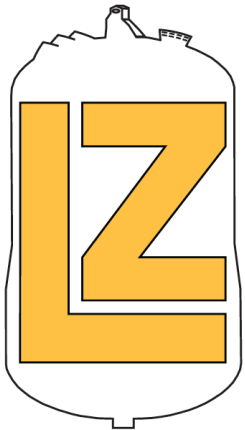


Noble gas purification for LZ and other rare event searches

Eric Miller

LRT – Jaca, Spain

May 20 2019





LZ Detector

Z position from S1 – S2 timing
X-Y positions from light pattern

Reject gammas by S2/S1 ratio
Expect > 99.5% rejection

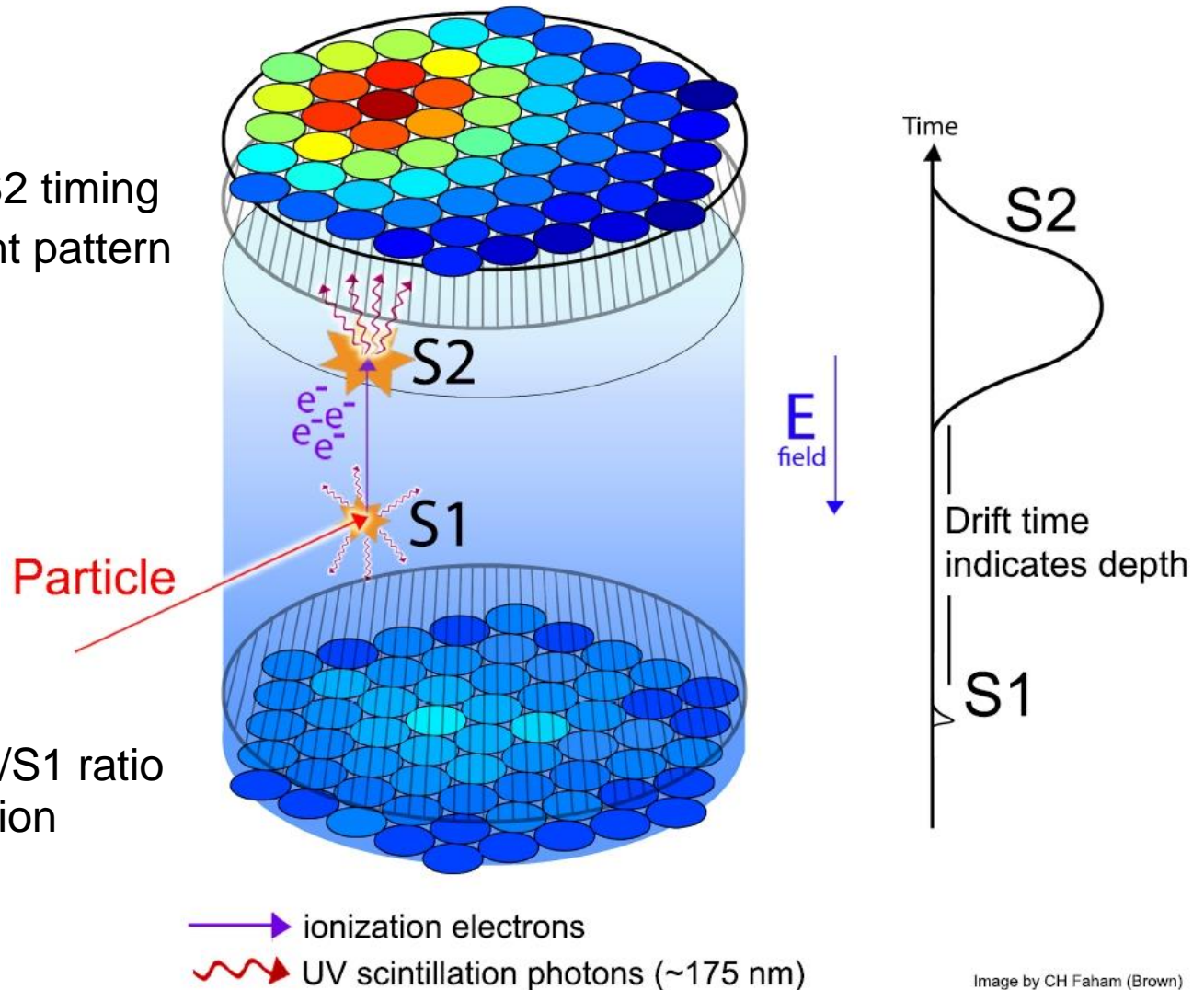
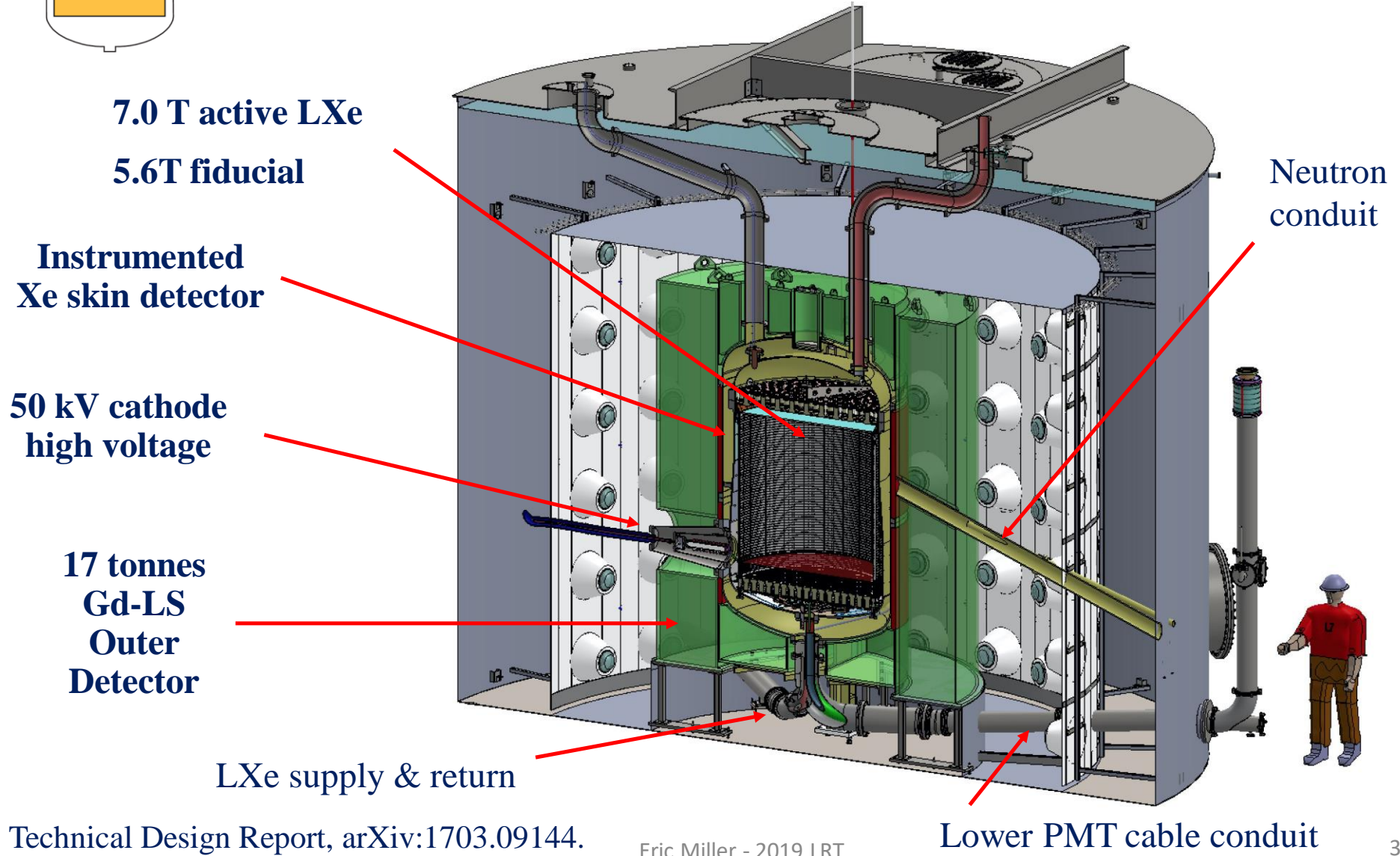


Image by CH Faham (Brown)



LUX-ZEPLIN (LZ) detector





Backgrounds uniform in LXe

- Solar neutrinos
- Contamination of the xenon by:
 - Non-noble gases, eg ^3H
 - Long-lived noble gases, eg ^{85}Kr , ^{39}Ar
 - Short-lived noble gases, eg ^{222}Rn

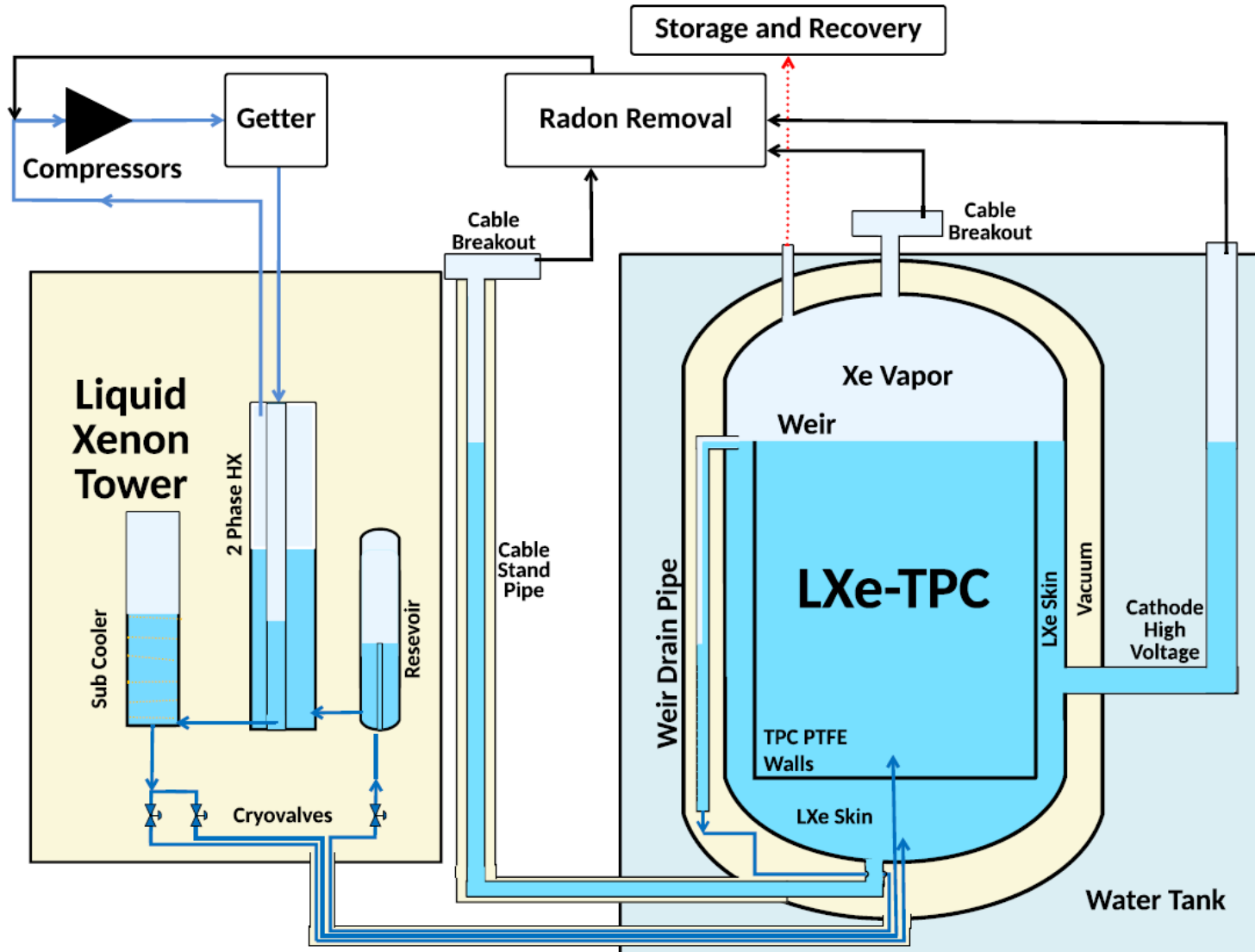


Backgrounds uniform in LXe

- Solar neutrinos
- Contamination of the xenon by:
 - Non-noble gases, eg ^3H
Removed by Getter
 - Long-lived noble gases, eg ^{85}Kr , ^{39}Ar
Removed before experiment start
 - Short-lived noble gases, eg ^{222}Rn
Mitigated by materials screening
Removed while experiment is running



LZ Circulation





Circulation Getter

- LZ's full 10 tonnes purified every 2.3 days
- Saes hot zirconium getter removes electronegative impurities
 - O_2 , N_2 , etc.
 - Critical for detector performance
- Getter also removes 3H
 - Eliminates this background





LZ – Radon Control

- Radon emanates from materials in contact with Xe
- Screening
 - Around 100 materials/components screened for LZ
 - Warm end of PMT cables potentially significant



LZ – Radon Control

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 - Around 100 materials/components screened for LZ
 - Warm end of PMT cables potentially significant
- In-line removal system
 - Impractical to purify 500 SLPM circulation
 - Practical to purify problematic areas

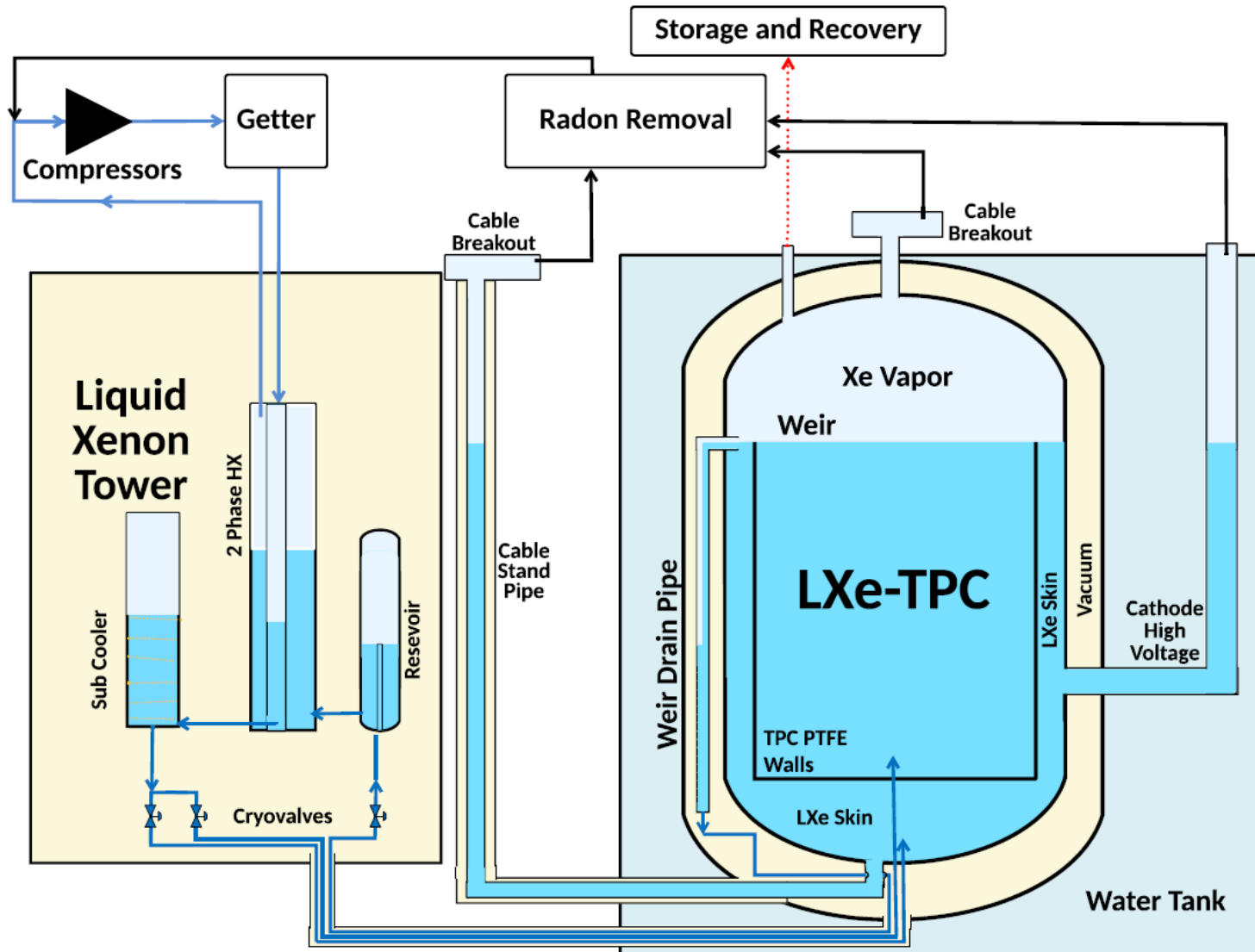


LZ – Radon Control

- Radon emanates from materials in contact with Xe
- Screening
 - Around 100 materials/components screened for LZ
 - Warm end of PMT cables potentially significant
- In-line removal system
 - Impractical to purify 500 SLPM circulation
 - Practical to purify problematic areas
- Projected Rn level:
 - $<2 \mu\text{Bq/kg}$



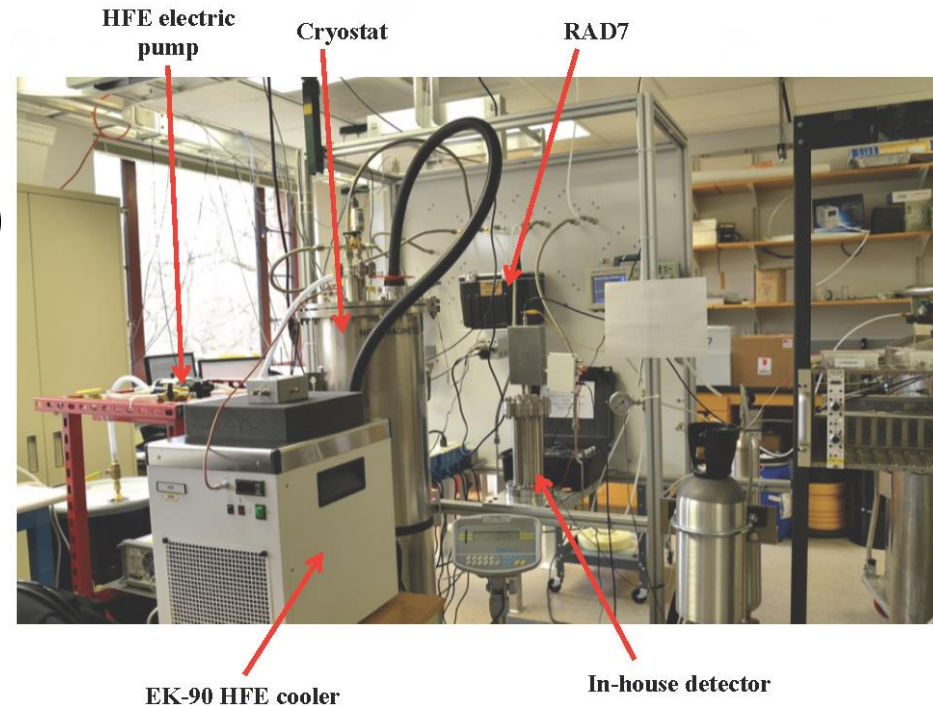
LZ Circulation





LZ – In-line radon removal

- Remove radon from subset of circulation flow
 - 0.1% of Xe flow, but significant Rn contribution
- Strategy: charcoal chromatography
 - Radon passes through charcoal slower than xenon
 - Design system to trap radon for many half-lives (3.8 days)
- Radon Removal system in development at the University of Michigan:





LZ – In-line radon removal

- Critical that charcoal remove more radon than it produces!
 - Identify low-emanation; high adsorption charcoal

Saratech



CarboAct



Shirasagi



Charcoal	Density (g/cm ³)	Surface area (m ² /g)	Spec. activity (mBq/kg)	Price (\$/kg)
Shirasagi	0.45	1,240	101 ± 8	27
CarboAct	0.28	1,000	0.23 ± 0.19	15,000
Saratech	0.60	1,340	1.71 ± 0.20	35
Saratach (HNO ₃)	0.60	1,340	0.51 ± 0.09	135



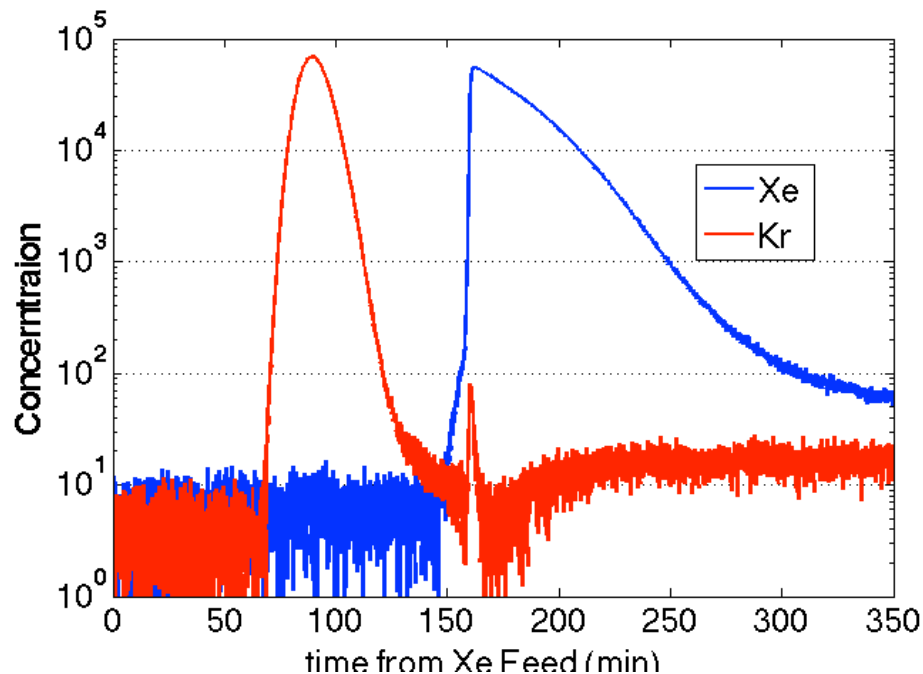
Any worry about cosmic-ray activation of xenon?

- Cosmic ray interactions produce radioactive byproducts in xenon cylinders at the Earth's surface
- Many of these are solids, and will not enter experiment
- ^3H will be removed by getter
- ^{127}Xe
 - 36-day half-life reduces impact
 - Production rate too low to be significant background
- ^{133}Xe
 - 5.2 day half-life reduces impact
- **We have the luxury of purifying Xe at the surface**



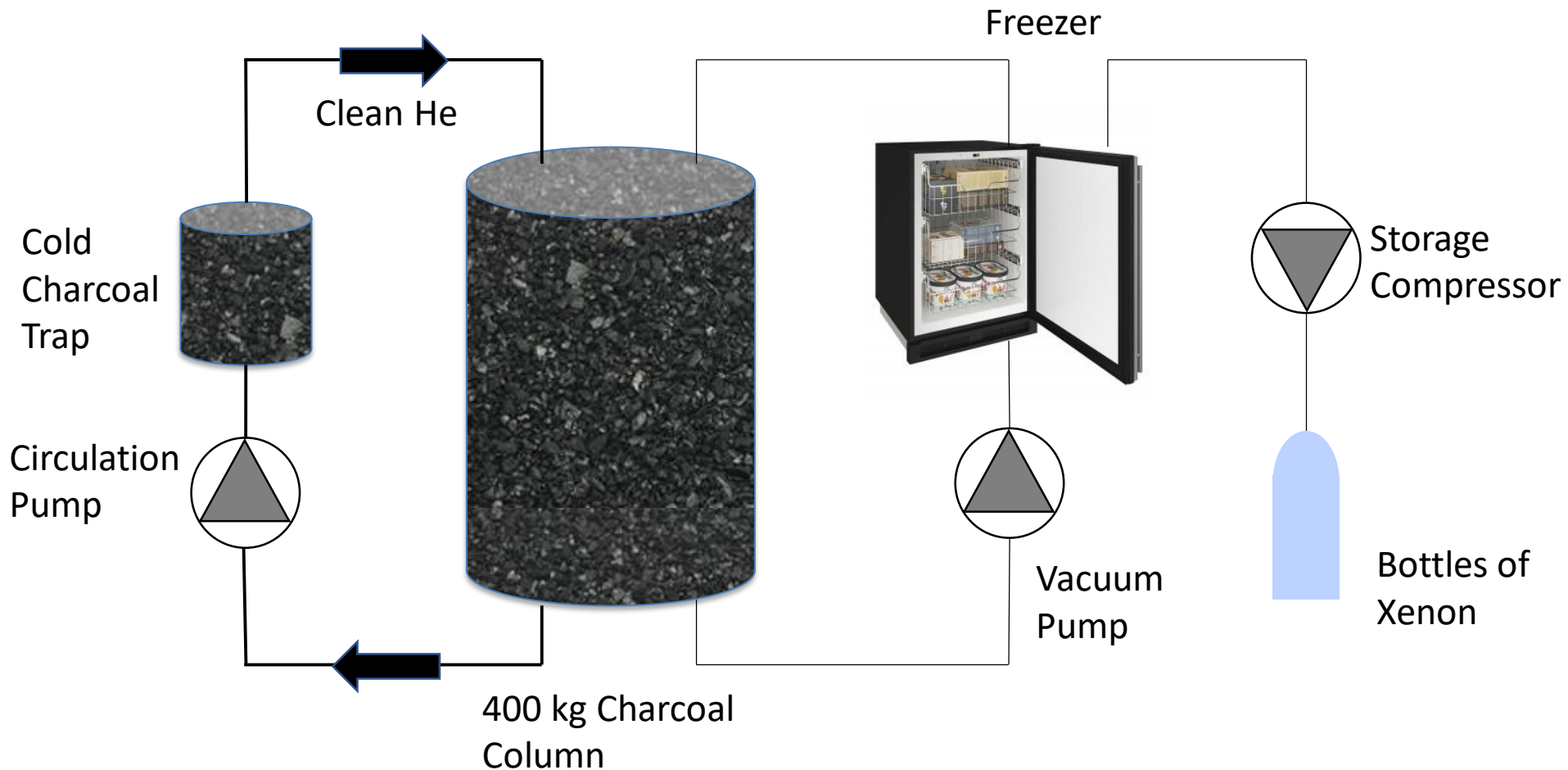
Kr Removal with Chromatography

- Remove via gas charcoal chromatography (with helium carrier gas)
- Kr has a faster flow rate through activated charcoal than Xe



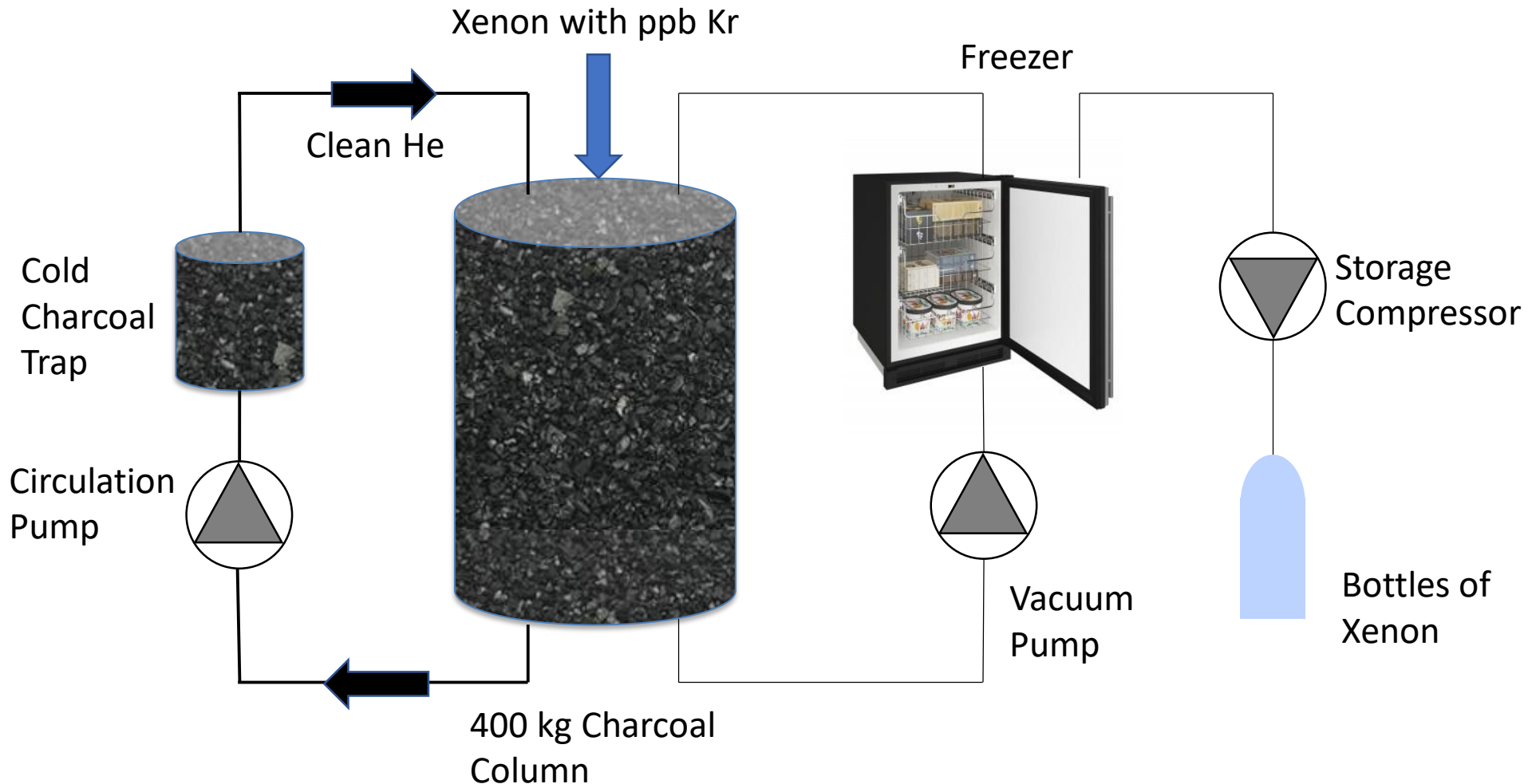


LZ Kr Removal - Chromatography



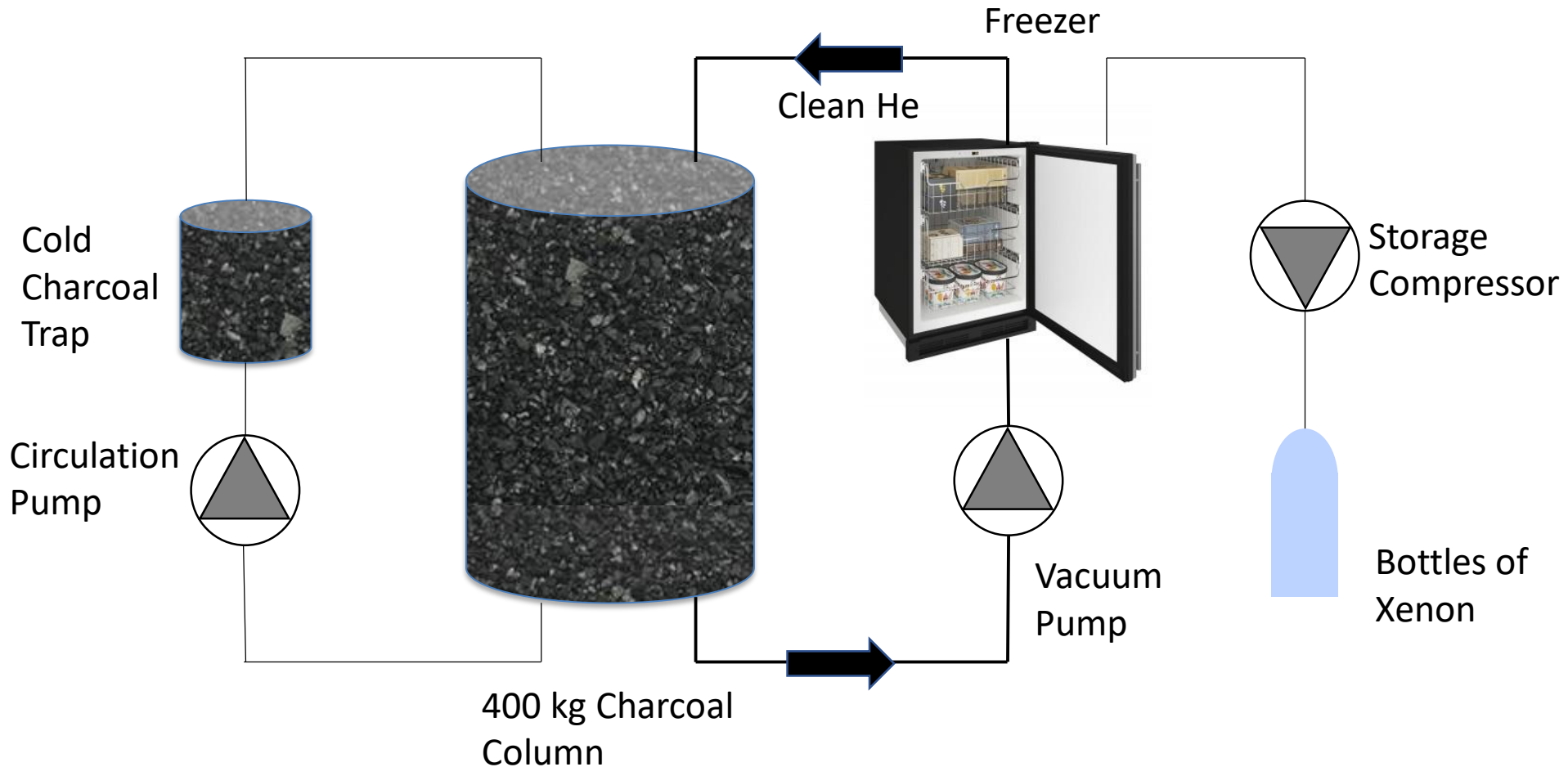


LZ Kr Removal - Chromatography



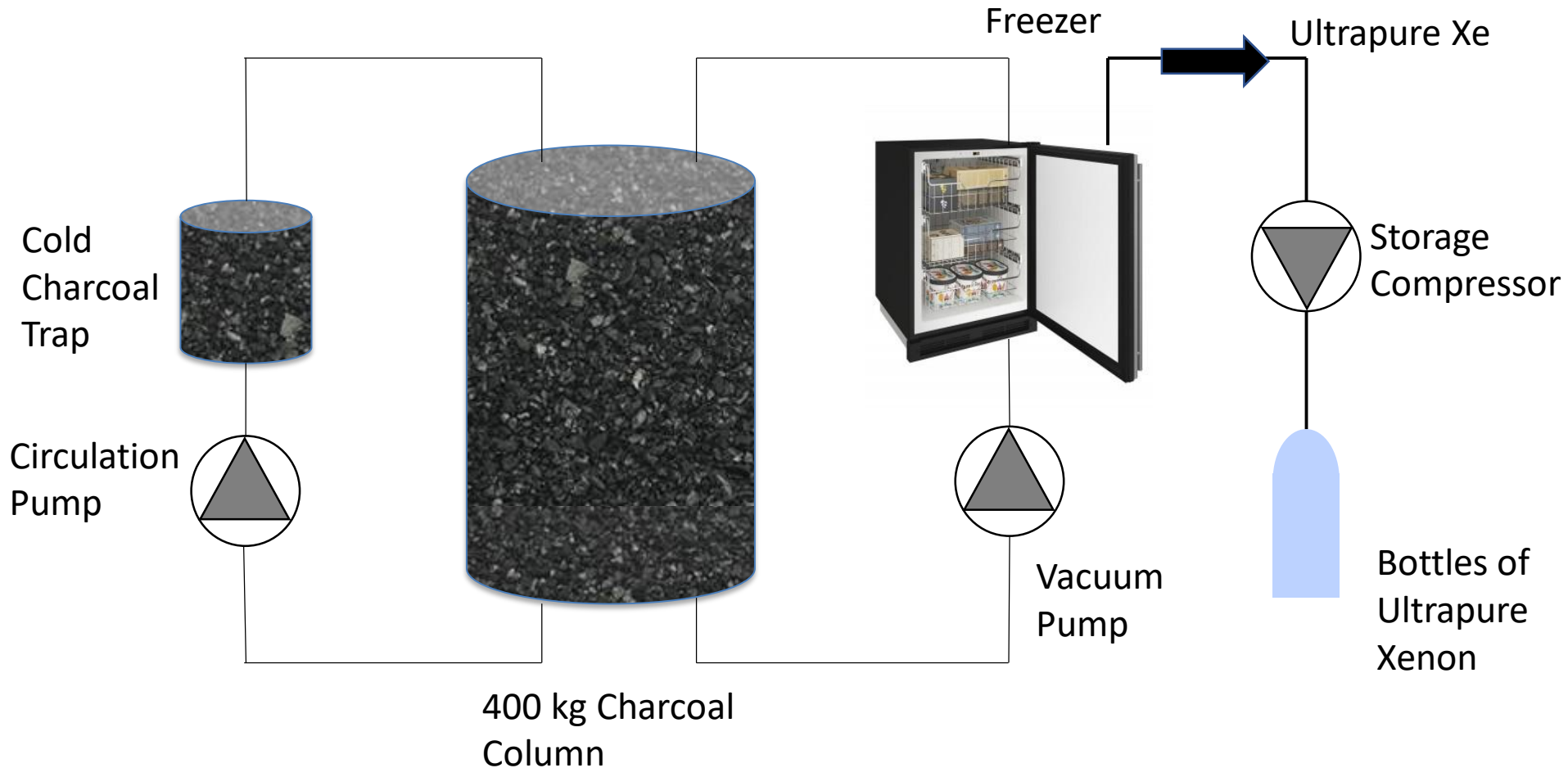


LZ Kr Removal - Recovery





LZ Kr Removal - Storage





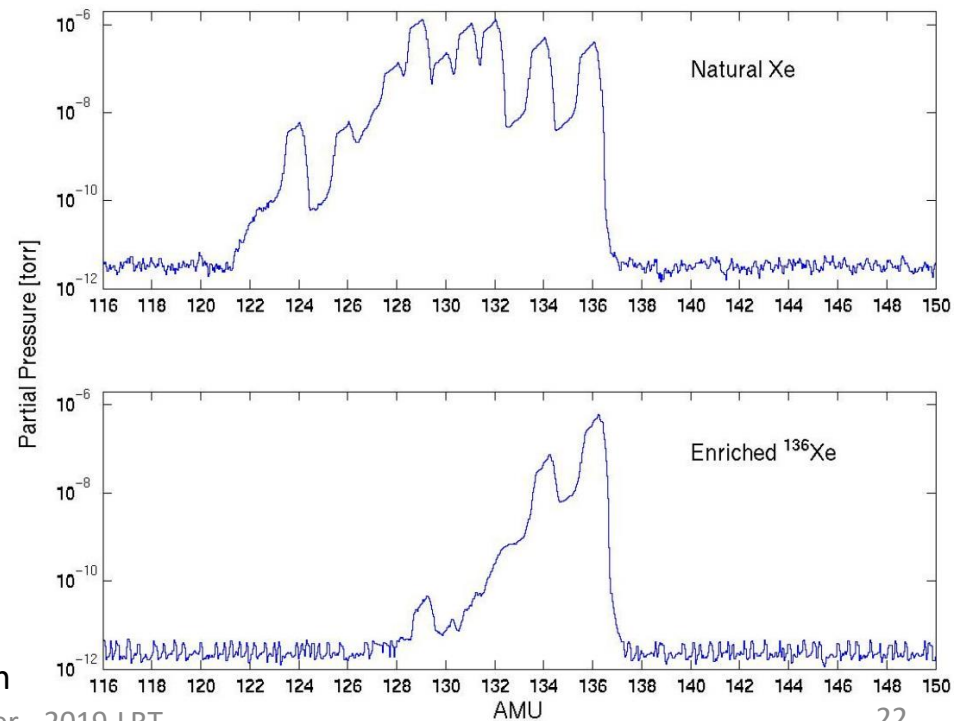
LZ – Krypton Removal

- Employ 2 columns to clean xenon twice as fast!
- LZ system to process 16 kg slugs every two hours
- Plan to purify 10 tonnes over 6 months
- R&D system reduced Kr content to 0.06 ppt
- LZ system designed to achieve 0.015 ppt (15 ppq)
 - Subdominant to solar neutrinos
 - LZ requires < 0.3 ppt
 - Currently commissioning system



Centrifuge Purification - EXO

- Enriched Xenon Observatory (EXO-200) searched for neutrinoless double-beta decay in ^{136}Xe
- Centrifuges used to enrich heavy isotopes of Xe
 - ^{136}Xe fraction increased from 8.9% to 80.6%
- Other lighter elements also removed by this process
 - Including ^{85}Kr and ^{39}Ar
- Kr concentration reduced to 16.3 ± 1.9 ppt



The EXO-200 detector, part I: detector design and construction, EXO Collaboration. Journal of Instrumentation 7 (05), P05010, 2012

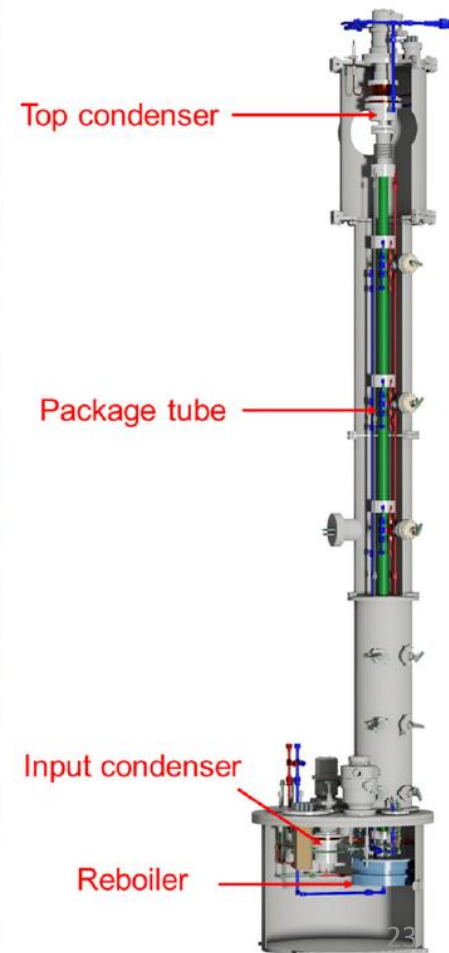


Cryogenic Distillation: Krypton

- Employed by XMASS, XENON100, XENON1T, PANDAX...
- Distillation tower for XENON1T →
- Operates at -98 C;
- Vapor pressure of Kr is 10.8x greater than of Xe
- High-Kr gas extracted from the top
- Low-Kr liquid extracted from bottom
- Achieved lowest reported Kr level:
< 17 ppq

Removing krypton from xenon by cryogenic distillation to the ppq level, XENON Collaboration, Eur. Phys. J. C (2017) 77: 275

Eric Miller - 2019 LRT



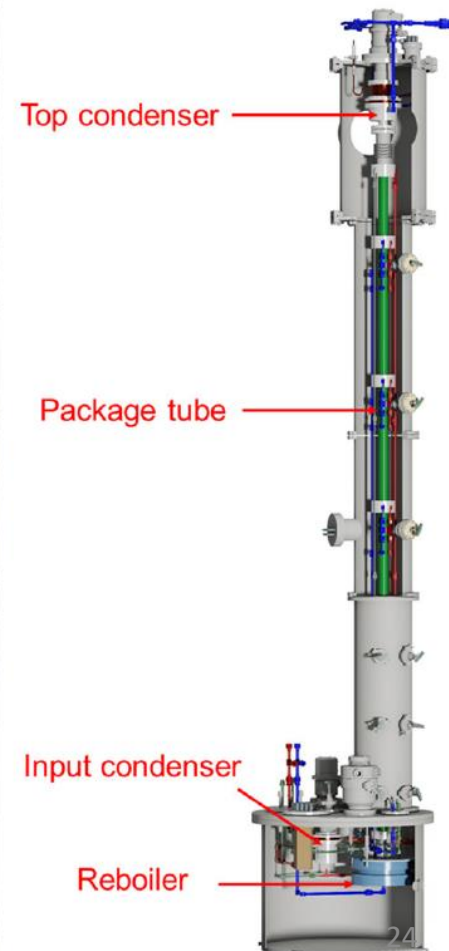


Cryogenic Distillation: Radon

- Demonstrated on XENON100
 - Installed in series with circulation system
- Operates at -96 C;
- Low-Rn gas extracted from the top
- Rn decays in liquid at bottom

See also talk by Hardy Simgen later this session!

Online ^{222}Rn removal by cryogenic distillation in the XENON100 experiment, Eur. Phys. J. C (2017) 77: 358





Kr purity achieved

Experiment	Technique	Purity Achieved (ppt g/g)
Panda X	Distillation	<30
XENON1T	Distillation	<0.017
XMASS	Distillation	2.1 ± 0.7
EXO-200	Centrifuge	16.3 ± 1.9
LUX	Chromatography	3.5
LZ R&D	Chromatography	0.06

Thanks for listening!



Bonus Slides



WIMP backgrounds summary

5.6 tonnes x 1000 days; ~1.5 to ~6.5 keV

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
^{222}Rn	681	0
^{220}Rn	111	0
natKr (0.015 ppt g/g)	24	0
natAr (0.45 ppb g/g)	3	0
Physics	322	0.51
^{136}Xe $2\nu\beta\beta$	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

Projected WIMP Sensitivity of the LUX-ZEPLIN (LZ)

Dark Matter Experiment, LZ Collaboration,

arXiv:1802.06039, 2018