Noble gas purification for LZ and other rare event searches

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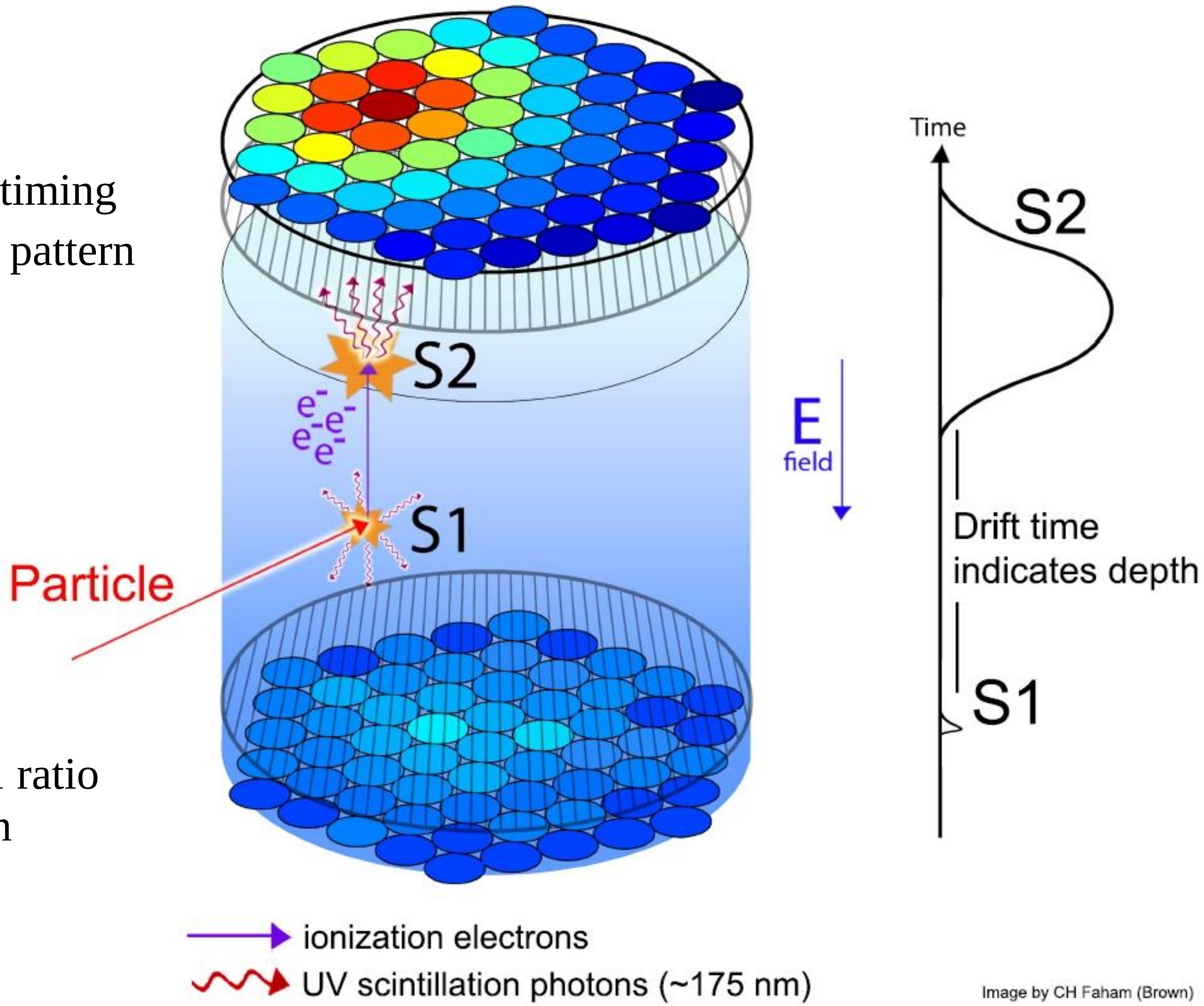
LZ Detector

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

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



LUX-ZEPLIN (LZ) detector

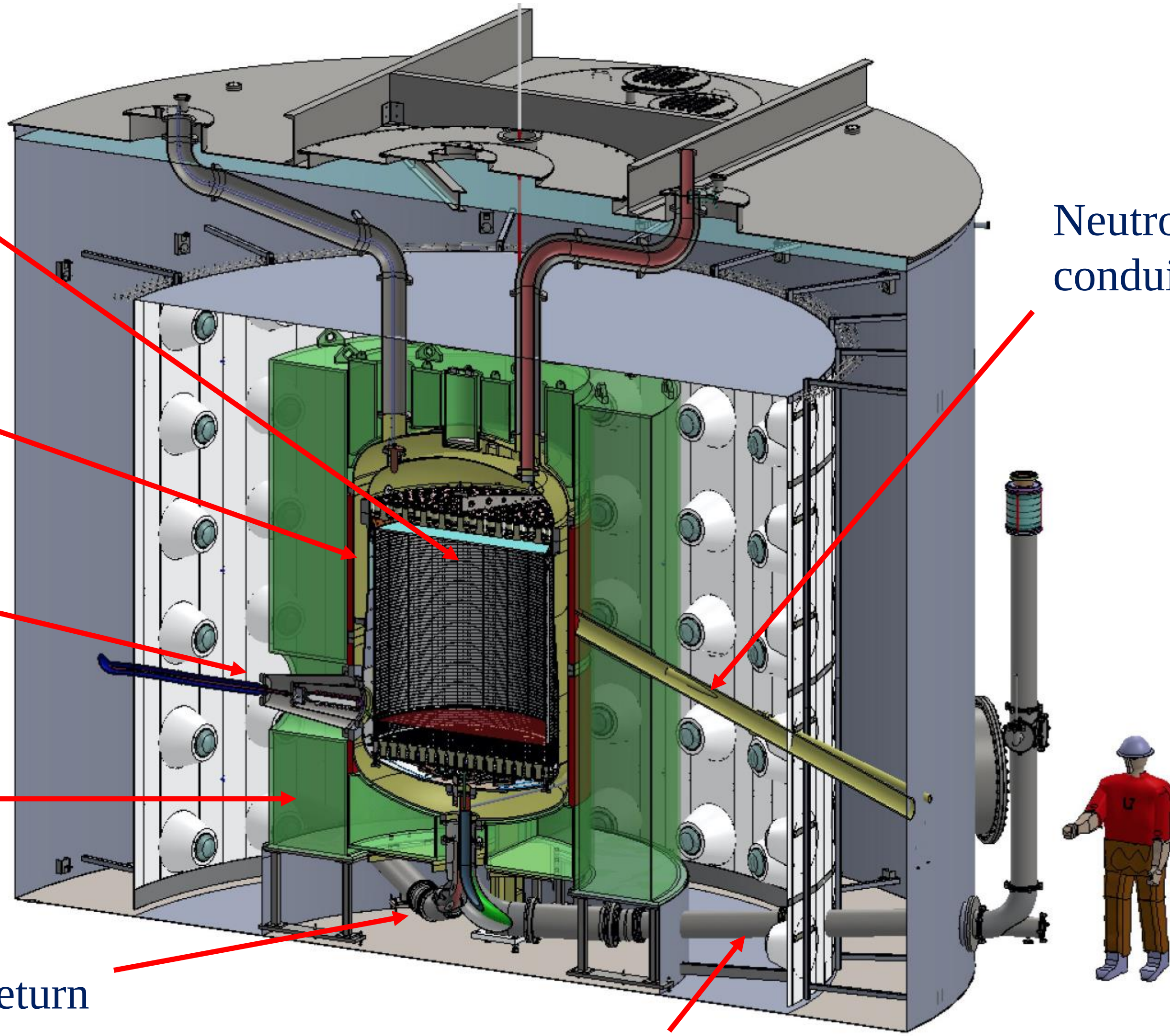
7.0 T active LXe

5.6T fiducial

Instrumented Xe skin detector

50 kV cathode high voltage

17 tonnes Gd-LS Outer Detector



Neutron conduit

LXe supply & return

Lower PMT cable conduit

Technical Design Report, arXiv:1703.09144.

Backgrounds uniform in LXe

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

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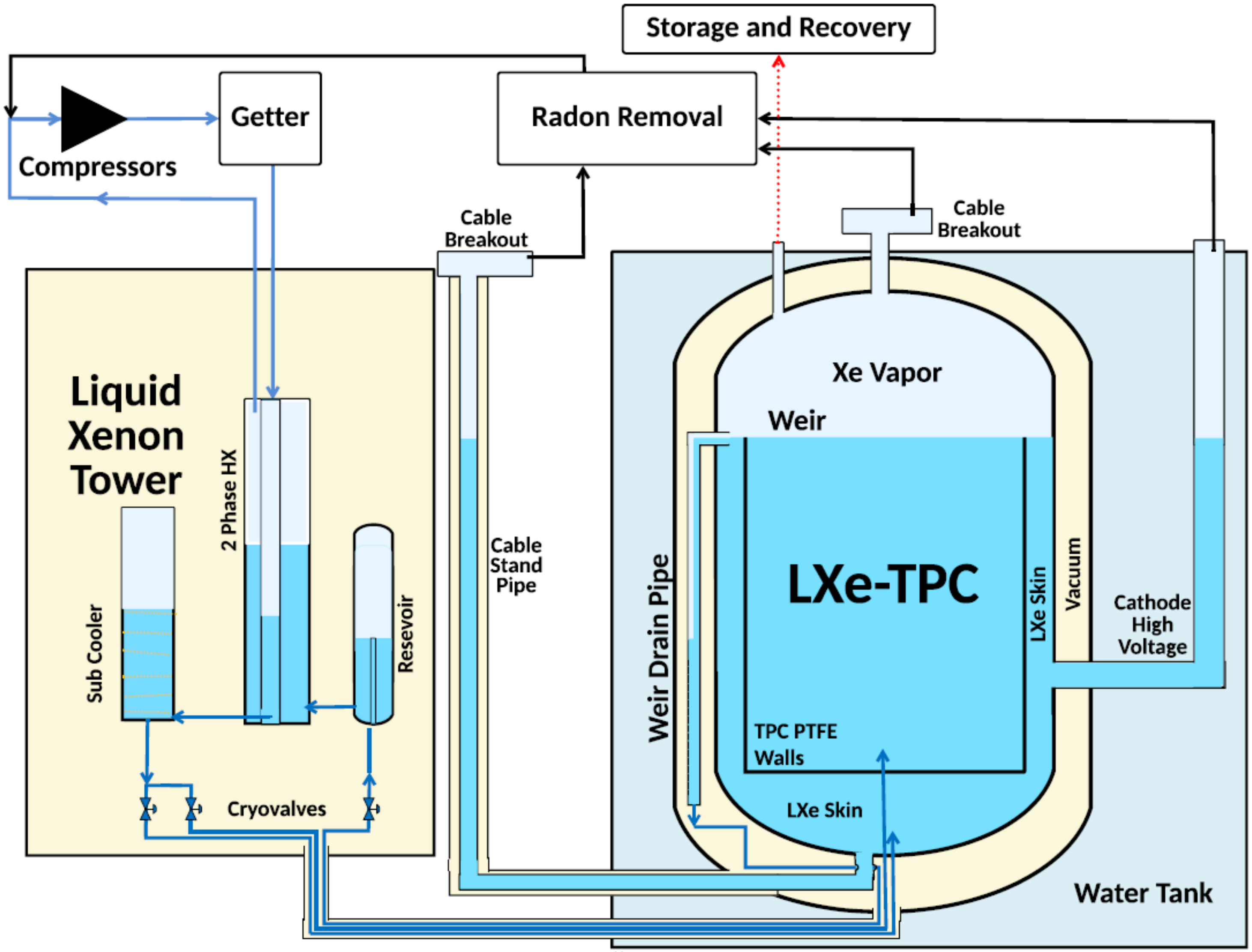
    Removed by Getter
  - Long-lived noble gases, eg ^{85}Kr, ^{39}Ar

    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

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- Screening
  - Around 100 materials/components screened for LZ
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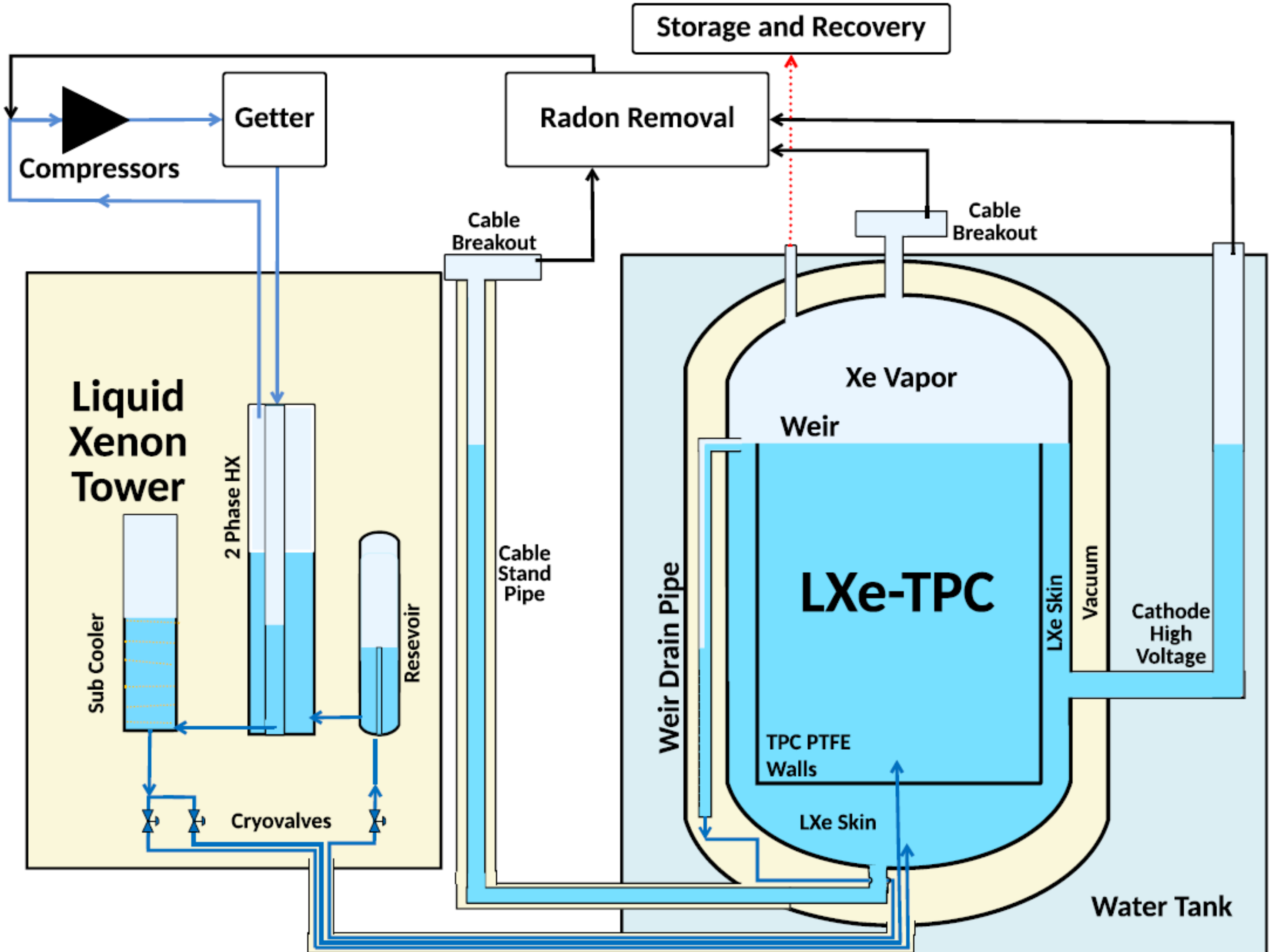
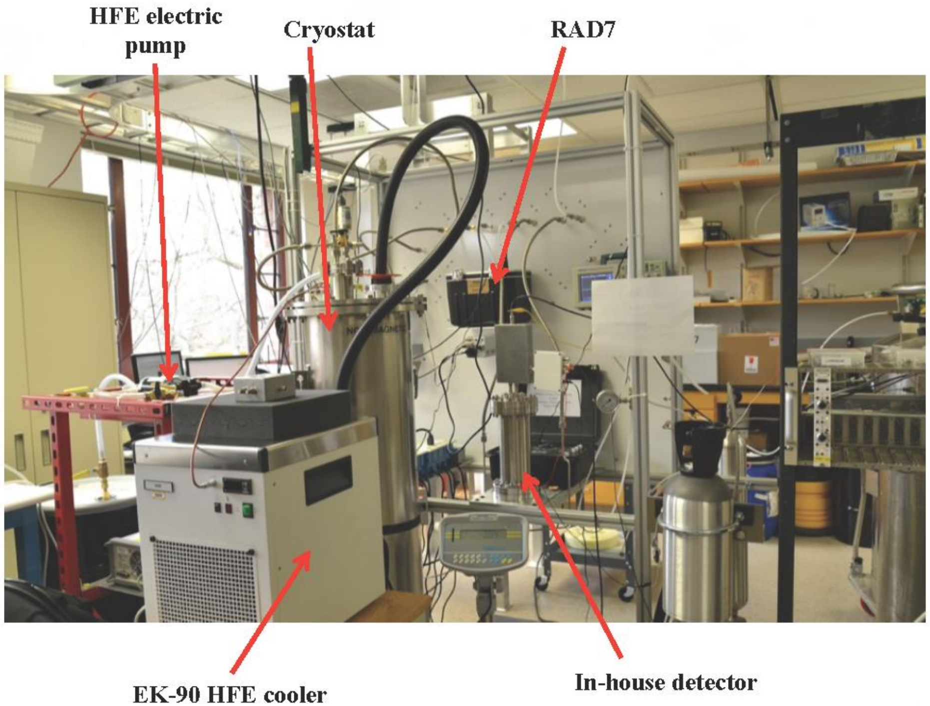
- Projected Rn level:
  - <2 µBq/kg

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

provided by Carter Hall

Any worry about cosmic-ray activation of xenon?

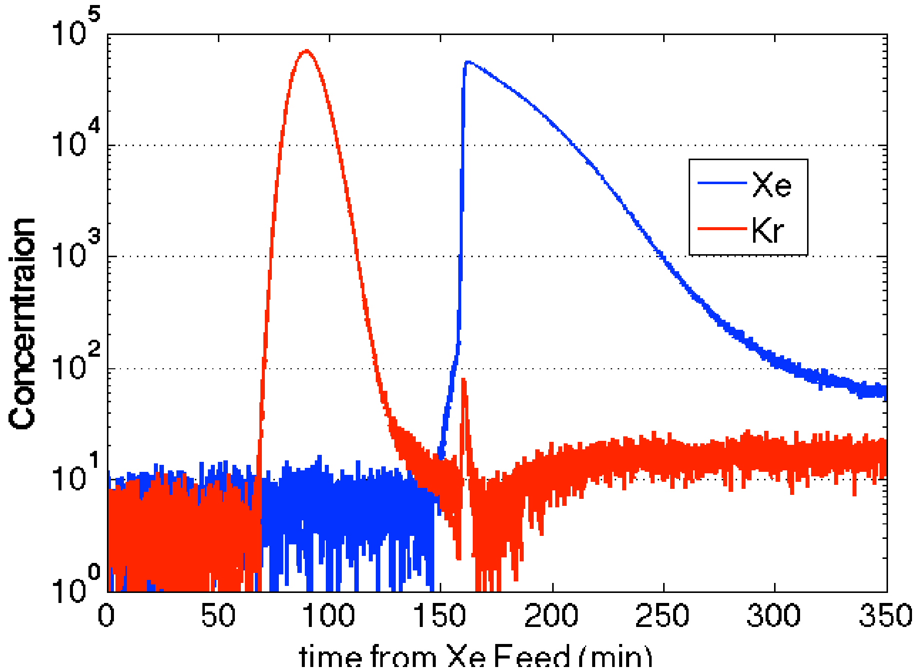
- Cosmic ray interactions produce radioactive byproducts in xenon cylinders at the Earth's surface
- Many of these are solids, and will not enter experiment
- ^{3}H will be removed by getter
- ^{127}Xe
  - 36-day half-life reduces impact
  - Production rate too low to be significant background
- ^{133}Xe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

- **We have the luxury of purifying Xe at the surface**

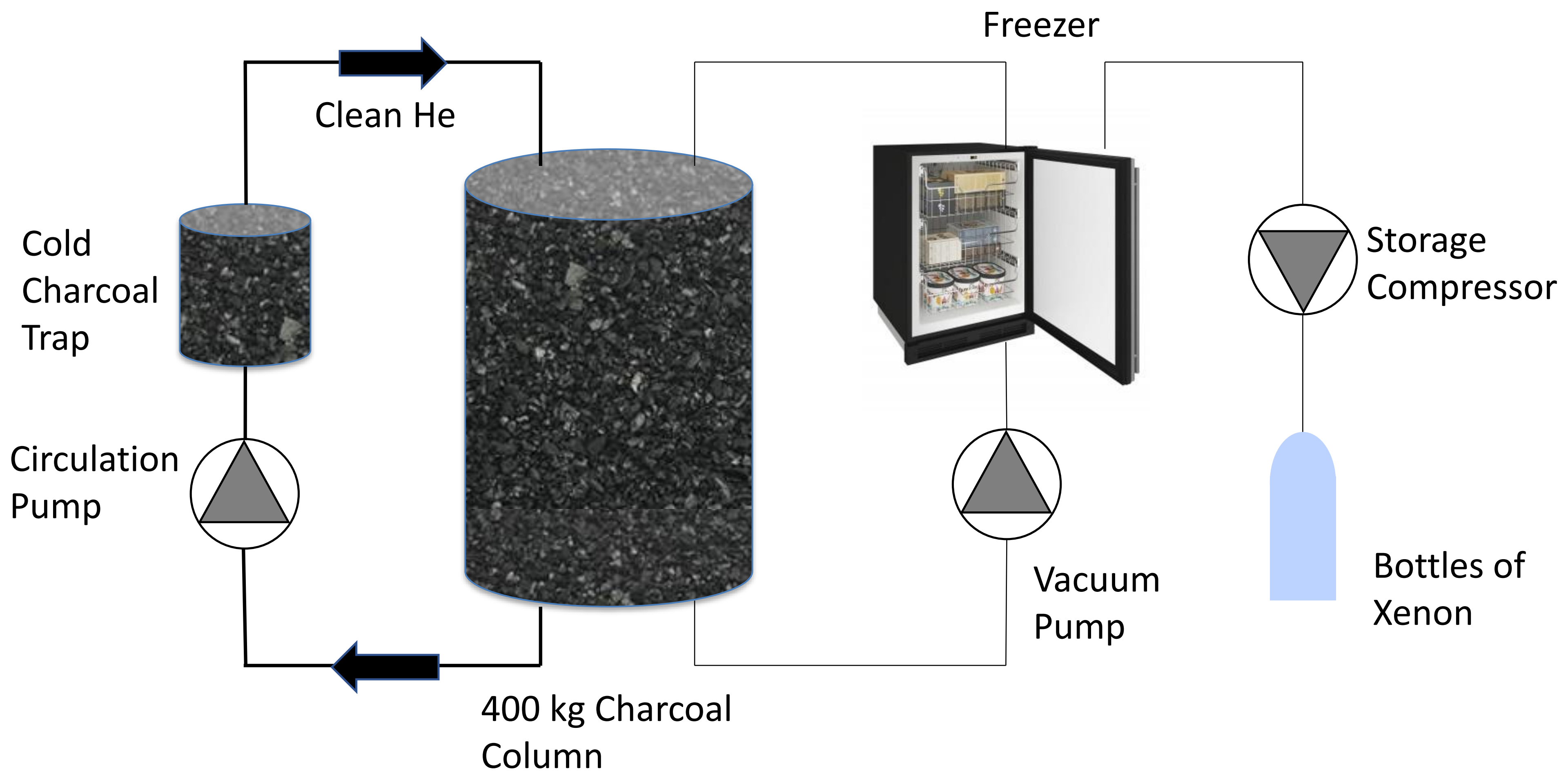
Cosmogenic activation of xenon and copper, Baudis et al., Eur. Phys. J. C (2015) 75: 485

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



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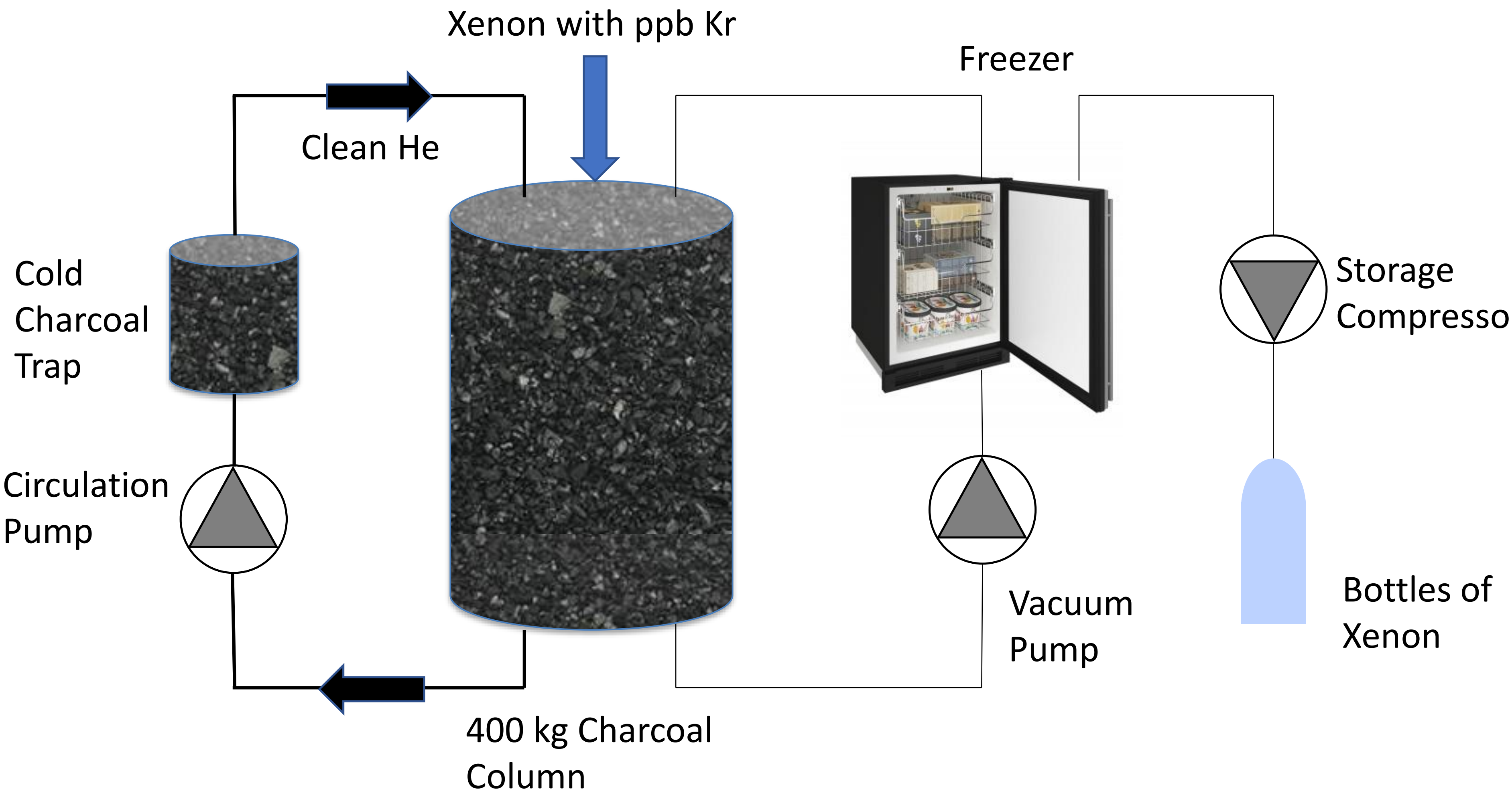
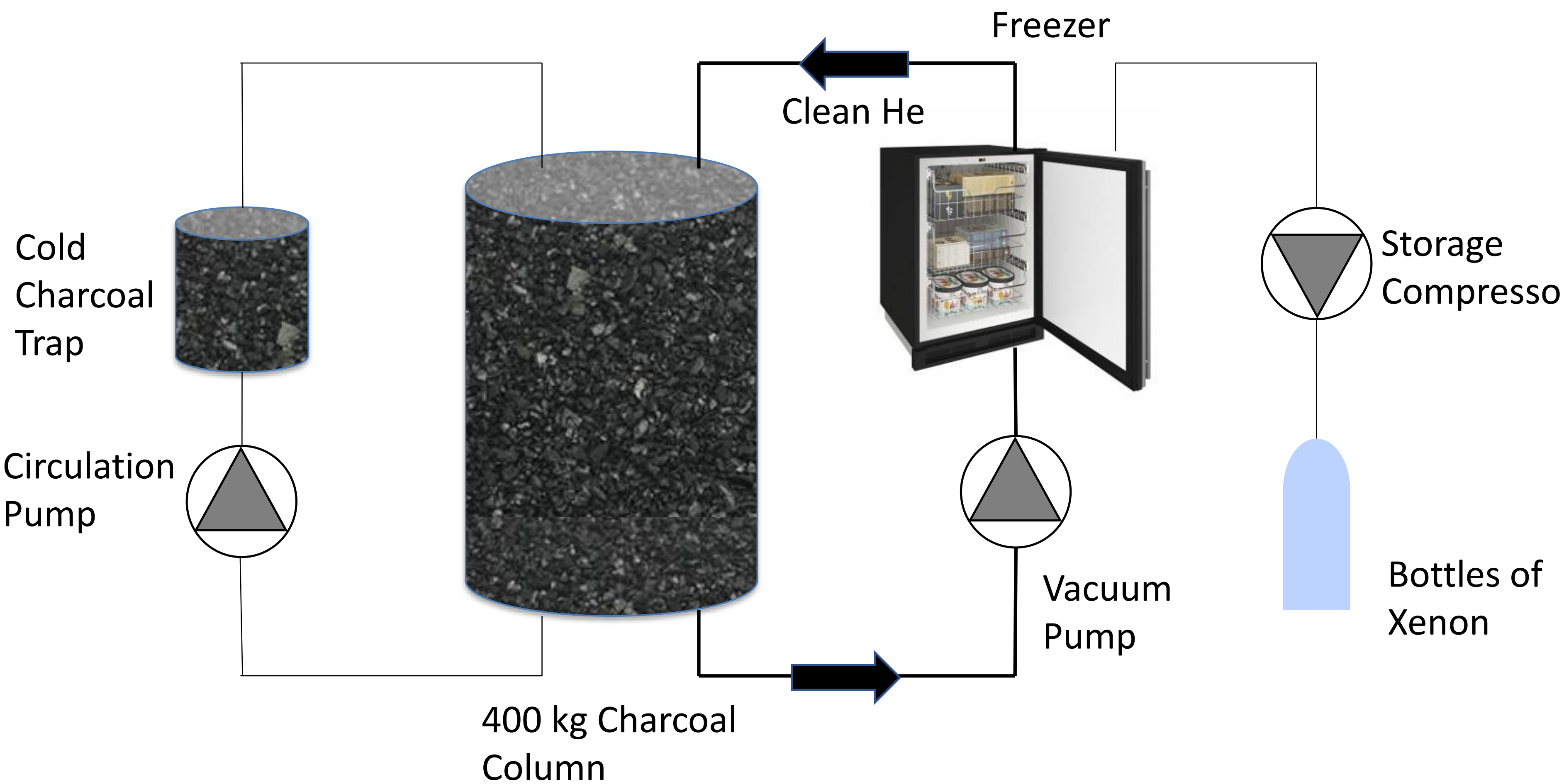
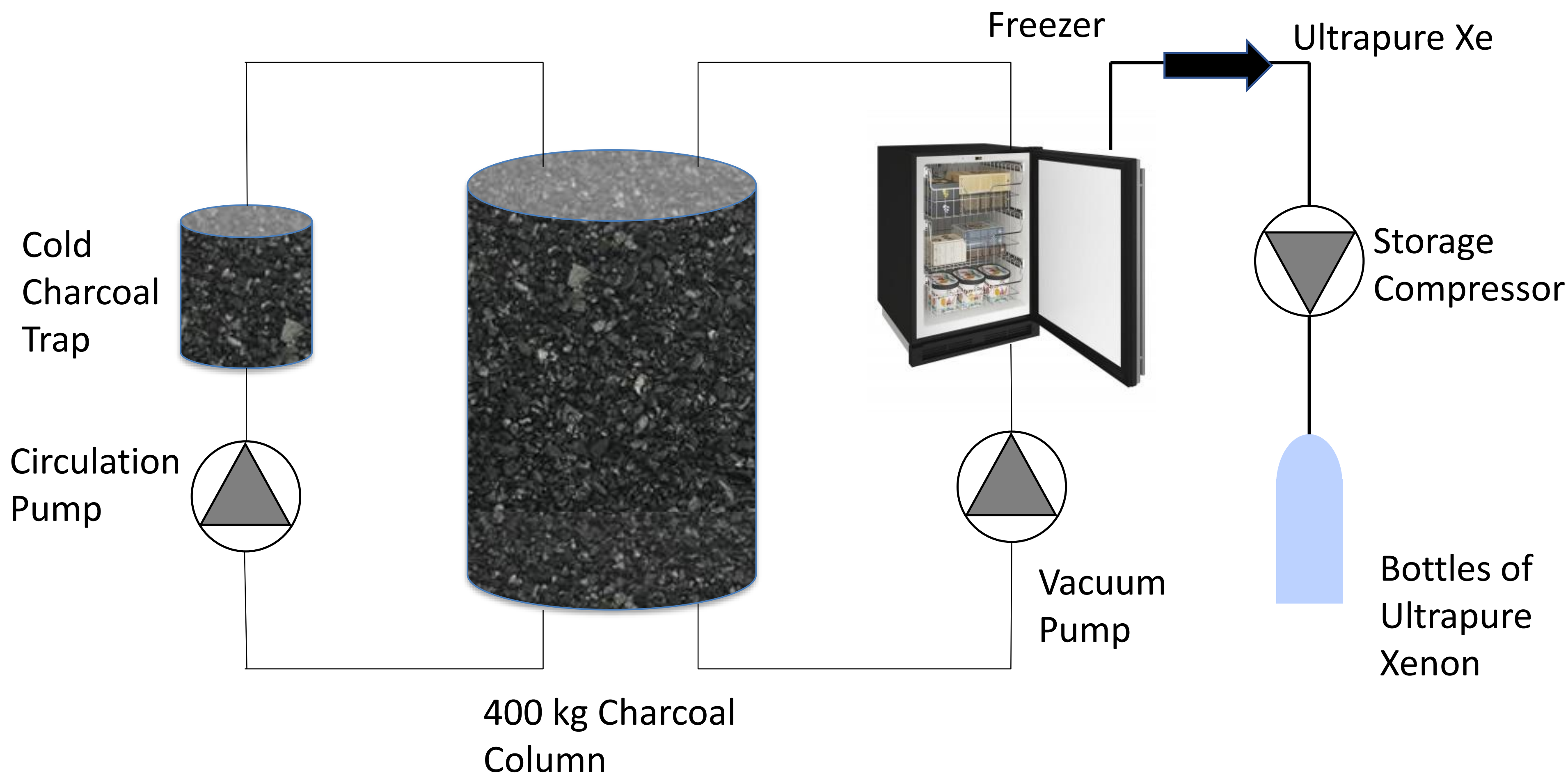


LZ Kr Removal - Recovery



LZ Kr Removal - Storage

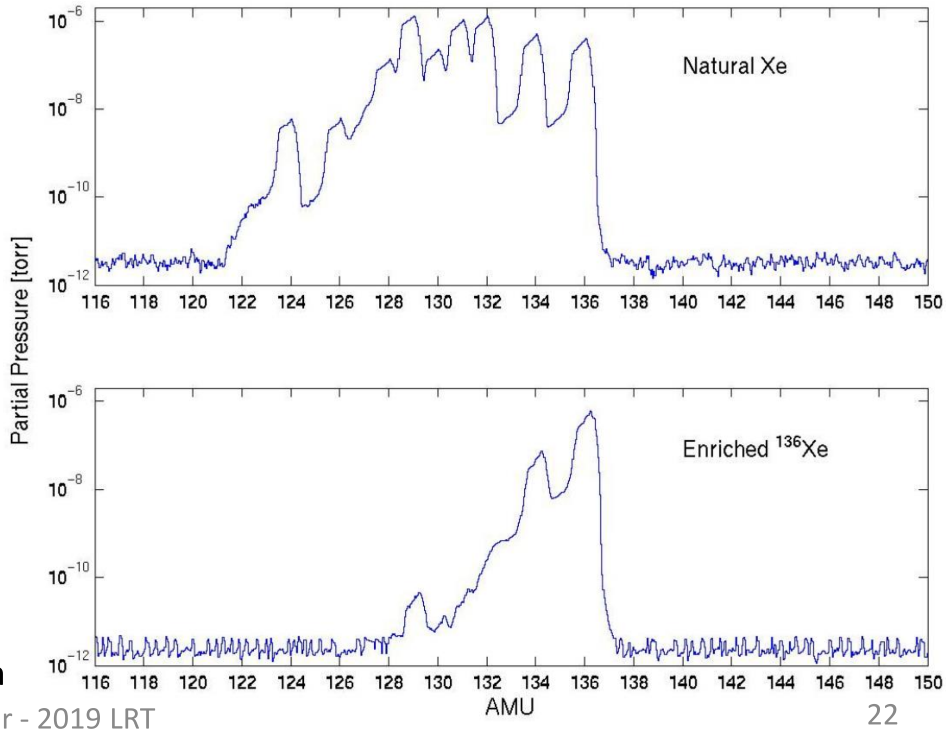


LZ – Krypton Removal

- 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



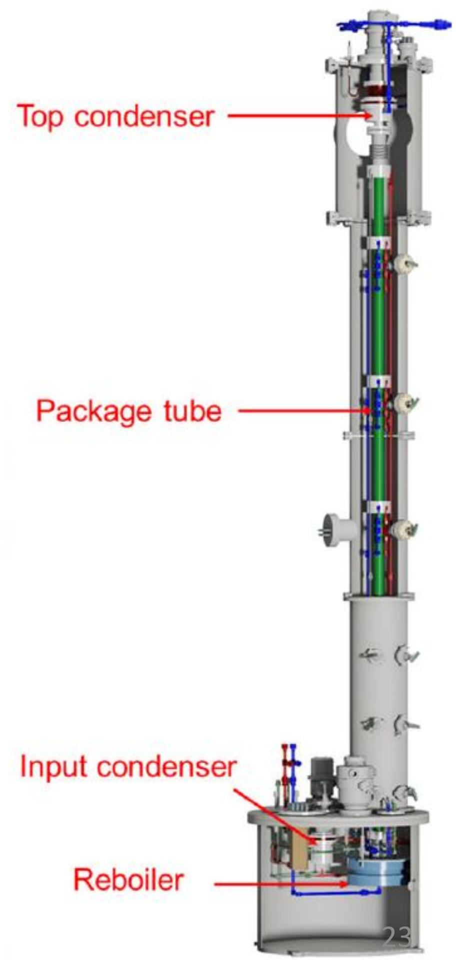
The EXO-200 detector, part I: detector design and construction, EXO Collaboration. Journal of Instrumentation 7 (05), P05010, 2012

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



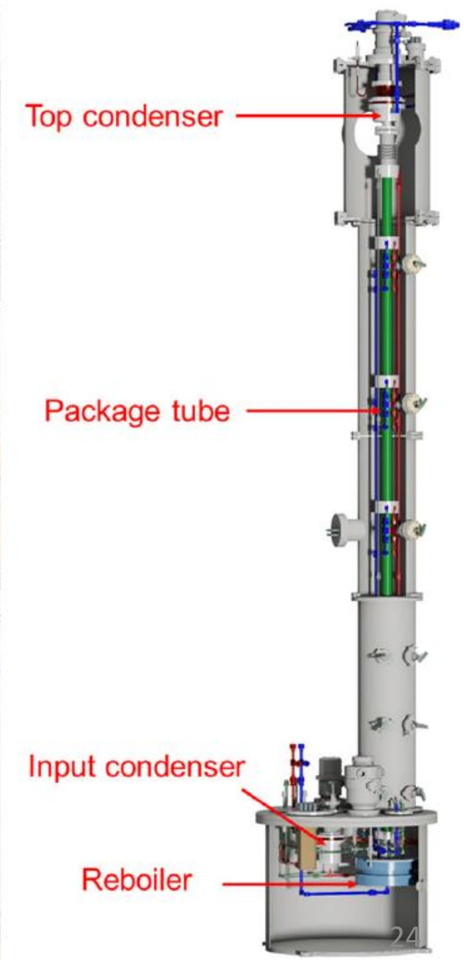
Removing krypton from xenon by cryogenic distillation to the ppq level, XENON Collaboration, Eur. Phys. J. C (2017) 77: 275

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 222Rn 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**
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**

Projected WIMP Sensitivity of the LUX-ZEPLIN (LZ) Dark Matter Experiment, LZ Collaboration, arXiv:1802.06039, 2018