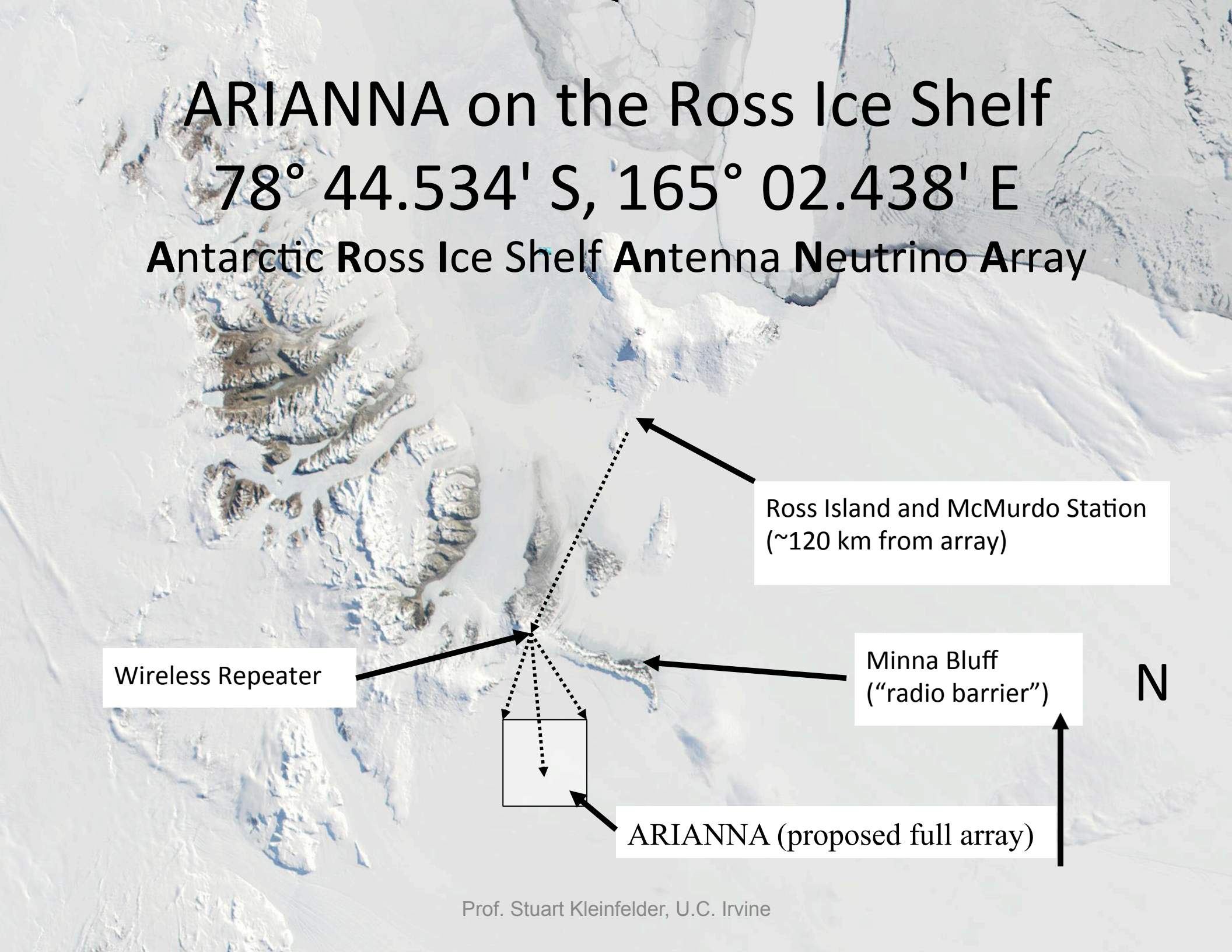
The ARIANNA Ultra-High-Energy Neutrino Experiment

Dr. Stuart Kleinfelder, Ph.D.
Professor, Dept. of Electrical Engineering and Computer Science
University of California, Irvine
and the ARIANNA Collaboration:
U.C. Irvine; Aarhus U., Denmark; U. Kansas; U.C. LBNL; SUNY, Stony Brook; Moscow Engineering and Physics Institute, Moscow; U. Nijmegen, Netherlands; U. Uppsala, Sweden; Washington U. St. Louis.

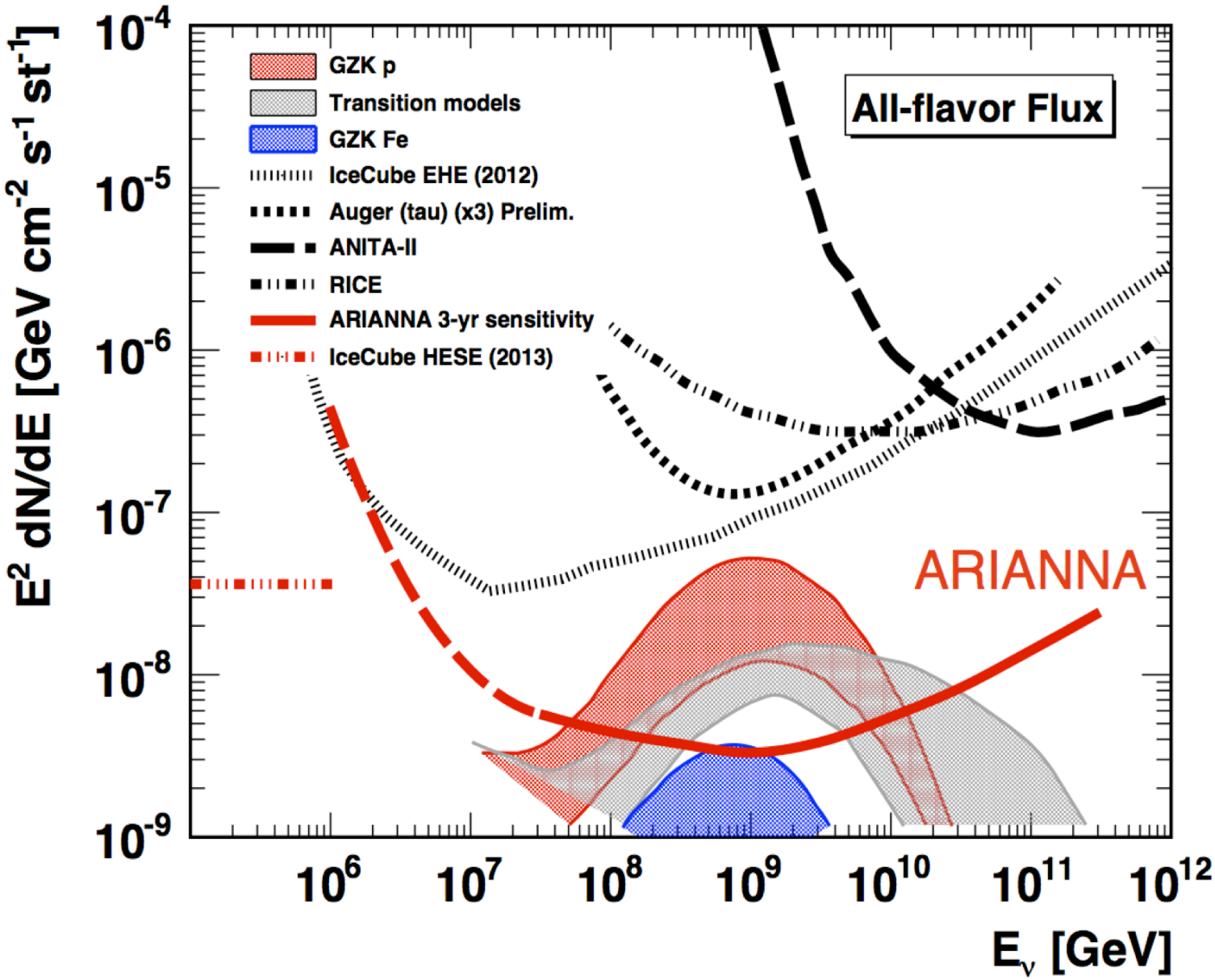
ARIANNA on the Ross Ice Shelf

78° 44.534' S, 165° 02.438' E

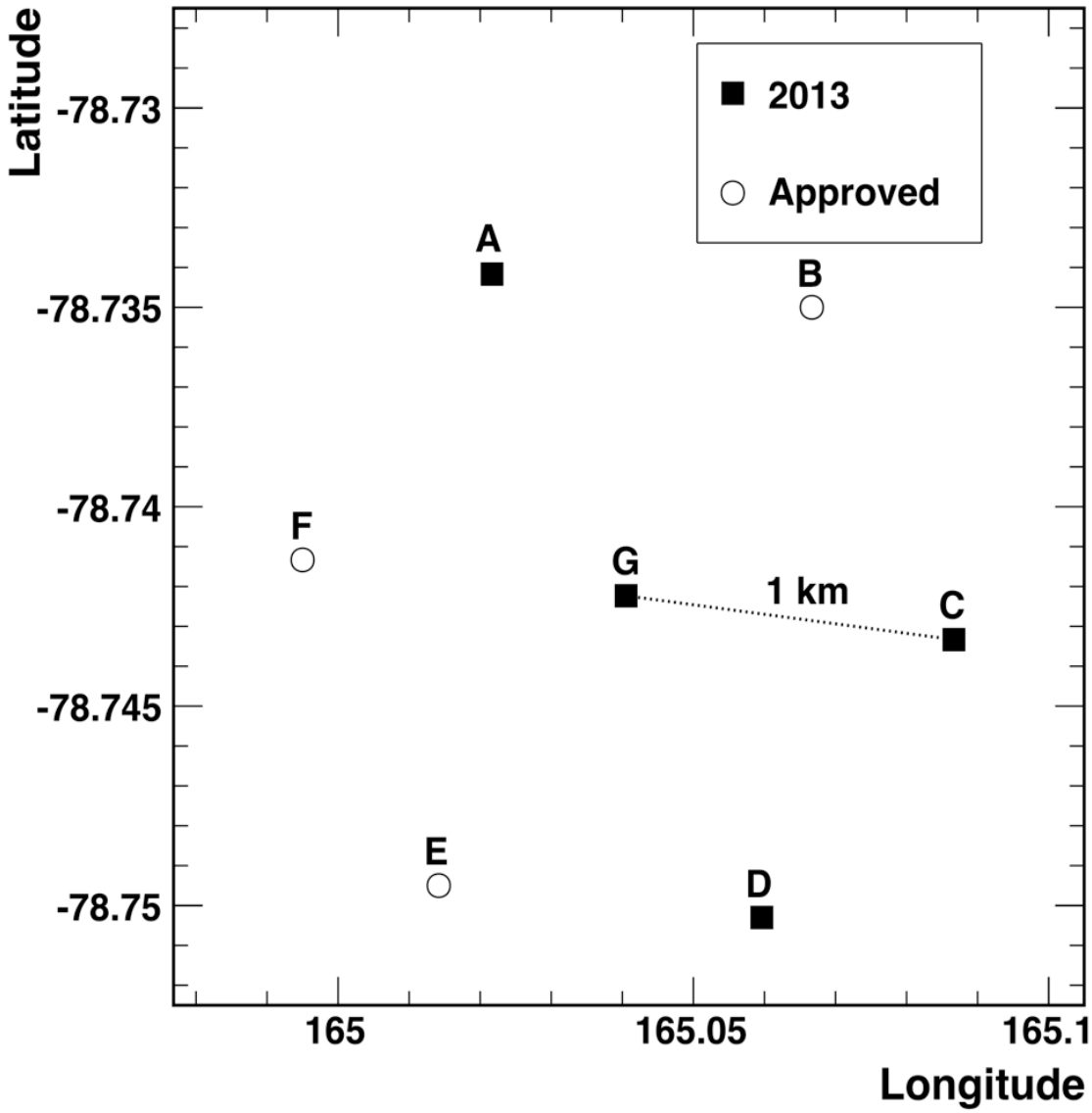
Antarctic **R**oss **I**ce Shelf **An**tenna **N**eutrino **A**rray



ARIANNA Sensitivity Comparison



Pilot Hexagonal Array Overview

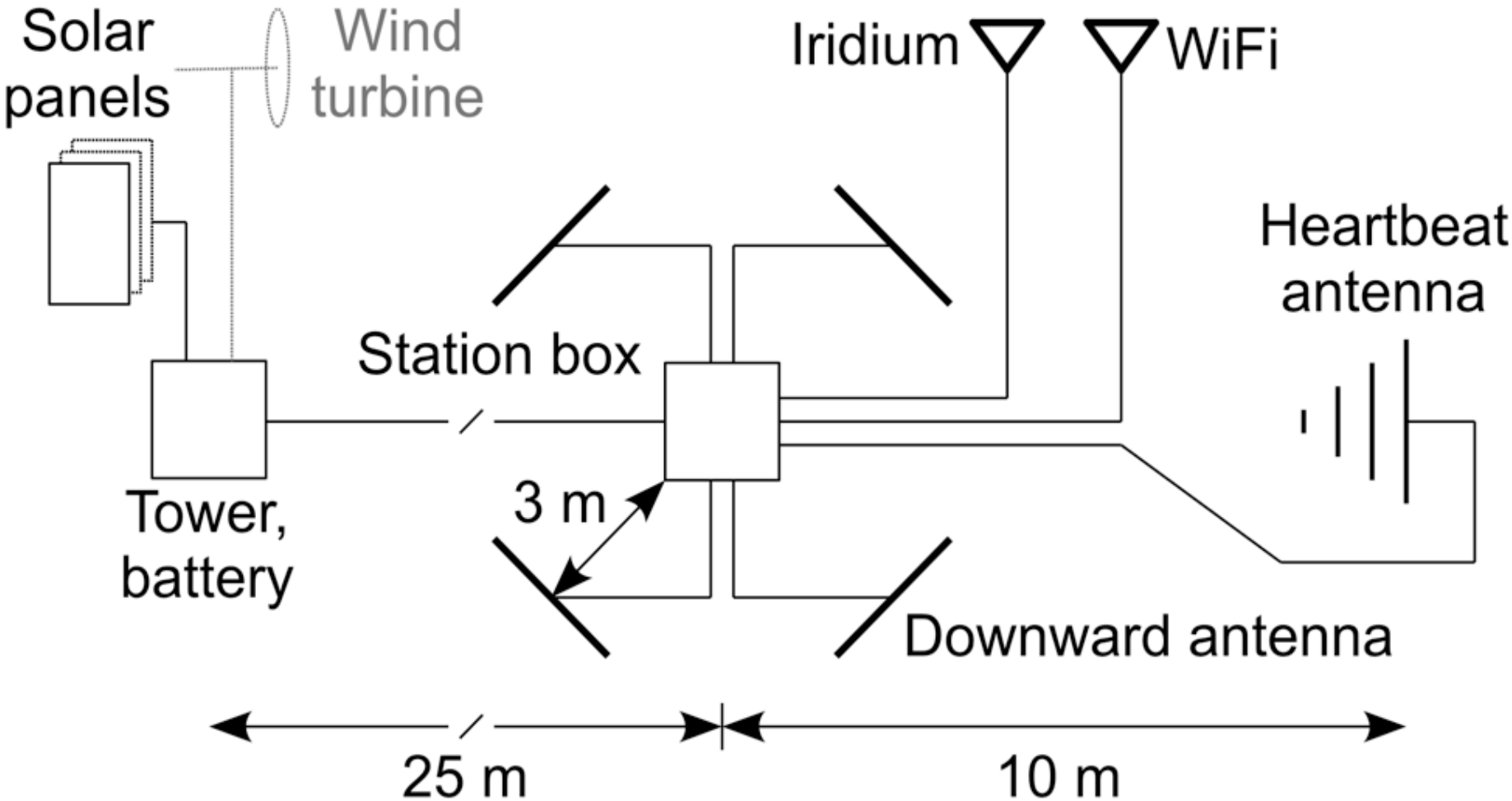


- Site A installed in 2012.
- Sites C, D and G installed in 2013, using lower-power, lower-noise second-generation systems.
- Brief service mission in 2013-2014 Austral summer, during which Sites C, D and G's calibration, noise floor and voltage tolerance was improved. Site A was converted to a weather station and secondary always-on WiFi link.
- Sites A, B, E and F planned for installation during the 2014-2015 Austral Summer.

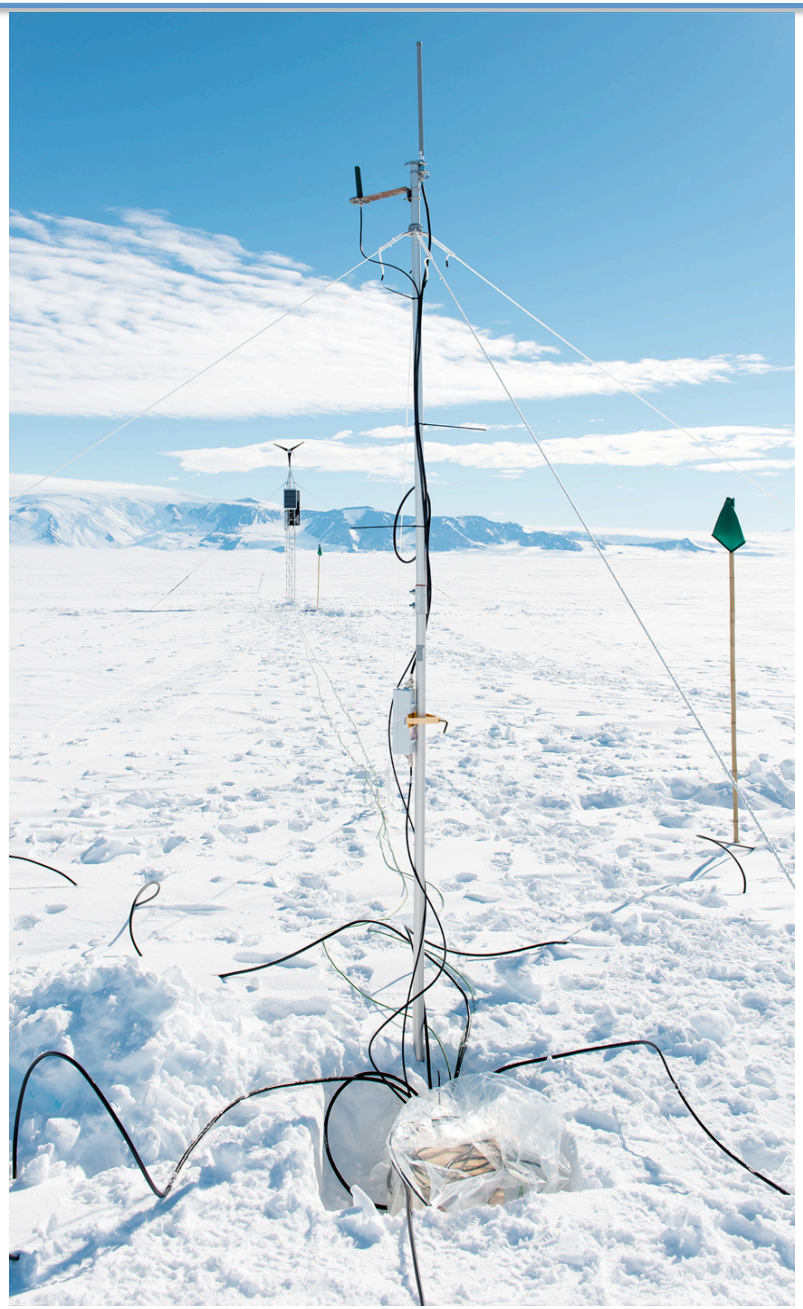
Station Site Overview

Power tower in background with battery box, WiFi and Iridium mast in foreground, flags mark antenna locations, system not seen in photo (not yet installed).

Station Overview



Power Tower and Comm. Mast



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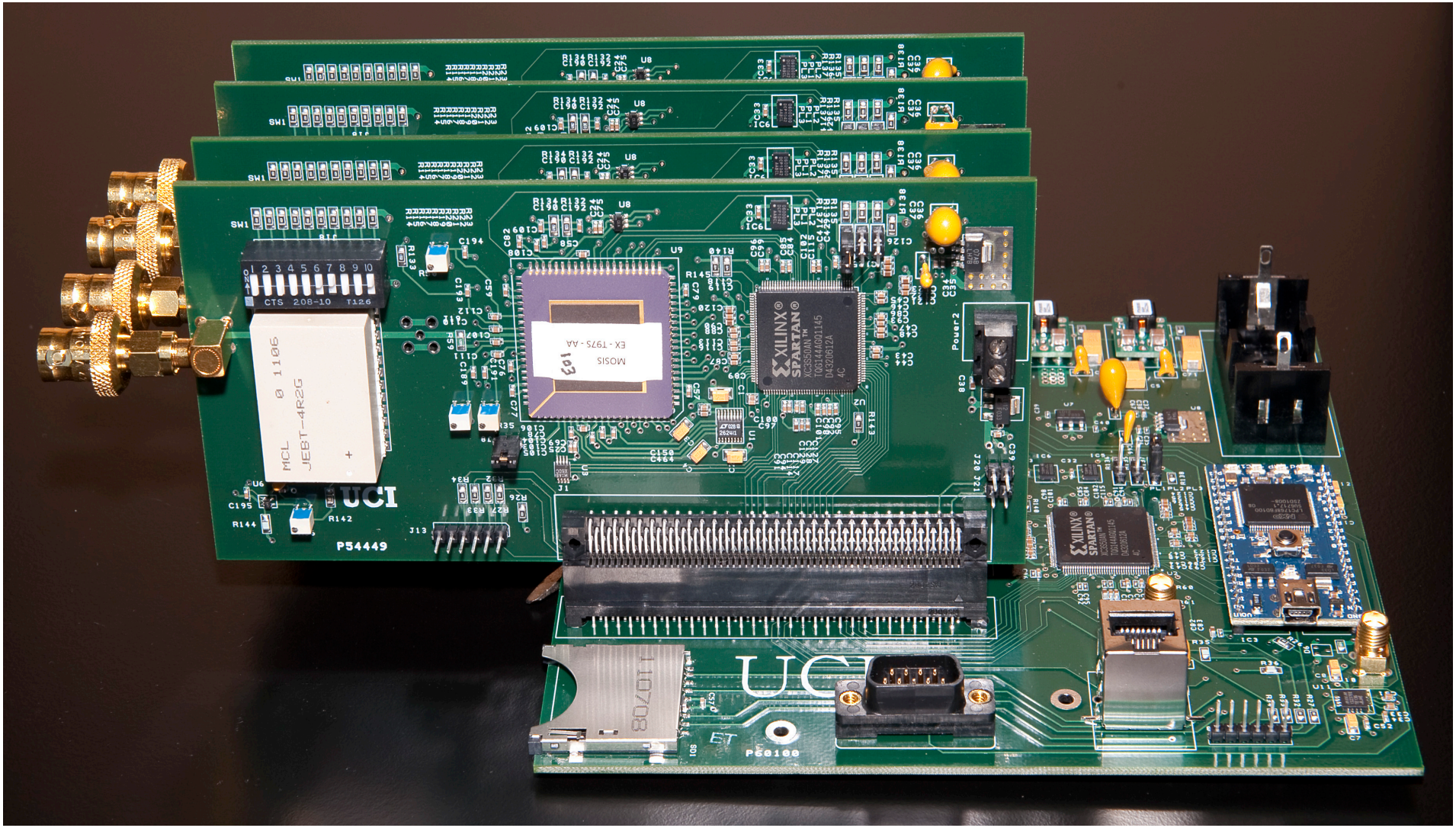
2012 ARIANNA DAQ System



Four data acquisition channels, 32-bit CPU, redundant communication paths (wireless and satellite), 32 GB flash memory event data storage, power conditioning and control for all primary components, trigger I/O, “heartbeat” pulse, etc. Uses <10W.

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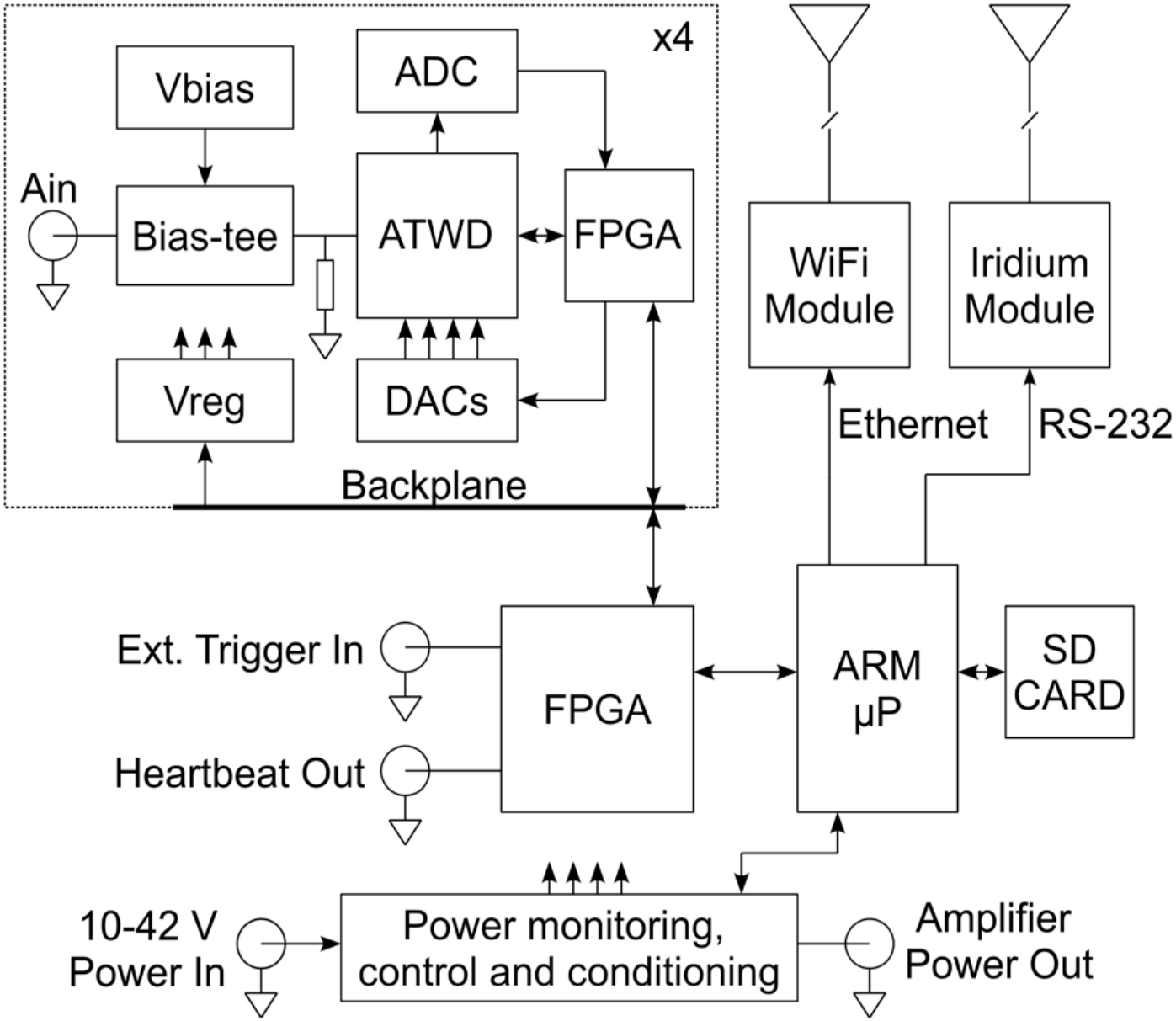
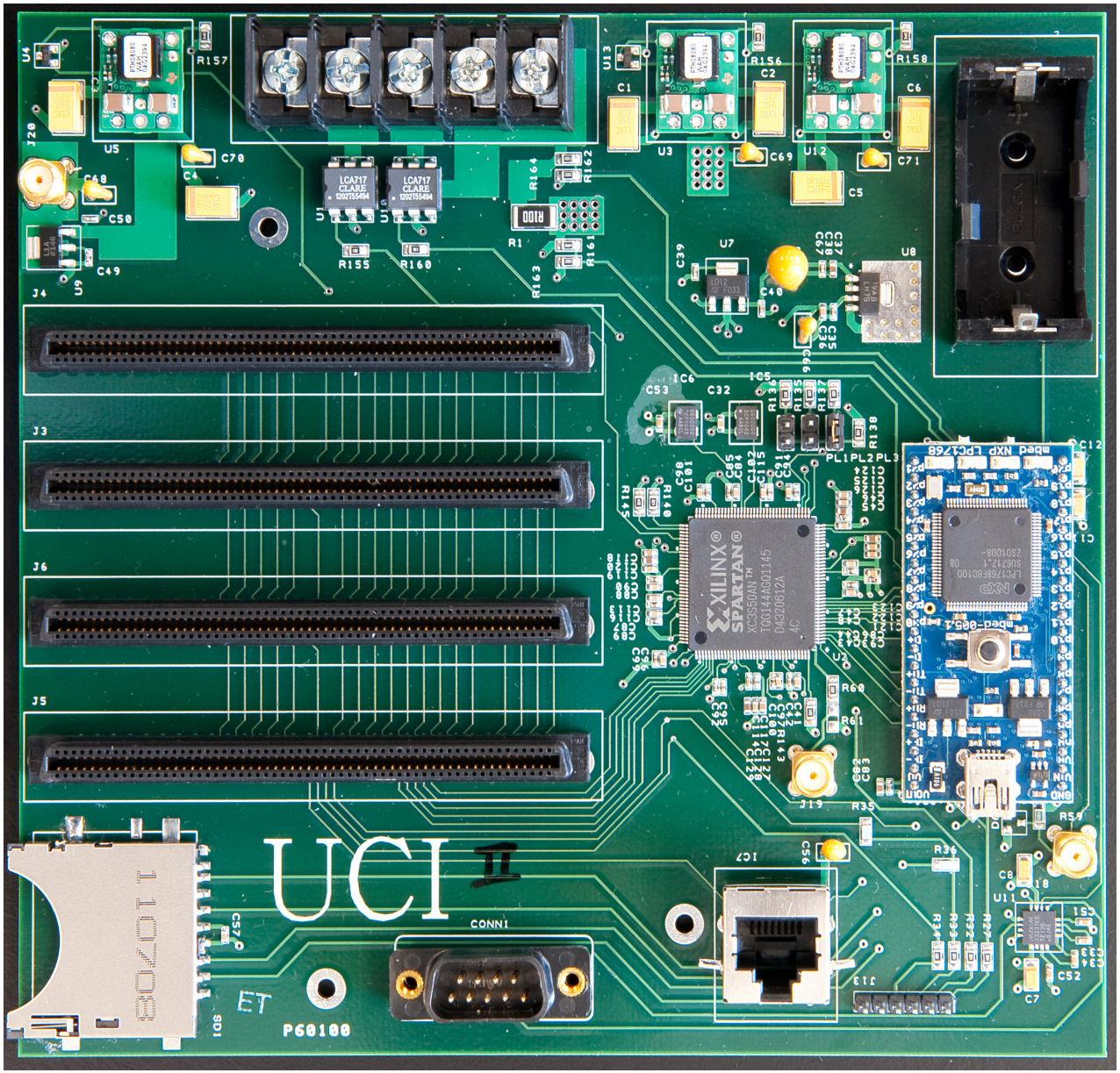
System Electronics Overview

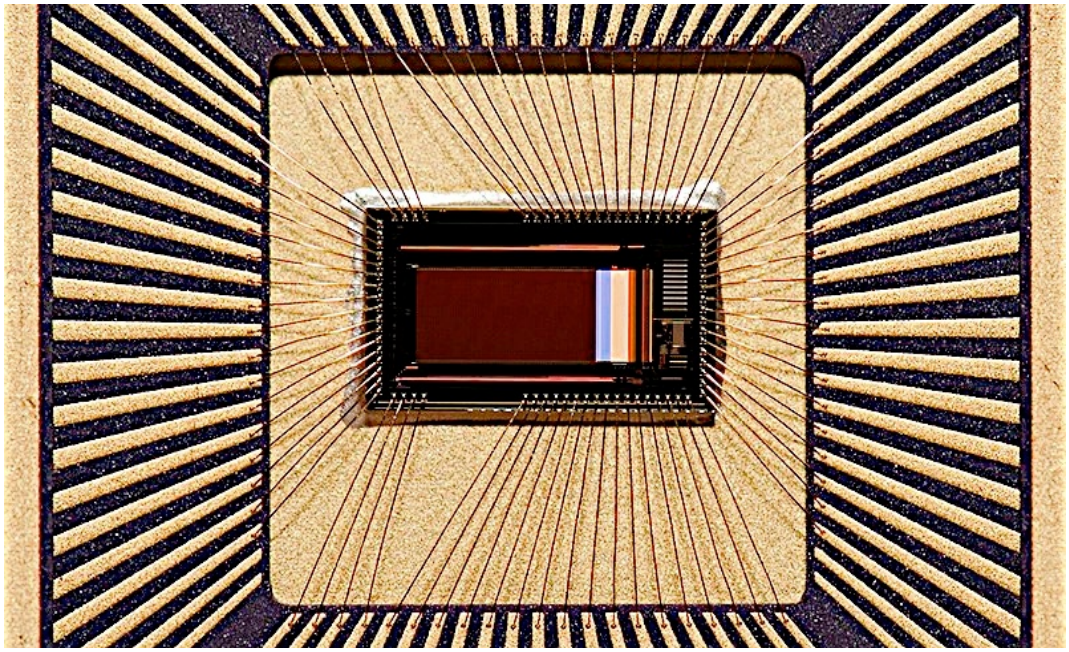


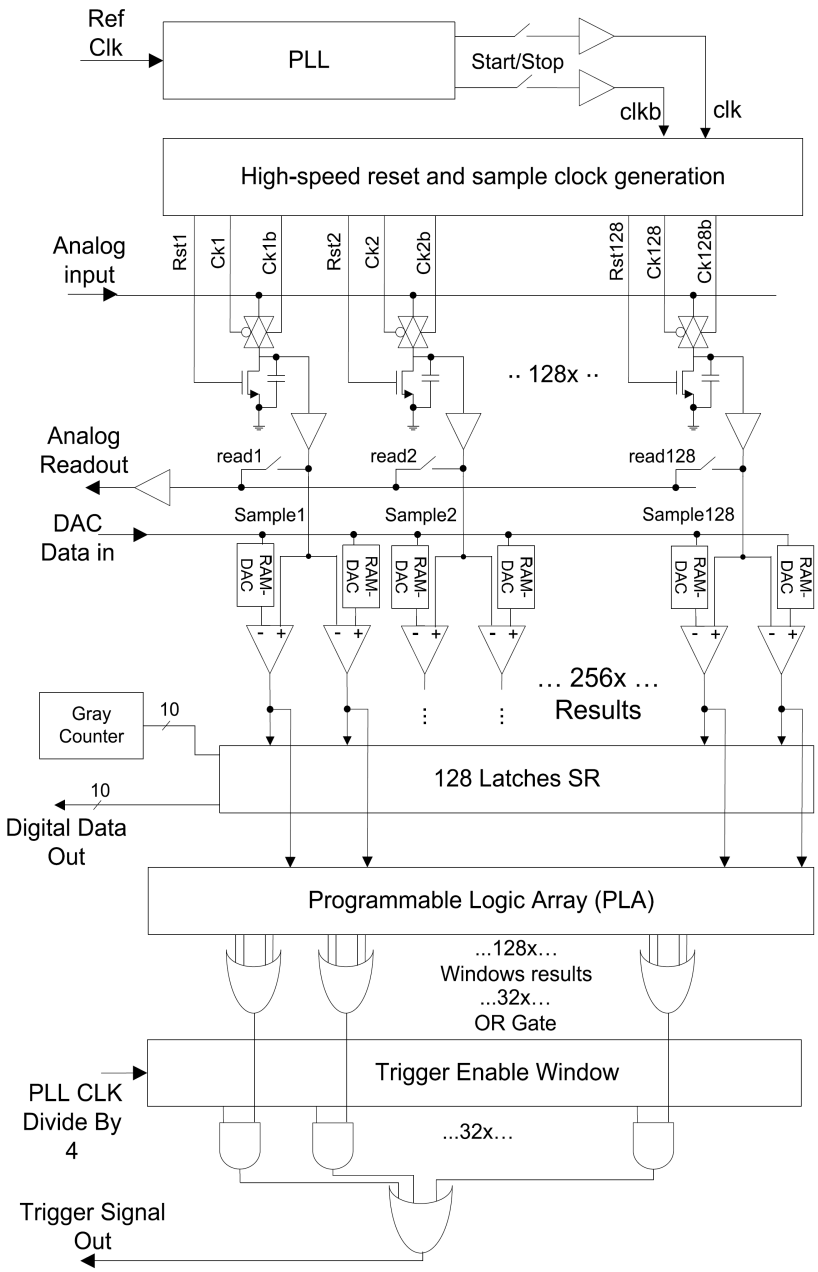
2012 ARIANNA Station Motherboard



- Four slot DAQ system
- 32-bit microcontroller
- Trigger input
- Trigger output
- A/D and D/A
- Ethernet (WiFi)
- RS-232 (Iridium SBD)
- 32 GB SD flash card slot
- 3x DC-DC converters
- Fast (<2ns FWHM) "heartbeat" pulser
- Battery backup for real-time clock (1.5 AH)
- Power control for:
  - Acquisition cards
  - Amplifiers
  - Iridium satellite
  - AFAR wireless
- Use $LiFePO_4$ main power.

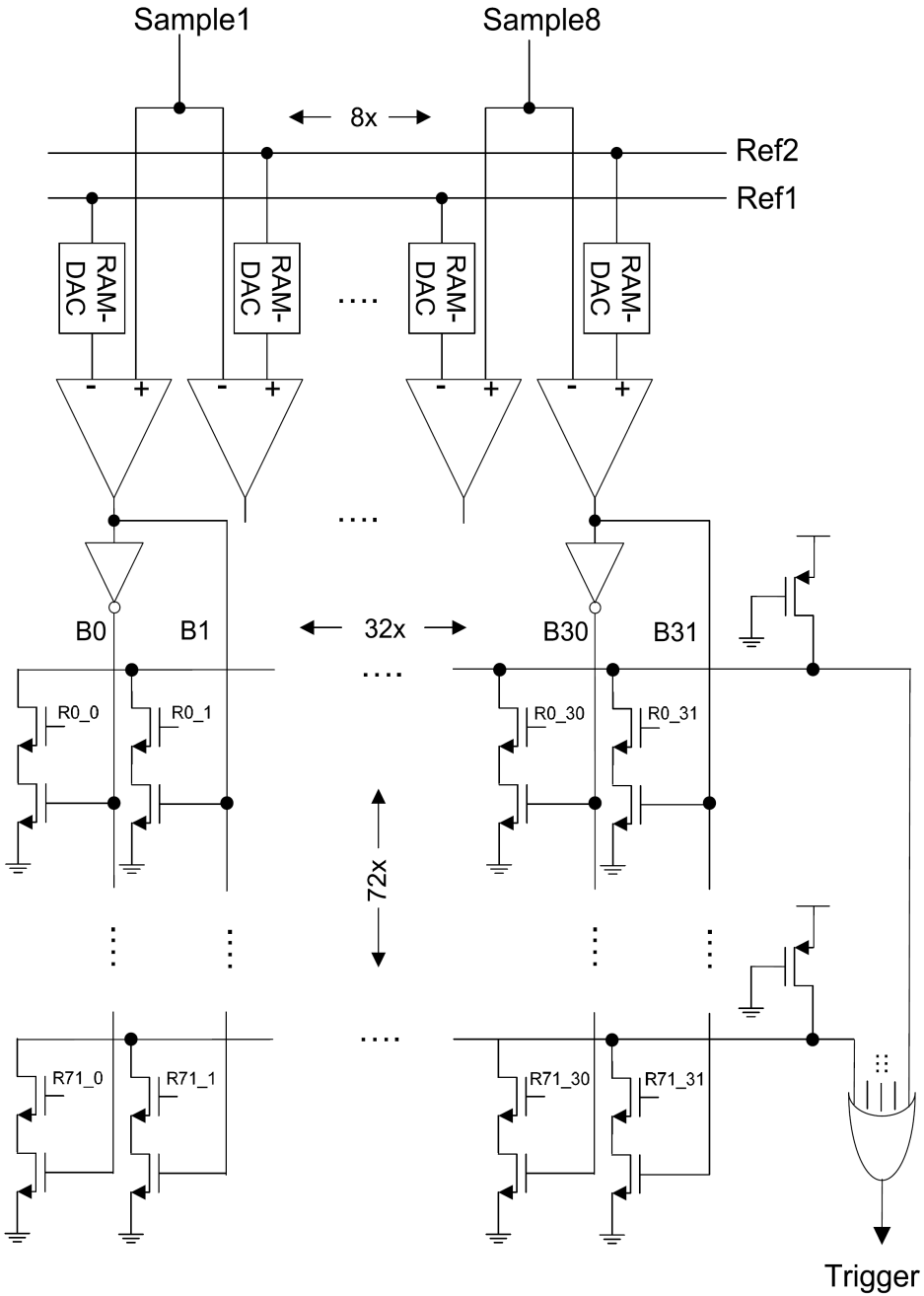
Advanced Transient Waveform Digitizer





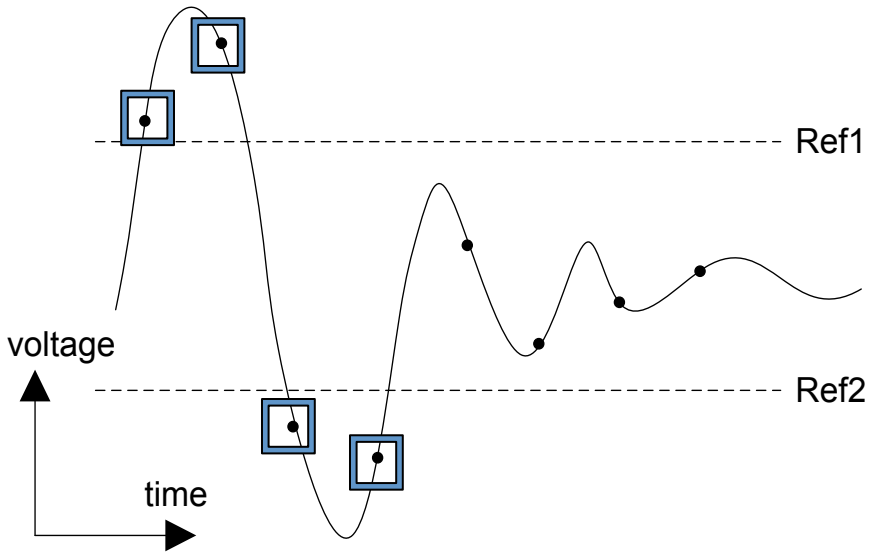
- Designed at UCI.
- Synchronous 2 GHz clocked timing.
- Jitter under 1 part per million.
- Two thresholds per sample.
- Real-time pattern-matching trigger system.
- Search for 72 patterns in samples.
- On-chip trigger window.
- On-chip digitization.
- Fixed pattern noise cancellation.

ATWD Pattern Trigger



- Trigger developed in real time.
- Two thresholds (high and low).
- Two comparators per sample.
- One 6-bit DAC per comparator for offset cancellation.
- Programmable logic array 128x72.
- Logic works in 8-sample windows.
- Windows overlap for complete coverage.
- A programmable revolving trigger window follows the signal and selects which triggers are valid.
- Final output is an OR of any triggers.
- Trigger produced in under 15 ns., allowing sufficient time to stop the acquisition before the sampler loops over the acquired waveform.

Programmable Trigger Example



Example Program:

HHLLXXXX

LLHHXXXX

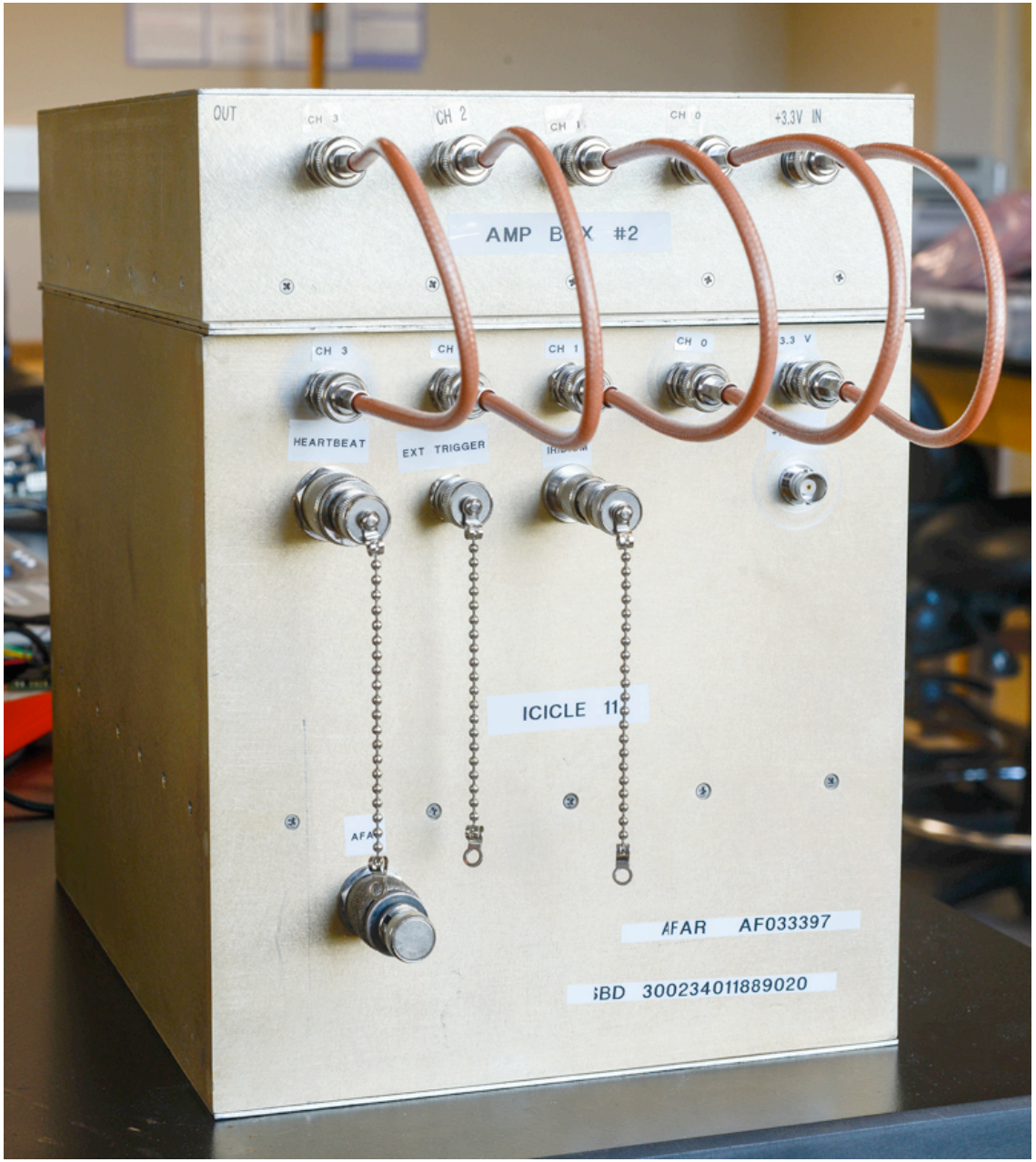
(…Up to 72 patterns)

Searches for two high (H) followed by two low (L) signals or the opposite (LLHH) (X = don't care)

The ATWD compares a transient voltages signal in real-time against a set of stored signatures. When a match is observed, the ATWD produces a trigger. The ability to search for waveform profiles greatly increases trigger selectivity.

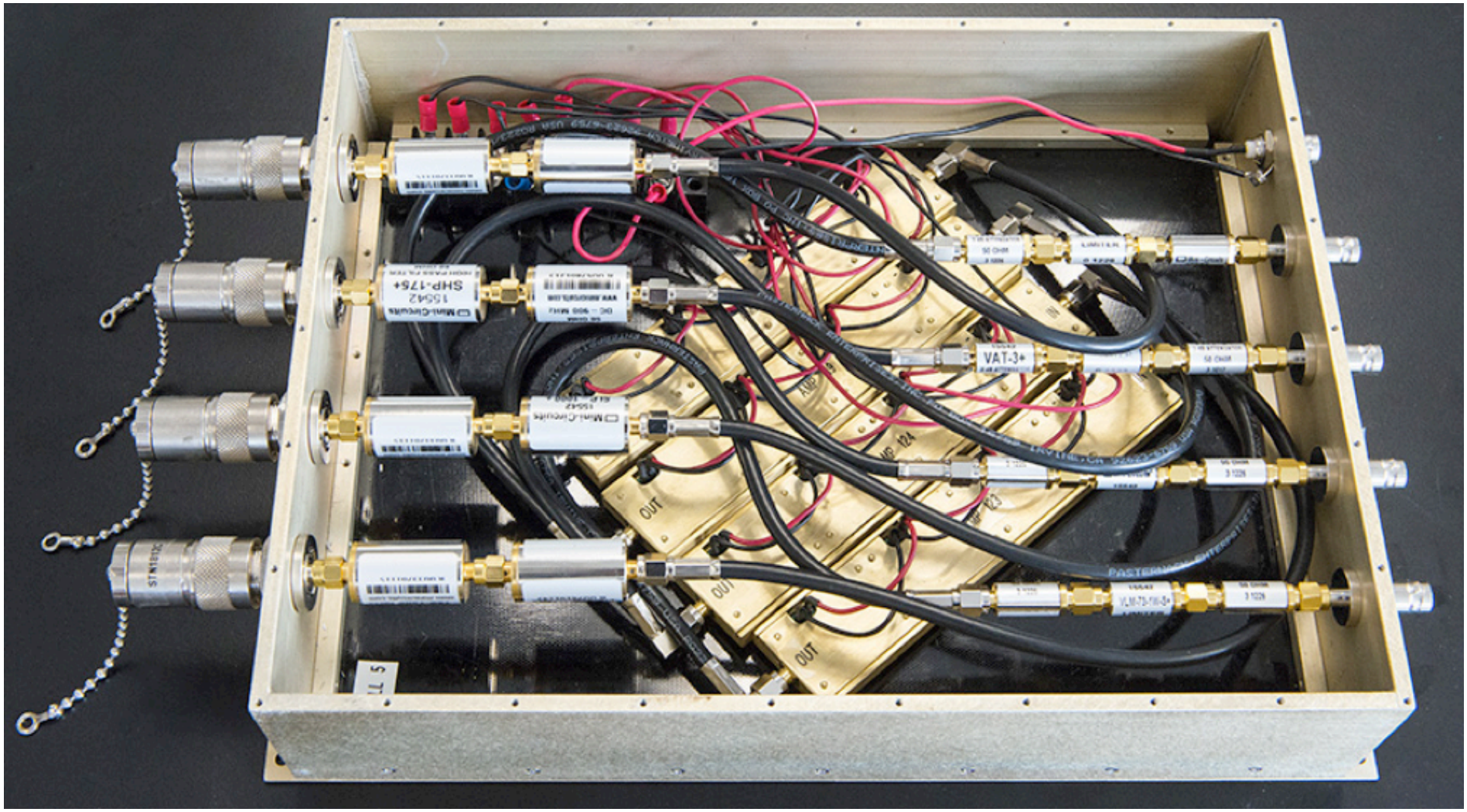
After a trigger is produced, the analog signals are digitized to 12 bits.

Amplification and System Boxes

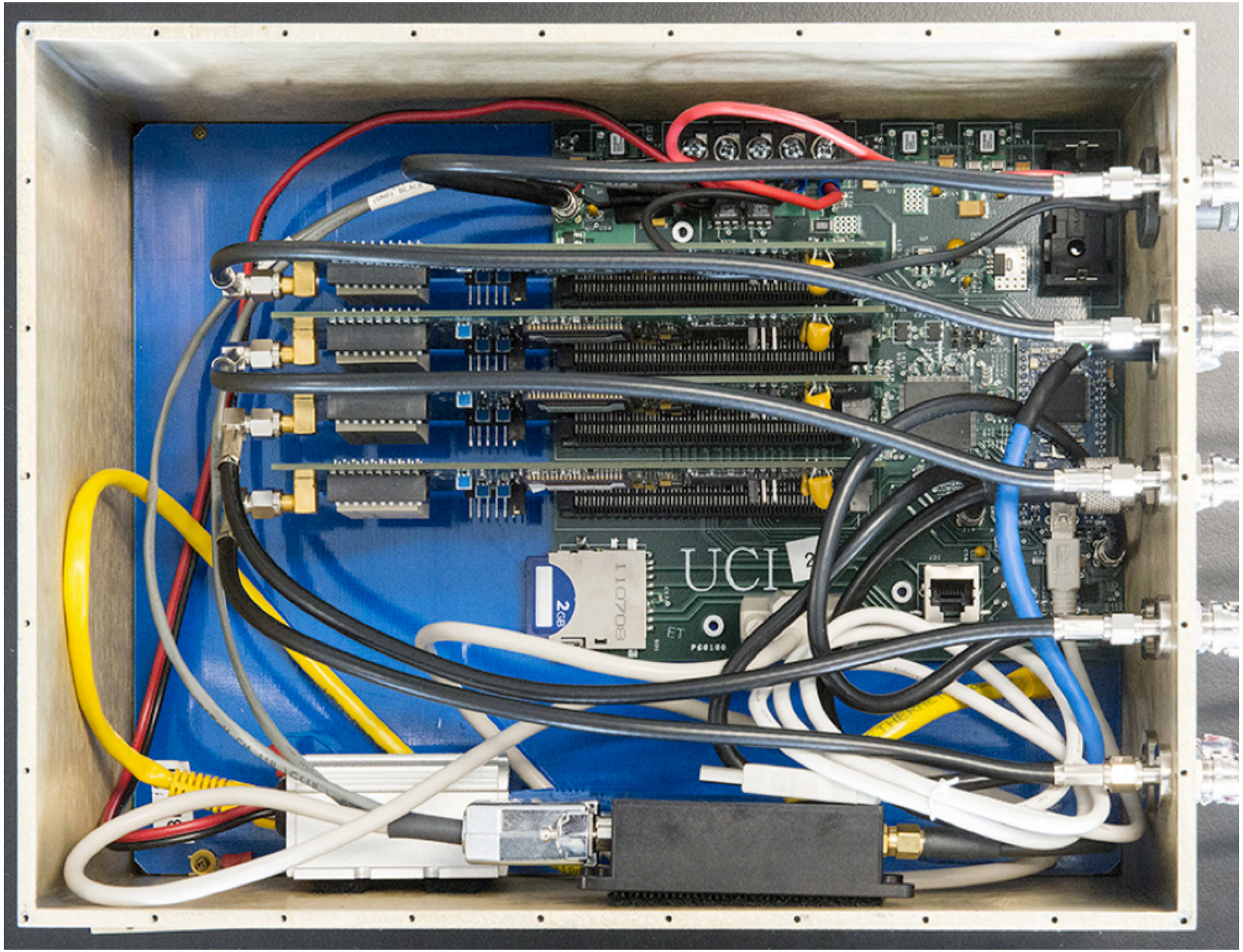


- Amplifier box contains 4 channels, N-type inputs, BNC outputs, with 3.3V power supplied via coax.
- System box encloses all DAQ electronics and WiFi and Iridium modules, includes heartbeat output, external trigger input, power control and conditioning.
- Boxes can be bolted together or kept separate.

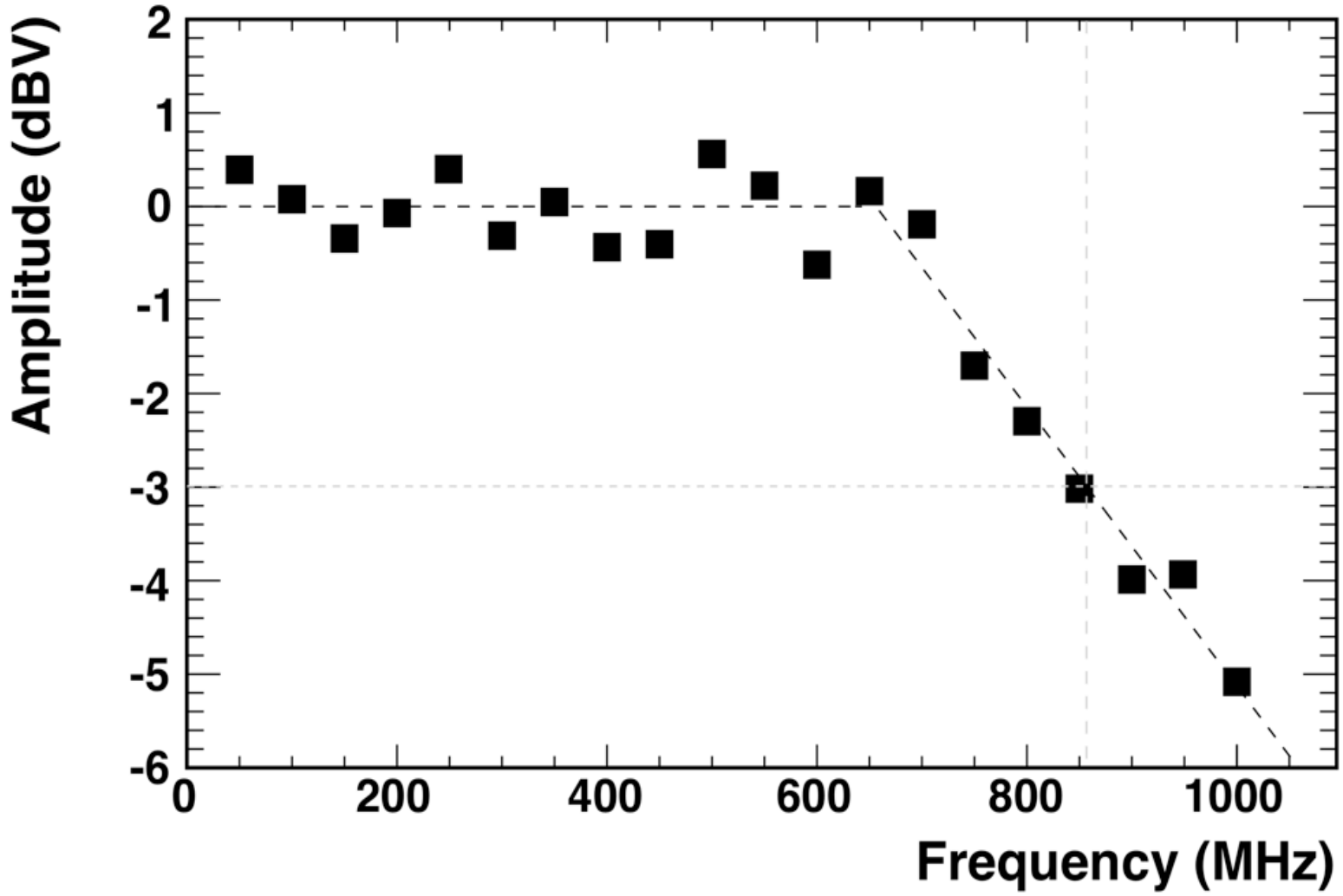
Inside the Amplifier Box



Inside the DAQ Box

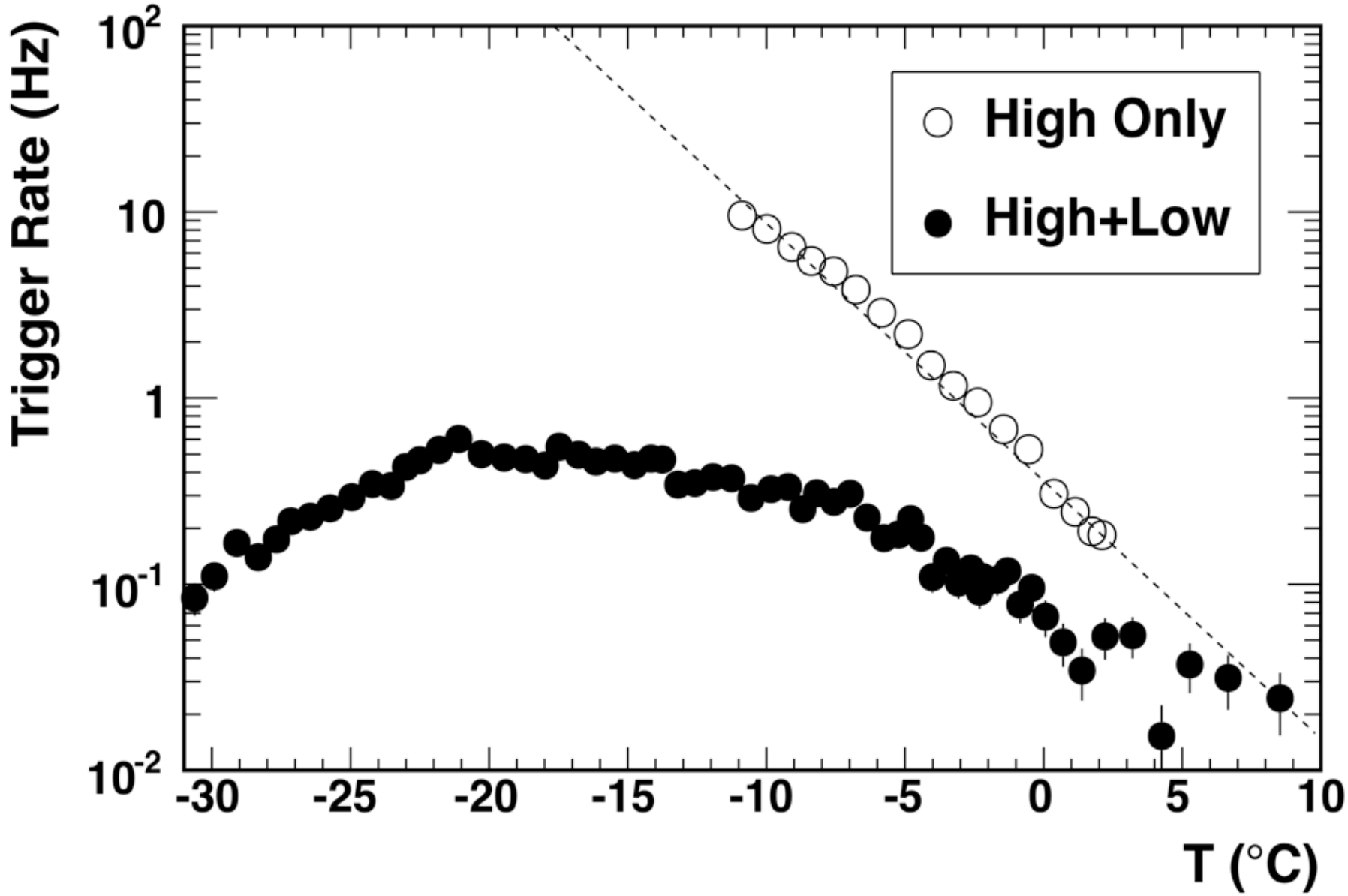


System Frequency Response

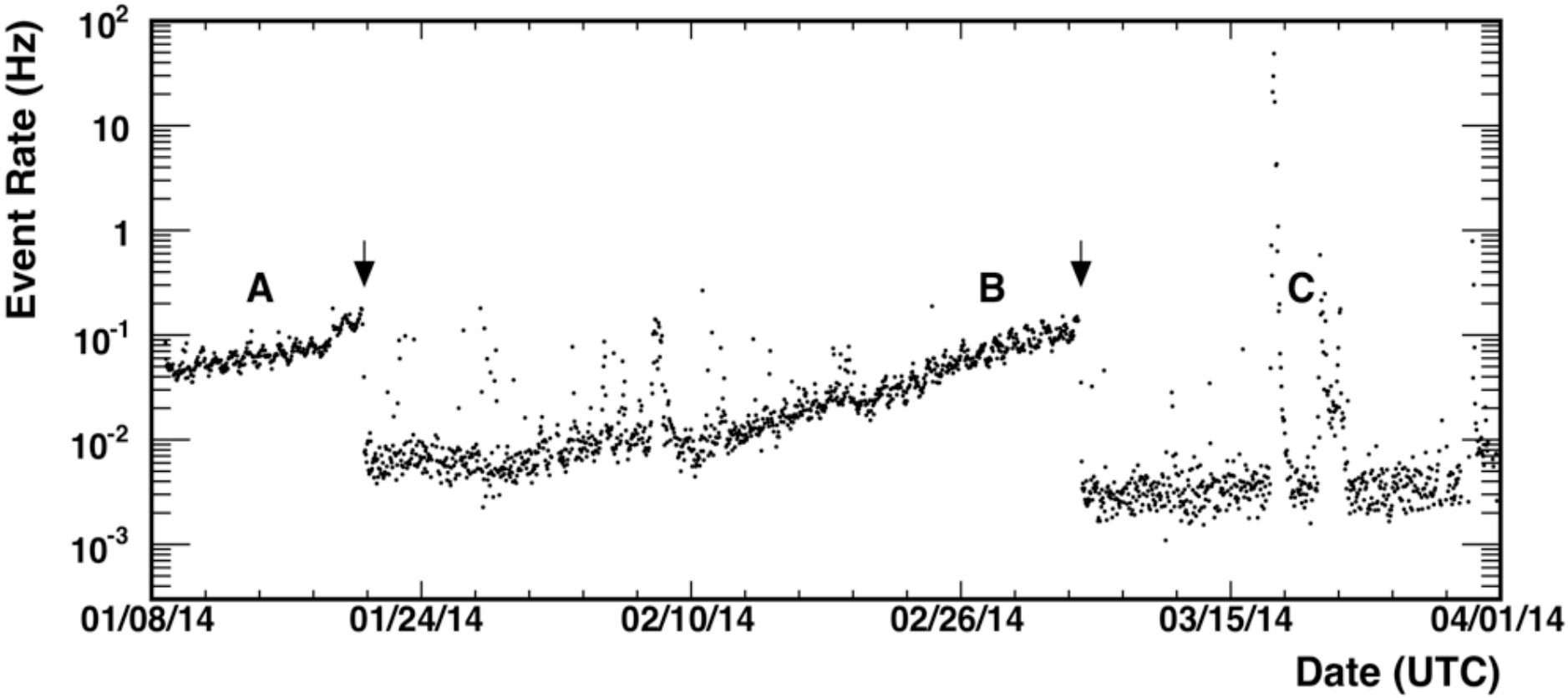


Flat to ~660 MHz, -3 dB at ~860 MHz (Nyquist is 960 MHz).

Trigger Stability vs. Temperature

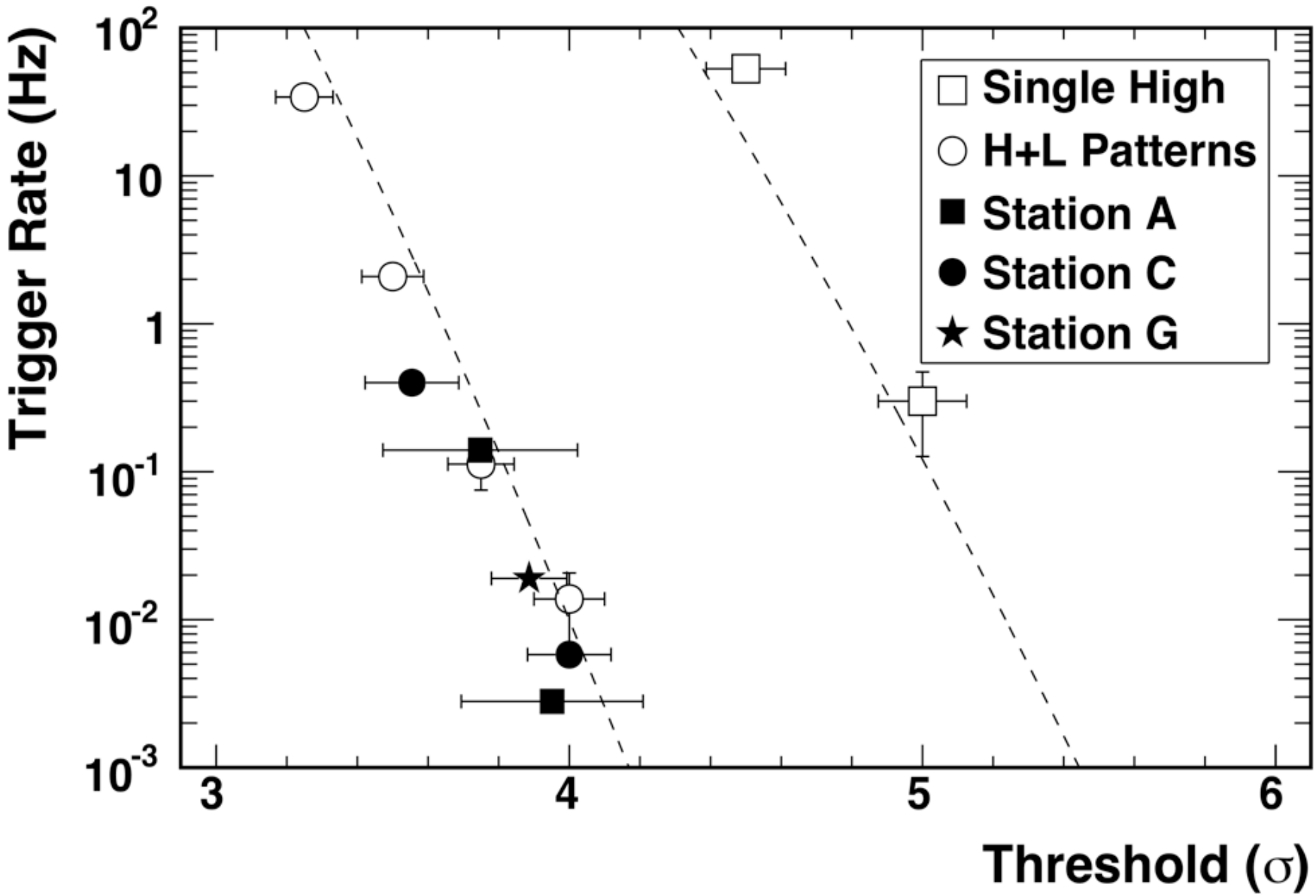


Trigger Rates vs. Time

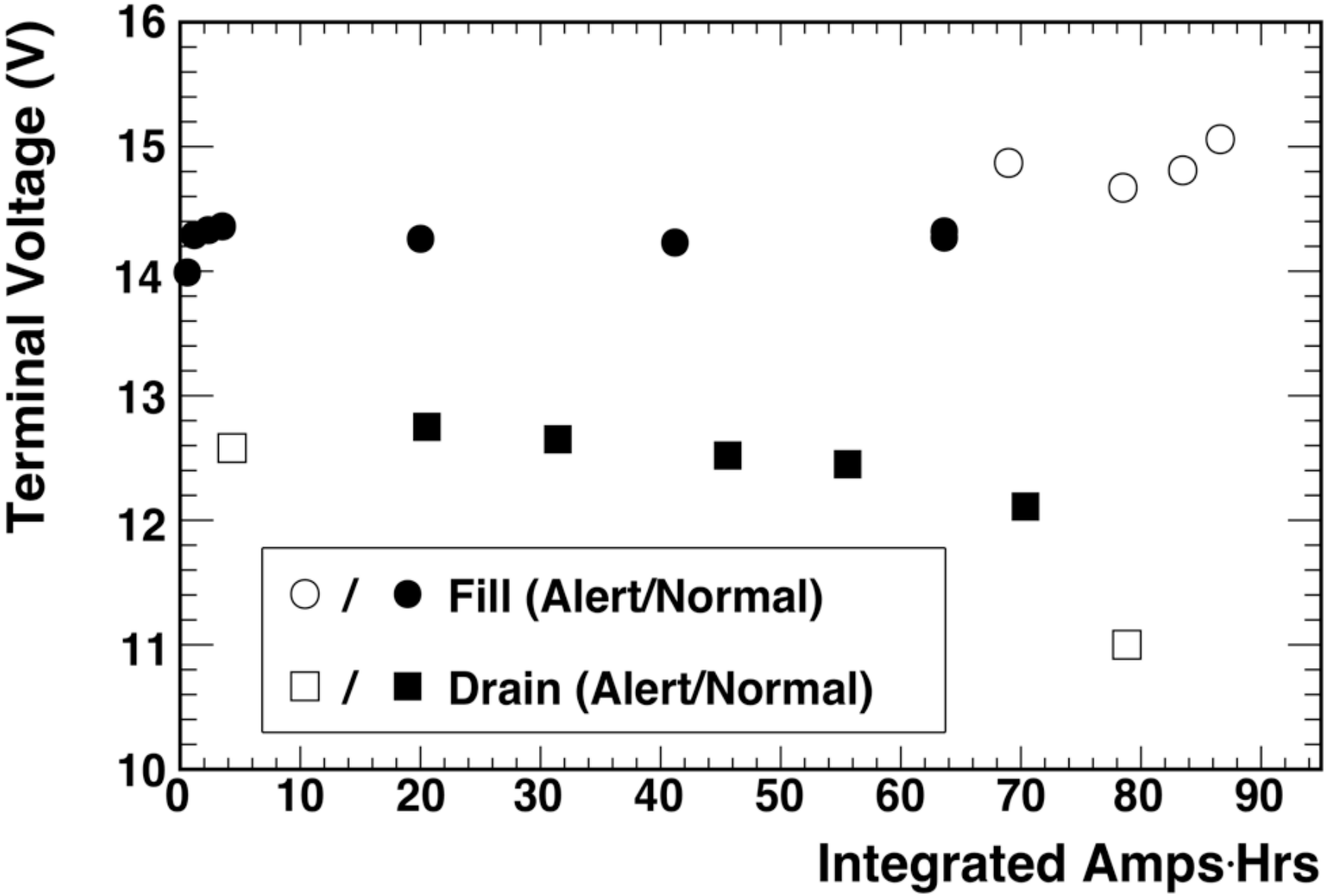


A: Basic threshold settings, diurnal changes noted.
First arrow: First threshold adjustment to ~0.005 Hz.
B: Seasonal temperature-related rate increase, minor diurnal changes.
Second arrow: Second threshold adjustment to ~0.002 Hz.
C: Storm-related trigger rate increase noted.

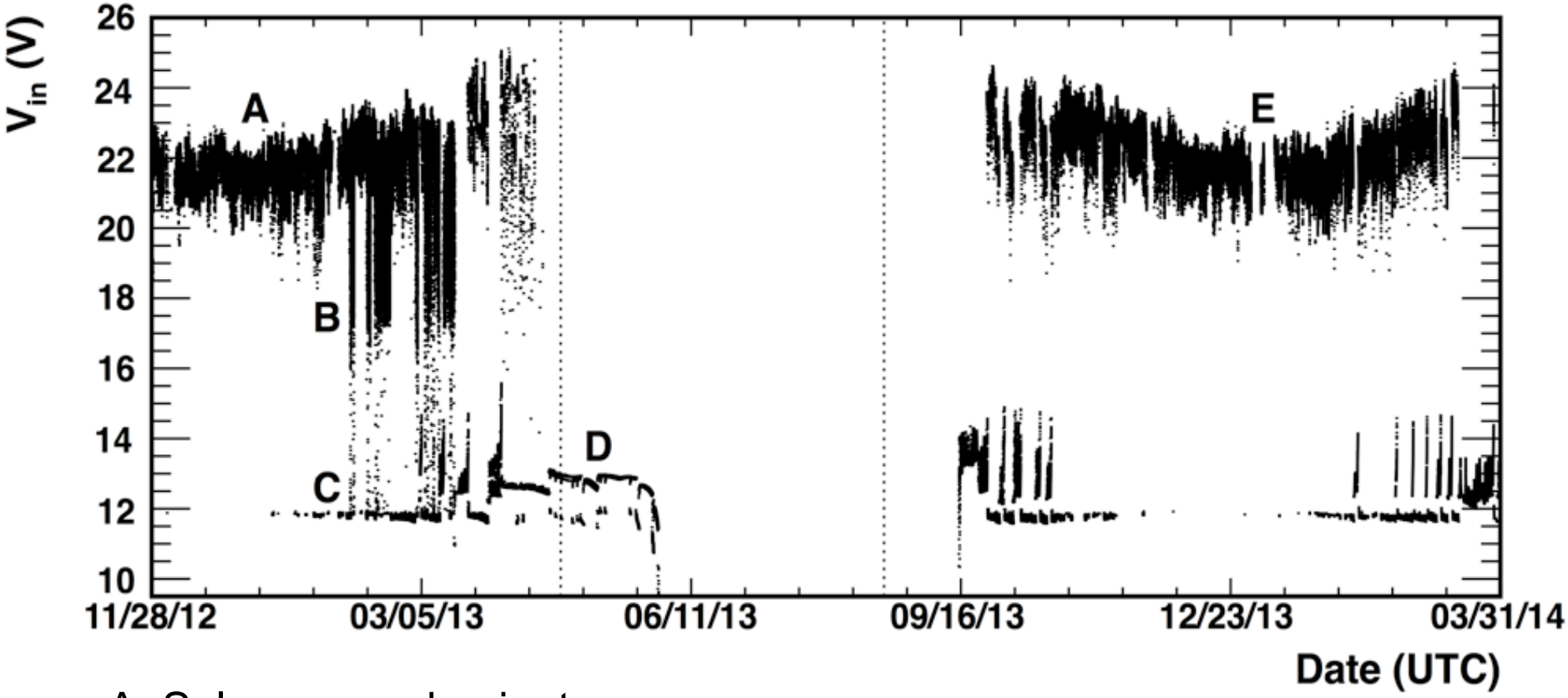
Trigger Rates vs. Threshold



LiFePo4 Battery Performance at -30C

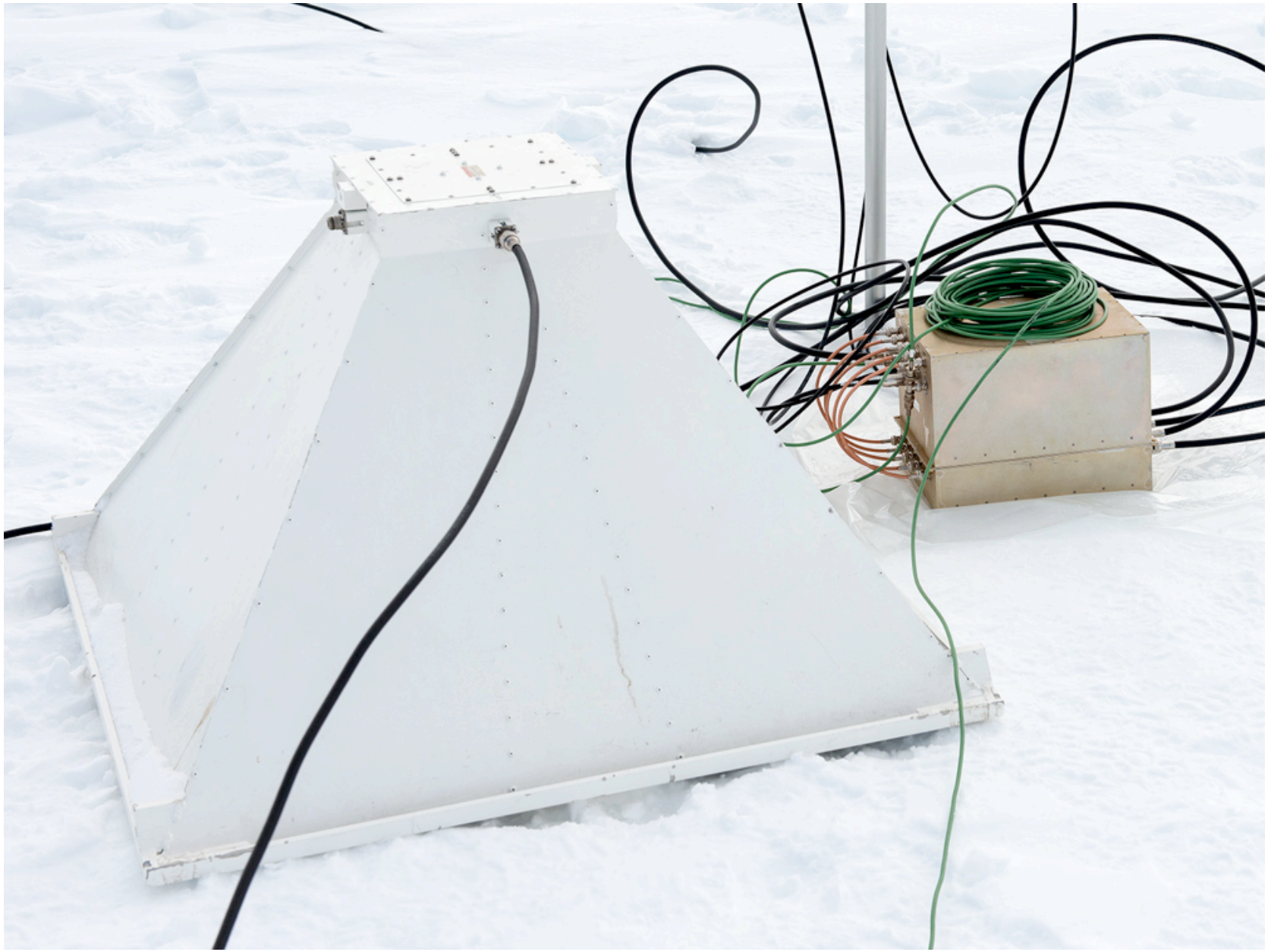


Power Supply Voltage vs. Time



A: Solar power dominates.
B: Wind turbine supplementing power generation.
C: Battery acting as backup power.
D: Battery acting as sole power supply.
E: Station down for servicing. Inverse seasonal voltage relationship noted.
Vertical dotted lines: Last sunset, first sunrise.

Reflection Studies Transmitter Horn



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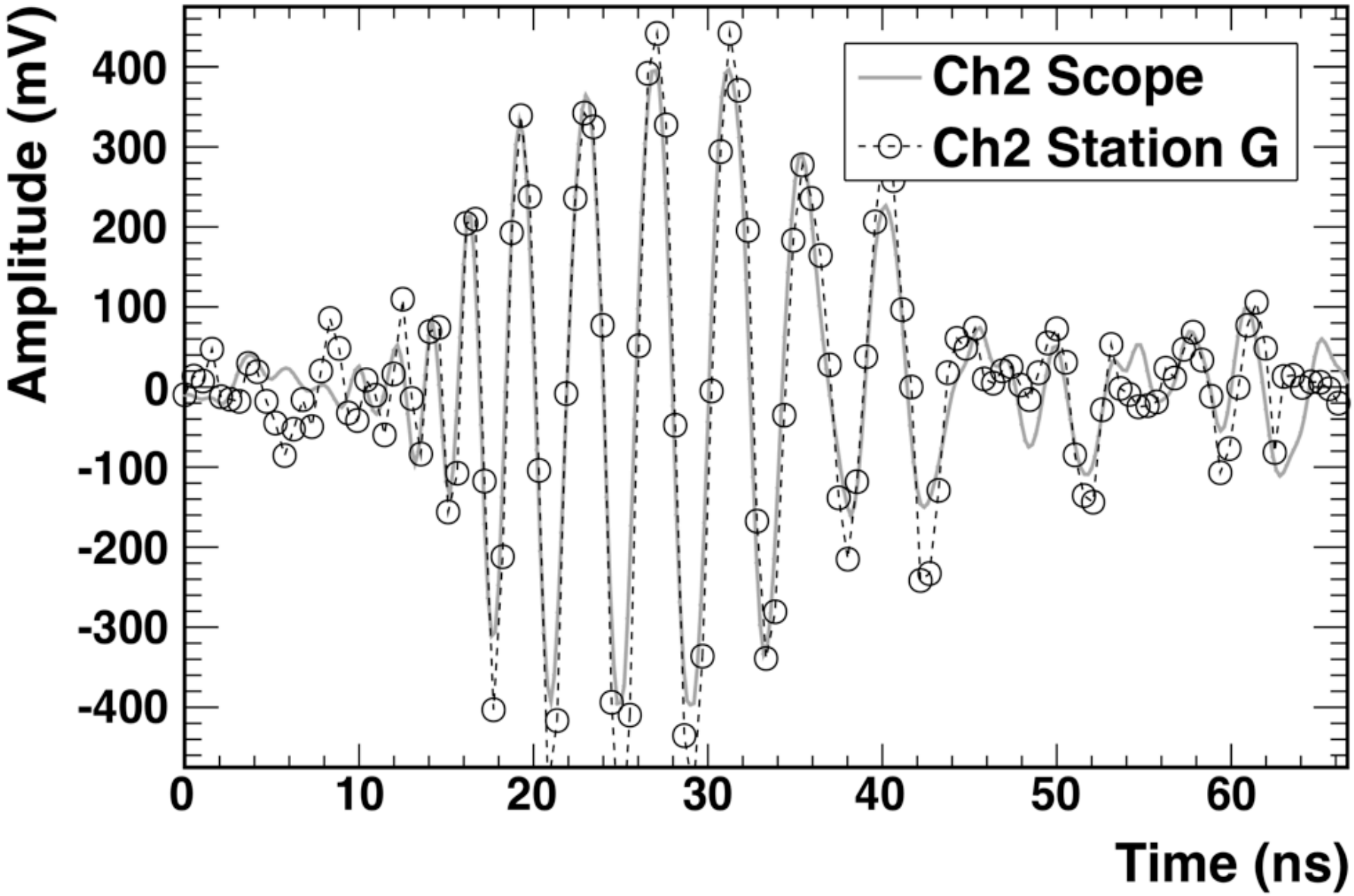
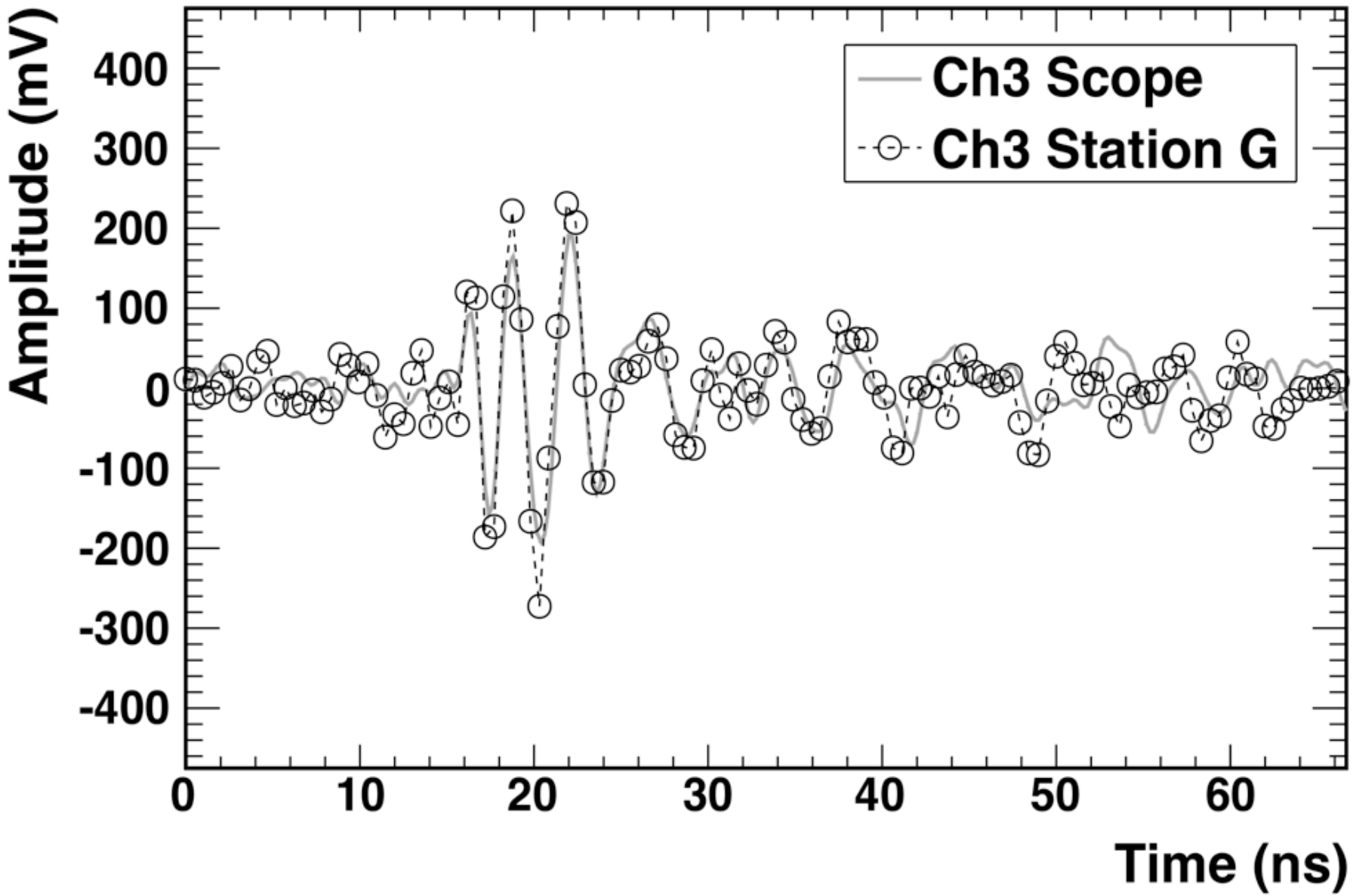
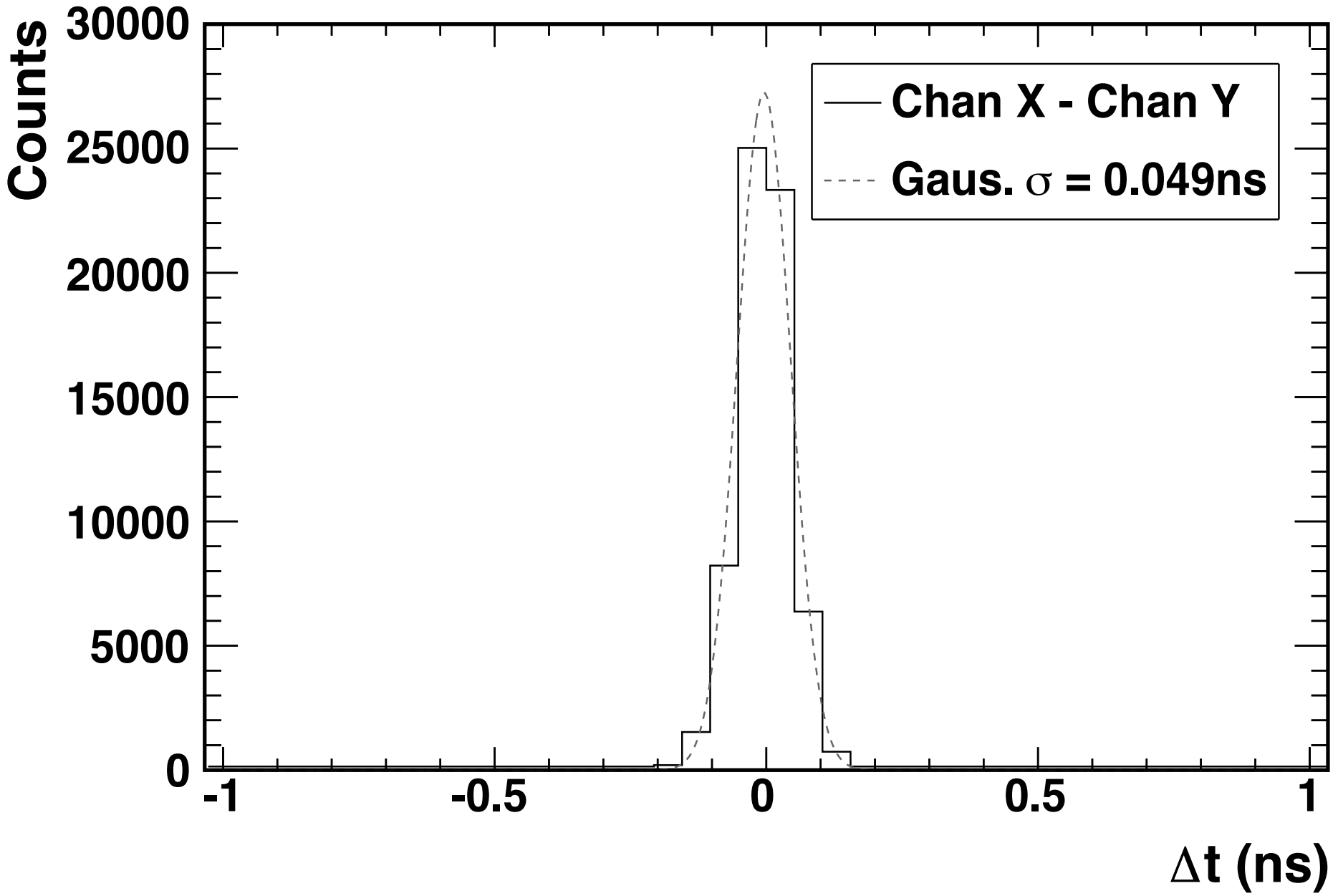
Reflected Signal Examples (Parallel)



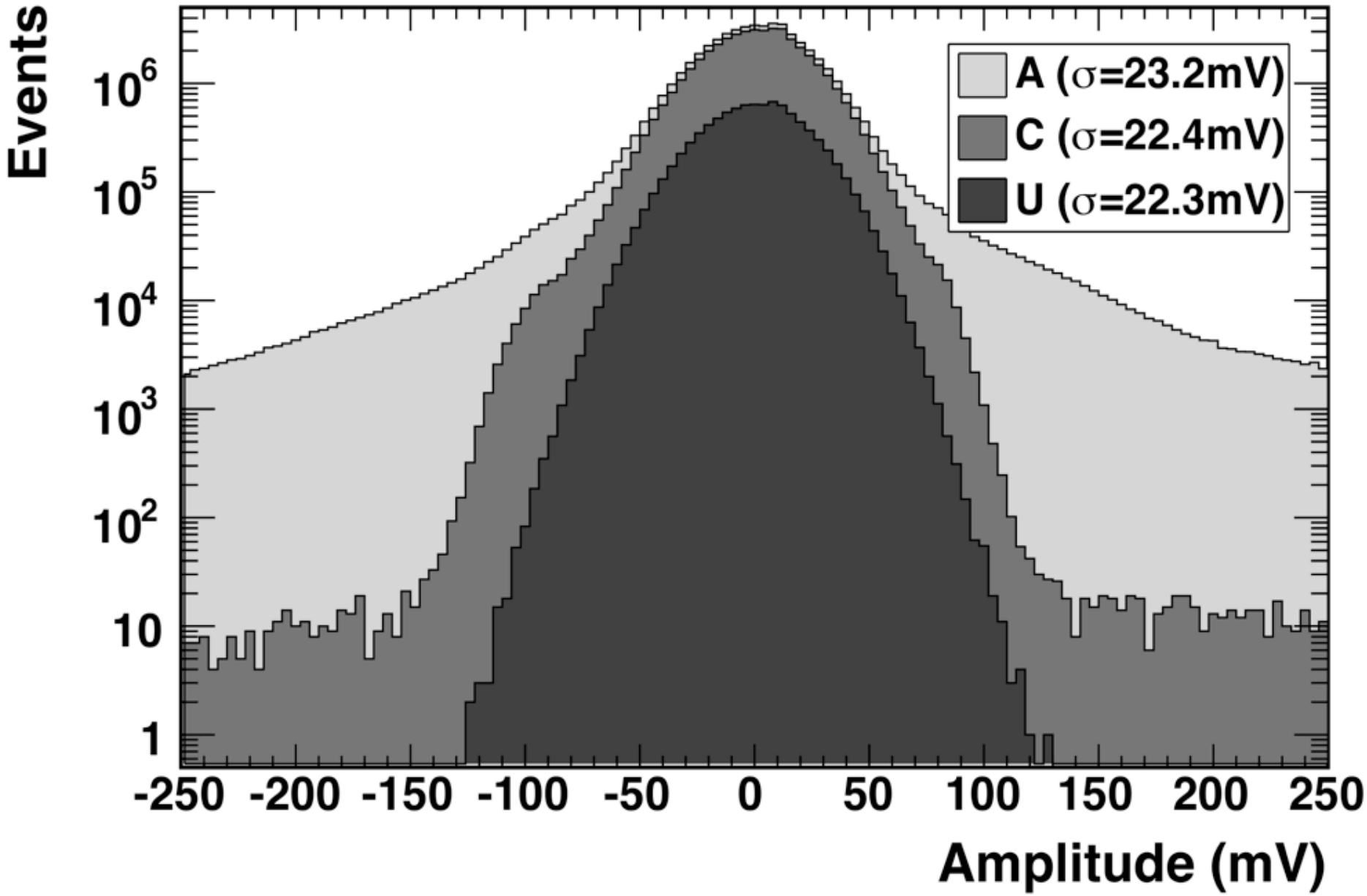
Reflected Signal Examples (Orthogonal)



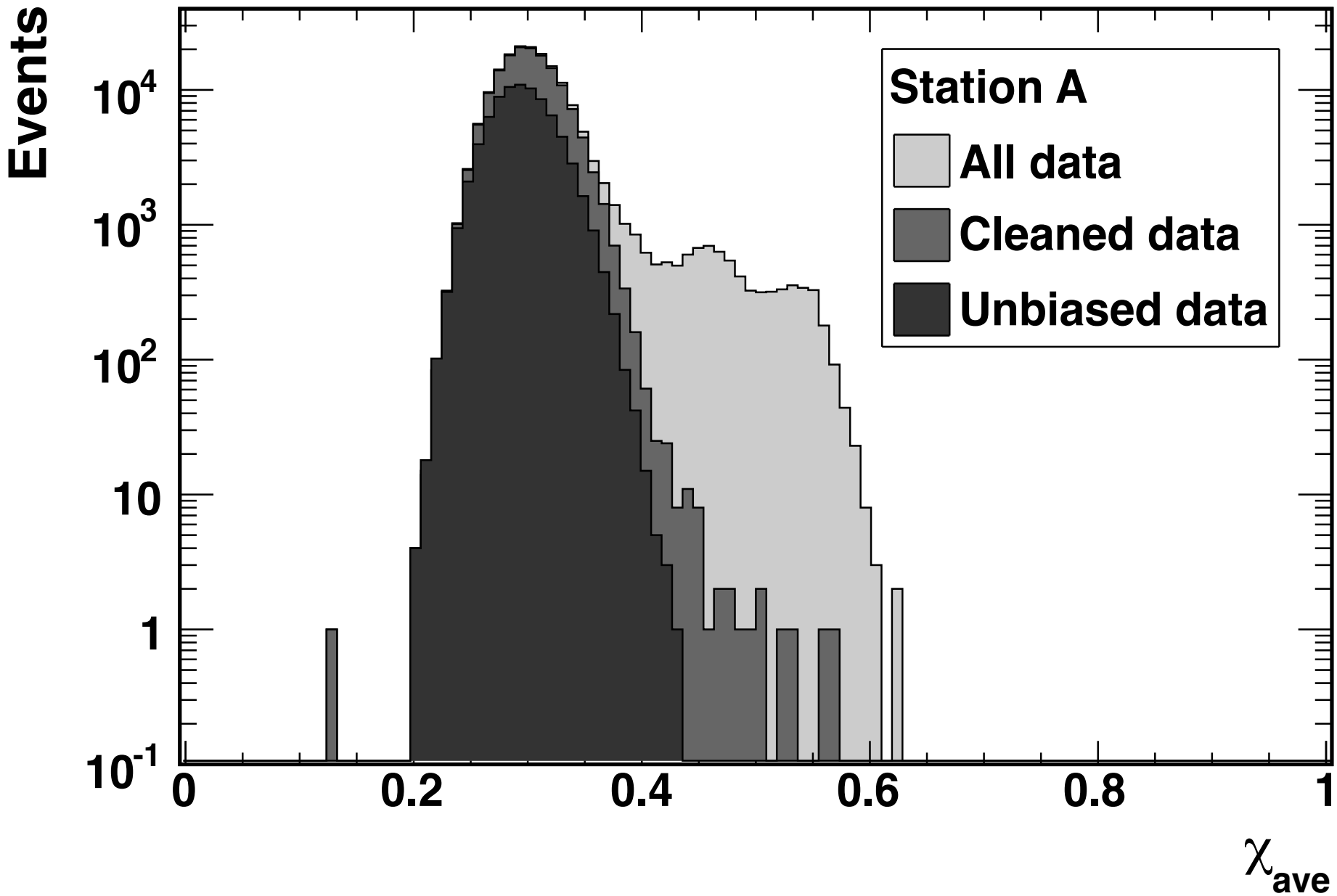
Data Acquisition Timing Resolution



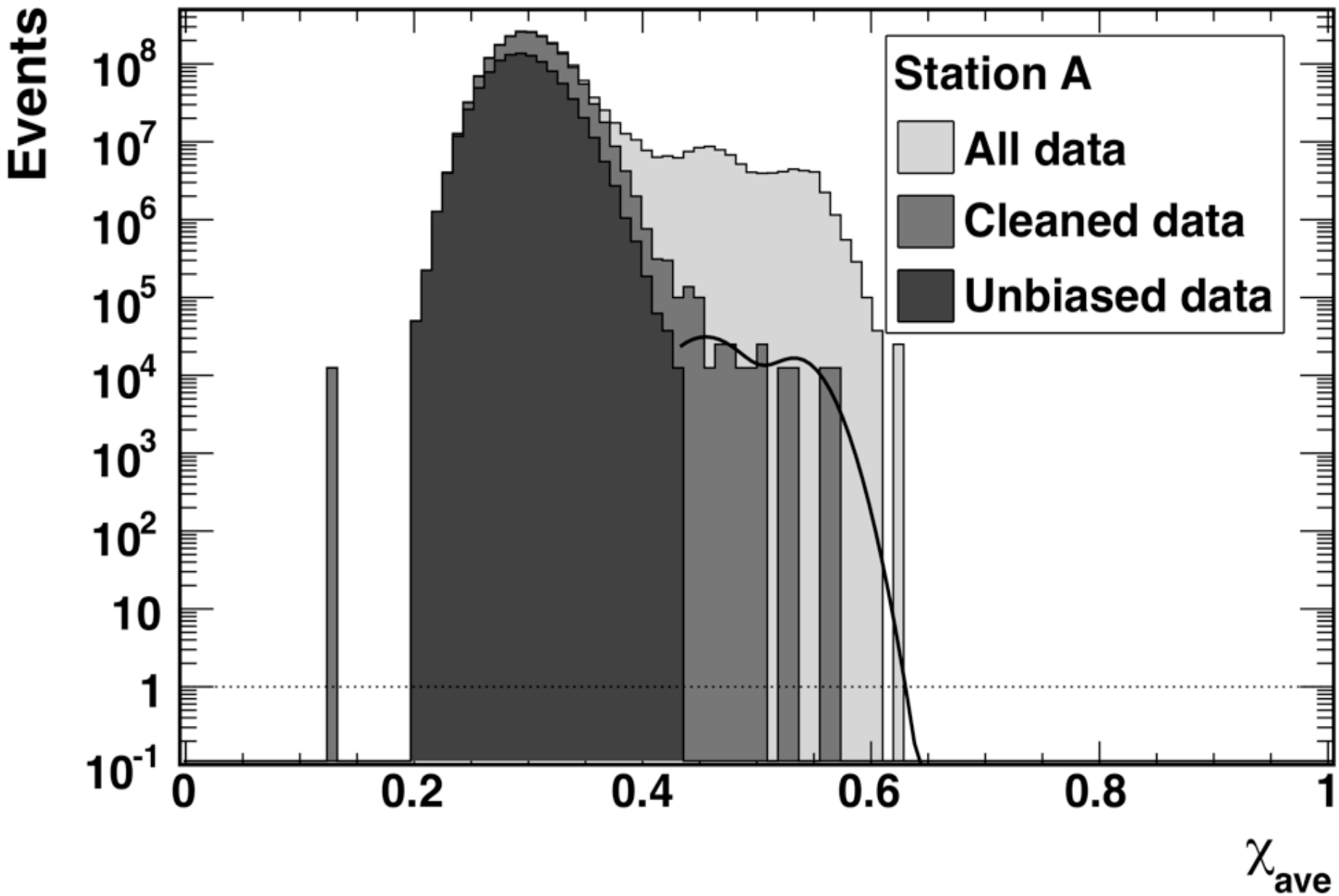
ADC Distributions (2014 data)



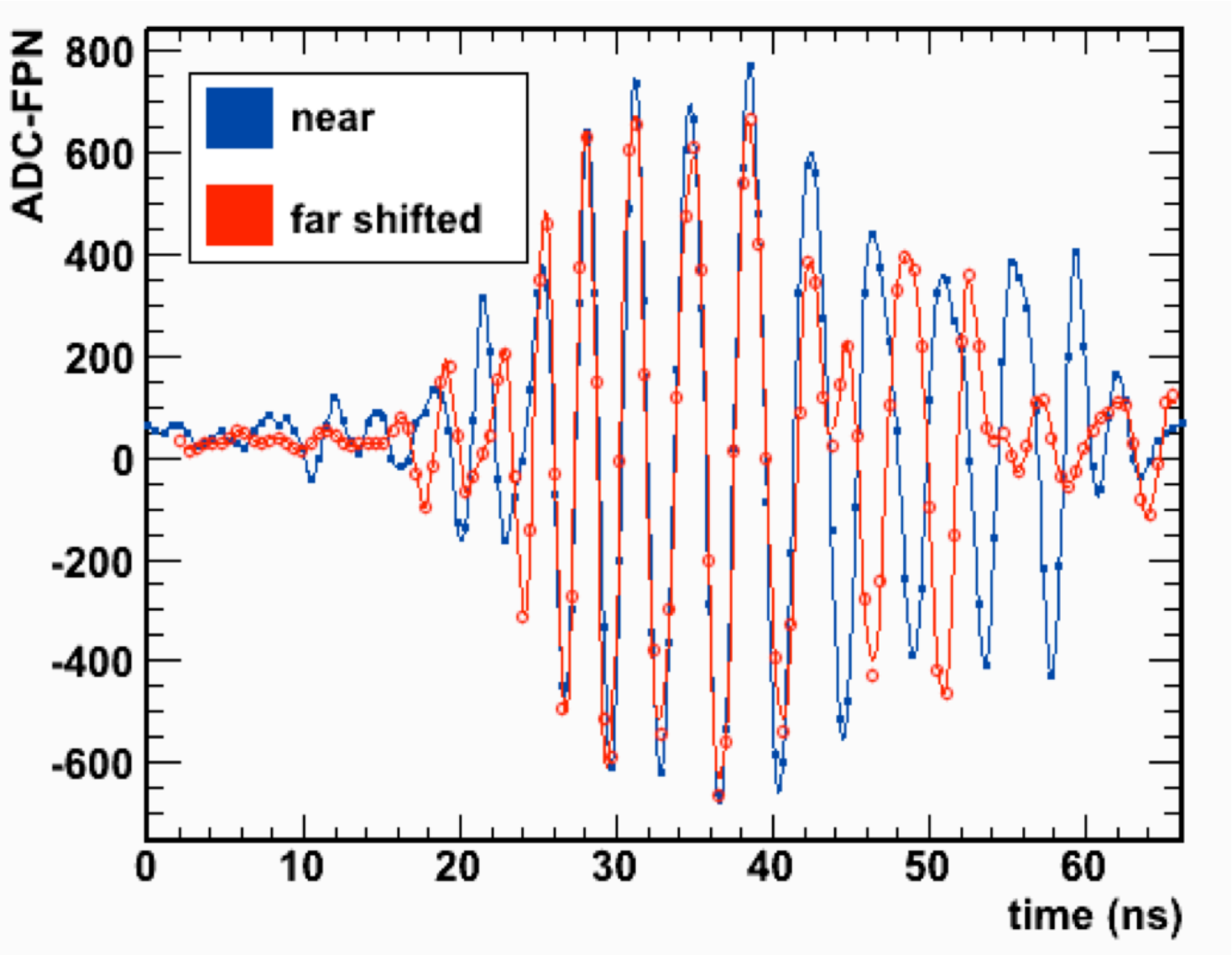
Average Chi Distributions



Scaled 3-Year Full-Project Projection

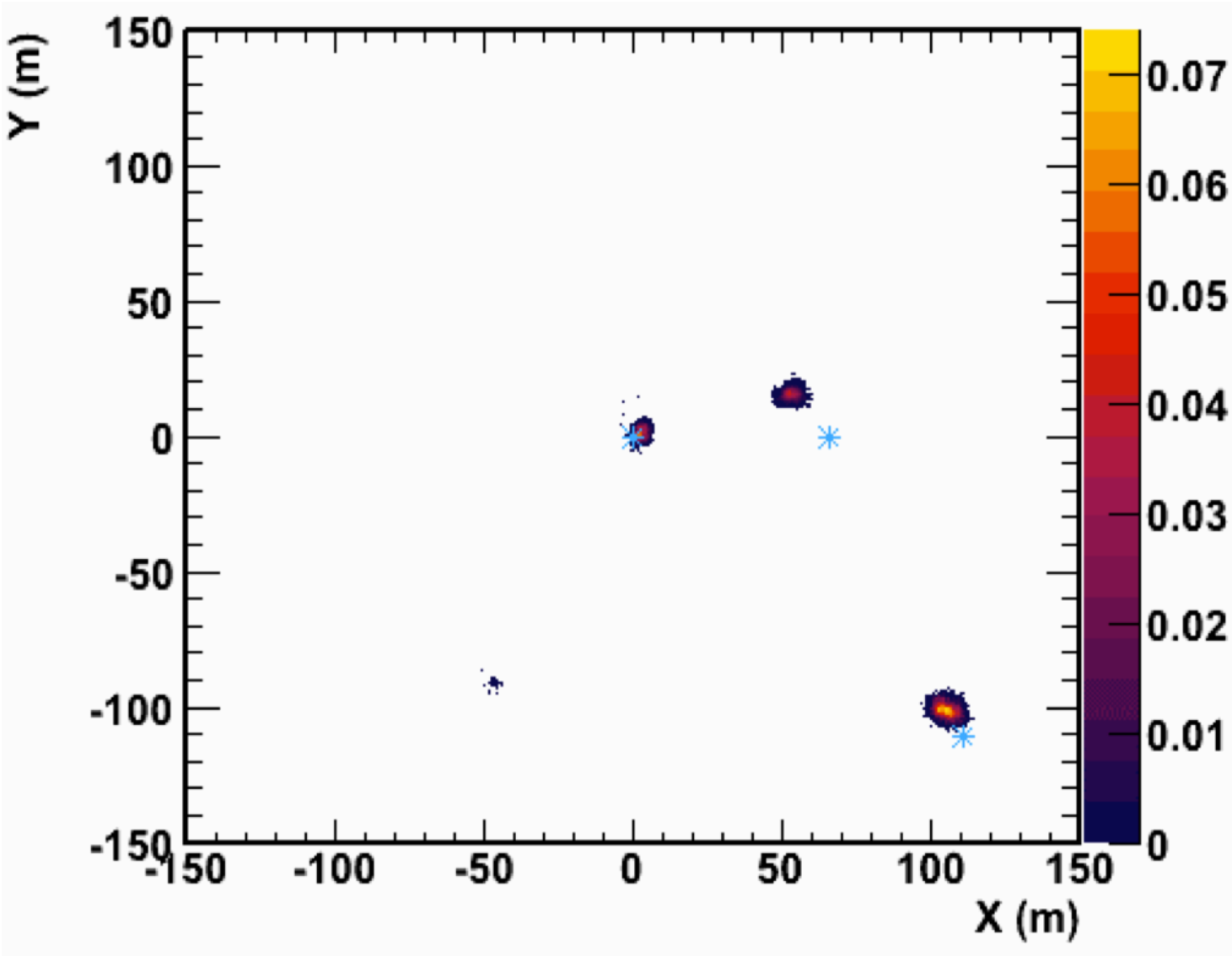


Correlate Signals for Timing Difference



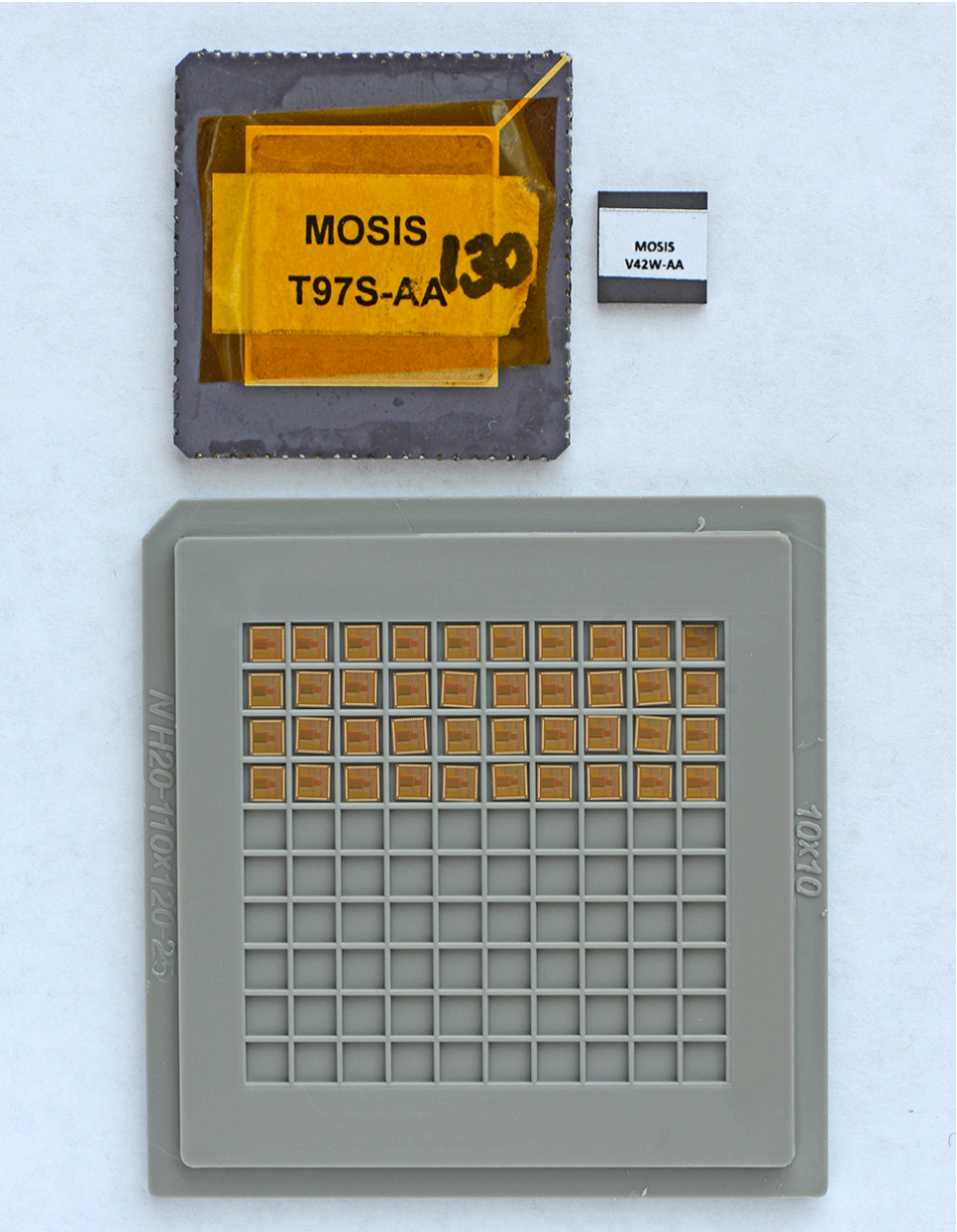
Direct down-and-up bounce vs. a bounce from 150 meters from the station, the latter shifted in time for maximum correlation.

2012-2013 Data Bounce Reconstruction



Median precision of angular resolution at different locations ranges from 0.14 to 0.17 degrees.

New SCA with Streamlined Trigger

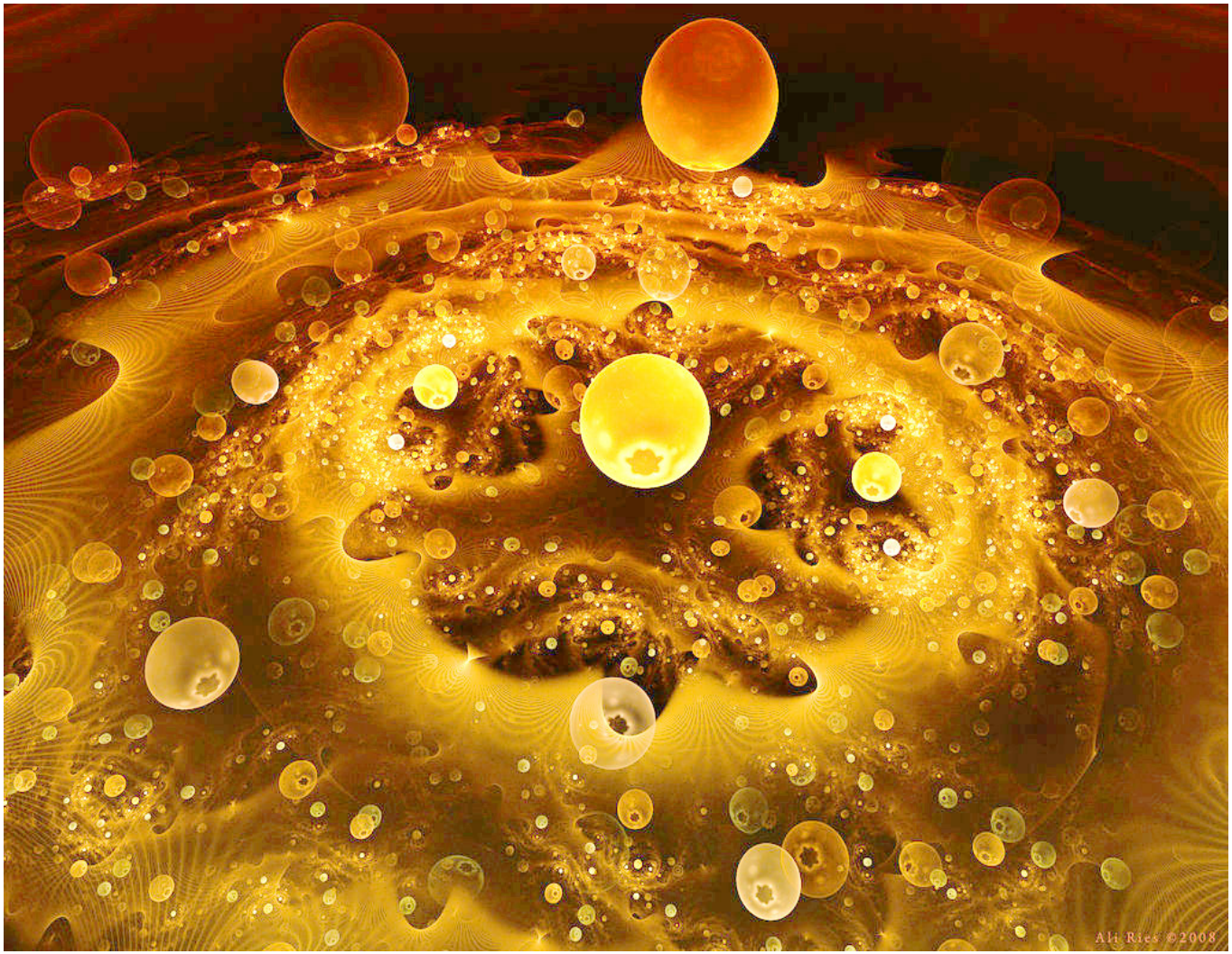


- Four channels of 256 samples per channel (vs. 1 of 128).
- *Fully synchronous* 2.5+ GHz sample rate, ~1 GHz -3dB BW.
- Consumes 6 times less power than previous chip.
- Optimized packaging.
- Timing uniformity set by external LVDS clock, e.g. net 1 ps jitter over full temp. range with no timing calibrations needed.
- Guaranteed common-start and common-stop within 1 ns.
- On-chip real-time bipolar trigger with coincidence features.
- Features easy rate monitoring and control.
- For use in single-board 4/8/12+ channel system.

Summary and Plans for 2014-2015

- Three 2012 second-generation stations successful:
  - All sources of anthropogenic noise virtually eliminated. Pattern trigger allowed 0.002 Hz trigger rates with 4 sigma thresholds.
  - Power consumption reduced to ≤ 10 W. Minimum of 0.58 calendar year full-power operation achieved on solar only with up to 0.7 year max.
  - Achieved full data transmission and control via wireless and Iridium.
  - New reflection studies performed, with inter-channel timing resolution sigma measured to be 49 ps.
  - Lithium batteries proved reliable.
- During 2014-2015 Austral summer, 4 stations to be installed:
  - New amplifier design is more stable, with flatter, more symmetrical response and includes band-pass filtering and limiting components.
  - New 4-channel chip uses much less power than old 1-channel chip, is fully-synchronous, easier to use and requires much less calibration.
  - Lower-cost single-board 4/8 channel system planned, 8-channels to use same power as old system, possible single enclosure including amps.
  - Iridium satellite-only communications proven sufficient.

Proof of the Multiverse?



Can ARIANNA, in probing the cosmos, capture the first images from alternate universes?

Proof of the Multiverse!

Stuart Kleinfelder in “our” universe.

Proof of the Multiverse!

Stuart Kleinfelder in a universe in which he never met David Nygren.

Thank You

Congratulations and *universe-wide* thanks
to **David Nygren**,
mentor, collaborator, and friend,
and thank you as well to *everyone* here.

Panorama of 2012 ARIANNA camp