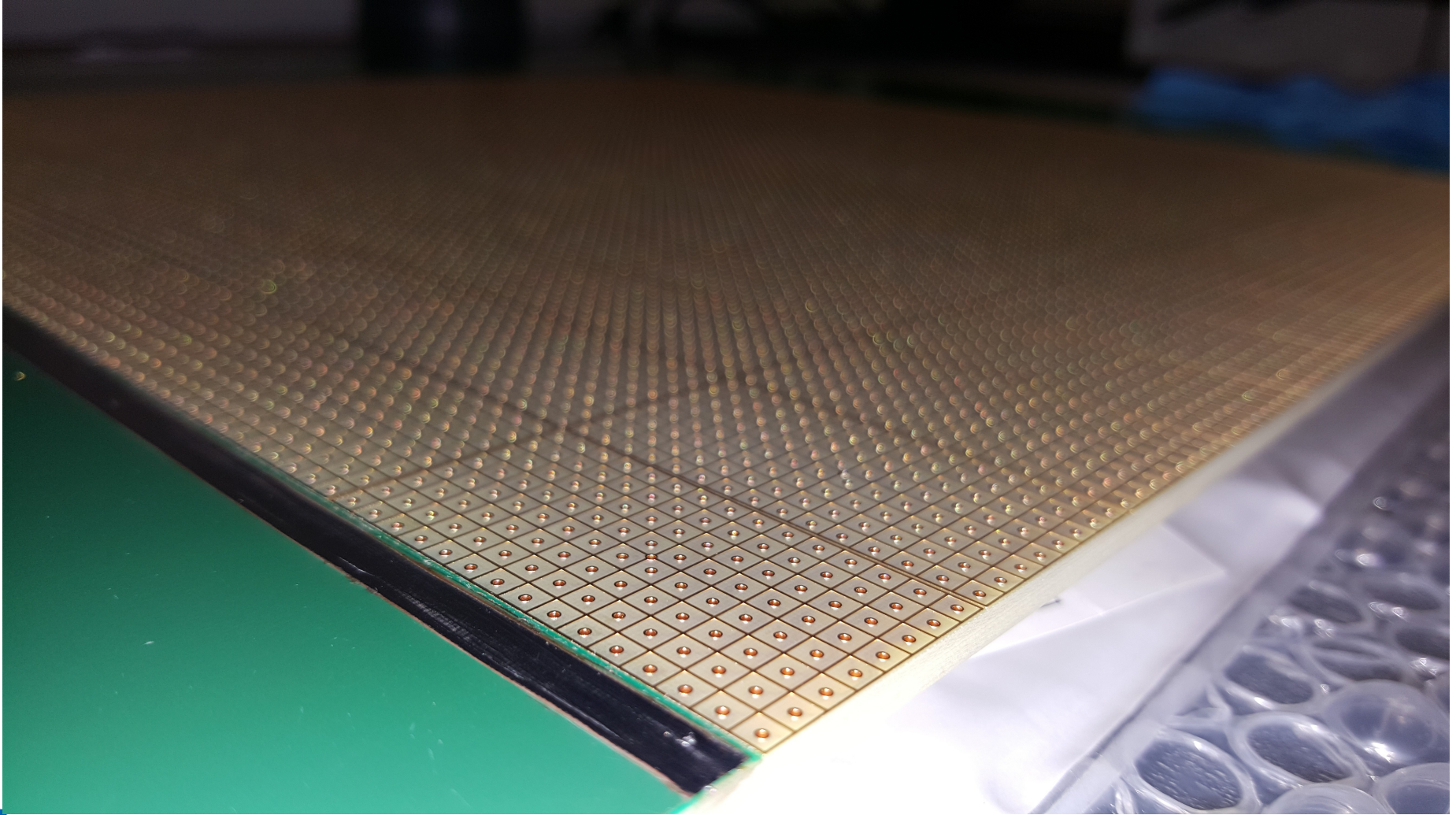
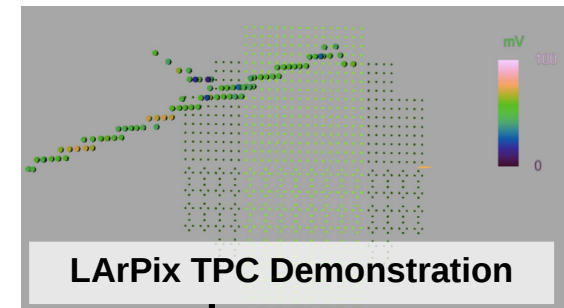
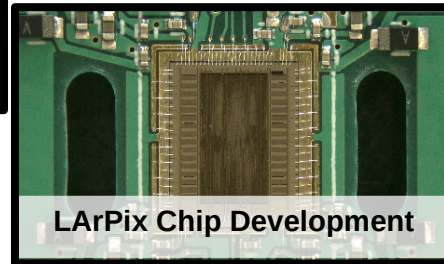
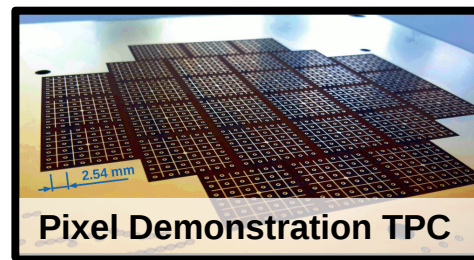


# Demonstration Roadmap



# Quick summary of what's been done

- There is a long R&D history leading to today's consideration of a LArTPC Pixel based detector
  - In recent years this has been pioneered by the University of Bern
  - Innovated new ideas being put forward (D. Nygren) sparking interest from within the community
- As this talk is not meant to be a history lesson, I will only pick a few highlights which lay the context for the work to come
  - Hopefully, these provide lessons and guideposts for the research plan we foresee in the next few years



2016

2017

2018

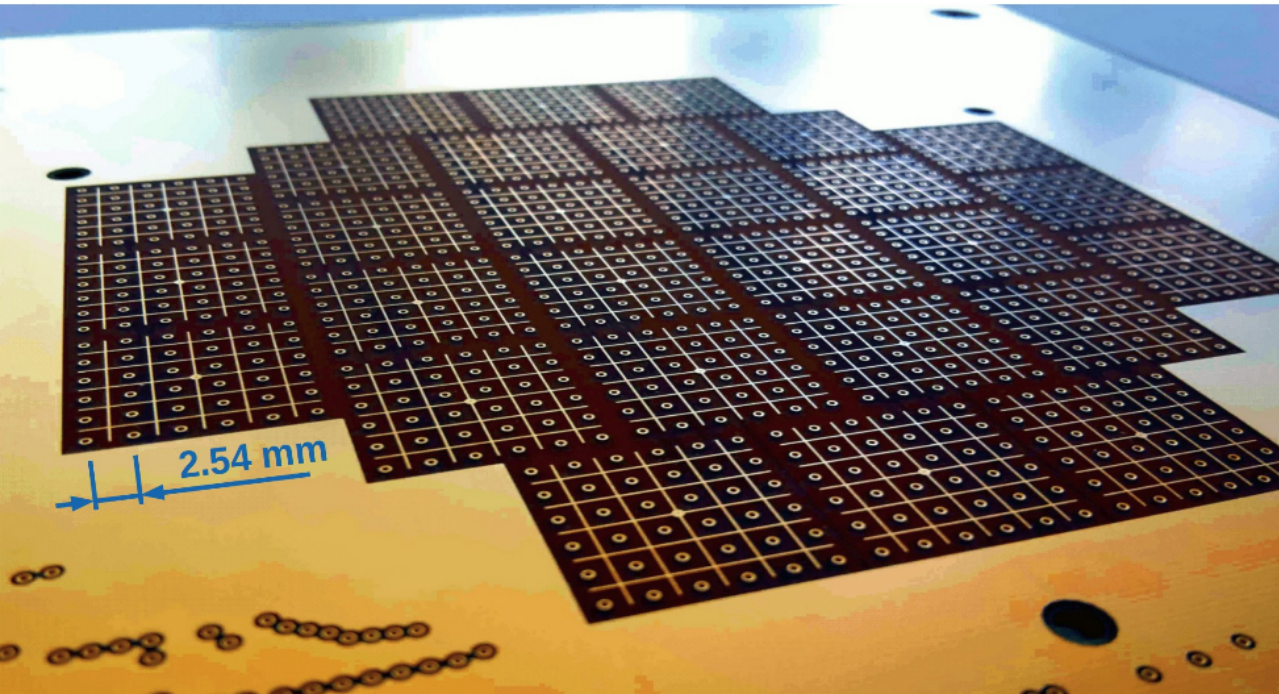
Today



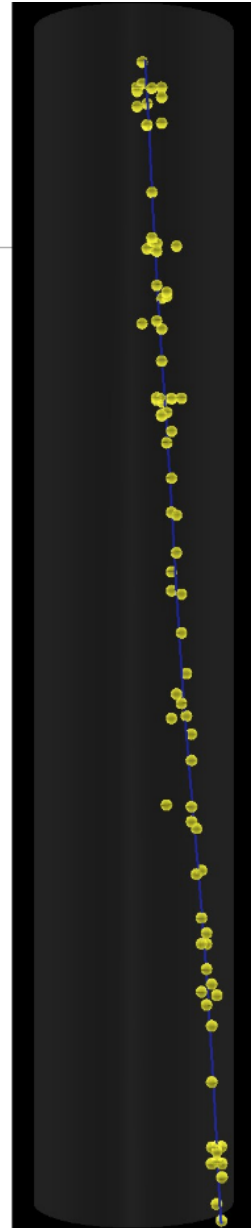
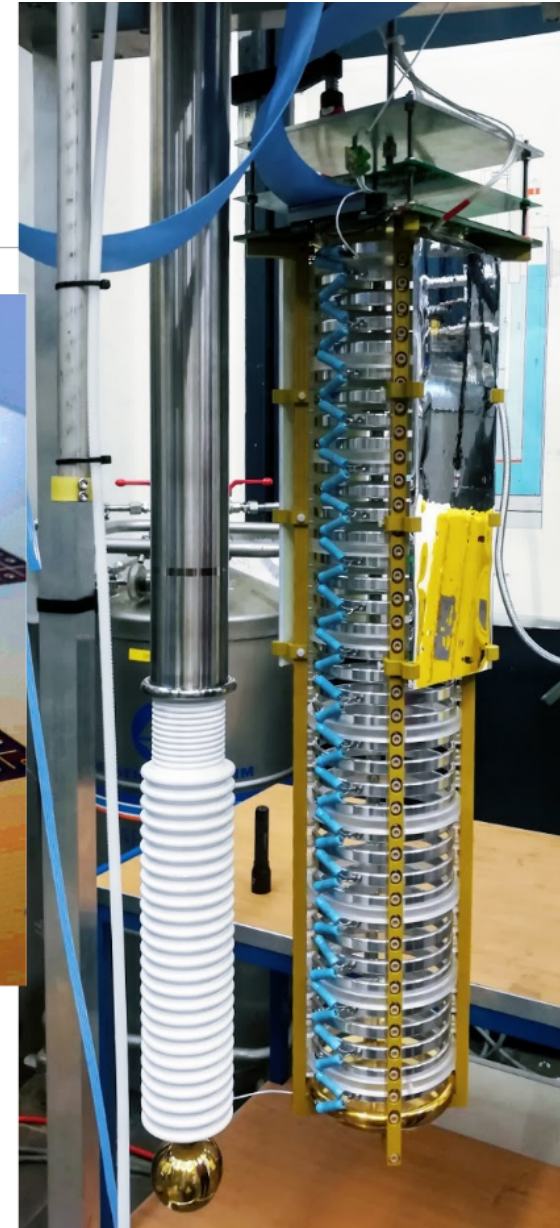
# Pixel TPC Demonstration

*Slide shamelessly stolen from James Sinclair's DUNE talk*

## Pixel Demonstration TPC



60 cm drift pixel demonstration TPC in Bern  
First operated 2016 ([arXiv:1801.08884](https://arxiv.org/abs/1801.08884))



- **Established the interest and plausibility of a pixel based LArTPC using existing cold electronics**
  - Had to use hardware based multiplexing, but showed the proof-of-principle

# PixLAr Test Beam Run

- **Scaled up version of the demonstration TPC**

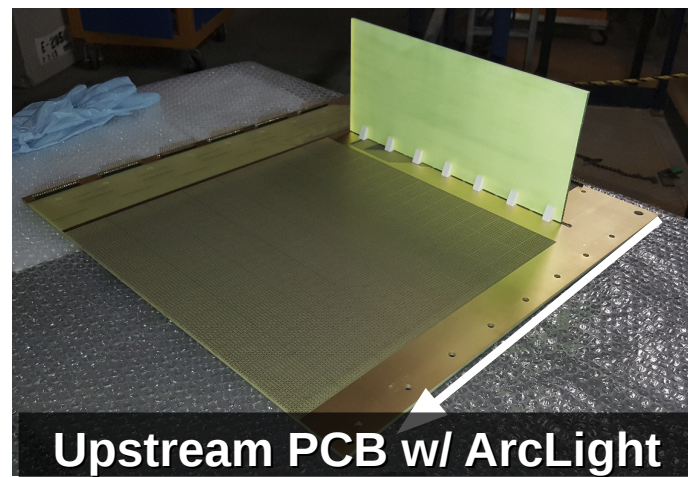
- 28,800 pixels readout with 480 existing cold electronics channels

- Still uses matching ROI's to pixels in order to create 3d spacepoints

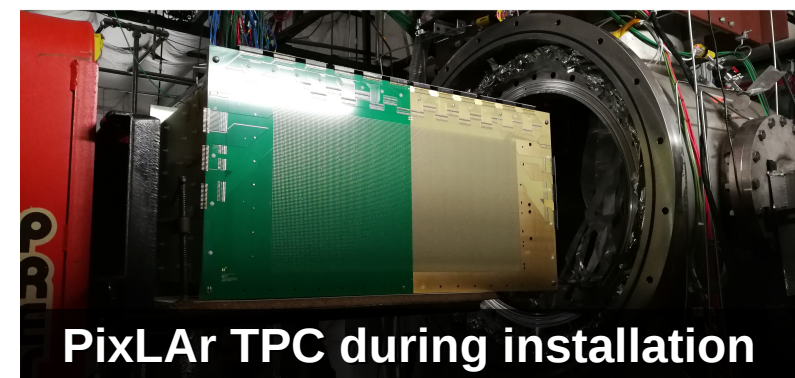
- Integrated two light detection devices (ArcLight and ARAPUCA) into the readout

- Collected 7 weeks of charge particle beam + comsics data

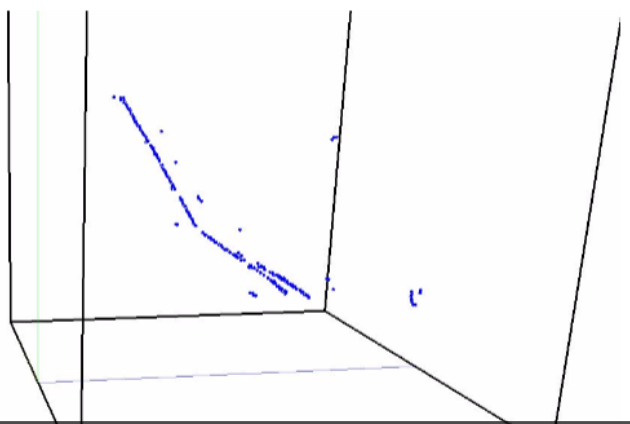
- Allows for integration of existing 3d reconstruction tools for pixel based readout



Upstream PCB w/ ArcLight



PixLAr TPC during installation



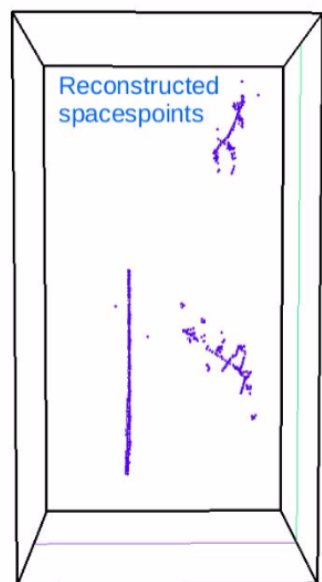
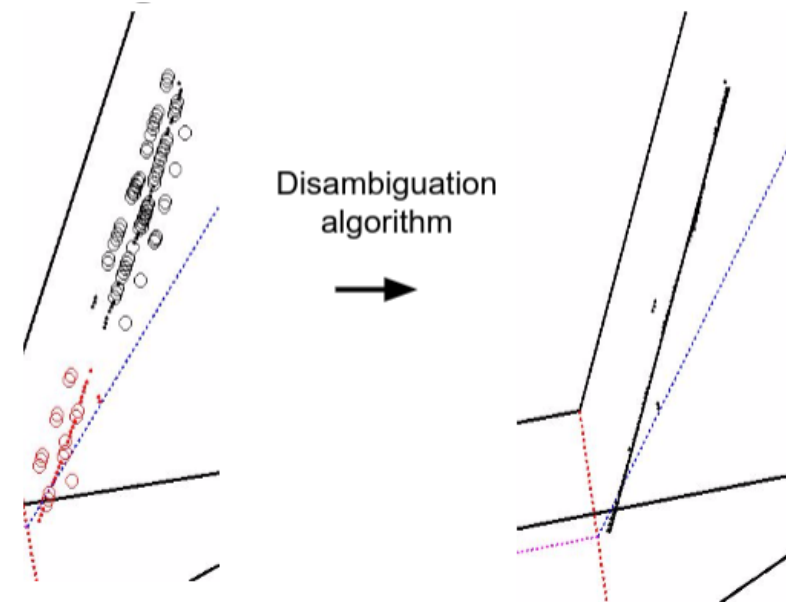
3d reconstructed spacepoints



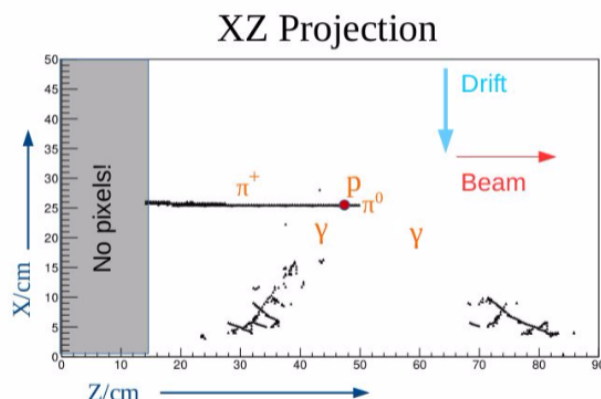
# PixLAr Test Beam Run

- One key thing we've gained/learned from the PixLAr run thus far is the adaptation of existing LArSoft reconstruction tools to **cluster/track/reconstruct pixel based readout**

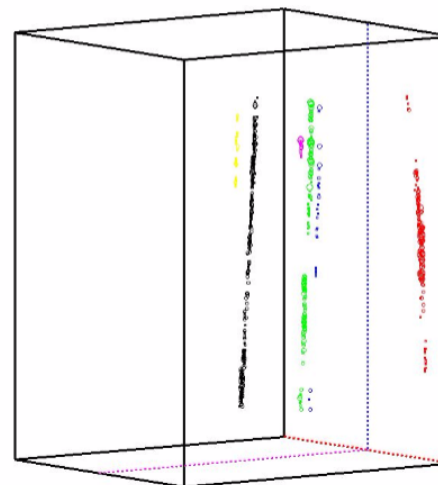
- Once the disambiguation from the hardware multiplexing is done what you have is equivalent (in form) to the true 3d readout you would get from LArPix chip
- LArSoft Redmine created as a subproject of LArIAT where much of this development has happened
  - <https://cdcv.sfnal.gov/redmine/projects/pixlar/repository>
- Should be of immense value to the forthcoming R&D



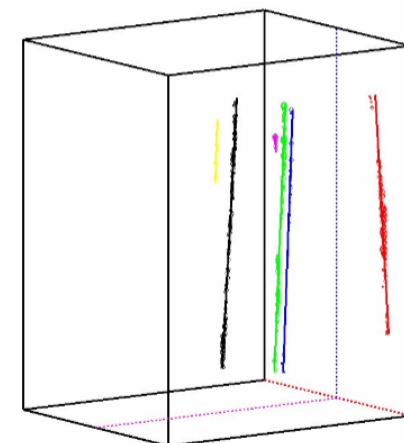
Simulated Pion Charge Exchange:  
 $E = 400 \text{ MeV}$



Clustering



Clustering and Tracking

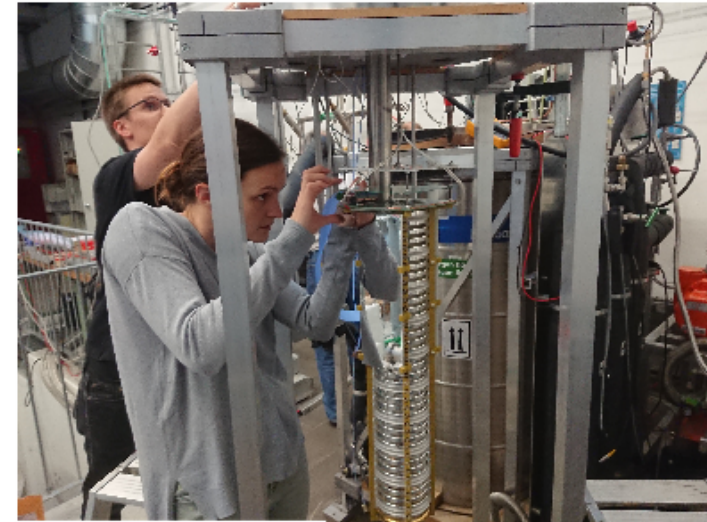


# LArPix Demonstration TPC

- As you've already heard about today, early this year the successful commissioning runs of the LArPix TPC at Bern and LBNL demonstrate potential of the true 3d readout technology

**Apr 2018:**

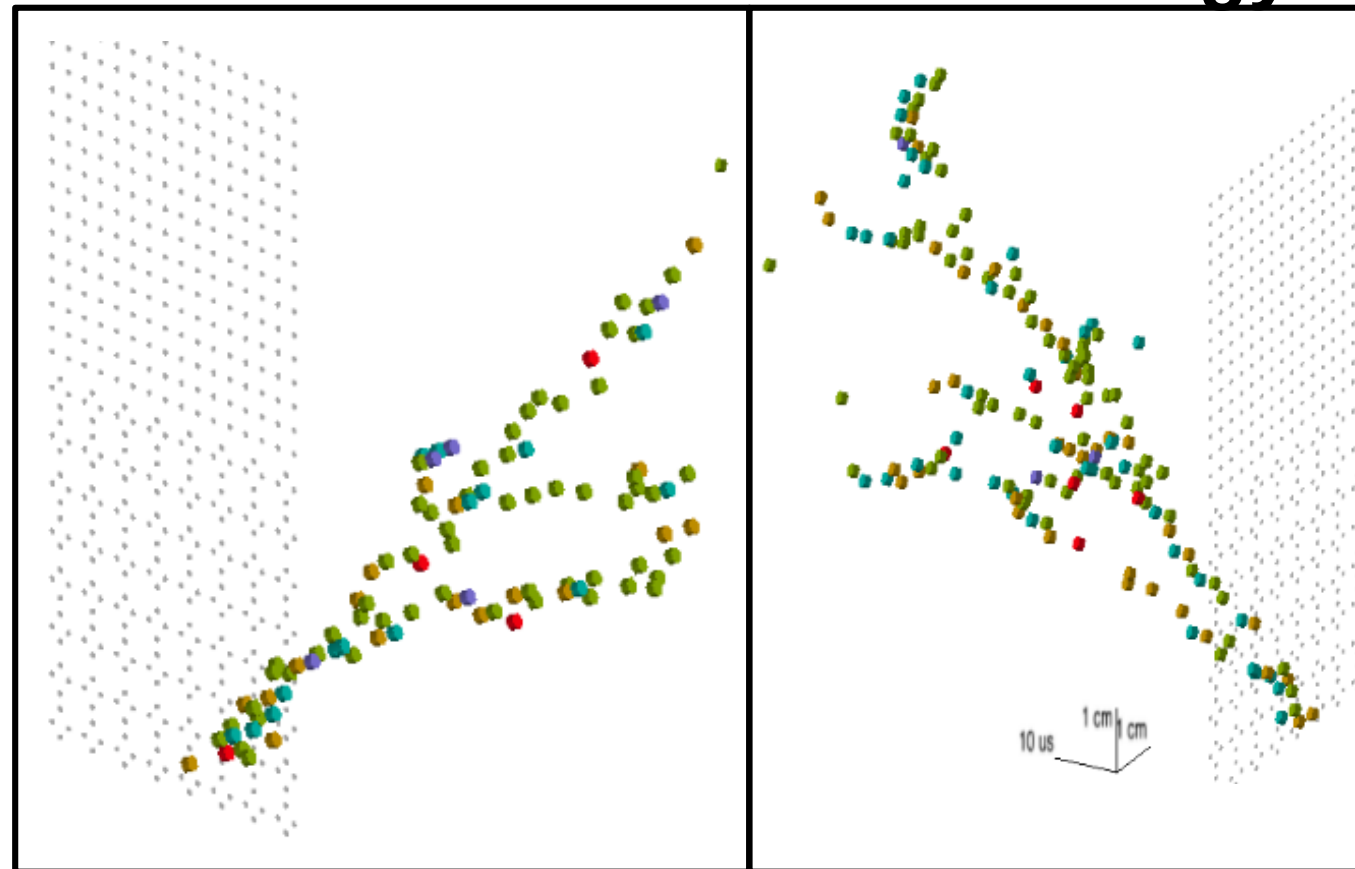
512-pixel system @ Bern  
60 cm drift, 1 kV/cm



LABORATORIUM FÜR HOCHENERGIEPHYSIK  
**LHEP**  
UNIVERSITÄT BERN



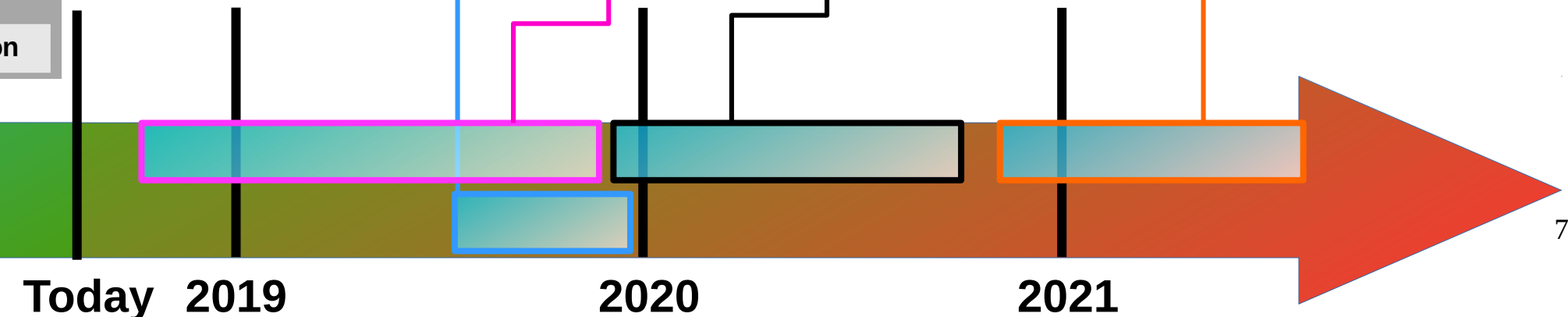
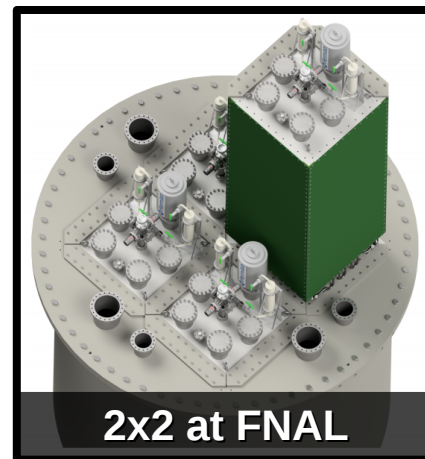
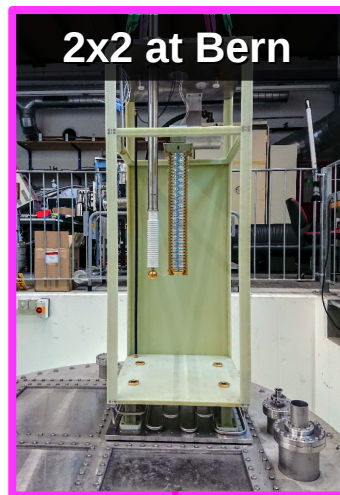
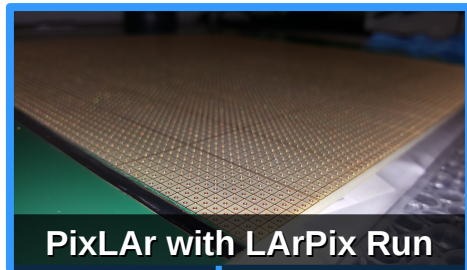
*Operated stably ~1 week*





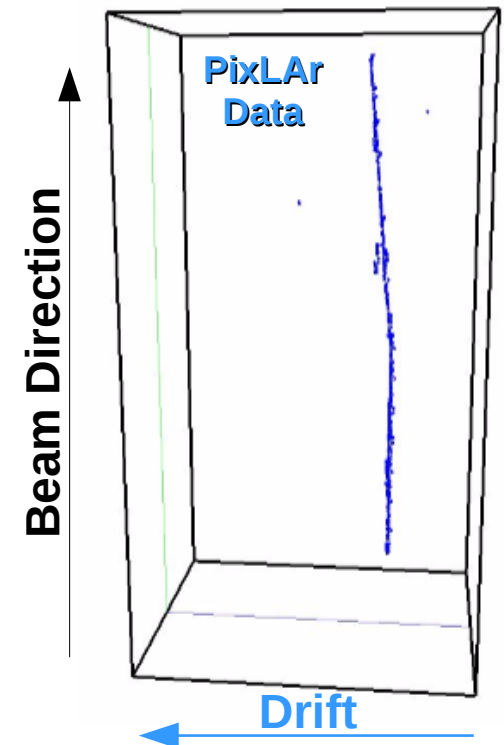
# Looking ahead

- Thinking ahead, there are a number of high level projects/demonstrations are targeted
  - There is an even larger number of smaller scale tests, exercises, and demonstrations that need to be accomplished
- I also think that there should be effort into the R&D of novel/new ideas (e.g. NetPix)
  - Part of why we do this is because pursuing new ideas is fun!
- What follows is a summary of some of these large/small scale tests that we would like to see happen

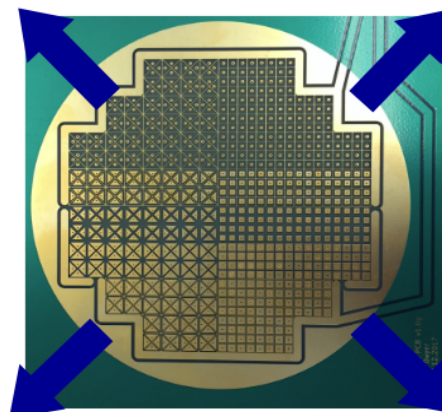


# PixLAR with LArPix

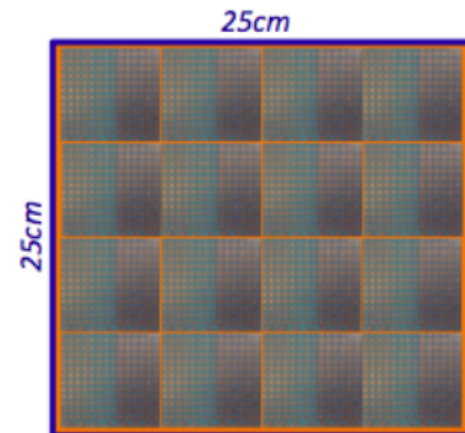
- Installing LArPix based pixel PCB into the testbeam setup at LArIAT offers some unique opportunities ahead of the full ArgonCube 2x2 testing
  - Charged particle testbeam allows for more robust tests of the full dynamic range of the chip
  - Pixel optimization studies can be done across an array of different types of scatters / particles
  - Test of tiling of pixel PCB and matching tracks across different pixel planes
  - Allows for the integration of the LArPix readout (ArtyZ7 board) with the ArcLight (Bern Frontend board) into the ArtDAQ framework
    - Immediately the data is available within the LArSoft framework
  - Leverage the PixLAR Run-1 reconstruction work to continue to adapt the reconstruction software for truly 3d readout



*Extend pixels edge-to-edge*



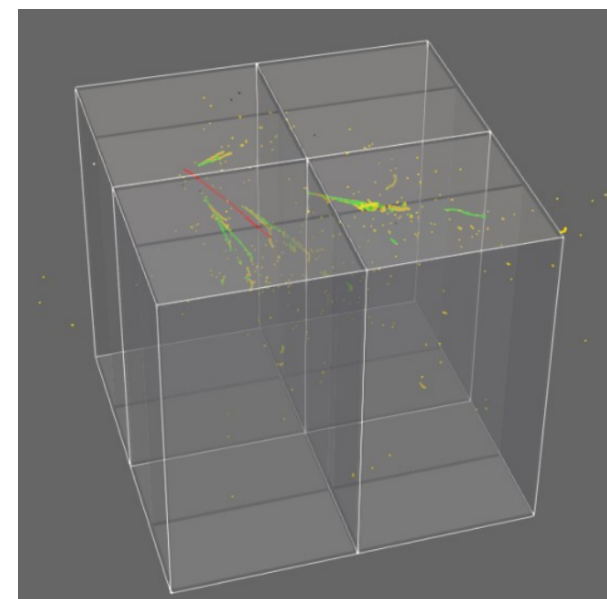
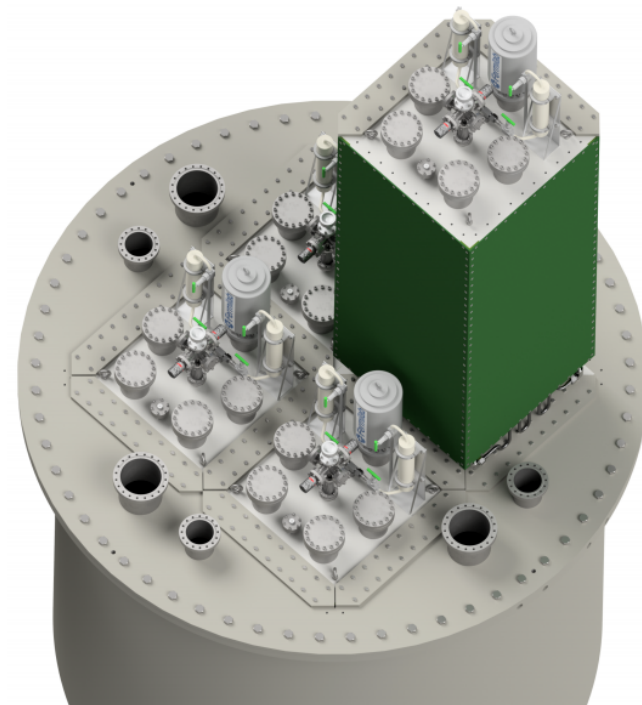
*Increase size*





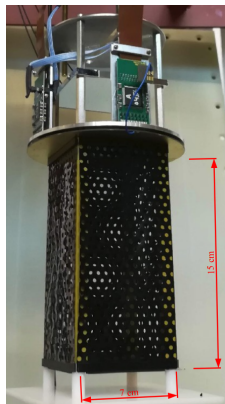
# ArgonCube 2x2

- **Now – Late 2019: ArgonCube 2x2 at Bern**
  - Build and test 2 full modules, third module will be 60 cm demonstrator TPC to act as purity monitor, fourth module will be a dummy module
  - Ongoing cryo-engineering work to allow for easy integration once deployed at Fermilab
  - Demonstration tests of cryo-extraction and insertion of modules
  - Data taking with cosmic rays
- **Late 2019 – 2020: ArgonCube 2x2 at FNAL**
  - Engineering run in the NuMI beam
    - Collect high energy neutrino events!
    - Test data acquisition and reconstruction
  - 4 complete modules with charge and light systems designed for use in the DUNE near detector
  - Operation with FNAL cryosystem
  - Opportunity for a proto-ND (proto-Near Detector for DUNE)



# Looking at the smaller tests

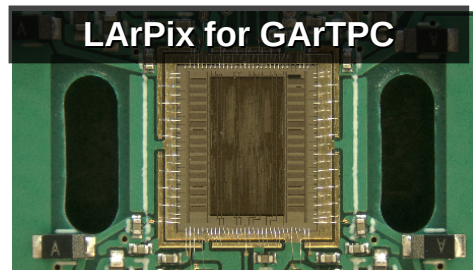
- There are also a number of small scale tests that need to go on concurrently with these large scale tests
  - Opportunity to expand collaboration and get new people involved



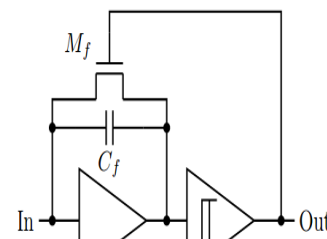
Resistive Field Shell Testing



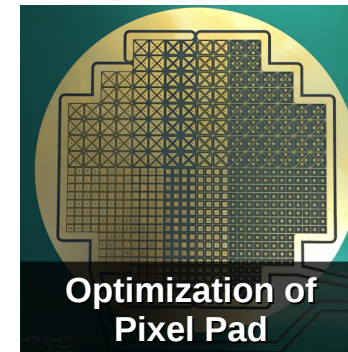
Array of Light Readout Teststands



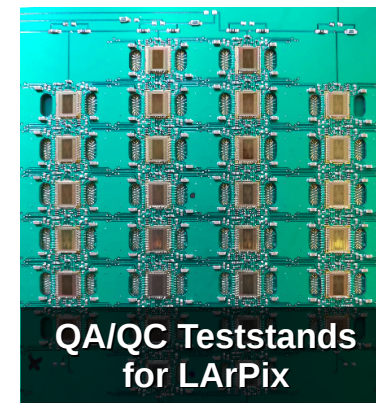
LArPix for GARTPC



Q-Pix Demo Chip?



Optimization of Pixel Pad



QA/QC Teststands for LArPix

Simulation Studies!!!!

2x2 at Bern

2x2 at FNAL

ProtoDUNE?

PixLAr

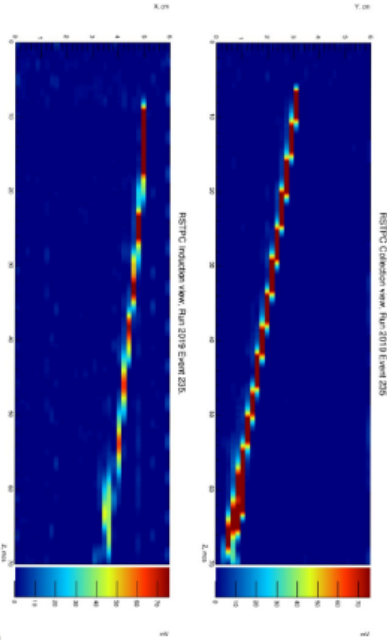
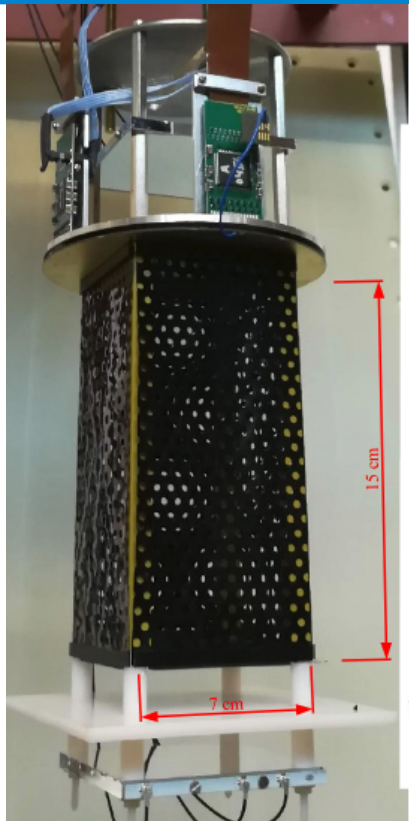
Today 2019

2020

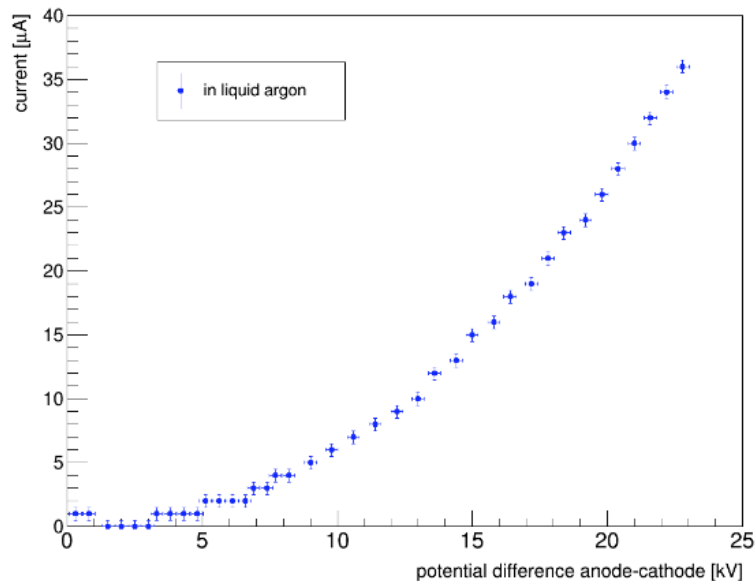
2021



# Resistive Field Cage Design

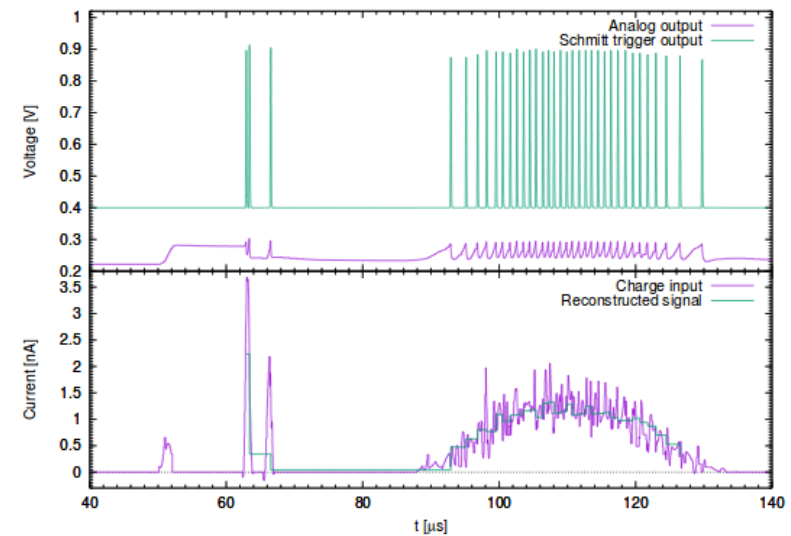
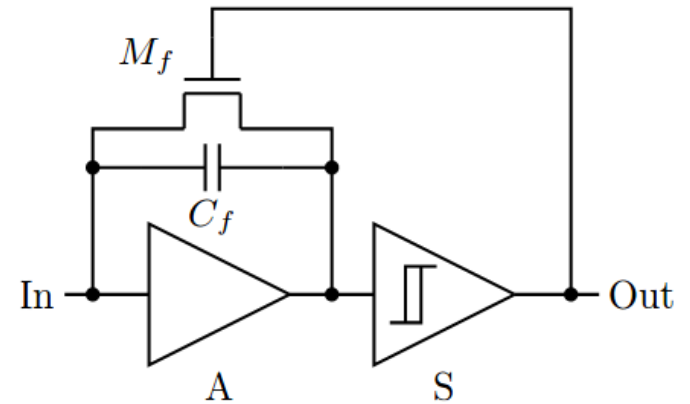


- Bern group is exploring using carbon loaded capton continuous resistive field cage
  - Minimizes amount of material between adjacent modules
  - Simplifies the field cage design and construction
- Initial tests show promising results in small TPC
  - Need to extend the testing of this idea to scale
    - Non-linear current vs potential seen
    - Small straight tracks observed, but need larger TPC to look for distortions, effects of spacecharge, etc...
    - Breakdown and recovery studies needed as well
  - Opportunity for collaboration



# Q-Pix Chip

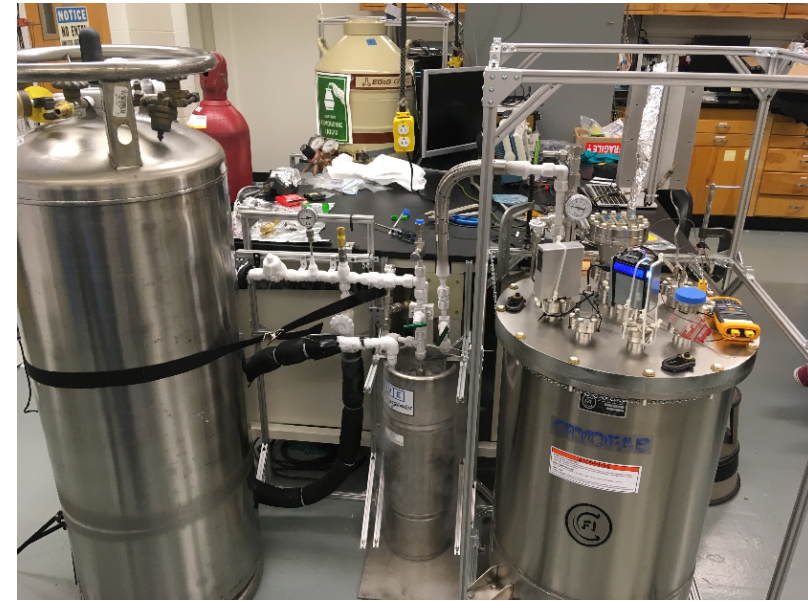
- Recent paper on the arXiv 1809.10213 (Nygren, Mei) explores an alternative readout scheme from what has been the focus of much of the R&D thus far.
  - Combines a charge-integrate/reset scheme with time stamping
  - Shows promising capture of the original input pulse in the “Reset Time Difference” measurement
  - May have ability to be used for photon detection as well
- Certainly should be pursued in R&D testing and prototyping
  - Many of the planned test-stands could be used/repurposed with a readout of this design
  - Interesting opportunity for side by side comparisons in the ArgonCube 2x2





# Electronics Testing

- Testing and QA/QC of the chip/tile/readout requires multiple institutions mobilizing to work
  - We can't make Dan sit at the lab bench all day and night!
- Bern, LBNL and UTA have liquid argon systems capable of doing some of this testing
  - Need more institutions interested in taking part
  - Likely need resources here as we prepare for DUNE-ND



*Purification System as built at LBNL*



*Purification System as built at UTA with the smaller 117 liter cryostat*

# All the things I am not highlighting

- **Simulation/Physics studies for near/far detector**
  - Lots of these studies are started, but many need more attention and people thinking and working on them
  - ND: Algorithms for pileup
  - ND & FD: Neutron Tagging Studies
  - FD: Physics Reach with pixel design
- **Calibrations**
  - How much of the existing DUNE calibration plan can be used for pixel readout? How much new do we need
- **All the rest of the readout!**
  - Connectors, cables, feedthroughs
  - Cable routing, pixel PCB mounting
  - Packaging and testing of chips
  - Grounding and shielding
- **All the things our small group isn't thinking about**
  - All the things that will pop up during the testing outlined earlier



# Conclusions

- **The research program for realizing a pixel based LArTPC has a long history**
  - Much longer then shown even in this talk
- **The road ahead is not so long and there is lots to do!**
  - Big scale projects:
    - PixLAr with LArPix
    - ArgonCube 2x2 Demo
  - Small scale projects:
    - Test-stand projects
    - QPix side-by-side LArPix
- ***Personal Opinion:***
  - **This is a fantastic group of people to do research with and is often one of highlights of my research time.**
  - If you are interested in joining the effort you should get in contact with the organizers (myself included) and we will plug you in