Towards the confirmation of the Migdal effect with MIGDAL

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MultiDark Multimessenger Approach for Dark Matter Detection

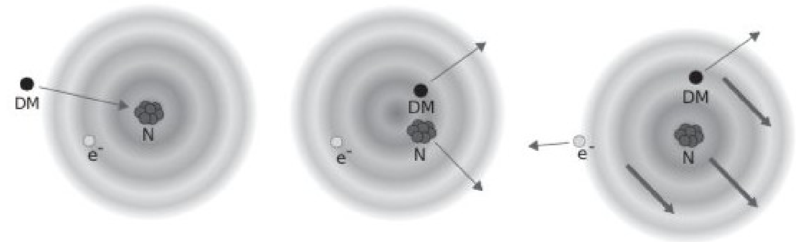
19th MultiDark workshop, 23rd of May of 2022

Overview

- Migdal effect
- MIGDAL experiment
- Optical TPC
- Bunker, shielding and collimator
- Backgrounds
- Status

Migdal effect

<u>Ionization</u> mechanism proposed by A. B. Migdal in 1941: emission of an atomic electron when the respective <u>nucleus</u> suddenly acquires a given velocity



Concept: the electron eigenstates for the moving nucleus,

$$|\Phi'_{ec}\rangle = e^{-im_e \sum_i \mathbf{v}\cdot\hat{\mathbf{x}}_i} |\Phi_{ec}\rangle \quad ,$$

are **not orthogonal** to those for the initial nucleus at rest, therefore the transition probability between ground and ionized electron states,

$$\mathcal{P} = |\langle \Phi^*_{ec} | \Phi'_{ec} \rangle|^2 \quad ,$$

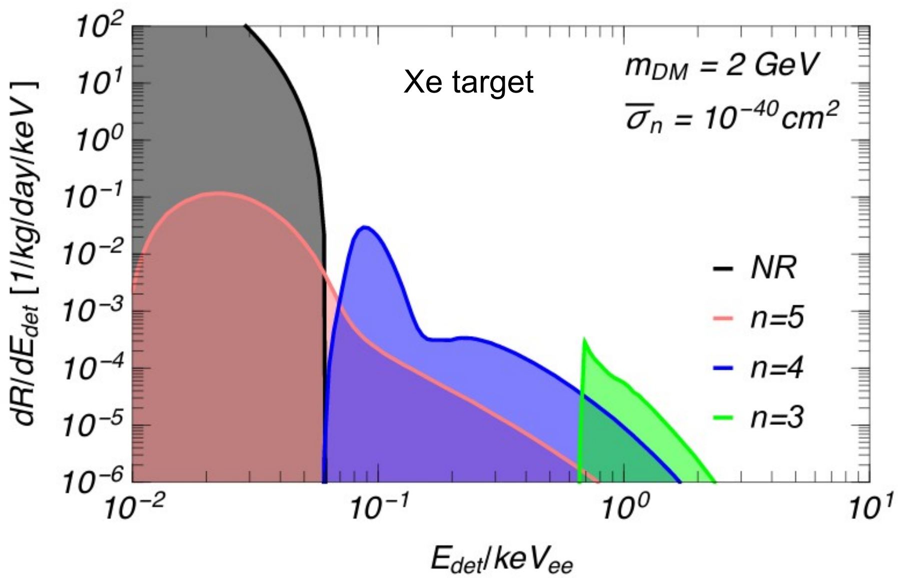
could be non-zero

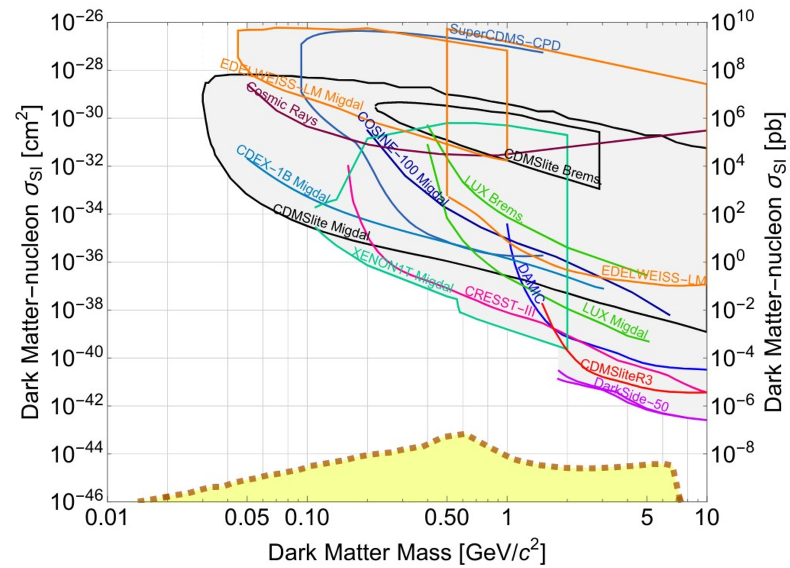
M. Ibe *et al.* have checked energy and momentum conservation in Migdal effect, in the context of direct DM searches

Migdal effect

However, the Migdal effect has **not been confirmed experimentally** yet

Several direct detection experiments have calculated exclusion limits assuming that Migdal effect exists





Migdal effect would imply that current experiments have increased sensitivity to sub-GeV DM particles: <u>inelastic process</u>, with <u>recoiling electron</u> in final state

MIGDAL experiment

RAL (UK) is currently developing an experiment to confirm the Migdal effect, funded by STFC (Xenon Futures R&D project): **MIGDAL experiment**

Among the collaborating institutes are Imperial College, CERN, and now UAM

The MIGDAL experiment:
Measuring a rare atomic process to help the search for dark matter

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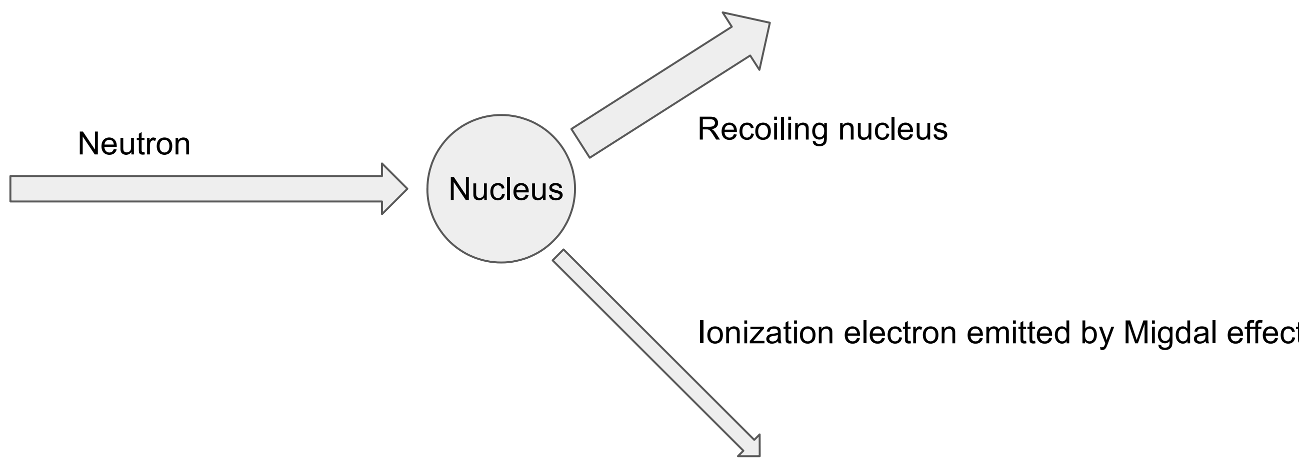
MIGDAL experiment

Concept: use **neutrons** to induce Migdal effect in atoms of a **target gas** contained in a **tracking detector**

Signal: two tracks that start from the same vertex: recoiling nucleus+Migdal ionization electron (~10 keV)



MIGDAL experiment

Neutron sources: using commercial fusion generators:

1) Deuterium-deuterium (D-D): 2.45 MeV neutrons @ 10^9 Hz

2) Deuterium-tritium (D-T): 14.1 MeV neutrons @ 10^{10} Hz

Target gas: carbon tetrafluoride (CF_4) at low pressure (50 torr), to have measurable Migdal electron tracks

At a later stage, planning to use mixtures of CF_4 plus noble gases, in order to study Migdal effect in atoms of relevance for DM searches

Tracking detector: <u>optical time projection chamber</u> (OTPC)

	Predicted signal (event/day)
D-D neutrons	~40
D-T neutrons	~140

Optical TPC

Consists of:

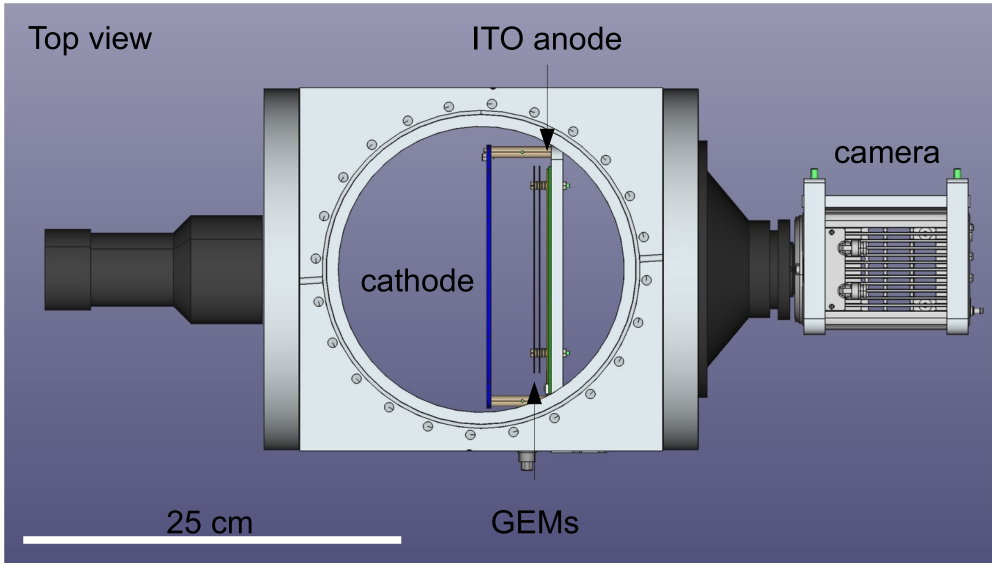
1) Cathode

2) **Gas electron multipliers (GEMs)**

3) **Indium-tin-oxide (ITO) anode** (transparent charge readout)

4) **Camera**

Plus a photomultiplier tube (PMT), mainly for trigger purposes



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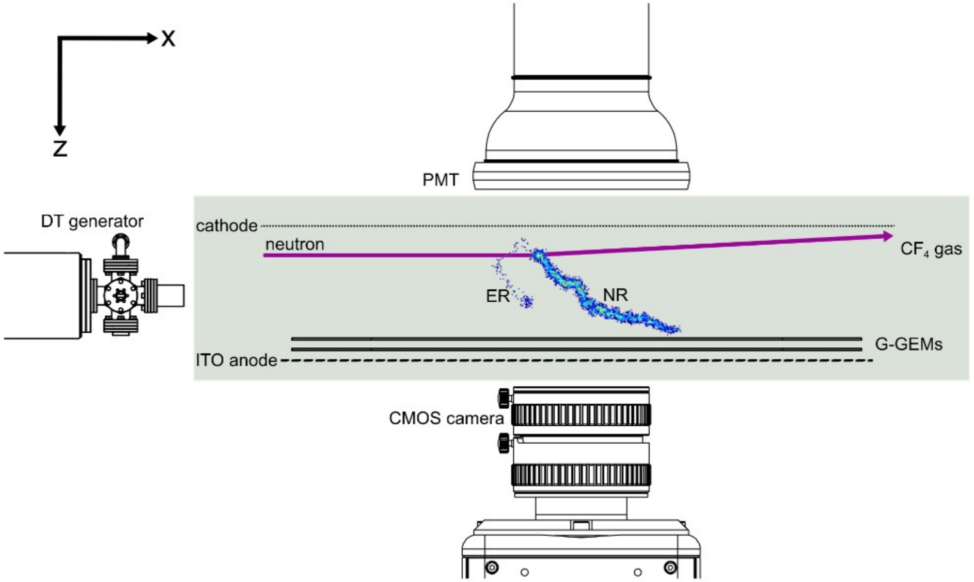
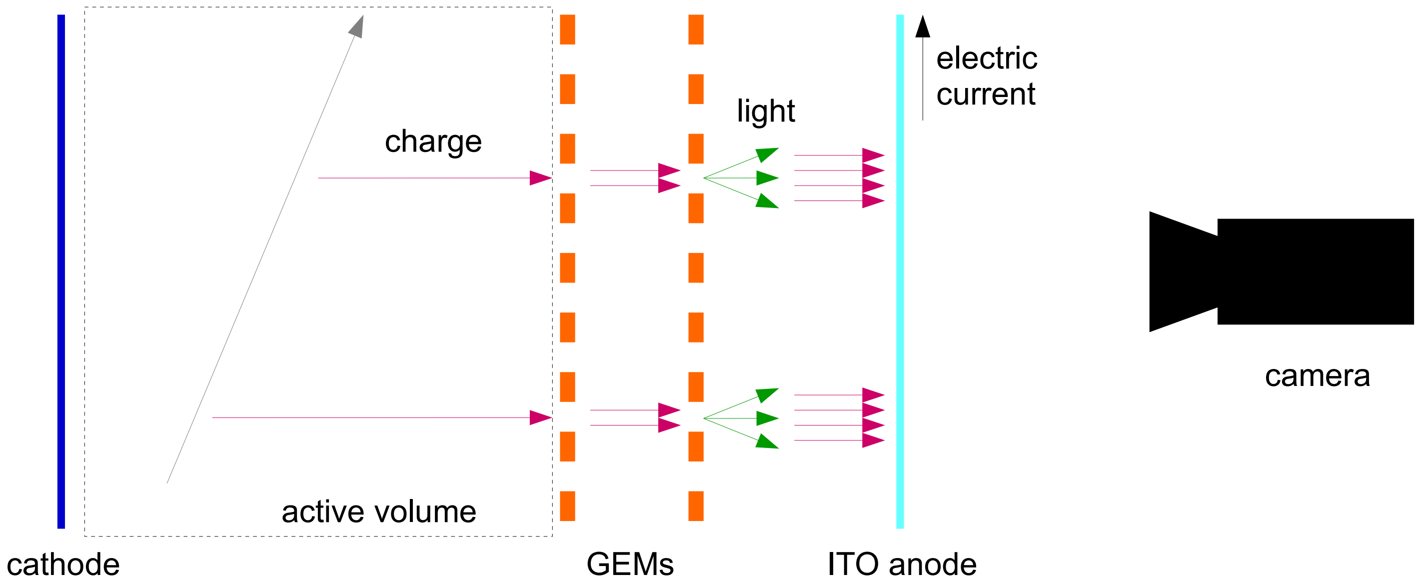


Optical TPC

Ionization tracks drift to GEMs, producing **amplified charge**, that in turn creates **scintillation light** in CF_4

Scintillation light is captured by the camera, and amplified charge is collected at the ITO anode

Image from scintillation light provides **2D projection of particle tracks**, while timing of collected charge provides **depth information**



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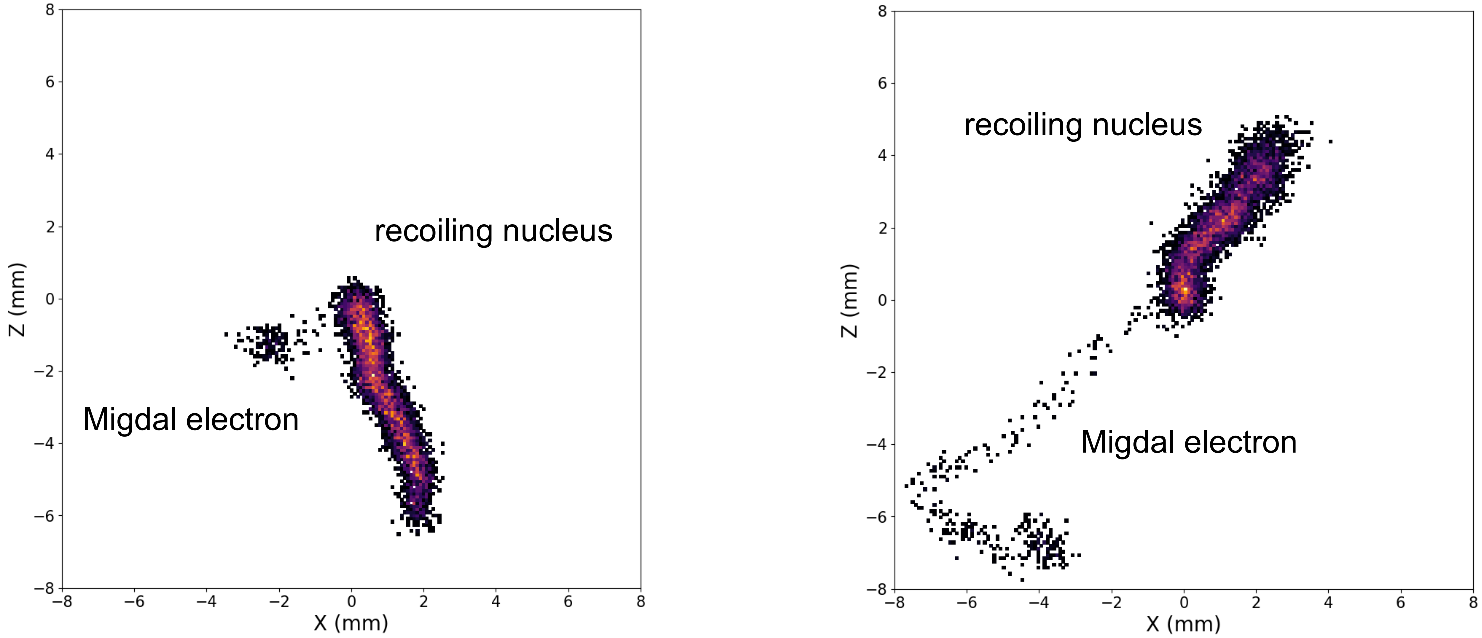
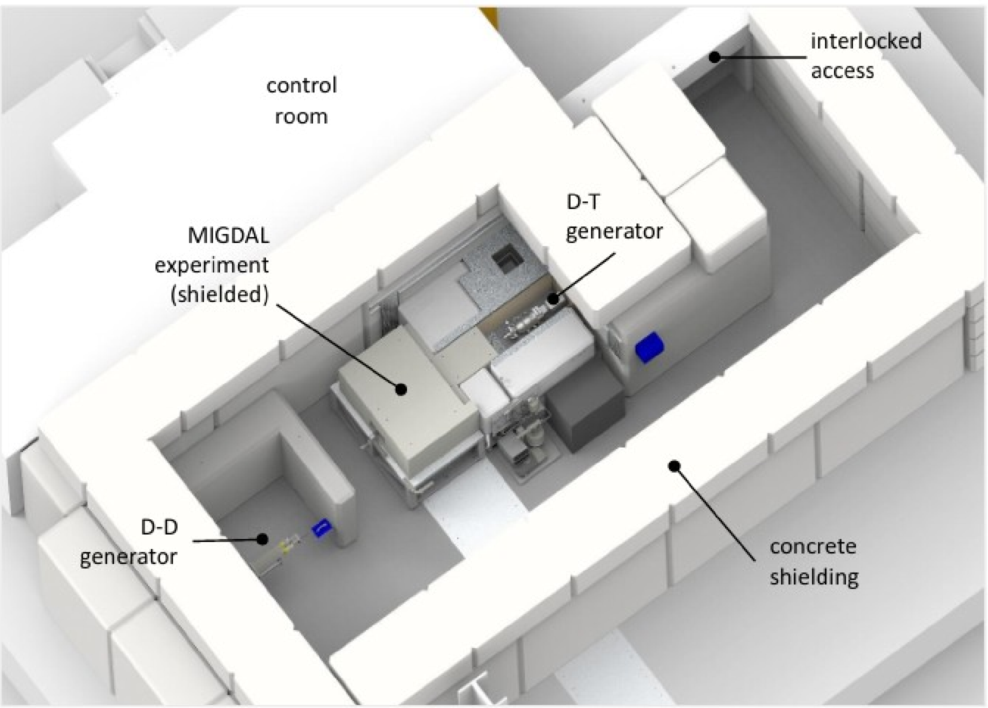
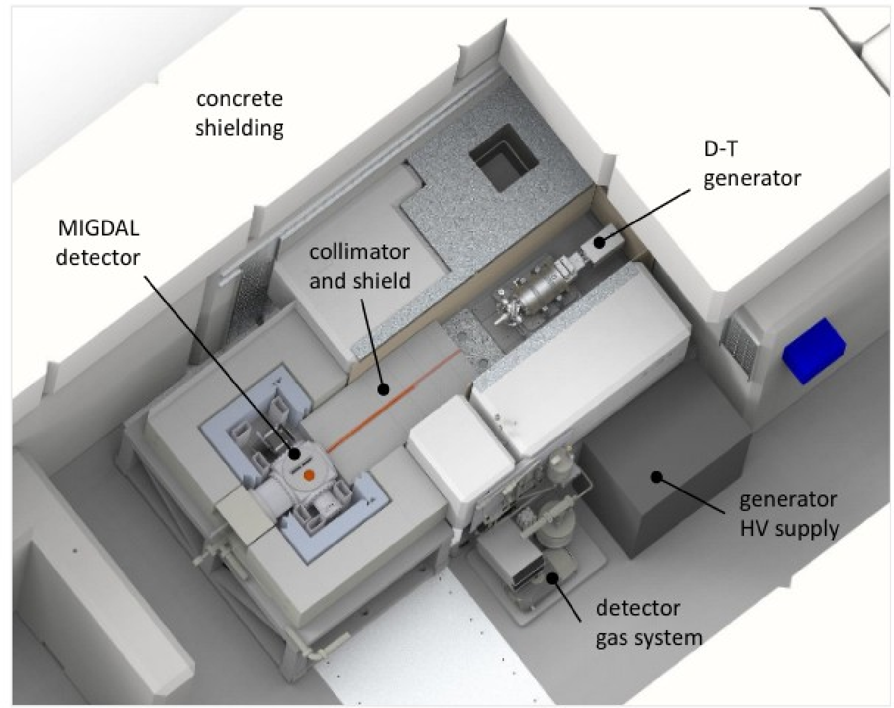


Bunker, shielding and collimator

The experiment needs to be operated in a **concrete bunker** for health and safety reasons: NILE facility at ISIS hall (RAL)

Fusion generators produces neutrons isotropically ⇒ Experiment requires to define a neutron beam focused on the active OTPC volume: **shield** and **collimator**

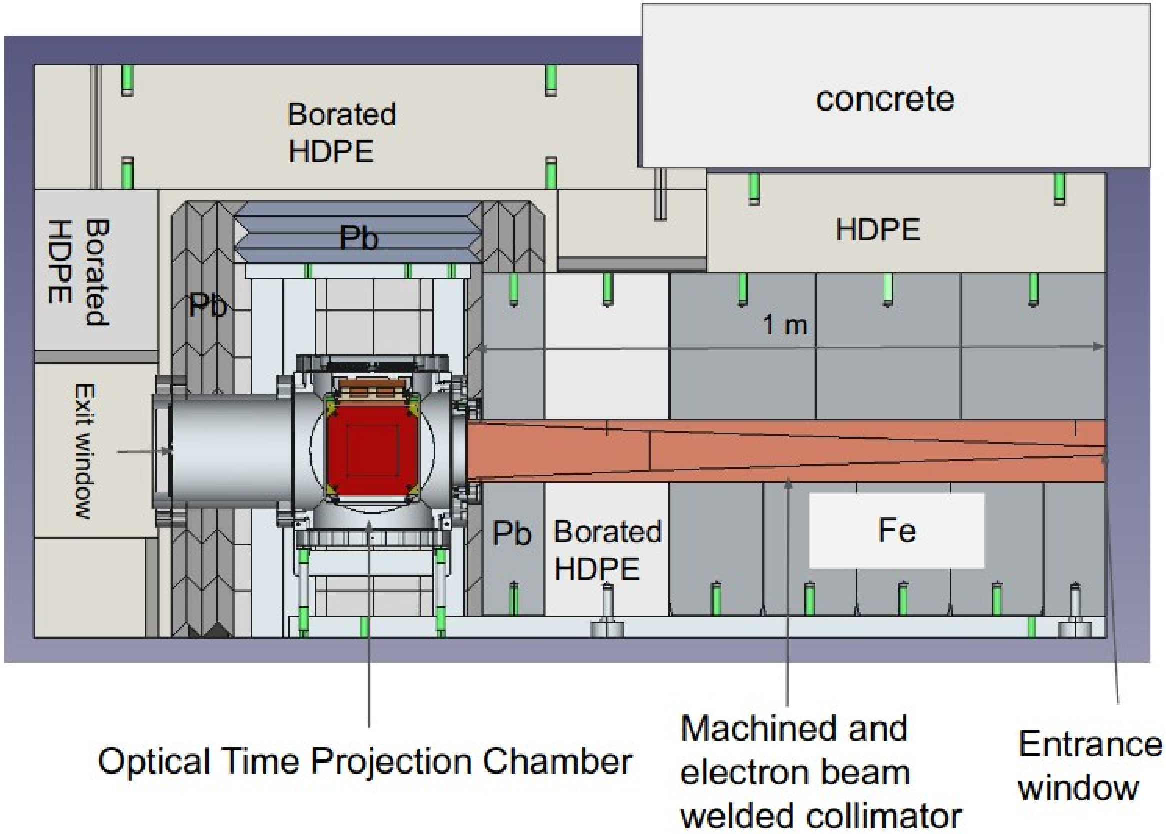




Bunker, shielding and collimator

Shield: borated polyethylene (neutron moderation)+Pb (gamma suppression)

In addition, front shield for D-T neutrons is preceded by thick Fe (neutron moderation by inelastic scattering)

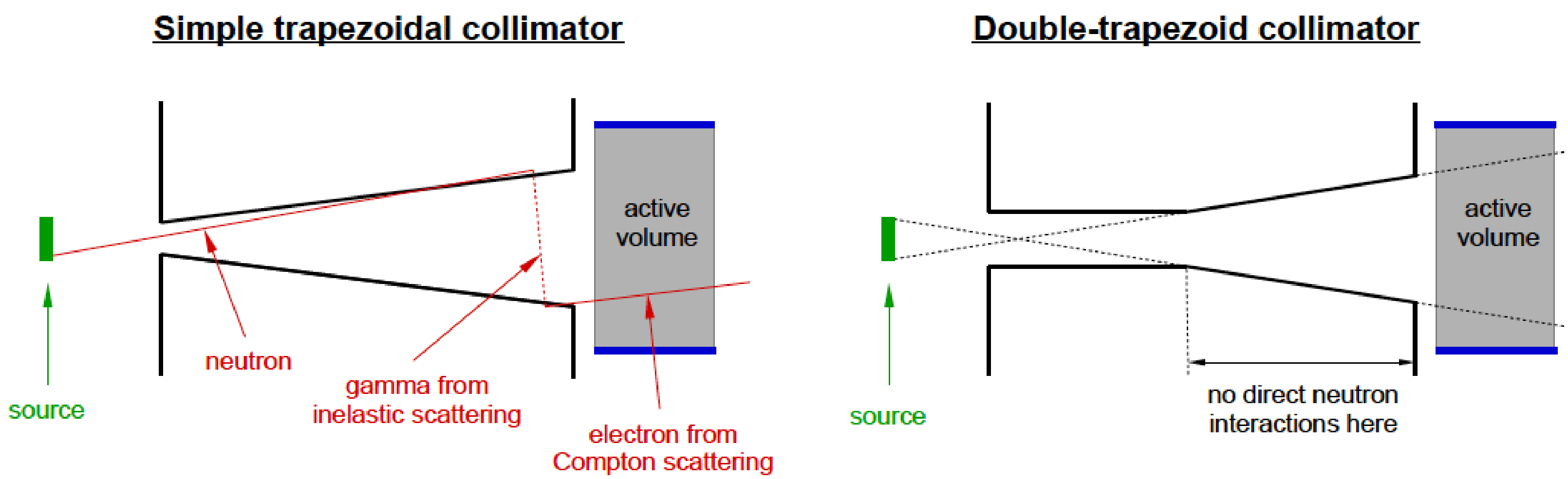


Bunker, shielding and collimator

Collimator: double-trapezoid tunnel:

1) D-D: borated polyethylene+Pb

2) D-T: Cu



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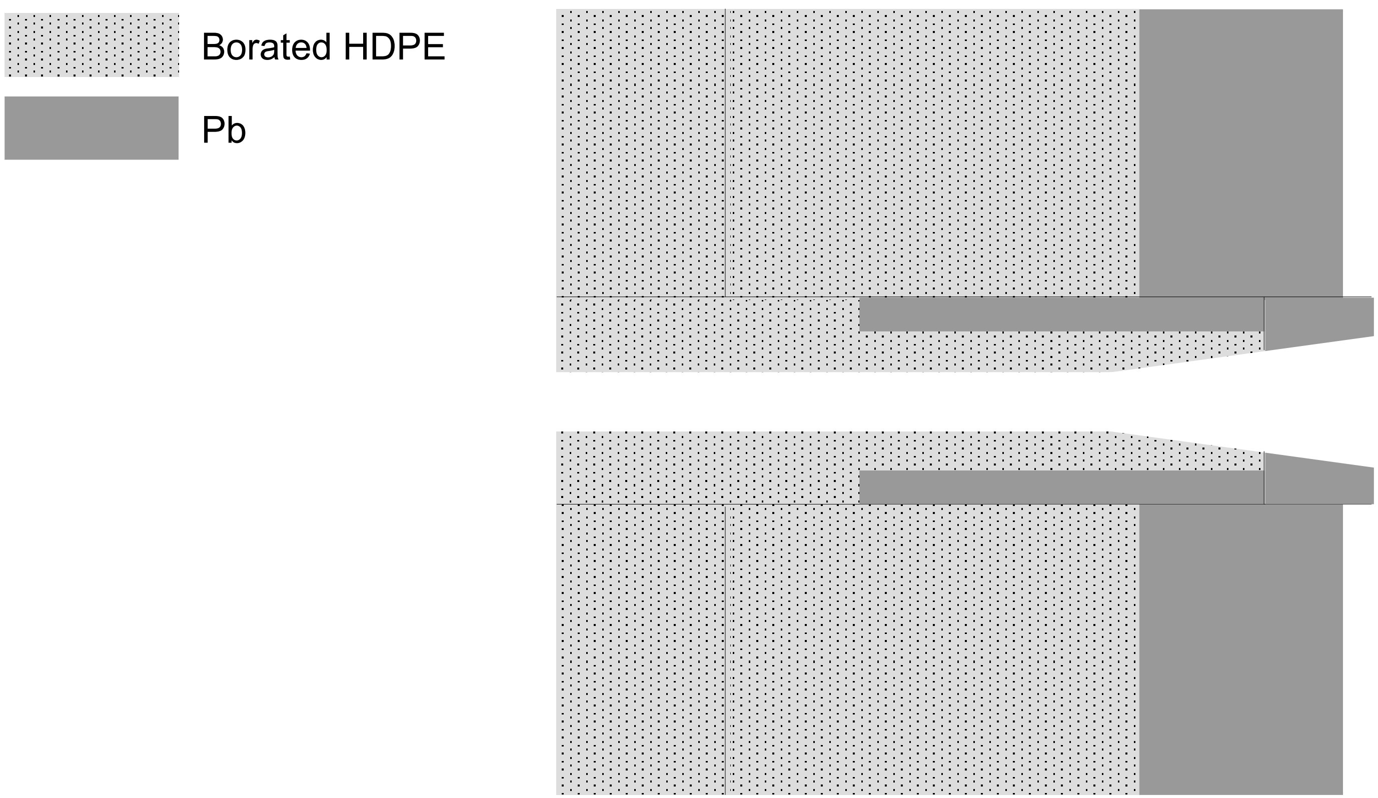

Backgrounds

Background event: nuclear recoil+electron track, satisfying:

1) Electron energy in [5, 15] keV window

2) Common vertex

Considered **background sources**:

1) Delta rays (energetic ionization electrons): electron below 5 keV

2) Particle-induced X-ray emission (PIXE): only above 5 keV for noble gases

3) Bremsstrahlung: negligible

4) Gammas from inelastic neutron scattering: below 1 event/day

5) Random track coincidences: negligible

Currently studying contribution from secondary nuclear recoils misidentified as electrons

Status

Currently finishing construction at RAL, expecting to start operations in summer 2022

Planning to use D-D neutrons on pure CF_4 gas target

Summary

- Migdal effect: atomic electron emission when nucleus is perturbed, not observed yet
- It would imply that current experiments have increased sensitivity to sub-GeV DM
- MIGDAL will use neutrons to induce Migdal effect in an optical TPC
- Signal: nuclear recoil+electron track from a common vertex
- Optical TPC: cathode+gas electron multipliers+ITO anode+camera
- MIGDAL will operate at NILE facility (RAL), along with a dedicated shielding and collimator
- Current estimates predict a favorable signal-to-background ratio
- Expecting to start operations in summer 2022

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Thank you for your attention

Supplementary slides

Gas electron multipliers