PR12-19-005
Beam-Dump Dark Matter Search Utilizing a Low-Threshold, Directional Dark Matter Detector (BDX-DRIFT) at Jefferson Lab

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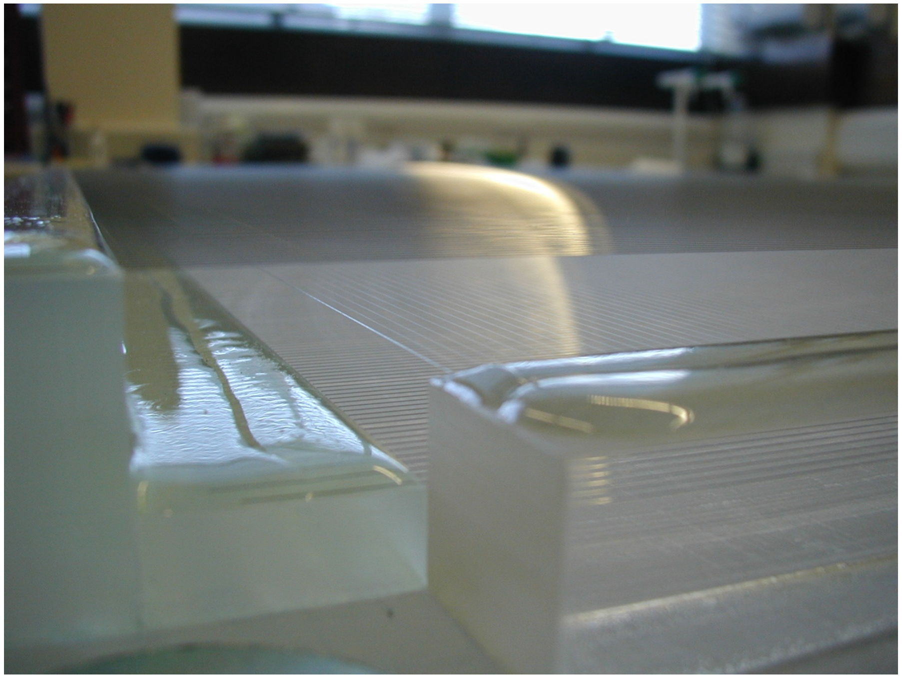
BDX Collaboration
July 30, 2019

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

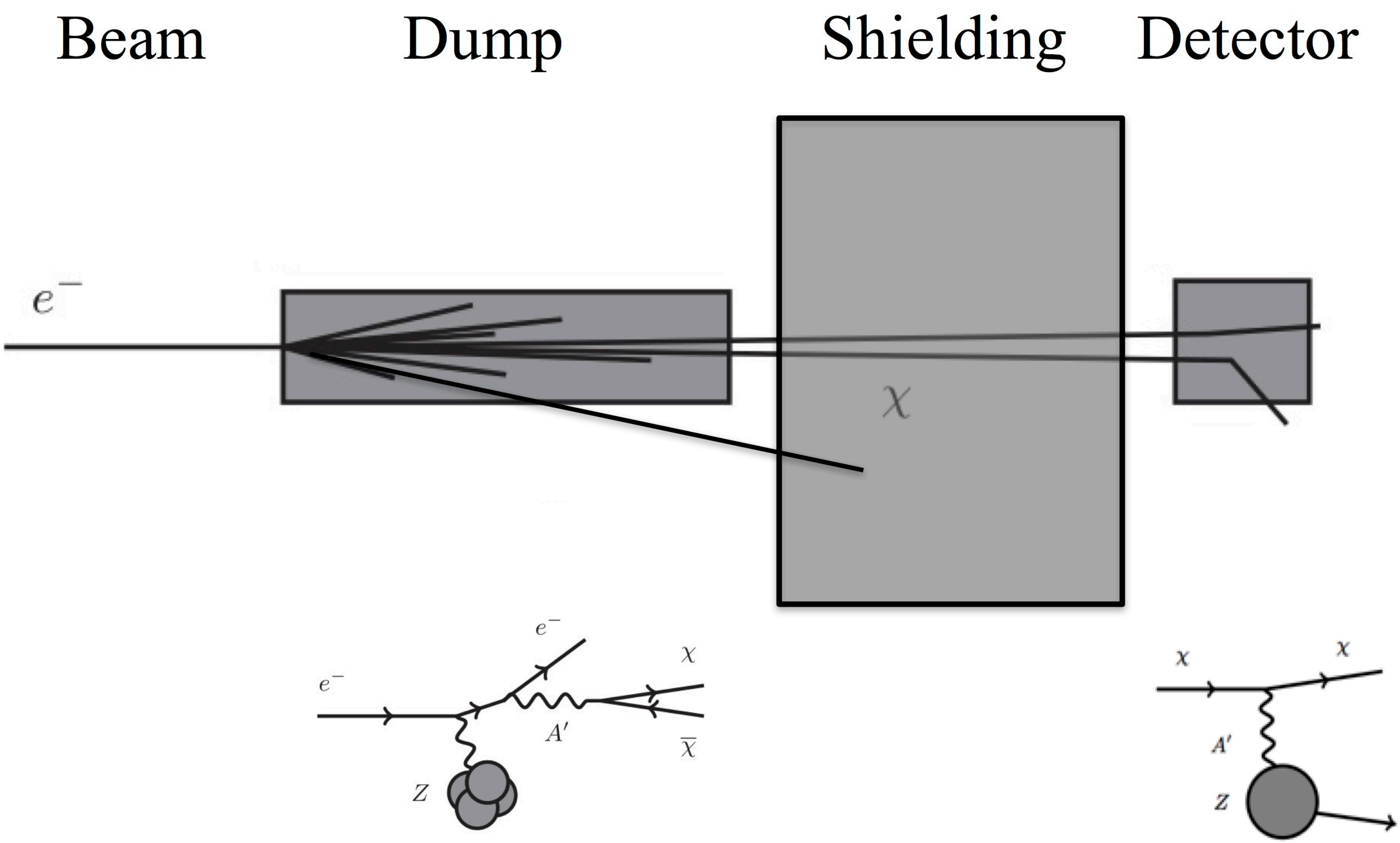
Low background

AstroPle, 91, 2017

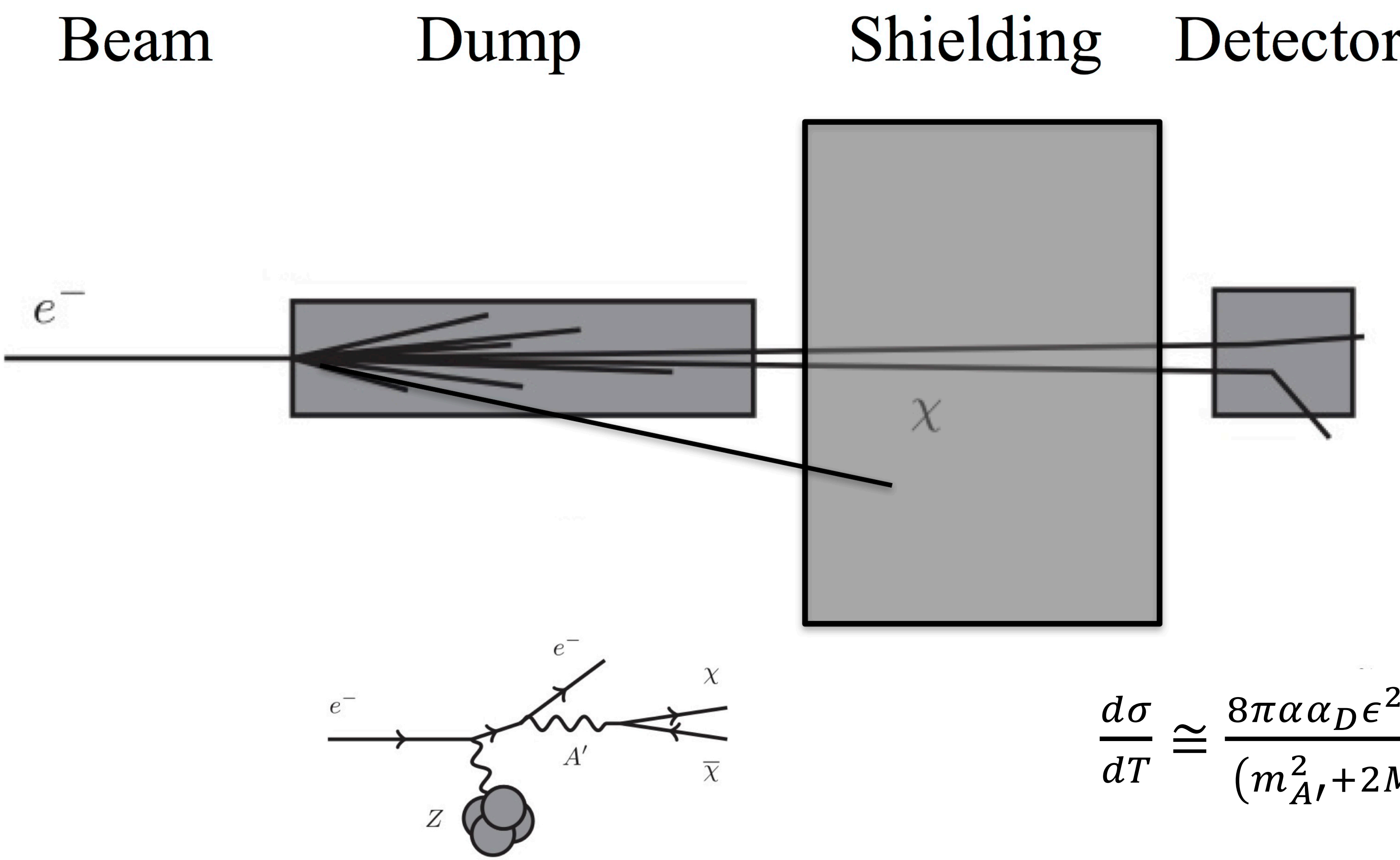
DRIFT + Beam Dump

- In recent years theorists have broadened their thinking about dark matter.
- Light dark matter, motivated by dark sector theories, has become a fruitful avenue of research, especially because of the possibility of creating it at high intensity accelerators, such as JLab.
- Last year BDX was approved to run parasitically at JLab. No need for beam time.
- We have been working together with BDX for almost 5 years now.
- BDX-DRIFT proposes to run in parallel with BDX adding reach and complementarity to the beam dump effort.

Detecting Light Dark Matter at Accelerators

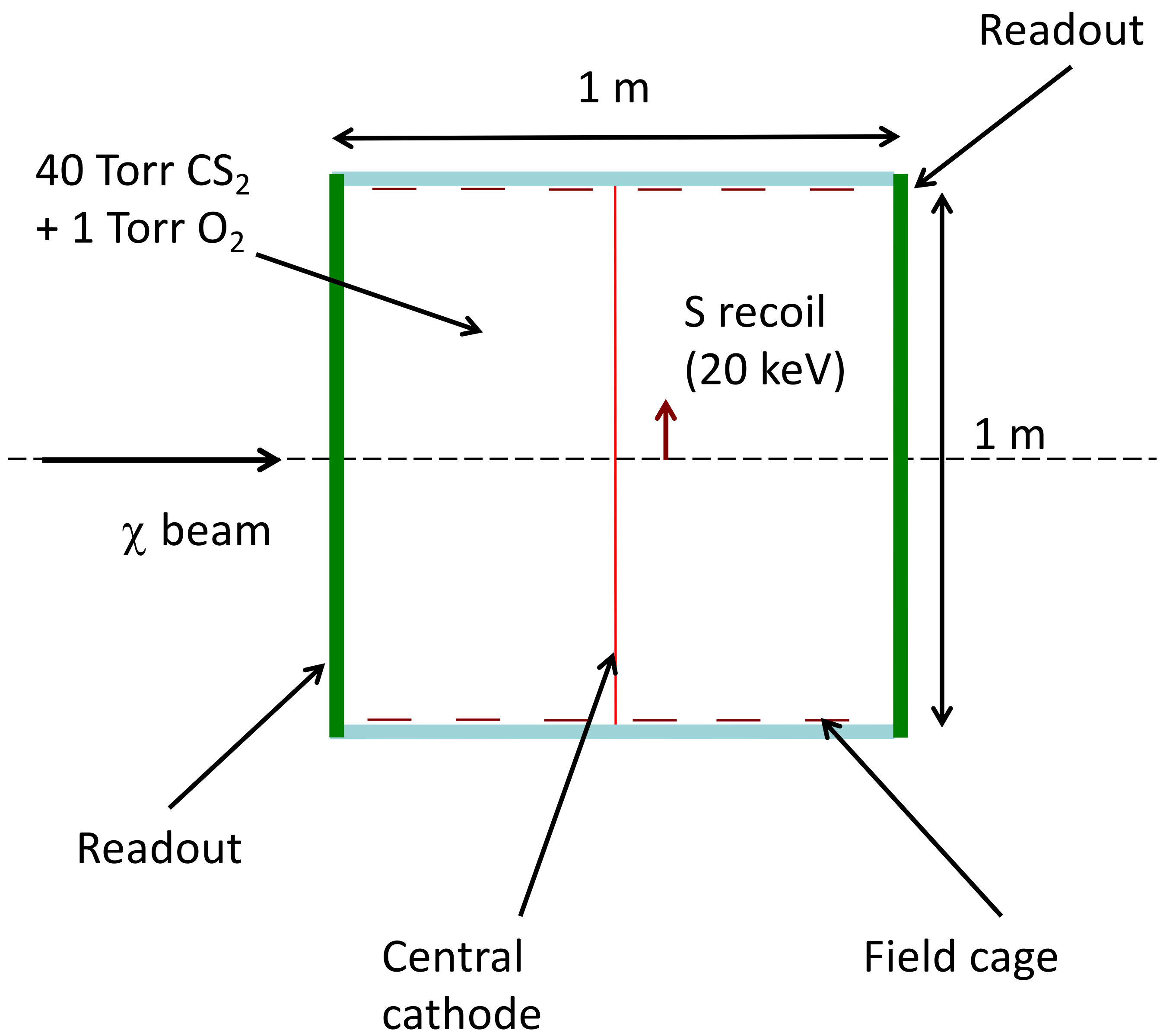


Detecting Light Dark Matter at Accelerators

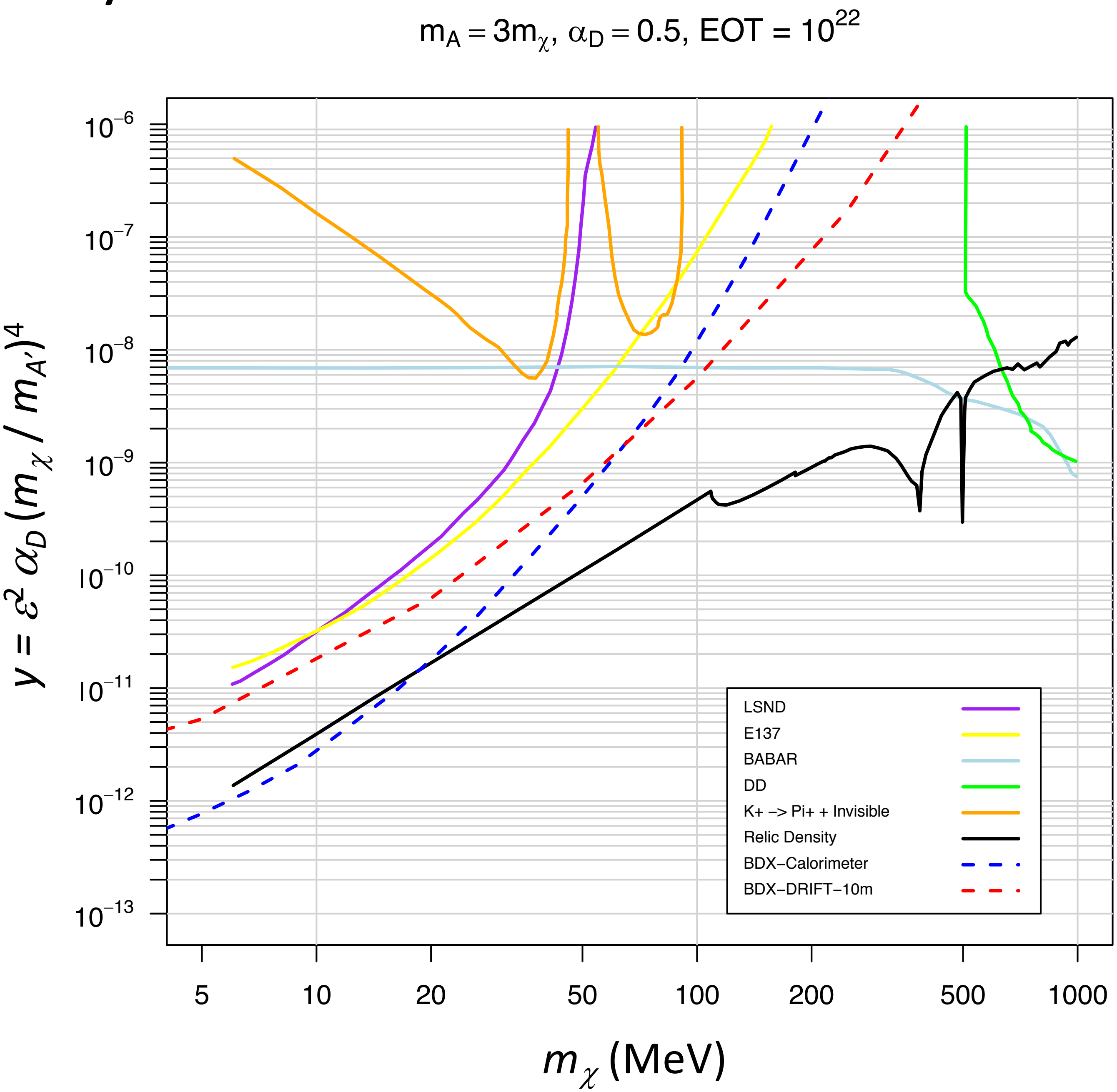


$$\frac{d\sigma}{dT} \cong \frac{8\pi\alpha\alpha_D\epsilon^2 Z^2 M}{\left(m_{A'}^2 + 2MT\right)^2}$$

BDX-DRIFT-1m Module



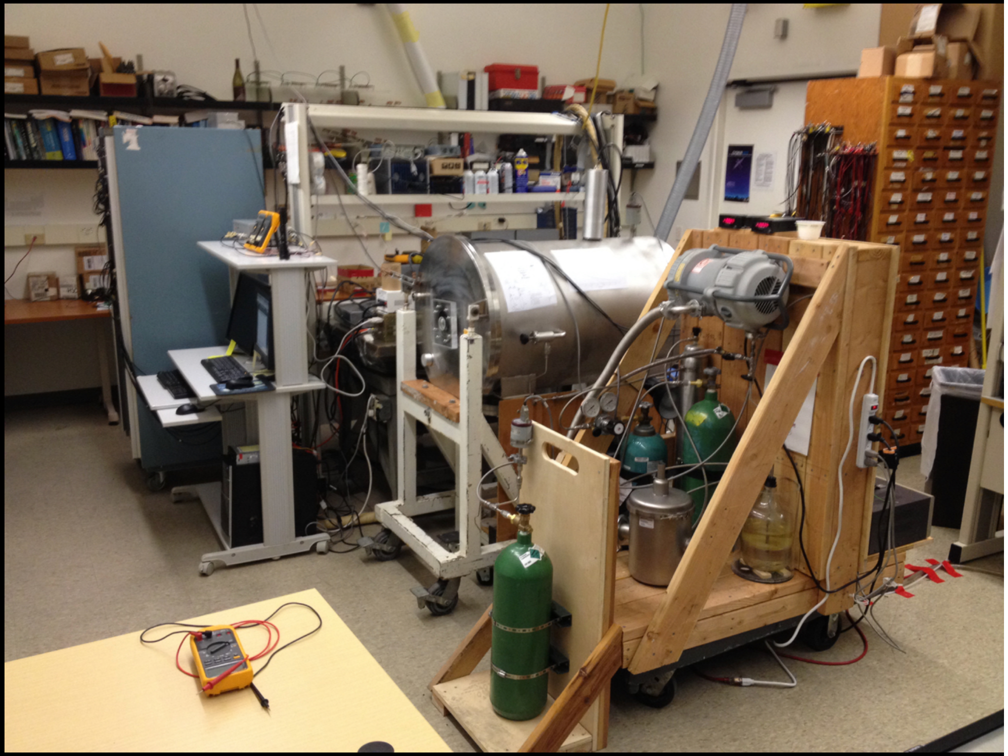
BDX-DRIFT - Sensitivity



Zero background assumed

Experimental Work

- BDX-DRIFT-0.3m
- Small and portable copy of DRIFT-IId
- Used to make surface measurements and benchmark cosmic ray simulations



SLAC Experiments

- ESTB aka ESA
- ~2 ft concrete overburden
- 3.8 days live time

- Tunnel to ESB
  - 20 ft dirt overburden
- 34.7 days live time

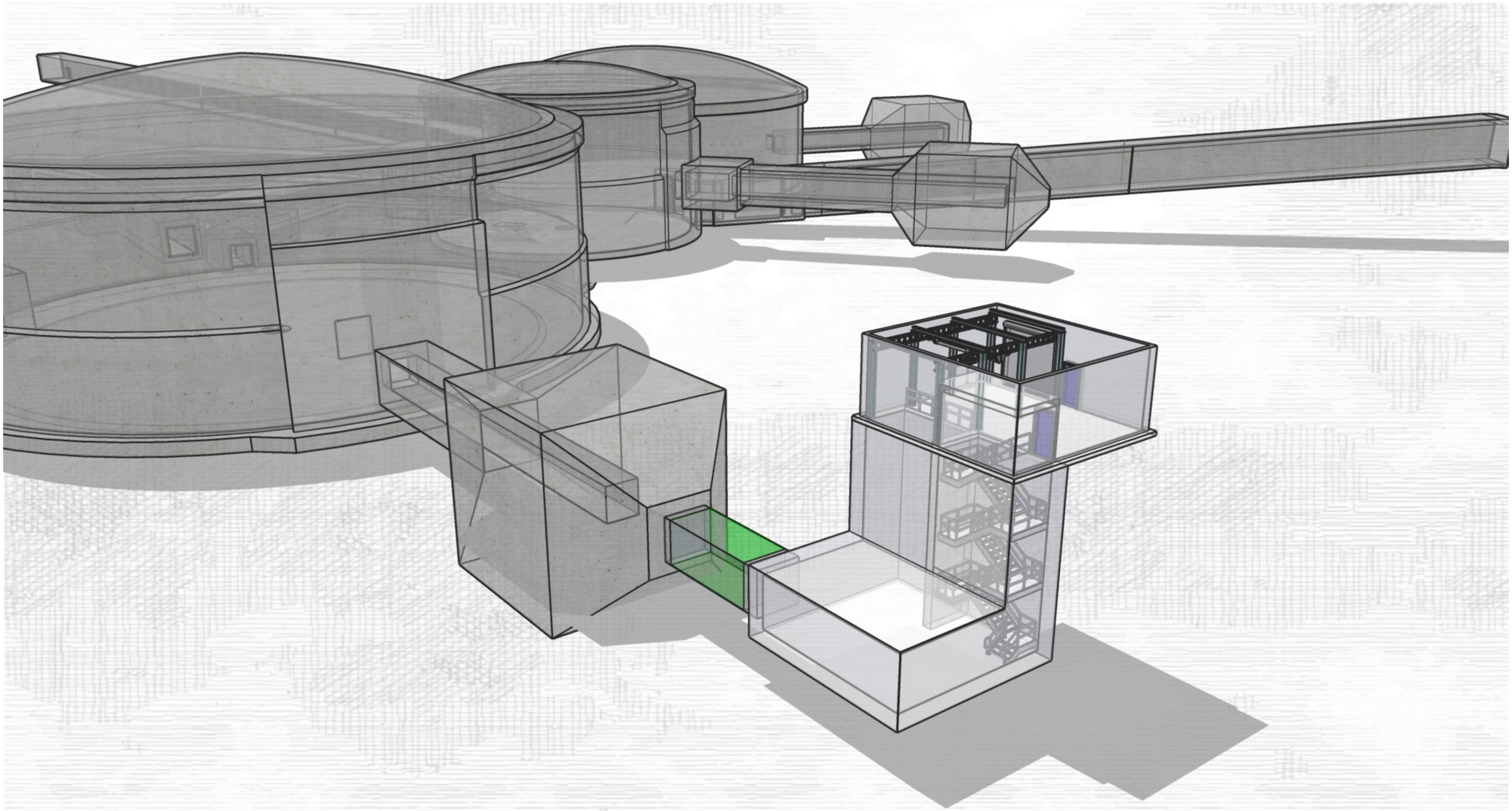
SLAC Results Agree with GEANT

Table 1 - Summary of Predicted (GEANT + Efficiency Map) and Experimental Results

Location	Cosmic-ray particle type	Predicted Rates (day^{-1})		Experimental Rates (day^{-1})
SLAC ESA	muon	0.38 +/- 0.01	3.8 +/- 0.1	3.4 +/- 0.9
	neutron	3.20 +/- 0.09		
	proton	0.17 +/- 0.02		
SLAC ESB	muon	0.13 +/- 0.01	0.14 +/- 0.01	0.23 +/- 0.08
	neutron	0.0037 +/- 0.0009		
	proton	0.00016 +/- 0.00008		

- Muon rate for these experiments was ~350,000 per day.
- Conclusion = BDX-DRIFT is sensitive only to nuclear recoils.
- We have a benchmarked code.

BDX-DRIFT at JLab



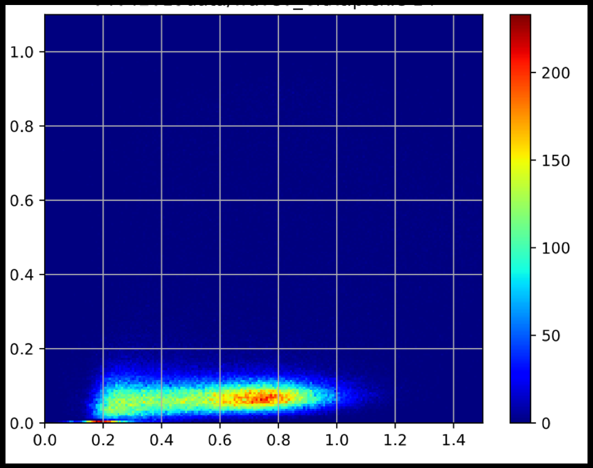
Muon-Neutron Veto

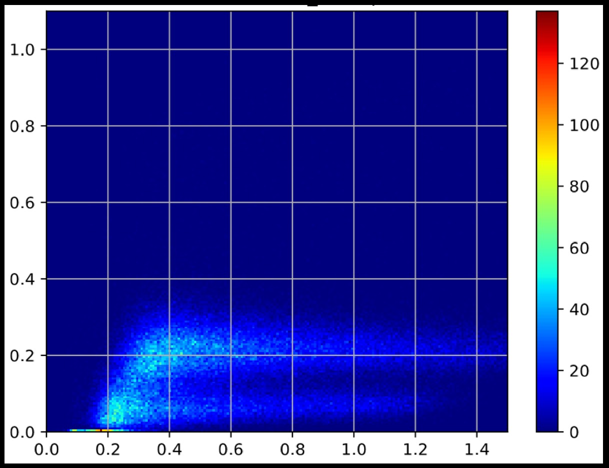
- Backgrounds due to neutrons produced by various sources are severe and therefore a muon-neutron veto (MNV) is required.
- We are investigating a MNV of liquid scintillator or water doped with B or Gd.
- For the proposal we assumed a Gd doped liquid scintillator, 75 cm thick, surrounding the vacuum vessel.
- GEANT simulations show a 99% rejection factor for neutrons causing recoils, similar to other studies.
- For muon backgrounds our research shows that 90% of the background recoils are caused by muon-induced neutrons AFTER the muon has traversed the veto, increasing our rejection factor to 99.9% for these backgrounds.
- As discussed in the proposal deadtime produced by the MNV is manageable by segregating events into two classes and applying different timing cuts in analysis.
- Time for R&D while underground hall is designed and constructed.

Veto Work at CSU

- Veto + Cf-252 n source
- Neutrons detected in liquid scintillator and H_20 + Gd

Cs-137 gammas





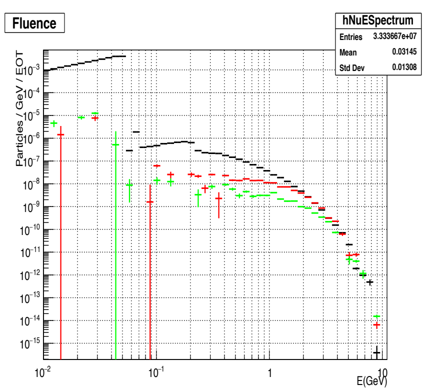
Cf-252 neutrons + gammas

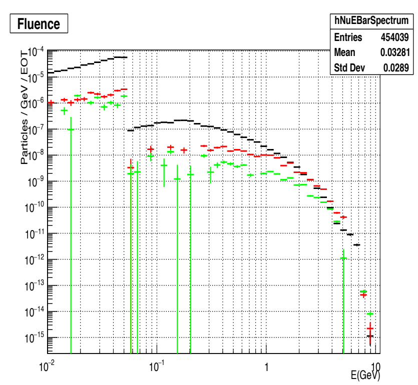
JLab Predictions

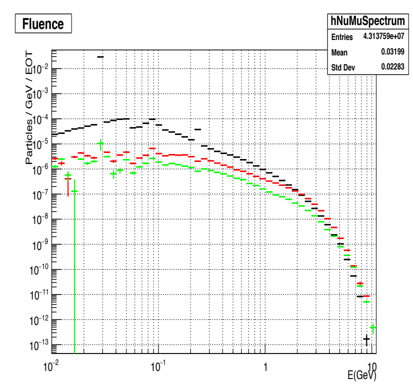
Table 2 - Summary of Background Estimates within 10 cm of the beamline			
Source	Particle	Veto Efficiency	N per 10^{22} EOT
Cosmic Rays	μ	99.9%	0.4
	n	99%	0.1
	p	99%	0.04
	Cosmic Ray Total		0.55
Beam	ν	0%	0.007
	μ	99.9%	0.009
	n	99%	0.09
	Beam total		0.1
Combined Total Background			0.7

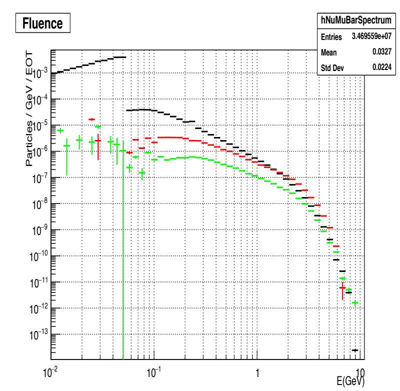
Neutrino Backgrounds

- We redid this calculation,
  - Utilizing the Fluka simulations by BDX, below, and scaling for geometry.
  - Including the target AND diffuser from MOLLER, as an example.
  - Including neutrino cross section energy dependence and recoil energy distribution.
  - We now get 0.05 events per 10^{22} EOT in the central 10 cm, up from 0.007.
- We have not included the effect of the MOLLER 1/r focusing magnets which could affect the neutrino background. This is being studied by the collaboration.

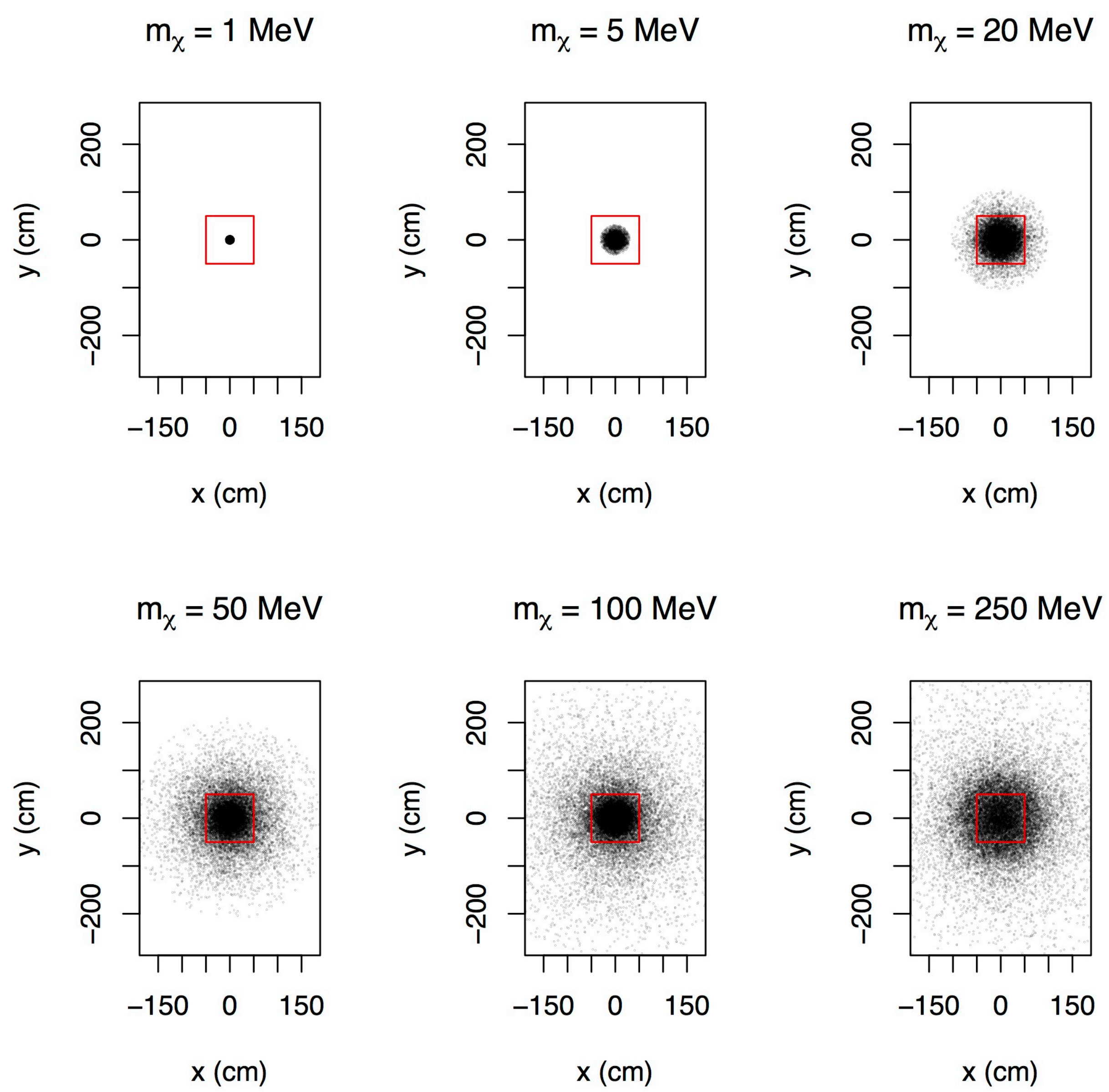






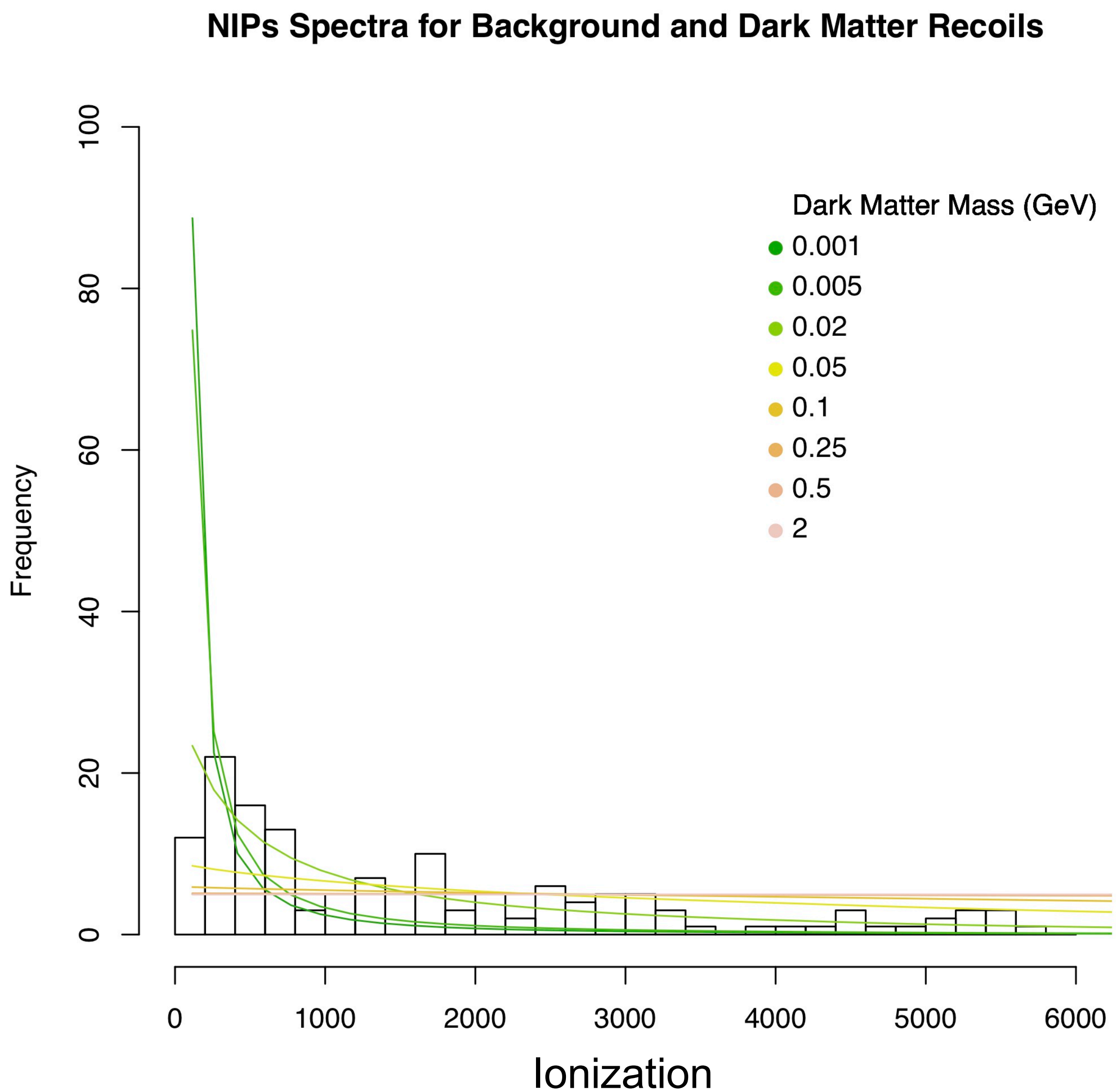


BDX-DRIFT Signatures – Position



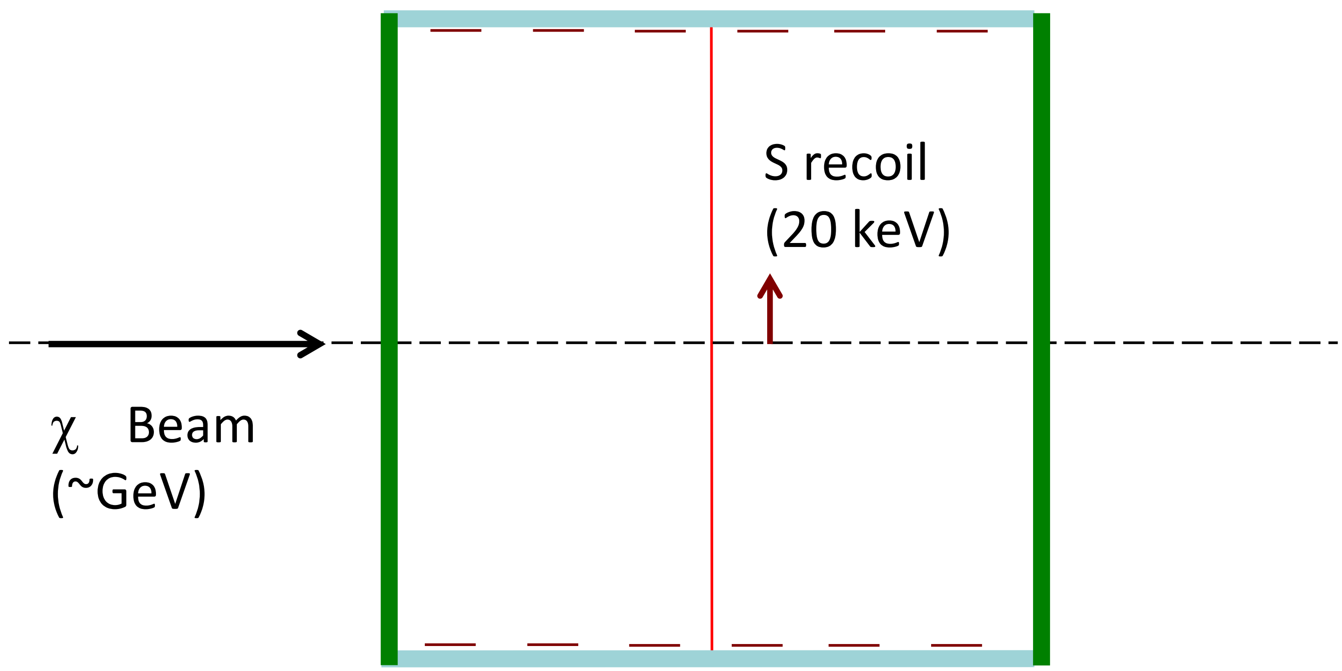
- Red box shows extent of the BDX-DRIFT detector
- Recoil distribution depends on m_χ
- Can be used to detect dark matter or reject background.
- Off-axis measurements could be made to reject ν backgrounds

BDX-DRIFT Signatures – Ionization

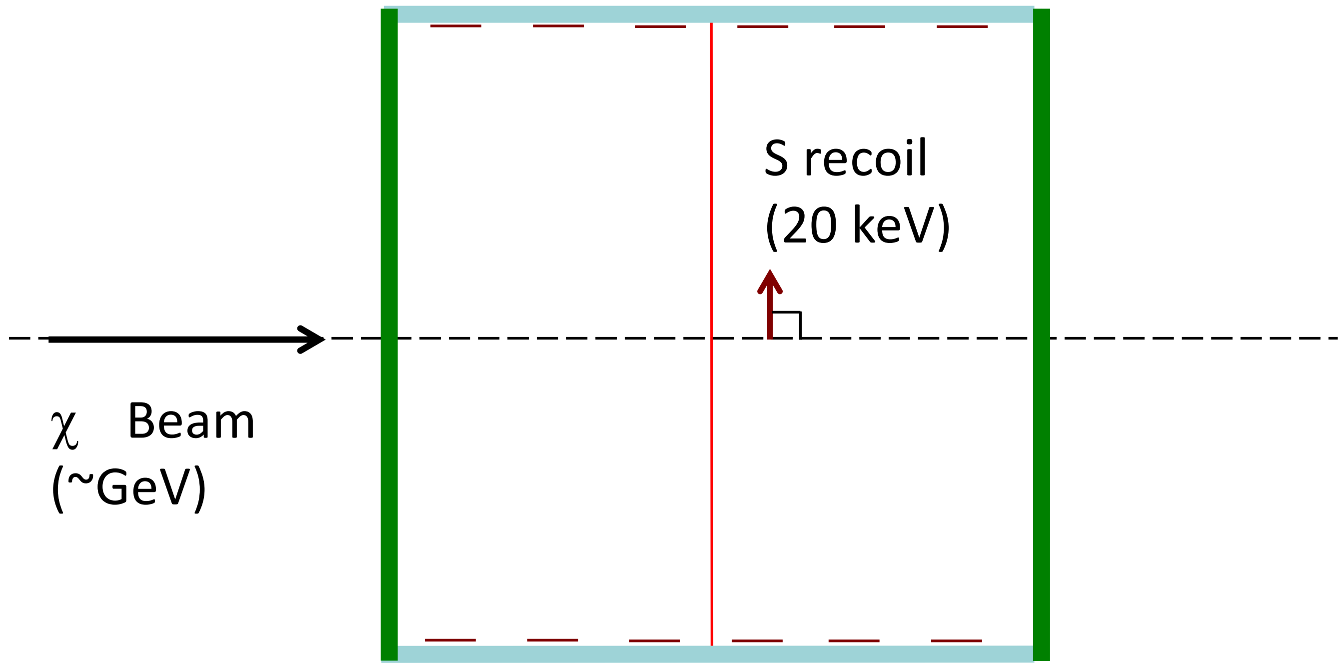


- Histogram shows background ionization distribution
- Colored curves indicate predicted ionization distribution from dark matter according to mass
- For most masses one could discriminate

BDX-DRIFT Signatures – Directional

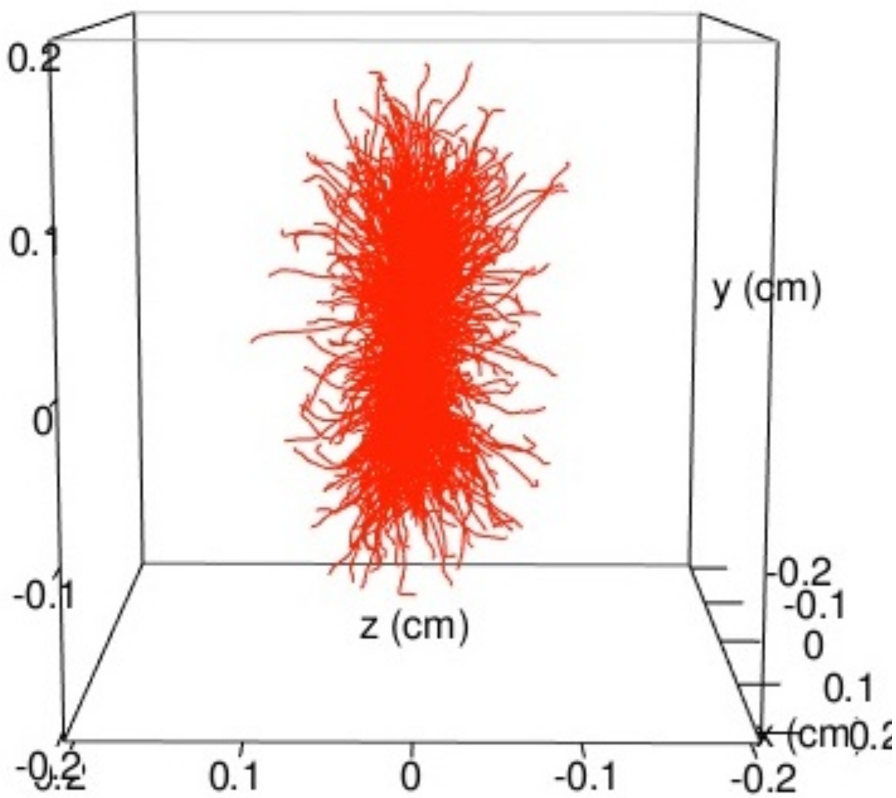


BDX-DRIFT Signatures – Directional

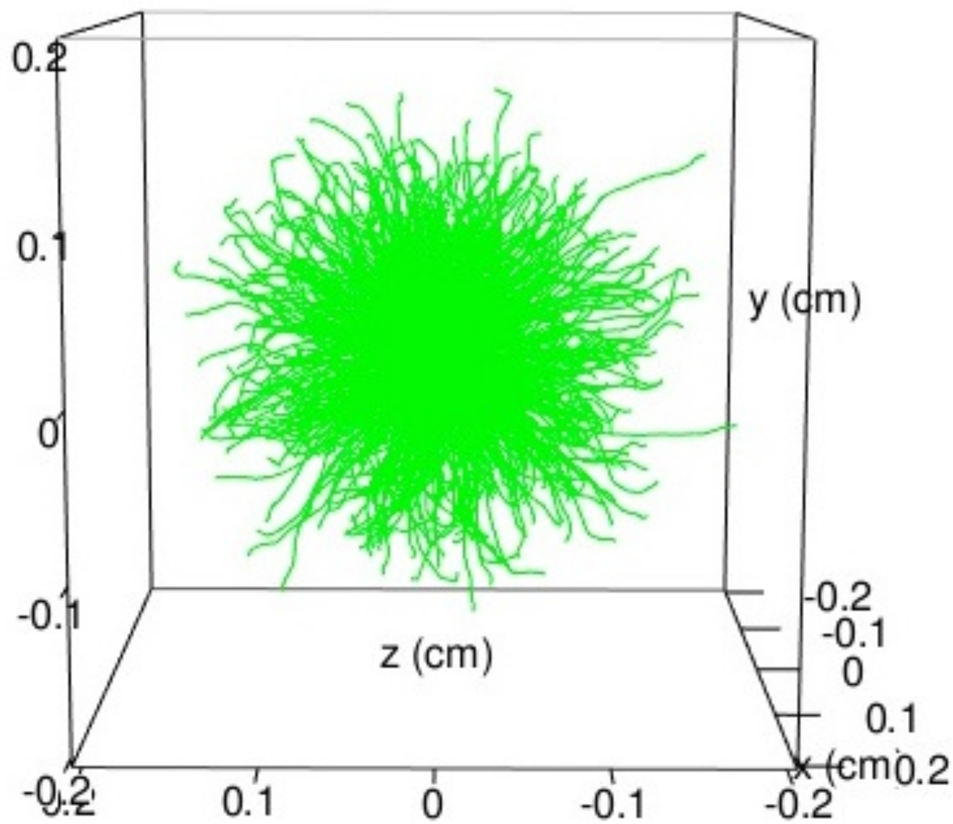


Directional Signal and Background

1,000 50 keV
signal events

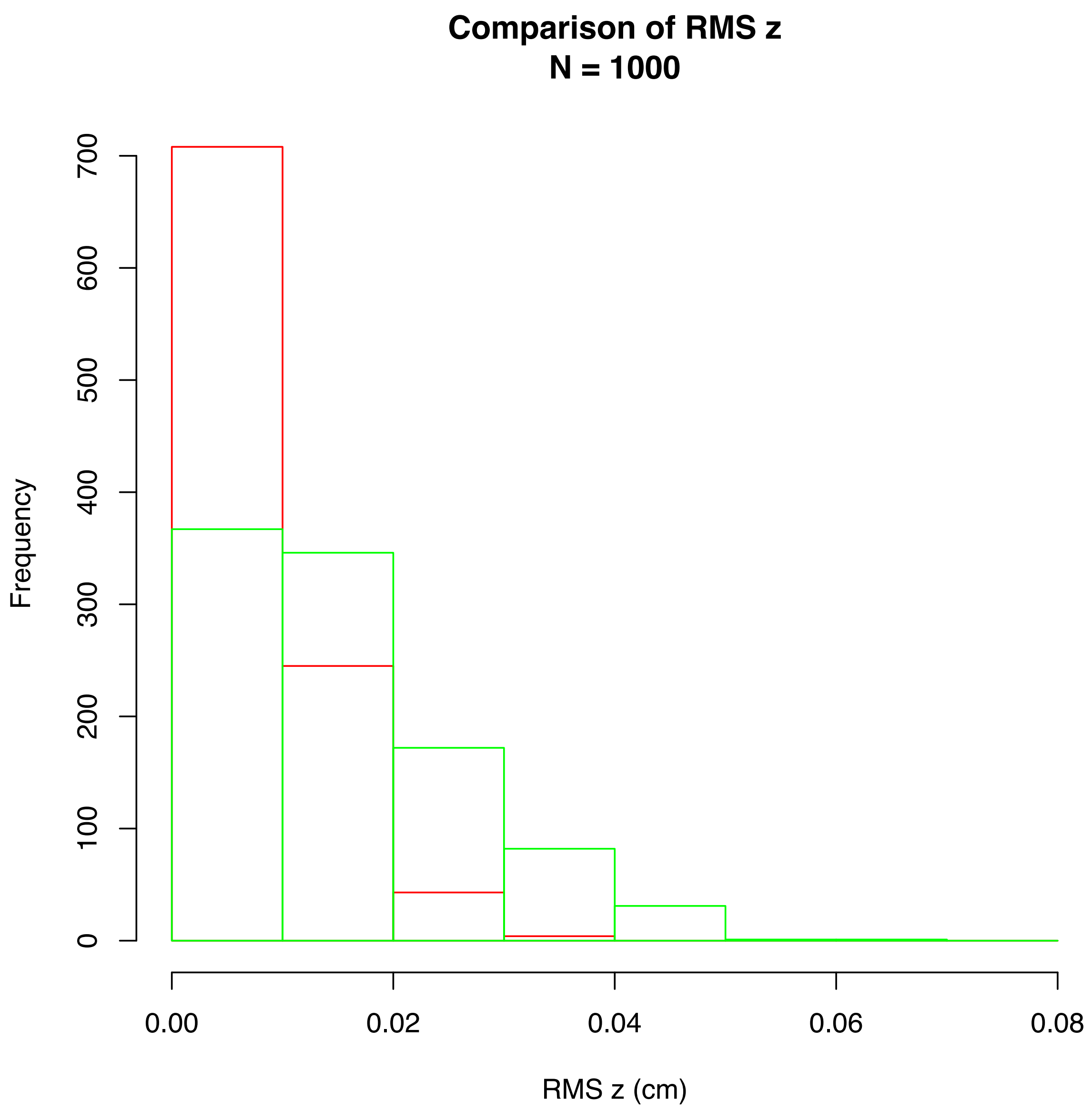


1,000 50 keV
background events

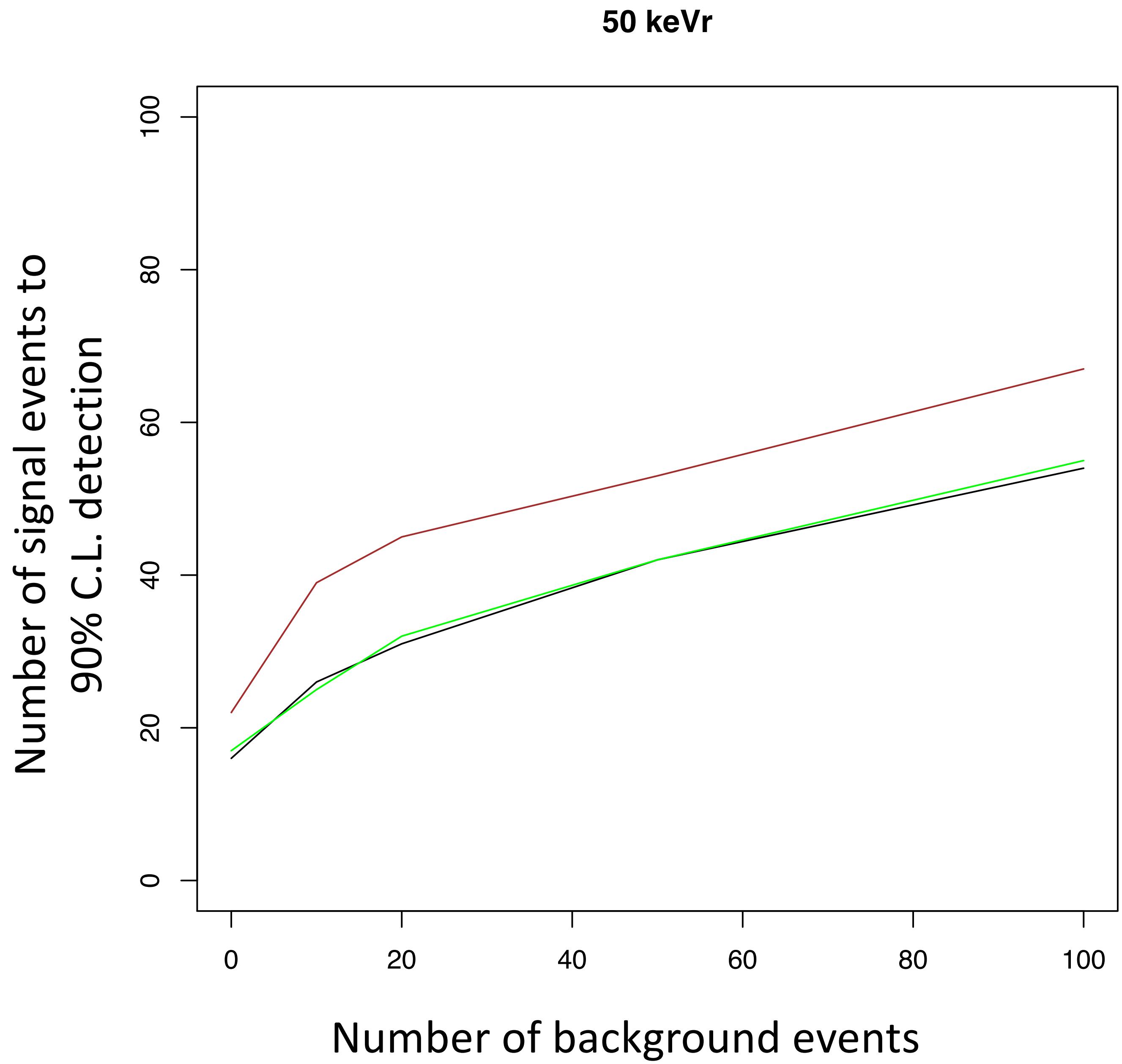


One of the easiest things to measure is the RMS in z.

Directional Signal vs Background



Pulling signal from background

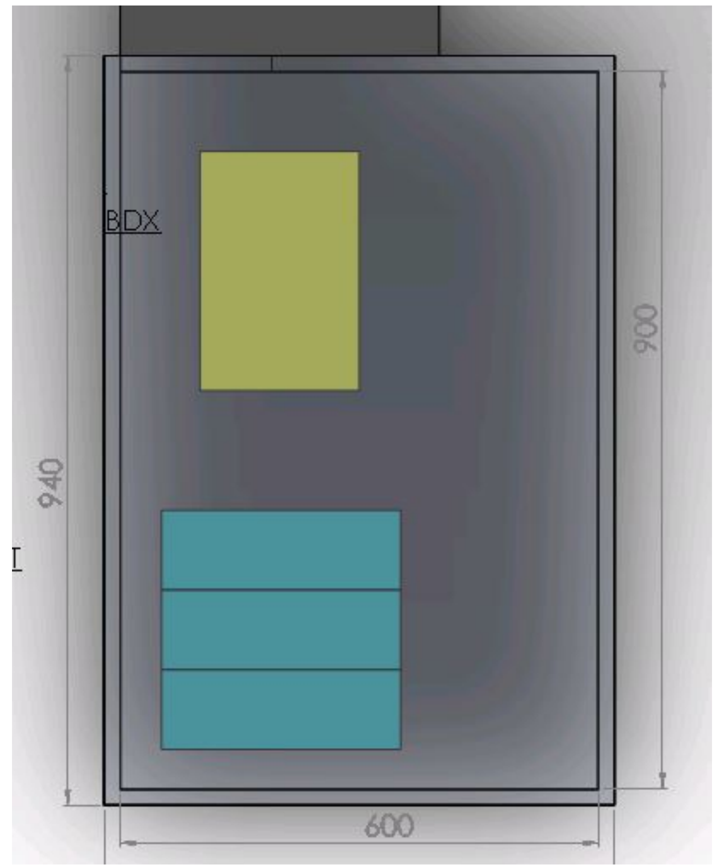


Other concerns

- As currently designed the underground facility could accommodate only a 1 m long BDX-DRIFT detector.

- BDX has a proposal in to the DOE's "Dark Matter New Initiatives" FOA to explore the design more fully. One focus of that effort would be to explore cost effective ways of increasing the available dark beam length.

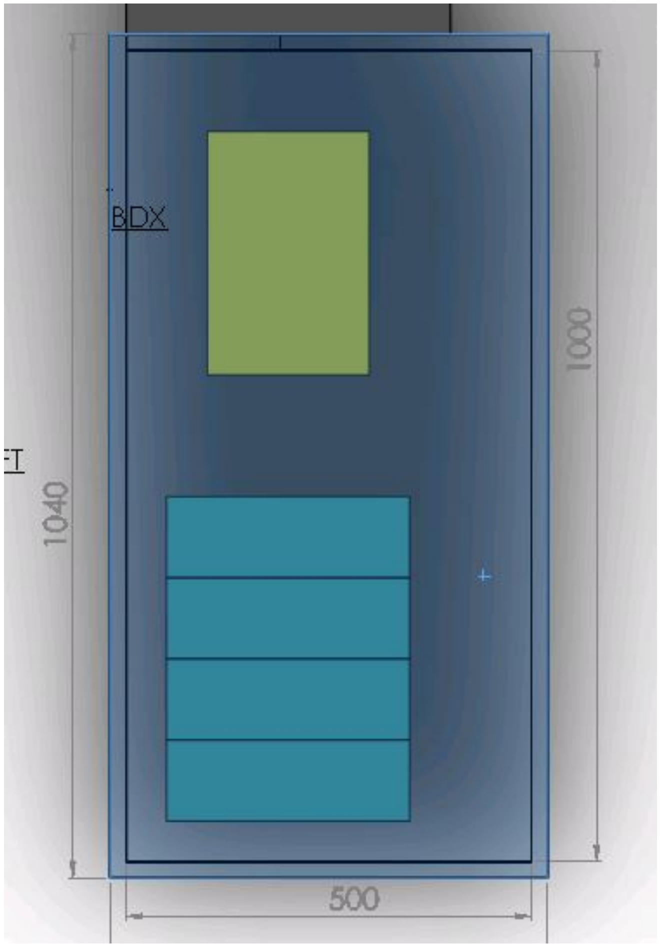
Current Plan
1 m



Other concerns

- Rearranging the available area would allow a 2 m long BDX-DRIFT detector.

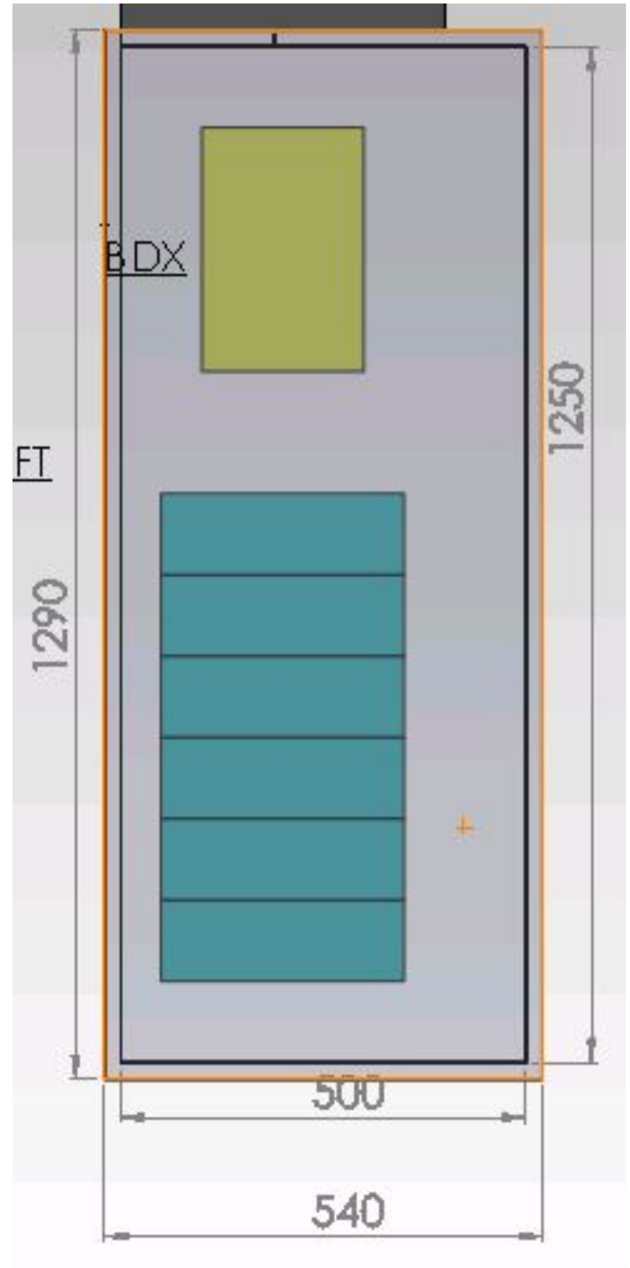
Same Area
2 m



Other concerns

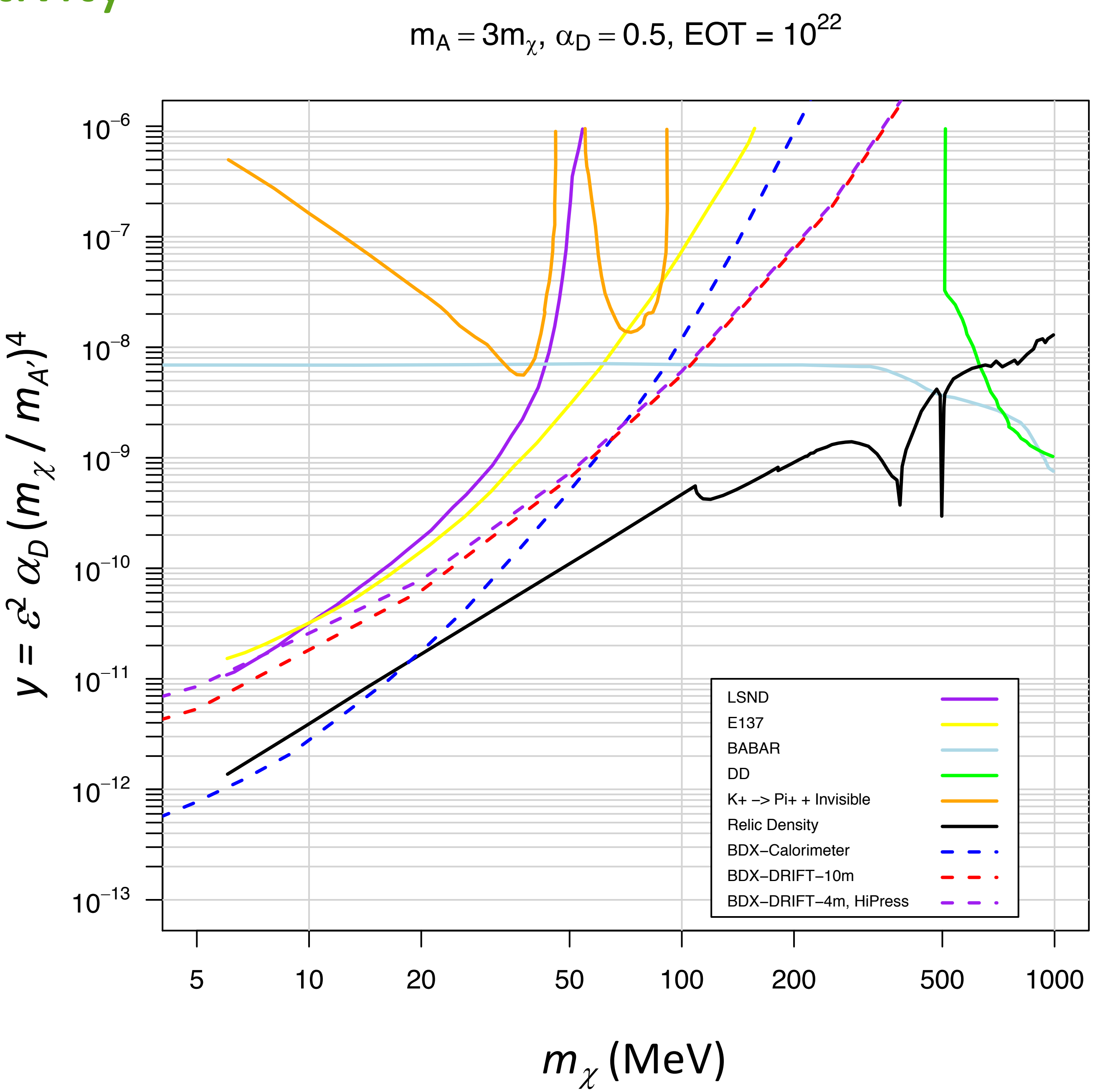
- Increasing the length of the excavation 15% would allow for a 4 m long BDX-DRIFT detector.

15% Longer Excavation
4 m



BDX-DRIFT - Sensitivity

In the event the design will only allow a shorter detector we could increase the pressure to compensate. This would require us to increase our threshold.



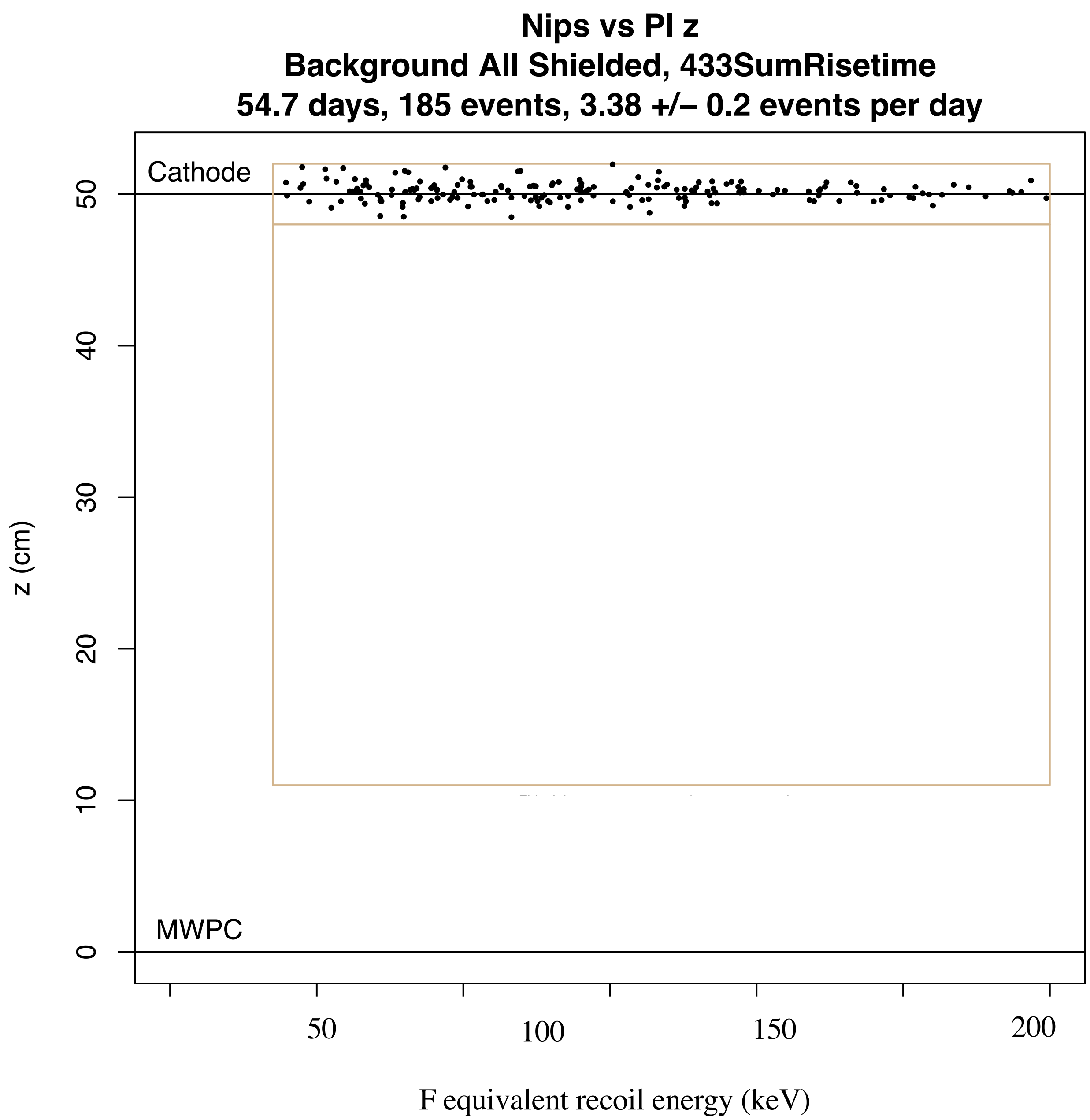
Conclusion

- BDX-DRIFT brings a unique, proven, halo-dark-matter detector to the search for light dark matter at accelerators.
- BDX-DRIFT proposes to run in parallel to the approved BDX experiment, with, again, no need for additional beam time.
- BDX-DRIFT will increase the reach of the BDX experiment.
- Backgrounds appear to be under control.
- Strategies are in place to mitigate risk.
- R&D can proceed in parallel with getting the beam dump facility constructed.
- It will add new, powerful signatures to the search for dark matter at Jlab making for robust detection if it is there.

The End

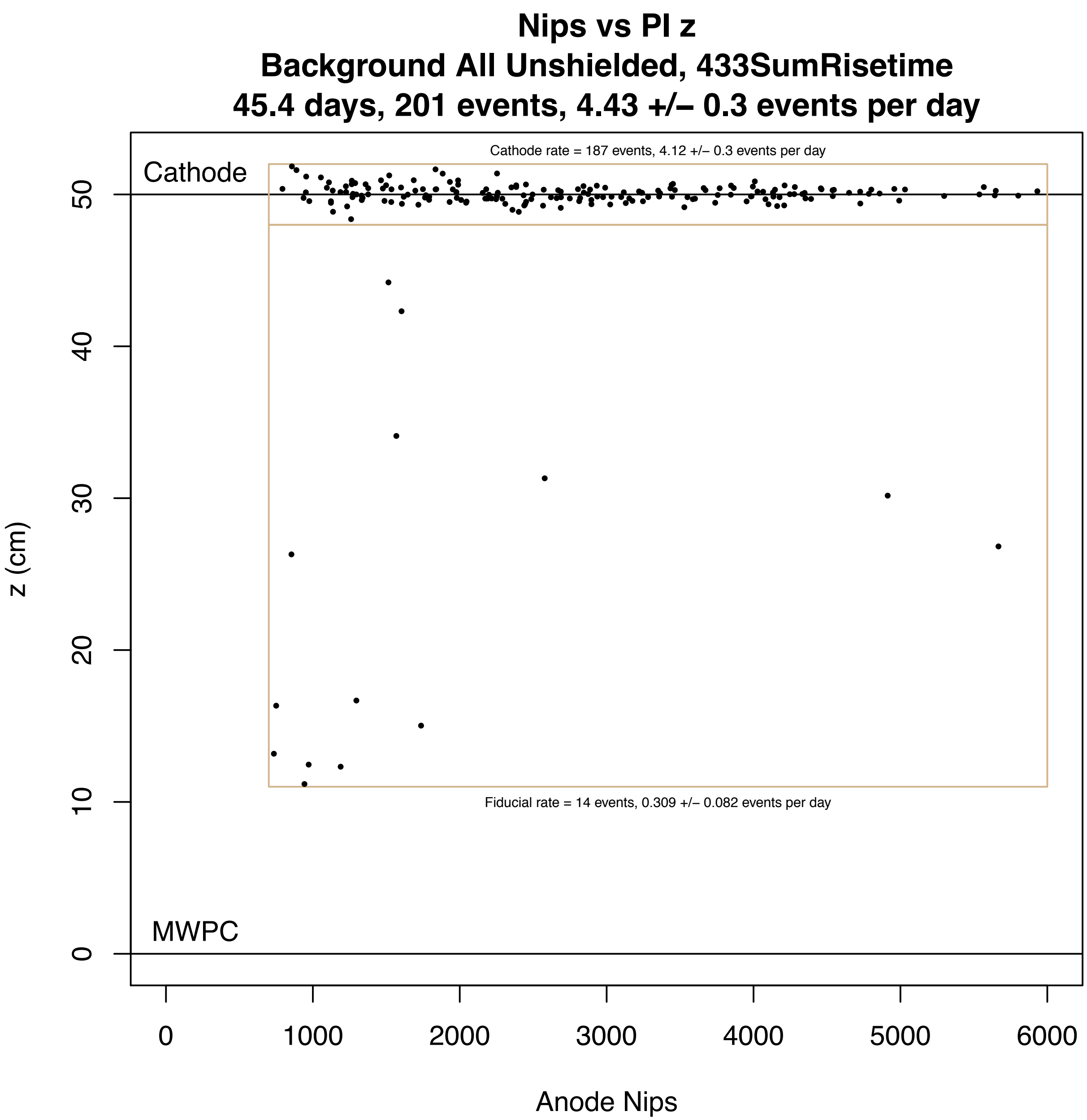
Extra Slides

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



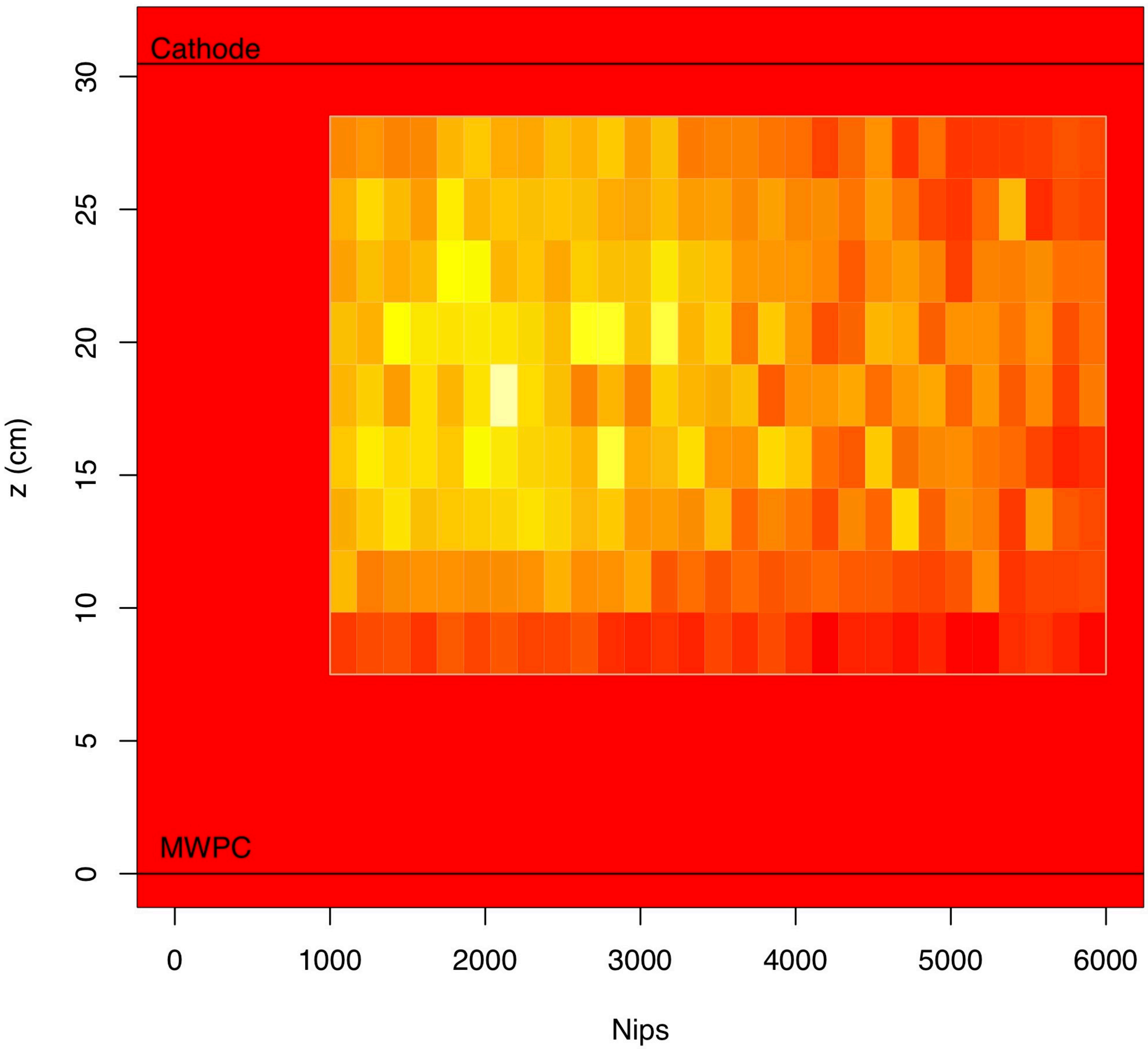
- 54.7 days of data taken in the Boulby Mine (~1 km underground) with poly shielding
- The events on the top are radon progeny recoils and low energy alphas emanating from the cathode
- No events were found in the fiducial region below = background free

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

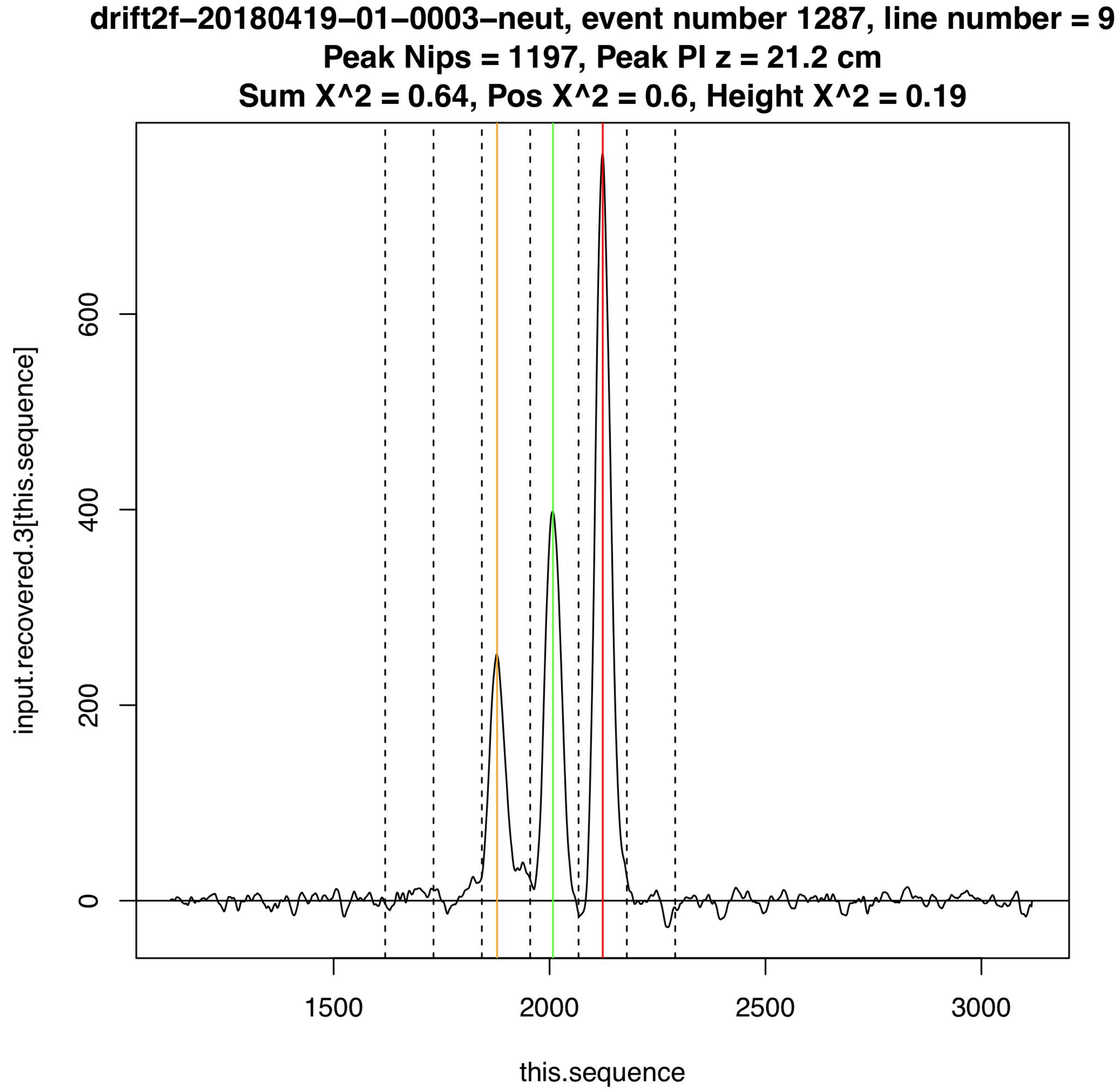


- 45.5 days of data taken with poly shielding **removed**
- The rate of events in the fiducial region matches a GEANT MC of neutrons emanating from the cavern walls

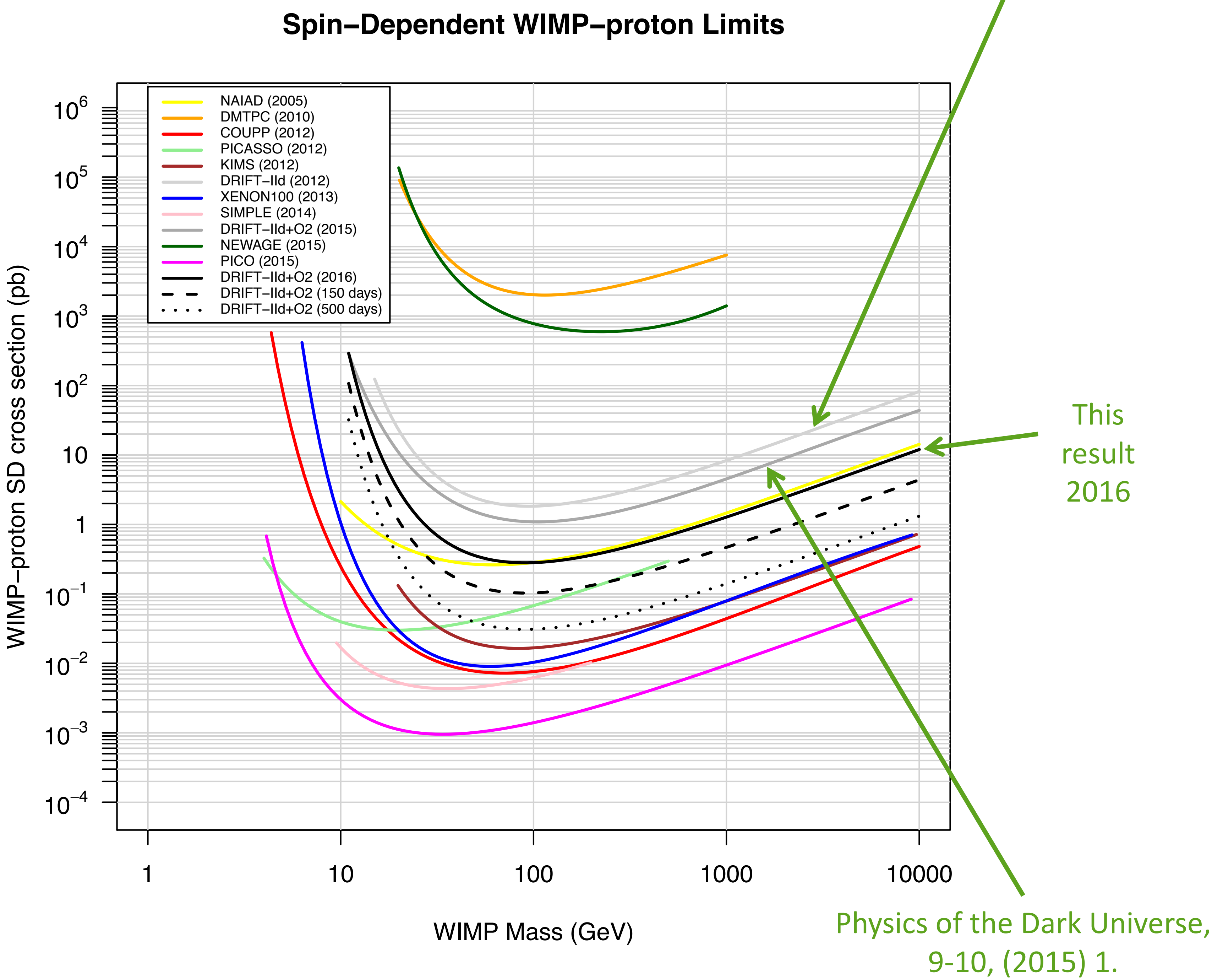
Efficiency Map from ESA Neutron Calibrations



Example Minority Carrier Event

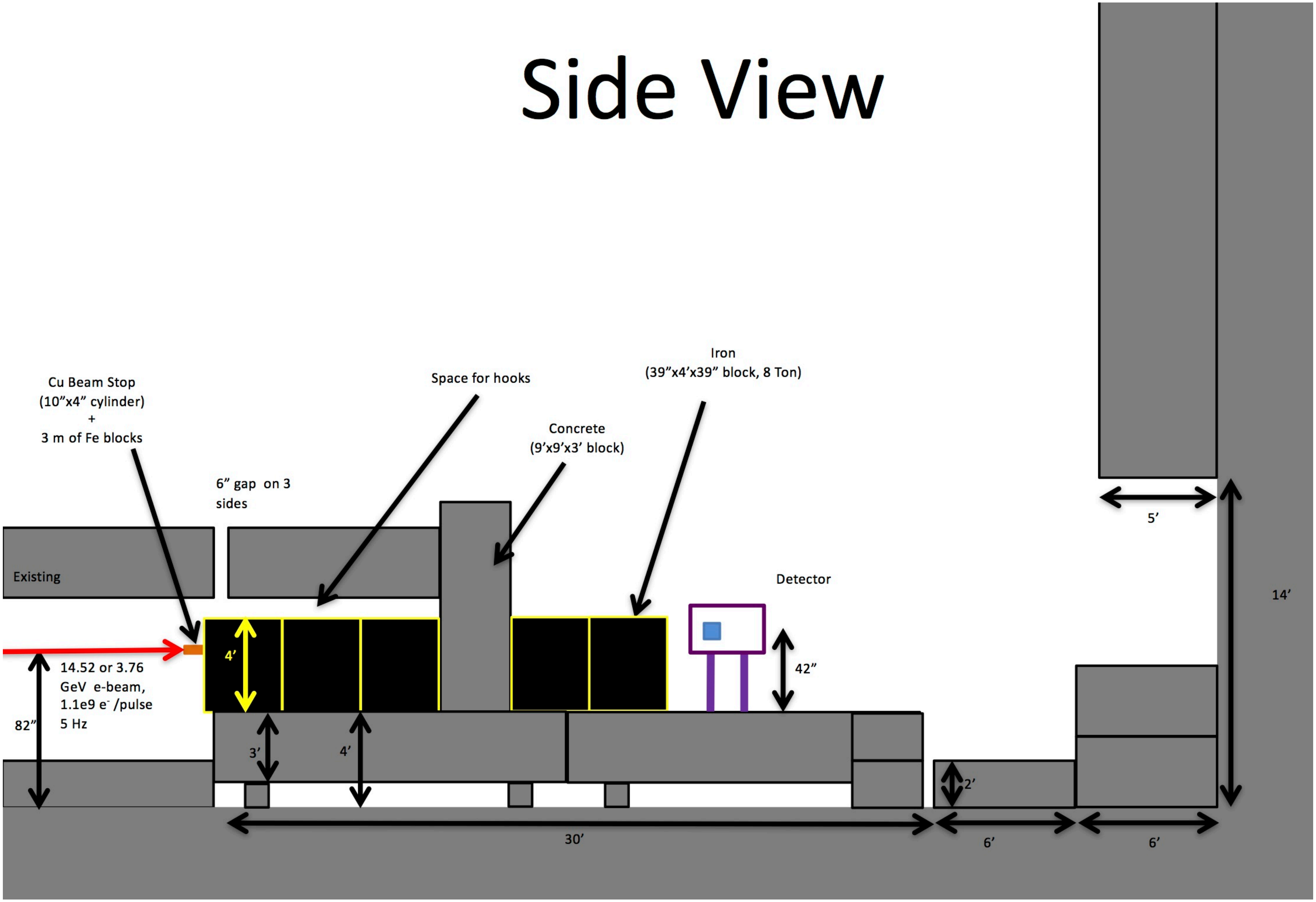


SD Limits



Spin−Dependent WIMP−proton Limits
NAIAD (2005)
DMTPC (2010)
COUPP (2012)
PICASSO (2012)
KIMS (2012)
DRIFT−IId (2012)
XENON100 (2013)
SIMPLE (2014)
DRIFT−IId+O2 (2015)
NEWAGE (2015)
PICO (2015)
DRIFT−IId+O2 (2016)
DRIFT−IId+O2 (150 days)
DRIFT−IId+O2 (500 days)
WIMP−proton SD cross section (pb)
WIMP Mass (GeV)
1
10
100
1000
10000
AstroPle, 35, (2012) 397.
This result 2016
Physics of the Dark Universe, 9-10, (2015) 1.

Initial Tests – SLAC Beam Run



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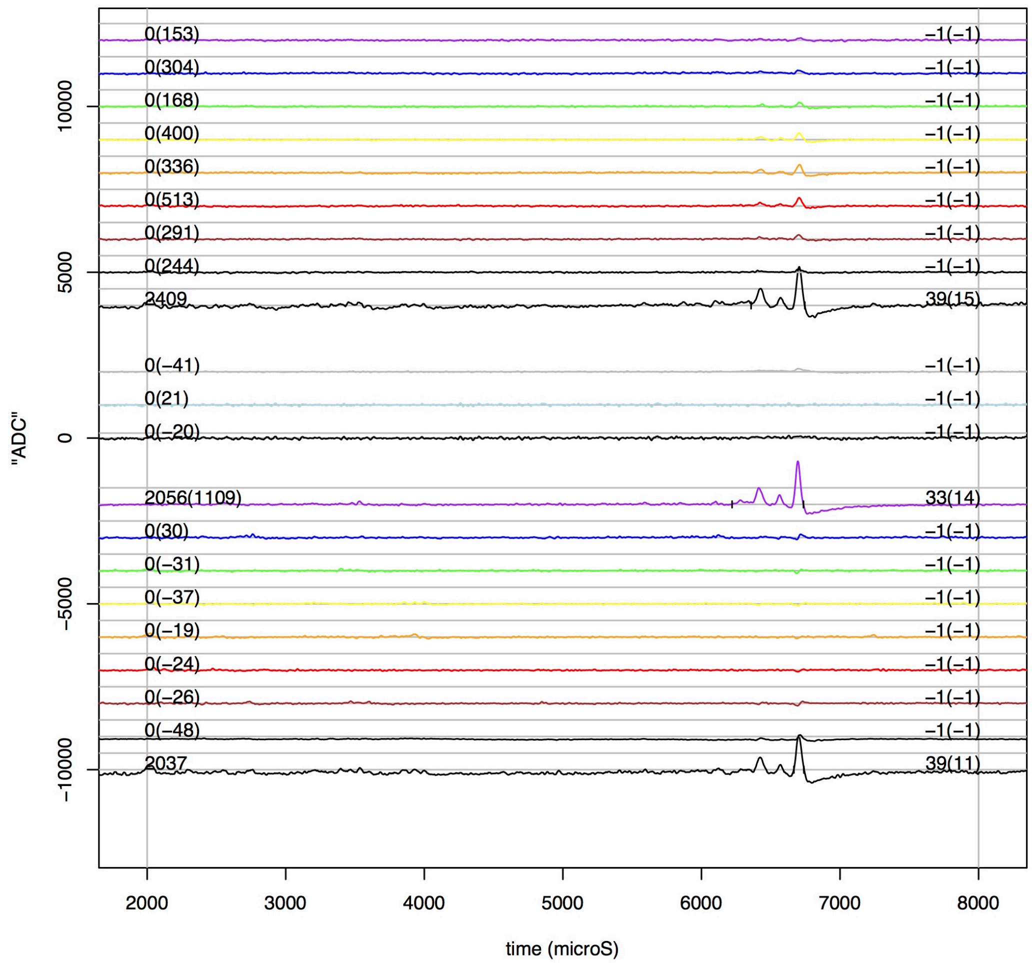

- Despite a crack in the shielding and an associated gamma flash, the performance of the detector was nominal. *You can operate a low-pressure TPC within 6 m of a beam-dump, even with poor shielding, at a nominal trigger rate.*