Status of the LZ dark matter search and projected sensitivity

Jui-Jen (Ryan) Wang

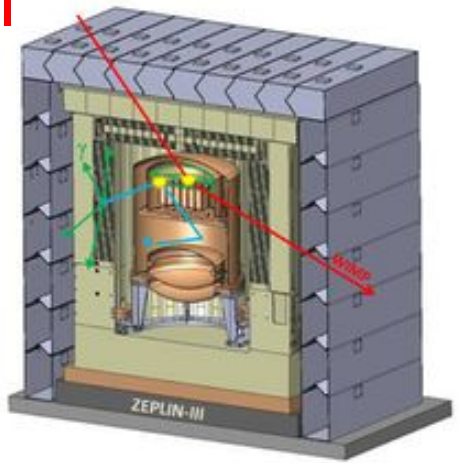
On behalf of LZ collaboration

PIC 2019

Taipei, Taiwan

+

ZEPLIN-III

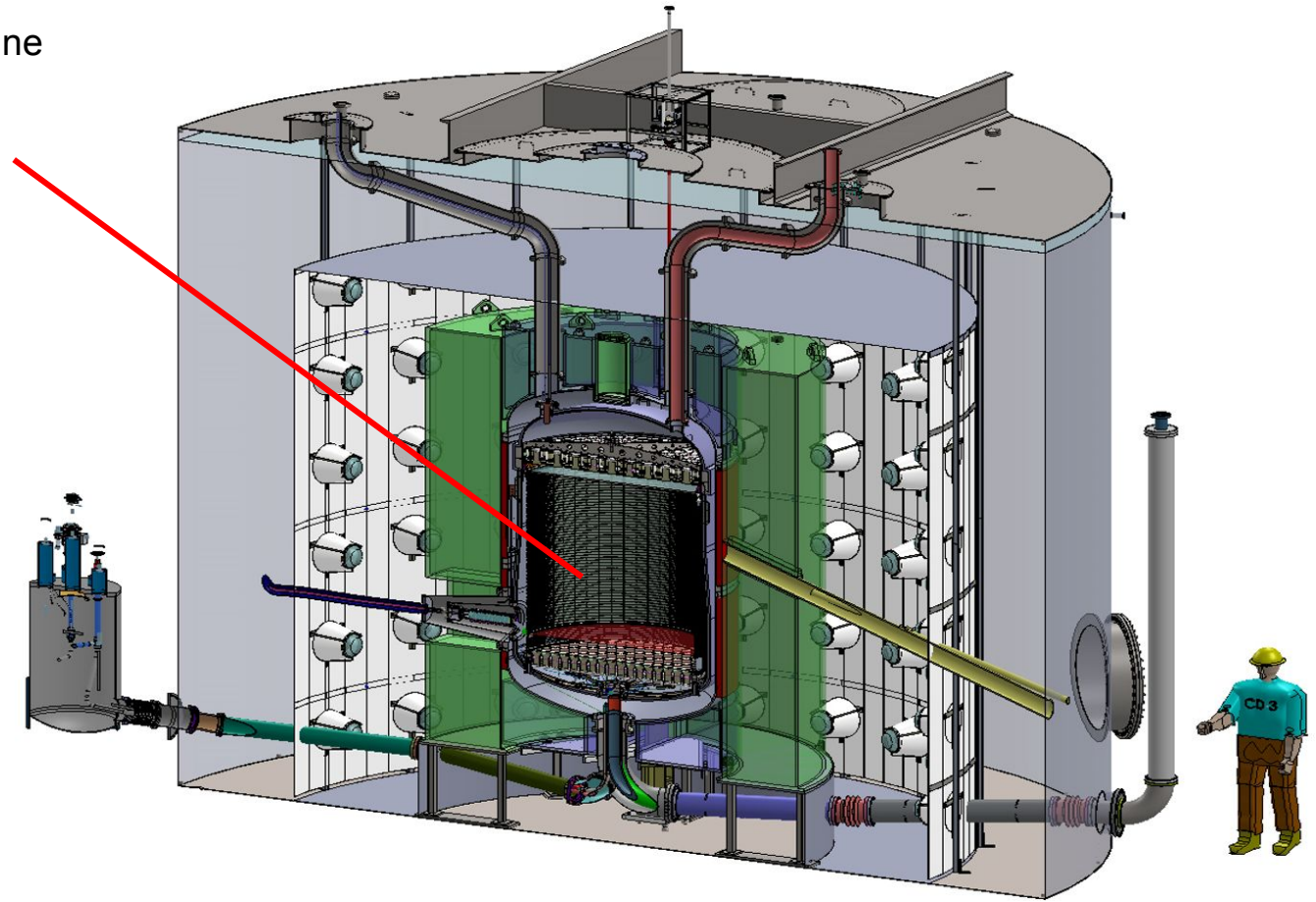


- 370 kg liquid xenon Time Projection Chamber (TPC).
- Was located at Sanford Underground Laboratory, SD USA (2013-2015)

- 12 kg liquid xenon Time Projection Chamber (TPC)
- Pioneered WIMP search with 2-phase xenon
- Was located at the Boulby Underground Laboratory, UK (2006-2011)

LZ Detector

7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber



LZ Detector

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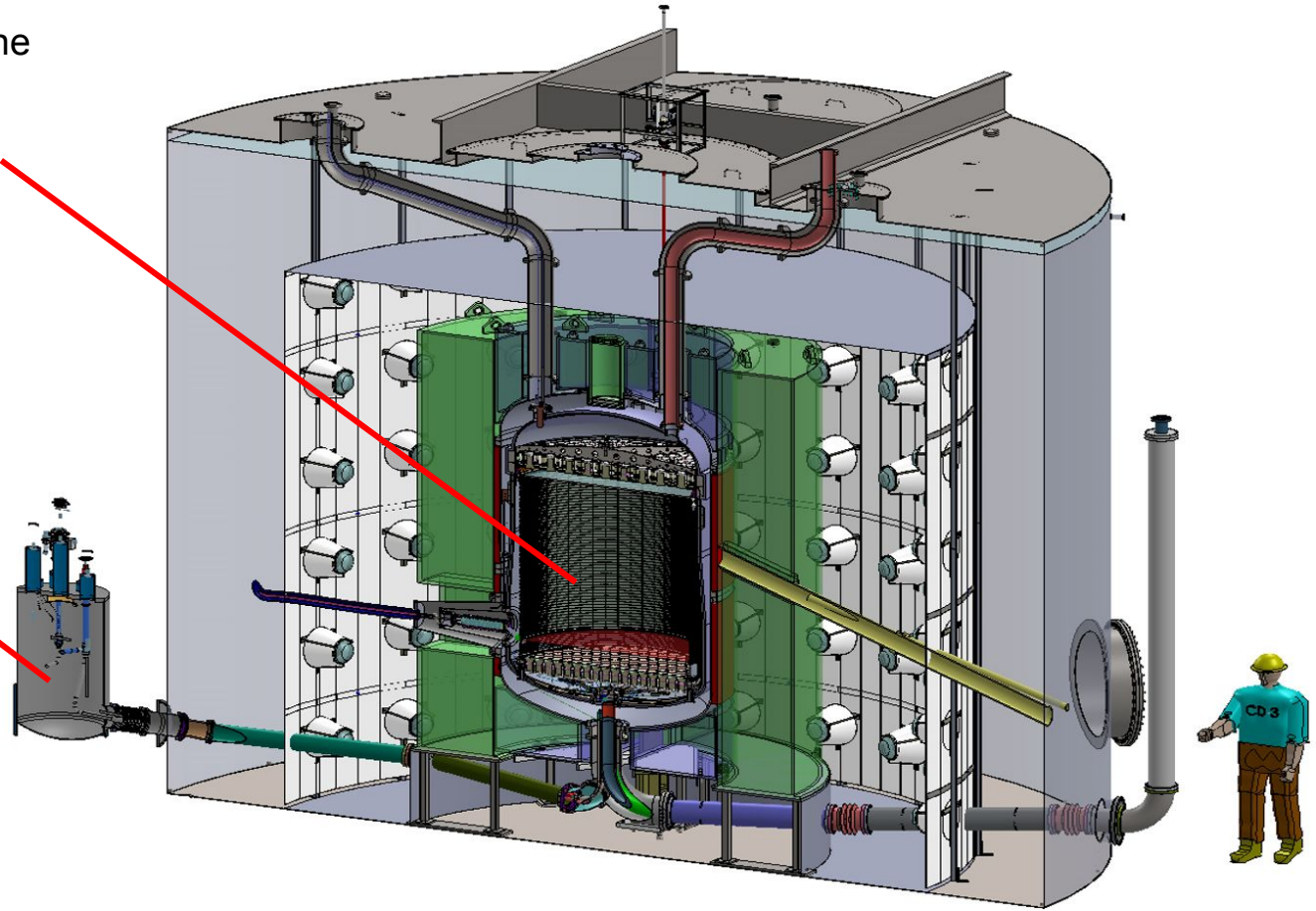
Liquid xenon heat exchanger

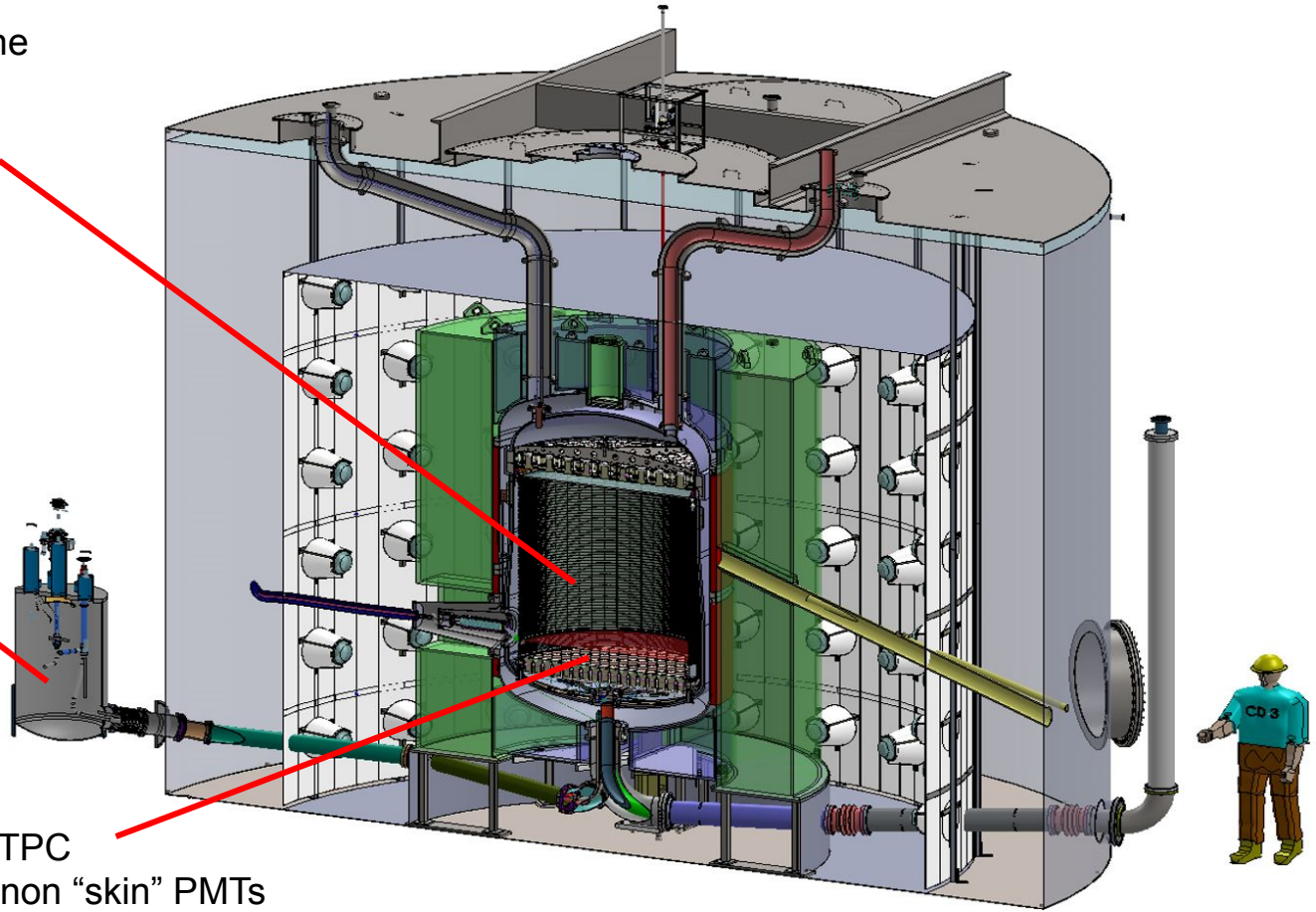


LZ Detector

7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber

Liquid xenon heat exchanger

494 PMTs (3”) in TPC
Additional 131 xenon “skin” PMTs



LZ Detector

7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber

Gadolinium-loaded liquid scintillator (~17 tonnes)

Liquid xenon heat exchanger

494 PMTs (3”) in TPC
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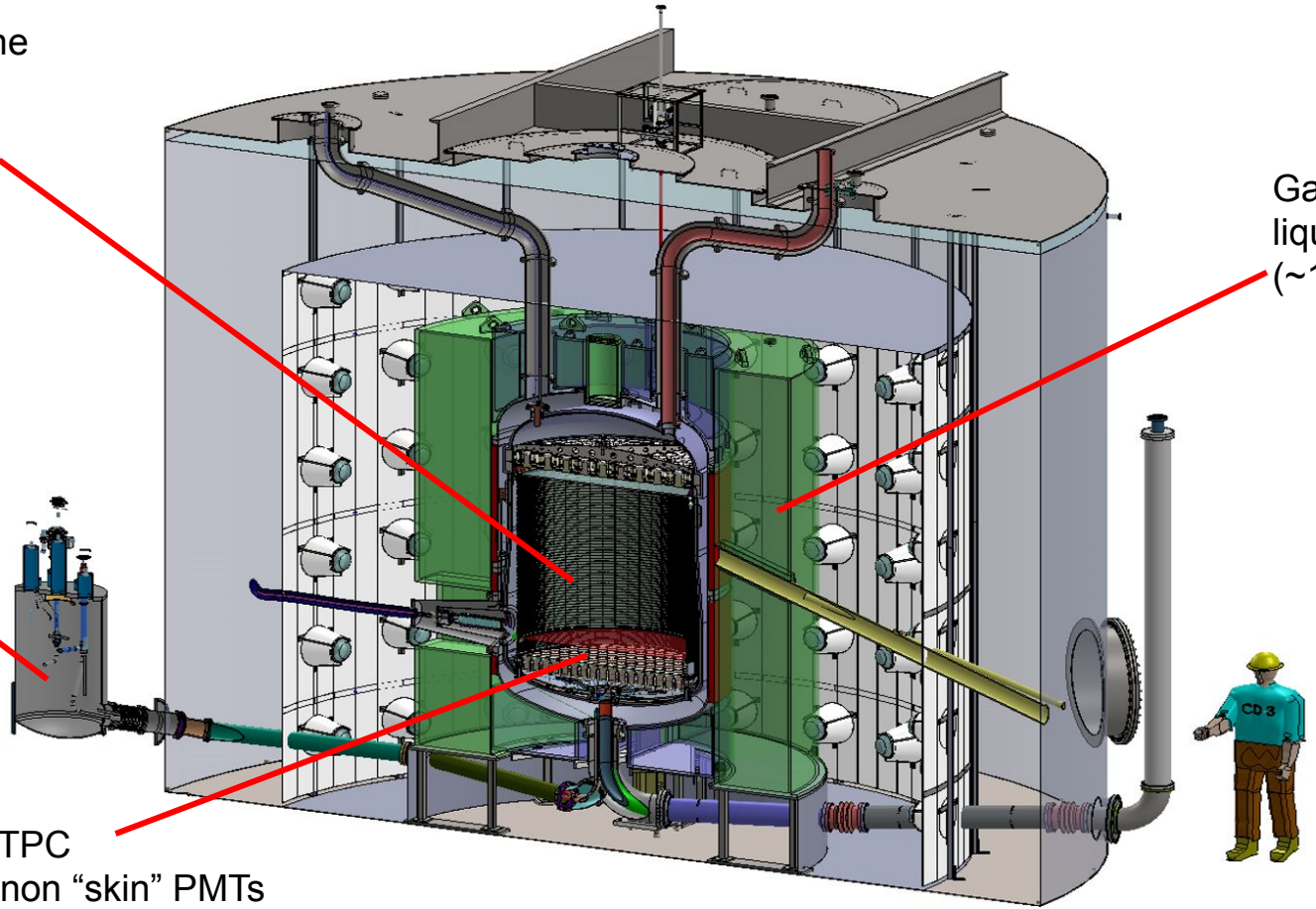
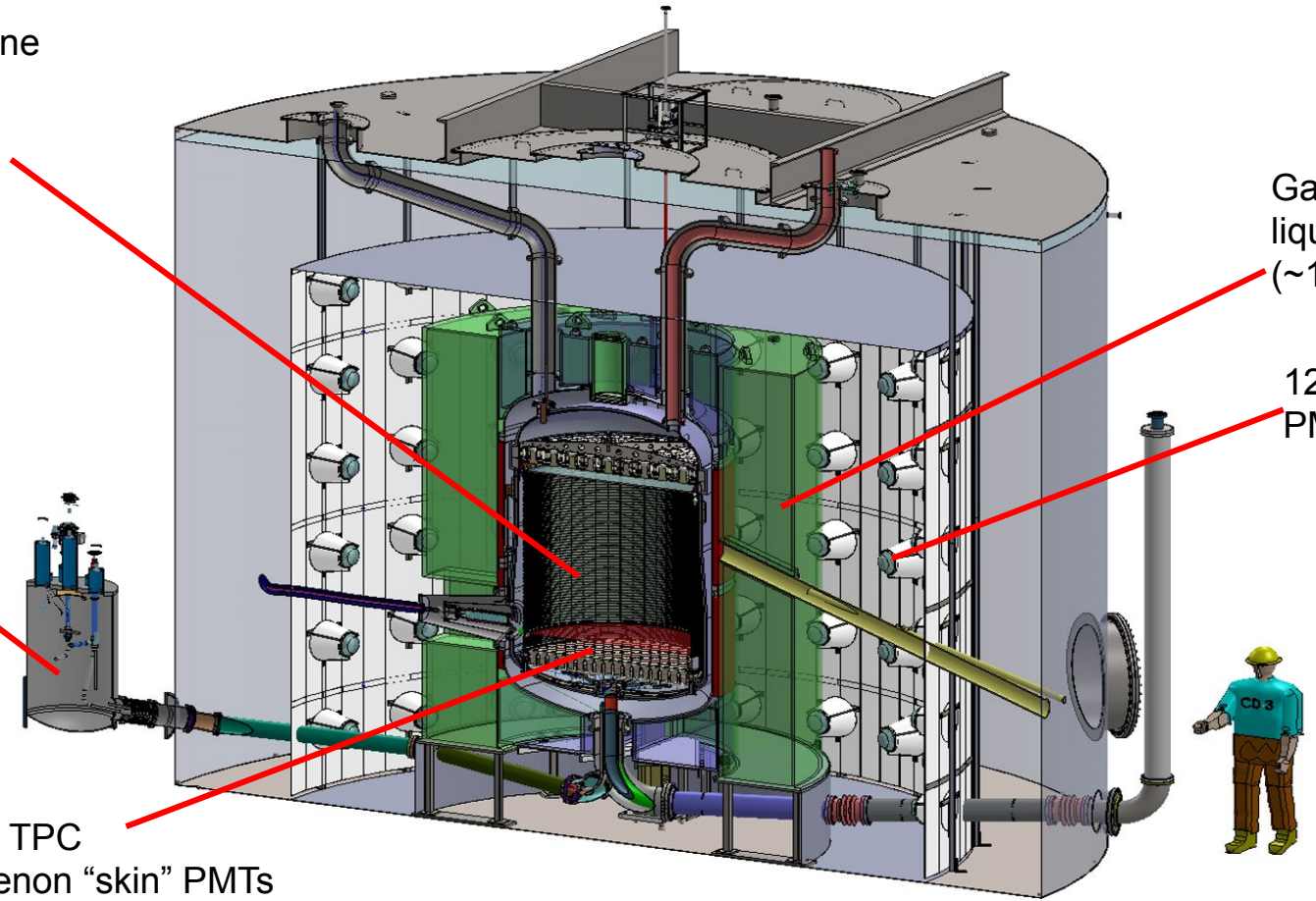
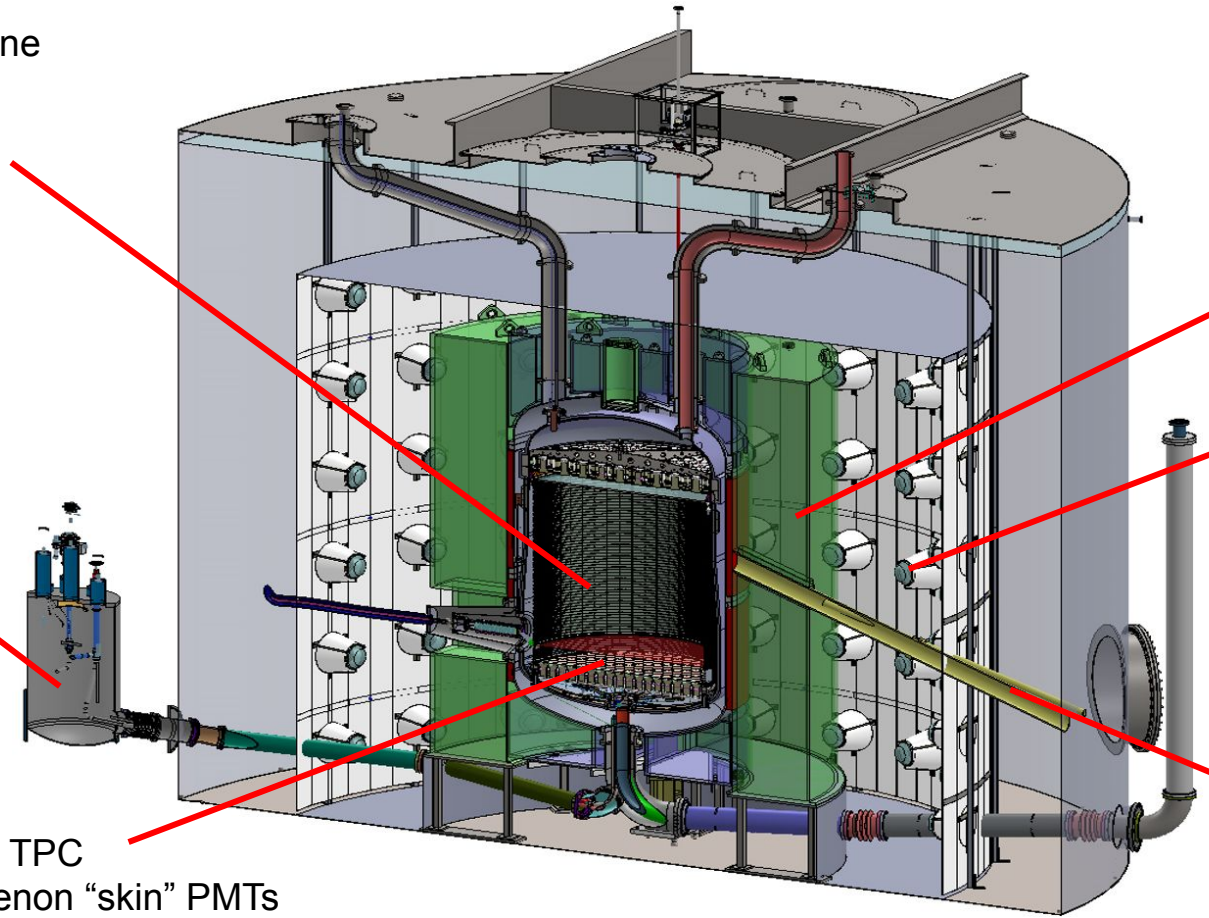


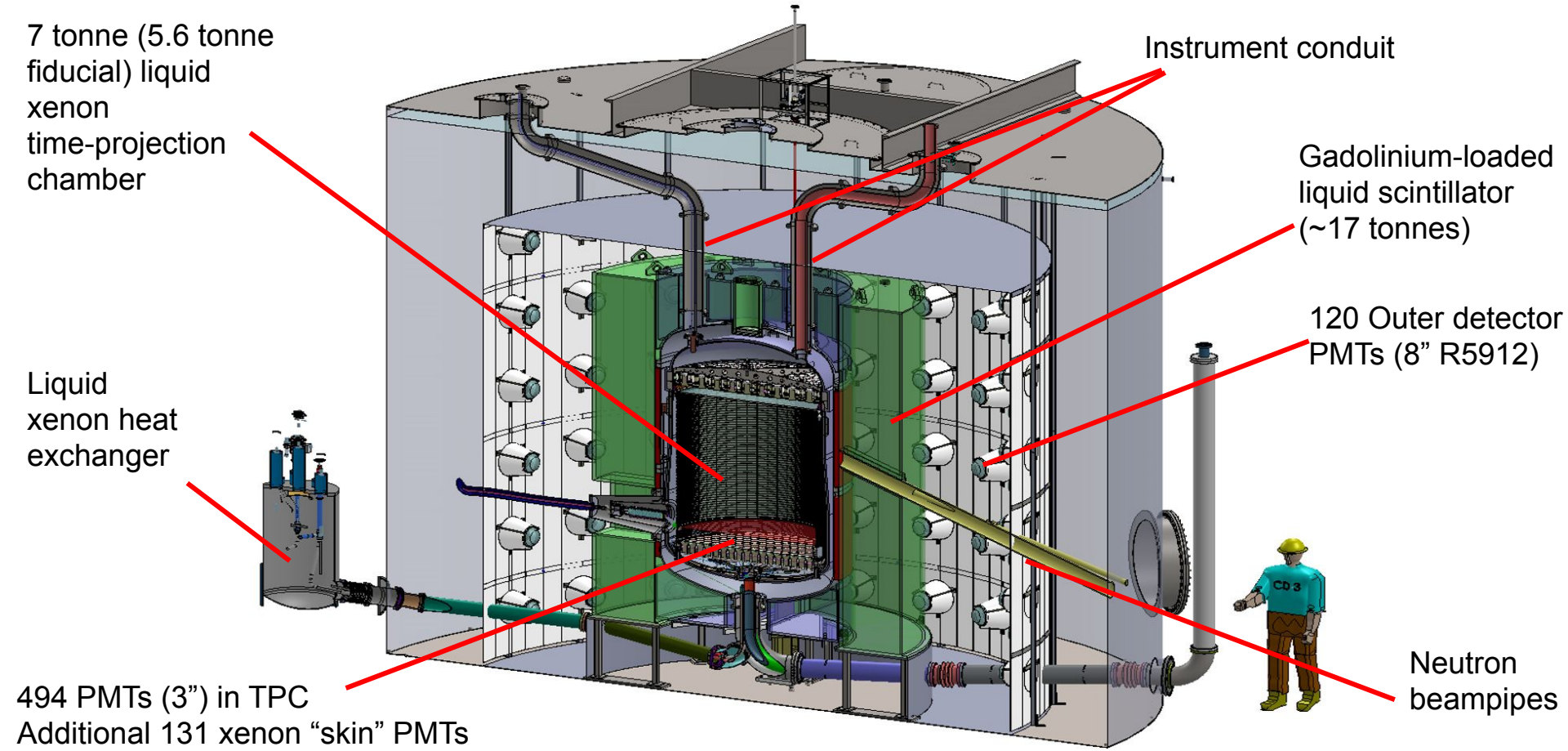
LZ Detector


7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber
Gadolinium-loaded liquid scintillator (~17 tonnes)
120 Outer detector PMTs (8” R5912)
Liquid xenon heat exchanger
494 PMTs (3”) in TPC
Additional 131 xenon “skin” PMTs

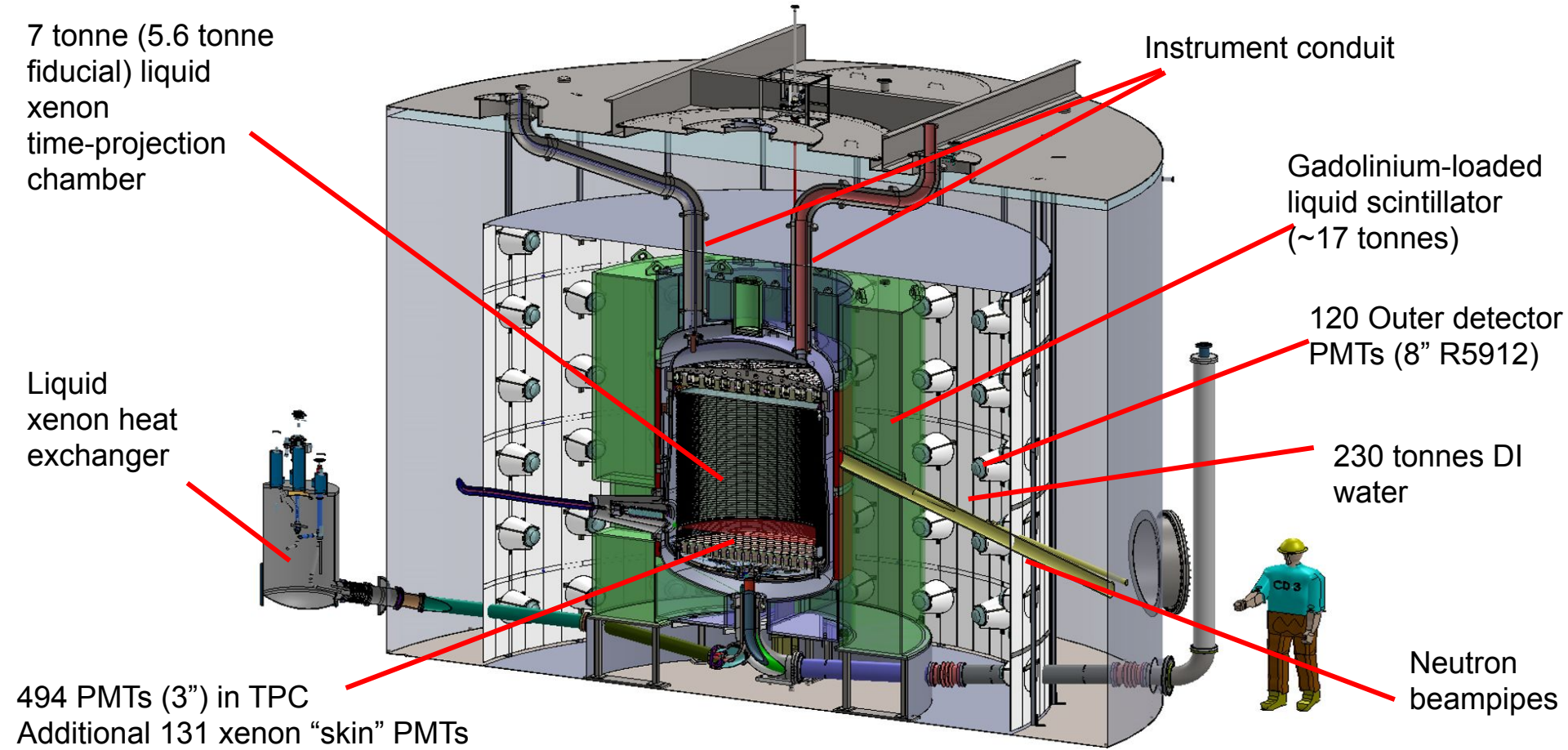
LZ Detector

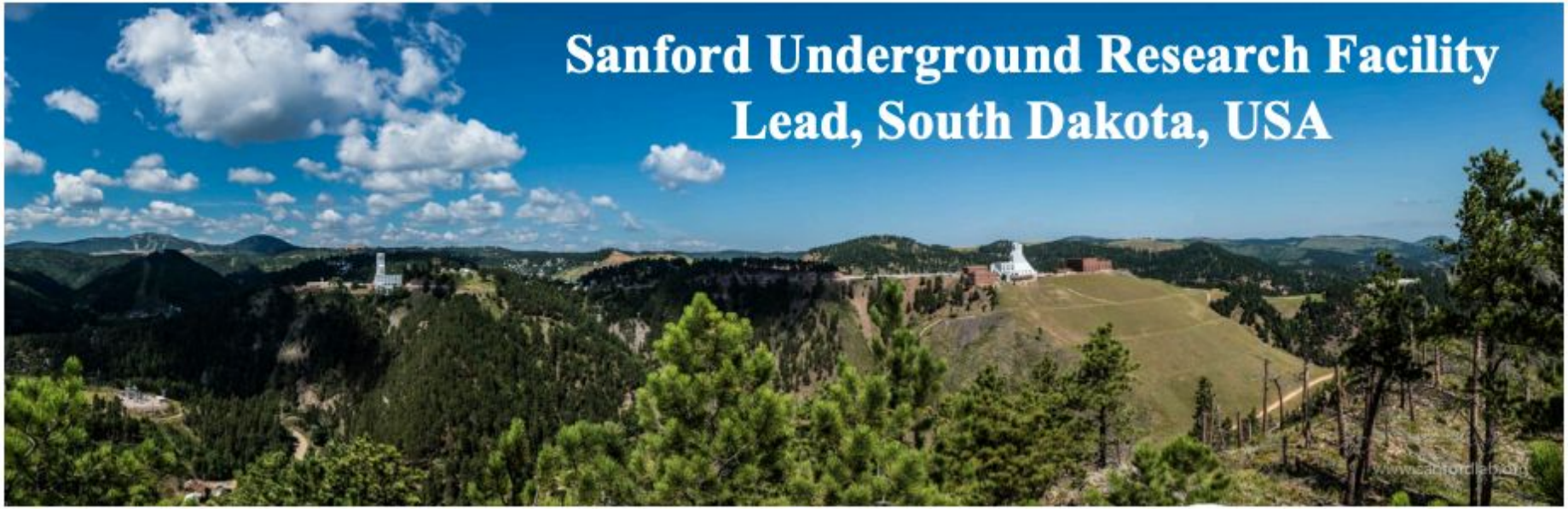

7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber
Gadolinium-loaded liquid scintillator (~17 tonnes)
120 Outer detector PMTs (8” R5912)
Liquid xenon heat exchanger
494 PMTs (3”) in TPC
Additional 131 xenon “skin” PMTs
Neutron beampipes

LZ Detector

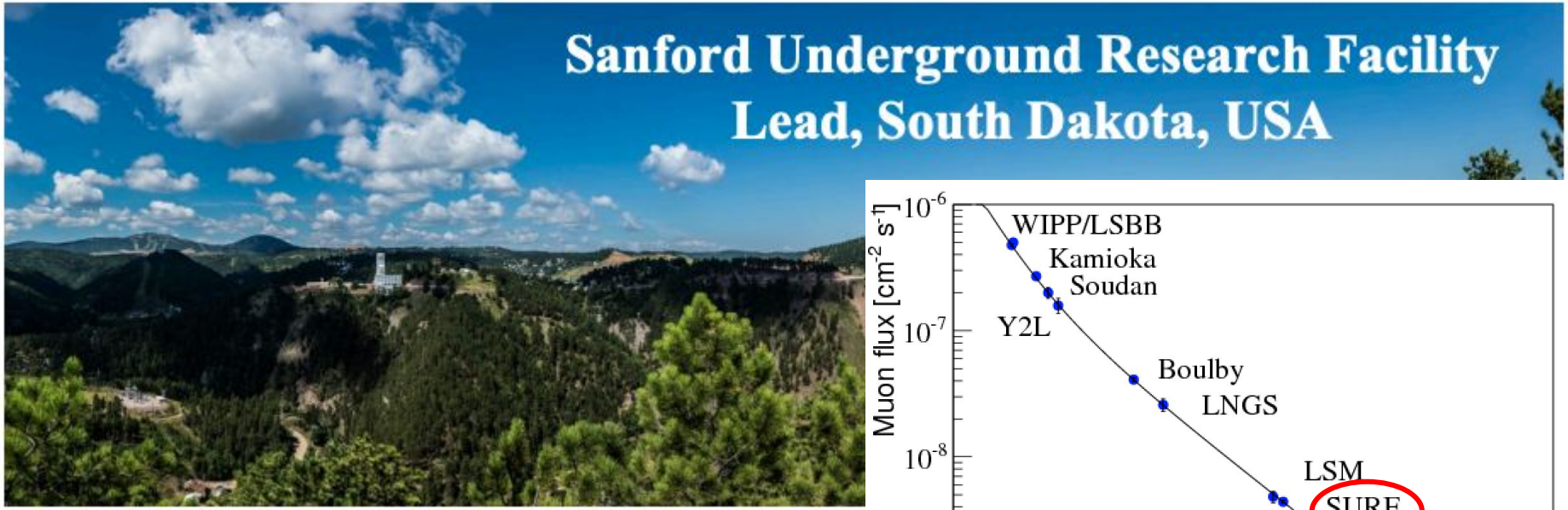

7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber
Instrument conduit
Gadolinium-loaded liquid scintillator (~17 tonnes)
120 Outer detector PMTs (8” R5912)
Liquid xenon heat exchanger
494 PMTs (3”) in TPC
Additional 131 xenon “skin” PMTs
Neutron beampipes

LZ Detector


7 tonne (5.6 tonne fiducial) liquid xenon time-projection chamber
Instrument conduit
Gadolinium-loaded liquid scintillator (~17 tonnes)
120 Outer detector PMTs (8” R5912)
230 tonnes DI water
Liquid xenon heat exchanger
Neutron beampipes
494 PMTs (3”) in TPC
Additional 131 xenon “skin” PMTs



- Previously was a deep underground gold mine (Homestake mine, 1878 - 2001).
- Famous Homestake experiment performed by Raymond Davis in 1960s, has long history related to particle physics.
- LZ located at Davis Campus (~ 1.5 km underground, 4300 mwe), also the future home of DUNE



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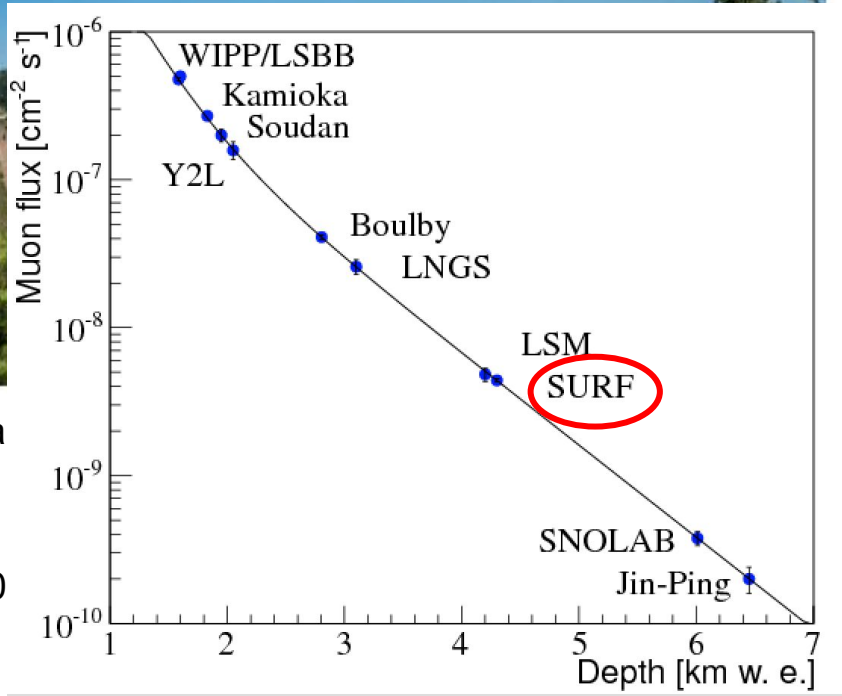
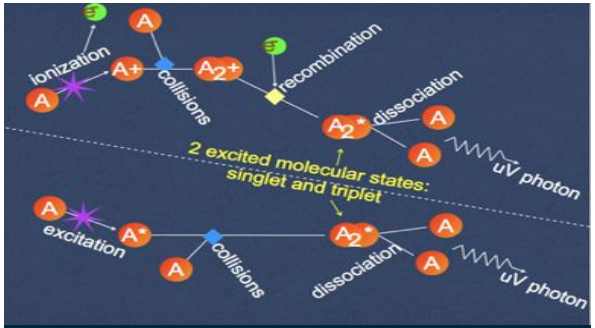
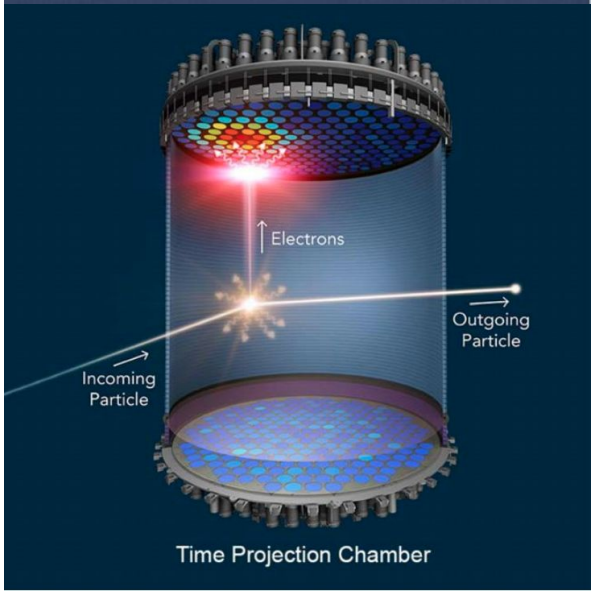


Time Projection Chamber

- Incident particle impinges on the target atoms to either ionize or excited the atoms.
- Excited atoms forms the diatomic molecule (dimers) after went through the three-body collision with neutral atom and subsequently emit the primary scintillation light (S1).
- Electrons coming out of ionized atoms are drifted to the gas phase and emit the scintillation light (S2).
- High purity xenon target ensures the long electron drift time.
- Electronic recoil backgrounds distinguished by ratio of charge(S2)/light(S1) signal.
- 3D imaging achieved by determine the timing of S1 and S2 (Z position) and light pattern (X-Y position)





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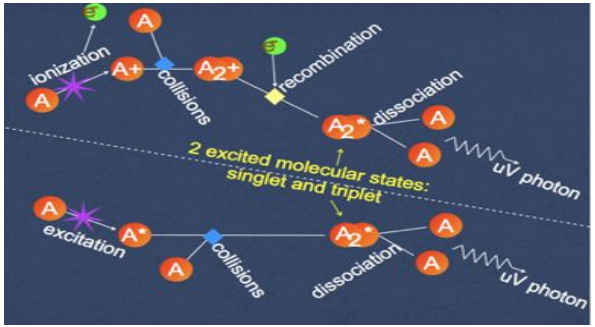
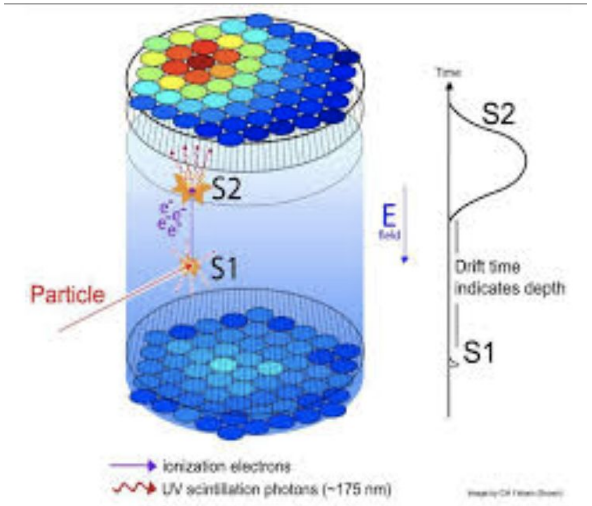
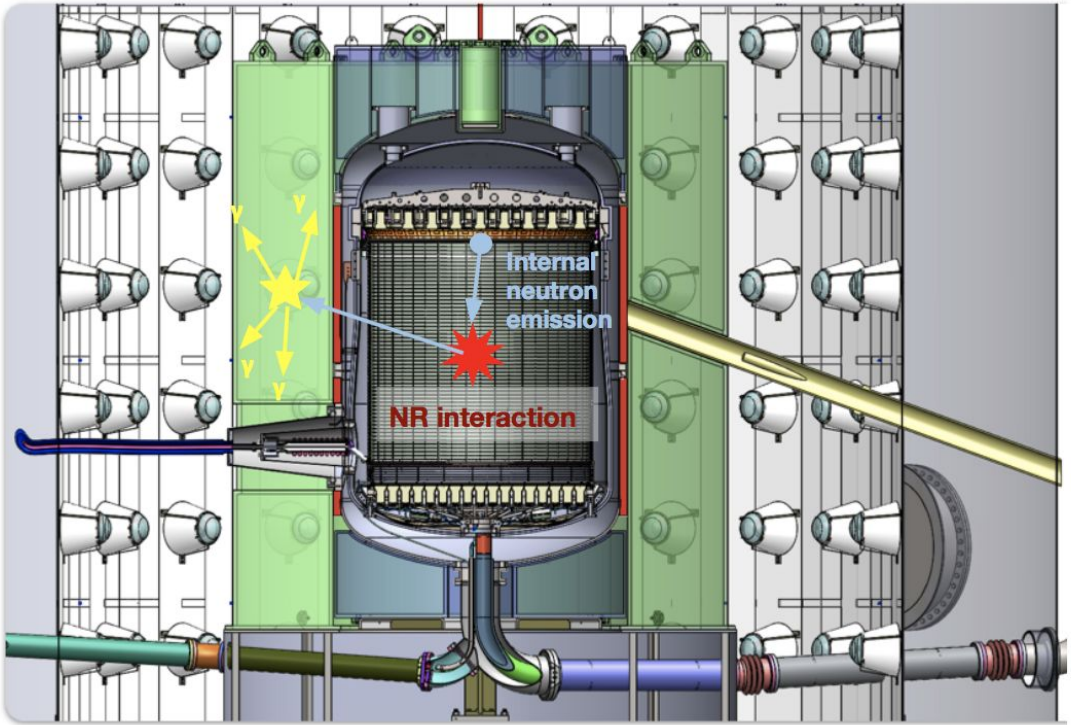
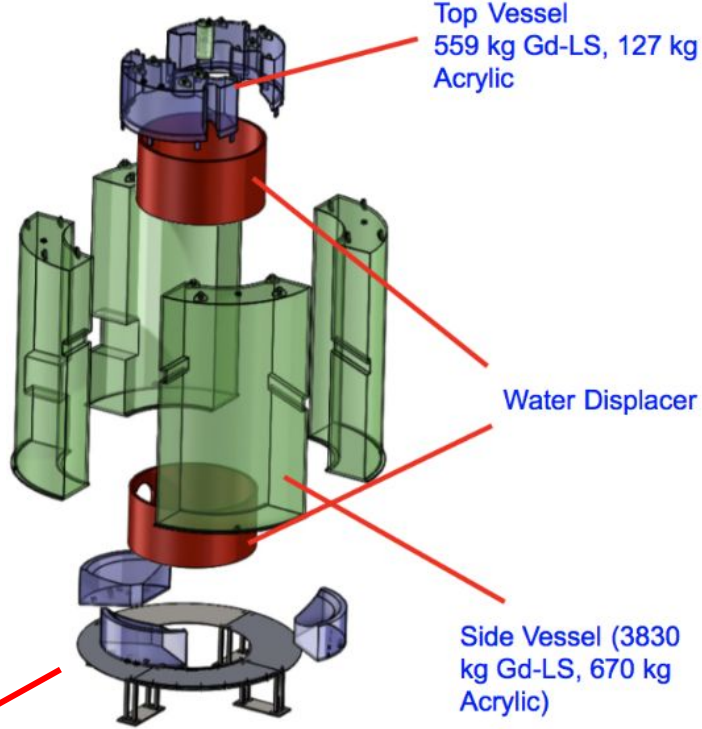




Outer detector

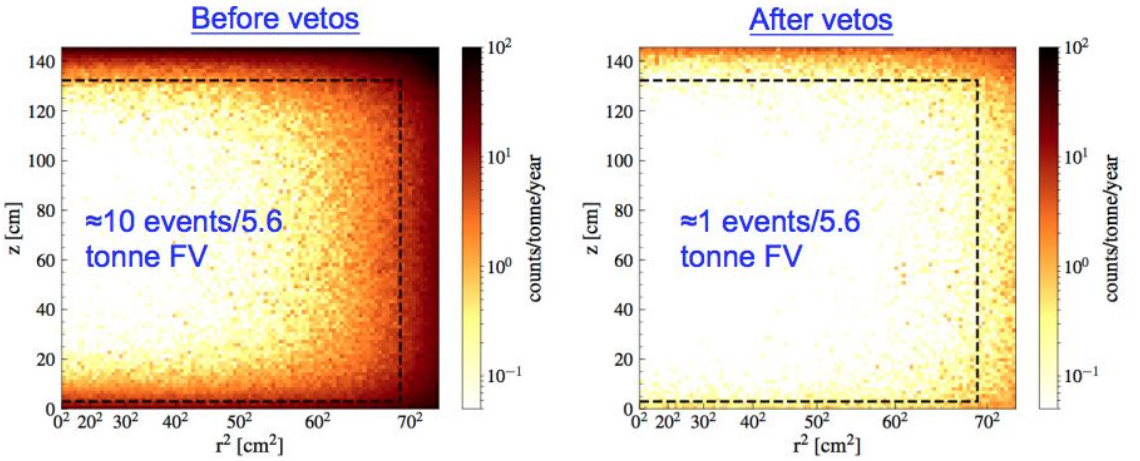


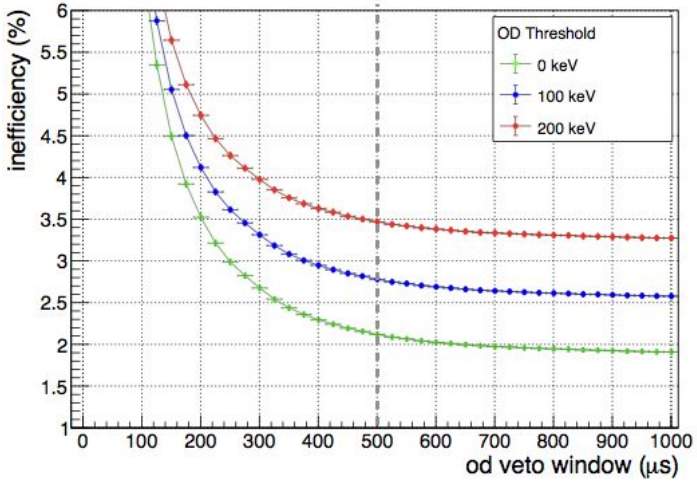


Veto system performance

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





https://arxiv.org/abs/1703.09144

- WIMP-like nuclear recoil backgrounds in 6-30 keV region of interest.
- Fiducial would be reduced from 5.6 to 3.2 tonnes without outer detector.
- Maybe possible to go to 100 keV threshold, reaching < 3% inefficiency.

Background summary

- Cosmological background
  - Rock gamma
  - Neutrino events
- Internal background
  - Charcoal chromatography to remove ^{85}Kr and ^{39}Ar
  - Dedicated facility at SLAC
  - Rn emanation screen campaign
    - Four Rn screening site
    - Target Rn activity = 2 μBq/kg
    - Total ~ 0.001 x Banana in 10 tonnes of Xenon
  - Rn daughter (plate-out)
    - TPC assembly in Rn-reduced cleanroom to limit daughter recoils on surface
  - Rn-daughter plate on TPC walls < 0.5 mBq/m^3

Background Source	ER (cts)	NR (cts)
Detector Components	**9**	**0.07**
Surface Contamination	**40**	**0.39**
Laboratory and Cosmogenics	**5**	**0.06**
Xenon Contaminants	**819**	**0**
222Rn	681	0
220Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	**322**	**0.51**
136Xe 2νββ	67	0
Solar neutrinos (pp+7Be+13N)	255	0
Diffuse supernova neutrinos	0	0.05
Atmospheric neutrinos	0	0.46
Total	1195	1.03
with 99.5% ER discrim., 50% NR eff.	**5.97**	**0.51**

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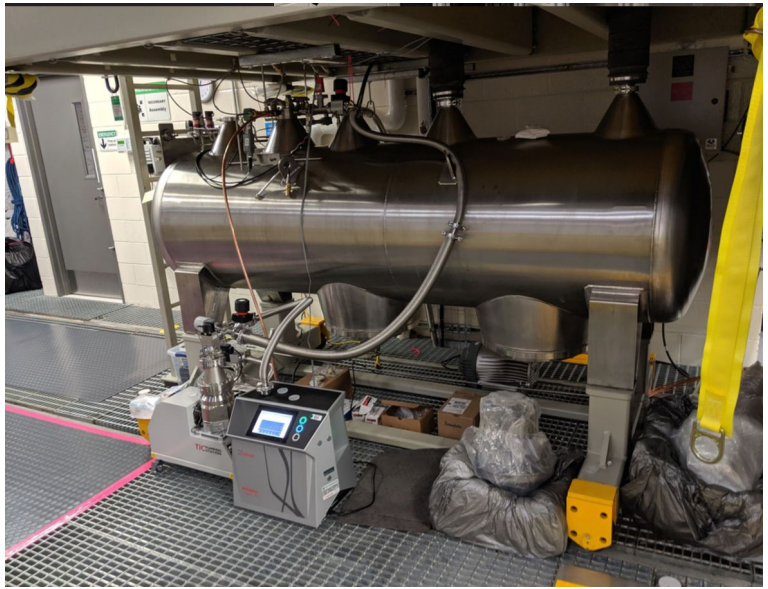
Construction @ SURF

COW
(Cryogen On Wheel)

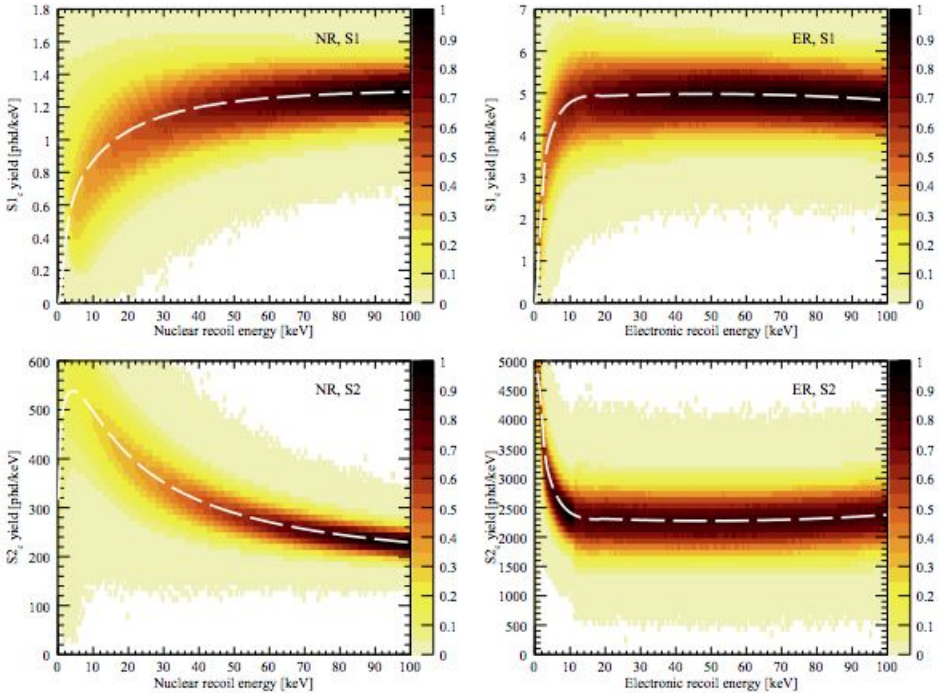


- Circulation system has been constructed and tested underground.
- Preparation of OD construction is undergoing, 16 (17.5 total) tonnes Gd-LS is produced at Brookhaven Nat. Lab.
- Calibration system will be deployed later this year !

TPC construction

- TPC assembly is done !
  - Assembled in low radon clean room
  - System checkout indicate all system installed properly
  - TPC has been inserted into Inner cryo-vessel (ICV)
  - Final checkout is underway
  - Pumping ICV down in few weeks
  - Move to underground facility in Mid-Oct !

Standard WIMPs analysis in LZ

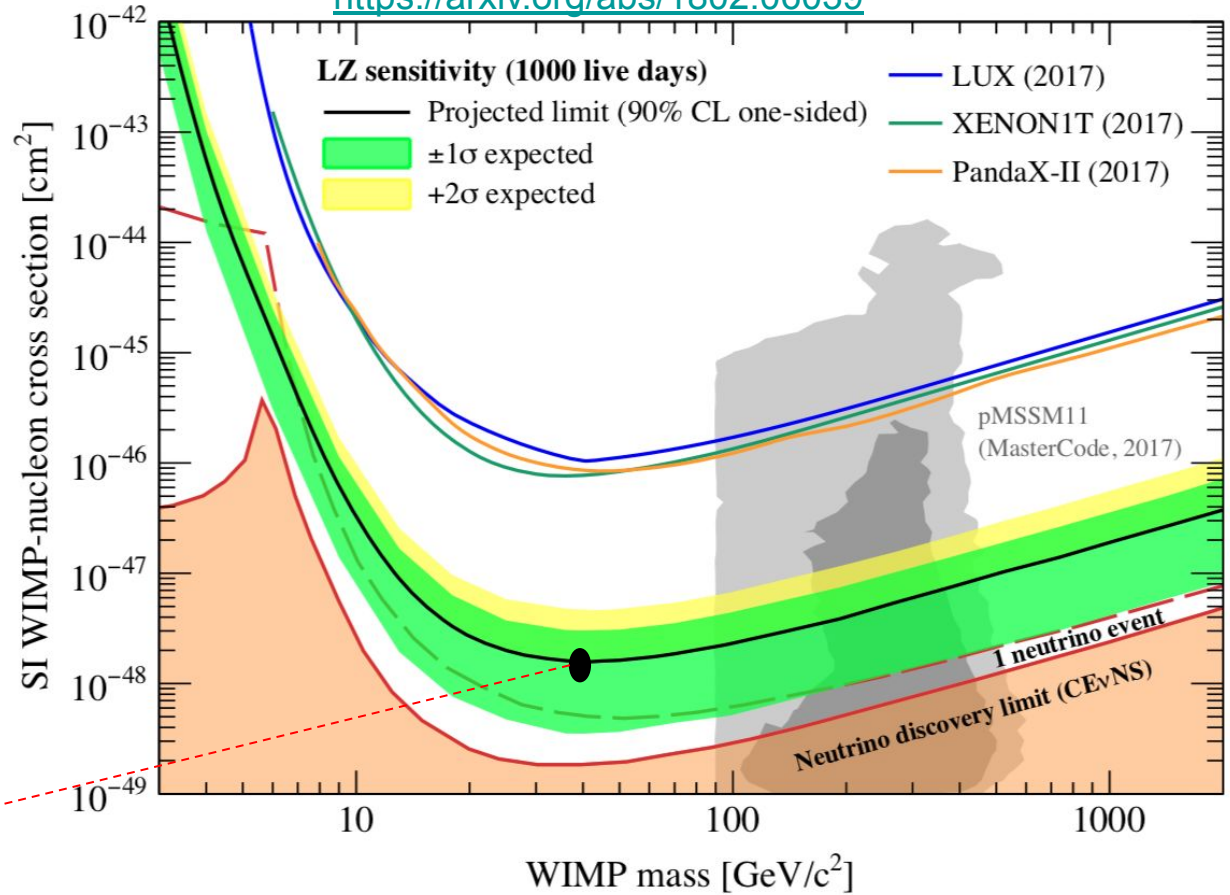


arXiv: 1802.06039

- Nuclear recoil events can be separated by discrimination parameters (S2/S1).
- Thorough study on detector response through MC simulation.
- Mock data is being produced to understand the the performance and ready for first scientific data !

Projected WIMP sensitivity (1000 live-days, 5.6 fiducial)

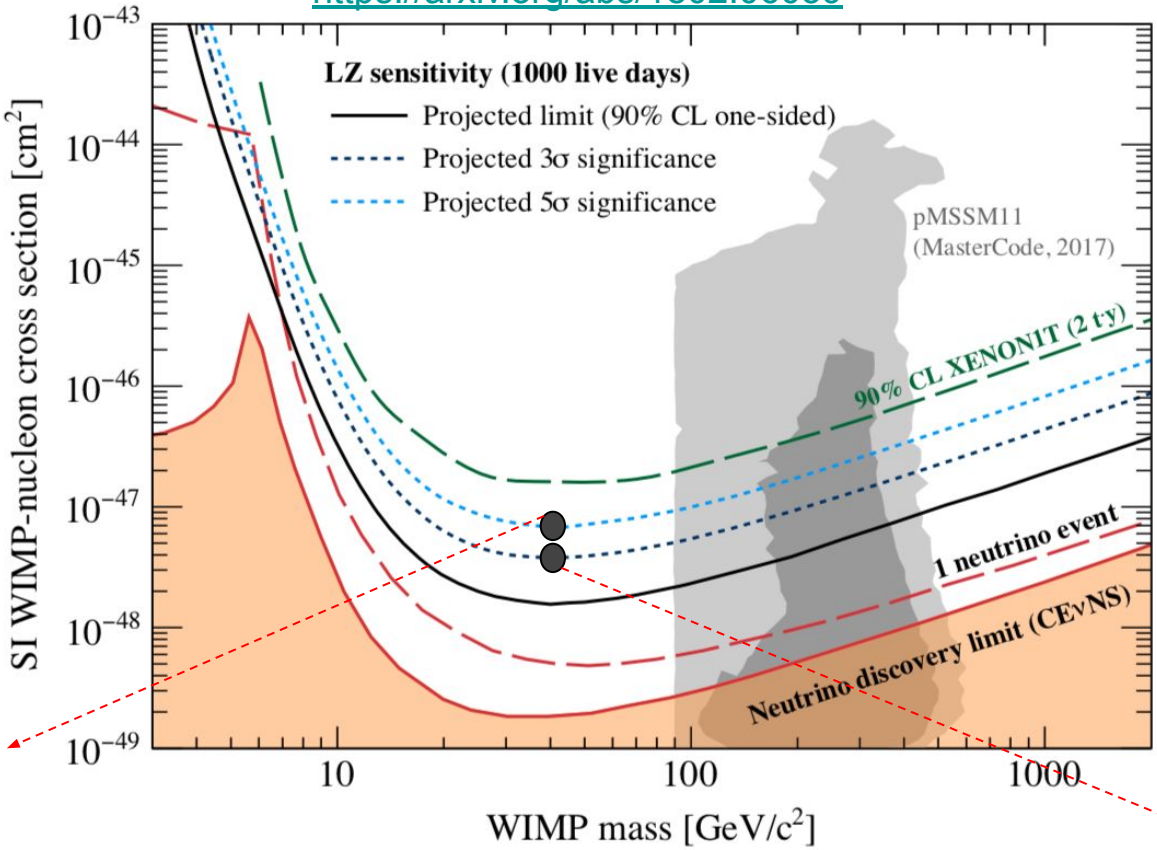
https://arxiv.org/abs/1802.06039



1.6 x 10^{-48} cm^2
@ 40 GeV/c^2

Discovery potential (1000 live-days, 5.6 fiducial)

https://arxiv.org/abs/1802.06039

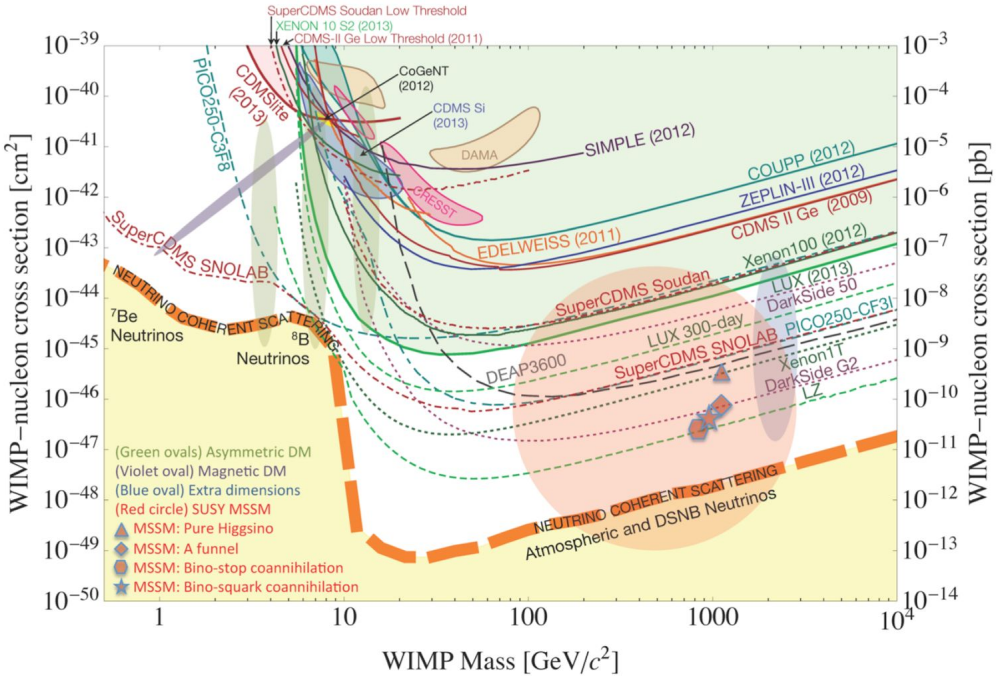


5 σ : 6.7 x 10^{-48} cm^2

3 σ : 3.8 x 10^{-48} cm^2

Summary

- LZ is optimised for WIMP discovery
  - 7-tonne active mass + low energy threshold
  - Extensive radio-assay and surface cleanliness -> BG control.
  - Near-hermetic active veto system suppresses remaining NR backgrounds.
- Main detector (TPC) has been assembled in Surface Assembly Laboratory (SAL) , will move to underground in Mid-Oct 2019.
- Cryogenic system is being installed and under test in underground.
- Various physics can be probed by LZ detector
  - Neutrinoless double beta decay
  - Electron recoil DM
  - Supernova neutrinos
  - Annual modulation signal
  - Inelastic DM
  - Momentum dependent DM
- Detector commissioning in ~ late spring 2020 !



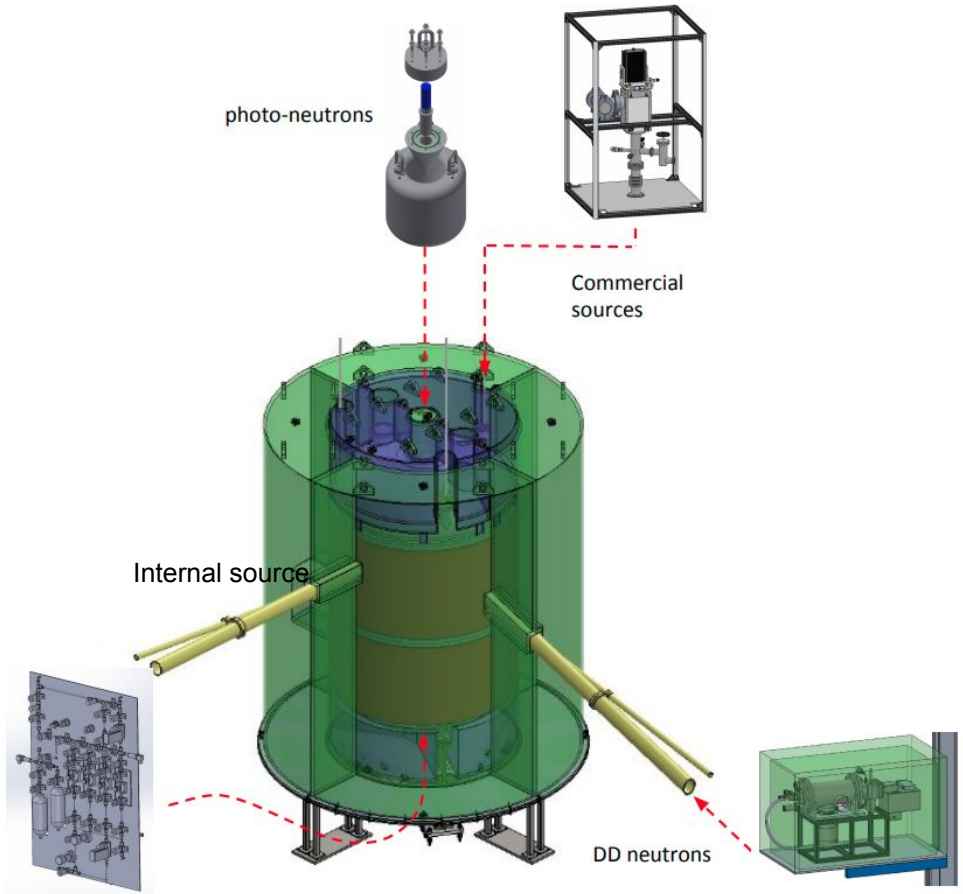
https://arxiv.org/abs/1310.8327

TPC insertion complete @ SAL

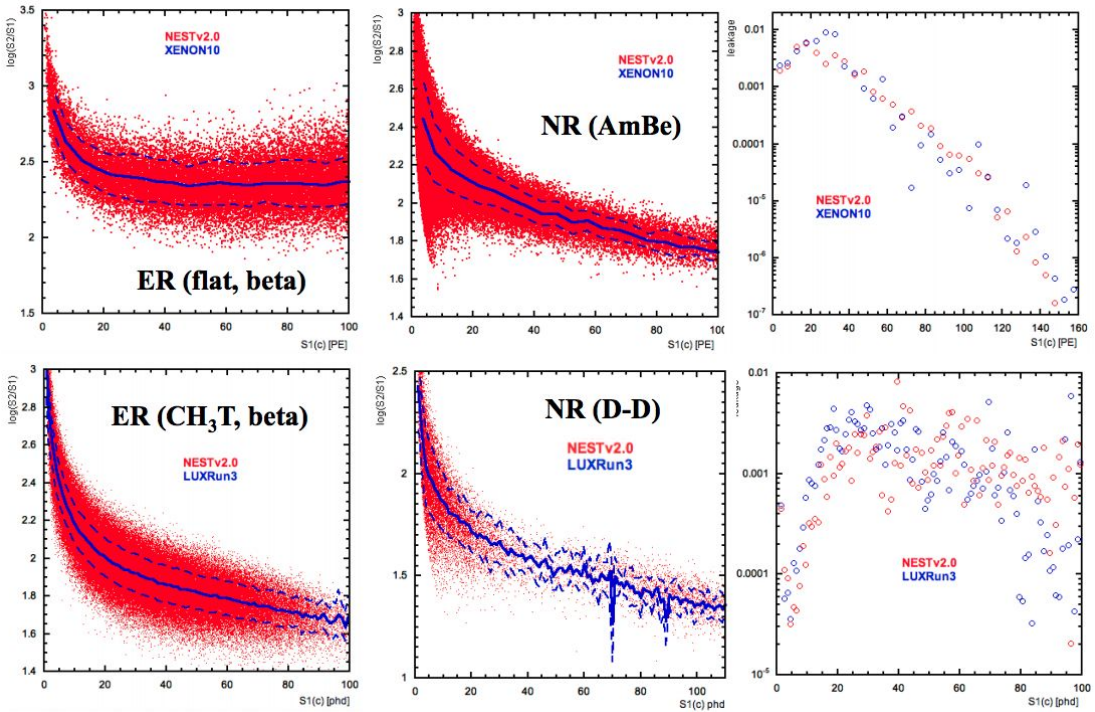
Backup Slides

Calibration

- Internal source
  - ^{83m}Kr (beta, 41 keV)
  - ^{131m}Kr (gamma 9.4 keV)
  - ^{220}Rn (alpha)
- Radioactive source
  - AmLi (alpha,n)
  - ^{22}Na (back to back 511 keV gamma)
- Photo-neutrons
  - ^{88}YBe (low-energy NR response)
- DD Generator
  - 2.4 MeV neutron (NR light and charge yields)
- Light sources
  - LED optical calibration

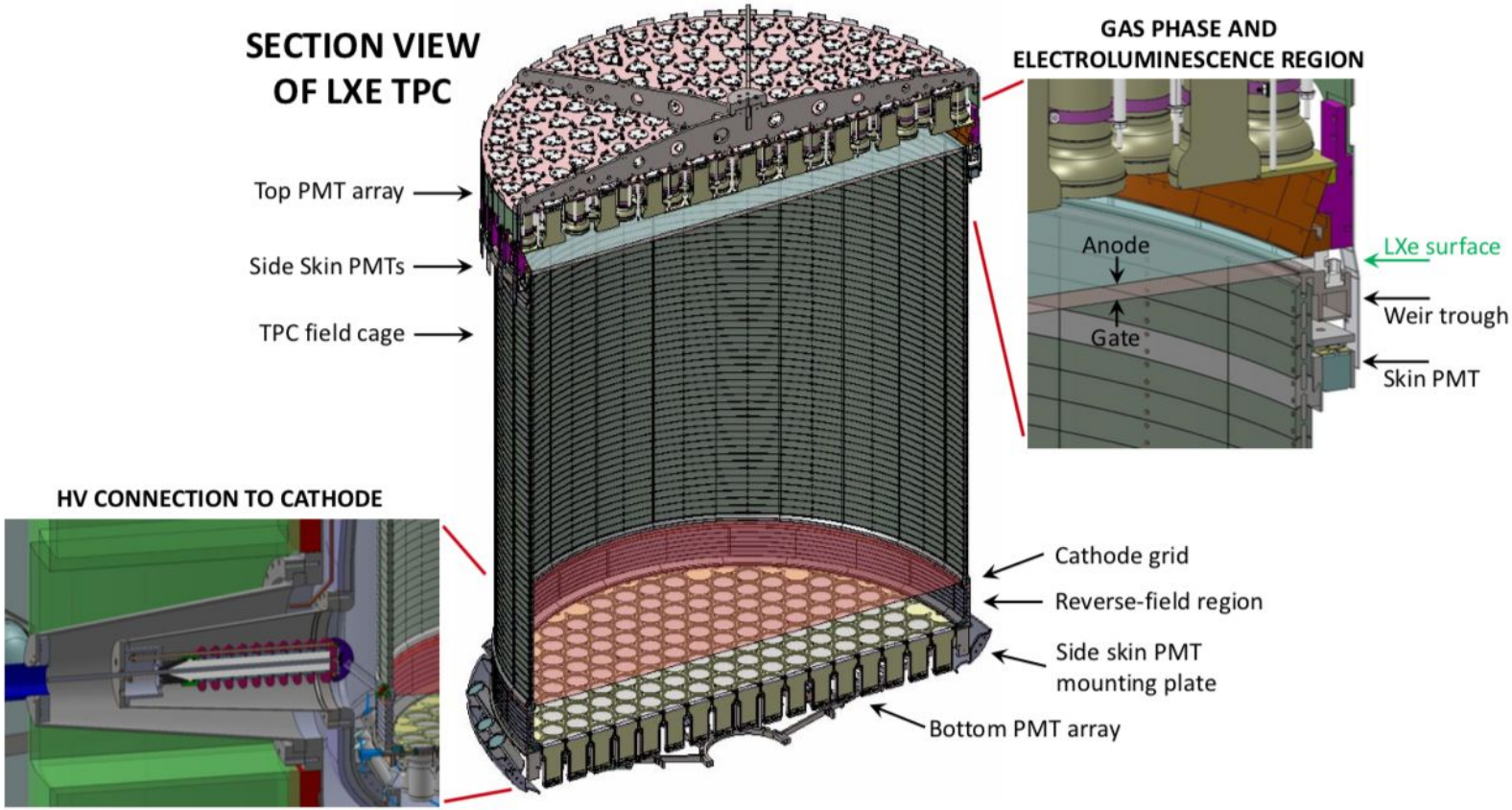


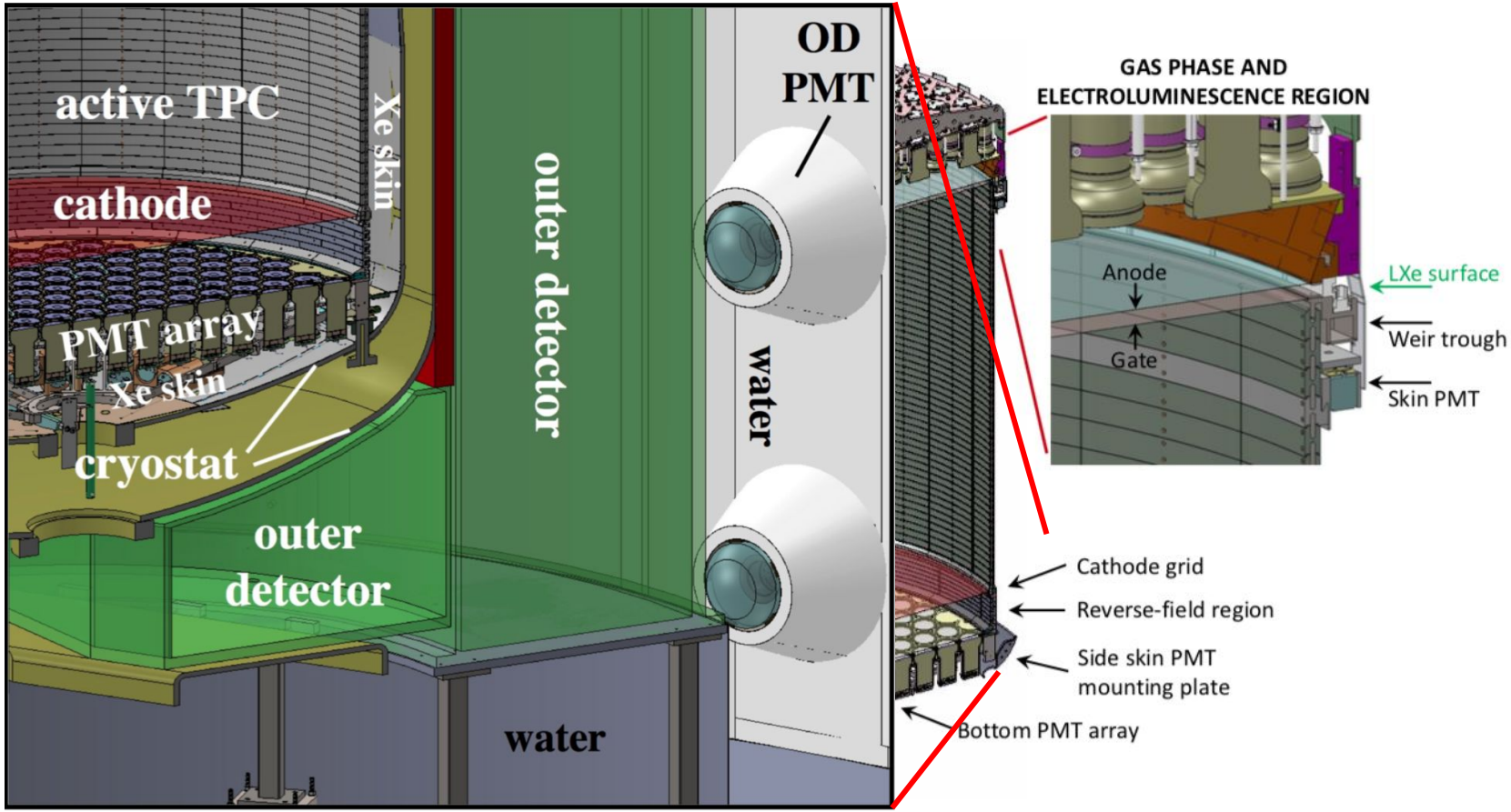
Detector Response in Simulation



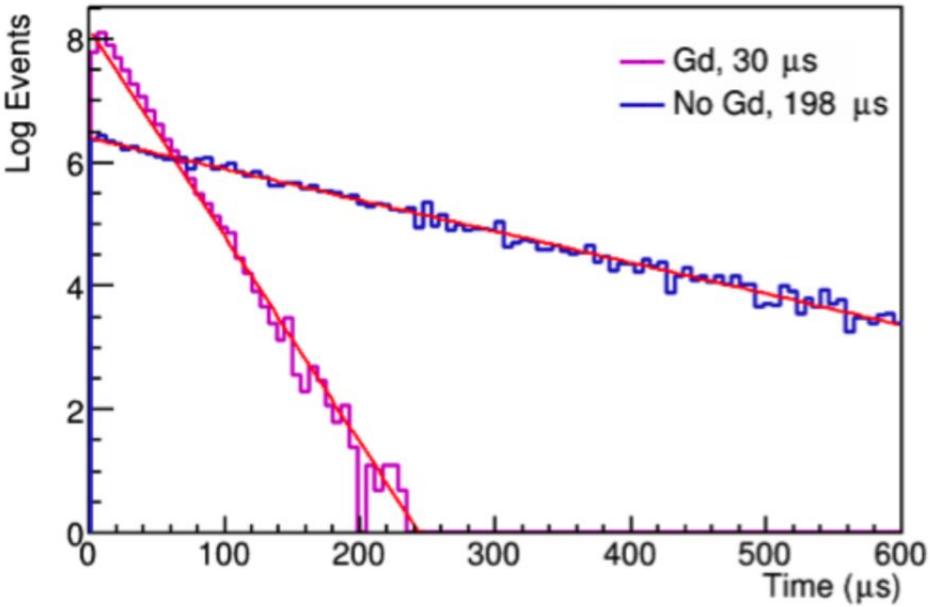
- Noble Element Simulation Technique (NEST) is a comprehensive model for explaining scintillation yield in liquid xenon.
- No complicated models in different energy regime.
- NEST is integrated into LZ simulation package which gives more realistic light yield and charge yield in the simulation.

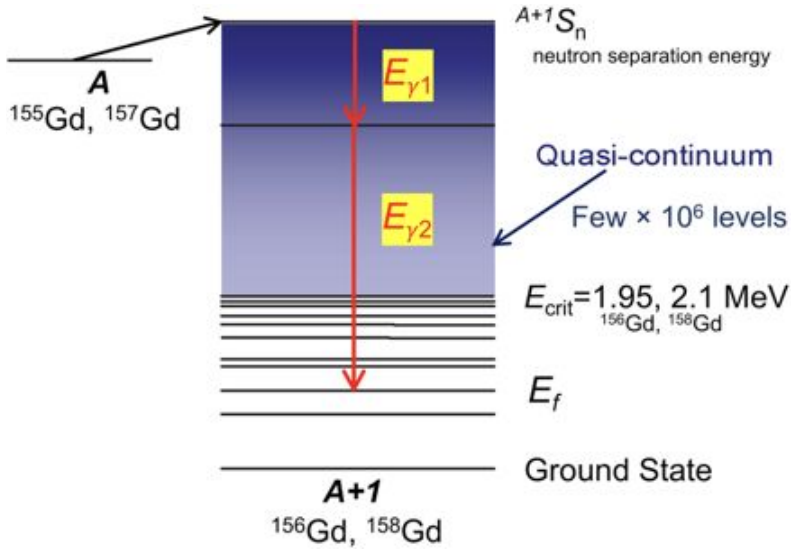
NEST v2.0: B. Lenardo, K. Kazkaz, A. Manalaysay, J. Mock, M. Szydagis, and M. Tripathi, IEEE Trans. Nucl. Sci. 62, 3387 (2015), arXiv:1412.4417 [astroph.IM].


SECTION VIEW
OF LXE TPC
Top PMT array
Side Skin PMTs
TPC field cage
GAS PHASE AND
ELECTROLUMINESCENCE REGION
Anode
Gate
LXe surface
Weir trough
Skin PMT
HV CONNECTION TO CATHODE
Cathode grid
Reverse-field region
Side skin PMT
mounting plate
Bottom PMT array


active TPC
cathode
PMT array
Xe skin
cryostat
Xe skin
outer detector
OD PMT
water
outer detector
water
GAS PHASE AND ELECTROLUMINESCENCE REGION
Anode
Gate
LXe surface
Weir trough
Skin PMT
Cathode grid
Reverse-field region
Side skin PMT mounting plate
Bottom PMT array

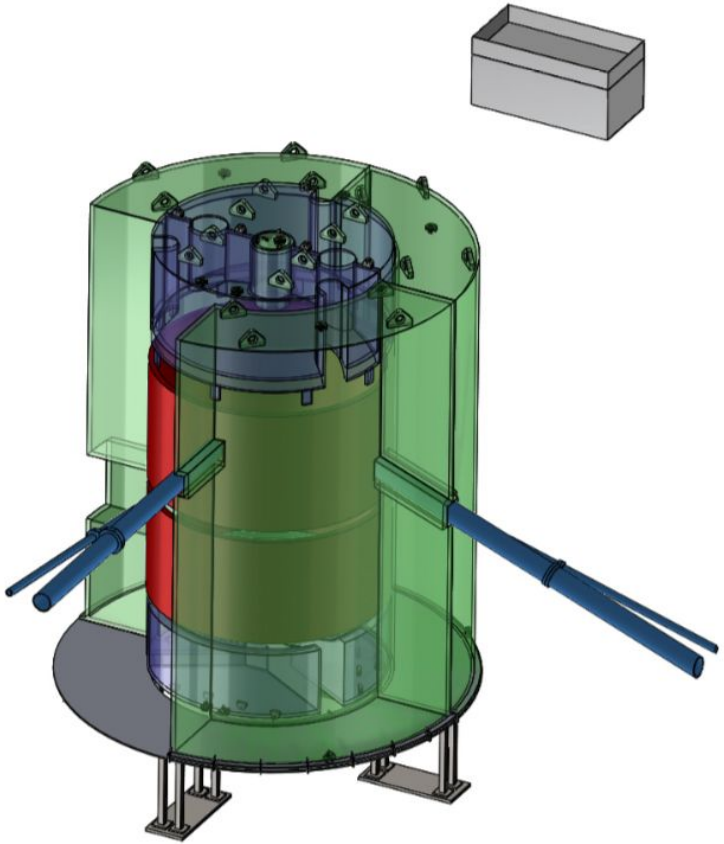
Neutron Capture on Gd

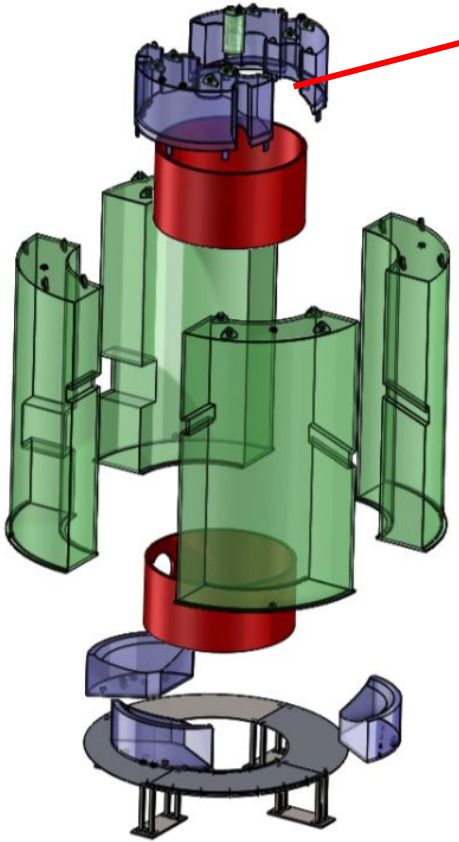




- Thermal neutron capture cross sections : ^{157}Gd : 254,000 barns, ^{155}Gd : 61,000 barns
- After neutron capture, 3-4 gammas released with total energy of ~ 8 MeV .

Outer detector

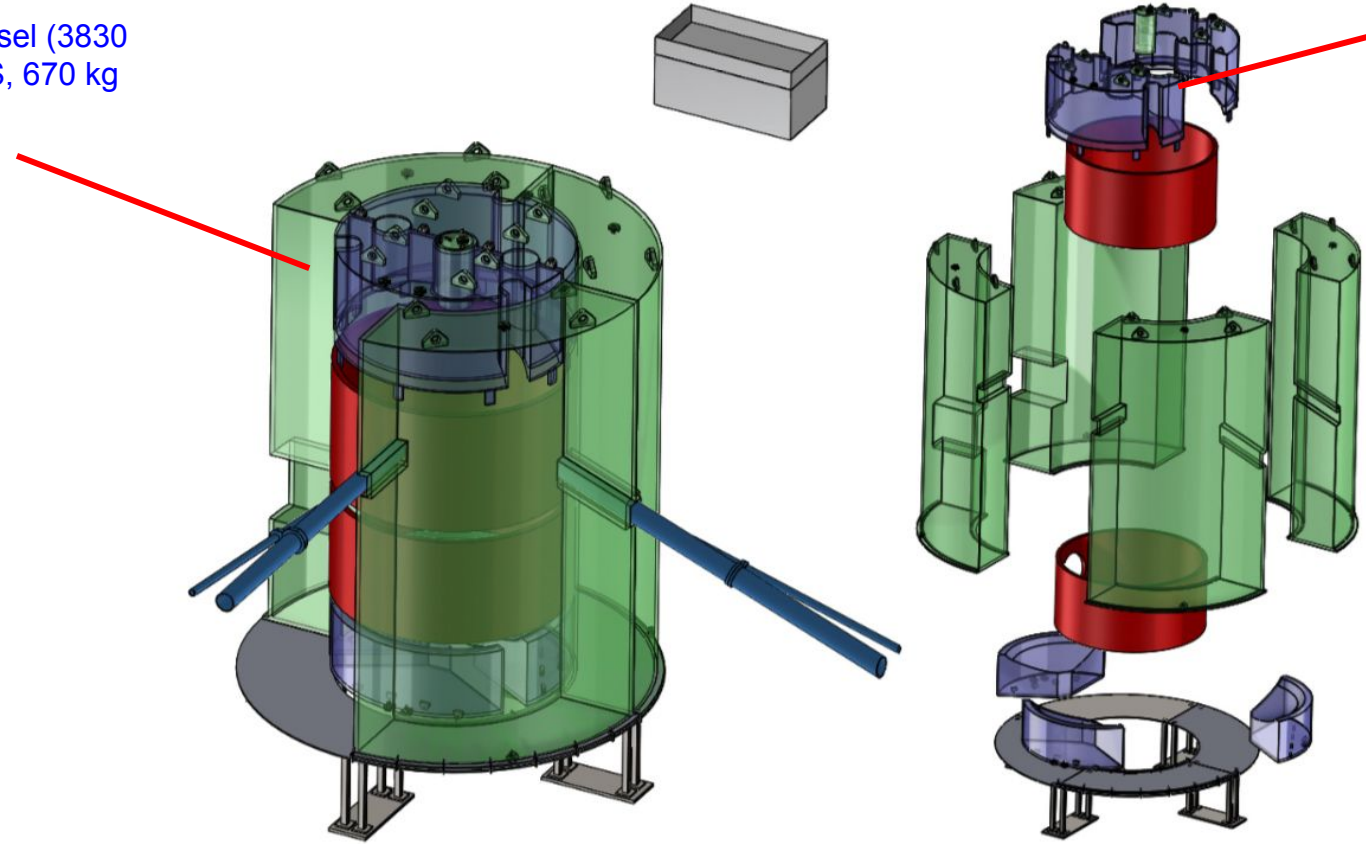




Outer detector

Side Vessel (3830 kg Gd-LS, 670 kg Acrylic)

Top Vessel 559 kg Gd-LS, 127 kg Acrylic

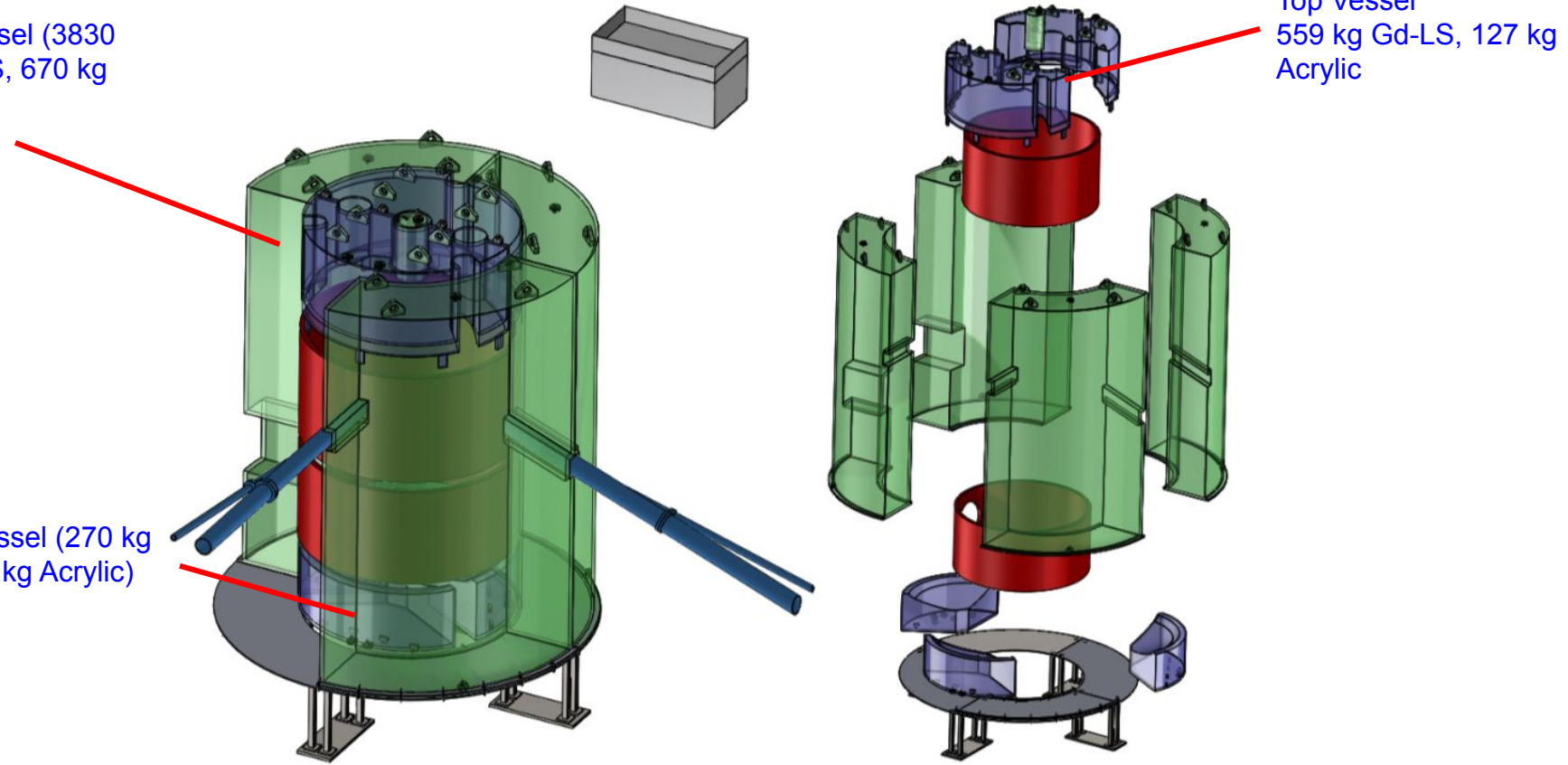


Outer detector

Side Vessel (3830 kg Gd-LS, 670 kg Acrylic)

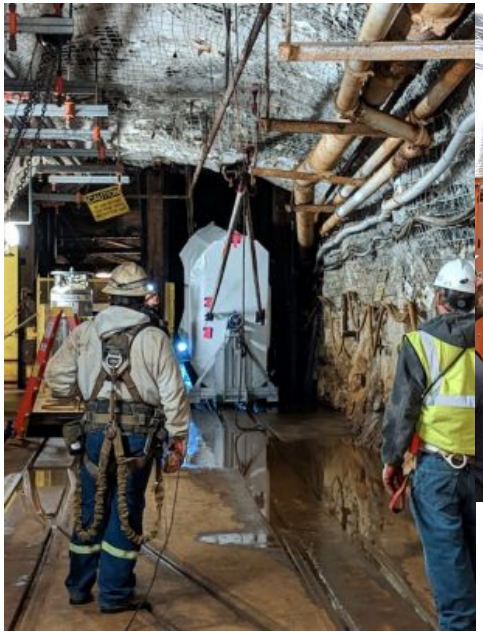
Top Vessel 559 kg Gd-LS, 127 kg Acrylic

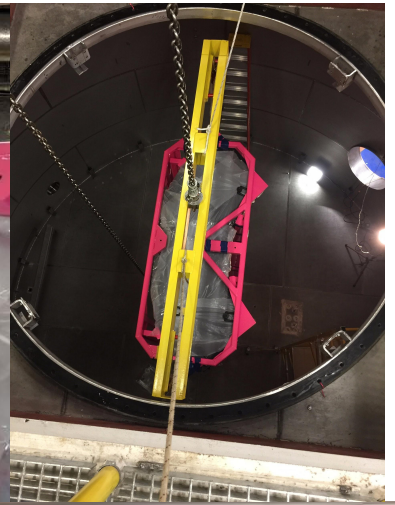
Bottom Vessel (270 kg Gd-LS, 60 kg Acrylic)



Outer detector

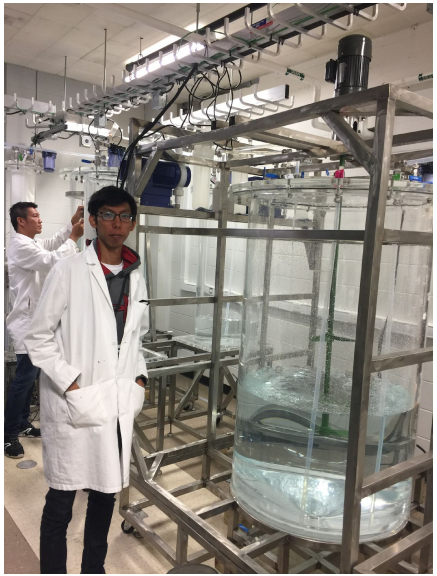
Acrylic Vessels





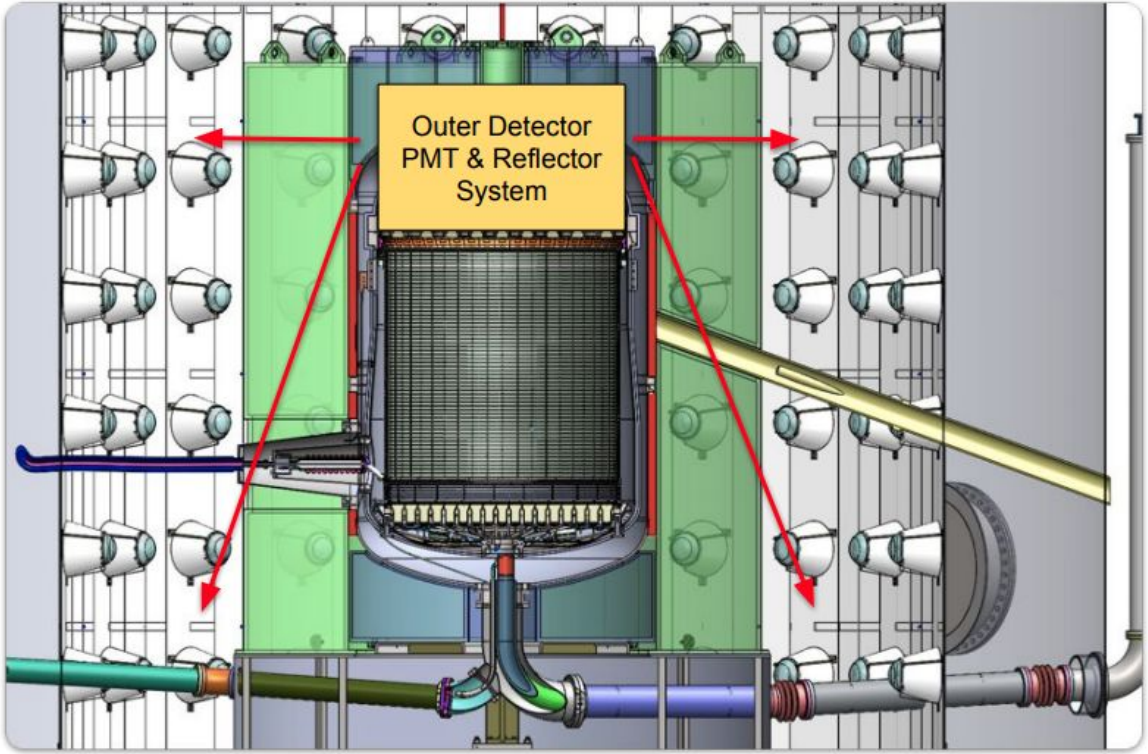
- All vessels were made and molded at Reynolds.
- Four side vessels has been placed in the water tank by the end o
  last year.
- Six small tanks will be delivered to SURF this month.

Gd-LS scintillator production



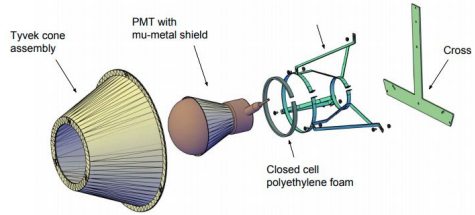
- BNL has started the mass production of Gd-LS since January 2019.
- Steadily producing Gd-LS at the rate of 3-4 batches (500 L for one batch) per week.
- Brandeis team has supported BNL on Gd-LS production
  - Summer undergrad student assisted the mixing system of Gd-LS.
  - I worked at BNL to build compton suppression system to monitor the background of Gd powder.
  - Working on attenuation length measurement of Gd-LS for QA/QC.

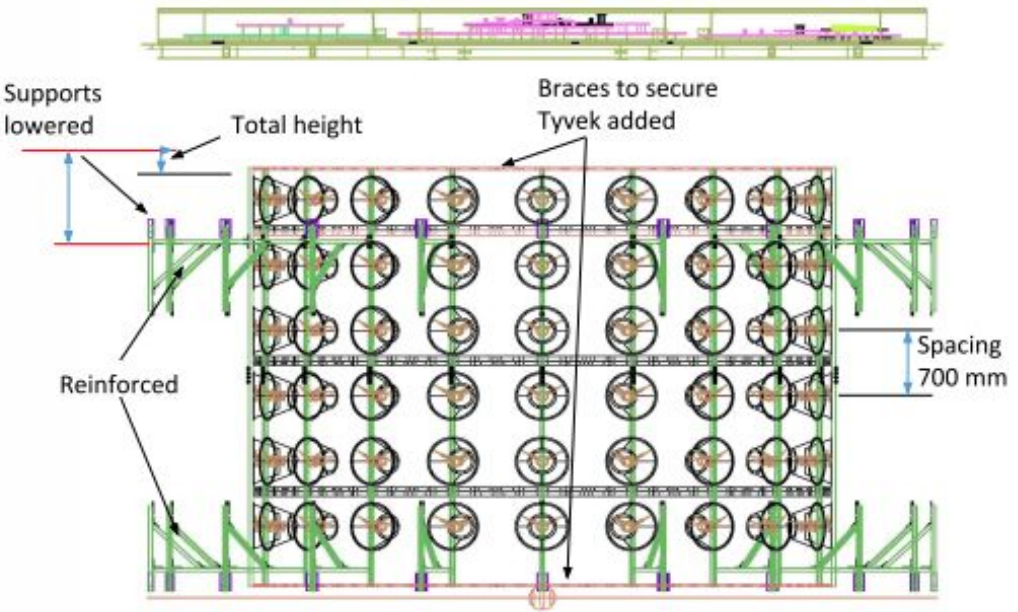
Outer detector PMT & support system



- Brandeis team led by Prof. Penning leads design, construction and commissioning of OD infrastructure.
- Installation is coming up.

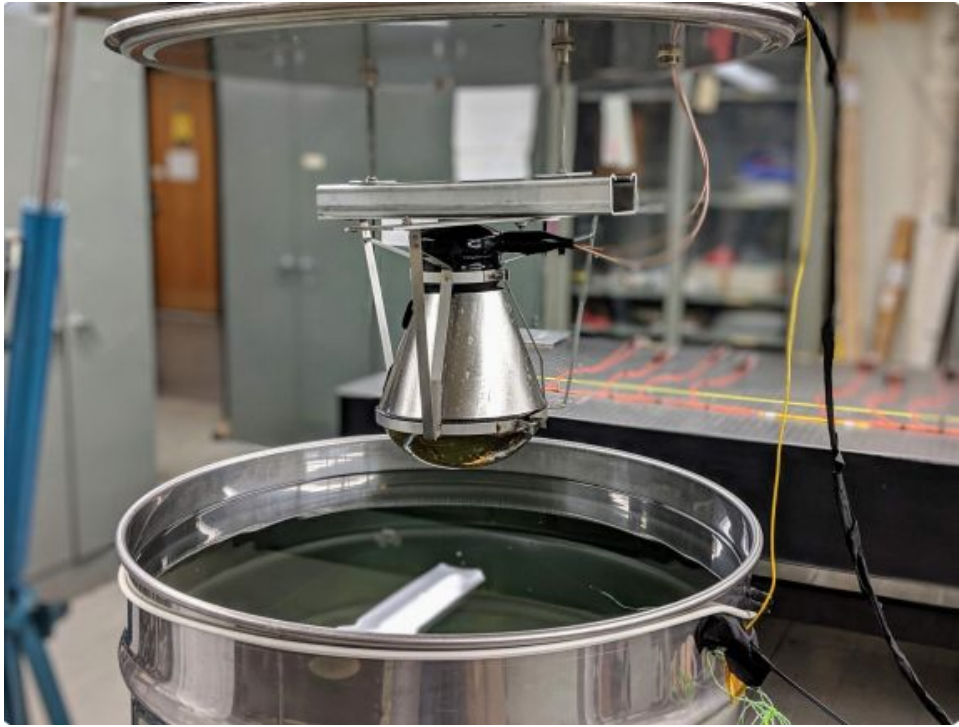
OD PMT support system



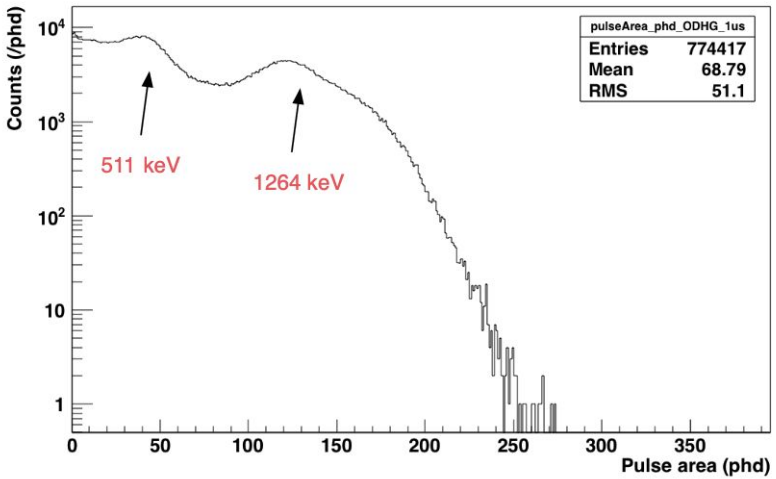


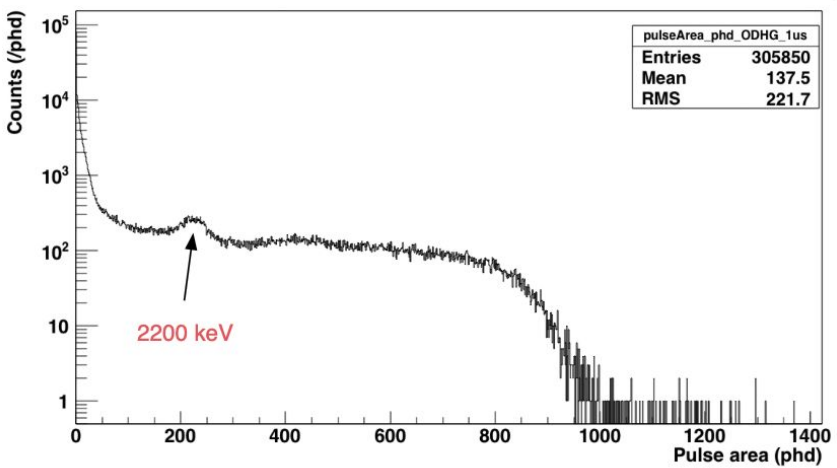
OD PMT

- Shipping 120 PMT from Korea to Brandeis for final assembly.
- Two PMTs shipped to Brandeis last year to perform preliminary test in water barrel test stand (ODTS).
- Submerged into water for long period of time to characterize the behavior of PMT in the full system.
  - Various dark rate measurement carried out by ODTS .
  - LZ optical calibration system (OCS, credit to U. Liverpool) has been installed in ODTS at Brandeis.
  - Data taking with full LZ electronic chain.

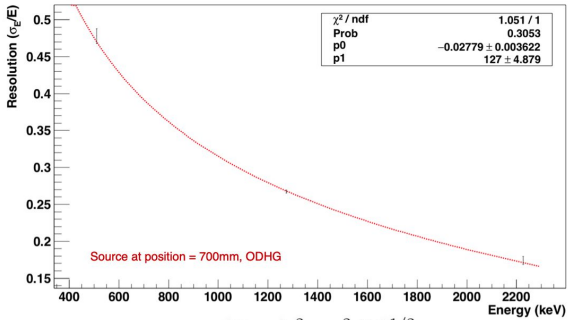


Gamma source



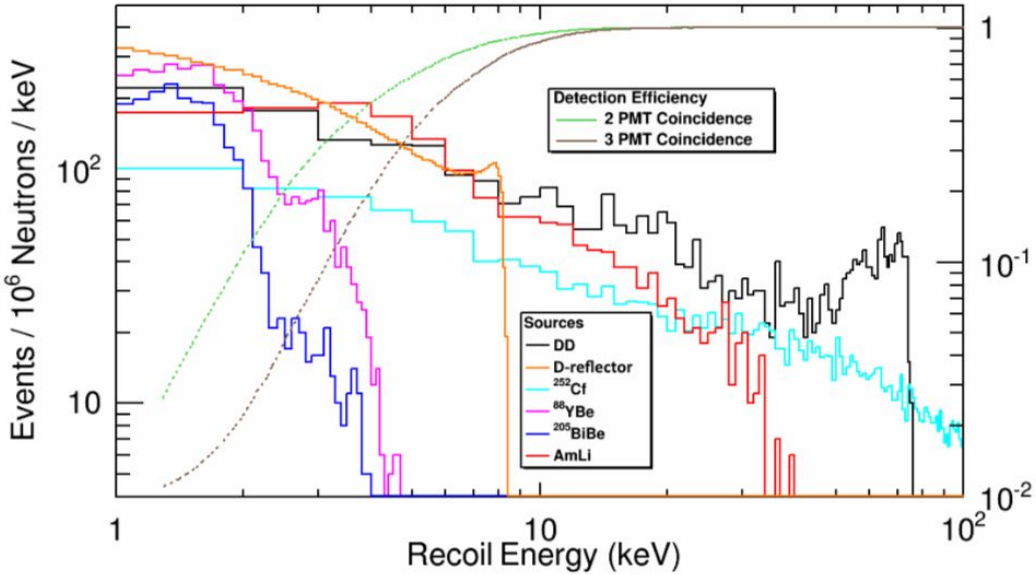


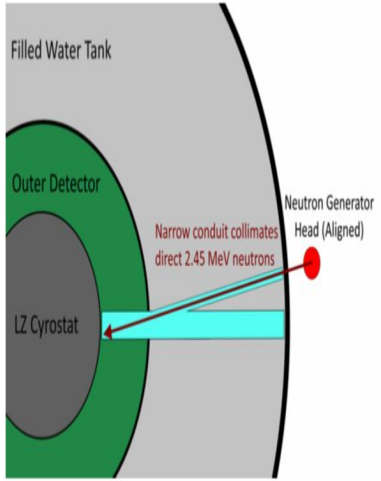
- Using gamma source to determine the energy scale of outer detector.
- ^{22}Na is used to check the timing between the LS and skin.

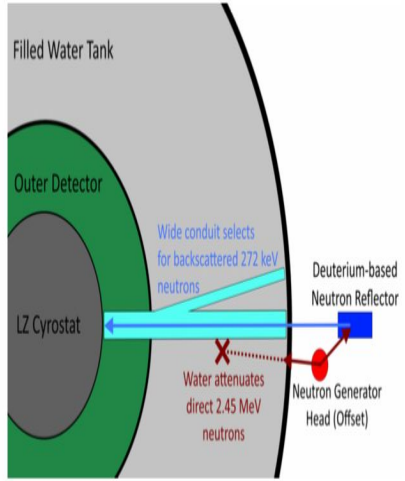


$\sigma_E/E = (p_0^2 + p_1^2/E)^{1/2}$

Neutron source





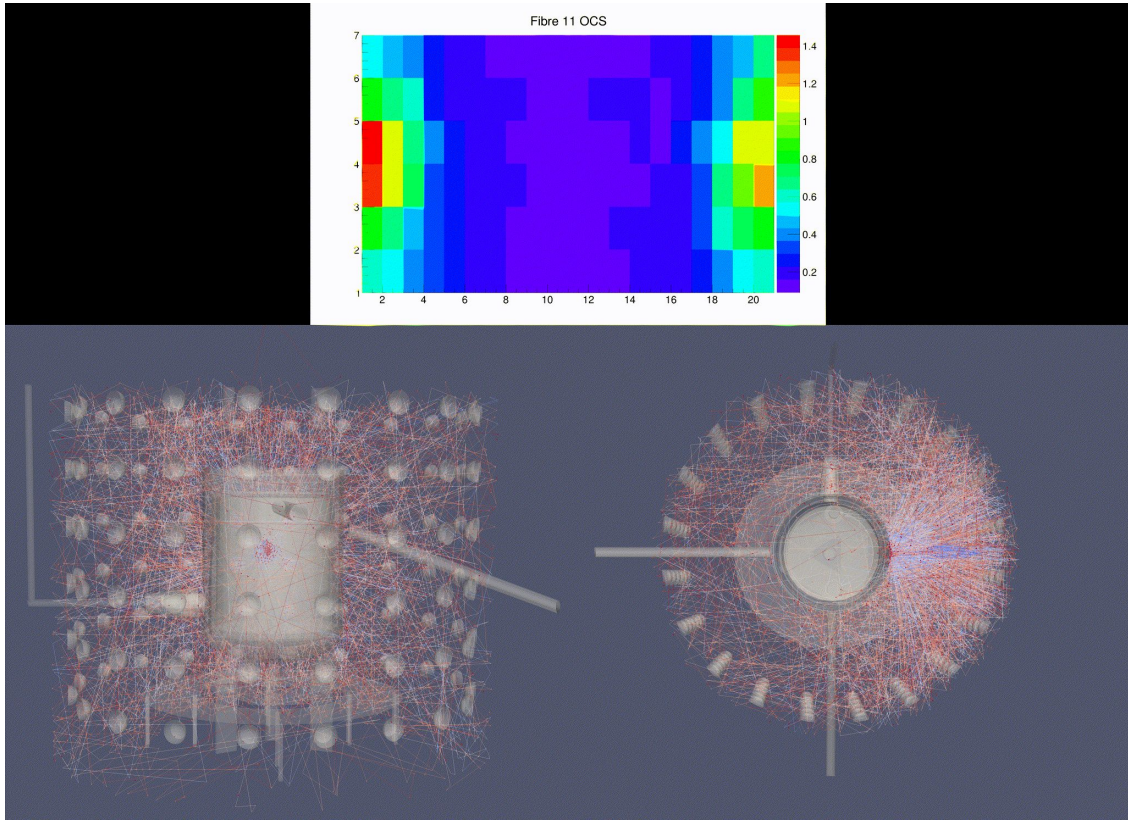


https://arxiv.org/abs/1703.09144

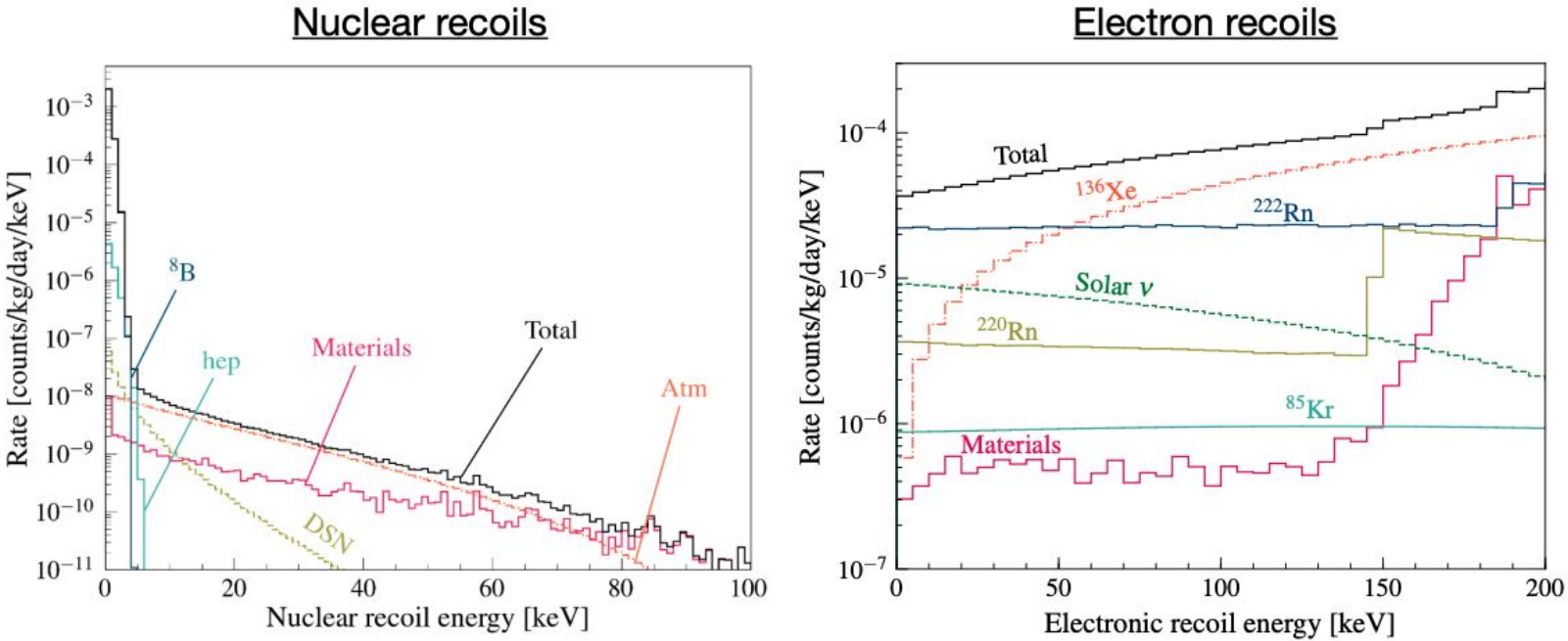
- Using 2-fold coincidence due to the shorter data taking time (3-fold default).
- DD generator provide various neutron energy range

OD Optical Calibration System (OCS)

- Inject a known number of photons into the OD.
- Allows for a calibration of the OD PMTs over the full sensitive range, 100's to 1E6 of photons
- Consists of 40 fibres injection points in the OD,
  - 30 around the OD pointing towards the center, 10 azimuthal locations, 3 different heights.
  - 10 fibres pointing upward into the LS tanks.
- Monitor and calibrate output in real time with a single photodiode per channel as well as a rack mounted monitoring PMT.



Background Rate



https://arxiv.org/abs/1802.06039

- Counts/kg/day/keV in 5.6 tonne fiducial volume
- Rn is the main background source in TPC.
- Single scatter events with no veto signal