TREX-DM:

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

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Universidad Zaragoza 1542

erc European Research Council

StG-2009: T-REX

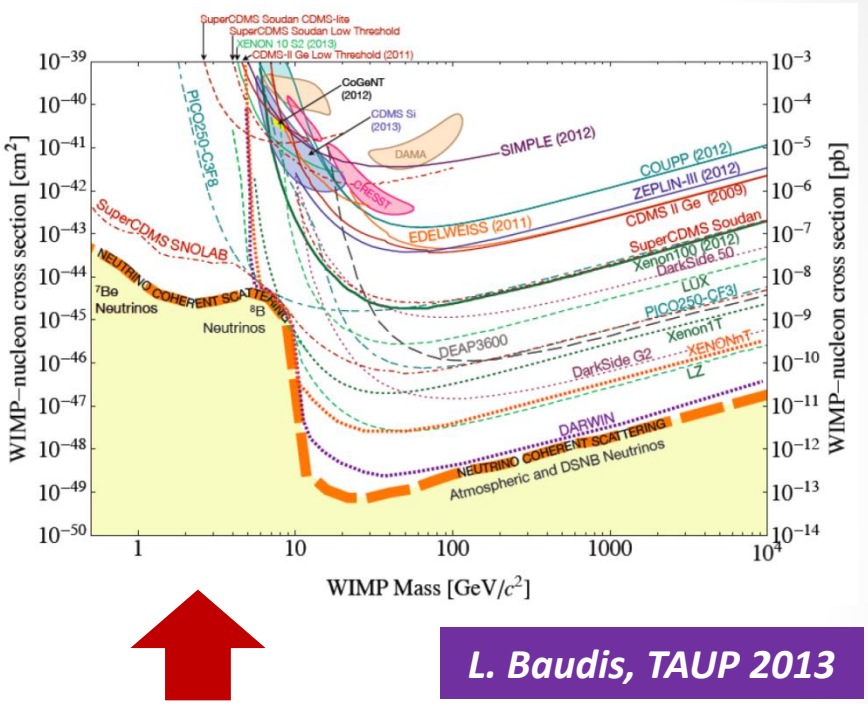
Outline

- Motivation for a low mass WIMPs Micromegas detector.
- TREX-DM: description & comissioning.
- Background model of TREX-DM in argon & neon-based gases.
- 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.



L. Baudis, TAUP 2013

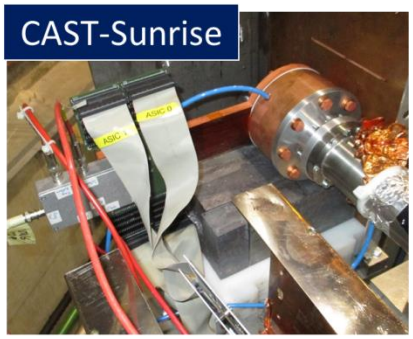
What happens if mass <10 GeV?

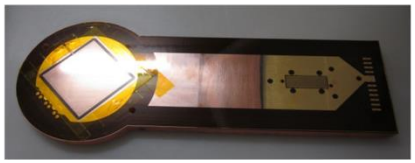
- Energy threshold < 1 keV.
- Electron/nuclear recoil discrimination.
- Quenching factor at keV energies.
- DAMA/LIBRA signal is near these masses.

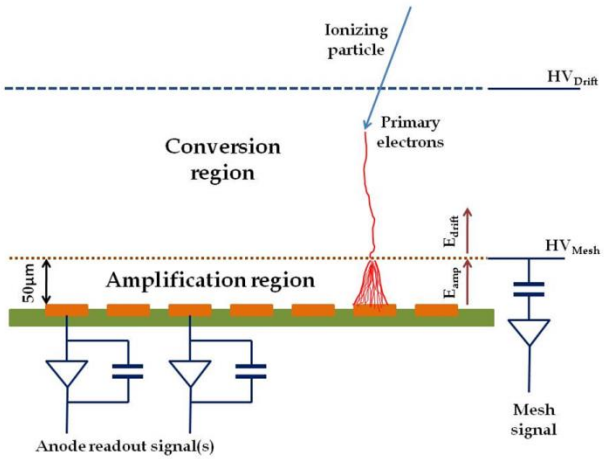
TREX-DM: commissioning and background model, F.J. Iguaz et al.

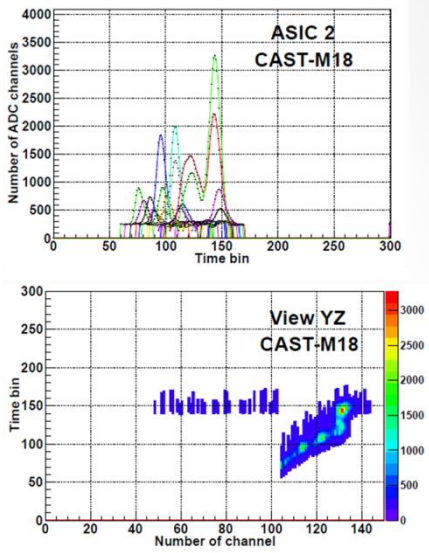
Micromegas: a TPC readout

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:** Mesh is mechanically fixed to the anode (CAST, ATLAS).
- **Bulk:** Mesh is bulked to the anode (COMPASS, T2K, CLAS-12, nTOF, MIMAC…)
- **Microbulk:** Anode & mesh built in one piece by chemical processing (CAST & nTOF).

Why a Micromegas TPC?

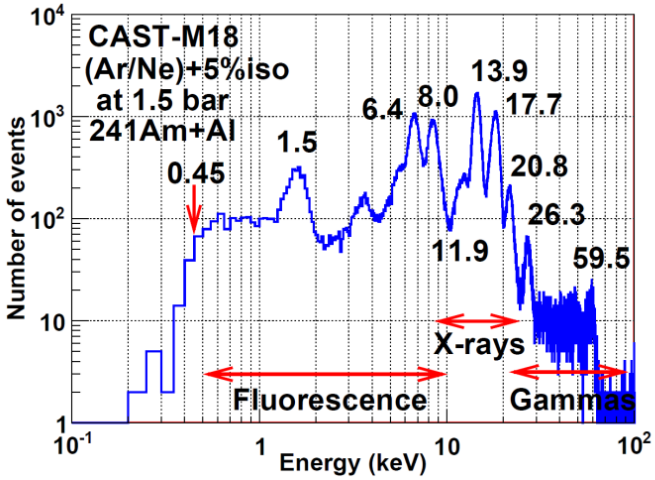
- Consolidated manufacture.
- Intrinsic radiopure (only kapton + copper).
- A low energy threshold (< **450 eV**) is feasible.
- Topology information available.
- Radiopurity control techniques can be applied.
- Scaling up experience in CAST/IAXO & NEXT.

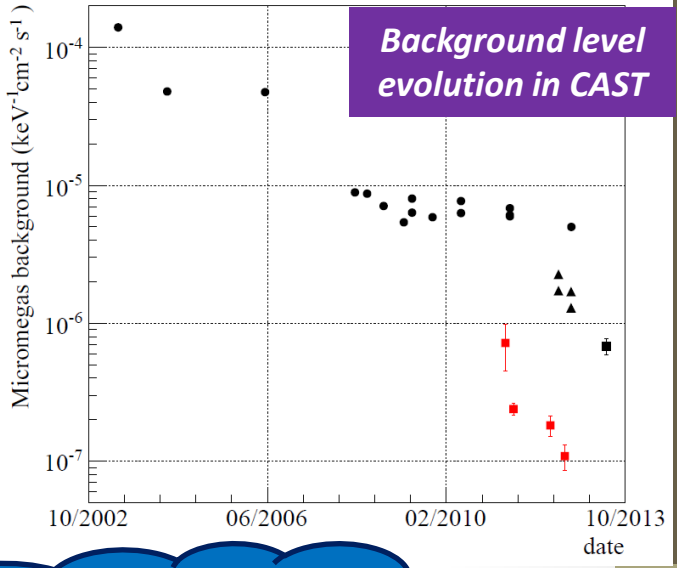
Challenges:

- 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.

References:

- Manufacture: ***JINST 7 (2012) P04007.***
- Radiopurity: ***Astr . Part. 34 (2011) 354***.
- Discrimination power: ***JINST 8 (2013) C12042.***
- Energy threshold: ***JINST 9 (2014) P01001.***
- Radiopurity control: ***JINST 8 (2013) C11012.***





J.An. García, Axion search with low background MM!

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**.

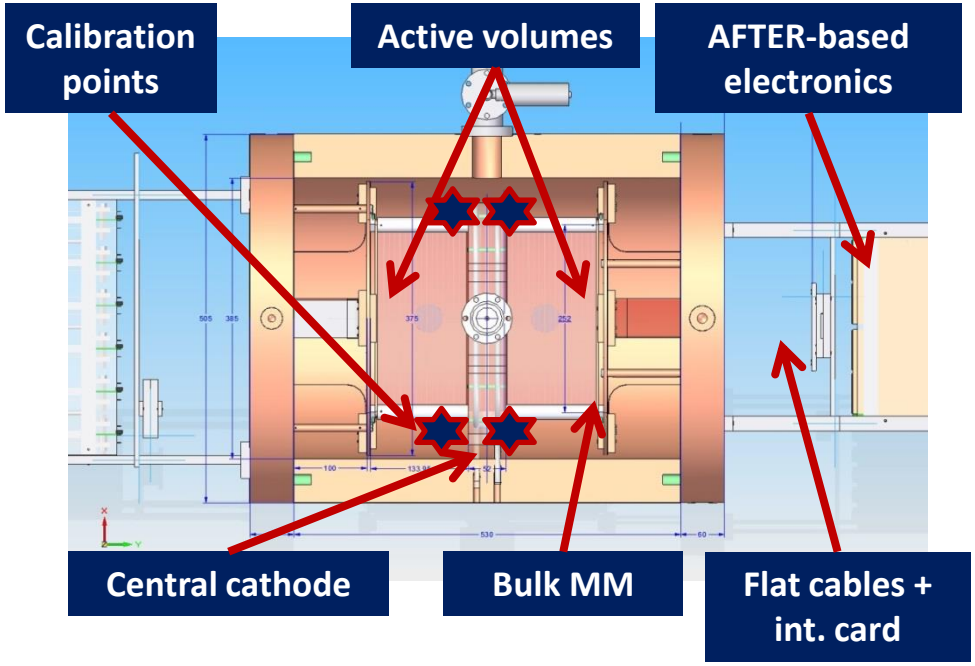
Timeline:

- **First version, not fully radiopure: 2012-15**
  - Design, construction & comissioning.
  - Systematic measurement of the radiopurity of all components.
  - General characterization of bulk MM in argon & neon based mixtures.
  - Study of energy threshold with electronics chain & pressure.
  - Discrimination of x-rays vs muons by cluster properties.

- **Radiopure version for a physics run: 2015-16.**
  - Installation of radiopure components: Micromegas detectors, flat cables, ...
  - Surface cleaning of all components.
  - Modification of the setup for a 10 cm thick lead shielding.
  - Possible installation at LSC in 2016 for a physics run. Still in study.

TREXDM: main features.

F.J. Iguaz et al, 7th Large TPC Symposium, arXiv:1503.07085



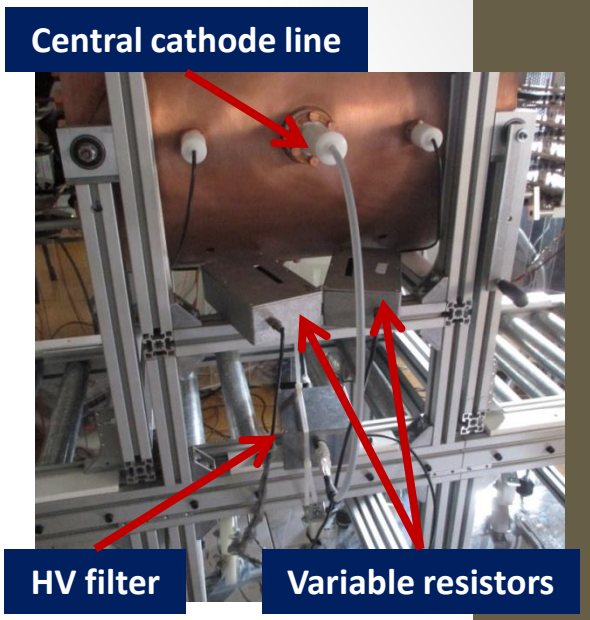
A view of TREX-DM

- Two active volumes & a central cathode.
- Copper vessel: 6 cm thickness, 0.5 m diameter, 0.5 m length.
- 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 (auto-trigger capabilities).
- 4 points/side of calibration for a ^{109}Cd source inside a plastic tube.

TREX-DM: Comissioning

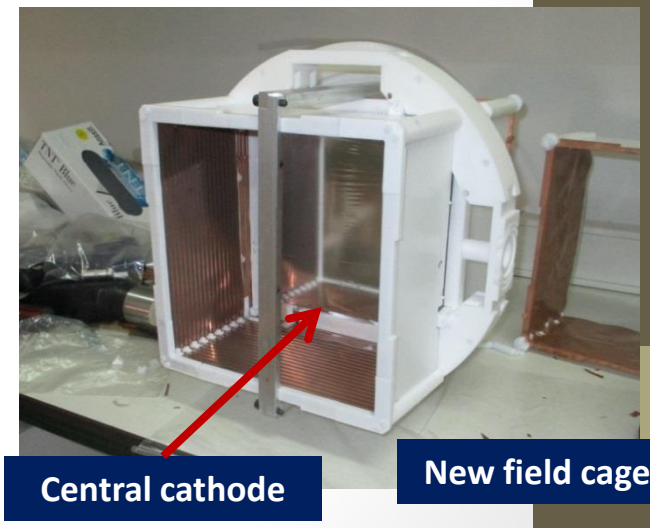
Changes during 2015:

- HV filter for central cathode line to reduce noise level.
- New field cage to reduce border effects & a better HV isolation.
- Central copper cathode replaced by mylar one (better for α's).
- Removed leaks >10^{-5} mbar l/sec, found at some feedthroughs and some o-rings. Outgassing rate = **4 x 10^{-4} mbar l/sec**
- New DAQ to read both detectors at a rate of 45 Hz each side.



Pending issues:

- HV cables inside the vessel to be replaced by radiopure ones & a better plastic isolation.
- An automatic calibration system, essential for LSC run.
- A bake-out system to further reduce the outgassing rate.
- **Grounding & noise level.**
- **Update for LSC (new flat cables & detector, …).**

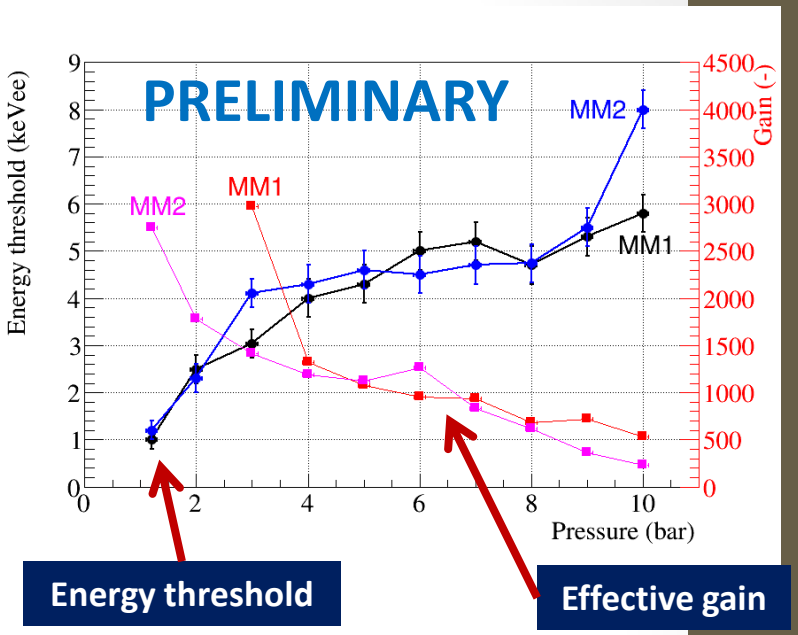


TREXDM: Comissioning.

J.G. Garza et al., MPGD 2015

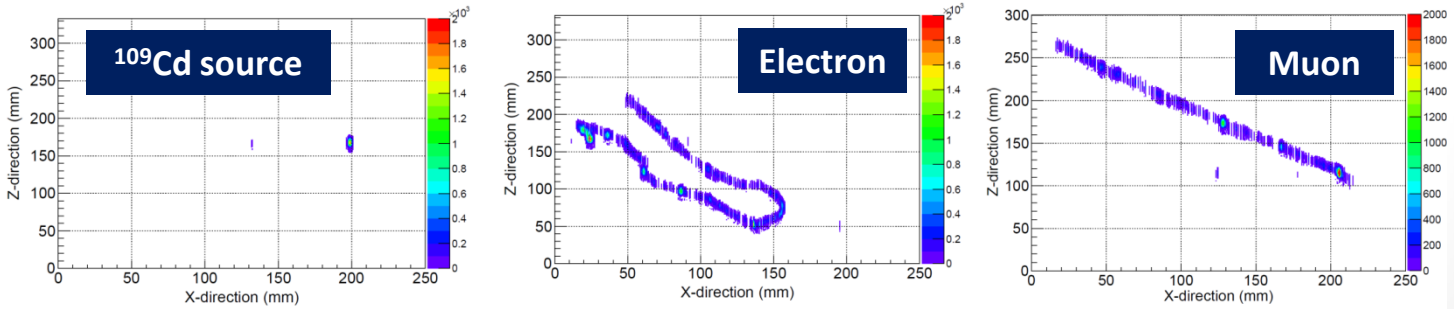
Main results in Ar+2%iso:

- Detectors characterized for pressures up to 10 bar.
- Operation gain decreased from 3 x 10^3 at 1.2 bar down to 5 x 10^2 at 10 bar.
- Energy threshold degraded from **1 to 6 keV**, using mesh signals. **Values should be better using strips.**
- Energy resolution at 22.1 keV degraded from 16% FWHM at 1 bar up to 26% FWHM at 10 bar.



Near-term changes:

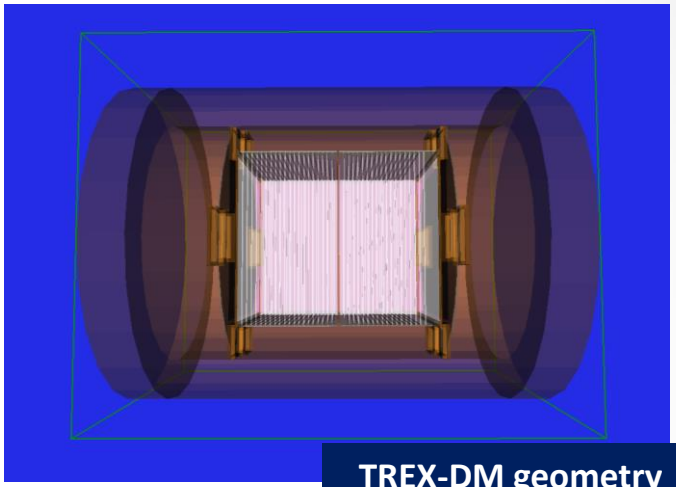
- **Noise issue**: new mesh cables, electrical isolation from gas tubes, preamplifiers,…
- **2% isobutane** may not be enough to absorb avalanche photons. 5% to be tested.



TREX-DM: commissioning and background model, F.J. Iguaz et al.

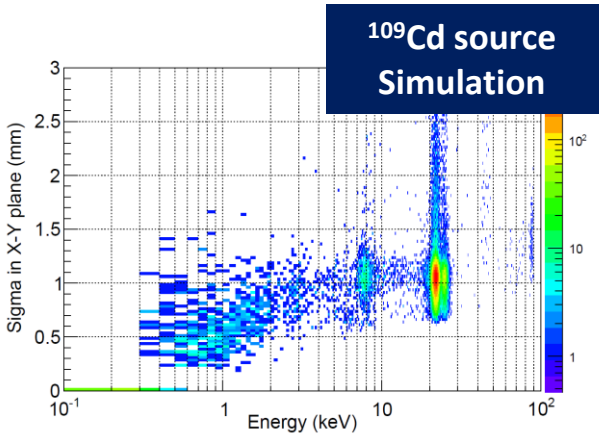
TREX-DM: a background model in Ar & Ne

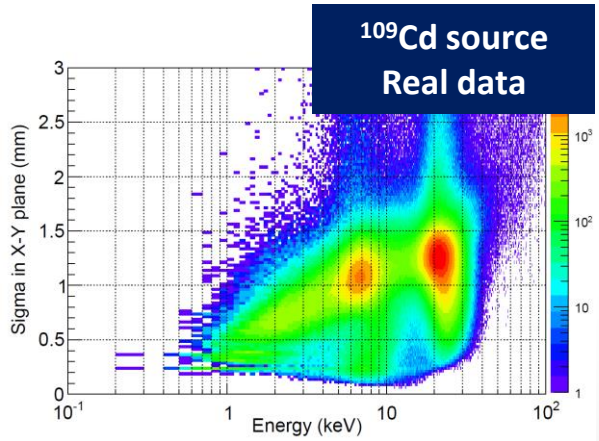
- TREX-DM geometry implemented in Geant4.
- CAST simulation code addapted to TREX-DM. Minor changes in data flow (two-volumes, diffusion).
- Final data in AFTER-based format. Same analysis may be applied to real & simulation data.
- Small differences in signal response between simulation and real data. To be clarified in future.
- Results are scaled by the measured activities.
  - Ar+2%iC_4H_{10} at 10 bar. **Mass = 300 gr**.
  - Ne+2%iC_4H_{10} at 10 bar. **Mass = 160 gr**.



TREX-DM geometry

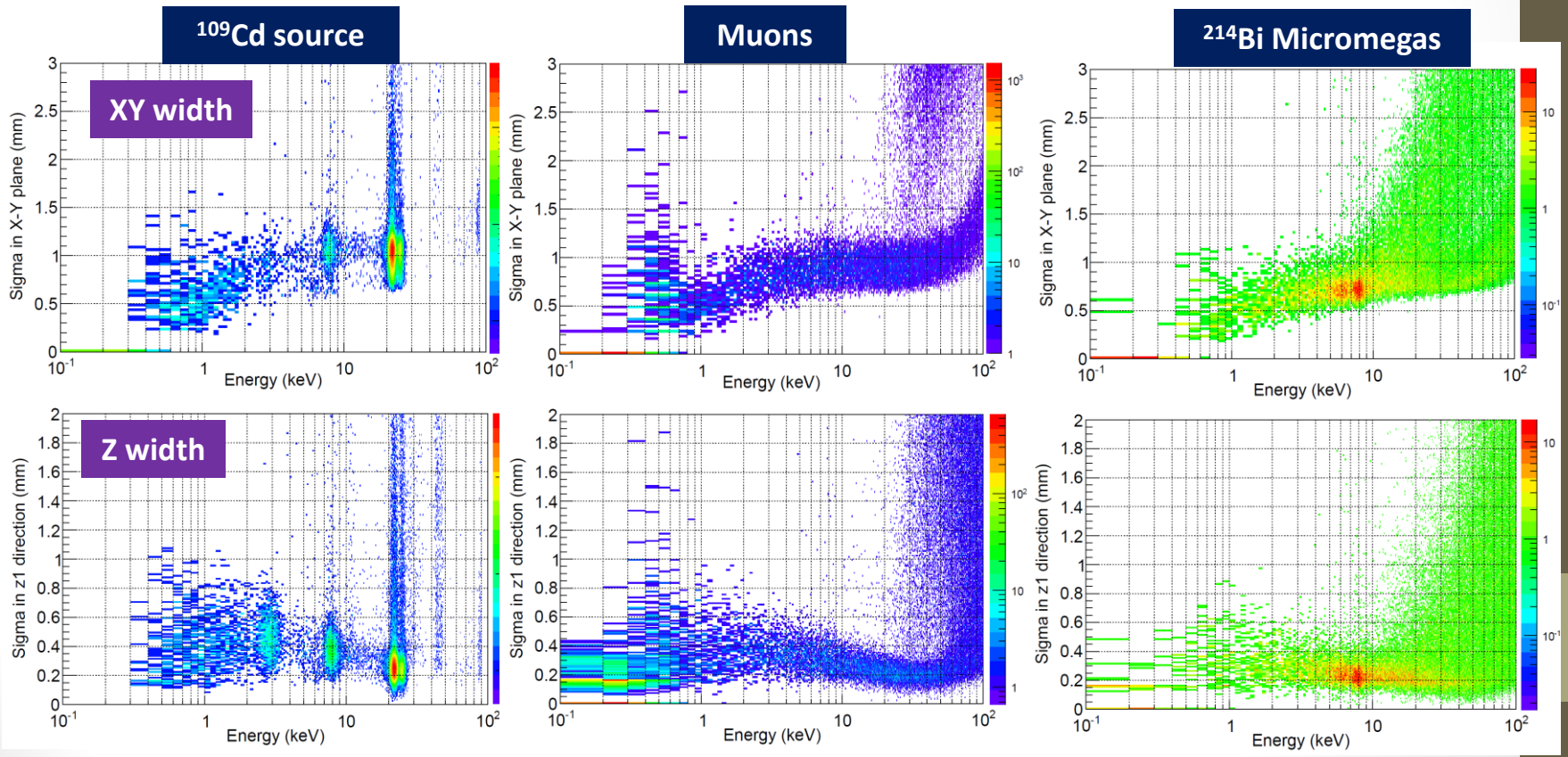
XY width





TREXDM analysis

- Extension of CAST analysis, used for axions events. RoI: **2-7 keV**.
- Low energy x-rays/muon discrimination based on clusters' features -> ^{109}Cd (22.1 keV).
- Pending issue: z-dependency of cluster features.
- Signal efficiency: **80%** (90% by fiducial area, 90% discrimination).

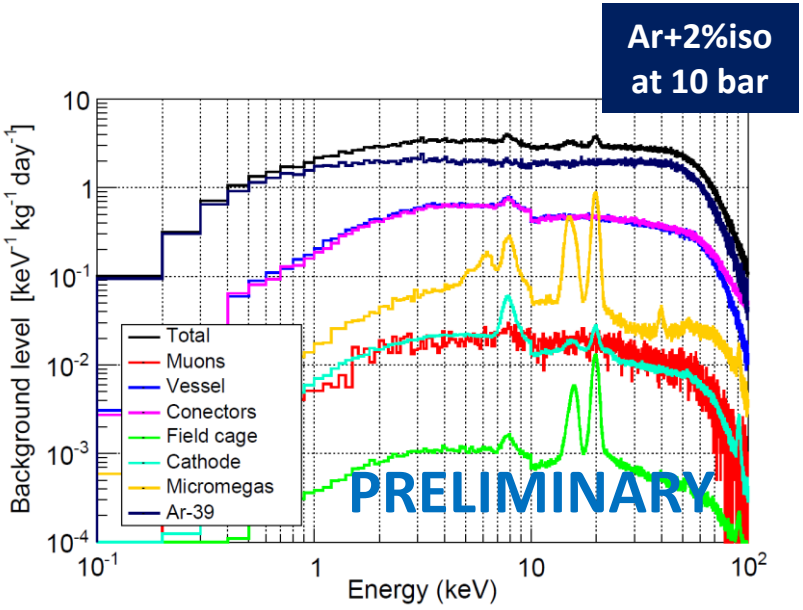


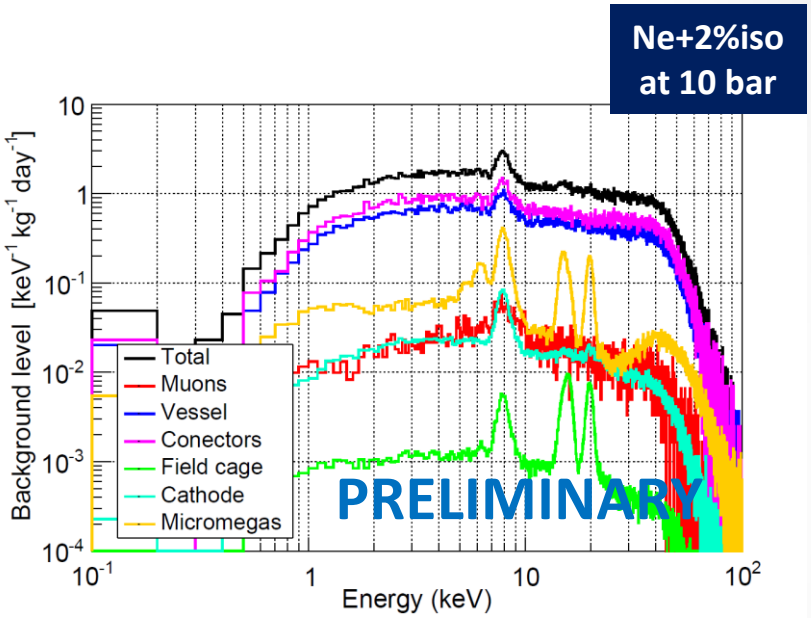
TREX-DM: background model in Ar & Ne

Component	Material	Back. level ($keV^{-1}kg^{-1}day^{-1}$) Argon	Neon	Reference	
Muons	-	0.019	0.026	LSC	G. Luzon, IDM 2008
Cosmogenics	^{39}Ar	**2.04**	-	DarkSide	J. Xu et al, Astr. Part 66 (2015) 53
Vessel	Copper	**< 0.33**	**< 0.37**	EXO-200	D.S. Leonard et al., NIMA 591 (2008) 490
Connectors	Fujipoly	**0.58**	**0.87**	T-REX	Unpublished
Field cage	Teflon	1.0×10^{-3}	1.2×10^{-3}	EXO-200	D.S. Leonard…
Cathode	Copper	< 0.020	< 0.022	EXO-200	D.S. Leonard…
mM detectors	Cu-Ka	< 0.1	< 0.084	BiPo	Unpublished
TOTAL		**3.09**	**1.38**		**Statistical error < 10%**

- Preliminar results for argon & neon at 2-7 keV: **3.09 & 1.38 keV^{-1} kg^{-1} day^{-1}**.
- Outer gamma flux, external shielding & neutrons not yet included.
- Main contributions: **^{39}Ar** (for argon based), **electrical connectors** and **vessel (limits)**.
- **^{39}Ar** contribution will be **2×10^2 keV^{-1} kg^{-1} day^{-1}** if argon comes from **surface** sources.

TREX-DM: background model in Ar & Ne





- Preliminar results for argon & neon at 2-7 keV: **3.09 & 1.38 keV^{-1} kg^{-1} day^{-1}**.
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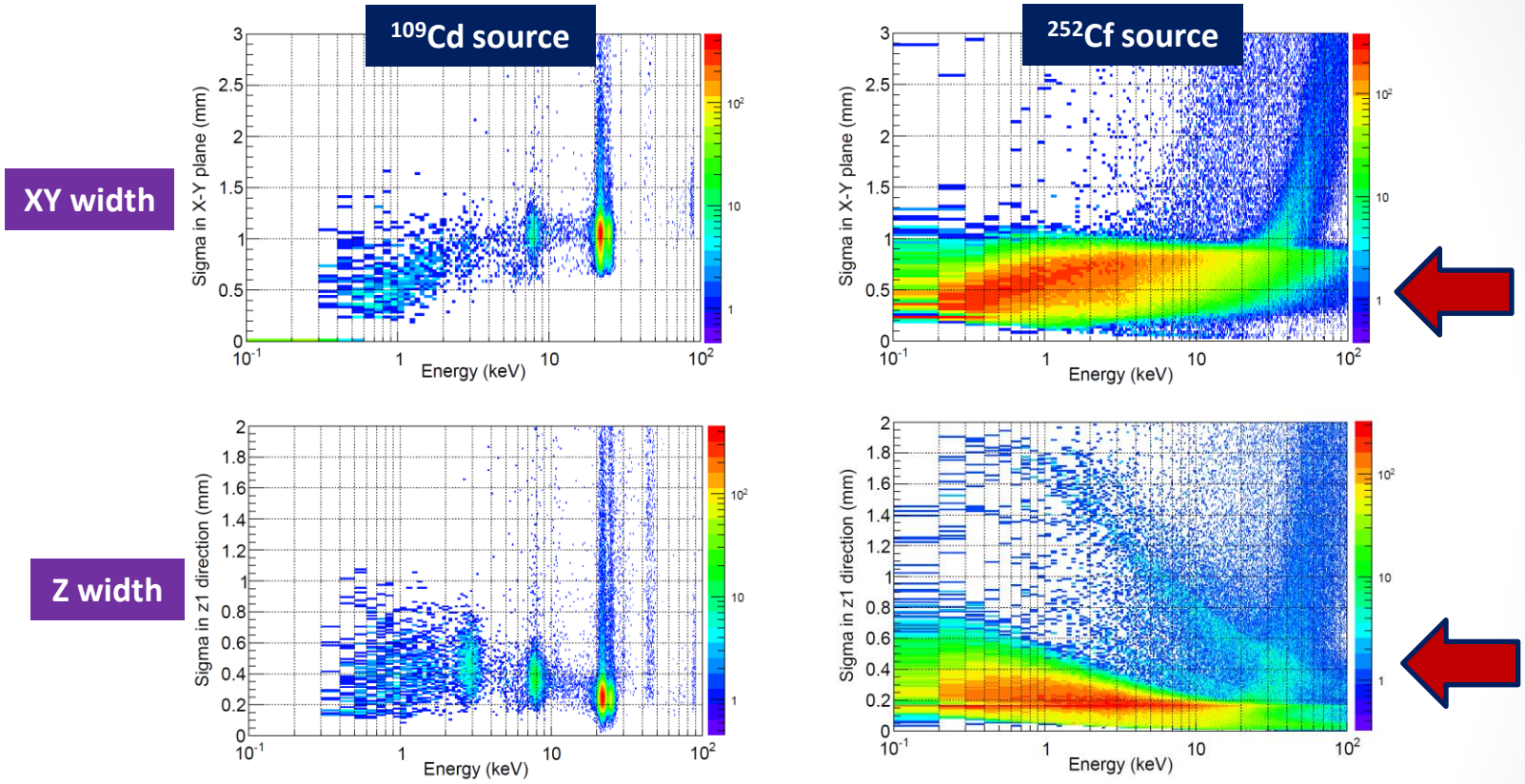
TREX-DM: commissioning and background model, F.J. Iguaz et al.

TREX-DM: electron/neutron discrimination



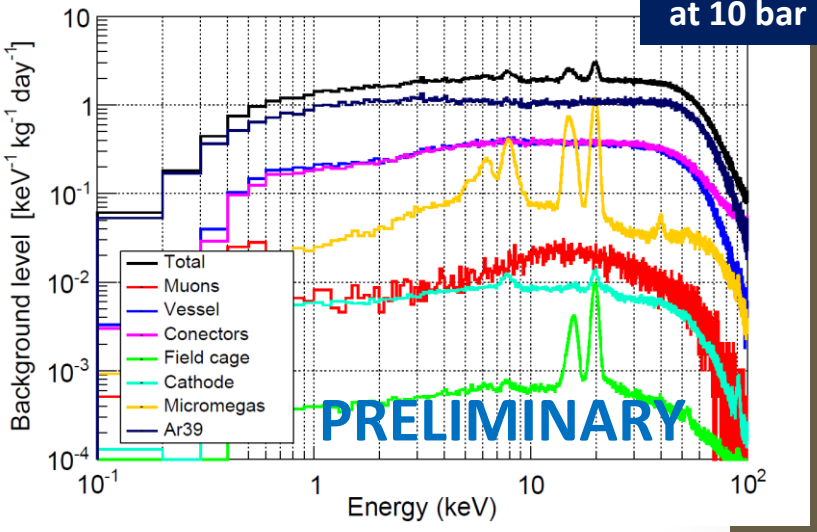
- A neutron source (^{252}Cf) has been simulated to verify if further background reduction could be reached by a neutron/electron discrimination.
- Neutrons show narrower cluster widths than x-rays but there is no clear separation between the two distributions.

TREX-DM: commissioning and background model, F.J. Iguaz et al.

TREX-DM: electron/neutron discrimination

Component	Material	Back. level ($keV^{-1}kg^{-1}day^{-1}$) ^{109}Cd analysis	^{252}Cf analysis
Muons	-	0.019	0.011
Cosmogenics	**^{39}Ar**	**< 2.04**	**< 1.14**
Vessel	Copper	**< 0.33**	**< 0.19**
Connectors	Fujipoly	**0.58**	**0.33**
Field cage	Teflon	1.0×10^{-3}	5.7×10^{-4}
Cathode	Copper	< 0.020	< 0.008
mM detectors	Cu-Ka	< 0.1	< 0.115
TOTAL		**3.09**	**1.79**

Ar+2%iso at 10 bar



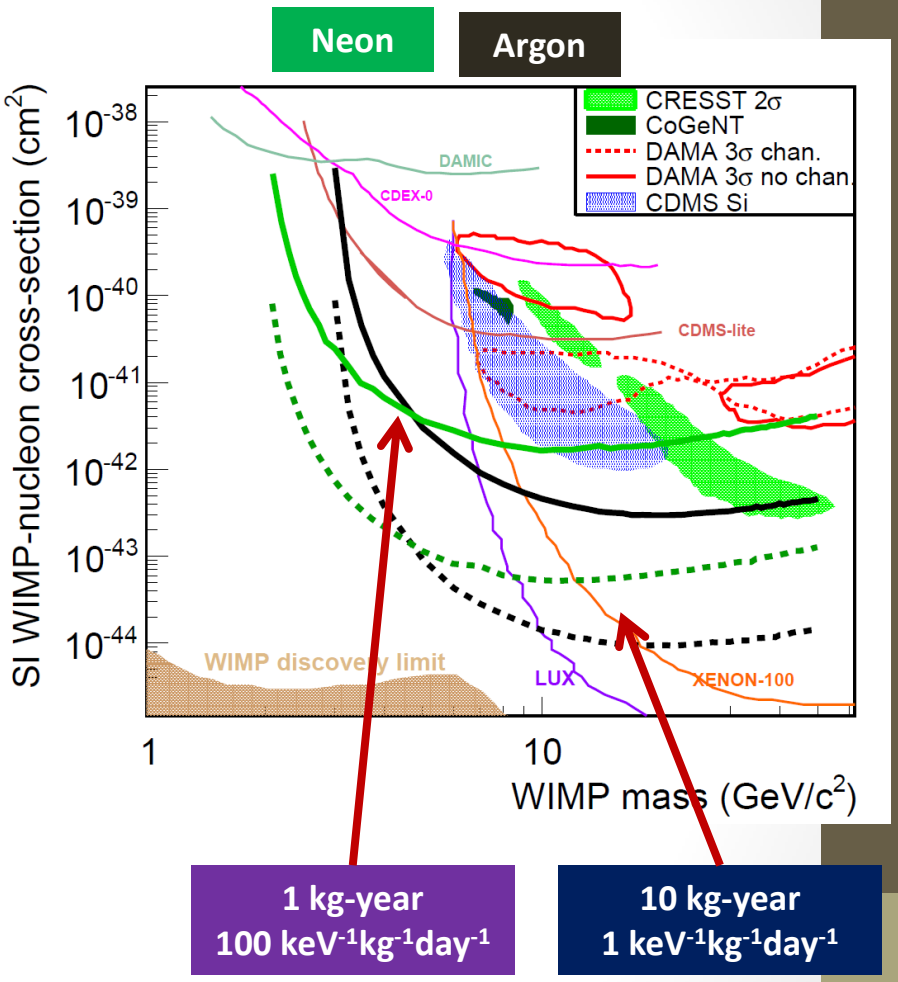
Statistical error < 10%

- Preliminary background reduction: **~44% (3.09 -> 1.79).**
- Effective for all components, except for Micromegas detectors (narrower clusters).

TREX-DM: prospects

Results by ^{109}Cd-based analysis:

- **Argon @ 10 bar**: ***3.09 keV^{-1} kg^{-1} day^{-1}***.
- **Neon @ 10 bar: *1.38 keV^{-1} kg^{-1} day^{-1}***.
- These values are mainly defined by the measured activities.
- Supossing a **0.4 keVee** energy threshold & this background model is valid, TREX-DM could be sensitive to the regions defined by hints of positive WIMPs signals in a conservative scenario.



Key points for near-term future:

- **Low energy threshold** at high pressures.
- **Quenching factor** must be measured.

TREX-DM: commissioning and background model, F.J. Iguaz et al.

Conclusions

TREX-DM: a large Micromegas-based TPC for low WIMP masses.

- **Challenges:** low energy threshold for a large detector area at high pressure.

Comissioning

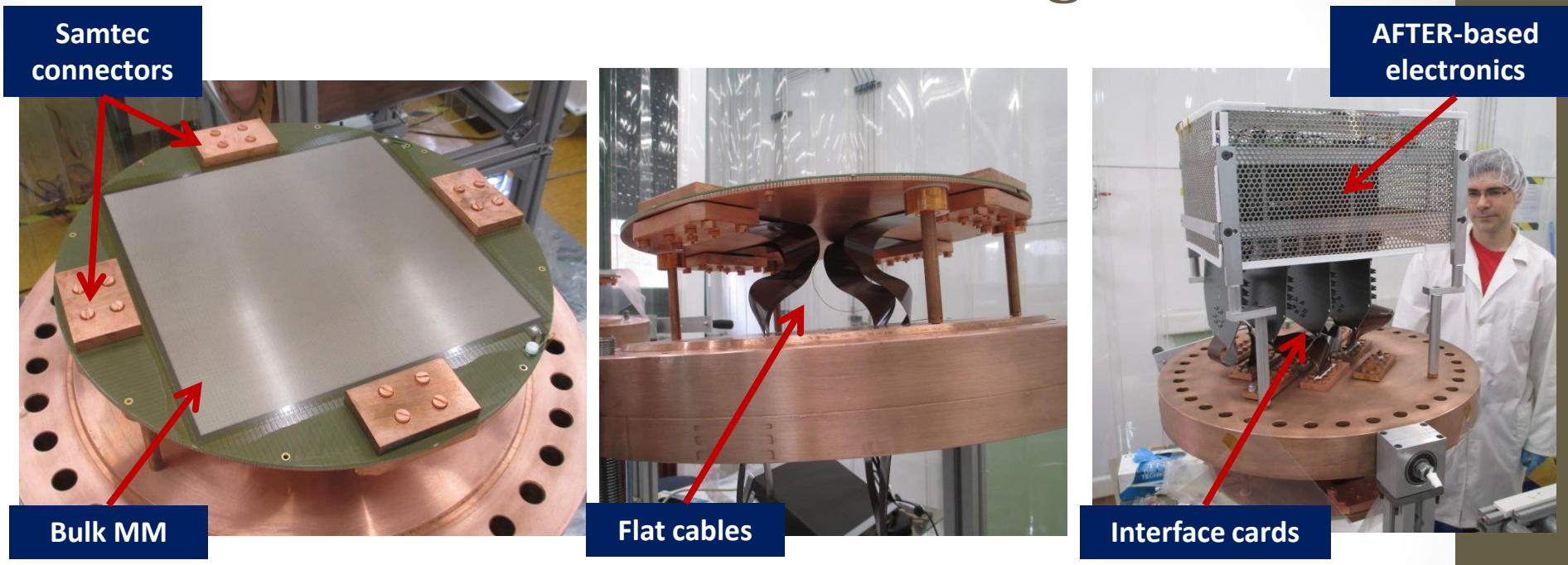
- **Actual status:** commissioning of a not fully radiopure setup.
  - Many components fixed in 2015 (field cage, filters, leaks..) Still some issues pending.
  - Detectors characterized in Ar+2%iso up to 10 bar.
  - A degradation observed in terms of operation gain, energy threshold & resolution.
  - An improvement expected by a better grounding or a higher quantity of quencher.
- **Near-term future**: update of several components for a fully radiopure setup, to be possibly installed at LSC during 2016.

Prospects:

- A first background model of TREX-DM in argon & neon-based gases has been created.
- Results are based on: Geant4 + simulation signal response + analysis + measurements.
- Background levels around **1-3 count keV^{-1} kg^{-1} day^{-1}** for a **80%** signal efficiency.
- Supossing a **0.4 keVee** energy threshold, TREX-DM could be sensitive to the regions defined by hints of positive WIMPs signals in a conservative scenario.

Back-up slides

TREXDM in detail: the Micromegas detector



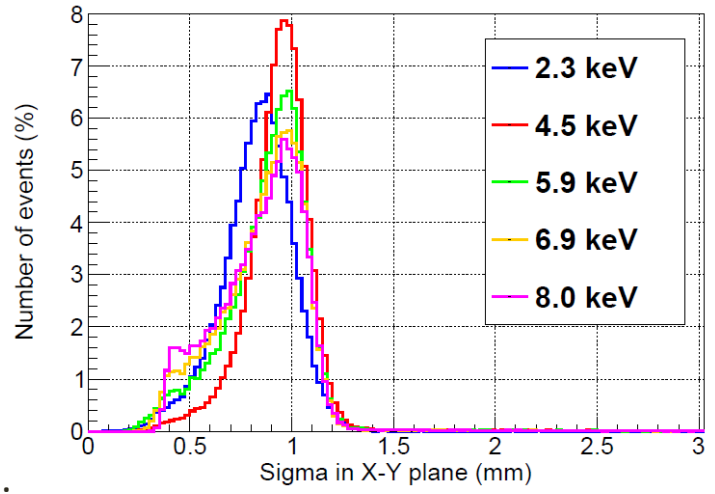
- 20 x 20 cm^2 bulk Micromegas: 432 X-strips & 432 Y-strips, 0.5 mm pitch, 128 μm gap.
- Strips signals extracted by 4 flat cables using 300-Samtec connectors. A small shielding included too: **1 cm copper + 1 cm lead**.
- An interface card links a flat cable to the FEC. Any short-cut may be eliminated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

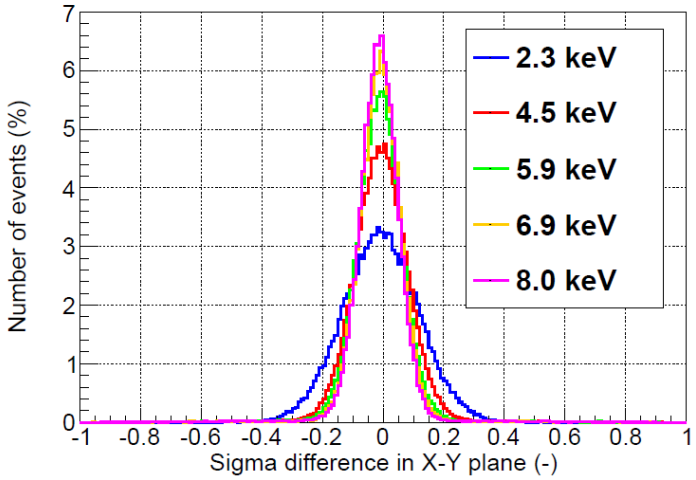
Many thanks to IRFU/SEDI-Micromegas workshop!!!

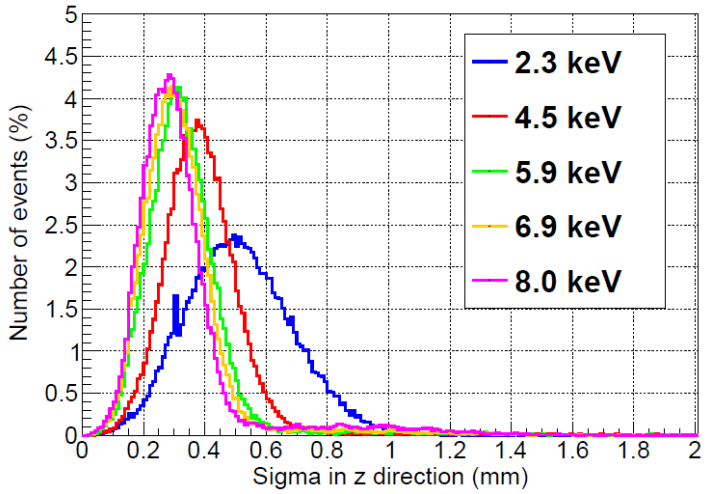
X-ray cluster's topology

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.



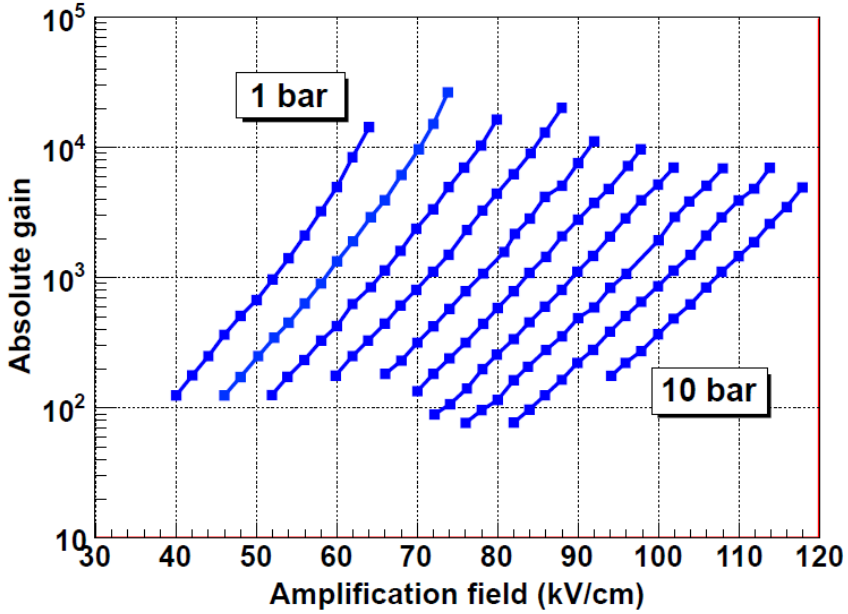




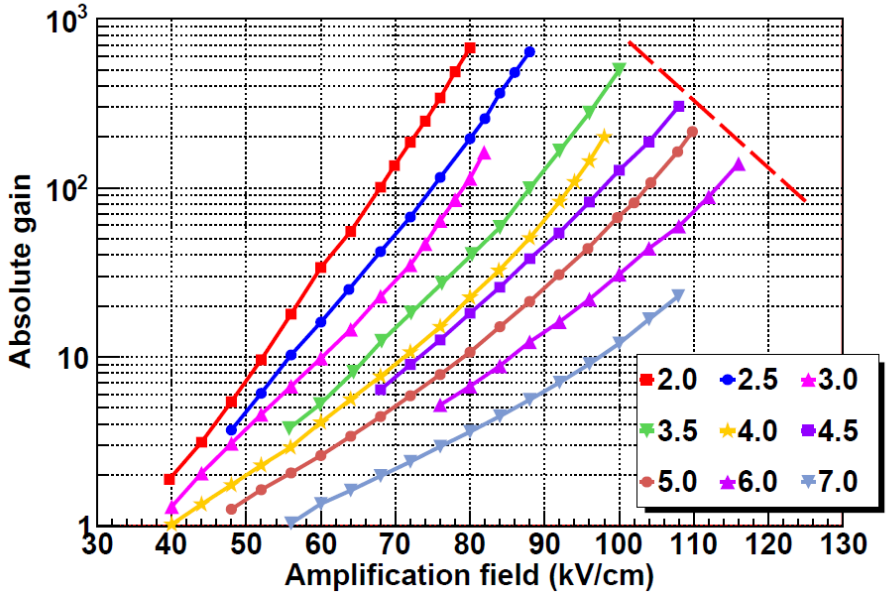
Argon-based at 1-10 bar

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

- Microbulk micromegas. 50 µm gap.



Ar+1%iso
^{57}Co source

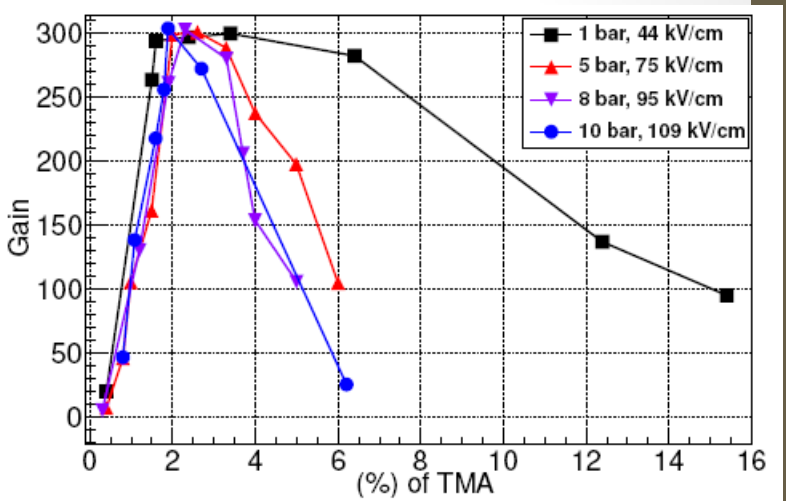


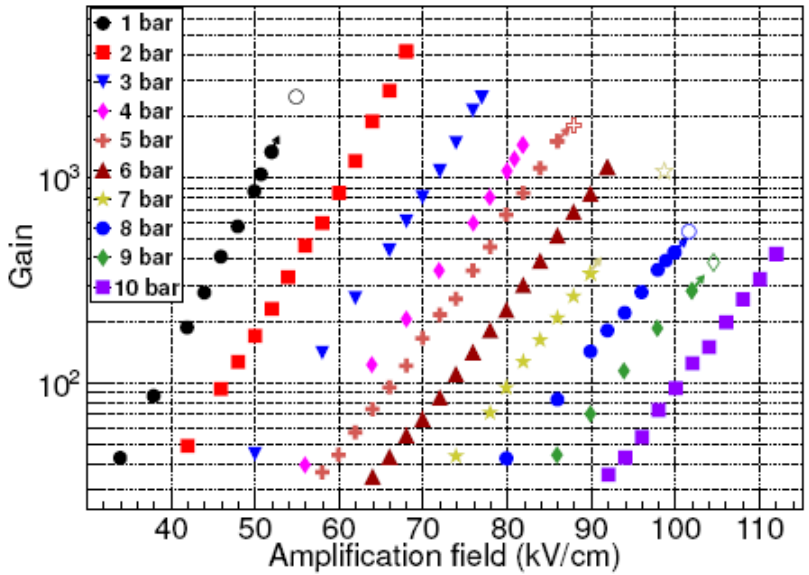
Pure argon
^{241}Am source

Xe-TMA at 1-10 bar

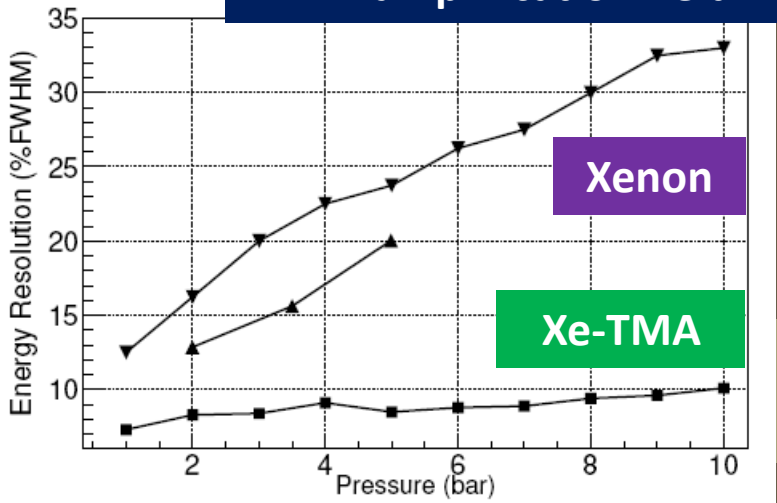
S. Cebrian et al., JINST 8 (2013) P01012
D C Herrera et al, J. Phys.: Conf. Ser. 460 012012

- 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.





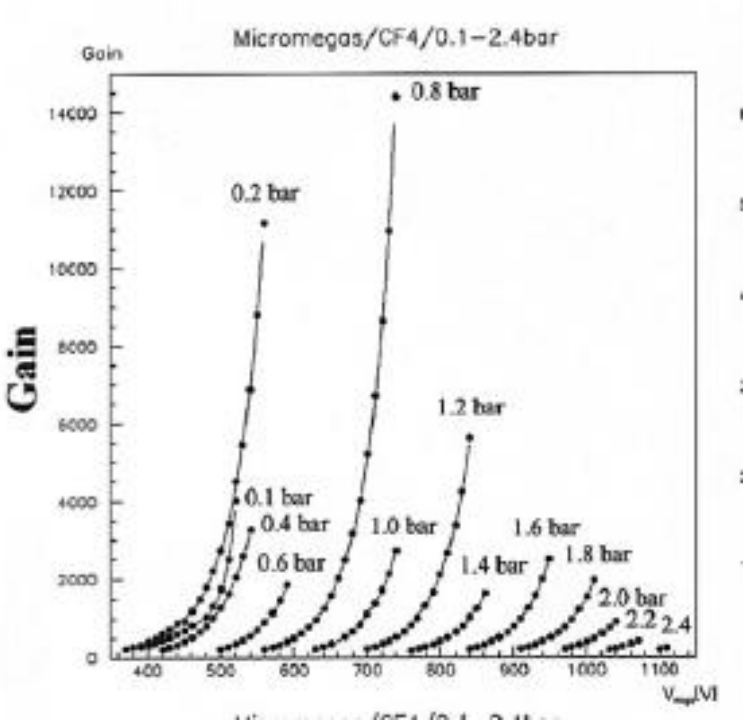
Gain vs %TMA for a fixed amplification field

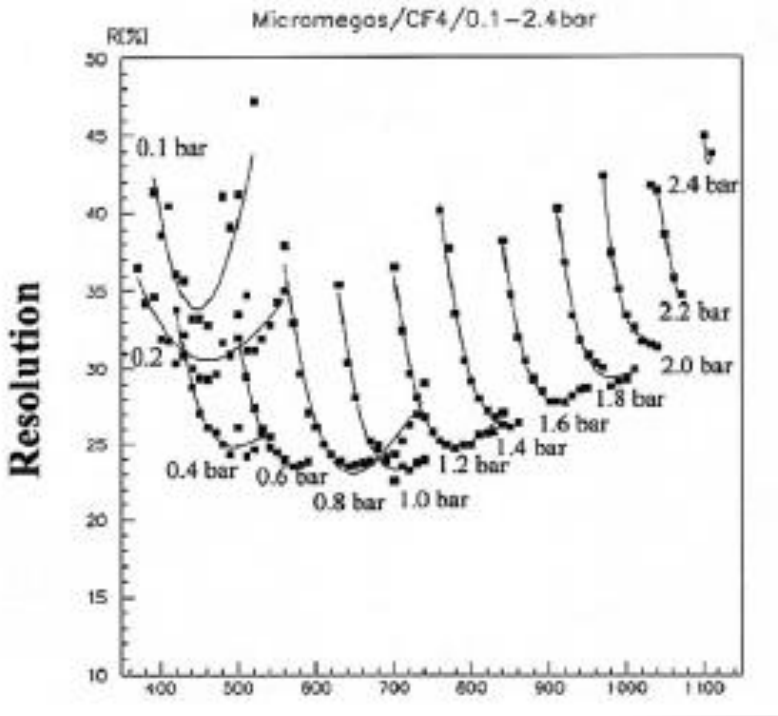


CF_4 at 0.1-2.4 bar

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

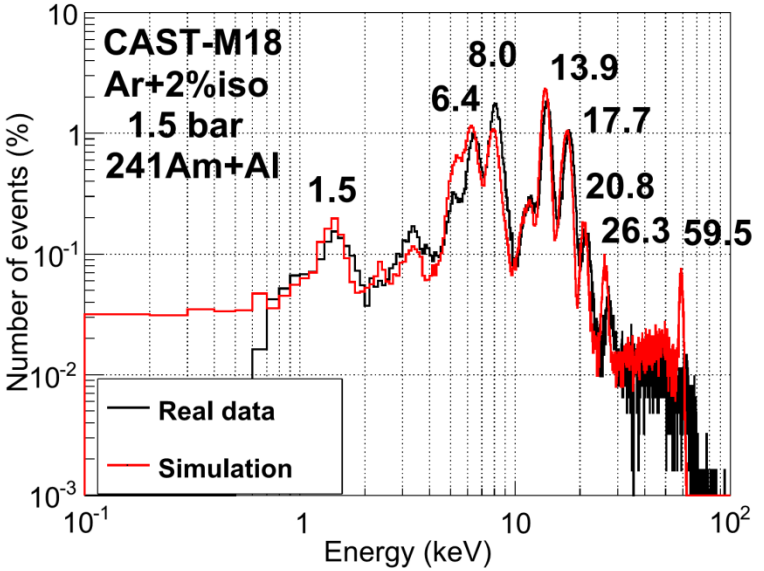
- Bulk micromegas. 128 µm gap.
- ^{55}Fe source (5.9 keV x-rays).





Data-flow: validation.

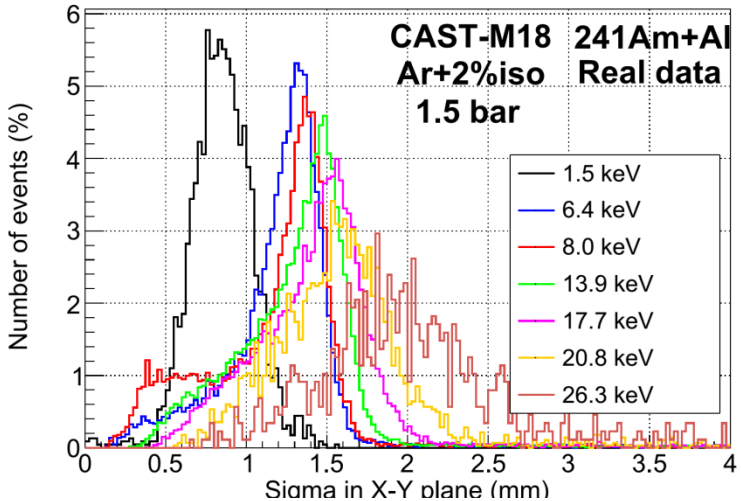
- As a validation of the complete chain, an ^{241}Am calibration of M18 has been used.
- Gas: Ar+2%iC_4H_{10} at 1.5 bar.
- **Pros:** many lines, energy dependece study.
- **Cons:** geometry of ^{241}Am not fully defined.
- Simulated the CAST-MM geometry implemented by A. Tomás & A. Rodríguez.
- Energy spectra quite similar. Big differences at high energy gammas (saturation?) and small ones at fluorescence lines.

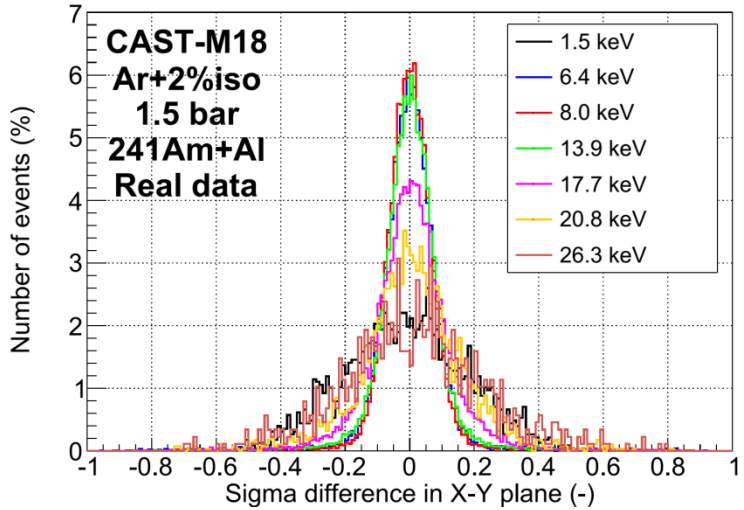


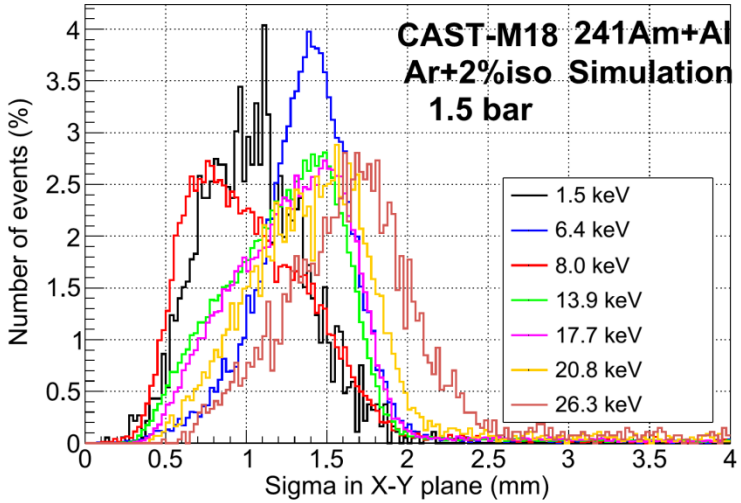
Conclusions

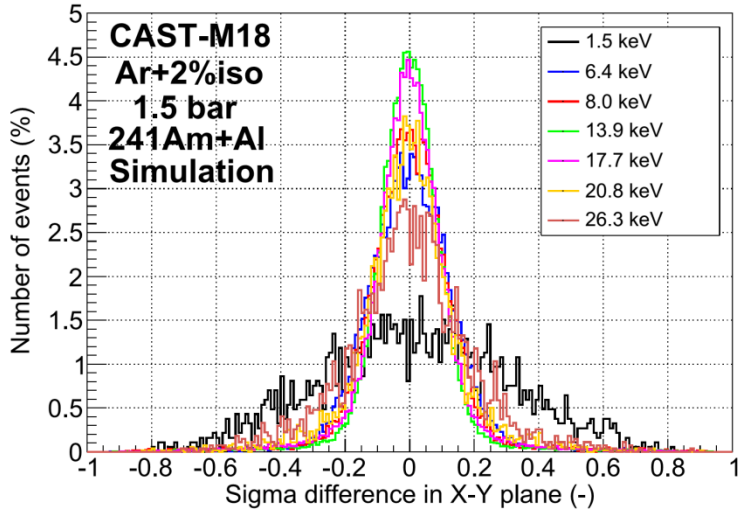
- Cluster width's distributions are quite similar, except for the 8 keV line (too much copper at the bottom?). Main differences at low widths.
- Less charge fluctuations between planes for real data at energies < 15 keV. At higher energies, the simulated fluctuations are little.

Data-flow: validation.



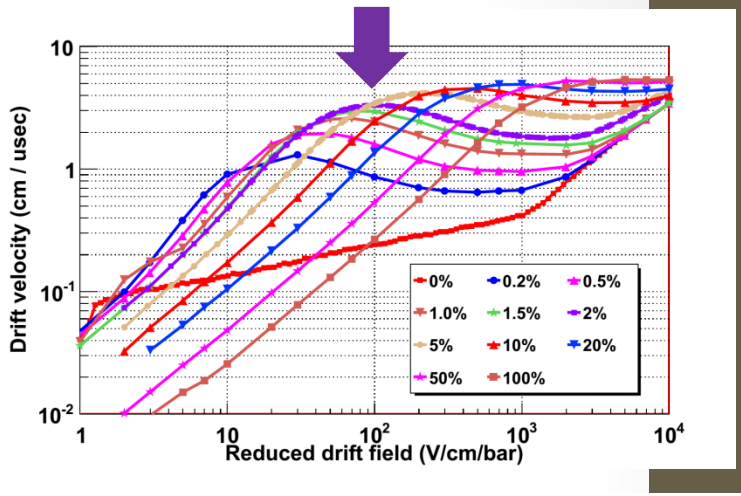


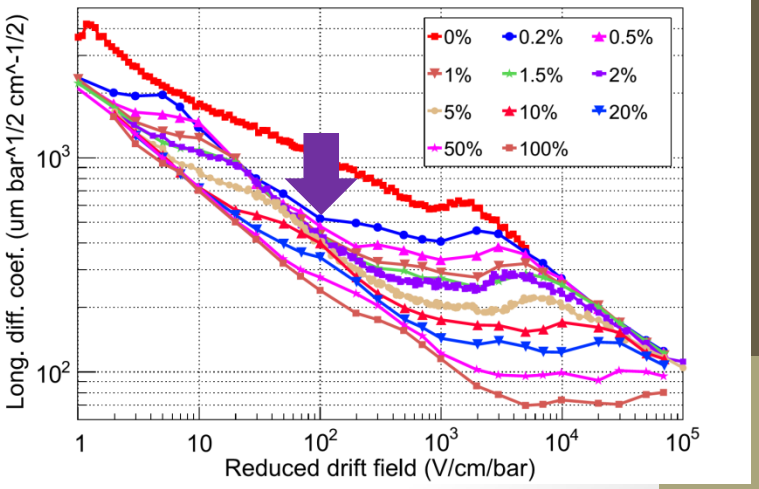




TREX-DM: gas & electronics

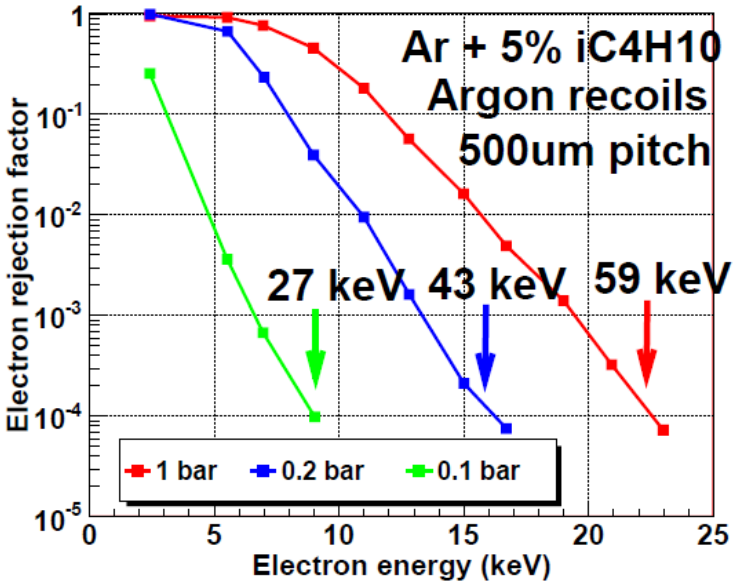
- Gas properties
  - Ar+2%iC_4H_{10} at 10 bar
  - Edrift = 100 V/cm/bar
  - Vdrift = 3.33 cm/µs
  - Transversal diffusion = 221 µm/$cm^{0.5}$
  - Longitudinal diffusion = 134 µm/$cm^{0.5}$
- Pixelization
  - Length = 0.5 mm
  - Sampling = 10 ns
  - Shaping time = 100 ns
  - Gain = 240 pF



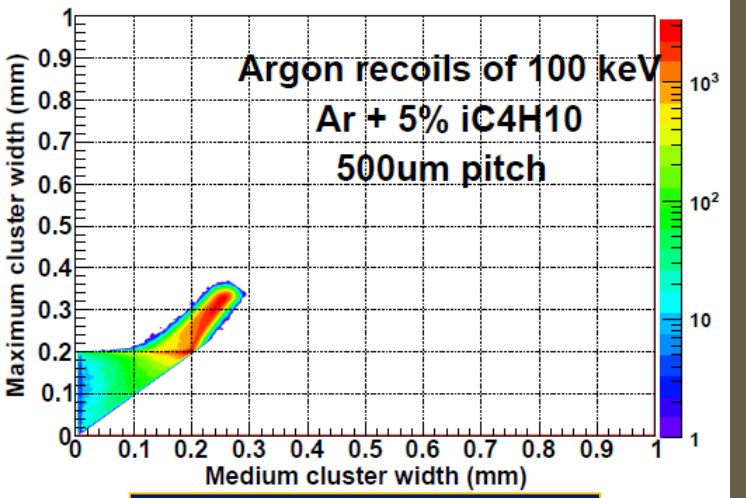


Electron/neutron discrimination

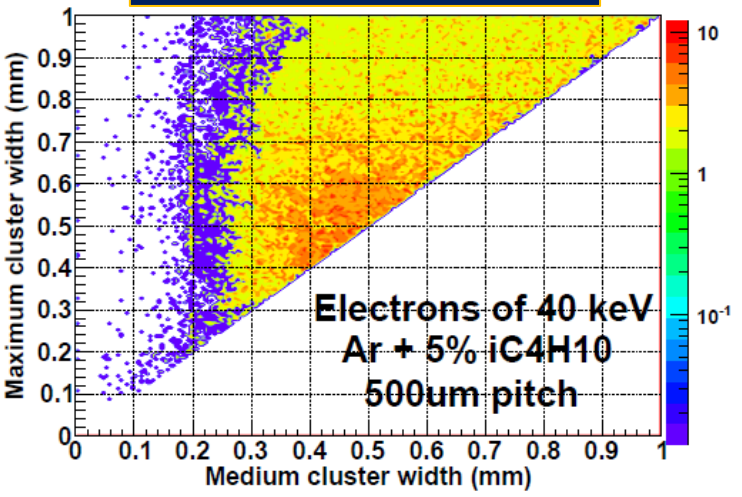
- First studies: A. Tomas in CYGNUS 2007.
- The cluster width is the key parameter and is more efficient at low pressures.
- It sharply increases from electrons but remains constant for neutrons.



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



Maximum and medium cluster widths



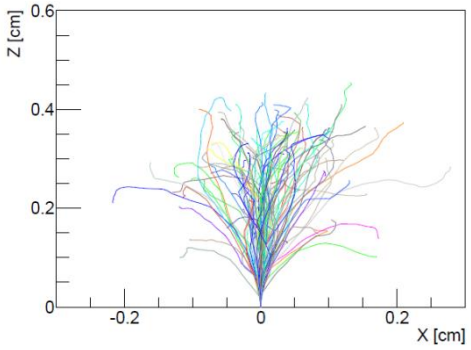
TREX-DM: commissioning and background model, F.J. Iguaz et al.

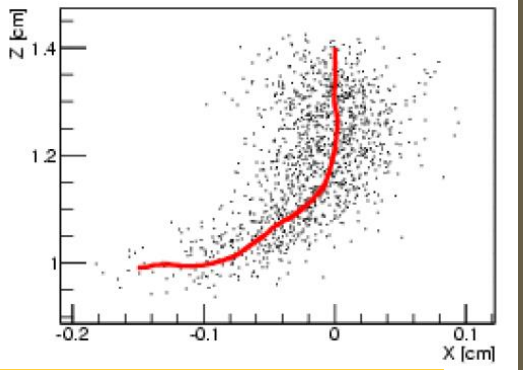
MIMAC directionality in CF_4

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

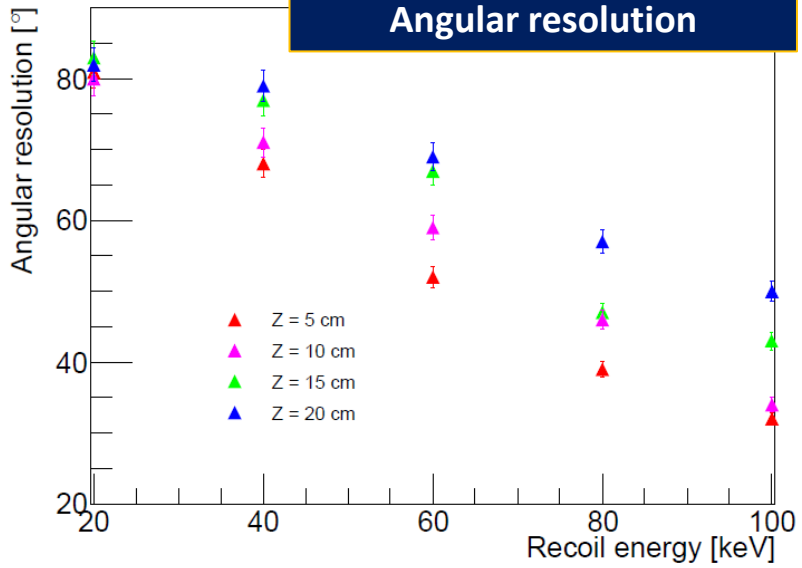
- The angular resolution & sense recognition depends on the energy and the drift distance.
- The sense recognition for recoil energies below 100 keV is unrealistic.
- Focus on axial directional detectors.

Fluorine recoil track

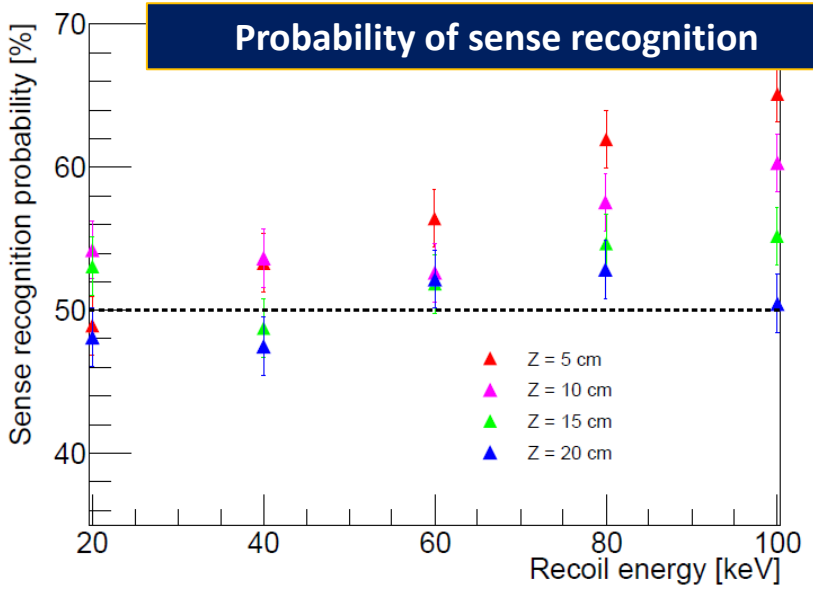




Angular resolution



Probability of sense recognition

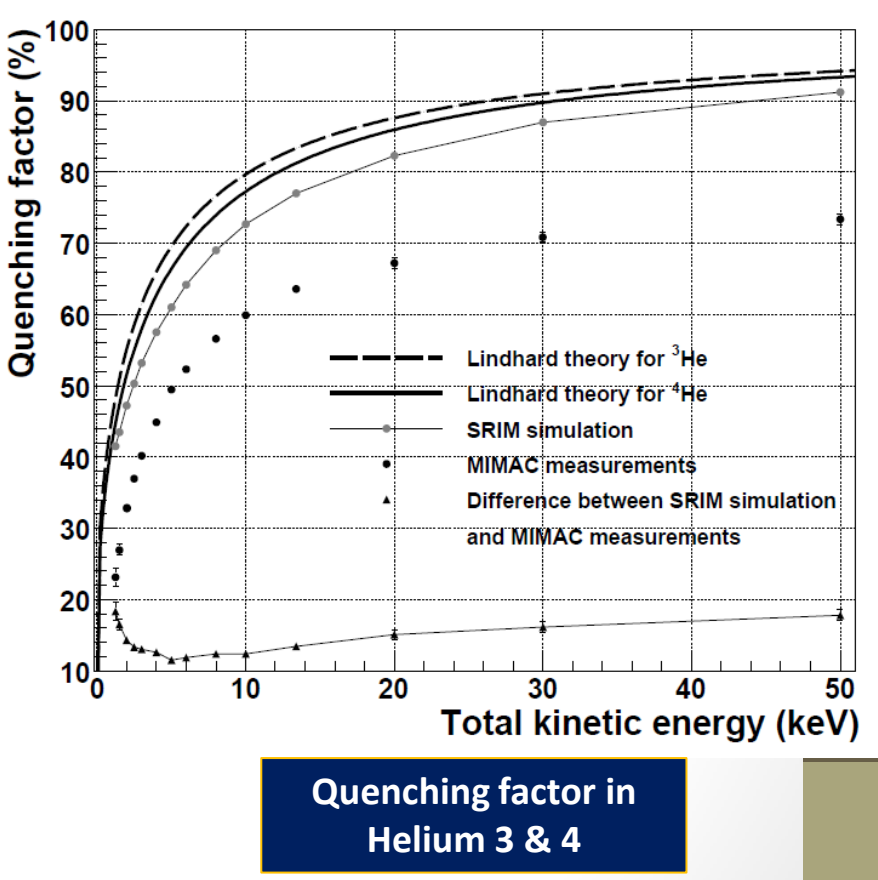


TREX-DM: commissioning and background model, F.J. Iguaz et al.

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