

LArPix:

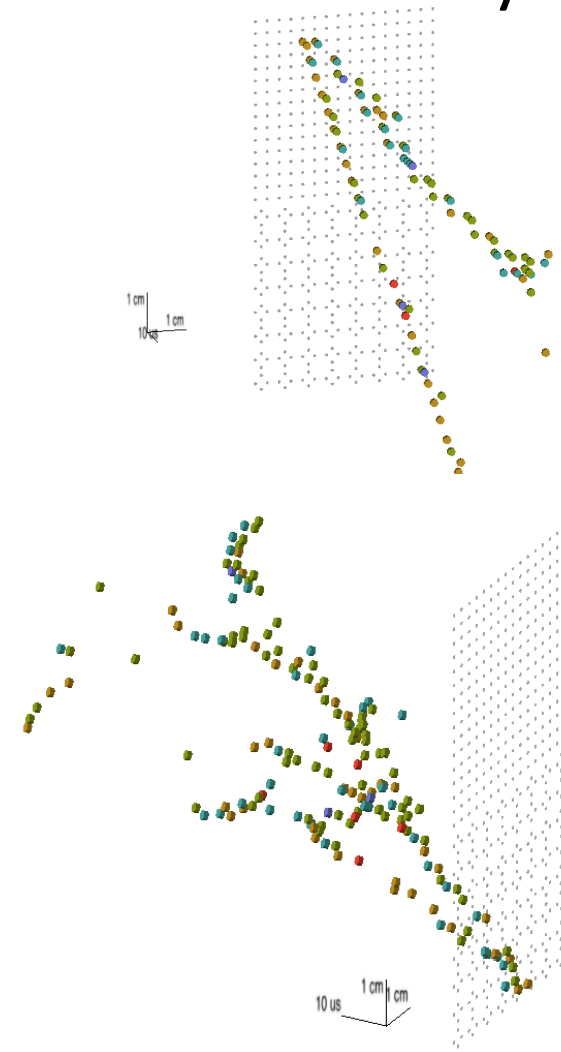
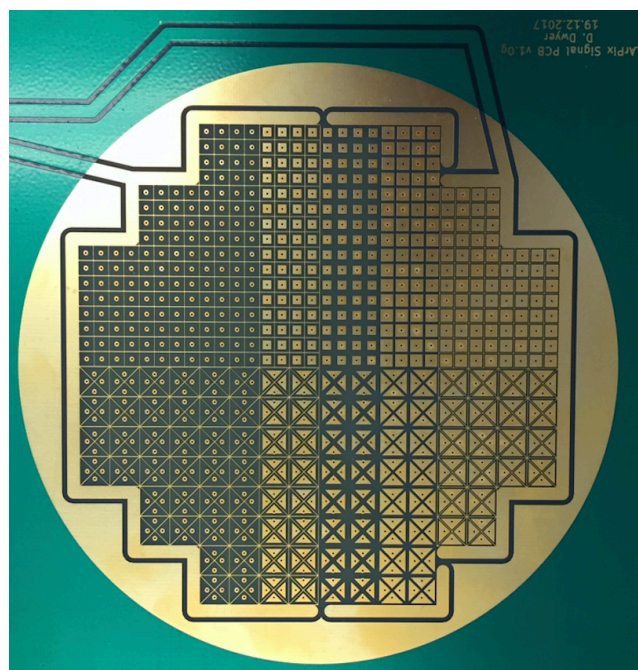
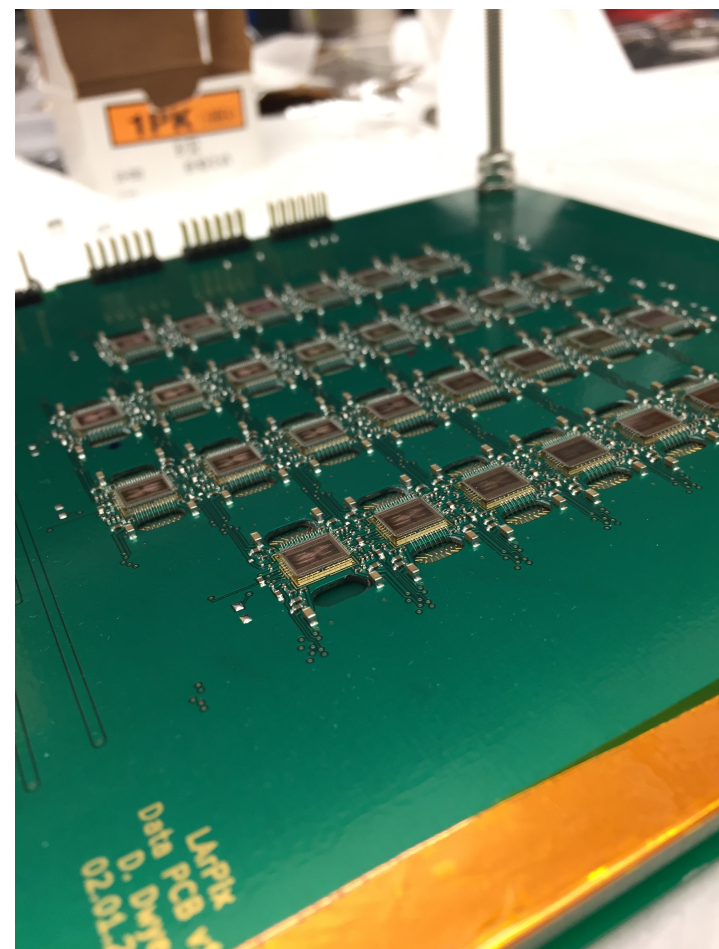
Pixelated Charge Readout for the DUNE Near Detector

Dan Dwyer (LBNL)

on behalf of the DUNE Collaboration

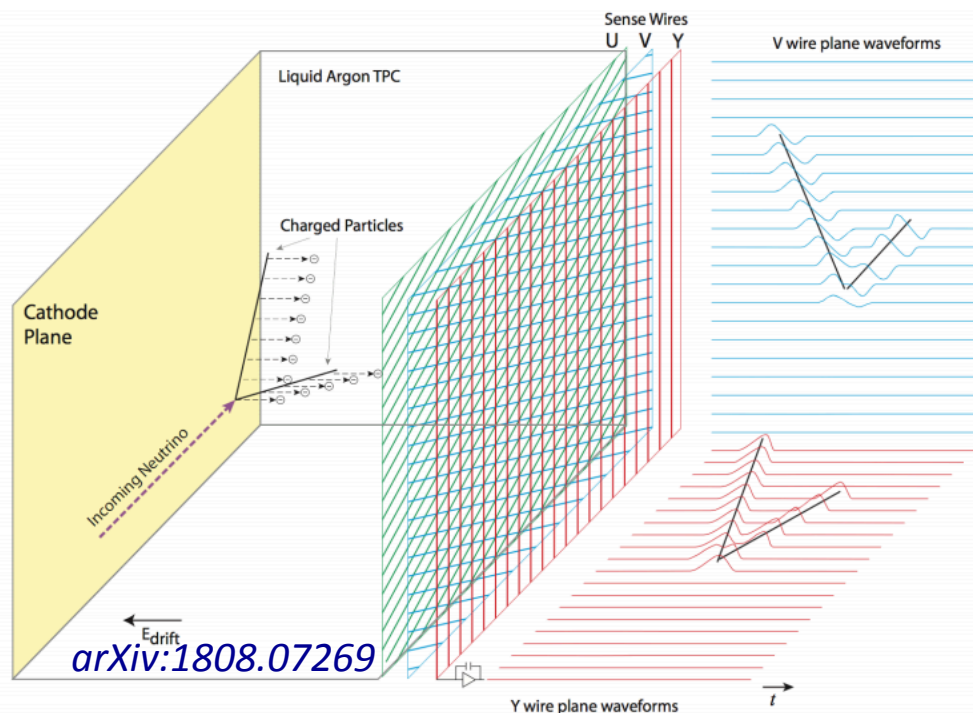
International Workshop on Next Generation Nucleon Decay
and Neutrino Detectors

Nov. 2, 2018

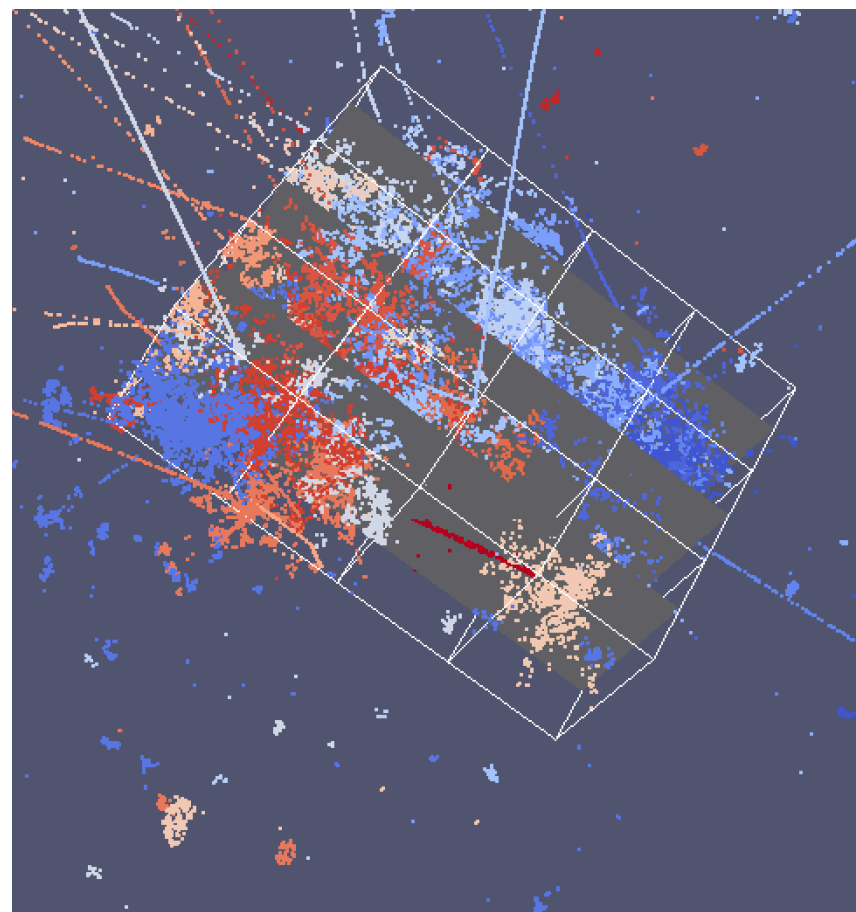


LArTPC Charge Readout

Existing LArTPCs infer 3D signal from three 2D views:



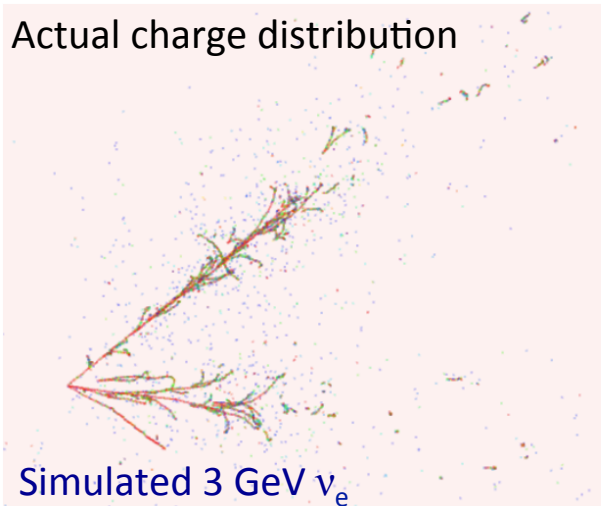
DUNE Near LArTPC:
High neutrino rate
exacerbates ambiguities.



*Example neutrino signals
from one LBNF spill*

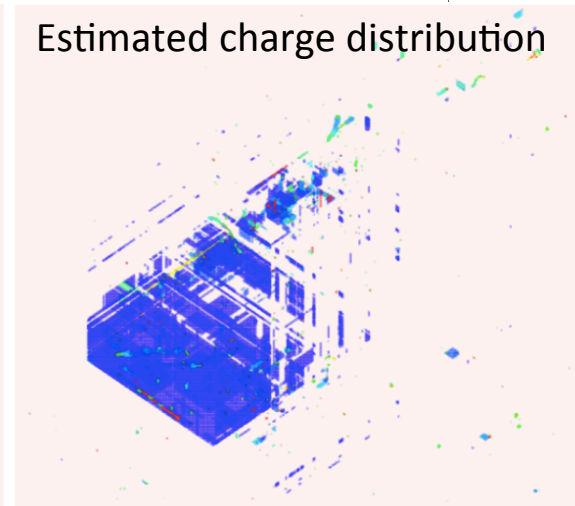
Ambiguities in projective wire readout:

Actual charge distribution



Simulated 3 GeV ν_e

Estimated charge distribution

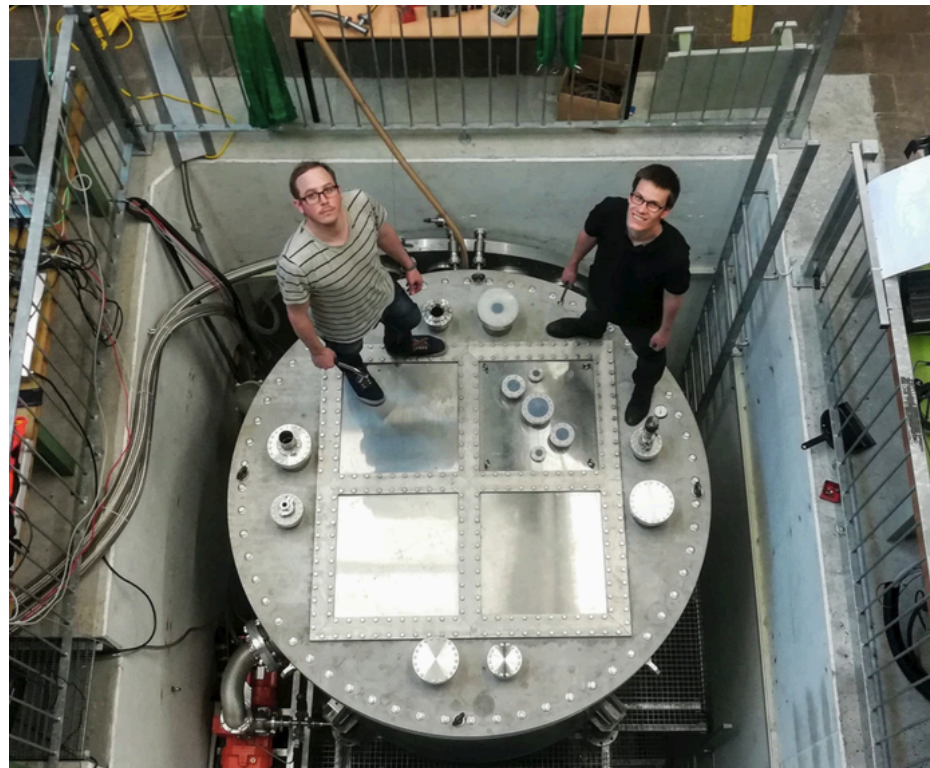
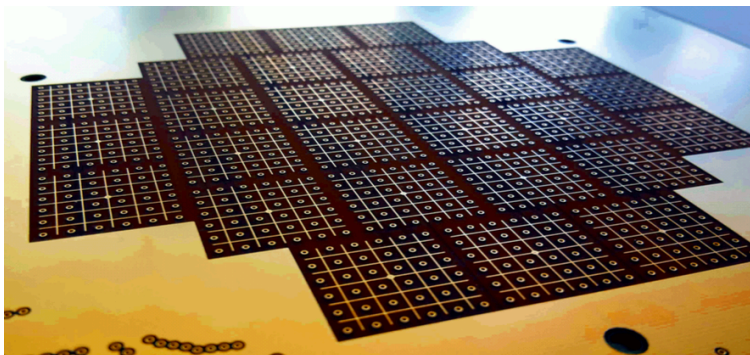


A True 3D LArTPC?

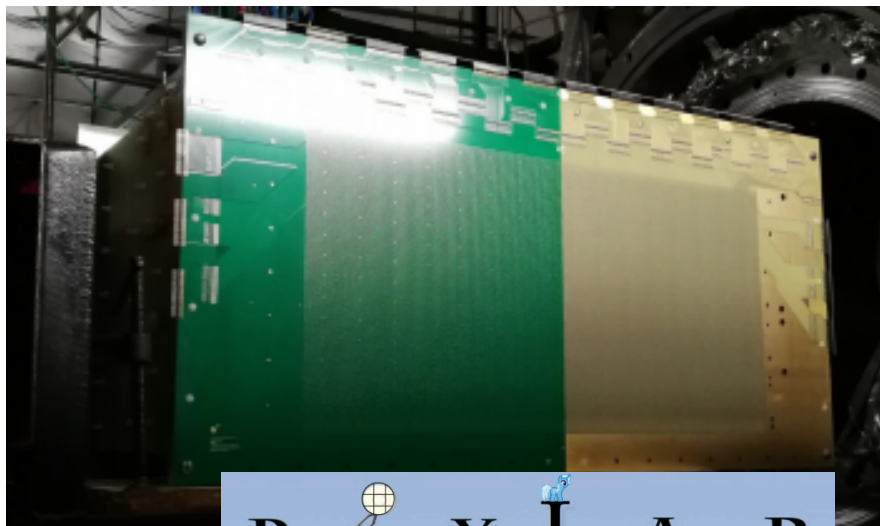
Pixel Readout Development

Demonstration of pixel sensor feasibility (Bern/ArgonCube)

See talk by J. Sinclair on broader ArgonCube LArTPC R&D program



Progress with in-beam tests (LArIAT/PixLAR)



Critical Technology: Pixel electronics

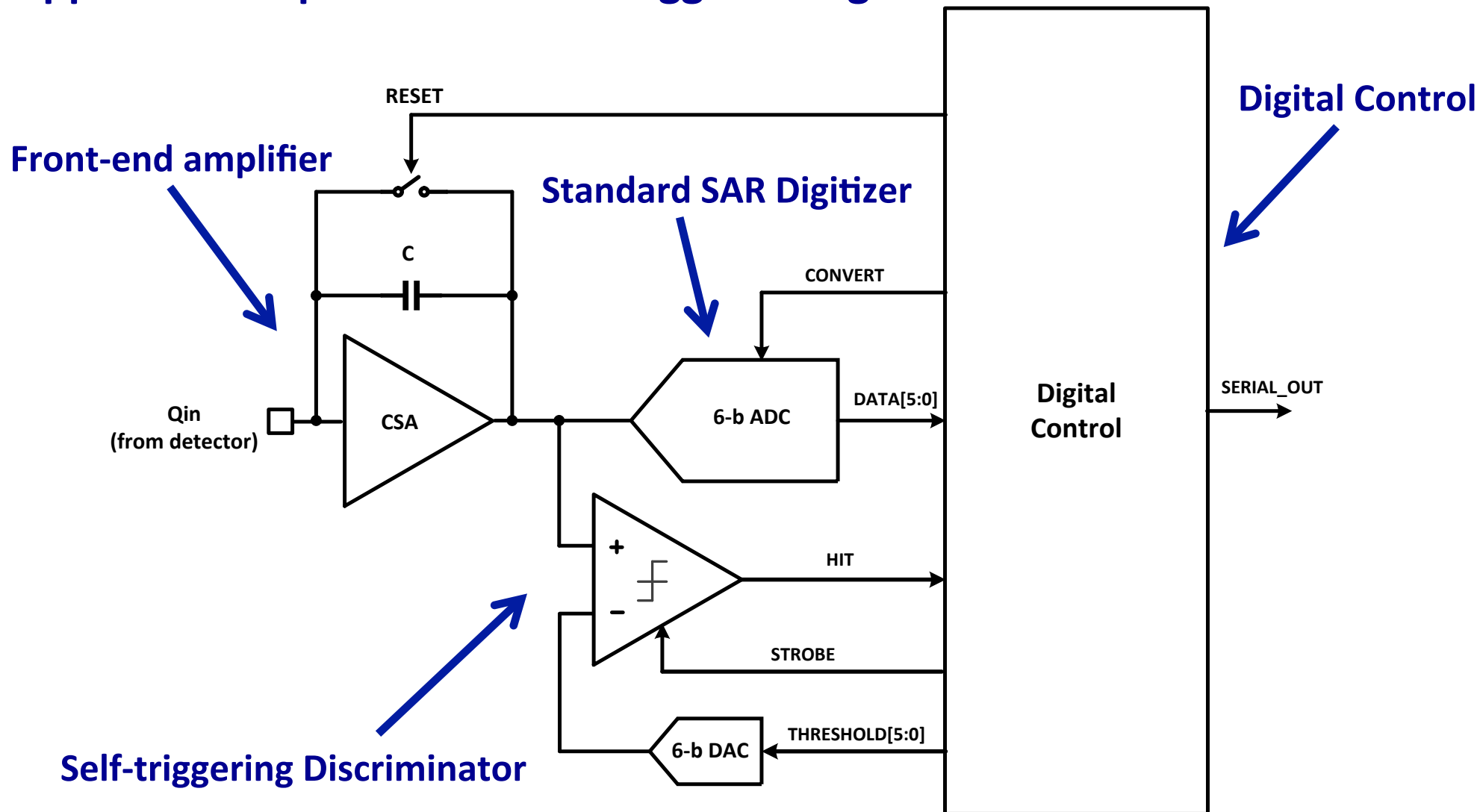
- Low-power, low-noise, cryo-compatible
- $O(10^5)$ channels / m^2

→ Focus of recent LBNL effort

LArPix-v1 Design

True 3D readout: A dedicated front-end channel for every pixel

Approach: Amplifier with Self-triggered Digitization and Readout



Achieve low power: avoid digitization and readout of mostly quiescent data.

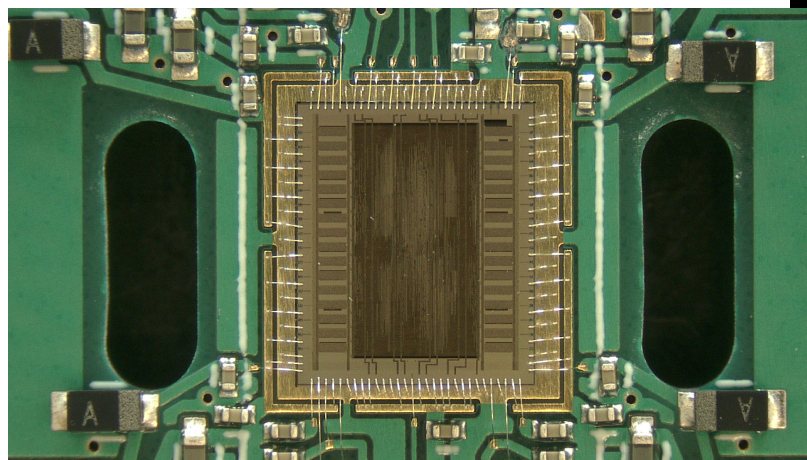
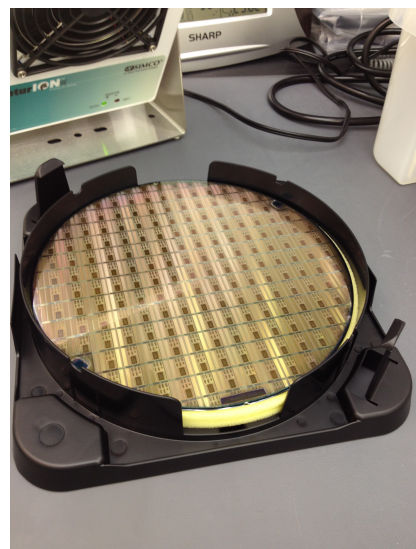
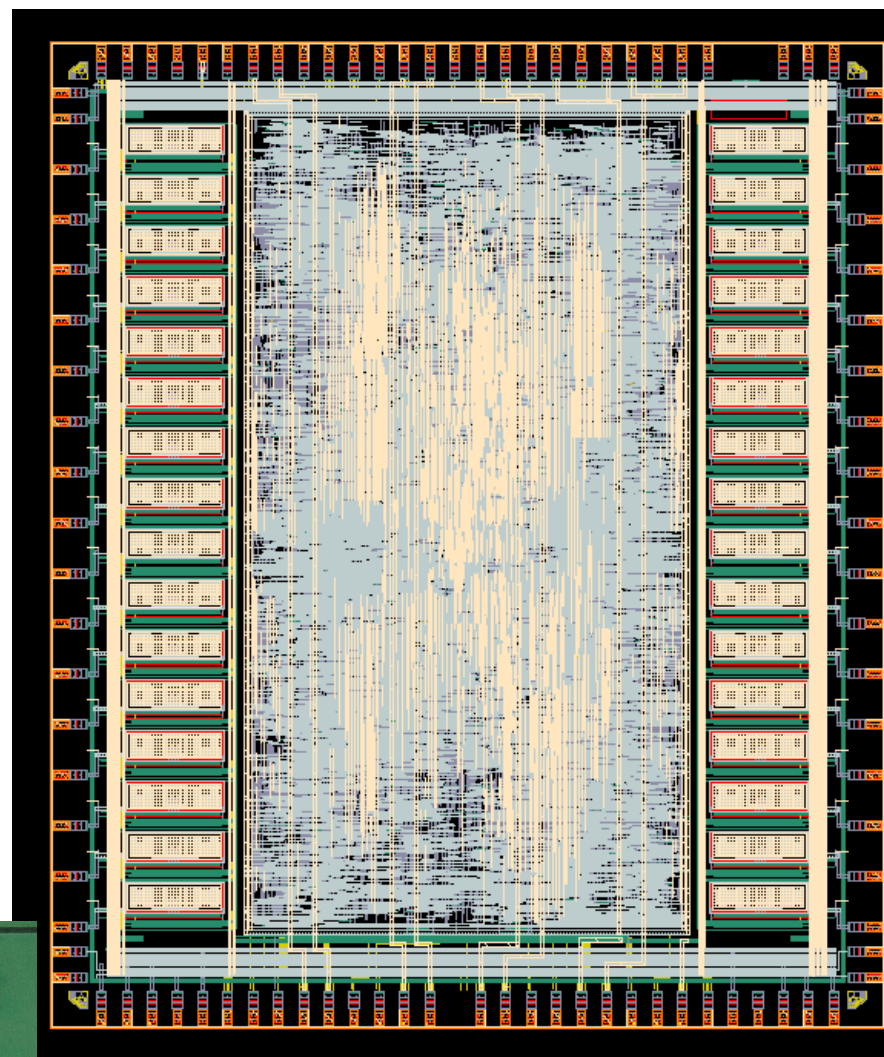
LArPix-v1 Progress

LArPix-v1 ASIC:

- Dec. 2016: Design began
- June 2017: Submitted for fabrication
- Oct. 2017: First chips, test boards @ LBNL
- Dec. 2017: Bench tests successfully completed
- Jan. 2018: Assembled sensor, integrated LArTPC

Recent Progress:

- Feb. 2018: First tracks from true 3D LArTPC @ LBNL
- Mar. 2018: Developed integrated control system
- Apr. 2018: Assembled scalable 512-channel system, operated in 60-cm-drift TPC @ Bern
- May 2018: Operated 832-channel system @ LBNL



Process: 180nm bulk CMOS

Design and testing team @ LBNL:

D. Dwyer, C. Grace, M. Garcia-Sciveres, A. Krieger, D. Gnani, T. Stezelberger, S. Kohn, P. Madigan, H. Steiner

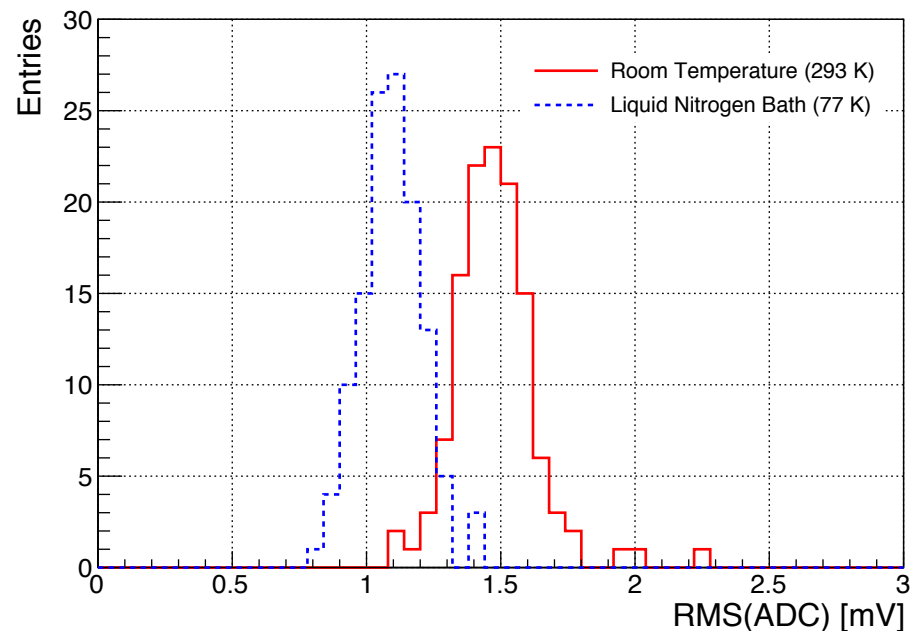
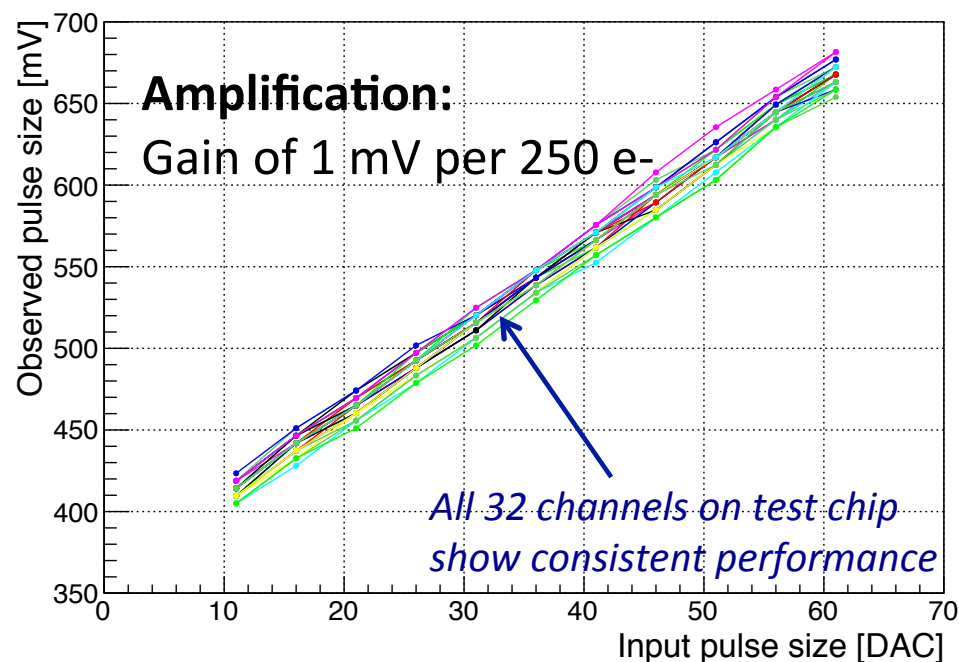
Initial Bench-testing Results

Demonstrated low-noise low-power cryogenic amplification, digitization, and readout:

Low Noise:

~1.5 mV (~375 e-) at room temp

~1.1 mV (~275 e-) in LN² bath



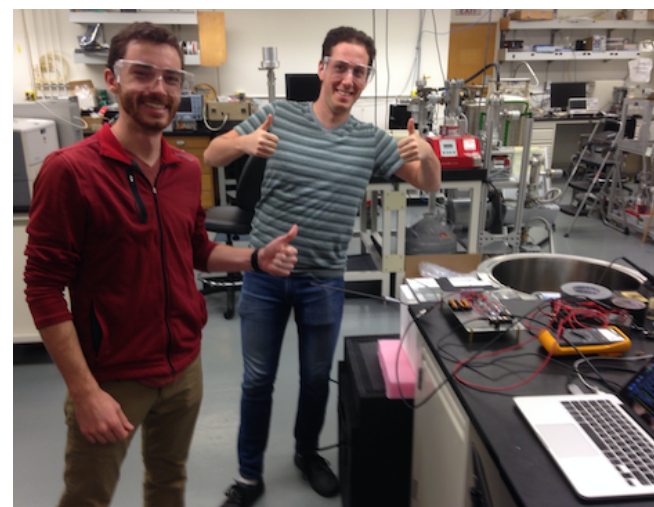
Low Power:

Average power for 128-channel readout:

- Analog: 24 μ W/channel
- Digital: 38 μ W/channel
- **Total: 62 μ W/channel**

Performance exceeds design targets:

- < 500 e- ENC
- < 100 μ W/channel

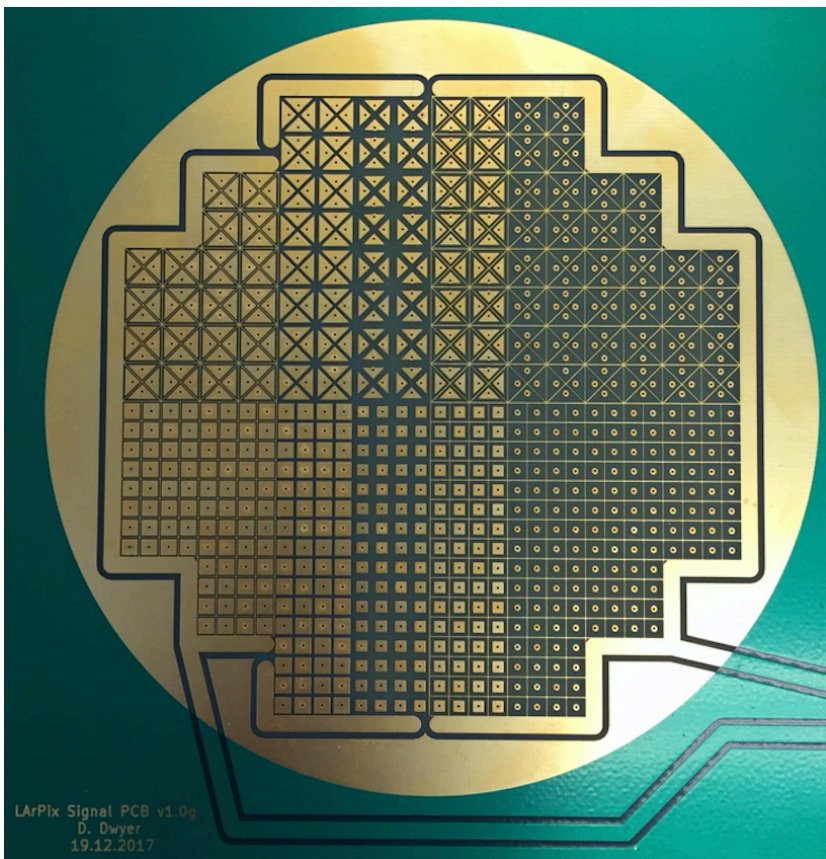


P. Madigan, S. Kohn: drove testing effort

LArPix-v1: Readout Assembly

Pixel Board:

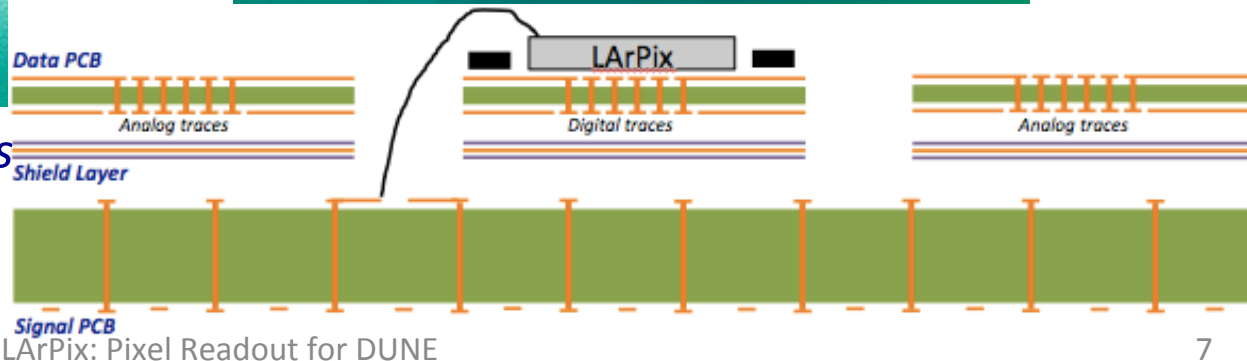
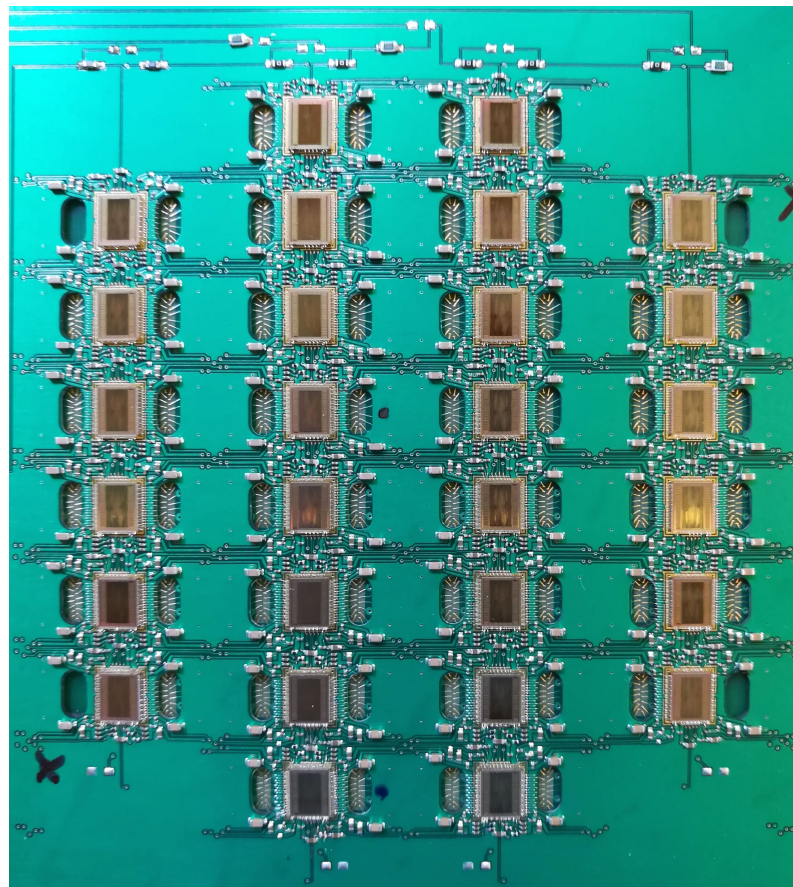
- Standard printed circuit board
- Fits Bern Pixel Demonstrator TPC
- 10 different pixel geometries



10 cm diameter, 3mm pitch, 832 pixels

Complete readout assembly

28-chip LArPix data board sandwiched to pixel board

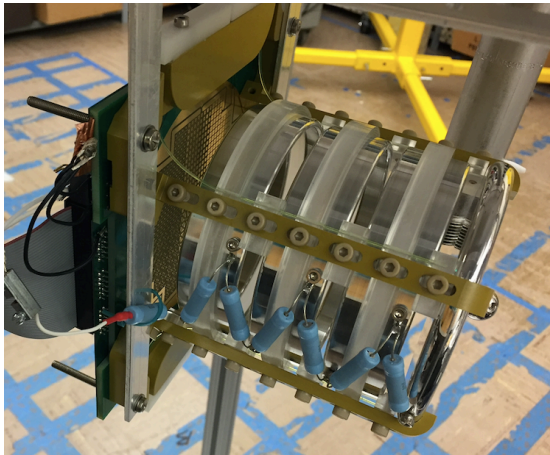


LArTPC Operation

Demonstration of cosmic ray detection at increasing scales

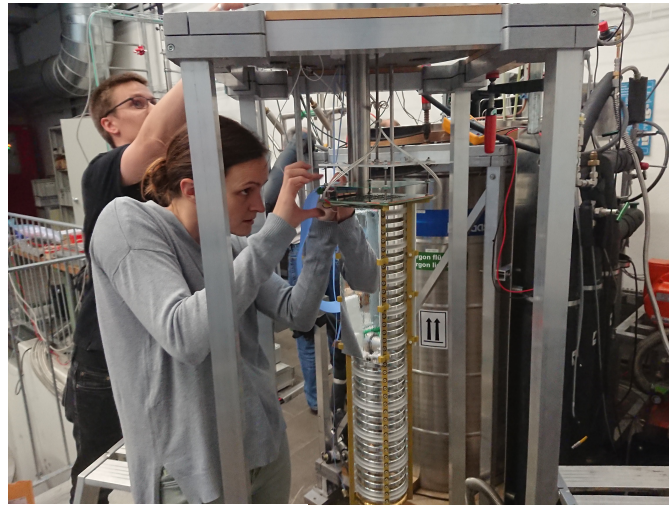
Feb 2018:

128-pixel system @ LBNL
10 cm drift, 200 V/cm



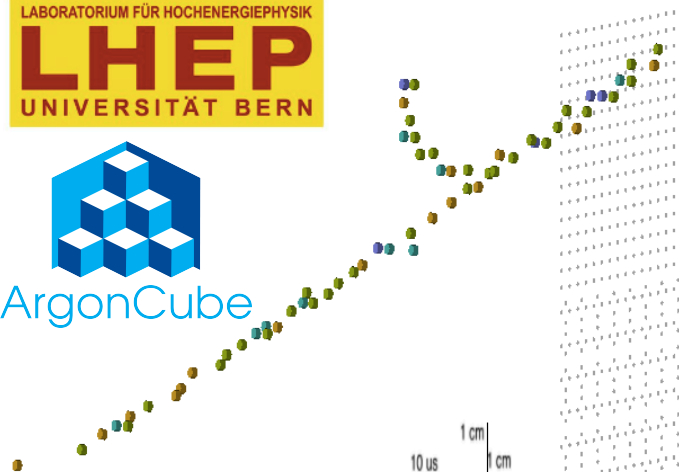
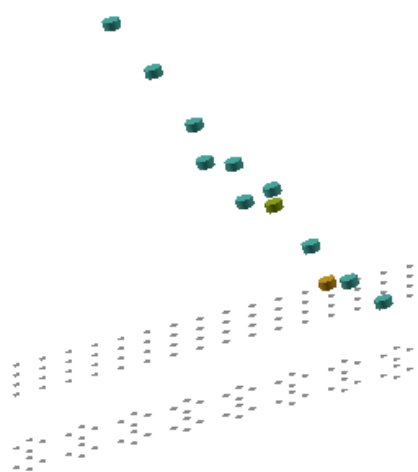
Apr 2018:

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



LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

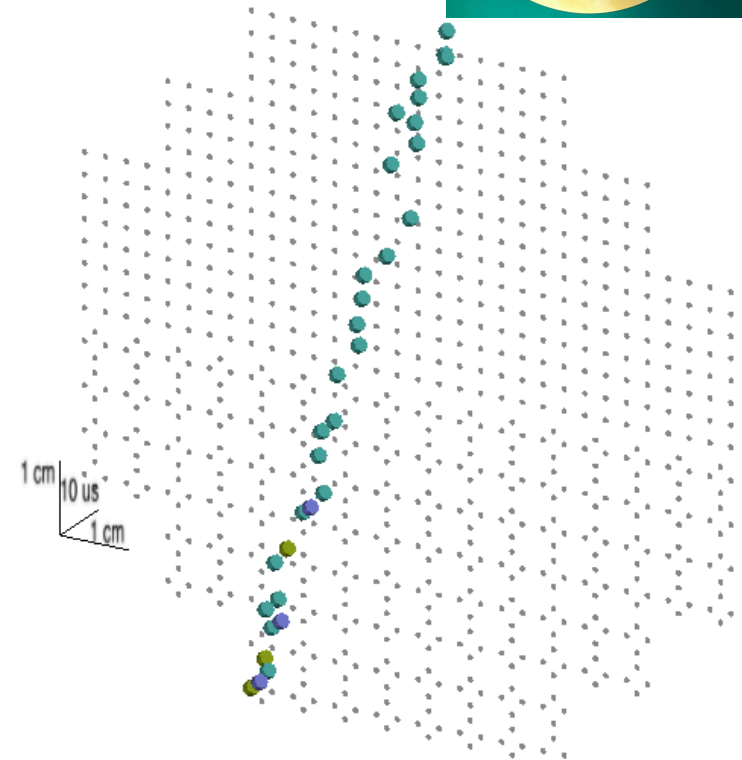
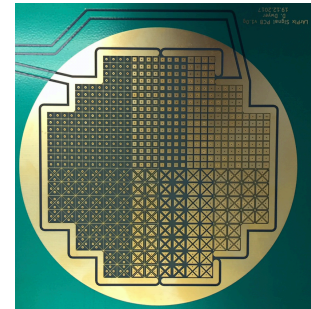

ArgonCube



Operated stably ~1 week

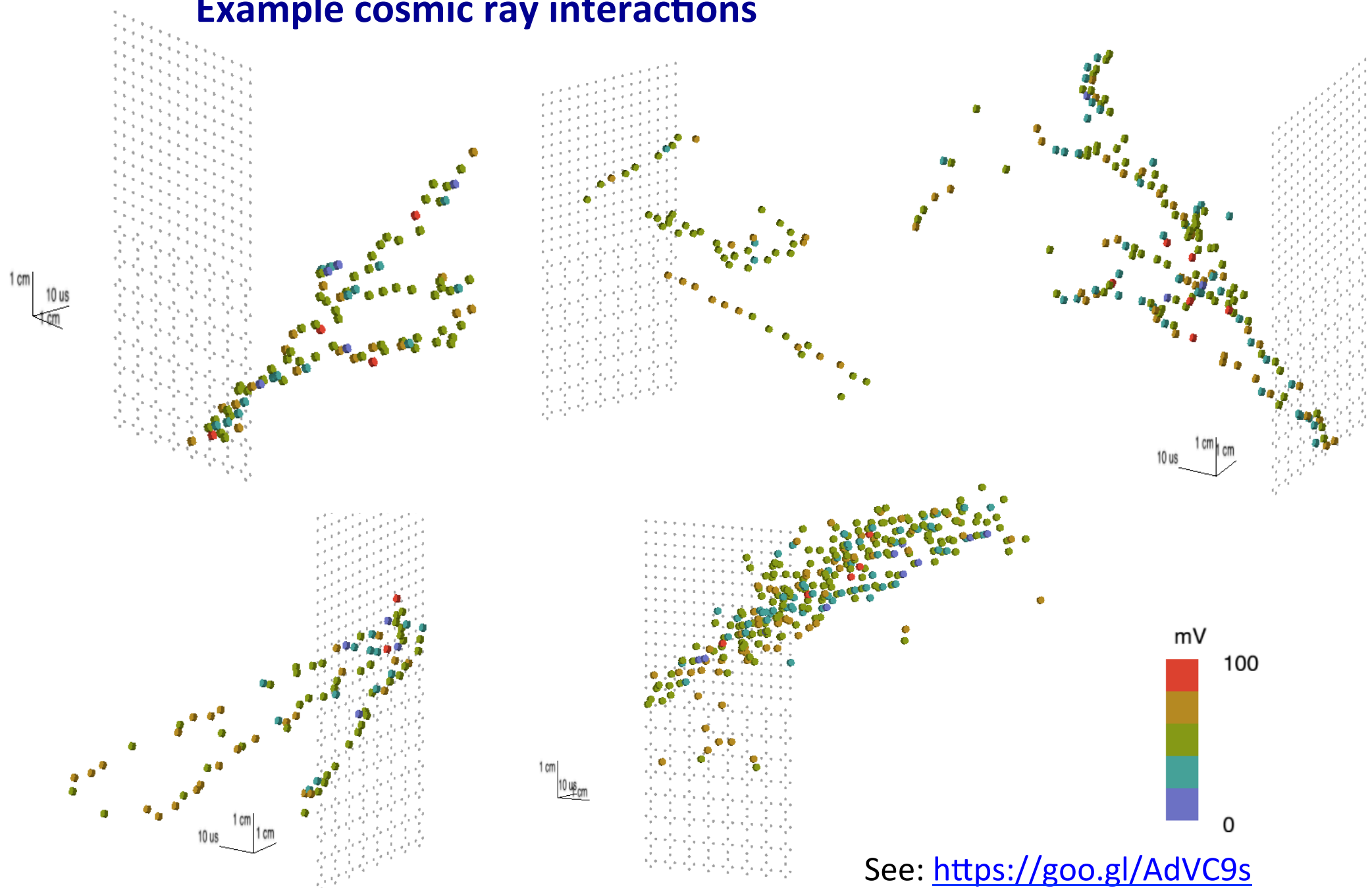
May 2018:

832-pixel system @ LBNL



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Example cosmic ray interactions



See: <https://goo.gl/AdVC9s>

LArPix Raw Data

Brief description of raw LArPix data

54-bit hit record: Pixel ID, ADC value, timestamp, status bits

Each colored point shows one self-triggered hit

- Hit x, y position from pixel location (3 mm precision)
- Position along drift given by timestamp (200 ns precision)
- Color shows hit amplitude (2 mV precision)
- ADC value converted to mV based on initial calibration

No filtering, manipulation applied to raw data.

→ Noise is very low: *>20:1 SNR for MIPs*

Comment on LArPix data rates:

Pixel self-triggering substantially reduces data volume:

LArPix operation @ Bern:

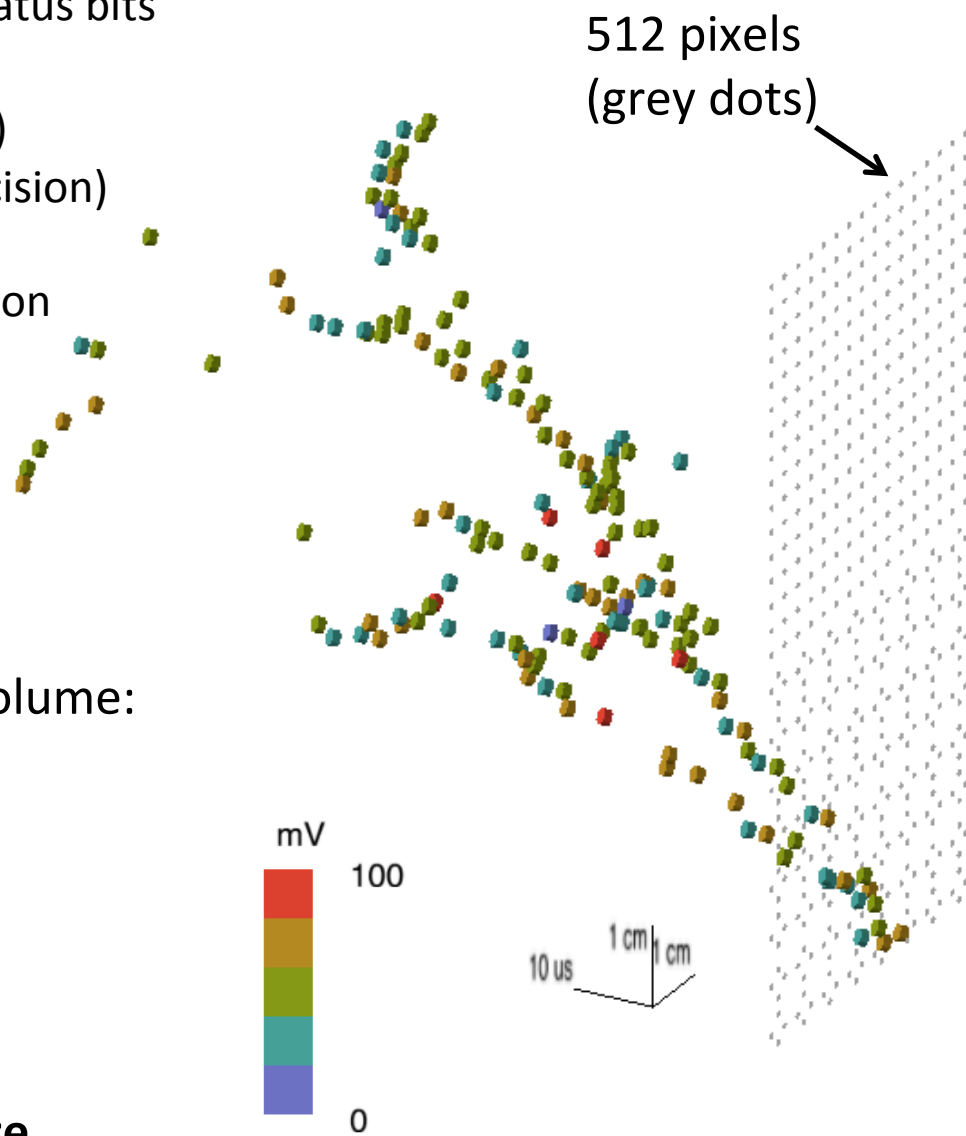
60cm drift at surface

512 pixels, ~ 0.3 Hz/pixel → **~ 3 kB/s total rate**

DUNE Near Detector:

50cm drift underground

8M pixels, ~ 0.01 Hz / pixel → **~ 2 MB/s total rate**

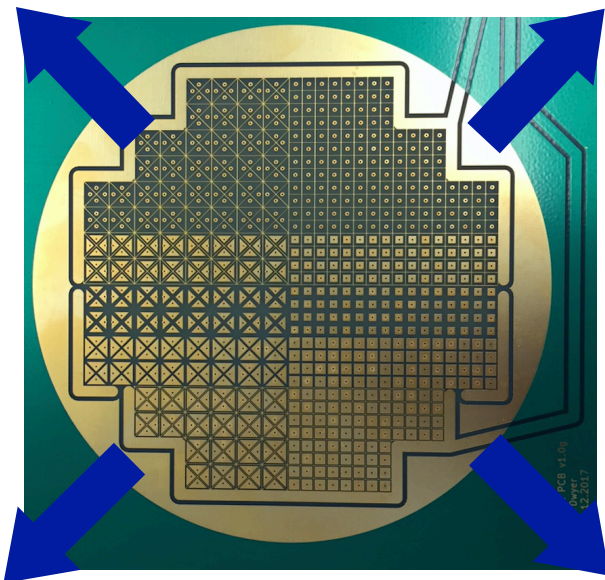


Next Steps: Scalability

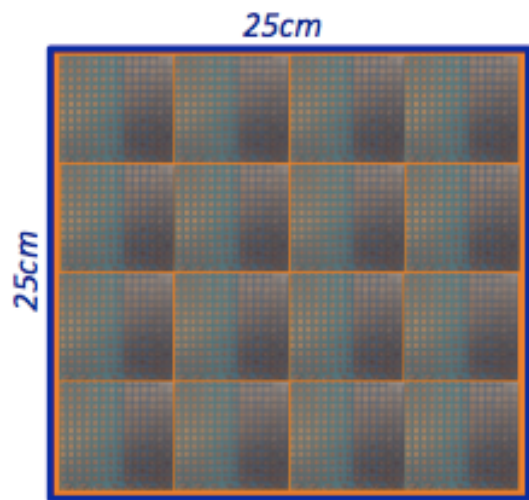
Design modular pixel tile for instrumenting large area sensors

- Standard size (e.g. 25cm x 25cm) for easy industrial production
- One tile = one LArPix daisy chain

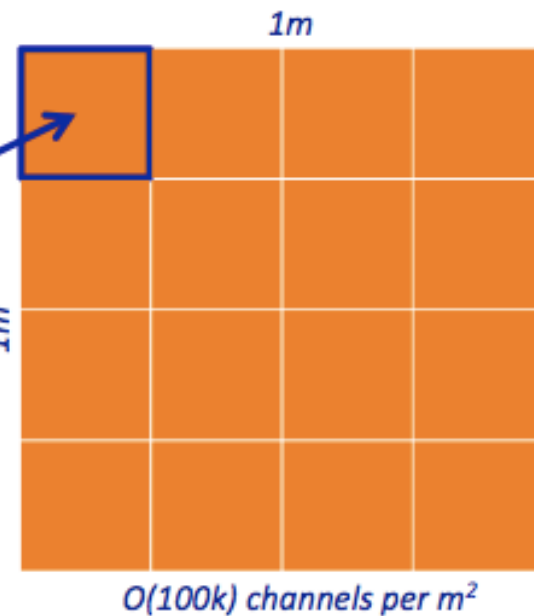
Extend pixels edge-to-edge



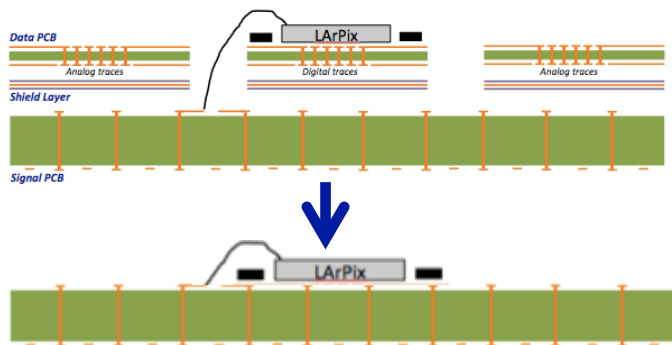
Increase size



Tile anode



Reduce to single PCB



e.g. Dual Phase G10 frame



Anode Frame?

- Support tiles from backside
- Support cabling
- Handle thermal contraction

Next Steps: LArPix-v2

Exploring LArPix-v2 for scalable assembly and improved physics performance:

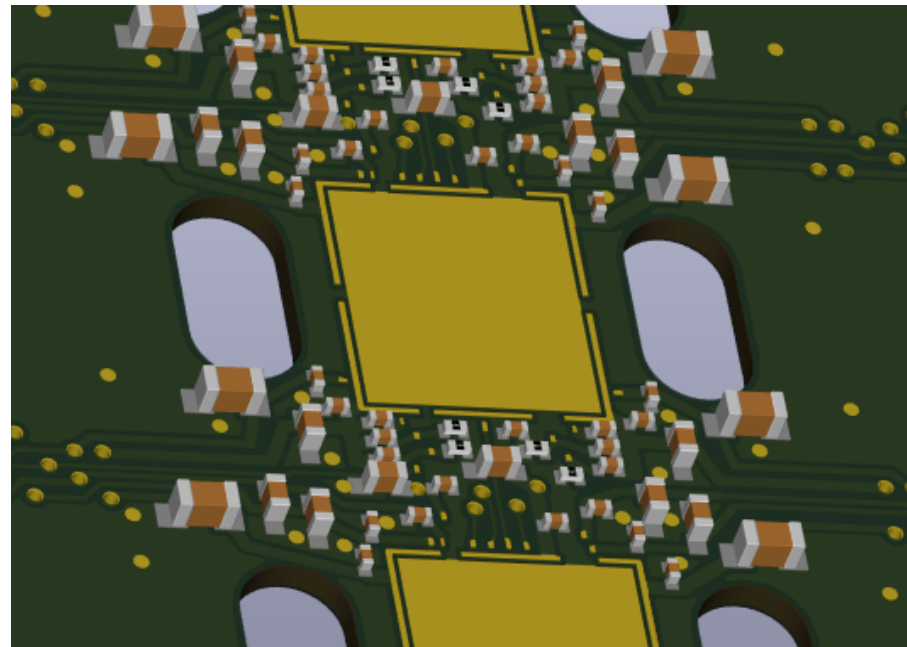
- Increase dynamic range for charge signal
- Double number of channels per chip (32→64)
- Make daisy chain I/O robust to chip failure.
- Substantially reduce external circuitry
- Improve hit timestamp
- Increase channel threshold range
- Improve front-end pulser
- Tailor bandwidth of discriminator
- Plus a number of other changes*

Test LArPix in packaged form:

- Many advantages for assembly and testing
- Layout seems manageable, but must demonstrate no adverse issues after packaging.



Currently crowded PCB layout



→ *Integrate external circuits into ASIC*

Goal:

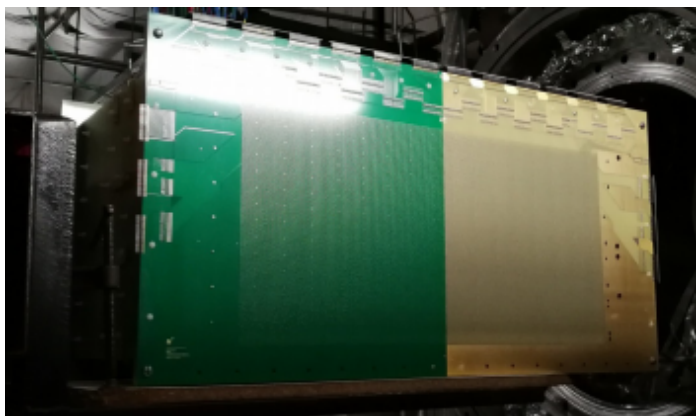
Dec. 2018: Complete v2 design

Apr. 2019: Complete v2 production

Next Steps: Demonstrators

Roadmap of potential demonstrations at larger scales:

LArIAT LArTPC



Readout area: 0.36 m²

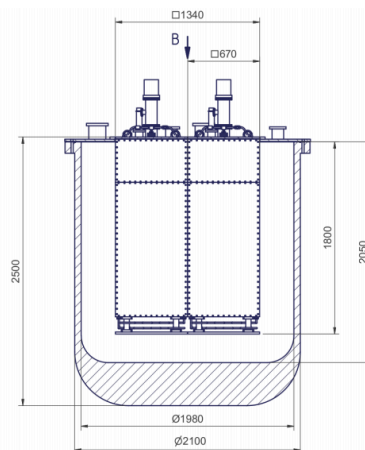
pixels: 22.5k

ASICs: 350

Target: Mid 2019

Provide known particle beam for detailed assessment of PID and energy performance.

ArgonCube 2x2 Demonstrator



Readout area: 6.4 m²

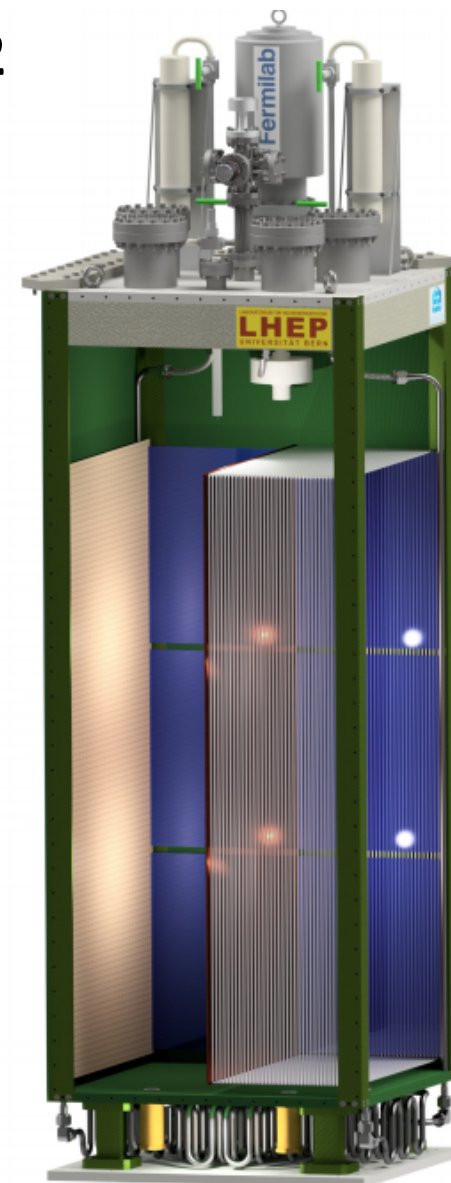
pixels: 400k

ASICs: 6.3k

Target: Late 2019

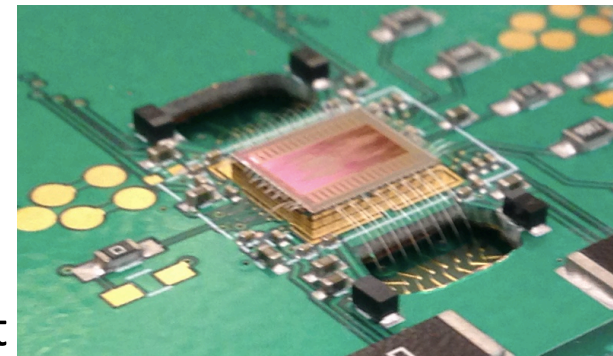
First module currently under construction.

Demonstrator for DUNE Near Detector



Also pursuing LArPix readout for High-pressure Ar gas TPC Near Detector Module with FNAL, others

LArPix Summary



3D pixelated charge readout for LArTPCs:

LArPix demonstrates feasibility of low-noise low-power 3D readout

Unique front-end channel for every pixel

Key purpose: overcome neutrino pileup in DUNE Near Detector LArTPC

Recent Progress:

Operation of complete 832-channel LArPix readout system

Development of new control electronics

Progress in LArPix analysis, reconstruction

Commissioning of new high-purity LAr system

Next Steps:

Aiming for technical demonstrations at larger scales

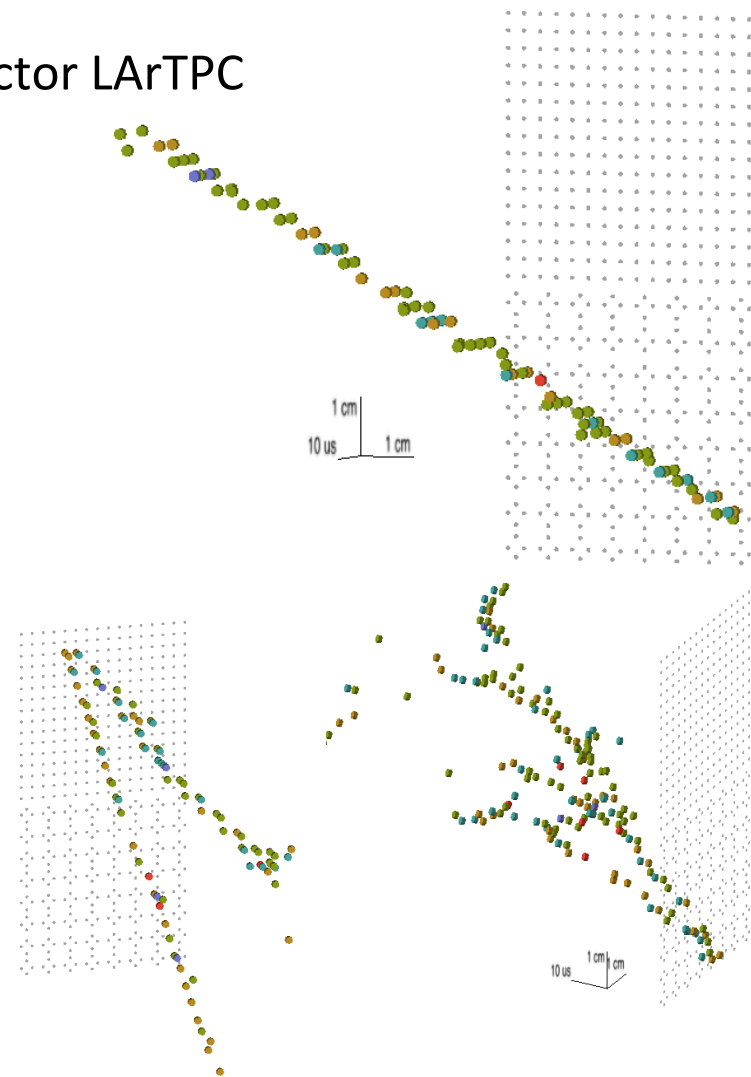
→ LArIAT, ArgonCube 2x2 Demonstrator

Many developments to ease large-scale production

- Modular pixel tile design

- Version 2 of LArPix ASIC

- Exploring partnerships for development of complete detector readout system



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