Low Background materials and fabrication techniques for cables and connectors of the MAJORANA DEMONSTRATOR

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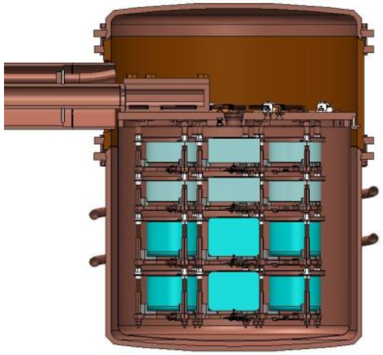
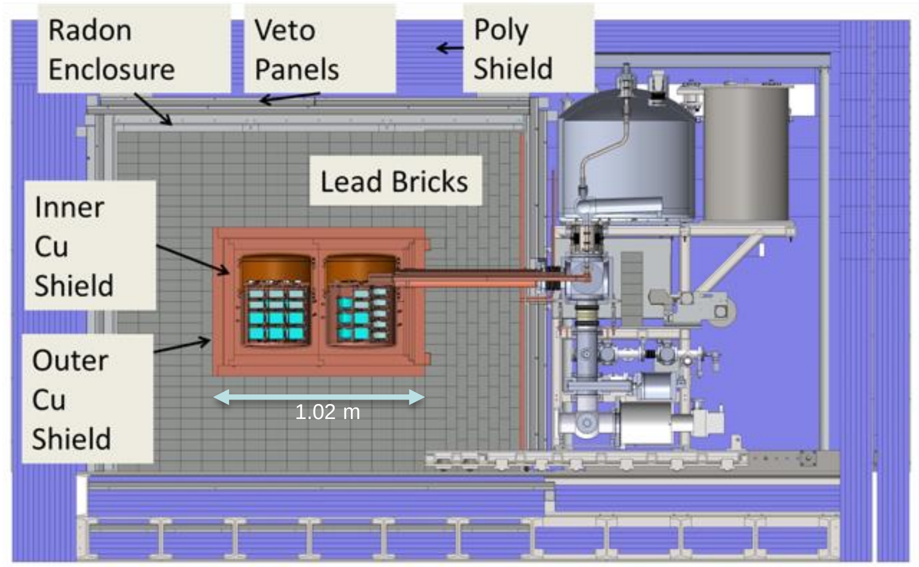
The MAJORANA DEMONSTRATOR

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

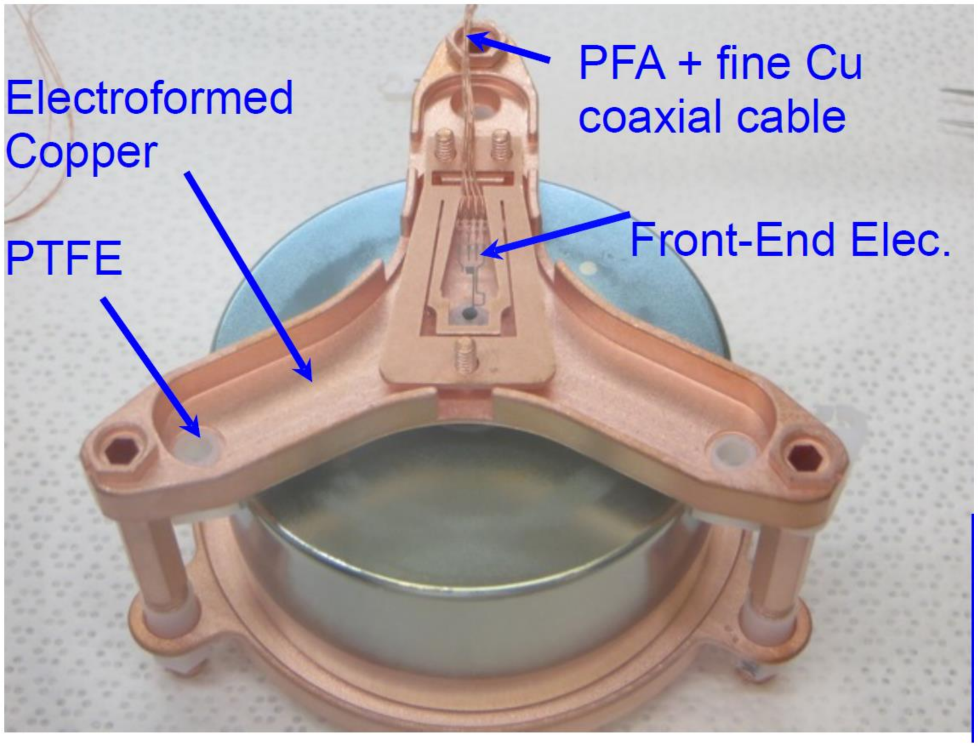
Goals: - Demonstrate backgrounds low enough to justify building a tonne scale experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Searches for additional physics beyond the standard model.

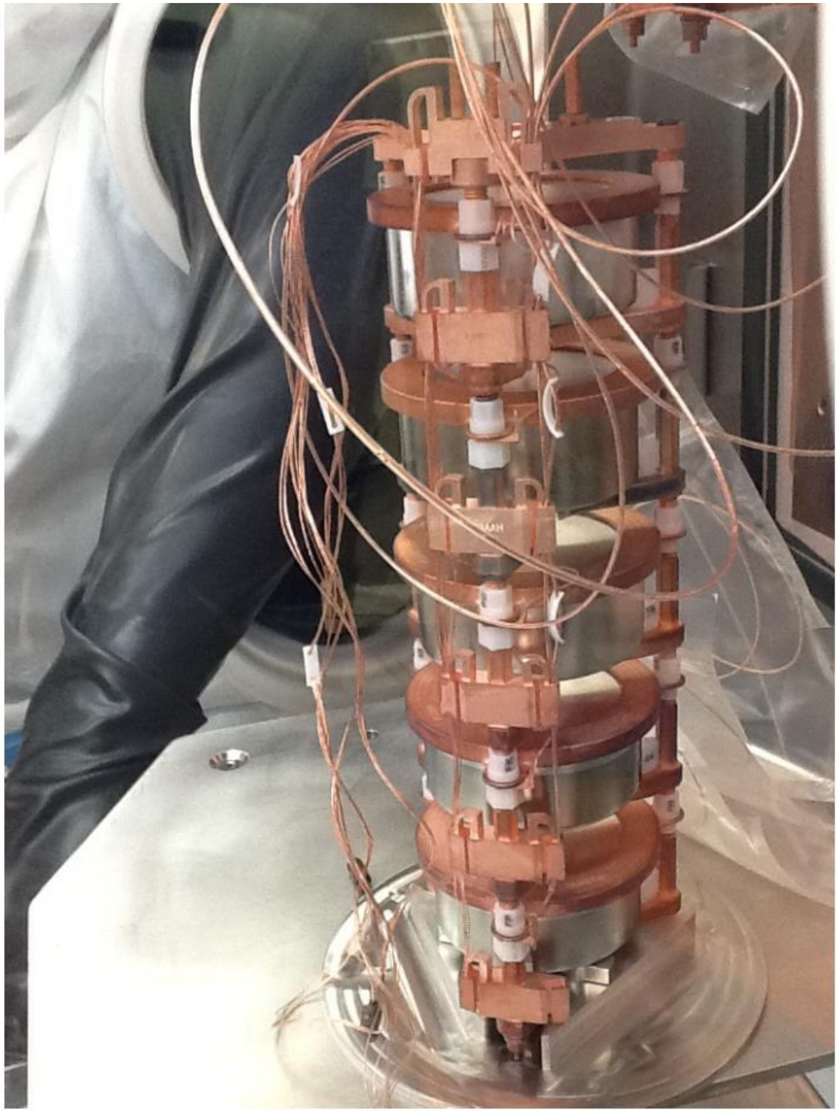


- Located underground at 4850' Sanford Underground Research Facility
- Background Goal in the peak region of interest (4 keV at 2039 keV)
  3 counts/ROI/t/y (after analysis cuts) Assay U.L. currently ≤ 3.5
  scales to 1 count/ROI/t/y for a tonne experiment
- 44.1-kg of Ge detectors
  - 29.7 kg of 88% enriched ^{76}Ge crystals
  - 14.4 kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - ultra-clean, electroformed Cu
  - 22 kg of detectors per cryostat
  - naturally scalable
- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto



Detector unit and string

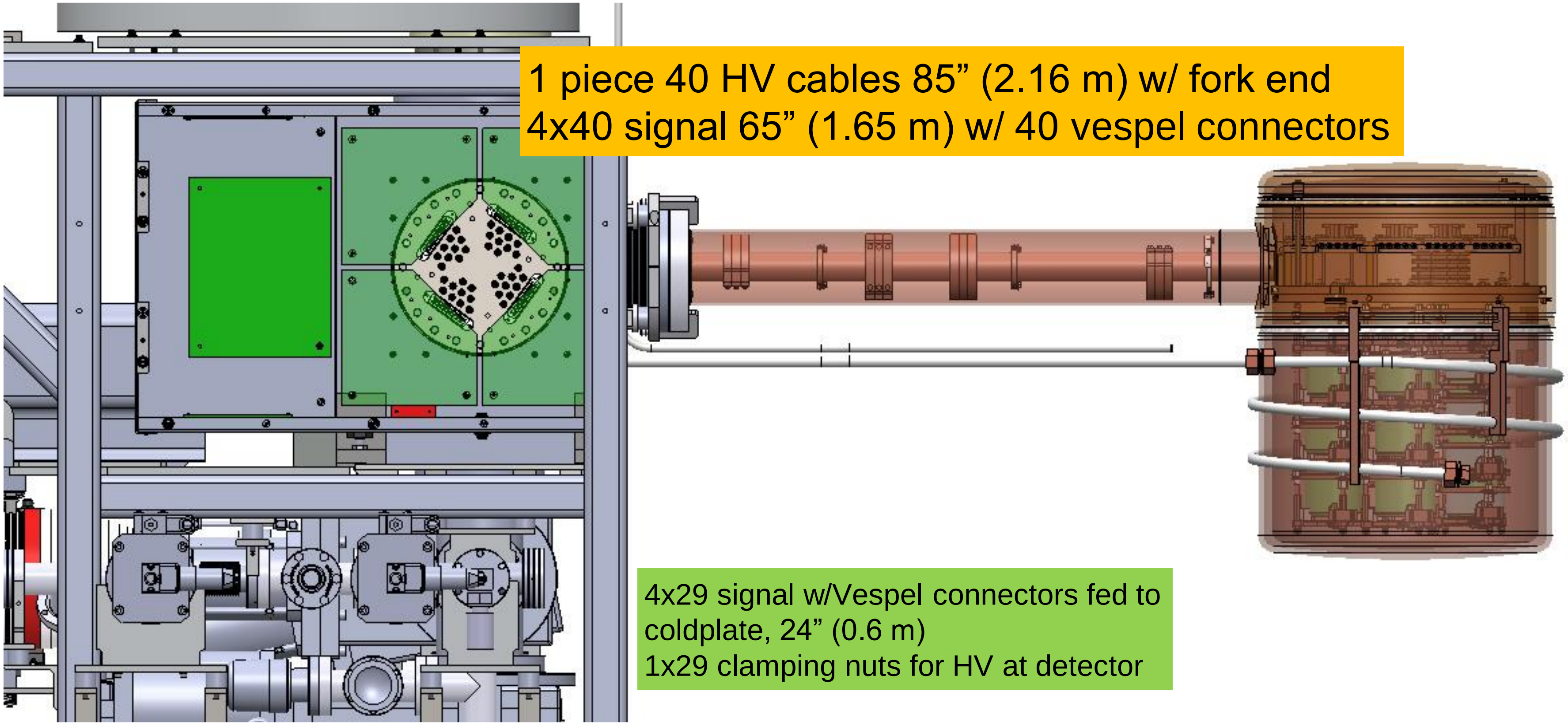




In vacuum Cables

40 channels wired in cross arm to provide spares

29 detectors installed and connected at cold plate

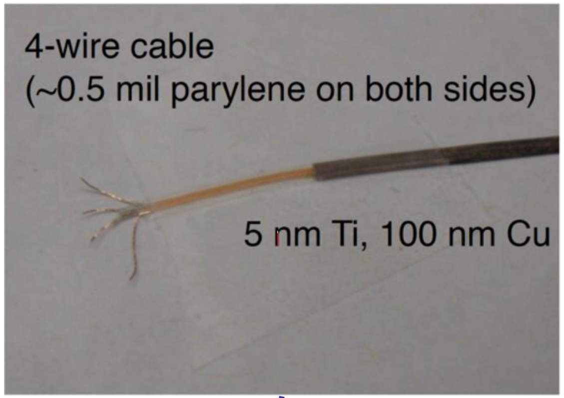


1 piece 40 HV cables 85” (2.16 m) w/ fork end
4x40 signal 65” (1.65 m) w/ 40 vespel connectors

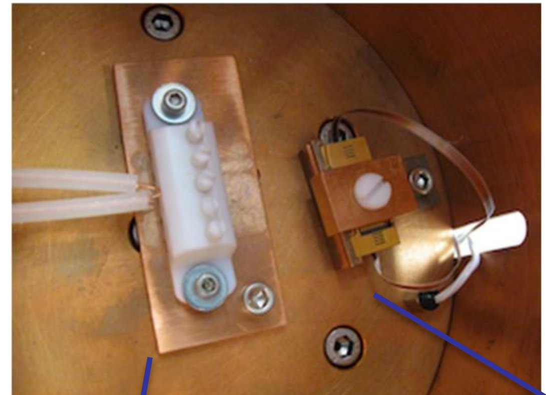
4x29 signal w/Vespel connectors fed to coldplate, 24” (0.6 m)
1x29 clamping nuts for HV at detector

2008-2014 development

Cables: in house ribbon

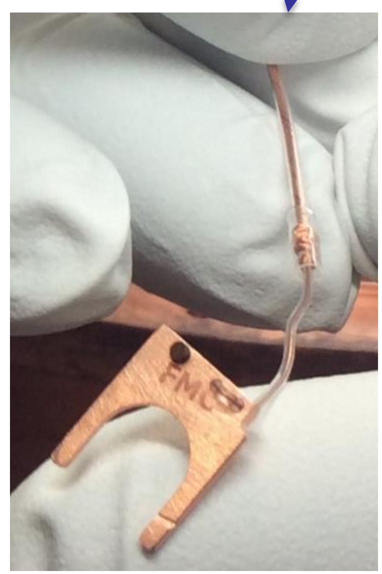


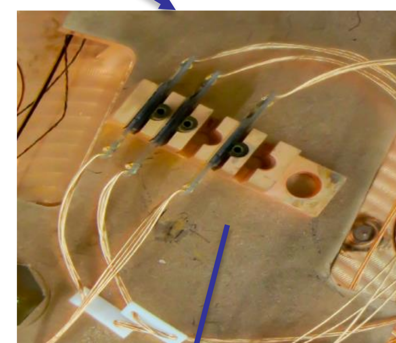
Cables: custom Axon' Picocoax



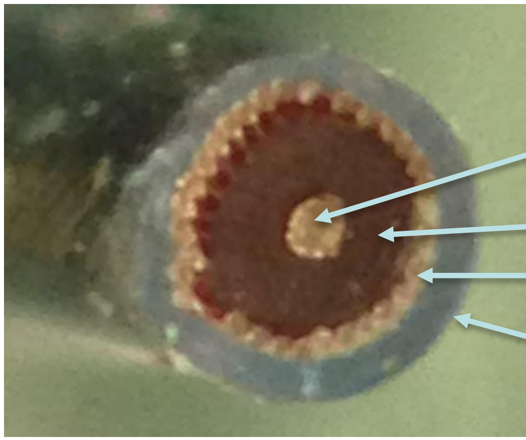
signal connection

HV connection





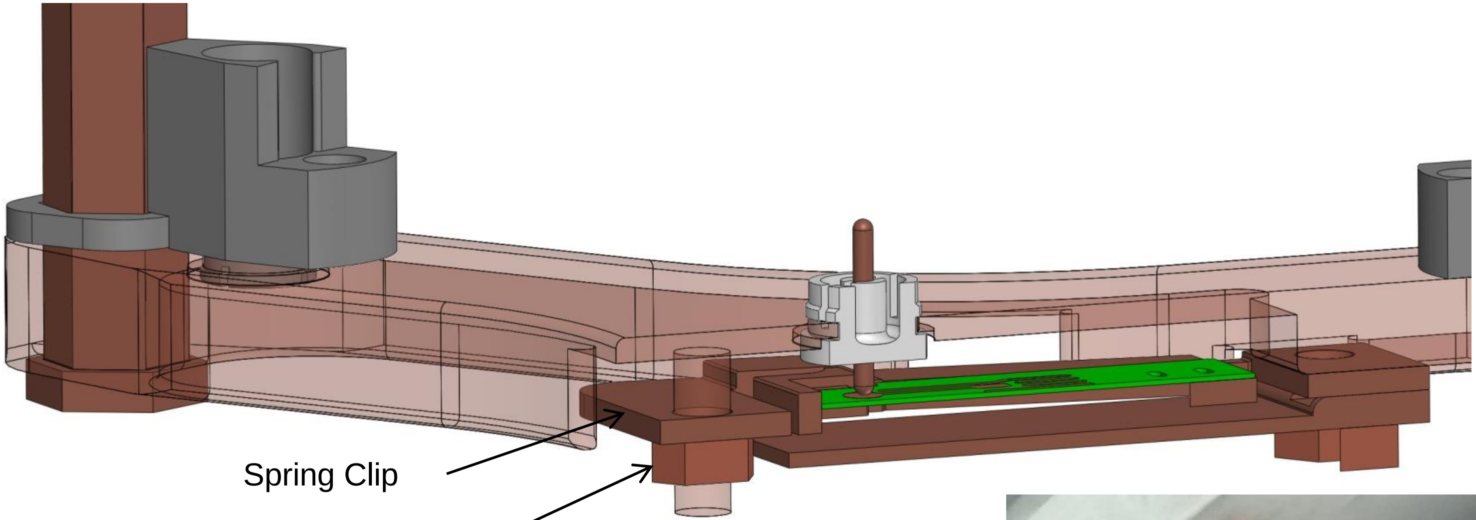
MAJORANA DEMONSTRATOR cable



Custom production from Axon' cable

- Signal cable
  - 50 Ω, 87pF/m, 0.4 g/m
  1. Conductor AWG 40 Dia. 0.076 mm
  2. Dielectric FEP OD 0.254 mm
  3. Spiral shield wires AWG 50 ~30 strands
  4. Jacket FEP OD 0.4mm
- HV Cable
  - Outer Diameter: 1.2mm
  - Approx mass: 3 g/m
  - 5kV DC

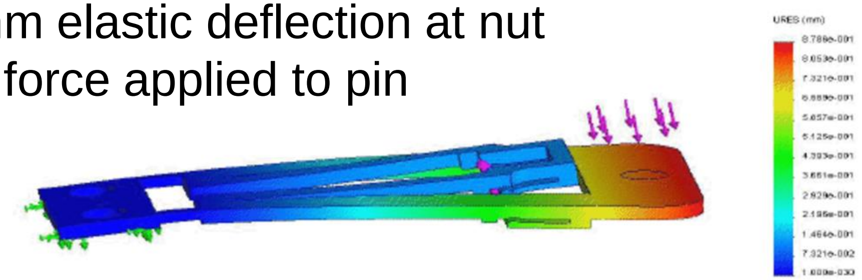
Signal connectors at detector



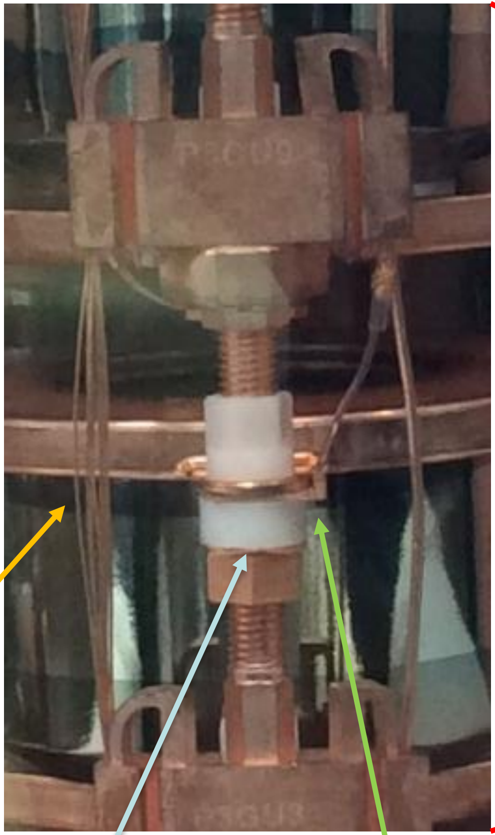
# Screw Turns	Deflection @Adjustment Screw (mm/(in))	Force @Contact Pin (N)	per 1/6 turn (N)	Safety Factor
Initial condition	0.27 (.011)	0.00		
1/6	0.39 (.015)	1N	1.00	1.3
2/6	0.47 (.019)	2N	1.00	1.18
	0.64 (.025)	3N	0.88	0.92
4/6	0.68 (.027)	4N	1.00	0.98
	0.74(.029)	5N	1.11	0.8

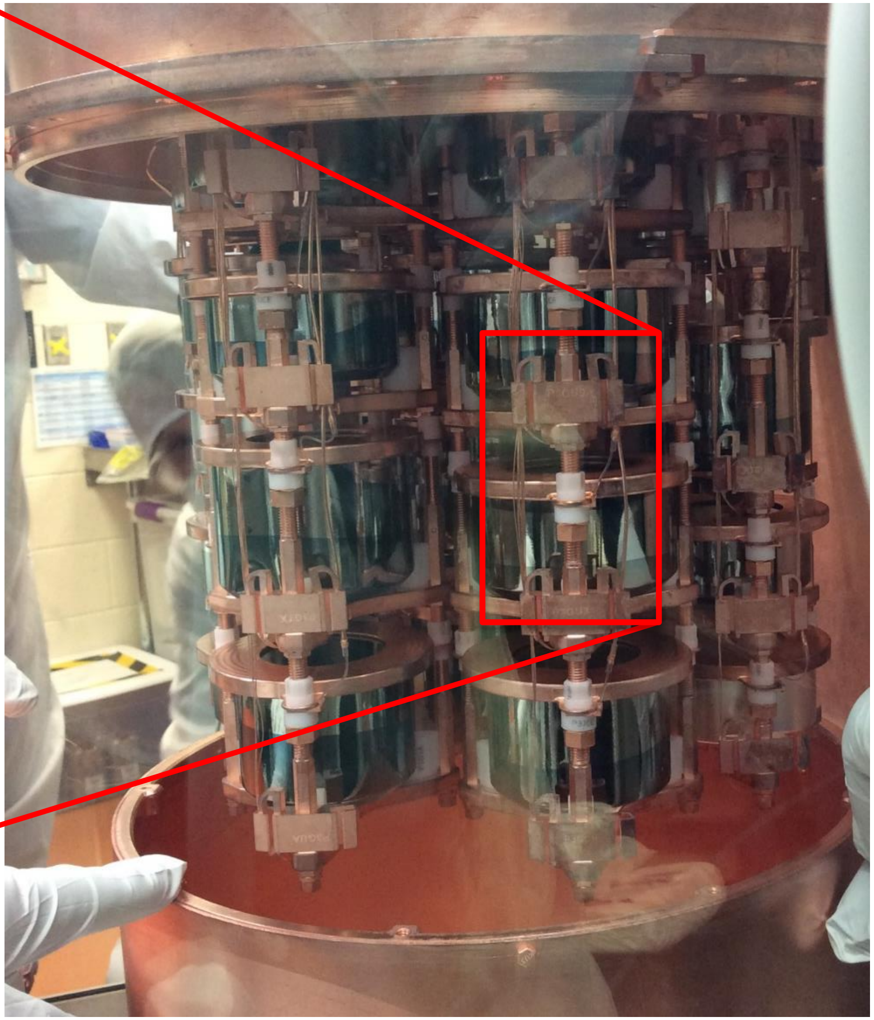
Model name: SpringClip Stiff
Study name: SimulationXpress Study
Plot type: Static displacement Displacement
Deformation scale: 4.77171

- 0.7 mm elastic deflection at nut
- 400g force applied to pin



HV fork connection





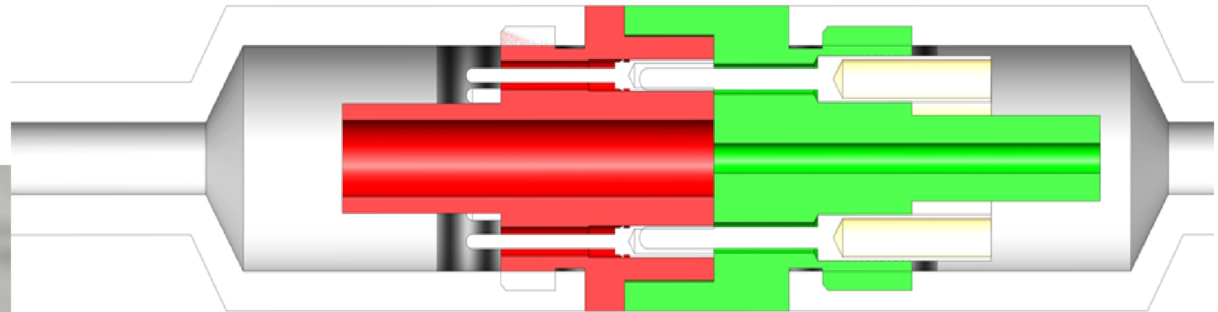
Phosphor Bronze spring washer

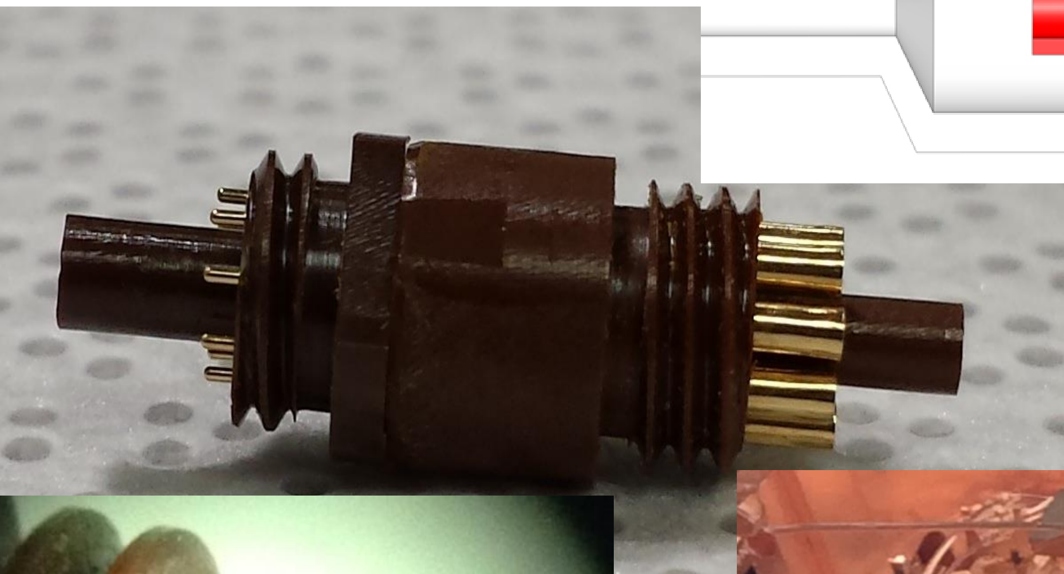
Installed signal wires

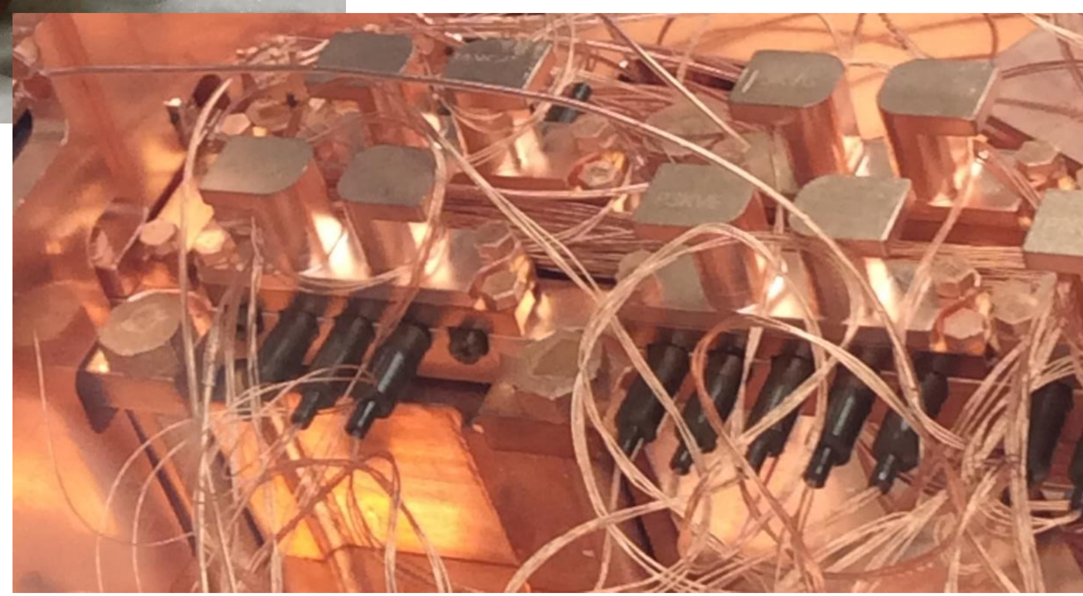
Installed HV fork

29 detectors installed under coldplate

Internal signal connectors 2015-2016

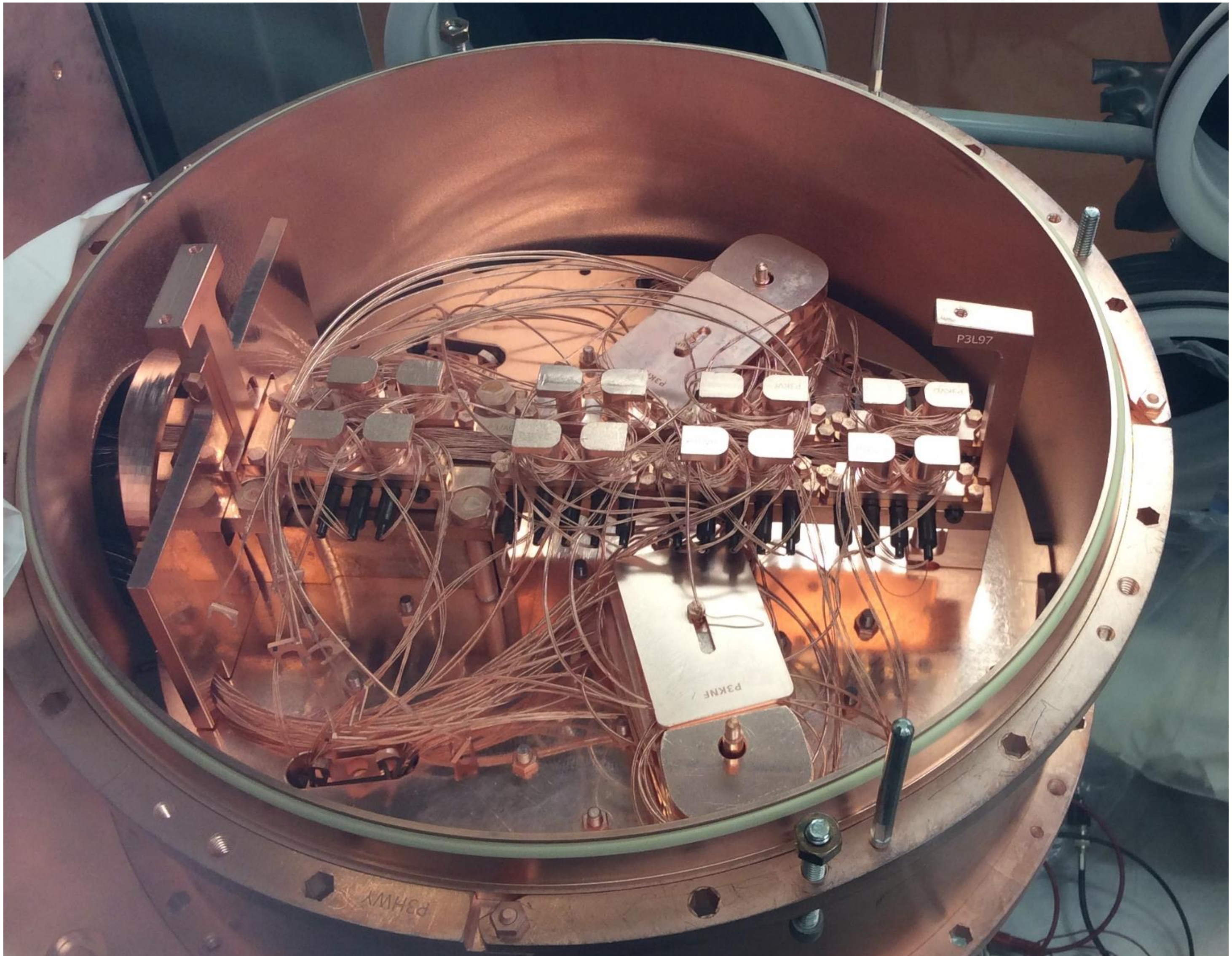






Wired cryostat w/ existing connectors

13” ID vacuum enclosure, 40 connectors available above coldplate

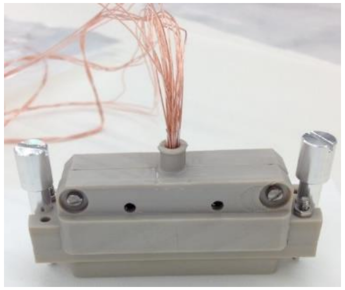


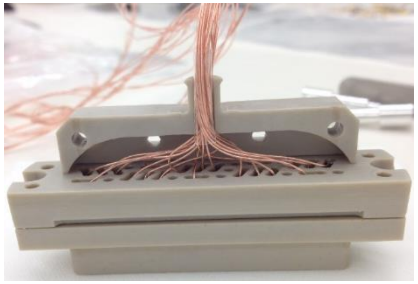
Vacuum feedthrough

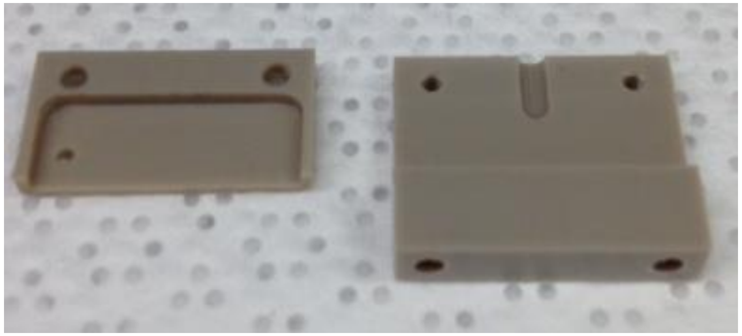
Reduced radiopurity requirements, but unique cables still require unique connectors

HV cable custom feedthrough connectors with commercial pins

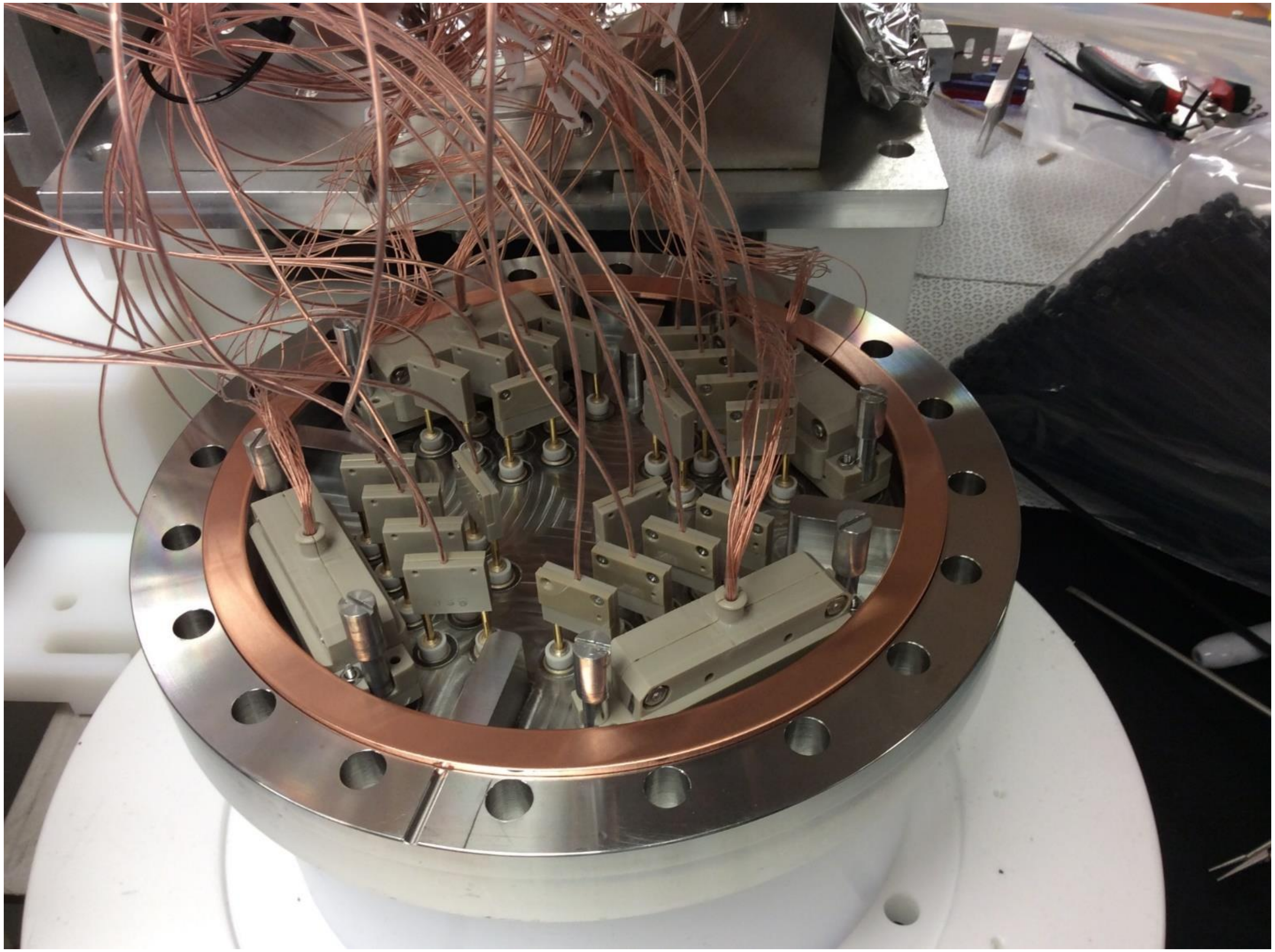
Signal cable customized commercial 50 pin D-sub







Vacuum side of 8” Conflat flange wired



Radiopurity performance

component	^{232}Th (10^{-12}g/g)	^{238}U (10^{-12}g/g)
Axon' cable	0.54+/- 0.05	11.7+/- 1.2
Vespel SP-1 connectors	<49	<45
Brass pins	1500+/-400	310+/-70
Brass pins w/CuBe inserts*	9900+/-300	64000+/-100
Phosphor Bronze	6.08+/-1.0	10.8+/-2.5
Silver epoxy (example)	56.7+/-7	67+/-8
solder	<100	<300
FEP heat shrink	<34	<100

*not used in experiment

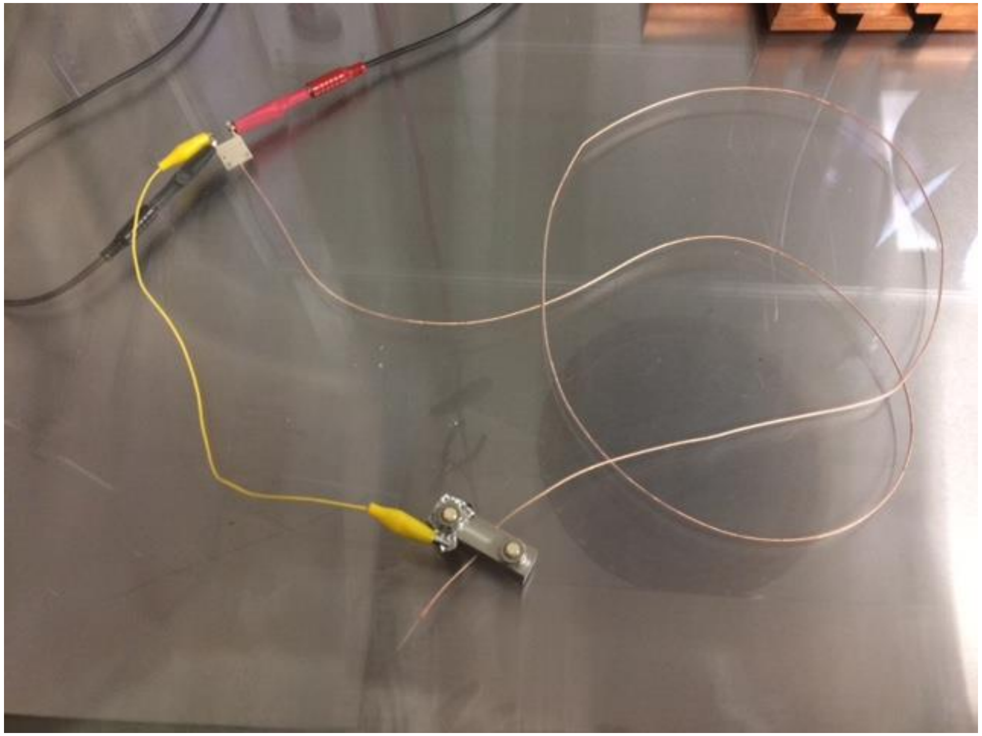
Excerpted from: The Majorana Demonstrator radioassay program [N. Abgrall et al. NIM **A828** (2016) 22]

Functional performance

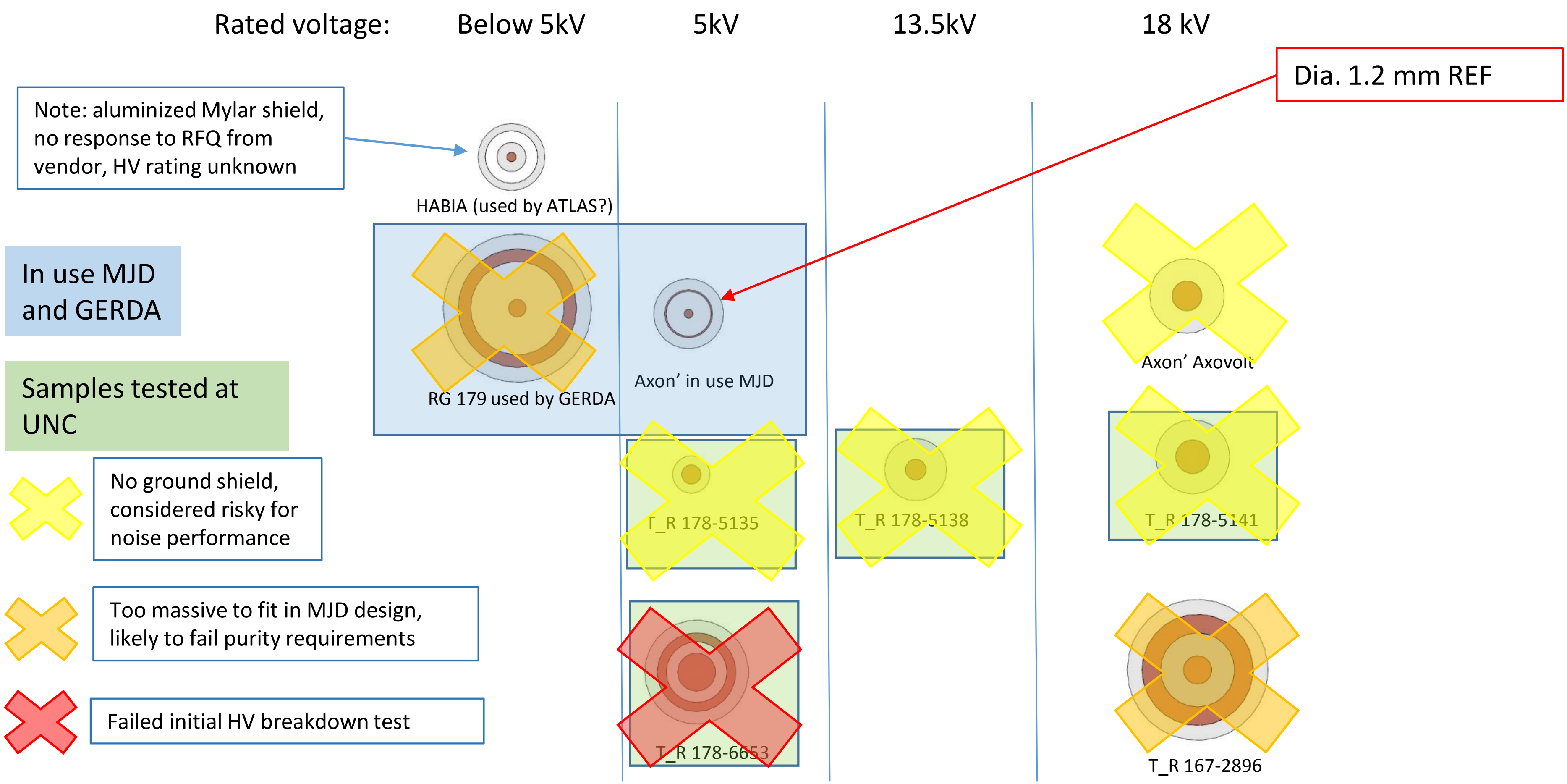
- 44 of 58 biased
  - 7 unbiased detectors have signal connection issues
  - 6 unbiased detectors have HV connection issues
  - 1 unbiased detector needs reprocessing
- 35 of 58 used in analysis thus far
  - Poor AvsE performance, maybe due to damaged HV cables that prevent full depletion
- Installed spare cables
  - 2 of 11 spare HV cables functional. HV fork clamp ineffective.
  - 0 of 11 spare signal cables functional. Poor connection quality at cold plate or feedthrough.

HV breakdown testing

- Pinching HV cables reproduces field observed breakdown behavior
- Replacement cables should be more robust or better protected from damage.



Various commercial small HV cables drawn to scale



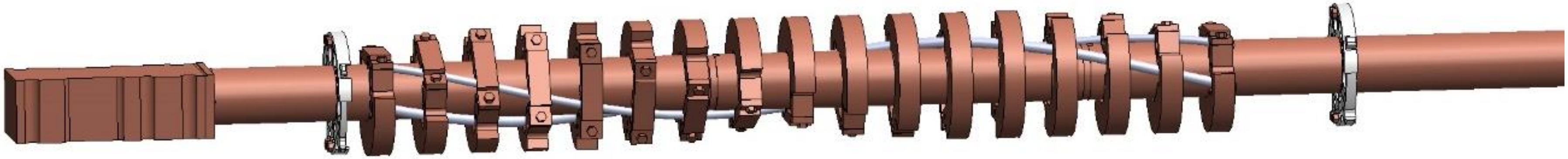
Best Option is to produce more robust custom cable with known clean copper. Most cost effective short term option is to use existing Axon' cable and protect it better during fabrication and installation

HV cable protection

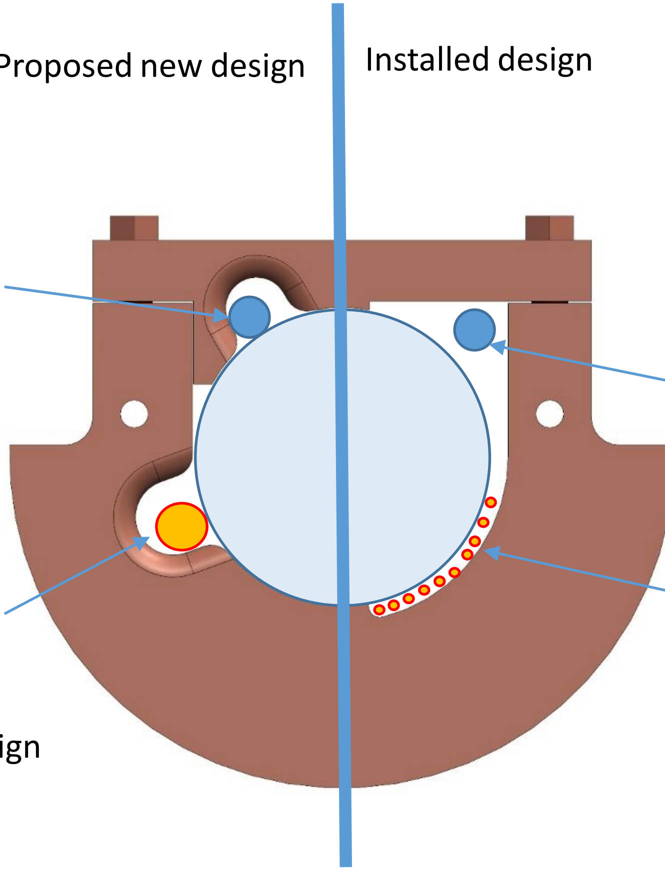
- Baffle plates guide cable and protect cable bundles during installation, and shield detectors from backgrounds originating outside of shield

installed

New design improves shielding and cable routing

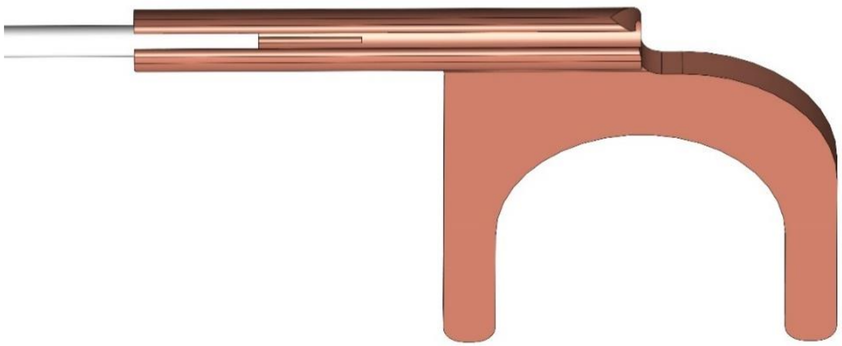


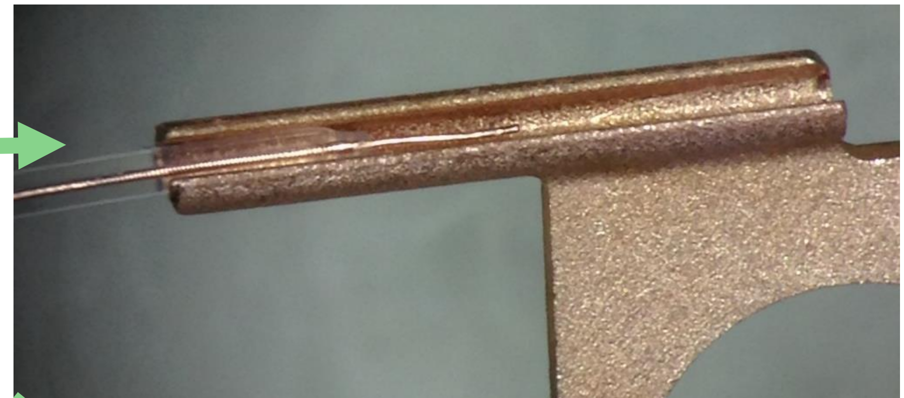
Test plates for improved cable routing

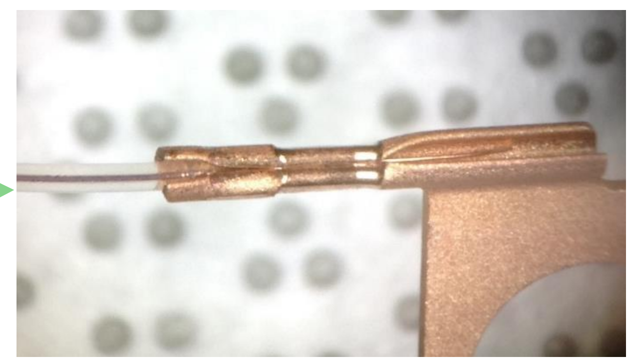


HV Fork

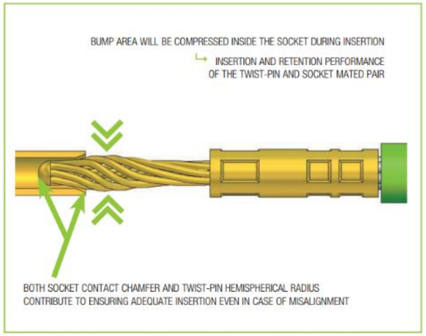
- Eliminates drilling holes and Vespel clamp plug
- Works with initial HV discharge testing
- Strain relief quality to be tested



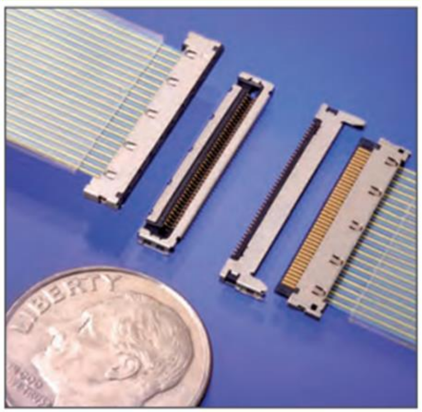




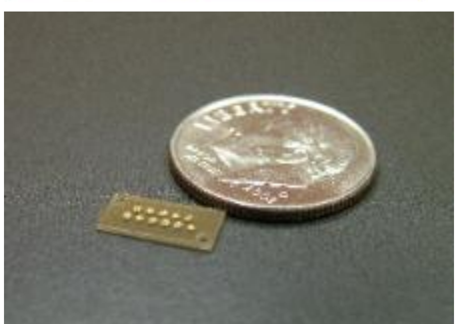
Commercial signal connector options



Nano twist pins: vendors unwilling to work with Axon' cable without a PCB interface, doesn't work with existing hardware form factors, no assay history but is CuBe free.

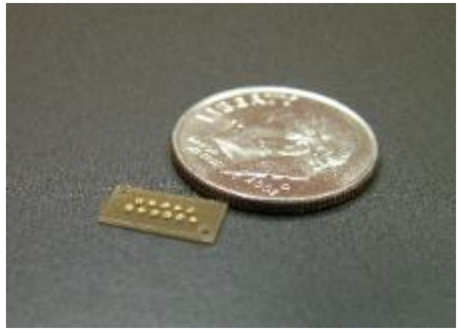


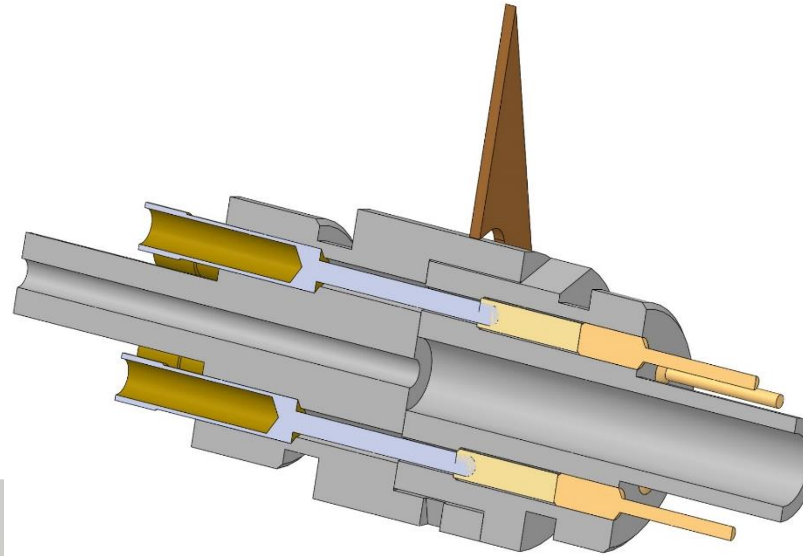
Micro IDT (Insulation Displacement Technology): vendor unwilling to make any customization for form factor or cleanliness without $100k minimum order, doesn't work with existing hardware form factors. No good assay history but is CuBe free.

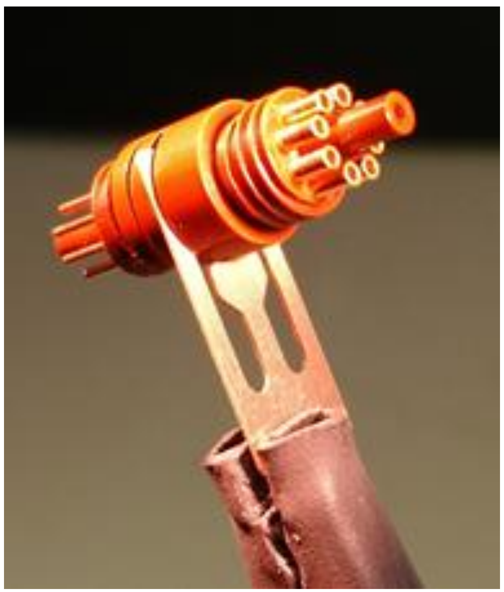


Fuzz Buttons: vendor is very helpful with custom solution that fits within current hardware form factor using assayed materials. Good assay history with CDMS experiment.

Replacement signal connectors

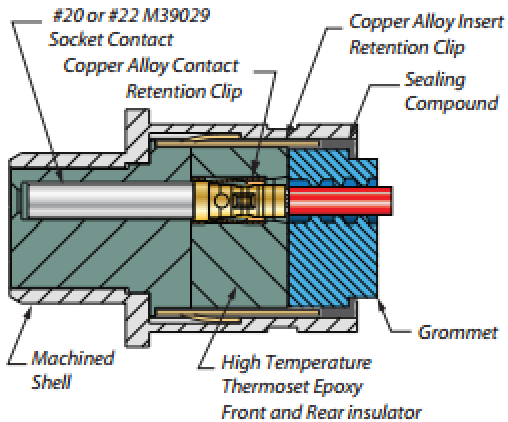




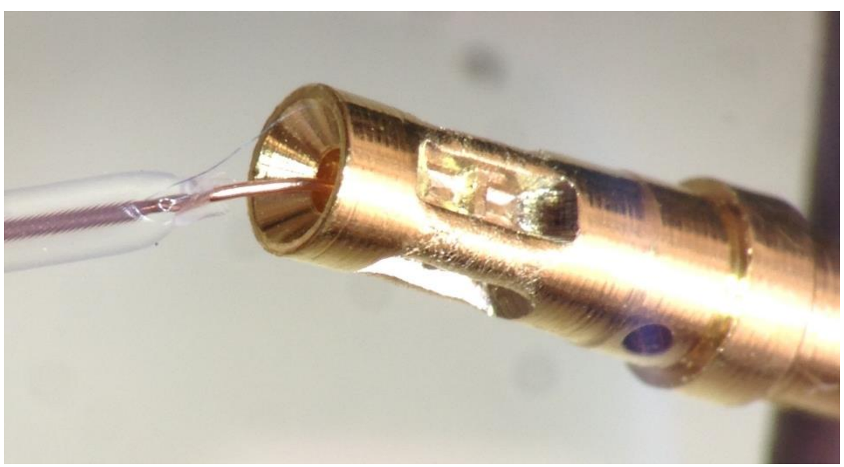


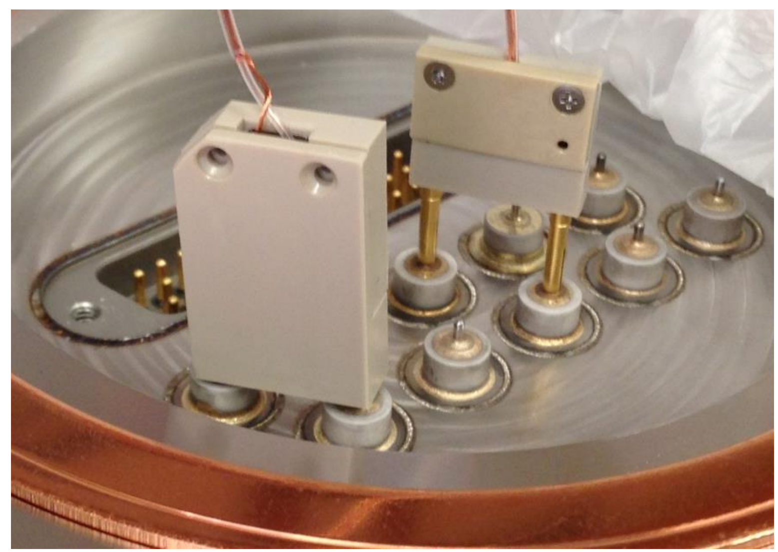
- Fuzz buttons from Custom Interconnects solve connector reliability issues so far in testing

Feedthrough connectors



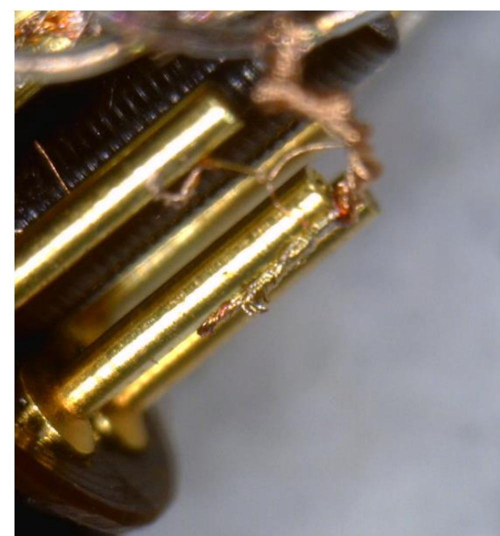
MIL SPEC and Space rated from Glenair (will be tested for vac compatibility, but meets NASA outgassing requirements)





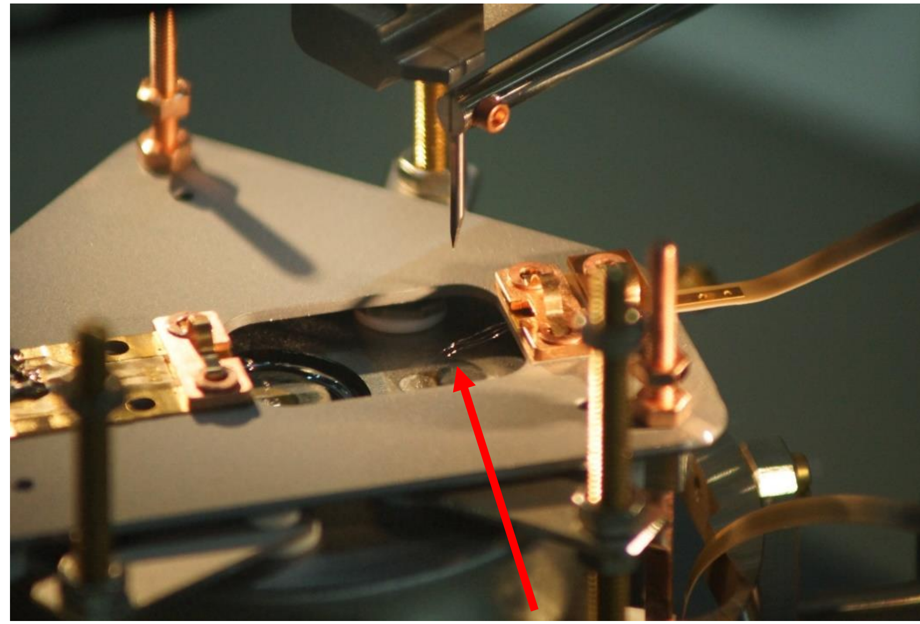
Micro-TIG and resistance welding

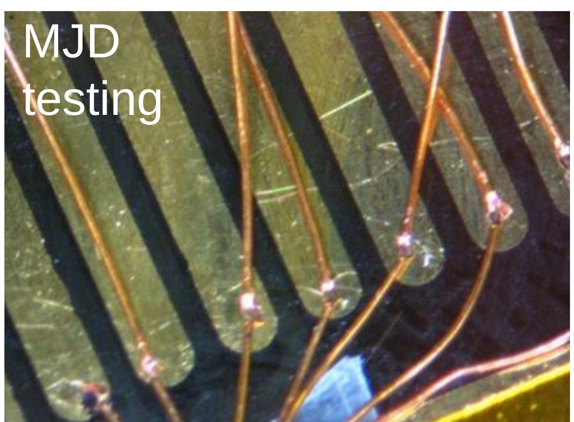
- Similar to wire bonding, but higher power density.
- Used in industry for battery terminals, solar panels, magnet wire and micro motor windings, and specialty aerospace applications.
- Will be tested for MJD upgrade and LEGEND, may provide more flexibility than wirebonding, solder, or silver epoxy



LEGEND cables and connectors

Wirebonding uses ultrasonic energy and light pressure to weld contacts



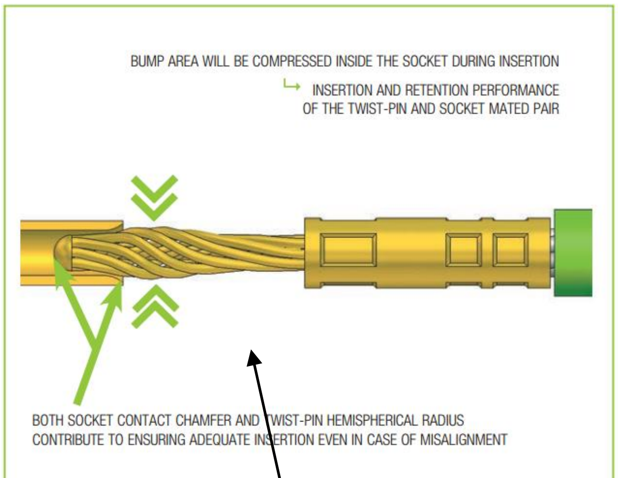


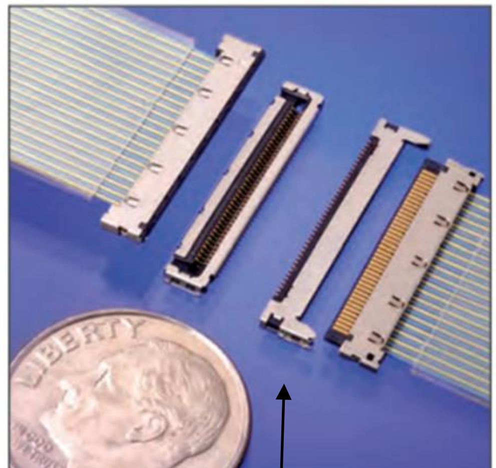
25 μm Al wires work well at detector, worked in the end for GERDA but some development difficulties at cable end related to inconsistencies in cables

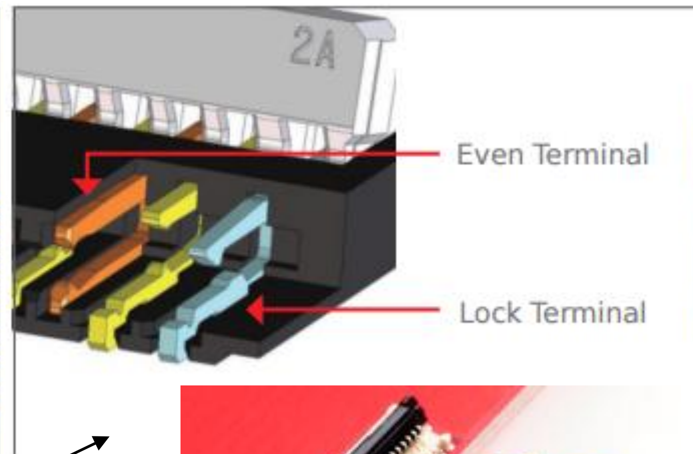
76 μm Cu wires inconsistent in testing c. 2010 (resistance or Micro-TIG may work better here)

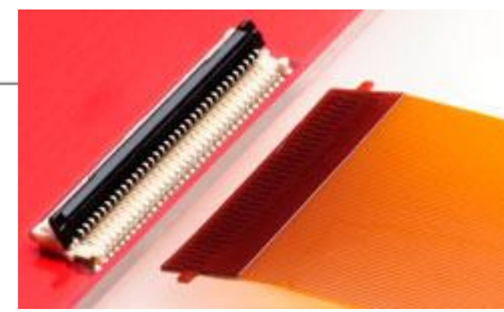
LEGEND development work

- Front end (ASIC) in flat circuit cable and/or multi conductor bundle
- Main pre-amp after L-Ar shielding, can use commercial CuBe free connectors (fuzz button, nano-twist, IDT, ZIF)









Nano twist are MILSpec and can be made hermetic for feethroughs. Requires some assay and/or custom materials

IDT and ZIF are from consumer electronics. Very low mass, but harder to customize and not as reliable or rugged.

Conclusions

- Low quality terminations and cable durability is a leading cause of detector failure in the MAJORANA DEMONSTRATOR
- Development work is underway to upgrade cables and connectors in the MAJORANA DEMONSTRATOR
- This cable upgrade will feed directly into design and development for LEGEND.

Extra slides

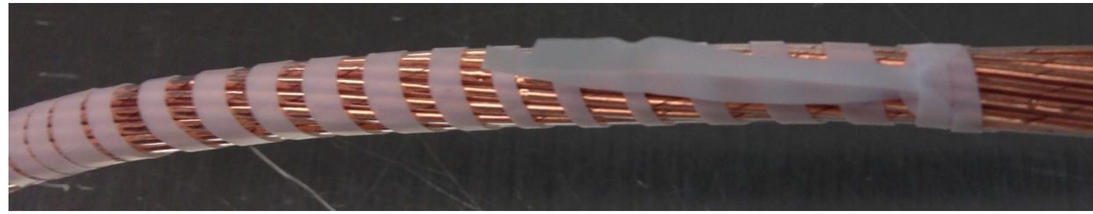
NASA QC process

- Read this: NASA-STD 8739.4A “Workmanship standard for crimping, interconnecting cables, harnesses, and wiring.”
- Don’t solder unless absolutely necessary to improve ruggedness and repeatability
- Pull-out strength and QC procedures for crimped connectors
- Overwrap and/or ties and installation guidelines for harness assembly

Wire Crimp pull testers

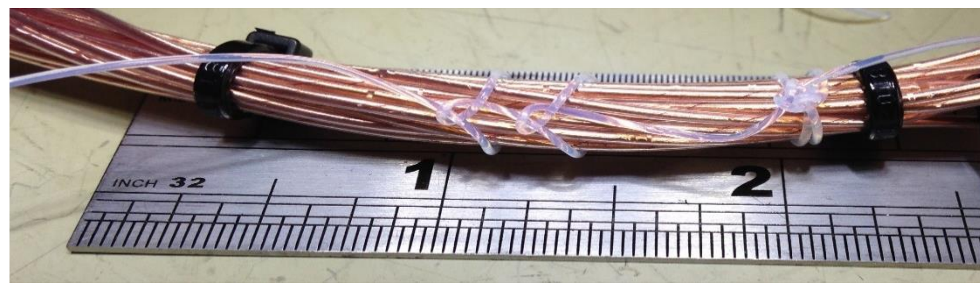
- Required for production QA to meet many test standards including NASA, UL,ISO,ASTM, SAE

Overwrap: work in progress

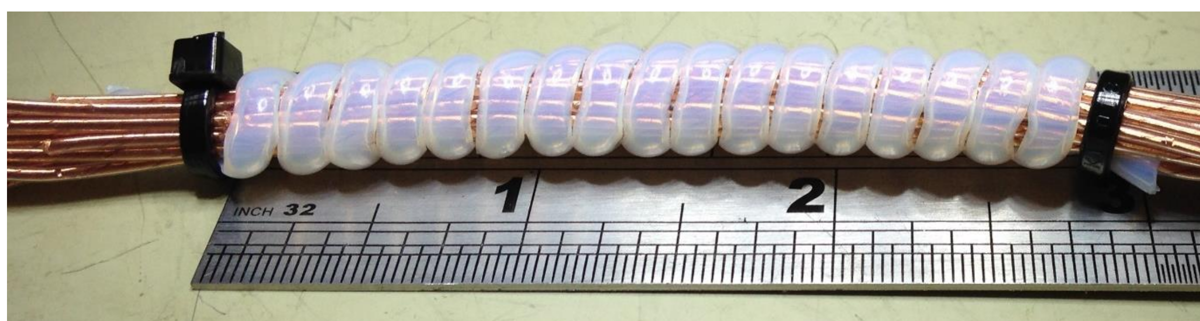


Previously assayed Clean PTFE film is not securable

Un-assayed PTFE monofilament sample is ineffective



Un-assayed PTFE spiral wrap is effective, but massive and requires restraint at ends



Quality Assurance

- Vespel machining: hand de-burr and test fit of connector body and threads for back shell
- Visual inspection at pin insertion
- Connectivity after soldering in air
- Paired connectivity with 4+ connections, ¾ must pass
- Samples dunked in LN (~3/4 pass)
- Complete harness pin-pin connectivity test (90% pass)
- Field installed in apparatus (75% pass)
- 44 of 58 installed detectors operating. Most failures are due to connectors and cables.
- HV breakdowns after installation indicated damaged HV cables on ~8 detectors

Cable and connector upgrade for MAJORANA DEMONSTRATOR

- Goal is to improve fraction of operating detectors from ~76% to 90%+
- Strategy:
  - ☑ Determine root cause of HV breakdowns
  - ☑ revisit commercial cable options
  - ☑ revisit commercial connector options
  - ☐ Test best options (in process)
  - ☐ Develop detailed production plan and QC process
  - ☐ Fabricate and test complete harnesses (late 2017)
  - ☐ Install in MAJORANA DEMONSTRATOR (late 2018)