Low background microbulk Micromegas detectors for axion searches

F.J. Iguaz, on behalf of Zaragoza group

Axions & IAXO in Spain – 27th October 2016

Work partially supported by Juan de la Cierva program

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Many thanks to my colleagues:
F. Aznar, J.F. Castel, T. Dafni, J.An. García*,
J.G. Garza, I.G. Irastorza, G. Luzón,
H. Mirallas & E. Ruiz-Chóliz.

* Now at Inst. High. Energy Phys., Beijing.

Outline

- Detection concept: TPCs + Micromegas
- Microbulk Micromegas readouts
- IAXO pathfinder at CAST
- IAXO-D0 project
- Conclusions

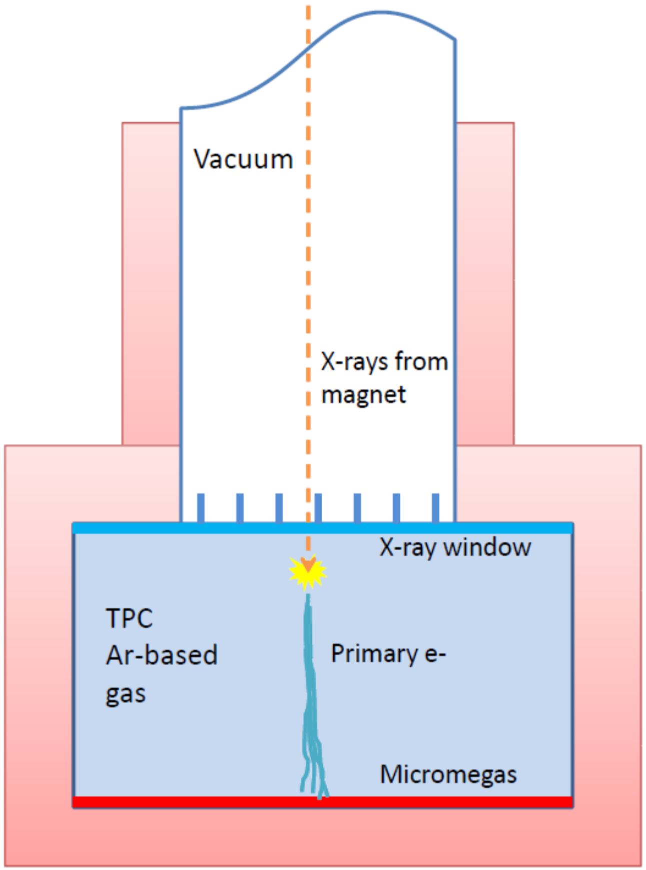
Detection concept - TPCs

Time Projection Chamber (TPC)

- Small gaseous chamber
- Cathode: thin window
  - Holds the detector gas.
  - Transparent to x-rays.
- Anode: A Micromegas readout plane.

TPC working principle

- Ionizing radiation creates primary charges.
- Charges drift towards the anode & amplified.
- Induced signals at the readout.



Microbulk Micromegas readouts

Micromegas readouts

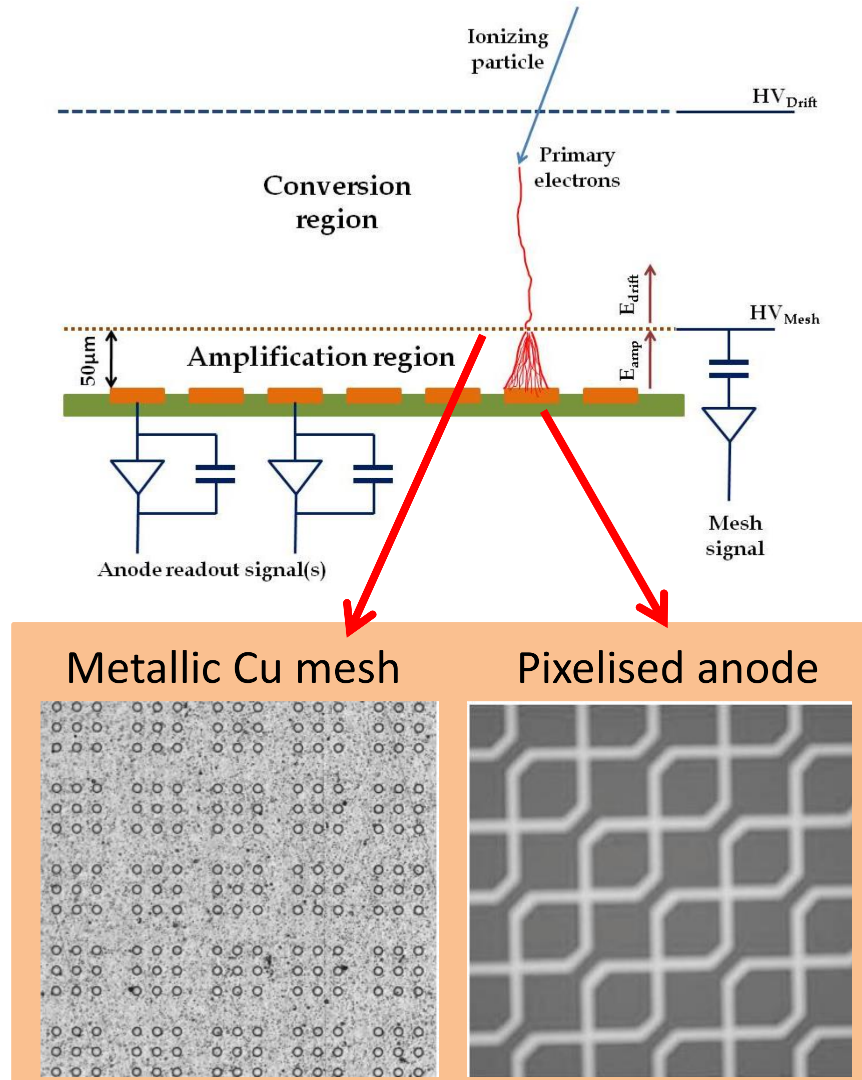
- Pixelized anode plane
- Suspended metallic (Cu) micromesh

Micromegas working principle

- Primary e-s go through mesh holes.
- Trigger an e- avalanche in the gas, inducing signals both mesh and anode.

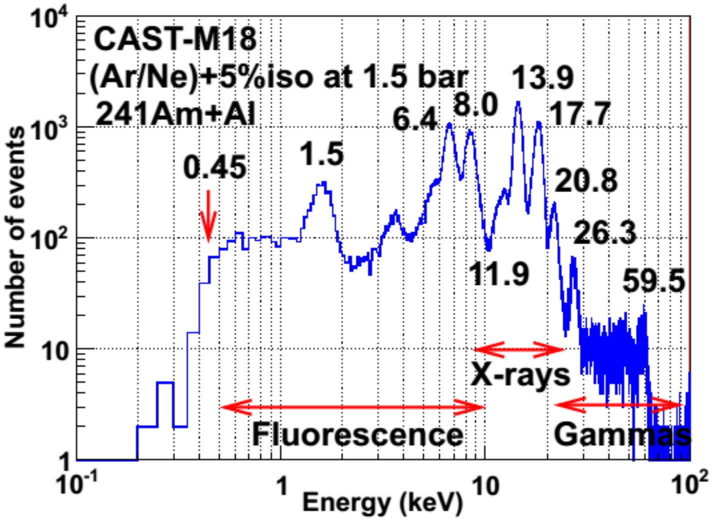
Microbulk fabrication technique

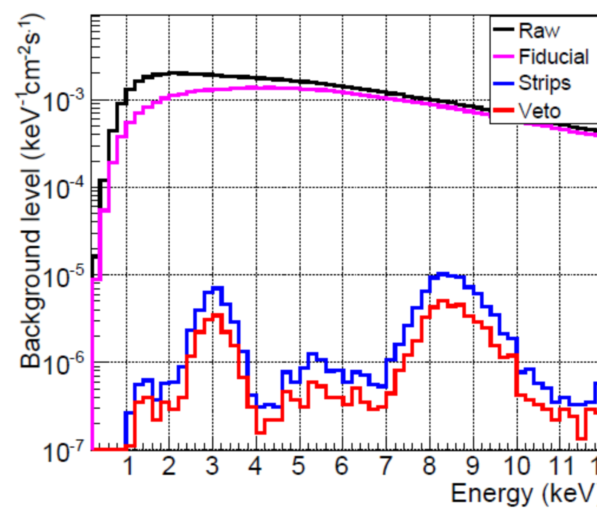
- Developped by CERN & CEA/Saclay.
- Kapton sheet double-clad with copper.
  - Radiopure materials.
- Highest precision in gap homogeneity
  - Good energy resolution.



Gas TPCs with microbulk Micromegas

- Consolidated structure and manufacture.
  - Good performance systematically obtained.
- Good energy resolution. (JINST 7 (2012) P04007)
  - 13% FWHM at 5.9 keV.
- Low energy threshold. (JINST 9 (2014) P01001)
  - 0.45 keV for a 6x6 cm^2 area, could be improved.
- Low intrinsic radioactivity. (JCAP 1601 (2016) 033)
  - Made out of Kapton and copper.
- Radioactivity control. (JINST 8 (2013) C11012)
  - Material study to select the cleanest components.
- Topological information. (JINST 8 (2013) C12042)
  - High power to discriminate x-rays from background.
- Scaling-up. (EJPC 76 (2016) 529)
  - Proven in NEXT-MM and TREX-DM experiments.





Radiopurity of microbulk Micromegas

A key feature for applications in Rear Event Searches.

- First measurement made in 2011 by a Ge detector, already better than PMTs.
- The limits obtained for ^{214}Bi & ^{208}Tl isotopes by BiPo-3 experiment in 2016 are *a factor 100 better* than those set by Ge.
- Two new samples (x10 larger area) have been measured in BiPo-3. Preliminary limits are a factor 3 better!

Sample	^{232}Th	^{235}U
Micromegas without mesh	4.6 ± 1.6	<6.2
Microbulk-Micromegas	<9.3	<13.9
Kapton–copper foil	<4.6[a]	<3.1[a]
Copper–kapton–copper foil	<4.6[a]	<3.1[a]

S. Cebrián et al., *Astropart. Phys.* **34** (2011) 354-359

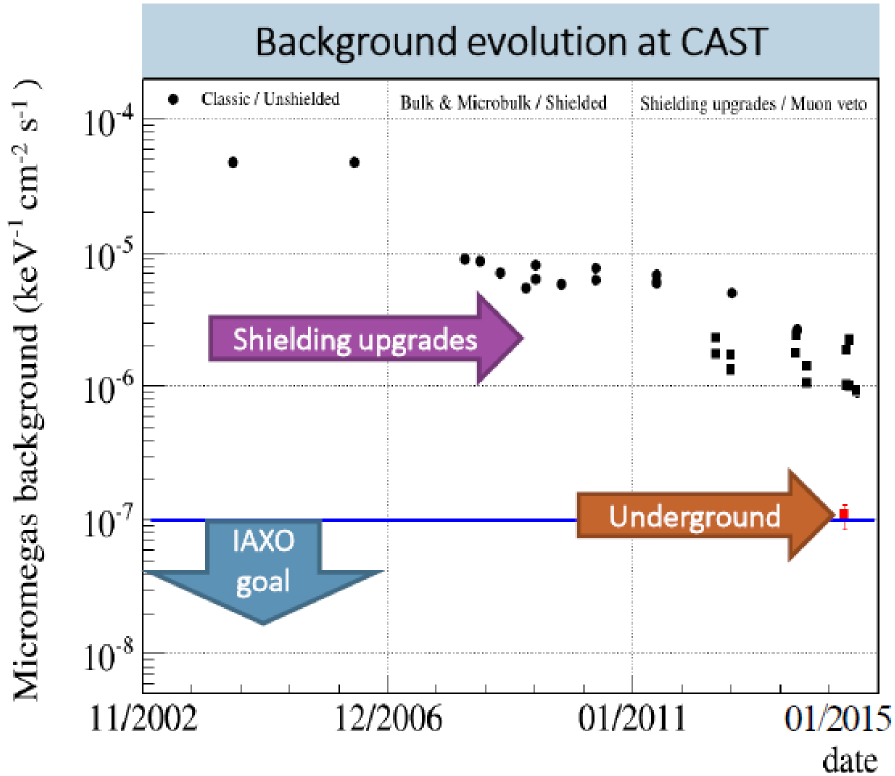
#	Material,Supplier	Method	Unit	^{214}Bi	^{208}Tl
16	Microbulk Micromegas, CAST/CERN	BiPo-3	μBq/cm^2	< 0.134	< 0.035
17	Cu-kapton-Cu foil, CERN	BiPo-3	μBq/cm^2	< 0.141	<0.012
18	Kapton-epoxy foil, CERN	BiPo-3	μBq/cm^2	< 0.033	<0.008
19	Vacrel foil, Saclay	BiPo-3	μBq/cm^2	< 0.032	<0.013
20	Kapton-diamond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

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

Evolution of MM background level

Background improvements

- Non-radiopure components replaced.
- Active shielding
  - Scintillators as muon vetos covering the maximum solid angle.
- Passive shielding
  - Detector chamber & tubes of copper.
  - 10 cm lead around the detector.
- Event topology
  - Time information of each strip signal -> 3D topology of each event.
  - Improvement in rejection algorithms.



Key numbers for comparison:

- **CAST ->** $(8.3 \pm 0.3) \times 10^{-7}$ counts keV^{-1} cm^{-2} s^{-1}
- **LSC ->** $(1.1 \pm 0.1) \times 10^{-7}$ counts keV^{-1} cm^{-2} s^{-1}
- **IAXO goal->** 10^{-7} - 10^{-8} counts keV^{-1} cm^{-2} s^{-1}

IAXO pathfinder at CAST

Combination of two IAXO techniques: x-ray optics + Micromegas detector

X-ray optics:

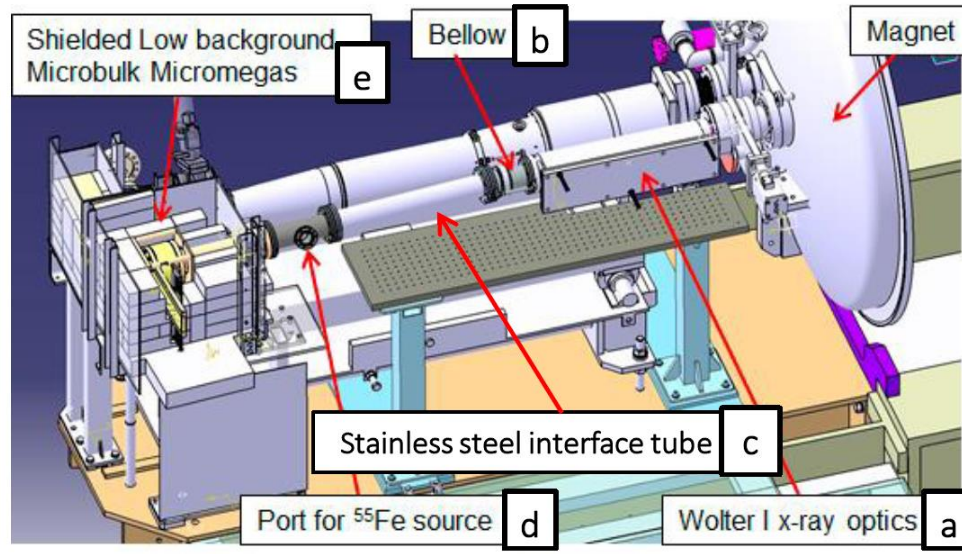
- Wolter I x-ray telescope
- Focal length: 1.5 m.
- Focusing spot: 1-5 mm^2.

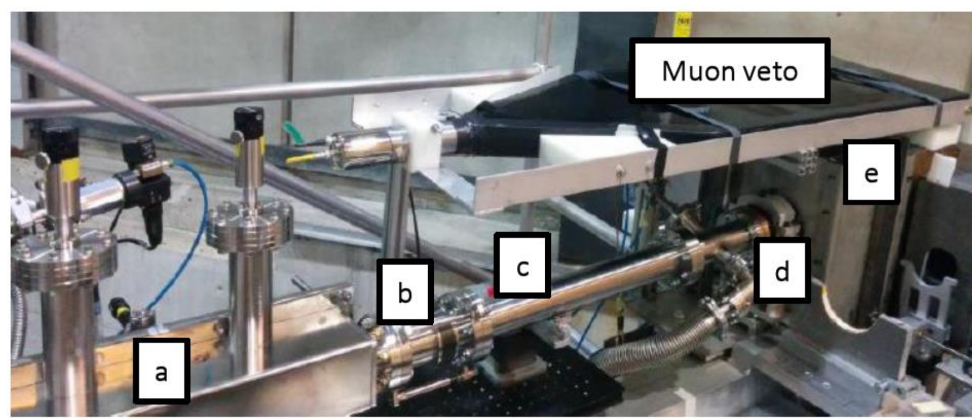
Micromegas detector:

- New design based on Cu & TFE.
- AGET-based electronics.
- Shielding: 20 mm Cu + 100 mm Pb.
- Plastic scintillators as veto.

Performance:

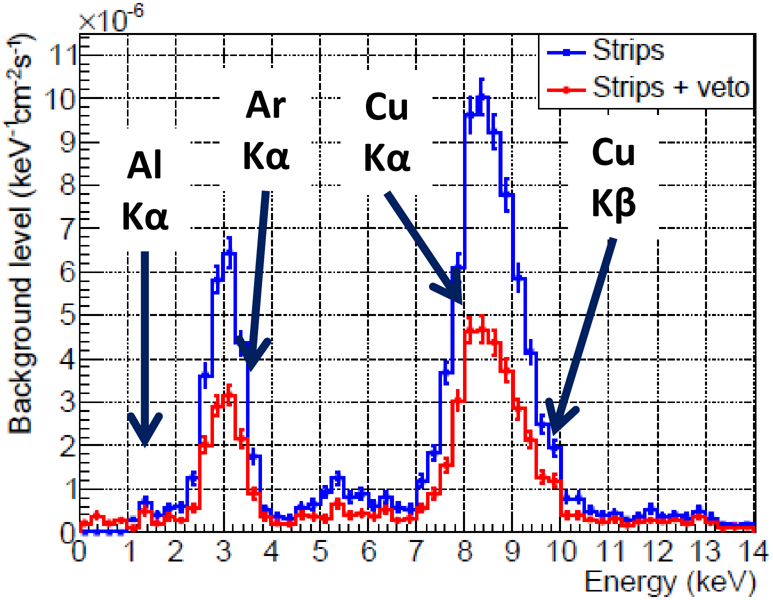
- 8 months of smooth data-taking.
- Best signal-to-noise ratio.
- Data will be used for CAST physics.





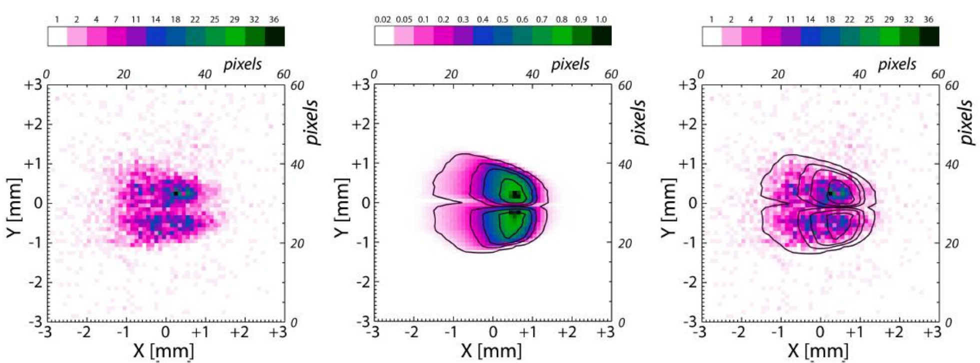
F. Aznar et al., *JCAP* **12** (2015) 008.

IAXO pathfinder performance



Best background level of a MM detector

- Strips + veto:
  - (8.3 ± 0.3) x 10^{-7} counts keV^{-1} cm^{-2} s^{-1}
- Spectrum dominated by:
  - Cu escape peak at 8 keV.
  - Ar fluorescence line at 3 keV.

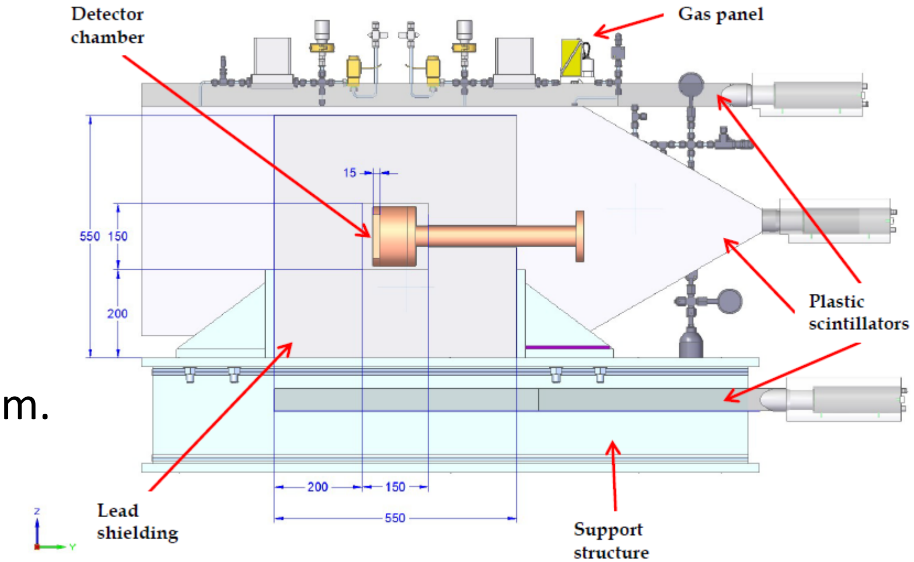


Data **Simulation** **Comparison**

The “axion spot”

- The area where the axion signal is expected.
- Spot stable during the data-taking.
- Agreement between simulation and measurements, i.e., proper alignement.

The IAXO-D0 setup at Zaragoza



Goals:

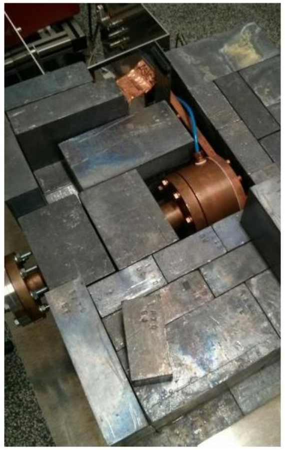
- Background level: 10^{-7}-10^{-8} keV^{-1} cm^{-2} s^{-1}.
- Energy threshold: ~0.1 keV.

Improvements:

- Enlarge the lead shielding from 10 to 20 cm.
- An improve active shielding, 4π coverage.
- New gas system to work with xenon.

Micromegas detector:

- Based on IAXO pathfinder detector.
  - 6x6 cm^2 readout area, strip pattern pitch.
  - Electroformed Cu chamber (3 cm thickness).
  - Spider-web strongback + 4 um Al mylar.
- AGET-based electronics, with auto-trigger capability for every readout channel.



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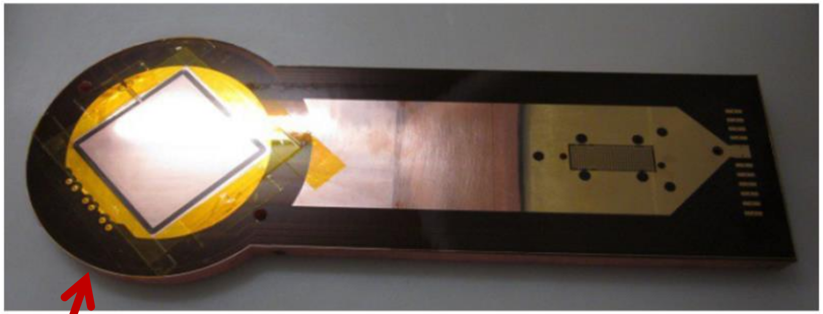

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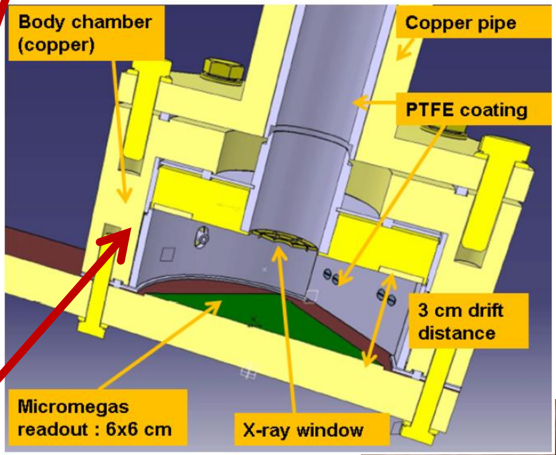

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IAXO-D0 shielding

Passive shielding:

Electroformed Cu chamber & pipes

- Innermost shielding for lead radiation.

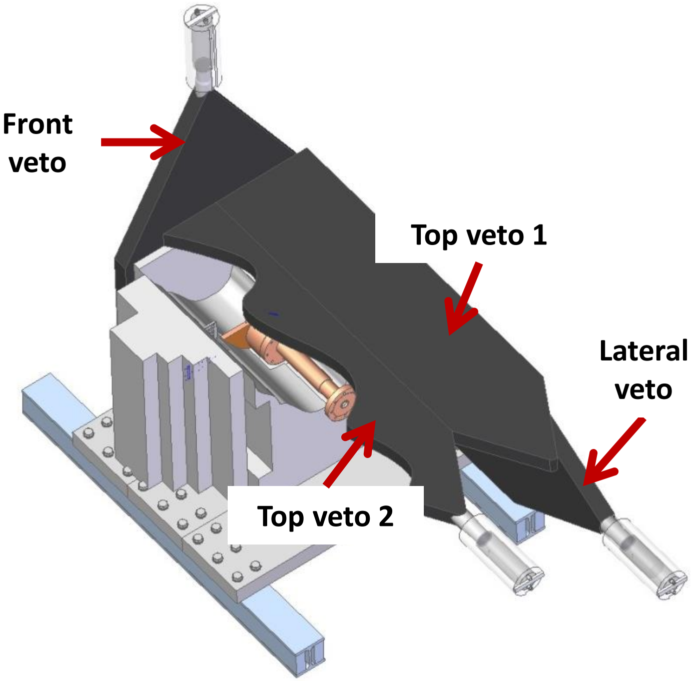
Lead shielding:

- 20 cm of lead, 4π coverage.
- Properly stop gamma radiation.

Active shielding:

Muon vetoes

- 5 scintillators to tag muons.
- Designed for a 4π coverage.



IAXO-D0 next steps

- Commissioning of the gas system.
- Operation with Xenon.
- Shielding optimization.
- Auto-trigger electronics.
- Background model completion.

First results expected mid-2017

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Conclusions

- **Microbulk Micromegas detectors** show nice features for axion searches
  - *Excellent radiopurity, good energy solution in RoI & consolidated manufacture.*
- **IAXO pathfinder** at CAST has proven that the combination of an x-ray focusing device together with a Micromegas detector gives good results in terms of performance and background levels.
- **IAXO-D0 setup** is an IAXO detector prototype that is being commissionned.
  - *Designed to minimize background level with a (new) better active & passive shielding.*
  - *First results are expected for mid-2017.*

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Thanks for your attention!

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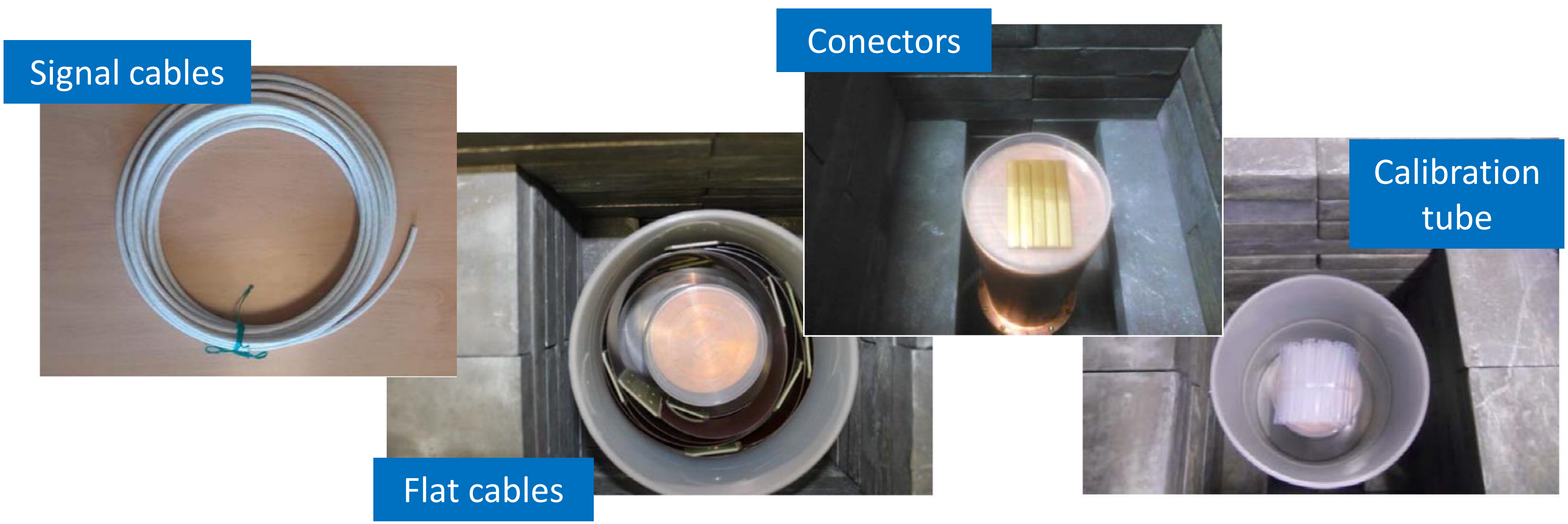
Back-up slides

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 & JCAP01(2016)033.



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Material screening program

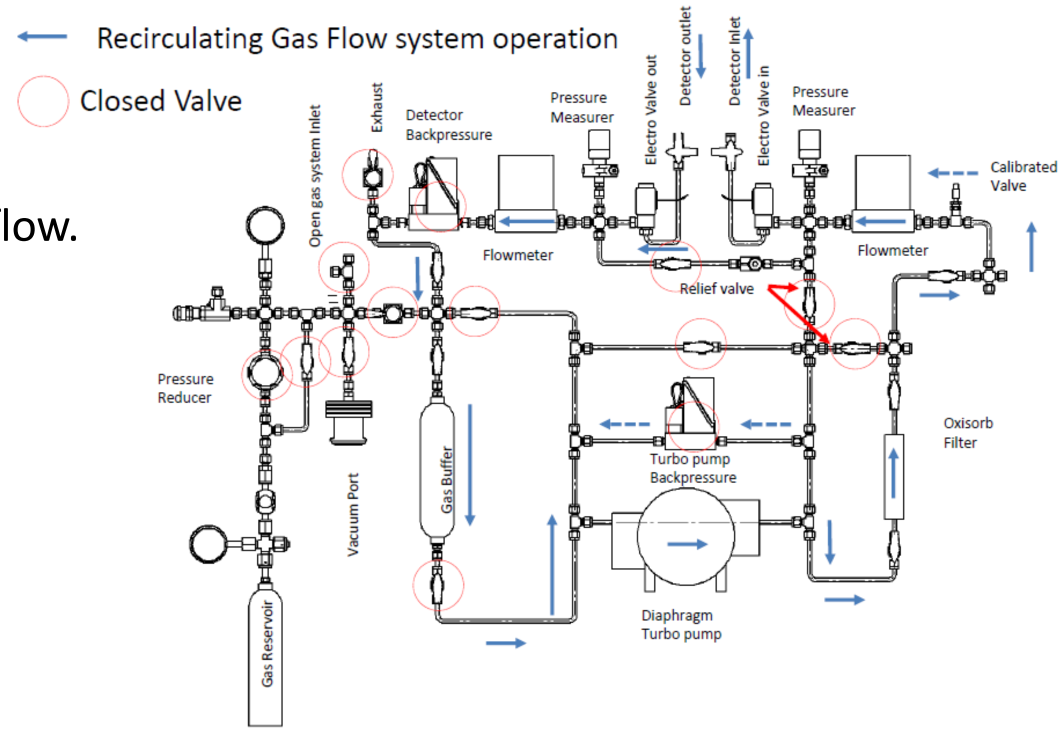
#	Material,Supplier	Technique	Unit	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co
1	Pb, Mifer	GDMS	mBq/kg	<1.2		< 0.41			0.31	
2	Pb, Mifer	GDMS	mBq/kg	0.33		0.10			1.2	
3	Cu, Sanmetal	GDMS	mBq/kg	<0.062		<0.020				
4	Cu, hot rolled, Luvata	GDMS	mBq/kg	<0.012		<0.0041			0.061	
5	Cu, cold rolled, Luvata	GDMS	mBq/kg	<0.012		<0.0041			0.091	
6	Cu, Luvata	Ge	mBq/kg		<7.4	<0.8	<4.3		<18	<0.8
7	Kapton-Cu, LabCircuits	Ge	μBq/cm^2	<160	<14	<12	<8	<2	<40	<2
8	Teflon, Sanmetal	Ge	mBq/kg	<157	<4.1	<6.6	<4.8	<4.8	<19	<1.2
9	Teflon tube, RS	Ge	mBq/kg	<943	<21	<37	<31	<19	510±170	<7.6
10	Stycast, Henkel	Ge	mBq/kg	(3.7±1.4)10^3	52±10	44±12	38±9		(0.32±0.11)10^3	<5.5
11	Epoxy Hysol, Henkel	Ge	mBq/kg	<273	<16	<20	<16		<83	<4.2
12	SMD resistor, Farnell	Ge	mBq/pc	2.3±1.0	0.16±0.03	0.30±0.06	0.30±0.05	<0.05	0.19±0.08	<0.02
13	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
14	CF40 flange, Pfeiffer	Ge	mBq/kg		14.3±2.8	9.7±2.3	16.2±3.9	3.2±1.1	<17	11.3±2.7
15	Connectors, Samtec	Ge	mBq/pc	<77	9.2±1.1	19.6±3.6	18.5±2.2	1.5±0.4	12.2±4.1	<0.6
16	Connectors, Panasonic	Ge	mBq/pc	<42	6.0±0.9	9.5±1.7	9.4±1.4	<0.95	4.1±1.5	<0.2
17	Connectors, Fujipoly	Ge	mBq/pc	<25	4.45±0.65	1.15±0.35	0.80±0.19		7.3±2.6	<0.1
18	Flat cable, Somacis	Ge	mBq/pc	<370	101±13	165±29	164±23		80±25	<5
19	Flat cable (rigid), Somacis	Ge	mBq/pc	<1.5 10^3	123±17	225±40	198±29		112±40	<5.8
20	Flat cable (flexible), Somacis	Ge	mBq/pc	<102	<3.8	<4.0	<1.4	<1.8	<15	<0.7
21	Flat cable, Somacis	Ge	mBq/pc	<45	<1.7	<1.8	<0.61	<0.77	<6.6	<0.3
22	Flat cable, Somacis	Ge	mBq/pc	<14	0.44±0.12	<0.33	<0.19	<0.19	1.8±0.7	<0.09
23	RG58 cable, Pro-Power	Ge	mBq/kg	(2.2±0.9)10^3	(0.9±0.1)10^3	40±12	29±8	<212	108±43	<9.2
24	Teflon cable, Druflon	Ge	mBq/kg	<104	<2.2	<3.7	< 1.7	<1.4	21.6±7.4	<0.7
25	Teflon cable, Axon	Ge	mBq/kg	<650	<24	<15	<9.9	<7.9	163±55	<4.3
26	Kapton tape, Tesa	Ge	mBq/kg	<1.7 10^3	<34	<40	<22	<14	(0.46±0.15)10^3	<10
27	FR4 PCB, Somacis	Ge	Bq/kg	31±11	15.3±2.1	25.5±4.4	22.5±3.5		15.5±4.7	<0.16
28	PTFE circuit, LabCircuits	Ge	Bq/kg	<36	4.7±0.6	5.0±1.1	6.2±0.9	<0.50	4.5±1.5	<0.16
29	Cuflon, Crane Polyflon	Ge	mBq/kg	<103	<3.7	<3.6	<1.4	<1.8	<13	<0.6
30	Classical Micromegas, CAST	Ge	μBq/cm^2	<40		4.6±1.6		<6.2	<46	<3.1
31	Microbulk Micromegas,CAST	Ge	μBq/cm^2	26±14		<9.3		<14	57±25	<3.1
32	Kapton-Cu foil, CERN	Ge	μBq/cm^2	<11		<4.6		<3.1	<7.7	<1.6
33	Cu-kapton-Cu foil, CERN	Ge	μBq/cm^2	<11		<4.6		<3.1	<7.7	<1.6
34	Vacrel, Saclay	Ge	μBq/cm^2	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10

F.J. Iguaz et al.,
EPJC **76** *(2016) 529*

The gas system of IAXO-D0 setup

Main features:

- Working pressure: 0.3-1.5 bara.
- Volume: 1 normal liter.
- Working modes: open & closed flow.
- Gas recovery by cryopumping.
- An oxisorb filter is available.
- Installed on a wheeled panel



Status:

- Leak tests in vacuum & pressure ended.
- Slow control based on NI-USB/6009 card.
- User manual & documentation in preparation.

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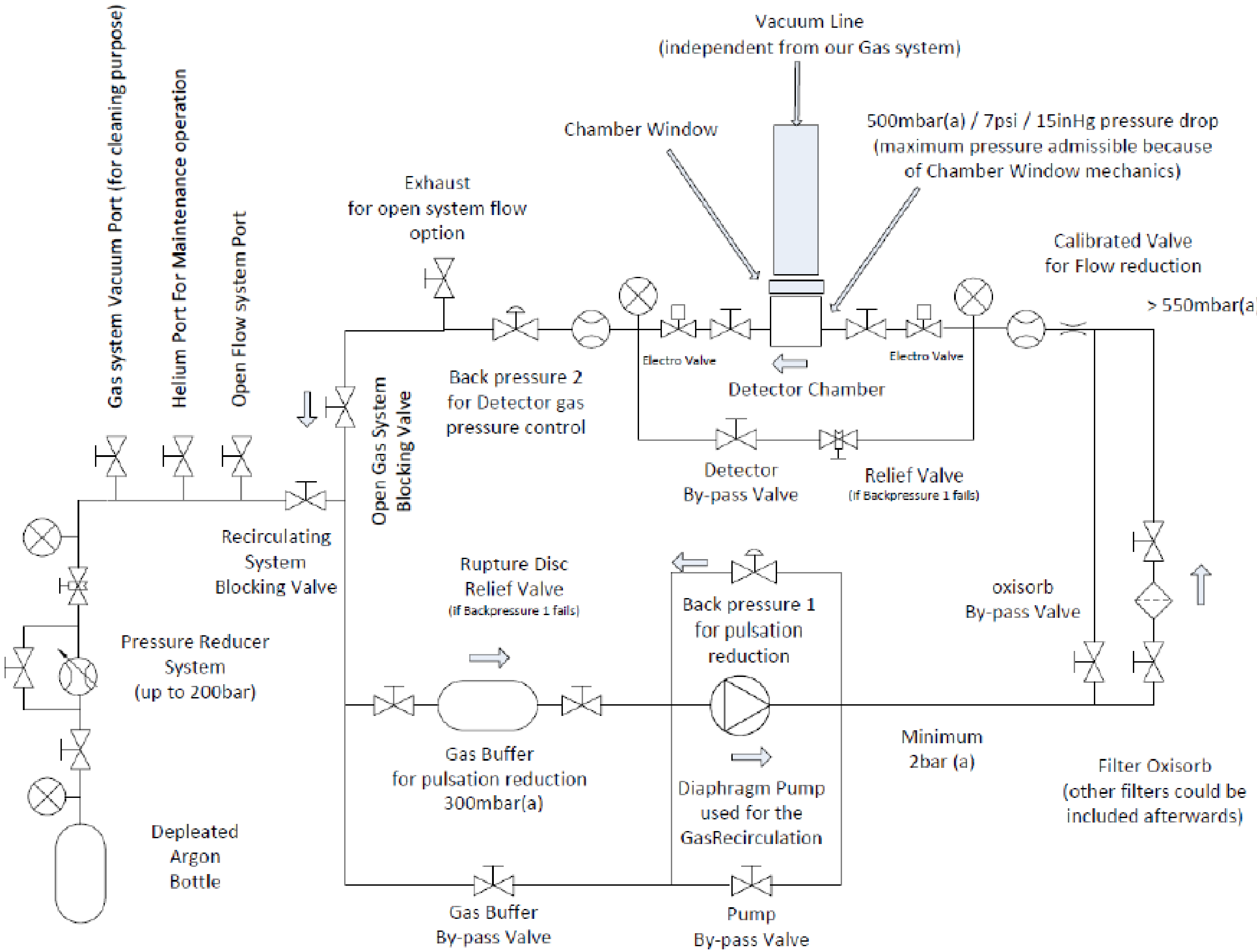
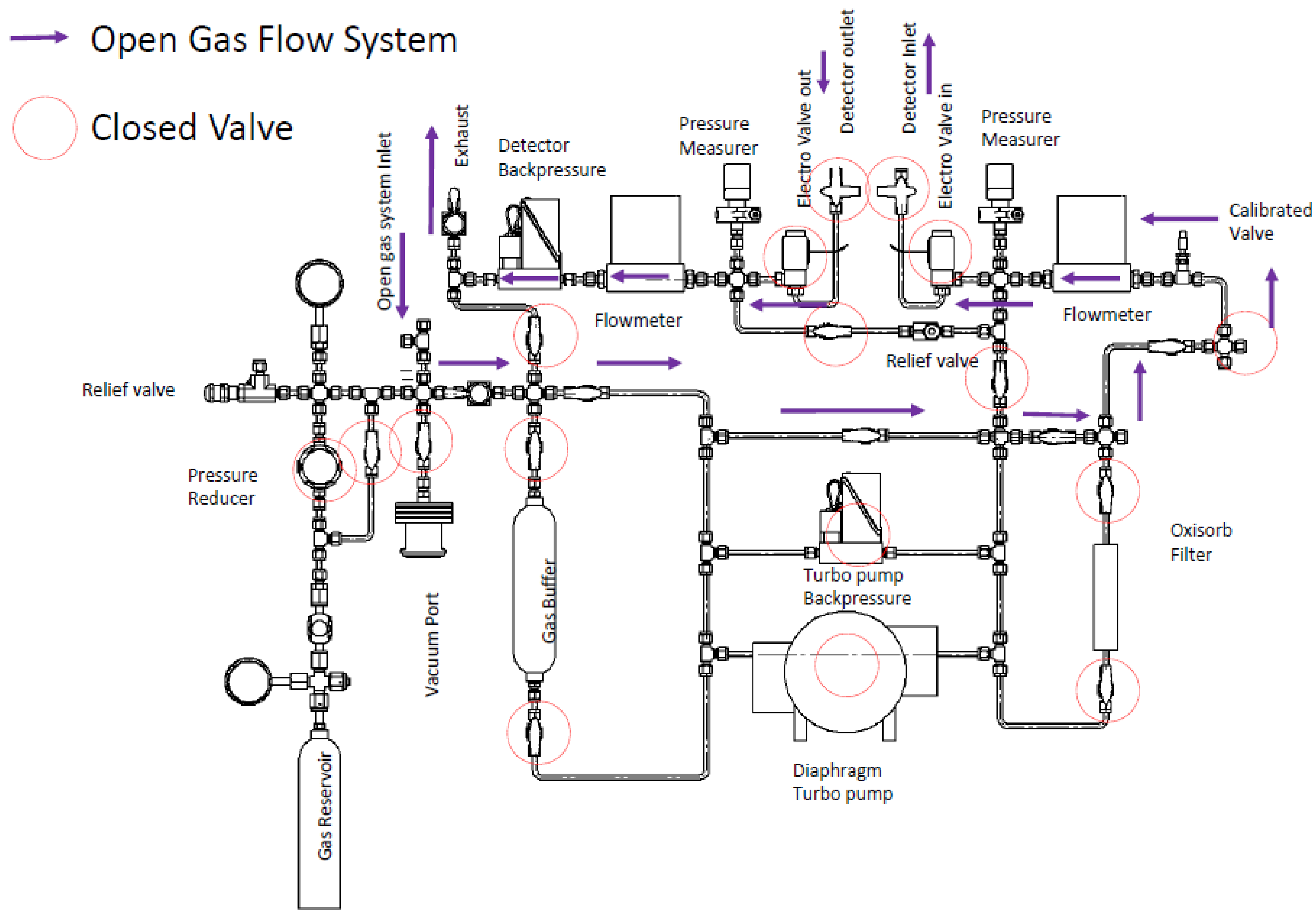
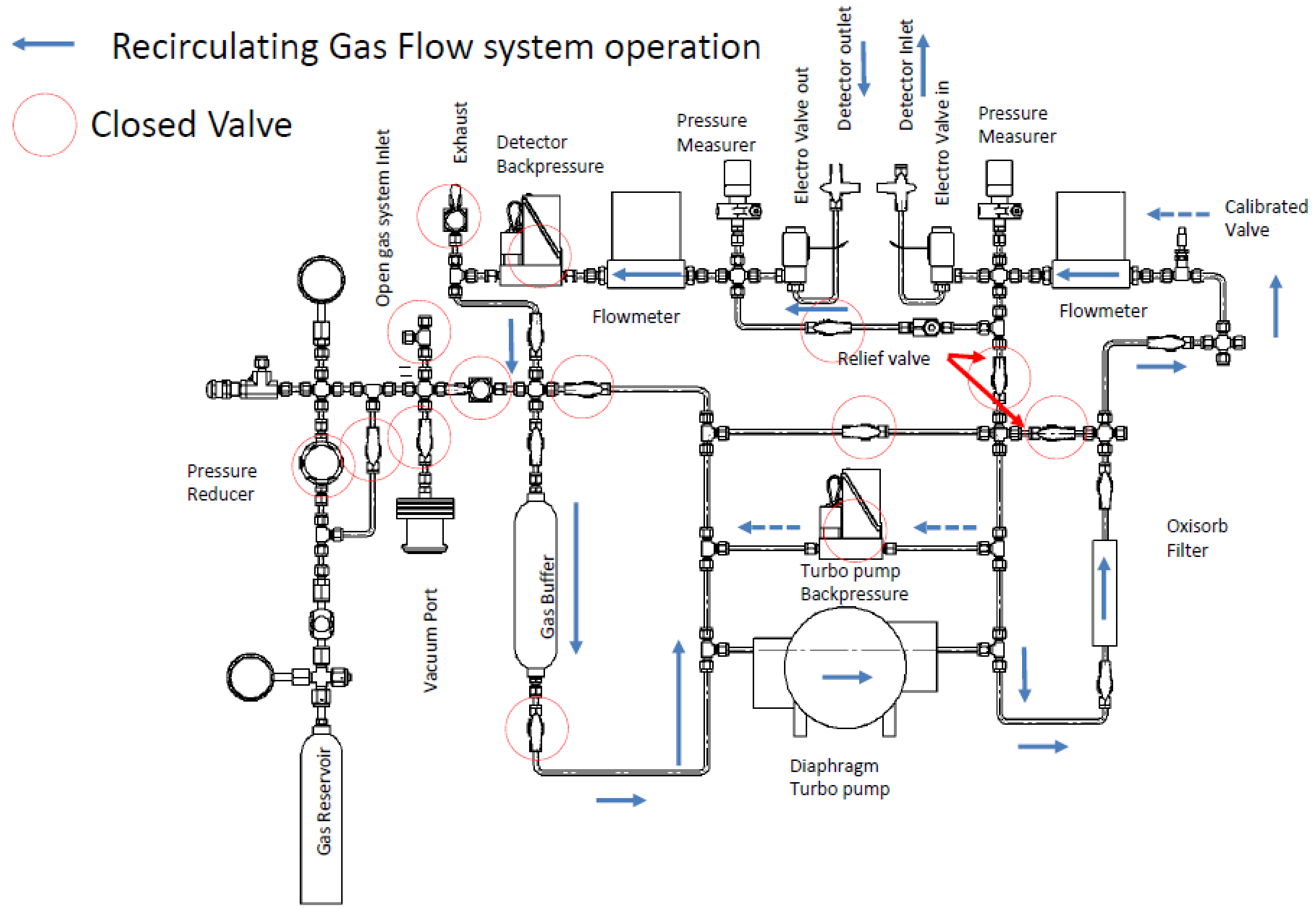
Gas system: conceptual design



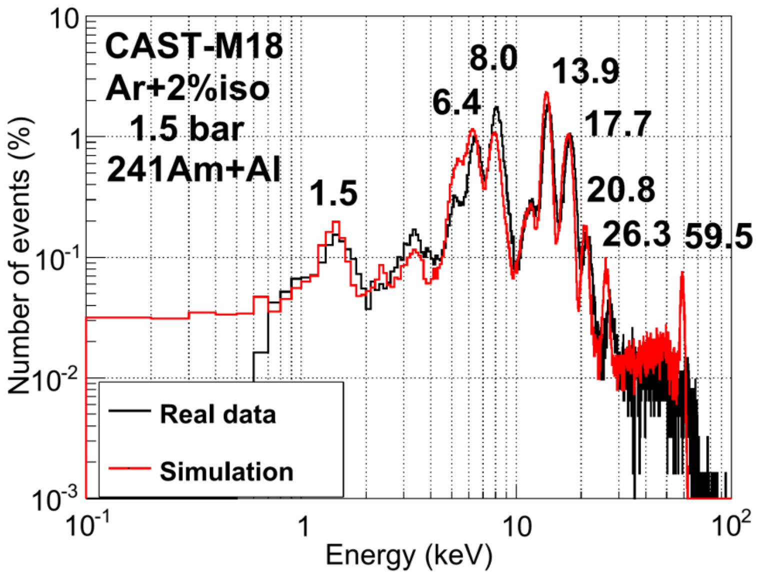
Gas system operations: open gas flow

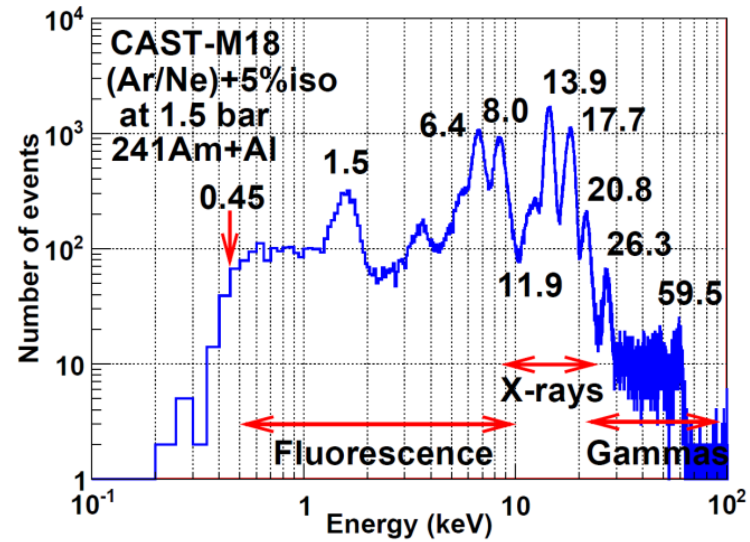


Gas system operations: recirculation



A cross-check: ^{241}Am+Al/Cu @ CAST-M18





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

- Several data-sets of ^{241}Am source + Al/Cu foils taken by CAST-M18 detector.
- CAST-MM geometry was modified to include an ^{241}Am source and a Cu/Al foil.
- Analysis results of data & simulation compared to validate the simulation.
- Energy spectra quite similar. Differences at high energy γ's. DAQ saturation?

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A cross-check: ^{241}Am+Al @ CAST-M18

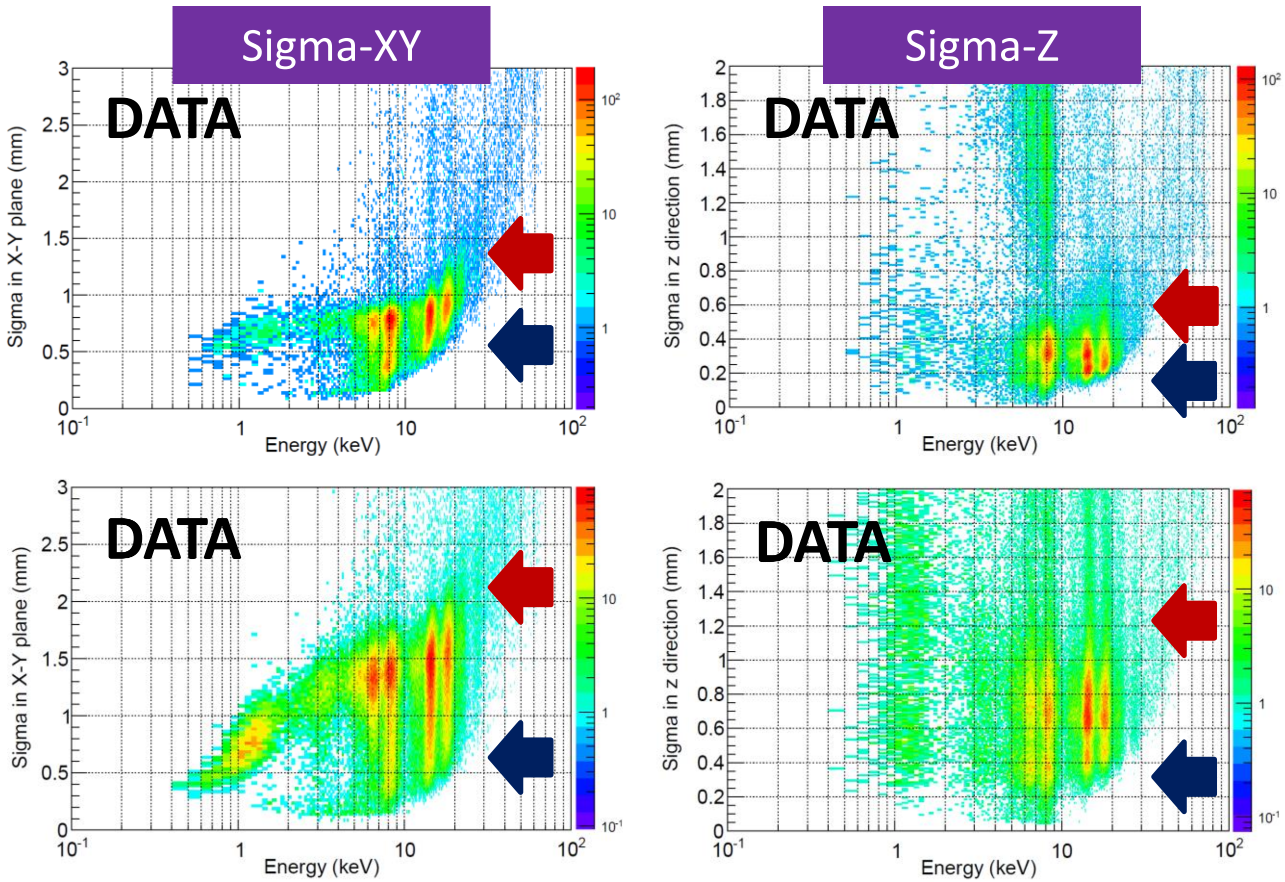
- Clearly dependence of cluster features on diffusion effects and the z-position.
- Larger differences on width between top (red) and bottom (blue) events.

Ar+10%iC_4H_{10}

Vel = 1.41 cm/μs
σ_T = 320 μm/cm$^{0.5}$
σ_L = 372 μm/cm$^{0.5}$

Ar+2.3%iC_4H_{10}

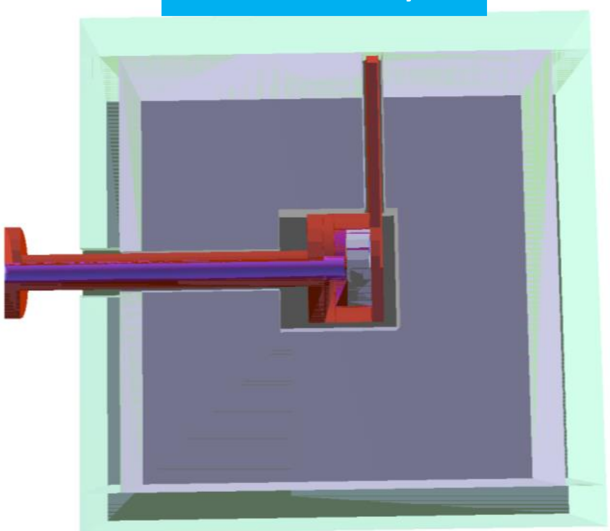
Vel = 2.92 cm/μs
σ_T = 560 μm/cm$^{0.5}$
σ_L = 446 μm/cm$^{0.5}$



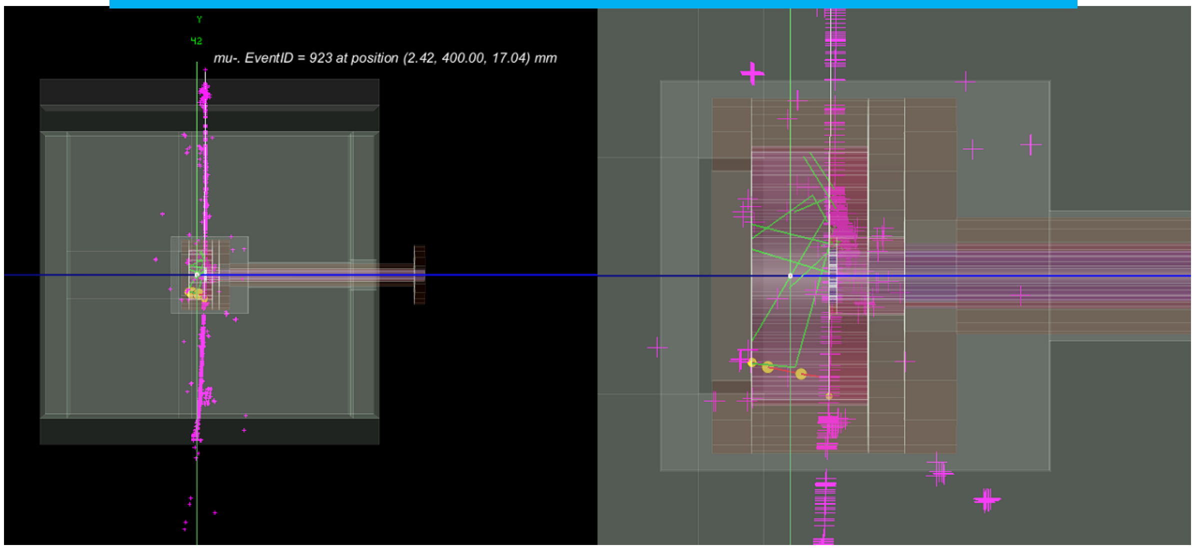
Status of IAXO-D0 background model

- IAXO-D0 geometry was implemented in Geant4.
- Shielding: 20 cm lead (passive) + 5 plastic scintillators (active).
- Work is still on going…
  - to validate the simulation of the detector response (update of REST code).
  - to create the background model of IAXO-D0.

Geometry



A cosmic muon interacting IAXO-D0 detector



S. Aune et al., JINST 9 (2014) P01001
F.J. Iguaz et al., PoS(TIPP2014)295

Status of IAXO-D0 background model

Contribution	Background level at RoI (counts keV^{-1} cm^{-2} s^{-1})	Measurement	Status
Radon	~8 x 10^{-7}	No N_2 flux @ LSC setup	Removed
Al cathode	(5.2 ± 1.2) x 10^{-7}	Cu/Al cathode @ LSC setup	Removed
Gamma flux	7 x 10^{-5} -> ~1 x 10^{-7} ?	No shielding @ CAST setup	Removed? 10 cm Pb
Muons	2 x 10^{-6} -> ~6 x 10^{-7}	No active veto @ CAST setup	Not full coverage
Unidentified	1.1 x 10^{-7}	20 cm lead @ LSC setup	

Potential background sources:

Signal efficiency: 75%

- Ar-39 isotope from the gas.
- Pb-210 from inner first cms of shielding.
- Cosmic muons.
- Cosmic gammas.
- Intrinsic detector radioactivity?
- Neutrons?
- Radon?