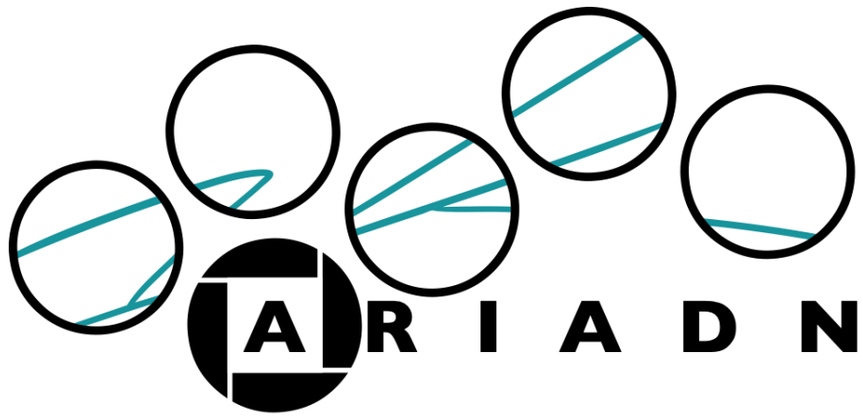

ARIADNE: A 1-ton Dual-Phase LArTPC with Optical Readout.

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http://hep.ph.liv.ac.uk/ariadne

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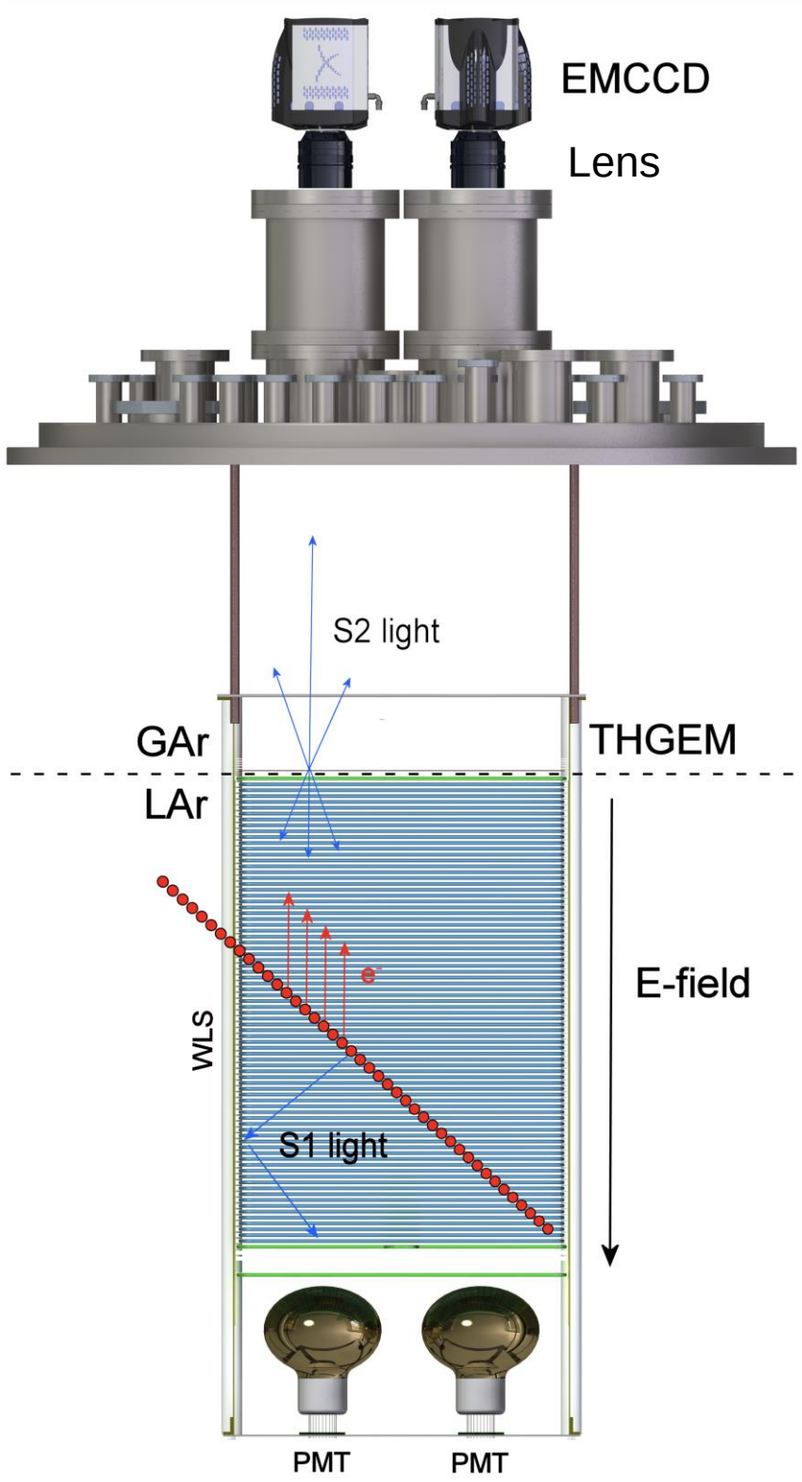
Outline

ARIADNE is a 1-ton two-phase liquid argon (LAr) time projection chamber (TPC) featuring a novel optical readout method. The goal is to develop this readout method as well as other future TPC technologies. The optical readout method has the potential to be an alternative to current charge readout methods for future large neutrino LArTPC detectors.

- What is optical readout of TPCs?
- The ARIADNE Detector
- Beamline characterisation at CERN
- Fast timing readout for full 3D reconstruction

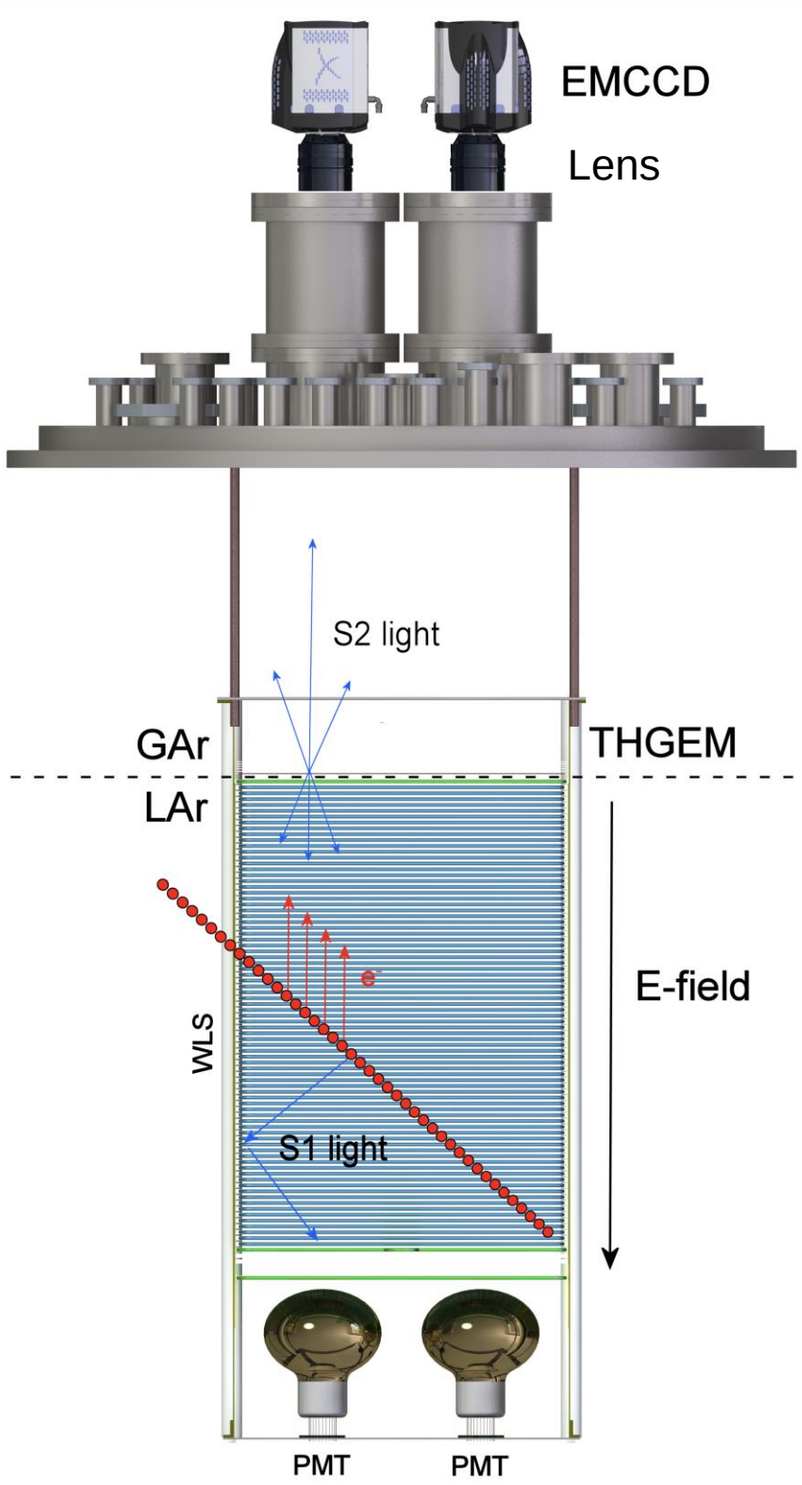
Optical Readout of TPCs



TRANSPORT AMPLIFICATION READOUT

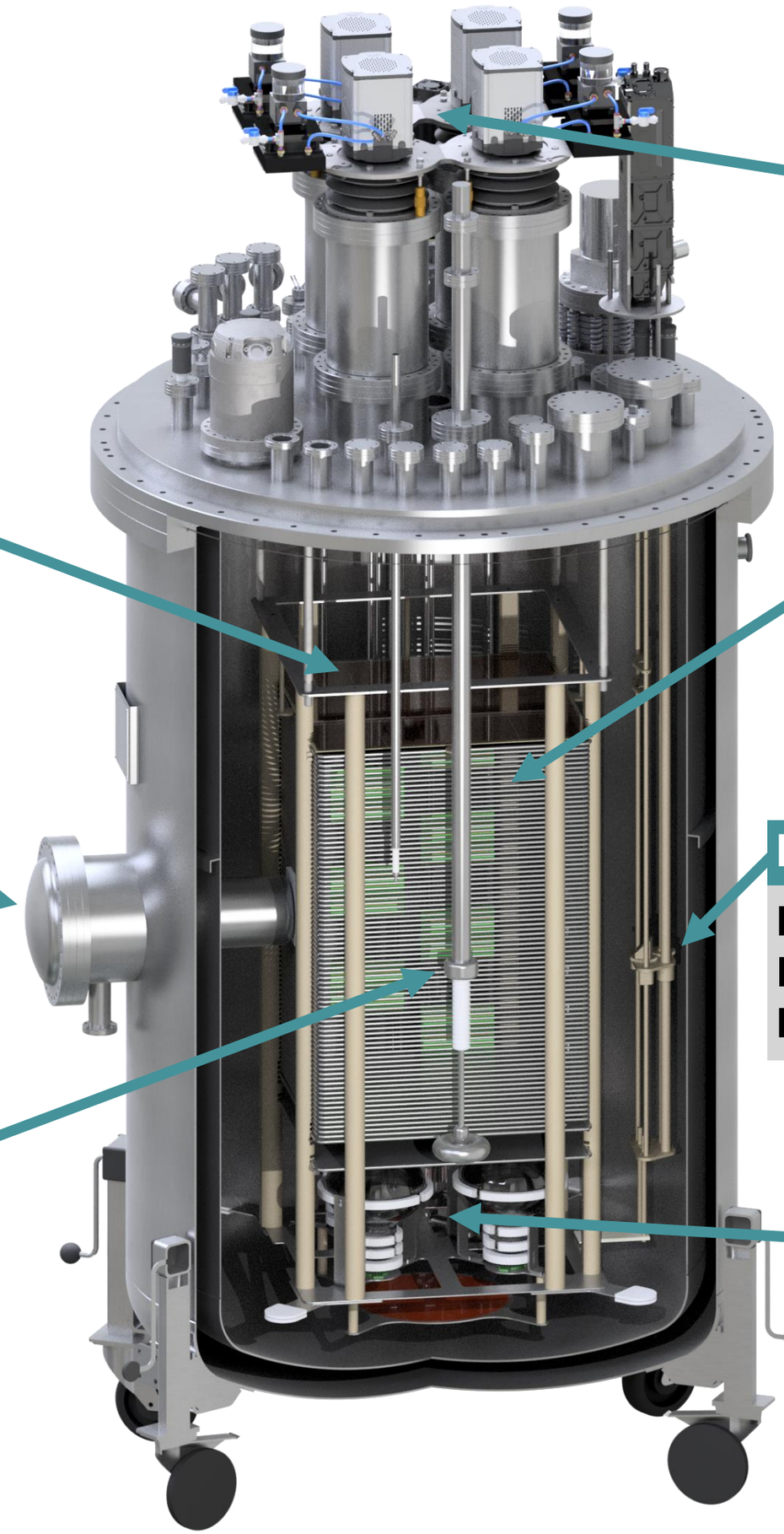
- Particles travelling in LAr deposit energy in Ar atoms causing scintillation (S1) and ionisation.
- Ionised electrons in active volume E-field drift towards extraction grid in liquid phase.
- Thick Gaseous Electron Multiplier (THGEM) in gas phase amplifies drifted charge and secondary scintillation light (S2) is emitted in Townsend discharge.
- Glass plane of TPB WLS above THGEM converts VUV S2 light to visible 430nm.
- S2 light captured with Electron Multiplying CCDs (EMCCDs).
- Provides high resolution 2D images of interactions along with calorimetry information.
- Quasi-3D reconstruction can be produced with combination of S1 and S2 timings from PMTs.

Benefits of Optical Readout



- **High resolution** — For eg. an EMCCD sensor is 1024x1024 pixels (run with 4x4 binning ≈ 1mm resolution).
- **Sensitivity to low energies** — gain is generated in the THGEM; cameras can be sensitive to single photons.
- **Very low noise** — Externally mounted cameras are decoupled from TPC electronic noise sources.
- **Ease of access** — Cameras can easily be replaced or upgraded - particularly useful during long-term cryogenic running.

The ARIADNE Detector



4x EMCCDs

Andor iXon 888
1024x1024 pixels
Single photon sensitivity

THGEM

54x54cm, 1mm thick
FR4, copper coated
500μm hole diameter
800μm hole pitch

Field Cage

80cm x 54cm x 54cm
active volume

Beam Window

Vacuum with thin steel
endcaps to minimise
radiation length

Laser Calibration System

Nd:YAG Laser @ 266nm
Internal movable mirror system
Multiple field cage entry points

HV Feedthrough

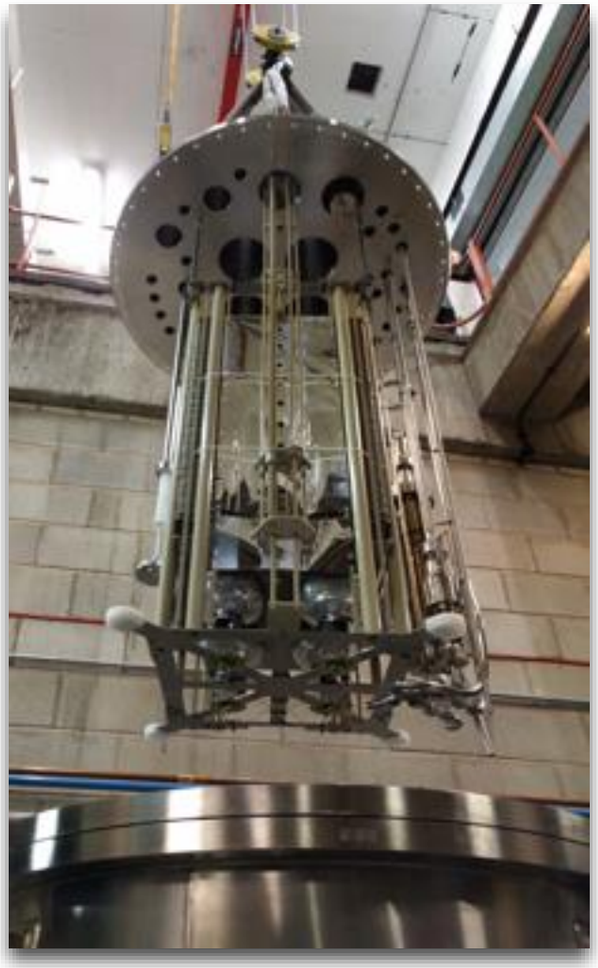
Cryogenically fitted
Capable of 100kV

4x PMTs

8” Hamamatsu PMTs
TPB WLS coated

ARIADNE TPC

TPC and detector systems



Assembly of TPC into cryostat

Laser entry slot

View of voltage dividers / inside TPC

100kV HV feedthrough

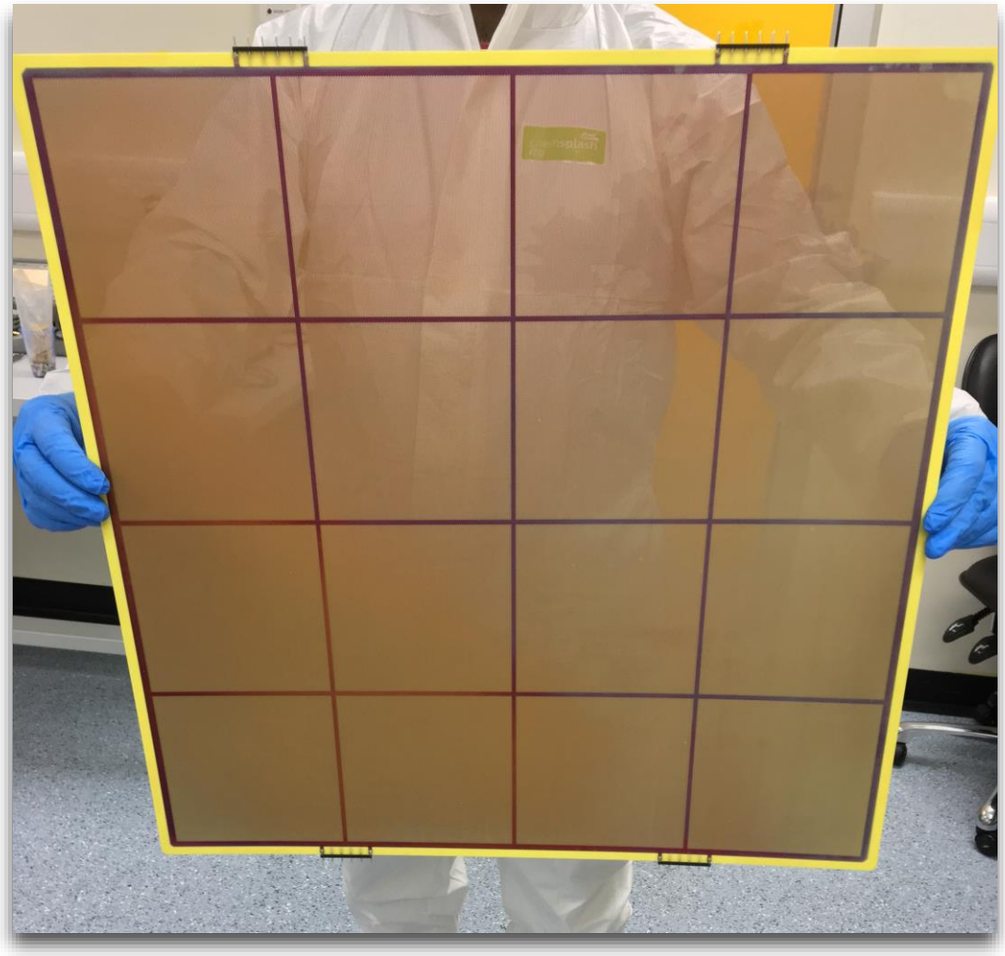
THGEM

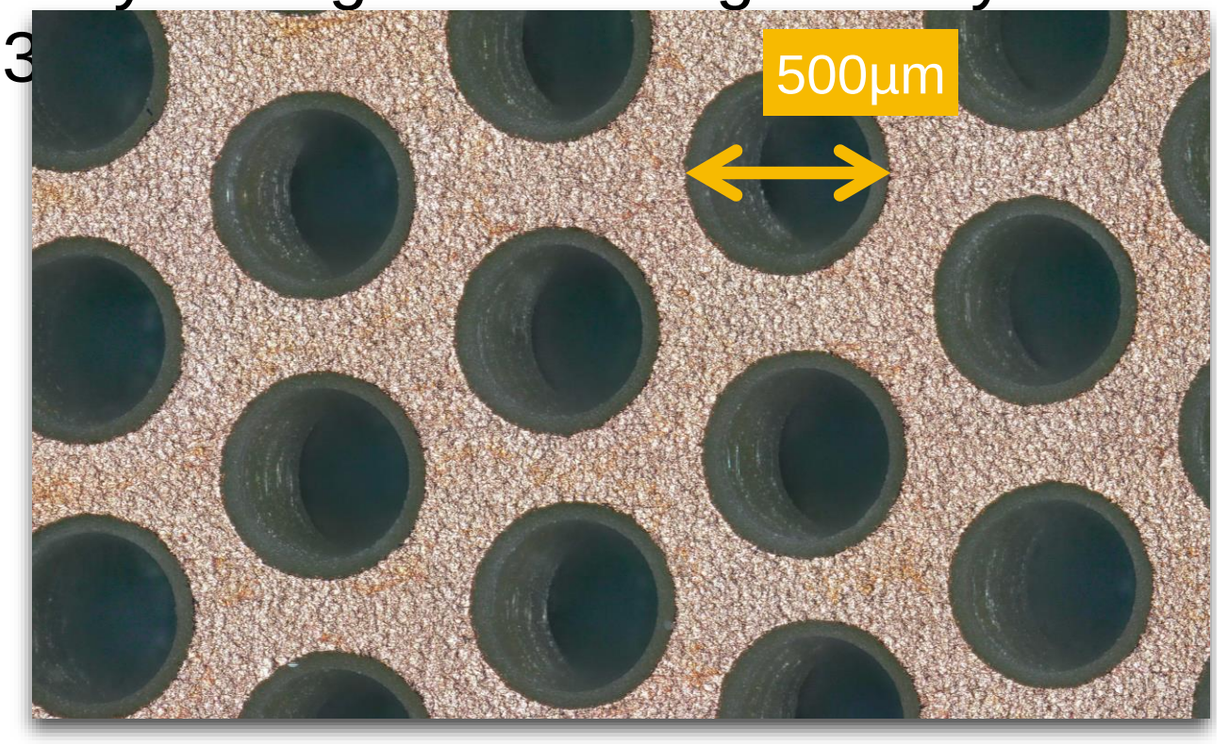
54cm x 54cm x 1mm FR4 board.

Copper coating on both faces.

500µm hole diameter; 800µm hole spacing.

Very strong E-Fields - generally 25-3





T9 Beam-line at CERN

T9 Beam-line at CERN

Beamline run March/April 2018.

~400,000 events negative polarity.

~400,000 events positive polarity.

0.5 GeV/c - 8 GeV/c.

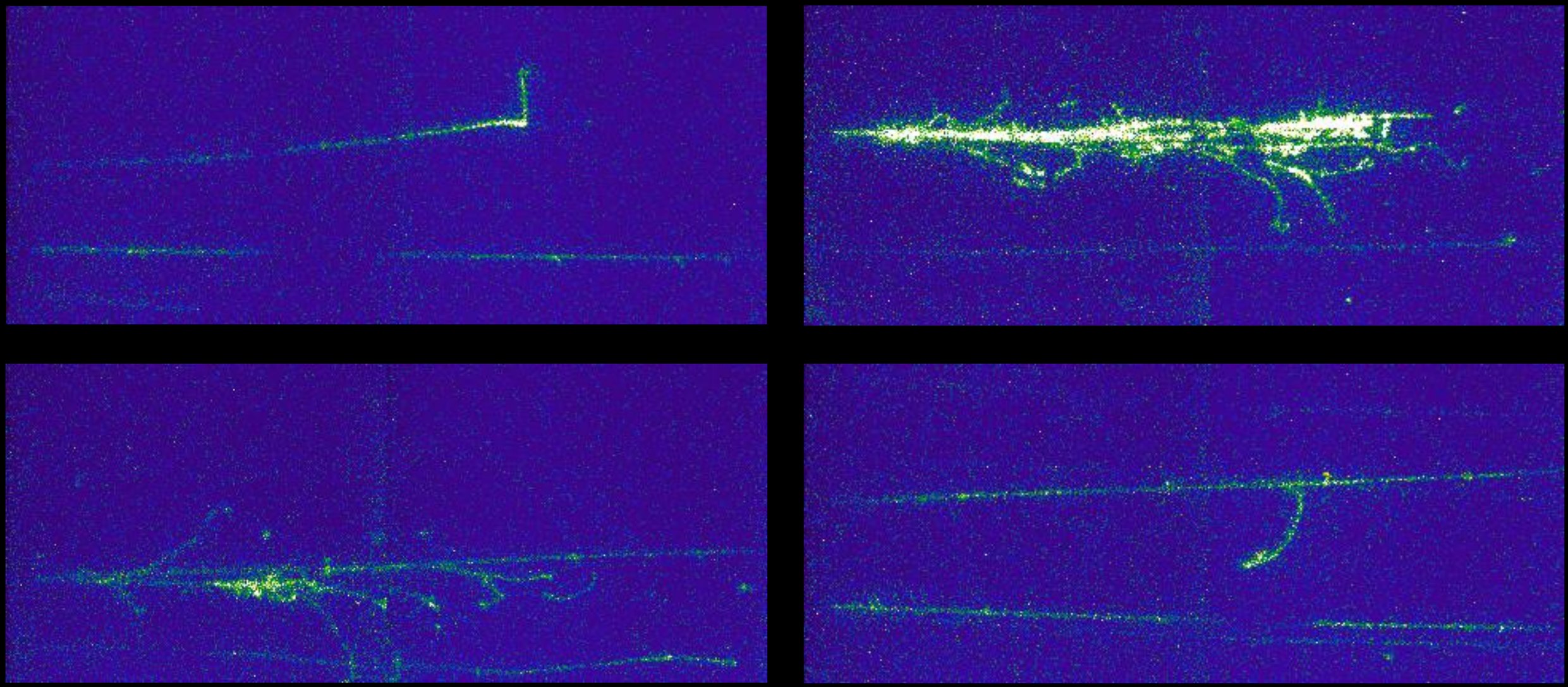
Mix of $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, $p^{\pm}$.

Data analysis in progress - dEdX analysis and use machine learning (CNNs) for track reconstruction and event classification.

First Demonstration of Optical Imaging of Beam-line Interactions in a Two Phase LArTPC

Beamline Events

1.1mm / pixel resolution



2D -> Full 3D Readout

- EMCCDs give great resolution and sensitivity, however acquisition rate of EMCCD sensors (~50Hz) slow compared to the drift speed of LArTPCs (~2mm/μs).

- Can only provide flattened 2D representation of event geometries.

- Z-axis can be calculated from timing information from S1 and S2 signals from PMTs - however only possible for simple track geometries and in low-pile up situations as correlation is challenging.

- A MUCH faster readout could give full 3D readout (whilst still requiring the sensitivity of EMCCDs).

Timepix3 Sensor

Silicon pixel readout chip developed by the Medipix collaboration.

Simultaneous 10 bit Time over Threshold (ToT) and 18 bit Time Of Arrival (TOA).

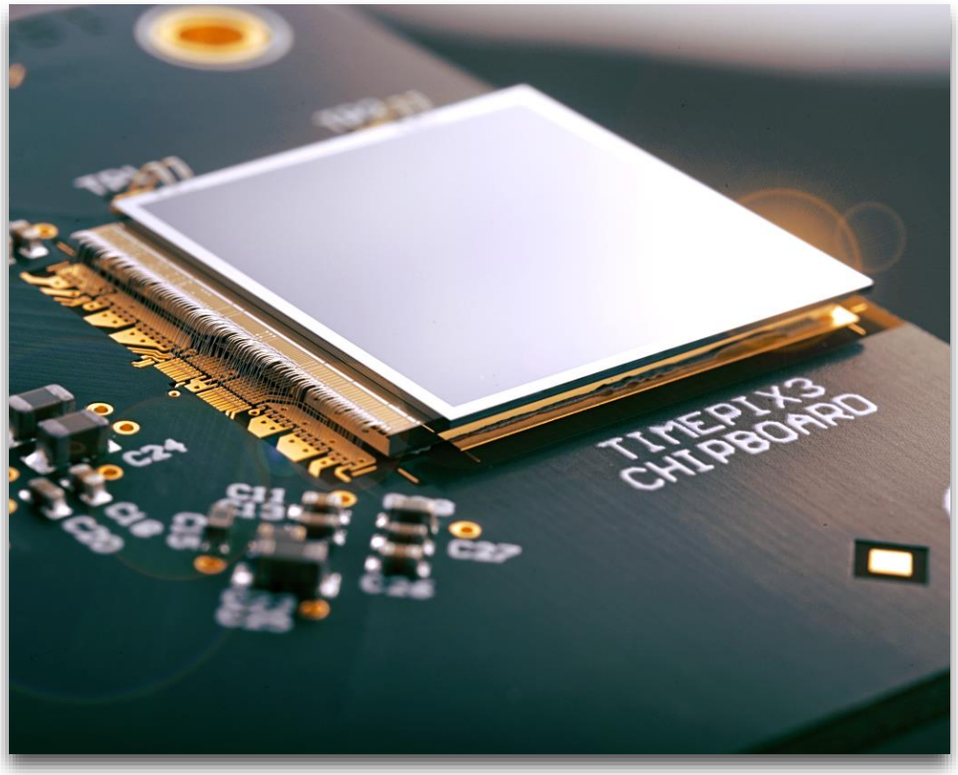
ToT allows accurate calorimetry measurements.

TOA allows accurate timing and 3D reconstruction.

“Data driven readout”: pixels read out asynchronously, allows very efficient sparse readout.

Possible to have continuous trigger-free readout.

Until recently only used to measure deposited charge.

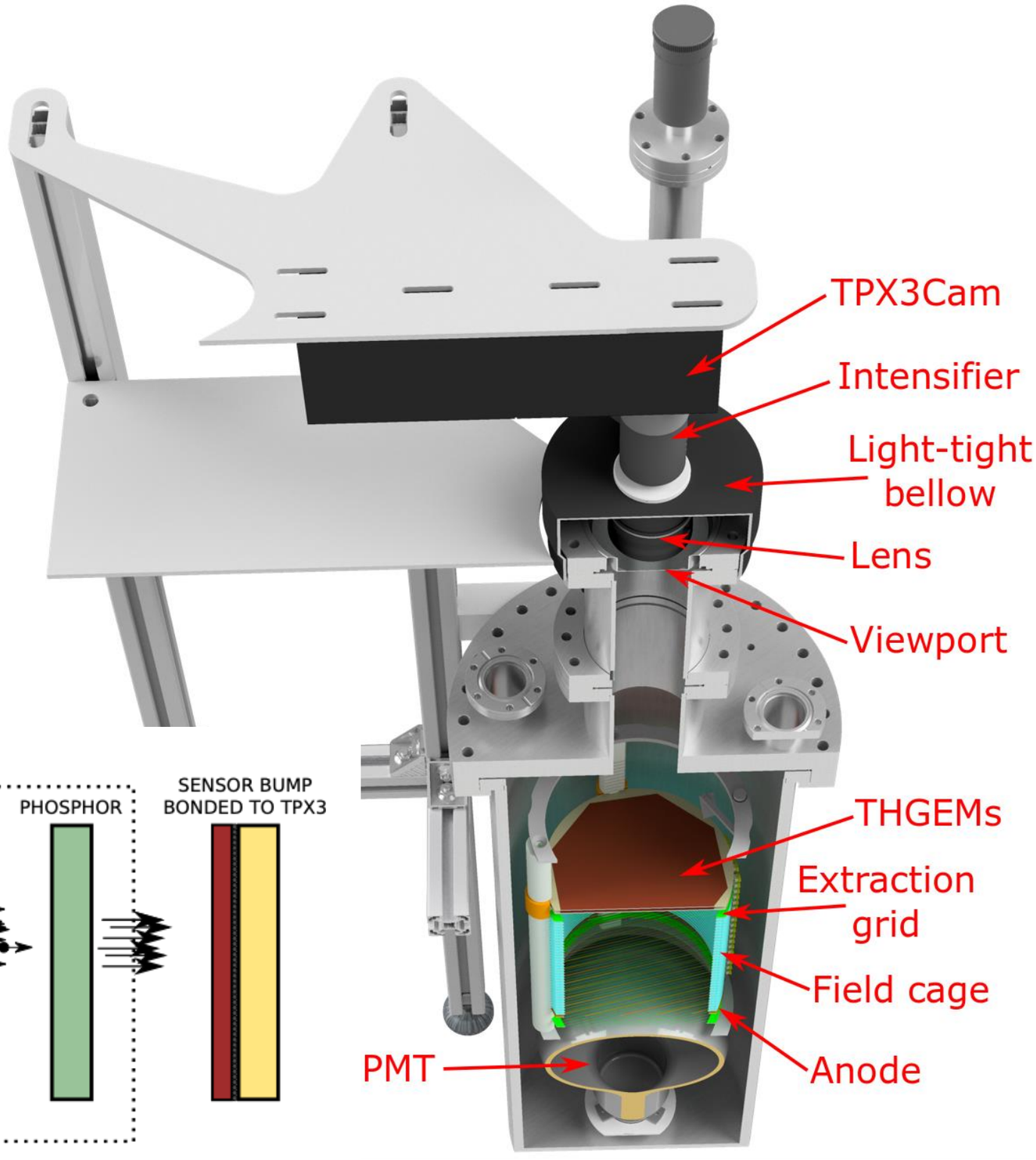


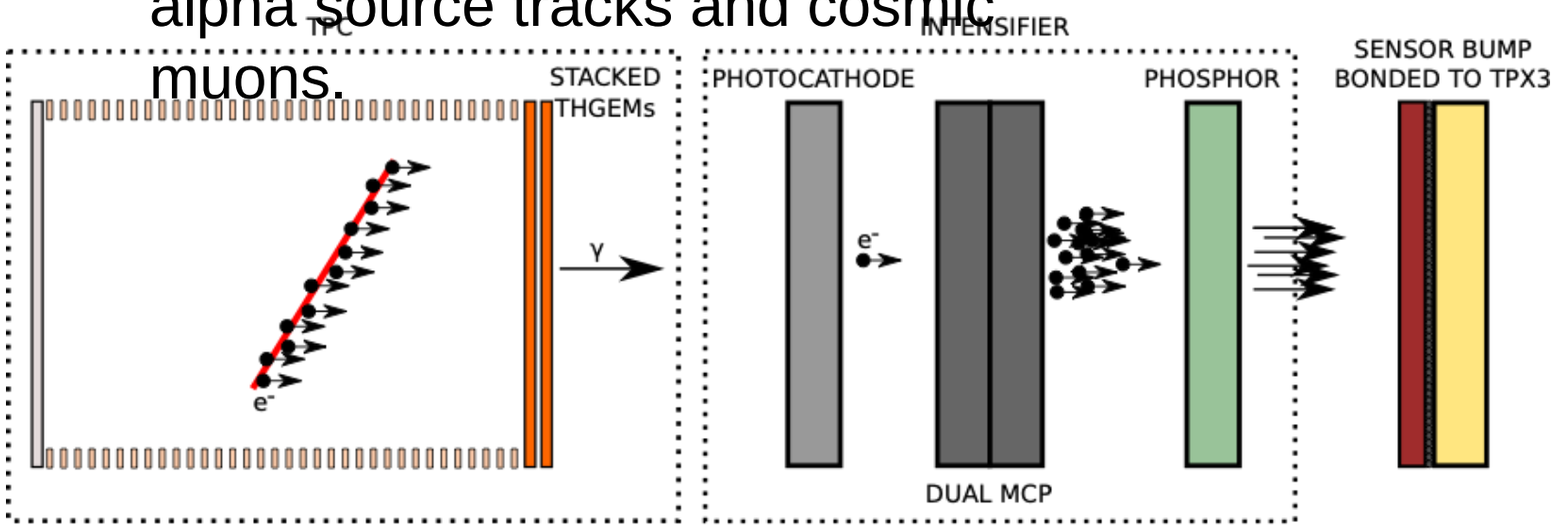
Sensor resolution	256x256 pixels
Pixel size	55µm x 55µm
Max readout rate	40Mhits•cm^{-2} •sec^{-1}
Technology	130nm CMOS

TPX3Cam on a TPC

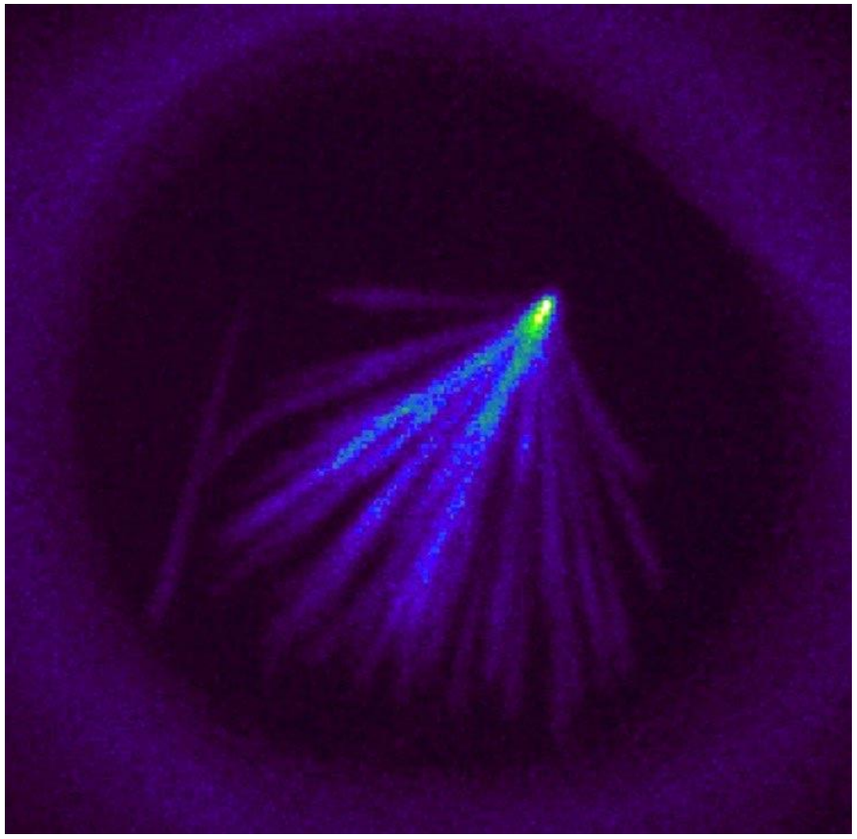
Initial tests on ARIADNE prototype TPC:

- Timepix3 chip bonded to a optical silicon pixel sensor.
- Combined with image intensifier.
- Tested on smaller TPC with CF_4 gas.
- Data taken of Americium-241 alpha source tracks and cosmic muons.



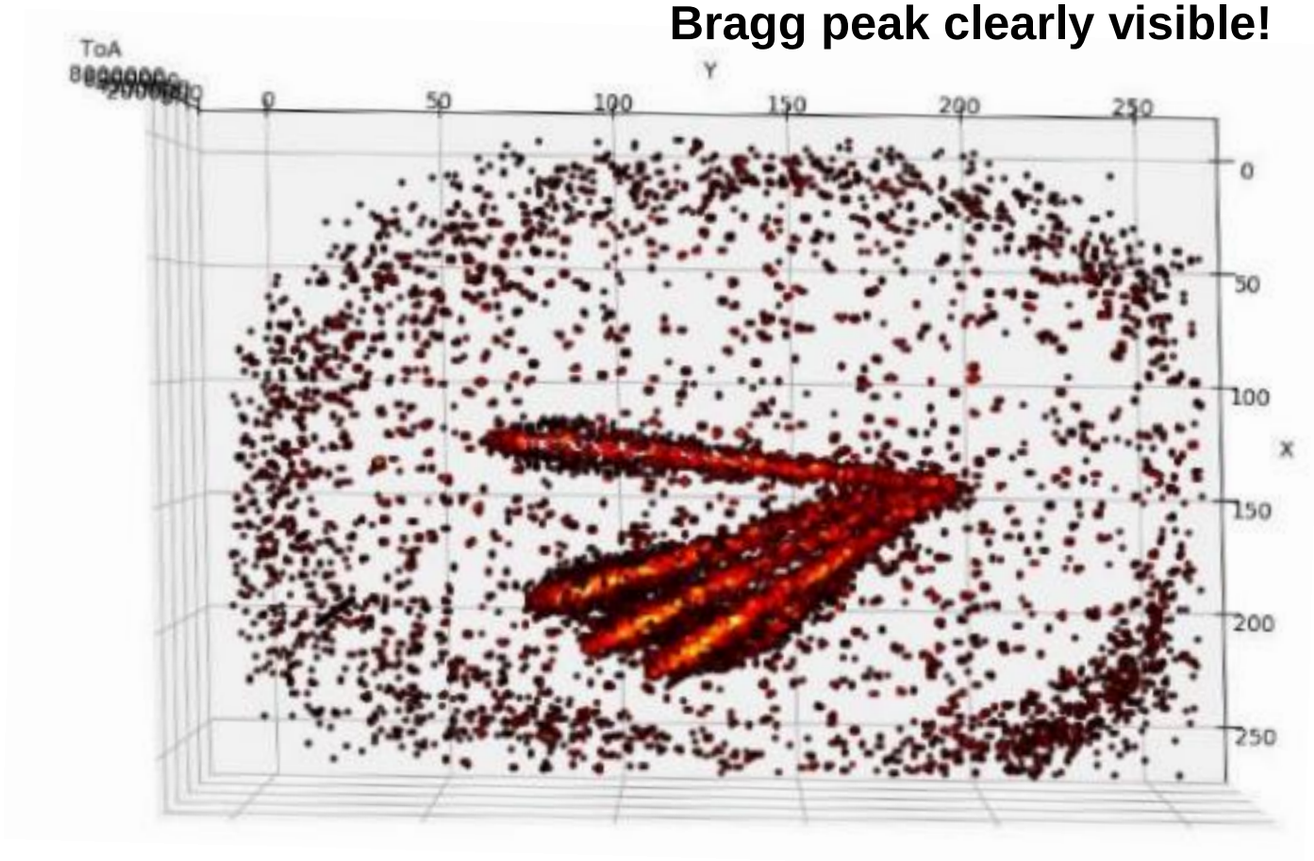


TPX3Cam Results



EMCCD

Bragg peak clearly visible!



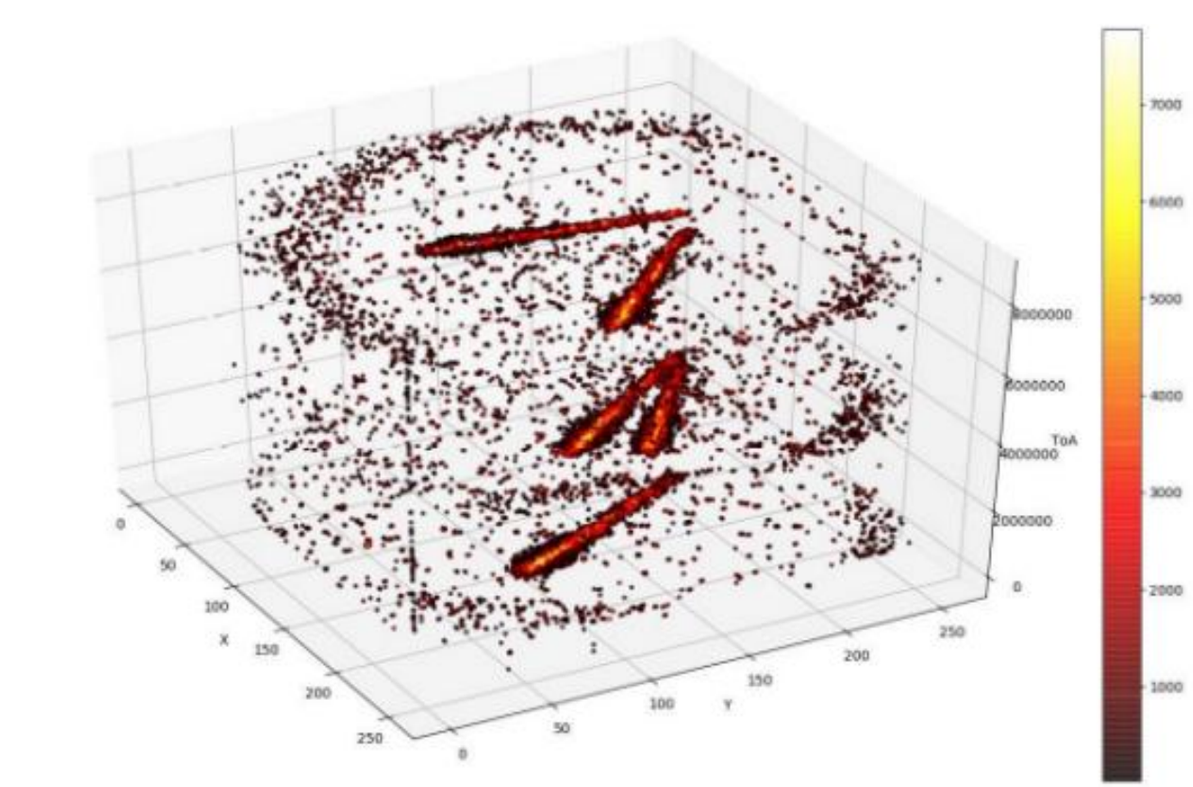
TPX3Cam

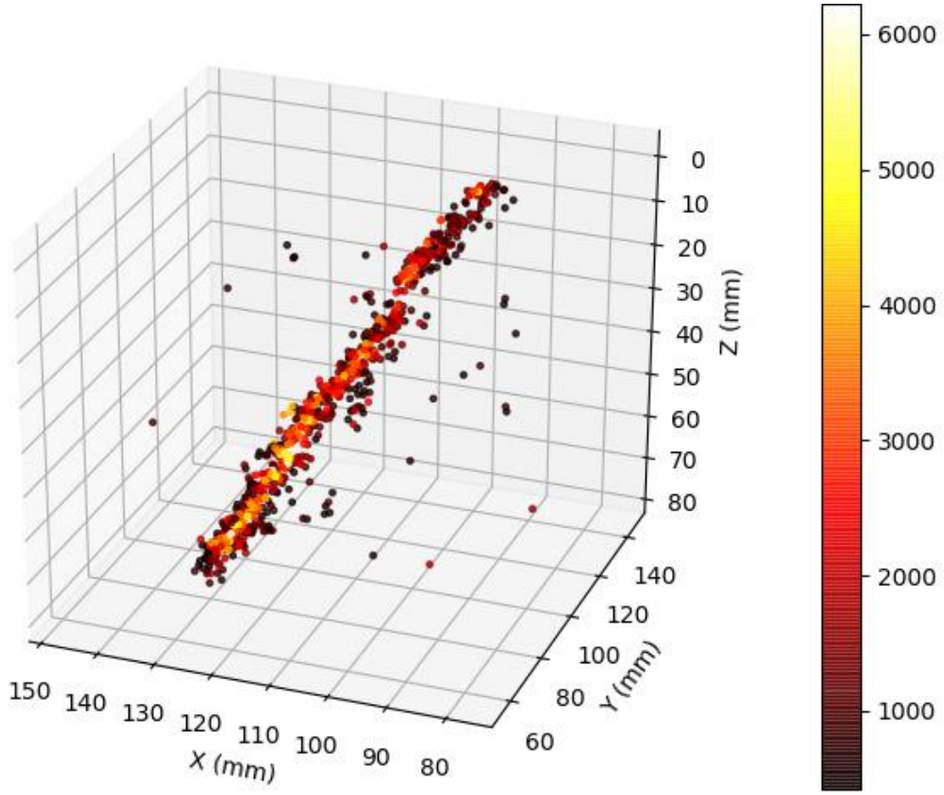
Internal Americium-241 alpha source.

“Halo” is light reflected off stainless steel viewport tube.

“First demonstration of 3D optical readout of a TPC using a single photon sensitive Timepix3 based camera’ - https://arxiv.org/abs/1810.09955

TPX3Cam Results





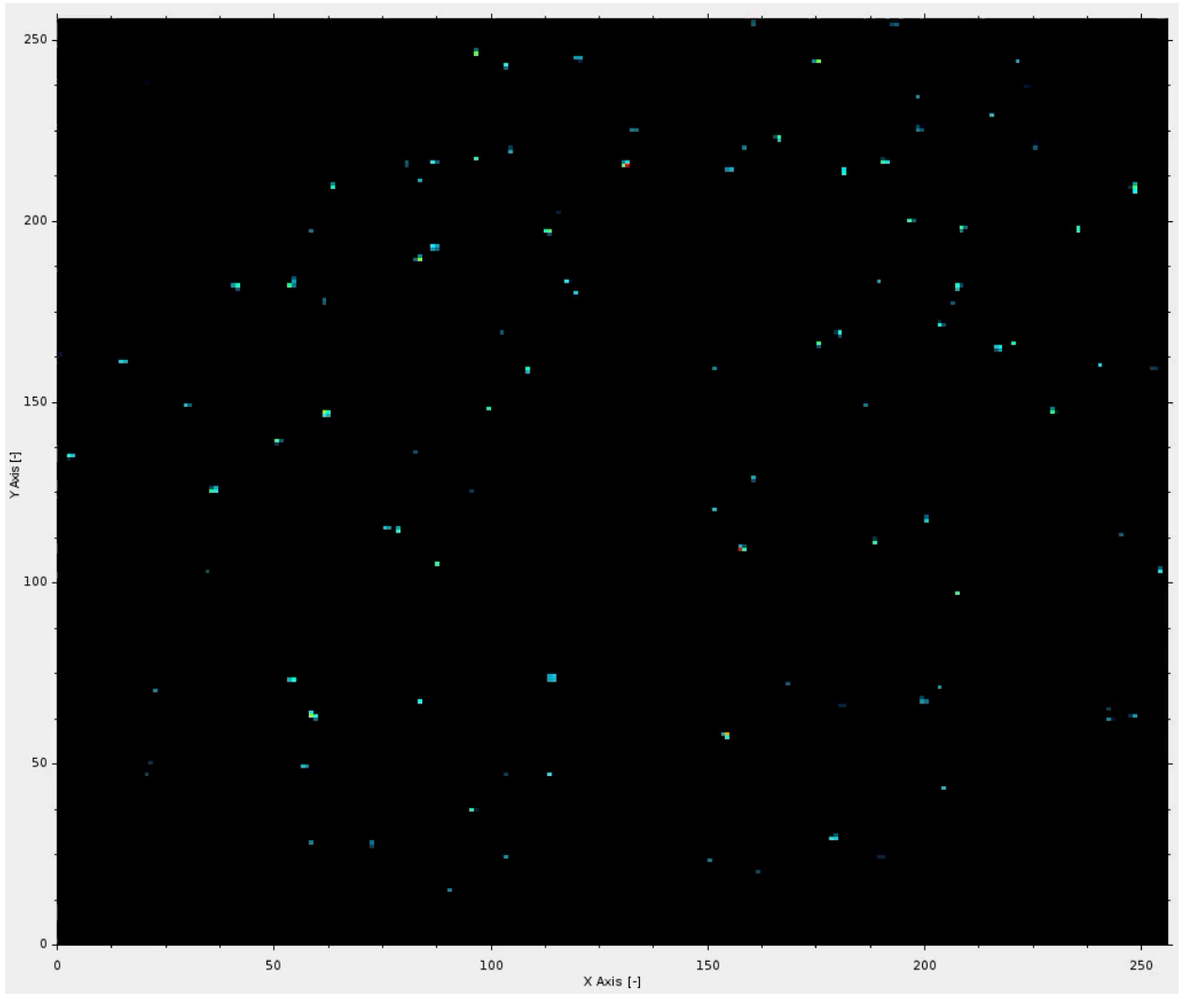
Resolution:
XY-axis: ~0.7mm
Z-axis: <0.1mm

***Better z-axis resolution can be achieved in LAr due to slower drift speed - likely diffusion limited**

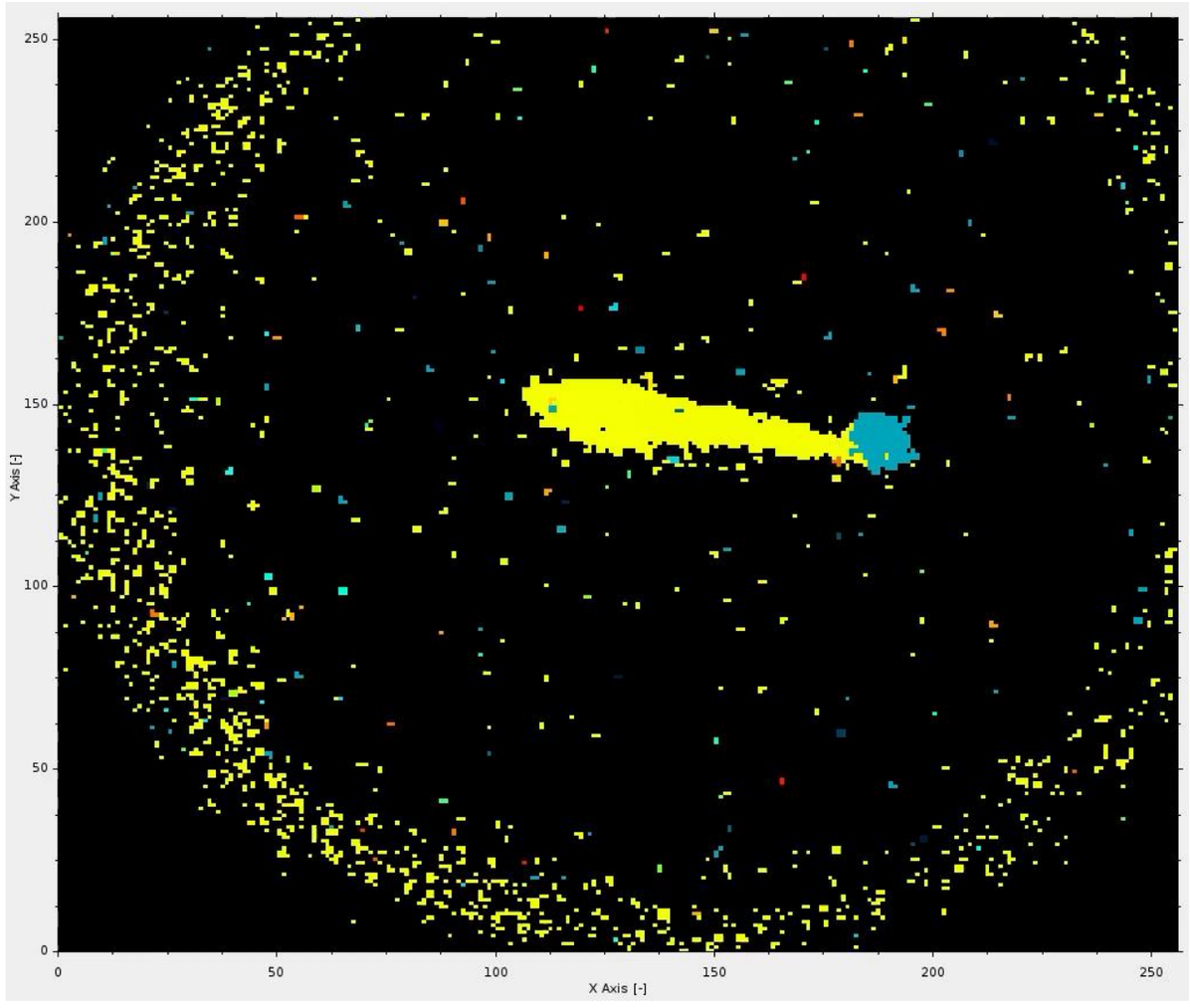
"First demonstration of 3D optical readout of a TPC using a single photon sensitive Timepix3 based camera' - https://arxiv.org/abs/1810.09955

TPX3Cam Results

Video: ToT 1 msec



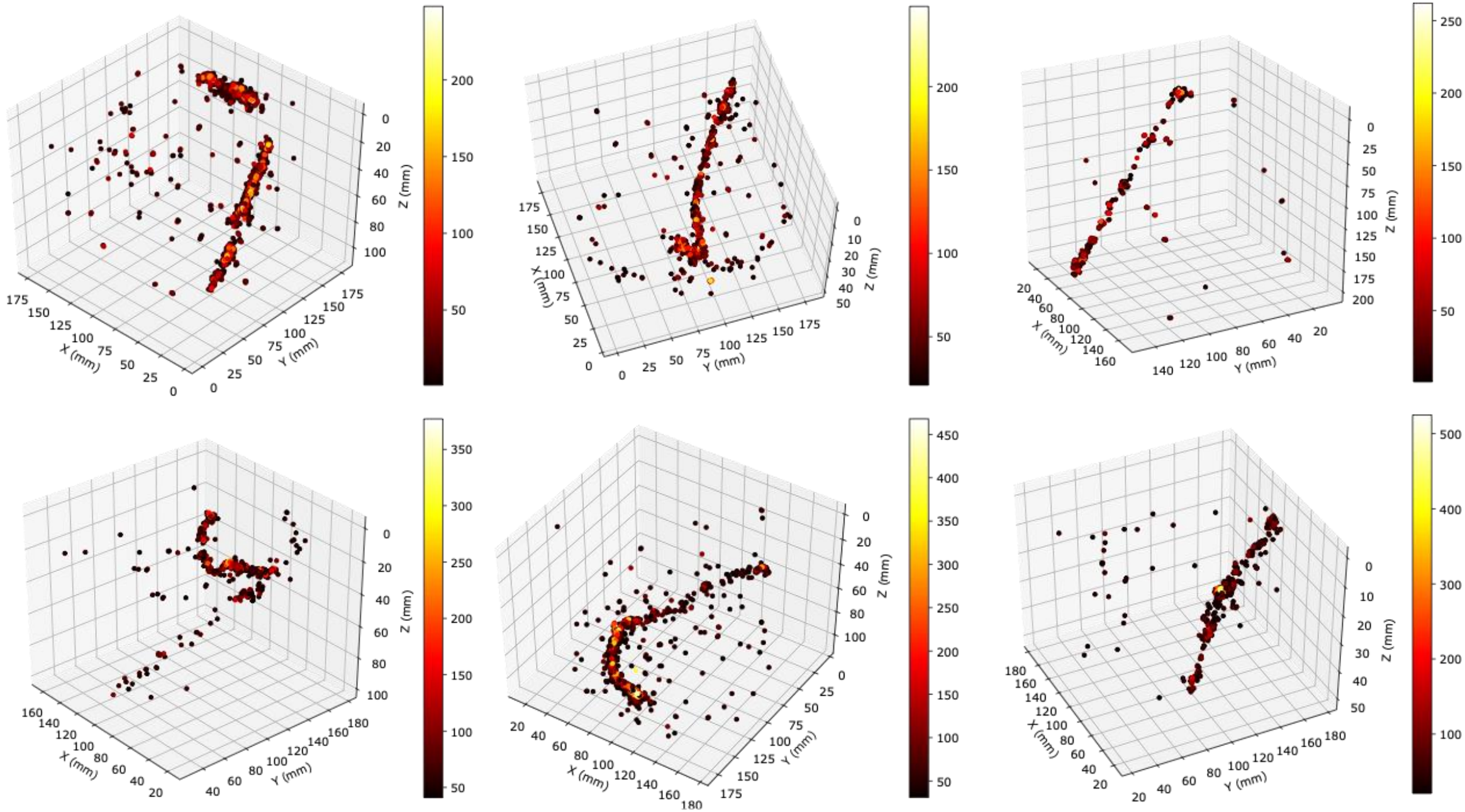
Video: ToA 1 msec



(Not enough colours to resolve ToA within tracks)

“First demonstration of 3D optical readout of a TPC using a single photon sensitive Timepix3 based camera’ - https://arxiv.org/abs/1810.09955

TPX3Cam Cosmics



“First demonstration of 3D optical readout of a TPC using a single photon sensitive Timepix3 based camera’ - https://arxiv.org/abs/1810.09955

TPX3Cam Next Steps

Near:

- LAr tests with ARIADNE detector: 2x EMCCDs and 2x TPX3Cams using optimised image intensifiers:

Curren
t

Q.E.: ≈ 20%
Dark Count: ≈ 10-20kHz

Nex
t

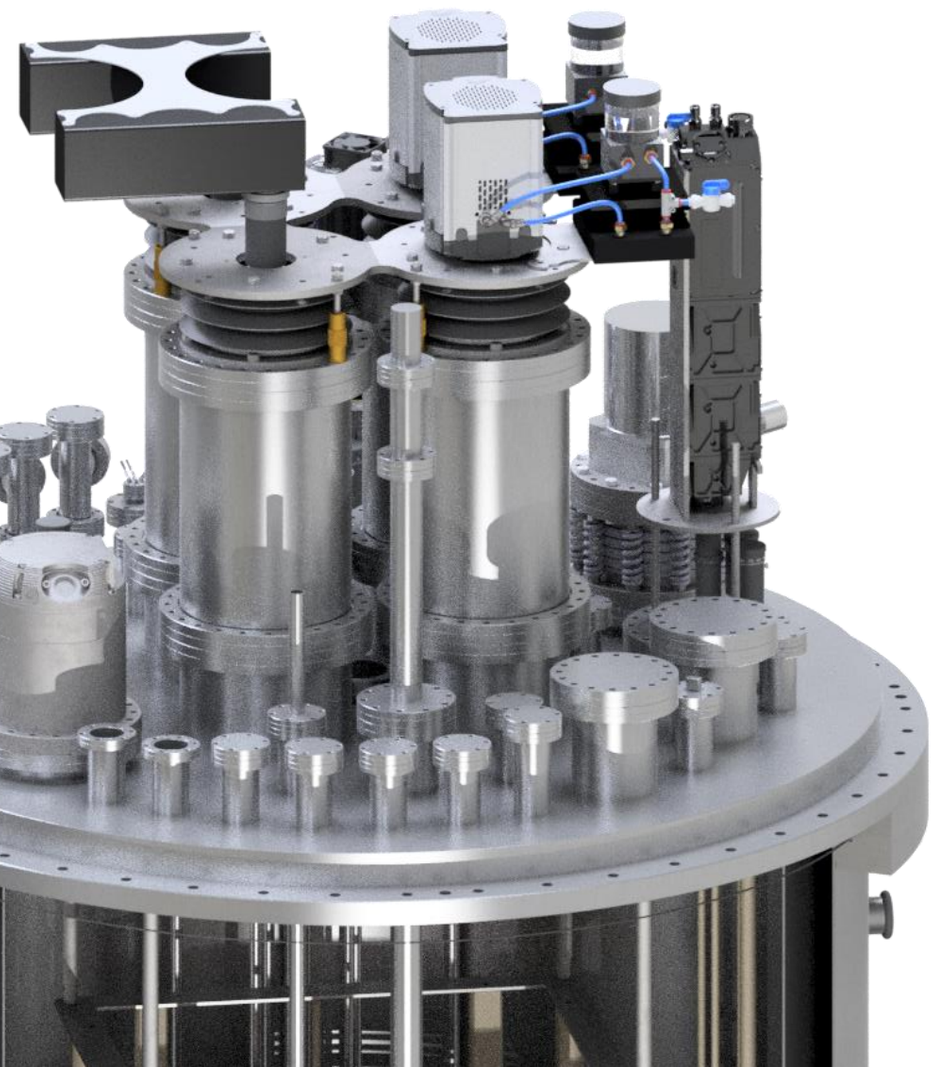
Q.E.: ≈ **30%**
Dark Count: ≈ **60Hz**

- Effect: Will remove most background noise seen in data

- With more R&D Q.E. could be improved even more.

- Image intensifier could be replaced with intensifier directly integrated with Timepix chip.

2x TPX3Cam **2x EMCCD**



Summary

ARIADNE has shown that optical readout of LArTPCs works.

Further tests this year with TPX3Cam will prove full 3D readout in liquid Argon.

Optical readout is a promising technology for future large neutrino LArTPC experiments.

Thank-you!

http://hep.ph.liv.ac.uk/ariadne

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European Commission | Horizon 2020 European Union funding for Research & Innovation
erc European Research Council Established by the European Commission

Extra: EMCCD Specs

Andor iXon 888

Models	iXon 888
Core attributes	Field of view, sensitivity and speed
Sensor format	1024 x 1024
Sensor diagonal	18.8 mm
QE Options	BV (Life) or BV, EX2, UVB (Ultra)
Pixel Size	13 µm
Frame Rate	26 fps (670 fps with 128 x 128 Crop Mode)
Read Noise	< 1 e- with EM Gain
Pixel well depth	80,000 e-
Interface	USB 3.0

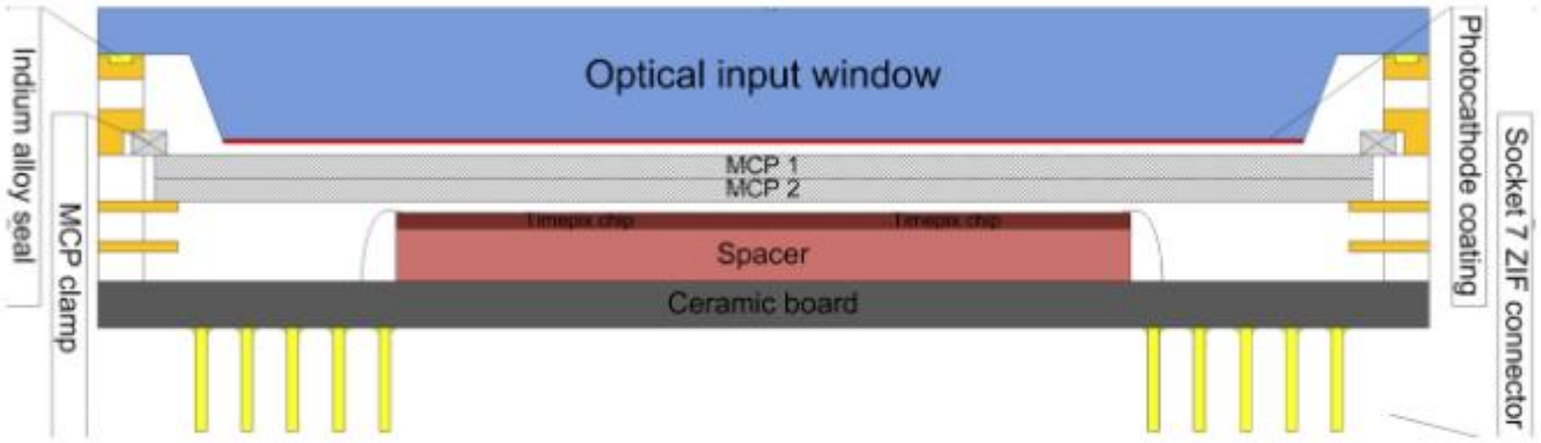
Extra: TPX3Cam Specs

TPX3Cam specifications

Sensor	
Material	silicon with enhanced light sensitivity
Wave length range	400 - 1000 nm
Detection limit	~1000 photons per pixel hit
Optics	
Sensor active area	14.1 x 14.1 mm^2
Type	C-mount
Minimal distance lens to sensor	42 mm
Imaging ASIC	
Type	Timepix3
Pixel pitch	55 µm
# of pixels	256 x 256
# of thresholds	1
Throughput	up to 80 Mhits/s for 10 Gb/s up to 15 Mhits/s for 1 Gb/s
Read-out dead time	Dead time zero, within allowed throughput

Time resolution	1.6 ns
Effective frame rate	> 500 MHz
Pixel hit dead time	~1 µs
Read-out mode	Data driven, simultaneous time and intensity by per pixel ToA and ToT detection
Other	
Computer interface	1 Gb/10 Gb Ethernet
External shutter control	Yes
External signal time stamping	260 ps
Weight	2.2 kg
Dimensions (l x w x h)	28.5 x 80 x 90 cm^3
Cooling	Air
Acquisition software	GUI for Windows/ Linux/Mac

Extra: Integrated Timepix



[2] http://iopscience.iop.org/article/10.1088/1748-0221/9/05/C05055/pdf

Optical MCP image tube with a quad Timepix readout: initial performance characterization

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