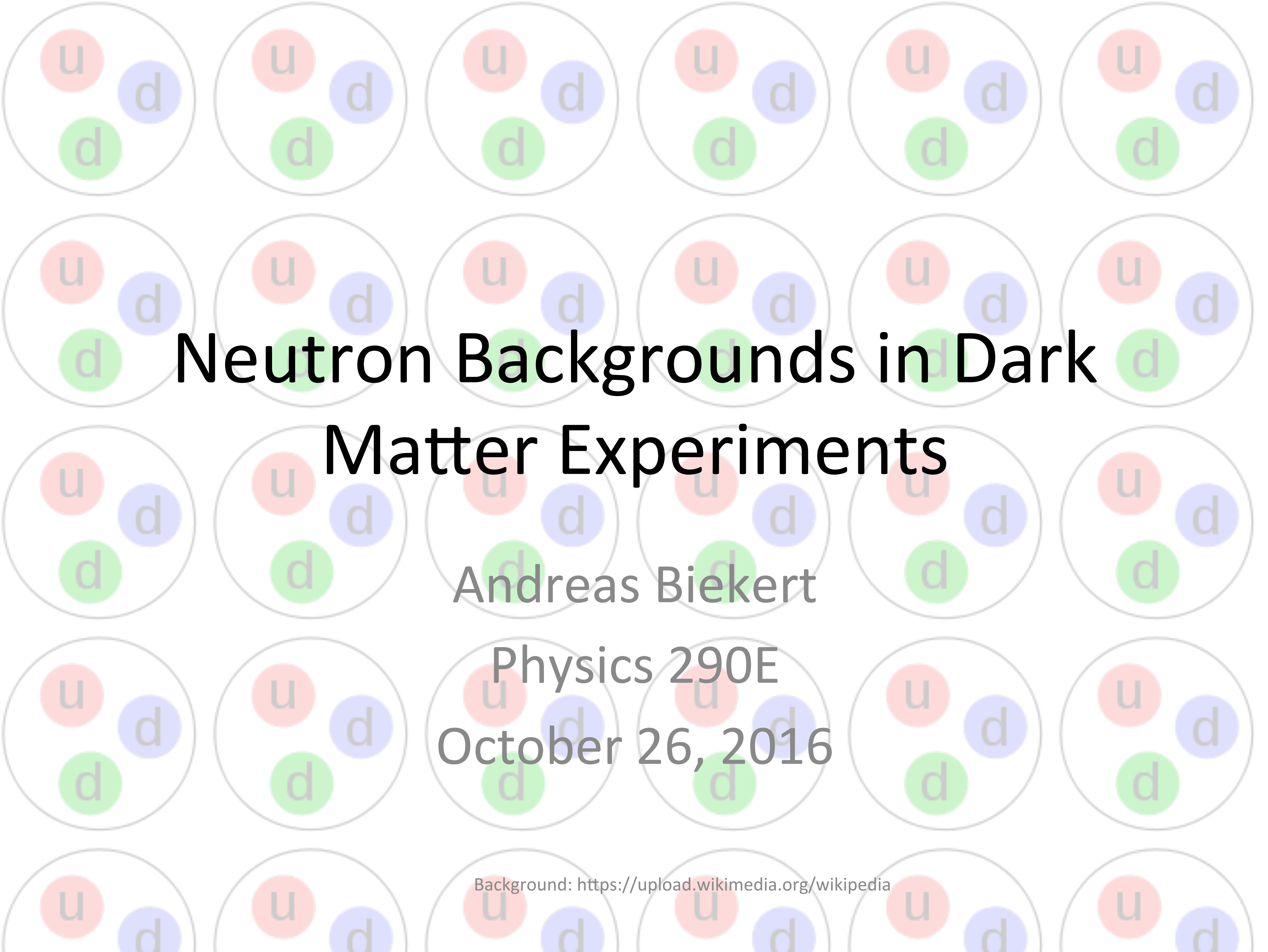

Neutron Backgrounds in Dark Matter Experiments

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Physics 290E

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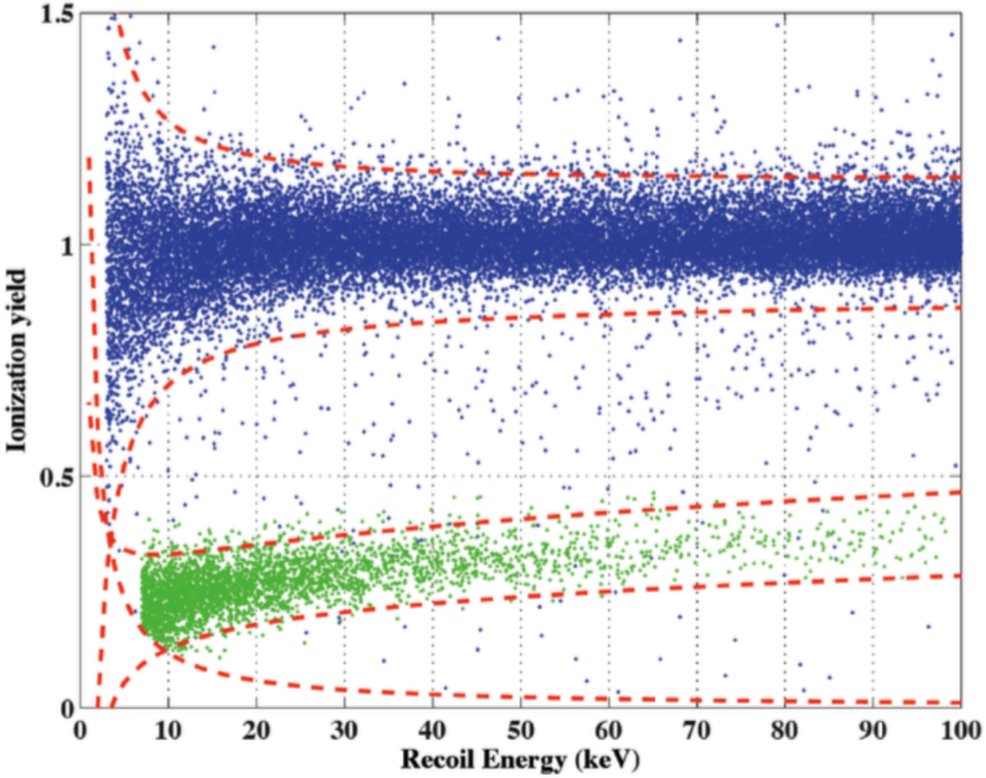
Background: https://upload.wikimedia.org/wikipedia

Backgrounds and Signal Discrimination

- Electron recoil (ER) events have much larger count rate than nuclear recoil (NR) events.
- Possible to discriminate between ER and NR.
- Neutron NR events can mimic WIMP signal.



Blue events from ER calibration (^{133}Ba) and Green events from NR calibration (^{252}Cf) in CDMS ZIP detector. From [1]

Understanding Neutron Backgrounds in Experiments

- Neutron backgrounds can be very site, detector, and environment specific.
- Can be difficult to measure accurately.
- Understanding comes from careful consideration of:
  - Theory (relevant sources, distributions, etc.)
  - Simulation (commonly with GEANT and/or FLUKA)
  - Measurements (rate counting)

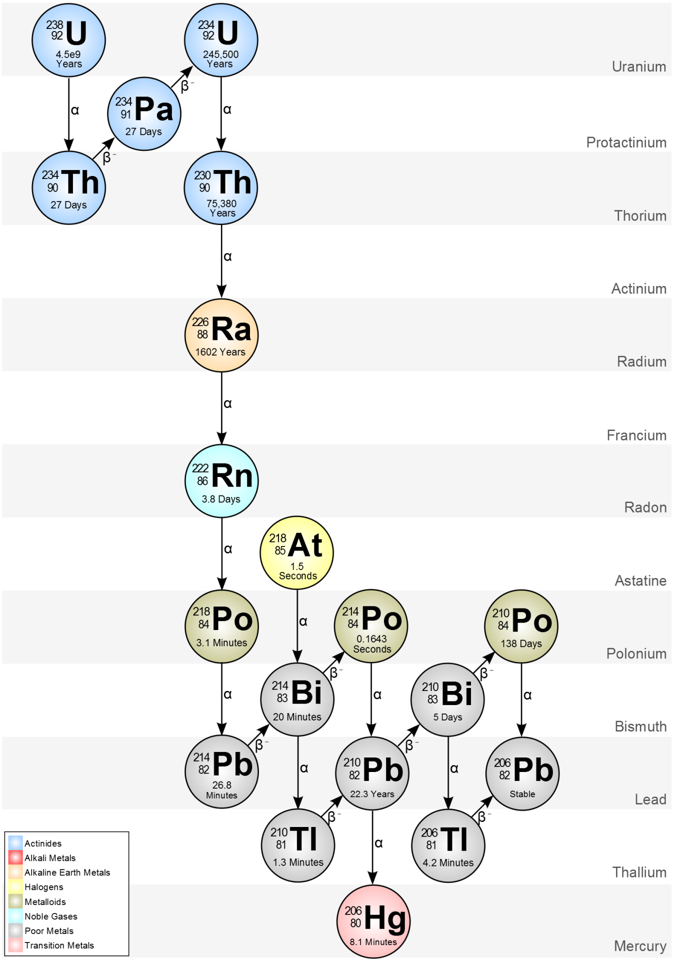
Main Sources of Neutrons

- Low energy neutrons from (α, n) reactions and spontaneous fission in surrounding rock and detector components
- High energy neutrons from muon interactions in surrounding rock and detector components

(α, n) reactions

- ^{238}U, ^{235}U, and ^{232}Th decay chains produce α's.
- Different isotopes have different energy cutoffs for (α, n) reactions

^{238}U:



From: https://upload.wikimedia.org/wikipedia/

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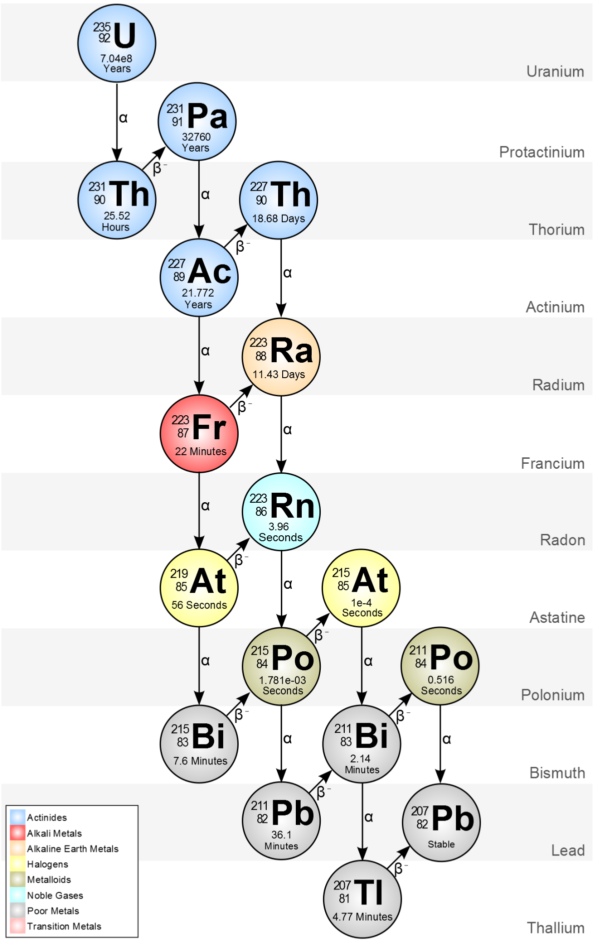


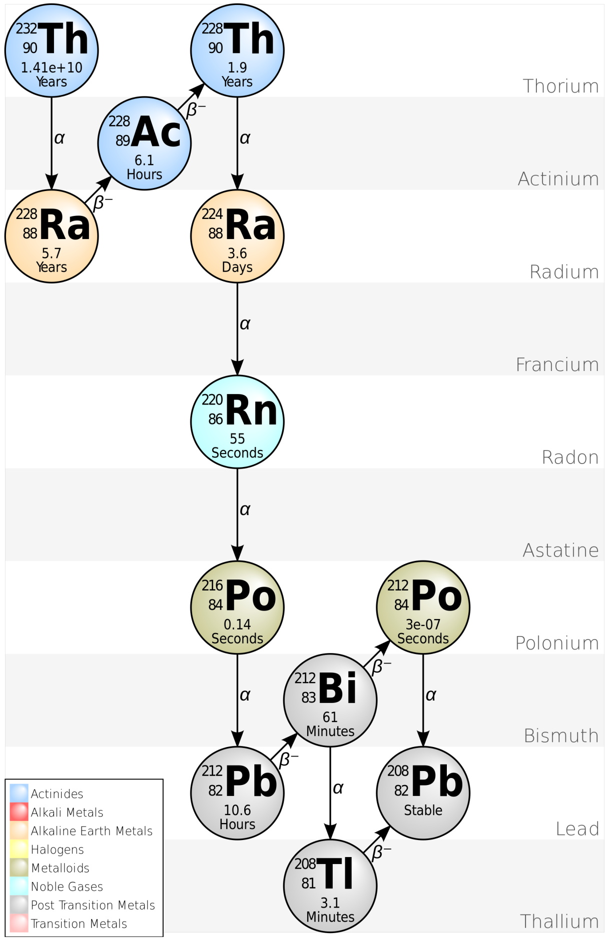
^{235}U:

From: https://upload.wikimedia.org/wikipedia/

(α, n) reactions

- ^{238}U, ^{235}U, and ^{232}Th decay chains produce α's.
- Different isotopes have different energy cutoffs for (α, n) reactions

^{232}Th:



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Decay Chain Relevance to Neutron Backgrounds

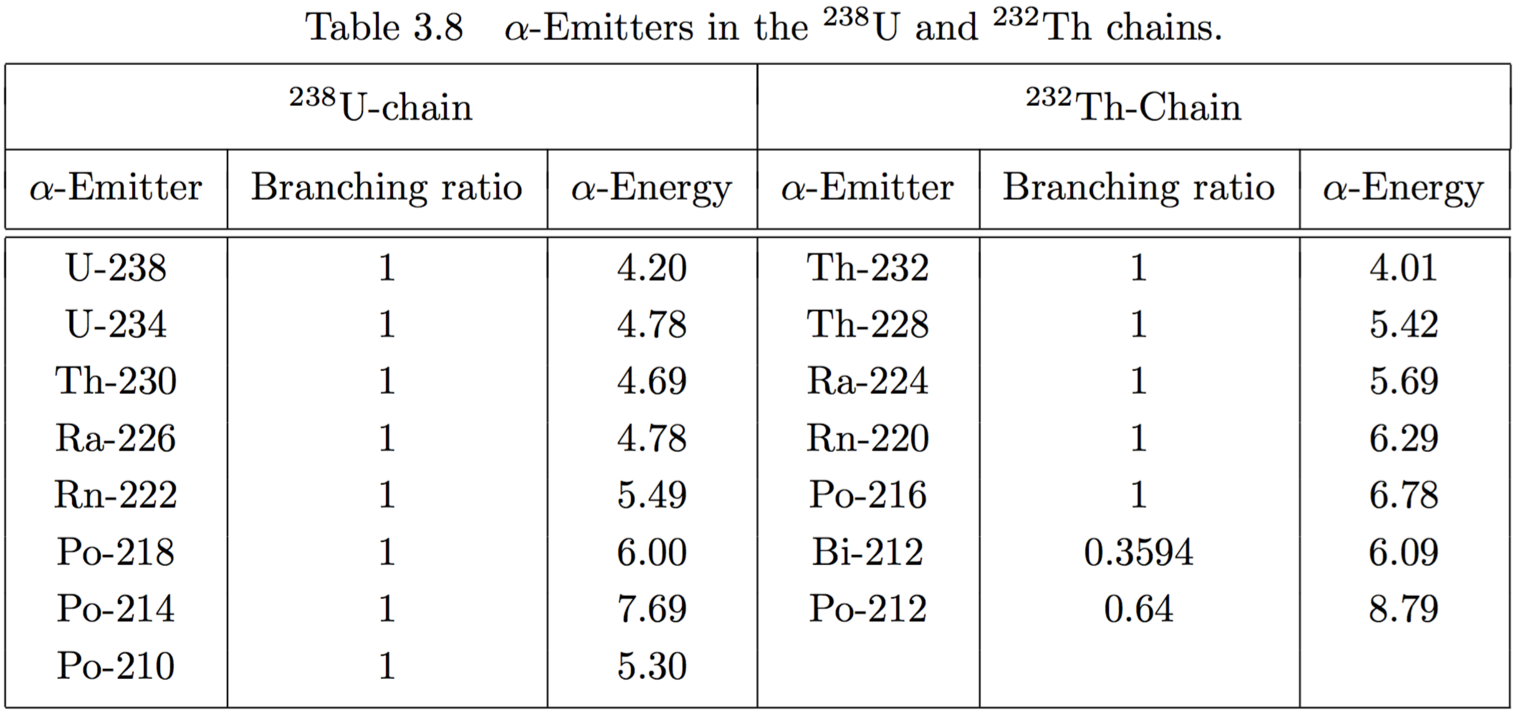


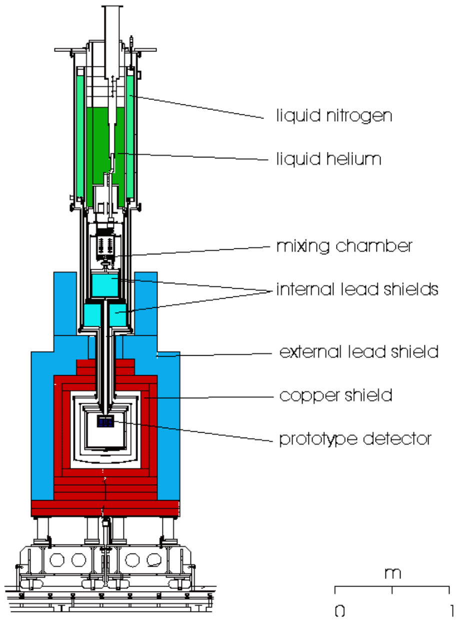
Table 3.8 α-Emitters in the ^{238}U and ^{232}Th chains.

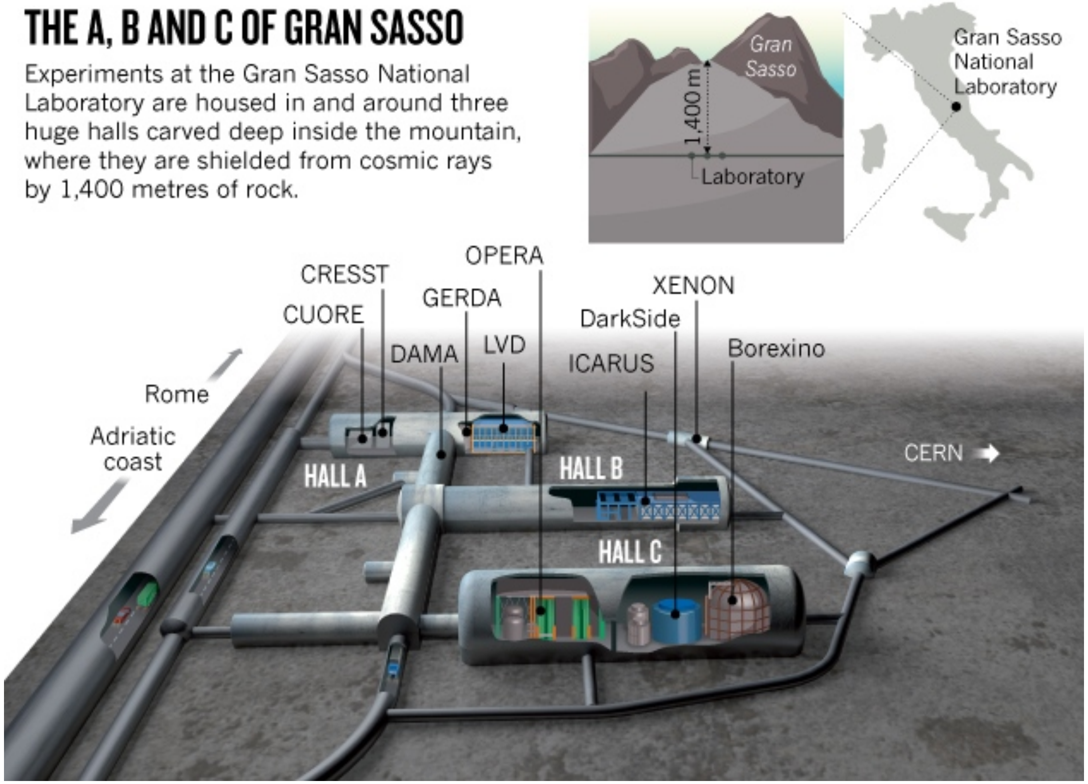
^{238}U-chain			^{232}Th-Chain		
α-Emitter	Branching ratio	α-Energy	α-Emitter	Branching ratio	α-Energy
U-238	1	4.20	Th-232	1	4.01
U-234	1	4.78	Th-228	1	5.42
Th-230	1	4.69	Ra-224	1	5.69
Ra-226	1	4.78	Rn-220	1	6.29
Rn-222	1	5.49	Po-216	1	6.78
Po-218	1	6.00	Bi-212	0.3594	6.09
Po-214	1	7.69	Po-212	0.64	8.79
Po-210	1	5.30			

From [2]

CRESST Gran Sasso Neutron Background Analysis (From [2])

- Experiment moved from Hall A to Hall C between generations.
- Prompted detailed neutron background study.





THE A, B AND C OF GRAN SASSO

Experiments at the Gran Sasso National Laboratory are housed in and around three huge halls carved deep inside the mountain, where they are shielded from cosmic rays by 1,400 metres of rock.

Right: http://www.nature.com/polopoly_fs/7.4565.1337781034!/image/gran-sasso-graphic-on-page.jpg_gen/derivatives/landscape_630/gran-sasso-graphic-on-page.jpg
Left: https://www.mppmu.mpg.de/english/cresst_image4.gif

CRESST Gran Sasso (α, n) Simulations

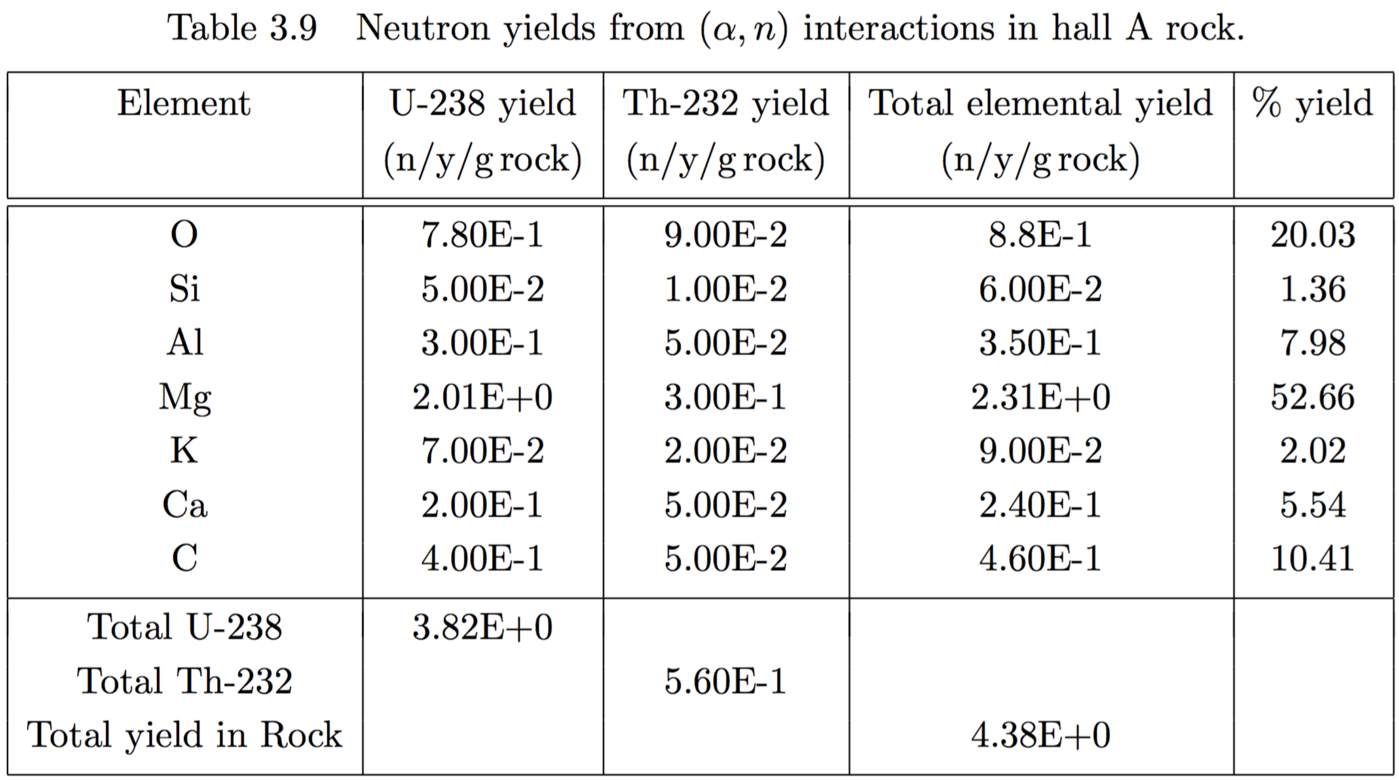


Table 3.9 Neutron yields from (α, n) interactions in hall A rock.

Element	U-238 yield (n/y/g rock)	Th-232 yield (n/y/g rock)	Total elemental yield (n/y/g rock)	% yield
O	7.80E-1	9.00E-2	8.8E-1	20.03
Si	5.00E-2	1.00E-2	6.00E-2	1.36
Al	3.00E-1	5.00E-2	3.50E-1	7.98
Mg	2.01E+0	3.00E-1	2.31E+0	52.66
K	7.00E-2	2.00E-2	9.00E-2	2.02
Ca	2.00E-1	5.00E-2	2.40E-1	5.54
C	4.00E-1	5.00E-2	4.60E-1	10.41
Total U-238	3.82E+0			
Total Th-232		5.60E-1		
Total yield in Rock			4.38E+0	

- Background rates specific to rock found around Hall A at Gran Sasso
- Contribution levels off after ~1m of rock/concrete

Spontaneous Fission

- Nucleus decays into two daughter nuclei and 2-3 neutrons.
- Possible in principle for our friends ^{238}U, ^{235}U, and ^{232}Th.
- In practice, only appreciable contribution is from ^{238}U.

CRESST Gran Sasso Total Neutron Flux Comparison

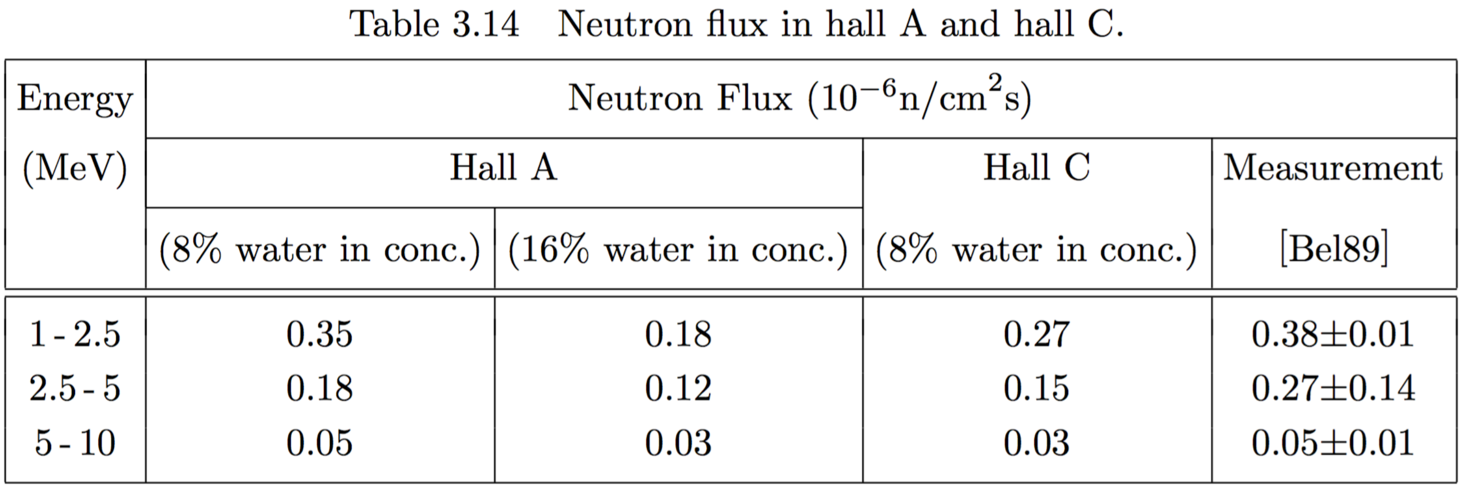


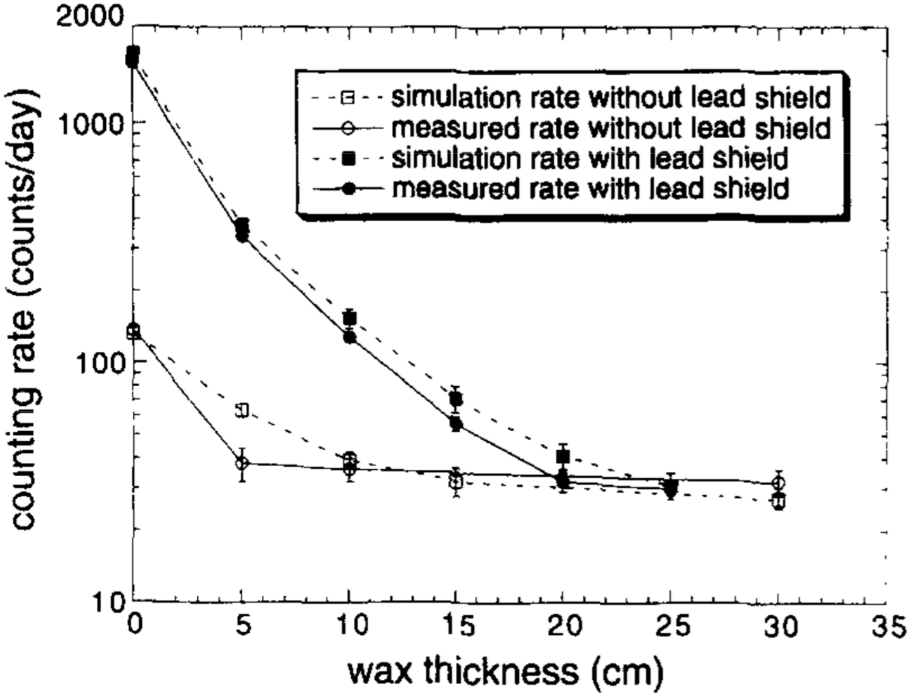
Table 3.14 Neutron flux in hall A and hall C.

Energy (MeV)	Neutron Flux (10^{-6}n/cm^{2}s)			
	Hall A		Hall C	Measurement
	(8% water in conc.)	(16% water in conc.)	(8% water in conc.)	[Bel89]
1 - 2.5	0.35	0.18	0.27	0.38±0.01
2.5 - 5	0.18	0.12	0.15	0.27±0.14
5 - 10	0.05	0.03	0.03	0.05±0.01

- Careful simulations can reproduce experimental data (measurement performed in hall A)
- Significance of water content to neutron flux raises questions about annual modulation of signal seen by DAMA
    - DAMA's signal persists and not conclusively explained

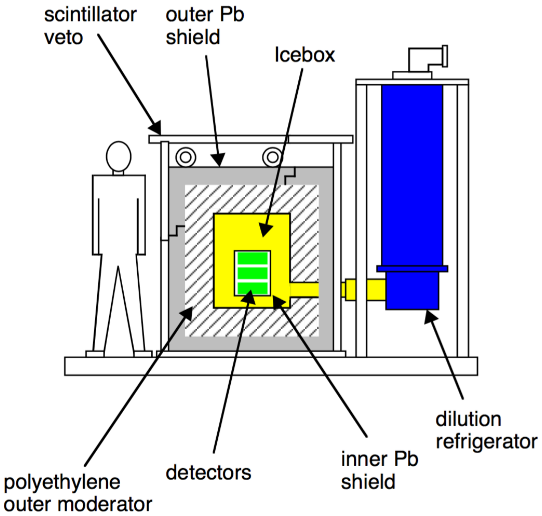
Passive Shielding

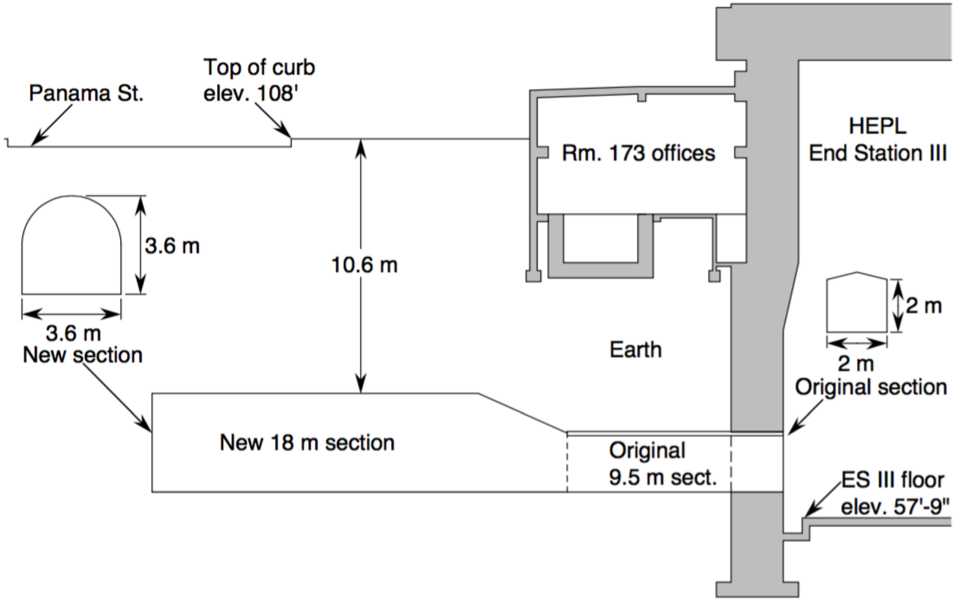
- Usually made of:
  - Wax
  - Hydrocarbon (Polyethylene, scintillator, etc.)
  - Water
- Attenuates neutron flux from external sources.



Effect of wax shielding around early CDMS experiment at Stanford Underground Facility. Lead shield designed to reduce ϒ flux in detector. From [3]

CDMS Stanford Underground Facility Neutron Background Analysis





- Images from [4]
- Experiment (CDMS I) conducted at much shallower depth.
- Background analysis on neutrons originating from muon interactions.

Neutron production processes by muons

- Muon capture followed by neutron emission. Falls off after 300 meter water equivalent
- Direct muon spallation ejects neutron

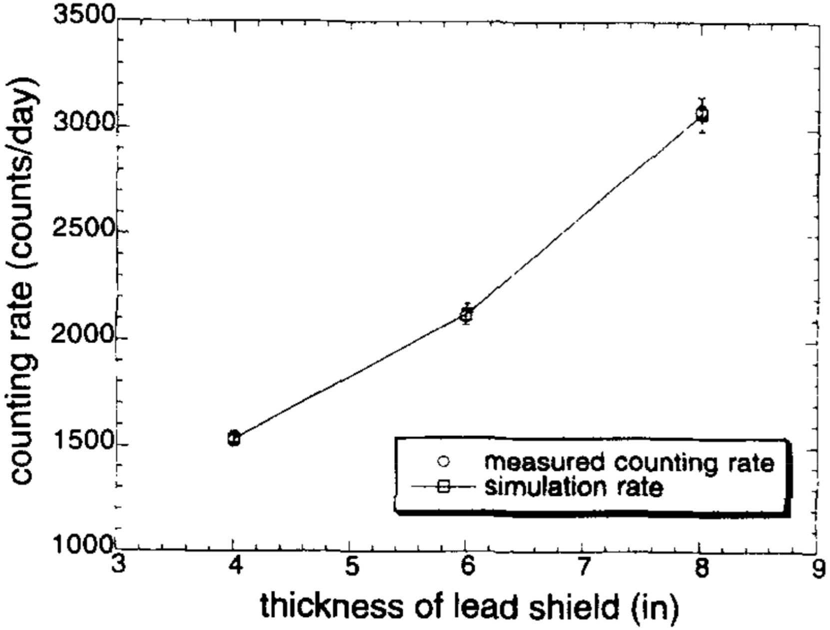
$$\mu + \text{Nucleus} \rightarrow \mu + \text{Nucleus}^* + \text{n}$$

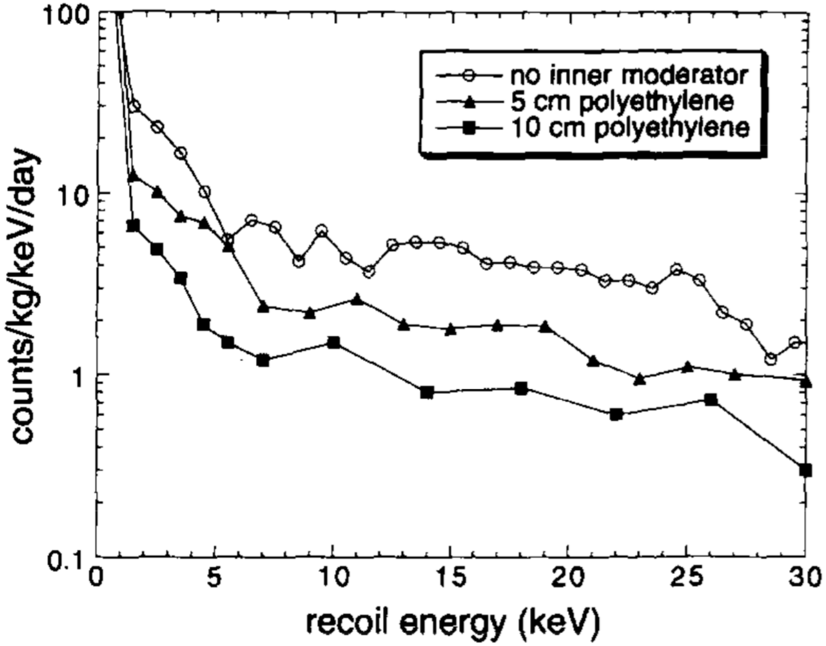
- Neutrons production by hadrons from muon-generated nuclear showers
- Neutrons produced by gammas in muon-generated electromagnetic showers

Muon Interactions in Detector Components

Lead shielding:

Copper Crysotat: Plots from [3]

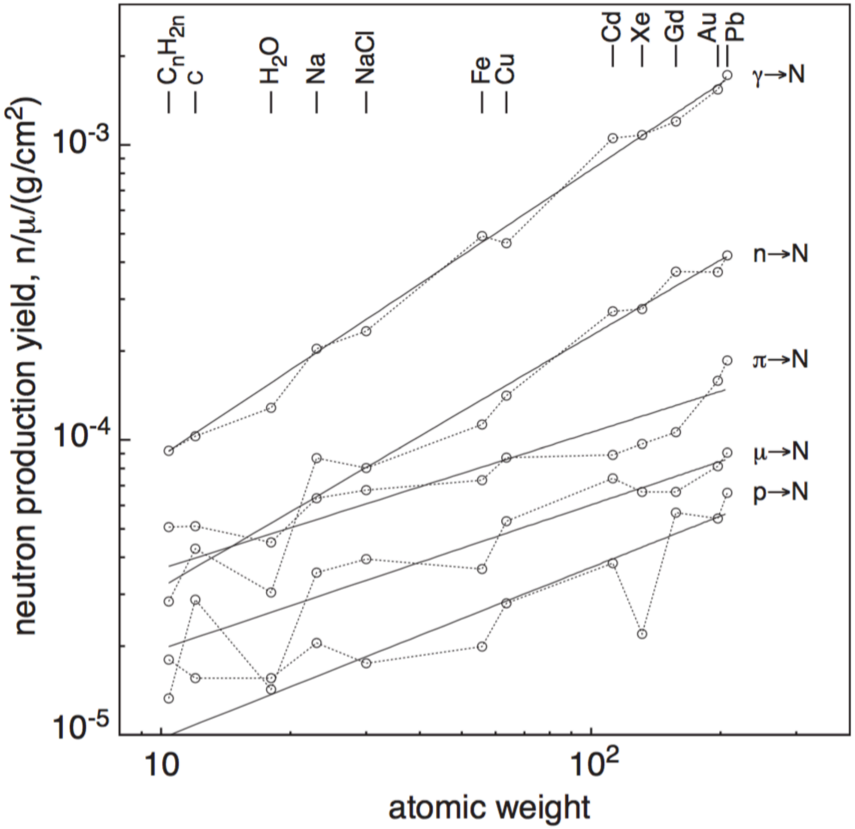




- Passive shielding works on neutrons generated by muons external to the detector (for the most part).
- Muons can generate neutrons inside detector by interacting with detector components.

Muon Interactions in Detector Components

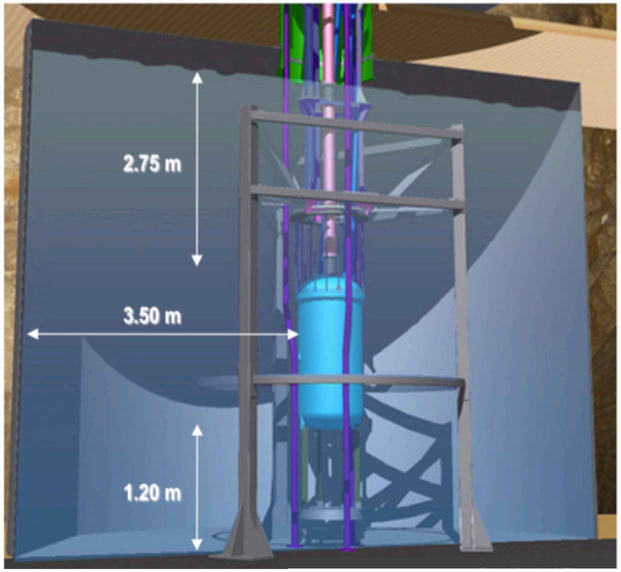
- Plot shows neutron flux resulting from different muon interaction processes (280 GeV muons).
- Different detector components have different sensitivities.



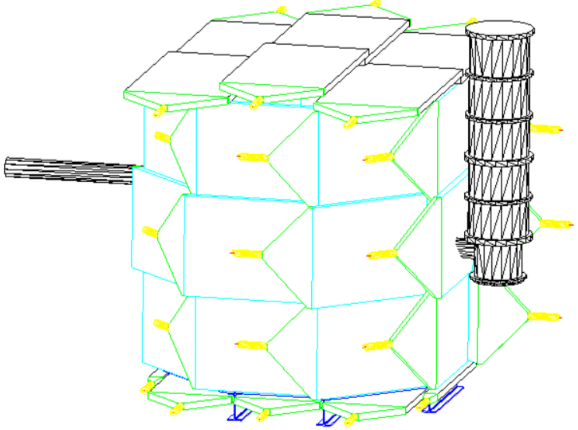
From [5]

Active Veto Layer

- Modern experiments have veto layers around experiments.
  - LUX used water with PMTs that monitor for Cherenkov radiation from muons.
  - CDMS II used plastic scintillator for similar purpose
- Veto layers can also detect some high energy ("punch-through") neutrons from external muon interactions



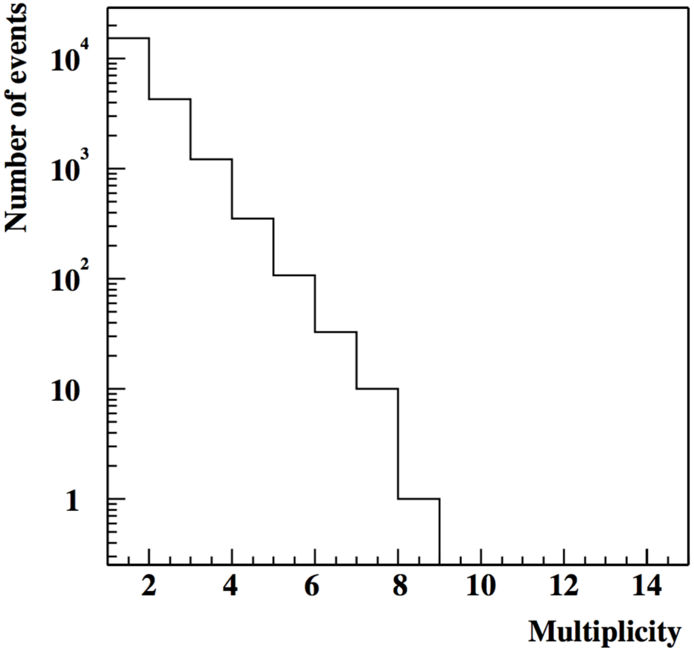
Left: LUX water shield. From [6]



Right: CDMS II plastic scintillator veto. From [1]

Additional Strategies

- Vetoing NR events with multiple scatterings in the detector
  - WIMPs not likely to multiple scatter in the detector
- Vetoing NR events with accompanying ER events
  - These are the result of neutron deep inelastic scattering
- Cleaner and cleaner detector materials



Simulation of neutron scattering multiplicity in a generic liquid xenon detector deep underground. From [7]

LUX Neutron Backgrounds [8]

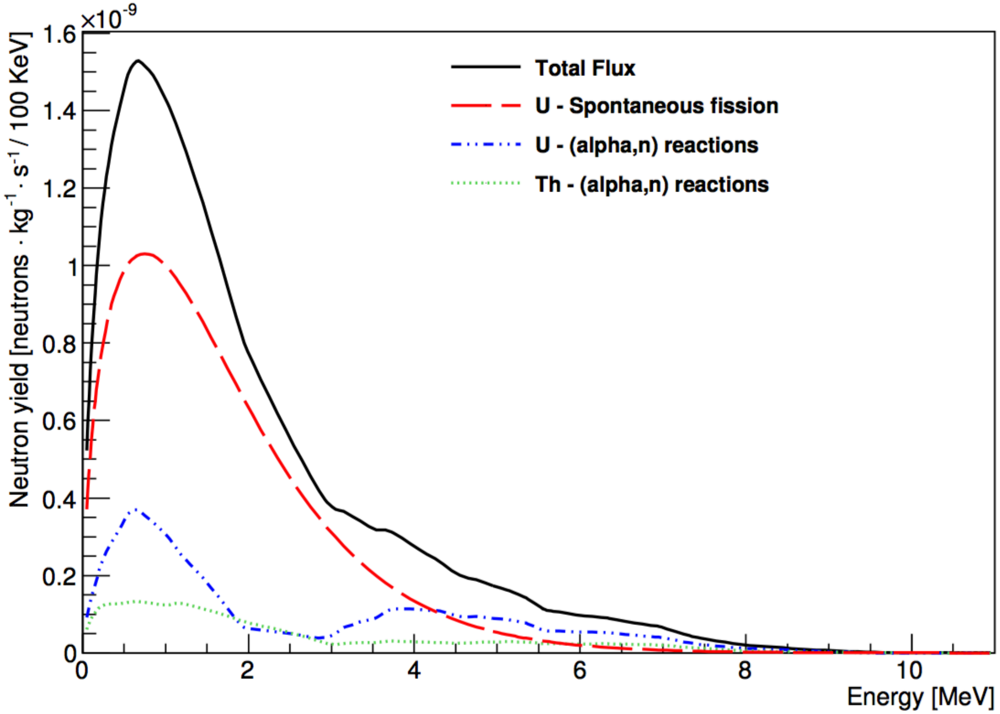
- Neutron sources are previously discussed (α, n) and spontaneous fission processes occurring in:
  - PMTs
  - Accumulation of ^{210}Pb daughters on detector surfaces (negligible)
  - Cryostats (30% of baseline PMT estimate)
- Punch-through neutrons from muon interactions in rock (30% of baseline PMT estimate)
- Final estimate translates to $3\text{x}10^{-4}$ NR events per day passing all cuts
- NR events subdominant background

CDMS II Neutron Background [1]

- Unvetoed muon-induced NR events for run
  - 0.214 ± 0.0081(stat.) ± 0.0086(syst.) for Ge detectors
  - 0.129 ± 0.0058(stat.) ± 0.0033(syst.) for Si detectors
- Detector component-generated neutron events for run also much less than 1.
- NR background entirely subdominant.

New Experiment – Nuclear Emulsion (From [9])

- Authors assume passive screening techniques for externally generated neutrons.
- Detailed calculations, simulations, and activity measurements to estimate intrinsic neutron background



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