Proposal for a New Experiment to Study Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) and Beyond the Standard Model (BSM) Physics

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νBDX-DRIFT
Neutrino
Beam Dump Experiment
Directional Recoil Identification From Tracks

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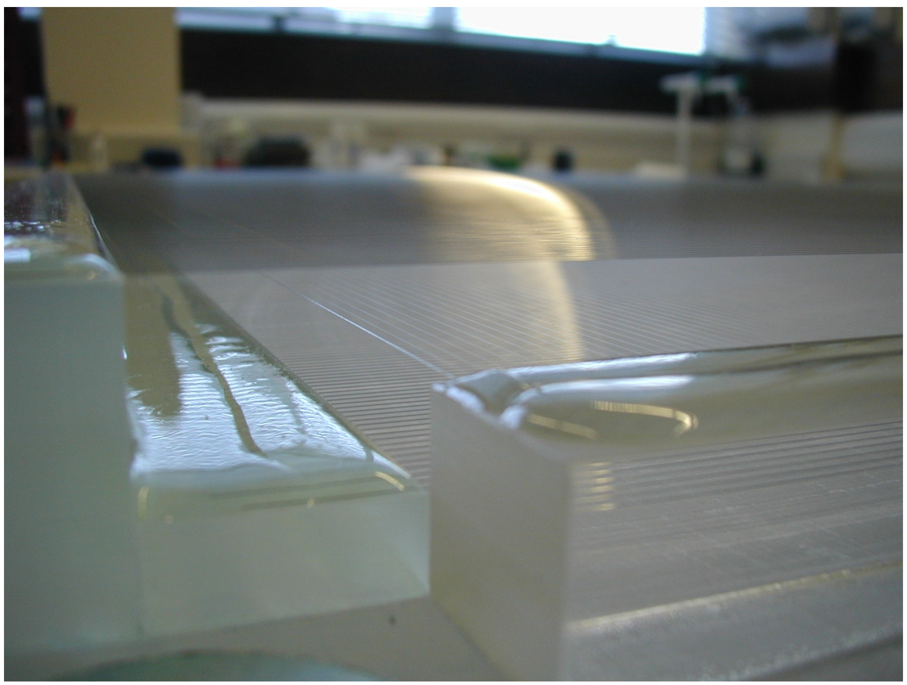
DRIFT: Lightning Summary

Started = 1998, US/UK

Directional WIMP dark matter detector

1/20 atm, 1 m^3 gaseous detector



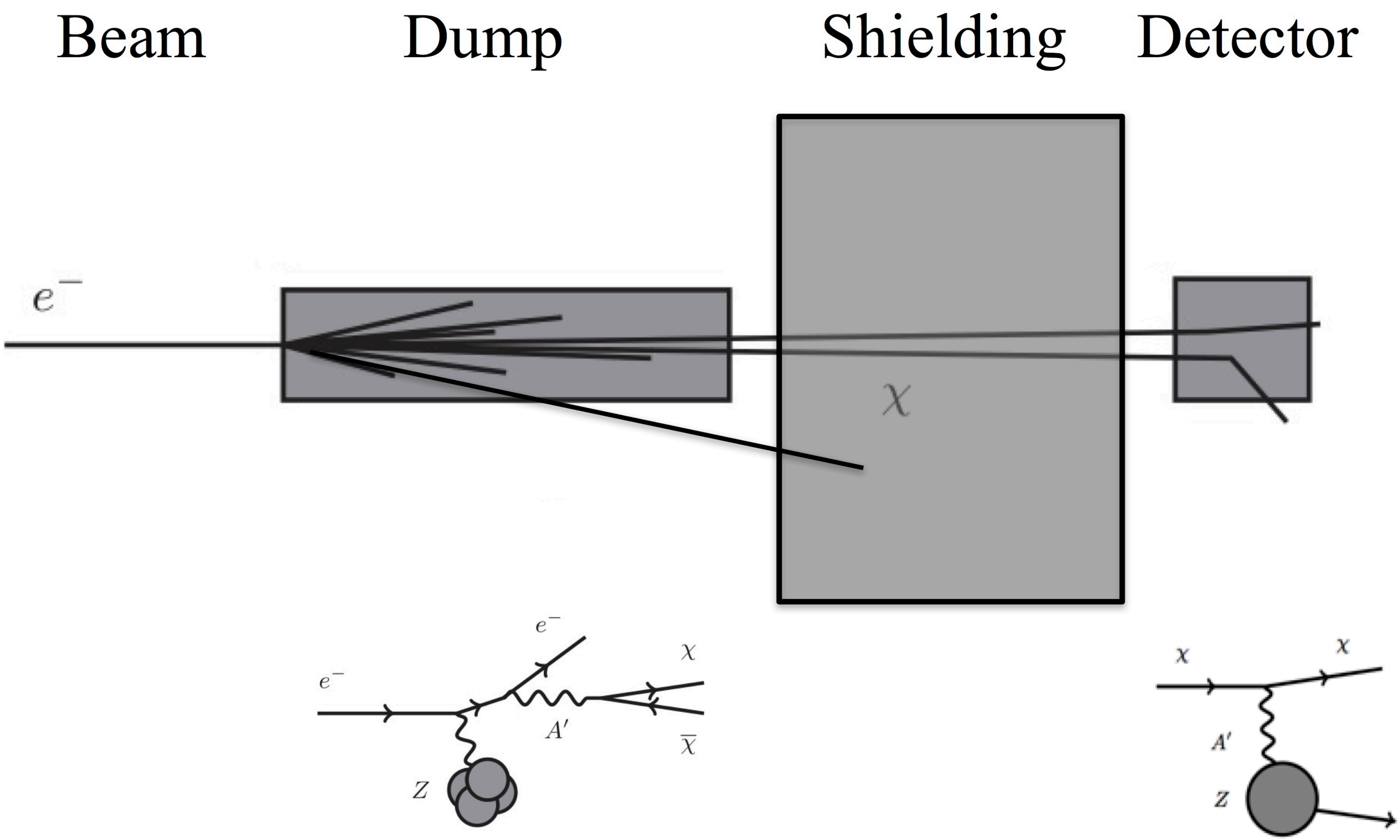
Unique and robust technology

Low energy (35 keV) threshold for nuclear recoils

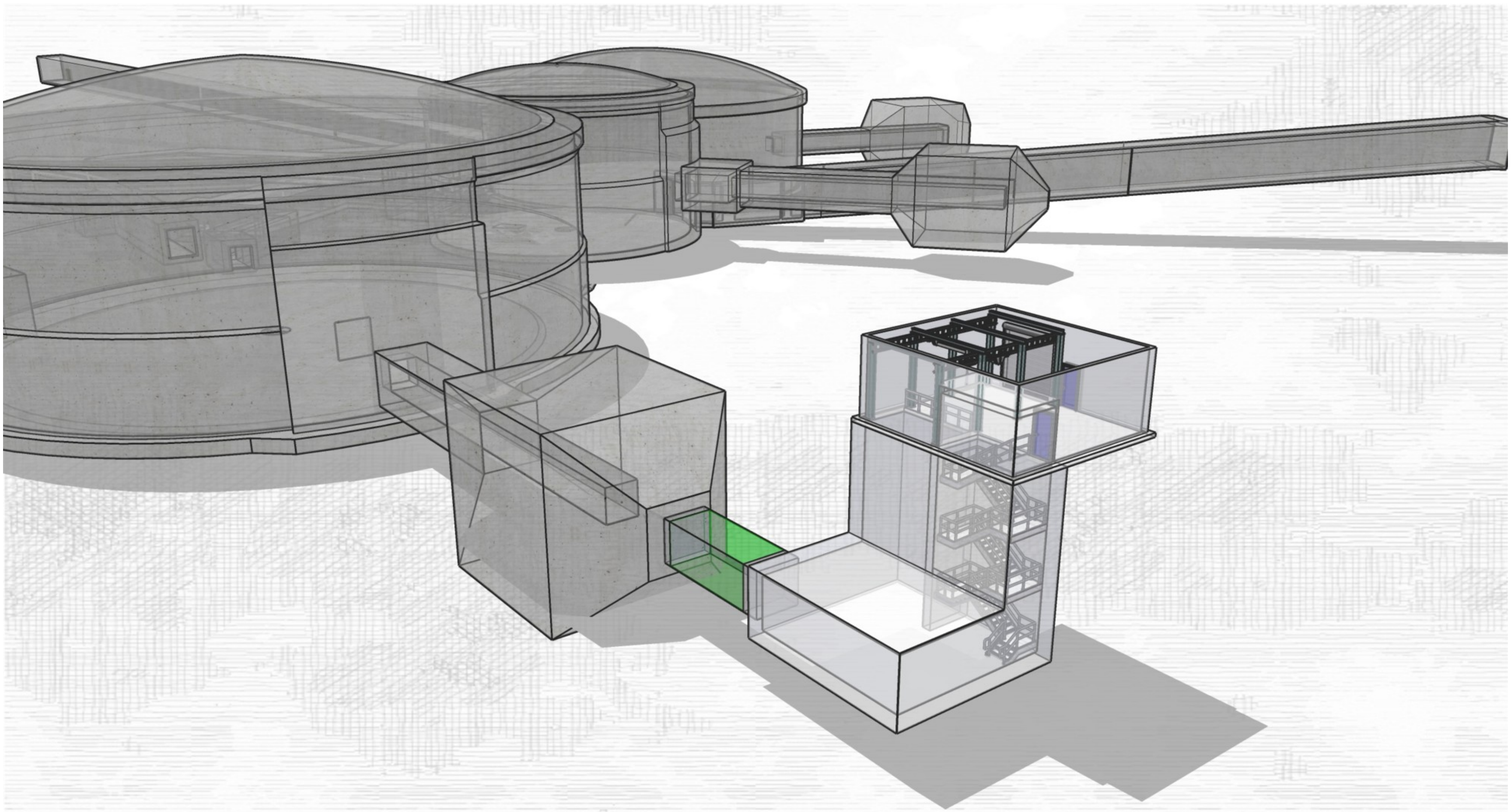
Low background

AstroPle, 91, 2017

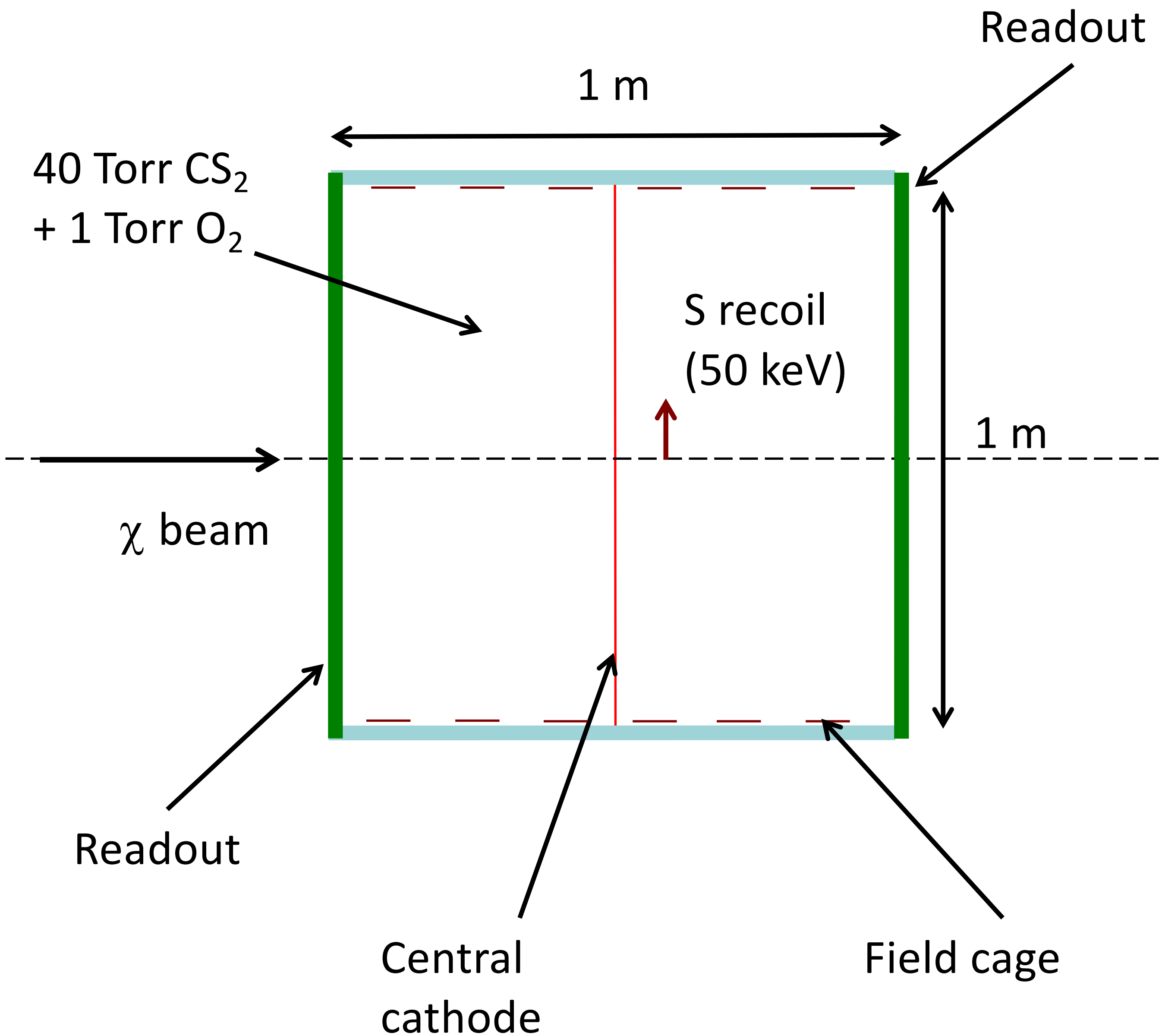
Detecting Light Dark Matter at Accelerators



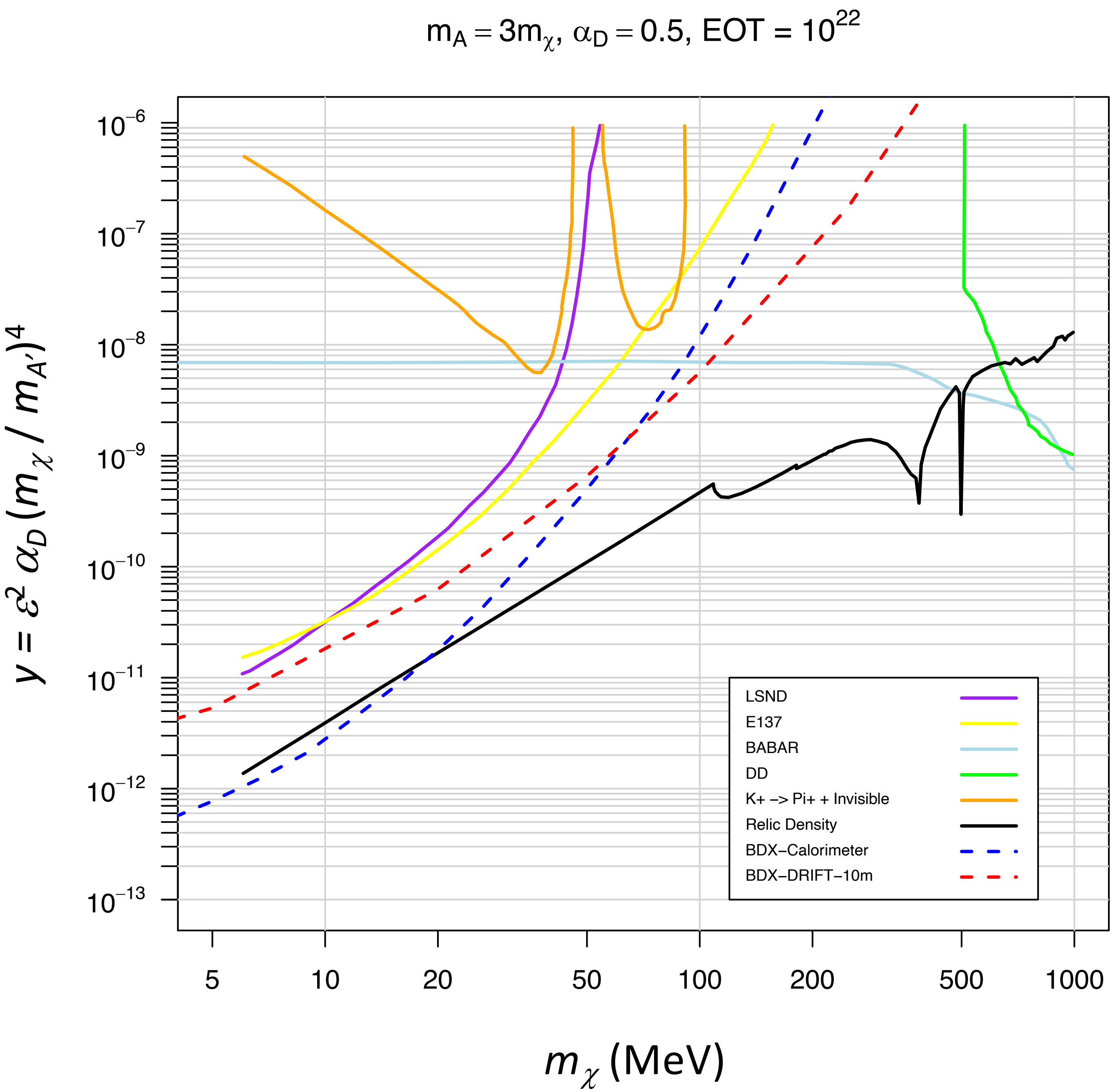
BDX-DRIFT at JLab



BDX-DRIFT-1m Module



BDX-DRIFT – Sensitivity at JLab



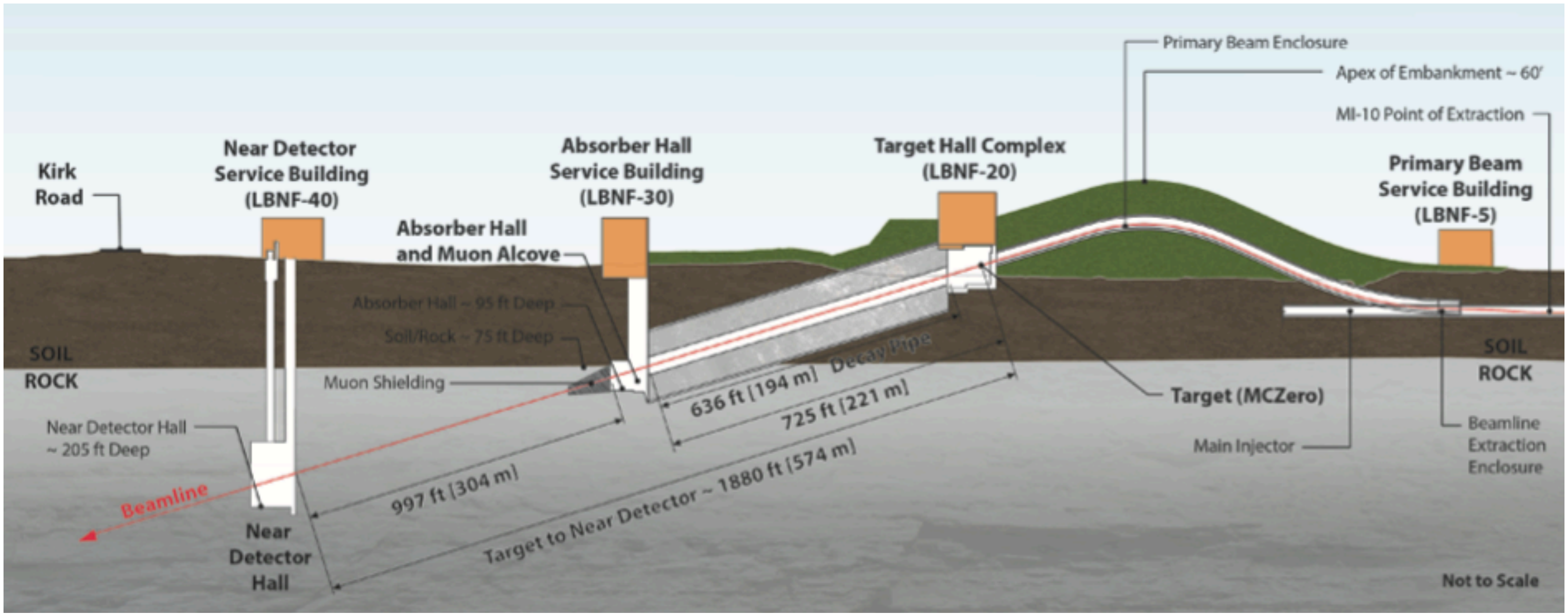
- How can BDX-DRIFT compete with a detector 1000x its mass?
- Nuclear recoils

$$\frac{d\sigma}{dT} \approx \frac{-8\pi\alpha\alpha_D\varepsilon^2 Z^2 M}{(m_{A'}^2 + 2MT)^2}$$

- Coherent Interactions (Form factor included)
- Low Threshold
- Low Background?

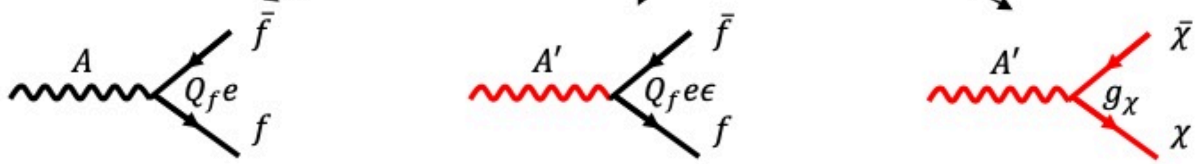
JLab PAC47

νBDX-DRIFT at DUNE

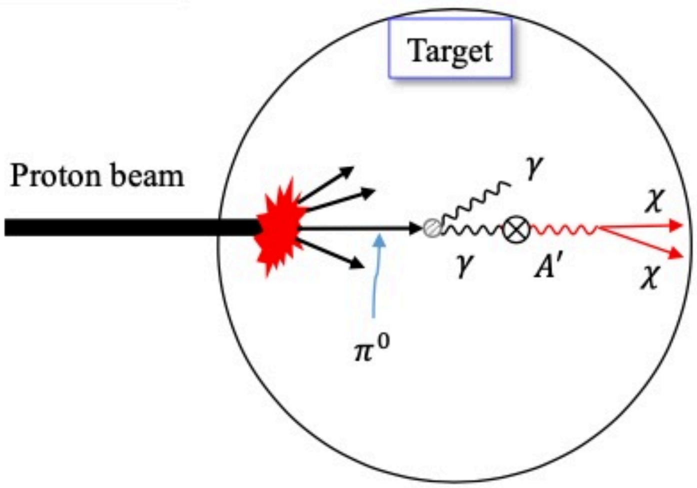


DUNE Near Detector LDM Production Mechanisms

$$\mathcal{L} \supset -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} + \frac{1}{2}m^2_{A'}A'_\mu A'^\mu + eA_\mu J^\mu_{\mathrm{EM}} + \epsilon e A'_\mu J^\mu_{\mathrm{EM}} + g_\chi A'_\mu J^\mu_D + \mathcal{O}(\epsilon^2)$$

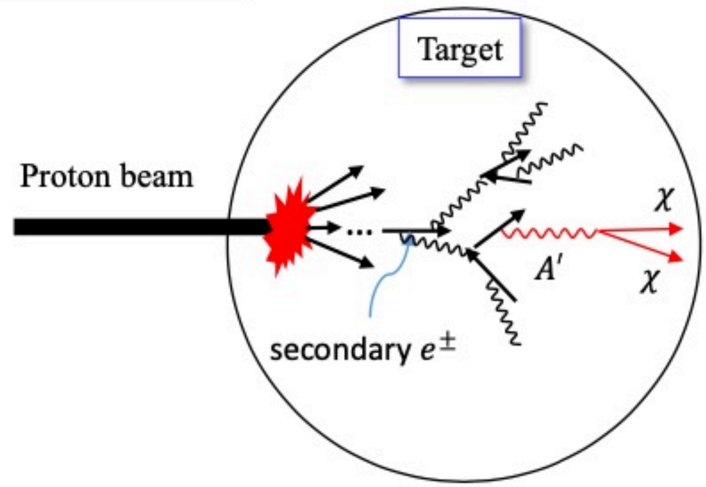


<u>π^0 contribution</u>



$\pi^0 \to \gamma + A'$ $\qquad$ $A' \to \chi + \chi$

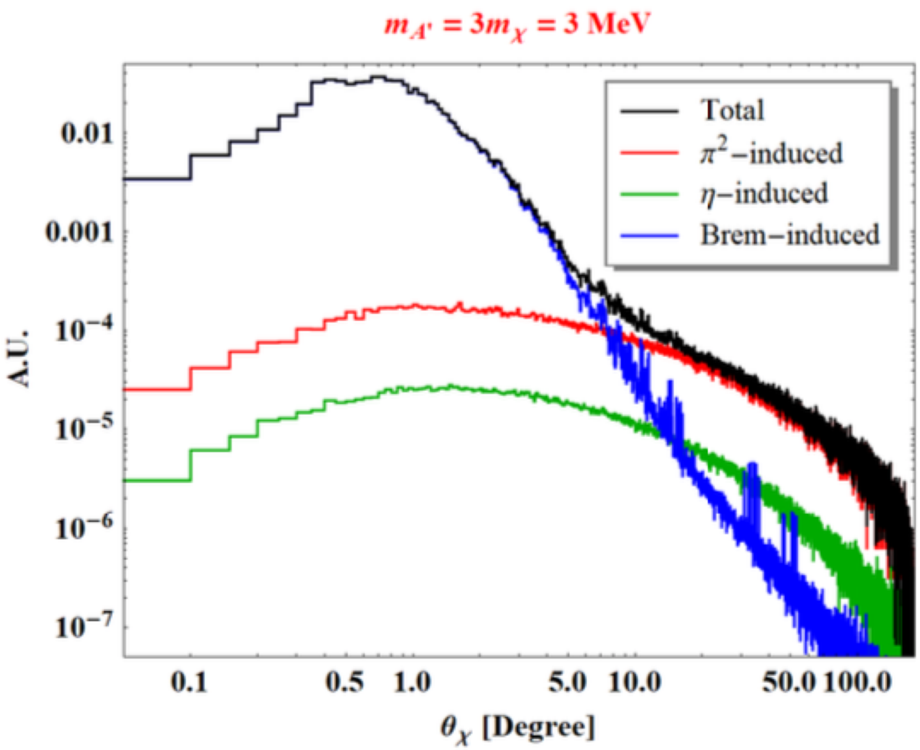
<u>Cascade contribution</u>

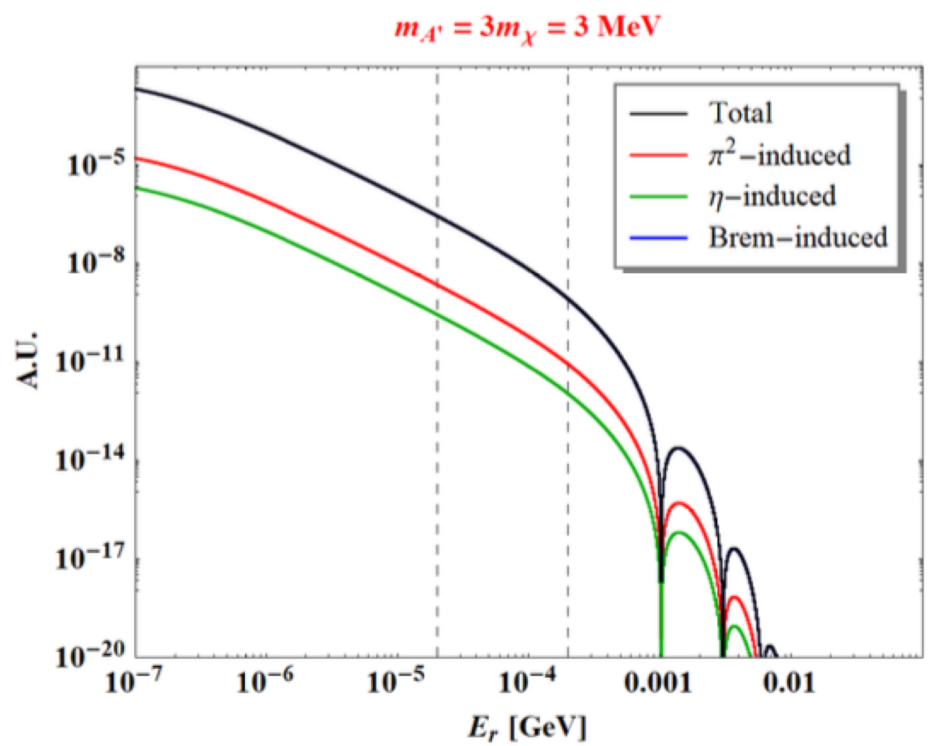


$e^{\pm *} \to e^\pm + A'$ $\qquad$ $A' \to \chi + \chi$

arXiv 2006.09386

Near Detector LDM Flux and Recoils





Near Detector LDM Flux

LBNF Beam Operating Parameters:

Main Injector Complex with PIP-II and PIP-III upgrades

Summary of key Beamline design parameters for $\leq$1.2 MW and $\leq$2.4 MW operation

Parameter	Protons per cycle	Cycle Time (sec)	Beam Power (MW)
≤ 1.2 MW Operation - Current Maximum Value for LBNF			
Proton Beam Energy (GeV):			
60	7.5E+13	0.7	1.03
80	7.5E+13	0.9	1.07
120	7.5E+13	1.2	1.20
≤ 2.4 MW Operation - Planned Maximum Value for LBNF 2nd Phase			
Proton Beam Energy (GeV):			
60	1.5E+14	0.7	2.06
80	1.5E+14	0.9	2.14
120	1.5E+14	1.2	2.40

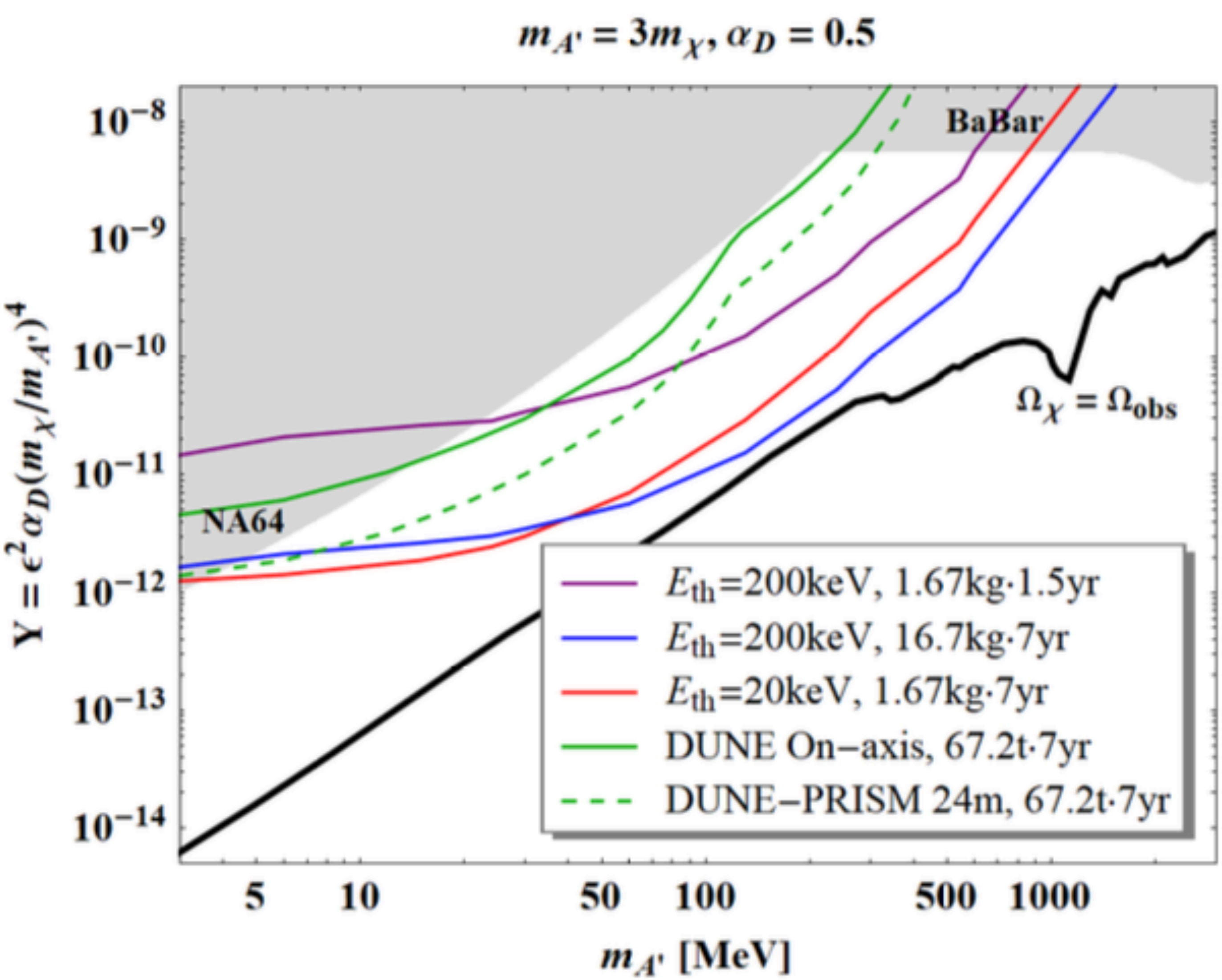
PIP-II

(1.1 – 1.9)x10^{21} POT/yr

PIP-III

Pulse duration: 10 μs
Beam size at target: tunable 1.0-4.0 mm

νBDX-DRIFT – Sensitivity at DUNE ND

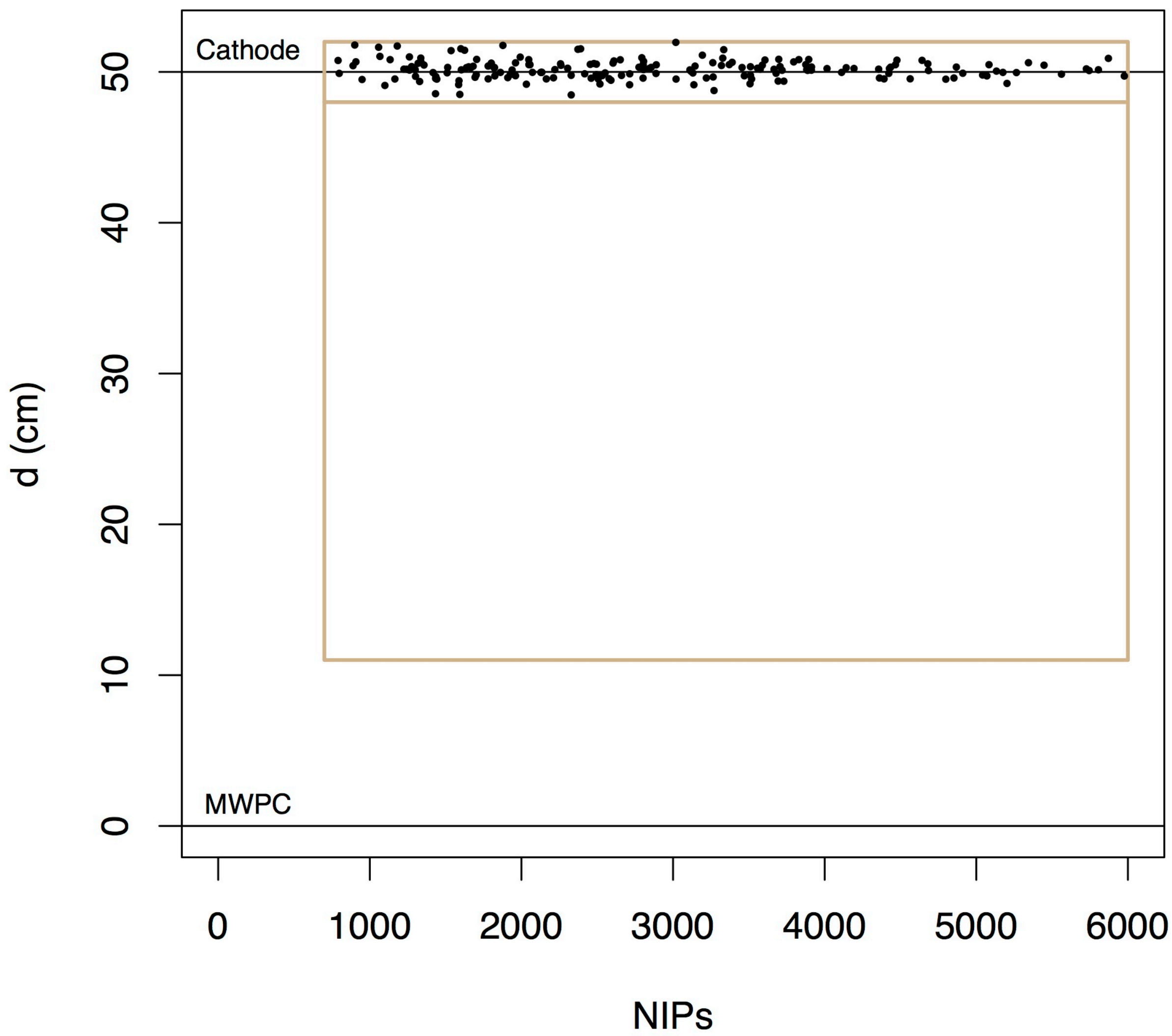


- Red line = 10 m^3 @ 40 Torr, nominal pressure, with 20 keV threshold
- Blue line = 10 m^3 @ 400 Torr with 200 keV threshold to preserve recoil length
- Purple line = 1 m^3 @ 400 Torr with 200 keV threshold
- All assume zero background

Backgrounds – Beam Unrelated

- Detector backgrounds

Shielded 30-10-1 Torr CS_2-CF_4-O_2 Data

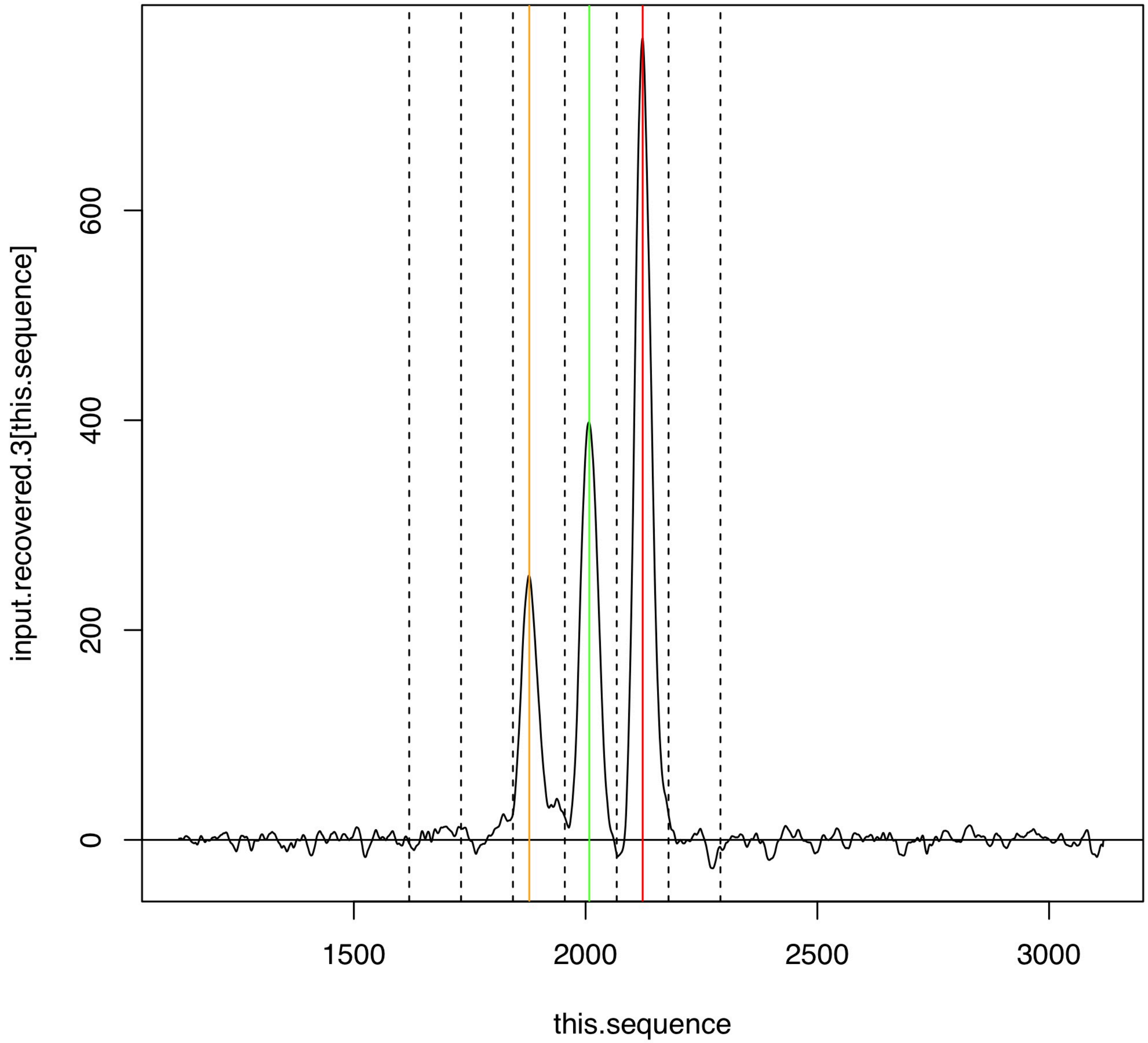


AstroPle, 91, 2017

- 54.7 days of data taken in the Boulby Mine (~1 km underground) with poly shielding
- The events on the top are radon progeny recoils and low energy alphas emanating from the cathode
- Zero events were found in the fiducial region below => background free

Fiducialization

- A unique feature of DRIFT is that it drifts CS_2 anions as charge carriers not e^-.
- μs -> ms but this allows DRIFT to limit diffusion in 3D without a large **B** field.
- AND with a small addition of O_2 it also allows for multiple anion charge carriers.
- Which allows for fiducialization.



RSI, 85, 2014

Backgrounds – Beam Unrelated

- Detector backgrounds
- Cosmic ray neutrons – Too deep to penetrate
- Cosmic ray muons

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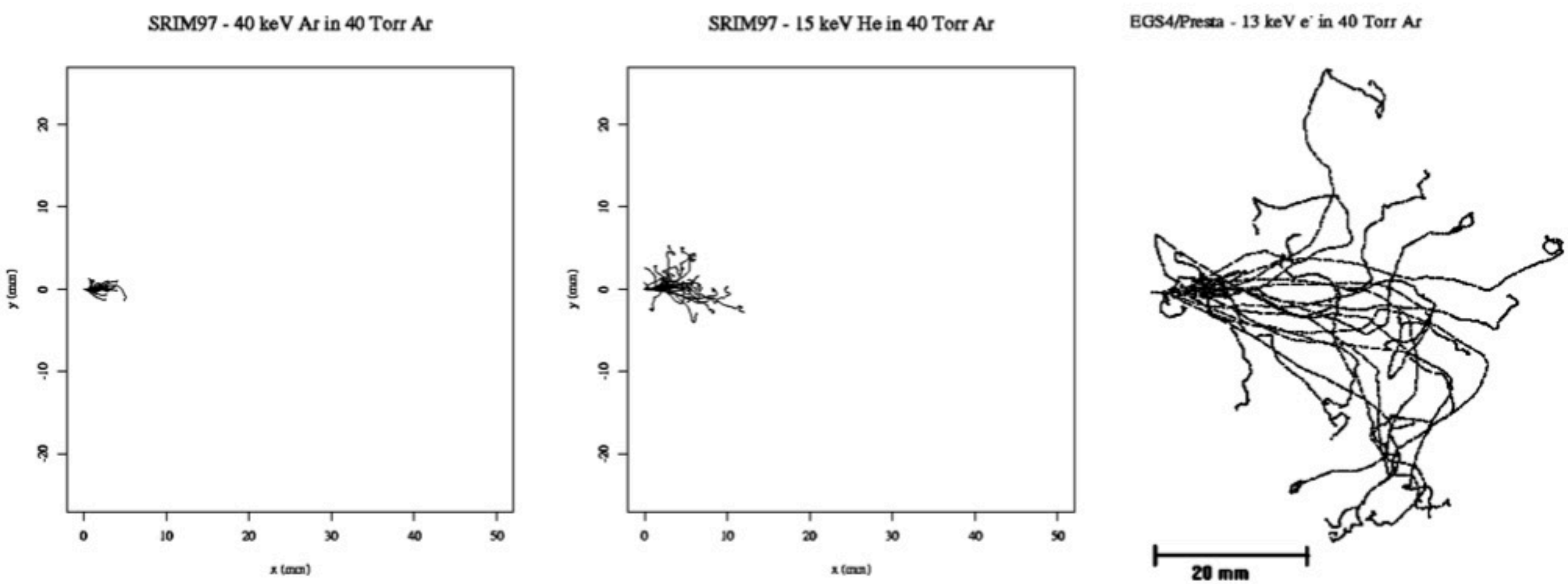


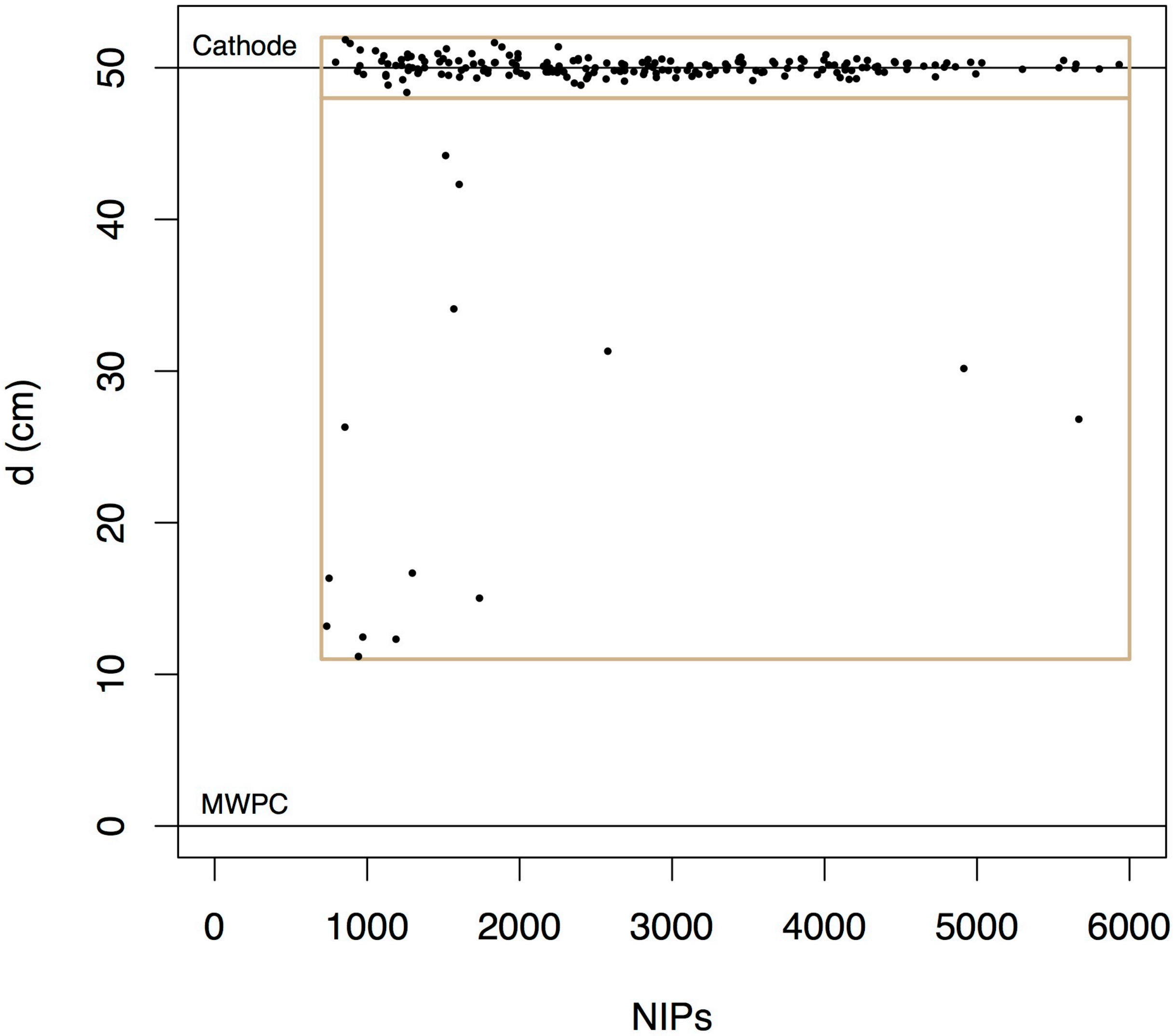
FIG. 2. The figures above show, from left to right, 40 keV Ar recoils, 5 keV alphas, and 13 keV electrons in 40 Torr Ar.

PRD, 61, 2000

Backgrounds – Beam Unrelated

- Detector backgrounds
- Cosmic ray neutrons – Too deep to penetrate
- Cosmic ray muons, betas and gammas
- Cosmic ray muon-induced neutrons – Orders of magnitude down from next
- Neutrons from radioactive decay (mostly alpha-n) in the walls

Unshielded 30-10-1 Torr CS_2-CF_4-O_2 Data



AstroPle, 91, 2017

- 45.5 days of data taken with poly shielding **removed**
- 14 events observed in the fiducial region
- The rate of events in the fiducial region matches a GEANT MC of elastic nuclear recoils from neutrons emanating from the cavern walls
- Background = 0.3 events per day

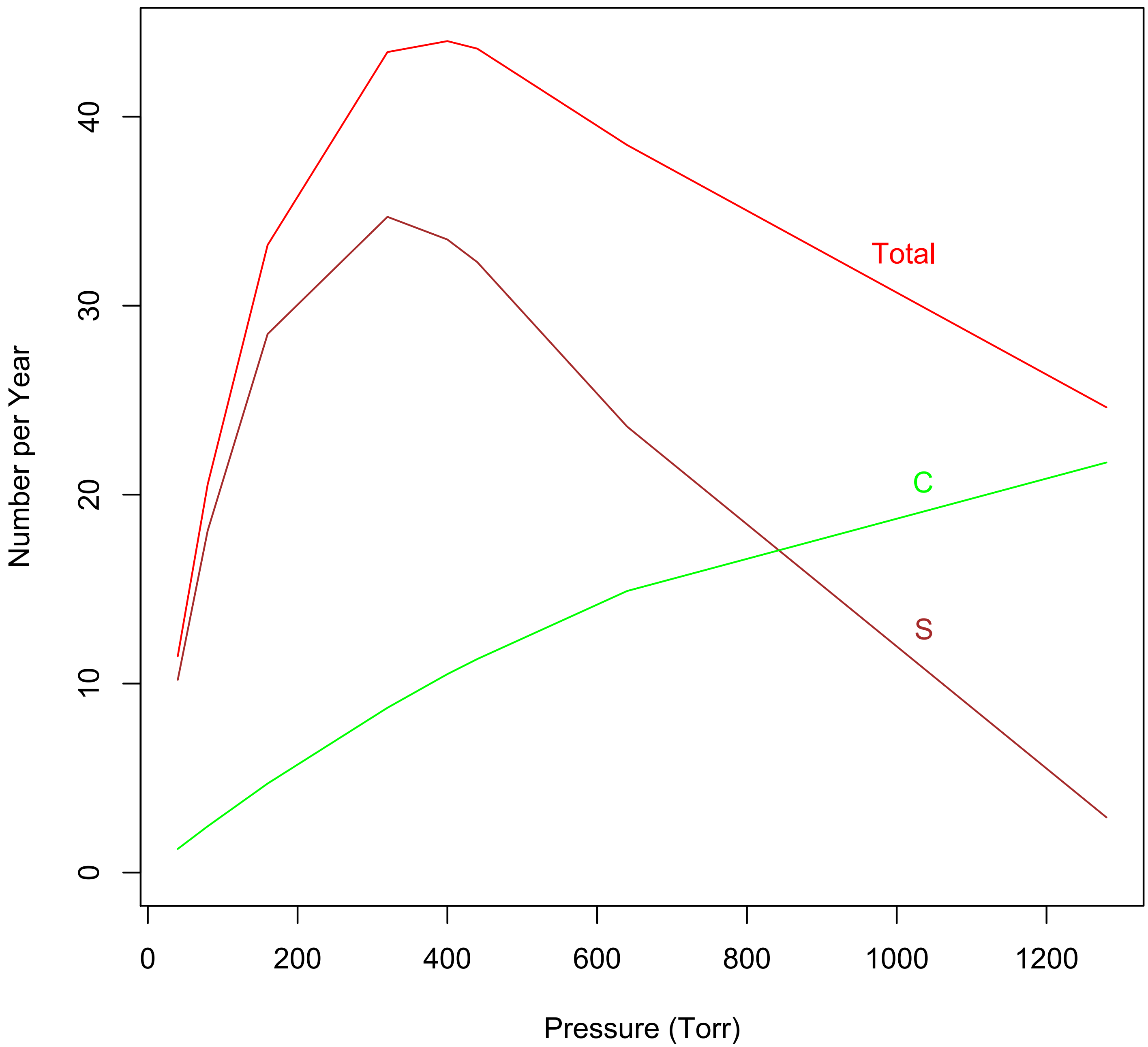
Backgrounds – Beam Unrelated

- Detector backgrounds
- Cosmic ray neutrons – Too deep to penetrate
- Cosmic ray muons, betas and gammas
- Cosmic ray muon-induced neutrons – Subdominant to radioactive decay
- Neutrons from radioactive decay in the walls – 0.3 events per day
- Beam timing - With fiducialization we expect to be able to calculate the time when the event occurred within the νBDX-DRIFT detector to within 10 μs. With this timing cut we expect to reduce any beam-unrelated backgrounds to zero for near-term exposures regardless of pressure.

Backgrounds – Beam Related

- "Rock muons" – Not a problem
- "Rock neutrons" – Could be a problem => passive shielding
- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) -

CEνNS per Year



- 10 m^3 detector
- 1 year exposure
- Threshold increased with pressure to preserve directionality and background rejection
- Helm form factor used for S and C nuclei

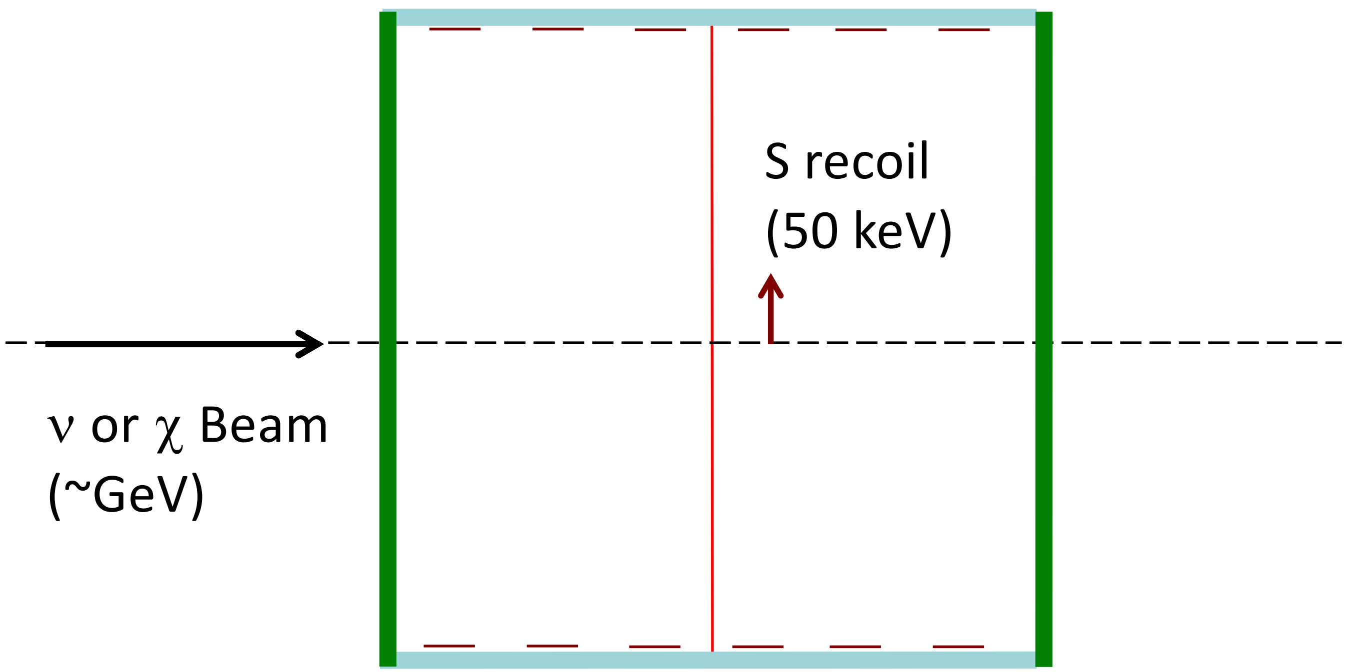
Backgrounds – Beam Related

- “Rock muons” – Not a problem
- “Rock neutrons” – Could be a problem => passive shielding
- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) – Low pressure, off-axis runs for LDM could lessen this background. On the other hand high pressure on-axis runs can be used to study neutrino scattering!

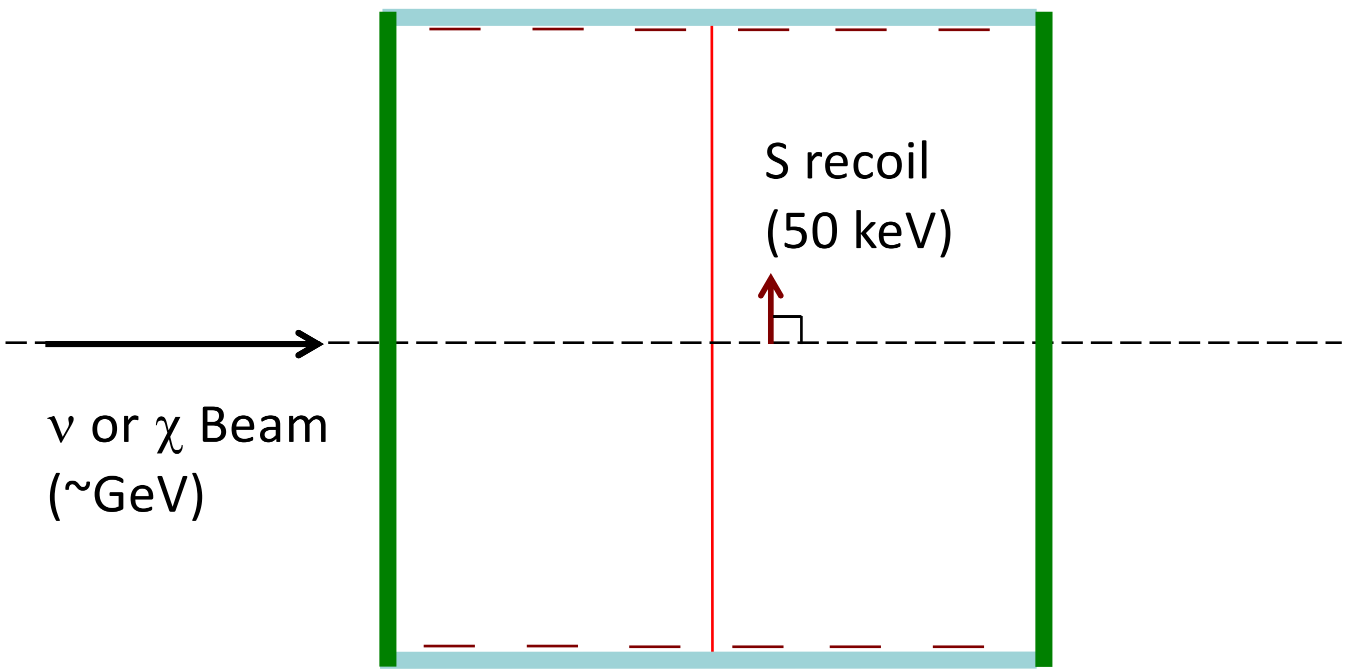
Backgrounds – Beam Related

- “Rock muons” – Not a problem
- “Rock neutrons” – Could be a problem => passive shielding
- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) – Low pressure, off-axis runs for LDM could lessen this background. On the other hand high pressure on-axis runs can be used to study neutrino scattering!
- ν-induced n from the vessel – We estimate ~1 event per year per m^3 detector run at 400 Torr. Most of the recoils produced, however, will fall below the 200 keV energy threshold for S recoils.
- We have a signature.

νBDX-DRIFT Signatures – Directional



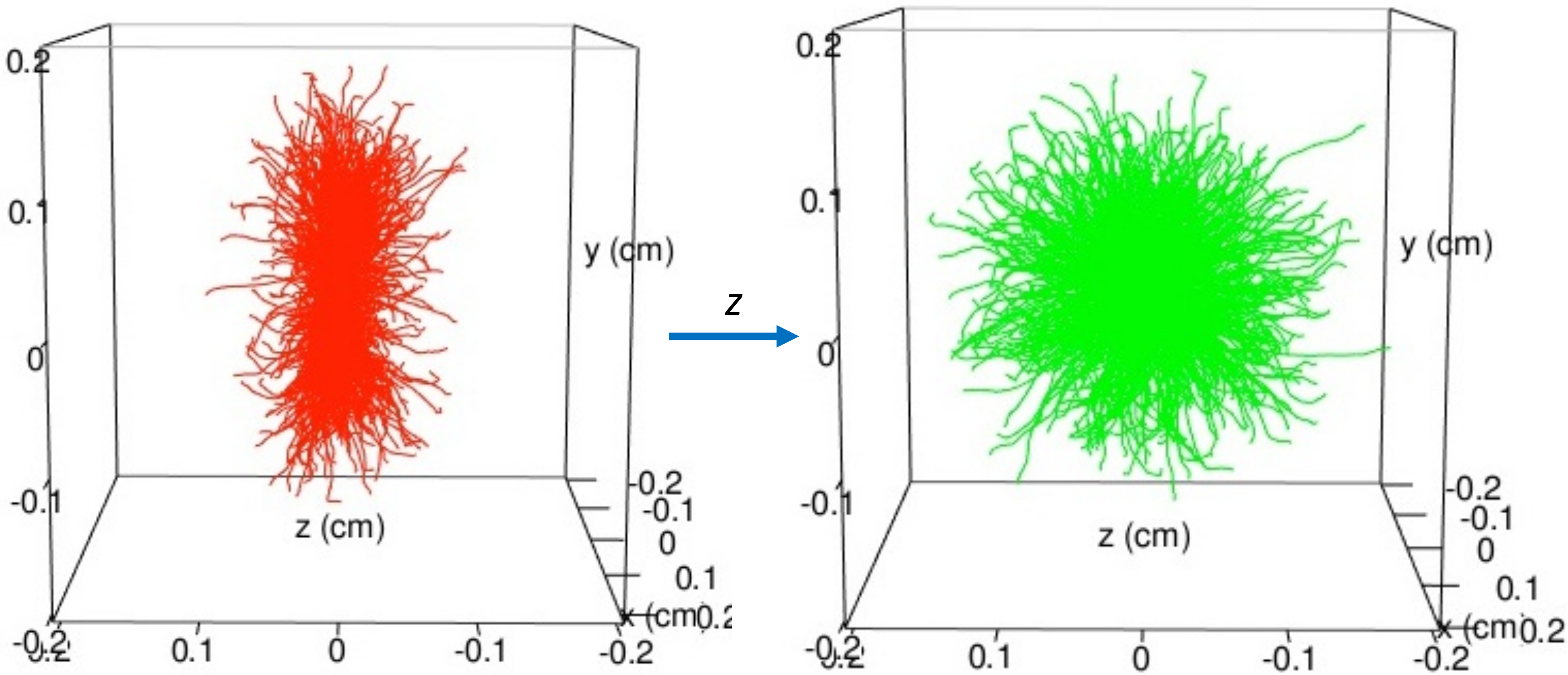
νBDX-DRIFT Signatures – Directional



Directional Signal and Background

1,000 50 keV signal events

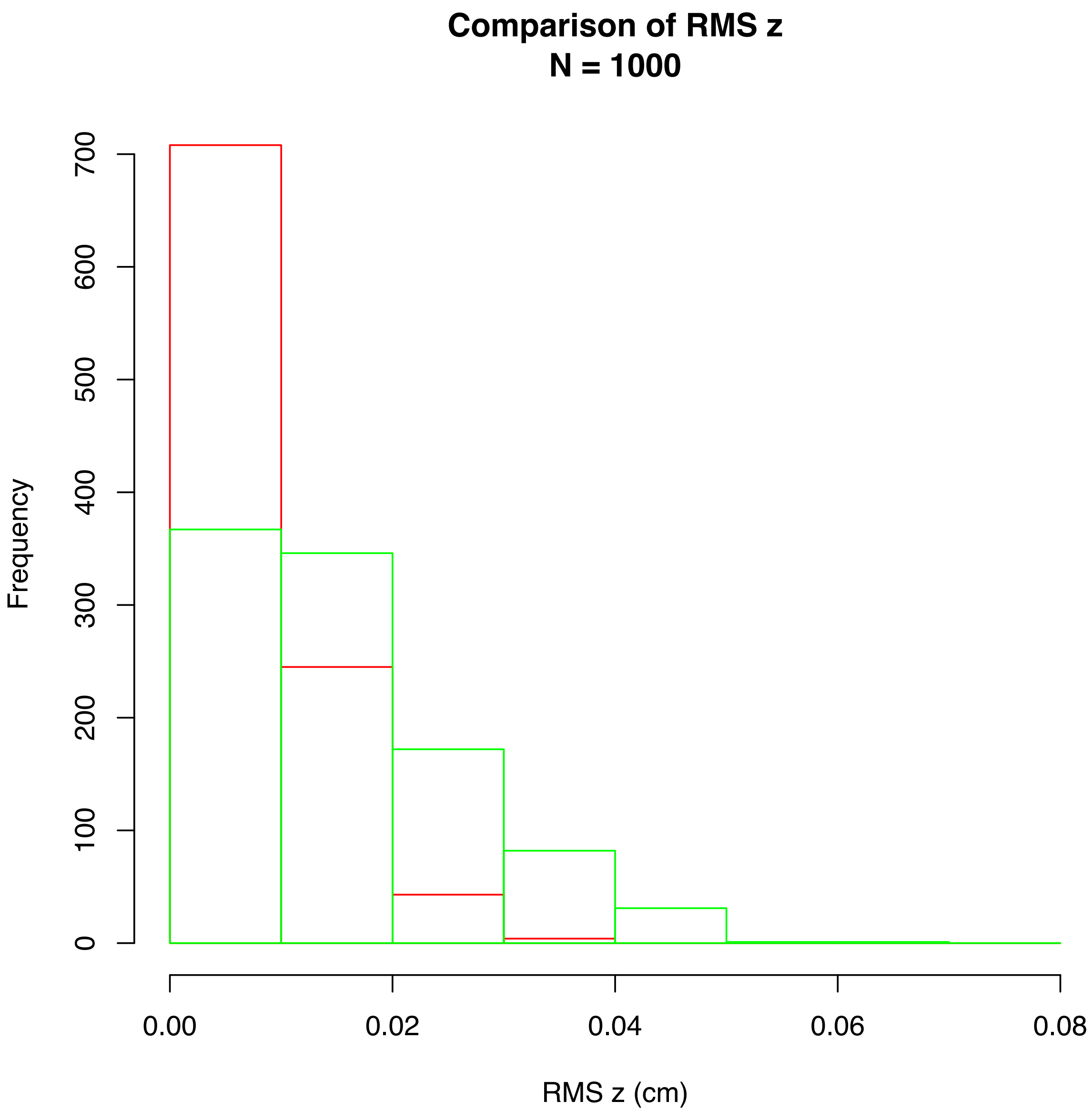
1,000 50 keV background events



One of the easiest things to measure is the RMS in z.

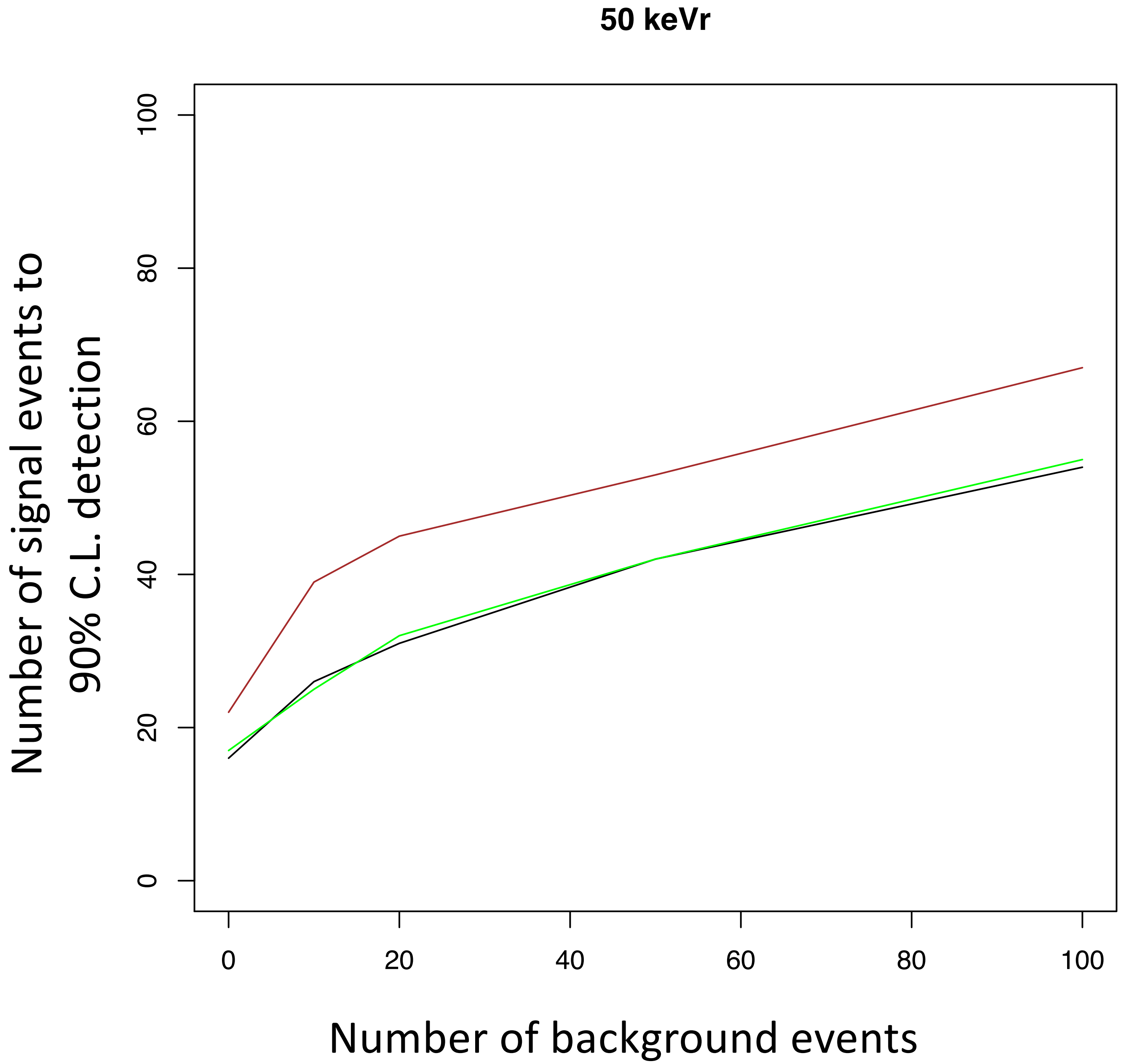
PRD, 99, 2019

Directional Signal vs Background



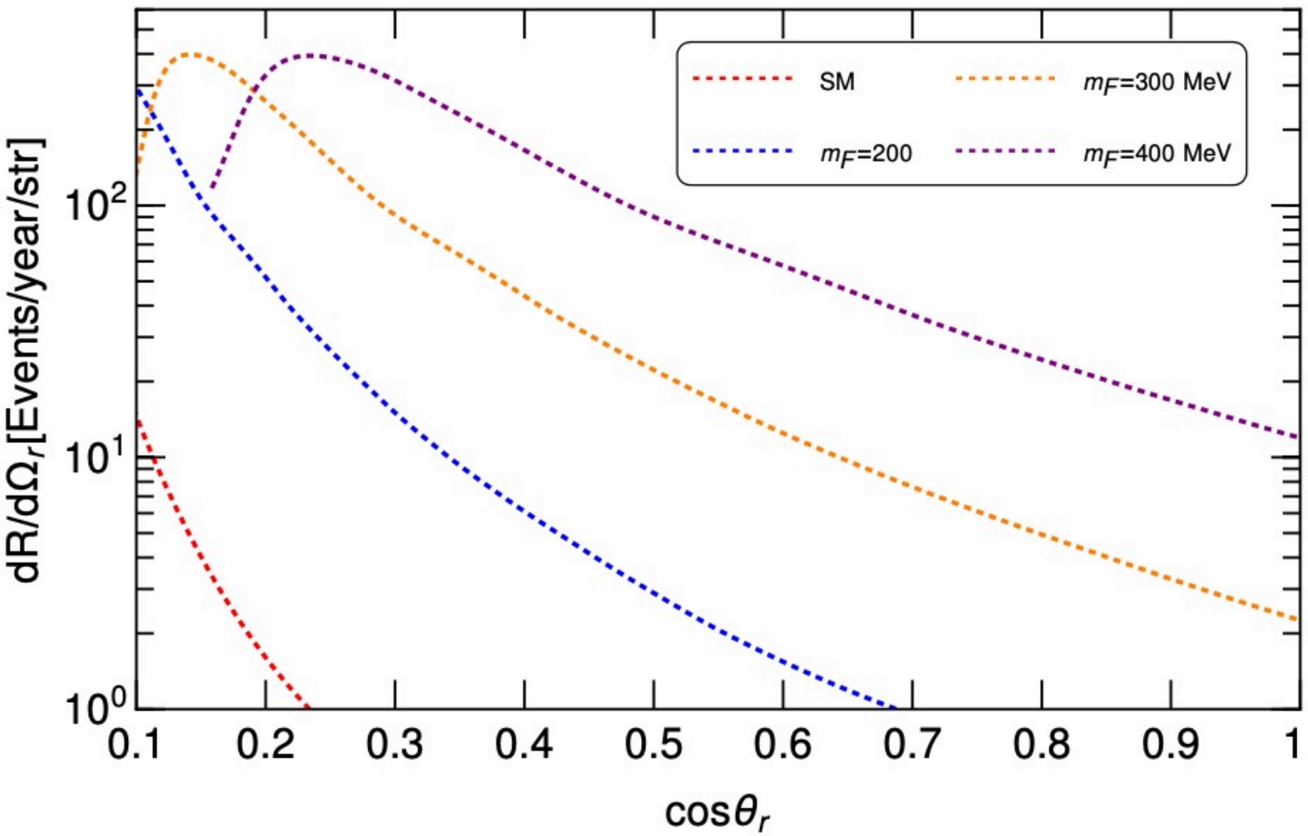
PRD, 99, 2019

Pulling signal from background



PRD, 99, 2019

Non-Perpendicular Scatters



- Inelastic neutrino collisions could provide a directional signal linked to the mass of the BSM scale.
- ν + N -> N + F
- F = heavy fermion, for example heavy right handed ν

Resources

- A spare DRIFT detector is available with refurbishment on a short timescale
- We are applying for funding

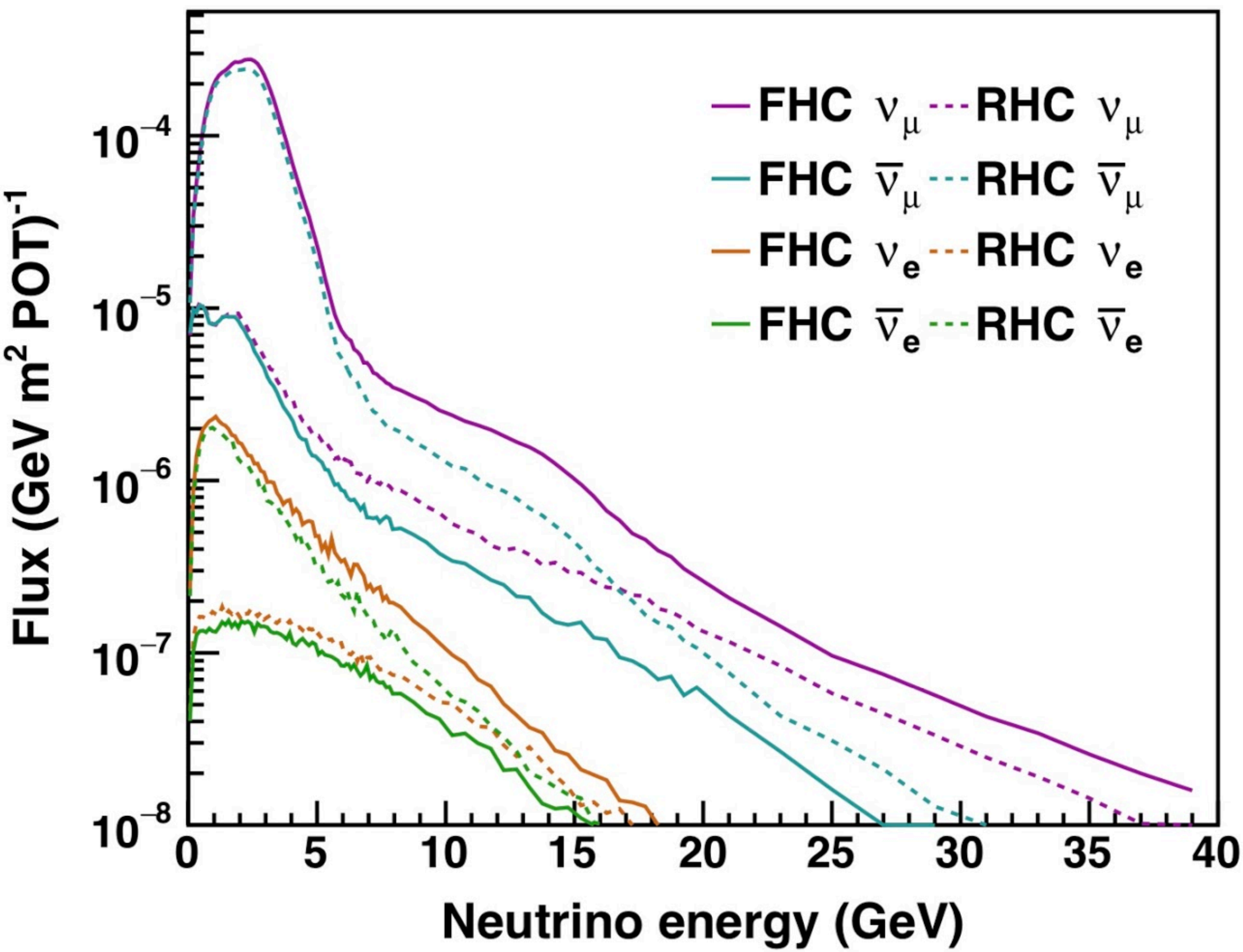
- ~20’ by 10’ of space in the MINOS Near Detector Hall in the NuMI beam
- Power and internet
- Access for ~1 month to set up
- Access every ~2 weeks for maintenance
- Run time ~1.5 years to for starters

Conclusion

- With its low-energy, nuclear-recoil detection capabilities νBDX-DRIFT will probe new regions of BSM parameter space.
- CEνNS events are another attractive target.
- Backgrounds for both are expected to be minimal.
- A directional signature is available for both.
- In the long term deploying νBDX-DRIFT alongside other DUNE detectors would provide a complete picture of couplings to the SM.

The End

Near Detector Hall ν Flux



PRD, 101, 2020