The MIGDAL experiment: towards the first observation of the Migdal effect

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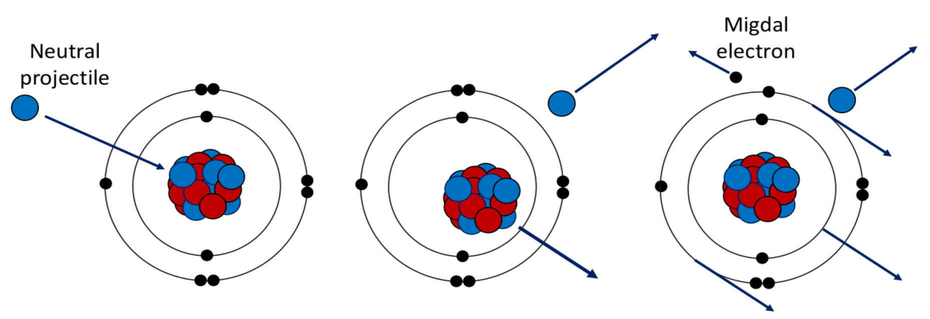
Migdal effect

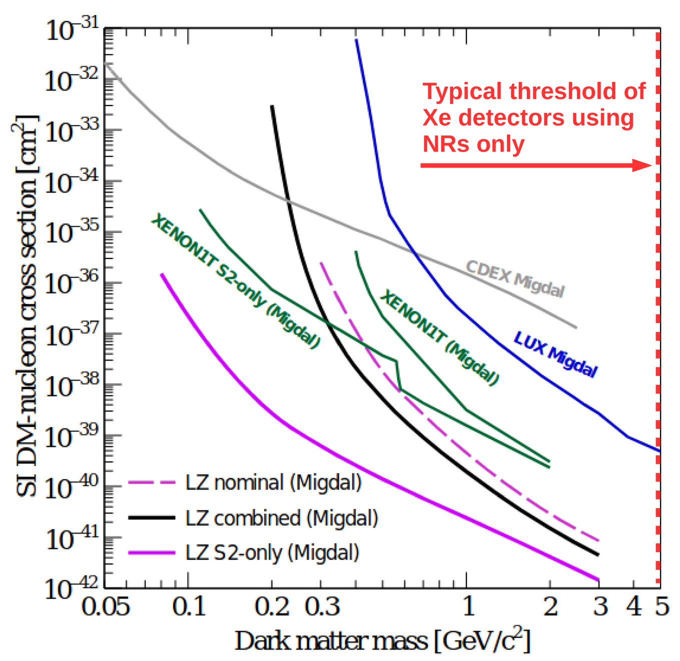
Migdal effect: emission of an atomic electron (ionization) when the respective nucleus is perturbed. Predicted by A. B. Migdal in 1941 [1]



Already observed in α and β decays [2][3], but not yet observed in nuclear recoils (NRs) caused by neutral particle scattering

Confirmation of Migdal effect in NRs would imply that direct detection experiments have increased sensitivity to sub-GeV dark matter particles [4]

Projected sensitivity of LZ to sub-GeV dark matter, assuming Migdal effect [5]



The Migdal In Galactic Dark mAtter expLoration (MIGDAL) experiment

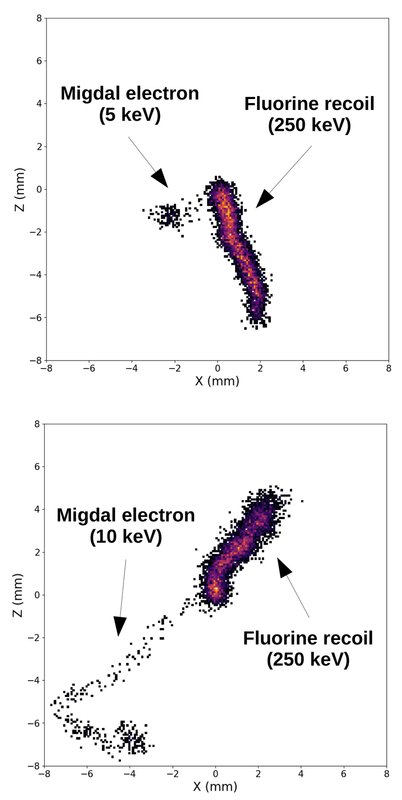
Objective: observe Migdal effect in NRs for the first time, initially on C and F atoms, and eventually on noble element atoms including Ar and Xe

Approach: use neutron beam to induce Migdal effect in gas atoms contained in a low-pressure tracking detector

Signal: NR track (> 100 keV)+Migdal electron track (5-15 keV), starting from a common position in space (vertex)

Neutron sources: deuterium-tritium (D-T) and deuterium-deuterium (D-D) fusion generators (14.1 and 2.45 MeV neutrons respectively)

Currently under construction, first operations expected by the end of this year



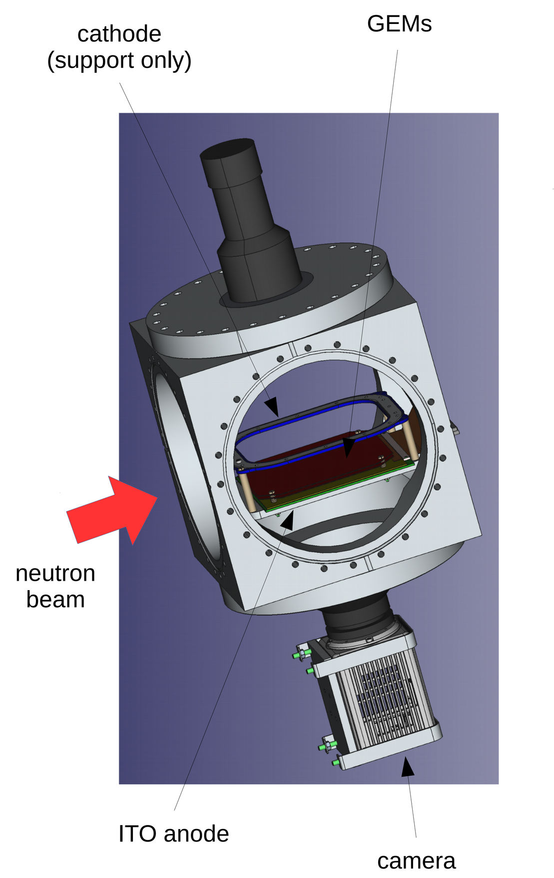
The MIGDAL optical time-projection chamber

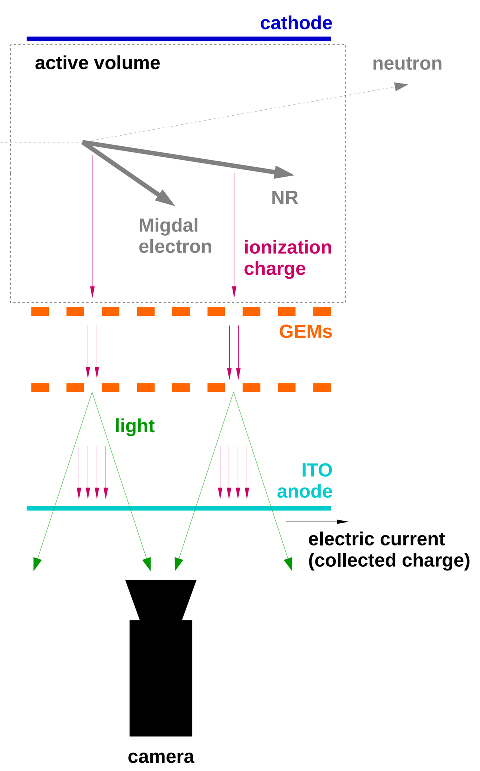
Target gas: pure CF_4 for initial observations, then CF_4 mixed with noble gases (from He to Xe). Active volume: 10 cm×10 cm×3 cm

Operated at low pressure (50 Torr) to ensure sufficient track length, and to suppress interaction of secondary photons in active volume

Concept:

- Ionization drifts towards two consecutive gaseous electron multipliers (GEMs), placed inside the CF_4 container
- Ionization charge is amplified at the GEMs, allowing to also enhance the scintillation light produced in the CF_4 gas
- A camera records the resulting scintillation light, and an ITO anode collects the amplified ionization charge





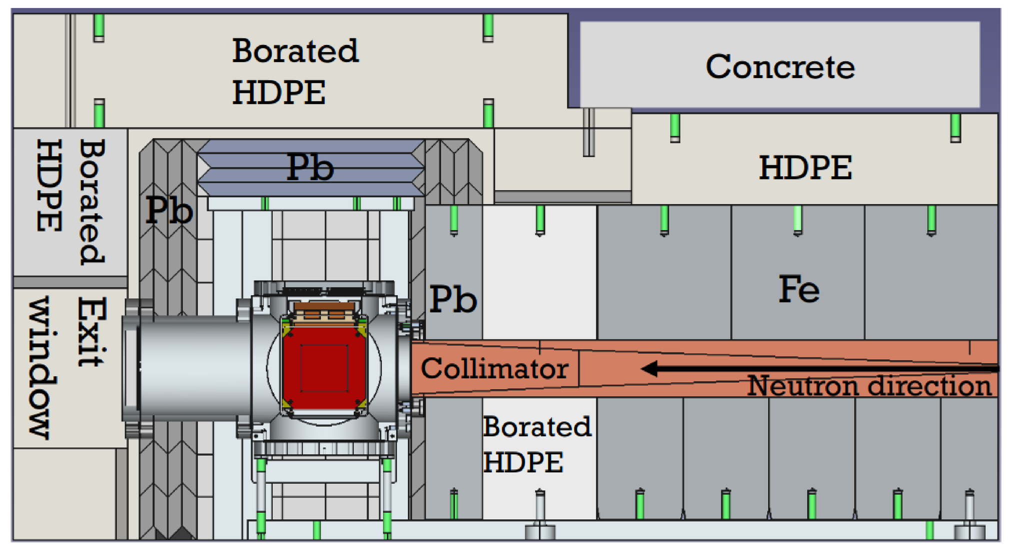
Shielding and collimator

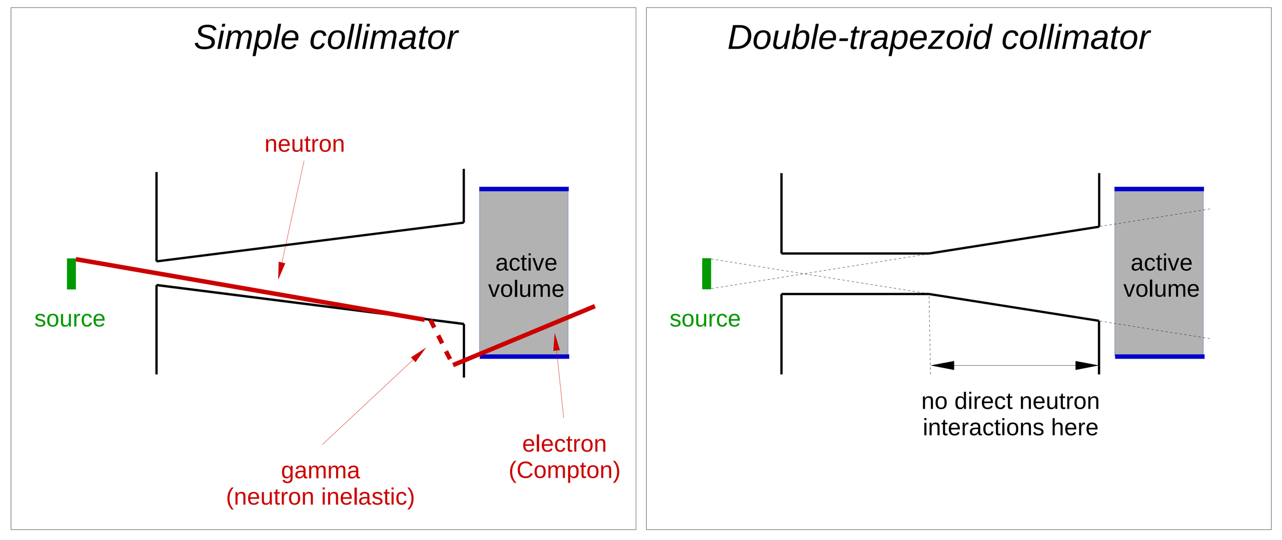
D-T and D-D neutron sources emit neutrons isotropically, therefore the experiment requires a device to select a neutron beam while suppressing any other primary or secondary radiation that might reach the active volume

This is achieved by placing layers of blocking material around the detector (shielding), with a dedicated penetration to allow a well-defined neutron beam towards the active volume (collimator)

Design of shielding and collimator for D-T neutrons already optimized, using Geant4 simulations:

- Front shielding: Fe (efficient moderation of fast neutrons down to ~5 MeV by inelastic scattering)+borated HDPE+Pb
- Side and back shielding: borated HDPE+Pb
- Collimator: double-trapezoid tunnel with Cu walls





Expected sensitivity to Migdal effect using D-T neutrons on pure CF_4

Signal: predicting ~20 Migdal events per million NR in active volume

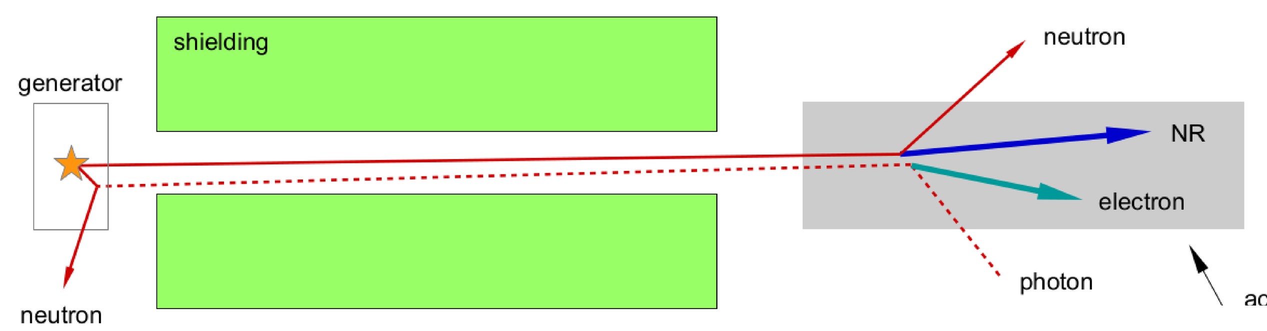
Background: any combination of a NR and an electron with energy in [5, 15] keV, isolated from other tracks, where both particles start in a volume smaller than the spatial resolution of the experiment

Background processes considered:

- Induced by NR itself: delta electrons, particle-induced X-ray emission, and various bremsstrahlung processes
- Inelastic neutron scattering on target F atoms producing a low-energy photon only (110 and 197 keV)
- Prompt β decays of unstable nuclei produced by inelastic neutron scattering on target atoms
- Random combination of NR+electron tracks

Only the last contribution is predicted to be relevant: ~4 events per million NR in active volume

Main source of electrons causing random track combinations: photons from inelastic scattering on D-T generator material, with energy in [40, 400] keV, propagating through collimator tunnel



Based on these signal and background estimates, expecting to observe Migdal effect on C and F with ~1 live day

References

[1] A. B. Migdal, J. Phys. Acad. Sci. USSR 4, 449 (1941)
[2] M. S. Rapaport, LBL-2978 (1974)
[3] C. Couratin, P. Velten, X. Fléchard *et al.*, Phys. Rev. Lett. 108, 243201 (2012)
[4] M. Ibe, W. Nakano, Y. Shoji and K. Suzuki, JHEP 03, 194 (2018)
[5] LZ Collaboration, arXiv:2021.08753 (2021)