

Optical Readout of the ARIADNE LArTPC Using a Timepix3-Based Camera

Adam Roberts (On behalf of the ARIADNE group)

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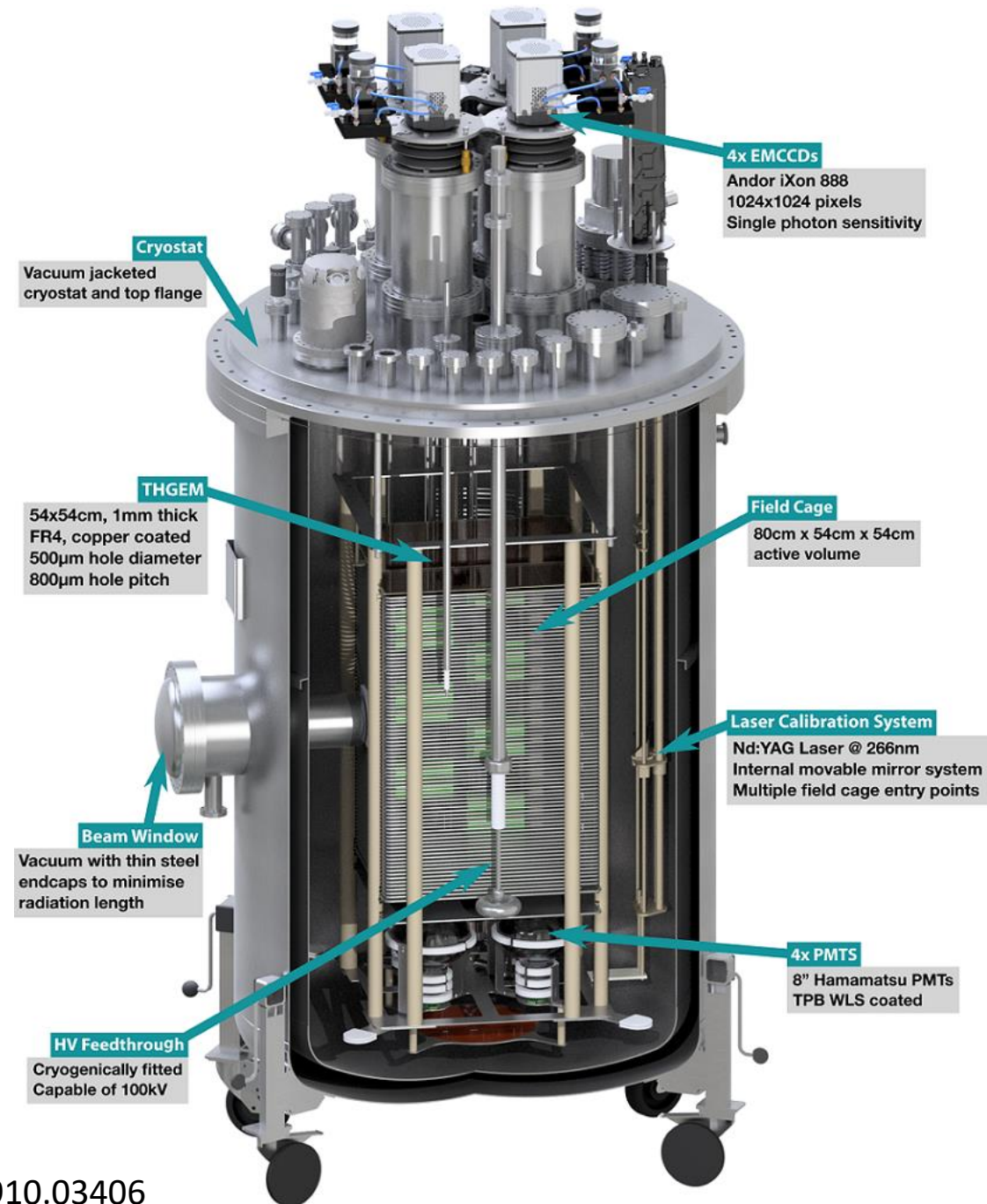
University of Liverpool

The ARIADNE detector

Designed for **optical readout** demonstration and R&D

330 kg fiducial mass dual-phase LAr TPC;

- 54cm x 54cm x 80cm active volume
- 100kV High voltage feedthrough
- External optical readout installed on top flange – Flexibility
- Beam window integrated into vacuum jacket for test beam operation



Technical design report: <https://arxiv.org/abs/1910.03406>

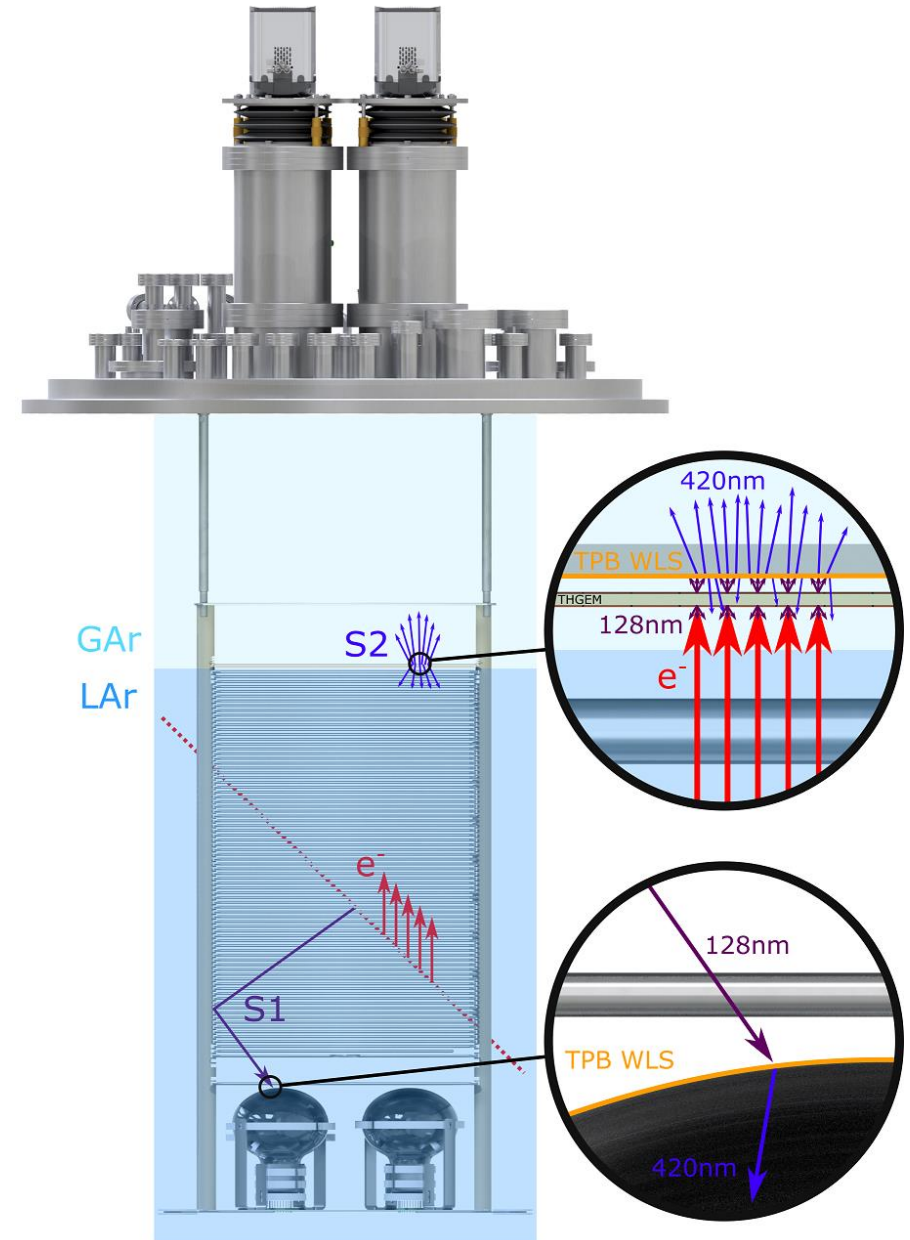
Detection principle

Throughgoing particles ionise Liquid Argon and produce prompt scintillation light (S1)

Ionisation electrons drifted to liquid surface and extracted into gaseous phase.

Electrons accelerated within THGEM holes, producing secondary scintillation light (S2) by gas Argon excitations.

Event reconstruction performed by detecting S2 light with externally mounted cameras.



ARIADNE THGEM

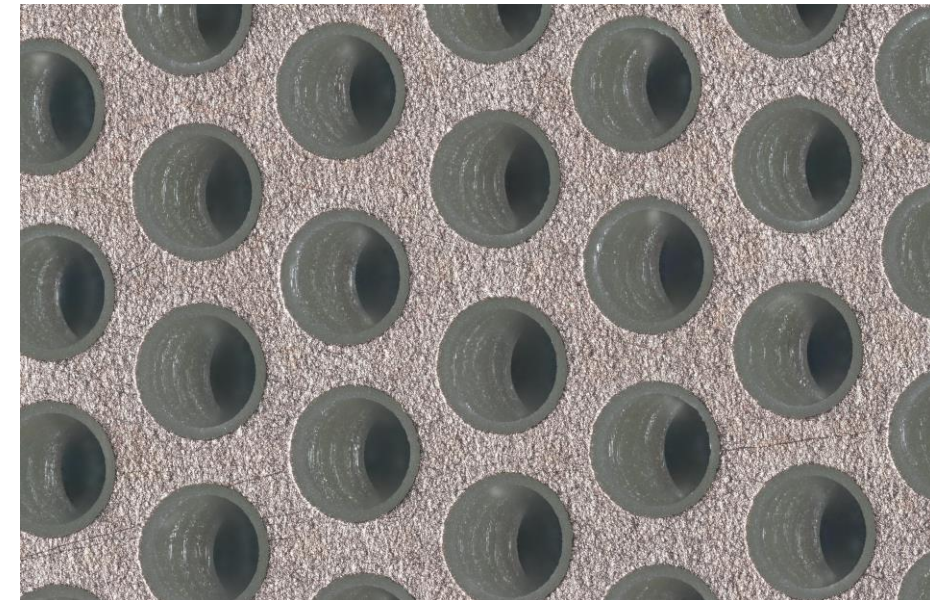
Traditional FR4 THGEM with typical specifications;

53cm x 53cm active area

1mm thick, 500 μ m diameter holes, 800 μ m hole-to-hole pitch.

Produced by CERN PCB workshop (Rui De Oliveira)

Maximum potential difference \sim 3.1kV

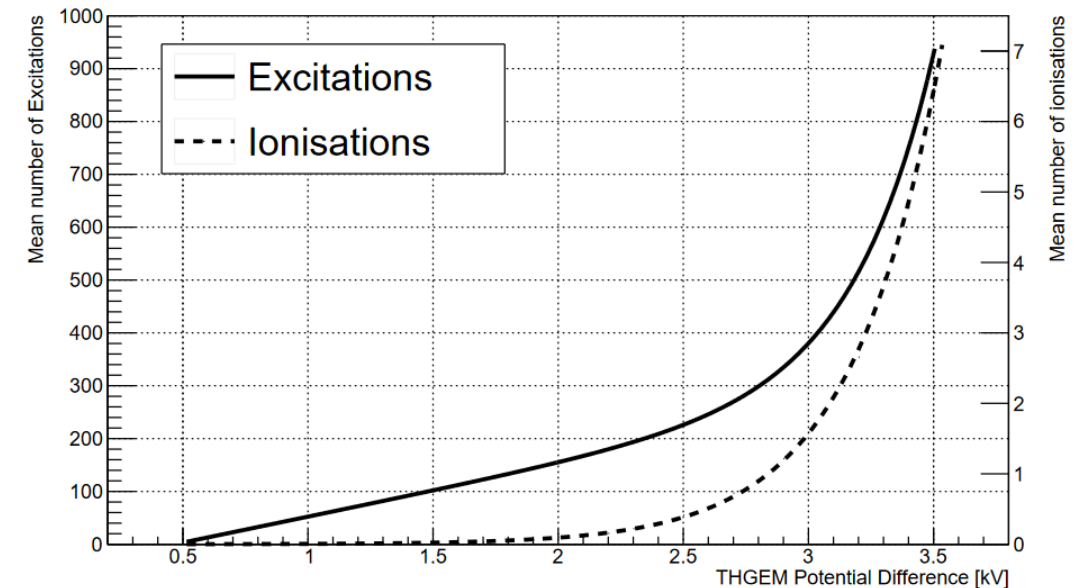
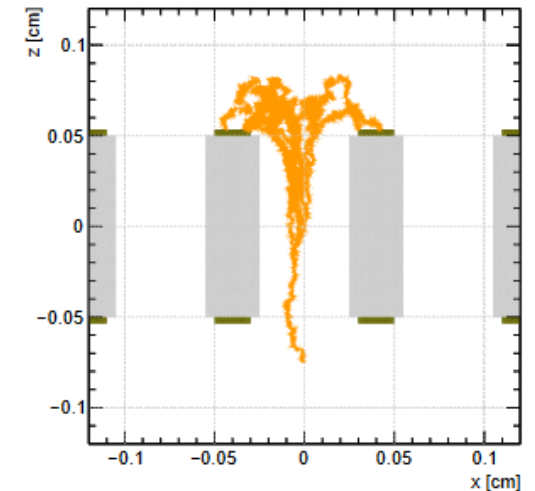


THGEM S2 light production

VUV (126nm) light produced through de-excitation of Argon gas.
TPB Wavelength shifter above THGEM converts to 430nm.

At low field ($<2\text{kV/cm}$), S2 light production is linearly proportional to THGEM field.
No charge gain. Very stable operation without discharges. No ion production.

At higher fields, electron multiplication occurs (Townsend avalanche).
Exponentially increasing S2 light production \rightarrow Improved sensitivity/threshold



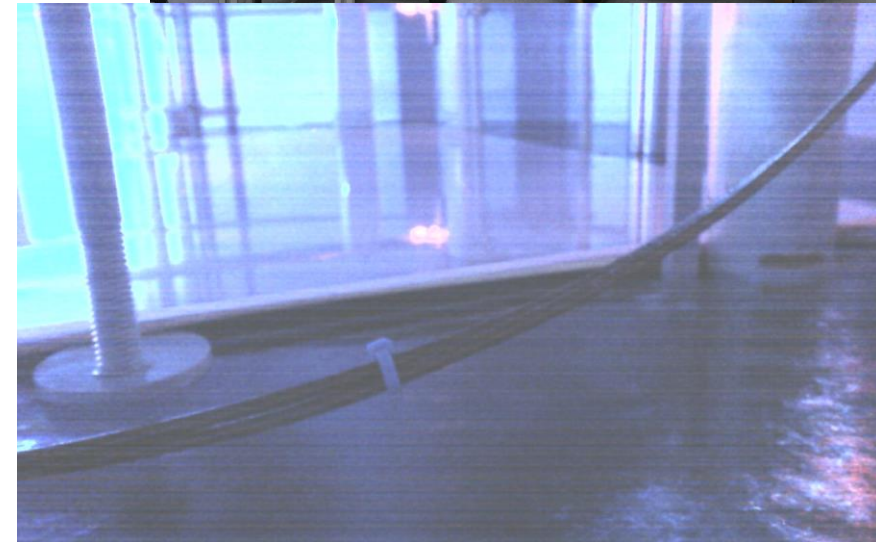
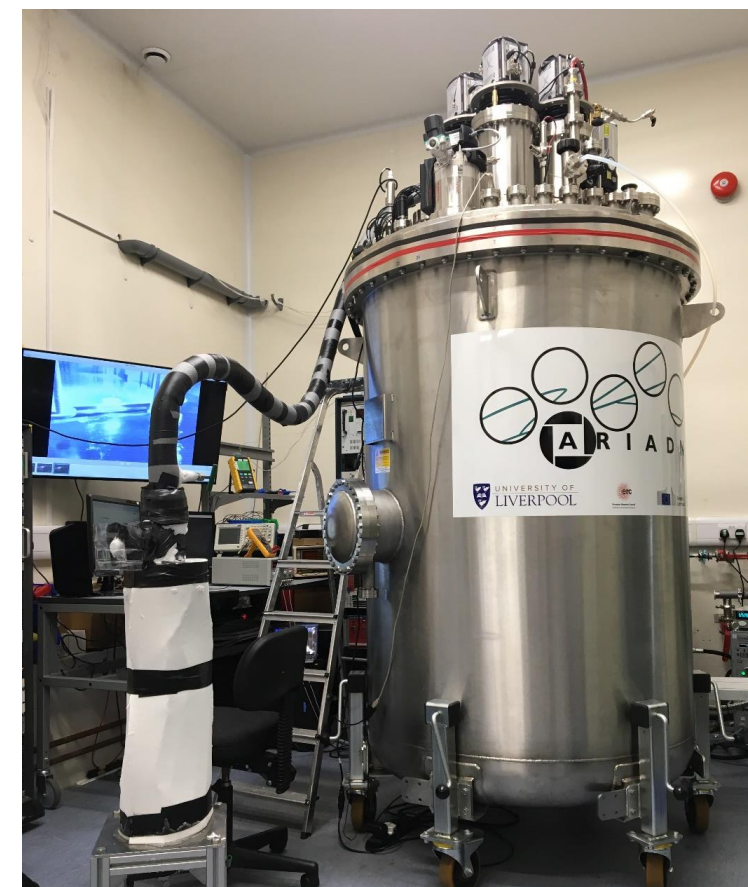
ARIADNE at Liverpool

Based at University of Liverpool Liquid Argon laboratory

Construction completed in December 2017.

Deployment to CERN T9 beamline March/April 2018.

Readout R&D upgrades / characterisation 2018 – present

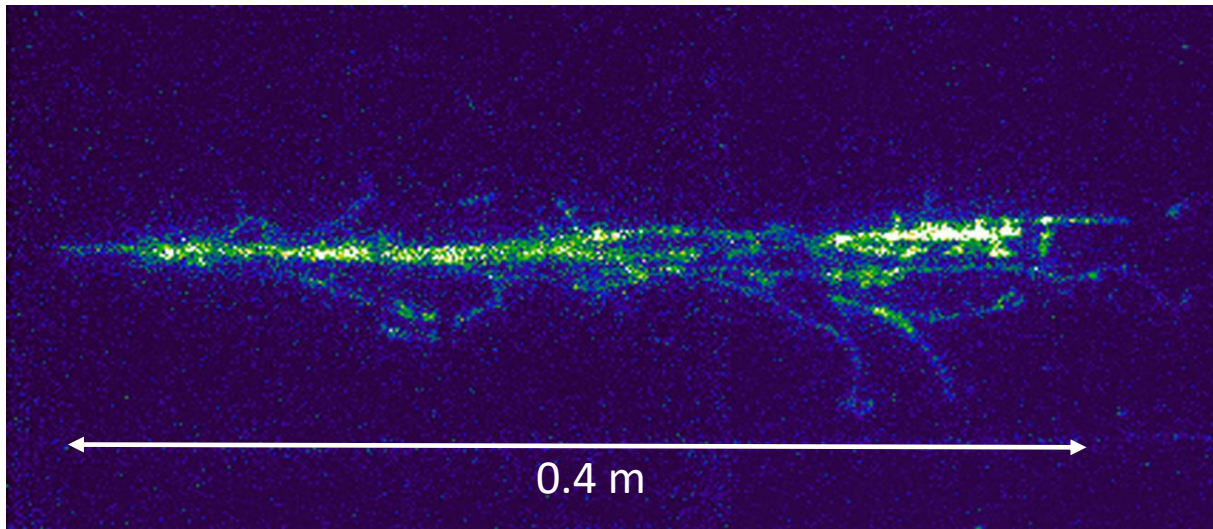


ARIADNE at CERN T9 beamline

Data taken over 0.5 – 8 GeV/c momentum range.

800,000 total events.

Mixture of e^\pm , μ^\pm , π^\pm , ρ^\pm



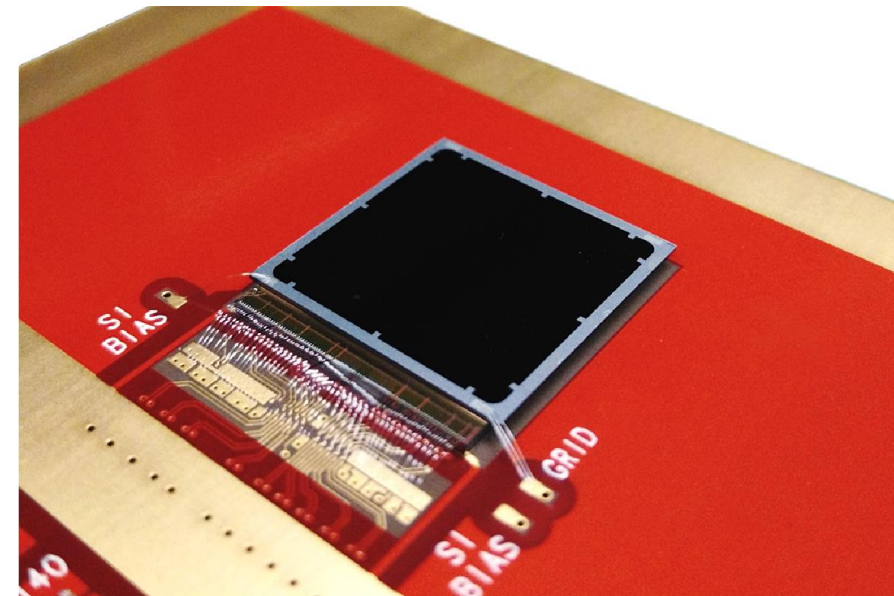
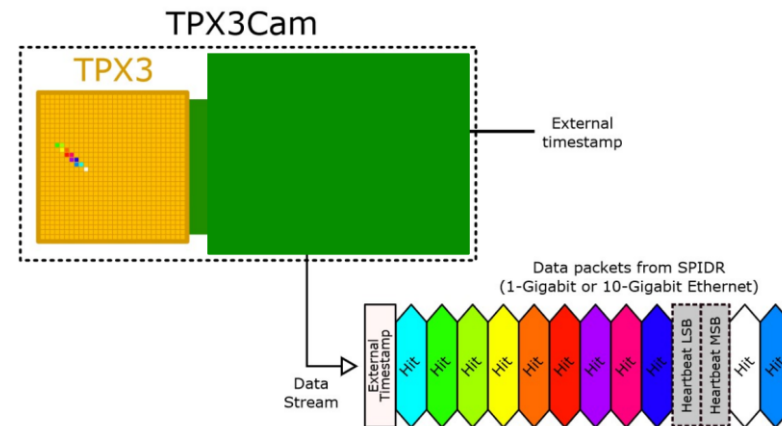
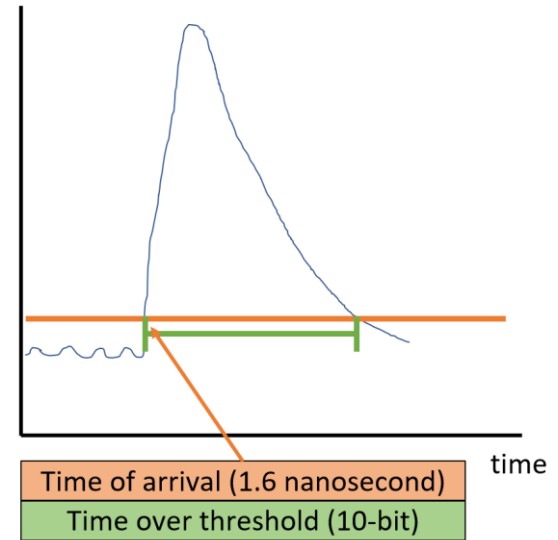
Post beamline detector upgrades

Active R&D program ongoing using Timepix3 (TPX3) ASIC bonded to optical sensor

TPX3 provides simultaneous time-over-threshold (ToT) and time-of-arrival (ToA). Complete (x,y,z,E) event reconstruction using a single device.

Time over threshold provides intensity / energy measurement -> 10-bit resolution.
Time of arrival provides z (drift) axis position information -> 1.6 nanosecond resolution.

Data driven readout -> Event streaming with native zero suppression.
Efficient raw data storage. Triggerless operation.



Timepix 3 optical readout

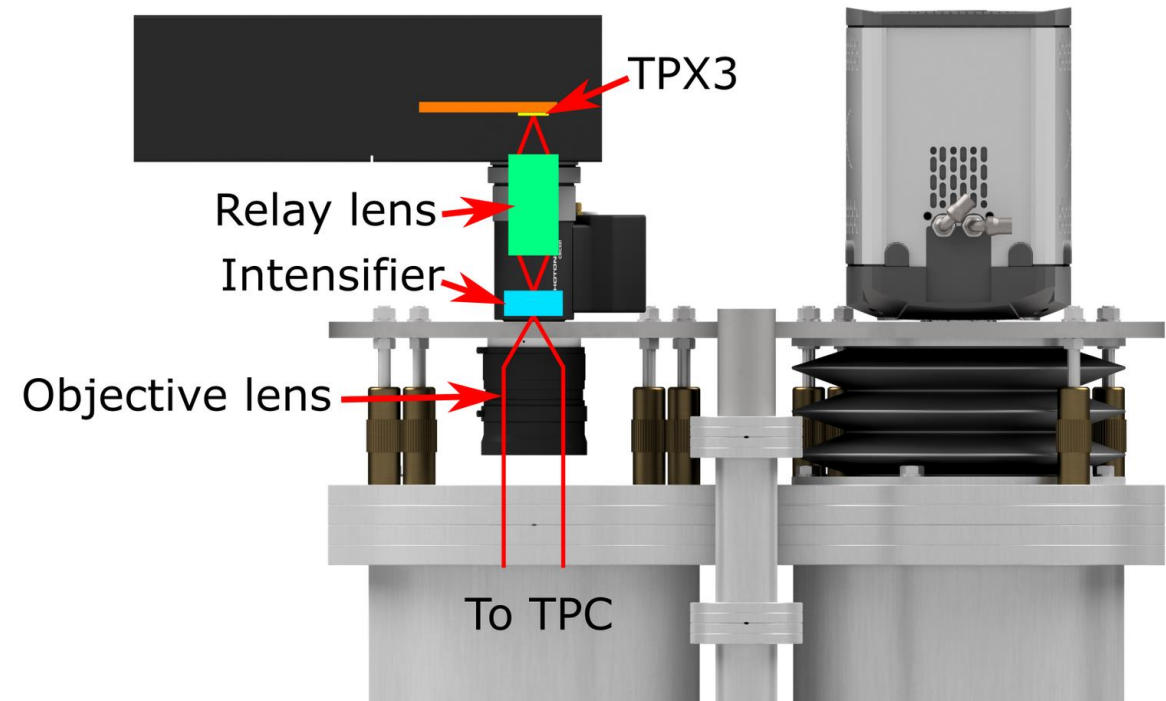
Active R&D program ongoing using optically sensitive TPX3 cameras

Commercial solutions available (<https://www.amscins.com/tpx3cam/>)

Single photon sensitivity when combined with image intensifier.
Intensifier gain $\sim 1E6$ photons/photon.

Relay lens couples intensified image onto light sensitive sensor which is bump bonded onto TPX3 ASIC.

Intensifier provides flexibility -> Many photocathode options are available to customise spectral sensitivity. Direct VUV?



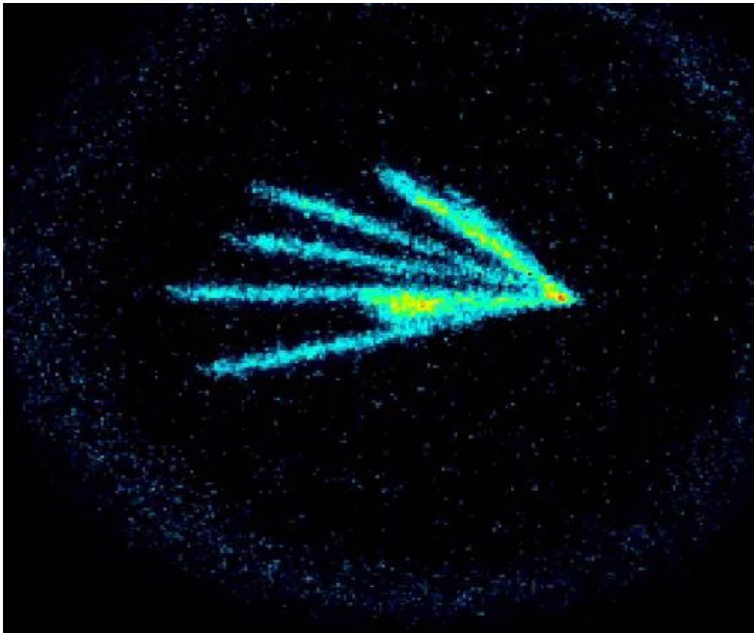
First demonstration using gaseous TPC

Initial demonstration / testing performed using a gaseous TPC (100mb CF₄)

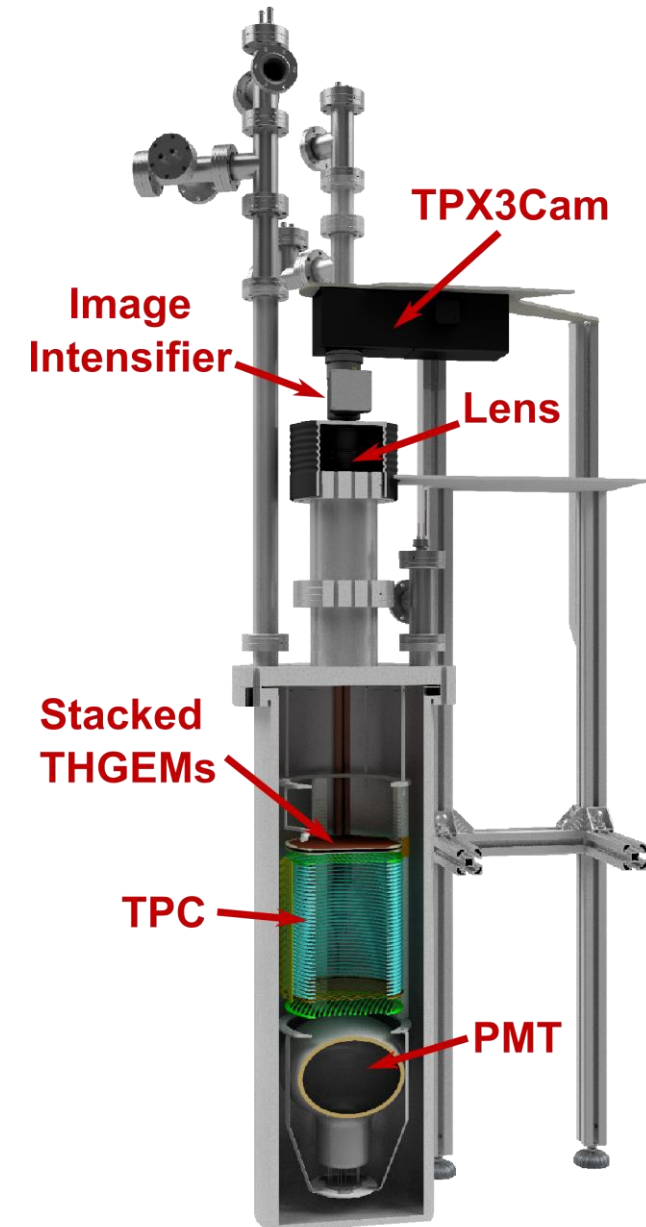
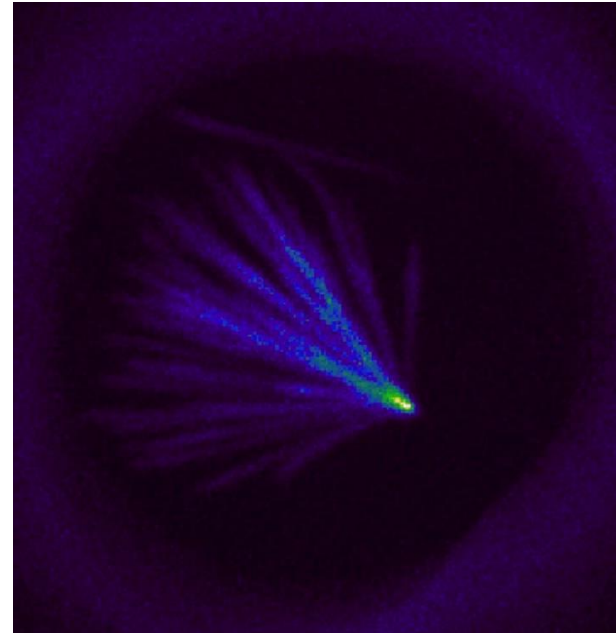
Dual THGEMs for increased light output.

Am-241 alpha source installed within the TPC.

Time-over-threshold (ToT) – TPX3Cam



EMCCD view



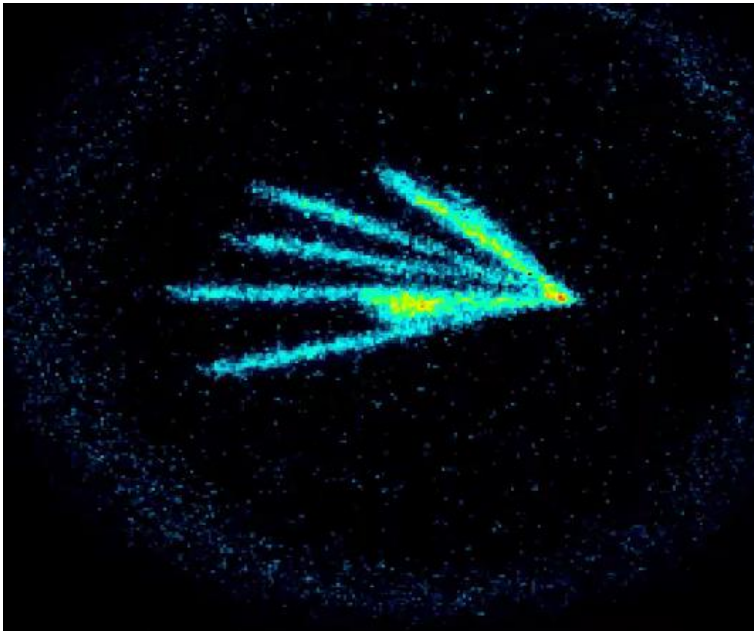
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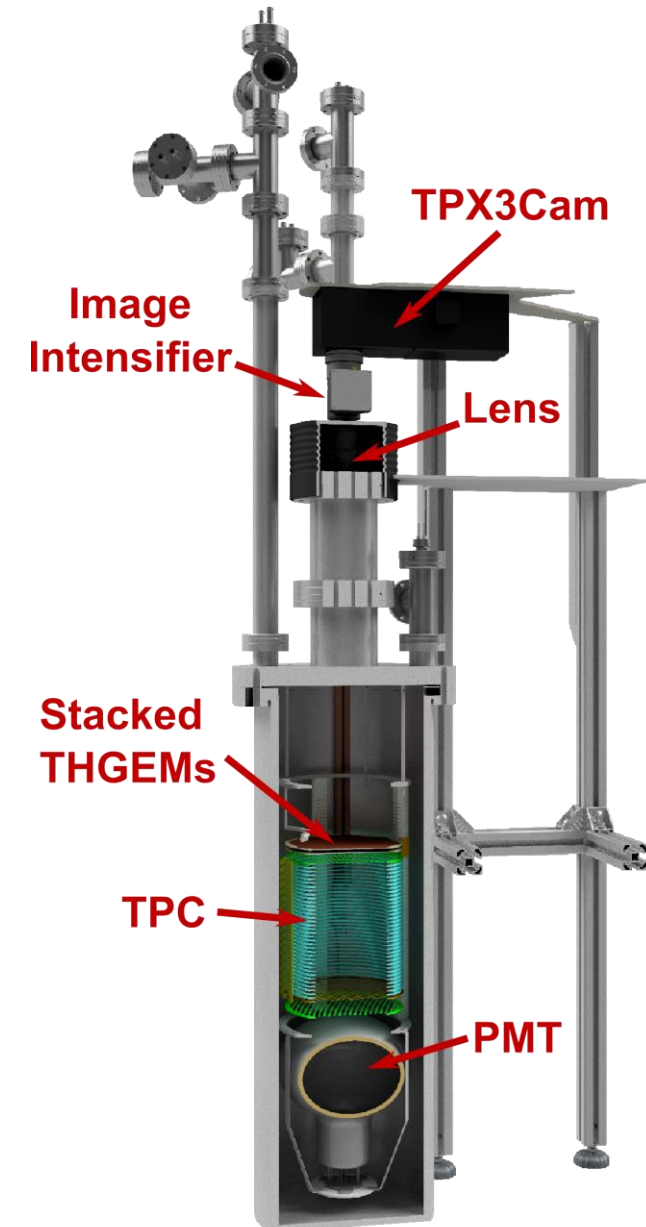
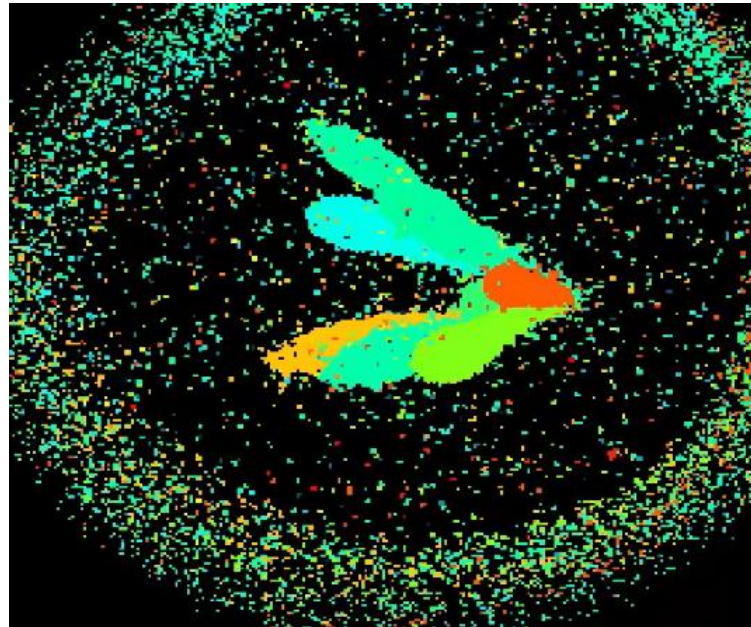
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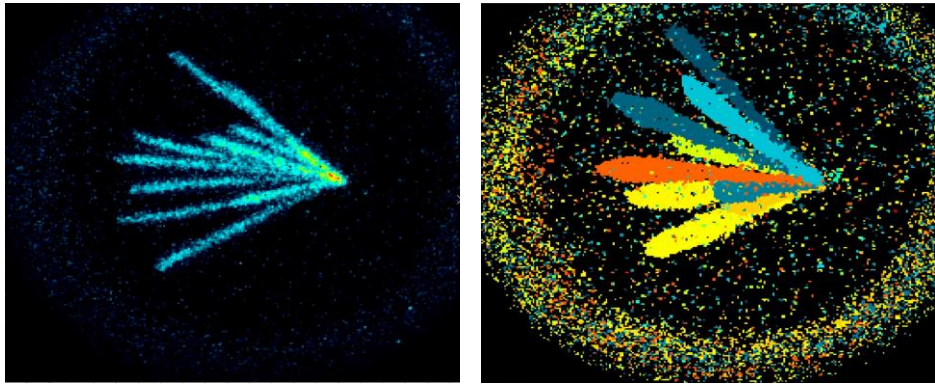
Time-over-threshold (ToT)



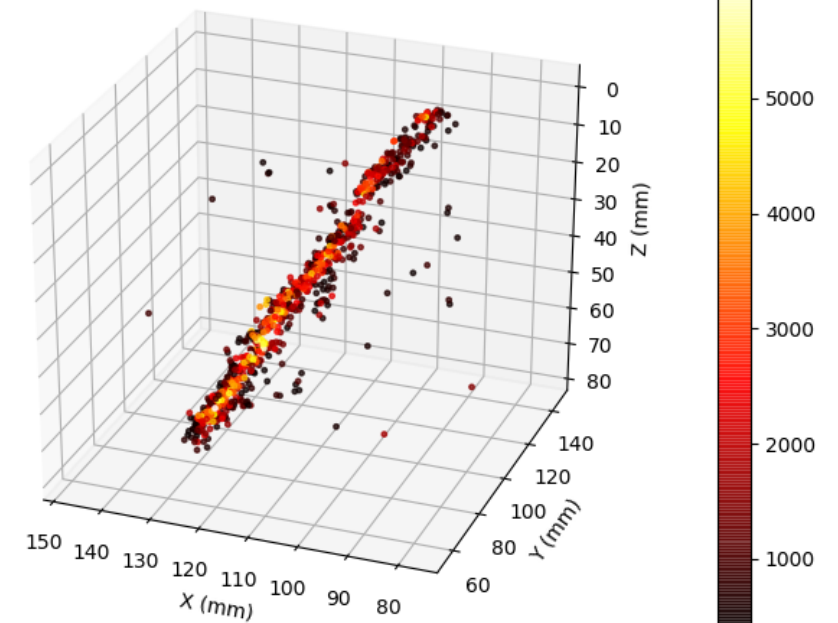
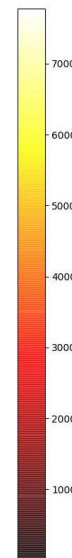
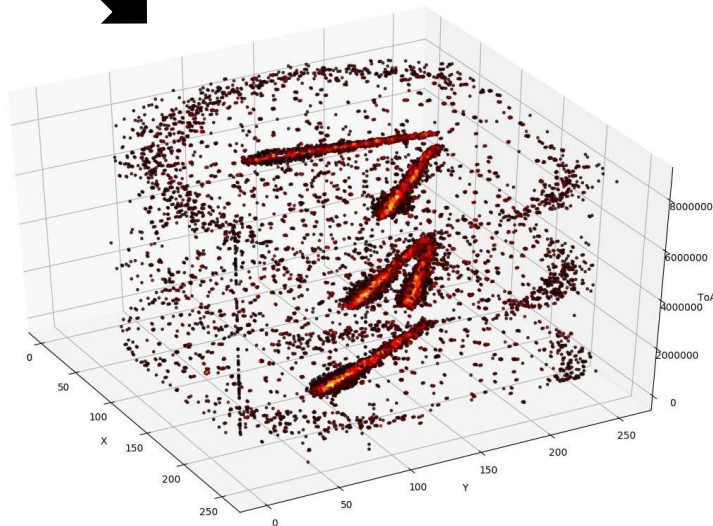
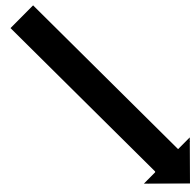
Time-of-arrival (ToA)



First demonstration using gaseous TPC



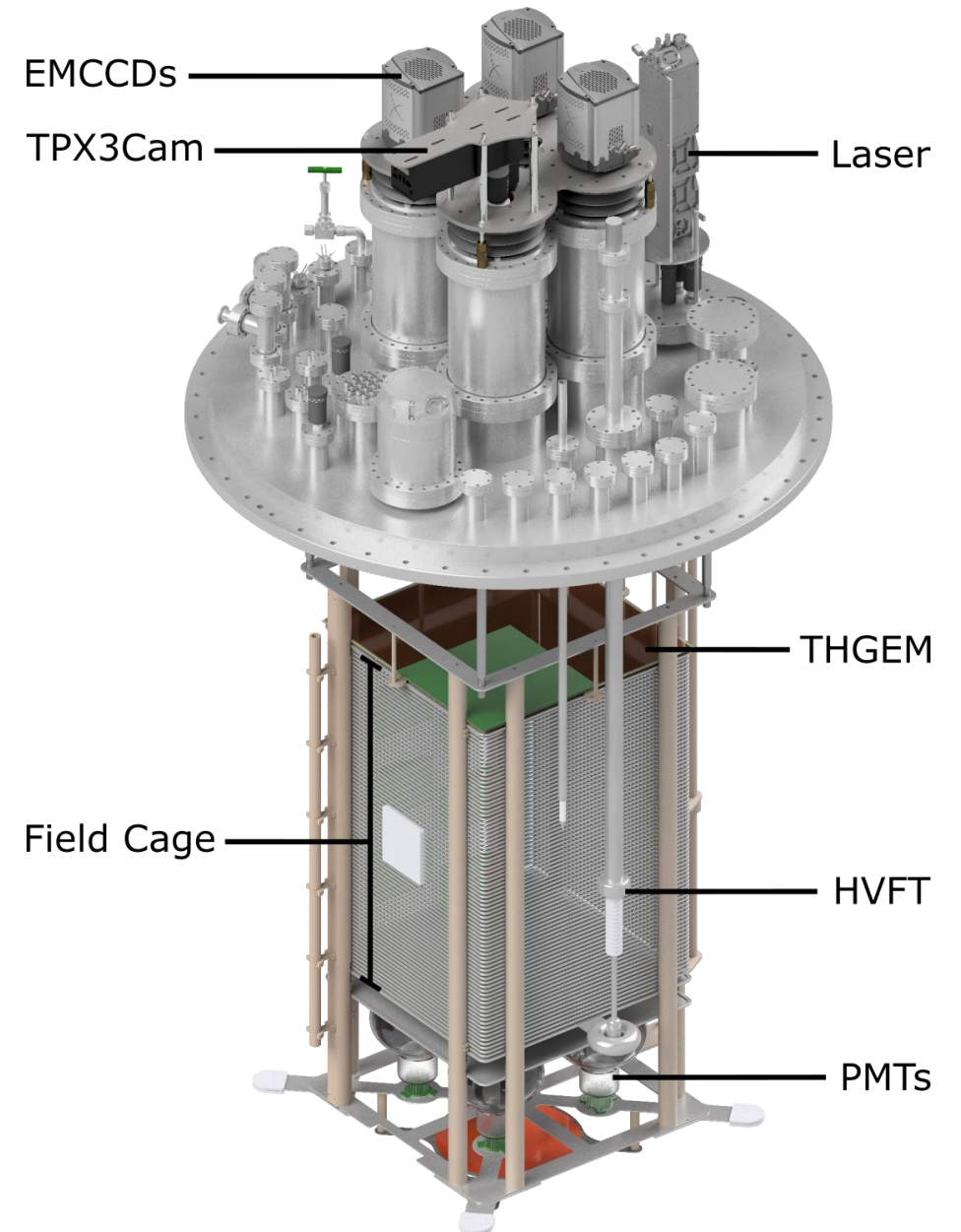
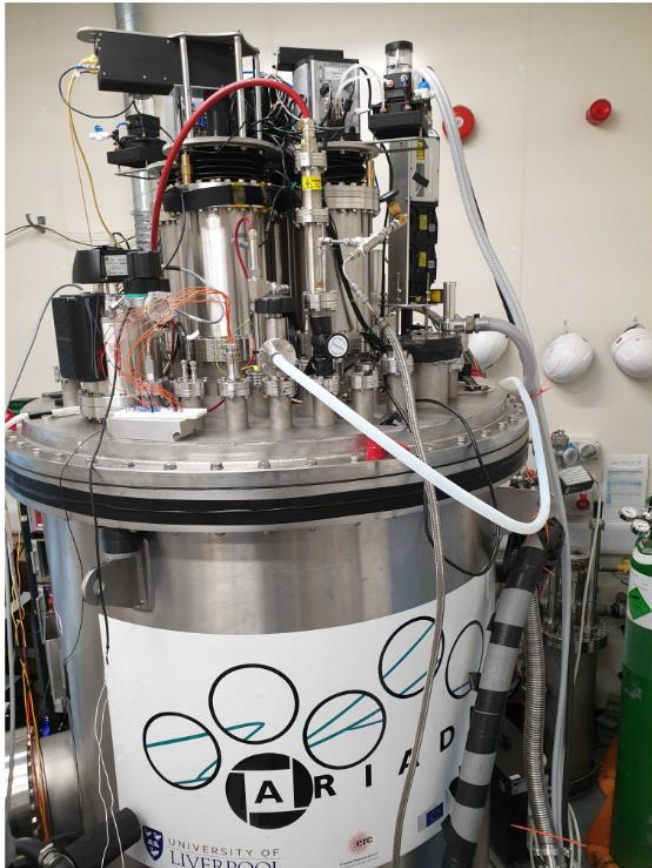
1.6ns time-of-arrival resolution sufficient for precise Z axis reconstruction even in gaseous TPCs with fast drift.



ARIADNE Timepix3 readout

Timepix3 camera installed in place of an EMMCD camera.
 ~ 26cm x 26cm field of view

Photonis Cricket image intensifier with Hi-QE green photocathode.
 30% quantum efficiency at 430nm (TPB peak emission)

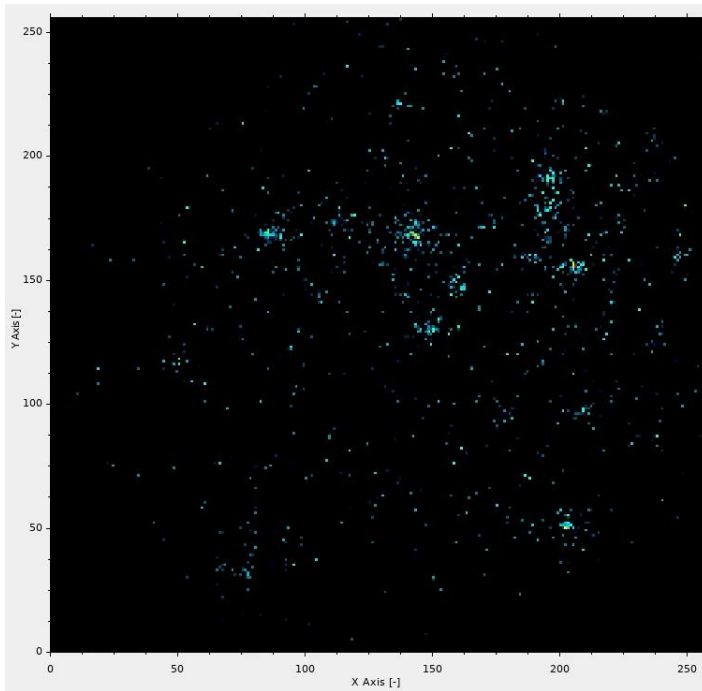


ARIADNE Timepix3 readout

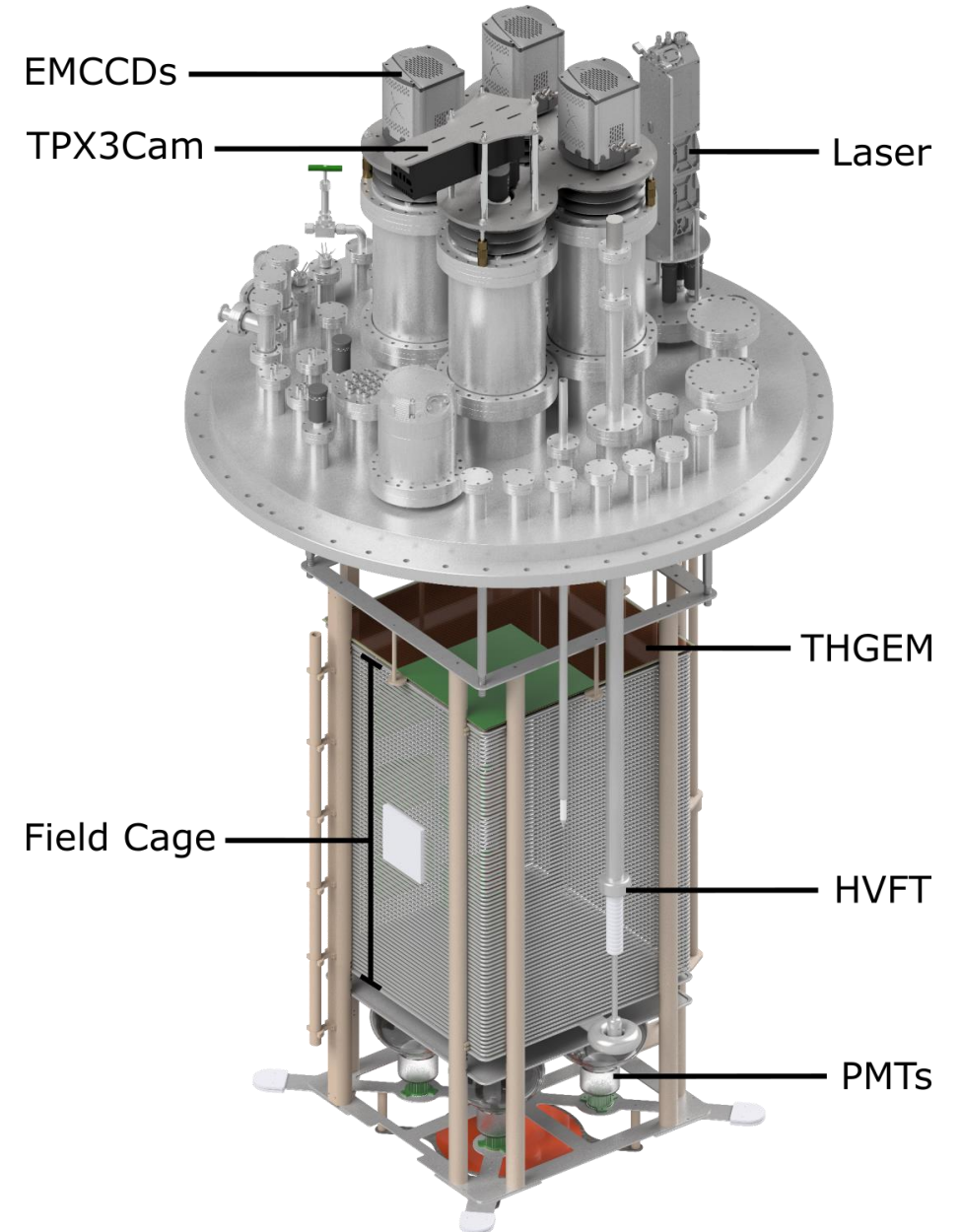
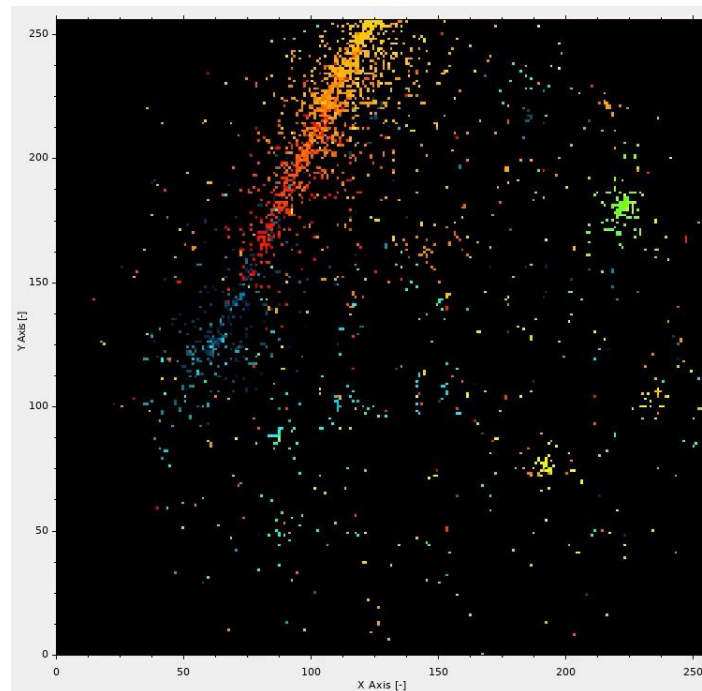
Timepix3 camera installed in place of an EMMCD camera.
~ 26cm x 26cm field of view

Photonis Cricket image intensifier with Hi-QE green photocathode.
30% quantum efficiency at 430nm (TPB peak emission)

Time-over-threshold (ToT)

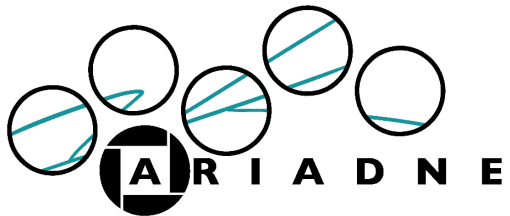
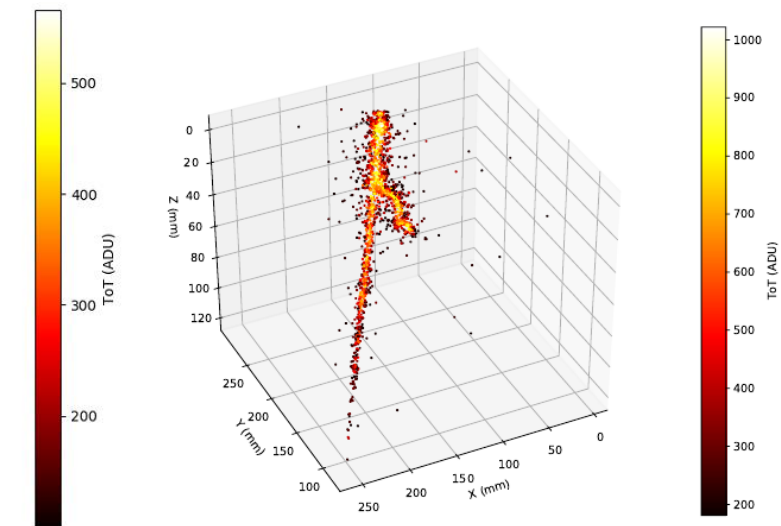
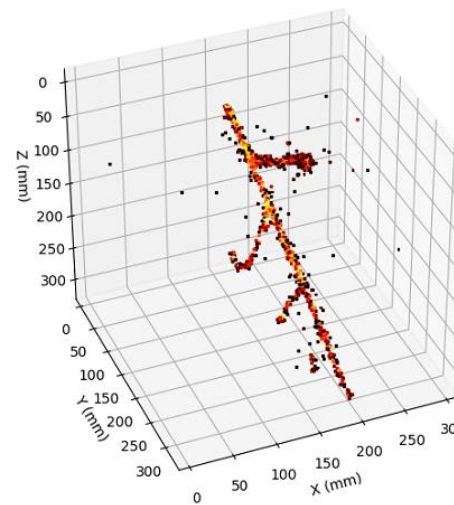
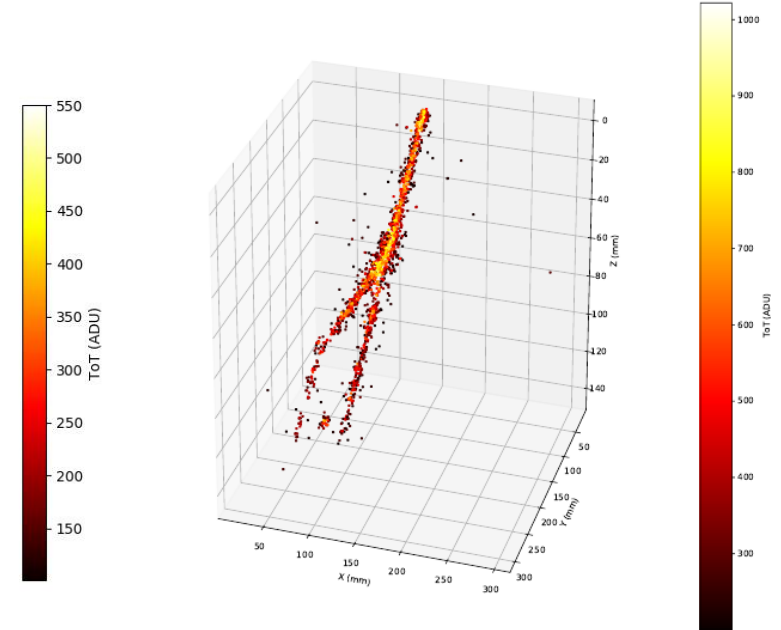
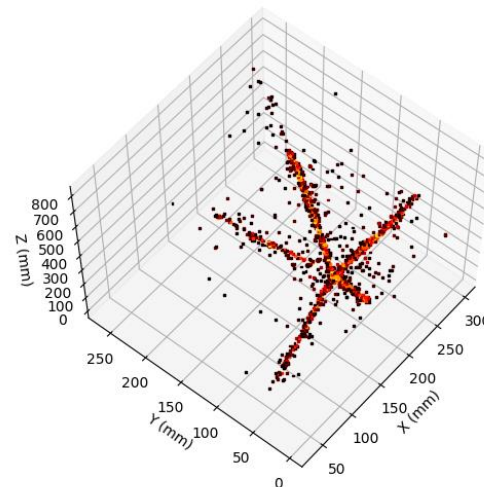
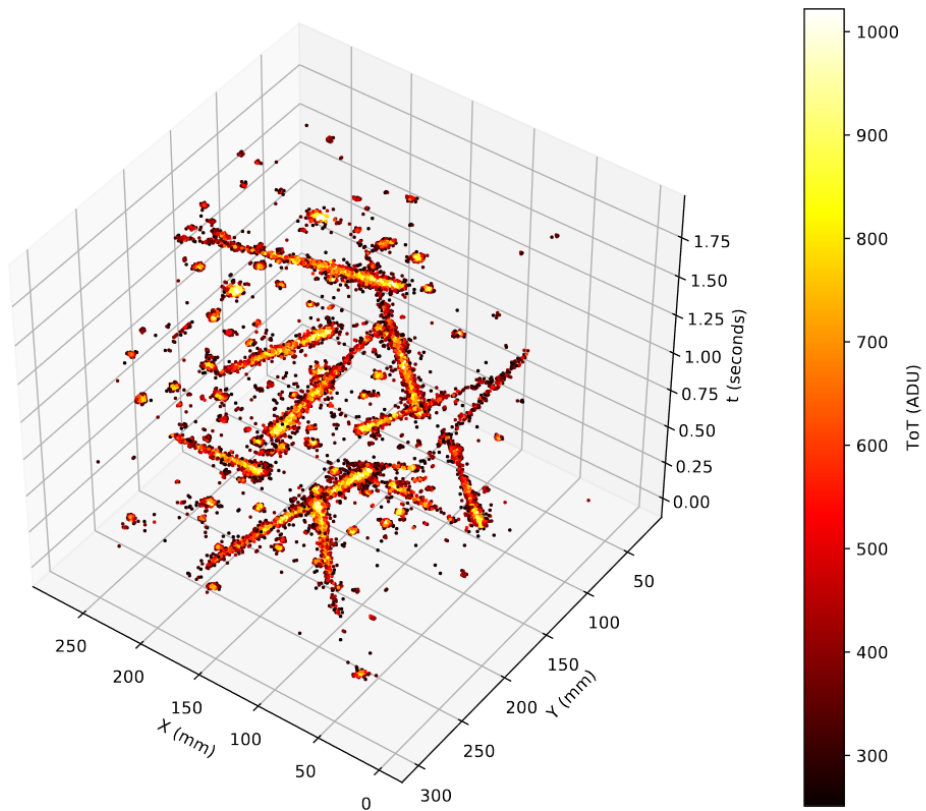


Time-of-arrival (ToA)



ARIADNE Timepix3 readout

Streaming data view (1 second window):

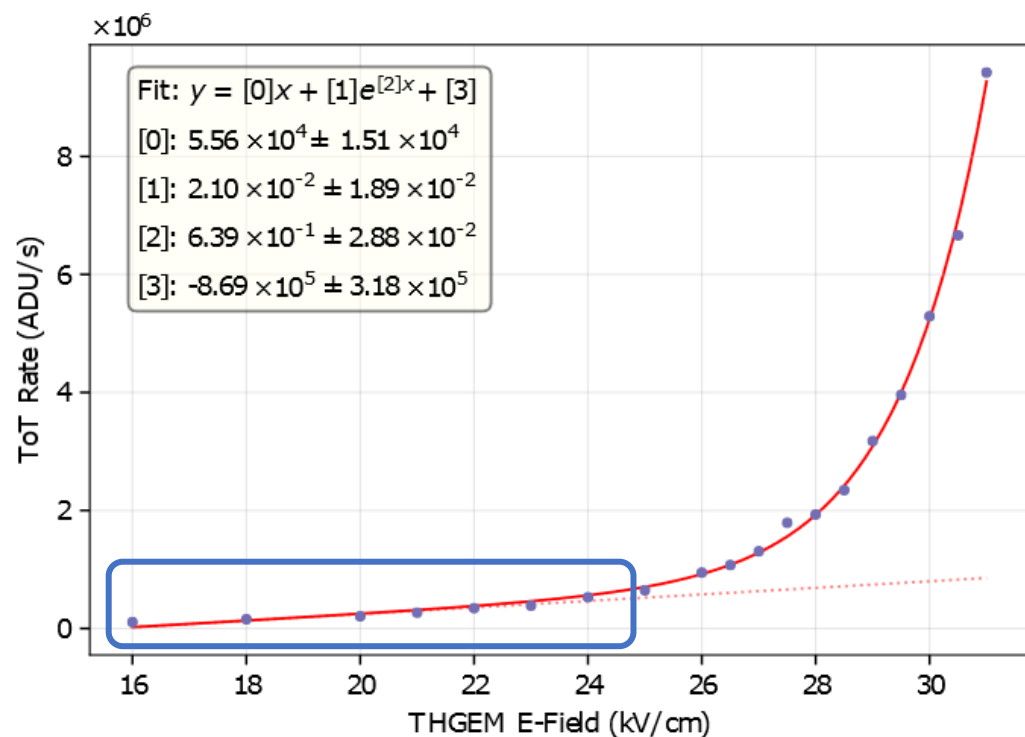


THGEM light production study

THGEM light production measured for THGEM bias between 1.6kV to 3.1kV

Sensitivity to linear/proportional electroluminescence regime.

Optical readout is possible in purely linear regime. Very stable THGEM bias. No ion production.

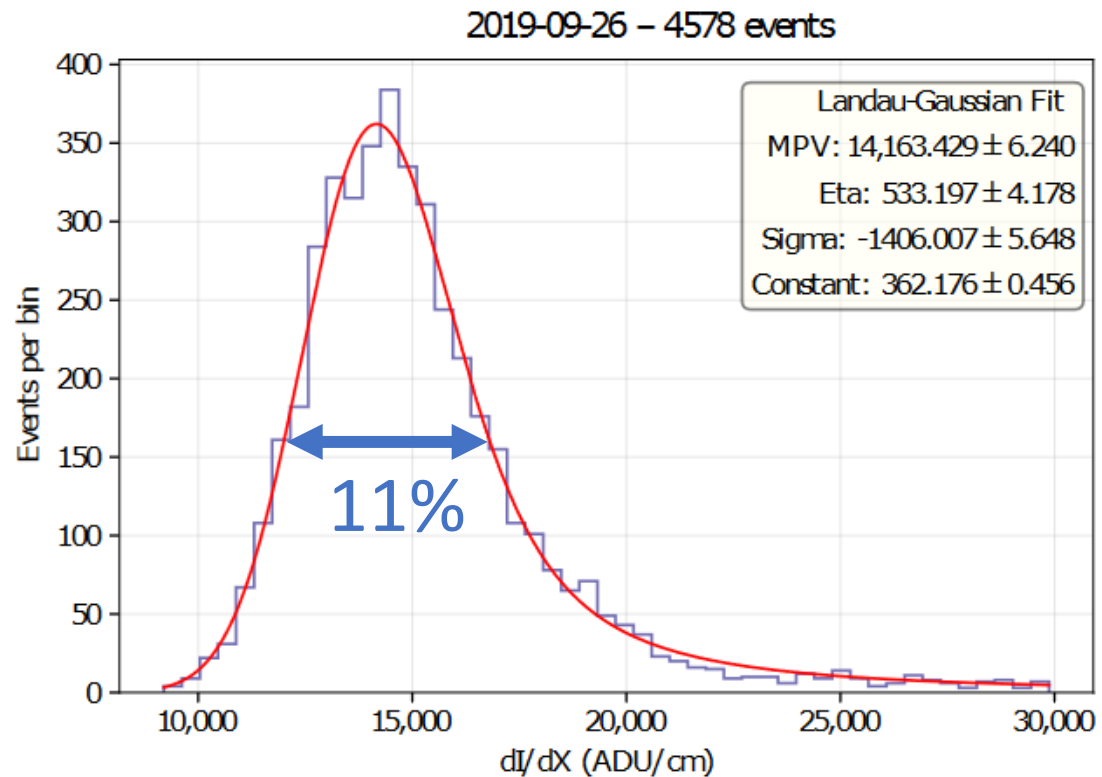


Energy resolution

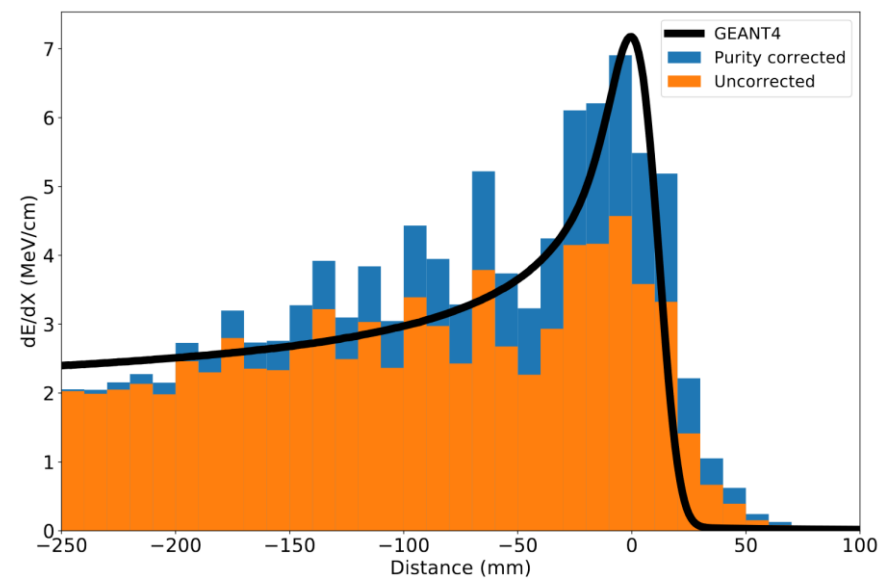
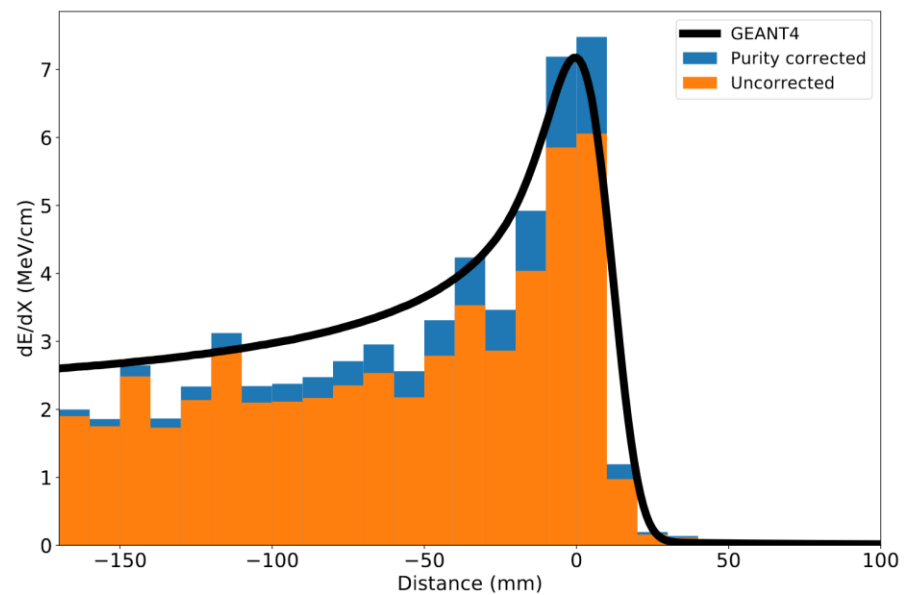
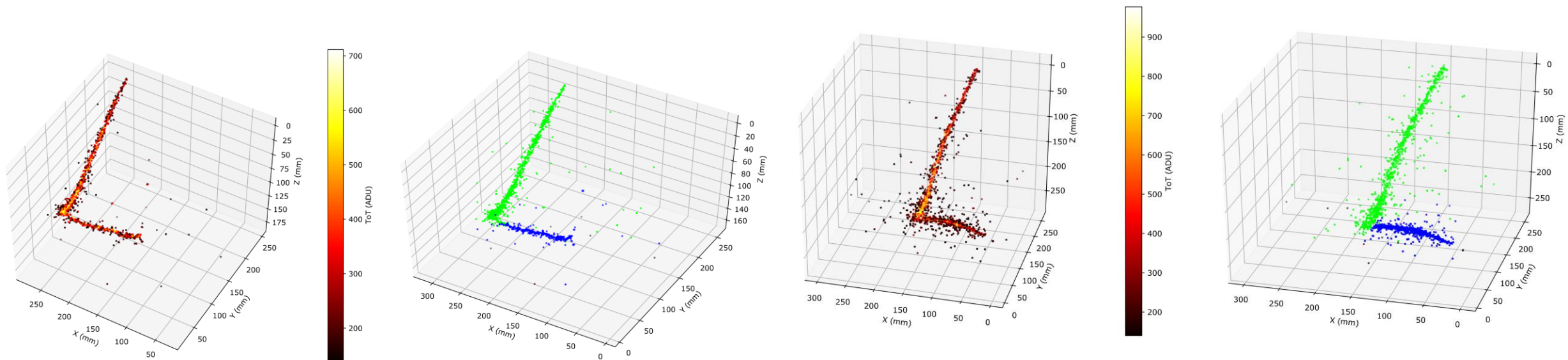
Energy resolution measured using cosmic muons.

Landau-Gauss distribution fitted to observed distribution.

Energy resolution, defined as the Landau (eta) and Gaussian (sigma) widths combined in quadrature and expressed as a fraction of the MPV, is 11%



Stopping muons



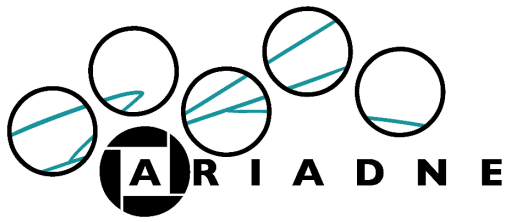
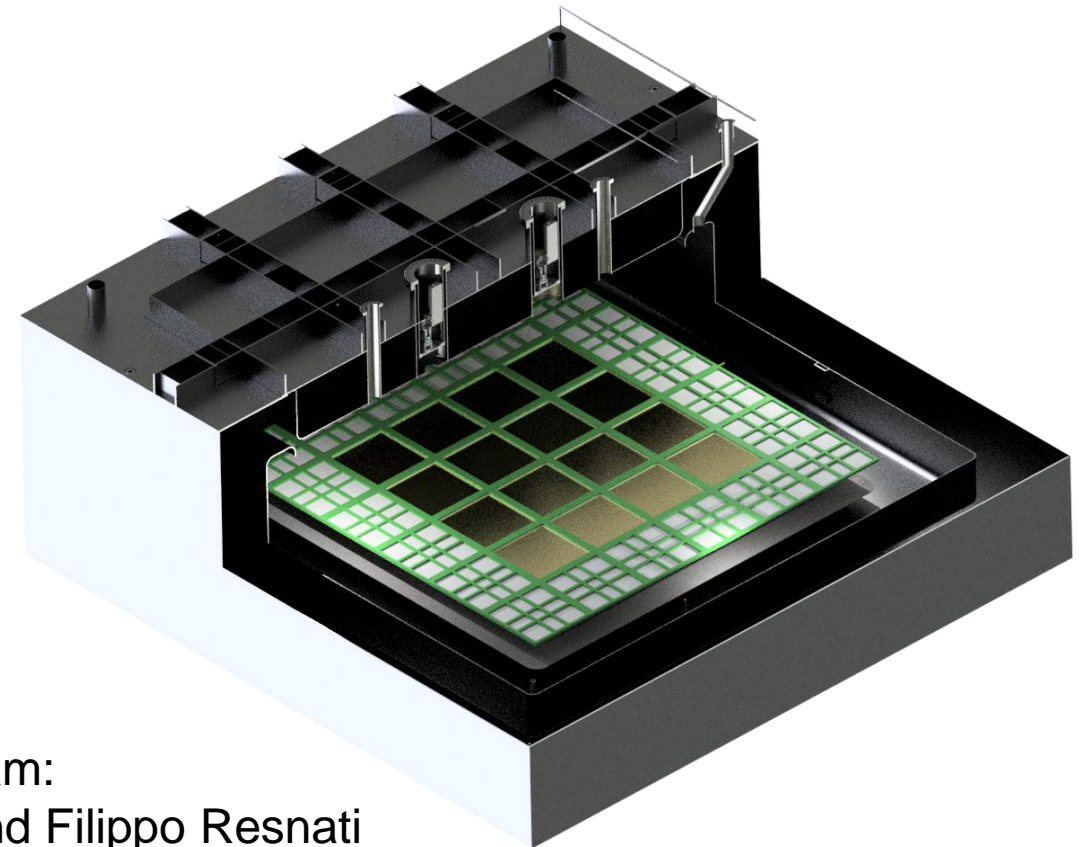
Outlook and next steps

Future plans to instrument 2m x 2m active area TPC using the coldbox at the CERN neutrino platform.

Larger field of view (1m x 1m per camera) will be tested.
Allowing large detector area to be covered with few cameras.

Direct VUV imaging using image intensifier sensitive to 126nm.

Timepix 4 may be available soon;
Larger sensor (512 x 448)
Improved energy resolution
200ps ToA resolution



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

Outlook and next steps

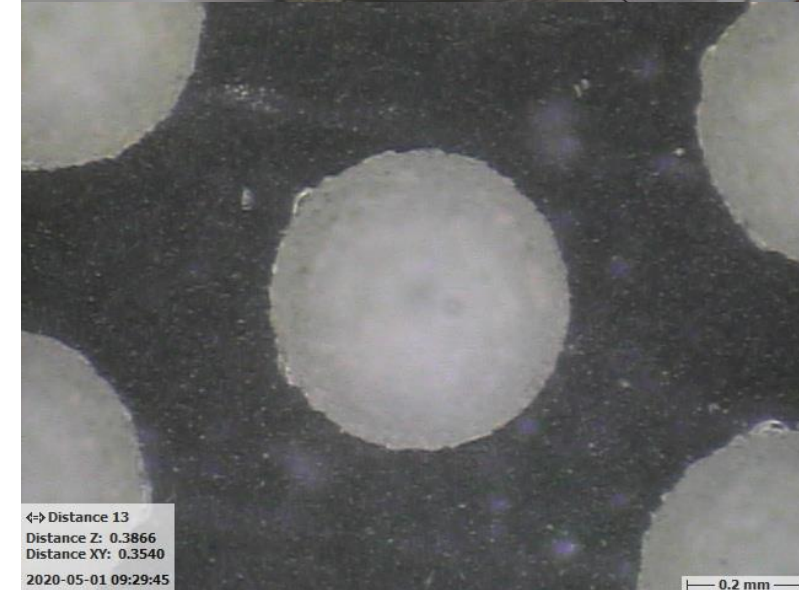
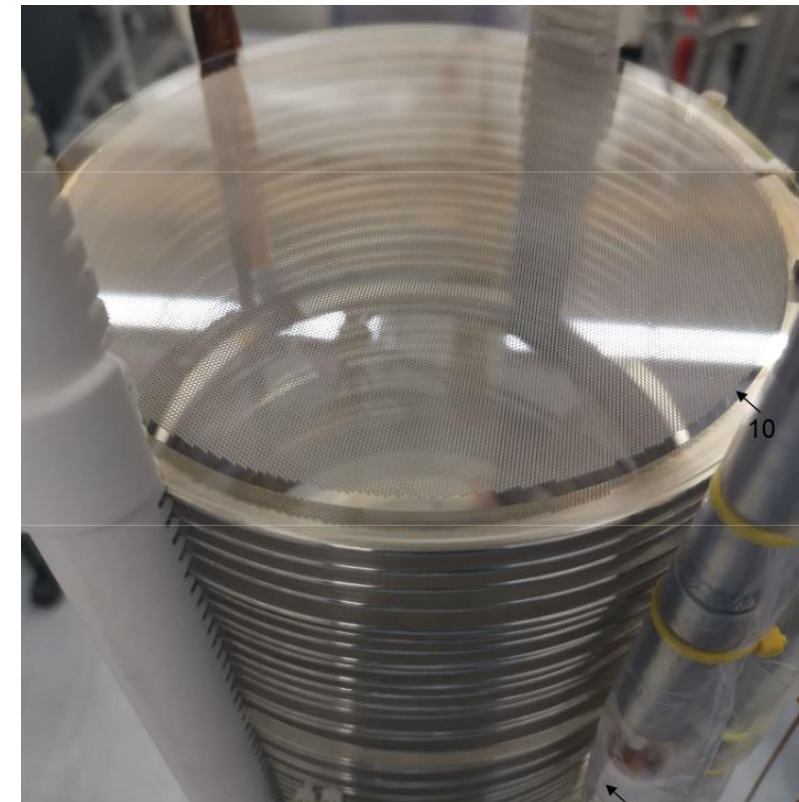
Proposing to use Glass THGEMs (developed at Liverpool) for large scale tests using the coldbox at CERN. Patent pending: GB2019563.2

Produced using a new manufacturing technique, allowing THGEMs to be produced from common glasses

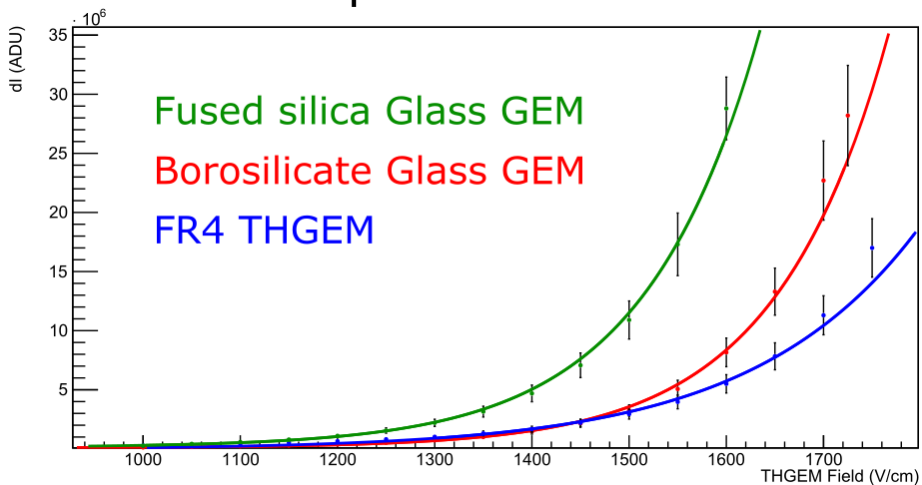
e.g. Borosilicate glass or fused silica (Radiopure)

Less thickness variation and lower outgassing compared to FR4

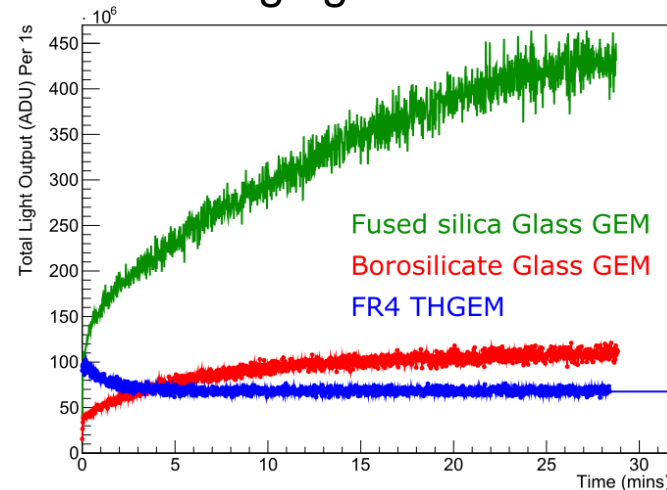
Top and bottom electrodes formed by transparent ITO coating.
Biconical hole shape. Gain increases when charging up.



Gain vs potential difference

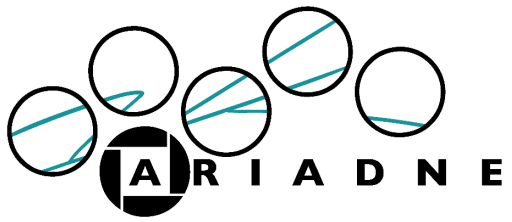


Charging behaviour



Thank you

Questions?



Backup – Timepix4

Timepix3 → Timepix4

		Timepix3	Timepix4
Technology		IBM 130nm	TSMC 65nm
Pixel Size		55 x 55 μm	$\leq 55 \times 55 \mu\text{m}$
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

Faster readout rates

Improved calorimetry