Building Low-Radioactive-Background Electronics Components

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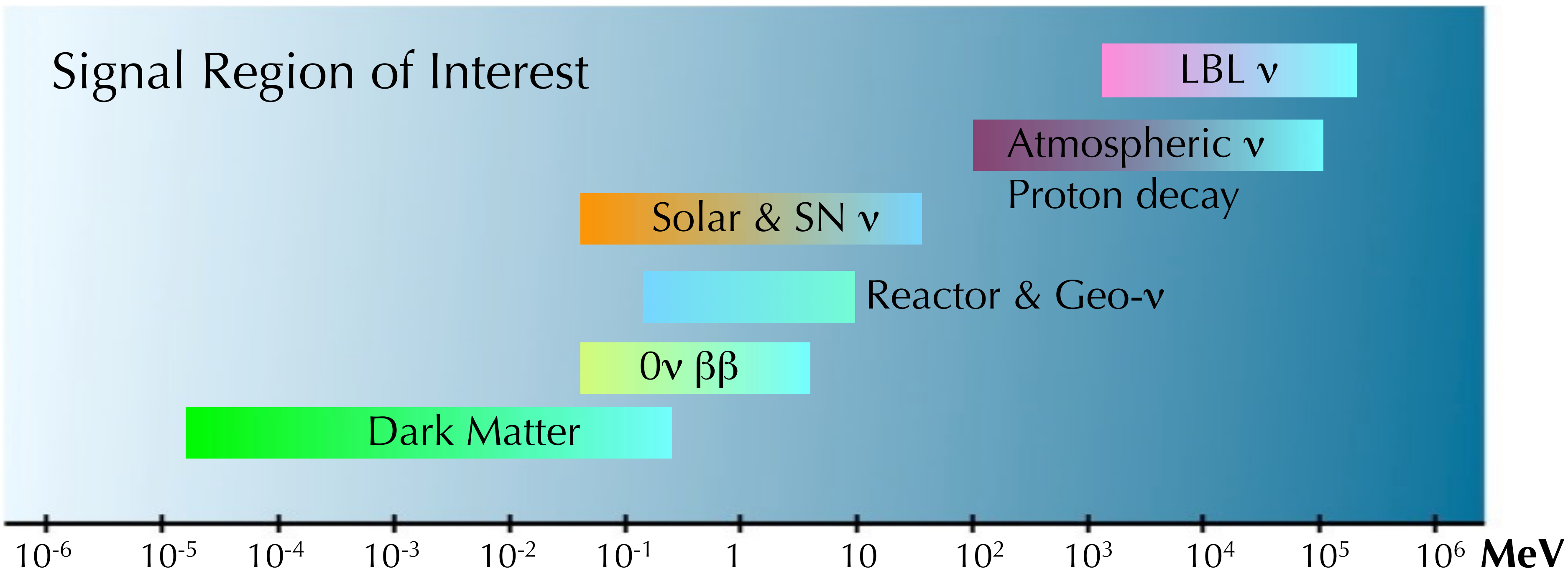
Outline

- What do you mean by “low radioactive background”?
- How to measure low level of radioactivity?
- Examples:
  - Detector system design
  - Front-end electronics for Ge detectors
  - Cables and interconnects

Types of Experiments and Backgrounds

- Signals:



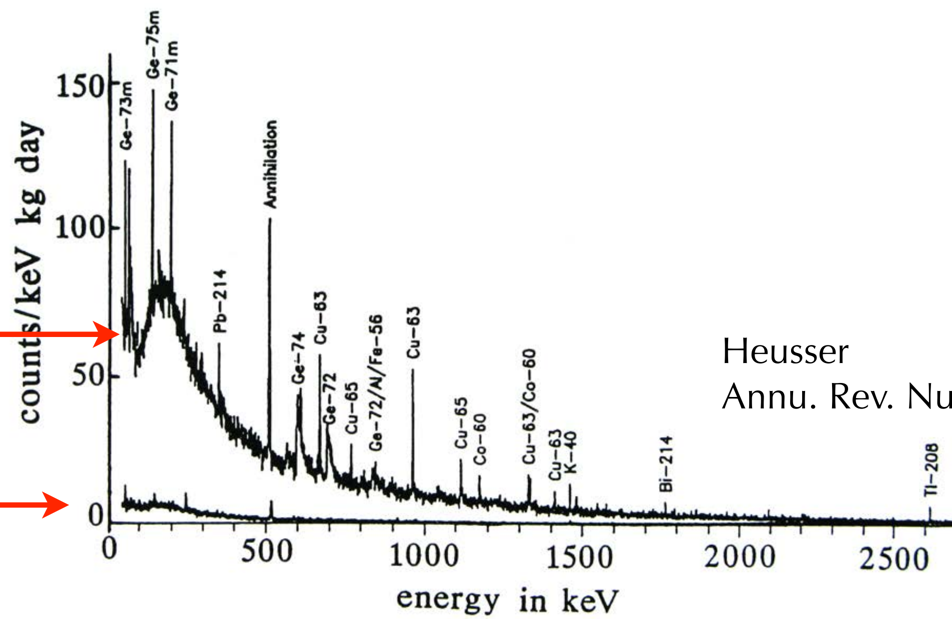
- Backgrounds:
  - Cosmic-ray primaries and secondaries produced in the atmosphere
  - Cosmic muons
  - Neutrons (“Cosmic” and “Environmental”)
  - α, β and γ (“Detector intrinsic” and “Environmental”)

Cosmic-ray Primaries & Secondaries

- Minimal overhead burden goes a long way in reducing backgrounds induced by nucleonics:

Sea level

15 m.w.e.



Heusser
Annu. Rev. Nucl. Part. Sci. 45: 543 (1995)

Figure 4 Background spectra of similar Ge spectrometers (0.9 kg active volume) with passive and active shielding at sea level (*top*) and at 15 m.w.e. (*bottom*).

- But next-generation DM and $0\nu\beta\beta$ experiments need to go below 4000' or more.

The deeper the better

Inconvenient truths (for low-background experiments)

- Time scales:

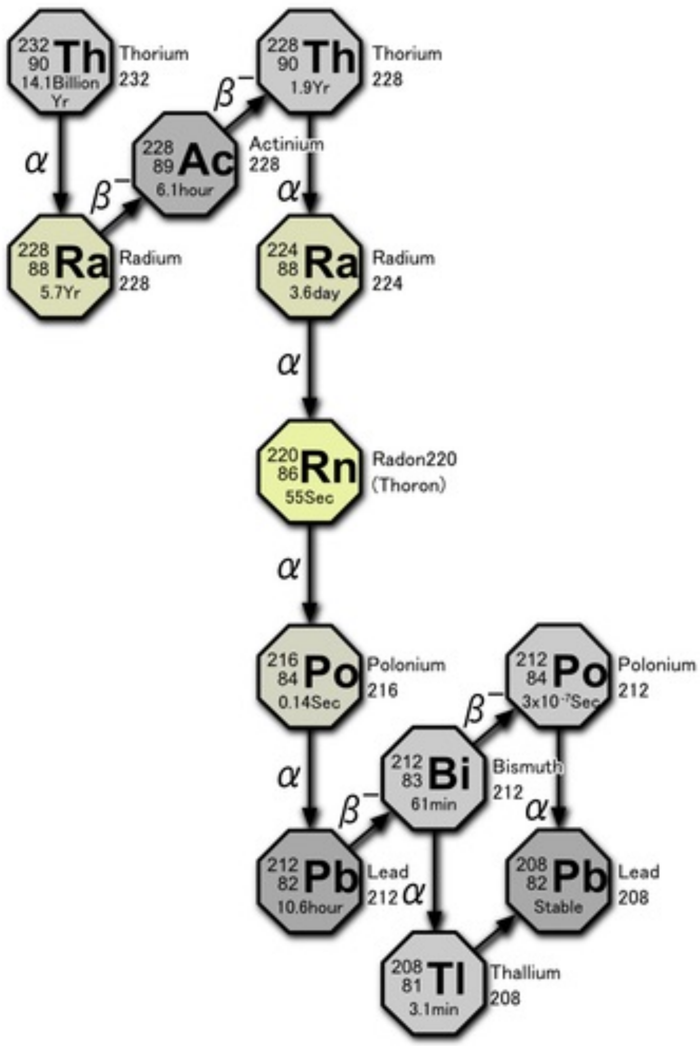
Age of the universe	13.8×10^9 years
Age of the Earth	4.5×10^9 years

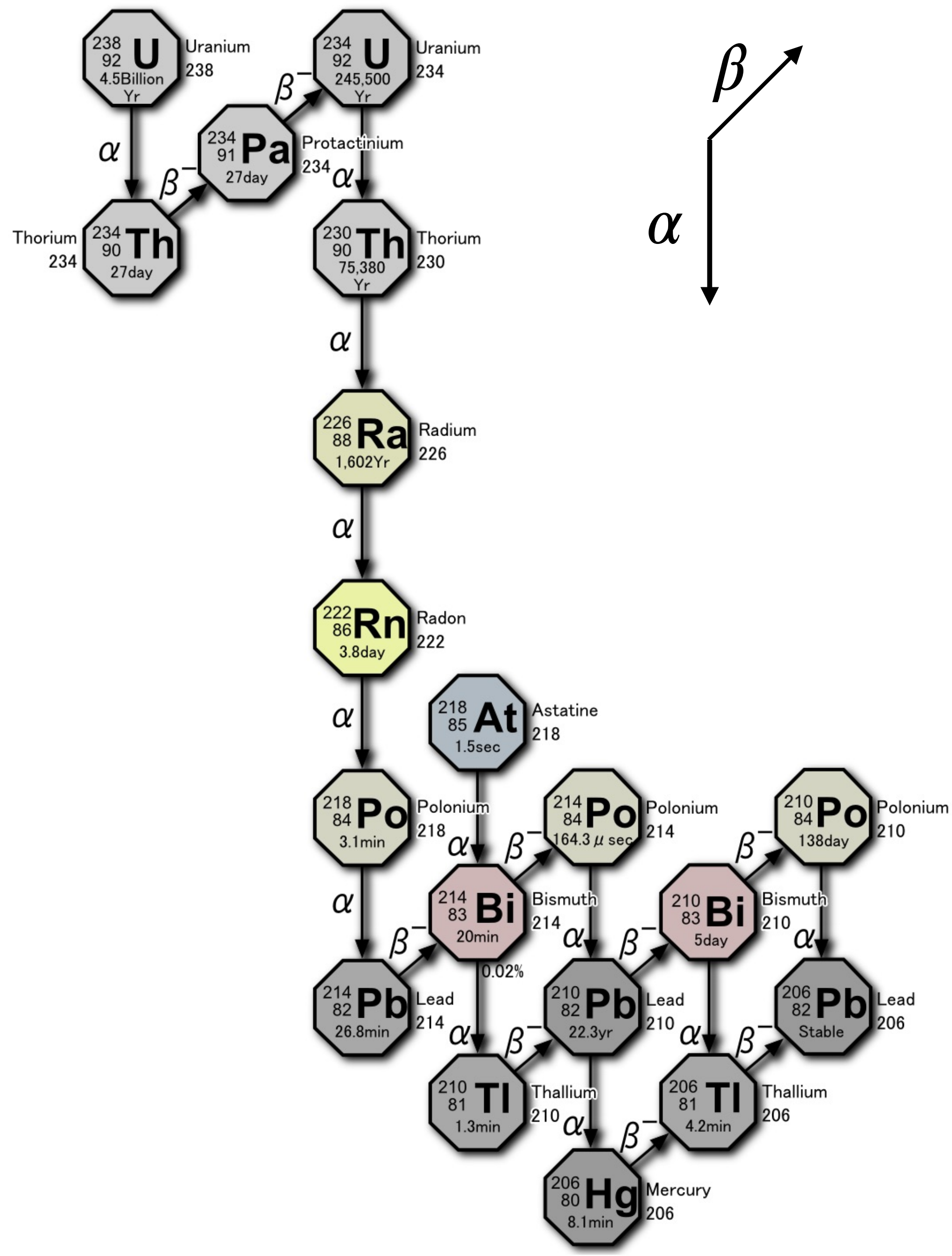
- Long-lived radioactive isotopes from supernova explosions in the past have been in our Earth since its formation.
- Radiogenic heat from the decays of ^{238}U, ^{232}Th and ^{40}K is a main component of our Earth's internal heat.
- Half-lives:

^{238}U	4.468×10^9 years
^{232}Th	14.05×10^9 years
^{40}K	1.251×10^9 years

These primordial radioisotopes do not decay away quickly

Decay Chains





α: quenched signal, (α,n)

β, γ: “tail” in the ROI

How low is low?

- Signal expected in real-time experiments

Type of experiment	Signal	Detection (*Background*) rate
SNO **Solar neutrino experiment (1998-2006)**	Cherenkov light from e^-	~15 events t^{-1} d^{-1}
LUX **WIMP search**	Scintillation light and ionization from nuclear recoils	(~*15 events t^{-1} d^{-1}*)
Majorana **neutrinoless double beta decay search**	e^- in Ge diode detectors	(< *1 event t^{-1} y^{-1}*)

- The SNO heavy water D_2O was purified to have ~10^{-15} (g ^{232}Th)/(g D_2O). The KamLAND liquid scintillator was purified to even higher purity.

Radiopurity of typical electronics components

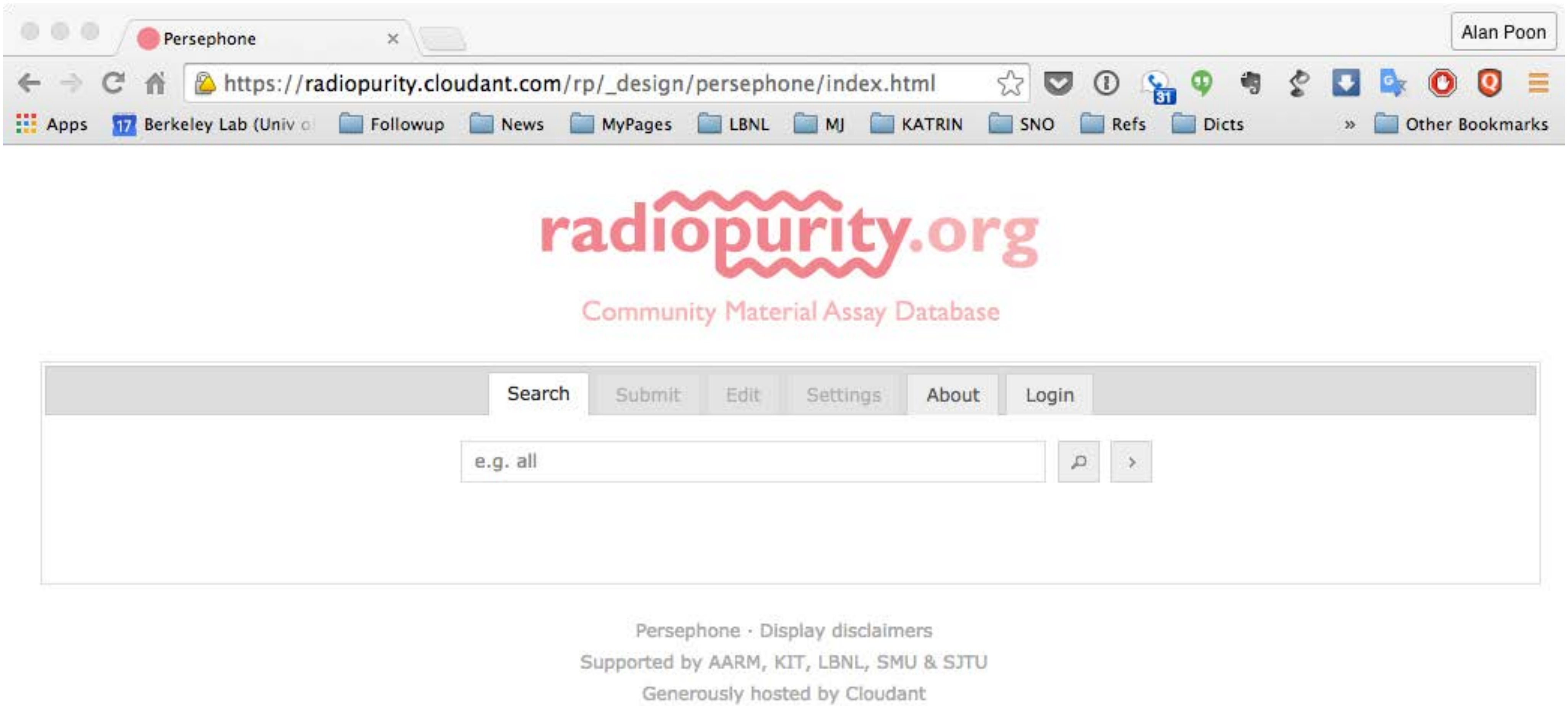
500 MΩ SMD resistor used by GERDA

Size	Th-234 [uBq/pc]	Ra-226 [uBq/pc]	Th-228 [uBq/pc]	K-40 [uBq/pc]	Pb-210 [uBq/pc]
0603 0.48 mm^3/pc 1.33 mg	4 ± 2	1.9 ± 0.3	0.6 ± 0.2	10 ± 4	46 ±5
0402 0.153 mm^3/pc 0.6 mg/pc	2 ± 1	0.7 ± 0.1	0.2 ± 0.1	< 2.6	32 ± 3

Cattadori, LRT 2015

1 μBq ≈ 0.1 / day

Radiopurity of typical electronics components



- A project started at LBNL, adopted by the community
- Experiments are adding their radioassay results to this database

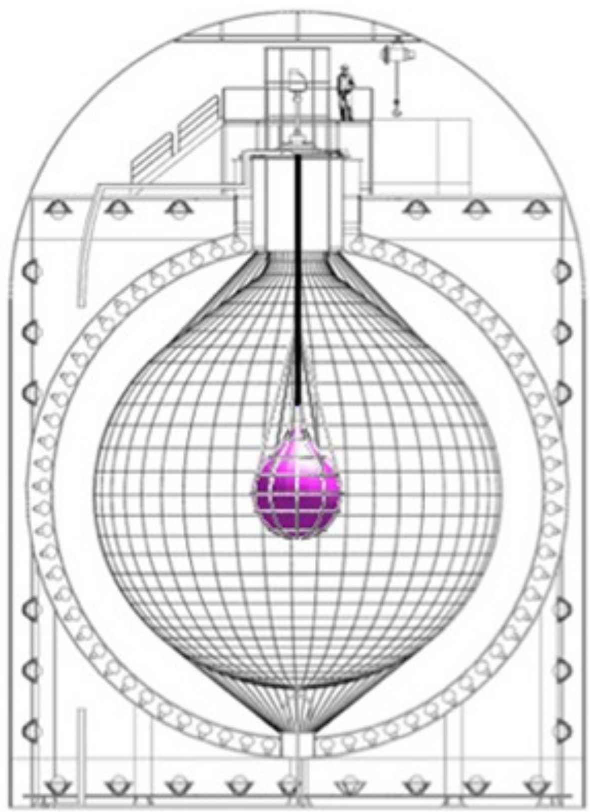
Radiopurity of typical electronics components

Grouping	Name	Isotope	Amount	Isotope	Amount		
EXO (2008)	Resistor paste, DuPont 1108	Th	4200 ppt	U	11500 ppt	...	✖
ILIAS UKDM	Resistor components, blue ceramic	Th-232	1600 ppb	U-238	480 ppb	...	✖
ILIAS UKDM	Resistor, Philips, metal on ceramic	Th-232	10300 ppb	U-238	2340 ppb	...	✖
ILIAS UKDM	Resistor, Allen-Bradley	Th-232	500 ppb	U-238	275 ppb	...	✖
ILIAS UKDM	Resistor components, NiCu	Th-232	3 ppb	U-238	0.5 ppb	...	✖
ILIAS UKDM	Resistor components: black ceramic + white su...						✖
ILIAS UKDM	Resistor components, Cu	Th-232	1 ppb	U-238	0.5 ppb	...	✖
ILIAS UKDM	Resistor components, blue ceramic						✖
ILIAS UKDM	Resistor, Welwyn, met. film	Th-232	3970 ppb	U-238	410 ppb	...	✖
ILIAS UKDM	Resistor, Kamaya, C core	Th-232	1140 ppb	U-238	480 ppb	...	✖
ILIAS UKDM	Resistor, Dale, metal film	Th-232	130 ppb	U-238	350 ppb	...	✖
ILIAS UKDM	Resistor components, SnPb	Th-232	1.5 ppb	U-238	1 ppb	...	✖
ILIAS UKDM	Resistor components, black ceramic + white su...	Th-232	28 ppb	U-238	200 ppb	...	✖
ILIAS UKDM	Resistor, Croster, C film	Th-232	3130 ppb	U-238	350 ppb	...	✖
ILIAS UKDM	Resistor components, Al2O3	Th-232	190 ppb	U-238	190 ppb	...	✖
ILIAS UKDM	Resistor, Allen-Bradley	Th-232	160 ppb	U-238	50 ppb	...	✖

The ALARA principle

- Choose radiopure materials
- Keep hot stuff away from active detector volume

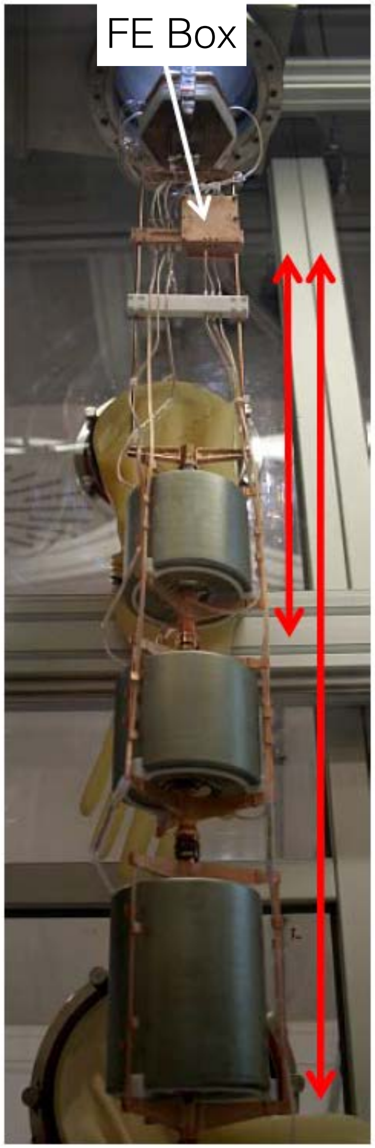
Self shielding, fiducial volume cut

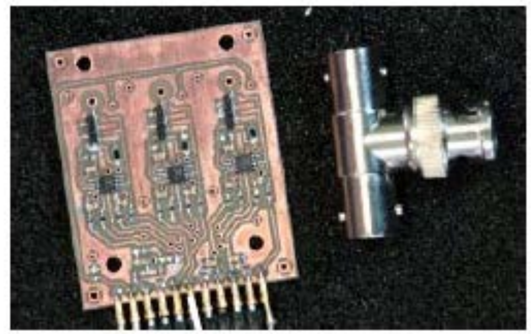


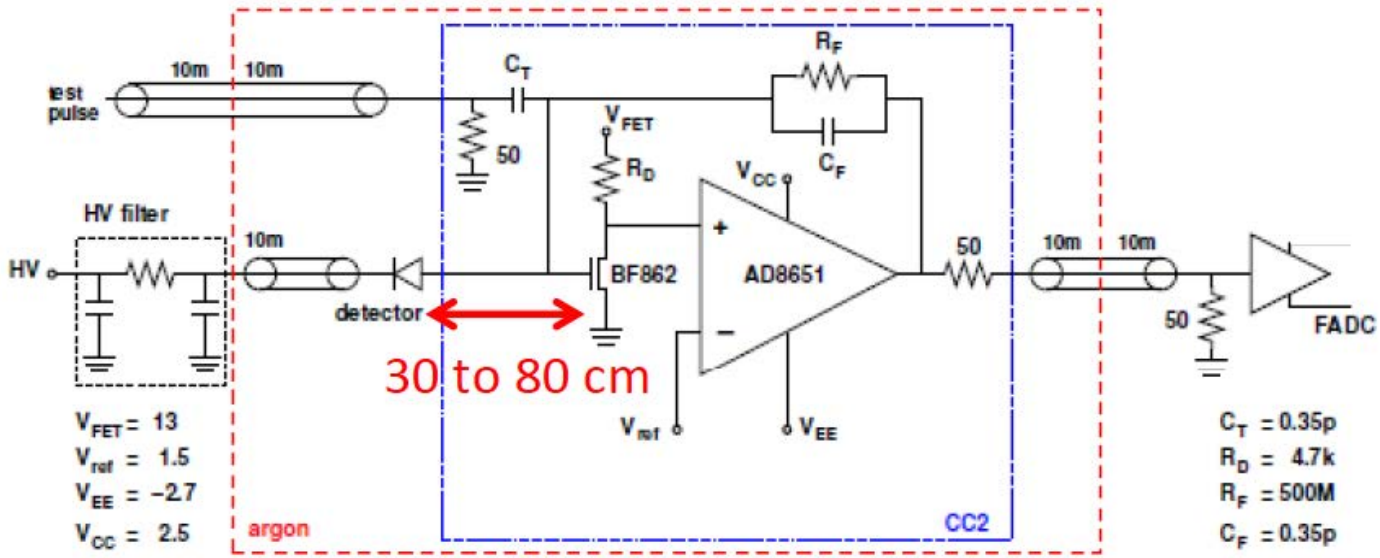
Ex: KamLAND-ZEN

The ALARA principle

- Choose radiopure materials
- Keep hot stuff away from active detector volume





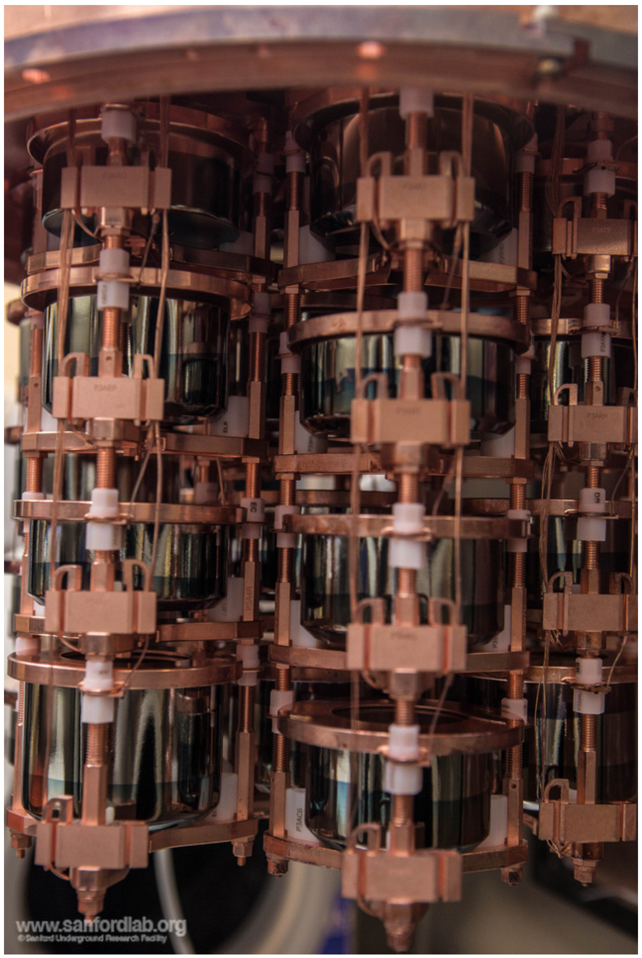


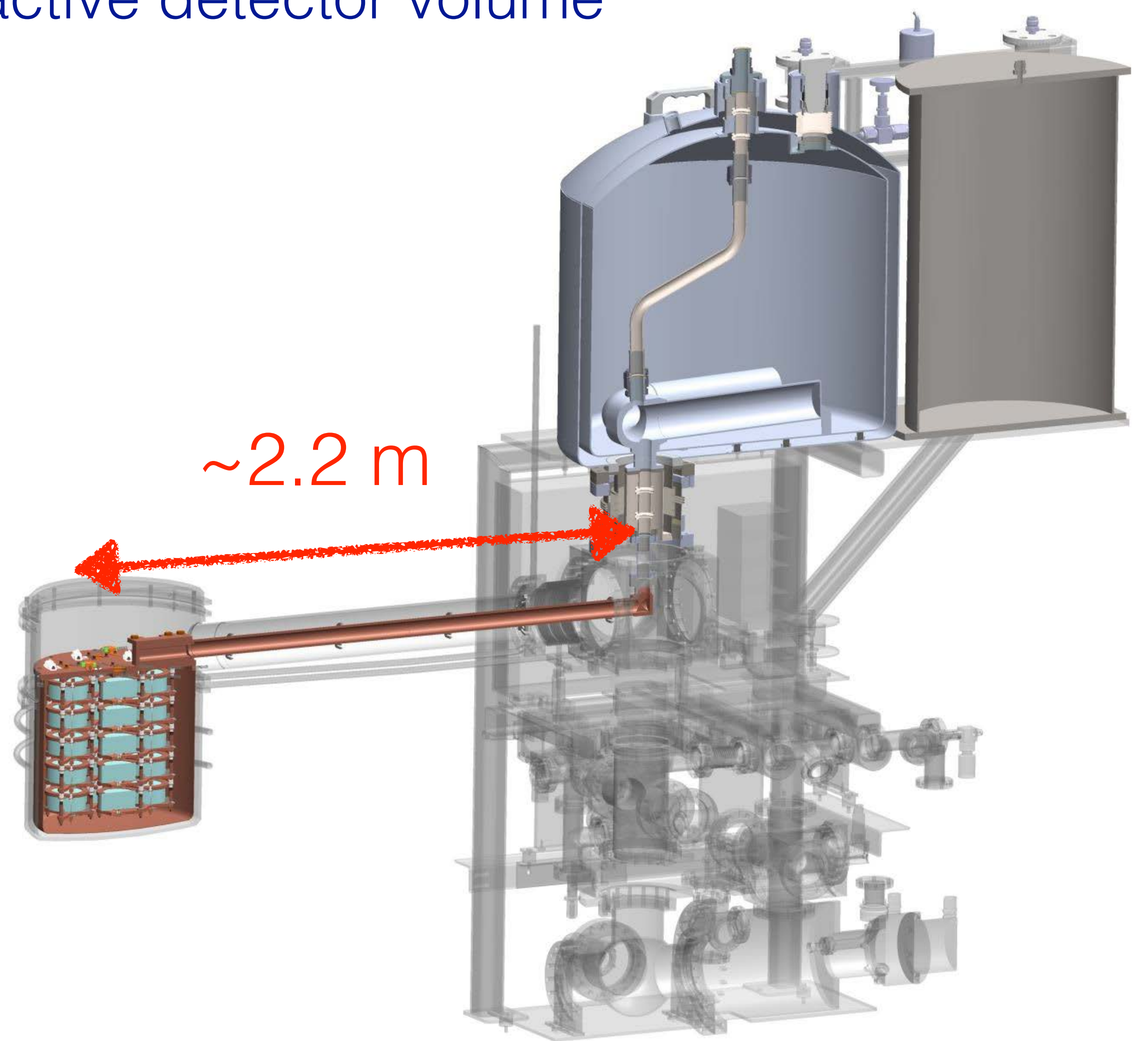
Ex: GERDA - Phase I

Cattadori, LRT 2015

The ALARA principle

- Choose radiopure materials
- Keep hot stuff away from active detector volume





Ex: MAJORANA DEMONSTRATOR

The ALARA principle

- GERDA Phase-I background results:

Eur. Phys. J. C (2014) 74:2764 Page 5 of 25 2764

Table 2 Gamma ray screening and ^{222}Rn emanation measurement results for hardware components and BIs derived from MC simulations. The activity of the mini shroud was derived from ICP-MS measurement assuming secular equilibrium of the ^{238}U decay chain. Estimates of the BI at $Q_{\beta\beta}$ are based on efficiencies obtained by MC simulations [13, 14] of the GERDA setup

Component	Units	^{40}K	^{214}Bi and ^{226}Ra	^{228}Th	^{60}Co	^{222}Rn	BI [10^{-3} cts/(keV kg yr)]
Close sources: up to 2 cm from detectors							
Copper det. support	µBq/det.	<7	<1.3	<1.5			<0.2
PTFE det. support	µBq/det.	6.0 (11)	0.25 (9)	0.31 (14)			0.1
PTFE in array	µBq/det	6.5 (16)	0.9 (2)				0.1
Mini shroud	µBq/det.		22 (7)				2.8
Li salt	mBq/kg		17 (5)				≈0.003[a]
Medium distance sources: 2–30 cm from detectors							
CC2 preamps	µBq/det.	600 (100)	95 (9)	50 (8)			0.8
Cables and suspension	mBq/m	1.40 (25)	0.4 (2)	0.9 (2)	76 (16)		0.2
Distant sources: further than 30 cm from detectors							
Cryostat	mBq					54.7 (35)	<0.7
Copper of cryostat	mBq	<784	264 (80)	216 (80)	288 (72)		<0.05 (copper and steel of cryostat together)
Steel of cryostat	kBq	<72	<30	<30	475		
Lock system	mBq					2.4 (3)	<0.03
^{228}Th calib. source	kBq			20			<1.0

[a] Value derived for 1 mg of Li salt absorbed into the surface of each detector

close

far

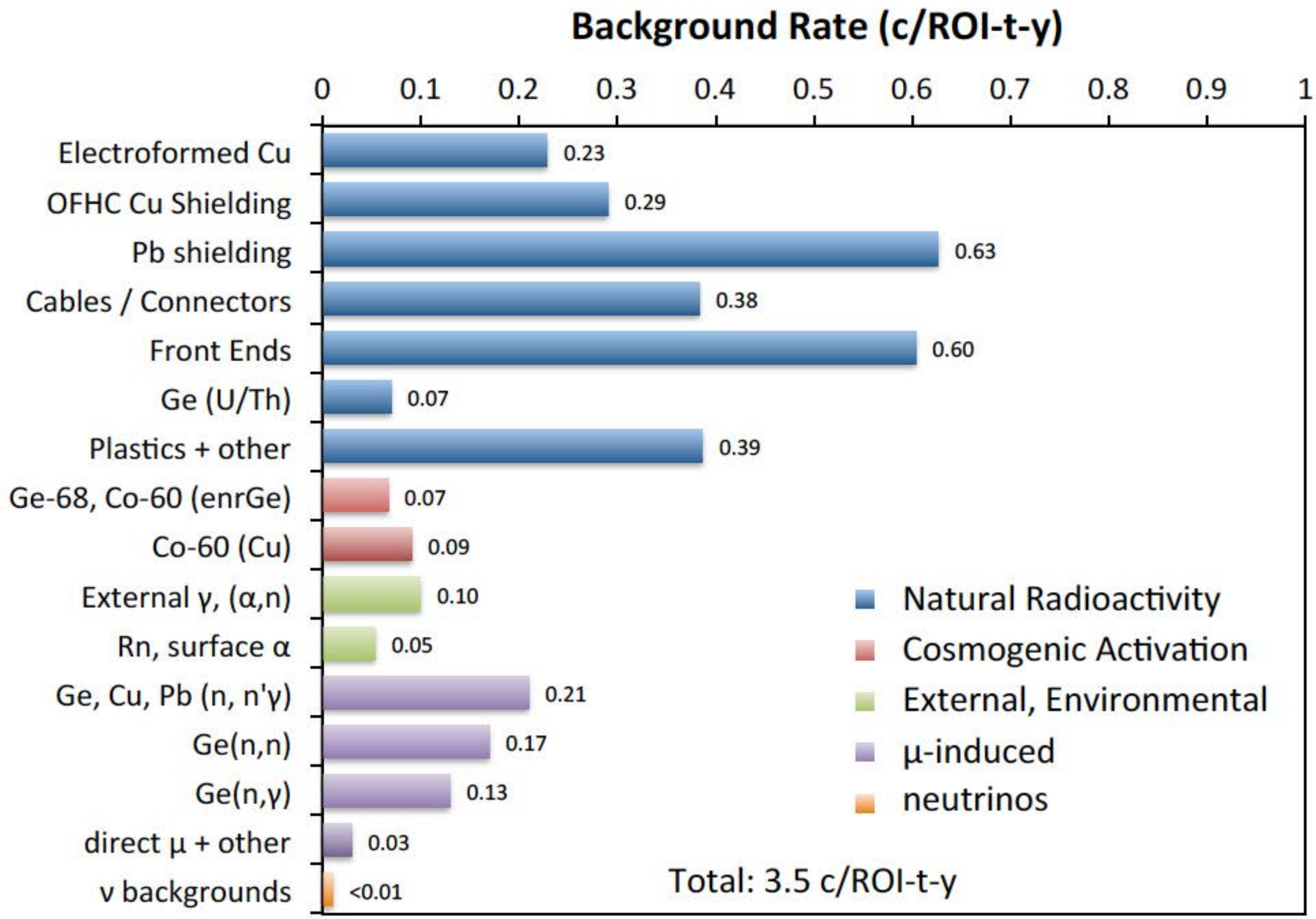
Hard to shield components close to the detectors (e.g. front-end electronics and cables)

The ALARA principle

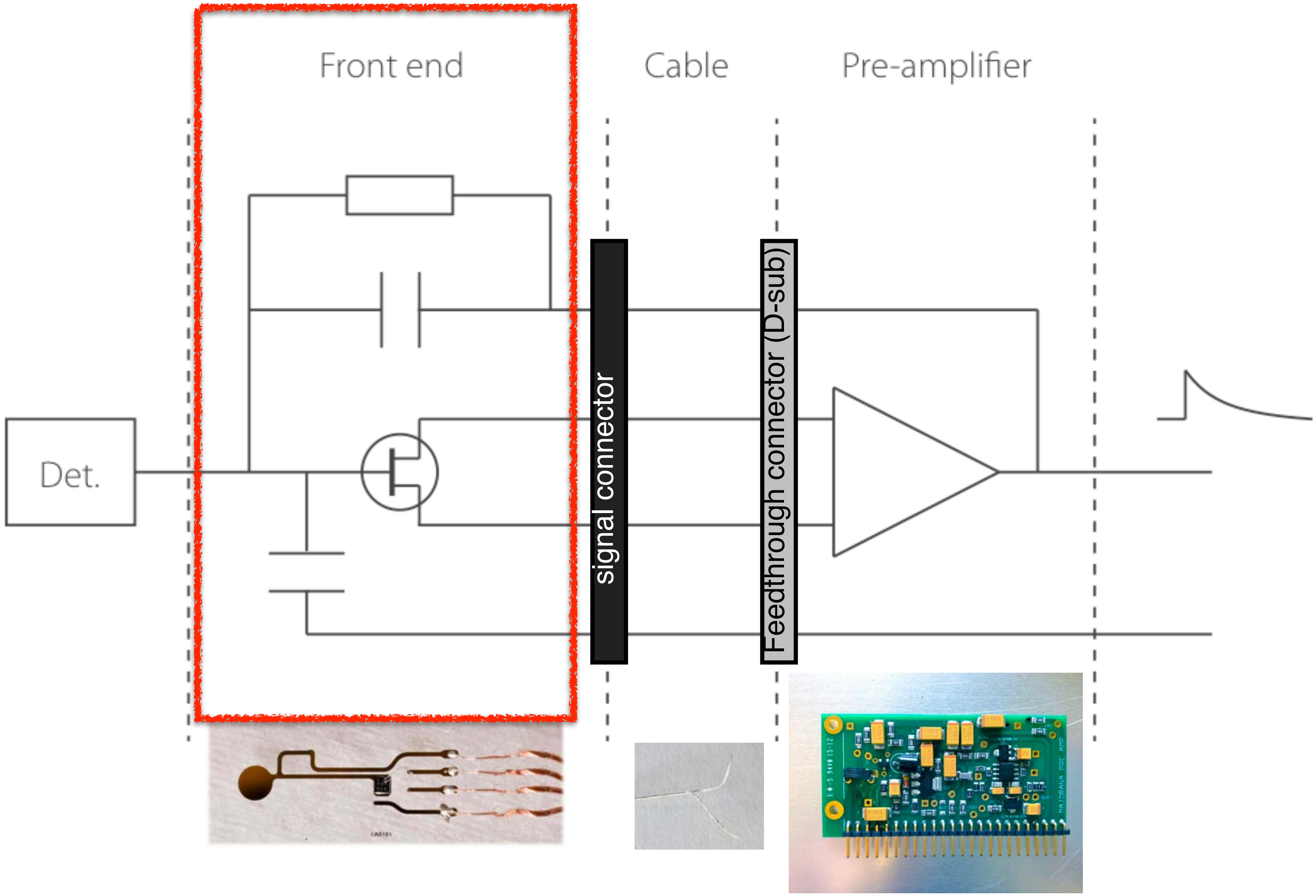
- MAJORANA DEMONSTRATOR background budget:

Based on achieved assays of materials
When UL, use UL as the contribution

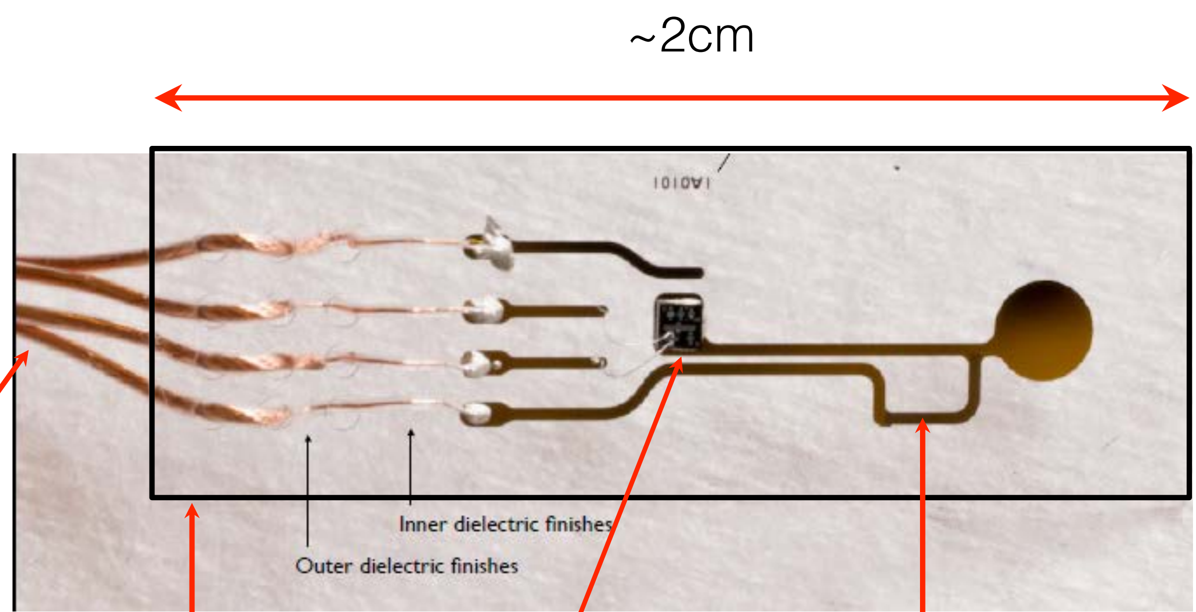
MJD goal: 3 cts / 4 keV / t-y (scale to 1 cts / 4 keV / t-y in large-scaleGe)



Making front-end electronics - MJD



Making front-end electronics - MJD



Cable (later)

Fused silica (Corning 7980)

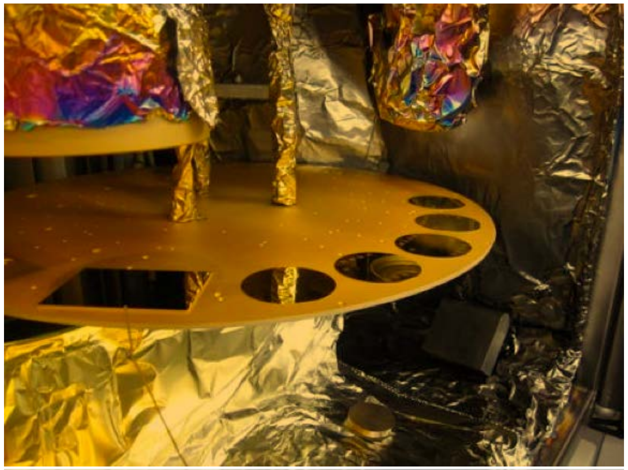
JFET (Moxtek MX11)

aGe film (feedback resistor; up to ~20 GΩ at 85 K)

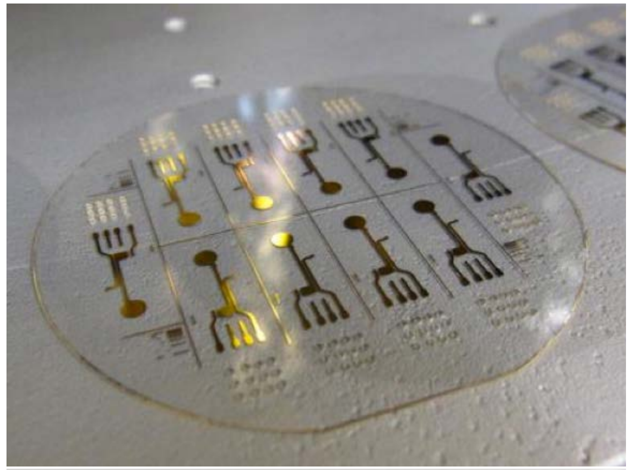
Reduced the component count by using stray capacitance as feedback capacitance

Production: wafers

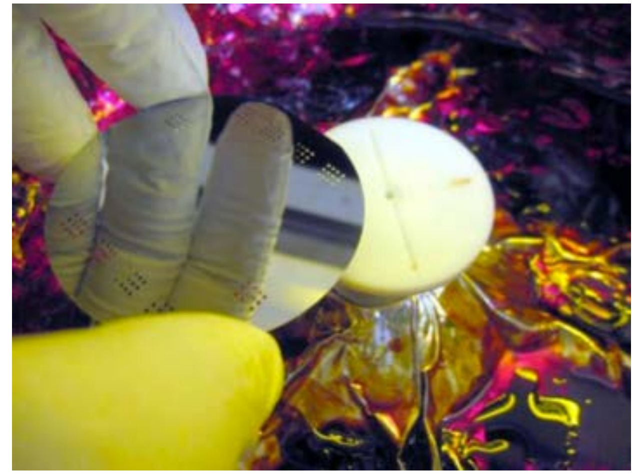
Ti/Au sputtering



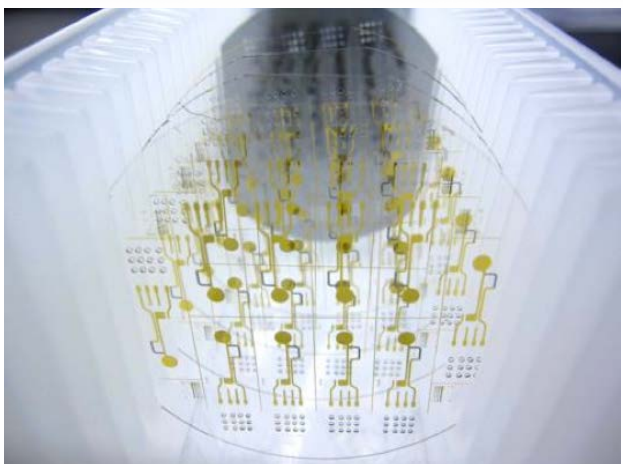
patterning traces



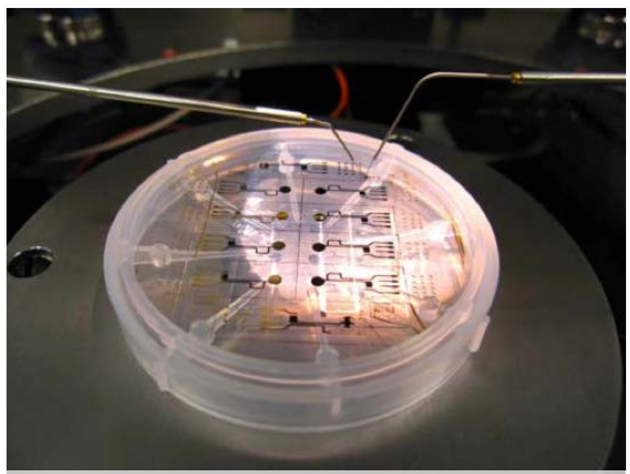
aGe sputtering



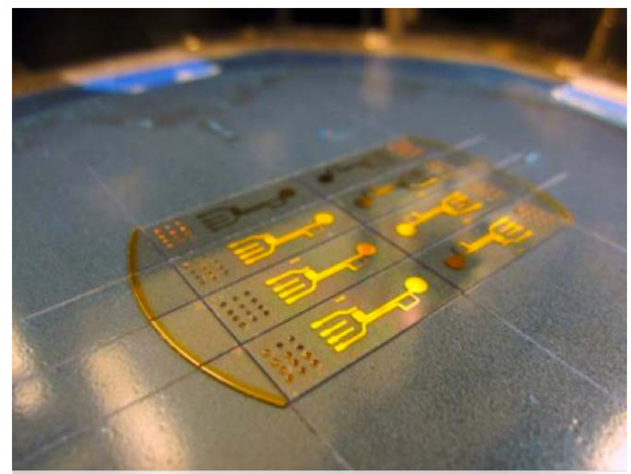
patterning aGe



electrical tests

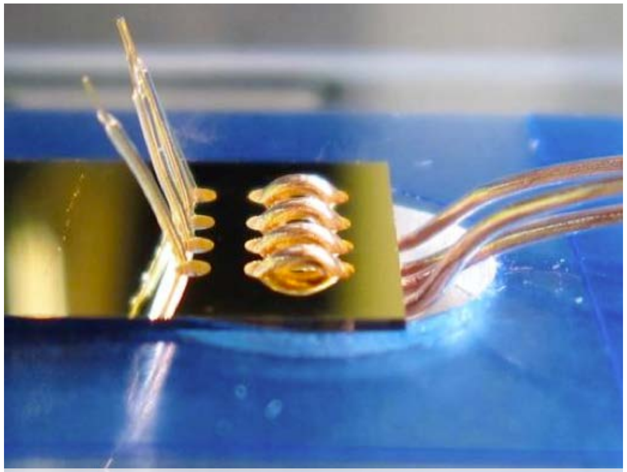


dicing boards

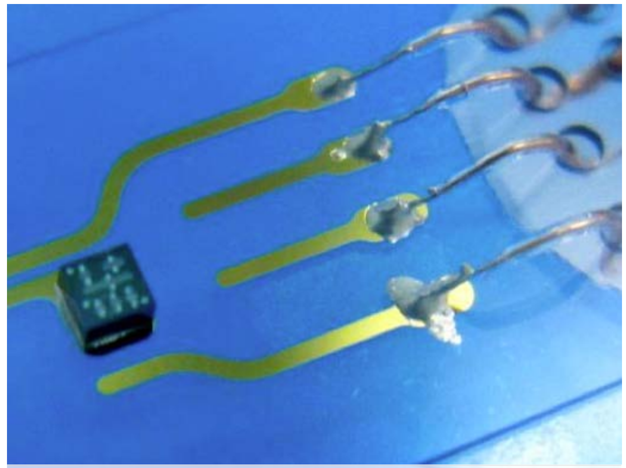


Production: on-board electronics

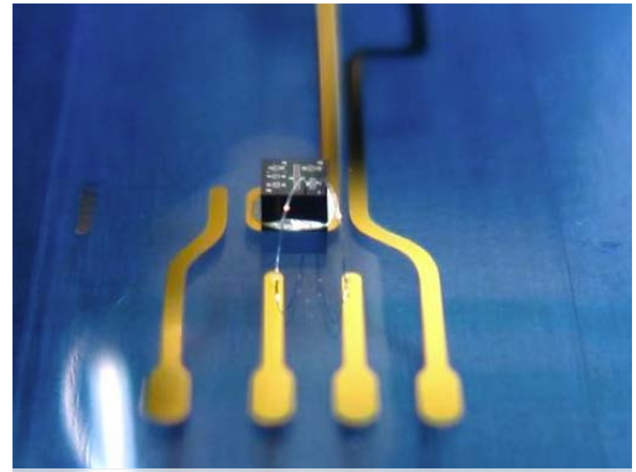
cable threading



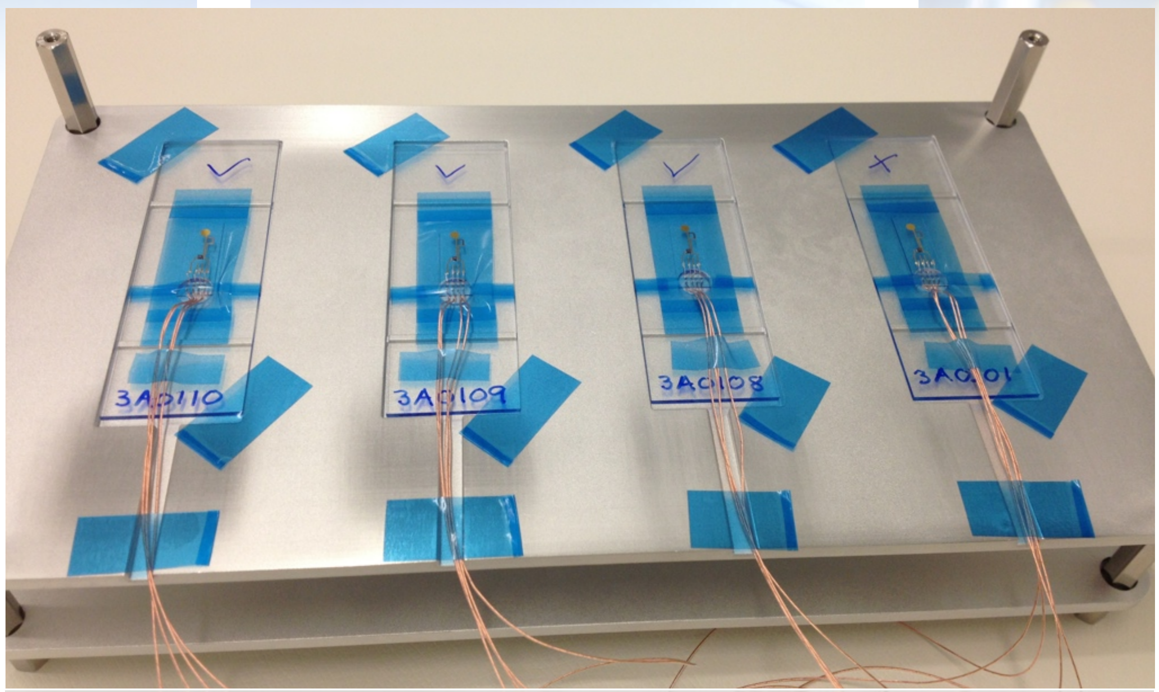
silver epoxying



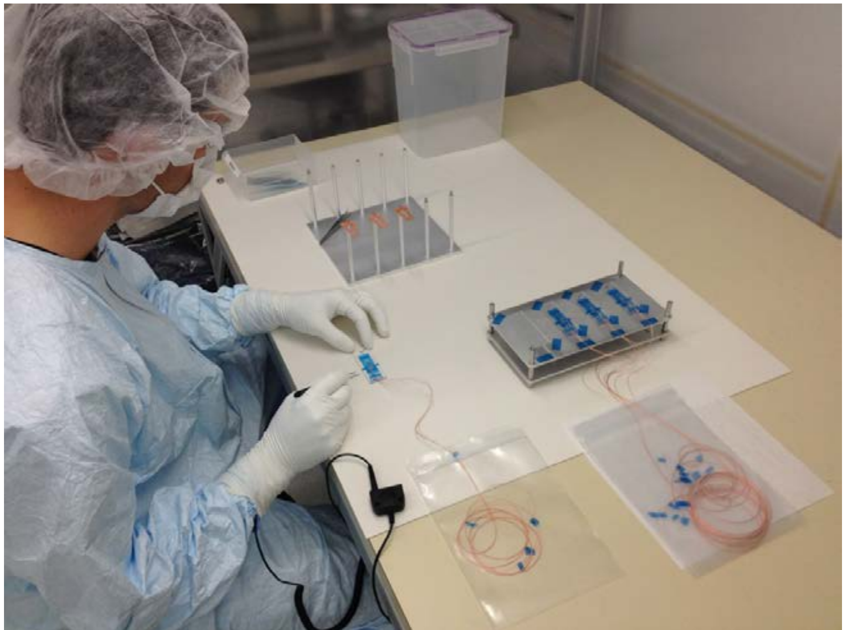
wire bonding



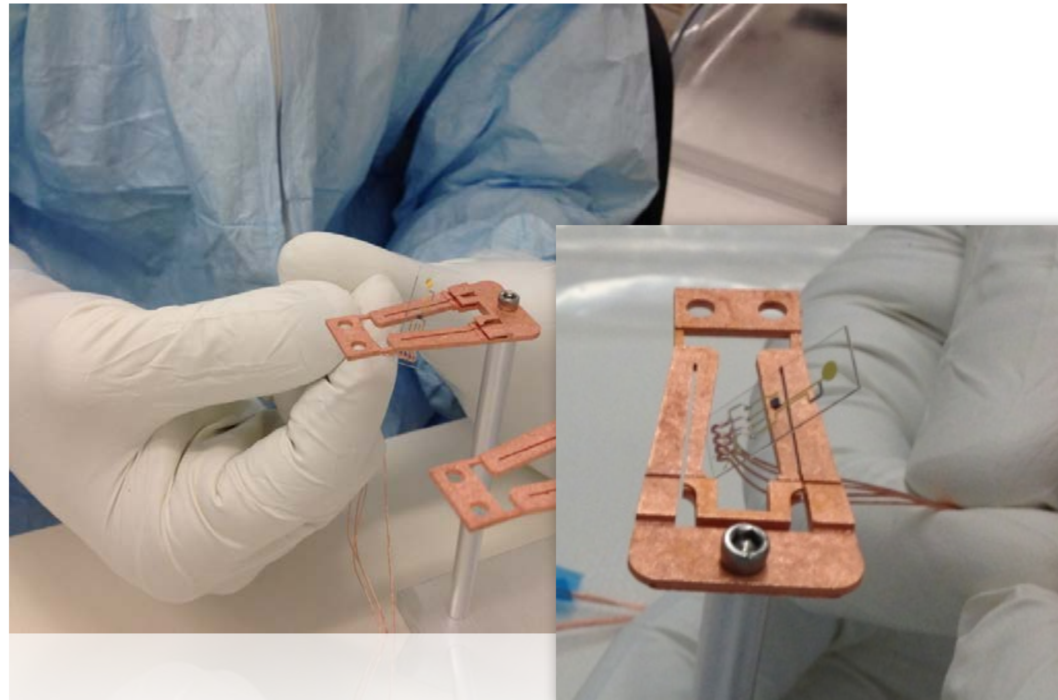
transport tray

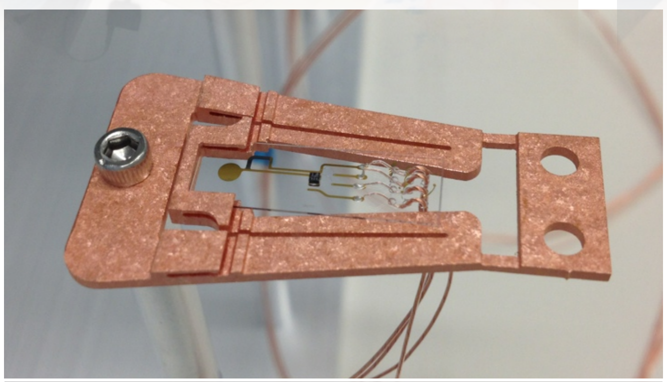


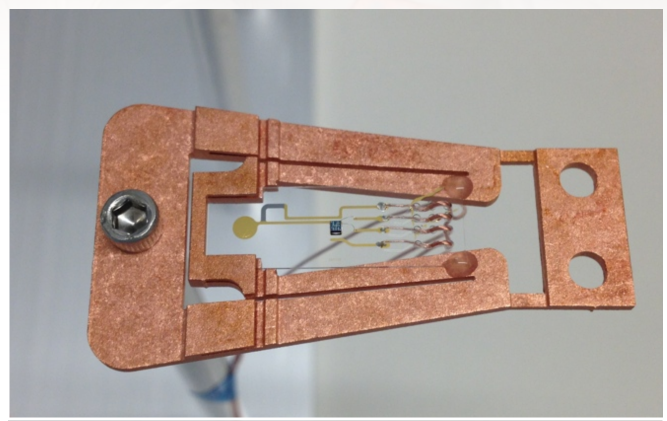
Production: loading on electroformed Cu clips



Paul Barton







Production: QA

mechanical QA

↳ pressure corresponding to 650g applied on board

electrical QA

Sophia Elia

↳ full signal path + preamp test
↳ check baseline
↳ pulser check of 1st and 2nd stages

Making front-end electronics - MJD

- Component assays prior to production:

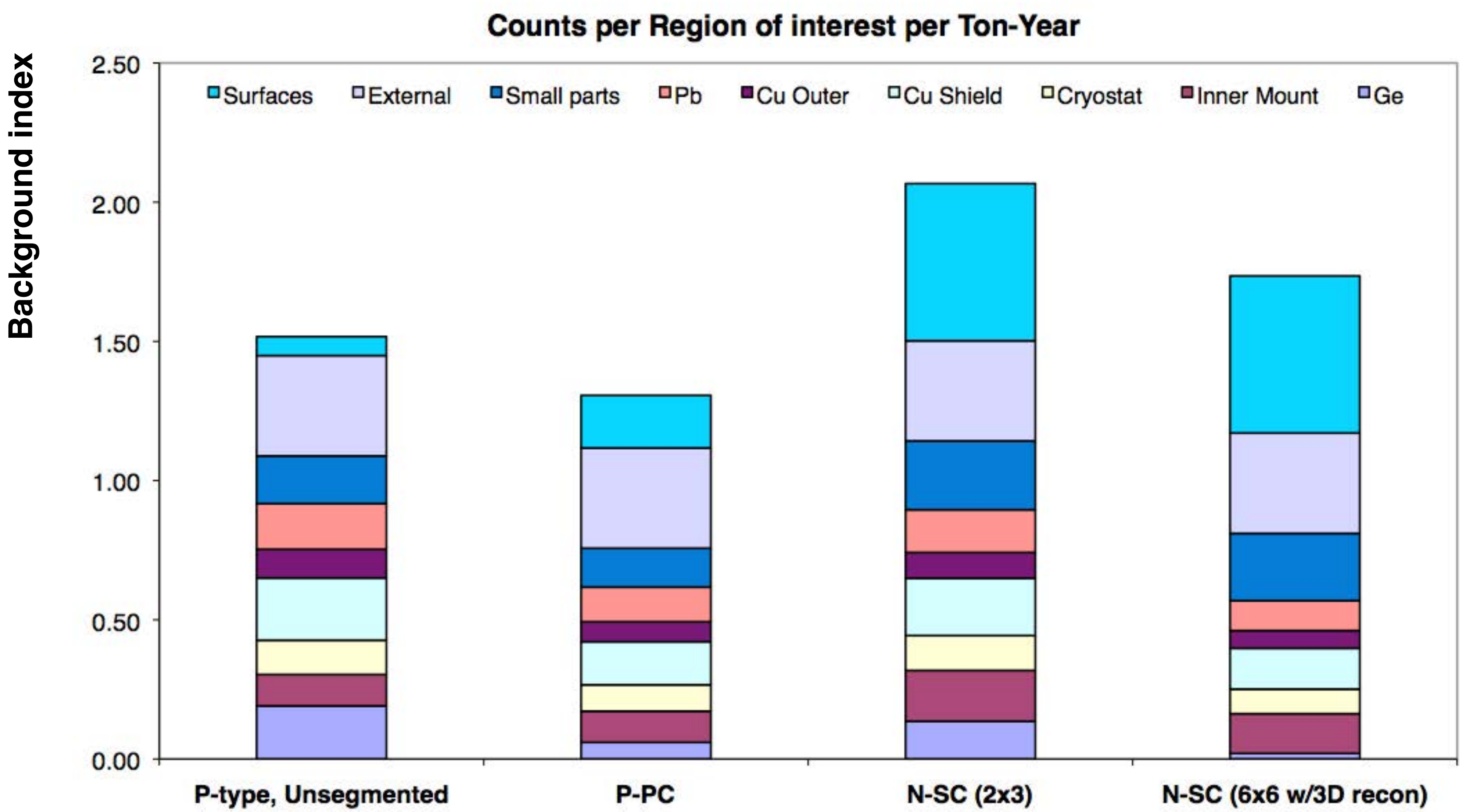
Component	Material	Purity (g / g)		Counts / ROI / t / y		Ref.
		^{232}Th	^{238}U	^{232}Th	^{238}U	
Substrate	Fused silica	101×10^{-12}	284×10^{-12}	0.0259	0.0616	MJ ICP-MS
Resistor	a-Ge	5×10^{-9}	5×10^{-9}	0.0001	0.0001	MJ ICP-MS
Traces	Au	$47(1)\times10^{-9}$	$2.0(0.3)\times10^{-9}$	0.0421	0.0015	MJ ICP-MS
Traces	Ti	$< 400\times10^{-12}$	$< 100\times10^{-12}$	~ 0	~ 0	MJ ICP-MS
FET	FET die	$< 2\times10^{-9}$	$< 141\times10^{-12}$	< 0.0107	< 0.0006	MJ ICP-MS
Bonding wire	Al	$91(2)\times10^{-9}$	$9.0(0.4)\times10^{-12}$	0.0004	~ 0	MJ ICP-MS
Epoxy	Silver epoxy	$< 70\times10^{-9}$	$< 10\times10^{-9}$	< 0.0685	< 0.0082	MJ gamma
Total				<0.1476	<0.0720	

- Largest backgrounds: fused silica substrate, gold traces
- Full board assays: ~2-3x higher in background

Less handling is always better

Less is (usually) better

- N-type segmented Ge detectors vs P-type detectors

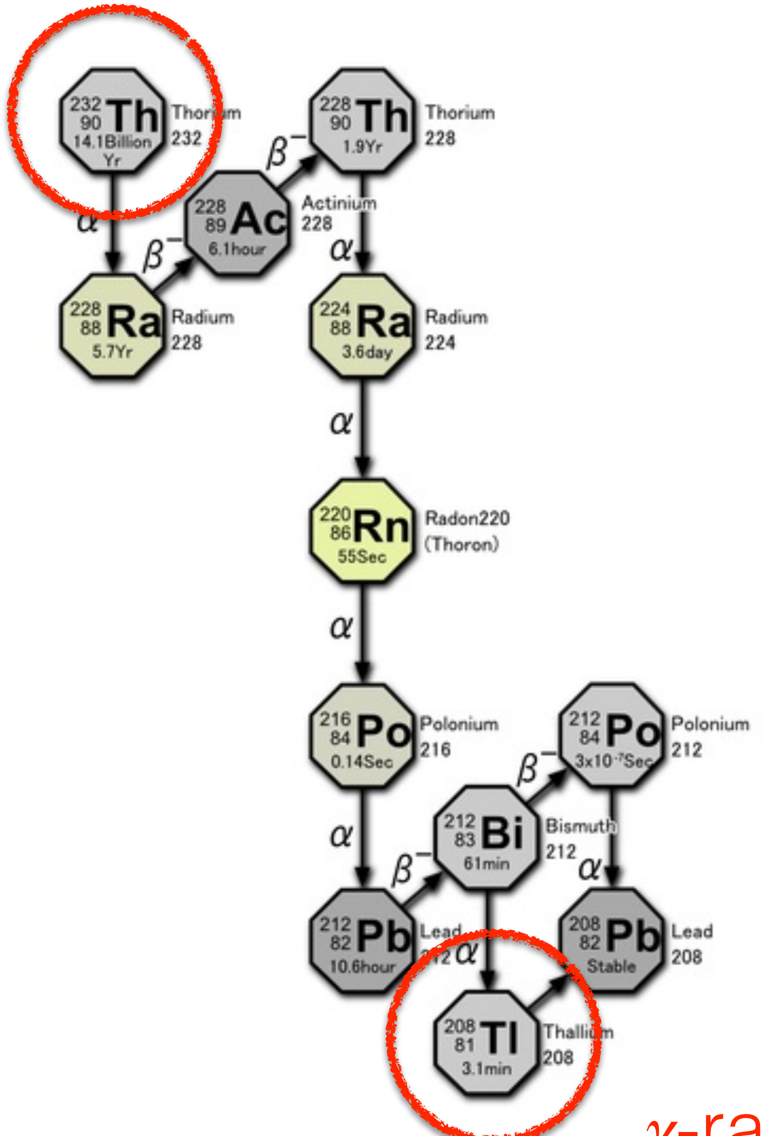


- N-type high-segmentation detectors have higher backgrounds from small parts (due to more readout components) and surface backgrounds (due to dead layer)

Aside: Understanding radioactivity of Au

Mass spectroscopy

- small sample size; sampling issue
- higher sensitivity

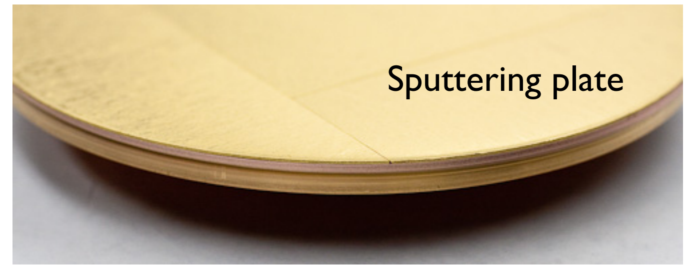


γ-ray spectroscopy

- large sample size needed
- lower sensitivity

Aside: Understanding radioactivity of Au

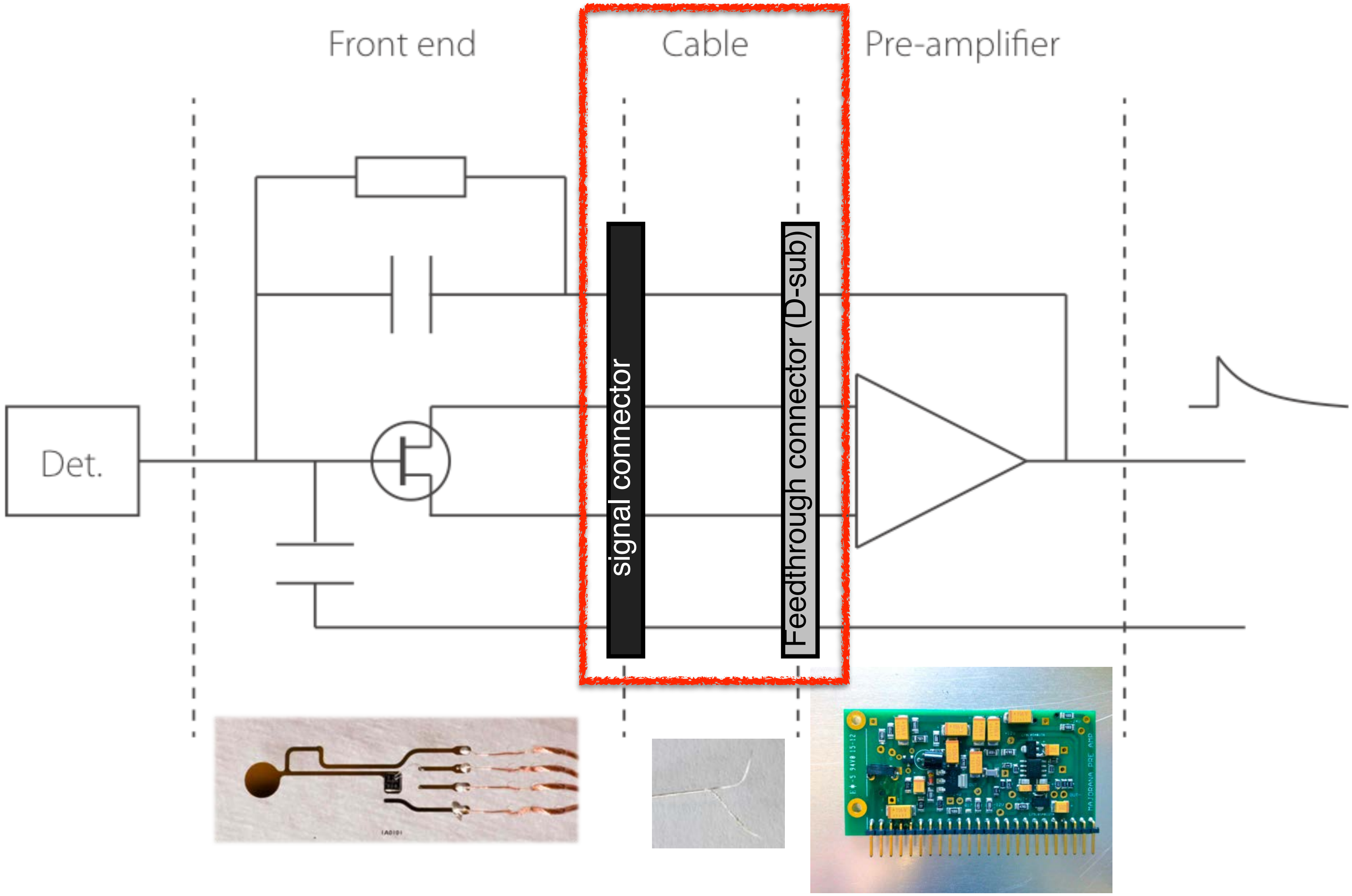
- High ^{232}Th observed in gold ICPMS measurements but not in a gamma cross-check
- Found to be complexing of ^{197}Au with ^{35}Cl in the aqua regia
  - Presence of unphysical mass ^{197}Au + 2 x ^{35}Cl
  - Reduction with less ^{35}Cl



Material	Method	^{232}Th ($\times 10^{-9}$ g/g)
Shot 3N5 Au (Lee)	ICP-MS	1274(36)
Shot 4N4 Au (Lee) I	ICP-MS	205(18)
Shot 4N4 Au (Lee) II	ICP-MS	271(46)
Sputtered 4N8 Au (Lee) A	ICP-MS	420(20)
Shot 5N Au (ACI alloys) I	ICP-MS	210(18)
Shot 5N Au (ACI alloys) II	ICP-MS	168(16)
Shot 4N4 Au shot (Lee)	Gamma	< 3
Sputtered 4N8 Au (Lee) B (prelim.)	ICP-MS	47

Do both types of assays if possible

Cables


Front end
Cable
Pre-amplifier
Det.
signal connector
Feedthrough connector (D-sub)

Coaxial Cables - GERDA

- GERDA Phase-1

^{228}Th: 1.1±0.5 mBq/kg
^{238}U < 59 mBq/kg
Cu/PTFE 1 mm OD
linear density = 2.7 g/m

Table 3 Cables deployed in the 1-string and 3-string locks.

cable	ref.	type	1-string	3-string
Habia SM50	[66]	50 Ω, coaxial	15	24
SAMI RG178	[67]	HV (4 kV), coaxial	4	-
Teledyne Reynolds 167-2896	[68]	HV (18 kV), coaxial	-	10
Teledyne Reynolds 167-2896	[68]	HV (5 kV), unshielded	1	2
total number			20	38

[arXiv:1212.4067v1]

Construction:		
Conductor	Silver plated high strength copper alloy (1x0,16)	0,16
Dielectric	Solid PTFE	0,52
Braid	Silver plated copper (0,06)	0,85
Jacket	FEP, Brown-transparent	1,00
Weight	2,7 kg/km	
Temperature rating (°C)	-55 / +200°C	
Order reference	**30000-050-00**	

Over an order of magnitude too radioactive for MJD

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Temperature rating (°C)	-55 / +200°C	
Order reference	**30000-050-00**	

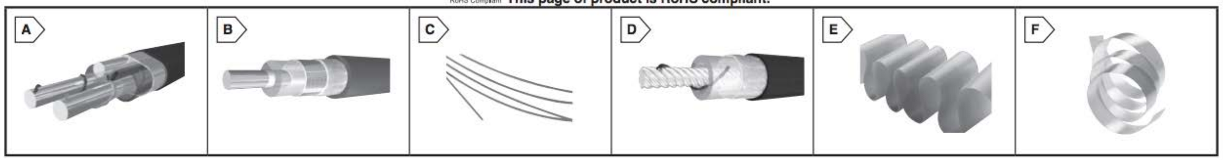
Over an order of magnitude too radioactive for MJD

- Silver-plated Cu is likely hot
- Scaling to a HV cable (5 kV DC rating) means even higher activity

Other commercial options?

Coaxial, Ribbon and Multi-Conductor Cables

RoHS Compliant This page of product is RoHS compliant.

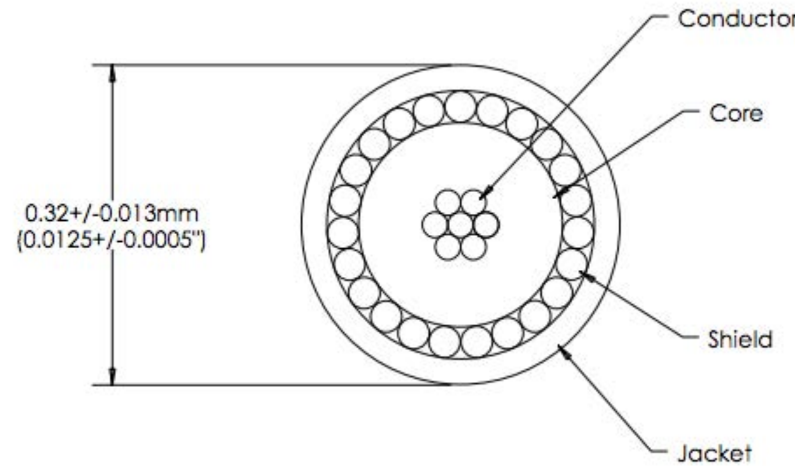


TEMP-FLEX a molex company **COAXIAL CABLES**

For quantities greater than listed, call for quote.

MOUSER STOCK NO.	Temp-Flex Part No.	Fig.	Nominal OD (in.)	Signal Conductors	Braid Shield	Color	Price Per Ft.			
							1	10	25	50
Twinax Cable • Capacitance: 14.5pF/ft. • Differential Impedance: 100+/-5 Ohms										
538-100TX-08	100TX-08	A	0.049+/-0.005	32AWG	44AWG	1-Blue, 1-Green	2.12	1.99	1.83	1.53
Flexible Microwave Coaxial Cables • Capacitance: 29.0pF/ft. (95pF/ft.) • Impedance: 50+/-1 Ohms										
538-141SC-1901	141SC-1901	B	0.157+/-0.005	19AWG	40AWG	Blue	11.56	10.87	9.96	8.37
538-047SC-2901	047SC-2901	B	0.056+/-0.003	29AWG	46AWG	Blue	4.49	4.22	3.87	3.25
Microminiature Coaxial Cable • Capacitance: 30pF/ft. Nominal • Impedance: 50+/-2 Ohms										
538-086SC-2401	086SC-2401	B	0.101+/-0.005	24AWG	40AWG	Blue	7.40	6.96	6.38	5.36
538-50MCX-37	50MCX-37	C	0.125+/-0.005	42AWG	48AWG	Blue	2.55	2.39	2.20	1.85
High Speed Data Cables • Capacitance: 30pF/ft. Nominal • Impedance: 50+/-2 Ohms										
538-50CX-41	50CX-41	D	0.071	30AWG, 7/38	40AWG	Black	2.81	2.64	2.42	2.04
538-50CX-42	50CX-42	D	0.100	26AWG, 7/34	38AWG	Black	3.64	3.42	3.14	2.63

TEMP-FLEX a molex company **FLAT FEP RIBBON CABLES**



Mouser catalogue

TEMP-FLEX a molex company

Enlarge

Mouser Part #: 538-50MCX-37

Manufacturer Part #: 50MCX-37

Manufacturer: Temp-Flex

Description: Coaxial Cables 42AWG PFA, 50 OHM MICRO COAX, PER FT

Learn more about Temp-Flex 50MCX-37

Page 1,389, Mouser Online Catalog
Page 1,389, PDF Catalog Page
Data Sheet

Radiopurity concerns:

- dye in the jacket
- silver-plated copper alloy in braid and central conductor

It became clear that we needed to do a special production run

Coaxial Cables - MJD

- FEP and PFA
  - have high dielectric strength (Dupont: 260 kV/mm)
  - are radiopure

Cu

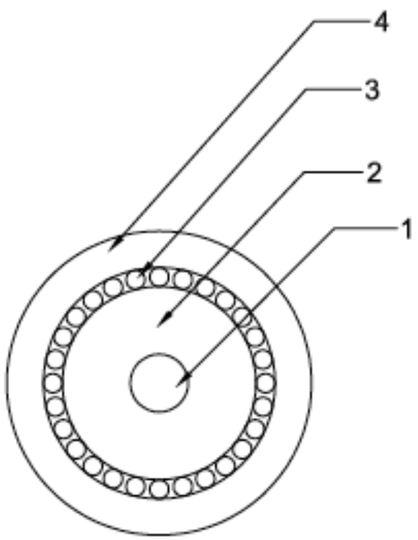
dielectric

Sample	Lab	Reported in pg/g				Reported in μBq/kg			
		^{232}Th	± 1σ	^{238}U	± 1σ	^{232}Th	± 1σ	^{238}U	± 1σ
Cu conductor wire (signal, CFW)	LBNL	<30	-	<50	-	<120	-	<620	-
Cu conductor wire (high voltage, CFW)	LBNL	<30	-	180	50	<120	-	2200	620
Cu wire 50AWG (uncleaned, MWS[1])	LBNL	120	20	73	28	490	80	910	350
Cu wire 50AWG (cleaned, MWS)	LBNL	30	30	42	10	120	120	520	120
PFA416[2]	PNNL	2.60	**	0.89	**	10.66	**	11.09	**
PFA340A[3]	PNNL	3.28	**	1.90	**	13.45	**	23.57	**
FEP 106	PNNL	0.11	**	1.96	**	0.43	**	24.36	**
FEP NP20	PNNL	0.99	**	0.61	**	4.05	**	7.60	**
FEPTE 9494	PNNL	4.03	**	0.71	**	16.52	**	8.75	**

- The radiopurity of the Cu drives the background budget:
  - reduce OD of central conductor
  - reduce OD of inner dielectric
  - helical shield (instead of braid)

Coaxial Cables - MJD

- Contracted Axon’ in France to make the “picocoax” cable



		Material	Signal	HV
1	central conductor	Bare Cu	0.0762 mm ϕ	0.152 mm ϕ
2	inner dielectric	FEP / PFA	0.254 mm ϕ	0.77 mm ϕ
3	helical shield	Bare Cu	AWG50	AWG50
4	jacket	FEP / PFA	0.4 mm ϕ	1.2 mm ϕ
Linear mass density			0.4 g/m	3 g/m

Coaxial Cables - MJD

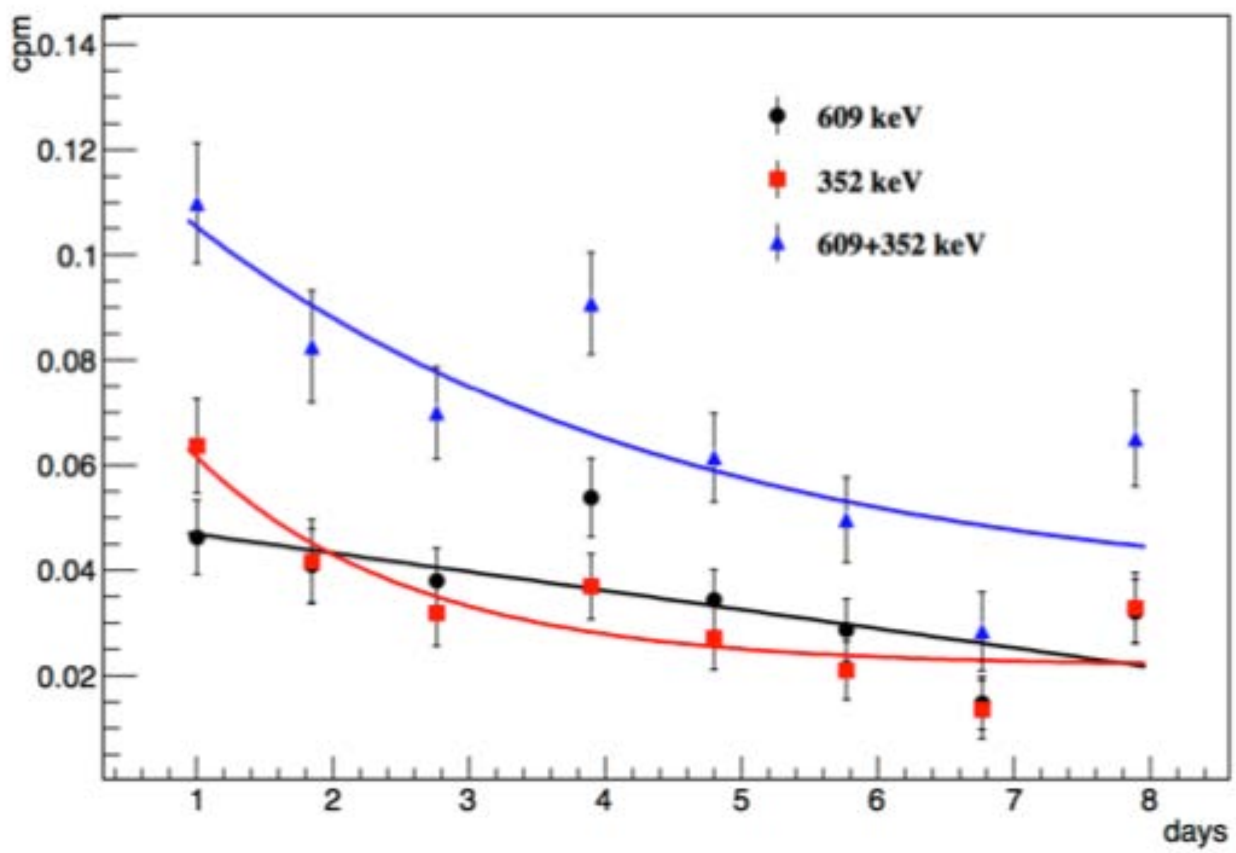
- Contracted Axon' in France to make the "picocoax" cable
- Additional testing, cleaning in ultrasonic bath and drying between production steps (conductor prep, inner dielectric extrusion, shielding, jacket extrusion).

HV Cable	Technique	Th (c/ROI/t/y)	U (c/ROI/t/y)
Projection	Simulation & assay	<0.02	<0.06
Axon' - Run 1 (QA issue at factory - no cleaning steps)	ICPMS	1.1	16.5
Axon' - Run 2	ICPMS & Gamma	<0.004	<0.081

Goal: << 1 c/ROI/t/y

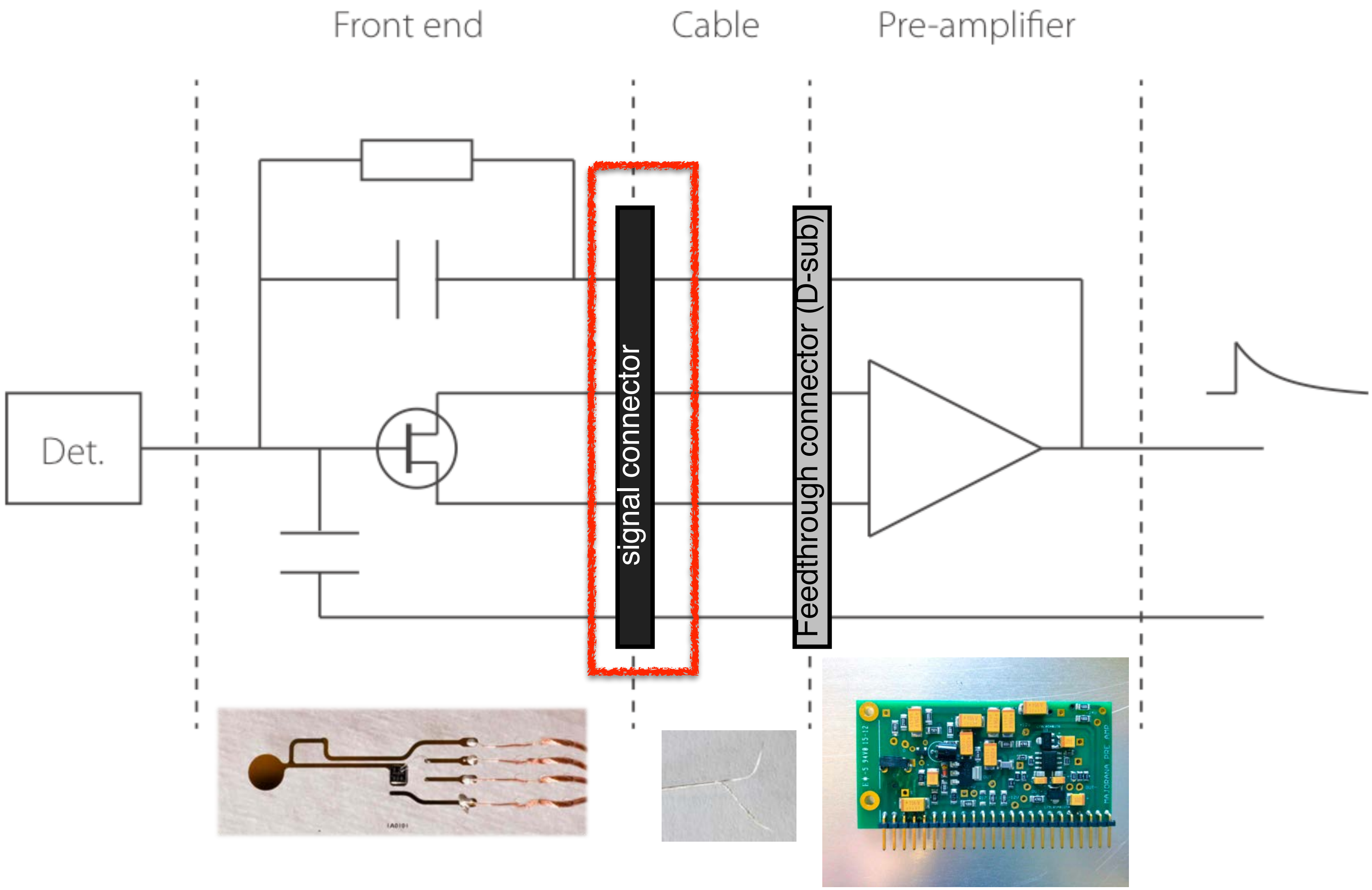
Coaxial Cables - MJD

- Contracted Axon' in France to make the "picocoax" cable
- The cables were stored in dry N_2 environment until they were being used.
- Room ^{222}Rn can stick to the outer jacket if not stored properly



Proper clean storage of components is essential

Making connectors



Technical Issue: Plug Design

- Cable connection: solder to tiny pins
- Pins are held in vespel housing that also provides strain relief
- Press-fit, keyed shell interface for ease of assembly in the glove box
- Vacuum tests indicate no significant virtual leaks.
- BeCu contact is too radioactive for MJD (~10 cts/t/y). Iterative prototyping to establish reliable connection during thermal cycling.
- Full body ICPMS indicates the connectors are sufficiently clean for MJD

Solder

- "Typical clean solder":

Grouping	Name	Isotope	Amount	Isotope	Amount		
SuperCDMS	Solder paster, Alpha WS-820	Th-232	5.28 mBq/kg	U-238	5.615 mBq/kg	...	×
ILIAS UKDM	Solder, SnCu	Th-232	1 ppb	U-238	5 ppb	...	×
ILIAS UKDM	Silfos (Ag, Cu, Sn solder)	Th-232	0.05 ppb	U-238	0.05 ppb	...	×
ILIAS UKDM	Silver solder	Th-232	0.072 ppb	U-238	0.1 ppb	...	×

- Low background ideas:
  - Roman Pb
  - Source clean solder (e.g. SnAg), use abietic acid as flux.

PCB in low-background experiment

S. Nisi *, A. Di Vacri, M.L. Di Vacri, A. Stramenga, M. Laubenstein

Laboratori Nazionali del Gran Sasso, INFN, S. S. 17/bis km 18+910, I-67010 Assergi (AQ), Italy

Applied Radiation and Isotopes 67 (2009) 828–832

Sample	^{40}K ($mBq\,kg^{-1}$)	^{232}Th ($mBq\,kg^{-1}$)	^{238}U ($mBq\,kg^{-1}$)
PEN			
γ-spectroscopy	510 ± 20	136 ± 3	242 ± 3 (^{226}Ra) 236 ± 68 (^{234m}Pa)
ICP-MS	370 ± 50	110 ± 10	200 ± 30
KAPTON® HN DuPont			
γ-spectroscopy	<5.4	1.4 ± 0.7	14 ± 1 (^{226}Ra) <27 (^{234m}Pa)
ICP-MS	7 ± 3	0.65 ± 0.08	17 ± 2
CuFlon®			
γ-spectroscopy	48 ± 15	<1.9	<0.84 (^{226}Ra) <132 (^{234m}Pa)
ICP-MS	6–2/+9	0.28–0.03/+0.04	0.36–0.04/+0.07

- CuFlon is cleaner than Kapton in U and Th, but it's much worse in ^{40}K

Processing PCBs

- Once selected the proper raw material →Important not to spoil its radiopurity by PCB process.
- Avoid finishing protective layers (soldermasks etc.)
- Minimize Cu deposition
- **Gold finishing required for bonding (typically <1 um) introduces significant U contaminations. Minimize golded surfaces (in GERDA few mm^2/detector)**

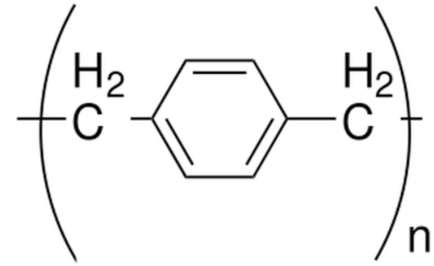
				Solfor		Fosfor		Cleanin g		PreAu		Micro Etchin		Gold		Nickel
39	K	ppb		2000		4900		6100		Saturate		96000		32000000		38000
208	Pb	ppb	<	0,3		0,7		11		28		17		2	<	10
232	Th	ppb	<	0,03		0,05	<	0,03		1		0,04		1,7	<	0,3
238	U	ppb		0,13		22		0,8		5,8		0,81		7,7	<	0,3

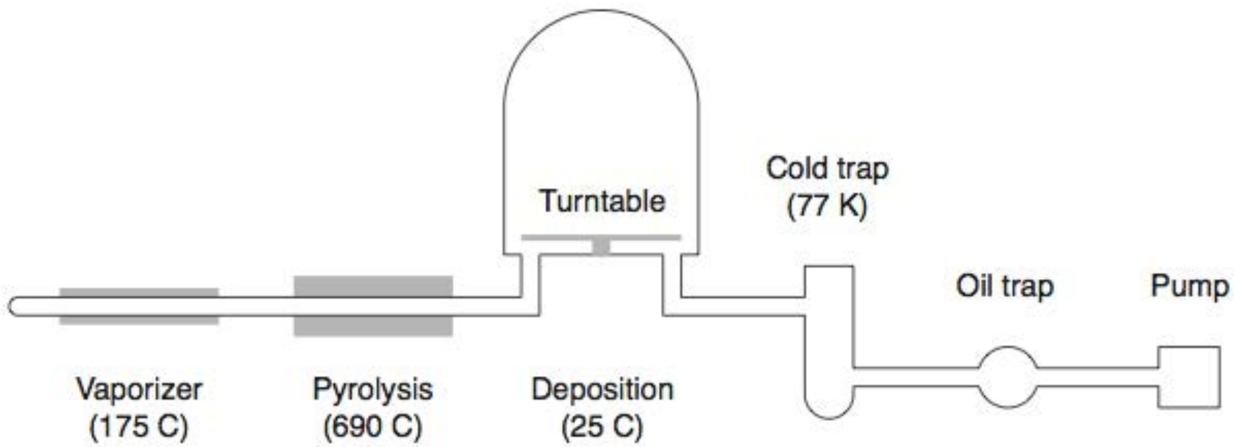
Cattadori, LRT 2015

A cryogenic temperature sensor

Microelectronics with **parylene** substrate:

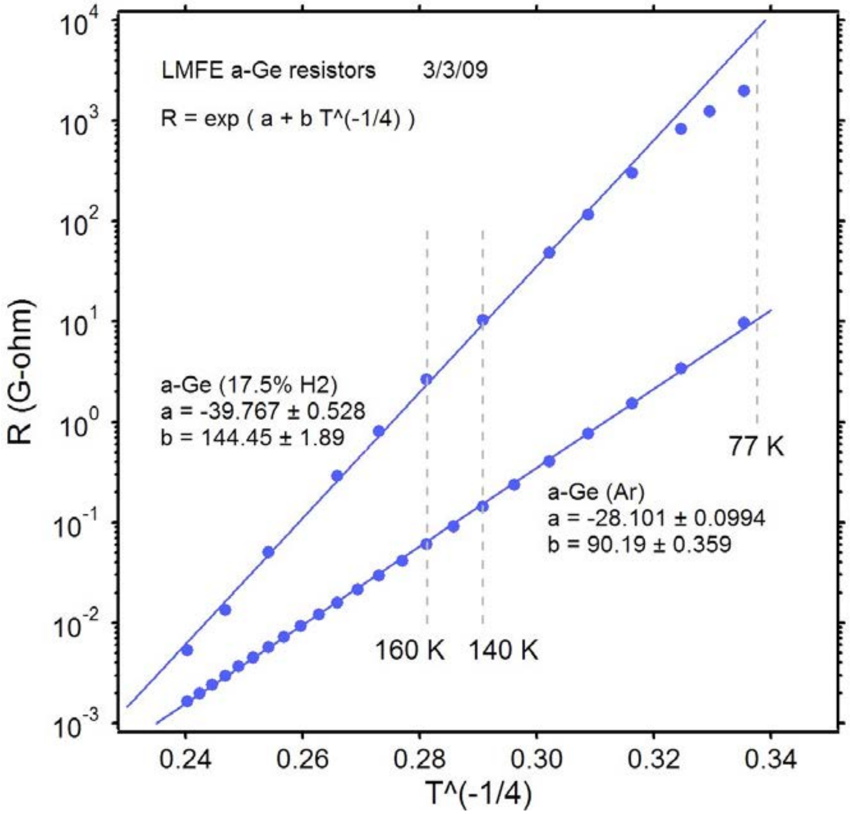
- Low background
- “flexible circuitry”
- applications in medical fields

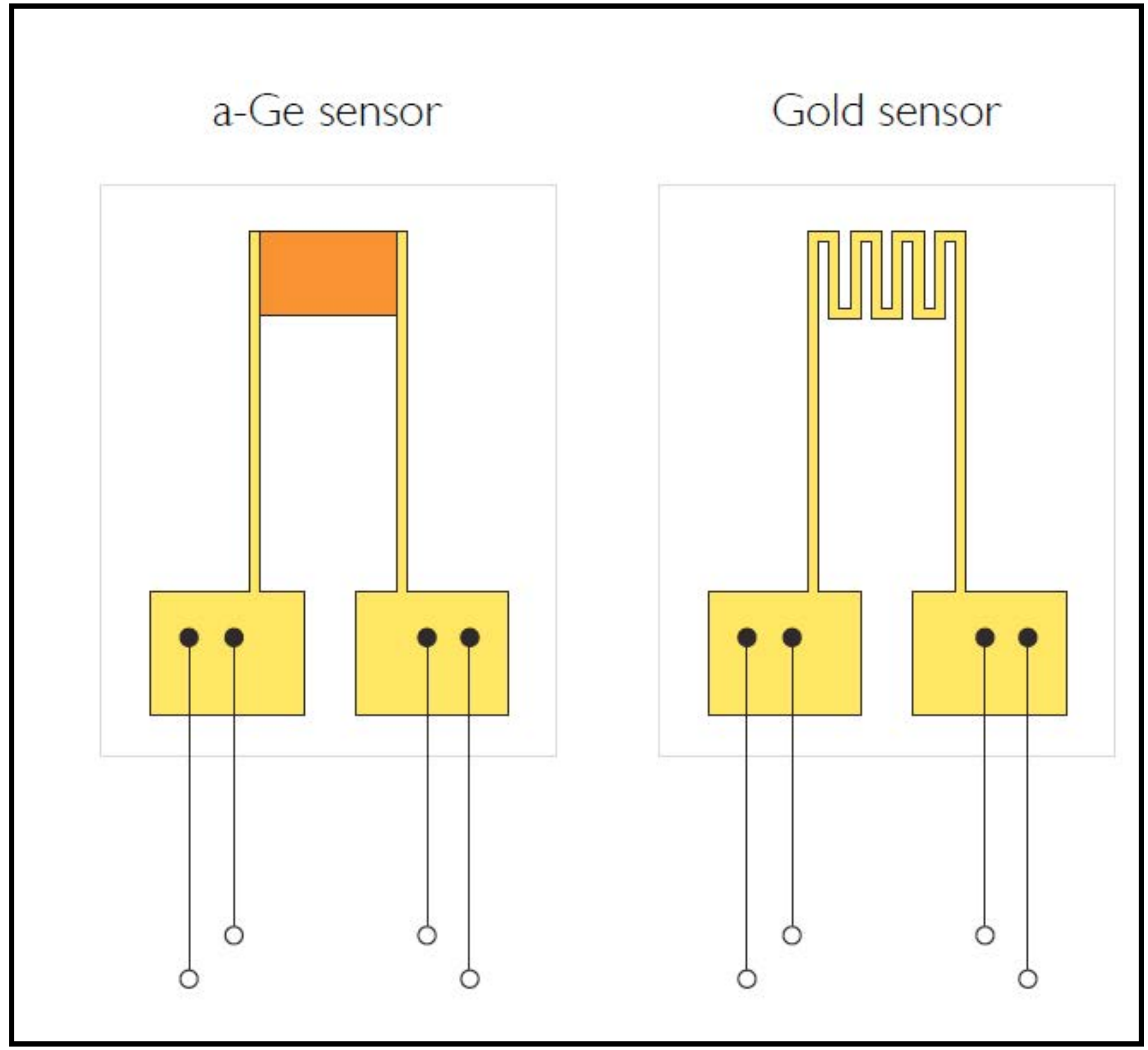




#	Material	Method	K (10^{-9} g/g)	^{232}Th (10^{-12} g/g)	^{238}U (10^{-12} g/g)
55	Parylene N dimer, Para Tech Coating Inc.	NAA	-	<50	<30
56	Parylene, Speciality Coating Systems™ Inc.	NAA	5800±1300	<850	<1700
57	Parylene C, dimer, Speciality Coating Systems™ Inc.	ICPMS	2110±15	390±30	6230±110
58	Parylene C, dimer pre cleaned, Spec. Coat. Sys. Inc.	ICPMS	<108	37±3	4230±60
59	Parylene C, infusion rod bump, Spec. Coat. Sys. Inc.	ICPMS	<320	250±60	46±20
60	Parylene C, inlet, Speciality Coating Systems™ Inc.	ICPMS	<430	140±30	83±24
61	Parylene C, table, Speciality Coating Systems™ Inc.	ICPMS	923±86	530±30	250±60

A cryogenic temperature sensor



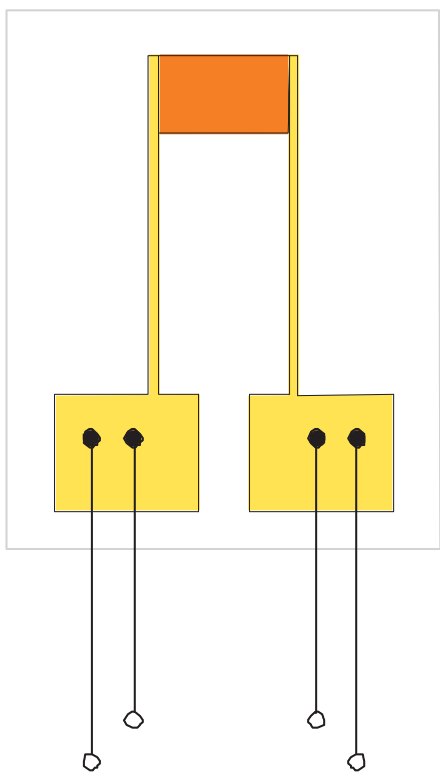


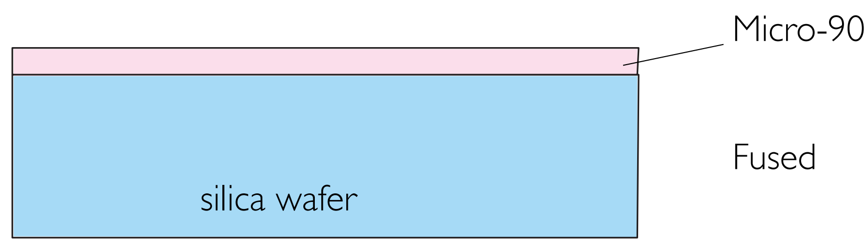
Designs

Details in arXiv:1508.05757

Design and fabrication

a-Ge sensor

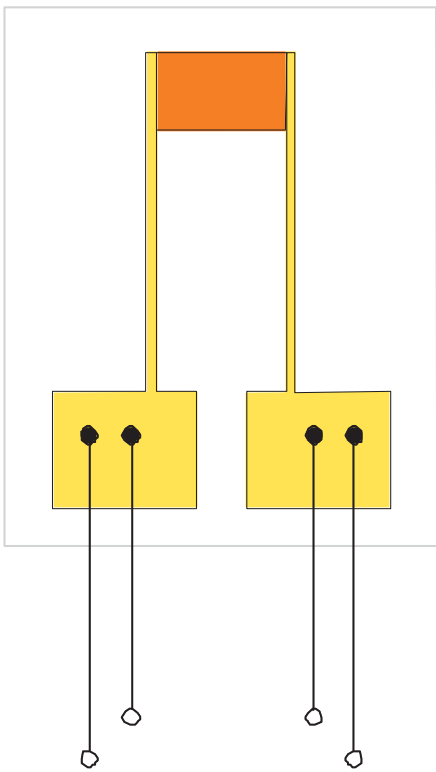


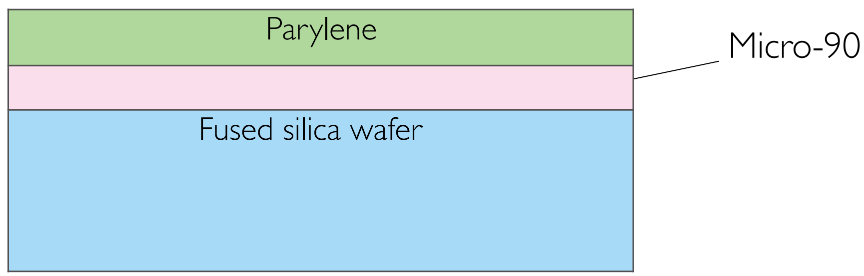


Optically-flat fused silica, coated with soap solution.

Design and fabrication

a-Ge sensor

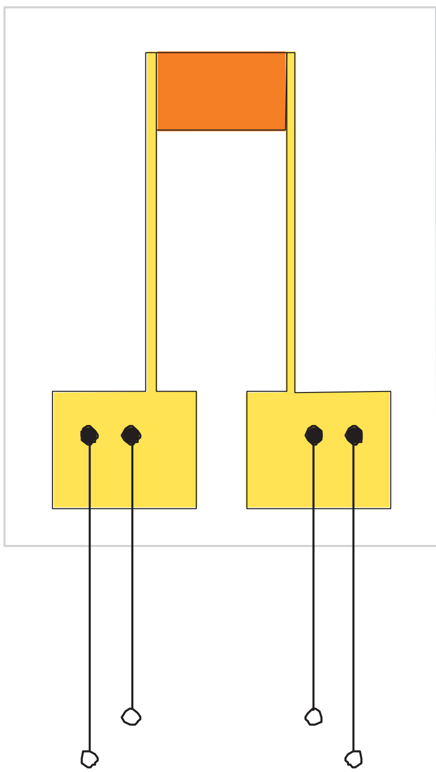


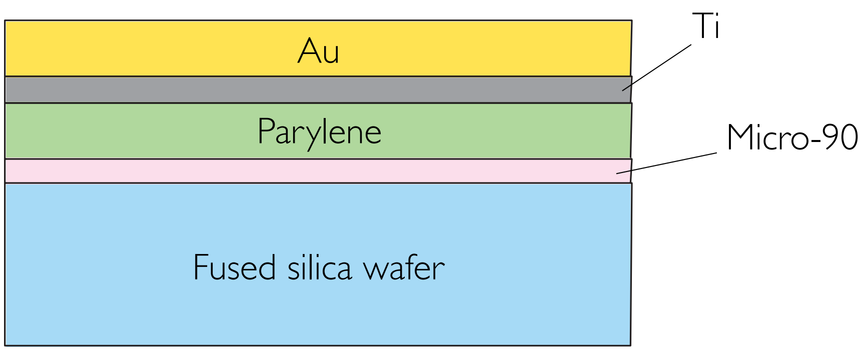


First parylene layer (0.25 mil)

Design and fabrication

a-Ge sensor

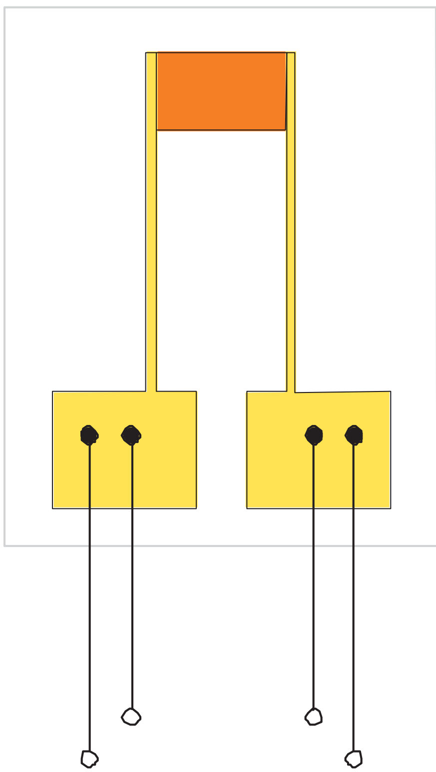


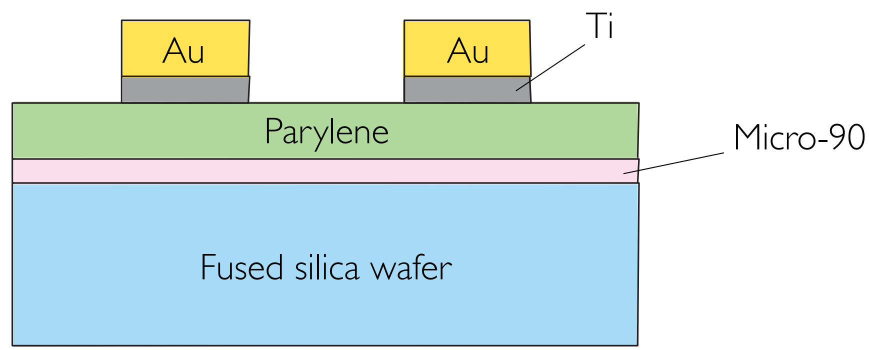


Sputtered titanium (150 nm) and gold (1 um)

Design and fabrication

a-Ge sensor

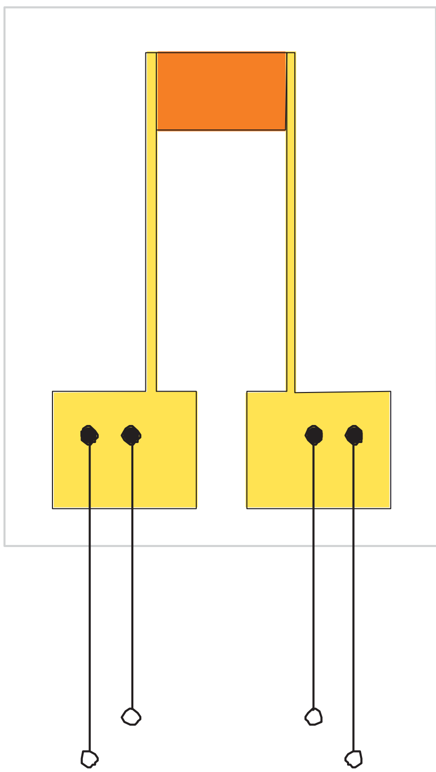


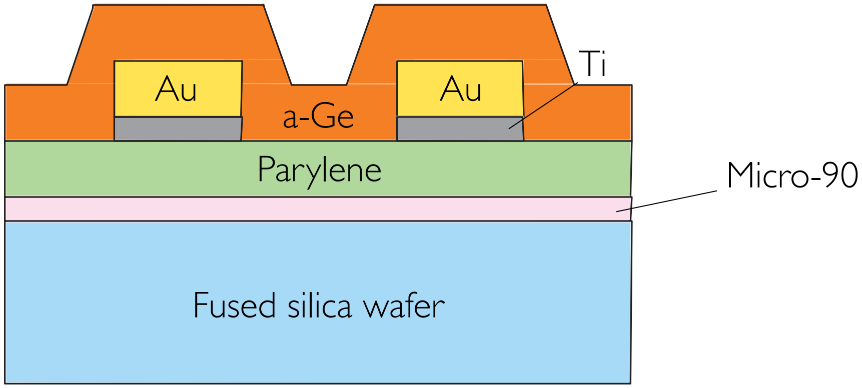


Photolithography (0.2 mil precision)

Design and fabrication

a-Ge sensor

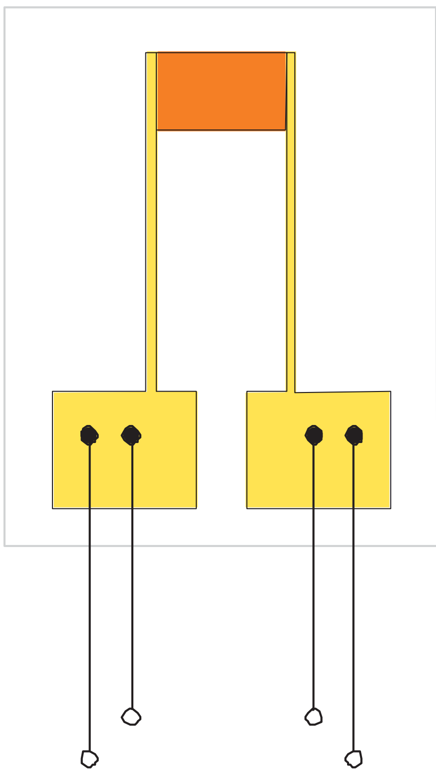


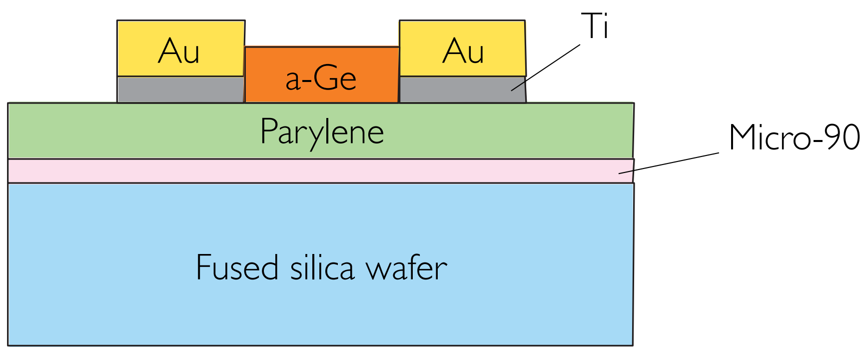


Sputtered germanium

Design and fabrication

a-Ge sensor

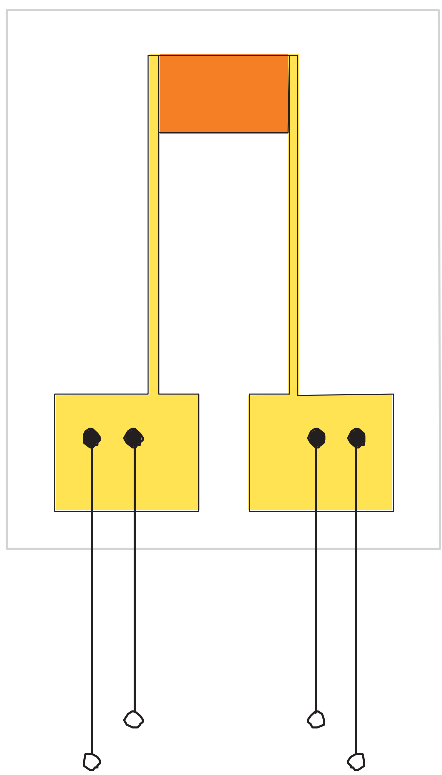


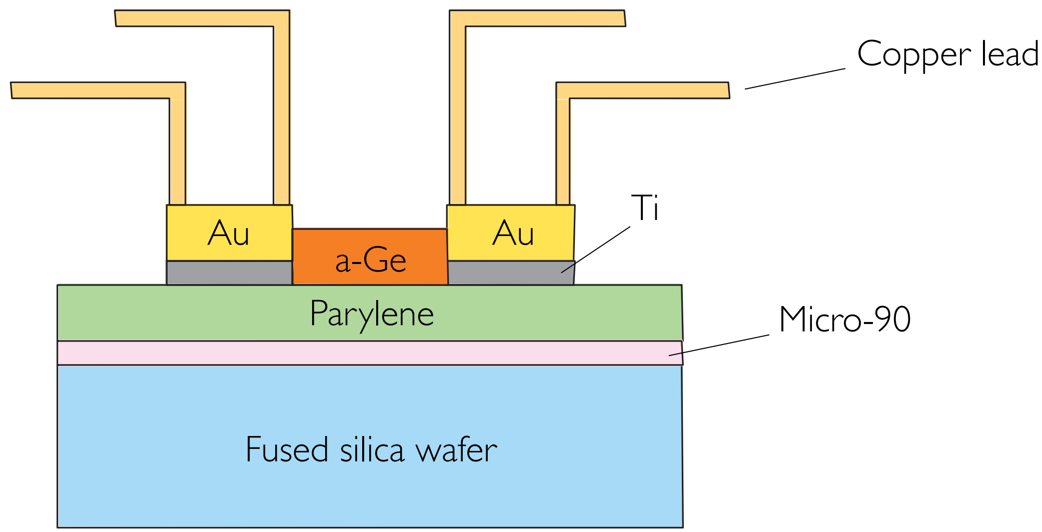


Photolithography

Design and fabrication

a-Ge sensor

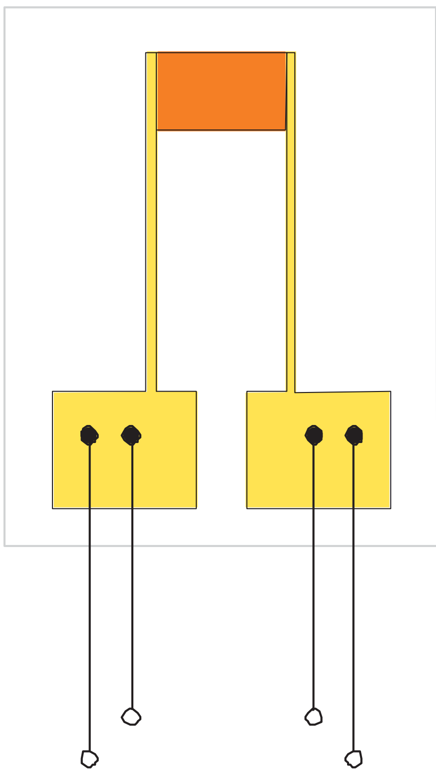


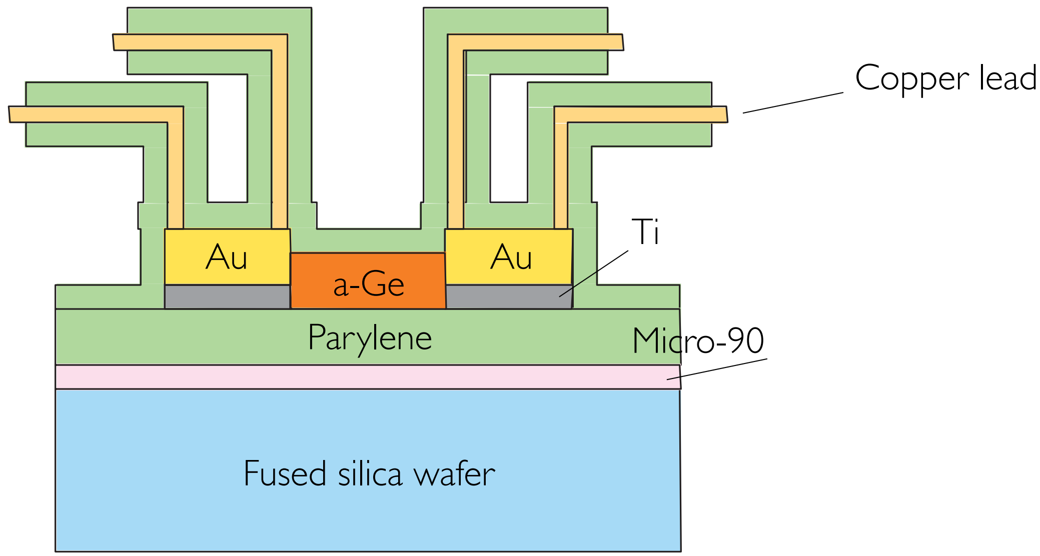


Wire-bond leads

Design and fabrication

a-Ge sensor

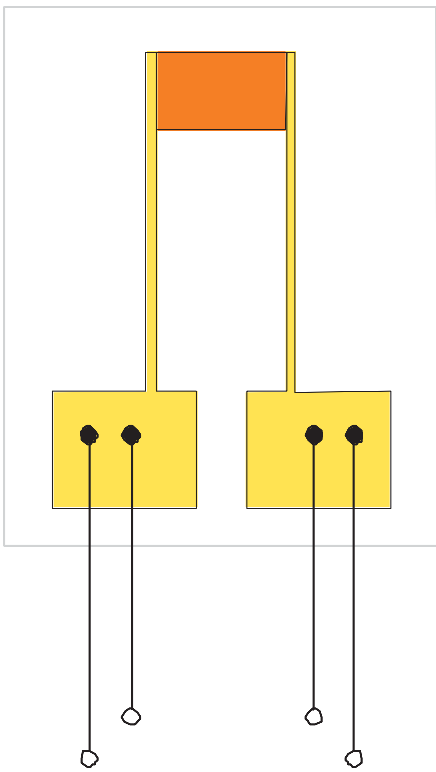


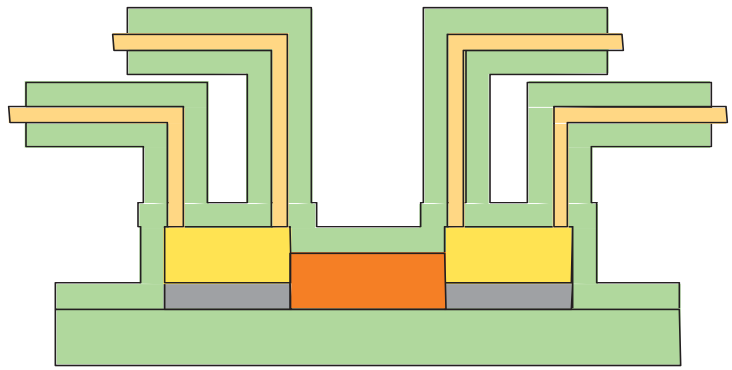


Second layer of parylene (0.25 mil)

Design and fabrication

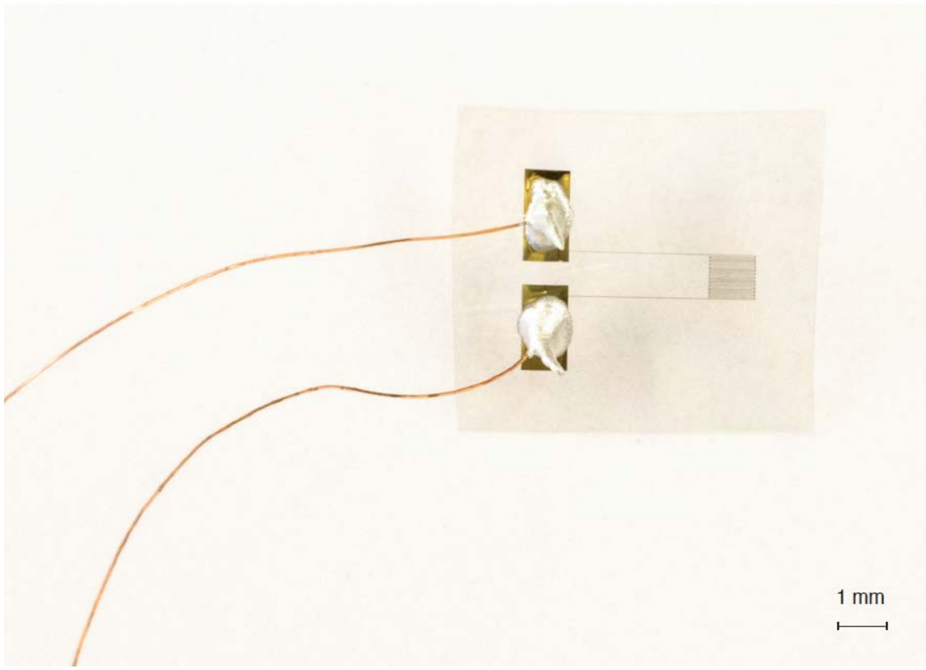
a-Ge sensor

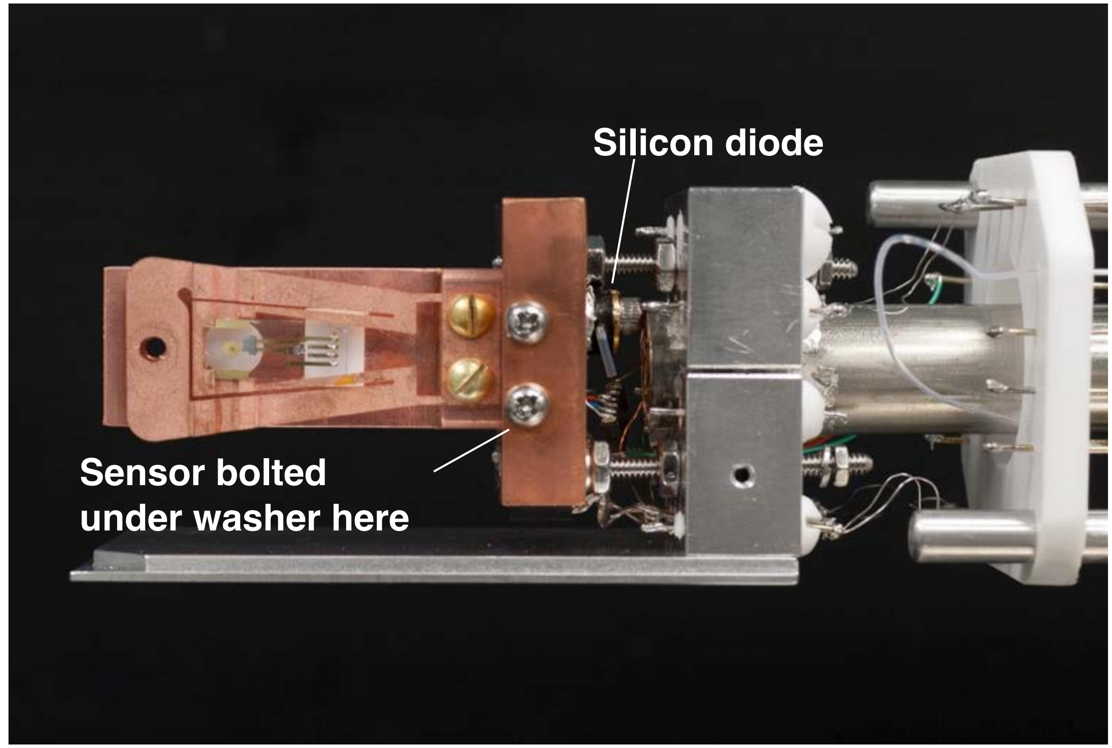




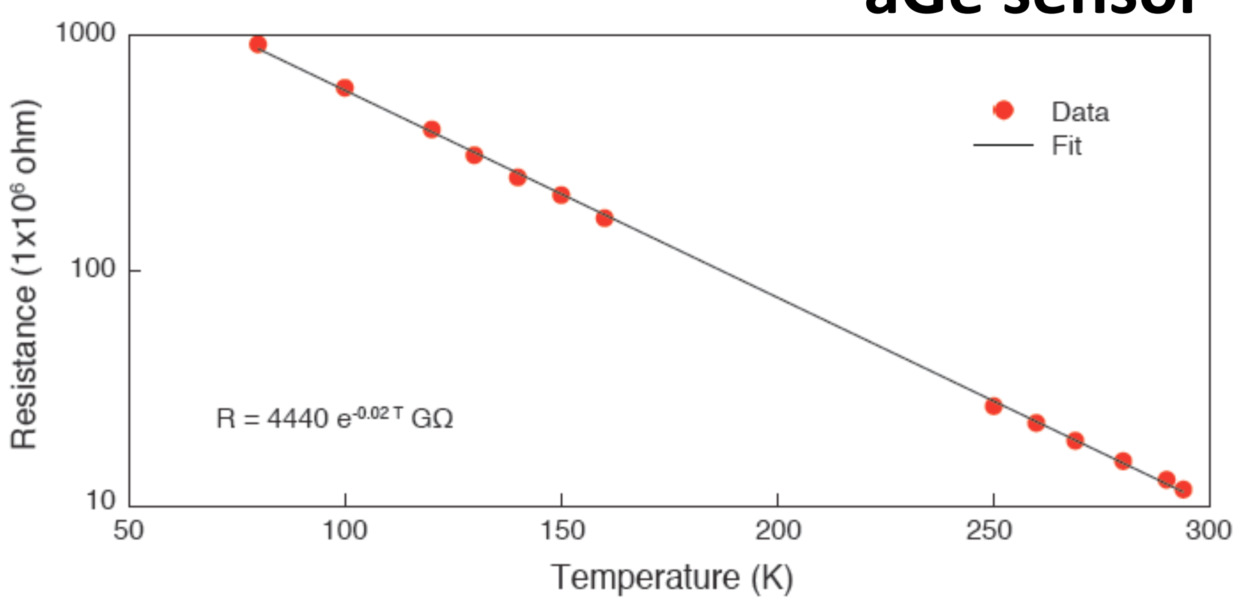
Peel off the substrate

Thermal testing





aGe sensor



Radiopurity

Total sensor mass was ~ 4 mg.

Item	Mass %	Conc. (ppb)		Activity (nBq)	
		Th-232	U-238	Th-232	U-238
		Au sensors			
Copper wire	32.0	< 0.087	< 0.040	< 0.431	< 0.608
Silver epoxy	12.2	< 0.079	< 0.011	< 0.150	< 0.064
Parylene C (sensor)	51.9	0.53(3)	0.25(6)	4.3(0.2)	6.2(1.5)
Parylene C (wires)	1.6	0.53(3)	0.25(6)	0.13(0.01)	0.19(0.05)
Micro-90	~ 0	< 1.5	< 0.6	~ 0	~ 0
Au traces	2.3	47.4(1.1)	2.0(0.4)	17.0(0.4)	2.2(0.4)
Ti traces	~ 0	< 0.4	< 0.1	~ 0	~ 0
Total	100.0			< 21.9	< 9.2
		a-Ge sensors			
Copper wire	32.3	< 0.087	< 0.040	< 0.431	< 0.608
Silver epoxy	12.4	< 0.079	< 0.011	< 0.150	< 0.064
Parylene C (sensor)	52.4	0.53(3)	0.25(6)	4.3(0.2)	6.2(1.5)
Parylene C (wires)	1.6	0.53(3)	0.25(6)	0.13(0.01)	0.19(0.05)
Micro-90	~ 0	< 1.5	< 0.6	~ 0	~ 0
Au traces	1.1	47.4(1.1)	2.0(0.4)	8.0(0.2)	1.0(0.2)
Ti traces	~ 0	< 0.4	< 0.1	~ 0	~ 0
Ge traces	0.2	2.4(0.7)	1.7(0.4)	0.08(0.02)	0.17(0.04)
Total	100.0			< 13.1	< 8.2

Other circuit components (concepts)

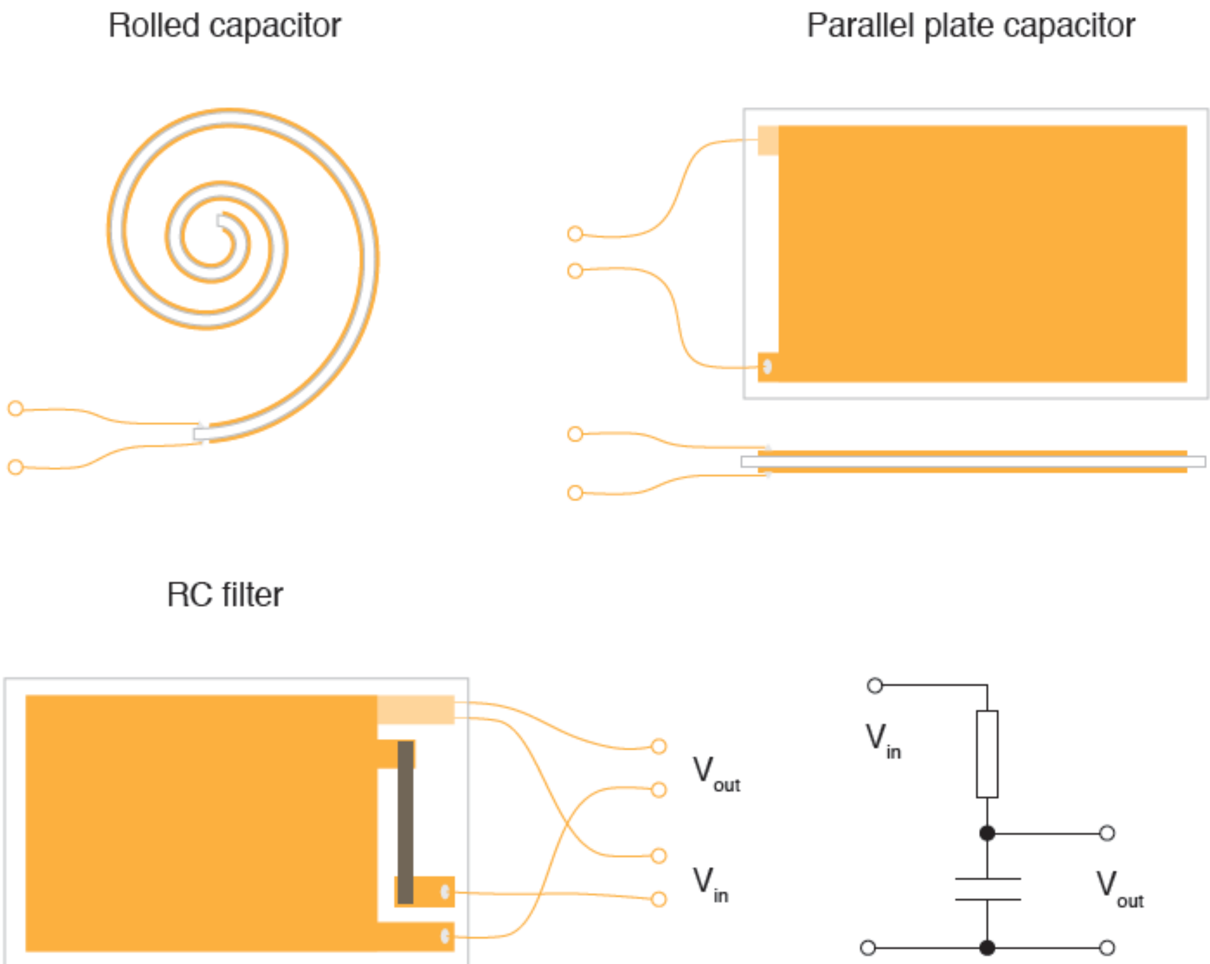
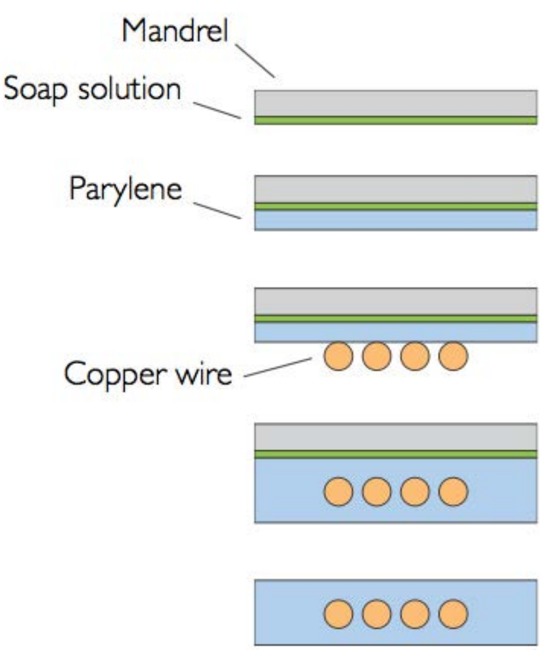


Figure 9: Designs for capacitors and an RC filter. For clarity these illustrations omit the outer, protective layer of parylene that could be applied to each circuit.

Can we make coaxial cables with parylene?

- MJD tried. Issues:
  - When the thickness of the parylene becomes thick (> ~5 mil), the "film" becomes more rigid. Whiskers begins to form.
  - Hard to do a good ground shield for surface that becomes non-uniform (from cutting the whiskers)



A prototype:
wrapped Cu foil;
heat shrink outside

Summary

- The next-generation underground rare-event search experiments demand ultrapure targets, and electronics and associated components.
- Painstaking sourcing and assaying of materials are necessary to meet the stringent radiopurity goals.
- Assays and special handling can add substantial cost and time to project.

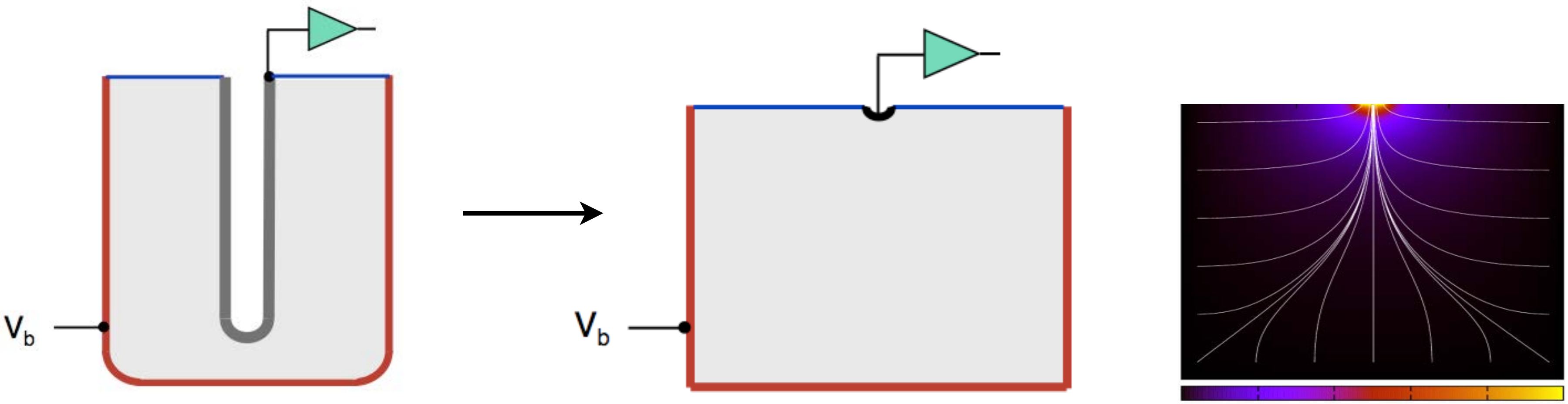
The End

Conversion factors

1 μBq/kg	^{238}U	8.1 x 10^{-14} g/g
	^{232}Th	2.46 x 10^{-13} g/g
	^{40}K	3.23 x 10^{-11} g/g ^{nat}K

Detector choice

- Both GERDA and MJD use p-type point-contact detectors



~20 pF

~1 pF

Weighting Potential

- Low capacitance: low noise possible
- p-type: easier handling in assembly
- “minimal” number of contacts: reduced component count
- Two commercial manufacturers can deliver P-PC detectors
- No timing / event position info

IEEE Trans. Nucl. Sci, 36, 926 (1989)
JCAP , 9, 9 (2007)