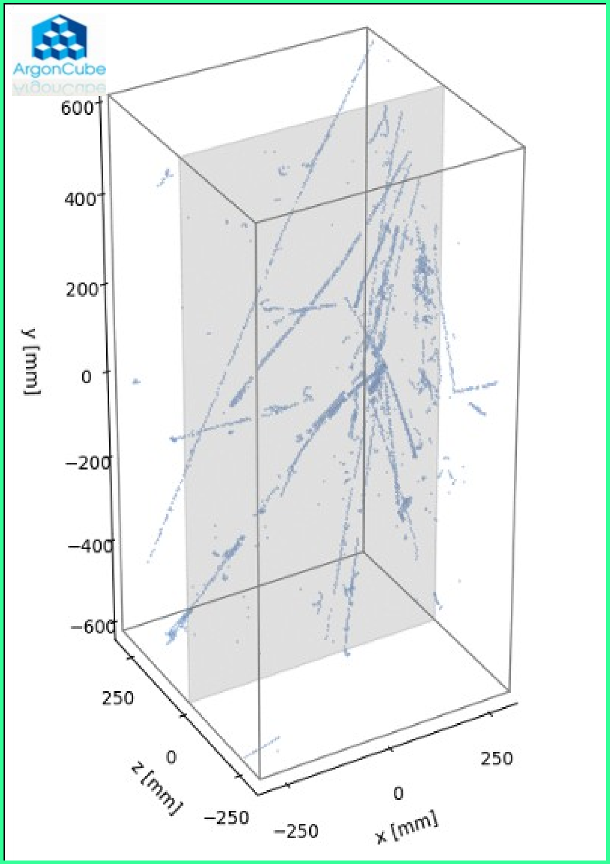
Task Force 2, Liquid Detectors

Charge collection in Noble liquids



ECFA Detector R&D Roadmap Symposium
9 April 2021 to 7 May 2021

ECFA
European Committee for Future Accelerators
ECFA Detector R&D Roadmap

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Liquefied noble gases as ionization media

	LAr	LXe
High density	1.4 cm3	3.1 g/cm3
Reasonable Wi	23.6 eV/e	15.6 eV/e
Submicron initial coordinate resolution	*	*
Cost	:-)	:-/
Radiopurity	^{39}Ar (269y)	^{136}Xe (2*10^{21}y)
Temperature range	84 K -87 K	161 K - 165 K
Purification	:-)	:-)

Ionization charge in noble liquids

- linear charge density : 2.1 MeV/cm ~9ke$^-$/mm for LAr, 4.0 MeV/cm ~26ke$^-$/mm LXe)

- charge recombination MIP@1kV/cm: ~0.72 for LAr, ~0.65 for LXe

- typical charge yield for typical TPC wire R/O resolution:

  3 mm wire pitch @1kV/cm ~ 19ke$^-$ for LAr, ~51ke- for LXe

- Fano factor : 0.1-0.2 for LXe & LAr (0.05 by Doke, double-phase LXe)

- charge drift in 1kV/cm electric field: 2.2×10^5 cm/s for electrons, O(cm/s) for ions

- electrons diffusion in E-field, longitudinal and transverse:

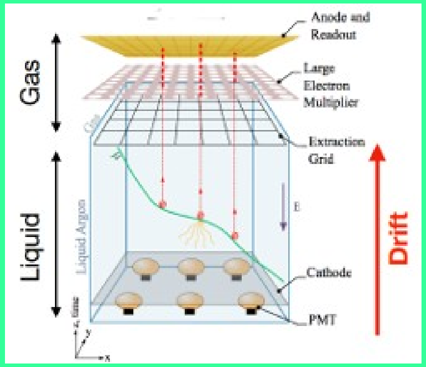
  LAr: D_L= 6.7 cm^2/s, D_T= 17.0 cm^2/s, ~ x4 larger for LXe
  17 cm^2/s → cloud FWHM = 4.1 mm/$\sqrt{\text{ms}}$

- electrons loss on impurities: exponential, ~ 300us / C[ppb], typical values for LAr: 1-10 ms

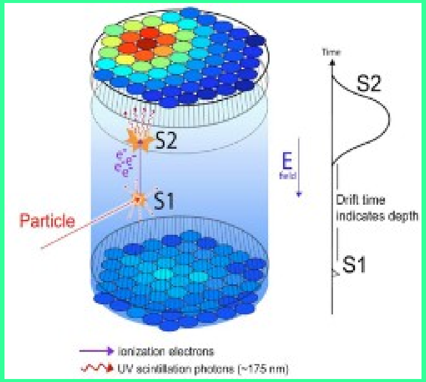
- typical final charge to collect - several fC, O(10ke-). Measureable, but not a lot!

https://userswww.pd.infn.it/~conti/LXe.html
https://lar.bnl.gov/properties/
https://arxiv.org/pdf/1609.04467.pdf

Charge amplification in noble liquids



- A trick: charge extraction to gas phase, amplification in GAr, gains ~ 100



- Dual - phase LXe TPCs: charge readout via luminescence

Nice review: A.Buzulutskov, Instruments 4 (2020) 2, 16

- Attempts to reach amplification in liquid phase
  unstable results for LAr...

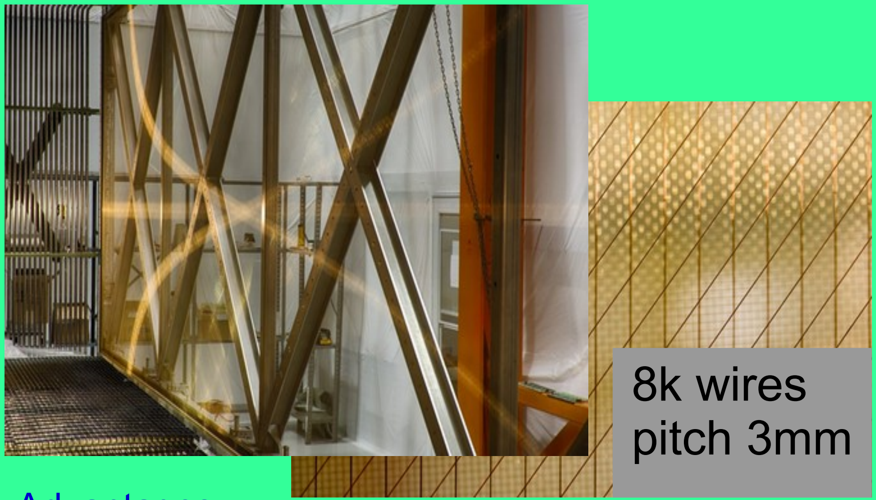
- Doping LAr with > 1 ppm of Xe: Gains ~100 demonstrated.

https://arxiv.org/pdf/hep-ex/0204033.pdf

- New ideas on <u>hybrid methods</u> (localized electroluminescence, for instance) ?

R&D within DARWIN collaboration : Freiburg University and University of California San Diego.

Charge collection in noble liquids: pixels vs wires



Advantages:

- projective readout -> low channel number

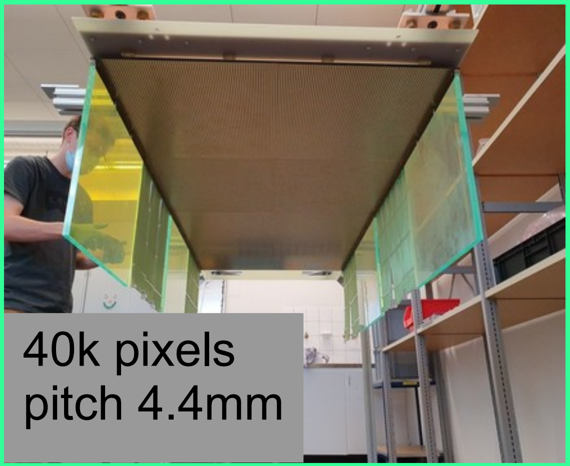
- optically transparent -> simple light readout

Drawbacks:

- Projective readout -> ambiguities, low track reco efficiency (60% in uBooNE)

- Mechanically sensitive (microphonic effect)

- Sensitive to single-point failures



Advantages:

- unambiguous true-3D readout -> easy reconstruction

- Mechanically robust

- Insensitive to single-point failures

Drawbacks:

- Many pixels - high initial channel number, need zero-suppression in-situ

- Non-transparent, require specific solutions for light readout

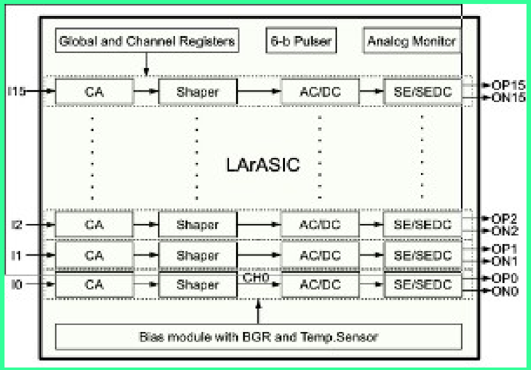
Charge collection in noble liquids: cryogenic charge amplifiers

Required bandwith ~ 1-10 MHz (defined by required resolution in drift direction)

Required ENC < 1000 e- for S/N~10 in typical geometries

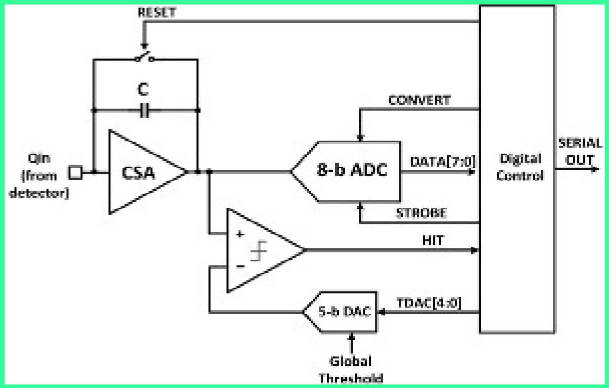
LArASIC4 (BNL) - 16 channels CSA chip for **wire** readout,

25 mV/fC, ~500 e- ENC, 10 mW/ch



LArPix v2 (LBL) - 64ch r/o charge processor for **pixel** r/o with zero-suppression

25 mV/fC, < 500 e- ENC, 62 uW/ch



Lowering power dissipation is very much desired.

The stage is open for new ideas and realizations !

Charge collection in noble liquids: ArgonCube technology

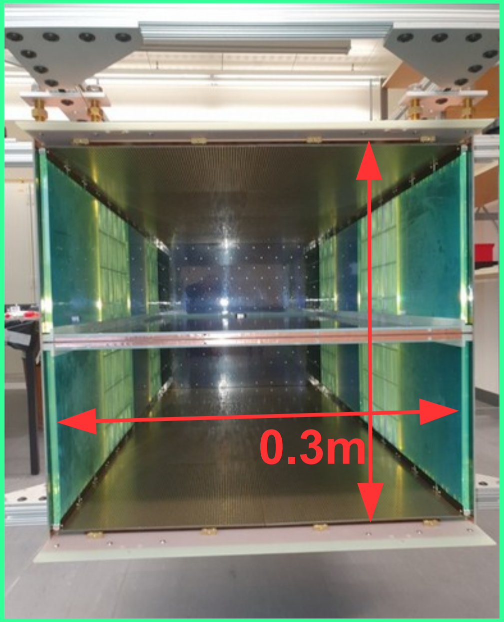
- Pixelated anode in DUNE ND-LAr 2x2 Demonstrator

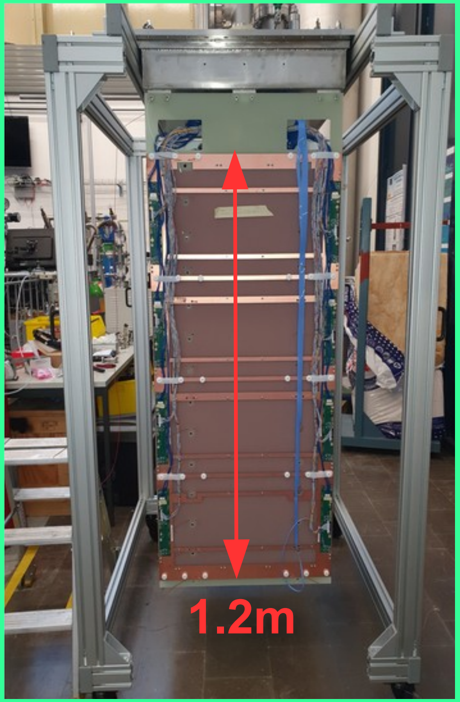
  78400 pixels / module, 4 modules

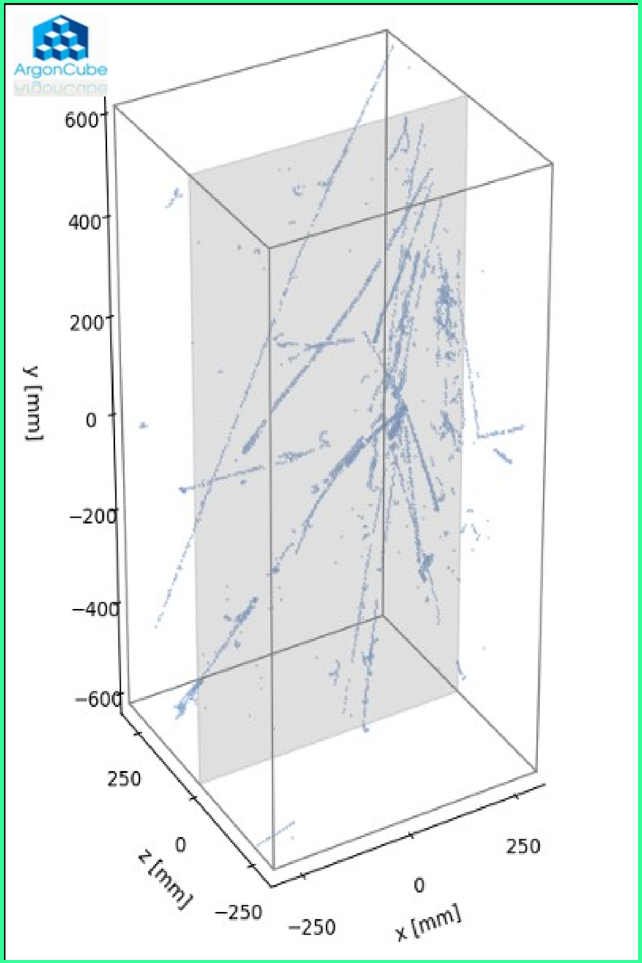
- Pixelated anode in ND-LAr

  ~300k pixels per module, 35 modules - challenging !

- Pixelated anodes for DUNE FD MoO ?



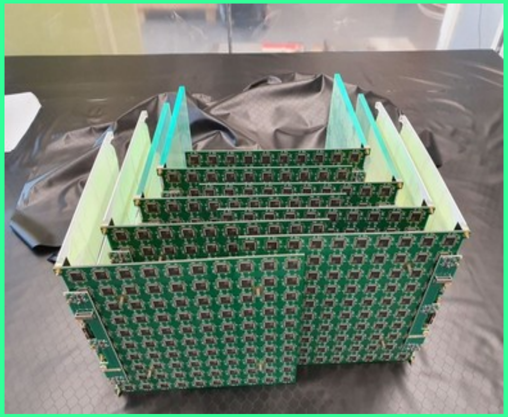




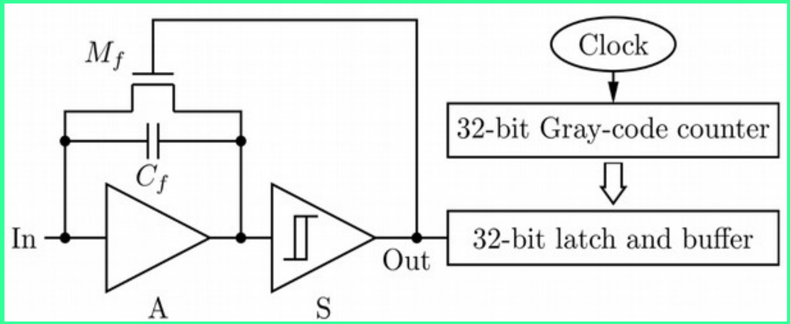
Charge collection in noble liquids: perspectives

Multi-channel charge processing ASICS:

LArPix new generation, speed up, more channels, lower power...



D. Nygren's Qpix ASIC (time-to-charge approach)



(https://indico.fnal.gov/event/21535/contributions/63303/attachments/39668/48006/QpixConceptFEelect2.pdf)

Integrated Charge Coupled readouts (a la CCD or CMOS)

Charge amplification in liquid : new dopants, new schemes

Charge collection in noble liquids: open questions

- Charge amplification in liquid - stability

- Hybrid readouts (charge → electroluminescence → high-granularity optical imagers) :
  scalability, cost, performance

- Pixel charge processing ASICs :
  dissipated power,
  data rate,
  S/N ratio

- Pixelated anodes scalability, cost

A lot to study in coming years !

Thank you!

Backup slides

Output data rate from the pixelated R/O

Example: pixelated anode based on LArPix V2 ASIC (LBNL)

Pixel tile: 30x30 cm, 100 ASICs, 4900 pixels.

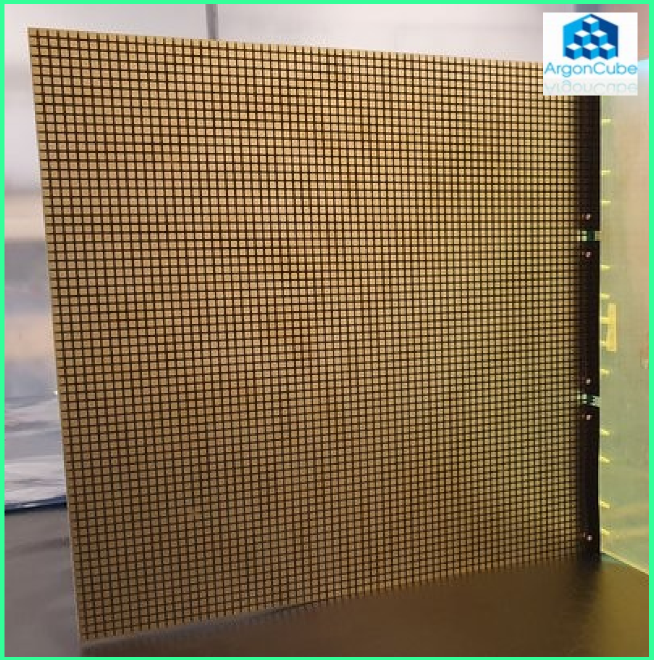
LAr TPC: Drift length 32cm, @1kV/cm

Pixel rate 0.4 Hz/pixel

Tile rate 2 kHz

Pixel packet size - 8+8 bytes

Data rate - 32 kB/s per tile or ~1 MB/s/m^3



ASICs heat dissipation

Example: pixelated anode based on LArPix V2 ASIC (LBNL)

Pixel tile: 30x30 cm, 100 ASICs, 4900 pixels.

LAr TPC: Drift length 2x32cm, 16 tiles, ~0.5 m3

1.6V Pseudo-LVDS signalling

P = 64 uW/ch

Total power 0.3 W/tile or 3W/m^2

No LAr boiling observed in the TPC.

The cost of the R/O ASIC and pixelated R/O

Example: pixelated anode based on LArPix V2 ASIC (LBNL)

Pixel tile: 30x30 cm, 100 ASICs, 4900 pixels 4.4 x 4.4mm.

Rough Cost O(50k$/$m^2$) - will be dramatically lower for mass production