Large-scale demonstration of the ARIADNE LArTPC optical readout system at the CERN Neutrino Platform

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

ARIADNE Background info/Achievements so far

- The ARIADNE Detector
- Operation at CERN T9 beamline with EMCCDs & first results
- ARIADNE upgrade at Liverpool and TPX3 cameras

This Proposal

- Larger scale demonstration within the CERN neutrino platform and future directions
Operation & Benefits

ARIADNE - developing optical readout, as an alternative to charge.

- **Two-phases**, Liquid and Gas Argon
- Particles interact with argon creating detectable scintillation light and ionization (charge)

**Innovation of ARIADNE:**
- **THGEM** in gas phase amplifies drifted charge by up to 100 times
- This creates secondary scintillation light (S2) that we photograph with high sensitivity cameras (EMCCDs or now TPX3)
Benefits over previous charge readout techniques:

- **High resolution** — For e.g. 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/acoustics.
- **Ease of access** — Cameras can easily be replaced or upgraded - particularly useful during long-term cryogenic running.
- **Cost efficient** (No need for thousands charge channels used in previous charge readout technology)
The ARIADNE Detector

- ERC funded project started 2016
- Two phase detector
- 1500L Cryostat
- Beam window
- Camera readout
T9 Beam-line at CERN Spring ‘18

- T9 Beam, CERN East Area
- 0.5GeV - 8 GeV
- -ve & +ve polarity beams
- $e^\pm$, $\mu^\pm$, $\pi^\pm$, $p^\pm$
First Demonstration of Optical Imaging of Beam-line Interactions in a Two Phase LArTPC
Beamline Events
1.1mm / pixel resolution (4x4 bin)
(@Low THGEM gain 27 kV/cm)

ARIADNE—A novel optical LArTPC: technical design report and initial characterisation using a secondary beam from the CERN PS and cosmic muons

https://iopscience.iop.org/article/10.1088/1748-0221/15/03/P03003
**2D -> Full 3D Readout**

**EMCCD Limitations**

- Great resolution and sensitivity, however acquisition rate of EMCCD sensors (~50Hz) is slow compared to the drift speed of LAr TPCs (~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

**The MUCH faster TPX3 readout can give full 3D readout!**
(whilst still having the sensitivity of EMCCDs)
2D -> Full 3D Readout

Silicon pixel readout chip developed by the Medipix collaboration. **Very well established** technology at CERN.

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

ToT allows accurate calorimetry measurements.

TOA 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, now also light [1].

![Silicon pixel readout chip](image)

<table>
<thead>
<tr>
<th>Sensor resolution</th>
<th>256x256 pixels</th>
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<tbody>
<tr>
<td>Pixel size</td>
<td>55µm x 55µm</td>
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<tr>
<td>Max readout rate</td>
<td>40Mhits cm⁻² sec⁻¹</td>
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<tr>
<td>Time resolution</td>
<td>1.6 ns</td>
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</table>

TPX3Cam on a TPC

- Timepix3 measures deposited charge
- Optical sensor bump bonded to Timepix3.
- This alone not sensitive enough - preface with image intensifier.

Initial tests done with CF$_4$ gas and an Am-241 source using the 40l setup: https://iopscience.iop.org/article/10.1088/1748-0221/14/06/P06001
TPX3Cam on a TPC

Lens: Spacecom VF50095M
(speed: f/0.95, focal length: 50 mm)

Image Intensifier: “Cricket” from Photonis.
(dark count rate: ~50Hz)

TPX3Cam: commercial Timepix3 camera from Amsterdam Scientific Instruments.

(Potential to integrate this into custom single assembly for cost savings and greater optical efficiency)
TPX3Cam

- All pixels read out
- No timing data within event

Data-driven Readout (TPX3CAM)

- Only active pixels read out
- Per pixel timing information
TPX3Cam ARIADNE LArTPC

Time over Threshold View (Calorimetry)  Time of Arrival View (Timing)
Video: Continuous streaming, 10 msec slice (1 ms jump per frame)
TPX3Cam on ARIADNE

- LAr Timepix3 test in Liverpool Argon Lab.
- One Timepix3 camera instrumenting 26x26cm region of detector.
TPX3Cam LAr Results

[Nominal drift velocity is 0.16 cm/μsec for 0.5kV/cm]

- 1.0 sec (1.7 km drift) data stream of cosmics
- 25x25cm readout area
- 1 Timepix camera

Cut on ToT only

No Complex noise filtering

No 3D reconstruction steps
TPX3Cam 3D Cosmics LAr

Gallery: 100μsec drift window, about 20cm tracks
TPX3Cam 3D Cosmos LAr

~100μsec drift window, about 20cm tracks

**Antiproton Candidates**

**Stopping muon Candidates**
Detector Characterisation

ADU (ToT) vs. THGEM Bias

MIP Energy Calibration

- $< 22$ kV/cm: Pure electroluminescence regime.
- $> 22$ kV/cm: Electroluminescence and electron avalanche regime ('gain' regime).

TPX3 Cam is sensitive to the very low gain of the THGEM, which is very stable

- Energy resolution: $10.6\% \pm 0.1\%$ stat
- $1$ MeV $\approx 6744$ ADU
TPX3Cam TPC Benefits

- Raw data is natively 3D. Just need to convert ToA to z position using known drift velocity in the TPC (drift velocity in LAr is 0.0016 mm/ns). x,y pixel number to mm using the known field of view of the lens.

- Huge readout rates are possible (80MHits/s)

- Zero suppressed readout comes for free (~few KBytes per event)

- Physics sensor (Timepix) being used for a Physics application

- Comparatively low cost

- Same readout is possible for two phase or gas TPCs
TPX3Cam - Cost for DUNE

Technology/performance is superb, Cost is of course important.

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

<table>
<thead>
<tr>
<th>Camera type</th>
<th>Sen. Size (pixels)</th>
<th>Cameras to cover 1m²</th>
<th>Resolution (mm/pix)</th>
<th>Total cameras (to cover 720m²)</th>
<th>Total cost (assuming €5k/camera*)</th>
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</thead>
<tbody>
<tr>
<td>TPX3</td>
<td>256x256</td>
<td>9</td>
<td>1.3 (~ARIADNE)</td>
<td>6480</td>
<td>32.4M</td>
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<td>TPX4</td>
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<td>0.66 (1.5m/cam)</td>
<td>3</td>
<td>320</td>
<td>1.6M</td>
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* Cost is a place holder based on discussions with ASI, assumes large production
ARIADNE technology is now an option for the 4\textsuperscript{th} Module of DUNE (Module of Opportunity).

Conceptual DUNE Dual Phase with Optical Readout

- 320 TPX4Cams within the cryostat chimneys
- Each camera images 1.5mx1.5m with 3mm/pixel resolution
- Total camera cost with optics ~3M Euro
Conceptual DUNE Dual Phase with Optical Readout

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If 12m e\textsuperscript{-} drift proves to be not possible due to HV limitation the detector would evolve to a hybrid of VD and optical readout
Larger scale Demonstration at the CERN Neutrino Platform

Test optical readout on a scale relevant for DUNE using the existing cold box

P. Amedo\textsuperscript{3}, D. González-Díaz\textsuperscript{3}, A. Lowe\textsuperscript{1}, K. Majumdar\textsuperscript{1}, K. Mavrokoridis\textsuperscript{*1}, M. Nessi\textsuperscript{12}, B. Philippou\textsuperscript{1}, F. Pietropaolo\textsuperscript{2}, F. Resnati\textsuperscript{2}, A. Roberts\textsuperscript{1}, Á. Saá Hernández\textsuperscript{3}, C. Touramanis\textsuperscript{1} and J. Vann\textsuperscript{1}

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\textsuperscript{3} Instituto Galego de Física de Altas Energías (IGFAE) Rúa de XiaoÁn Díaz de Ráhago, s/n, Campus Vida, 15782 Santiago de Compostela, Spain

CERN LOI: https://cds.cern.ch/record/2739360
Larger scale demonstration at CERN: The Current Cold box

The cryo-vessel used to test the protoDUNE THGEMs. The cold box will be modified and shared between optical readout and Vertical Drift CRP tests
Cold Box Modification

- Extension of the cold box opening
- 6x new penetrations on the fixed roof
Cold Box Position at EHN1

NP02 pit
Larger scale demonstration at CERN: Conceptual Design

L2 = 665 mm with ~22cm drift and 10cm cathode clearance to cold box floor.

- 4 TPX3 cams, 4m² active area, Only 22 cm drift
- FoV of 1 camera ~1.1mx1.1m; 4 THGEMs/camera; 4mm/pixel resolution.
Cold Box Optical configuration

TPX3 Camera assembly

Light Readout Plane (LRP)
TPX3 Camera assembly and re-entrance viewport

Viewports arrived at Liverpool

TPX3 Camera (in GN$_2$ environment)

Relay optics

Intensifier

Objective lens

TPX3 cameras are being assembled and tested at Liverpool
Light Readout Plane (LRP)

- CRP/LRP Suspension feedthroughs
- LRP Structure (Invar)
- THGEM + WLS Array (2m x 2m) – THGEMs ordered
- Extraction grid array (3m x 3m)
- Same cathode as in vertical drift
Cold box ports to be used for the optical readout

- 4 camera viewports (DN275CF)
- 2 x service ports (DN200CF)
- Webcam, LEDs, level sensors and HV for LRP
THGEM/Extraction region sandwich

• Conceptual readout sandwich:
  • THGEM with PEN WLS sheet on top
  • Extraction grid made from etched stainless steel in supporting frame
  • PEEK spacers used to define 10mm extraction region (flatness defined by THGEM array structure)
Testing Novel Glass THGEMs

Prototype Liverpool GGEM already tested (paper in progress)

16 50cmx50cm Glass THGEMs order is placed

• Glass THGEMs developed at Liverpool (Patent pending GB2019563.2):
  • Glass wafer/sheet with ITO coated electrode - holes produced using abrasive etching
  • Improvements to radiopurity/outgassing and gain uniformity compared to FR4
  • Robust and resistant to damage by discharges
  • GGEMs can be made from most types of glass and large areas are possible (towards 1m x 1m - glass dependent)
Request from SPSC

- We request support for the use of the current infrastructure at the CERN Neutrino Platform (NP)
  - including cryogenics, re-circulation and purification of LAr for the operation of the already existing 5m×5m cold box
  - Semi clean room use in the NP for assembly of the readout plane
  - Technical support for the integration
Schedule - Coherent with Vertical Drift

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* Optical Readout test and CRP 2 test will take place between January and end May 2022. The order will be decided upon lessons learnt from CRP 1 and production readiness
Extra Slides
TPX3Cam SPIDR readout

- The SPIDR readout board generates a stream of data packets, which encode all information taking during operation.
- This data stream is written to disk over a gigabit Ethernet connection or fiber link, if higher data rates are required.
- The data packets are parsed and decoded in offline analysis, where the events can be reconstructed.
Timepix3 SPIDR

Timepix3 time measurement

- ToA and ToT measurement using 40 MHz counters
- ToA: 14 bits (resolution 25 ns, range 409 µs)
- ToT: 10 bits (resolution 25 ns, range 25 µs)
- Fast ToA measurement (640 MHz counter)
- 4 bits (resolution 1.56 ns, range 25 ns)
- common stop TDC -> subtract fast TDC value from time measurement