ARIADNE: Fast optical readout of large-scale dual-phase LArTPCs for neutrino physics

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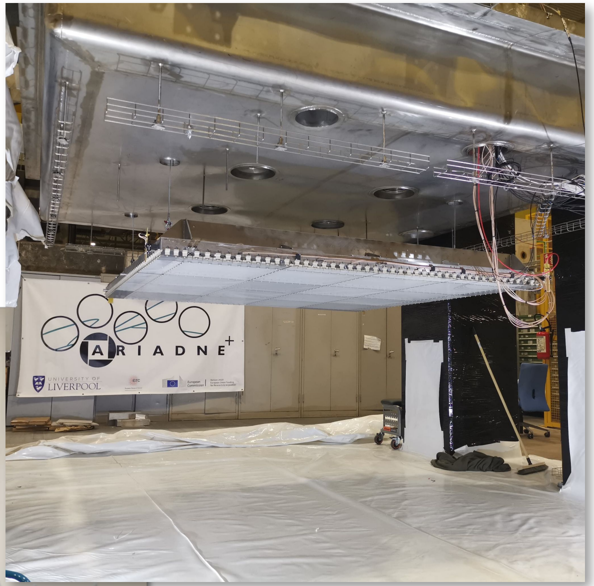
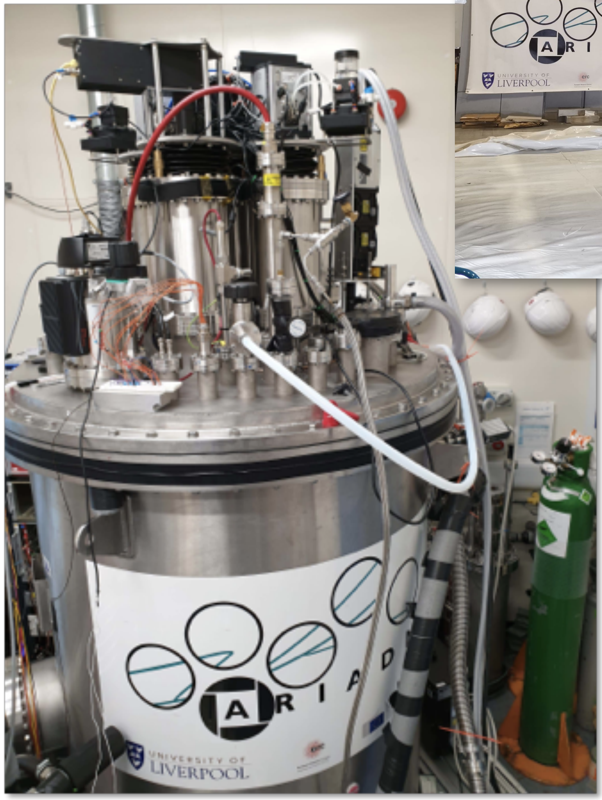


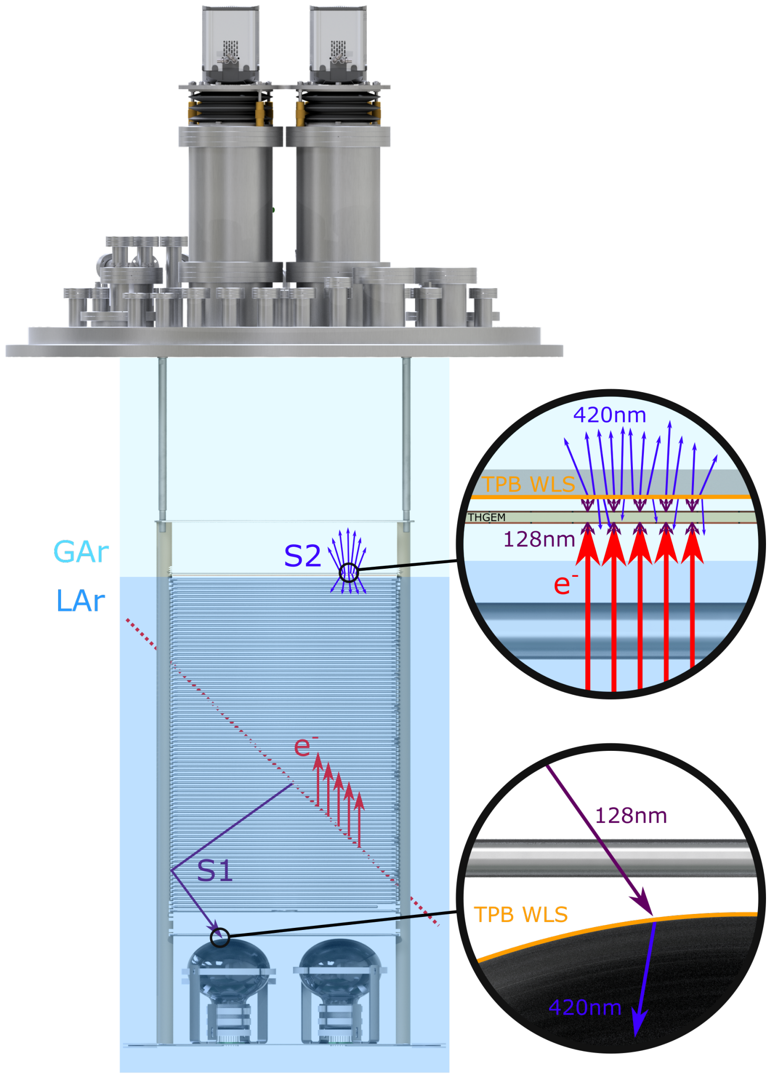


https://hep.ph.liv.ac.uk/ariadne

ARIADNE Detection Principle

ARIADNE aims to demonstrate light readout as a viable alternative to charge in dual-phase TPC neutrino experiments

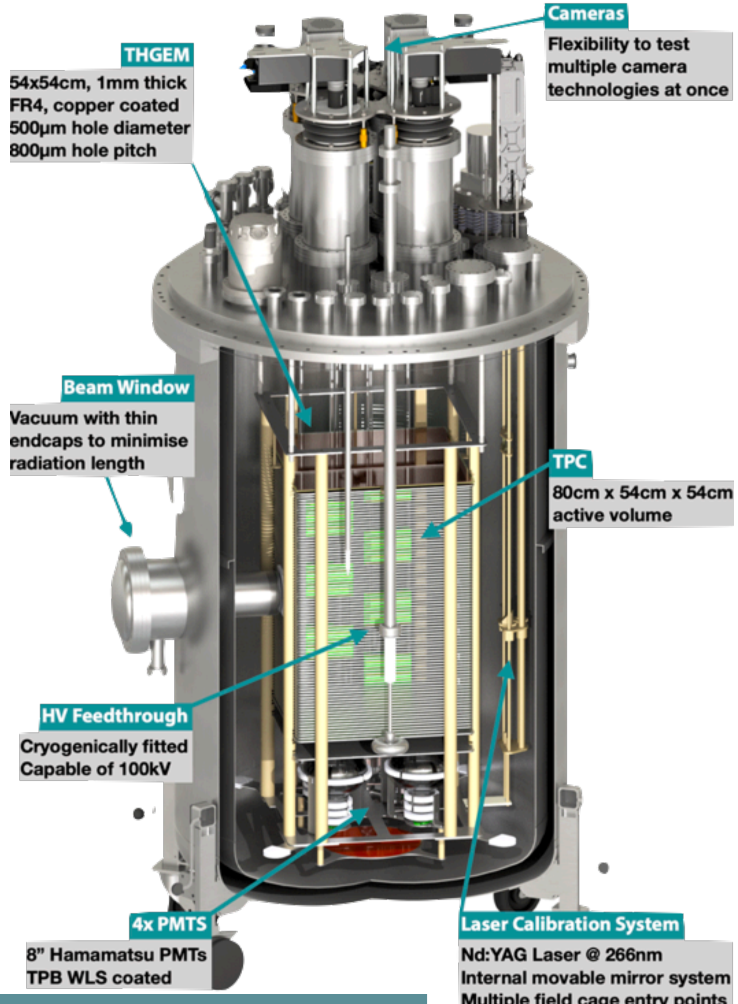
- Incoming particles ionise LAr and create **prompt scintillation** light (**S1**)
- Electrons drift towards the **extraction grid** situated below the liquid level
- A **THGEM** (THick-Gaseous Electron Multiplier) amplifies drift charge (capable of >30 kV/cm in LAr) generating **secondary scintillation** light (**S2**) in the Vacuum Ultraviolet (VUV) range
- **WLS** (Wavelength Shifting) for an intensifier stage before imaging with Timepix3 camera



***ARIADNE** (**AR**gon Im**A**ging **D**etectio**N** chamb**E**r)*

The ARIADNE Advantage - Optical TPCs

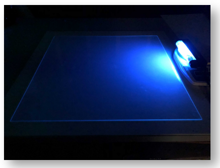
- Benefits over previous charge readout methods:
  - **High Resolution:** For e.g. TPX3 camera has 256 x 256 pixels, imaging 35 x 35 cm area, as on ARIADNE, gives ≈1 mm resolution
  - **Sensitivity to low energies:** Gain is generated by the THGEM; a THGEM accelerated electron can generate upwards of 100 photons, cameras can be sensitive to single photons
  - **Very low Noise:** Sensors are decoupled from TPC electronics
  - **Ease of Access:** Technology can be swapped in and out even with TPC operating
  - **Cost Efficient:** No need for thousands of internal charge TPC readout channels, pre-amps etc.



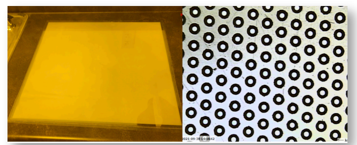
ARIADNE 1-tonne detector

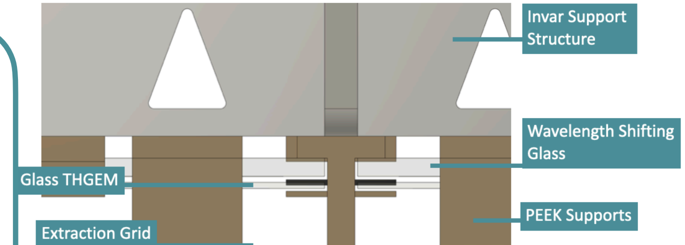
ARIADNE⁺ Detector @ CERN (Feb-April 2022)

Polyethylene Naphthalate (PEN) Film coated glass panels for Wavelength Shifting (WLS)

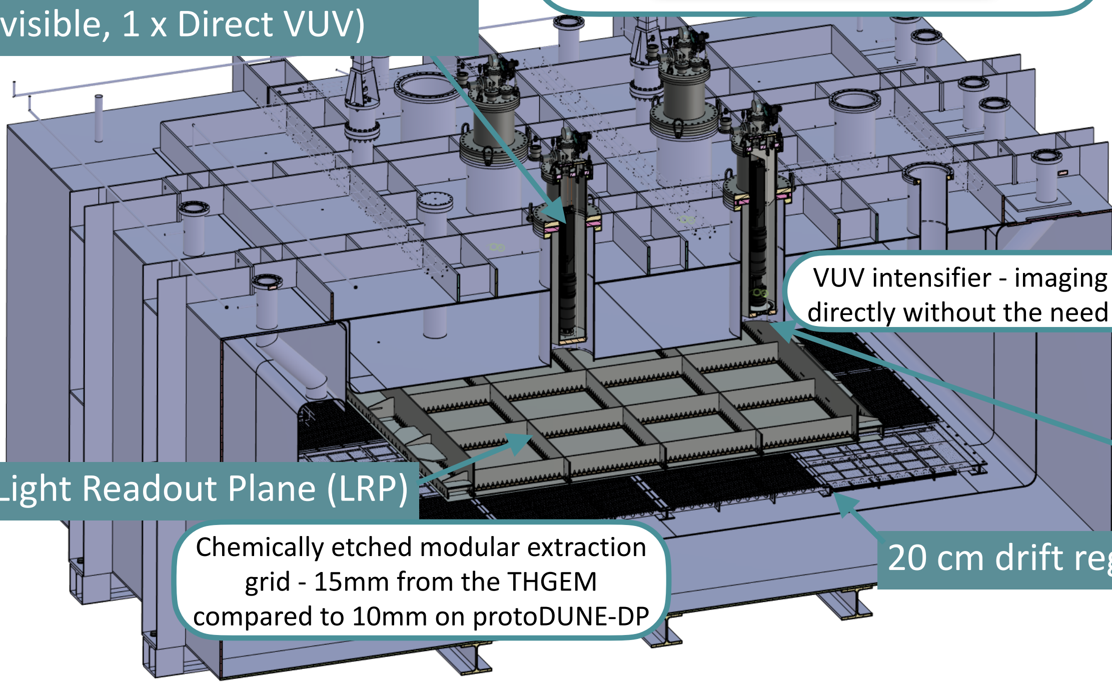


Glass THGEMs - Less prone to sagging compared to FR4 at larger surface areas. Conical hole shape collects charge and increases light output





4 TPX3 Cameras imaging 1 x 1 m active region each (3 x visible, 1 x Direct VUV)



VUV intensifier - imaging the THGEM directly without the need for any WLS

Light Readout Plane (LRP)

Chemically etched modular extraction grid - 15mm from the THGEM compared to 10mm on protoDUNE-DP

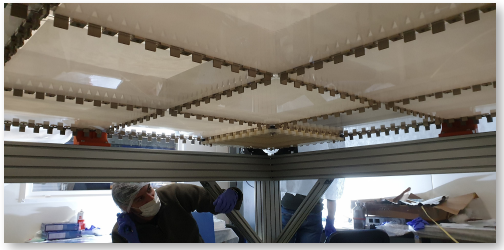
20 cm drift region

Custom made VUV MgF_2 Lens (f3, 11mm, 5mm diameter)

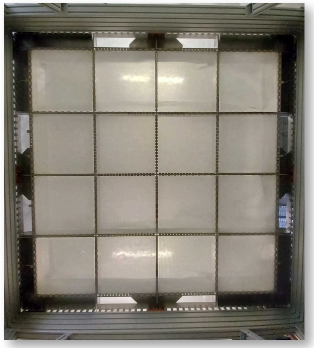
Visible (f0.95, 10.5 mm)

My LTA @ CERN - October ’22 to September ’23

- Preparation for ARIADNE+:
  - Building the cleanroom at the CERN Neutrino Platform
  - Setting up power supplies, DAQ and lab consumables

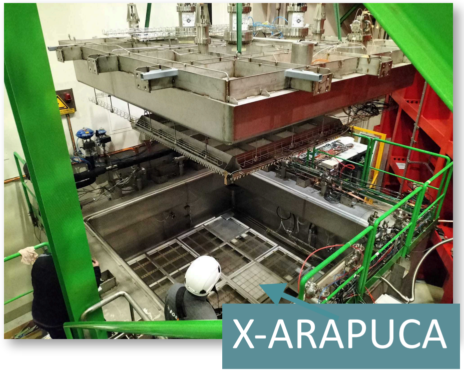


- Construction of the Light Readout Plane (LRP):
  - 1000 PEEK support pieces mounted on the Invar support frame
  - Glass THGEM testing in Mini-ARIADNE (MARIA) before securing in the LRP
  - Tensioning the extraction grid to ensure a flat extraction surface

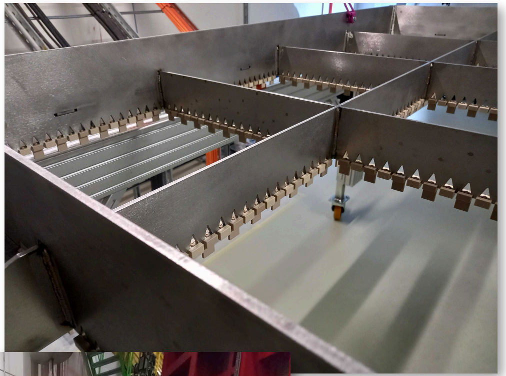


Finished Product

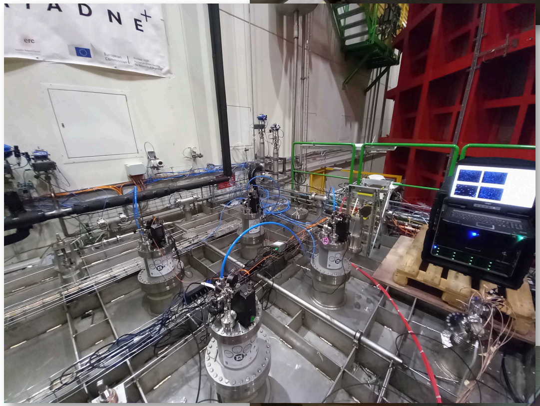
- Data Collection:
  - Collected over two weeks with a refill to ensure good argon purity
  - Various THGEM biases and gas pressures
  - In collaboration with the Galician Institute for High Energy Physics (IGFAE), S1 data was taken with X-ARAPUCS embedded in cold box cathode



My LTA @ CERN - October '22 to September '23



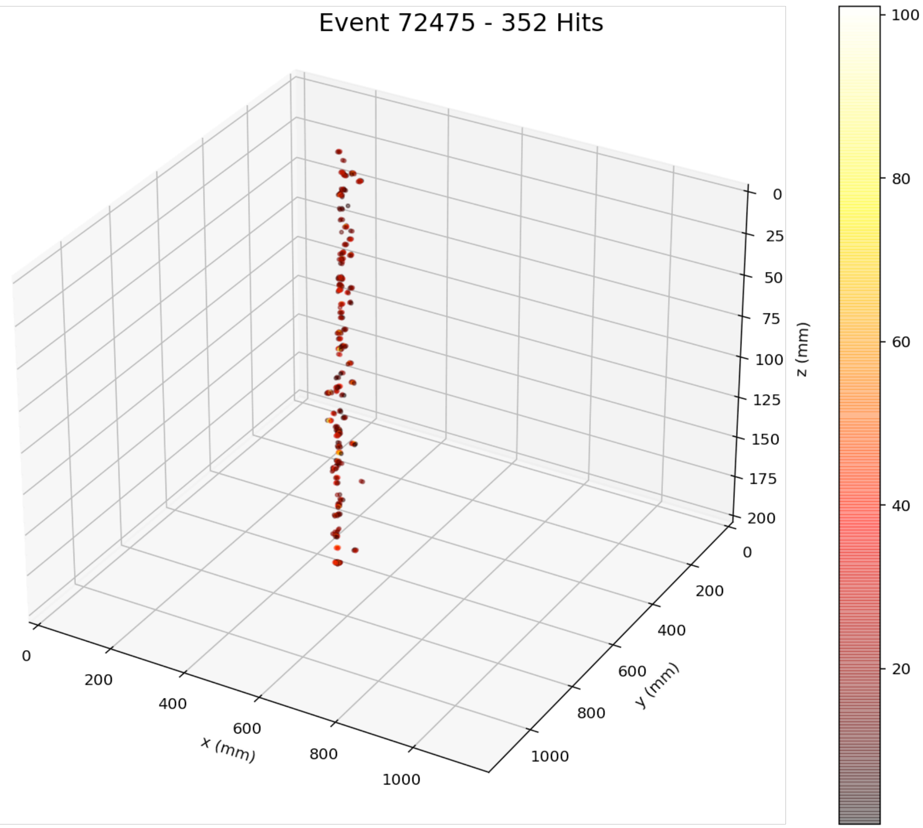
- Decomissioning:
  - Successful full LRP emersion stress test
  - Evaluating glass THGEM durability
  - LRP and TPX3 chimneys remain at CERN for possible additional runs

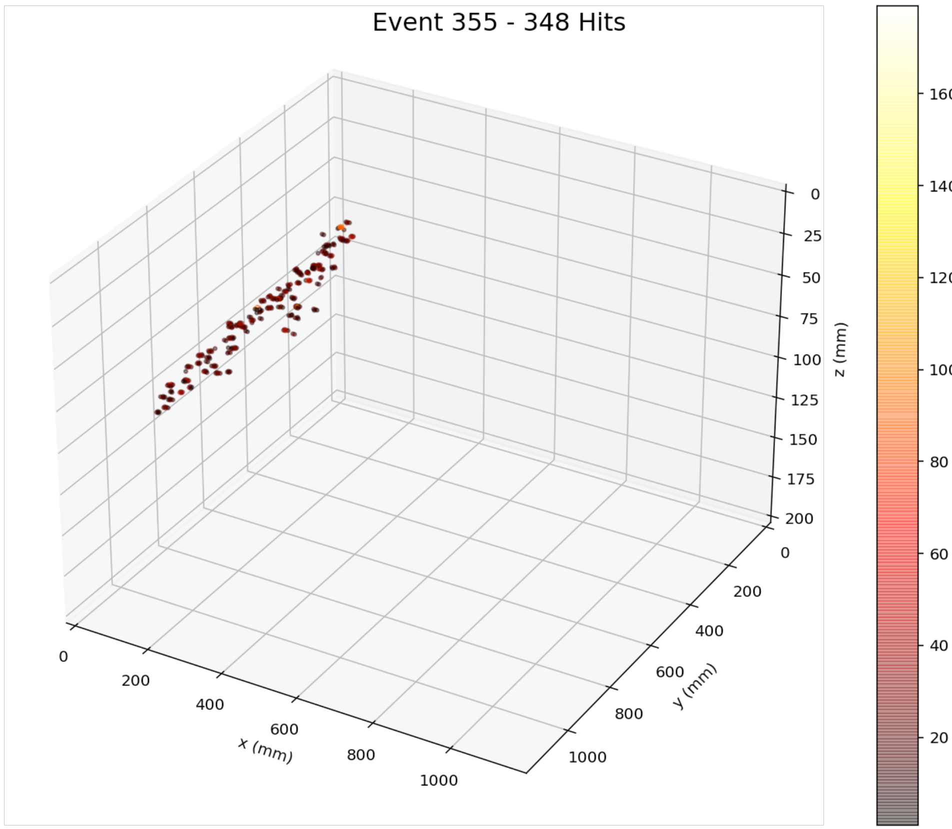


- Preliminary data analysis:
  - Track gallery - visible and VUV
  - Detector performance

- NuFACT23 Talk:
  - Presented in the detector working group at the 2023 Neutrinos From ACcelerators conference in Salt Lake City, Utah
  - Published proceedings (https://doi.org/10.48550/arXiv.2301.02530)

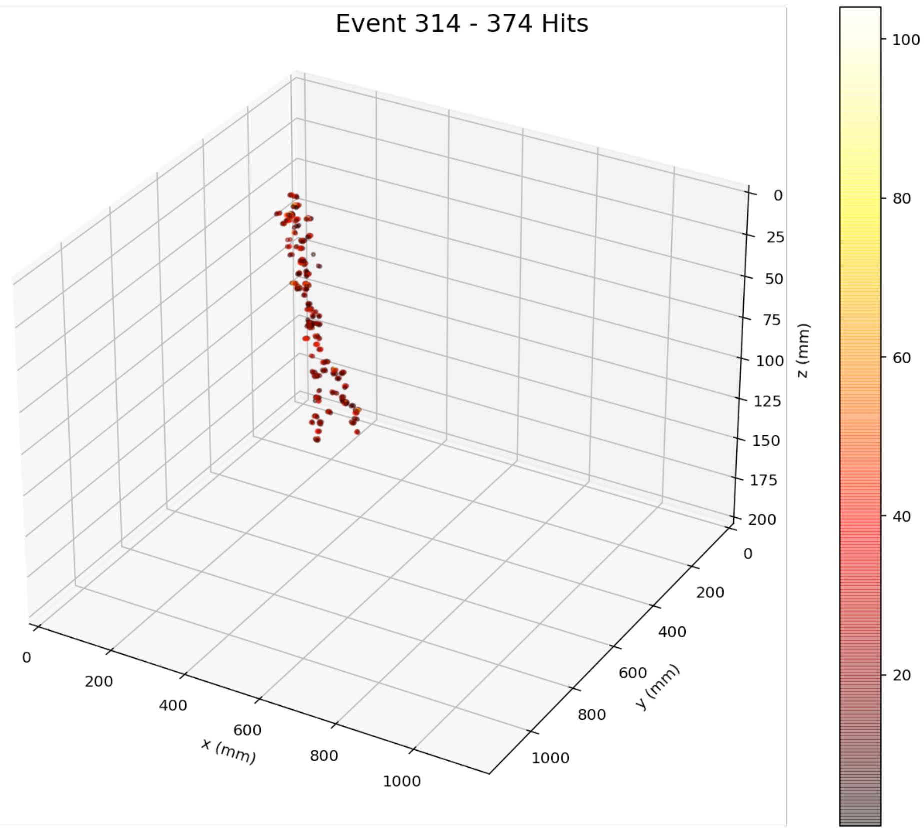
Gallery of Events - Visible Light

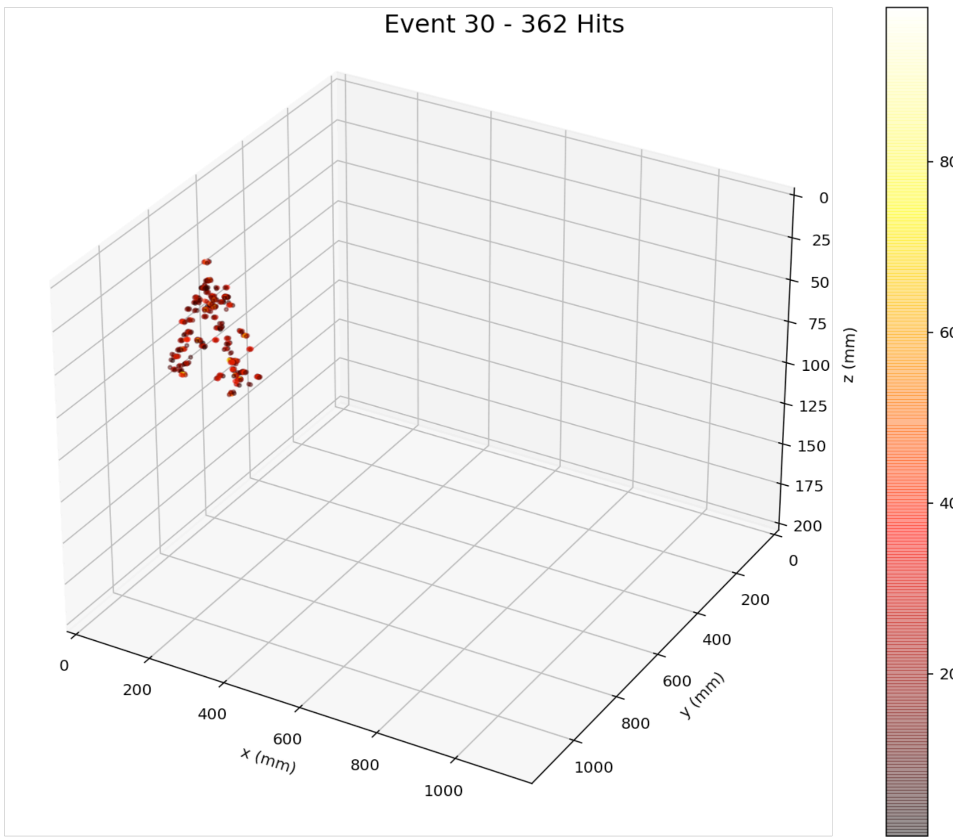




~4 mm Resolution

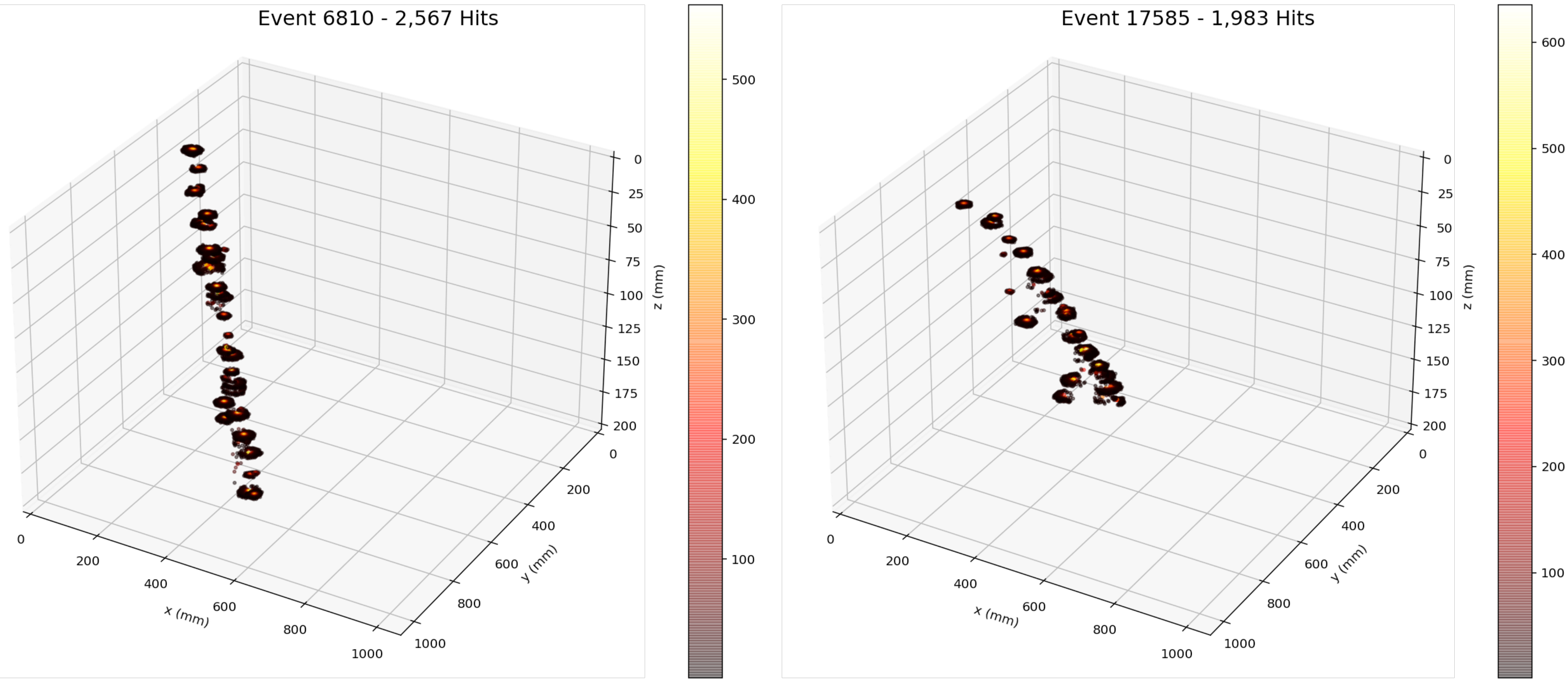
Gallery of Events - Visible Light





~4 mm Resolution

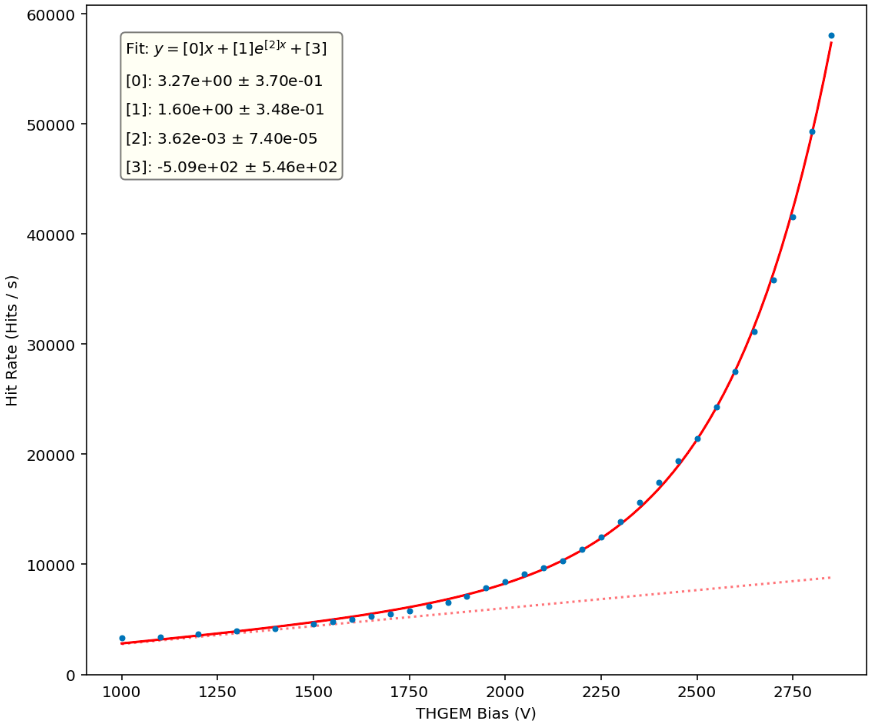
Gallery of Events - VUV



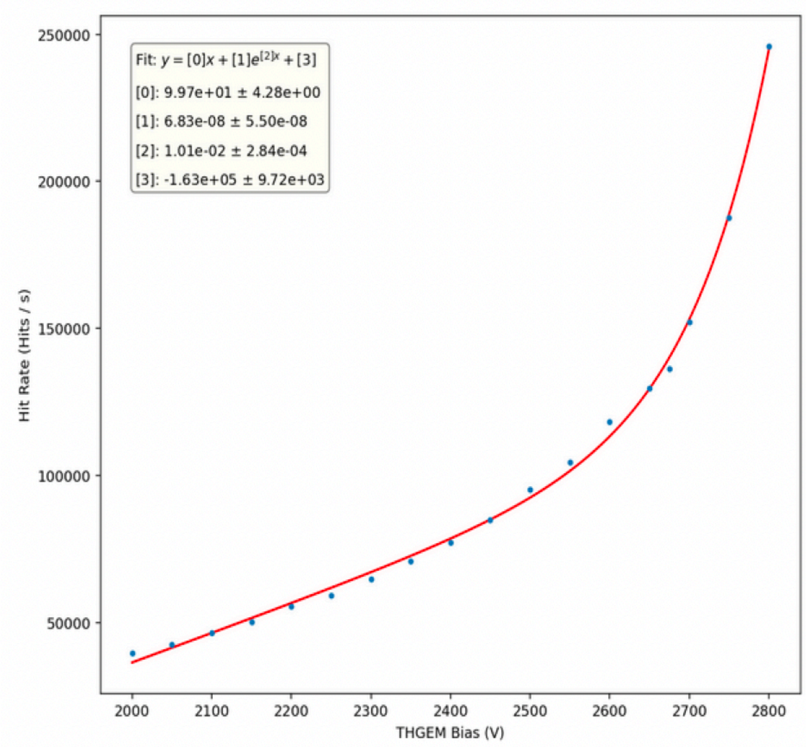
~4 mm Resolution

Glass THGEM Light Study

Visible Light

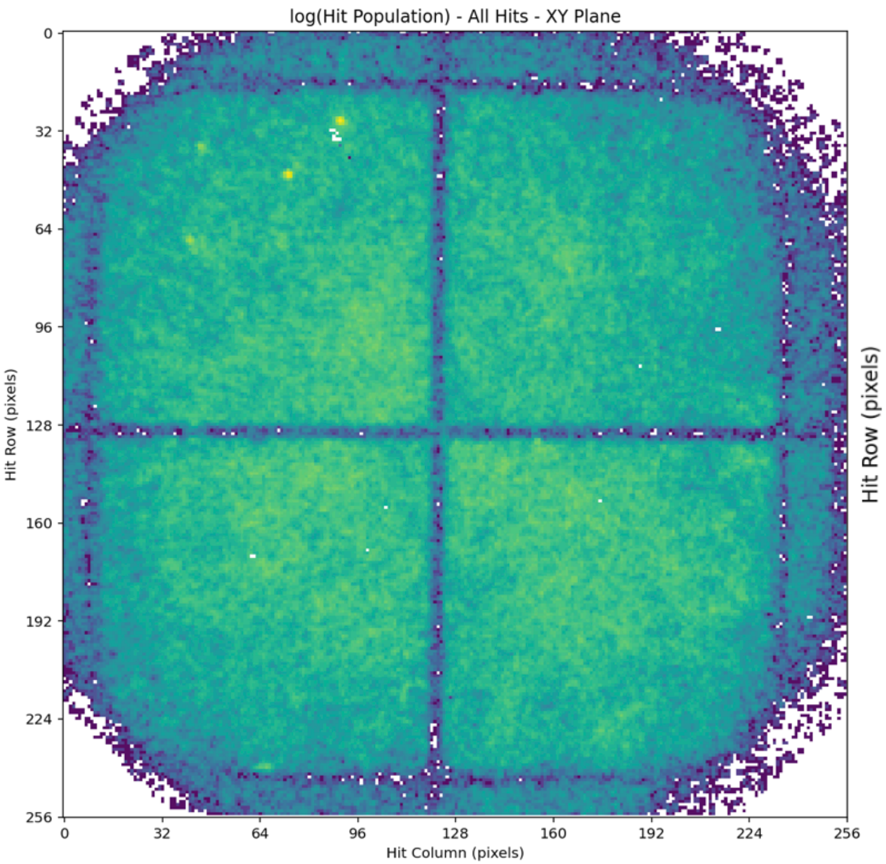


VUV Light

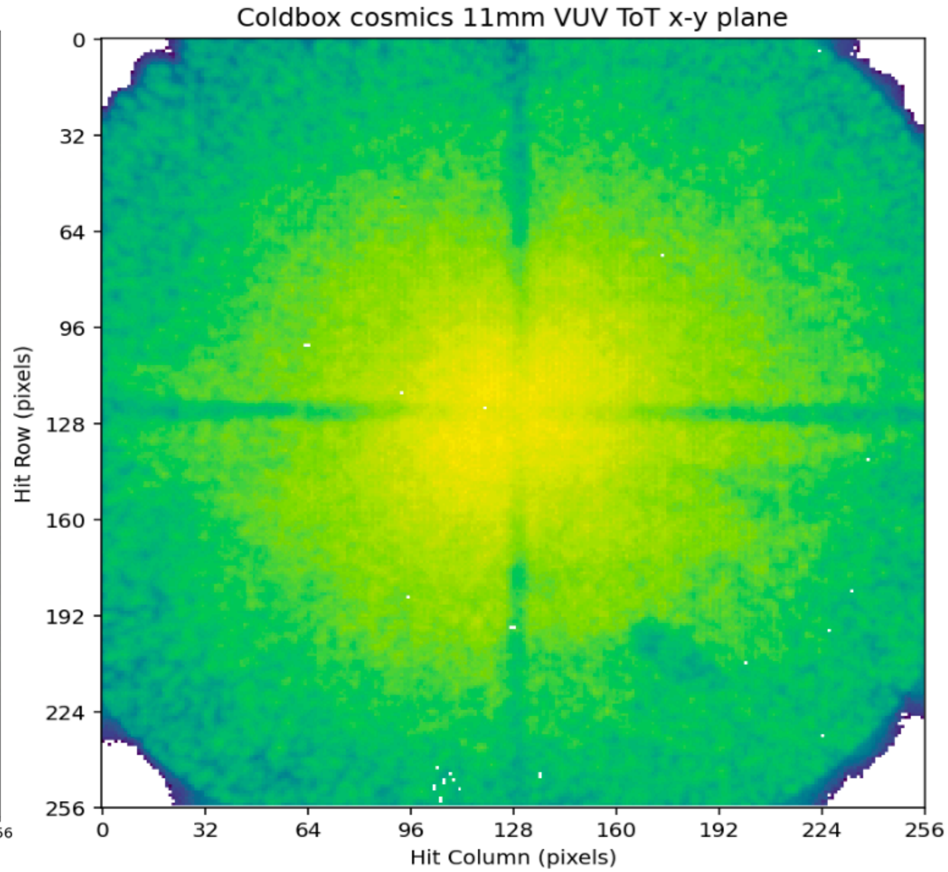


30 Second Exposure Cosmics

Visible Light

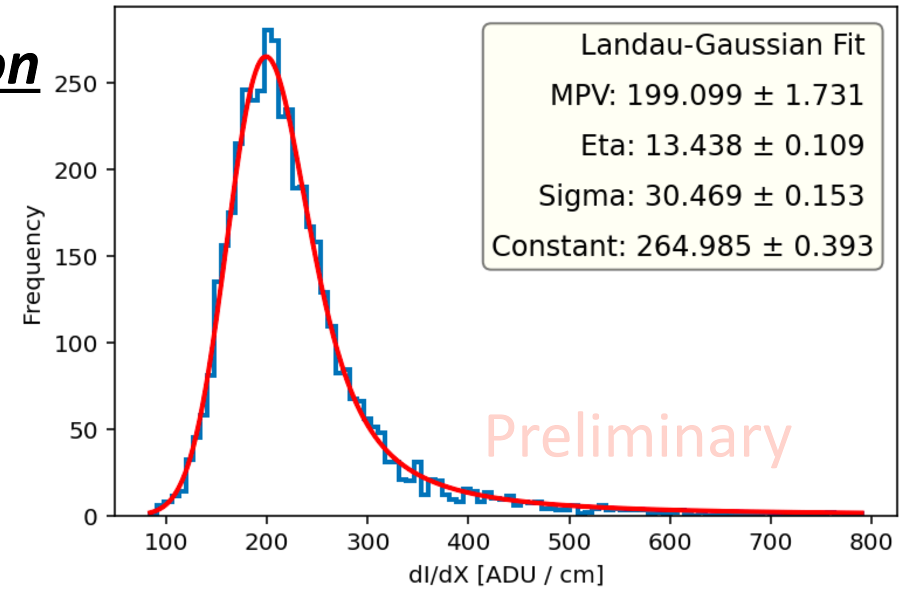


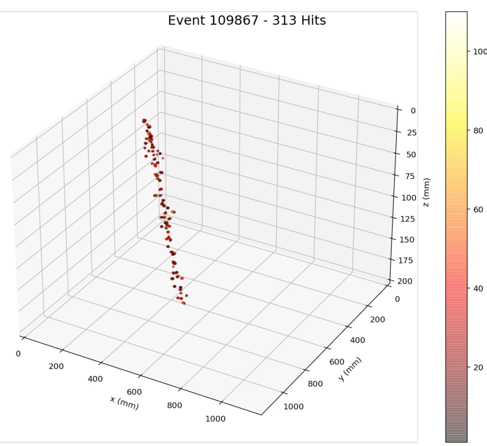
VUV Light

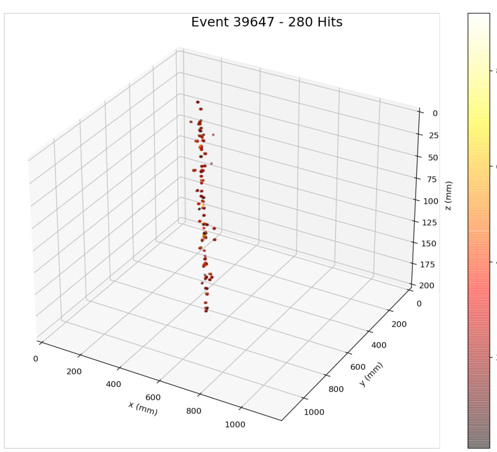


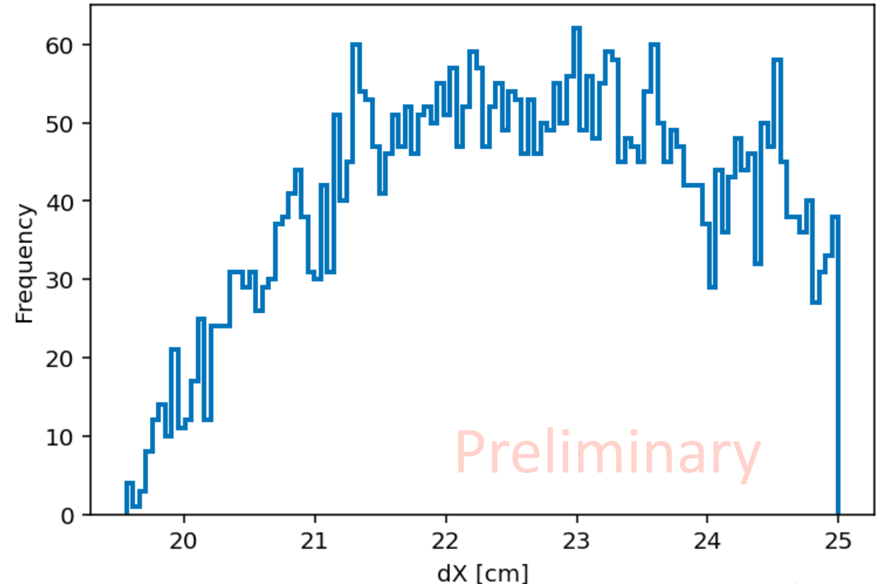
Energy Calibration and Resolution

- Track fitting to through going muons (Through THGEM and greater than 19 cm depth)
- Energy conversion : **199.10 ± 1.73 ADU / MeV**
- Energy resolution : **16.73 ± 0.16 %**



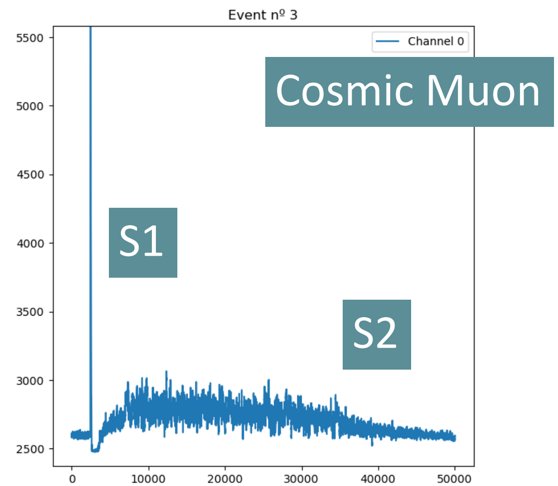


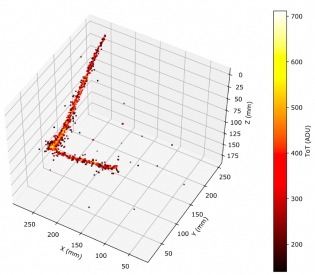


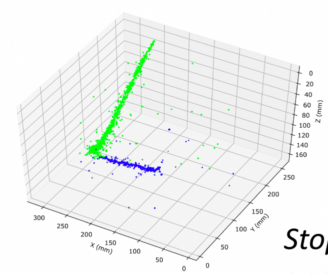


ARIADNE+ ongoing analysis

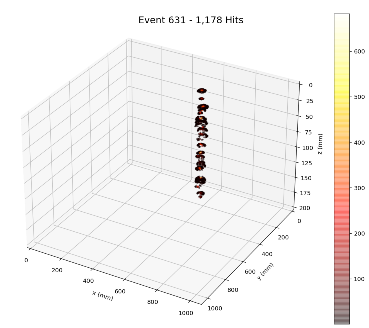
- Studies into discriminating between S1 and S2 signals. Analysis is ongoing - correlation between X-ARAPUCA signal and ARIADNE+ data in collaboration with IGFAE
- dI/dX for horizontal vs. vertical tracks to further understand TPX3 performance
- dI/dX per THGEM bias at similar detector conditions
- Stopping muon analysis
- Characterising the VUV intensifier further with additional tests at Liverpool - horizontal vs. vertical tracks





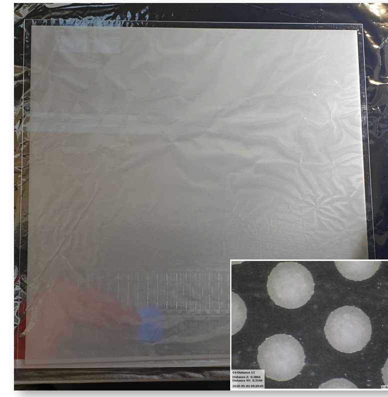


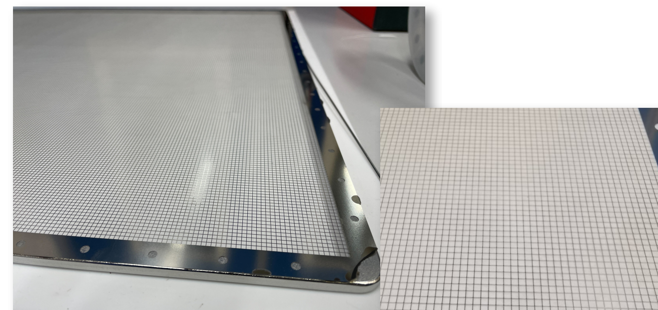
Stopping muon analysis within ARIADNE



ARIADNE Upgrade - Hardware + DAQ

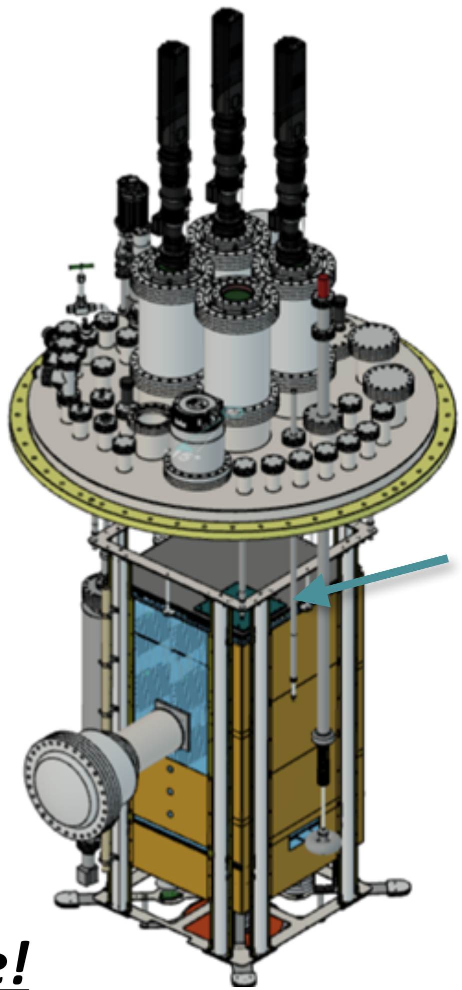
- Swapping the existing FR4 GEM with a glass THGEM
- Replacing the extraction grid, with a mesh identical to those used within ARIADNE+, bonded to a stainless steel, electropolished frame
- Improved DAQ software including a streaming digitiser - allows for live PMT signal analysis whilst simultaneously recording data
- Upgrade to the liquid recirculation system
- Introduction of a calibration source for probing the low-energy threshold of the detector





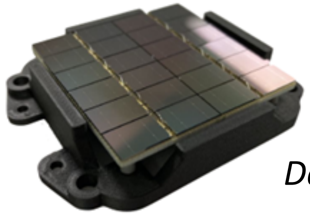
ARIADNE Upgrade - Optics

- First time running multiple Timepix3 cameras on ARIADNE
- Two different types of intensifier - one previously used on ARIADNE and the new intensifier on ARIADNE+
- One camera mounted at the same distance from the THGEM as on ARIADNE+ for making direct comparisons



- Using TPB coated glass for WLS instead of PEN - assessing difference in light quantity
- Central 2" PMT with condenser lens for monitoring overall light quantities
- Addition of a Darkside PDU for investigating Dark Matter detection feasibility (light saturation etc.) (**See Adam R's talk from yesterday**)

Watch this space!



Darkside SiPM

Thank You for Listening!

Any questions?

Extra Slides

TPX3 to TPX4

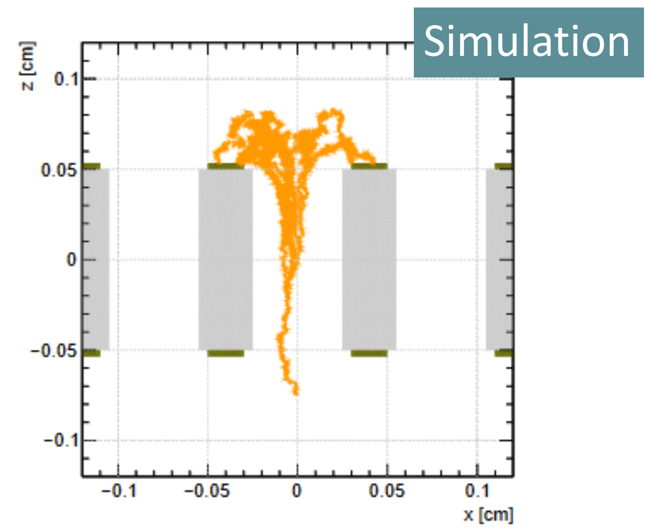
			Timepix3 (2013)	Timepix4 (2019)	
Technology			130nm – 8 metal	65nm – 10 metal	
Pixel Size			55 x 55 µm	55 x 55 µm	
Pixel arrangement			3-side buttable 256 x 256	4-side buttable 512 x 448	3.5x
Sensitive area			1.98 cm^2	6.94 cm^2	
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA		
		Event Packet	48-bit	64-bit	33%
		Max rate	0.43×10^6 hits/mm^2/s	**3.58×10^6 hits/mm^2/s**	8x
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel**	
	Frame based (Imaging)	Mode	PC (10-bit) and iTOT (14-bit)	CRW: PC (8 or 16-bit)	
		Frame	Zero-suppressed (with pixel addr)	Full Frame (without pixel addr)	
		Max count rate	~0.82×10^9 hits/mm^2/s	~5×10^9 hits/mm^2/s	6x
TOT energy resolution			< 2KeV	**< 1Kev**	2x
Time resolution			1.56ns	**195.3125ps**	8x
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	≤163.84 Gbps (16x @10.24 Gbps)	32x
Target global minimum threshold			<500 e^-	<500 e^-	

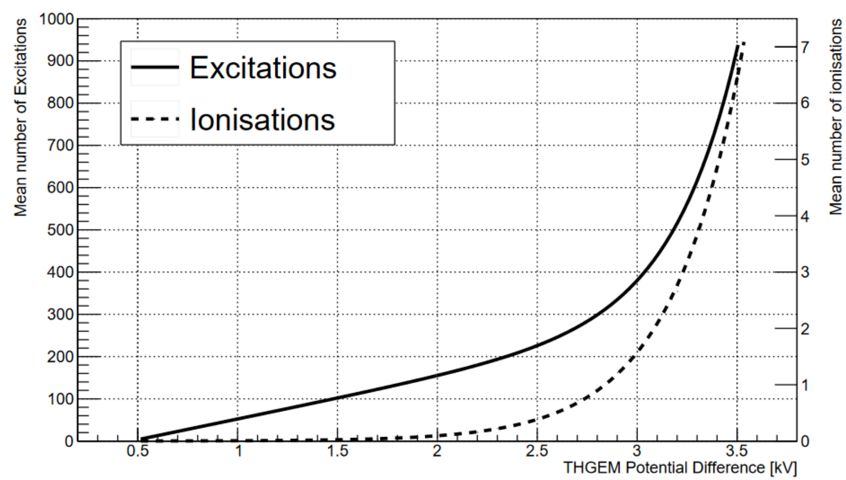
THGEM S2 Light Production

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

At low field (<2kV/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 -> Improved sensitivity/threshold

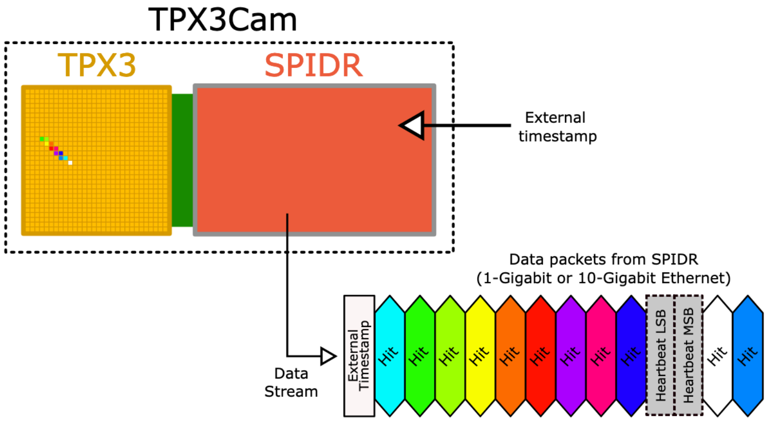




TPX3 Data Packets

Each Hit (Min 500 electrons):

- X Position
- Y Position
- Time of Arrival (ToA)
- Time over Threshold (ToT)



THGEM Characterisation

Mean TPX3Cam ToT rate (calculated as the summed ToT of all hits in a run divided by the total duration of the run and measured in ADU per second) as a function of the electric field across the THGEM. A single function—comprising a combination of linear and exponential functions is fitted to the data

Energy Calibration and Resolution

Simply the conversion between the incident light intensity in ADU and the corresponding physical energy in MeV

Through-going muons are ideal for calculating this calibration, they are minimum-ionising particles ("MIPs") with a well-known mean energy deposition rate, dE/dX , of 2.12 MeV/cm

The summed ToT is calculated across all hits which comprise each event, and this summation is divided by the 3D track length of the through-going track.

The energy resolution, defined as the Landau (eta) and Gaussian (sigma) widths combined in quadrature and expressed as a fraction of the MPV

ARIADNE: Optical Readout for kilo-tonne scale LAr TPCs

- Proven scalable technology
- Cost efficient, comparable performance to other readout methods
- An option for a **DUNE Far** LAr Detector?

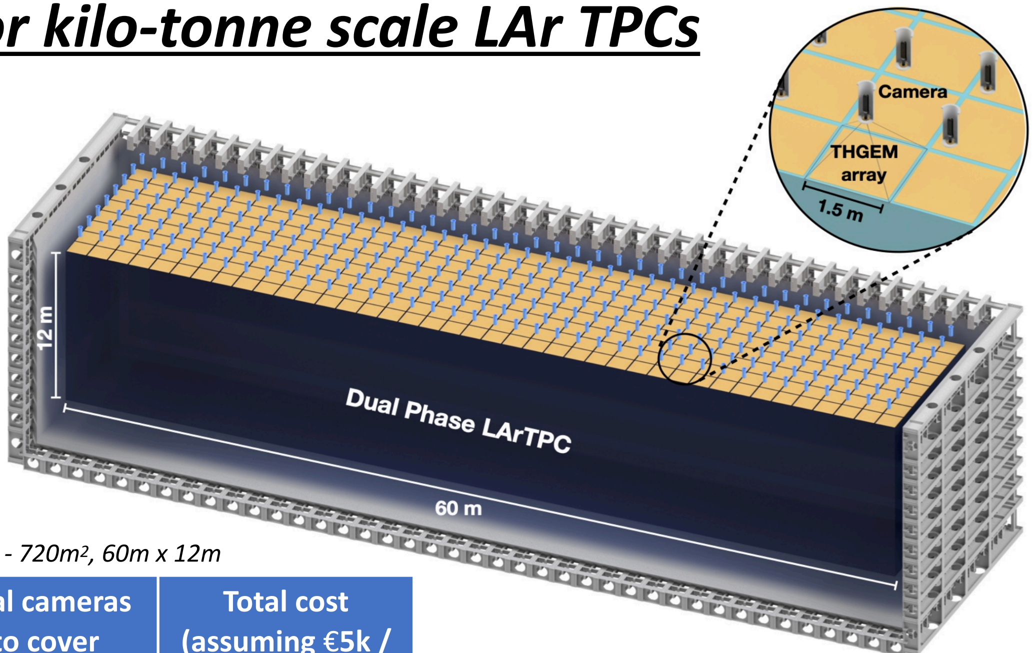
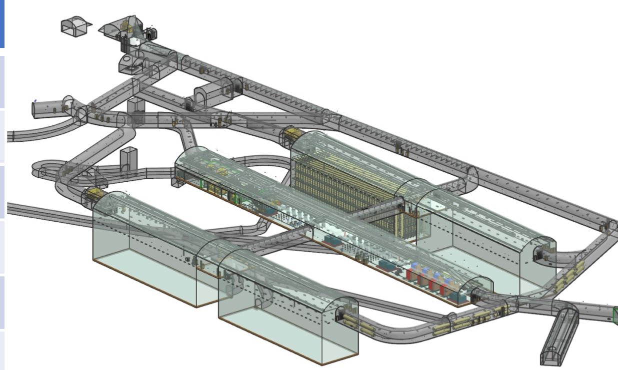


Table: As an example, demonstration figures for use of TimePix within Dune - 720m², 60m x 12m

Camera type	Sen. Size (pixels)	Cameras to cover $1m^2$	Resolution (mm/pix)	Total cameras (to cover $720m^2$)	Total cost (assuming €5k / camera*)
TPX3	256x256	9	1.3 (~ARIADNE)	6480	32.4M
TPX3	256x256	4	2	2880	14.4M
TPX3	256x256	1	4 (~ARIADNE$^+$)	720	3.6M
TPX4	512x448	4	1	2880	14.4M
TPX4	512x448	1	2	720	3.6M
TPX4	**512x448**	**0.66 (1.5m/cam)**	**3**	**320**	**1.6M**



* Cost is a place holder based on discussions with ASI, assumes large production - double value for intensifiers

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