The νBDX-DRIFT Experiment to Study CEνNS and New Physics at Fermilab

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The νBDX-DRIFT Collaboration

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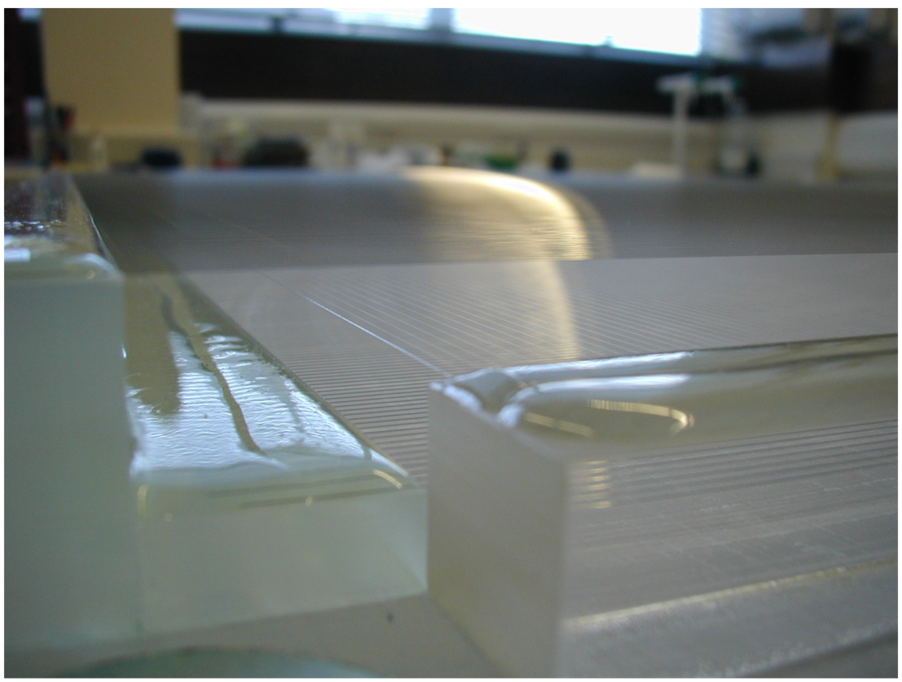
Fermilab

DRIFT: Lightning Summary

Started = 1998, US/UK

Directional WIMP dark matter detector

40 Torr, 1 m^3 gaseous detector



Unique and robust technology

Low energy (35 keV) threshold for nuclear recoils

Low background

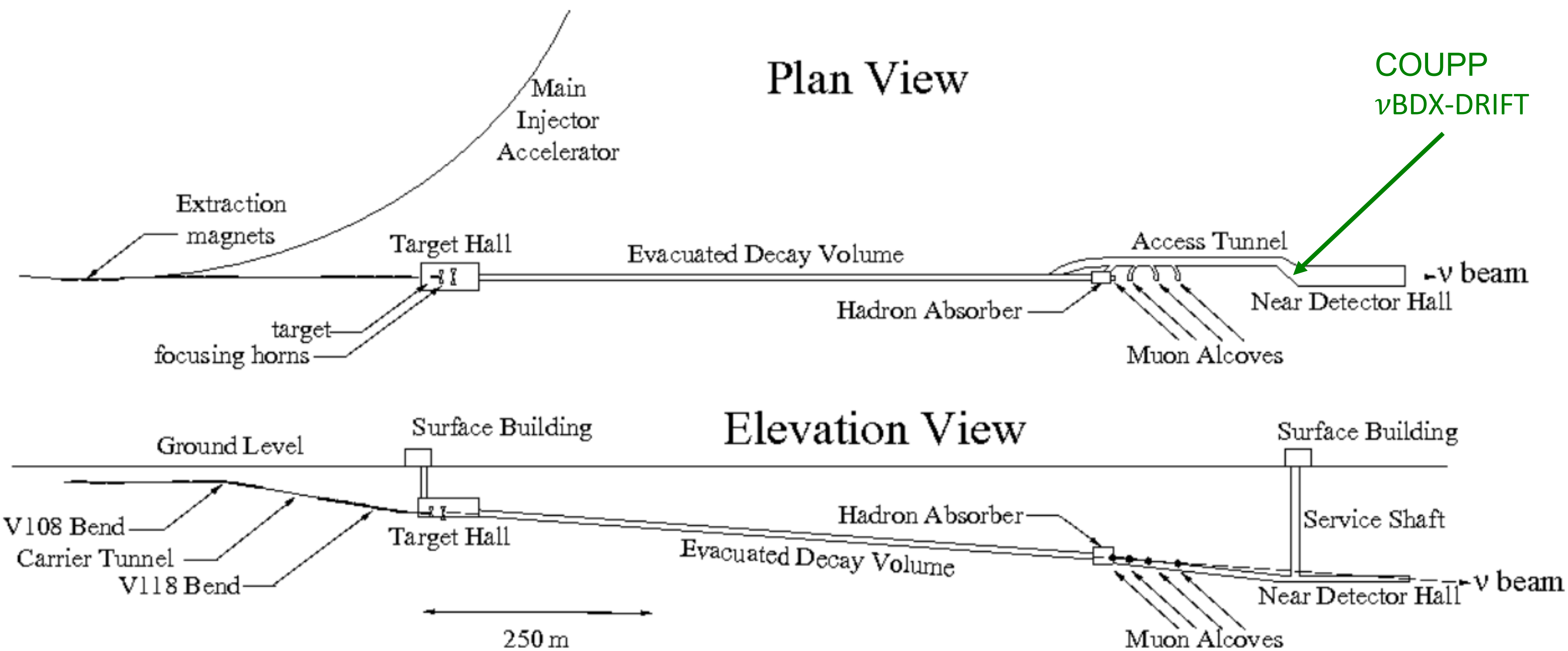
AstroPle, 91, 2017

Backgrounds

PAC 2020 Request

Since backgrounds need to be estimated to evaluate experimental sensitivity to any physics case, the PAC recommends the collaboration to perform a quantitative investigation of the current knowledge on the rock neutrons background in NuMI, in order to estimate the physics reach of a pilot run with NuMI beam on-axis.

νBDX-DRIFT at NuMI



Backgrounds - Inputs

- Dolomite composition from Fermilab

> I updated the ND rock using information in MINOS-doc-1083 and 2777, particularly the quoted water content in doc-2777, and Wikipedia's composition for shale. I also assumed that we've drained half the water out since the water content was measured. The result was:

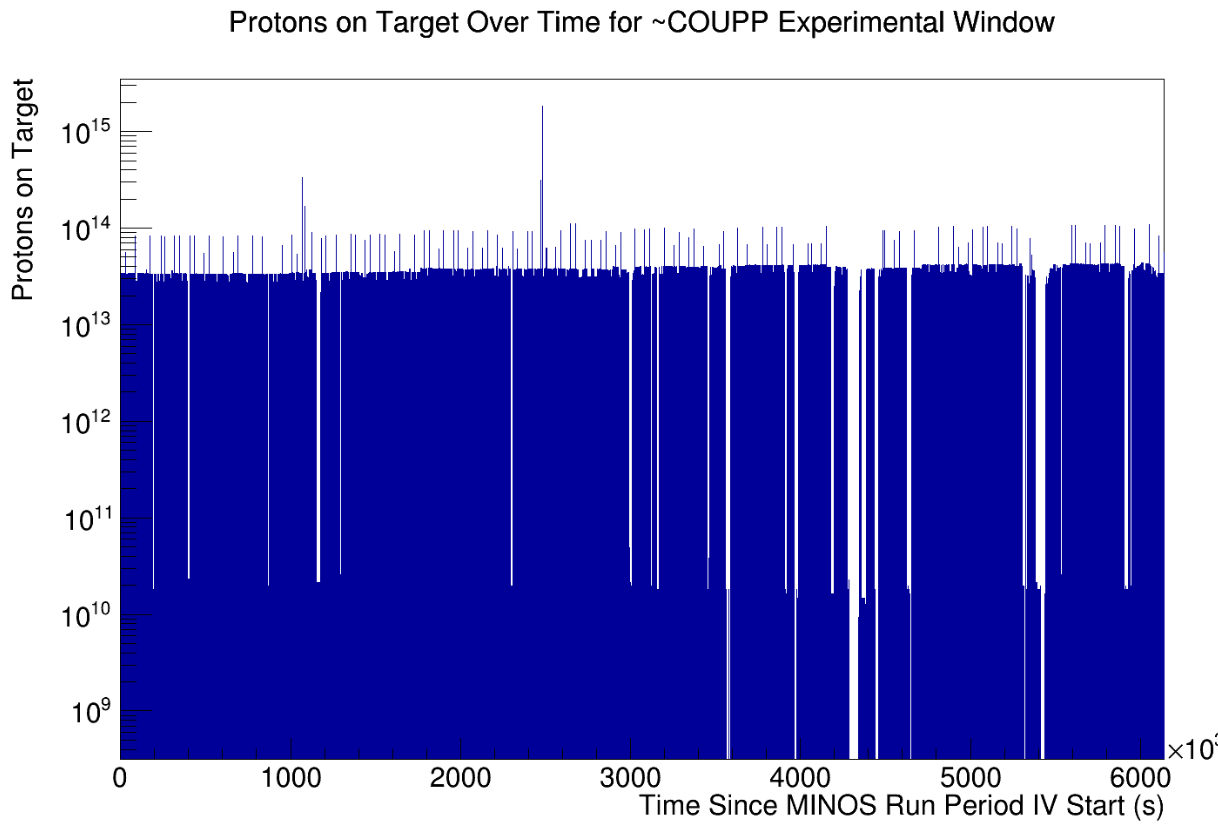
>

> <D value="2.33" unit="g/cm3"/>
> <fraction n="0.0147547" ref="Hydrogen"/>
> <fraction n="0.0114328" ref="Carbon" />
> <fraction n="0.5637993" ref="Oxygen" />
> <fraction n="0.0431255" ref="Calcium" />
> <fraction n="0.0028548" ref="Sodium" />
> <fraction n="0.0946920" ref="Aluminum"/>
> <fraction n="0.0179492" ref="Iron" />
> <fraction n="0.2420140" ref="Silicon" />
> <fraction n="0.0093778" ref="Potassium"/>

>

Backgrounds - Inputs

- Dolomite composition from Fermilab
- POT per pulse average = 2.67e13
- Time between pulses= 2.3s



Backgrounds - Inputs

- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses
- NuMI neutrino flux
- LE mode

The NuMI Beam at FNAL and its Use for Neutrino Cross Section Measurements

Sacha E. Kopp

Department of Physics, University of Texas, Austin, TX 78712 USA

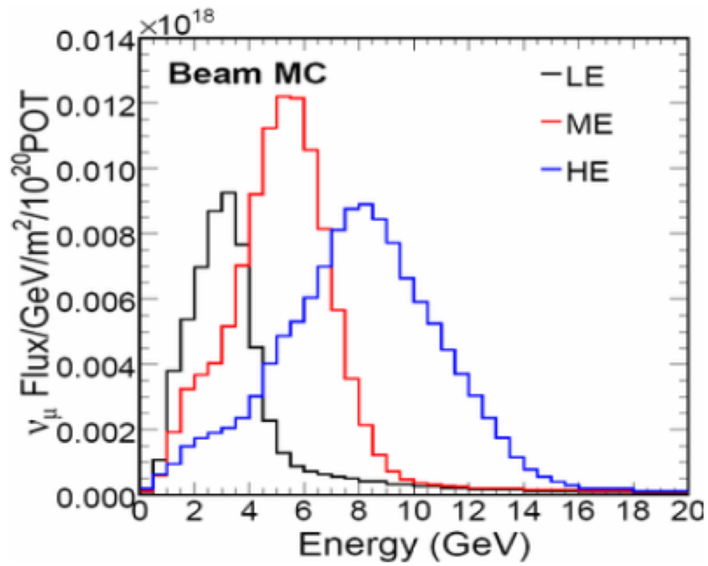


FIGURE 2. Neutrino energy spectra achieved at a distance of 1040 m from the NuMI target with the horns separated by 10 m and the target inside the first horn (LE), or retracted 1 m (ME) or 2.5 m (HE).

Backgrounds - Code

- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses
- NuMI neutrino flux
- LE mode
- Used Genie to generate end-state particles coming from ν - nuclei interactions

Backgrounds - Code

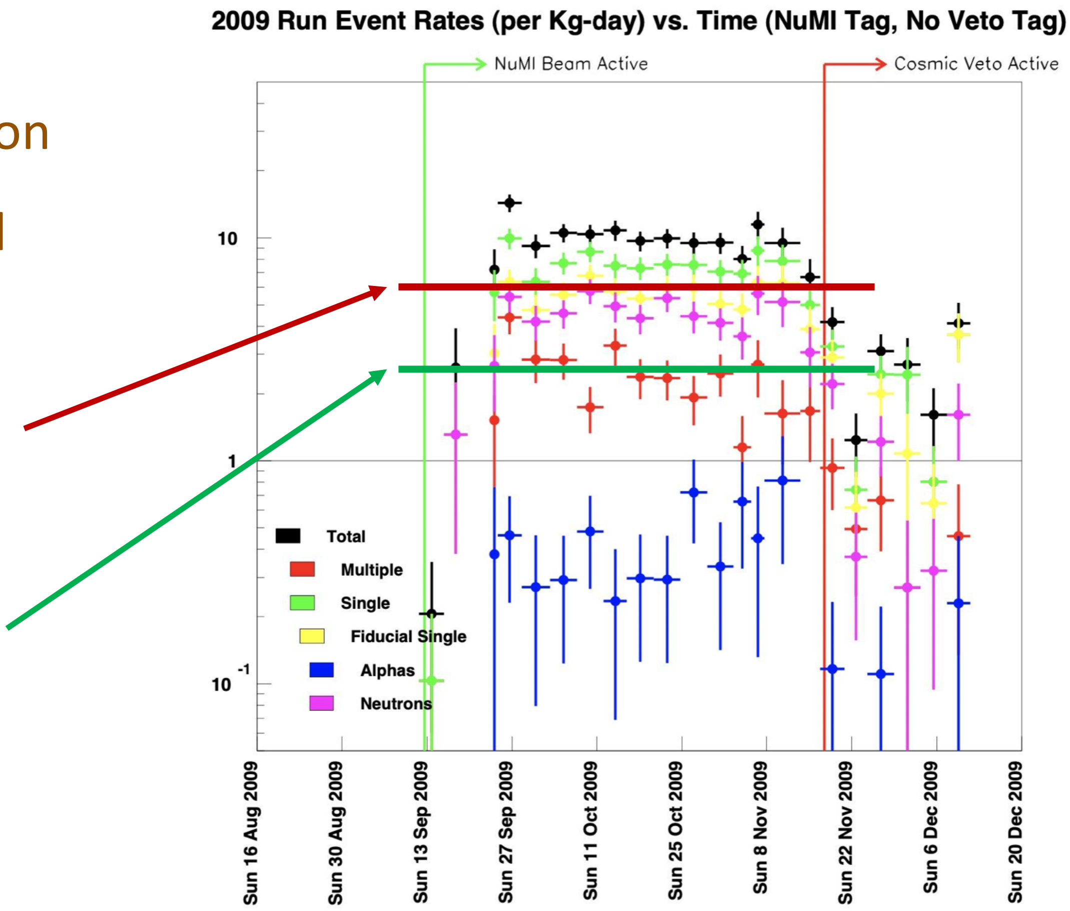
- Dolomite composition from Fermilab
- POT per pulse
- Time between pulses
- NuMI neutrino flux
- LE mode
- Used Genie to generate end-state particles coming from ν - nuclei interactions
- Used GEANT to generate recoils

Backgrounds - Benchmarking

- Use COUPP 2009 nuclear recoil data to benchmark the simulation
- COUPP (unpublished) measured

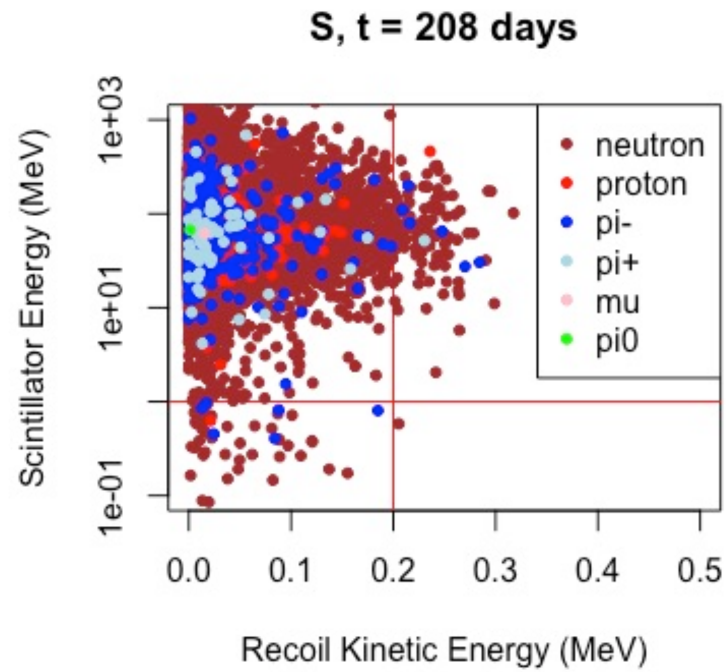
  5.9 +/- 0.2 events/kg/day
- 3.25 kg CF_3I, 19 keV F threshold
- Genie/GEANT predict

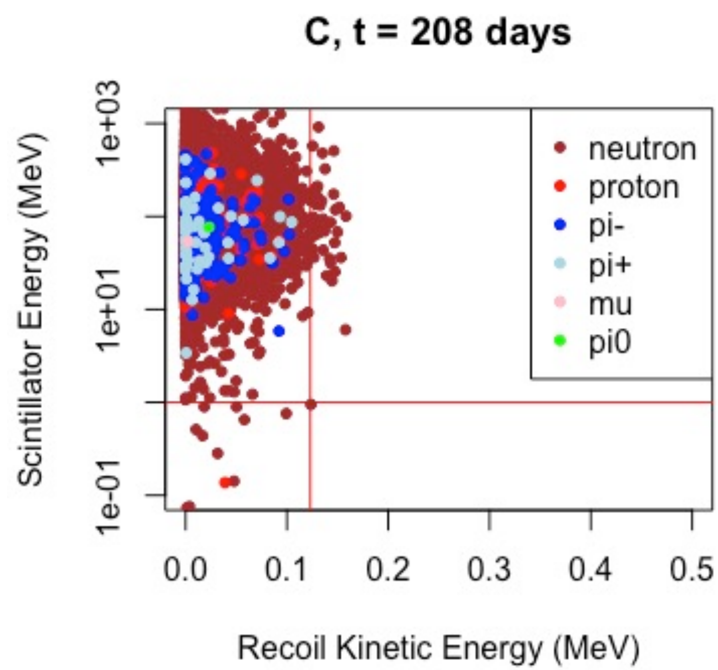
  1.6 +/- 0.1 events/kg/day
- x3.5 difference



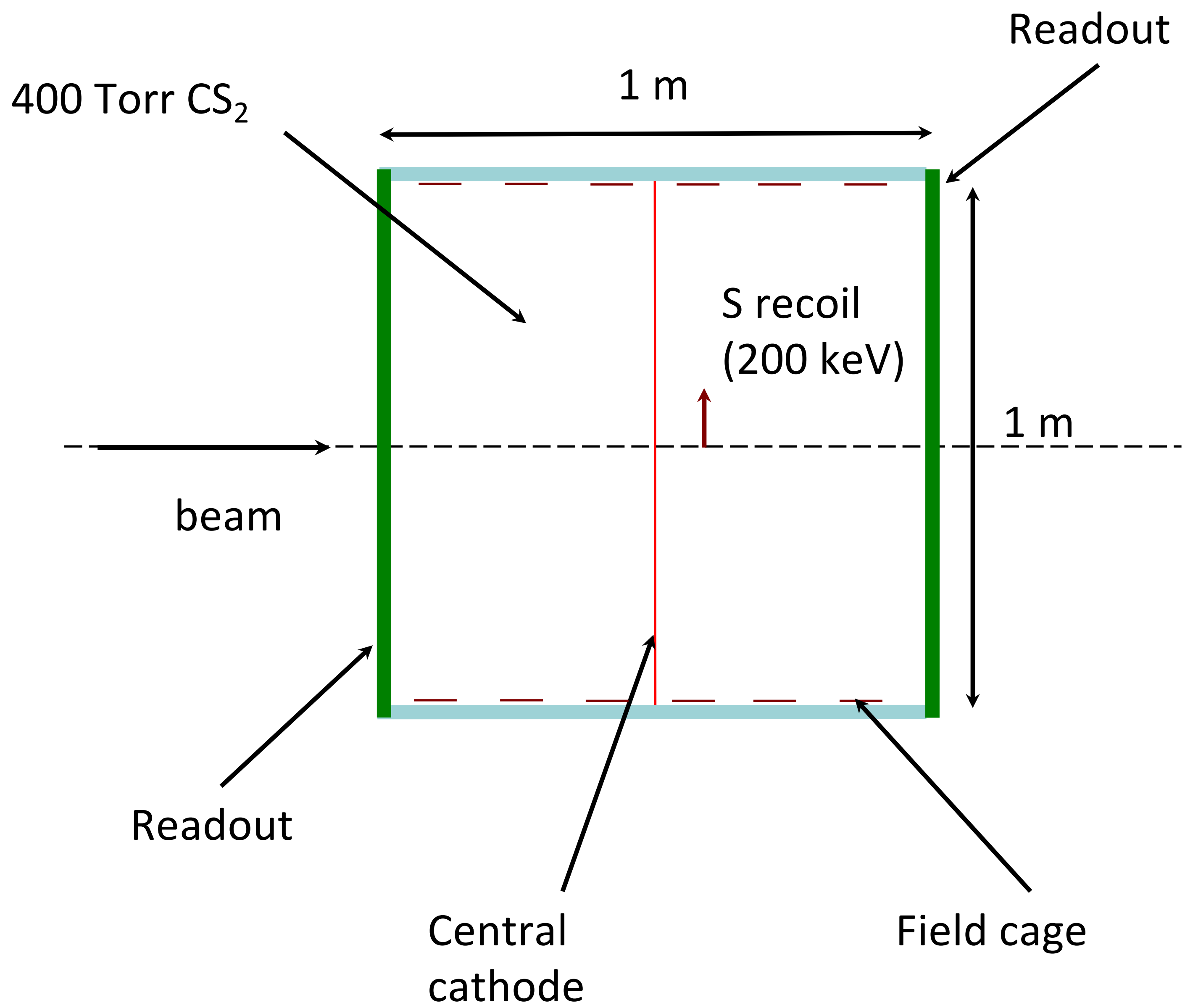
Backgrounds - Predictions

- 1 m^3 νBDX-DRIFT detector filled with 400 Torr CS_2
- Used benchmarking to scale rate and updated to current operating parameters
- 0.77 +/- 0.06 events per day above νBDX-DRIFT threshold (200 keV S, 123 keV C)
- This rate can be significantly reduced by adding a Gd-loaded scintillator around the νBDX-DRIFT detector





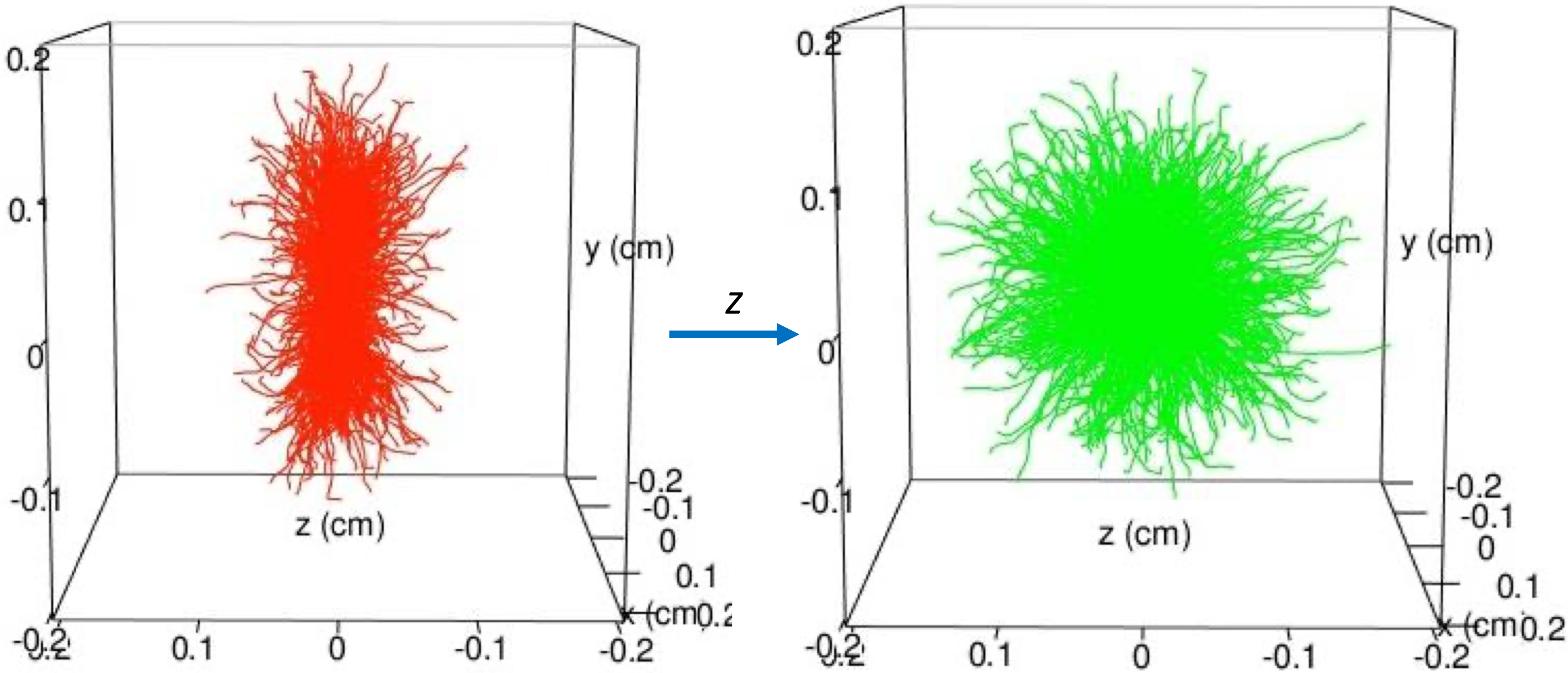
Directionality



Directional Signal and Background

1,000 50 keV
signal events

1,000 50 keV
background events



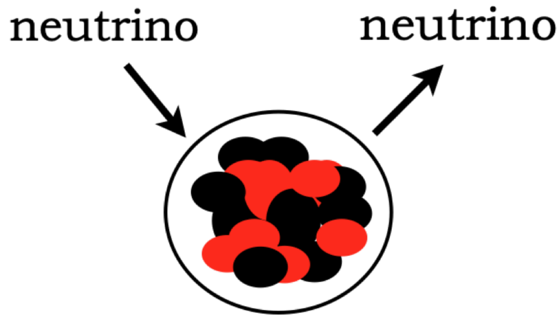
PRD, 99, 2019

Physics Reach

PAC 2020 Request

The proposing team is encouraged to explore the full physics potential of this setup including the sensitivity to CEvNS, a larger parameter space in boosted dark matter scenarios, and other beyond standard model scenarios.

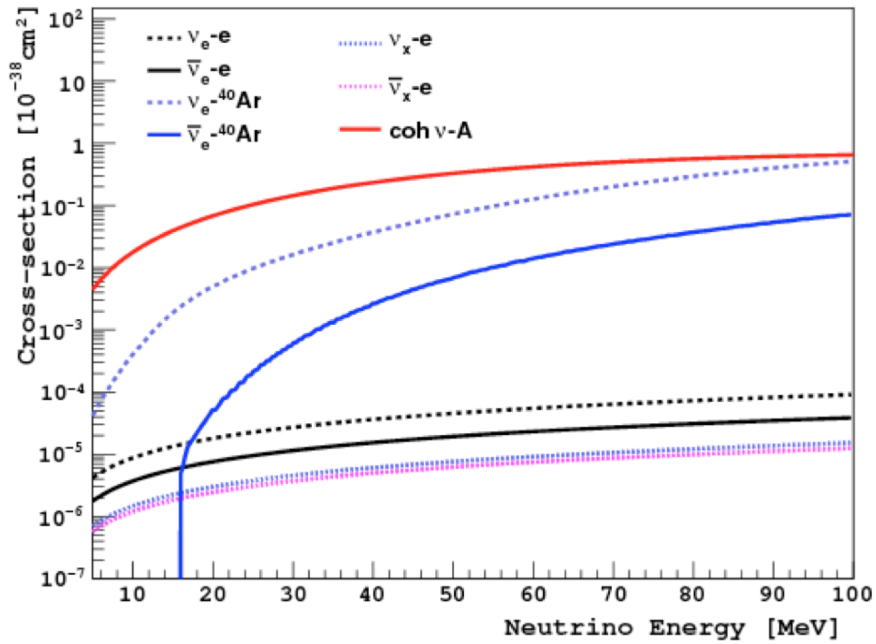
Coherent neutrino-nucleus scattering (CEνNS)

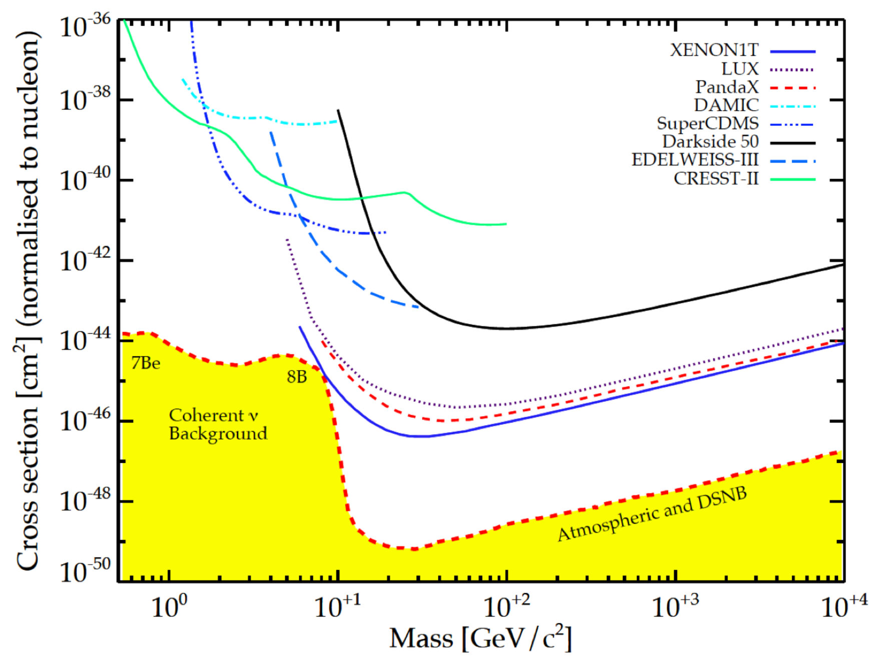


$$\frac{d\sigma}{dT} \sim \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$

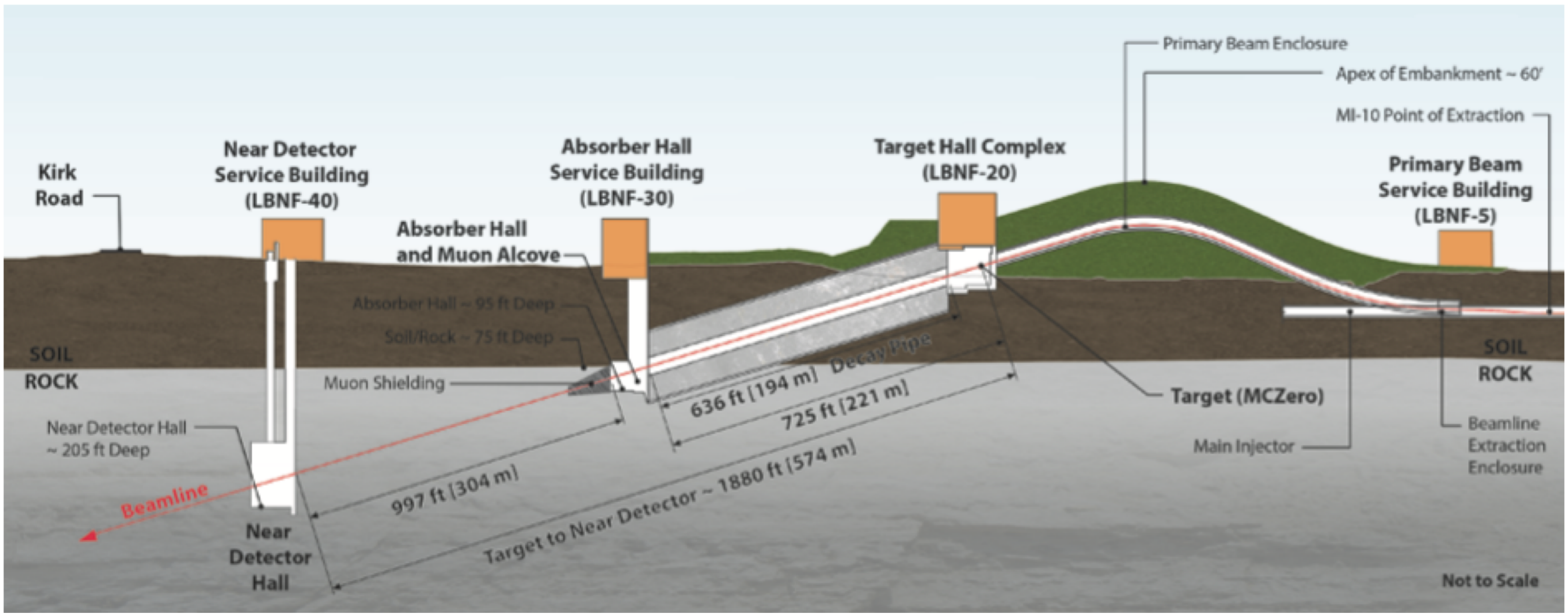
$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

- Small momentum transfer relative to target size implies coherent enhancement
- Due to Standard Model couplings coherent enhancement due to neutrons
- Low energy recoil distribution implies difficult to detect

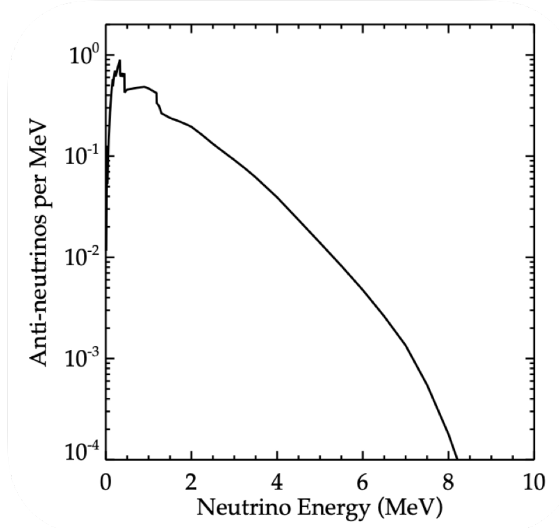


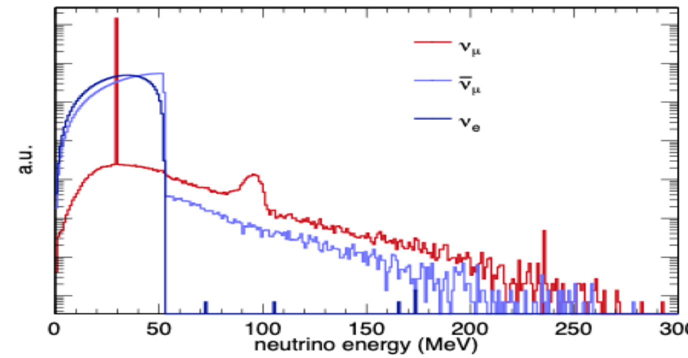


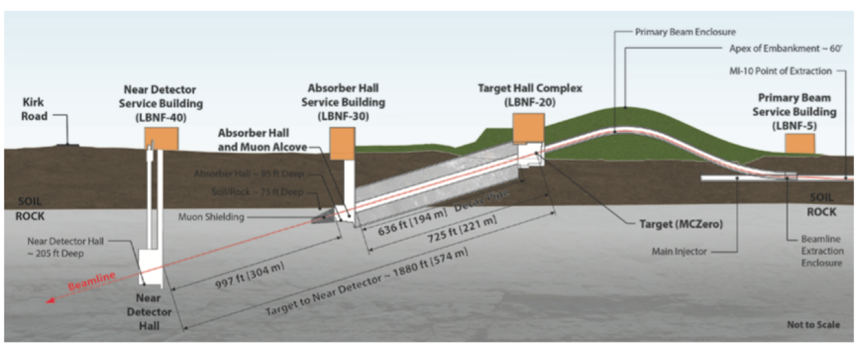
νBDX-DRIFT at DUNE

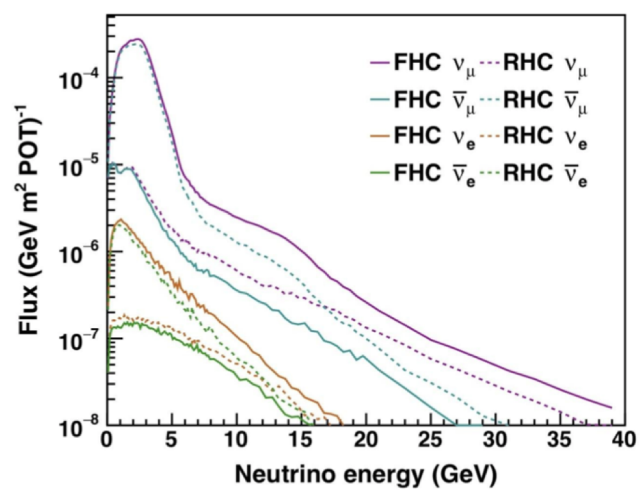


Sources for CEνNS









CEνNS Measurements and Limits

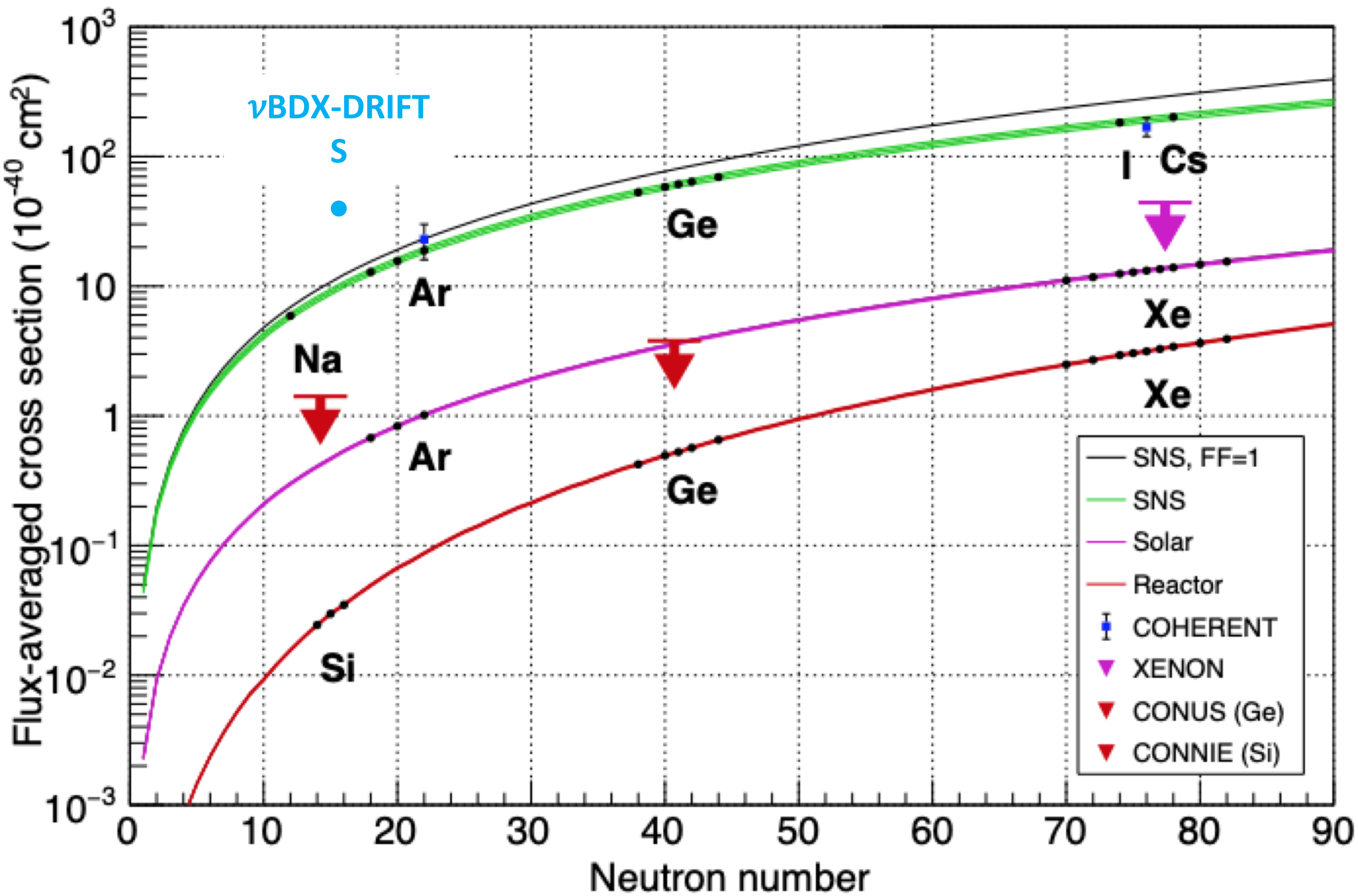
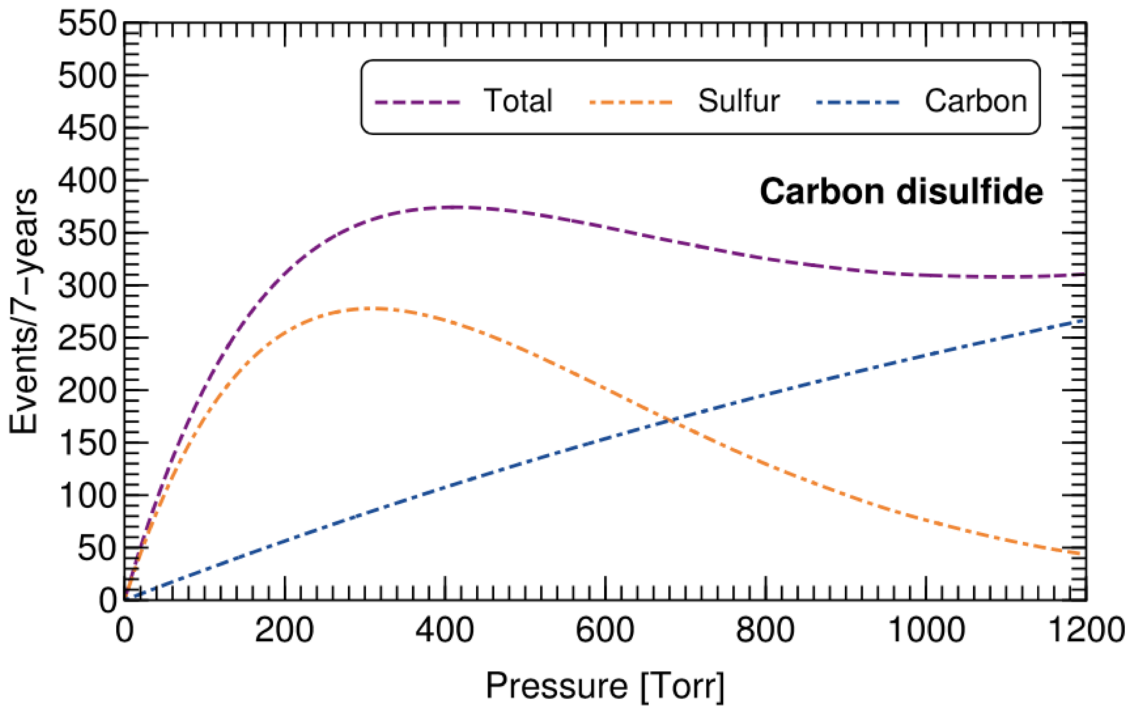


Figure: K. Scholberg

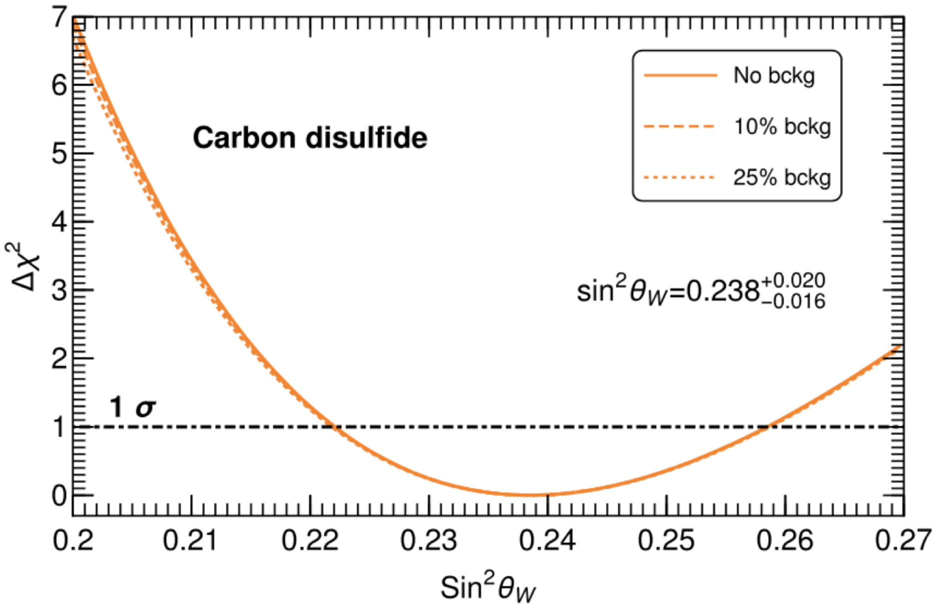
CEνNS Physics – Event Rates

- Recoil energy threshold proportional to pressure
- Max rate @ 400 Torr CS_2
- Significant detection, ~400 events for 7 yrs with 10 m^3
- Different nuclei possible
- Directionality for signature



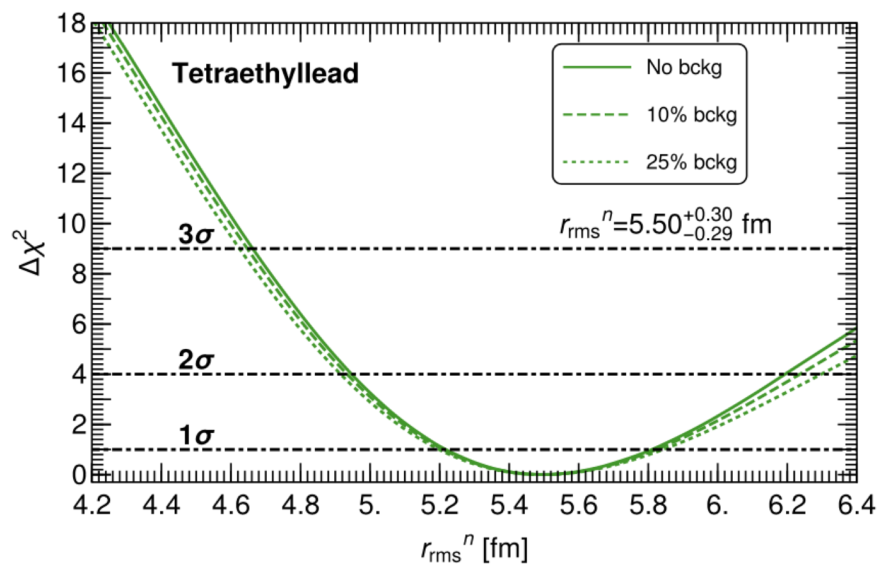
PRD 104, 2021, arXiv:2103.10857, Aristizabal-Sierra et al.

CEνNS Physics - Measurements



- Measurement of the weak mixing angle on S to 8%

- Measurement neutron distribution in Pb to 5% and skin
- Larger neutrino energy => Sufficient stats at high Q
- Systematics on form factor are small
- Comparison with PREX



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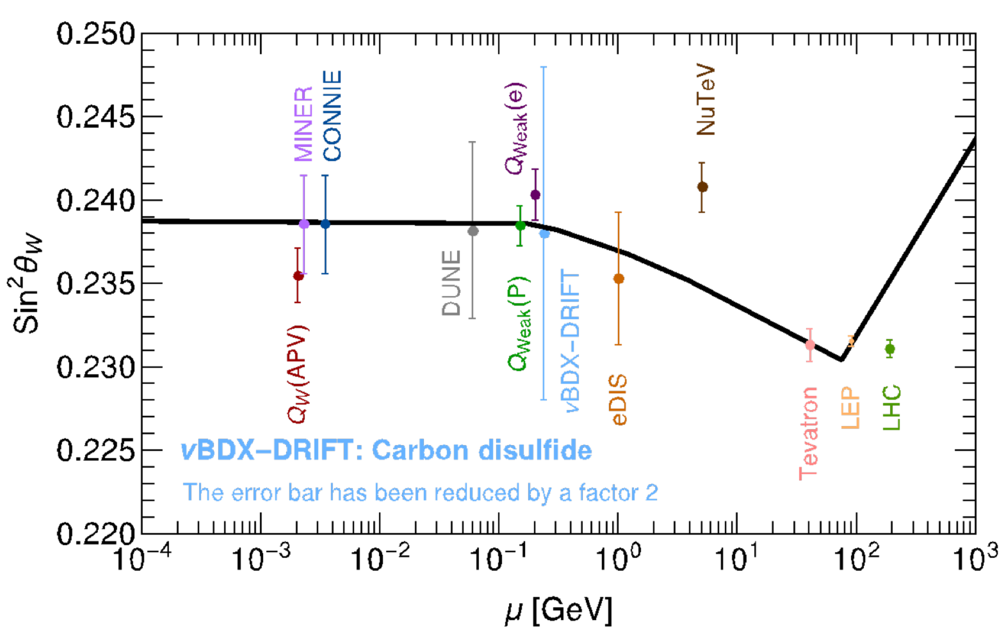
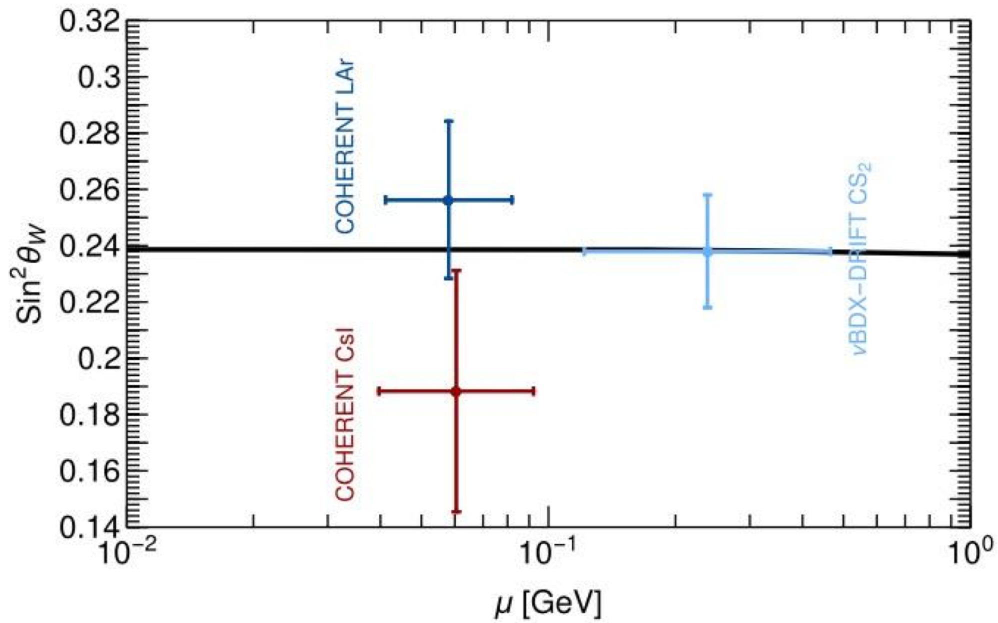
New Probe of Weak Mixing Angle

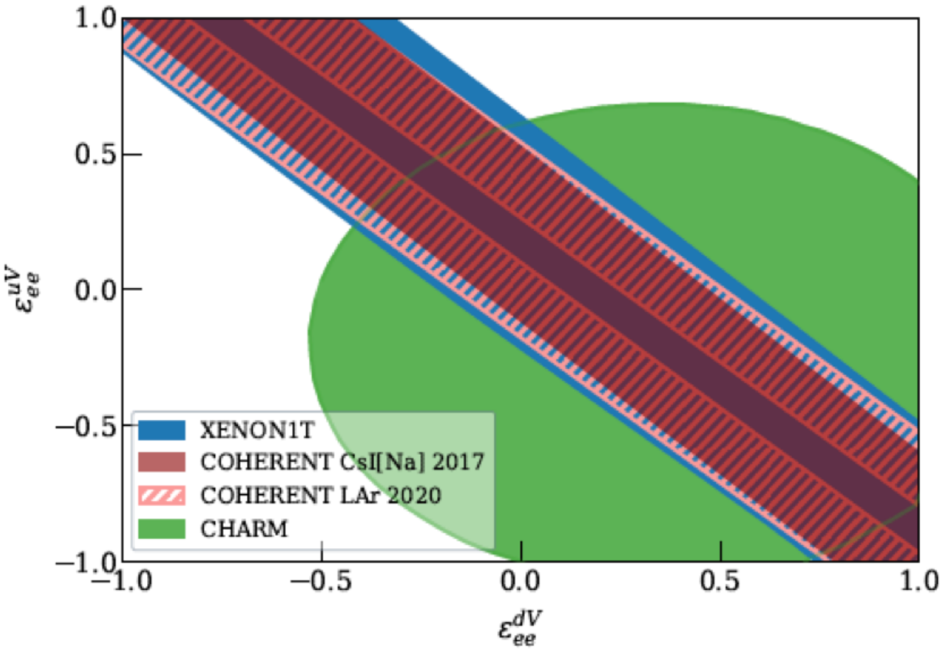


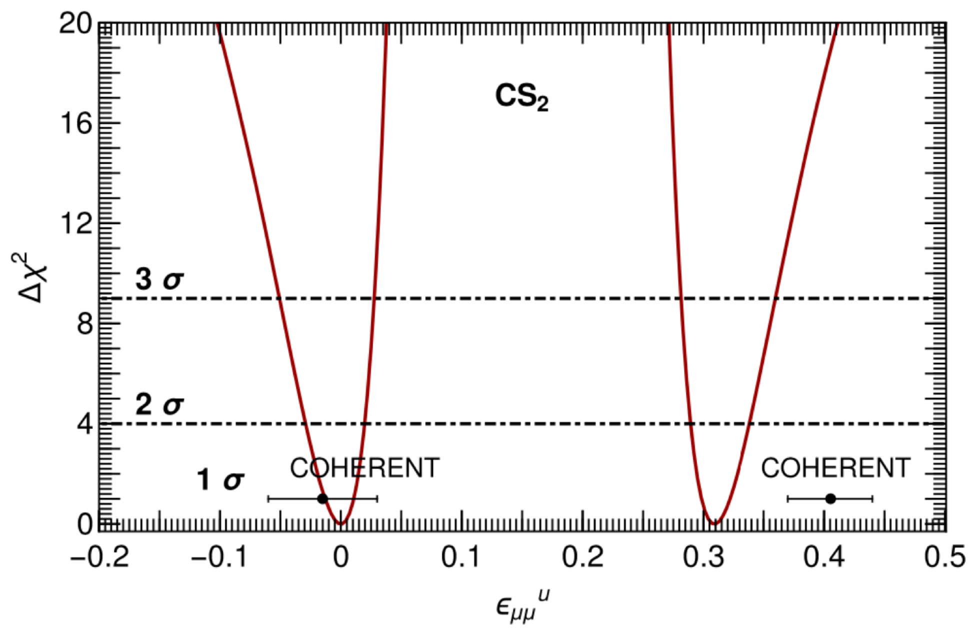


- Probes weak mixing via scattering on quarks
- Measurement of weak mixing angle at new energy scale

PRD 104, 2021, arXiv:2103.10857, Aristizabal-Sierra et al.

Non-Standard Neutrino Interactions (NSI)





Xenon collaboration 2021

PRD 104, 2021, arXiv:2103.10857,

Aristizabal-Sierra et al.

Beyond the Standard Model physics

- Low background and directional sensitivities will be utilized to investigate BSM physics
- Light dark-matter and axion-like particles
- Dark matter and neutrino inelastic up-scattering processes including directionality: primary recoil + secondary (displaced) decay
- Various types of dark matter and neutrino interactions
- Decays of various types of light mediators
- Complementarity with DUNE

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 400 CEνNS events in a 7-year run
- νBDX-DRIFT offers interesting new capabilities and complementarity for CEνNS research
- Measurements of WMA and n distribution available
- NSI, BSM and new physics
- Backgrounds are expected to be minimal
- In the near term we hope to deploy an existing 1 m^3 νBDX-DRIFT detector in the NuMI beam at Fermilab to test these ideas out

The End