Towards an observation of the Migdal effect in nuclear scattering: Design and construction of the MIGDAL experiment

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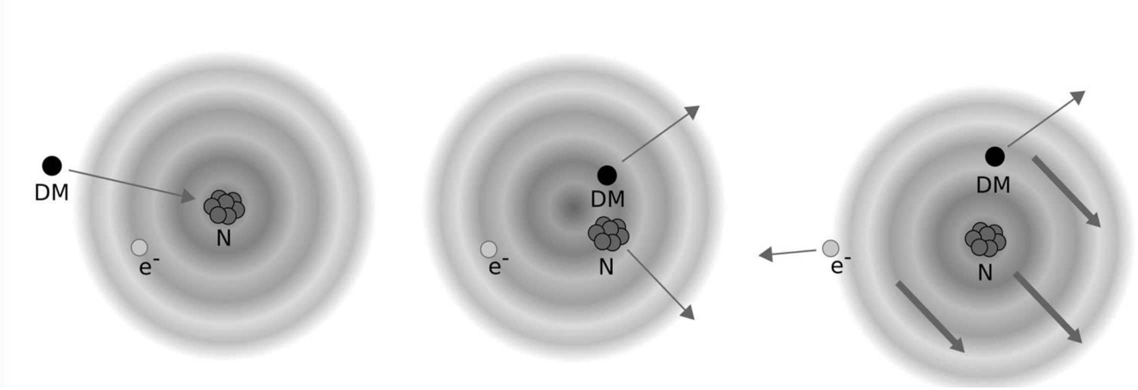
On behalf of the Migdal collaboration

Outline

- **The Migdal effect and Dark Matter**
- **The Migdal Experiment**
- **Optical Time Projection Chamber (O-TPC)**
- **3D reconstruction of the events**
- **Summary**

The Migdal Effect and Dark Matter

- **Electron emission due to the shake-off of the nucleus**
- **Theoretically described by A. Migdal in 1939**



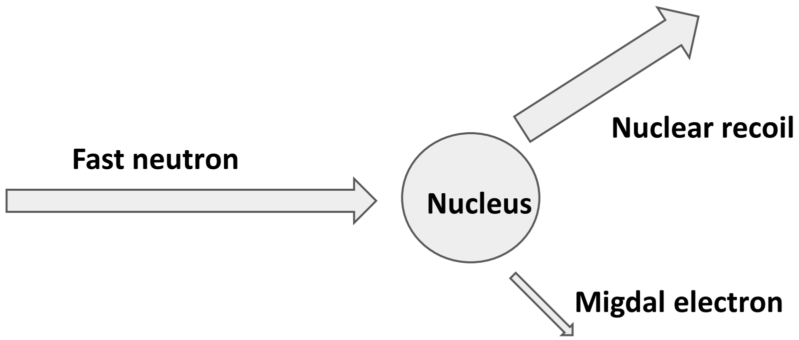
Migdal Effect : nucleus moves relative to the electron cloud, an electron might be ejected leading to ionisation.

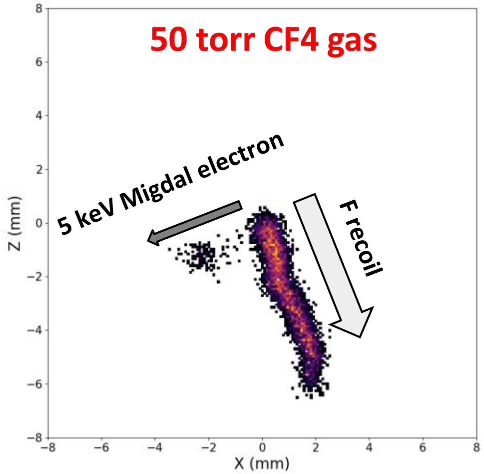
Dark matter community is interested in experimental measurement of the effect in neutron scattering process, where the situation is very similar to dark matter scattering from nucleus

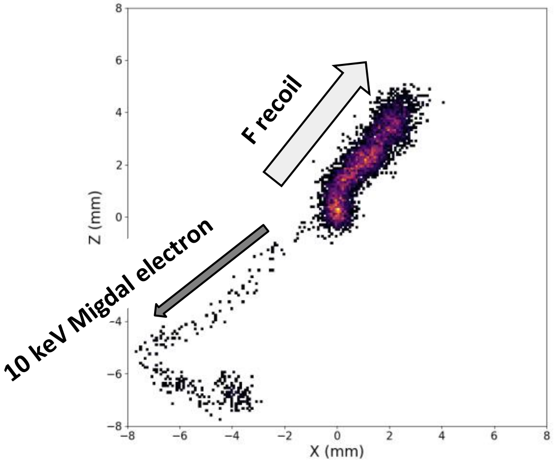
The Migdal Experiment

- Aim : Observation and measurement of the Migdal effect by taking images of ionization tracks at low gas pressures

- Migdal events: Nuclear recoil and electron recoil emerging from the same vertex







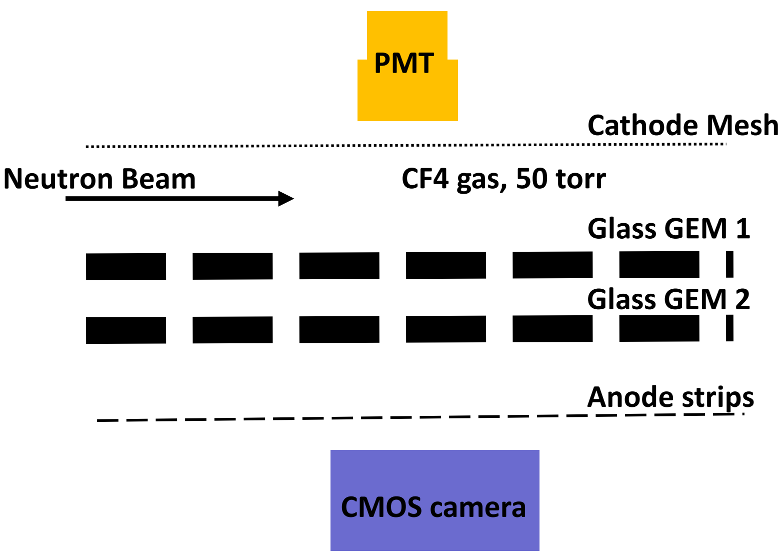
- High yield DD and DT neutron generators

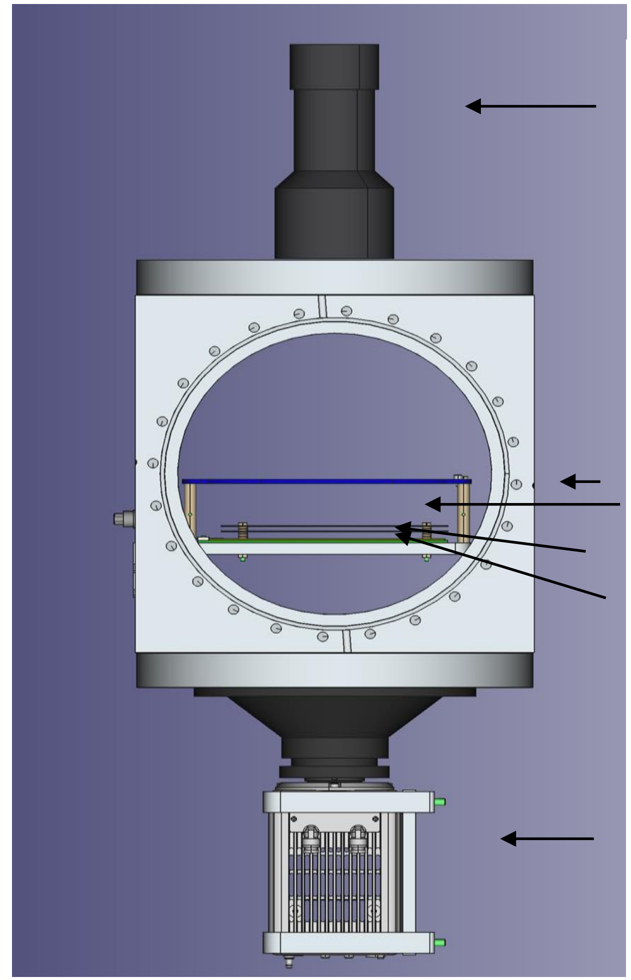
- The NILE facility at RAL, UK

- 3D images: Optical Time Projection Chamber (O-TPC)

The Optical Time Projection Chamber

- **Our O-TPC:**
  - **3D images:**
    CMOS camera + Striped anode

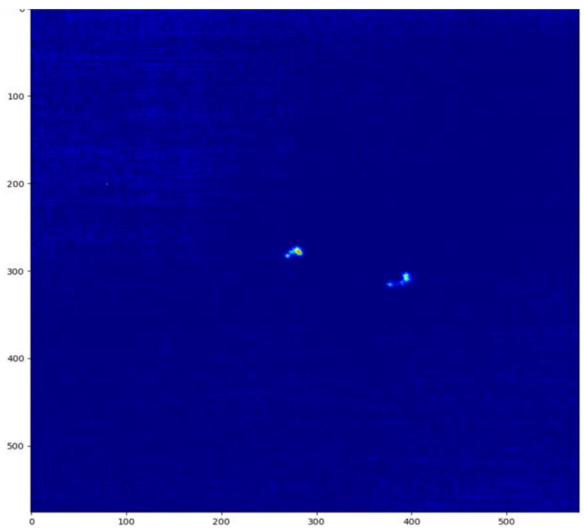


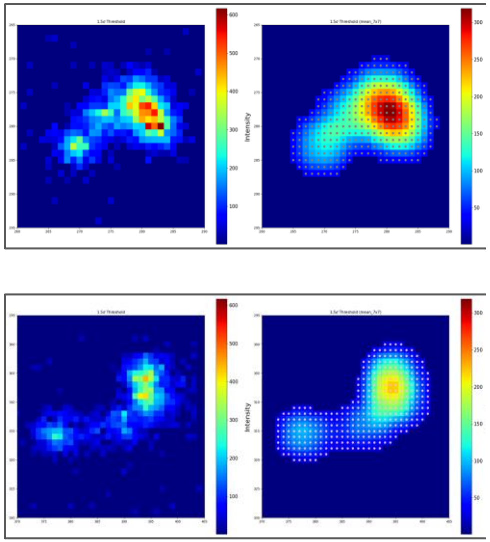


- **Aluminium chamber: 25.4 cm cube**
- **TPC active area: 10 cm x 10 cm**
- **Drift gap: 3 cm**
- **Amplification with 2 x standard glass-GEM (2 mm transfer gap)**
- **Anode: 15 cm x 15 cm with 120 readout strips (2 mm induction gap)**

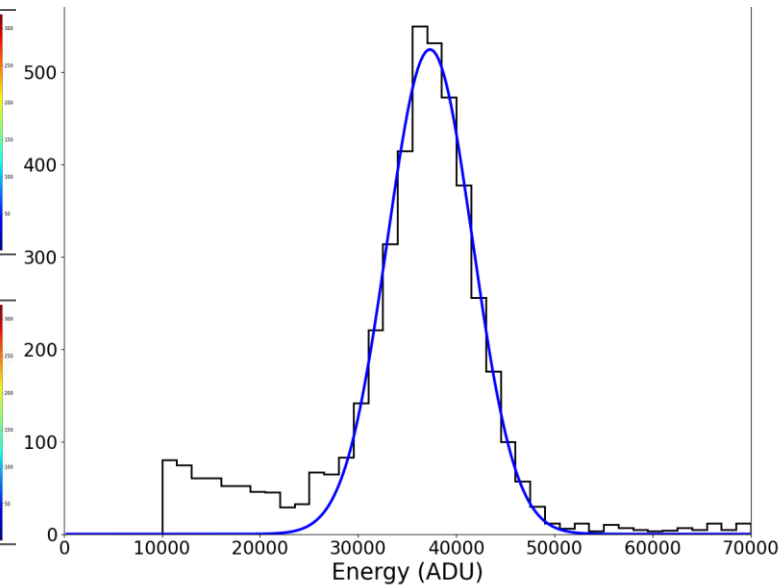
The Optical Time Projection Chamber

- **2D imaging capabilities:**
  - **Measurements with x-rays from Fe-55, GDD group at CERN**





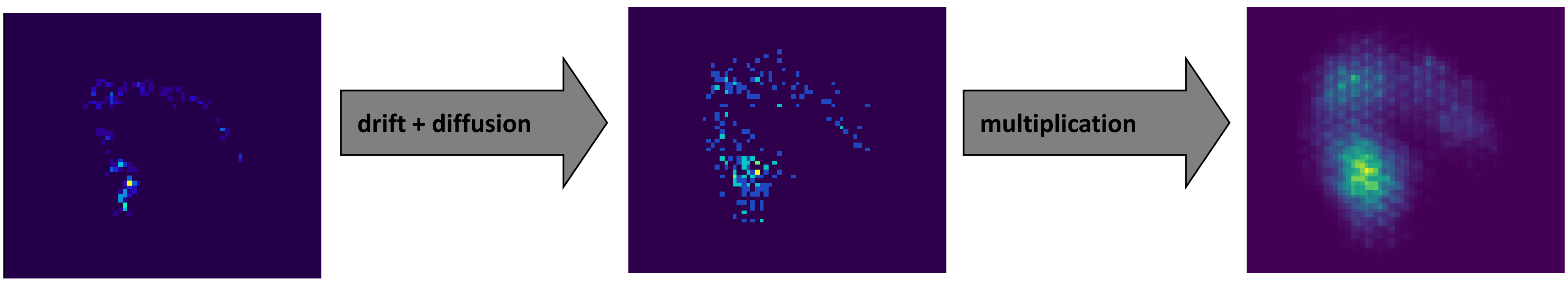
Energy resolution %27

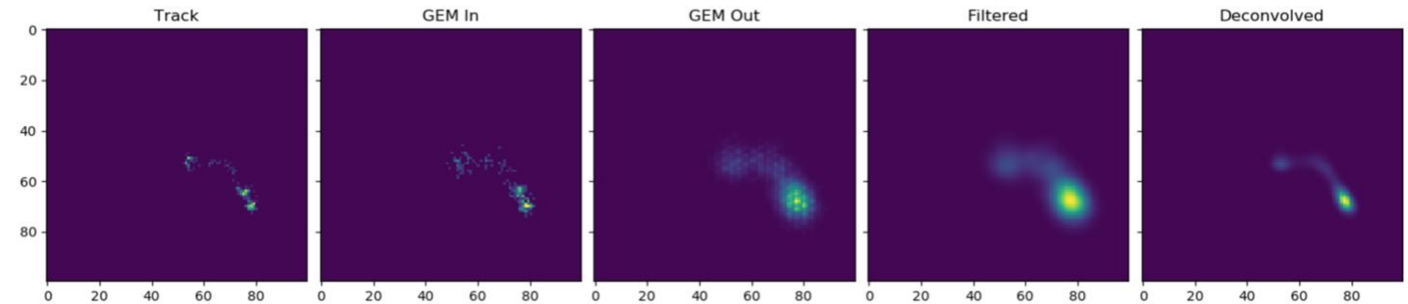


- **A few mm long tracks, Head and Tail information**
- **The image quality can be improved by minimizing the effect of the diffusion of electrons** → **Deconvolution**

The Optical Time Projection Chamber

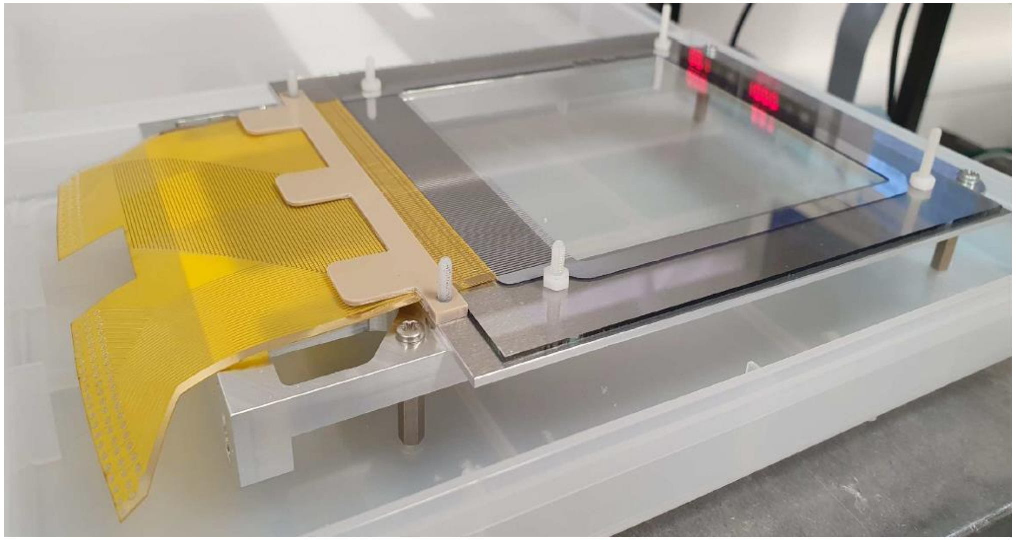
- **The image deconvolution method:**
  - **PSF: a Gaussian function**
  - **GEM pattern was removed by using a filter in the frequency domain**
  - **The technique was examined using simulated events:**



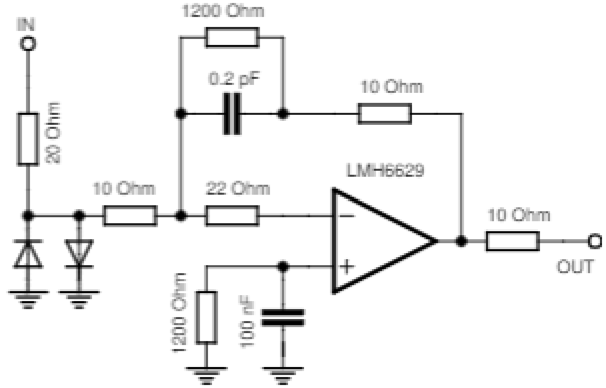


The Optical Time Projection Chamber

- **The z-coordinate: Signal from anode strips**
  - **Indium Tin Oxide (ITO): Optically transparent, Electrically conductive**
  - **Anode strips: 0.6 mm wide, 0.8 mm pitch**
  - **A multi-channel current-sensitive preamplifier board has been developed**



Amplifier circuit



- **Signals will be recorded with a 60 channels digitizer,**
- **8-bit resolution, 2 ns sampling interval**

3D Reconstruction of the Events

- **Simulation study: ITO pulses were fully simulated**
  - **Ionization tracks were generated: SRIM (NR) and Degrad (ER)**
  - **Tracks were diffused using Magboltz data**
  - **Induced signals were calculated with the code chain:**

Gmsh →Elmer →Garfield++

Gmsh is used to define the geometry,
Elmer calculates electrostatic fields,
Garfield++ drifts electrons and calculates the resulting signals.

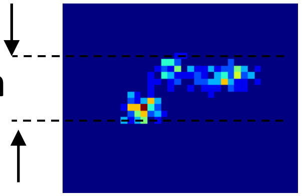
  - **Electronic transfer functions were applied**

Amplifier transfer function

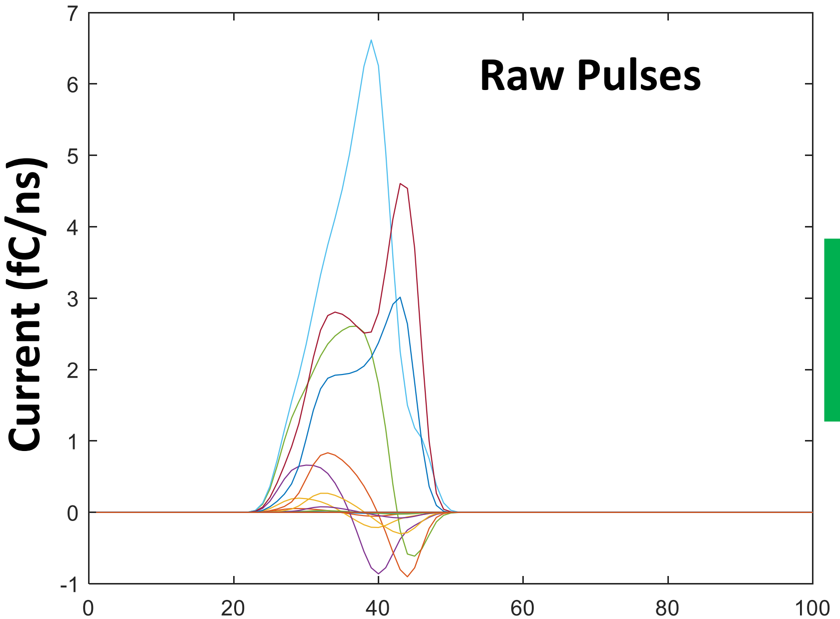
Cross-talk effect

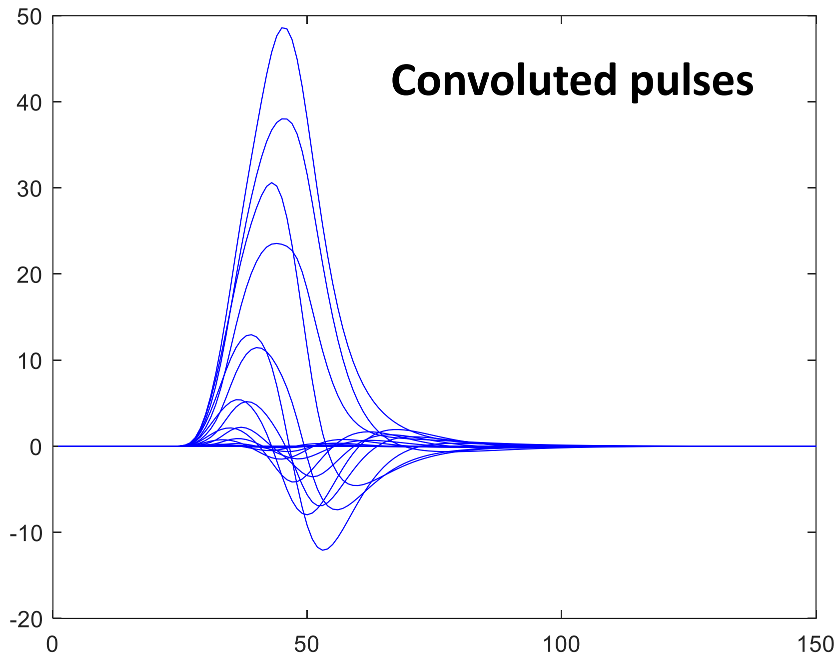
3D Reconstruction of the Events

- **Example of simulated pulses**



$$i(t) = q(t)v.E_w$$





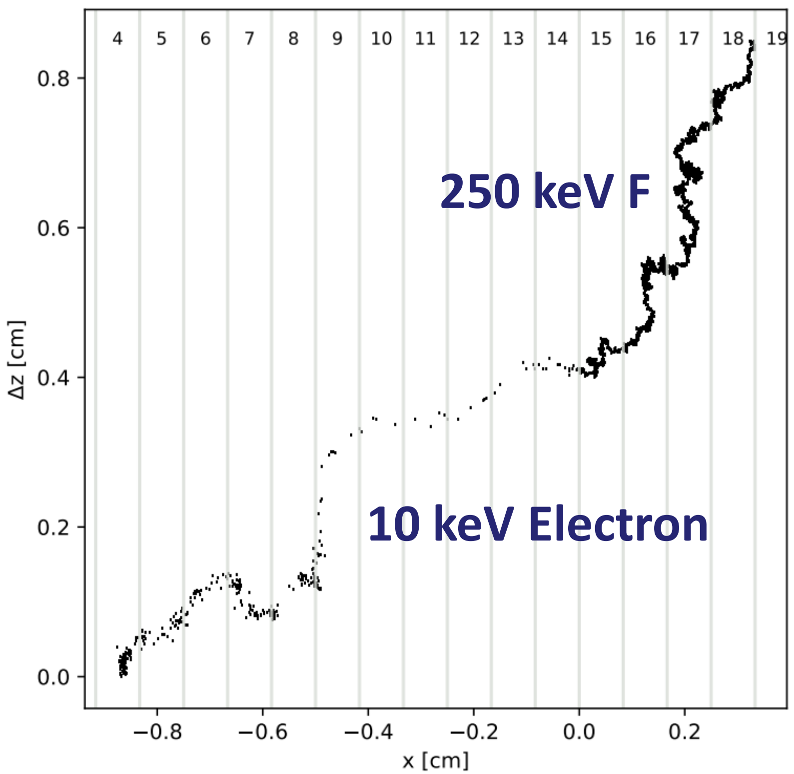
Time (ns)

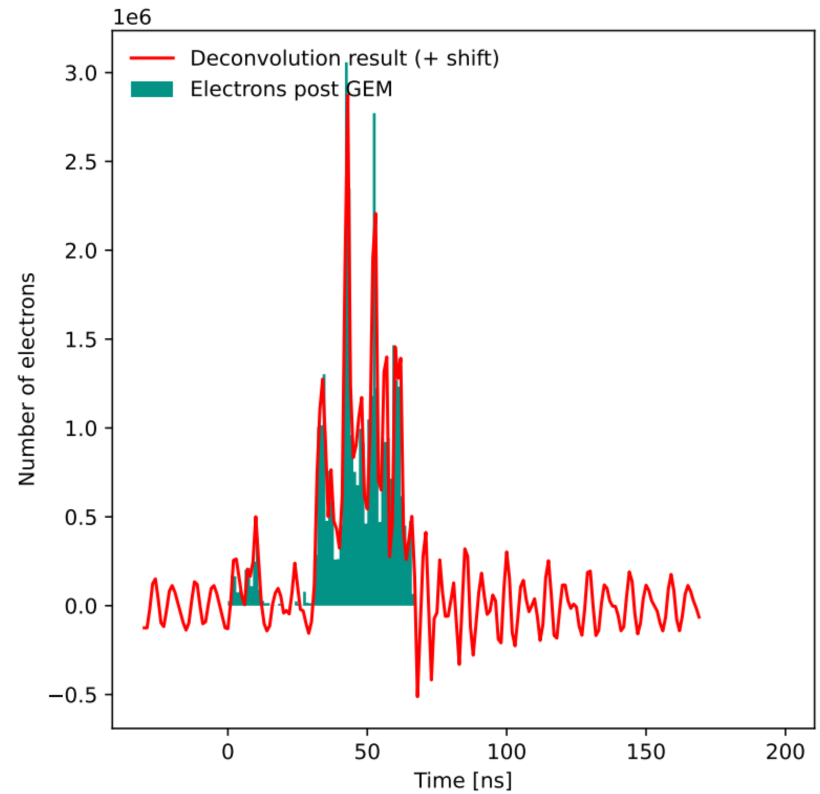
- **Electronic responses smear the information in the time profile of the pulses**

Deconvolution

3D Reconstruction of the Events

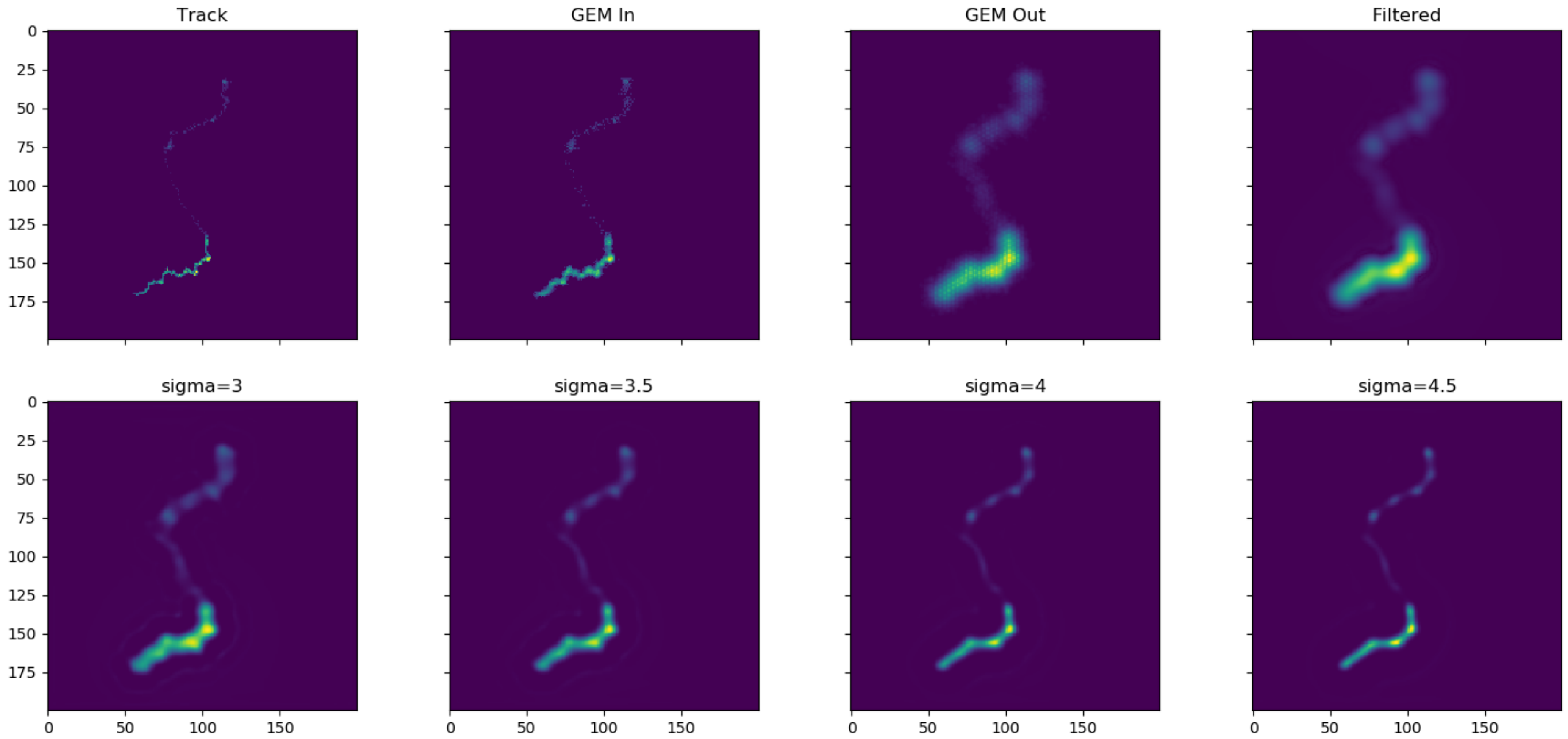
- **2D deconvolution technique:**
  detector response, amplifier transfer function, cross-talk between strips
- **Similar technique developed by MicroBooNE collaboration, 2019**
- **Simulated Migdal event:**





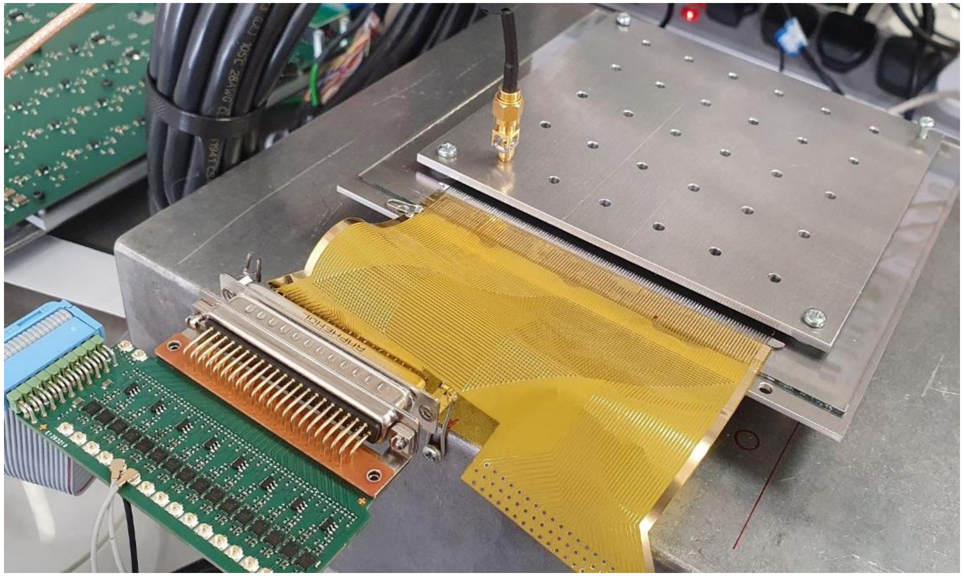
3D Reconstruction of the Events

- **Migdal-like event: Deconvoluted image**



3D Reconstruction of the Events

- **Experimental measurements of the system responses**



- **A probe was designed to inject charge to strips**
- **The responses of strips will be recorded to be used in the deconvolution**

Summary

- An O-TPC was designed and is now under construction for the Migdal experiment.
- Deconvolution technique was successfully applied to the camera images to reduce the effect of electrons diffusion.
- 2D deconvolution technique has been successfully used for the extraction of z-information.
- Experimental measurements will be started very soon.

Thank you !