Improvement and assessment of the radiopurity of Micromegas readout planes

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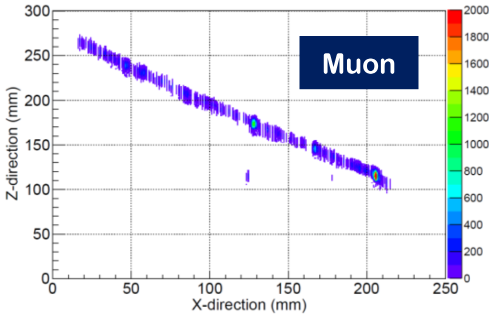
- Motivation and goals
- Techniques
- Sample preparation
- Measurements
- Results

Motivation and goals

Micromegas (Micromesh Gas Structures, MM) as readout of gaseous **TPCs** are being considered in experiments investigating rare phenomena thanks to:

- Good performance on spatial and energy resolution
- Topological information to discriminate signal from background
- Operation stability and homogeneity
- Possibility of scaling-up
- Potential ultra-low background conditions:
  made mainly of radiopure materials like Cu and Kapton



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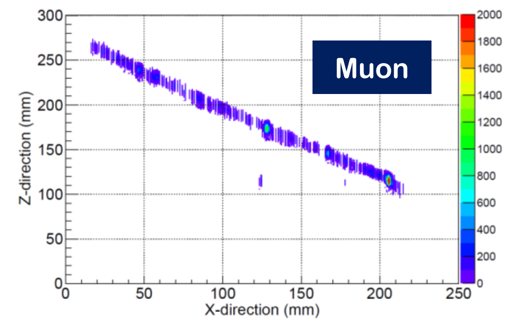
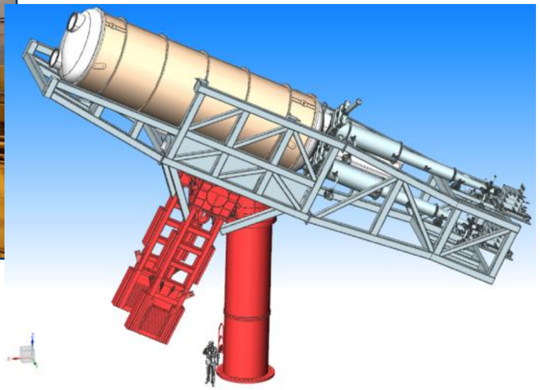
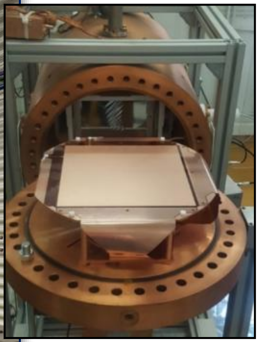


Used in **CAST** at CERN and being considered for future **IAXO**, covering small areas (6×6 cm^2)



Larger MM (25×25 cm^2) using a HP-TPC in **TREX-DM** at LSC



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After a promising first study of the radiopurity of MM readout planes, new results have been obtained, after

Radiopurity of Micromegas readout planes
S. Cebrián et al, Astropart. Phys. 34 (2011) 354

✓ Dedicated development at **CERN** to implement different changes in the **manufacturing techniques**

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✓ Dedicated development at **CERN** to implement different changes in the **manufacturing techniques**

✓ Several, successive **radioassays**, performed at the **Canfranc Underground Laboratory (LSC)**, combining different, complementary techniques to quantify radiopurity and then to assess the effectiveness of the different procedures applied

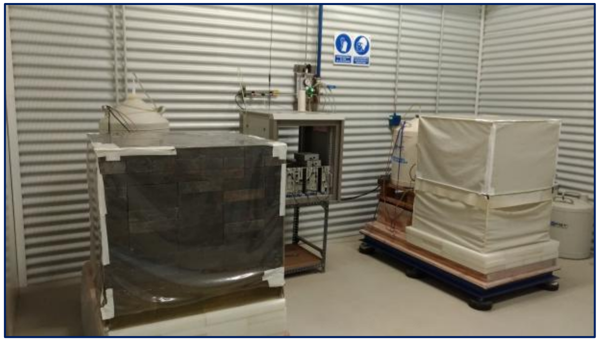
- using the BiPo-3 detector, analysis of BiPo sequences for isotopes in the lower parts of the ^{238}**U** and ^{232}**Th** natural chains
- using HPGe detectors, gamma spectroscopy mainly for ^{40}**K** content

Techniques

Gamma spectroscopy measurements with several HPGe detectors at LSC

	Paquito	GeAnayet	GeLatuca	GeOroel
Location	LAB2500	Hall C, LAB2400	Hall C, LAB2400	Hall C, LAB2400
Volume (cm^3)	190	410	410	420
Mass (kg)	$\sim$1	2.18	2.18	2.24
FWHM (keV)	2.6	2.0	1.9	2.2
Integral	79±2	433±1	314±2	148±1
583.2 keV (^{208}Tl)	0.27±0.09	3.68±0.33	3.57±0.33	1.29±0.16
609.3 keV (^{214}Bi)	0.48±0.21	0.71±0.14	1.16±0.16	1.13±0.15
1460.8 keV (^{40}K)	0.25±0.13	0.74±0.08	0.56±0.15	0.68±0.11

FWHM at 1332 keV
Background counting rates in **$kg^{-1}d^{-1}$** (integral from 0.1 to 2.7 MeV)



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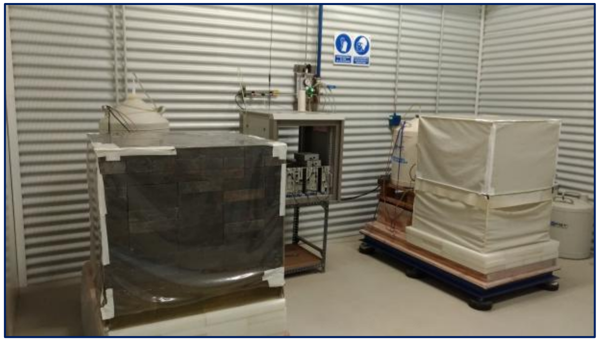
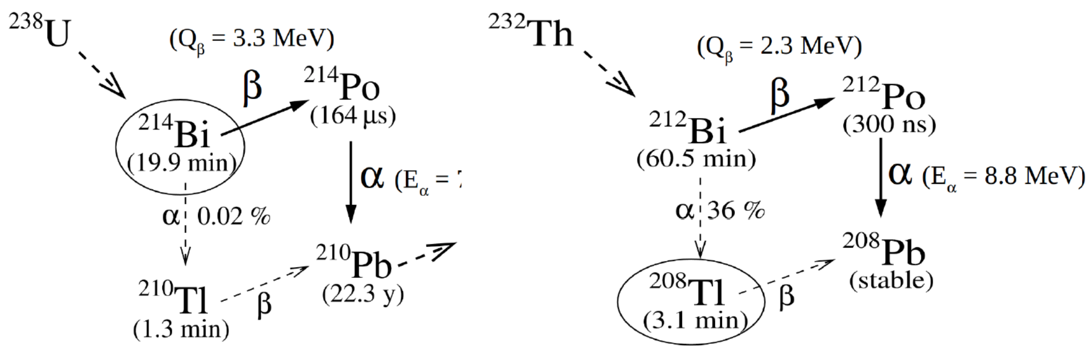


- Standard gamma spectroscopy **analysis techniques** applied to background and sample long measurements
- **Detection efficiency** for each sample from Monte Carlo simulations with Geant4, validated with a calibrated source

Techniques

BiPo-3 detector built by the SuperNEMO col. and operated at LSC (now dismantled)
Sensitive to levels of **μBq/kg** of the lower parts of ^{238}U, ^{232}Th through **BiPo α–β coincidences** in **very thin** samples (<100-200 μm thick)



The BiPo-3 detector for the measurement of ultra low natural radioactivities of thin materials
A.S. Barabash et al, 2017 JINST 12 P06002

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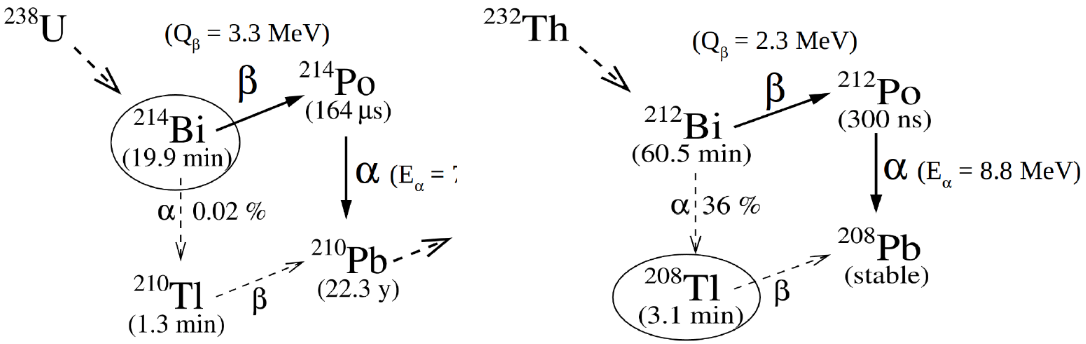

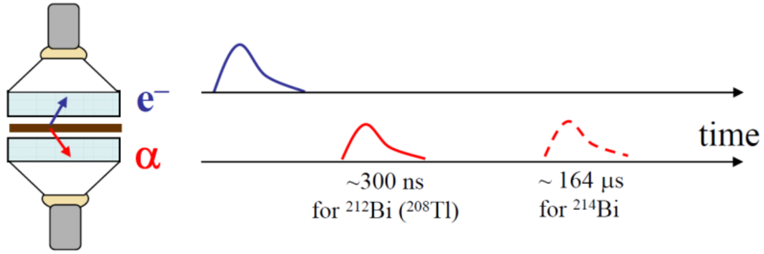

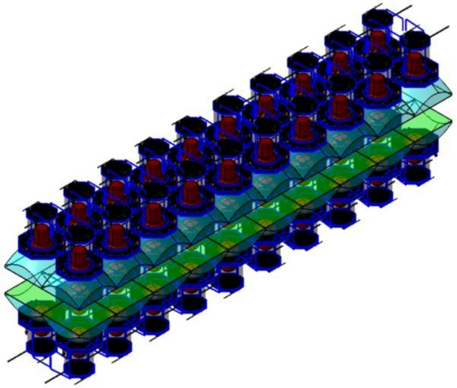

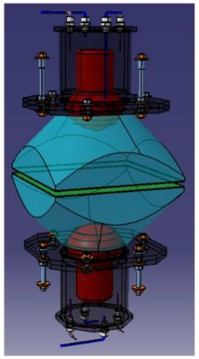

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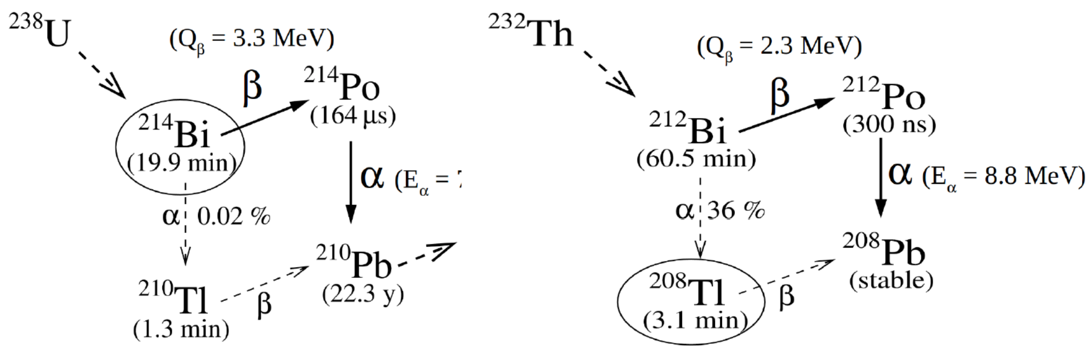
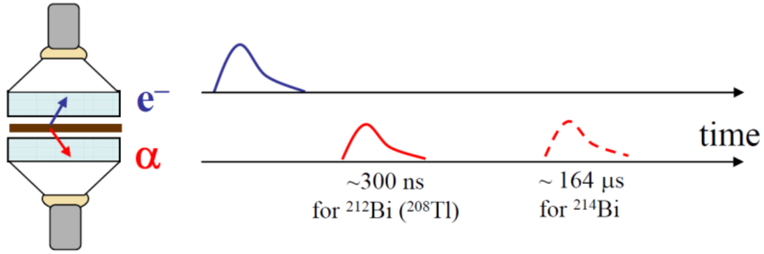
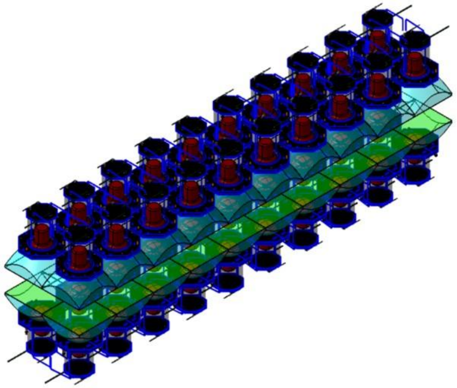
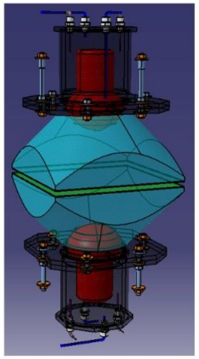




- MATACQ boards to sample PMT signals
- Insertion of samples at LSC clean room





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BiPo-3 detector

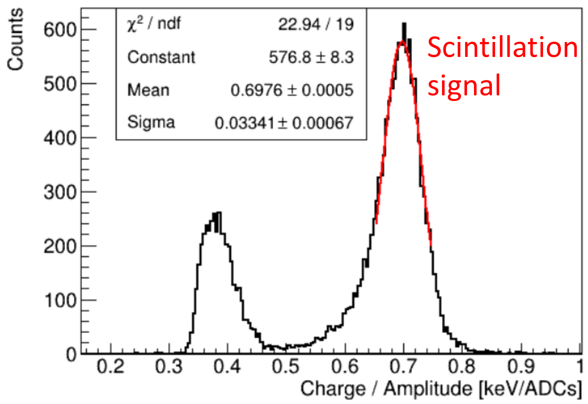
Analysis of full statistics collected for MM-related samples using the **REST-for-physics code** following the procedure established by the SuperNEMO collaboration

K. Altenmüller et al. Comp. Phys. Comm. 273, 108281 (2022)

Event selection criteria

	^{212}BiPo	^{214}BiPo
Threshold E_{prompt}	200 keV	200 keV
Threshold E_{delay}	300 keV (100−700 keV for MM#0)	300 keV (300−600 keV for MM#0)
Δt	50 − 1400 ns	1.5 − 1000 μs
Crosstalk	10 mV (∼20 keV)	10 mV (∼20 keV)
Q/A	Mean $\pm 3\sigma$	Mean $\pm 3\sigma$
First days rejection	3 days	15 days

PSD for PMT noise rejection



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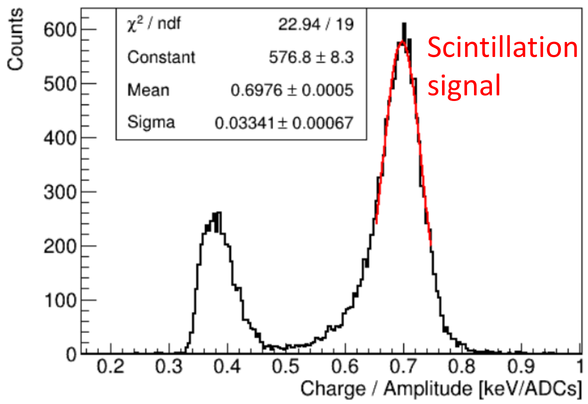
- **Detection efficiency** for each sample from Monte Carlo simulations with Geant4 and considering the event selection applied to real data
- **Bayesian statistical approach** (cross-checked with Feldman-Cousins method) applied to derive upper limits on the activity

PSD for PMT noise rejection



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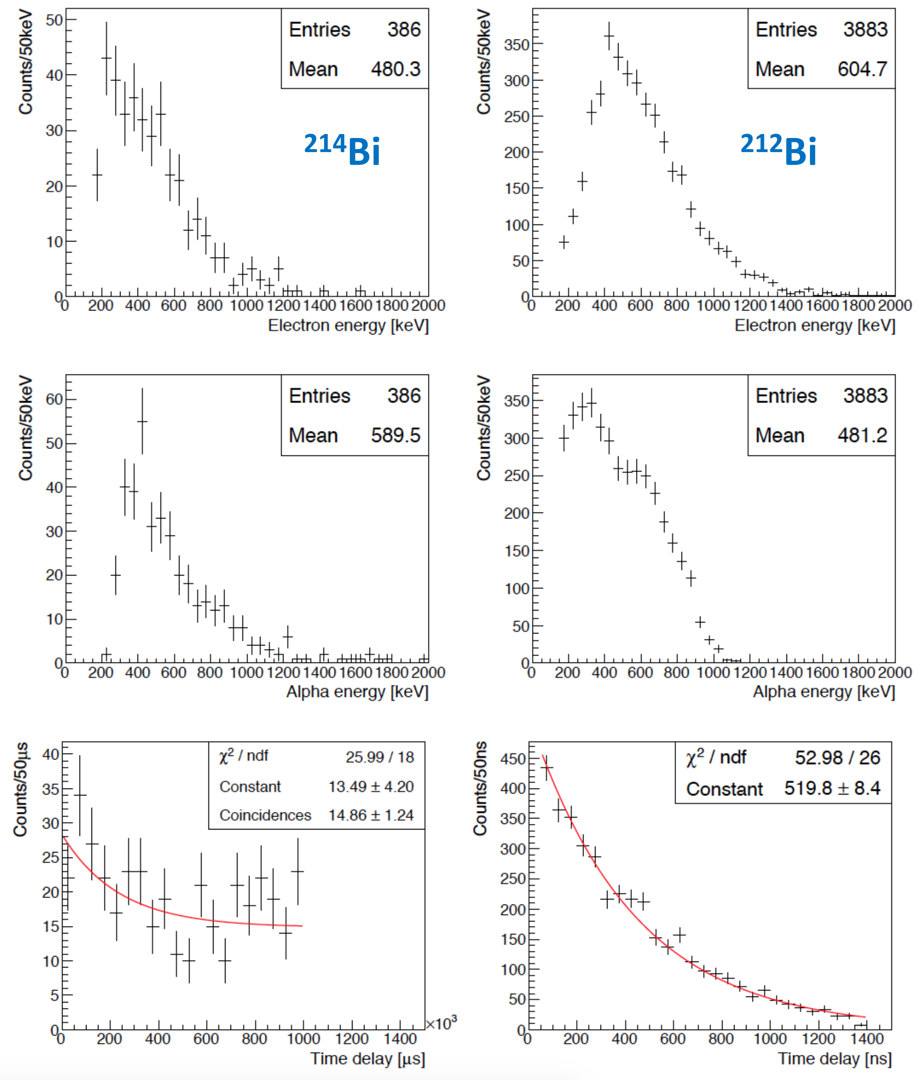
Validation with a **calibrated Al foil**

- **Time separation** between prompt (e) and delayed (α) pulses follows the expected decay (red line) considering the half-lives



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BiPo-3 detector

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- **Time separation** between prompt (e) and delayed (α) pulses follows the expected decay (red line) considering the half-lives

- Derived **activities** in agreement with those from HPGe spectroscopy

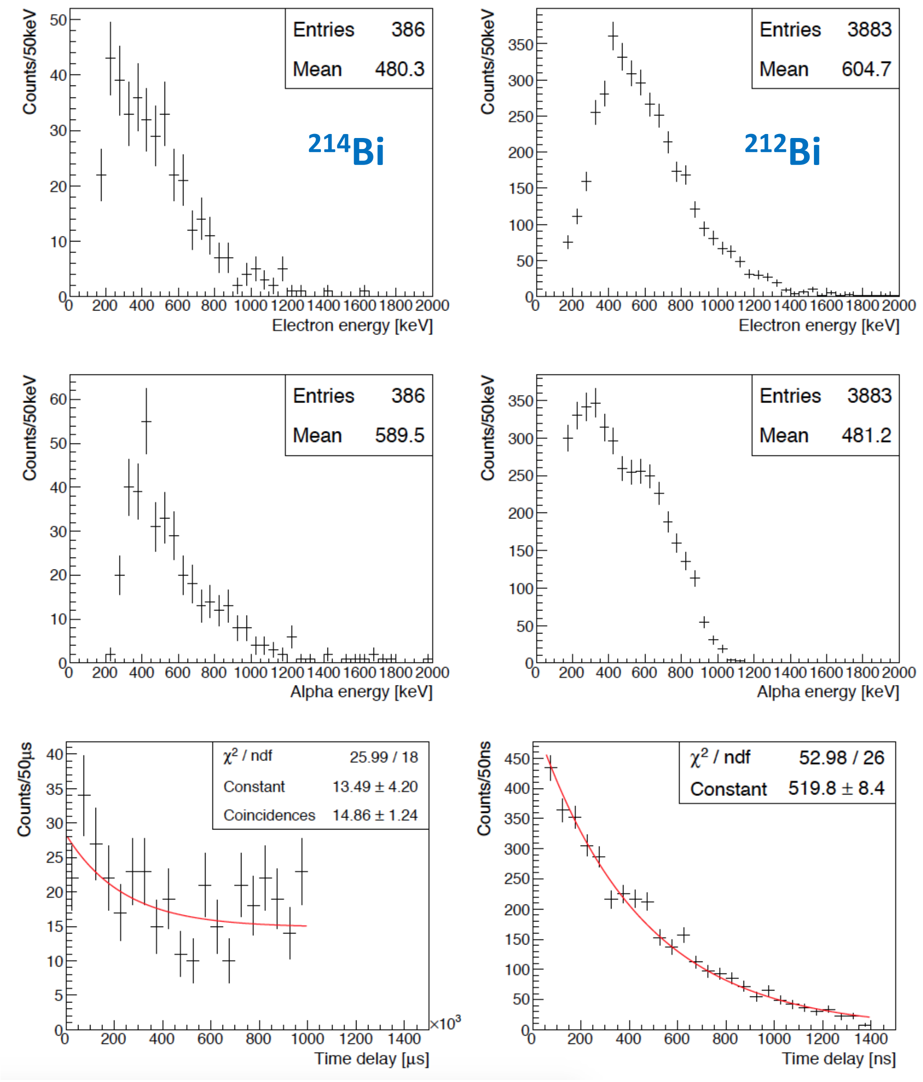
$$\mathcal{A}\left({}^{208}\mathrm{Tl}\right) = 72.6 \pm 1.3\ (\mathrm{stat.})\ \ \pm 12\ (\mathrm{syst.})\ \ \mathrm{mBq/kg}$$

$$\mathcal{A}\left({}^{214}\mathrm{Bi}\right) = 6.2 \pm 1.9\ (\mathrm{stat.})\ \ \pm 0.9\ (\mathrm{syst.})\ \ \mathrm{mBq/kg}$$

HPGe:

$$\mathcal{A}\left({}^{208}\mathrm{Tl}\right) = 83 \pm 4\ (\mathrm{stat.})\ \ \pm 15\ (\mathrm{syst.})\ \ \mathrm{mBq/kg}$$

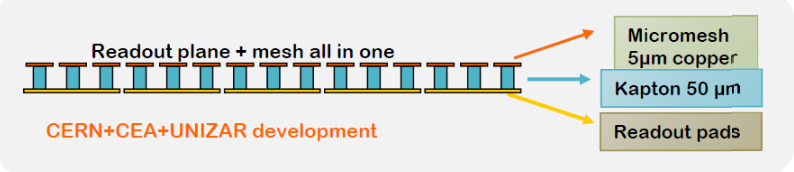
$$\mathcal{A}\left({}^{214}\mathrm{Bi}\right) = 9.2 \pm 3.3\ (\mathrm{stat.})\ \ \pm 0.9\ (\mathrm{syst.})\ \ \mathrm{mBq/kg}$$

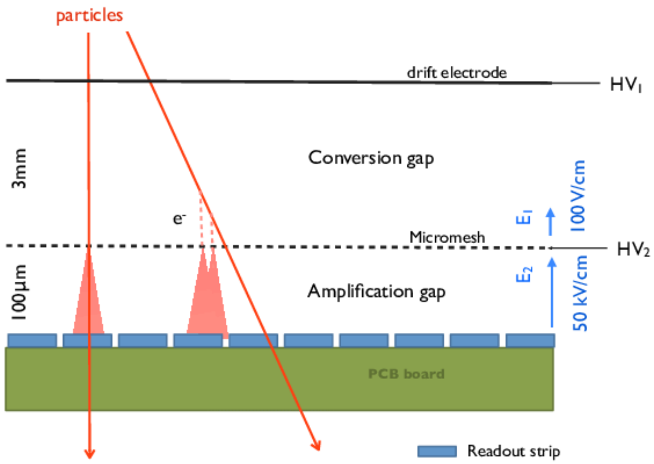


Samples: fabrication and preparation

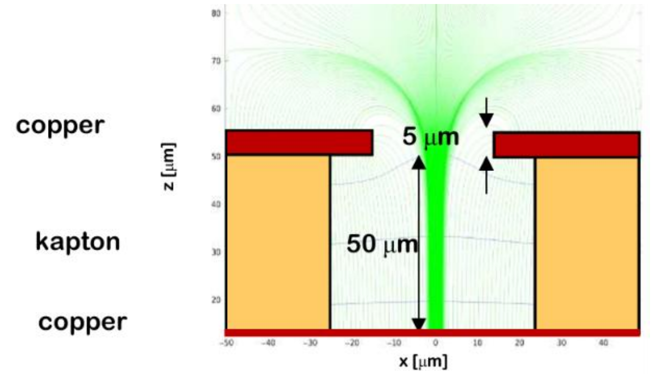
Different **MM technologies**:

- Classical (CAST, COMPASS, ATLAS)
- Bulk (T2K, nTOF, MIMAC)
- **Microbulk**: more homogeneous (CAST, IAXO, TREX)





- Constructed out of a **Kapton** foil, doubly-clad with **copper**, with anode and micromesh patterns engraved
- Amplification gap created by **chemically** removing part of the Kapton layer below the mesh holes



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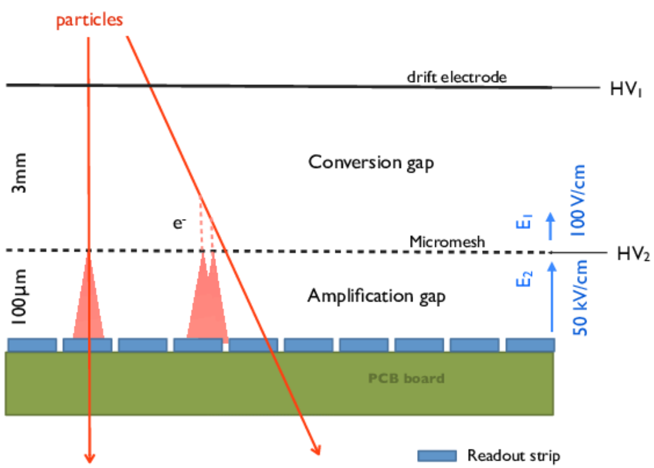

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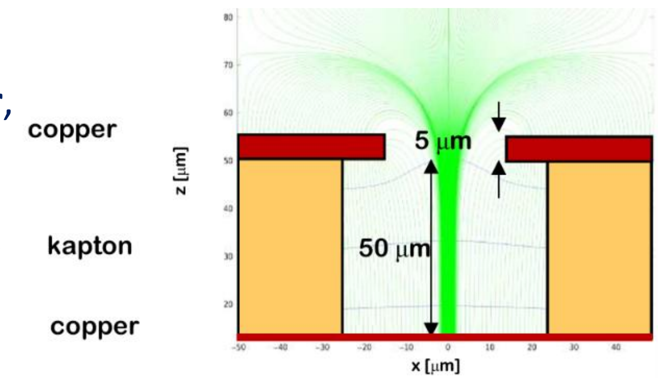
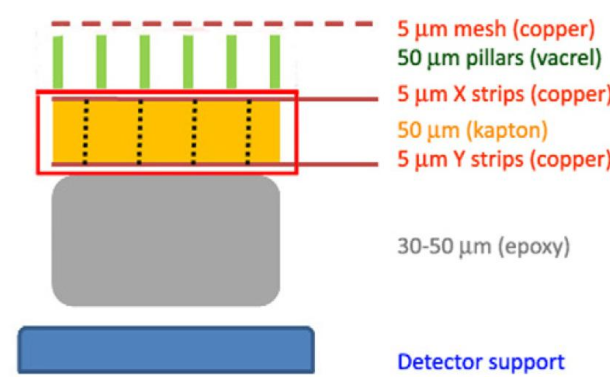


First study of MM radiopurity from HPGe measurements on some samples of manufactured readouts from **CAST** and **raw materials**: promising results but limited sensitivity

Two samples reanalysed at **BiPo-3** detector:

Cu-Kapton-Cu foil and **CAST Micromegas** (microbulk)



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Sample MM#0

- Larger quantity, faulty MM circuits produced at CERN, **without holes**
- Both **BiPo-3** and **Ge** measurements

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- Several **Ge** assays after different cleaning procedures with tap or deionized (DI) water

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- **Witness sample** of Microbulk MM for TREX-DM produced
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Other materials used in MM fabrication analyzed using **Ge** and/or **BiPo-3** detectors:
- **Vacrel** film: used in **bulk MM**
- **Kapton-C**: diamond-coated polyimide used in **resistive microbulk MM**
- **Kapton-epoxy**: foil used in **microbulk MM** (AKAFLEX, from Krempel GmnH)
- **Isotac:** adhesive (Isotac 3M VHB)

Measurements

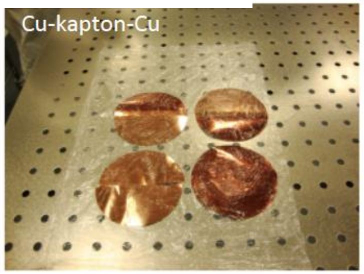
Sample	Mass (g)	Surface (cm^2)	Meas.	Detector	Time (d)	Description
MM#0	73.8	1587	#0	GeLatuca	50.6	As produced and measured in BiPo-3
MM#1	165.9	12373	#0	GeOroel	41.6	As produced
			#1	GeOroel	29.0	After first cleaning (DI, tap water)
			#2	GeOroel	30.9	After second cleaning (DI water)
MM#2	86.2	7000	#0	Paquito	60.6	As produced
			#1a	Paquito	76.8	After first cleaning (DI water)
			#1b	GeOroel	46.5	After first cleaning (DI water)
MM#3	637	51735	#0	GeAnayet	31.9	As produced
MM#4	116.5	8250	#0	GeAnayet	29.7	As produced
			#1	GeAnayet	58.7	After first cleaning (DI water)
			#2	GeAnayet	30.4	After second cleaning (potassium permanganate)
Vacrel	65.5	4800	#0	Paquito	32.3	Also measured in BiPo-3
Kapton-C	2.8	189	#0	Paquito	40.3	Also measured in BiPo-3
Isotac	19.4	3202	#0	Paquito	44.4	

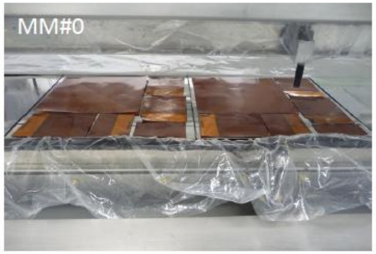
Features of samples and **HPGe** radioassays

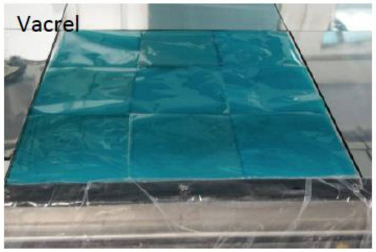
Measurements

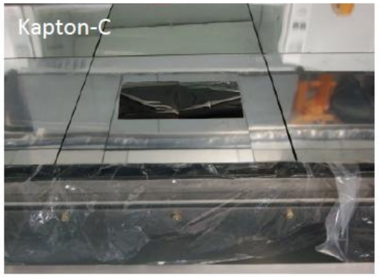
Sample	Mass (g)	Surface (cm^2)	Time (^{212}BiPo) (d)	Efficiency (^{212}BiPo) (%)	Time (^{214}BiPo) (d)	Efficiency (^{214}BiPo) (%)
Cu-Kapton-Cu	4.7	380	158	7.22	134	4.12
CAST Micromegas	2.8	95	79	7.42	67	4.23
MM#0	73.8	1587	253	3.89	241	0.83
Vacrel	13.1	900	166	4.14	154	2.27
Kapton-C	2.8	189	166	13.41	154	7.80
Kapton-epoxy	9.4	900	79	8.79	67	7.01

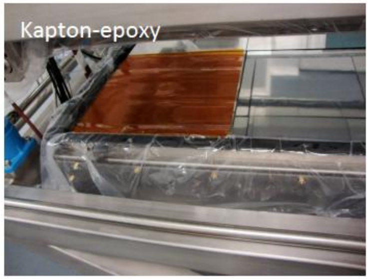
Features of samples and **BiPo-3** radioassays











Results

Activity (in μBq/cm²) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
	BiPo-3		<0.070		<0.035					67.5
Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

Values of **^{238}U** and **^{232}Th** correspond to upper part of chains, those of **^{226}Ra** and **^{228}Th** to lower parts
Values from BiPo-3 come from the deduced activities of ^{214}Bi and ^{212}Bi

Results

Activity (in μBq/cm²) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
	BiPo-3		<0.070		<0.035					67.5
Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

Upper limits derived at 95% C.L. and reported values include 1σ uncertainties

Results

Activity (in μBq/cm²) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
	BiPo-3		<0.070		<0.035					67.5
Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

Intrinsic purity of base raw materials better than manufactured MM

Results

Activity (in μBq/cm²) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
	BiPo-3		<0.070		<0.035					67.5
Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

- Upper limits set for all radioisotopes, including **^{40}K** (**no holes** made using K compounds)
- Limits from BiPo-3 lower than from Ge by more than one order of magnitude: tens of nBq/cm²

Results

Activity (in µBq/cm²) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapto										7.5
										7.5
Isotac										5.1
Kapto										5.7

- At first screening: only ^{40}K **quantified** (specific activity (258±30) mBq/kg), confirming that K content is related to hole production
- After first cleaning (with tap water): ^{40}K reduced by a factor ~4, but important activities for upper parts of chains measured; after considering other origins, most plausible hypothesis is that it was related to water baths
- No effect of additional cleaning with DI water

Results

Activity (in µBq/cm^2) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
	BiPo-3		<0.070		<0.035					67.5
Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

- ^{40}K **reduction** from cleaning with only DI water confirmed by a factor ~4 (needing a more sensitive detector)
- More massive sample needed to quantify ^{40}K activity for a further reduction

Results

Activity (in µBq/cm^2) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
CAST MM	BiPo-3		<0.39		<0.20					33.9
MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
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Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
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Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

Lowest **^{40}K activity** quantified (specific activity (8.3±2.4) mBq/kg), with an overall **reduction by a factor ~34**

Results

Activity (in µBq/cm^2) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
Cu-Kapton-Cu foil	BiPo-3		<0.038		<0.043					80.9
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MM#0	#0	<49	<0.70	<1.2	<0.35	<0.22	<2.3	<0.14	<0.13	21.5
	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
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MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
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Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

- **^{40}K reduction** could not be quantified due to a lower activity as starting point
- Comparable activity limits after cleaning using $KMnO_4$ (improving MM performance)

Results

Activity (in μBq/cm^2) from HPGe and BiPo-3 detectors (factor F to convert to mBq/kg)

Sample	Measurement	^{238}U	^{226}Ra	^{232}Th	^{228}Th	^{235}U	^{40}K	^{60}Co	^{137}Cs	F
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	BiPo-3		<0.064		<0.016					21.5
MM#1	#0	<5.2	<0.10	<0.22	<0.08	<0.03	3.45±0.40	<0.02	<0.02	74.6
	#1	7.41±0.81	<0.21	0.19±0.05	<0.11	0.36±0.04	0.84±0.16	<0.02	<0.03	74.6
	#2	7.87±0.89	<0.17	0.14±0.04	0.07±0.02	0.36±0.04	0.81±0.15	<0.03	<0.02	74.6
MM#2	#0	<11	<0.28	<0.26	<0.17	<0.11	1.80±0.65	<0.06	<0.08	81.2
	#1a	<11	<0.25	<0.26	<0.15	<0.14	<1.1	<0.06	<0.07	81.2
	#1b	<4.1	0.140±0.017	<0.19	<0.068	<0.04	0.43±0.13	<0.03	<0.02	81.2
MM#3	#0	<2.5	0.035±0.004	<0.067	<0.018	0.022±0.004	0.102±0.030	<0.006	<0.008	81.2
MM#4	#0	<17	<0.19	<0.58	<0.14	<0.13	1.07±0.23	<0.03	<0.04	70.8
	#1	<12	<0.12	<0.49	<0.10	< 0.07	<0.63	<0.03	<0.03	70.8
	#2	<16	<0.13	<0.41	<0.14	< 0.10	<1.2	<0.03	<0.05	70.8
Vacrel	#0	<19	<0.61	<0.63	<0.72	<0.19	4.6±1.9	<0.10	<0.14	73.3
	BiPo-3		<0.037		<0.024					68.7
Kapton-C	#0	<350	<13	<14	<11	<6	<51	<2	<3	67.5
	BiPo-3		<0.070		<0.035					67.5
Isotac	#0	<18	<0.45	<0.43	<0.22	<0.18	<2.3	<0.10	<0.14	165.1
Kapton-epoxy	BiPo-3		<0.030		<0.024					95.7

- Good radiopurity found for all materials
- Limits from BiPo-3 significantly lower than those from Ge

Summary and conclusions

- Radiopurity of **Micromegas planes** used as readouts in gaseous TPCs has been improved and assayed thanks to a **dedicated development at CERN** and **activity measurements at LSC**
  - Controlled production
  - Massive samples prepared
  - Radioassays at different steps of the production
  - Complementary techniques pushing sensitivity to their limits

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- These results confirm the suitability of the use of Micromegas as extremely radiopure readouts for rare event searches

^{226}Ra: <64 nBq/cm^2
^{228}Th: < 16 nBq /cm^2
^{40}K: (102±30) nBq/cm^2

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