# Directional CE$\nu$NS Measurement at Fermilab

Dan Snowden-Ifft / Occidental College
November 19, 2020

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


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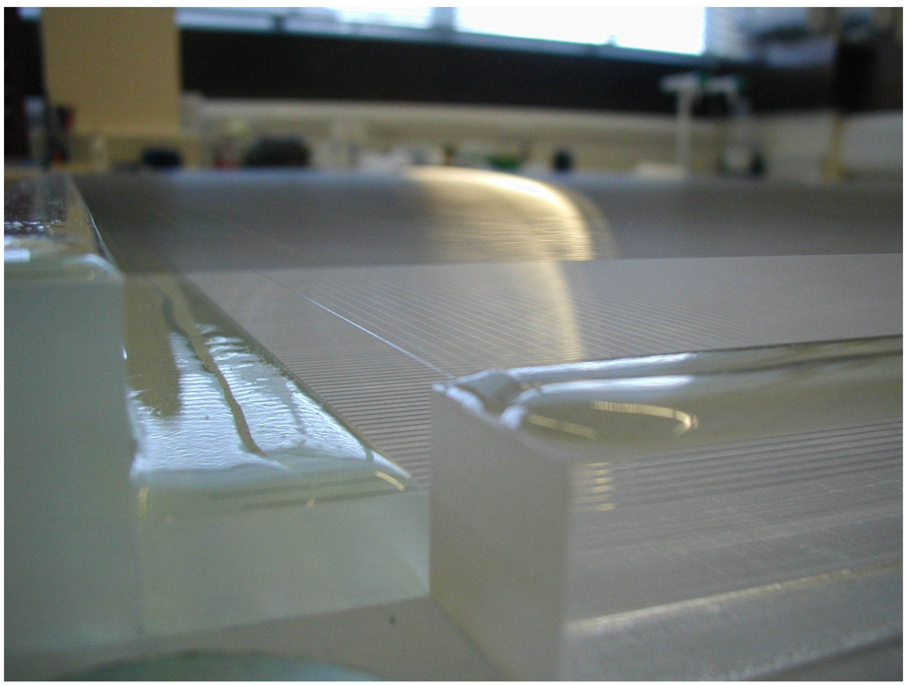
# DRIFT: Lightning Summary

Started = 1998, US/UK

Directional WIMP dark matter detector

1/20 atm, 1 $m^3$ gaseous detector



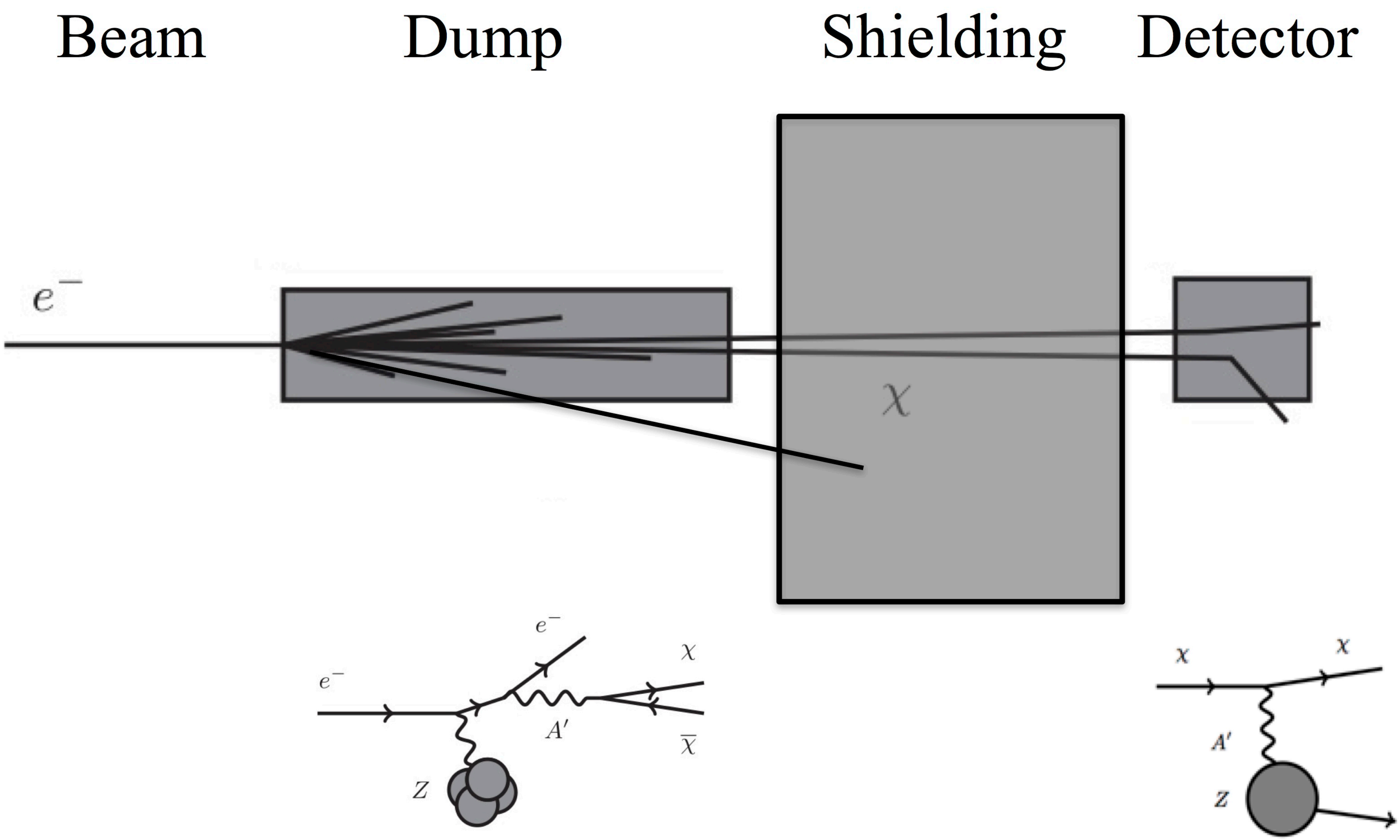
Unique and robust technology

Low energy (35 keV) threshold for nuclear recoils

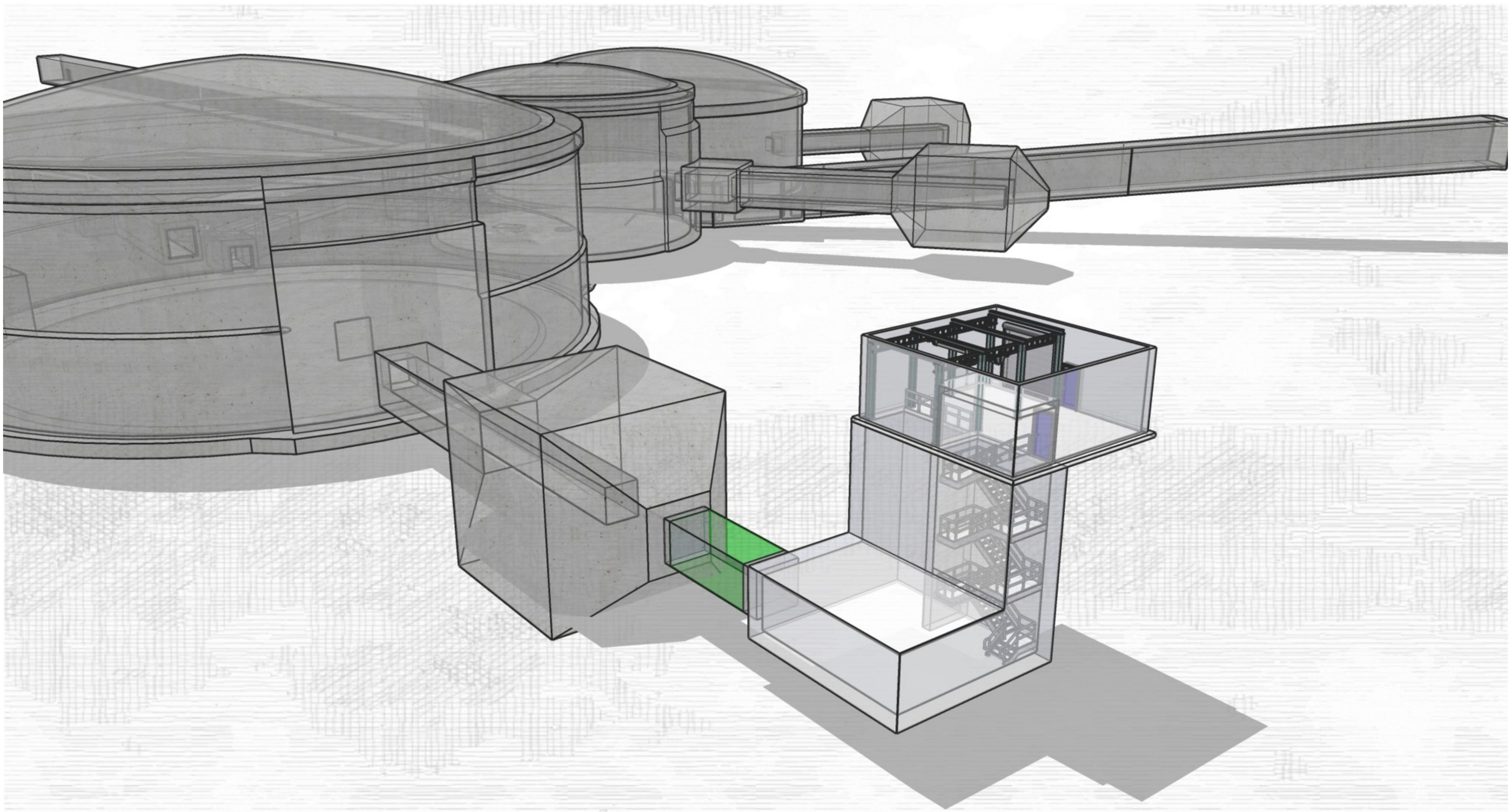
Low background

AstroPle, 91, 2017

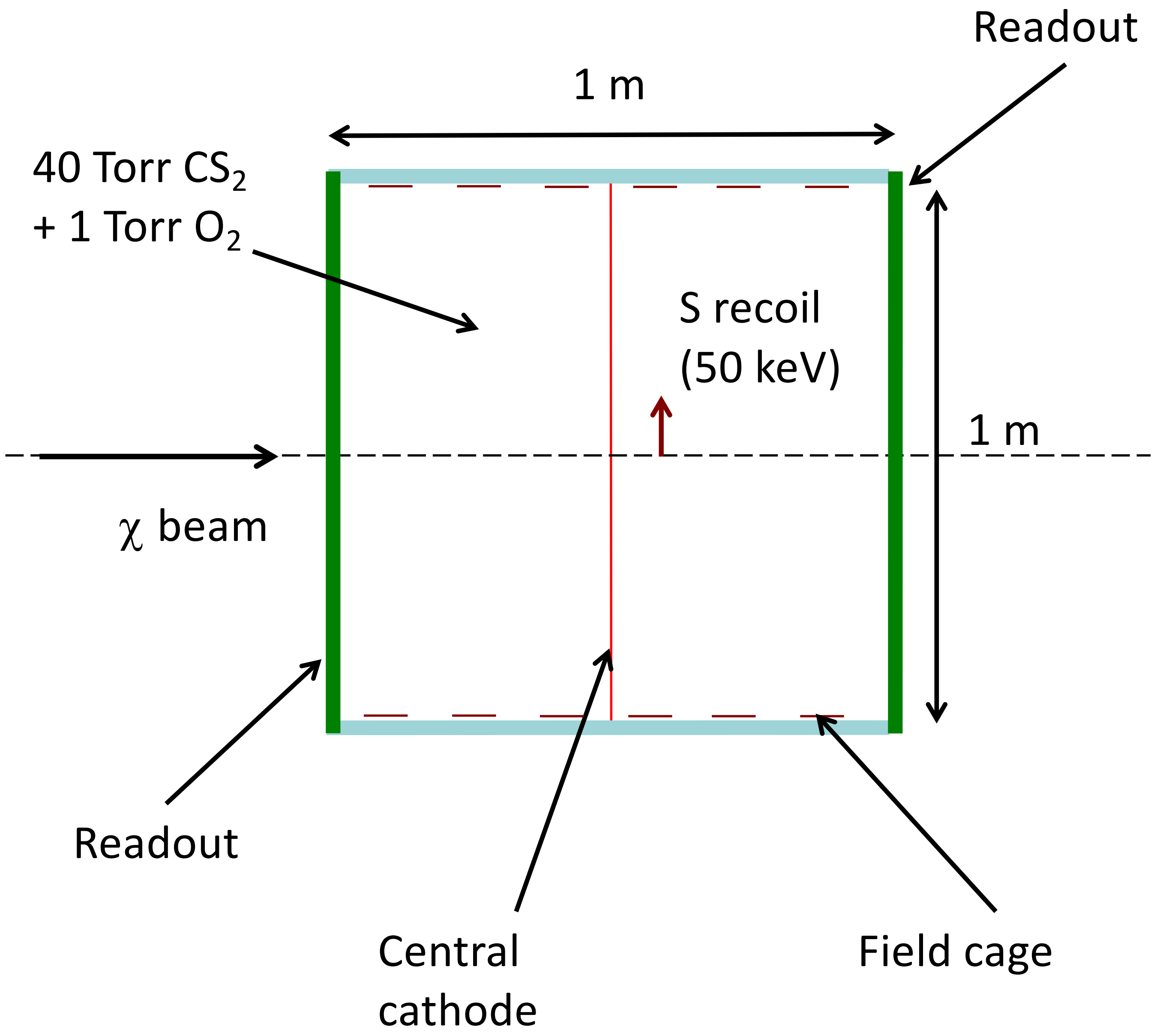
# Detecting Light Dark Matter at Accelerators



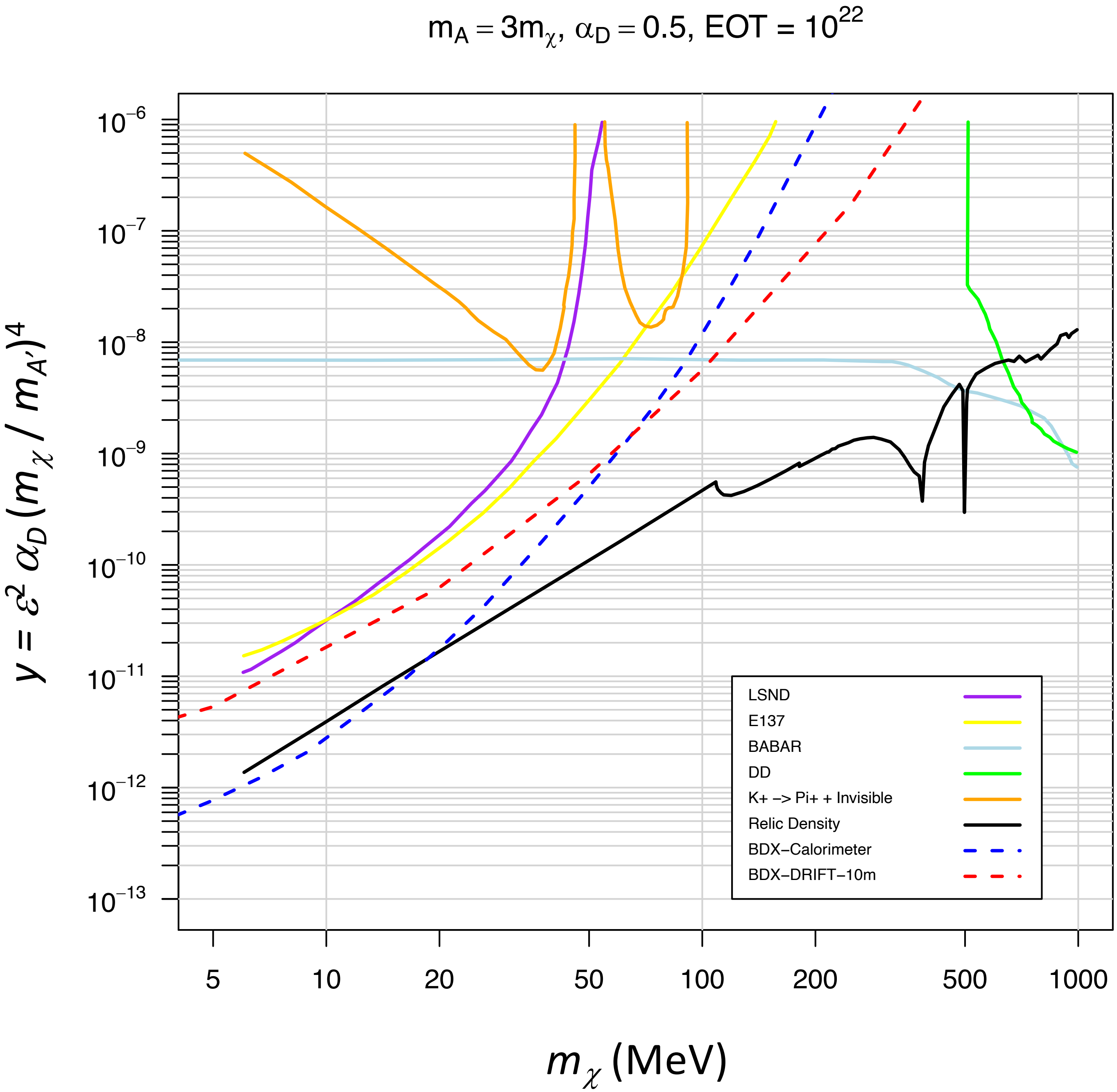
# BDX-DRIFT at JLab



# BDX-DRIFT-1m Module

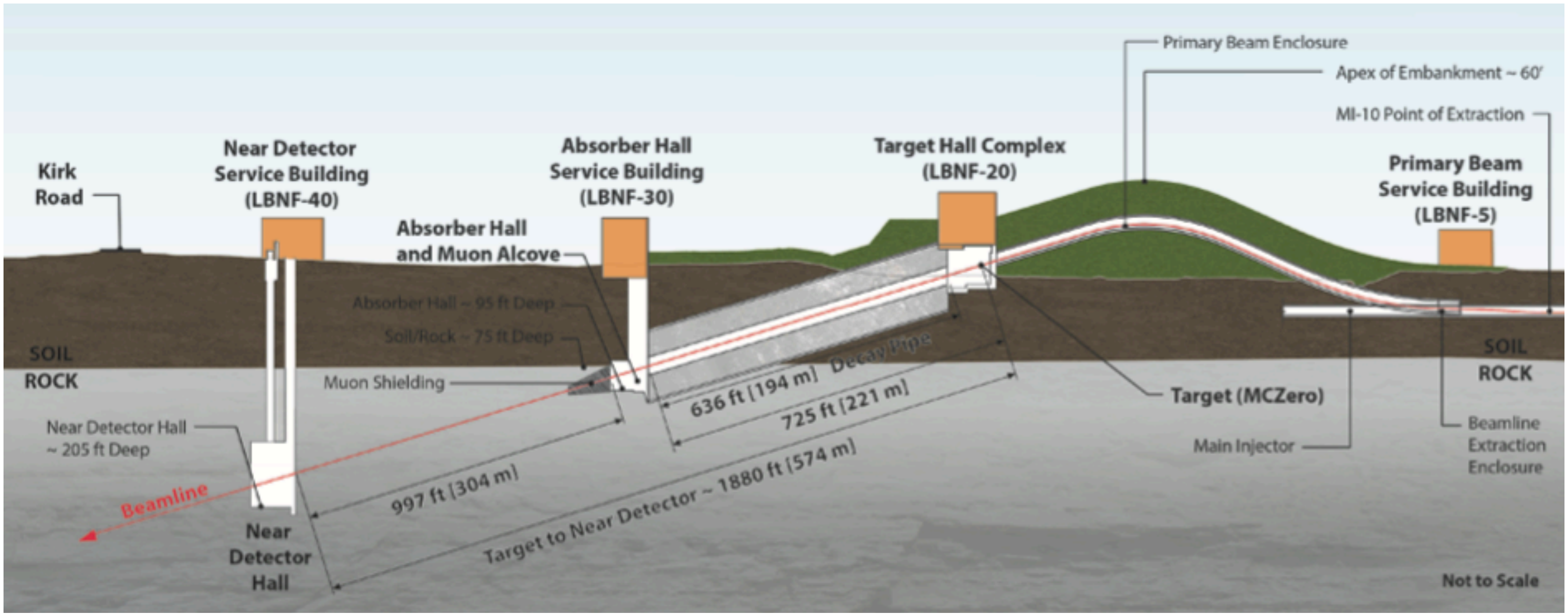


# BDX-DRIFT - Sensitivity

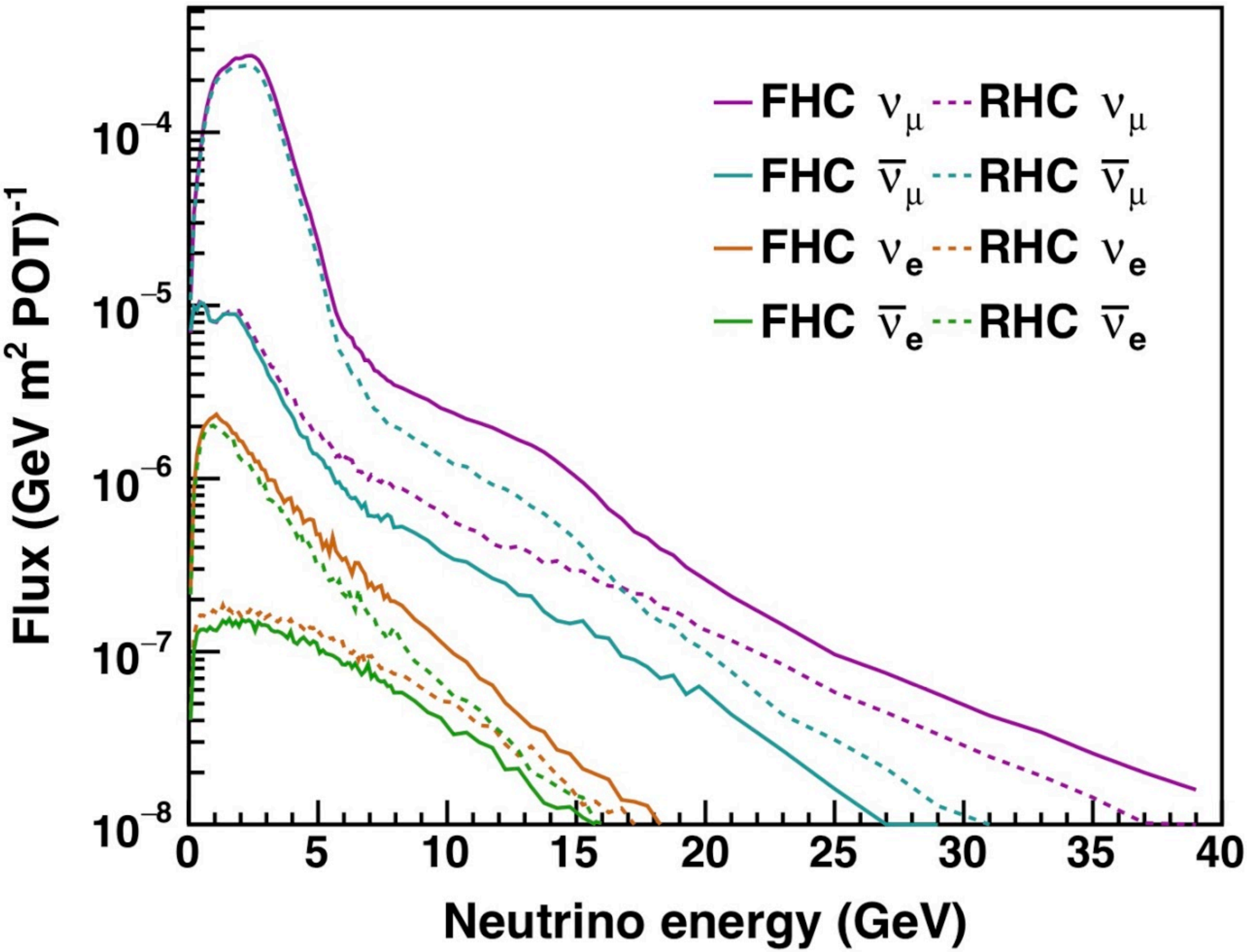



PRD, 99, 2019

# Fermilab and DUNE



# Near Detector Hall ν Flux




PRD, 101, 2020

# Near Detector ν Flux

## LBNF Beam Operating Parameters:

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

Summary of key Beamline design parameters for ≤1.2 MW and ≤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 |

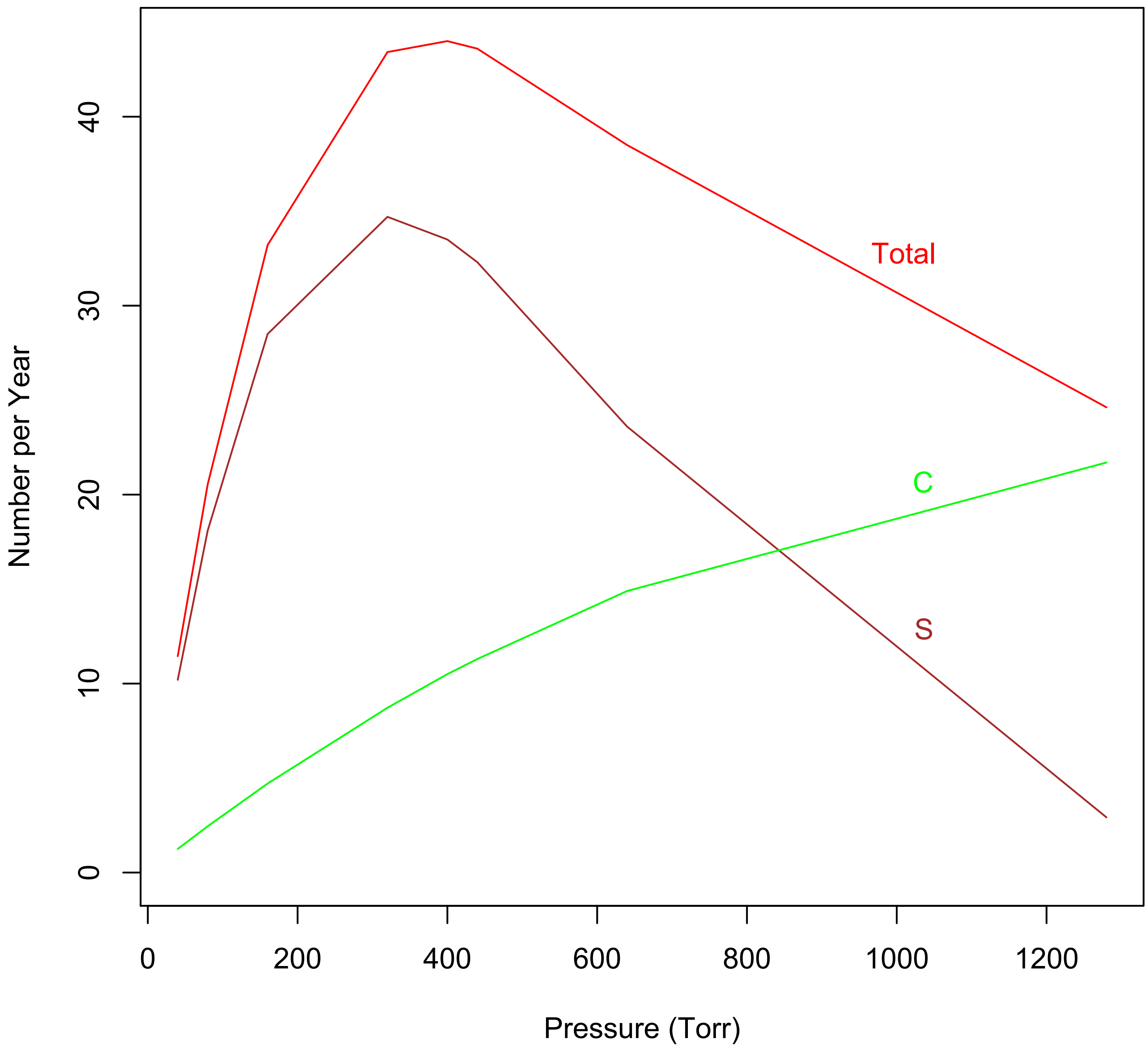
*PIP-II*

$(1.1 - 1.9) \times 10^{21}$ POT/yr

*PIP-III*

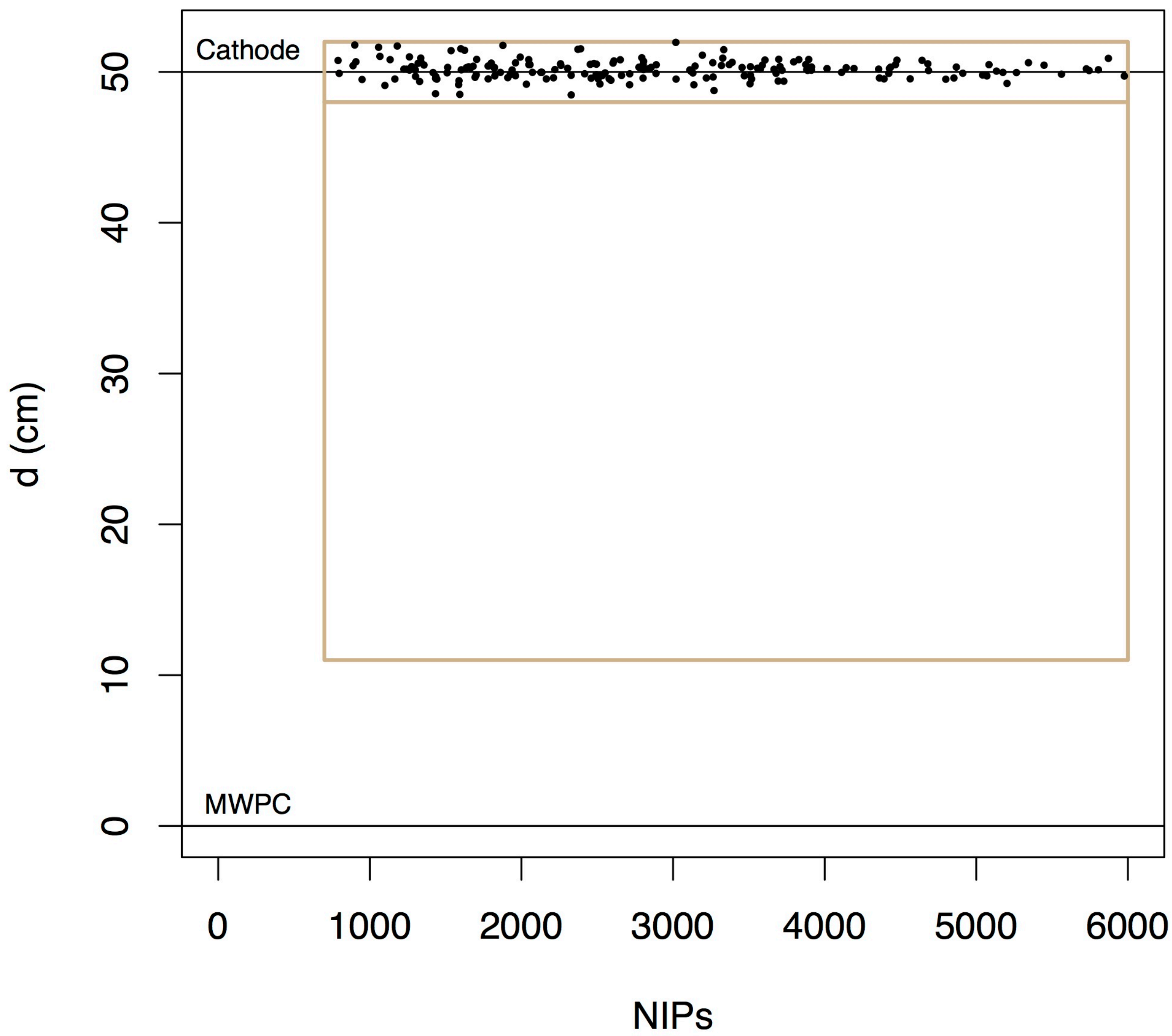
Pulse duration: 10 μs
Beam size at target: tunable 1.0-4.0 mm

# 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

# **Shielded** 30-10-1 Torr $CS_2$-$CF_4$-$O_2$ Data

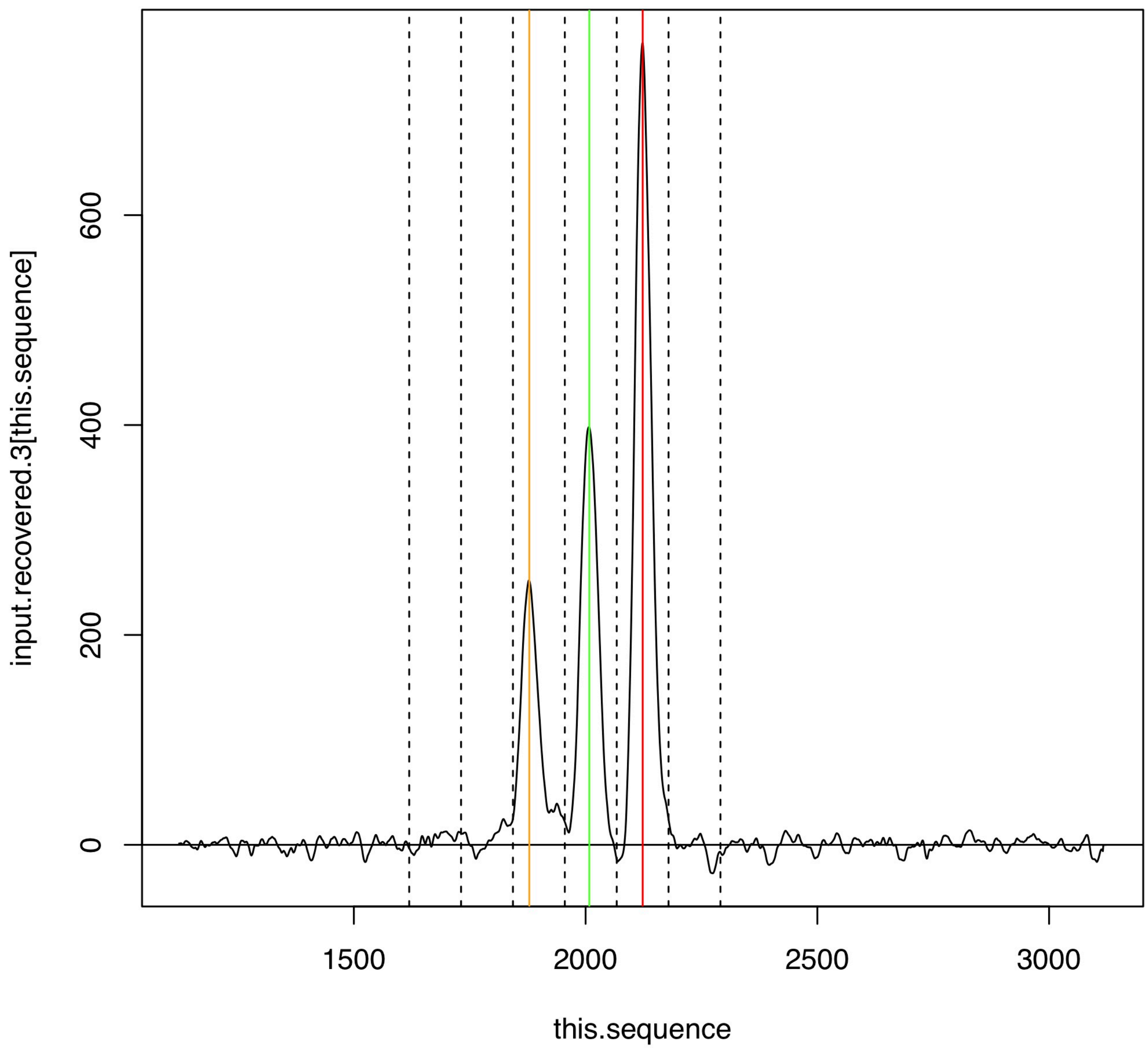



AstroPle, 91, 2017

- 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

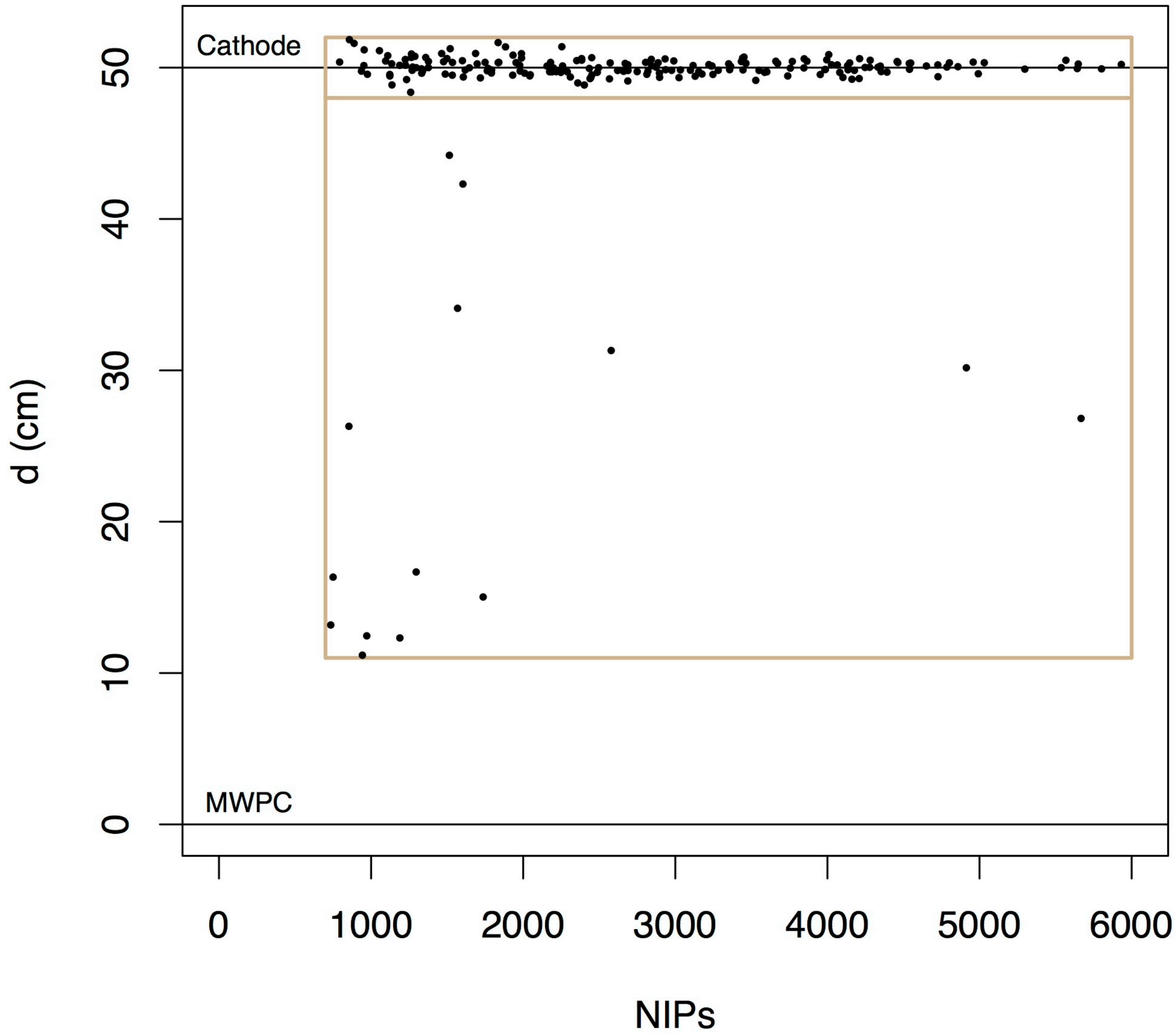
# Fiducialization

- 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

# **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

# Beam timing

## LBNF Beam Operating Parameters:

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*PIP-II*

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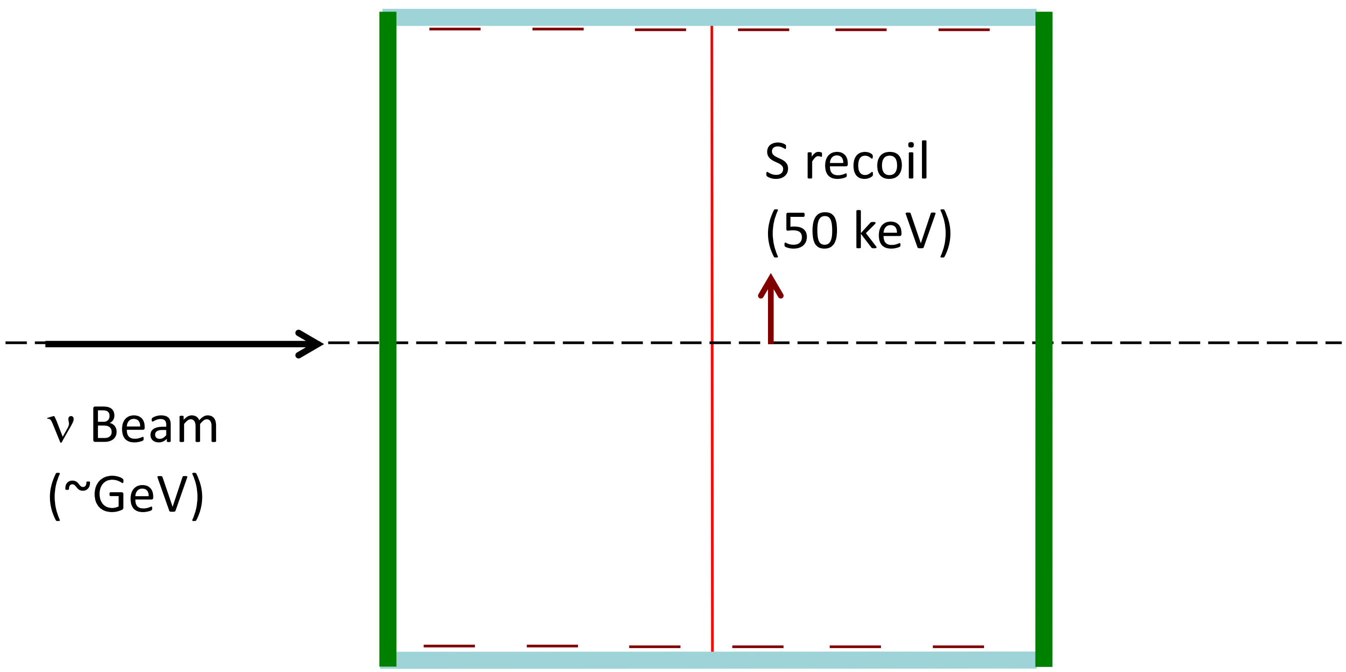
*PIP-III*

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

6 14 Aug 2015 Jim Strait | LBNF Neutrino Beam LBNF

- Cycle time for the beam is of order 1 second
- Duration is 10 μs
- We estimate our timing resolution at ~10 μs
- Background reduction of ~$10^5$
- No coincidental backgrounds expected on the year timescale.

# νBDX-DRIFT Signatures – Directional



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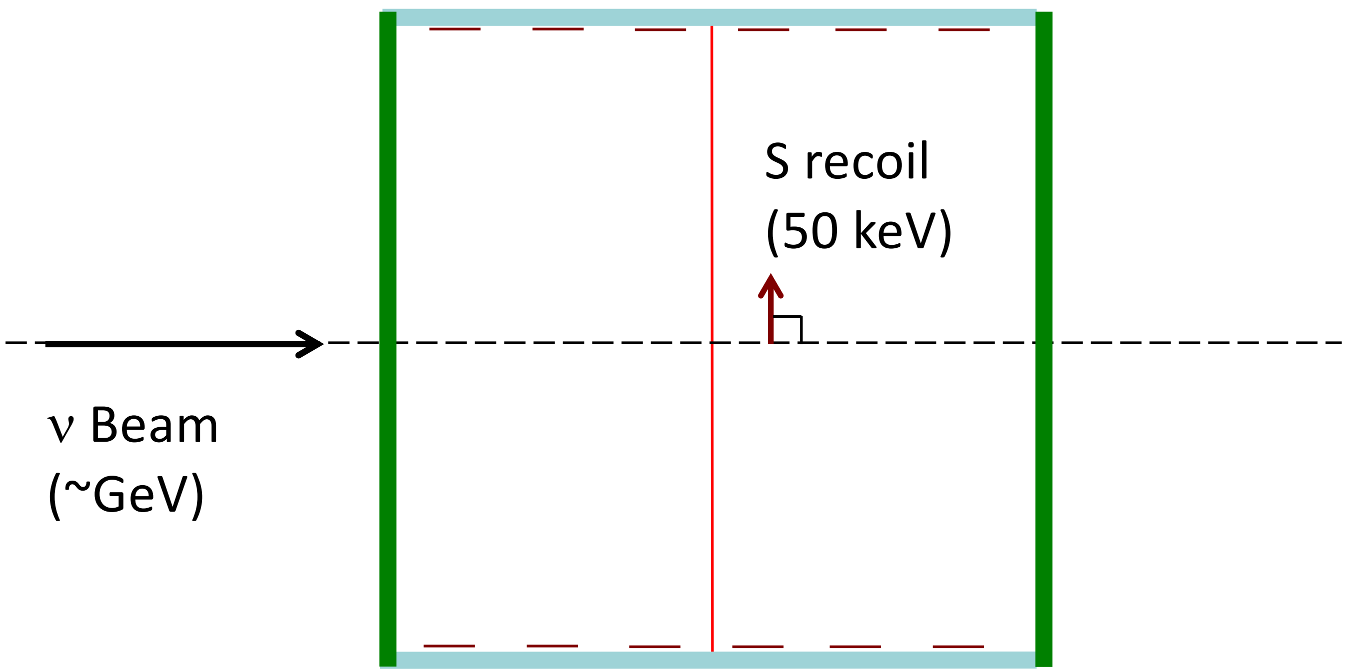
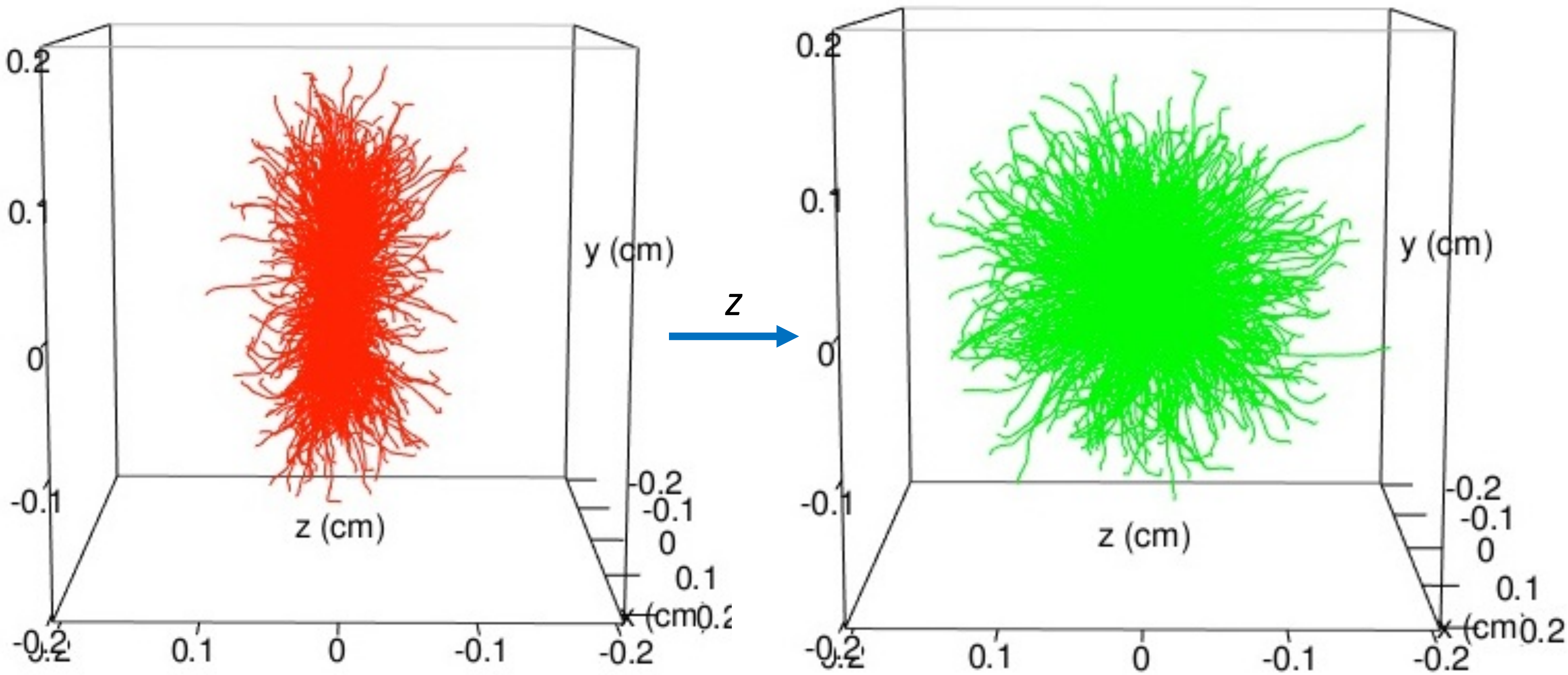


# Directional Signal and Background

1,000 50 keV
signal events

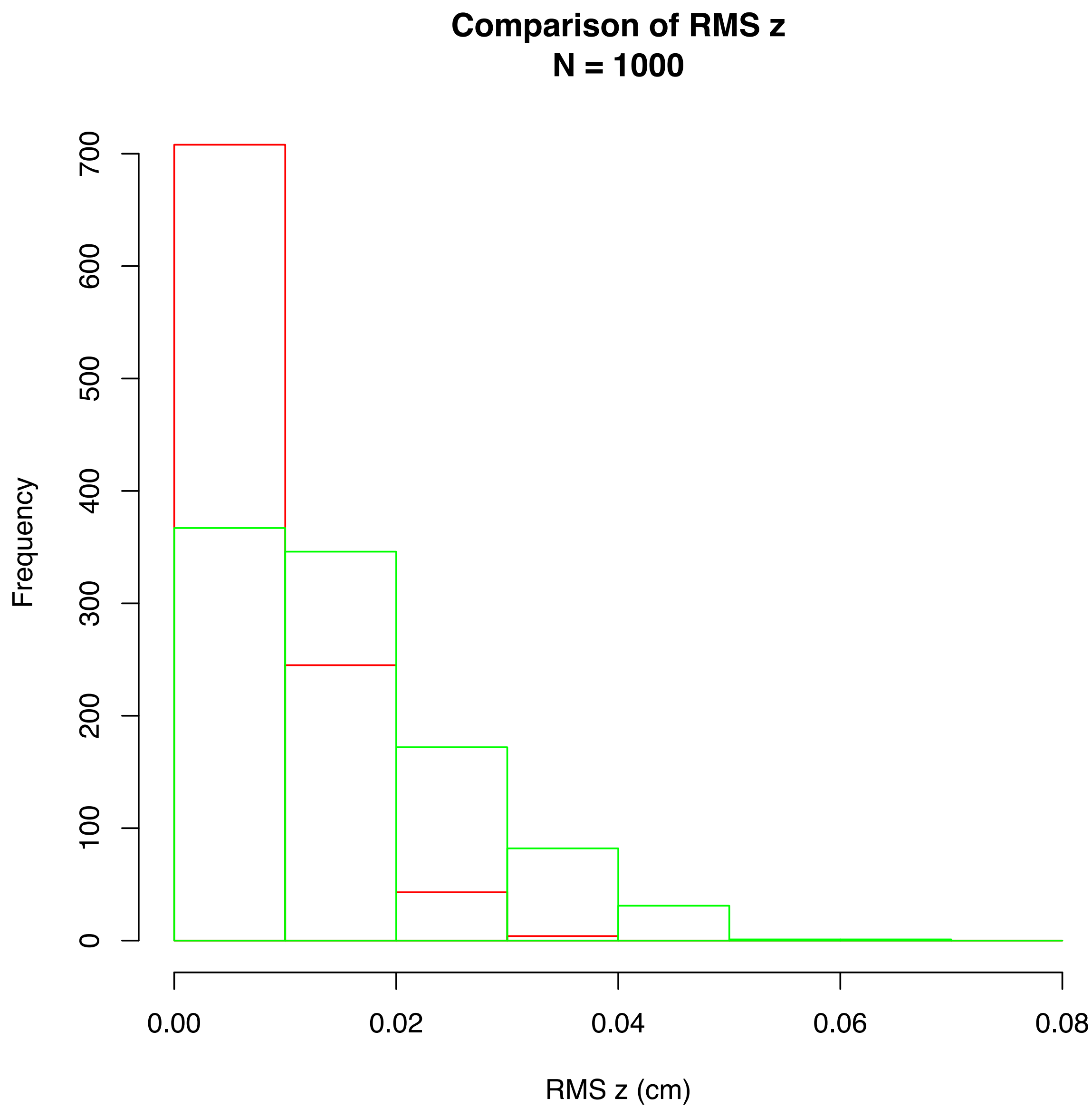
1,000 50 keV
background events




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

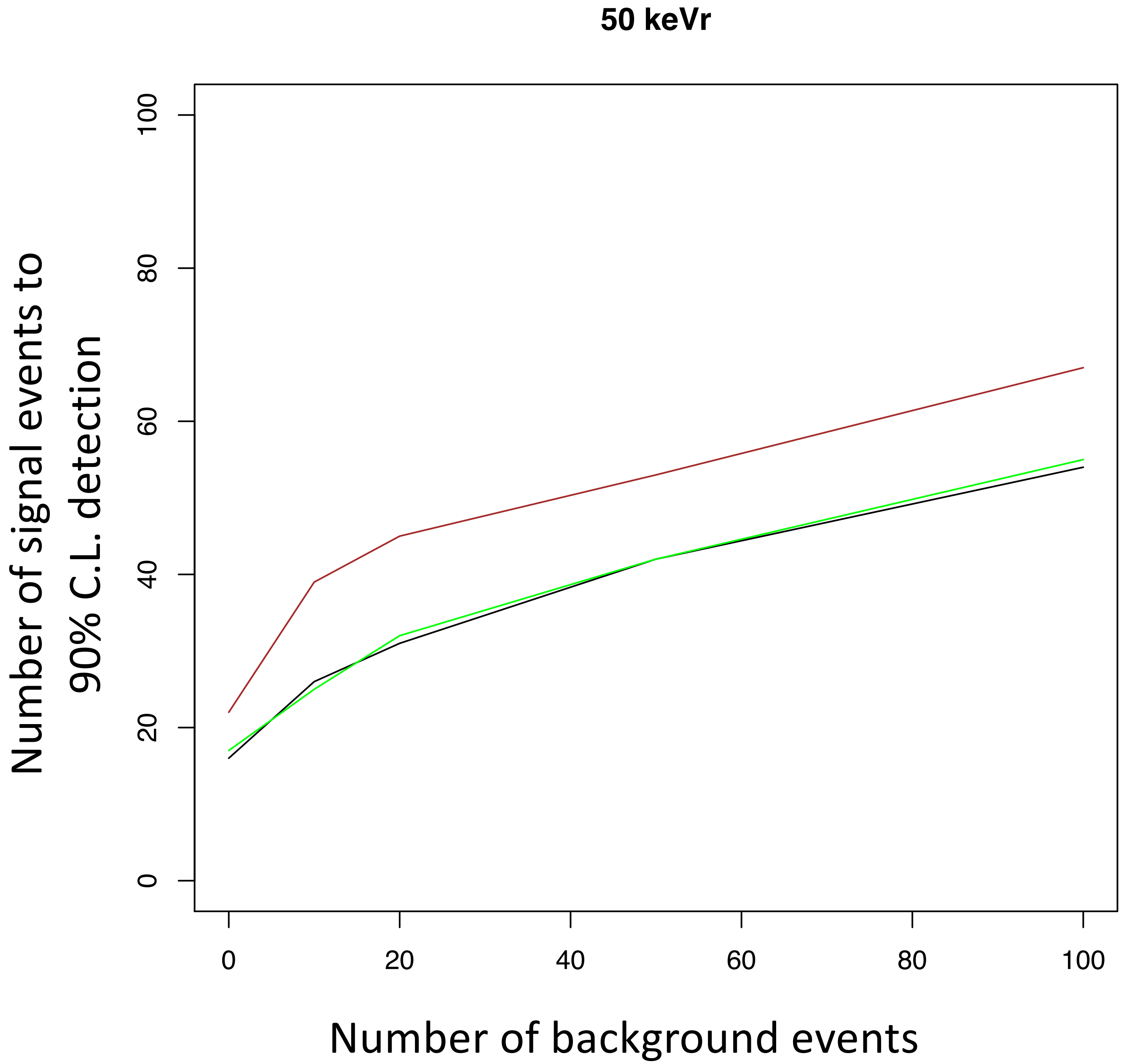
PRD, 99, 2019

# Directional Signal vs Background




PRD, 99, 2019

# Pulling signal from background




PRD, 99, 2019

# Conclusion

- νBDX-DRIFT brings a unique, proven, halo-dark-matter detector to CEνNS research.
- A 10 $m^3$ νBDX-DRIFT detector in the Near Detector hall in DUNE could detect 10s of CEνNS events per year.
- + A clear directional signature of CEνNS events is available.
- + νBDX-DRIFT will use C and S as target nuclei. Adding gaseous molecules with additional nuclear targets is relatively easy.
- + The νs will be GeV energy scale bringing a new energy scale to bear on CEνNS research, including larger energy recoils.
- + Data on inelastic processes will also be available.

# Conclusion

- + Backgrounds are expected to be minimal.
- In the near term we hope to deploy a 1 $m^3$ $\nu$BDX-DRIFT prototype in the NuMI beam at Fermilab to test these ideas out.
- Simultaneously we plan on exploring what such a detector could do in the search for BSM physics, including light dark matter and ALPs.

# The End