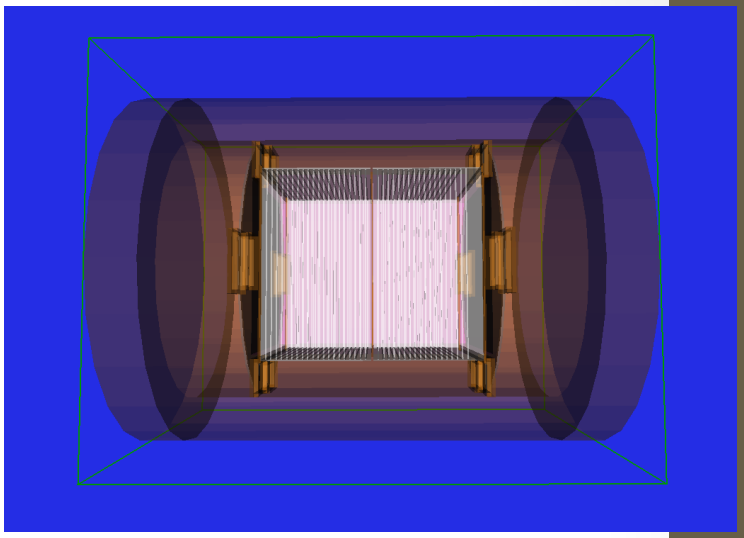
- Characterization at pressures up to 10 bar.
- Possible use of other gases: 5%iso, or neon-based.
- Some near-term updates:
  - Filter for cathode voltage.
  - Better grounding. Not fully understood.



TREX-DM: a background model in Argon

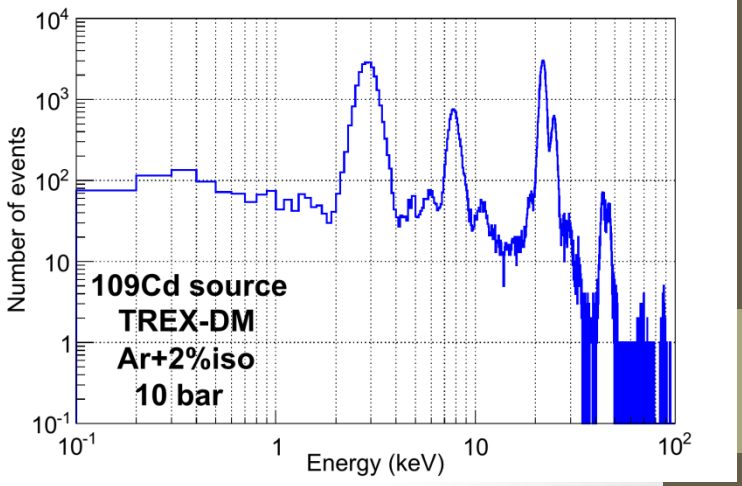
Simulation

- TREX-DM geometry implemented in Geant4.
- CAST simulation code addapted. Some minor changes in data flow (two-volumes, diffusion).
- Final data in AFTER-based format. Same analysis may be applied to real & simulation data.
- First validation: calibrations of CAST-MM detectors.
- Gas: Ar+2%iC_4H_{10} at 10 bar. **Mass = 300 gr**.



Analysis: extension of CAST-MM

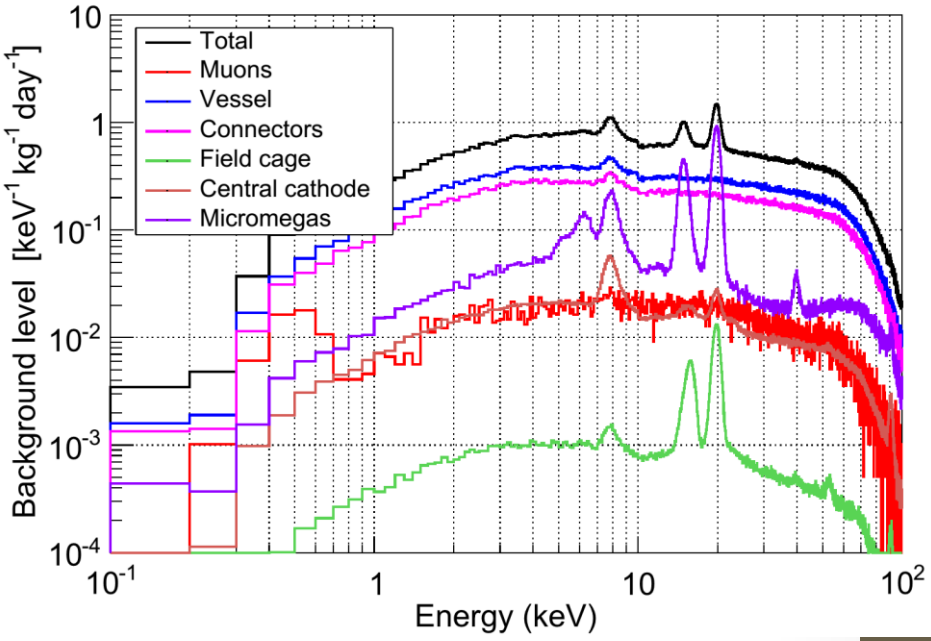
- Low energy x-rays/muon discrimination.
- Likelihood method based on x-ray's features of a ^{109}Cd source at a calibration point.
- RoI: 2-7 keV.
- **Selection criteria:**
  - **Fiducial area**: first 5 mm of MM are used as veto (91.8% of efficiency).
  - **Cluster features** (90% of efficiency).



TREX-DM: a MM-TPC for low mass WIMP detection, F.J. Iguaz et al.

TREX-DM: background model in Argon

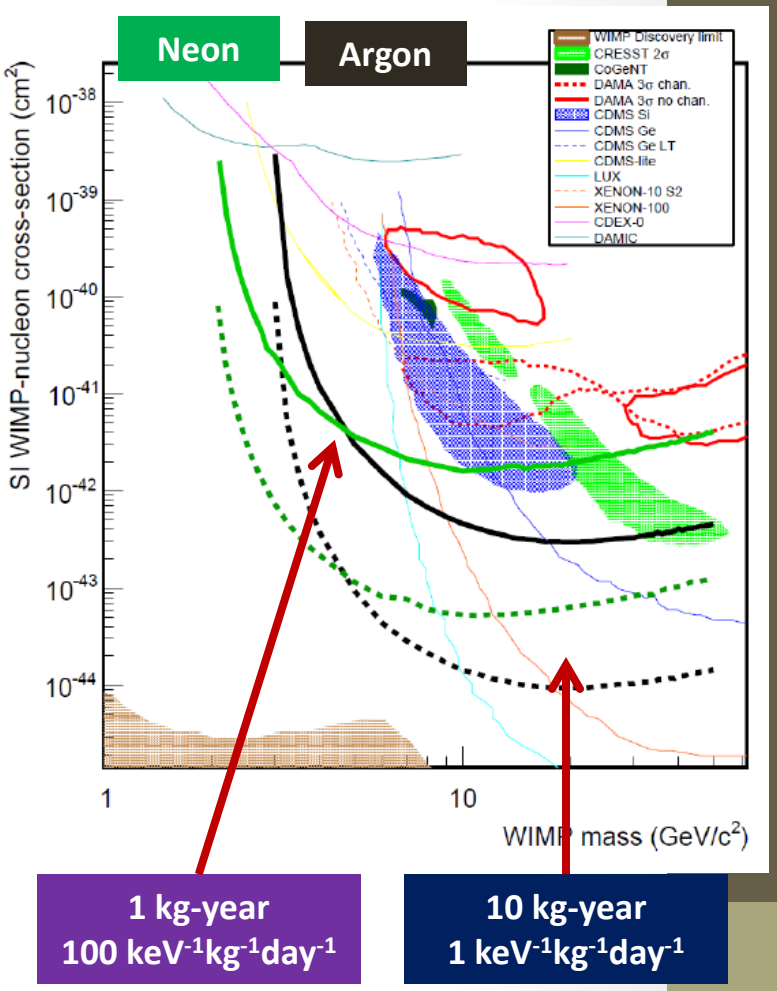
Component	Material	Bck level ($keV^{-1}kg^{-1}day^{-1}$)
Muons	-	2×10^{-2}
^{39}Ar	-	**2×10^{2}**
Vessel	Copper	**4×10^{-1}**
Connectors	Fujipoly	**3×10^{-1}**
Drift structure	Teflon	10^{-3}
Central cathode	Copper	2×10^{-2}
mM detector	Cu-Ka	**10^{-1}**
TOTAL	Without ^{39}Ar	**8×10^{-1}**



- Preliminar result: **2×10^{2} keV^{-1} kg^{-1} day^{-1}**.
- Outer gamma flux & external shielding not yet included.
- Main contribution due to the **^{39}Ar isotope**. If excluded, level is **~1 keV^{-1} kg^{-1} day^{-1}**.
- Other main contributions: copper vessel & inner electrical connectors.

TREX-DM: prospects

- Preliminar background levels based on this analysis:
  - **Argon**: ***2 x 10^2 keV^{-1} kg^{-1} day^{-1}***. Mass = 0.300 kg.
  - **Neon:** ***2 keV^{-1} kg^{-1} day^{-1}***. Mass = 0.160 kg.
- Not yet included a z-dependency.
- Further reduction expected with a neutron/electron discrimination (***J. Billard et al, JCAP 07 (2012) 020***).
- Supossing a 0.5 keV energy threshold, TREX-DM could be sensitive to DAMA signal for a 1 kg-year exposure in a conservative scenario.



Key points for near-term future

- Demostrating a **low energy threshold** increasing mass (pressure).
- **Quenching factor** must be measured. **Common interest for several groups!**

Conclusions & prospects

Conclusions

- Actual Dark Matter experiments are focused on >50 GeV WIMP masses. For lower masses we need: **low energy threshold keeping low background levels.**
- **TREX-DM**: a large Micromegas-based TPC for low WIMP masses.
- **Challenges:** low energy threshold for a large detector area at high pressure.
- **Actual status:** comissioning on surface. Most components validated.
- Micromegas detectors acharacterized at 1.2 bar in Ar+2%iC_4H_{10}. Modest values for energy resolution (**19% FWHM at 22 keV**) and gain **(< 10^3)** , probably due to the low quencher quantity. Improvements expected at higher pressures.
- First data taken with AFTER-based electronics.

Prospects

- Characterization up to 10 bar. Other possible gases: 5%iso, or neon-based.
- Installation of radiopure components in 2015: detectors, flat cables, ...
- Possible installation at LSC in 2016 for a physics run. Still in study.

In memoriam…

Marc Anfreville

Michel Boyer

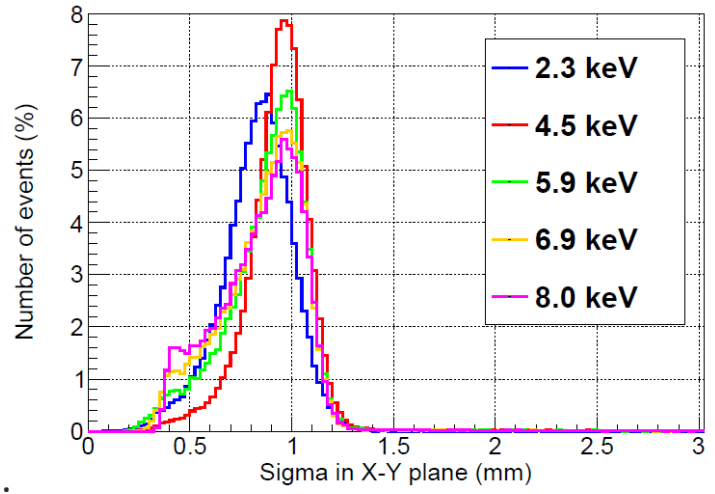
My IRFU/SEDI colleagues, who left us this year.

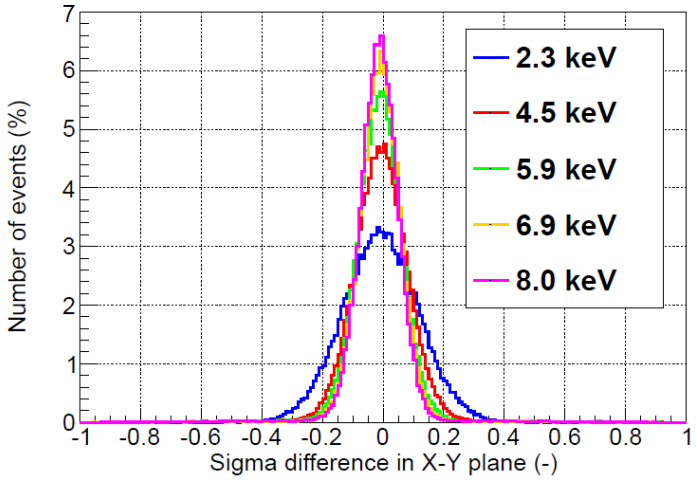
Back-up slides

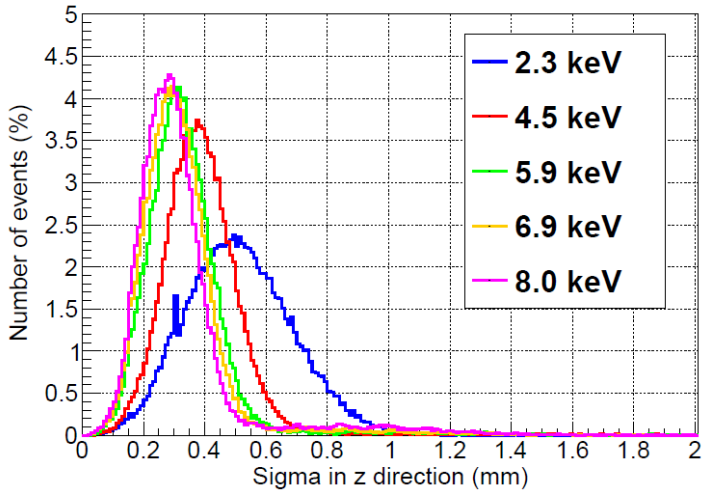
X-ray cluster's topology

J.G. Garza et al., JINST 8 (2013) C12042
F.J. Iguaz et al., PoS(TIPP2014)295

- CAST Microbulk micromegas. 50 µm gap.
- Electron beam at CAST Detector Laboratory.
- Fluorescence lines from 2.3 (gold) to 8.0 keV (copper) used to calculate the signal efficiency.
- Clusters are wider at low energies because most of the x-rays are absorbed in the first mms just after the window and suffer more diffusion.
- Cluster differences increase at low energies as more charge fluctuations between the XY planes.



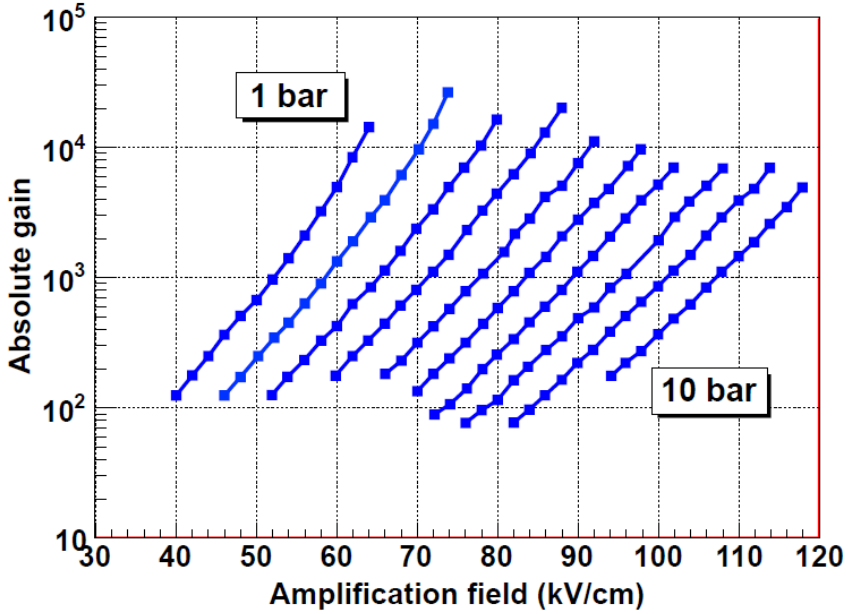




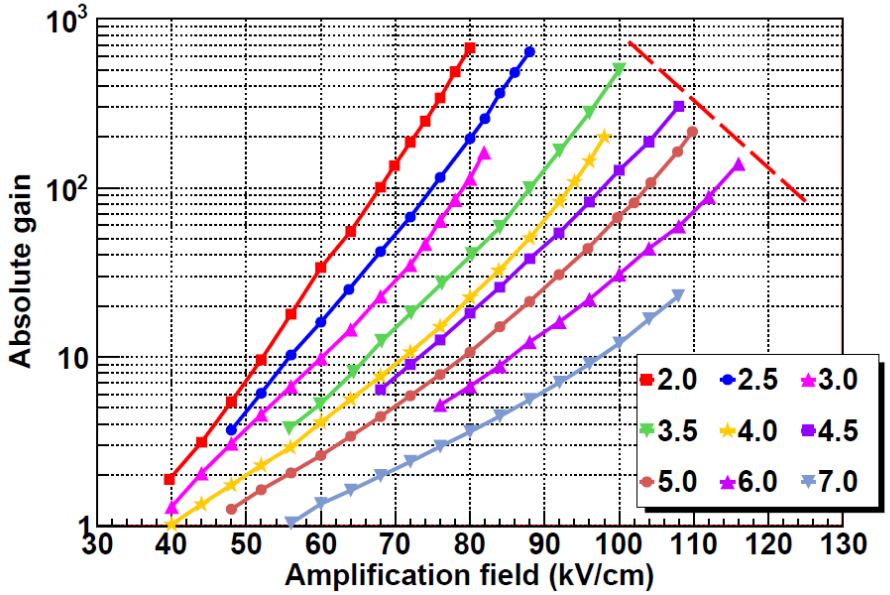
Argon-based at 1-10 bar

F.J. Iguaz et al., RD51 meeting, Fribourg May 2010

- Microbulk micromegas. 50 µm gap.



Ar+1%iso
^{57}Co source

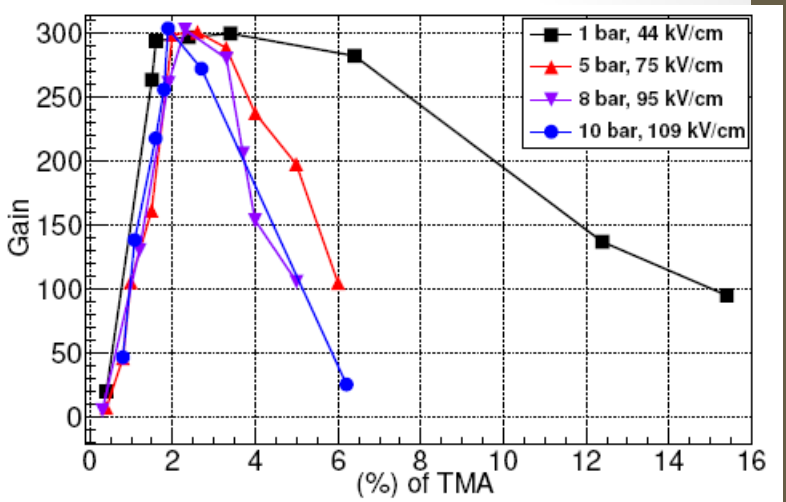


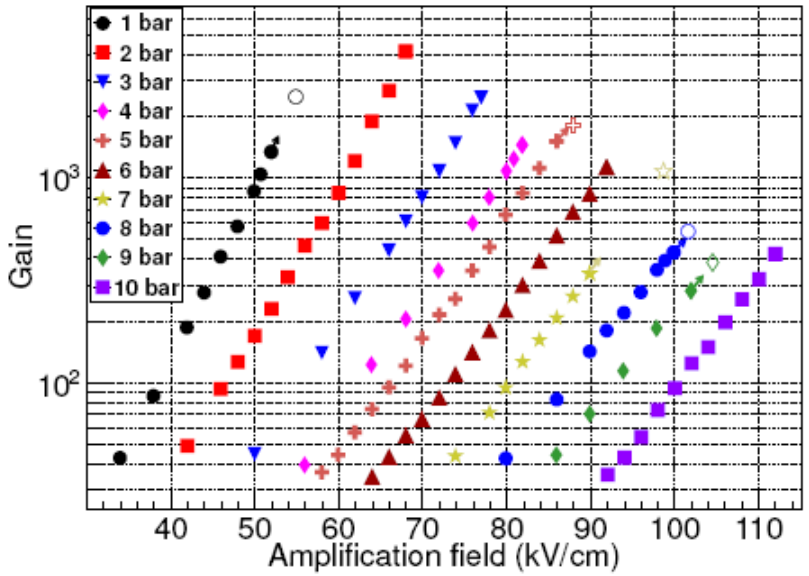
Pure argon
^{241}Am source

Xe-TMA at 1-10 bar

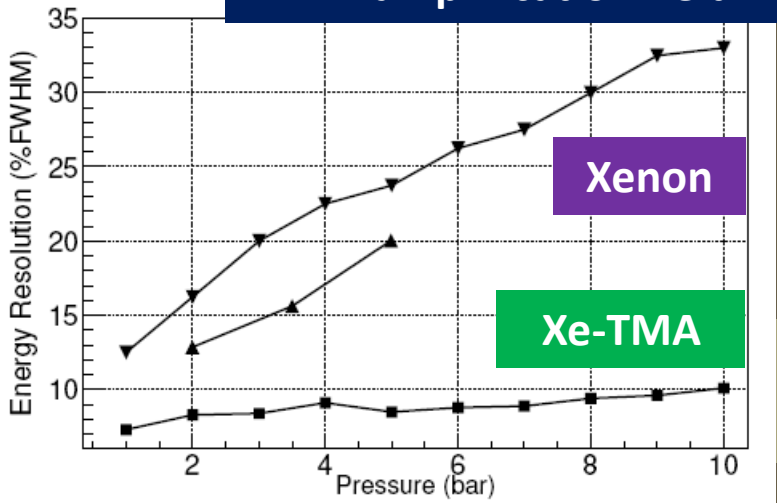
S. Cebrian et al., JINST 8 (2013) P01012
D C Herrera et al, J. Phys.: Conf. Ser. 460 012012

- Microbulk micromegas. 50 µm gap.
- ^{109}Cd source (22.1 keV x-rays).
- Best performance for 1.5-2.5% TMA.
- Maximum gain of $2x10^3$ (5×10^2) at 1 (10) bar, i.e., x3 than in pure xenon.
- Energy resolution: 7.3 (9.6) % FWHM at 22.1 keV for 1 (10) bar, i.e., a factor 2 (3) better than in pure xenon.





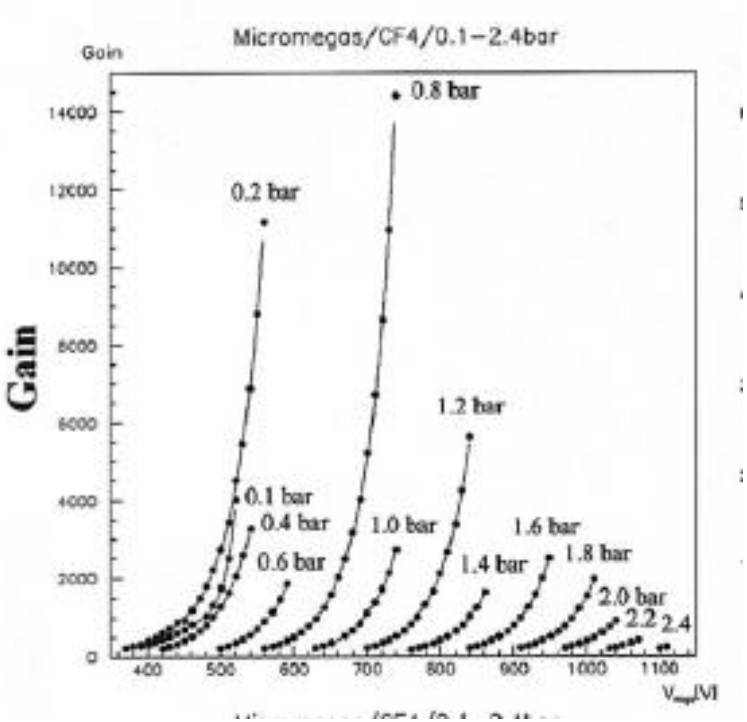
Gain vs %TMA for a fixed amplification field

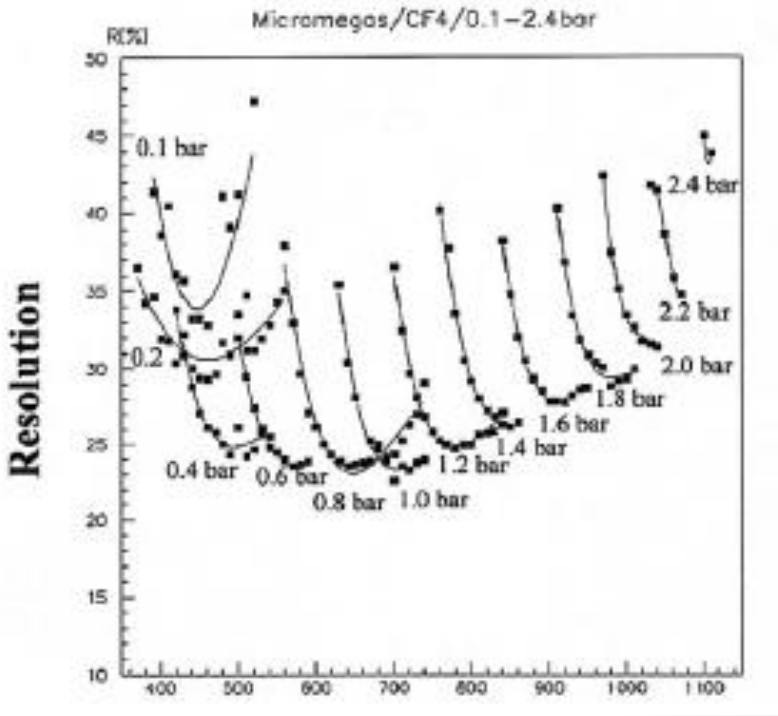


CF_4 at 0.1-2.4 bar

P. Jeanneret et al., NIM A 500 (2003) 133

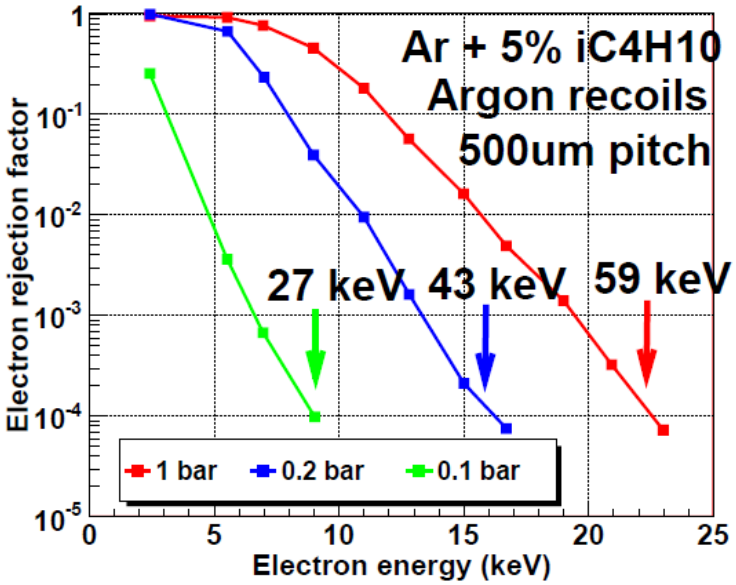
- Bulk micromegas. 128 µm gap.
- ^{55}Fe source (5.9 keV x-rays).



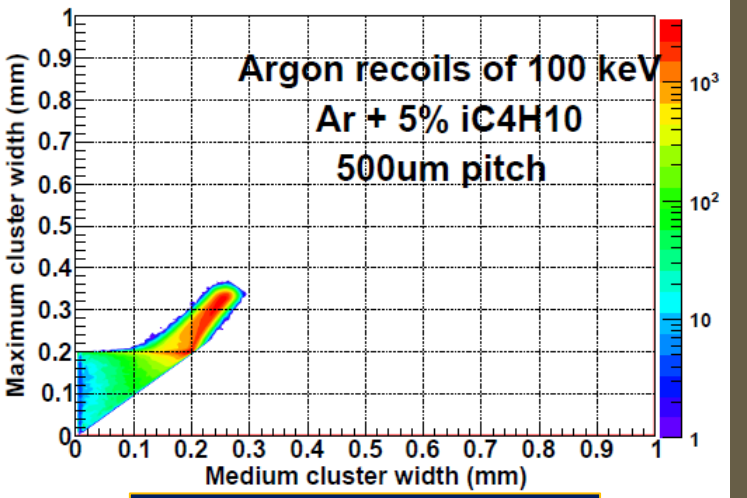


Electron/neutron discrimination

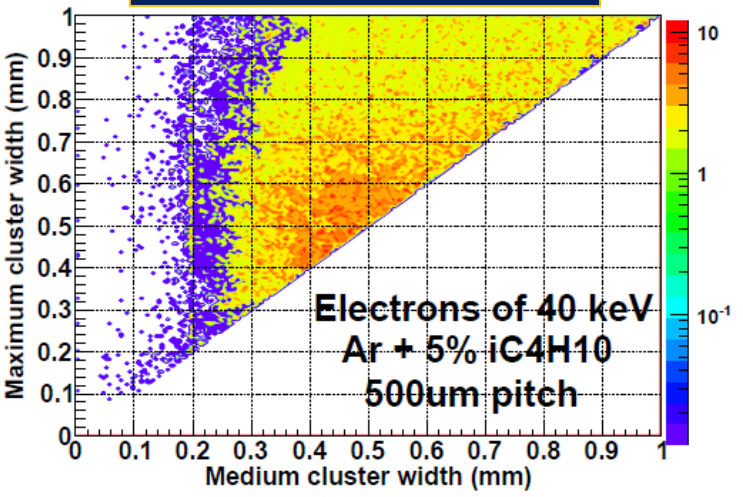
- First studies: A. Tomas in CYGNUS 2007.
- The cluster width is the key parameter and is more efficient at low pressures.
- It sharply increases from electrons but remains constant for neutrons.



F.J. Iguaz, Phys. Proc. 37 (2012) 1079



Maximum and medium cluster widths

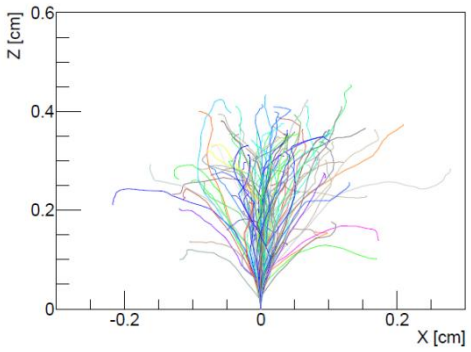


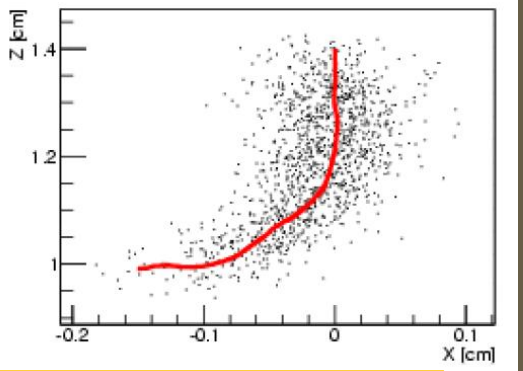
MIMAC directionality in CF_4

J. Billard, F. Mayet, D. Santos, JCAP 04 (2012) 006

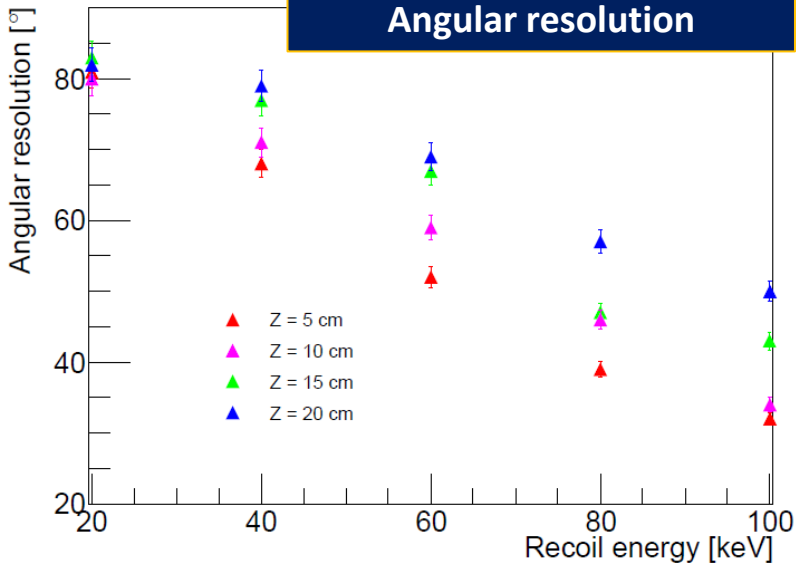
- The angular resolution & sense recognition depends on the energy and the drift distance.
- The sense recognition for recoil energies below 100 keV is unrealistic.
- Focus on axial directional detectors.

Fluorine recoil track

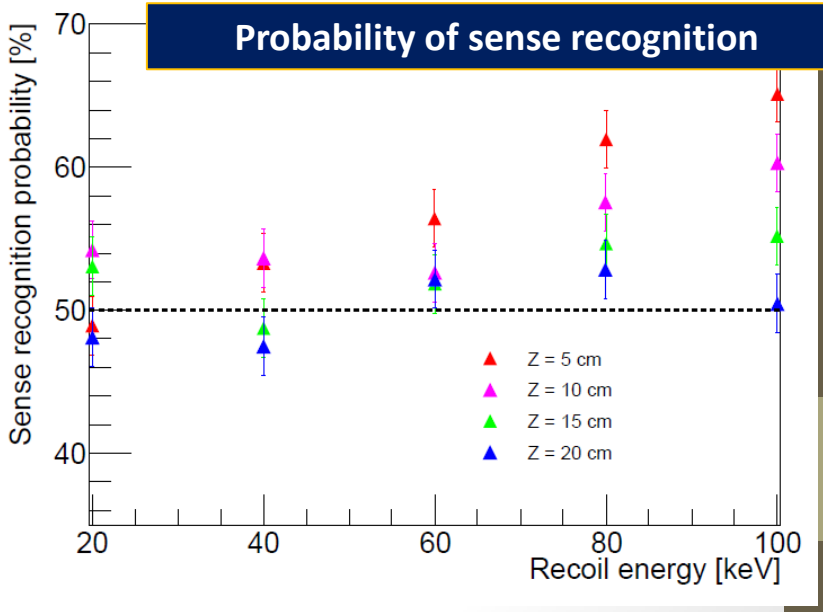




Angular resolution



Probability of sense recognition

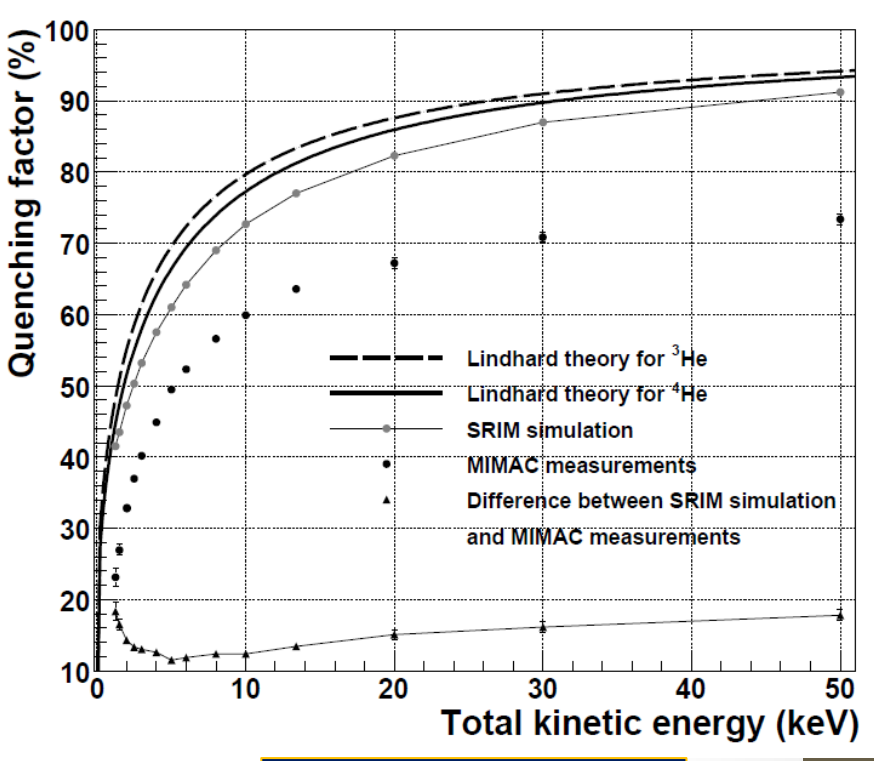


TREX-DM: a MM-TPC for low mass WIMP detection, F.J. Iguaz et al.

Measurement of quenching factor by MIMAC experiment

D. Santos et al., arXiv:0810.1137
O. Guillaudin et al., arXiv:1110.2042

- A complete R&D program to measure the quenching factor of energy recoils in different gas mixtures.
- Measured in ^{3}He & ^{4}He.
- Actual efforts focused on CF4.



Quenching factor in Helium 3 & 4

Quenching factor in CF_4 & CF_4-CF_3