Krypton removal via chromatography for the LZ dark matter experiment

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On behalf of the LZ collaboration

SLAC NATIONAL ACCELERATOR LABORATORY

Why Krypton Removal?

- Xenon extracted from the atmosphere contains trace krypton
  - Research grade: ~1-100 ppb ^{nat}Kr g/g
  - ~1 ppt ^{85}Kr in ^{nat}Kr
- □-decays of ^{85}Kr create **electron recoil backgrounds** in LZ
- Uniformly distributed in LXe — cannot be mitigated by shielding
- Long half-life (~11 yr), and not removed by getter
- Science goals of LZ require < 0.3 ppt Kr

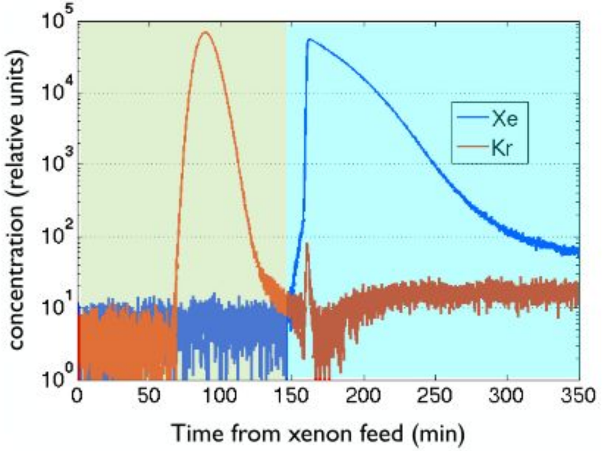
Background sources in LZ

Source	NR cts	ER cts
Detector components	0.07	9
Xenon contaminants	0	819
Laboratory and cosmogenics	0.06	5
Surface contaminants	0.39	40
Physics (neutrinos, ^{136}Xe $2\nu\beta\beta$)	0.51	258
Total	1.03	1195
Total with 99.5% ER discrimination, 50% NR efficiency	**0.52**	**5.66**

Isotope	ER cts
^{222}Rn (1.8 μBq/kg)	681
^{220}Rn (0.09 μBq/kg)	111
^{nat}Kr (0.015 ppt g/g)	24.5
^{nat}Ar (0.45 ppb g/g)	2.5

Based on 1000 day WIMP search exposure; ER, NR ROI for ~40 GeV WIMP
arXiv:1802.06039

Kr Removal via Gas Chromatography



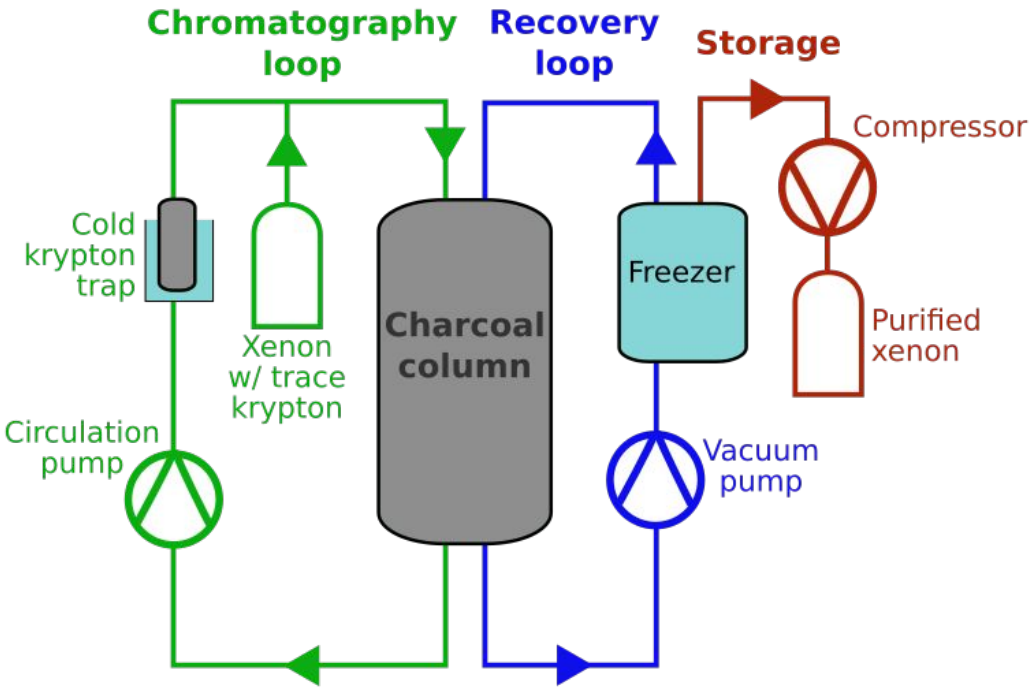
- **Solution**: remove Kr from Xe at SLAC before beginning of the experiment
- **Gas chromatography:** Separation of a mixture of gasses based on differing transit times through stationary medium
  - Stationary medium = column filled with **activated charcoal**
- Kr has weaker van der Waals attraction to charcoal than Xe ⇒ Kr transits faster
  - Ar even more weakly attracted — ^{39}Ar contamination easily reduced by same process
- Helium carrier gas maintains flow through column, with rate tunable for optimal separation

Kr Removal Process: 3 main phases

1. **Chromatography loop:**
   Separation of Xe and Kr

2. **Recovery loop:**
   Remove purified Xe from column

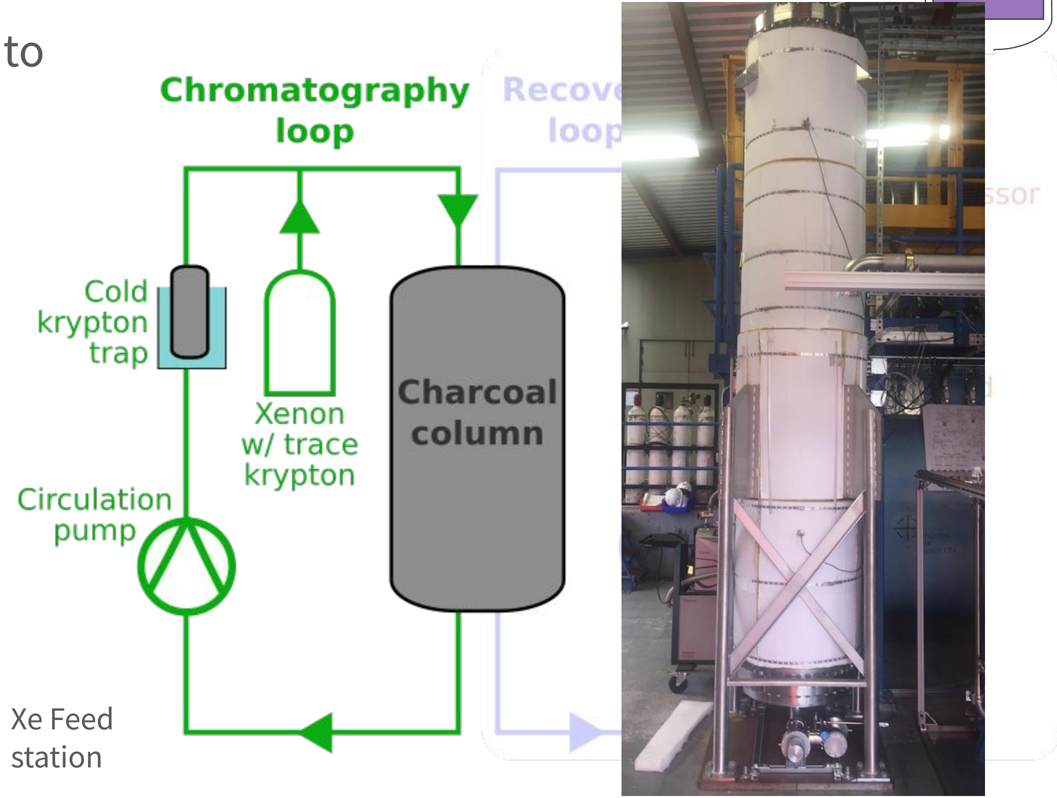
3. **Storage:**
   Purified Xe compressed into cylinders



Kr Removal Process: Chromatography Loop

- Inject 16 kg of Xe (w/ ~1-10 ppb Kr) into column with He circulating
- Tunable He flow rate to optimize separation vs processing time
- Capture Kr in cold charcoal trap
- Monitor column output with RGA; circulation stops when Xe detected

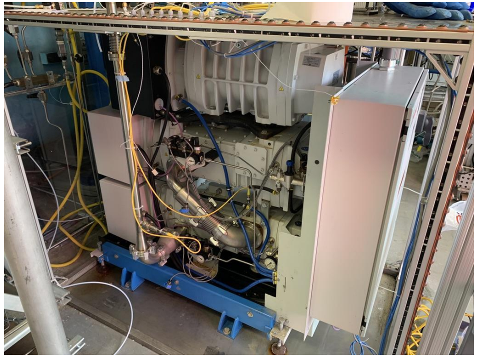
Xe Feed station



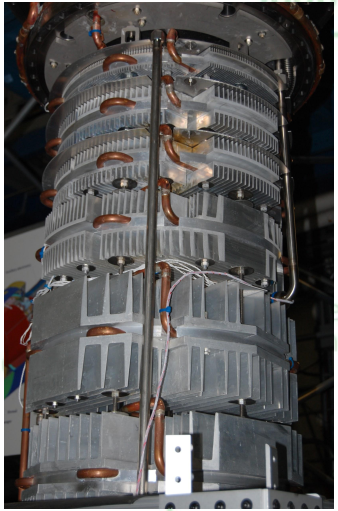
Charcoal column

Kr Removal Process: Recovery Loop

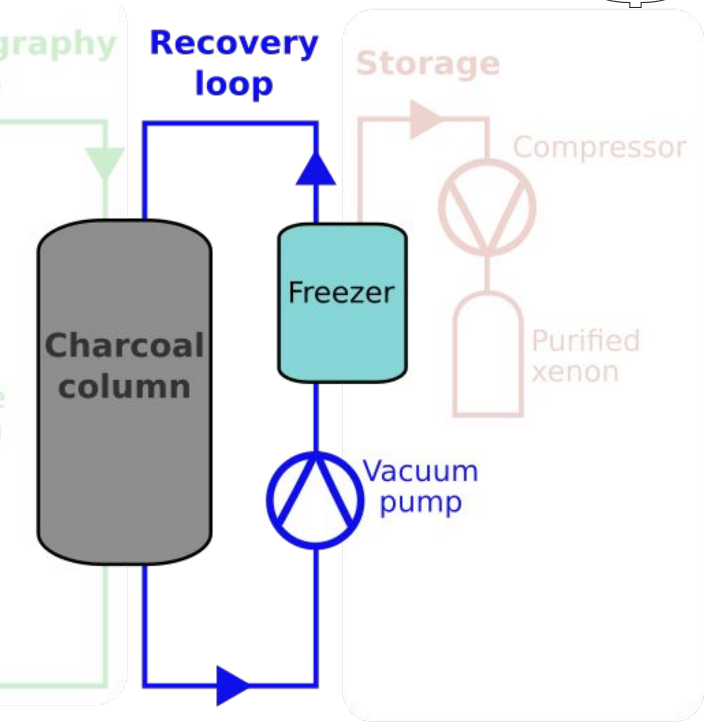
- Pump column down to ~10 mbar for max Xe removal efficiency
- Xe freezes out of Xe/He stream at LN temps
- Assay samples for Kr, other impurities (UMD sampling system)



Leybold 3-stage recovery vacuum pump



Freezer interior

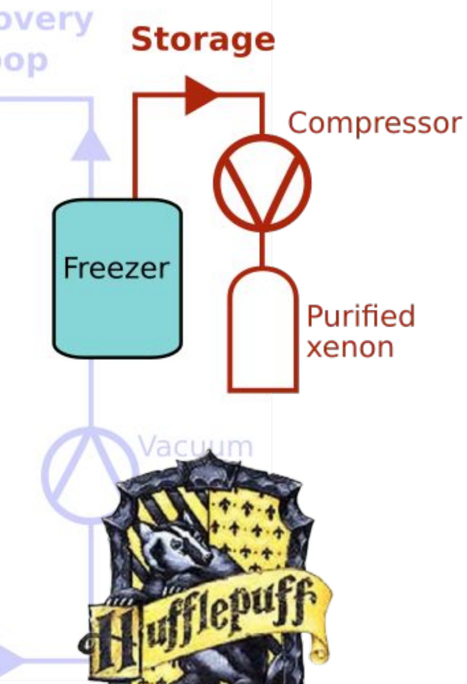


Kr Removal Process: Xenon Storage

- Collect purified Xe in freezer over multiple chromatography / recovery cycles (~300 kg)
- Warm freezer, compress Xe gas into cylinders (~80 bar)

Xe storage packs (designed & instrumented by UW-PSL)

Storage compressor

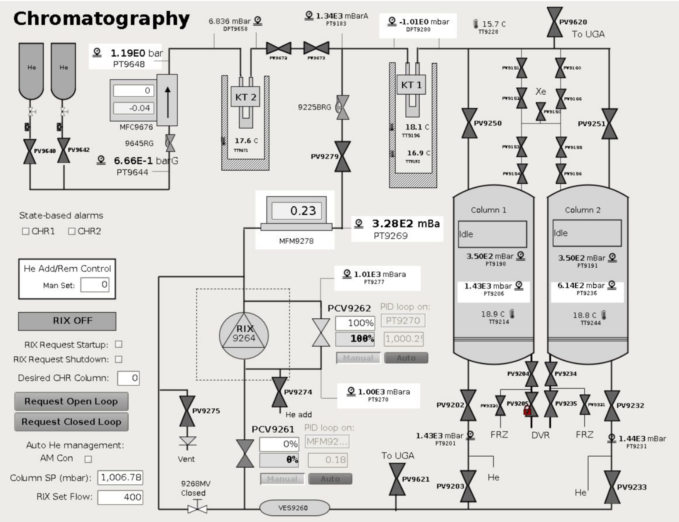


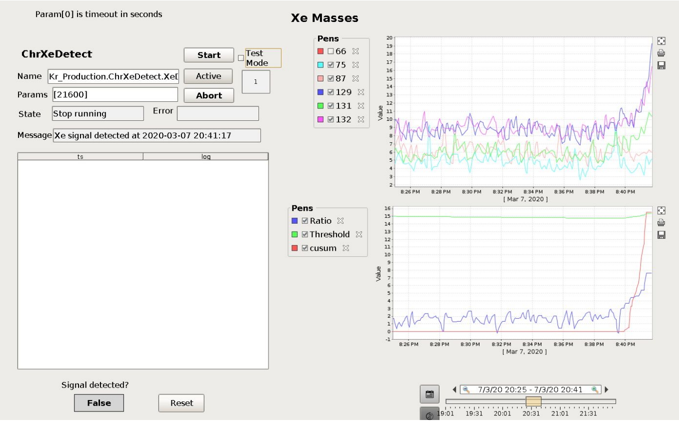
Kr Removal System

- 2 columns = parallel processing
- 400 kg activated charcoal / column
- One chromatography + recovery cycle = ~5-6 hours
- **Final product:** 10 tonnes of Xe with < 0.3 ppt ^{nat}Kr

System Automation

- Individual processes automated via PLC
  - Chromatography, recovery, Xe injection, freezer cooling and heating, LN delivery
- Python scripting coordinates timing and transitions between states
- Interface to queue multiple runs for continuous unattended operation
- Data continually aggregated and plotted for fast comparison between runs



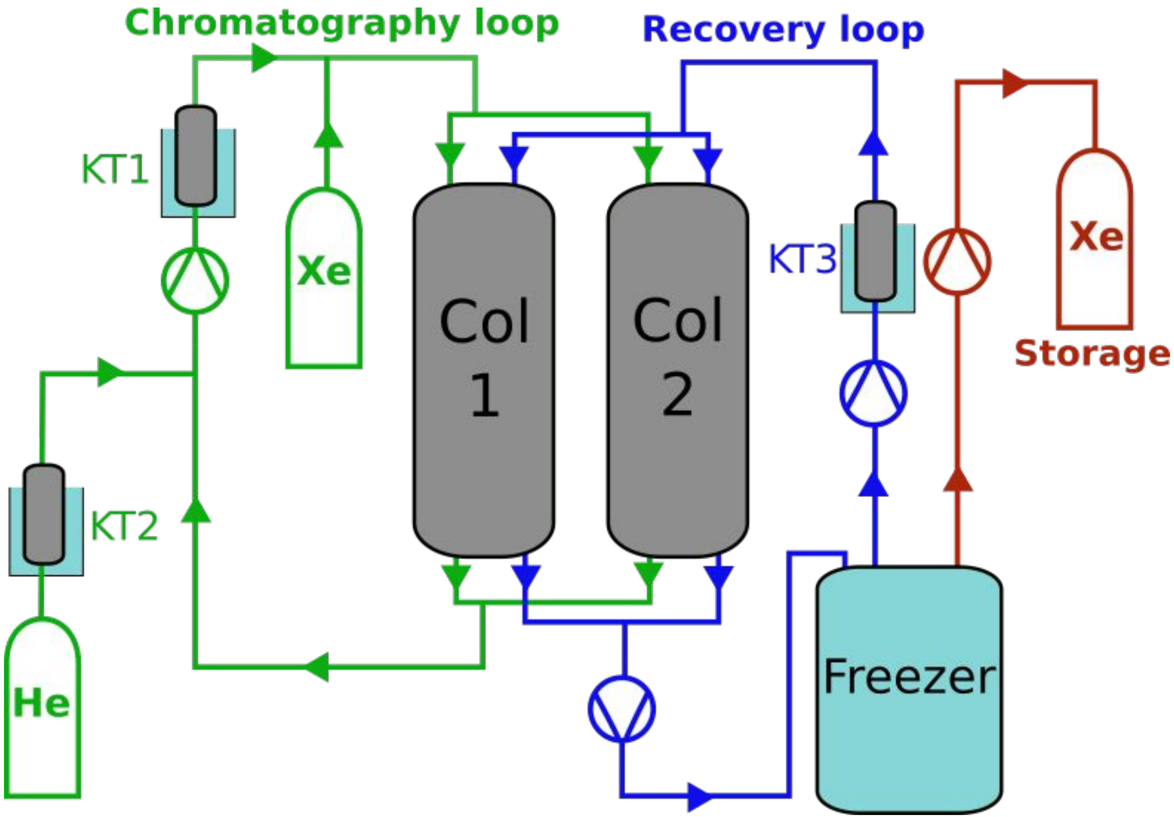


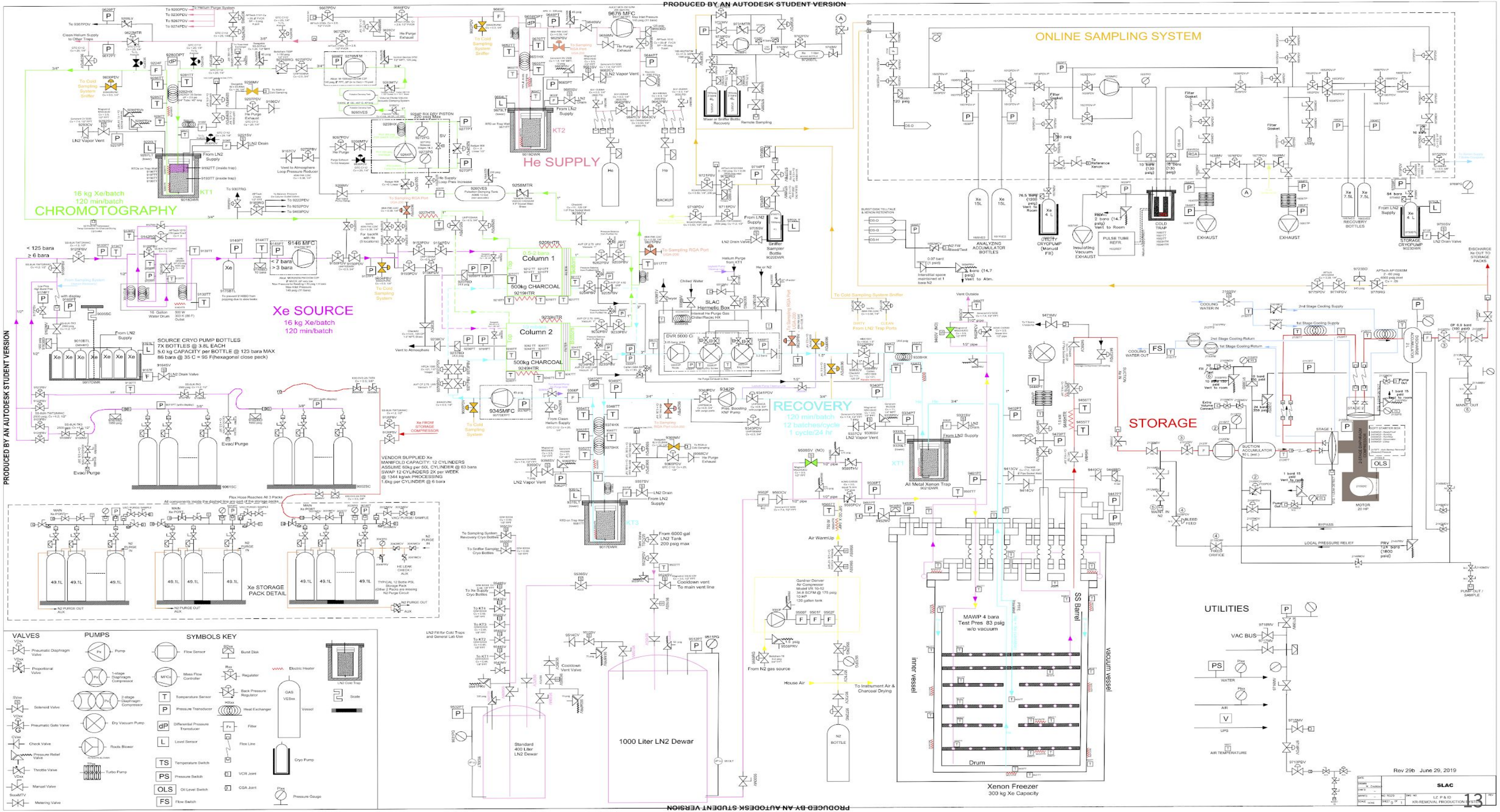
System Status & Next Steps

- We have achieved a purity of 0.1 ppt in initial runs on ~1 ppb Xe (< 0.3 ppt)
- Successful storage of ~100 kg batches from freezer to bottles
- With automated continuous operation, will explore and optimize more parameters
  - Ambient temp affects chromatography transit time -- explore this relationship and mitigate by changing flow rate
  - Optimal column pressure for most efficient recovery of purified Xe?
- Lab work is currently on hiatus due to COVID-19 precautions
  - System has been put into a stable state, ready for restart as soon as we can return
  - Once processing resumes, begin large-scale processing and move toward unattended continuous operation

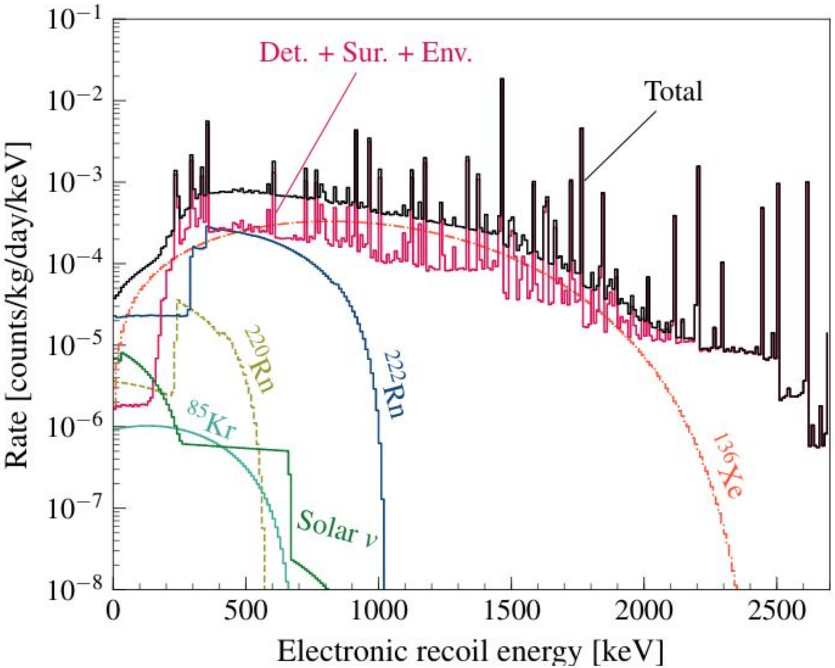
Thank you!

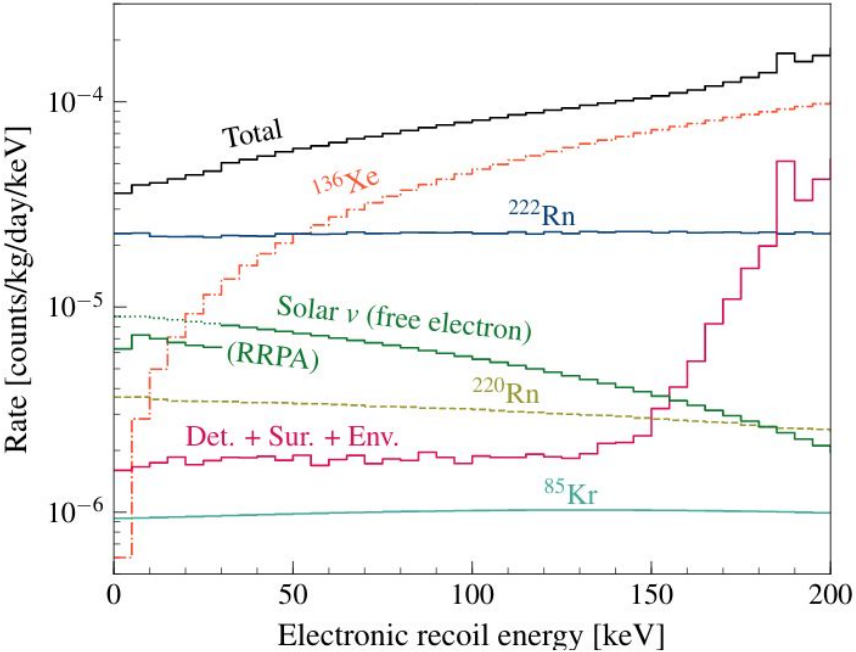
System diagram




ONLINE SAMPLING SYSTEM
CHROMOTOGRAPHY
16 kg Xe/batch
120 min/batch
He SUPPLY
Xe SOURCE
16 kg Xe/batch
120 min/batch
Column 1
500kg CHARCOAL
Column 2
500kg CHARCOAL
9148 MFC
9676 MFC
9345MFC
SLAC Hermetic Box
DVR 5000 Ci
RECOVERY
120 min/batch
12 batches/cycle
1 cycle/24 hr
STORAGE
SOURCE CRYO PUMP BOTTLES
7X BOTTLES @ 3.8L EACH
5.0 kg CAPACITY per BOTTLE @ 123 bara MAX
86 bara @ 35 C = 95 F(hexagonal close pack)
VENDOR SUPPLIED Xe
MANIFOLD CAPACITY: 12 CYLINDERS
ASSUME 60kg per 60L CYLINDER @ 63 bara
SWAP 12 CYLINDERS 2X per WEEK
@ 1344 kg/wk PROCESSING
1.6kg per CYLINDER @ 6 bara
Xe STORAGE PACK DETAIL
All Metal Xenon Trap
MAWP 4 bara
Test Pres 83 psig
w/o vacuum
inner vessel
vacuum vessel
SS Barrel
Drum
Xenon Freezer
300 kg Xe Capacity
Standard 400 Liter LN2 Dewar
1000 Liter LN2 Dewar
UTILITIES
ANALYZING ACCUMULATOR BOTTLES
UTILITY CRYOPUMP
PULSE TUBE REFR
COLD TRAP
EXHAUST
RECOVERY BOTTLES
STORAGE CRYOPUMP
DISCHARGE Xe OUT TO STORAGE PACKS
SUCTION ACCUMULATOR
MOTOR 20 HP
VALVES
PUMPS
SYMBOLS KEY
Rev 29b June 29, 2019
SLAC
LZ P & ID
KR-REMOVAL PRODUCTION SYST

ER Background Spectra





ER background spectra in the 5.6-tonne fiducial volume for single scatter events, without vetos or cuts
arXiv:1802.06039