Overview of New Proposed Background Model

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DEEP UNDERGROUND NEUTRINO EXPERIMENT

DUNE Backgrounds Mitigation Strategies Workshop

July 20, 2020

Radiological Model 1.0 (MCC11 & TDR) and Requirements

=> *Requirements on radiopurity driven by intrinsic Ar-39 level in LAr (1.01 Bq / kg)*

(assumed it would require 'Manhattan-Project' style effort to mitigate for DUNE)

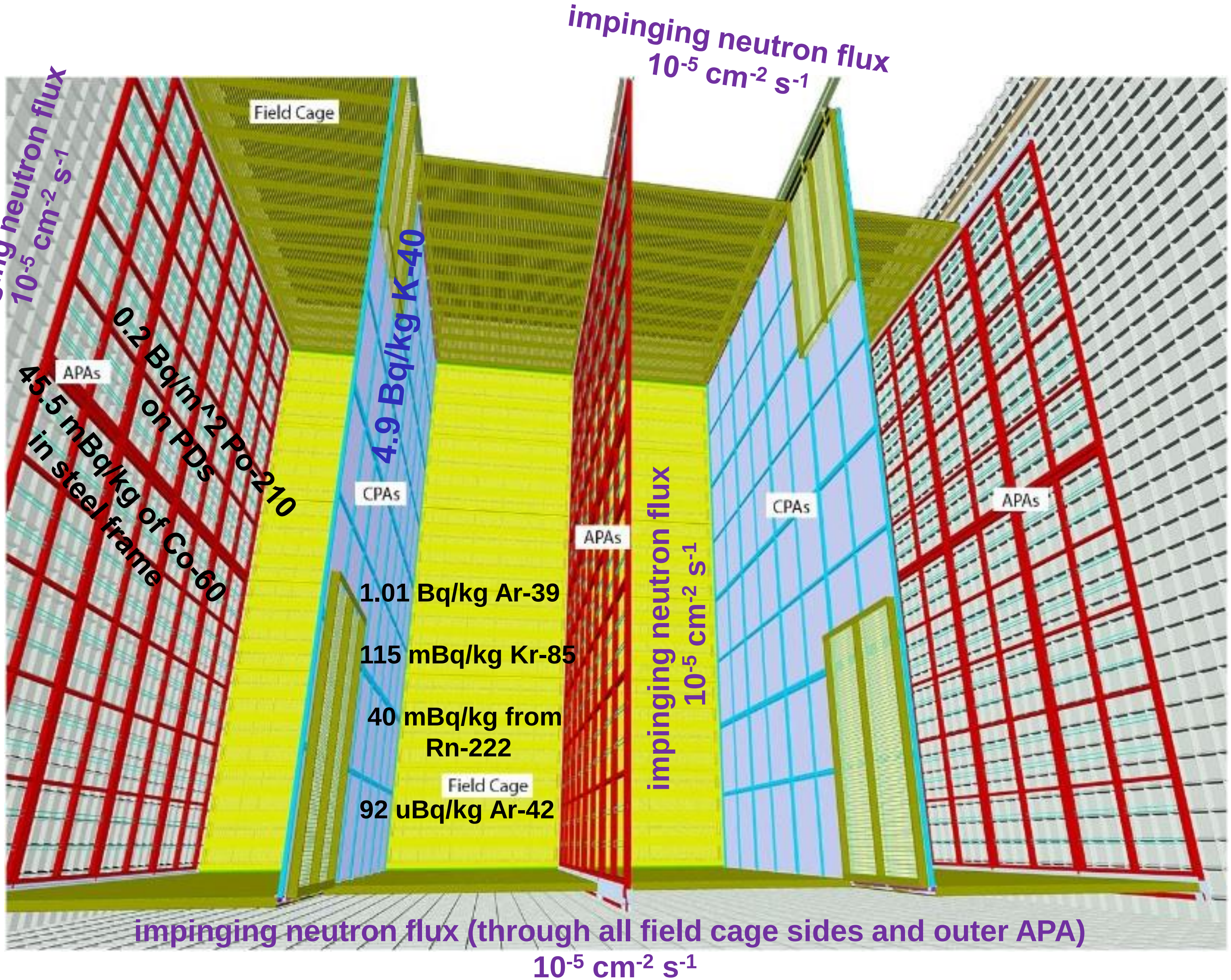
=> Paradigm for defining radiopurity requirements:
All other background signals should be order of magnitude below Ar-39 signal in every cm^3 voxel of the detector

- **Developed full-blown radiological model that is condensed into one LArSoft fcl producer file that is already input for SNB, DAQ, cosmogenics, atmospheric nu's, pdk etc.**

- **LArSoft simulations with full-blown radiological model validated requirements set on various radiological backgrounds**
  (-> Jason Stock @ APS 2017, MCC-11 2018 used for TDR, @ COSSURF 2019, DUNE BGs Mitigation Strategies Workshop CERN 2019)

- **Demonstrated that radiological control not critical for ProtoDUNE but for far detector it is!**
  (-> done its job, but time to move on to Radiological Model 2.0)

Synopsis of Simulated Radiological Backgrounds 1.0 (MCC11 & TDR)



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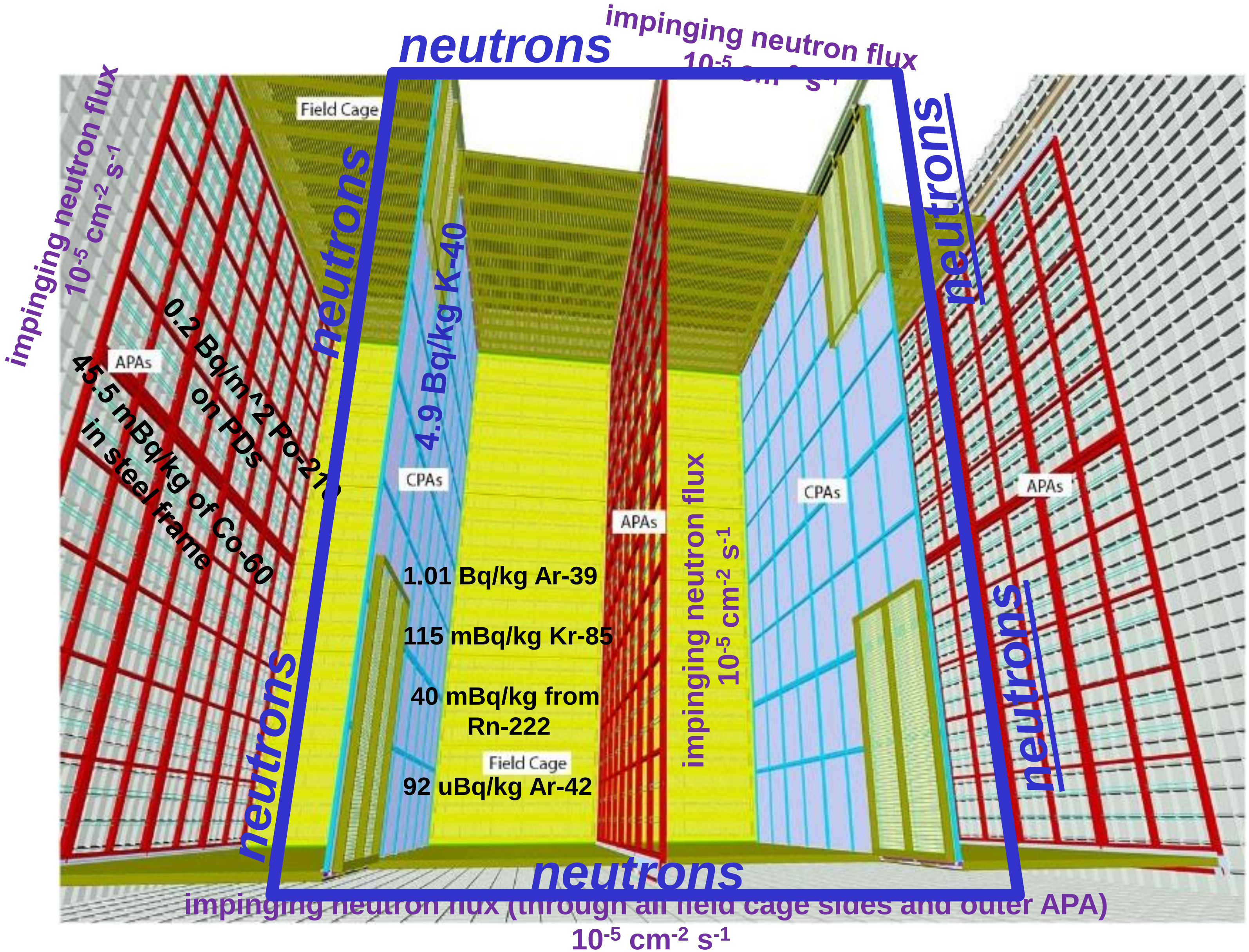
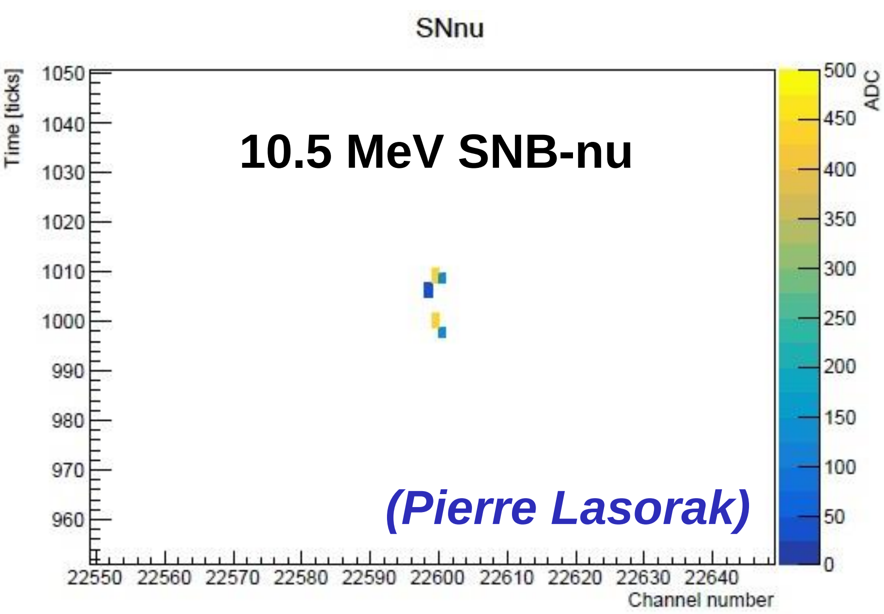
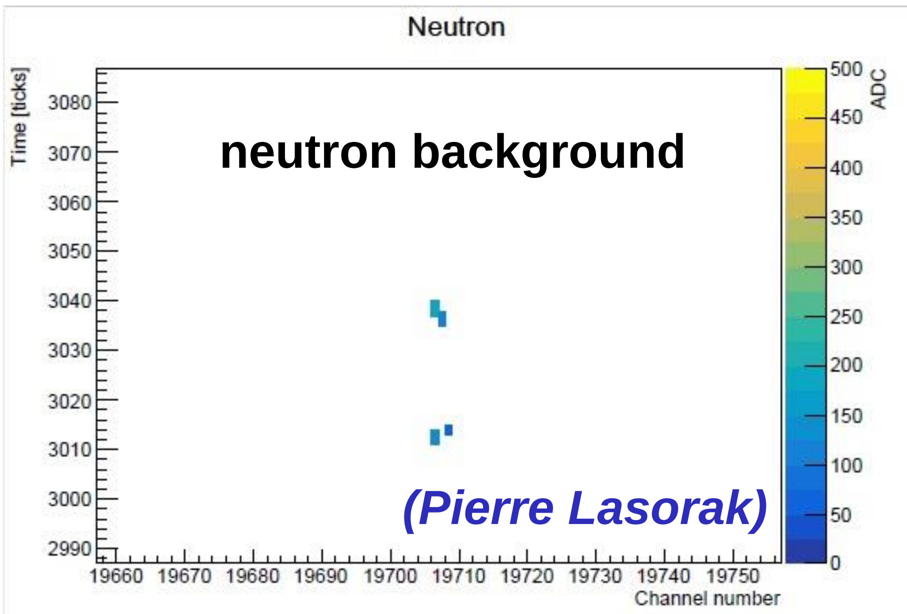


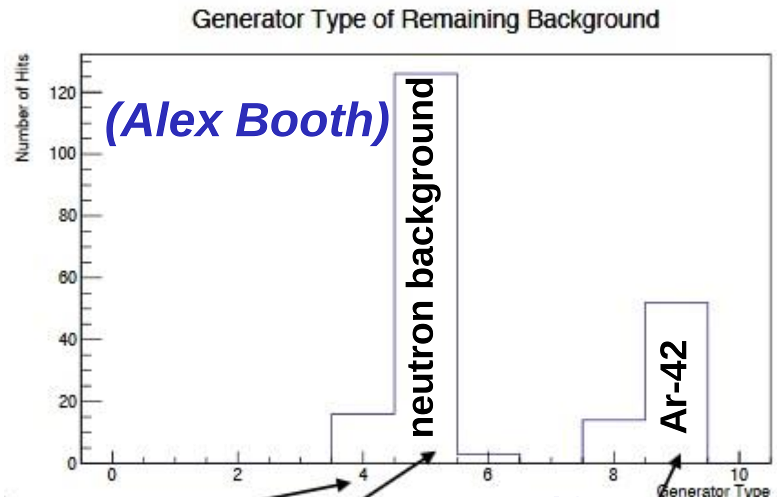
FD Sim Geometry 1x2x6 (just 1 APA in middle)!

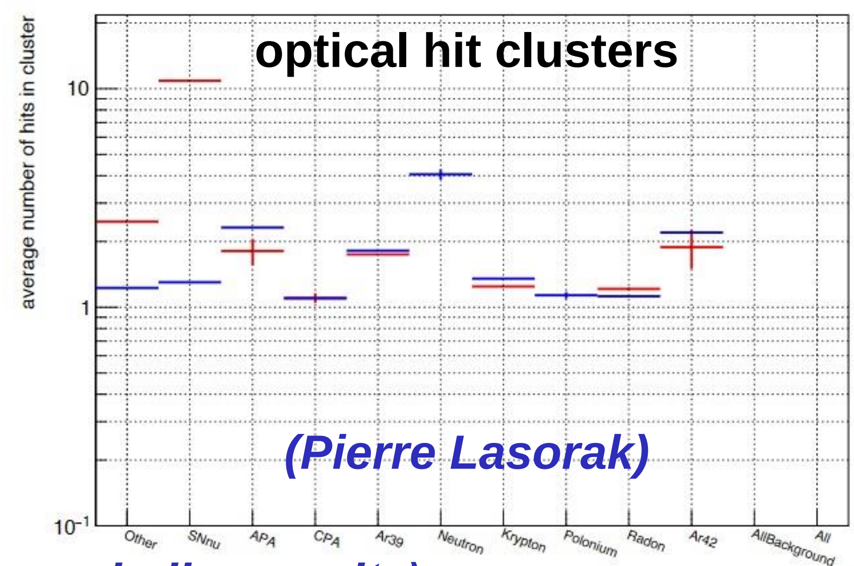
Neutron Background Critical for SNB-ν Triggering 1.0 (MCC11 & TDR)





SN Efficiency: 81.2%, Bkgd: 0.19Hz





(Georgia's group has similar results)

Lessons: Paola's and Juergen's Comparison (6/19/19)
Input Radiological Neutron Flux

Juergen:

(measured himself at Ross campus): **7.6 e-6 neutrons cm^-2 sec^-1**

- Heise: "The Poorman rock formation surrounding the Ross Campus is slightly higher in natural radioactivity: 2.58 ppm U, 10.48 ppm Th"
- Best et al 2015 measurement of 8.1 e-6 neutrons cm^-2 sec^-1 (SURF TCR)
- Dongming et al: 3.43 ppm U and 7.11 ppm Th -> 5.1 e-6 neutrons cm^-2 sec^-1 predicted

Paola:

4.2 e-7 neutrons cm^-2 sec^-1 => factor 18 discrepancy [flux factor]

(from Gran Sasso Hall C with 0.66 ppm U-238 and 0.066 ppm Th-232 neutron measurement Arneodo et al 1999)

- Best et al 2015 measurement of 3.2 e-7 neutrons cm^-2 sec^-1 (Gran Sasso Hall A with 6.80 ppm U-238 and 2.17 ppm Th-232) *-> does this make sense?*

- two measurements of 3 e-6 neutrons cm^-2 sec^-1 (E. Bellotti 1985 & M. Cribier 1995)

(Paola's foam contribution becomes then subdominant compared to the much higher neutron flux at SURF compared to Gran Sasso)

Lessons: Paola’s and Juergen’s Comparison (6/19/19) Fiducialization

Paola's inner fiducialization:

-> factor 10 reduction [**fiducialization factor**]

DUNE cannot easily do because we have to use full active TPC volume for triggering

Lessons: Paola’s and Juergen’s Comparison (6/19/19)
Moderation in Foam of Cryostat Membrane

=> factor 3 reduction due to moderation in 80 cm thick 0.1 g/cm^3 PUF foam

Juergen presented same reduction number from his external MCNP/Geant4 He-3 test stand study (see slide 17+18 in Juergen's workshop presentation and slide 14 in Paola's workshop presentation)

=> factor 3 reduction due to extinction in 40 cm thick "dead" LAr shell

Juergen's hypothesis and Paola found it reasonable

=> implement and simulate full 10 kton detector geometry into LArSoft

Lessons: Paola's and Juergen's Comparison (6/19/19) Comparison of Neutron Capture Rates

Paola's (200 events / year / ton) * 10 * 10^3 tons / (3e7 sec / year) *

- 18 [flux factor] * 10 [fiducialization factor] *
- 3 [PUF foam moderation] * 3 [dead LAr shell extinction]

= 108 neutrons / sec captured

in good agreement with:

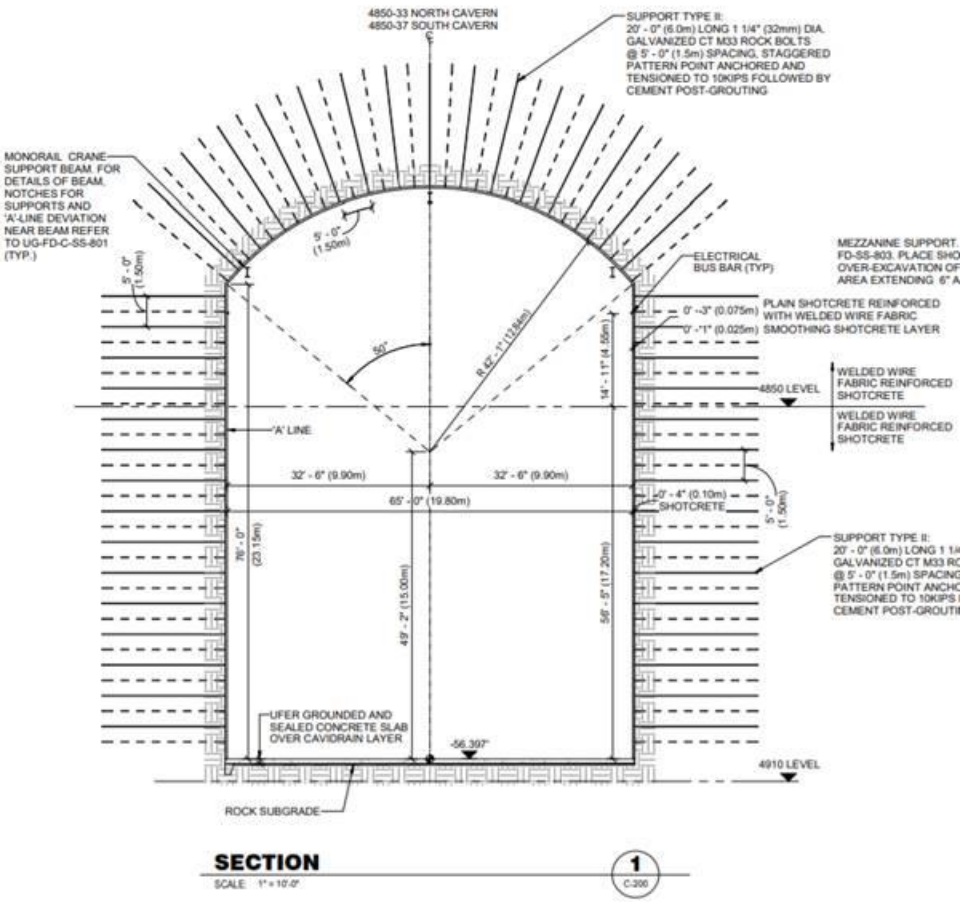
104 Hz DUNE LArSoft (Geant4)

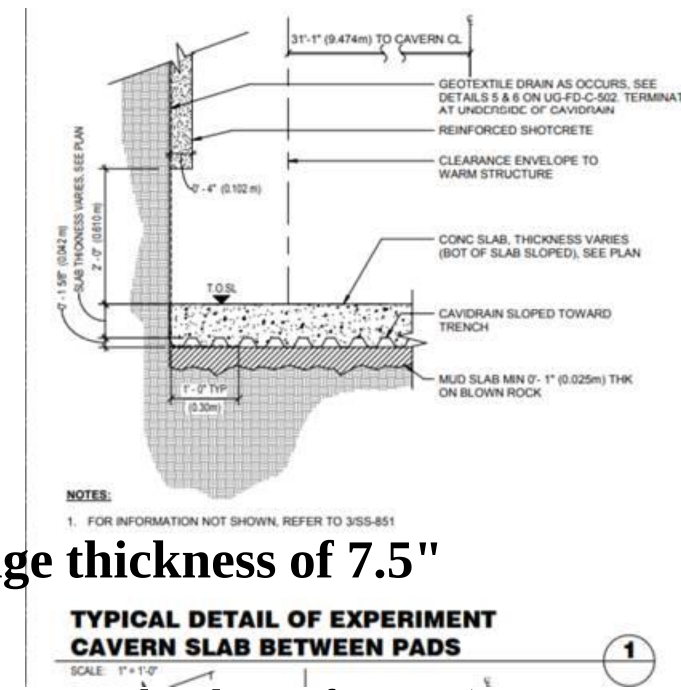
81 Hz Beacom et al (FLUKA)

=> Can expect reduction of these numbers by one order of magnitude when simulating full cryostat geometry with LArSoft!

Cavern Shotcrete 1.) and Concrete 2.) Details

1.) cavern walls and the ceiling assume an average **thickness of 6" for the shotcrete** (lower 6 ft on the walls will be just left to be bare rock)





2.) For the bottom **concrete slab assume an average thickness of 7.5"**

2.b) 1" thick layer of grout (Sikadur 42?) is just locally placed under the support I-beams (-> leave void volume for now)

Identified 3 Different Potential Suppliers (Collected and Analyzed Detailed Ingredients at SDSMT)

(example Pete Lien & Sons)

Cement:	Type I-II (LA), GCC Dacotah Cement, Rapid City, SD
Fly Ash:	Class F Modified, Boral Resources, Coal Creek, ND
Coarse Aggr.:	Crushed Limestone, Pete Lien & Sons, Inc., Rapid City, SD
Fine Aggr.:	Natural Sand, Pete Lien & Sons, Inc., Oral, SD
Fine Aggr.:	Fine Limestone, Pete Lien & Sons, Inc., Rapid City, SD
Admixtures:	BASF Admixtures Co., Air Entraining Agent, MBVR Water Reducing Agent, Polyheed 997 & 322N

Required Strength:	4000 PSI Comp. @ 28 Days
Maximum Size Course Aggr.:	3/4 Inch ASTM C-33
Slump:	4 ± 1 Inch
Air Content:	4.5 – 7.5%

Cement (Sp. Gr. 3.15):	452 Lbs.	2.30 CF
Fly Ash: (Sp.Gr. 2.59):	112 Lbs.	0.69 CF
Course Aggr. (Sp. Gr. 2.68):	1745 Lbs.	10.43 CF
Fine Aggr. Oral (Sp. Gr. 2.62):	394 Lbs.	2.41 CF
Fine Aggr. Rapid City (Sp. Gr. 2.66)	917 Lbs.	5.52 CF
Water (@ Maximum Slump):	30.5 Gals. (254 Lbs.)	4.07 CF
MBVR:	3 Ozs. (Approx.)	1.62 CF
997:	12.0 Ozs. (Approx.)	
322N:	12.0 Ozs. (Aprrox.)	
Theoretical Yield @ 6.0% Air		27.04 CF

Water/Cementitious Ratio:	.45
Percent Fine Aggregate:	43%
Cementitious Factor:	6.00 Sacks

⇒ **Goal not only to realistically simulate external neutron backgrounds but also to identify best possible supplier regarding background mitigation!**

Chemical Composition & Density of Rock and Shotcrete Materials Measured at SDSMT

sample	description	*density [g/cm^3]*	*error*	O [a%]	Fe [a%]	Mn [a%]	Ca [a%]	K [a%]	Si [a%]	Al [a%]	Mg [a%]	Na [a%]	N [a%]	C [a%]	H [a%]
#1	DUNE Ross - #6 Winze	2.67	0.05	55.3	2.8	0.0	0.0	0.3	13.9	6.0	6.8	0.2	0.0	0.0	14.8
#2	DUNE Ross - Governor's Corner	2.65	0.10	62.4	0.6	0.1	0.0	2.0	26.2	3.1	1.1	0.5	0.0	0.0	4.0
#3	DUNE Ross - Test Blast Site	2.68	0.10	54.8	2.5	0.0	0.1	0.4	13.3	6.6	6.1	0.1	0.0	0.0	16.0
#4	DUNE Ross - #4 Winze	2.60	0.09	62.8	0.0	0.0	0.4	3.7	26.8	3.9	0.0	2.0	0.0	0.0	0.5
mean	**mean DUNE rock**	**2.65**	**0.04**	**58.742**	**1.501**	**0.030**	**0.112**	**1.554**	**19.854**	**4.940**	**3.580**	**0.692**	**0.000**	**0.000**	**8.996**
mean	Serenity's x-check on DUNE rock			58.9	1.5	0.0	0.1	1.6	20.0	4.9	3.5	0.7	0.0	0.0	8.8
mean	Vitaly/Aran early numbers			59.0	2.3	0.0	0.1	1.4	18.3	7.6	2.2	0.6	0.0	0.0	8.5
shotcrete	***& concrete ingredients:***		<XRF>	56.4	4.1	0.05	6.63	3.04	21.32	4.95	2.29				
Pete Lien	sand (Cheyenne River, Oral/SD)	2.56	0.09	64.3	0.0	0.0	0.0	2.7	26.3	2.4	0.0	1.2	0.0	3.1	0.0
TCC	sand (commercial bag)	2.66	0.10	64.6	0.0	0.0	0.0	2.4	28.3	2.2	0.0	1.1	0.0	1.4	0.0
Croell	sand (Fisher in Nisland/SD)														
Pete Lien	gravel (Rapid City limestone quarry)	2.57	0.09	58.4	0.0	0.0	24.7	0.0	0.5	0.0	0.0	0.0	0.0	16.4	0.0
TCC	gravel (bag from South America)	2.49	0.09	63.1	0.0	0.0	0.0	5.1	27.4	3.6	0.0	0.8	0.0	0.0	0.0
Croell	gravel (Rogers Pit, Sundance/WY)	*2.9 cement?*													
GCC	Portland cement (Rapid City)	1.34	0.14	54.1	0.2	0.0	29.9	0.0	6.5	0.1	2.3	0.0	0.6	3.4	3.0
Whelan Energy	fly ash (power plant, Hastings/NE)	2.90	0.04	44.1	3.8	0.0	21.1	0.2	14.3	8.8	4.1	0.0	0.0	0.0	0
SURF	water (4850 Davis industrial & sump)	1.00	0.01	33.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	66.7
mean	**mean Pete Lien**	2.332		**56.538**	**0.132**	**0.001**	**21.061**	**0.283**	**4.173**	**0.514**	**0.382**	**0.120**	**0.067**	**12.005**	**4.724**
mean	mean TCC	2.501		60.121	0.132	0.001	4.100	3.123	23.129	2.630	0.382	0.717	0.067	0.874	4.724
mean	mean Croell		<XRF>	53.787	2.737	0.055	28.798	0.550	7.033	1.291	0.359				4.724
mean	mean combined contractors	2.40	0.10	56.815	1.000	0.019	17.986	1.319	11.445	1.479	0.375	0.279	0.044	4.293	4.724

⇒ **Also measured composition of PUF foam of cryo insulation**

⇒ **Composition of steel of I-beams and SS of cryostat wall are well specified by LBNF**

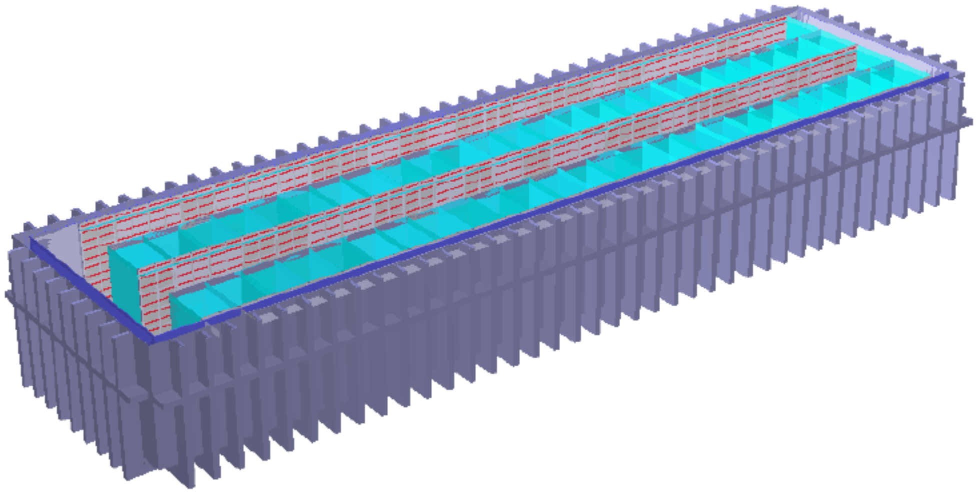
Radioactivity of Rock and Shotcrete Materials Measured at SDSMT

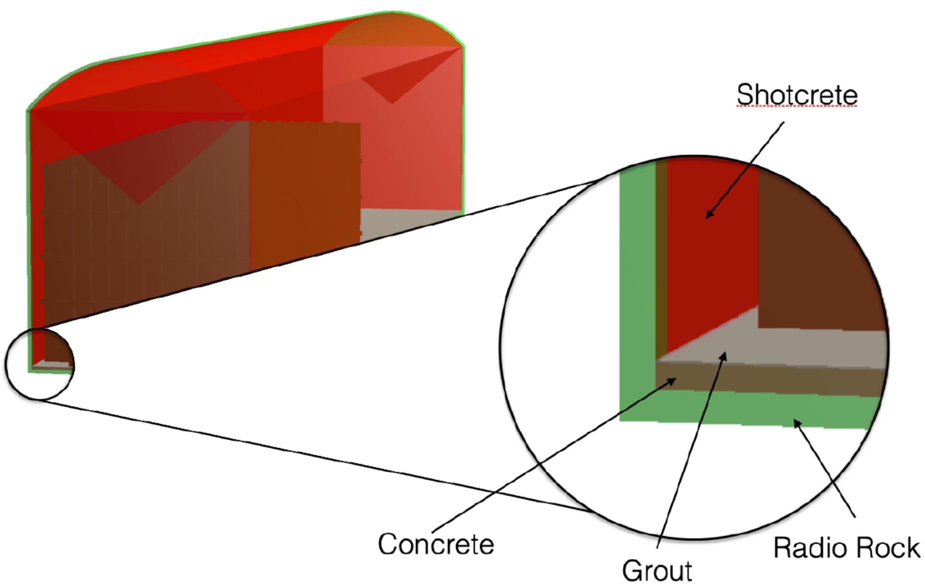
sample	description	U-238 [Bq/kg]	error [Bq/kg]	ppm U	err. [ppm]	Ra-226 [Bq/kg]	error [Bq/kg]	Th-232 [Bq/kg]	error [Bq/kg]	ppm Th	err. [ppm]	K-40 [Bq/kg]	error [Bq/kg
#1	DUNE Ross - #6 Winze	35.6	5.0	2.88	0.40	66.0	0.8	48.9	0.4	12.03	0.09	435.3	1.7
#2	DUNE Ross - Governor's Corner	24.4	6.9	1.98	0.56	79.1	1.1	20.5	0.4	5.05	0.10	420.6	2.4
#3	DUNE Ross - Test Blast Site	63.0	7.8	5.11	0.63	146.0	1.5	19.6	0.4	4.83	0.11	376.3	2.3
#4	DUNE Ross - #4 Winze	107.0	9.5	8.66	0.77	172.5	1.3	38.1	0.5	9.38	0.13	1429.7	4.0
mean	**mean DUNE rock**	**57.5**	3.7	**4.66**	0.30	**115.9**	0.6	**31.8**	0.2	**7.82**	0.05	**665.5**	1.4
mean	Serenity's x-check on DUNE rock	18.4		1.5		25.8		7.1		1.8		255.0	
mean	Vitaly/Aran early numbers	36.7		3.0		51.5		14.2		3.5		510.1	
shotcrete	***& concrete ingredients:***	U-238 [Bq/kg]	error [Bq/kg]	ppm U	err. [ppm]	Ra-226 [Bq/kg]	error [Bq/kg]	Th-232 [Bq/kg]	error [Bq/kg]	ppm Th	err. [ppm]	K-40 [Bq/kg]	error [Bq/kg
Pete Lien	sand (Cheyenne River, Oral/SD)	33.9	12.2	2.75	0.99	38.3	1.2	15.8	0.5	3.89	0.12	647.3	3.9
TCC	sand (commercial bag)	54.0	18.3	4.38	1.48	42.4	1.9	19.1	0.8	4.70	0.19	613.1	5.8
Croell	sand (Fisher in Nisland/SD)	75.4	24.5	6.11	1.98	119.3	3.1	40.3	1.2	9.91	0.30	442.8	6.0
Pete Lien	gravel (Rapid City limestone quarry)	28.1	6.5	2.28	0.53	38.2	0.9	0.8	0.3	0.20	0.06	28.1	6.5
TCC	gravel (bag from South America)	42.6	11.2	3.45	0.91	98.2	1.5	7.8	0.4	1.92	0.11	42.6	11.2
Croell	gravel (Rogers Pit, Sundance/WY)	15.1	7.6	1.22	0.61	27.1	1.0	1.0	0.3	0.25	0.07	15.1	7.6
GCC	Portland cement (Rapid City)	47.1	16.4	3.81	1.33	65.1	2.1	12.7	0.7	3.13	0.18	147.7	3.3
Whelan Energy	fly ash (power plant, Hastings/NE)	100.7	21.5	8.16	1.74	174.6	3.3	80.6	1.4	19.83	0.33	119.4	3.2
SURF	water (4850 Davis industrial & sump)	3.8	6.4	0.31	0.52	0.6	0.7	0.1	0.2	0.03	0.06	0.0	0.0
mean	**mean Pete Lien**	**31.430**		**2.546**		**42.832**		**5.996**		**1.475**		**105.849**	
mean	mean TCC	46.114		3.735		71.267		13.795		3.393		247.358	
mean	mean Croell	40.981		3.319		65.272		17.915		4.407		177.330	
mean	mean combined contractors	39.5		3.2		59.8		12.6		3.1		176.8	

- ⇒ **Also measured radioactivity of steel of I-beams and SS of cryostat wall (ProtoDUNE samples)**
- ⇒ **Also measured radioactivity of LAr filter materials for predicting dominant radon emanation into LAr**
- ⇒ **Still to be measured is radioactivity of PUF foam of cryo insulation**

New Full 10 kton Geometry

Aran Borkum, Pierre, James, Juergen





Plus additionally:

- Cavern rock
- 6” thick shotcrete layer
- 7.5” thick concrete slab

Outlook

- Simulate external neutron backgrounds with detailed propagation through rock, shotcrete, cryostat steel, foam and dead LAr

- Simulate SF and (alpha, n) backgrounds in rock, shotcrete, steel, foam, LAr according to measured sample activities and calculated detailed neutron spectra

- Identify best possible shotcrete/concrete supplier regarding background mitigation

=> In ideal case we would not even need a passive shielding!

- Realistic estimate of radon content in our LAr based on γ-ray and cold emanation sample measurements

- Migration model of radon daughter ions in LAr

- Radiological model 2.0 needed for more detailed physics studies