Characterizing the SNOLAB radiation environment

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PICO

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The SNOLAB radiation environment

The measurements:

Thermal neutrons

SNO S5-200A-1 NCD detector measurement : $\sim 4140 \pm 120\ neutrons\ m^{-2} day^{-1} (4\pi sr)^{-1}$

Fast neutrons

- SNO collaboration estimate, $\sim 4000 \pm 120\ neutrons\ m^{-2} day^{-1} (2\pi sr)^{-1}$

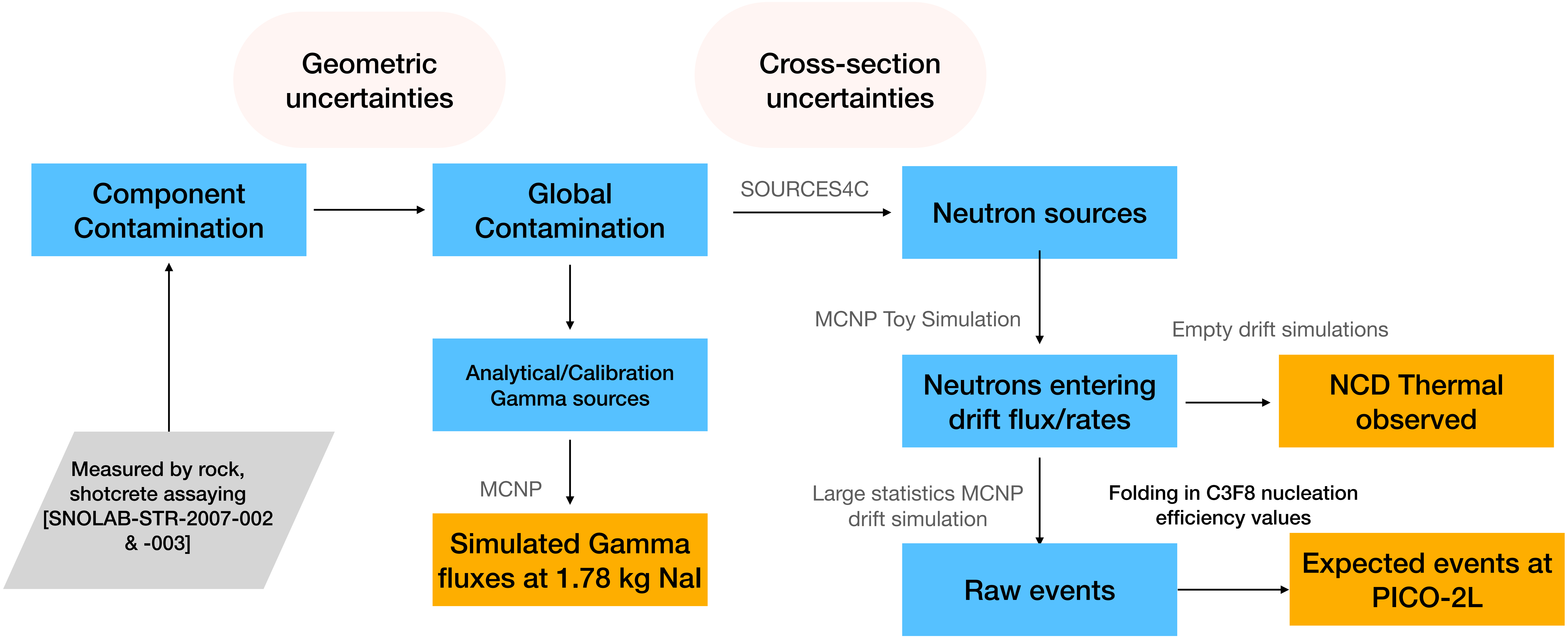
with an unknown spectrum [SNOLAB SL-SCI-RES-00-001-P].

- PICO-2L (shield-off) took measurement for 104 (35) single bubble candidates over 18.64 (19.46) days, for 3.2 (42) keV.

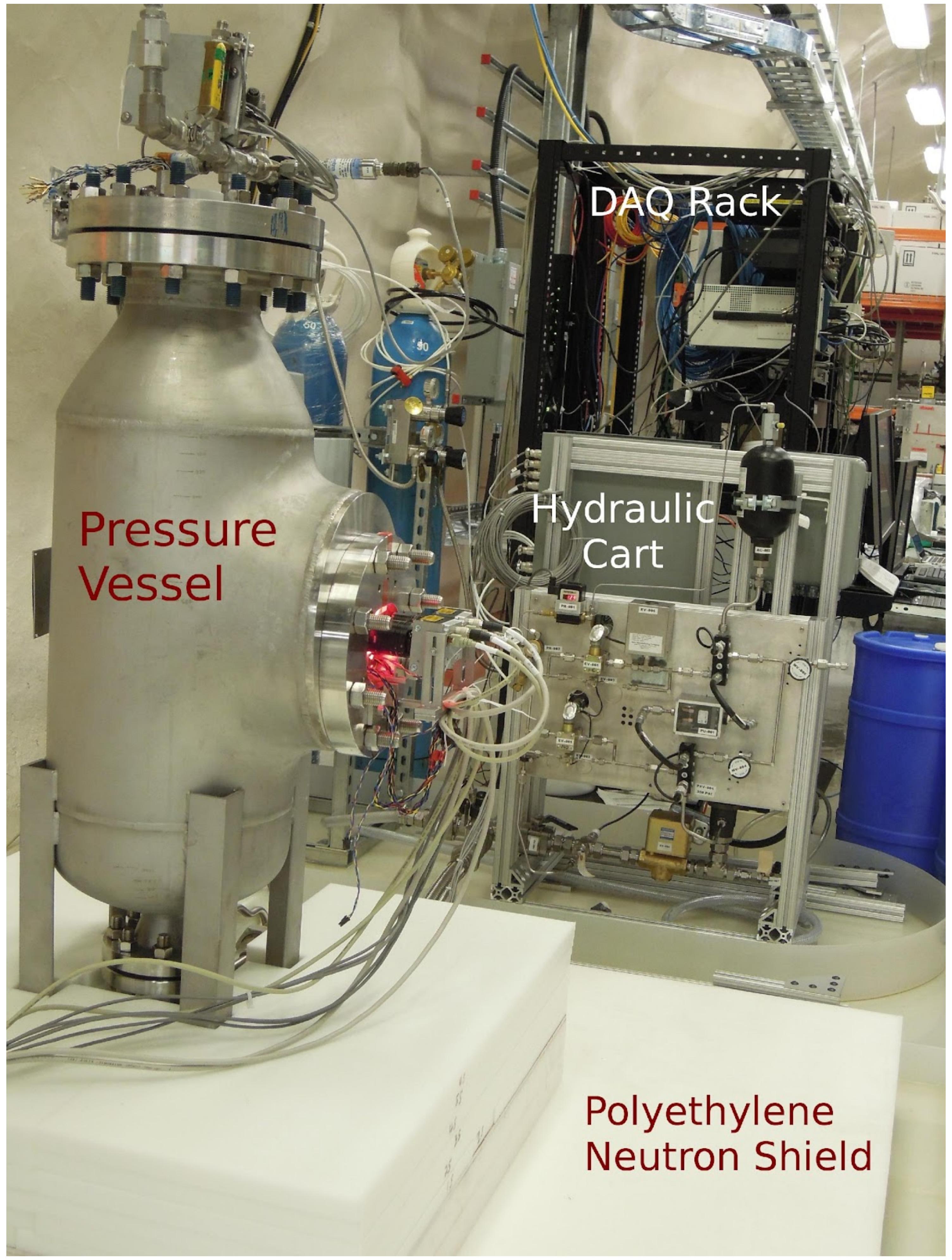
Gamma photons

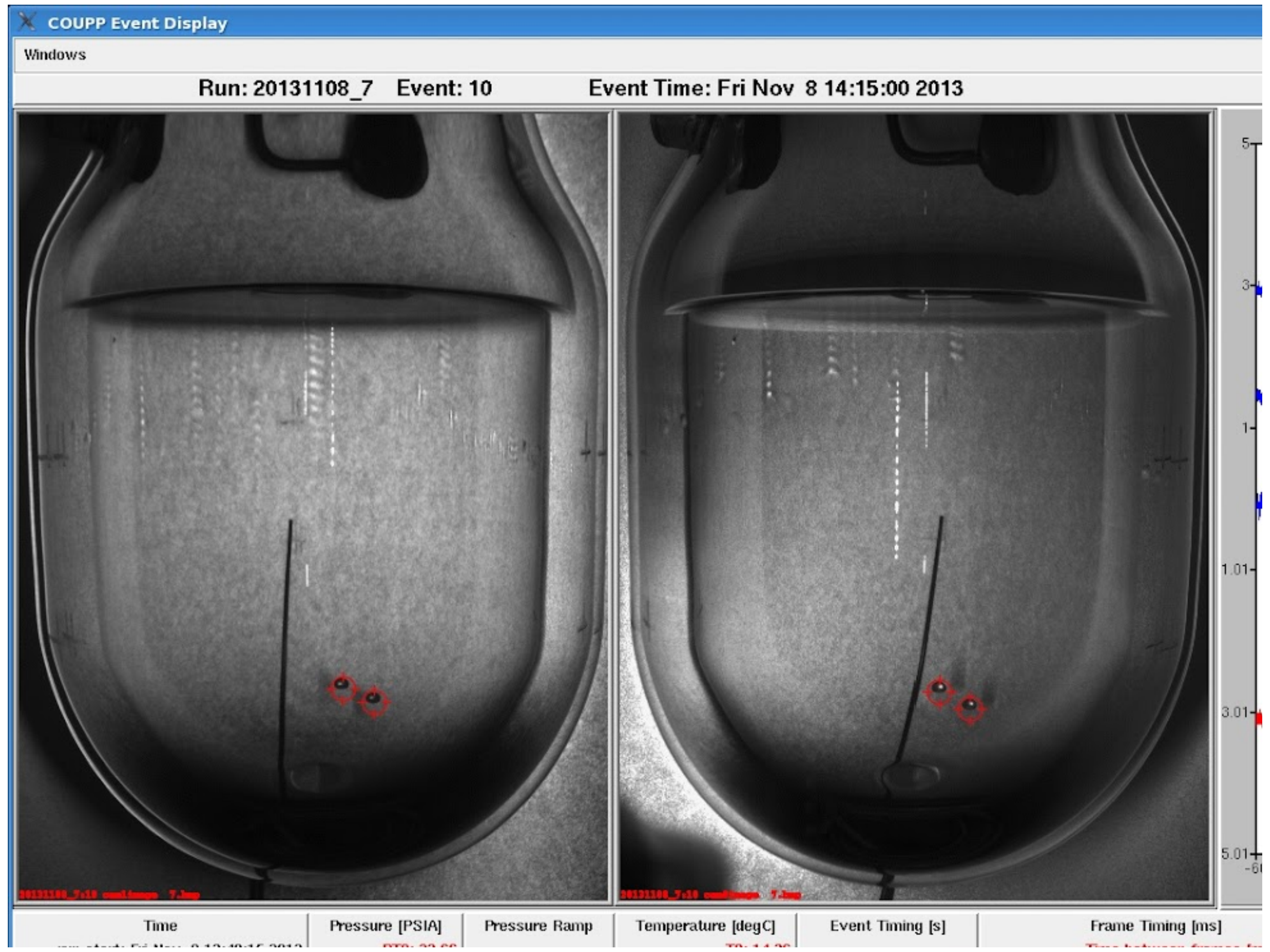
- NaI(Tl) 1.78 kg measurement at PICO-2L location $\sim 1191.1\ \gamma\ m^{-2} day^{-1} (4\pi sr)^{-1}$
- SNOLAB Cavern Perillo Isaac et. al (1997 SNO-STR-97-009).

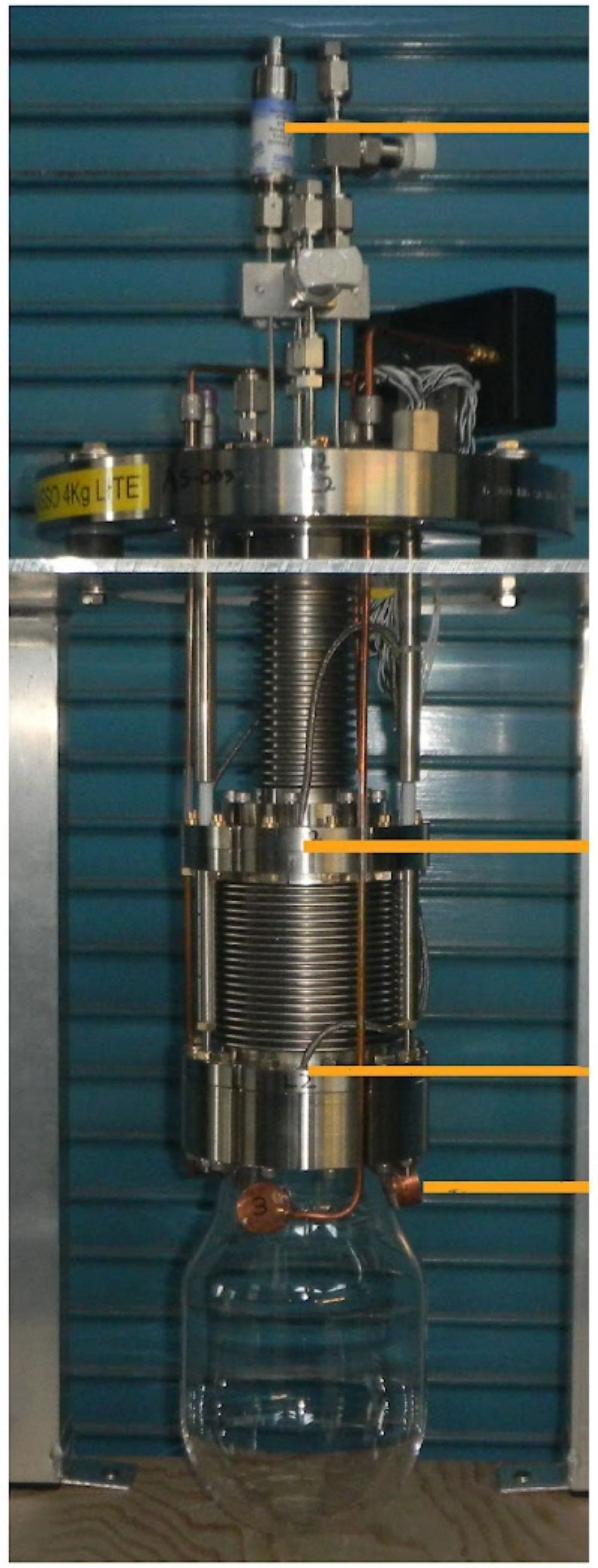
The Simulation Framework



PICO-2L





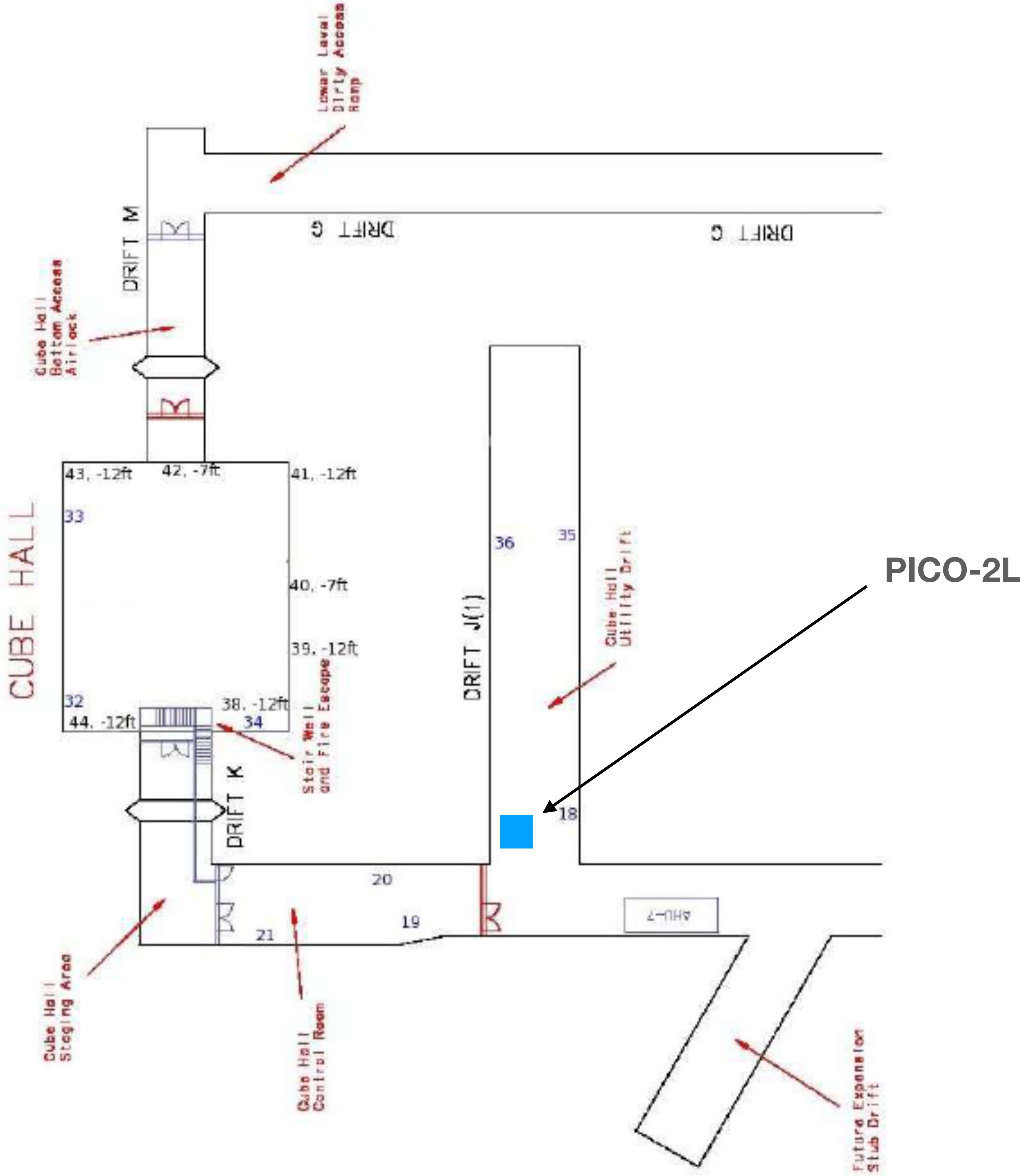


Phys. Rev. D
93, 061101
(2016)

PICO-2L

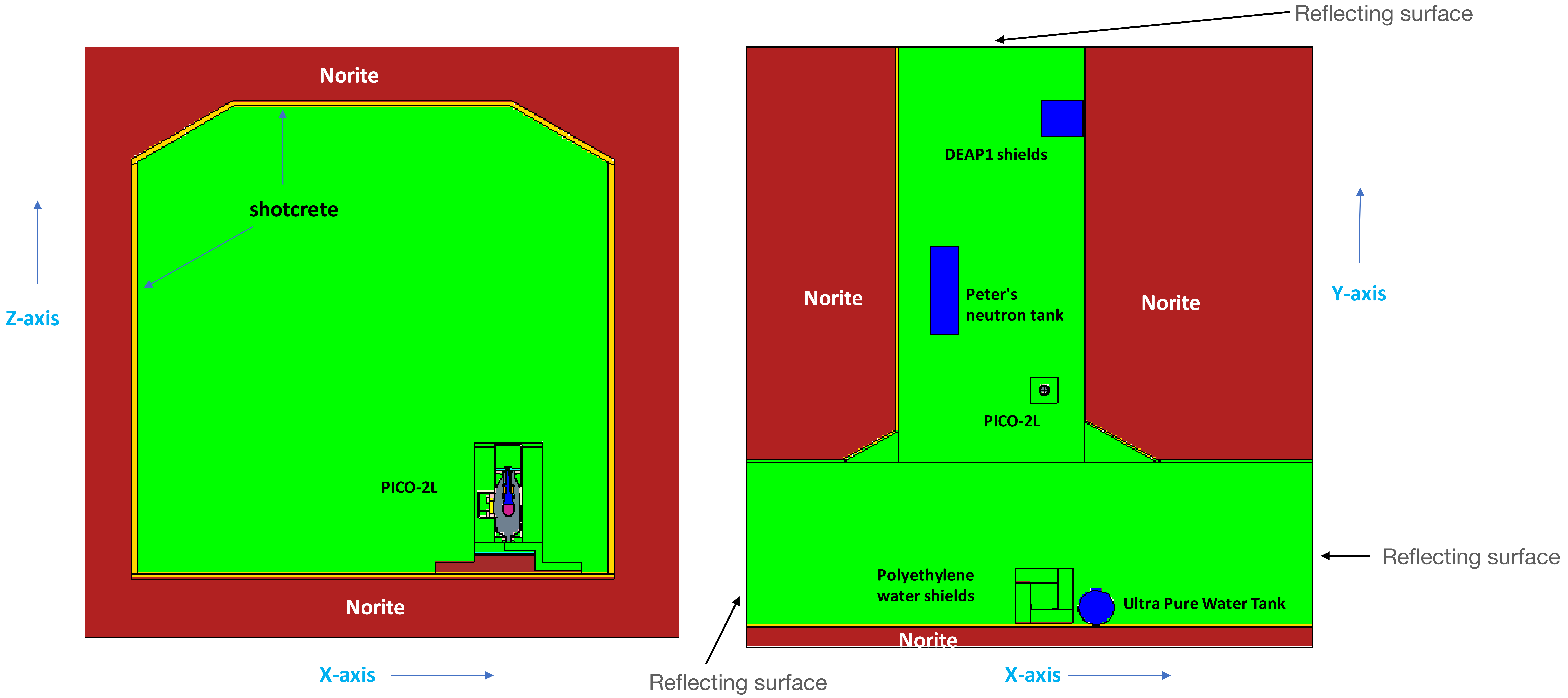
Configuration for dark matter run

Water shields removed for fast neutron measurements



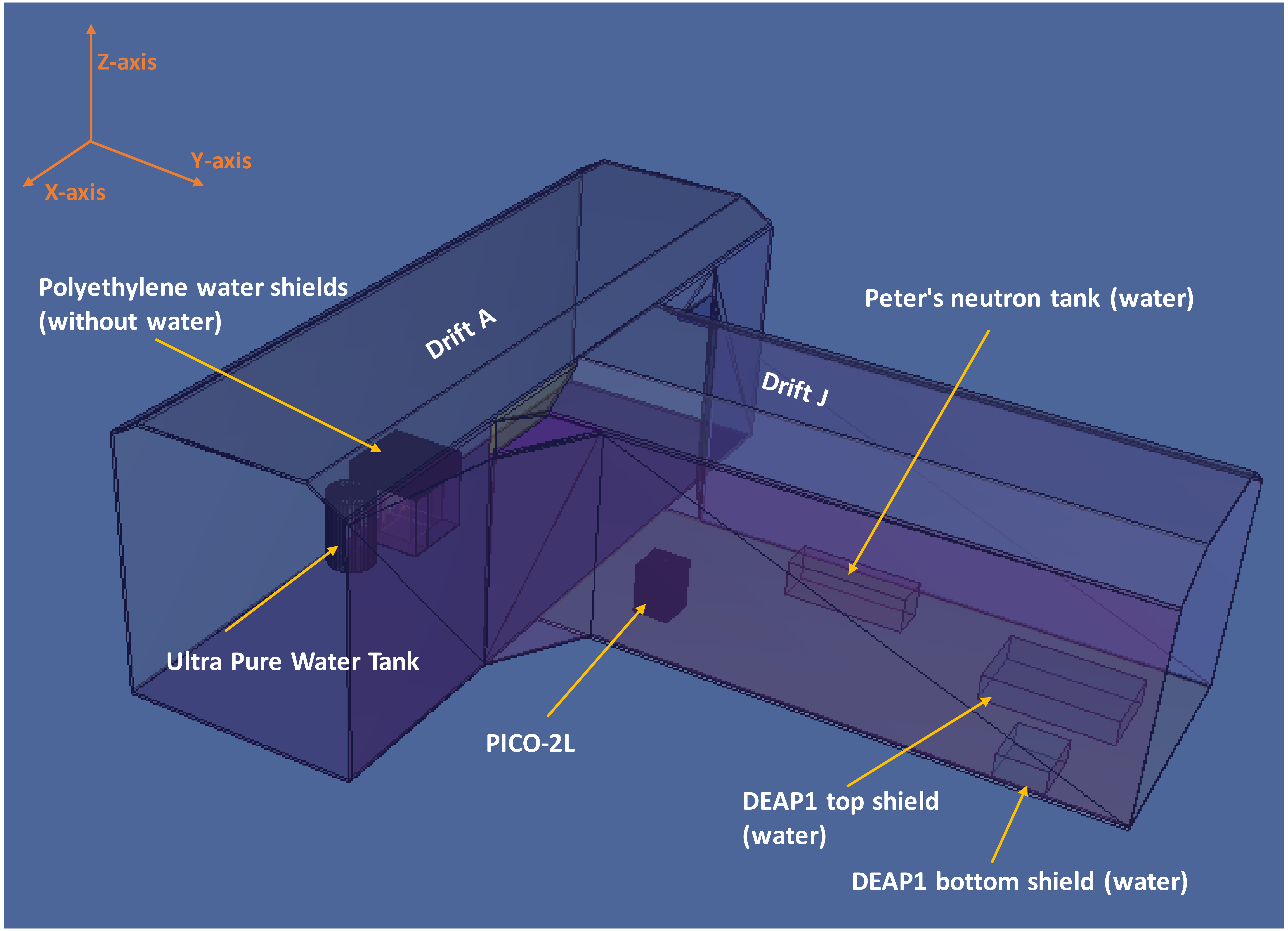
Layout taken from SNOLAB STR-2007-02.

Drift-J geometry as modelled in MCNP-Polimi simulation



The neutron source considered: 232Th & 238U chains for shotcrete and norite rock, 222Rn in air.

Drift-J geometry as modelled in MCNP-Polimi simulation

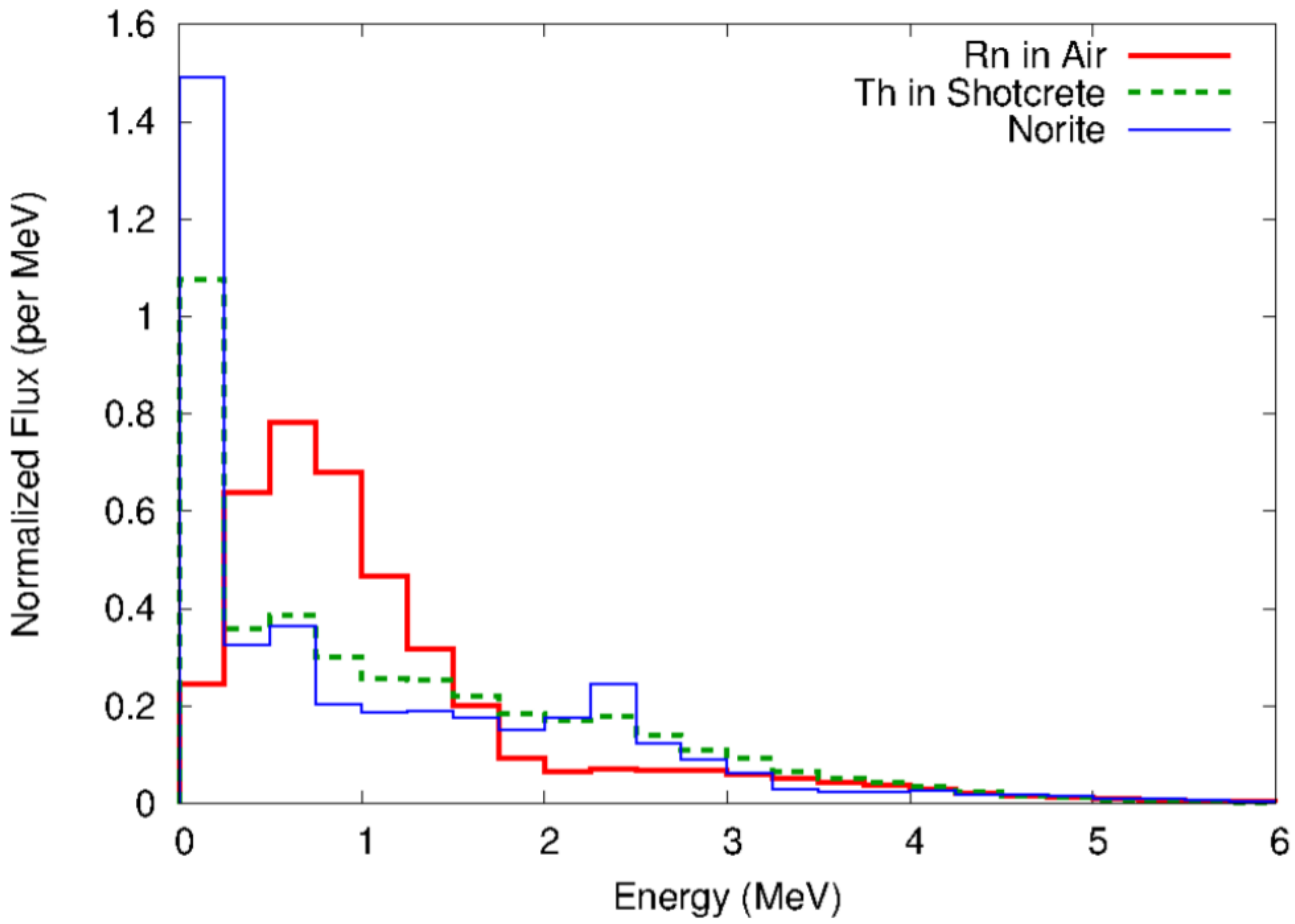


Source rate prediction

Material	Source	Activity [n/kg/yr]
Norite	1.3 ppm U, 6.5 ppm Th	5010
Shotcrete	2.46 ppm U, 15.24 ppm Th	12000
Radon (in air)	131 Bq/m3	13700

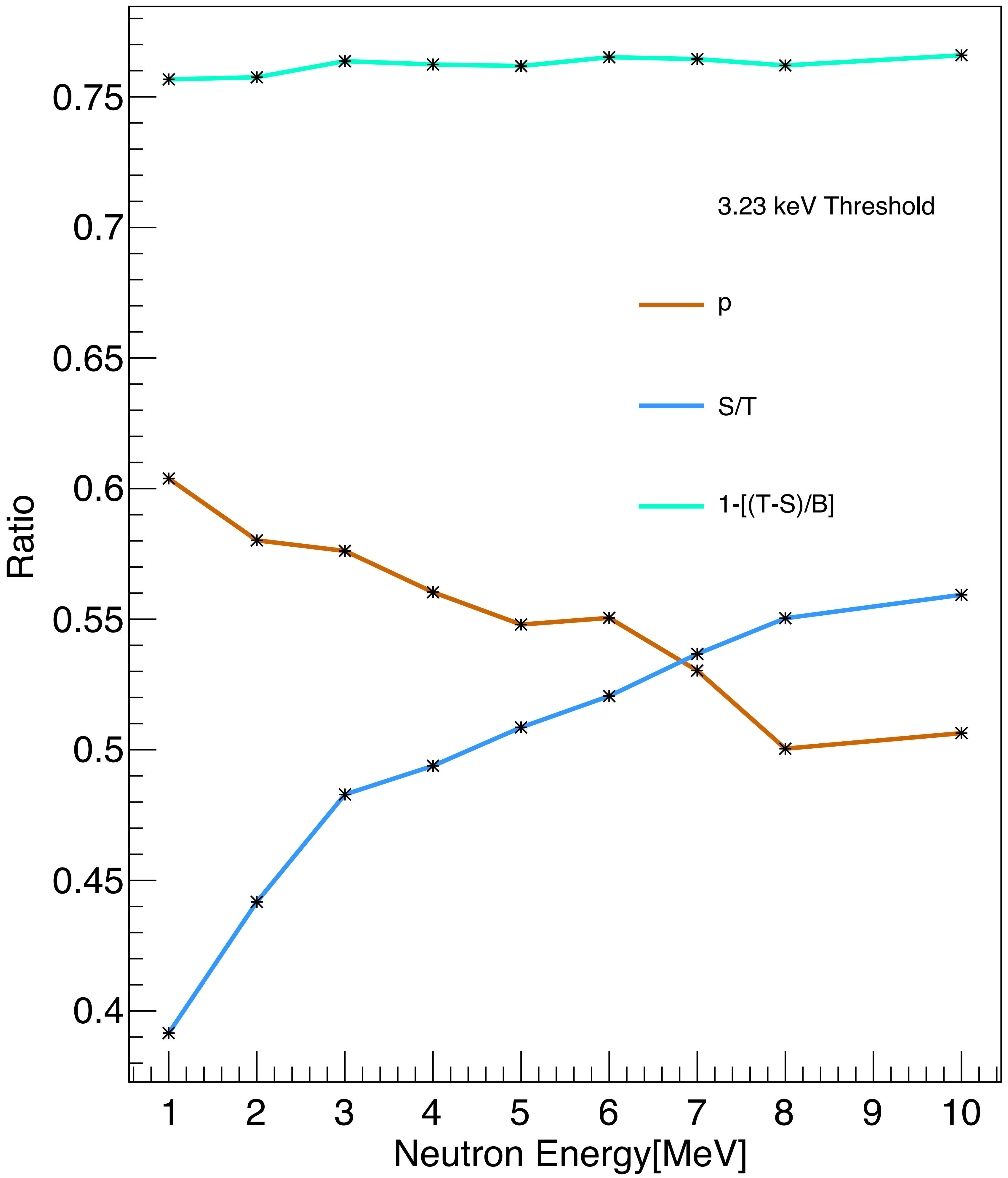
Neutron rate prediction calculated using SOURCES-4C

Material	Source	Rate
air	^{228}Rn	46.1 n m^{-3} day^{-1}
shotcrete	^{232}Th	6.80 n y^{-1} g^{-1} @ 15.24 ppm ^{232}Th
shotcrete	^{238}U	3.25 n y^{-1} g^{-1} @ 2.46 ppm ^{238}U
norite	^{232}Th	43.1 n y^{-1} cm^{-2} $(2\pi sr)^{-1}$ for 3 inch shotcrete thickness
norite	^{238}U	75.3 n y^{-1} cm^{-2} $(2\pi sr)^{-1}$ for 3 inch shotcrete thickness



Neutron rate prediction calculated using SOURCES-4C and as used in the PICO-2L simulation

Monoenergetic neutron study



The bubble multiplicity (n) and the total event rate (T) are related by the expression:

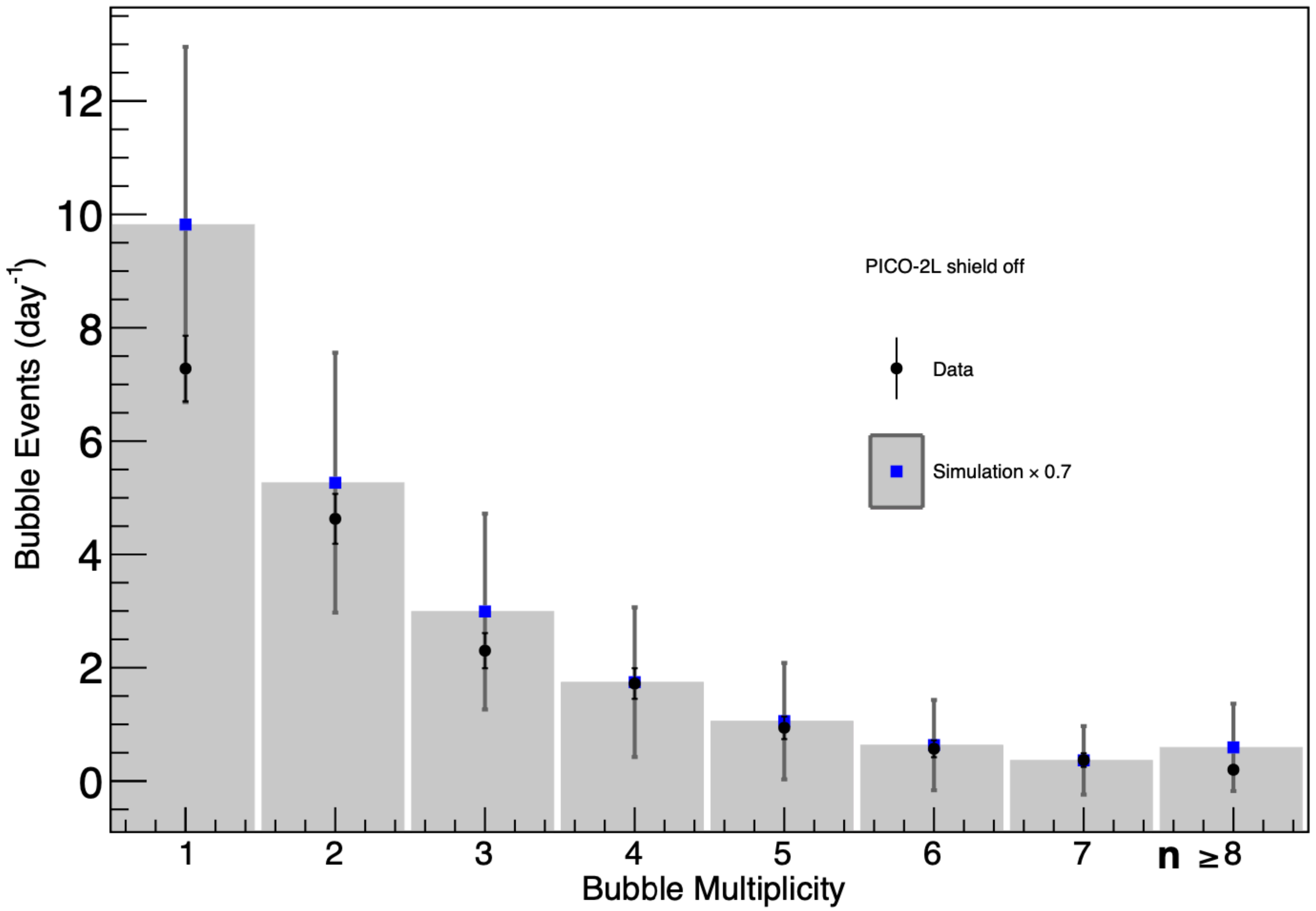
$$T(n) = T(1-p)p^n,$$

$$\hat{p} = \frac{\sum_{i=1}^{N}(n_i - 1)}{\sum_{i=1}^{N}\Theta(n_i - 1)}.$$

θ : Heaviside step function

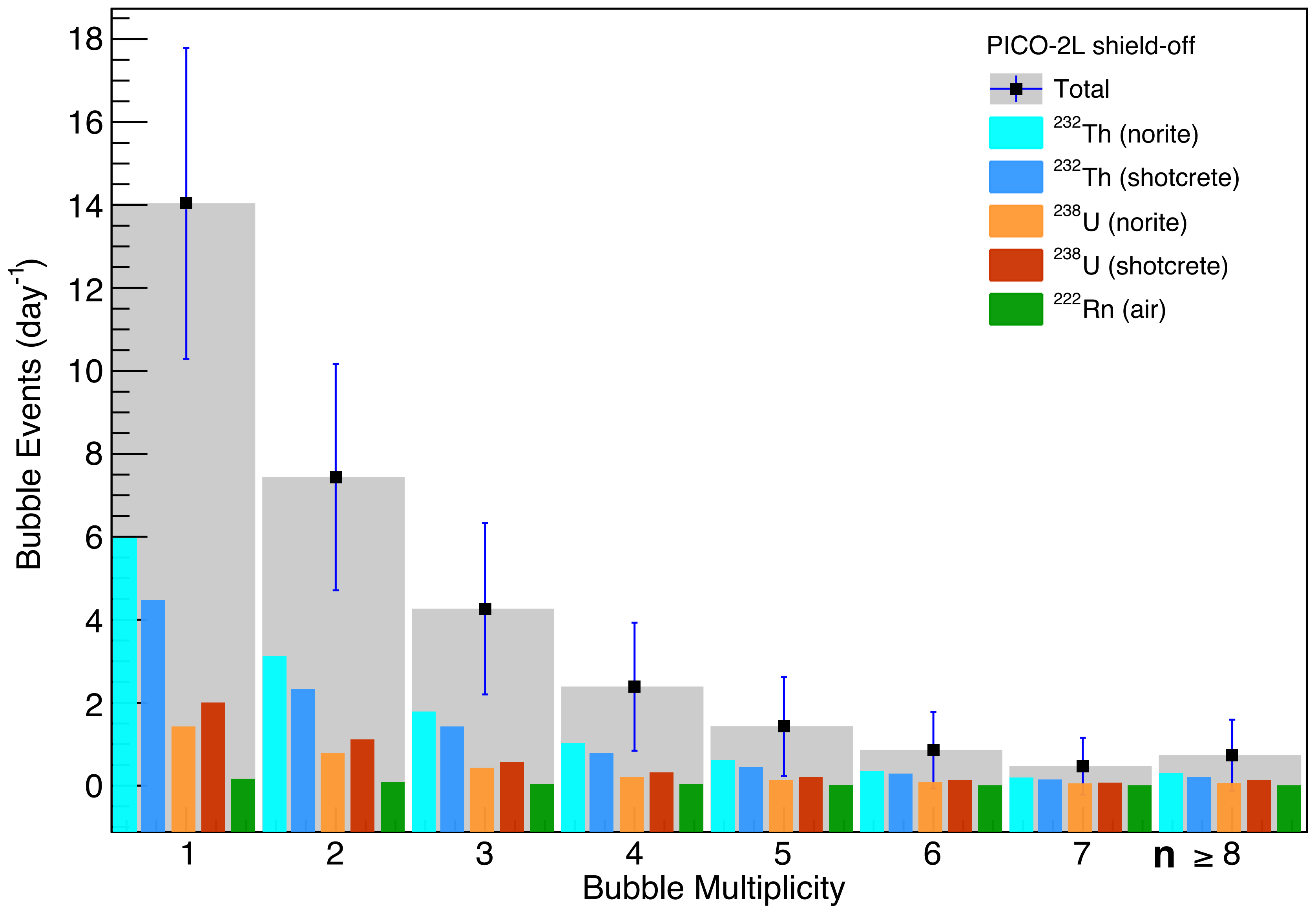
geometric model the approximates the observed simulation results for bubble multiplicities n>=2

Results for PICO-2L shield-off



Multiplicity	Data (3.45 kev) (day^{-1})	Simulation(3.23 kev) (day^{-1})	Ratio (D/S)
1	7.28±0.58	14.04±3.75	0.52±0.14
2	4.63±0.44	7.44±2.73	0.62±0.24
3	2.30±0.31	4.26±2.07	0.54±0.27
4	1.72±0.27	2.38±1.54	0.72±0.48
5	0.94±0.20	1.43±1.20	0.66±0.57
6	0.57±0.15	0.86±0.93	0.66±0.74
7	0.37±0.12	0.47±0.68	0.79±1.18
≥8	0.20±0.06	0.73±0.86	0.27±0.33
Total	18.02 ±0.88	31.61 ±5.62	0.57±0.01

Source	Singles	Total	S/T	p	S/T-(1-p)
^{222}Rn	0.1648± 0.4059	0.3734±0.6111	0.4413±1.3052	0.5913±1.8215	0.0326±2.2409
^{232}Th(shotcrete)	4.4768± 2.1158	10.1137±3.1802	0.4426±0.2513	0.5789±0.3640	0.0215±0.4423
^{238}U(shotcrete)	2.0017± 1.4148	4.5667±2.1370	0.4383±0.3716	0.5940±0.5130	0.0323±0.6334
^{232}Th(norite)	5.9737± 2.4441	13.3773±3.6575	0.4466±0.2197	0.5829±0.3159	0.0294±0.3848
^{238} U(norite)	1.4224± 1.1926	3.1824±1.7839	0.4469±0.4508	0.5699±0.6726	0.0168±0.8097



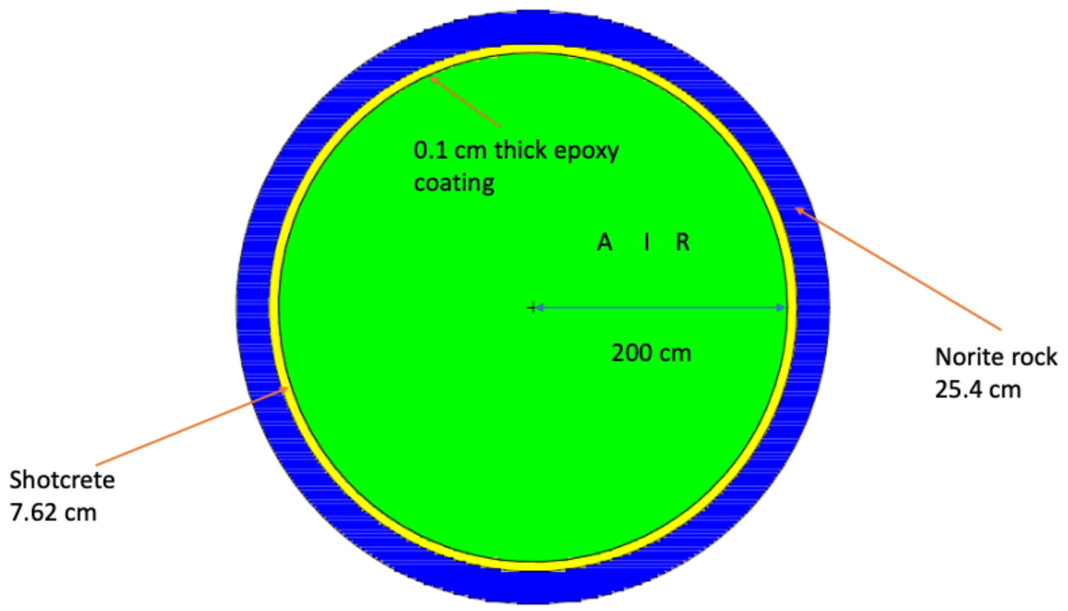
Systematic uncertainties

Effect of bubble wrap: 3 mm thickness polyethylene, density 0.017 g/cm, results in the change in the event rates is < 5%.

Effect of the drift geometry ~ 5 %

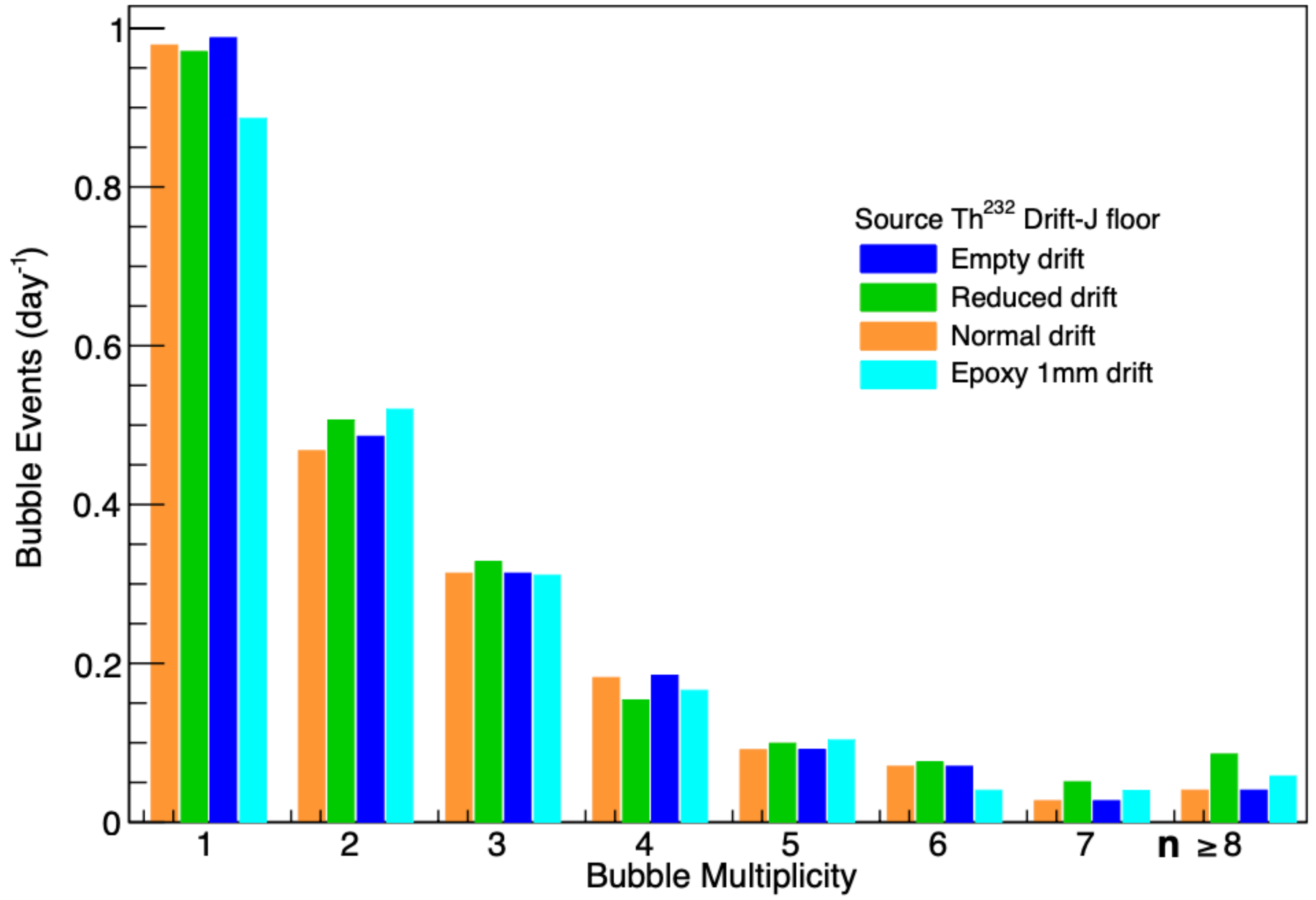
Presence of moderating materials < 2%

Epoxy layer coating ~ 1 mm thickness : < 2%



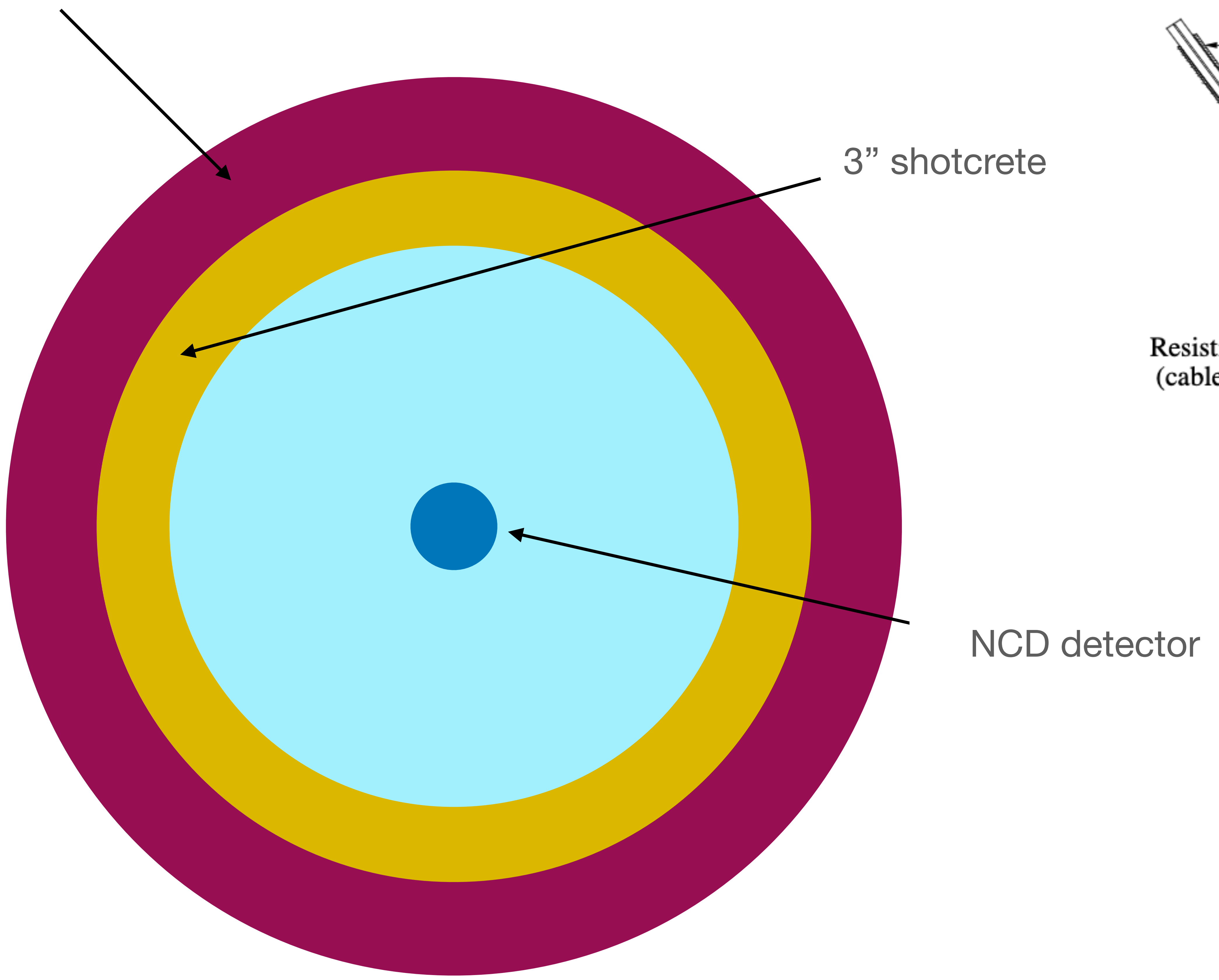
1 m epoxy coating	Rn (air)	Th (crete)	U (crete)	Th (norite)	U (norite)
% change in MFP 1 mm epoxy coating	1.32	1.97	2.0	1.01	0.96

Quantity	Original drift	Reduced Drift Volume	No-moderators config.
p-value	0.583629	0.622059 (6.58466 %)	0.58025 (-0.578964 %)
S/T	0.450749	0.427299 (-5.20245 %)	0.448658 (-0.463895 %)
S/T-(1-p)	0.0343785	0.0493577(43.5714 %)	0.0289083(-15.9117 %)
Total events	2.17166	2.27186 (4.61398 %)	2.20203 (1.39847 %)

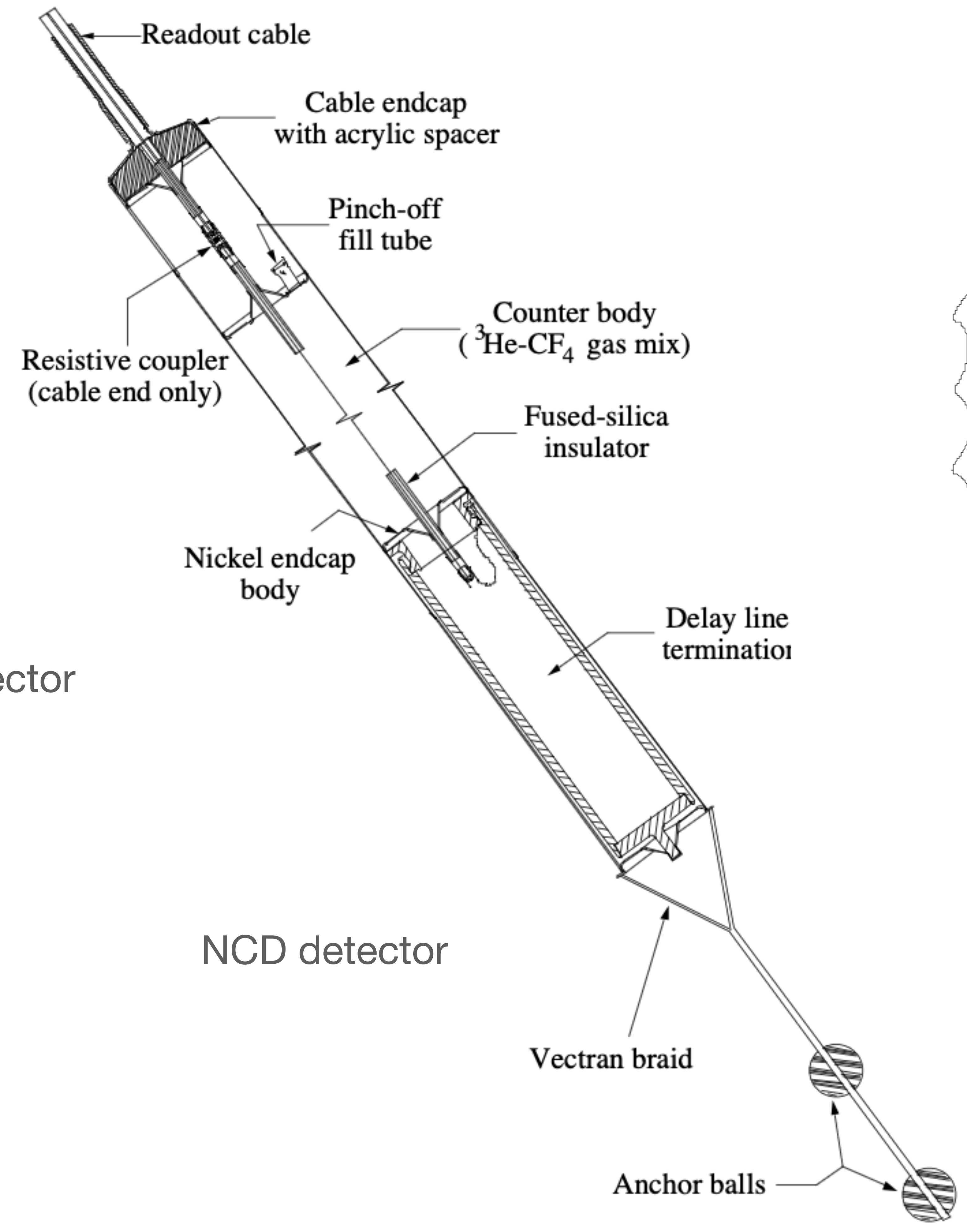


Total Systematic uncertainty ~ 8%

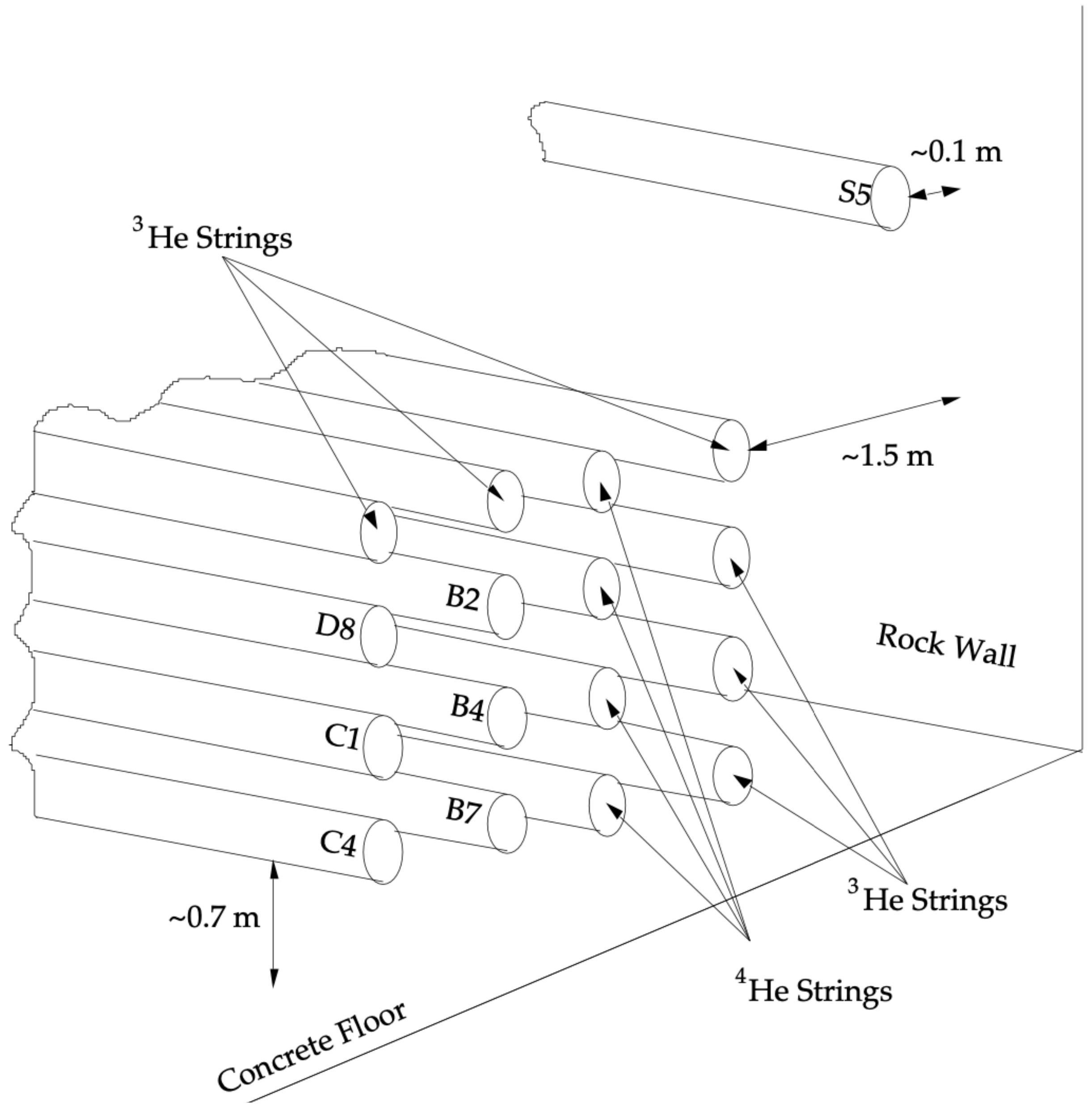
Thermal neutrons: NCD Simulation



Simple MCNP Simulation geometry (not to scale)



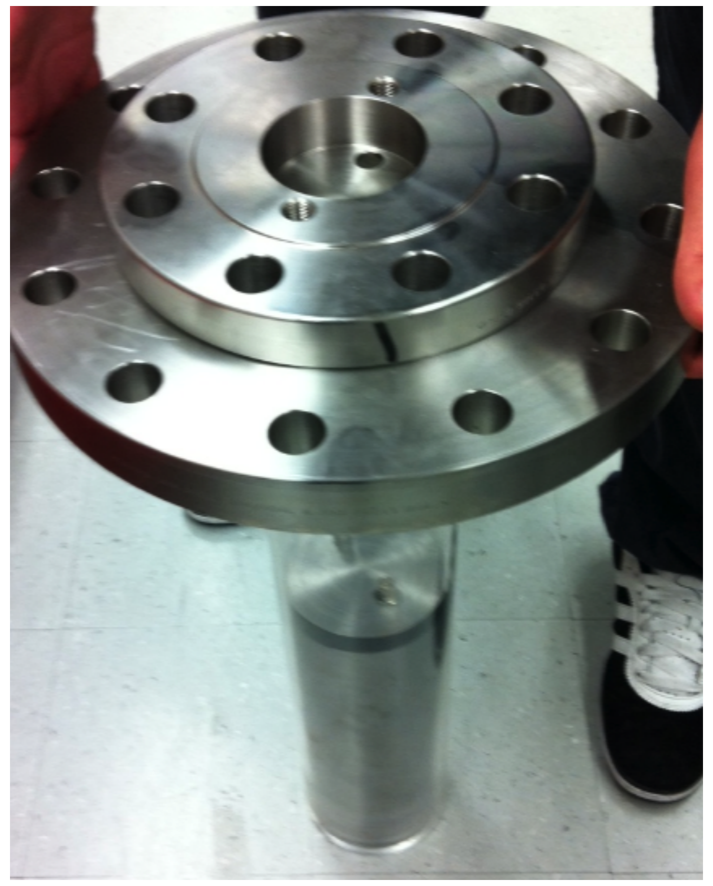
NCD detector



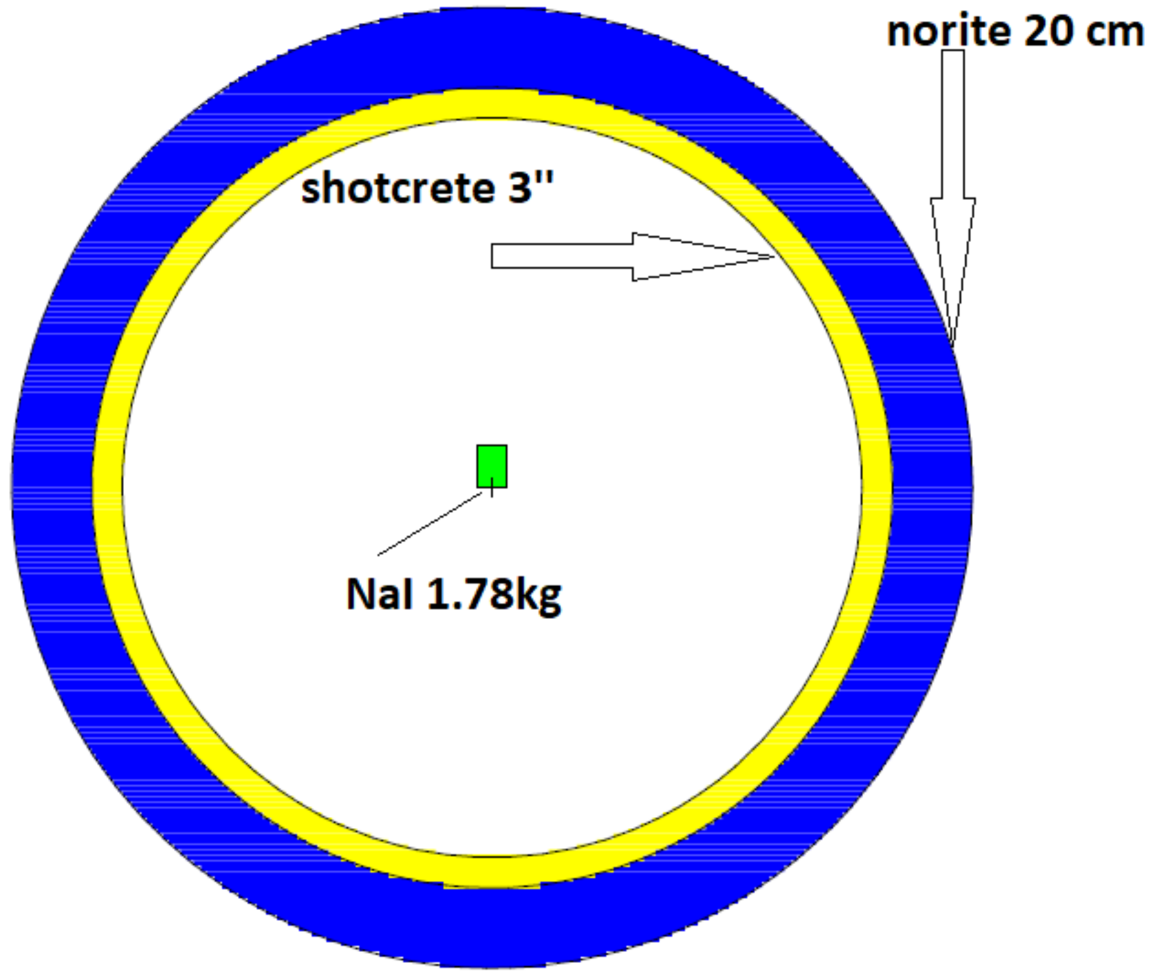
Ref. Browne thesis

Work In progress

Measurements & MCNP Simulations with 1.78 kg NaI(Tl)

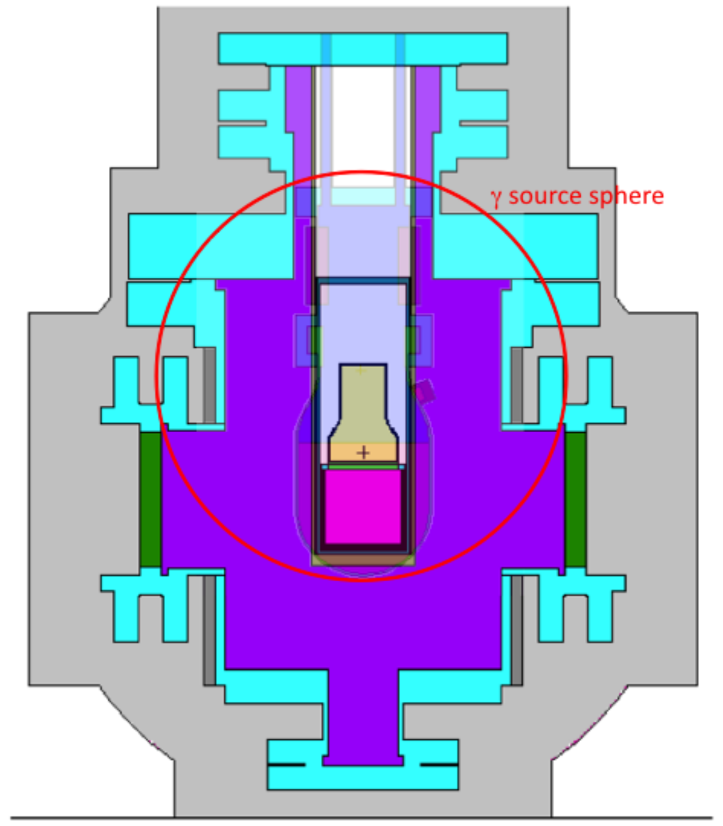


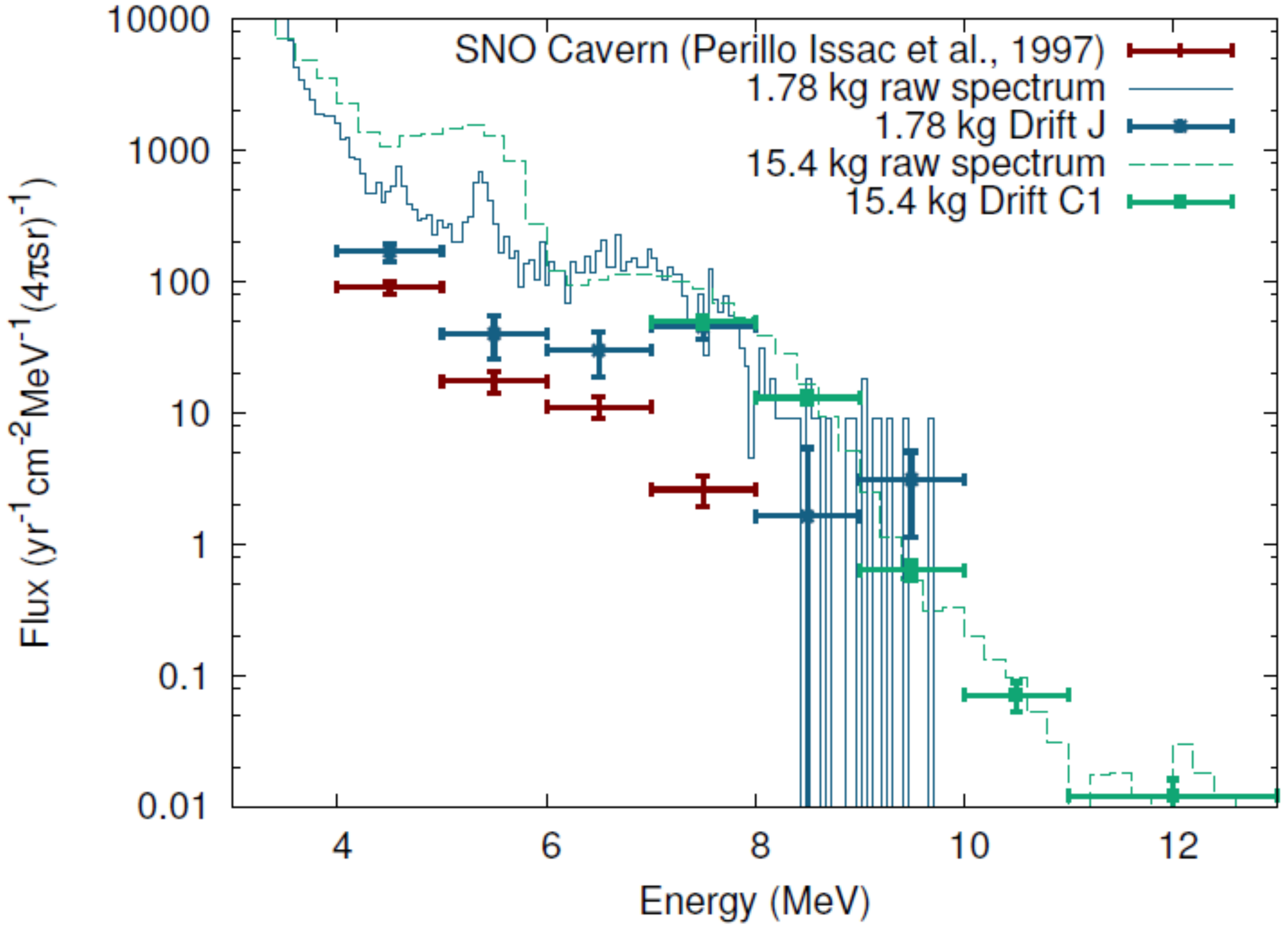
1.78 kg NaI(Tl) detector [Thesis, Alan Robinson

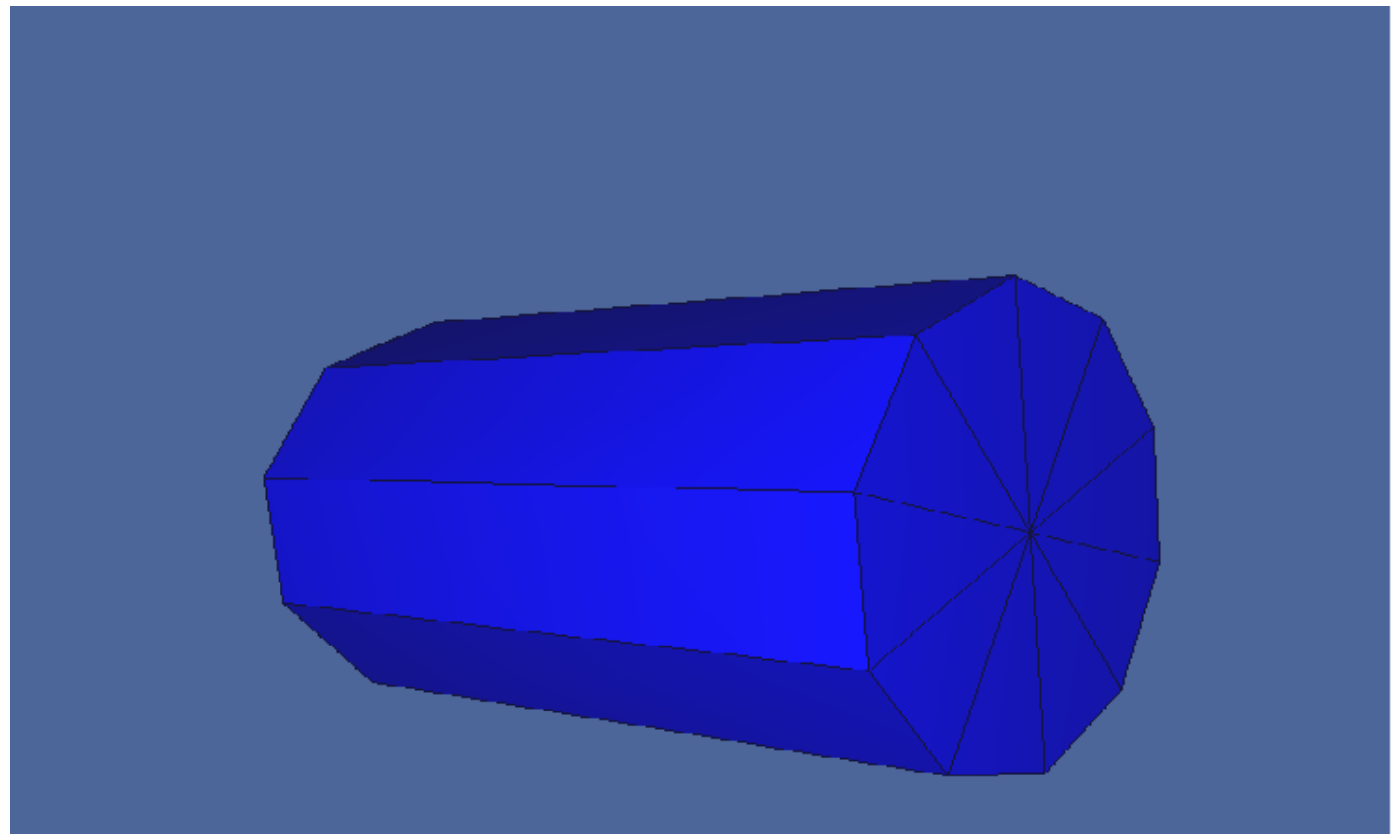


Simple NaI geometry in MCNP simulation

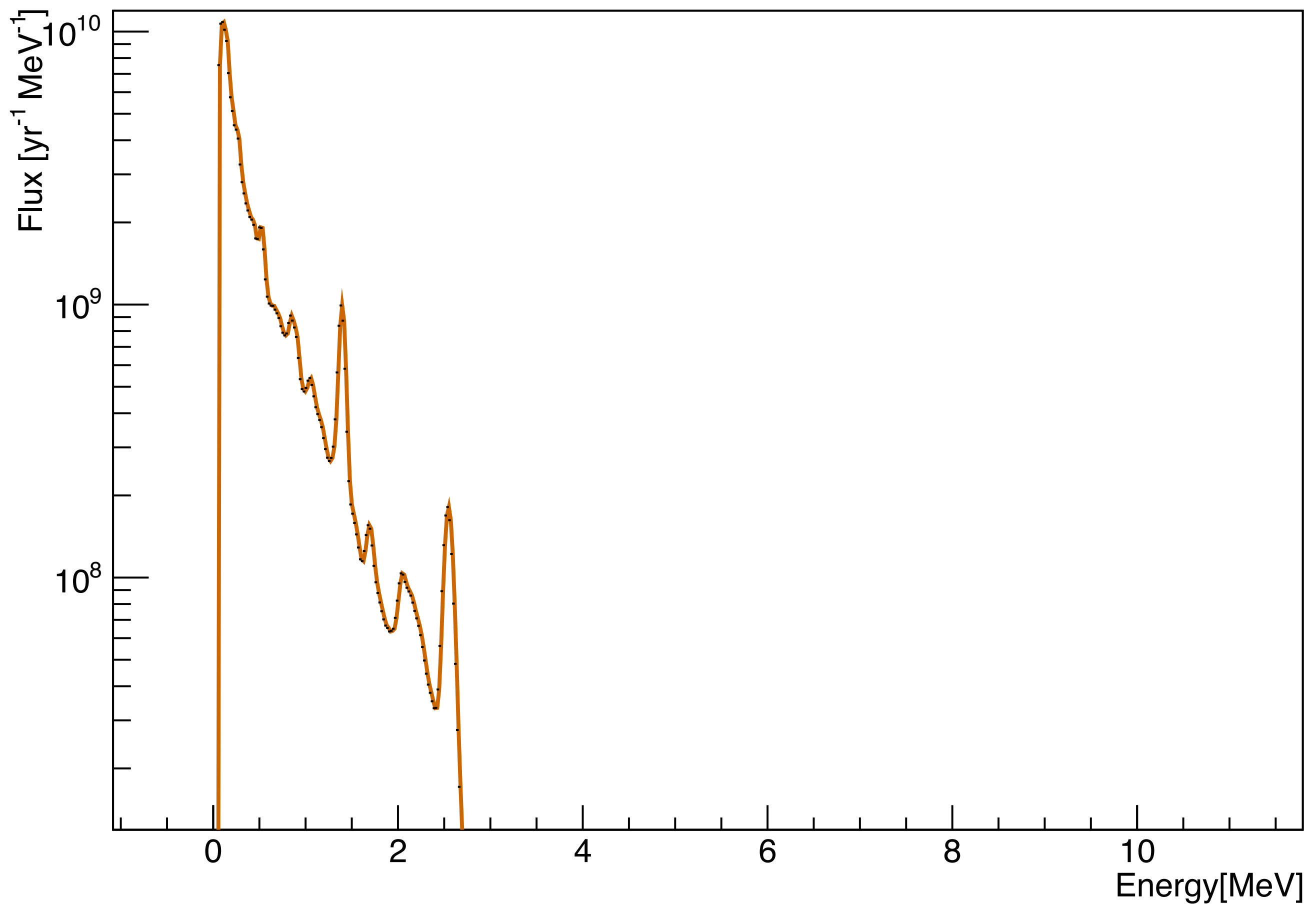
Thesis, Alan Robinson







NaI γ measurements



Work In progress

Summary & Conclusions

- Through comparing and correlating the simulations with PICO-2L and previous measurements for gamma fluxes, slow and fast neutrons, and understanding the radioactive contamination of the materials around the detector, a coherent model for the radiation environment in the SNOLAB drifts can be constructed.

- We carried out a detailed simulation of neutron propagation for PICO-2L and comparison with data is needed to understand:
  - the spectral shape of the fast neutron flux
  - the detector sensitivity
  - the effect of the drift environment on neutron propagation

- A detailed study of systematics is underway.

- Tech-note drafted, gearing up towards a publication!

- Effort is on to understand and characterize other backgrounds. Comparing the measured NaI gamma data with the gamma MCNP simulations.

- Comparison of NCD measurements and related simulation would be useful too.