Taking DRIFT to the Limit

Directional Recoil Identification From Tracks

DRIFT Collaboration

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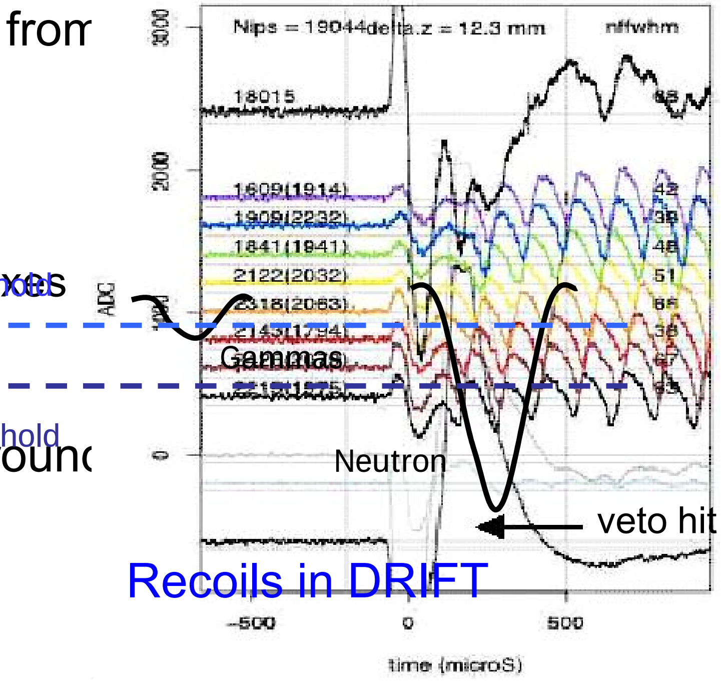
Introduction

- Advantage of TPC - offers directional capabilities
- Focus on sensitivity reach of current technology
- Unwanted interactions disregarded
- WIMP signature virtually indistinguishable from
- Neutron rates crucial
- Mine environment extensively studied
  - Cosmic ray rates
  - Direct measurement of ambient neutron fluxes
  - Mass spectrometry of rock samples
  - Monte Carlo simulations of event rates
- Determine lowest possible neutron background
- Simulation of proposed setup
  - Passive shielding
  - Active neutron veto system

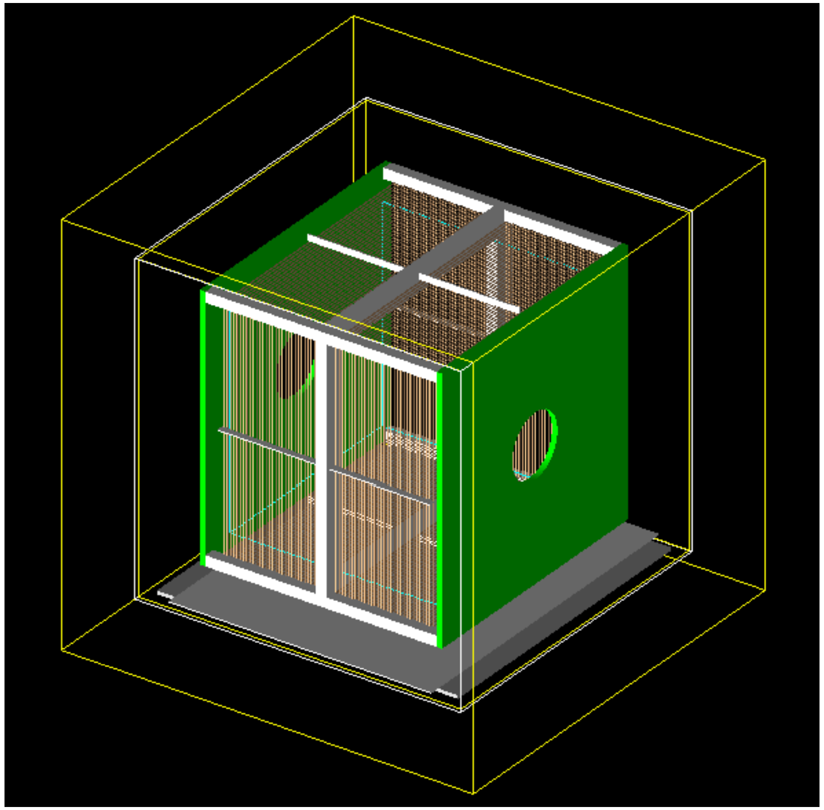


Alpha event in DRIFT

What is being simulated?

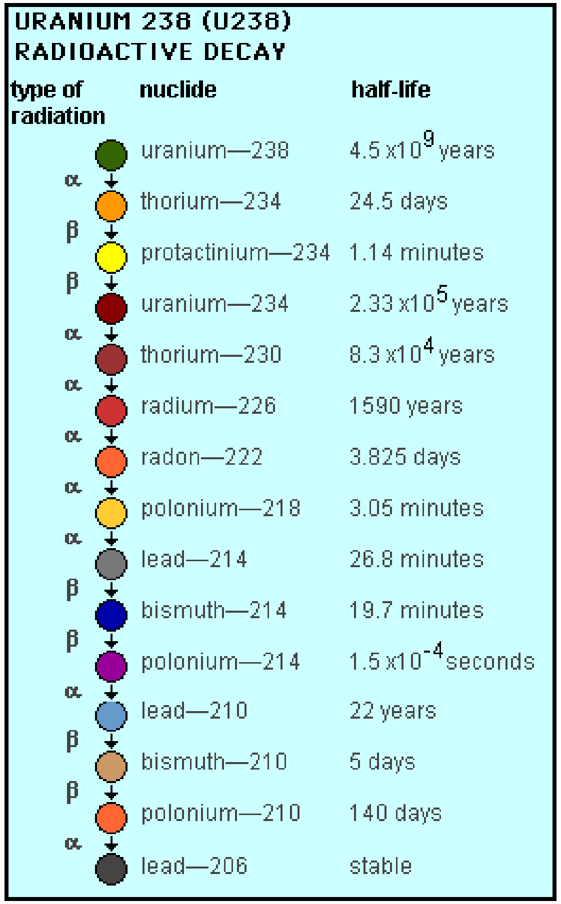
- DRIFT module inside 1.5m^3 stainless steel vessel:
  - 1m^3 fiducial volume: 167g of 40 Torr CS_2
  - Field rings
  - Skate plate
  - All plastic: MWPC strong backs, field ring combs, corner posts, HHV shielding….
- 20cm thickness of enriched boron loaded liquid scintillator (BC-523-A) surrounds vessel.
- 2m thick water shielding

  → Dominant source of background neutrons remaining comes from detector vessel.



Neutron Production

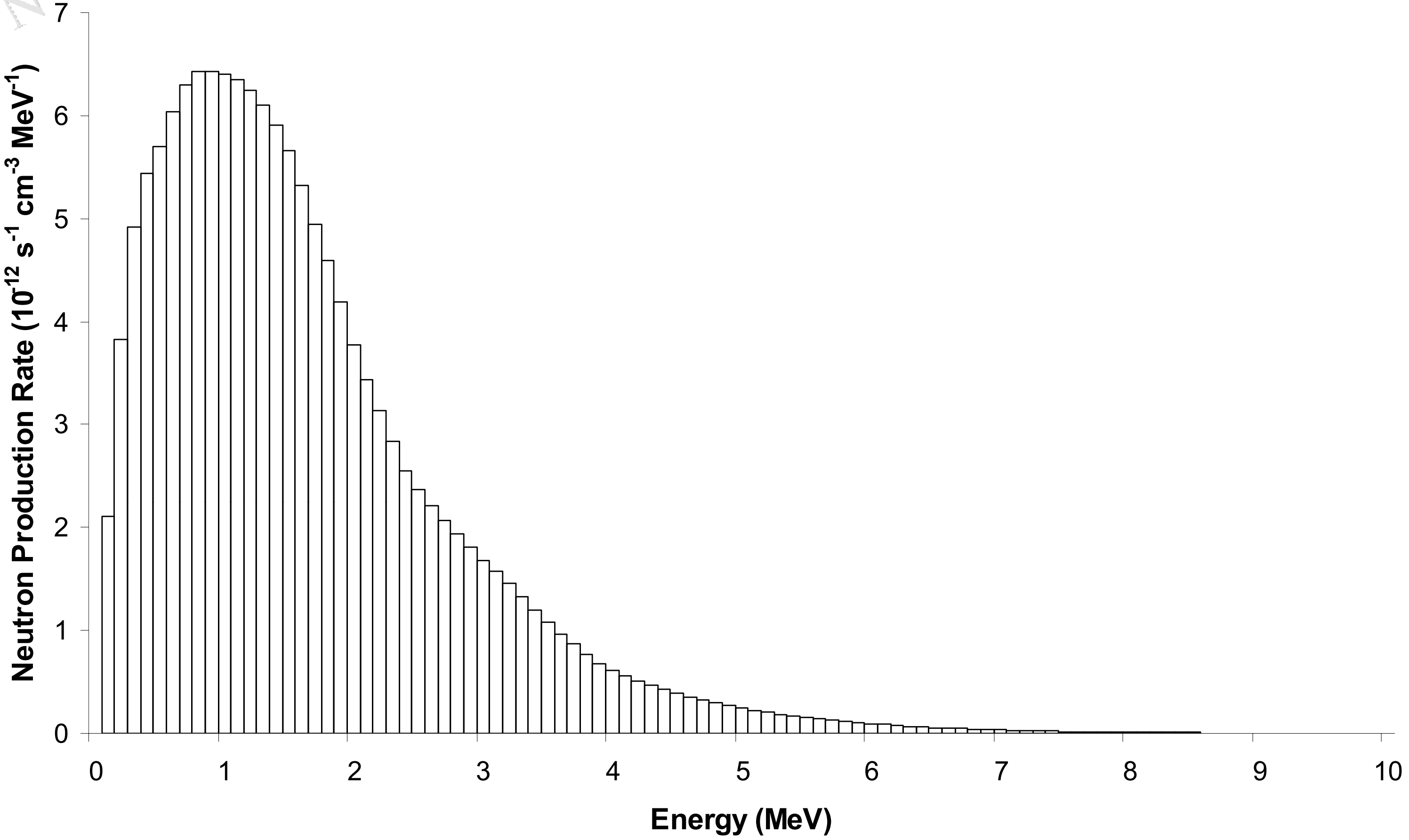
- U & Th decay in steel gives rise to (alpha,n) reactions.
- Neutron spectra for 1 ppb U and 1 ppb Th produced using SOURCES
- Steel density 8.027 g/cm^3
- 1ppb U → 1.474 × 10^{-10} neutrons/sec/cm^3
- 1ppb Th → 5.164 × 10^{-11} neutrons/sec/cm^3
- Total neutron production = 2.5 × 10^{-11} neutrons/sec/g



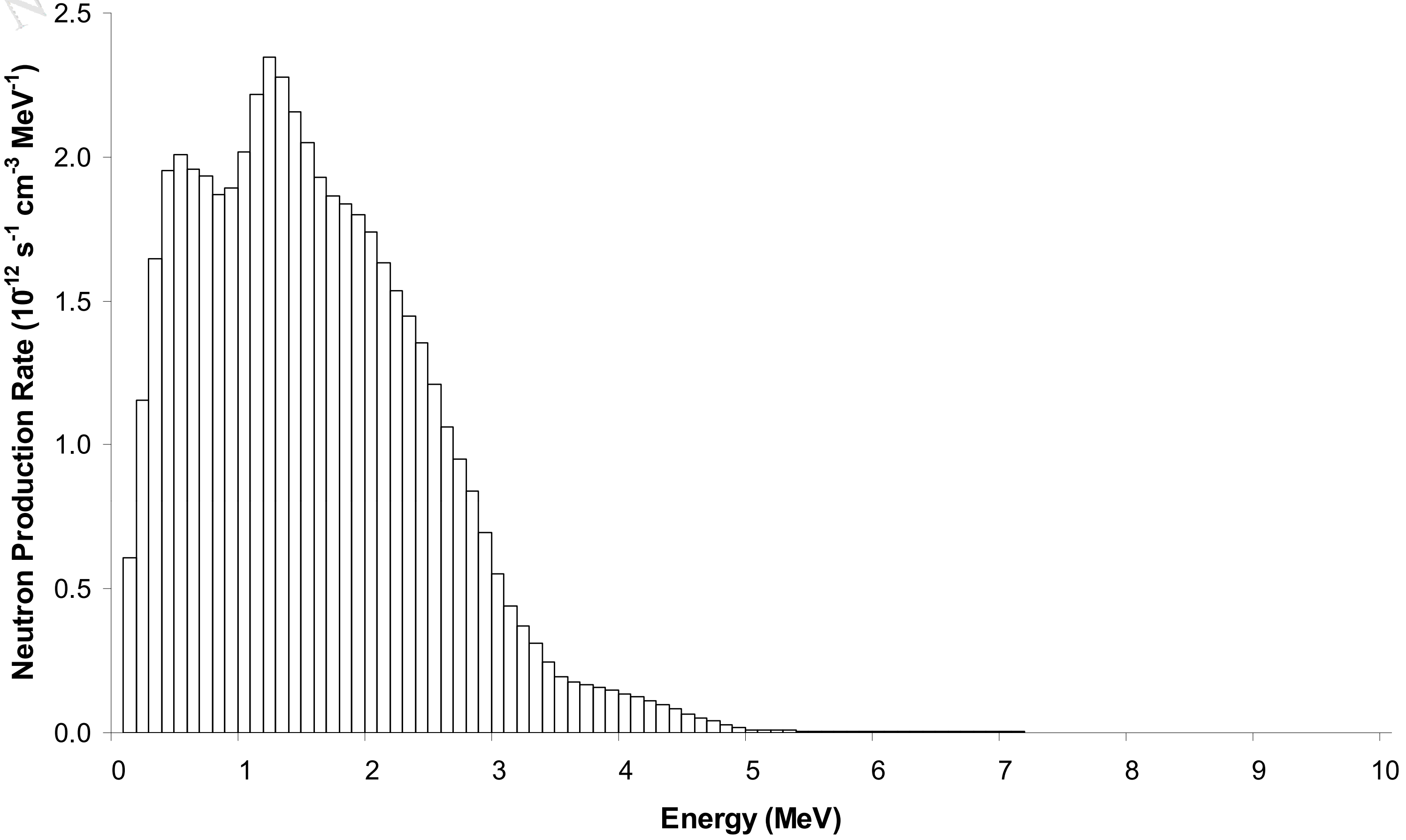
URANIUM 238 (U238)
RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium—238	4.5 x10^9 years
α		
	thorium—234	24.5 days
β		
	protactinium—234	1.14 minutes
β		
	uranium—234	2.33 x10^5 years
α		
	thorium—230	8.3 x10^4 years
α		
	radium—226	1590 years
α		
	radon—222	3.825 days
α		
	polonium—218	3.05 minutes
α		
	lead—214	26.8 minutes
β		
	bismuth—214	19.7 minutes
β		
	polonium—214	1.5 x10^{-4} seconds
α		
	lead—210	22 years
β		
	bismuth—210	5 days
β		
	polonium—210	140 days
α		
	lead—206	stable

Neutron Production From U



Neutron Production From Th



Simulated FV Rate

Geant4 simulation:

- Carbon + Sulphur Events
- 1ppb U
  → 8.56 × 10^6 neutrons fired
- 1ppb Th
  → 3 × 10^6 neutrons fired

NB only half (~867kg) volume of steel in simulation
→ 2.19 x neutron production in real life vessel

Reports indicate 0.6ppb U, 0.7ppb Th partially offsetting this factor

- Defines minimum background levels achievable using present day technology

Threshold (NIPs / keV (C) / keV (S))			**Nuclear recoil event rate (C / S / Total) (events kg^{-1} day^{-1})**			**Error (%)**
0	0	0	1.7×10^{-3}	1.4×10^{-3}	**3.1×10^{-3}**	2
20	0.7	1.1	5.7×10^{-4}	8.5×10^{-4}	**1.4×10^{-3}**	3
100	3.3	5.6	4.8×10^{-4}	6.7×10^{-4}	**1.2×10^{-3}**	3
500*	16	27	3.6×10^{-4}	2.9×10^{-4}	**6.5×10^{-4}**	4
1000	32	48	3.0×10^{-4}	1.9×10^{-4}	**4.8×10^{-4}**	4
1500	42	62	2.5×10^{-4}	1.4×10^{-4}	**4.0×10^{-4}**	5
2000	52	78	2.4×10^{-4}	1.1×10^{-4}	**3.5×10^{-4}**	5
2500	65	95	2.0×10^{-4}	9.5×10^{-5}	**3.0×10^{-4}**	6
3000	79	111	1.9×10^{-4}	7.5×10^{-5}	**2.6×10^{-4}**	6
3500	93	127	1.6×10^{-4}	6.2×10^{-5}	**2.2×10^{-4}**	7
4000	107	144	1.5×10^{-4}	5.2×10^{-5}	**2.0×10^{-4}**	7
4500	120	160	1.4×10^{-4}	3.9×10^{-5}	**1.7×10^{-4}**	7
5000	134	176	1.2×10^{-4}	3.0×10^{-5}	**1.5×10^{-4}**	8
5500	148	192	1.0×10^{-4}	2.2×10^{-5}	**1.2×10^{-4}**	9
6000	162	209	9.2×10^{-5}	1.7×10^{-5}	**1.1×10^{-4}**	10

* 500 NIPs = ~16 keV for Carbon recoils, ~ 27 keV for Sulphur recoils

Vetoed Events - Effect of Scintillator Threshold

20cm scintillator, quenching factor 0.4, Carbon + Sulphur Events

Fiducial volume threshold (NIPs)	**Percentage of events in the fiducial volume also having an event above threshold (as indicated) in the veto**			
	0 keV	**50 keV**	**100 keV**	**500 keV**
0	95.38	92.57	90.70	79.66
20	96.41	93.93	92.34	84.21
100	97.03	95.07	93.46	85.47
500	97.30	96.10	94.90	87.41
1000	97.58	96.37	95.77	89.11
1500	97.55	96.32	95.59	89.46
2000	97.18	95.77	95.49	89.01
2500	97.06	96.08	95.75	90.20
3000	97.03	95.91	95.54	90.71
3500	96.51	96.07	95.63	92.58
4000	97.07	96.59	96.10	92.68
4500	97.19	96.63	96.07	92.70
5000	96.69	96.03	95.36	92.72
5500	96.03	95.24	94.44	92.86
6000	96.40	95.50	94.59	92.79

What does un-vetoed rate mean?

500 NIPs in FV, 50 keV scintillator threshold

- 20cm scintillator >96% neutron events tagged

  Simulated geometry gives un-vetoed rate of

  ➢ $1.53 \times 10^{-3} \pm 20\%$ events/module/year

  Simulation has less than half true volume of steel. For real vessel expect

  ➢ $3.35 \times 10^{-3} \pm 20\%$ events/module/year

  Target mass required to leave 1 un-vetoed event/year

  ➢ 50 kg = 300 modules at 40 Torr running for 1 year

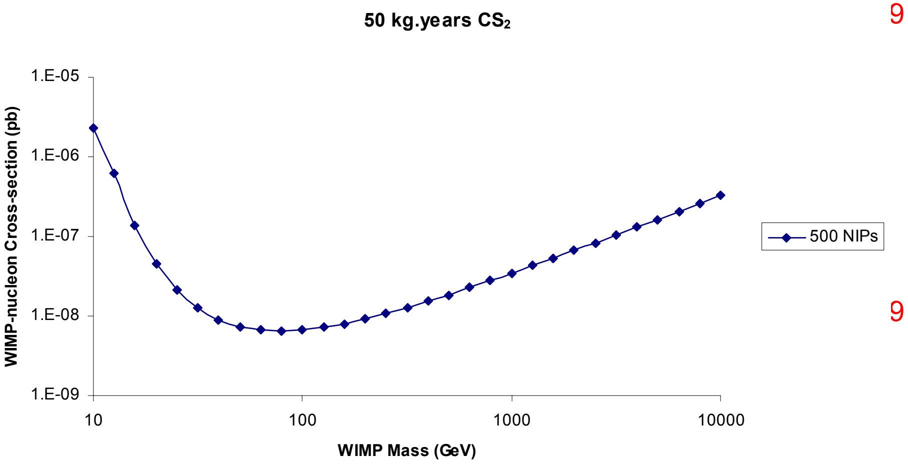
  M ^{9} pb

- 30cm scintillator

  Target mass requ

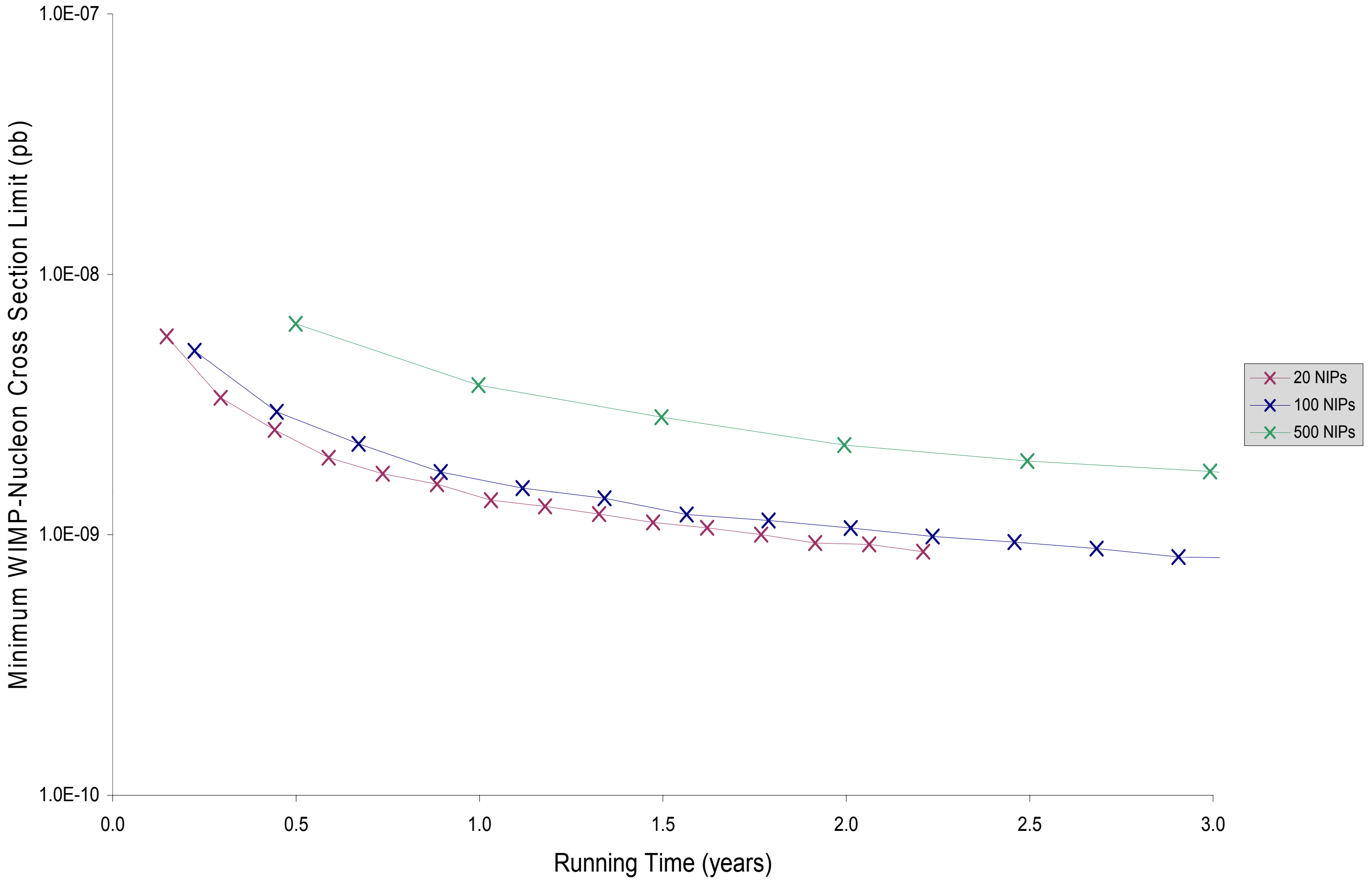
  ➢ 72 k

  M ^{9} pb



Limits for varying NIPs in FV

20cm scintillator (50 keV threshold), 100kg CS_2 = 600 modules



Sensitivity

- Sensitivity limit ultimately determined by mass of CS_2 and running time but background rate does worsen limit
- CS_2 detector at 500 NIP threshold for 300 kg.years with zero background

  → 8×10^{-10} pb
- DRIFT-type detector at 500 NIP threshold for 300 kg.years with a 20cm thick veto scintillator (six background events)

  → 1.75×10^{-9} pb
- Proposed veto system approaches fundamental limit
- What prevents further improvements?

What happens to untagged neutrons?

			Number un-vetoed events that terminate in:		
	Number of nuclear recoil events				
Threshold of fiducial volume (NIPs)	In fiducial volume	In fiducial volume and not seen in veto	plastic	vessel	Other*
0	3161	235	82	96	57
20	1450	88	24	36	28
100	1177	58	19	24	15
500	667	26	8	9	9
1000	496	18	6	6	6
1500	408	15	4	5	6
2000	355	15	4	5	6
2500	306	12	3	4	5
3000	269	11	3	4	4
3500	229	9	3	3	3
4000	205	7	2	3	2
4500	178	6	1	3	2
5000	151	6	1	3	2
5500	126	6	1	3	2
6000	111	5	1	3	1

* mainly skate plate, also field rings & scintillator (low energy)

Improvements

To reduce neutron background rate

- Reduce plastic in detector
- Reduce volume of steel
- Place veto within steel vessel
- Use copper vessel
  - 0.01ppb U and 0.01ppb Th
  - Young’s modulus for stainless steel is 190 GPa
  - Young’s modulus for copper is 120 GPa
  - Assuming twice the mass of copper required this results in a factor ~85 times less neutron background than stainless steel.

Lower background allows for larger systems with longer running time which in turn gives better limit.

- MICROMEGAS
  - Improved readout resolution
  - Increased mass of CS_2

Conclusions

- TPC Competitive technology
  - Advantage of directional capabilities

- Present day technology
  - Extended shielded array (hundreds of modules) coupled to active veto
  - WIMP-nucleon cross section of order 1×10^{-9} pb
  - Improvements with radiologically pure materials

- MICROMEGAS readout
  - Increased mass per vessel
  - Fewer modules required in array

- Proposed array approaches fundamental limit of CS_2 gaseous system

- Financially competitive with proposed tonne scale alternative technologies

Thanks to DRIFT COLLABORATION

References

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