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

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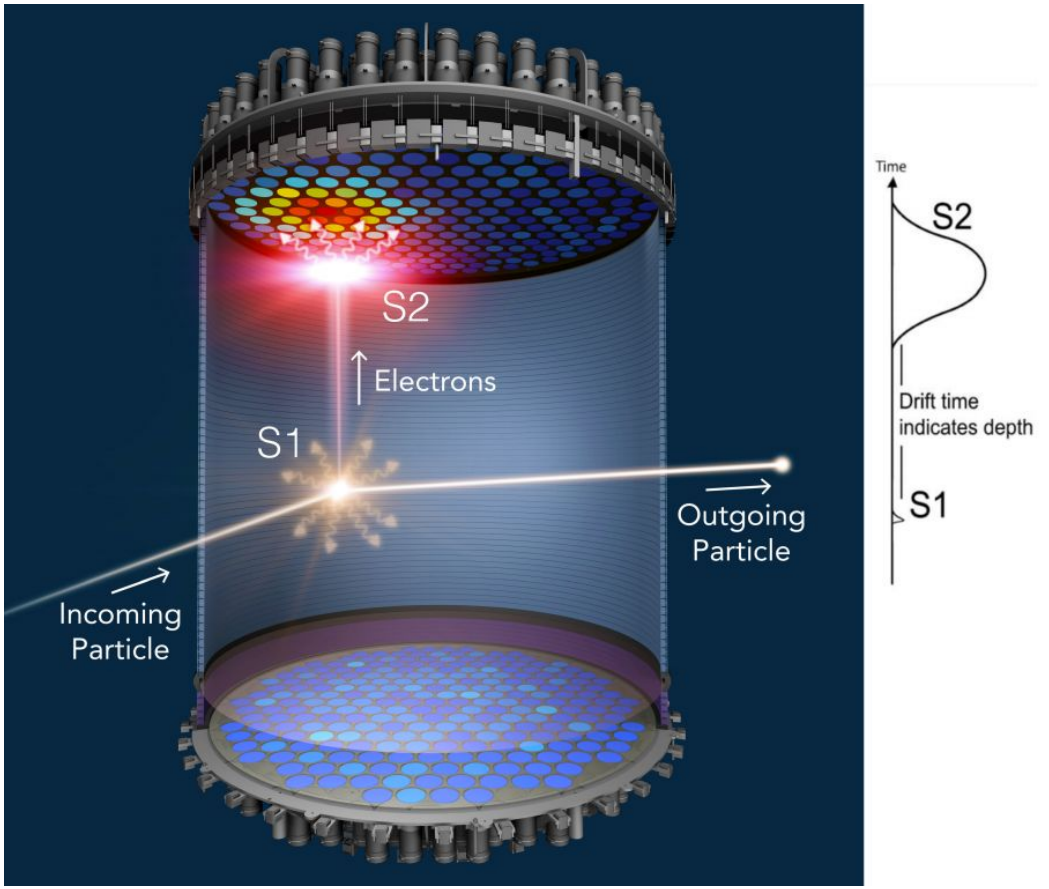
LUX-ZEPLIN Overview

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

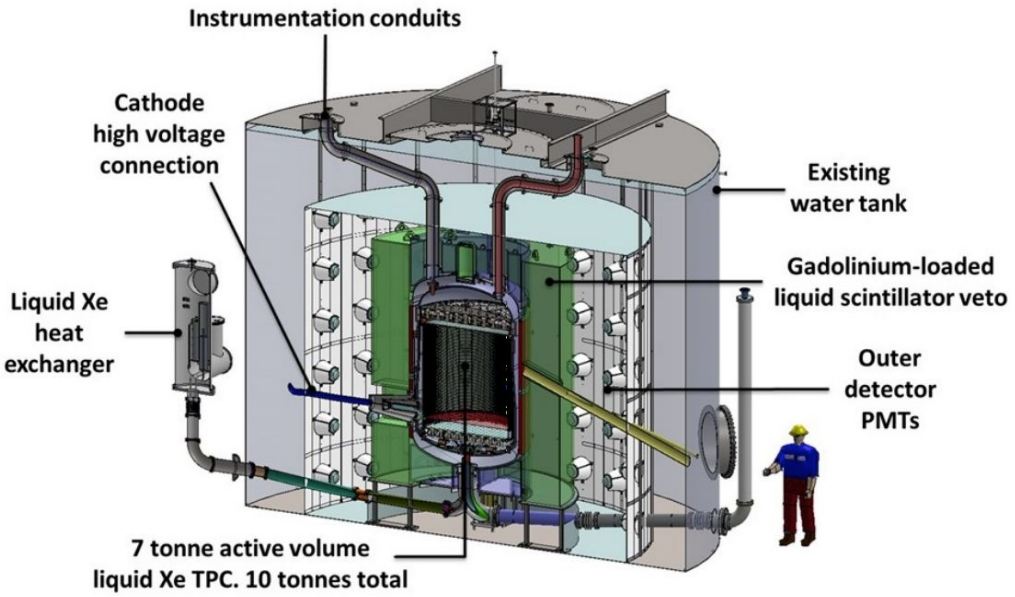


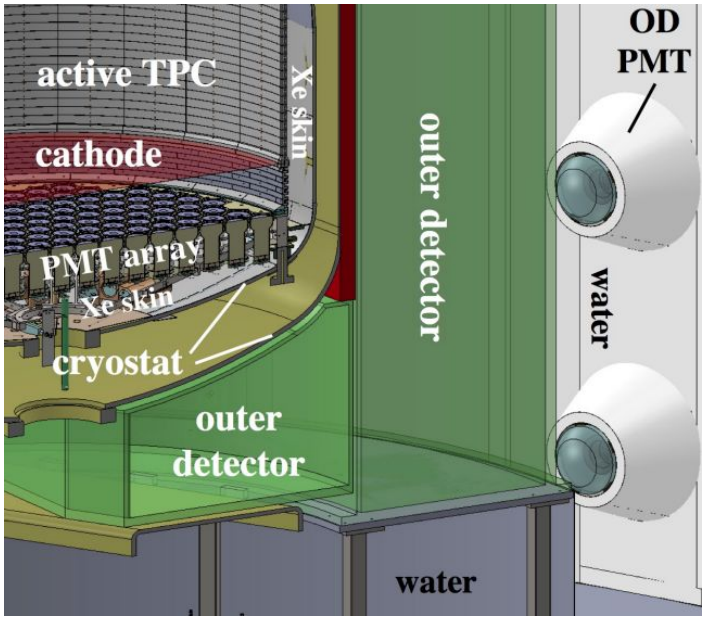
LUX-ZEPLIN

- 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/c^2 WIMP-nucleon SI cross-section sensitivity: 1.4x10^{-48} cm^2, 1000 days live time

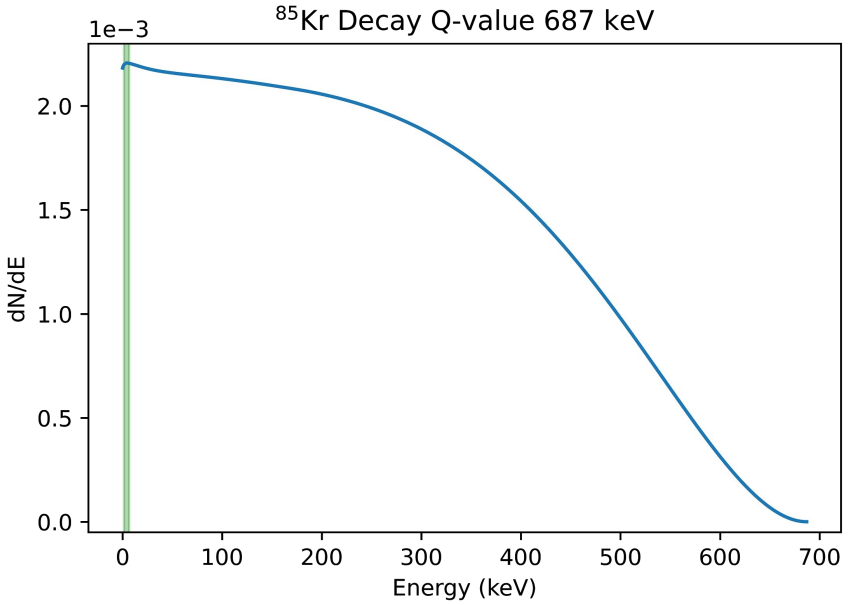


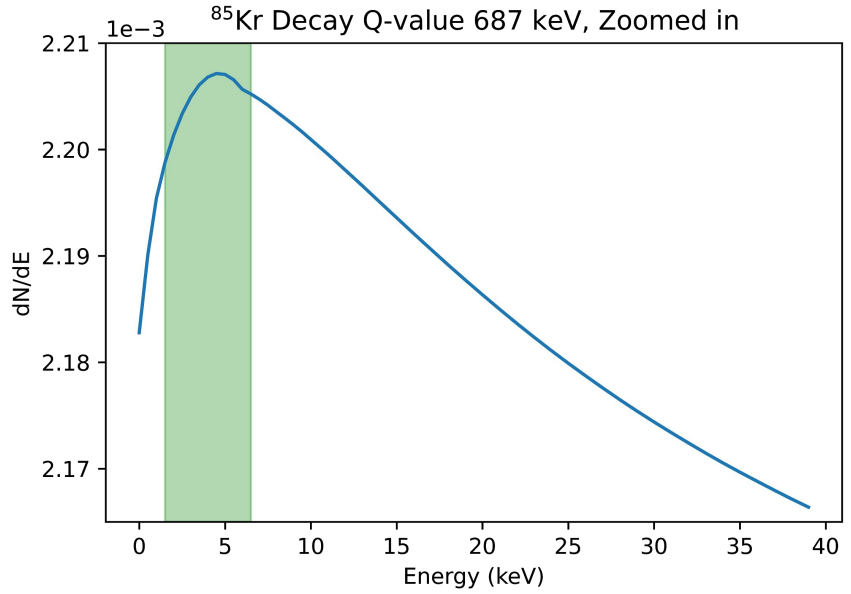


LZ Technical Design Report - https://arxiv.org/abs/1703.09144

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 ^{Nat}Kr/Xe (g/g)
    - In situ, real time measurement



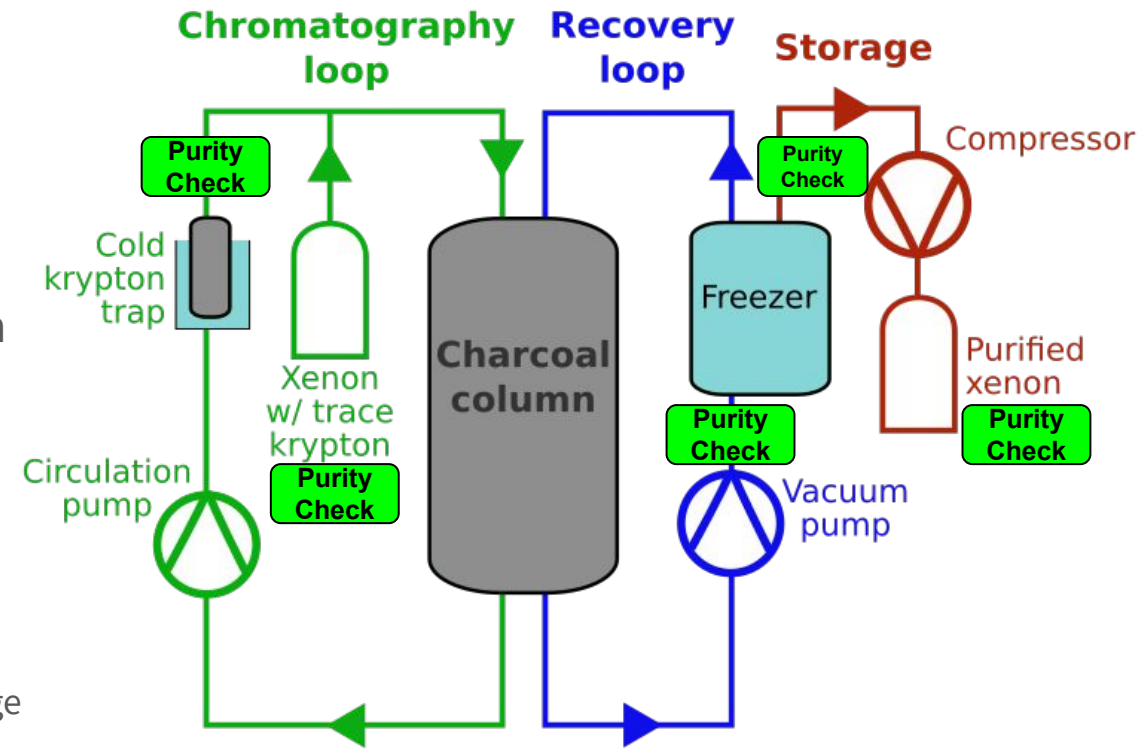


Krypton Removal

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

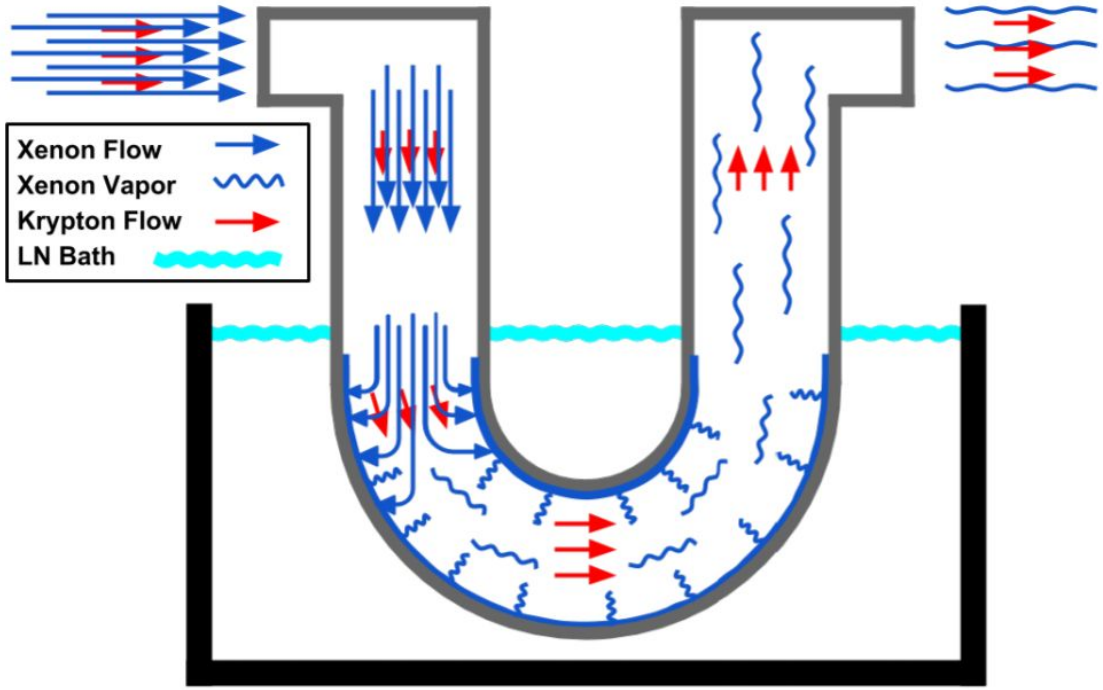


Each check is unique to that component.

Krypton Removal: SLAC

Measuring Xenon Purity Theory

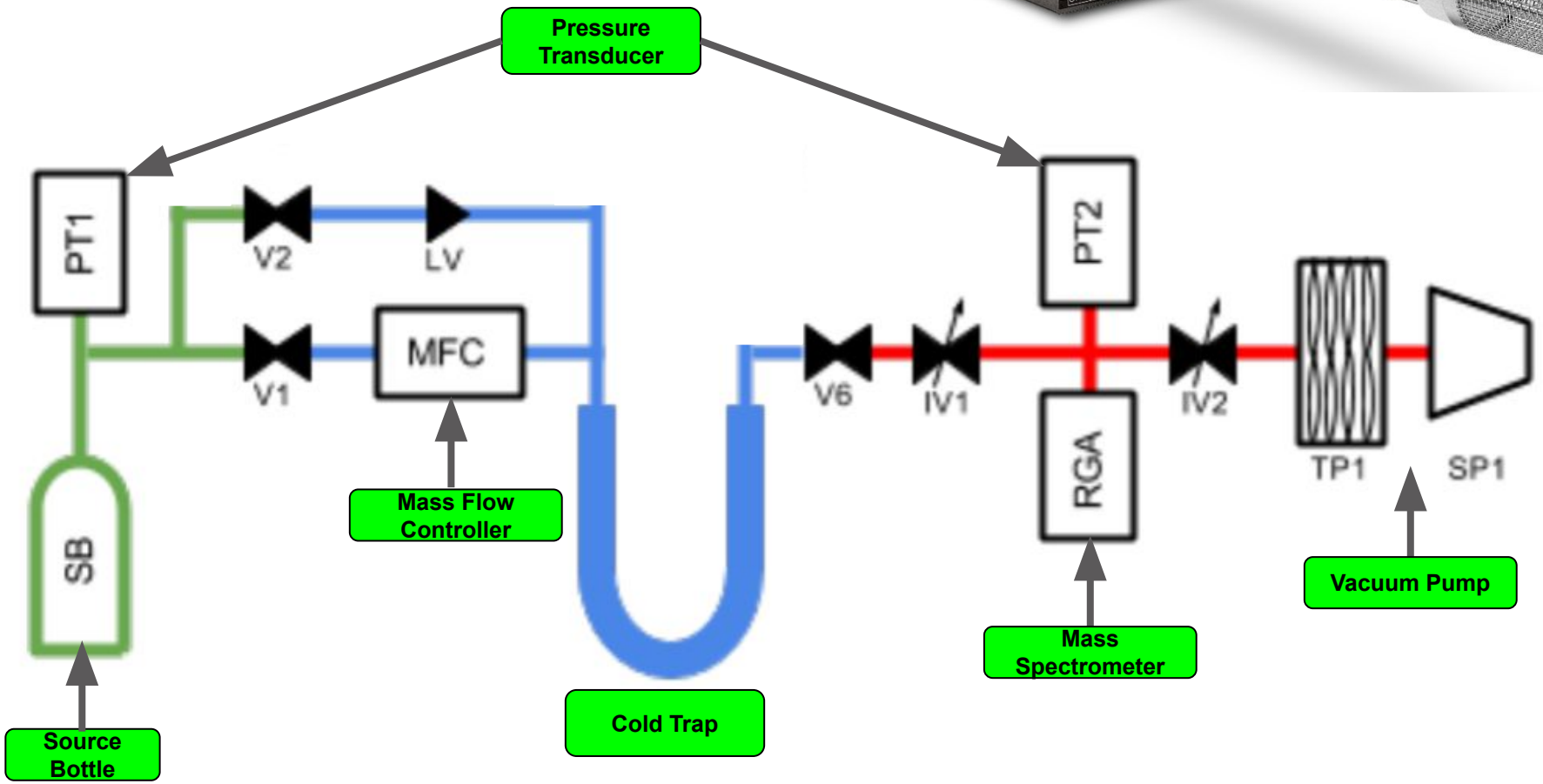
- Overcoming Mass Spec limitations
  - Residual Gas Analyzer (RGA)
  - Sensitive to PPM scale
  - Max operating pressure 10^{-5} torr
  - Environmental dependence
  - Cold Trap
  - Impedance tuning
- Signal proportional to
  - Impedance parameters
  - Flow Rate
  - Efficiency parameter
  - Sample concentration



Hardware

Mass Spectrometer (SRS RGA 200)

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

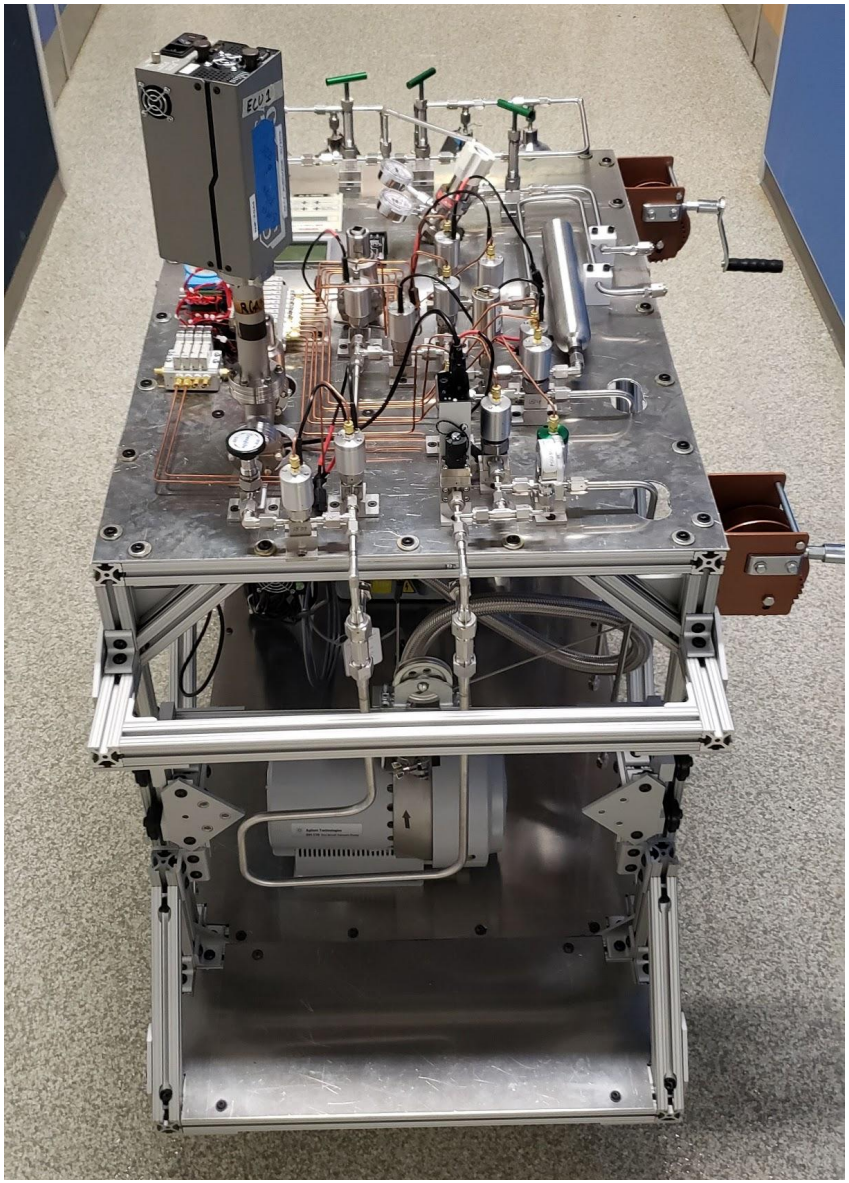


Uses

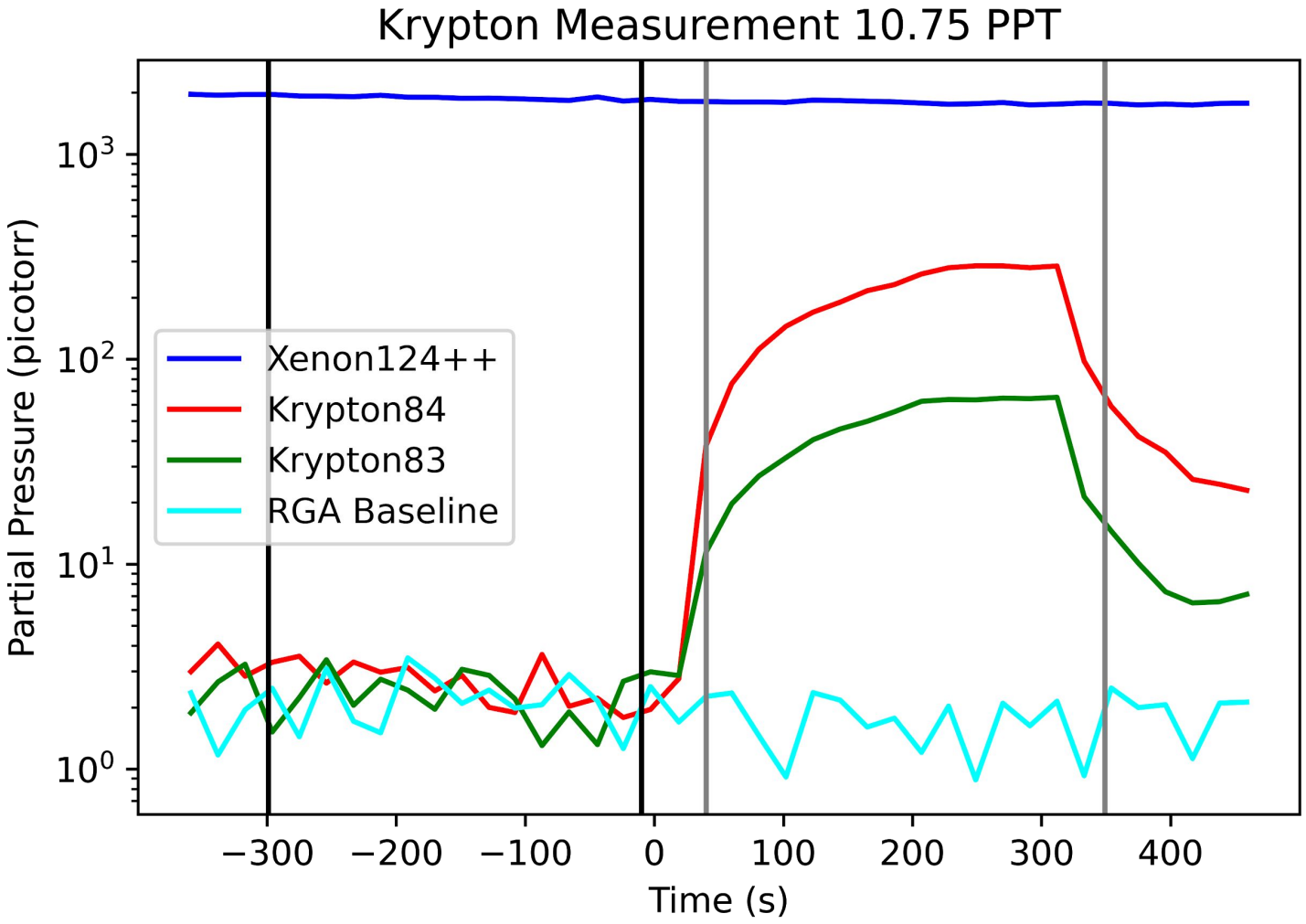
- Purity spot check
- Clean small batch xenon
- Integrated leak check
- Custom gas mixtures
- Different cooling methods
  - Liquid nitrogen
  - Pulse tube refrigerator
- Systems at
  - SLAC
  - SURF
  - UMD

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



Black lines: Background Interval

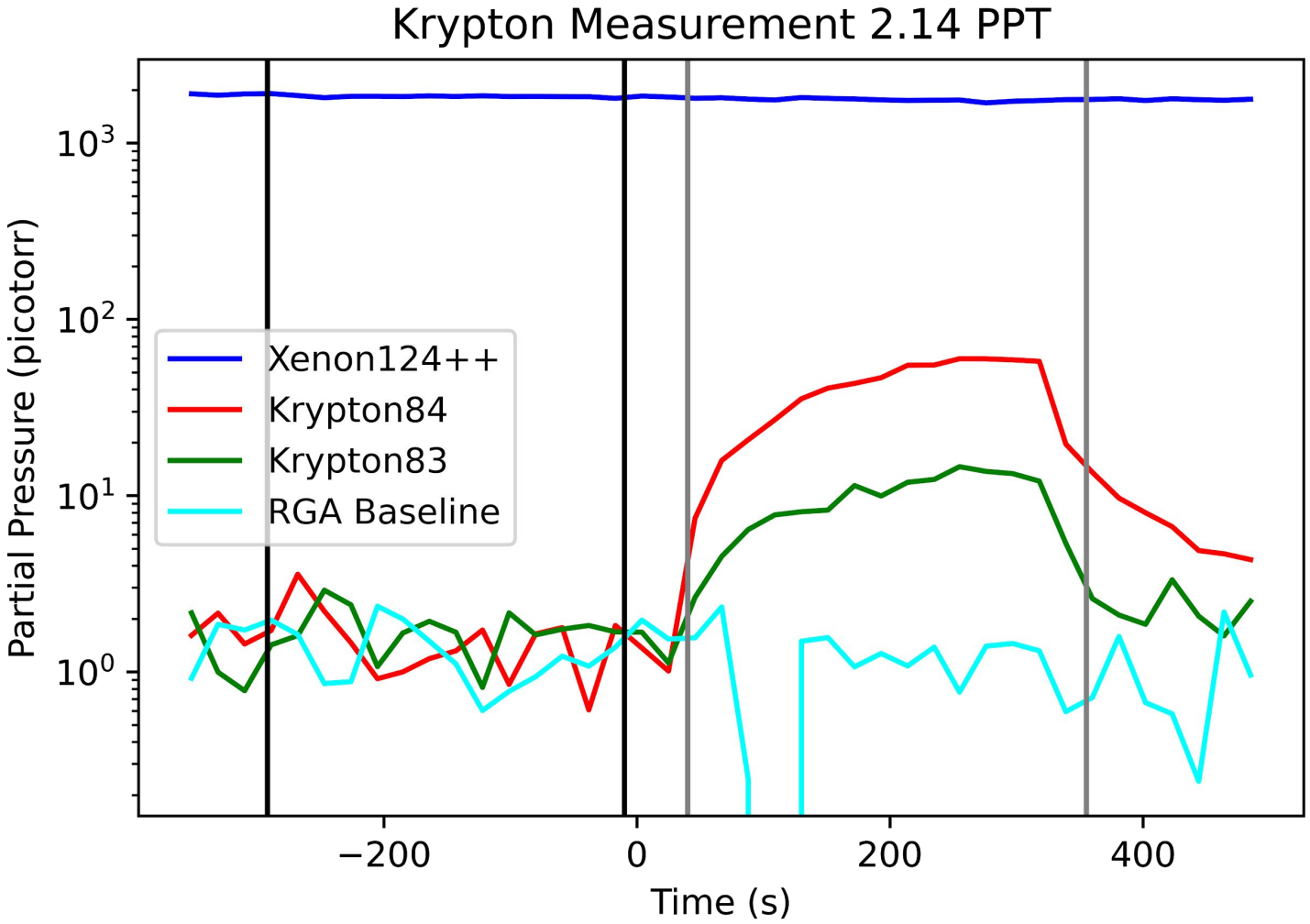
Grey lines: Signal Interval

Limit of detection 7.5 ppq

Krypton isotopes cross check

Baseline channel for pressure response

Smaller Signal



Same xenon as previous slide

Measurement cycle reduces Kr by ~1.3x

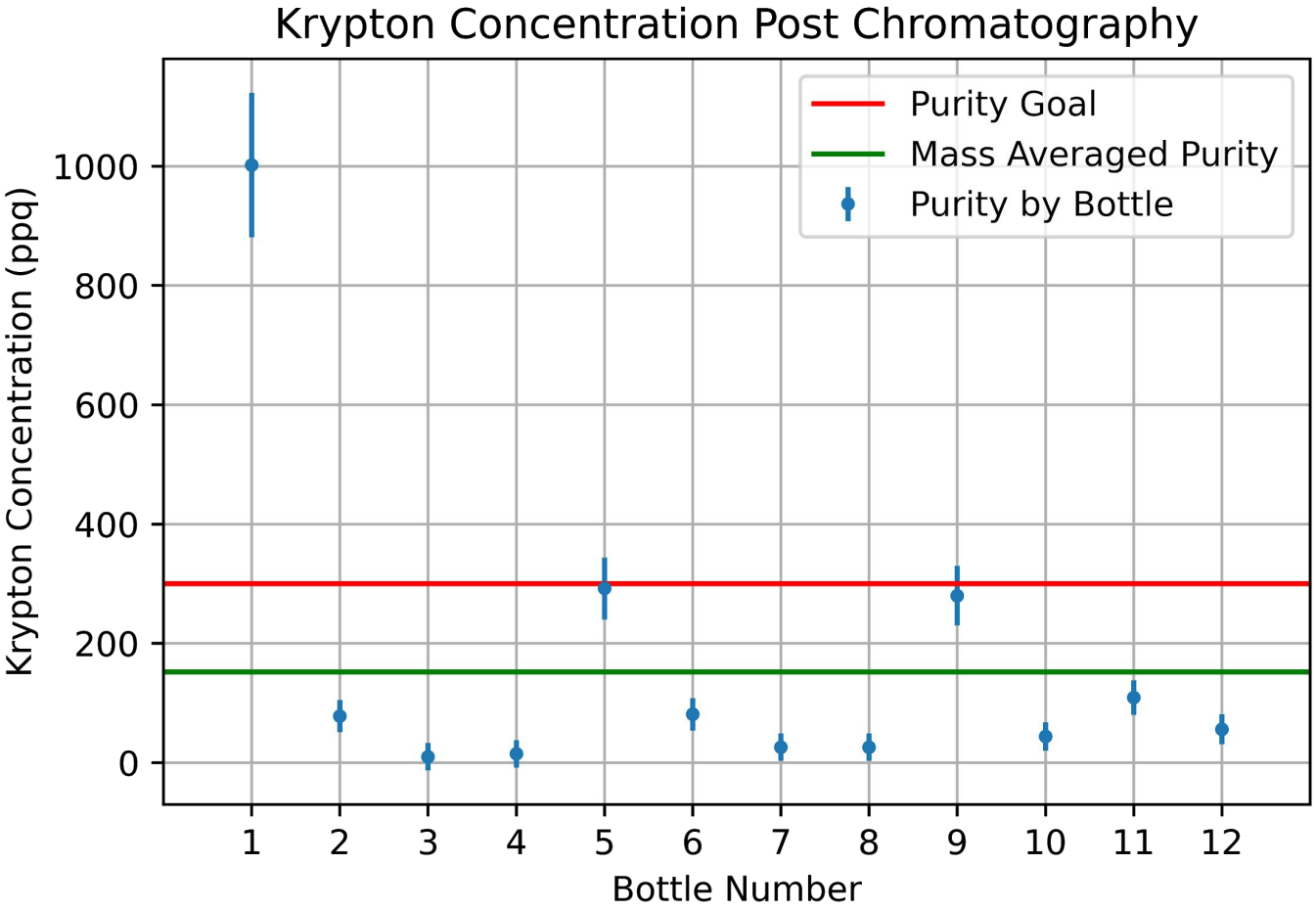
Devoted cold trap cleaning cycle reduces Kr by ~4x

Limit of detection 7.5 ppq

Krypton isotopes cross check

Baseline channel for pressure response

De-Kryptonated Xenon



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

Control

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)