ARIADNE

MicroPattern Detector Facility

Liquid Argon R&D Group Update

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HEP Annual Meeting, May 2025

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

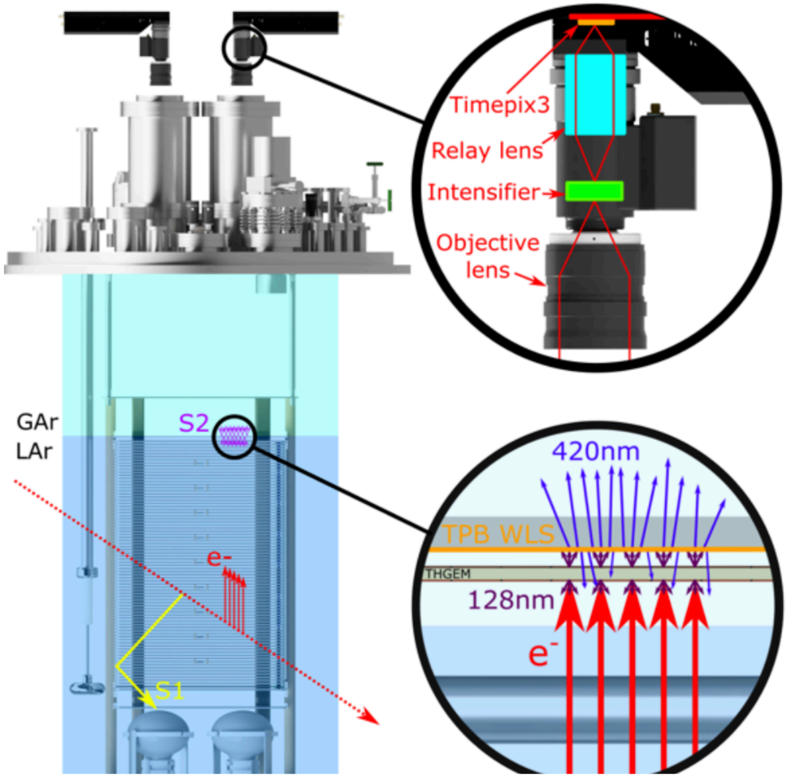
UNIVERSITY OF LIVERPOOL

ARIADNE

ARIADNE Detection Principle:

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

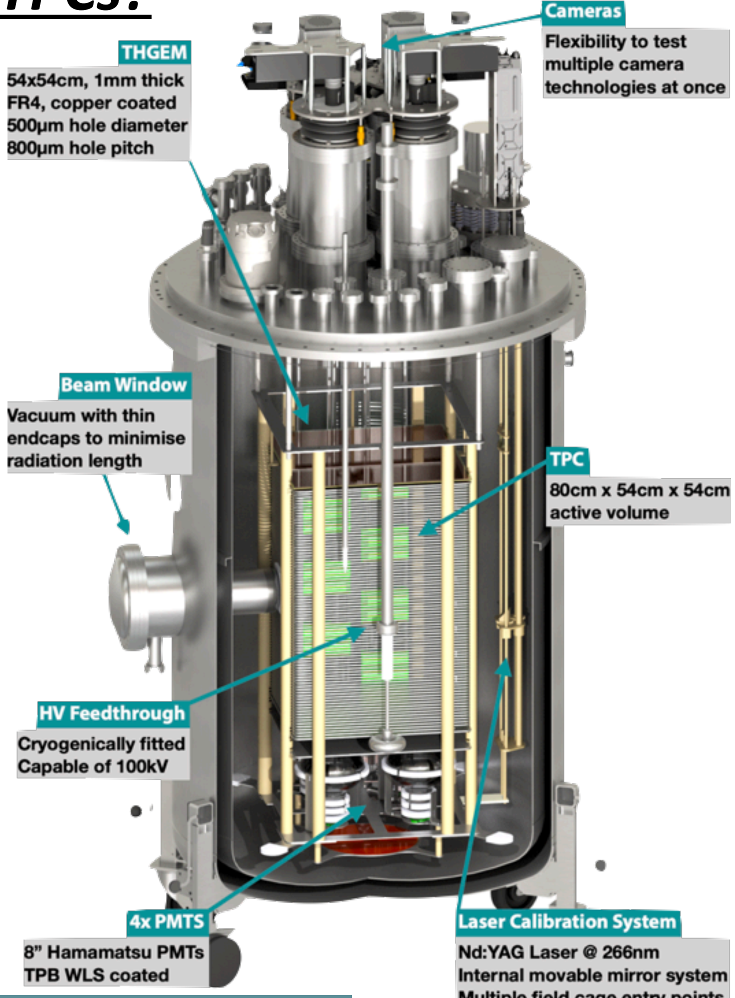
- Incoming particles ionise LAr and create **prompt scintillation** light (**S1**)
- Electrons drift towards the **extraction grid** situated below the liquid level
- A **THGEM** (THick-Gaseous Electron Multiplier) amplifies drift charge (capable of >30 kV/cm in GAr) generating **secondary scintillation**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



__ARIADNE__ (__AR__gon __I__m__A__ging __D__etectio__N__ chamb__E__r)

The ARIADNE Advantage - Why Optical TPCs?

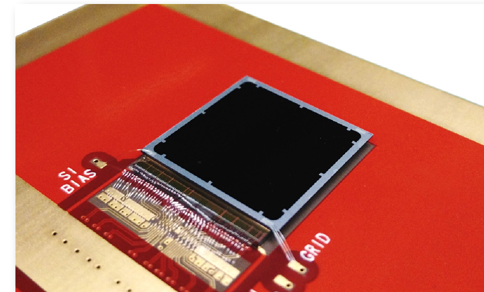
- Benefits over previous charge readout methods:
  - **High Resolution:** For e.g. TPX3 camera has 256 x 256 pixels, imaging 35 x 35 cm area, as on ARIADNE, gives ≈1 mm resolution
  - **Sensitivity to low energies:** Gain is generated by the THGEM; a THGEM accelerated electron can generate upwards of 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.



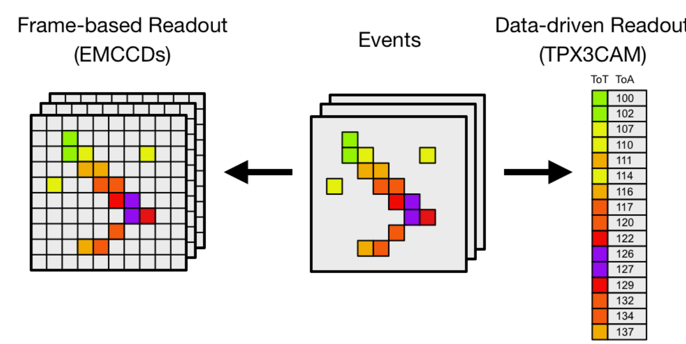
ARIADNE 1-tonne detector

The ARIADNE Advantage - Full 3D optical readout with Timepix3

- Well established technology by the **CERN** Medipix collaboration:
  - **Natively 3D:** Timepix chip gives X and Y position, Time of Arrival (ToA) (which is equivalent to z position) and Time over Threshold (ToT) (equivalent to intensity)
  - **Zero Background Suppression:** Data driven readout based on hits rather than frame
  - **Efficient data storage:** Continuous streaming, triggerless operation - few kBytes per event
  - **Many applications beyond TPCs:** Already tested Timepix3 cameras for neutron detection and ion imaging within the department



TPX3 ASIC Chip bump bonded to an optical sensor

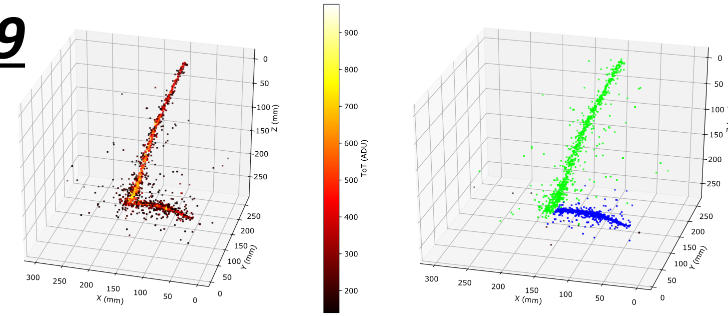


Sensor resolution	256x256 pixels
Pixel size	55μm x 55μm
Max readout rate	80Mhits•sec^{-1}
Time resolution	1.6 ns
Time over Threshold Resolution	10 bit

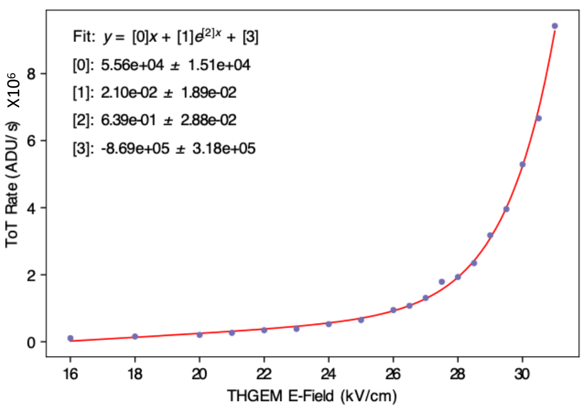
ARIADNE Detector Timepix3 Results 2019

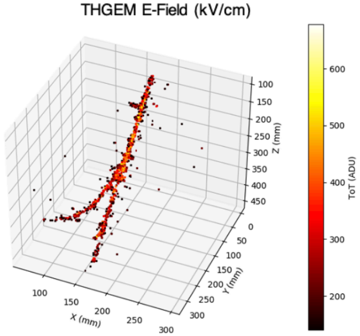
https://www.mdpi.com/2410-390X/4/4/35

- Analysis done on through going muons and stopping muons
- Energy resolution of **11%**

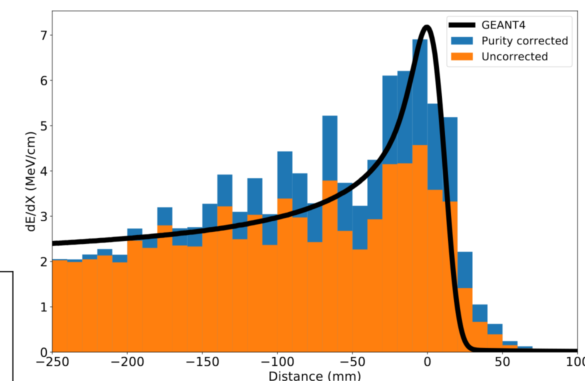


THGEM Bias vs. S2 Light Production

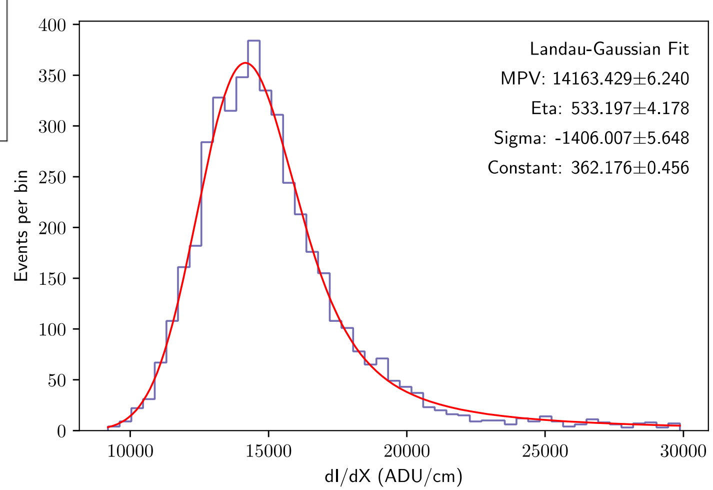


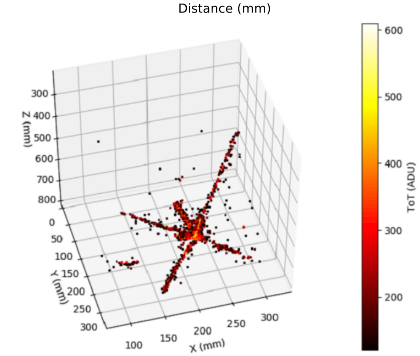


Stopping Muon



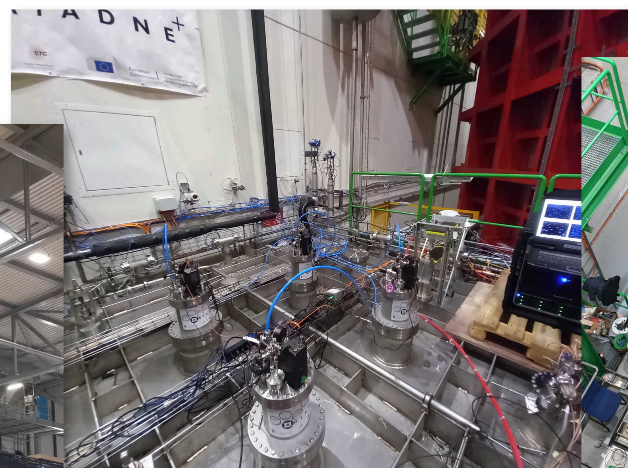
ADU/cm vs. No. Of Events





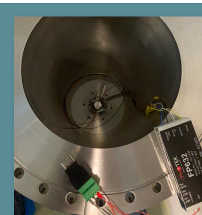
Bringing novel 3D optical dual-phase LArTPCs to the large scale: ARIADNE+

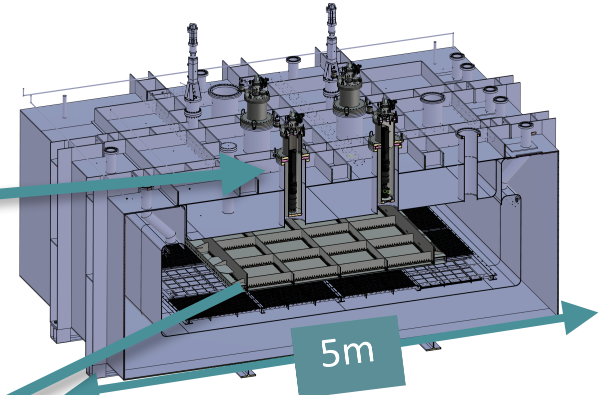
- Proven scalable technology, cost efficient and comparable performance to other readout methods
- For testing optical readout on a scale relevant for experiments such as DUNE, ARIADNE+ is a 15 tonne detector constructed at the CERN Neutrino Platform
- Operating March-April 2022



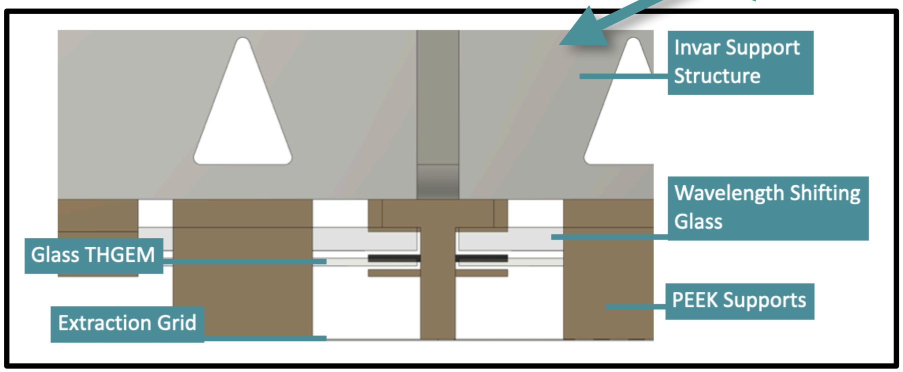
ARIADNE^{+}: Innovative Ideas

4 x Timepix3 Cameras - 3 x Visible Light and 1 x Direct VUV light using a custom made VUV imaging intensifier



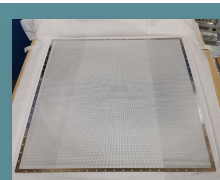


16 Glass THGEMs - Less prone to sagging compared to FR4 at larger surface areas, conical hole shape collects charge over time and increases light output

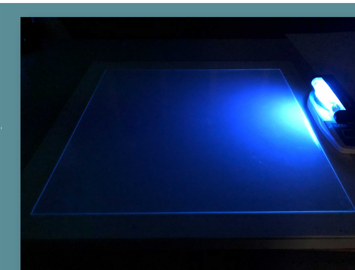


Invar support structure - Uniquely low coefficient of thermal contraction

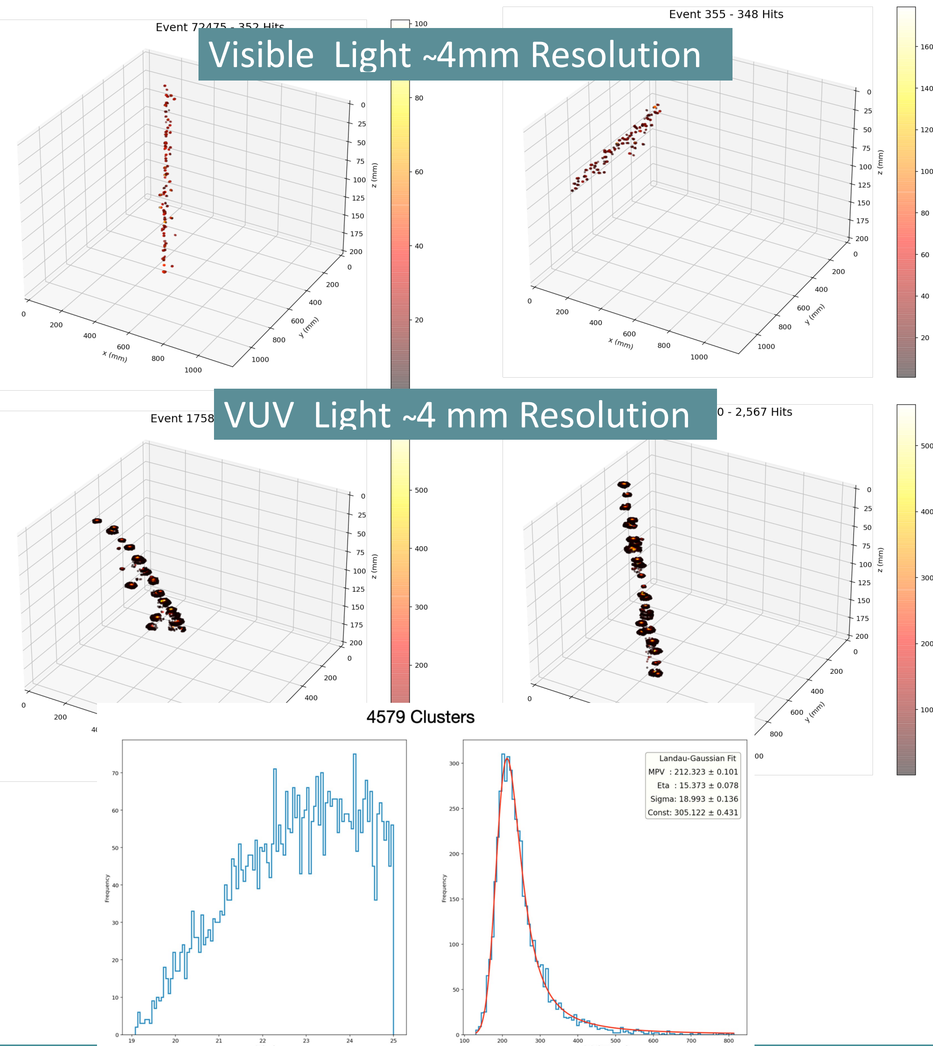
Chemically etched extraction grid - 15 mm from THGEM instead of 10 mm on ProtoDUNE dual-phase

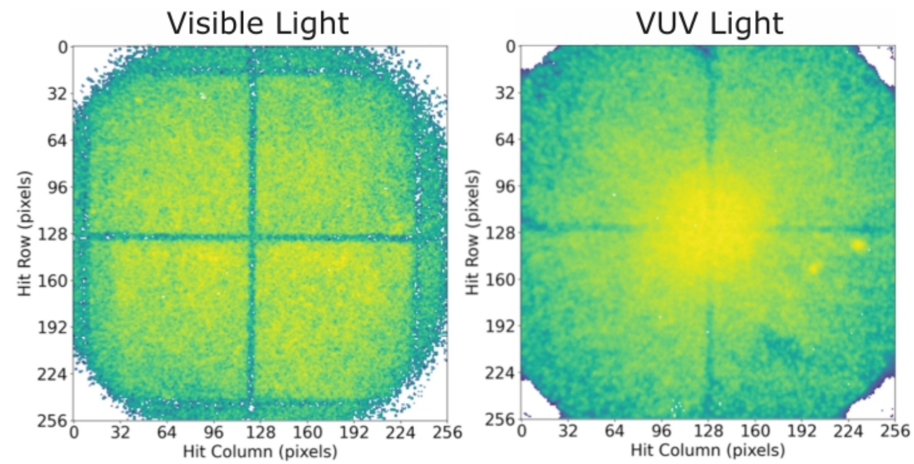


Polyethylene Naphthalate (PEN) Film coated glass panels for Wavelength Shifting (WLS) - commercially available, easier to apply to surfaces then alternatives (TPB)



ARIADNE+: Results



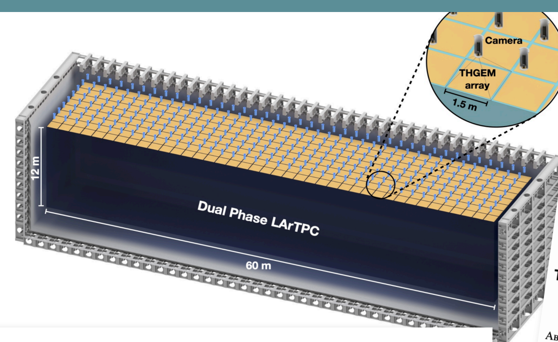


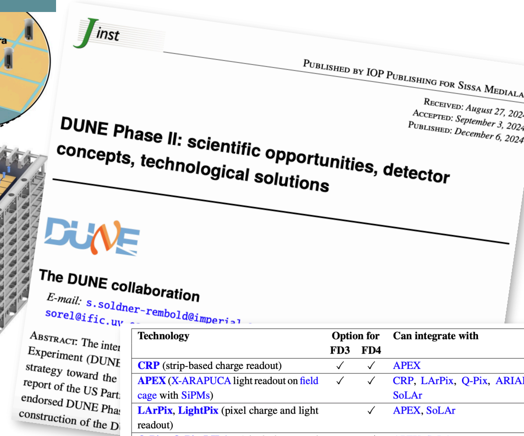
- Energy conversion : **100.15 ± 0.05 ADU / MeV**
- Energy resolution of **11.5%**, comparable to previous Timepix3 runs on ARIADNE
- Successfully constructed the largest ever glass-THGEM array to date
- Stable extraction grid with no known sparking issues
- For the first time in a detector of this type, demonstrated imaging and tracking using pure VUV light!

ARIADNE Papers Update

- ARIADNE technology is now considered an option for use within far detector four as part of **DUNE Phase-II**!

DUNE Module of Opportunity (FD4) https://tinyurl.com/ywfeed75





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DUNE Phase II: scientific opportunities, detector concepts, technological solutions

The DUNE collaboration

E-mail: s.soldner-rembold@imperial…
sorel@ific.uv…

Abstract: The inter… Experiment (DUNE… strategy toward the… report of the US Part… endorsed DUNE Pha… construction of the D…

Technology	Option for FD3	Option for FD4	Can integrate with
CRP (strip-based charge readout)	✓	✓	APEX
APEX (X-ARAPUCA light readout on field cage with SiPMs)	✓	✓	CRP, LArPix, Q-Pix, ARIADNE, SoLAr
LArPix, **LightPix** (pixel charge and light readout)		✓	APEX, SoLAr
Q-Pix, **Q-Pix-LILAr** (pixel charge and light readout)		✓	APEX, SoLAr
ARIADNE (dual-phase with optical read-out of ionization signal)		✓	APEX
SoLAr (integrated charge and light pixel readout)		✓	APEX, LArPix, Q-Pix
Hybrid Cherenkov + scintillation		✓	N.A.

- One paper **published** and one **accepted** on ARIADNE+

https://www.mdpi.com/2673-9984/8/1/46

physical sciences forum MDPI

Proceeding Paper

ARIADNE+: Large Scale Demonstration of Fast Optical Readout for Dual-Phase LArTPCs at the CERN Neutrino Platform †

Adam John Lowe [1,*], Pablo Amedo-Martinez [2], Diego González-Díaz [2], Alexander Deisting [3], Krishanu Majumdar [1], Konstantinos Mavrokoridis [1], Marzio Nessi [4], Barney Philippou [1], Francesco Pietropaolo [4], Sudikshan Ravinthiran [1], Filippo Resnati [4], Adam Roberts [1], Angela Saá Hernández [2], Christos Touramanis [1] and Jared Vann [1]

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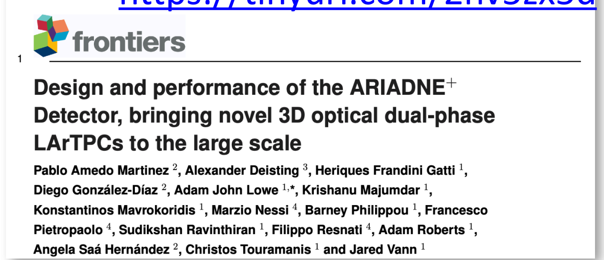
2 Instituto Galego de Física de Altas Enerxías (IGFAE), Universidade de Santiago de Compostela, 15705 Santiago de Compostela, Spain
3 Department of Physics, Royal Holloway University of London, Tolansky Building, Surrey TW20 0EX, UK
4 European Organization for Particle Physics (CERN), Geneva P.O. Box 1211, Switzerland
* Correspondence: a.j.lowe@liverpool.ac.uk
† Presented at the 23rd International Workshop on Neutrinos from Accelerators, Salt Lake City, UT, USA, 30–31 July 2022.

https://tinyurl.com/2hv5zx5d

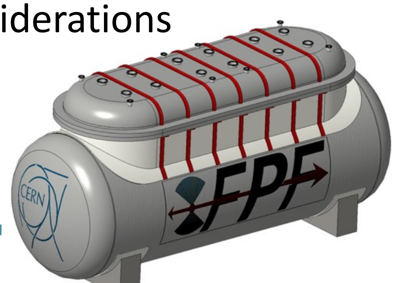


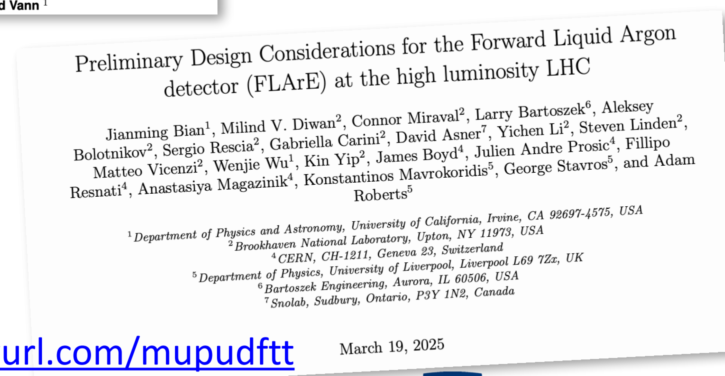
frontiers

Design and performance of the ARIADNE+ Detector, bringing novel 3D optical dual-phase LArTPCs to the large scale

Pablo Amedo Martinez [2], Alexander Deisting [3], Heriques Frandini Gatti [1], Diego González-Díaz [2], Adam John Lowe [1,*], Krishanu Majumdar [1], Konstantinos Mavrokoridis [1], Marzio Nessi [4], Barney Philippou [1], Francesco Pietropaolo [4], Sudikshan Ravinthiran [1], Filippo Resnati [4], Adam Roberts [1], Angela Saá Hernández [2], Christos Touramanis [1] and Jared Vann [1]

- ARIADNE technology considered an option for the **FLArE TPC** as part of the **Forward Physics Facility** preliminary design considerations





Preliminary Design Considerations for the Forward Liquid Argon detector (FLArE) at the high luminosity LHC

Jianming Bian[1], Milind V. Diwan[2], Connor Miraval[2], Larry Bartoszek[6], Aleksey Bolotnikov[2], Sergio Rescia[2], Gabriella Carini[2], David Asner[7], Yichen Li[2], Steven Linden[2], Matteo Vicenzi[2], Wenjie Wu[1], Kin Yip[2], James Boyd[4], Julien Andre Prosic[4], Fillipo Resnati[4], Anastasiya Magazinik[4], Konstantinos Mavrokoridis[5], George Stavros[5], and Adam Roberts[5]

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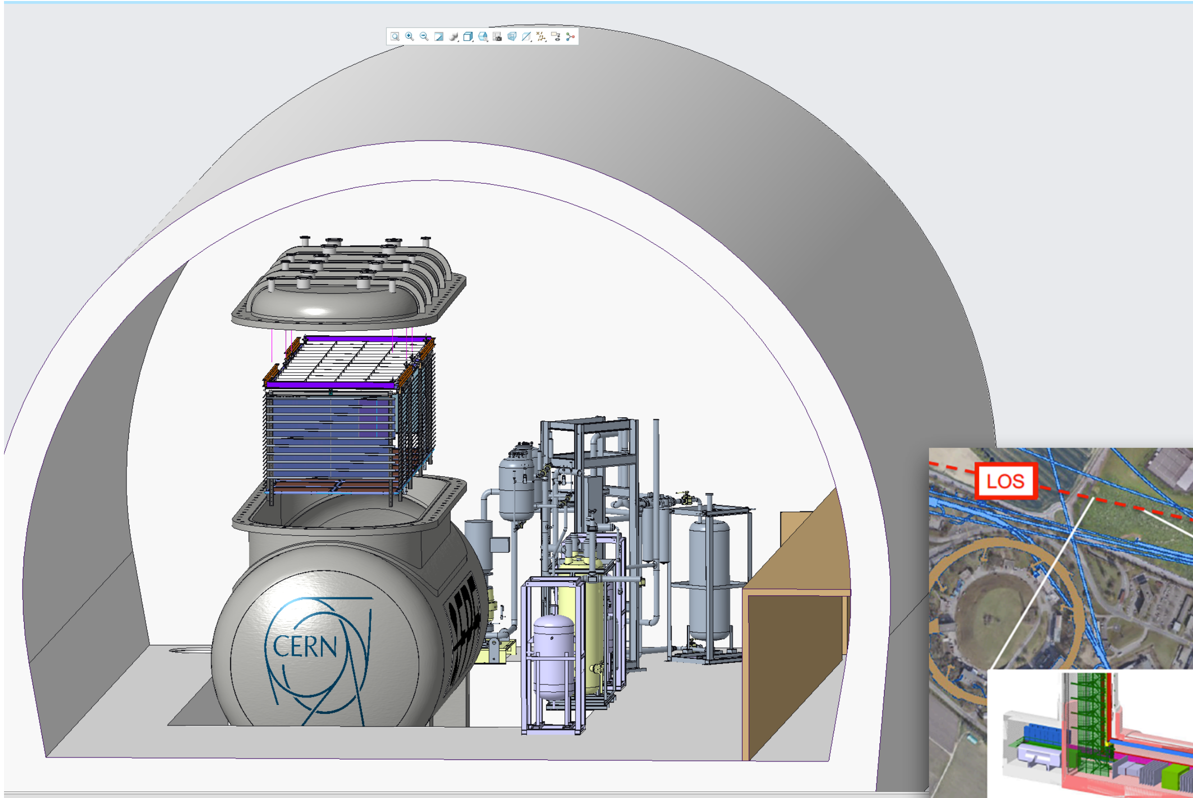
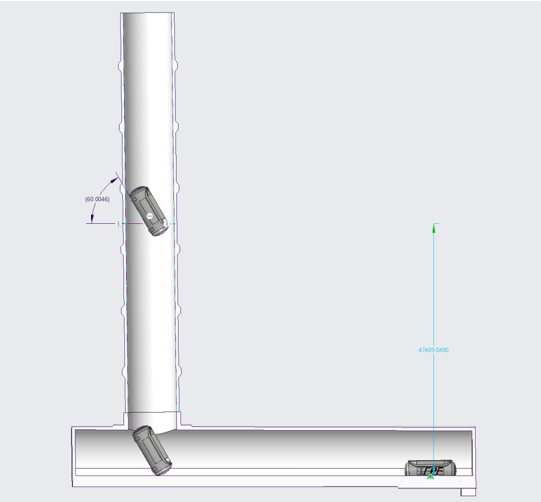
[2] Brookhaven National Laboratory, Upton, NY 11973, USA
[4] CERN, CH-1211, Geneva 23, Switzerland
[5] Department of Physics, University of Liverpool, Liverpool L69 7Zx, UK
[6] Bartoszek Engineering, Aurora, IL 60506, USA
[7] Snolab, Sudbury, Ontario, P3Y 1N2, Canada

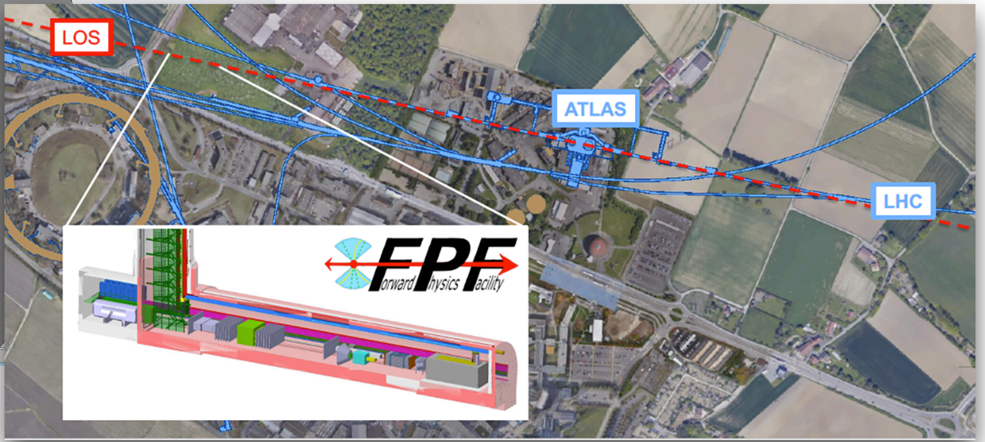
March 19, 2025

https://tinyurl.com/mupudftt

An alternative to charge readout at FPF - using ARIADNE optical readout system for FLArE TPC

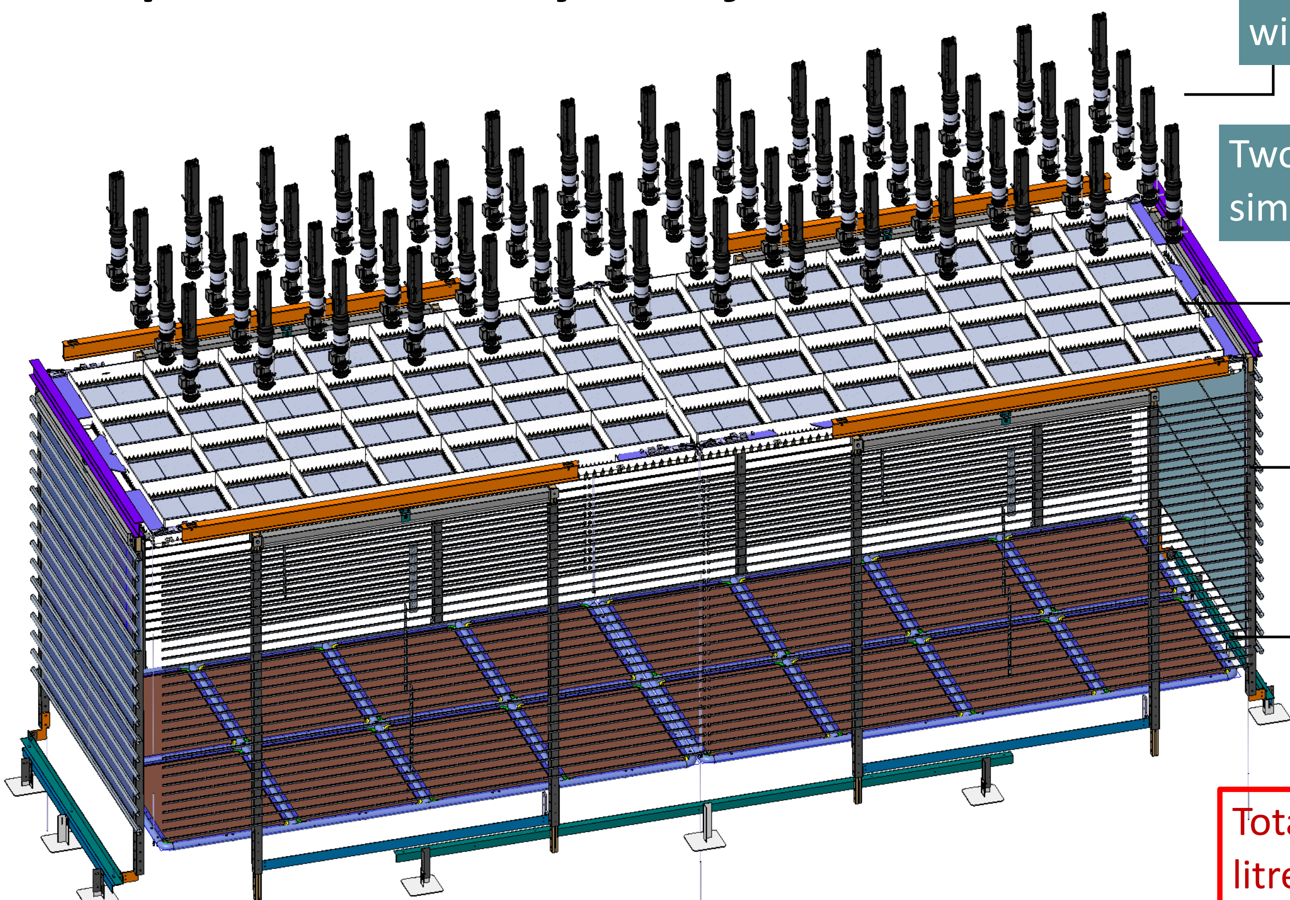






Rich physics opportunities provided by the enormous flux of particles produced in the far-forward direction

An alternative to charge readout at FPF - using ARIADNE optical readout system for FLArE TPC



56 TPX3 Cams in cryostat ports. This will provide 1.8mm/pixel resolution

Two invar LRPs with 56 glass THGEMs, similar to the ARIADNE cold box test

Aluminium profile Field Cage (similar to ProtoDUNE)

Two CPAs (same size as LRPs)

Total instrumented LAr volume 20000 litres/32 tons

CAD by G.Stavrakis

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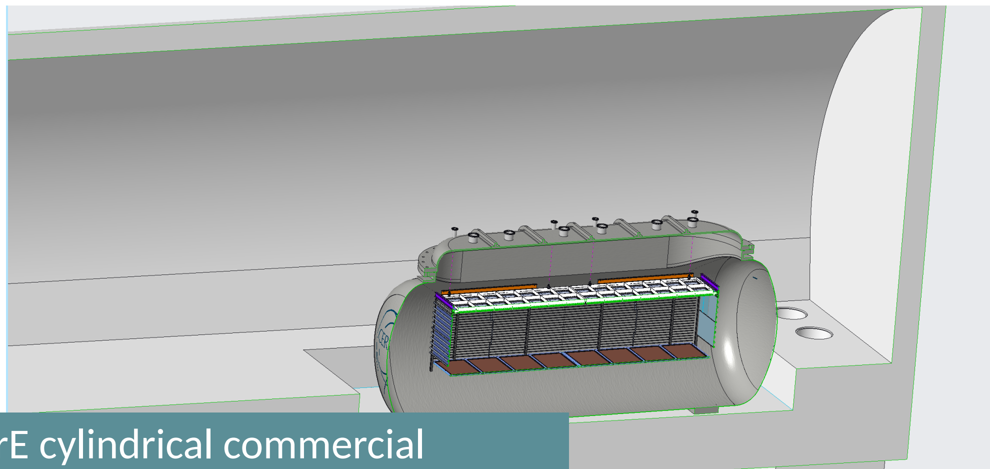
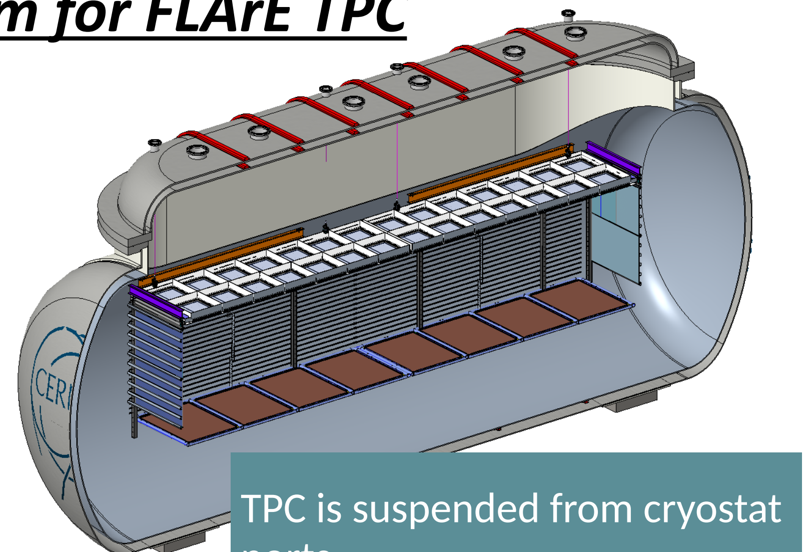
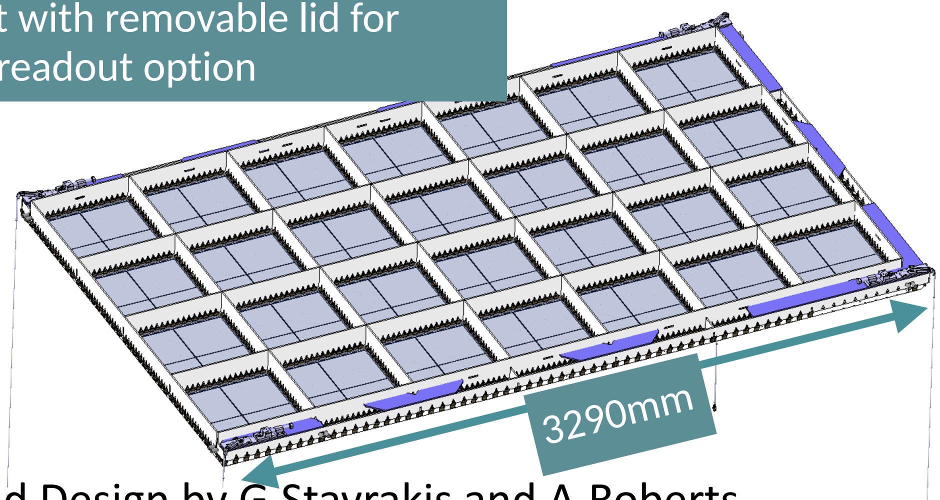
Using ARIADNE optical readout system for FLArE TPC



FLArE cylindrical commercial cryostat with removable lid for optical readout option



TPC is suspended from cryostat ports



- One LRP to contain 7x4 Glass THGEMS (similar to ARIADNE LRP)
- Made out of Invar
- Will hang from 4/6 top cryostat ports and will be able to move up down using levelling motors

CAD and Design by G.Stavrakis and A.Roberts

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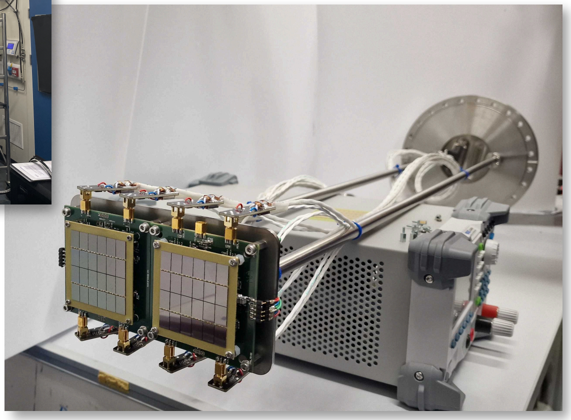
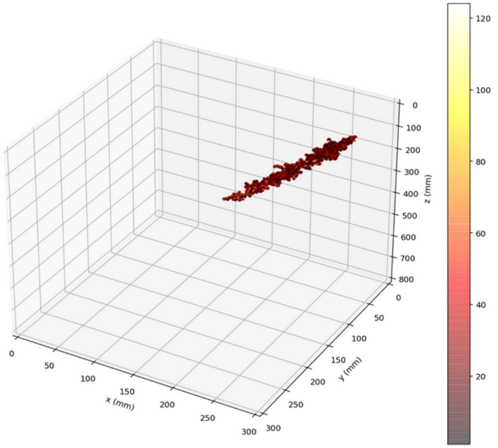
ARIADNE Upgrade - 2023/24

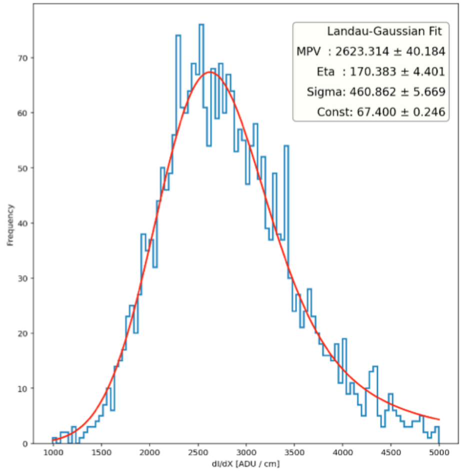
- Multiple Timepix3 cameras on ARIADNE and glass THGEM installed
- First time testing different models of intensifier on the same detector
- Addition of 2 Darkside Si-PM tiles for investigating Dark Matter detection feasibility (light saturation etc.) - Neutrino & DM …



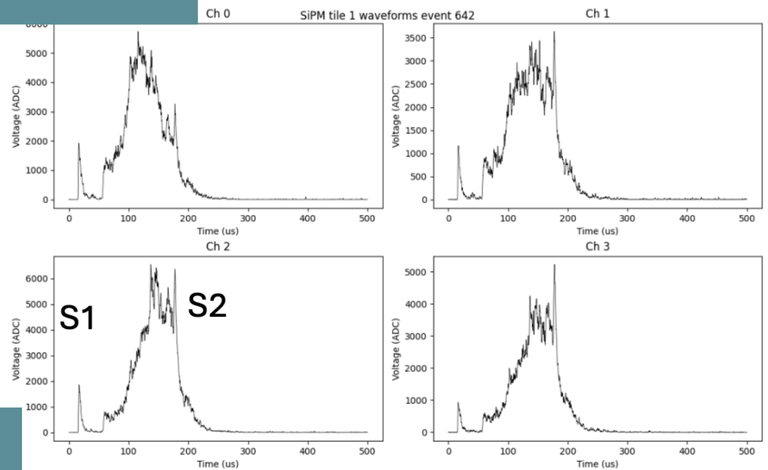
Cosmic muon as detected by the Si-PMs



Cosmic muon



New intensifier detector calibration



Glass-THGEM R&D

Liverpool Micropattern Detector Facility

- To be commissioned soon, the new facility allows for production of Glass-THGEMs in house at Liverpool based on our patented manufacturing procedure

- Position ourselves as a hub for glass-THGEM production in the UK - DRD1 and DRD2 links

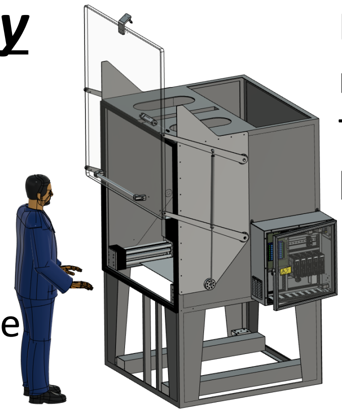
- Facility to apply photomasks and clean after machining holes

- Machine has motion in three axes, will have one nozzle to start but capacity for multiple - THGEMs up to **85 x 85cm**

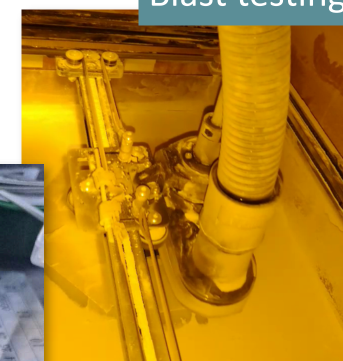
- Optical inspection built in using mounted camera

- Plans to manufacture the first in-house Glass-THGEM in the coming weeks

- Open to explore complex geometry machining across the department - **get in touch!**

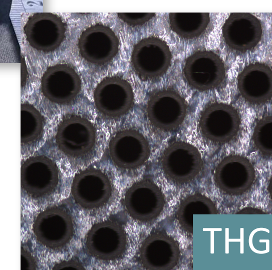


Machine design and mechanism by A.Roberts
Testing and procedures by H.Gatti

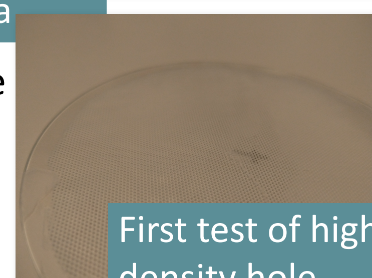


Blast testing

Assembled inspection camera



THGEM image

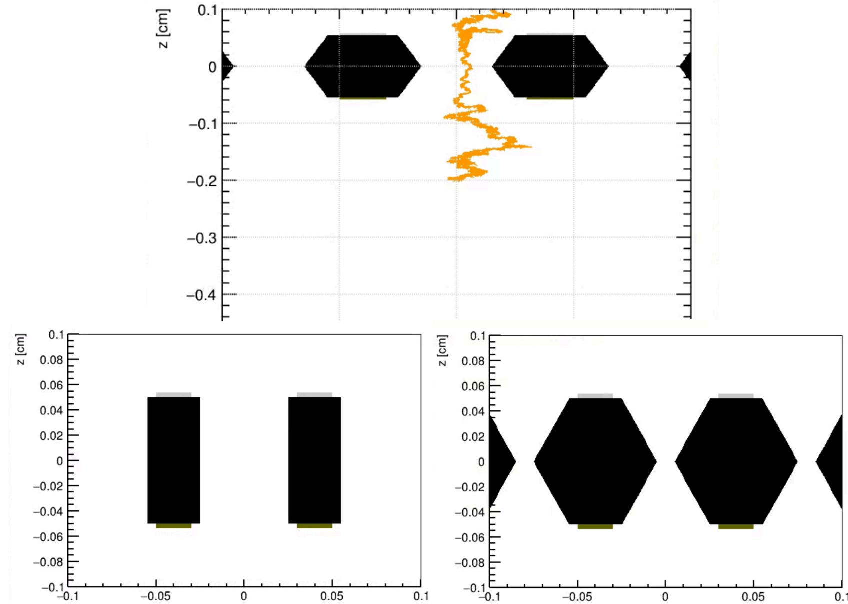


First test of high-density hole blasted glass

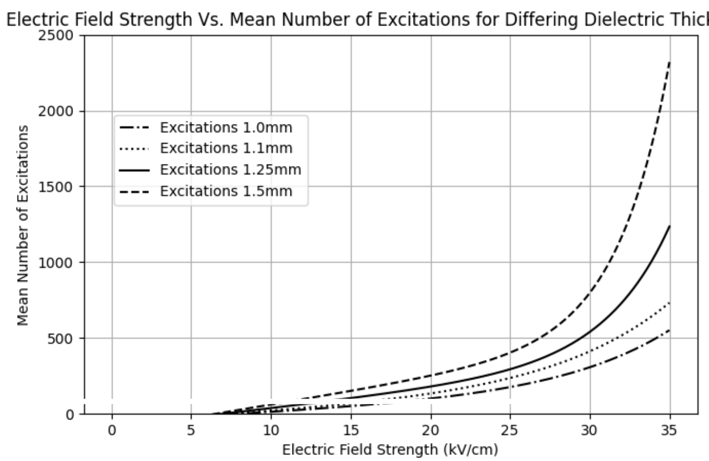
MicroPattern Detector Facility

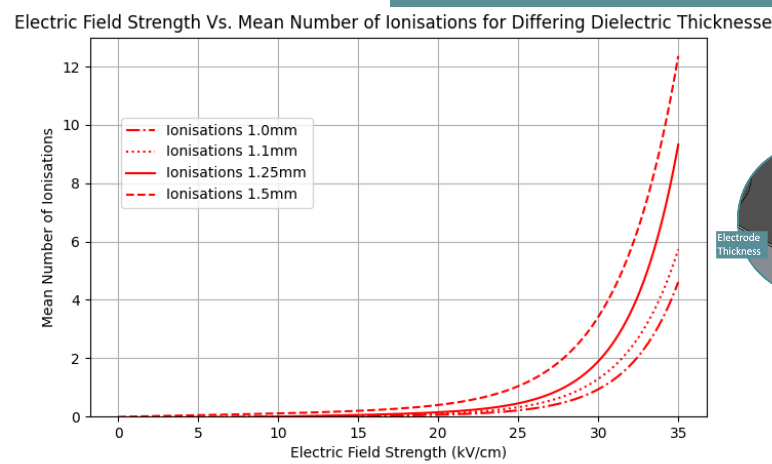
Glass-THGEM GArField Simulations

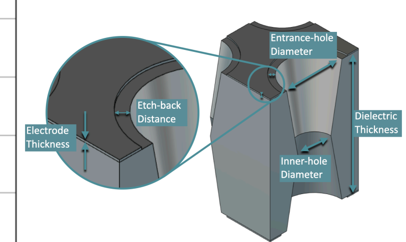
- ARIADNE developed abrasive machining allows for unprecedented versatility in THGEM patterning in terms of hole shape and layout
- GArField++ is a toolkit for the detailed simulation of particle detectors based on ionisation measurement in gases - ideal for THGEM simulations
- A fully parametrised GEM/THGEM geometry for GArField simulations has been developed to assist THGEM production R&D
- Paper in the works and code to be made available



Example of use - insulator thickness study







Outlook

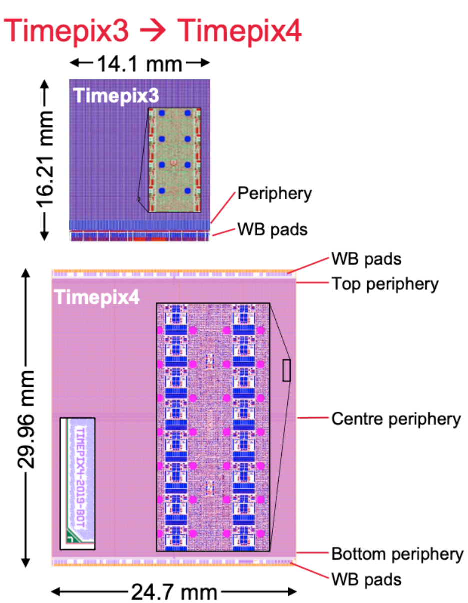
TPX4 CAD by G.Stavrakis

MicroPattern Detector Facility

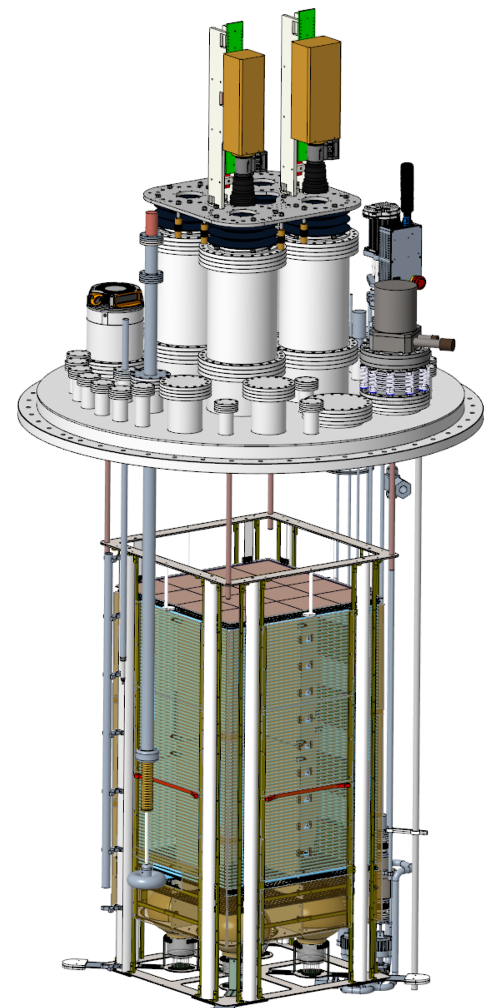
ARIADNE Run - Summer/Autumn 2025

Timepix4

- Working in collaboration with Amsterdam Scientific Instruments (ASI), we are acquiring a Timepix4 for testing with the 40L gas demonstrator and ARIADNE
- Planned paper, with ASI, on the performance of TPX4 for tracking and energy resolution compared to TPX3



			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
Sensitive area			1.98 cm²	**6.94 cm²** 3.5x
Readout Modes	Data driven (Tracking)	Mode	TOT and TOA	
		Event Packet	48-bit	64-bit
		Max rate	0.43x10⁶ hits/mm²/s	**3.58x10⁶ hits/mm²/s**
		Max Pix rate	1.3 KHz/pixel	**10.8 KHz/pixel** 8x
	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 x 10⁹ hits/mm²/s	~5 x 10⁹ hits/mm²/s
TOT energy resolution			< 2KeV	**< 1Kev**
TOA binning resolution			1.56ns	**195ps** 8x
TOA dynamic range			409.6 μs (14-bits @ 40MHz)	**1.6384 ms** (16-bits @ 40MHz)
Readout bandwidth			≤5.12Gb (8x SLVS@640 Mbps)	**≤163.84 Gbps (16x @10.24 Gbps)** 32x
Target minimum threshold			<500 e⁻	<500 e⁻



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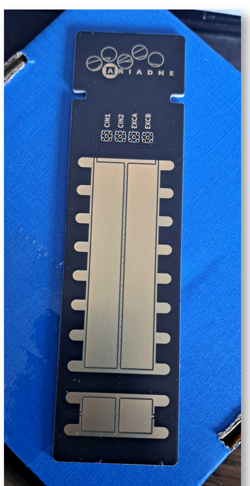
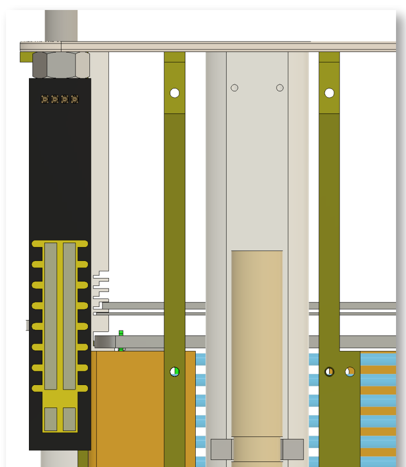
ARIADNE Run - Summer/Autumn 2025

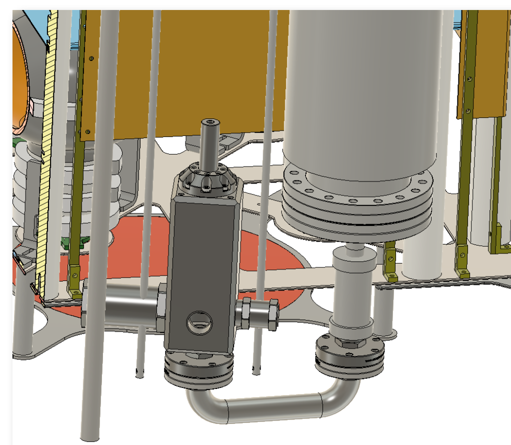
MicroPattern Detector Facility

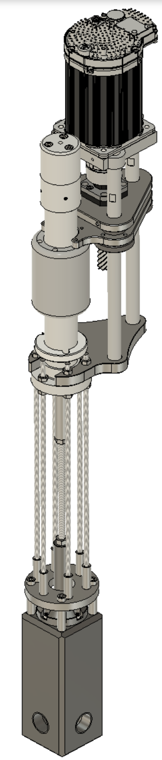
Additional Detector Upgrades

- Introduction of the Timepix3 QUAD from ASI - 4 TPX3 ASIC mosaic creating a 512 x 512 pixel sensor (https://inspirehep.net/files/0d645abf22e9e30063b70a74b69b0b6e)
- Glass THGEM in ARIADNE to be cleaned using the MicroPattern Detector Facility
- Replacing existing bellows pump with new piston driven pump
- Installation of capacitance level meters









Level meters and pump designed by A.Roberts

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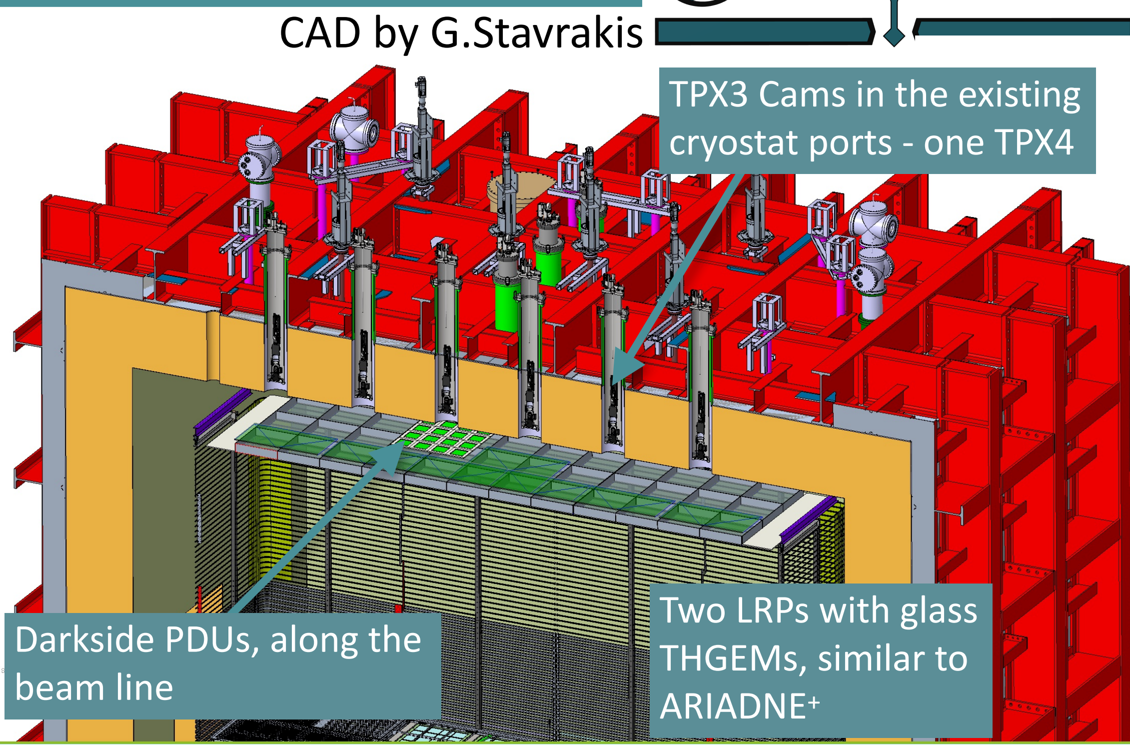
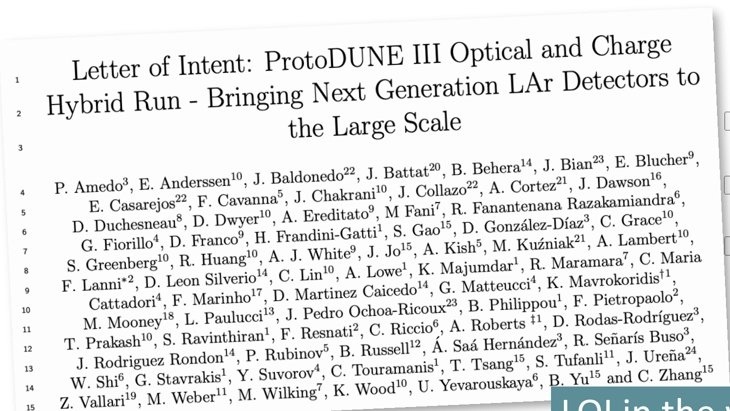
Proposed ProtoDUNE Instrumentation

- Using Proto-DUNE dual-phase to test optical readouts for Neutrinos and DM; TPX3Cams, DarkSide PDUs & X-ARAPUCAS
- TPX3 cam superb 3D tracking capability with energy sensitivity down to ~100keV
- DarkSide-20k type Photo Detection Modules (single keV energy threshold)

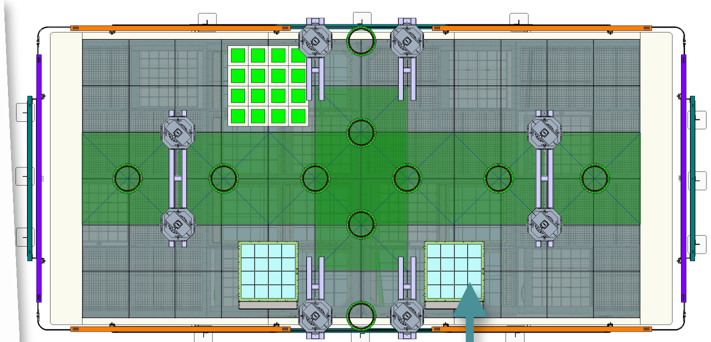




Letter of Intent: ProtoDUNE III Optical and Charge Hybrid Run - Bringing Next Generation LAr Detectors to the Large Scale

P. Amedo[3], E. Anderssen[10], J. Baldonedo[22], J. Battat[20], B. Behera[14], J. Bian[23], E. Blucher[9], E. Casarejos[22], F. Cavanna[5], J. Chakrani[10], J. Collazo[22], A. Cortez[21], J. Dawson[16], D. Duchesneau[8], D. Dwyer[10], A. Ereditato[9], M Fani[7], R. Fanantenana Razakamiandra[6], G. Fiorillo[4], D. Franco[9], H. Frandini-Gatti[1], S. Gao[15], D. González-Díaz[3], C. Grace[10], S. Greenberg[10], R. Huang[10], A. J. White[9], J. Jo[15], A. Kish[5], M. Kuźniak[21], A. Lambert[10], F. Lanni[*2], D. Leon Silverio[14], C. Lin[10], A. Lowe[1], K. Majumdar[1], R. Maramara[7], C. Maria Cattadori[4], F. Marinho[17], D. Martinez Caicedo[14], G. Matteucci[4], K. Mavrokoridis[†1], M. Mooney[18], L. Paulucci[13], J. Pedro Ochoa-Ricoux[23], B. Philippou[1], F. Pietropaolo[2], T. Prakash[10], S. Ravinthiran[1], F. Resnati[2], C. Riccio[6], A. Roberts [‡1], D. Rodas-Rodríguez[3], J. Rodriguez Rondon[14], P. Rubinov[5], B. Russell[12], Á. Saá Hernández[3], R. Señarís Buso[3], W. Shi[6], G. Stavrakis[1], Y. Suvorov[4], C. Touramanis[1], T. Tsang[15], S. Tufanli[11], J. Ureña[24], Z. Vallari[19], M. Weber[11], M. Wilking[7], K. Wood[10], U. Yevarouskaya[6], B. Yu[15] and C. Zhang[15]

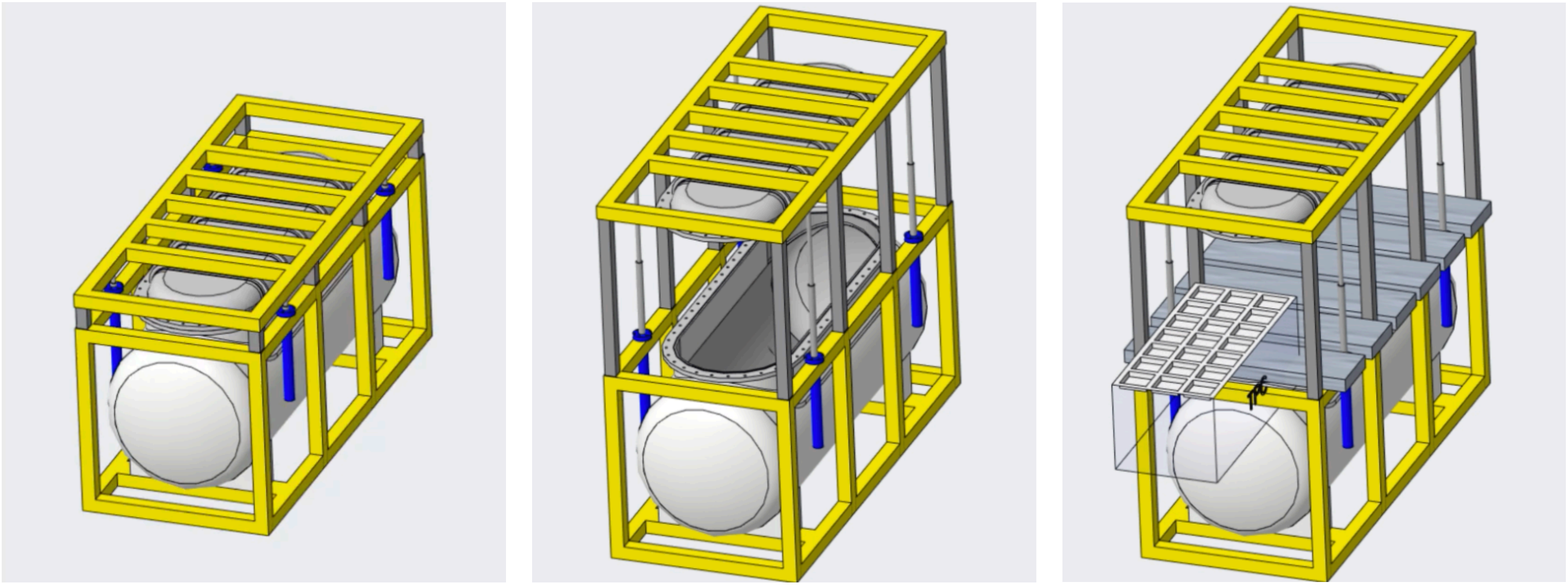
LOI in the works



In dark green shade is the FoV of the TPX cameras(1mx1m) using the current cryostat ports

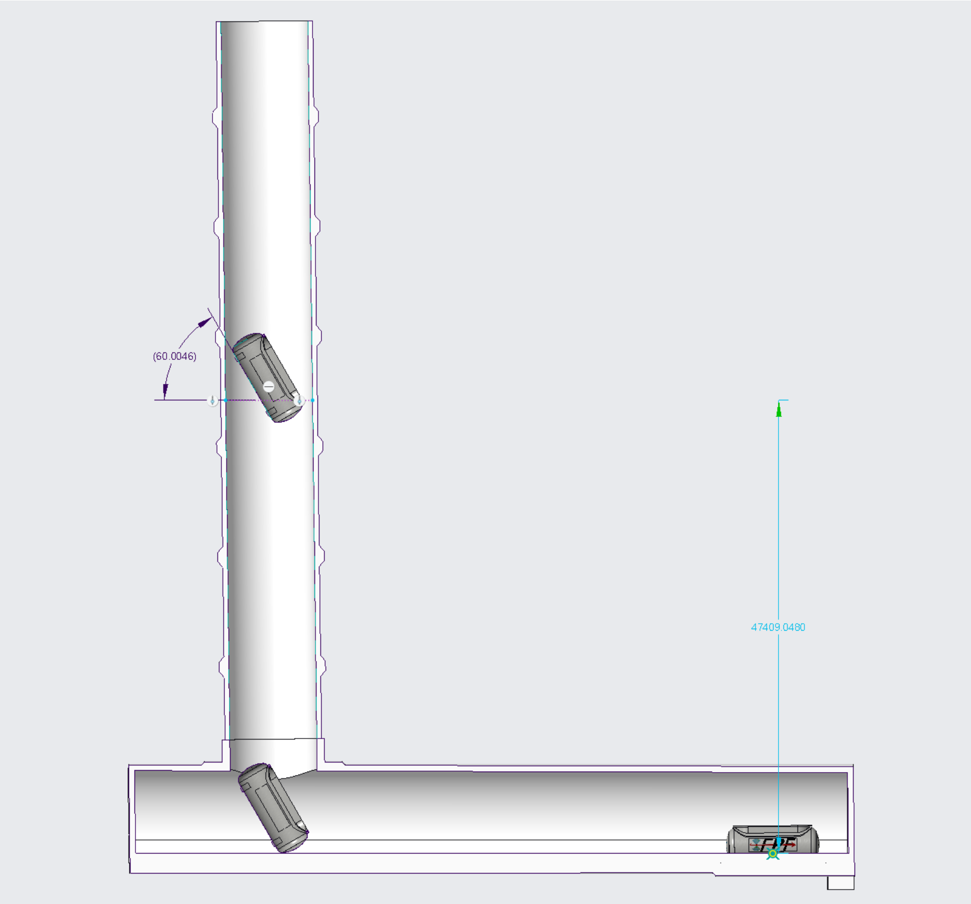
Extra Slides

FLArE: Hydraulic lifting since no crane access



CAD by H.Gatti

FLArE: Lifting down the shaft

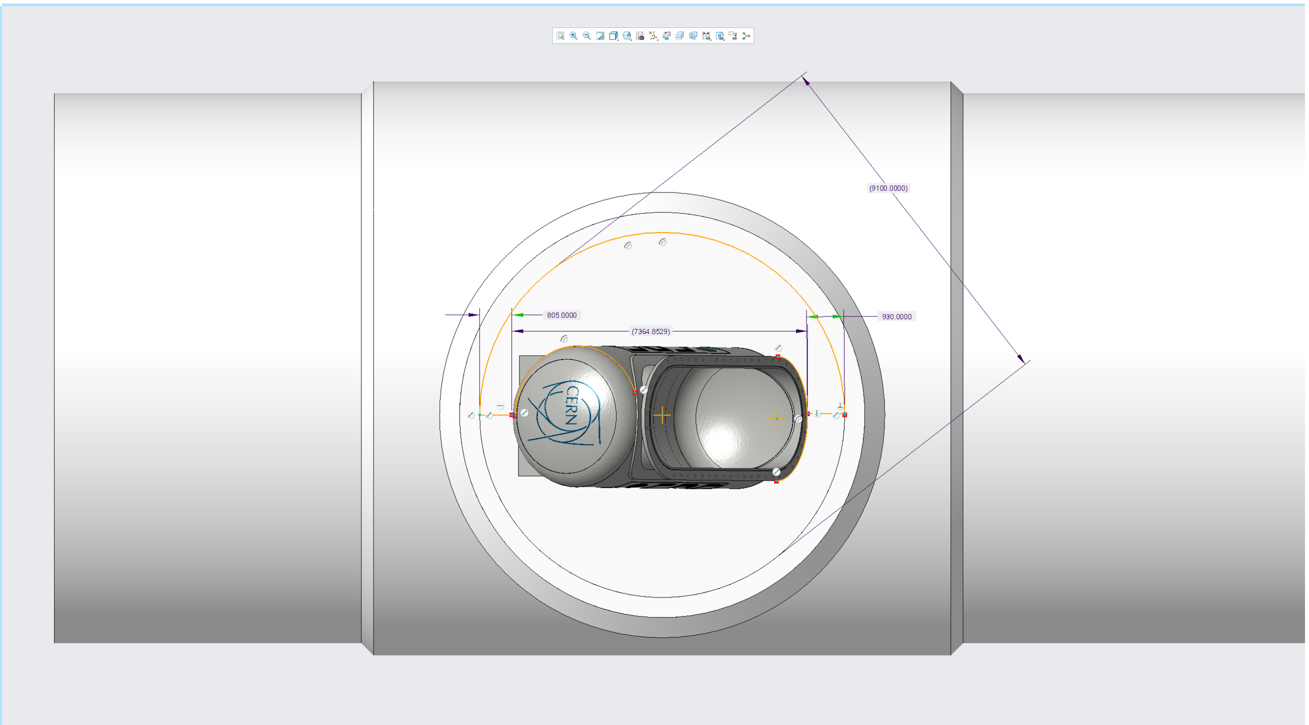


Commercial cryostat - lowers down in one unit

Possible to take down at 60 degrees (before install lift and stairs in the shaft)

Lower cryostat without lid keeping the weight below 25t (currently is 30t for 15mm thick skin)

FLArE: Lifting down the shaft



Possible to take down at 60 degrees (before install lift and stairs in the shaft)

Clearance around 90 cm from each side

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

Simulation