



Appl. Phys. Lett. 129, 134101 (2026)

Prospect of detecting the Migdal effect in liquid xenon

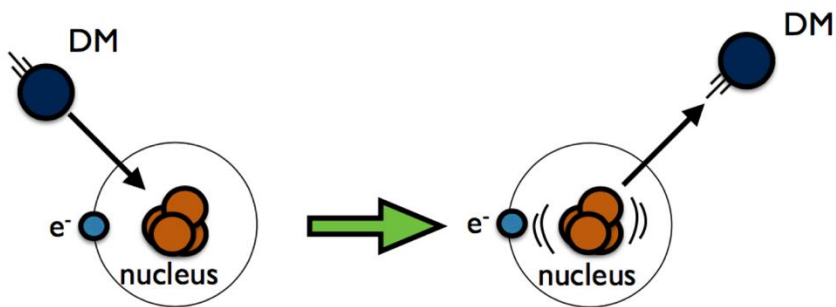
CPAD 2026, Seattle, WA
Jingke Xu

Lawrence Livermore National Laboratory

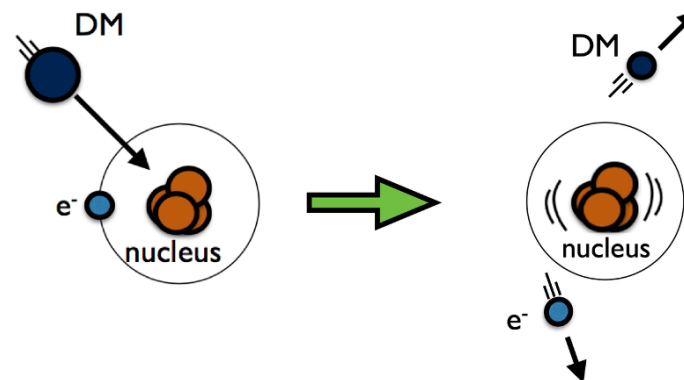
Prepared by LLNL under Contract DE-AC52-07NA27344.

Migdal effect

- A.B. Migdal ([Migdal 1941](#)) predicted that changes in the nuclear state (charge, momentum) can lead to atomic ionization or excitation
- Ibe et al ([Ibe 2018](#)) reformulated the nuclear recoil (NR) Migdal effect to simultaneously conserve energy, momentum and interaction probability
- Theory on application to dark matter searches further developed by many: [Essig 2020](#), [Baxter 2020](#), [Liu 2020](#), [Cox 2022](#), [Berghaus 2023](#), etc



A dark matter particle produces a recoiling nucleus

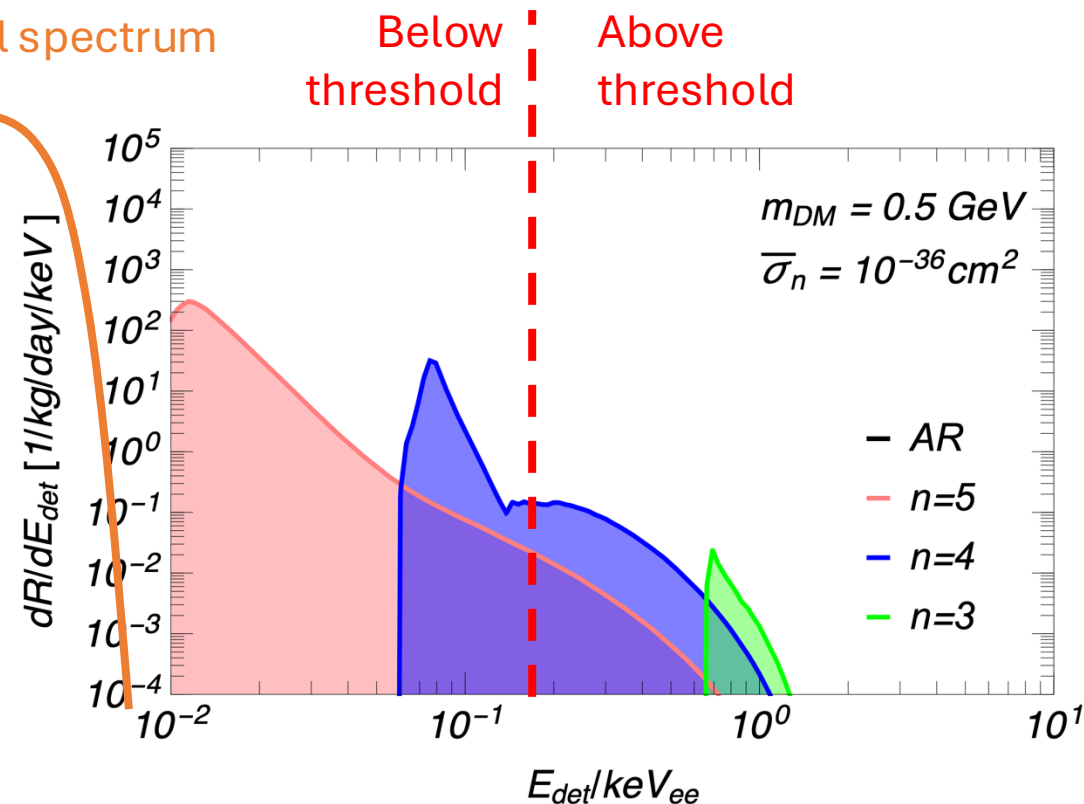


A dark matter particle produces a recoiling nucleus and a recoiling electron through the Migdal process

A blessing to LXe experiments

- Liquid xenon (LXe) detectors demonstrated unparallel dark matter sensitivities above $\sim 0.1 \text{ keV}_{ee}$
- below this threshold sensitivities diminish
- The Migdal effect can lift a small fraction of below-threshold dark matter interactions to above threshold
 - Extraordinarily low background levels in LXe allows Migdal signals to be observed

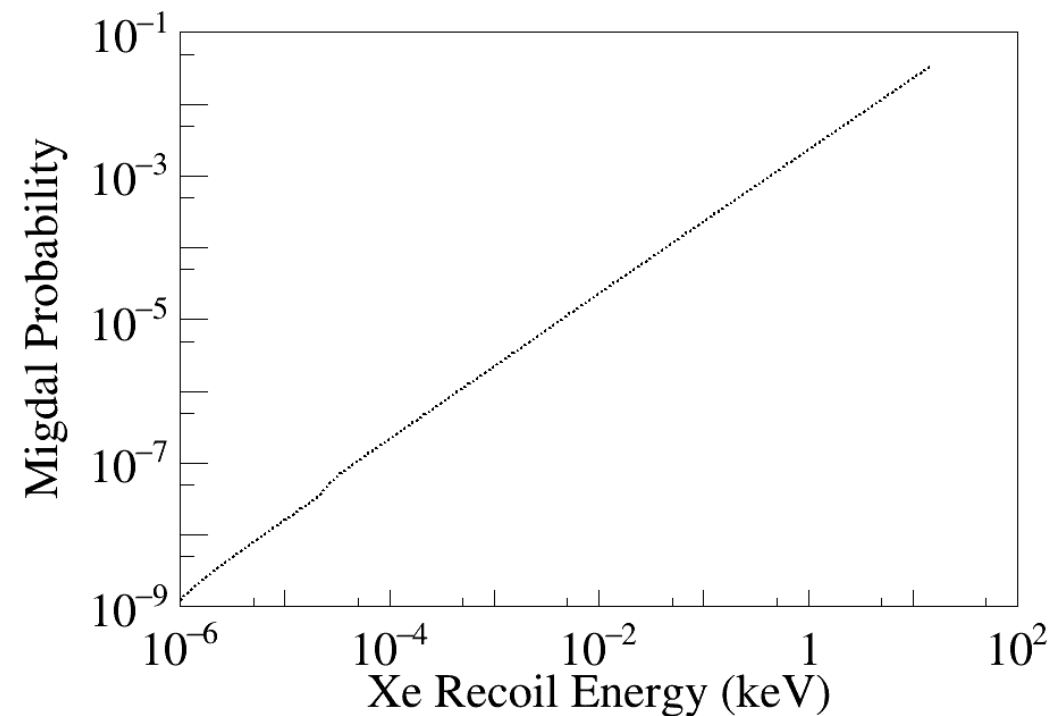
Illustrative nuclear recoil spectrum



Observable energy for Migdal interactions induced by 0.5 GeV dark matter in liquid xenon, *Ibe, et al, JHEP, 03 (2018), 194*

A blessing to LXe experiments

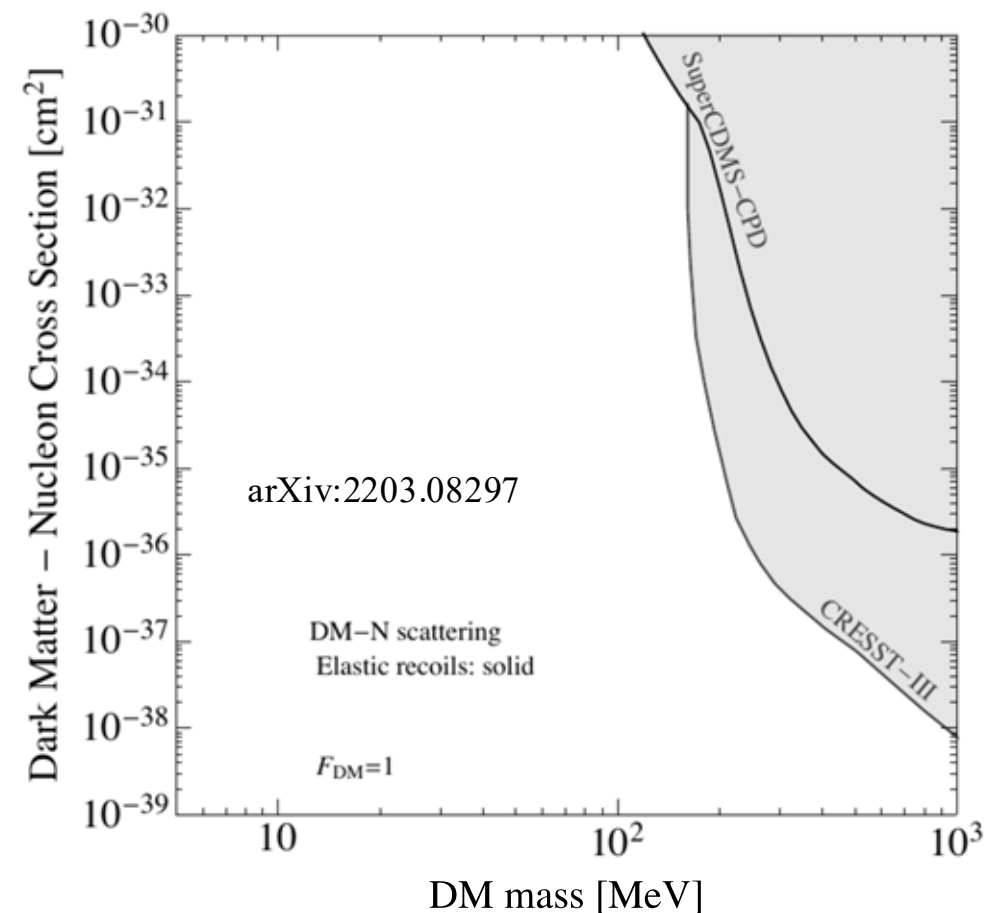
- Liquid xenon (LXe) detectors demonstrated unparallel dark matter sensitivities above $\sim 0.1 \text{ keV}_{\text{ee}}$
- below this threshold sensitivities diminish
- The Migdal effect can lift a small fraction of below-threshold dark matter interactions to above threshold
 - Extraordinarily low background levels in LXe allows Migdal signals to be observed
 - Large LXe masses in existing experiments compensate reduced interaction rates



Probability of overall Migdal interaction probability as a function of nuclear recoil energy (assuming abundant projectile energy)

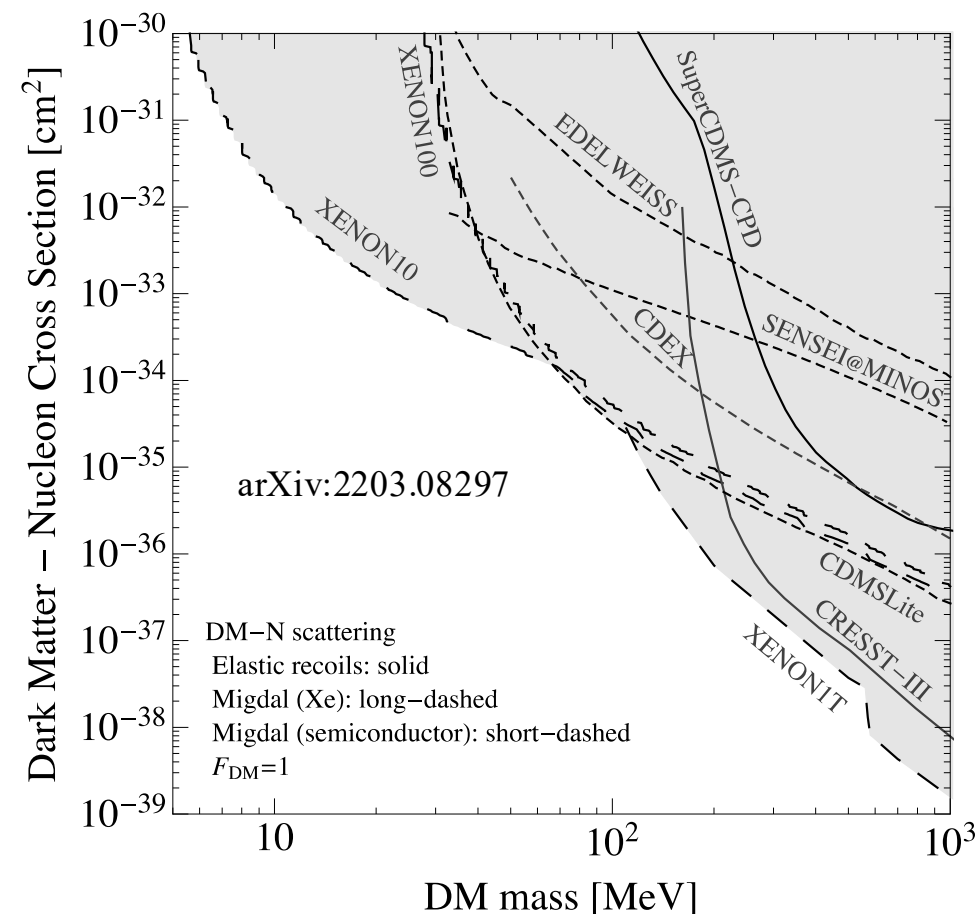
Newfound sensitivity in existing experiments

- Potential enhancement of low-mass dark matter sensitivity has been extensively explored
 - *LUX*, PRL 122 131301 (2019)
 - *XENON1T*, PRL 123, 241803 (2019), PRD.106.022001 (2022)
 - *DarkSide50*, PRL 130, 101001 (2023)
 - *EDELWEISS*, PRD 106, 062004 (2022)
 - *CDEX-1B*, PRL 123.161301 (2019)
 - *SuperCDMS*, PRD 107, 112013 (2023)
 - *PandaX*, PRL 131, 191002 (2023)
 - and more ...



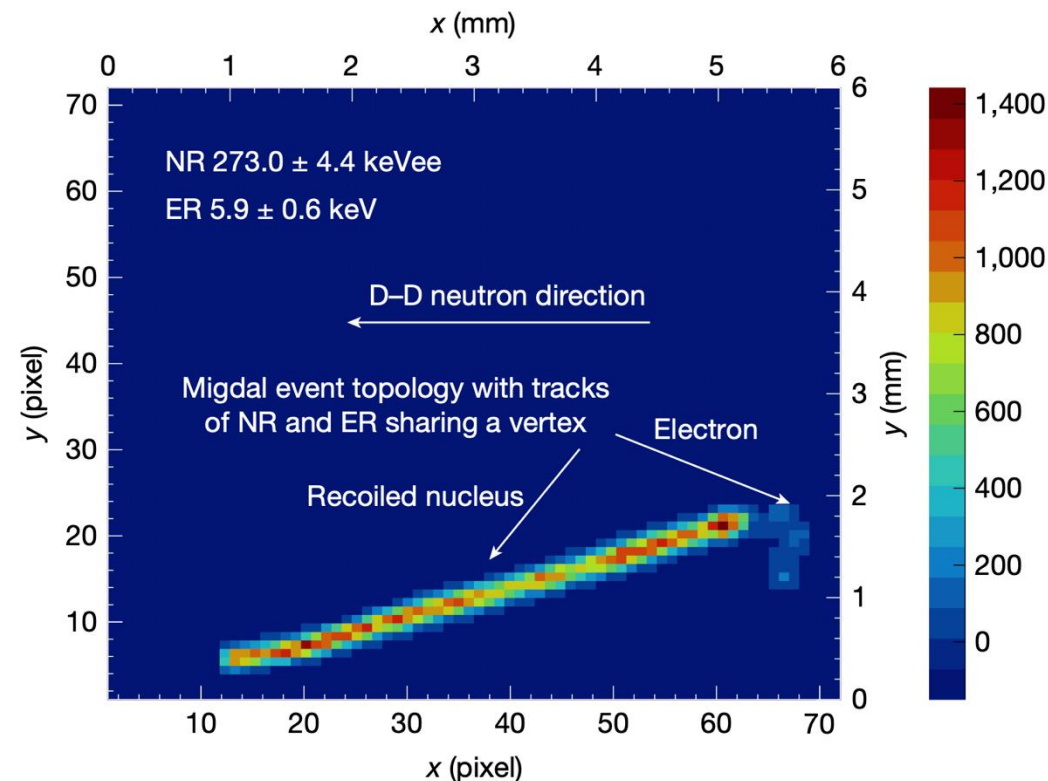
Newfound sensitivity in existing experiments

- Potential enhancement of low-mass dark matter sensitivity has been extensively explored
 - *LUX*, PRL 122 131301 (2019)
 - *XENON1T*, PRL 123, 241803 (2019), PRD.106.022001 (2022)
 - *DarkSide50*, PRL 130, 101001 (2023)
 - *EDELWEISS*, PRD 106, 062004 (2022)
 - *CDEX-1B*, PRL 123.161301 (2019)
 - *SuperCDMS*, PRD 107, 112013 (2023)
 - *PandaX*, PRL 131, 191002 (2023)
 - and more ...



Migdal effect is only observed in gas recently

- The importance of experimentally verifying the Migdal effect has drawn substantial community interests
 - [Bell 2020](#), [Nakamura 2020](#), [Bell 2022](#), [Adams 2022](#), [UKMigdal 2023](#), [Xu 2024](#), [Yi 2026](#),
- The effect was only recently observed in a gas detector medium
- A direct verification in a dark matter detection medium, especially LXe, remains to be demonstrated

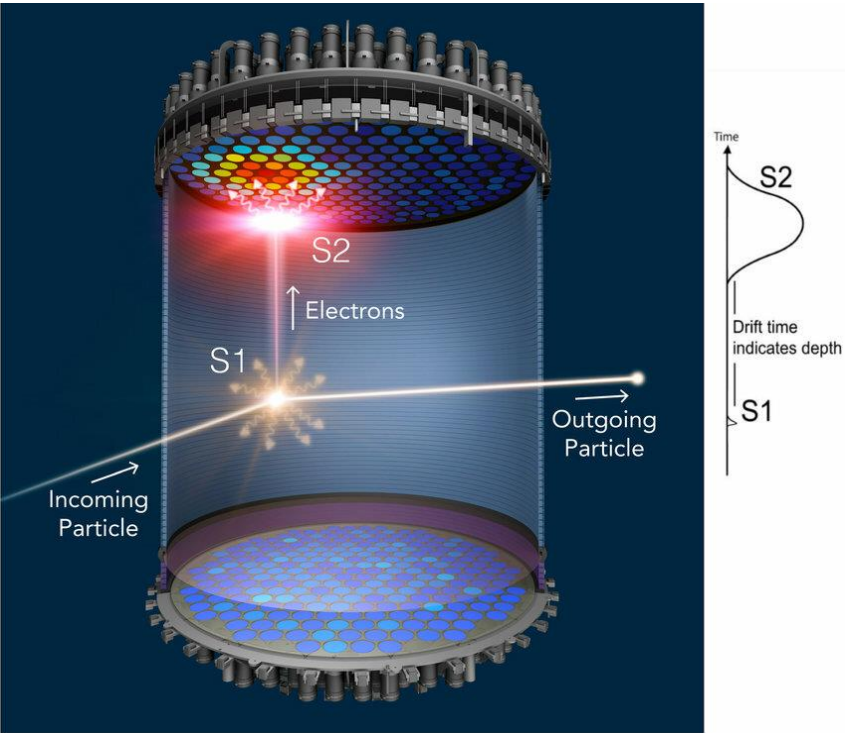


Observed co-located electron recoil and nuclear recoil tracks in a neutron Migdal interaction in gas

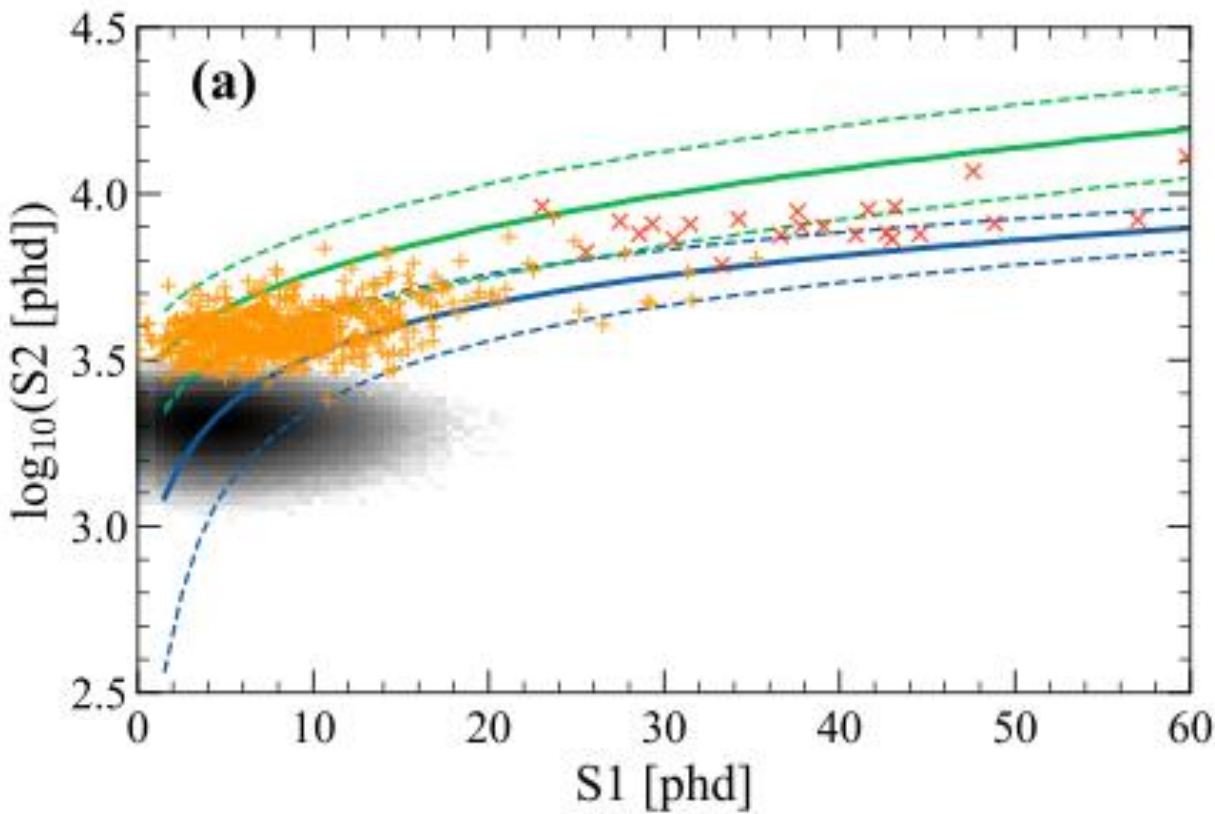
[Yi, et al, Nature 649, 2026](#)

Predicted signal behavior in LXe TPCs

A LXe TPC collects both scintillation (S1) and ionization (S2) signals



The S1-S2 energy partition can infer the type of particle interactions (electron or nuclear recoil)

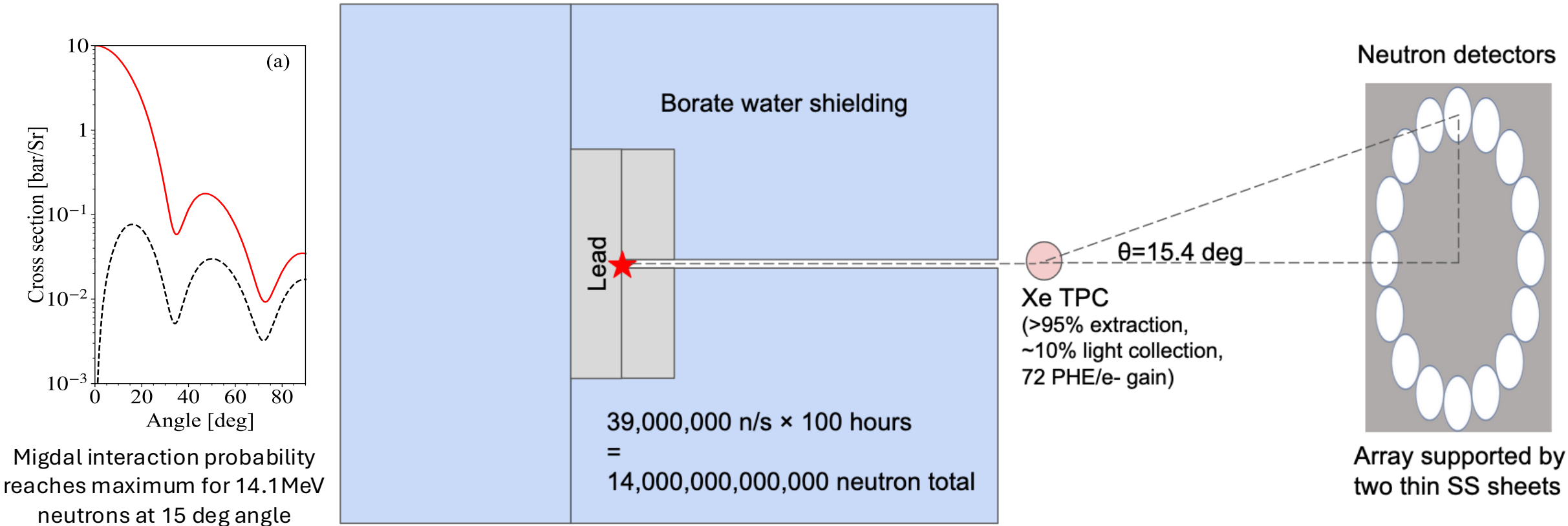


Predicted M- and L-shell Migdal signals for 7keV xenon recoils in a LXe TPC

The first Migdal measurement attempt in LXe

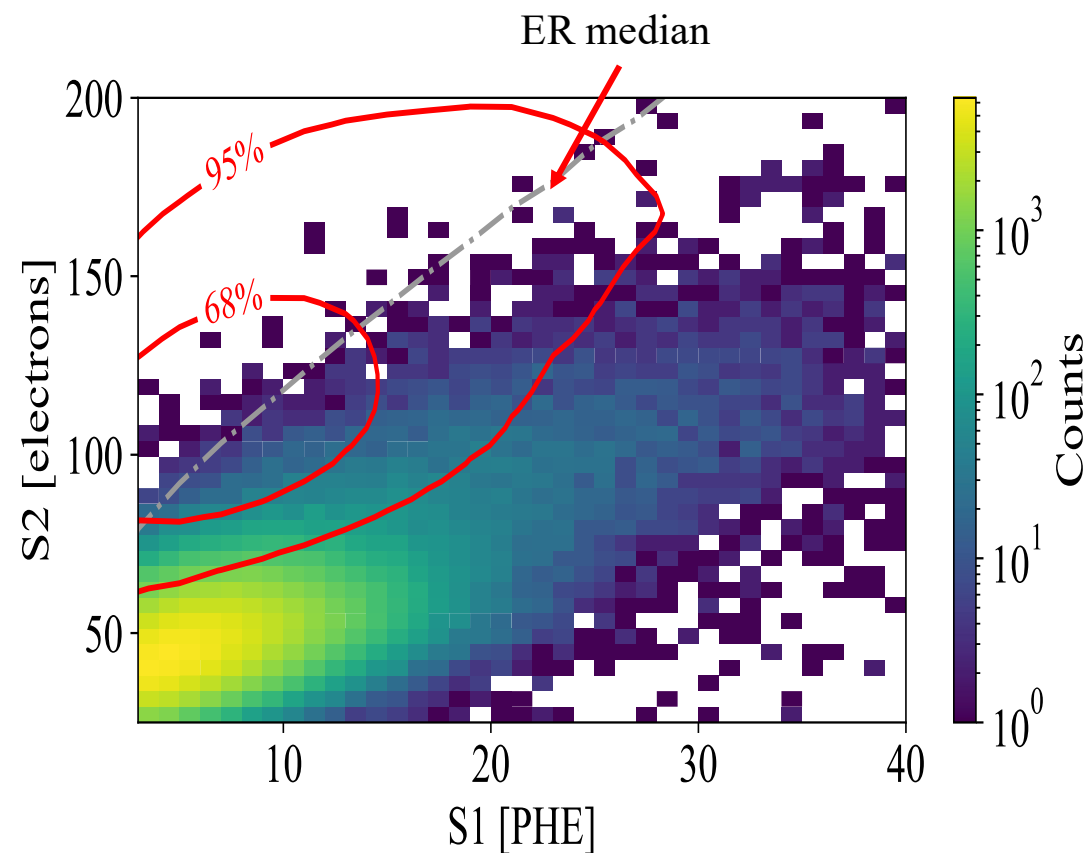
We carried out a direct Migdal search with 7keV xenon recoils by scattering 14.1 MeV neutrons off xenon

[Xu, et al 2024](#)



An apparent discrepancy with predictions

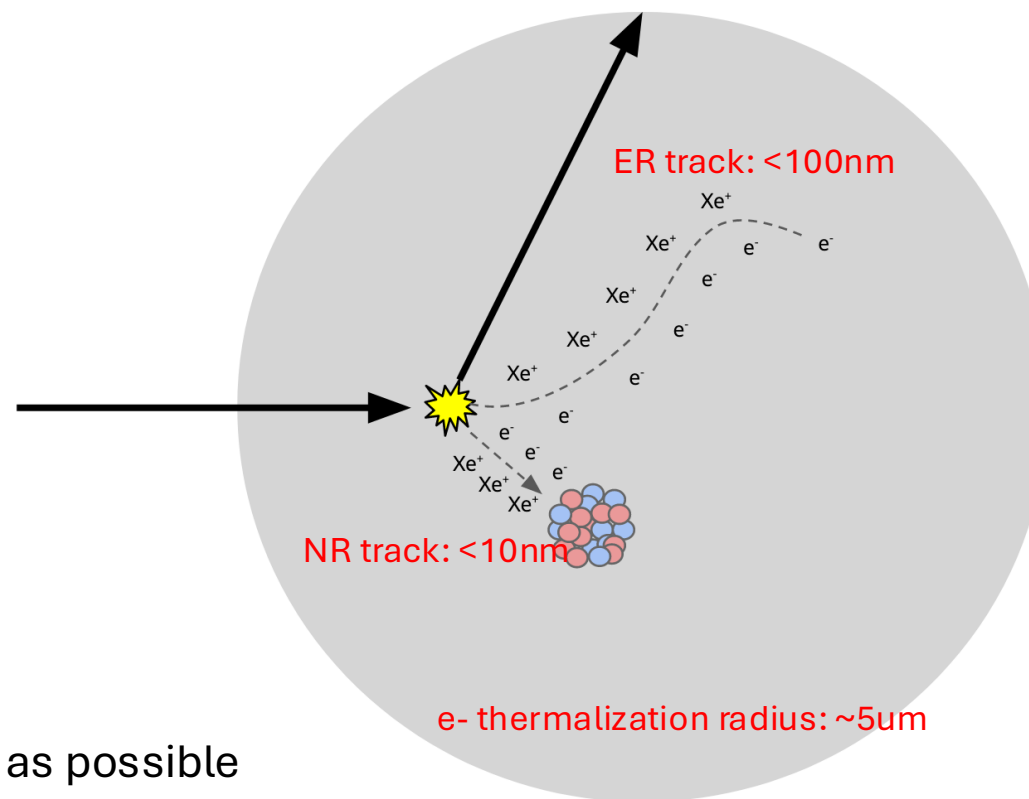
- Few events are observed in predicted signal region despite $O(100)$ signals expected
- Theory prediction is robust
- Experimental background rejection is strong
- What caused the discrepancy?



Data set used for the M-shell Migdal interaction ($E_{ER} > 0.5 \text{ keV}$) search

Reality check #1: Migdal signal quenching

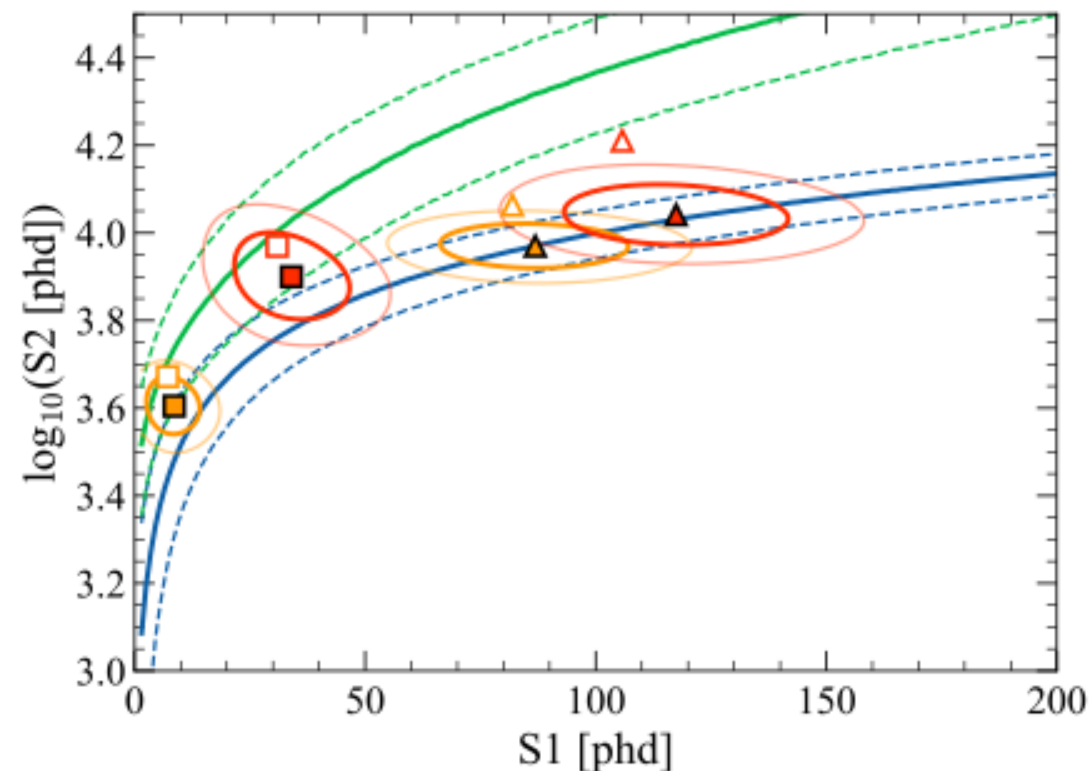
- A Migdal interaction produce overlapping electron recoil and nuclear recoil tracks
- Ionization signal generation from each track can get additionally quenched by the other



Each ionization electron sees more ions as possible recombination site, reducing electron escaping probability

Reality check #1: Migdal signal quenching

- A Migdal interaction produce overlapping electron recoil and nuclear recoil tracks
- Ionization signal generation from each track can get additionally quenched by the other
- Quenched Migdal signals are closer to nuclear recoil backgrounds, especially for high energy xenon recoils



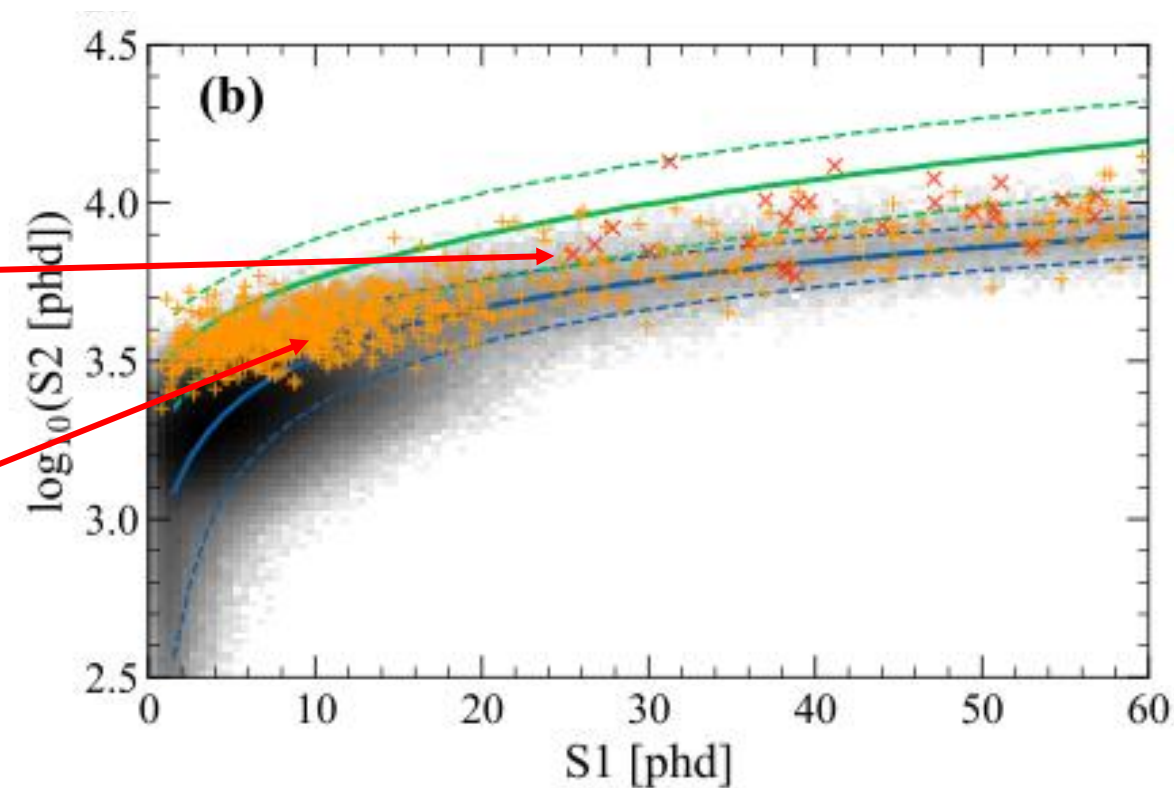
Predicted M- and L-shell Migdal signals for 7keV (squares) and 60keV (triangles) xenon recoils before (hollow) and after (filled) considering cross-track quenching

* Effect already reflected on Slide #8

Reality check #2: neutron multi-scatter background

Despite neutron multi-scatter mitigation

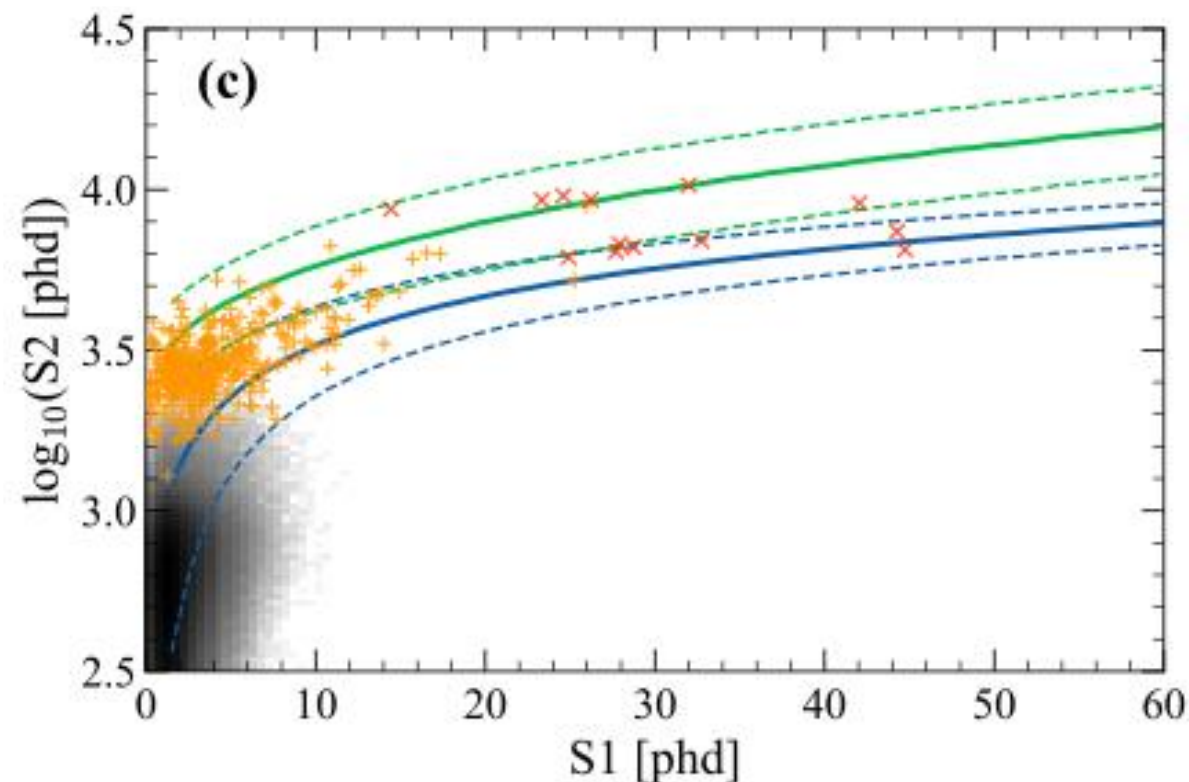
- Neutrons may scatter in passive materials and produce off-peak xenon recoils
- Neutrons may scatter multiple times in LXe and produce signals between electron recoils and nuclear recoils



Signal region moves down, and NR background region moves up

A possible path toward Migdal confirmation in LXe

- Lower energy xenon recoils are less susceptible to NR-ER signal quenching
- Multiscatters of neutrons of low-enough energy cannot contaminate the Migdal signal region, at the cost of low signal rate
- Simulations predict a definitive Migdal confirmation in LXe assuming sufficient background control



Predicted M- and L-shell Migdal signals for <4 keV xenon recoils produced by 100keV neutrons

Conclusion

- The Migdal effect can substantially enhance existing LXe TPCs' sensitivities to low-mass dark matter interactions
- This effect has only been observed recently in a gas medium; a confirmation in LXe remains critical for its application to dark matter searches
- We carried out the first direct Migdal effect search in LXe
- Multiple experimental effects led to a null result in our first search
- A promising path toward a definitive Migdal measurement in LXe has been identified
- Stay tuned!