

Kiloton-scale pixelated liquid noble TPCs

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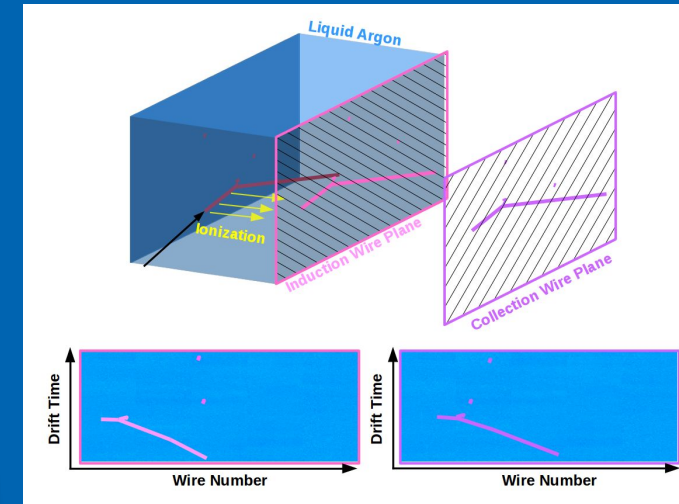
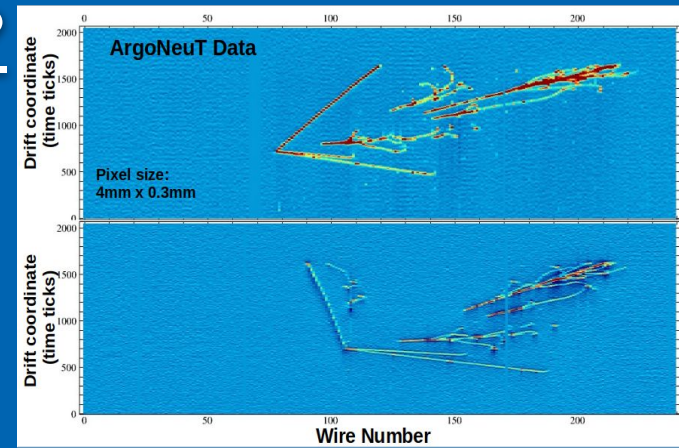


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Why pixelated liquid noble TPCs?

- Noble Element Time Projection Chambers offer access to very high quality information
- Leveraging this information allows unprecedented access to detailed neutrino interaction specifics from MeV - GeV scales
- Capturing this data w/o compromise and maintaining the intrinsic 3-D quality is an essential component of all readouts!
- Conventional charge readout uses sets of wire planes at different orientations to reconstruct the 3D image
 - Challenge in reconstruction of some topologies
- Pixel based charge readout is a natural solution



What is to be gained? (3D vs 2D Readout)

- Simulation studies comparing the readout of 2D projective Liquid Argon TPCs (LArTPC's) to 3D pixel LArTPC's shows that **3D based readout offers significant improvement in all physics categories!**
 - ν_e -CC inclusive: 17% gain in efficiency and 12 % gain in purity
 - ν_μ -CC inclusive: 10% gain in efficiency for 99% purity
 - $\text{NC}\pi^0$: 13% gain in efficiency and 6% gain in purity
 - Also offers gains in Neutrino-ID classification and final state topology ID

Table 2: Confusion matrix for neutrino interaction.

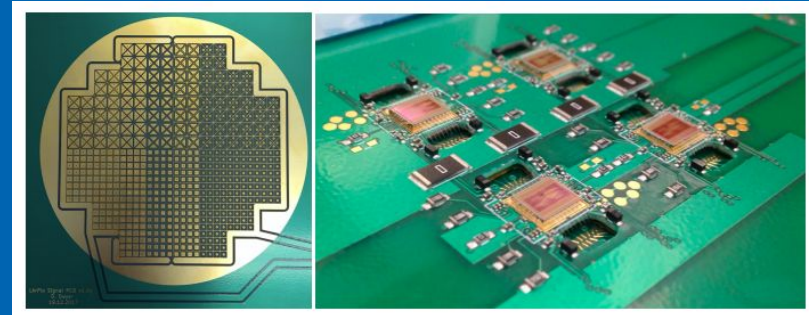
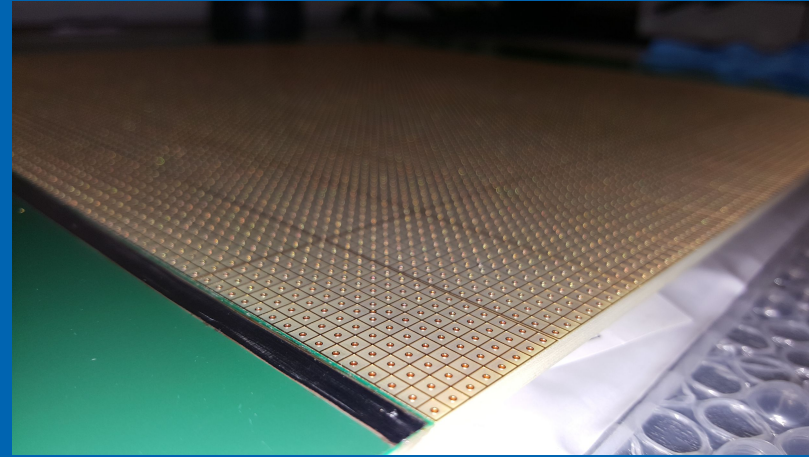
		3D Truth Label			2D Truth Label		
		ν_e CC	ν_μ CC	NC	ν_e CC	ν_μ CC	NC
Predicted Label	ν_e CC	0.96	0.01	0.02	0.93	0.02	0.03
	ν_μ CC	0.02	0.95	0.07	0.02	0.91	0.07
	NC	0.02	0.04	0.91	0.05	0.07	0.90

Table 3: Confusion matrix for the proton multiplicity classification.

		3D Truth Label			2D Truth Label		
		$N_p = 0$	$N_p = 1$	$N_p \geq 2$	$N_p = 0$	$N_p = 1$	$N_p \geq 2$
Pred. Label	$N_p = 0$	0.928	0.076	0.005	0.841	0.064	0.005
	$N_p = 1$	0.062	0.884	0.059	0.143	0.853	0.069
	$N_p \geq 2$	0.010	0.040	0.936	0.016	0.084	0.926

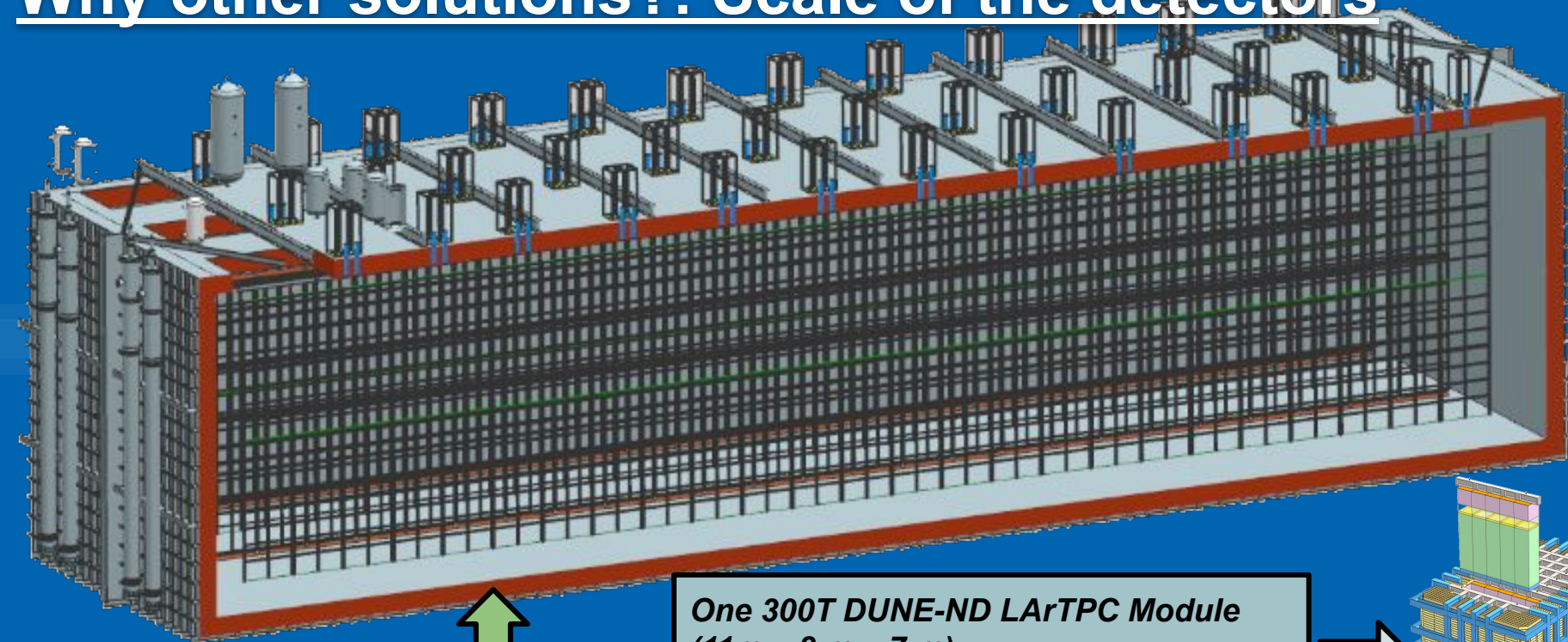
So pixelate them, what's so hard?

- Readout of a TPC using pixels instead of wires comes at the “cost” of many more channels (Example: 2 meter x 2 meter readout)
 - 3mm wire pitch w/ three planes = 2450 channels
 - 3mm pixel pitch = 422,000 channels
- LArPix (JINST 13 P10007) readout has pioneered this frontier showing a low power pixel based readout can be done
 - Currently targeted to the DUNE near detector to allow a LArTPC to cope with the high event rates
 - Other solutions are being explored for kiloton scale underground LArTPCs



(JINST 13 P10007)

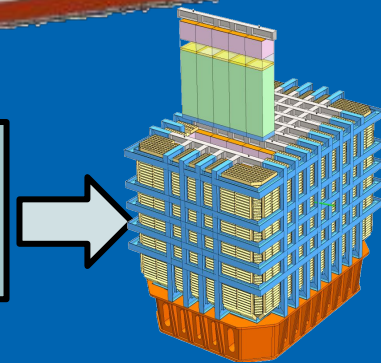
Why other solutions?: Scale of the detectors



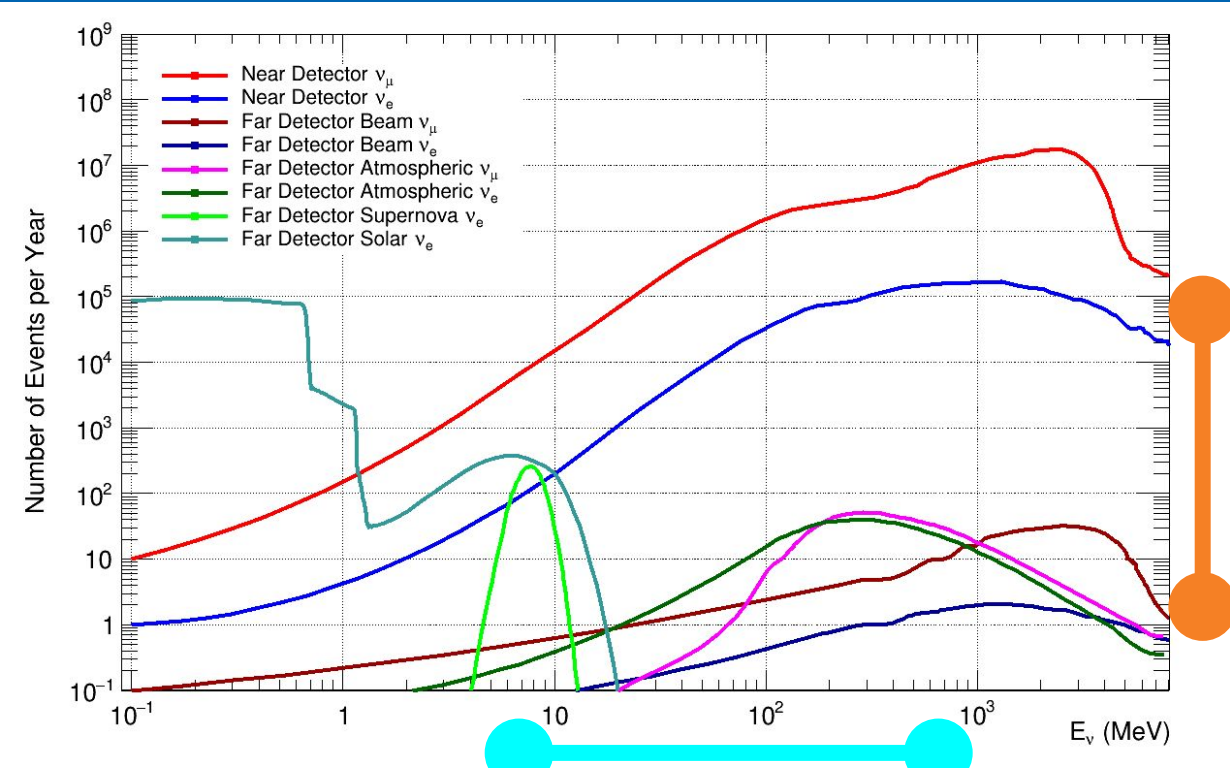
One 10kT DUNE LArTPC Module (18 m x 19 m x 66 m)
¼ the total size of DUNE
O (130 million) 4mm pixels

One 300T DUNE-ND LArTPC Module
(11m x 8 m x 7 m)
O (7 million) 4mm pixels

~18x more channels Far/Near



Scale of the detectors



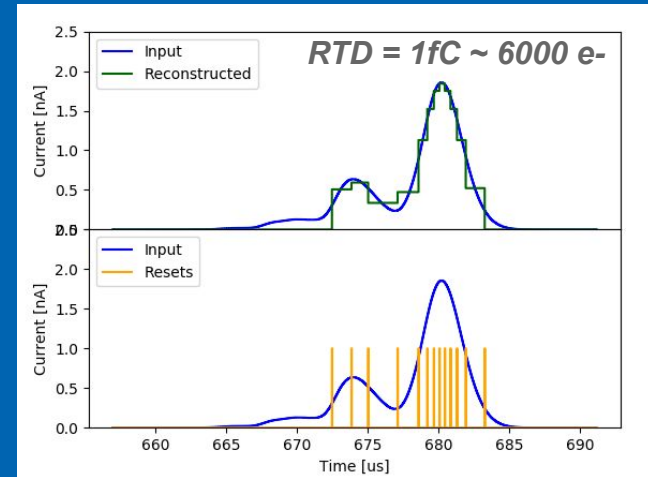
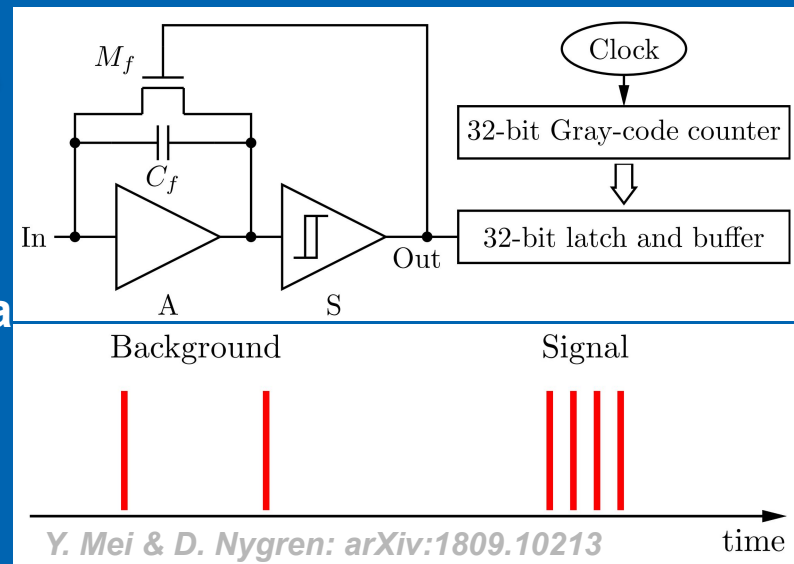
Estimated event rates in the DUNE LArTPC Near Detector (ArgonCube) and a single DUNE 10kTon Far Detector Module

- 10⁵ - 10⁶ difference in event rate from beam events near/far
- Same number of events from the beam as from astrophysical sources
 - Spans 10² MeV energy range

Scaling pixel based readout to the multi-kiloton detector may require an “unorthodox” solution

An unorthodox solution: Q-Pix

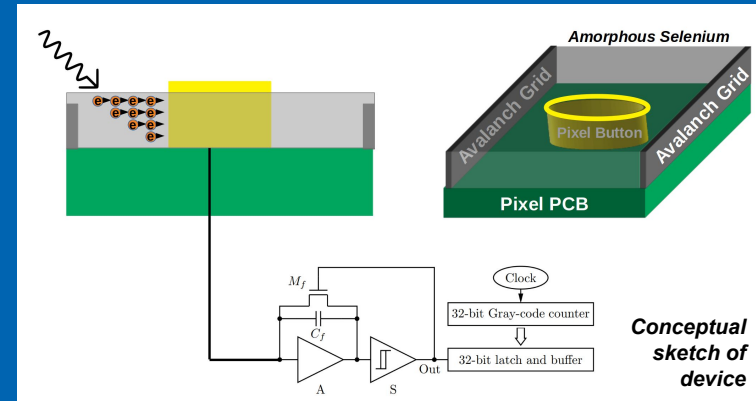
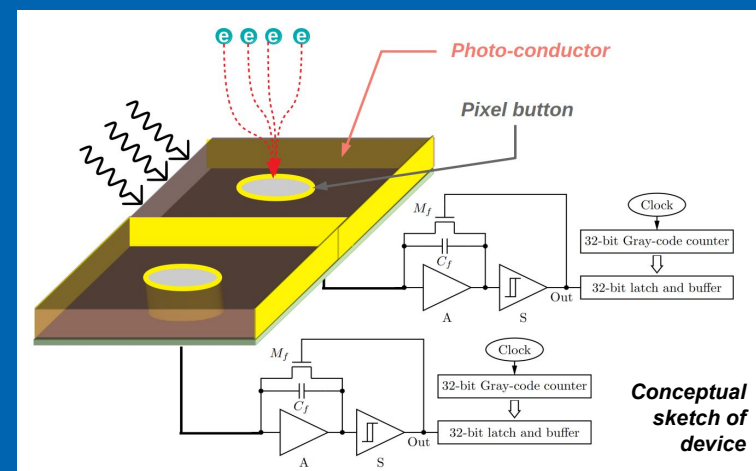
- The Q-Pix pixel readout follows the “electronic principle of least action”
 - Don't do anything unless there is something to do
- Offers an innovation in signal capture with a new approach in measuring **time-to-charge: (ΔQ)**
 - Keeps the detailed waveforms of the LArTPC
- Take the difference between sequential resets
 - Reset Time Difference = **RTD = ΔQ**
- RTD's measure the **instantaneous current** and captures the waveform
 - Small average current (background) = **Large RTD**
 - Background from ^{39}Ar ~ 100 nA
 - Large average current (signal) = **Small RTD**
 - Typical minimum ionizing track ~ 1.5 nA



An unorthodox solution: Q-Pix

Such a low power & low threshold charge readout of Q-Pix opens the opportunity to “blue sky” R&D into an integrated Q+L pixel sensor

- If realized, offers a transformative opportunity in Noble Element TPC's
- Currently exploring different thin-film photo-conductors (e.g. a-Se, ZnO, PZT, etc)
 - Possible to be sensitive to a broad range of wavelengths (including directly to VUV)
 - Can greatly enhance the photo-coverage of a TPC by making the charge sensitive area the same as the photon sensitive area
 - **Current surface area instrumentation is < 1%**



Much to be worked on: Q-Pix Consortium

- Six central ideas being worked on
 - **Circuit Design:** A prototype of the front-end + oscillator is expected to be completed in the next 6 months
 - **Physics Simulations:** Quantify the conferred benefit of pixel vs. wire readout and the requirements of the ASIC design
 - **CIR Input:** all extraneous leakage current at the input node needs to be small (aA)
 - **Clock:** $\delta f/f \sim 10^{-6}$ per second
 - **Digital Network:** Robust readout through dynamic networks
 - **Light Detection:** Exploring new ideas using photoconductors on the surface of the pixels
- Many more interesting ideas/applications than what can be squeezed into this flash talk (more to come out during Snowmass process)
 - Happy to collaborate & talk about ideas with interested parties!