MIGDAL

Migdal In Galactic Dark mAtter expLoration

The MIGDAL experiment:

Towards observation and measurement of the Migdal Effect to help low mass WIMP searches

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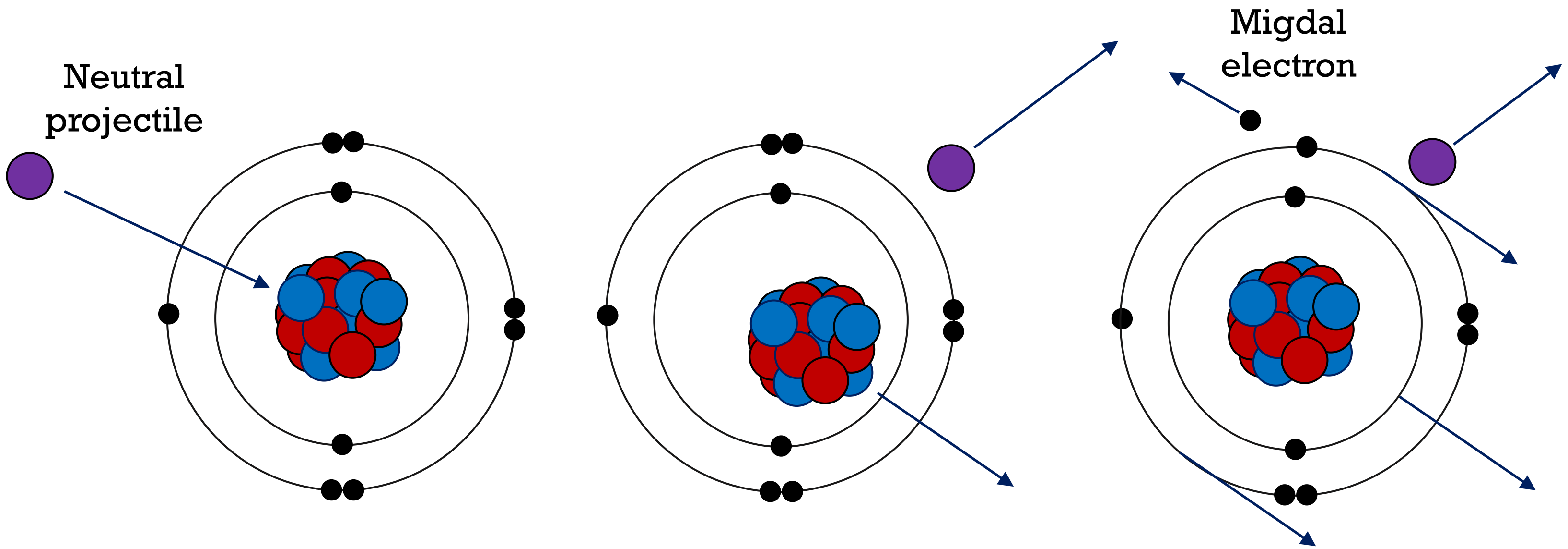
For the MIGDAL collaboration

Outline

- The Migdal effect and Dark Matter
- Observation of the Migdal effect in radioactive decays
- The MIGDAL experiment
- Low-pressure gas Optical-TPC
- Tests with low energy electrons
- Status & Conclusions

The Migdal Effect

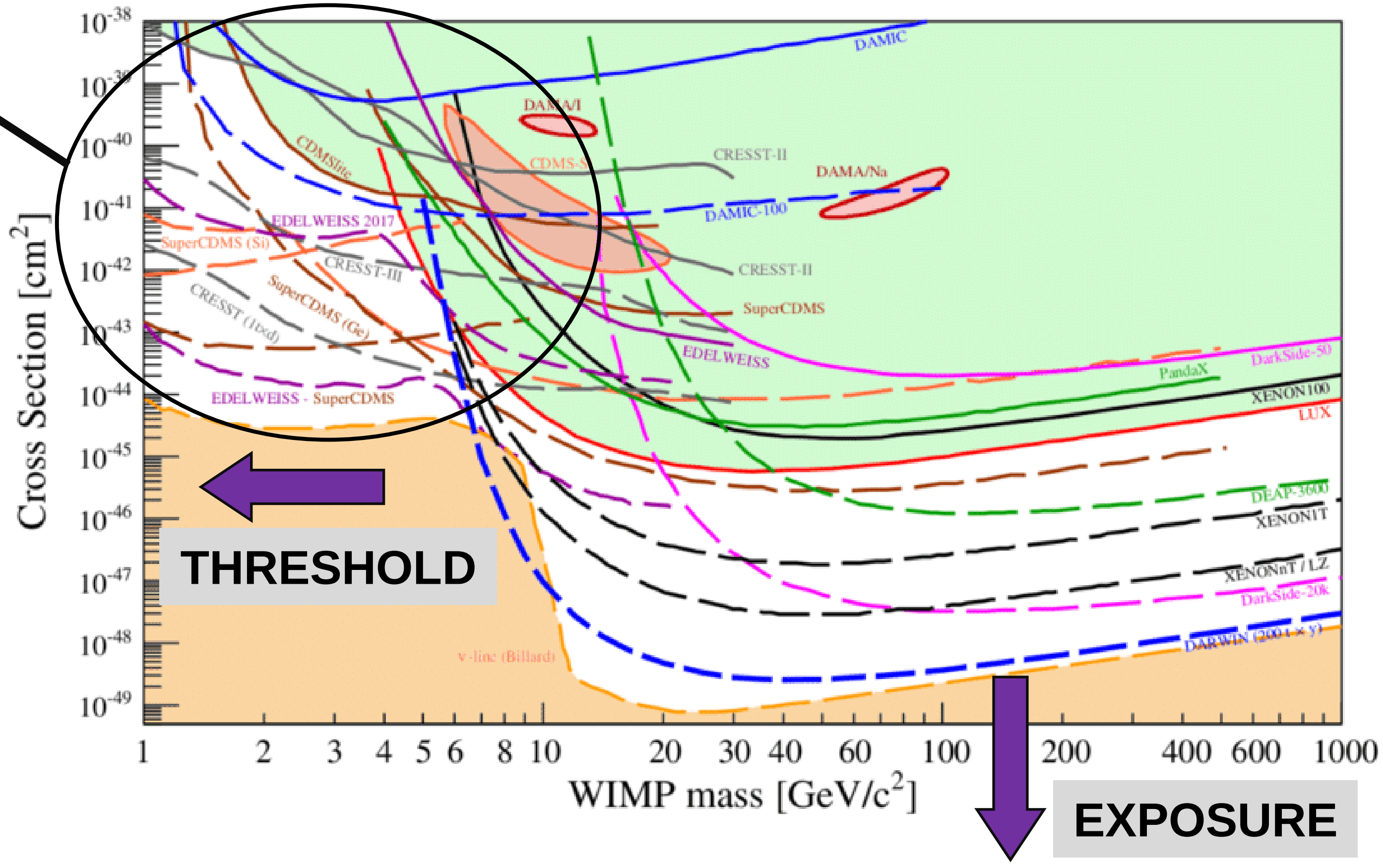


- DM searches use signal from nuclear recoils as a signature of the DM interaction with the detector medium.
- When a nucleus moves relative to the electron cloud, an individual electron might be ejected leading to ionisation.
- Sub-threshold nuclear interactions may be accompanied by a more detectable electron recoil.

How does this effect help DM searches?

- Parameter space reachable in principle by detectors with a low mass target material.
- Low energy NRs are not detectable in high mass target elements such as Xe/Ar due to kinematics, technology limits, and quenching.
- Electrons are not affected by quenching.
- If Migdal is experimentally confirmed, ionisation electrons can become a signal from low mass DM particles (if the ER background is sufficiently low).

LHCSki 2016 - A First Discussion of 13 TeV Results



Huge attention from the DM community

- Migdal effect calculations reformulated by M. Ibe et al. with ionisation probabilities for atoms and recoil energies relevant to Dark Matter searches.
- Papers in the past from:
    - LUX, XENON1T, EDELWEISS, CDEX-1B, SENSEI, DarkSide, and more
- Including targets:
    - Ge, Si, Xe and Ar
- Claiming sensitivity to WIMPs with mass well below 1 GeV.

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Migdal effect in dark matter direct detection experiments

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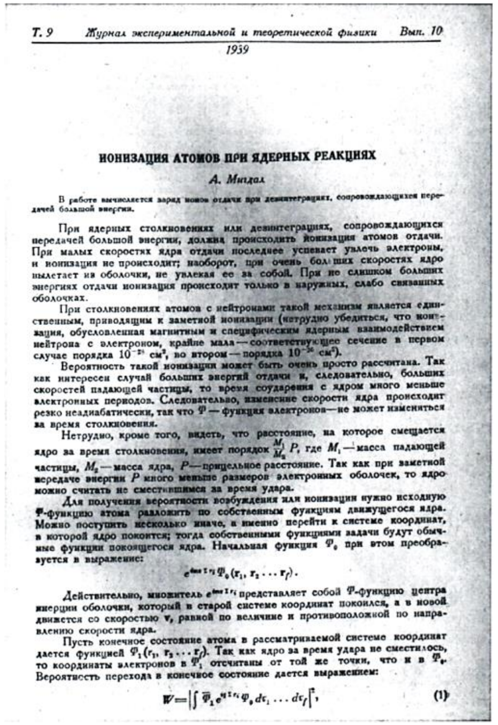
So far ~100 citations of this paper

What do we know about the Migdal effect?

- 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 [?]



Т. 9 Журнал экспериментальной и теоретической физики Вып. 10
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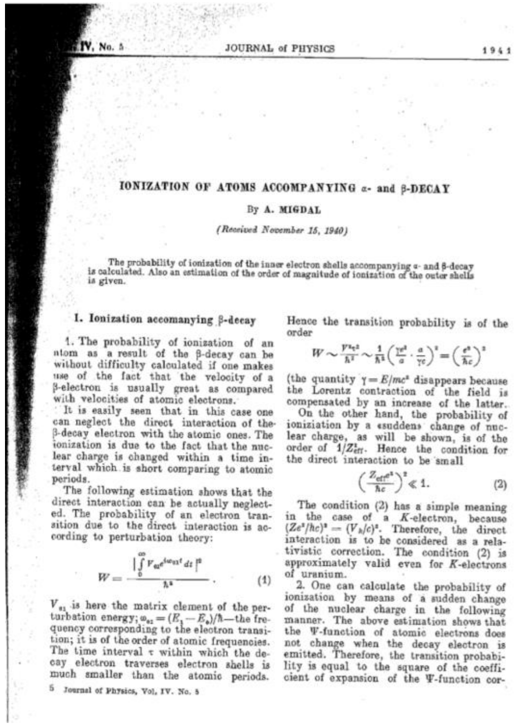
ИОНИЗАЦИЯ АТОМОВ ПРИ ЯДЕРНЫХ РЕАКЦИЯХ

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 accompanying β-decay

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"

[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 6He+Ions, PRL 108, 243201 (2012)
[6] X. Fabian et al., Electron Shakeoff following the β+ decay of Trapped 19Ne+ and 35Ar+ trapped ions, PRA, 97, 023402 (2018)

Migdal In Galactic Dark mAtter expLoration

- Create a dedicated environment for an unambiguous first observation of the Migdal effect in nuclear scattering with a suppressed background.
- Phase 1: Observe the effect in CF4 in high energy recoils.
- Phase 2: Observe the Migdal effect in CF4 + noble gases.

This experiment is not designed for observation and measurement of the effect at DM energy scale.

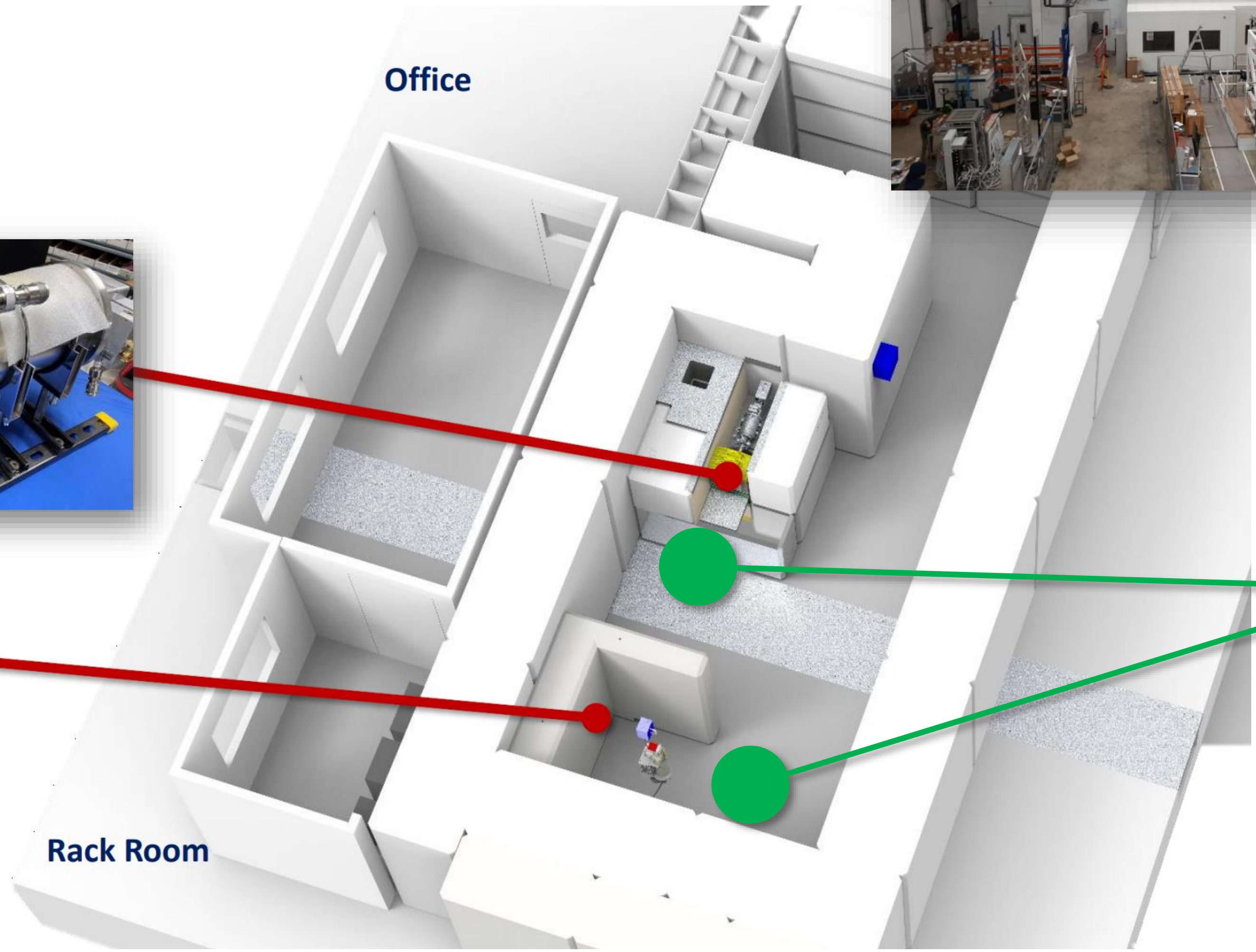
NILE facility at ISIS, RAL

14.1 MeV DT neutron source

Flux: 10^{10} n / sec

2.45 MeV DD neutron source

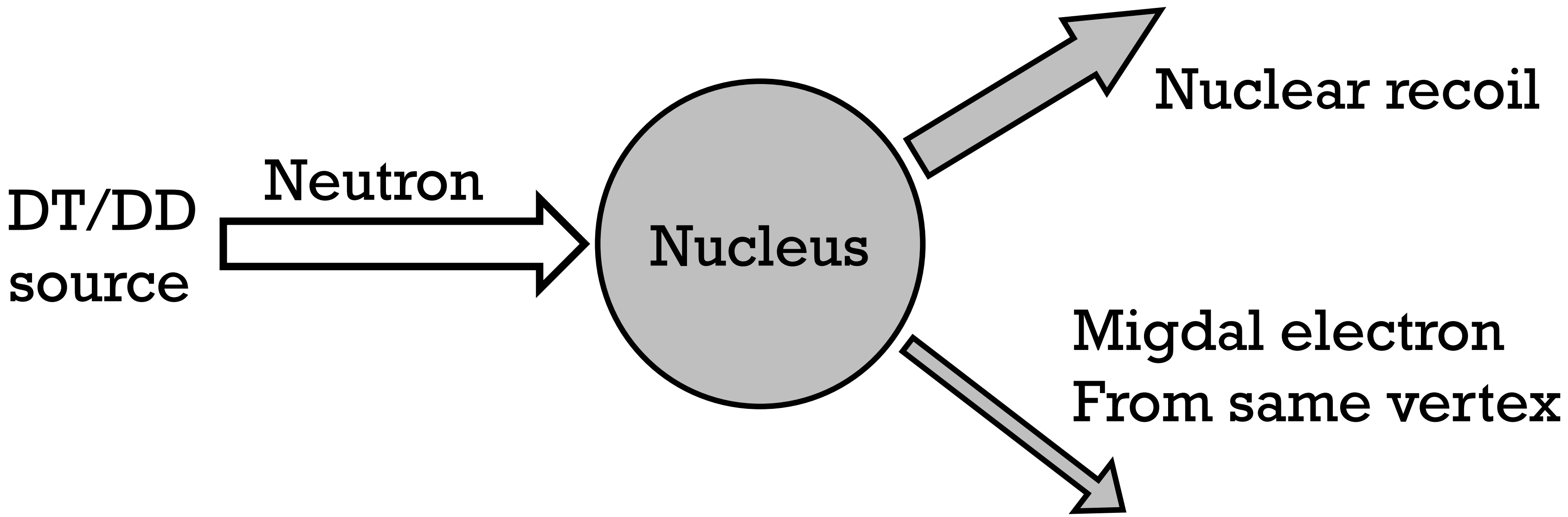
Flux: 10^{9} n / sec



Chamber positions

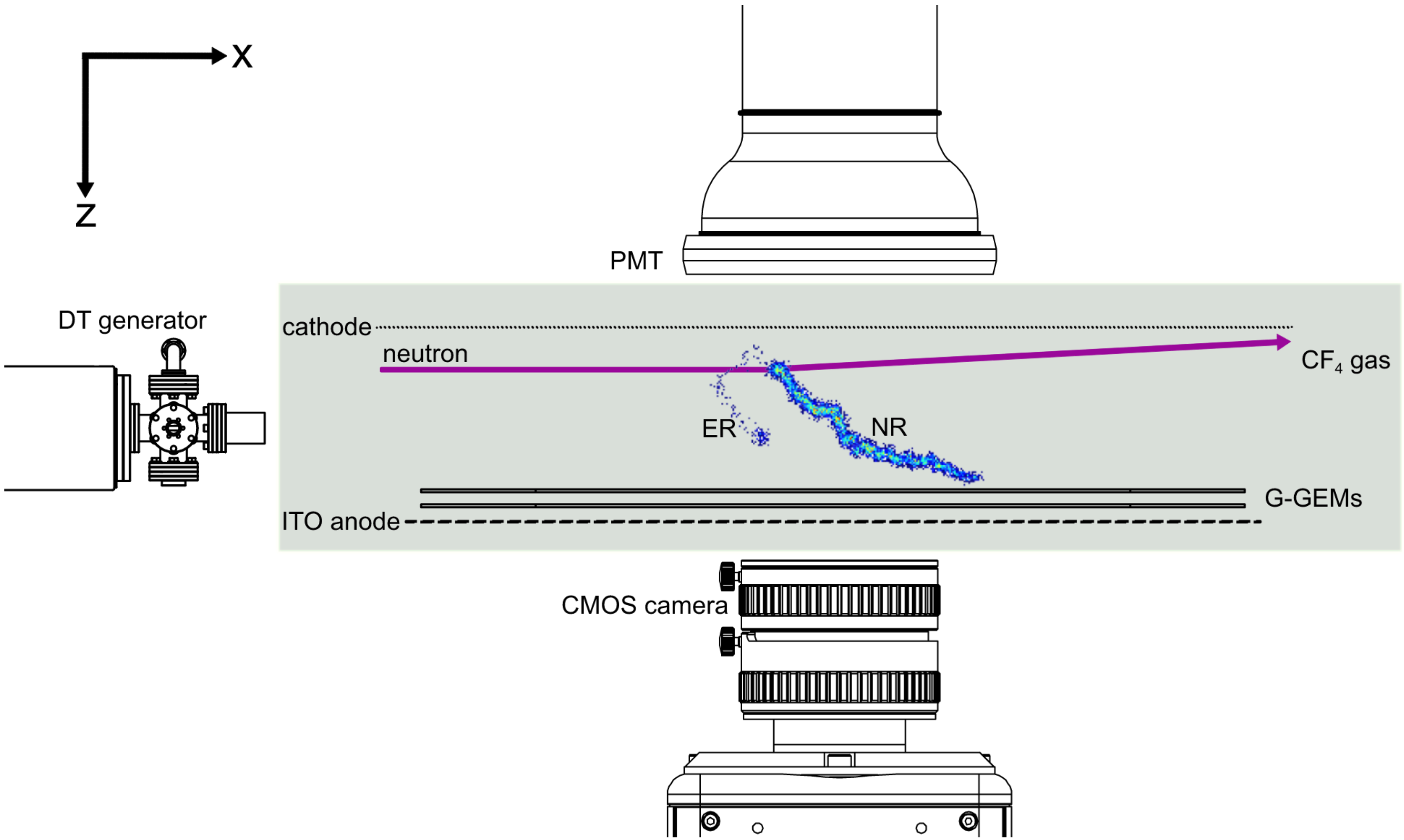
Experimental goal

- Direct observation of two simultaneously created tracks of the ionisation electron and the nuclear recoil originating from the same vertex using GEM-based OTPC.



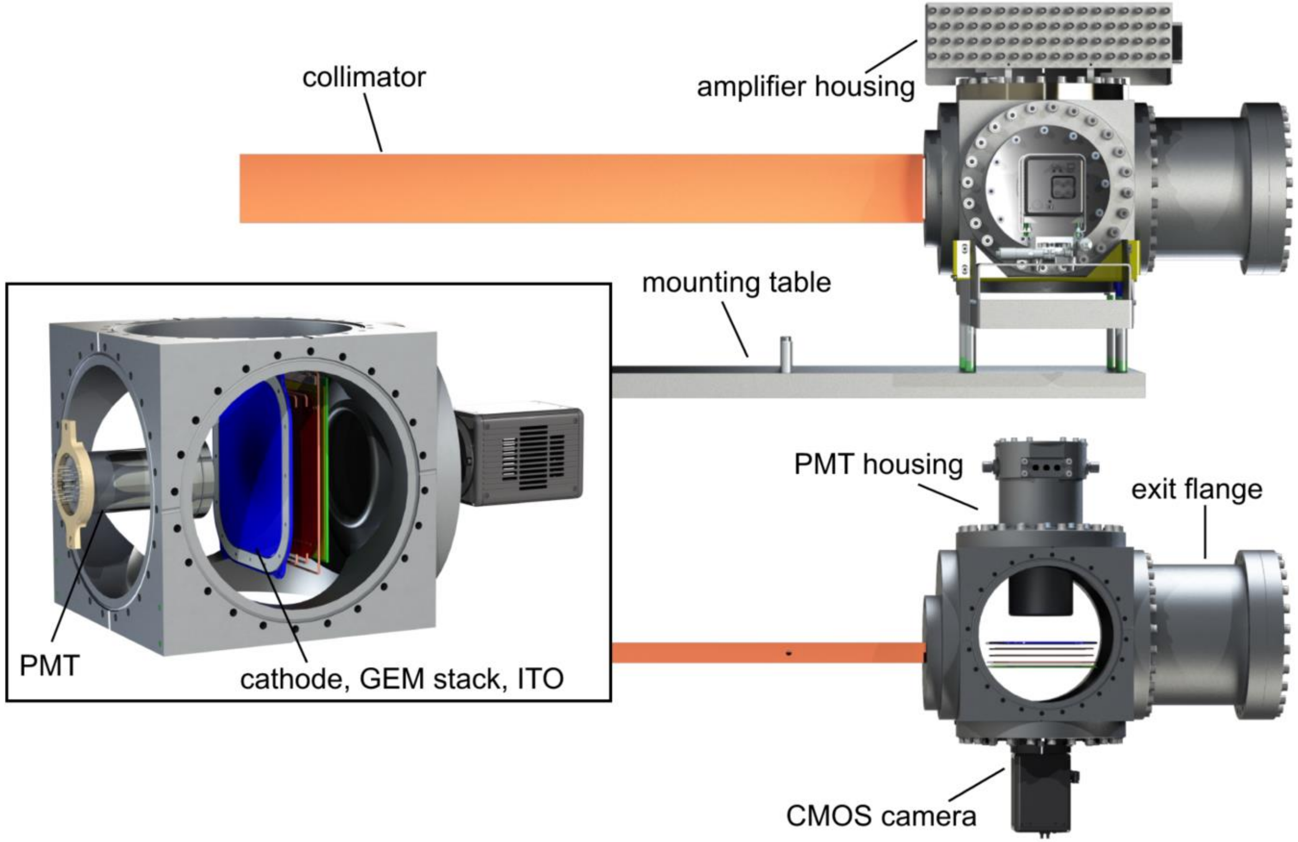
Optical Time Projection Chamber

- This is a schematic of the Migdal OTPC.
- The active area of the GEMs is 10×10 cm^2.
- The drift region is 3 cm.
- The ITO anode collects charge timing information (3D reconstruction).
- The example Migdal event contains a 10 keV electron + 250 keV fluorine recoil which has been scaled-up by a factor of 3.



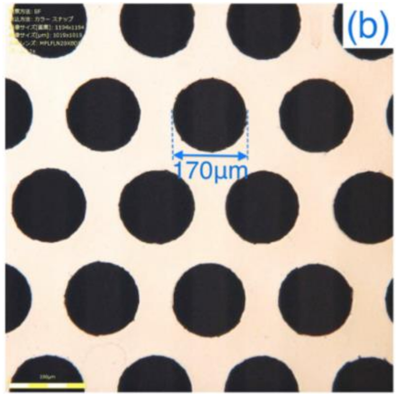
Chamber Design

- The neutrons enter the chamber through a 1 m copper collimator.
- Rate of neutrons from DT generator at the front of the TPC: ~ 400 kHz.
- Event rate in the TPC ~ 80 Hz.
- Camera is the Hamamatsu Orca-Fusion with a Schneider Xenon f/0.95 lens.



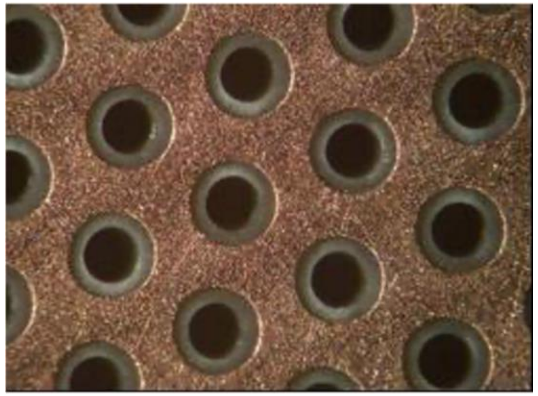
GEM tests with ^{55}Fe source

Glass GEM

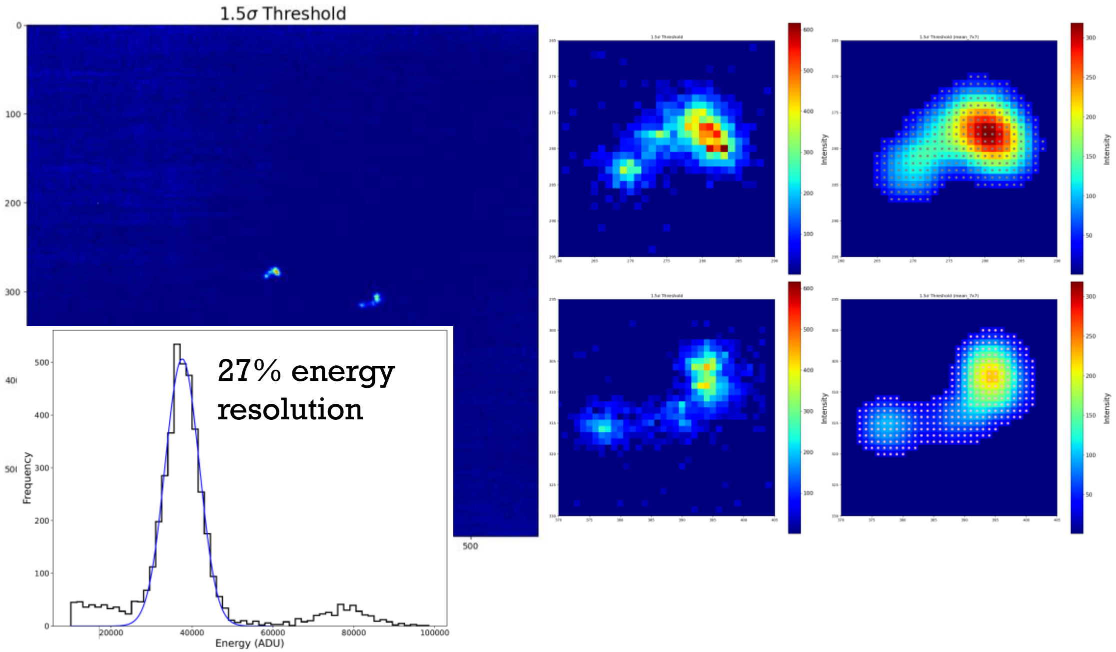


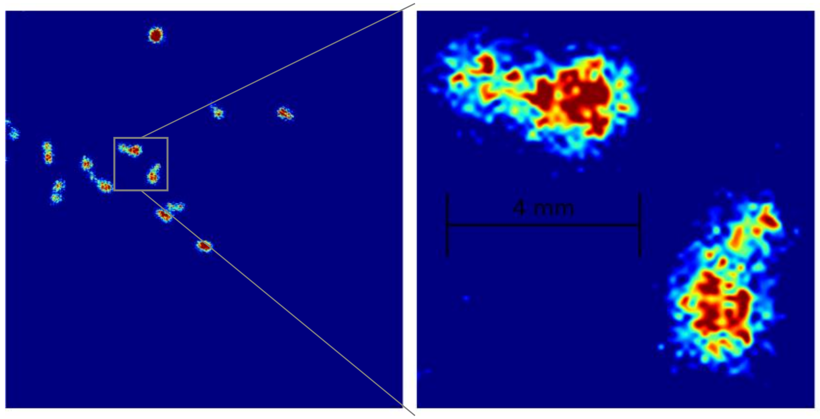
- 0.55 mm thick glass with 2 um copper on both sides.
- Pitch: 280 um
- Hole diameter : 170 um

Thick GEM



- 1 mm thick PCB with 20 um copper on both sides.
- Pitch: 700 um
- Hole diameter : 400 um

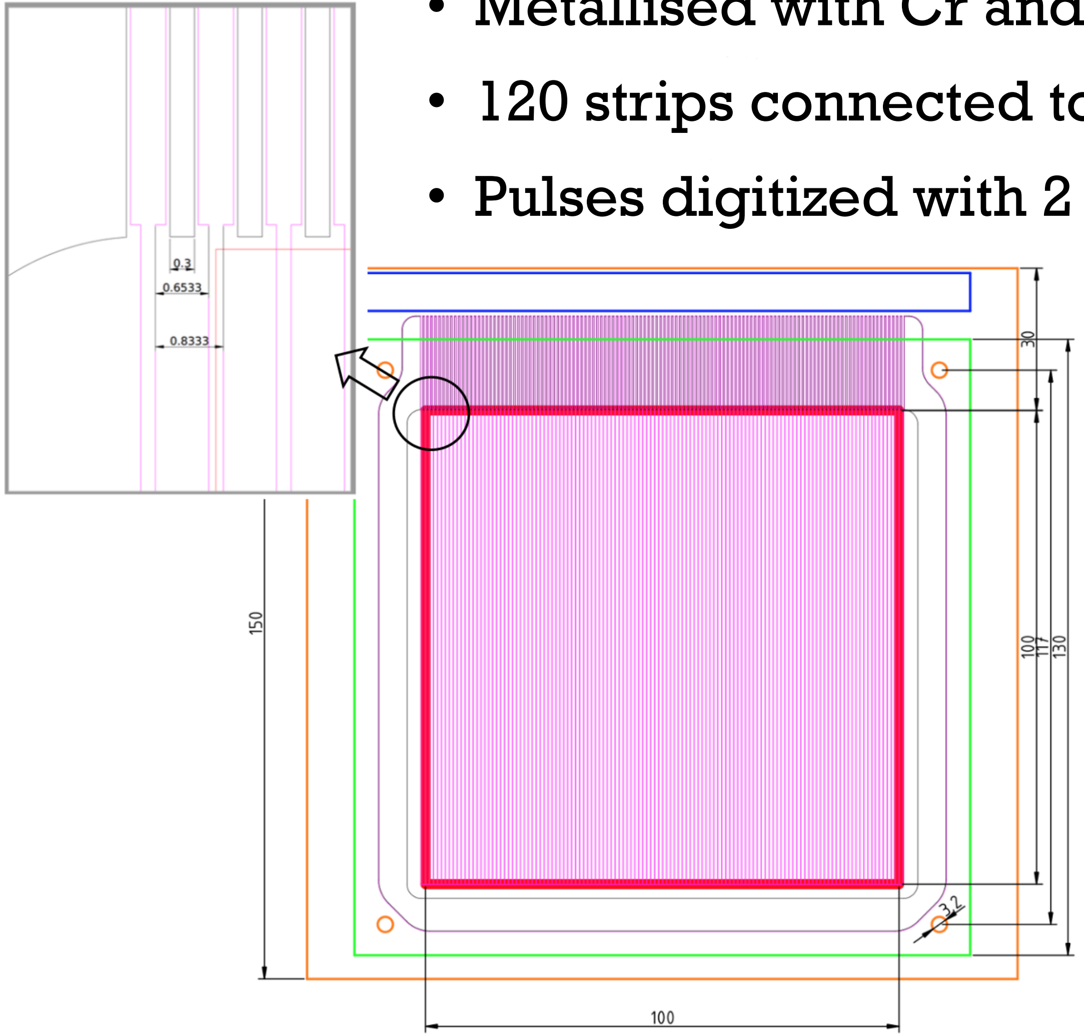


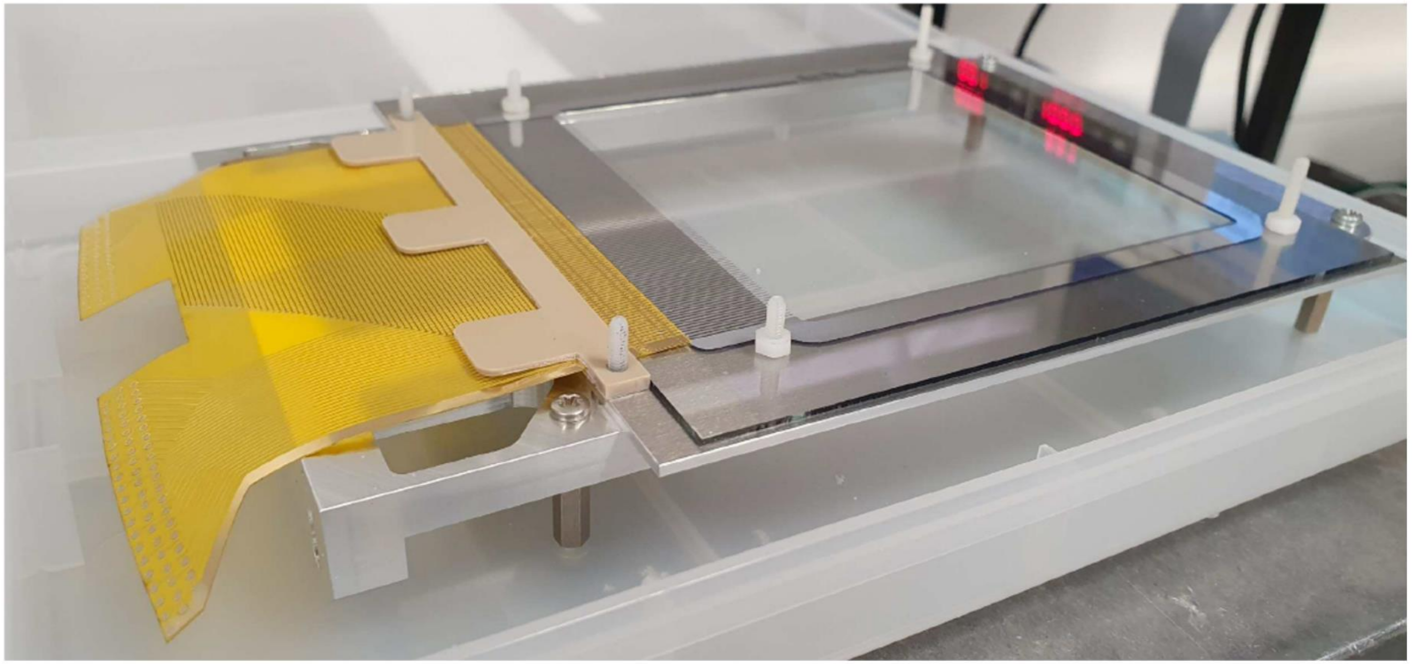


Images of low energy electron tracks produced by 55Fe x-ray source in 50 Torr CF4. Track head and tail structure is clearly resolvable.

ITO

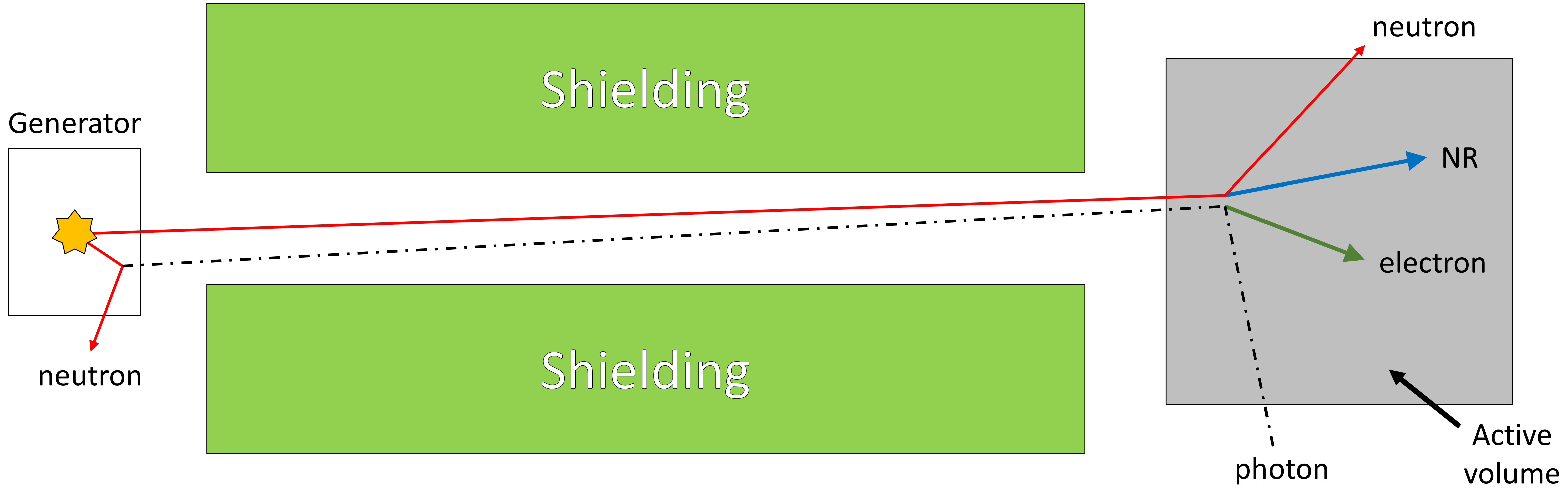
- 1.1 mm thick ITOGLASS 04 (transparent for camera).
- Metallised with Cr and Aluminium for wire bonding.
- 120 strips connected to Acqiris 60 channel digitizer.
- Pulses digitized with 2 ns sampling rate.



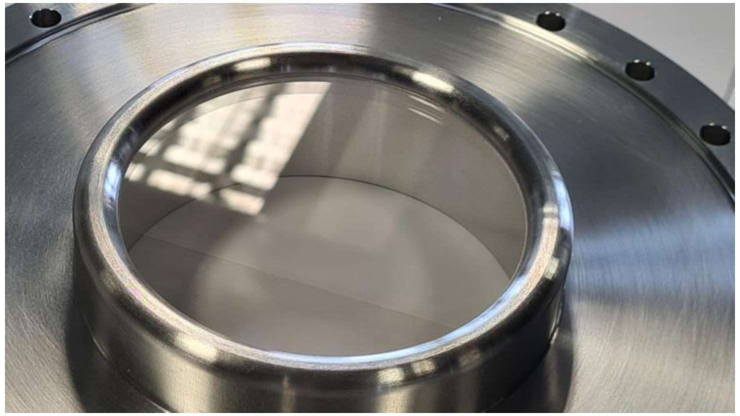


Background

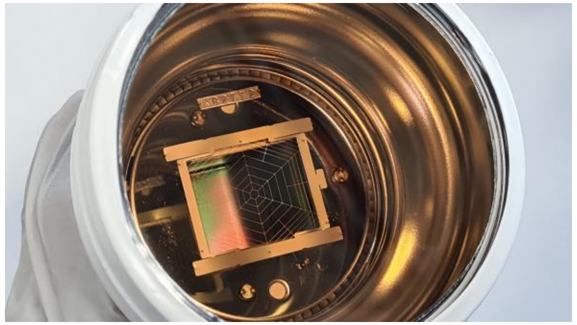
- Photons are produced from inelastic neutron scattering inside the detector itself. These photons are the dominant source of background for Migdal search as they can produce Compton electrons near NR vertices (looks like Migdal to our camera).
- Predicted background rate: 21 ± 2 events/day (will reduce with timing information from FPGA).



Status & Summary



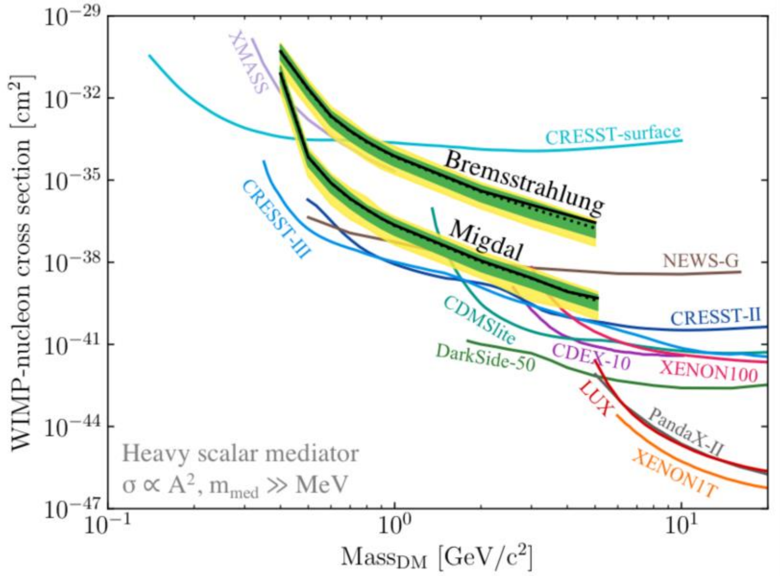
- Design & background simulations are complete.
- End-to-end simulations are ongoing.
- All detector components and shielding have been procured and are at RAL.
- Detector assembly is underway.
- Detector commissioning planned for December.
- Runs with neutrons from D-D & D-T in early 2022.

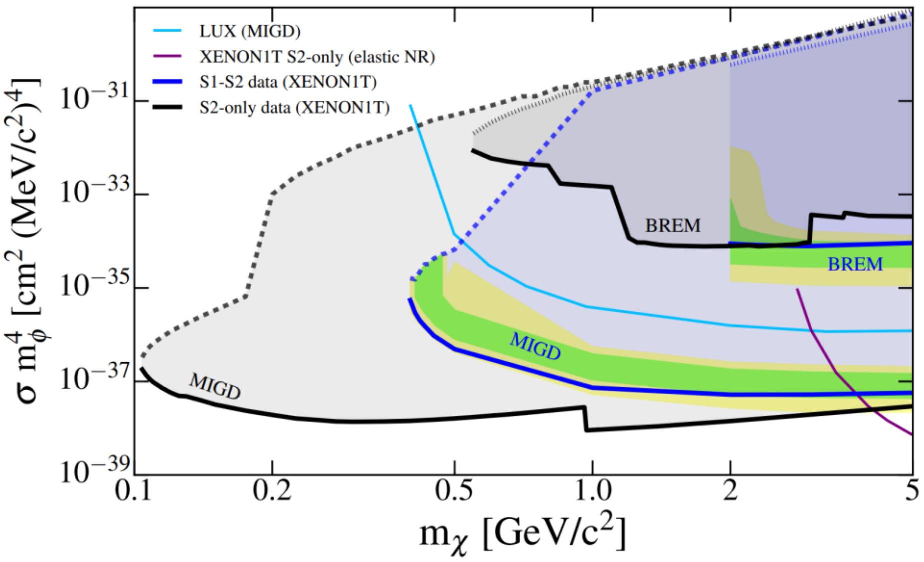


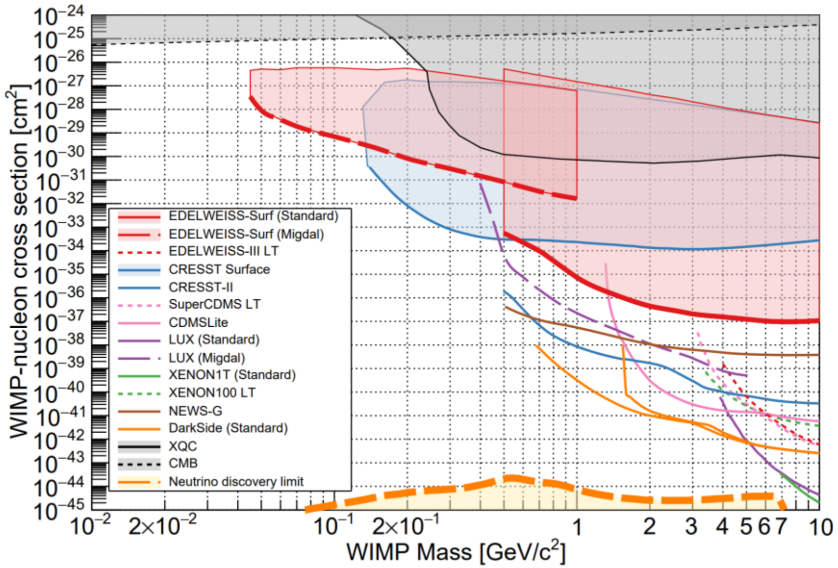
Backup

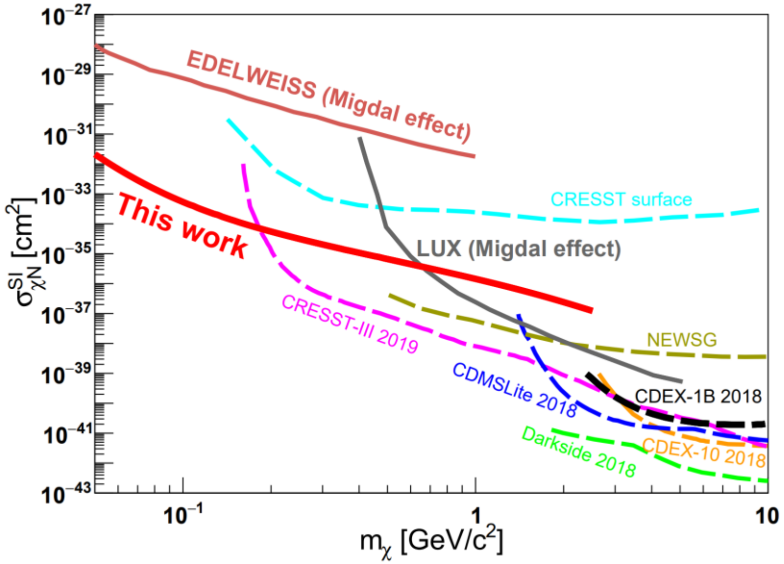
DM sensitivity extension

- **LUX (Xenon)** "Results of a Search for Sub-GeV Dark Matter Using 2013 LUX Data" https://arxiv.org/pdf/1811.11241.pdf
- **XENON1T (Xenon)** "A Search for Light Dark Matter Interactions Enhanced by the Migdal effect or Bremsstrahlung in XENON1T" https://arxiv.org/pdf/1907.12771.pdf
- **EDELWEISS (Germanium)** "Searching for low-mass dark matter particles with a massive Ge bolometer operated above-ground" https://arxiv.org/abs/1901.03588
- **CDEX-1B (Germanium)** "Constraints on Spin-Independent Nucleus Scattering with sub-GeV Weakly Interacting Massive Particle Dark Matter from the CDEX-1B Experiment at the China Jin-Ping Laboratory" https://arxiv.org/pdf/1905.00354.pdf



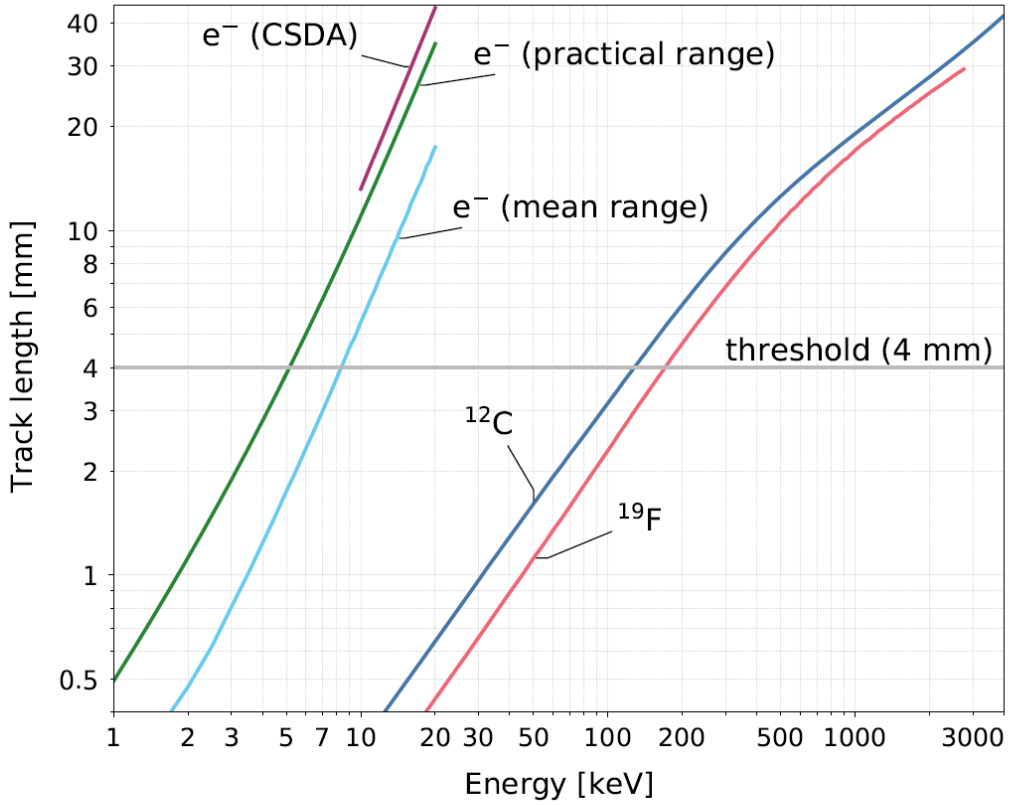


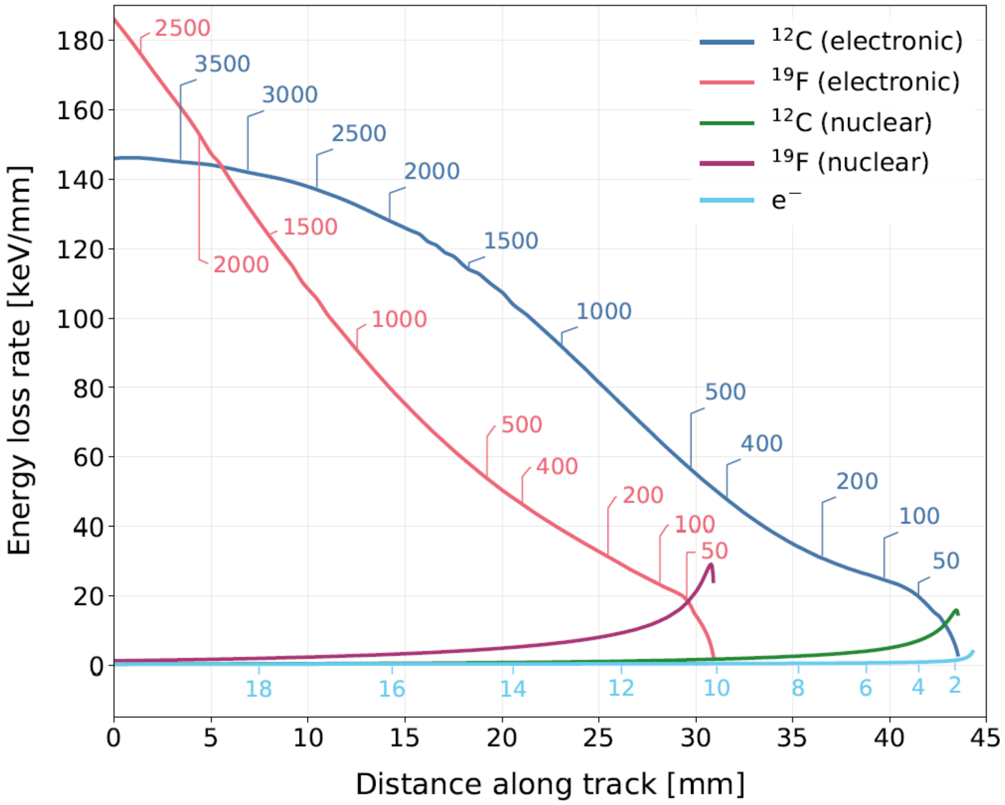




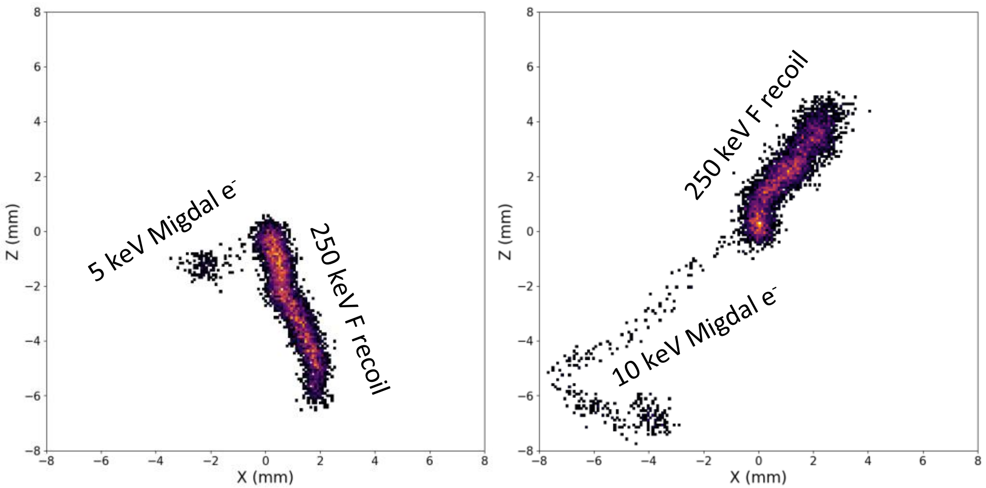
Track length and dE/dx

- Electrons with energies 5 - 10 keV have track lengths between 4 - 10mm.
- Nuclear recoils with energies E > 150 keV have track length > 4 mm.
- dE/dx for nuclear recoils is highest at the beginning, but highest at the end for electrons.

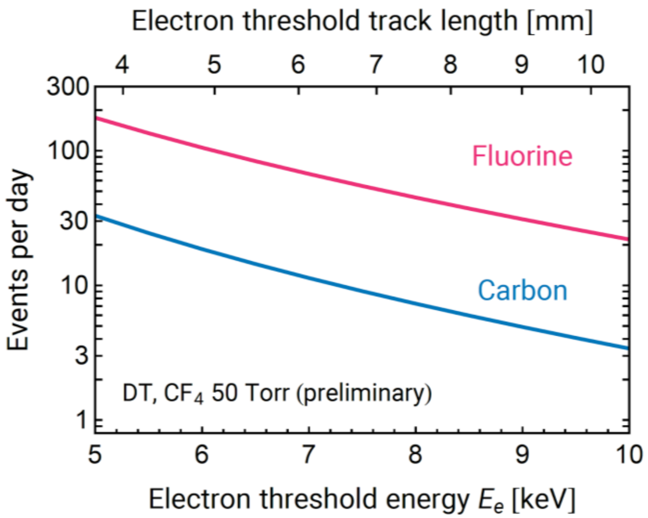




Migdal rates



- Above is an example Migdal signal topology after 10 mm drift in pure CF_4 at 50 Torr.
- Simulated with SRIM & Garfield++ (NR) and DEGRAD (e^-)
- To the right are calculated Migdal rates in **events/day** for nuclear recoils with $E_r > 150$ keV, and Migdal electrons with $E_e > 5$ keV.



	DT source (10^{10} n/s)	DD source (10^9 n/s)
Fluorine	190	23
Carbon	20	3

Fluorine rate is very high because each CF_4 has 4 fluorines.

Assumptions:

- Detection volume: 5x5x5 cm3
- Pure CF4
- Pressure: 50 Torr
- Temperature: 293.15 K.
- DT & DD sources are 1.4 m & 1 m away from the detection volume respectively.