

ProtoDUNE-SP Cold Electronics

Matthew Worcester (BNL)
representing the Cold Electronics team

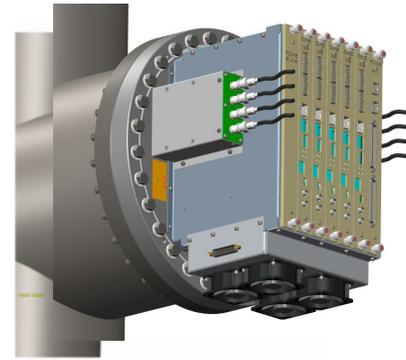
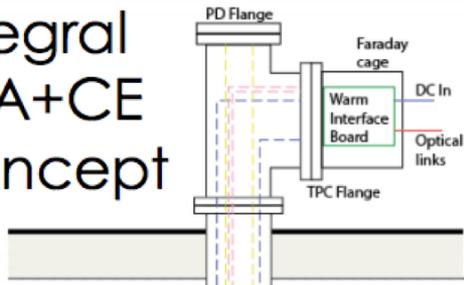
LBNC Review
February 2018

Outline

- Integrated LArTPC Concept
- Components
 - Front-End and ADC ASICs
 - Front-End motherboard
 - Signal feed-through
 - Warm electronics
 - CE flange and warm interface electronics crate
- APA testing at CERN

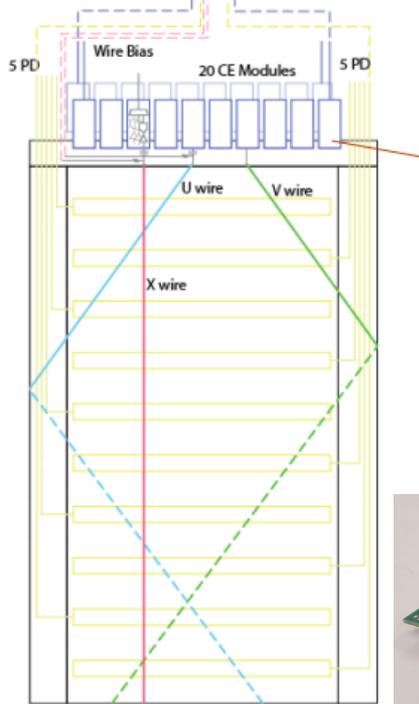
Integrated LArTPC Readout

Integral
APA+CE
Concept



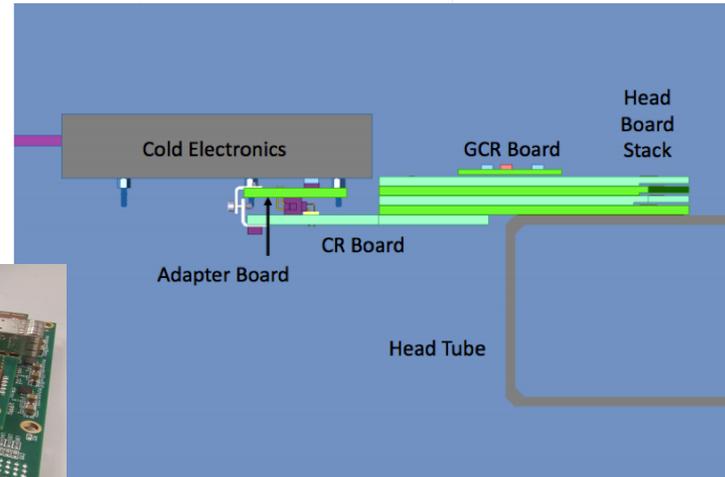
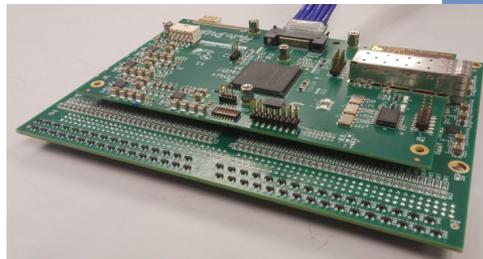
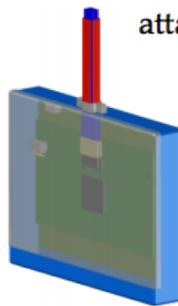
Each APA is isolated inside the cryostat and only connected to the detector ground through the CE at its own CE flange.

Warm Interface Electronics: interface from CE to DAQ with shielding and local real-time diagnostics.



ProtoDUNE-SP

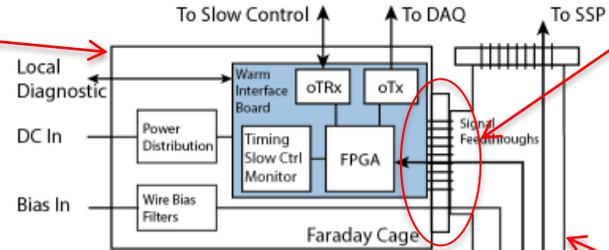
Cold electronics module and its attachment to the APA frame



ProtoDUNE-SP Cold Electronics

Warm electronics

- Warm Interface Electronics Crate (6)
- Warm Interface Board (30)
- Power and Timing Card (6)
- Power and Timing Backplane (6)



CE flange

Flange assembly with cable strain relief and flange PCB for cable/WIB connection (6)

Signal feed-through

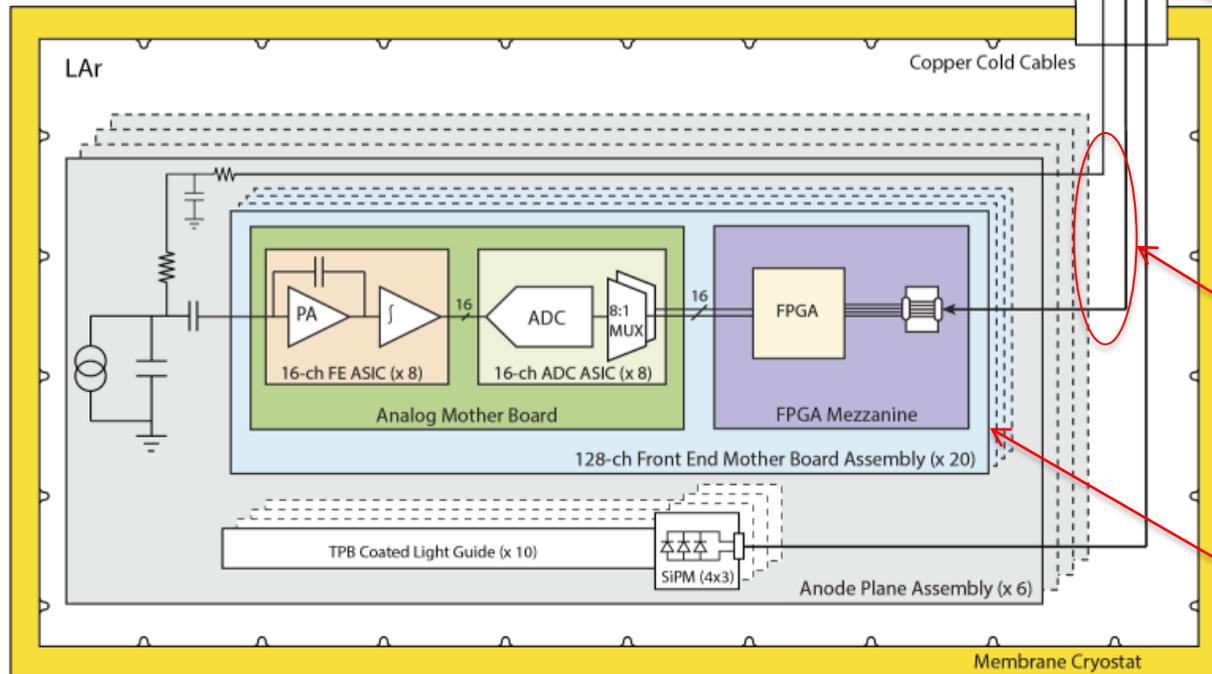
Tee pipe with 14" Conflat flanges and crossing tube cable (CTC) support (6)

Cold cable

LV and data cable (120+120) to FEMB and APA wire-bias SHV cable (48)

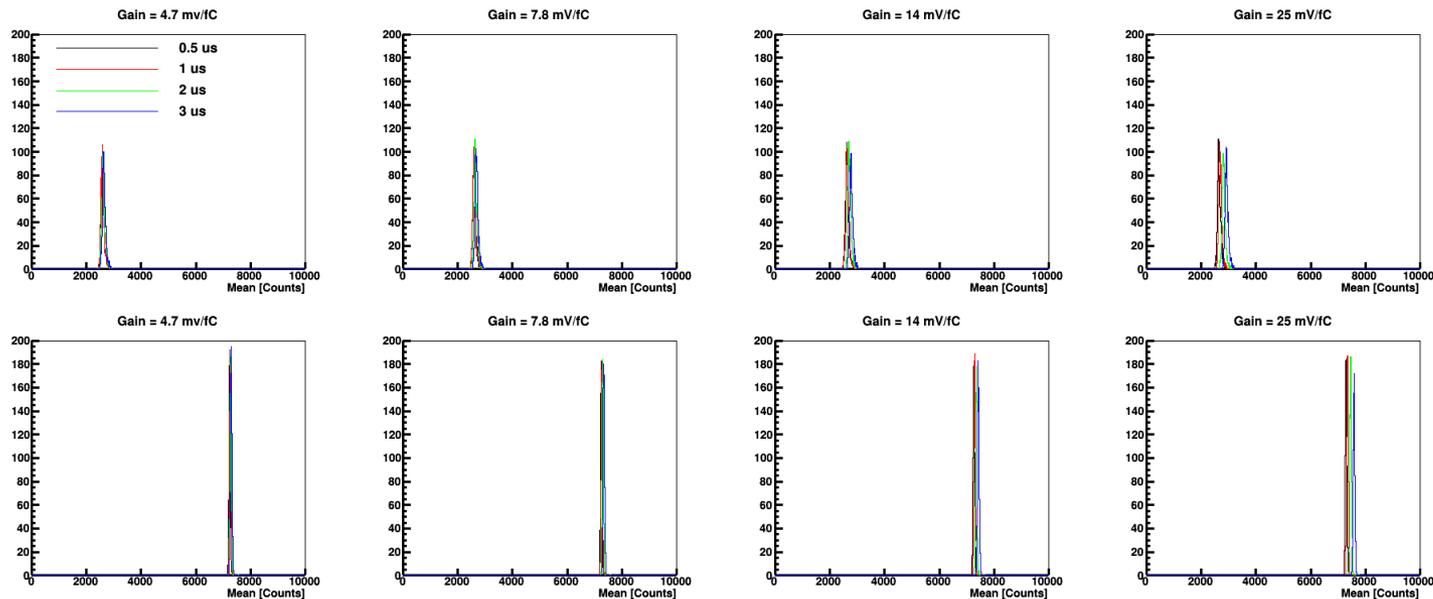
Front End Motherboard

(FEMB) 128 channels of digitized wire readout enclosed in CE Box (120)



FE ASICs

- All 268 FE ASICs for APA1 tested in July
 - 200 selected for FEMB for APA1
 - All selected FEs tested under multiple thermal cycles on FEMB
- ~1500 of 5000 production FE ASICs tested to date
 - Sufficient for all protoDUNE-SP, plus possible boards for APA7/small TPC at FNAL
 - Selected 824 for FEMB for APA2-5 and 40% APA tests at BNL
- All ASICs for APA6 will be selected by 3/9

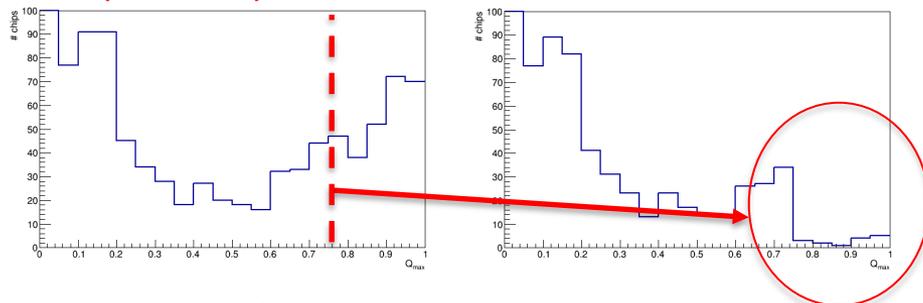


Mean baseline, raw 14-bit ADC counts, all channels, top row: 200 mV; bottom 900 mV

ADC ASICs

- All 395 ADC ASICs for APA1 tested in July
 - Precision voltage ramp input used to test entire dynamic range with high statistics
 - Provides “Q metric” for ADC quality
 - 200 with the highest Q score selected for FEMB for APA1
- ~2500 of 5000 ADC ASICs tested to date
 - 744 with $Q > 0.7$ selected for FEMB for APA2-5
 - 80 selected for 40% APA FEMB
 - All selected ADCs tested under multiple thermal cycles on FEMB

Q (all ADCs) before and after APA2-3 selection

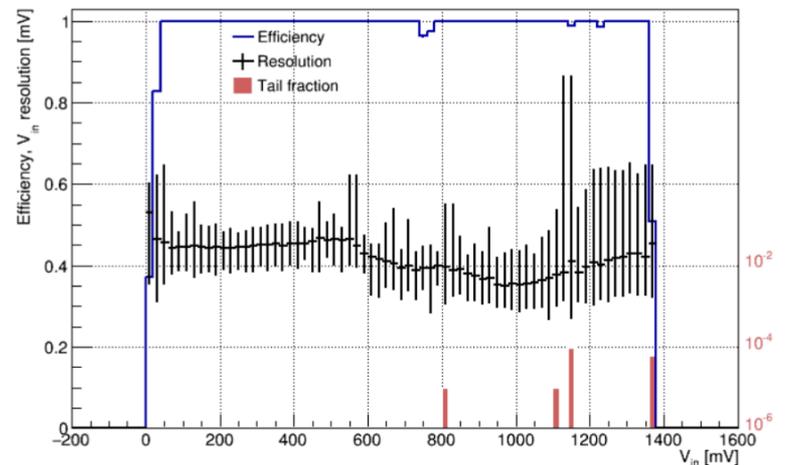


- All ASICs for APA6 will be selected by 3/9
- Every test result stored in QC database:

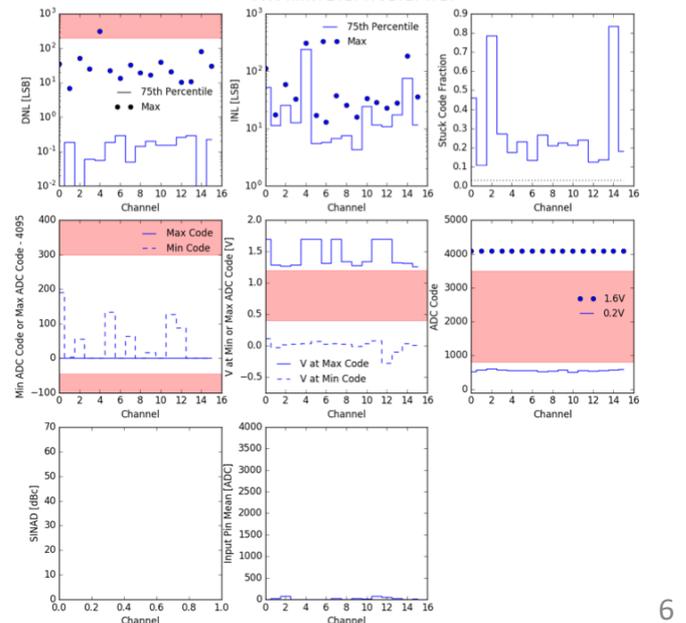
<http://www.phy.bnl.gov/coldelec/summary/>

Example efficiency and resolution vs. V_{in}

201703a_D04 channel 7 actual performance for RMS < 1 mV



ADC D0005, External Clock, 2 MHz,
Test Time: 20170731T174727



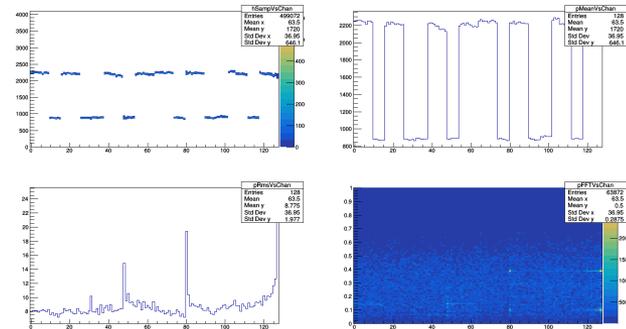
FEMB

- 102 FEMB received and tested at BNL
 - 60 CE Boxes installed on APA1-3
 - 8 CE Boxes used for 40% APA testing
 - 23 at or sent to CERN for APA4
- 12 FEMB received at BNL for APA5 and are being tested
 - 14 FEMB for APA5 will be sent for assembly next week
- All CE Box components have been received at BNL
- All cold cables received at BNL

protoDUNE FEMB EMT Summary: CE Box 1

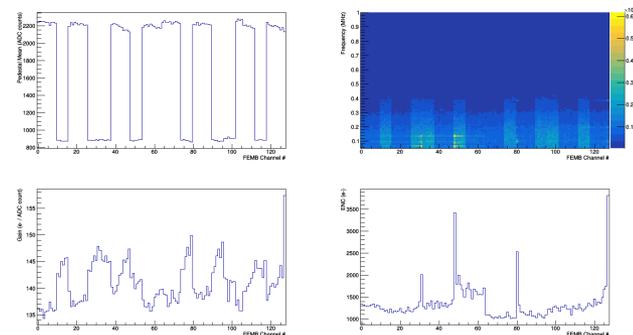
Timestamp: 20170831T074515 Tested by: C. Morris Temperature: RT

Simple Measurement



Average ENC measured with internal pulser (electrons): 1333

Gain/ENC Measurement: Gain = 14 mV/FC, Shaping Time = 2 us, Internal Pulser



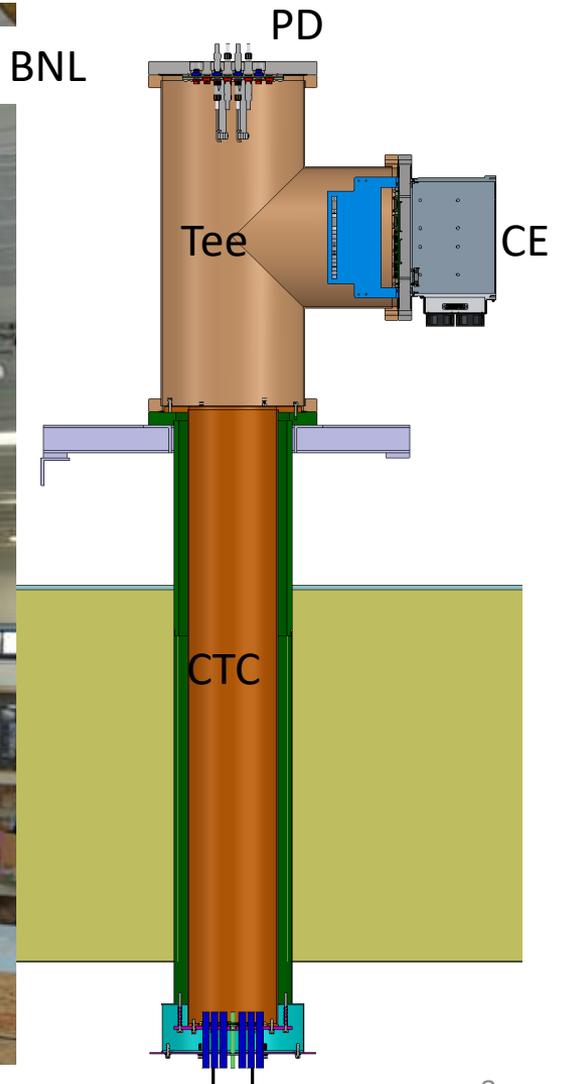
Current Monitoring:

Nominal Voltage	4.2 V	3 V	2.5 V	1.5 V	5 V
Voltage (V):	4.06	2.89	2.39	1.43	4.80
Current (A):	0.06	0.35	1.27	0.49	0.03

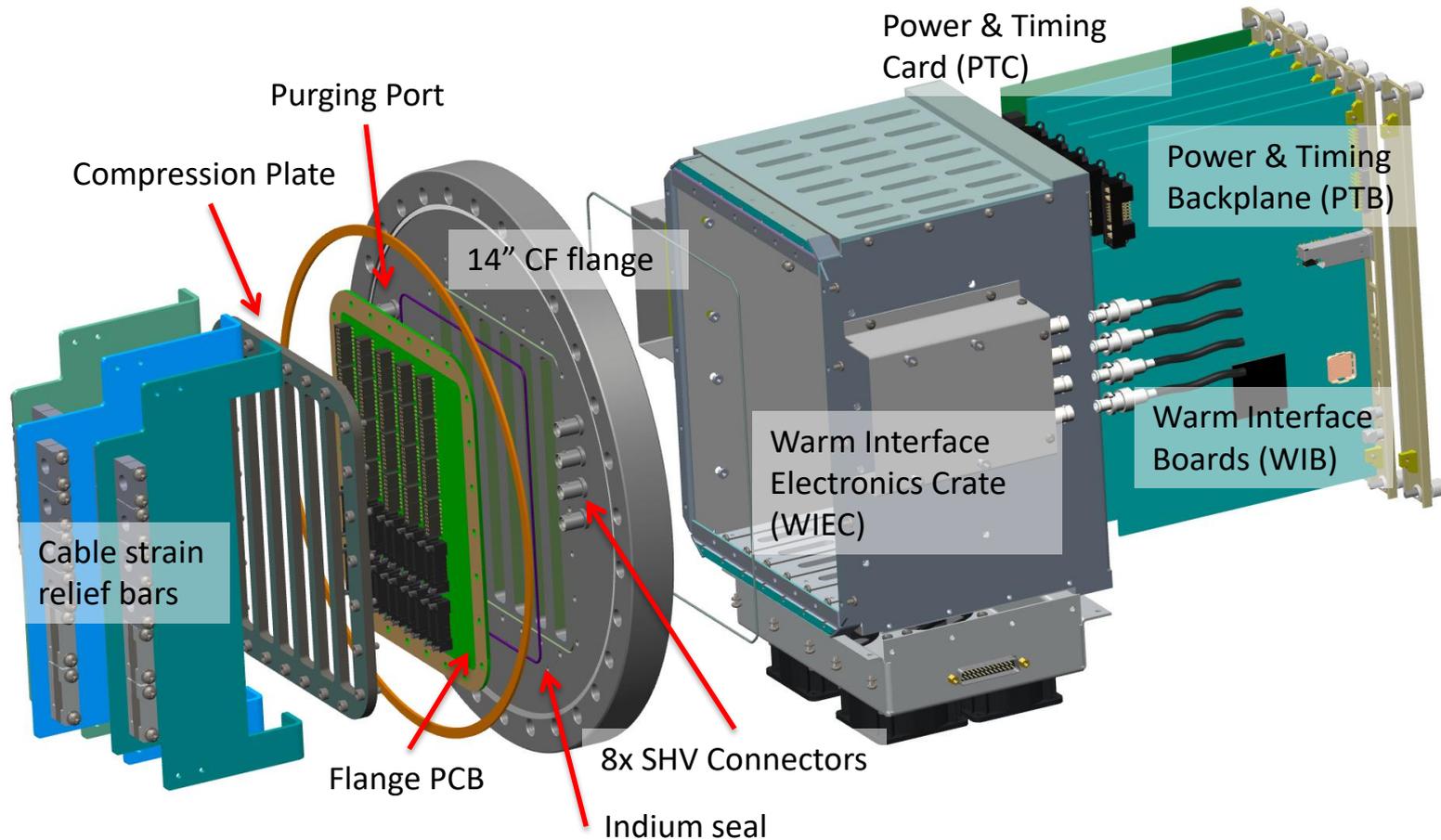
Data stored on hunkdaq: /dsk/1/data/oper/femb/wib_sbnd_v109_femb_protodune_v308/20170831T074515
Position on WIB for test: 1

Signal Feed-through

- All production Tee pipes received at BNL and checked
 - 7 delivered to CERN
 - 1 installed on the cold box
- Prototype Crossing Tube Cable (CTC) support assembled at BNL and tested
 - 3 installed on cryostat for APA1-3
 - 4 shipped to CERN for APA4-6

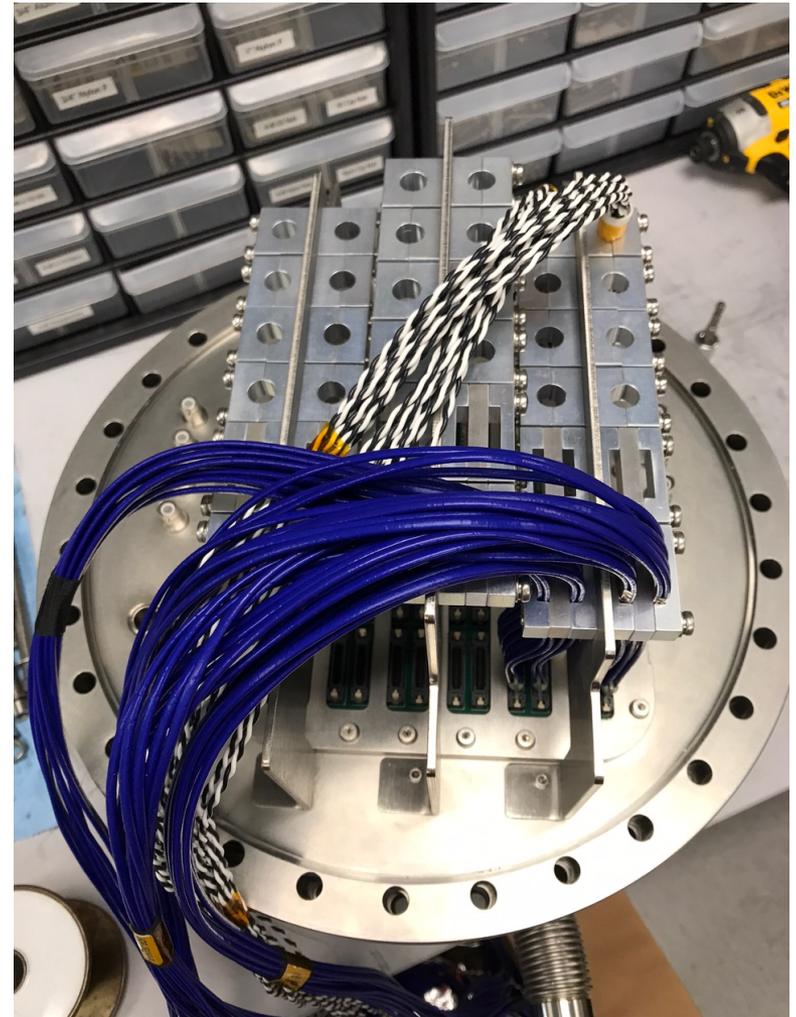
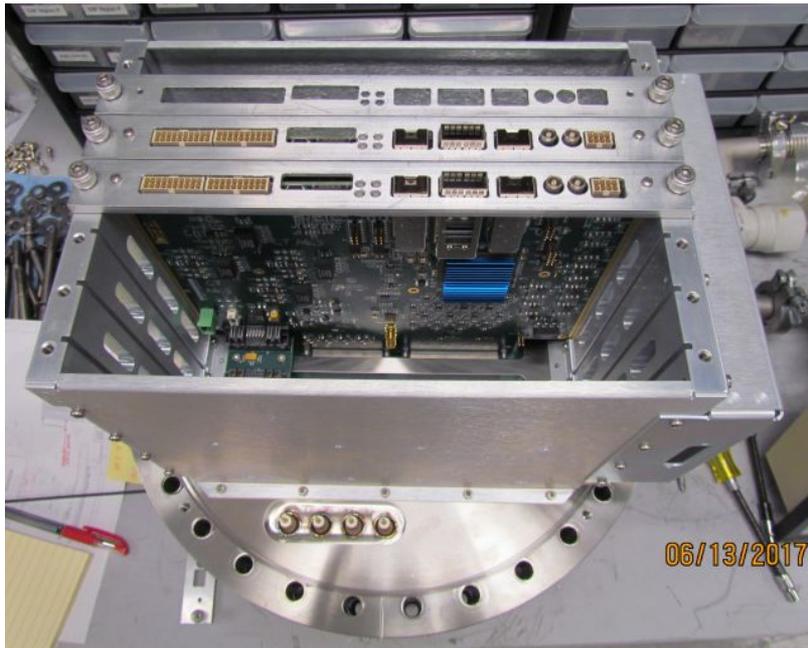


CE Warm Components



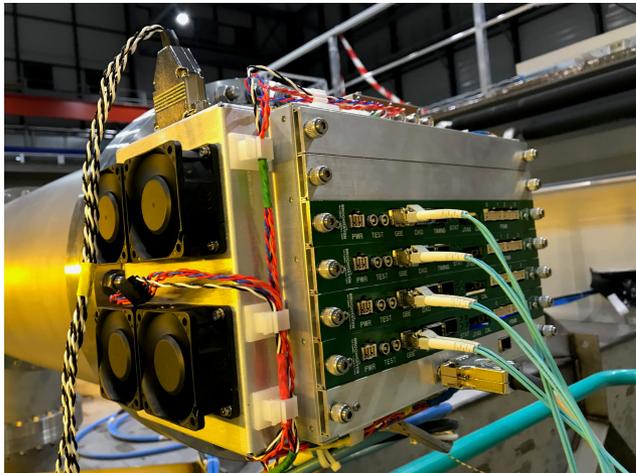
CE Flange and WIEC

- Final prototype flange and WIEC installed on cold box
- 4 full production flange/WIEC units at CERN
- 3 more being assembled at BNL



WIB

- Collaboration between BNL (hardware) and Boston University (firmware)
- V2 WIB are working well
 - Links to DAQ (both RCE and FELIX) and slow control have been tested on the CERN vertical slice and cold box WIBs
- 18 V2 WIBs delivered to CERN for cold box integration and APA1-3
- 13 more shipped to CERN to complete APA1-3
- 14 more being validated at BNL

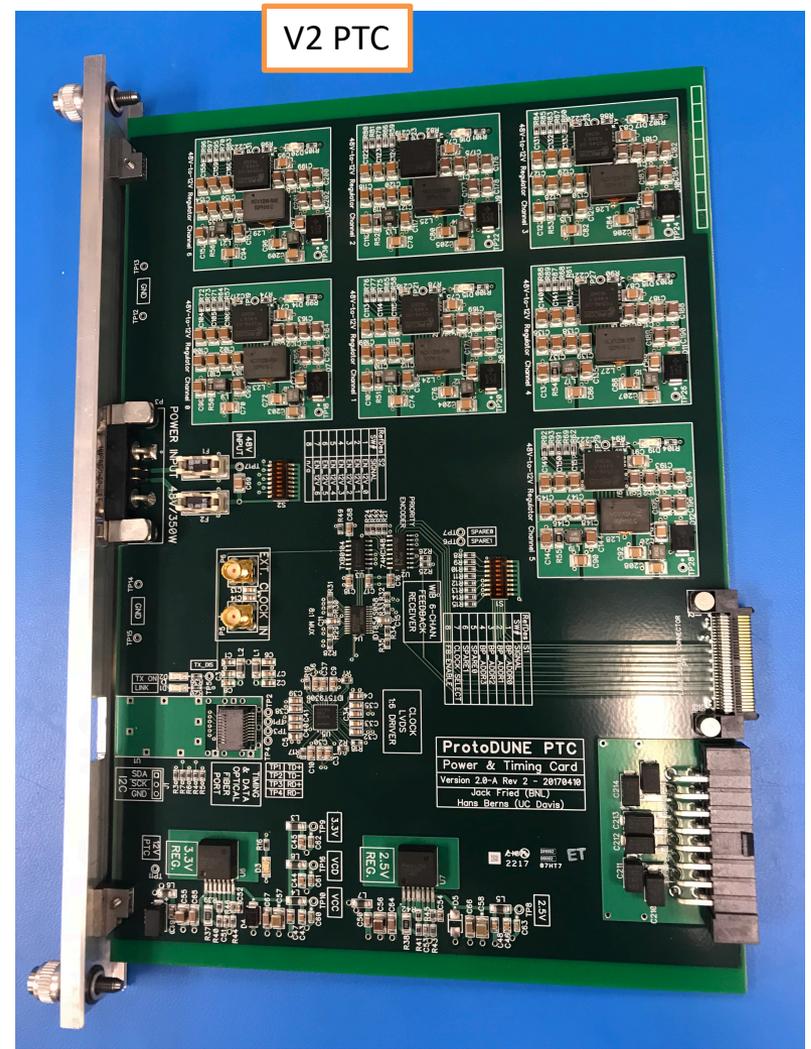


ProtoDUNE V2 WIB

PTC/PTB

- Collaboration between BNL and UC Davis
- V2 PTC are working well
 - Power and timing distribution have been validated at CERN
 - 2 V2 PTC at CERN for cold box integration
 - 2 V2 shipped to CERN for APA1-3
- V3 PTC quotes have been received
 - Improved filtering of DC/DC converters
 - Improved grounding connection
- Passive backplane in WIEC
 - PTB:

7 new PTB
shipped to CERN
for improved
grounding in WIEC



APA1 Installation

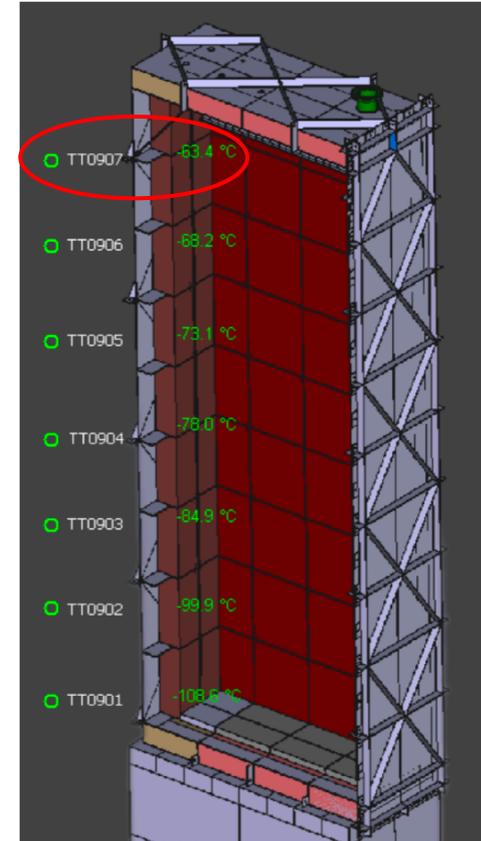
- 20 FEMB inside CE Box assemblies installed by BNL team and collaborators from LSU, MSU, and Houston on the first APA @ CERN
- Check out test was done on all FEMBs in the week of September 4 by BNL engineers and post-docs
 - Built-in electronics calibration circuit was used to characterize the readout electronics system
- **All 2,560 front end channels were confirmed to be 100% functioning well**
 - Only one front-end channel was not connected to APA properly from upstream of cold electronics



Manhong Zhao and Ken Sexton installing CE Box assemblies

Shanshan Gao and Jack Fried: check out tests

CERN Cold Box Test

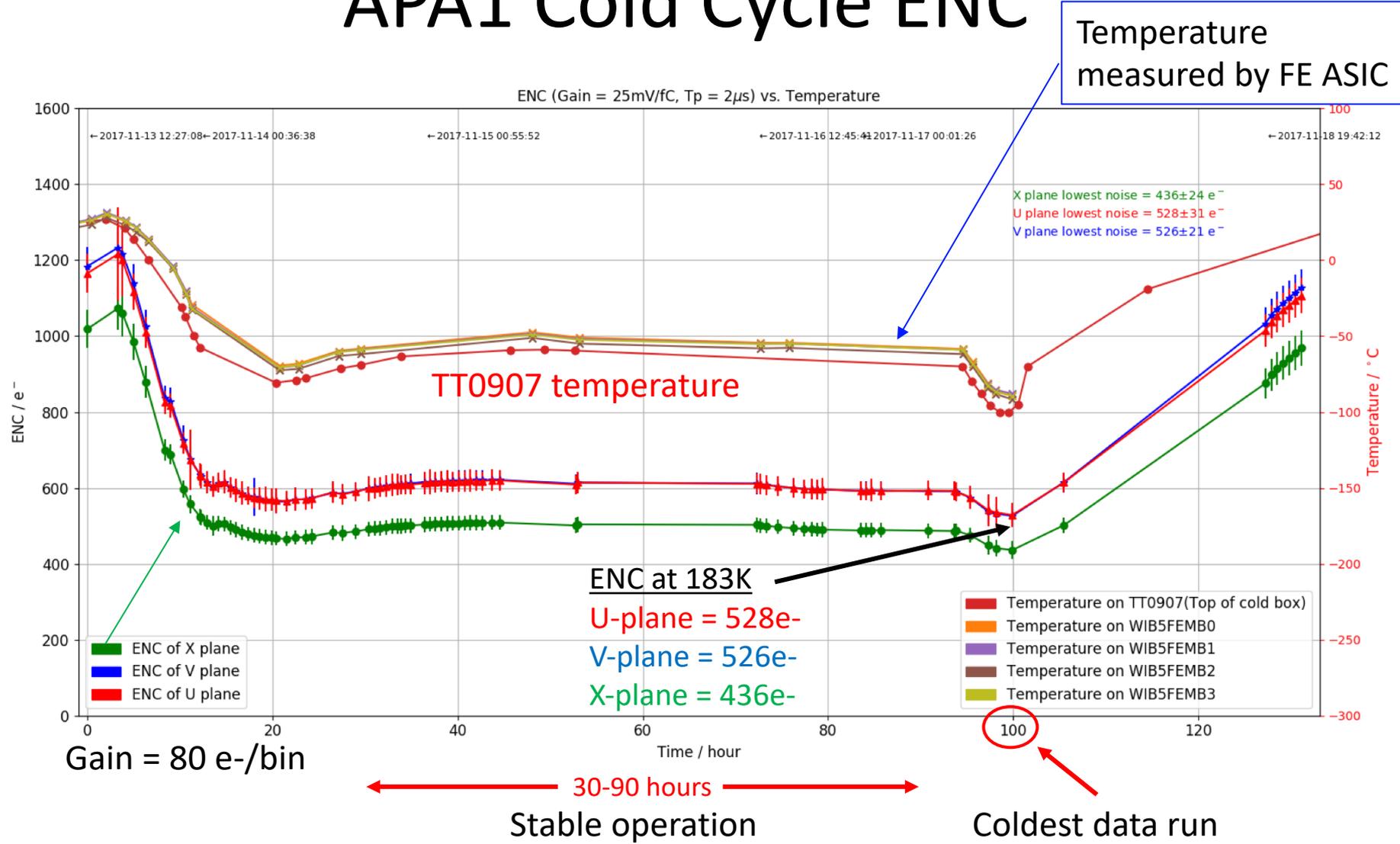


Temperature monitoring

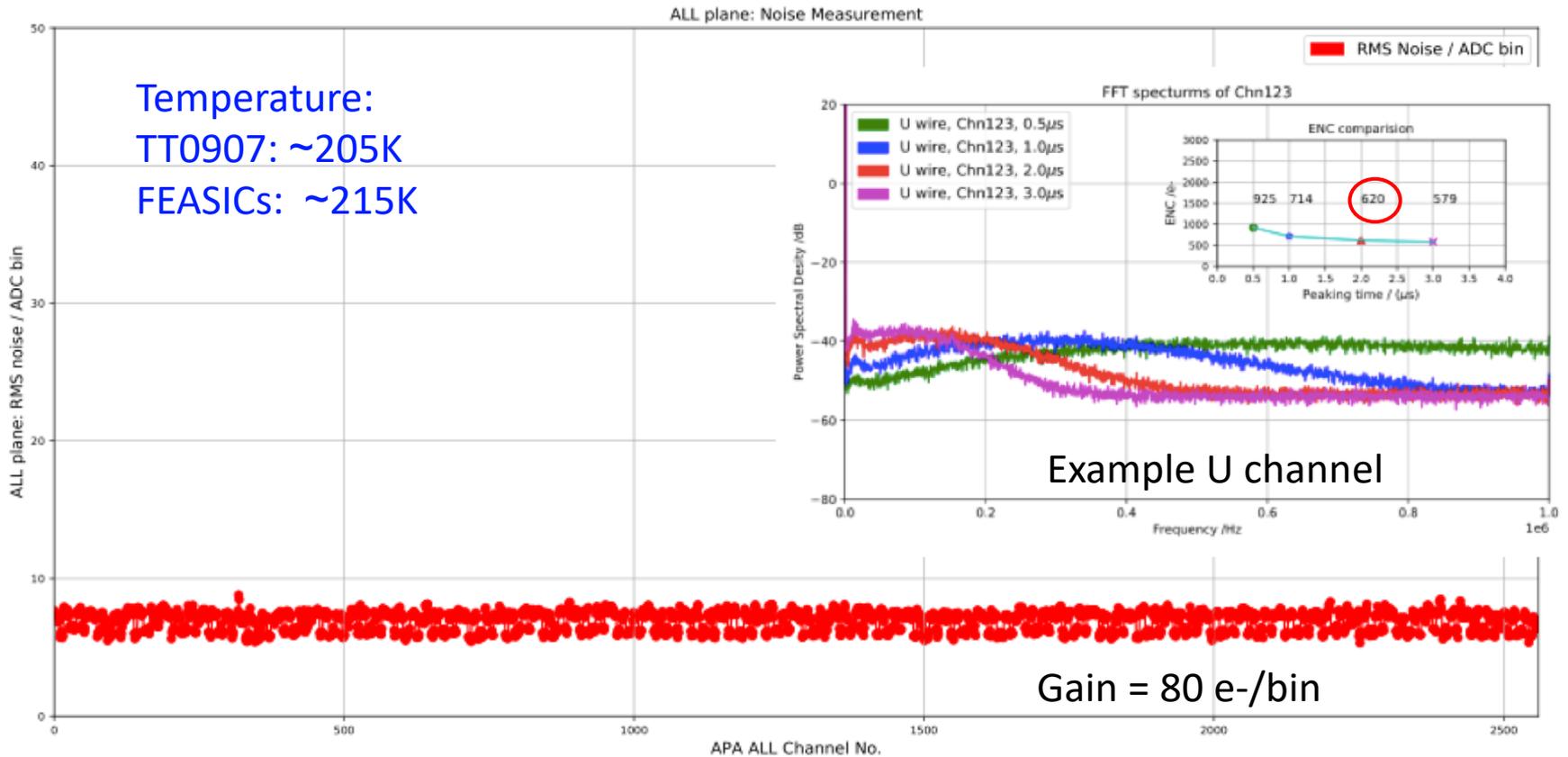
- TT0907 sensor at top of cold box
- Internal FE ASIC temperature sensor is readout through a scope

APA1 moved into Cold Box on 10/13

APA1 Cold Cycle ENC

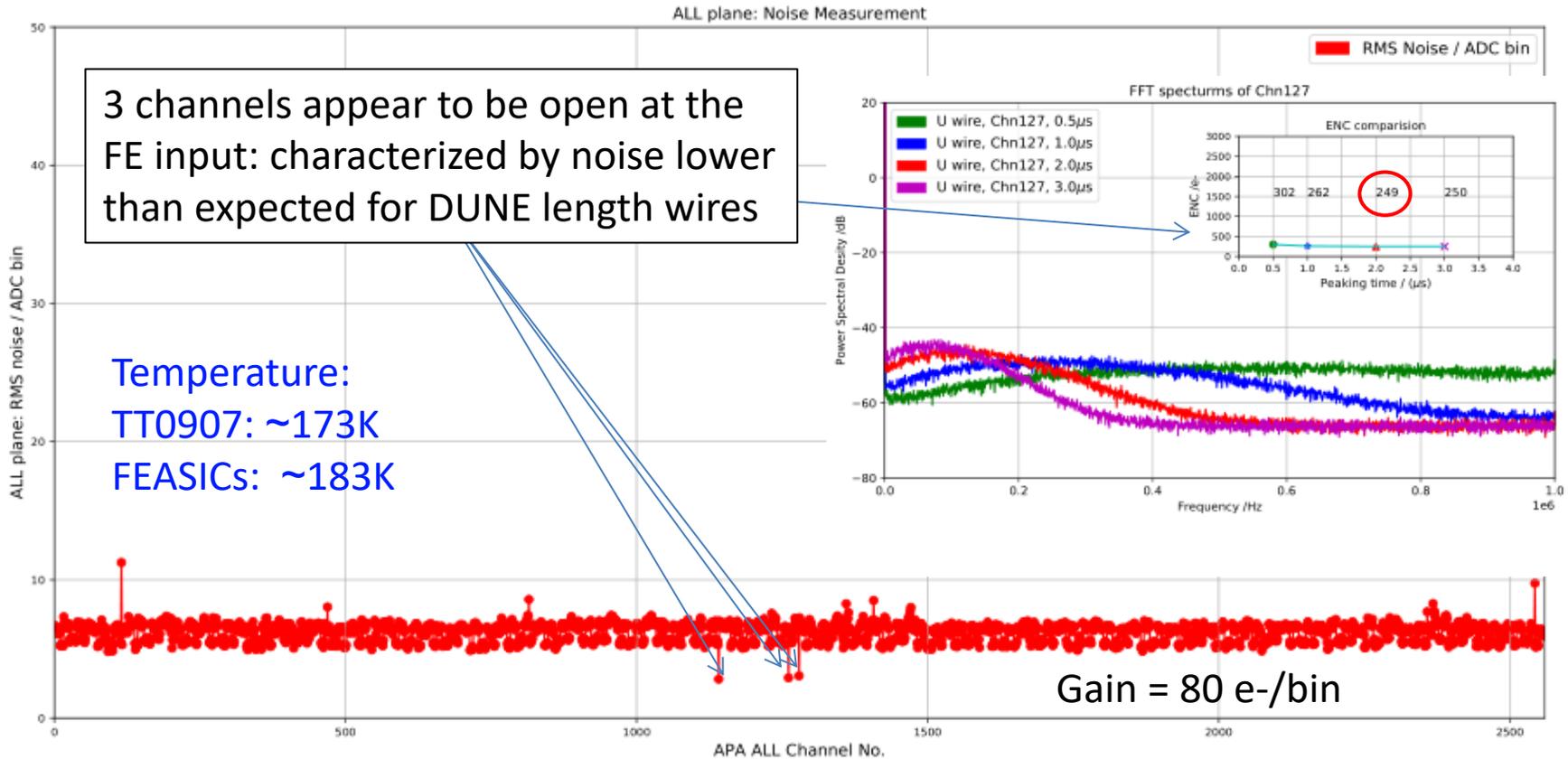


APA1 Noise at 215K (30-90 Hours)

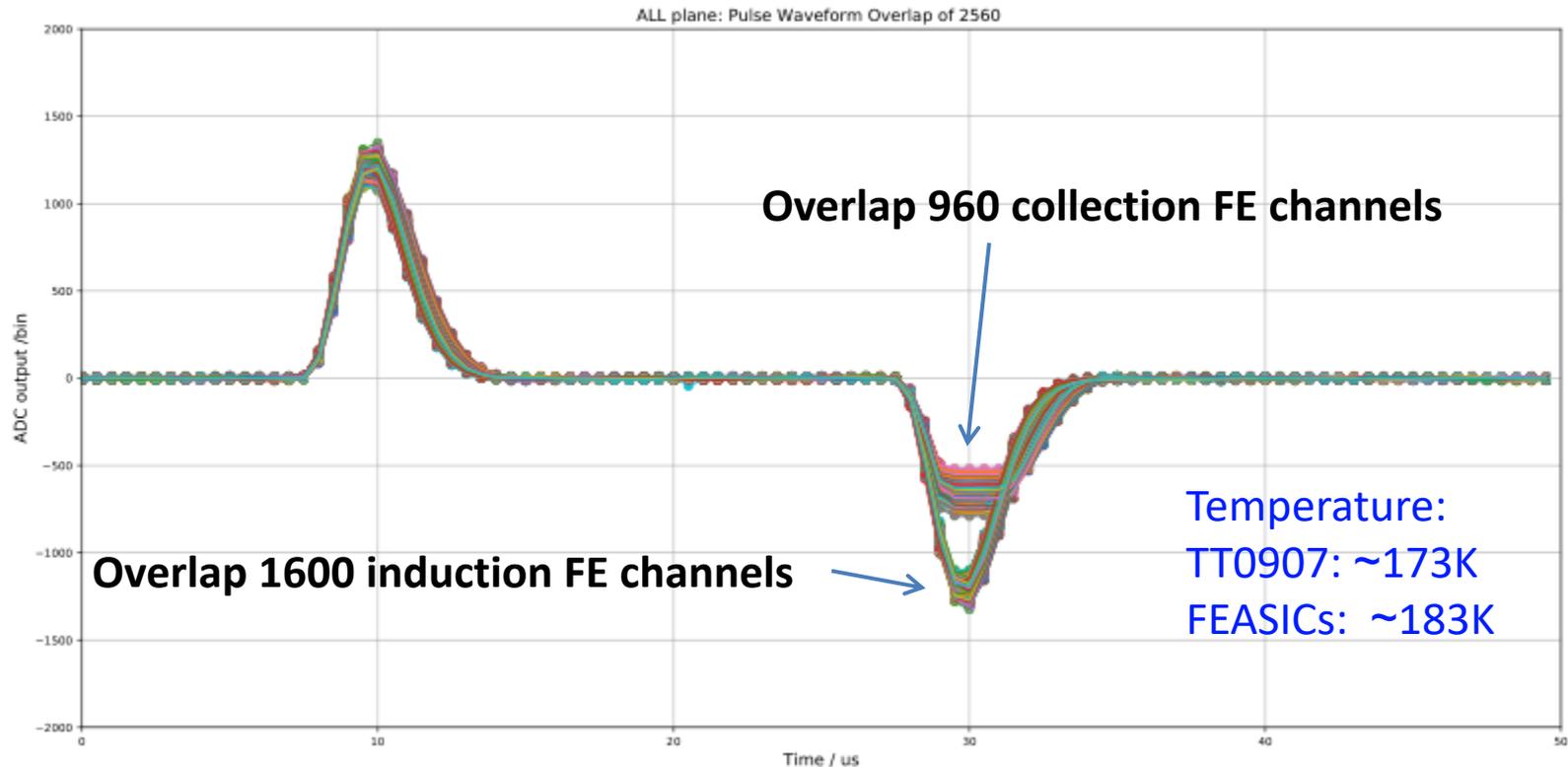


All 2,560 wires (channels) are functioning well
 Several levels of RMS noise due to wrapped (U/V) vs straight (X) wires

APA1 Noise at 183K (100 Hours)



APA1 Electronics Checkout at 183K



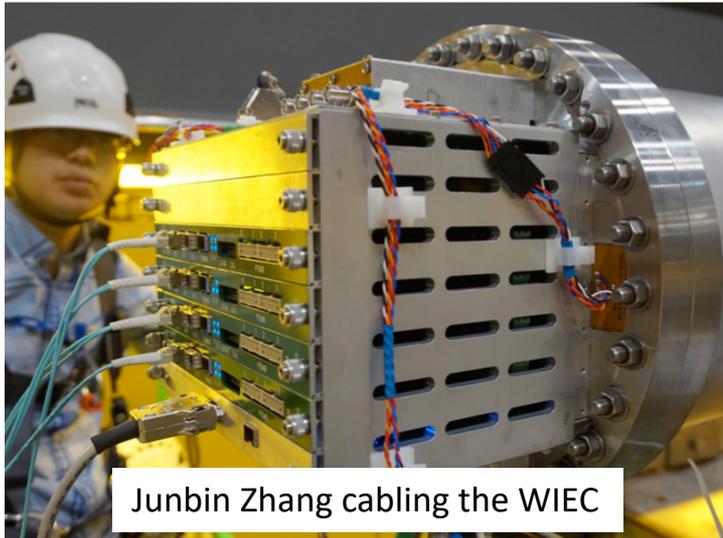
Inject bipolar pulses from electronics calibration circuit built in to FE ASIC

All front end channels are confirmed to be **100%** functioning well with lowest temperature in the Cold Box

All CE channels functioned normally after APA1 warmup

APA2 Installation

- 20 CE Box assemblies installed on APA2 on Dec. 9-11 by BNL team and collaborators
 - All 2560 electronics channels validated at room temperature with internal calibration pulser
 - Found 7 abnormal wires, 6 low noise, 1 high at RT
- Cold cycle complete on Jan. 19



Junbin Zhang cabling the WIEC



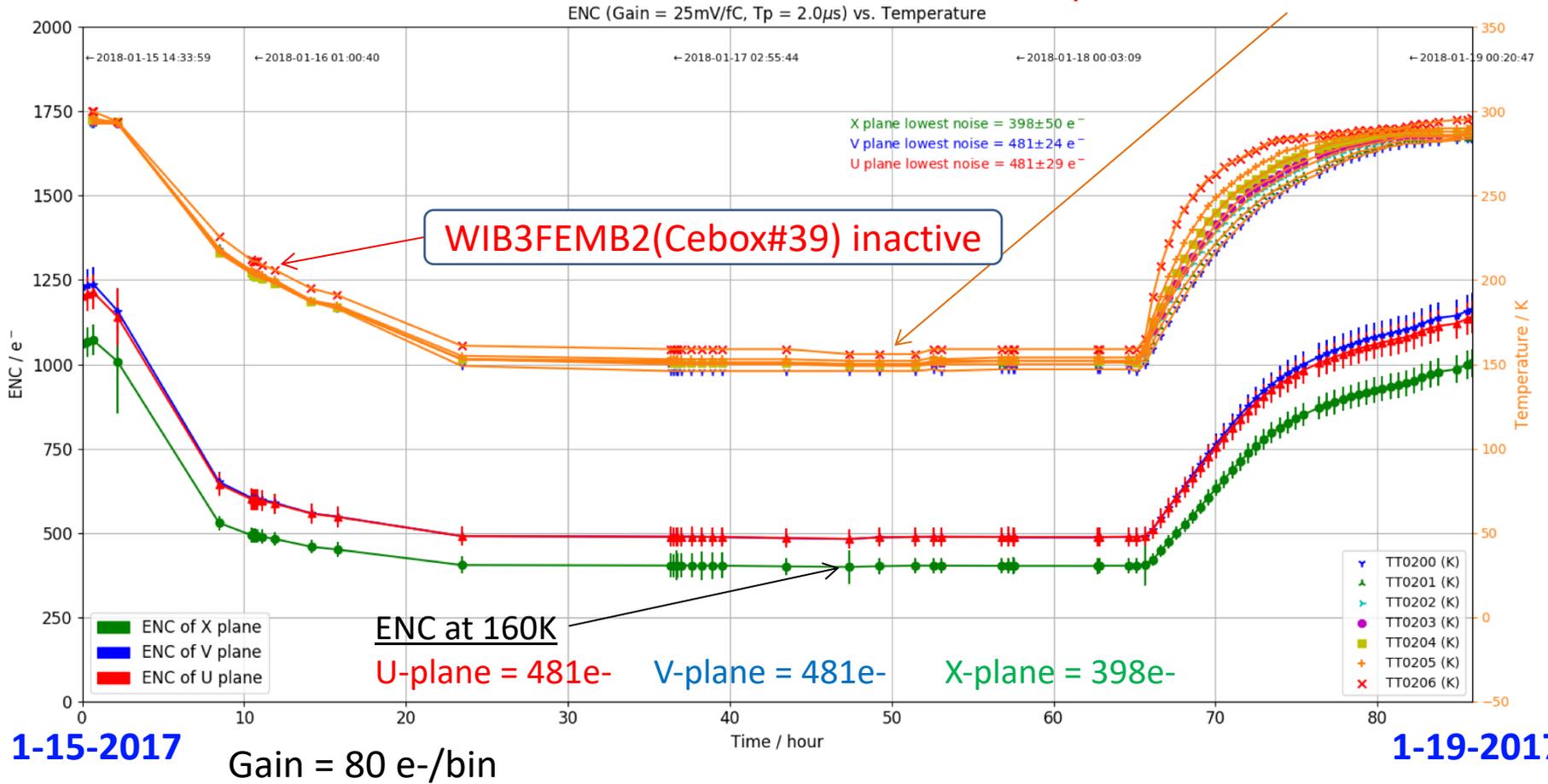
Maura Spanu and Serhan Tufanli installing CE Boxes



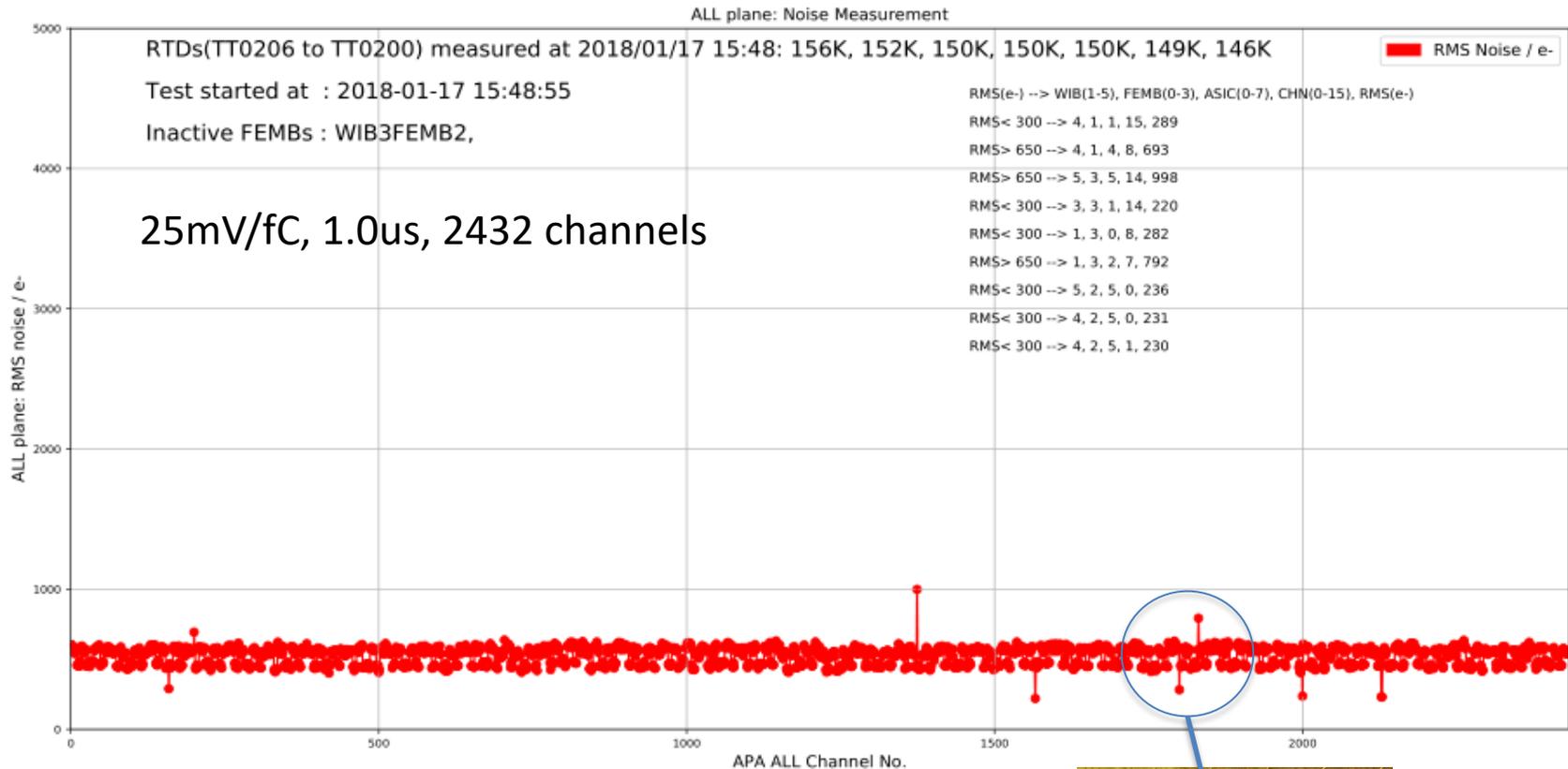
Augie, Maura, and Junbin at the top of the cold box

APA2 Cold Cycle ENC

Lowest temperature at electronics: ~160K



APA2 Noise at 160K (52 Hours)

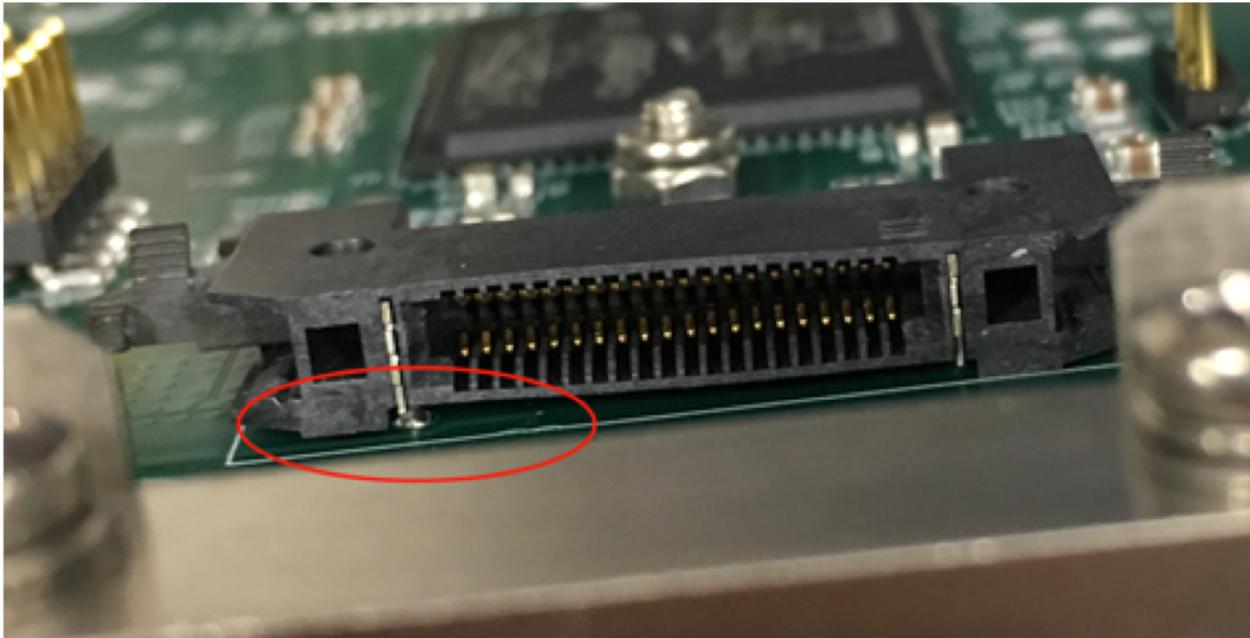


Found 2 abnormal V wires where a wire was cut (low noise) and soldered to its neighbor (high noise)
All electronics channels (aside from 1 FEMB) functioned well after warmup: open channels remain



CE Box #39

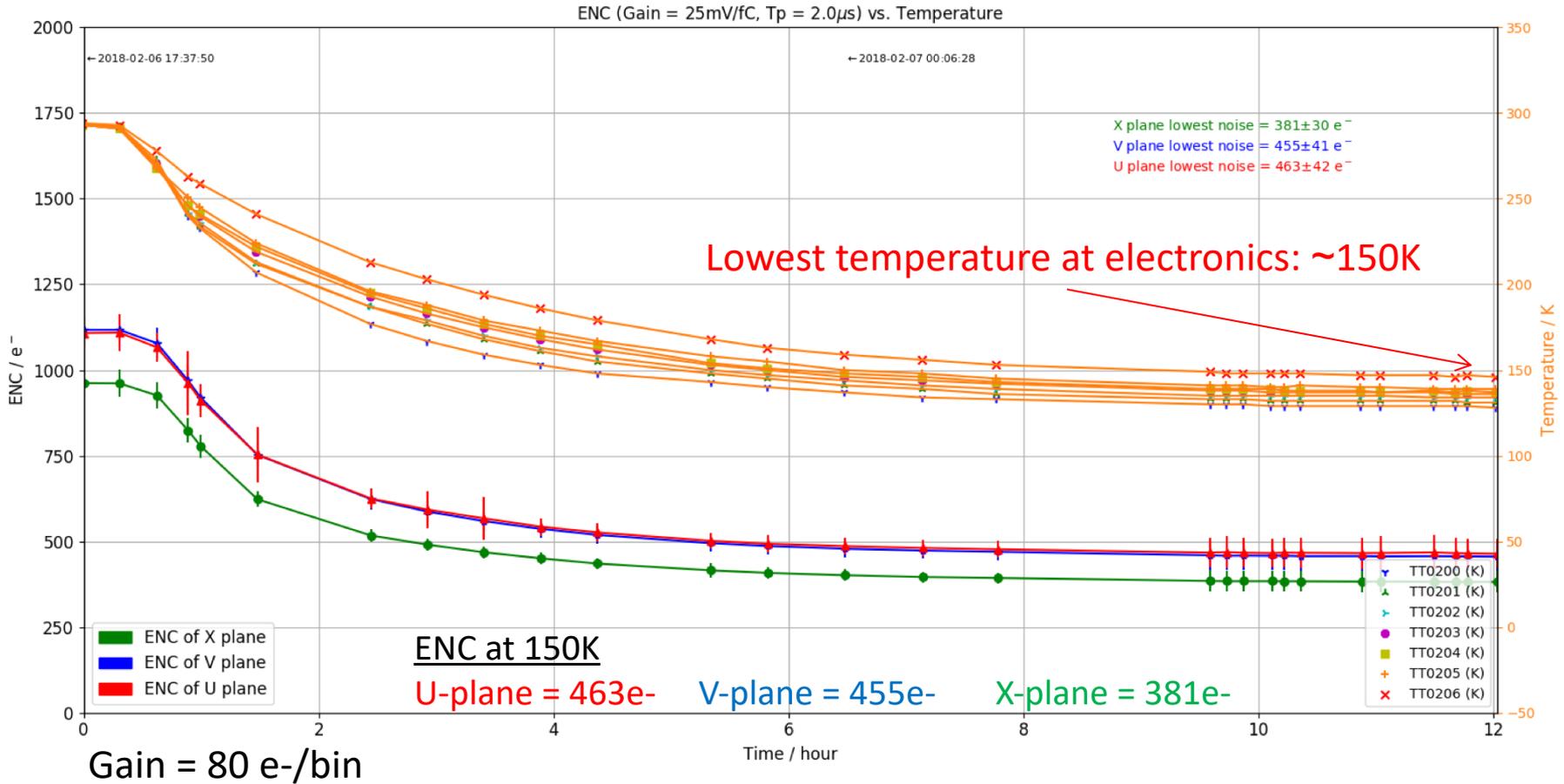
- Did not recover after warm up in the cold box
- Inspection reveals damage to the data cable connector on the mezzanine
 - Suspect that the issue is in the installation of the FEMB into the CE Box done for APA2-3 Boxes: modifying all Boxes on APA2-3 to match APA1
- This CE Box replaced before APA2 moved into the cryostat



APA3

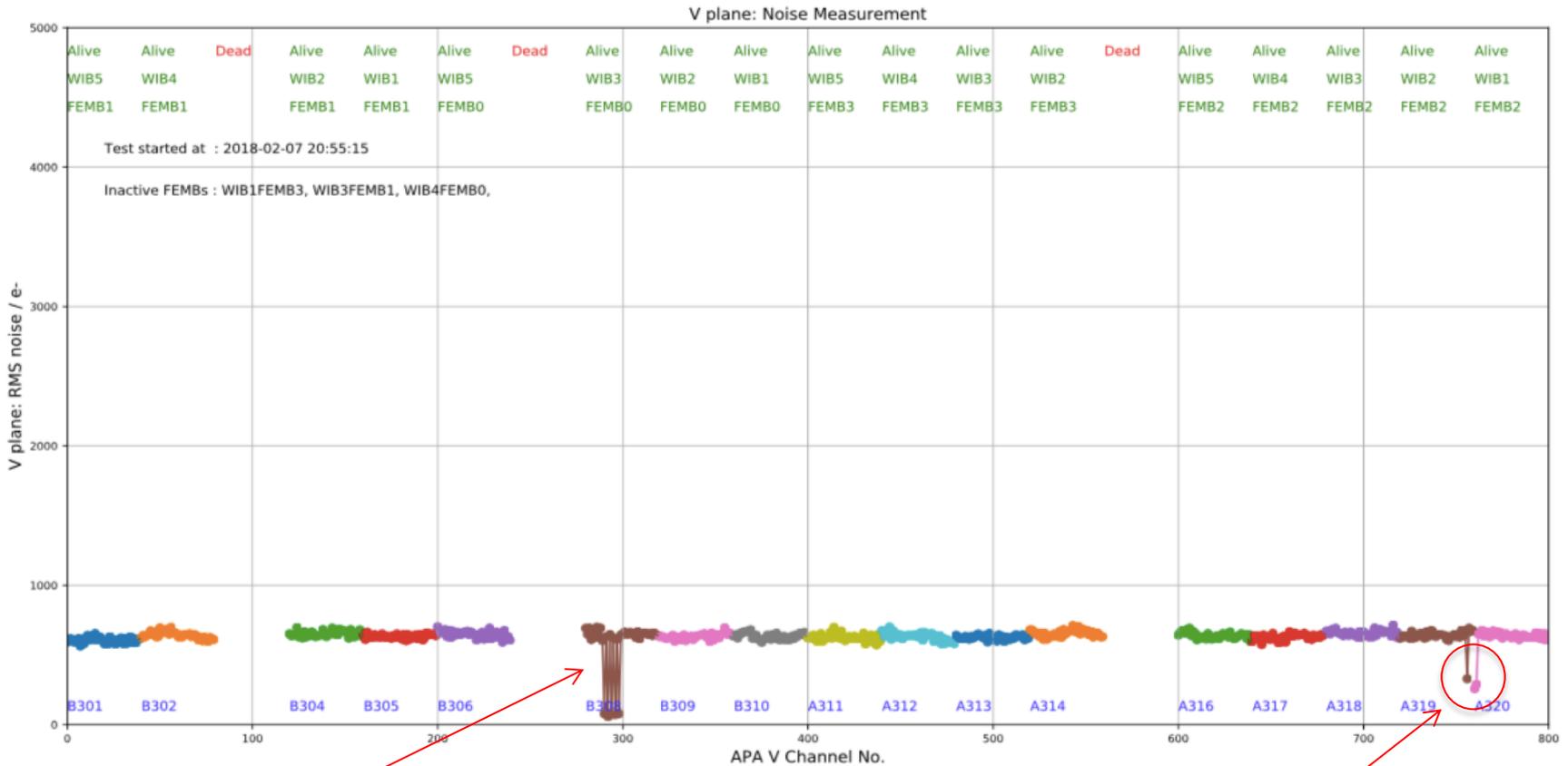
- CE installation on 1/25-26 by BNL team and collaborators
- APA3 moved into cold box on 1/31 and cabled to the flange on 2/1
 - Check-out test at 300K found 2 CE Boxes not sending data
 - On 2/4 a 3rd CE Box stopped sending data at 300K
 - Appears to be same connector issue as Box #39 on APA2
- APA3 cool test started on 2/6
 - Remaining 2176 channels verified to be working well before cooldown

APA3 Cool Down ENC



After CE check out during cooldown, turned Cold Box WIBs over to DAQ for testing

APA3 Noise at 150K



3 open connections to the FE found on the V plane
 Data from 1 FE ASIC stopped working during the cold cycle: CE Box replaced
 3 non-operational Boxes replaced after APA3 removed from Cold Box

Summary

- The APA+cold readout+Faraday Cage/Feedthrough with Warm Interface and Local Diagnostics should be treated as an integrated whole and installed as such
 - Coordinated TPC grounding and shielding between CE, PD, APA, CERN teams is working well on the Cold Box
- Component testing and selection at BNL is meeting APA installation schedule at CERN
- Measurement of ENC on APA1-3 very promising
 - Cold box is doing its job: identifying issues before installation in the cryostat
 - The noise uniformity of CE enables simple identification of open connections between sense wires and FE
- Preliminary results from DAQ runs with cool APA3 are comparable to the noise measured with the the BNL analysis