UNIVERSITY OF LIVERPOOL

Noble Liquids Detector R&D

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PPTAP, June 2021

Challenges/Outline

Link to the ECFA talk:
https://indico.cern.ch/event/999815/

- Cryogenics stability at the very large scale
- High Voltage and uniform Electric Field
- Tracking LAr Detectors –wires, pixels, perforated PCBs, THGEM/cameras
    - *precision tracking in very large volumes (mm) and complex 3D reconstruction*
- S1 light optimisation
    - VUV, IFR, WLS, Xe doping
    - - see also photodetectors session on Friday
- S2 light production optimisation
- S2 collection optimisation
    - Darkside SiPMs, radiopure PMTs - see photodetectors session on Friday
- Low background/Radiopurity
- Underground calibration

LAr & LXe Properties

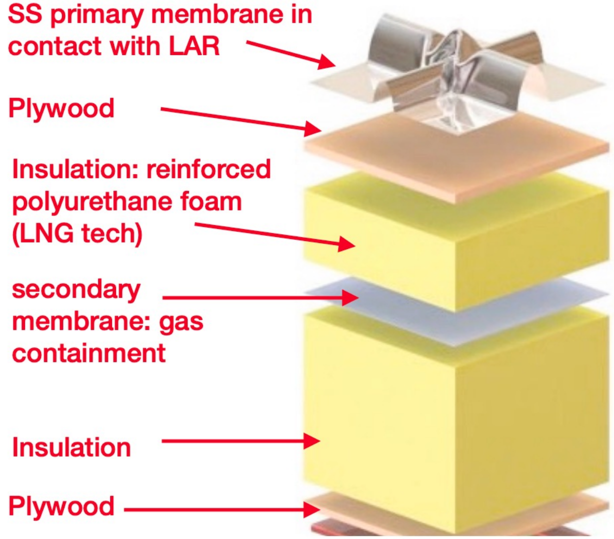
Property	Argon	Xenon
Atomic No. (Z)	18	54
Max recoil energy (% of incident n energy)	9.5	3.0
Boiling point	87.3	165
Density (g/cc)	1.4	3.0
Electron mobility (cm2/v*s)	400	2200
Ion drift velocity at 1kV/cm (mm/µs)	2.2	2.4
Energy resolution (FWHM@ 662 keV) scint. only (%)	8%	8%
Scintillation wavelength (nm)	128 (WLS /doping) also NIR	175 (UV quartz PMT window)
Scintillation yield (photons/MeV)	40000	42000
Fast decay time (ns)	7 (25% light)	4.3
Slow decay time (ns)	1500 (75% light)	22 (100% in ≤ 22 nm)

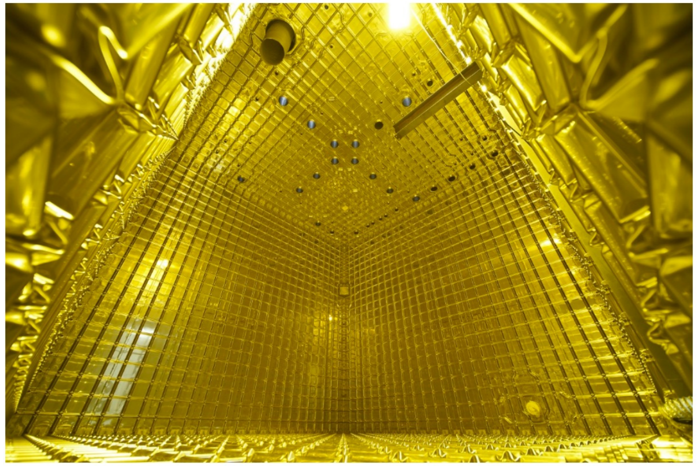
LAr & LXe Properties

Property	Argon	Xenon
Superradience	to be discovered	to be discovered
Dielectric constant ε	1.505	1.85
Break down voltage (kV/cm)	40 -100 (depends on purity, stressed electrode area, pressure)	40-100 (depends on purity, stressed electrode area, pressure)
W value for ionization (eV/pair)	23.6	15.6
Rayleigh scattering length (cm)	54	36
Radiopurity	^{39}Ar 1Bq/kg (need depleted for DM)	^{136}Xe < 10uBq/kg
Cost ($/kg)	≈ 2.0	≈ 1500
Availability	Abundant (1 % in atmosphere)	limited

Working with Cryogenics at the large scale

- Accurate liquid leveling in particular for dual phase detectors
- Large cryostats and stable cryogenic operation over long period
- Purification and recirculation system to achieve <1 ppb electronegative impurities
- For dark matter purification cartridge also needs to be Radon free





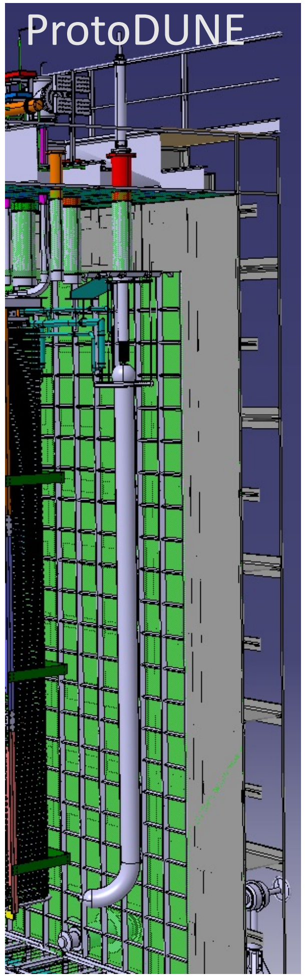
ProtoDUNE cryostat

High Voltage

Property	Argon	Xenon
Dielectric constant ε	1.505	1.85
Break down voltage (kV/cm)	40 -100 (depends on purity, stressed electrode area, pressure)	40-100 (depends on purity, stressed electrode area, pressure)

https://arxiv.org/pdf/1908.06888.pdf

- In order to drift at 0.5kV/cm over 12 m you will need 600kV at the cathode!
- Need to develop new HV FTs and power supplies availability limited to 350kV.
- For DM an extra challenge is radiopurity
- Photodetectors have to operate in high field



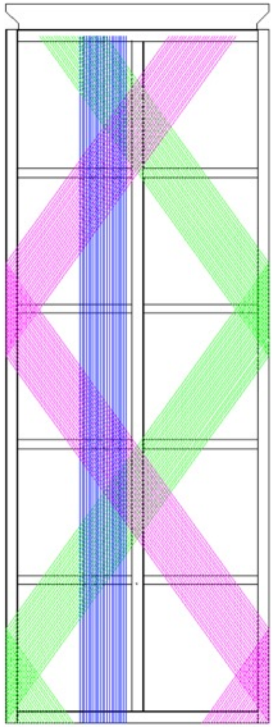
Anode technologies: Wire chamber (APA)

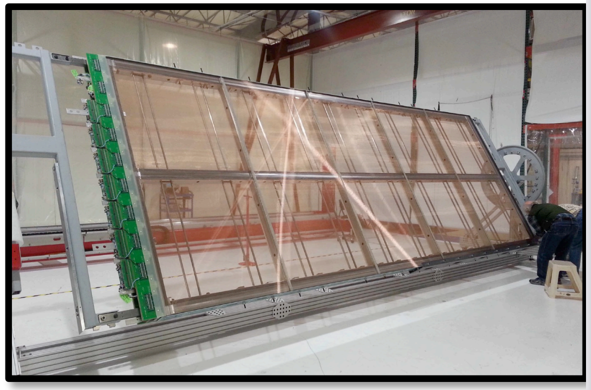
X=0°, U=+30°, V=-30°

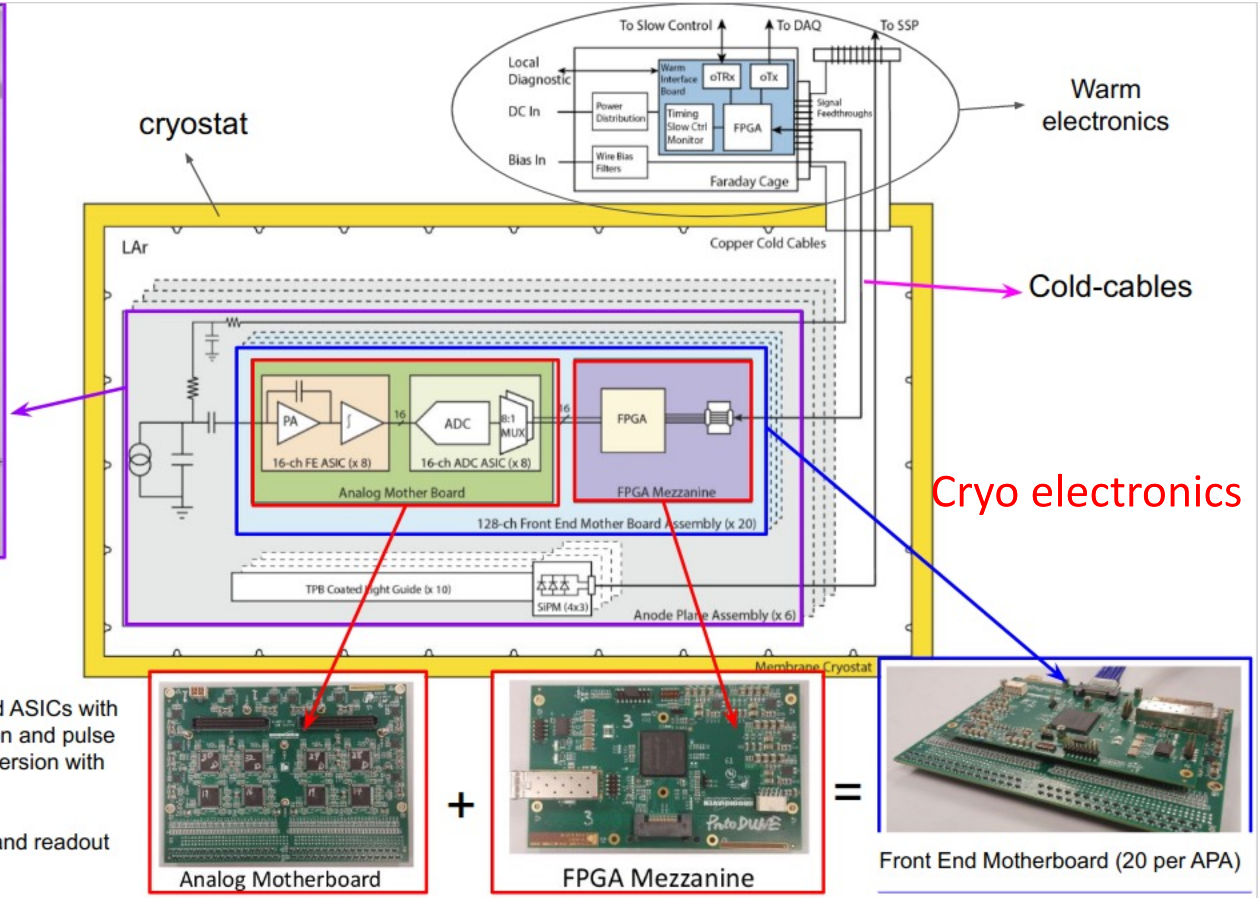
3d wires, 150μm BeCu

protoDUNE S/N~40

Solution adopted for the DUNE single phase first far detector



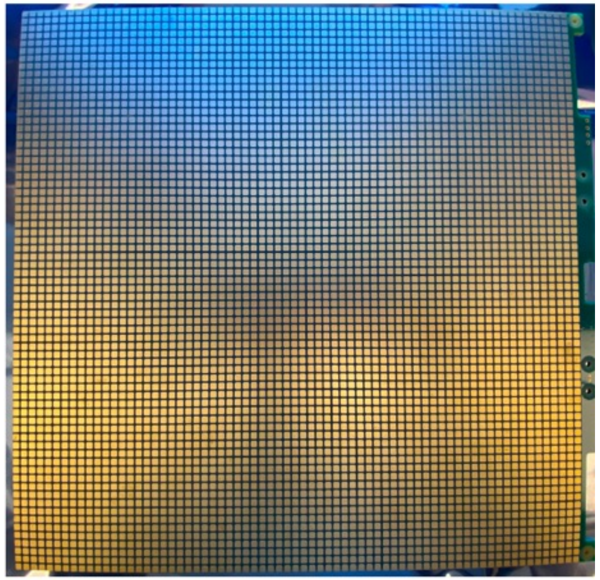




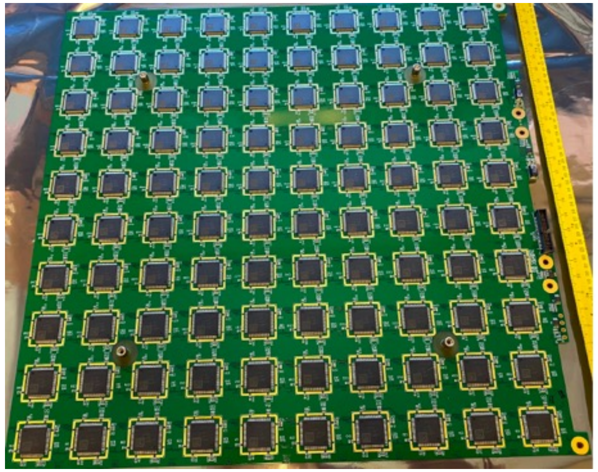
Analog Motherboard: 8 front end ASICs with CMOS technology for amplification and pulse shaping. 8 analog to digital conversion with ADC ASICs

FPGA Mezzanine: Multiplexing and readout of digitized signals

Anode technologies: Pixel anode readout



- ✓ 1000 cm^2 anode tile prototype
- ✓ 100 ASICs with 4 IO entry-points
- ✓ 6'400 channels
- ✓ ~ 4x 4 mm^2 pixels



LArPix v1 ASIC:

low noise (~300e-)
low power (~60uW/ch)
3D readout , 64 ch

Adopted for the LAr DUNE Near Detector

LArPix-v2 bare die

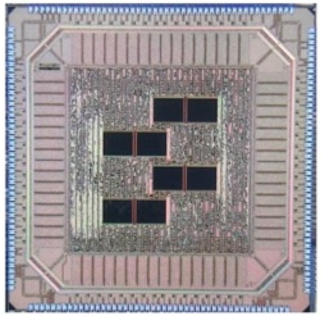
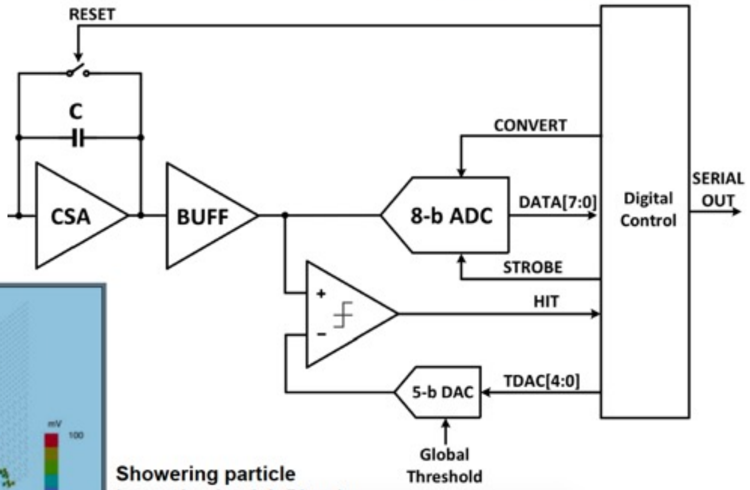
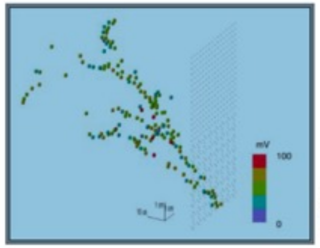


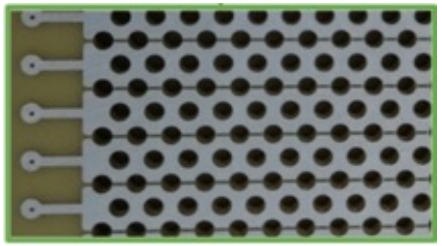
Diagram LArPix front-end and readout chain

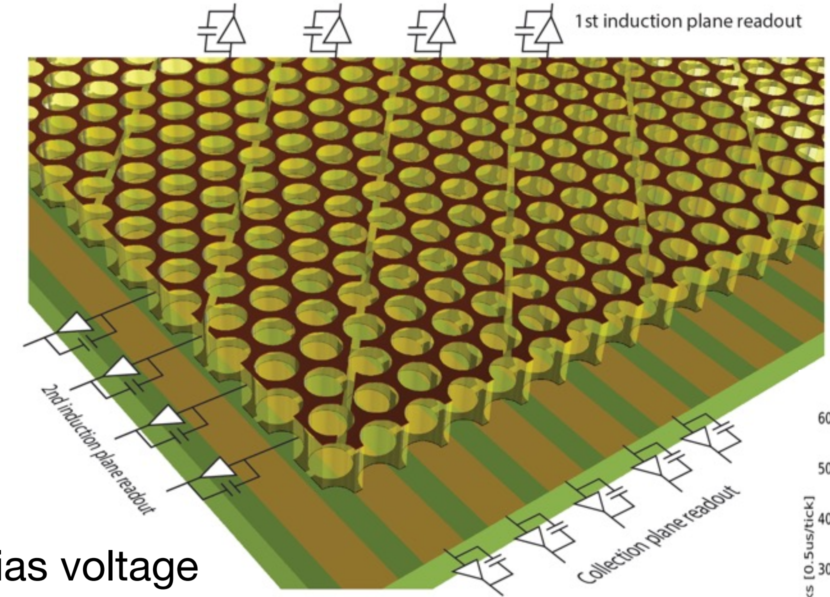




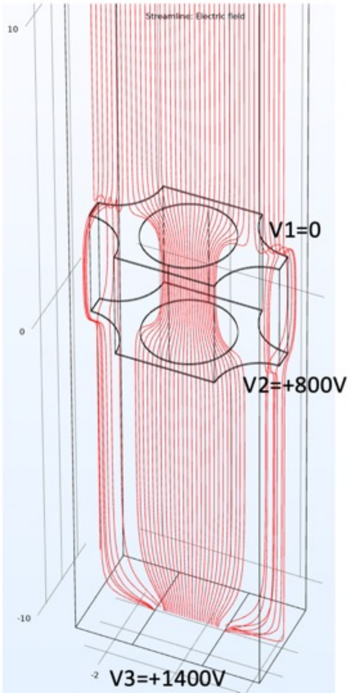
Showering particle imaged using LArPix v1

Anode technologies: Perforated PCB strips





Solution adopted for the DUNE single phase Vertical Drift second far detector

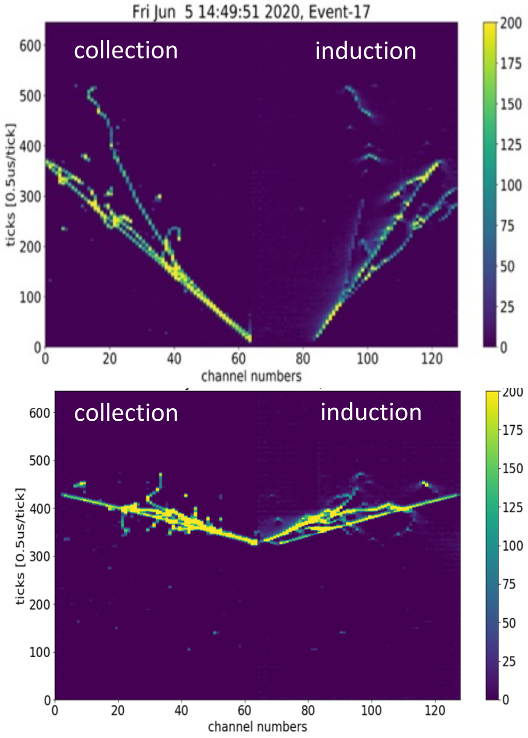


Electron paths from a line charge in a 3-view configuration

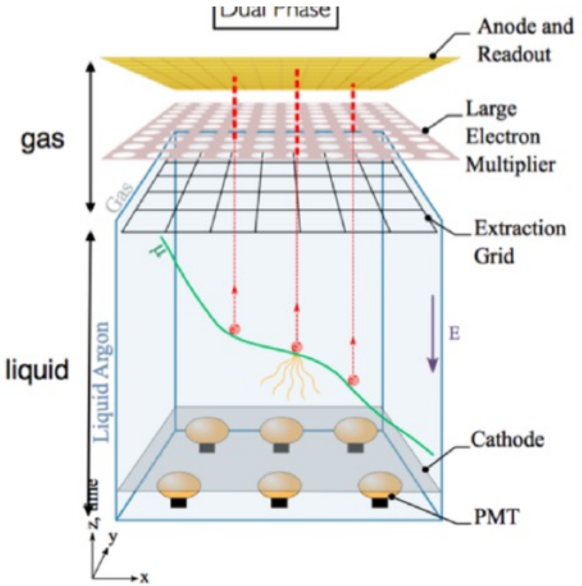
The bias voltage needed across the two sides of the perforated anode PCB to pull electrons through the holes strongly depends on the optical transparency and the thickness of the PCB.

PCB strips ~ 5mm

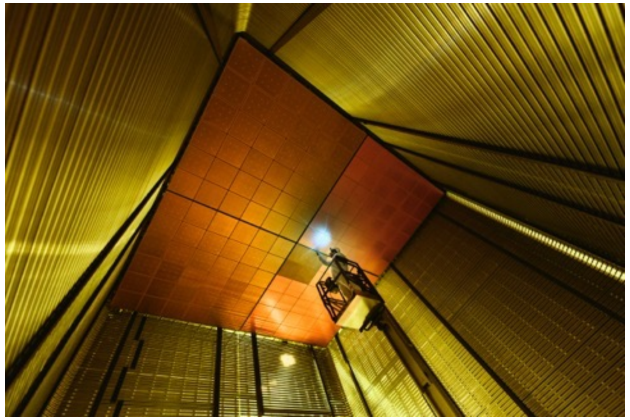
Holes diameter 2mm



Anode technologies: DP (Double Phase Charge)

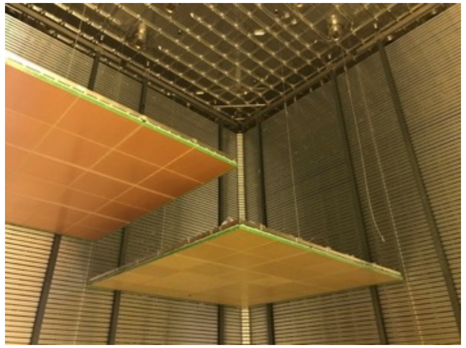


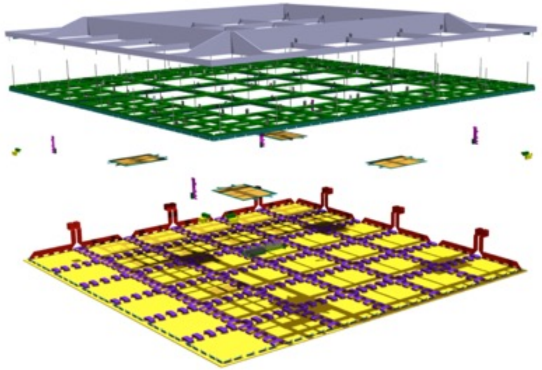
LEM S/N > 50 expectation



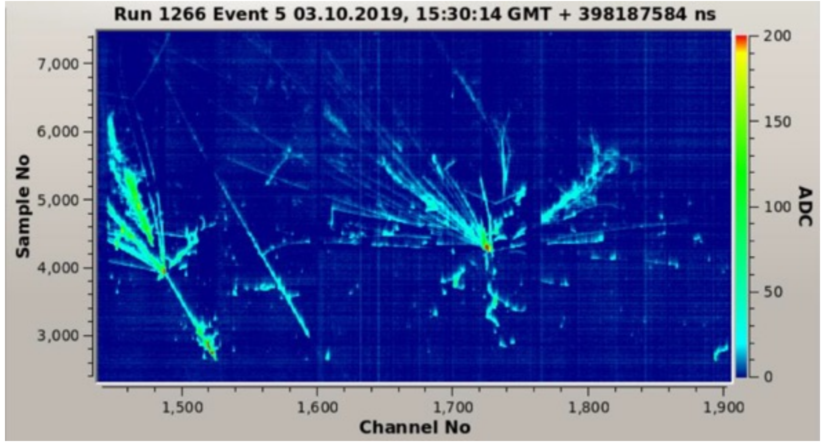
Solution tested in ProtoDUNE @ CERN
Needs more R&D to solve stability problems

High amplification in the gas difficult to stabilize !!



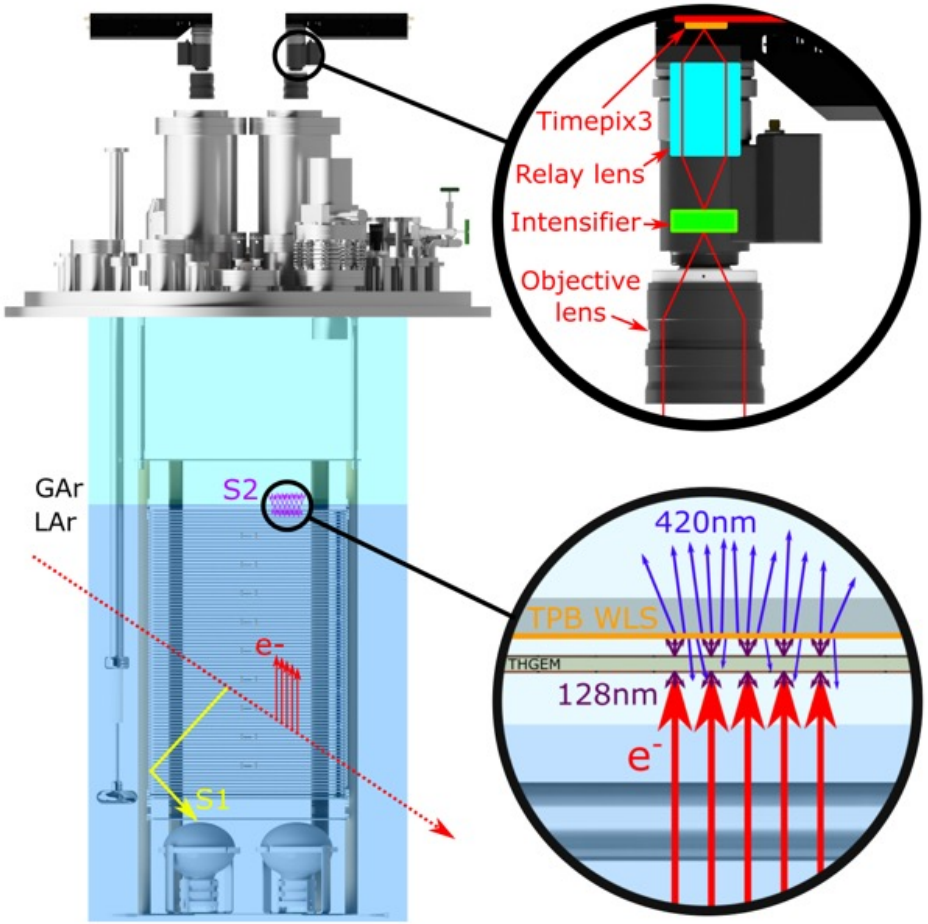


LEM : thick GEM technology



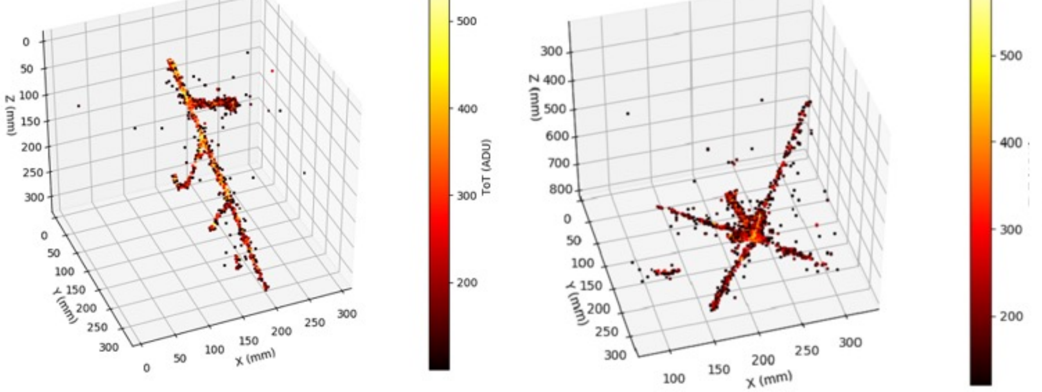
Anode Technologies: DP Optical Readout

https://www.mdpi.com/2410-390X/4/4/35

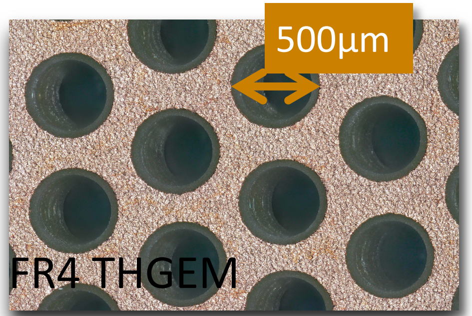


Detection principle of dual phase optical TPC readout with TimePIX3 camera, first demonstrated in the ARIADNE detector.

LAr Cosmics



Instead of reading out the charge from the THGEM, fast TPX3 Cameras photograph the S2 light generated in the THGEM holes



TPX3Cam benefits:

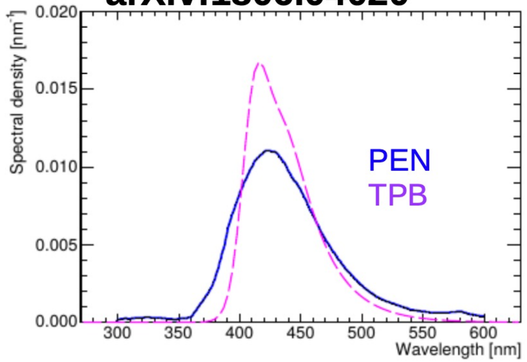
- Raw data is natively 3D
- Huge readout rates are possible (80MHits/s)
- Zero suppressed readout comes for free (~few KBytes per event)
- Physics sensor (Timepix) being used for a Physics application
- Relatively low cost
- Same readout is possible for two phase or gas TPCs

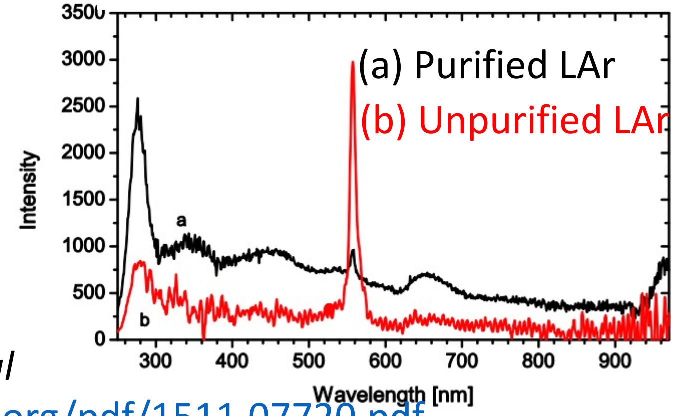
S1 Light Collection Optimisation

Property	Argon	Xenon
Scintillation wavelength (nm)	128/NIR	175
Scintillation yield (photons/MeV)	40000	42000
Fast decay time (ns)	7 (25% light)	4.3
Slow decay time (ns)	1500 (75% light)	22 (100% in ≤ 22 nm)

- Reflectors and WLS combination
  - New WLS ideas using PEN foil avoiding TPB
- Shift 128nm to 175nm by doping LAr with few ppm level Xe (tested successfully in ProtoDUNE)
- Other dopands for Xe: H2, D2
- NIR light could also potentially provide an alternative to the challenges faced by VUV
  - Need further accurate determination of NIR Light yield (current LAr results indicate 500 photons/MeV)

arXiv:1806.04020



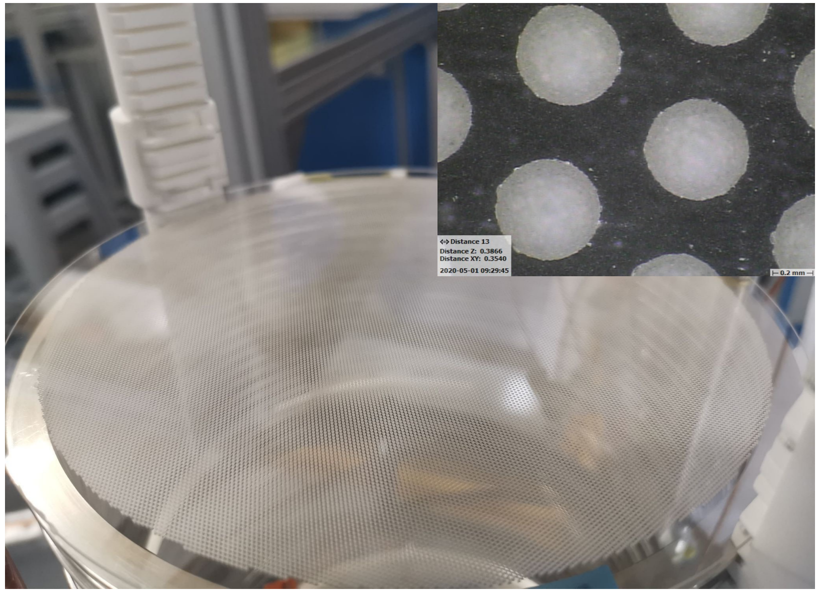


T. Heindl *et al*
https://arxiv.org/pdf/1511.07720.pdf

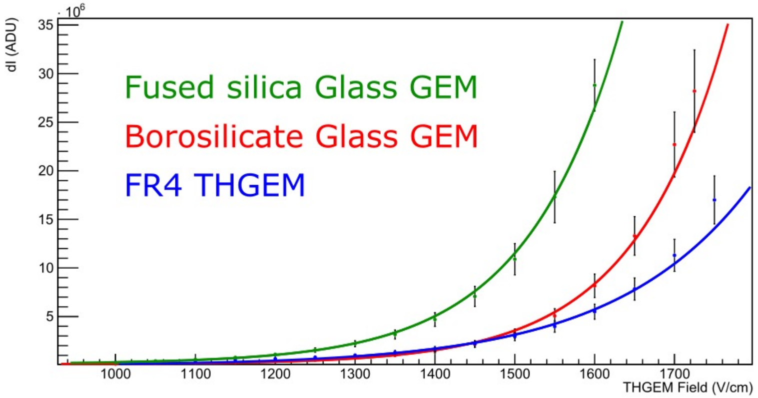
S2 light production optimisation

- Typically for DM detectors generate S2 electroluminescence light between extraction grid and transparent anode/second grid
- In neutrinos looking S2 in the avalanche regime of THGEMs
- New R&D and production method of glass THGEM out of any glass material (Liverpool Patent pending). Allows use of large scale radiopure glass opening application also to Dark Matter
- Aid low threshold Migdal and ionization (S2) only searches

40 l setup at Liverpool with glass THGEM

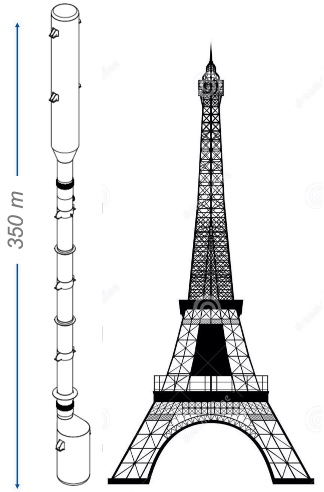


Gain vs potential difference



Low Background for DM

- Material assay and assembly procedures: photodetectors and electronics, cabling, feedthroughs, cryostat etc.
    - Facility in Boulby in place, UK strength
- Veto system
- <u>^{39}Ar, Kr and Rn removal:</u>



ARIA -distillation column

ARIA project (Darkside Collab.), production of depleted argon, below the UAr levels

Kr distillation column for XENON1T/nT, EPJ- C 77 (2017) 5

Rn distillation column for XENONnT

Calibrating Large detectors Underground

Property	Argon	Xenon
Radiopurity	^{39}Ar 1Bq/kg	^{136}Xe < 10uBq/kg
W value for ionization (eV/pair)	23.6	15.6

Very few cosmics need alternatives!

- **^{39}Ar (Q=565 keV)**
- **DD pulse neutron generator**
- **LASER (**Multiphoton Ionisation**)**
- **Standard isotopes, but will need clever engineering to move sources around the DM detectors**

thanks