Status of the TREX-DM experiment at the Canfranc Underground Laboratory

- Motivation and goals
- Detector description
- Detector performance
- Background model
- Sensitivity
- Work plan

S. Cebrián, on behalf of the TREX-DM team

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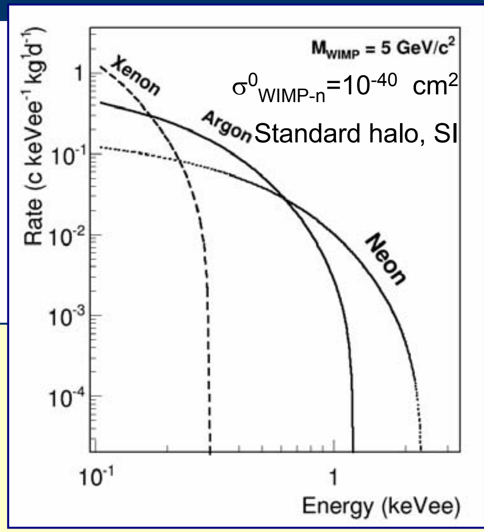
Universidad Zaragoza

LSC Laboratorio Subterráneo de Canfranc

Motivation and goals



Requirements to search for low mass WIMPs**:**

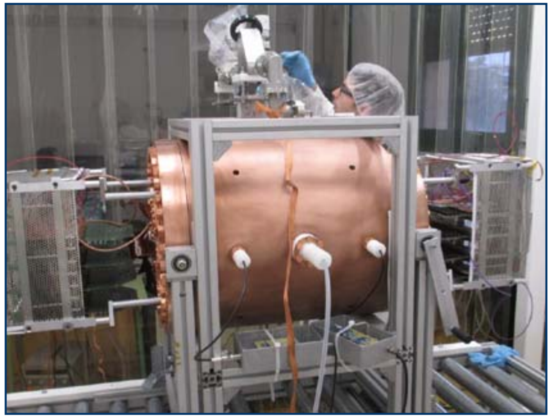
- Very low energy **threshold** (<1 keV$_{ee}$)
- Light elements as target
- Radiopure componentes to reduce **background**

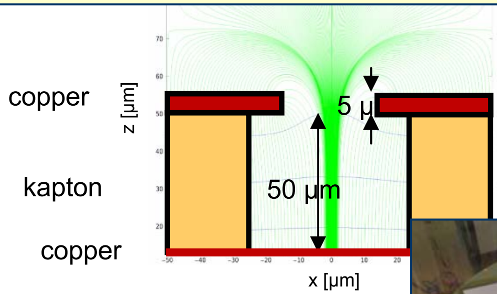
TREX-DM

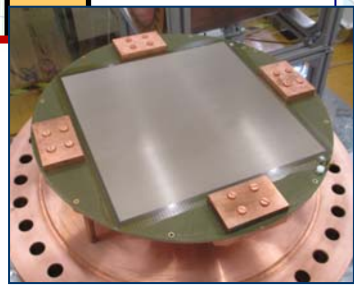
(*TPC for Rare Event eXperiments-Dark Matter*) conceived to

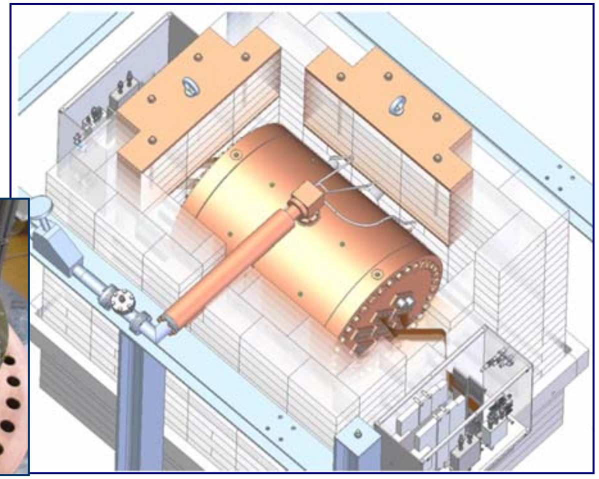
- look for **low mass WIMPs**
- using a **gas Time Projection Chamber** holding
- 20 l of pressurized gas (flexible target: **~0.3 kg Ar, ~0.16 kg Ne** at **10 b**)
- equipped with novel micromesh gas structures (**Micromegas**) readouts
- at the **Canfranc Underground Laboratory** (Spain)

Status: approved experiment by the Scientific Committee, at the commissioning phase



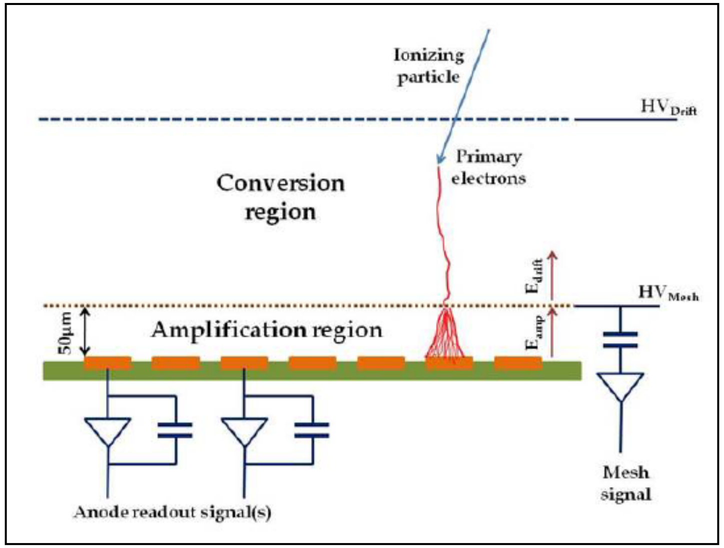






Detector: Micromegas

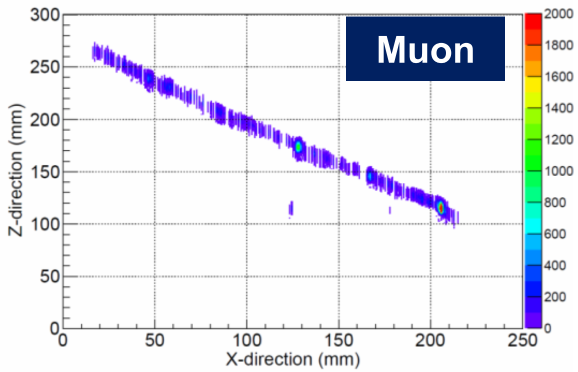
- **Micromegas** are consolidated **readout structures**:
  simple, high granularity, large surfaces
- Different **technologies**:
  - Classical (CAST, COMPASS, ATLAS)
  - Bulk (T2K, CLAS-12, nTOF, MIMAC)
  - **Microbulk**: more homogeneus, radiopure (CAST, nTOF)



- Important **advantages for rare event detection**:
  - **Topological information**: to discriminate backgrounds from expected signal by dark matter (few microns track → point-like event)
  - **Scaling-up**

20 x 20 cm^2
Largest single microbulk so far

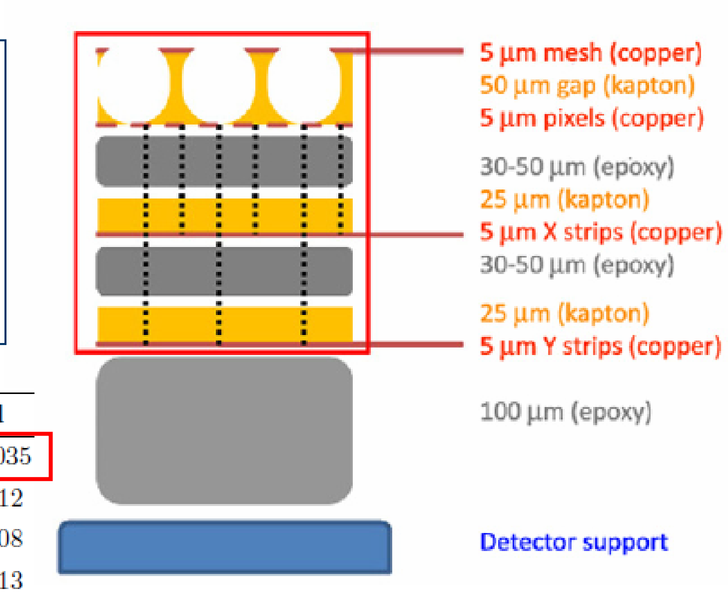
25 x 25 cm^2
TREX-DM in fabrication at CERN



Detector: Micromegas

- Important **advantages for Rare Event detection**:
  - **Low intrinsic radioactivity:** made out of kapton and copper, potentially very clean

- First screening using a germanium detector in Canfranc S. Cebrián et al, Astropart. Phys. 34 (2011) 354
- More sensitive measurements using the BiPo-3 detector at Canfranc and a germanium detector for more massive samples



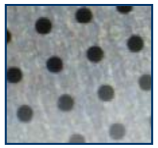
#	Material,Supplier	Method	Unit	^{214}Bi	^{208}Tl
16	Microbulk Micromegas, CAST/CERN	BiPo-3	μBq/cm^2	< 0.134	< 0.035
17	Cu-kapton-Cu foil, CERN	BiPo-3	μBq/cm^2	< 0.141	<0.012
18	Kapton-epoxy foil, CERN	BiPo-3	μBq/cm^2	< 0.033	<0.008
19	Vacrel foil, Saclay	BiPo-3	μBq/cm^2	< 0.032	<0.013
20	Kapton-diamond foil, CERN	BiPo-3	μBq/cm^2	< 0.055	<0.016

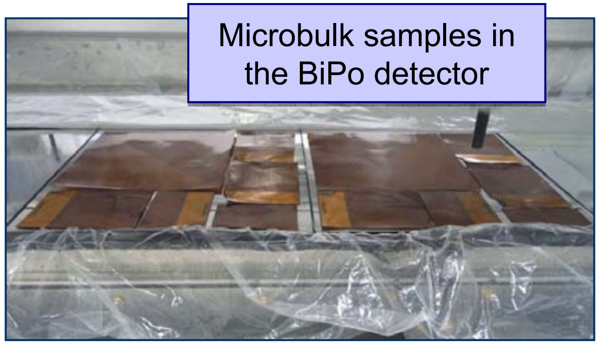
I.G. Irastorza et al, JCAP 01 (2016) 033

^{40}**K:** (3.45 ± 0.40) μBq/cm^2

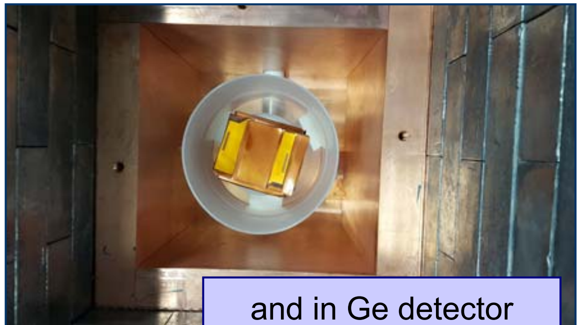
< 2.3 μBq/cm^2

(in a sample without holes produced by kapton etching containing potassium)





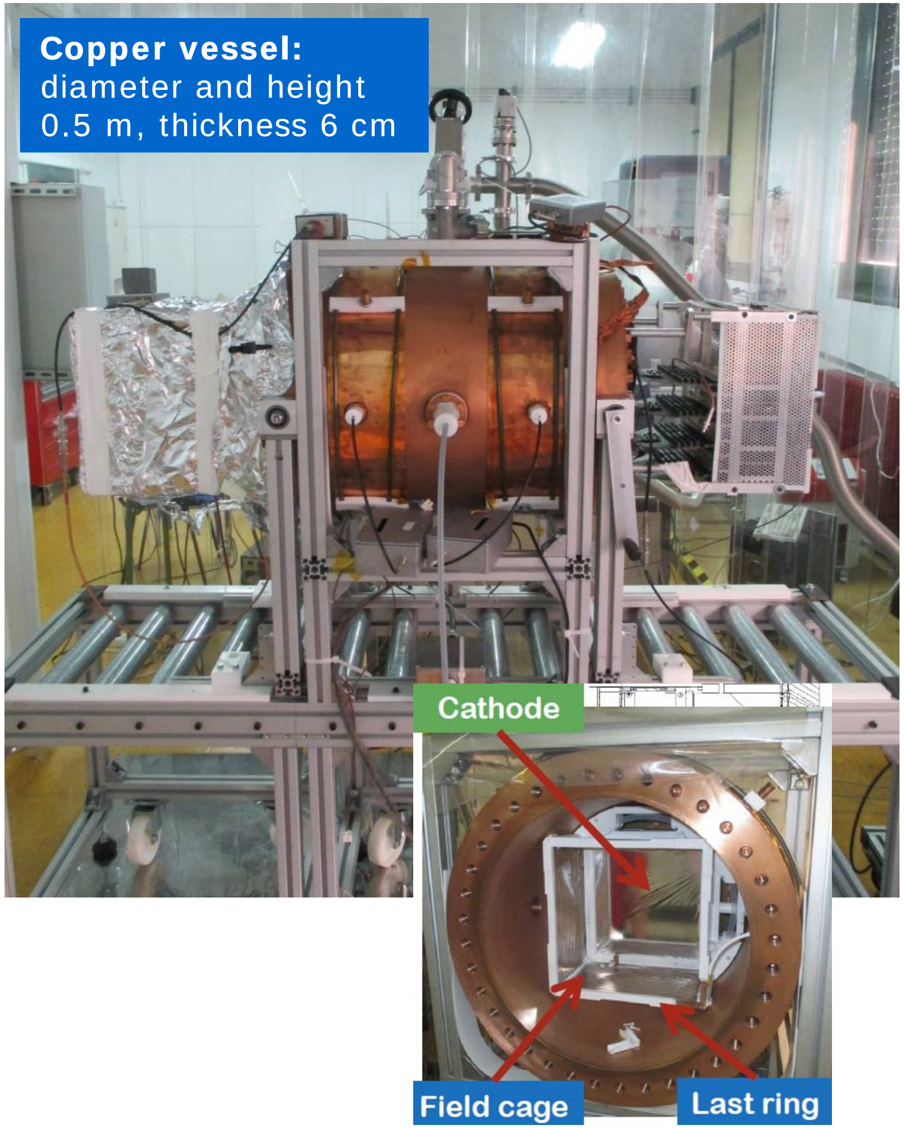
Microbulk samples in the BiPo detector

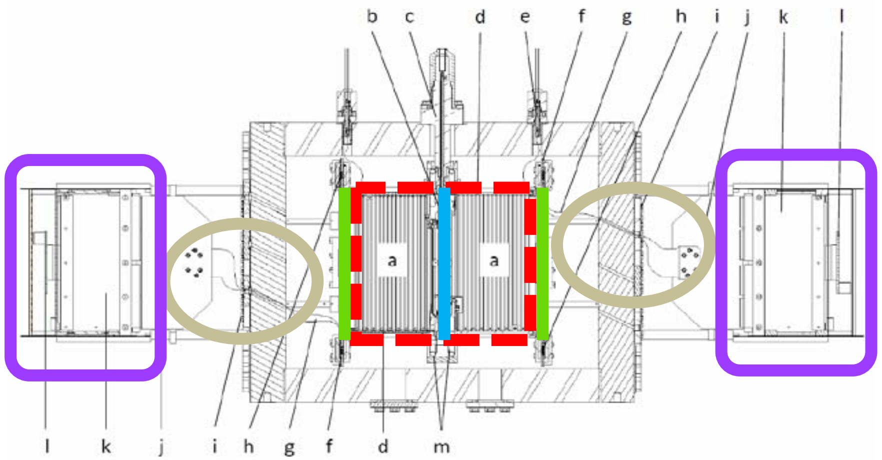


and in Ge detector

Detector: vessel + field cage

- **Detector** as built at University of Zaragoza (non fully radiopure)





Two active volumes: 19 x 25 x 25 cm^3 each

Field cage: kapton & copper + resistors, covered by Teflon

Bulk MM: 25x25cm^2, 2D anode plane (2x432 strips)

Central cathode: mylar, isolated by Teflon

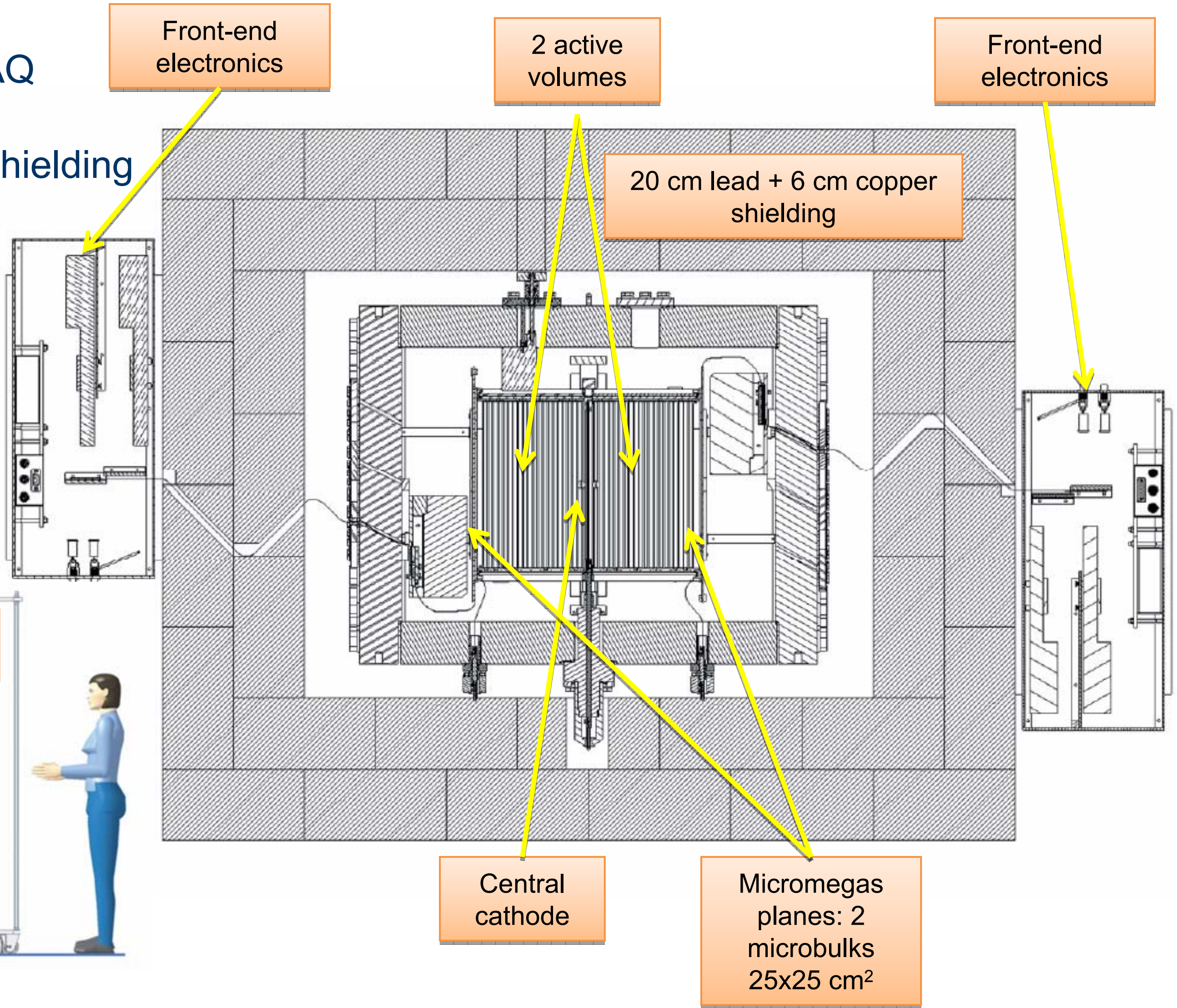
AFTER-based electronics

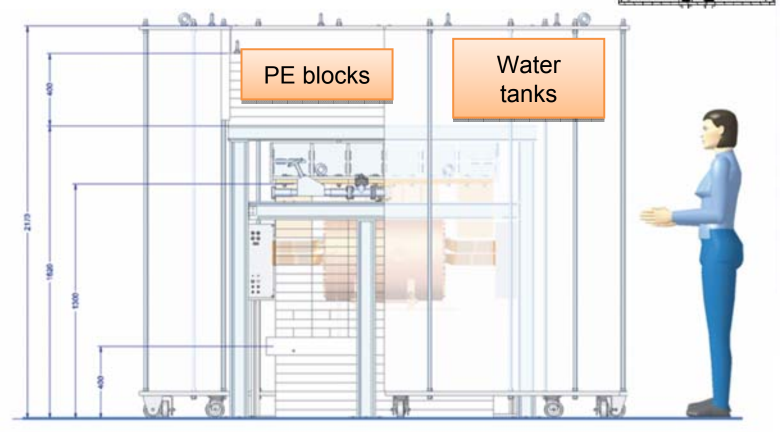
Signals extracted by flat cables

Detector: shielding

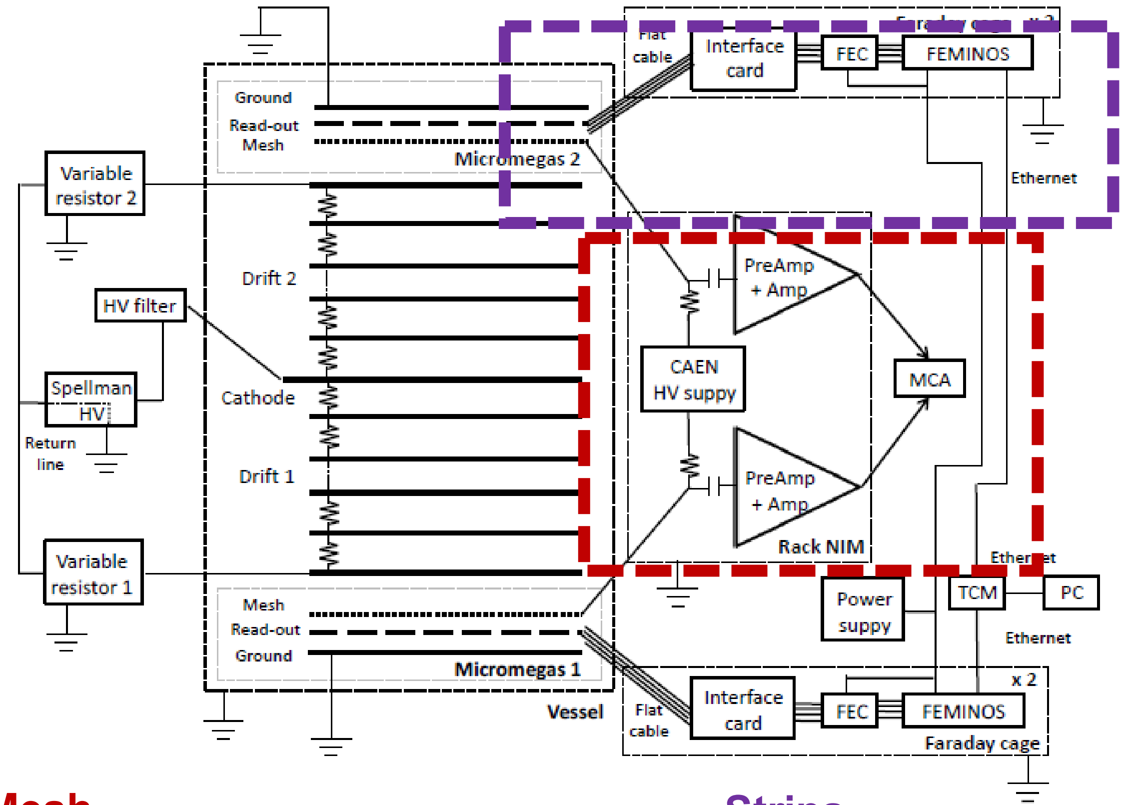
- Detector **set-up** at hall A of Canfranc Underground Laboratory

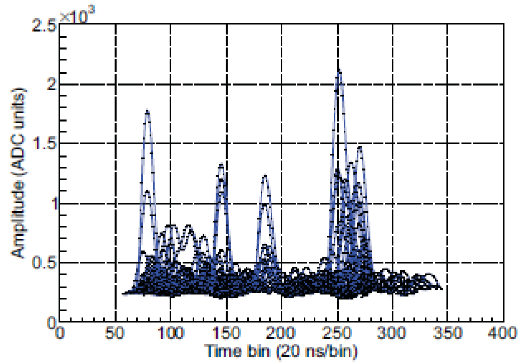
Upgrade to microbulks
Upgrade to AGET-based DAQ
DAQ outside the shielding
Rn-free atmosphere inside shielding



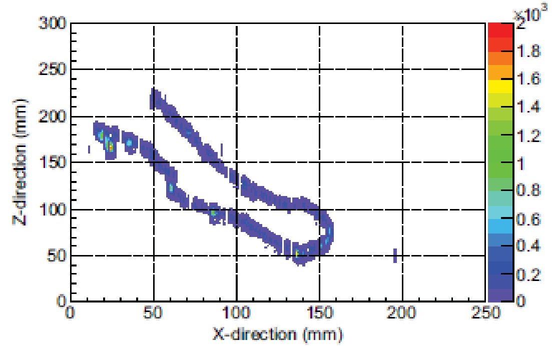


Detector: readout electronics





Acquired pulses and reconstructed event



Mesh

Preamplifier + amplifier → **Spectrum**

Strips

248 X strips, 248 Y strips, 1 mm pitch → **Tracking**

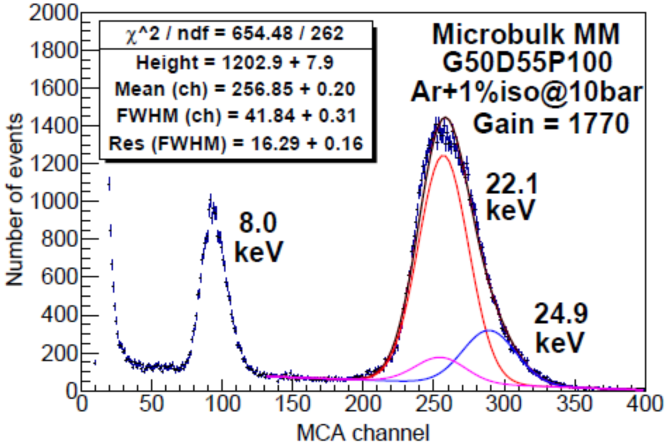
Sampling rate 50 MHz, 512 samples, window 10.2 μs

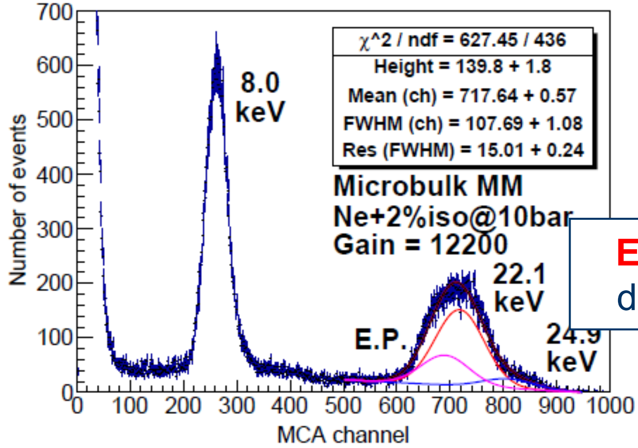
- **Gas system**
  - For non-flammable gases (simplified installation underground)
  - Work open or in closed loop
  - Recirculation part + purification branch + gas recovery system (for Ar)

Detector performance

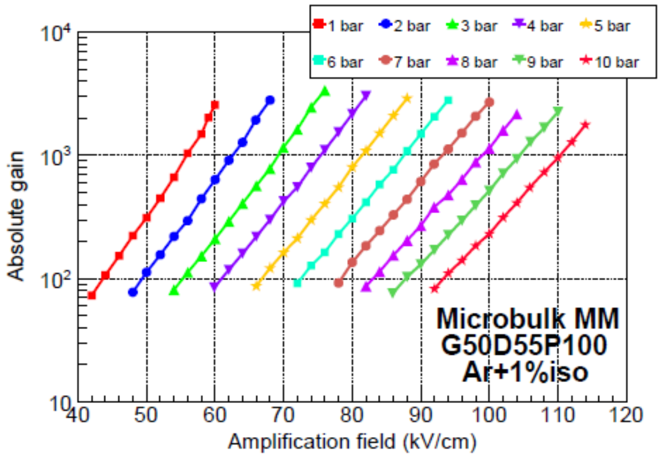
- **Commissioning run on surface** at University of Zaragoza
  - Characterization of **microbulk** micromegas
  - **Ar**+1%iC_4H_{10} and **Ne**+2%iC_4H_{10} at **1-10 bar**.
  - Source: **^{109}Cd**

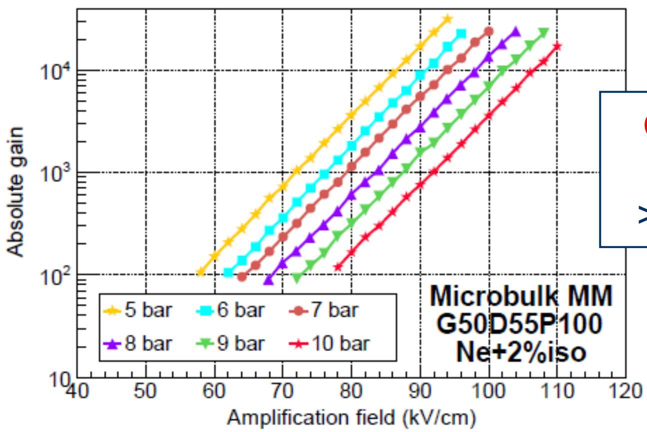
F. J. Iguaz et al, Eur. Phys. J. C 76 (2016) 529





Energy resolution: some degradation with pressure



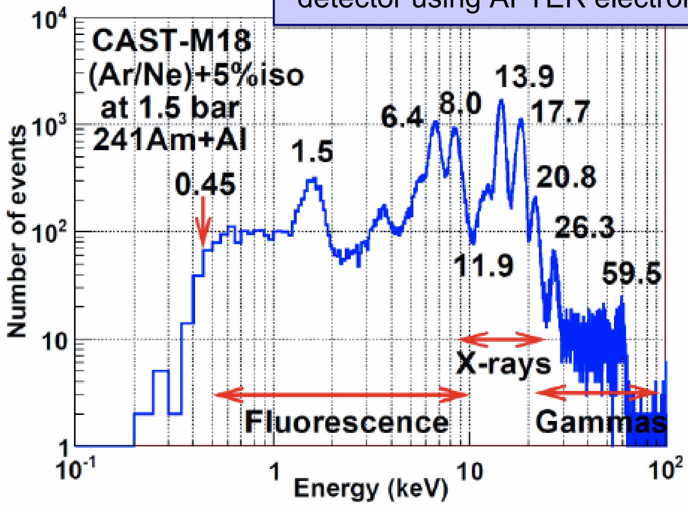


Gain: excellent behaviour, maximum >10^3 in Ar and >10^4 in Ne for all pressures

Detector performance

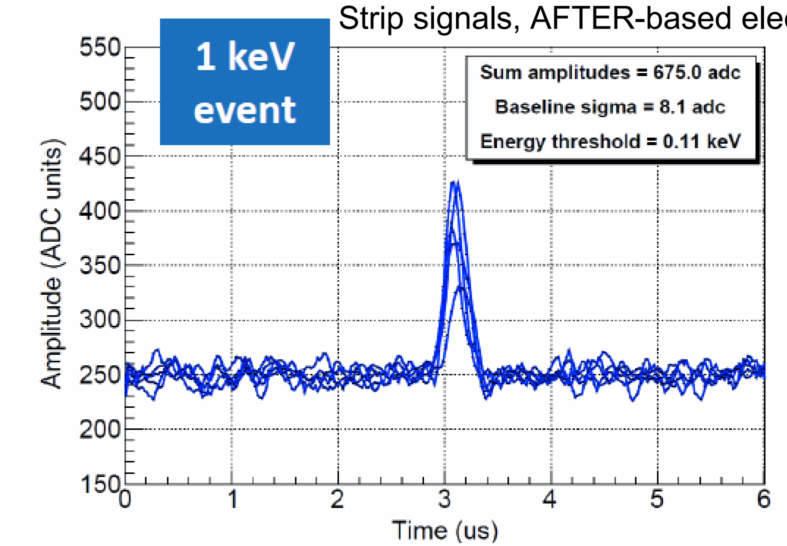
- **Energy threshold**
  - Intrinsic amplification in gas → very low threshold possible
  - In practice, readout area, sensor capacitance, electronic noise and general complexity set the threshold.

Currently achieved in CAST-like detector using AFTER electronics



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

Strip signals, AFTER-based electronics

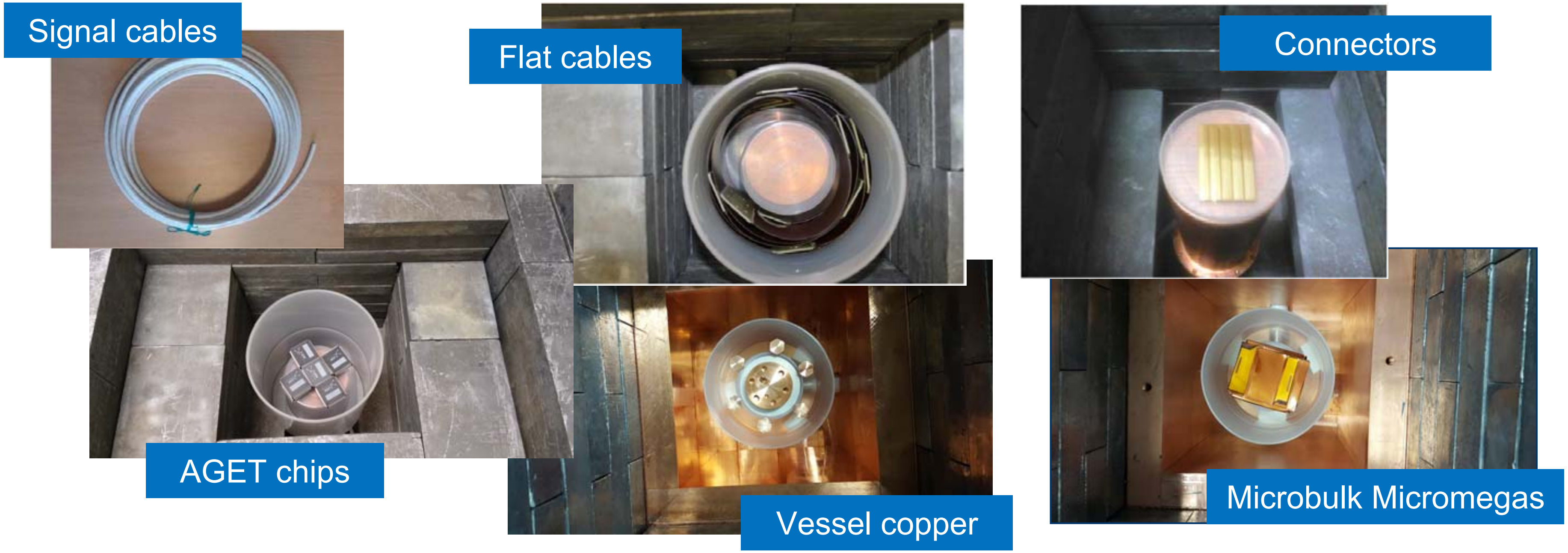


−Trigger was limited by the mesh channel noise level → trigger from low capacitance strips → AGET electronics

TREX-DM aim for sub-keV$_{ee}$ **effective threshold:** 100 eV$_{ee}$ (400 eV$_{ee}$) nominal (conservative)

Background model

- **Inputs for main background sources**
  - Measured fluxes of environmental backgrounds in Canfranc laboratory (gamma, neutrons, muons)
  - Activity measurements from an extensive material screening program underway for several year to select components
    - mainly based on germanium gamma spectrometry in Canfranc
    - complemented by GDMS, ICPMS, BiPo-3 measurements



Background model

#	Material,Supplier	Method	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs
1	Pb, Mifer	GDMS	mBq/kg	0.33		0.10			1.2		
2	OFE Cu, Luvata	GDMS	mBq/kg	<0.012		<0.0041			0.061		
3	ETP Cu, Sanmetal	GDMS	mBq/kg	<0.062		<0.020					
4	Kapton-Cu, LabCircuits	Ge	μBq/cm^2	<160	<14	<12	<8	<2	<40	<2	<2
5	Epoxy Hysol, Henkel	Ge	mBq/kg	<273	<16	<20	<16		<83	<4.2	<4.5
6	SM5D resistor, Finechem	Ge	mBq/pc	0.4±0.2	0.022±0.007	<0.023	<0.016	0.012±0.005	0.17±0.07	<0.005	<0.005
7	Gold connectors, Fujipoly	Ge	mBq/pc	<25	4.45±0.65	1.15±0.35	0.80±0.19		7.3±2.6	<0.1	<0.4
8	Flat cable, Somacis	Ge	mBq/pc	<14	0.44±0.12	<0.33	<0.19	<0.19	1.8±0.7	<0.09	<0.10
9	Teflon cable, Druflon	Ge	mBq/kg	<104	<2.2	<3.7	< 1.7	<1.4	21.6±7.4	<0.7	<0.8
10	Coaxial cable, Axon	Ge	mBq/kg	<650	<24	<15	<9.9	<7.9	163±55	<4.3	<5.1
11	Classical Micromegas, CAST	Ge	μBq/cm^2	<40		4.6±1.6		<6.2	<46	<3.1	
12	Microbulk MM, CAST	Ge	μBq/cm^2	26±14		<9.3		<14	57±25	<3.1	
13	Kapton-Cu foil, CERN	Ge	μBq/cm^2	<11		<4.6		<3.1	<7.7	<1.6	
14	Cu-kapton-Cu foil, CERN	Ge	μBq/cm^2	<11		<4.6		<3.1	<7.7	<1.6	
15	Pyralux, Saclay	Ge	μBq/cm^2	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14
#	**Material,Supplier**	**Method**	**Unit**		**^{214}Bi**	**^{208}Tl**					
16	Microbulk MM, CAST	BiPo-3	μBq/cm^2		<0.134	<0.035					
17	Cu-kapton-Cu foil, CERN	BiPo-3	μBq/cm^2		<0.141	<0.012					
18	Microbulk MM, CERN	BiPo-3	μBq/cm^2		<0.045	<0.014					
19	Kapton-epoxy foil, CERN	BiPo-3	μBq/cm^2		<0.033	<0.008					
20	Pyralux foil, Saclay	BiPo-3	μBq/cm^2		<0.032	<0.013					

Table 2: Activities measured for the most relevant samples analyzed in the ra-

#	Material,Supplier	Method	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs
1	Silver connectors, Fujipoly	Ge	mBq/pc	<55	5.68±0.81	6.1±1.1	6.17±0.72		12.2±3.8	<0.3	<0.3
2	Carbon connectors, Fujipoly	Ge	mBq/pc	14.5±6.0	2.77±0.38	1.17±0.23	1.14±0.14		7.5±2.3	<0.1	<0.1
3	Electronic board	Ge	Bq/kg	94±38	41.4±5.6	59±10	53.6±7.4		19.5±6.1	<0.67	<1.1
4	Chips AGET, CEA	Ge	mBq/pc	<8.7	0.48±0.07	0.16±0.06	0.47±0.09		0.83±0.29	<0.04	<0.04
5	PFA tube, Emtecnik	Ge	mBq/m	<31	<0.58	<0.53	<0.34	<0.29	<2.6	<0.16	<0.18
6	PTFE tube, Tecnyfluor	Ge	mBq/m	<19	<0.48	<0.54	<0.41	<0.26	<2.5	<0.14	<0.17
7	Stainless steel mesh	Ge	µBq/cm^2	<53	<1.5	<1.7	<0.9	<0.6	<8.7	<0.3	<0.5

Table 3: Activities measured for samples analyzed along 2016 for TREX-DM. Values reported for ^{238}U and ^{232}Th correspond to the upper part of the chains and those of ^{226}Ra and ^{228}Th give activities of the lower parts. Reported errors correspond to 1σ uncertainties and upper limits are evaluated at 95% C.L.

Background model

- **Simulation of the detector response**

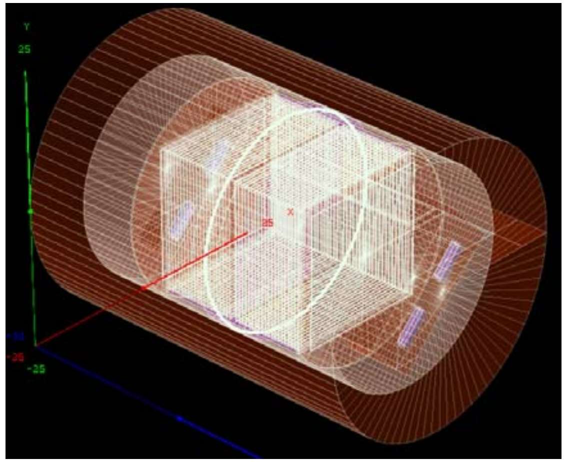
– Based on **Geant4** (Physics processes) **+ REST code**
  - electron generation in gas
  - difussion effects during drift
  - charge amplification at Micromegas
  - signals at mesh and strips

– Analysis to discriminate point-like events from complex topologies

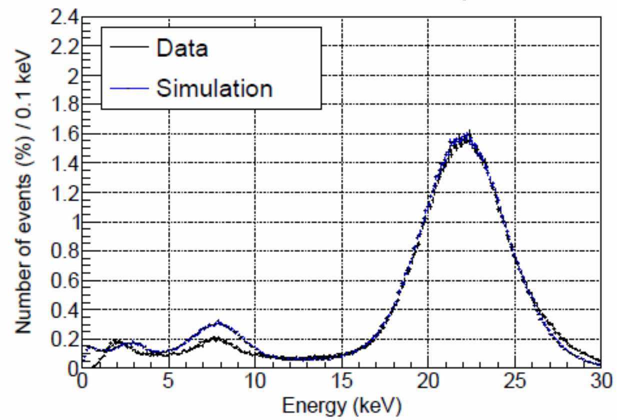
– Detailed geometry including shielding implemented

– For **Ar** and **Ne** mixtures at 10 b

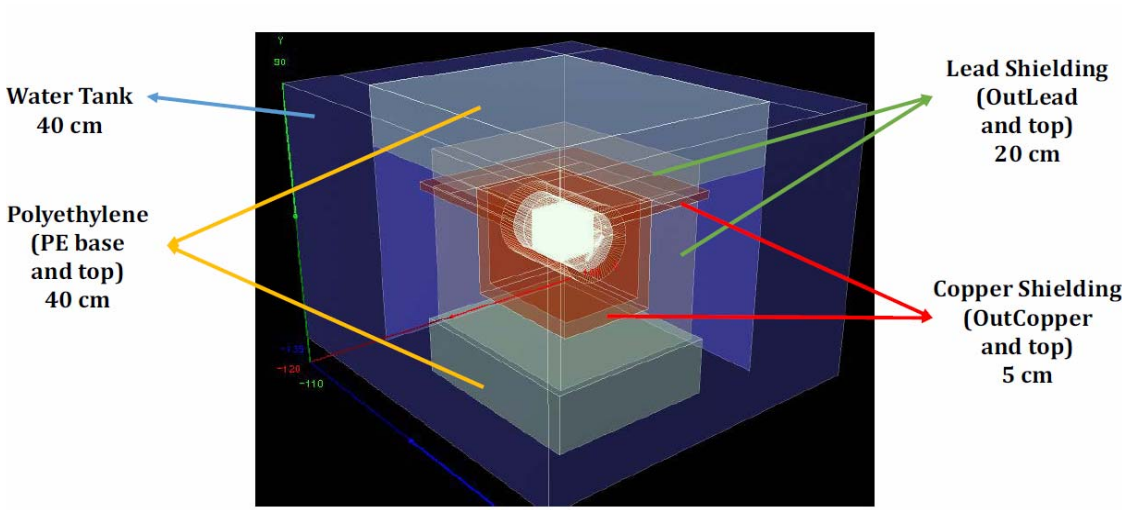
– Successful **validation** against experimental data



^{109}Cd source at calibration point



Ar+2%iC_4H_{10} at 2 bar



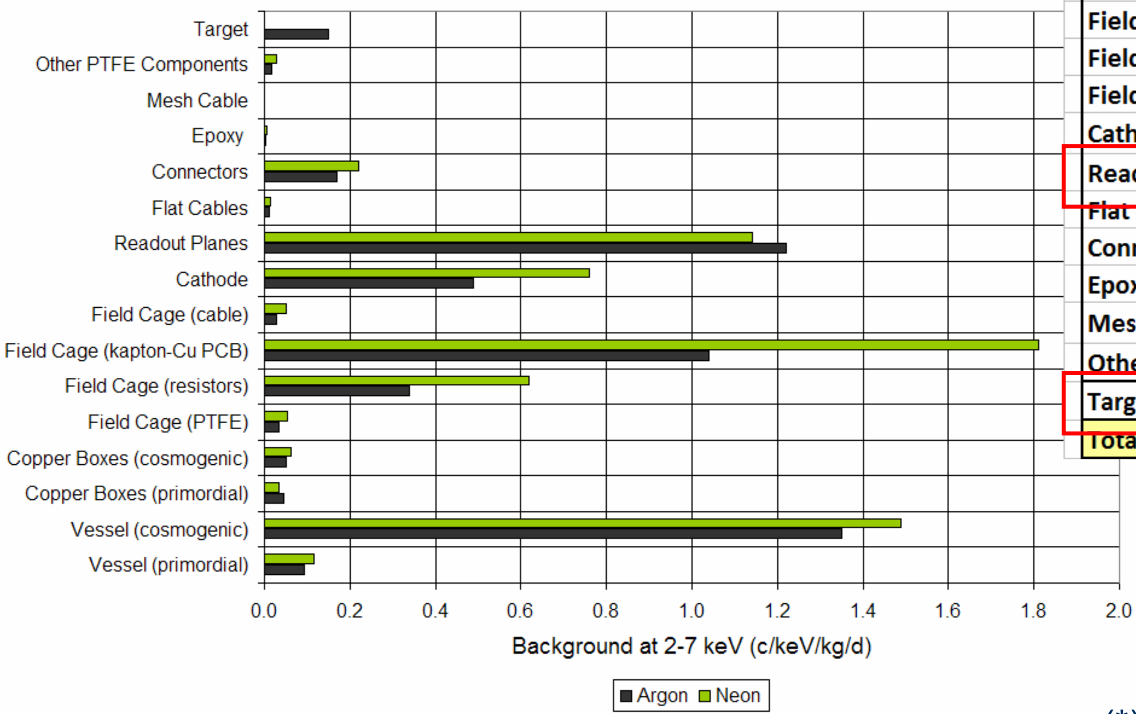
Background model

Background rates in 2-7 keV_{ee} in c keV^{-1} kg^{-1} d^{-1} (*)

- From primordial/cosmogenic **activity** in components **inside or close to the vessel**

Cu vessel activated after a few y at sea level: (0.24±0.05) mBq/kg of ^{60}Co from dedicated measurement
→ contribution suppressed for a new vessel

Measured ^{40}K in **micromegas**, related to kapton etching



Component		Argon	Neon	Main contr.
Vessel (primordial)	<	0.093	0.116	238U
Vessel (cosmogenic)		1.35	1.49	60Co
Copper Boxes (primordial)	<	0.046	0.035	238U
Copper Boxes (cosmogenic)		0.052	0.063	60Co
Field Cage (PTFE)	<	0.033	0.054	238U
Field Cage (resistors)	<	0.34	0.62	238U
Field Cage (kapton-Cu PCB)	<	1.04	1.81	238U
Field Cage (cable)	<	0.027	0.05	238U
Cathode	<	0.49	0.76	238U & ^{40}K
Readout Planes	<	1.22	1.14	40K
Flat Cables	<	0.010	0.015	238U
Connectors	<	0.17	0.22	238U
Epoxy	<	0.0042	0.0052	232Th
Mesh Cable	<	$5.6\cdot10^{-4}$	$7.2\cdot10^{-4}$	238U
Other PTFE Components	<	0.016	0.027	238U
Target		0.15		
Total	<	5.04	6.41	

^{39}**Ar** activity for underground **argon** (as DarkSide)

(*) 5.2-16.3 keV_{nr} for Ar, 5.5-17.1 keV_{nr} for Ne

Background model

Background rates in 2-7 keV_{ee} in counts keV^{-1} kg^{-1} d^{-1} (*)

• From primordial/cosmogenic **activity** in components **outside the vessel** and **background at the lab**

Contribution from **muons** and environmental **neutrons** under control

Radon-induced activity: <0.32 mBq/cm^2 of ^{210}**Pb** from a direct germanium measurement on exposed copper

Component	Argon	Neon
Neutrons at LSC	$(2.52 \pm 0.22)\cdot10^{-2}$	$(7.06 \pm 0.61)\cdot10^{-2}$
Neutrons from ^{238}U fission in Pb	$(5.82 \pm 0.39)\cdot10^{-5}$	$(1.094 \pm 0.074)\cdot10^{-4}$
Neutrons from ^{238}U fission in Cu	$<2.1\cdot10^{-6}$	$<4.1\cdot10^{-6}$
Muons (+ muon-induced neutrons)	0.205 ± 0.021	0.336 ± 0.034
^{210}Pb in Pb shielding (*)	<0.12	
Surface ^{210}Pb on Cu vessel	$<3.5\cdot10^{-3}$	$<6.2\cdot10^{-3}$
Surface ^{210}Pb on Cu shielding (*)	<0.025	
Cosmogenic ^{60}Co in Cu shielding	0.0250 ± 0.0018	0.0288 ± 0.0020
^{222}Rn in air	0.1495 ± 0.0024	0.0841 ± 0.0013
External gammas from ^{232}Th (*)	<9.9	
External gammas from ^{238}U (*)	<18	
External gammas from ^{40}K (*)	<27	

(*) 90%CL limits when no event in simulation

TREX-DM expected **background**: 1 (nominal) - 10 (conservative) c/keV/kg/d

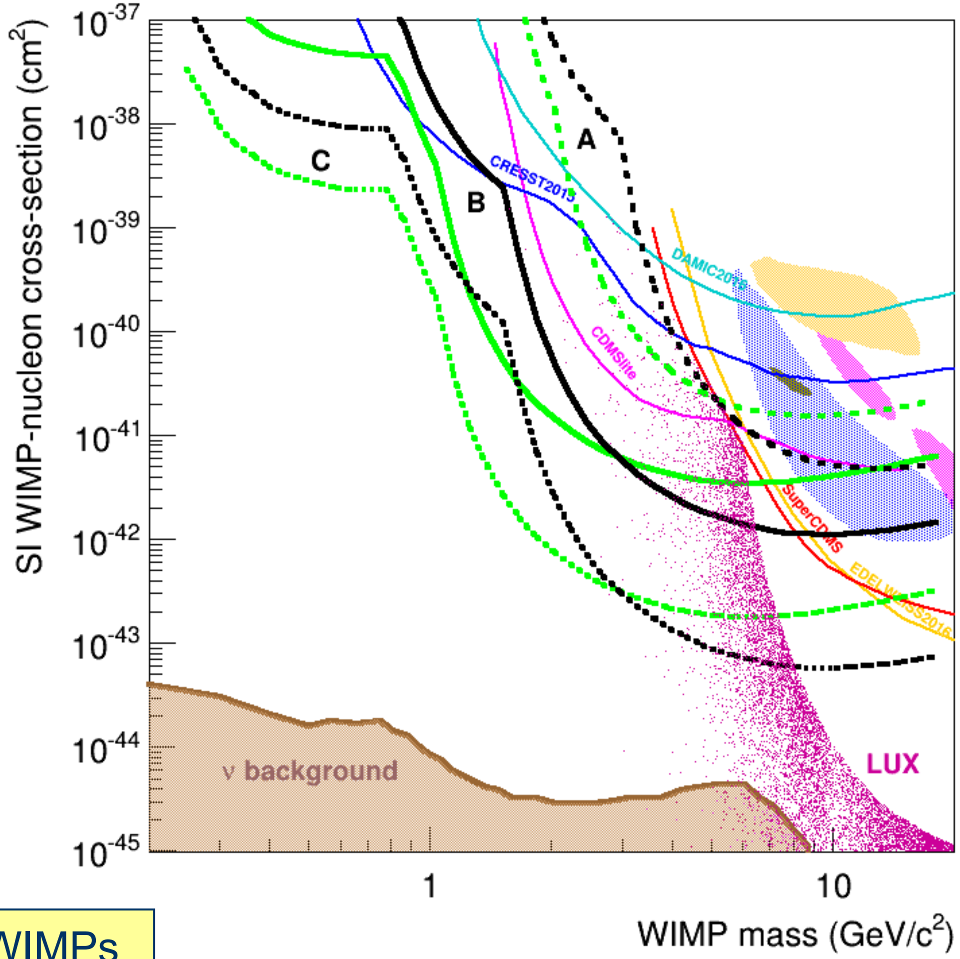
(*) 5.2-16.3 keV_{nr} for Ar, 5.5-17.1 keV_{nr} for Ne

Sensitivity

Prospects for **exclusion plots** (90% C.L.)

- SI interaction
- Standard halo model
- 10 bar pressure
- Different conditions:

	A	B	C
Background level (c keV^{-1} kg^{-1} d^{-1})	10	1	0.1
Energy threshold (keV_{ee})	0.4	0.1	0.1
Exposure (kg y)	0.3	0.3	10



Potential to be sensitive to low mass WIMPs (0.1-10 GeV/c^2) beyond current bounds

Ne-2% iC_4H_{10} , Ar-1% iC_4H_{10}

Work plan

- **Detector improvements** underway:
  - Shielding
  - Radiopure components
  - Readout planes: microbulk micromegas
  - AGET-based DAQ outside shielding

- Estimated **timeline**:
  - Commissioning at Canfranc: ~1 year (2017)
  - Physics Runs: ~2 years

Tentative data-taking programme

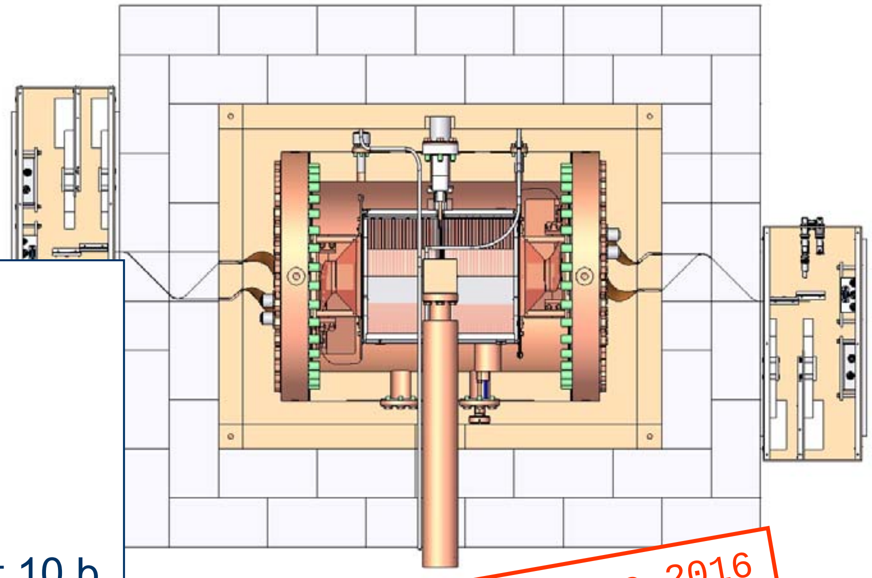
- Ne-2% iC4H10 at 1-10 b: 1 year (2018)
- Evaluation of data: threshold, background
- Possible upgrades of setup
- Restart data taking: possibility of depleted Ar at 10 b

Experiment Proposal to the Scientific Committee of LSC

TREX-DM

A low-background low-threshold Micromegas-based Time Projection Chamber for low-mass WIMP searches

November 18, 2016



Accepted by LSC Dec 2016

Summary

✓ **Gas TPCs with Micromegas planes** have excellent features for rare event searches:

low background levels and thresholds, topological information of events, scaling up possibilities, flexibility in target gas

Still some challenges to be addressed:

performance over large areas, quenching factor

✓ **The TREX-DM experiment** is a Micromegas-read High Pressure TPC for low-mass WIMP searches (not focused on directionality, unique detector of its kind)

- Detector built and operated at surface (University of Zaragoza) as proof of concept
- Prospects for **energy threshold:** ~0.4 keV_{ee} down to 0.1 keV_{ee}
- Radiopure version (following an exhaustive material screening campaign) at commissioning phase in Canfranc
- **Background** model points to levels 1-10 count keV^{-1} kg^{-1} day^{-1}
- Good sensitivity prospects to explore regions beyond the current bounds

Gaseous time projection chambers for rare event detection: results from the T-REX project. II. Dark matter
I.G. Irastorza et al, JCAP 01 (2016) 034
TREX-DM: a low-background Micromegas-based TPC for low-massWIMP detection
F. J. Iguaz et al, Eur. Phys. J. C 76 (2016) 529