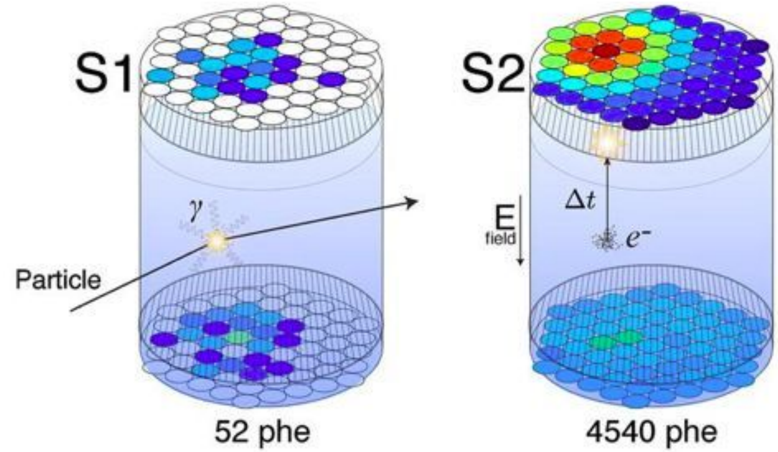
Radioactive Screening, Material Selection, and Cleanliness for the LUX-ZEPLIN Experiment

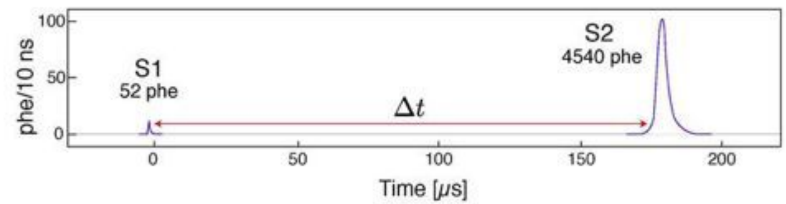
Dr. Alvine Kamaha
University at Albany, State University of New York
(On behalf of the LZ collaboration)

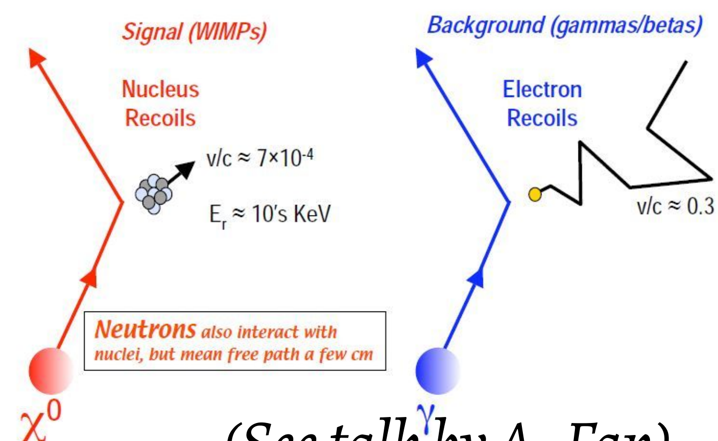
LUX-ZEPLIN (LZ)

- LZ is primarily a dark matter search experiment using a **dual phase noble LXe TPC** to search for WIMPs (494 3" PMTs viewing 7 tonnes LXe TPC)
  - S1: Primary scintillation
  - S2: Proportional scintillation (light emitted by electrons extracted into gas phase) - proportional to the charge
  - Full 3D position reconstruction → target fiducialisation
    - Z from S1-S2 timing
    - X-Y from light patterns in PMT array(s)
  - Size of S1, S2 allows for **NR/ER discrimination**
    $(S2/S1)_{ER} >> (S2/S1)_{NR}$
    → 99.95% ER background (β,γ) discriminations against signal (WIMPs)

[LZ Technical Design Report, arxiv:1703.09144]

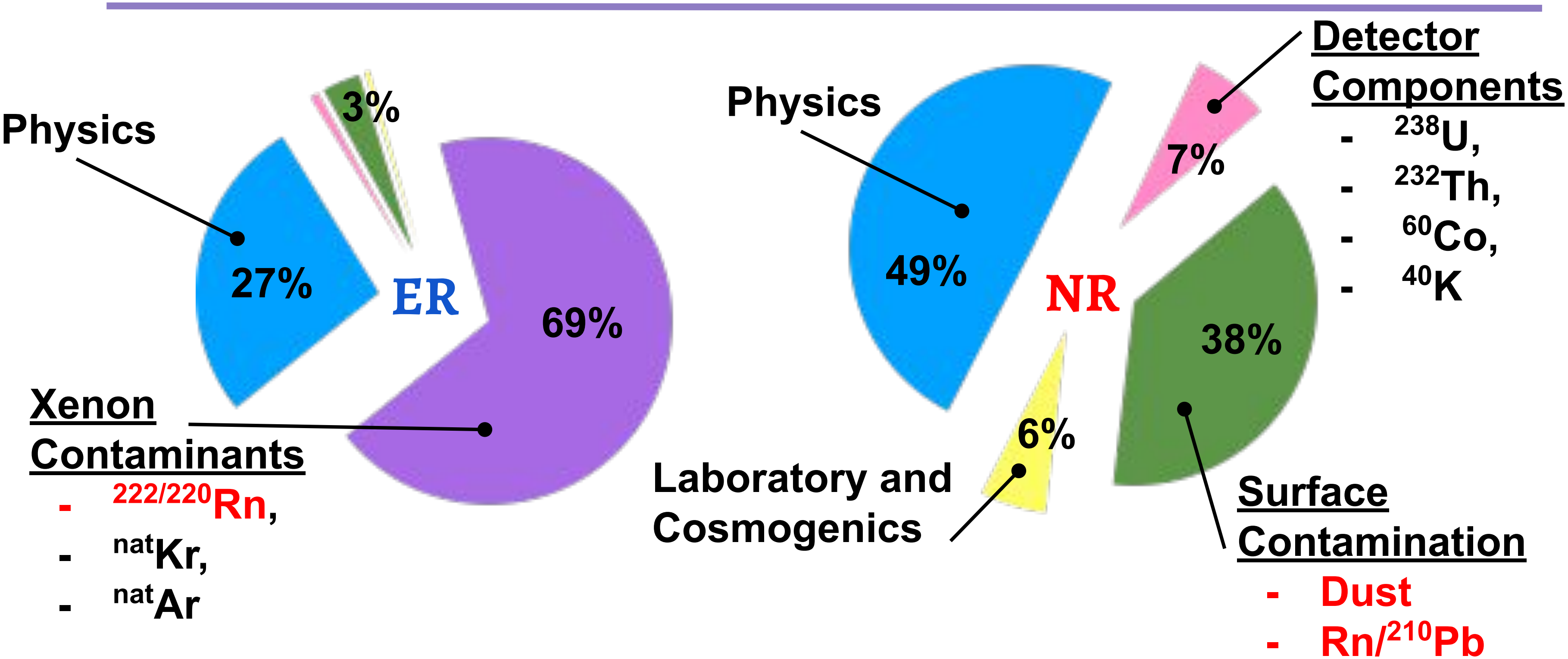






(See talk by A. Fan)

Backgrounds Origins in LZ

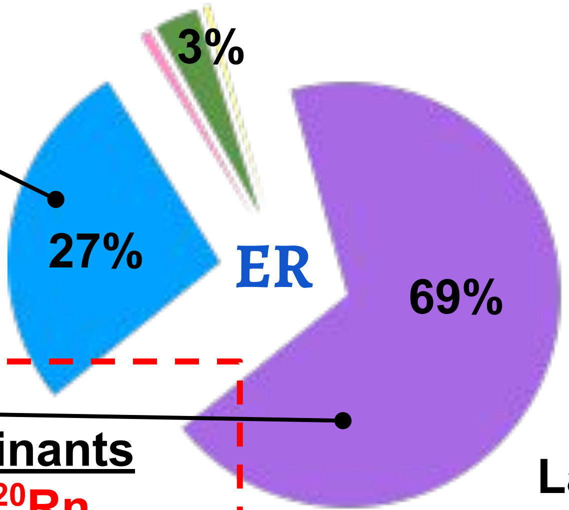


(See talk by A. Cottle)

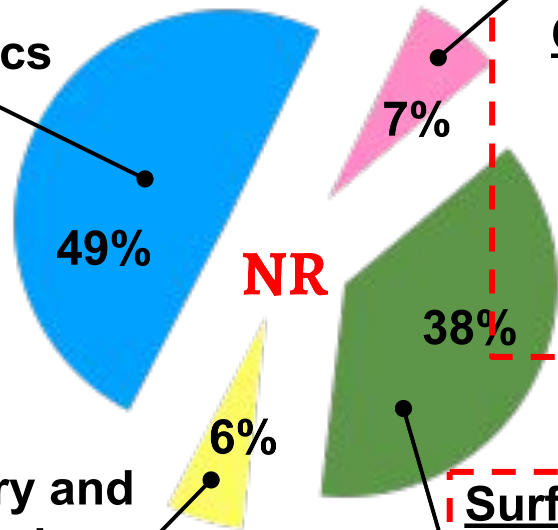
Total:	**1195 ER**	**1.03 NR**
After cuts:	**5.97 ER**	**0.52 NR**

[LZ Projected WIMP sensitivity for 1000 live days, 5.6 tonnes FV, arxiv:1802.06039v1]

Backgrounds Origins in LZ



Xenon Contaminants
- $^{222/220}$Rn,
- ^{nat}Kr,
- ^{nat}Ar



Detector Components
- ^{238}U,
- ^{232}Th,
- ^{60}Co,
- ^{40}K

Surface Contamination
- Dust
- Rn/^{210}Pb Plateout

Total:	**1195 ER**	**1.03 NR**
After cuts:	**5.97 ER**	**0.52 NR**

[LZ Projected WIMP sensitivity for 1000 live days, 5.6 tonnes FV, arxiv:1802.06039v1]

Backgrounds Control in LZ

- Fixed contaminants: Screening campaign of detector materials to know intrinsic (U, Th, K, Co) background content

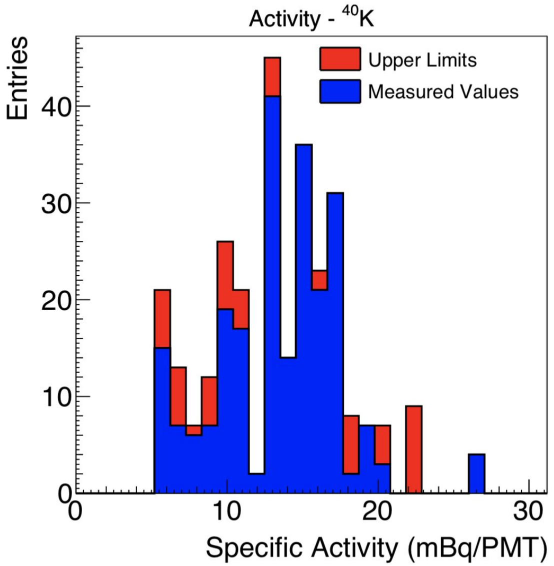
- Rn Emanation program of detector materials to determine the amount of Rn being emanated by these materials

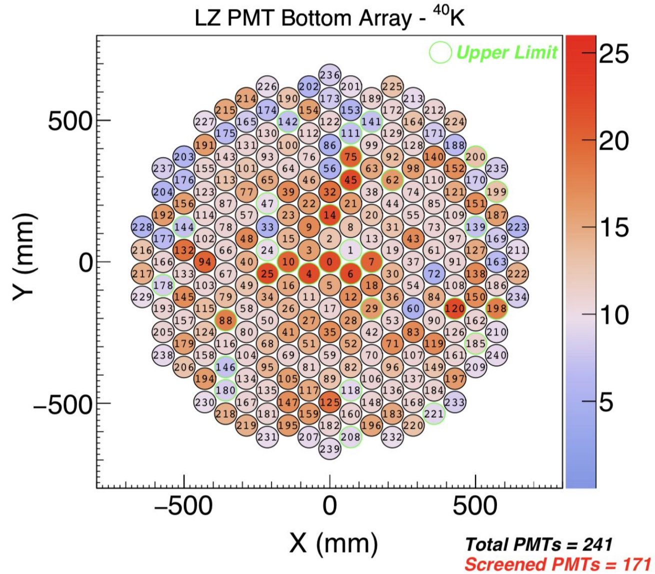
- Surface contamination tracking & minimization program during detector construction to know Rn & dust deposited on TPC surface during assembly

Screening campaign

- 5 year screening campaign using HPGe & ICP-MS detectors across many sites in US, UK & Korea
- Cross-calibration of detectors for consistency checks
- Assay results used to determine material suitability & component location where this is a concern - e.g. PMTs
- Campaign covered everything from raw materials through to fully constructed detector components
  - Ongoing QC measurements to tackle potential radio purity issues

(11±3) mBq/PMT average ^{40}K
→ Below requirement

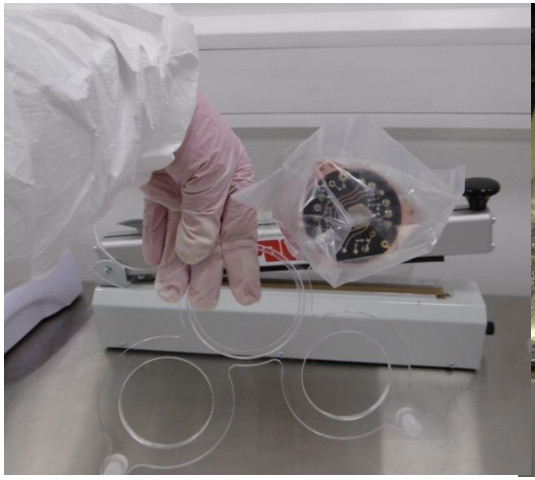
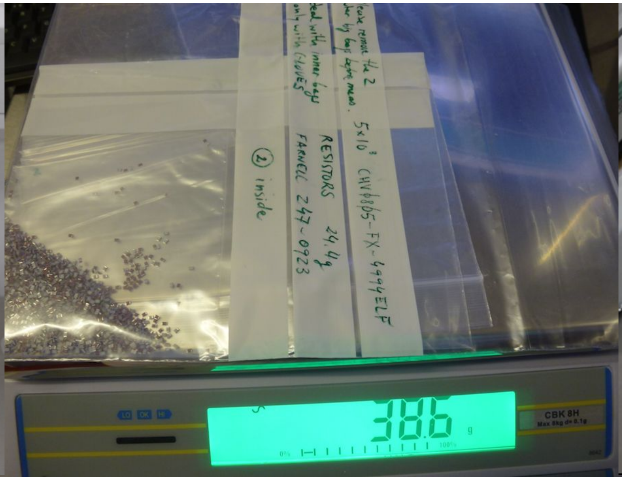




Screening campaign

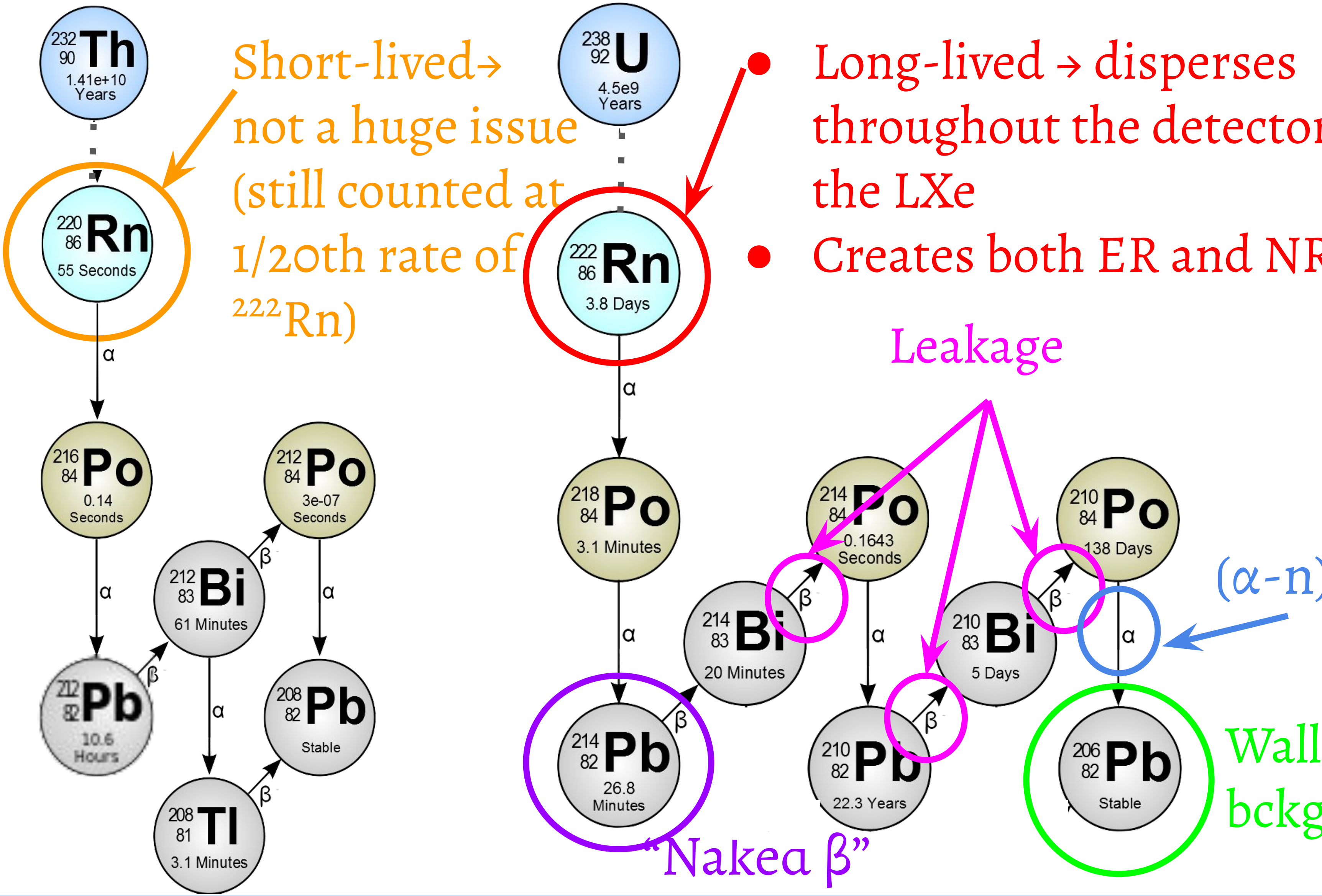
- More success stories
  - Titanium used for cryostat vessel below expectation [arxiv: 1702.02646]
  - PMT Bases (Example raw materials - constructed LZ item)
  - Excellent agreement between component prediction and measurement

	Values in uBq/base					
	U238(e)	**U238(l)**	**Th232(e)**	**Th232(l)**	**K40**	**Co60**
Measured	1900 ± 700	390 ± 50	200 ± 50	170 ± 20	< 2500	< 14
Component	1700 ± 40	390 ± 8	150 ± 5	140 ± 5	380 ± 20	< 7

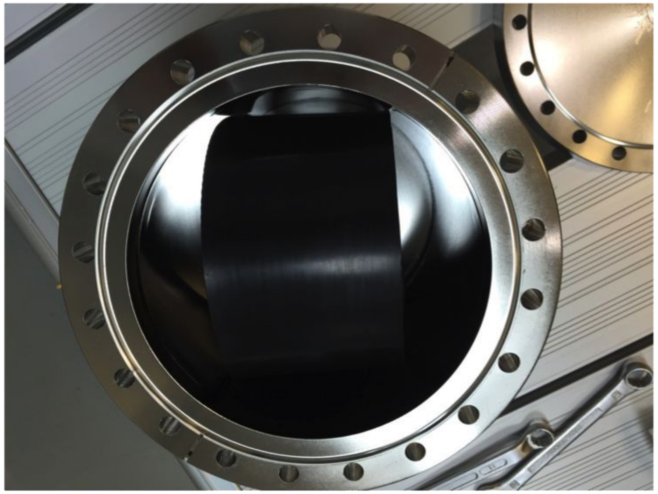
Rn Emanation campaign

- Long-lived → disperses throughout the detector in the LXe
- Creates both ER and NR



Rn Emanation campaign

- Rn emanation detectors across 4 sites in UK&US
  - 2 different Rn emanation techniques
    - Dissolve Rn into liquid scintillator and identifies radon by the ^{214}Bi-^{214}Po timing coincidence
    - silicon-pin diode which measures the alpha decays from ^{214}Po and ^{218}Po
- Cross-calibration campaigns of all Rn emanation detectors
- **All** detector components & combined systems Rn emanated
  - *E.g.*
    - ICV Emmanation
    - Xe tower Emanation
    - Getter Emmanation (2.26±0.28 mBq, within expectation)

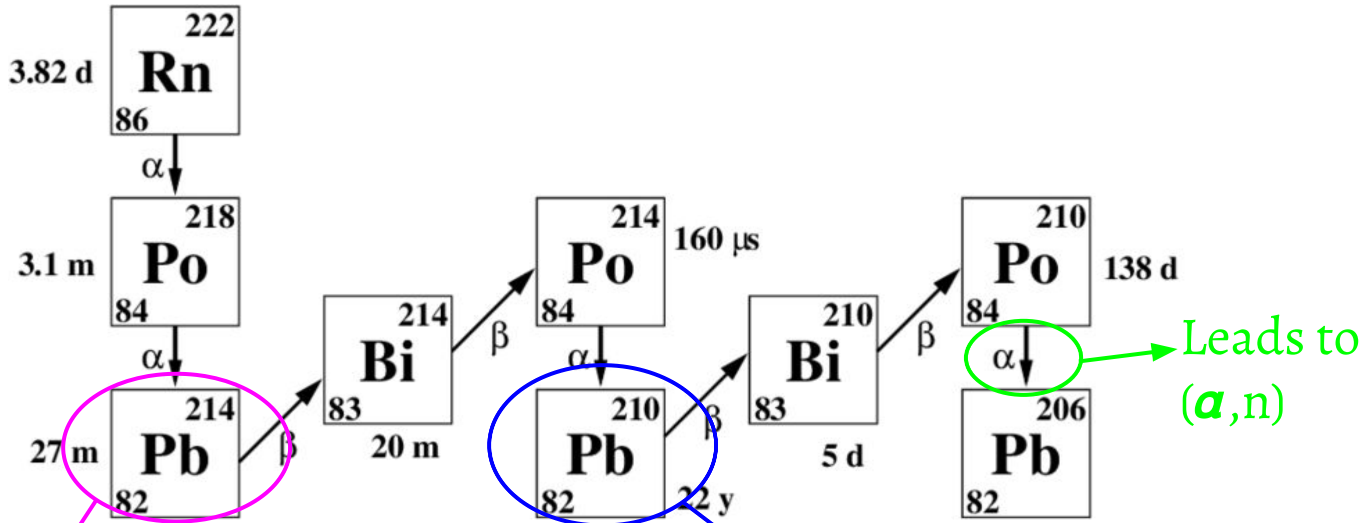


Cross-calibration with various samples

Getter (Xe purifier) Rn emanation

Surface contamination during construction

- Exposure to ambient air in the assembly clean room facility leads to Rn & dust deposition on TPC surfaces during LZ detector construction



Rn emanated from dust accumulated on surfaces during construction slowly dispersed in TPC

Leads to ^{214}Pb naked in LXe fiducial volume during data taking → ER background

Requirement: <500 ng/cm²

Plate-out onto TPC surfaces, long-lived isotope

Resulting **α** from ^{210}Po can produce **n** via (**α**,n) → NR background

Plateout on TPC inner wall creates complicated wall background

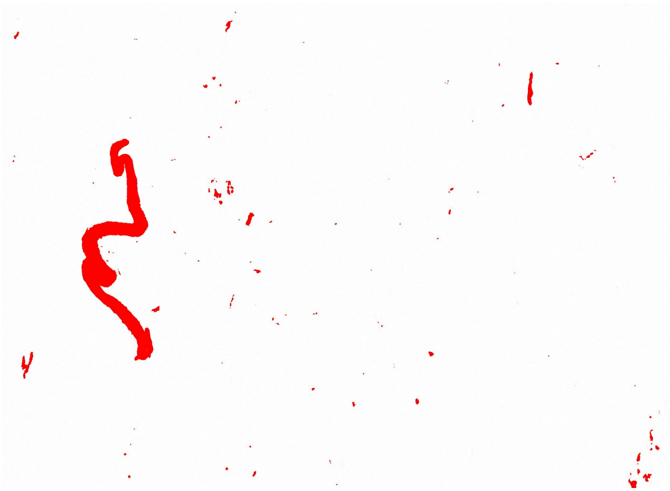
Requirement <0.5 uBq/m² on inner TPC Teflon

Dust deposition estimation

- Two technical probes utilized
  - witness coupons & tape lifts
- Two models developed
  - modified SNO model & ASML model
    - Focus on modified SNO model (originally developed by Hallman & Stokstad, 1991)

$$\frac{dm}{dt} = \int_{D \geq 0.5\mu m} \frac{\pi}{6} n(D) \rho D^3 v \eta \quad dD$$

Modified factor added due to LZ cleanroom conditions (*e.g.* humidity)



witness coupons image under microscope showing dust particulates of different sizes

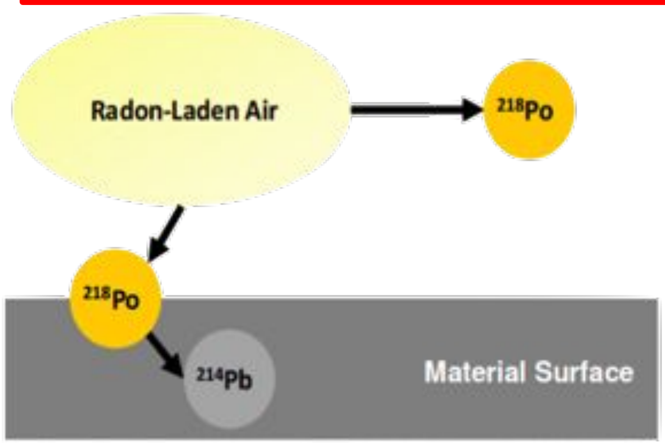
- Excellent agreement between technical probes & models enabling accurate estimation of dust deposition on TPC surfaces

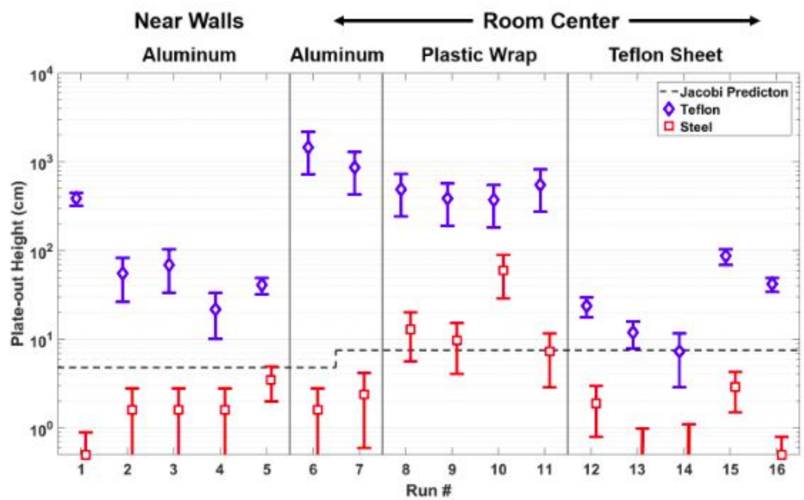
Rn progeny plate-out estimation

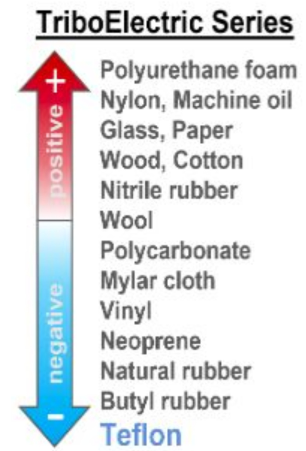
- Plate-out estimated using Jacobi model validated/calibrated for this purpose [arXiv:1708.08534]

- Plate-out rate mostly depends on clean room parameters & exposure time of surfaces to ambient air

$$\boxed{R_p = C_{Rn}\lambda_{Pb_{210}}\frac{\Lambda_d}{(\Lambda_d+\Lambda_v)}\frac{V}{A} * T}$$

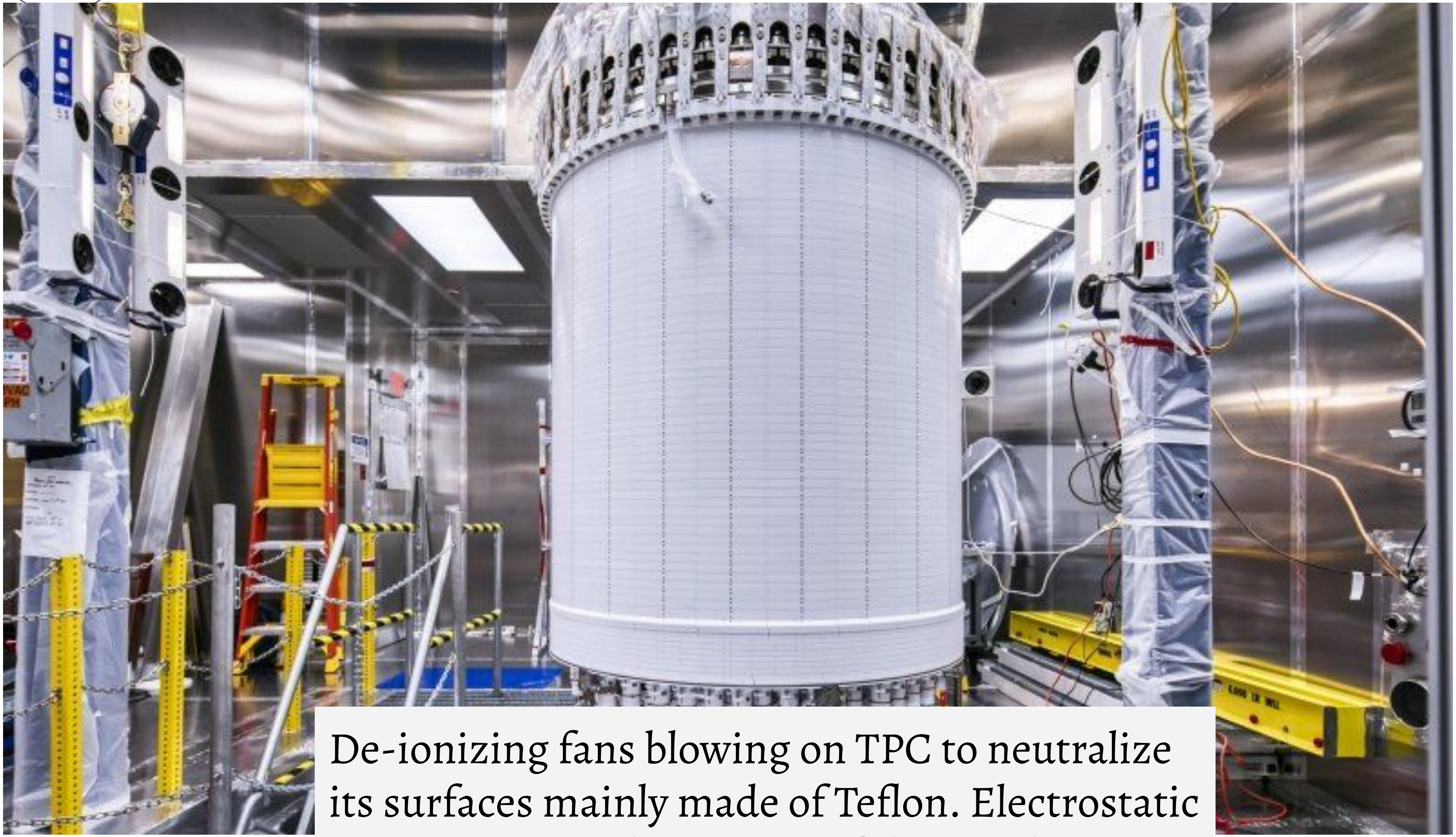






- Correct prediction of plate-out onto neutral metallic surfaces
- Underestimation of plate-out onto Teflon (highly triboelectric) so correction factor T=50-100 included.
  - Mitigation: LZ procured de-ionizing fans to successfully neutralize Teflon → T=1

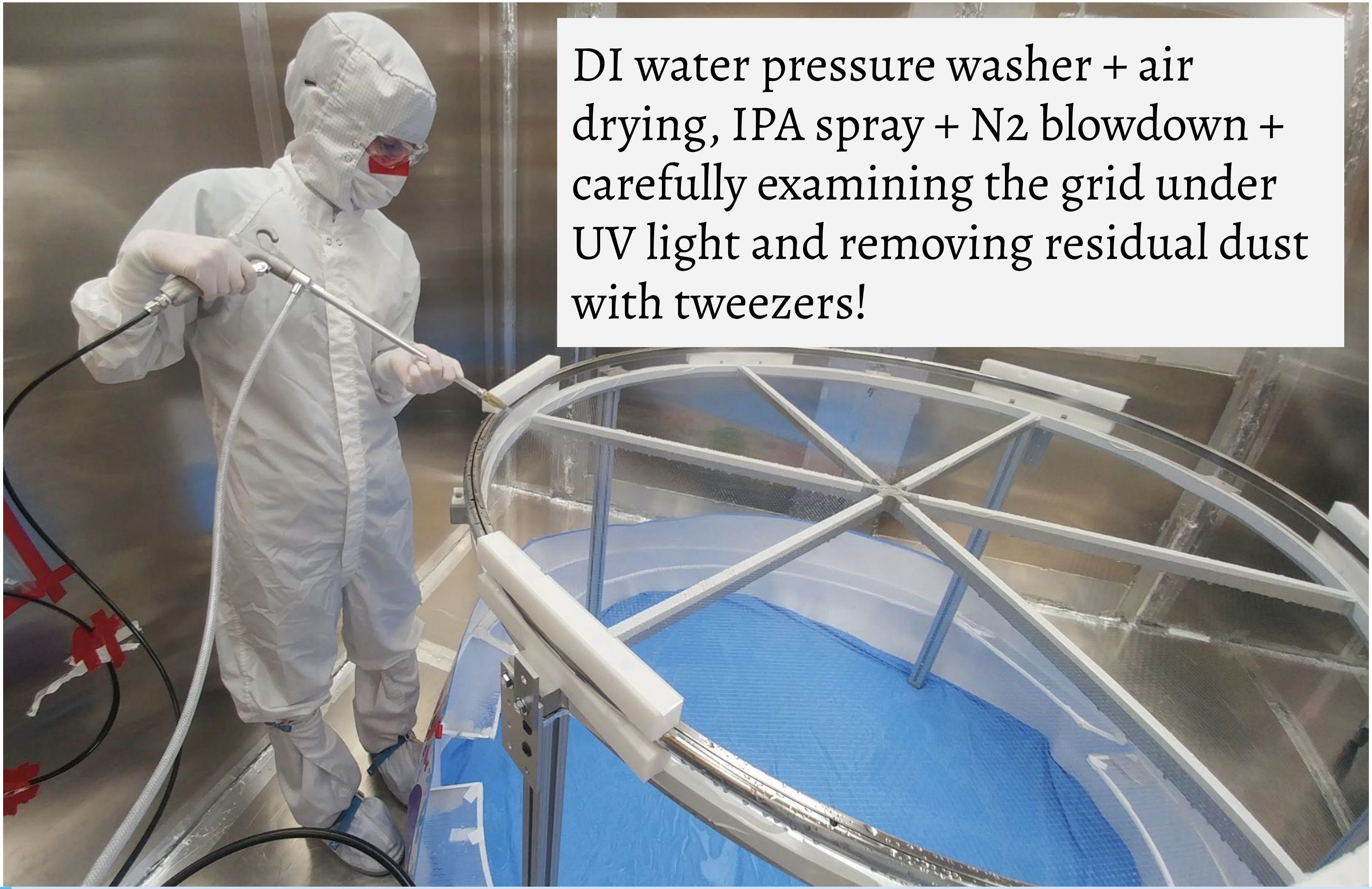
Surface contamination mitigation



De-ionizing fans blowing on TPC to neutralize its surfaces mainly made of Teflon. Electrostatic measurements show successful neutralization

Surface contamination mitigation

Surface contamination mitigation



DI water pressure washer + air drying, IPA spray + N_2 blowdown + carefully examining the grid under UV light and removing residual dust with tweezers!

LZ cleanliness program in numbers

- >20,000 parts,
- ~1200 screening and Rn emanation assays,
- >100 cleaning protocols, applications and references
- >1000h of cleaning since the assembly started

	LZ Requirement	Current Best Estimate
Rn Plateout (inner TPC)	0.5 mBq/m^2	**0.107 ± 0.020 mBq/m^2**
Dust Deposition (entire TPC)	500 ng/cm^2	**210 ± 16 ng/cm^2**
Total Rn Emanation	20 mBq	**Underway...**

PRELIMINARY

Conclusion

- LZ has gone through an extensive and stringent radio-contaminant control program to build the cleanest and biggest TPC detector to date!

- Vast screening campaign to select ultra-low bckg components → e.g. Ti used for Cryostat vessel [LZ Titanium paper, arxiv: 1702.02646]

- Rigorous surface contamination tracking, control & response program during TPC detector construction.
  - This is the first elaborated cleanliness program in the DM field!
  - TPC construction is now complete and accumulated surface deposition well below requirement
  - <1g of dust accumulated on the entire TPC after remedial cleaning!

- LZ radio-contaminant control program paper coming out *soon*

Keep an eye out for ….

- The LUX-Zeplin Dark Matter Experiment
  - *Talk by Alden Fan in DM2-202 Session (Monday, 14:40)*
- Backgrounds and Simulations for the LUX-ZEPLIN Experiment
  - *Talk by Amy Cottle in DM4-202 Session (Monday, 16:30)*
- The LZ Outer Detector
  - *Talk by Bjoem Penning in DM16-202 Session (Thursday, 14:40)*
- Development and performance of high voltage electrodes for the LZ experiment
  - *Talk by Kelly Stiffer in DM16-202 Session (Thursday, 15:00)*

Thank you

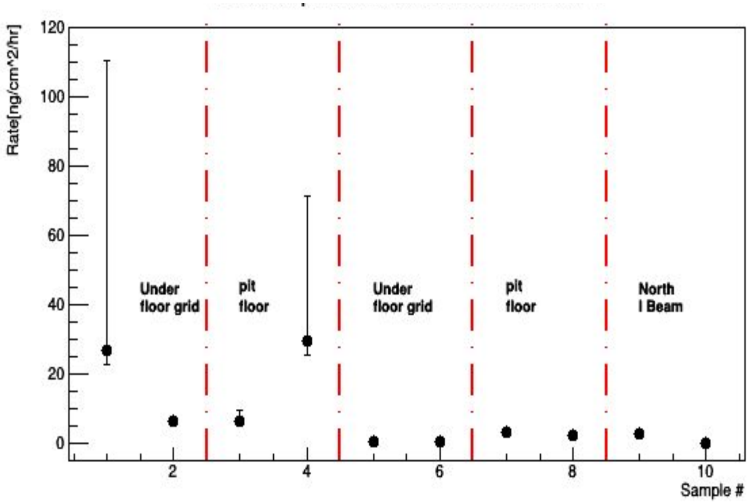
LZ Materials assay & cleanliness Group

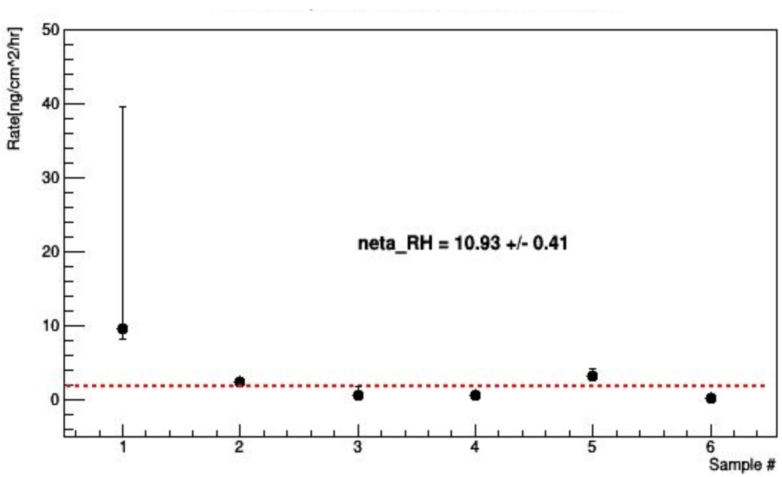
Kevin Lesko
Chamkaur Ghag
Aaron Manalaysay
Jerry Busenitz
Cecilia Levy
Paul Scovell
Richard Schnee
Bai Xai
Juergen Reichenbacher
Andy Cole
Pavel Zarzhitsky
Jack Genovesi
Stefan Aviles
Umit Utku
Nicolas Angelides
Rick Gaitskell, Casey Rhine, Devon Seymour,…
Thomas Slusser

Back up

Dust deposition

- Agreement between the 3 probes utilized by LZ to track dust deposition on TPC surfaces
- Calibration of modified SNO model using witness coupons





- Calibrated modified SNO model vs tape lift results in excellent agreement!

Tape lift date	Exposure time (days)	Dust deposition: modified SNO model (ng/cm^2)	Dust deposition: tape lifts (ng/cm^2)
09/27/2018	1	285 +/- 53	220 +50 -20
11/29/2018	64	829 +/- 154	750 -800

Surface contamination mitigation

- Detector construction in class 1000 Radon Reduced Cleanroom (RCR)
- Rn & dust constantly monitored & cleanliness protocols applied whenever needed. Eg. of developed cleanliness protocols
  - Reduce personnel to strict minimum within RCR
  - Frequent change of garb and gloves
  - Detector assembly & Cleaning done under de-ionizing fans
  - Constant UV inspection & cleaning of components prior and after assembly
  - Adequate storage of components after work shifts (2*Nylon bagged and N_2 setup & ready to be used when needed), etc…

Rn Emanation campaign

- Rn emanation detectors across 4 sites in UK&US
  - 2 different Rn emanation techniques
    - Dissolve Rn into liquid scintillator and identifies radon by the ^{214}Bi-^{214}Po timing coincidence
    - silicon-pin diode which measures the alpha decays from ^{214}Po and ^{218}Po

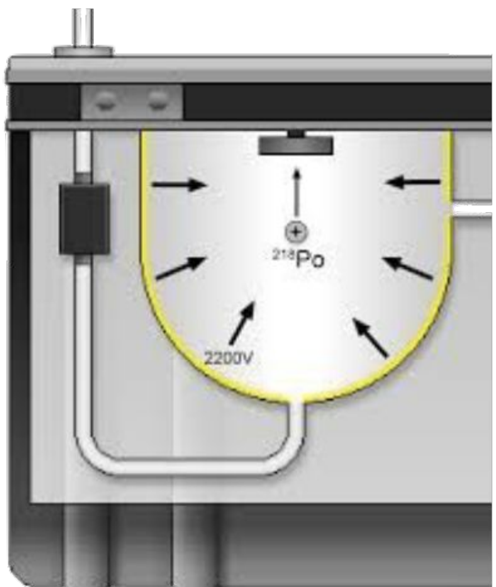
Emanation chamber where sample outgases

Evacuation: Rn freezes in cold trap

N2 flowing with Rn into Detection chamber

^{222}Rn decays, ^{218}Po is positively charged and collect to the diode

^{218}Po and ^{214}Po alpha and are readout by the diode



[LZ, Constraining Rn background, arxiv:1708.08533]