DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Cold Electronics system for ProtoDUNE-SP LAr-TPC

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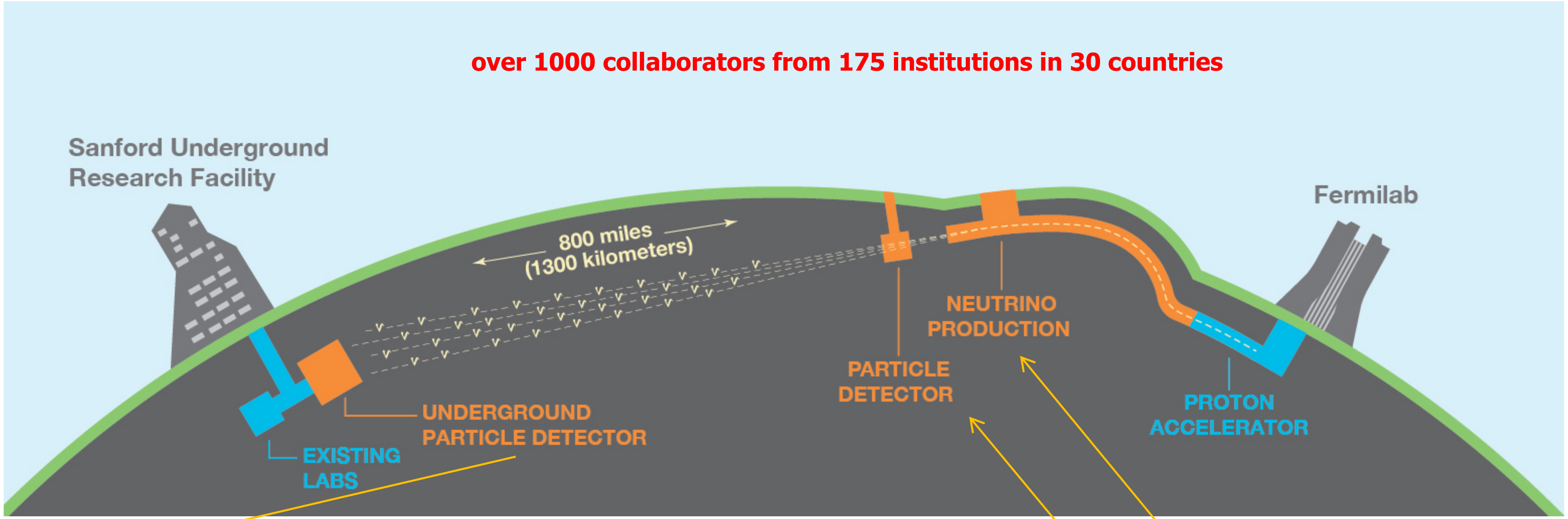
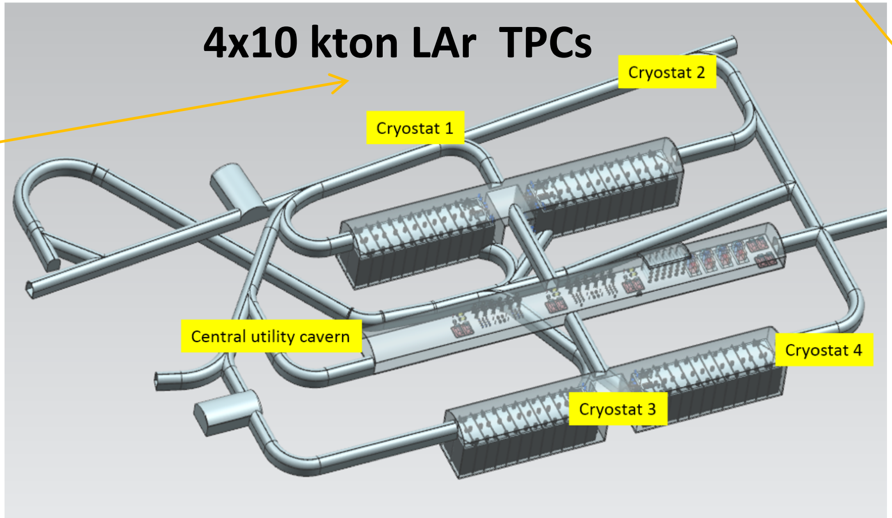
on behalf of ProtoDUNE-SP collaboration

14th Pisa Meeting on Advanced Detectors – May - June 2018

Deep Underground Neutrino Experiment (DUNE)





Far Detector at 1.5km underground:
4x10 kton Liquid Argon Time Projection Chambers (TPCs)

Two TPC concepts:
- Single Phase (LAr)
- Dual Phase (Ar gas+LAr)

The first 10 kton TPC will be Single Phase (LAr)

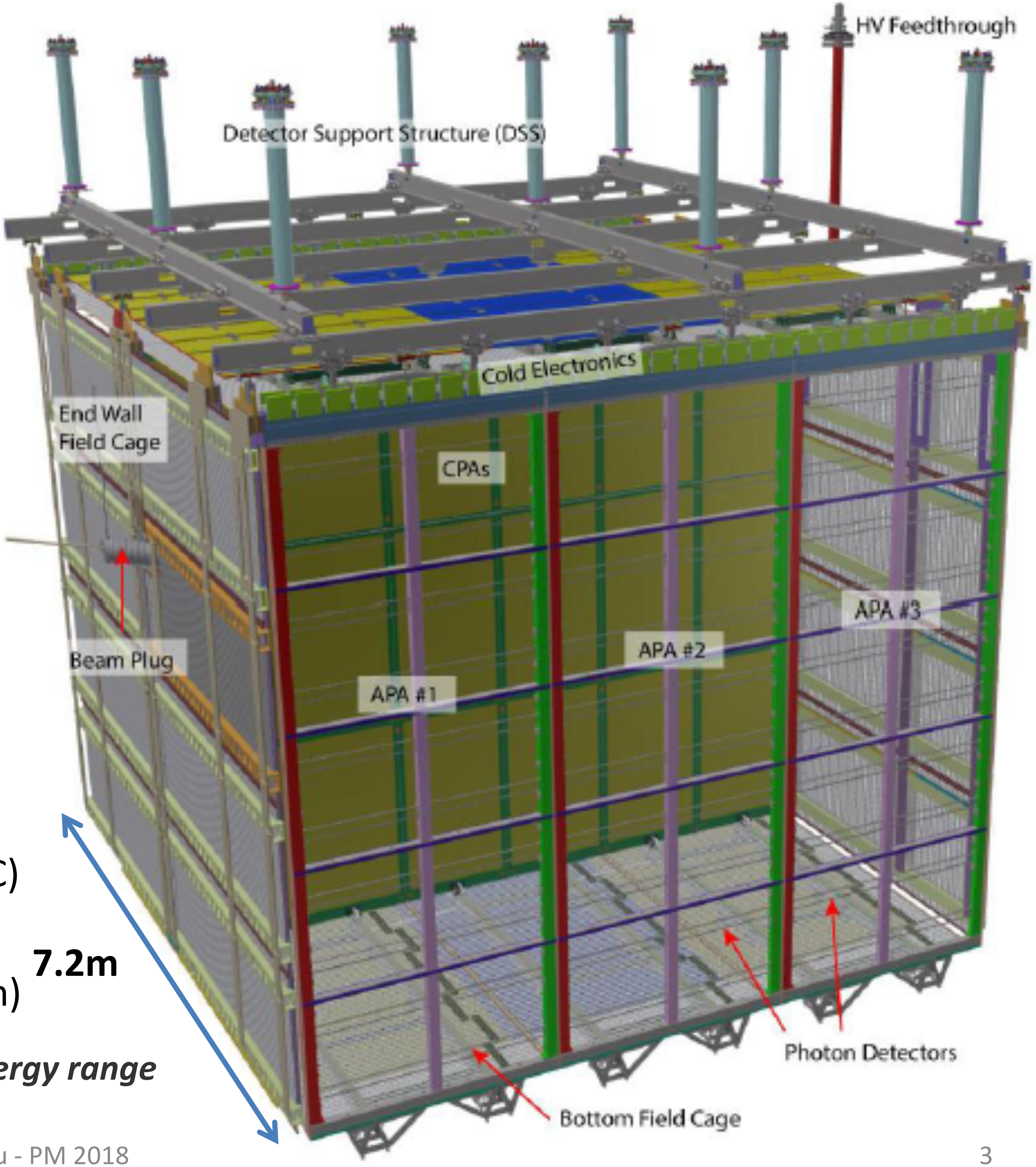
New **megawatt-power beam** at Fermilab

Near Detector at Fermilab

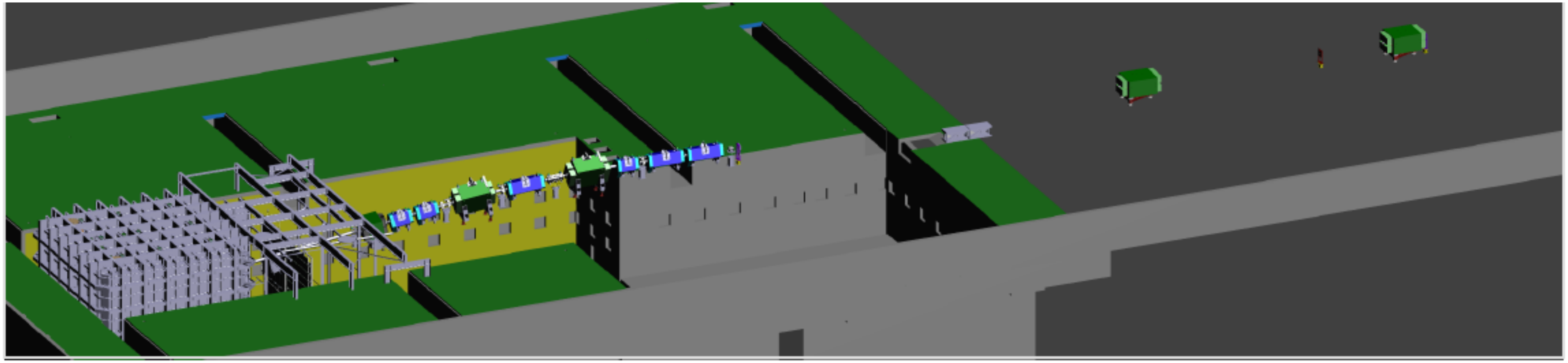
ProtoDUNE ~1% of DUNE

~ 400 tons LAr (*Fiducial mass*) ~4x10 kton LAr

- Single-Phase LAr TPC prototype:
  - **6 full-size (6x2.5 m^2) Anode Plane Assemblies (APAs)**
  - 3 Cathode Plane Assemblies (CPA)
    - 2 x 3.6m drift regions
    - **Total of 15,360 TPC sense wires and electronic channels**
- Key test of design concepts and construction:
  - TPC sense wire planes
  - **Cold electronics** integral to wire planes
  - **Cryostat feedtroughs** to integral warm interface (WIEC)
  - **Scintillator SiPM** Photon Detectors (PD)
  - **HV system**, field cage and cathode, for long drift (3.6m)



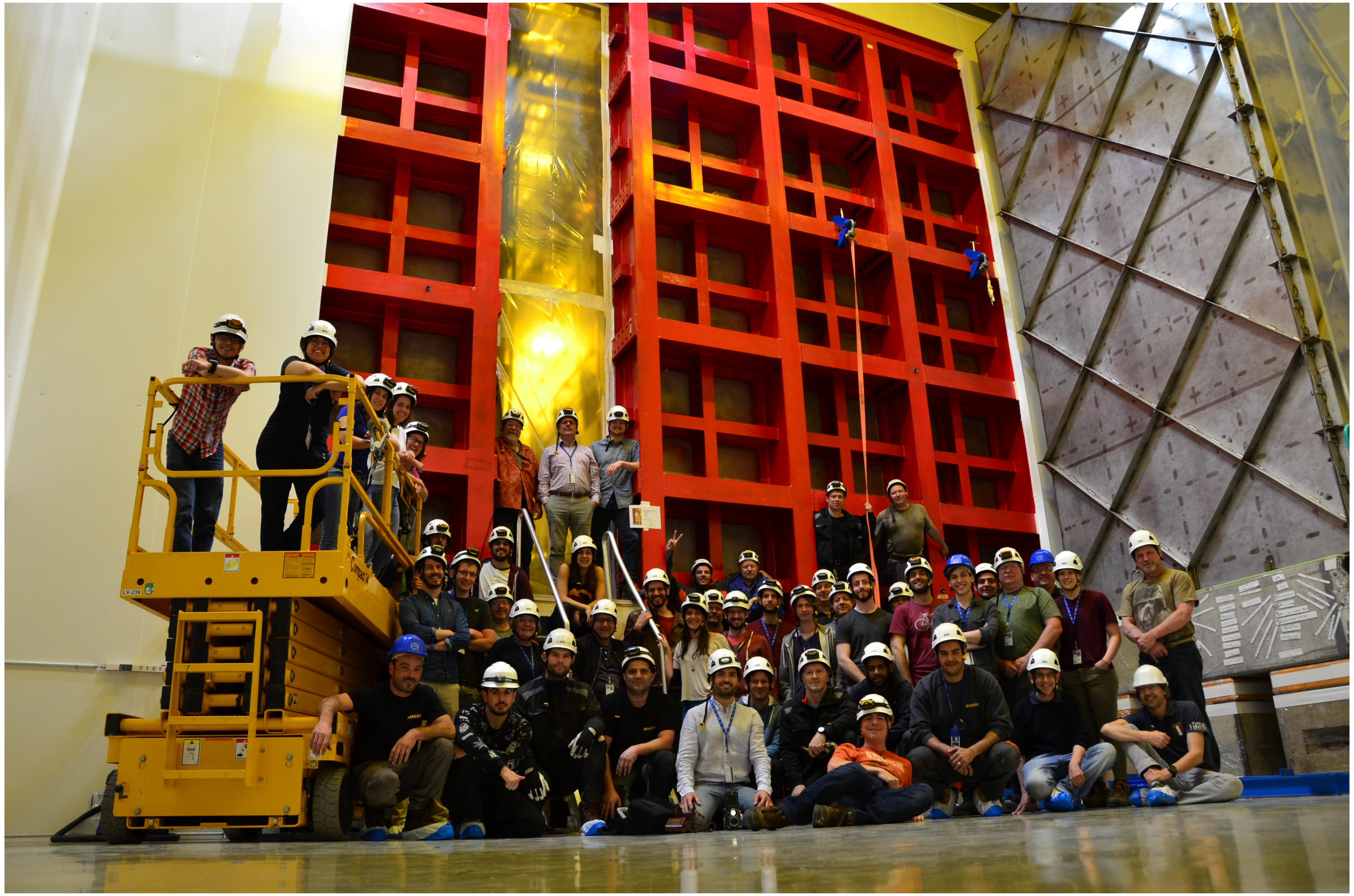
R. Acciarri - ProtoDUNE: prototyping the ultimate medium – high energy range (MeV - GeV) neutrino detector

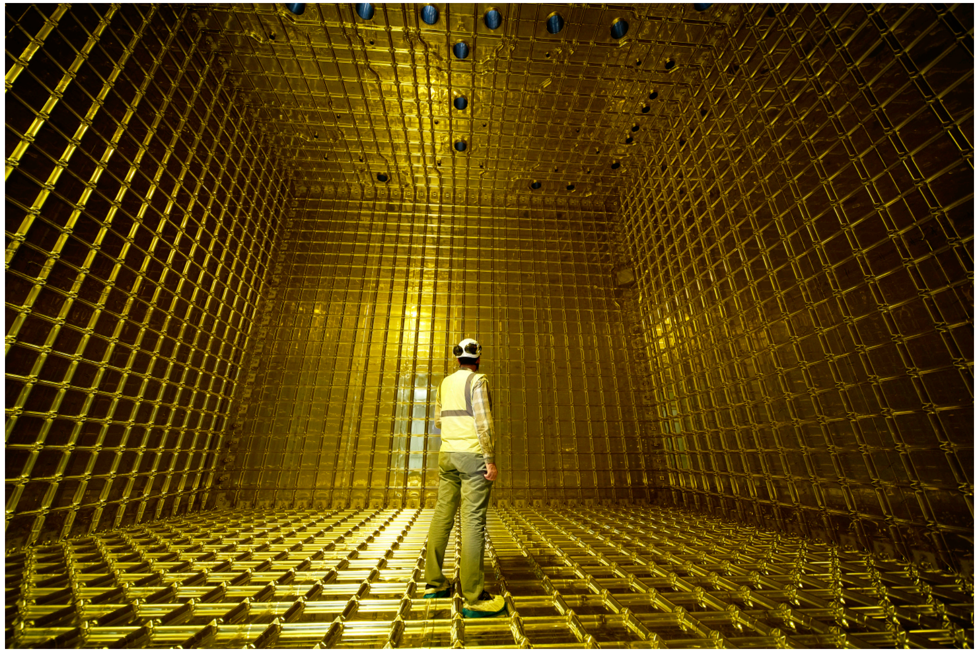


protoDUNE-SP Goals

- Prototyping production and installation procedures for DUNE far Detector Design *[task of the ongoing effort]*
- Validate design from perspective of basic detector performance
- Accumulate test-beam data to understand/calibrate response of detector to different ptcl. species
- Demonstrate long term operational stability of the detector

What a great team!

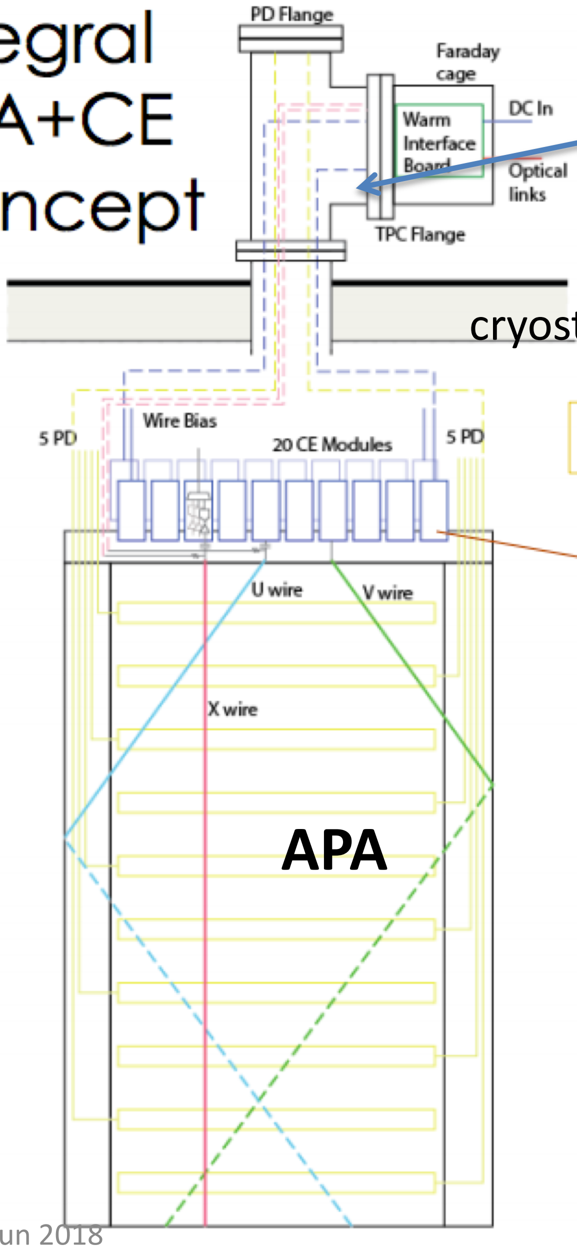




Project approved December 2015, TPC installation completed on Apr 2018, data taking End Summer-Fall 2018 → results available before the **2019 DUNE FD** Technical Design Review

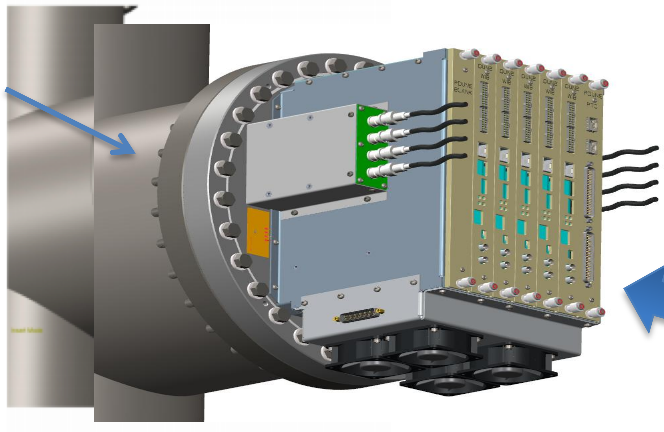
Integrated LAr-TPC Readout

Integral APA+CE Concept



Feedthrough

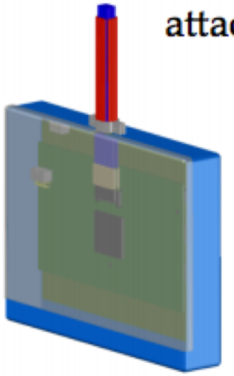
ProtoDUNE-SP

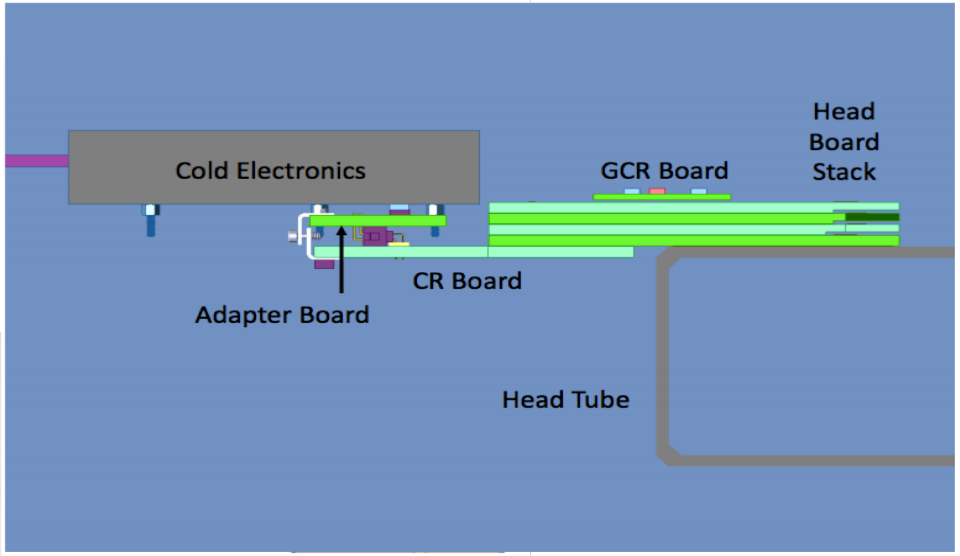


Each APA is isolated inside the cryostat and only connected to the cryostat through the CE at its own CE flange.

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

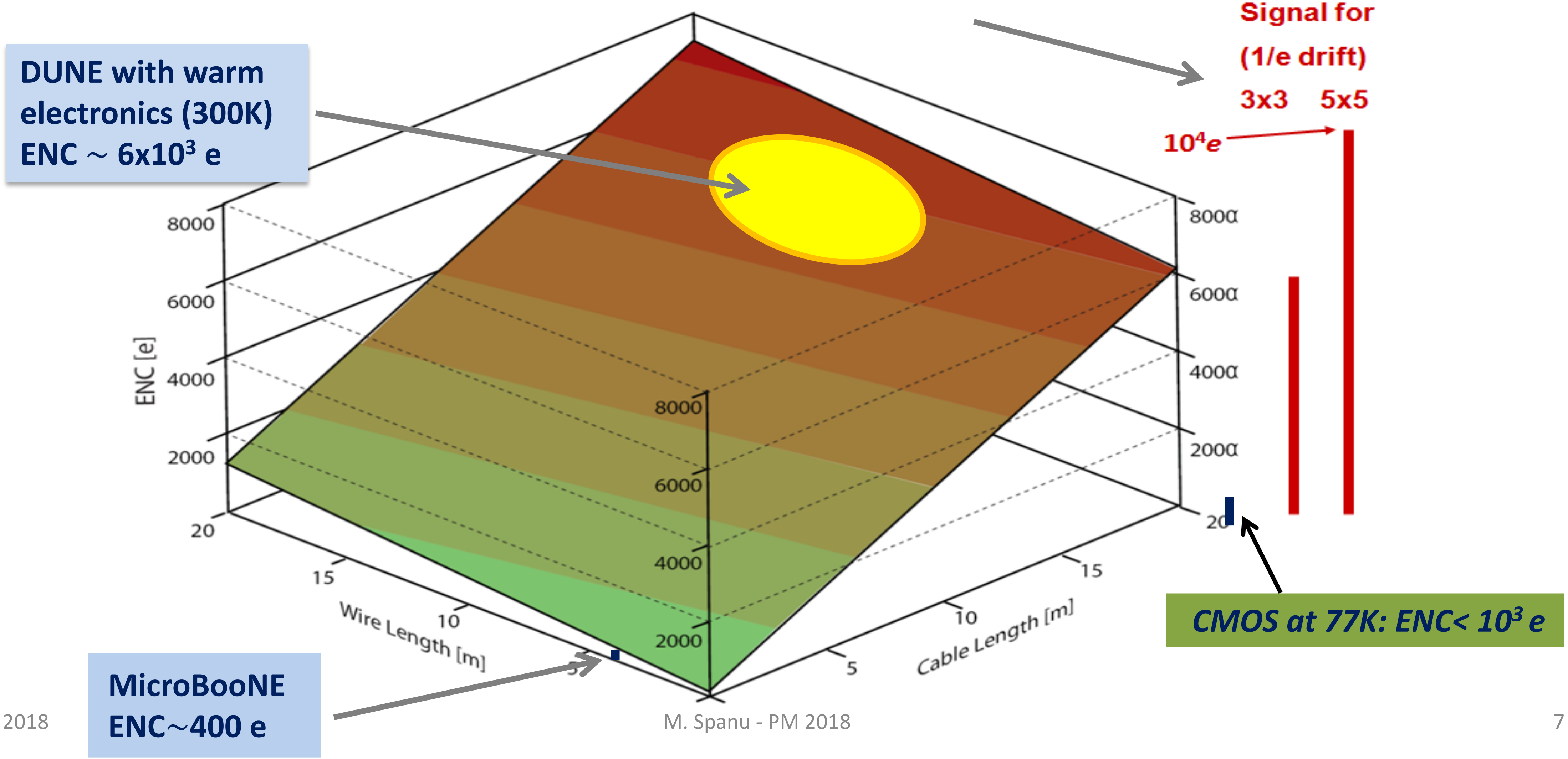
Cold electronics module and its attachment to the APA frame



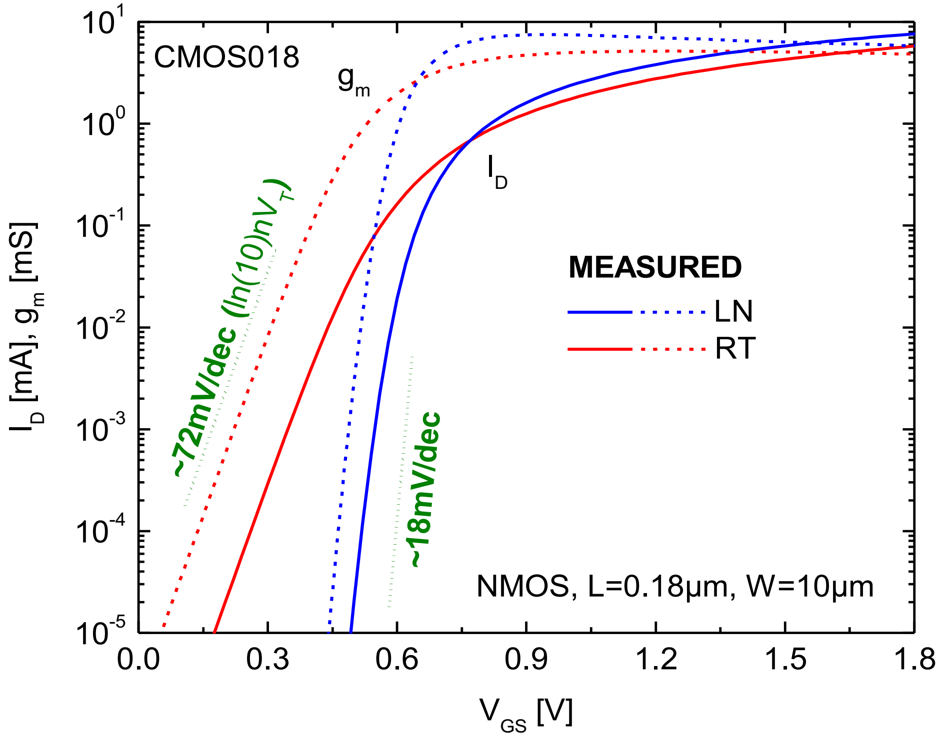


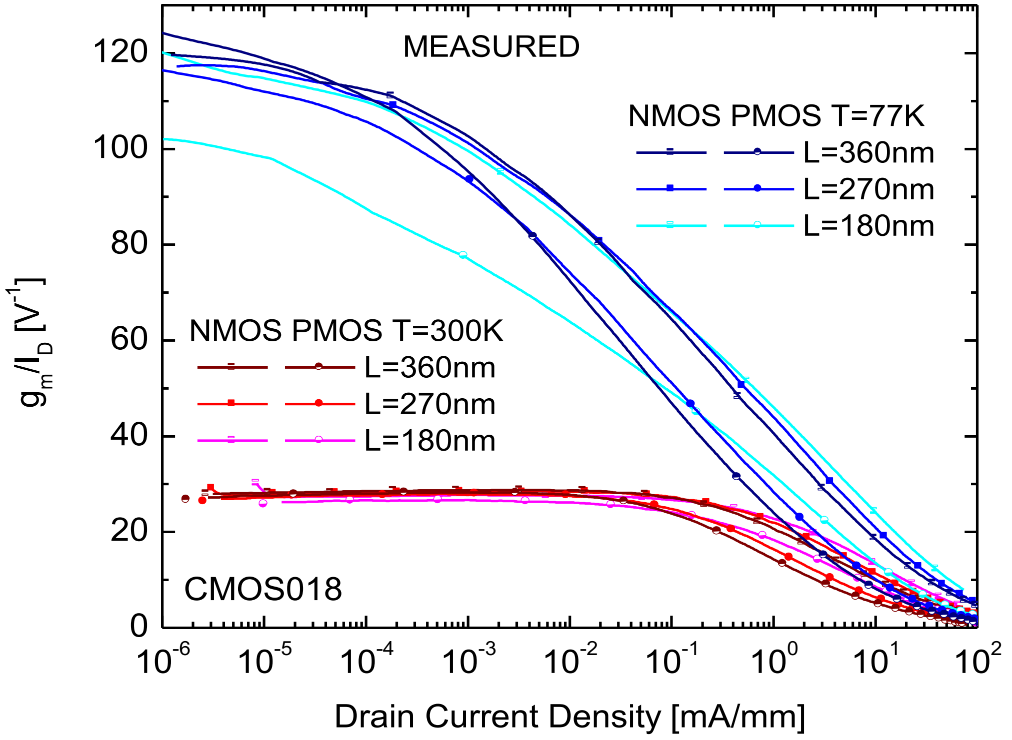
Noise (ENC) vs TPC Sense Wire and Signal Cable Length for CMOS at 300K and 89K

MIP Signal for 3x3 and 5x5 mm Sense Wire Spacing



Cold vs. Warm CMOS: static characteristics vs. T





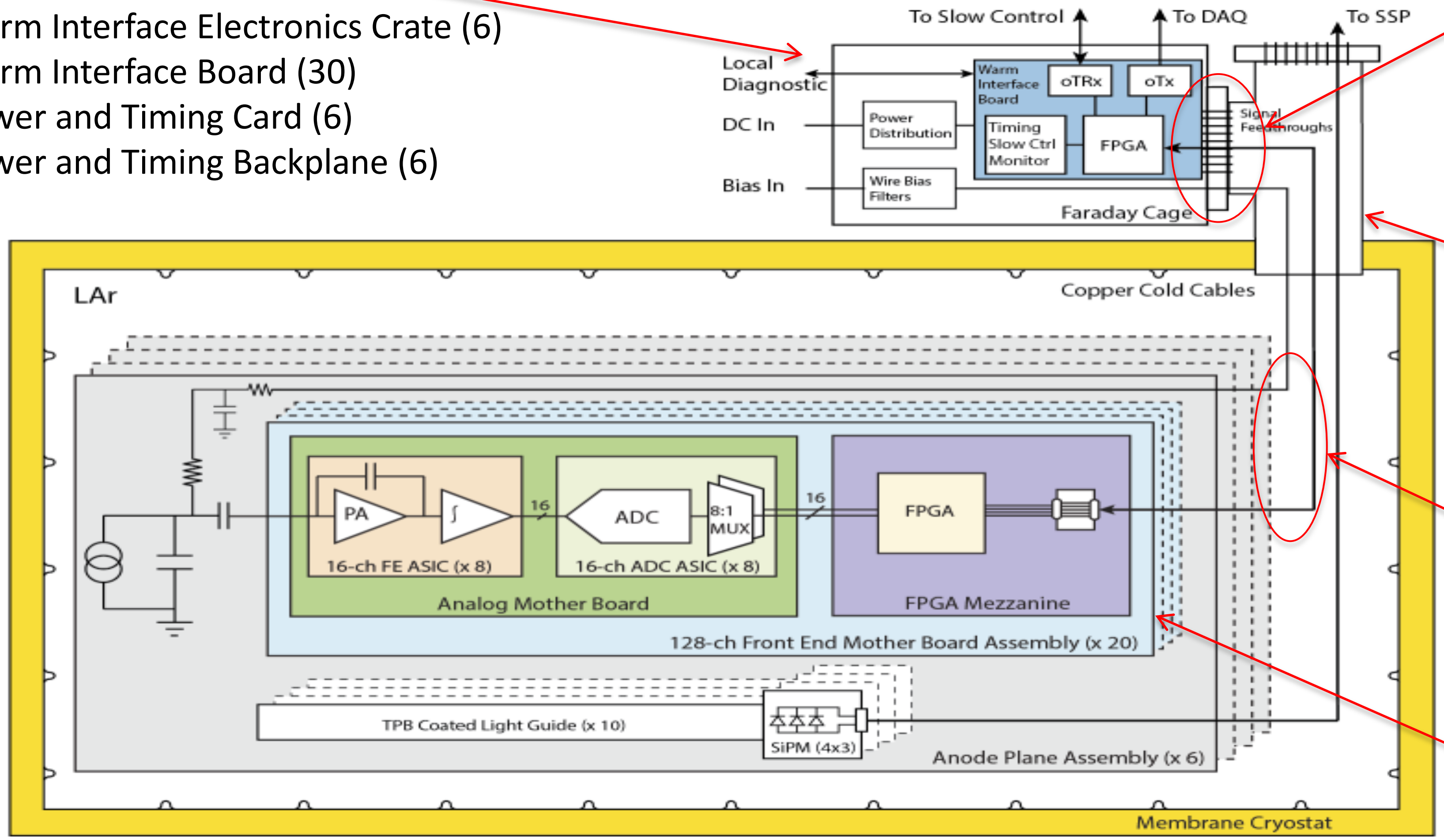
Transconductance / drain current

$$\frac{g_m}{I_D} \to \frac{q}{nk_BT} = \begin{cases} \sim 30 \;\; at \;\; T = 300K \\ \sim 116 \;\; at \;\; T = 77K \end{cases}$$

At 77-89K, charge carrier ***mobility*** in silicon <u>*increases*</u>, ***thermal fluctuations*** <u>*decrease*</u> with ***kT/e***, resulting in a ***higher gain***, ***higher g_m /I***, ***higher speed*** and ***lower noise***.

ProtoDUNE-SP Cold Electronics

Warm electronics
Local diagnostics
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)

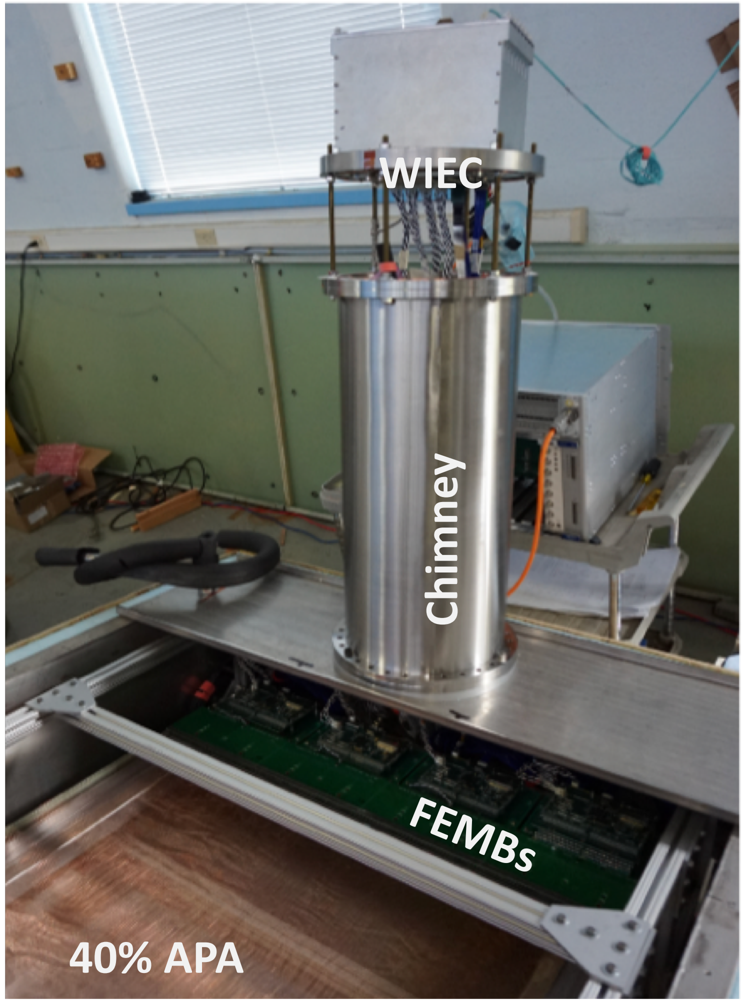
Signal feed-through
Tee pipe with 14” Conflat flanges and crossing tube cable (CTC) support (6)

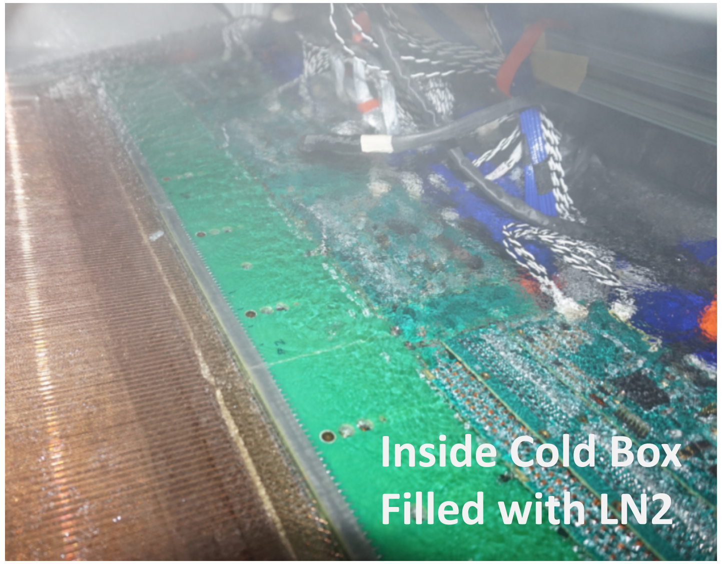
Cold cable
LV and data cable (120+120) to FEMB and APA wire-bias SHV cable (48)

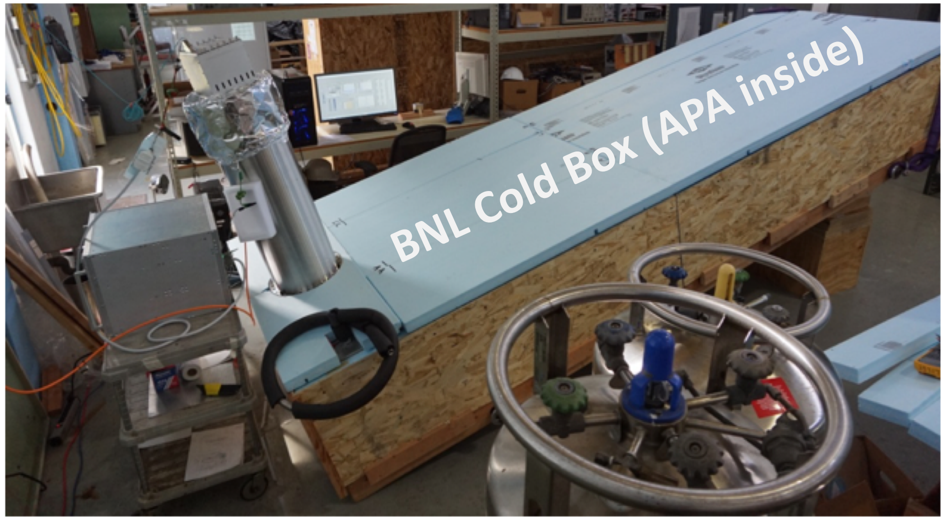
Front End Motherboard
(FEMB) 128 channels of digitized wire readout enclosed in CE Box (120)

Front End Electronics production at BNL

- CE boxes were assembled at **Brookhaven National Laboratory** (BNL) and shipped to CERN after a comprehensive set of QA/QC tests.
- Integration tests in LN2 were performed at BNL by a **40%** of DUNE APA (2.8 m x 1.0 m) in a smaller cold box.



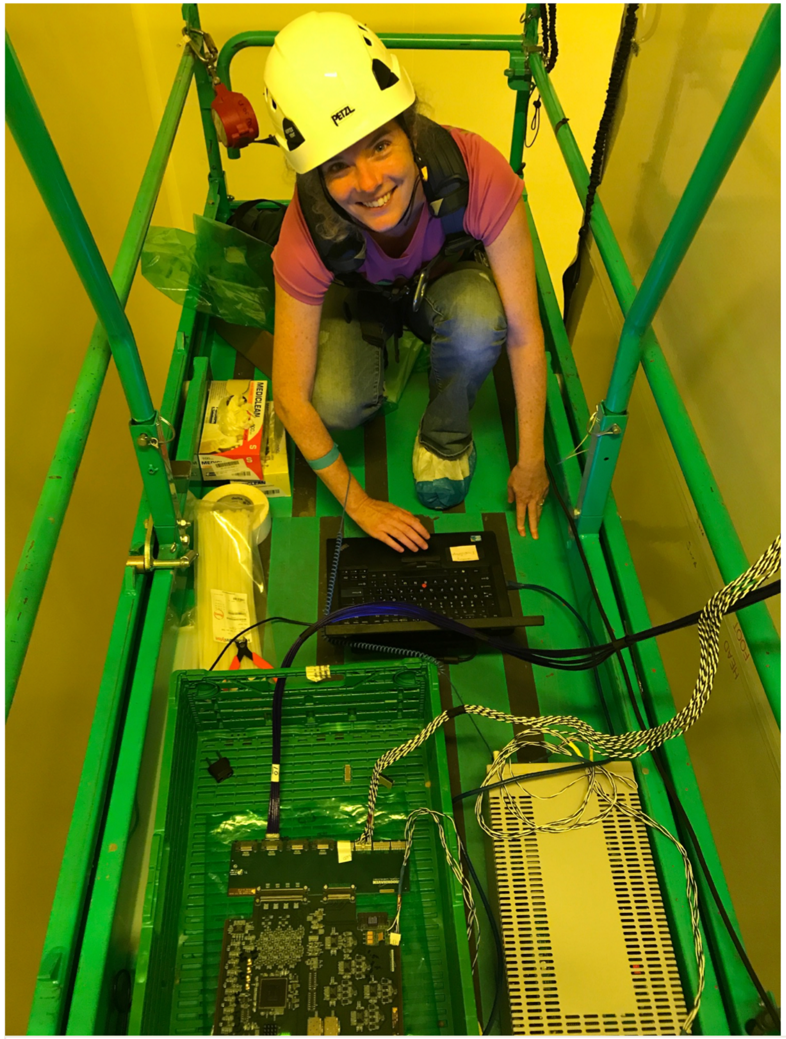




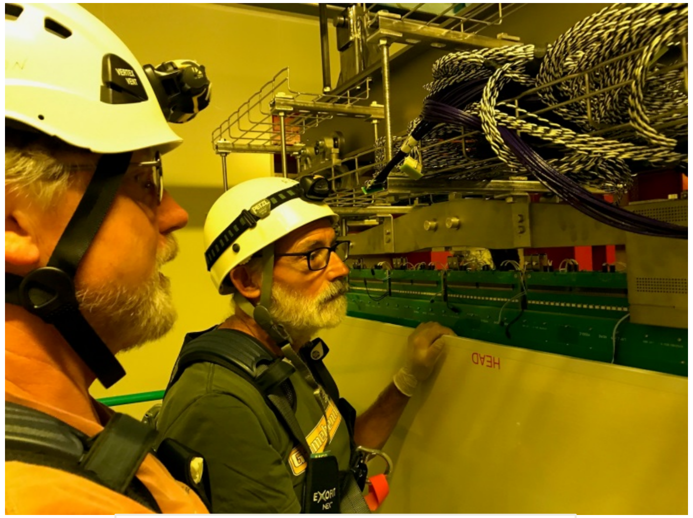
CE installation on Anode Plane Assembly (APA)

CE boxes installation on APA

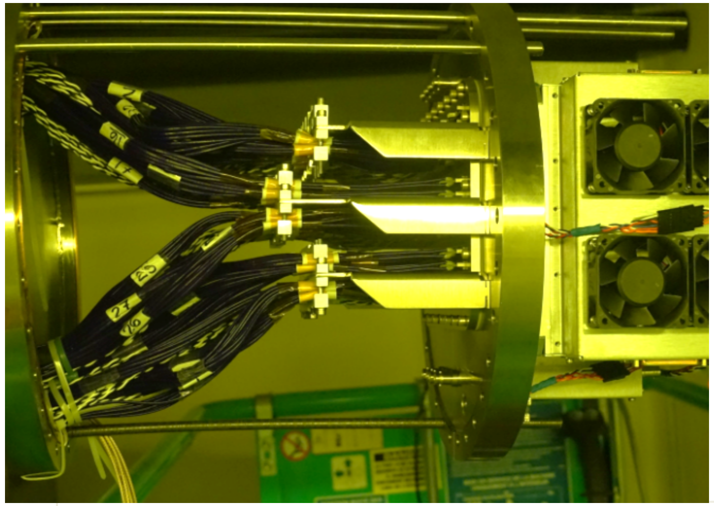
Installed CE boxes



CE boxes test after installation on APA



Cabling on cable tray



Cable hook up to feedthrough

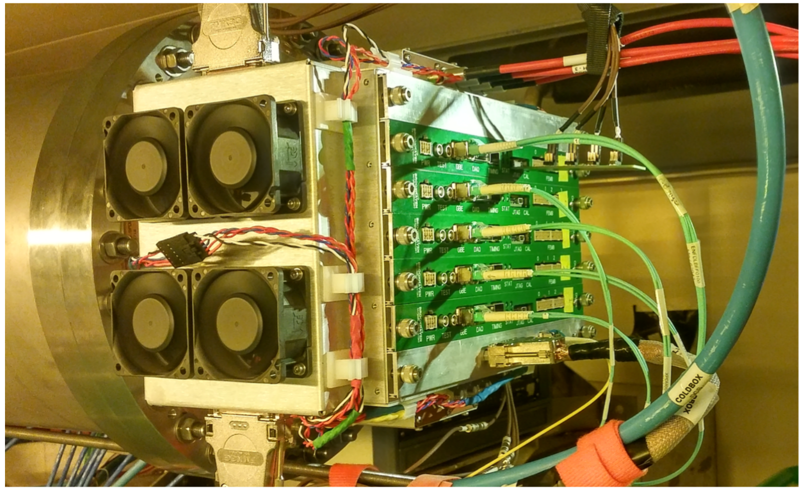
A Cold Box for testing APAs

Cold box allows integral test of electronics and photodetectors on production APAs

- Follows the same power and grounding rules for the detector electronics
- Incorporates a full scale **warm feed-through** and use cables and readout identical to the production system

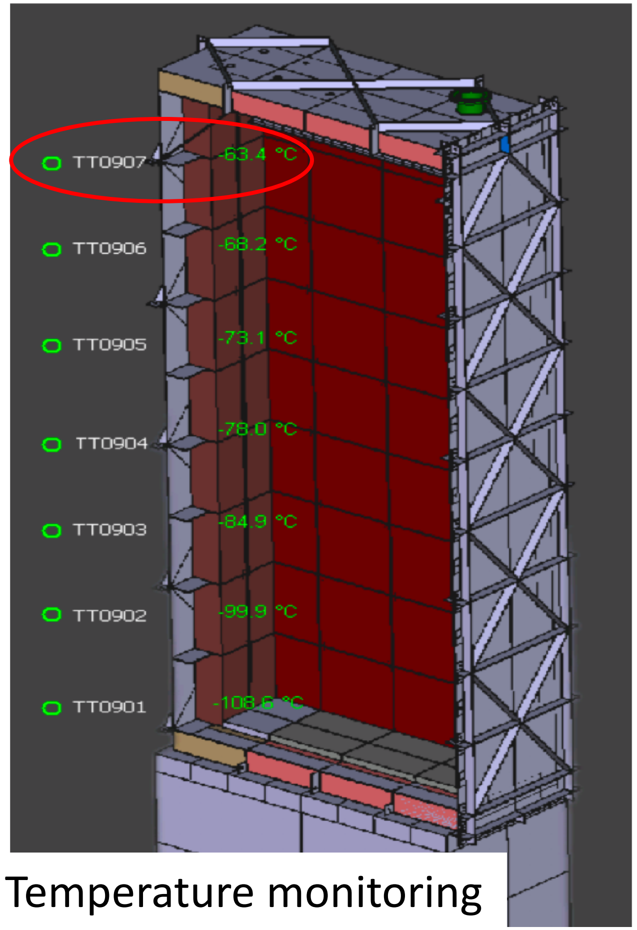
FEMB readout through **optical links** from WIB on top of the signal feed-through allows a **real time study** of detector performance in cold box tests and during installation of APAs.

Warm Interface



APA Test in cold Nitrogen gas

APA being moved into Cold Box



Temperature monitoring

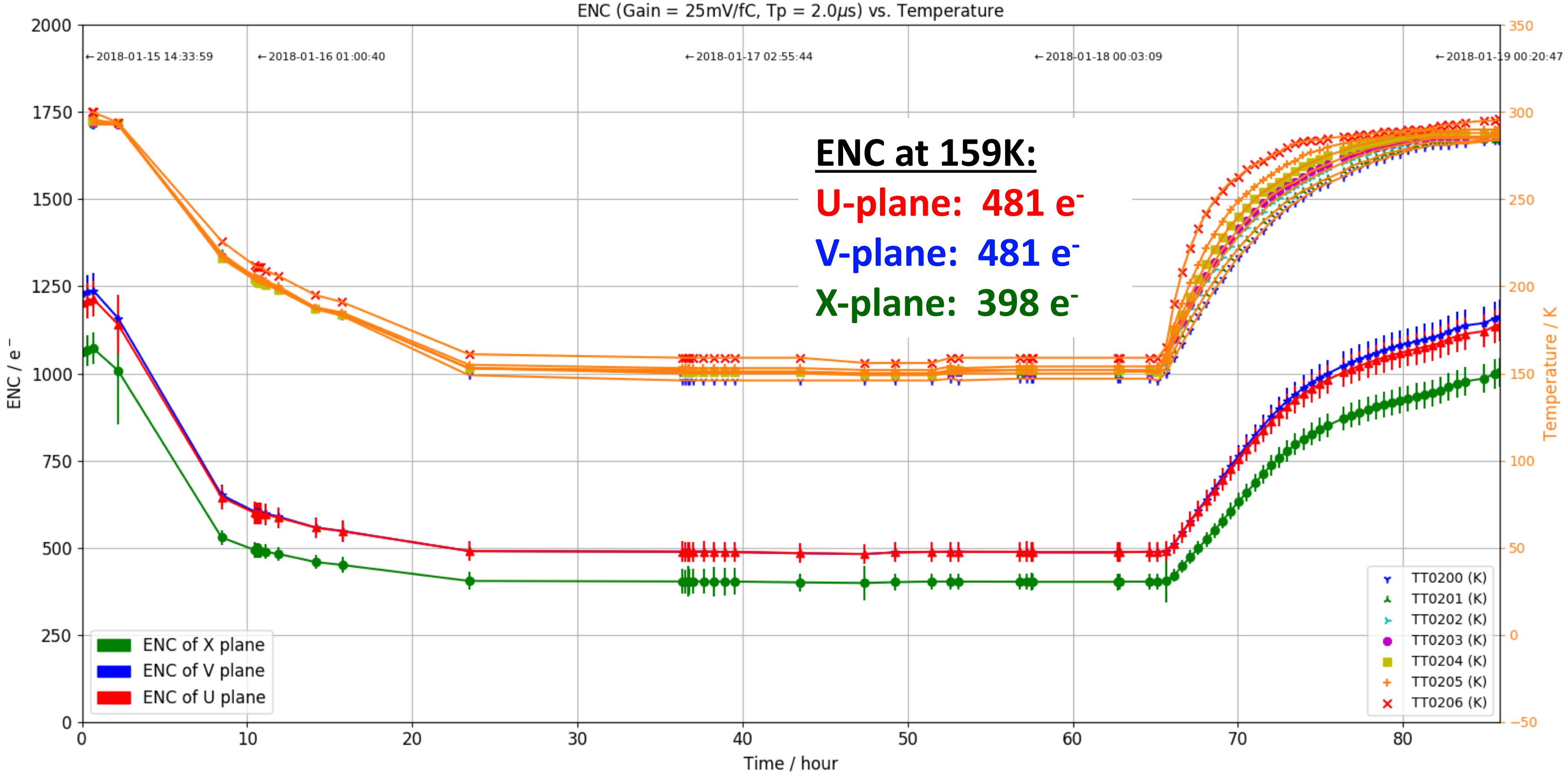
- TT0907 sensor at top of cold box
- Internal FE ASIC temperature sensor is readout through a scope

Noise vs Temperature – Cold Box Cooldown

APA2 (2018-01)

Lowest temperature reached

TT0907 ~ **159K**



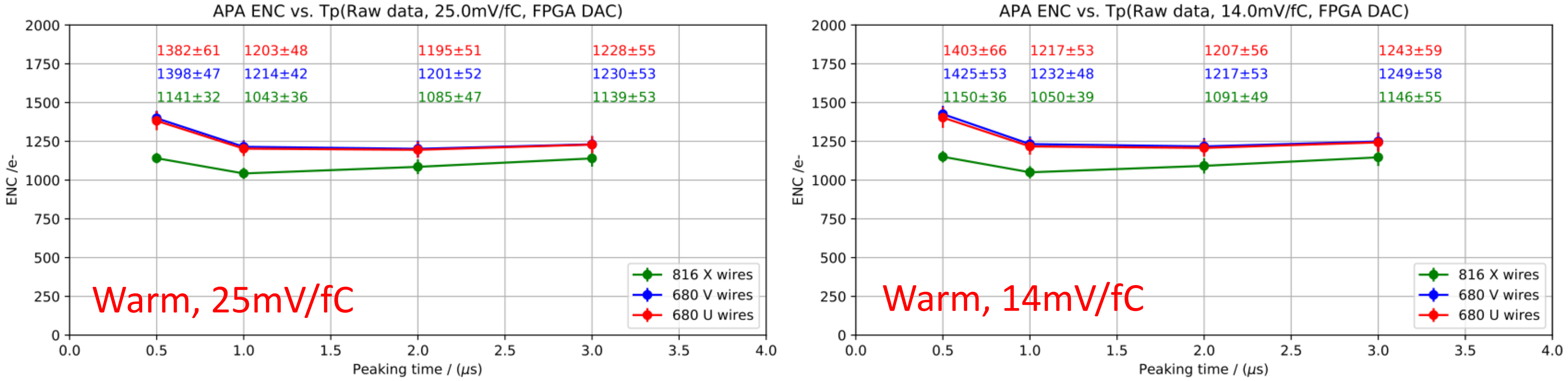
1. Uniform gain (77 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off

Overall ENC Performance - Warm vs. Cold

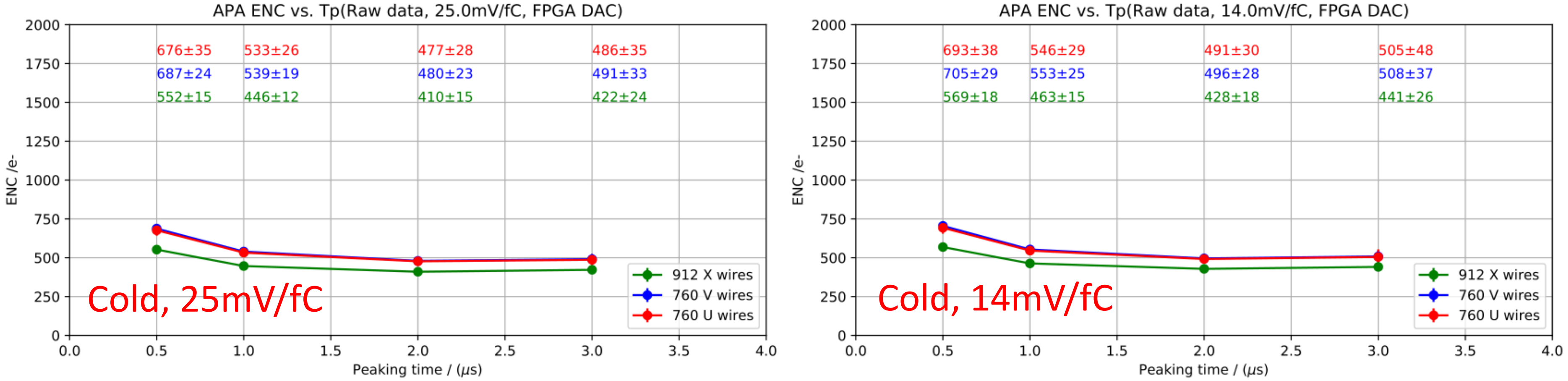
APA4 (2018-03)

Done by local diagnostic function
(every channel uses its own gain calibrated by FPGA-DAC)

Noise Measurement



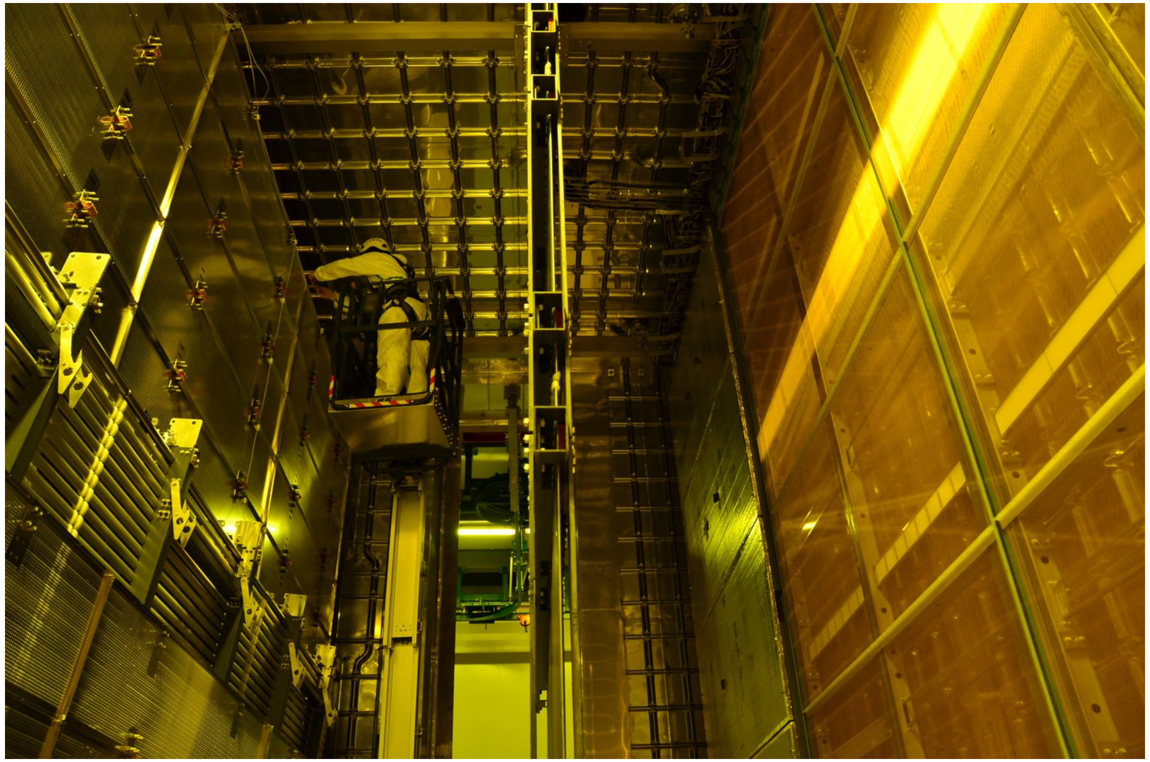
Noise Measurement



ProtoDUNE-SP – Present and Future

After the cold test, all **6 APAs** and **3 CPAs** have been installed into the ProtoDUNE-SP cryostat

- Electronics and photodetectors have been tested before and after the installation on APAs
- All CE and PD cables are routed though the chimney out of the cryostat and connected to the corresponding crate



What's next?

The detector is assembled, so now let's make it work!

- Installation CRT, purity monitors, temperature gradient monitors, HV feedthrough (ongoing now)
- Purge, cooldown, fill the detector (July – August)
- Turn on the detector and make it work stably, smoothly, and noise free (end of August)
- **Beam Run (August 29th → November 11th)**
- …

Summary

- **Readout electronics** developed at BNL for low temperatures (77K-89K) is an **enabling** technology for noble liquid detectors for neutrino experiments
- **ProtoDUNE-SP** project at the CERN Neutrino Platform facility will provide validation of LAr-TPC technology, detector response and long-term stability for DUNE FD optimization. The TPC **installation** was completed on Apr 2018
- Different expert teams are now at work on the activation procedures of the different TPC components
- We're almost ready for the **beam run**… Looking forward to see the results!

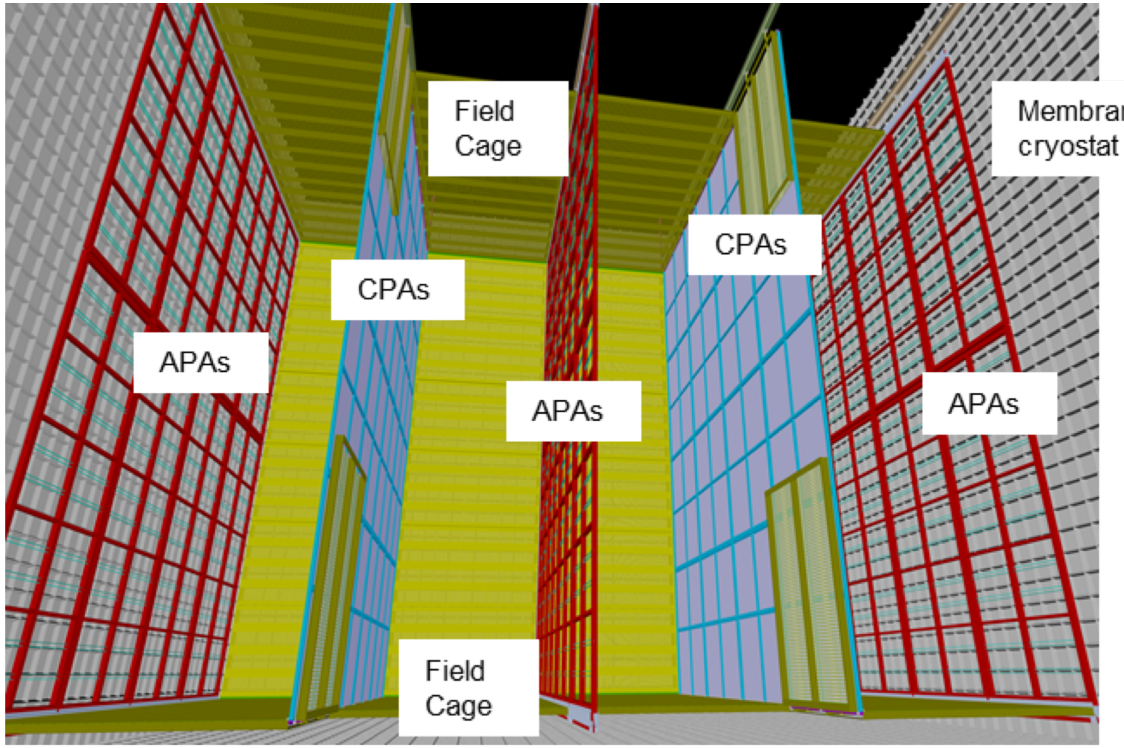
References

- S. Li, J. Ma, G. De Geronimo, H. Chen, and V. Radeka, “LAr TPC electronics CMOS lifetime at 300 K and 77 K and reliability under thermal cycling,” *IEEE Trans. Nuclear Science*, vol. 60, no. 6, pp. 4737-4743, Dec. 2013.
- G. De Geronimo, A. D’Andragora, S. Li, N. Nambiar, S. Rescia, E. Vernon, H. Chen, F. Lanni, D. Makowiecki, V. Radeka, C. Thorn, and B. Yu, “Front-end ASIC for a liquid argon TPC,” *IEEE Trans. Nuclear Science*, vol. 58, no. 3, pp. 1376-1385, June 2011.
- J. R. Hoff, R. Aroar, J. D. Cressler, G. W. Deptuch, P. Gui, N. E. Lourenco, G. Wu, and R. J. Yarema, “Lifetime studies of 130 nm nMOS transisors intended for long-duration, cryogenic high-energy physics experiments,” *IEEE Trans. Nuclear Science*, vol. 59, no. 4, pp. 1757-1766, Aug. 2012.
- V. Radeka, H. Chen, G. Deptuch, G. De Geronimo, F. Lanni, S. Li, N. Nambiar, S. Rescia, C. Thorn, R. Yarema, and B. Yu, “Cold electronics for “giant” liquid argon time projection chambers”. *1st International Workshop towards the Giant Liquid Argon Charge Imaging Experiment*, volume 308 of *Journal of Physics: Conference Series*, 2011.

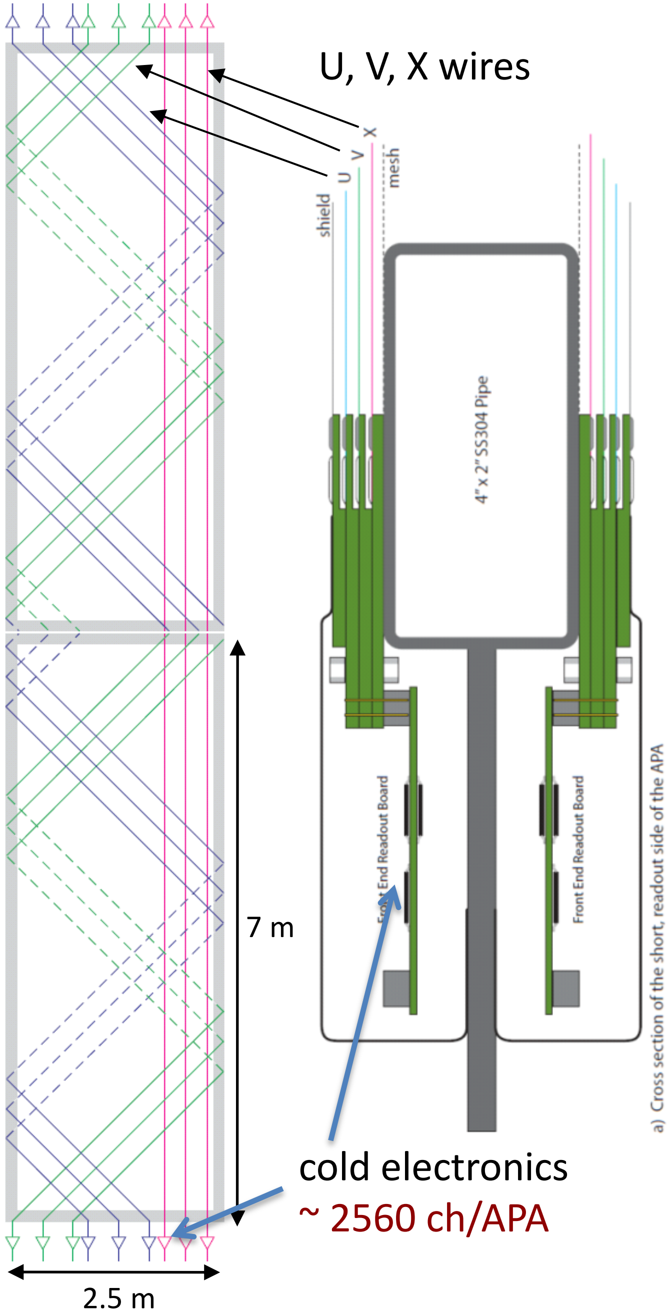
Thank you for your attention!

Backup slides

DUNE Far Detector



- APA, CPA & front end cold electronics system for single phase DUNE far detector
- DUNE 10 kt Far Detector
  - ***<u>384,000 channels</u>***
  - 24,000 FE ASICs/24,000 ADC ASICs
  - 6,000 COLDATA ASICs
  - 3,000 Front End Mother Board assemblies



ProtoDUNE SP facility – EHN1 at CERN

Clean Room

Cryostat

Detector Control System (DCS) room

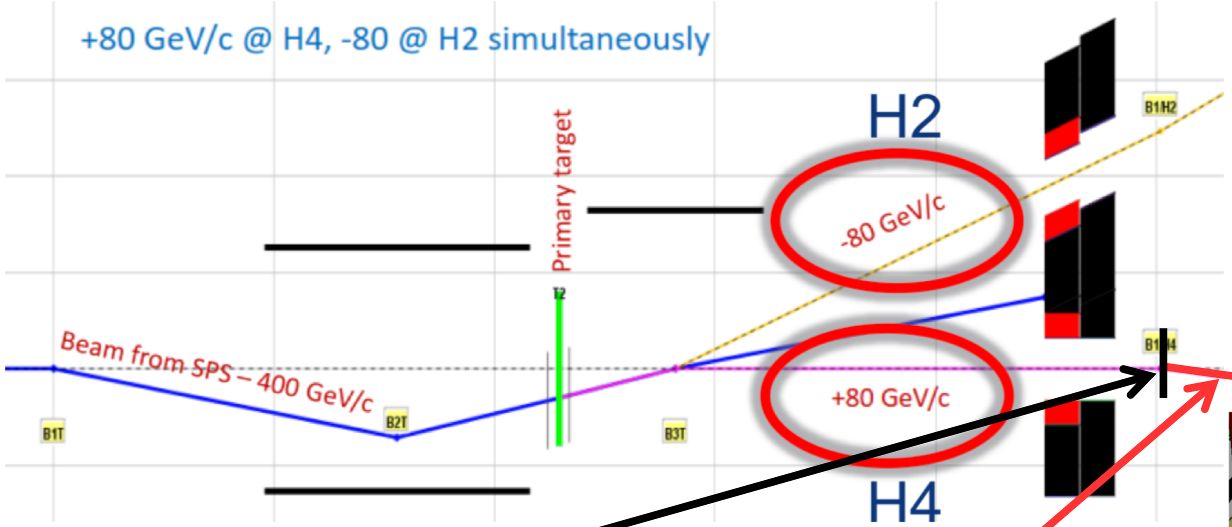
Grounding Status Monitor

Cold Box
(inside)

Cooling System

N2 dewar

H4 VLE Beam line



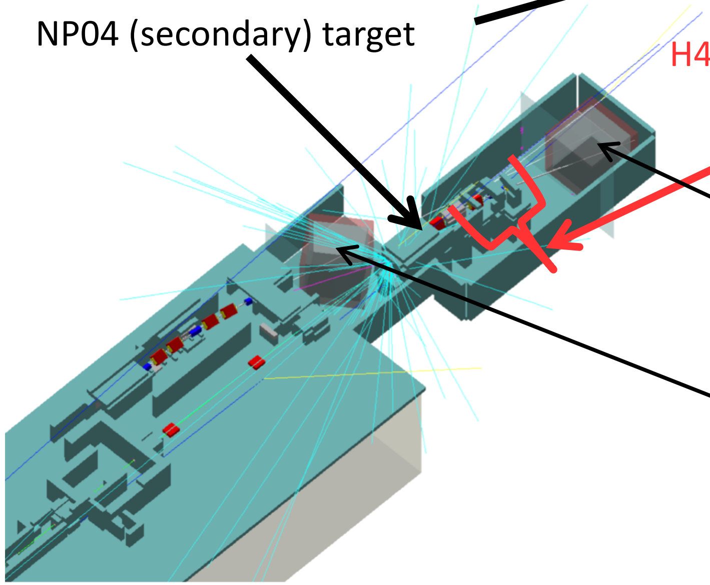
400 GeV/c P beam from SPS

80 GeV/c secondary □$^+$ beam

~0.5 – 7 GeV/c tertiary e^-,p,μ^+,□$^+$ beam

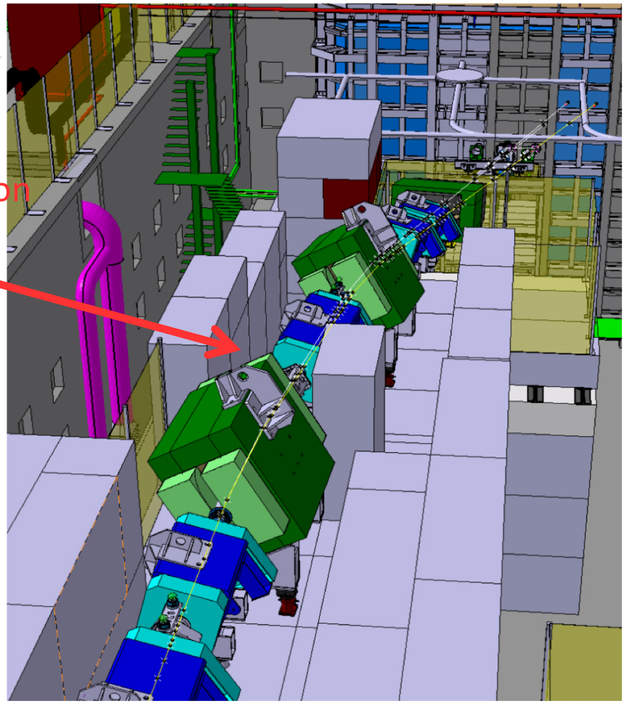
NP04 (secondary) target

H4 VLE beam line under construction

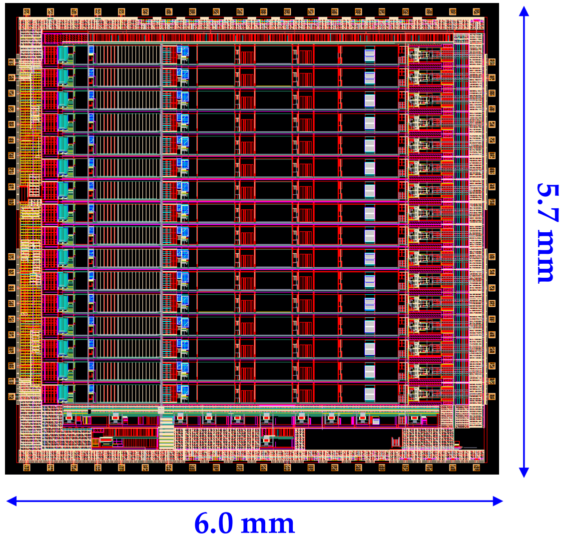


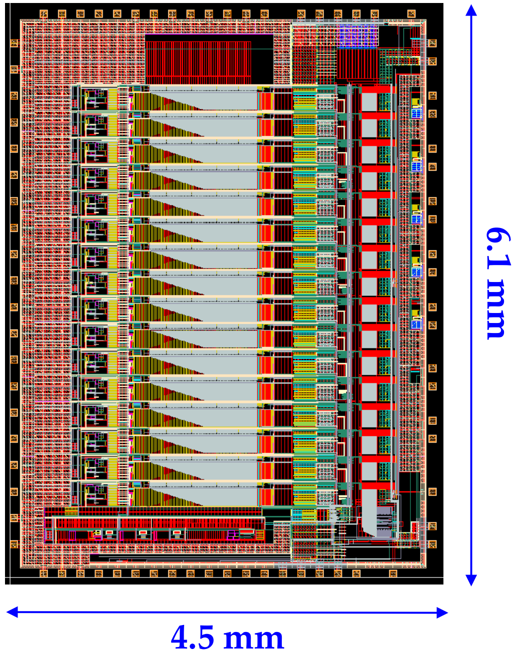
ProtoDUNE-SP cryostat

ProtoDUNE-DP cryostat



CMOS Cold ASICs Upgrades Implemented

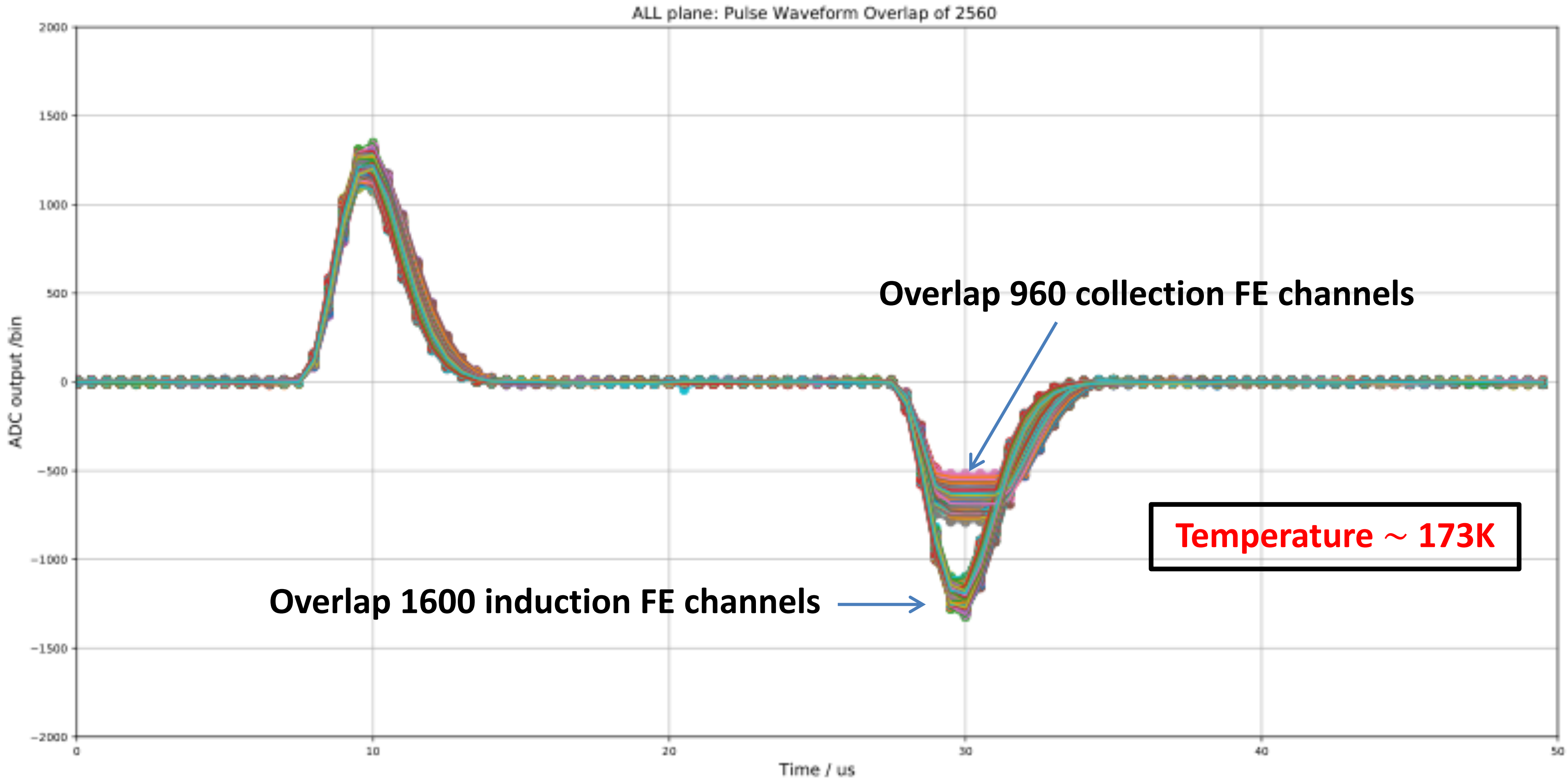




- FE ASIC
  - Built-in 6-bit DAC for calibration pulse generation
  - Built-in analog monitoring output for debug
  - Address pole-zero cancellation and drive capability in buffer-off mode
  - Add higher bias current (1nA and 5nA) options and smart reset
  - Revise BGR start-up circuit and increase ESD protection on I/O
  - ***Will be used to instrument SBND and ProtoDUNE-SP***
- ADC ASIC
  - Implement COLDATA (DUNE baseline design by FNAL, ***prototype expected in FY19***) compatible interface and FE ASIC compatible configuration
  - Address the early saturation and roll-back
  - Implement power-on default configuration and extend soft-control functions
  - Revise BGR start-up circuit and increase ESD protection on I/O
  - Improve ADC INL/DNL → not completely resolved
  - ***Will be used to instrument ProtoDUNE-SP***
  - ***SBND is exploring COTS ADC option***
  - Cold ADC ASIC development is very challenging given the ***amplified mismatch error*** and ***inaccurate simulation model*** in cryogenic temperature

APA1 - Pulse response

Inject bipolar pulses from electronics calibration circuit on FEMB

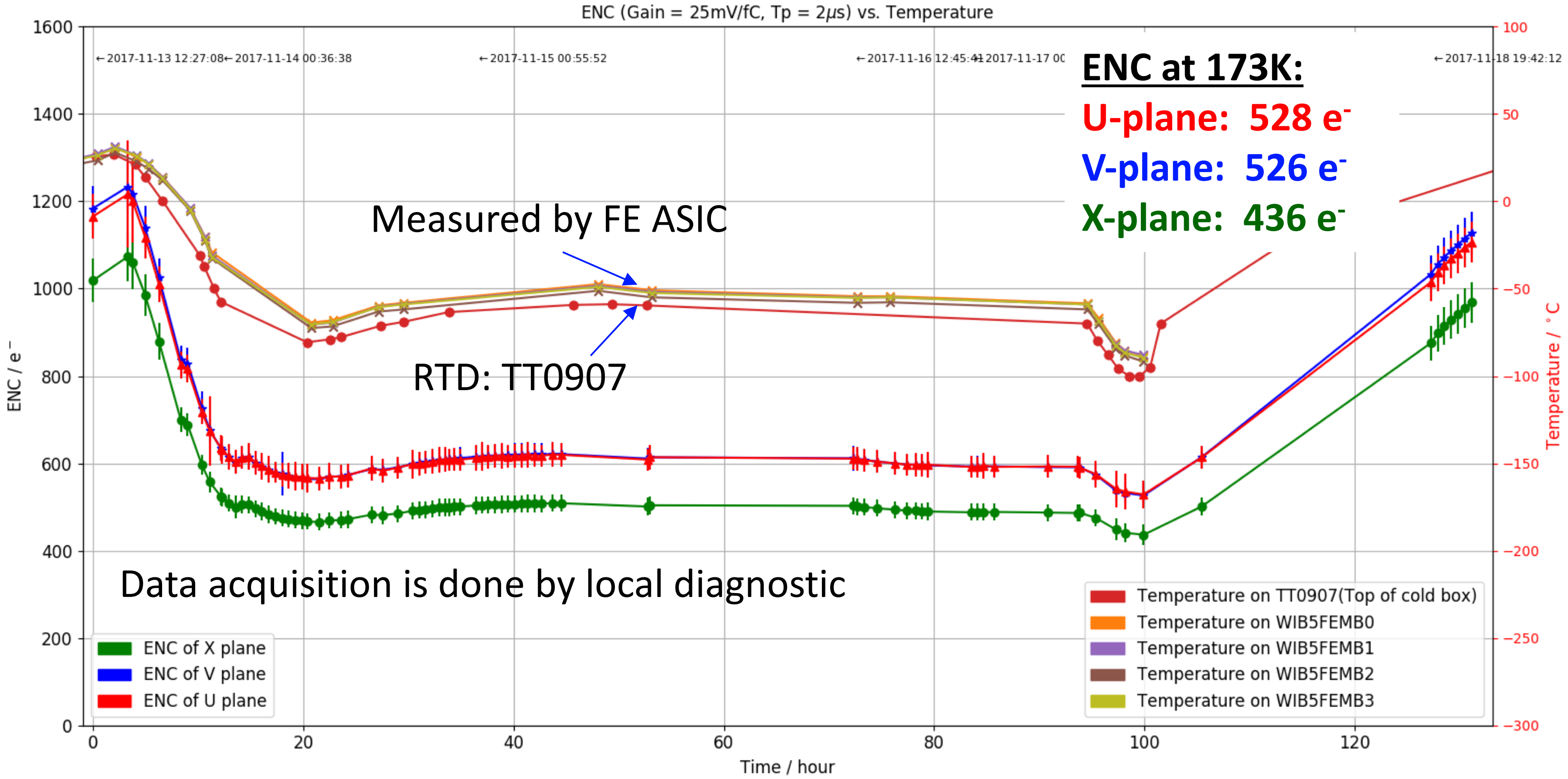


Noise vs Temperature – Cold Box Cooldown

APA1 (2017-11)

Lowest temperature reached

TT0907 ~**173K** FEASICs ~ **183K**

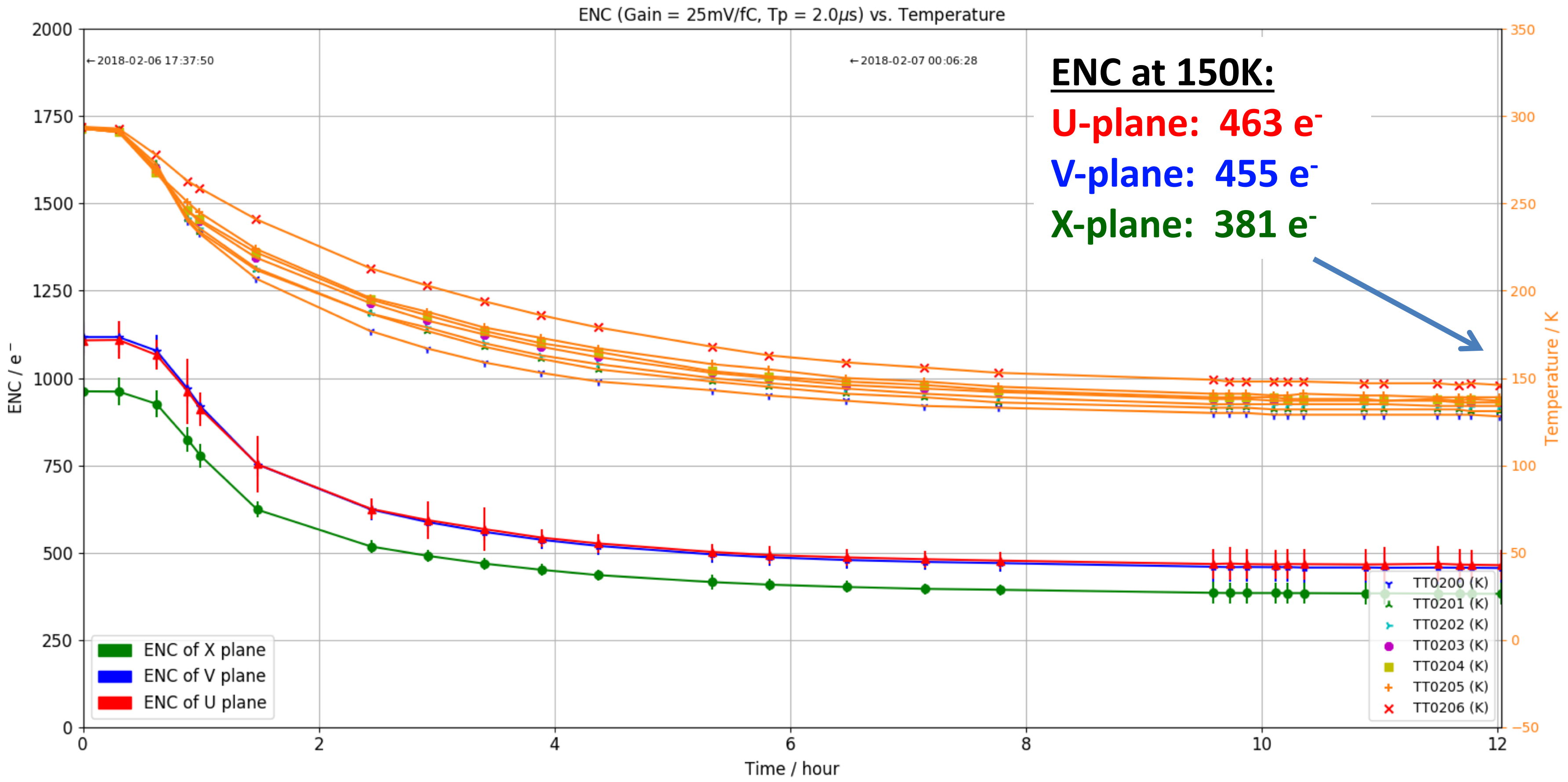


1. Uniform gain (80 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off

Noise vs Temperature – Cold Box Cooldown

APA3(2018-02)

Lowest temperature reached
TT0907 ~ **150K**



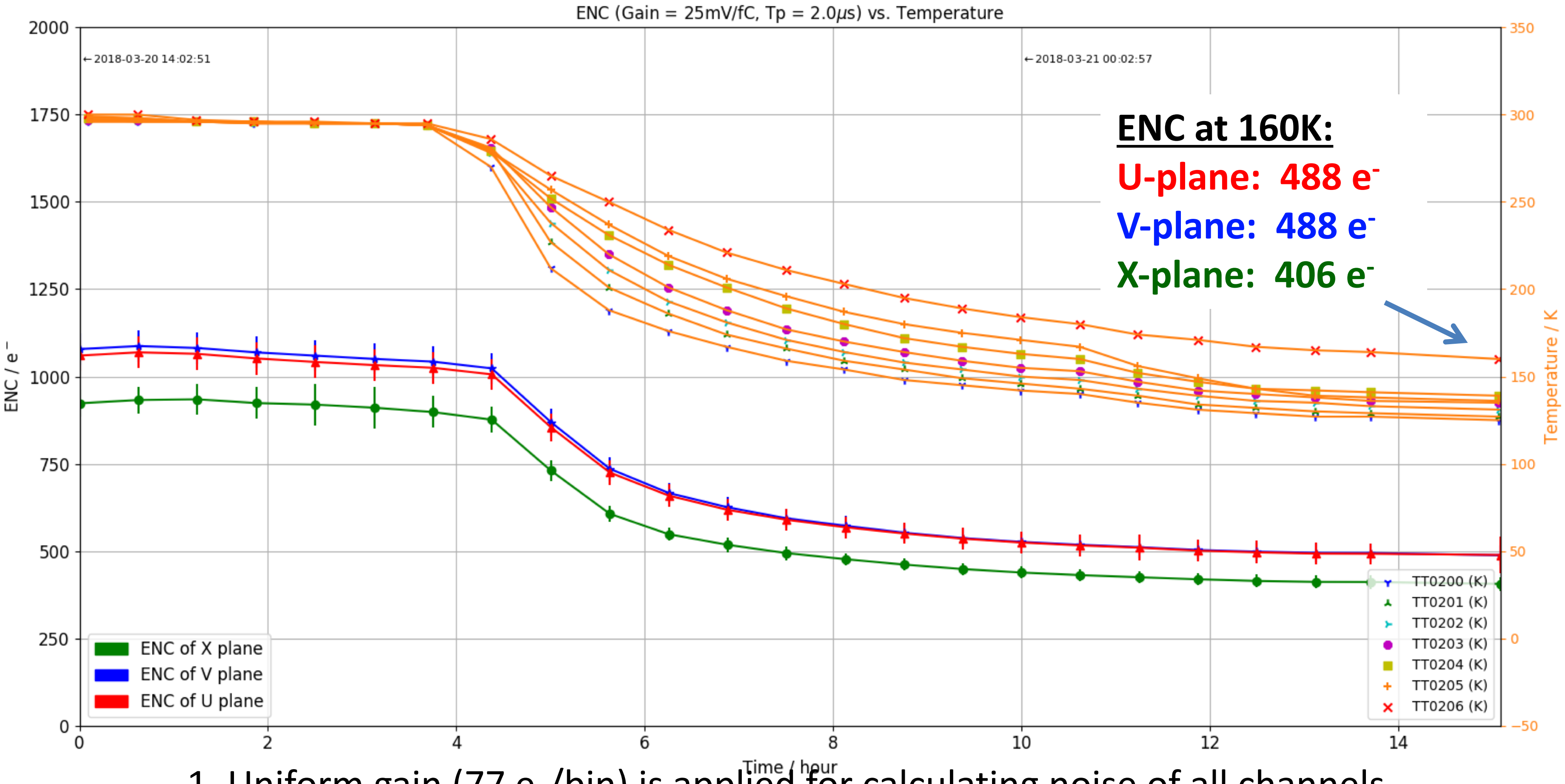
1. Uniform gain (77 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off

Noise vs Temperature – Cold Box Cooldown

APA4(2018-03)

Lowest temperature reached

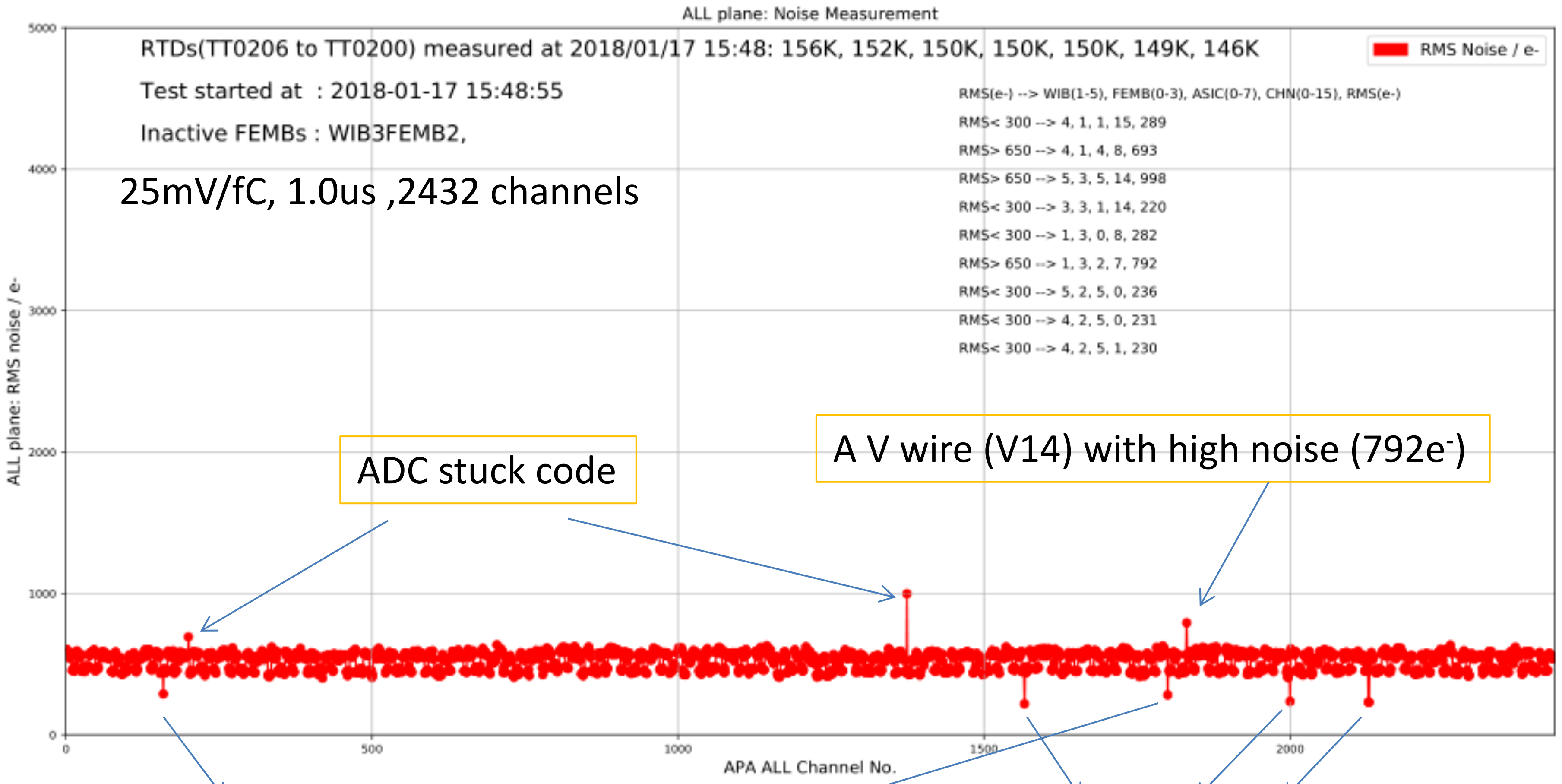
TT0907 ~ **160K**



1. Uniform gain (77 e-/bin) is applied for calculating noise of all channels
2. Bias voltages were off
3. WIB2FEMB1 was inactive before cooldown

Diagnostics on Abnormal Channels (18 Out Of 15360)

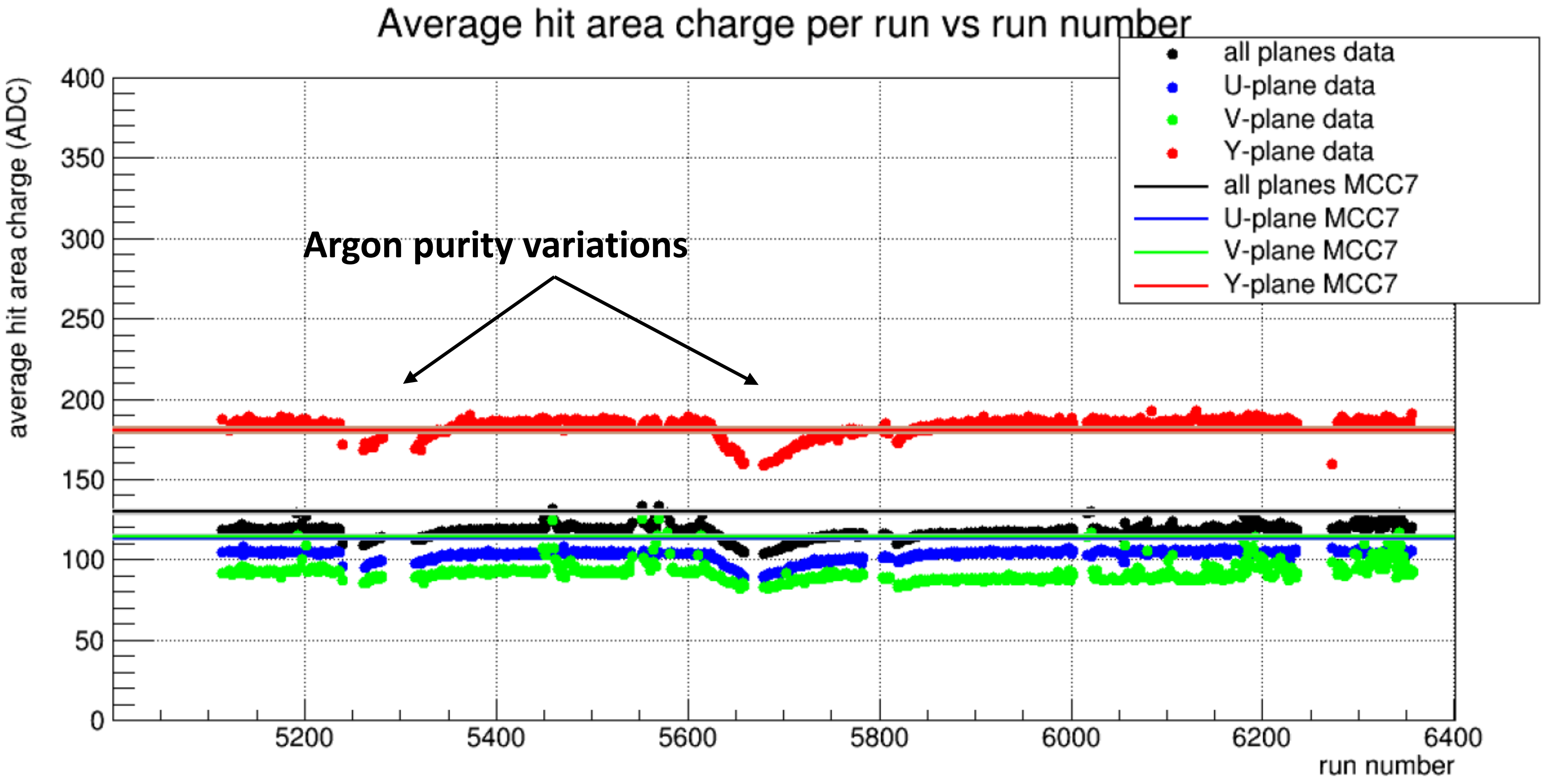
APA2 (2018-01)



Missing wire connections
ENC ~280e$^-$ → consistent with the FEMB seeing the additional capacitance from the CR board

Missing wire connections
ENC ~220e$^-$ → consistent with the FEMB when it sees nothing

MicroBooNE long term stability of average MIP response, incl. argon purity variations



FE ASICs in LAr: (gain) variations <0.2% over >2years

MICROBOONE-NOTE-1013-INT