TREX-DM

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

J.G. Garza* & F.J. Iguaz, on behalf of TREX-DM group

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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.

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TREX-DM: a low background Micromegas-based TPC for low mass WIMP detection

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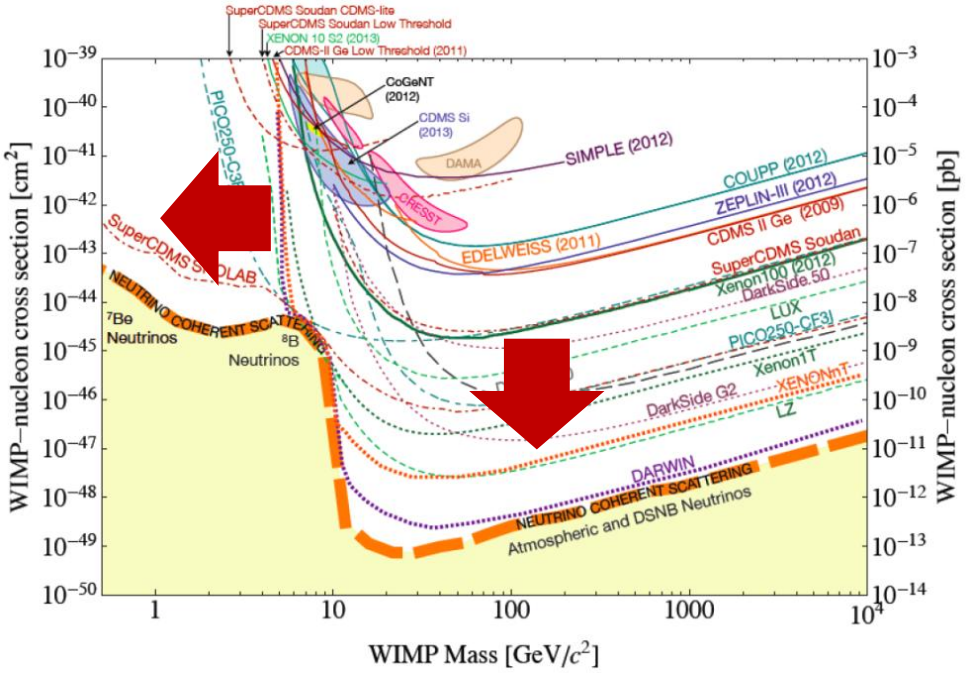
Motivation: low mass WIMP detection

Leading Dark Matter experiments focused on ~50-200 GeV WIMPs

- Heavy target nuclei (A^2 - coherence).
- Low background levels:
  - Electron/nuclear recoil discrimination -> high effective threshold -> less sensitive to low WIMP masses.



What happens if mass <10 GeV?

- Very low energy deposits, typically below threshold → exclusions based on the high velocity tail of the distribution (the most uncertain).
- A robust detection or exclusion must imply that a substantial fraction (order 50%) of the WIMP spectrum is over the experimental threshold.
  → light target nuclei.
  → sub-keV detection threshold.

Many experimental efforts in this direction: mainstream experiments bypassing their nuclear/electron discrimination, and new experiments specifically focused in the low-mass range.

TREX-DM: a gaseous Micromegas based-TPC for low mass WIMPs

Flexibility in the choice of target gas and pressure.

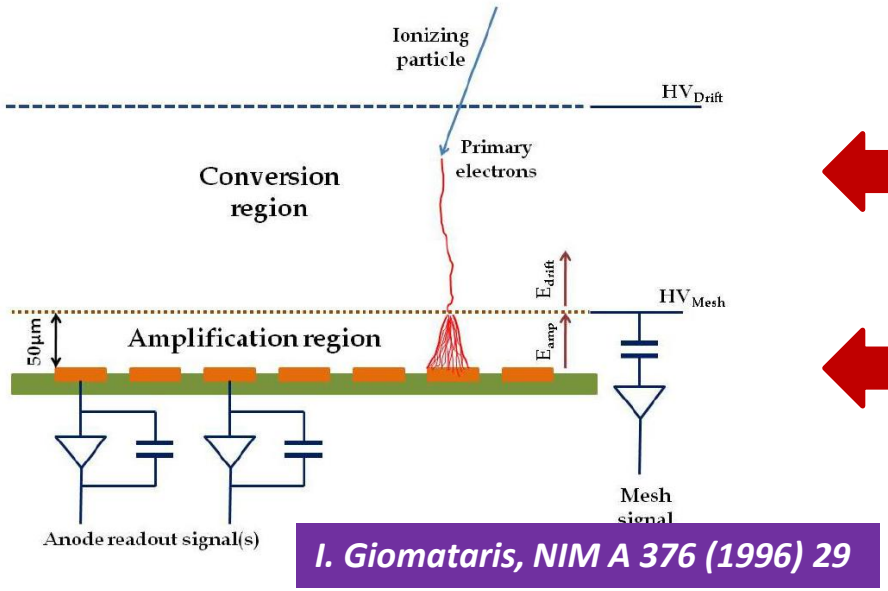
Operate 300 g of light nuclei (Ar, Ne) with a **low background level** (~1 keV^{-1} kg^{-1} day^{-1}).

NOT focused in directionality like MIMAC & DRIFT & DMTPC -> **operation at high pressure**.

Electron/nuclear discrimination less effective.

Experimental stregth: Intrinsic charge amplification with Micromegas, potential **low energy threshold** (< 1 keV).

A Micromegas TPC for Dark Matter detection



I. Giomataris, NIM A 376 (1996) 29

Radiation create electrons, which drift to the readout.

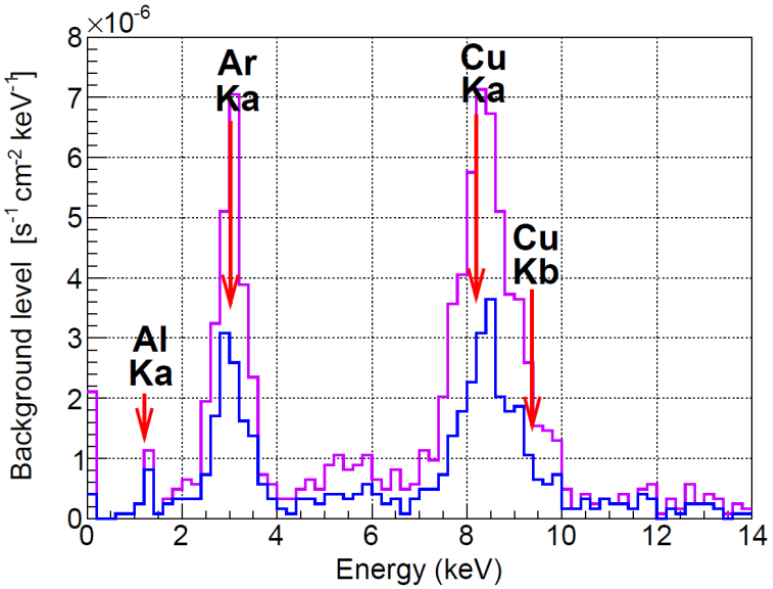
*Electrons are amplified & the electron-ion movement induces signals in both **mesh & strips**.*

- It is an amplification structure used as readout in a TPC.
- Invented in 1996. Many developments since then. Extensively used in particle phyiscs (ATLAS, T2K, nTOF, COMPASS, CLAS-12, MIMAC, CAST)…
- Many interesting feautres for Dark Matter searches.

A Micromegas TPC for Dark Matter detection

It is a consolidated manufacture…

… as good performance is systematically obtained.

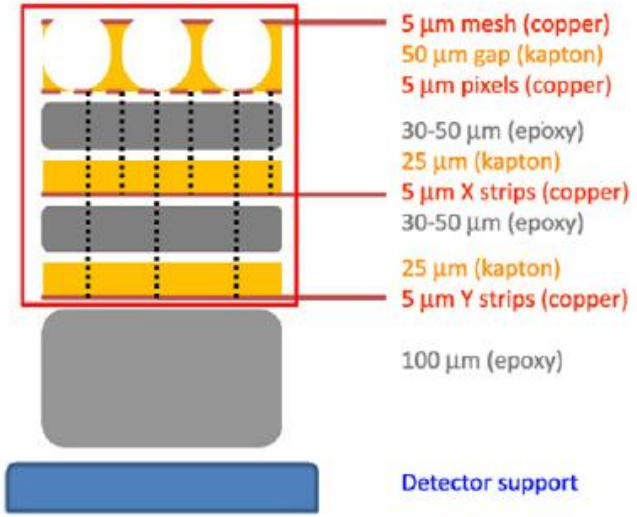


Background spectrum in a CAST-MM detector

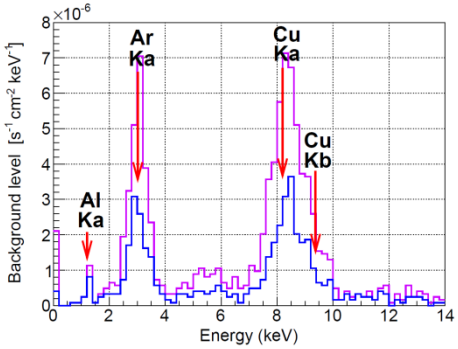
J.G. Garza *et al., MPGD 2015*

A Micromegas TPC for Dark Matter detection

It is intrisic radiopure if only made of kapton & copper…

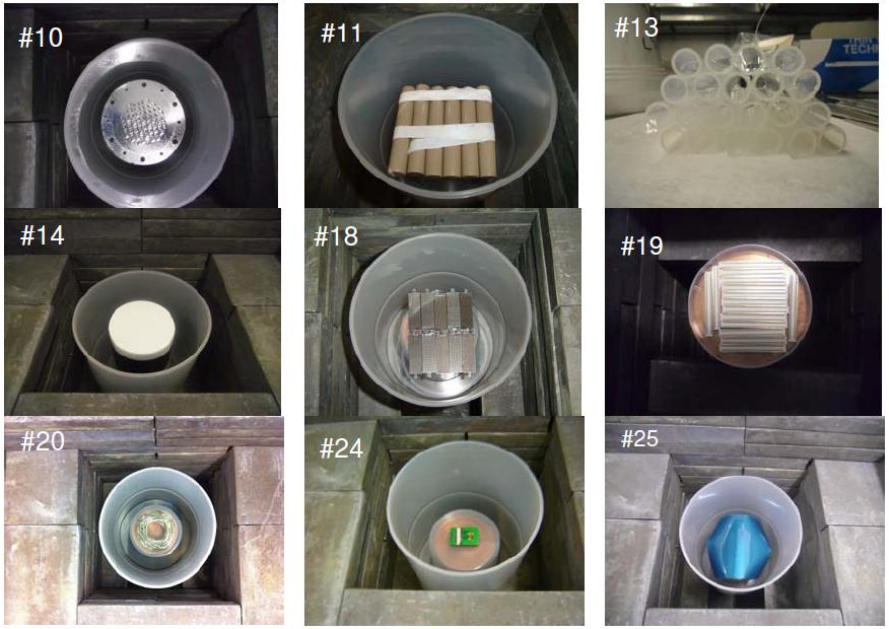


S. Cebrian *et al., Astr . Part.* **34** (2011) 354

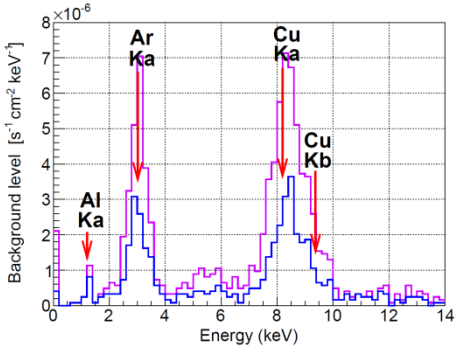


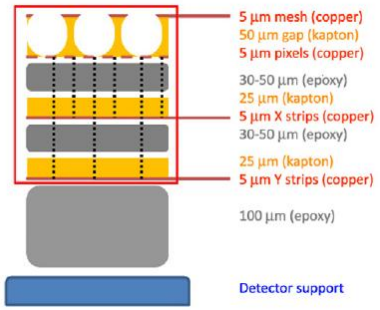
A Micromegas TPC for Dark Matter detection

… and radiopurity control techniques can be applied.



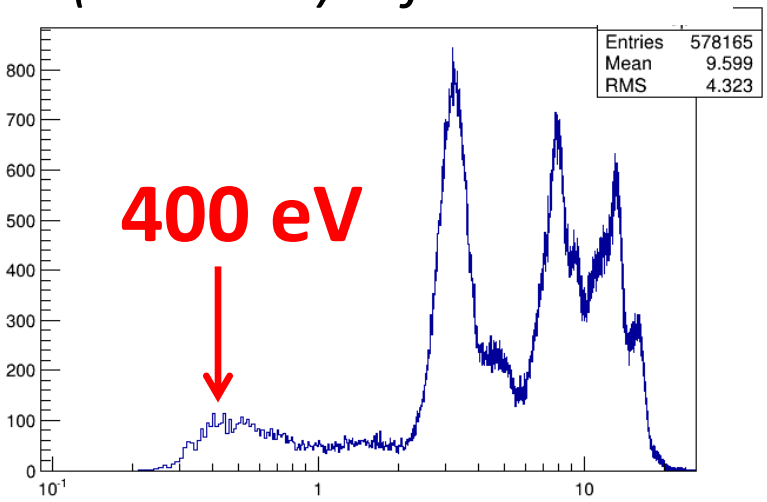
F. Aznar *et al., JINST* **8** (2013) C11012

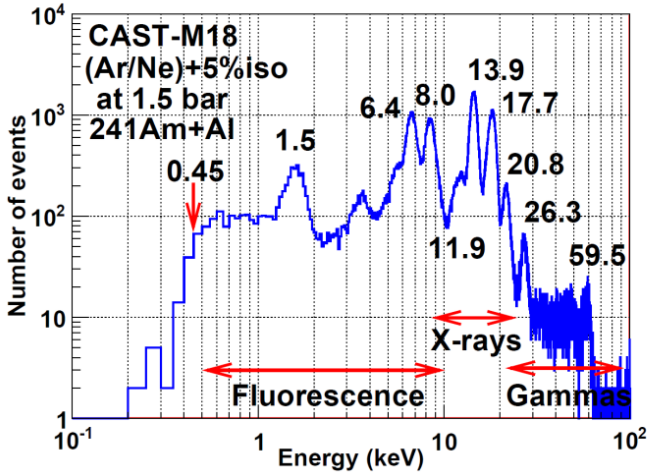




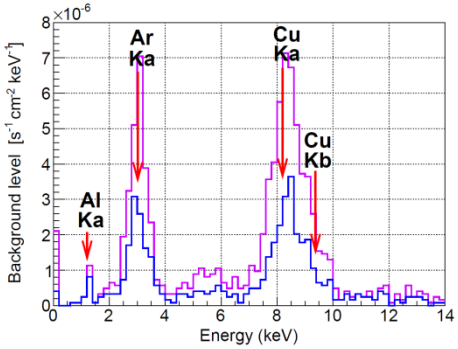
A Micromegas TPC for Dark Matter detection

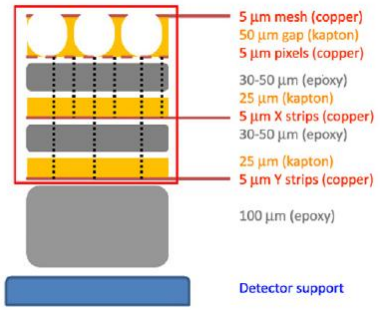
*A low energy threshold (**< 450 eV**) is feasible.*

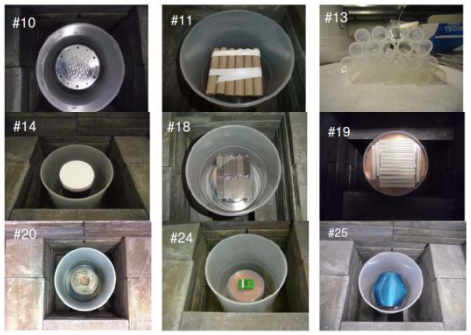




*S. Aune et al., JINST **9** (2014) P01001.*

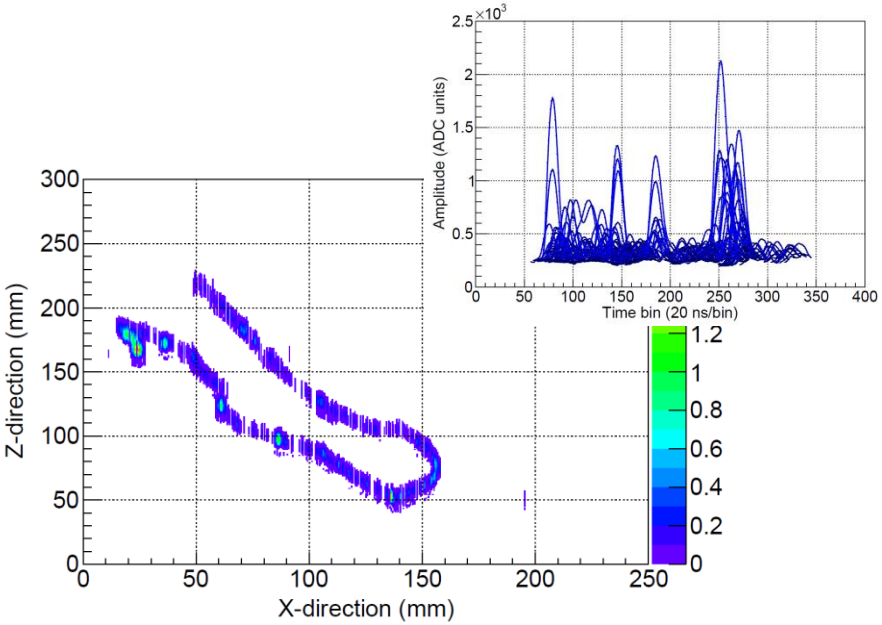


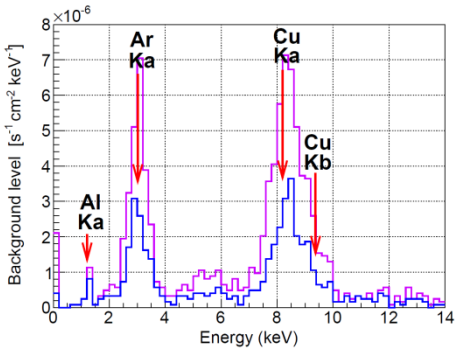


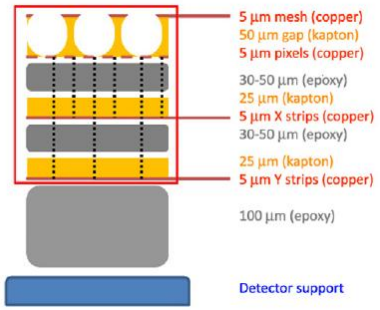


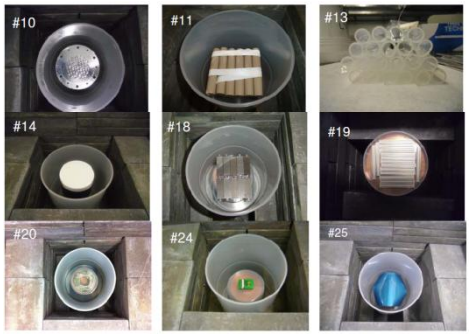
A Micromegas TPC for Dark Matter detection

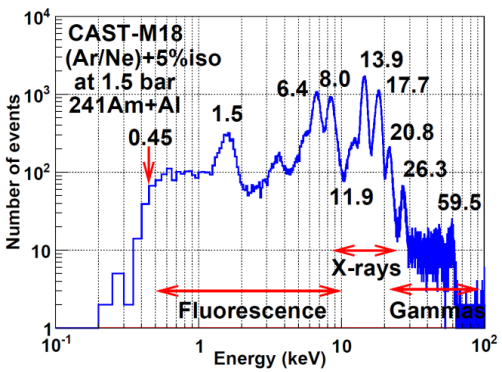
A rich topological information is available.











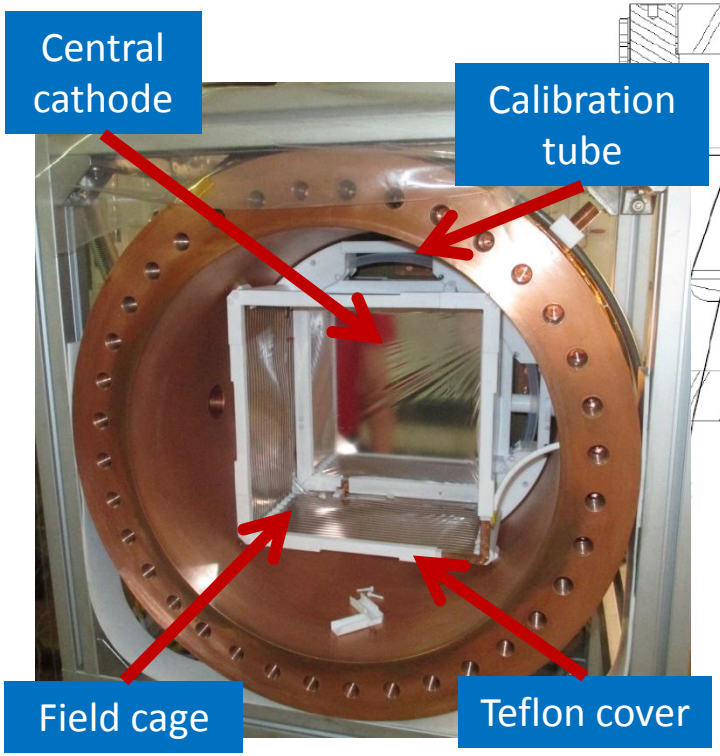
TREX-DM: a MM-TPC for low mass WIMPs

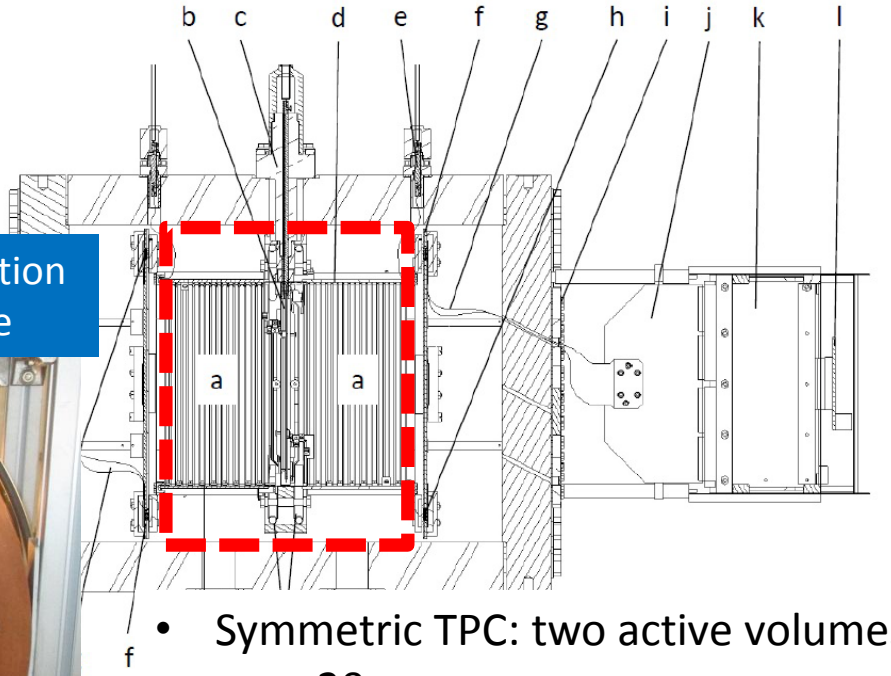
Timeline:

- **2012-15: Proof of concept, not fully radiopure.**
  - Design, construction & comissioning.
  - Systematic measurement of the radiopurity of all components.
  - Test bulk MM in argon- & neon-based mixtures at high pressure.
    - Study of the dependence of the energy threshold with pressure.
    - Validation of the simulation chain.
  - **Pending issue:** An automatic calibration system.

- **2015-16: Radiopure version for a physics run at LSC.**
  - Installation of radiopure components: Micromegas detectors, flat cables, ...
  - Modification of the setup for a 10 cm thick lead shielding.

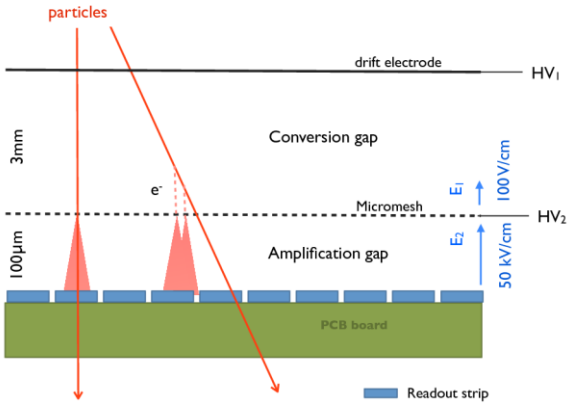
TREX-DM: a MM-TPC for low mass WIMPs

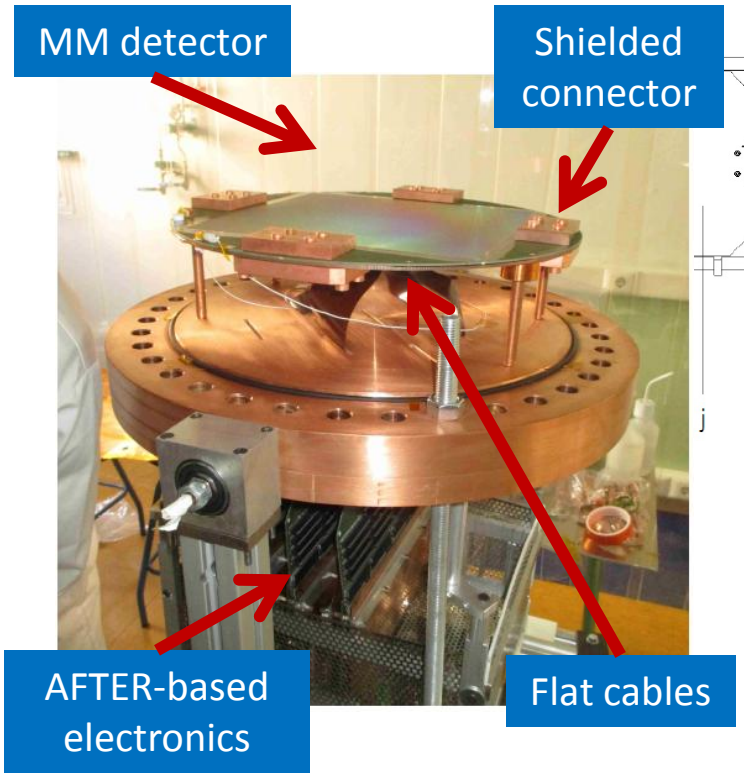


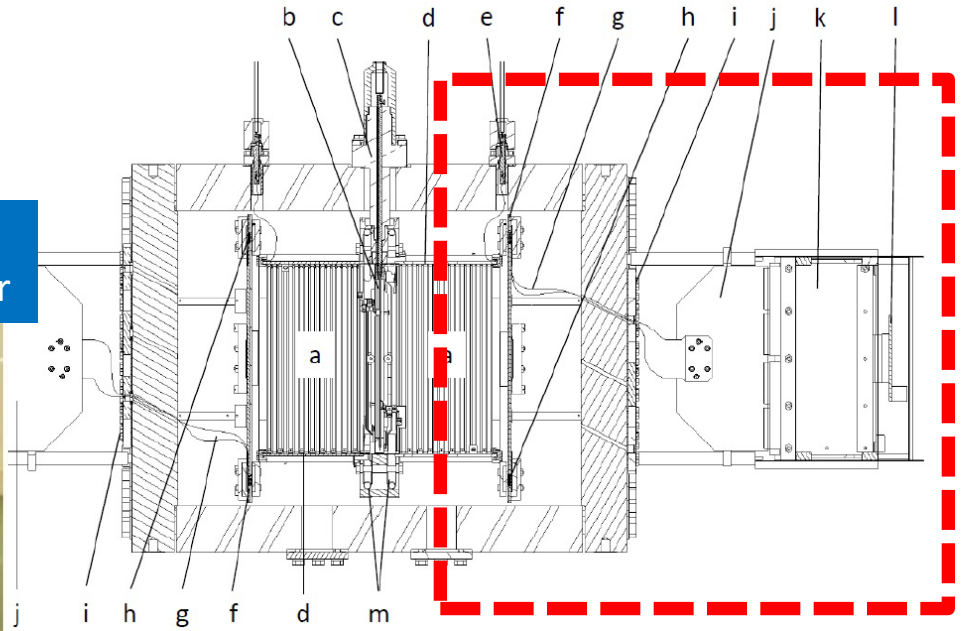


- Symmetric TPC: two active volumes: 19 cm x 20 cm x 20 cm.
- Central cathode of mylar, electrically isolated from inner walls by teflon.
- Field cage made of kapton & copper, covered by teflon walls. No soldering used.
- Calibration by ^{109}Cd, inside a Teflon tube.

TREX-DM: detector & electronics

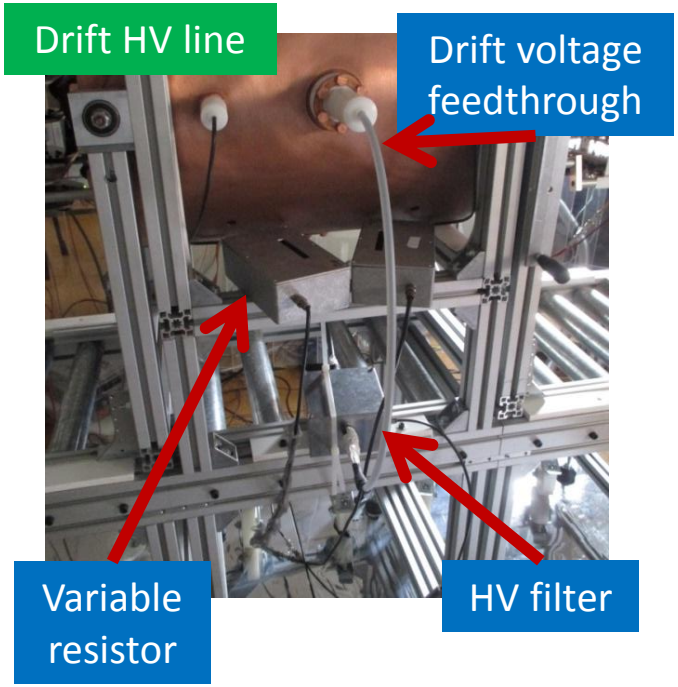


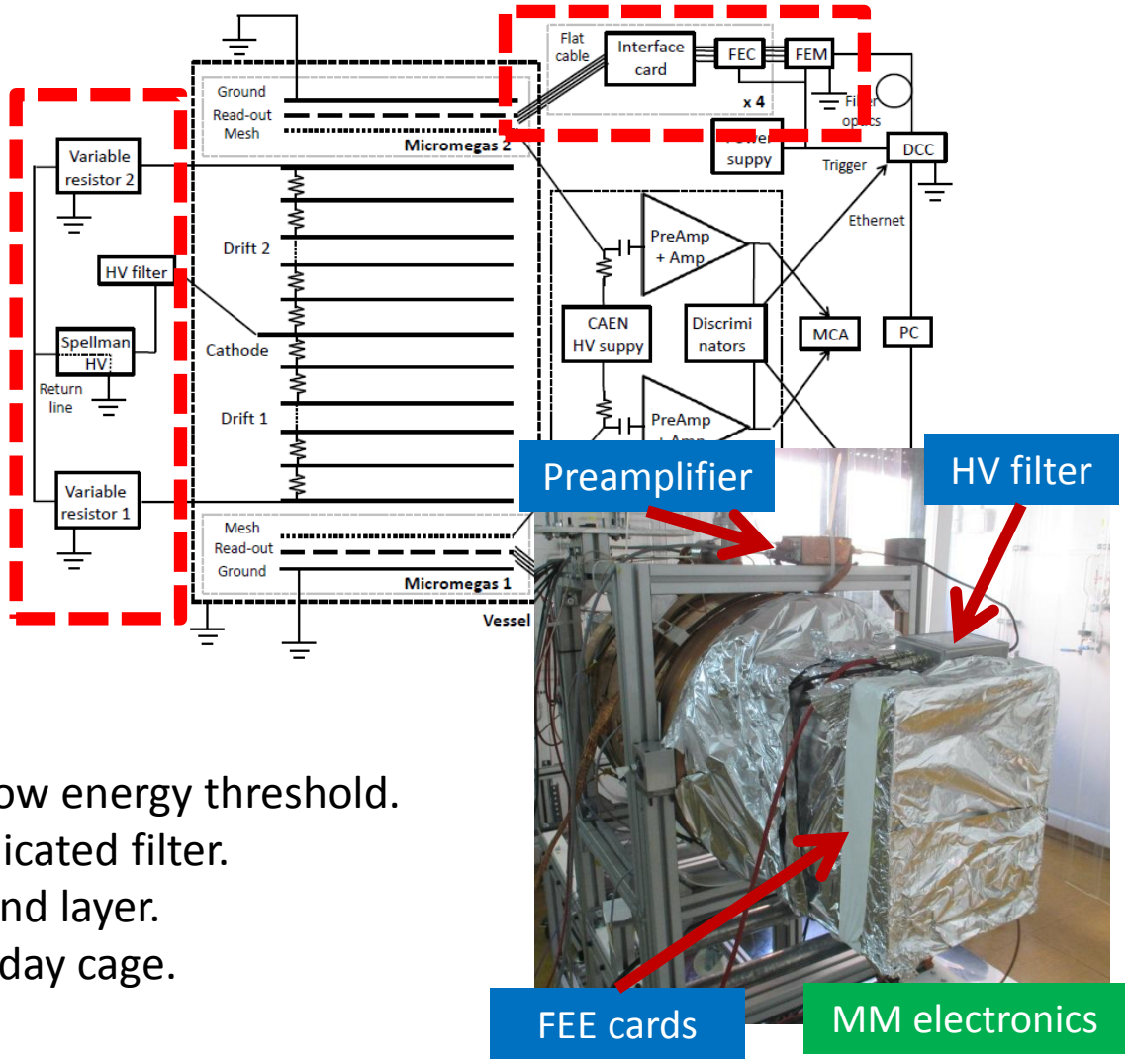




- 20 x 20 cm^2 bulk MM detectors.
- Signals extracted by flat cables + feedthroughs.
- Sampling-ADC electronics record strip signals with external (mesh) trigger. Possible update to auto-trigger electronics → lower threholds expected.

TREX-DM: detector & electronics

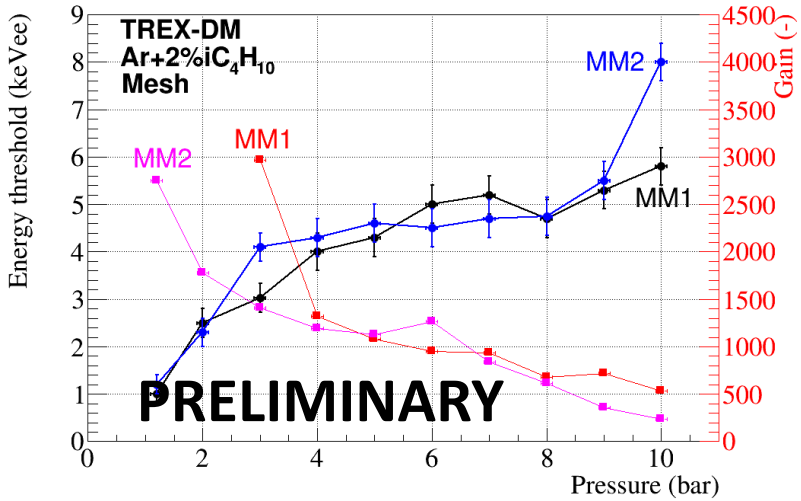




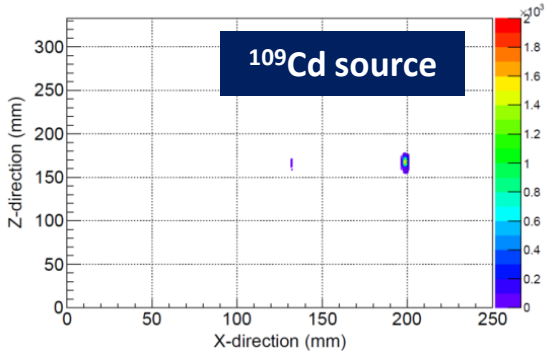
- Special care in grounding for a low energy threshold.
- All high voltage lines have a dedicated filter.
- Strips signals shielded by a ground layer.
- FE electronic cards inside a Faraday cage.

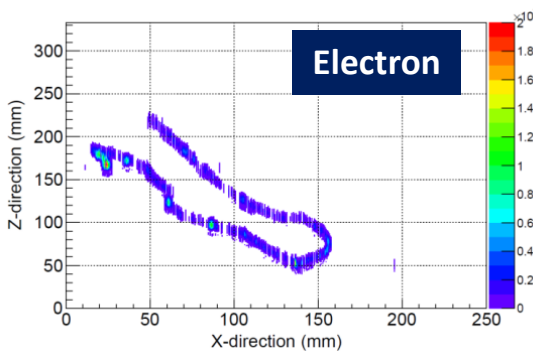
Some preliminary results…

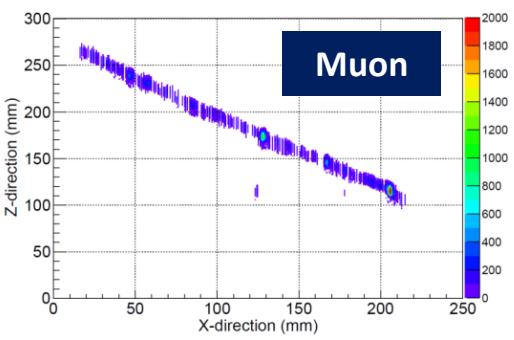
- Detectors characterized in Ar+2%iso up to 10 bar.
- Degradation of performance with pressure:
  - **Gain:** 3 x 10^3 (1.2 bar) -> 5 x 10^2 (10 bar).
  - **Threshold:** 1.0 keV -> 6.0 keV.
  - **Resolution:** 16% FWHM -> 27% FWHM.
- Results limited by noise (later removed) & a low quantity of quencher.
- New data-taking in Ar+5%iso on going. Better results already obtained.
- Near-term: neon-based mixtures.



J.G. Garza *et al., MPGD 2015*

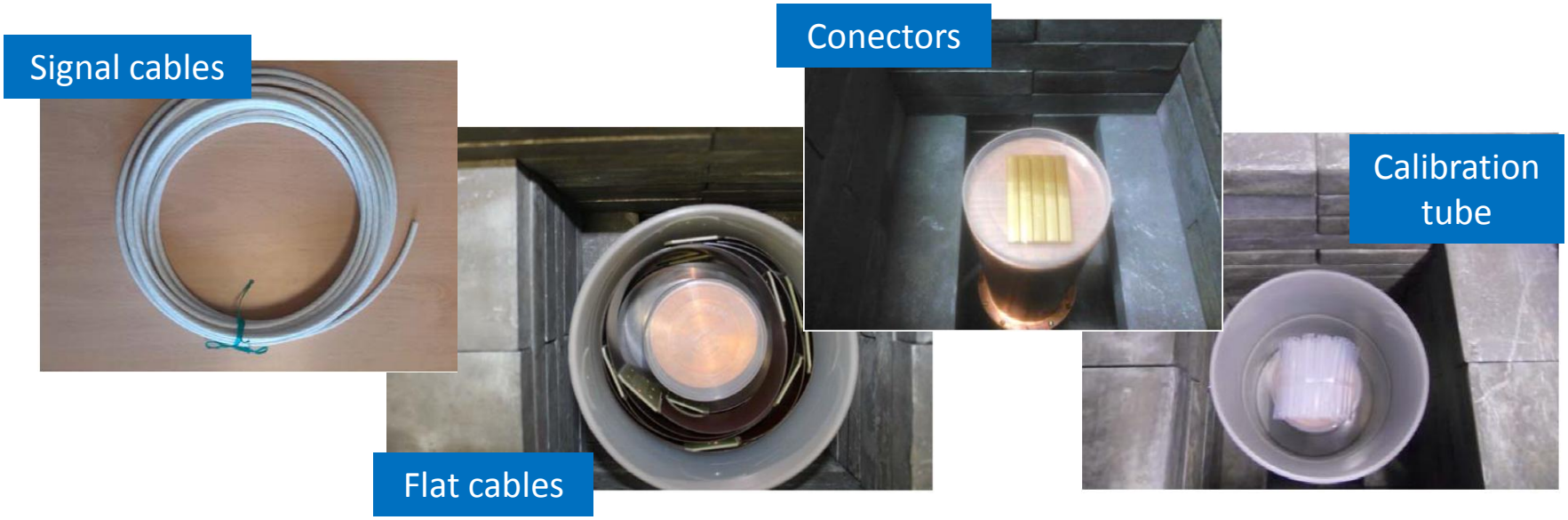






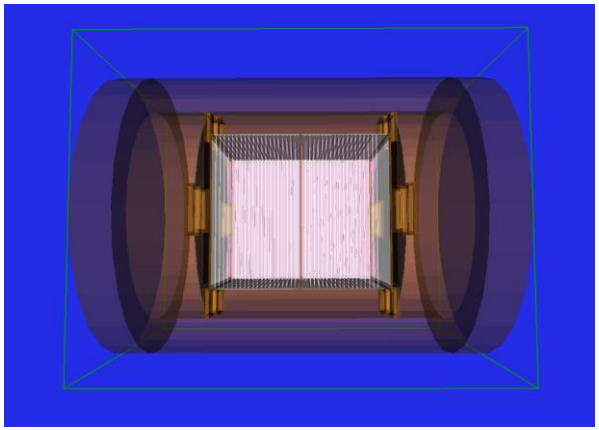
Material screening program

- The radioactivity measurement of all relevant components of the experiment: shielding, vessel, calibration system, field cage, electronics & detectors.
- Mainly based on a germanium gamma-ray spectrometry at LSC.
- Found radiopure versions of the micromegas detectors, flat cables and conectors. They will be installed in the final version for LSC.
- More details: F. Aznar *et al., JINST* **8** (2013) C11012 & future article.



Background model in argon & neon

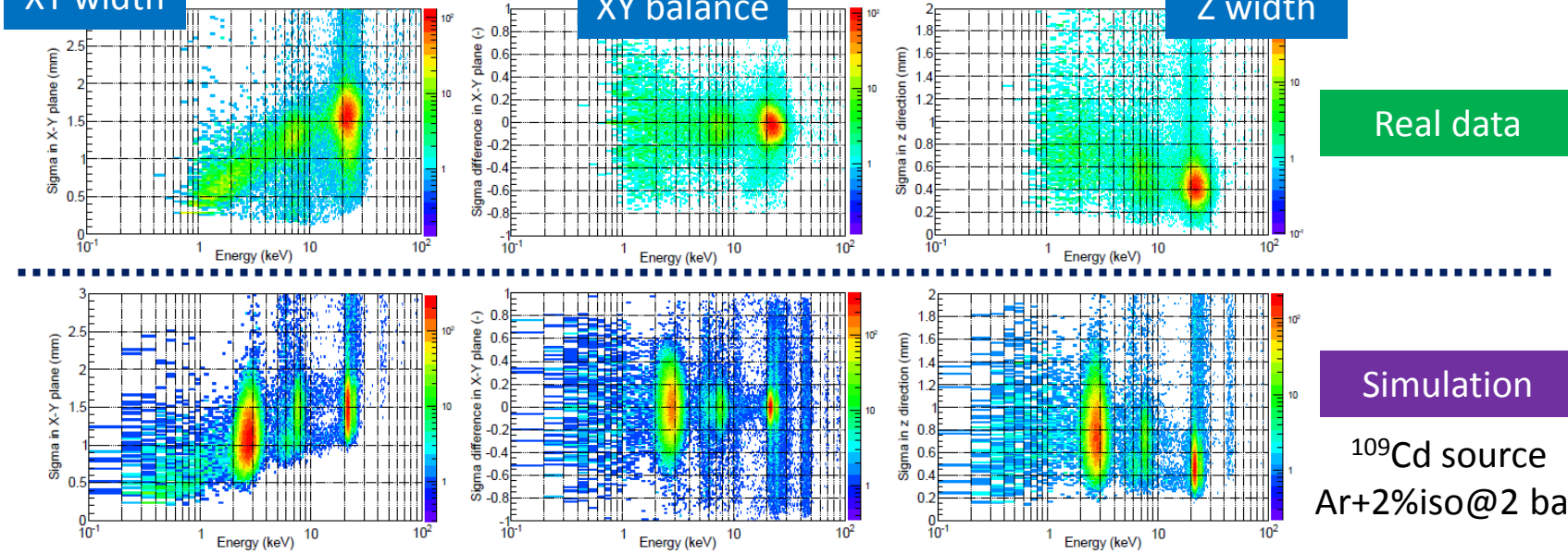
- Two gases studied: Ar & Ne + 2%iso @ 10 bar.
- Results are scaled by the measured activities.
- Geant4 + REST code + cluster analysis + discrimination.
- Final data in FEE-based format.
- Analysis based on cluster features.
- Simulation chain validated by real data.



XY width

XY balance

Z width



Real data

Simulation

^{109}Cd source
Ar+2%iso@2 bar

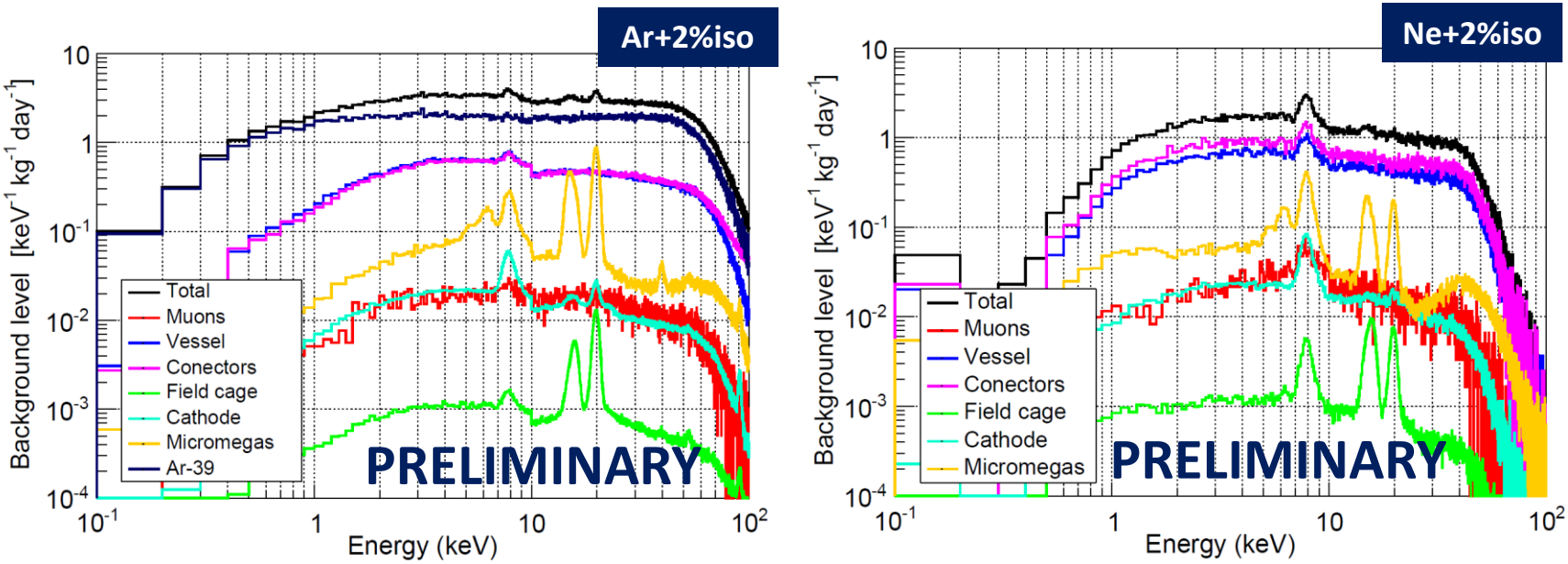
Background model in argon & neon

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**	This work	
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**		

RoI: 2-7 keV. Statistical error < 10%. 80% signal efficiency.

- Results mainly determined by the measured activities.
- **Pending issues:** outer gamma flux, external shielding & neutrons not yet included.
- Main contributions: **^{39}Ar** (for argon based), **electrical connectors** and **vessel**.
- **^{39}Ar** contribution will be **2×10^{2} keV^{-1} kg^{-1} day^{-1}** if argon comes from **surface** sources, i.e., not depleted.

Background model in argon & neon



- Results mainly determined by the measured activities (statistical error < 5%).
- **Pending issues:** 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 x 10^{2} keV^{-1} kg^{-1} day^{-1}** if argon comes from **surface** sources.

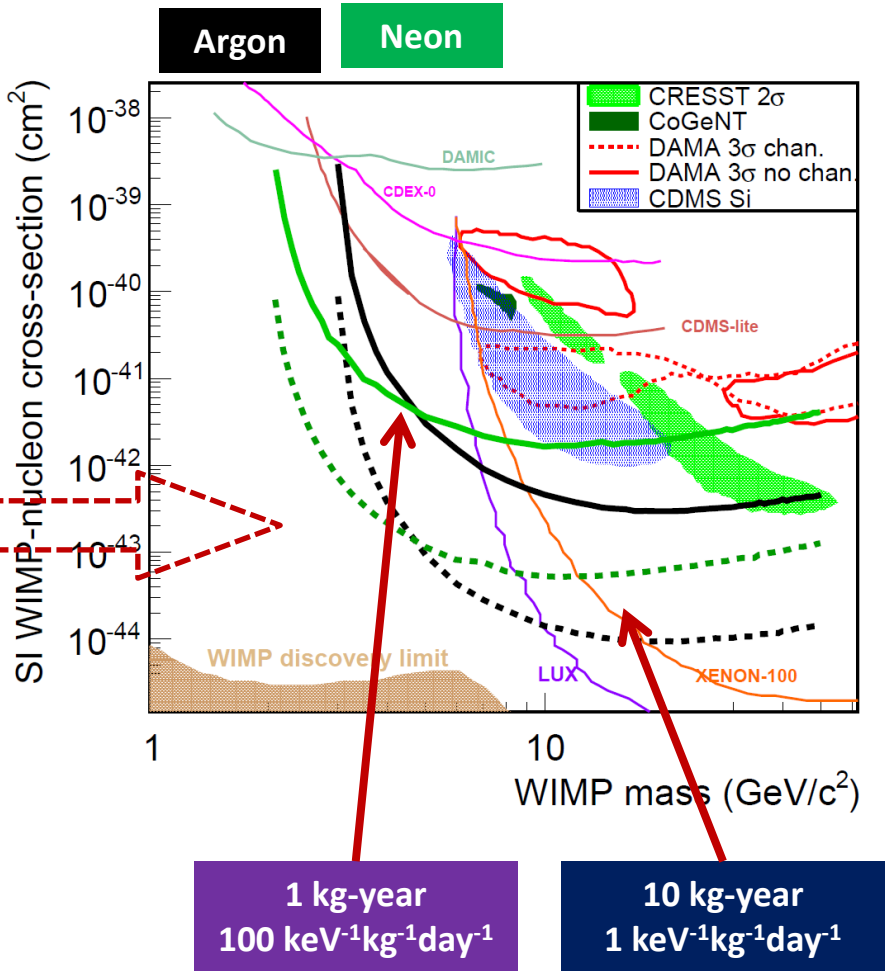
Prospects of TREX-DM experiment

Summary of background levels:

- **Argon @ 10 bar**: ***3.09 keV^{-1} kg^{-1} day^{-1}***.
- **Neon @ 10 bar: *1.38 keV^{-1} kg^{-1} day^{-1}***.

(mainly defined by the measured activities)

*Supossing a **0.4 keVee** energy threshold & that this background model is valid, it could be sensitive to the regions defined by WIMPs hints in a conservative scenario.*



Challenges for near-term future:

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

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.
  - Test bulk MM in argon- & neon-based mixtures at high pressure.
    - Study of energy threshold with electronics chain & pressure.
    - Validation of the simulation chain.
  - Pending issue: An automatic calibration system.
- **Future**: update to 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.
- 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 be sensitive to the regions defined by WIMPs hints in a conservative scenario.

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Thanks for your attention!

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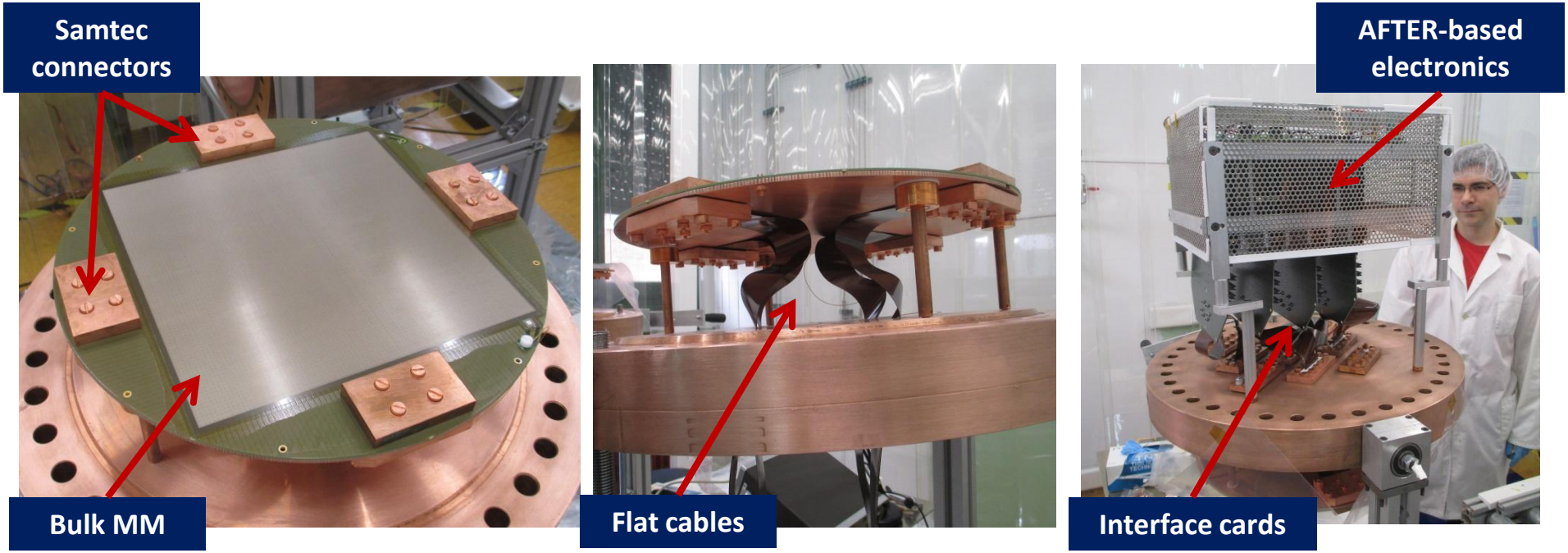
Back-up slides

The Micromegas detectors in detail



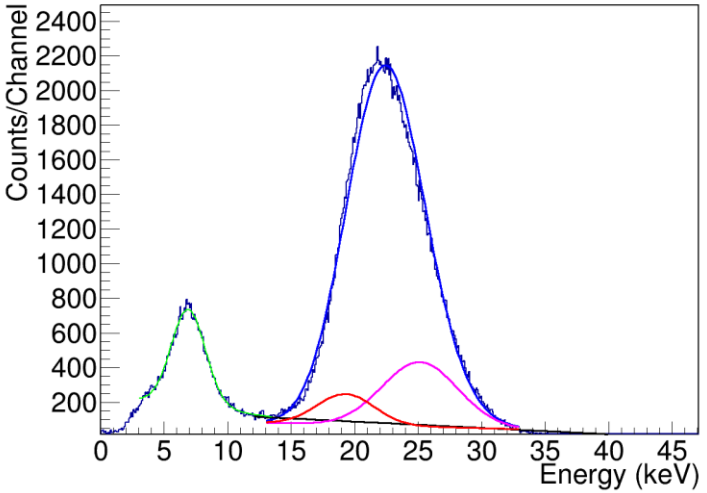
- 20 x 20 cm² bulk Micromegas: 432 X-strips & 432 Y-strips, 0.6 mm pitch, 128 μm gap.
- Signals extracted by 4 flat cables using 300-Samtec connectors. A small shielding included too: **1 cm copper + 1 cm lead**.
- An interface card links a flat cable to the FEC. Any short-cut may be eliminated by a jumper.
- **AFTER**-based electronics. Possible update to **AGET**, with **autotrigger capabilities**.

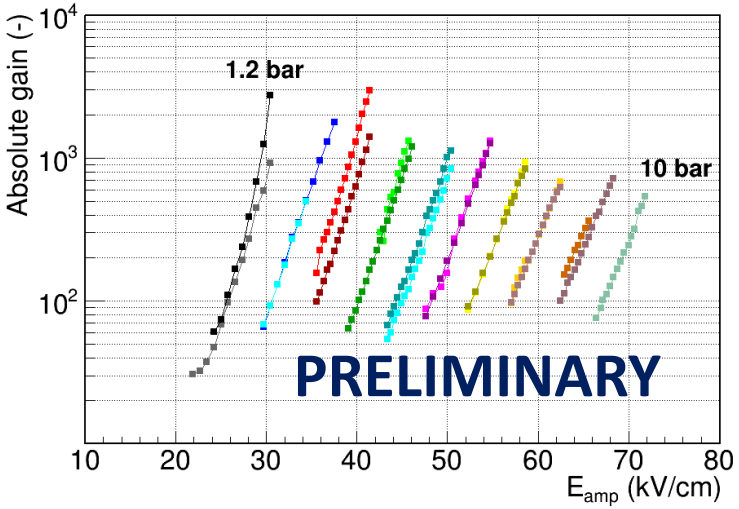
Many thanks to IRFU/SEDI-Micromegas workshop!!!

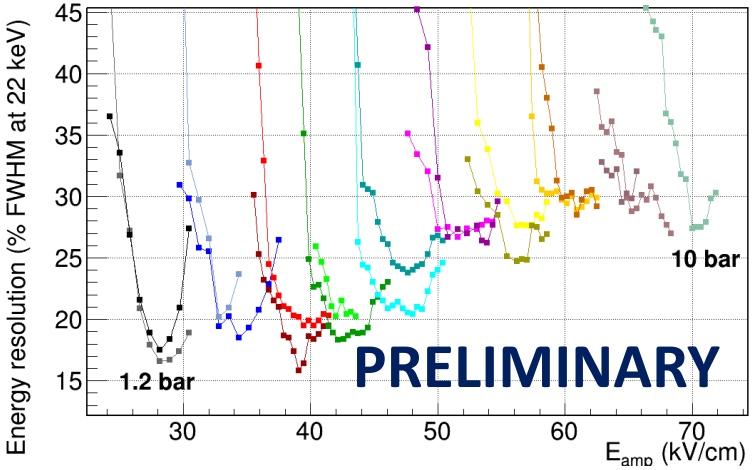
Some preliminary results

J.G. Garza *et al.*, *MPGD 2015*

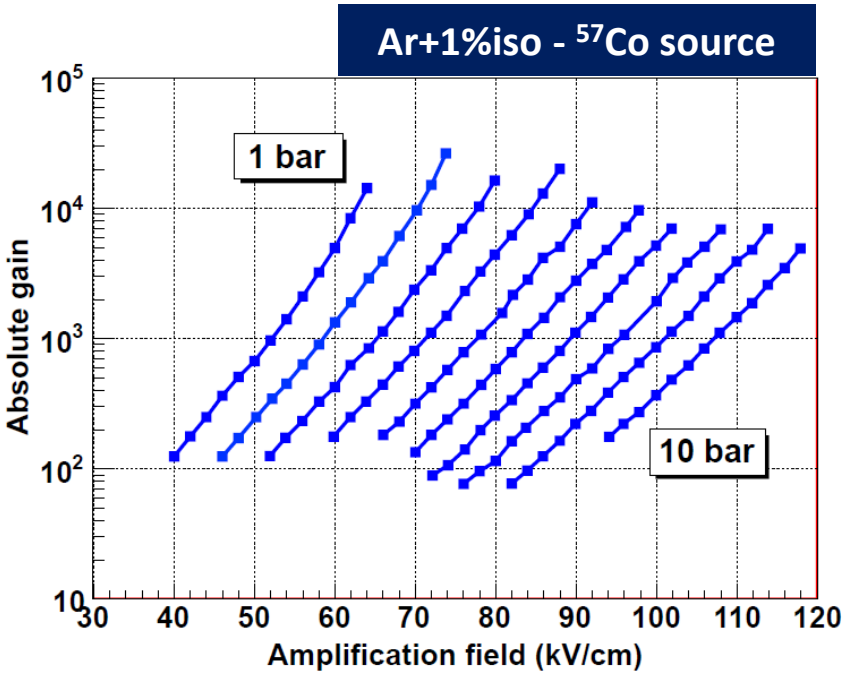
- Detectors characterized in Ar+2%iso up to 10 bar.
- Degradation of performance with pressure:
  - **Gain:** 3 x 10^3 (1.2 bar) -> 5 x 10^2 (10 bar).
  - **Threshold:** 1.0 keV -> 6.0 keV.
  - **Resolution:** 16% FWHM -> 24% FWHM.
- Results limited by noise (later removed) & a low quantity of quencher.

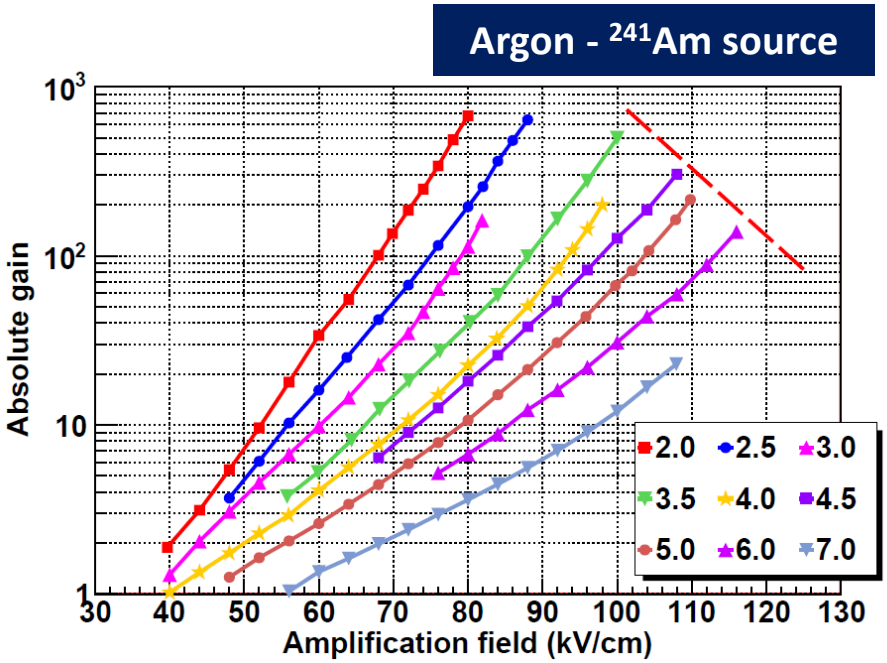






Micromegas detectors at high pressure



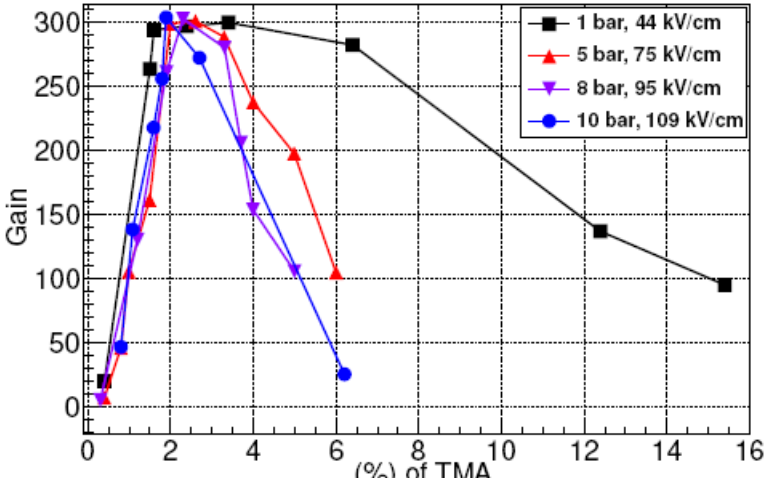


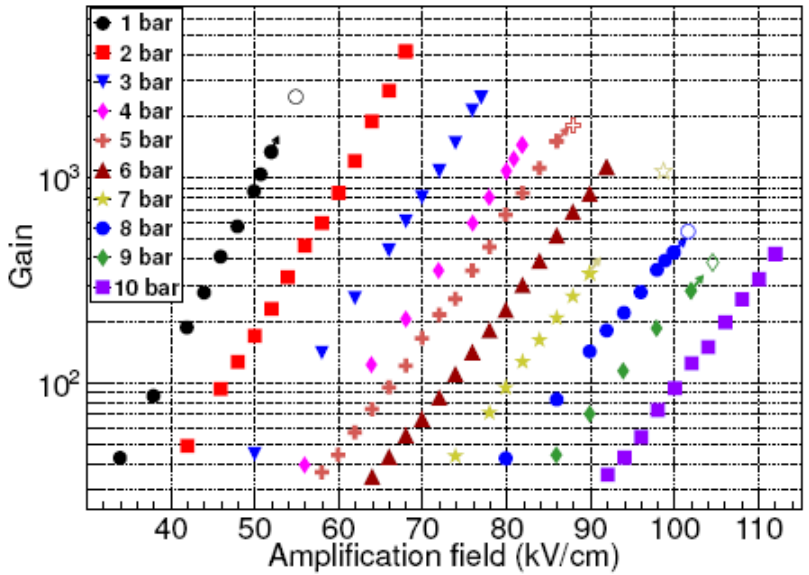
- Microbulk micromegas. 50 µm gap.
- Argon-based mixtures.

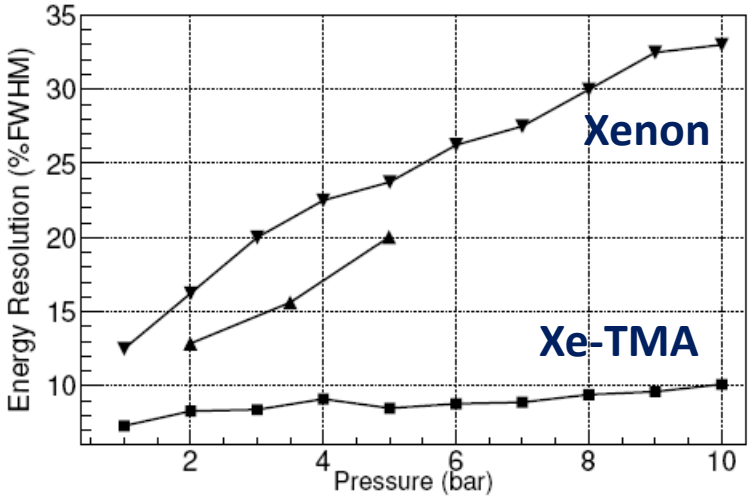
F.J. Iguaz et al., RD51 meeting, Fribourg May 2010

Micromegas detectors at high pressure

- Microbulk micromegas. 50 µm gap.
- Xenon-TMA mixtures.
- ^{109}Cd source (22.1 keV x-rays).
- Best performance for 1.5-2.5% TMA.
- Max, gain: 2x10^3 (5 x 10^2) at 1 (10) bar.
- Energy resolution: 7.3 (9.6) % FWHM at 22.1 keV for 1 (10) bar.



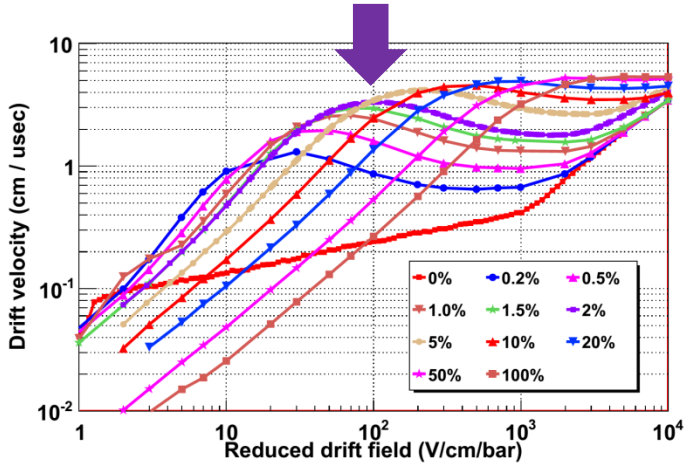


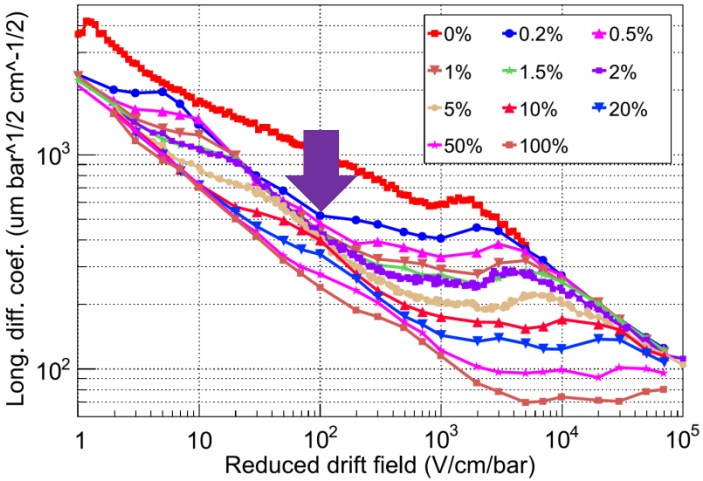


S. Cebrian et al., JINST 8 (2013) P01012

Simulation chain: gas & electronics

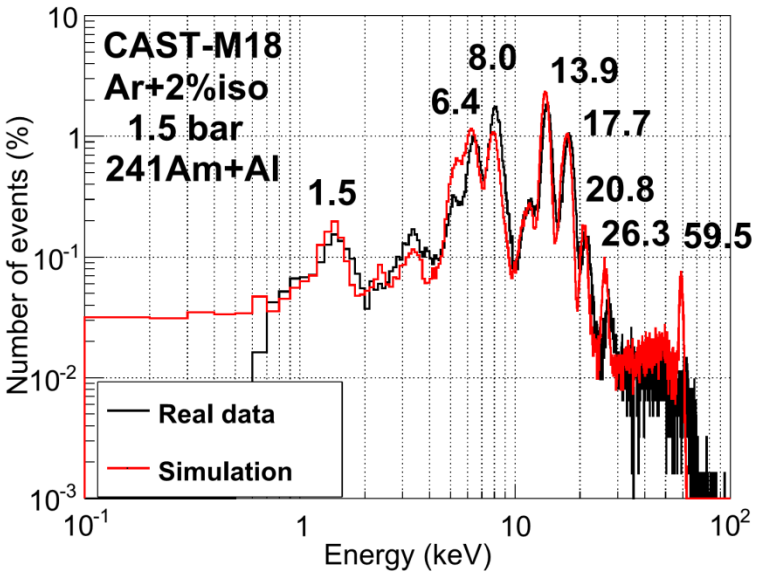
- Gas properties
  - Ar+2%iC_4H_{10} at 10 bar
  - Edrift = 100 V/cm/bar
  - Vdrift = 3.33 cm/µs
  - Transversal diffusion = 221 µm/$cm^{0.5}$
  - Longitudinal diffusion = 134 µm/$cm^{0.5}$
- Pixelization
  - Length = 0.5 mm
  - Sampling = 10 ns
  - Shaping time = 100 ns
  - Gain = 240 pF





Validation of the simulation chain

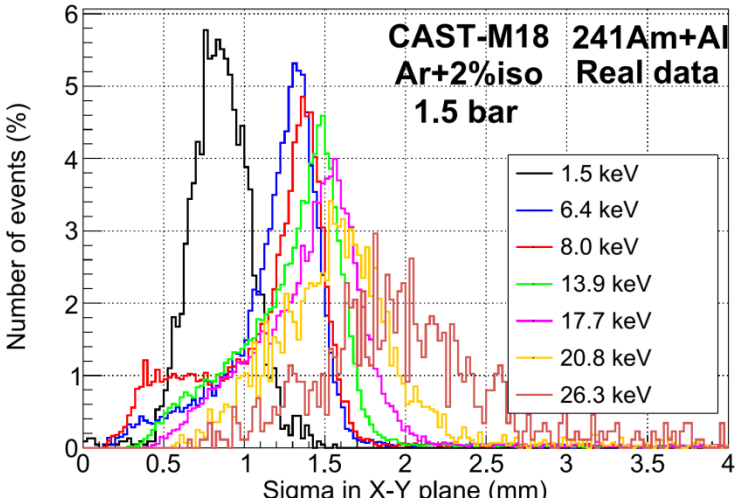
- As a validation of the complete chain, an ^{241}Am calibration of M18 has been used.
- Gas: Ar+2%iC_4H_{10} at 1.5 bar.
- **Pros:** many lines, energy dependece study.
- **Cons:** geometry of ^{241}Am not fully defined.
- Simulated the CAST-MM geometry implemented by A. Tomás & A. Rodríguez.
- Energy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

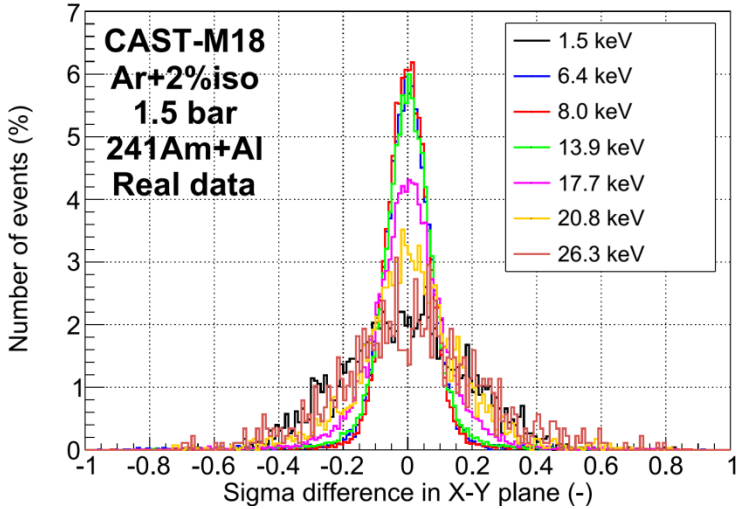


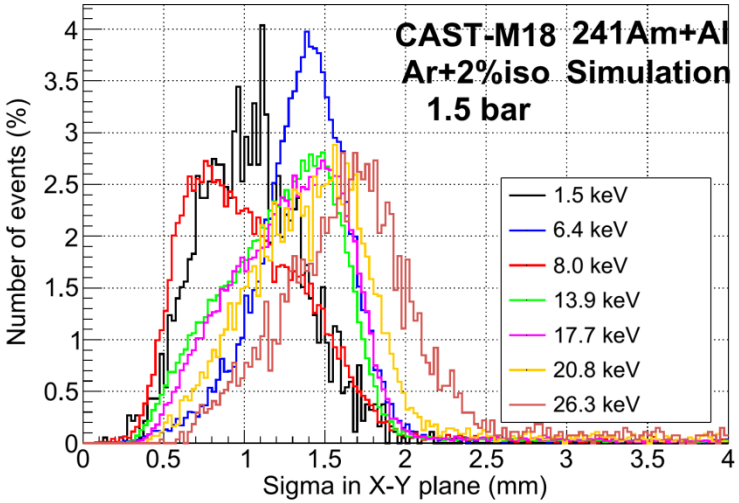
Conclusions

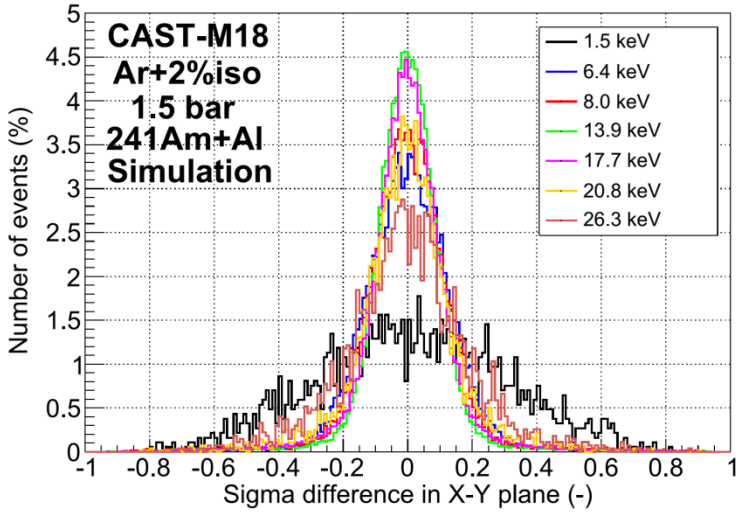
- Cluster width's distributions are quite similar, except for the 8 keV line (too much copper at the bottom?). Main differences at low widths.
- Less charge fluctuations between planes for real data at energies < 15 keV. At higher energies, the simulated fluctuations are little.

Validation of the simulation chain





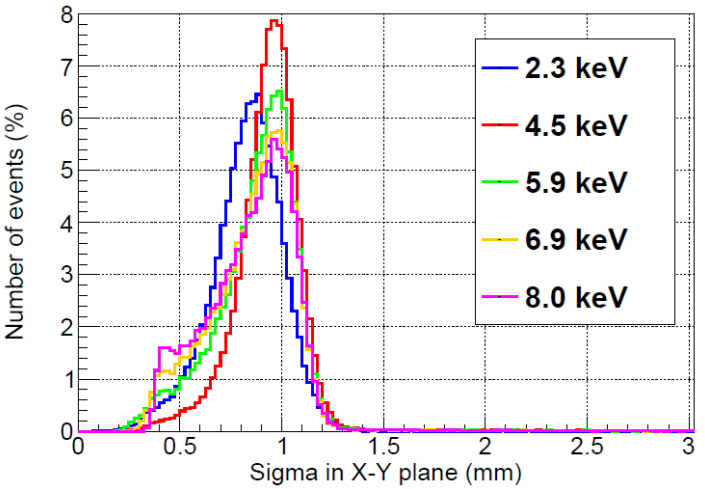


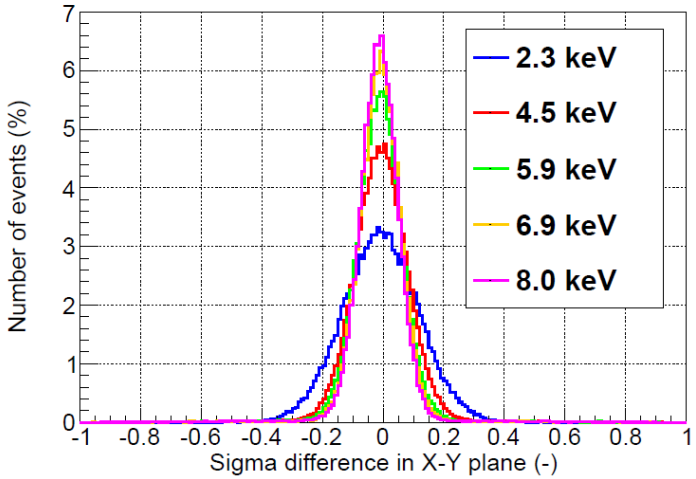


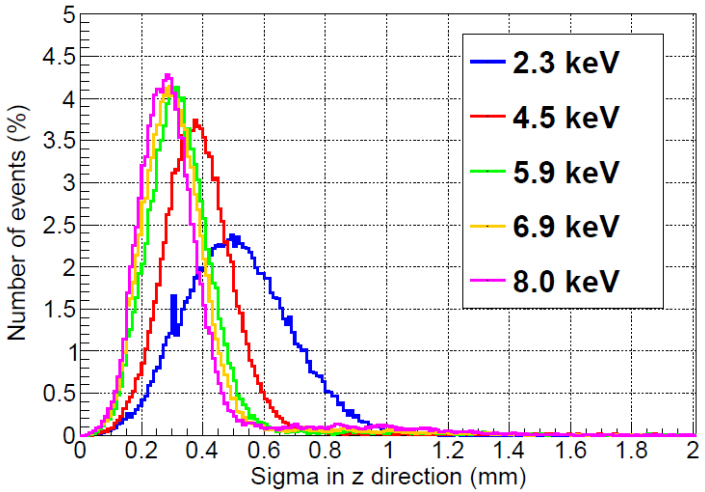
J.G. Garza et al., JINST 8 (2013) C12042
F.J. Iguaz et al., PoS(TIPP2014)295

X-ray cluster's topology

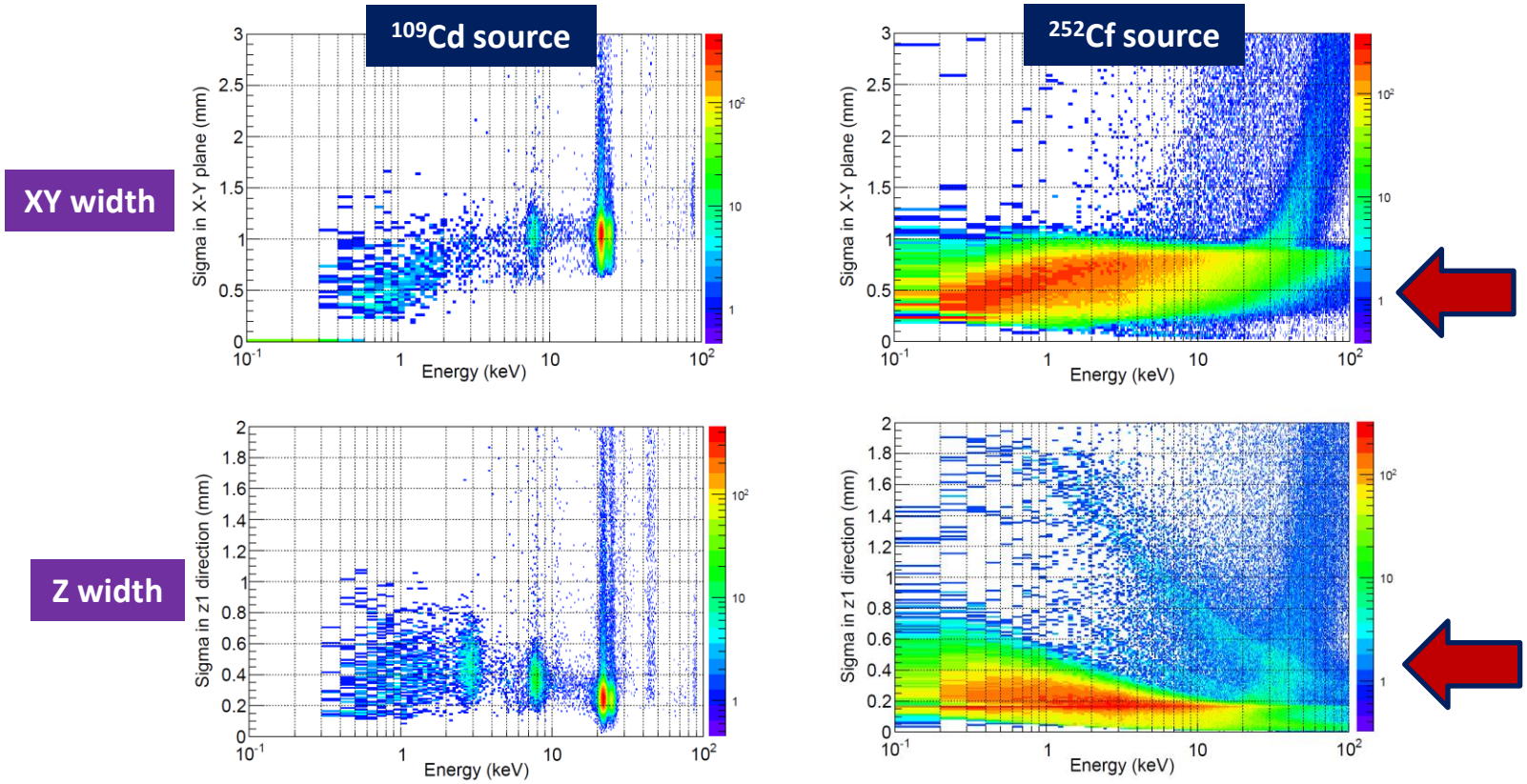
- CAST Microbulk micromegas. 50 µm gap.
- Electron beam at CAST Detector Laboratory.
- Fluorescence lines from 2.3 (gold) to 8.0 keV (copper) used to calculate the signal efficiency.
- Clusters are wider at low energies because most of the x-rays are absorbed in the first mms just after the window and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







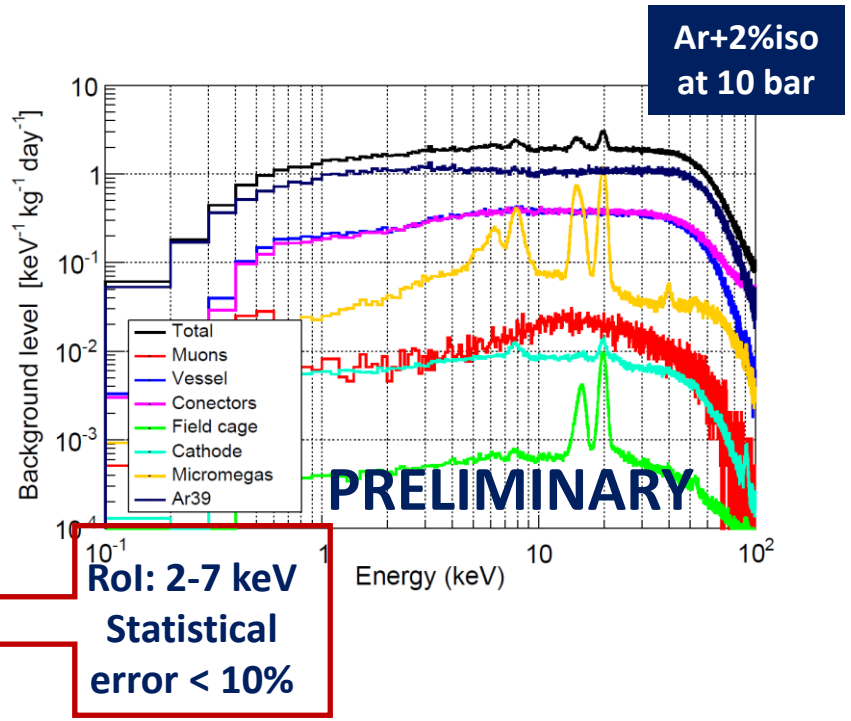
Electron/neutron discrimination



- 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.

Electron/neutron discrimination

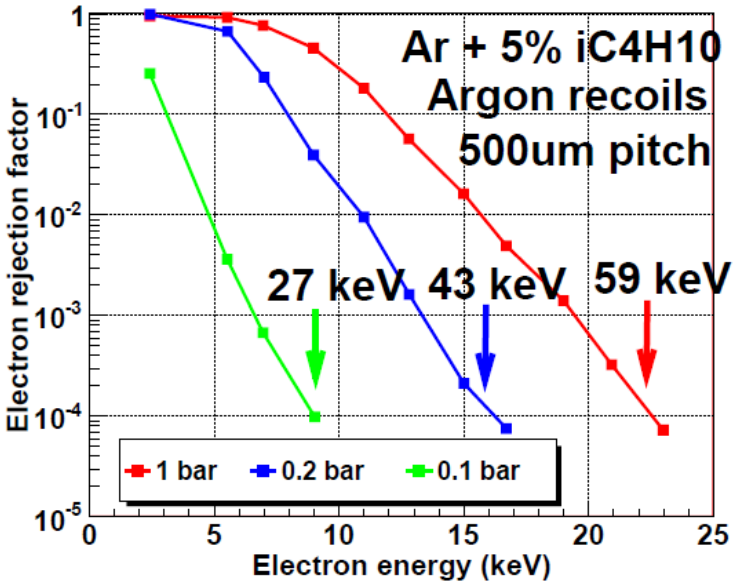
Component	Material	Back. level ($keV^{-1}kg^{-1}day^{-1}$) ^{109}Cd analysis	^{252}Cf analysis
Muons	-	0.019	0.011
Cosmogenics	**^{39}Ar**	**< 2.04**	**< 1.14**
Vessel	Copper	**< 0.33**	**< 0.19**
Connectors	Fujipoly	**0.58**	**0.33**
Field cage	Teflon	1.0×10^{-3}	5.7×10^{-4}
Cathode	Copper	< 0.020	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

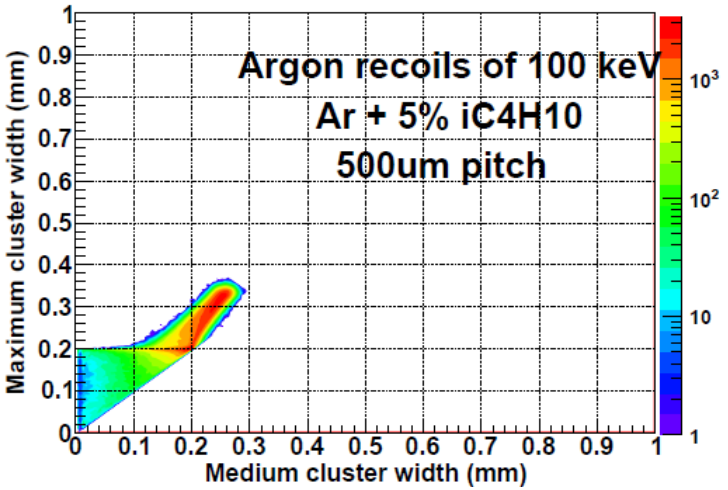


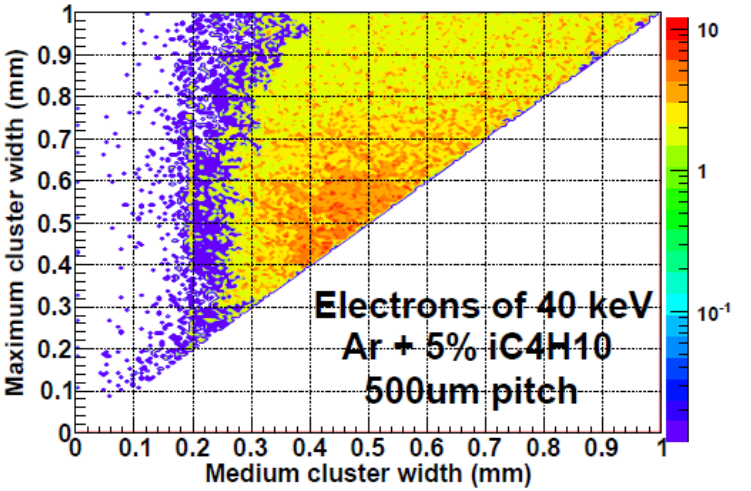
- Preliminary background reduction: **~44% (3.09 -> 1.79).**
- Effective for all components, except for Micromegas detectors (narrower clusters).

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.







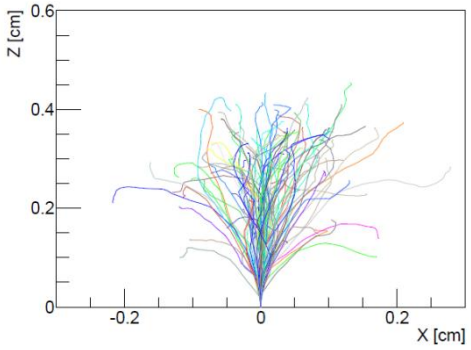
***F.J. Iguaz, Phys. Proc. 37 (2012)* 1079**

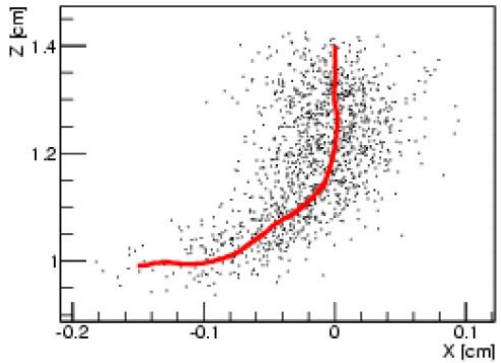
MIMAC directionality in CF_4

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

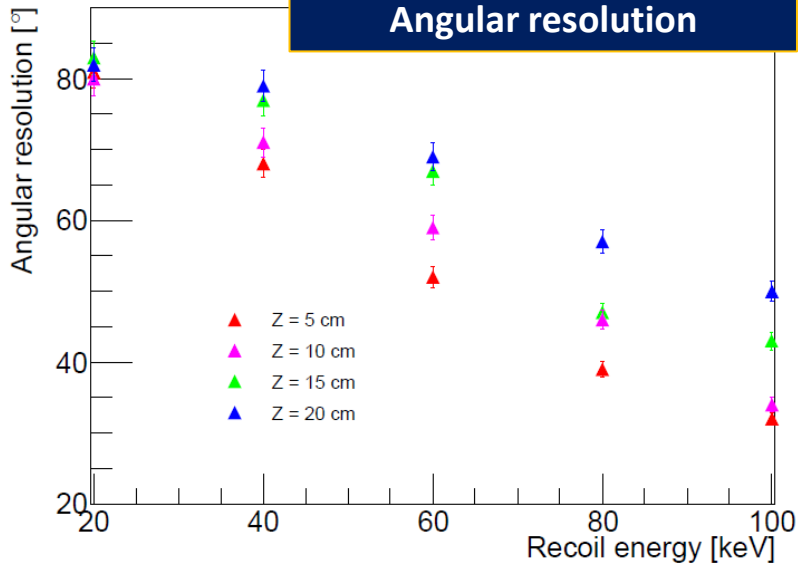
- The angular resolution & sense recognition depends on the energy and the drift distance.
- The sense recognition for recoil energies below 100 keV is unrealistic.
- Focus on axial directional detectors.

Fluorine recoil track

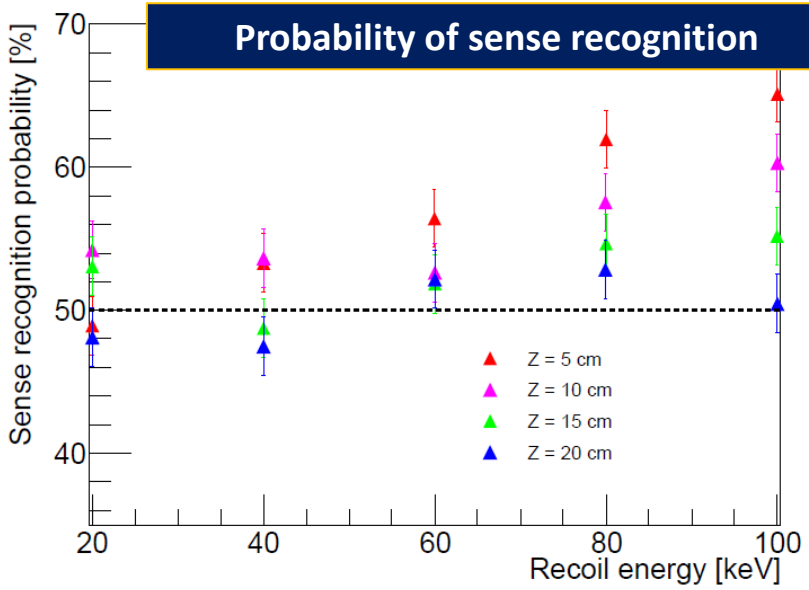




Angular resolution



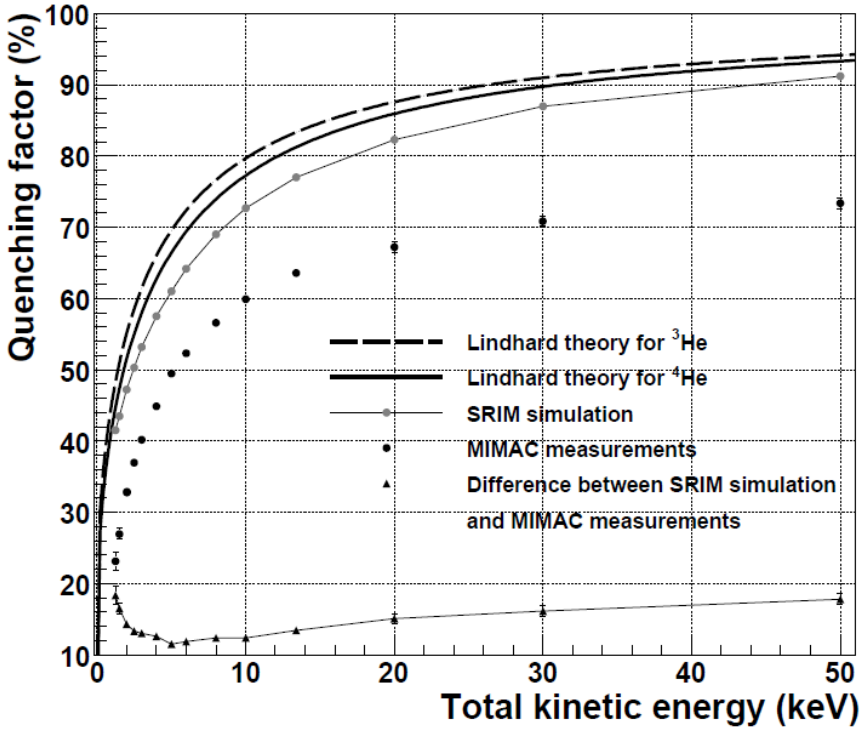
Probability of sense recognition



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