Developments in Measuring the Migdal Effect

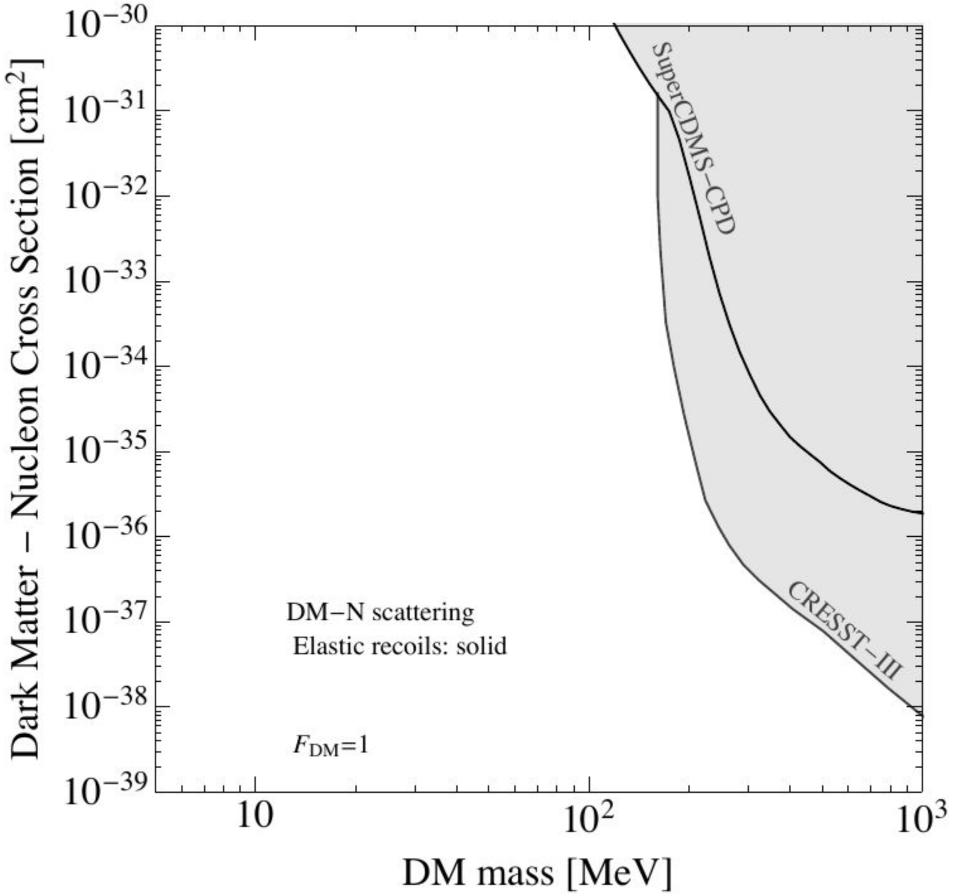
Duncan Adams

Outline

- Motivation and background
- Overview of detection strategy
- Results from search in LXe
- Conclusions and future directions

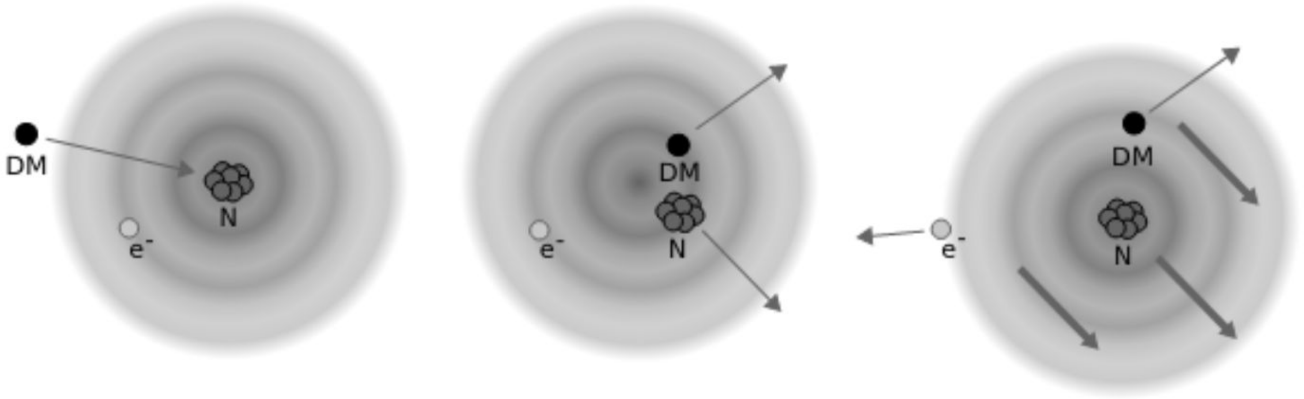
Motivation - Sub-GeV Dark Matter

- Existing direct detection techniques limited by ~ keV thresholds
- Since $v_{DM} \sim 10^{-3}$, rapidly lose sensitivity around $m_{DM} \sim 1$ GeV
- Need new techniques to push limits lower…
- Migdal effect!



Migdal Effect

- In simple terms, kinematically induced ionization from a nuclear recoil
- Nucleus is displaced, some electrons might not “catch up”
- Prediction of ‘basic’ quantum mechanics, sudden approximation
- Should happen in gas, liquids, and even semiconductors!



Incoming DM scatters off nucleus, with electron being ejected from its shell

Dolan, Kahlhoefer, McCabe: 1711.09906

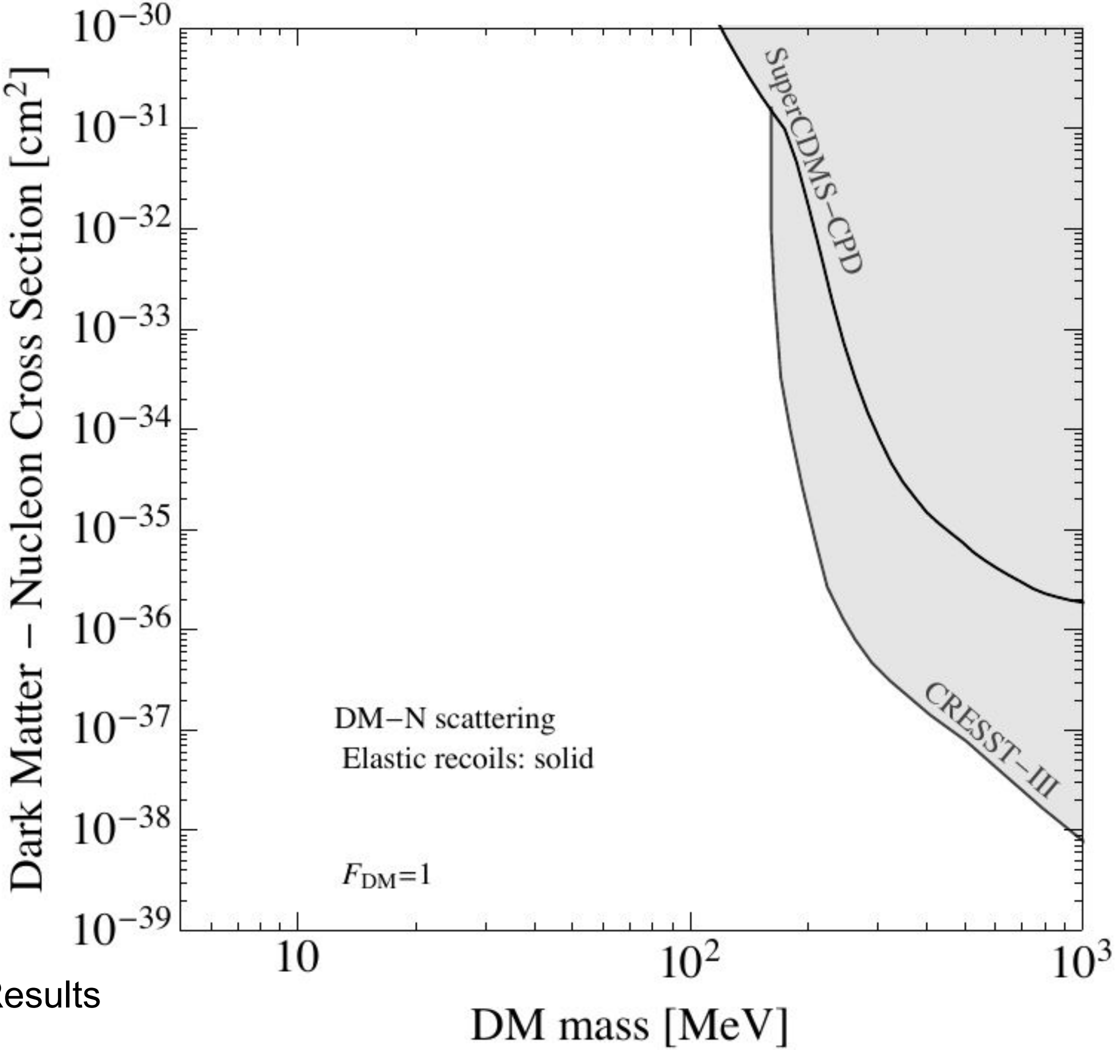


Fig: Compiled Migdal Results
Essig et al: 2203.0829

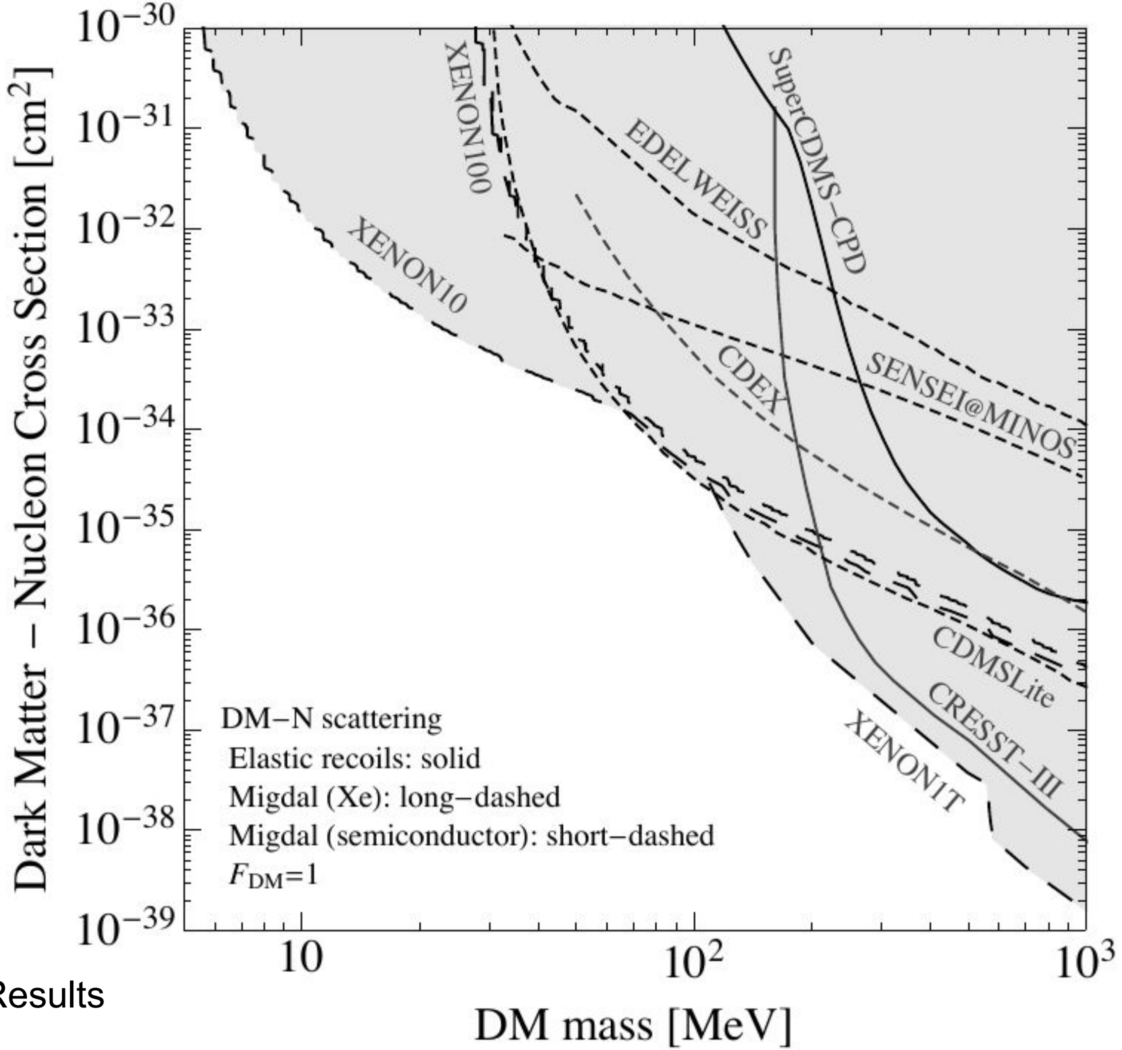


Fig: Compiled Migdal Results

Essig et al: 2203.0829

Problem….

No definitive detection of Migdal ionization using standard model probes!

Migdal Search at LLNL

Lawrence Livermore National Laboratory

Jingke Xu
Teal Pershing
Rachel Mannino
Ethan Bernard
Eli Mizrachi
Vladimir Mozin
Phil Kerr
Adam Bernstein

Berkeley UNIVERSITY OF CALIFORNIA

Junsong Lin

Stony Brook University

Duncan Adams
Rouven Essig

UC DAVIS UNIVERSITY OF CALIFORNIA

James Kingston
Mani Tripathi

SLAC NATIONAL ACCELERATOR LABORATORY

Brian Lenardo

Migdal Detection - Neutron Scattering

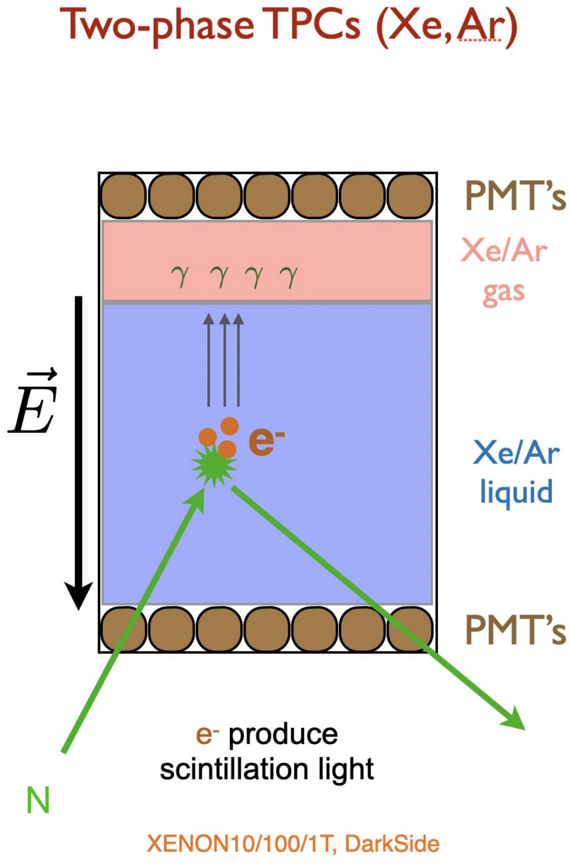
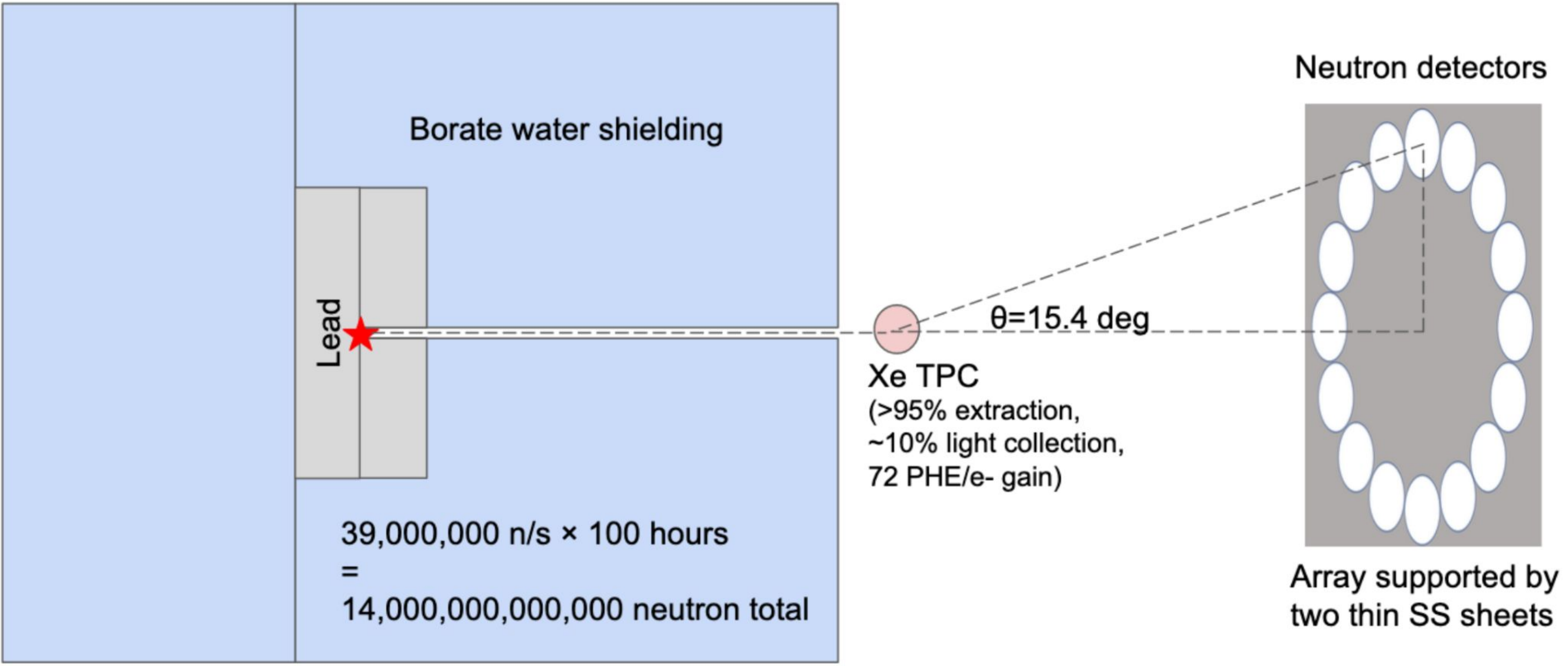


Image Credit: R. Essig

- Scattering experiment on a dual phase LXe TPC @ LLNL
- Using similar setup to detector calibration studies with a backing array - allows tagging scattering angle
- Theorists compute angular Migdal spectra, and experimentalists put it to the test!


Borate water shielding
Lead
39,000,000 n/s × 100 hours
=
14,000,000,000,000 neutron total
θ=15.4 deg
Xe TPC
(>95% extraction,
~10% light collection,
72 PHE/e- gain)
Neutron detectors
Array supported by
two thin SS sheets


LXe TPC (hidden) internals
5cm diameter
CAUTION
RADIATION AREA
FRAGILE

Migdal Detection - Calculation of angular distribution

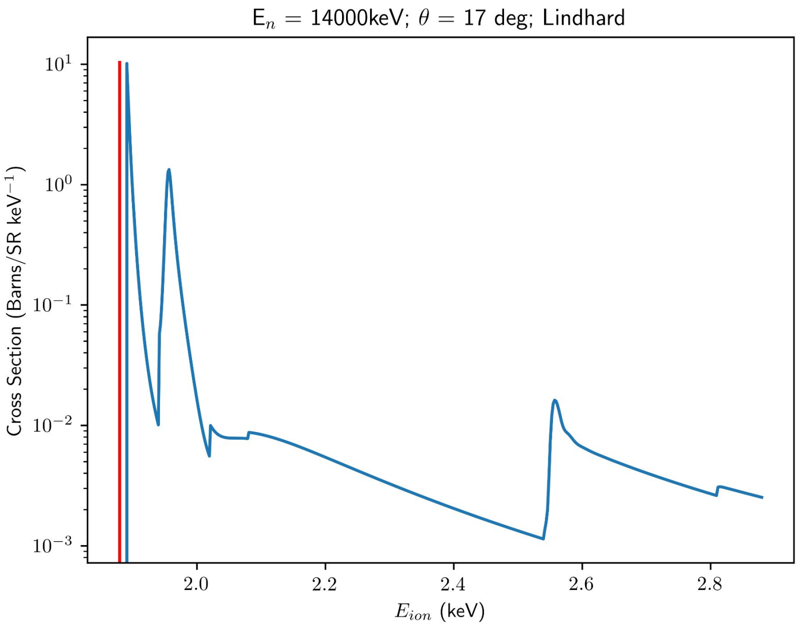
- A key result of the existing Migdal literature is factorization

$$R_M \sim R_{\text{elastic}} \times P_{\text{Mig}}$$

- The Migdal piece is isotropic, inherits angular dependence from elastic recoil

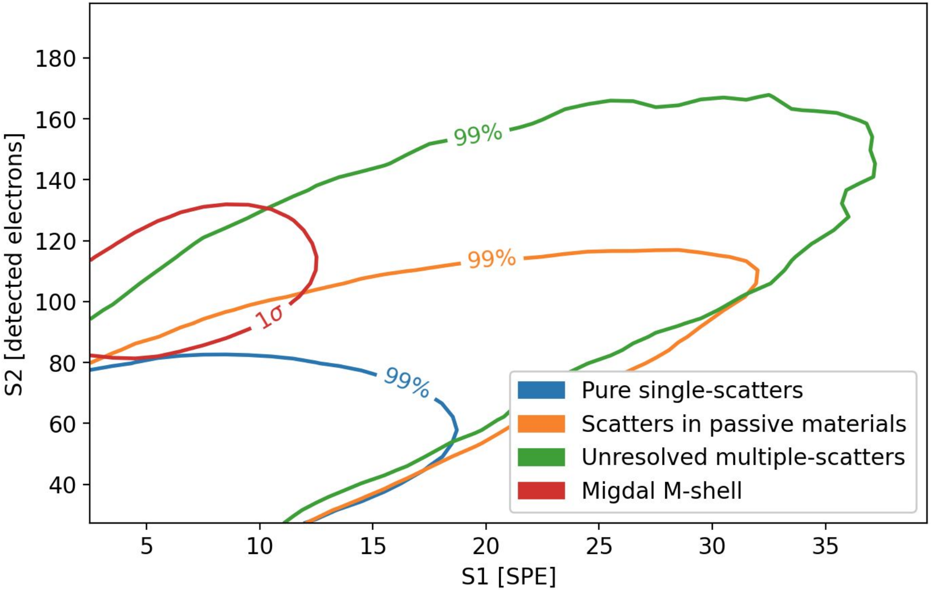
$$\frac{dR}{d\cos\theta} \sim \frac{dR_{\text{el}}}{d\cos\theta} \times P_{\text{Mig}}(E_e)$$

- Elastic recoils are monoenergetic, Migdal creates a spectrum at fixed angle



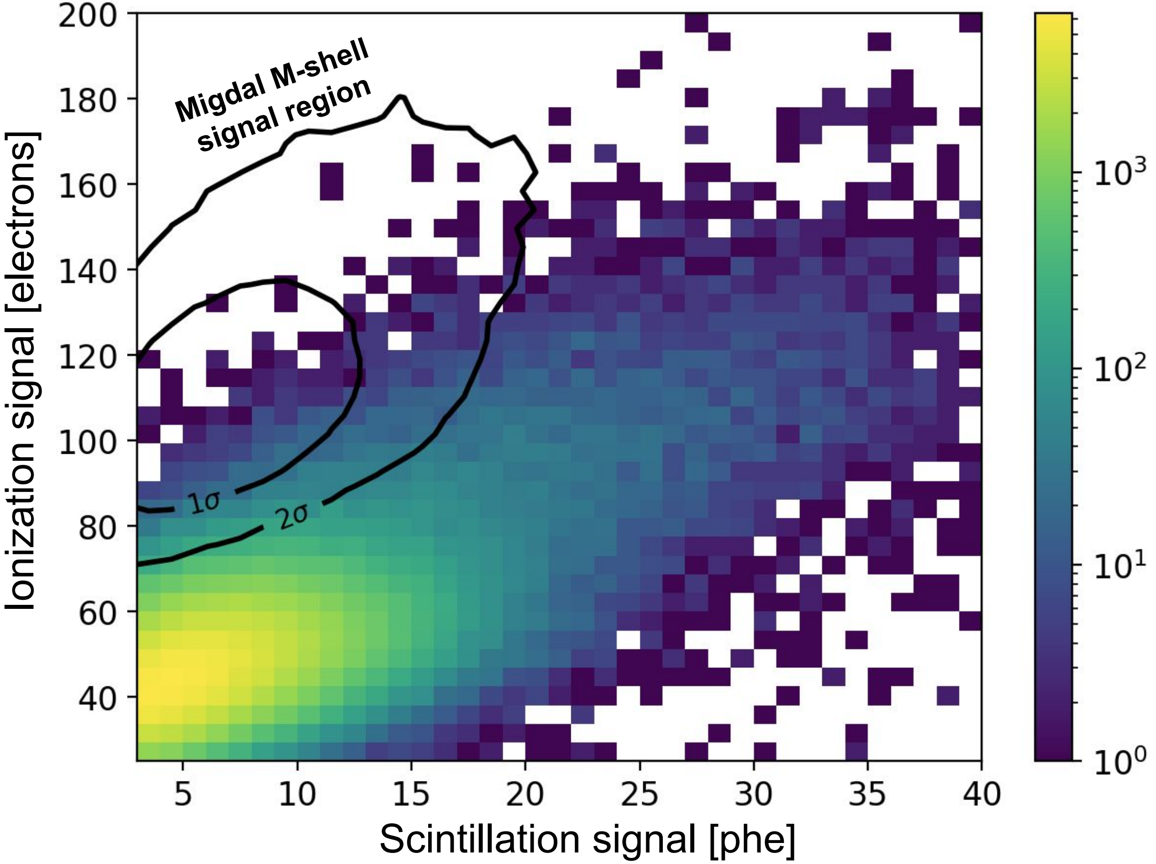
Example ionization spectrum in xenon

Migdal Detection - Simulated Signal



- Using computed angular spectra, do an MCMC run in Geant4
- Determine distributions of S1 and S2 in the TPC using NEST
- M shell (n = 3) in Xe leads to ~5 keV x rays
- Higher s2 than pure NR, separating Migdal into its own band

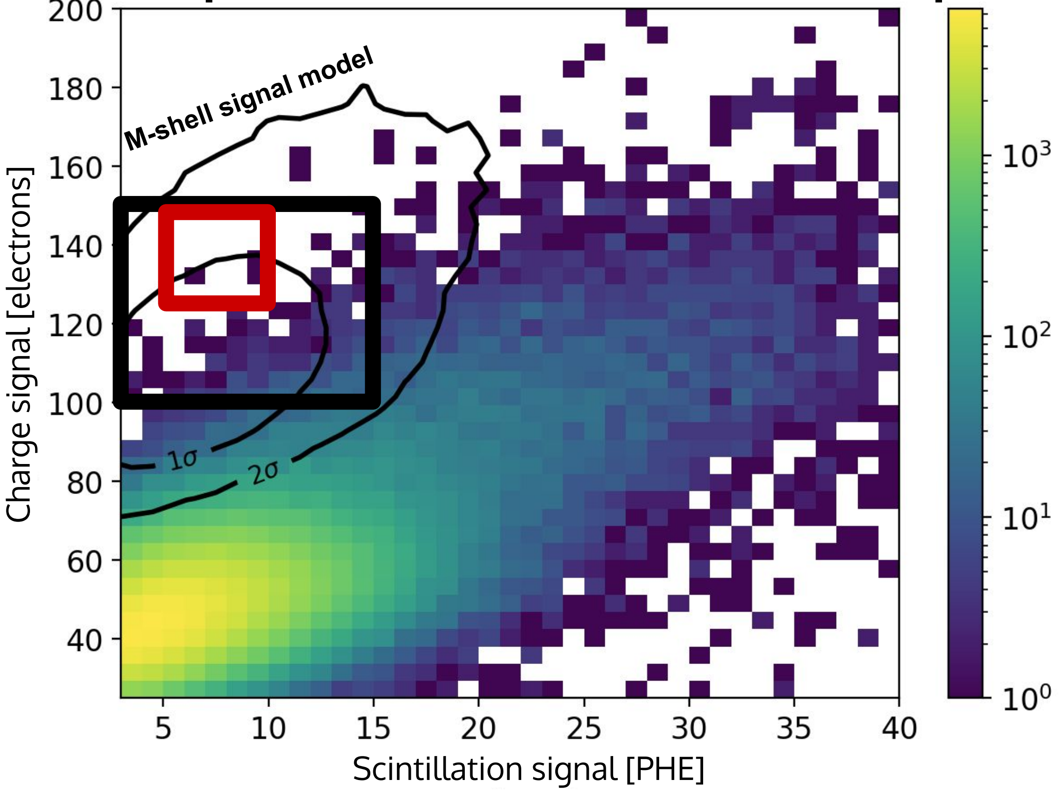
Migdal Detection - Data



We end up with 300,000 neutron scattering events passing our cuts

Predict ~200 M-shell Migdal events in this event sample

Migdal Detection - Data
Simple cut and count comparison



Preliminary counting analysis

S1 cut	S2 cut	Bkg-only model*	Signal+bkg model	Observed
[5,10]	[125,150]	2.6	19.2	**3**
[3,15]	[100,150]	362.6	496.5	**335**

Our data are consistent with our predicted backgrounds, and **disfavor the presence of Migdal events in our expected signal region**

***Note:** systematic uncertainties in background models are still being finalized

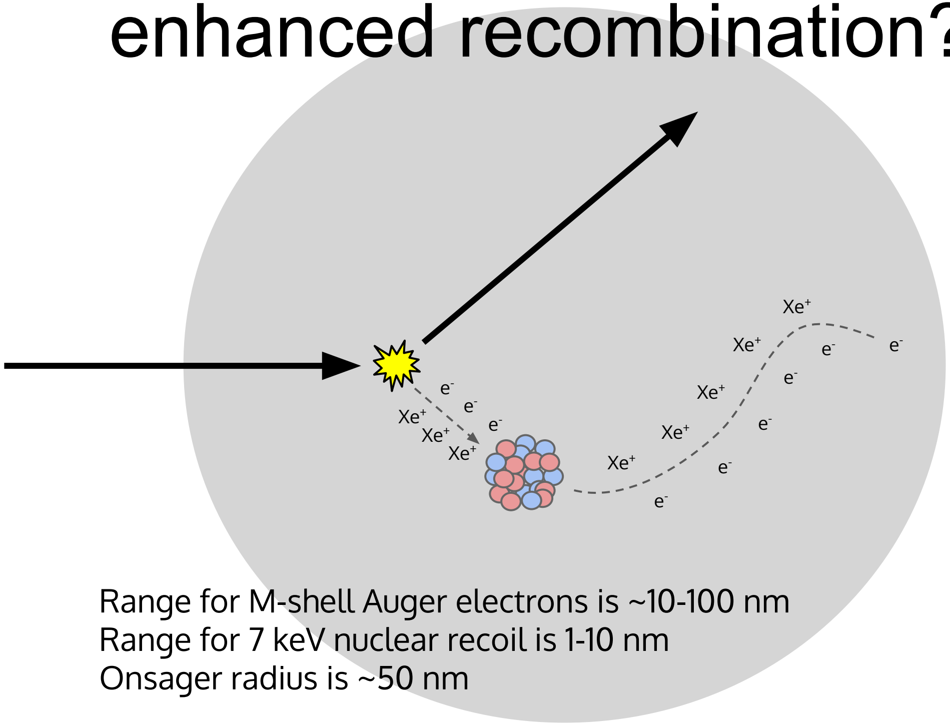
Migdal Detection - Conclusions

- We see a complete lack of signal in the expected region

- The experiment is not very sensitive to mis-modelling of nuclear recoils and the migdal signal should live in a low background region

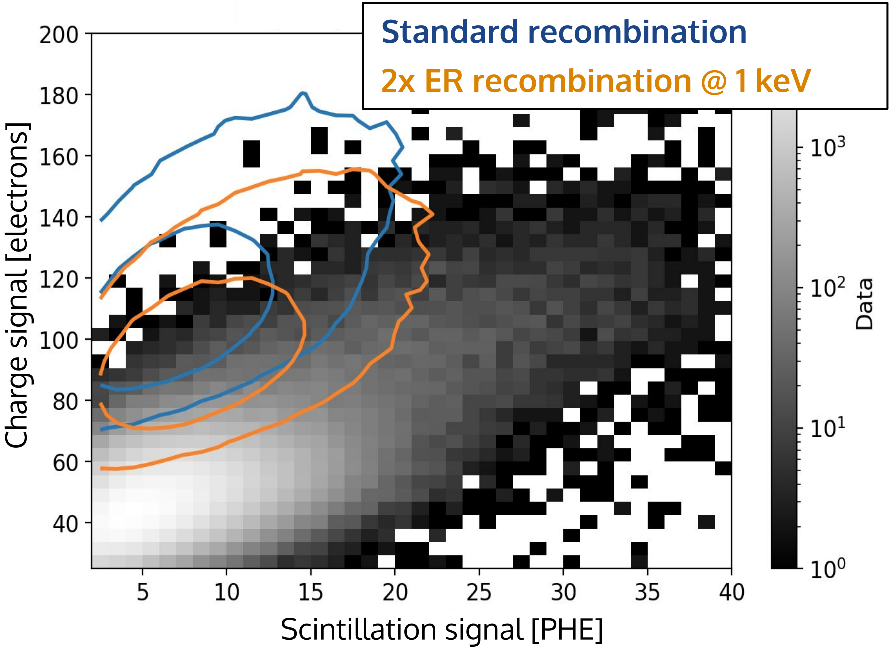
- Perhaps treating Migdal as a nuclear recoil with an associated electron recoil is to naive?

A possible hypothesis: enhanced recombination?



Range for M-shell Auger electrons is ~10-100 nm
Range for 7 keV nuclear recoil is 1-10 nm
Onsager radius is ~50 nm

Could the electrons from the ER component be recombining with the ions from the NR component?



Courtesy of B. Lenardo

Future Directions

- Planned follow up at LLNL with lower energy neutrons and improved timing resolution (Xu, Leonardo, et al)

- Nascent collaboration with folks at Princeton for a LAr campaign

- Planned measurement campaign in Si, based on 2210.04917 (DA, Baxter, Day, Essig, Kahn)

Bibliography

- 1707.07258 (Ibe, Nakano, Shoji, Suzuki)
- 2208.12222 (Cox, Dolan, McCabe, Quiney)
- 2007.10965 (Liu, Wu, Chi, Chen)
- 2112.08514 (Bell, Dent, Lang, Newstead, Ritter)

Thank you!