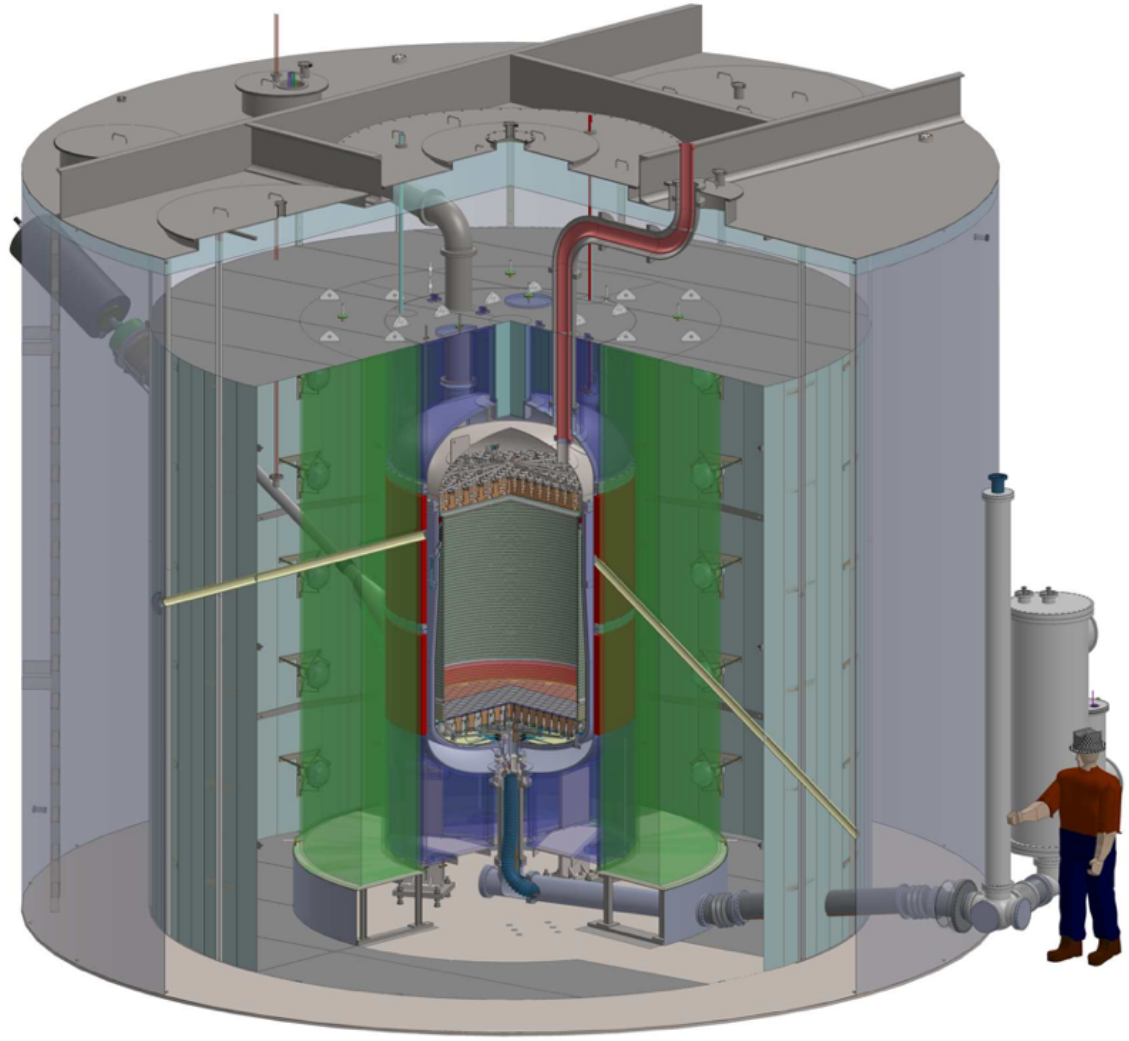


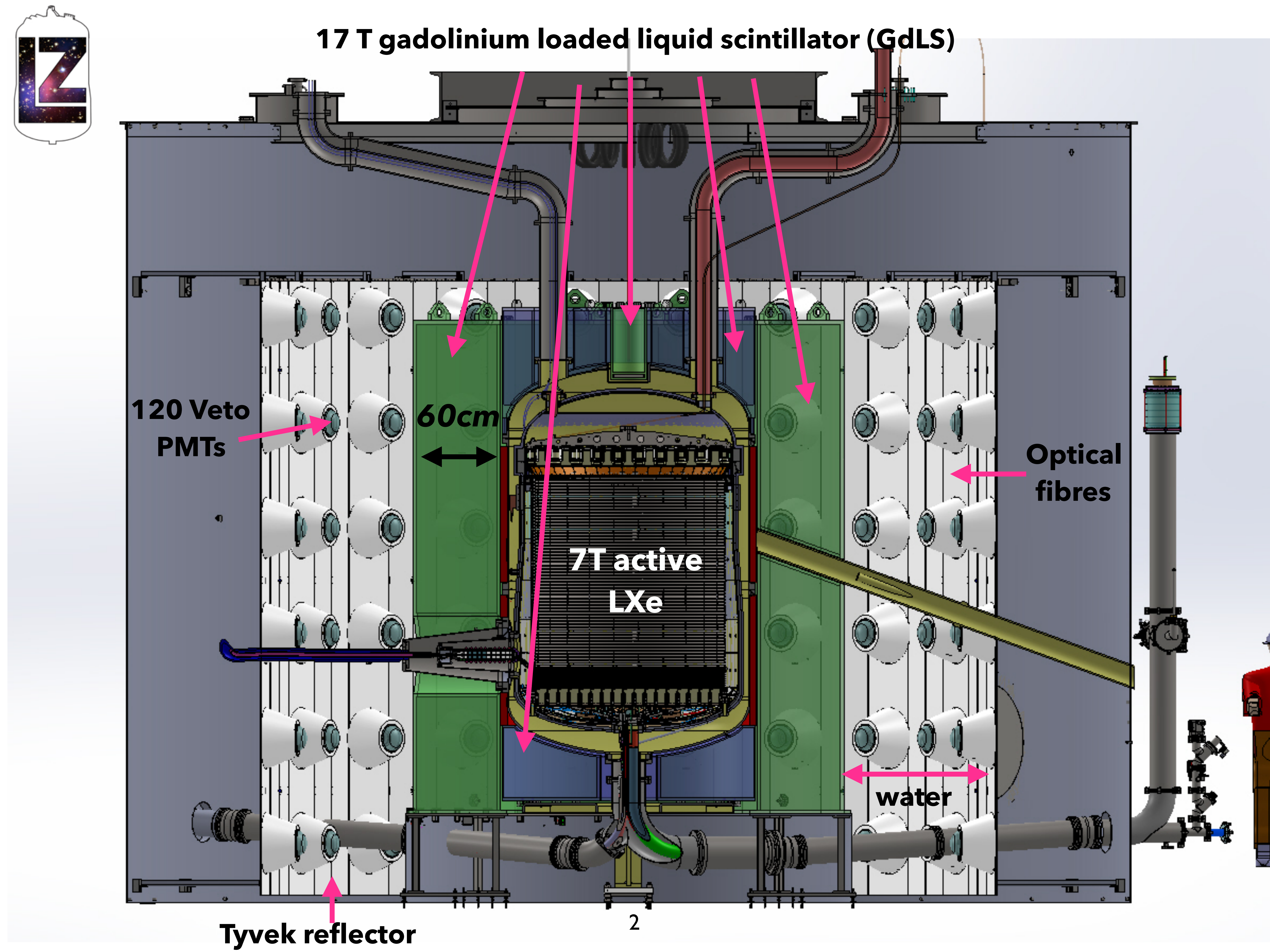
THE LZ OUTER DETECTOR

UCLA Dark Matter

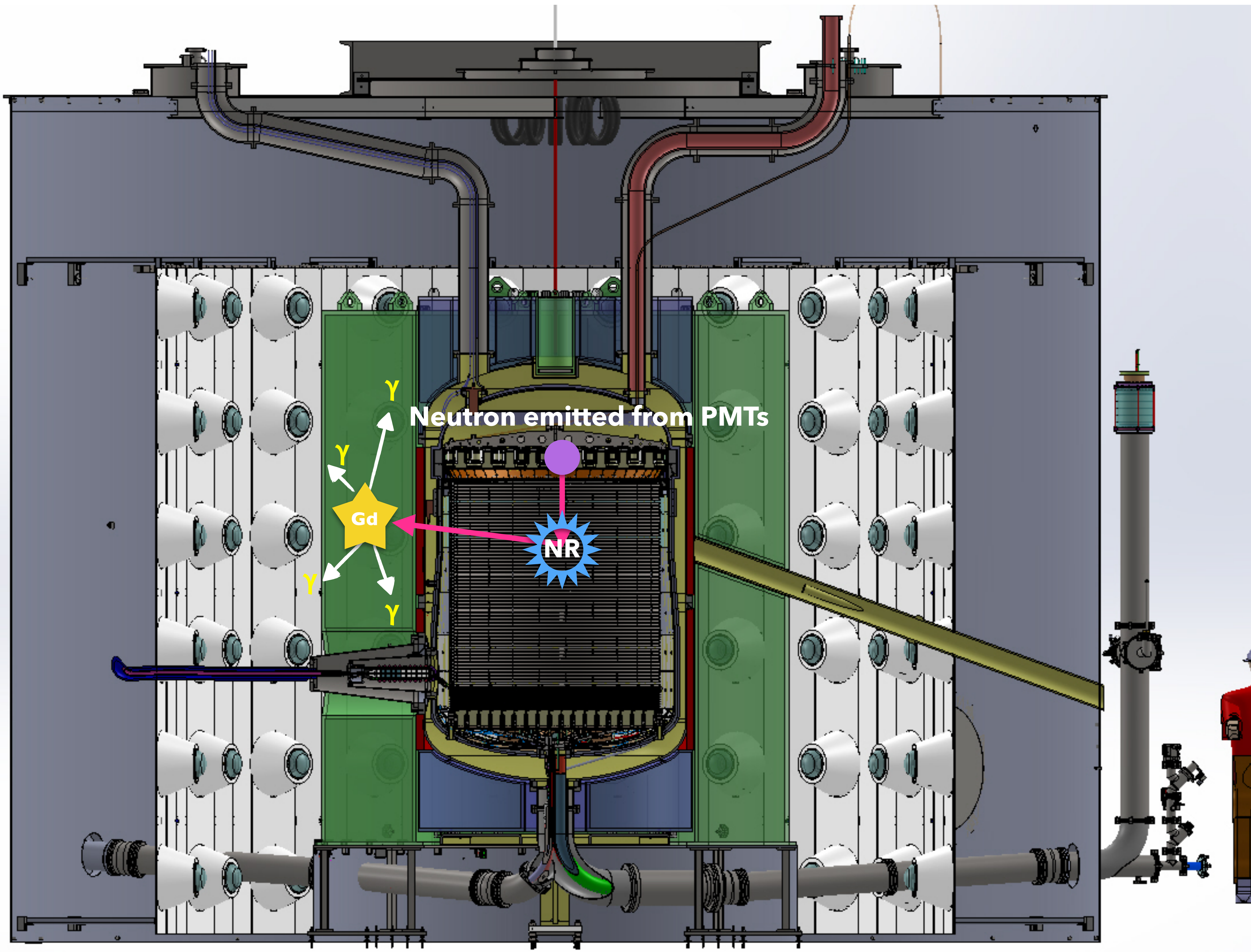
23/02/2018

Sally Shaw

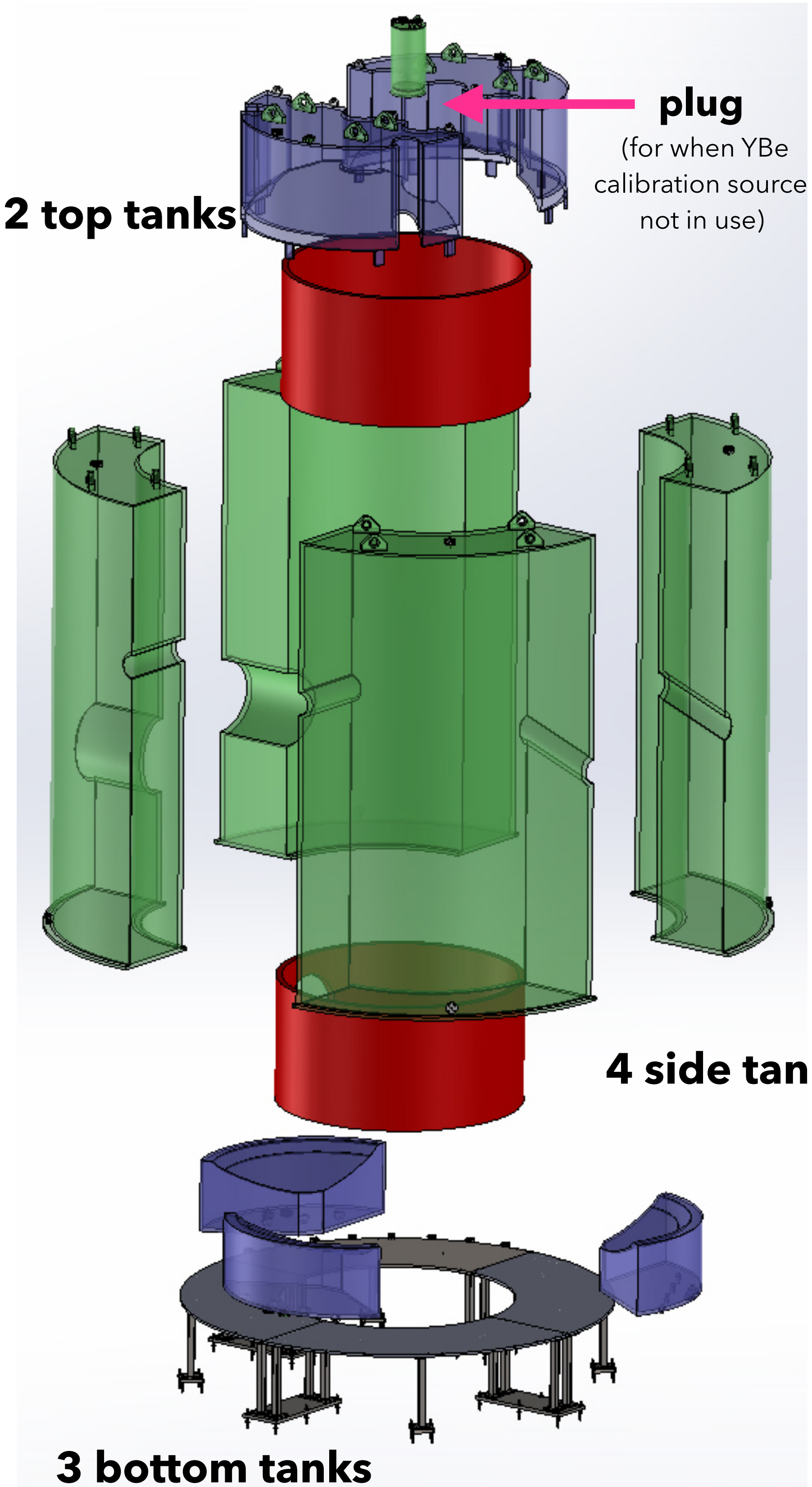
UC SANTA BARBARA PHYSICS



17 T gadolinium loaded liquid scintillator (GdLS)
120 Veto PMTs
60cm
7T active LXe
Optical fibres
water
Tyvek reflector


Neutron emitted from PMTs
Gd
NR
γ
γ
γ
γ

Acrylic Tanks



- → ICP-MS radioassay
- → UV transmission tested
- → radon exposure & dust monitored
- → strength & hardness tested

Reynolds POLYMER TECHNOLOGY, INC.
Building the Impossible

Segmented tanks - easier transport and installation underground

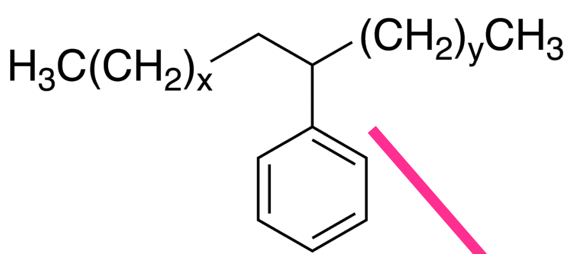
Test run with tank frame mock-up - transport tanks down shaft, through mine to Davis cavern

Fabrication almost complete - tanks are in the oven right now!

Side tank panel

side tank

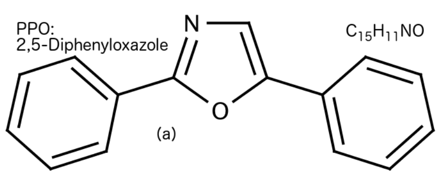
Liquid Scintillator



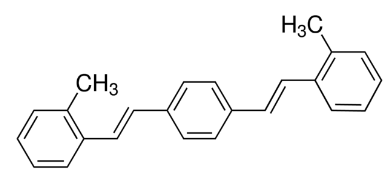
Solvent - **Linear Alkylbenzene (LAB)**

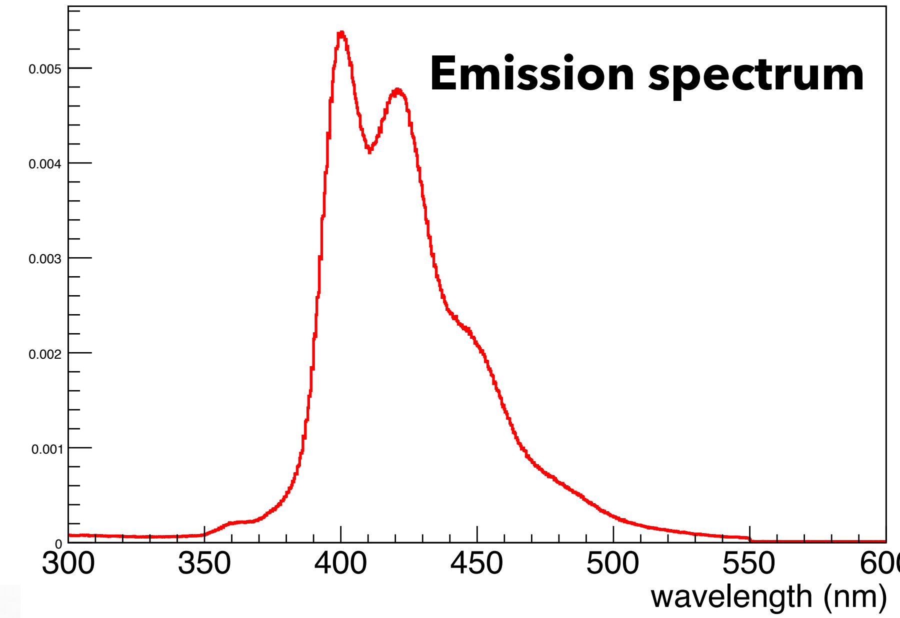
Technique - **chelation of Gd** with TMHA in LAB
→ result 0.1% Gd by mass

Fluor: PPO

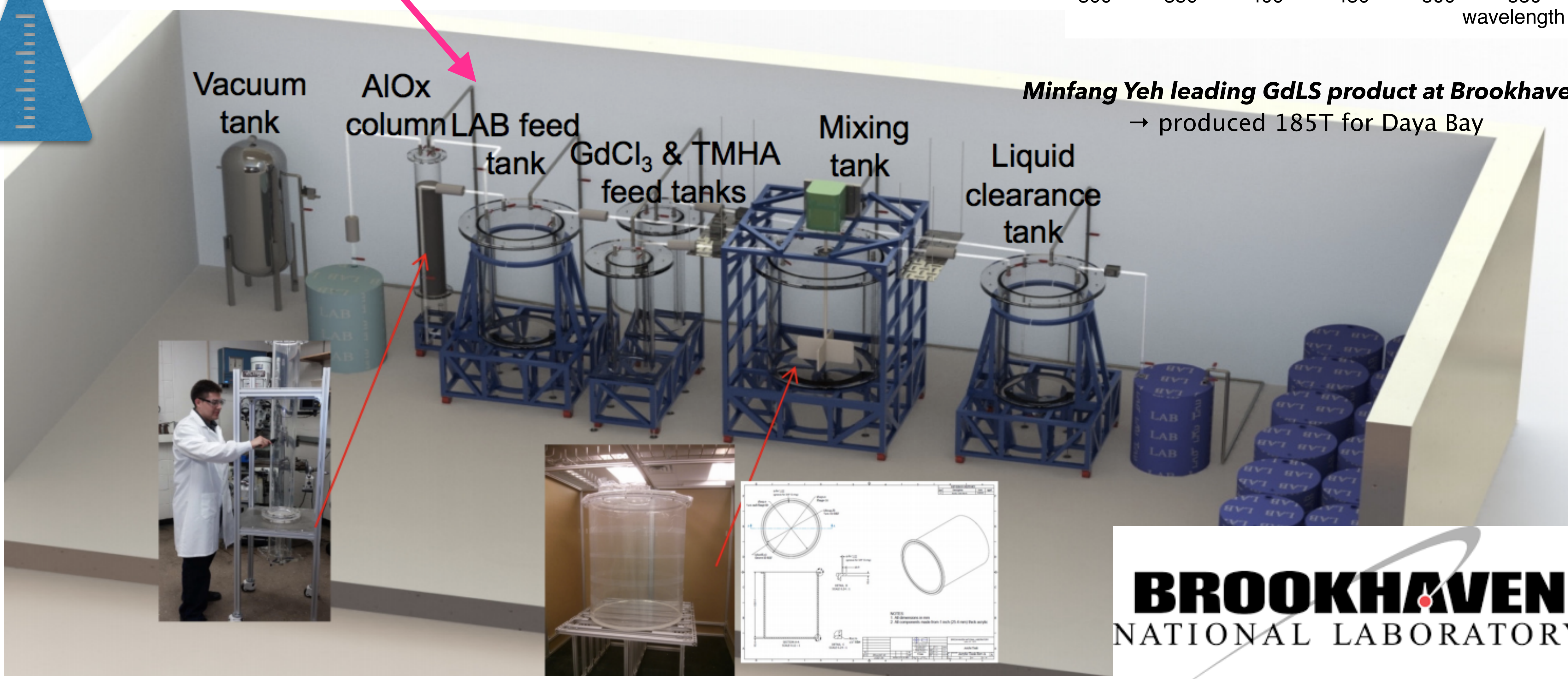


Wavelength shifter: bis-MSB



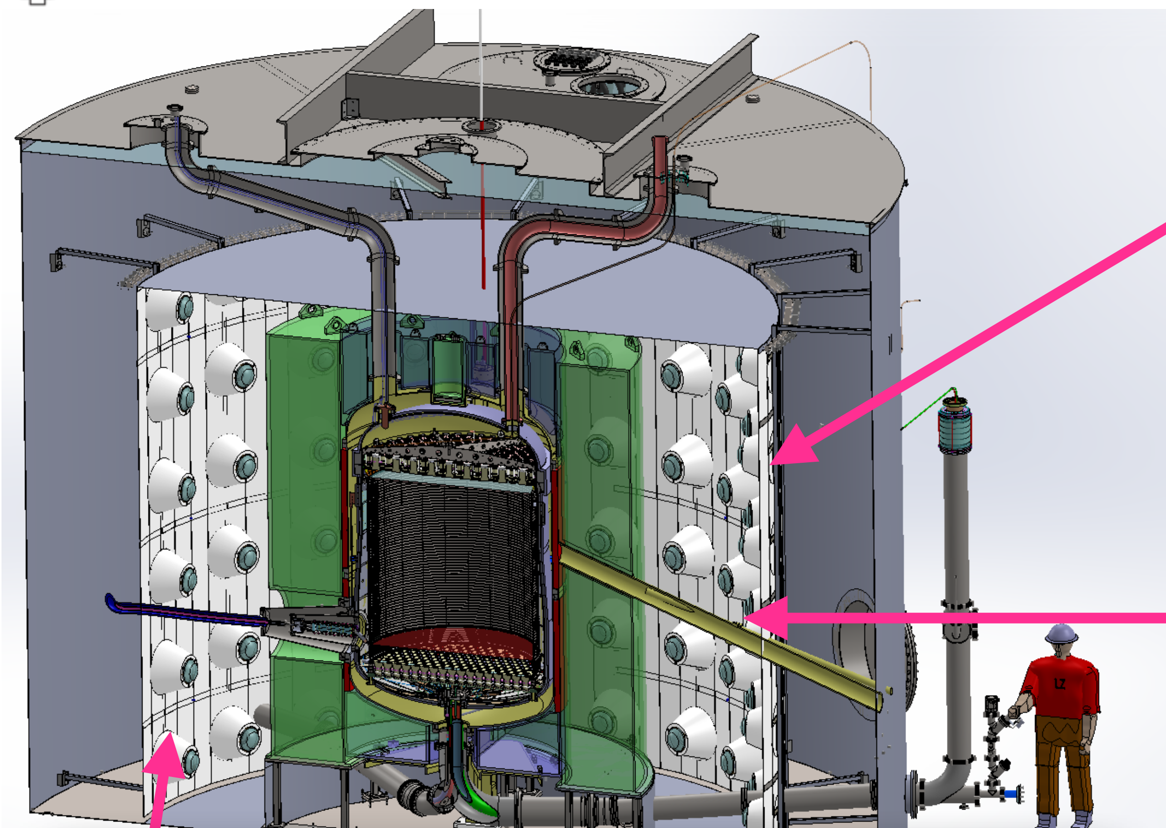


Minfang Yeh leading GdLS product at Brookhaven
→ produced 185T for Daya Bay



BROOKHAVEN NATIONAL LABORATORY

Light Collection



Brandeis University

Building and testing PMT assemblies and holders

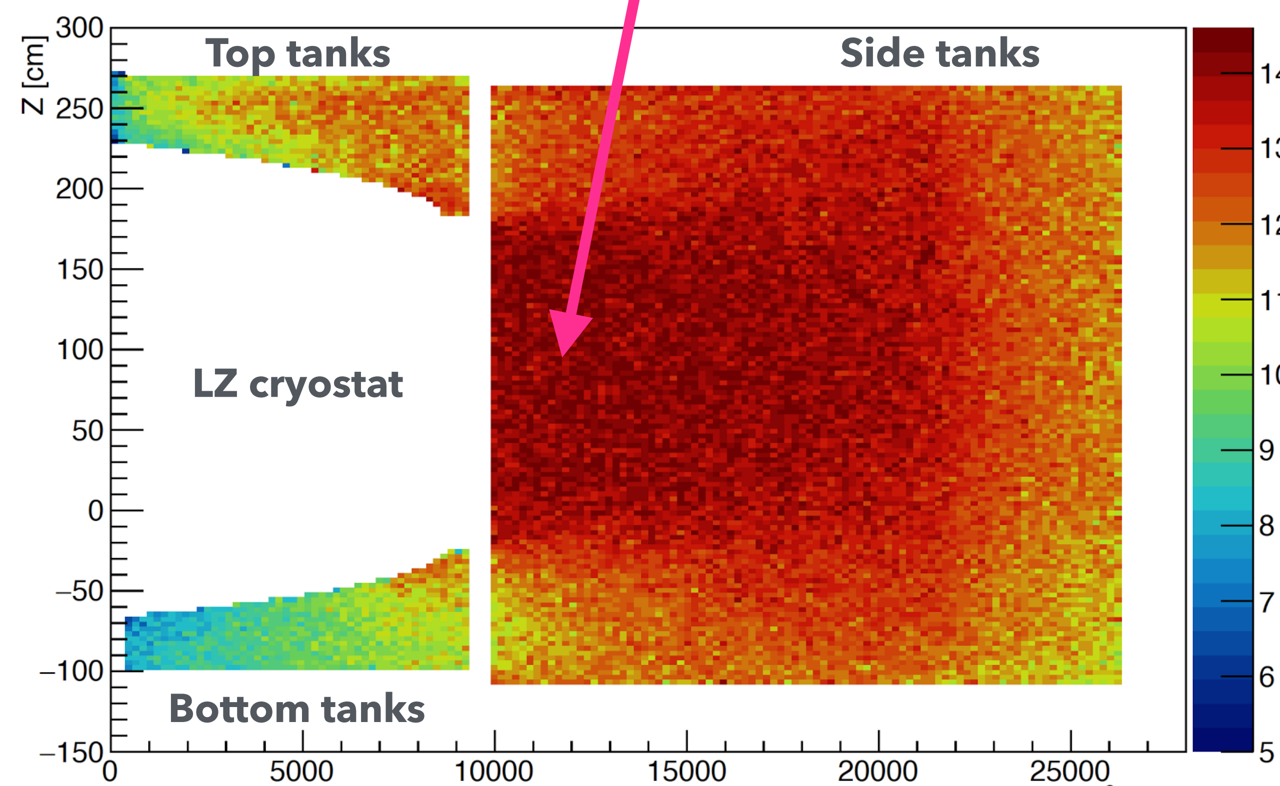
Requirement:
> 80 phe / MeV

120 Hamamatsu 8-inch PMTs procured, being tested at the IBS, South Korea

UNIVERSITY OF LIVERPOOL

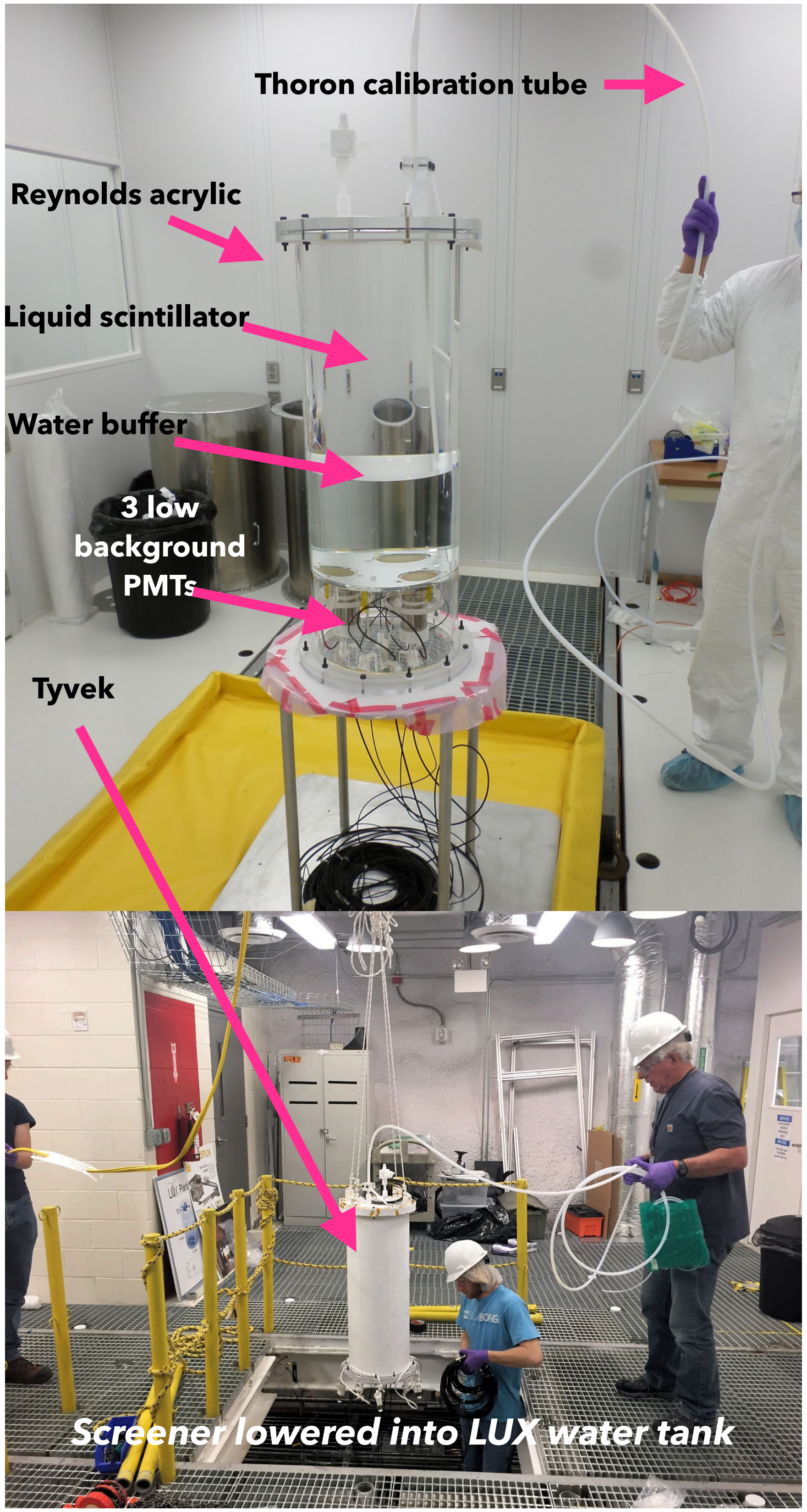
Developing optical calibration system consisting of 35 optical fibre assemblies

Enhancement from tyvek surrounding cryostat



Light collection map for uniform ^{152}Gd α-decays

Prototype - LS Screener



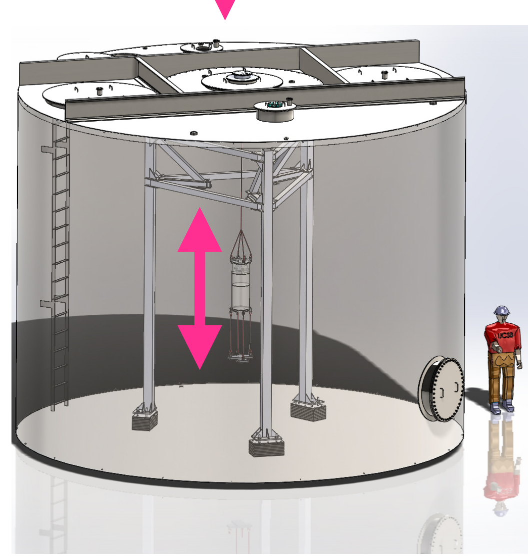
Sensitive to α, β, γ:

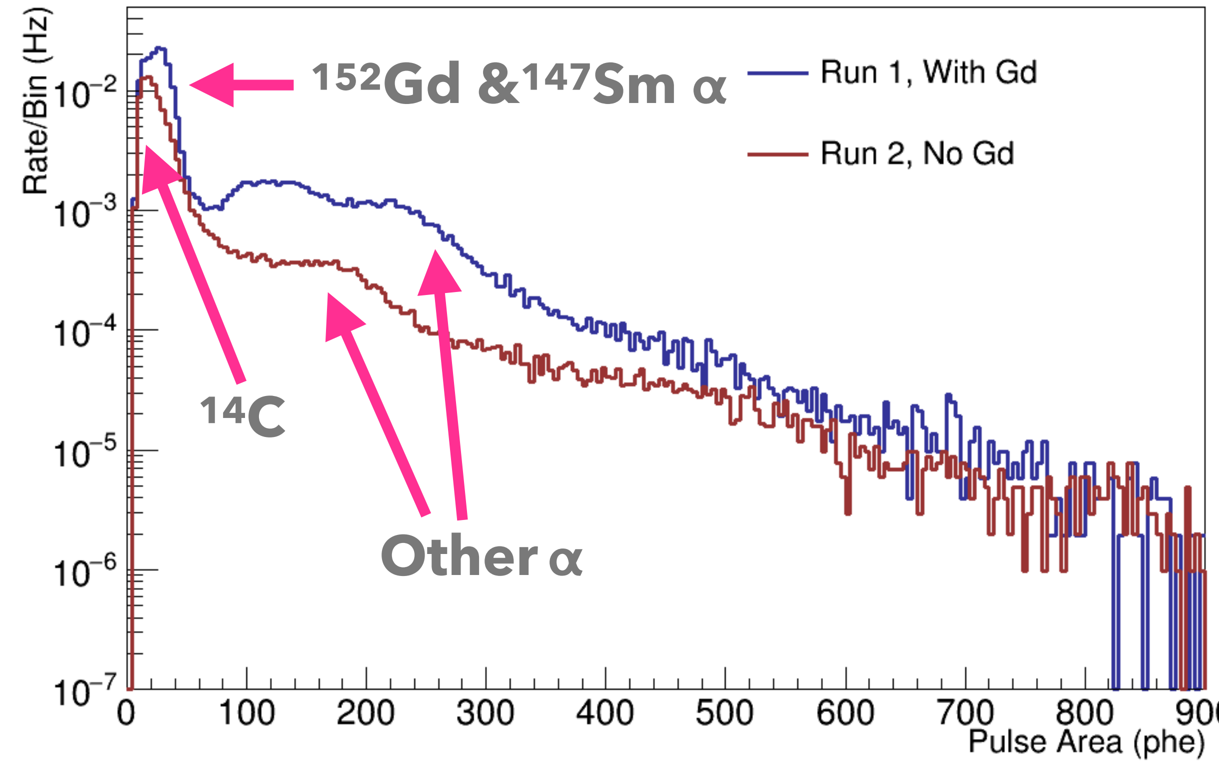
→ measure whole ^{238}U & ^{232}Th chains

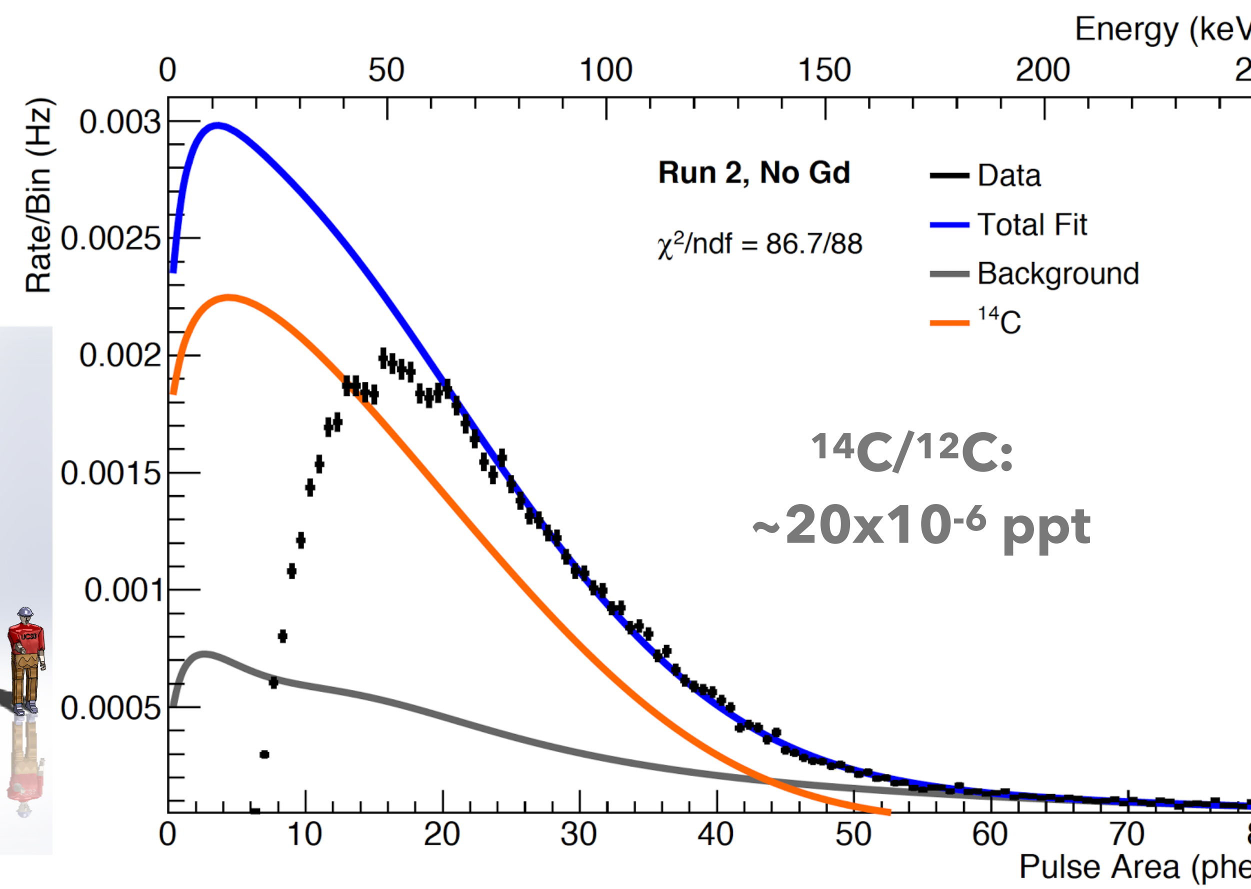
→ ^{40}K, ^{14}C

→ ^{152}Gd, ^{147}Sm low energy α-particles

→ cavern background (z-scan)







Cavern Backgrounds

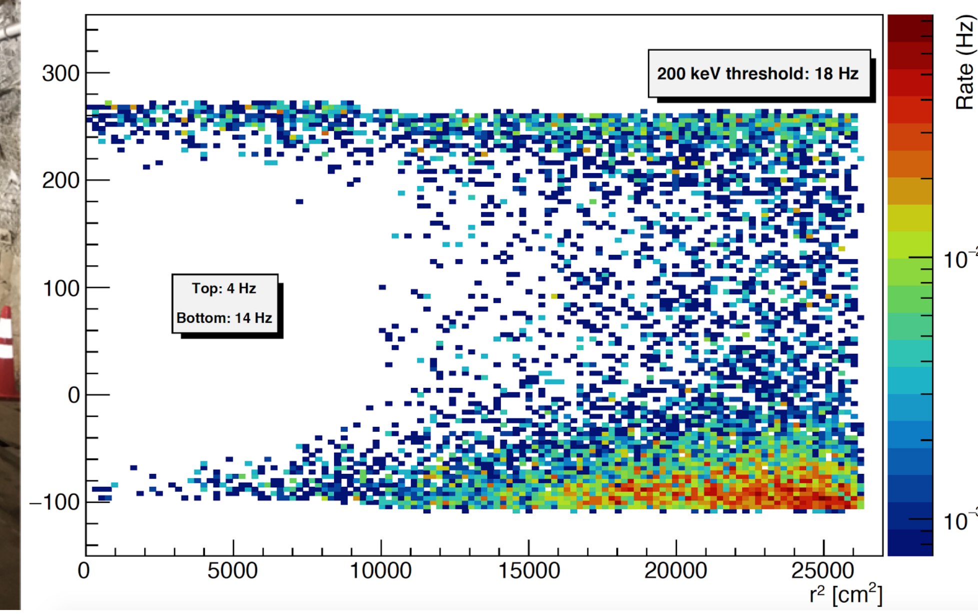
OD backgrounds & expected rates

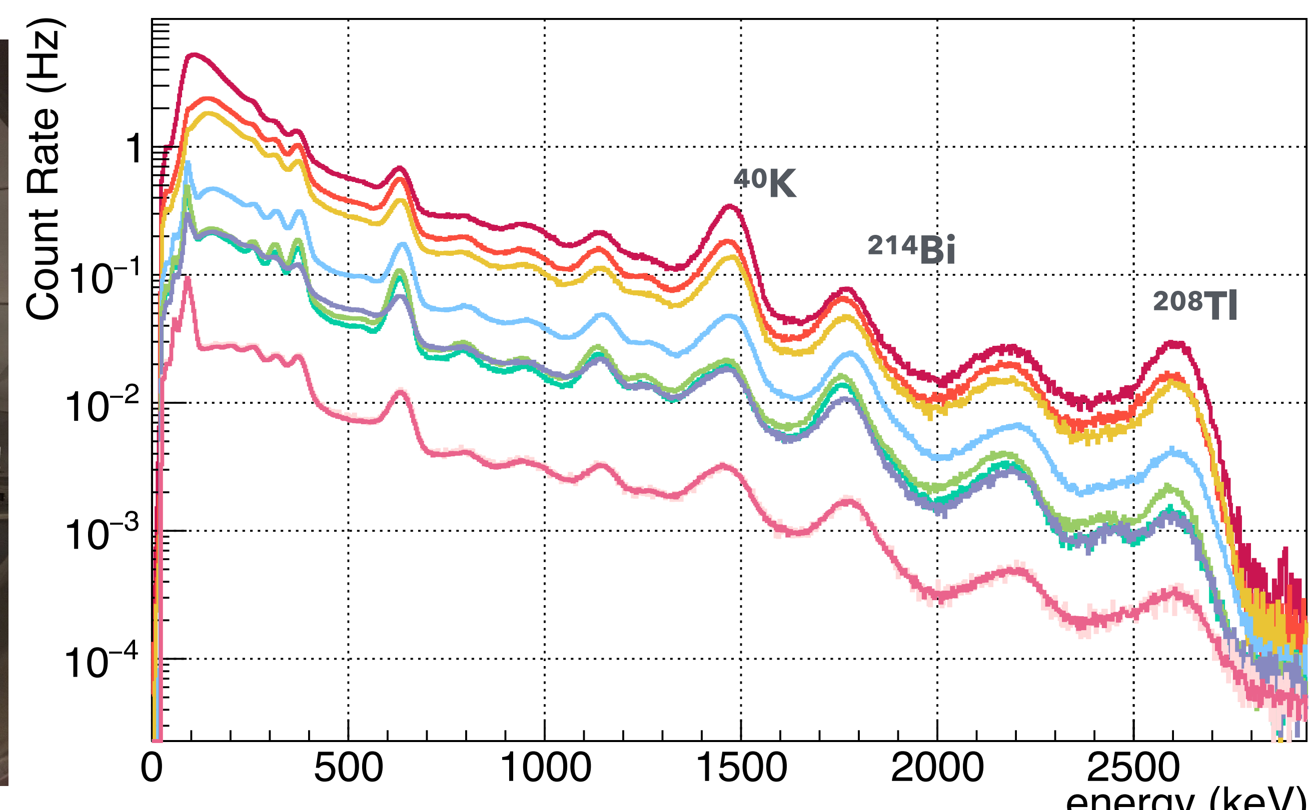
Background	**Rate (Hz)**
Gd/Sm α-decays	36 (100 keV)
Internals (^{238}U/^{232}Th/^{40}K/^{14}C)	8-24 (100 keV) ~few (200 keV)
LZ Components	7 (100 keV)
Acrylic / dust	<5 (100 keV)
Cavern γ-rays	~~91~~ 18 (200 keV)

Initial simulations suggested cavern was dominant background in OD at > 90 Hz, but Davis cavern **γ**-flux was uncertain.

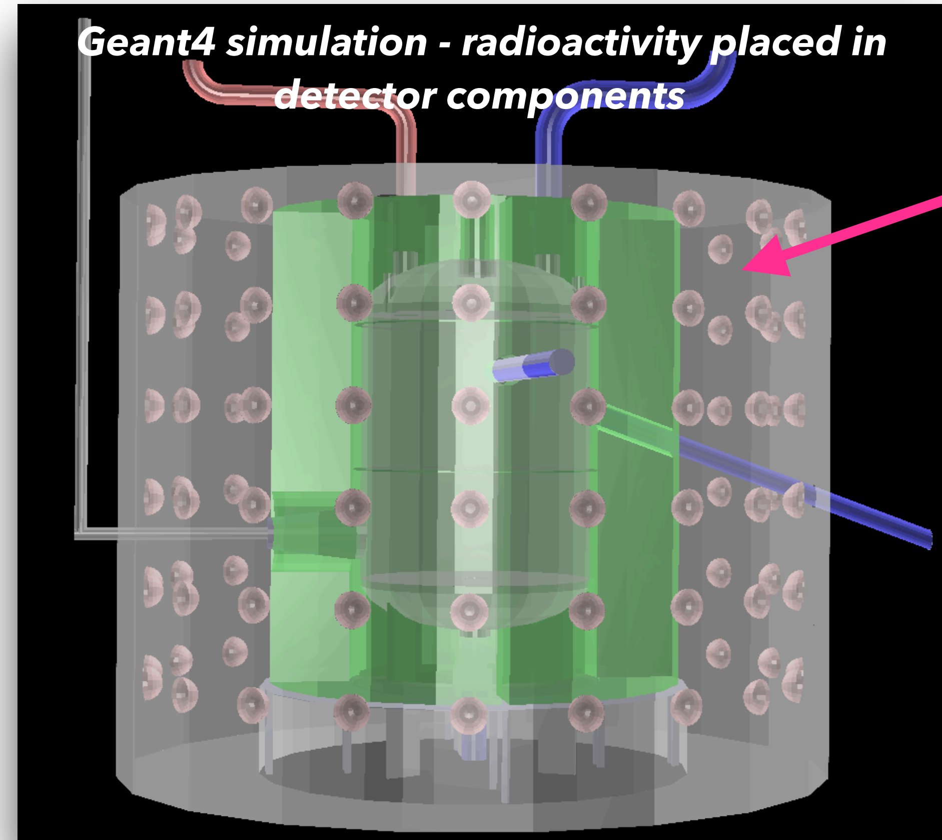
Oct 2017: Cavern flux measurement team

New measurements of ^{40}K, ^{238}U and ^{232}Th concentrations in rock used to simulate rate in OD - **now 18 Hz**





LZ Backgrounds

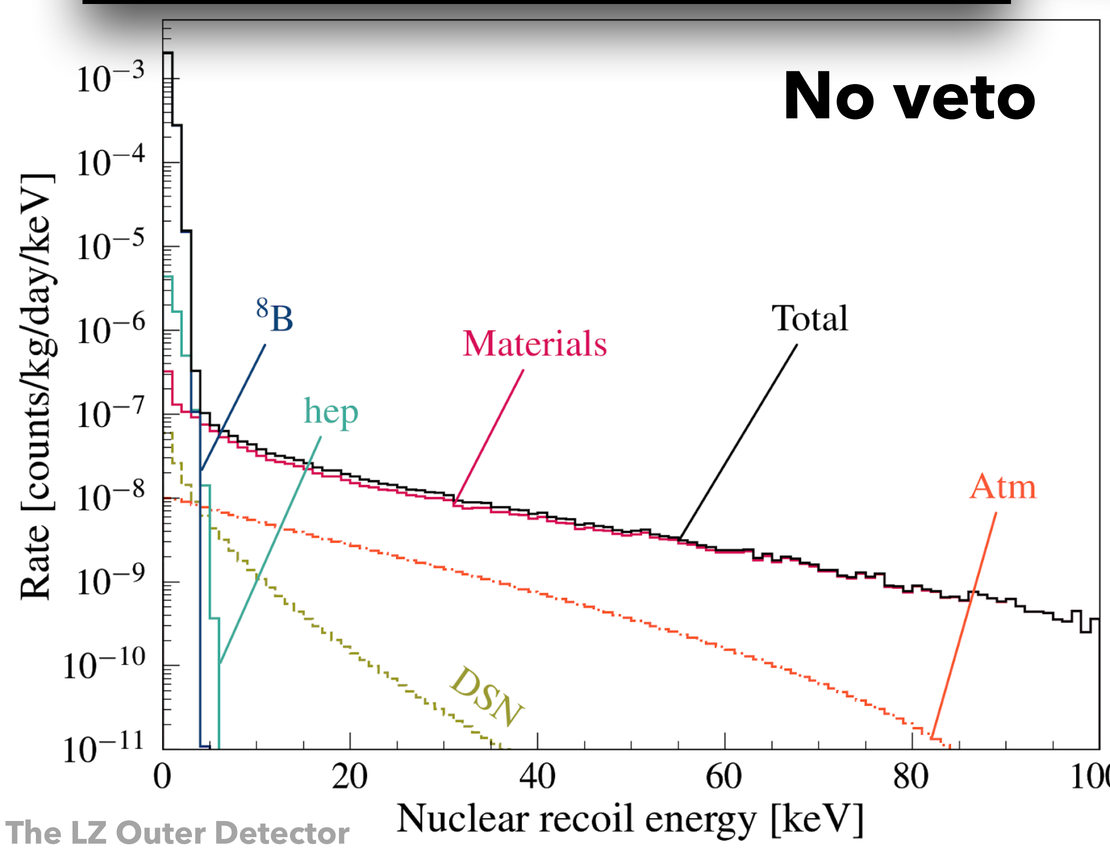


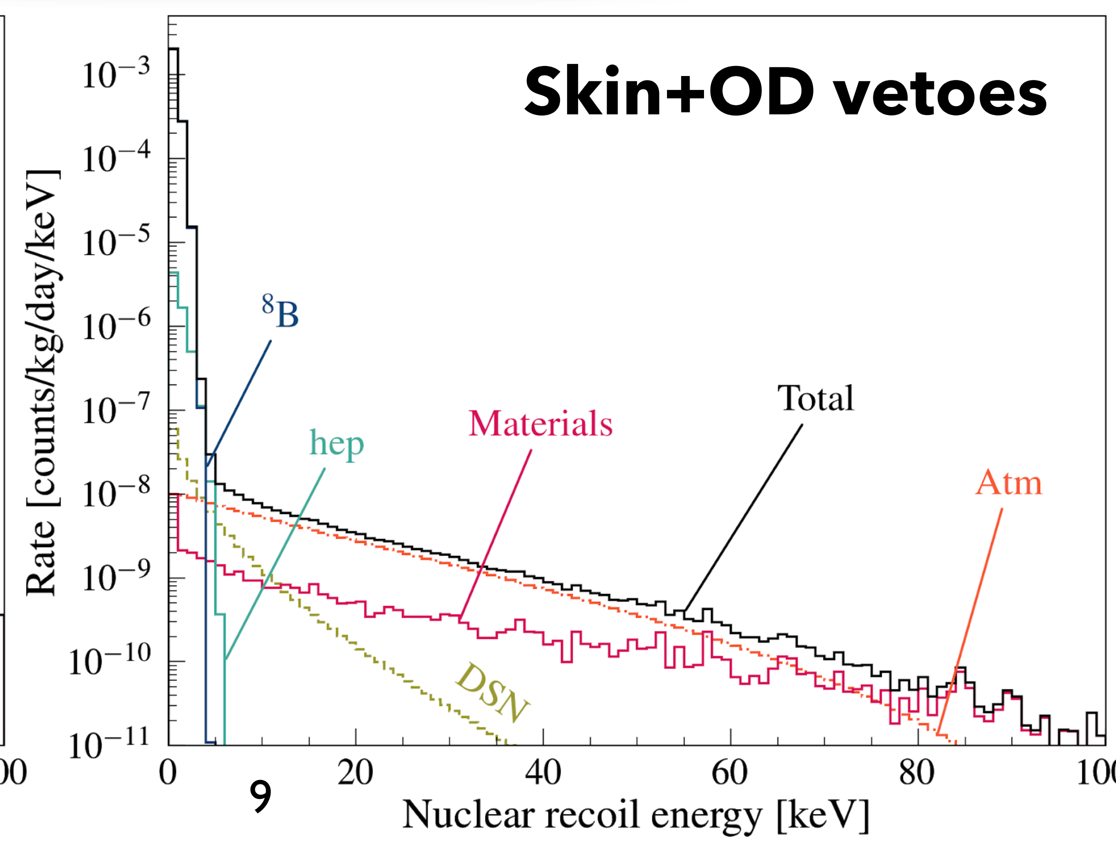
In simulation, veto an event if: energy deposit > 200 keV in OD, within 500μs of S1 in TPC

With sim, can assess whether we meet requirements:
Veto >95% of neutrons that scatter in TPC
Veto >70% of γ -rays that scatter in TPC

Background	Expected NR (post cuts, pre 50% acceptance)
PMTs	0.027
TPC (field rings, PTFE)	0.022
Cryostat	0.018
Muon induced neutrons	0.06
Surface Contamination (α,n)	0.23
Ion Misreconstruction	0.16
Neutrinos	0.51

neutrons backgrounds beaten down by OD

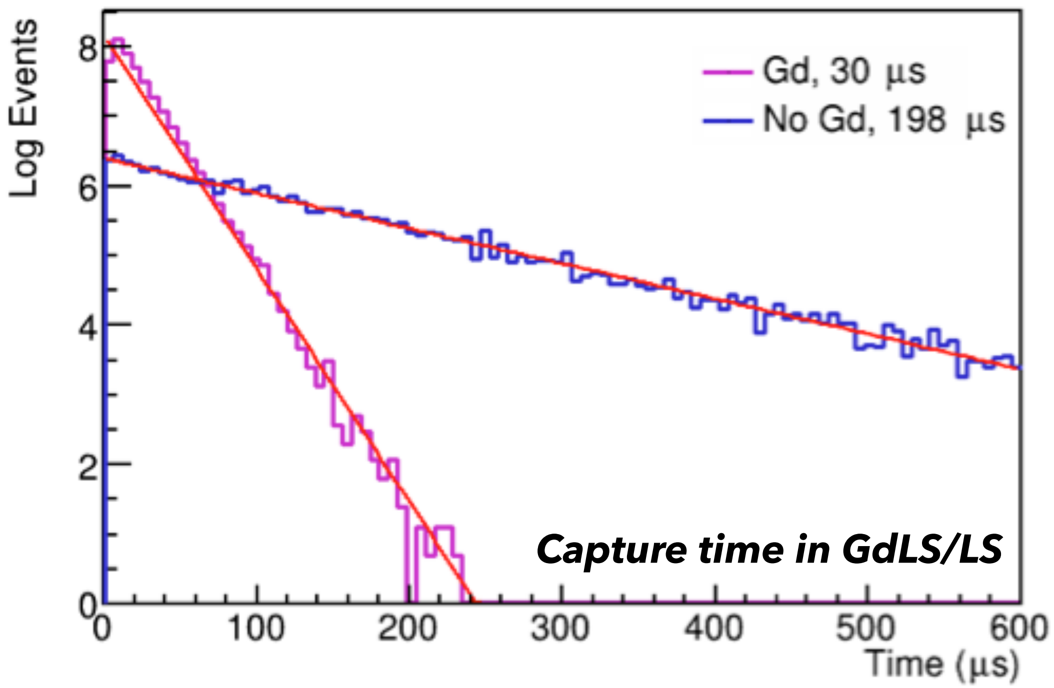


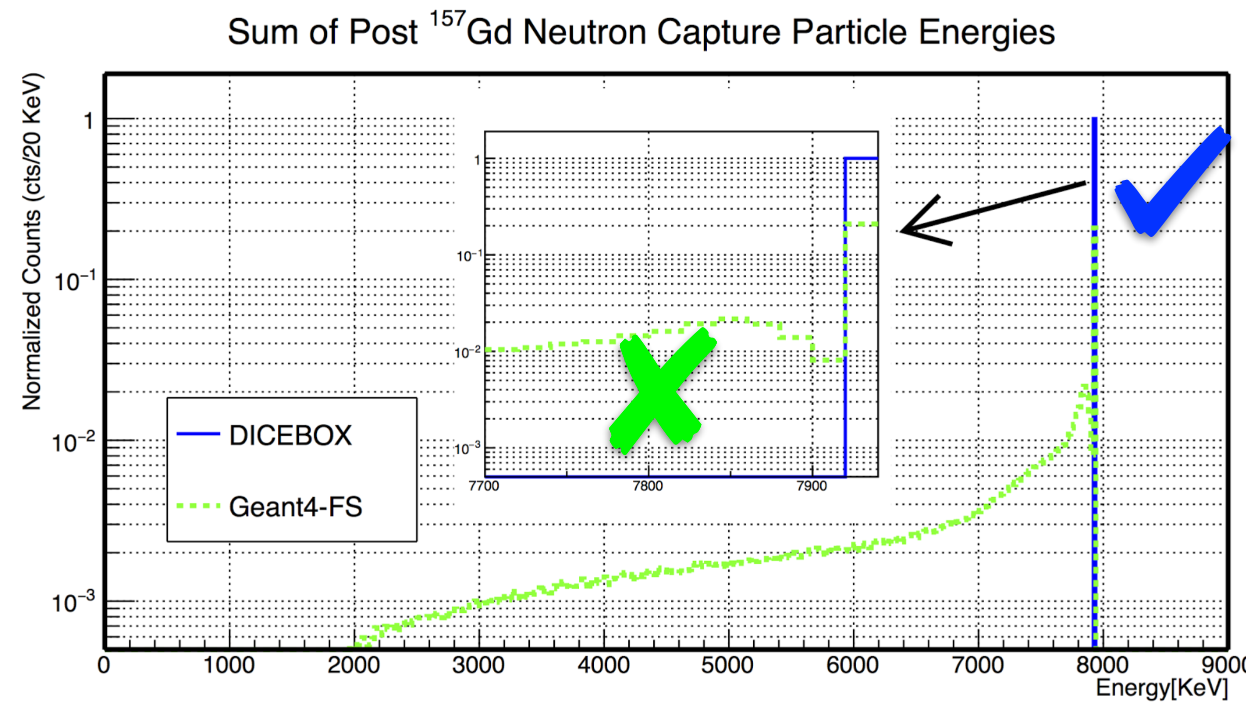


See talk by J. Dobson on LZ sensitivity

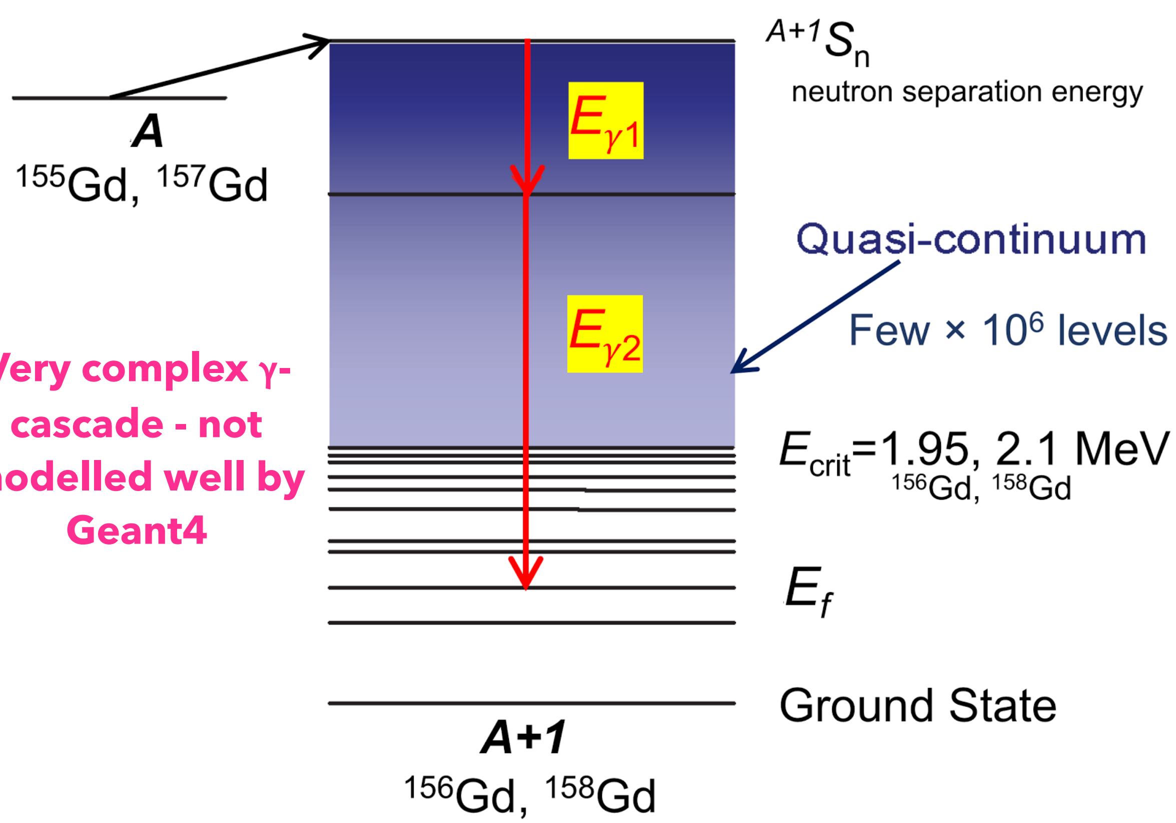
Neutron Capture on Gd

Thermal neutron capture cross sections:
^{157}Gd: 254,000 barns ^{155}Gd: 61,000 barns

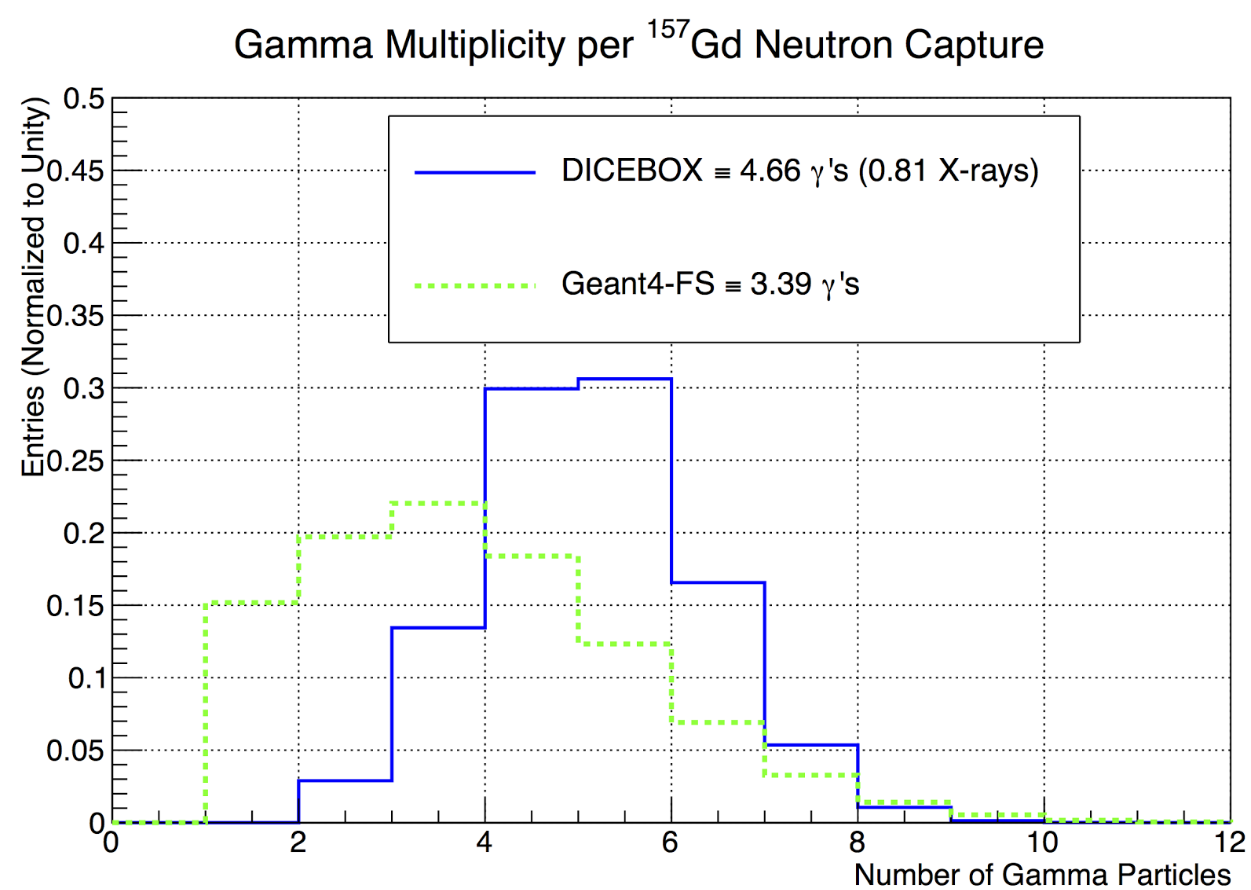




Integration of DICEBOX γ -cascade code with LZ simulation → 25% increase in vetoing efficiency!



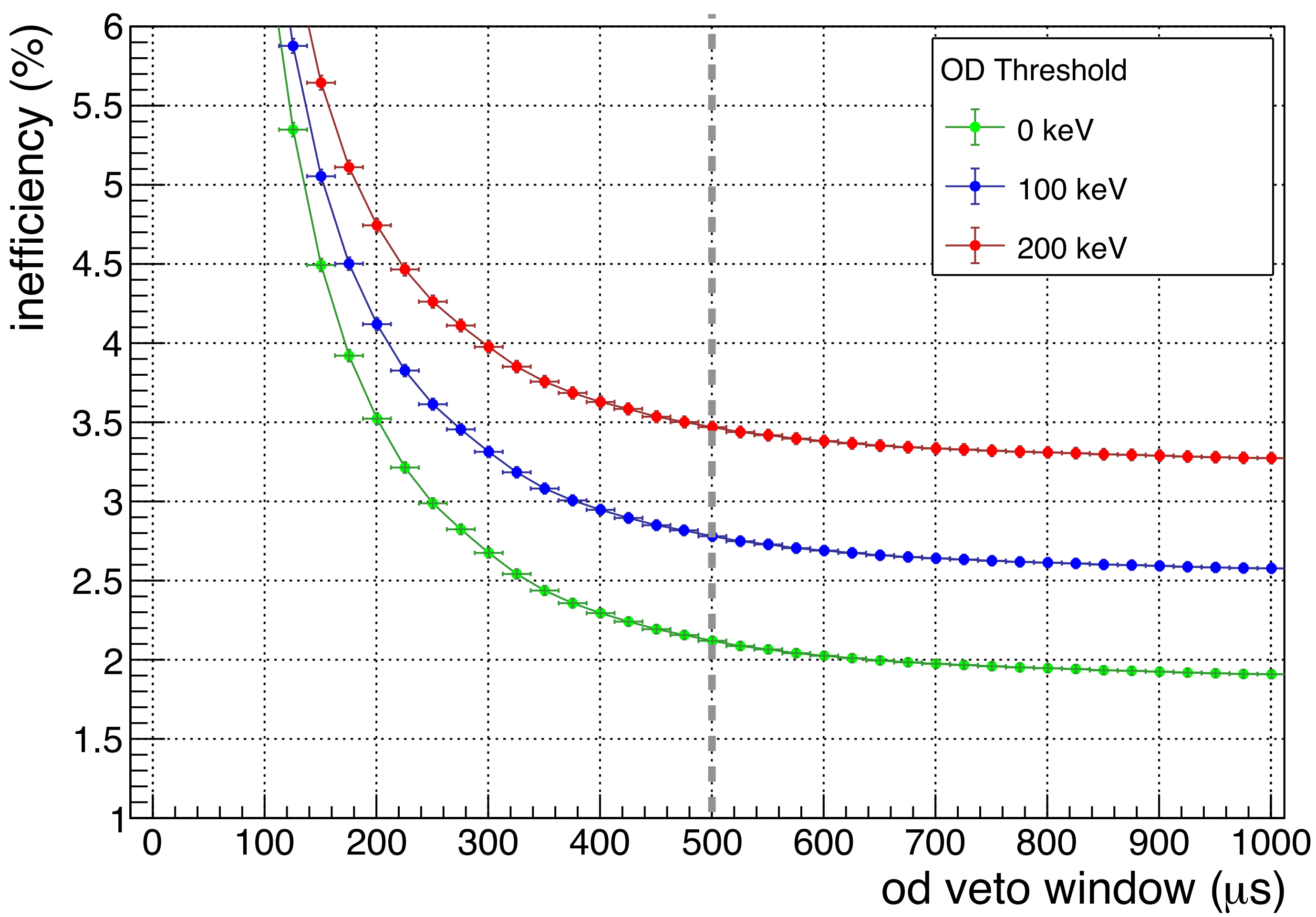
Very complex γ-cascade - not modelled well by Geant4



Performance

At 200 keV threshold, 500μs window, the OD is only 3.5% inefficient!

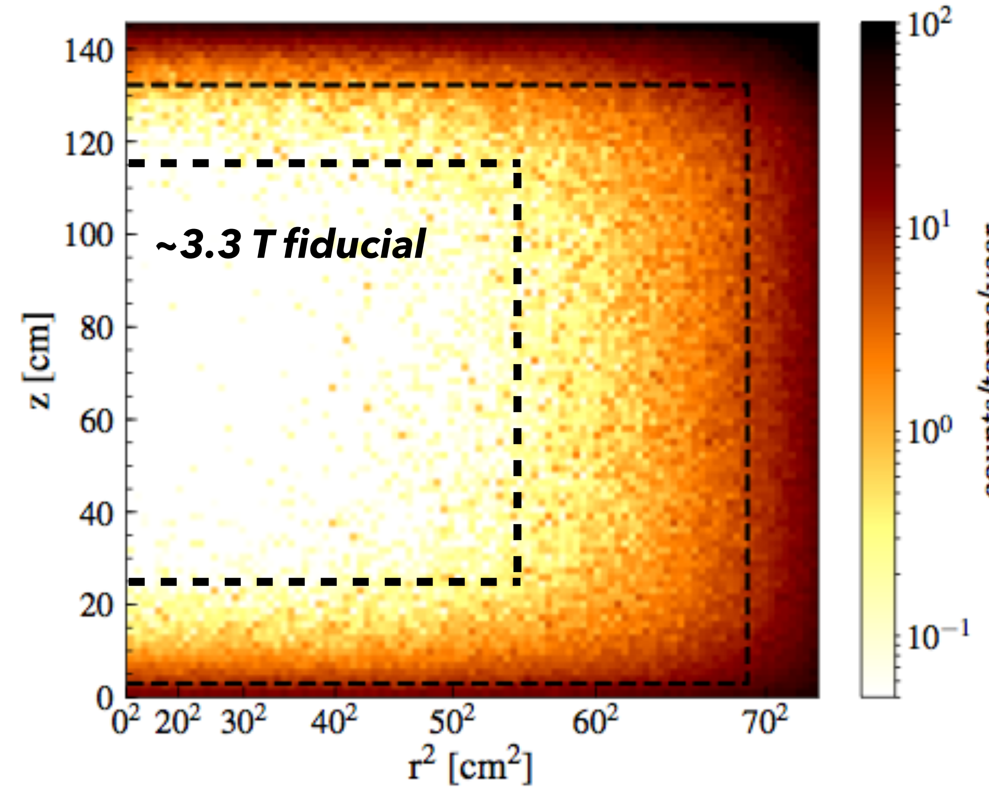
→96.5 % of neutrons that single scatter within the region of interest in the TPC (mimicking a WIMP) are vetoed



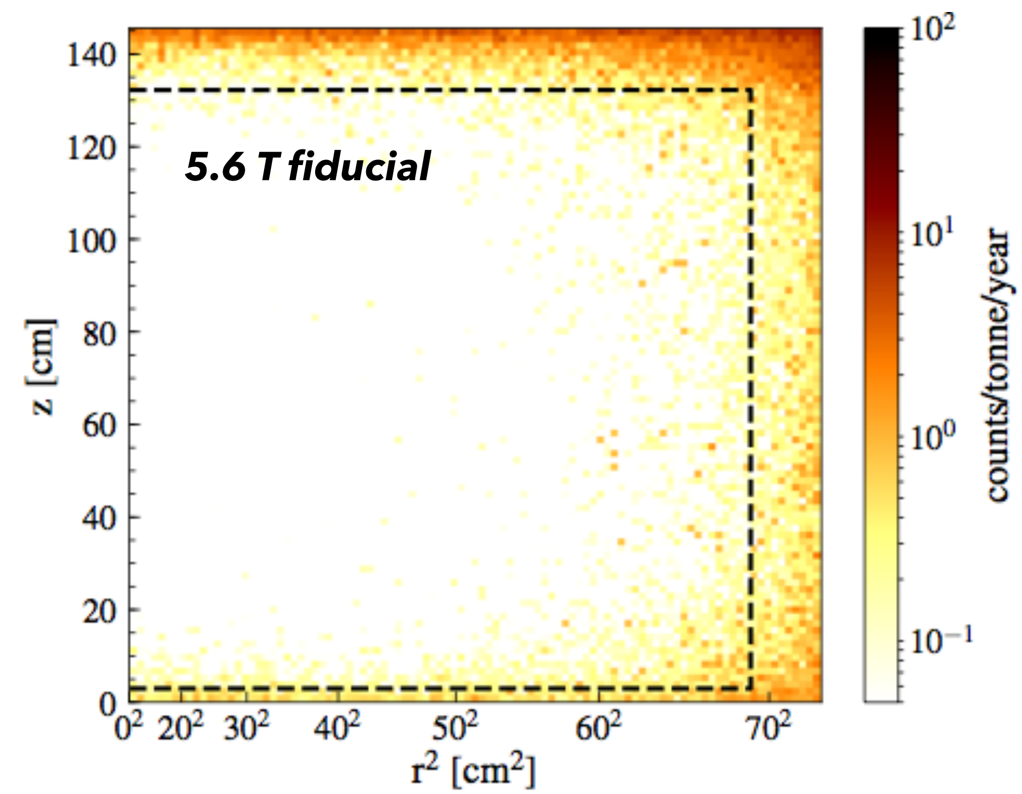
Time between S1 in TPC & signal in OD (μs)

May be possible to go to 100 keV threshold, reaching < 3% inefficiency

No veto: 12.31 counts/1000 days



OD + Skin veto: 1.24 counts/1000 days



Summary

- Construction of LZ veto detector well underway
    - Tanks almost complete, arriving at SURF in next couple of months
    - Liquid scintillator production starting July
- Analysis of prototype (LS screener) data ongoing, but already learnt a lot about contaminants and LS handling
    - ^{14}C measurement, light yield, quenching
    - Unexpected backgrounds - ^{147}Sm, ^{176}Lu, ^{7}Be …
    - Data used to test LZ data analysis framework
- Analysis of NaI measurements of cavern **γ**-rays also ongoing, but so far suggests 5x lower background rate in OD than first thought
- Performance of OD in simulation so far meeting all goals - vetoes 97.5% of WIMP search background neutrons
- Commission and calibration in 2020 - exciting physics to come!

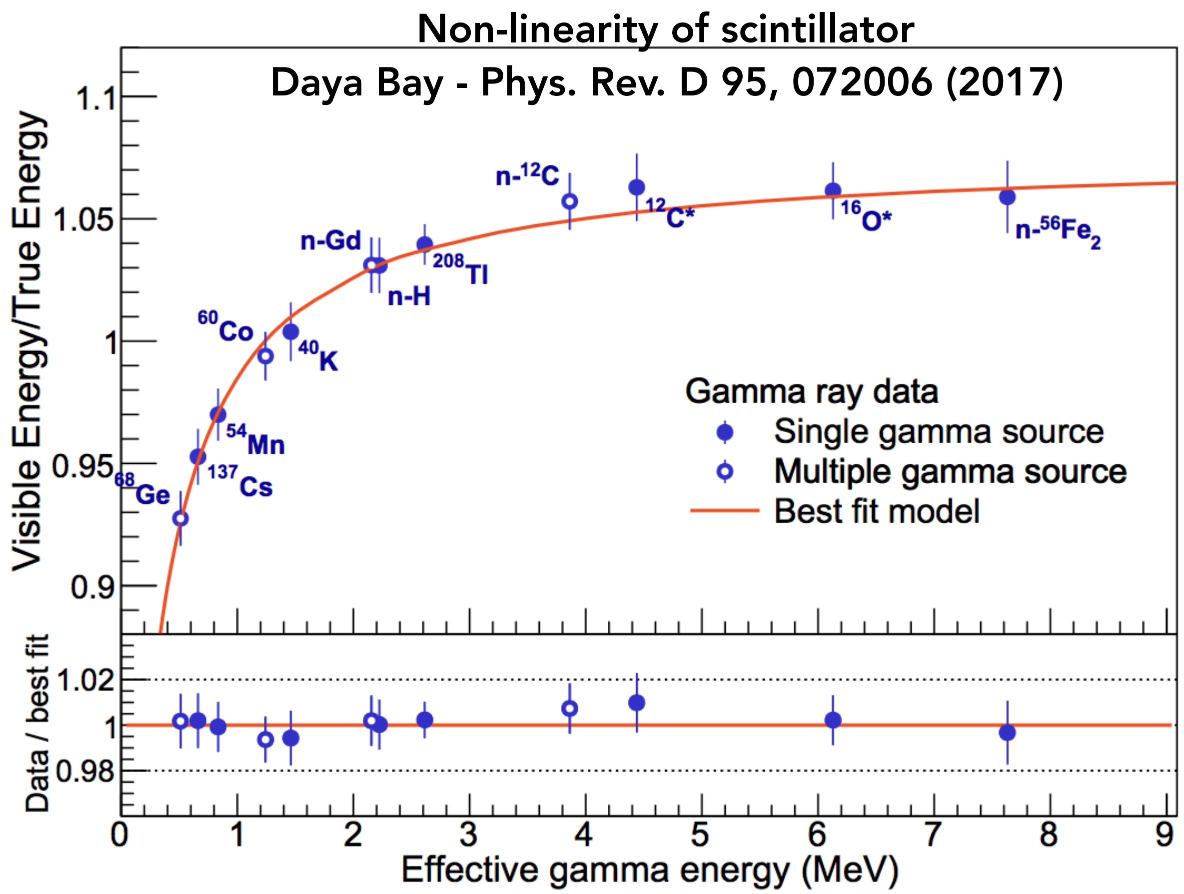
Thanks!

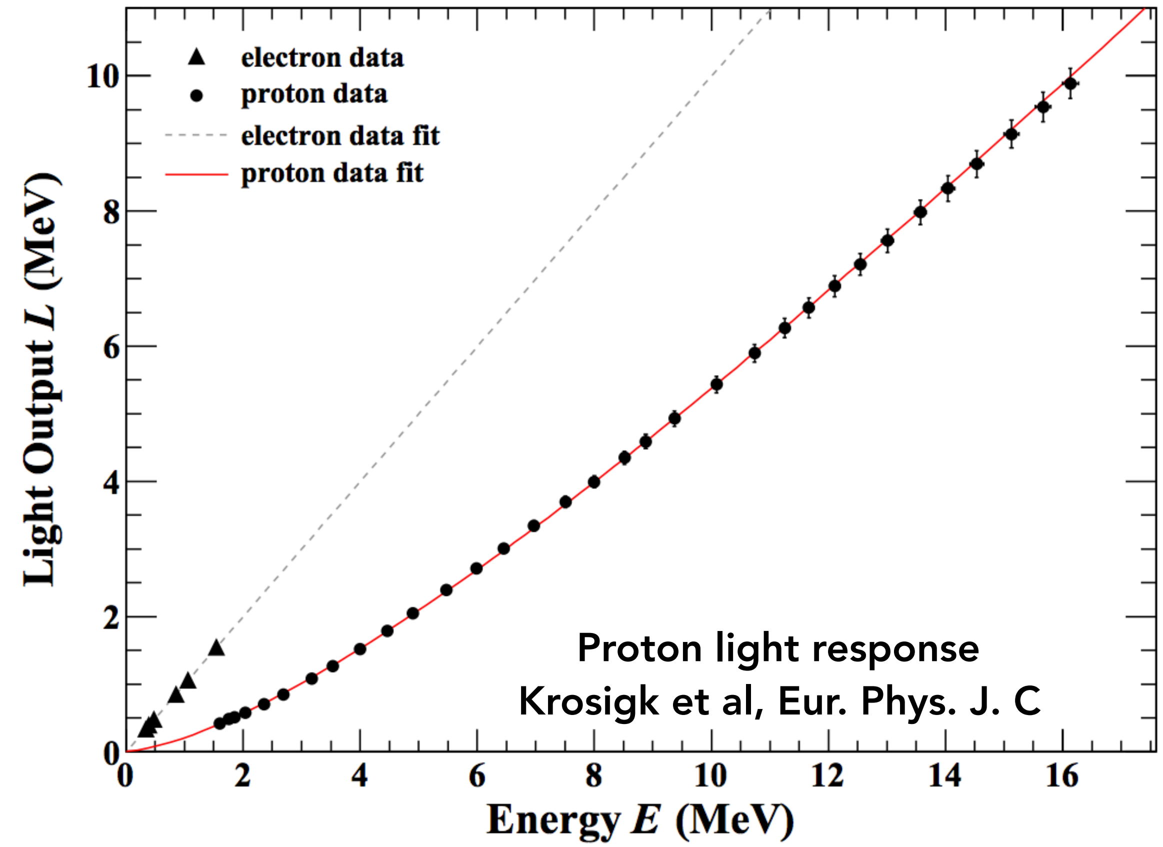
Backup

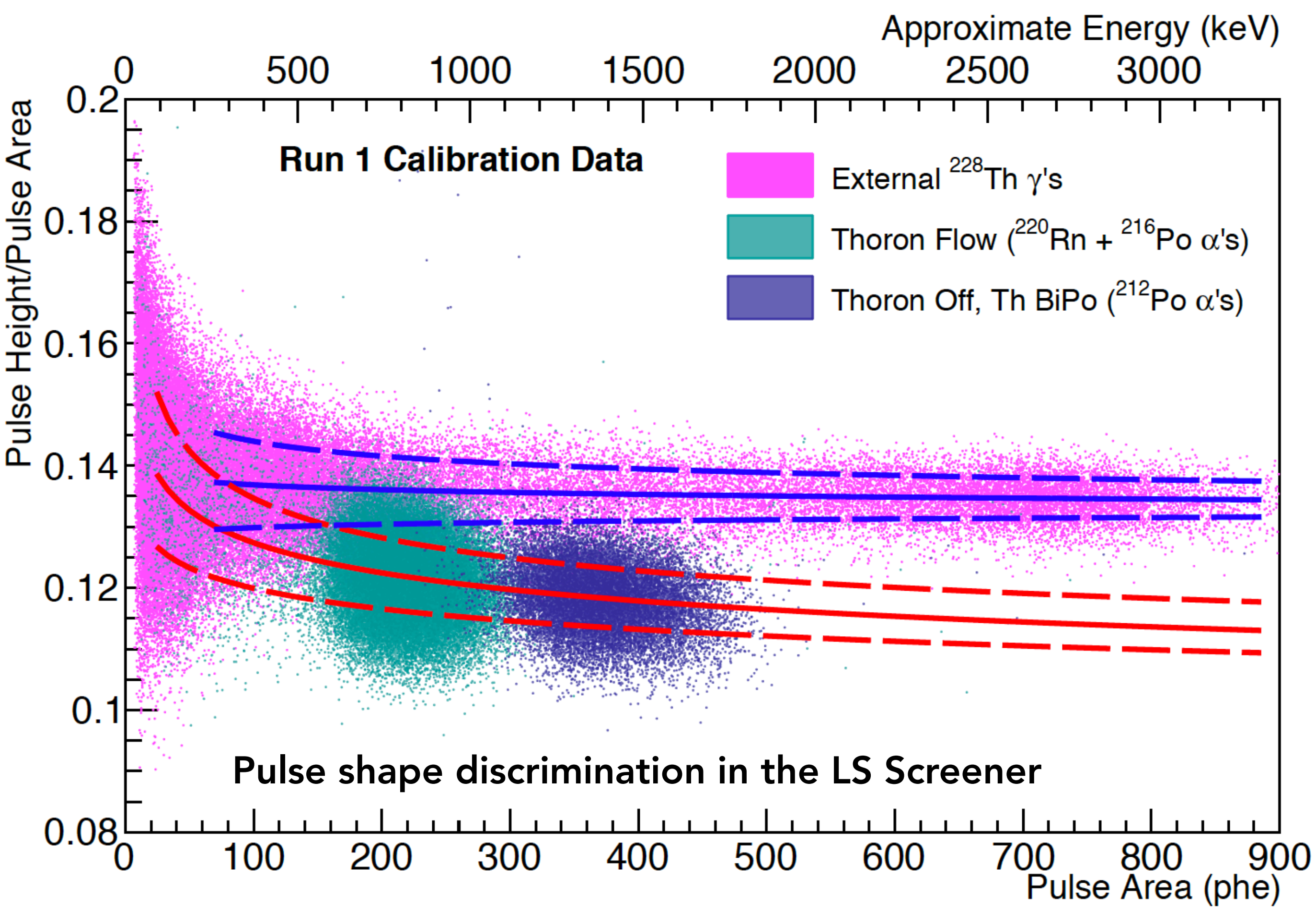
WBS	Description	Quantity
1.6	**Outer Detector System**	
	Weight of Gd-loaded LAB scintillator	17.5 tonnes
	Number of acrylic vessels, total acrylic mass	9 vessels, 3.1 tonnes
	Number of 8-inch PMTs	120
	Minimum thickness of scintillator	0.61 m
	Diameter of water tank	7.62 m
	Height of water tank	5.92 m
	Approximate weight of water	228 tonnes

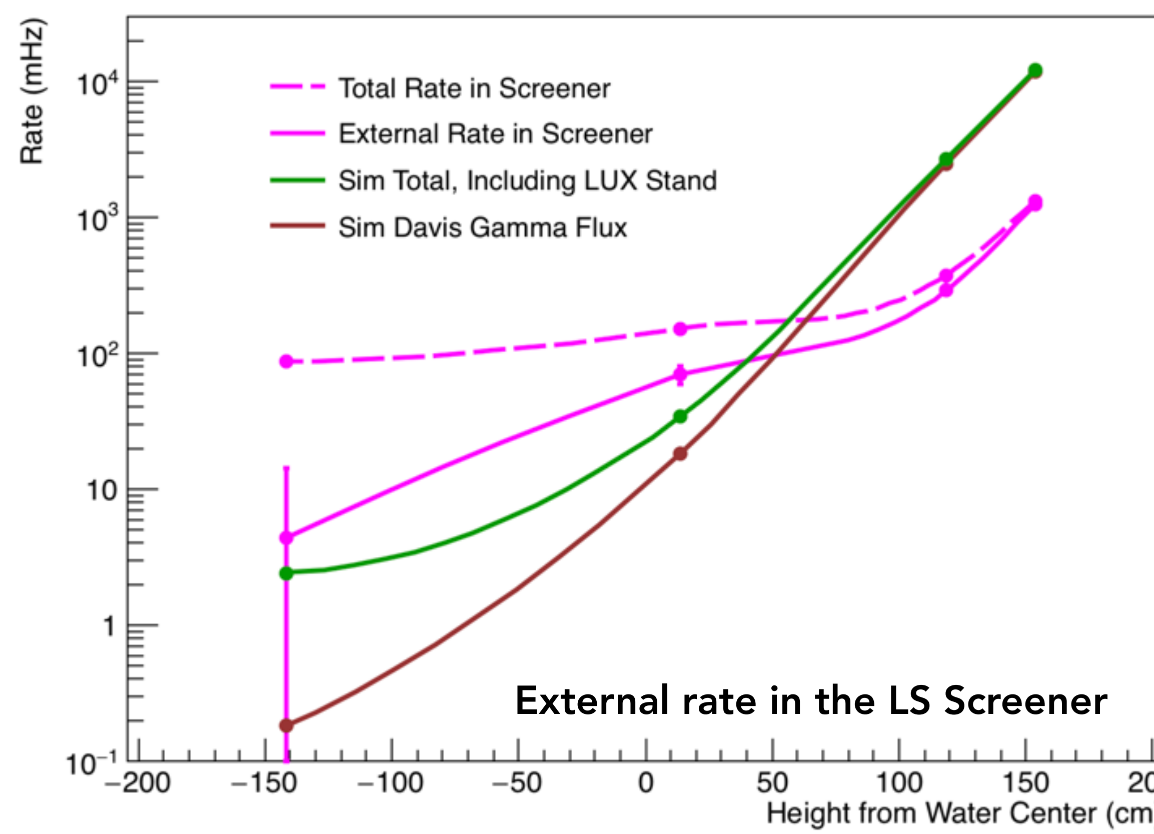
TABLE III. Estimated backgrounds from all significant sources in the LZ 1000 day WIMP search exposure. Counts are for a region of interest relevant to a 40 GeV/c^2 WIMP: approximately 1.5–6.5 keV for ERs and 6–30 keV for NRs; and after application of the single scatter, skin and OD veto, and 5.6 tonne fiducial volume cuts. Mass-weighted average activities are shown for composite materials and the ^{238}U and ^{232}Th chains are split into contributions from early- and late-chain, with the latter defined as those coming from isotopes below and including ^{226}Ra and ^{224}Ra, respectively.

Background Source	**Mass (kg)**	^{238}**U**$_e$	^{238}**U**$_l$	^{232}**Th**$_e$	^{232}**Th**$_l$	^{60}**Co**	^{40}**K**	**n/yr**	**ER (cts)**	**NR (cts)**
		mBq/kg								
Detector Components										
PMT systems	308	31.2	5.20	2.32	2.29	1.46	18.6	248	2.82	0.027
TPC systems	373	3.28	1.01	0.84	0.76	2.58	7.80	79.9	4.33	0.022
Cryostat	2778	2.88	0.63	0.48	0.51	0.31	2.62	323	1.27	0.018
Outer detector (OD)	22950	6.13	4.74	3.78	3.71	0.33	13.8	8061	0.62	0.001
All else	358	3.61	1.25	0.55	0.65	1.31	2.64	39.1	0.11	0.003
								subtotal	**9**	**0.07**

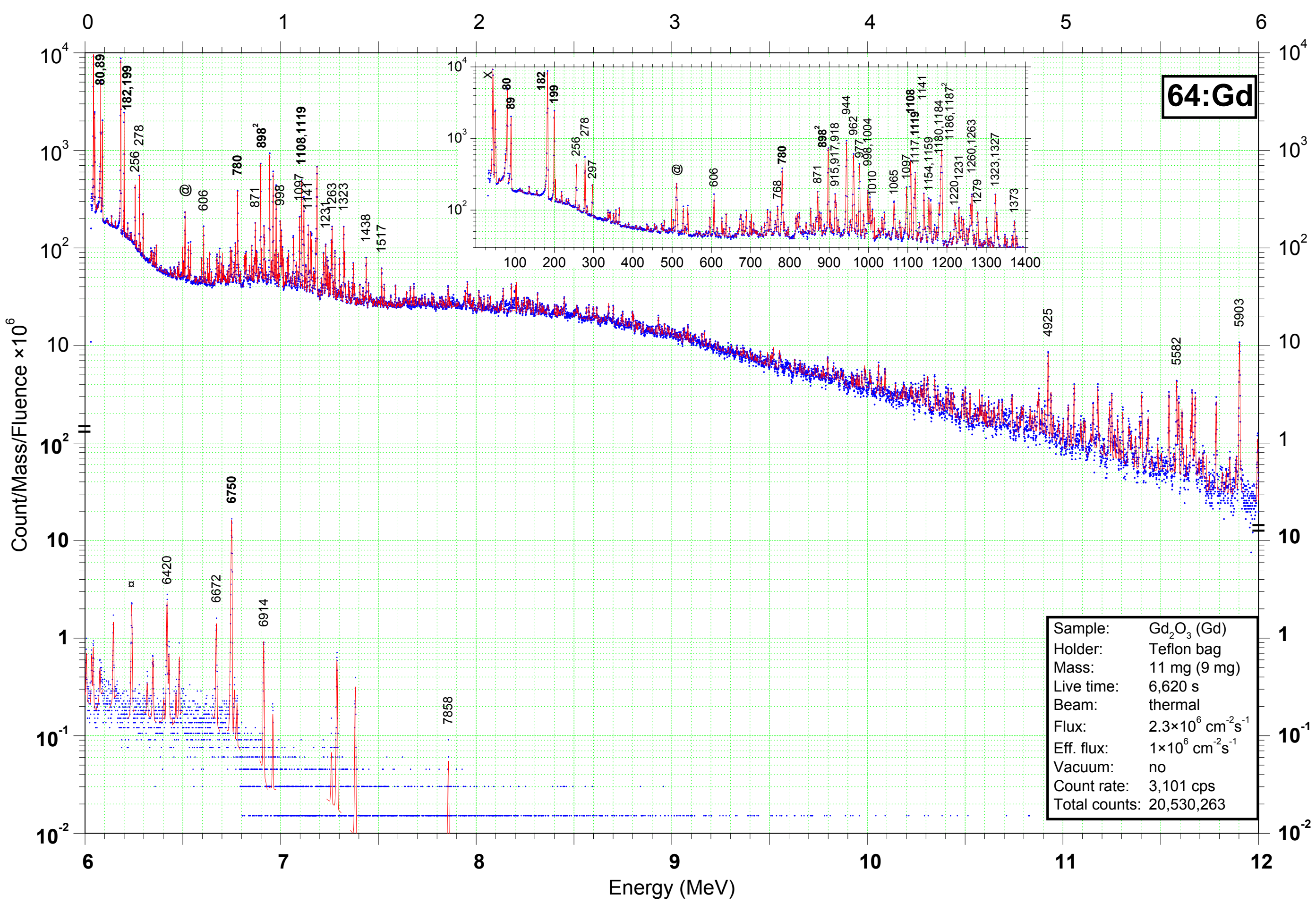

Non-linearity of scintillator
Daya Bay - Phys. Rev. D 95, 072006 (2017)
Visible Energy/True Energy
Gamma ray data
Single gamma source
Multiple gamma source
Best fit model
68Ge
137Cs
54Mn
60Co
40K
n-Gd
n-H
208Tl
n-12C
12C*
16O*
n-56Fe2
Data / best fit
Effective gamma energy (MeV)

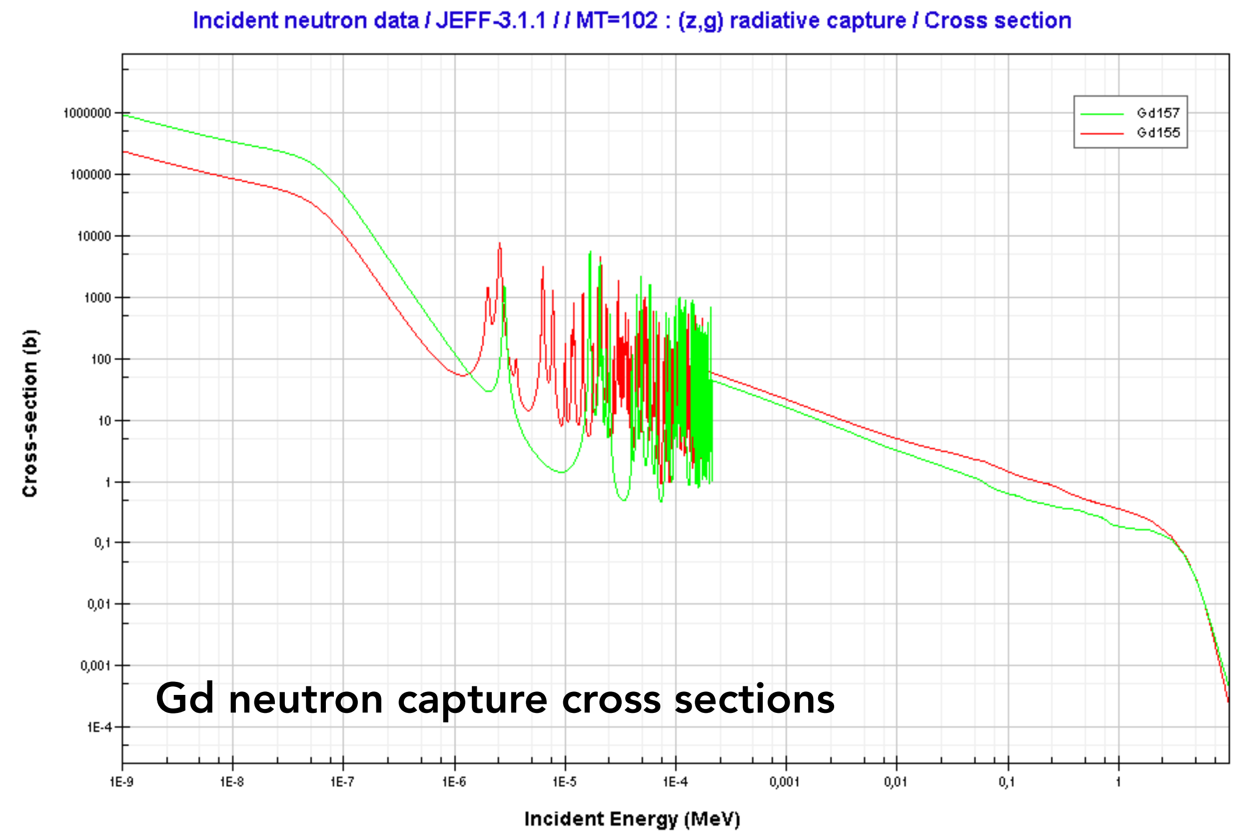

electron data
proton data
electron data fit
proton data fit
Light Output L (MeV)
Energy E (MeV)
Proton light response
Krosigk et al, Eur. Phys. J. C


Approximate Energy (keV)
Run 1 Calibration Data
External 228Th γ's
Thoron Flow (220Rn + 216Po α's)
Thoron Off, Th BiPo (212Po α's)
Pulse Height/Pulse Area
Pulse shape discrimination in the LS Screener
Pulse Area (phe)

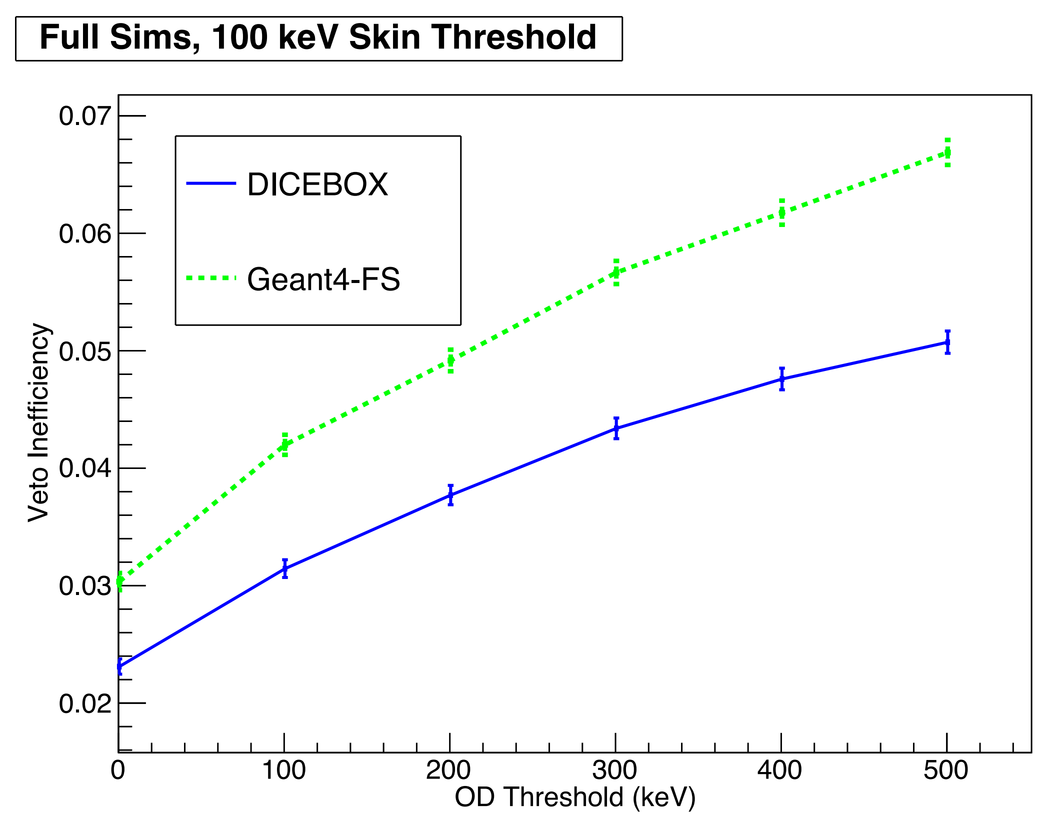

Total Rate in Screener
External Rate in Screener
Sim Total, Including LUX Stand
Sim Davis Gamma Flux
Rate (mHz)
External rate in the LS Screener
Height from Water Center (cm)

Gd(n,γ) spectrum
(G. L. Molnar, ed., Handbook of Prompt Gamma Activation Analysis)





Gd neutron capture cross sections



Veto inefficiency (DICEBOX vs default Geant4)