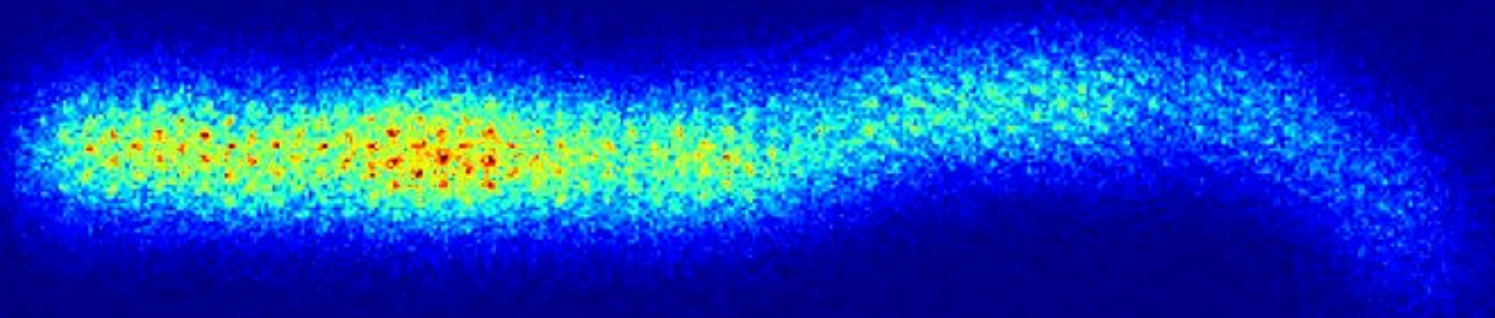
Investigations of the Migdal effect in elements relevant to dark matter searches using the MIGDAL experiment at the NILE/ISIS facility at RAL



Paweł Majewski (RAL/PPD) &
Henrique Araújo (Imperial College London)

MIGDAL
Migdal In Galactic Dark mAtter expLoration

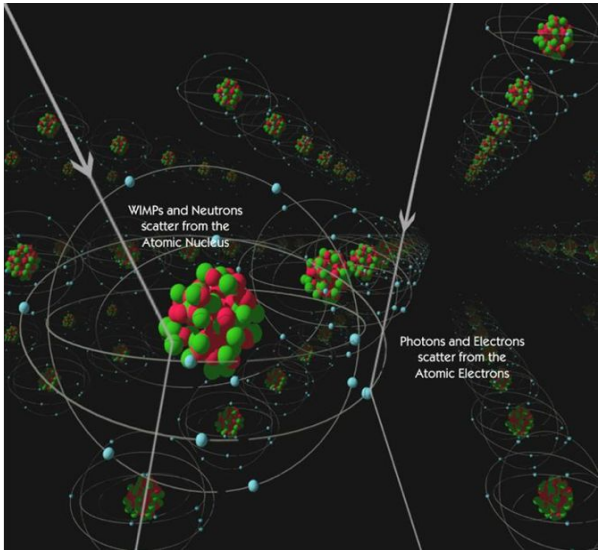
UNIVERSITY OF BIRMINGHAM · GDD Gas Detectors Development Group · Universität Hamburg · Imperial College London · KING'S College LONDON · LIP · LULEÅ UNIVERSITY OF TECHNOLOGY · UAM · THE UNIVERSITY OF NEW MEXICO · OXFORD · ROYAL HOLLOWAY UNIVERSITY OF LONDON · Science & Technology Facilities Council Rutherford Appleton Laboratory · The University of Sheffield.

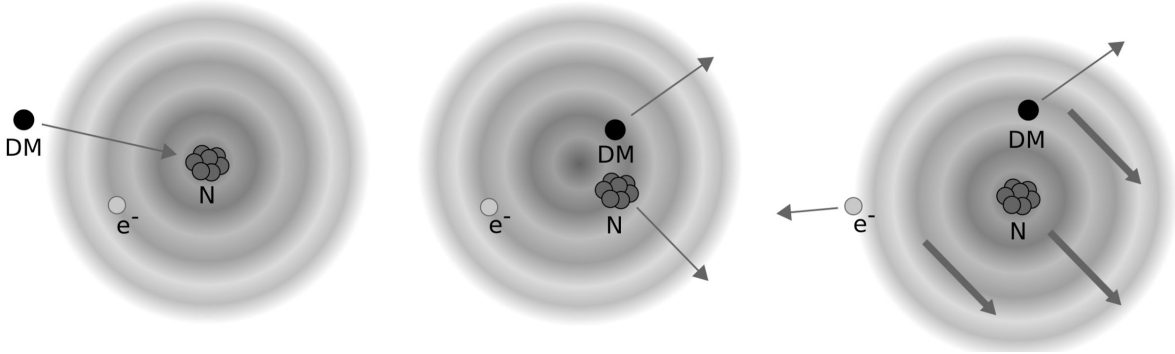
The Dark Matter Problem

- The dark matter problem is the longest outstanding problem in modern physics.
- What we observe in the universe, starting from here, our planet Earth, the galaxies are made of matter.
- However, there's more to the universe than the matter we can see - an elusive substance, which neither emits nor absorbs the light and yet affects us by shaping our universe.
- Scientists around the world are trying to figure out what it is.
- The MIGDAL project is to help them out in their endeavour.

Credit : link

What the Migdal effect is and why it matters in DM searches ?

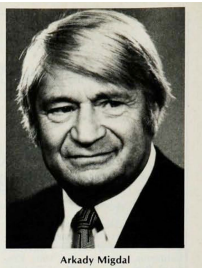


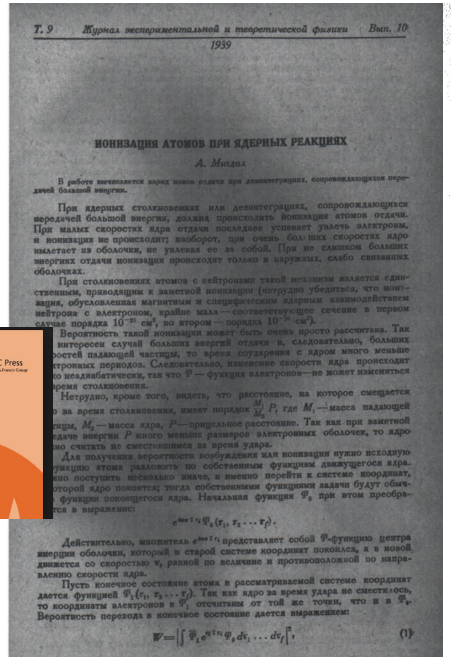


Migdal Effect - nucleus moves relative to the electron cloud. Individual electron might be ejected leading to ionisation.

- DM searches use signal from nuclear recoils as a signature of the DM interaction with the detector medium
- Targets with heavy elements such as **Xenon and Argon** are immune to light WIMPs unless Migdal effect is experimentally confirmed

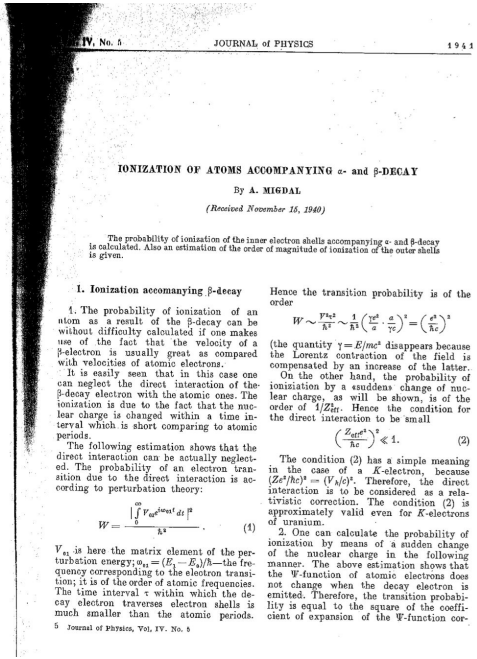
What do we already know about the Migdal effect ?


Arkady Migdal


Журнал экспериментальной и теоретической физики Вып. 10
1939

ИОНИЗАЦИЯ АТОМОВ ПРИ ЯДЕРНЫХ РЕАКЦИЯХ

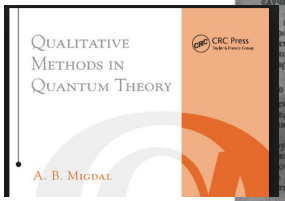
А. Мигдал


JOURNAL of PHYSICS 1941

IONIZATION OF ATOMS ACCOMPANYING α- and β-DECAY

By A. MIGDAL

(Received November 15, 1940)



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)*

Migdal effect and Dark Matter

Migdal effect calculations reformulated by M. Ibe et al. with ionisation probabilities for atoms and recoil energies relevant to Dark Matter searches:

Published for SISSA by Springer

Received: *August 23, 2017*
Revised: *January 15, 2018*
Accepted: *March 8, 2018*
Published: *March 30, 2018*

Migdal effect in dark matter direct detection experiments

Masahiro Ibe,[a,b] Wakutaka Nakano,[a] Yutaro Shoji[a] and Kazumine Suzuki[a]

[a] *ICRR, The University of Tokyo, Kashiwa, Chiba 277-8582, Japan*
[b] *Kavli IPMU (WPI), UTIAS, The University of Tokyo, Kashiwa, Chiba 277-8583, Japan*

E-mail: ibe@icrr.u-tokyo.ac.jp, m156077@icrr.u-tokyo.ac.jp, yshoji@icrr.u-tokyo.ac.jp, ksuzuki@icrr.u-tokyo.ac.jp

PHYSICAL REVIEW D **107,** 035032 (2023)

Precise predictions and new insights for atomic ionization from the Migdal effect

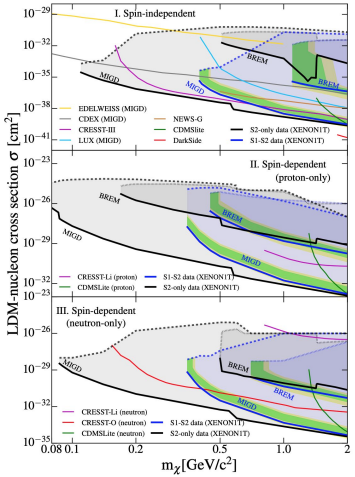
Peter Cox,[1,*] Matthew J. Dolan,[1,†] Christopher McCabe,[2,‡] and Harry M. Quiney[3,§]

[1] *ARC Centre of Excellence for Dark Matter Particle Physics, School of Physics, The University of Melbourne, Parkville, Victoria 3010, Australia*
[2] *Theoretical Particle Physics and Cosmology Group, Department of Physics, King's College London, London WC2R 2LS, United Kingdom*
[3] *School of Physics, The University of Melbourne, Parkville, Victoria 3010, Australia*

(Received 18 September 2022; accepted 12 January 2023; published 27 February 2023)

Extended model of the Migdal effect calculated by C. McCabe.

Dark Matter searches and Migdal Effect
- sensitivity extension to low mass region -

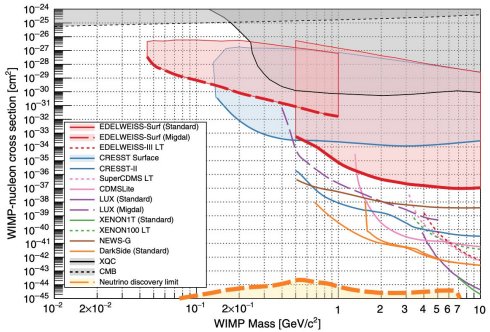


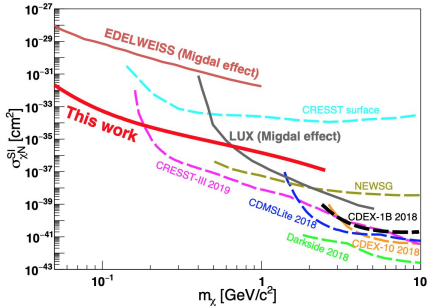
LUX (Xenon)
"Results of a Search for Sub-GeV Dark Matter Using 2013 LUX Data"
https://arxiv.org/pdf/1811.11241.pdf

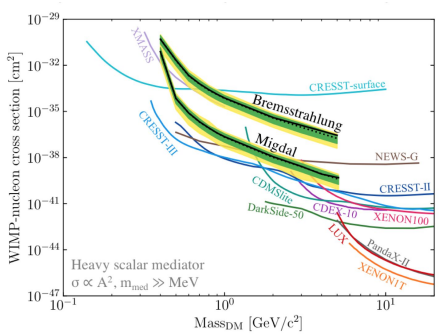
XENON1T (Xenon)
"A Search for Light Dark Matter Interactions Enhanced by the Migdal effect or Bremsstrahlung in XENON1T"
https://arxiv.org/pdf/1907.12771.pdf

EDELWEISS (Germanium)
"Searching for low-mass dark matter particles with a massive Ge bolometer operated above-ground"
https://arxiv.org/abs/1901.03588

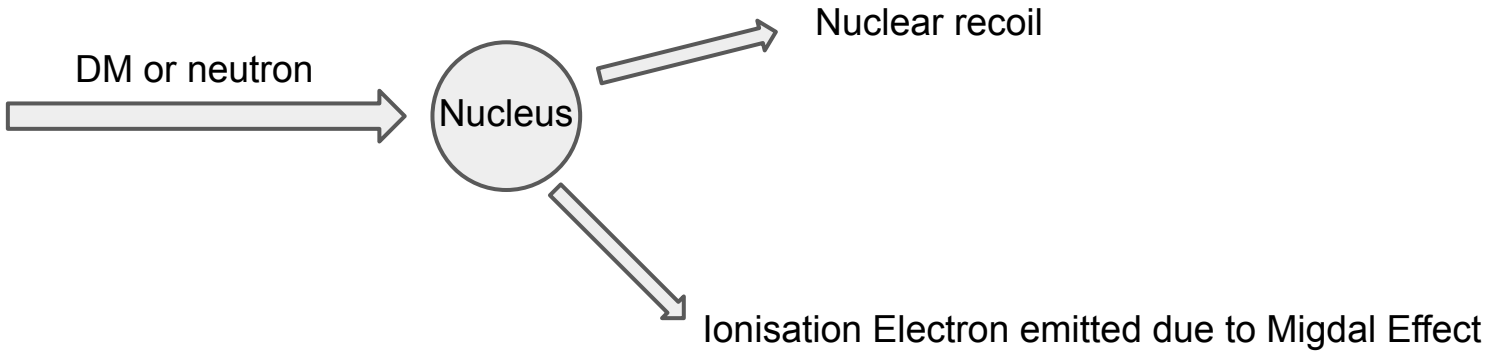
CDEX-1B (Germanium)
"Constraints on Spin-Independent Nucleus Scattering with sub-GeV Weakly Interacting Massive Particle Dark Matter from the CDEX-1B Experiment at the China Jin-Ping Laboratory"
https://arxiv.org/pdf/1905.00354.pdf







Migdal **I**n **G**alactic **D**ark m**A**tter exp**L**oration experiment

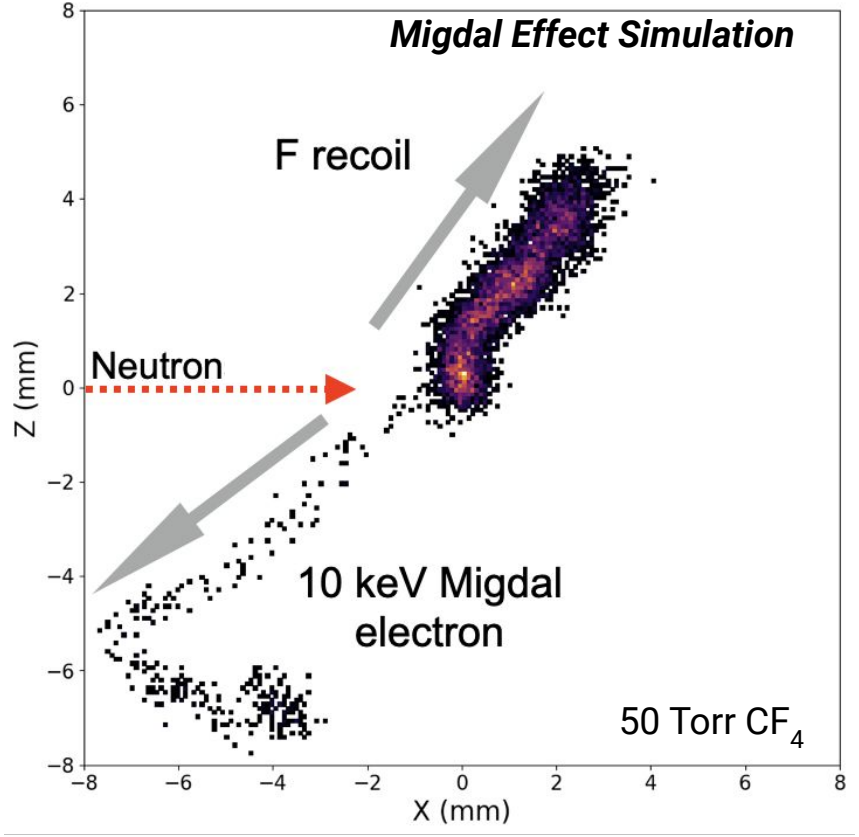


- Extremely challenging experiment : Looking for a rare (10^{-5}) atomic phenomenon never before observed in the nuclear scattering using high flux neutron generators 10^{10} / 10^{9} n/s with D-T/ D-D
- Aim of the MIGDAL experiment - unambiguous observation and measurement of the Migdal effect using a low pressure Optical TPC

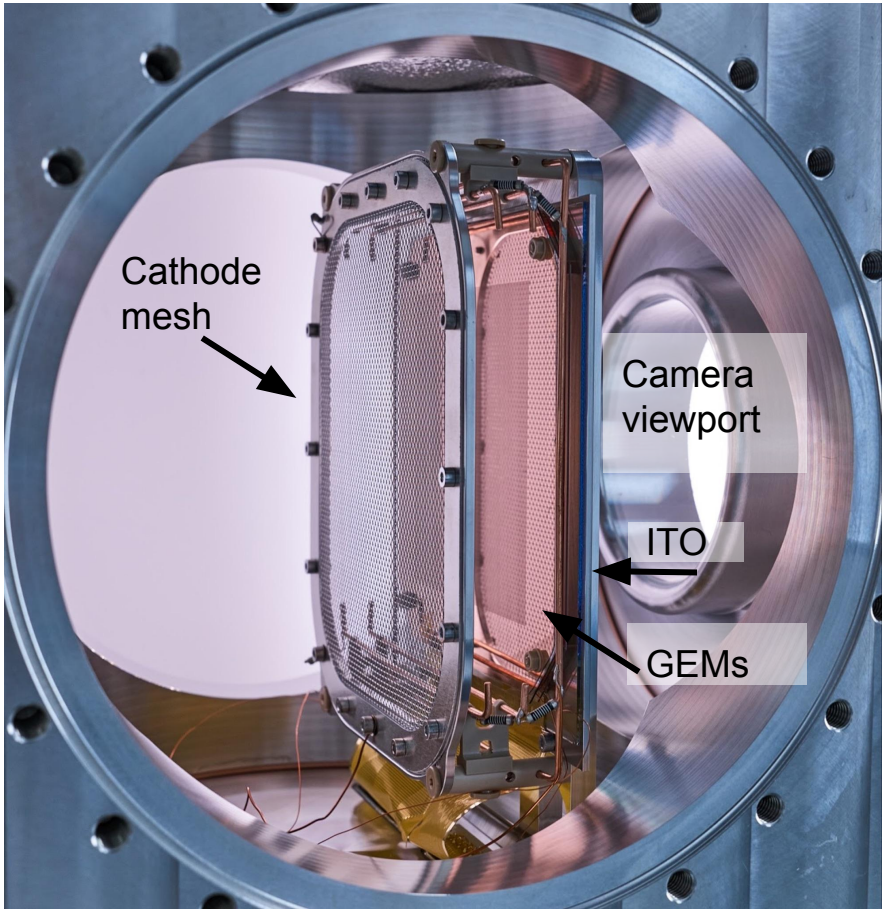
Experimental Goal

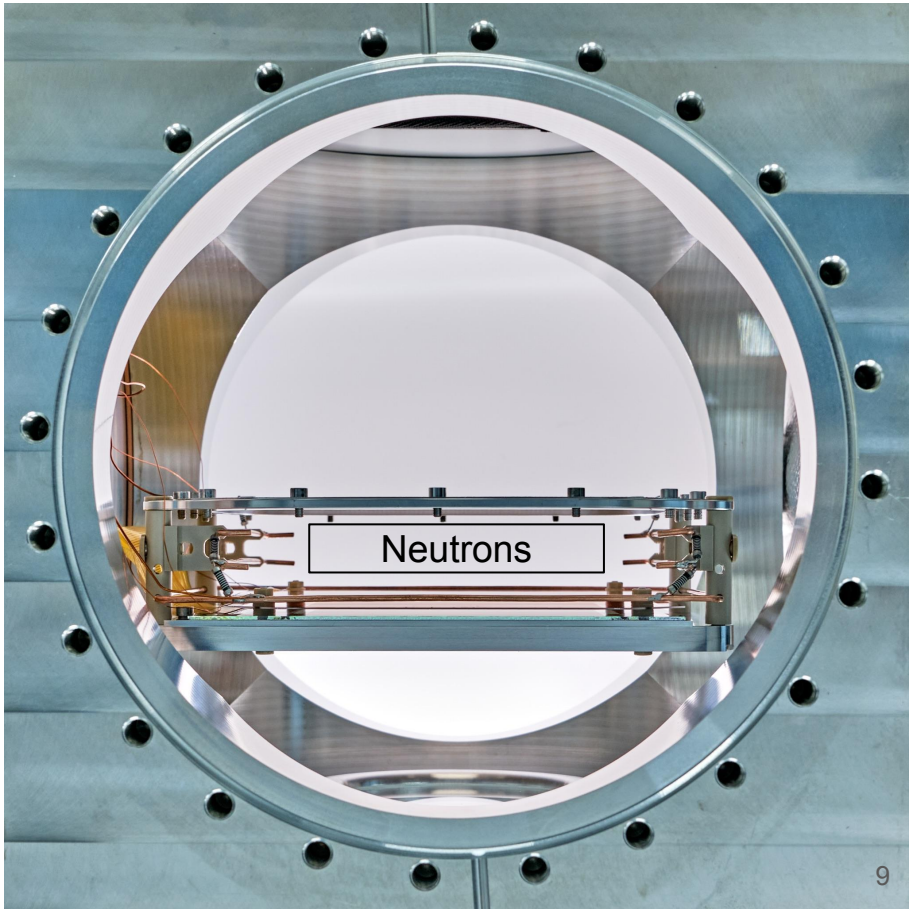
- Observation of two tracks - a nuclear recoil and an electron - sharing the same vertex
- Aim to make the first unambiguous observation and measurement by capturing both electron and nuclear recoil

The MIGDAL Experiment has a discovery potential!



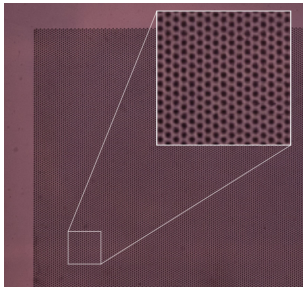
The MIGDAL Optical Time Projection Chamber





The MIGDAL Optical Time Projection Chamber

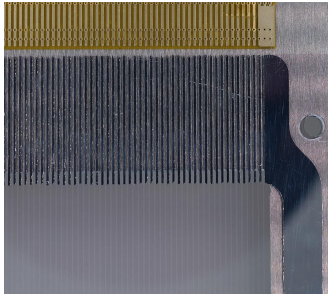
GEMs

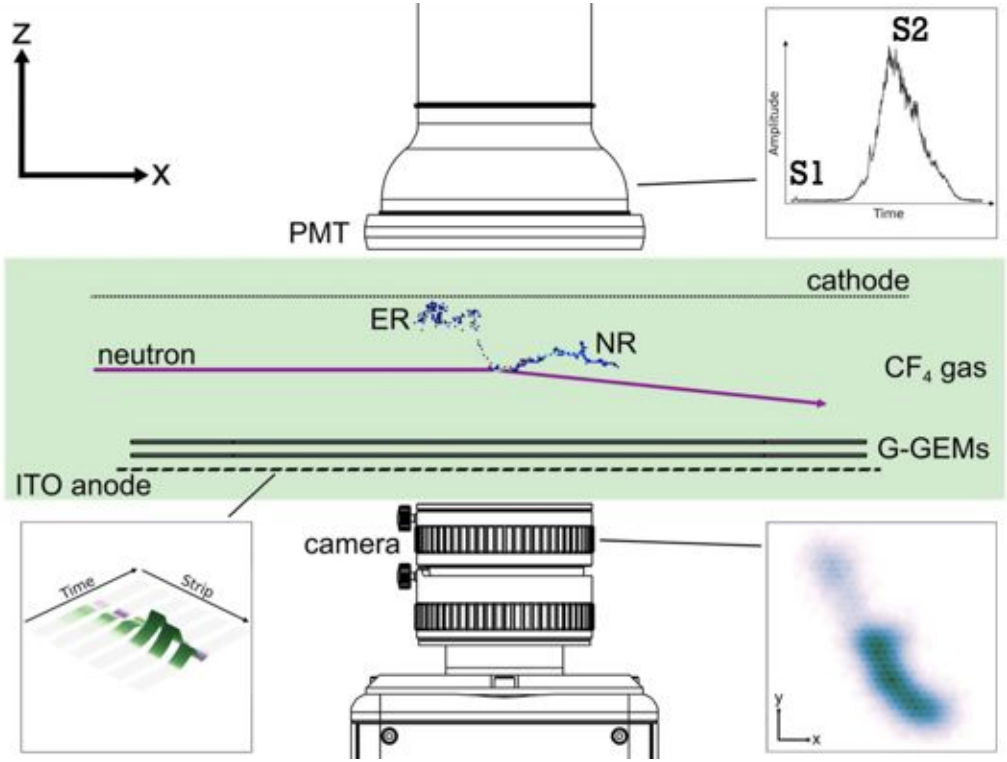


Neutrons

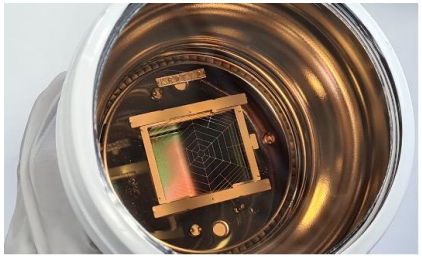
2.45 MeV neutrons from a DD generator at the NILE facility

ITO Anode





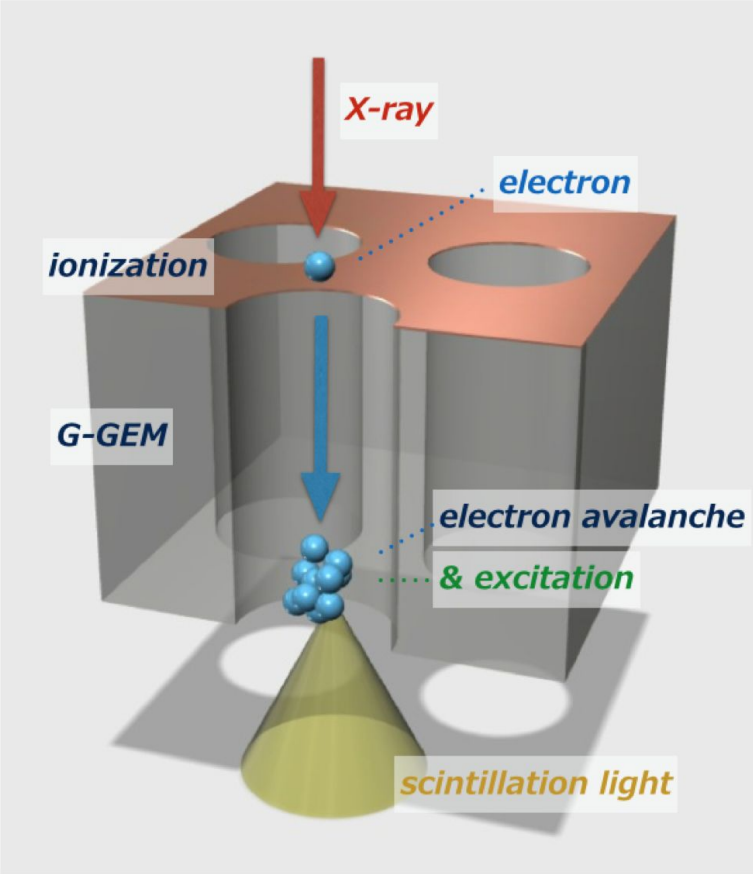
PMT

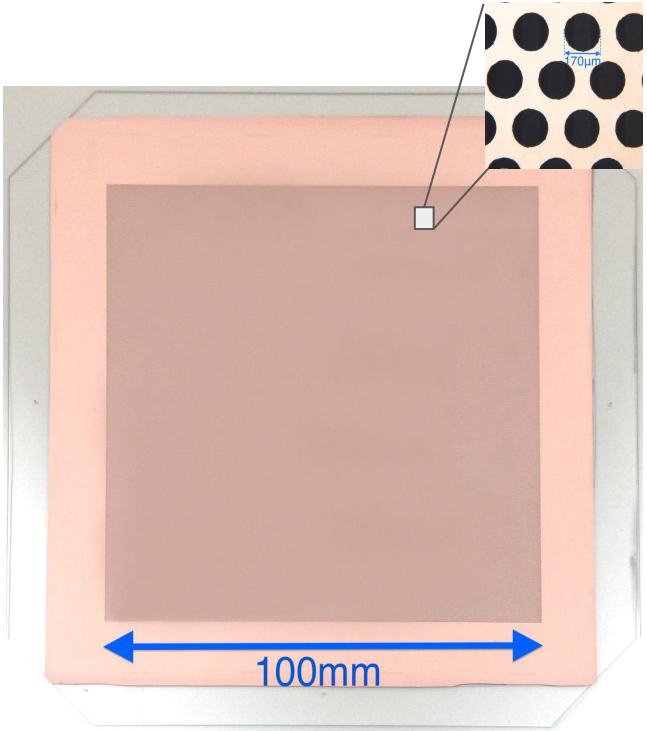


CMOS Camera

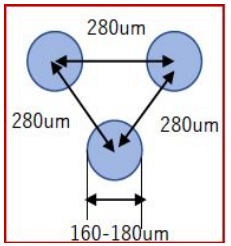
Astropart.Phys. 151 (2023) 102853

Glass-GEMs

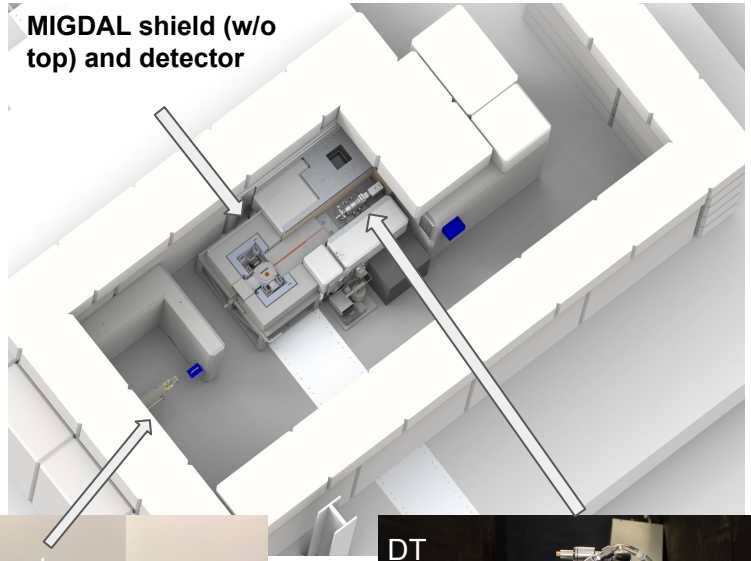


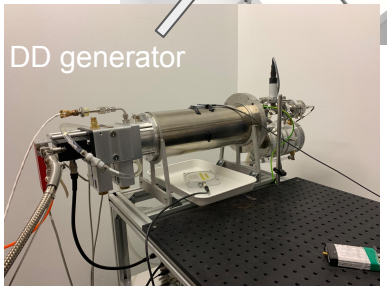


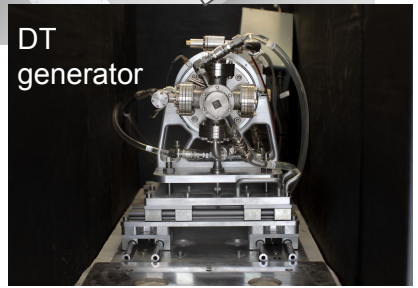
Glass thickness : 570 um



NILE facility and neutron generators

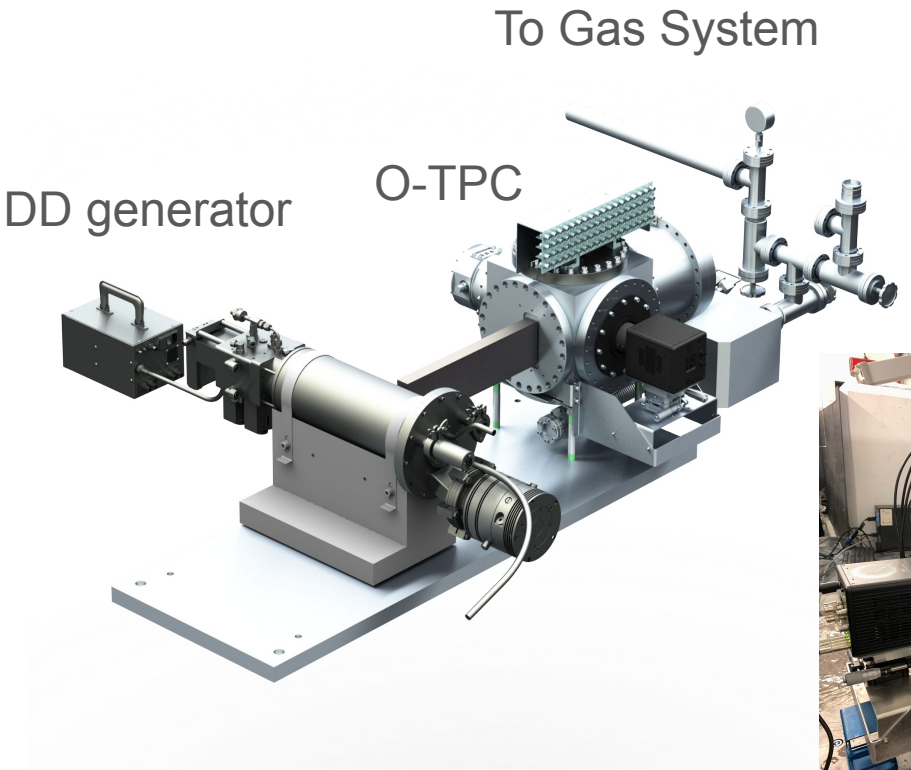


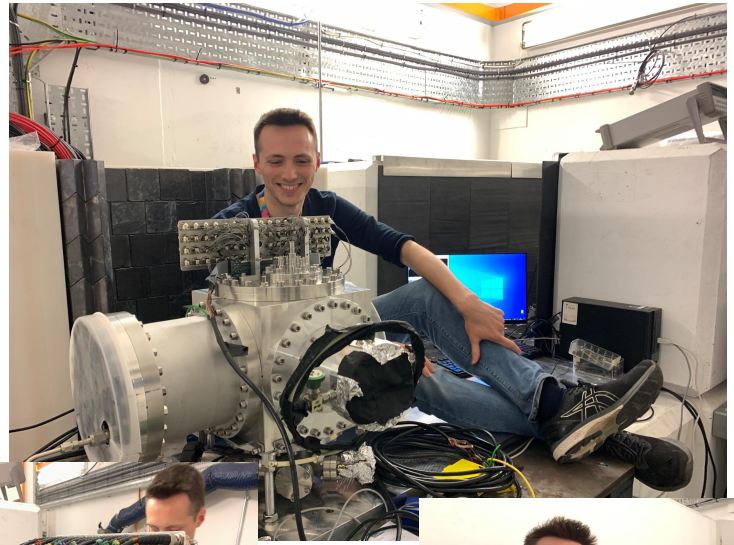


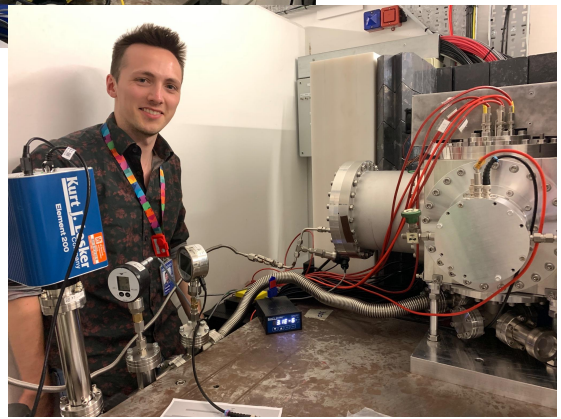


- Commissioning of DD and the MIGDAL experiment - Summer 2023
- First and Second Science Runs (3 weeks each) have accumulated tens of millions of images.

MIGDAL assembly at NILE

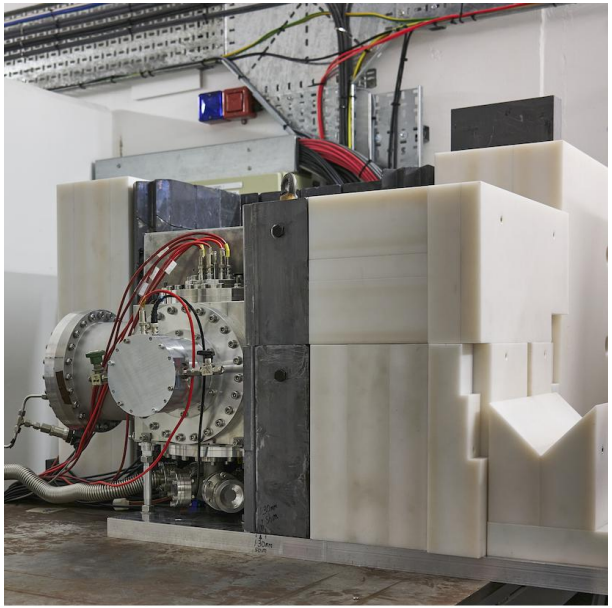




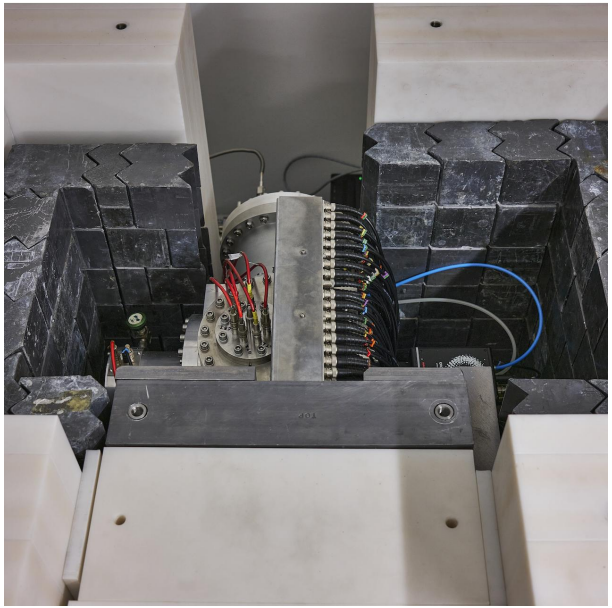


MIGDAL assembly at NILE

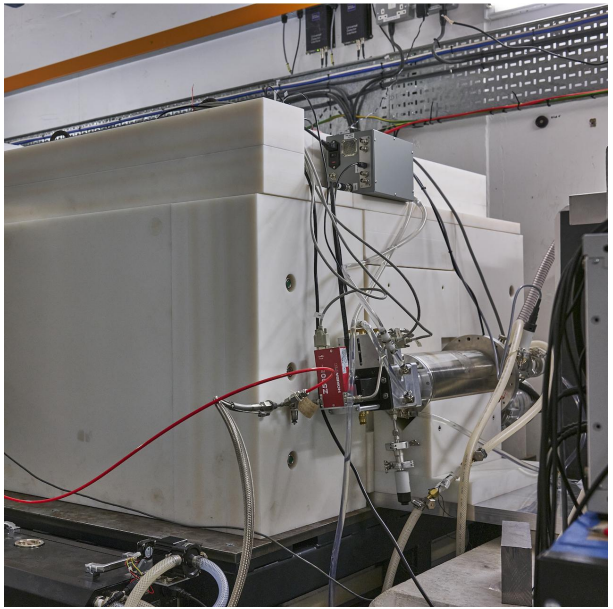
The MIGDAL Experiment at NILE



MIGDAL experiment shielded by borated high density polyethylene (moderates and stops neutrons).

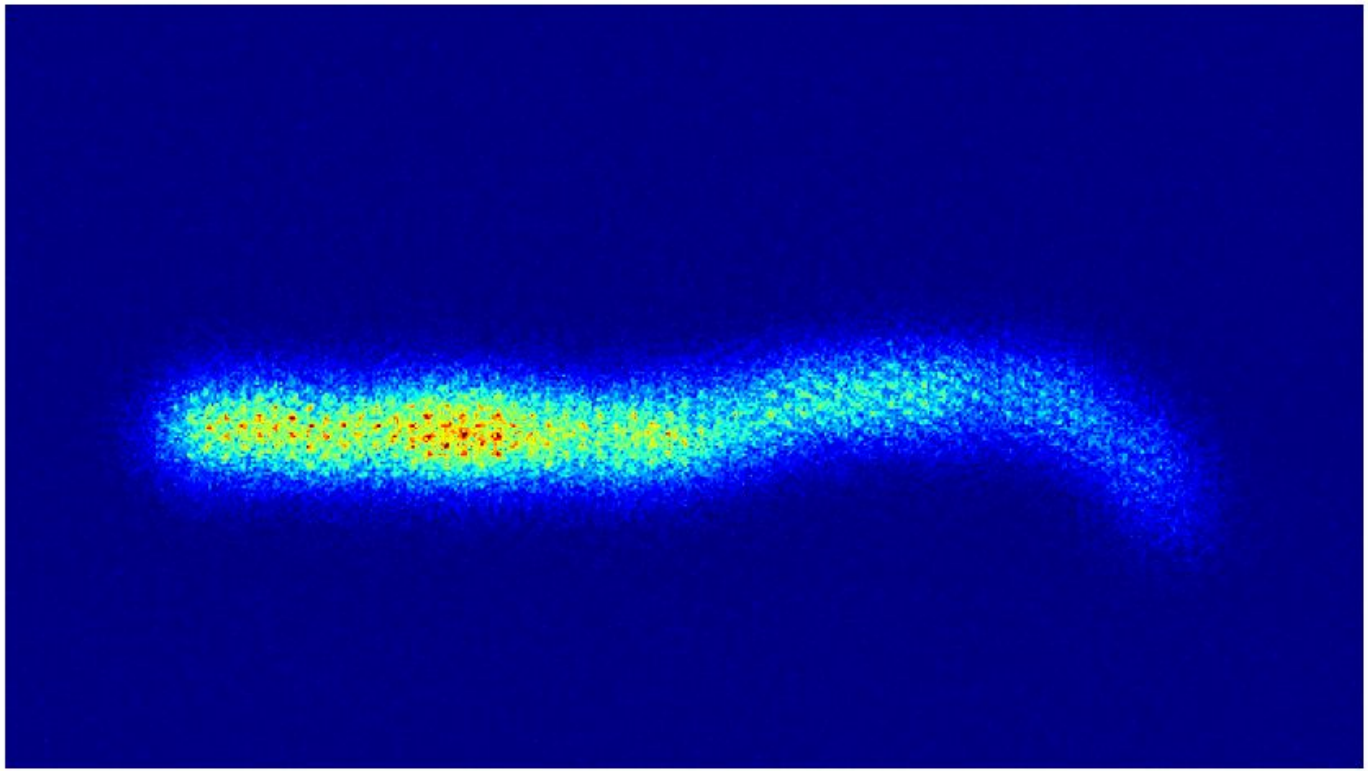


Lead shielding surrounds MIGDAL detector (captures gammas from inelastics and radiative capture).



Fully integrated experimental setup with DD generator at entrance of collimator.

The MIGDAL Experiment at NILE

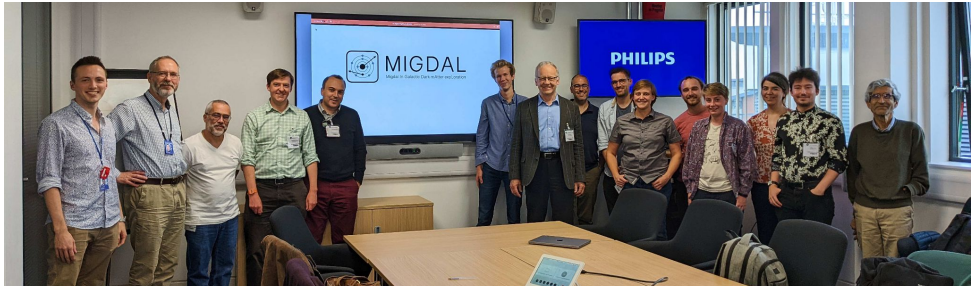


One of the first nuclear recoils captured by the MIGDAL experiment.

The MIGDAL Collaboration

- Over 35 physicists and engineers from 15 institutions across 8 countries led by PPD/RAL and Imperial College
- Supported by RD51, GDD/CERN and ISIS/NILE

Science and Technology Facilities Council
U.S. DEPARTMENT OF ENERGY
FCT Fundação para a Ciência e a Tecnologia
Horizon 2020 European Union Funding for Research & Innovation
NSF National Science Foundation
MARIE CURIE ACTIONS



If you are thinking about :

- *Joining an exciting project with a discovery potential impacting globally the dark matter searches*
- *Working with a cutting edge detector technology and detector R&D in the National Laboratory at RAL*
- *Working in a friendly environment with a medium scale international collaboration*
- *Analysing data using extensively machine learning with object detection*
- *Having your expermeriment “next door” and accessing the data as soons as it is recorded*
- *Presenting results at international conferences*
- *Being recognised by the dark matter community*

This young explorer can be YOU

The MIGDAL project is for you !

More information about MIGDAL: *https://migdal.pp.rl.ac.uk*