R&D towards **Large** LAr Detectors

FPD Planning meeting

James Sinclair

July 16th, 2024

SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

Charge in Argon

After recombination, a MIP produces ~5k electrons/mm at 0.5 kV/cm.

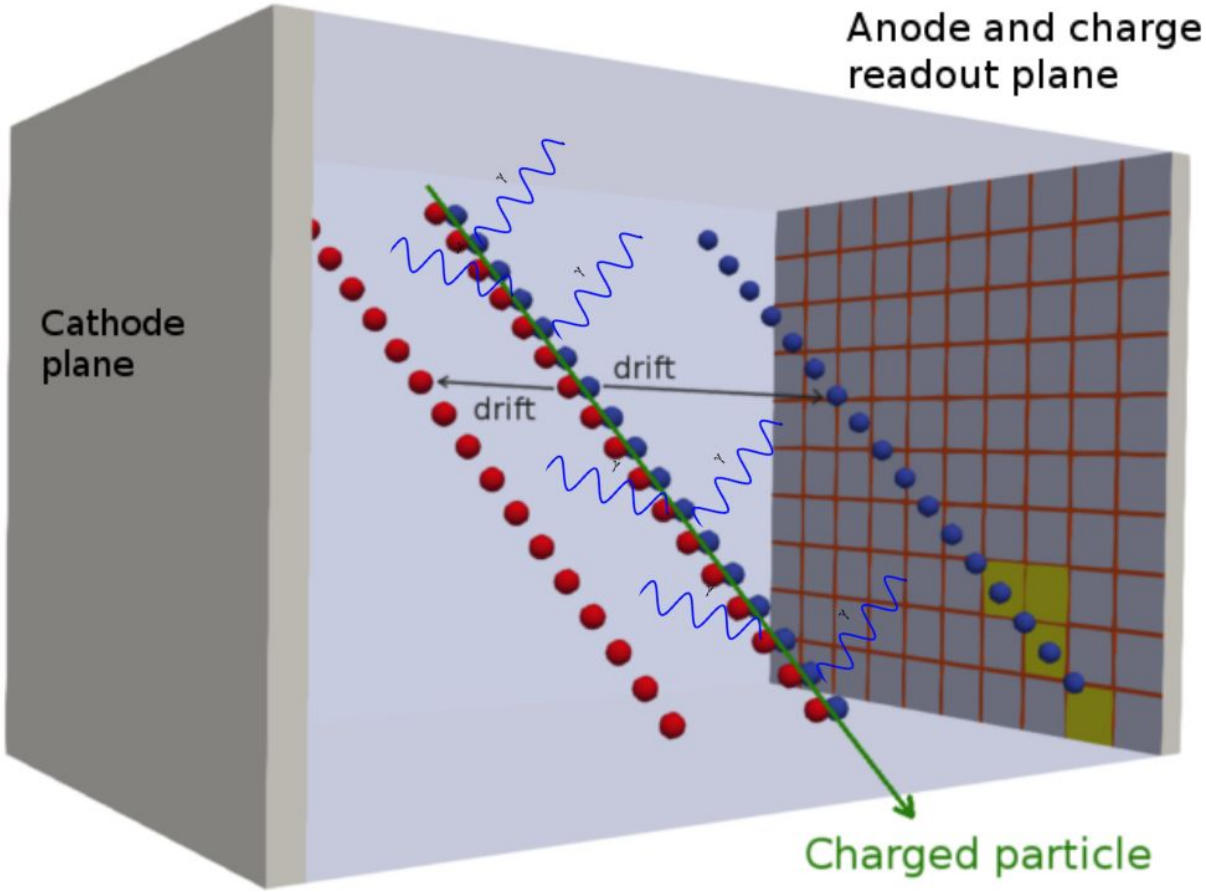
Electron drift speed is O(1)mm/μs at 0.5 kV/cm.

Transverse diffusion is ~1 mm^2 after 1 m drift at 0.5 kV/cm.

Pixel/Wire pitch should be set based on desired ENC and charge sharing.

Charge lifetimes >90 ms are achievable. 9.5 m drift with 10% reduction in charge.

-charge is not limiting large LArTPCs.

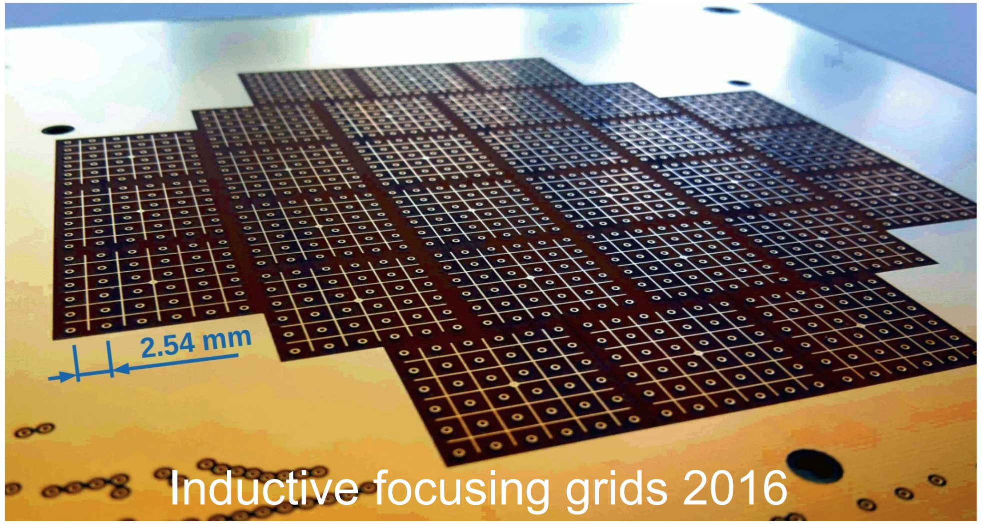


Pixel problems in Argon

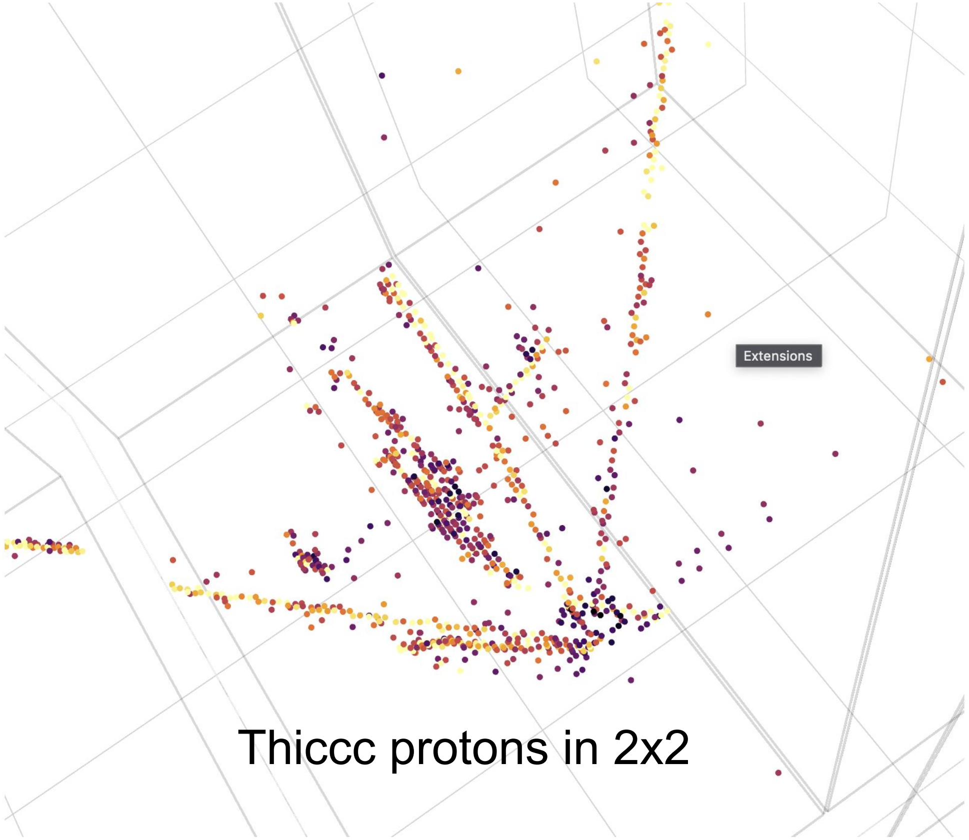
Wires had some drawbacks, but there are some intrinsic benefits:

- Cover a very large area with a limited number of channels
- Minimal heat input, especially with warm electronics
- Inductive focusing

Recent applications of pixels have illustrated the need for inductive focusing.



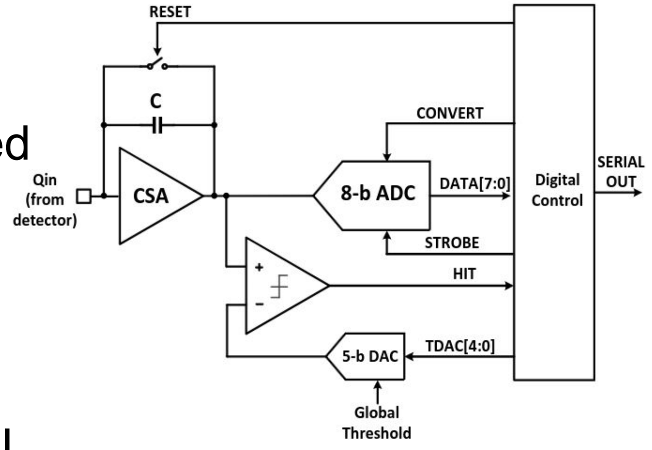
Inductive focusing grids 2016



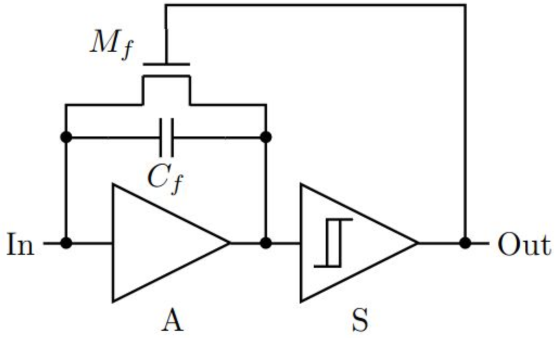
Thiccc protons in 2x2

Approaches to Pixels

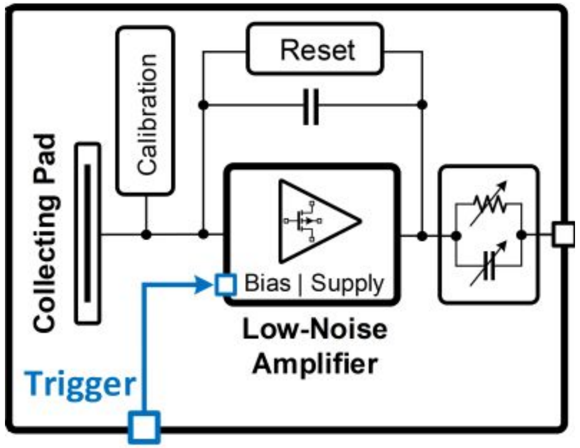
LArPix (2017 liquid) - designed for high multiplicity ND, low-power amplifier with triggered ADC, 500 ENC



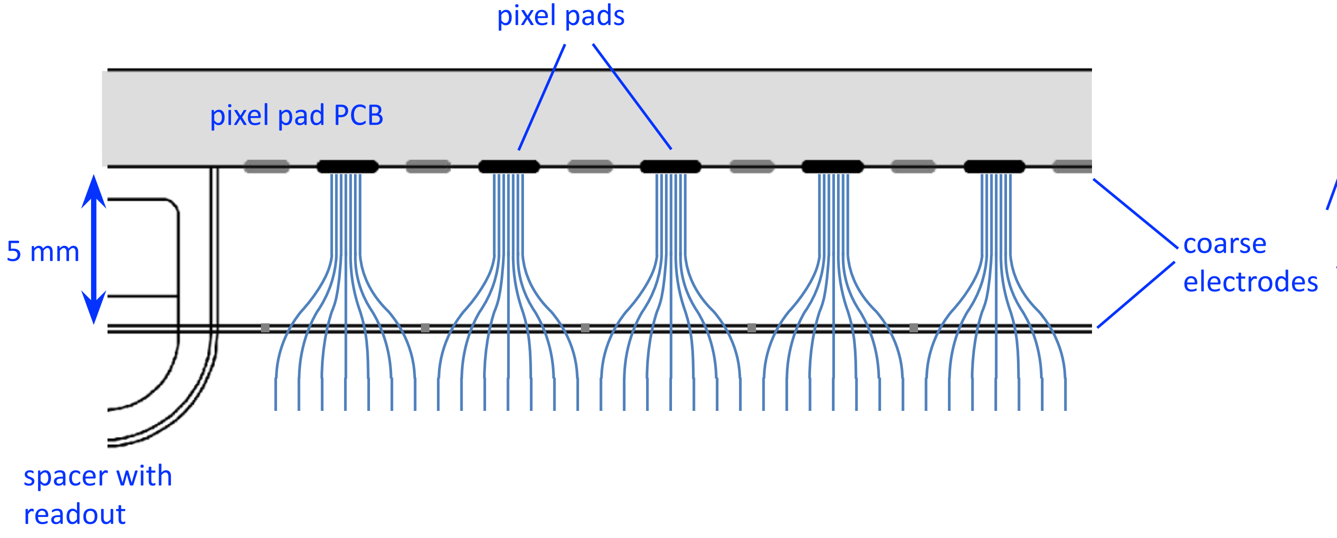
QPix (2023 gas) - designed for DUNE, continual charge integration and Schmitt trigger, goal <500 ENC

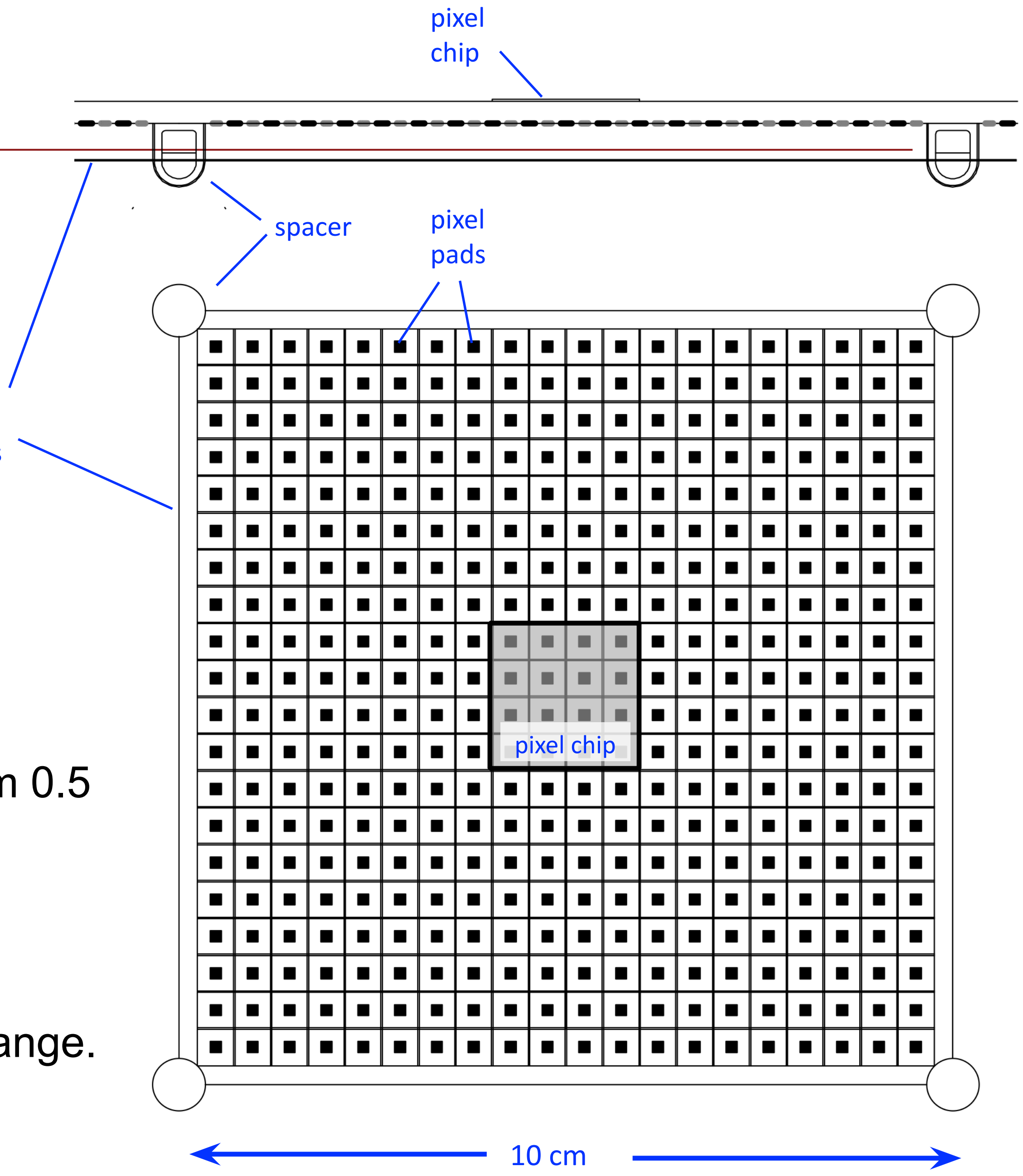


GAMPix - design for Gamma ray searches, high-power/low-noise externally-triggered amplifier, goal 25 ENC



GAMPix for DUNE





Pixel pitch should roughly match diffusion: increase pitch from 0.5 mm to 3 mm to 5 mm.

No coarse grids. Read out focussing electrodes instead

Initial study: pixel noise ENC ~50 e-, or 2.5 keV.

Coarse electrode similar or higher, depending on dynamic range.

SLAC

Light in Argon

A MIP produces ~5k photons/cm at 128 nm from different excited states:

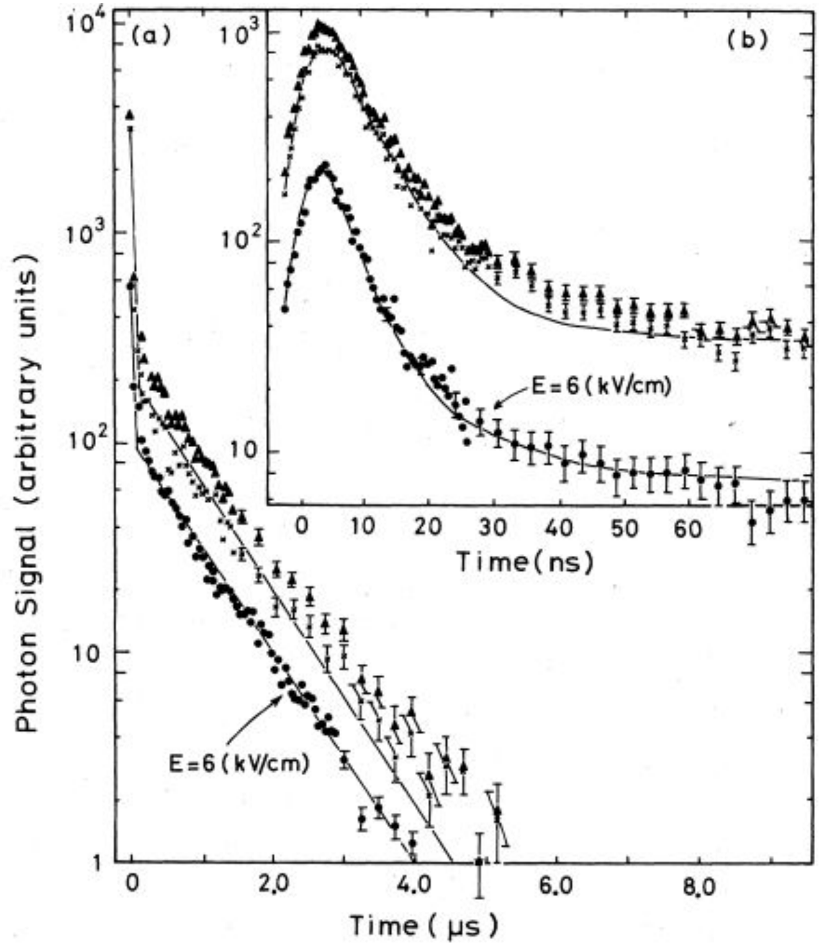
- Singlet states have a decay lifetime of a few nanoseconds.
- Triplet states have a lifetime of several microseconds.

N2 suppresses the slow component, Xe recovers it.

Rayleigh scattering smears out photon arrival times by **O (10) ns** for propagation distances of **O (1) m**.

If sensors are multiple metres from the interaction, timing is degraded.

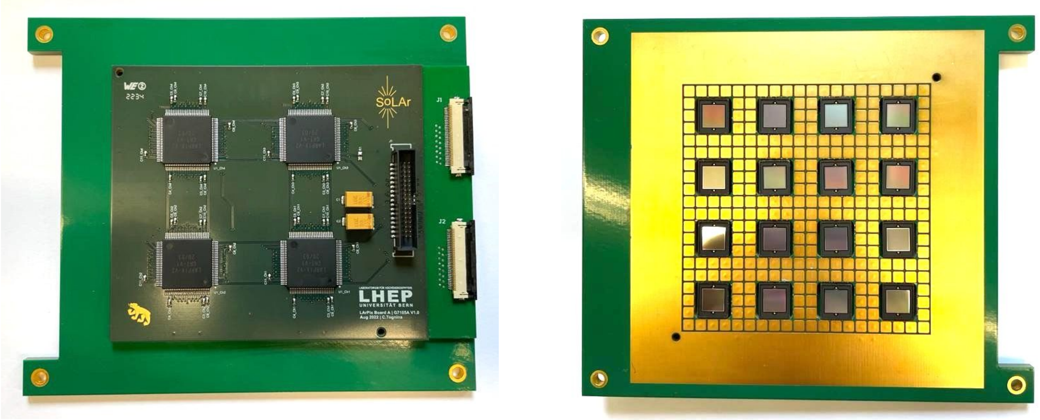
- this is the problem for going big in LAr.



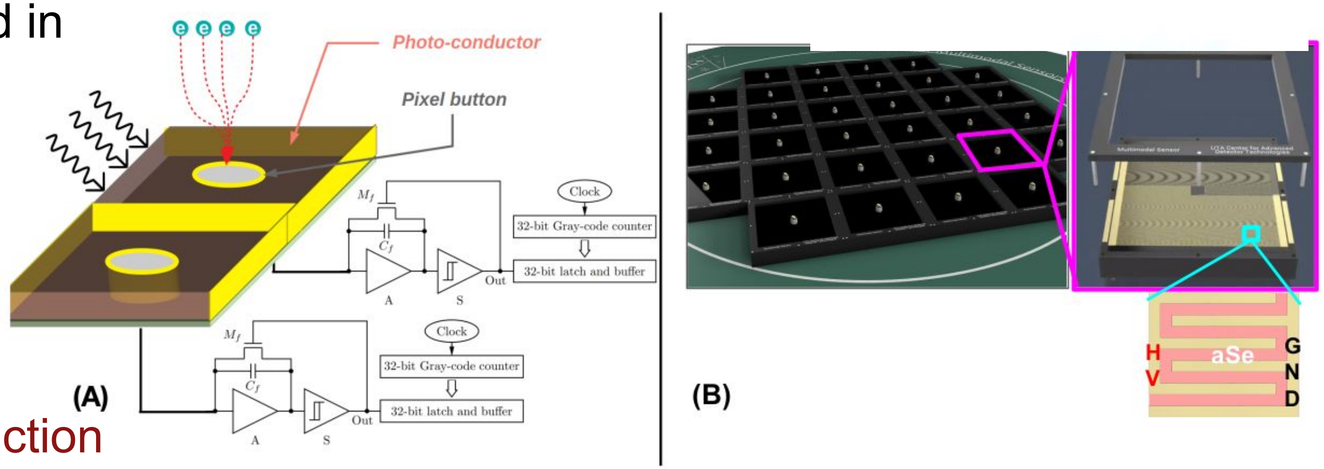
Current efforts in Light

Multiple groups are working to combine light and charge readout in the same PCB:

SoLAr/LightPix is using SiPMs with ASIC backend.



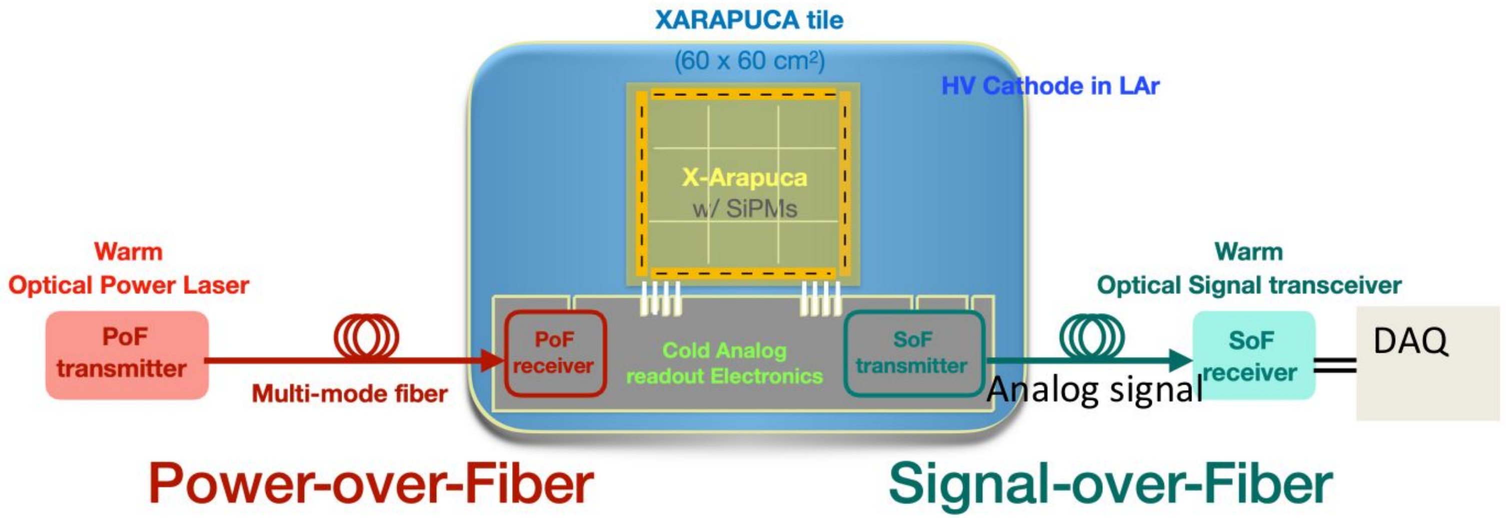
QPix-LILAr is using charge amplifiers coated in photoconductive material.



But, the anode can be metres from the interaction

Power over Fibre in DUNE

FNAL has developed a power-over-fibre (PoF) and Signal-over-fibre (SoF) system to instrument the cathode in VD:



The power is limited to ~1 W (2W IR laser at 50% efficient).

The SiPMs cannot be digitized cold.

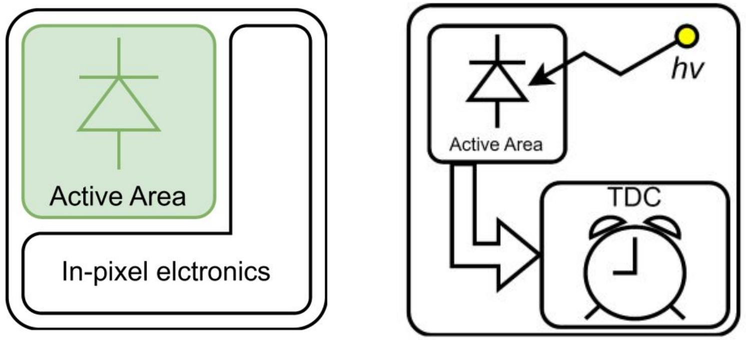
Signals sent out via analogue multiplexing for external digitization.

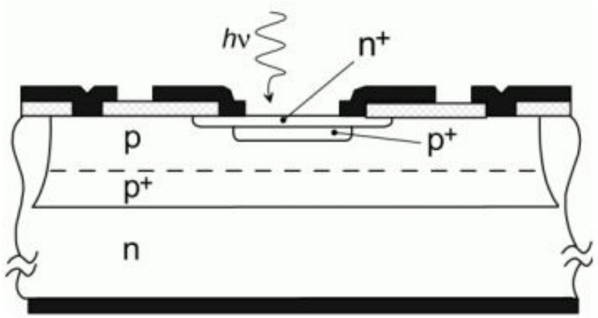
Light trap (Arapuca) used to increase coverage. Timing is degraded by photon traps.

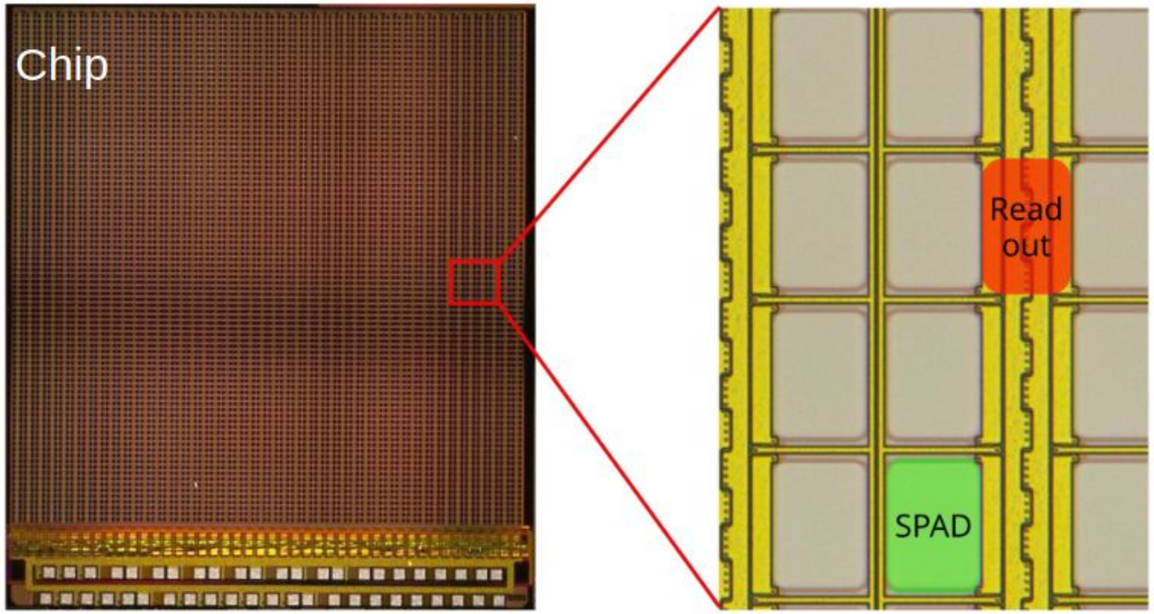
SiPMs: Analogue to Digital

SiPMs are arrays of SPADs, summed to give a linear response. SPADs are intrinsically digital detectors.

SPADs can be coupled directly to TDCs in CMOS, providing exquisite timing, O(100)ps, with very low power and noise. Digital (d)SiPMS:







Heidelberg’s DARWIN dSIPMs

dSiPMs state of the art

DESY has been developing the concept for medical imaging since 2015.

FBK are producing these for medical imaging.

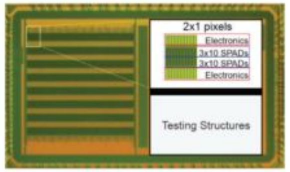
ORNL are using them for neutron imaging with.

Heidelberg is testing them for DARWIN (LXe).

Sherbrooke and TRIUMF have been developing them for nEXO.

As yet not applied in HEP, but SLAC is now working with FBK.

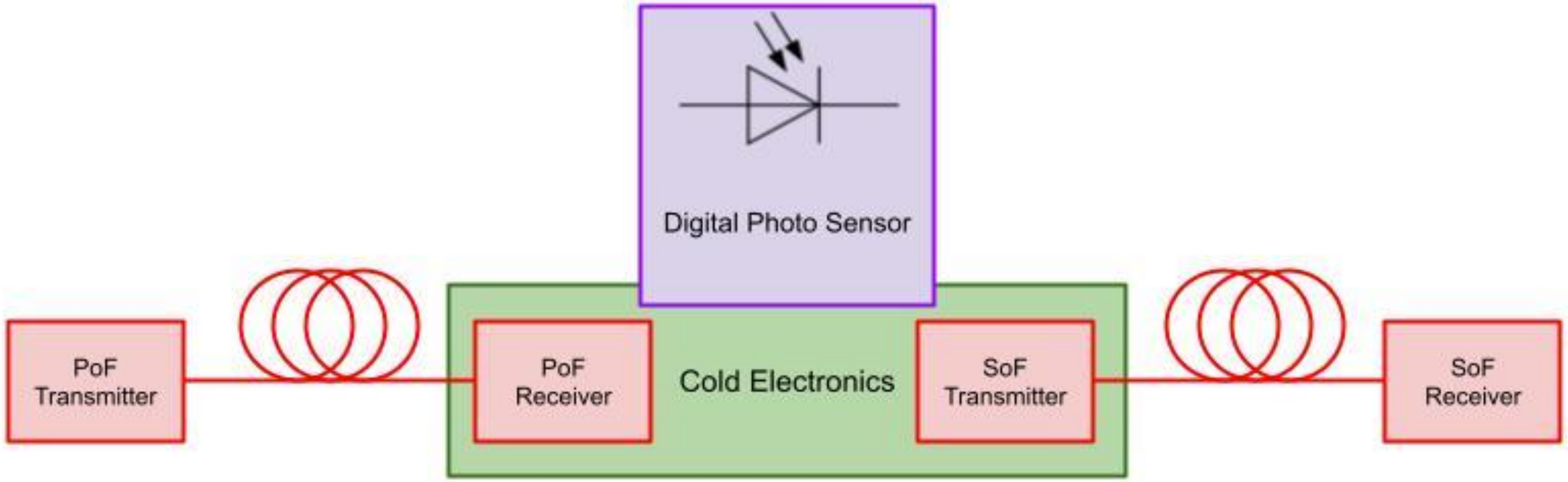
CMOS Imager Summary



	Parameters	SBAM
Chip	Tipology	Digital-SiPM
Chip	Technology	150 nm
Chip	Pixel pitch [µm]	250 x 125
Chip	Array size	16 x 8
Chip	Fill-factor [%]	32.1
Chip	DCR median [Hz]	500
Chip	High Voltage for SPAD	18V – 21V
Chip	Power supply for electronics	1.8V
Chip	Power consumption	< 57 mW
TDC	Time resolution [ps]	80
TDC	Full scale range [ns]	81.8
Readout	Frame-rate [fps]	20k
Readout	SRAM in pixel	Yes
Readout	Output	Time-stamp

dSiPMs + PoF

Use power and signal over fiber as enabling technologies to deploy dSiPMs:



Power via LDO: 48 V for SiPM bias, 5 V for electronics, ~ 1 W total.
(Achieved by FNAL)

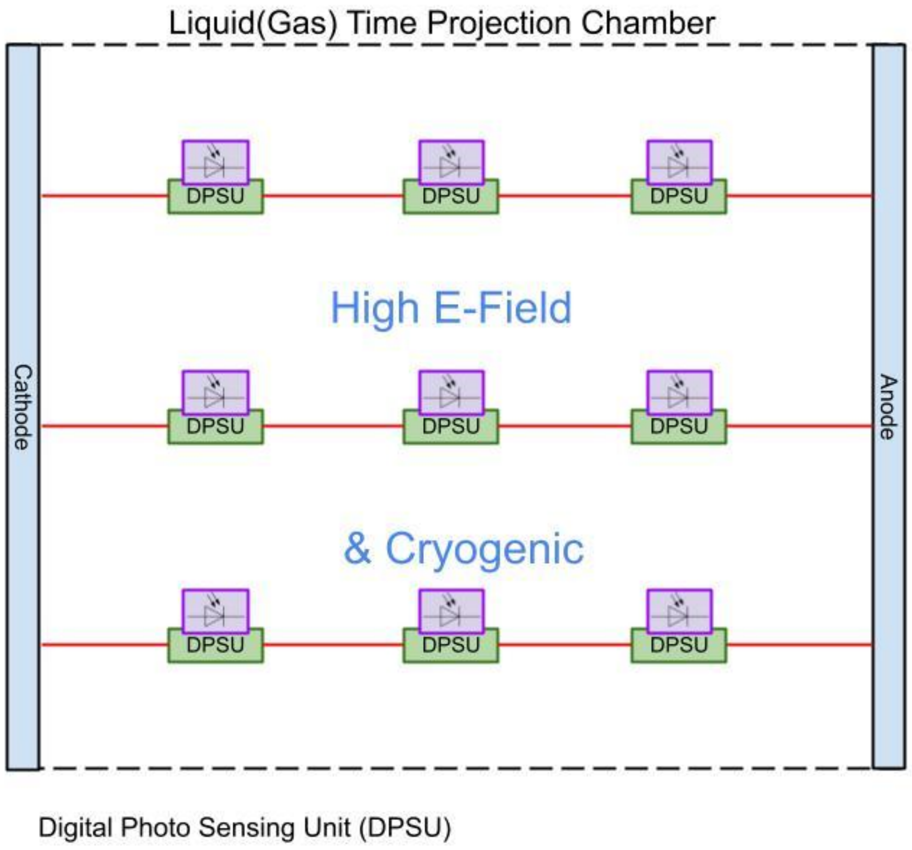
What these device enable?

Fiber-coupled dSiPMs could be strung between anode and cathode in an array like IceCube's DOMs.

Picosecond timing enables:

- Track directionality.
- Providing localized triggers for low-E events.
- Particle identification through timing.
- Tagging non-obviously-spatially-correlated activity (neutrons).

It would also simplify the DAQ and reduce computing requirements. No more waveforms.



Funding agency drivers

Snowmass instrumentation - Photodetectors and photon to digital converters:

'IF02-1.. Counting single photos... We now need to pursue R&D to implement these in HEP experiments...'

'IF02-2... New photodetector developments for future neutrinoless experiments... We now need to move from conceptual phase 2 working detectors...

Basic research needs for HEP

PRD9 Thrust 1 'Adapt photodetectors for extreme environments'

PRD26 Thrust 2 'Addressing challenges in scaling technologies'

2021 ECFA research and development roadmap:

'The main challenges facing near to long-term future experiments are photosensor coverage huge surfaces (DRDT 2.4), in extreme environments (DRDT 2.1) and with single-photon sensitivity (DRDT 2.2).'

'Radio purity of light collection, sensing, front and electronics and signal transmission technologies is an essential wire and for dark matter experiments,...'

'..digital devices are very viable alternative as they ultimately promise improved performance...'

Some Possible Future LArTPC Activities

FPD Planning meeting

Mark Convery

July 16th, 2024

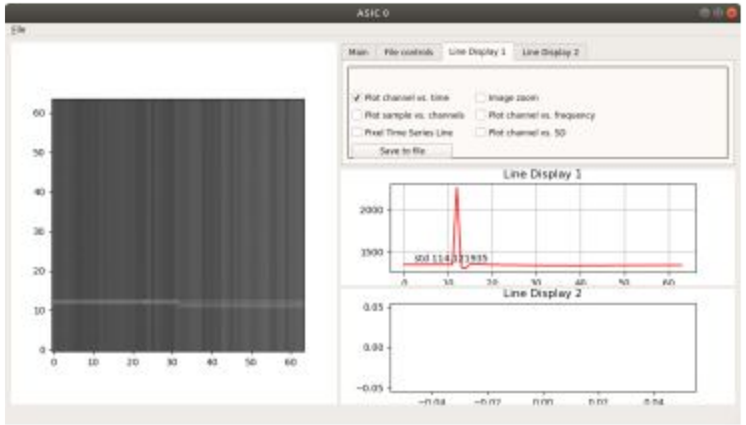
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University | U.S. DEPARTMENT OF ENERGY

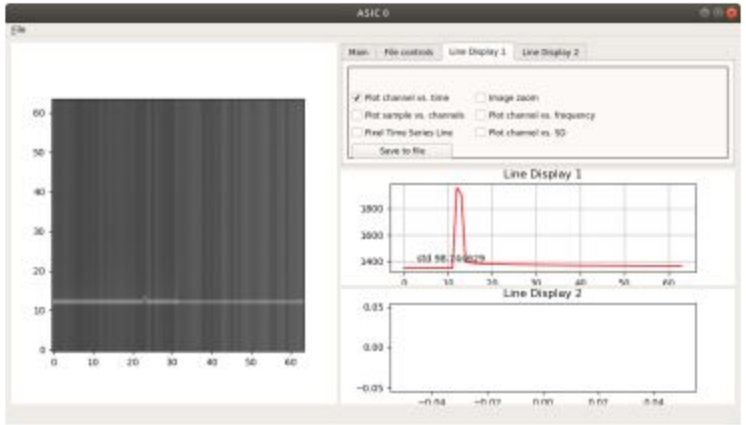
Future LArTPCs - Cryo ASIC development

- CRYO ASIC was proposed for nEXO, and adapted to possible use in DUNE
- Combines three functions (pre-AMP, ADC, digital multiplexing) of the DUNE chain into a single ASIC. For 64 channels, need 1 ASIC, instead of 9.
- Any future wire-based LArTPC could benefit from this simplification
- Ran into trouble with performance at LN2 temperature, current studies under-way

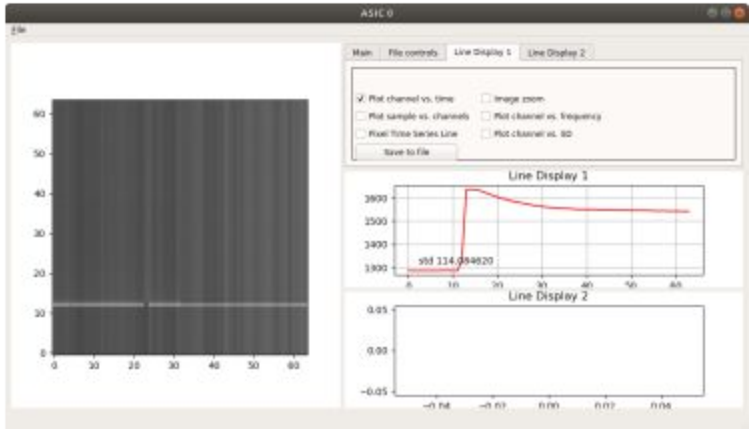
12:33:46
LDO=1.086
T=130K



12:39:08
LDO=1.093
T=120K



12:42:23
LDO=1.105
T=116K



SLAC

Future LArTPCs - GAMPix ASIC development

- CRYO noise performance is not expected to be better than the DUNE chain
- Pixel-based detectors offer advantages, but noise in LArPix or Qpix is not much better than wires. Strange because C_{det} is the source of thermal noise
- However, noise is also dependent on pre-amp power, which is limited due to high channel count in pixels. Low C_{det} and low power effects mostly cancel out
- Solution may be to do a “pulsed power” solution, where the pre-amp is off for the majority of the time. Allows higher pre-amp power -> lower noise
- Need trigger for pulsed power
  - Would have been a great solution for ND LArTPC!
  - In FD, need to trigger on charge in induction plane (or maybe PDS). Pre-amp can be turned in < 1 microsecond
- Tom Shutt developing GAMPix for space-based GammaTPC
- Possible applications for DUNE Phase 2
  - Noise <50e- seems achievable.
  - Physics case needs to be made

Future LArTPCs - FLArE Experiment at CERN

- Proposal for LArTPC-based neutrino experiment in ATLAS forward region
- TeV neutrino detection
- SLAC ATLAS colleagues have asked if we are interested
- https://indico.cern.ch/event/1216905/contributions/5448933/attachments/2702685/4691235/FLArE_NuFACT_2023_08_25.pdf