



Measurement of Trace Krypton for the LUX-ZEPLIN WIMP Dark Matter Search

John Silk
University of Maryland





Content

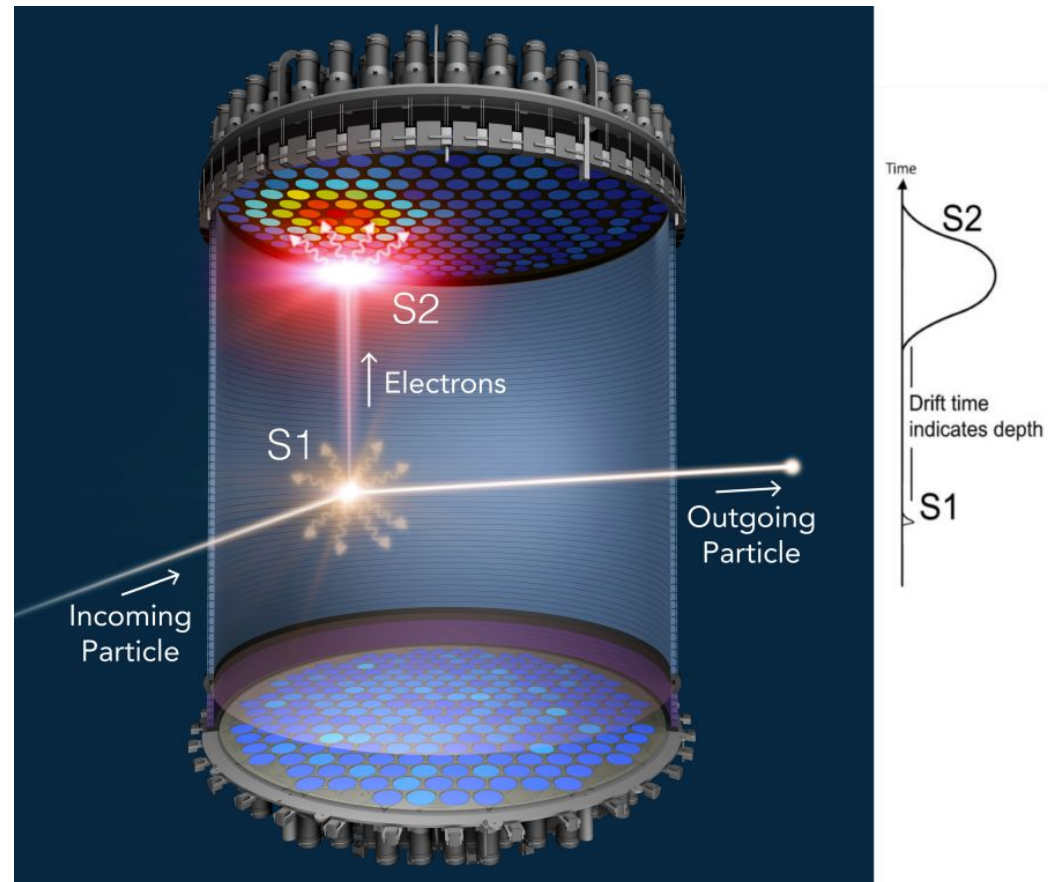
- 1. LUX-ZEPLIN overview**
- 2. Backgrounds**
- 3. Krypton Removal**
- 4. Measuring Xenon Purity**
- 5. Current Purity Results**
- 6. Acknowledgements**



LUX-ZEPLIN Overview

G2 Dual-Phase Liquid Xenon (LXe) Time Projection Chamber (TPC)

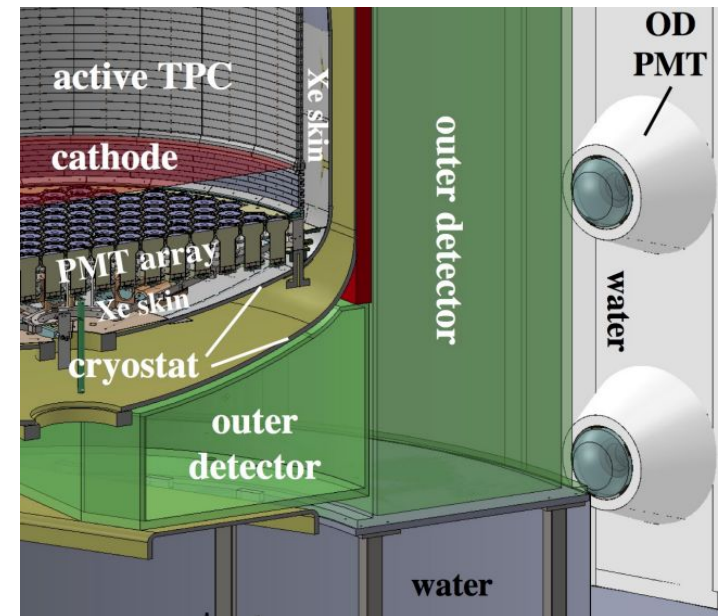
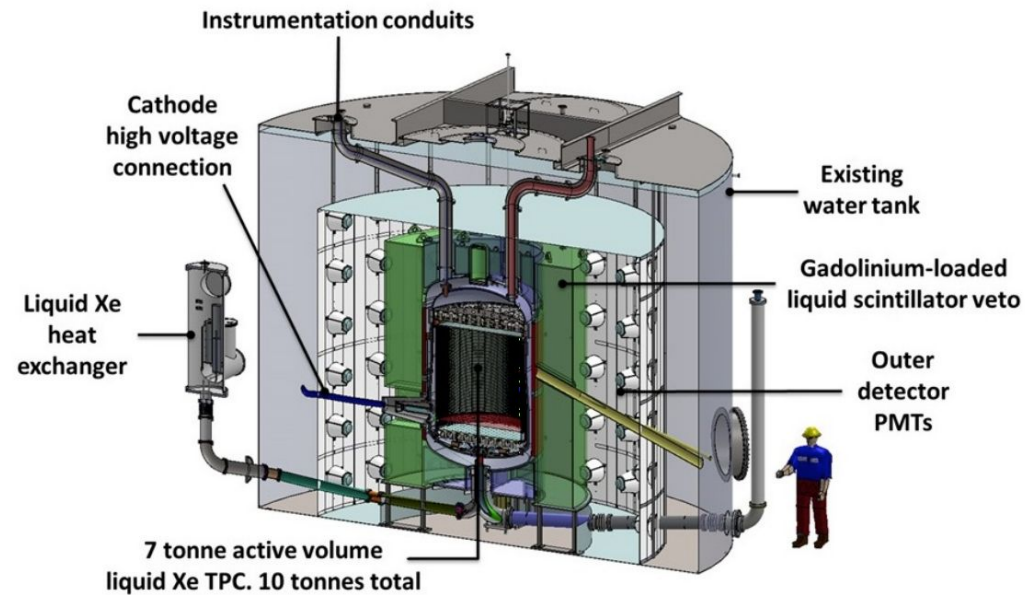
- Two channels of energy collection
 - S1: Light
 - S2: Charge
- Position reconstruction
 - S2 X-Y location
 - S1 and S2 time delay z position
- Energy reconstruction
 - S1 + S2
- Election and Nuclear recoil discrimination
 - Ratio of S1 to S2
 - ER interactions favor S2





LUX-ZEPLIN

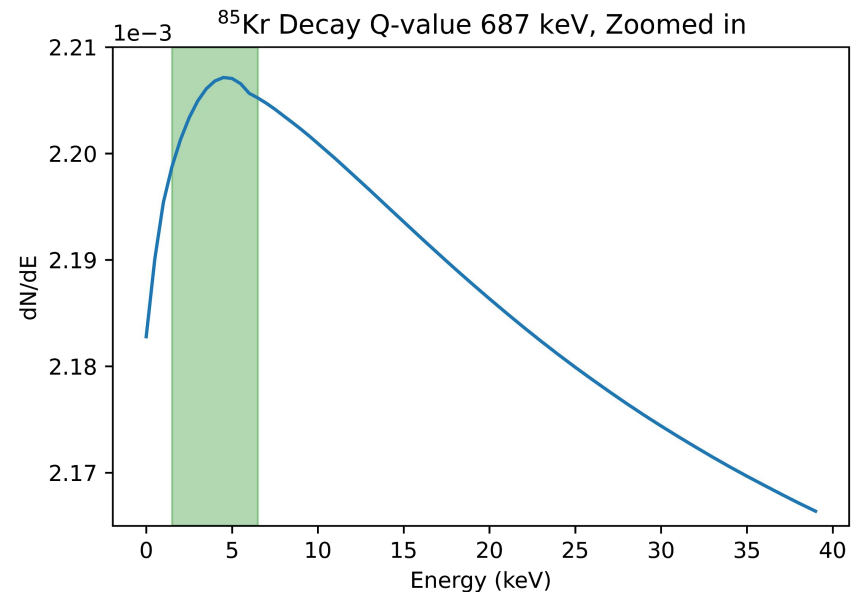
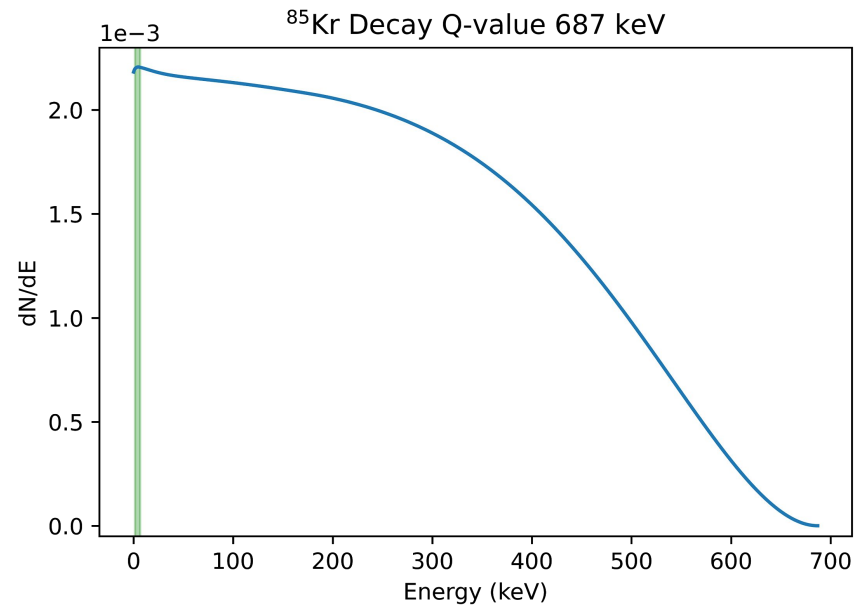
- Location: Davis Cavern, 4850L of the Sanford Underground Research Facility (SURF), Lead SD. ~250 scientists, from 35 institutions
- Water tank + Gadolinium Loaded Liquid Scintillator (Veto, 120 PMTs)
- Titanium Inner Cryostat
 - 1.5 meter diameter, 1.5 meter height (active mass 7 tonnes Xe)
 - Xenon Skin Layer (Veto, 131 PMTs)
 - Fiducial region (494 PMTs, 5.6 tonnes)
- LXe target in 300 V/cm electric field
- Projected 40 GeV/c² WIMP-nucleon SI cross-section sensitivity: 1.4×10^{-48} cm², 1000 days live time





Backgrounds

- **Nuclear Recoils**
 - WIMP Region of interest 6-30 keV
- **Electron Recoils**
 - WIMP Region of interest 1.5-6.5 keV
- **^{85}Kr**
 - **Beta Decay**
 - Q-value 687 keV: 99.6%
 - Q-value 173 keV: 0.4%
 - **Gamma Decay**
 - 514 keV: <0.01%
 - Half life of 10.8 years
 - Dispersed Contaminant
 - Noble element
- **Background Goal ^{85}Kr**
 - 490 counts per 15 Tonne*year
 - Low stats
 - 300 parts per quadrillion $^{\text{Nat}}\text{Kr/Xe}$ (g/g)
 - In situ, real time measurement





Krypton Removal

1. Chromatography loop:

Separation of Xe and Kr

Check source Xe and Kr trap

2. Recovery loop:

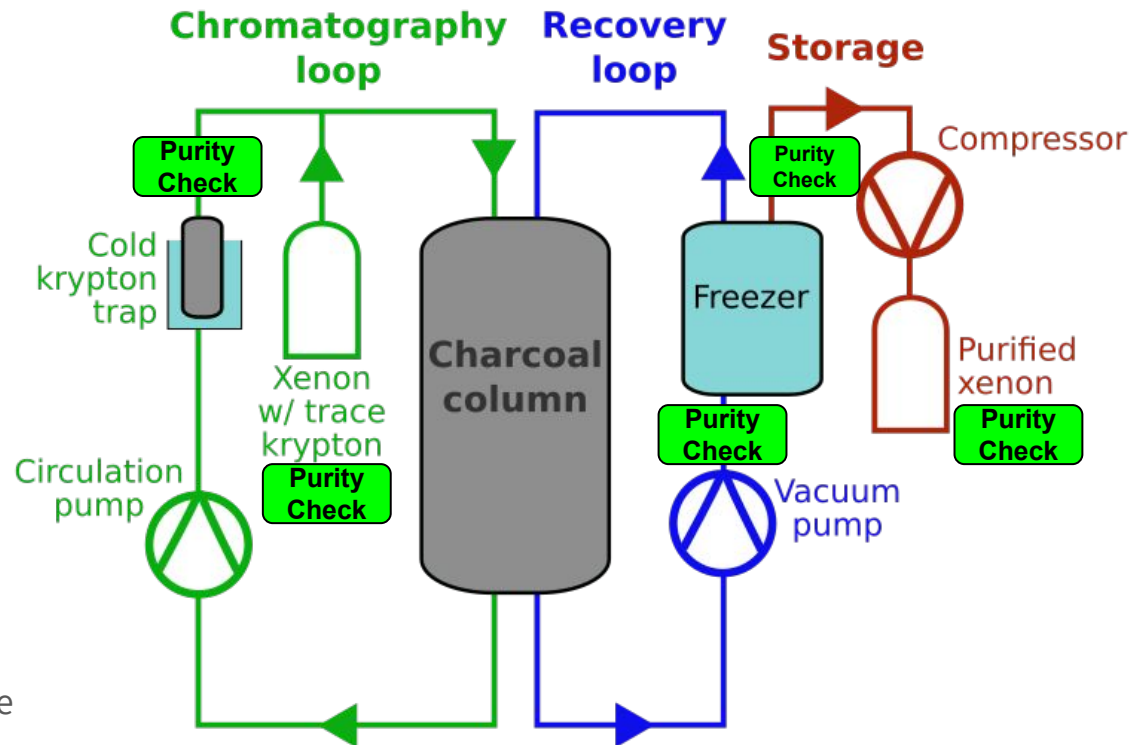
Remove purified Xe from column

Check purified Xe post charcoal column

3. Storage:

Purified Xe compressed into cylinders

Check purified Xe prior to, and post storage



Each check is unique to that component.

Krypton Removal: SLAC





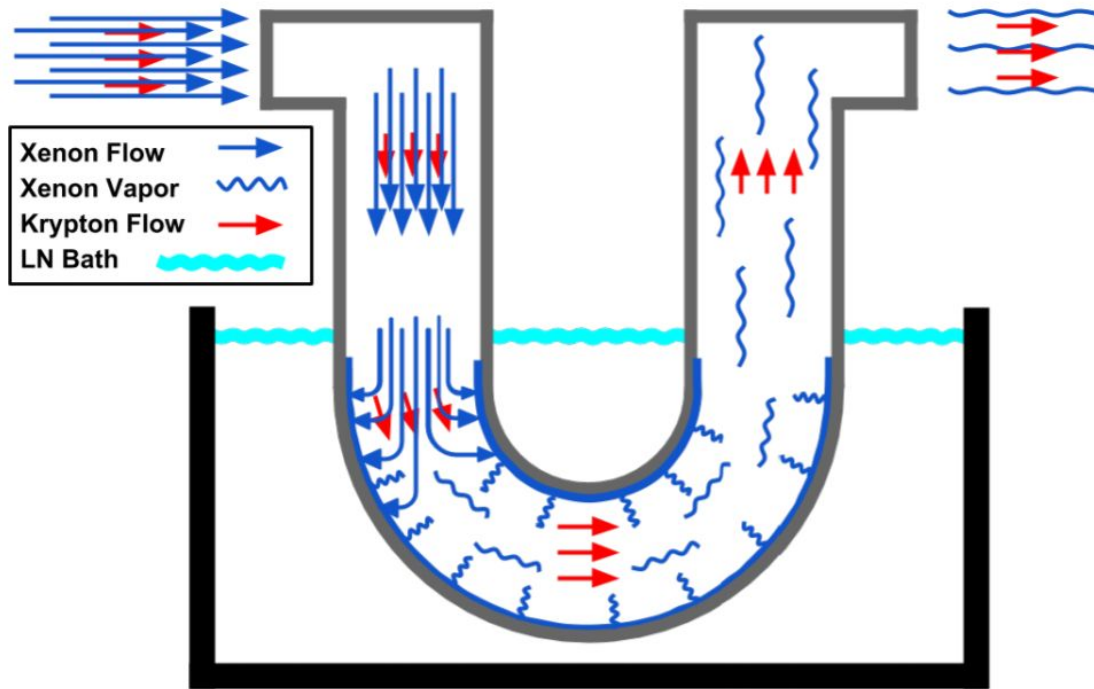
Measuring Xenon Purity Theory

- Overcoming Mass Spec limitations

- Residual Gas Analyzer (RGA)
- Sensitive to PPM scale
- Max operating pressure 10^{-5} torr
- Environmental dependence
- Cold Trap
- Impedance tuning

- Signal proportional to

- Impedance parameters
- Flow Rate
- Efficiency parameter
- Sample concentration

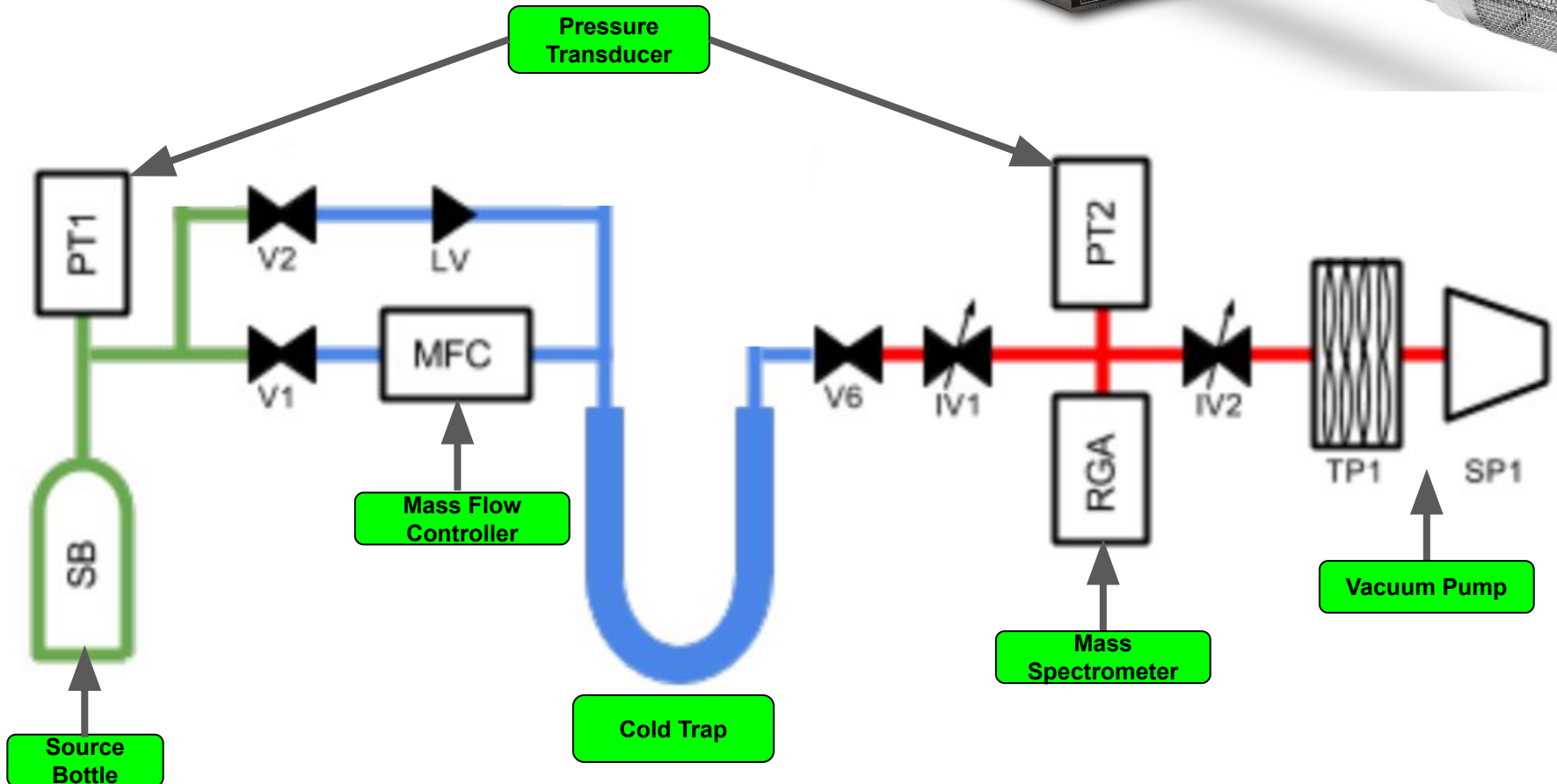




Hardware

Mass Spectrometer (SRS RGA 200)

- Ionizer
- RF Quadrupole Ion Filter
- Faraday cup/CDEM



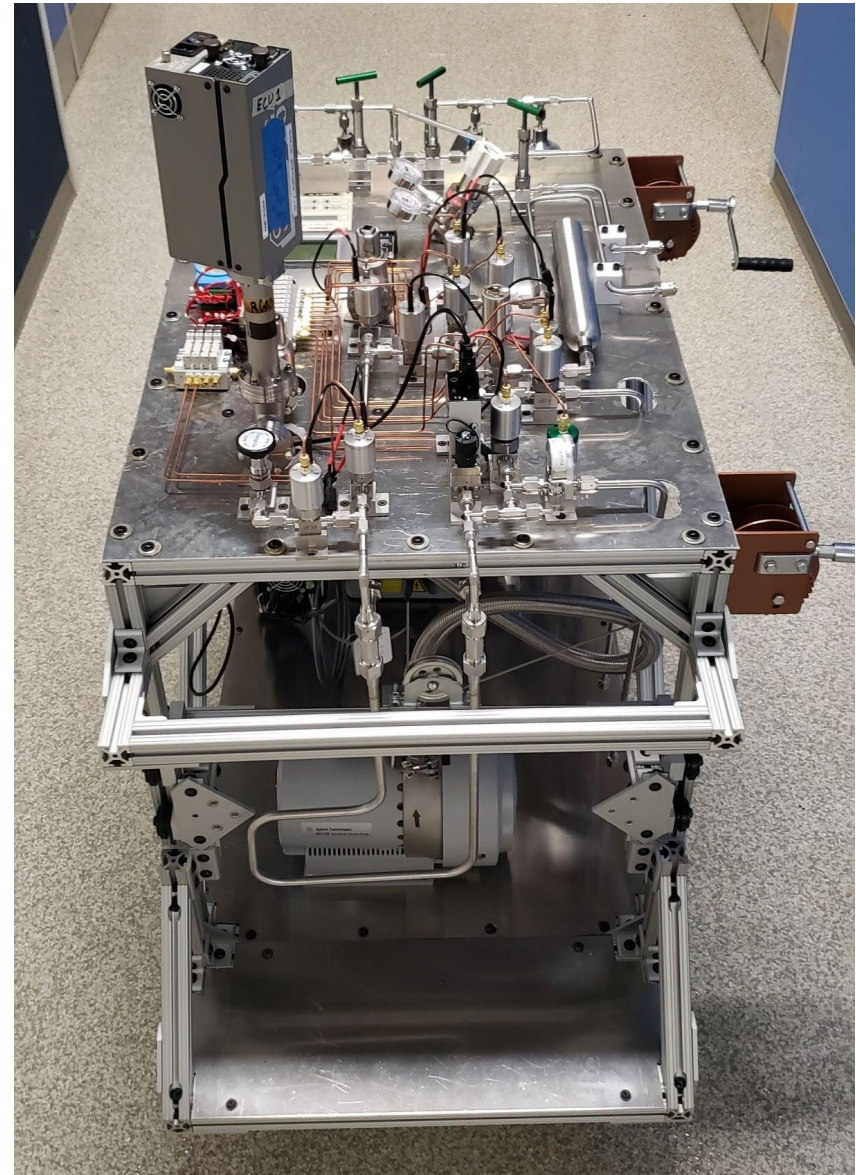


Uses

- Purity spot check
- Clean small batch xenon
- Integrated leak check
- Custom gas mixtures
- Different cooling methods
 - Liquid nitrogen
 - Pulse tube refrigerator
- Systems at
 - SLAC
 - SURF
 - UMD

Standard measurement procedure (4 hrs)

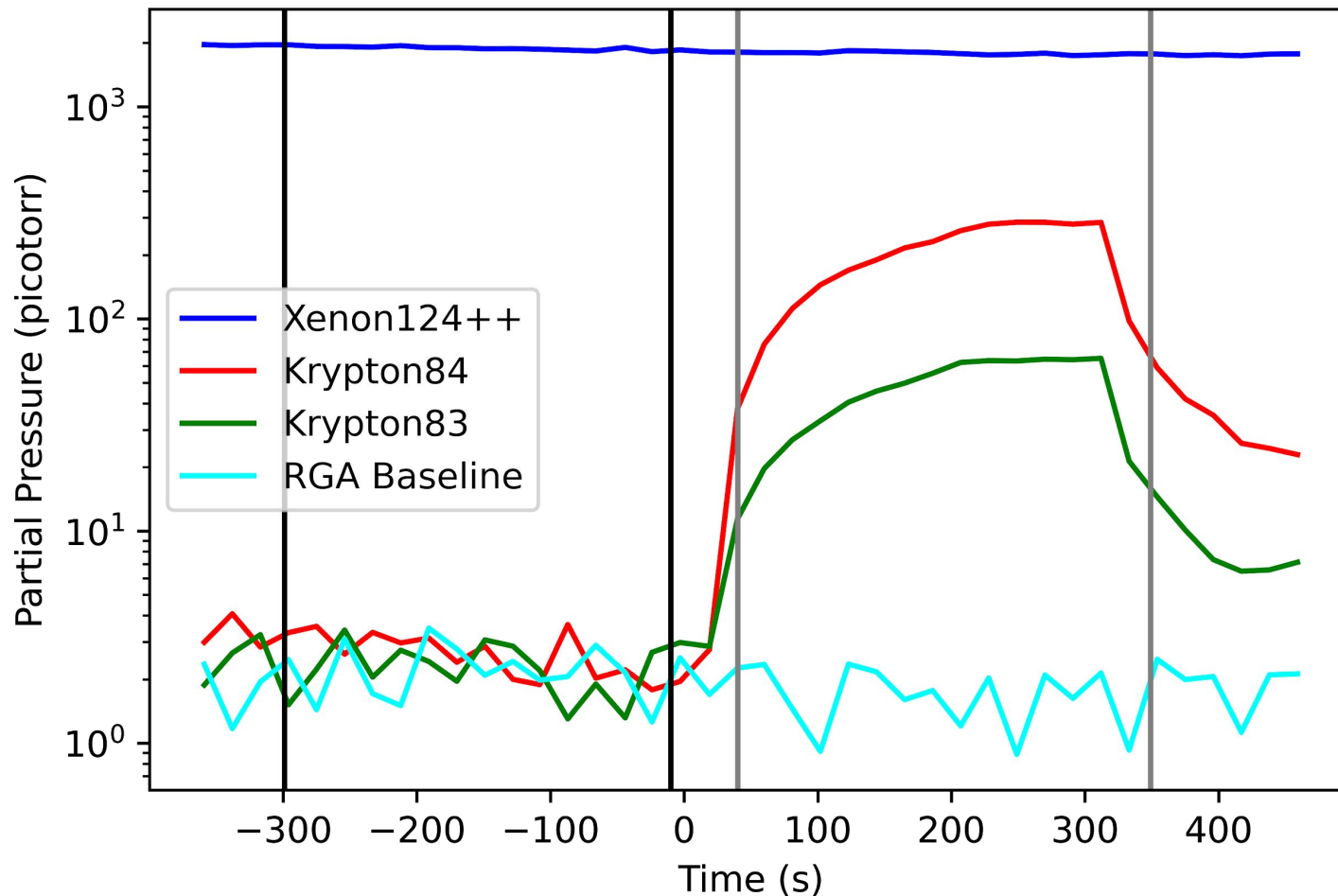
1. Xenon collected
2. High sensitivity (ppb) measurement
 - He, N₂, Ar
3. Helium removal
4. Ultra high sensitivity Kr (ppq) measurement
5. Recover xenon





Real Measurement

Krypton Measurement 10.75 PPT



Black lines: Background Interval

Grey lines: Signal Interval

Limit of detection 7.5 ppq

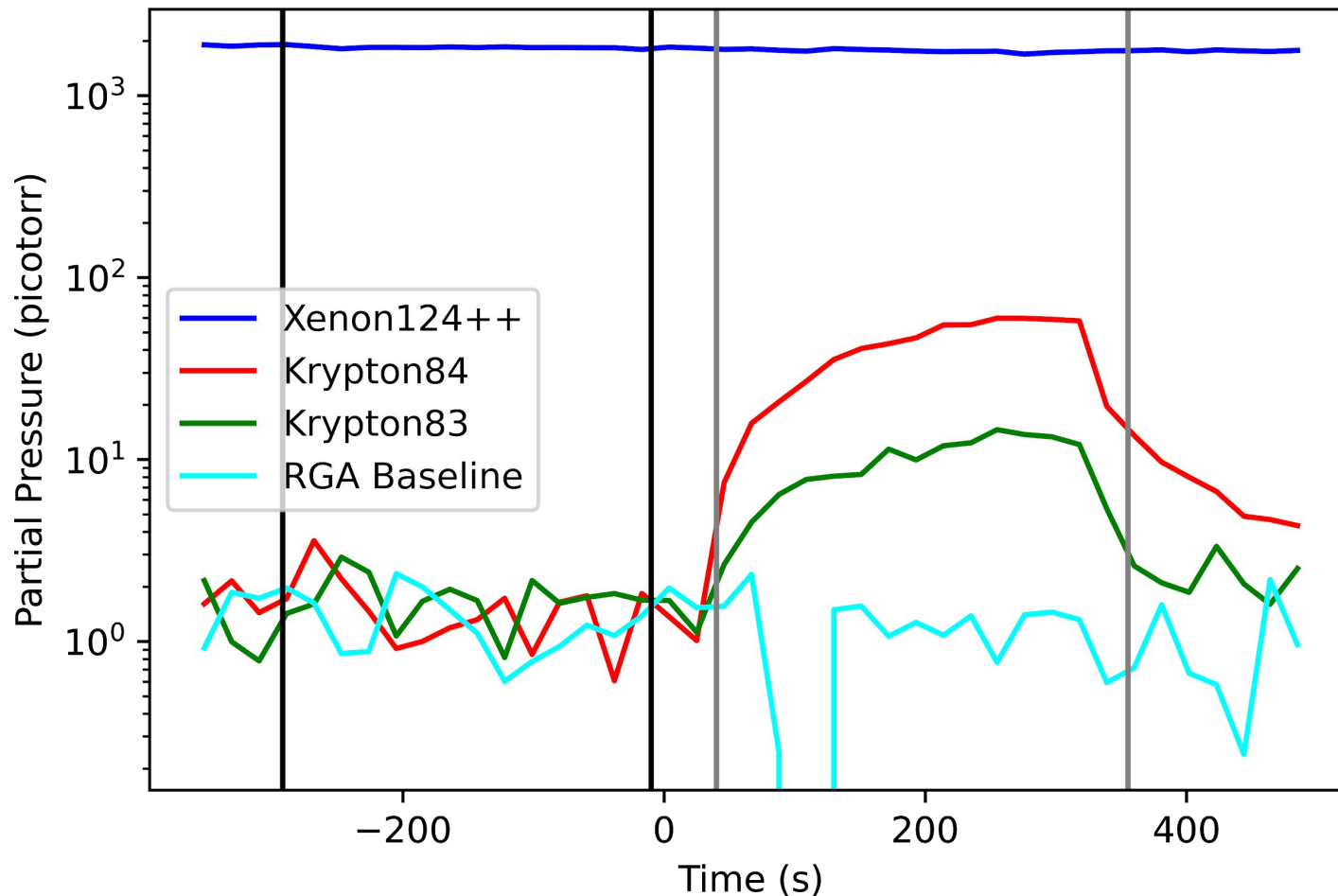
Krypton isotopes cross check

Baseline channel for pressure response



Smaller Signal

Krypton Measurement 2.14 PPT



Same xenon as previous slide

Measurement cycle reduces Kr by ~1.3x

Devoted cold trap cleaning cycle reduces Kr by ~4x

Limit of detection 7.5 ppq

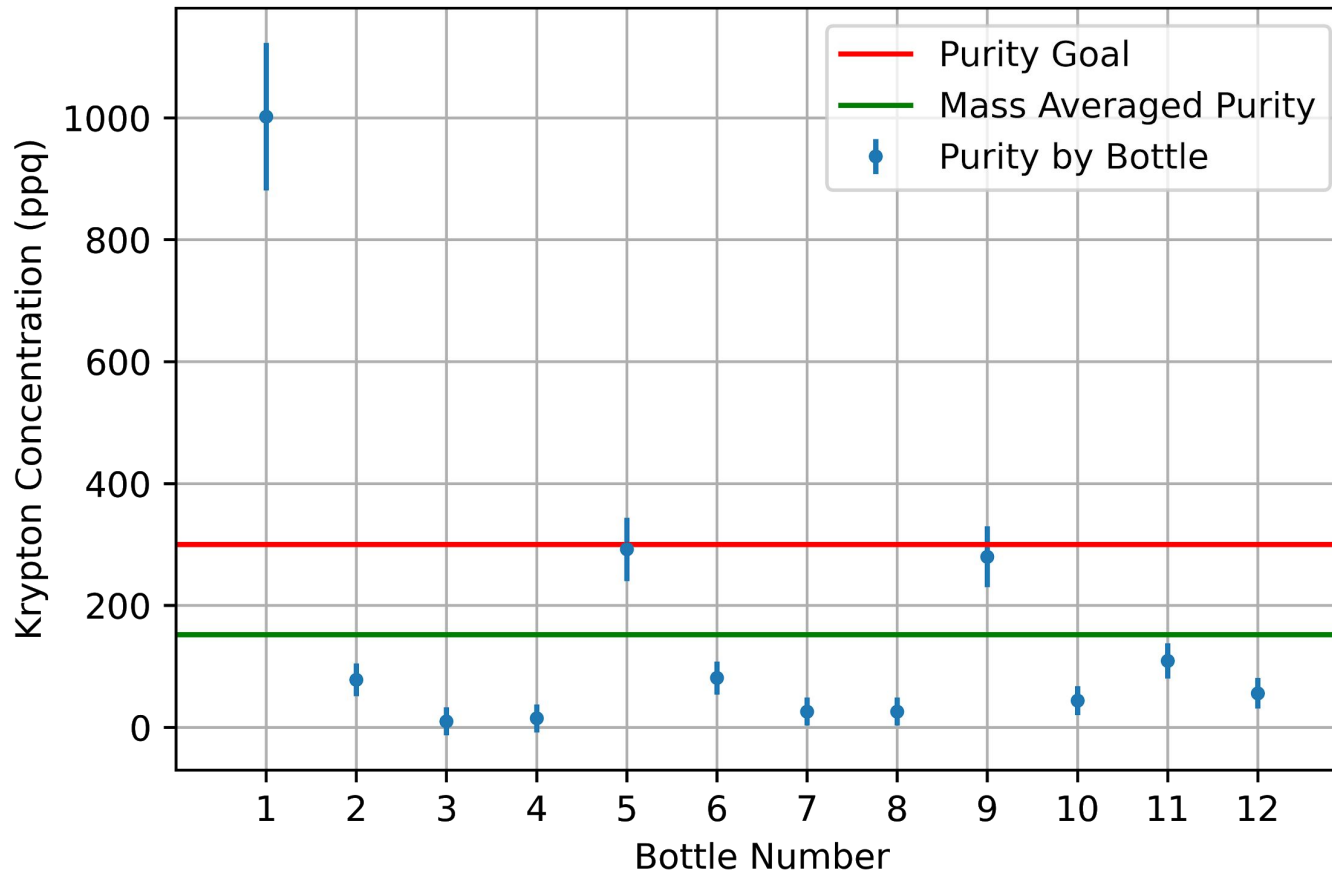
Krypton isotopes cross check

Baseline channel for pressure response



De-Kryptonated Xenon

Krypton Concentration Post Chromatography



Cleaned xenon is put into storage pack of 12 bottles

Result above is ~970 kg, with a total mass averaged purity of 152 ppq ^{nat}Kr g/g, satisfying the 300 ppq purity goal





Thanks

Thank you to all my collaborators

Carter Hall - Advisor

John Armstrong

Jon Balajthy

Dan Akerib

Christina Ignarra

Eric Miller

Drew Ames

+ Many more



Science and
Technology
Facilities Council



Integration with krypton removal system and to end automation (right)

Run browser complete history of samples. Currently displaying a 210 ppq result from bottle 1012 (below)

Sampling
IR2 LZ System Test

Locked systems: 0 Disabled interlocks: 1 Hi jssik! You are a System Developer

Mixing

Queue Mixing Op

Remove Op

Error Reset

Start

Abort

Krypton Run

Mixing Queue

Production Sampler Abort Mixing Mixing Krypton Run

Start Time	TimeStamp	Event
Mar 7, 2021 8:42 PM	Mar 7, 2021 8:04 PM	Static Pumpout Mixing
Mar 7, 2021 8:42 PM	Mar 7, 2021 7:14 PM	Static Pumpout Mixing
Mar 7, 2021 8:42 PM	Mar 7, 2021 5:26 PM	ABORTED Transfer Mixing
Mar 6, 2021 6:45 PM	Mar 6, 2021 6:52 PM	Clean Run Mixing
Mar 6, 2021 6:18 PM	Mar 6, 2021 6:23 PM	Clean Run Mixing

Sniffer

Queue Sniffer Op

Remove Op

Error Reset

Start

Abort

Pumpout

Sniffer Queue

Production Sampler Abort Sniffer Sniffer Krypton Run

Start Time	TimeStamp	Event
Mar 7, 2021 7:40 PM		Pumpout Sniffer
Mar 7, 2021 7:09 PM		Cryodump Sniffer
Mar 7, 2021 5:26 PM		Transfer Sniffer
Mar 7, 2021 5:01 PM		Vialmap Sniffer
Mar 7, 2021 4:28 PM		Static Pumpout Sniffer
Mar 7, 2021 3:03 PM		ABORTED Static Pumpout Sniffer
Mar 7, 2021 2:56 PM		Freeze Sniffer

Storage

Queue Storage Op

Remove Op

Error Reset

Start

Abort

Cryodump

Storage Queue

Production Sampler Abort Storage Storage Cryodump

Start Time	TimeStamp	Event
Mar 5, 2021 4:48 PM	Mar 5, 2021 5:09 PM	ABORTED Cryodump Storage
Mar 4, 2021 7:08	Mar 4, 2021 7:19	Cryodump Storage
Mar 4, 2021 6:57	Mar 4, 2021 6:59	ABORTED Cryodump Storage
Mar 3, 2021 7:26 PM	Mar 3, 2021 7:32 PM	Cryodump Storage
Mar 3, 2021 5:58 PM	Mar 3, 2021 6:05 PM	Cryodump Storage
Mar 3, 2021 4:46 PM	Mar 3, 2021 4:54 PM	Cryodump Storage

Trap LN

Autofill Start: -194 Postfill Time (s): 15

Autofill Stop: 0

Sniffer LN

Autofill Start: -194 Postfill Time (s): 80

Autofill Stop: 0

Cryodump LN

Autofill Start: -194 Postfill Time (s): 75

Autofill Stop: 0

System Queue

Queue Op

Sniff, Transfer, Measure, Empty

Device Queue

Calibration Line

Request From

Cryodump

Request From

ROA

Request From

Transfer Line

Request From

Utility Pump

Request From

SNIFER

Sniff Not Requested

Not Ready to Sniff

CRB Not Ready

Sniffer Not Sniffing

CHRAORTED

No Sniffer Script Name...

Manual Sniff

Request Sniff

Number of Sniffs: 7

Trigger Sniffing

Currently in Mixing
Krypton Run

Currently in Sniffer
Pumpout Sniffer

REQUEST DENIED FEATURES BELOW
Let me know how to make this page better - john
I've a button to quickly go between mixing/sniffing pages?
Video feed if it doesn't slow stuff down too much?
Small script monitor would be helpful
Let you can change how the graphs are displayed if you're using power tables - would make it easier to read if most of the script name was removed
Larger power tables
Avoid red about card!

Run Viewer
IR2 LZ System Test

Run Parameter History Table - select run here

runID	snfID	runType	transferTL	setHV	setNF	setMassL	calibration	calPhi	calParam	saturation
20210306_1	col2_run063	Krypton Run	Dec 31, 19...	1,426	0	62,84,83,4...		0.0000	2.0799999...	
20210306_1	col2_run063	Krypton Run	Dec 31, 19...	1,426	0	62,84,83,4...		0.0000	2.0799999...	
20210304_1	run062_stor	Krypton Run	Dec 31, 19...	1,426	0	62,84,83,4...		0.0000	2.0799999...	
20210304_1	run062_stor	Krypton Run	Dec 31, 19...	1,416	0	62,84,83,4...		0.0000	2.0799999...	
20210304_0	run061_BTL	Krypton Run	Dec 31, 19...	0	0	62,84,83,4...		0.0000	0.0679640...	
20210304_0	run061_BTL	Krypton Run	Dec 31, 19...	1,416	0	62,84,83,4...		0.0000	2.0799999...	
20210303_2	run061_BTL	Krypton Run	Dec 31, 19...	0	0	62,84,83,4...		0.0000	0.0679640...	
20210303_2	run061_BTL	Krypton Run	Dec 31, 19...	1,416	0	62,84,83,4...		0.0000	2.0799999...	
20210303_1	run061_BTL	Krypton Run	Dec 31, 19...	0	0	62,84,83,4...		0.0000	0.0679640...	
20210303_1	run061_BTL	Krypton Run	Dec 31, 19...	1,426	0	62,84,83,4...		0.0000	2.0799999...	
20210303_1	run061_BTL	Krypton Run	Dec 31, 19...	0	0	62,84,83,4...		0.0000	0.0679640...	
20210303_1	run061_BTL	Krypton Run	Dec 31, 19...	1,436	0	62,84,83,4...		0.0000	2.0799999...	

Sampler Analysis

Name: Production Sampler yted Analysis_n

Params: run045_0608

State: Stop running

Message: ConResult: 31.299227514 Krypton Run Mixing RunID: 20210303

Run Viewer Instructions

1) Select run from "Run Parameter History Table" by clicking row of interest.
2) If the snfID selected is incorrect, it can be updated using the text area above the "Update: snfID" button, clicking the button applies the update (this can also be used for quick notes of a run, DO NOT USE SPACES, USE _ INSTEAD.
3) With the proper run selected, and the proper snfID in place, click "Select Run" button to populate the tables and plots to the right of the page. This may take up to 10s, be patient.
4) The table at the top right reports results, the second table is a detailed copy of the run parameters from the selected row, the plot is the ROA traces, and the table at the bottom is the raw data.
5) Export the data using the button. Three files will be made available to save in a path of your choosing, and named automatically.
6) Update the "Pisac-sampler-nodes" channel in slack chat as necessary.

ts log

Mar 7, 2021 8:40 PM Step running

Mar 7, 2021 8:40 PM Run OK

Mar 7, 2021 8:40 PM ConResult: 31.299227514 Krypton Run Mixing RunID: 20210304_1621 SnfID: run062_storageStop

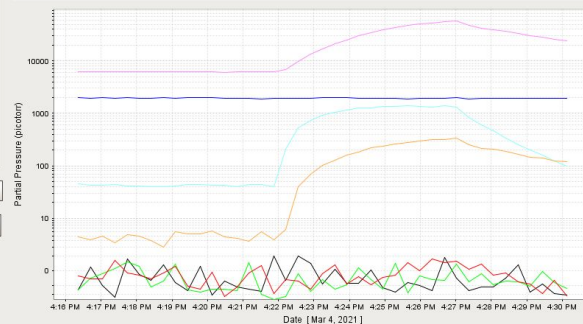
Mar 7, 2021 8:40 PM get here

Mar 7, 2021 8:40 PM readTag BR2X9/Sampling SystemRun ControlSample TrackingRun ViewedPost Delay Hz >>> 50

Mar 7, 2021 8:40 PM readTag BR2X9/Sampling SystemRun ControlSample TrackingRun ViewedPre Delay Hz >>> 20

description	62	84	83	40	28	4	87
Results in PPO	-807.22	31.3	1.59	4,994.47	493,240.18	2,336.18	5.26
Error in PPO	-90.72	3.13	0.16	499.45	49,324.02	233.62	0.53
Signal Size	-8,652.35	125.37	6.44	66,817.33	9,645,450.61	345,348.57	35.73
Average Backgr...	-27.92	0.4	0.02	215.84	31,128.42	1,114.57	0.12
Average Backgr...	1,664.75	-0.53	-0.68	3.6	6,149.1	42.11	-0.78
Std of Backgr...	24.98	0.76	0.83	0.93	43.37	1.72	0.98

runID	snfID	runType	transferTL	setHV	setNF	calibration	calPhi	calParam	saturation
20210304_1	run062_stor	Krypton Run	Dec 31, 19...	1,426	0		0.0000	2.07999992...	



timeStamp	62	84	83	40	28	4	87
16:16:21	1,993.22	-0.28	-1.45	3.71	6,168.43	44.76	-1.5
16:16:42	1,964.53	-0.5	-0.46	3.19	6,159.78	43.05	0.17
16:17:02	1,969.5	-0.46	-0.15	3.93	6,141.97	42.3	-1.05
16:17:23	1,926.25	0.63	0.19	2.68	6,106.69	43.62	-2.45
16:17:44	2,001.68	-0.1	0.5	4.35	6,147.97	40.74	0.77
16:18:05	1,959	-0.26	0.22	3.94	6,254.68	41.19	-0.21
16:18:25	1,941.27	-0.5	-1.17	3.06	6,126.03	39.78	-0.59