MIGDAL
Migdal In Galactic Dark mAtter expLoration

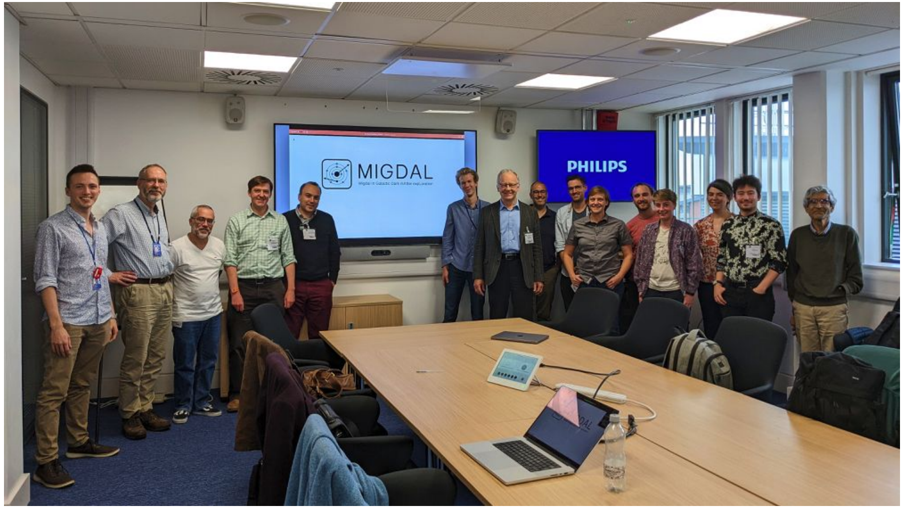
MIGDAL experiment at the NILE facility at RAL

Pawel Majewski
(STFC/Rutherford Appleton Laboratory)
for the MIGDAL collaboration

DMUK meeting, 22 September 2022

University of Birmingham, UAM Universidad Autónoma de Madrid, GDD Gas Detectors Development Group, Helsinki Institute of Physics, Imperial College London, King's College London, LIP, The University of New Mexico, University of Oxford, Royal Holloway University of London, Science & Technology Facilities Council Rutherford Appleton Laboratory, The University Of Sheffield.

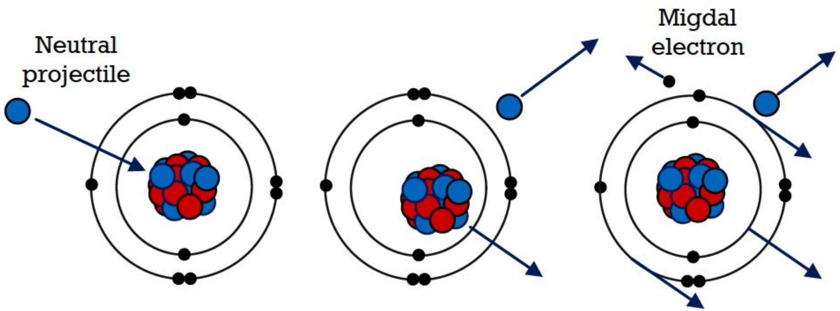
MIGDAL data analysis workshop at RAL, 11-13 September 2022



15 in-person participants from UK, Portugal and US plus 3 on zoom from Spain, US and CERN.

In the lab showing how MIGDAL O-TPC works

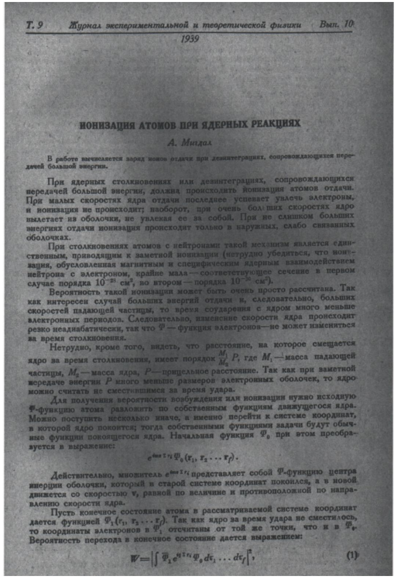
Migdal effect



Migdal event topology involves a nuclear recoil and electron recoil originating from the same vertex.

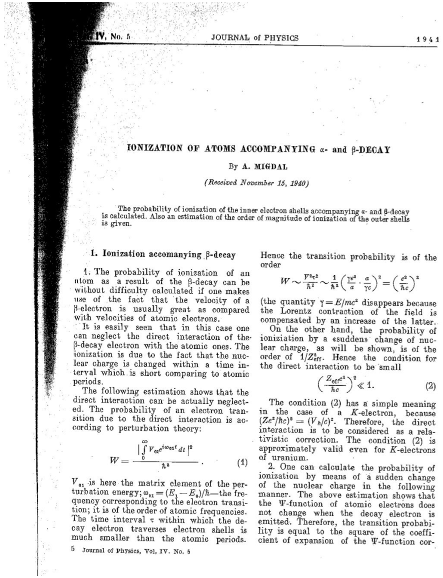
- Looking for a rare (10^{-5}) atomic phenomenon never before observed in the nuclear scattering
- Migdal effect increases sensitivity of DM experiments to low mass WIMPs
- Aim of the MIGDAL experiment - unambiguous observation and measurement of the Migdal effect using a low pressure Optical TPC
- Signal signature: “V-like” shaped event with two tracks from electron and NR with different dE/dx and sharing the same vertex

What do we already know about the Migdal effect ?


Т. 9 Журнал экспериментальной и теоретической физики Вып. 10
1939

ИОНИЗАЦИЯ АТОМОВ ПРИ ЯДЕРНЫХ РЕАКЦИЯХ

А. Мигдал


IV, No. 5 JOURNAL of PHYSICS 1941

IONIZATION OF ATOMS ACCOMPANYING α- and β-DECAY

By A. MIGDAL

(Received November 15, 1940)

The probability of ionization of the inner electron shells accompanying α- and β-decay is calculated. Also an estimation of the order of magnitude of ionization of the outer shells is given.

I. Ionization accomanying β-decay

A. Migdal publications:

- Ionisation in nuclear reactions [1]
- Ionisation in radioactive decays [2]

First observations of the Migdal effect in :

- Alpha decay [3,4]
- Beta decay [5]
- Positron decay [6]
- Nuclear scattering [ ]

[1] A. Migdal *Ionizatsiya atomov pri yadernykh reaktsiyakh, ZhETF, 9, 1163-1165 (1939)*

[2] A. Migdal *Ionizatsiya atomov pri α- i β- raspade, ZhETF, 11, 207-212 (1941)*

[3] M.S. Rapaport, F. Asaro and I. Pearlman *K-shell electron shake-off accompanying alpha decay, PRC **11**, 1740-1745 (1975)*

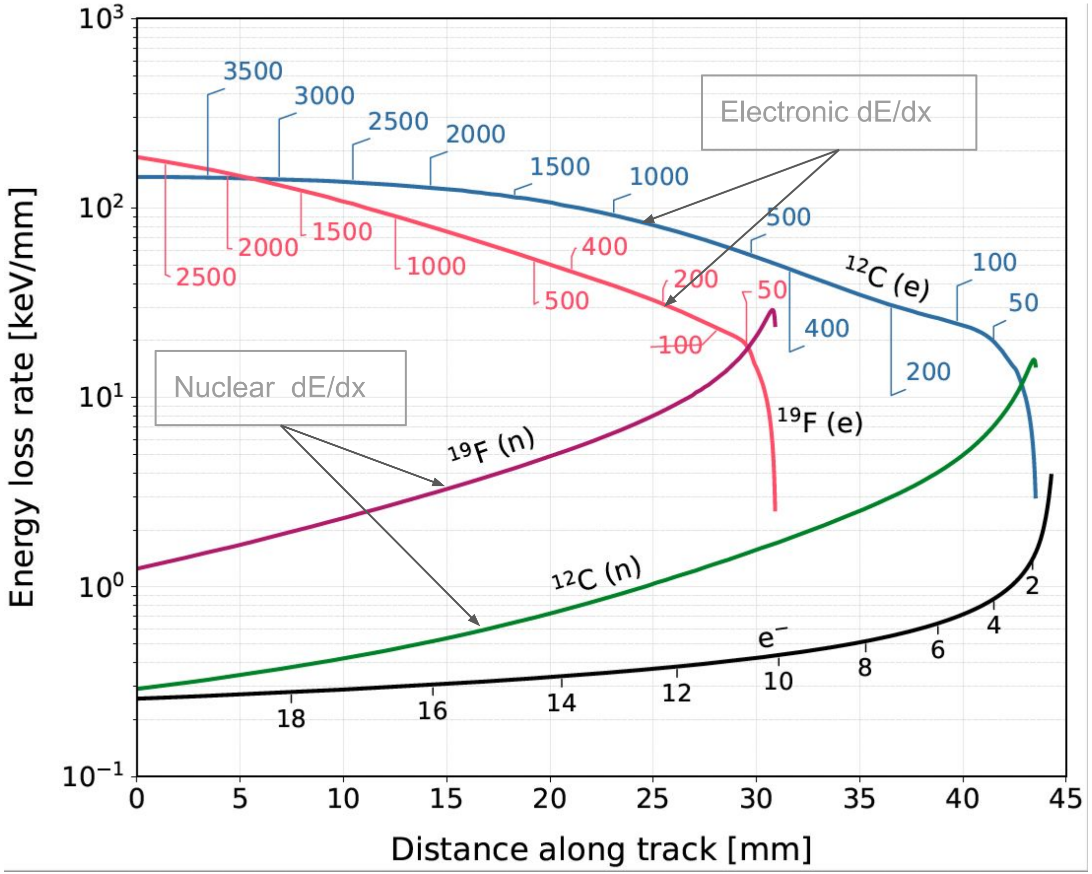
[4] M.S. Rapaport, F. Asaro and I. Pearlman *L- and M-shell electron shake-off accompanying alpha decay, PRC **11**, 1746-1754 (1975)*

[5] C. Couratin et al. , *First Measurement of Pure Electron Shakeoff in the β Decay of Trapped $^{6}He^{+}$ Ions, PRL **108**, 243201 (2012)*

[6] X. Fabian et al., *Electron Shakeoff following the β^{+} decay of Trapped $^{19}Ne^{+}$ and $^{35}Ar^{+}$ trapped ions, PRA, **97**, 023402 (2018)*

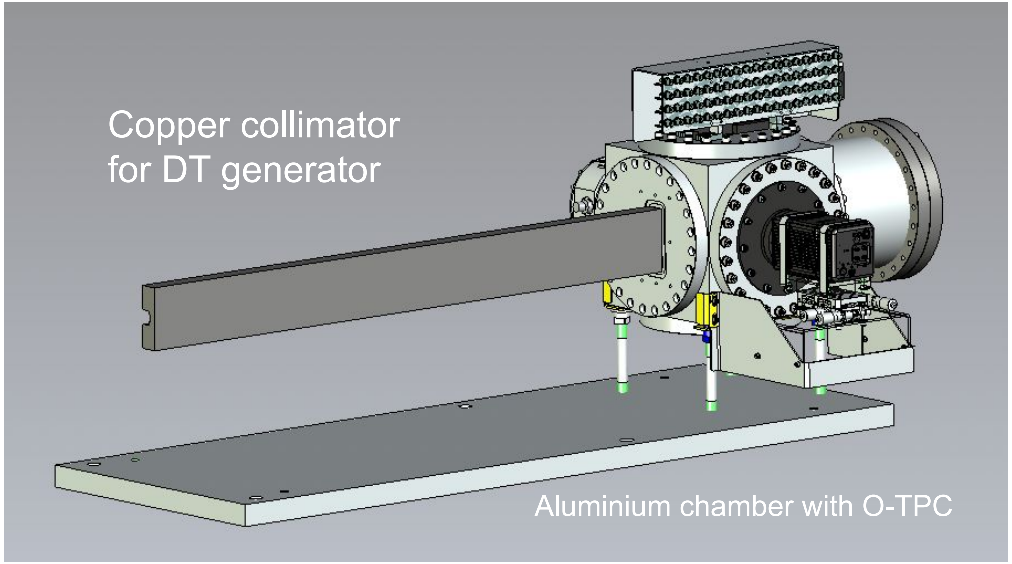
Also in A.B. Migdal "Qualitative Methods in Quantum Theory"
Advanced Book Classics CRC Press, 2000
L. Landau and E. Lifshitz "Quantum Mechanics : Non-relativistic Theory"

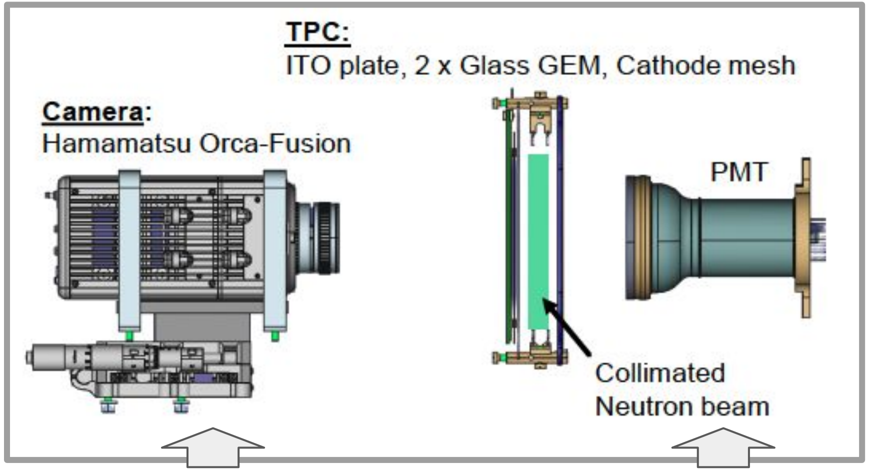
dE/dx and required dynamic range

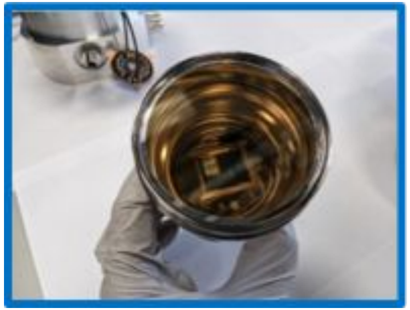


- Distinctive difference in dE/dx between NRs and electrons
- Huge dynamic range required at vertex where dE/dx at maximum for NRs and at minimum for electrons
- With high gain to see low energy electrons can lead to approaching the Raether limit and unwanted gaseous discharges in the lower GEM
- Plan for testing different THGEMs structures for robustness with fission fragments (RD-51 2 year grant)

Detector

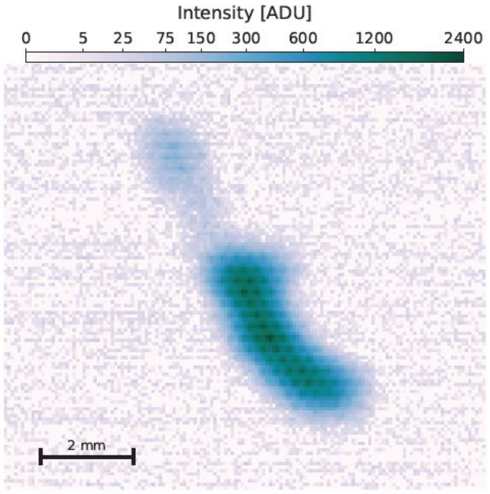






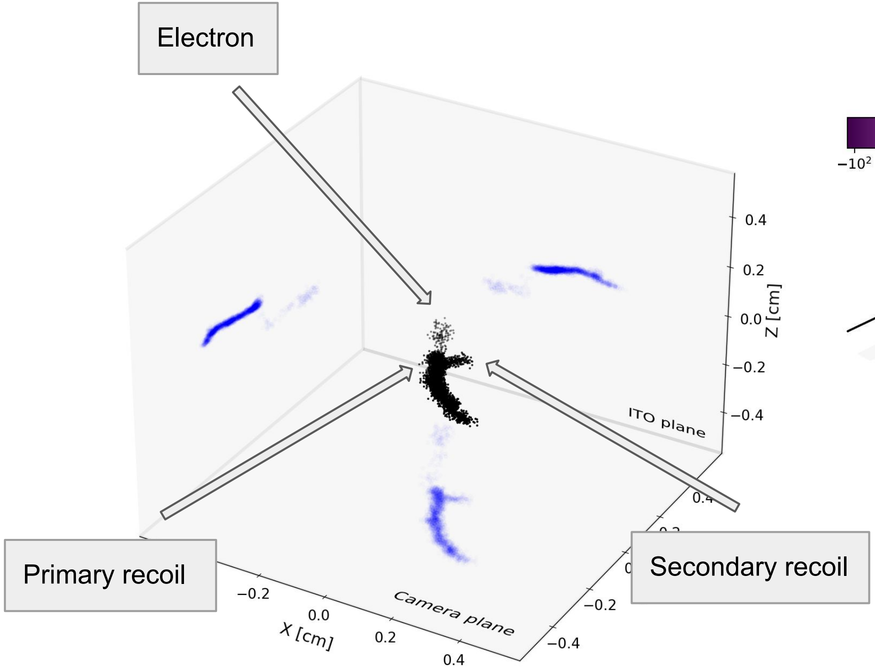
- Gas : 100% CF_4 at 50 Torr
    - (planned mixtures with all noble gases)
- Operating with low drift E-field for minimum diffusion
- Signal amplification with two glass-GEMs
- Light readout with fast CMOS camera: 2300 px x 2300 px, 89 frames/s and 25 mm f 0.85 EHD Imaging lens
- Charge readout using ITO strips, trigger from Hamamatsu PMT R11410

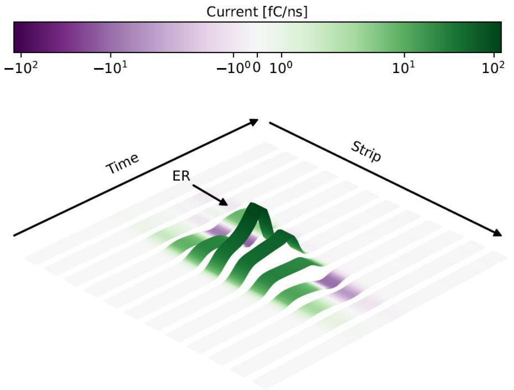
End-to-end simulation of Migdal events in 100% CF_4 at 50 Torr



Camera readout

Drift+diffusion+GEMs+image



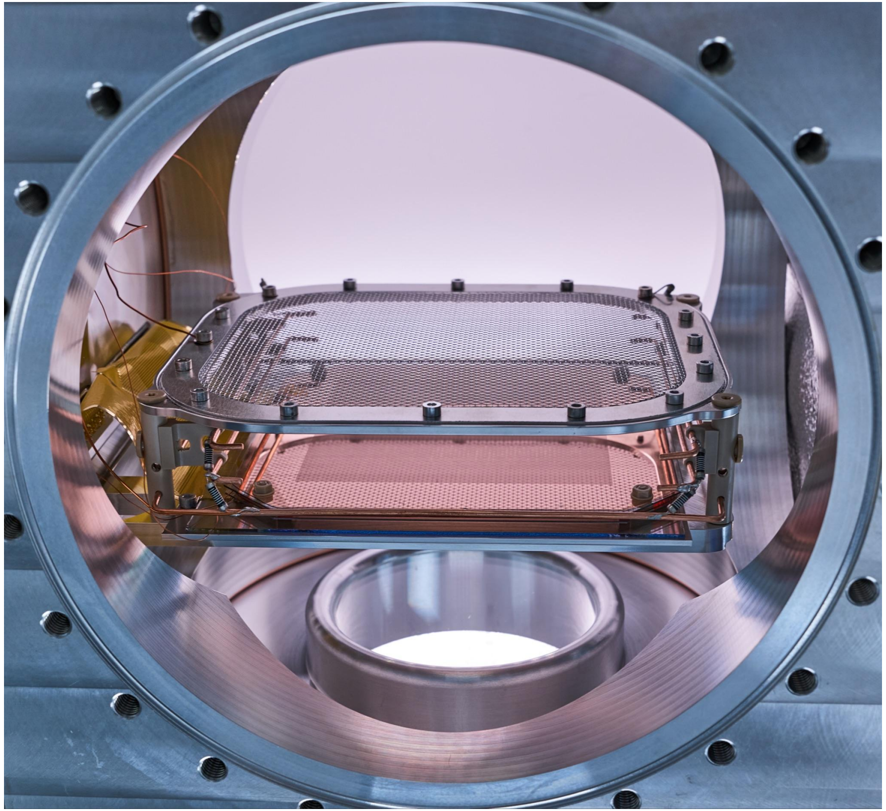


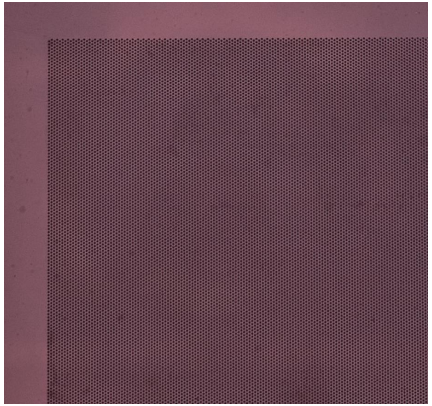
Anode strip readout

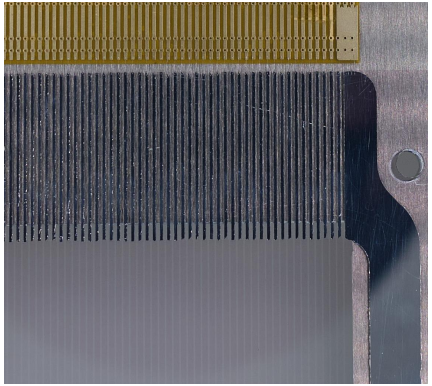
Including electronics response

- Ionisation from electron using DEGRAD and full recoil cascade simulation using TRIM
- 150 keV Fluorine recoils and 5 keV electron (secondary recoil clearly visible)

TPC







Two glass-GEMs:

- 570 um thick
- OD /pitch: 180/280 um
- active area: 10x10 cm^2

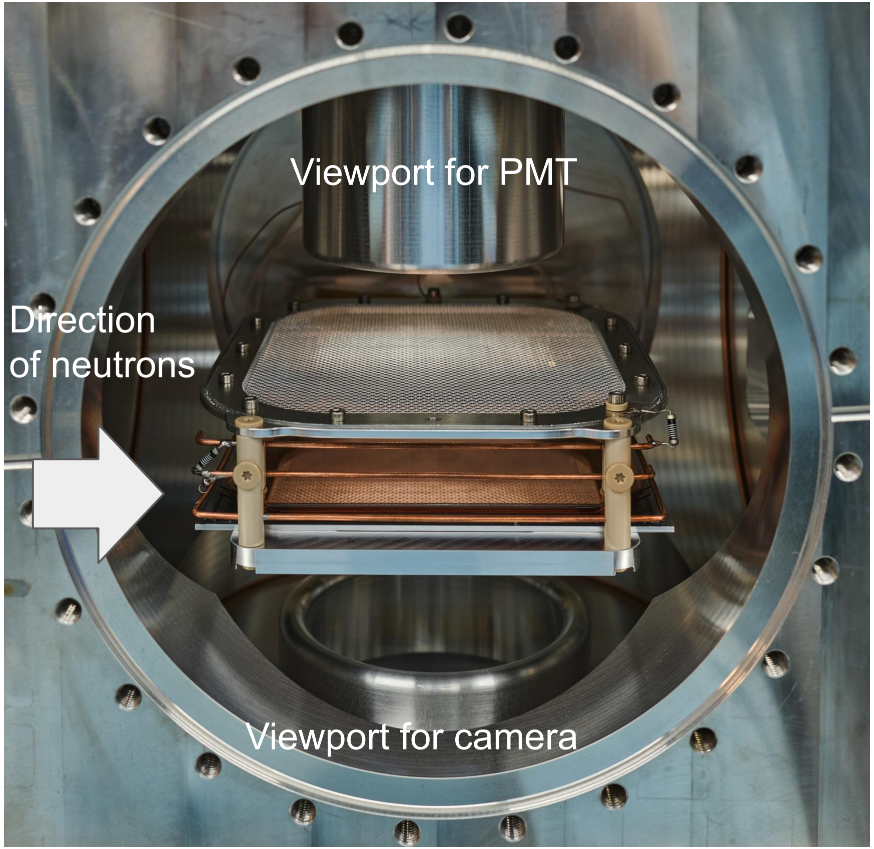
ITO strips wire bonded to readout

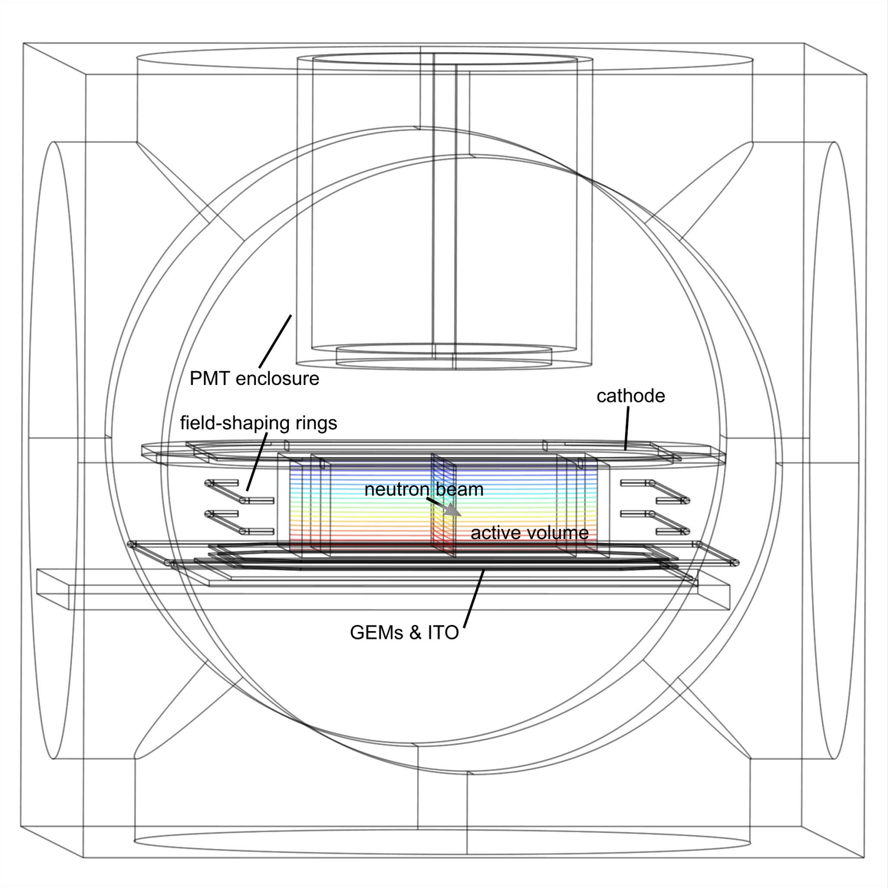
- 120 strips
- width/pitch: 0.65/0.83 mm

Three field shaping copper wires

- TPC inside of the central aluminium cube
- Drift gap: 3 cm between woven mesh and cascade of two glass-GEMs
- Transfer and signal induction gaps : 2 mm
- Low outgassing materials; vacuum before fill 2*10-6 mbar; signal visible several days after the fill

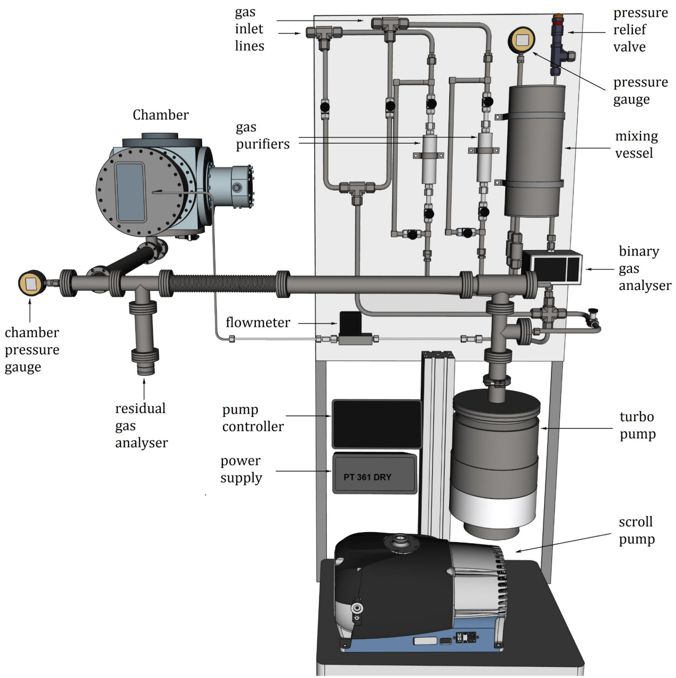
TPC





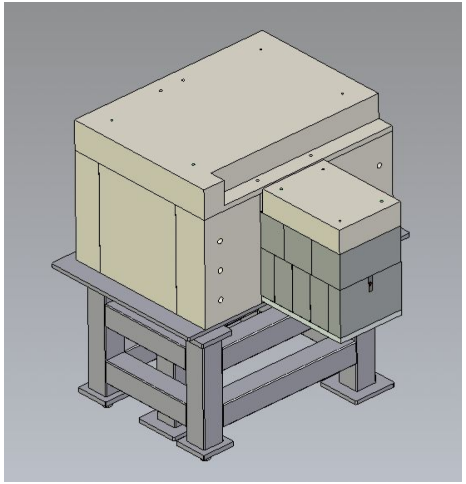
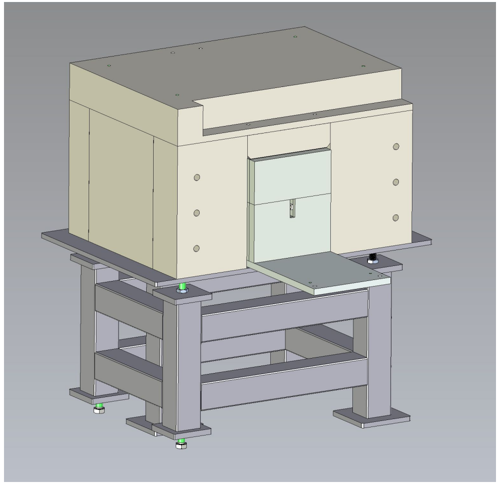
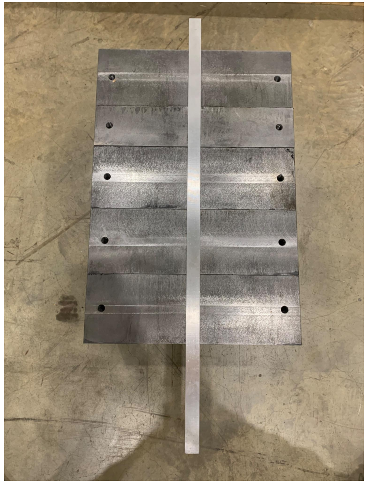
Electric field uniformity in the active volume simulated with COMSOL : fiducial area 8 cm x 8 cm

Gas system for single or two gases mixture operation



- Detector performance
  - Low outgassing materials
  - Pre-fill two day pumping to 2*10-6 mbar
  - Signal visible even four days after the filling

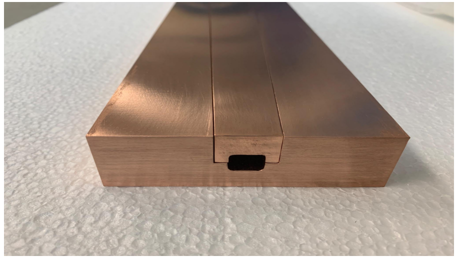
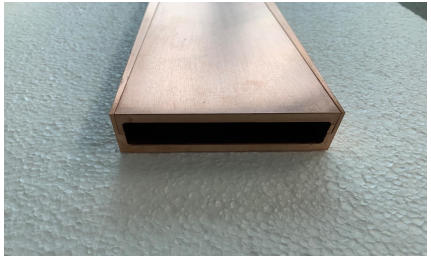
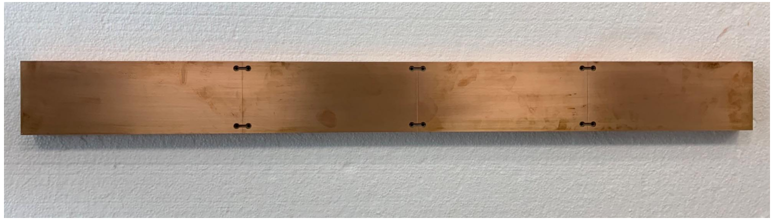
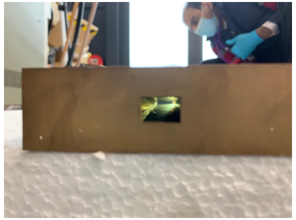
Shielding

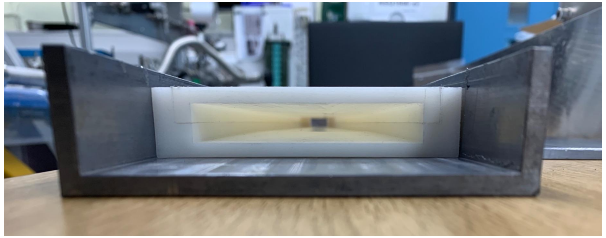
- Full shielding for the experiment with DT generator
  - Front shielding: Iron + borated HDPE + Pb
  - 1 m long copper collimator
- Full shielding for the experiment with DD generator
  - Same as for DT generator
- Front shielding for the experiment with DD generator
  - borated HDPE + Pb
  - 35 cm long borated HDPE+Pb envelope collimator

Collimators

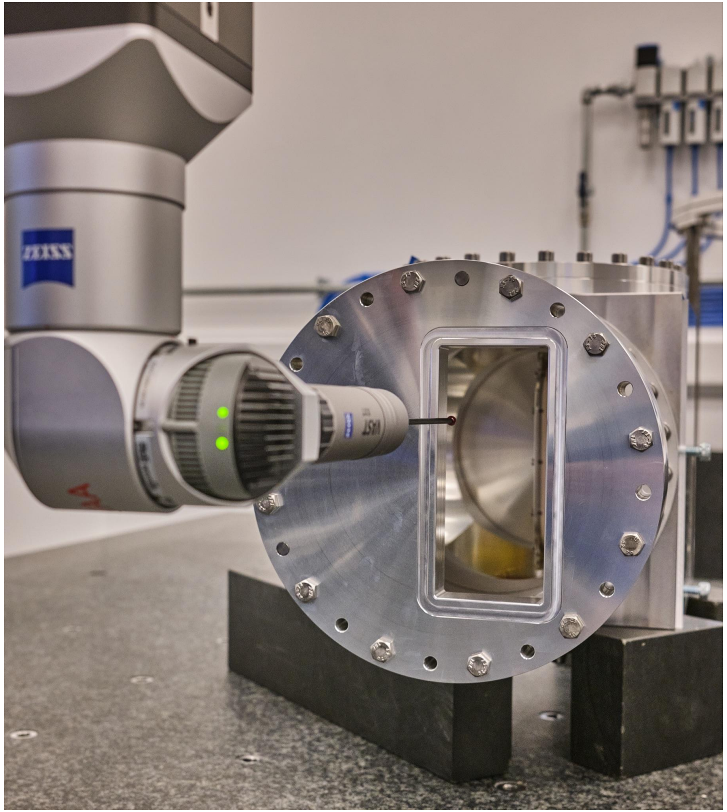
1m long copper collimator for DT generator (CNC machining & wire erosion)


35 cm long collimator for DD generator HDPE centre + lead envelope

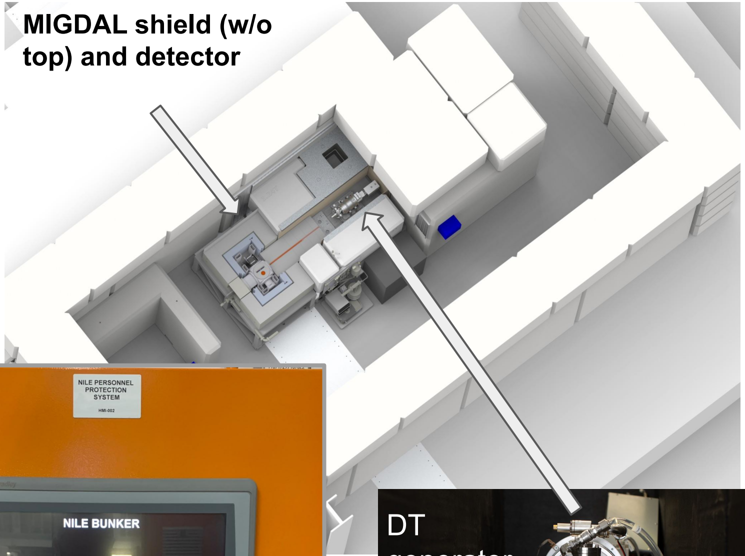



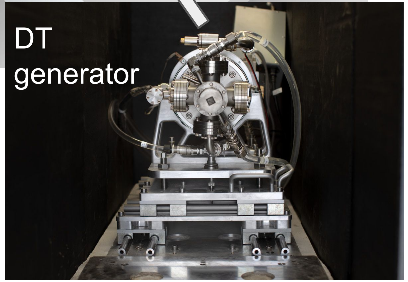
Detector Metrology

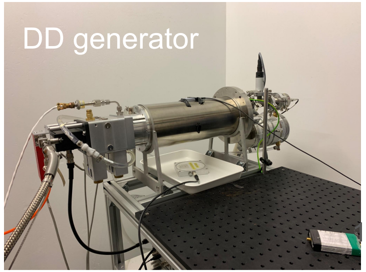


- Chamber with the O-TPC check for parallelism and alignment between all the elements
- Main focus on alignment between beam entrance/exit window and the drift gap of the TPC
- Largest deviation found - 0.5 mm

NILE facility and neutron generators

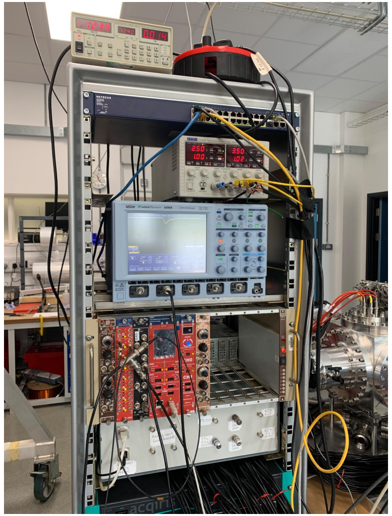


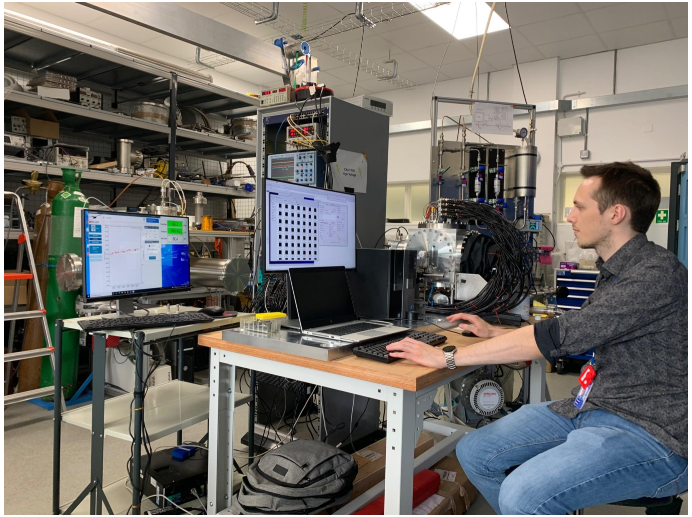




- Commissioning of both DD and DT neutron generators at the NILE facility at ISIS (RAL) is underway.
- MIGDAL experiment will start with DD generator.

Detector commissioning





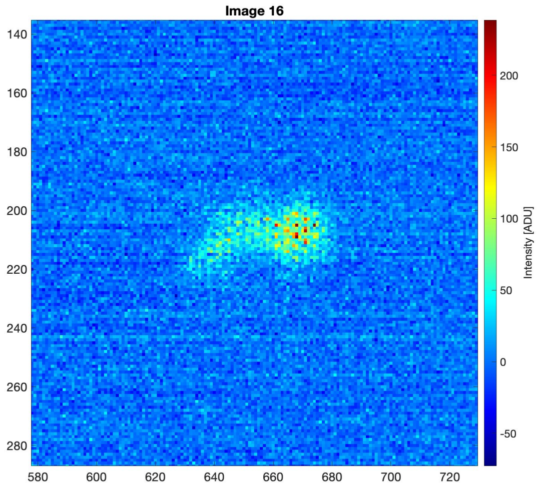
- Testing detector with 100 % CF4 and 80% CF4 and 20% Ar (at 50 Torr)
- Primary calibration source Fe-55 generating low energy electrons
- Plan to use Cf-252 and Am-241 for tests with highly ionising particles

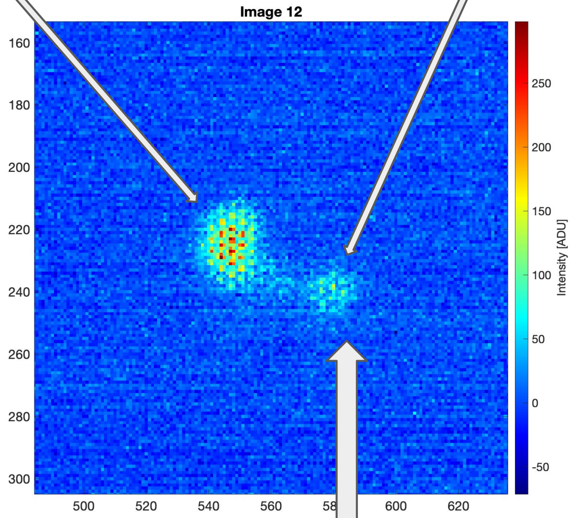
Acquiring images using Fe-55 source (5.9 keV X-ray)

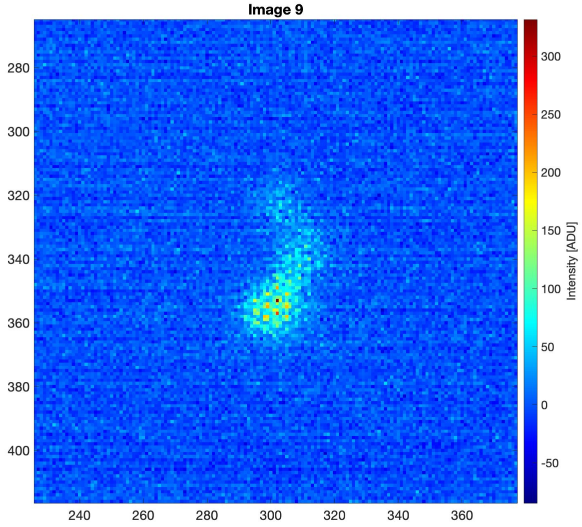
5.2 keV photoelectron from Fluorine

End

Start

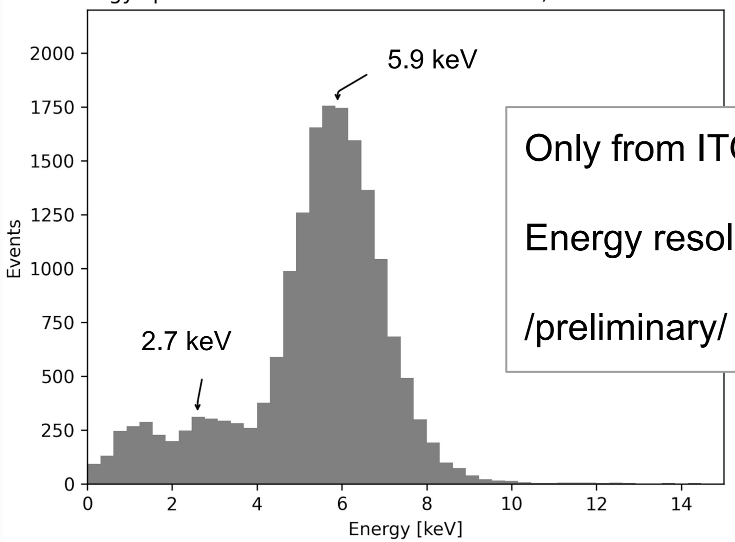






Extra charge at the start from Fluorine 650 eV Auger Electron

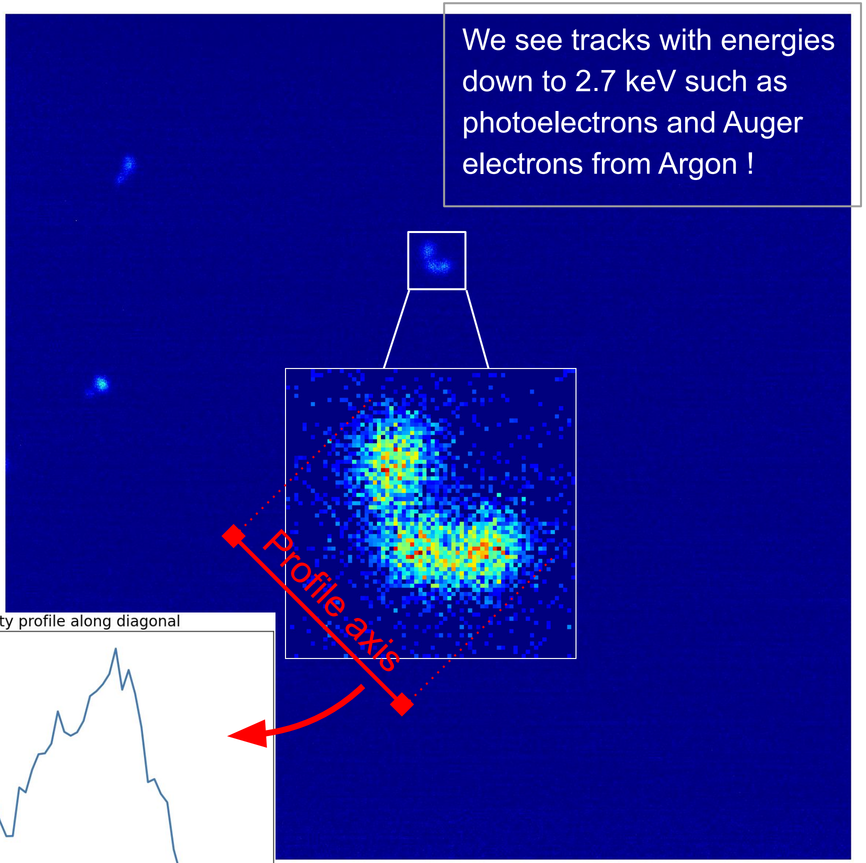
Running with CF4 / Ar at 50 Torr



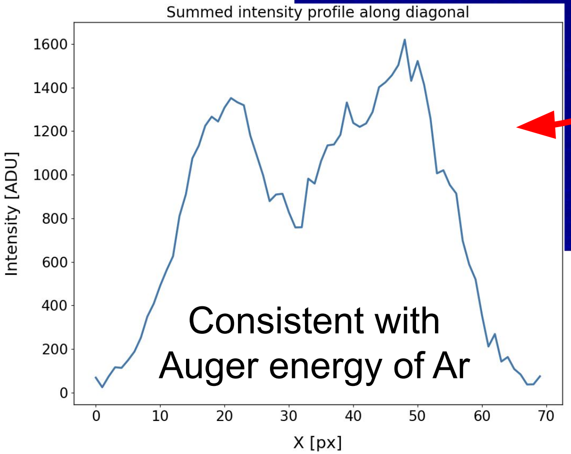
Only from ITO pulses.

Energy resolution ~ 18 %

/preliminary/



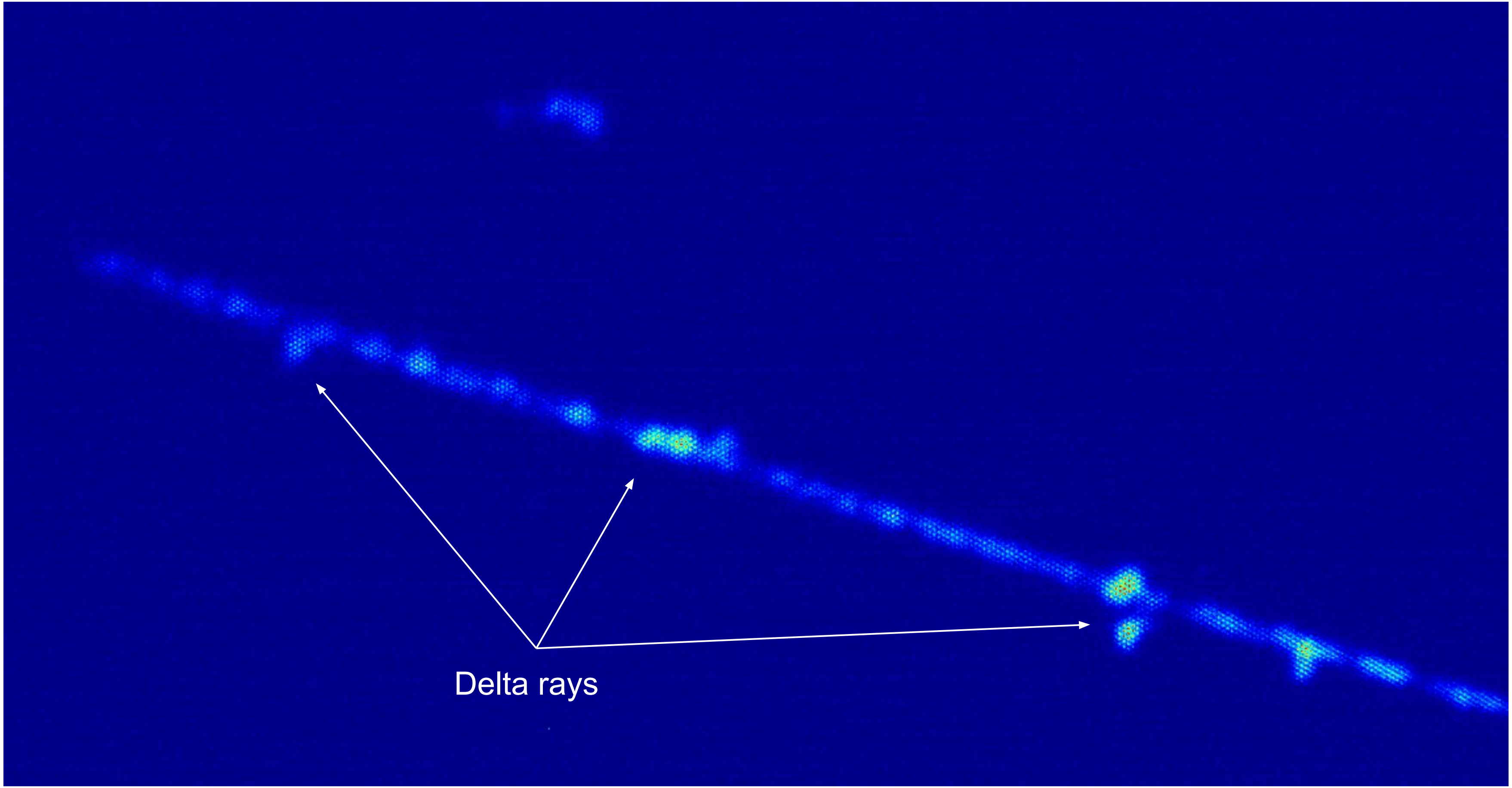
We see tracks with energies down to 2.7 keV such as photoelectrons and Auger electrons from Argon !



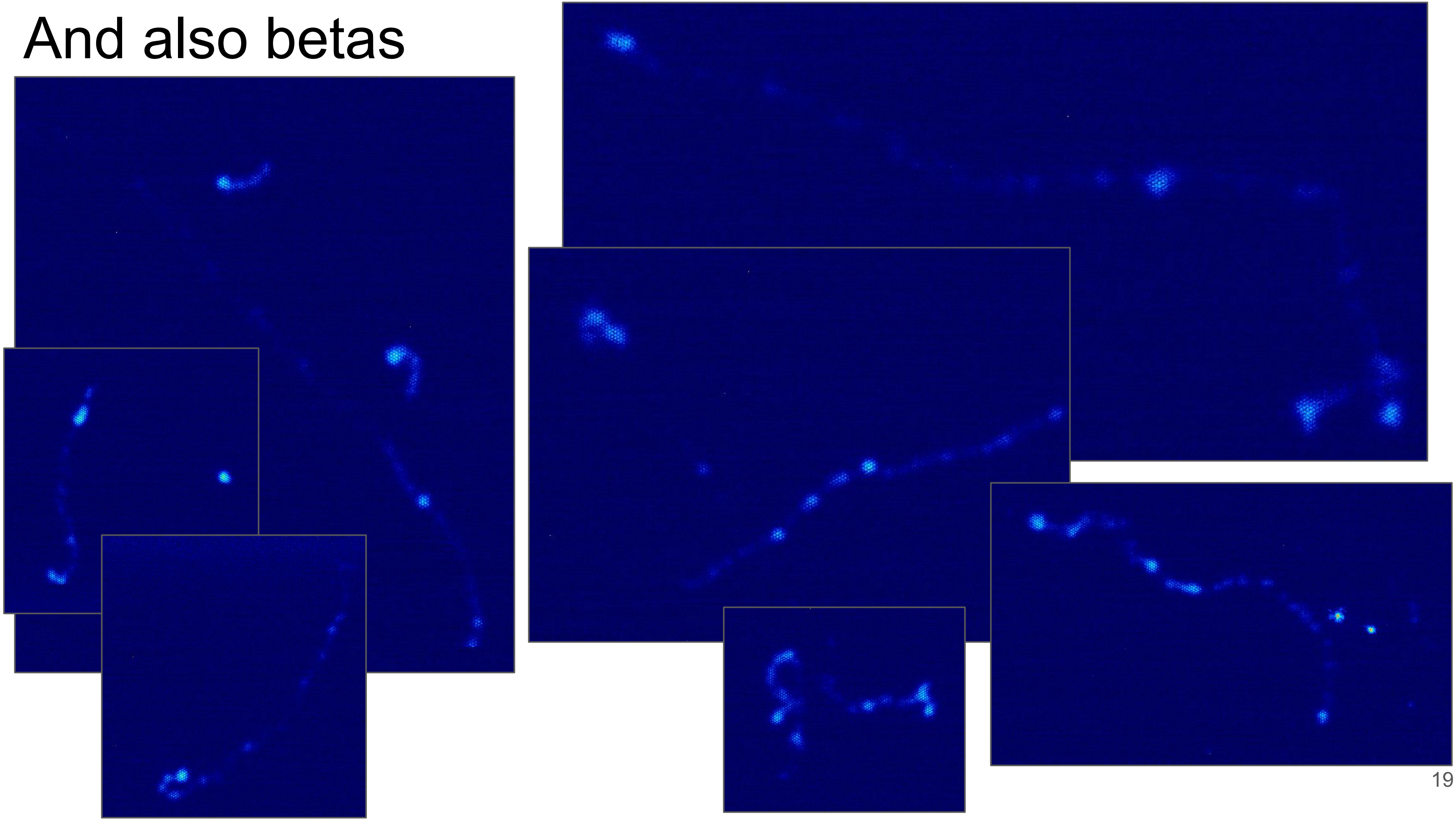
Consistent with Auger energy of Ar

- Stable operation for several hours
- Recorded 190k events and 100k frames
- Total number of sparks : 32

We see higher energy long tracks too

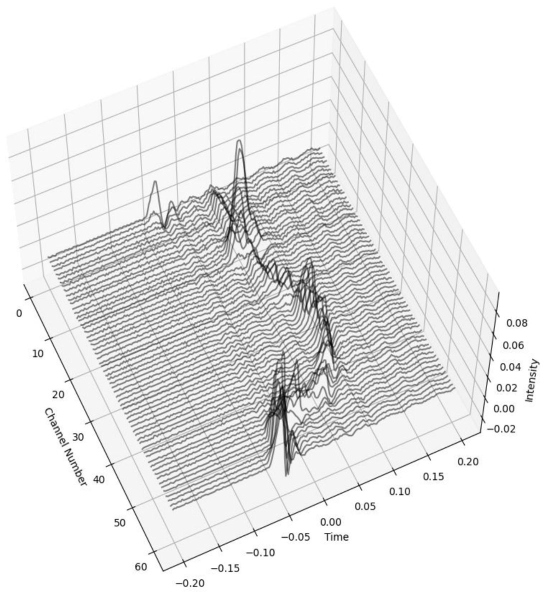


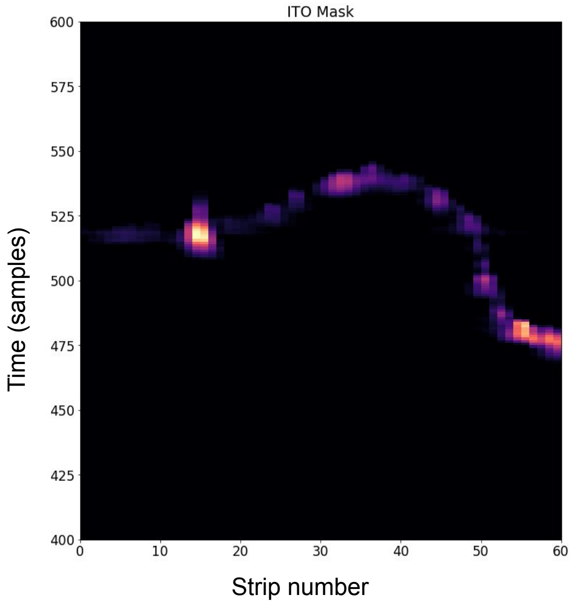
And also betas



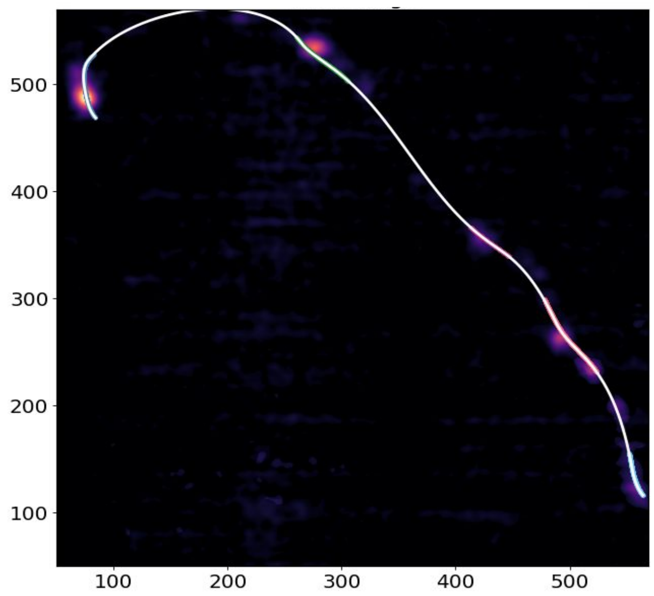
3D track reconstruction (long track)

Waveforms from ITO strips

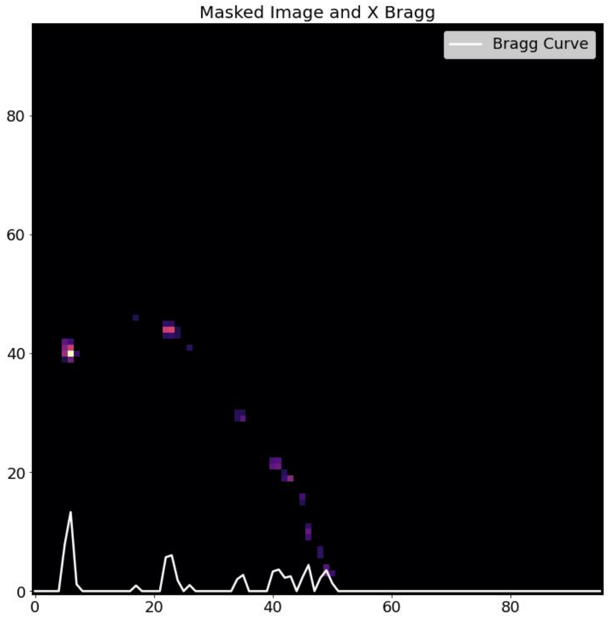


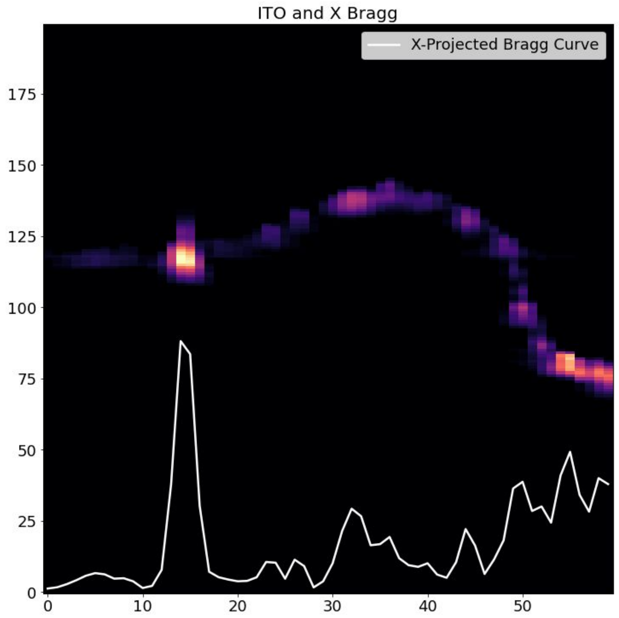


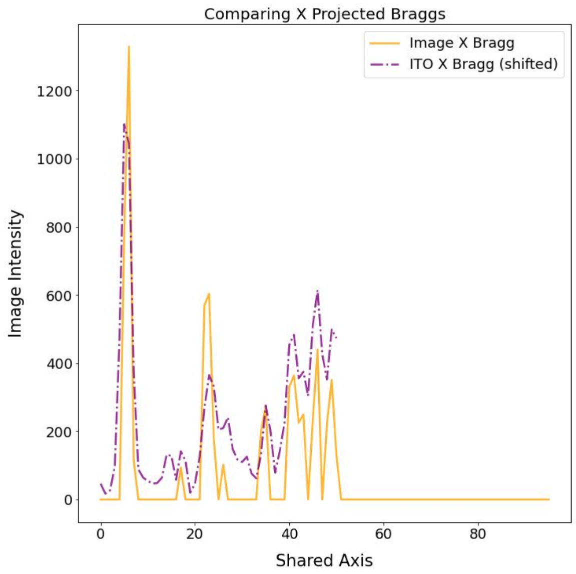
Imaged track with applied ridge findner



3D track reconstruction (Bragg curves from image and ITO)

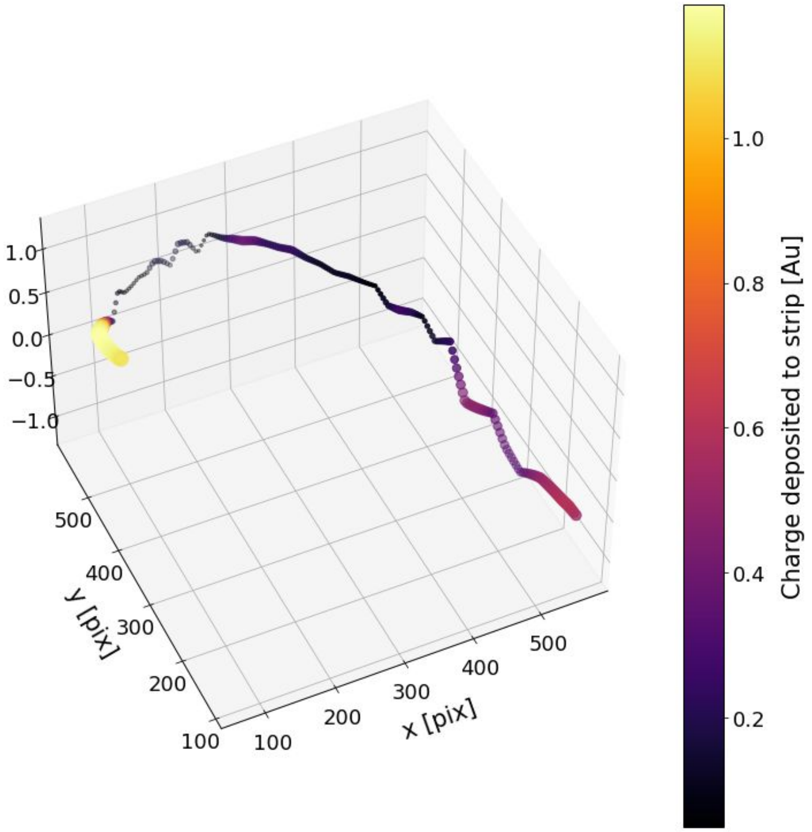




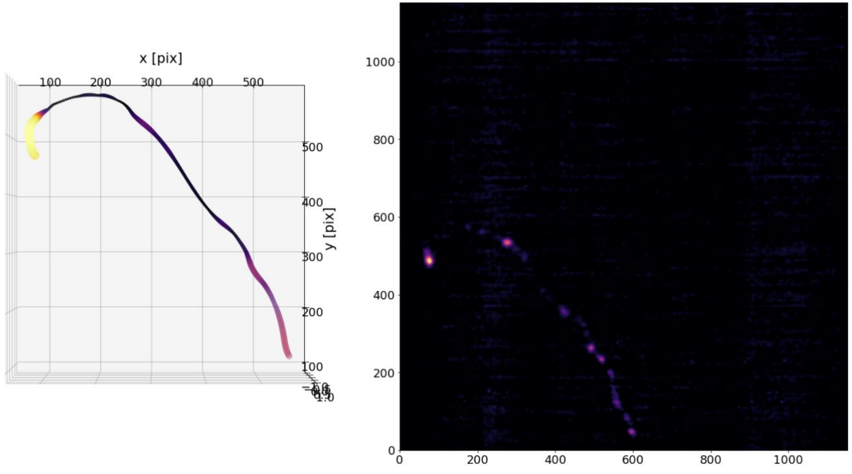


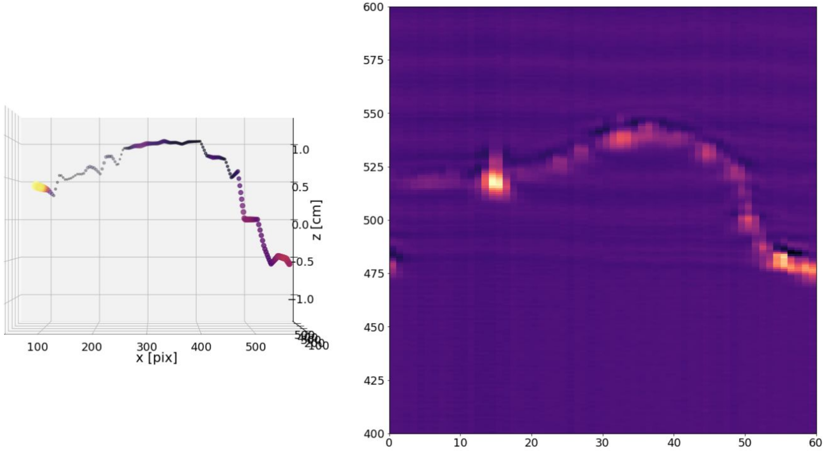
Alignment before stitching using x-coordinate

3D track reconstruction



Fully 3D reconstructed electron track (~20 keV)

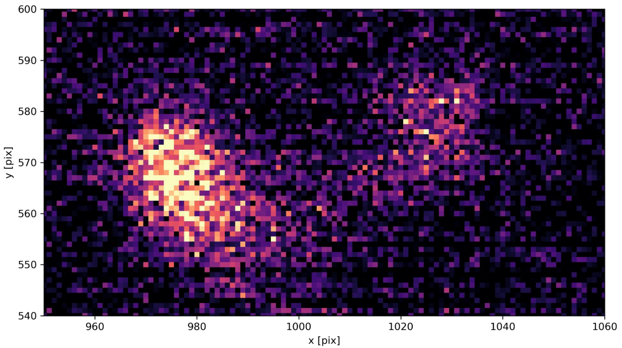


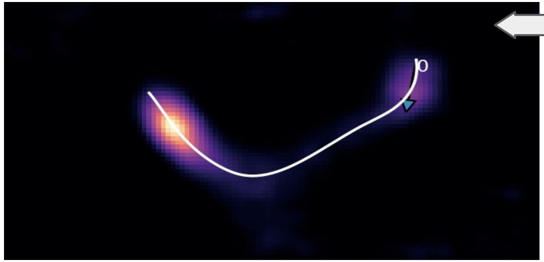


Projections onto the redout planes

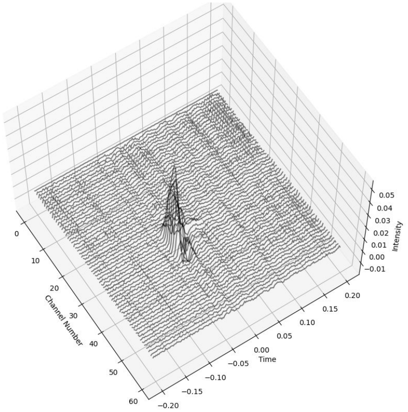
3D track reconstruction (low energy Fluorine photoelectron)

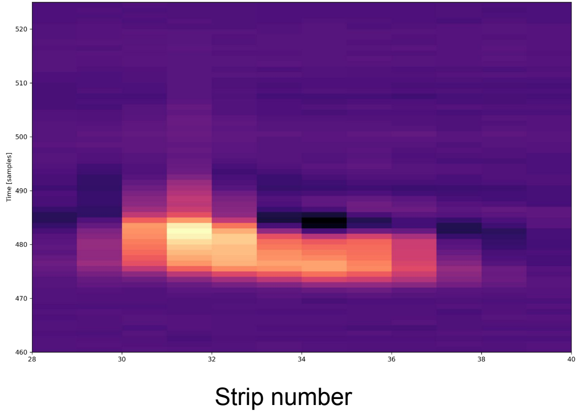
Imaged track (top) and with applied deconvolution and ridge findner (bottom)



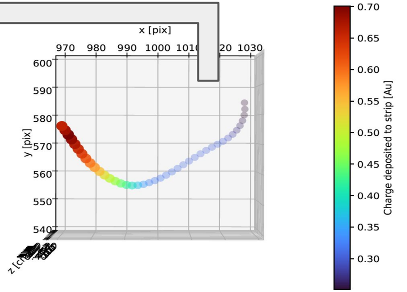


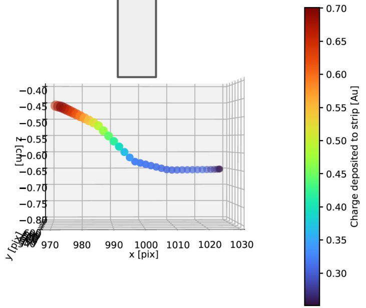
Waveforms from ITO strips





3D track projections onto readout planes





Conclusions

- We have a running detector performing as expected
- We established a stable operation with CF4+ Ar at 50 Torr
- We can detect and image events down to 3 keV
- We can can perform 3D track reconstruction using images and waveforms from ITO strips
- All parts are at RAL and shielding construction is underway
- Commissioning of the DD and DT generator is underway
- Remaining detector dynamic range tests with alphas and fission fragments to happen very soon.
- We are entering very exciting period nearing the experiment at the NILE facility.

MIGDAL

Migdal In Galactic Dark mAtter expLoration

Experiment paper: https://arxiv.org/abs/2207.08284