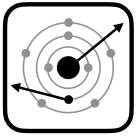


MIGDAL

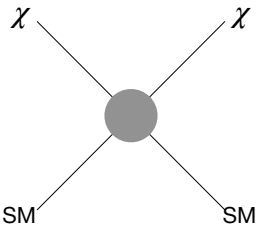
Migdal In Galactic Dark mAtter expLoration

Tom Neep, on behalf of the MIGDAL collaboration

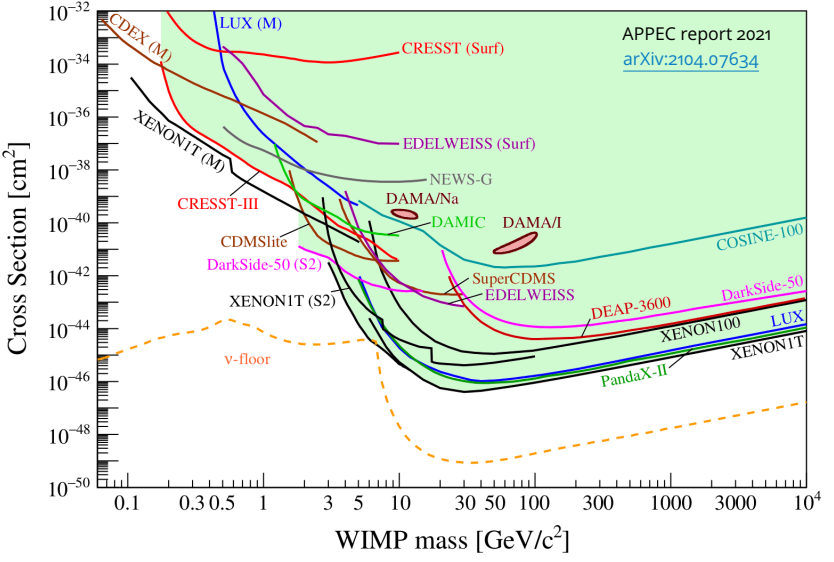
Dark Matter UK, University of Birmingham

May 5, 2022

Where are we?



- Direct dark matter searches have made great strides in excluding WIMP-like dark matter
- Increasing interest in pushing towards lower masses, $\mathcal{O}(100\ \mathrm{MeV})$



The Migdal effect

- Typically we assume that the electron cloud in an atom move instantaneously with a nuclear recoil
- In reality the electrons take a short amount if time to catch up with the recoiling nucleus
- This can cause ionisation and excitation of the atoms, emission of one or more **Migdal electrons**
- Electronic recoil detection increases the sensitivity of our detectors to light WIMPs
- First described by A. Migdal in 1939 A. Migdal, ZhETF, 9, 1163-1165 (1939), ZhETF, 11, 207-212 (1941)

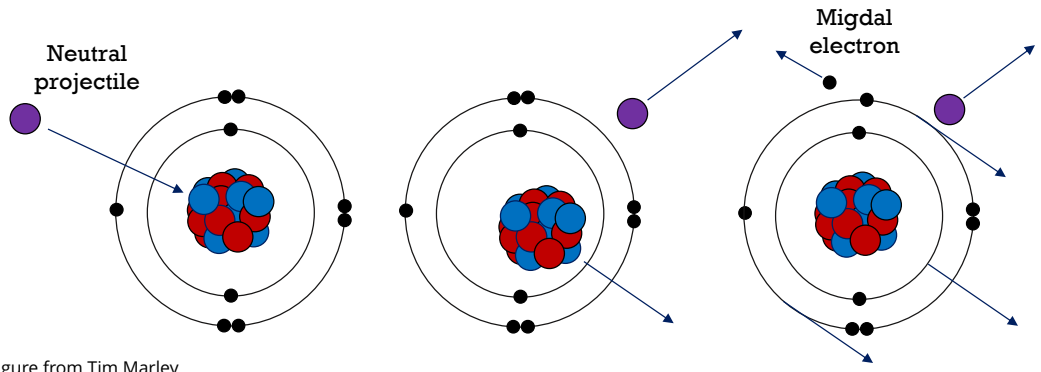


Figure from Tim Marley

The Migdal effect

- The Migdal effect has been observed in:
  - α decay ✓ Phys. Rev. C 11 (1975), 1740-1745, Phys. Rev. C 11 (1975), 1746-1754
  - β^- decay ✓ Phys. Rev. 93 (1954), 518-523
  - β^+ decay ✓ Phys. Rev. A 97 (2018), 023402
- **However,** it has not yet been observed in nuclear scattering, the key process we want to use it in

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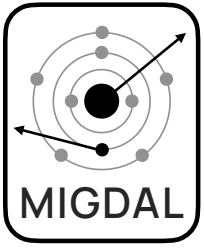
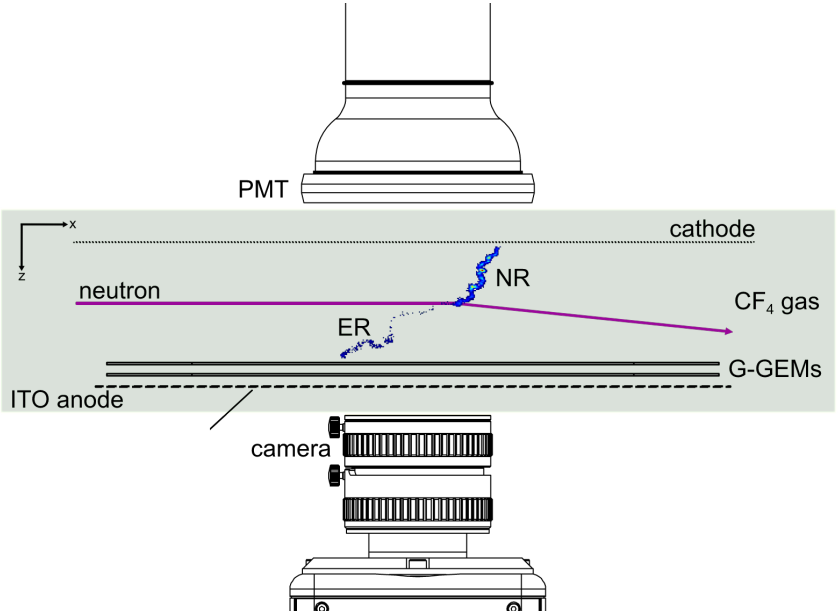
- **However,** it has not yet been observed in nuclear scattering, the key process we want to use it in

---

- The **M**igdal **I**n **G**alactic **D**ark M**A**tter Exp**L**oration experiment aims to make an unambiguous observation of the Migdal effect in nuclear scattering using an optical time projection chamber
- **Two phases:**
  1. Measure the Migdal effect in pure **Carbon tetrafluoride** (CF_4)
  2. Observe the Migdal effect in CF_4 + **other gas (Ar, Xe, . . .)** mixtures
- **Observe** the Migdal effect in the regime relevant for DM searches
- **Searching** for nuclear recoils with accompanying electronic recoils from the same vertex

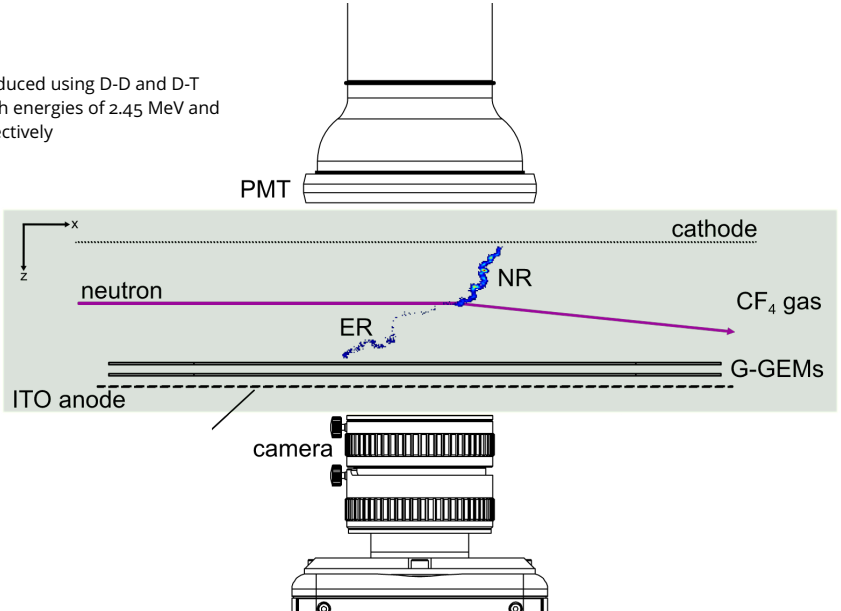


The MIGDAL detector: An Optical TPC



The MIGDAL detector: An Optical TPC

- **Neutrons** produced using D-D and D-T generators with energies of 2.45 MeV and 14.1 MeV, respectively



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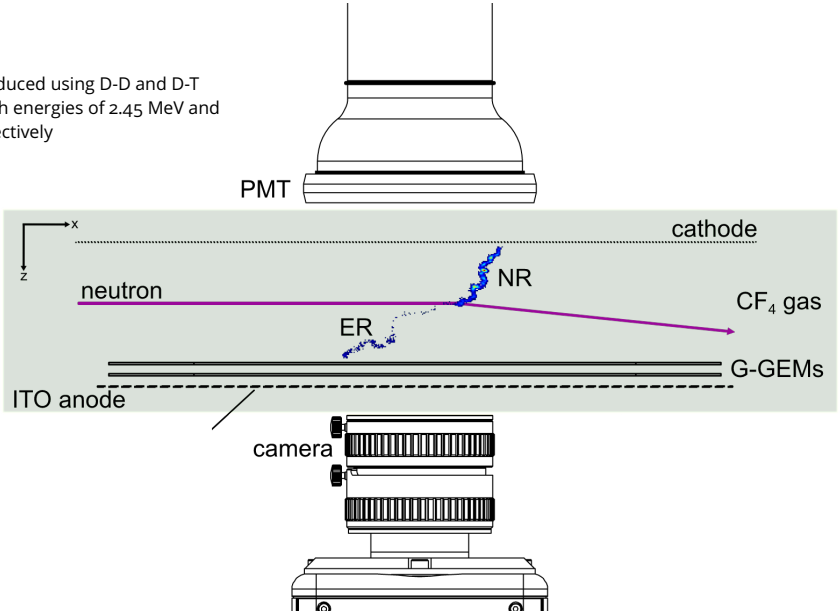

- Electrons avalanche in **double glass GEM**

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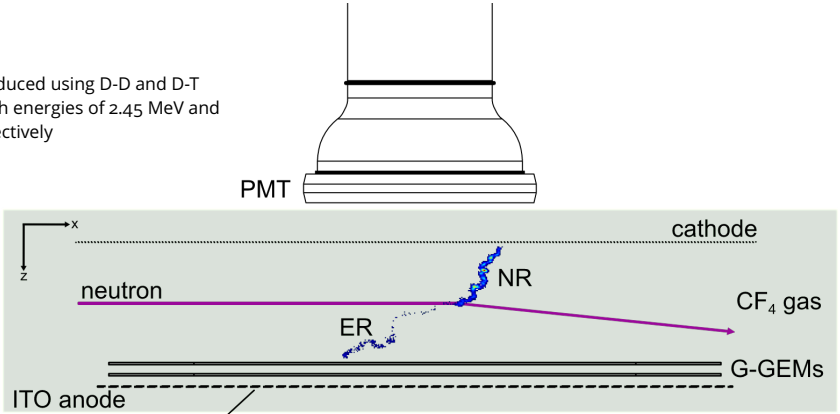

- Electrons avalanche in **double glass GEM**

- **ITO** (Indium tin oxide) **anode** is transparent, allowing light to pass through
- Measures the **charge** produced
- Strips running perpendicular to the x-direction give information in the **x—z plane**

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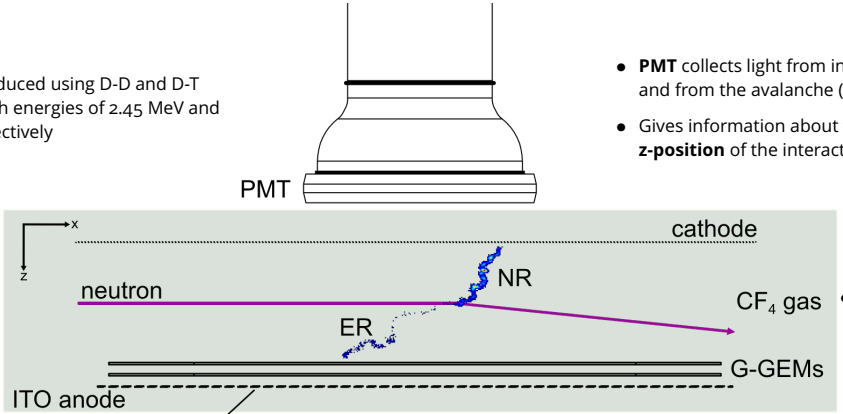

- **PMT** collects light from initial ionisation (**S1**) and from the avalanche (**S2**)
- Gives information about the **absolute z-position** of the interaction
- Electrons avalanche in **double glass GEM**
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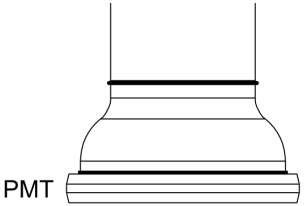

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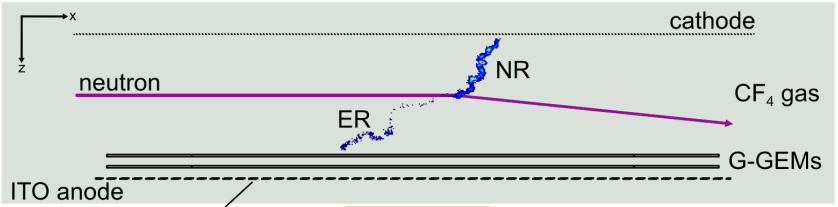

- Electrons avalanche in **double glass GEM**

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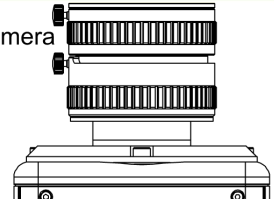
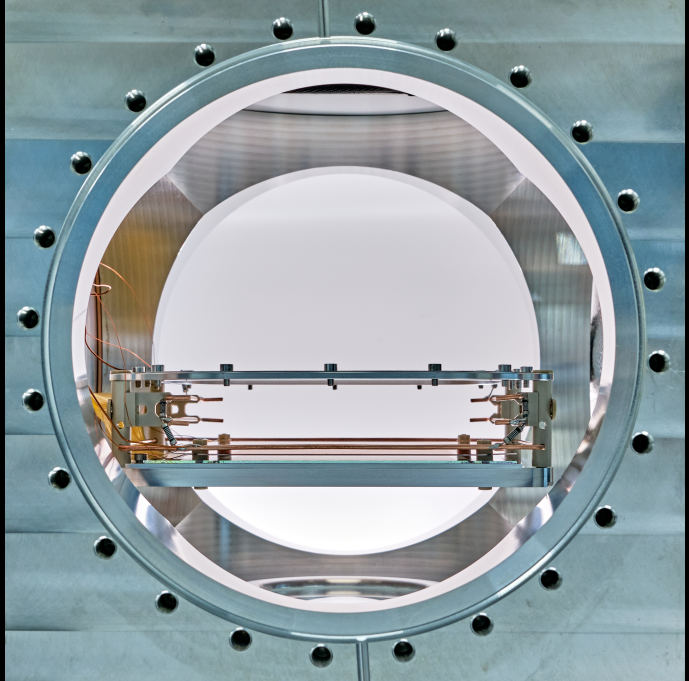
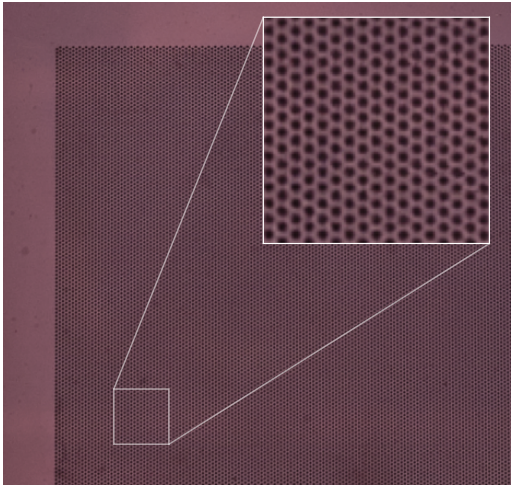


- **CMOS camera** records the light produced in the avalanche
- Gives us an image in the **x—y plane**
- Information can be combined with ITO for **3D track reconstruction**



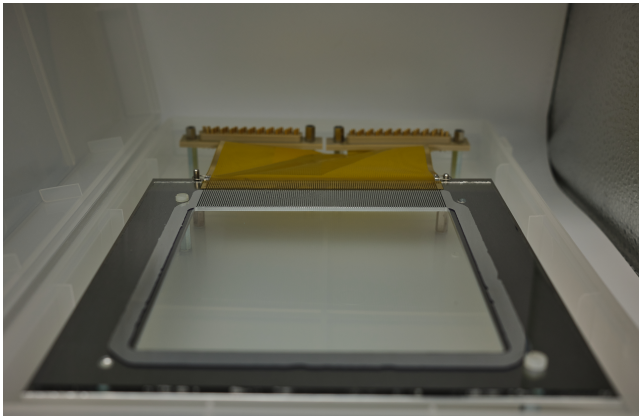
Gas Electron Multipliers



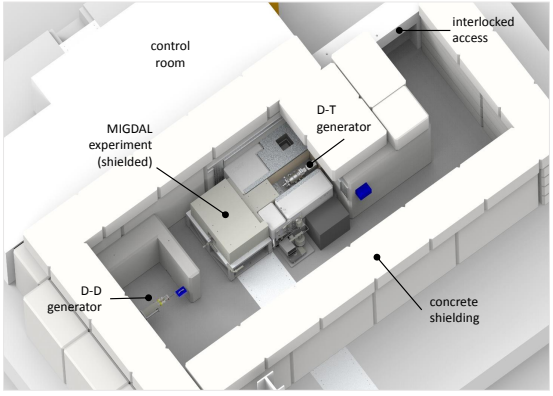
- **Gas Electron Multipliers** are micropattern gas detectors
- Many tiny holes, 170μm in diameter, 280μm pitch
- Glass sandwiched with copper (0.55 mm thick glass with 2 μm of copper on either side)
- Voltage applied across dielectric, results in strong electric field inside holes where **Townsend avalanche** occurs
- We use a double GEM

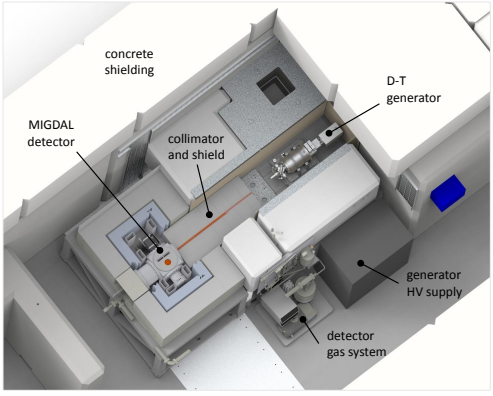
ITO anode

- 120 **Indium tin oxide (ITO)** strips with 60 readout channels allow us to readout the charge produced
- Strips 0.6 mm wide with a 0.8mm pitch
- Digitised with 2 ns sampling rate
- Charge arrival times give us information about the depth of the track in the z-direction
- Crucially, the anode is **transparent** so that light produced in the avalanche can be recorded by the CMOS camera



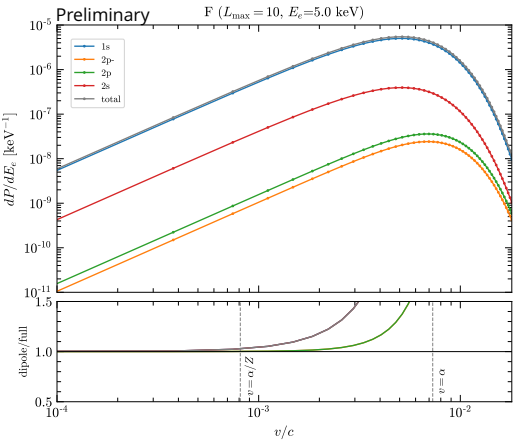
The NILE facility at ISIS, RAL





Rates

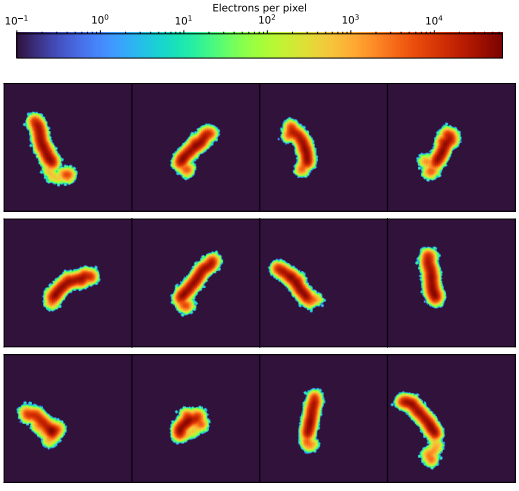
- **One billion neutrons per second** produced by the D-D generator
- Expect ≈ **60 nuclear recoils per second** in the TPC
- Migdal event rate $\mathcal{O}$(**10 events**) per day
- **Challenging!**



Plot from Chris McCabe

End-to-end simulation

- We have a full end-to-end simulation combining:
  - DEGRAD
  - SRIM/TRIM
  - Garfield++
  - Magboltz
  - Gmsh/Elmer & ANSYS
- Plots show Migdal-like events with a 250 keV NR and a 5 keV ER
- Studying various methods to identify Migdal events (dE/dx, track lengths, etc)
- Currently estimate $\approx$ 75% Migdal identification efficiency for the most promising energies



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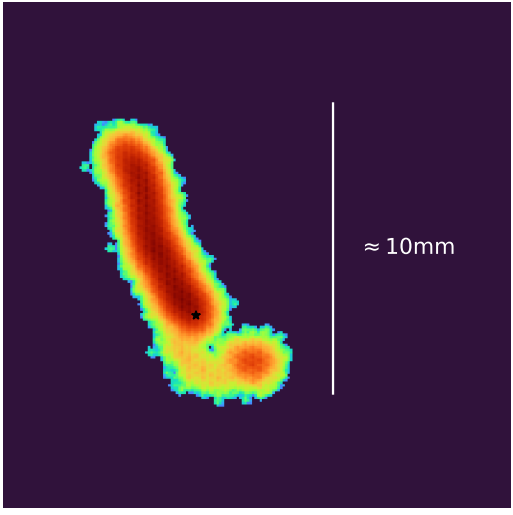
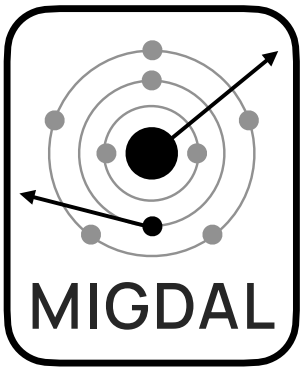


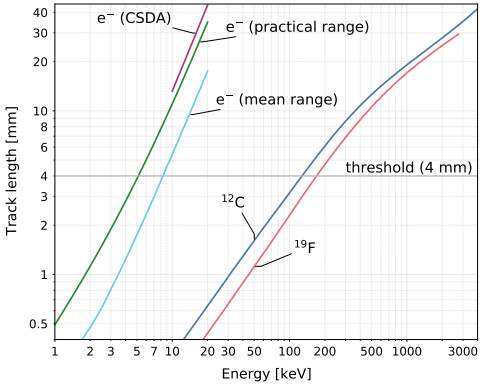
Summary

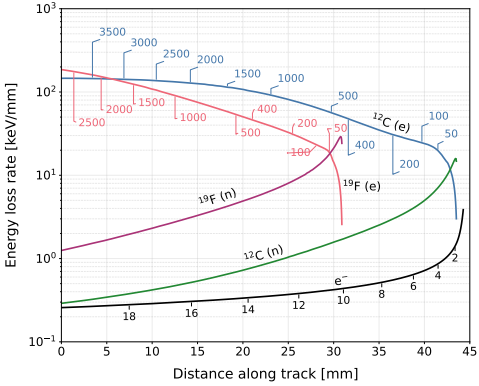
- The **MIGDAL** experiment aims to perform an unambiguous observation the Migdal effect
- Design of the experiment is complete
- End-to-end simulation chain in place
- Detector is constructed and is being tested
- Calibration with ^{55}Fe and fission-fragment sources are about to begin
- Runs with D-D generator neutrons will begin very soon!



Back-up

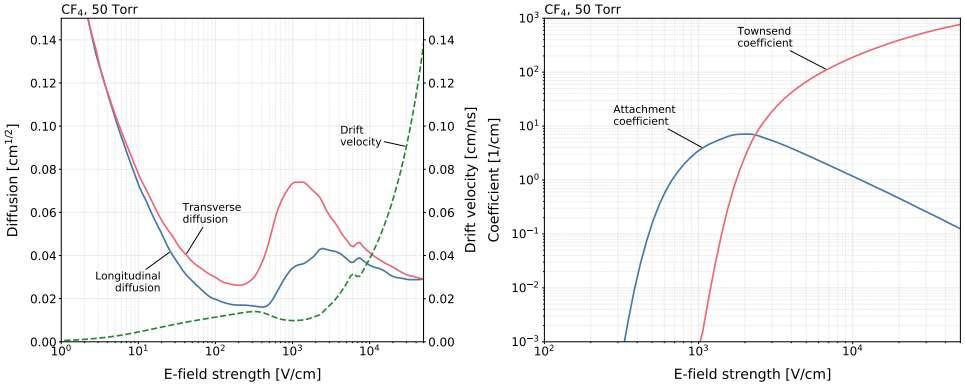
Tracks





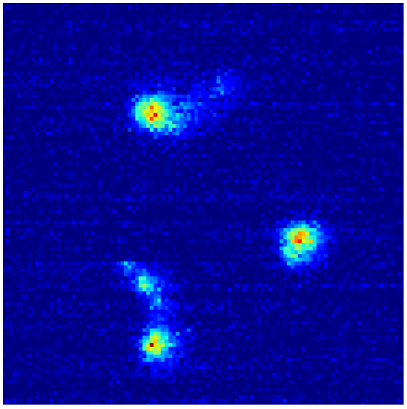
- We can exploit different track lenghts and dE/dx to distinguish nuclear and electronic recoils
- Nuclear recoils deposit more of their energy at the beginning of the track, while electrons deposit more energy at the end of the track

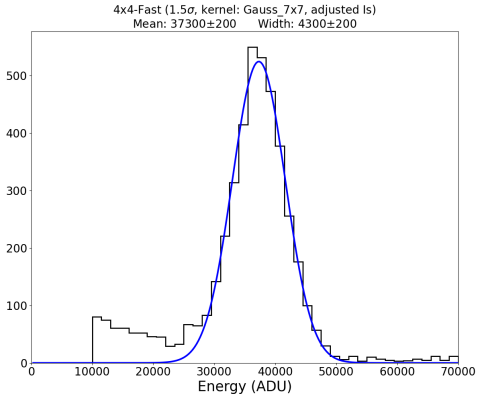
Gas properties



- Gas properties for CF_4 at 50 Torr, calculated with Magboltz
- Electric fields chosen to minimize diffusion and attachment

GEM tests @ CERN





- Successful tests have been performed using glass-GEMs by the GDD group at CERN with CF_4 at 50 Torr
- Tracks from ^{55}Fe (5.9 keV γ) decays are well resolved with an energy resolution of 27%
- Track head and tail clearly resolved for low energy electrons

Experimental setup