Study of High Voltage Contacts in Liquid Nitrogen

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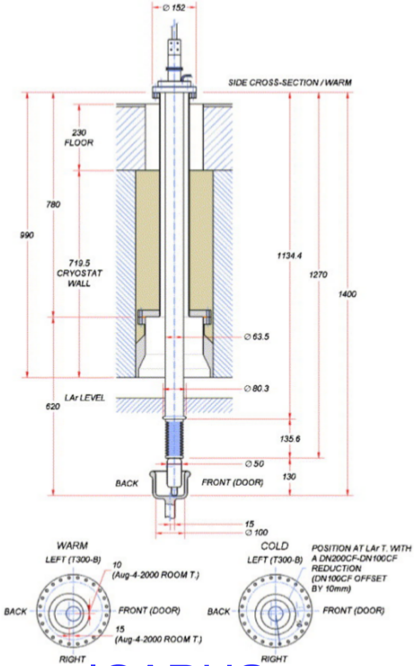
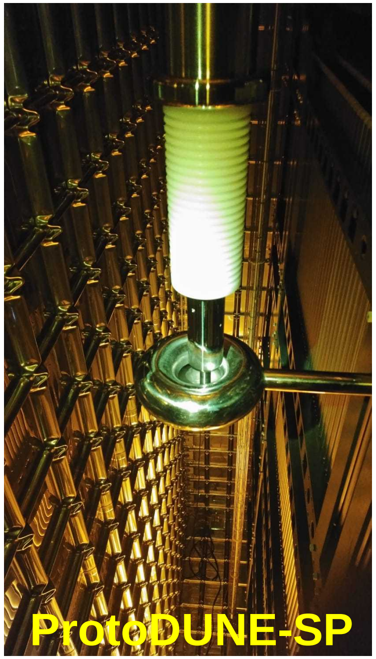
HV system consortium meeting
SEP 03, 2019

Motivation: High Voltage Contact Issues



ICARUS



- Spring contact design was first used by the ICARUS experiment*
- MicroBooNE's HV feedthrough experienced contact issues
  - Observed small voltage fluctuations in 1-2 year time scale, thought to be caused by contact problems.
  - The fluctuations were eliminated by "scraping the contact" using freedom provided by the mounting bellows to move the contact tip sideways
  - This led to the hypothesis that the source of the contact problems might be an ice layer between the high voltage contact tip and the cathode receptacle cup

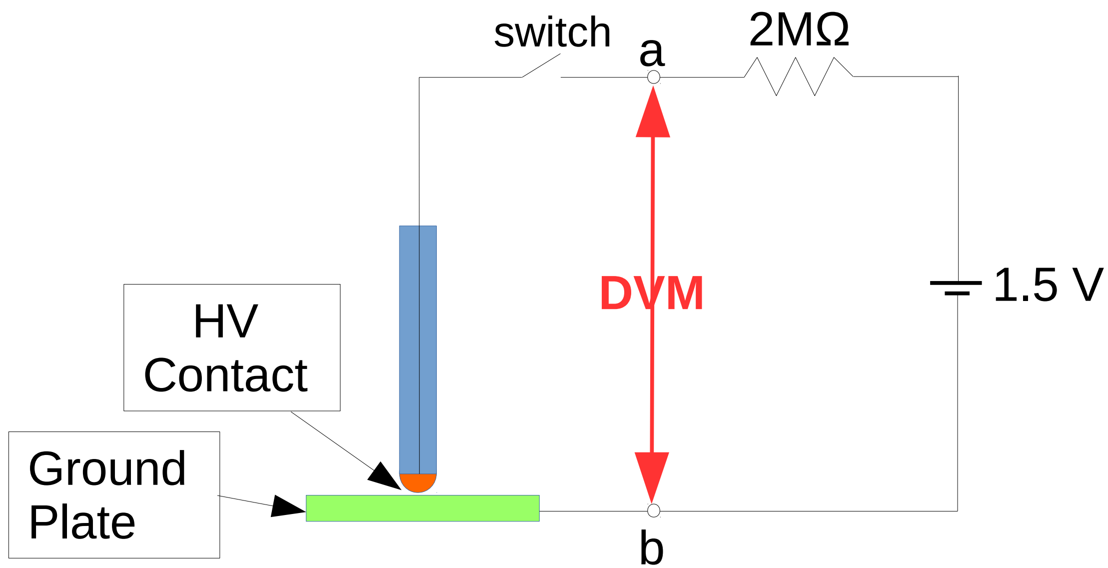
*ICARUS collaboration, "Design, construction and tests of the ICARUS T600 detector" Nucl. Inst. Meth., A527 329-410 (2004)

Solving the Bad Contact Problem: Trying Various Solutions

- Previous method to solve the contact problem
  Scratching → Inconvenient since the experiment has to be interrupted

- The methods we studied to make good contacts
  - Add pressure to the contact by reducing area
  - Add pressure on the contact surface by increasing force
  - Contact Shape
  - Multi-finger contact
  - High Voltage Sparking
  - Prevent the ice layer from forming between the two contacts

Experimental Setup



- Measured Observable: $V_{ab} \rightarrow \begin{cases} \sim 0 \text{ if good contact} \\ \text{Open circuit if bad contact} \end{cases}$

General Procedure for Each Measurement

- Clean up the ground plate
- Refill LN_2 (open dewar)
- Wait for the ice condensation on the ground plate (~2 hours)
- Clean up the contact before the measurement
- Find the bad contact spots
  (Gently move the finger, not to destroy /scratch the bad contact spots)

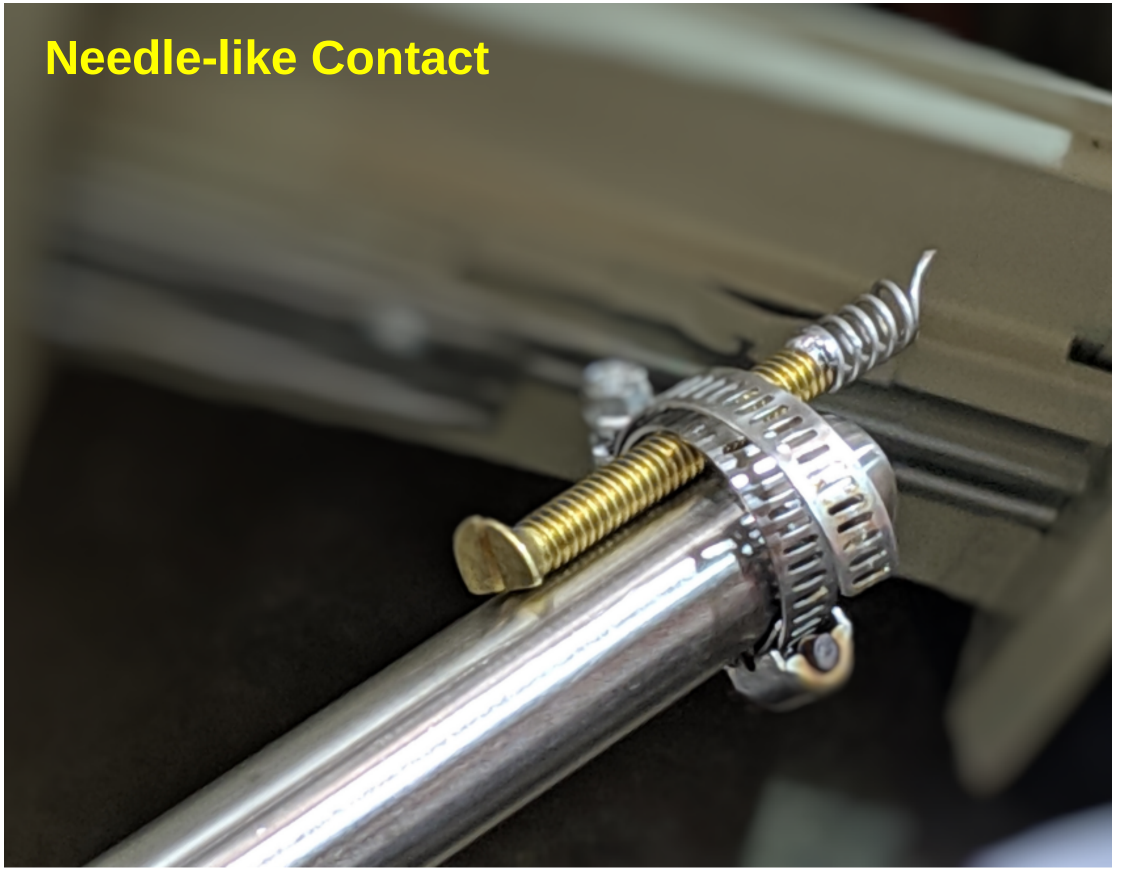
More info: After we covered the dewar and waited for one day, there was less “ice” condensation and all spots were good. → “Water” comes from the environment.

Add Pressure on the Contact: Increase Force

- 2 bad contact spots were used
- Finger: 3/8" steel ball
- Applied calibrated weights on the ball contact* (1.25 kg, 1.35 kg, and 2.27 kg)
- Result:
  → Bad spot #1 became good after 2.27 kg load
  → Bad spot #2 became good after 1.35 kg / 2.27 kg load
- This effect is repeatable
  → After removing the load, bad spots stayed bad

*Rough estimate of contact force without the added weigh: < 100 g

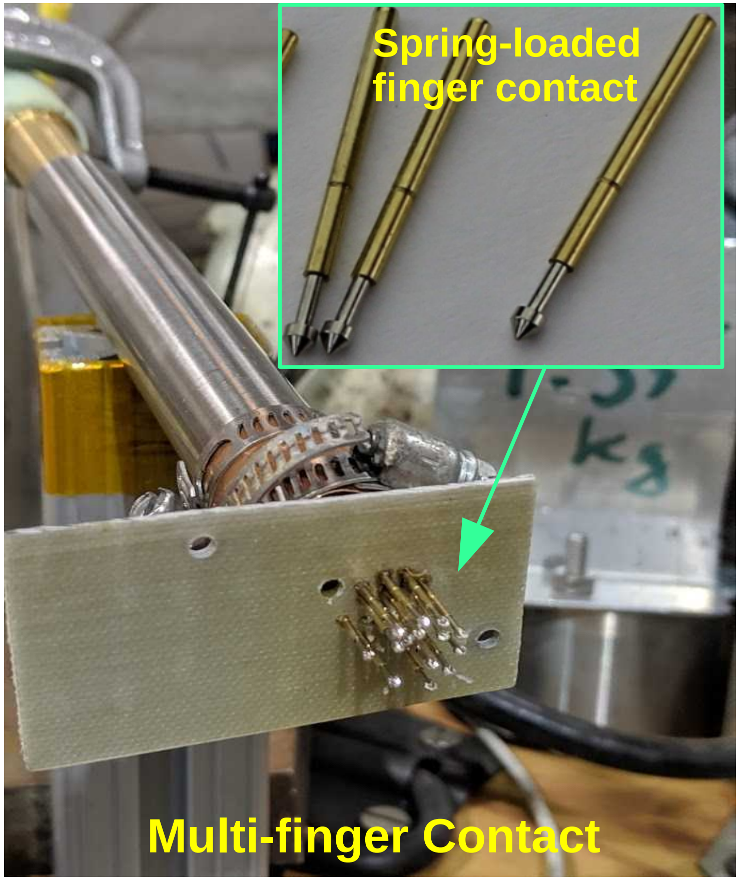
Add Pressure on the Contact: Reduce Contact Area



- Use reference finger to locate the bad spots
- Use needle-like contact for the measurement
- All the bad spots* became good after using the sharp contact

* ~10 bad spots in total

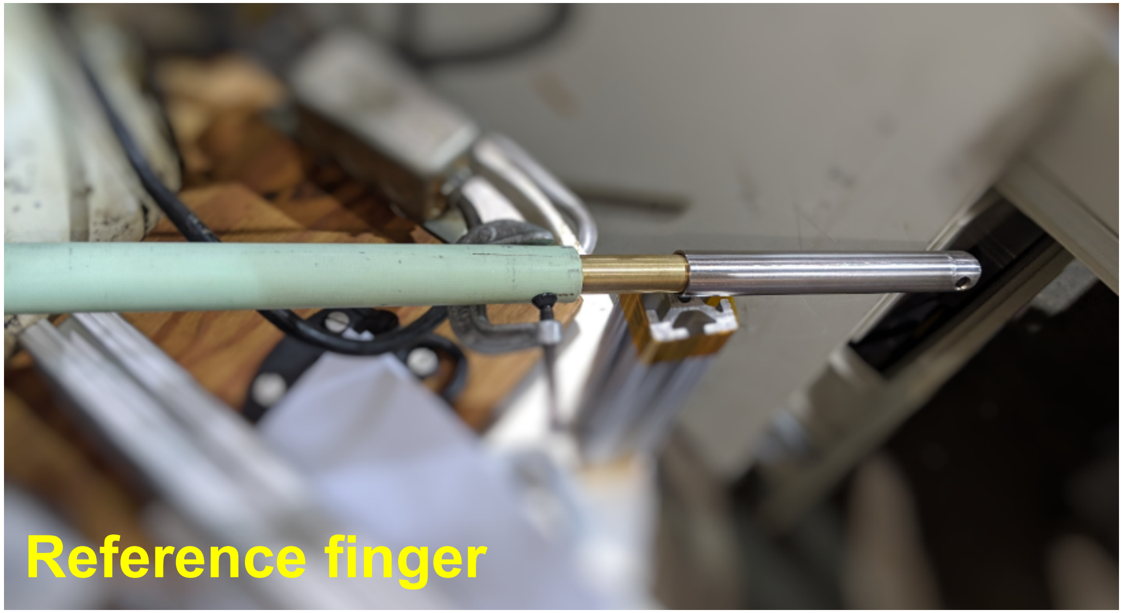
Add Pressure on the Contact: Multi-finger



- Advantages of using multi-finger contact:
  Probing multiple areas
- Use a contact with 13 fingers
- Test environment:
  Ground plate covered with a heavy ice layer
- Result:
  ~50% of bad spots* → Good right away
  ~50% of bad spots → Good after applying a very slight pressure (O(100 g))

* ~10 bad spots in total

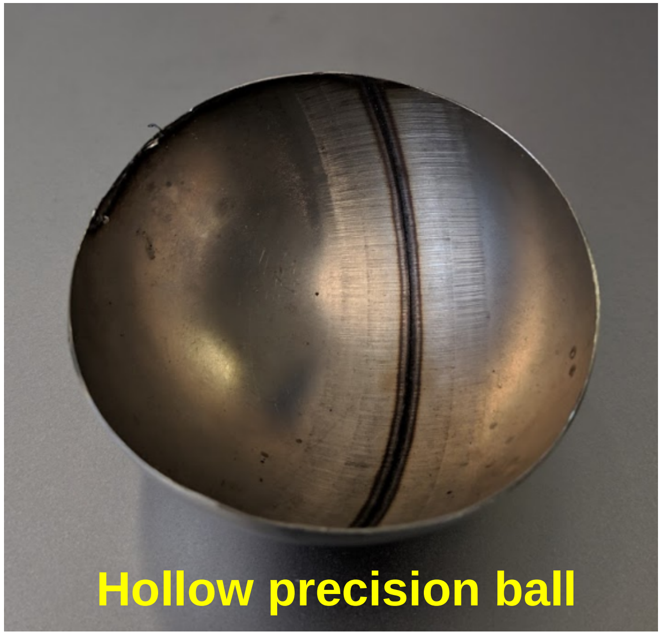
High Voltage Sparking

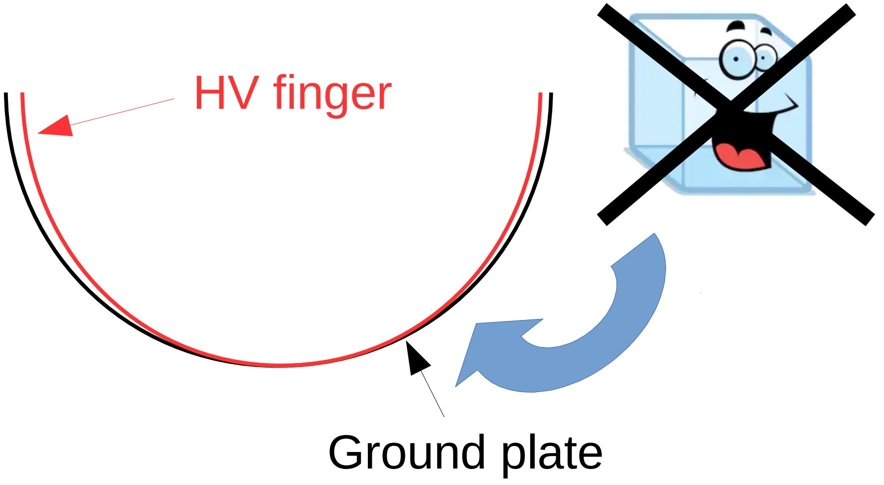


- Reference finger for the measurement
- Applied 500 V – 3 kV on the reference finger
- 9 bad contact spots were used
- Result:
  - Bad spots remained good at 1.5 V after “HV sparking”
  +3 bad spots became good at lower voltages(500 V, 1 kV, and 1.3 kV)
  +3 bad spots became good at 3 kV
  - 3 stayed bad at 3 kV
  → Explanation: Different thicknesses of the insulating layers

Prevent the insulating layer from forming between the two contacts

- Indication of an insulating layer building up in between the contact area
- Use two half hollow precision balls to make the contacts
- Very small gap between the 2 contacts provides a barrier to ice/water entering
- No contact issues during our measurement





*See slide #20, based on the known composition of the atmosphere, ice is a good guess

Some Thoughts about the Contact Design

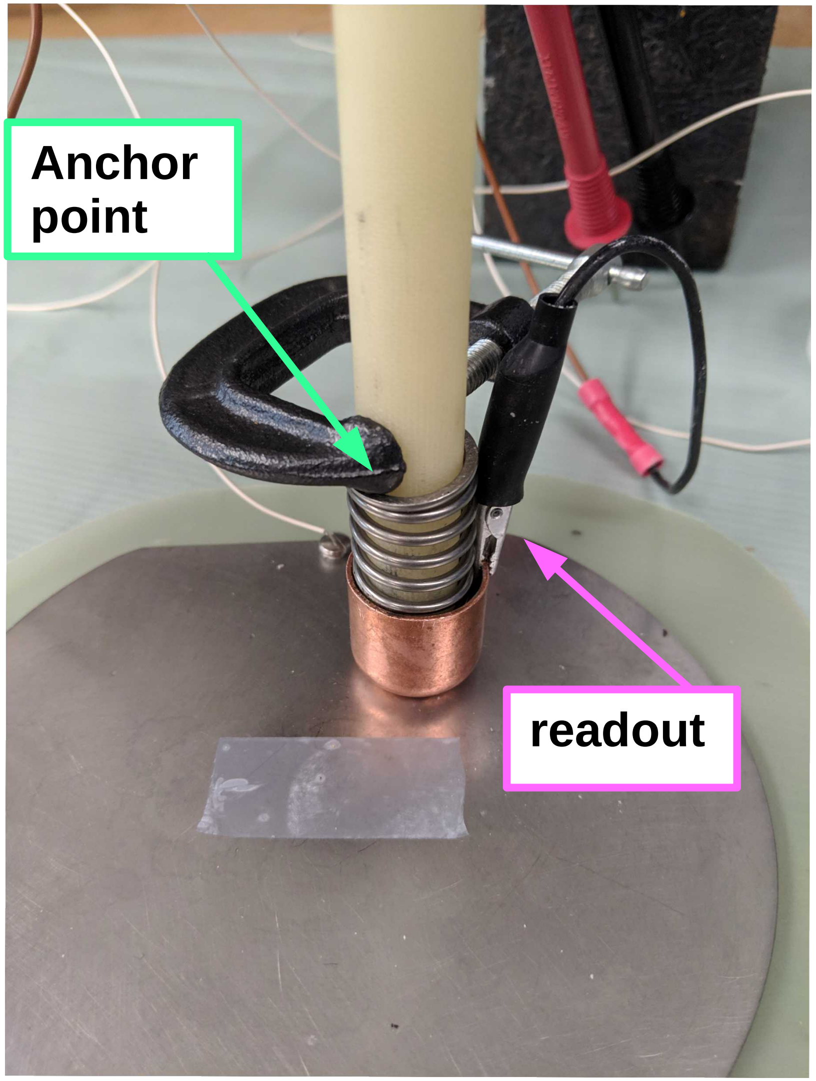
- It would be desirable to come up with a design that is not too different from the current design, yet will be reliable in the long run
- Or we can do the maintaince to “clean up” contact area annually
- Other approaches like seal the contact area, ...

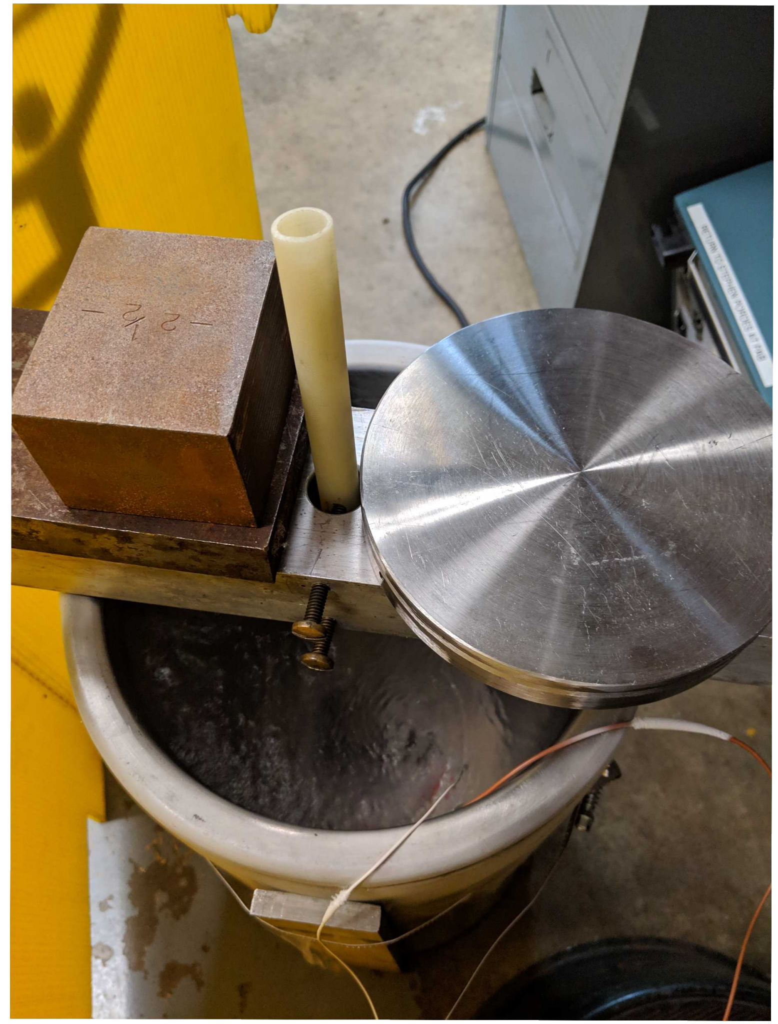
Summary & Outlook

- Our study indicates that bad high voltage contact issue in LN_2 is due to the formation of an insulating layer between the contact finger and the ground plate.
- The insulating layer can be removed by
  (1) mechanical scraping,
  (2) increasing the contact pressure (sharp needle contact),
  (3) multiple contacts,
  (4) high voltage sparking.
- The layer can also be prevented from entering the contact area
- The study is documented in the DocDB #14251 (https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=14251)

Backup

“Ice Thickness” Measurement

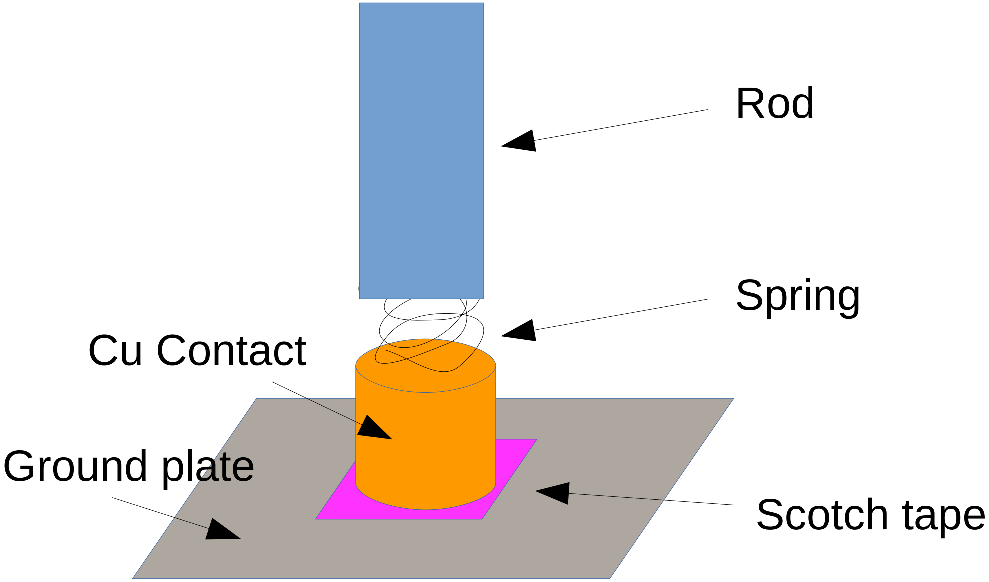




"Ice Thickness" Measurement: Calibration

	Measured Capacitance [in air]
Direct contact	18.57 uF
Scotch tape in between	101.5 pF

p.s. ~ 16 pF without any connection



Spec of Scotch Tape

Catalog Number	Description
Scotch® Magic™ Tape 810	A tape that is frosty in appearance on the roll, yet invisible on most office papers. Ideal for permanent paper mending and splicing. Pulls of the roll smoothly and cuts easily. Comes on 1 inch and 3 inch cores, multiple widths

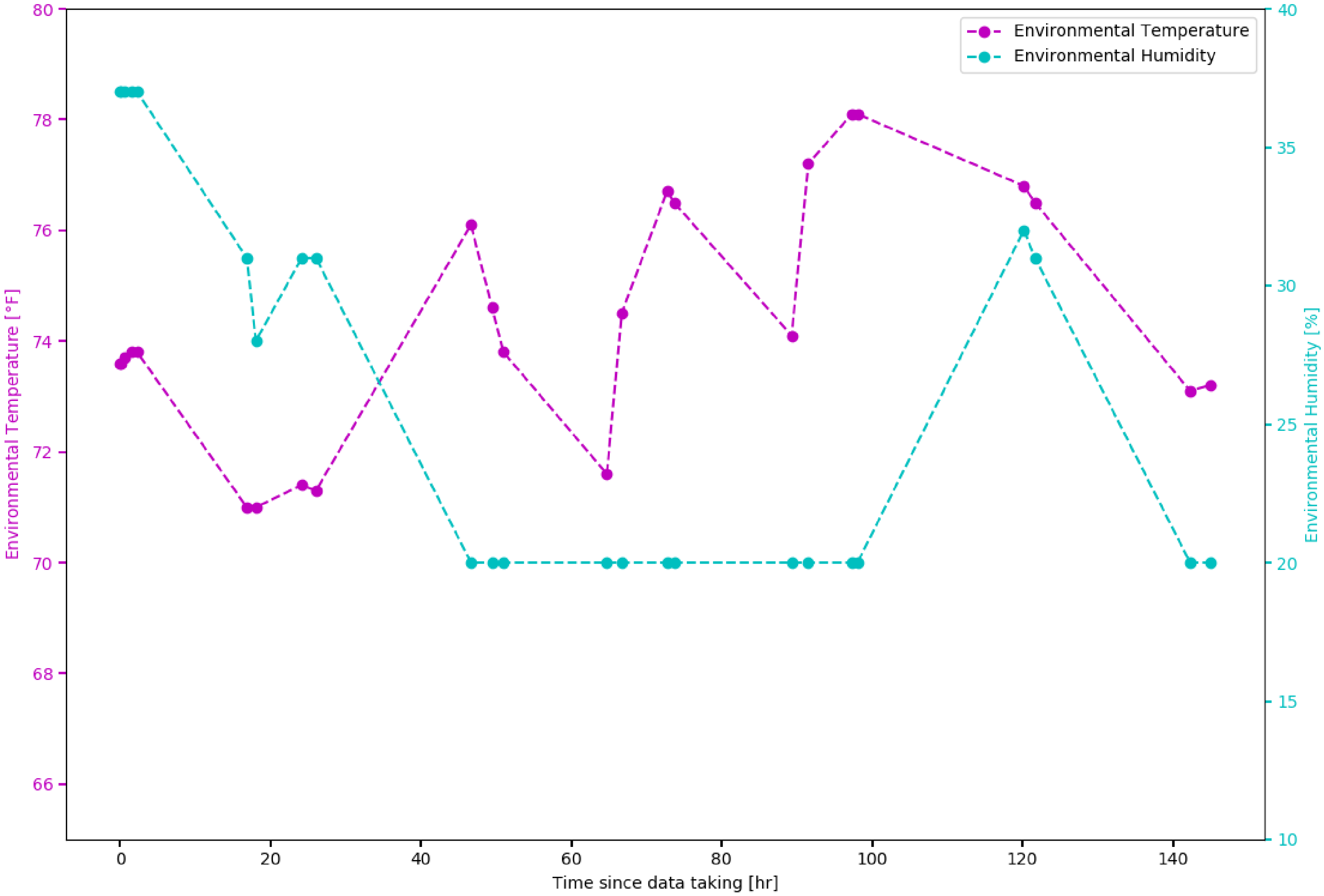
Product Characteristic	Value
Backing:	Matte cellulose acetate
Backing thickness	38 microns
Adhesive:	Synthetic Acrylic
Adhesive thickness	22 microns
Adhesion to Steel:	2,5 N/cm ASTM D-3330 / AFERA 4001
Unwinding force :	75 cN/cm ASTM D-3811/ AFERA 4008
Tensile Strength:	2.6 daN/cm ASTM D-3759/ AFERA 4004
Elongation at break:	25% ASTM D-3759/ AFERA 4004
Total Thickness:	0.060 mm ASTM D-3652/ AFERA 4006
pH	5,8

“Ice Thickness” Calculation

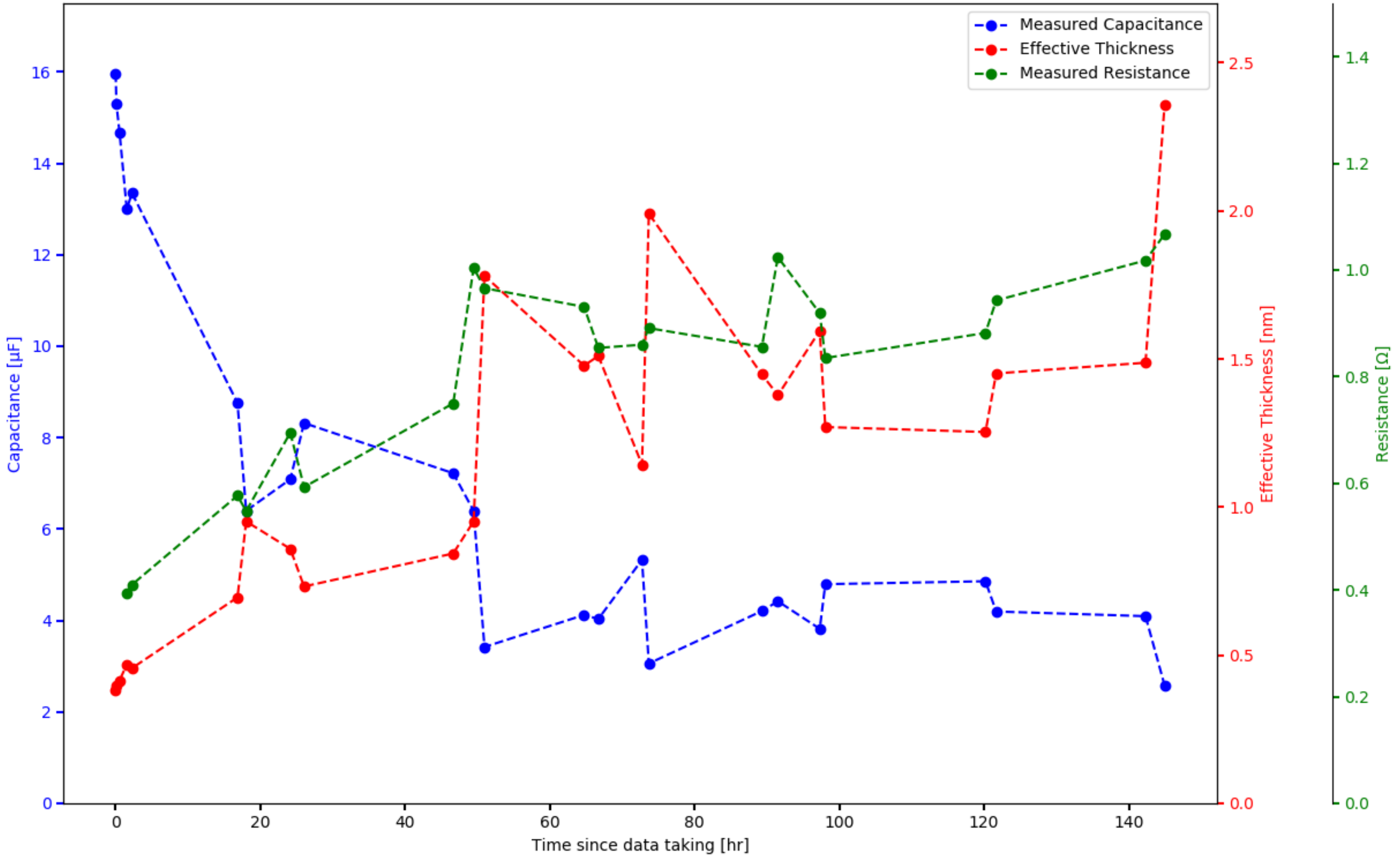
- Use a simple calculation to have a rough estimation on the ice thickness
- Use the thickness of Scotch tape as a reference for the estimation of ice thickness

  - Assume the thickness of Scotch tape doesn’t change
  - C1d1=C2d2
  - Equivalent thickness
    d=(60 μm*101.5 pF)/(measured capacitance)

“Ice Thickness” Measurement: Environment



“Ice Thickness” Measurement: Result



Major constituents of dry air, by volume

	Volume (in %)	Freezing Point (°C)	Freezing Point (°F)
N_2	78.084	-210°C	-346°F
O_2	20.946	-218.8°C	-361.8°F
Ar	0.9340	-189.4°C	-308.8°F
CO_2	0.041332	-78.5°C	-109.2°F
Ne	0.001818	-248.6°C	-415.5°F
He	0.000524	-272.2°C	-458°F
CH_4	0.000187	-182°C	-295.6°F
Kr	0.000114	-157.4°C	-251.2°F
Water Vapor	0-3 %	0°C	32°F