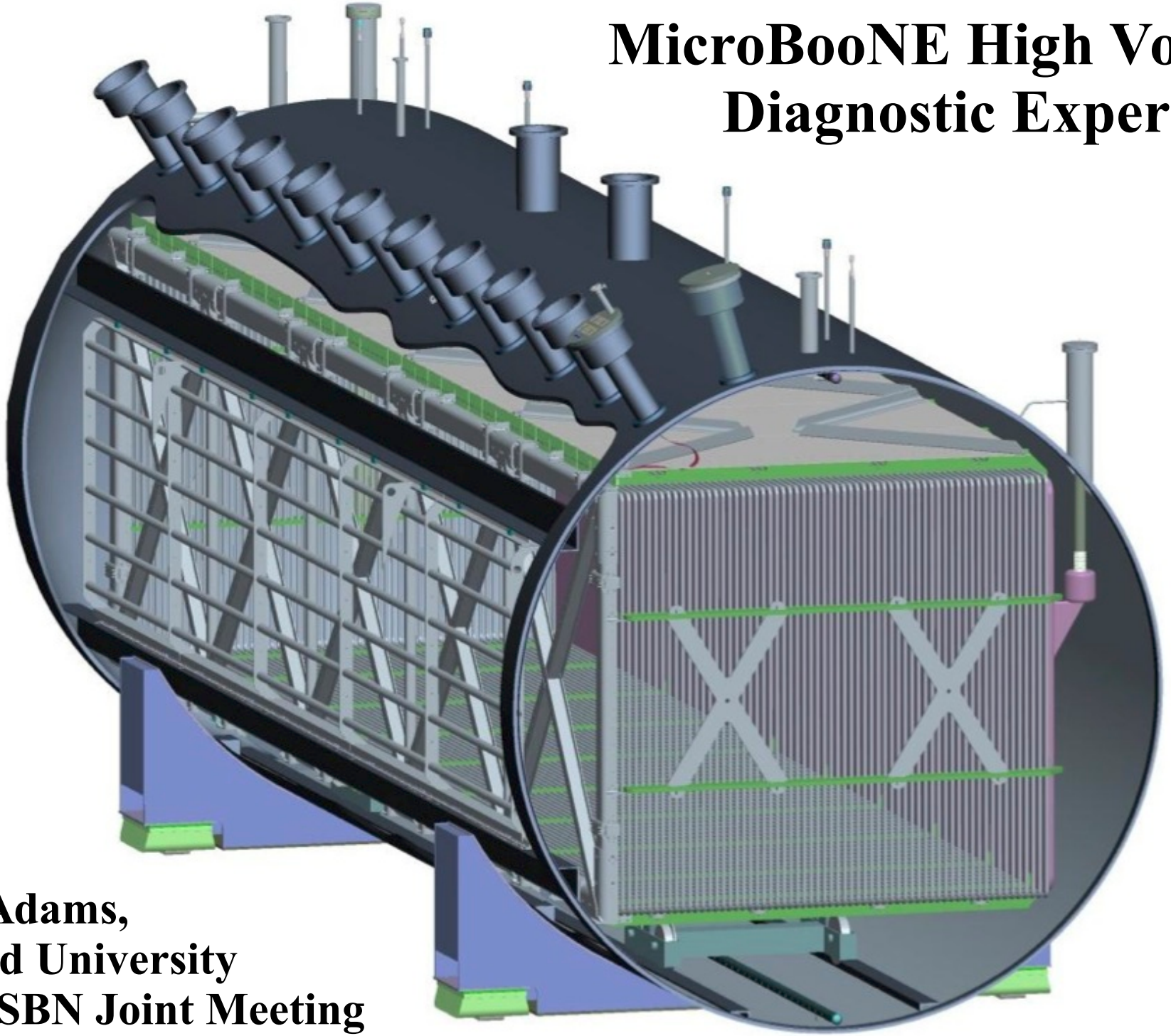
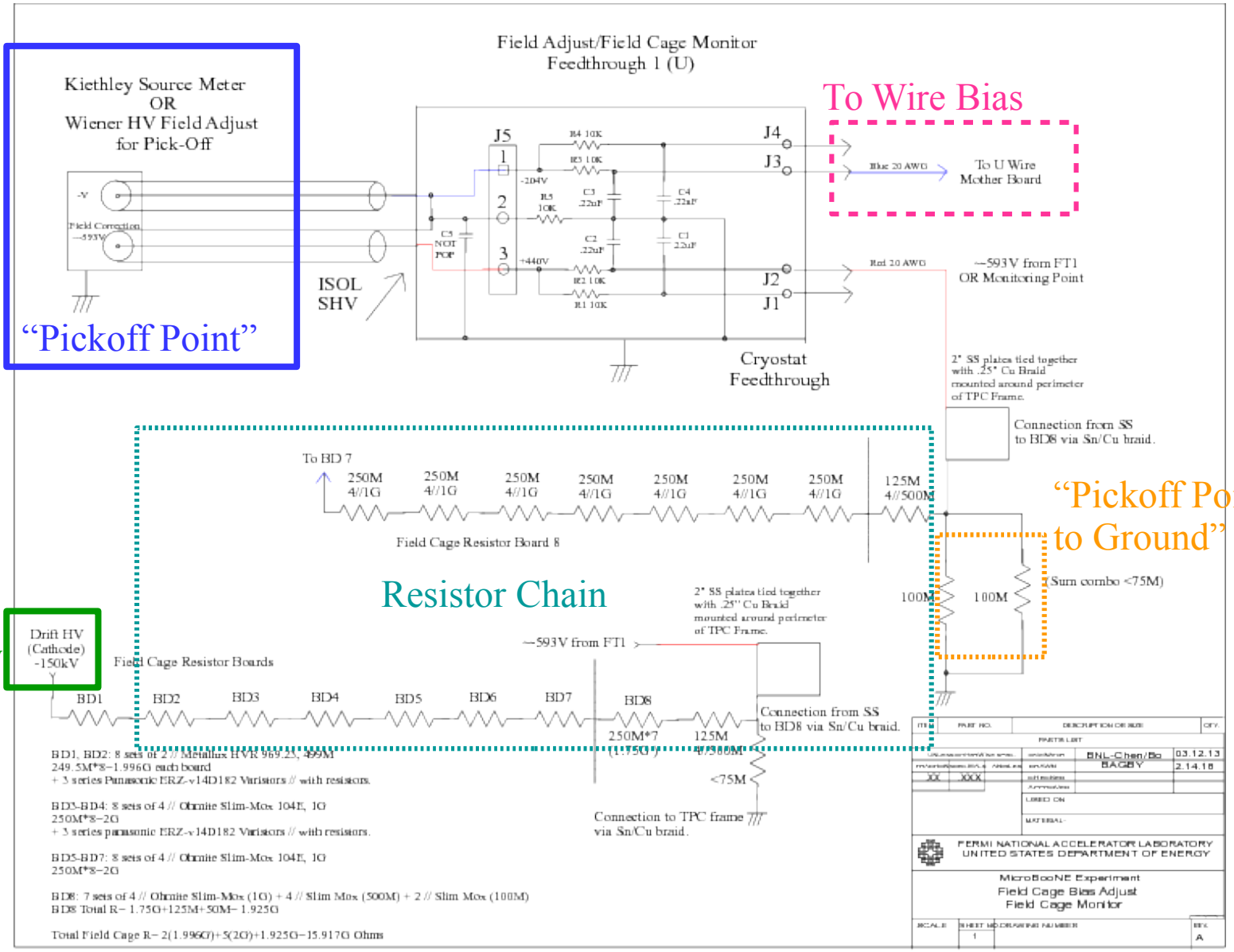
MicroBooNE High Voltage Diagnostic Experience

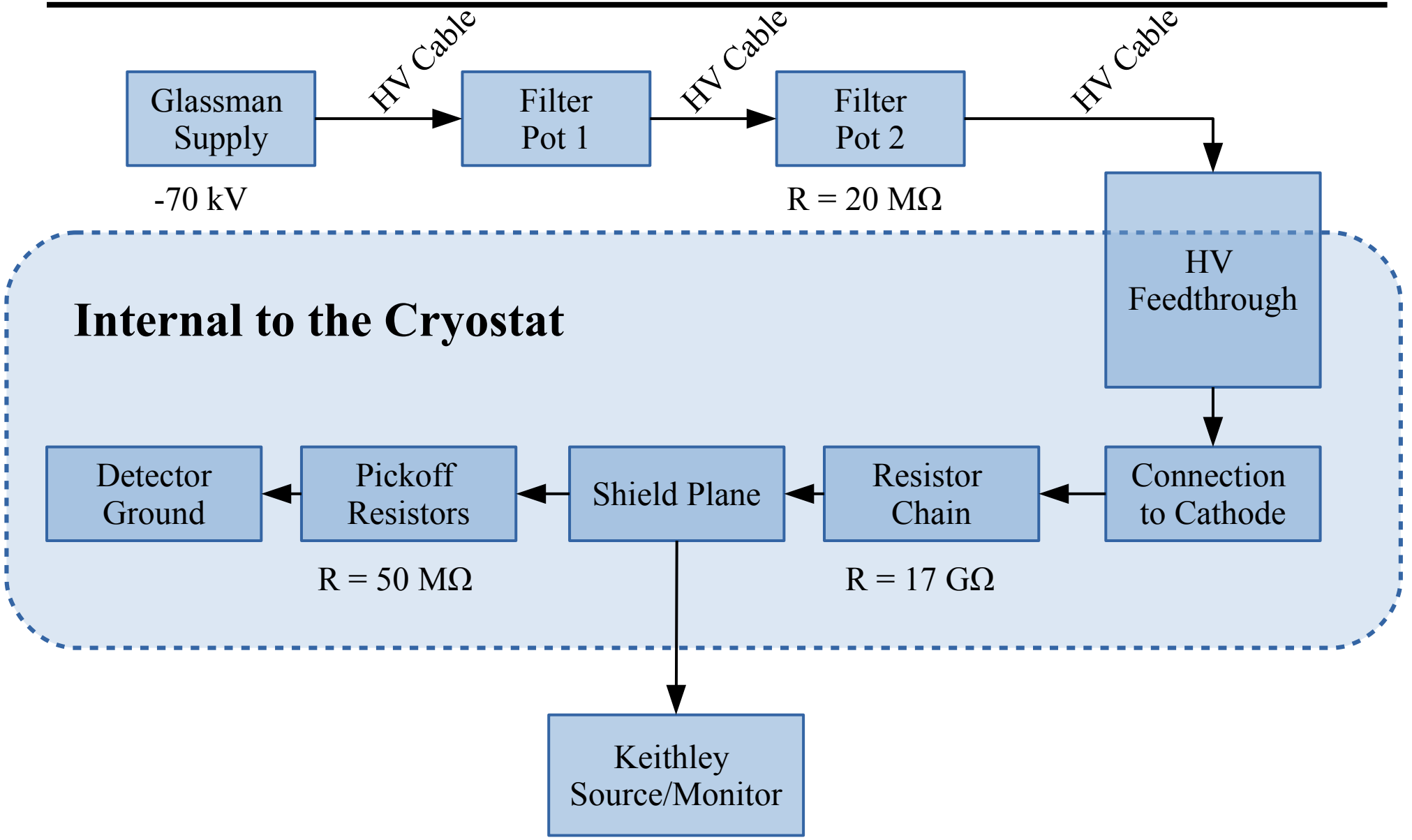


Corey Adams,
Harvard University
DUNE/SBN Joint Meeting
May 15, 2017

MicroBooNE High Voltage System



Simplified High Voltage System



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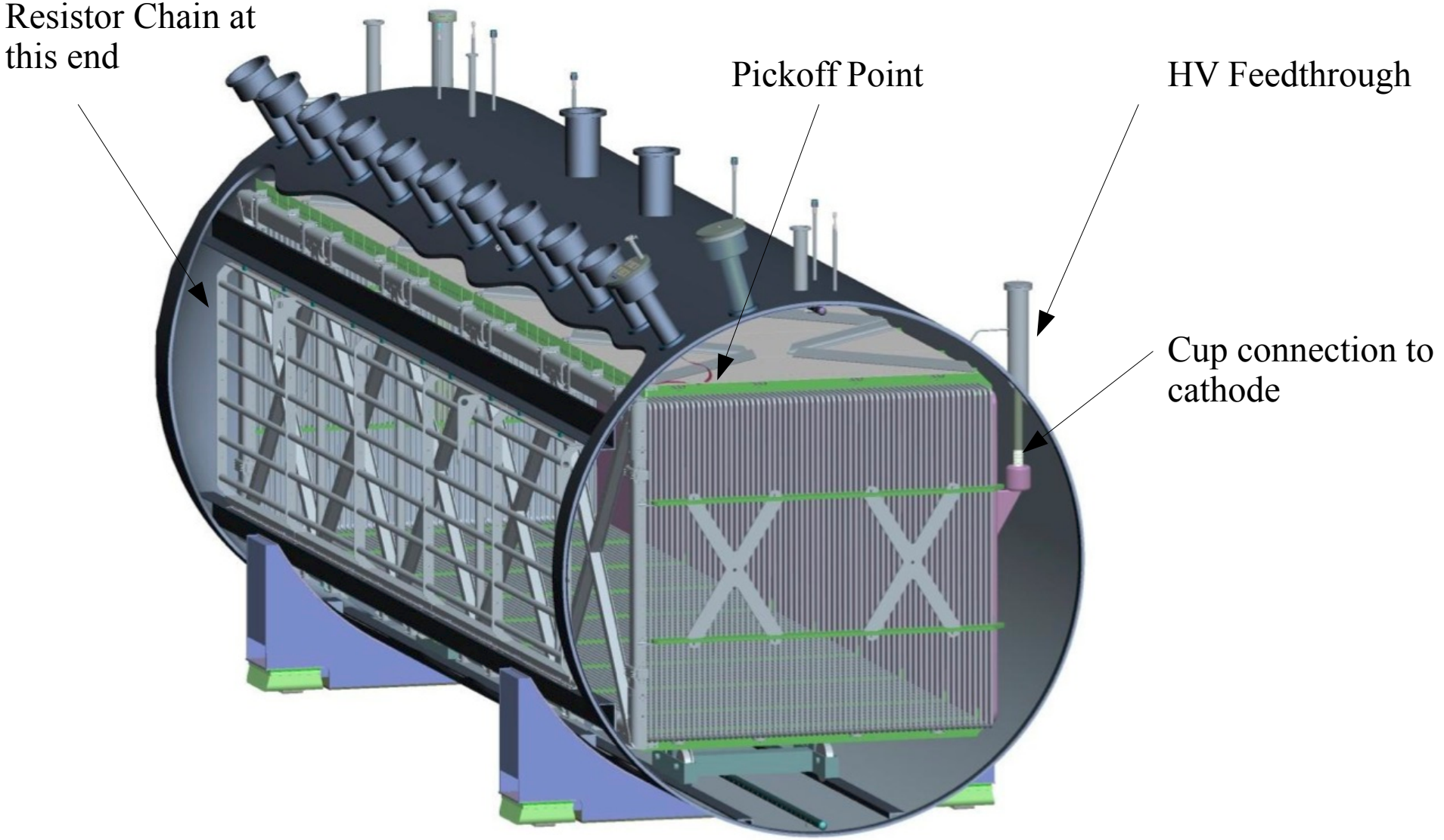
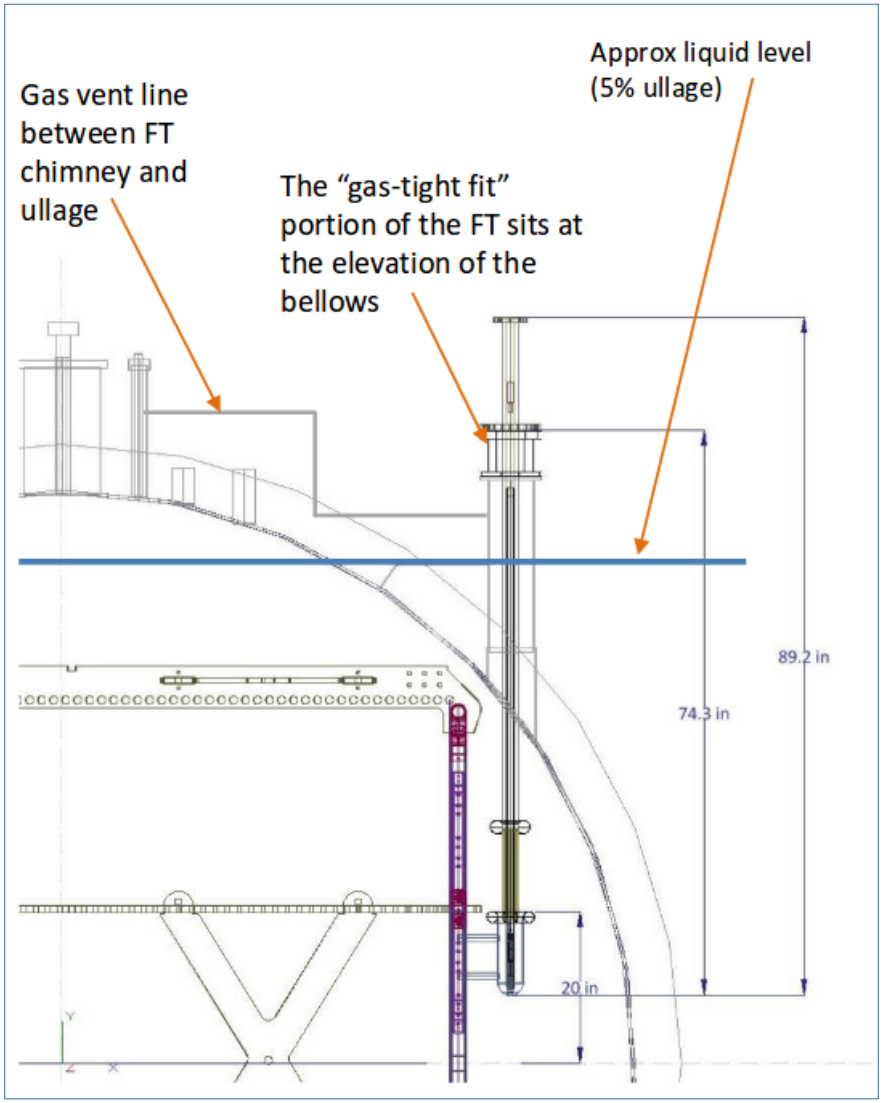


FT Connection to Cathode



Microboone docdb 7049, Cat J.

HV Feedthrough

↓

Connection to Cathode

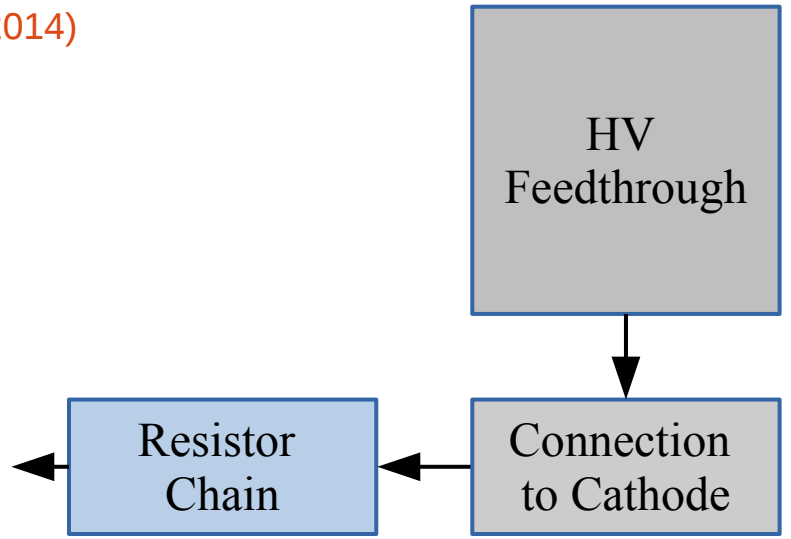
Microboone docdb 3024, Sarah L. and Hans J.

Resistor Chain

Detail – attachment of resistor chain to the cathode

We picked these resistors to withstand possible current surges:

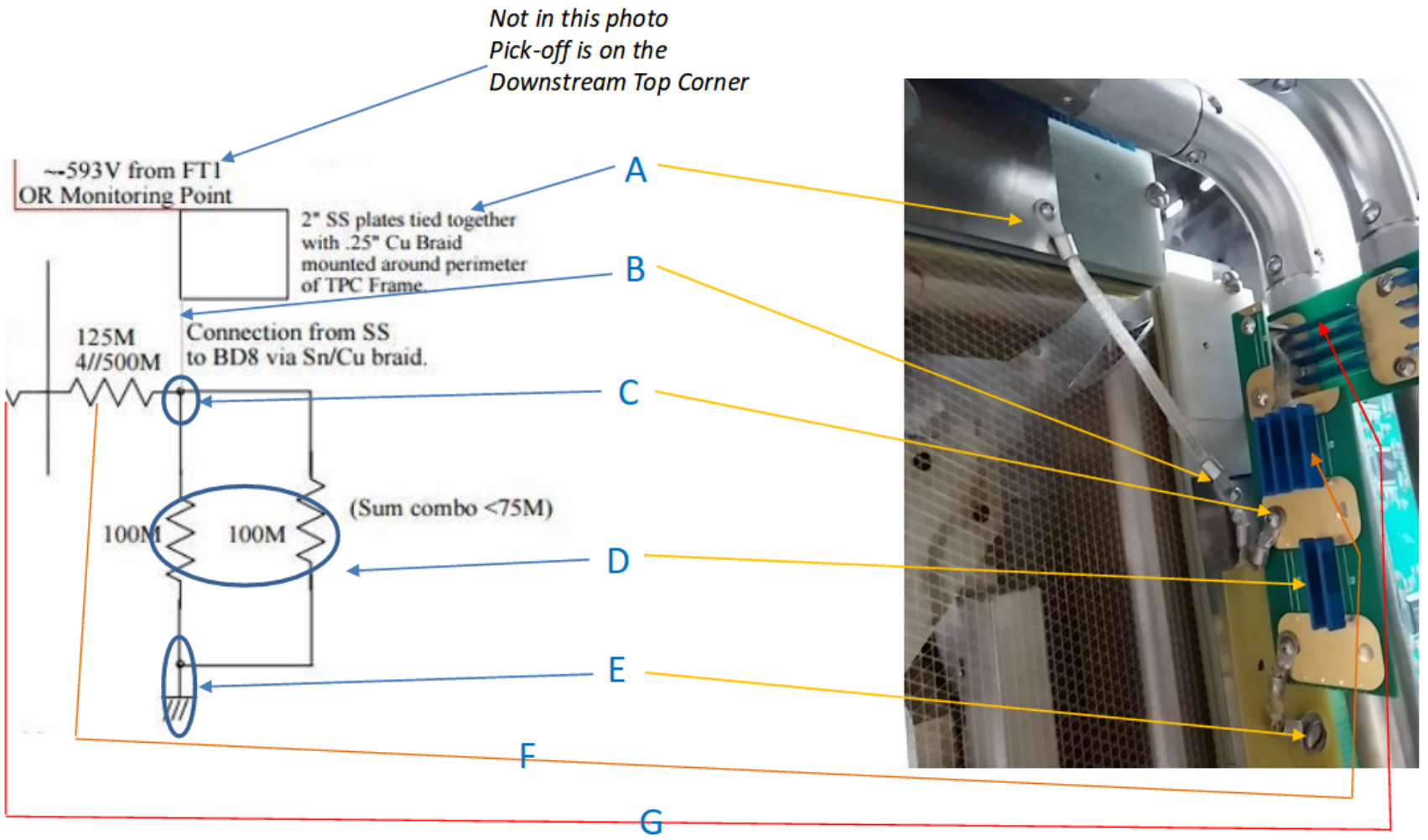
JINST 9, P09002 (2014)



R = 17 GΩ

Microboone docdb 7049, Cat J.

Field Cage Termination



Microboone docdb
7049, Cat J.

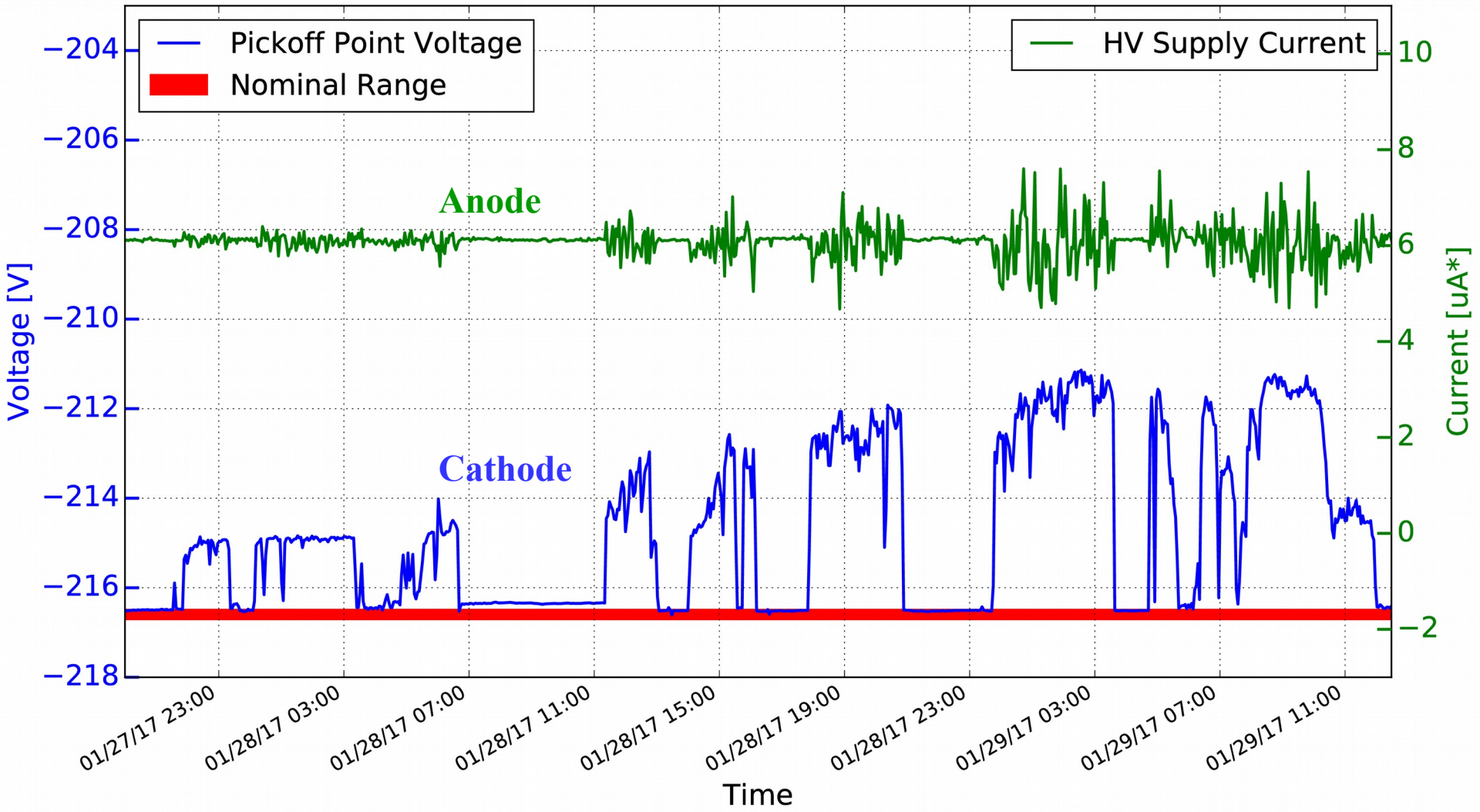
Monitoring Variables

- HV Power Supply
  - Set Voltage
  - Readback Voltage
  - Calculated Current
    - RMS of Calculated Current
- Pickoff Point (held at I = 0)
  - Measured Voltage
    - Time variation of Voltage
- Pickoff Point (held at $V = V_0$)
  - Measured Current

Monitoring Complications

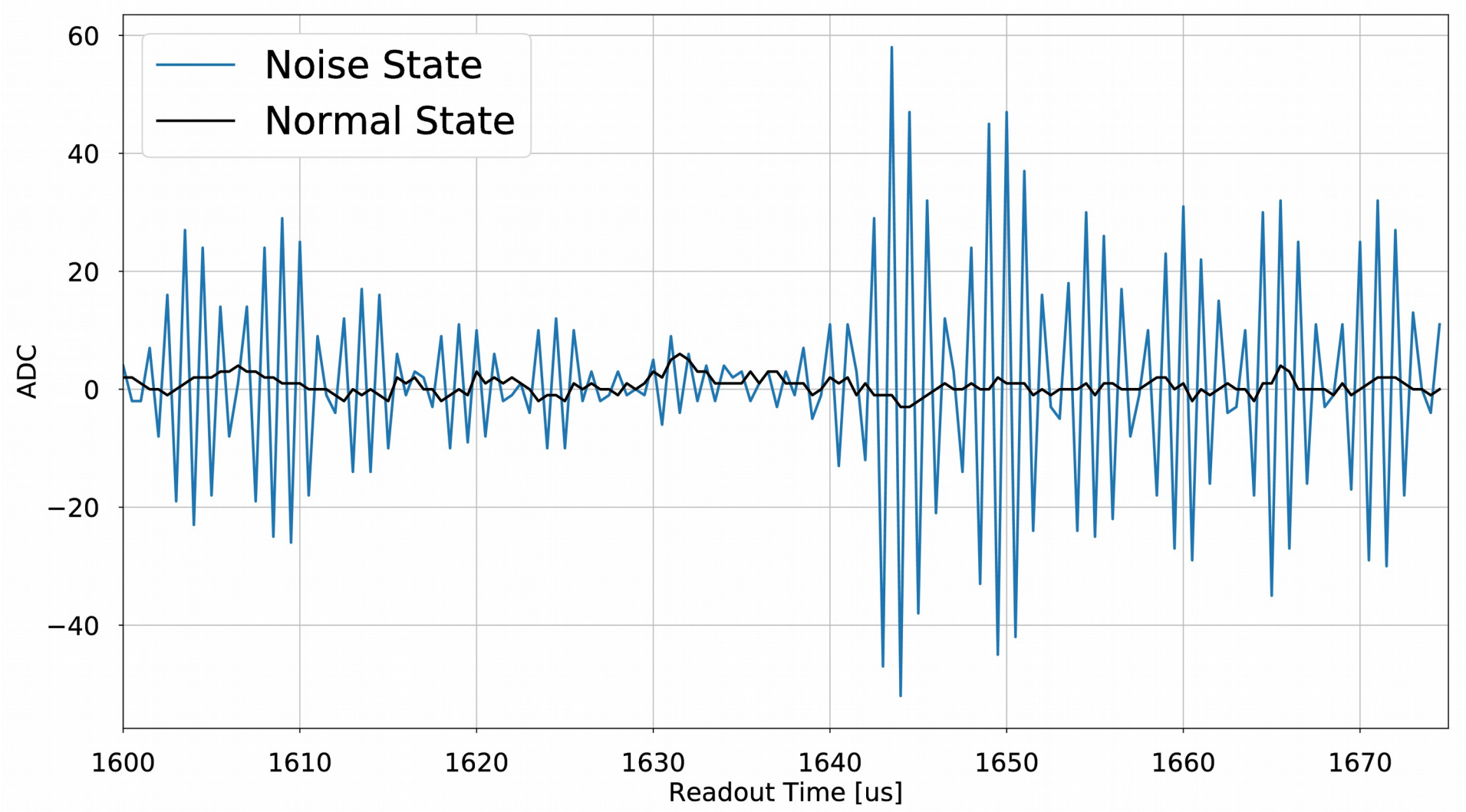
- HV Power Supply
  - Calculated Current is small, not precisely calibrated
    - (This was something of an issue – pick your supply carefully!)
- Pickoff Point (held at I = 0)
  - Large RC constant between pickoff point and cathode, no prompt measurements of cathode activity
- Pickoff Point (held at $V = V_0$)
  - (Same as above)

Abnormal Operations

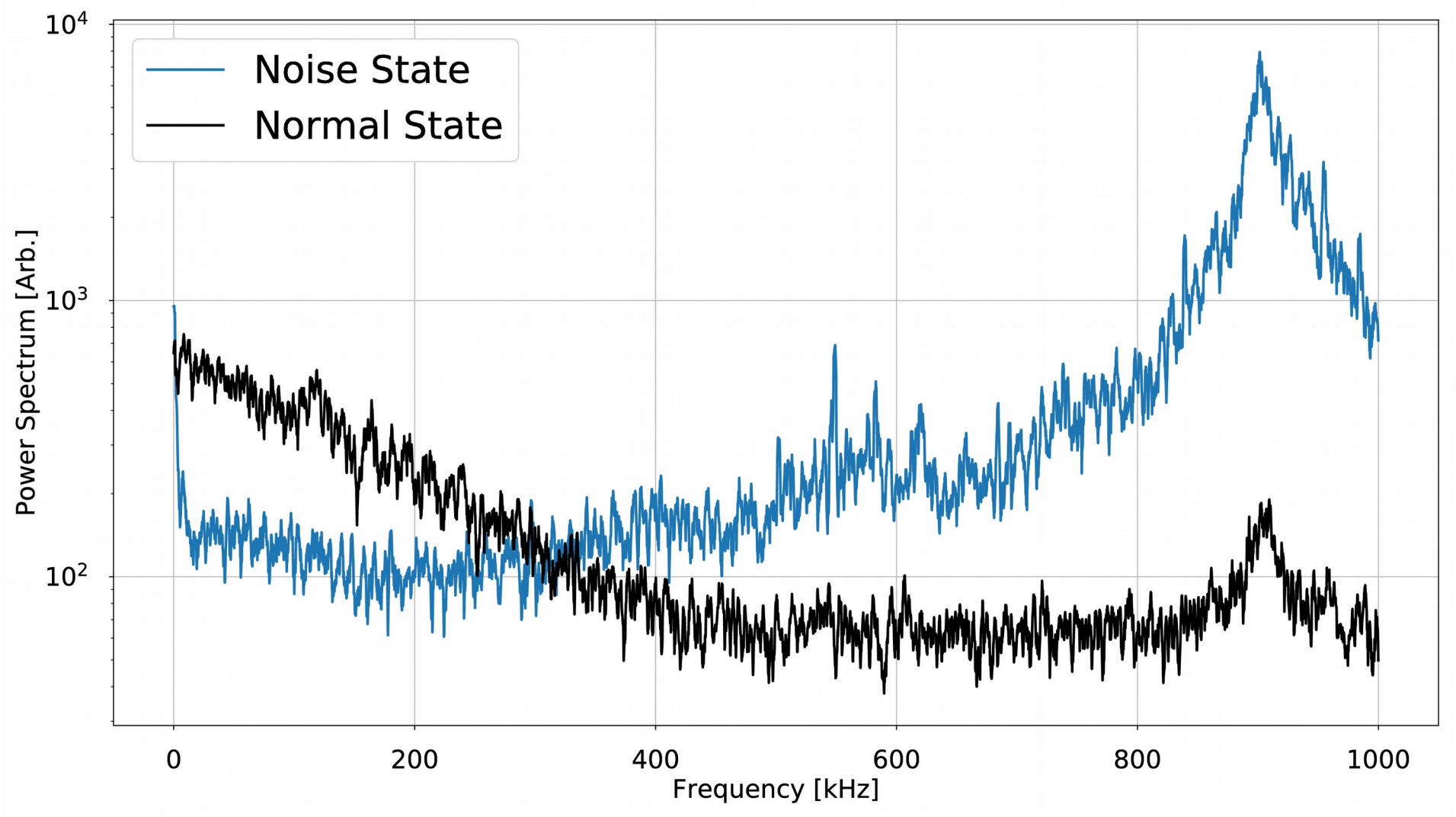


Abnormal Operations - Noise

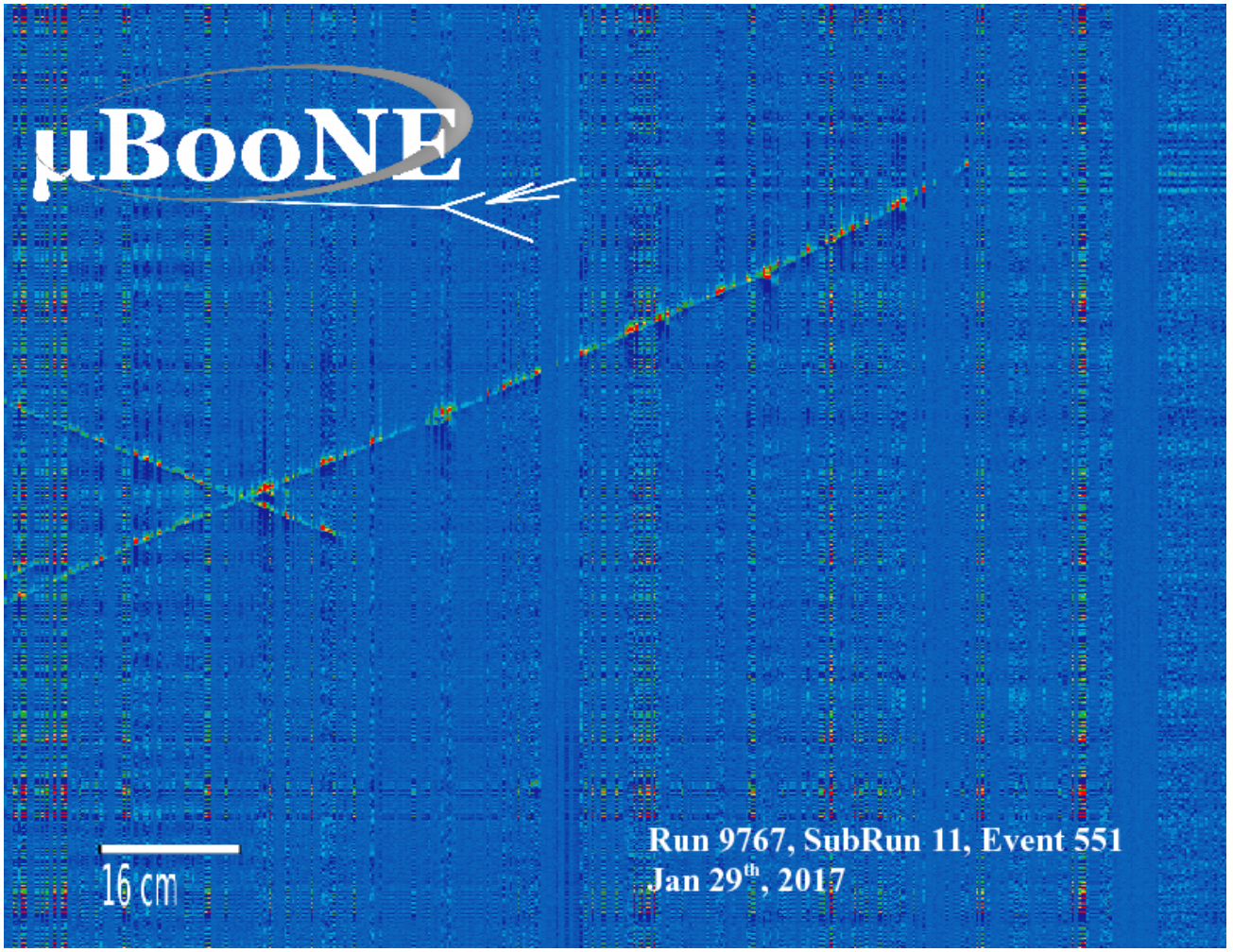
We also saw increased noise on electronics channels:



Abnormal Operations – Noise FFT



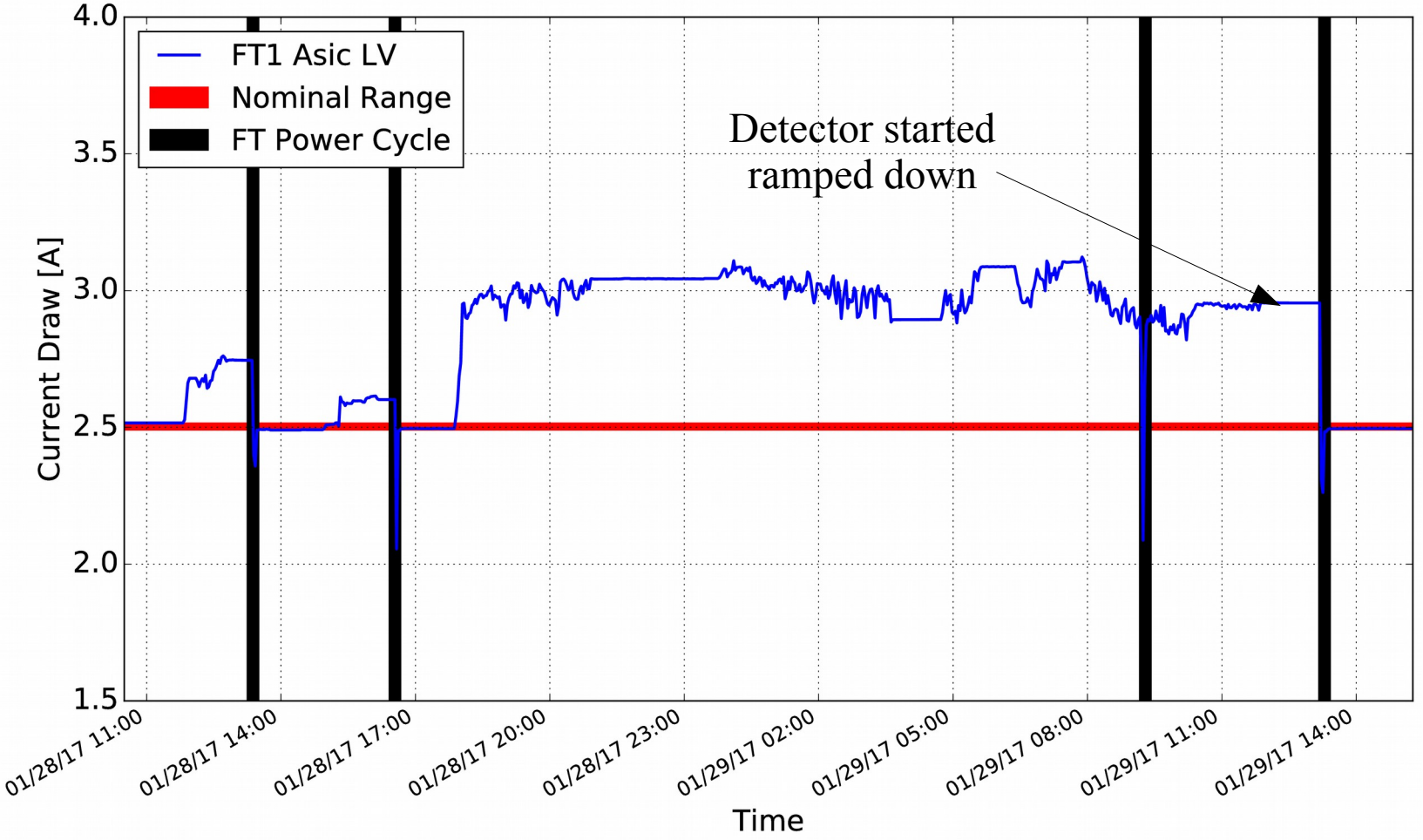
Abnormal Operations



Part of the detector went into a persistent, high frequency noise state.

High voltage effect, or electronics effect triggered by HV instabilities?

Abnormal – Power Draw on Cold Asics



Very high current draw on channels in noise state, not always fixed with power cycle.

MicroBooNE Goes Down

- A number of factors triggered us to ramp the detector down:
  - Deviations on the pickoff point
  - Instabilities on the current draw by the HV power supply
  - High current draw on the electronics, primarily at the downstream end (closest to HV Feedthrough)
- It was unclear if we were risking permanent damage to the detector.

MicroBooNE was down for 4 weeks while diagnosing and resolving this problem.

Careful Investigation: Null Results

- Replaced HV Power Supply
- Checked for AC noise - none
- Checked connects of HV cables at both filter pots, HV Feedthrough – no problems
- Checked for stability at lower drift fields
  - Still saw problems
- Ran the HV supply "in-air" - testing all the components of the warm supply, without connection to the HV Feedthrough
  - Everything is perfect
  - **The problem must be downstream of the HV supply and filter.**

Careful Investigation: Null Results

- Replaced HV Power Supply
- C
- C
- C
- I
- C
- I

of

We carefully checked components in the order of accessibility and risk to the experiment.

We frequently postponed tests that carried risk to the experiment until we decided it was the best way to proceed.

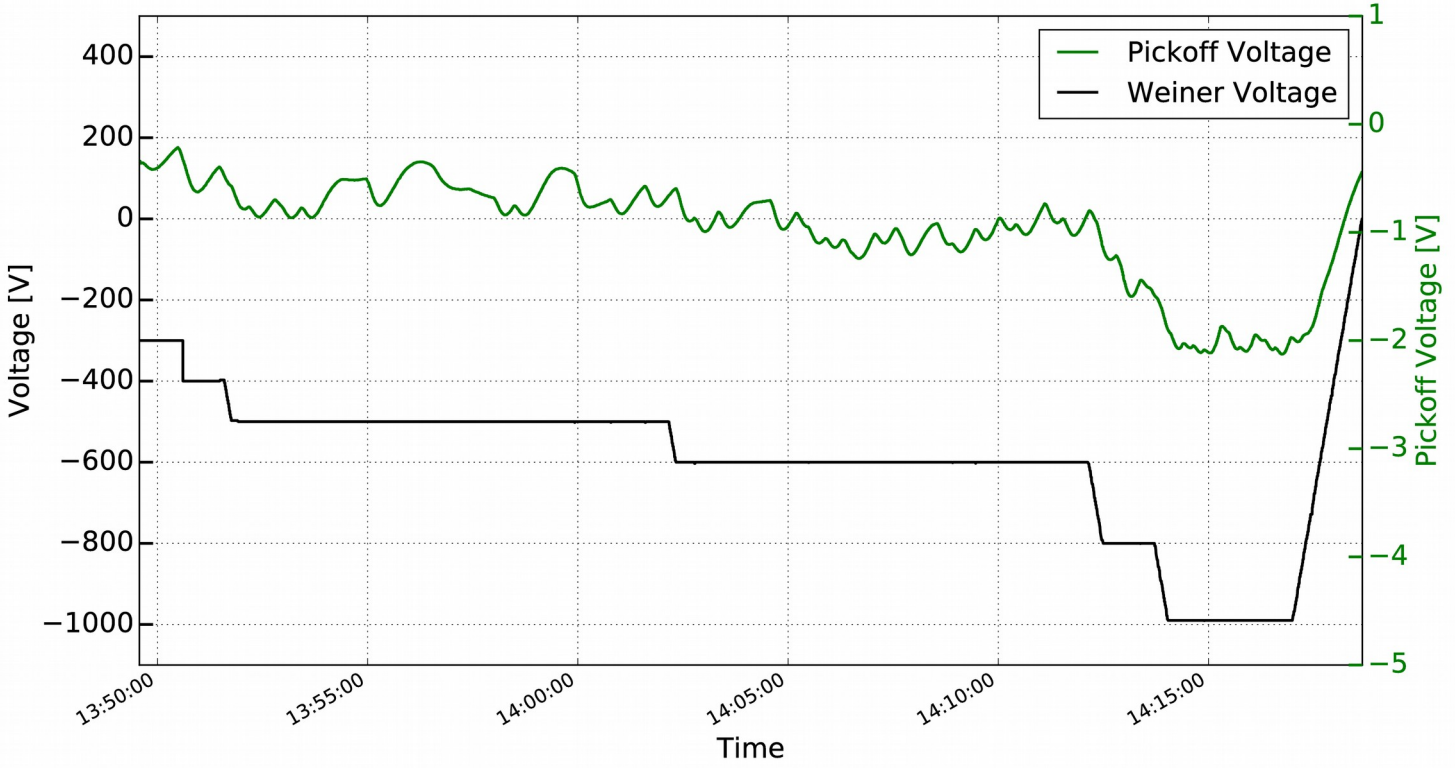
The problem must be downstream of the HV supply and filter.

Measuring as Much as Possible

- Measured resistance of the field cage
  - More on this …
- Measured resistance of the pickoff point to ground
  - Pickoff point monitor also acts as a source meter, so we biased the pickoff point and found its resistance was as designed.
- Through all of this, kept the DAQ running with an external trigger and careful documentation of the running conditions (HV, wire bias on/off, pickoff point settings, etc).
  - Seems obvious, but the offline data analysis was **essential**.

Resistance of Field Cage: V vs. V

- With some wire and tape, we connected an external Weiner supply to the HV FT and ran at low voltage with a very well know supply.



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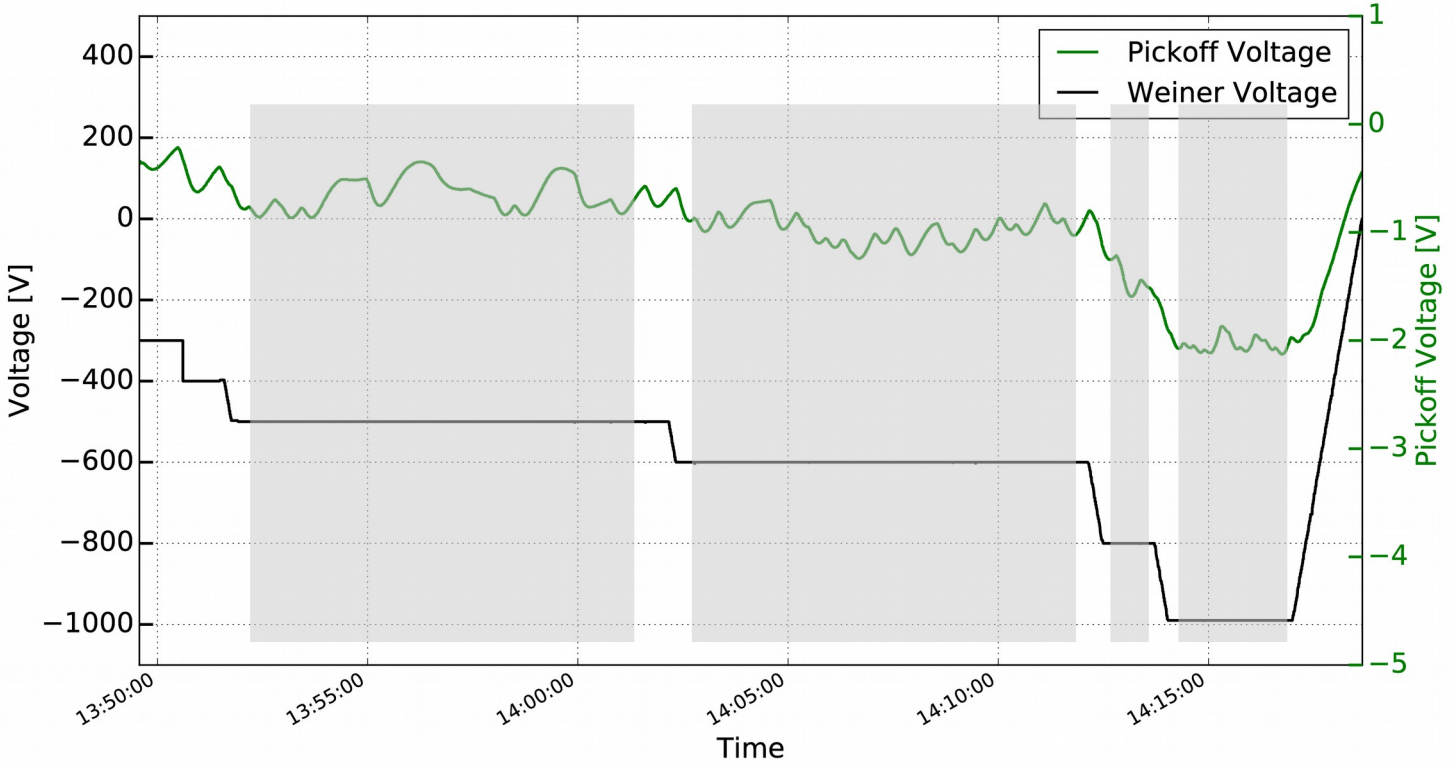
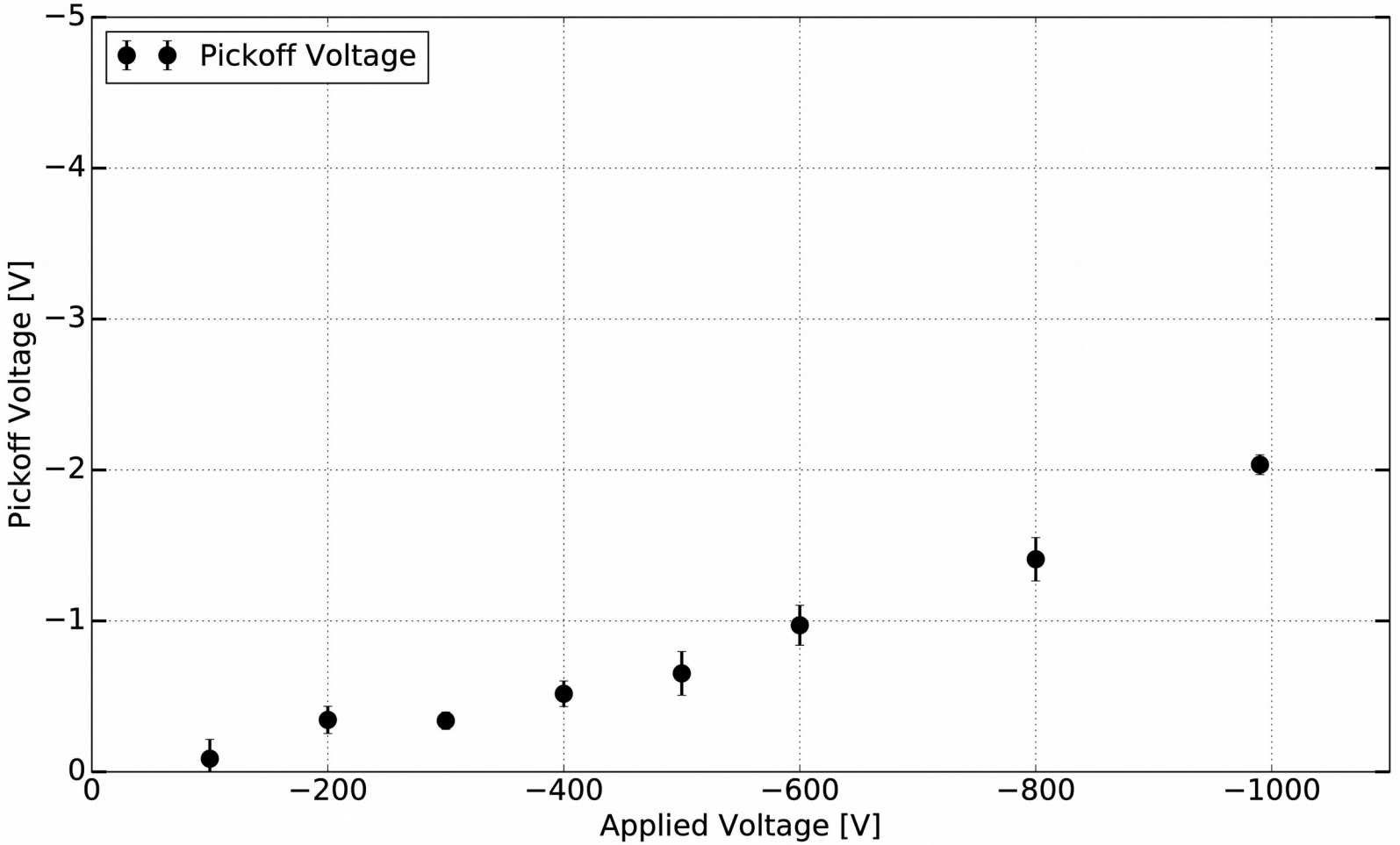


Resistance of Field Cage: V vs. V

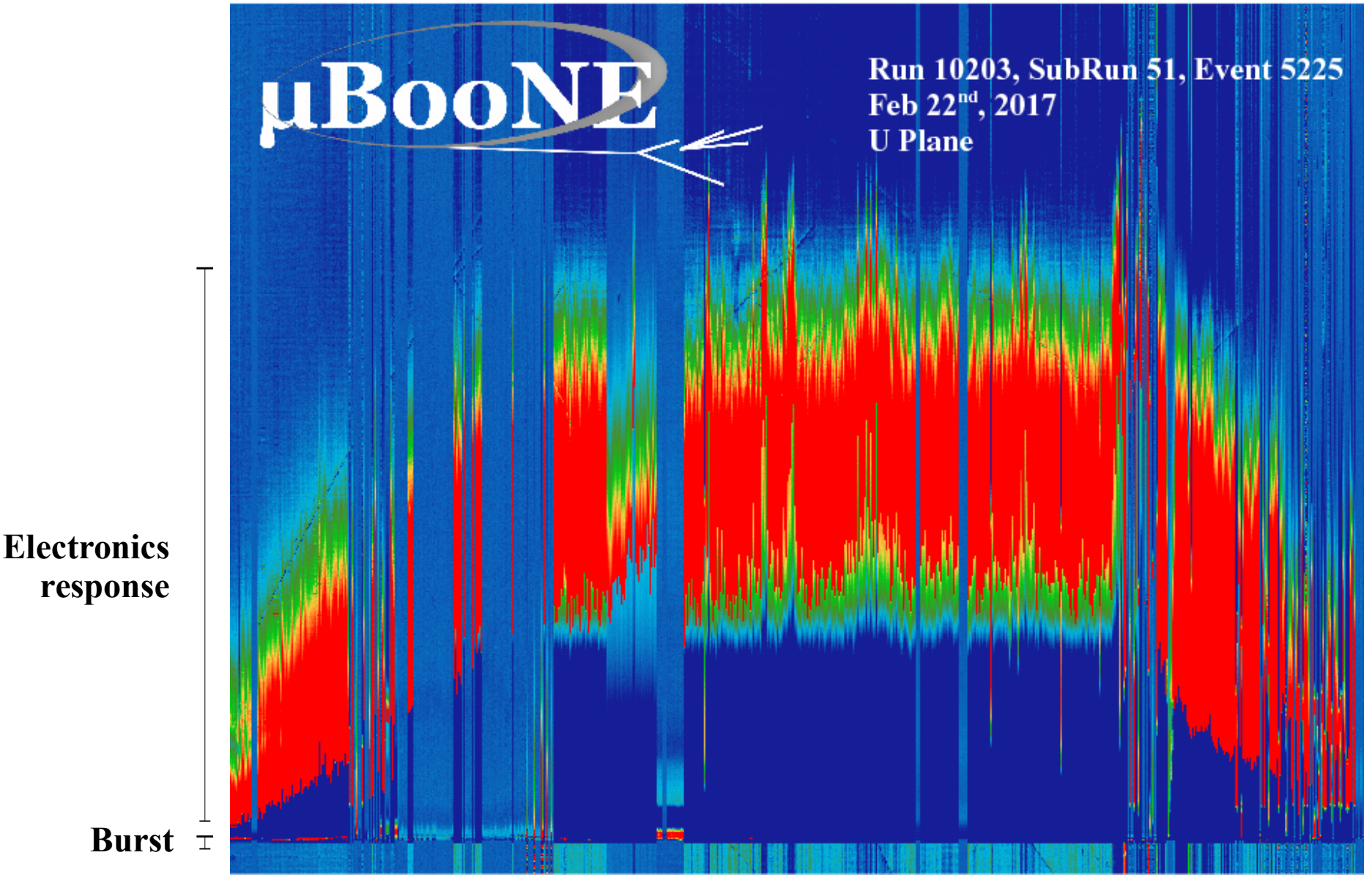


"If you violate Ohm's Law, you've done something wrong." - M. Matulik, MicroBooNE E.E. support

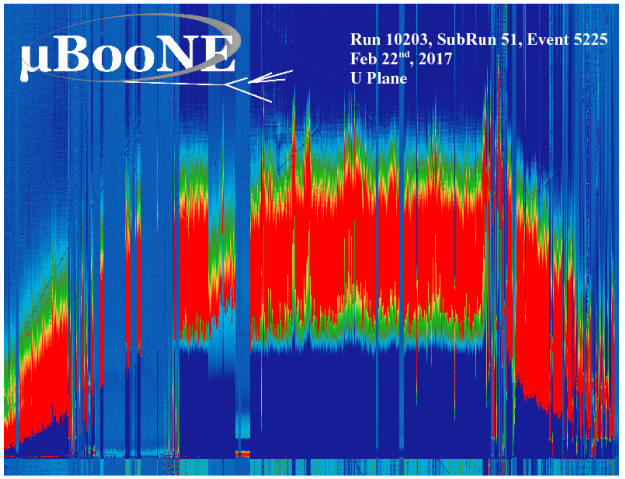
Narrowing in on the Problem

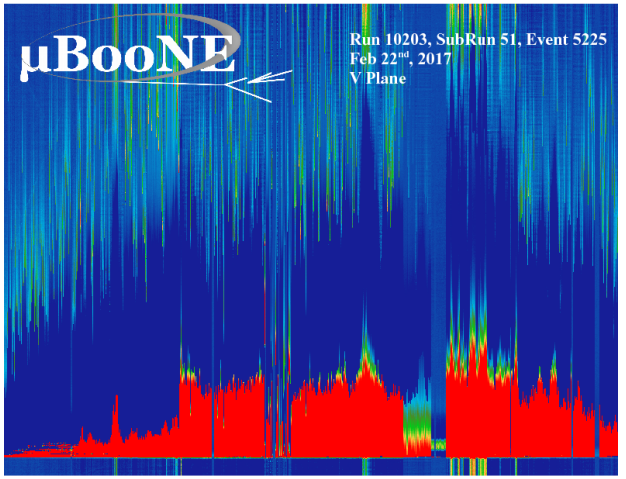
At this point, we are sure there is a bad connection somewhere inside the cryostat. Our offline analysis really nailed down where it is.

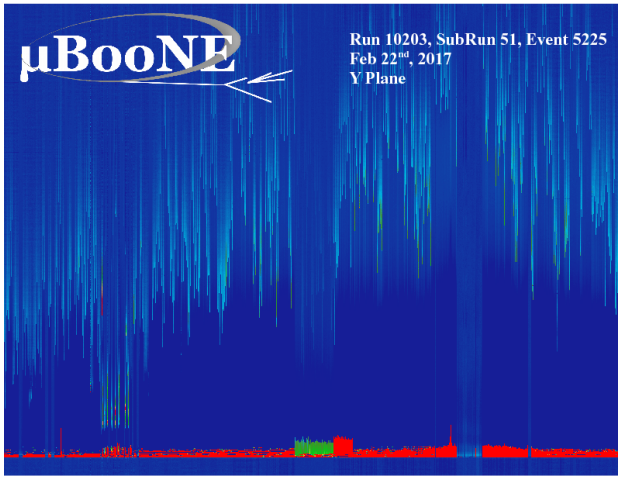
“Burst” Events

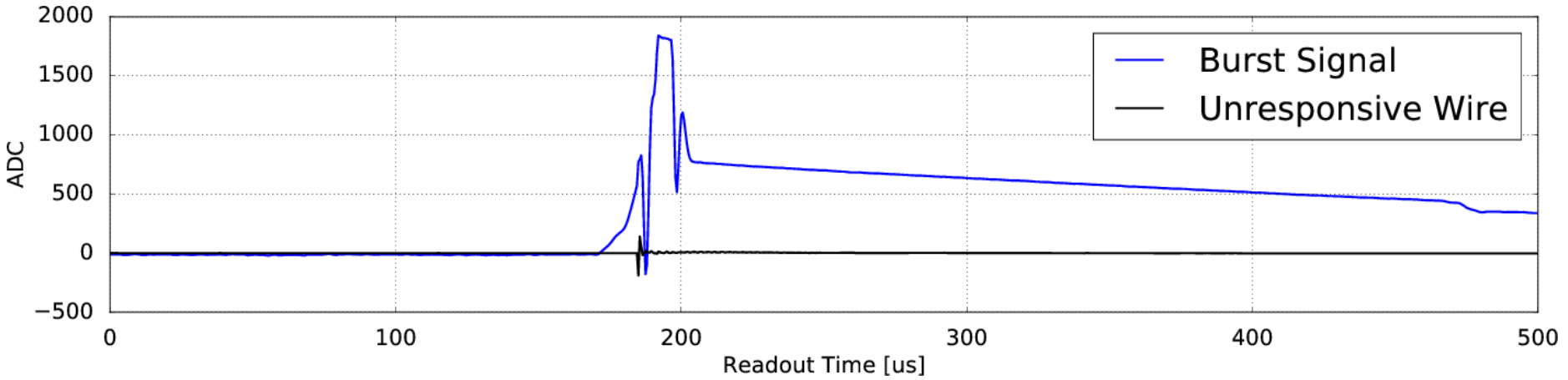


“Burst” Events



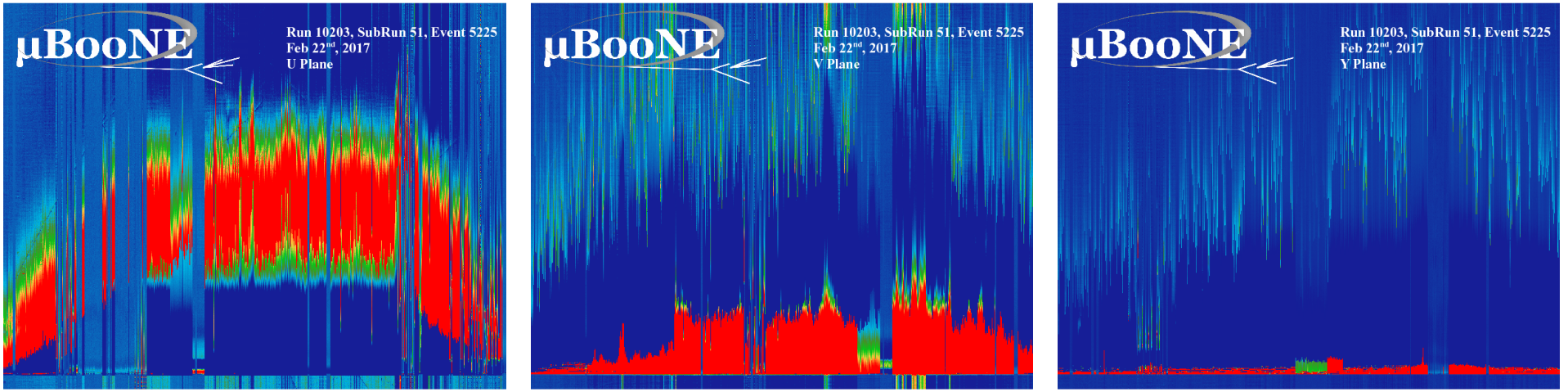






Much work done by MicroBooNE team showed these bursts have correlations with HV instabilities, and the biggest amplitude bursts have clear signs of **light**.

“Burst” Events



- Amplitude is highest on U plane (closest to the cathode) and decreases on V and Y planes.
- Amplitude shows a dependence on wire length.
- Indicates probably capacitive coupling of anode to cathode (distance ~ 2.5 m), rather than drifting electrons.

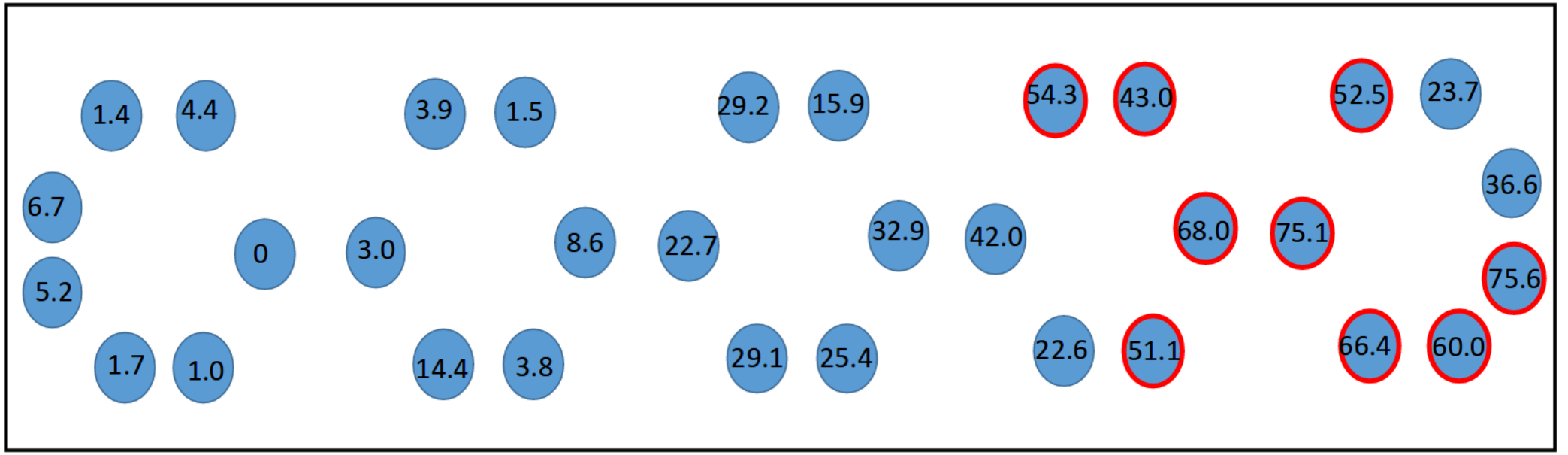
PMT Correlation to Bursts

PMT light

Resistor chain
Upstream Z=0

More light in the downstream side!

Cathode FT cup
Downstream Z=10m



Number in the circle: PMT flash amplitude in ADC, average over all burst events with correlated PMT flash.

Note: the amplitude is calculated with gain calibration and subtract 2048 as common pedestal. Numbers are relative. (not absolute accurate.)

8

Microboone docdb 7222,
Xiao L. and Elena G.

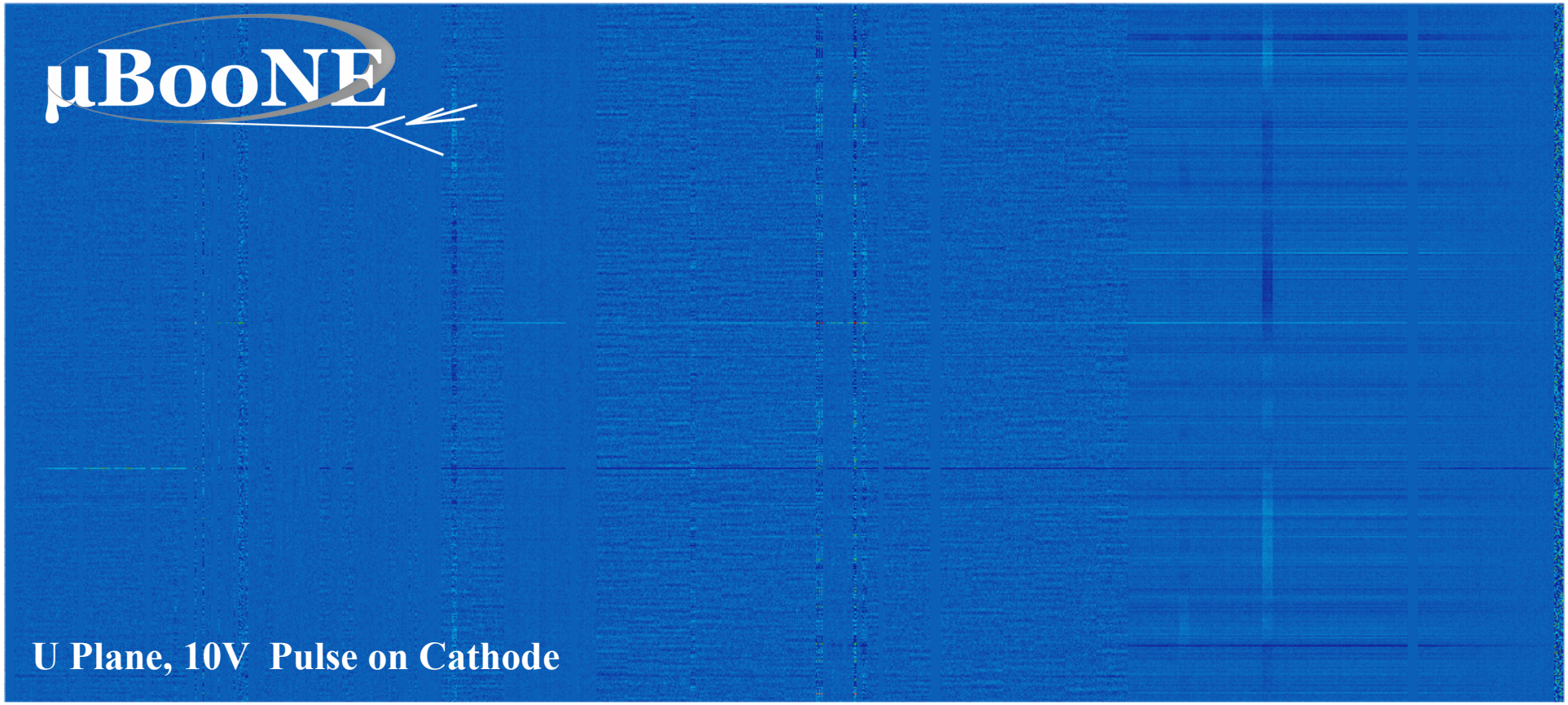
A Hypothesis

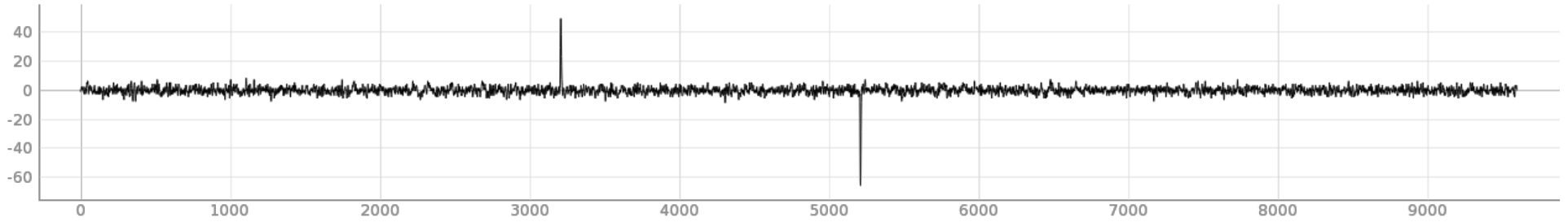
- Burst events are caused by transients on the cathode that capacitively couple to the wires.
  - Can we figure out a way to check this?

A Hypothesis

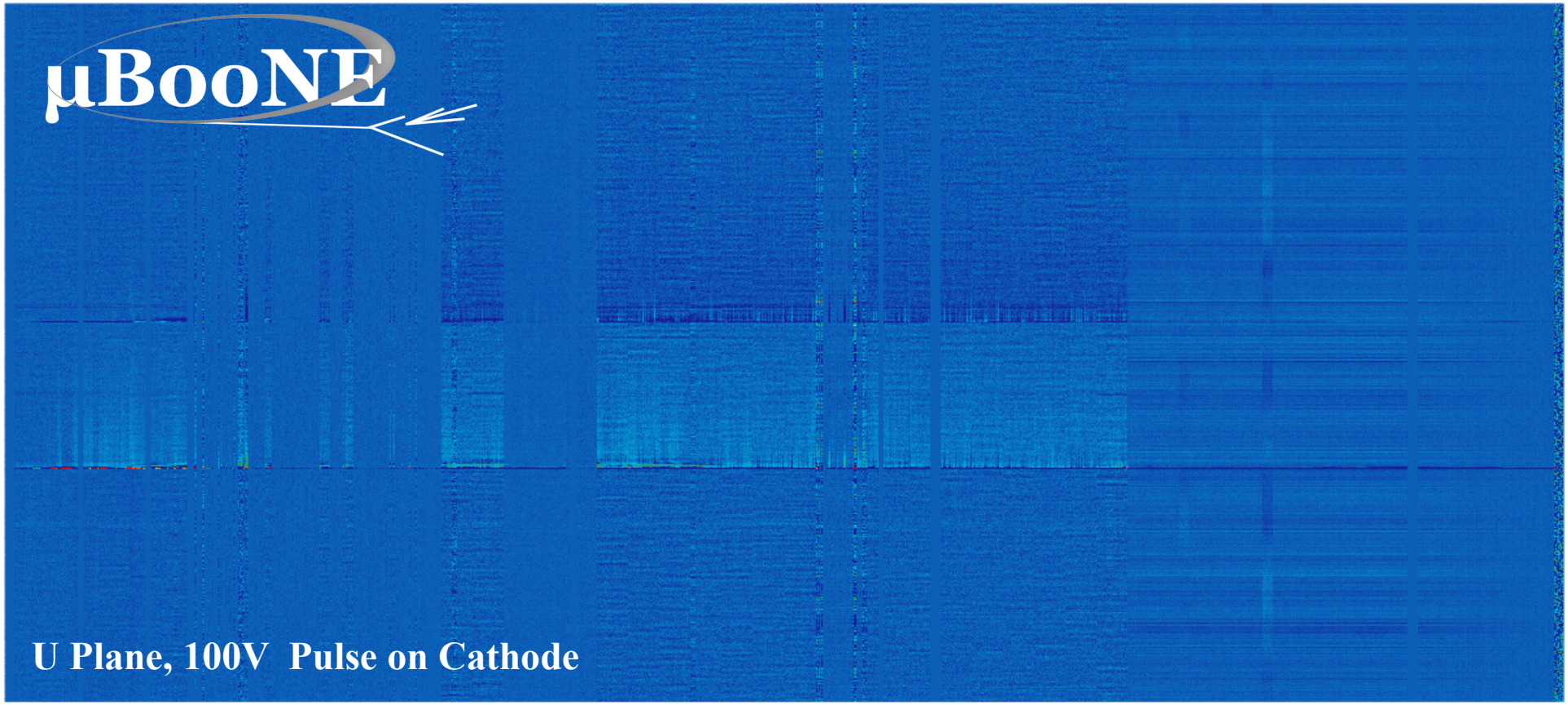
- Burst events are caused by transients on the cathode that capacitively couple to the wires.
  - Can we figure out a way to check this?
- Yes – used anode as diagnostic tool for cathode activity.
  - We attached a high voltage pulser to the HV Feedthrough in place of the Glassman HV supply, and took pulses at increased V up to 300 V.
  - We saw a clear progression from small pulses on the wires to “burst” pulses...

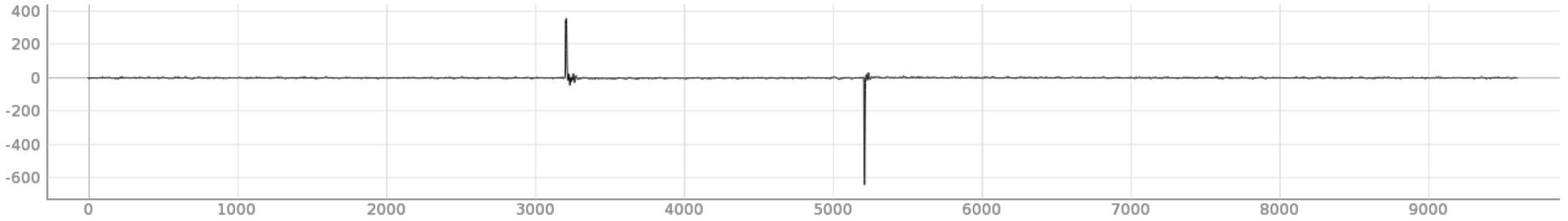
10V Pulse


µBooNE
U Plane, 10V Pulse on Cathode

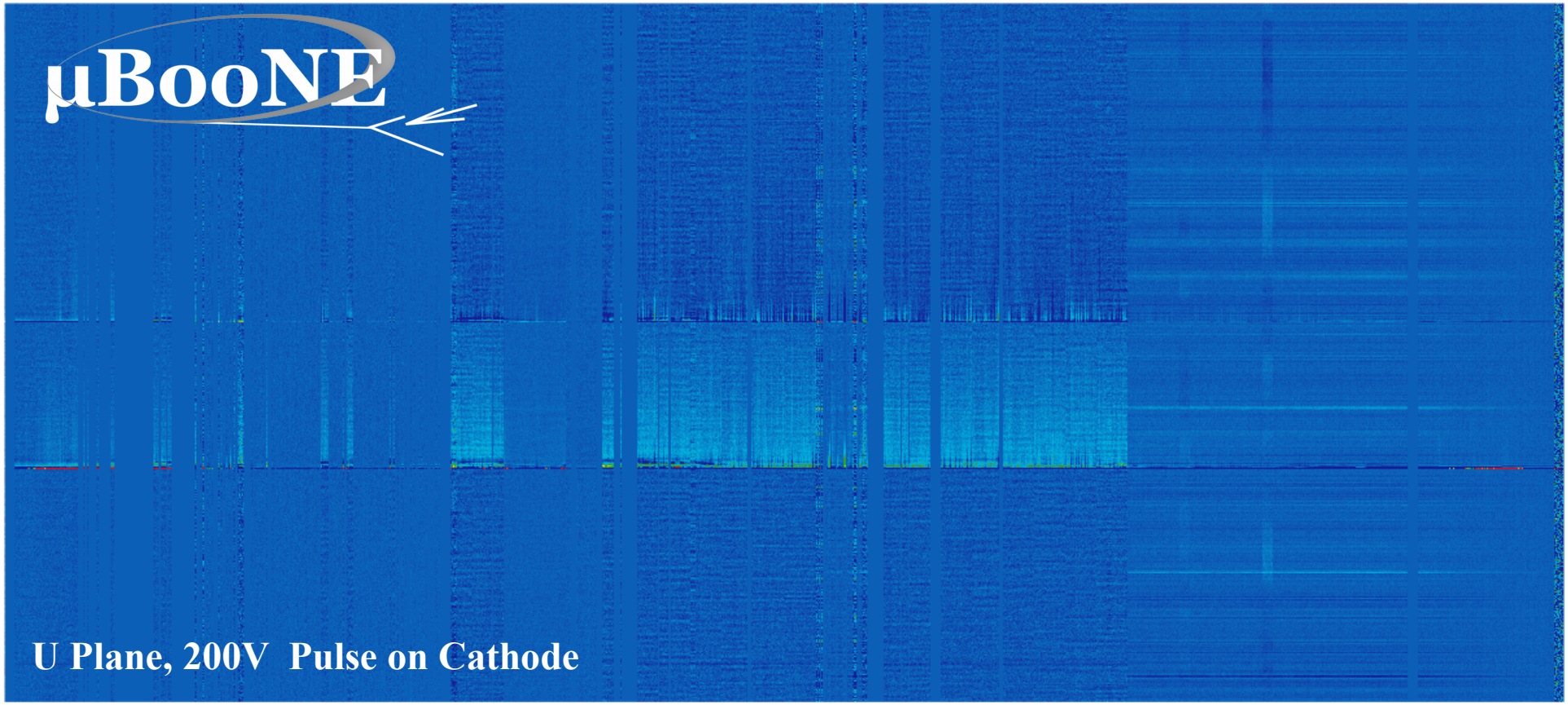

40
20
0
-20
-40
-60
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

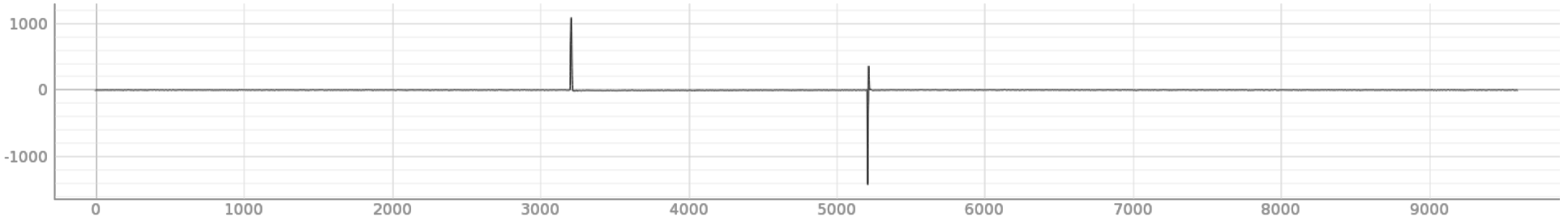
100V Pulse


µBooNE
U Plane, 100V Pulse on Cathode


400
200
0
-200
-400
-600
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

200V Pulse


µBooNE
U Plane, 200V Pulse on Cathode


1000
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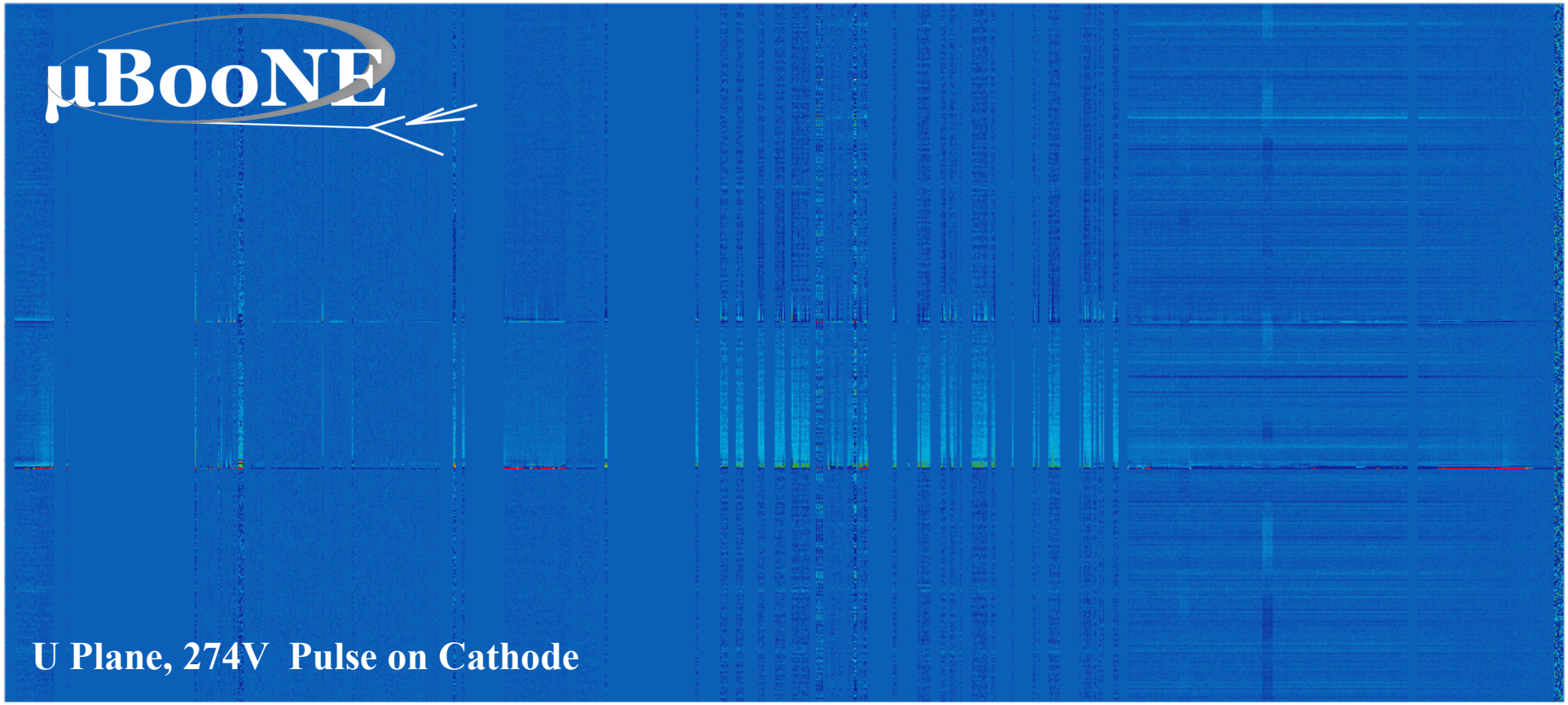
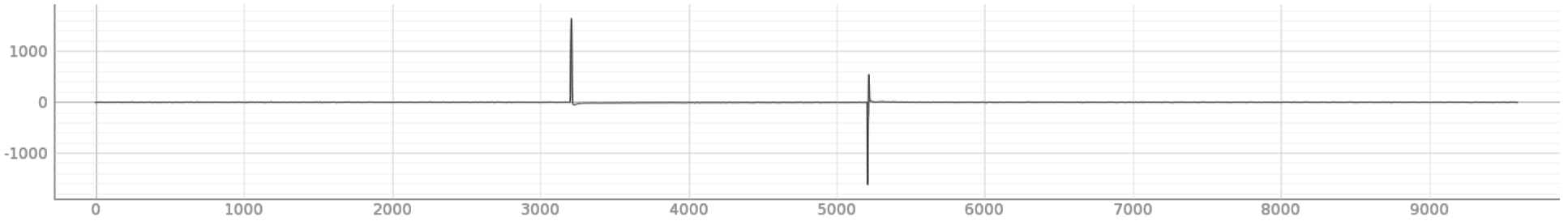
274V Pulse


µBooNE
U Plane, 274V Pulse on Cathode


1000
0
-1000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

Theory: Bad Connection at the cup?

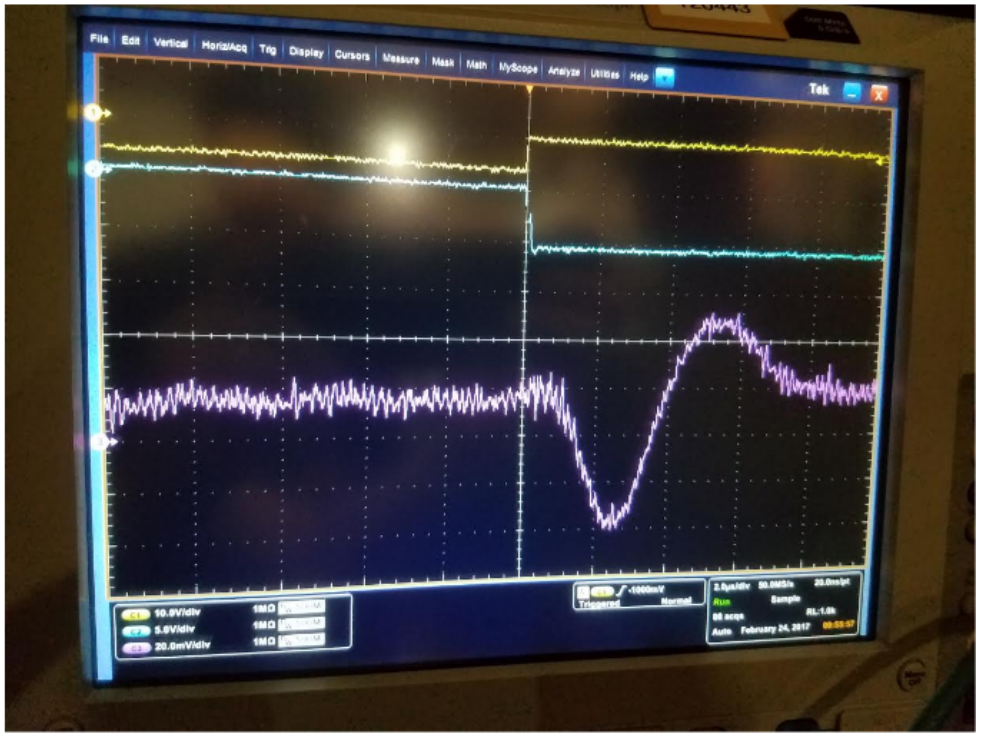
- Transients on the cathode are the cause of the burst events.
  - They also agree with other symptoms of stability.
- Based on the polarity of the pulses, we can tell which way the cathode transients are moving.
  - **Cathode voltage is getting more negative.**
  - This implies a bad connection to the cathode from the HV supply, and **not** a discharge from cathode to detector ground.

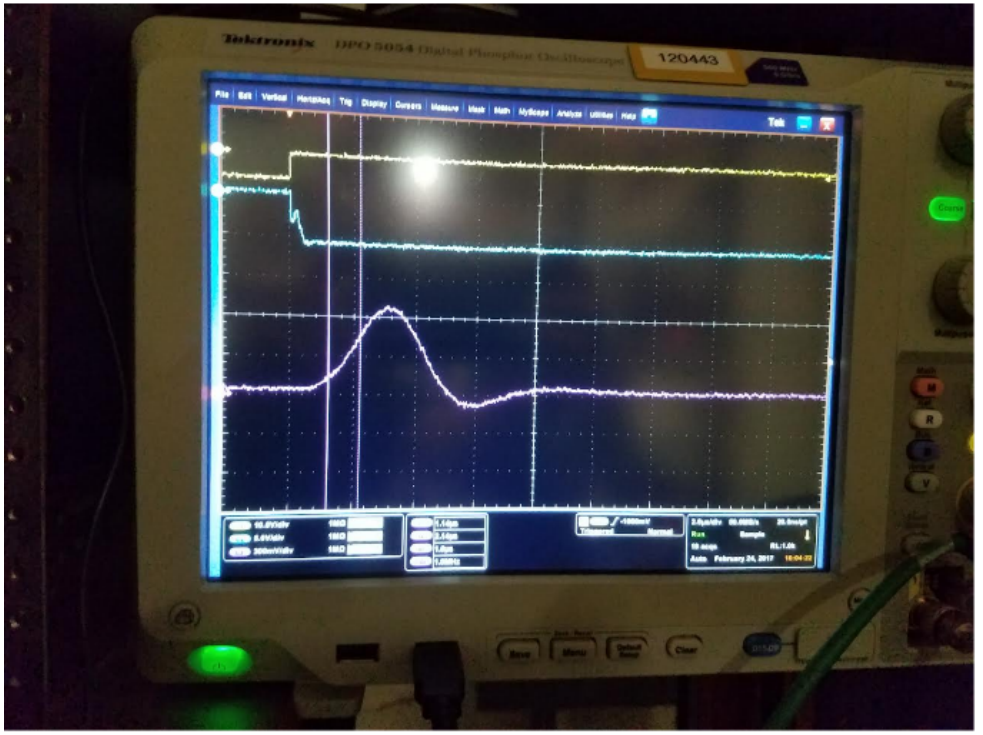
Ice Ball?!

- Our cryo team pointed out that an ice ball had formed below the port for the HV feedthrough.
- We melted it and decided to adjust the belows (shown here) to slightly move the tip of the feedthrough in the cup.

The Magic Wrench

While adjusting, we pulsed the cathode and read back the wires on an oscilloscope

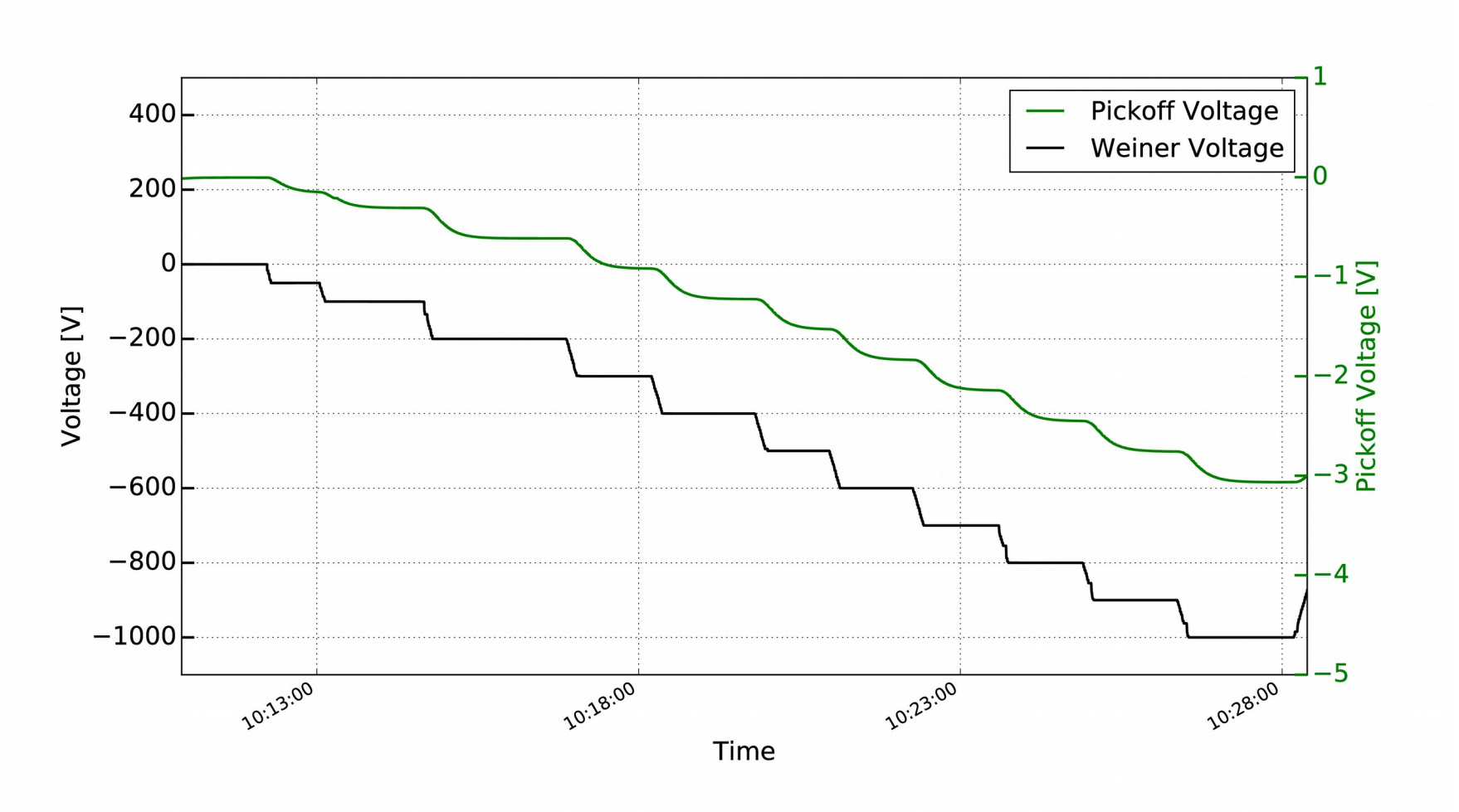




When the wrench loosened the first locking nut, we saw an immediate change. **We have been stable since then.**

Restoring Normal Operations

- Immediately we checked the V vs. V curves to see if we were still violating Ohm's law ...



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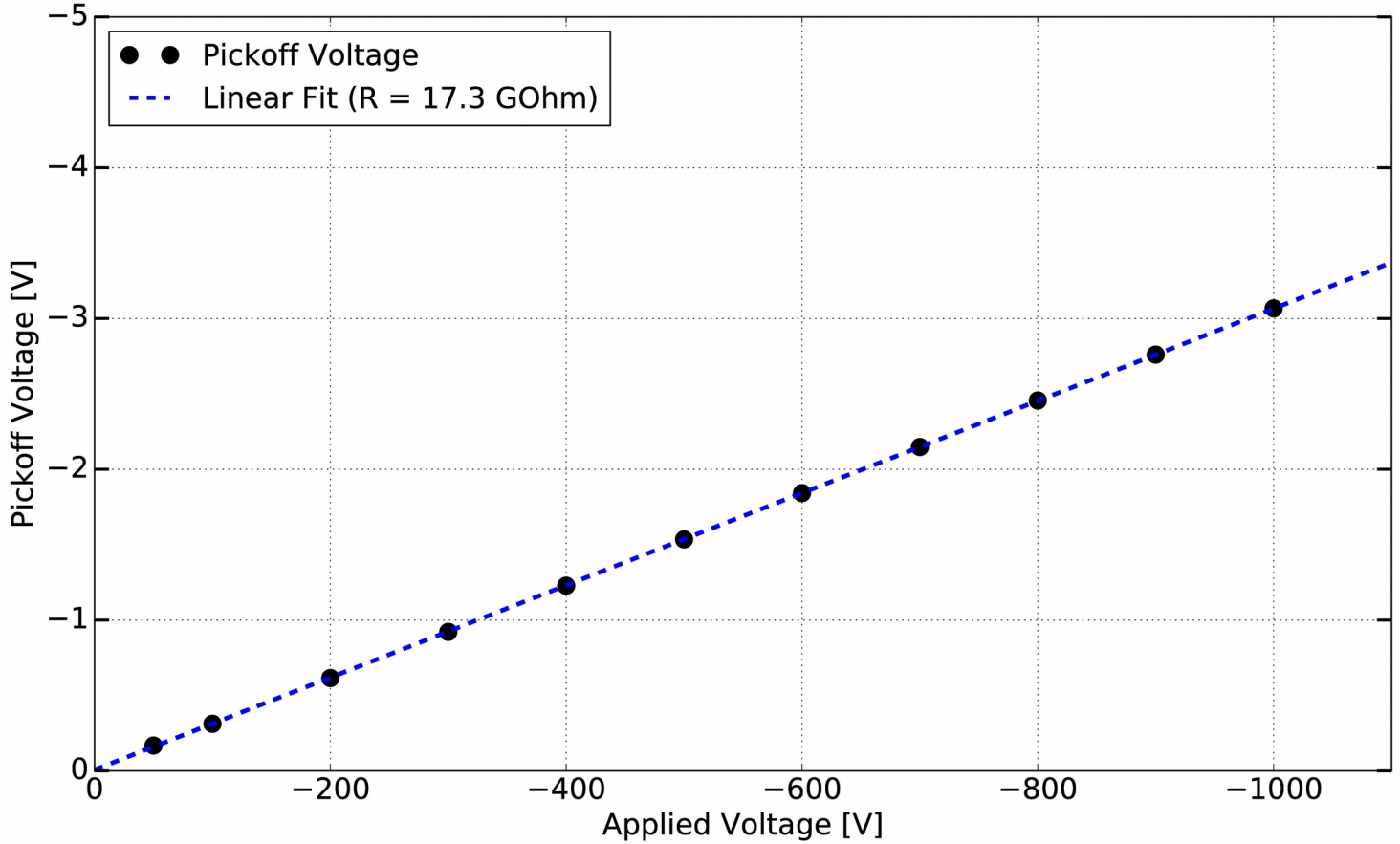

Lessons Learned

- Watch out for ice balls?
- It's indispensable to have the following diagnostic tools:
  - Pickoff point measurements of each resistor chain, including ability to bias the pickoff point.
  - Ability to put high voltage pulses on the cathode and read back the wires, either through the DAQ or an oscilloscope.
    - Cold digitization will prohibit oscilloscope use, which slows things down.
  - Careful measurement and archiving of values (including RMS/noise measurements) of current draws and voltage settings for the history of the experiment.
  - When installing the detector, take base line measurements of resistors, capacitors, currents, etc for the high voltage system as a baseline to compare for later problems.
- When dealing with problems, **keep taking data!**
  - TPC and PMT data are both essential! (even at 0 V/cm field)

Wish List …

- The HV feedthrough is an almost-inaccessible, single point failure in MicroBooNE.
  - It sure would be nice to have way to either service the feedthrough or have a second entry point for high voltage.
- We spent a lot of time reconfiguring our external HV connection to allow V vs. V tests or pulsing the cathode.
  - This type of functionality should be built into the system.
- I have no proposed mechanism but:
  - It is essential to be able to verify the (good!) connectivity of the HV supply to the cathode.