DUNE Near Detector TPC R&D: Kapton Material Studies

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on behalf of the SLAC DUNE group

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SLAC NATIONAL ACCELERATOR LABORATORY

Summary of activities

Current TPC hardware research group at SLAC:

- H. Tanaka
- Two postdocs: R. Itay, F. Drielsma
- Two grad. students: L. Domine, D.H. Koh
- Two summer students: M. Vives, J. Weaver
- One mechanical engineer: K. Skarpaas
- One technician: R. Conley

Main involvements in detector R&D:

1. Local cryostat (R. Itay, L. Domine, J. Weaver, K. Skarpaas)
2. **Kapton studies** (F. Drielsma, D.H. Koh, M. Vives, K. Skarpaas)
3. ArgonCube 2x2 TPC module design (K. Skarpaas)

Kapton as a TPC resistive shell

Motivations for resistive shell:

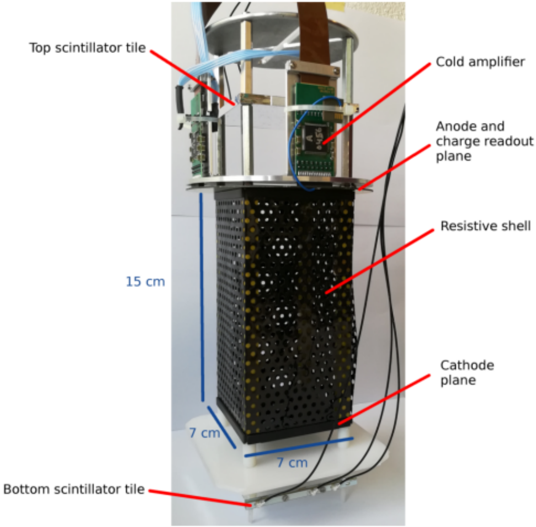
1. Remove failure points (resistors) of field-shaping ring designs
2. Less components, less complex
3. Smaller footprint

Requirements:

1. $\mathcal{O}(1)$ G$\Omega \cdot \square$ sheet resistance $(R_s = \rho/t)$
2. Cryoproof

$\rightarrow$ **Dupont DR8 C-doped Kapton** is an ideal candidate as it is robust to cold temperatures and has adequate resistivity.

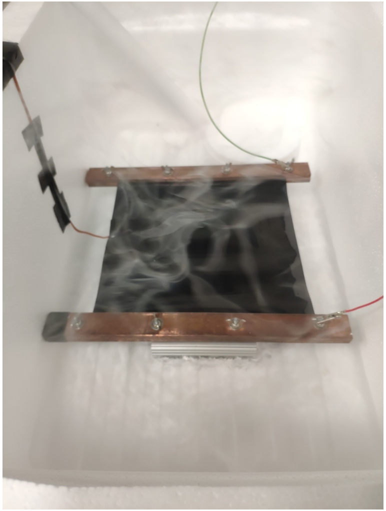
Ref: arXiv:1903.11858, R. Berner et al.



Kapton field cage studies

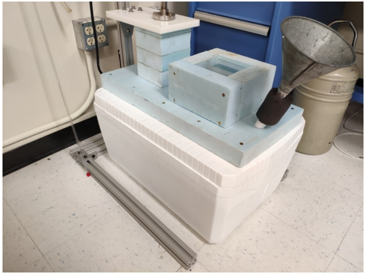
Studies underway:

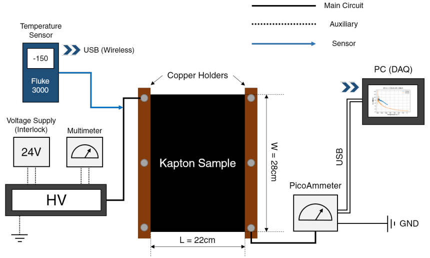
1. Material studies
   - Temperature dependence
   - High voltage scan
   - Uniformity
   - Stability
2. Lamination on G10 (fiberglass)
   - Epoxy glue
3. Metalization
   - Aluminum foil + epoxy glue
   - Copper tape

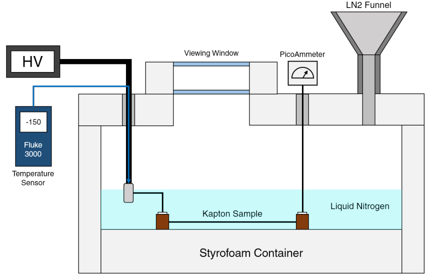


Kapton material studies apparatus

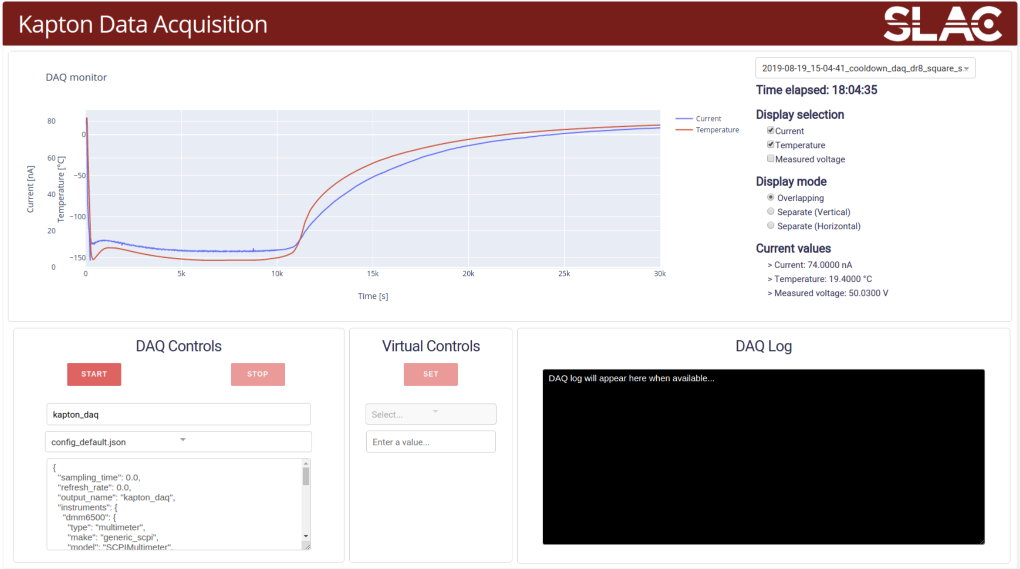
- 28x22 cm sheets of DR8 C-doped Kapton
- Voltage sources:
  - HP E3631A 0–50 V DC, 0–1 A
  - Glassman ER-series 0–40 kV DC, 0–6 mA
- Fluke T3000 K-type thermocouple
- Current readout in series:
  - Keithley DMM6500 (10^{-11} A res.)
  - Keithley 485 picoammeter (10^{-13} A res)



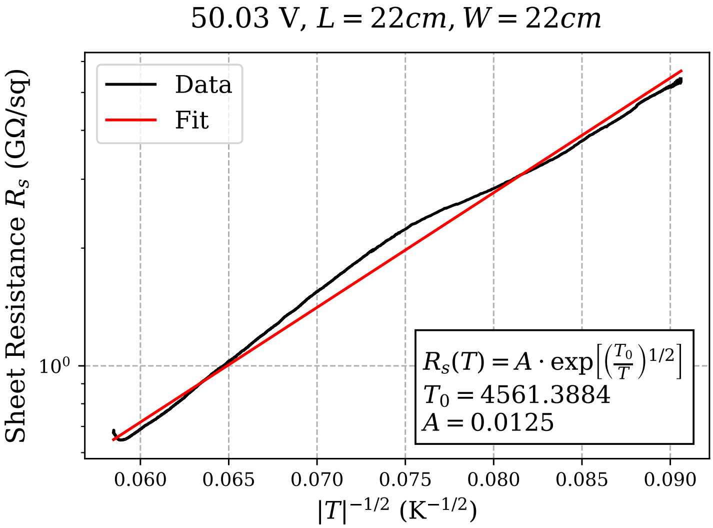




Kapton material studies DAQ



Kapton resistivity: temperature



Setup:

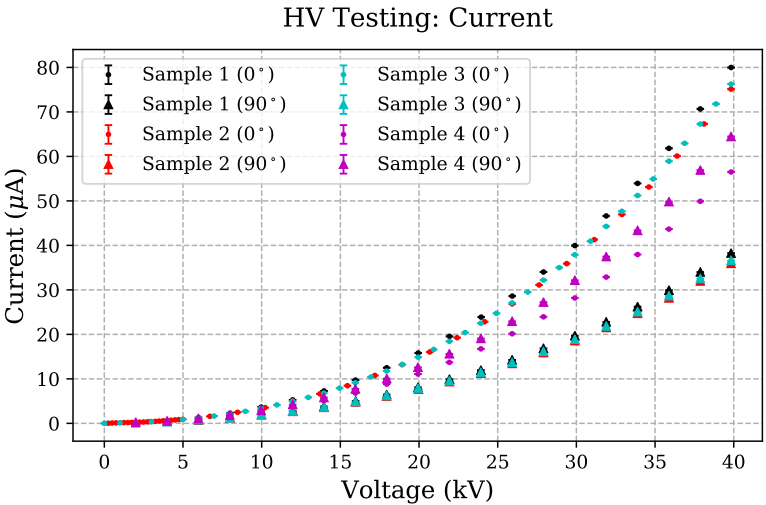
- 50 V DC
- TC against Kapton
- Kapton raised on stand-offs above an LN_2 bath

Behavior compatible with hopping transport model, i.e.

$$\rho \propto \exp\left[1/\sqrt{T}\right]$$

Factor ~ 10 increase in res. in LN_2 (seen at Bern)

Kapton resistivity: voltage

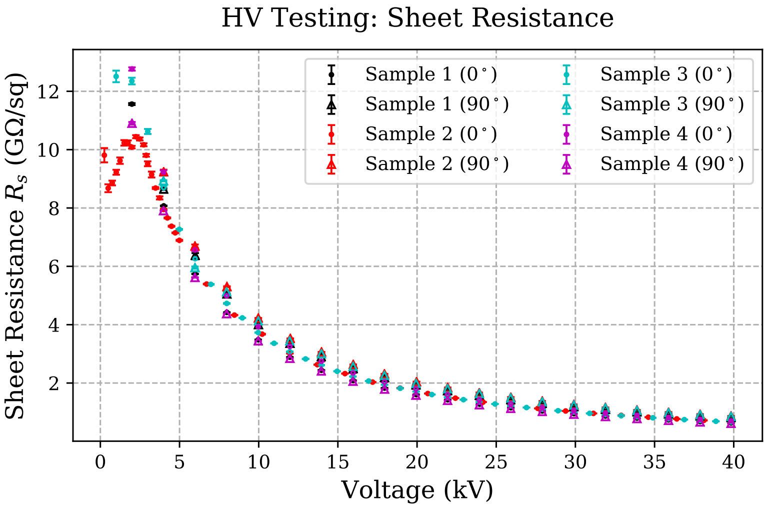


Setup:

- 0–40 kV DC
- Kapton submerged in LN_2 ($\sim$77 K)
- Three 28x22 cm + one 22x22 cm sheets
  - 0°: $E \perp$ length
  - 90°: $E \parallel$ length

Variations between orientations, sample to sample

Kapton resistivity: voltage



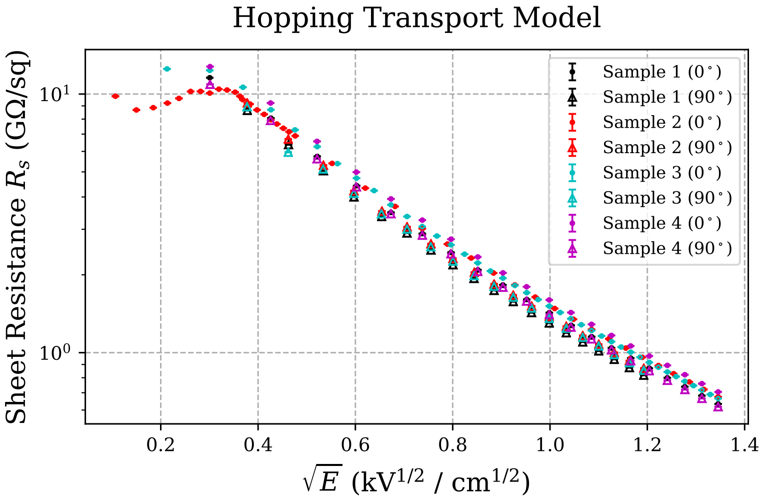
Setup:

- 0–40 kV DC
- Kapton submerged in LN_2 (∼ 77 K)
- Three 28x22 cm + one 22x22 cm sheets
  - 0°: $E \perp$ length
  - 90°: $E \parallel$ length

Factor ∼ 10 drop in resistivity at 40kV (seen at Bern)

Peculiar resonance in resistivity around 2.5 kV. Will repeat measurement.

Kapton resistivity studies: E field



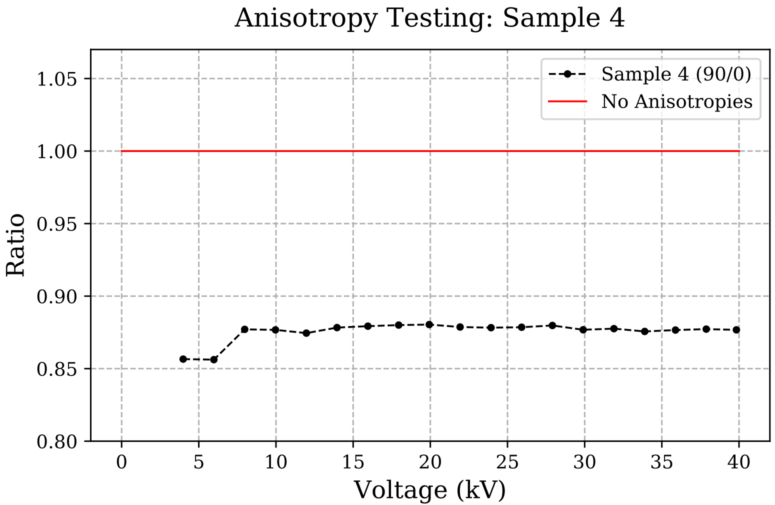
Setup:

- 0–40 kV DC
- Kapton submerged in LN_2 ($\sim$77 K)
- Three 28x22 cm + one 22x22 cm sheets
  - 0°: $E \perp$ length
  - 90°: $E \parallel$ length

Behavior compatible with hopping transport model, i.e.

$$\rho \propto \exp\left[-\sqrt{E}\right]$$

Kapton resistivity studies: anisotropy

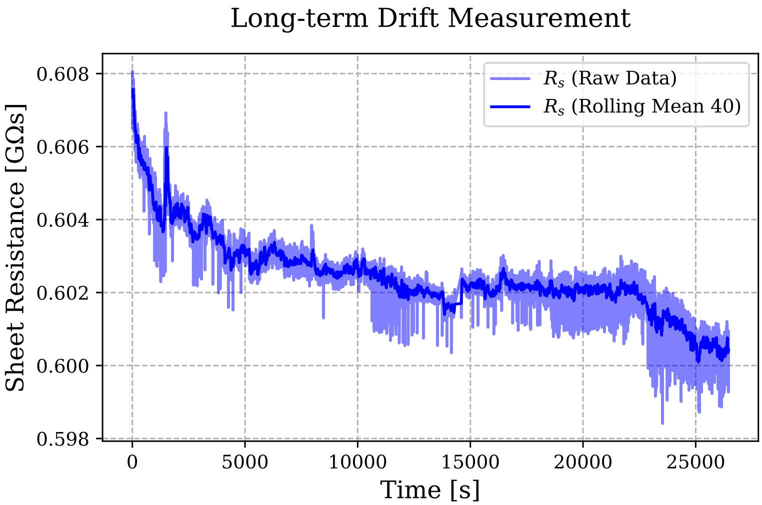


Setup:

- 0–40 kV DC
- Kapton submerged in LN_2 ($\sim$77 K)
- One 22x22 cm sheet
  - 0°: $E \perp$ length
  - 90°: $E \parallel$ length

Difference in field does not fully account for asymmetry between orientations.

Kapton resistivity studies: stability



Setup:

- 40 kV DC
- Kapton submerged in LN_2 ($\sim$77 K)
- One 28x22 cm sheet
- $\sim$7 hrs of recording

Order 1 % decrease in resistance over full time.

Small but robust effect, will extend measurement duration in local cryostat with better controlled environment.

Kapton lamination studies

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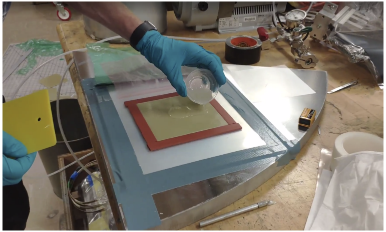
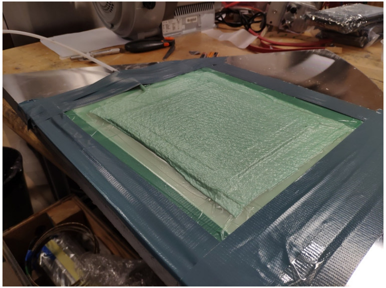
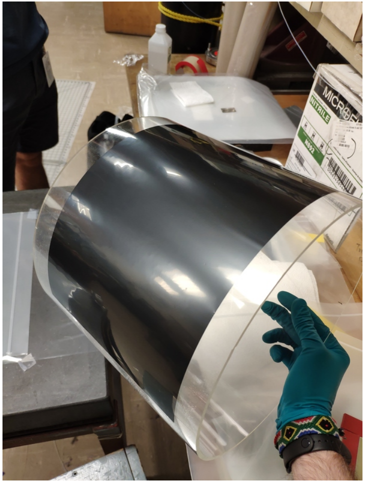
Basic procedure:

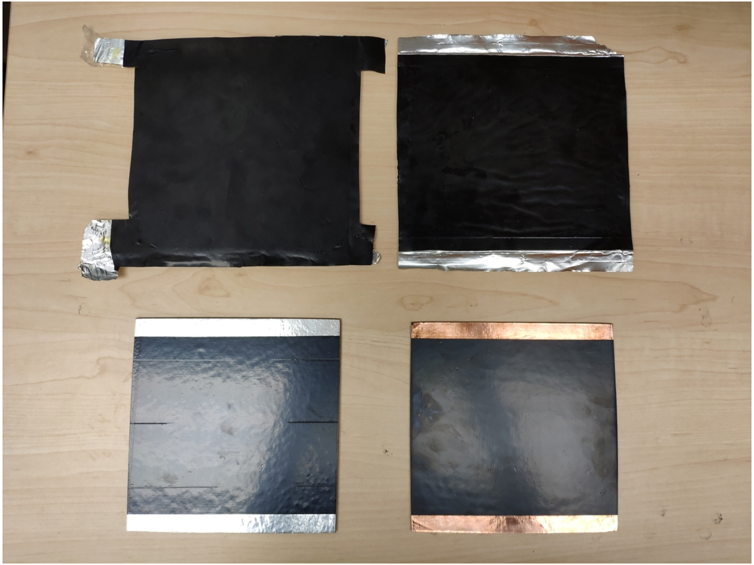
- Piece of G10
- Layer of exoxy glue
- Roll sheet of Kapton (used Dupont XC for tests, $R_S \sim \mathrm{M}\Omega \cdot \square$)
- Bleeder cloth
- Seal in bag
- Vacuum pump
- Cure (5 days)







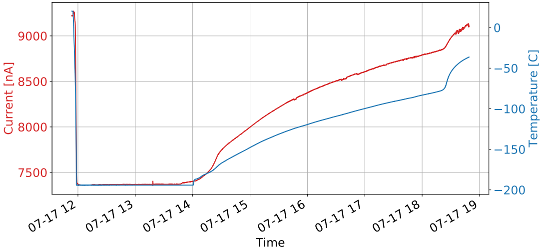
Kapton lamination variants

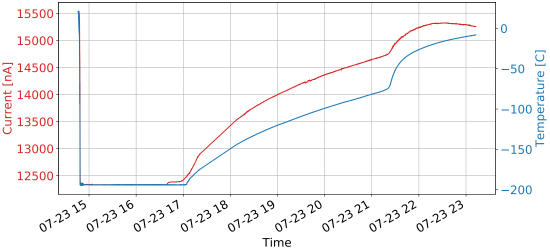


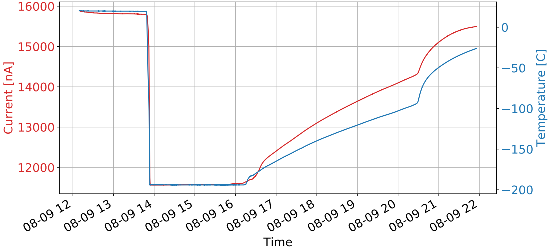
Left to right, top to bottom:

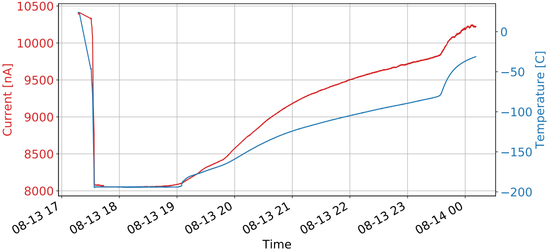
1. Aluminum metalization between Kapton and G10
   - Excess glue
2. Identical + rubber bands
   - Wavy lamination
3. Two step lamination, aluminum glued with epoxy on top of Kapton
   - Successful
4. Single lamination, copper tape on top of Kapton
   - Successful

Kapton lamination cold tests: curves









Kapton lamination cold tests: figures-of-merit

		Current [μA]	R_S [M$\Omega \cdot \square$]	Fraction
Al between (1)	Before	9.222	3.795	1
	Cold	7.363	4.753	1.253
	After	8.981	3.897	1.027
Al between (2)	Before	15.830	2.211	1
	Cold	12.416	2.819	1.275
	After	15.073	2.322	1.050
Al top	Before	16.140	1.859	1
	Cold	11.732	2.557	**1.376**
	After	15.885	1.889	1.016
	Cold	11.562	2.595	**1.396**
	Final	15.723	1.908	1.026
Cu top	Before	10.402	2.884	1
	Cold	8.078	3.714	**1.288**
	After	9.936	3.019	1.047
	Cold	8.054	3.725	**1.292**
	Final	9.873	3.039	1.054

Stantard testing procedure:

- 25V DC metal to metal
- Measurement taken after lamination (*before*)
- Measurement at LN_2 temperature (*cold*)
- Measurement after slow warm up (*after*)

Observations:

- Order % increase in resistance after a cold cycle, seems reasonable

Summary

Prelimary tests confirm Kapton as a viable TPC resistive shell

- Exhibits desired resistance at LN_2 temperature and realistic fields ($\mathcal{O}(1)$ kV/cm)
- Can be bonded to G10 sheets without de-laminating in LN_2
- Can be metalized in multiple ways without loss of conductivity at cryogenic temperatures

Material studies show good predictive power of VRH model:

- Resistance increases as temperature decreases as $\exp\left[T^{-1/2}\right]$
- Resistance decreases as the electric field increases as $\exp\left[E^{1/2}\right]$

To be investigated:

- 100 V/cm resonance with high voltage probe
- Longer-term stability tests

Technical note being assembled.