LZ Backgrounds and Mitigation

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July 25, 2017

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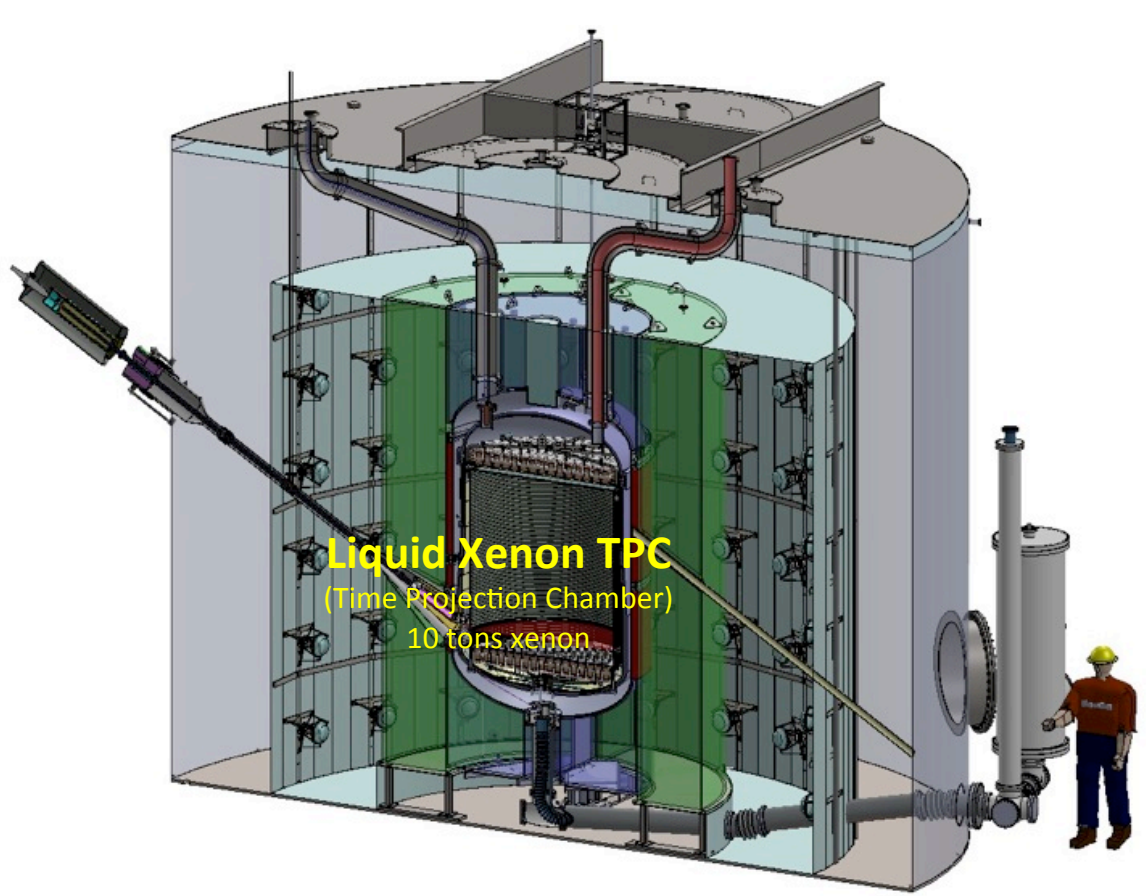
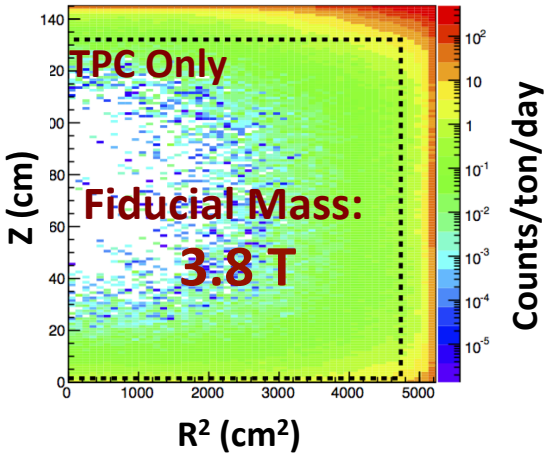
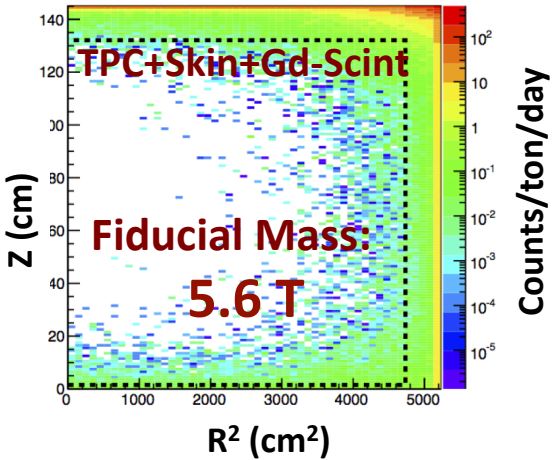
LZ Shielding

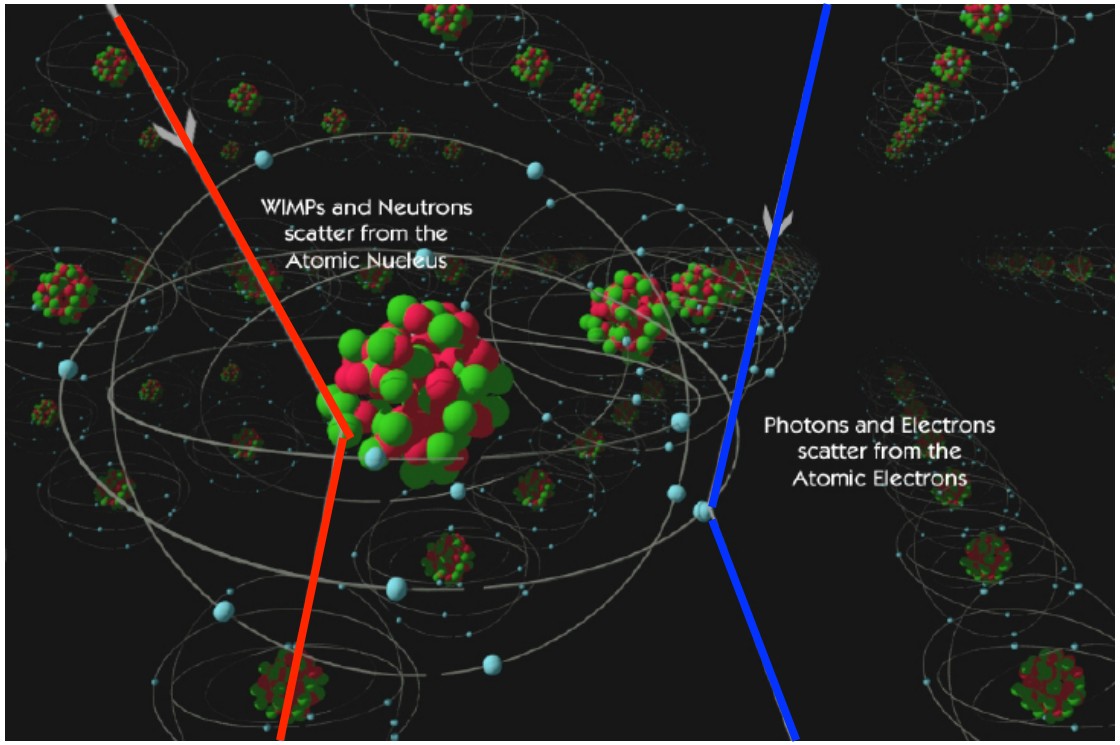






Event Discrimination

- Detect WIMPs via Nuclear Recoils (NR)
- Most of our background events are Electron Recoils (ER)
- These two types of events produce different amounts of light and charge in the detector
  - Characterize charge-to-light ratios (S2 vs S1) and amounts as a function of energy



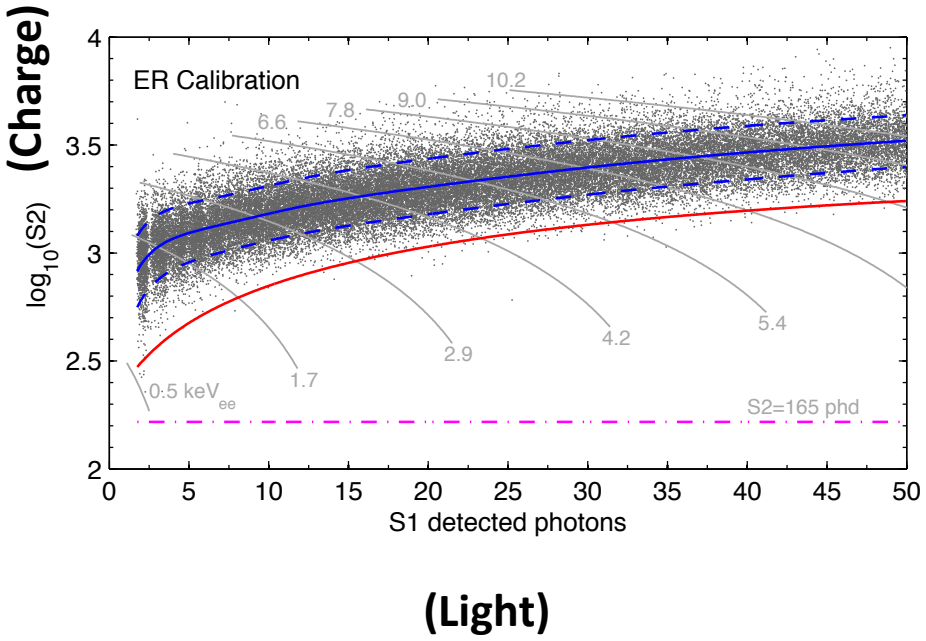
Background and Signal Calibrations

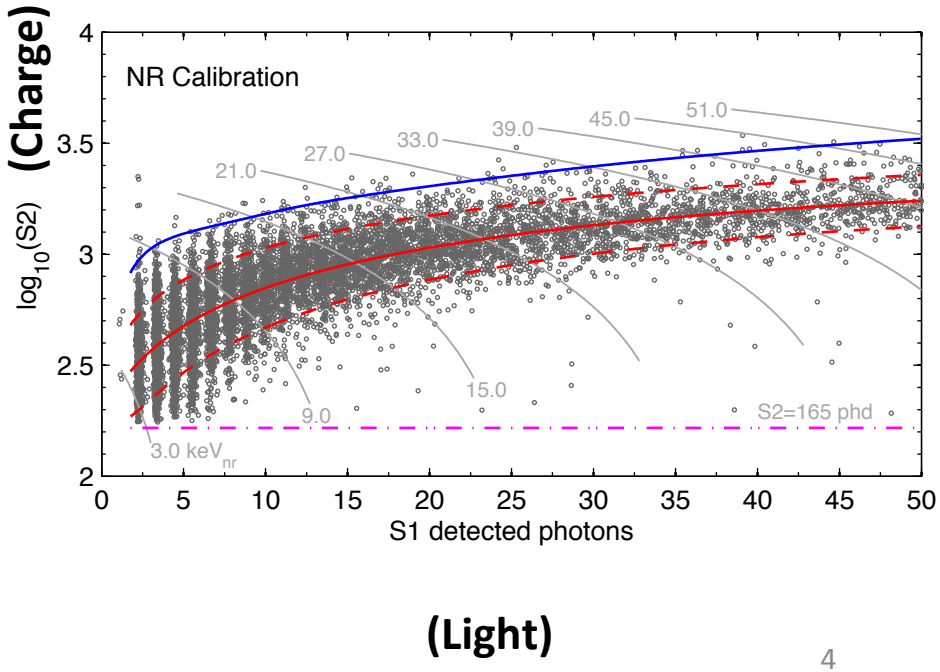
Background Events

- Electron Recoil (ER)
- Higher charge-to-light ratio
- Calibrate using high-statistics tritium dataset (LUX)

Signal Events (WIMP-like)

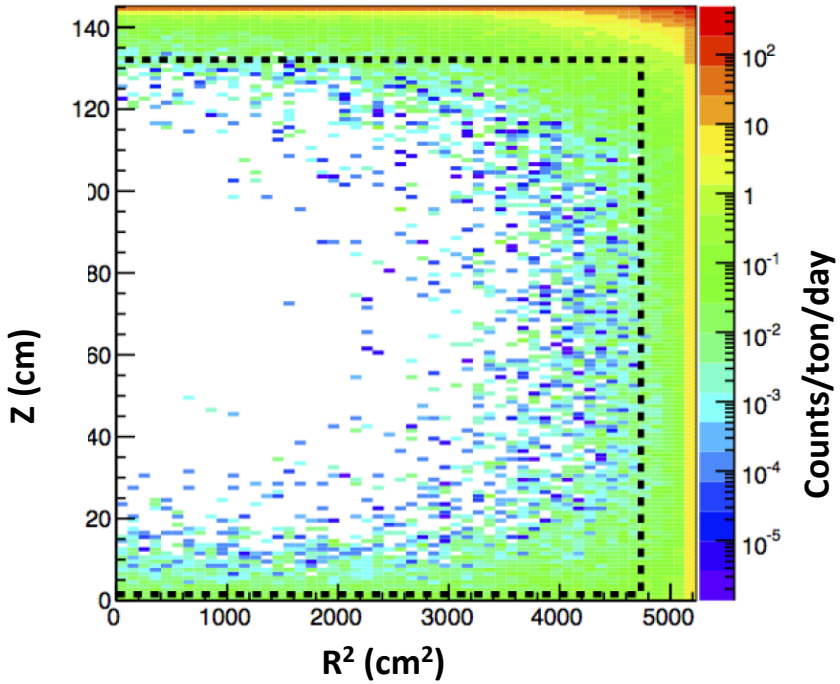
- Nuclear Recoils (NR)
- Lower charge-to-light ratio
- Calibrate using D-D neutrons (LUX)
  - *In-situ* nuclear recoil (NR) calibration





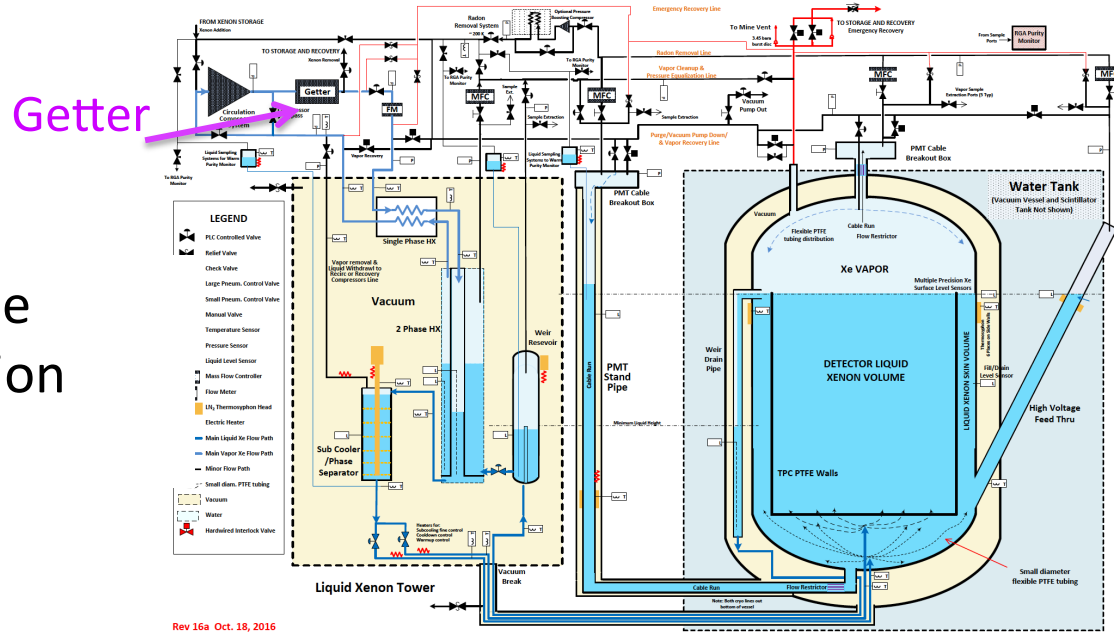
External Backgrounds

- Mitigated by xenon's self shielding properties
- Quantified by position reconstruction



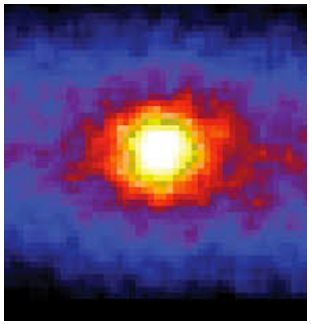
Reactive Backgrounds

- Mostly outgassing from detector materials
- Constant gas phase circulation/purification to maintain free electron lifetime
  - Requirement: 670 µs, already achieved with LUX
- Heated zirconium getter (commercial) removes non-noble impurities

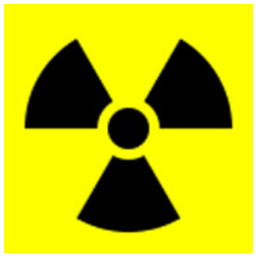


Remaining Backgrounds in The Bulk Xenon
(Luckily these are ER backgrounds…)

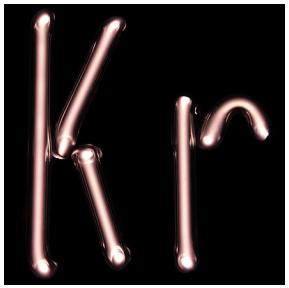
- Solar neutrinos
  - Irreducible
  - ~1 event per day in LZ



- Radon
  - Prevent during construction
  - Internal mitigation
  - Goal: 0.67 mBq



- Krypton
  - Present in the air and therefore commercial Xenon
  - Removed in advance
  - Goal: 0.0015 ppt (1/10 of solar neutrino background)



Rn-222

- Radon emanation material screening program underway
- Two components to mitigation: Cold LXe volume vs. warm gas system:
  - LXe volume: 150 μm FEP cable cladding reduces dust and other contamination from steel braiding of the cables
  - Gas system: 8.6 kg charcoal filter added to online gas system, held at 186 K, traps 90% of radon from warm cables & PMT feedthroughs

		Radon Emanation (mBq)			
Item	**Component**	**estimated**	**w/ cladding only**	**w/ trap only**	**w/ cladding & trap combined**
PMT HV Cables	warm insulation	0.27	0.41	0.027	0.04
	warm braiding	1.88	0.47	0.19	0.05
	warm dust	13	0	1.30	0
	cold insulation	2.7×10^{-4}	4.1×10^{-4}	2.7×10^{-4}	4.1×10^{-4}
	cold braiding	1.88	0	1.88	0
	cold dust	13	0	13	0
PMT HV Cables	Subtotal	30.0	0.88	16.4	0.09
Cabling Conduits	warm & cold	0.1	0.1	0.055	0.055
PMT Feedthroughs	warm	7.3	7.3	0.73	0.73
	Total	**37.4**	**8.3**	**17.2**	**0.87**

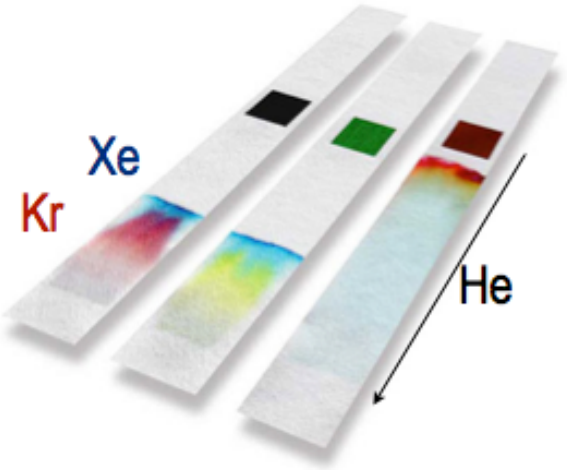
Kr-85

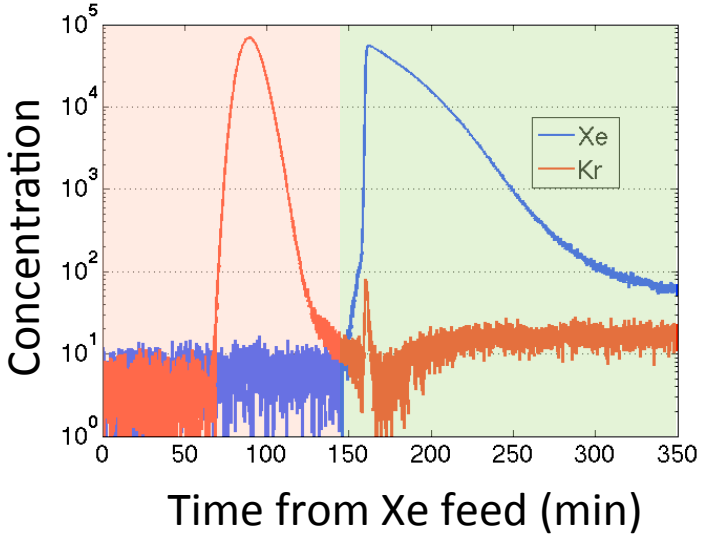
- Kr-85 is an ER-like background (beta emitter)
  - Present in the atmosphere, half life of 10 years

~10,000 ppt → 3 ppt → 0.015 ppt (0.300 ppt)

Commercial Xe LUX LZ Goal (LZ requirement)

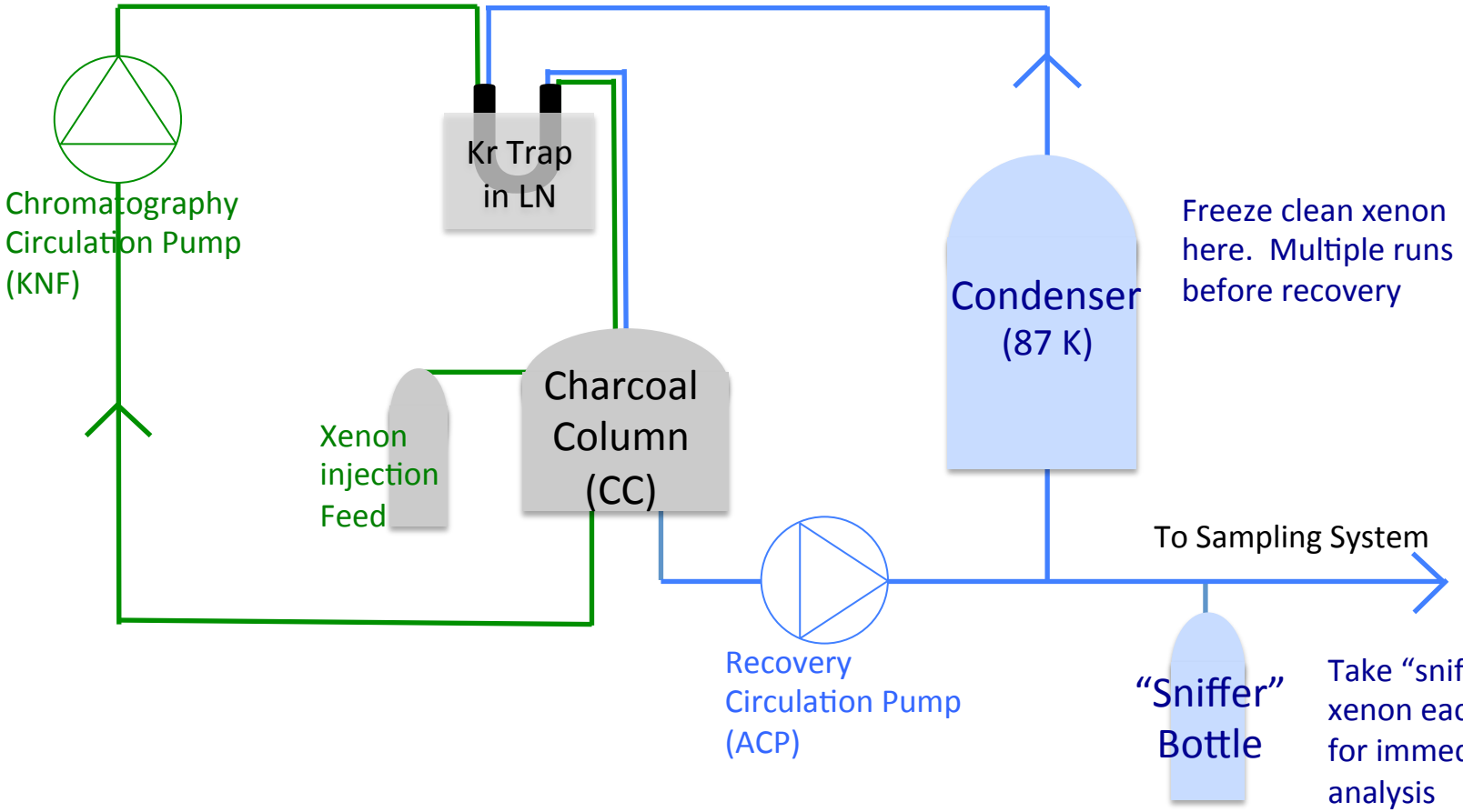
- 0.015 ppt corresponds to only a shotglass of air in 10 tons of xenon
- Remove via gas charcoal chromatography (with helium carrier gas)
  - Kr has a faster flow rate through activated charcoal than Xe





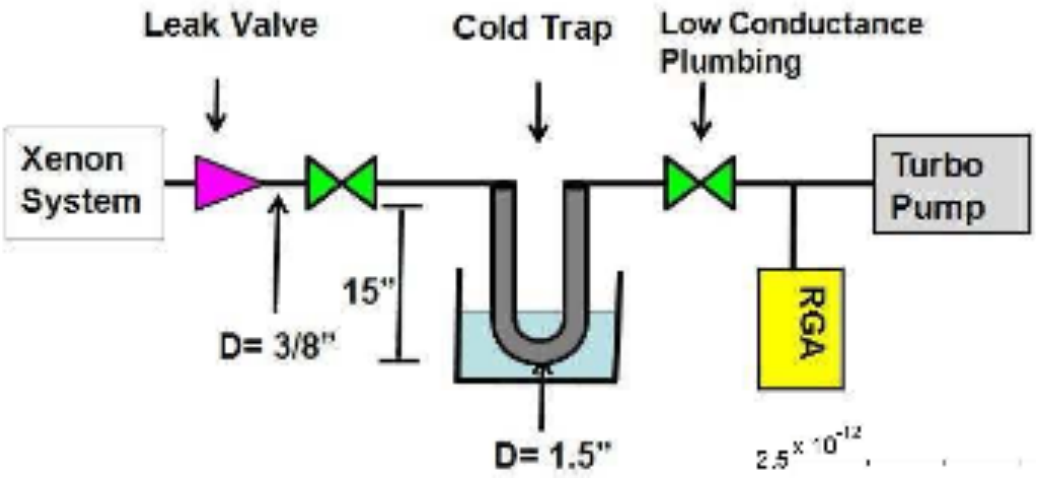
Kr Removal R&D System at SLAC

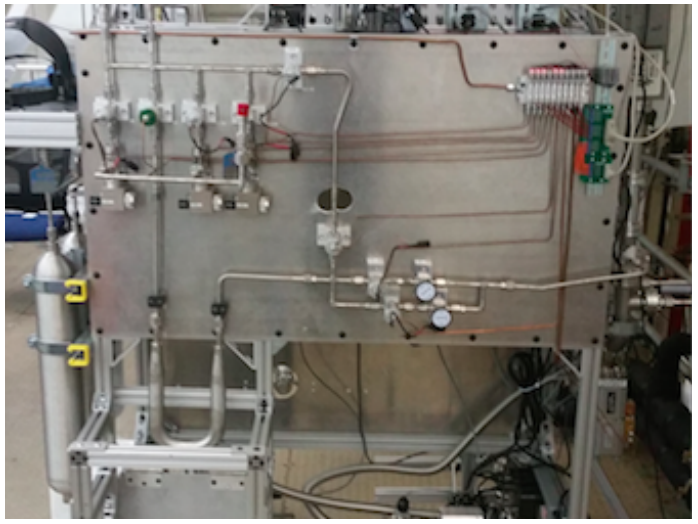
- Upgraded version of LUX Kr removal system (arxiv:1605.03844)
- Run through **Chromatography Loop** to trap Kr
- Then switch to **Recovery Loop** to recover purified xenon into condenser



Distillation Assay System

- Cold-trap assisted RGA (arXiv:1103.2714)
- Sensitivity at the 0.005 parts per trillion level
- Will be moved to LZ for online purity monitoring





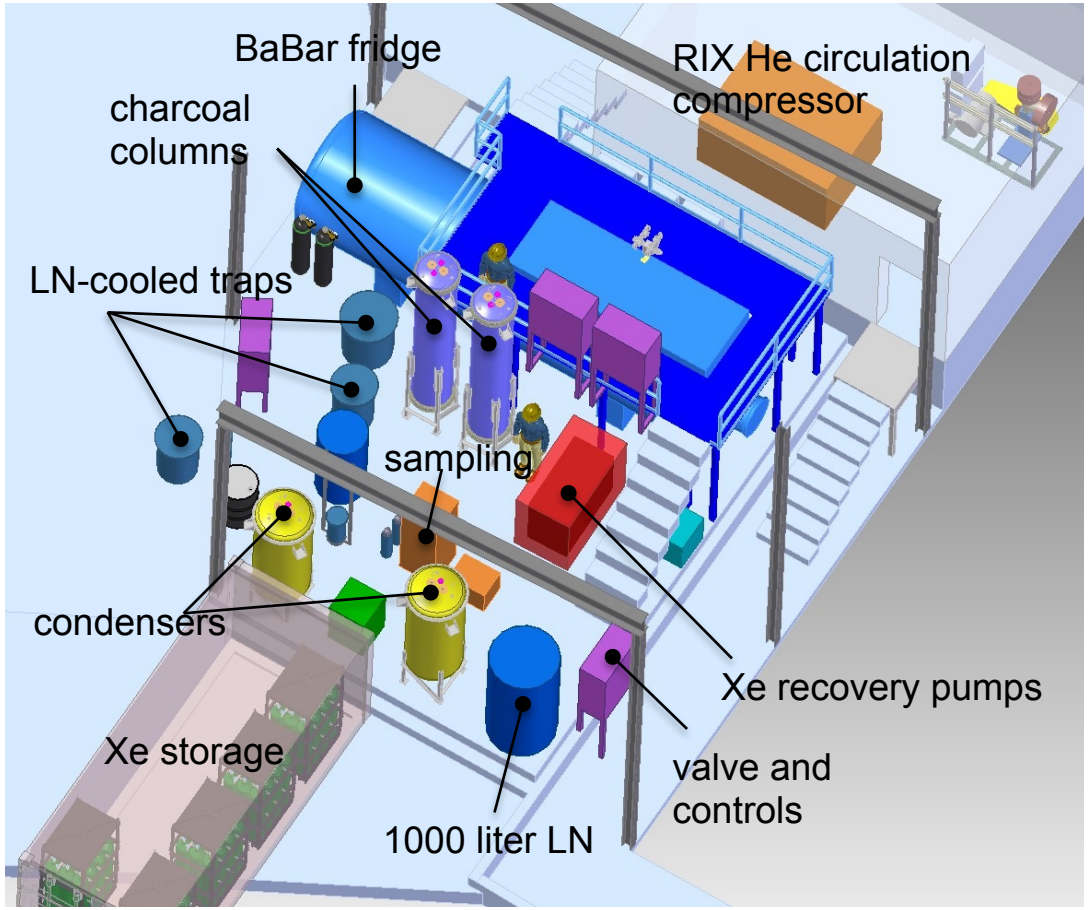
Results of Kr R&D

Commercial Xe:	1,000-100,000 ppt
LUX:	3 ppt
LZ Requirement:	0.3 ppt
LZ Goal:	0.015 ppt
R&D result	0.060 ppt

- Main challenges were cross-contamination and trace impurities in our UHP Helium
- Developed diagnostic tools such as a clean-xenon-backflow to systematically check isolated regions and components of the system
- Left with one more kr source in system which we could not fix
  - 'Virtual leak' from the gearbox of our recovery pump into the process space
  - Production system will use a different pump design without this failure mode

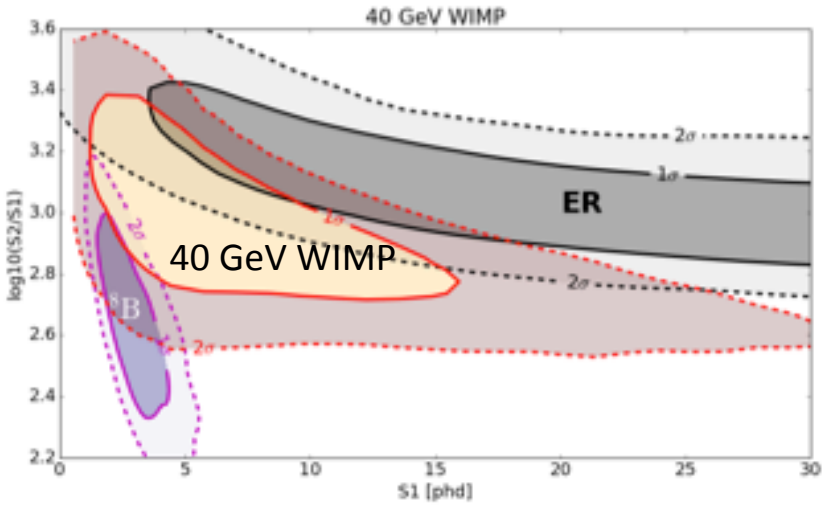
Kr Removal Production System

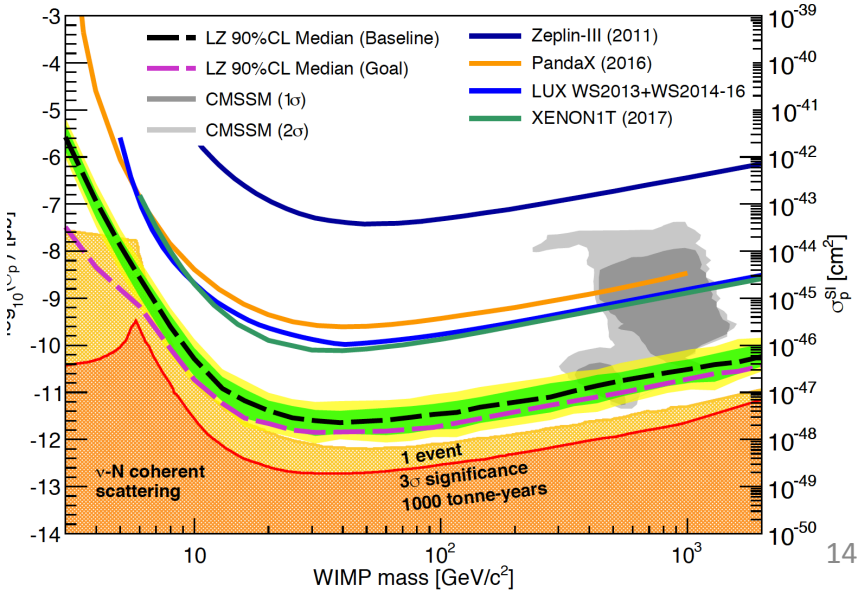
- Process all xenon at SLAC then ship to SURF
- About 1/2 of the LZ Xenon has already arrived and been assayed
- Scale up batch size by factor of 8 and overall processing rate by a factor of 20
  - 2 charcoal columns for continuous running



Conclusion

- Surpassed our Kr-85 requirement of 0.3 ppt by a factor of 5 and expect to reach our 0.015 ppt goal with production system
- Radon emanation screening program underway
- PLR-based analysis allows us to fully exploit ER & NR calibrations and profiling of backgrounds
- LZ is fully funded and construction has begun! Turns on in early 2020

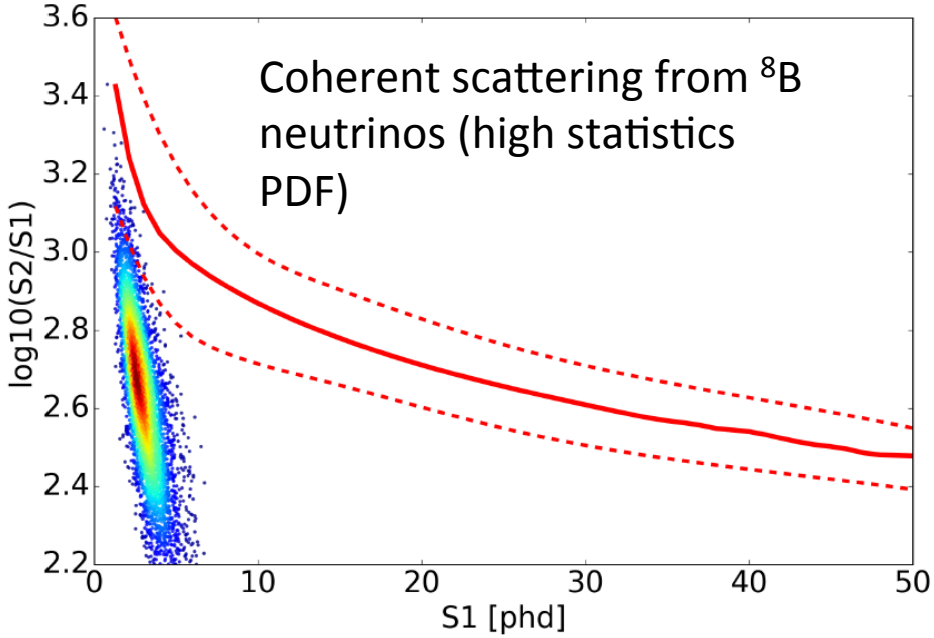


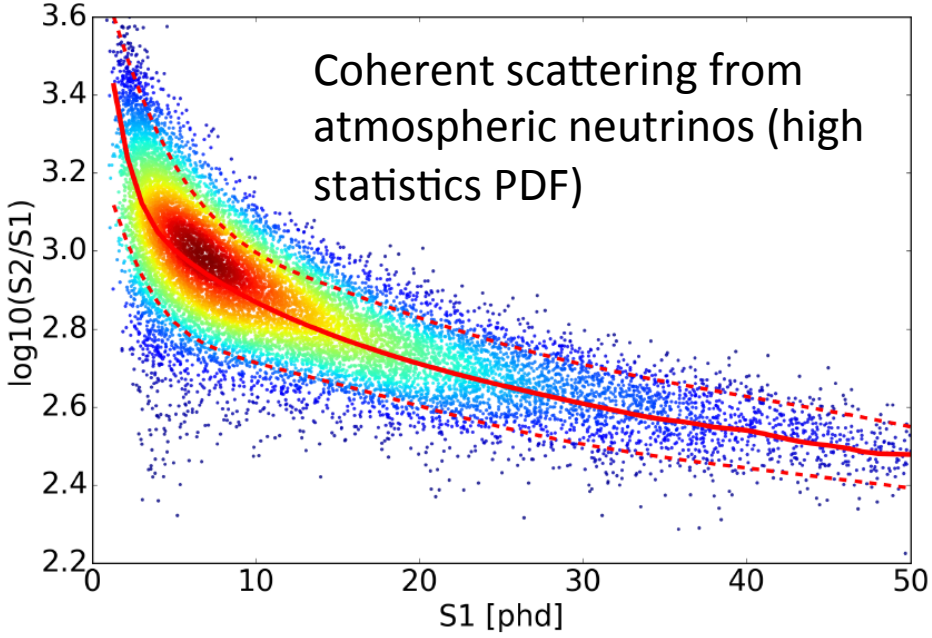


Backup

Neutrino background

- Expect ~900 ER events, mostly from pp fusion chain
- Expect 7 coherent neutrino scattering (NR) events from ^{8}B, plan to fit and subtract
- Expect 0.5 coherent scattering events from atmospheric neutrinos, irreducible, looks like high-mass WIMP

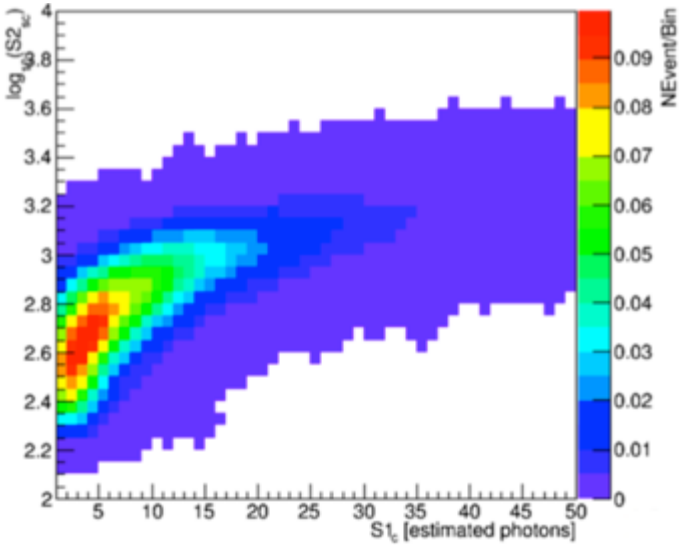


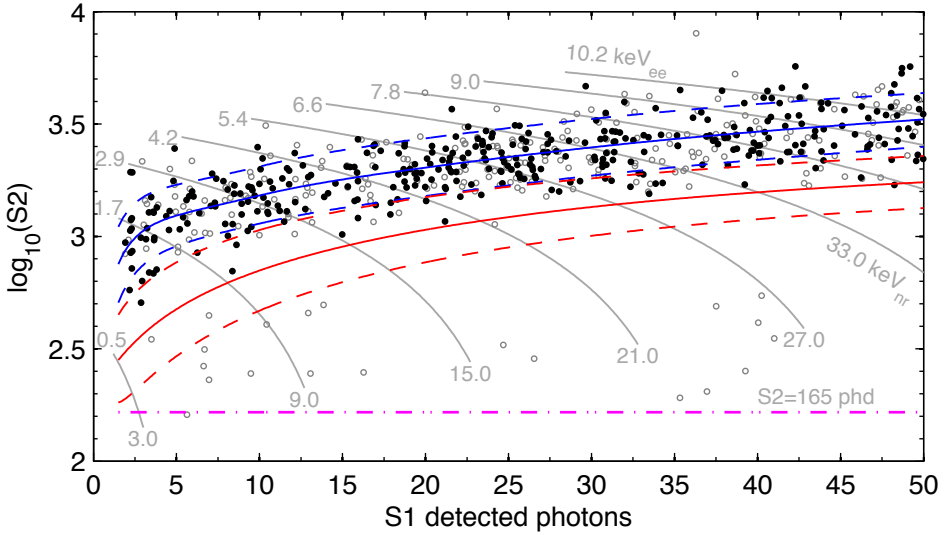


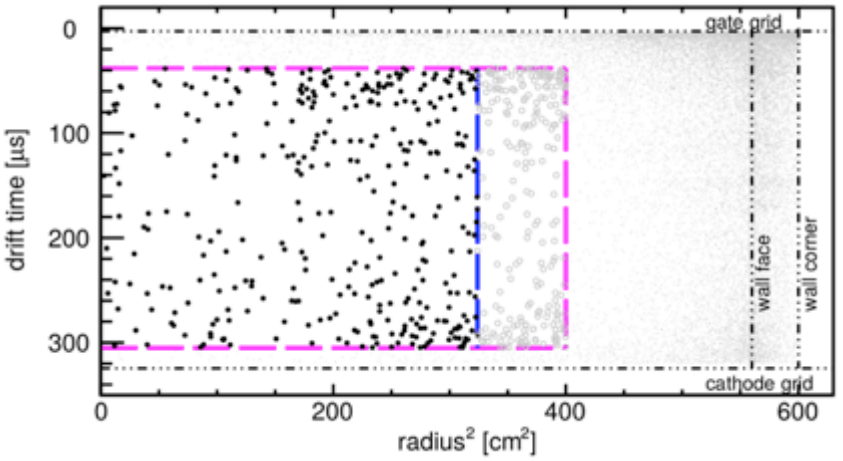
Profile Likelihood Ratio (PLR)

- Compares data to background distribution and signal distributions for different mass models
- Function of S1, S2, radius, and depth
- Fit for systematic parameters (derived from DD data)

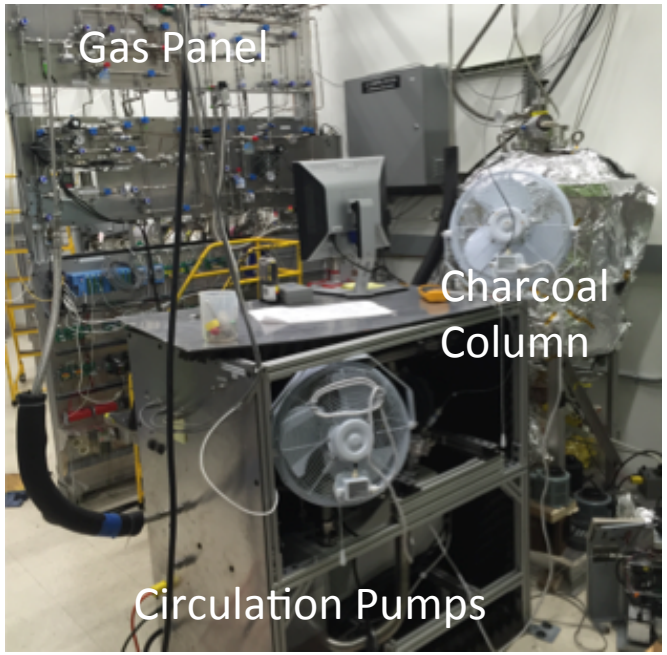
i.e. Expected signal distribution for a 33 GeV WIMP

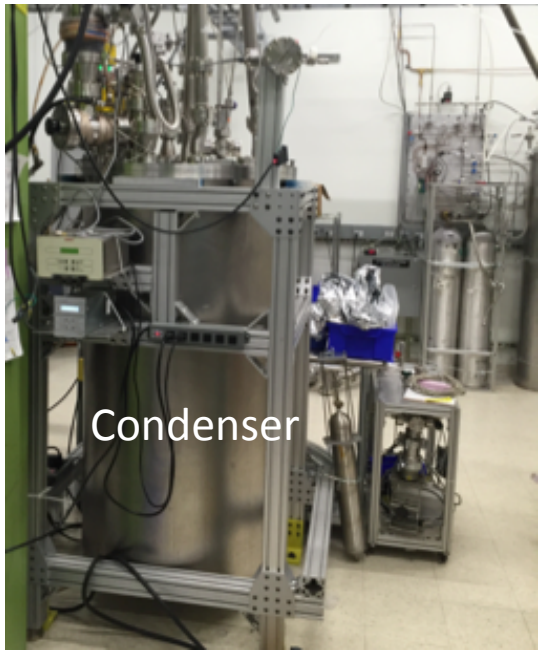


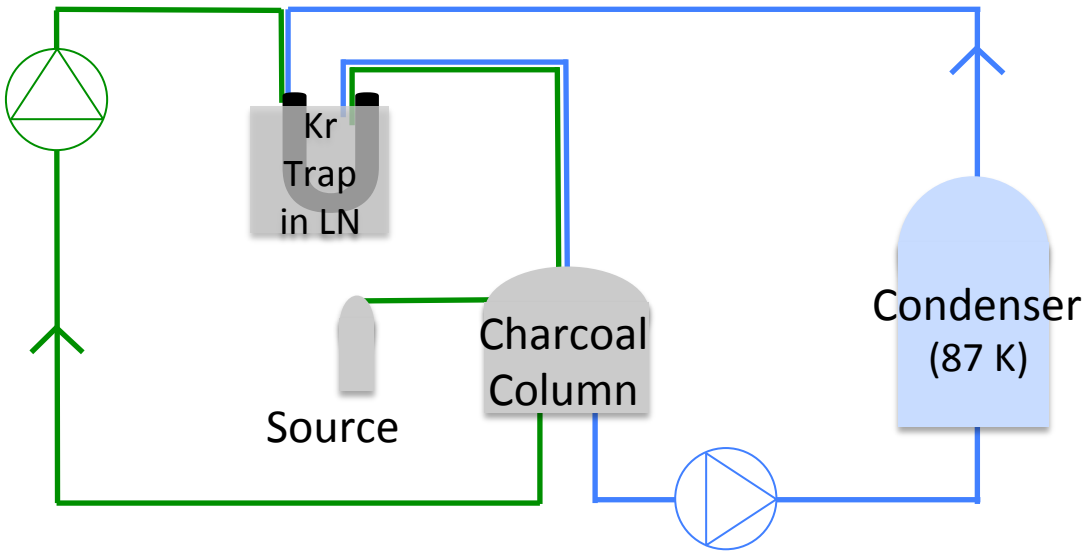




Photos of SLAC R&D System



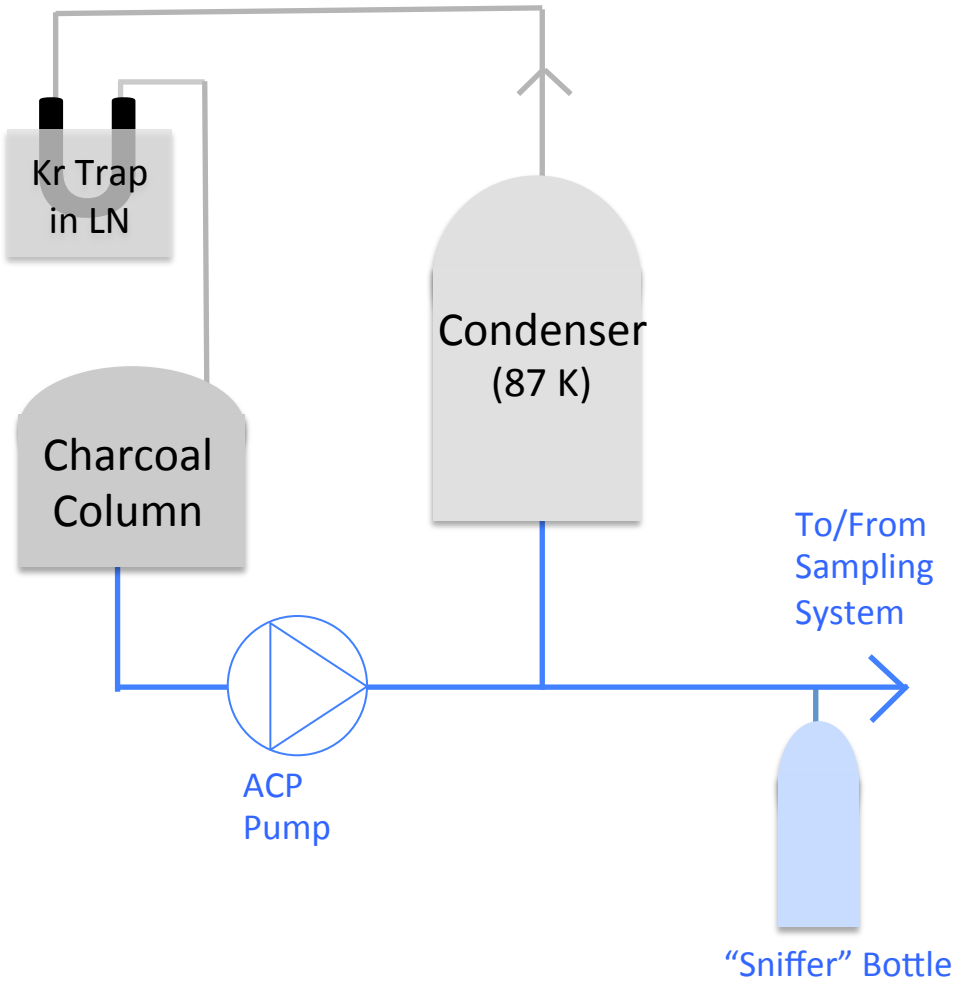




Diagnostics: Clean Xenon Backflow

Can make small amounts of <5 ppq Xenon with assay system

- Backflow small amount of xenon into test space
- Can diagnose contamination sources
  - led us to remove certain components from the recovery line and to discover the virtual leak in the recovery pump



LZ Kr Removal System Scale up From LUX

Scaling	LUX	LZ	
Column / slug size	2 kg Xe slug in 60 kg charcoal	16 kg Xe slug in 500 kg charcoal	Saturation: fix M
Chromatography	120 min: 100 LPM 50 SLPM @ 0.5 bar	120 min: 1000 LPM 500 SLPM @ 0.5 bar up to 2000 SLPM @ 2 bar	Transit time ~ M flow); higher pressure reduces diffusion
Recovery	180 min: 1500 LPM 15 SLPM He @ 10 mbar 120 SLPM Xe at peak	120 min: 25000 LPM 250 SLPM He @ 10 mbar	Match chromatography time; conservative scaling since 1.5 faster × 8 M volume flow, or 18000 LPM
Processing rate	2 kg / 5 hours 10 kg/day 50 kg/week, incl. storage	16 kg / 2 hrs 192 kg/day 20T / 120 days (85% uptime)	Continuous processing in LZ - no downtime for storage; 2 passes of 10 T

More info in arxiv:1703.09144

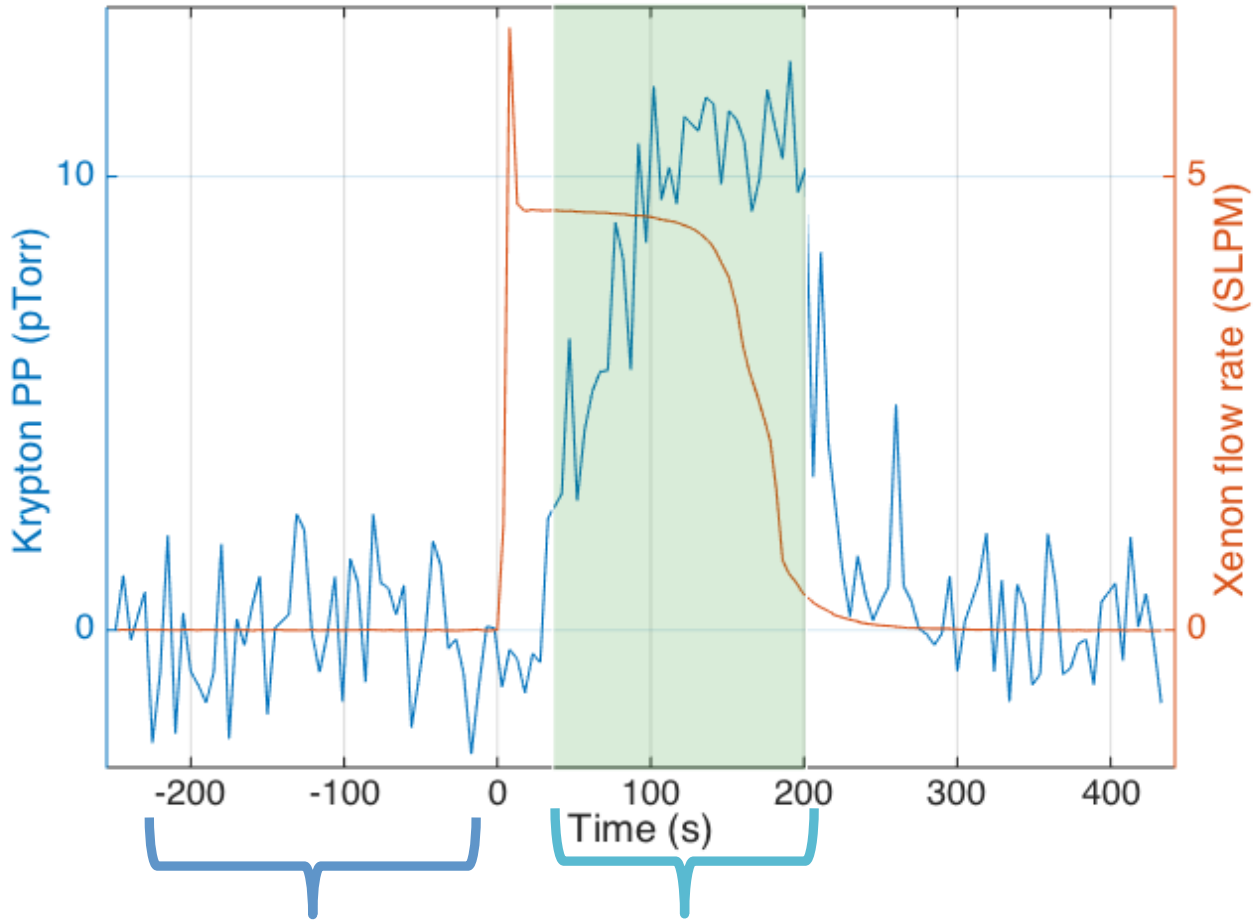
Materials Screening

- Dedicated gamma counting facilities
  - Primary gamma emitting isotopes: ^{40}K, ^{137}Cs, ^{60}Co, ^{238}U, ^{235}U, ^{232}Th, (U and Th chains also responsible for neutron production)
- Intrinsic radioactivity goals for fixed contamination in detector components: single scatter rate less than 0.4 NR counts and less than 37 x 10^{-6} events/keV/kg/d (37 μdru).
- Direct measurements of radon emanation from construction materials
  - Maximum tolerable activity is 10 mBq throughout LXe, 1 mBq goal for emanation
  - ^{210}Pb activity on surfaces < 10 mBq/m^2, 0.5 for inner TPC surfaces
- Screening programs for cryostat titanium, detector PTFE, PMT bases & components, etc
- Robust cleanliness protocols during assembly

Materials Screening Techniques

Technique	Isotopic Sensitivity	Typical Sensitivity Limits	Sample Mass	Sampling Duration	Destructive/Non-destructive and Notes
HPGe	^{238}U, ^{235}U, ^{232}Th chains, ^{40}K, ^{60}Co, ^{137}Cs any γ-ray emitter	50 ppt U, 100 ppt Th	kg	Up to 2 weeks	Non-destructive, very versatile, not as sensitive as other techniques, large samples
ICP-MS	^{238}U, ^{235}U, ^{232}Th (top of chain)	10^{-12} g/g	mg to g	Days	Destructive, requires sample digestion, preparation critical
NAA	^{238}U, ^{235}U, ^{232}Th (top of chain), K	10^{-12} g/g to 10^{-14} g/g	g	Days to weeks	Destructive, sensitive to some contaminants
GD-MS	^{238}U, ^{235}U, ^{232}Th (top of chain)	10^{-10} g/g	mg to g	Days	Destructive, minimal matrix effects, cannot analyze ceramics and other insulators
Radon Emanation	^{222}Rn, ^{220}Rn	0.1 mBq	kg	1 to 3 weeks	Non-destructive, large samples, limited by size of emanation chamber

Distillation Assay System Signal



Average here to get pressure baseline

Signal integration window

Distillation Assay System Linearity

- Create stock calibration xenon with known Kr content
- Dilute with clean Xenon to map linearity
- Tune impedances of system and cold trap parameters to optimize signal and linearity