Low Background Signal Electronics for the MAJORANA DEMONSTRATOR

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The MAJORANA Collaboration

Low Radioactivity Techniques

March 18, 2015

UNIVERSITY of WASHINGTON

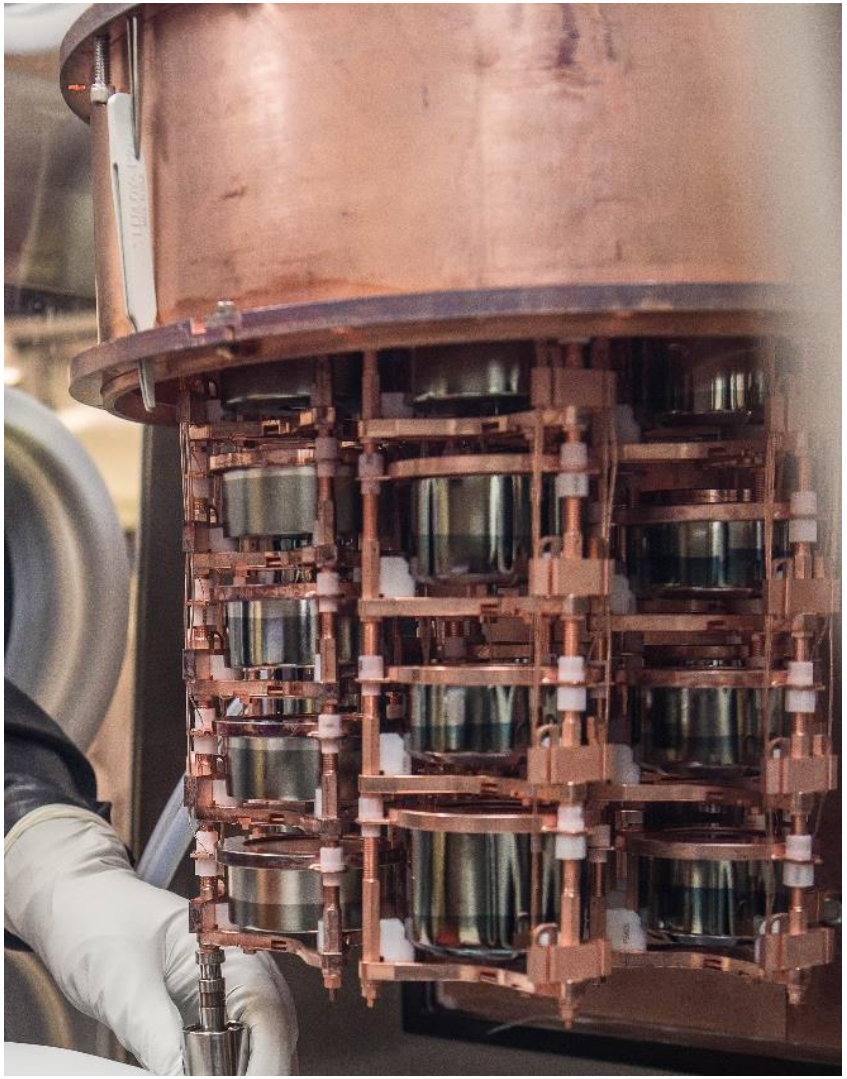
U.S. DEPARTMENT OF ENERGY | Office of Science

Office of Nuclear Physics

NSF

Outline

- The MAJORANA DEMONSTRATOR
  - Estimation of backgrounds
- Signal Electronics
  - Requirements
  - Front end boards
  - Signal Cables
- Signal Connectors
  - Original design
  - New Designs

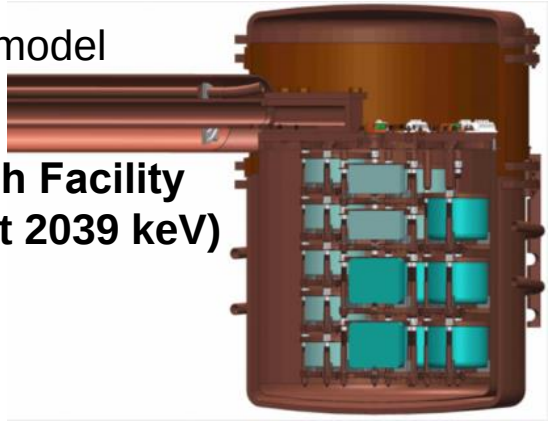


MJD Overview

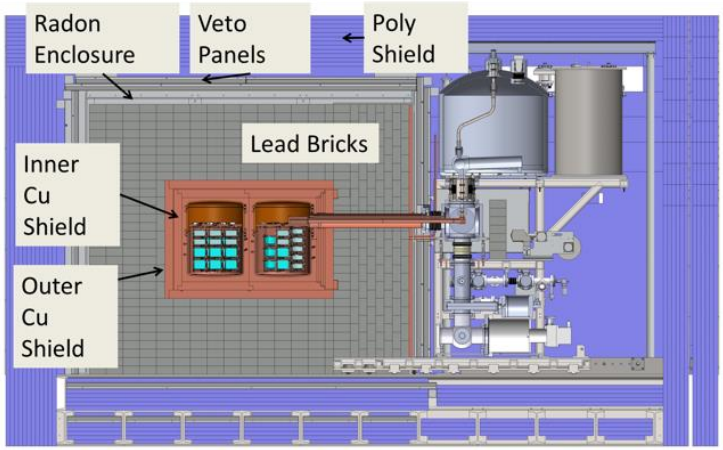
Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

Goals:

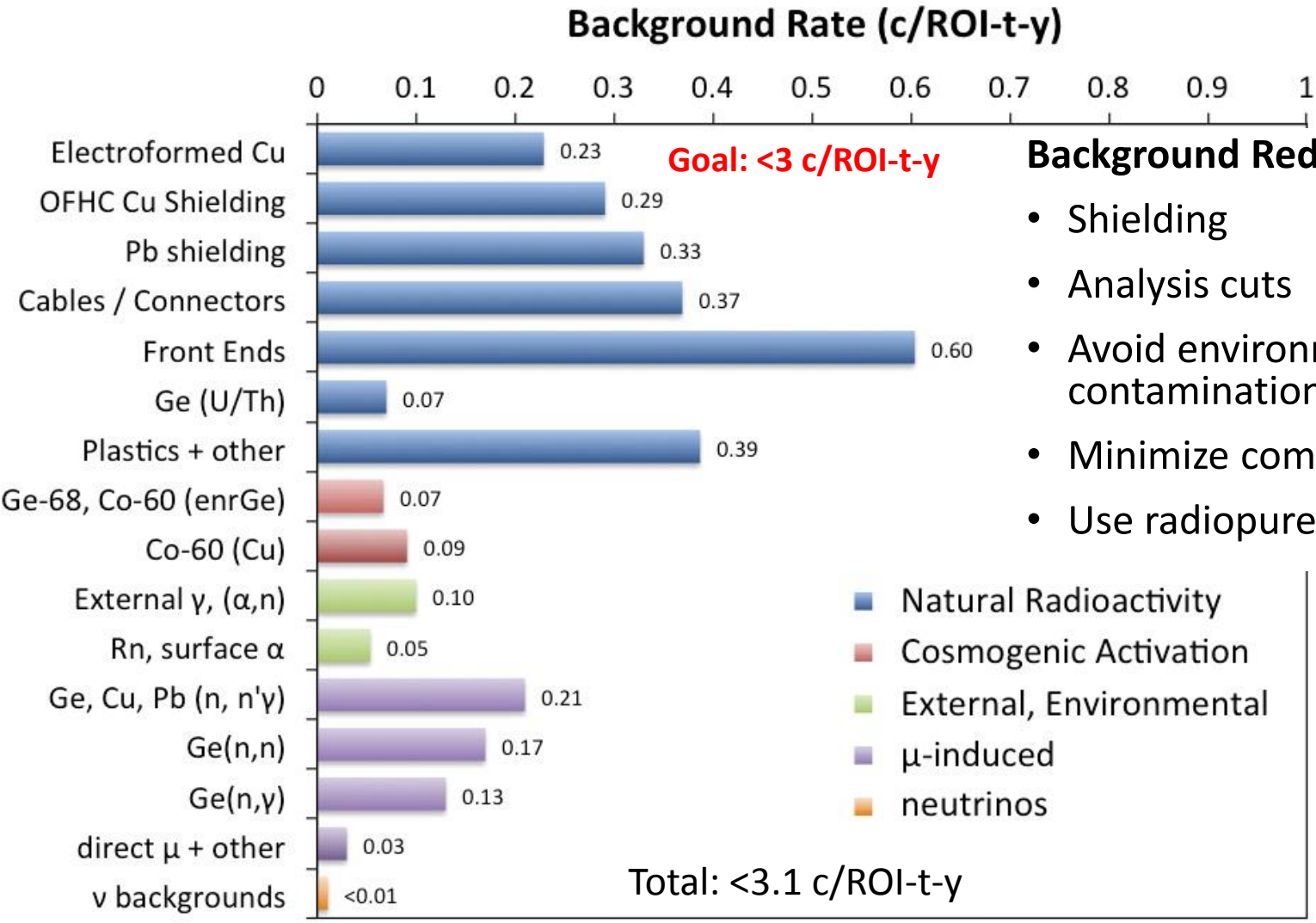
- Demonstrate backgrounds low enough to justify building a ton-scale ^{76}Ge experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Searches for additional physics beyond the standard model



- **Located underground at 4850' Sanford Underground Research Facility**
- **Background Goal in the 0νββ peak region of interest (4 keV at 2039 keV)**
  3 counts/ROI/t/y (after analysis cuts)
  scales to 1 count/ROI/t/y for a ton-scale experiment
- **40-kg of Ge detectors**
  - 30-kg of 87% enriched ^{76}Ge crystals & 10-kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.
- **2 independent cryostats**
  - ultra-clean, electroformed Cu
  - 20 kg of detectors per cryostat
  - naturally scalable
- **Compact Shield**
  - low-background passive Cu and Pb shield with active muon veto



Background - Summary



Background Reduction Strategies

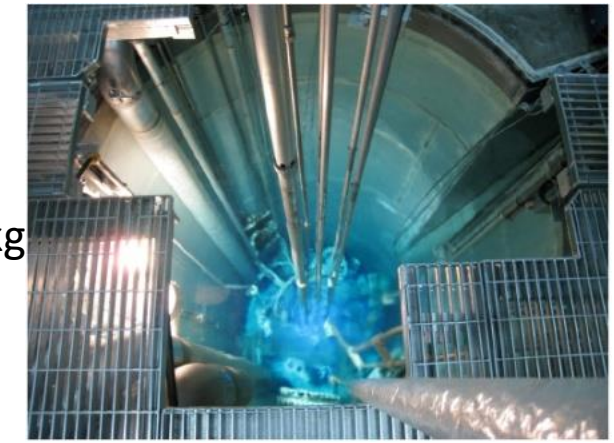
- Shielding
- Analysis cuts
- Avoid environmental contamination/cosmogenics
- Minimize component mass
- Use radiopure materials

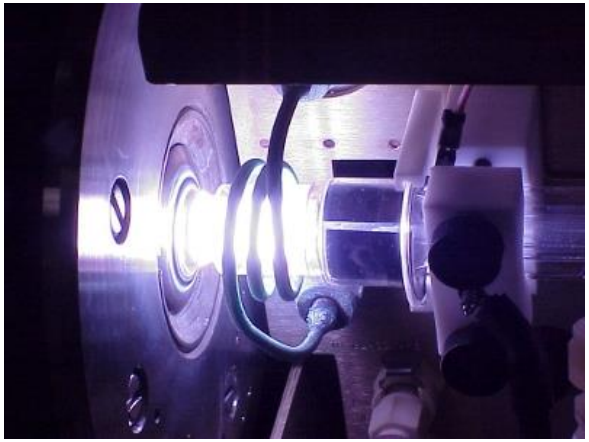
Background Estimation

Perform radioassay of all materials that will go inside of shielding

γ-counting:
Sensitivity ~mBq/kg

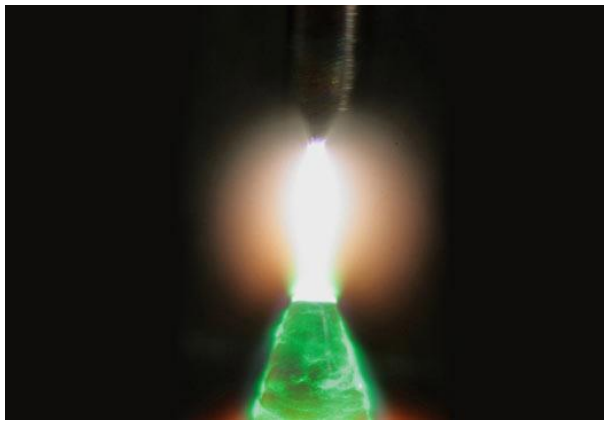
Neutron Activation Analysis (NAA): Sensitivity ~0.1 μBq/kg



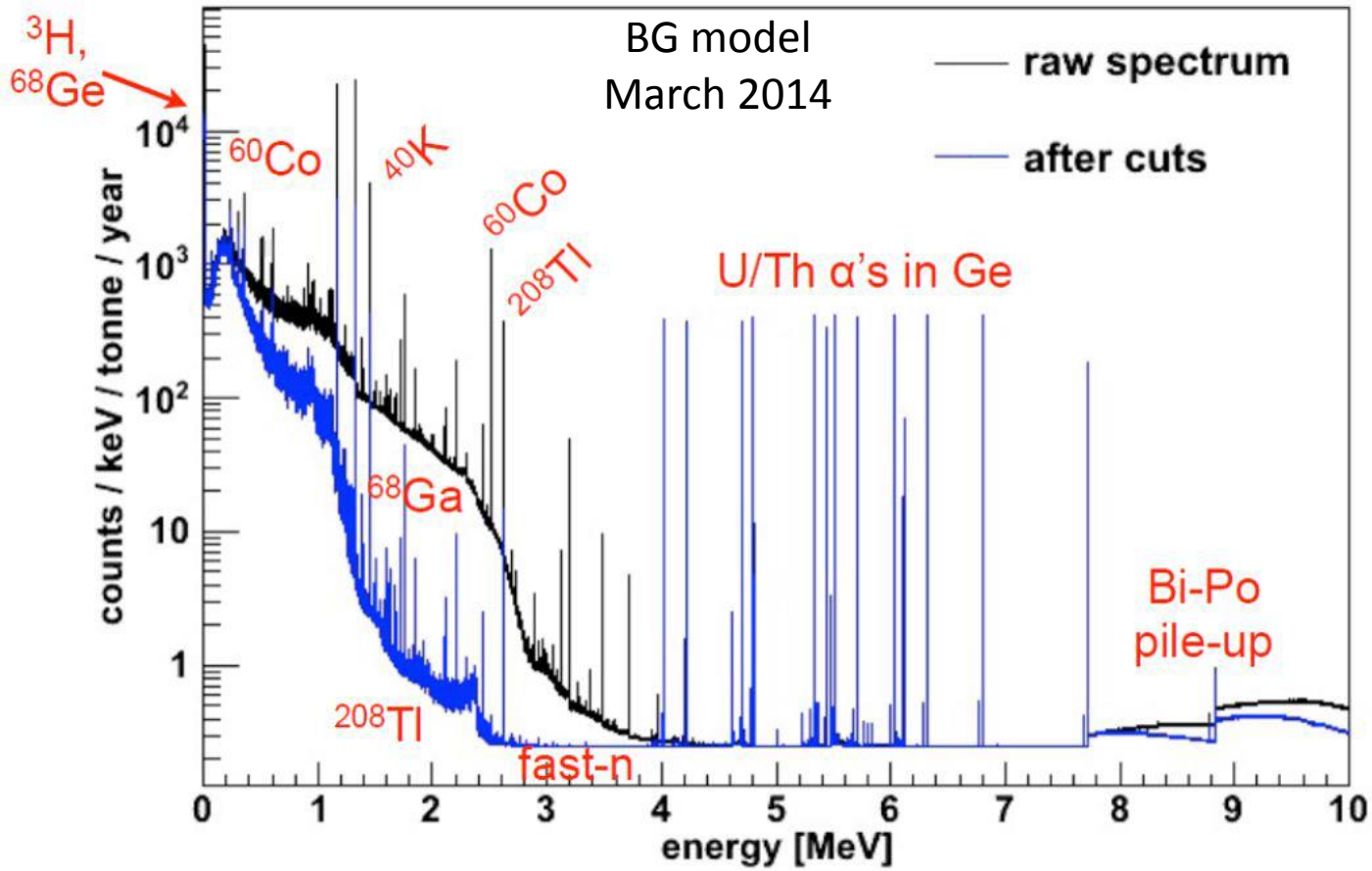


Inductively Coupled Plasma Mass Spectrometry (ICP-MS):
Sensitivity ~0.1 μBq/kg

Glow Discharge Mass Spectrometry (GDMS):
Sensitivity ~0.1 μBq/kg

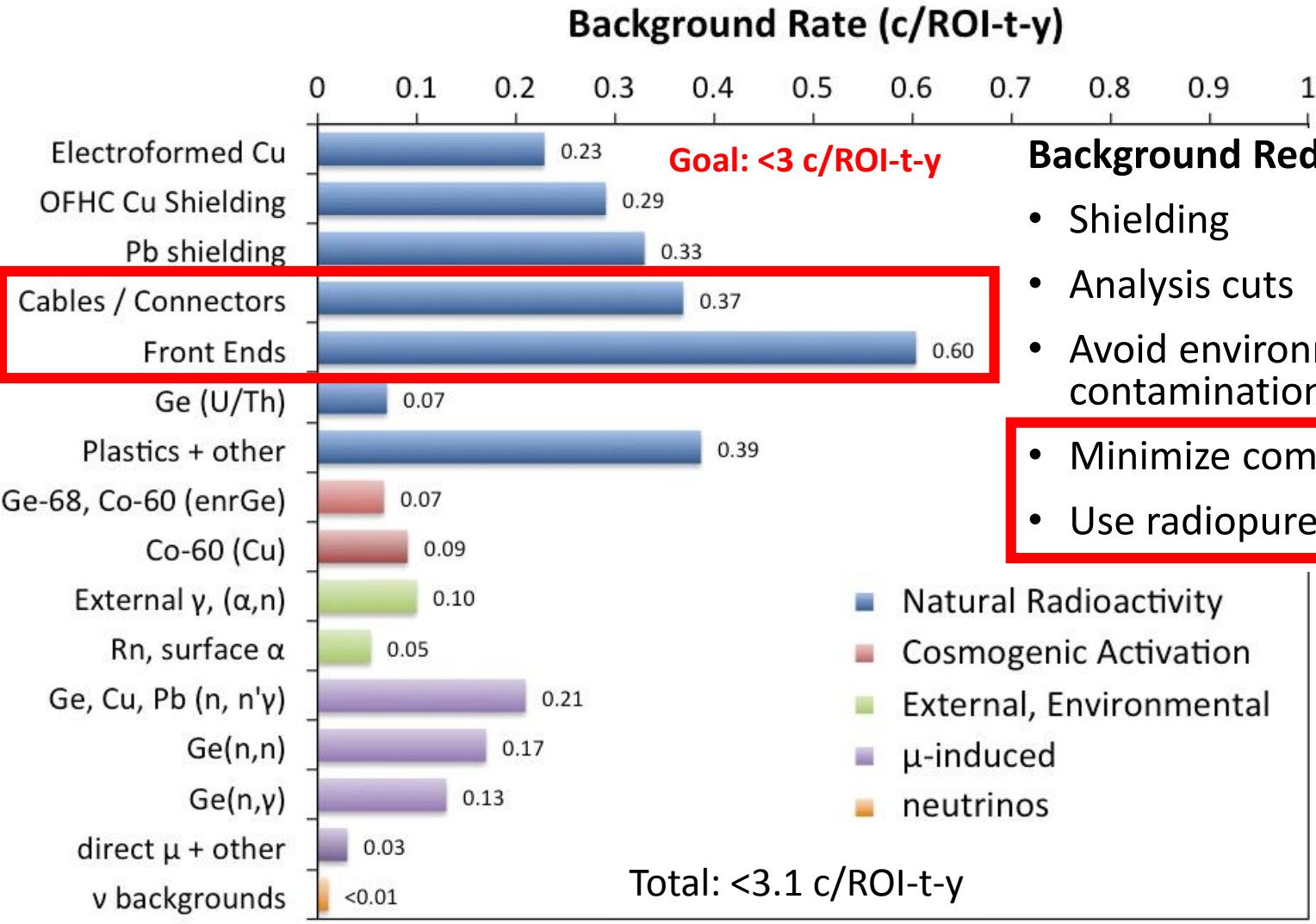


Background Estimation



Detailed model of geometry in Geant4 is used to estimate background detection efficiency for each component.

Background - Summary



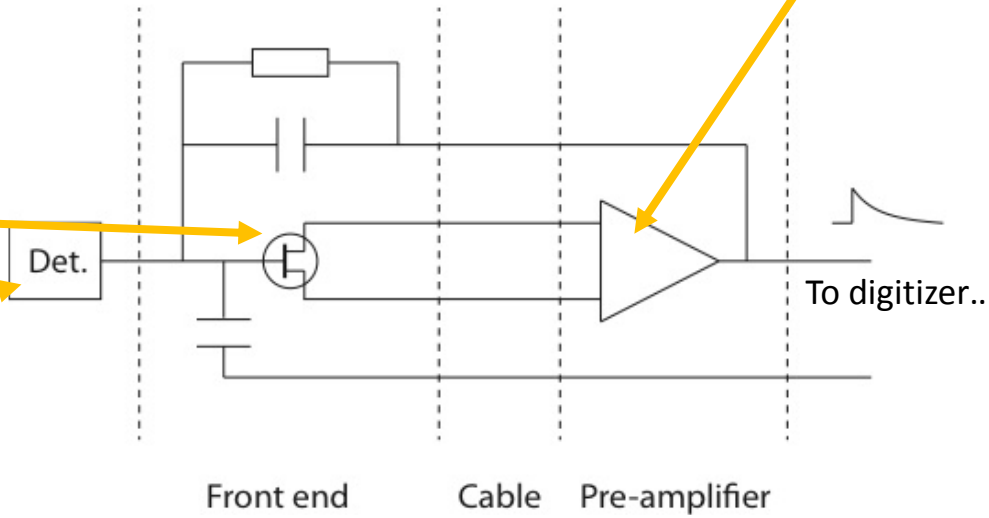
Background Reduction Strategies

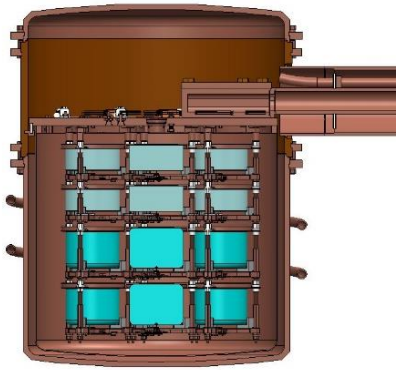
- Shielding
- Analysis cuts
- Avoid environmental contamination/cosmogenics
- Minimize component mass
- Use radiopure materials

Signal Electronics

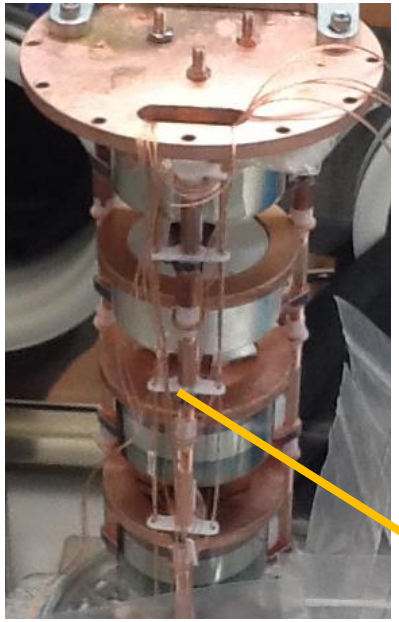
Charge Sensitive Amplifier

Stages separated by ~1.5 m of cable

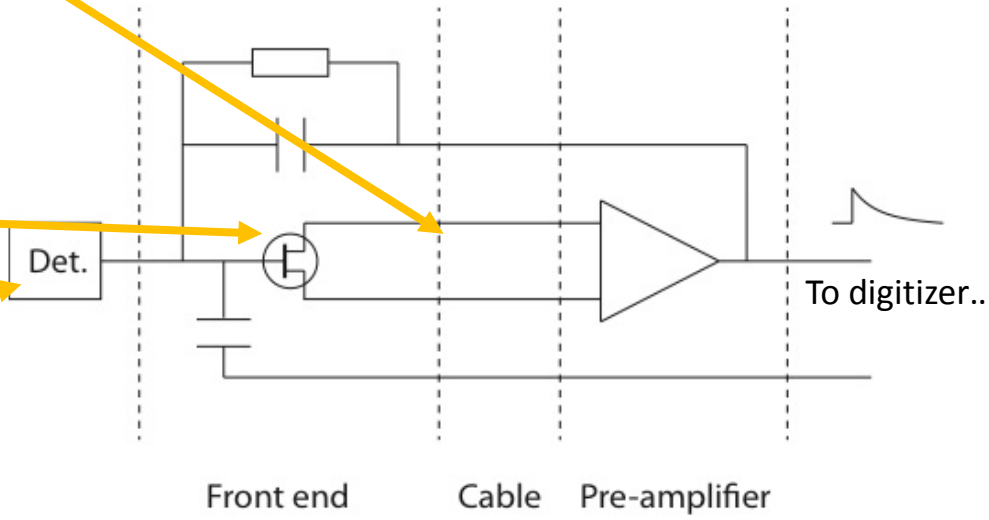


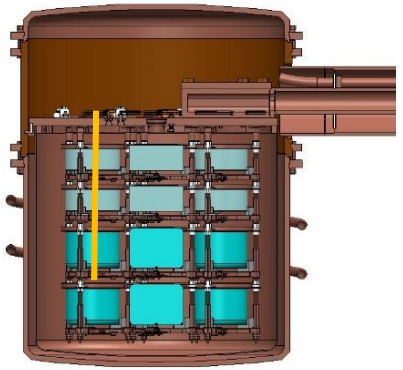


Signal Electronics

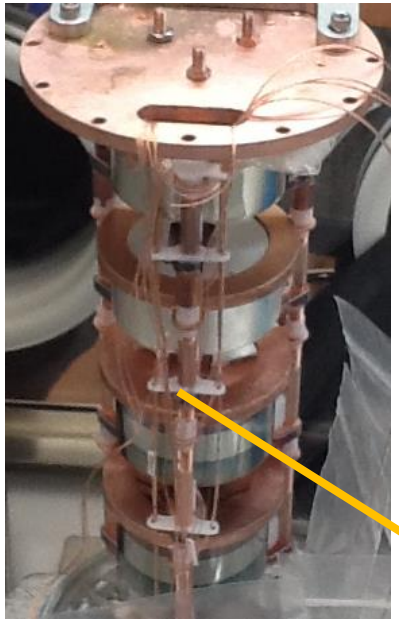


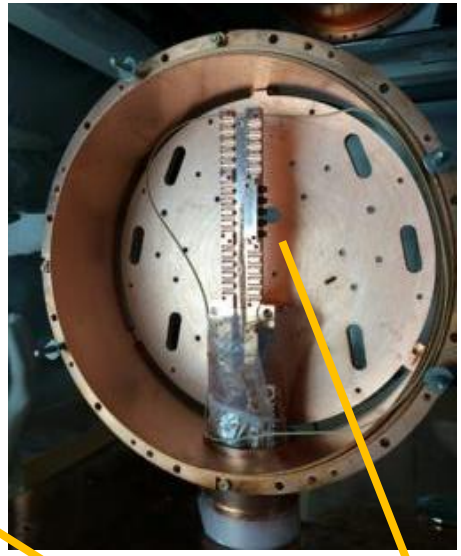
Pulse travels up signal cables along string…



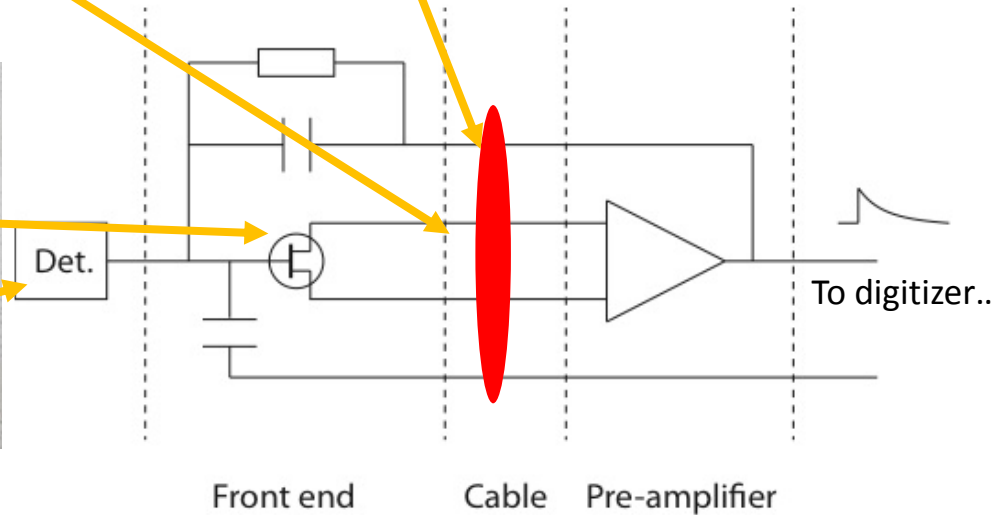


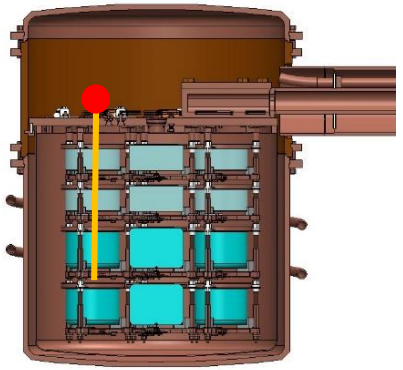
Signal Electronics



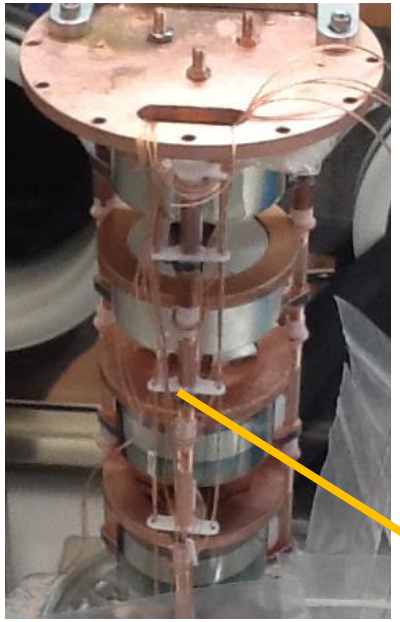


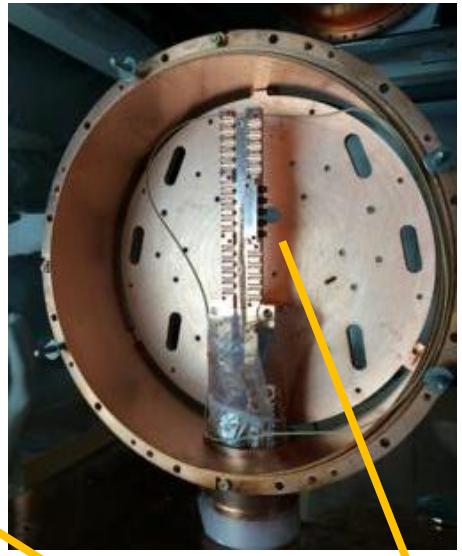
…through signal connectors above cold plate…

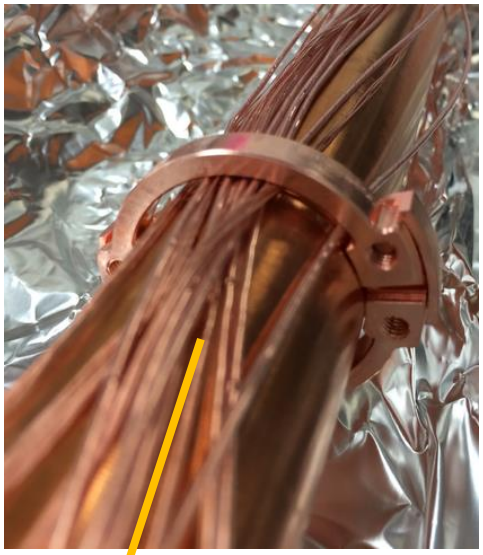




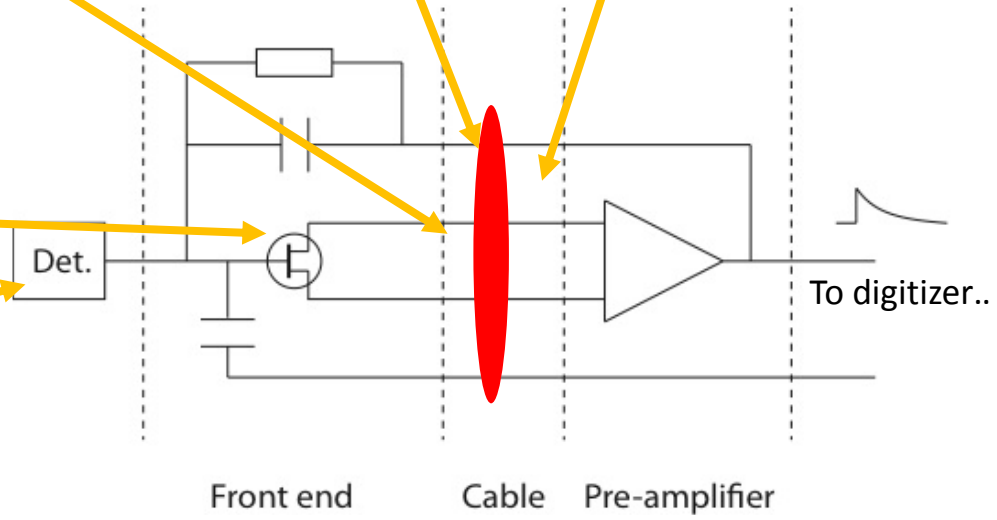
Signal Electronics

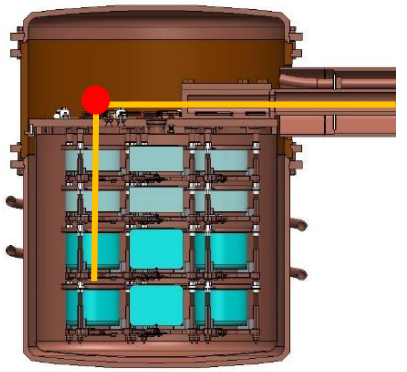




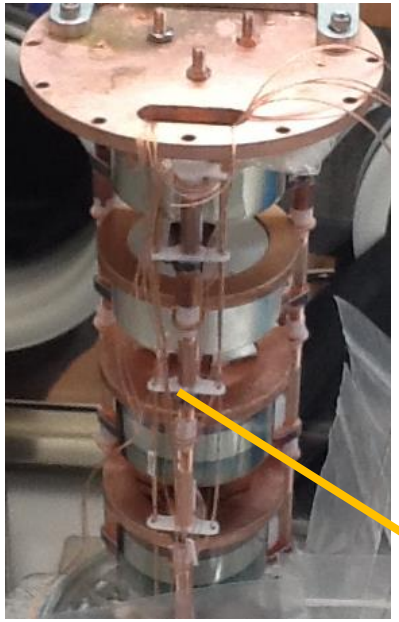


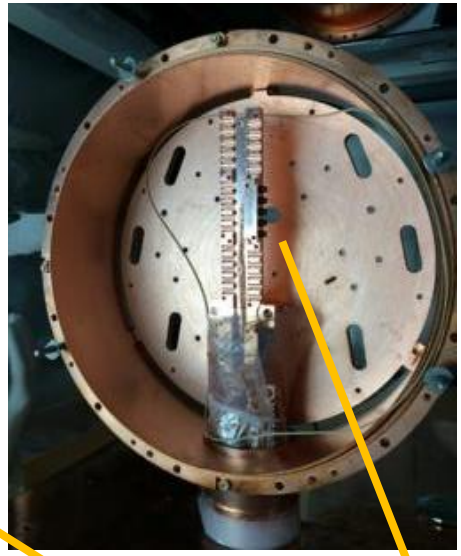
…along thermosyphon crossarm…

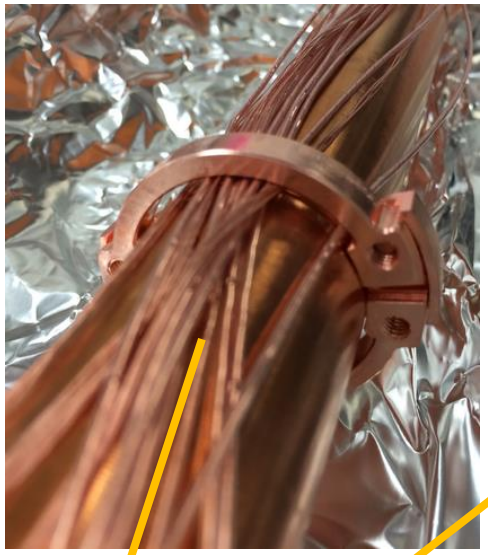


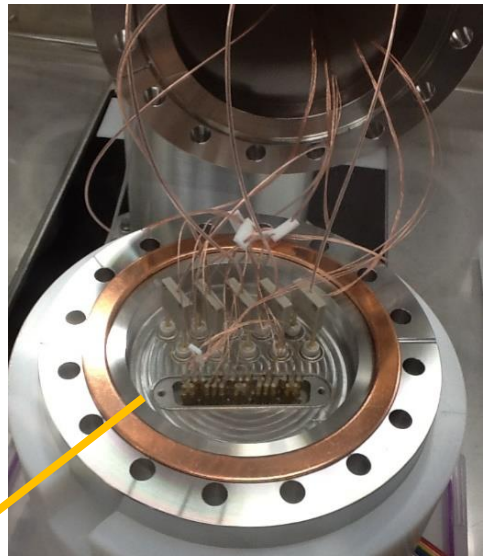


Signal Electronics

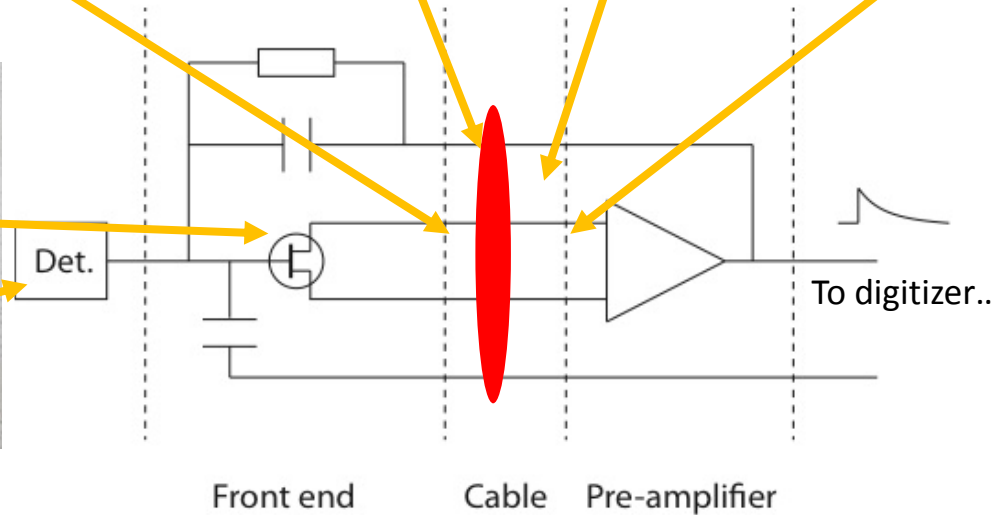


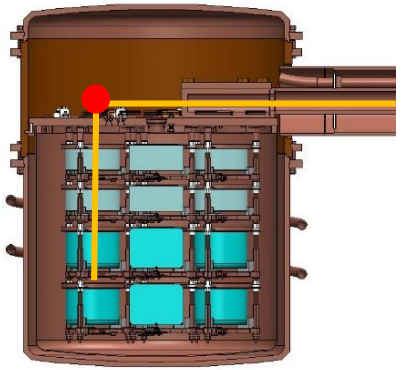






…and out of cryostat

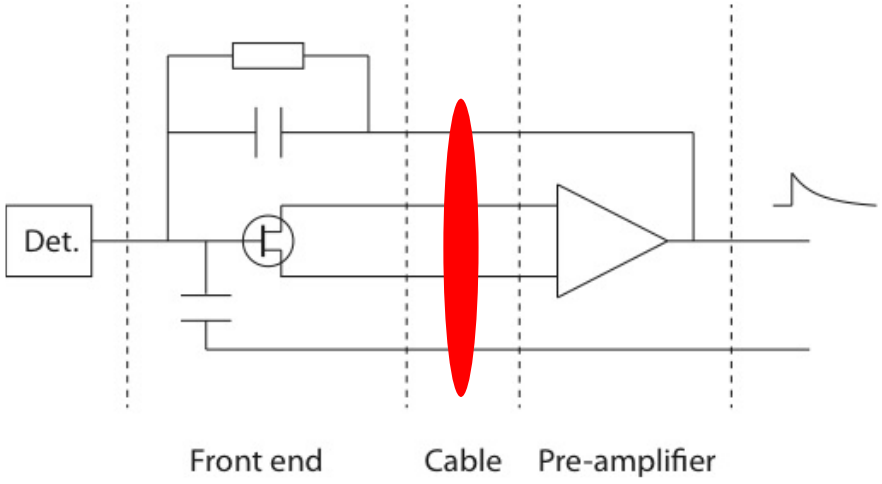


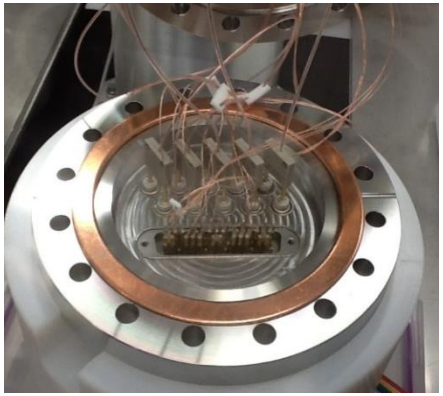


Signal Electronics

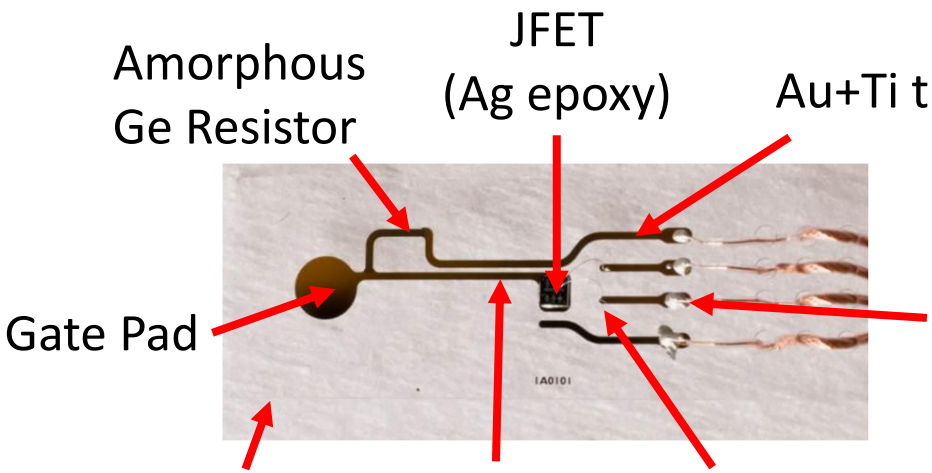
Requirements

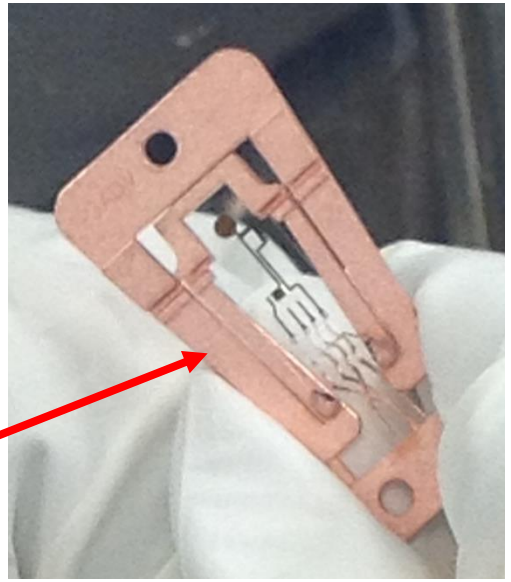
- 1 channel for each detector
- 4 cables for each channel
- Low background materials
- Low mass
- Low noise
- Easy to manipulate in glove box
- Robust under vacuum and thermal cycling to LN temperature

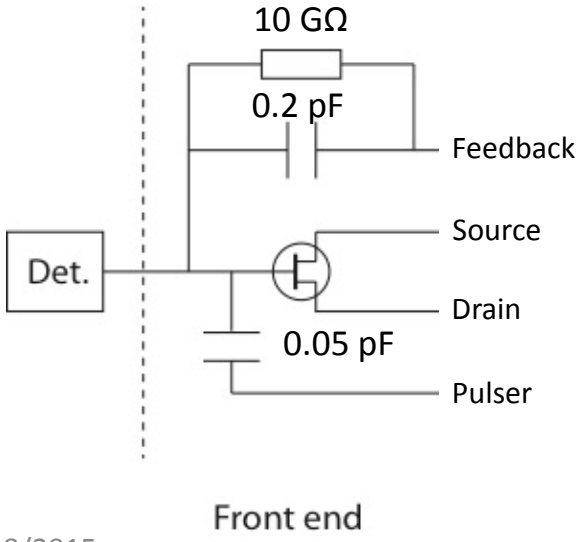


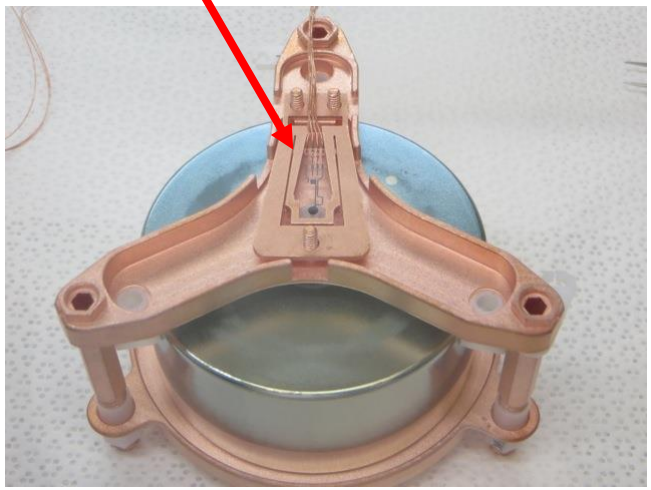


Low Mass Front End (LMFE)









Low Mass Front End (LMFE)

U+Th activity from totaling components:

- **715 nBq/frontend**
- **0.27 cts/ROI/t/y**

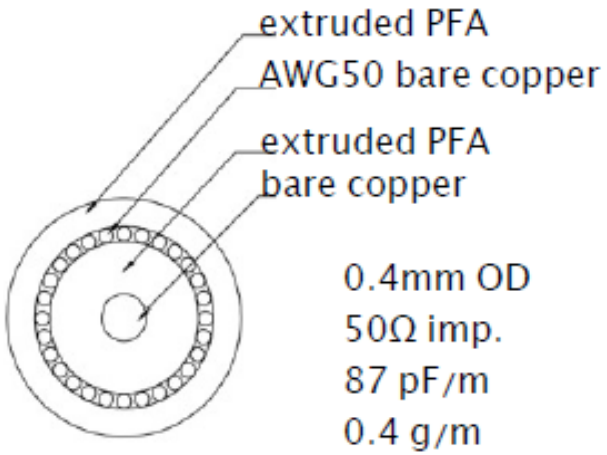
Material	Assay Method	Isotope	purity [pg/g]	MJD BG [c/ROI/t/y]
Fused Silica	ICP-MS	^{238}U	284	0.0616
		^{232}Th	101	0.0259
aGe	ICP-MS	^{238}U	5000	0.0001
		^{232}Th	5000	0.0001
Au	ICP-MS	^{238}U	2000	0.0015
		^{232}Th	47000	0.0421
Ti	ICP-MS	^{238}U	<100	~0
		^{232}Th	<400	~0
FET die	ICP-MS	^{238}U	<141	<0.0006
		^{232}Th	<2000	<0.0107
Al	ICP-MS	^{238}U	91000	0.0004
		^{232}Th	9.0	~0
Ag epoxy	γ-counting	^{238}U	<10000	<0.0082
		^{232}Th	<70000	<0.0685
EFCu Spring Clip	ICP-MS	^{238}U	<0.015	0.0005
		^{232}Th	<0.014	0.0003

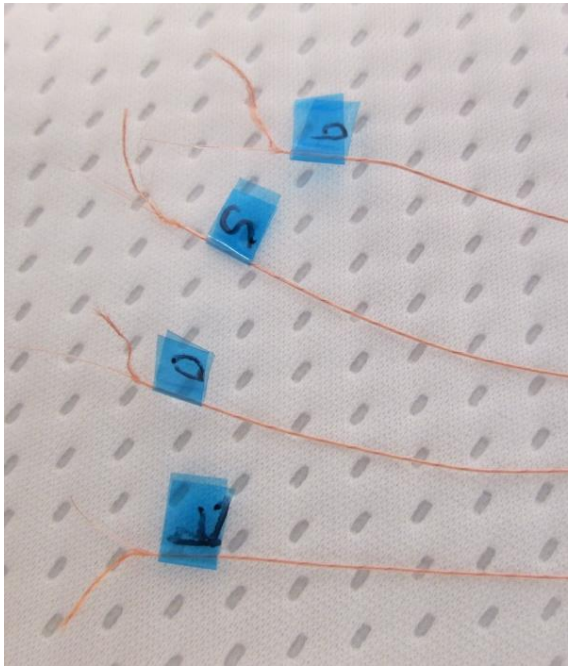
ICP-MS of the full LMFE yields slightly higher U+Th backgrounds of

- **1590 nBq/frontend**
- **0.6 cts/ROI/t/y**

Signal Cables

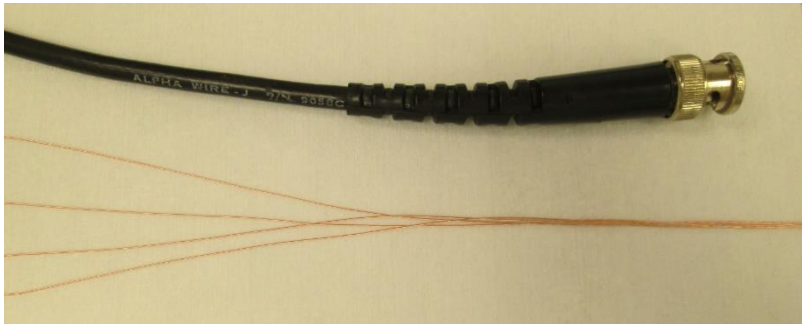
Axon Picocoax® Cables





Bundles of 4

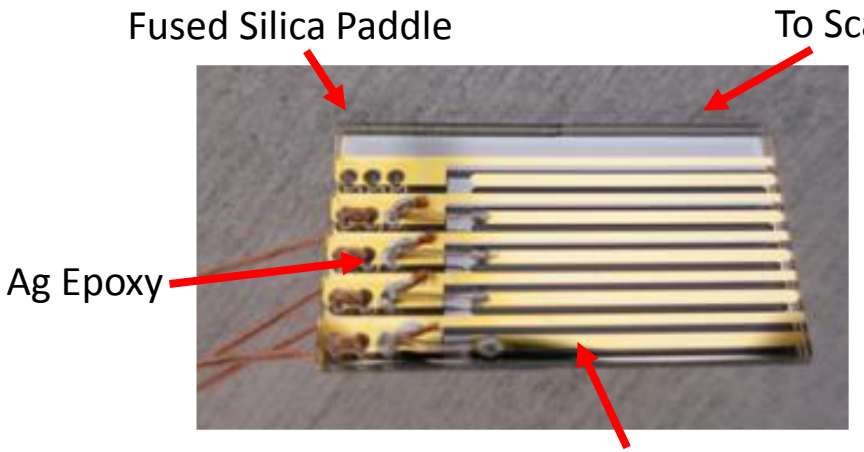
U and Th backgrounds from ICP-MS
59 nBq/m
0.085 cts/ROI/t/y



Signal Connectors

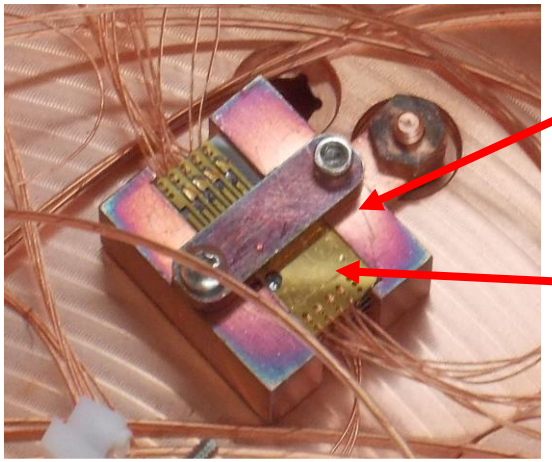
Challenge: Most connectors use BeCu springs. BeCu is too radioactive for MJD!

Original Design: "Paddle Garage"



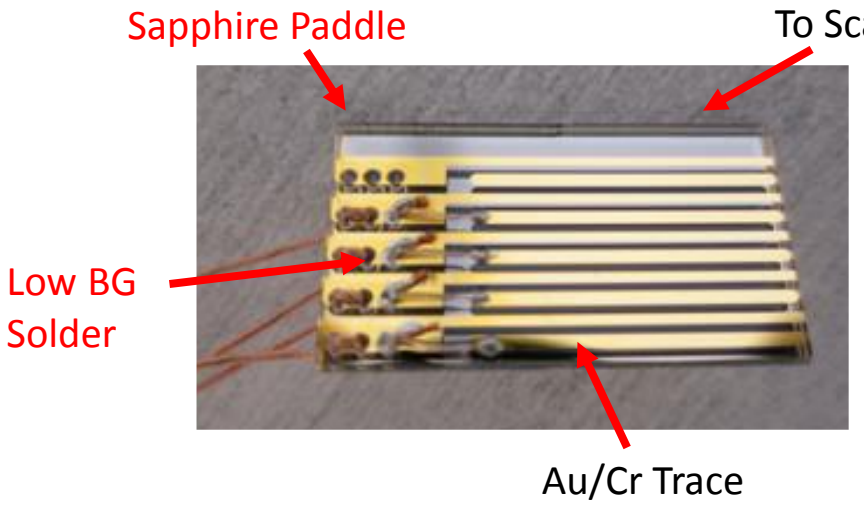
Problems:

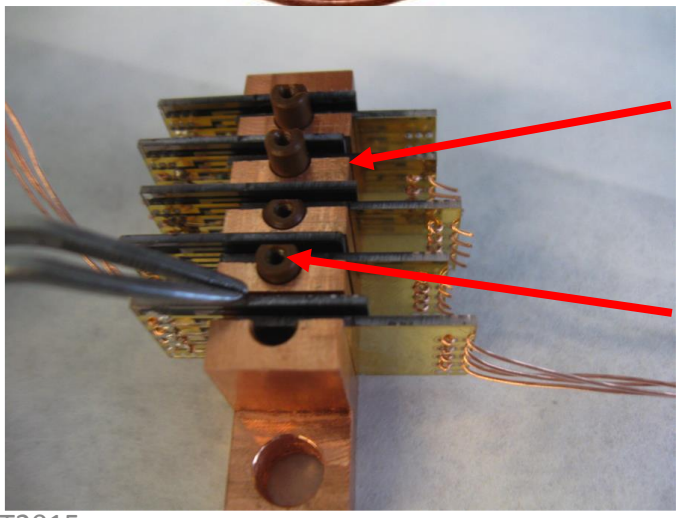
- Difficult to assemble
- Cannot disconnect a single detector
- Ag Epoxy fails
- Paddles break easily



Signal Connectors

Attempted Redesign: Paddle Comb



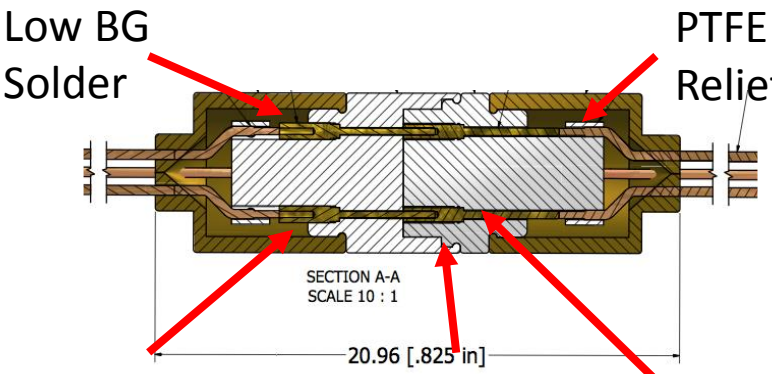


Easier to manipulate, but…

- Sapphire paddles still broke
- Sapphire was not flat -> flaky

Plug Design

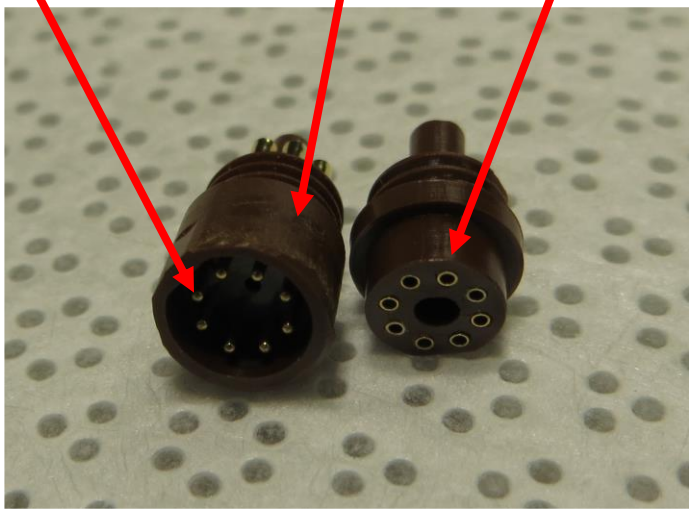
Contact force from Spring action of misaligned pins

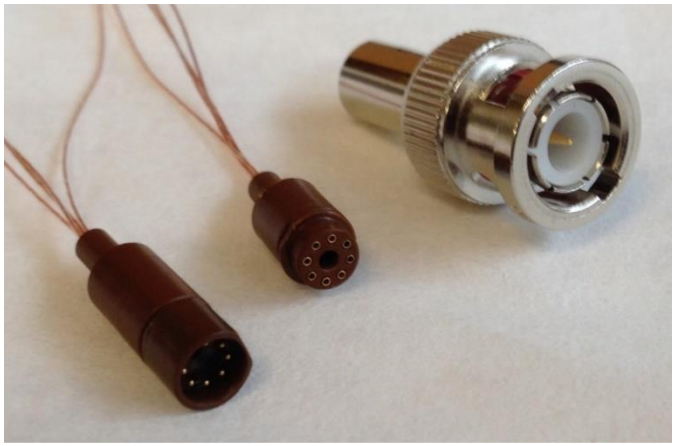


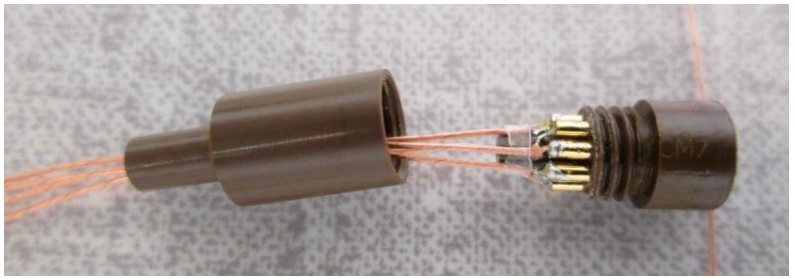
Mill-Max® Pins with springs removed

Vespel Housing

Sockets







Problems

- High Precision machining -> some pairings fail

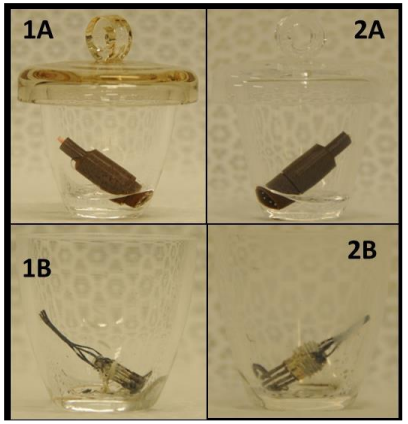
Assay Limits

U and Th backgrounds from full body ICP-MS:

1521 nBq/connector

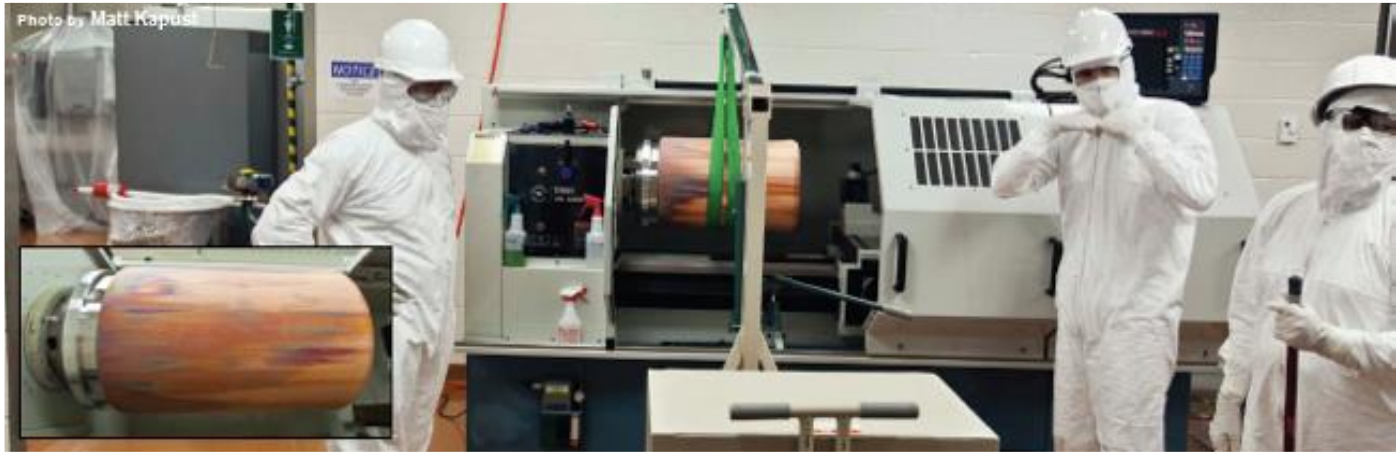
0.28 cts/ROI/t/y

Assay results consistent with connector activity dominated by pins

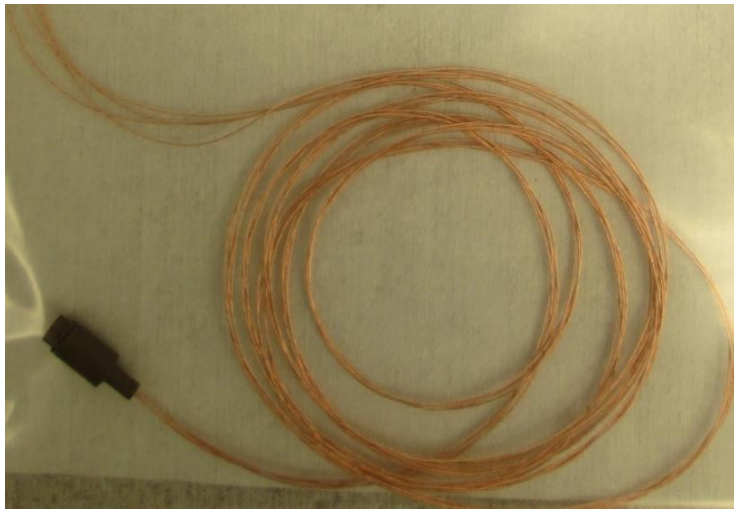


Material	Assay Method	Mass [g per pair]	Isotope	Activity [μBq/kg]	MJD BG [c/ROI/t/y]
Pins (w/BeCu)	ICP-MS	0.056	^{238}U	795000 ± 12000	8.8 ± 0.1
			^{232}Th	41000 ± 1000	2.3 ± 0.1
Pins (no BeCu)	ICP-MS	0.056	^{238}U	4600 ± 1500	0.05 ± 0.02
			^{232}Th	5800 ± 100	0.32 ± 0.01
Vespel SP-1	NAA	0.95	^{238}U	<1000	<0.20
			^{232}Th	<12	<0.01
Solder	GDMS	0.04	^{238}U	5600 ± 1000	0.04 ± 0.008
			^{232}Th	<12	<0.0004
Solder flux	GDMS	0.04	^{238}U	1200 ± 200	0.008 ± 0.001
			^{232}Th	<400	<0.016

Electronics Production



EFCu and Vespel parts machined at 4850’ level of SURF

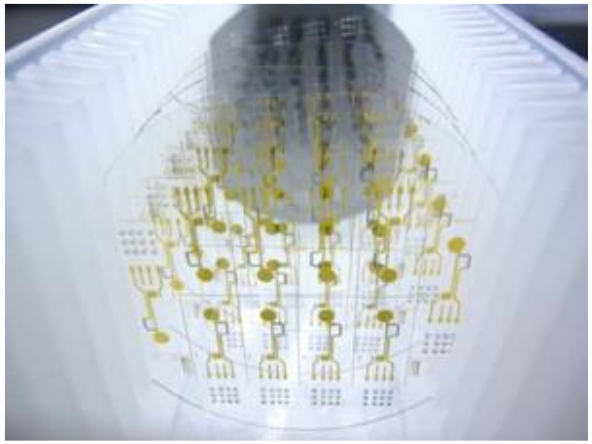


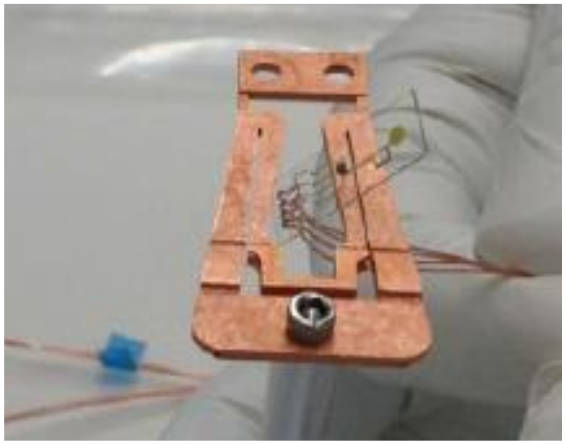
Pins pressed into plug housing

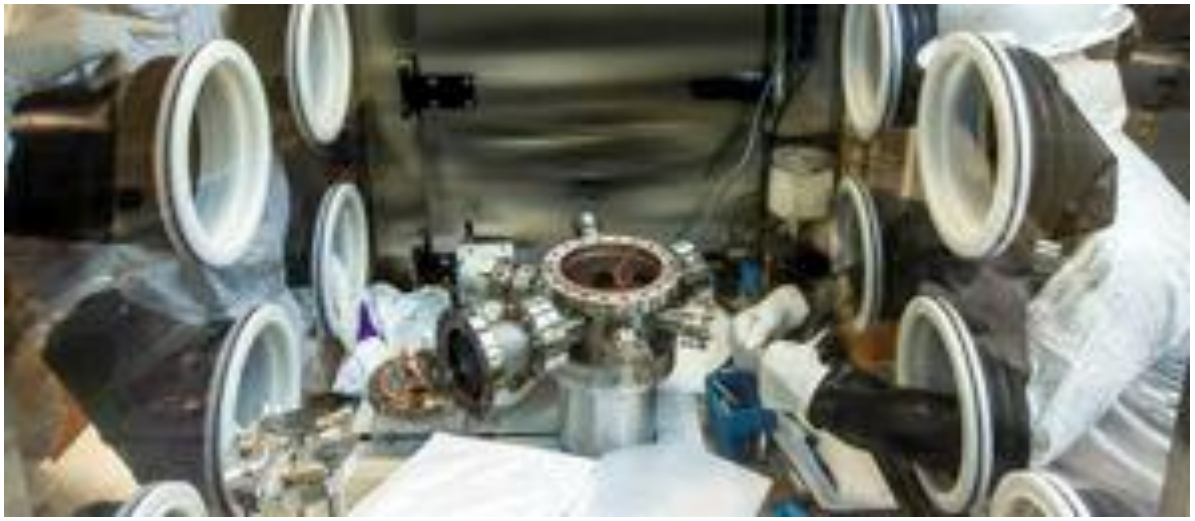
Plugs are QC’d and soldered to cable bundles at UW

Electronics Production

LMFEs are manufactured and attached to signal cables at LBNL







LMFEs are mounted on detectors and cables are connected in glove box at 4850' level of SURF

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