Pixelated Readout for Liquid Argon Time-Projection Chambers

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Physics 290E Seminar
UC Berkeley
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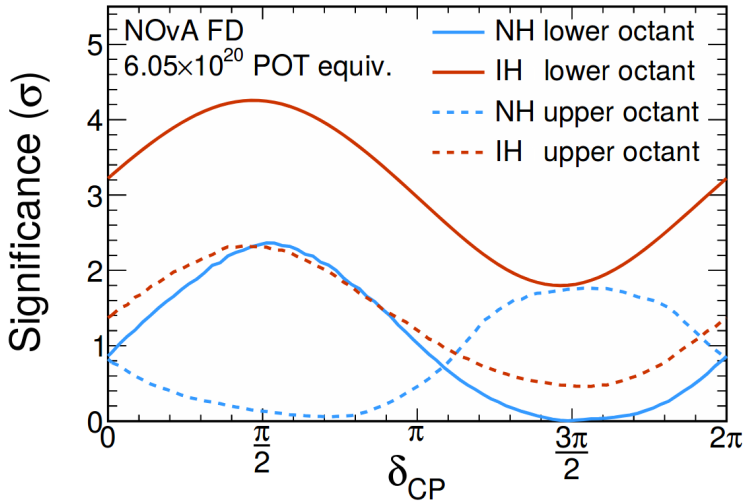
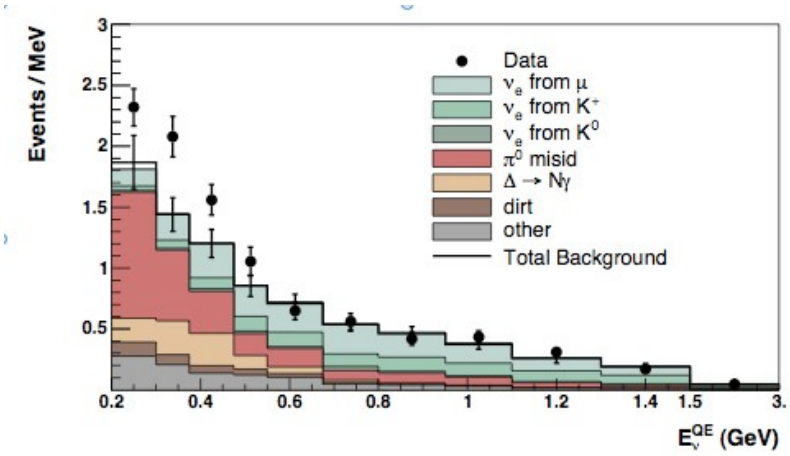
Neutrino physics with LArTPCs

- DUNE: measuring the mass ordering and δ_{CP}
- MicroBooNE: resolving the short baseline anomaly (sterile neutrinos?)
- This talk will focus on the ongoing design effort for TPC readout in DUNE

NOvA constraints on δ_{CP} and mass ordering



MiniBooNE short baseline anomaly

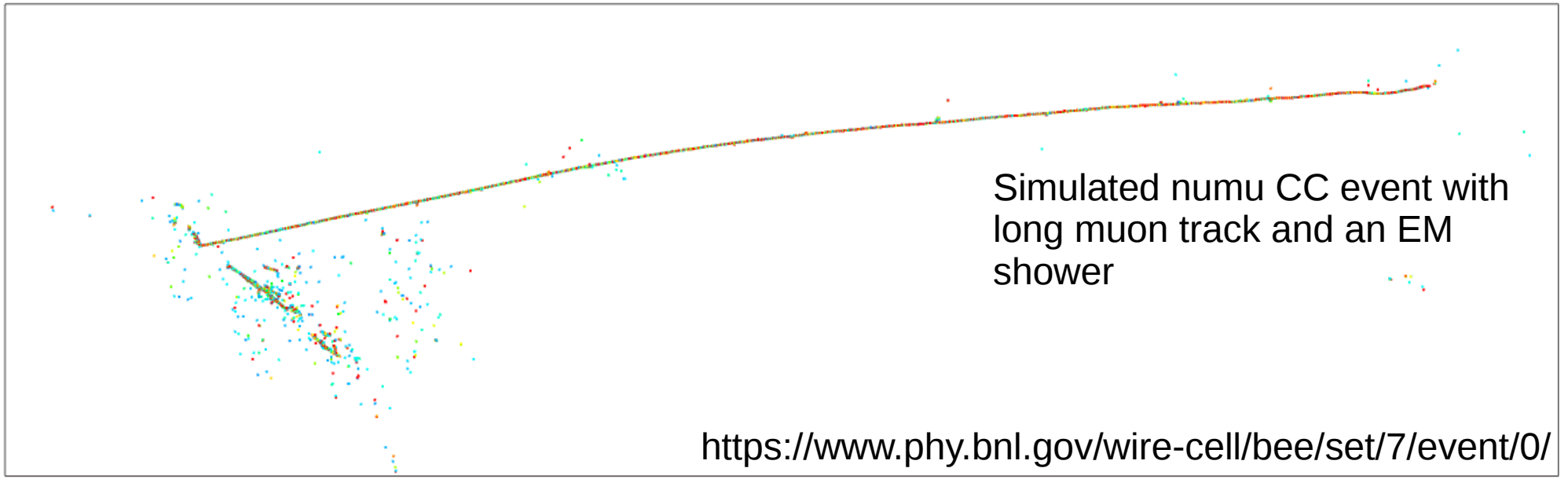


Phys. Rev. Lett. 118, 231801 (2017)

PRL 105, 181801 (2010)

LArTPC design goals

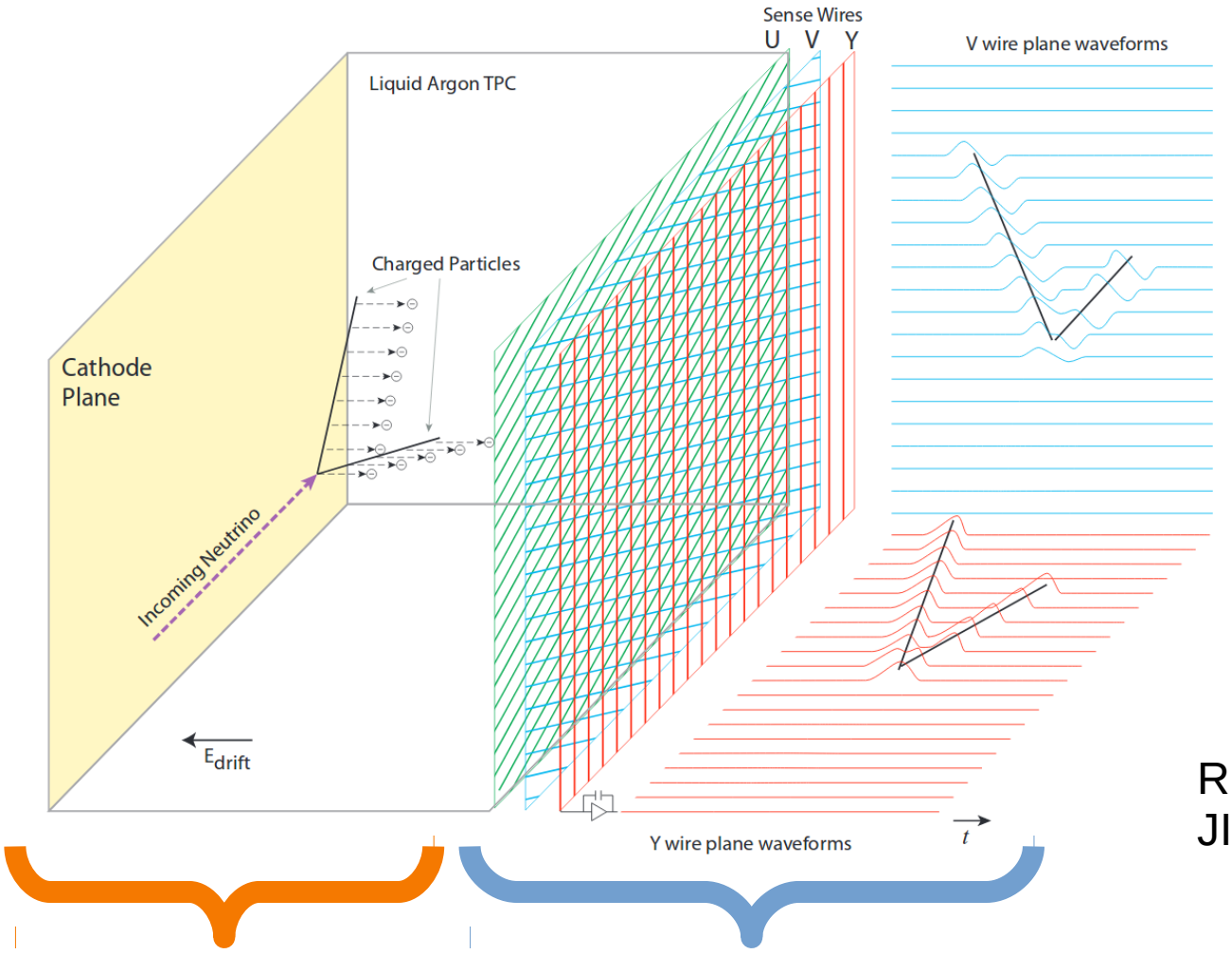
- Measurements depend on identifying flavor and sign of neutrinos (e, mu, tau, nu/nubar)
- Must be able to identify tracks, showers, primary/secondary vertex gap, etc.



Simulated numu CC event with long muon track and an EM shower

https://www.phy.bnl.gov/wire-cell/bee/set/7/event/0/

General LArTPC design



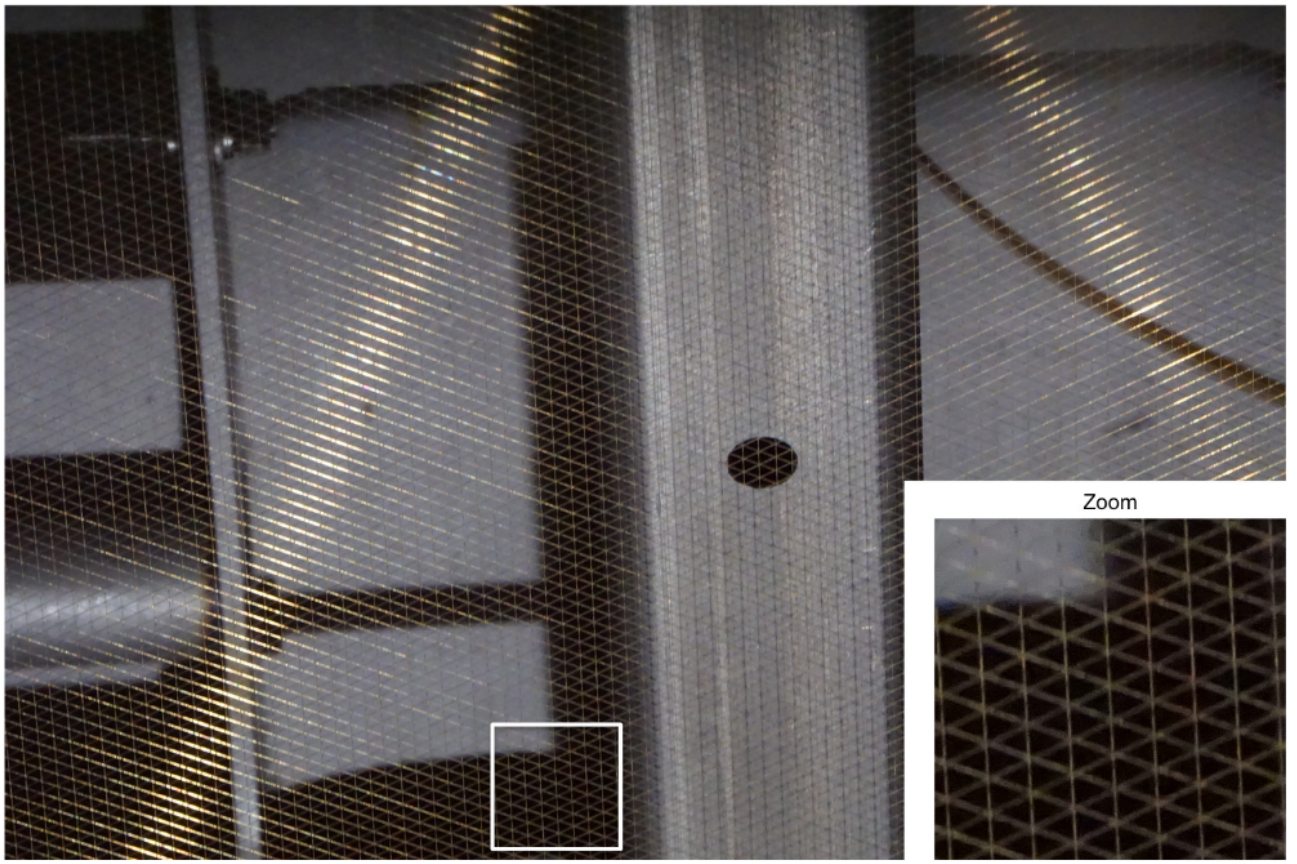
- Energy from sum of all charge in detector (calorimetric)
- Tracks from geometric distribution of readout hits

R. Acciarri et al 2017
JINST 12 P02017

All LArTPCs

Specific readout method
(In other TPCs e.g. Lux this is a PMT array)

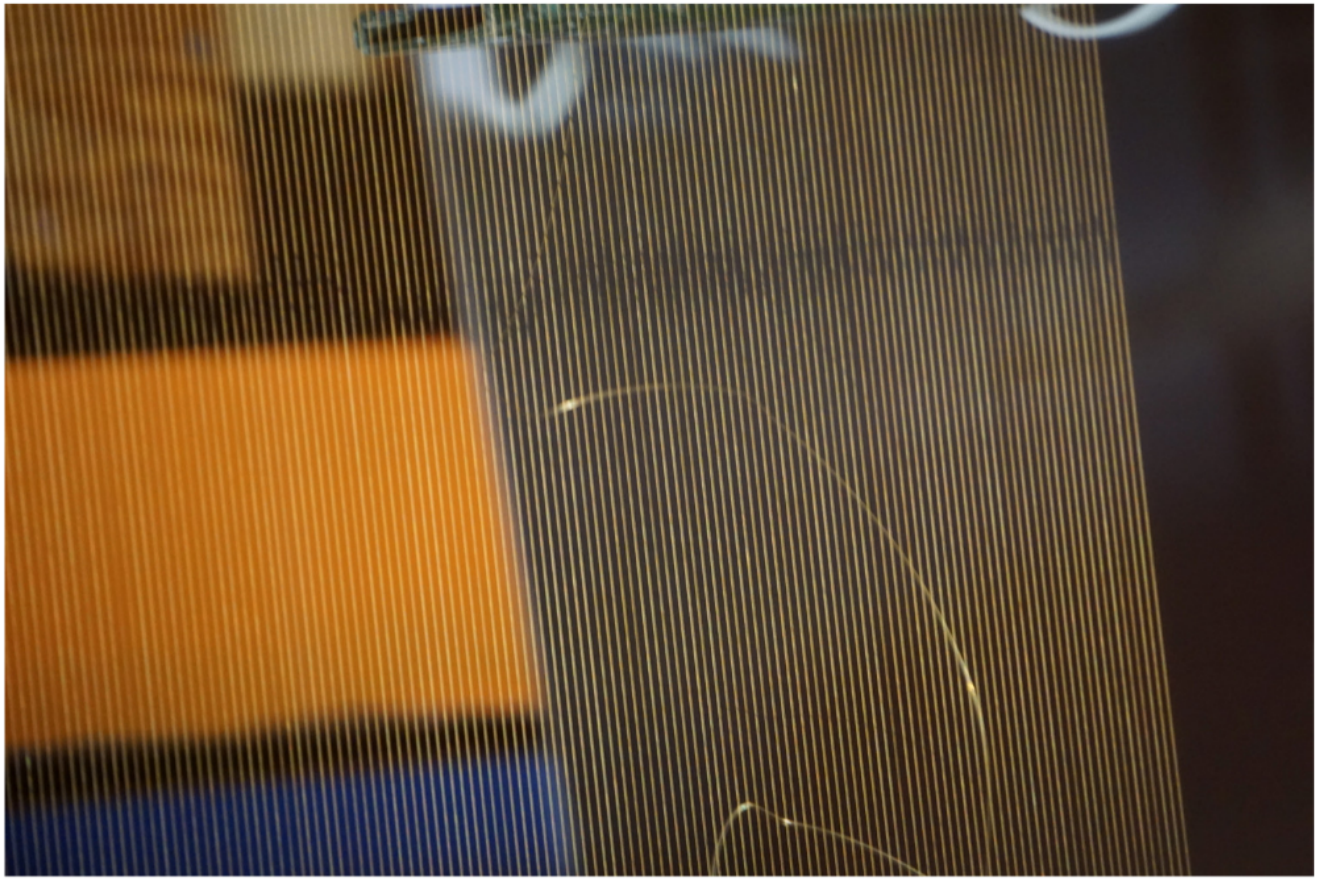
Example of wire plane LArTPCs



MicroBooNE has >8200 wires, 150 micron diameter @ 3mm spacing (gold-plated stainless steel)

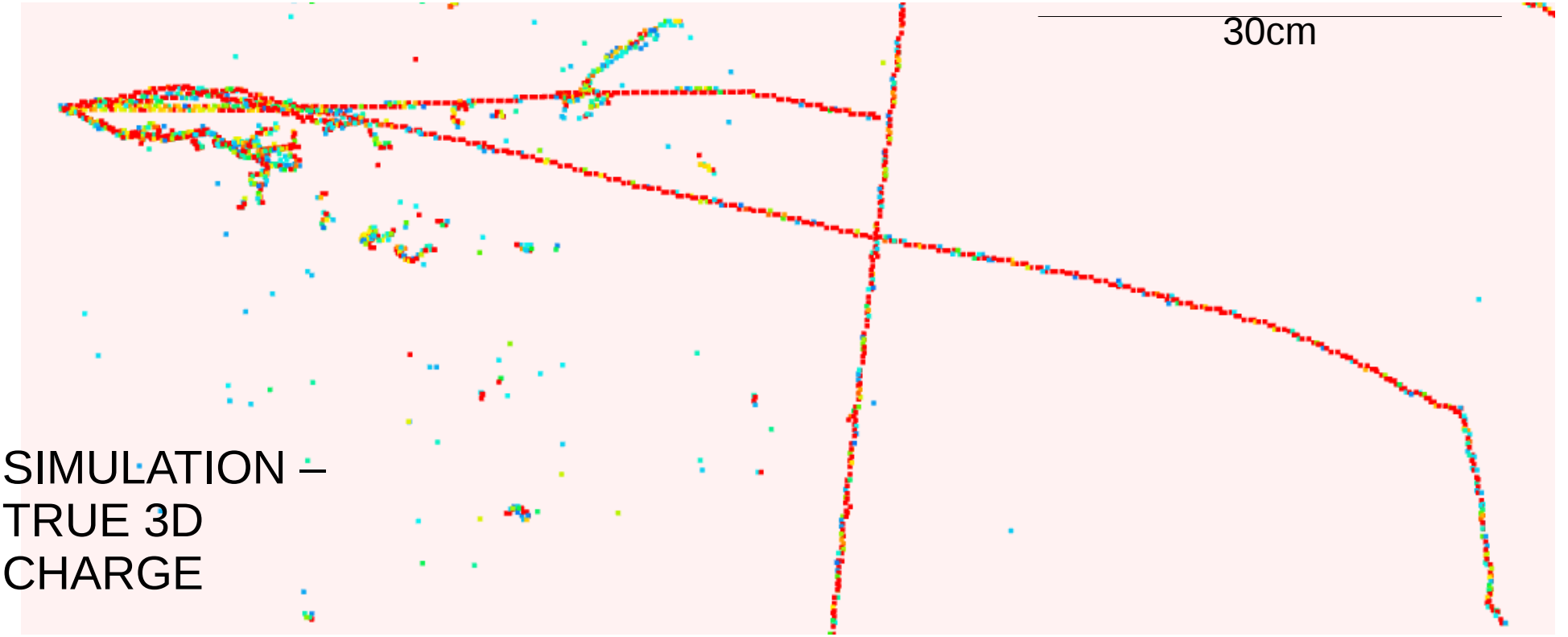
https://arxiv.org/pdf/1507.02508.pdf

Broken wires



- Short circuits across other wires/channels
- Missing channel incrementally degrades energy and position resolution across entire detector

Ambiguities

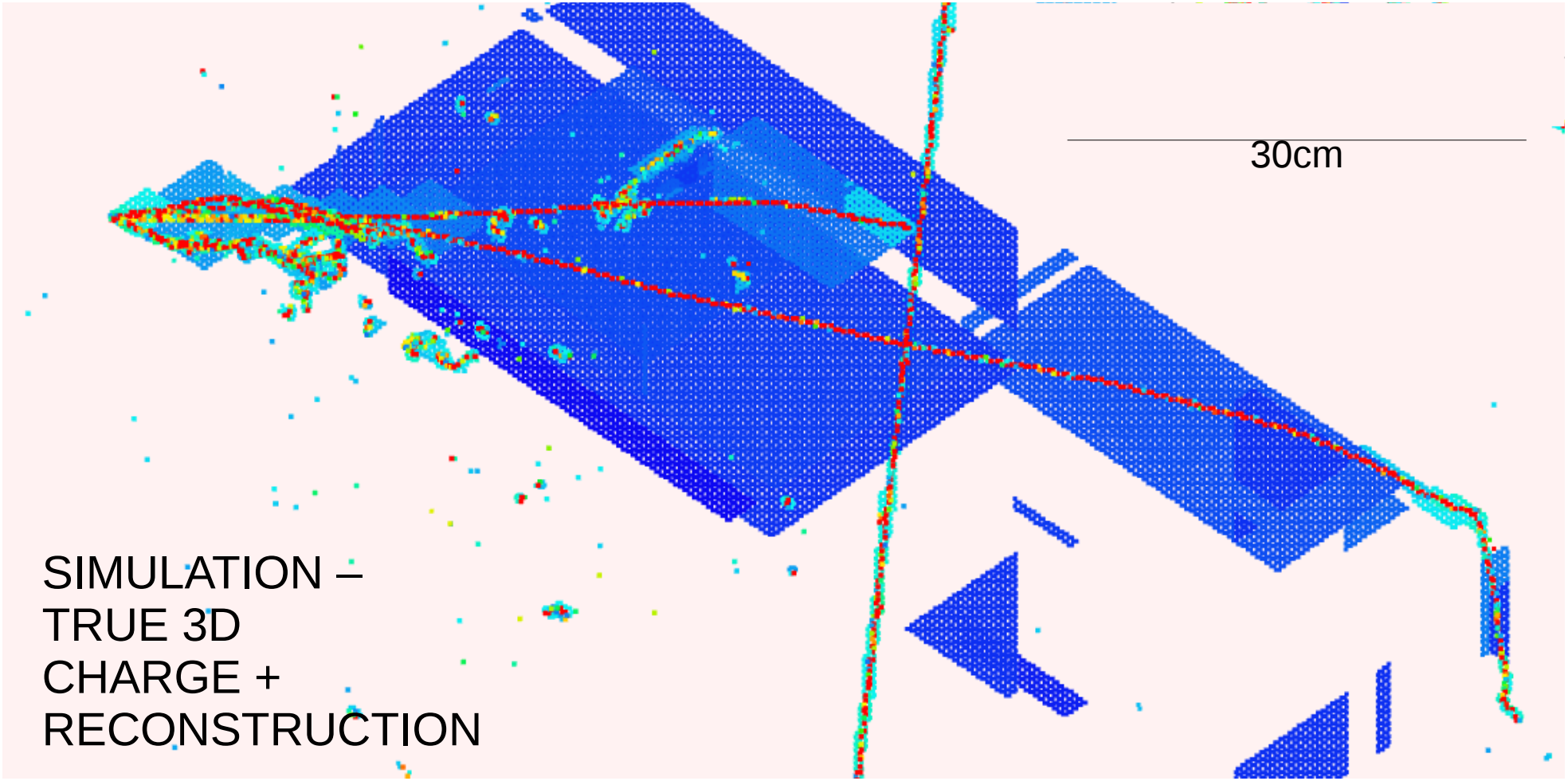


SIMULATION – TRUE 3D CHARGE

A ν_e charged current event (plus a cosmic ray muon)

https://www.phy.bnl.gov/wire-cell/bee/set/12/event/32/

Ambiguities

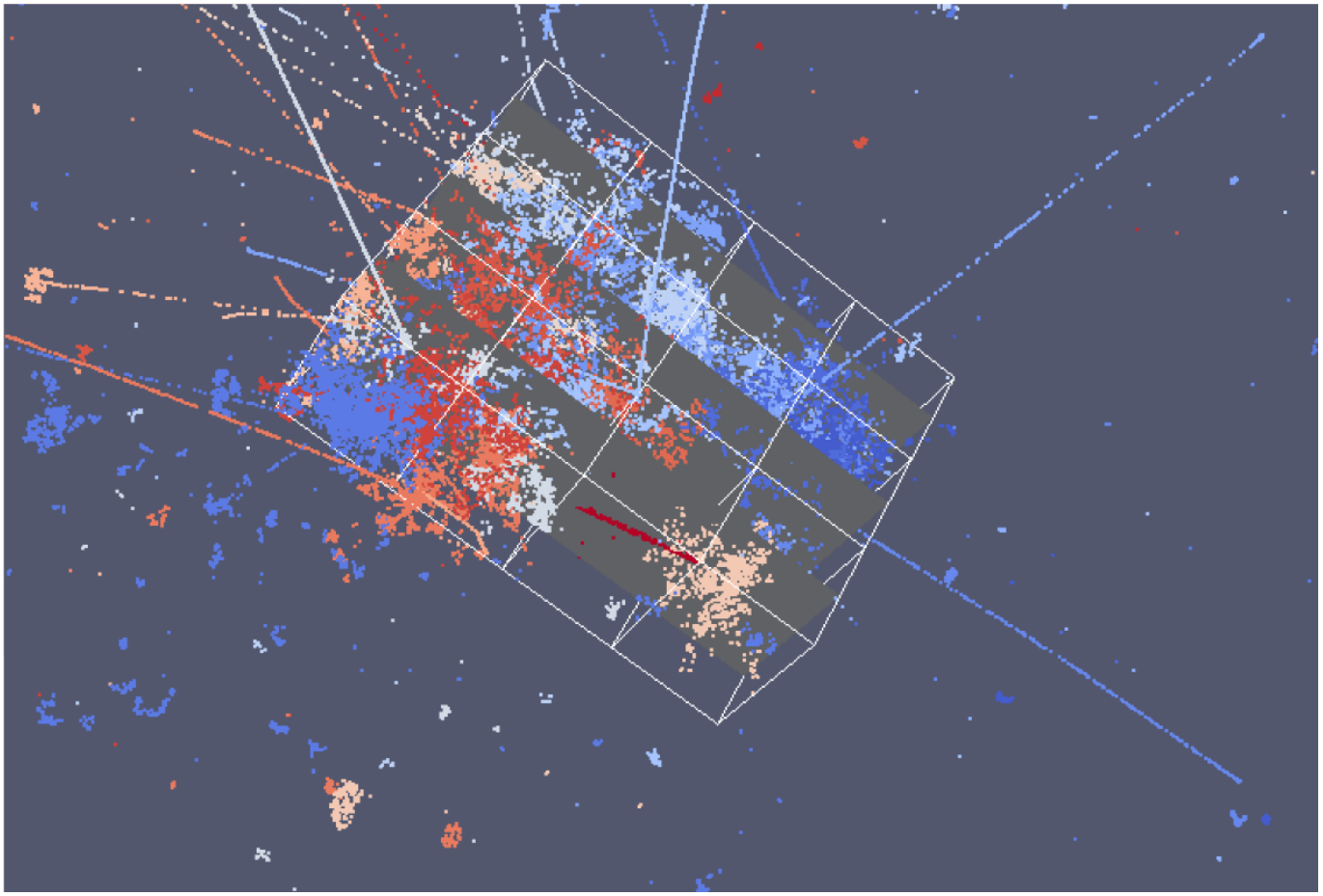


A ν_e charged current event (plus a cosmic ray muon)

https://www.phy.bnl.gov/wire-cell/bee/set/12/event/32/

See also https://www.phy.bnl.gov/wire-cell/bee/set/22/event/10/

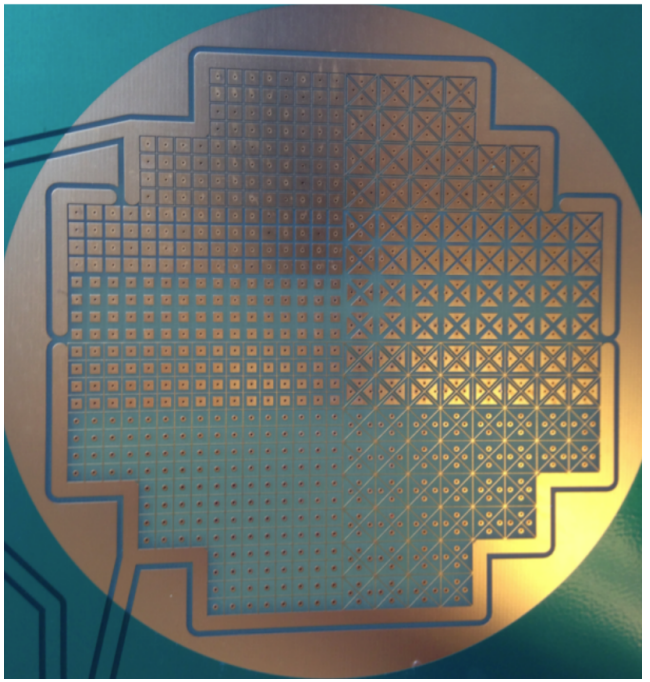
Ambiguities



- One simulated beam spill at DUNE near detector
- Each color is a different neutrino interaction
- Good luck

Pixelated readout

- Each channel sensitive in only a small area rather than a long line
- Pixel is a metal pad on a PCB
- Channel ID immediately tells you the (x, y) position of the hit
- No need to analyze wire crossings
- No ambiguities
- No broken wires



Example pixel plane testing multiple pixel geometries

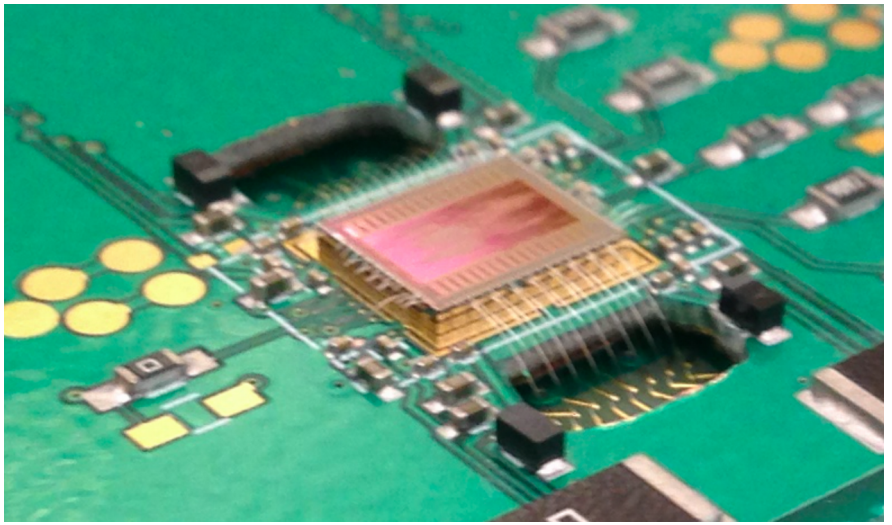
Pixelated readout challenges

Some barriers to using pixelated readout

- Channel count goes like L^2 instead of L (length scale of detector)
  - DUNE far detector would be $O(10^7)$ per 10kt module
  - Compare to $O(10^4)$ for wire readout
- Need more ADC channels
- Consume more power (may boil LAr!)
- More cryostat penetrations

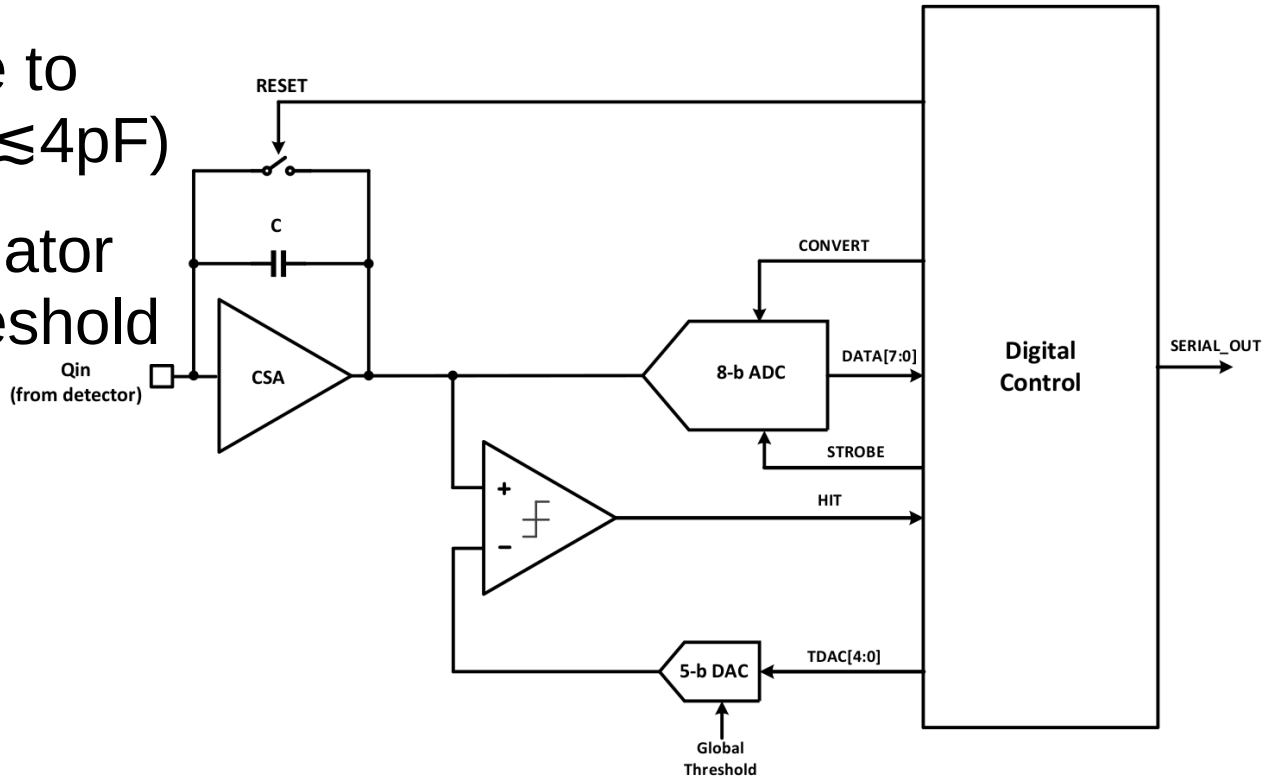
Introducing LArPix

- ASIC for pixel-based readout
- (Plus sensor plane, signal routing, etc.)
- Low power (100 μW/ch)
- Low noise (<500e^-)
- And more!



LArPix Specs

- 32 channels/chip (64-channel chip under consideration)
- Preamp/CSA (4 μV/e)
- No shaper required due to low input capacitance (≲4pF)
- Self-triggering discriminator with programmable threshold
- On-board 8-bit ADC
- 2048-deep FIFO output packet buffer



Addressing pixel readout challenges

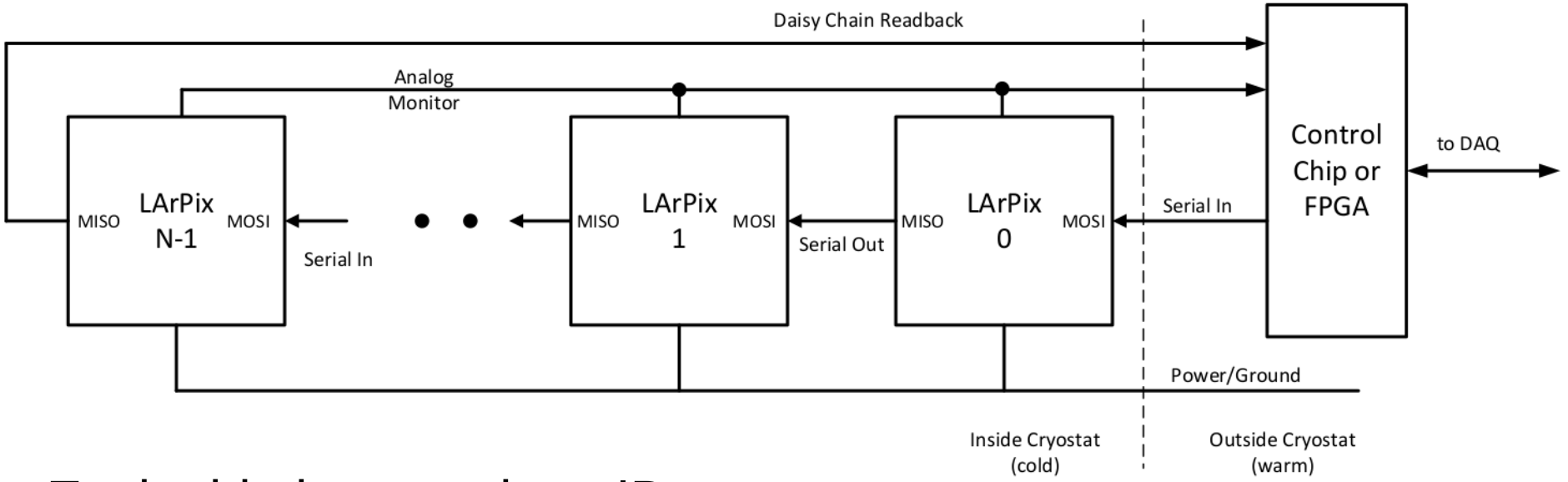
Challenge

- Heat load (too much power consumption will boil LAr)
- L^2 cryostat penetrations ($$$ and also contributes to heat load)

Resolution

- Save power through
  - Slow 10MHz CLK
  - No shaping amp
  - Self-trigger logic
  - Custom preamp design
- Save cryo penetrations through chained communication

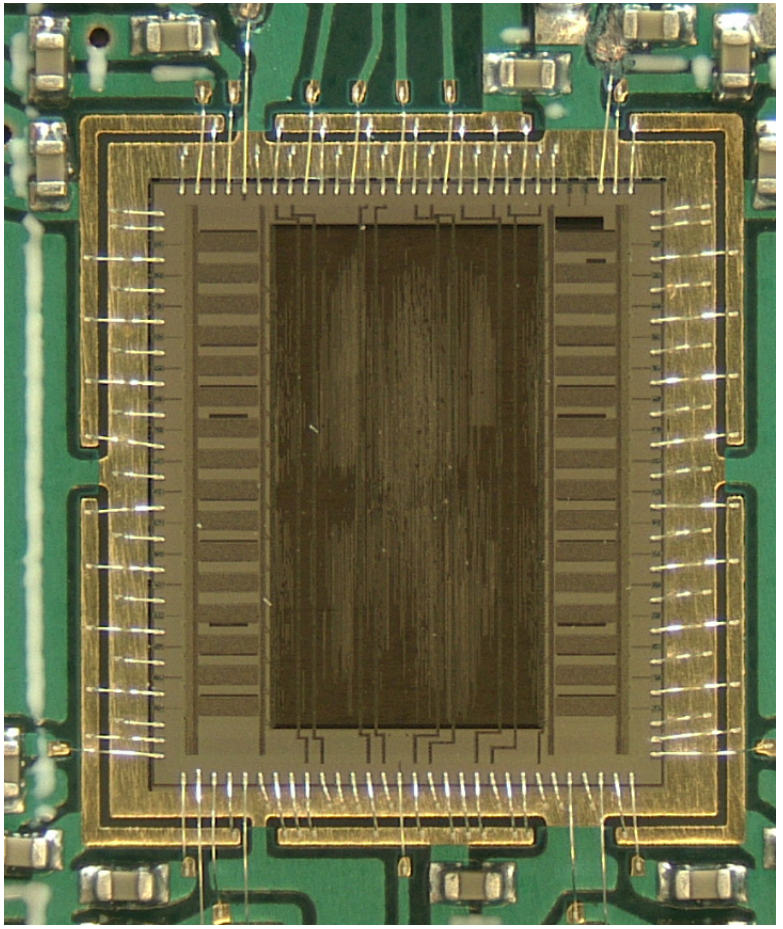
LArPix “daisy chain”

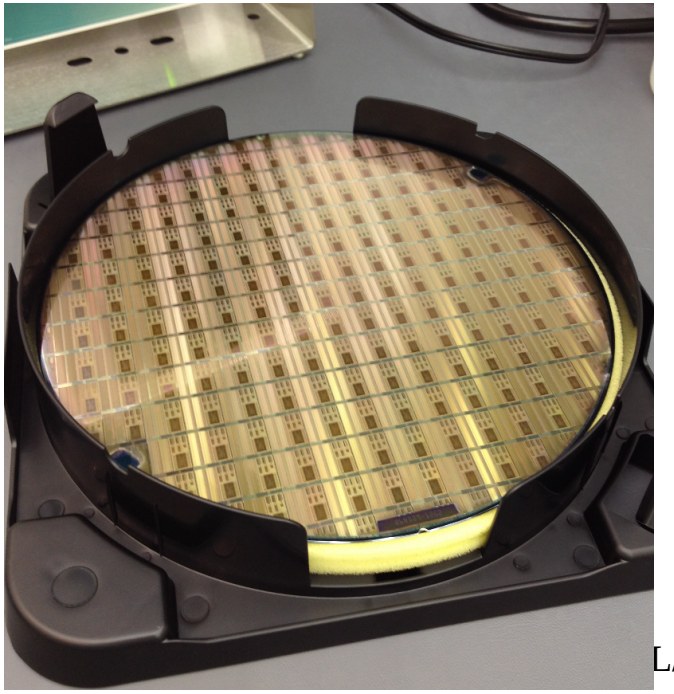


- Each chip has a unique ID
- Communications packets include chip ID
- Chips send along packets not meant for them
- Only 2 cryo penetrations per 256 chips (8192 channels)!
- Still L^2 but now it’s $L^2/256$

LArPix implementation

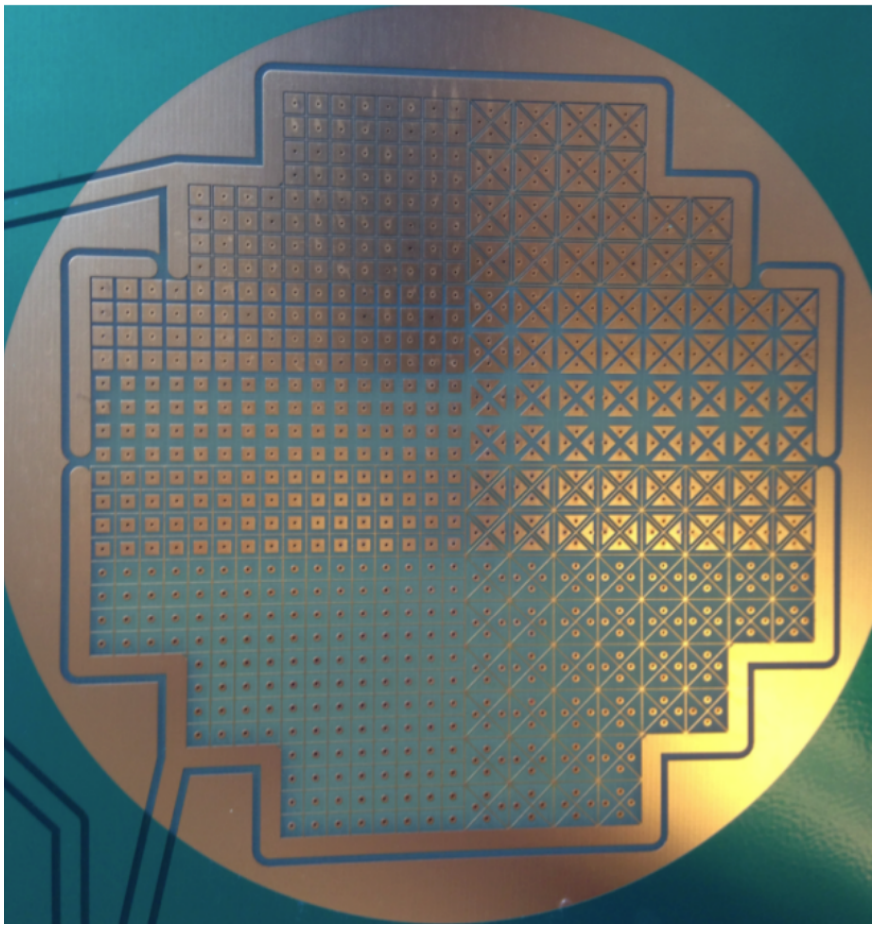
- 5.3x6.3mm
- Digital logic in the middle (dark area)
- Analog along the edges (tiled pattern for 32 channels)



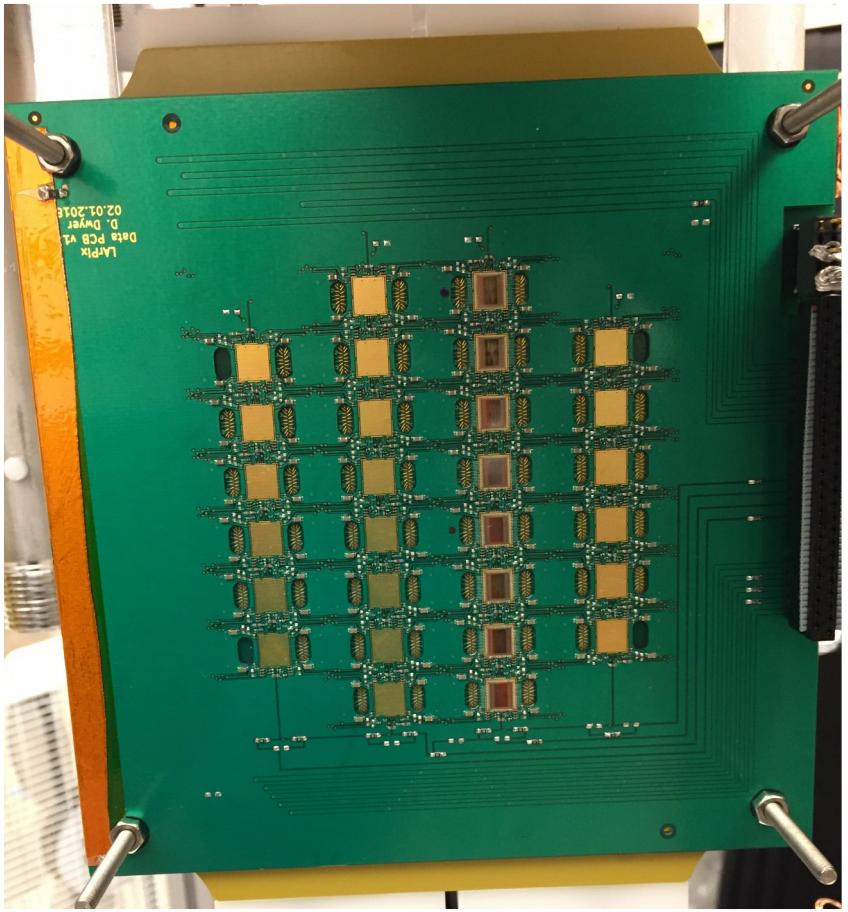


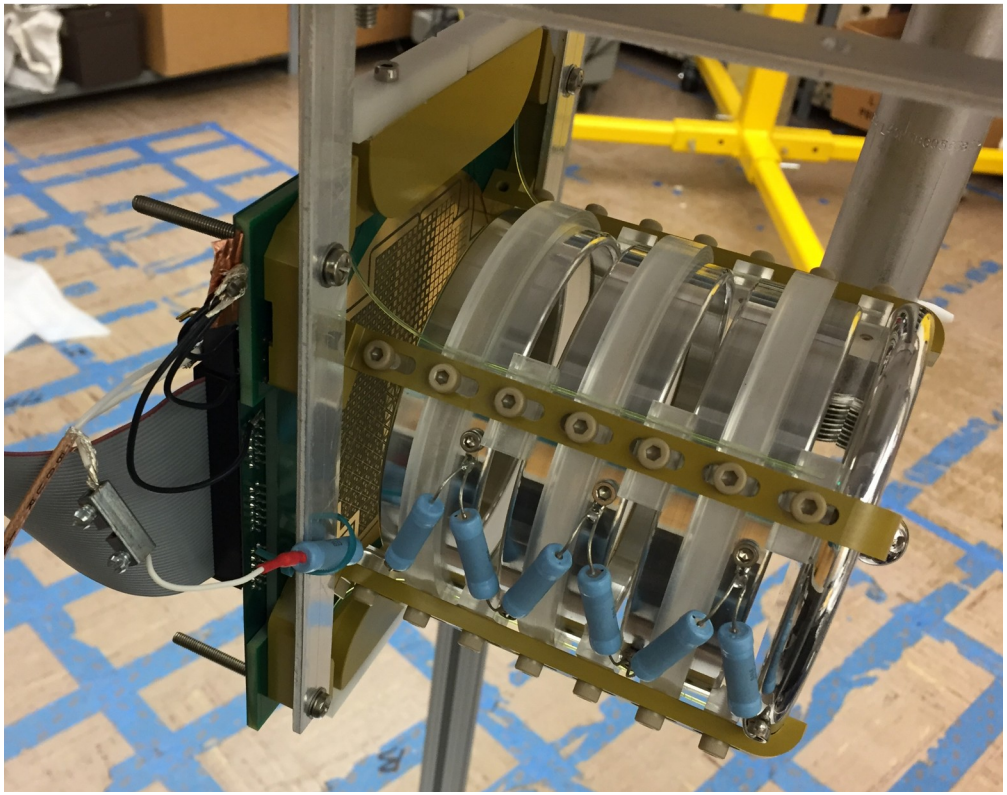
Pixel plane

- PCB with exposed pads to collect drifting electrons
- Testing 10 different geometries
- Two different shapes: square and triangle
- Three pad layouts: via only, half-full pad, full pad
- With/without focusing grid



LArPix in situ





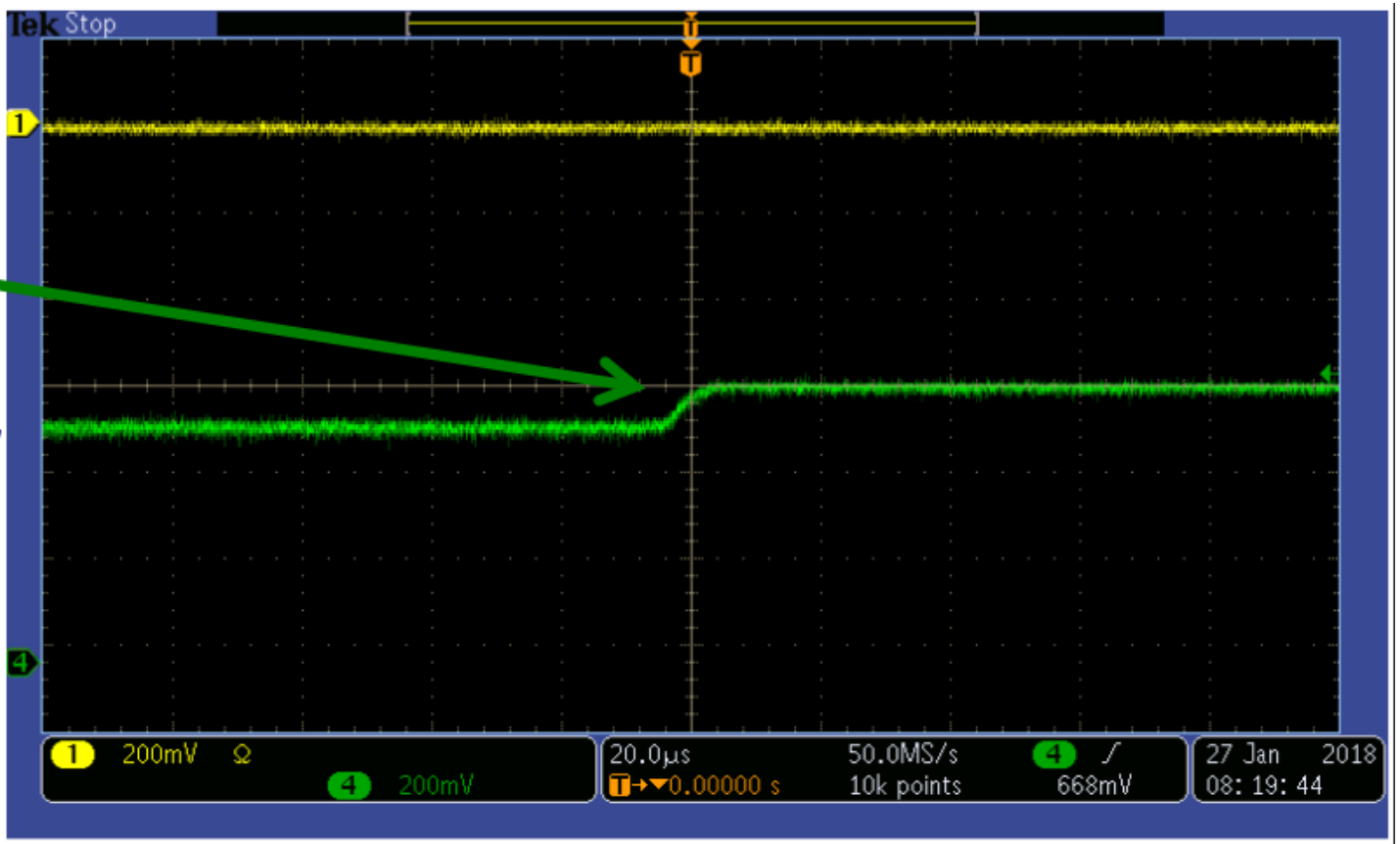
8 LArPix chips on a PCB
mounted on our TPC

Cryostat system

Thanks LZ group for letting us borrow your cryostat

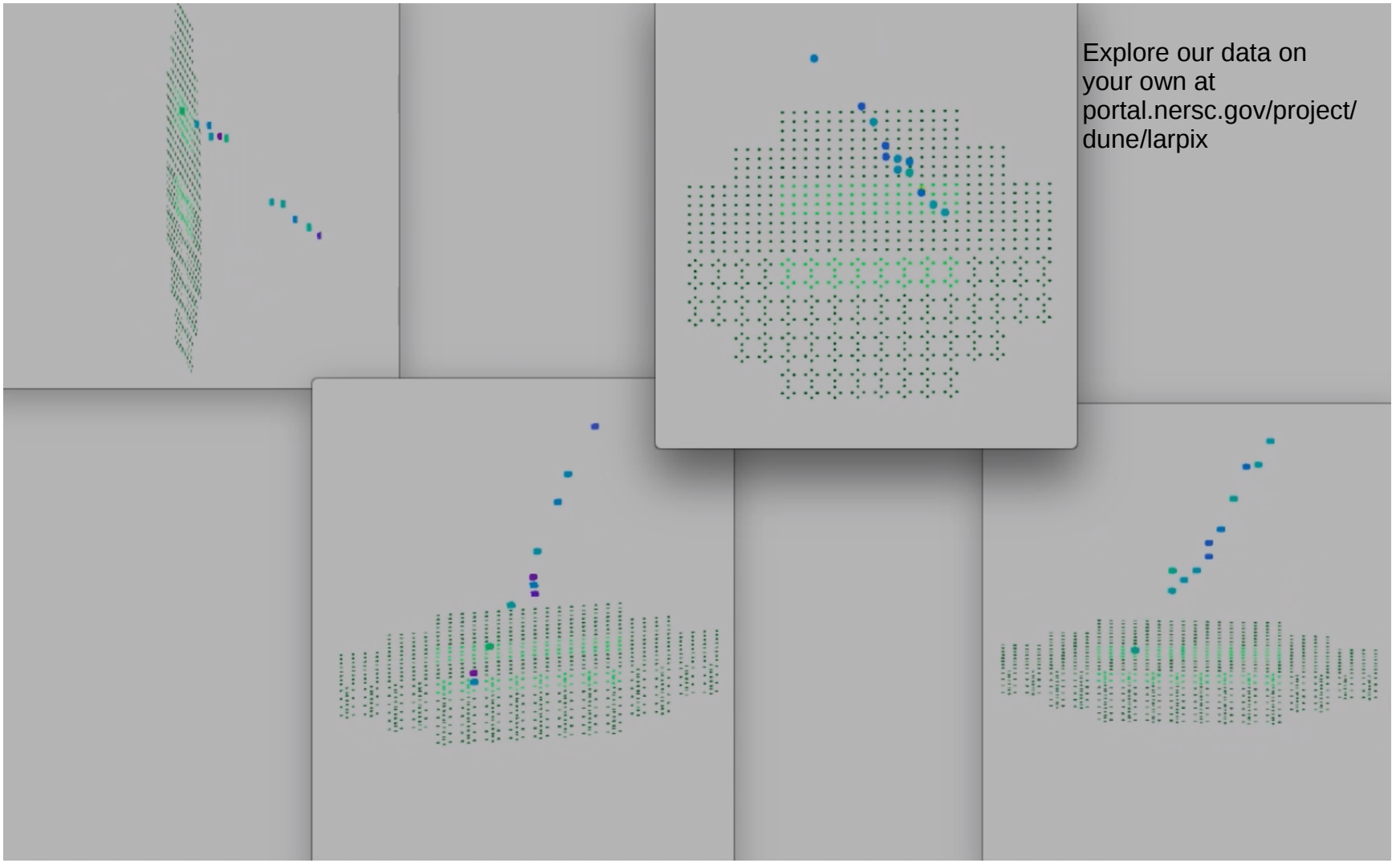
Results (finally!)

Observed pulse consistent with ~25k e- signal (using integrated analog monitor)



Our first observation of charge drift through LAr on a single pixel

Tracks!



- Bright green pixels are active
- Color corresponds to amount of charge
- Not calibrated yet so I am omitting the color scale

Outlook

- Full 28-chip board
- Redesign PCBs for faster, more consistent assembly
- Prepare LArPix-v2 ASIC
- Medium-term: beam test at LArIAT
- Medium-term: large-scale test in Bern with ArgonCube TPC
- Long-term goal: Use for the DUNE near detector!