

# High Voltage Testing at the 35t

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Long Baseline Neutrino Committee (LBNC): ProtoDUNE-SP

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February 20, 2018

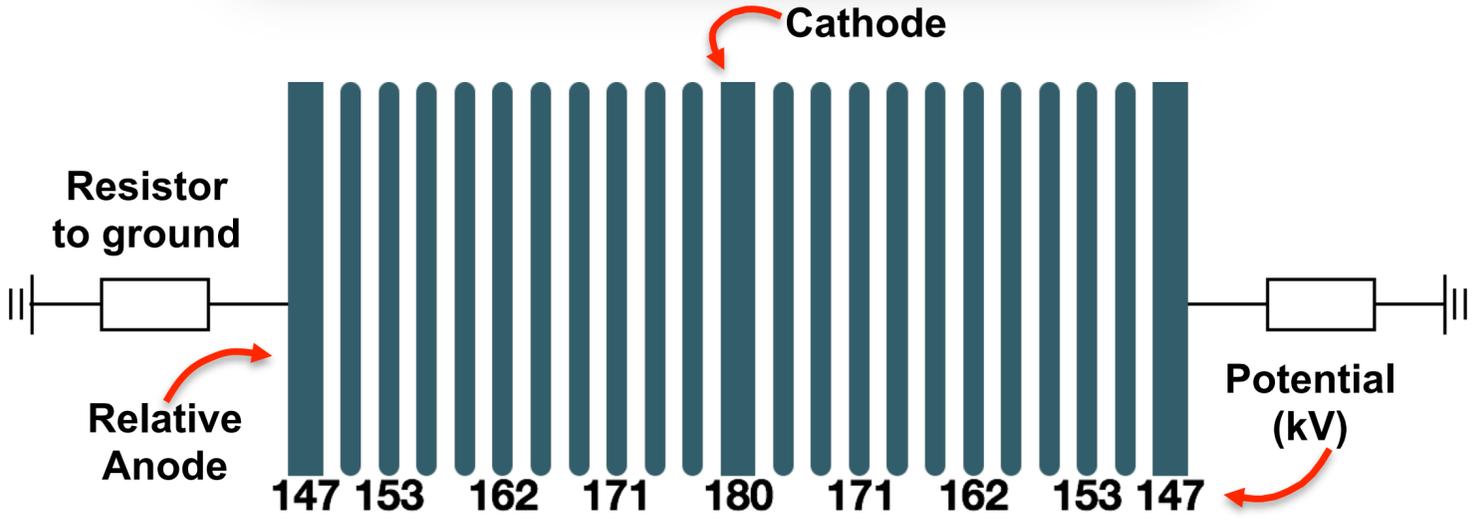
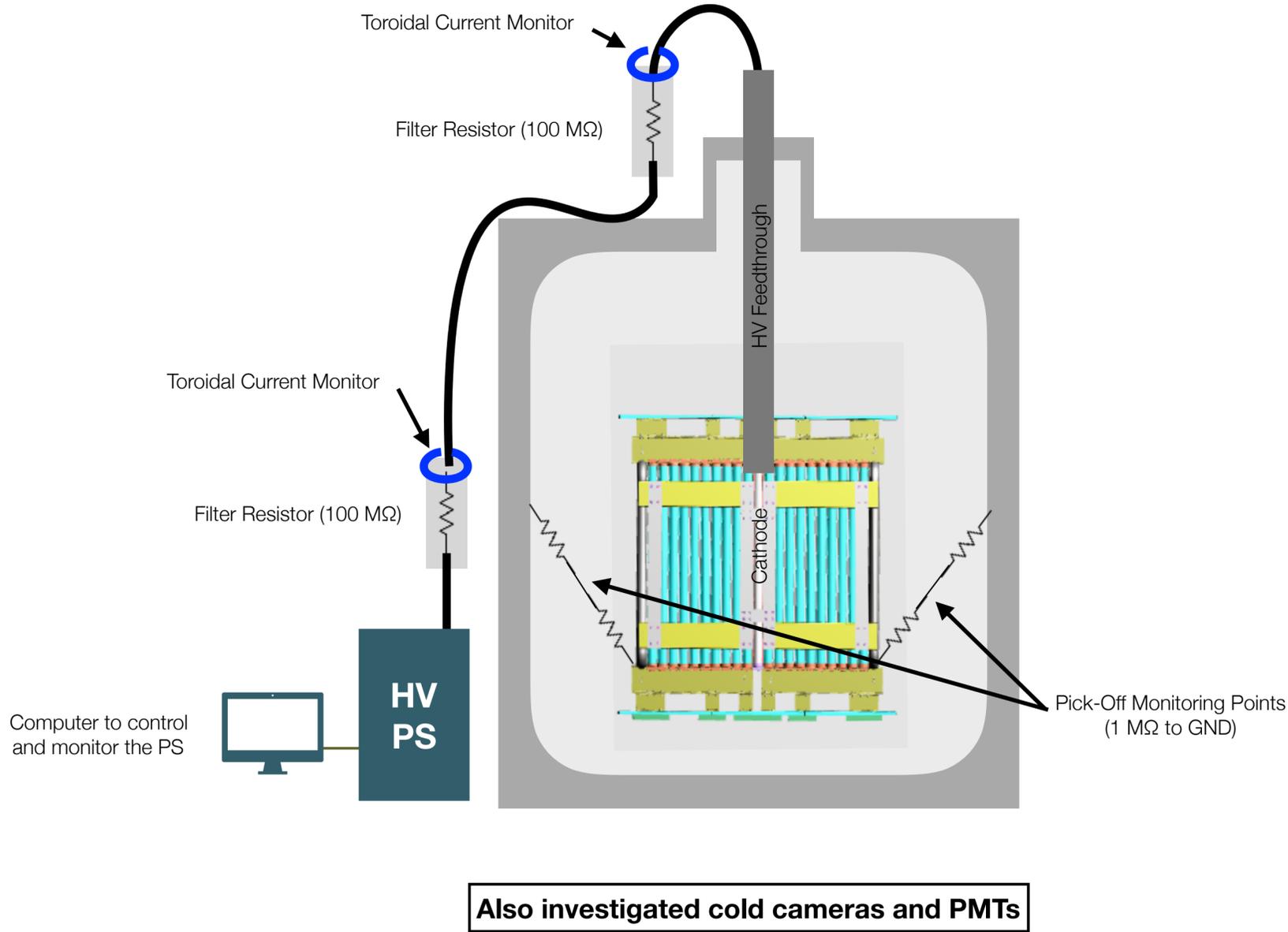
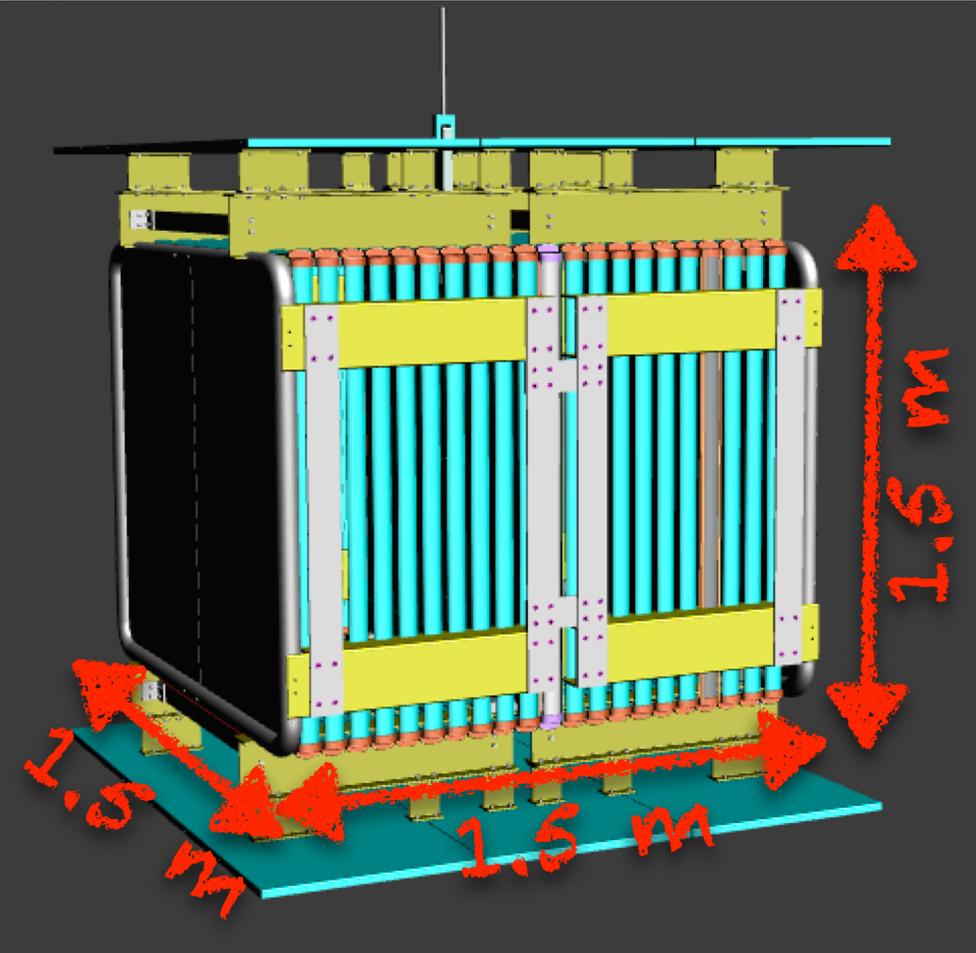
**ANL (eng), W&M (prof., student, tech), LBNL (scientist, eng), KSU (prof, post doc, student), U.C. Davis (prof., post doc), U of Houston (prof), UCLA (prof), BNL (scientists), FNAL (scientists, techs)**

# Motivation

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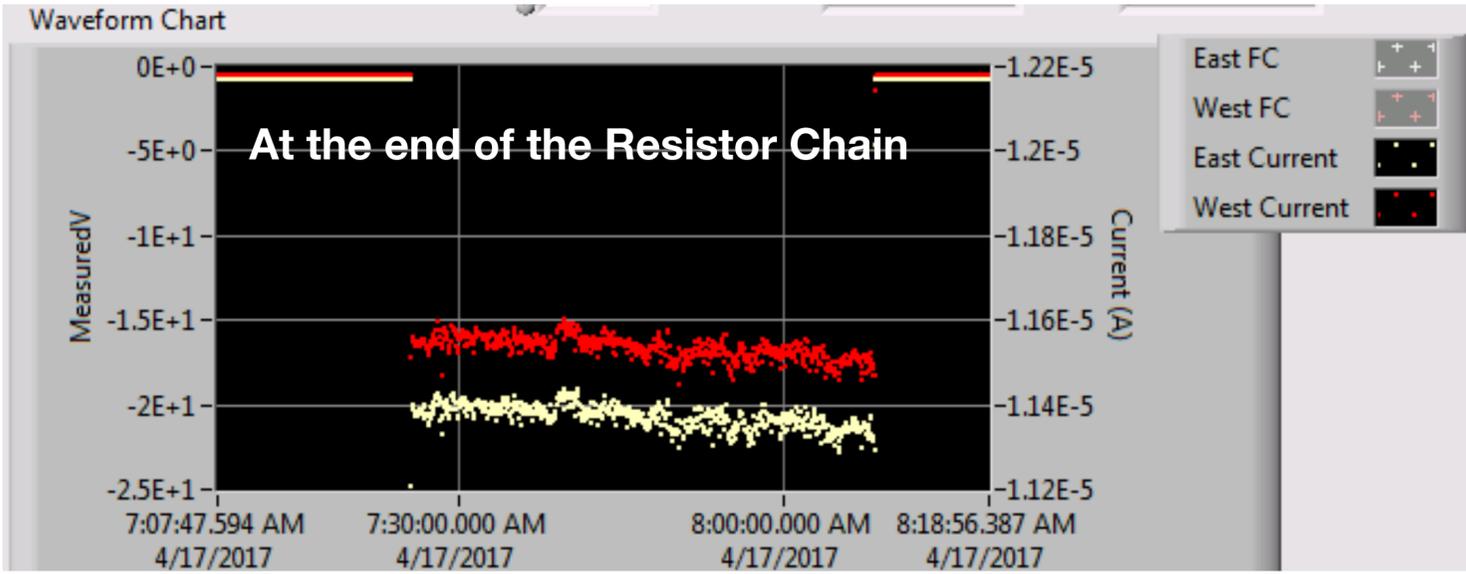
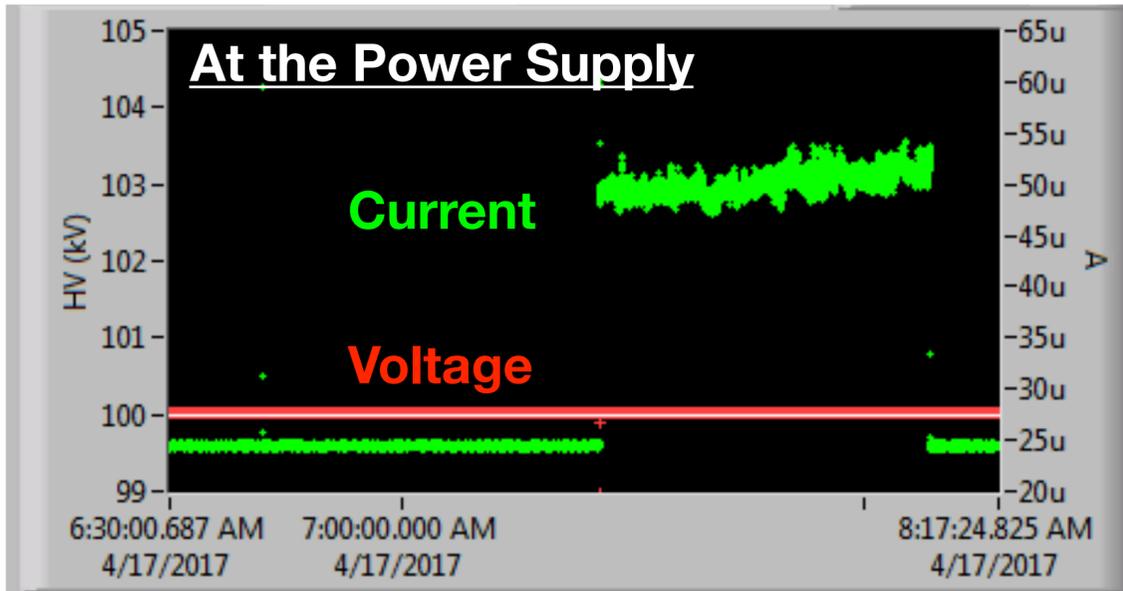
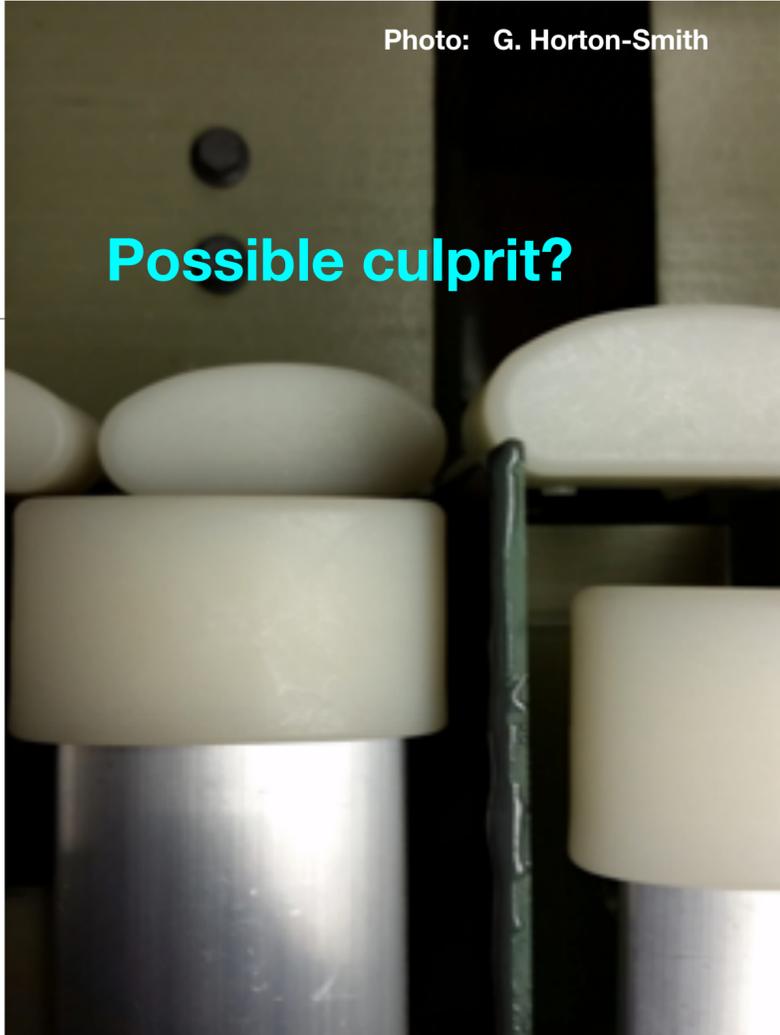
- Short answer: HV performance is not well understood in LAr.
  - Recently, work has been done on “breakdown” measurements, but
    - The setups are small and just consider breakdown between stainless steel parts
      - Field cages have a more varied setup — not just larger — insulators, resistive materials...
    - Studies primarily consider breakdowns or classical sparks
      - More types of issues can occur — slower events? elevated current draws?
- The 35t test was designed to test the ProtoDUNE-SP design with regard to HV performance.

# Test 1: Field Cage Test



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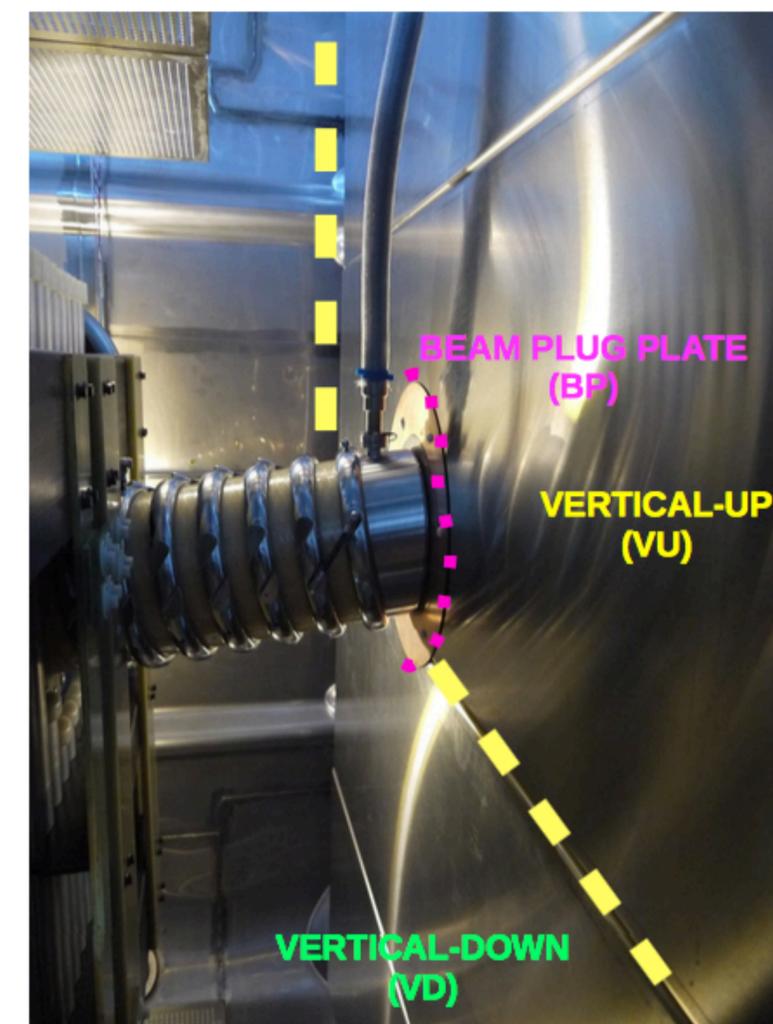
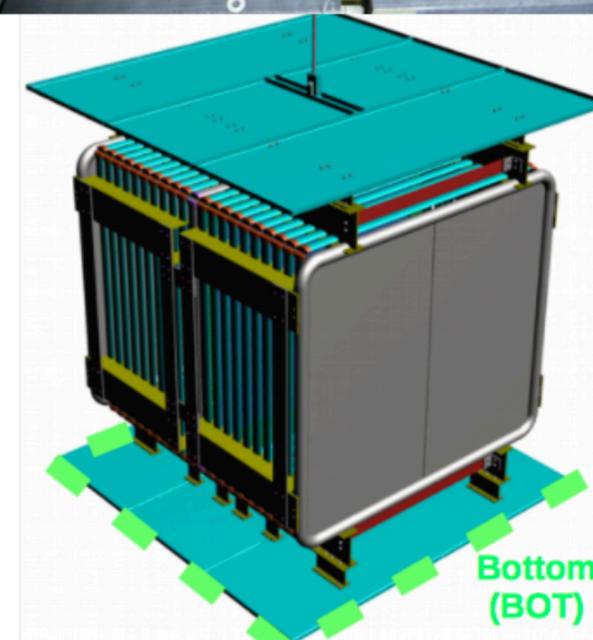
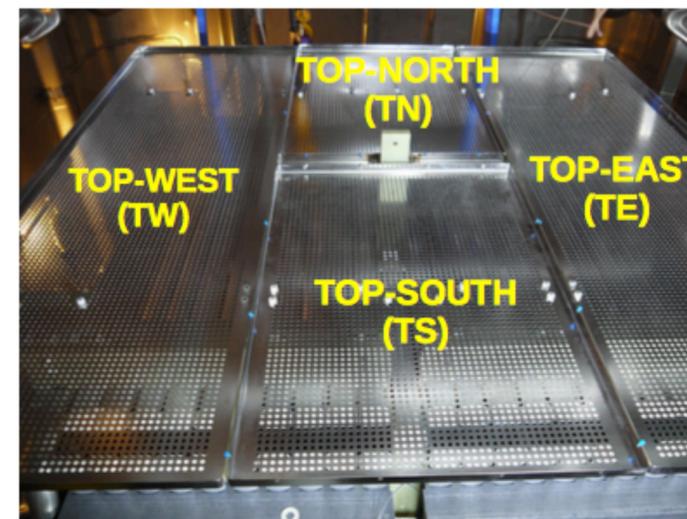
- The run highlighted (and was limited by) a design flaw
- Since modified in PD-SP design



## Test 2: Field Cage + Beam Plug

- Schedule necessitated that we test the beam plug next.
- Modified the cathode frame strips to the new ProtoDUNE-SP design
- Added the beam plug
- Also instrumented the ground planes:

### Setup of Ground Planes Instrumentation



From H. Liao

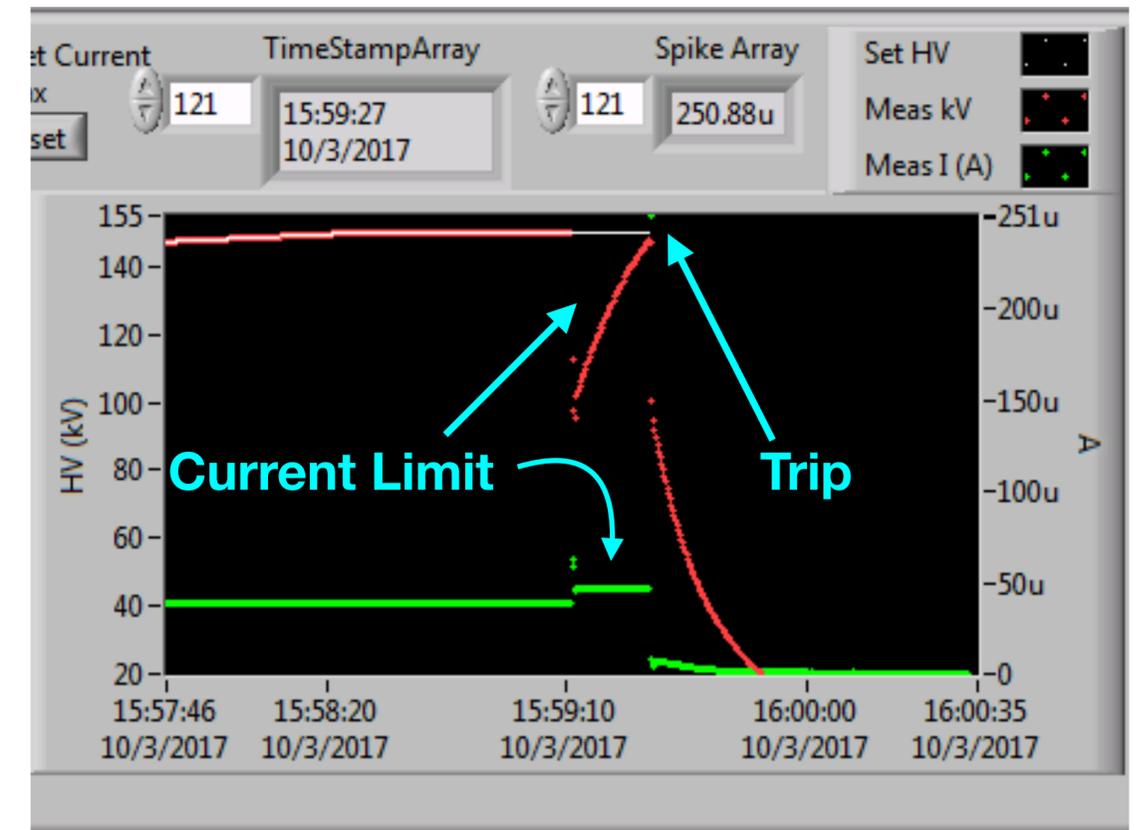
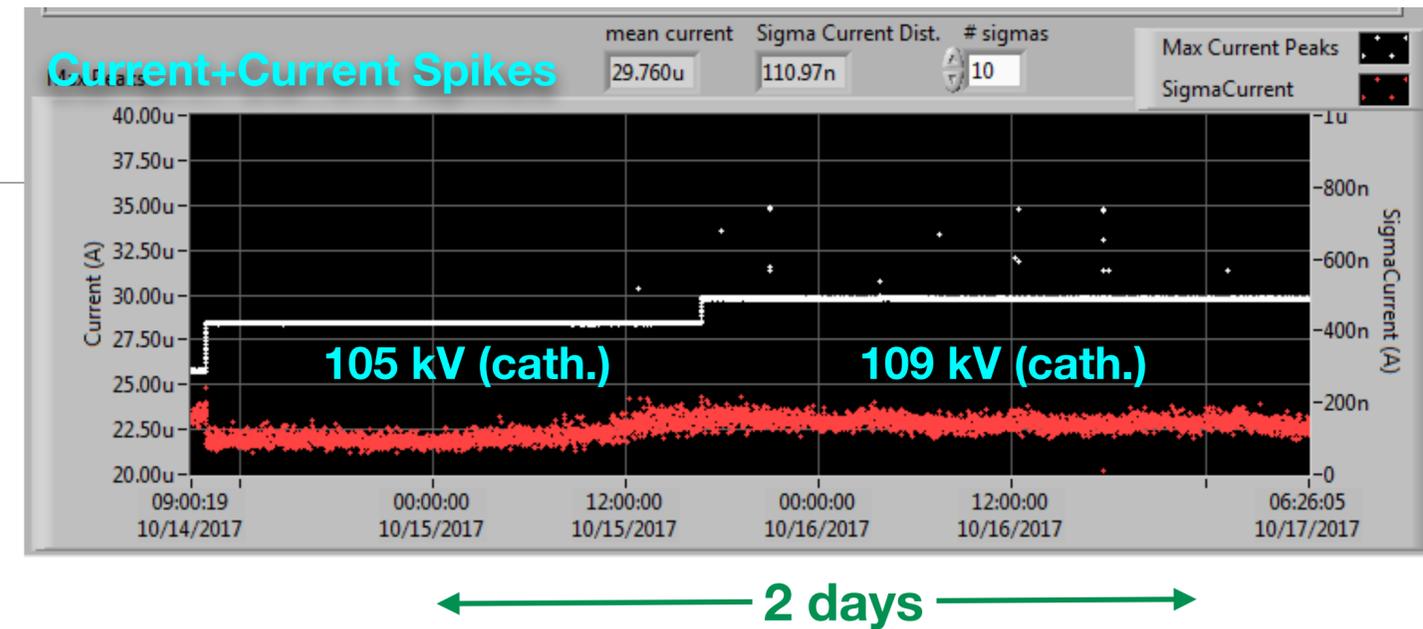
# Test 2: Field Cage + Beam Plug: Preliminaries

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- We have a *current-limiting* supply meaning the PS drops the voltages when a level of current is detected at this limit.
  - We consider these **current-limiting events slow discharges**
  - The current can momentarily go beyond this limit — the current rise is so fast the supply does not respond
    - We call these **fast discharges** (accompanied with a toroid signal)
  - Beyond a current limit, there is another user-defined setting: a **trip threshold** where the output is turned off in software.
- For this run, a typical current limit was 25% over the expected current draw and a typical trip setting was 4x the current limit.

# Test 2: Field Cage + Beam Plug Running

- There was excess current activity; Quick summary:
  - 109 kV (cathode) was held reliably without tripping in TPC-quality argon
  - 114 kV could be held for days. At one point it tripped.
  - Also held 138 kV for a two days
  - Could not explore > 152 kV without immediately tripping
  - Current activity generally increased in frequency and magnitude with higher voltages.
    - At 105 kV, there was essentially no activity
    - At 109 kV, a < 1s spike of a few uA was seen every 3-6 hours.



# Test 2: Field Cage + Beam Plug Running

- The ground plane data showed the activity was not localized
  - also not evenly distributed
  - Vertical up (VU) was a frequent channel
  - Top South (TS) events mostly happened during a ~1 hour period while trying to provoke activity
- NVH is no visible hit meaning none of the ground planes saw evidence of collected charge.
  - All fast discharge events (created a toroid signal) were NVH
  - One event looked like NVH, but had a lone negative point (signal is negative). Are we missing the fast signal by only sampling at 1 kHz? Glitch?
  - Motivated a desire for improvement in the GP readout timing.

Total GP #	155
Run Time	31.04 days

Event Classification	Fraction (%)
TW	1.3
TS	15.5
TN	0.0
TE	0.6
VU	40.0
VD	13.5
BP	1.9
BOT	2.6
TS+TW	0.6
NVH	18.7
NVHD	5.2

Table from H. Liao

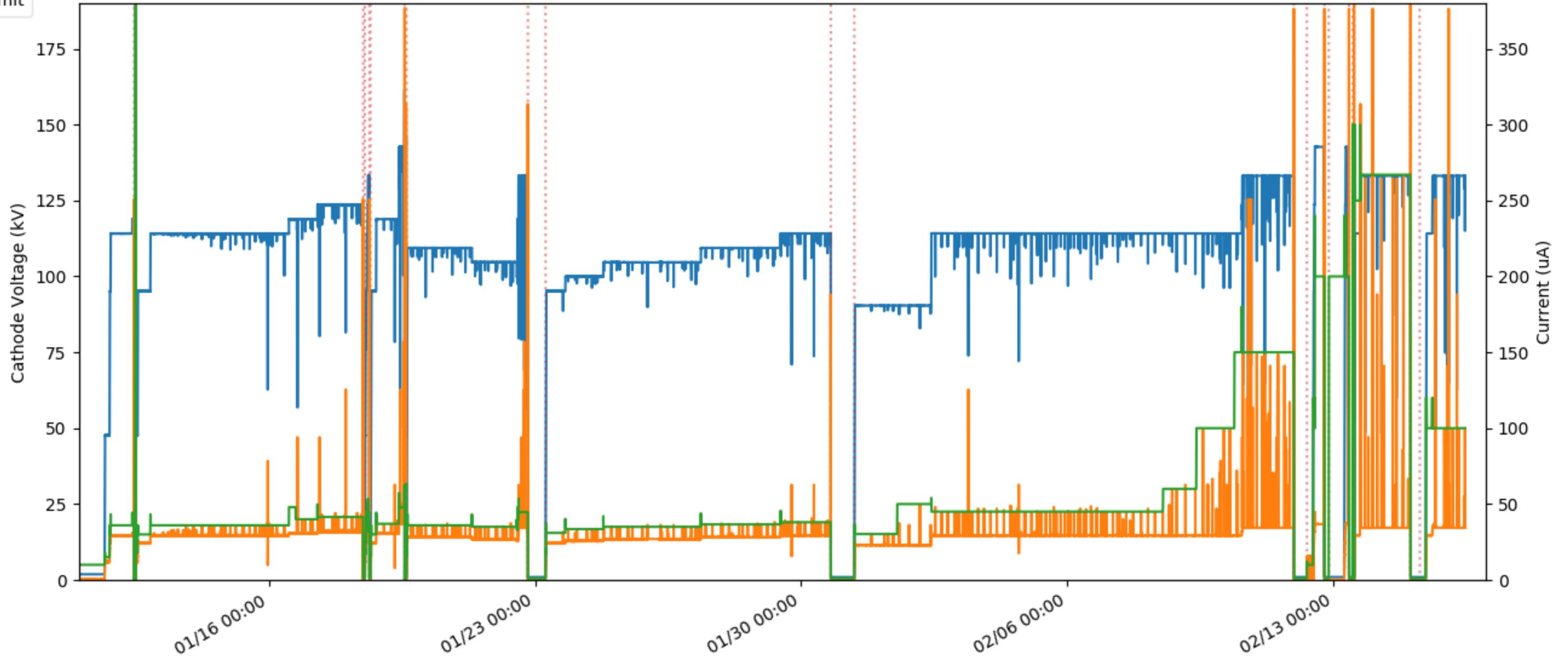
## Run 3: Field Cage Only

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- In December 2017, the beam plug was removed and a normal end was installed.
- The GP readout rate was able to be increased by changing the data format and triggering. 1 kHz  $\rightarrow$  20 kHz.
- Purged, recirculated, filled — Process started before winter break. Had  $> 1$  ms argon by MLK day

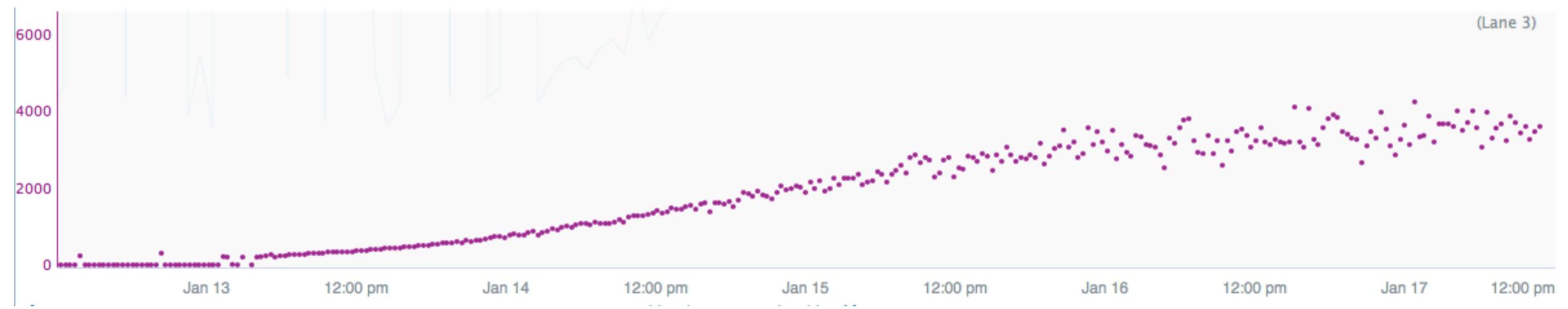
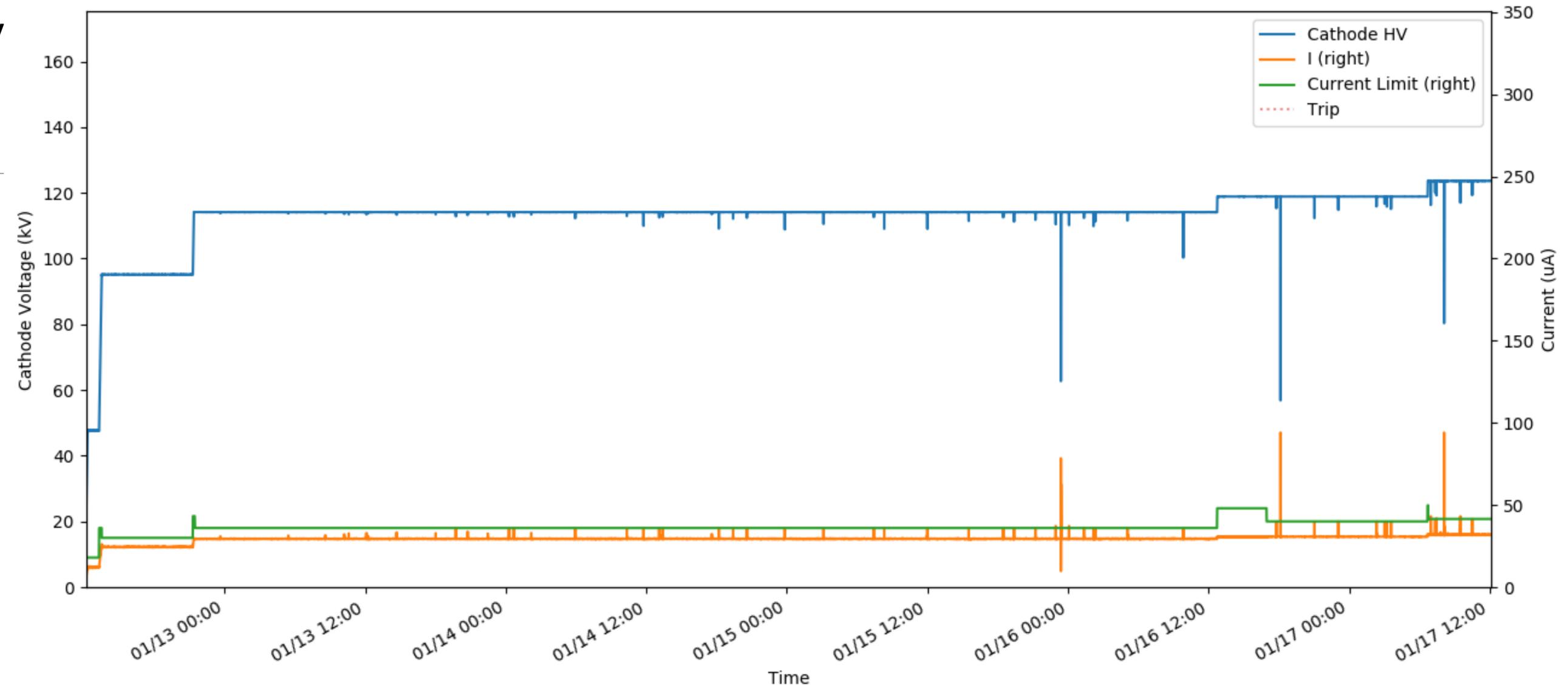
# Run 3: Field Cage Only

[Online Plot](#)



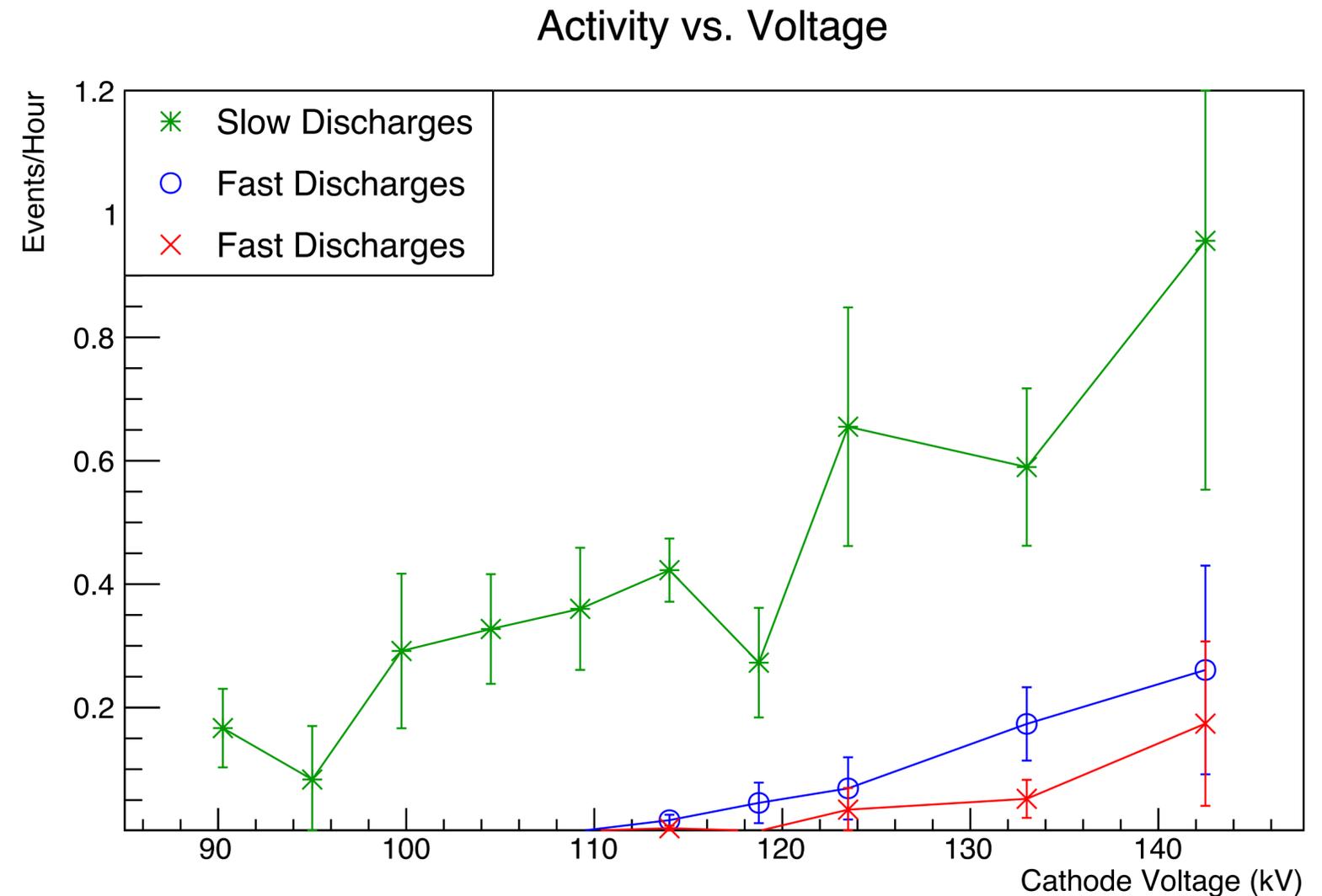
# Run 3: Purity Matters

- Above: HV, Current, Current Limit
- Below: Lifetime from short purity monitor
- Activity increases with purity



# Run 3: Field Cage Only: Activity vs. Voltage

- Slow discharges: current-limited events. Do not trigger toroid. Later, when the current limit range was explored, simply defined by lack of toroid signal.
- Fast discharge: triggers toroid. With a tight current limit, too fast to be controlled by the supply
- Trip: Caveat: this action is a result of a user defined setting. By the end of the run, we had non-tripping fast discharges that would have tripped the supply earlier.



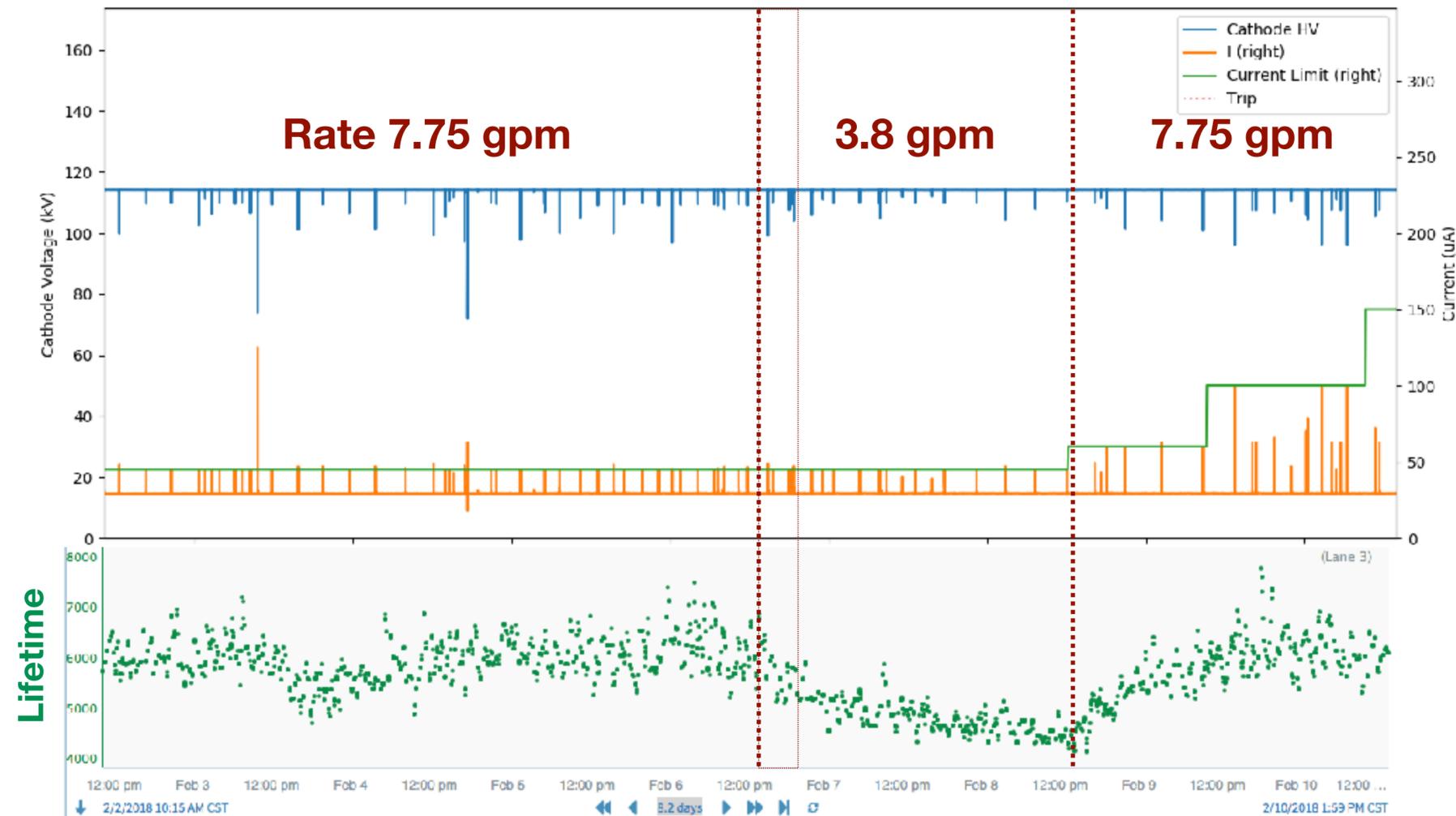
# Run 3: Field Cage Only: Running Highlights & A Point

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- In the second half of the run, we investigated loosening the current/trip limits.
- Held 114 kV (cathode) for ~week straight (then raised the voltage)
  - Note, we did trip once with a tighter (25%) current setting.
- Held 133 kV for ~1.5 days with looser settings; tripped after 6 hours with tighter settings
- 143 kV: very quiet for 6 hours (trip), 2 hours (trip), (trip while ramping)
- Points:
  - The CL & Trip values are user defined
  - There are no hard-set rules on where to set the values... yet
    - We do not know what the impact of the events is on TPC data. Start conservatively...

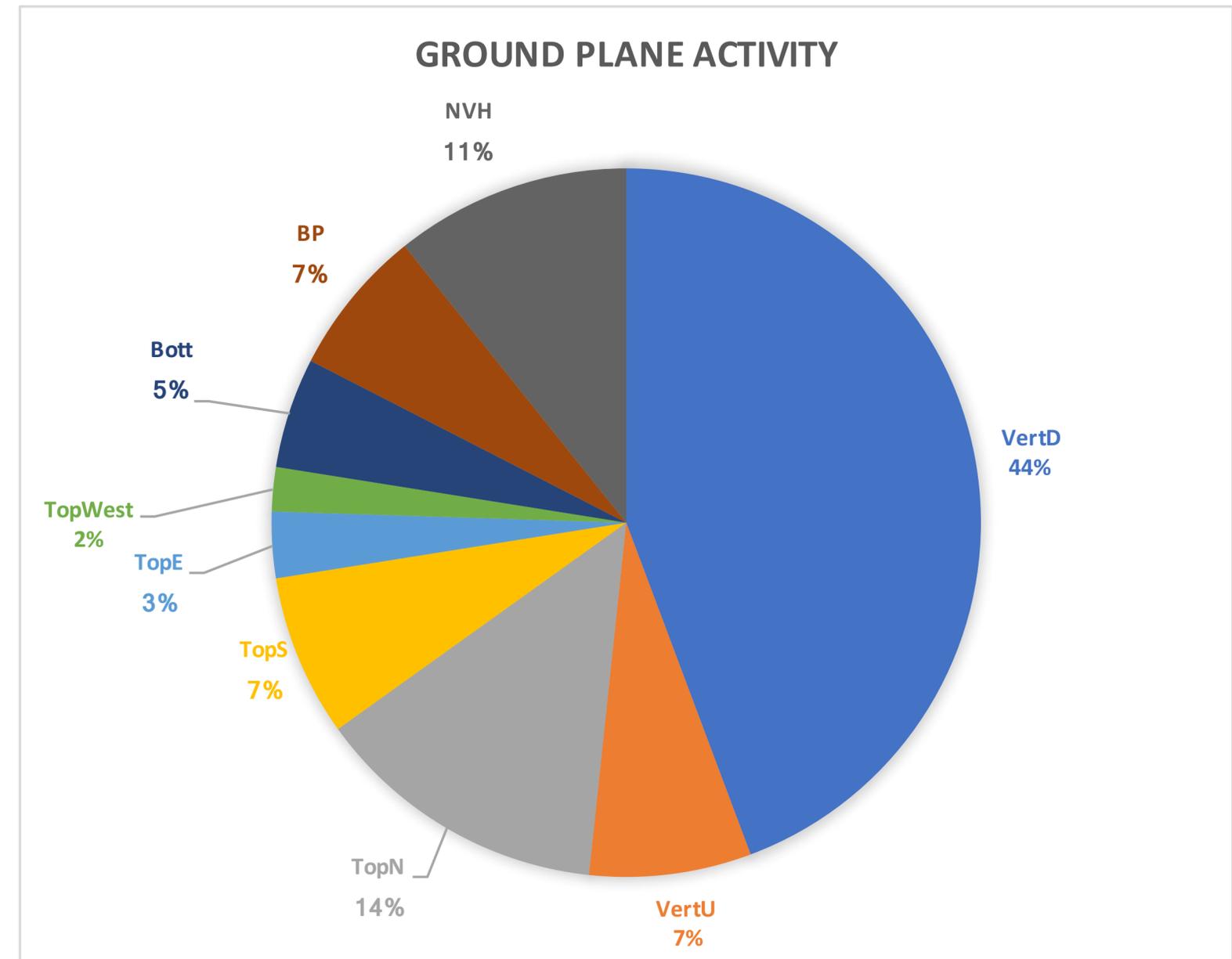
# Run 3: Field Cage Only: Pump Flow Rate

- ICARUS had two cryostats: one with an older pump, and one with a 2x new pump
  - The field cage in the old pump cryostat attained 150 kV whereas the new pump partner saw high currents above 75 kV
- It was suggested that we try to vary the pump flow
- Did not see an obvious immediate effect.
  - Event rate of  $\sim 0.8/\text{hr}$  in first and last periods. If one considers the first 6 hours of the slower pump rate, it's about 0.83.
- Purity did decrease... (Rate in remaining slower pump rate period is  $\sim 0.34$ ).



# Run 3: Field Cage Only: Ground Planes

- Again, the activity was not localized, but is also not evening distributed.
  - Note, the lower and upper ground planes are ~23 cm from the field cage; the vertical ground plane is ~37 cm from the field cage.
- Results very preliminary
  - Does not include fast discharges
- Confident that vertical down is the most frequent category.
  - ~9/10 are on the west side according to pick-off data
  - This is where the beam plug was in the previous run



# Closing

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- The run data is still being analyzed & digested. We just finished running on Friday.
- **Cleared the beam plug:** concluded that the beam plug did not noticeably degrade HV performance
  - It is being installed in ProtoDUNE-SP
- **Gained operational experience:** developed PS experience, have an idea of what features we may encounter
  - But we can not guarantee what we'll see in ProtoDUNE-SP (scale?, prototyped pieces vs production)
  - It is unclear how the electronics will respond to elevated current spikes.
- Developed instrumentation: saw no evidence of light (visible or UV) with installed PMTs/cameras (did see pick-up electrical signal), **developed ground plane instrumentation** to help isolate problem areas
- Through three runs, showed **the field cage chain is robust** to major discharges