ARA-Next: a new DAQ and trigger architecture for the Askaryan Radio Array

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Askaryan Radio Array - Experiment
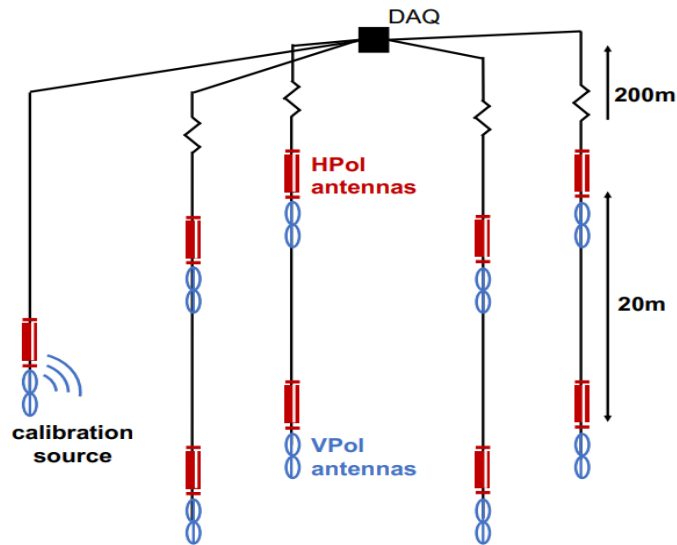
❑ Neutrino detector based on Askaryan radiation principle

❑ Traditional ARA station contains 16 receiving antennas(8 Vpols, 8 Hpols) and calibration pulser antennas

❑ **Why Radio detector?**

 - ice is low-loss to radio frequency and field attenuation length goes up kilometer


Schematic diagram of ARA station
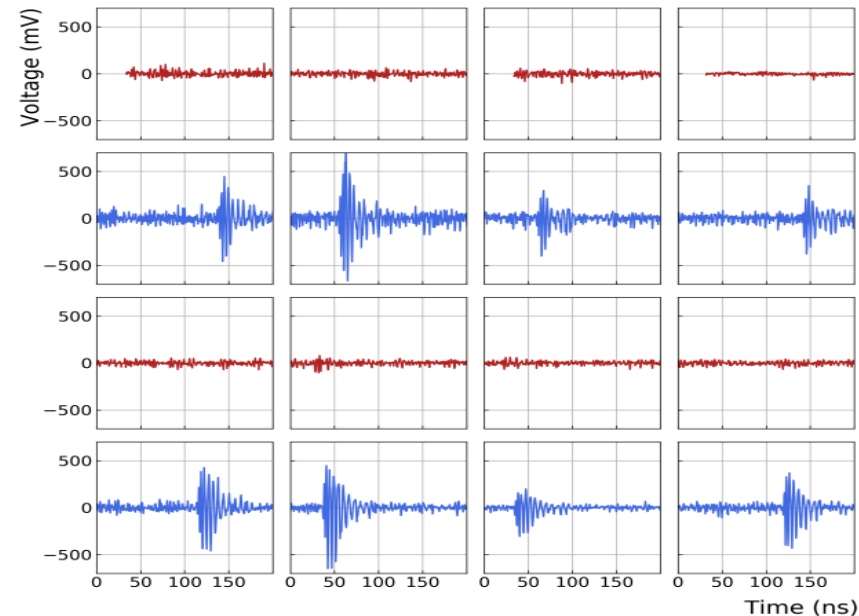
Calibration event recorded on ARA2

Pawan Giri (UNL)

ARA DAQ Upgrade

Current DAQ:

❑ Based on a custom motherboard ARA Trigger and Readout Interface(ATRI)

❑ Each incoming string from ice carries signal from four channels

❑ Signal goes into digitizer (DDA) and trigger (TDA) simultaneously via splitter

❑ At FPGA, trigger logic is performed(3 hit logic)

Current ARA DAQ

ARA-Next DAQ will be based on **RFSoC**
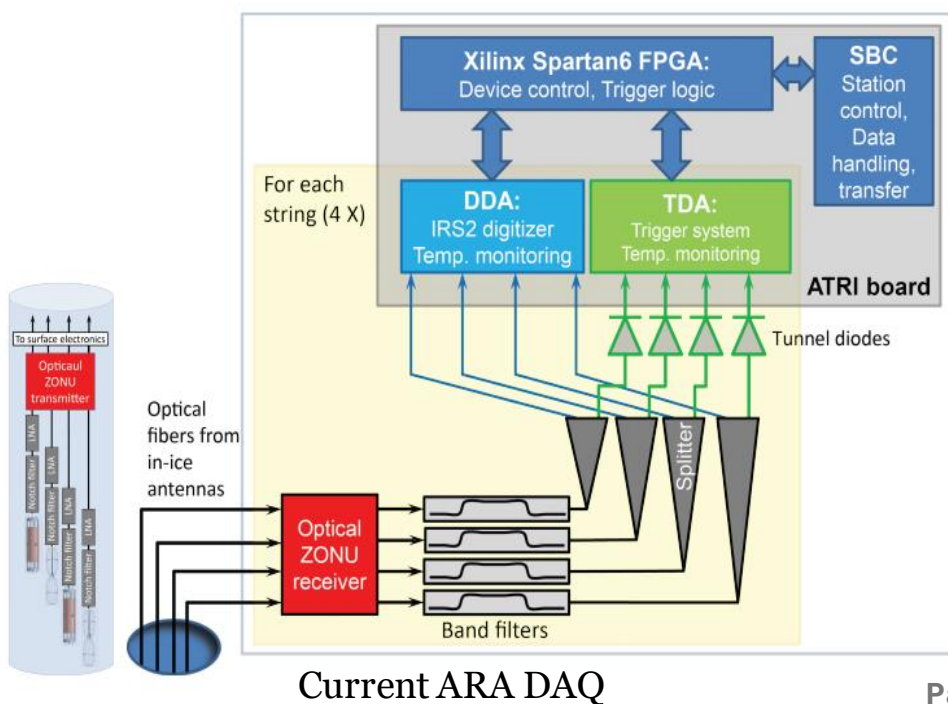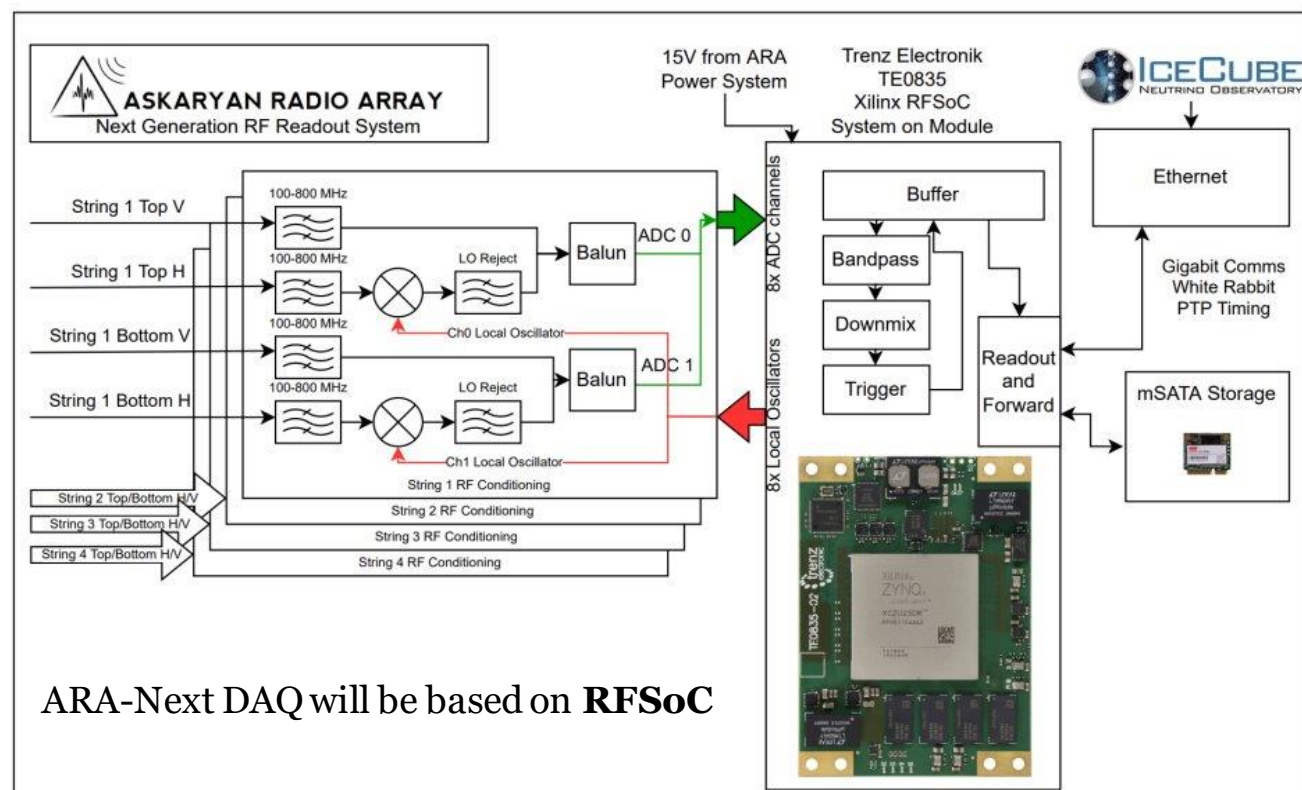
RFSoC Overview

❑ Integrated circuit that combines an FPGA with ADCs and DACs on a single chip

RFSoC devices :

❑ Highly flexible and programmable, rich in customization

❑ Wide range of application

❑ Development tools and programming languages

❑ High speed signal processing

❑ Can operate at low power levels

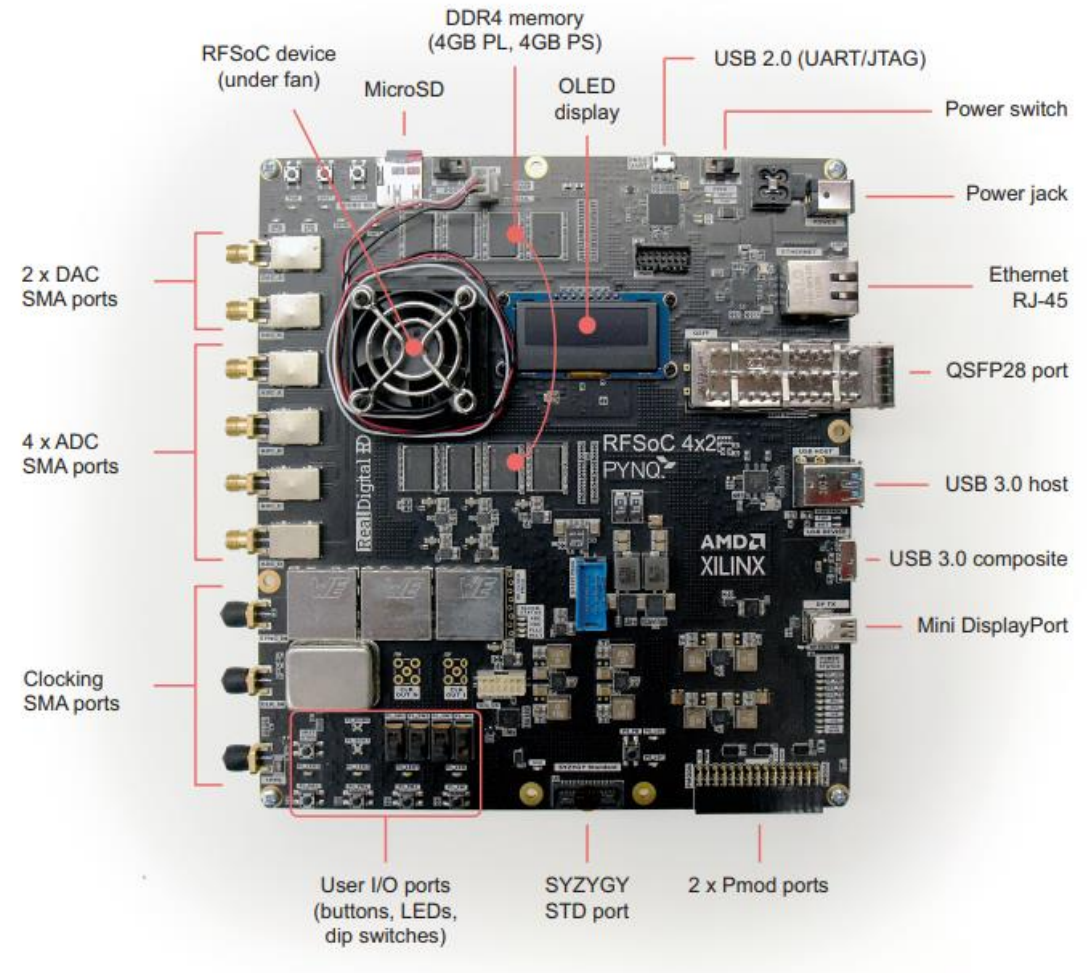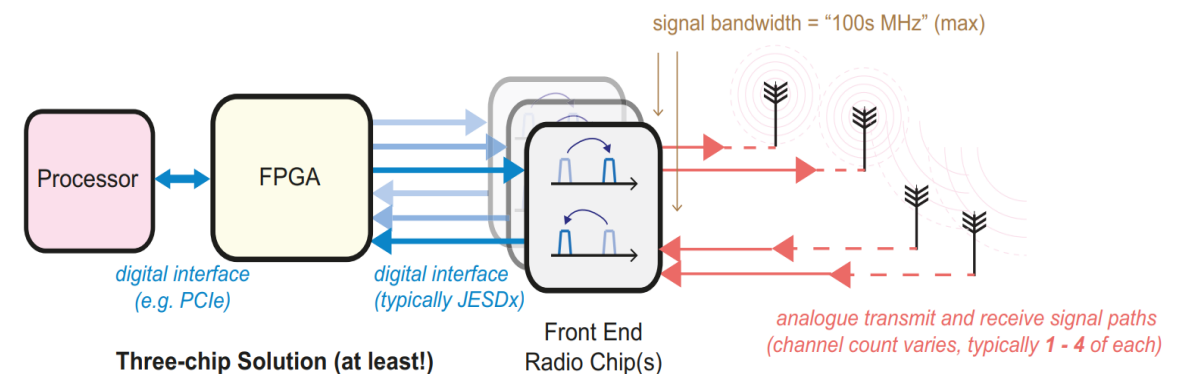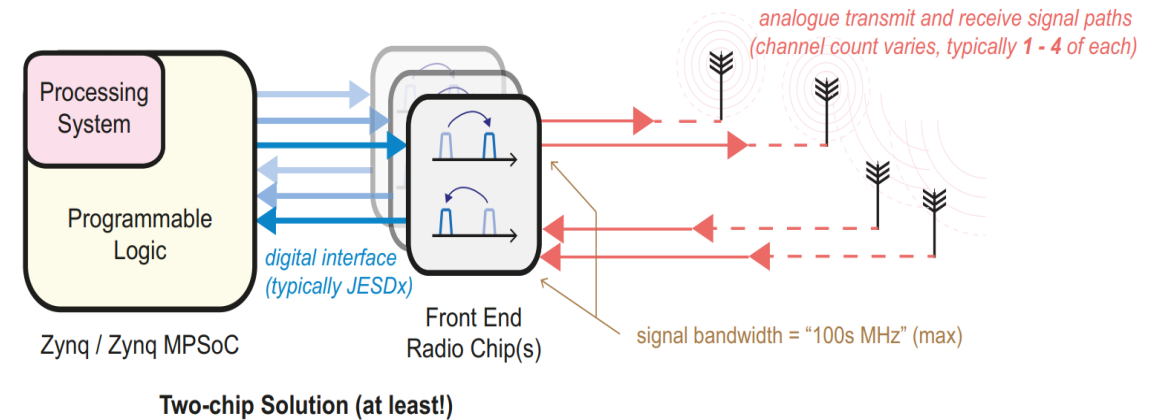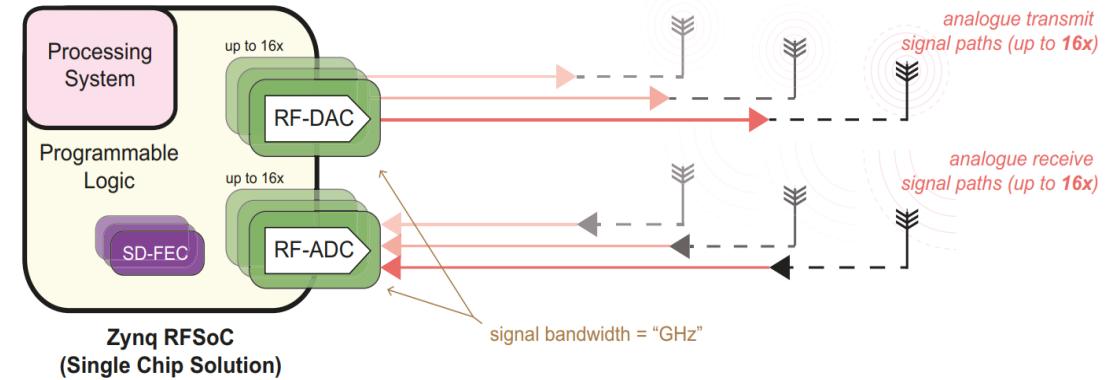Fig : **R**adio **F**requency **S**ystem **o**n Chip(**RFSoC**)

RFSoC Vs Other Alternatives

- ❑ No more need of traditional Front end radio chips
- ❑ All the radio components available in a single device
- ❑ Faster than traditional radio receiver/transmitter
- ❑ Lesser the radio components, less the power loss

Complex trigger ideas

❑ **Trigger with 3 hits among all 16 channels (no longer only HPols or VPols)**
- ARA has observed power split in VPol and HPol receivers for a signal coming from a distant VPol pulser (Birefringence : previous talk by ***Alan S. Gomez***)

❑ **New DAQ will be flexible to record waveforms of variable length**
- We can optimize the trigger to search for the "double-bang" signature of tau neutrinos

❑ **ARA can take advantage of multi-messenger astronomy**
- Keeping an eye on known astrophysical sources from other experiments

❑ **Tag or reject/veto anthropogenic events**
- Unusually long radio pulses ("fish tails"), multiple pulses in a small-time window, pointing towards the ice surface, etc..
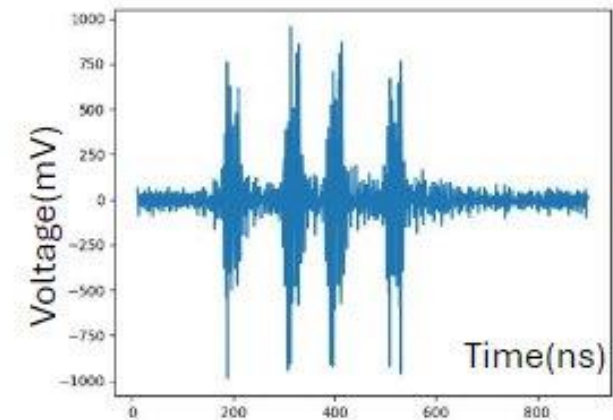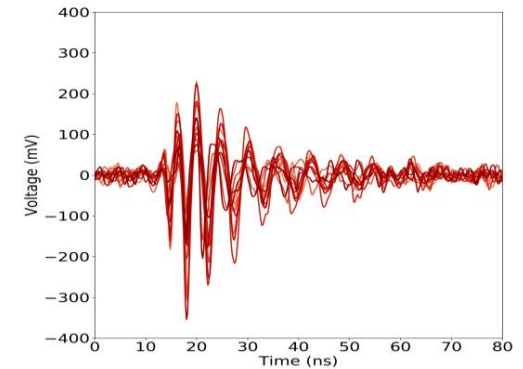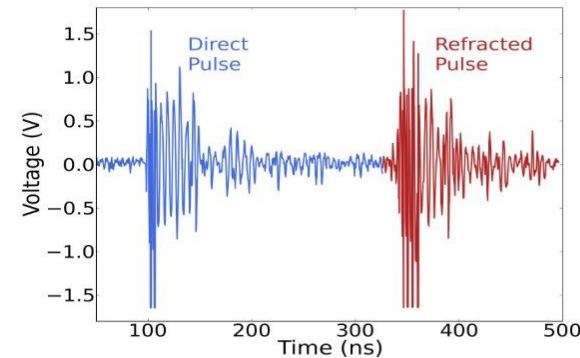
Complex trigger ideas ..

❑ **Tag events with a physical time sequence of hits**

   - This will make sure non-physical events discarded at trigger level

❑ **Tag events with double pulses (n out of N channels having double pulses)**

   - Potential deep-ice neutrino event

❑ **Tag events with possible cosmic ray pulses**

   - Unique waveform shape from cosmic ray interaction
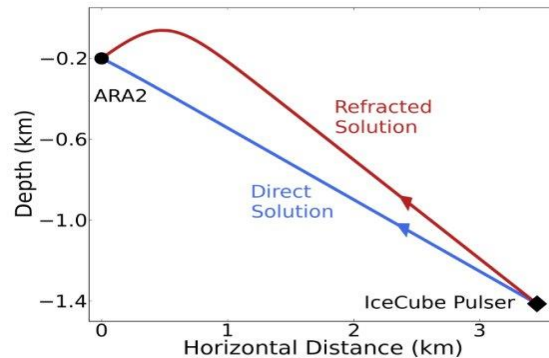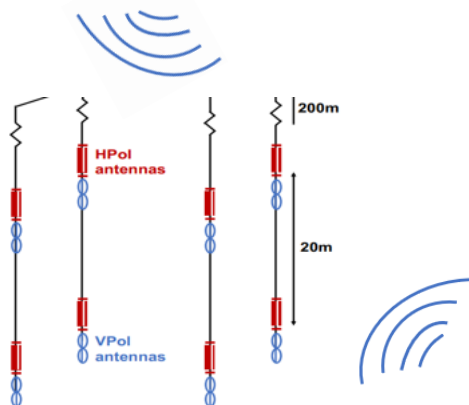
Goals with ARA-Next ..

❑ We will explore the potential of machine learning algorithms at the trigger level

❑ Recently, RNO-G studied and concluded that CNNs can be implemented on FPGAs, which should be easier on RFSoC

❑ Implementation of new threshold techniques in addition to or in place of the existing 3-hit technique in ARA:

    - This will lower the threshold value for stations/channels, increasing the likelihood of detecting weaker neutrino signals from larger distances

    - This ultimately increases the effective volume and enhances ARA's sensitivity as a radio neutrino detector

    - Several possibilities exist for this, such as cross-correlating waveforms with neutrino templates from simulations
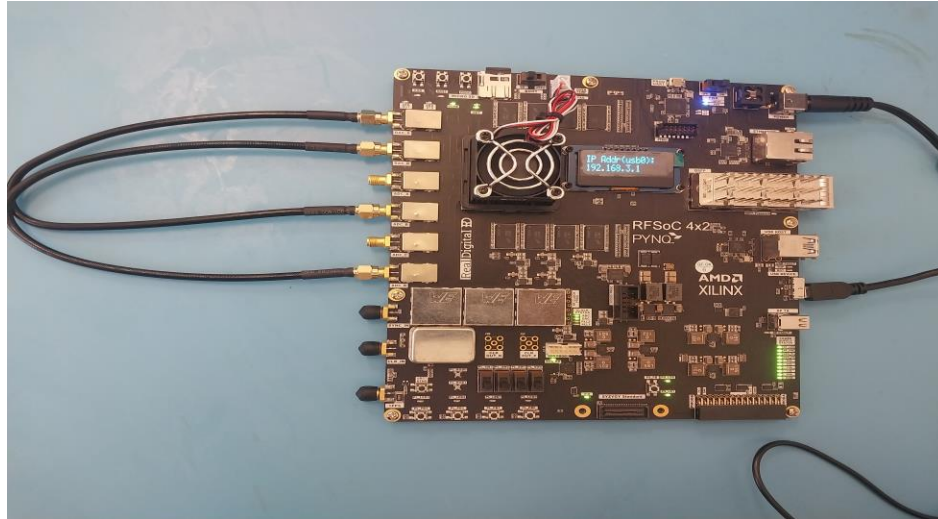
Not only ARA and RNO-G, but IceCube-Gen2 is also exploring the potential use of RFSoC for data acquisition
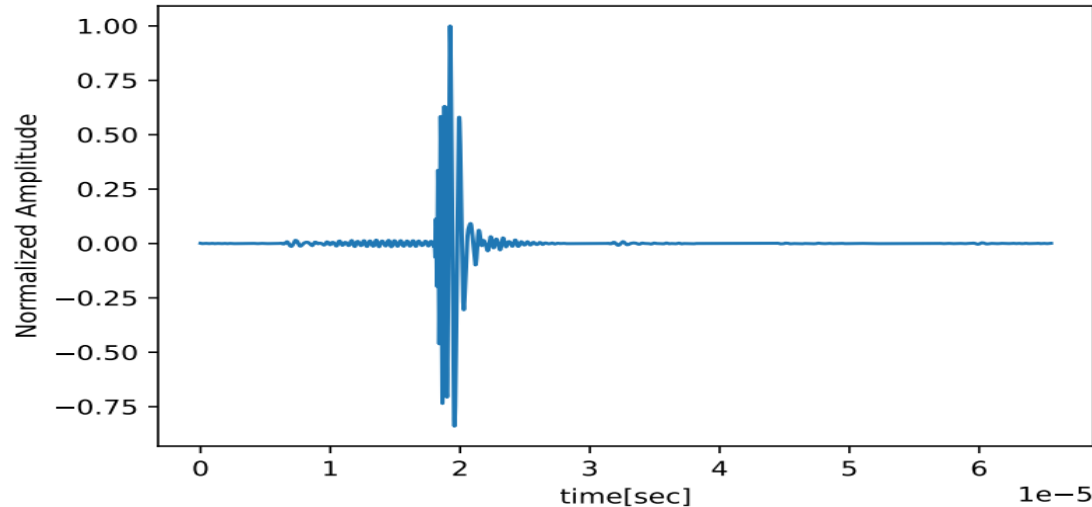
RFSoC testbench at UNL
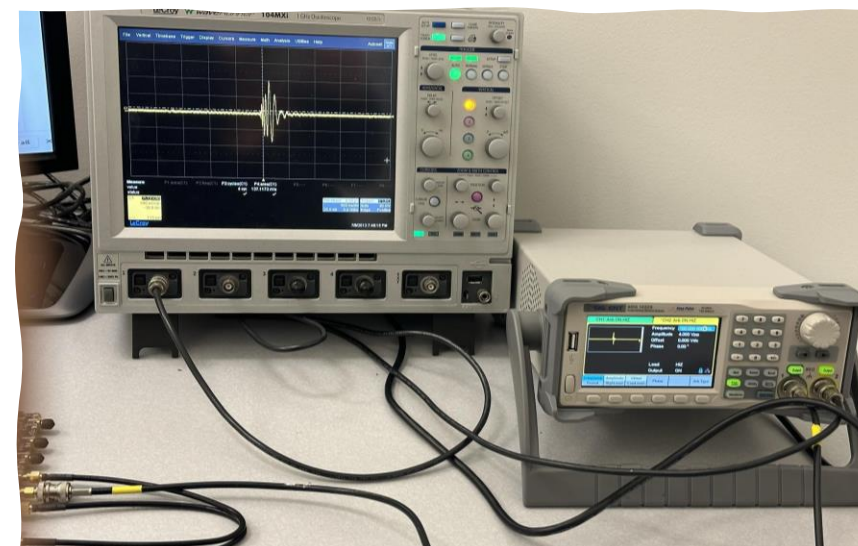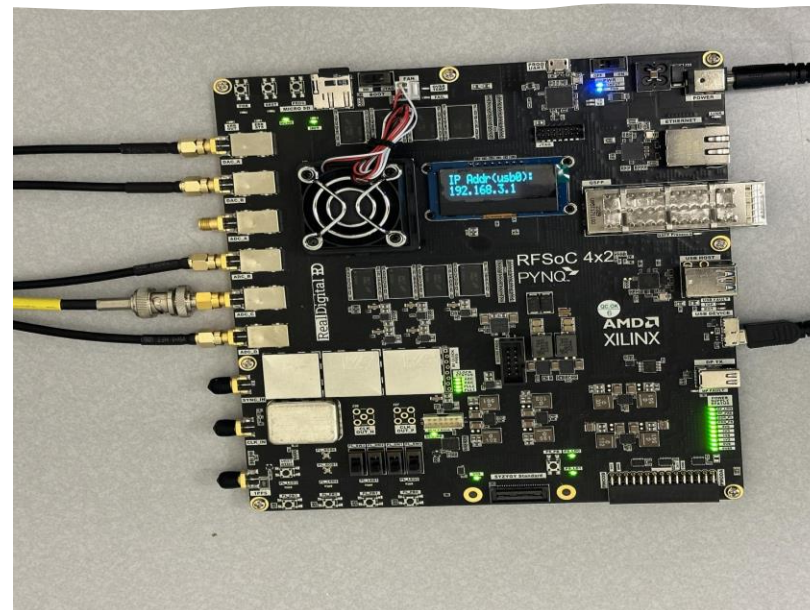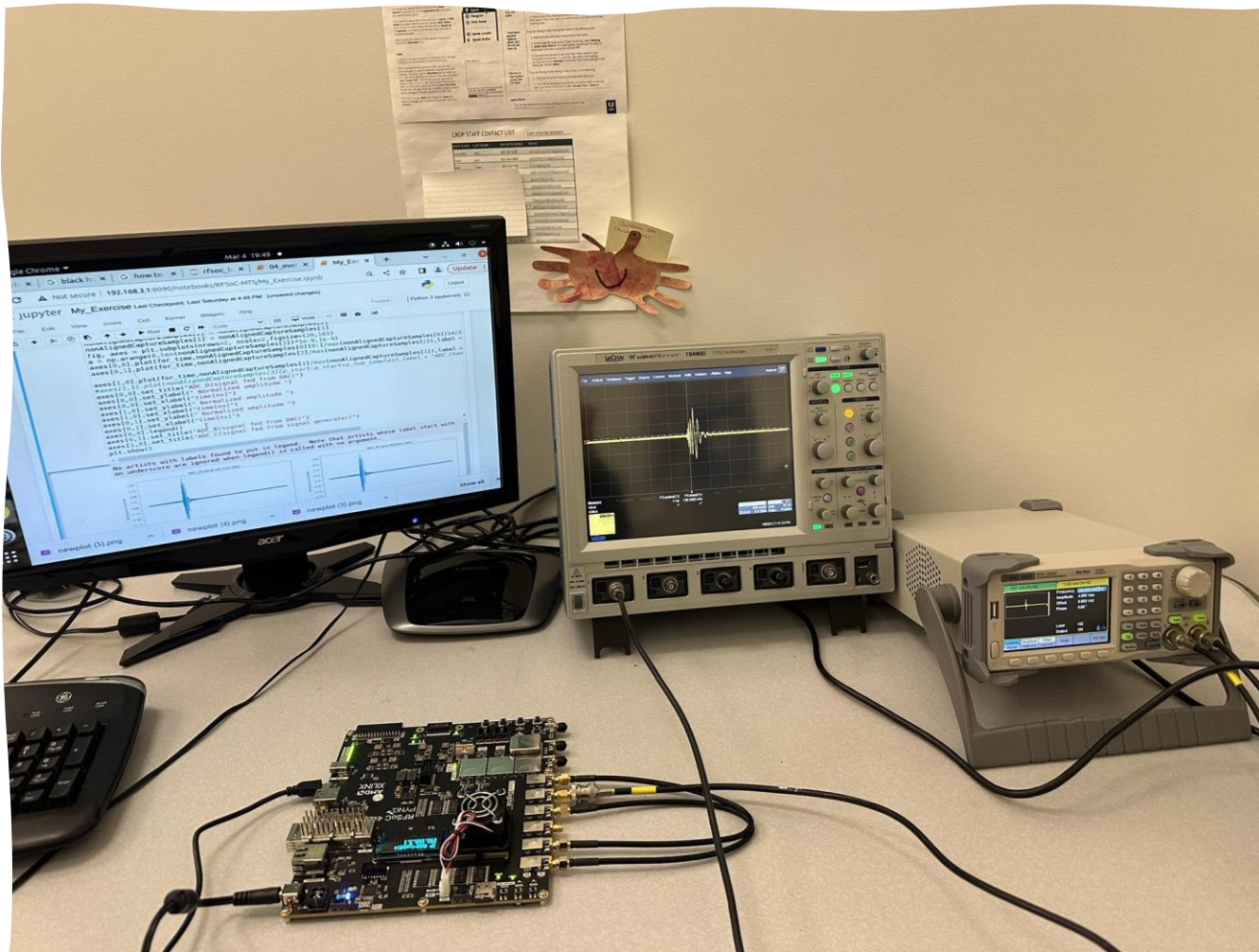
Test waveforms in RFSoC

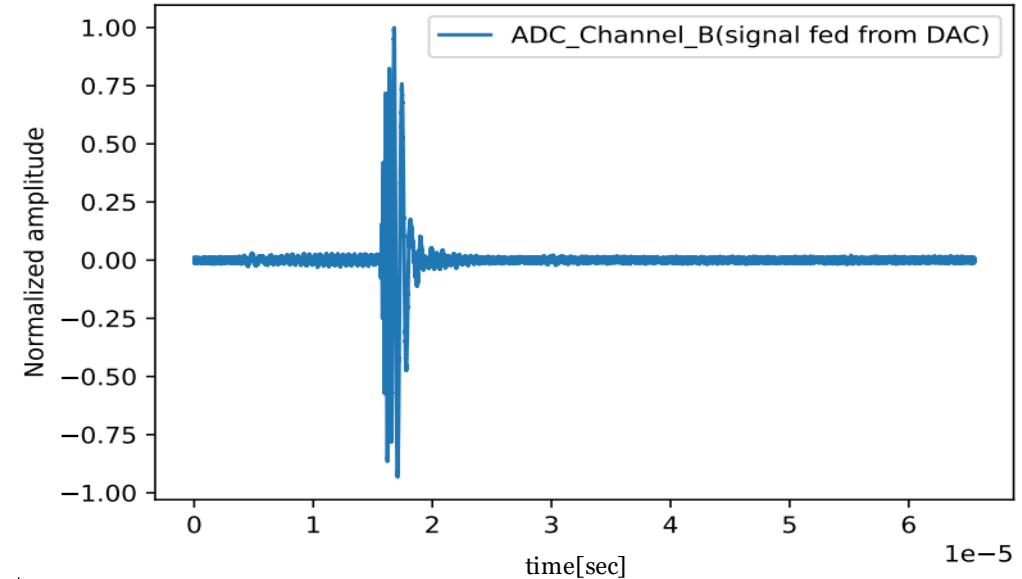**Used a signal pattern originally used by Jakob Henrich (RNOG from DESY) for RADIANT board testing**

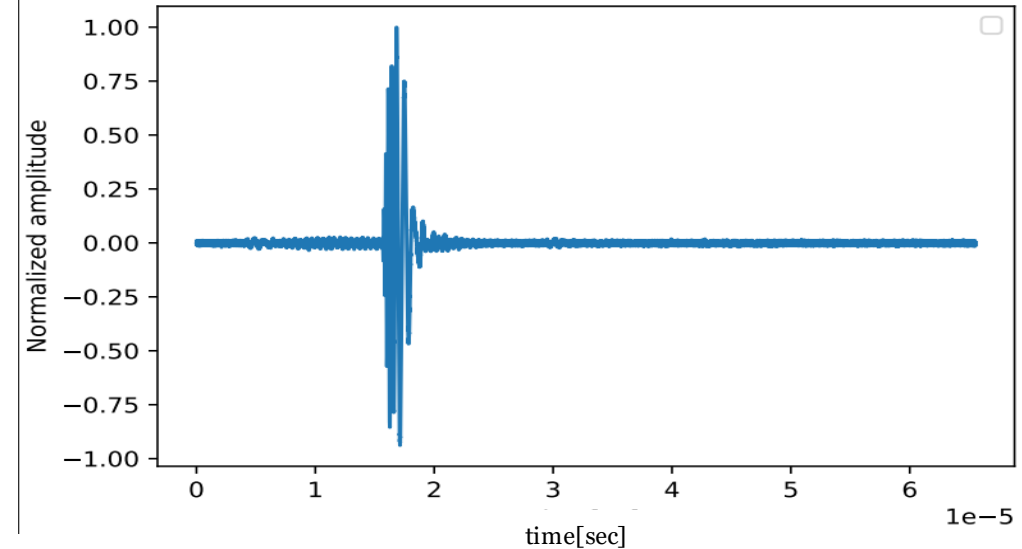ADC_B(signal fed from DAC)

DAC Waveform Replay

ADC_D(signal fed from DAC)

Summary

❑ ARA-Next will be more advanced, significantly enhancing ARA's sensitivity

❑ With RFSoC, we will be able to add numerous new features to the ARA DAQ, such as:

  - Designing a new trigger system
  - Adding more tags and event classifications
  - Rejecting surface events
  - Identifying known traces at the trigger level

❑ ARA plans to upgrade at least one station's DAQ with ARA-Next DAQ in the coming pole season

❑ Exploration of RFSoC and development of the ARA-Next DAQ are ongoing

❑ **Dr. Patrick Allison** (OSU) is working on the optimal development of the hardware configuration for ARA-Next DAQ

Thank you !