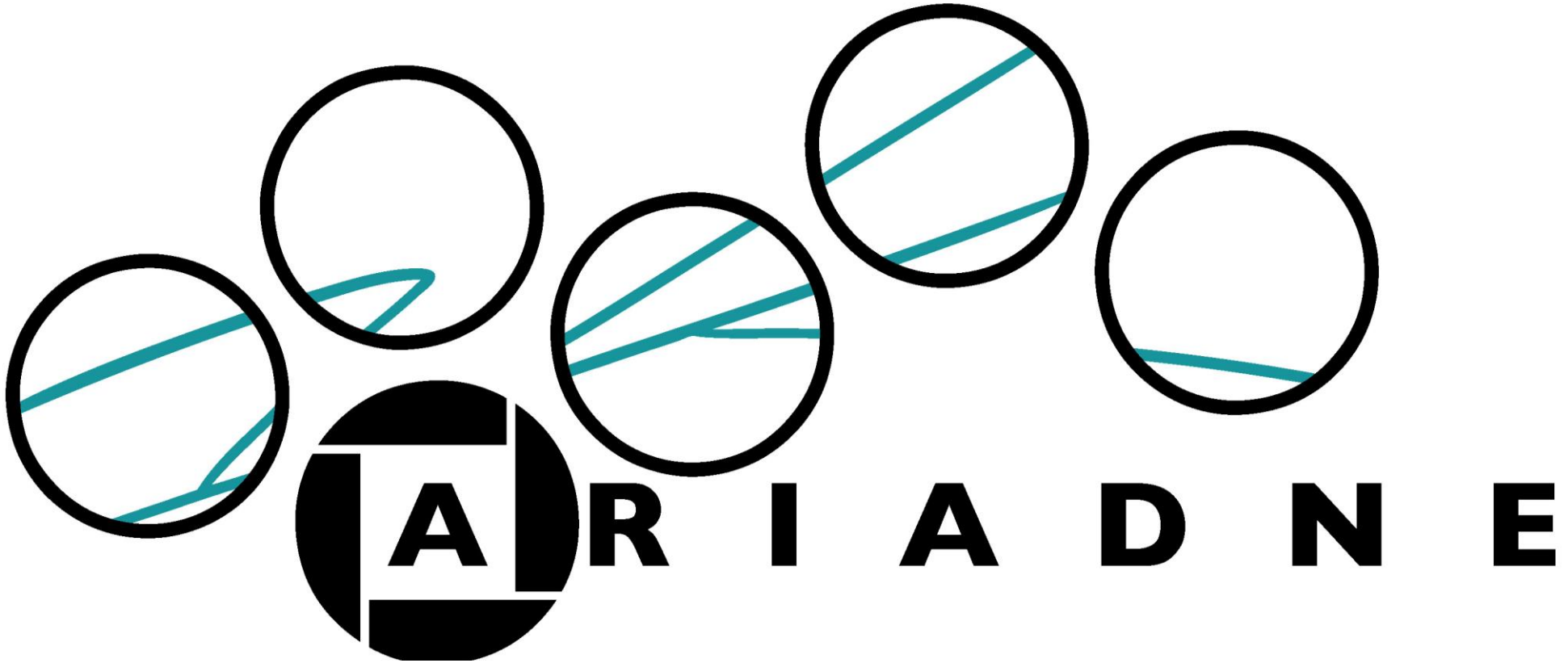

ARIADNE
A 1-ton dual phase LArTPC with novel optical readout

Adam Roberts, University of Liverpool

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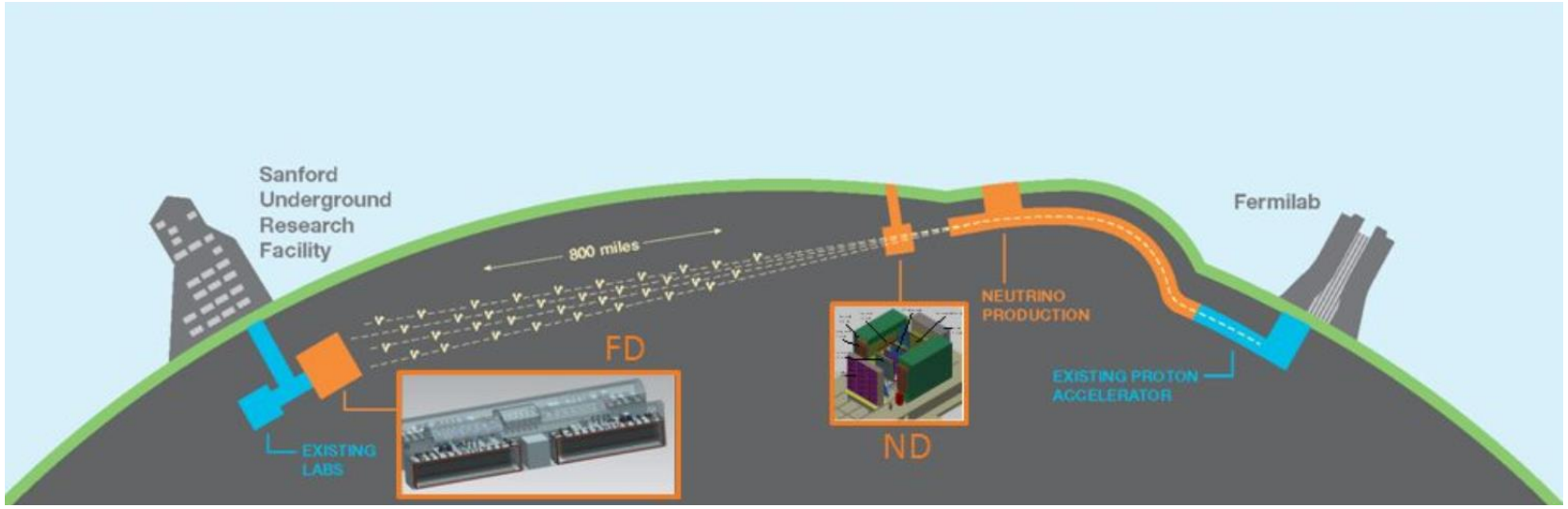
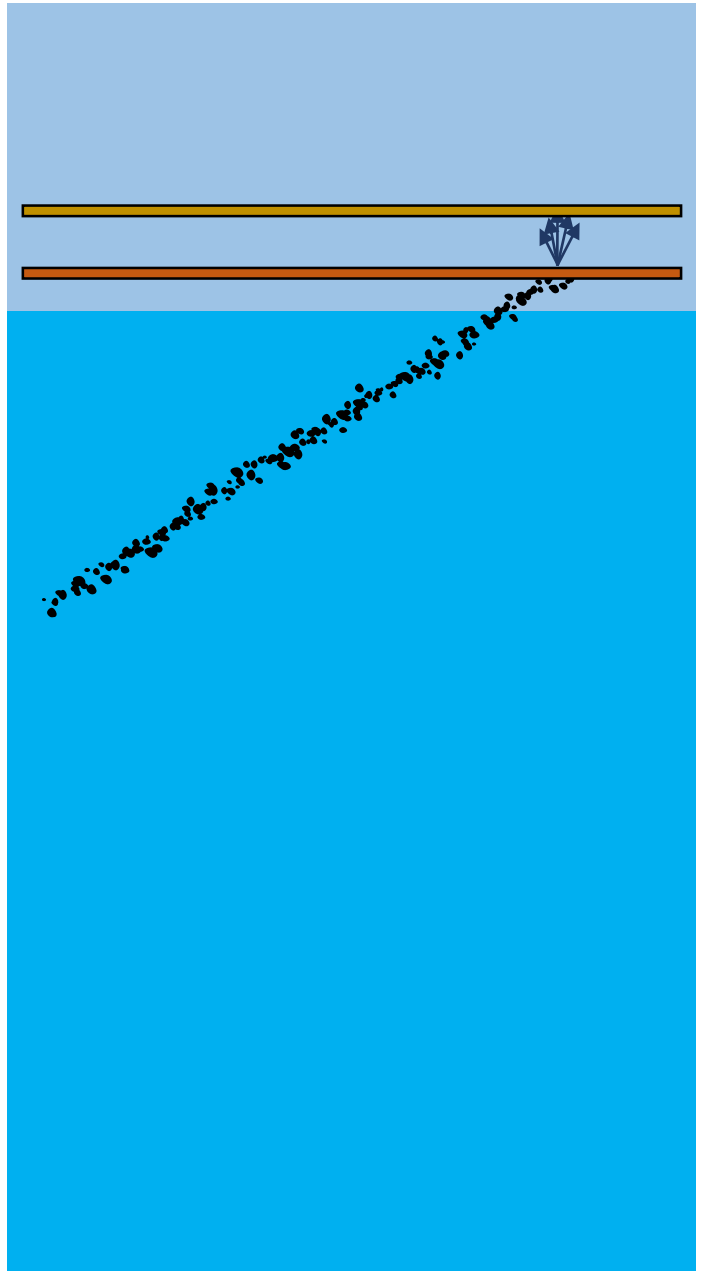
Why are we building colossal liquid Argon experiments?



- What is the origin of the matter-antimatter asymmetry in the Universe?
- Is there a Grand Unified Theory of the Universe?
- How do supernovae explode and what new physics will we learn from a neutrino burst?

Building these huge detectors is expensive and complicated

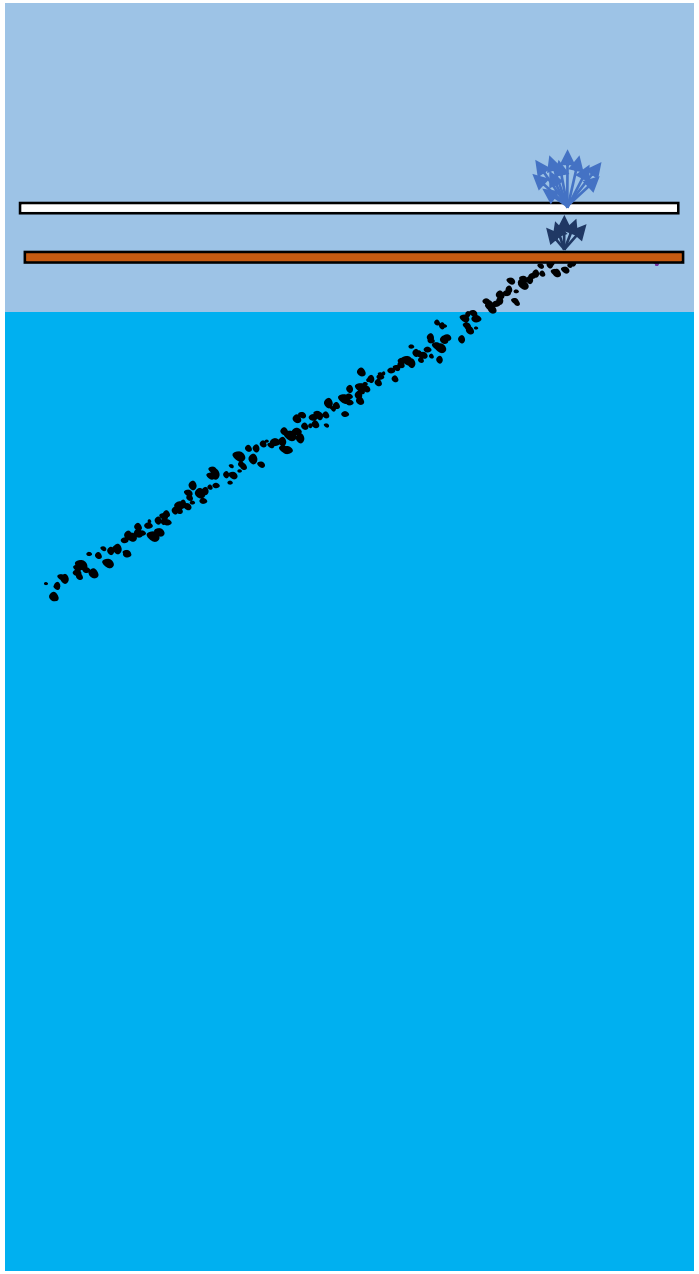


Classical Dual Phase LAr TPCs

TPC charge signal is amplified using a THGEM. Amplified charge signal is collected using a segmented anode.

Electron gain gives greatly improved signal to noise and lower detection thresholds. Can be very helpful for detectors with very long drifts.

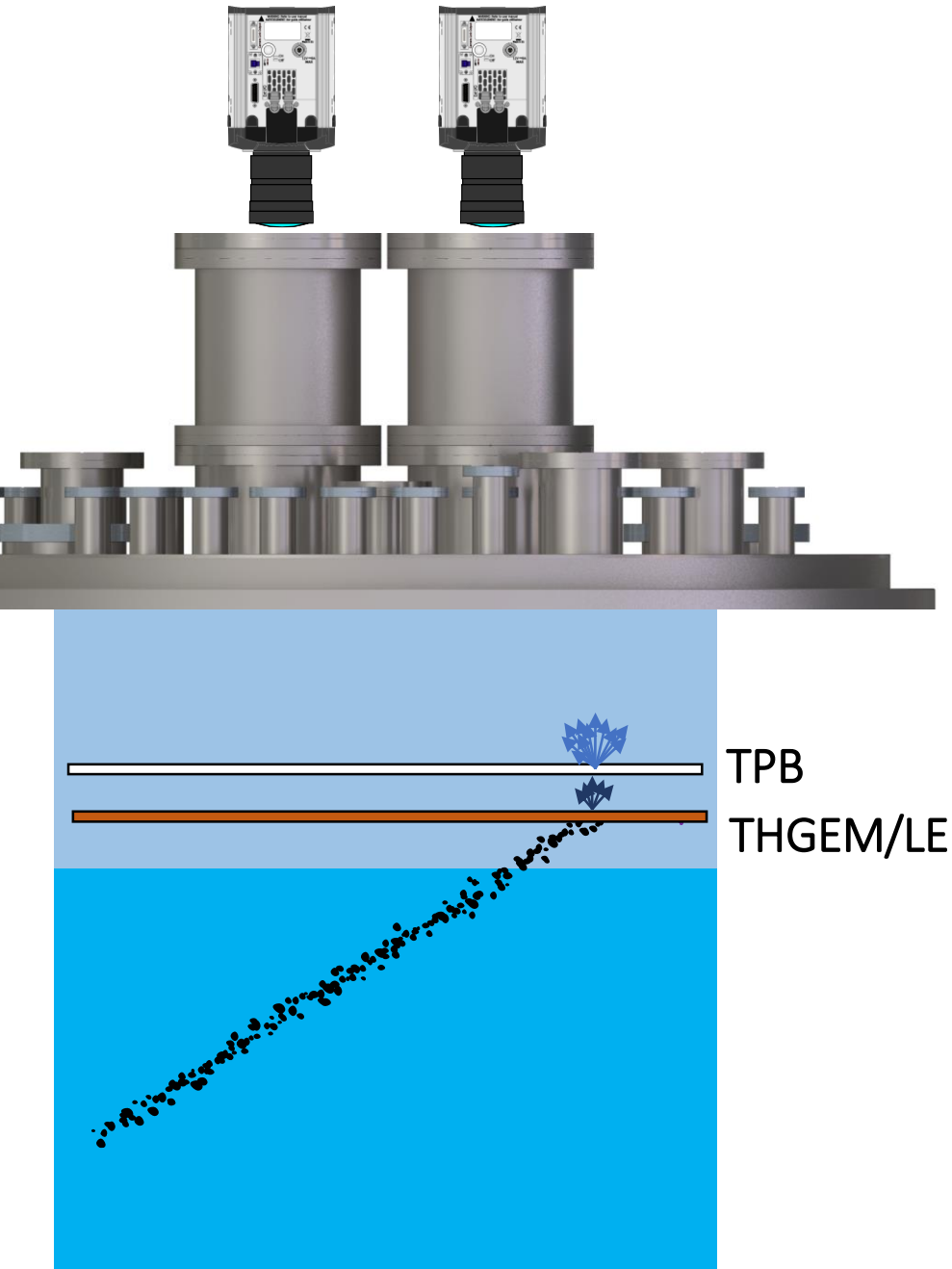
Large gain in pure Argon can be a challenge due to electrical instability.



Optical Dual Phase LAr TPC

TPC charge signal is accelerated in the THGEM holes, producing electroluminescence light (S2). Large photon yield of ~500+ photons/electron.

VUV photons are wavelength shifted to 430nm using a TPB coated glass sheet.



Optical Dual Phase LAr TPC

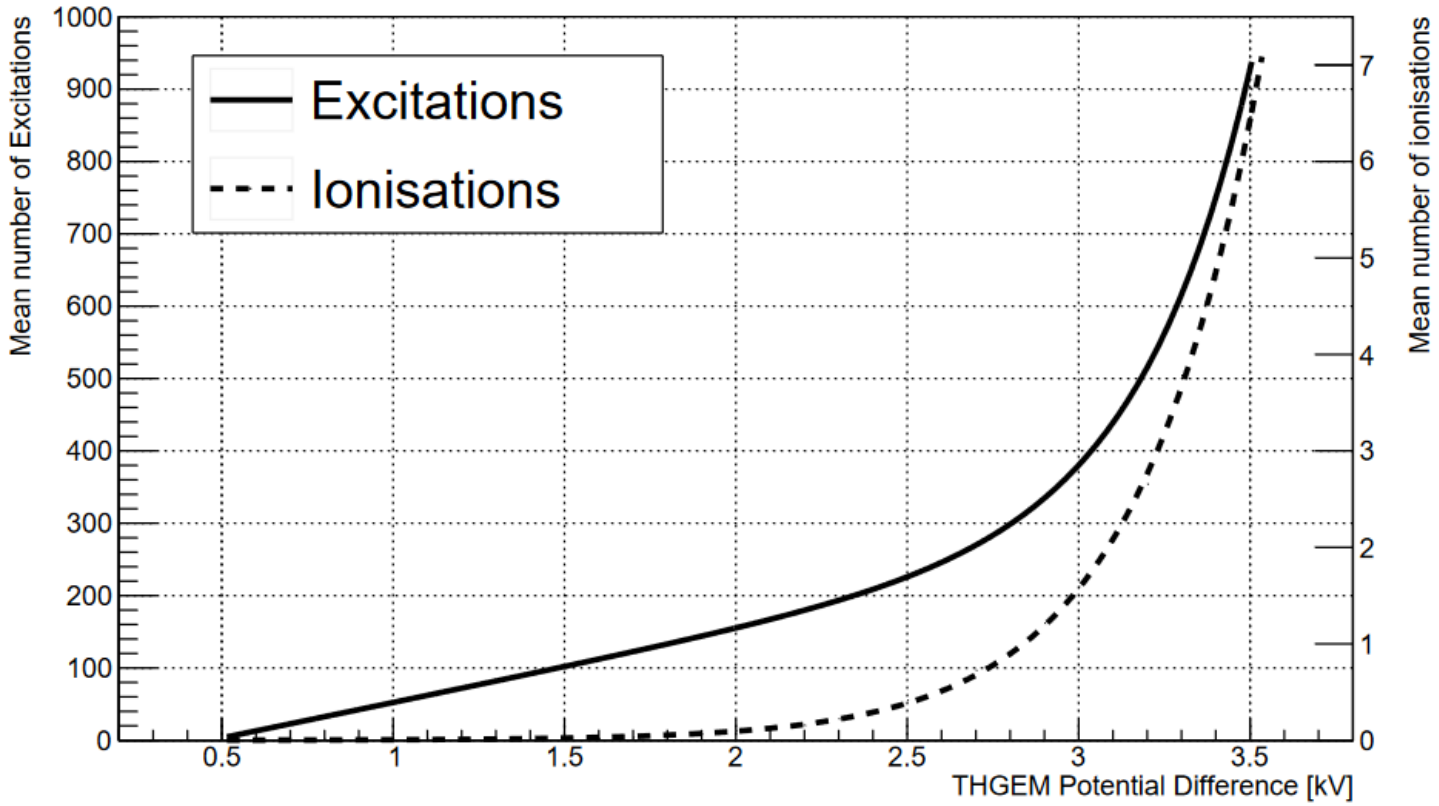
TPC charge signal is accelerated in the THGEM holes, producing electroluminescence light (S2). Large photon yield of ~500+ photons/electron.

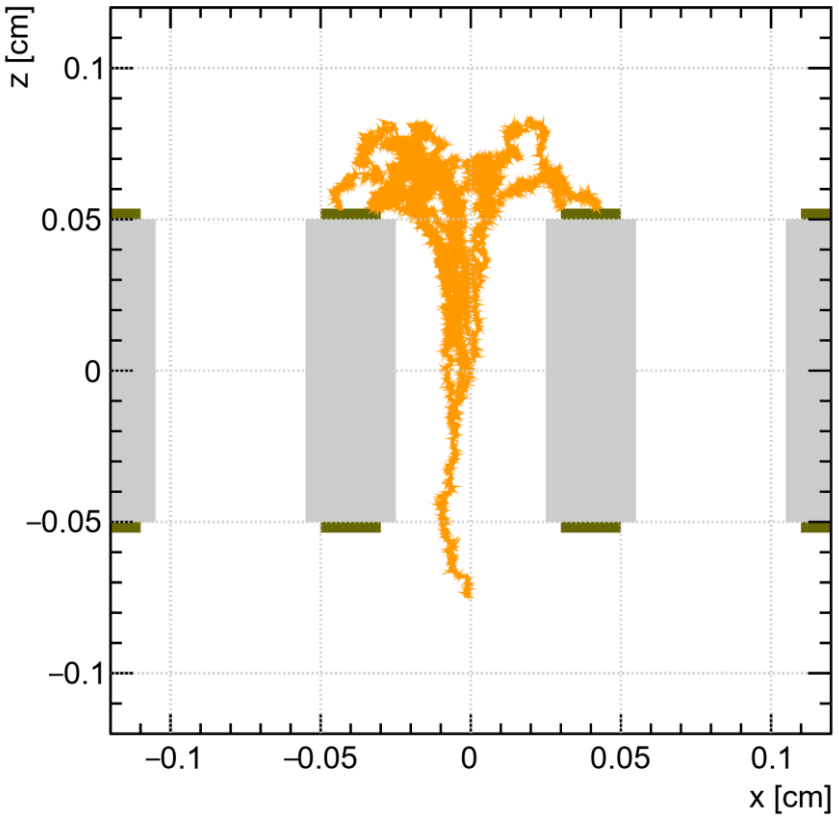
VUV photons are wavelength shifted to 430nm using a TPB coated glass sheet.

Light signal is detected using a camera.

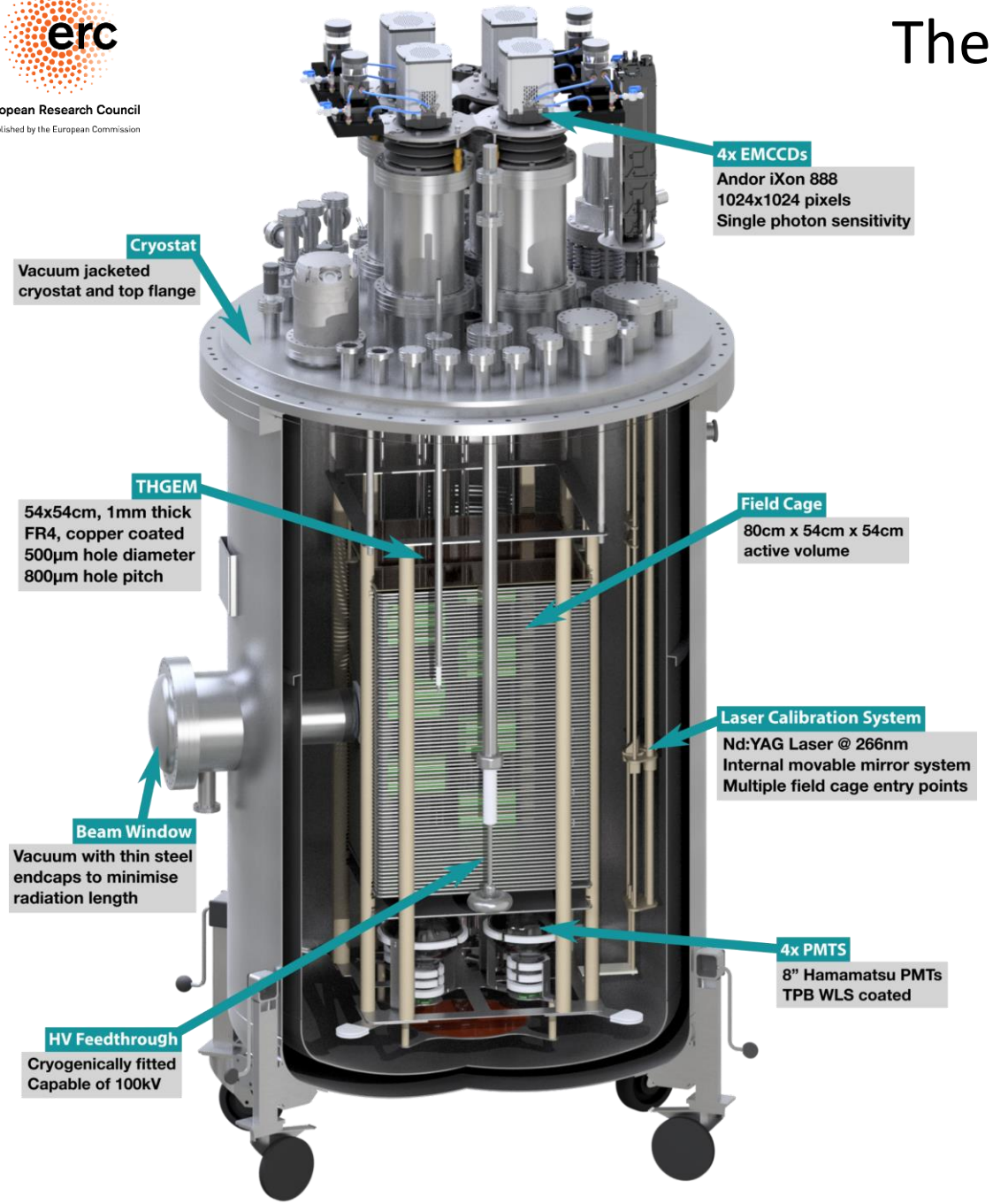
Light production in a THGEM

- Proportional electroluminescence at low THGEM fields (zero ion production)
- Exponentially enhanced light production once in the charge multiplication regime.



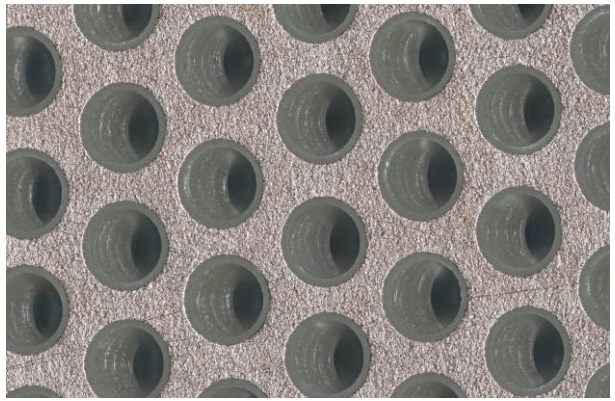


The ARIADNE detector

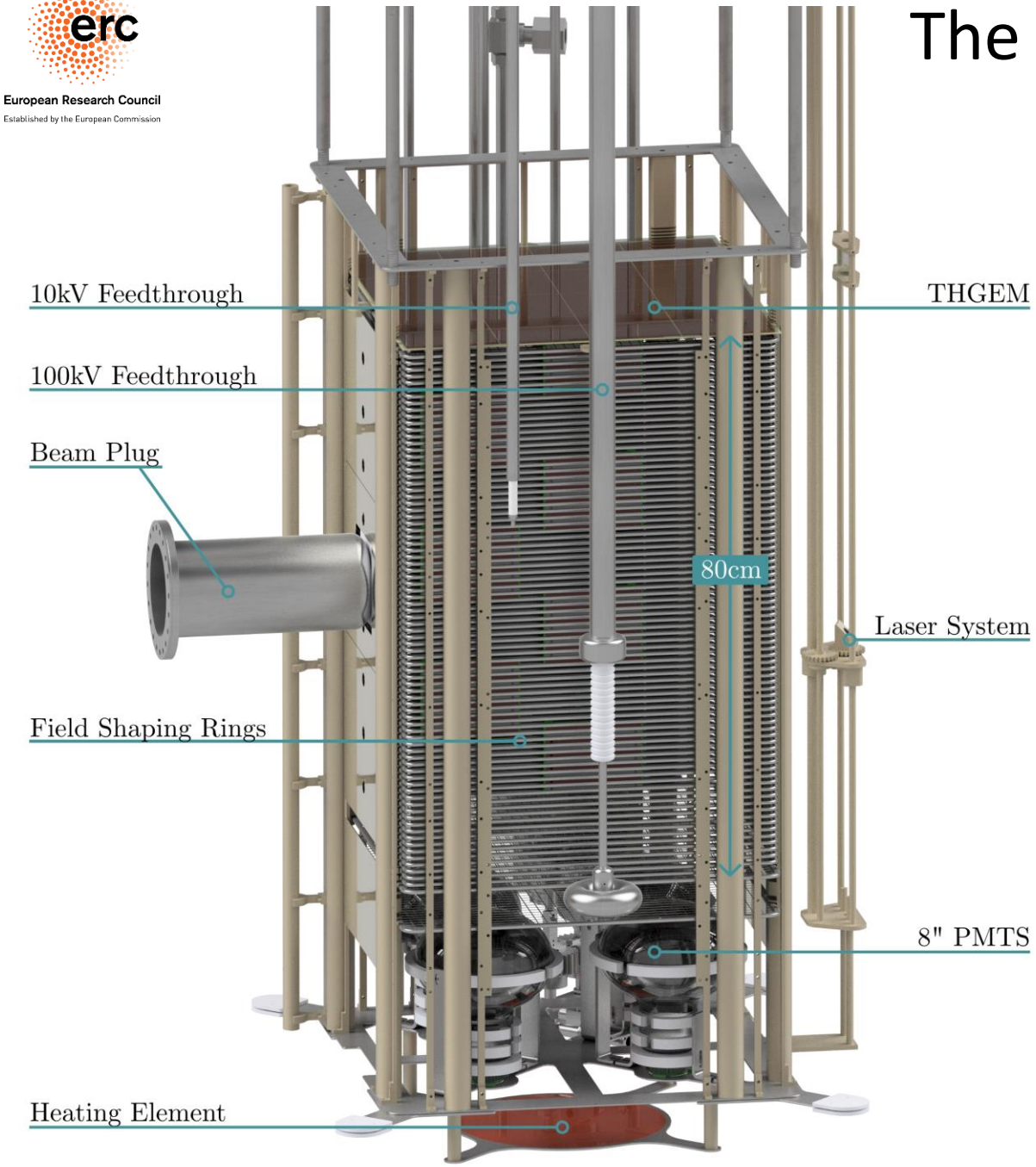


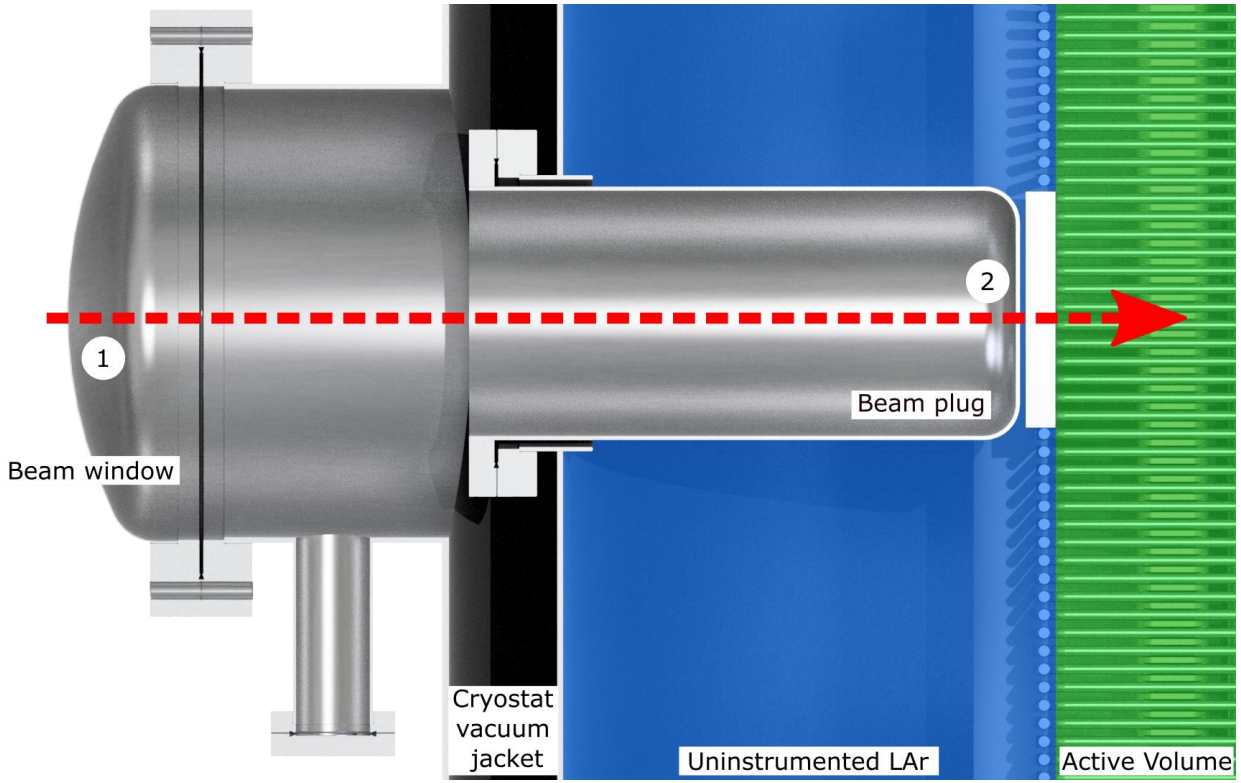
This talk:

- ARIADNE commissioning and characterisation in a mixed charged particle beam (T9 at CERN)
- Recent technological developments
- Next steps towards larger area detectors



The ARIADNE detector



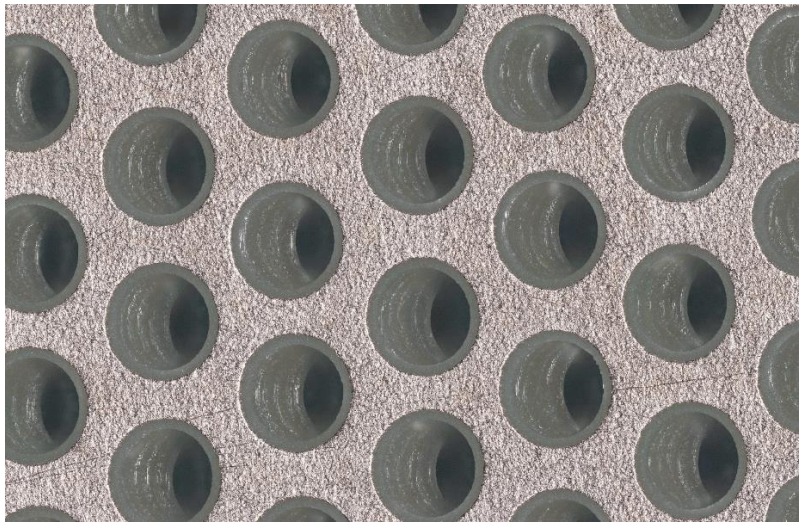


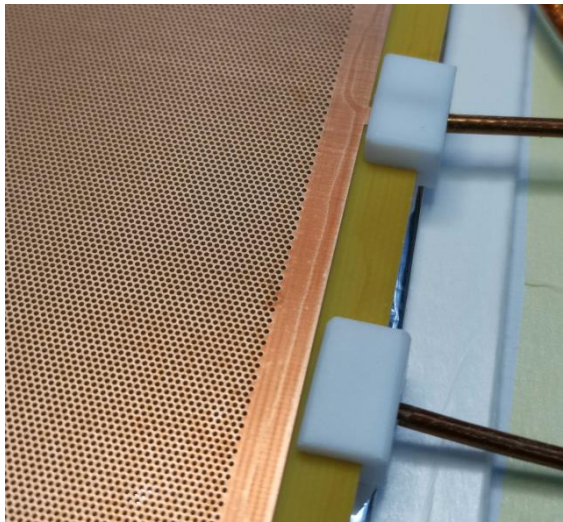
Beam plug allows improved transport of beamline particles into the TPC ($0.22X_0$)

The ARIADNE THGEM

Typical dimensions, identical specs to LEMs used in dual-phase protoDUNE;

- 500 micrometer diameter holes
- 50 micrometer dielectric rim
- 800 micrometer hole to hole pitch, hexagonal array
- 54cm x 54cm x 1mm thick

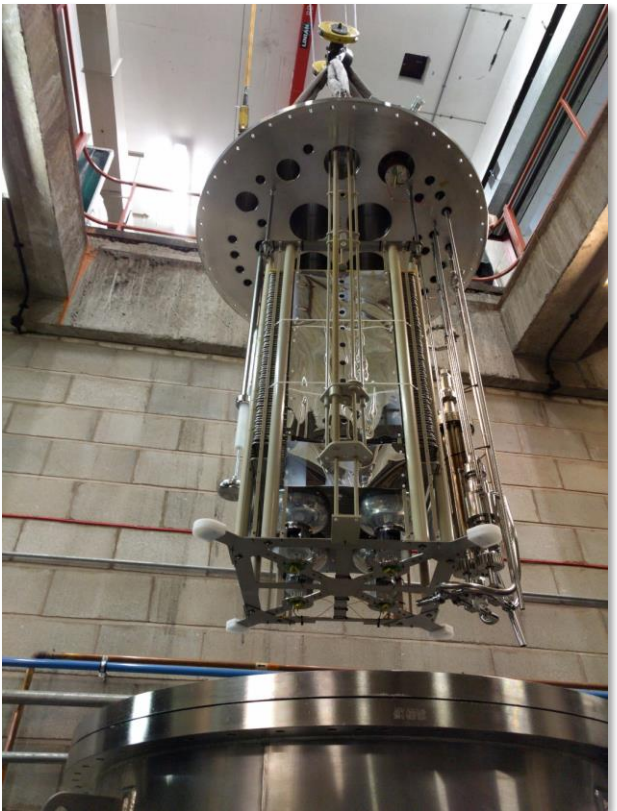


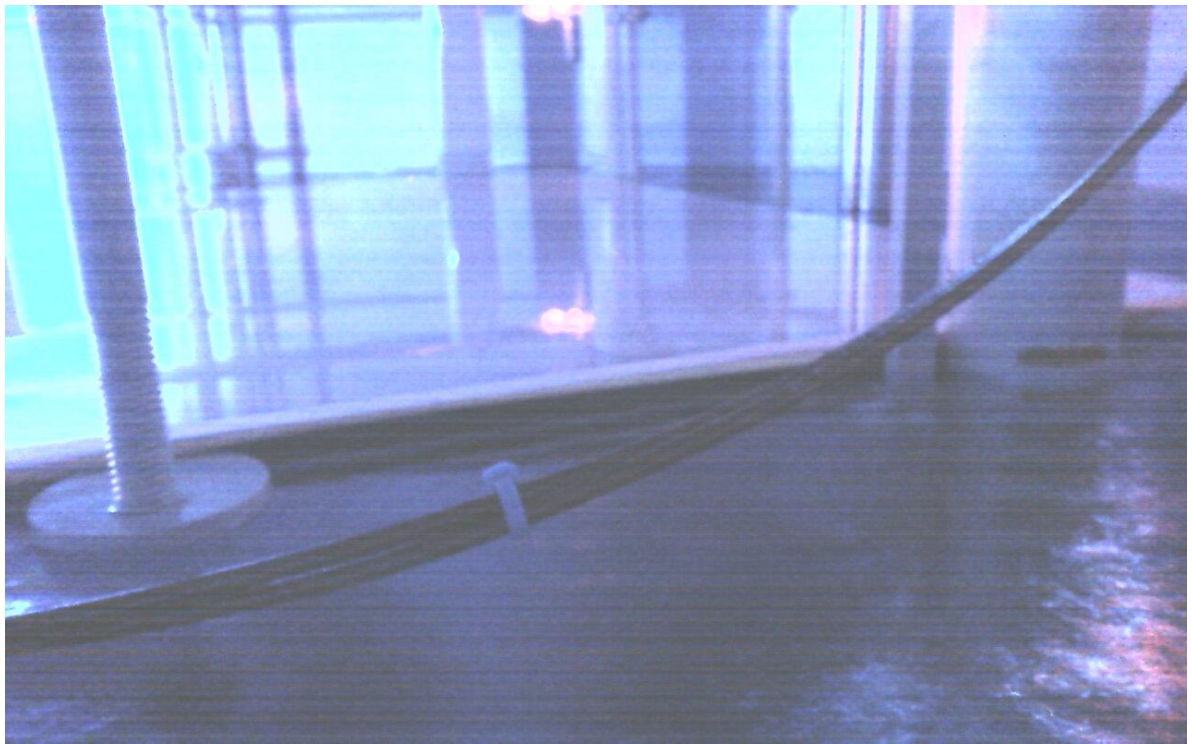


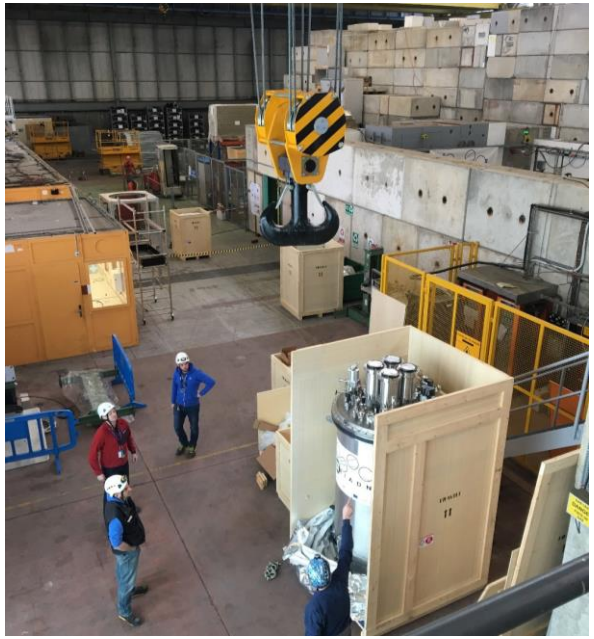
ARIADNE at Liverpool

Detector construction completed end of 2017

Initial cosmic tests in Liverpool
Deployment to T9 beamline in March 2018



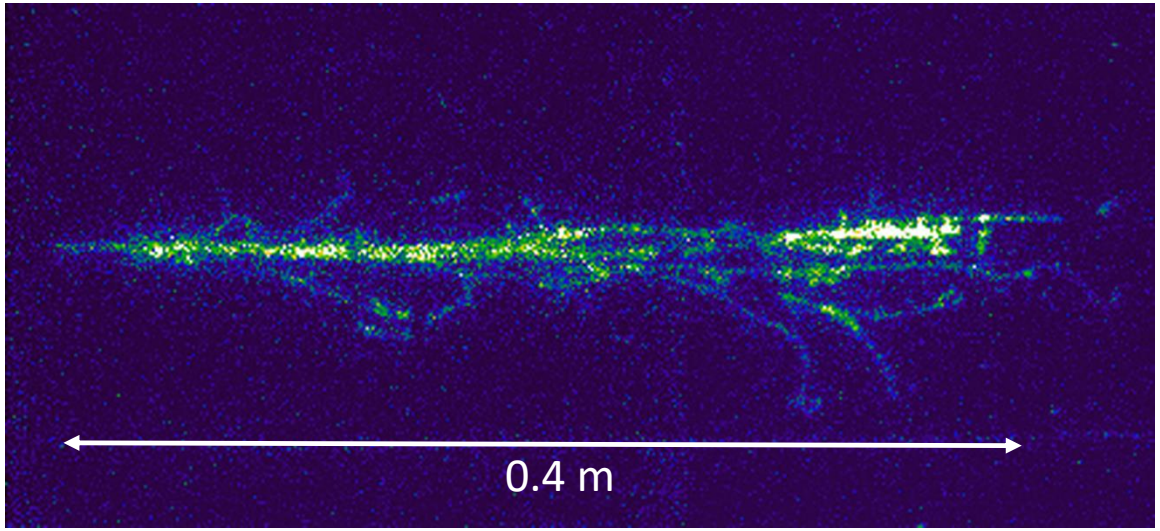


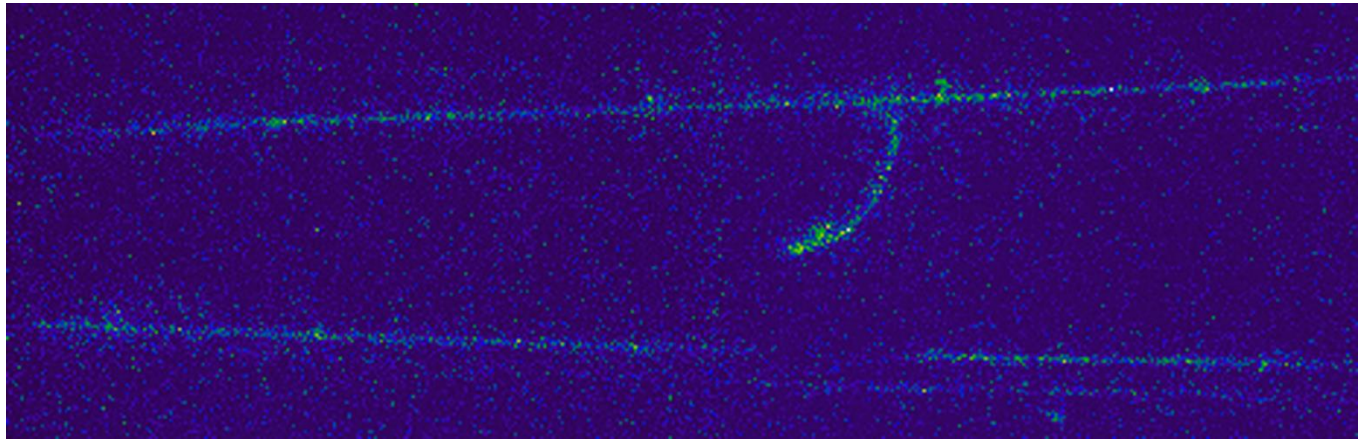


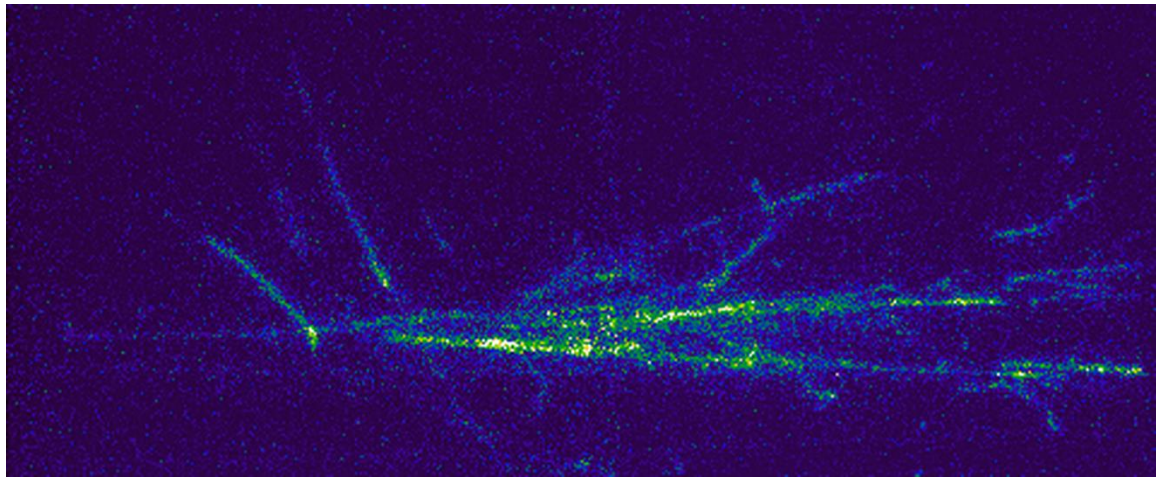
ARIADNE at CERN

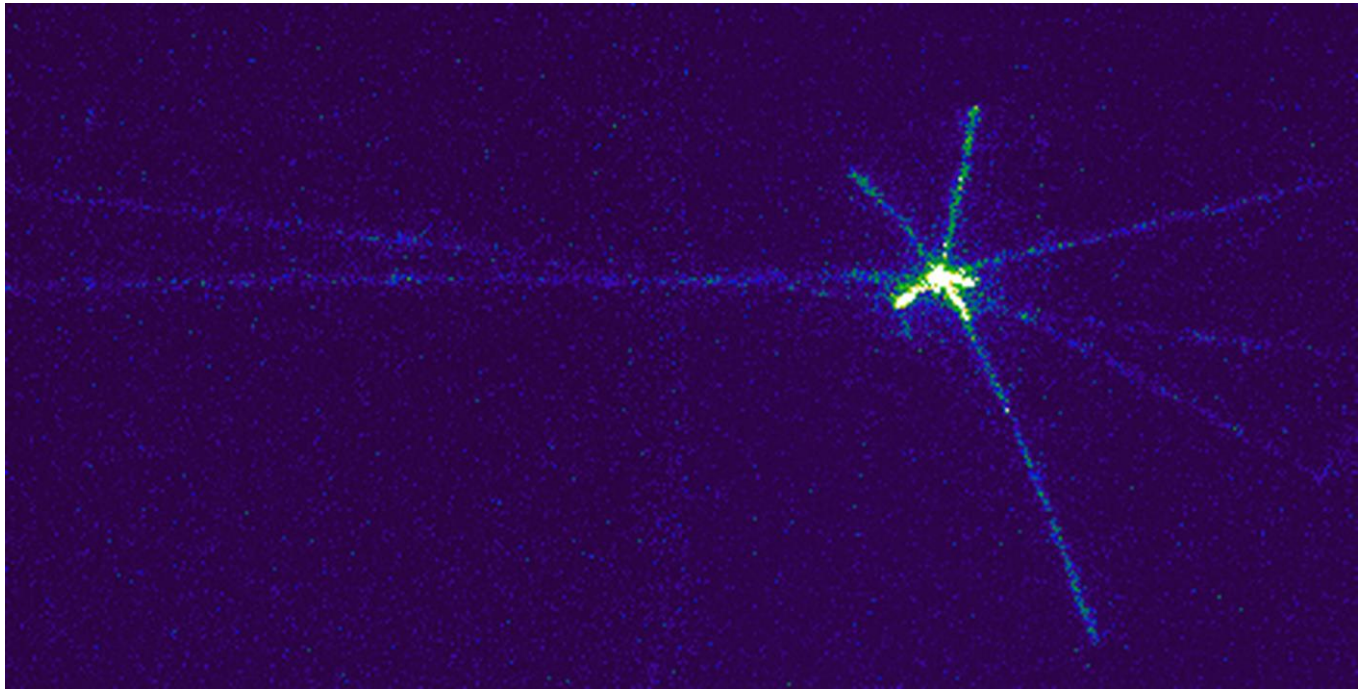
Total of 800,000 events collected between 0.5 – 8 GeV
Mixture of muons, anti-protons, electrons, etc

First demonstration of beamline optical readout



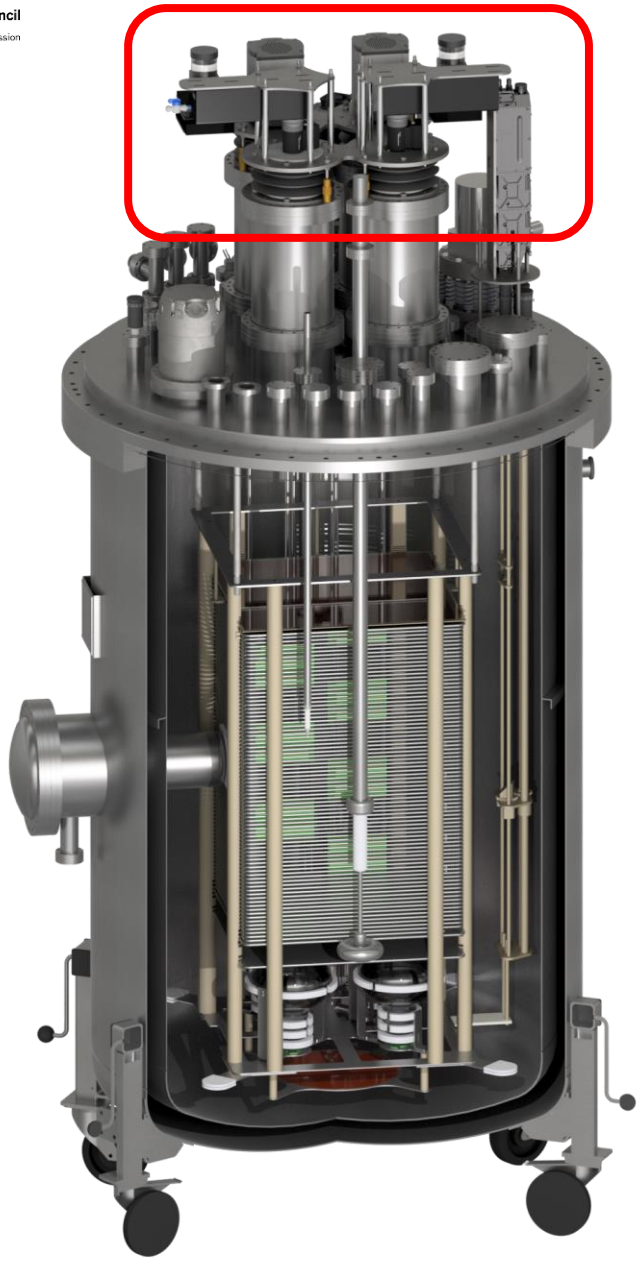






1mm / pixel x,y resolution

ARIADNE Camera upgrades



EMCCD cameras showed excellent x,y resolution but z dimension information is limited

EMCCD cameras only provide an integrated 2D image of the TPC volume

Full 3D reconstruction would require very high frame rates, not possible with full frame readout (1.6Mfps for 1mm resolution in z)

A new approach was needed.
The idea: A camera with high resolution time of arrival (ToA) information would allow for full 3D reconstruction of events in the TPC.

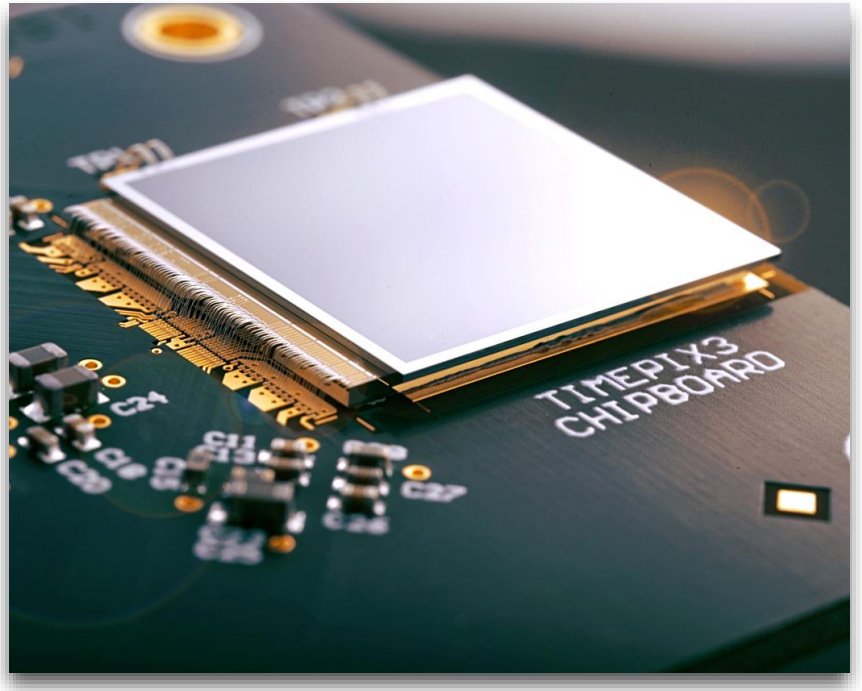
The Timepix3 ASIC

- Data driven (triggerless) readout:
  Each pixel operates independently, allowing for sparse readout with high data rates.

Each hit contains;

- Pixel x,y address
- Hit time of arrival - ToA (1.6ns resolution)
- Hit time over threshold - ToT (10-bit resolution)

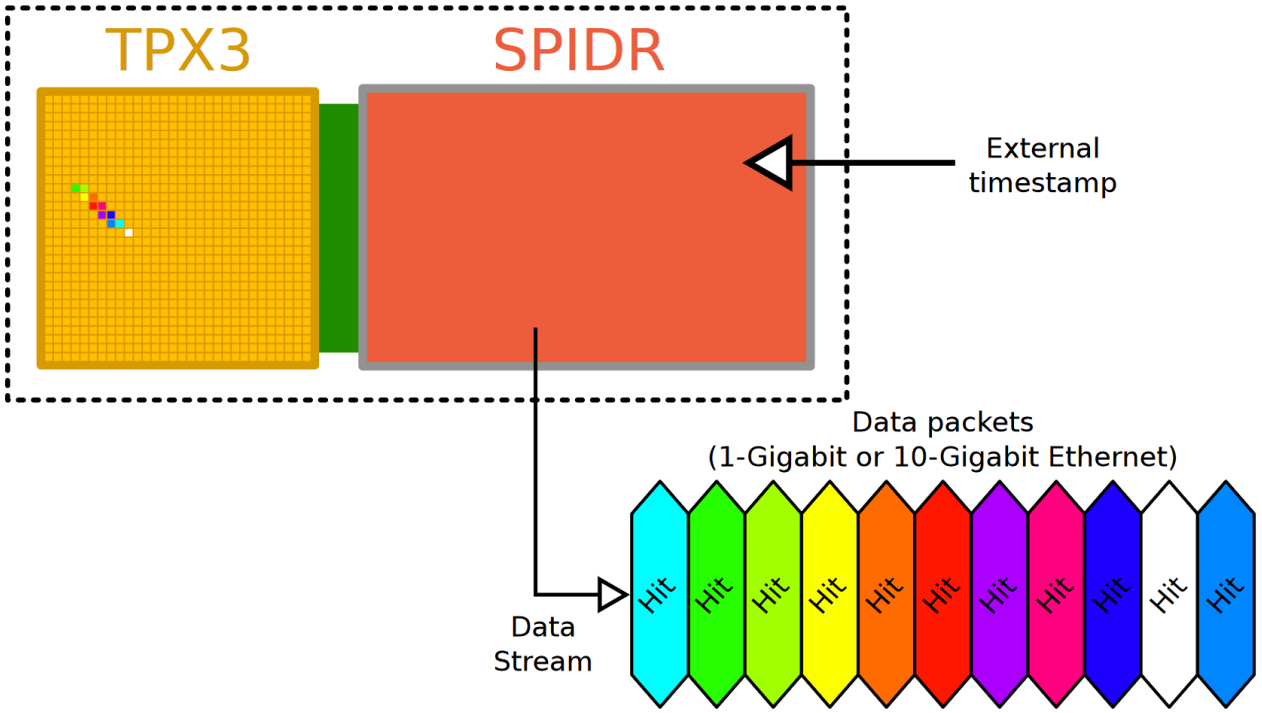
Data from the ASIC is a continuous stream of hits, up to 80 Mhits/s



256 x 256 pixels, 55 micron

Developed by the Medipix collaboration at CERN.
CMOS 130nm process.
Commercially available.

The Timepix3 camera



Recent sensor developments allow for the detection of optical photons:

M. Fisher-Levine and A. Nomerotski, TimepixCam: a fast optical imager with time-stamping, Journal of Instrumentation 11 (03) (2016) C03016

1.6ns ToA resolution allows for precise Z position reconstruction
(drift velocity in LAr is 0.0016 mm/ns)

Data from the camera is a stream of hits containing (x,y) pixel address, time over threshold (ToT) and time of arrival (ToA)

Intensified Timepix 3 camera

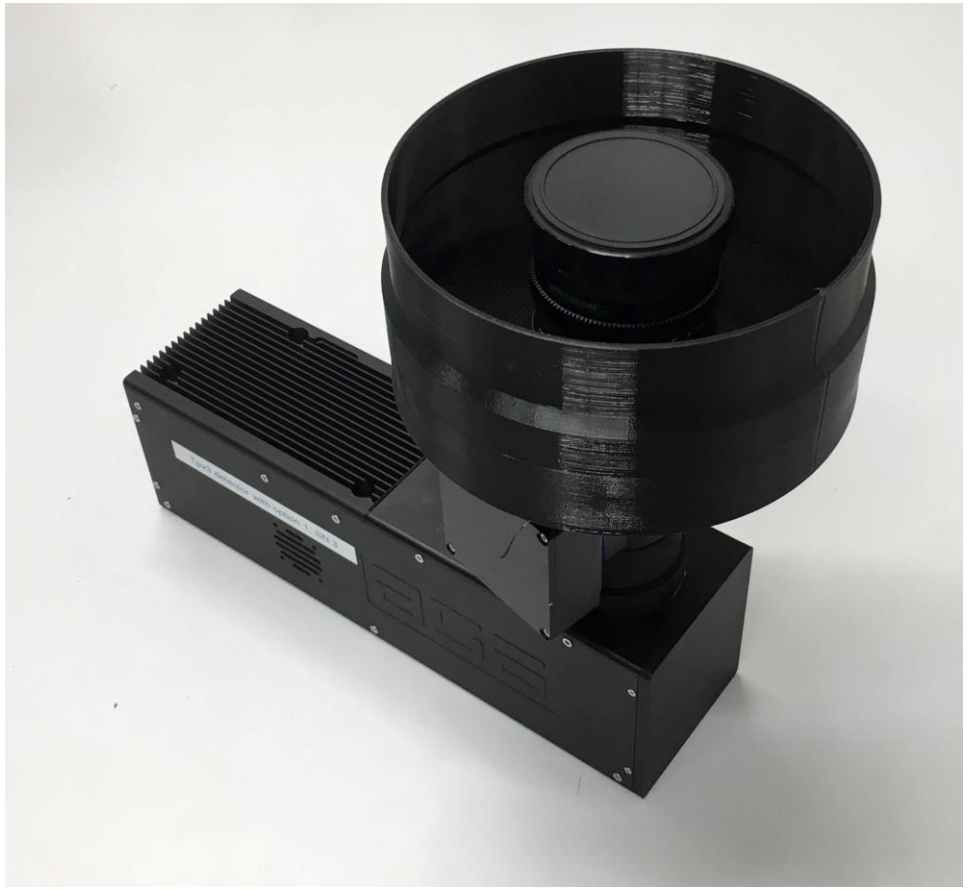
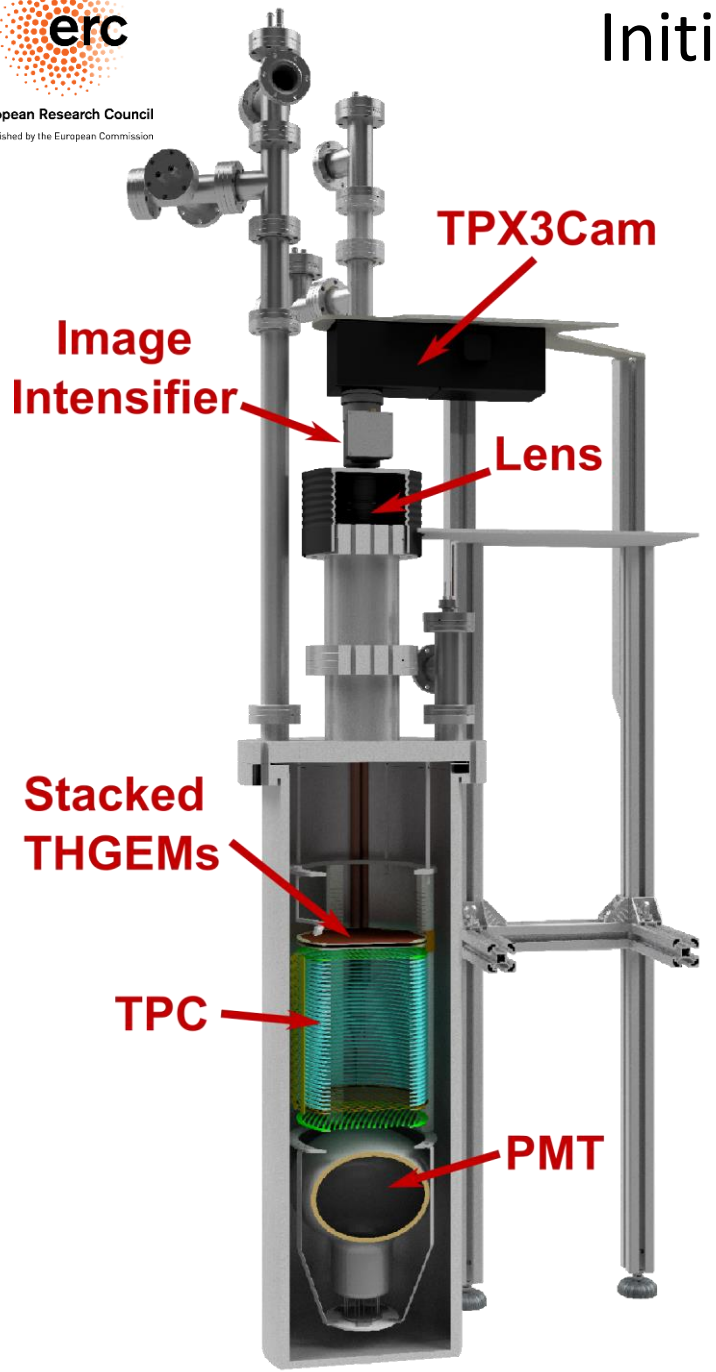


Image intensifier provides single photon sensitivity
(Overcomes the ~60electron front end noise of TPX3).

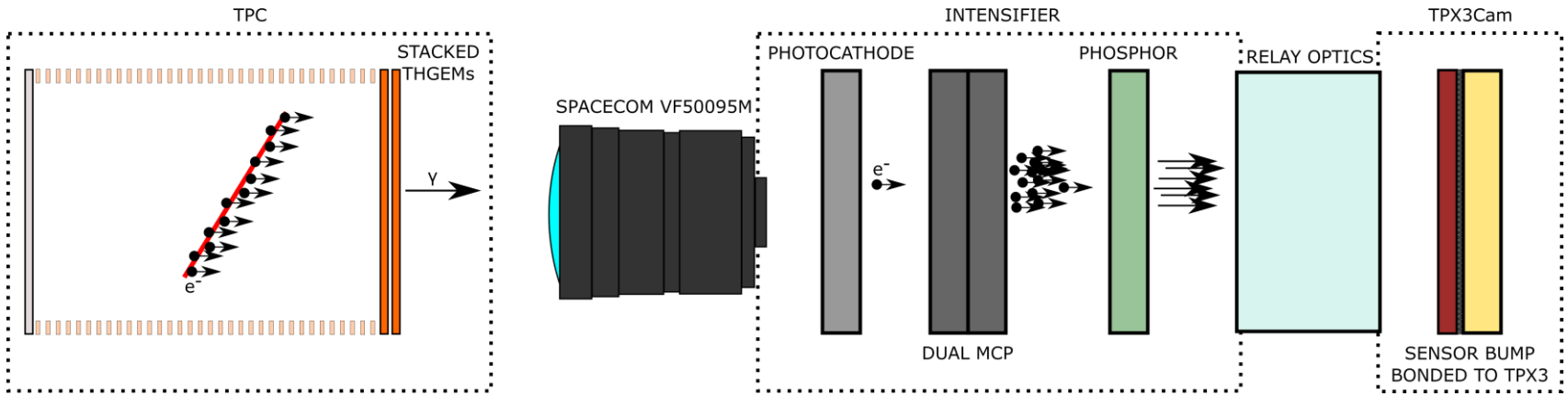
Many photocathode options are possible to customise spectral sensitivity.

Initial demonstration in Gas CF4



- 100 mbar CF4
- Peak scintillation wavelength 620nm
- Very fast drift velocity compared to LAr (10 cm/µs compared to 0.16 cm/µs)

- 1kHz Am-241 alpha source placed inside the TPC.

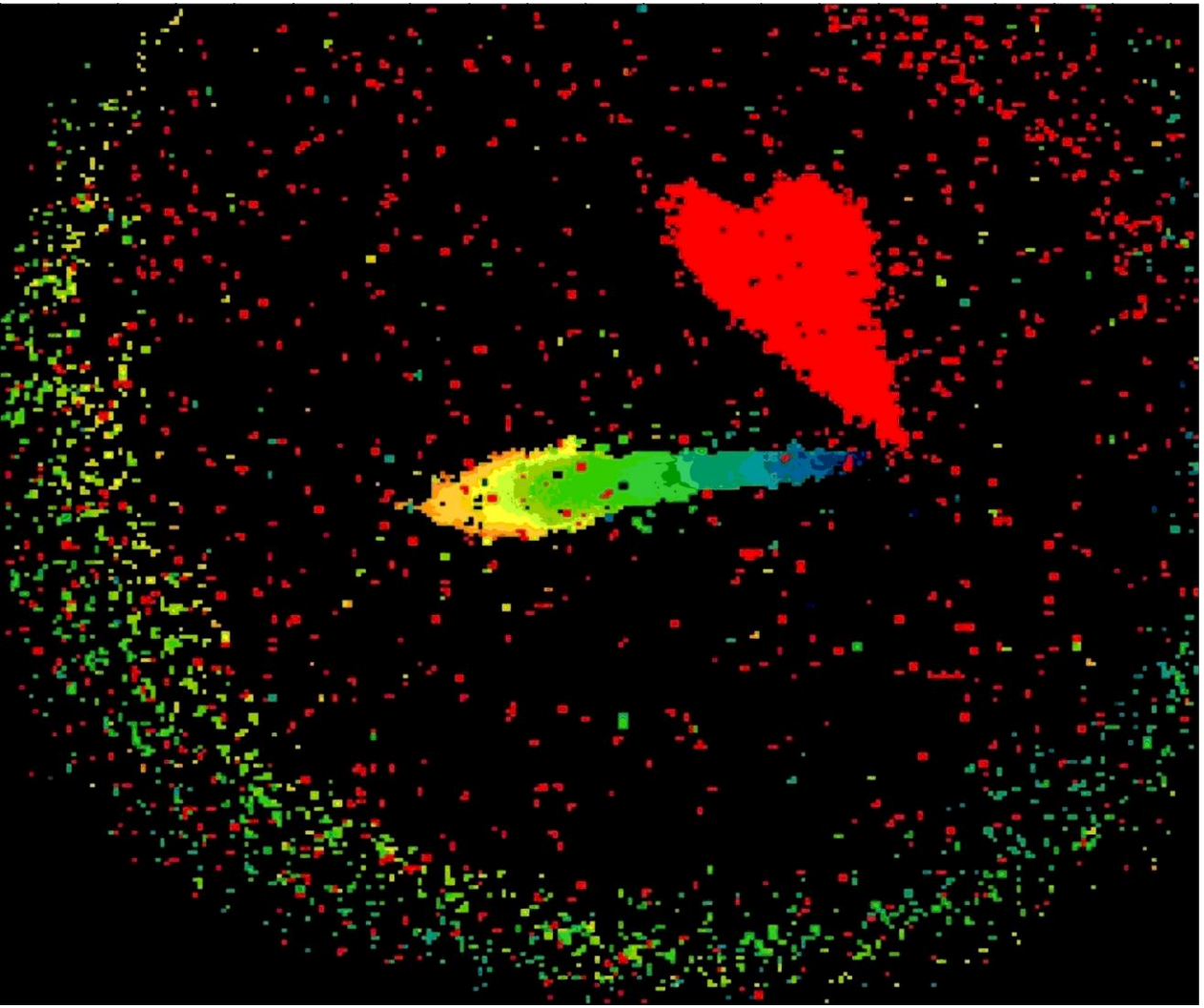


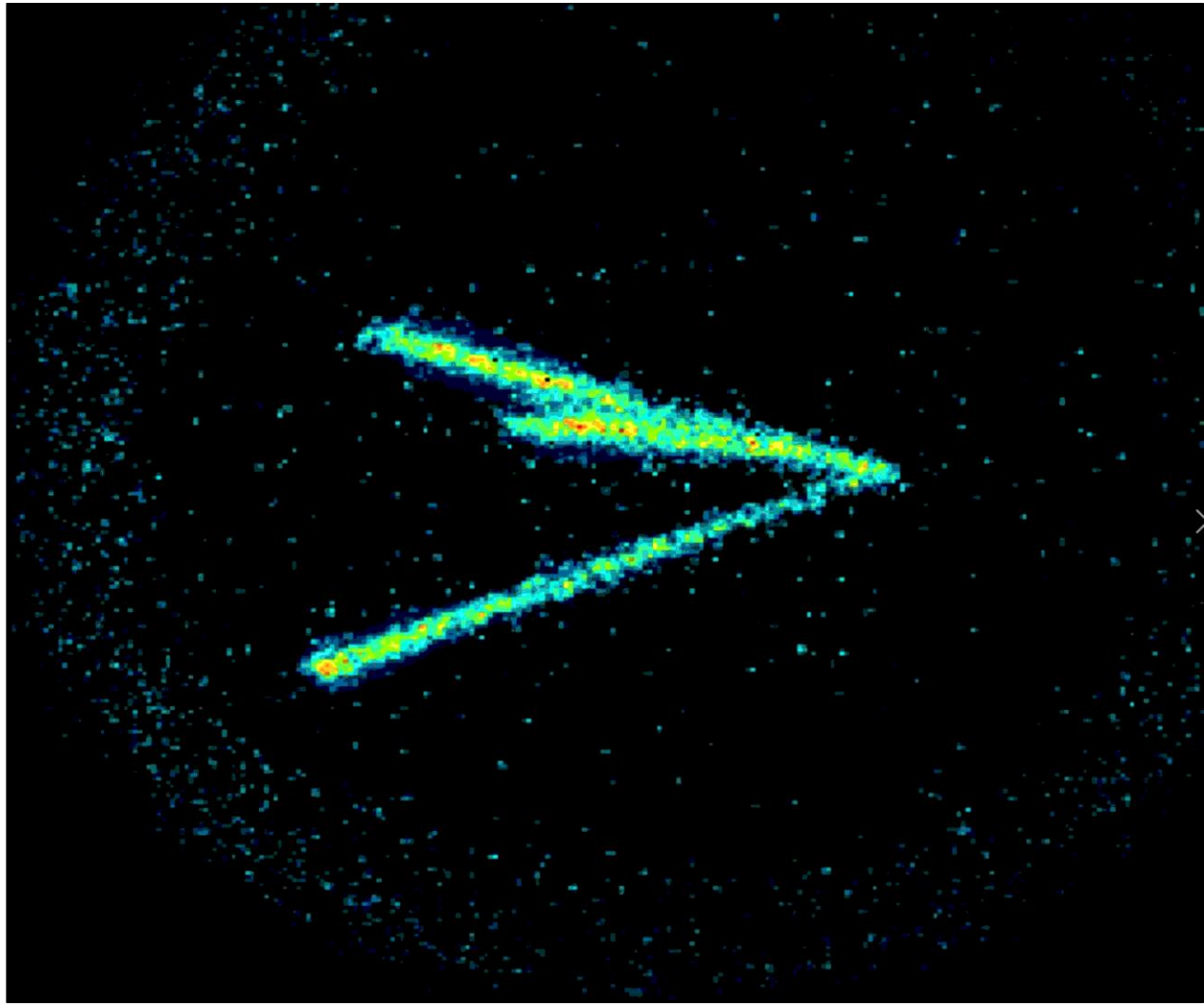
Publication: https://arxiv.org/abs/1810.09955

Collaboration with Brookhaven, CFEL, DESY and Czech Technical University

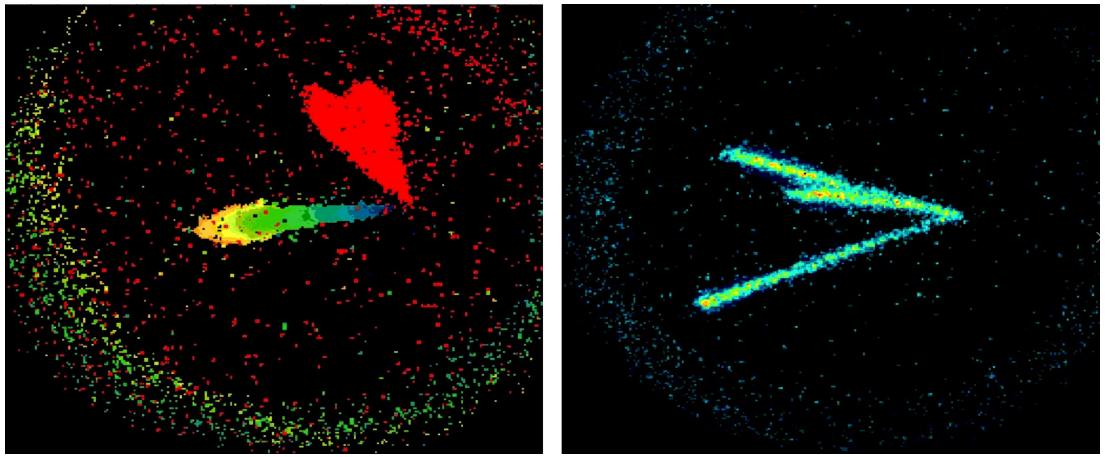
Results in 100mbar CF4 gas

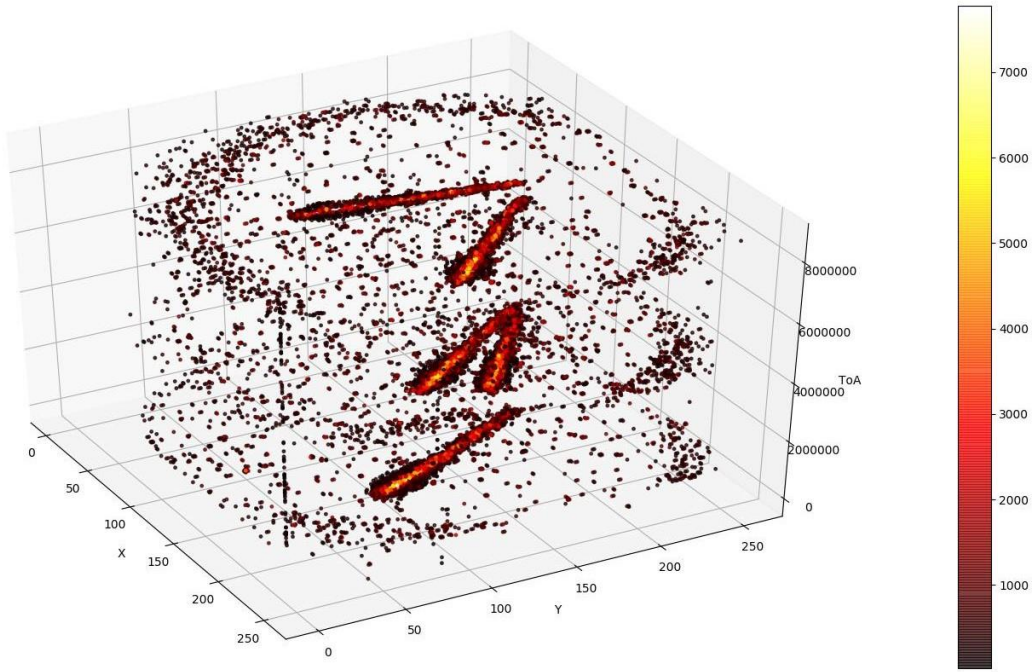
Simultaneous readout of ToT and ToA

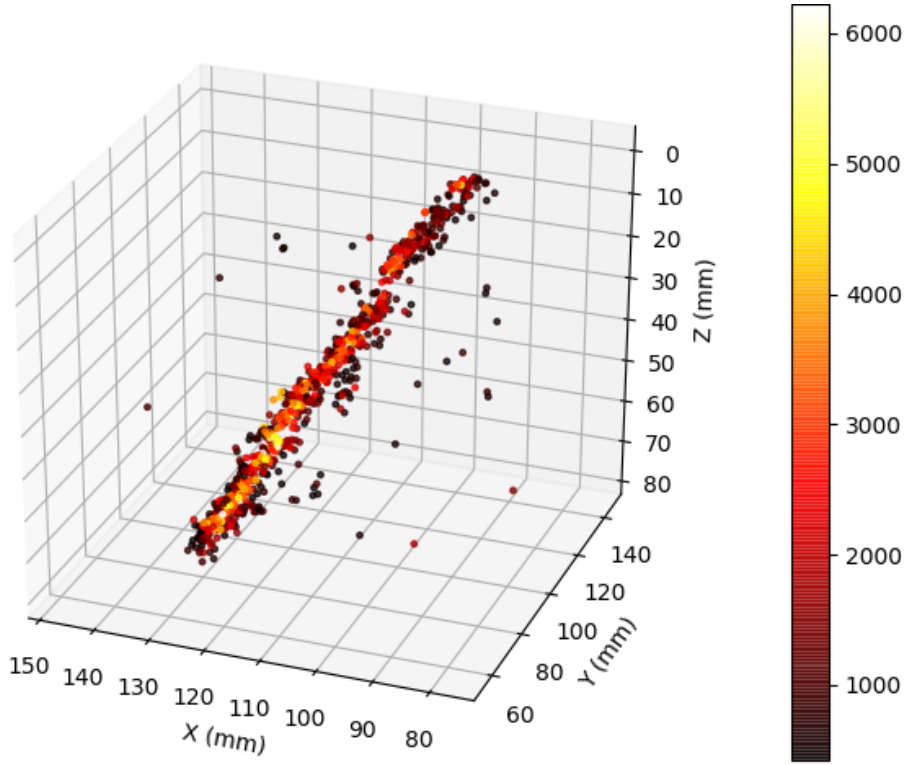




Initial demonstration in Gas CF4

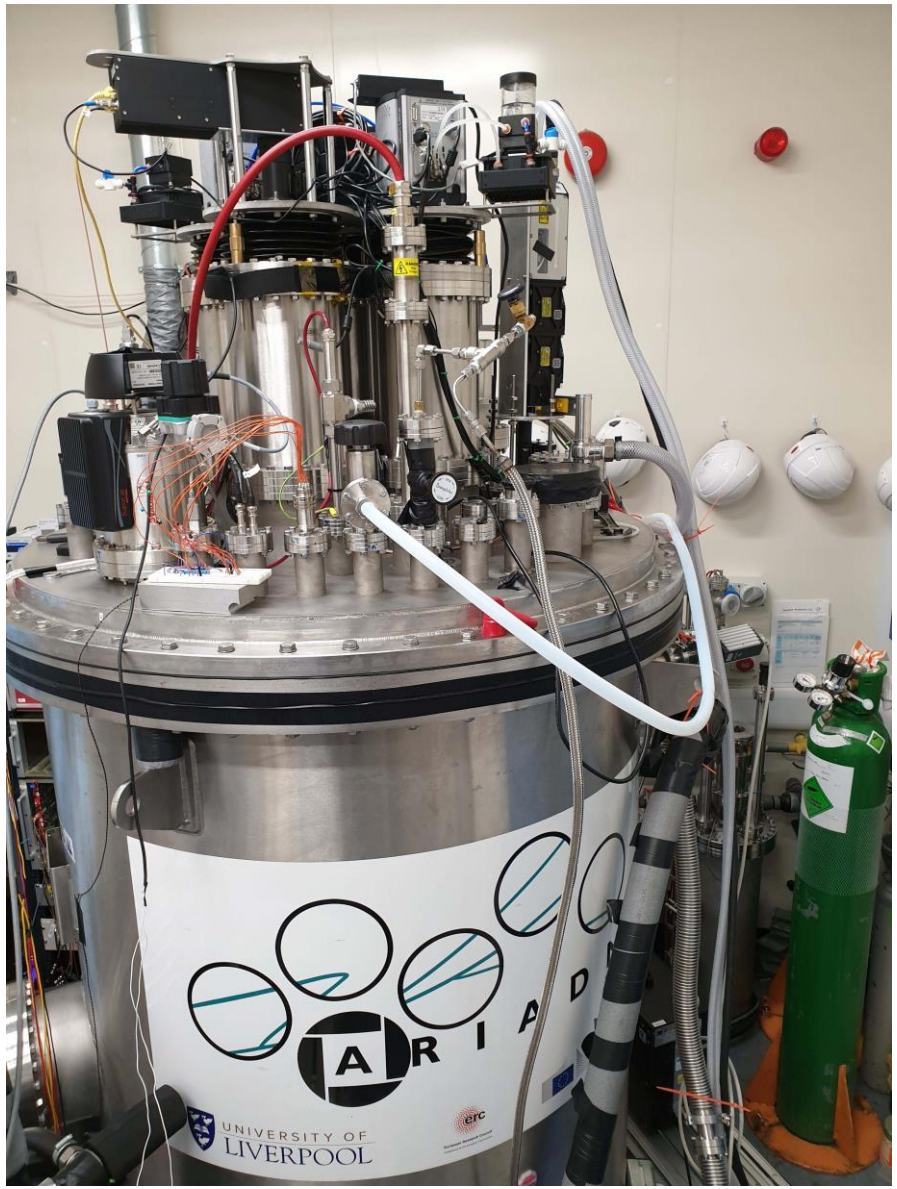






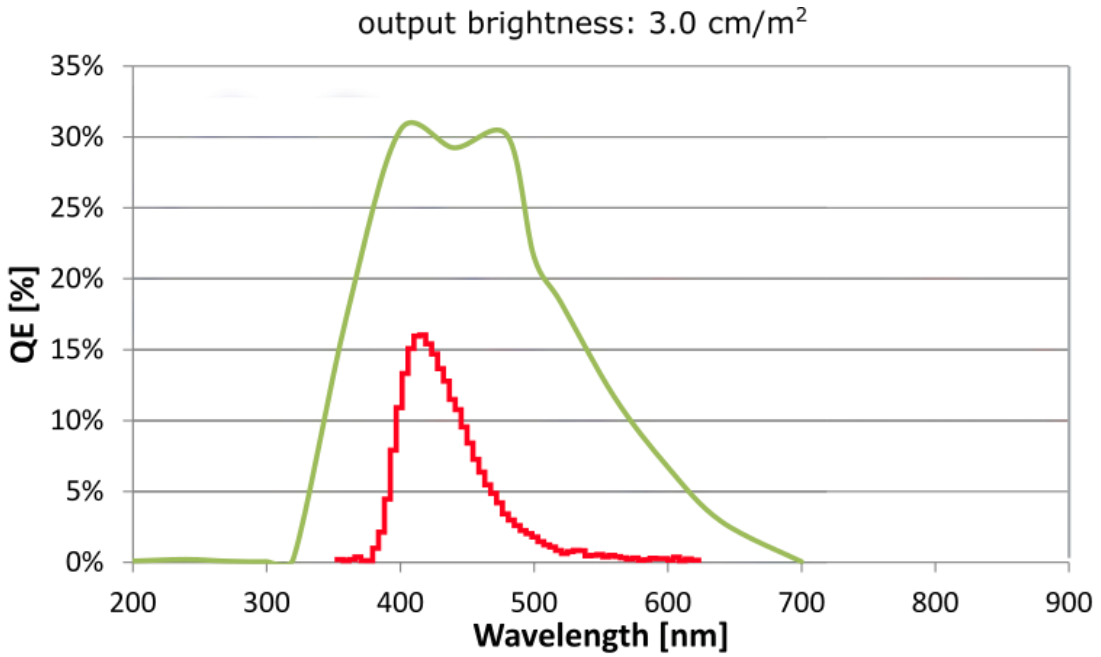
Publication: https://arxiv.org/abs/1810.09955

Liquid Argon Demonstration



A simple change of intensifier allows for sensitivity to light emitted from TPB.

Photonis Cricket image intensifier with 30% Quantum efficiency at 430nm.

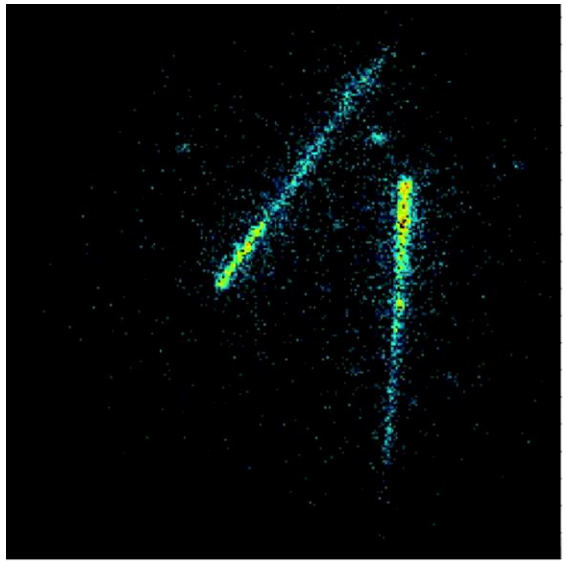
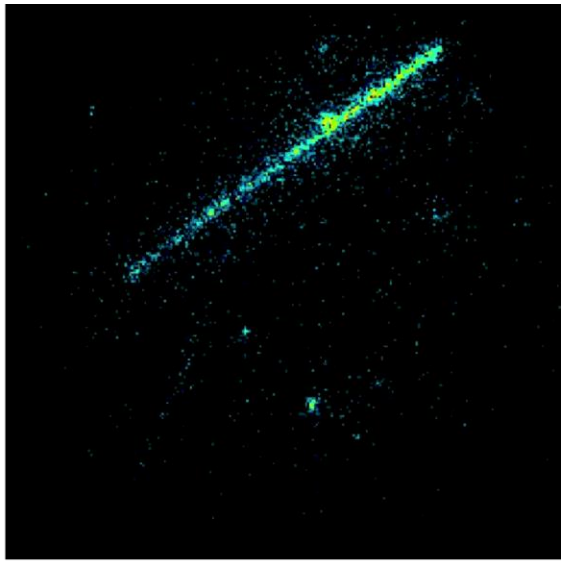
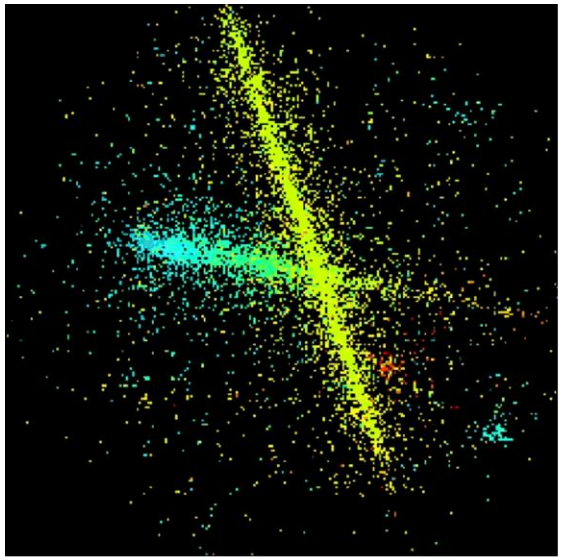
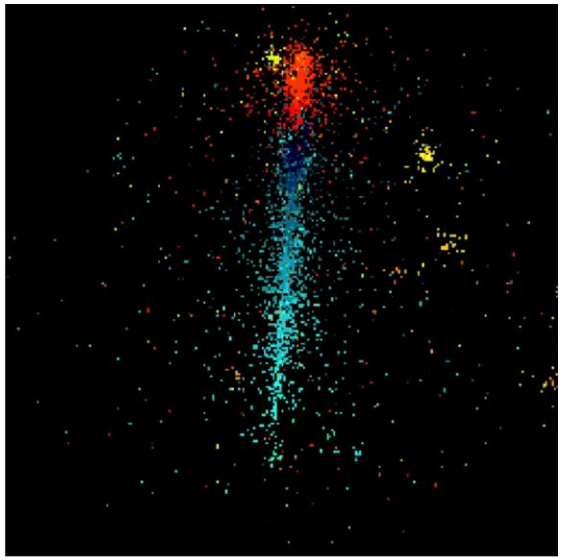
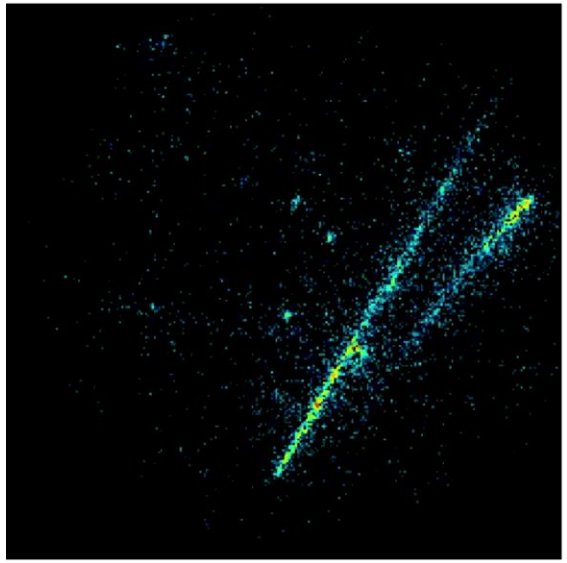
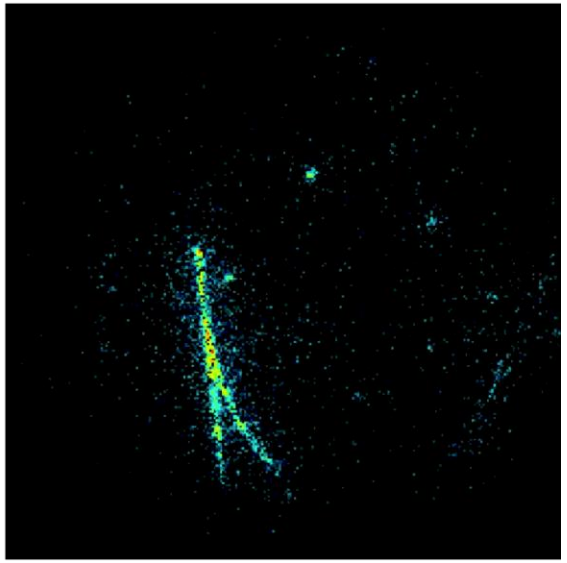
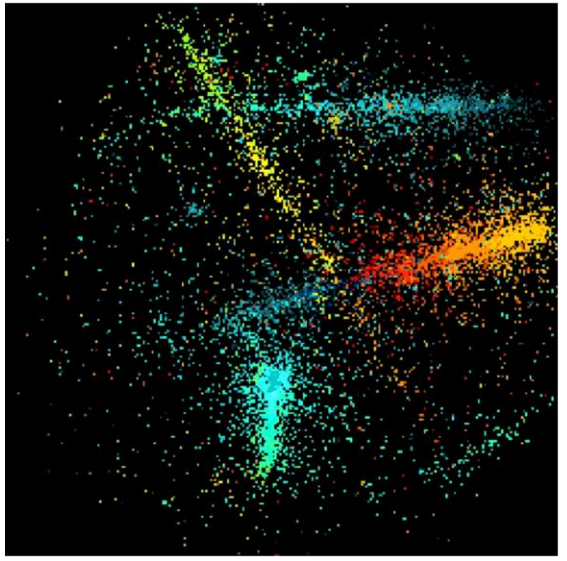
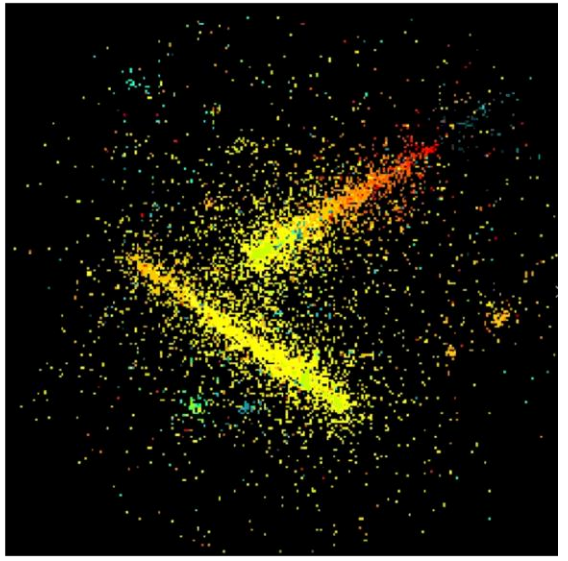


TPB spectrum from https://arxiv.org/abs/1104.3259

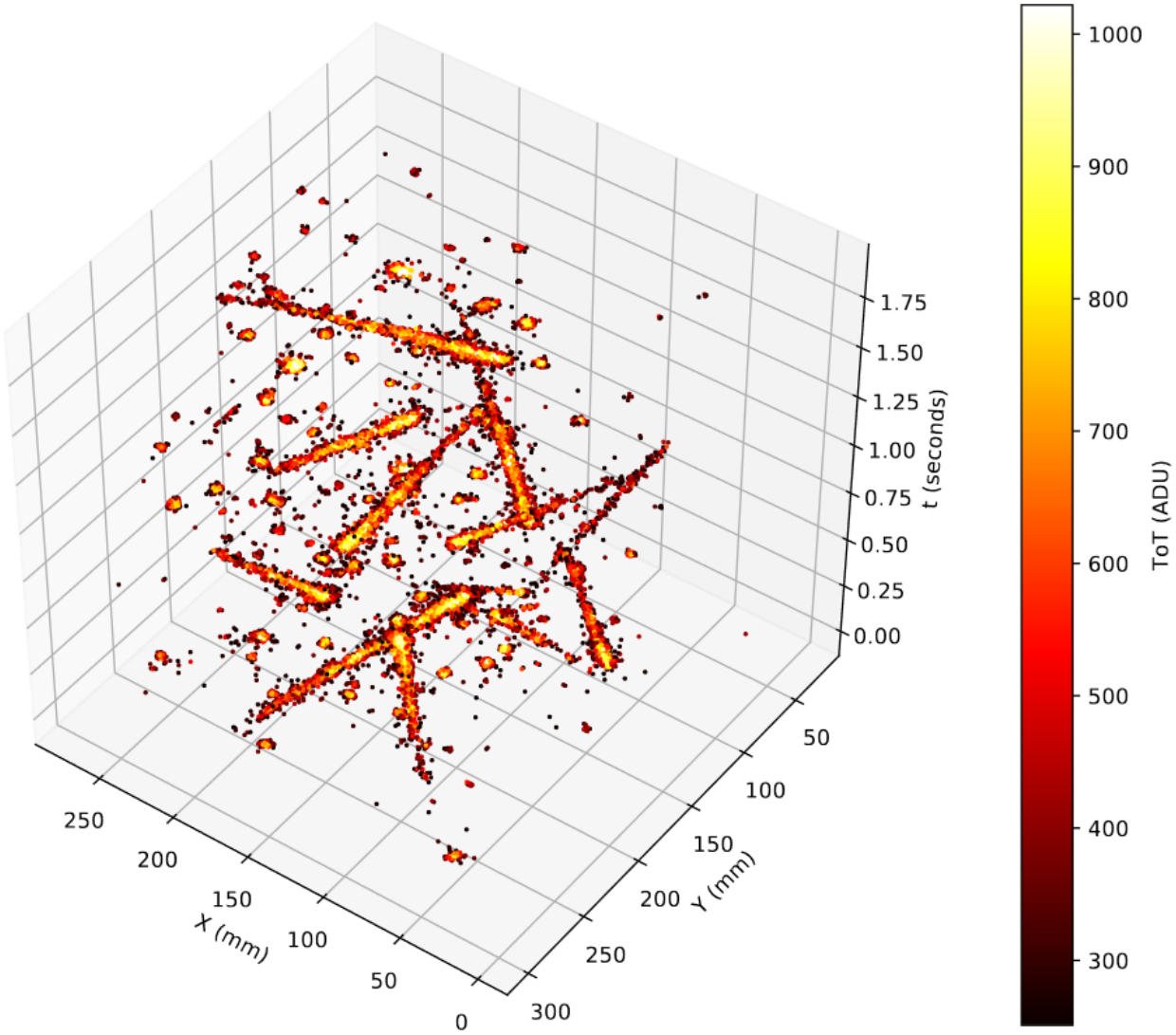
Liquid Argon Demonstration

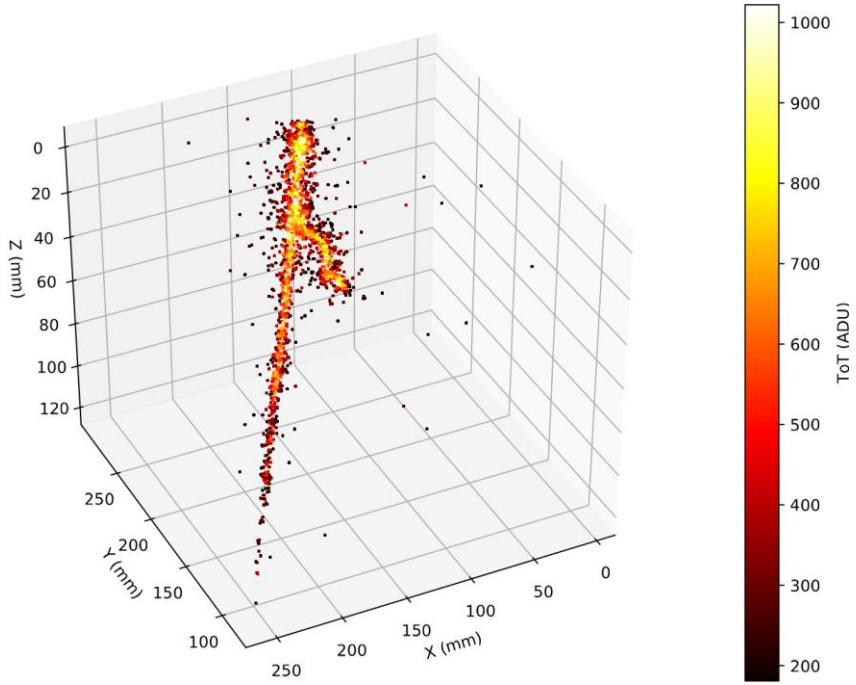
Time over threshold

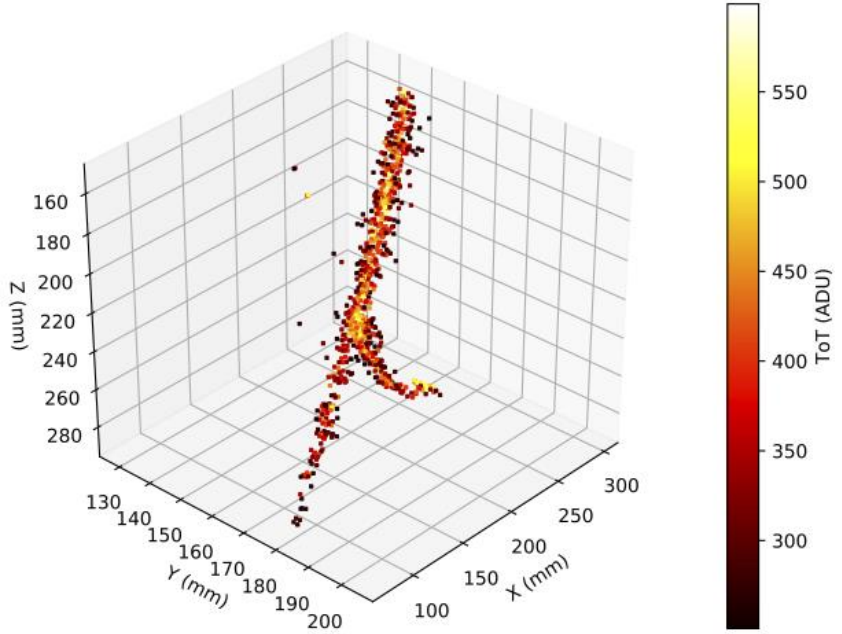
Time of Arrival

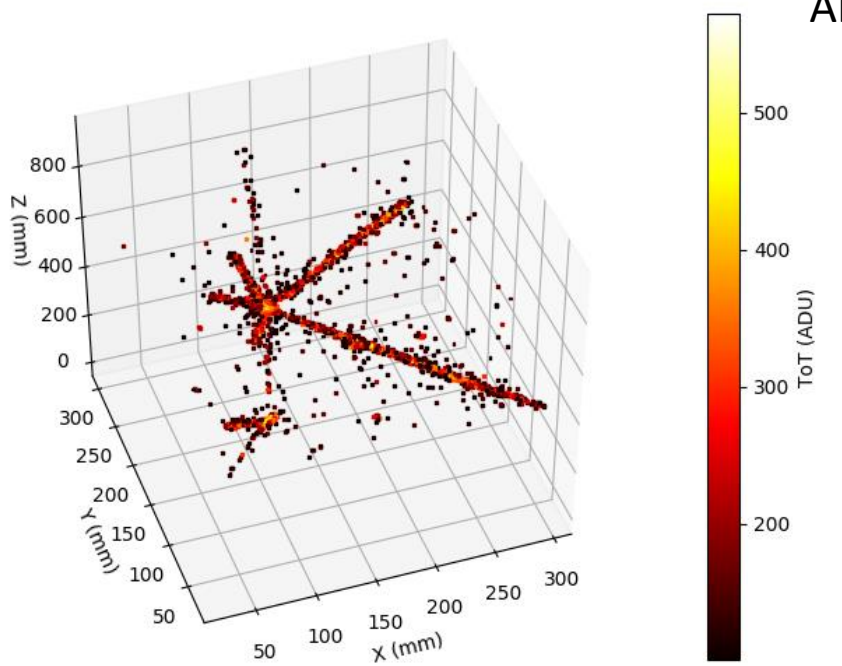
2 seconds streaming in ARIADNE:

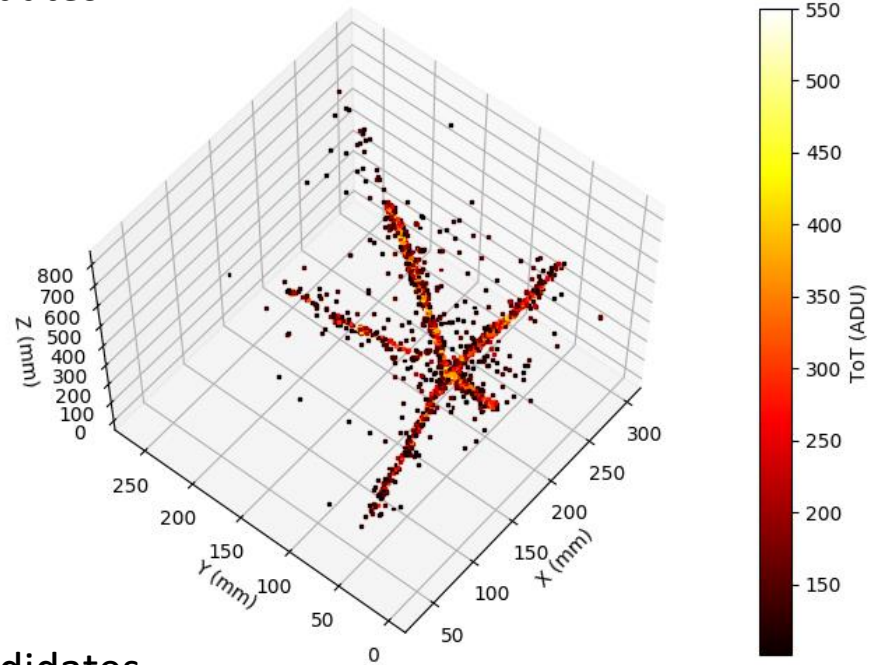




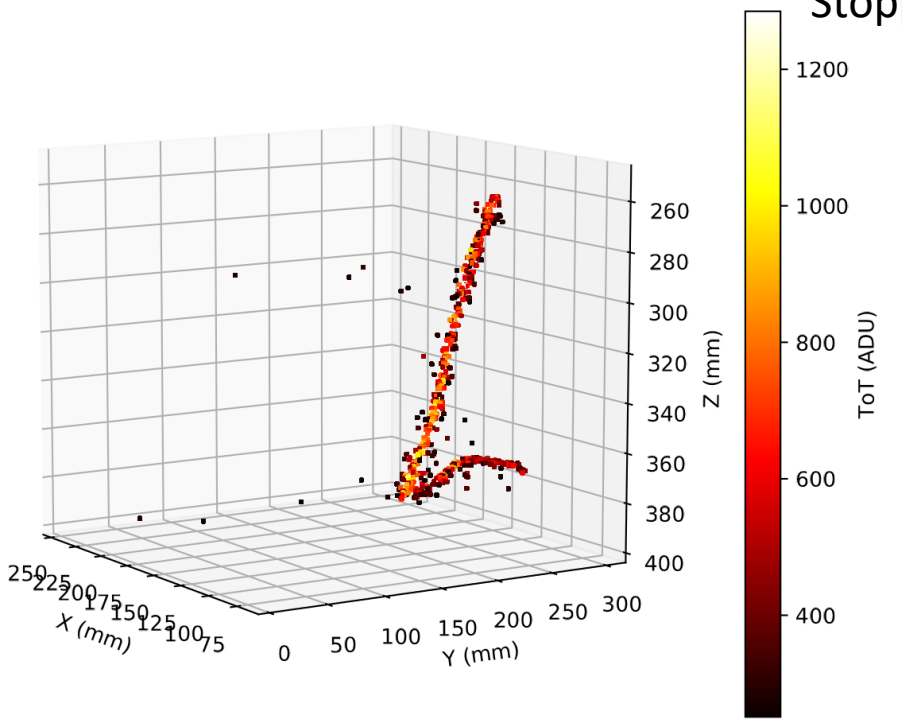


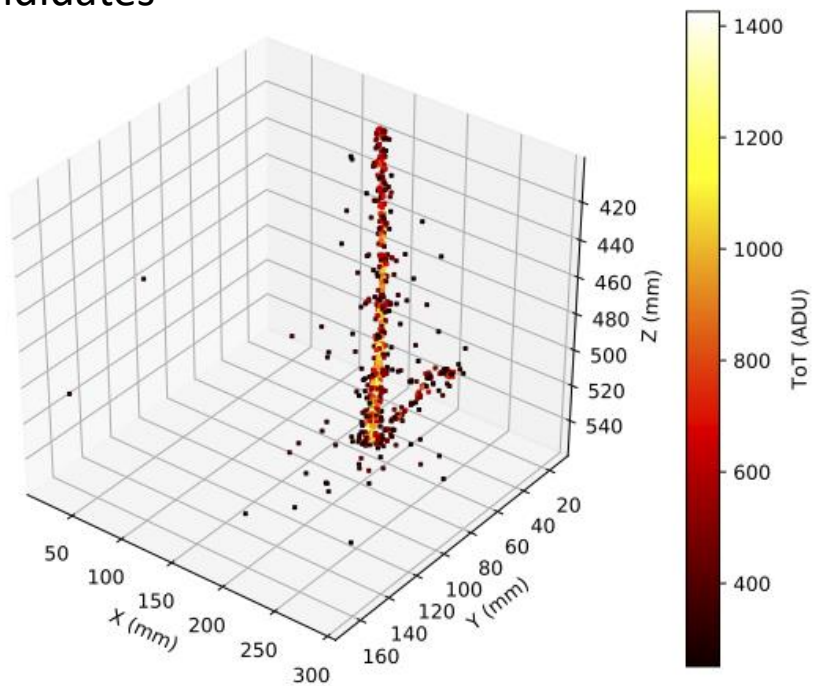
Antiproton candidates



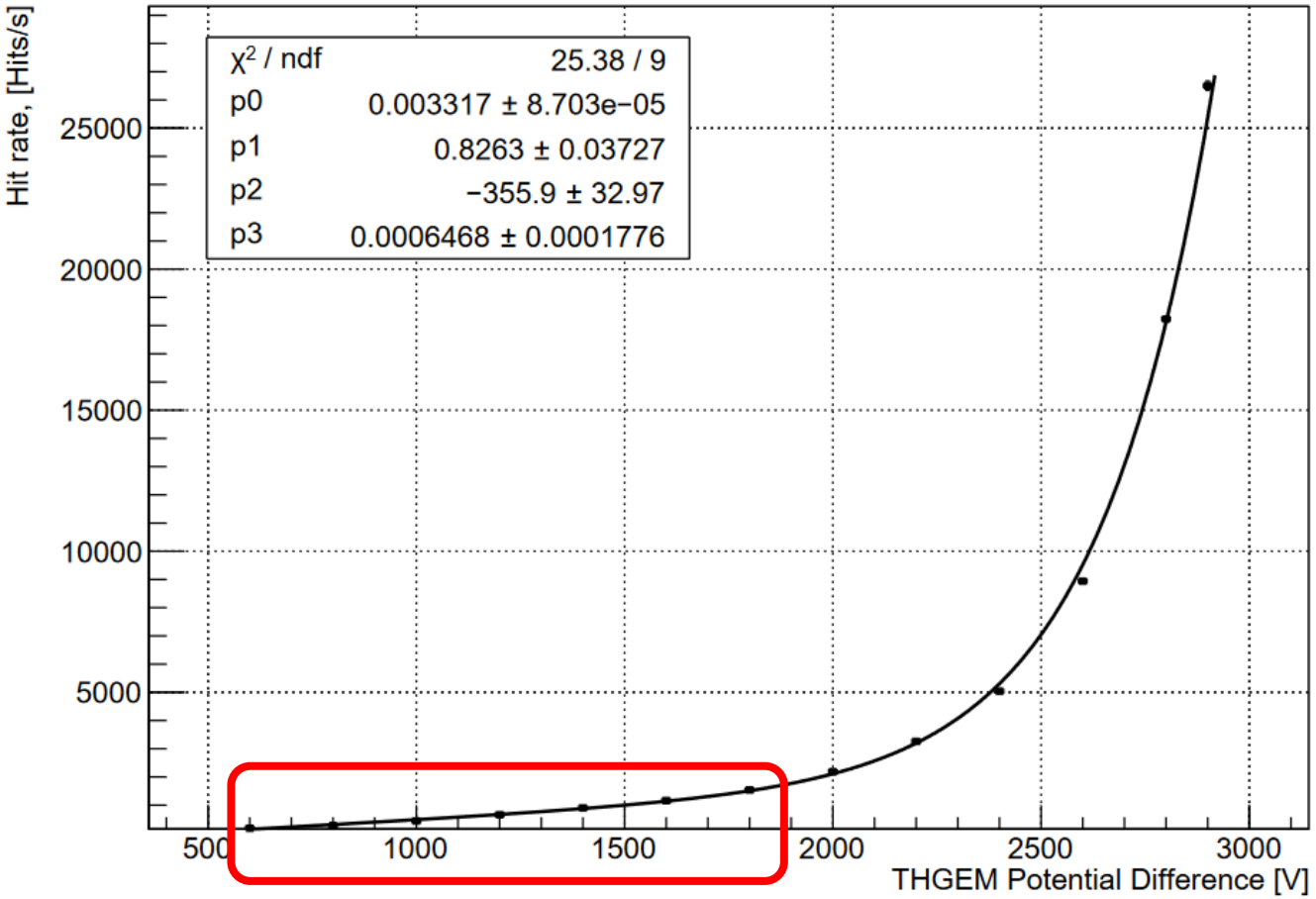


Stopping muon candidates





Sensitivity to electroluminescence

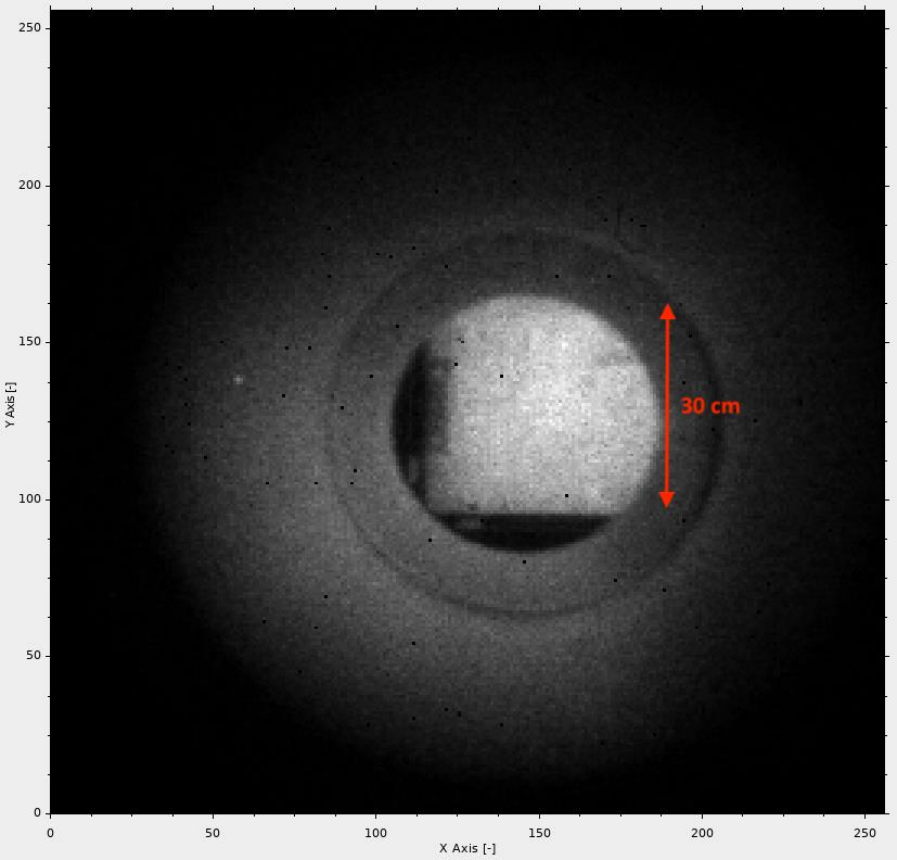


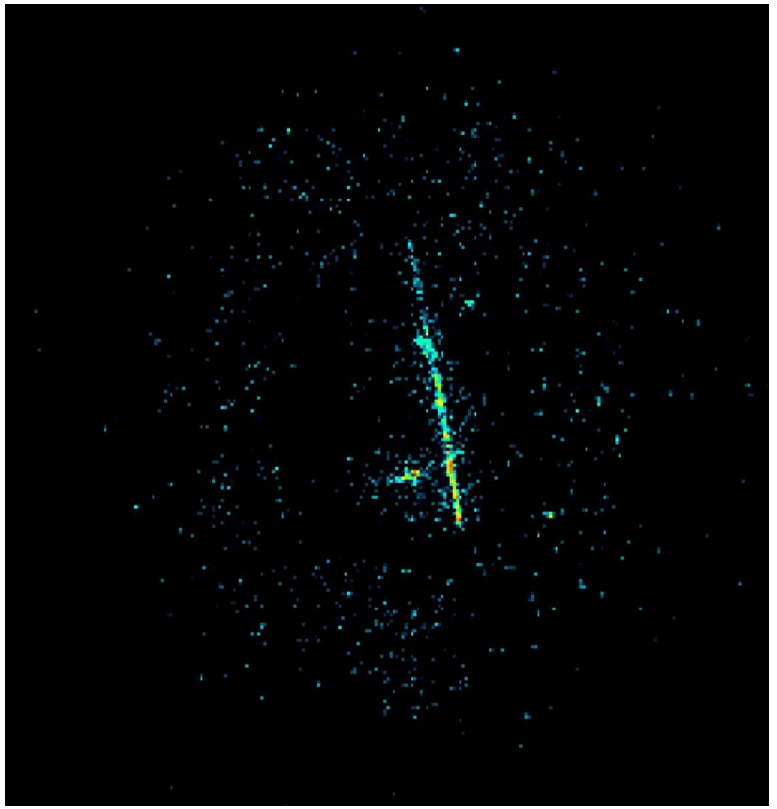
The intensified Timepix3 camera has excellent sensitivity, even in the proportional regime of light production.

Zero charge gain in this regime, therefore zero ion production in the THGEM

Light production model: Ax + Bxexp(Cx) + D

Towards larger readout areas

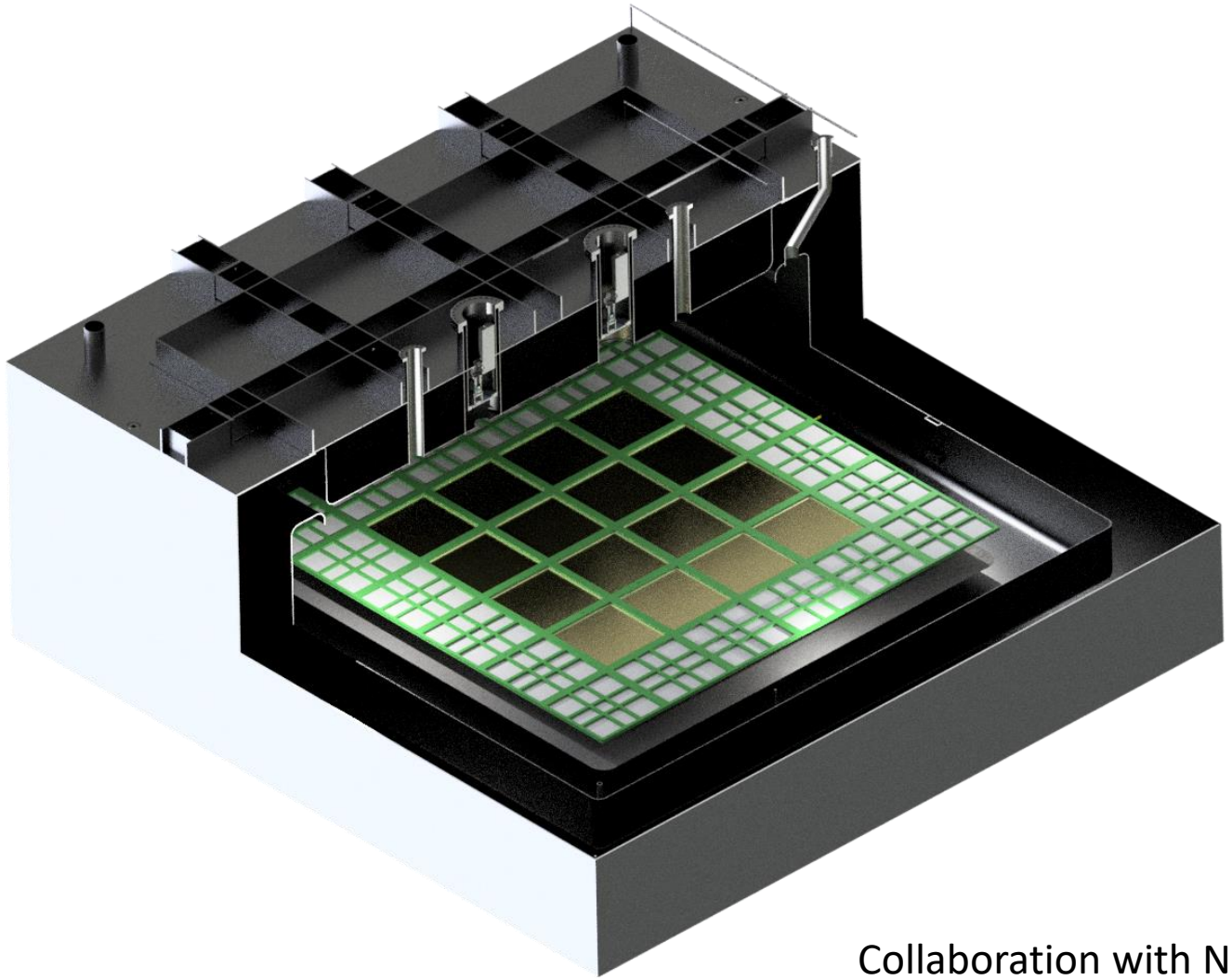




We recently tested the camera using a 15mm focal length lens.
Field of view is 1m x 1m per camera, 4mm/pixel resolution

Scaling this readout approach to large detectors looks very promising.

Next steps: Large scale demonstrator at the CERN neutrino platform

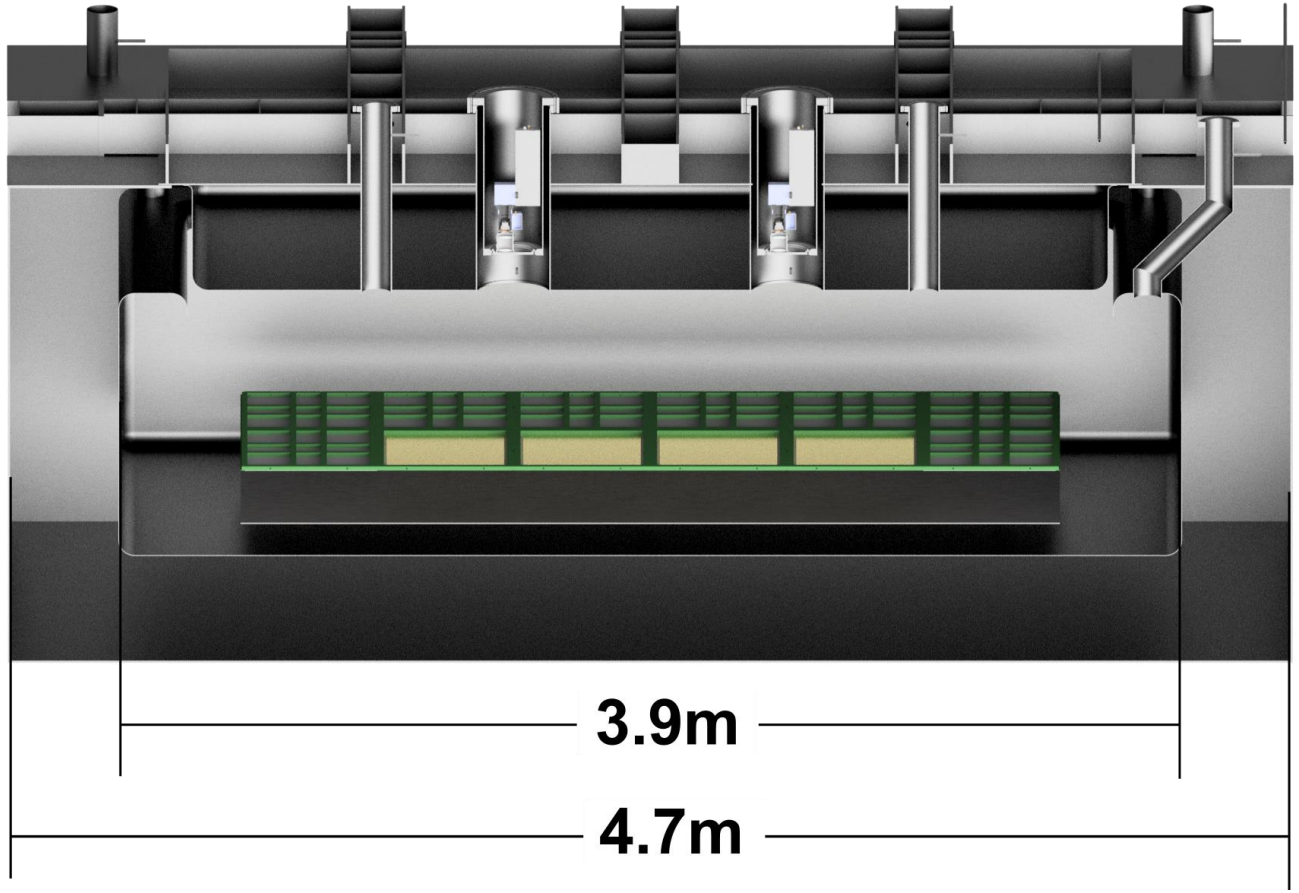


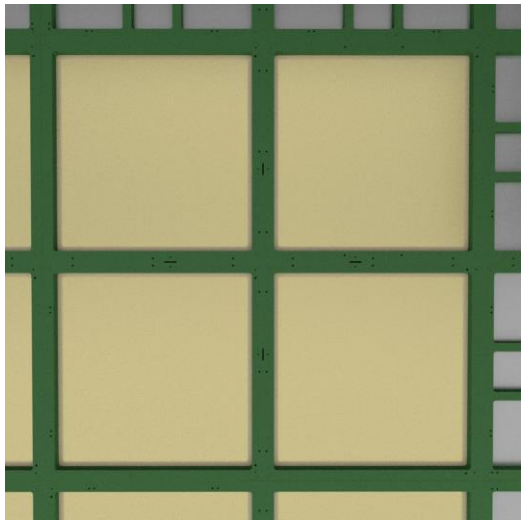
Demonstration of 2m x 2m active area readout using four TPX3 cameras (4mm/pixel)

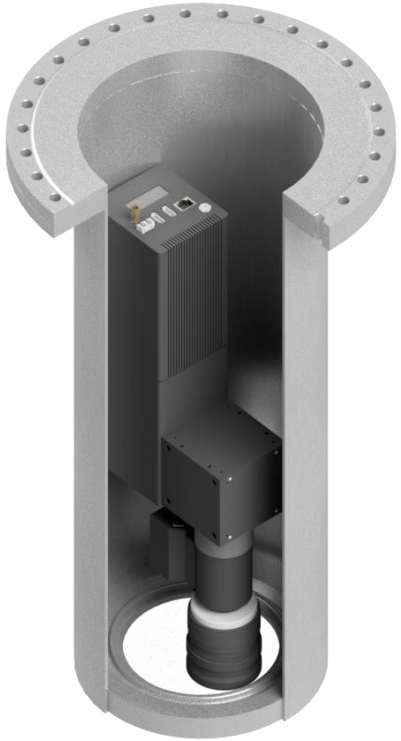
Short (20cm) drift length

Collaboration with Neutrino Platform team:
Marzio Nessi, Francesco Pietropaolo and Filippo Resnati

Next steps: Large scale demonstrator at the CERN neutrino platform



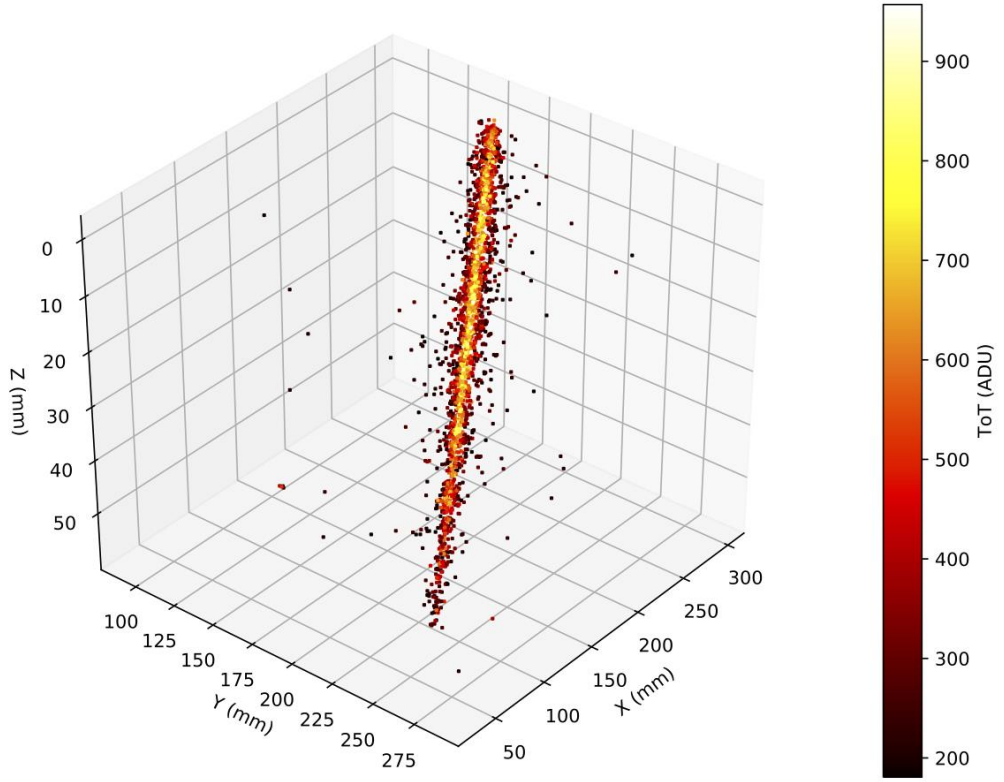




Collaboration with Neutrino Platform team:
Marzio Nessi, Francesco Pietropaolo and Filippo Resnati

Benefits

- Raw data is natively 3D. Only need a multiplicative factor on each axis to convert to physical units.
- Huge readout rates are possible (80MHits/s)
- Zero suppressed readout comes for free (~several KBytes per event)
- Physics sensor (Timepix) being used for a Physics application
- Low cost solution for readout of large detector areas. Commercial solutions are ready to go.
- Same readout is possible for two phase or gas TPCs. Flexible application depending on image intensifier specification.
- Cameras are decoupled from TPC electronic noise sources.
- Externally mounted cameras are easily accessed for upgrade/maintenance. No readout electronics/cables in the cryogenic volume. Flexible for future developments.



Outlook

Further improvement is possible with some R&D:

- Timepix4 will have closer to 512x512 pixels (cover 4x the area per camera or cover the same area with 4x the resolution)
- Direct VUV imaging
- Optimise THGEM design for electroluminescence

Please get in touch if you would like to be involved in the upcoming tests.

Thank you!

Backup – Timepix upgrade path

Timepix3 → Timepix4

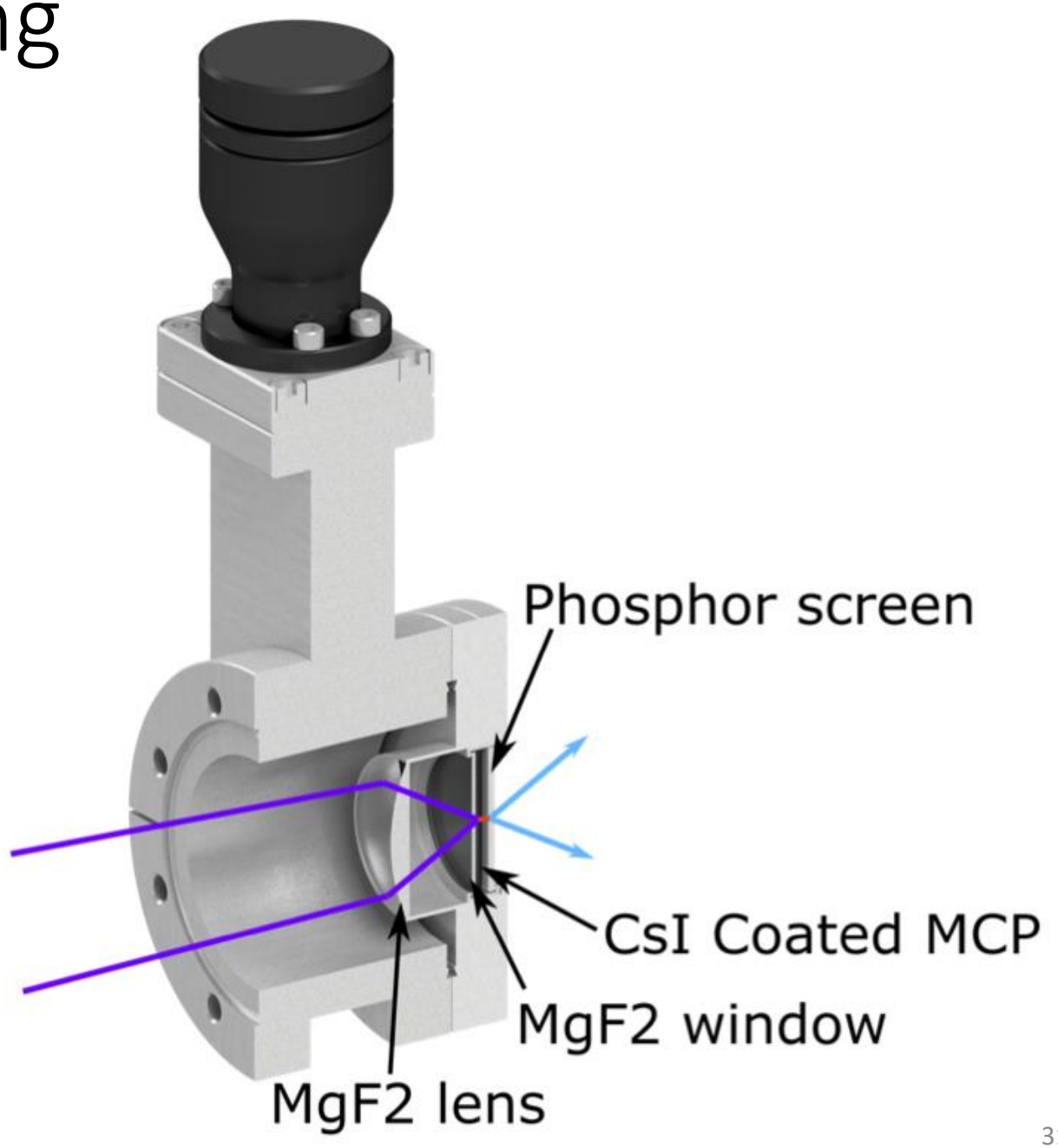
		Timepix3	Timepix4
Technology		IBM 130nm	TSMC 65nm
Pixel Size		55 x 55 µm	≤ 55 x 55 µm
Pixel arrangement		3-side buttable 256 x 256	4-side buttable 256 x 256 or bigger
Operating Modes	Data driven	PC (10-bit) and TOT (14-bit)	CRW: PC and iTOT (12...16-bit)
	Frame based	TOT and TOA	
Zero-Suppressed Readout	Data driven	< 80 MHits/s	< 500 MHits/s
	Frame based	YES	YES
TOT energy resolution		< 2KeV	< **1Kev**
Time resolution		1.56ns	**~200ps**
Readout bandwidth		5.12Gb (8x SLVS@640 Gbps)	20.48 Gbps (4x 5.12 Gbps)
Front-end		"with" Volcano	No volcano → Dynamic gain But supply only 1.2V

Higher x,y resolution (or larger area with one camera)

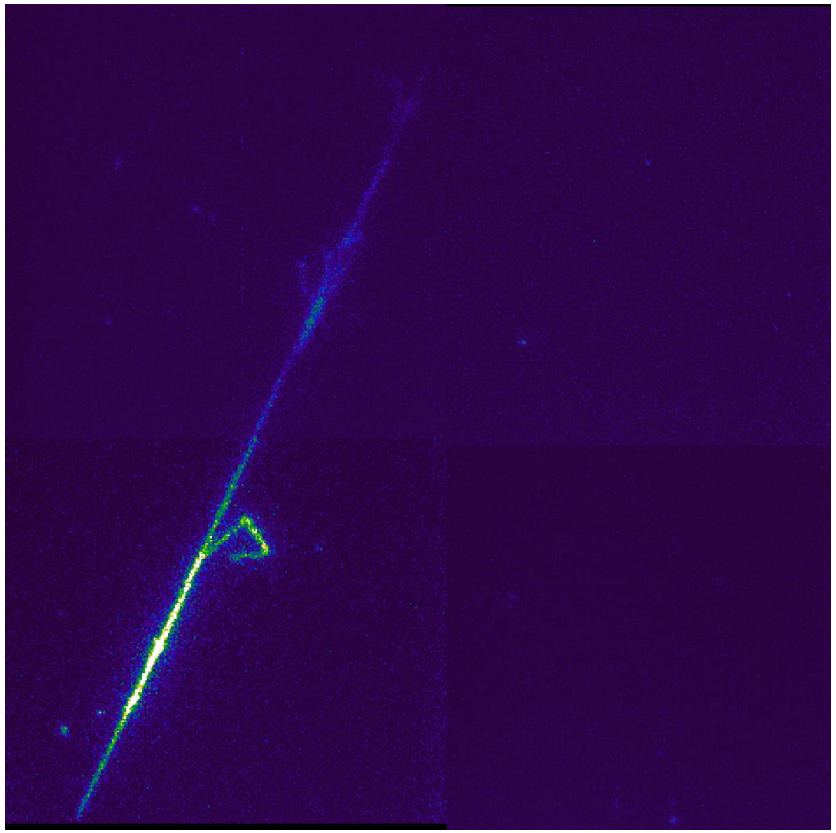
Faster readout rates

Improved calorimetry

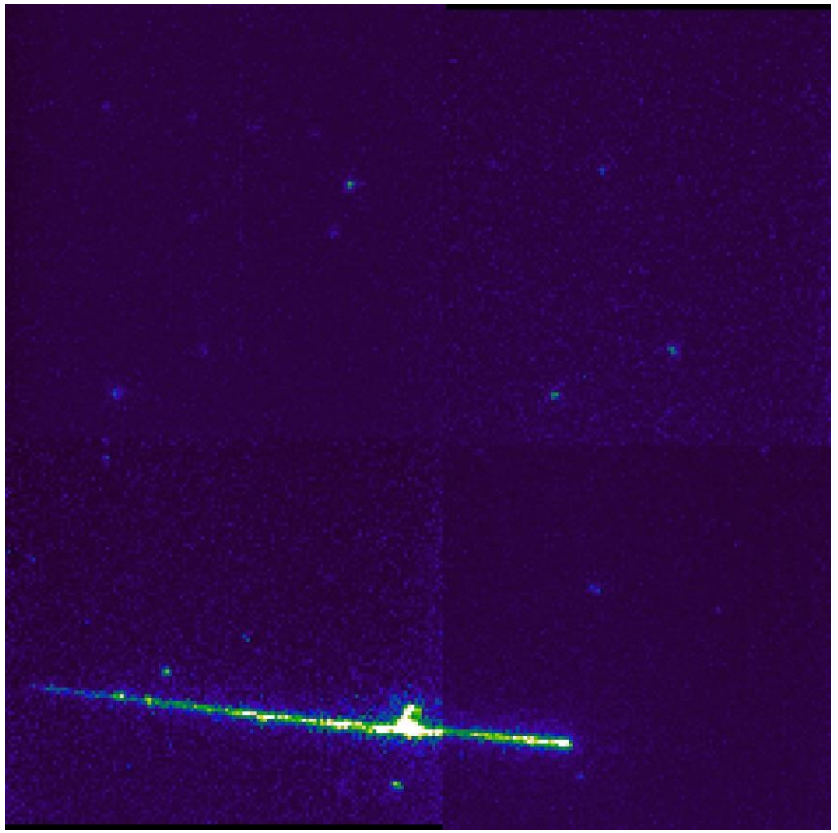
Backup: Direct VUV imaging



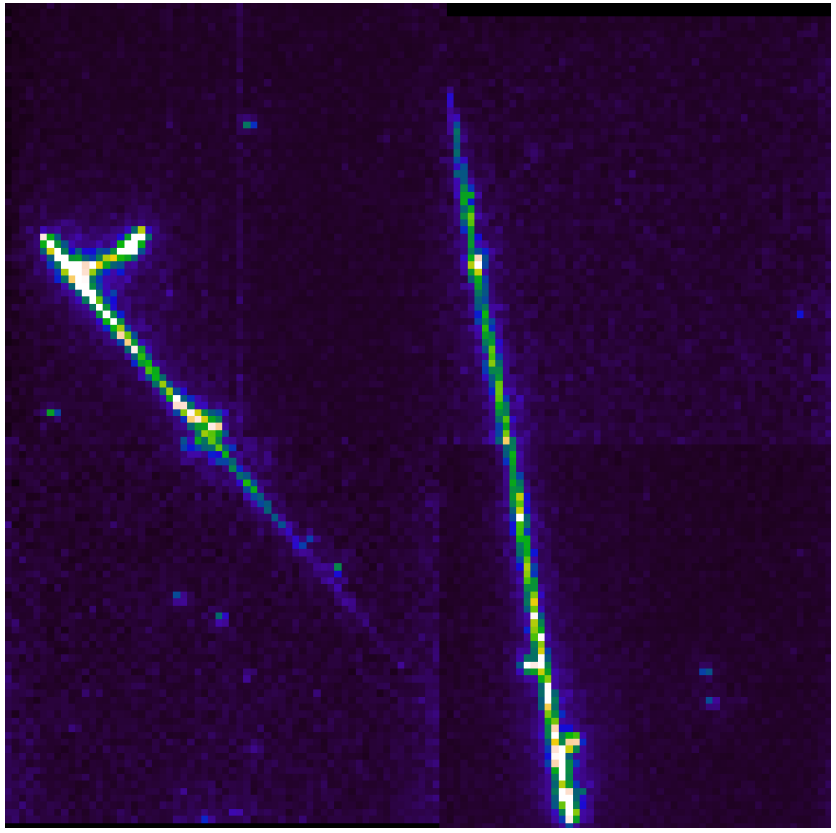
Backup: Pixel resolution



1.1mm/pixel



2.2mm/pixel



4.4mm/pixel

Backup: Timepix4

Timepix3 → Timepix4

		Timepix3	Timepix4
Technology		IBM 130nm	TSMC 65nm
Pixel Size		55 x 55 µm	≤ 55 x 55 µm
Pixel arrangement		3-side buttable 256 x 256	4-side buttable 256 x 256 or bigger
Operating Modes	Data driven	PC (10-bit) and TOT (14-bit)	CRW: PC and iTOT (12...16-bit)
	Frame based	TOT and TOA	
Zero-Suppressed Readout	Data driven	< 80 MHits/s	< 500 MHits/s
	Frame based	YES	YES
TOT energy resolution		< 2KeV	< **1Kev**
Time resolution		1.56ns	**~200ps**
Readout bandwidth		5.12Gb (8x SLVS@640 Gbps)	20.48 Gbps (4x 5.12 Gbps)
Front-end		"with" Volcano	No volcano → Dynamic gain But supply only 1.2V

Higher x,y resolution (or cover more area with one camera)

Faster readout rates

Improved calorimetry