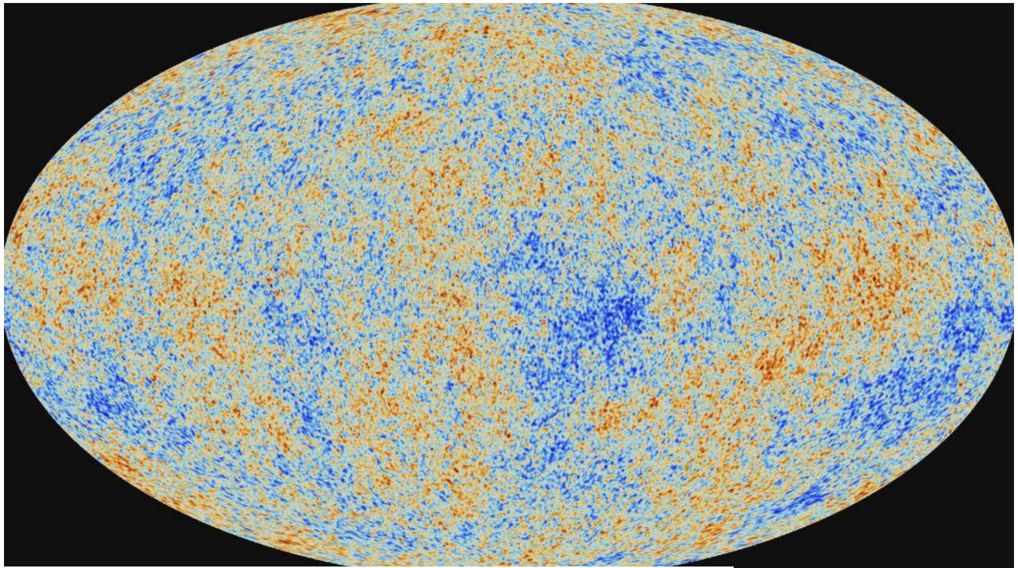
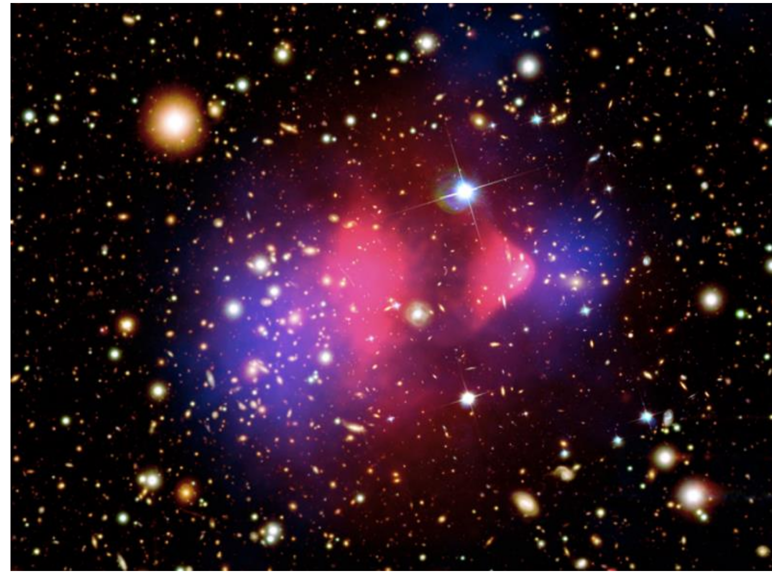
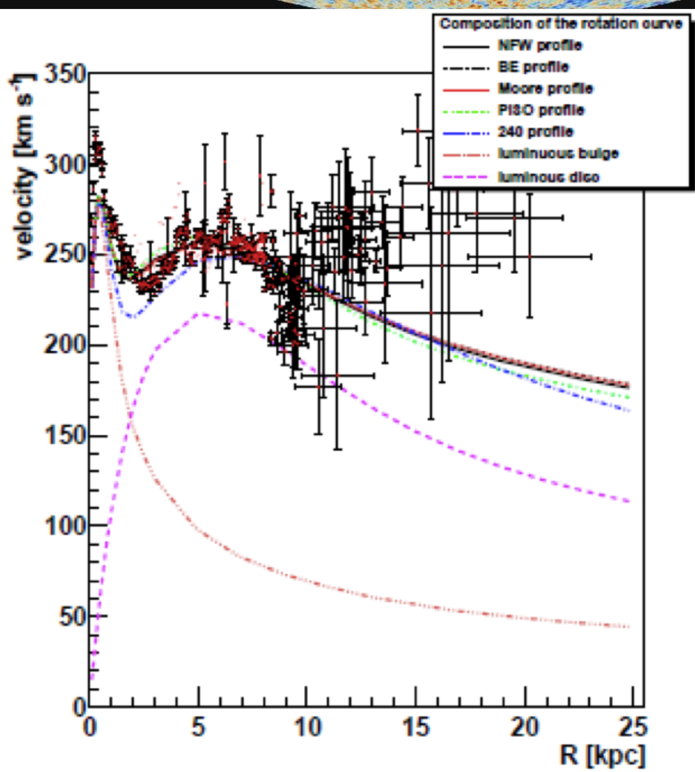
LUX Results
Gas Sampling and Calibrating with Tritium

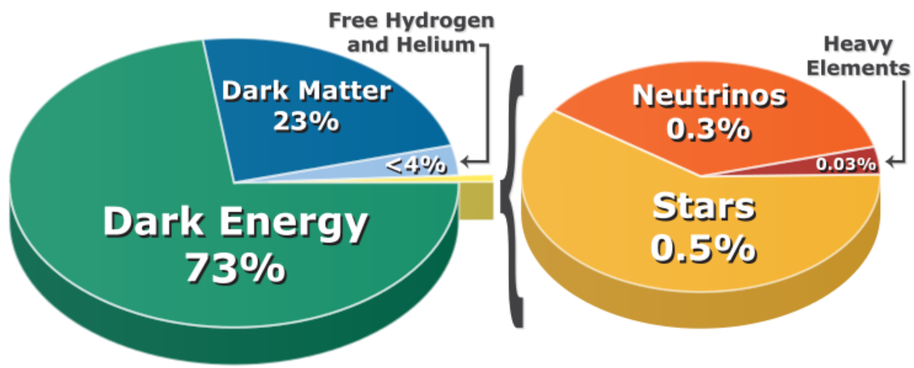
Attila Dobi
July 15th, SLAC
UNIVERSITY OF MARYLAND





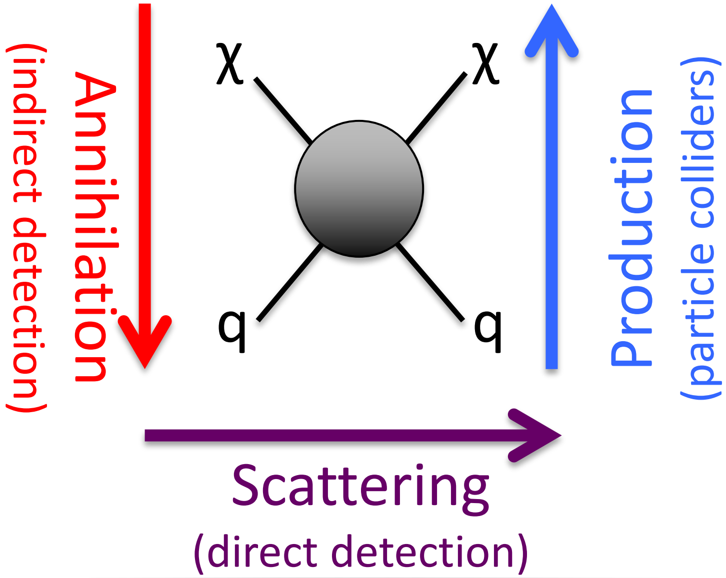


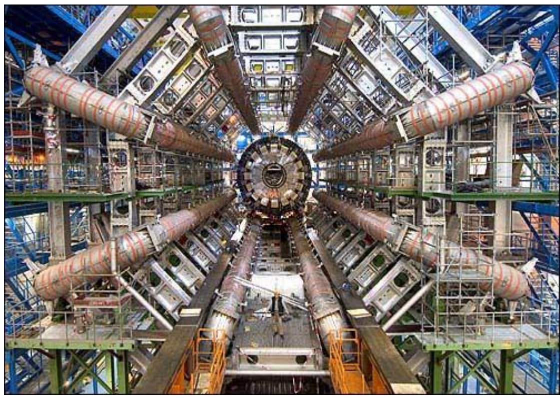
(a) Rotation curve (z = 0 kpc), non-averaged

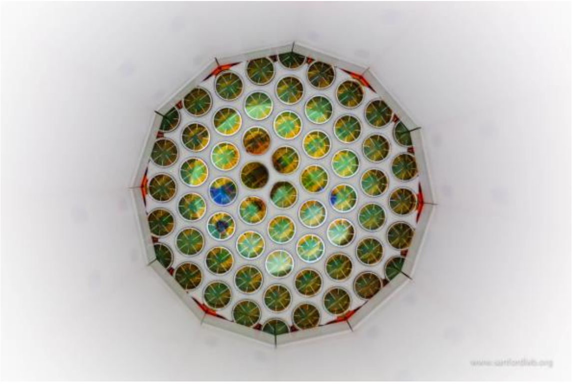


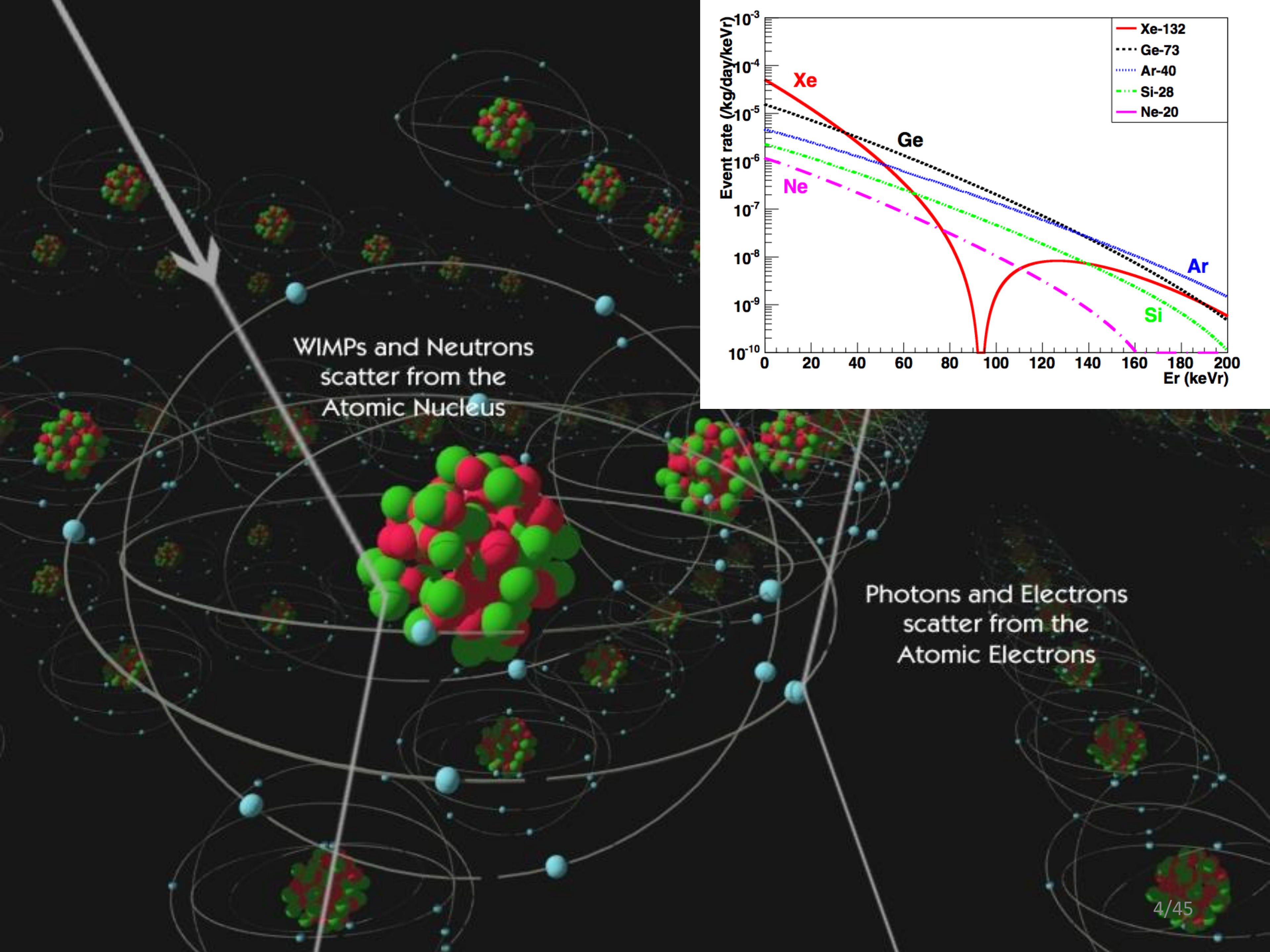
My apologies for making you sit through another dark matter overview

Detecting Dark Matter



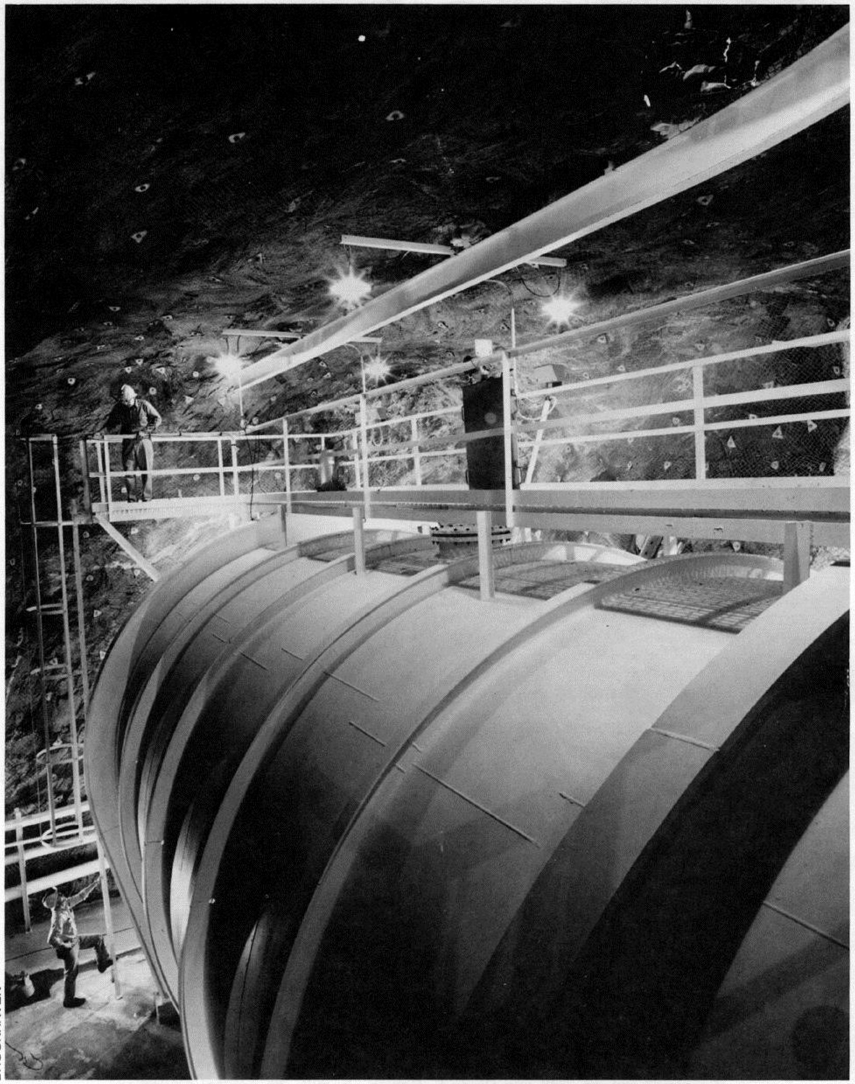





WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
Event rate (/kg/day/keVr)
Er (keVr)
Xe-132
Ge-73
Ar-40
Si-28
Ne-20
Xe
Ge
Ne
Ar
Si

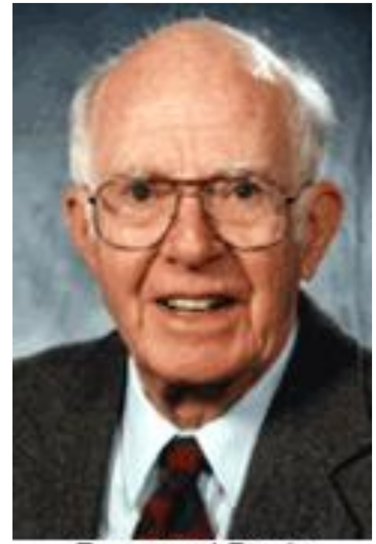
Sanford Underground Research Facility, Lead, South Dakota

Ray Davis – Homestake Solar Neutrino Experiment



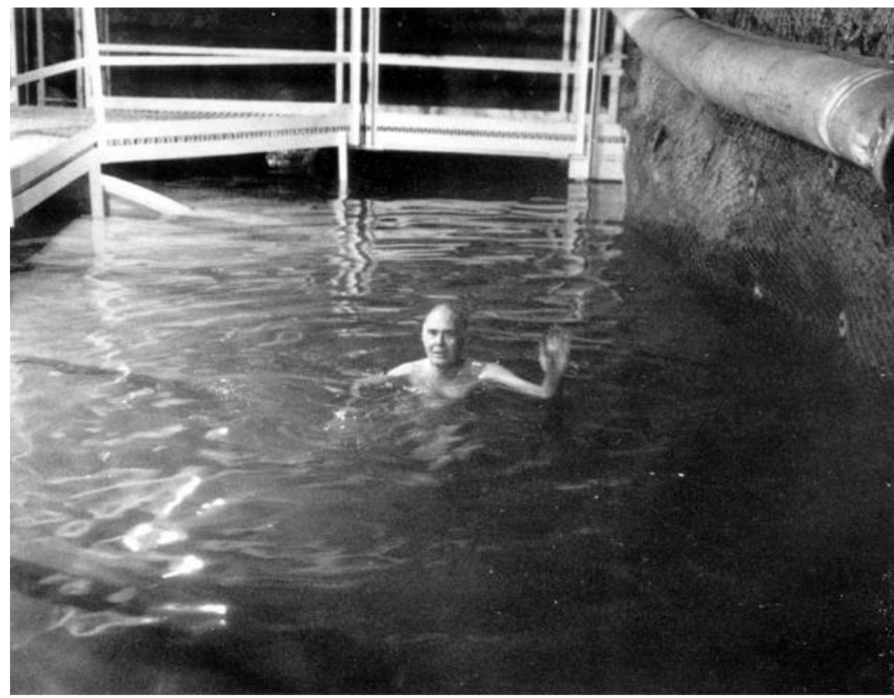
BROOKHAVEN

Davis' neutrino detection apparatus one kilometer underground in the Homestake Gold Mine, Lead, South Dakota. The tank contains 400,000 liters of perchloroethylene.



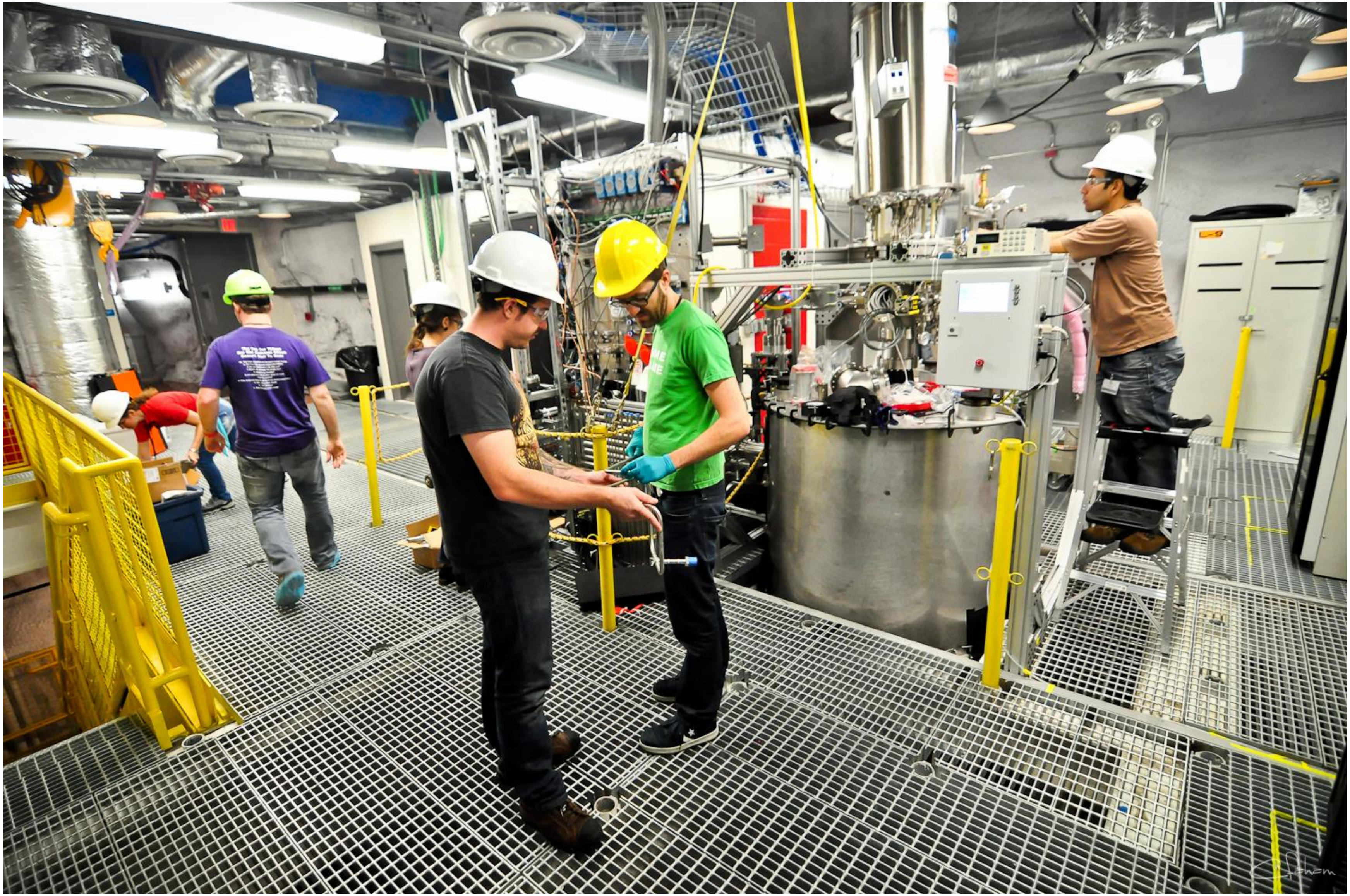
Raymond Davis

2002



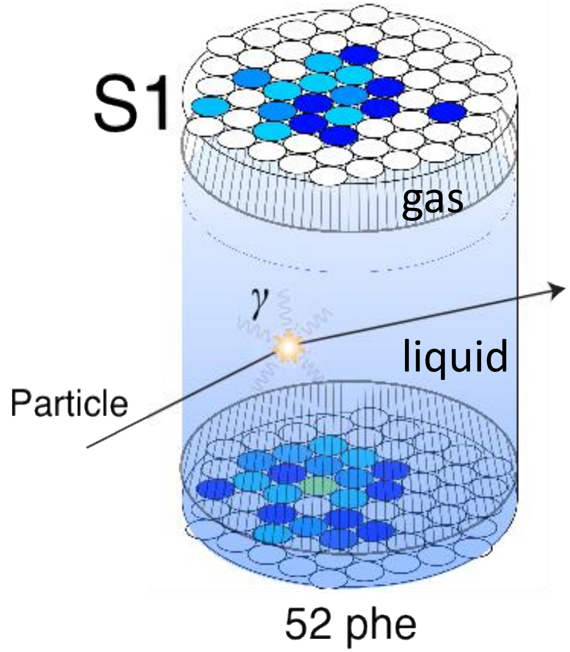
Davis Cavern @ SURF, September 2009

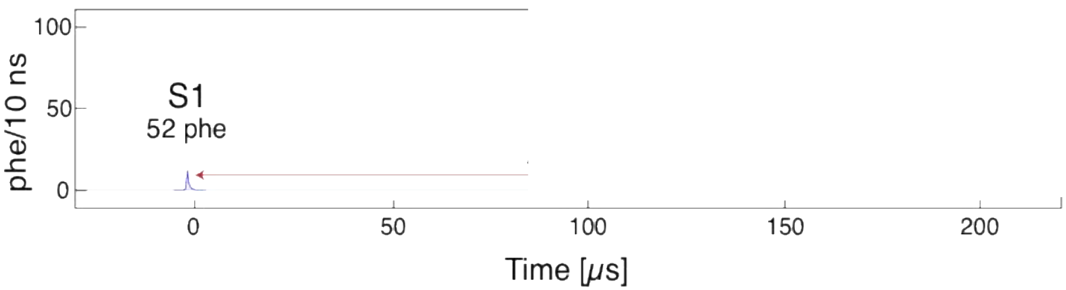
On top of the water shield, Sept. 2012

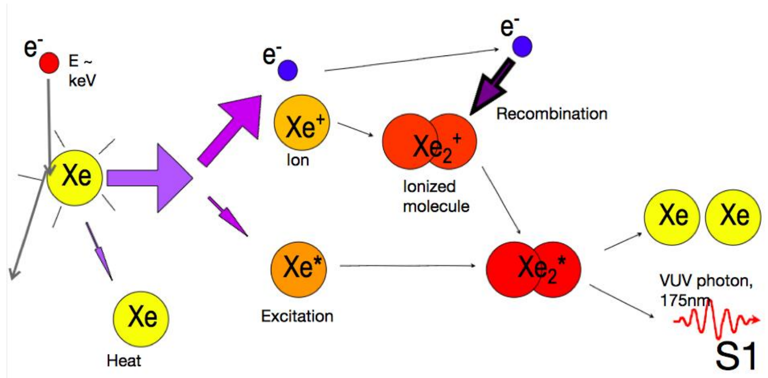


LUX installed in the water tank, Sept. 2012

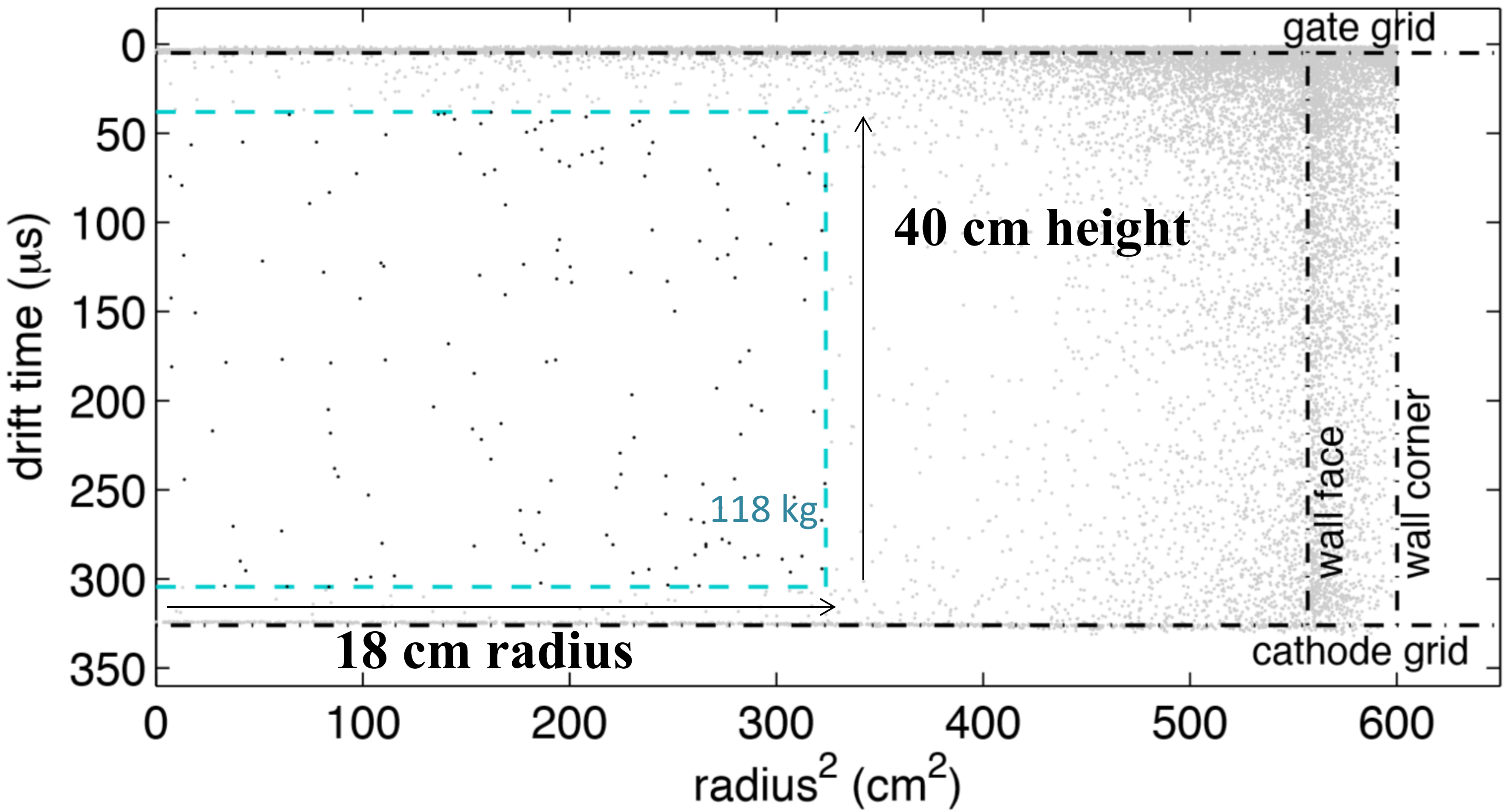
LUX TPC


S1
gas
γ
liquid
Particle
52 phe

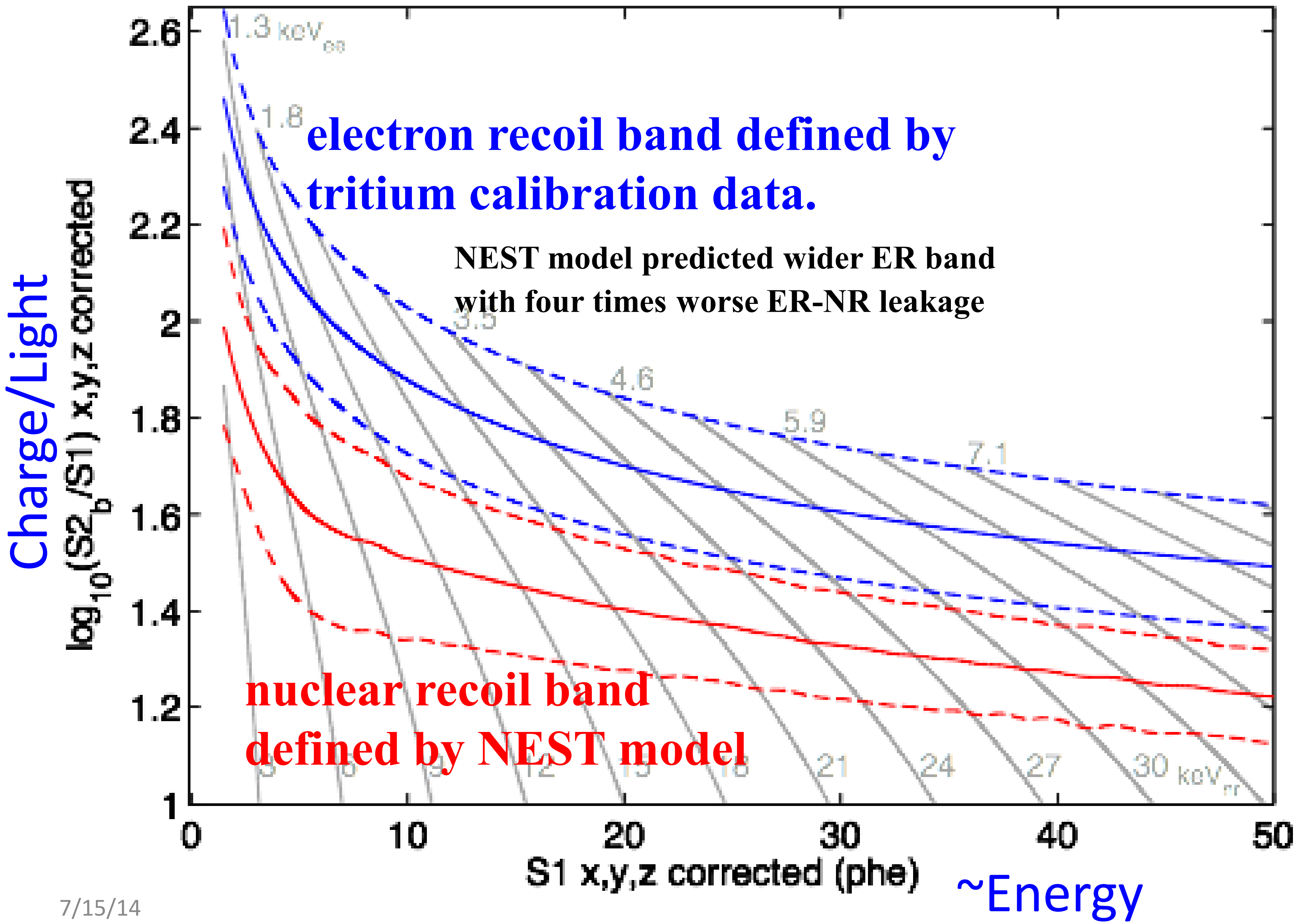

phe/10 ns
100
50
0
S1
52 phe
0
50
100
150
200
Time [μs]


e-
E ~ keV
Xe
Heat
e-
Xe+
Ion
Xe*
Excitation
e-
Recombination
Xe2+
Ionized molecule
Xe2*
Xe
Xe
VUV photon, 175nm
S1

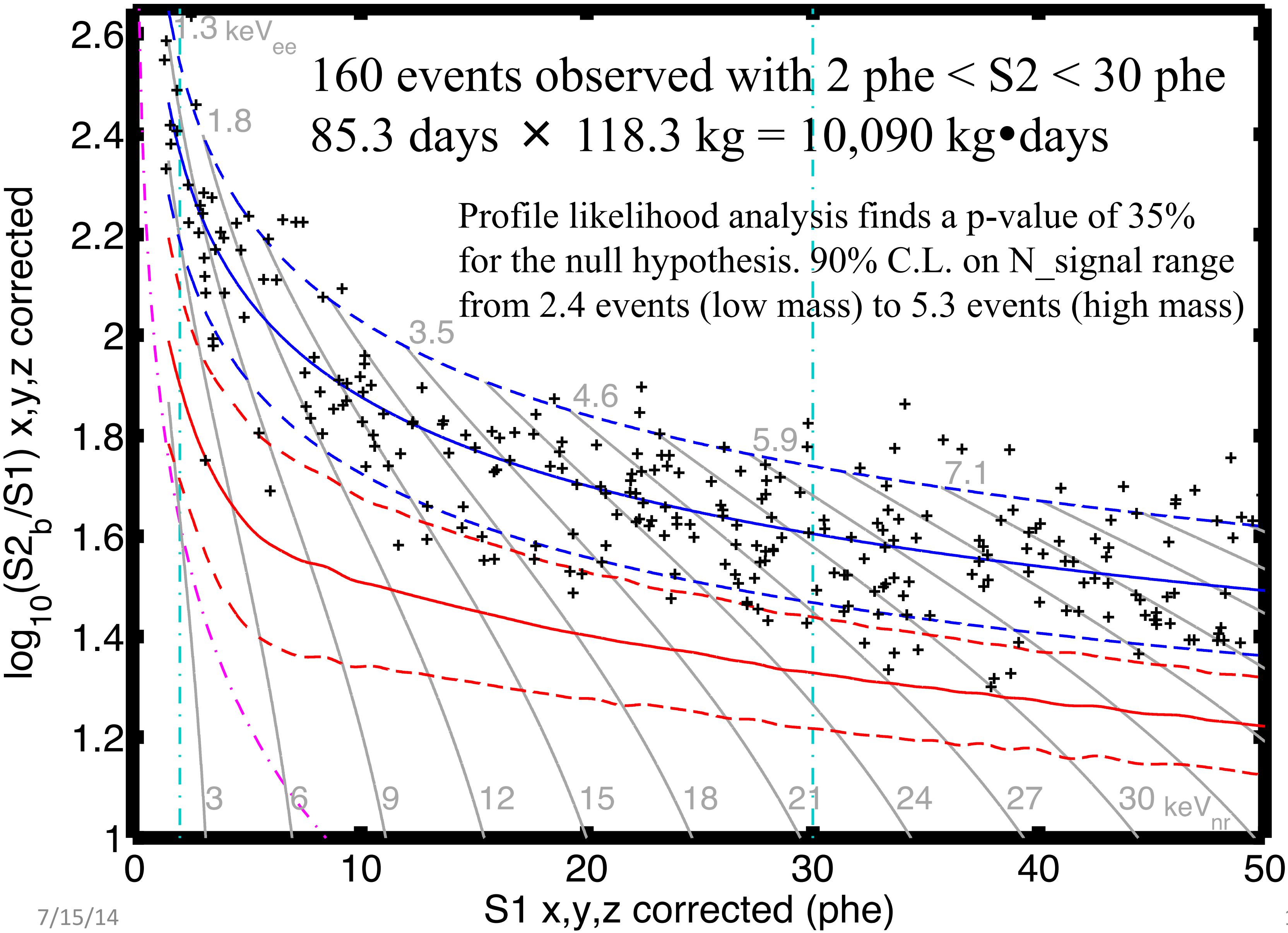
LUX fiducial volume cut – 118 kg



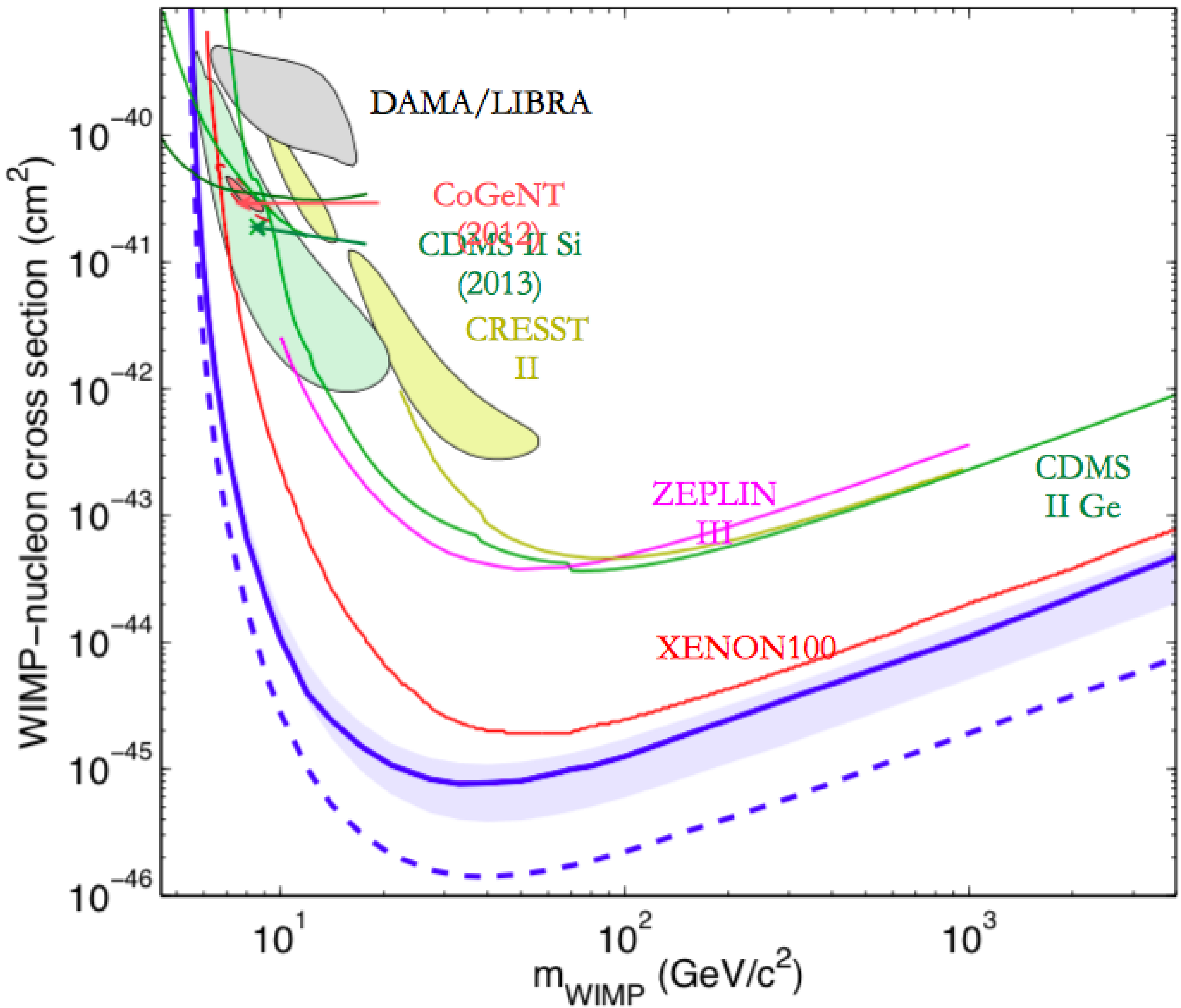
LUX keV_{ee} and keV_{nr} energy scales



LUX WIMP search data



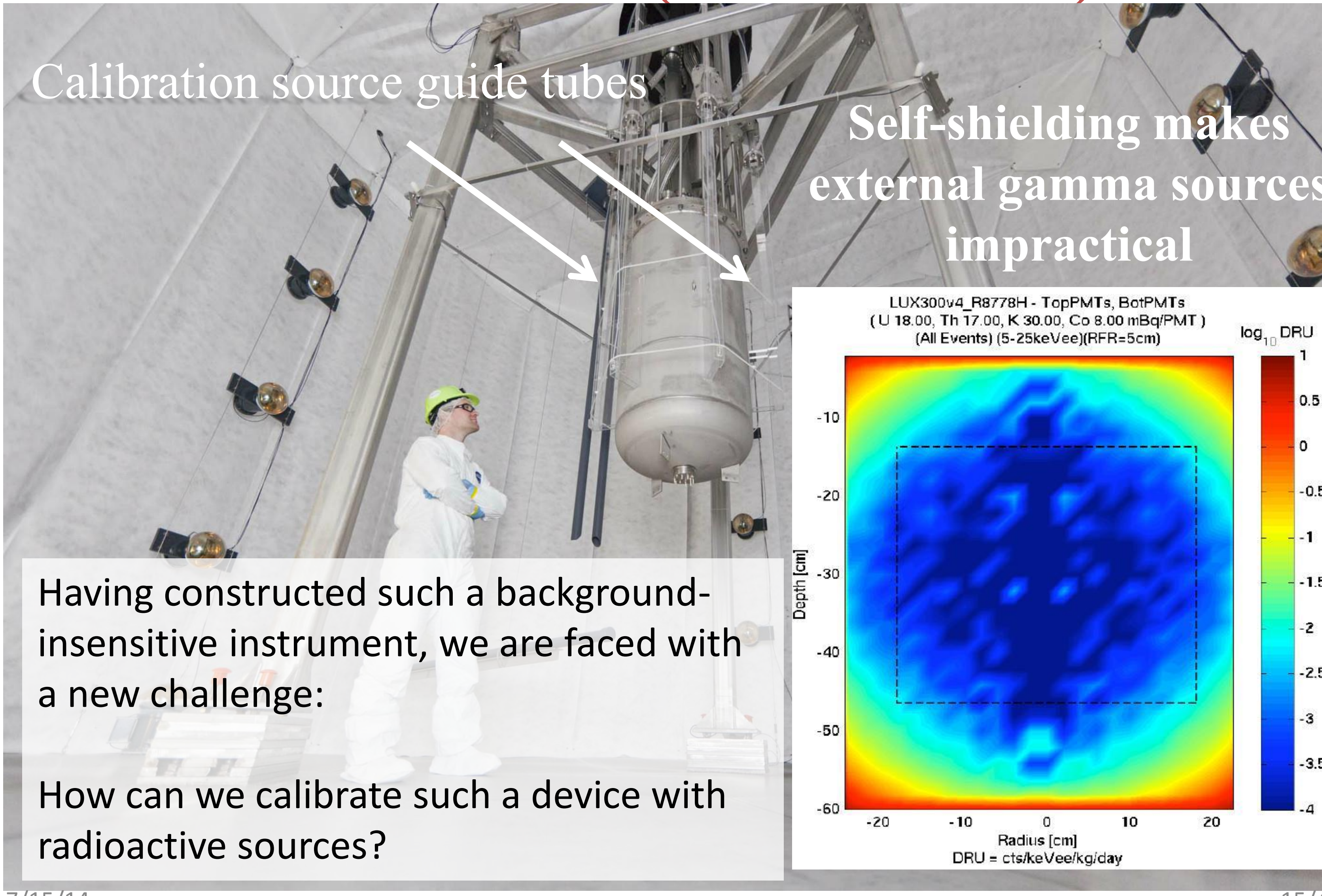
LUX limits



LUX 85d (2013)
With ±1σ expected

Projected LUX 300 d
(2014)

External calibration sources: ^{137}Cs & neutrons (AmBe & ^{252}Cf)

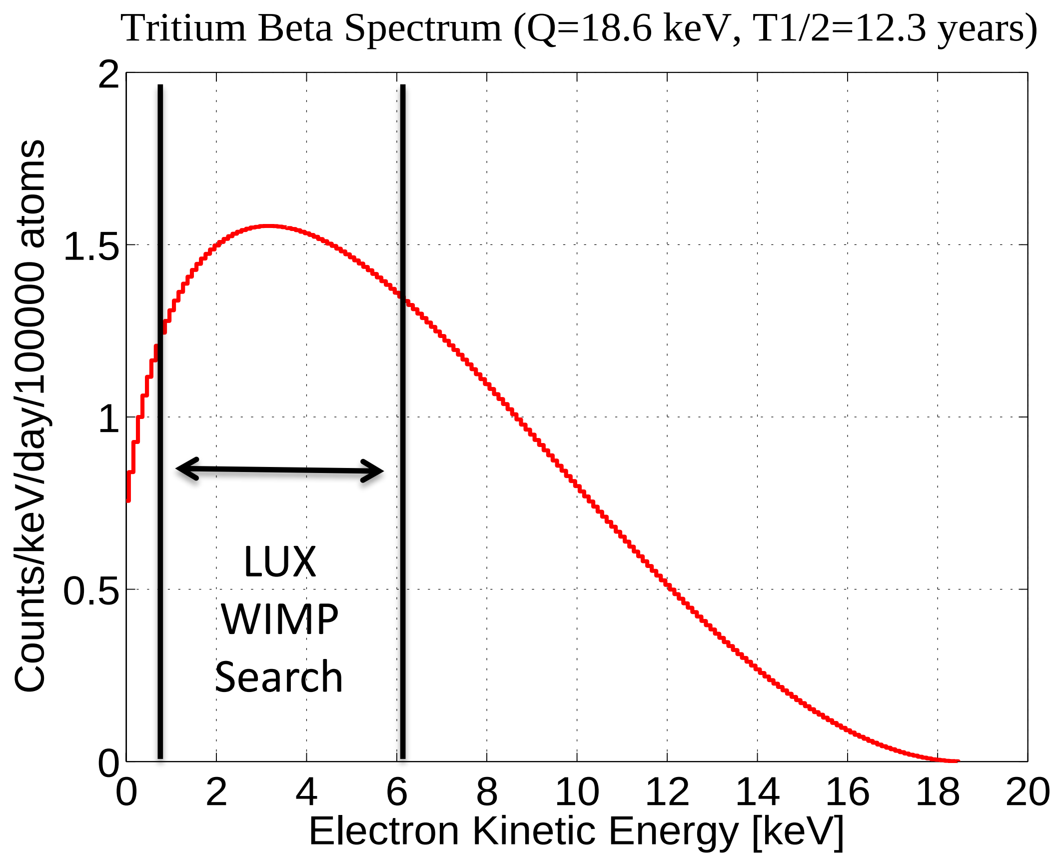


Having constructed such a background-insensitive instrument, we are faced with a new challenge:

How can we calibrate such a device with radioactive sources?

Tritium, The Ideal ER Calibration Source

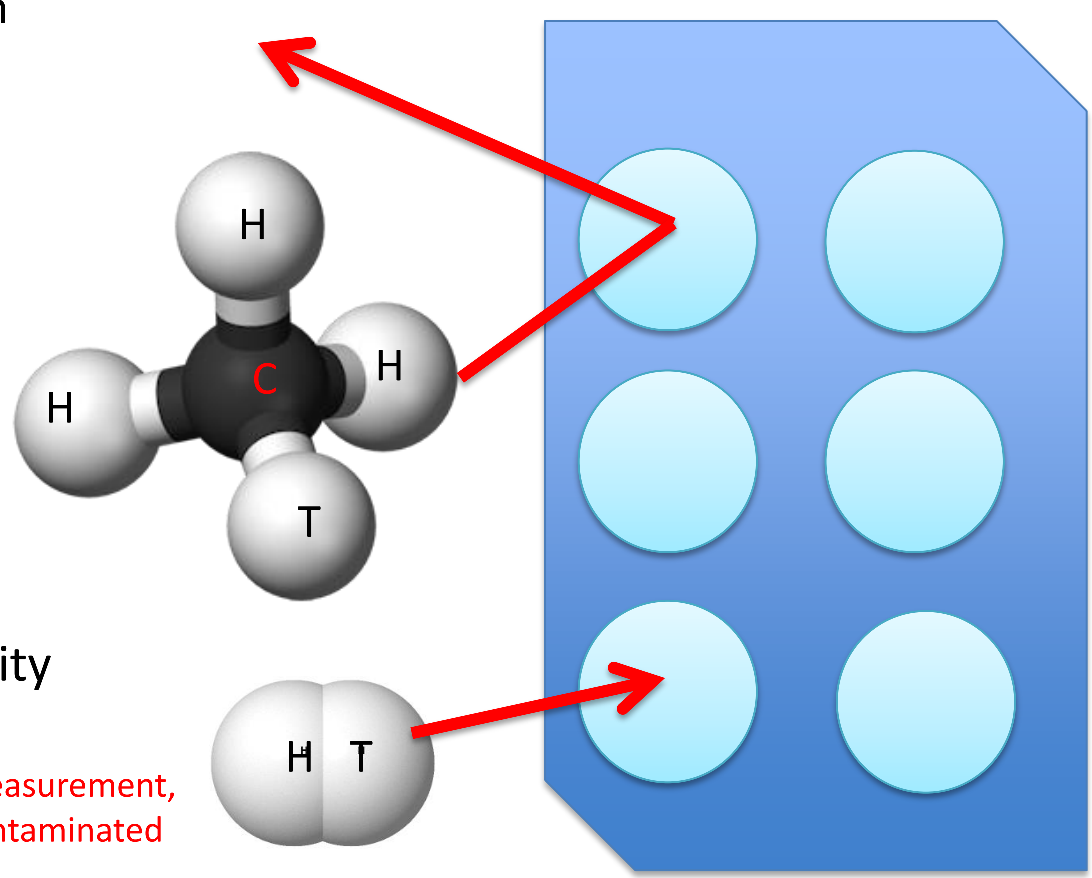
- Single Scatter events in energy region of interest:
- Q = 18.6 keV
- Mean energy: 5 keV
- Peak energy: 3 keV



- Bare tritium diffuses quickly into detector components.
- Must be removed after calibration.
- Can't afford to simply wait for activity to decay away.
- 12.3 year half-life!

Use Tritiated Methane

- Methane is non-polar, and has saturated covalent C-H bonds, which makes it chemically very inert.
- Well-known that methane will dissolve in liquid xenon.
- As a larger and heavier molecule, tritiated methane has a smaller diffusion constant than bare tritium.
- Methane diffusion and permeability in Teflon is 11x less than tritium.



H. Miyake, et. Al. J. Vac. Sci. Technol. A 1, 1447 (1983).

They were only able to perform a single tritium measurement, because their Geiger counter was permanently contaminated with tritium after the first measurement.

First step: Needed to characterize the removal of methane from xenon with standard gettering technology (heated zirconium from SAES).

Problems To Solve For Tritium Injection

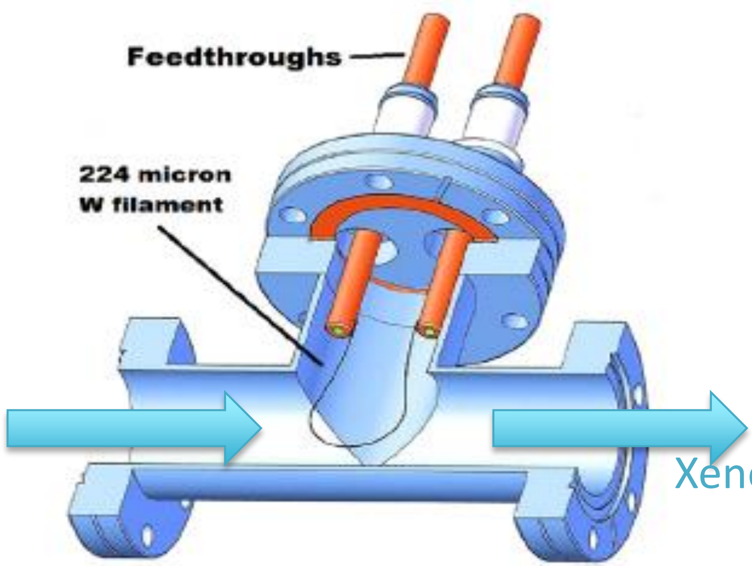
- How can we calibrate such a large xenon detector?
  - Use tritium
- How to minimize the diffusion of tritium into detector components?
  - Use tiritiated methane
- If we inject methane can we remove it with standard purification technology?
- How can we measure impurities in xenon to ppt (10^{-12}) levels?
- Implications of detecting impurities in xenon at ppt levels for monitoring internal radioactivity.

First attempt at purity detection in xenon

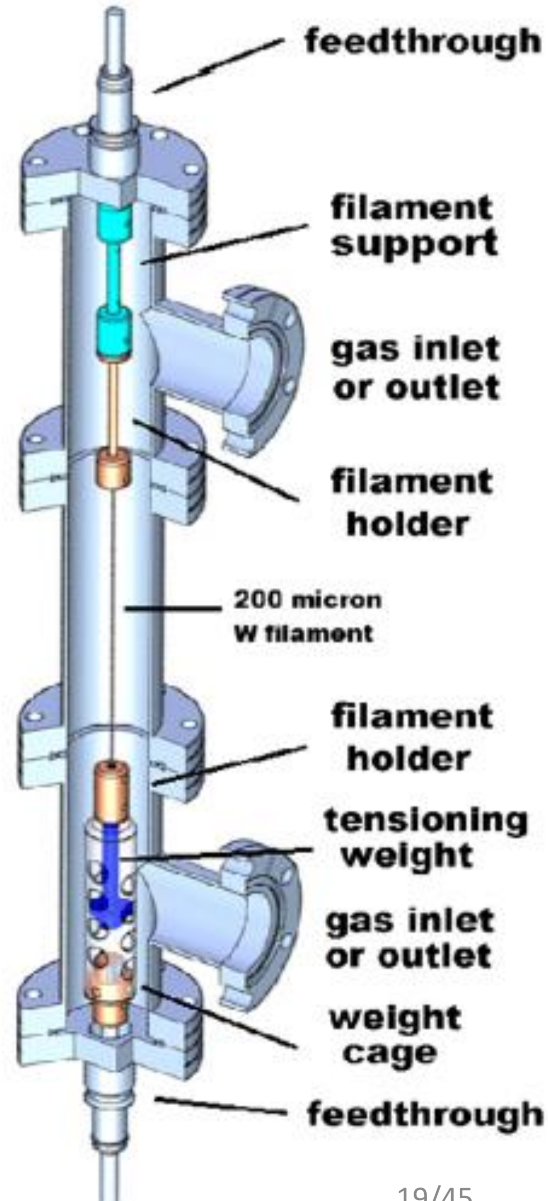
Technique:

Burn a tungsten filament in an atmosphere of gaseous xenon. Measure thermionic emission current on cathode.

- Provides real time continuous monitoring to catch air leaks.
- Practical for measuring electro-negative impurities such as oxygen, water.

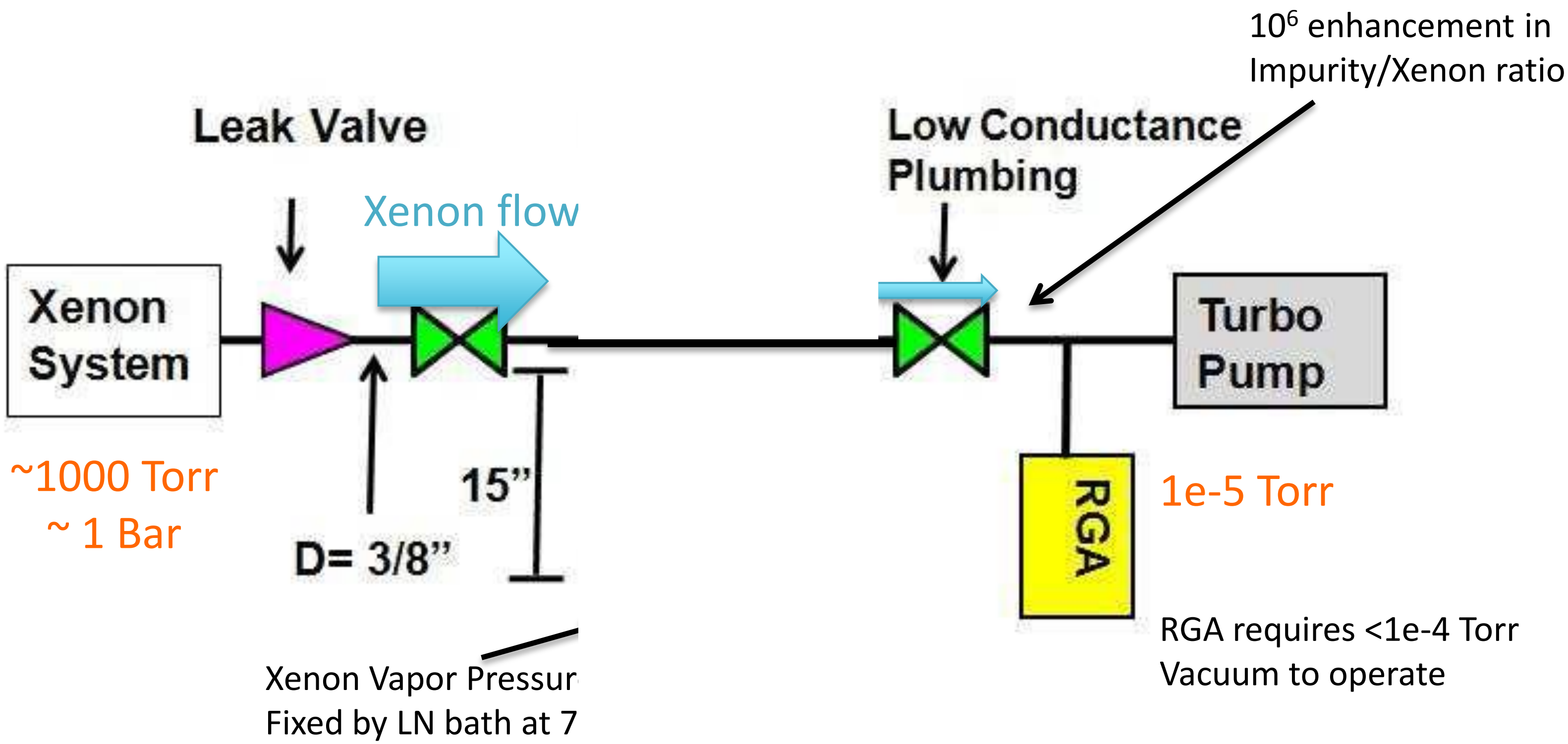


Xenon gas flow



Dobi, et. NIMA. A. Volume 659. 215:228 (2011).

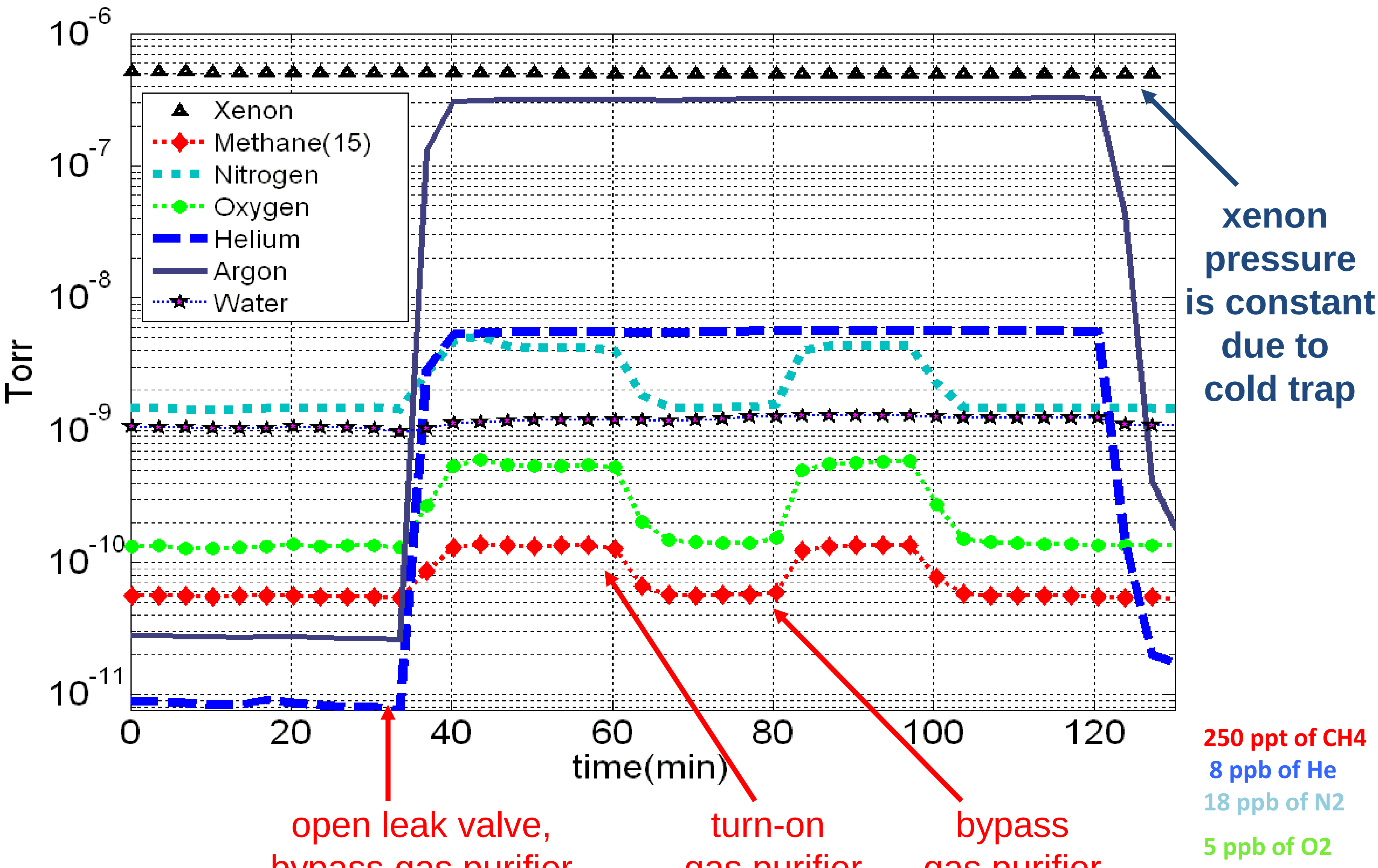
Mass spectroscopy enhanced with coldrap



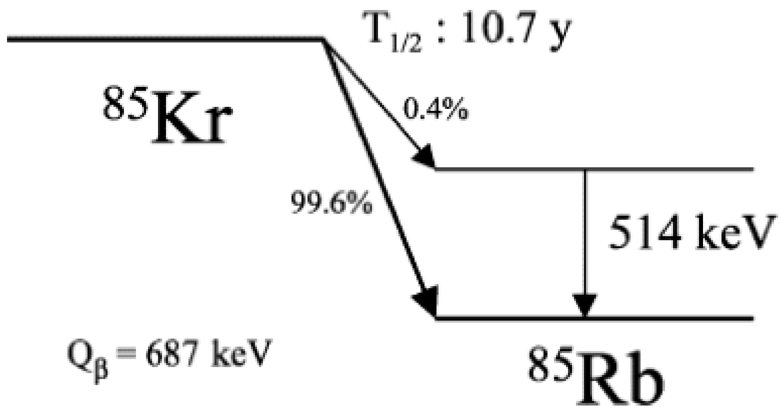
- Cold trap technique boosts the sensitivity of the mass spectrometer by a factor of ~10^6.
- Simple and affordable.
- Used to characterized SEAS getter for use with Xenon gas.

Dobi, A. *et al.* Nucl.Instrum.Meth. A620 (2010)
Leonard, D.S. *et al.* Nucl.Instrum.Meth. A621 (2010)
Dobi, A. et al. Nucl.Instrum.Meth. A665 (2011)
Dobi, A. et al. Nucl.Instrum.Meth. A675 (2012)

Typical cold-trap operation, showing purification of methane, O_2, N_2 as the purifier is switched between bypass and purify mode

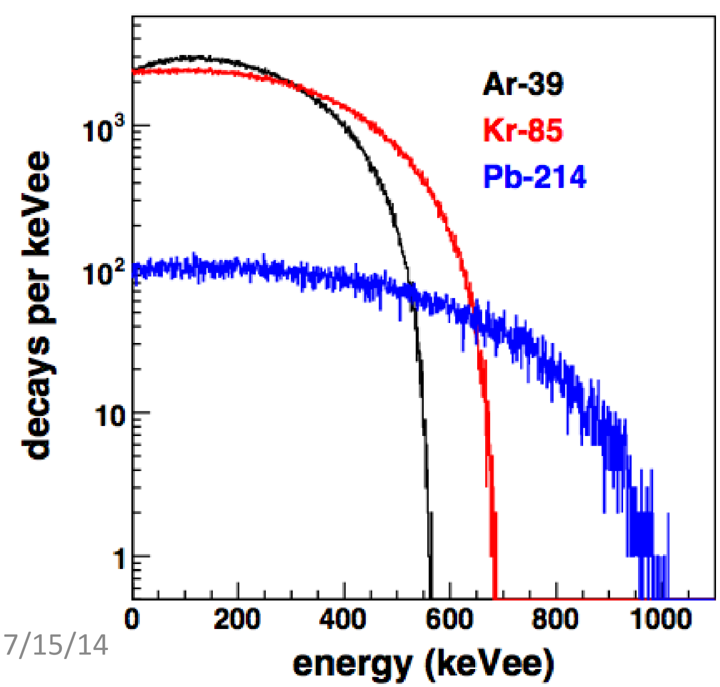


Internal radioactive backgrounds in LUX

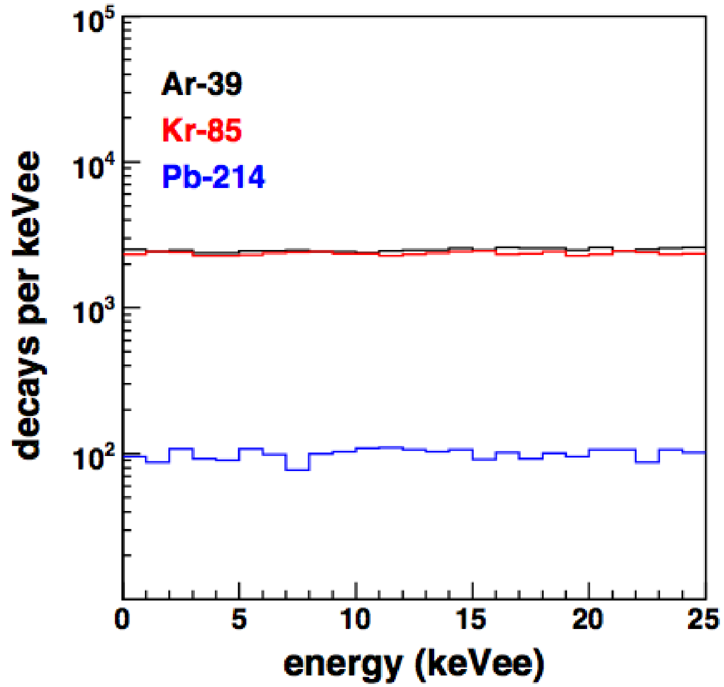


- Krypton-85 is the most important source of internal radioactivity
- Vendor-supplied xenon contains residual krypton at a relative concentration of ~10^{-7}
- LUX goal: reduce Krypton concentration to ~5 x 10^{-12} (1/4 of external γ background)

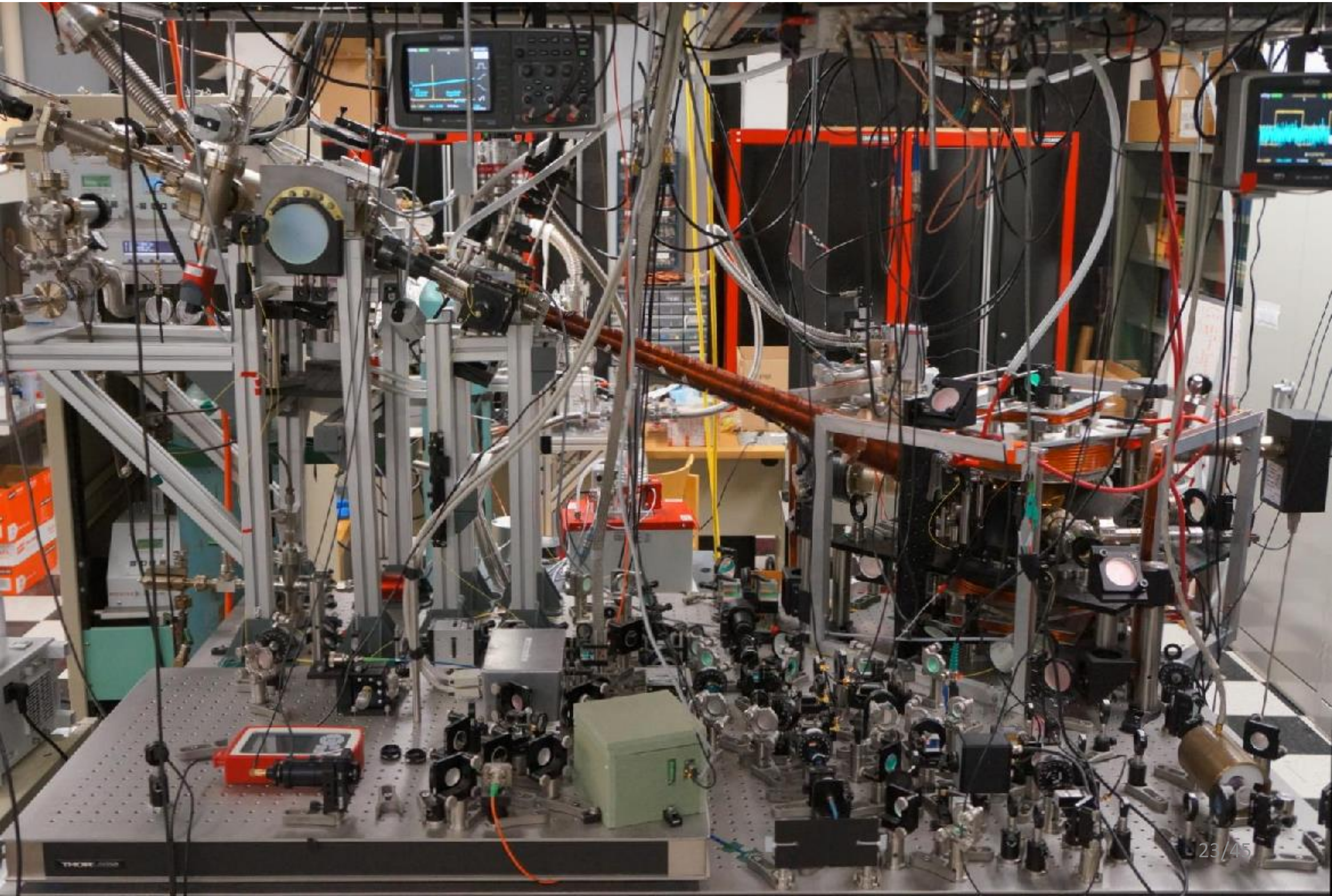
complete spectra



low energy zoom



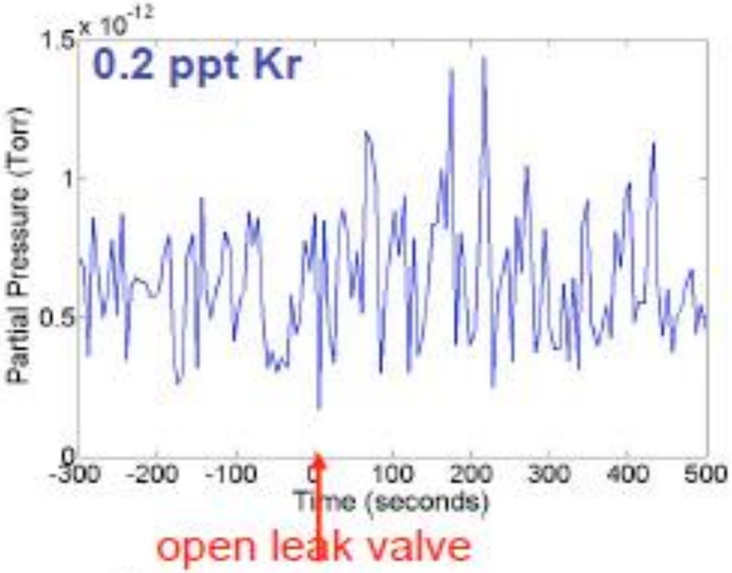
ATTA at Columbia
(has yet to demonstrate ppt Kr/Xe sensitivity)

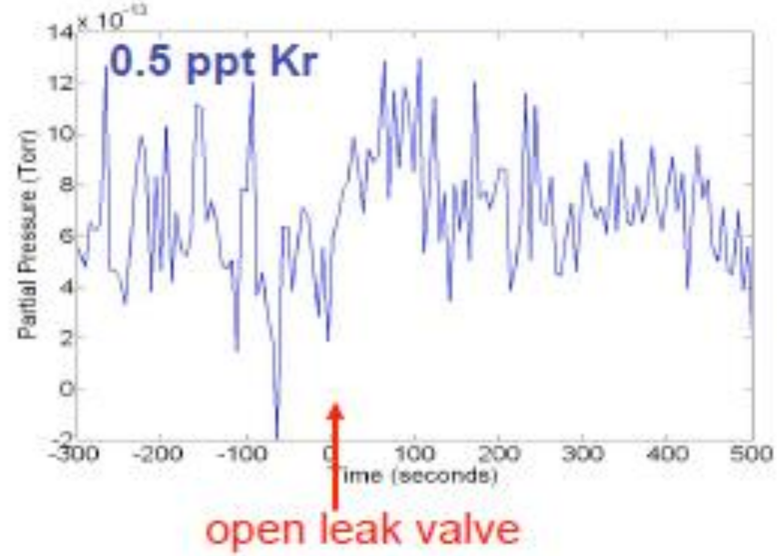


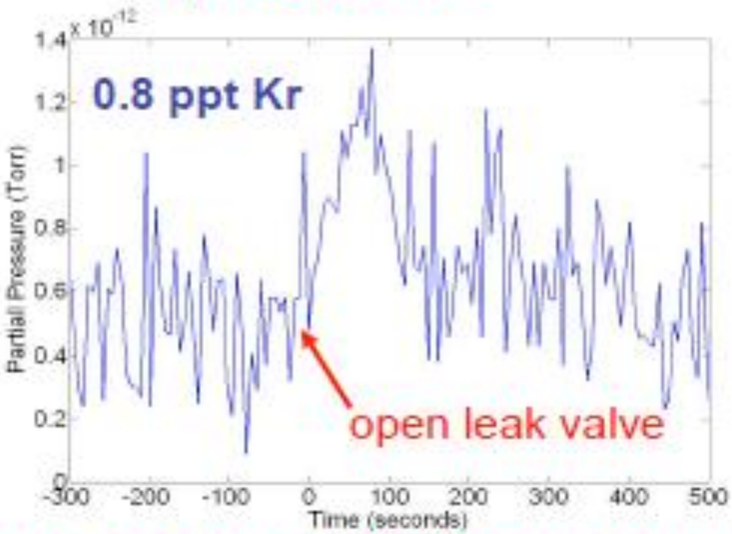
Purity Analysis for EXO

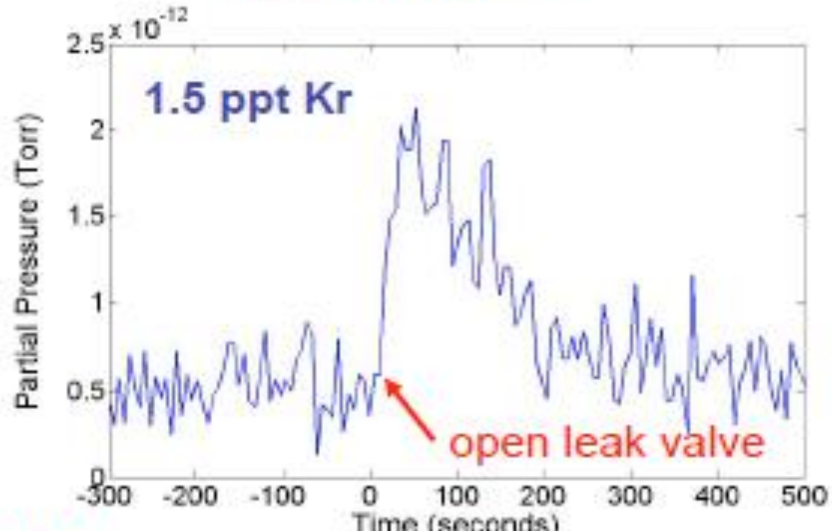
Purity Analysis for LUX

Detection of krypton at the part-per-trillion level





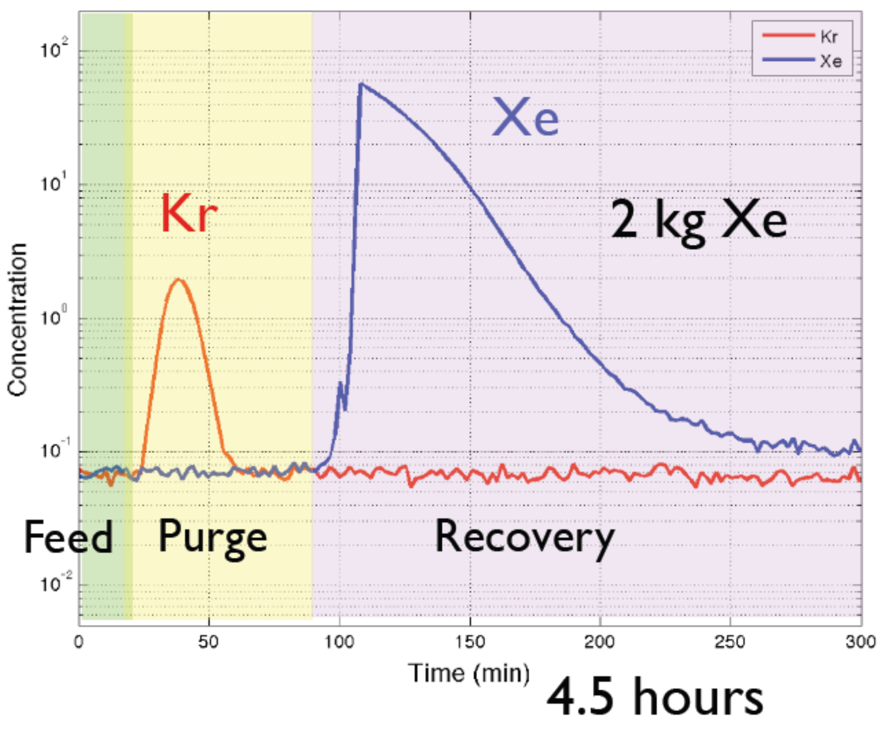


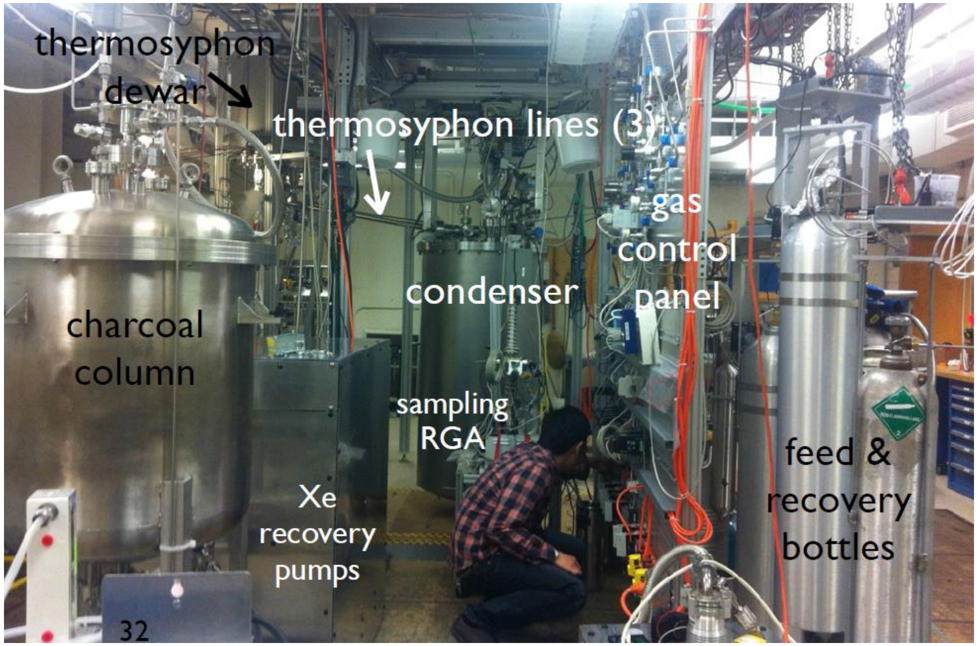


Allows xenon to be screened prior to physics running, confirm effectiveness of krypton removal.

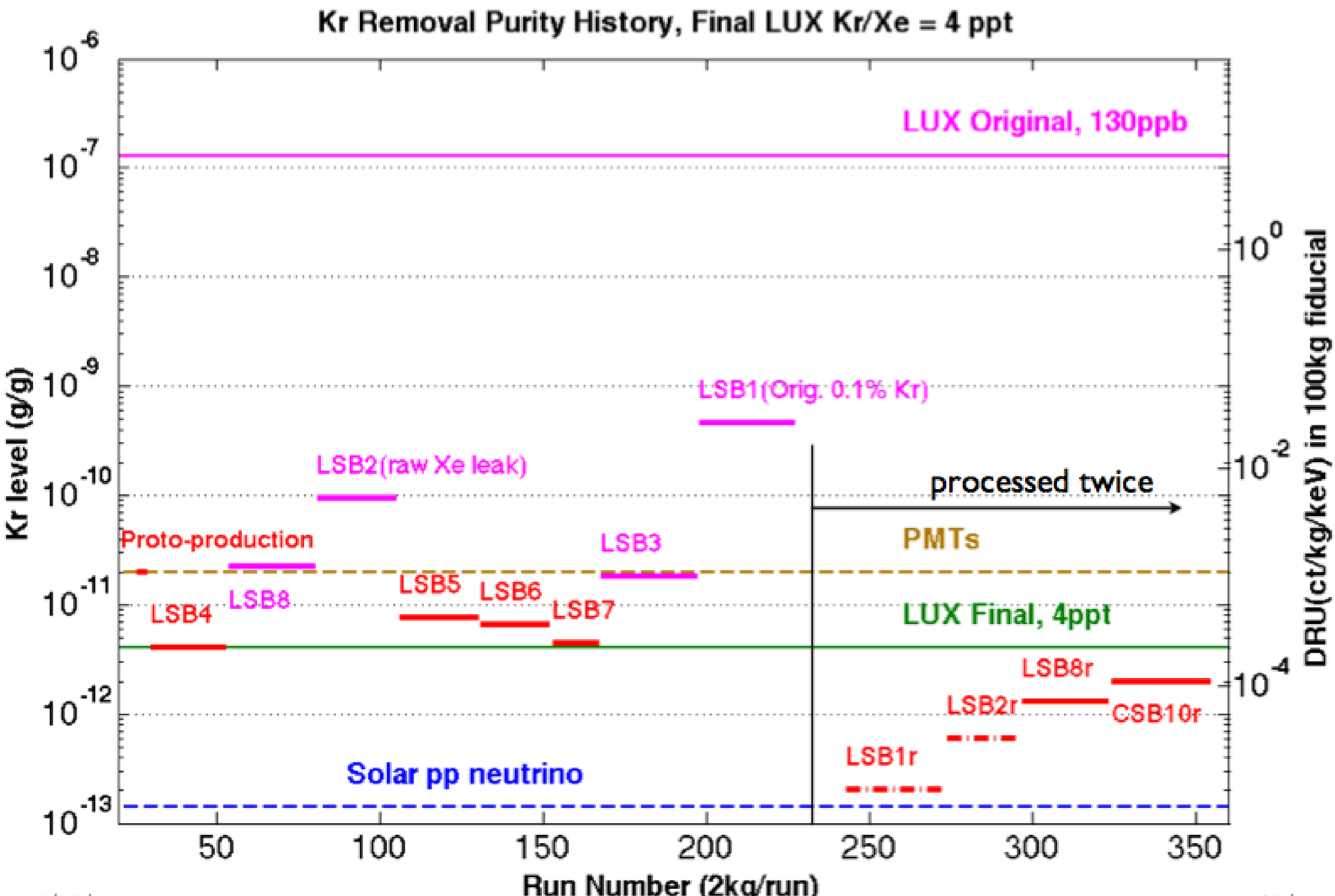
Dobi, A. et al. Nucl.Instrum.Meth. A665 (2011)
arXiv:1103:2714

Chromatographic Krypton Removal System @ Case Western (Aug. – Dec. 2012)

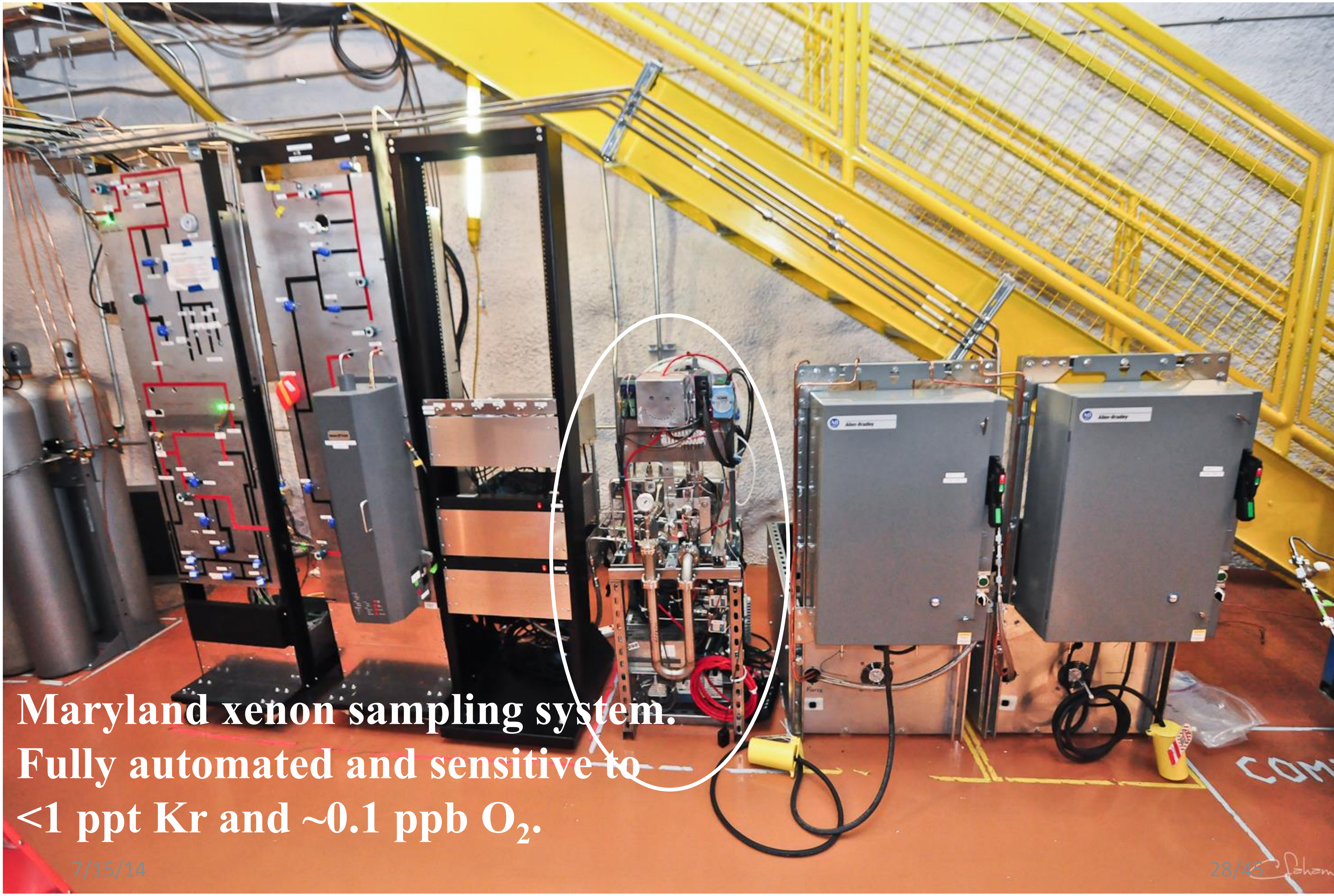




LUX Krypton removal – Fall 2012

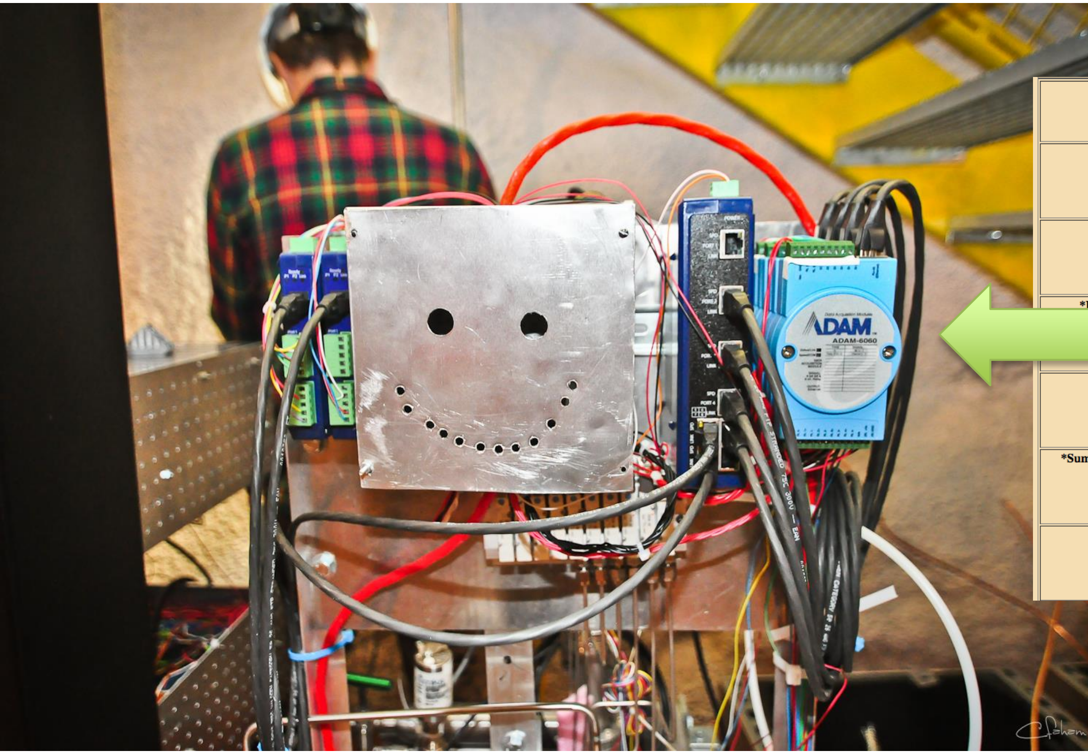


LUX purification system and impurity monitoring



Maryland xenon sampling system.
Fully automated and sensitive to
<1 ppt Kr and ~0.1 ppb O_2.

In Situ Xenon Sampling



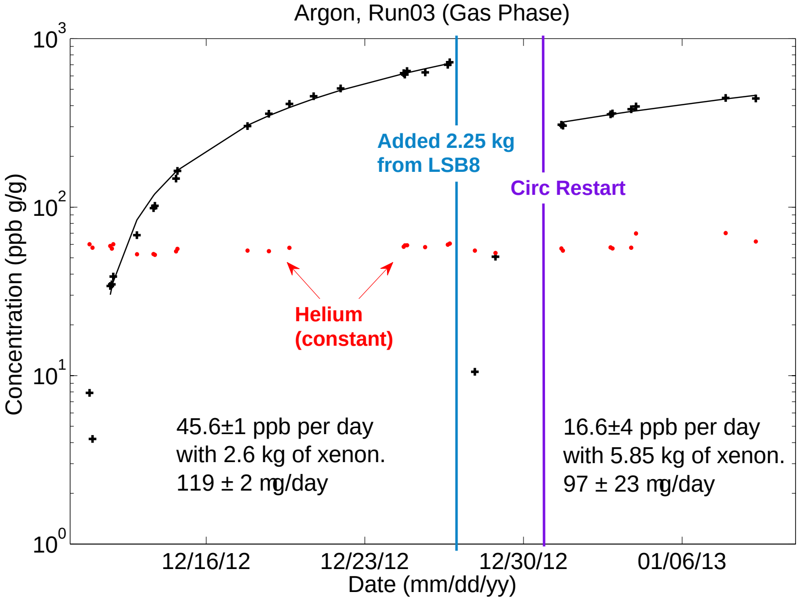
#SAM Run Status# (SAM_wait) **OK**	#Sampling System Error Status# (Analysis_Error) **None**	#Sampling System Status# (Analysis_Status) **Idle**
$ Last Sampling Location $ (SAM_Port) **PMT Purge**	* Sample Number * (SAM_Number) **123.000** (Number)	*Ar Concentration* (Purity_Ar) **140.704** (ppb g/g)
CH4 Concentration (Purity_CH4) **0.011** (ppb g/g)	*He Concentration* (Purity_He) **229.998** (ppb g/g)	*Kr Concentration (82+84+86)* (Purity_Kr_Sum) **0.025** (ppb g/g)
Kr Concen[illegible]on (from 82) (Purity_Kr82) **[illegible]0e-3** (ppb g/g)	*Kr Concentration (from 84)* (Purity_Kr) **0.026** (ppb g/g)	*Kr Concentration (from 86)* (Purity_Kr86) **0.029** (ppb g/g)
N2 C[illegible]ncentration (Purity_N2) **4.075** (ppb g/g)	*O2 Concentration* (Purity_O2) **0.157** (ppb g/g)	*Sum Xe Mass Pumped to SRV* (SAM_Mass_SRV) **221.534** (grams)
Sum Xenon Mass Pumped Out (SAM_Mass_Out) **244.000** (grams)	< Last Analysis [hours ago] > (Last_Analysis_t) **28.271** (hours)	< Last Calibration [hours ago] > (Last_CAL_time) **241.920** (hours)
Analysis Flow Rate (Analysis_Flow) **1.589** (Torr/s)	Calibration Flow Rate (Cal_Flow) **0.571** (Torr/s)	SAM CM Gauge [PT-SAM2] (SAM_CM_Gauge) **2.732** (Torr)

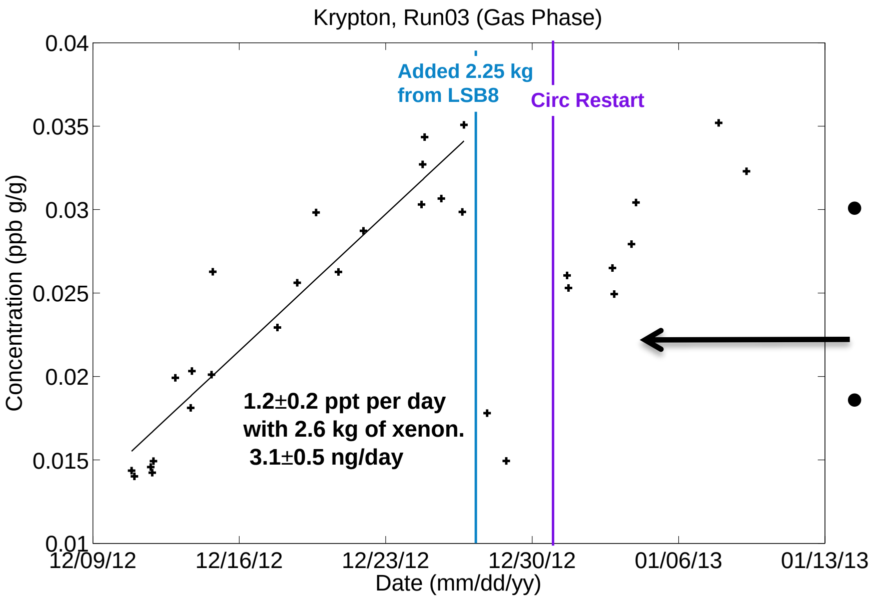
- Just add LN and Xe then push a button → Purity Result! (ppt levels!!)
- All data recorded in slow control
- **Purity Result for N_2, O_2, He, Ar, Kr, H_2, CH_4**
- Plumbed into six sample locations along the circulation path.
- All xenon sampled is recovered storage vessel (no loss!)
- 1 hour between samples, can be upgraded for continuous sampling.

Application of Gas Purity Analysis

- Xenon Bottle Screening (proved useful for EXO-200 and LUX)
- Electro-negative impurities attenuate electron drift
  - Require sub ppb O_2 eq. for ~10cm drift
- Useful for leak-detection during science run.
  - ^{39}Ar and ^{85}Kr are backgrounds in darkmatter searches
- Helium diffuses through glass and degrades PMTs
- Can study outgassing rates since detectors (ex. LUX, EXO) are typically back-filled with purge gasses (N_2 or Ar)
- Can set limits on external Radon emanation from Ar accumulation.

Outgassing Studies Dec. 2012
(Prior to detector cool down)





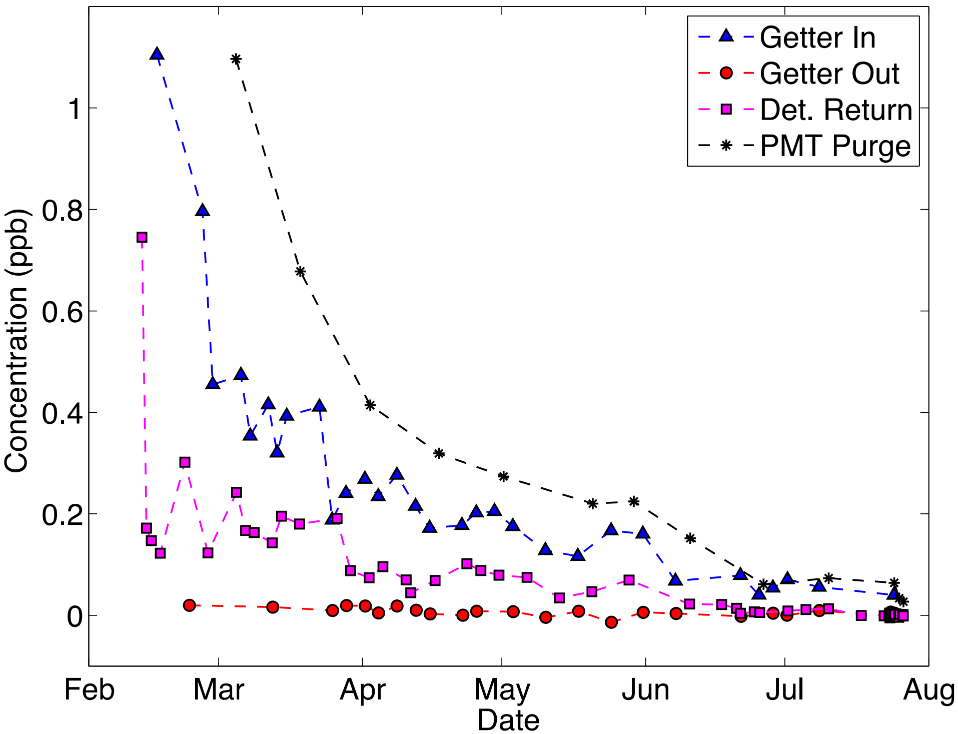
	Emanation rate	Worst Case (room temp), after 1 year in 350 kg
Argon	120 µg/day	+ 120 ppb
Krypton	3.1 ng/day	+ 3.5 ppt

Outgassing was reduced after cool down

- LUX had the ability to observe nano-grams of krypton outgassing from room-temperature detector internals.
- Important for diffusion studies and LZ design.

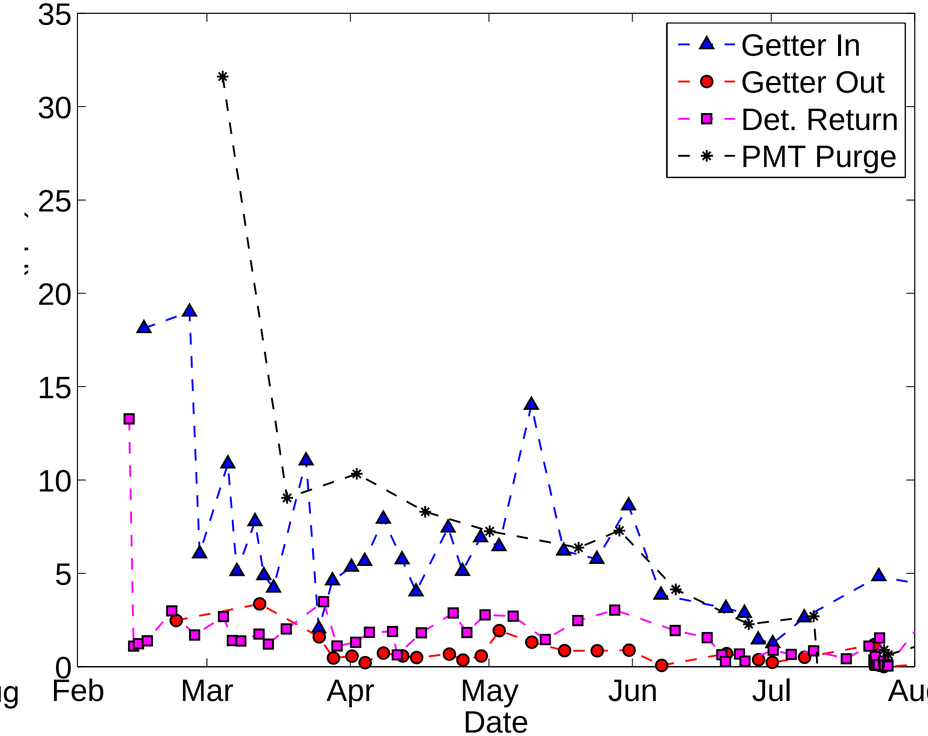
Monitoring of impurities in the LUX xenon with the LUX sampling system

O_2 Run 03 Sampling



2013

N_2 Run 03 Sampling

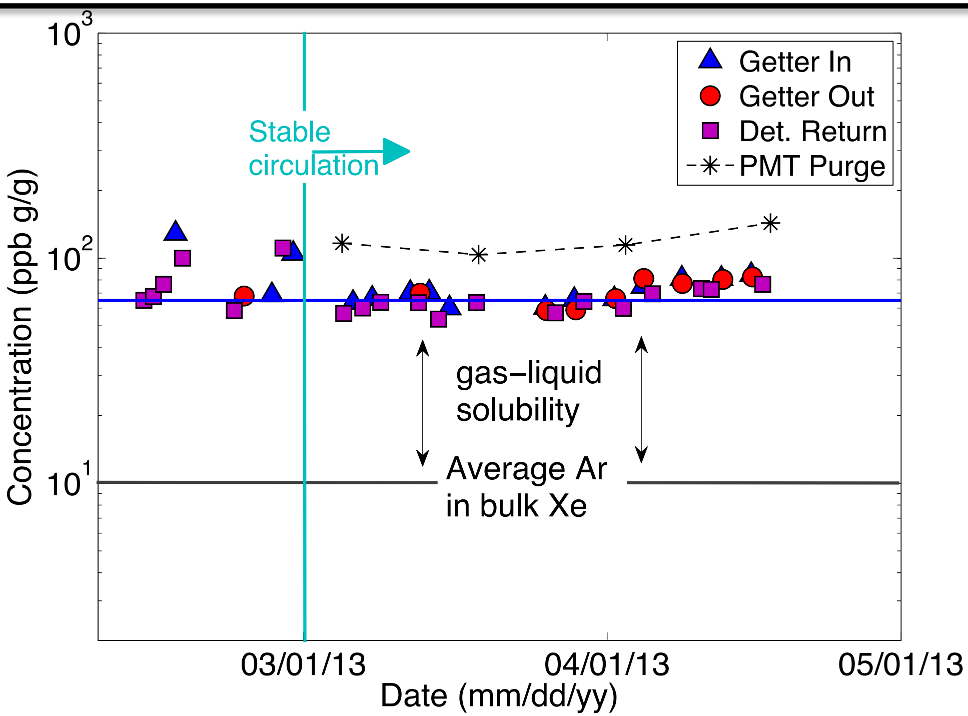


2013

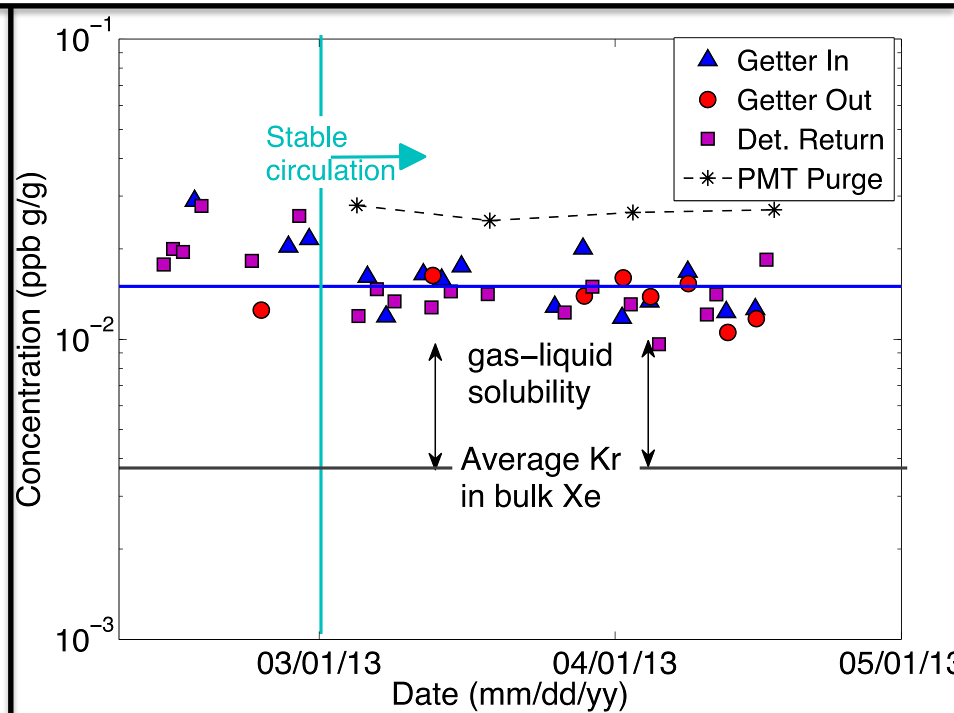
Enables real-time detection of air leaks, purifier malfunctions, ect.

Xenon Liquid-Gas Solubility, LUX

Ar Run 03 Sampling



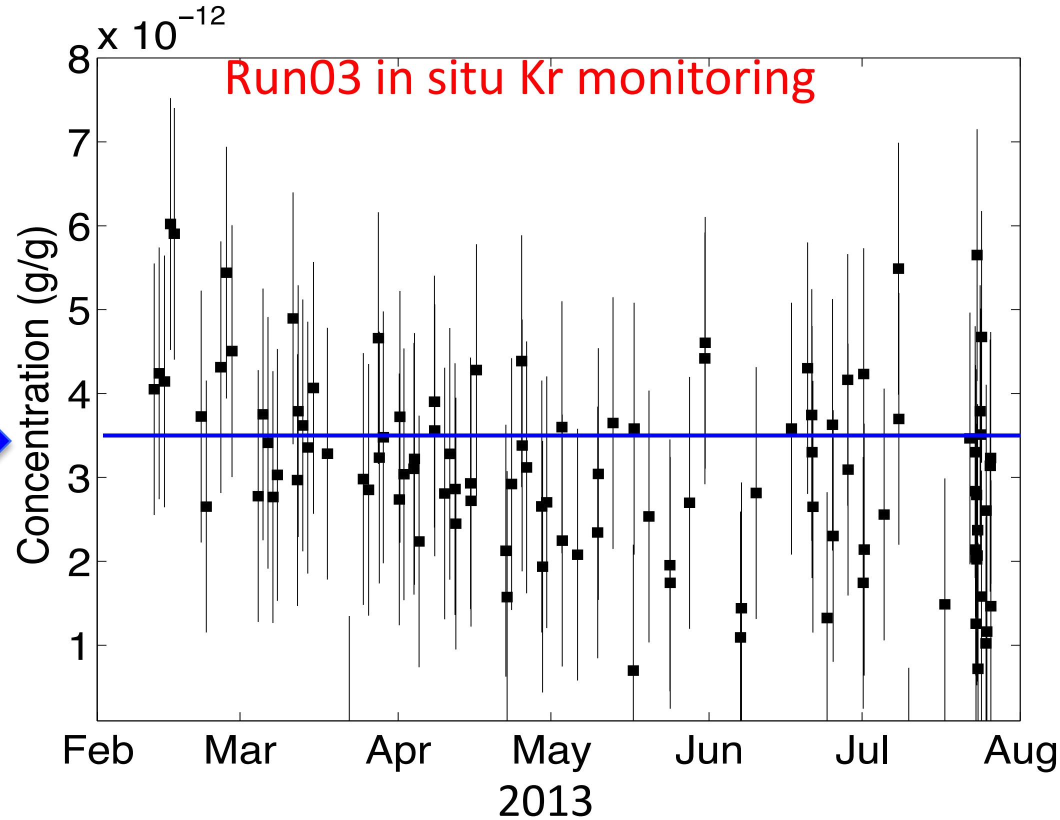
Kr Run 03 Sampling



Ar and Kr detection enhanced by liquid-gas solubility.
Henry's constants in xenon have yet to be characterized

Monitoring ^{85}Kr background in LUX xenon

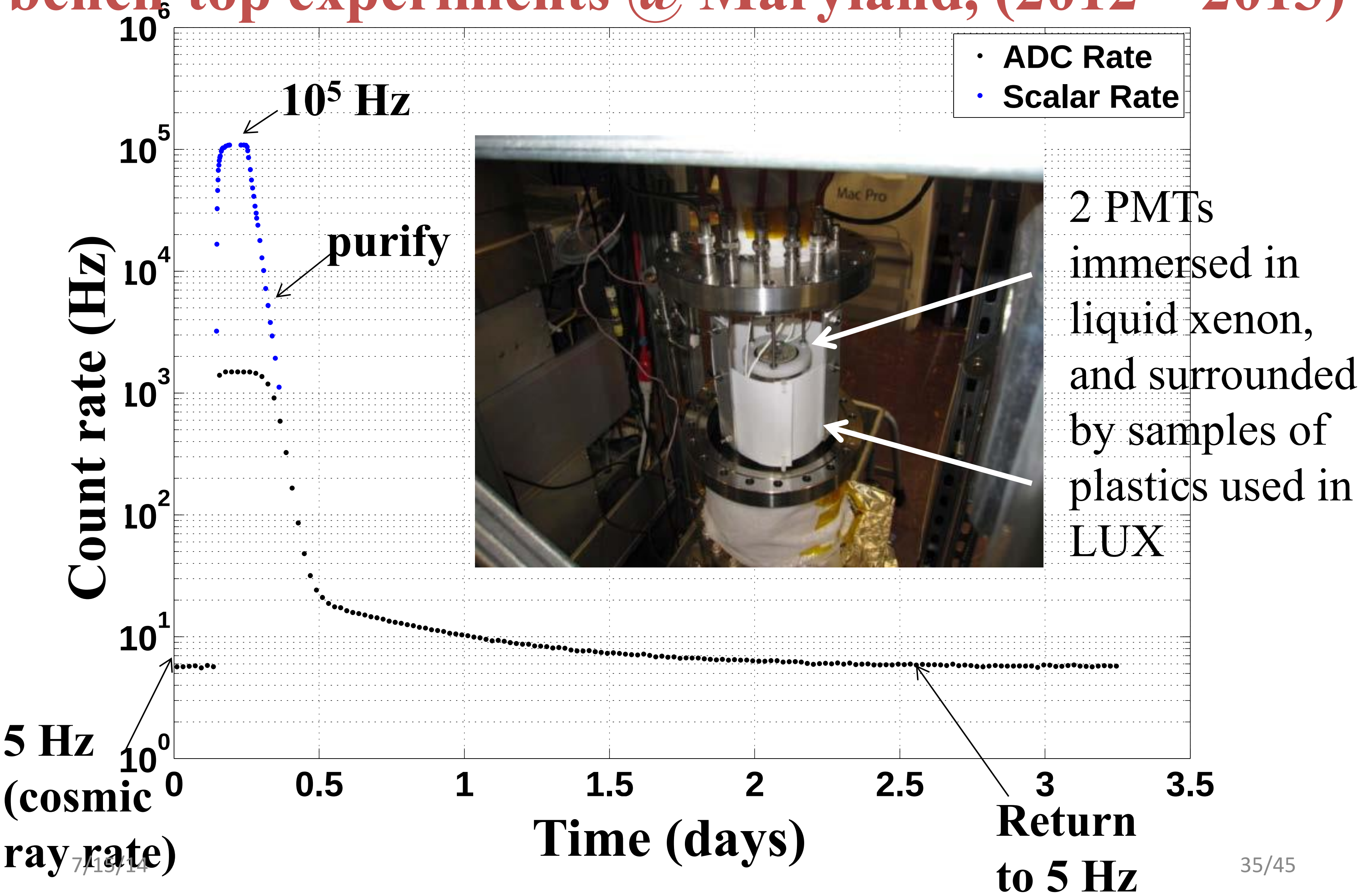
- Measure ^{84}Kr and to infer ^{nat}Kr/Xe
- Assume atmospheric abundance: ^{85}Kr/^{nat}Kr ratio: 2 x 10^{-11}
- Background goal: < 5 ppt Kr/Xe
- By the time ^{85}Kr decays show up in data analysis… It's too late!
  Set Xenon100 back a year
  (1 liter of air is all it takes)



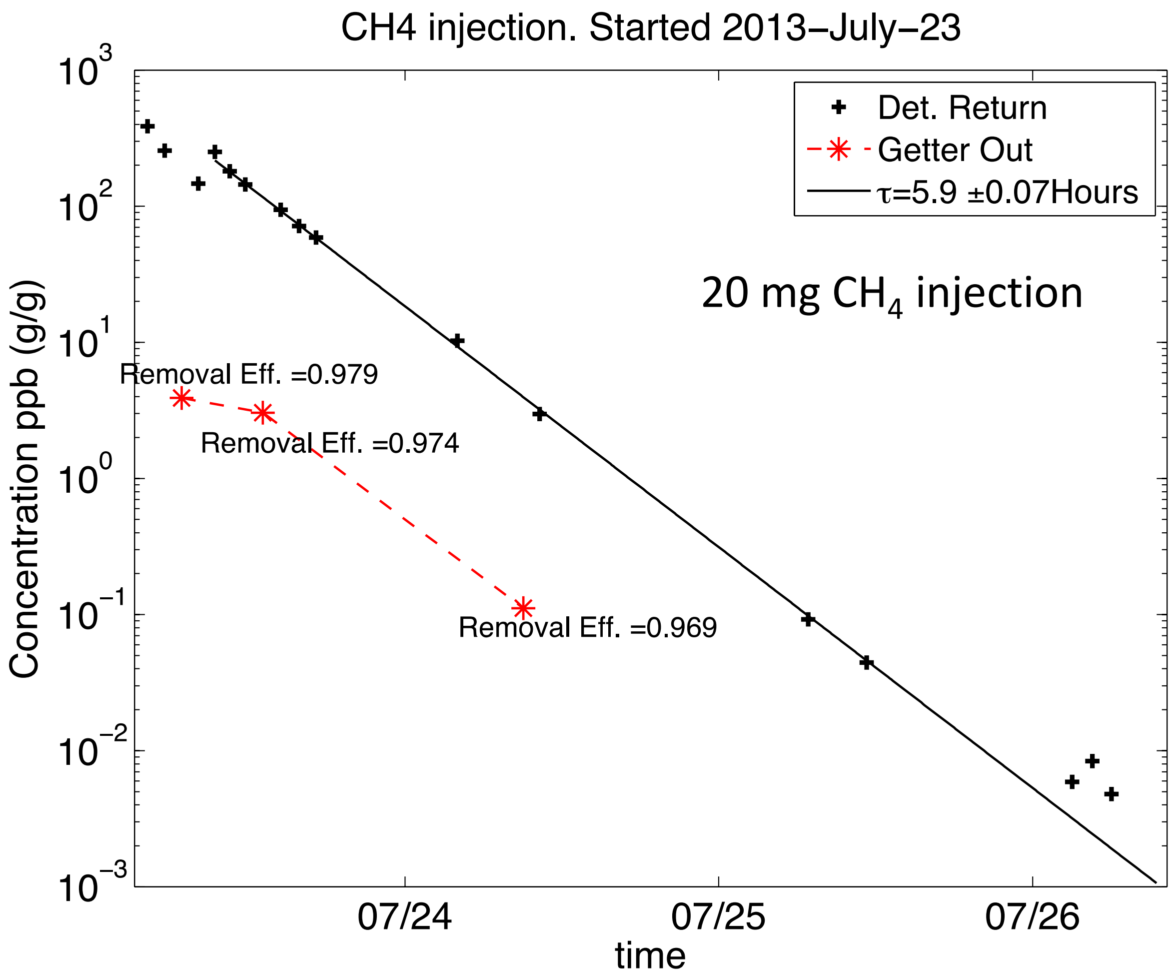
Source	Background Rate [mDRU$_{ee}$]
γ rays	$1.8 \pm 0.2_{\mathrm{stat}} \pm 0.3_{\mathrm{sys}}$
^{127}Xe	$0.5 \pm 0.02_{\mathrm{stat}} \pm 0.1_{\mathrm{sys}}$
^{214}Pb	$0.11 - 0.22$ (0.20 expected)
^{85}Kr	$0.17 \pm 0.10_{\mathrm{sys}}$
Total predicted	$2.6 \pm 0.2_{\mathrm{stat}} \pm 0.4_{\mathrm{sys}}$
Total observed	$3.6 \pm 0.3_{\mathrm{stat}}$

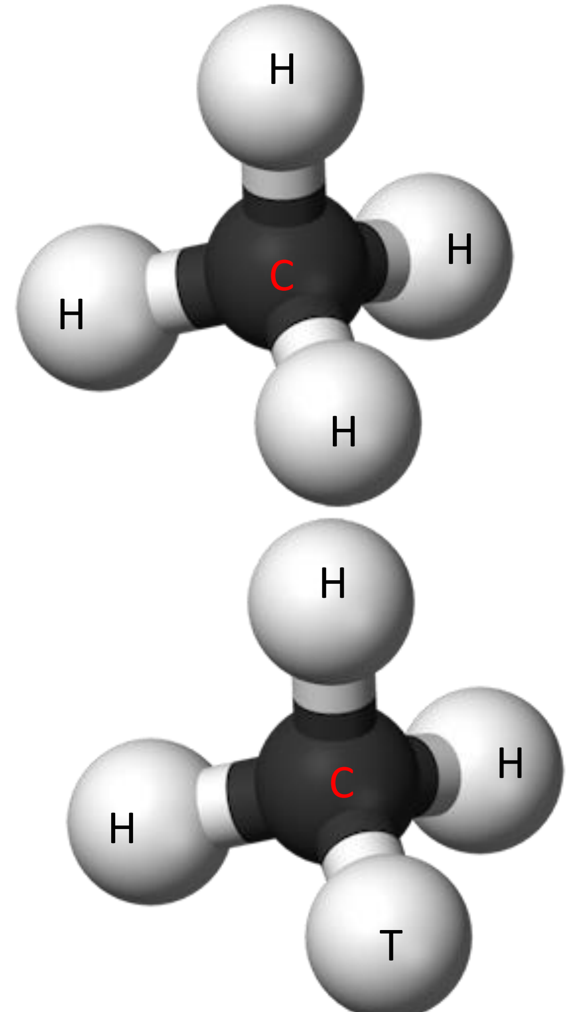
arXiv:1403.1299

Removal of ‘tritiated methane’ from liquid xenon – bench-top experiments @ Maryland, (2012 – 2013)



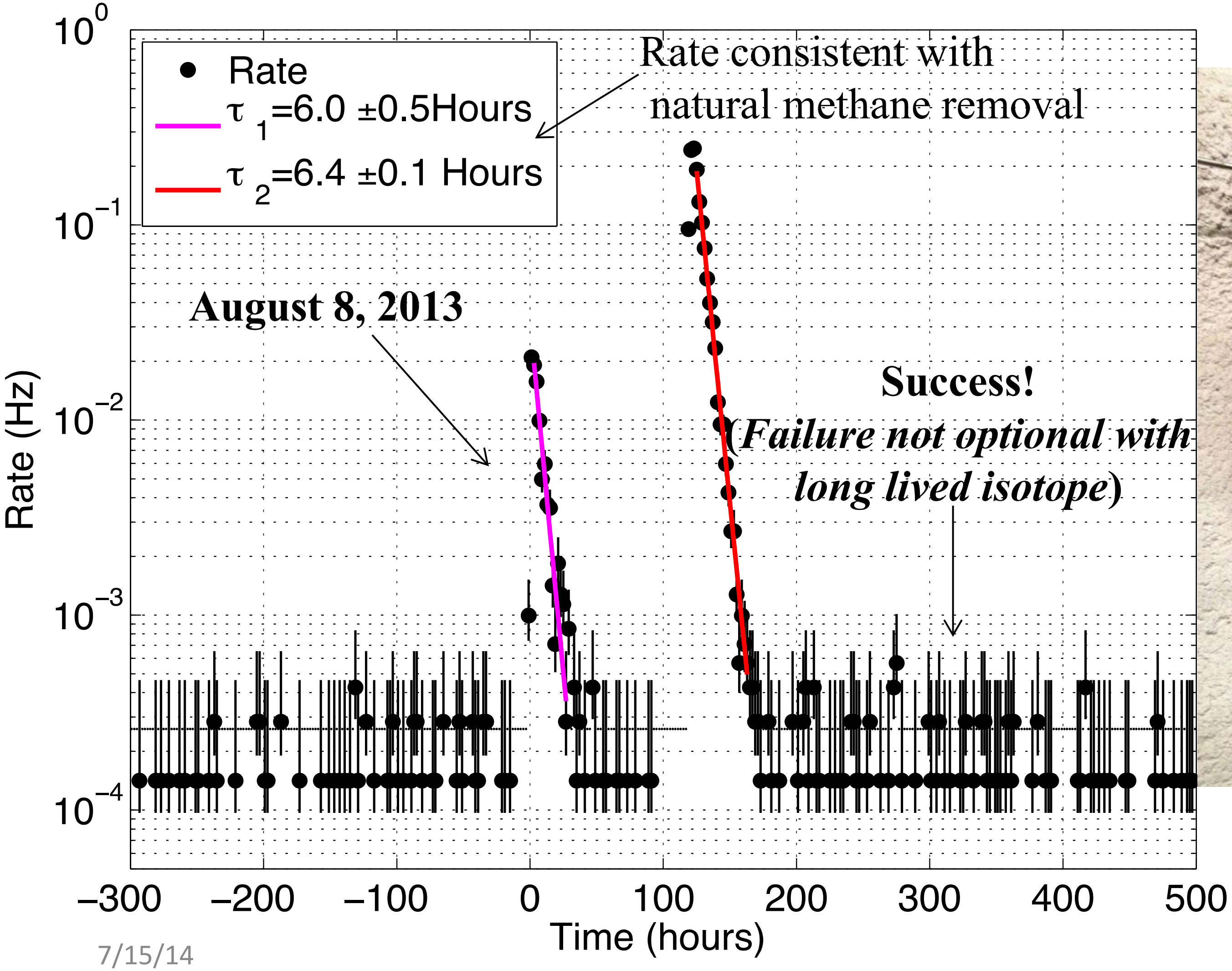
Removal of Methane from Xenon. LUX detector using the Sampling System





- Tritiated methane is chemically identical to Methane.
- Demonstrated 10^5 removal, plenty to return LUX to 5% of BG

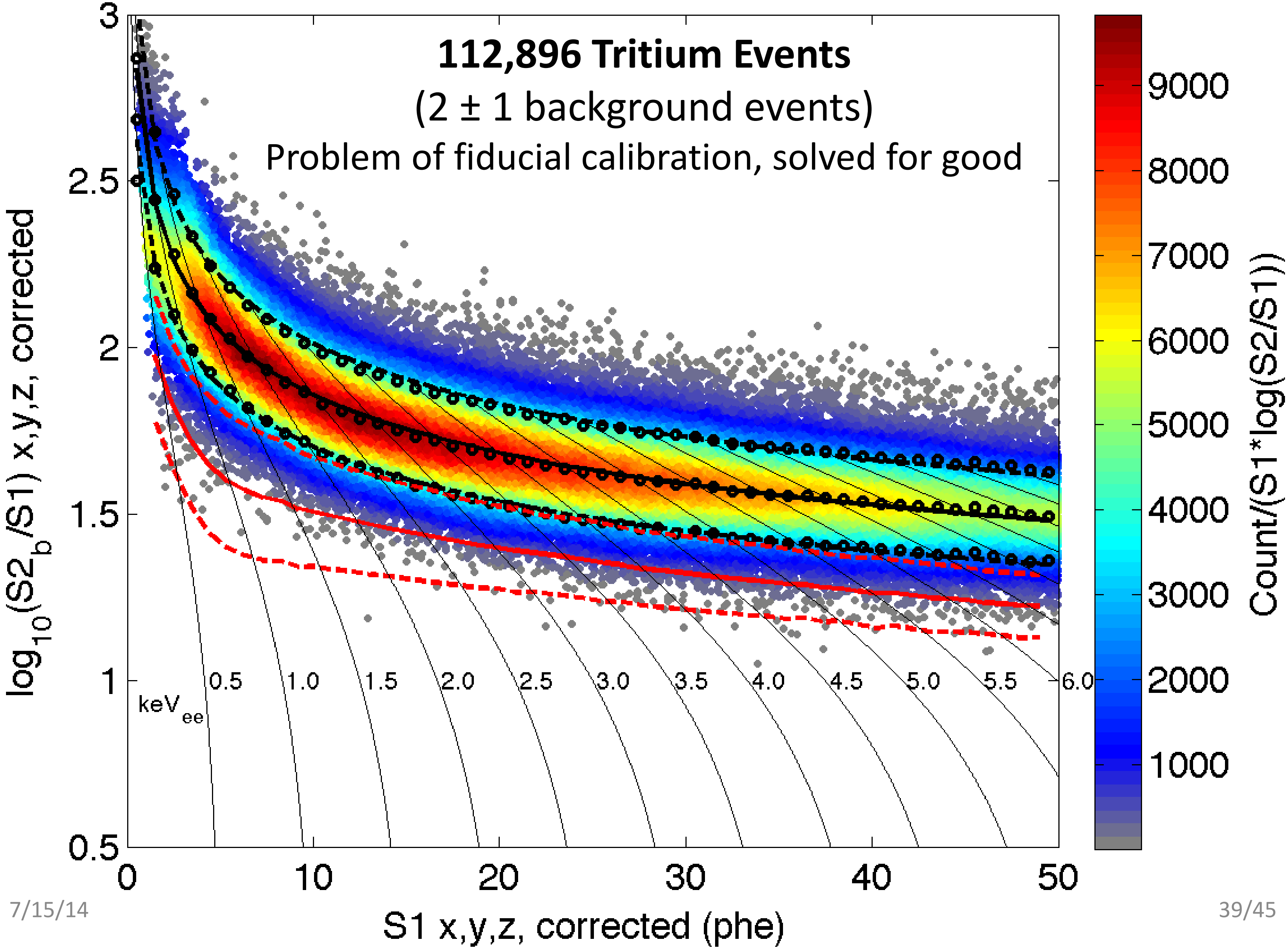
Injection and removal of tritiated methane from LUX, August 2013



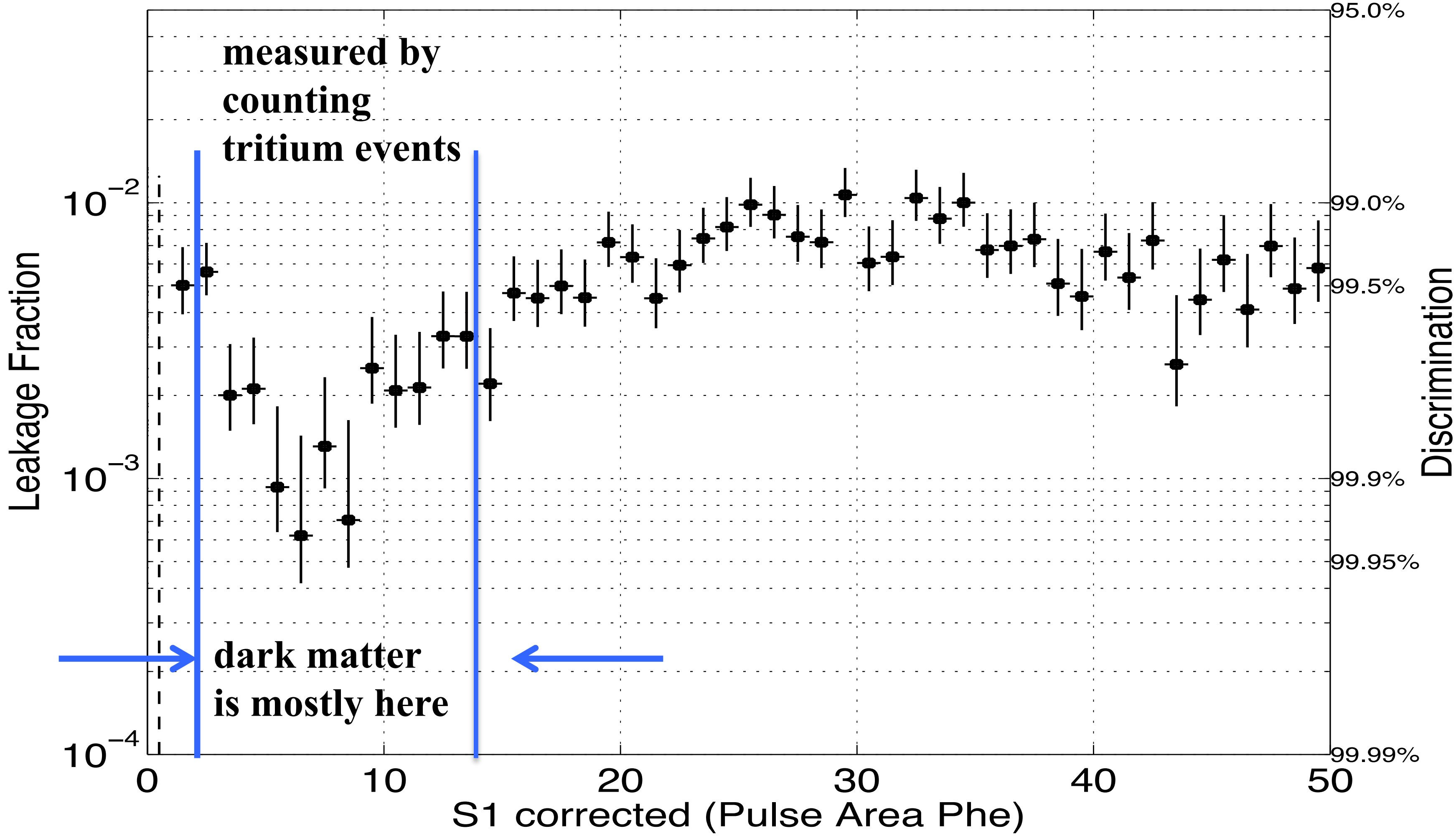
UMD/LUX tritium injection system

CH_3T Mixing in LUX

Tritium Electron-recoil calibration data



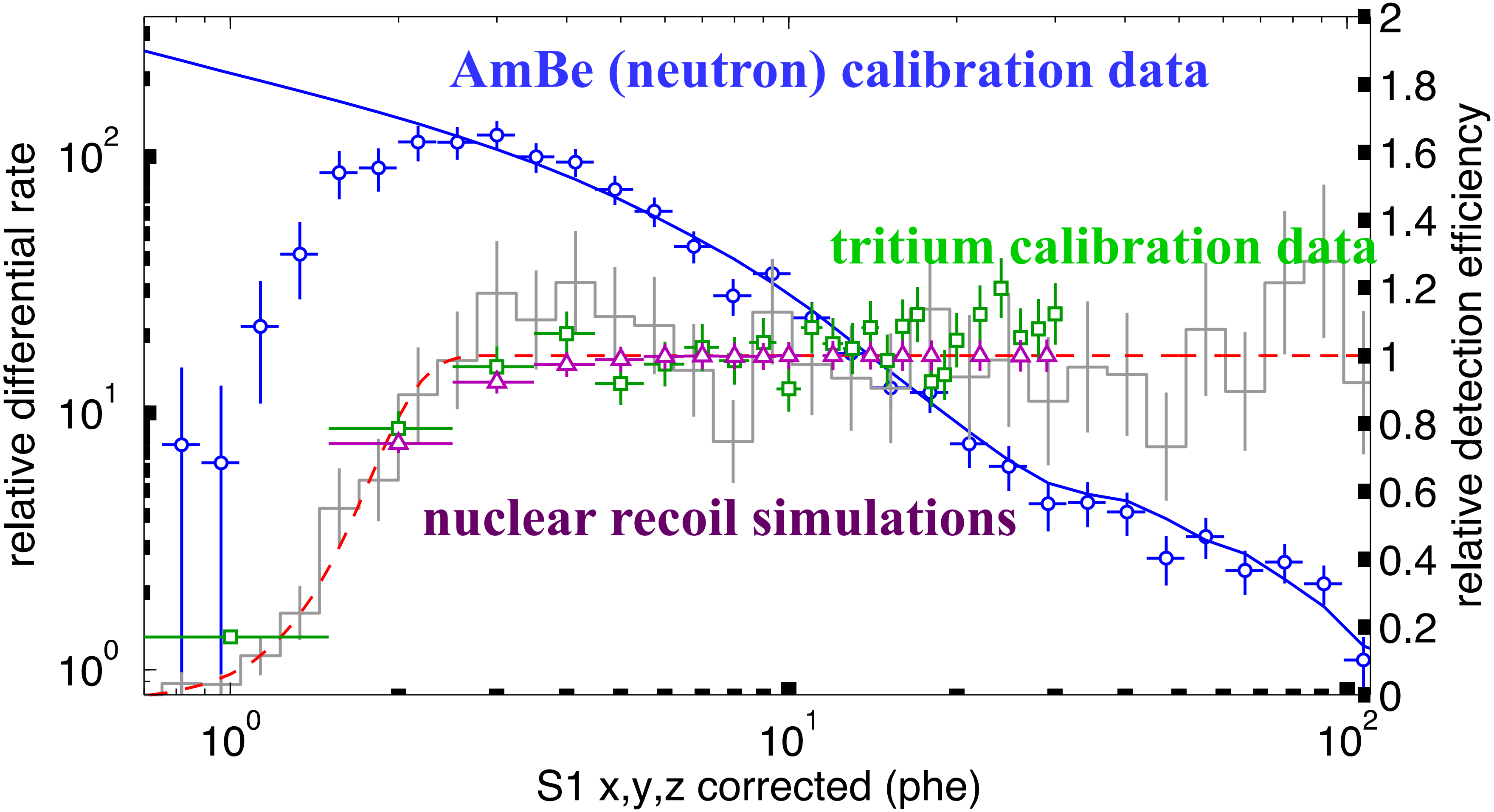
Electron-recoil discrimination figure of merit



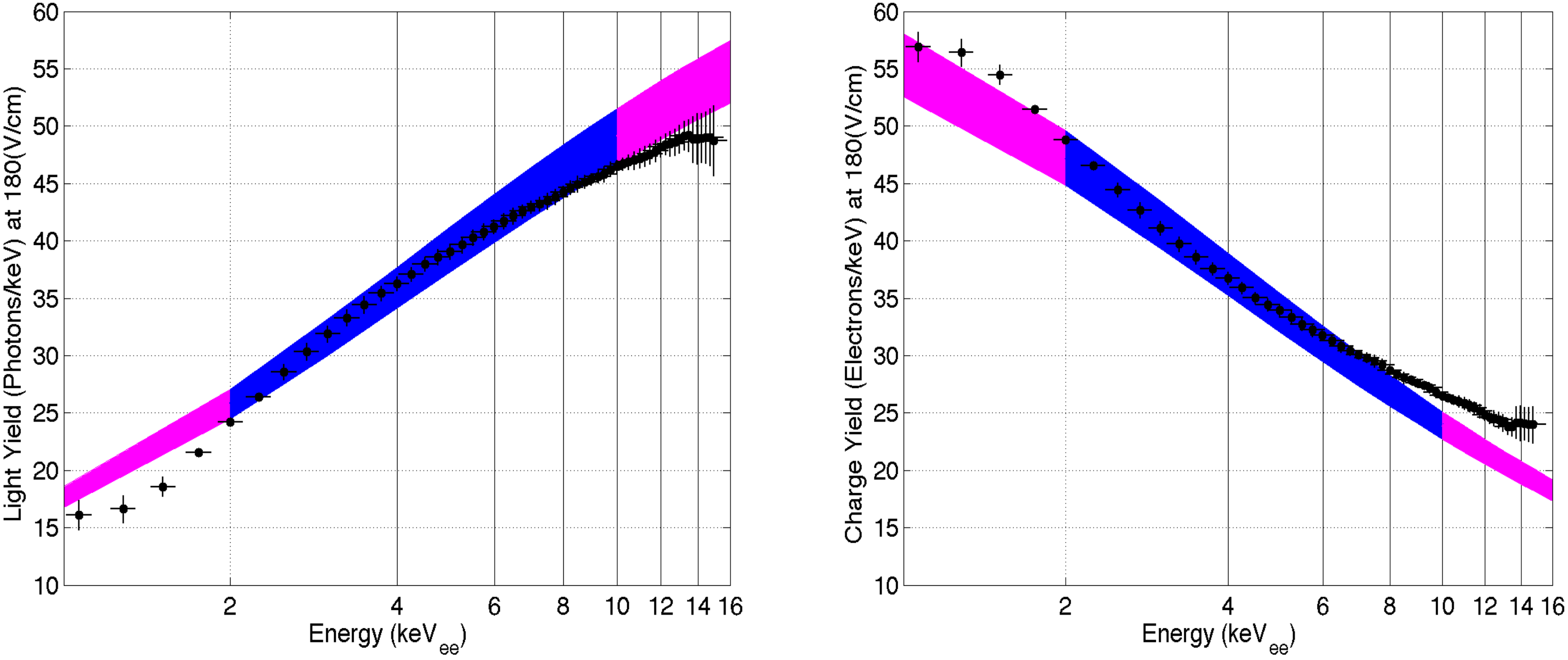
Average discrimination between 2 and 30 S1 photo-electrons measured with tritium to be 99.6% (LUX goal was 99.4%) with 50% nuclear recoil acceptance.

- Don't need to rely on Gaussian Band assumption. Can build PDF.

LUX detector threshold vs S1



Tritium. Light/Charge Yield, & NEST. 180 V/cm

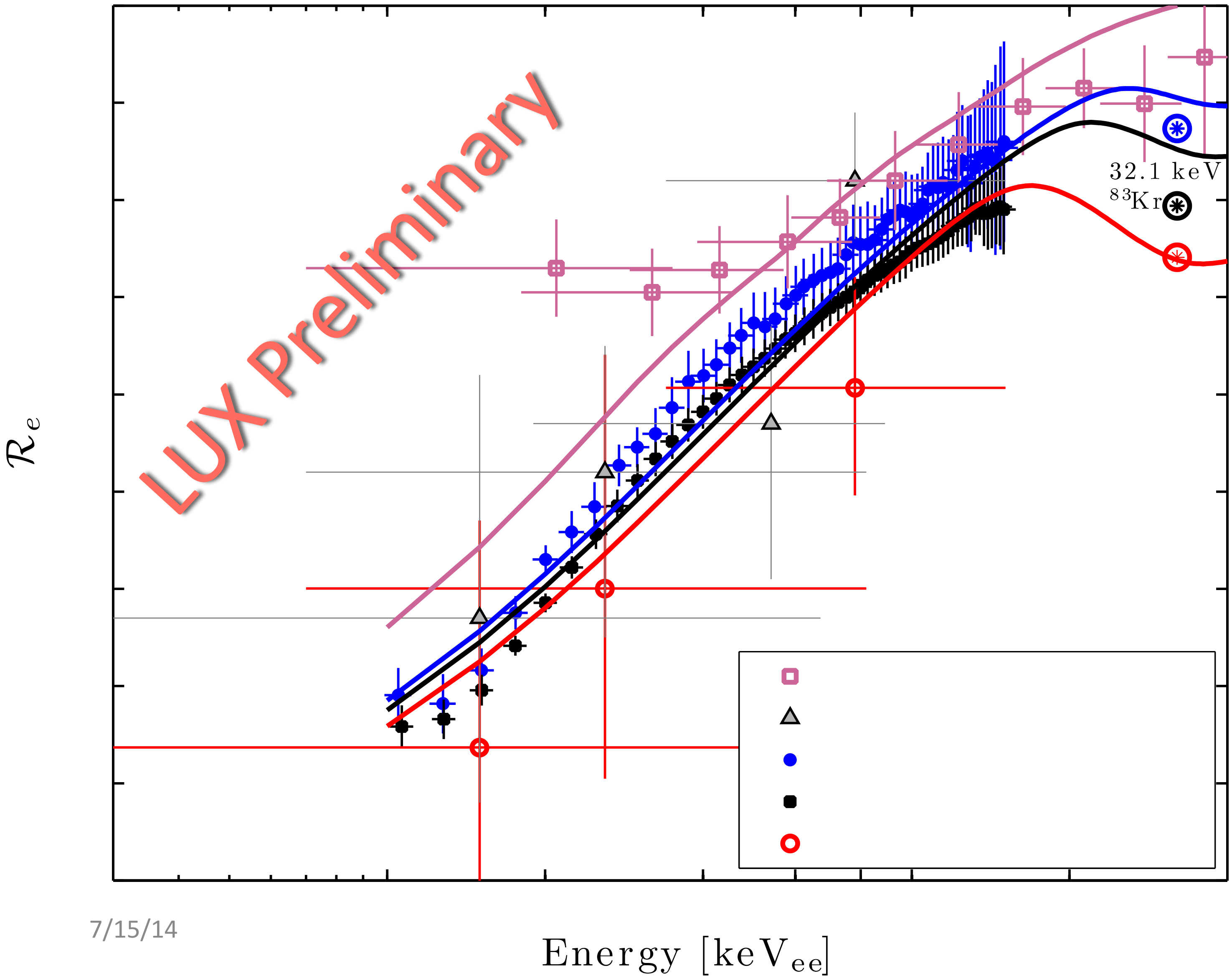


Black: Tritium Data.

Blue: NEST, region vetted by data (2-8 keV ER)

Magenta: NEST extrapolation

Light Yield from Beta decay is in good agreement with Compton scattering measurements



Solid lines represent NEST.

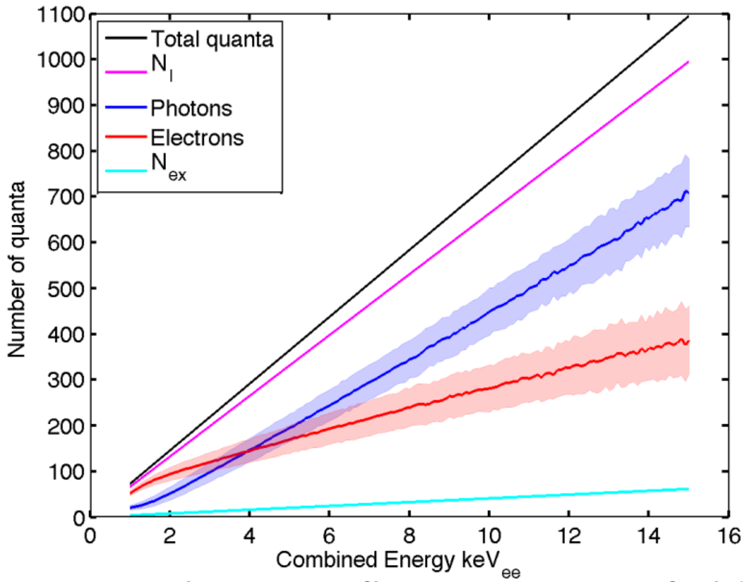
R_e== Light Yield normalized to Yield of 32.1 keV of Kr83.

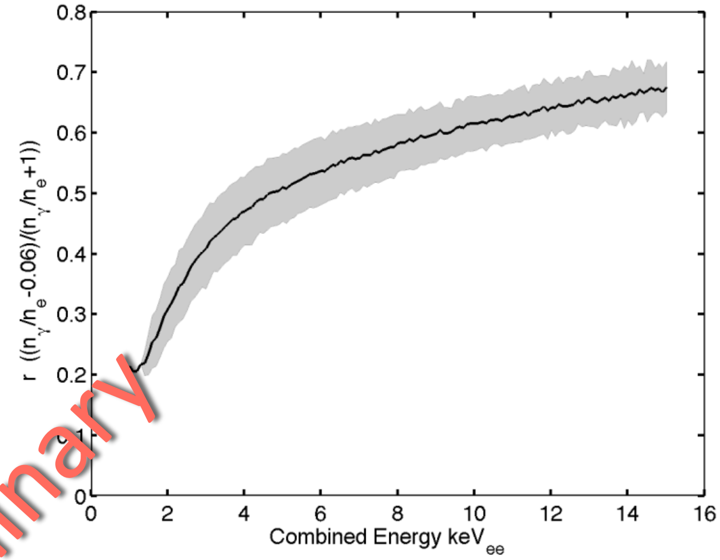
The tritium Beta calibration applies to our ER backgrounds (mainly gamma).

Sub ppt Methane in xenon does not quench light yield

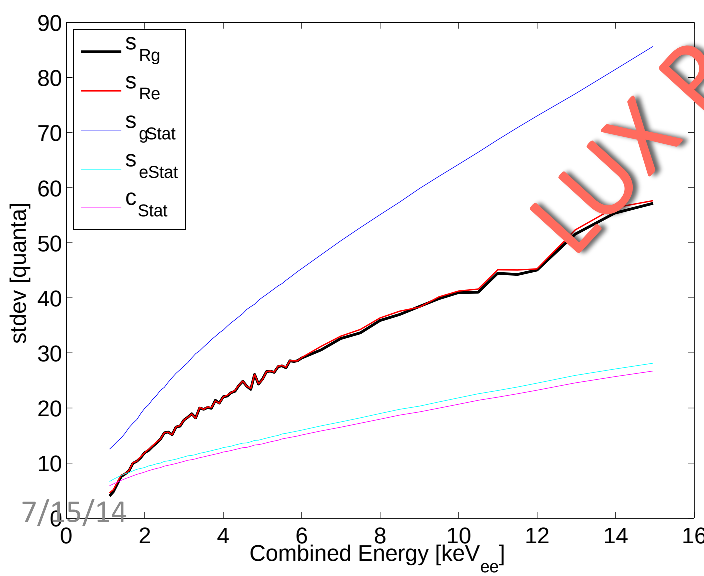
To come, LUX tritium calibration vs. Field for fundamental liquid xenon physics

Map recombination vs. field

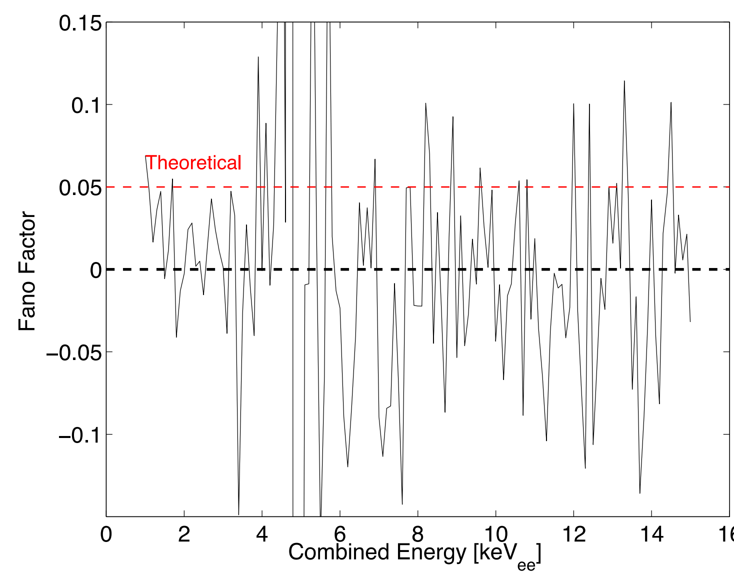




Map recombination fluctuations vs. field



Measure Fano factor in LXe with more Stats



LUX Preliminary

LUX Collaboration

Back Up Slides

LUX
Xe detector firsts/future:

External low energy calibration of 100 kg scale Xe detector impossible
Tritium ER calibration solves the problem.

Sub ppt detection of Kr in Xenon is possible, and has been successfully demonstrated in LUX. Allows for an independent check of internal radio active background while keeping data analysis blinded.

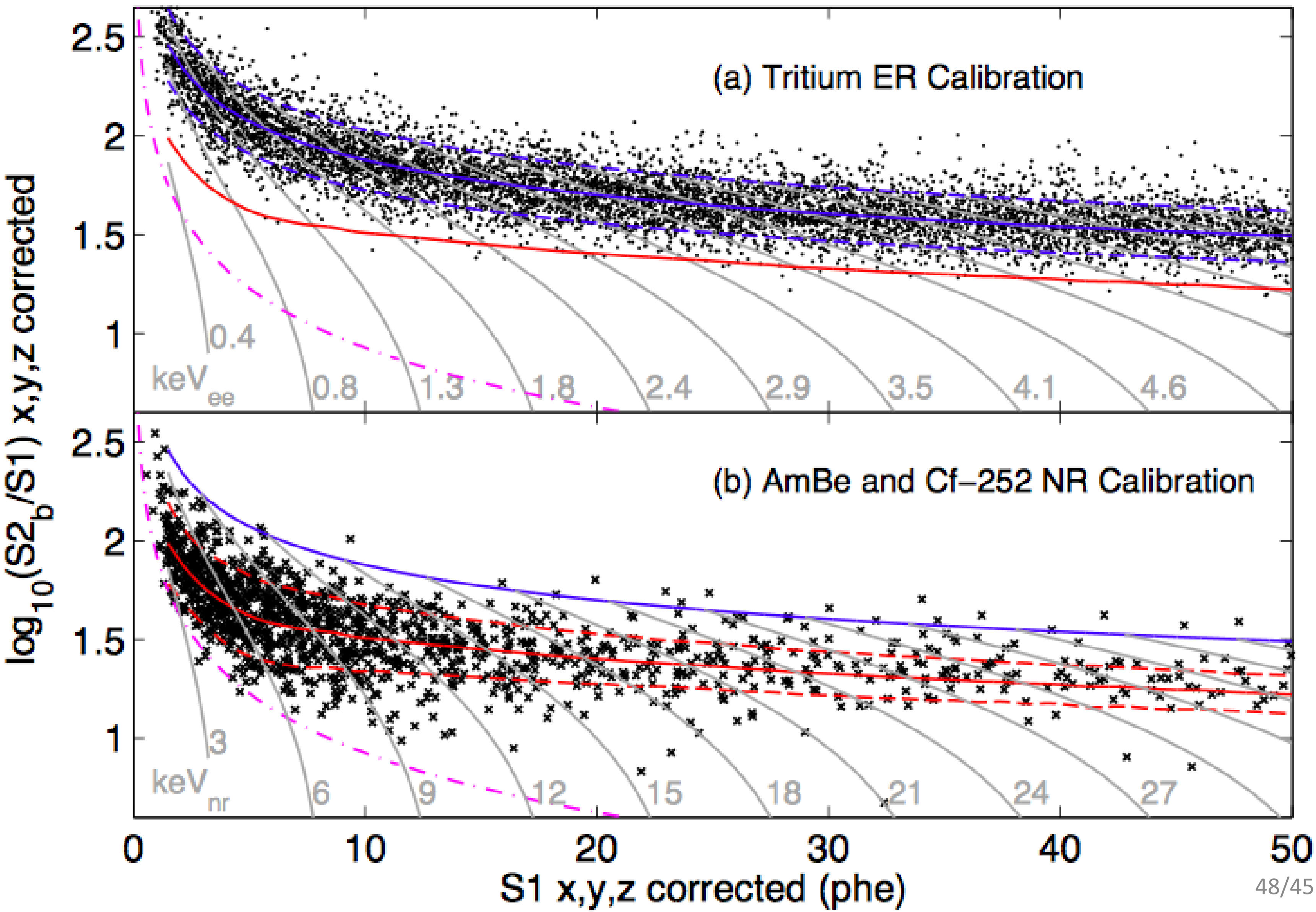
LUX has demonstrated a method for in situ gas analysis. Xenon purity is checked at every step of the way. Each bottle transfer, each compression, daily when circulating. There is no room for error. Only 0.5 L of air means months of Kr removal!

Tritium calibration can be used to measure: Light Yield, Charge Yield, Recombination.

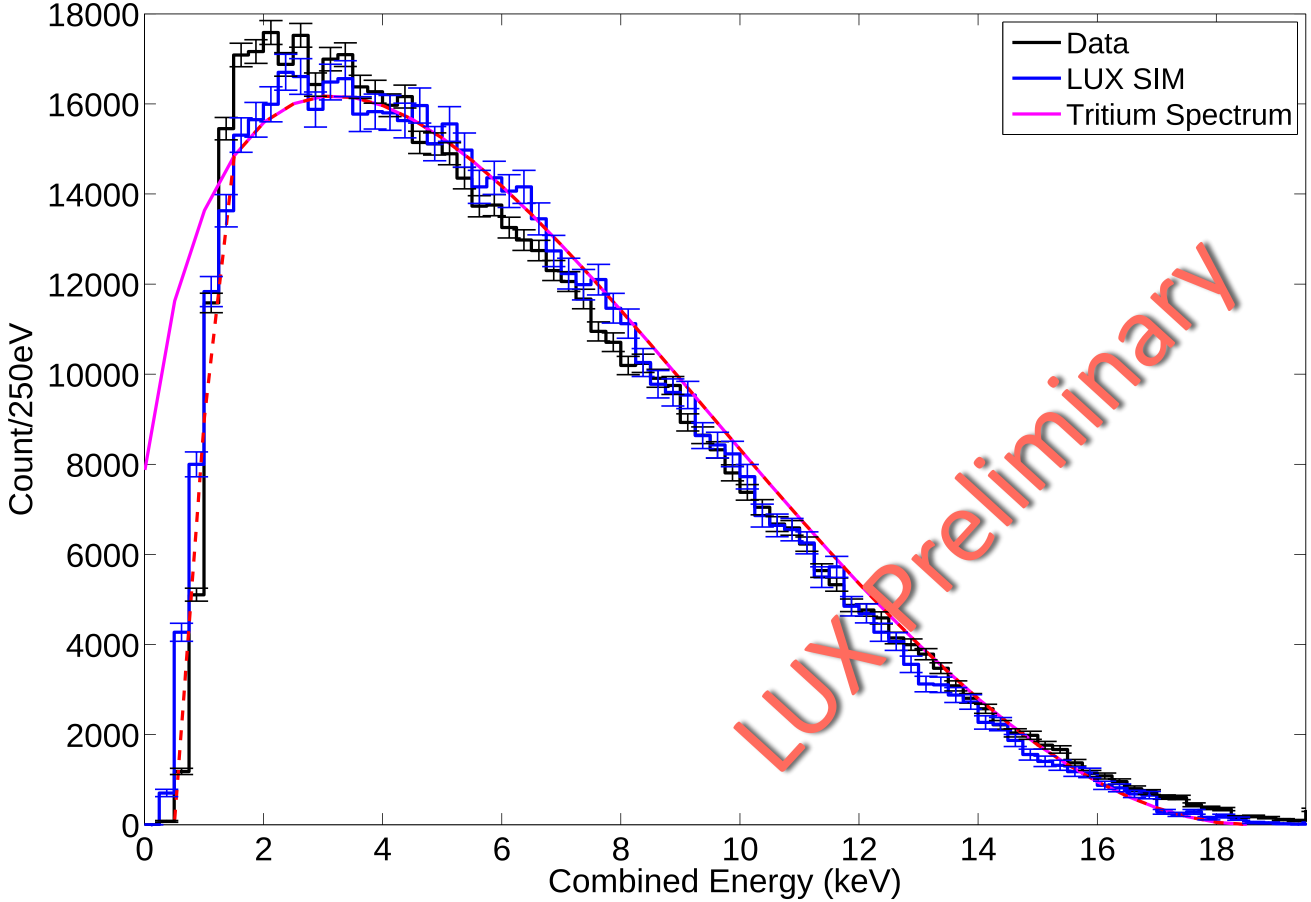
Low energy field dependence of discrimination (Background Rejection) is unknown. Tritium data at many drift-fields will reveal the answer…

Current thinking: Higher field → better WIMP result. In reality not understood at low energies (sub 2 keVee). Experiments will have to find a balance between S1 threshold (low field) and discrimination (maybe higher field) for optimal WIMP search result.

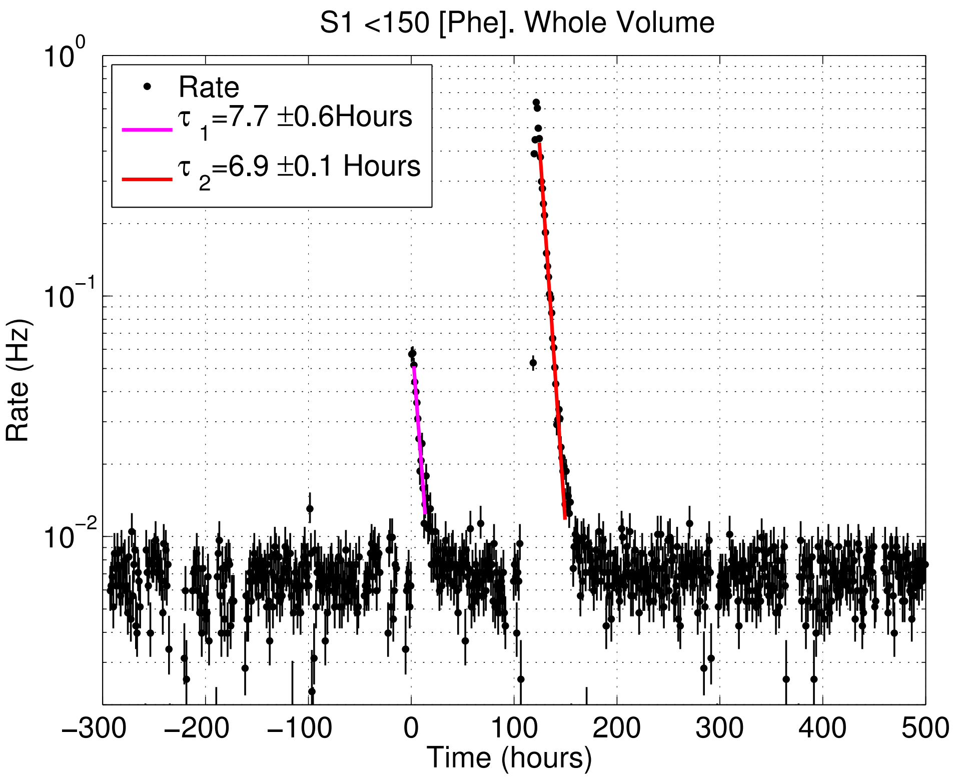
LUX Run03 Calibration

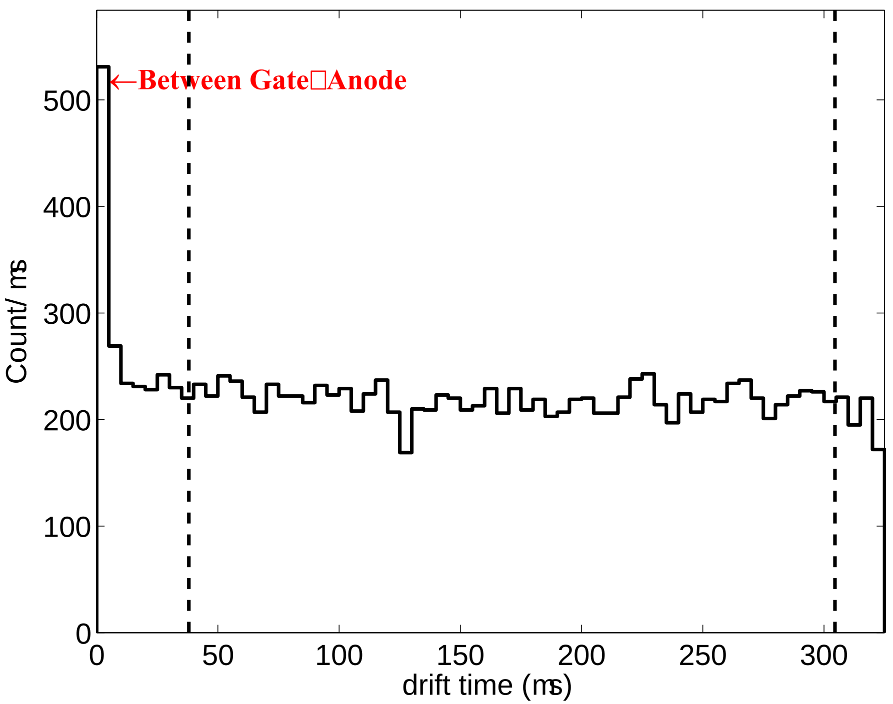


Tritium Spectrum



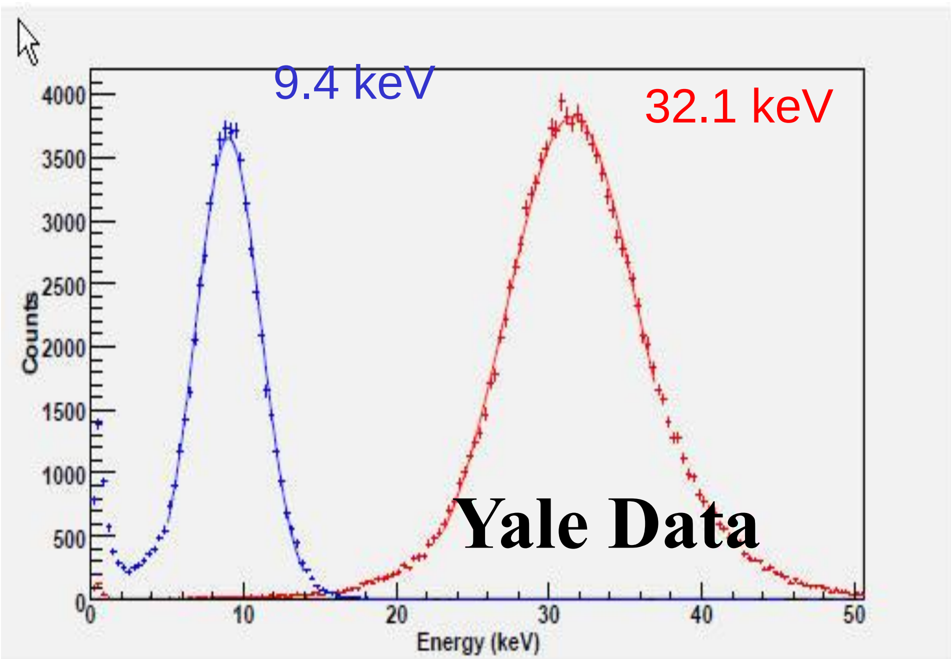
Tritium Rate and Z distribution





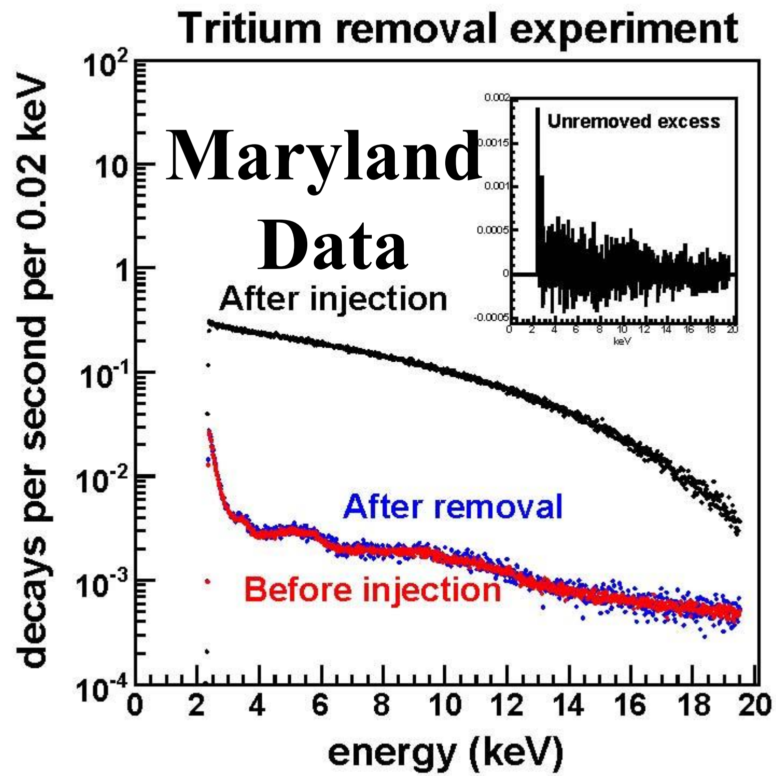
Internal calibration sources: ^{83m}Kr and Tritium - Dissolve them directly in the liquid xenon

83mKr conversion electrons
($T_{1/2}$ = 1.86 hours)



L. Kastens et al., Phys. Rev. C80: 045809,2009,
A. Manalaysay et al., Rev. Sci. Instr. 81, 073303 (2010)

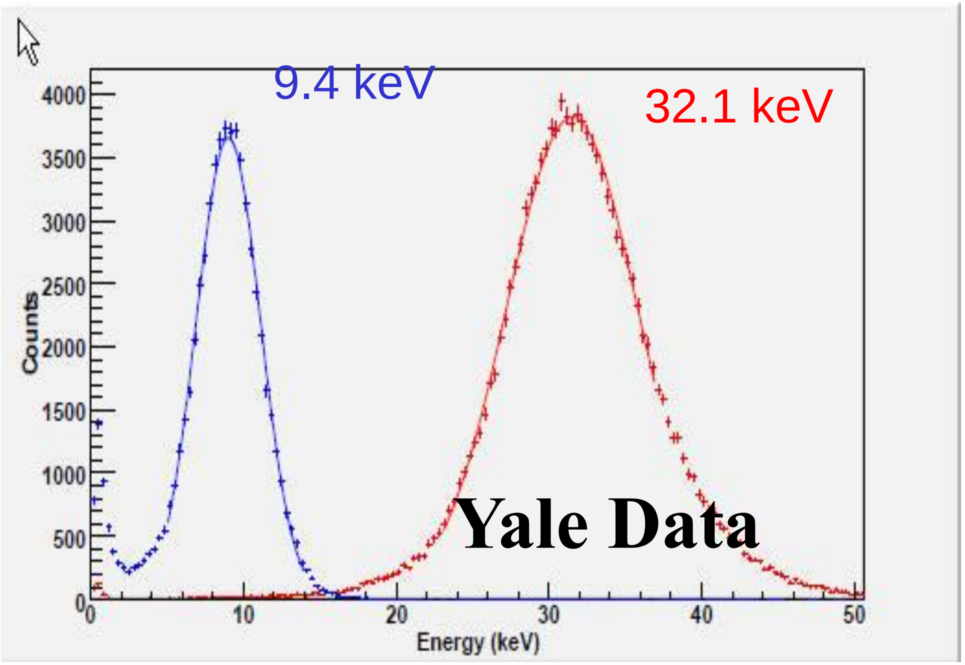
Tritium beta decay ($T_{1/2}$ = 12.6 yrs)



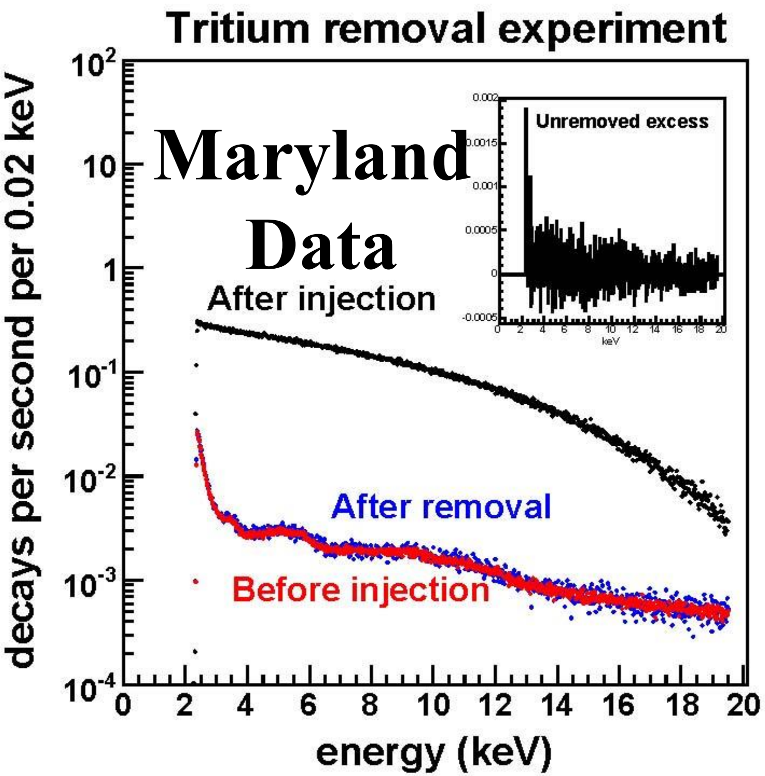
- Chemical form is CH_3T
- Remove with zirconium getter
- Dozens of tritium injection & removal experiments performed
- One-pass removal efficiency > 99%

Internal calibration sources: ^{83m}Kr and Tritium

83mKr conversion electrons ($T_{1/2}$ = 1.86 hours)



Tritium beta decay ($T_{1/2}$ = 12.6 yrs)



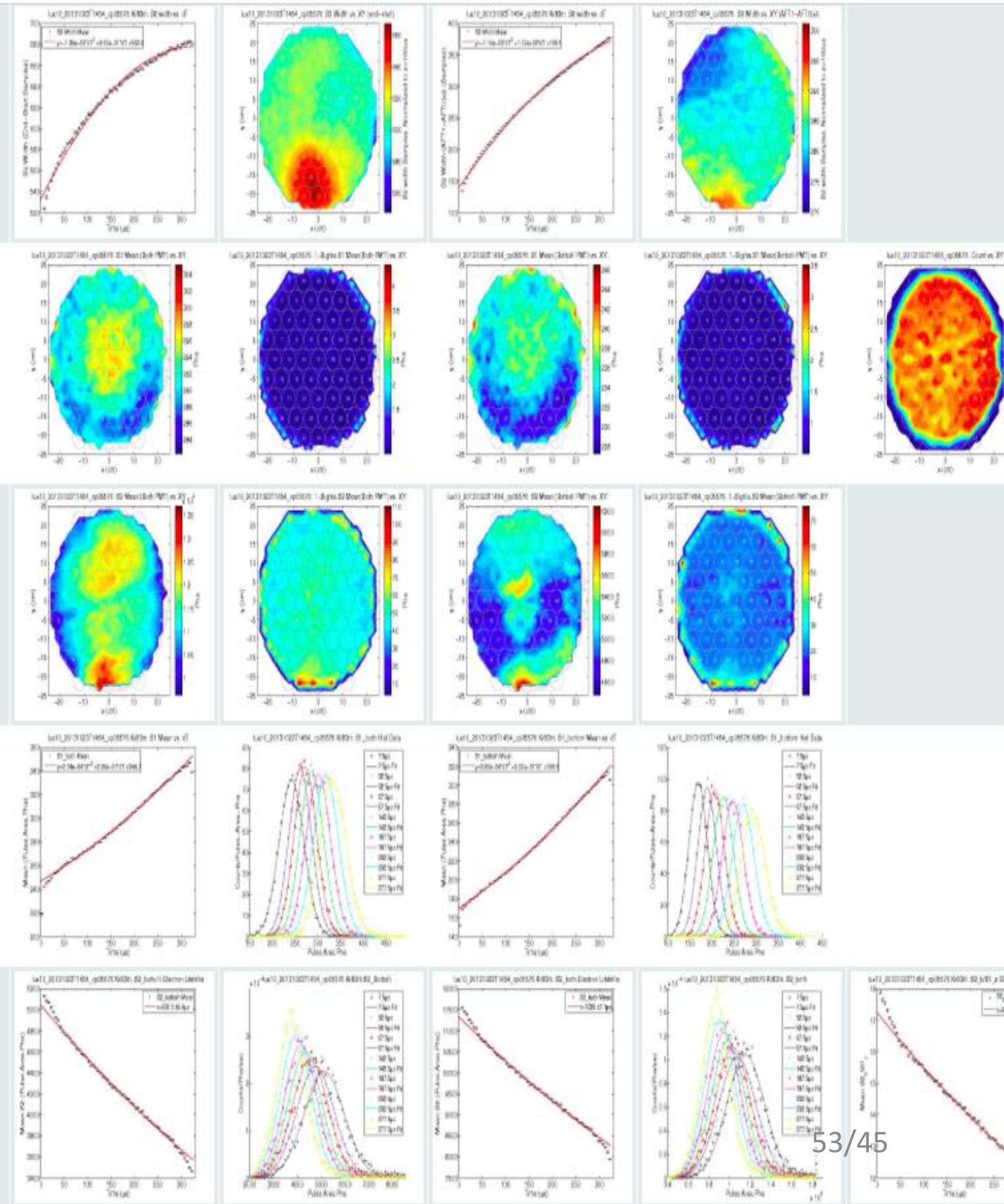
- Periodic measurement of the detector's scintillation collection function and free electron lifetime with high statistics

- Ideal source for determination of the detector's electron recoil band and low energy threshold

Kr-83m Calibration

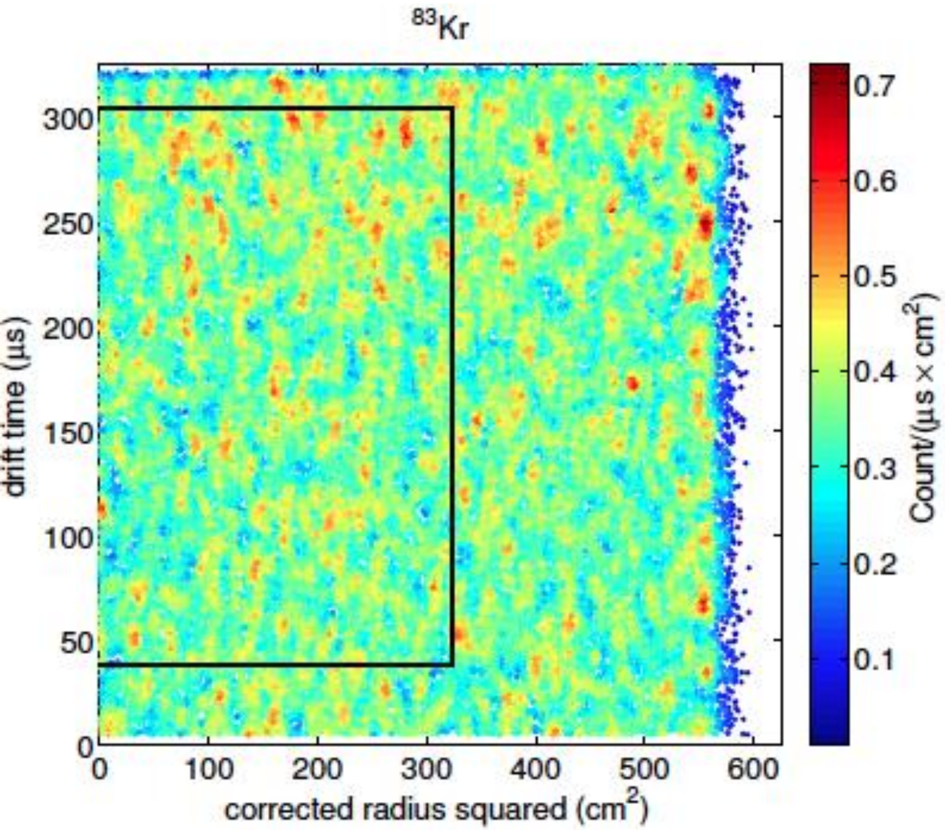
Weekly calibrations are used for XYZ corrections

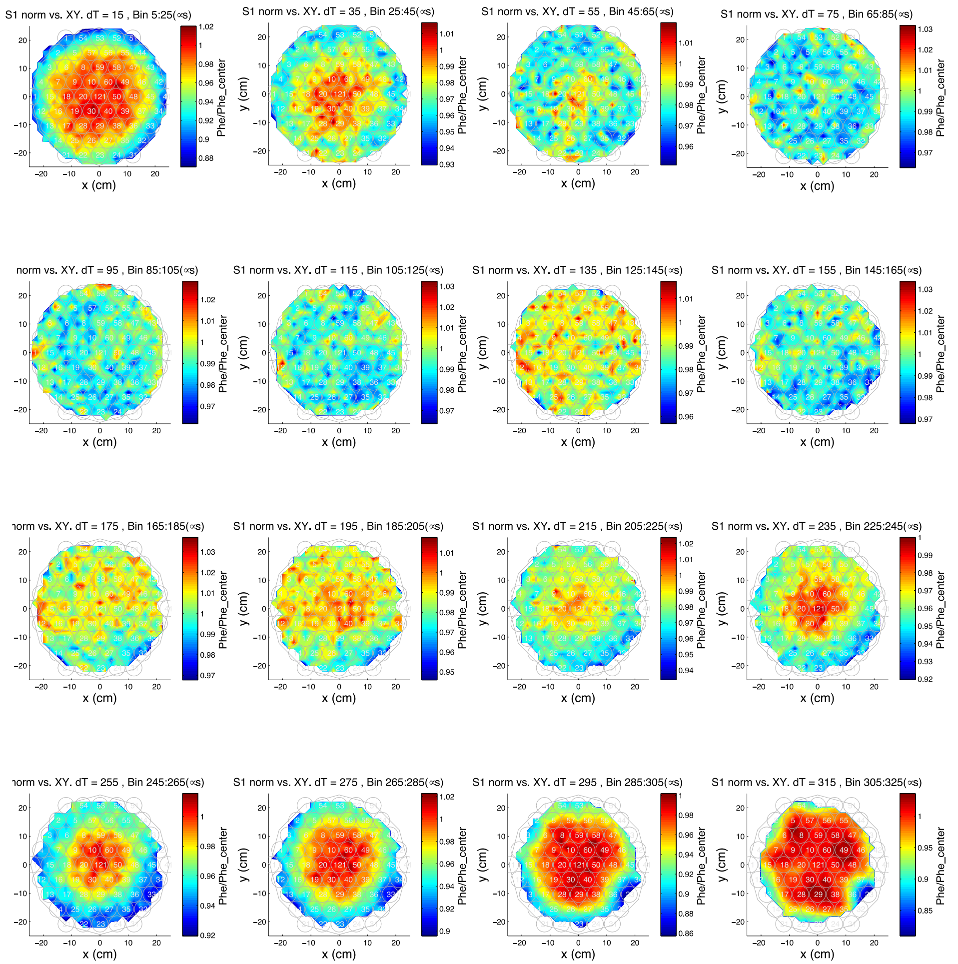
s2_width_kr **S2 width**	LUXkrypCal	1.30	Kr-83	<iq> <global> <filename_prefix>lux10_20131023T1454</filename_prefix> <computed_by>AttilaDobi</computed_by> <computed_date>20131030T2021</computed_date> <source>Kr-83</source> <source_id>unknown</source_id> <notes> </notes> <algorithm_name>L More ...	Kr83 Calibration	
s1_xy_correction **S1 XY**	LUXkrypCal	1.30	Kr-83	<iq> <global> <filename_prefix>lux10_20131023T1454</filename_prefix> <cp_number>05576</cp_number> <gs_number>815</gs_number> <computed_by>AttilaDobi</computed_by> <computed_date>20131030T2021</computed_date> <source>Kr-83</source> <source_i More ...	Kr83 Calibration	
s2_xy_correction **S2 XY**	LUXkrypCal	1.30	Kr-83	<iq> <global> <filename_prefix>lux10_20131023T1454</filename_prefix> <cp_number>05576</cp_number> <gs_number>815</gs_number> <computed_by>AttilaDobi</computed_by> <computed_date>20131030T2021</computed_date> <source>Kr-83</source> <source_i More ...	Kr83 Calibration	
z_dep_s1_correction **S1 Z**	LUXkrypCal	1.30	Kr-83	<iq> <global> <filename_prefix>lux10_20131023T1454</filename_prefix> <cp_number>05576</cp_number> <gs_number>815</gs_number> <computed_by>AttilaDobi</computed_by> <computed_date>20131030T2021</computed_date> <source>Kr-83</source> <source_i More ...	Kr83 Calibration	
electron_lifetime **S2 Z**	LUXkrypCal	1.30	Kr-83	<iq> <global> <filename_prefix>lux10_20131023T1454</filename_prefix> <cp_number>05576</cp_number> <gs_number>815</gs_number> <computed_by>AttilaDobi</computed_by> <computed_date>20131030T2021</computed_date> <source>Kr-83</source> <source_i More ...	Kr83 Calibration	



XYZ Correction with Kr-83m Calibration

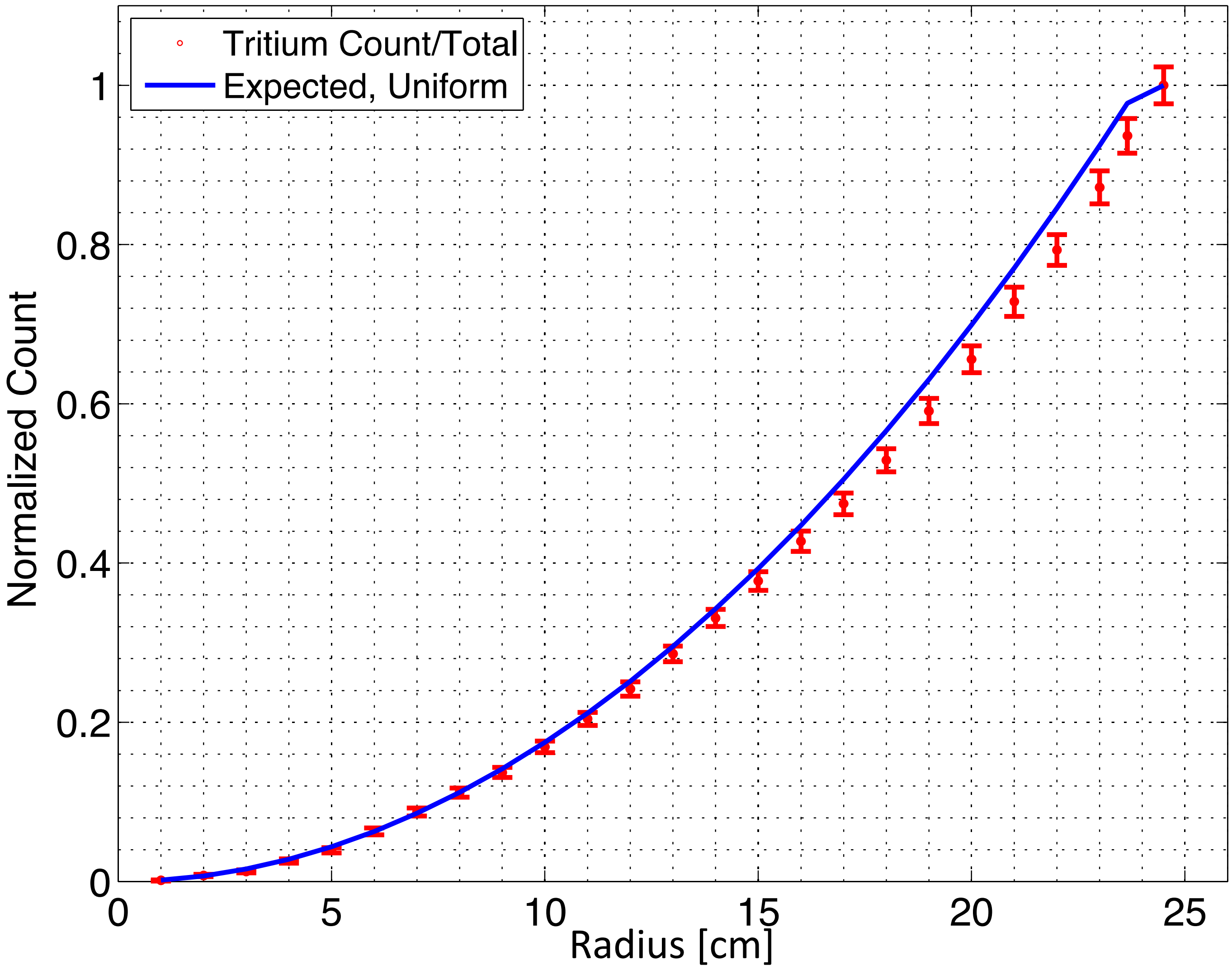
Over 1 million Kr-83m events, spread uniformly through the detector.



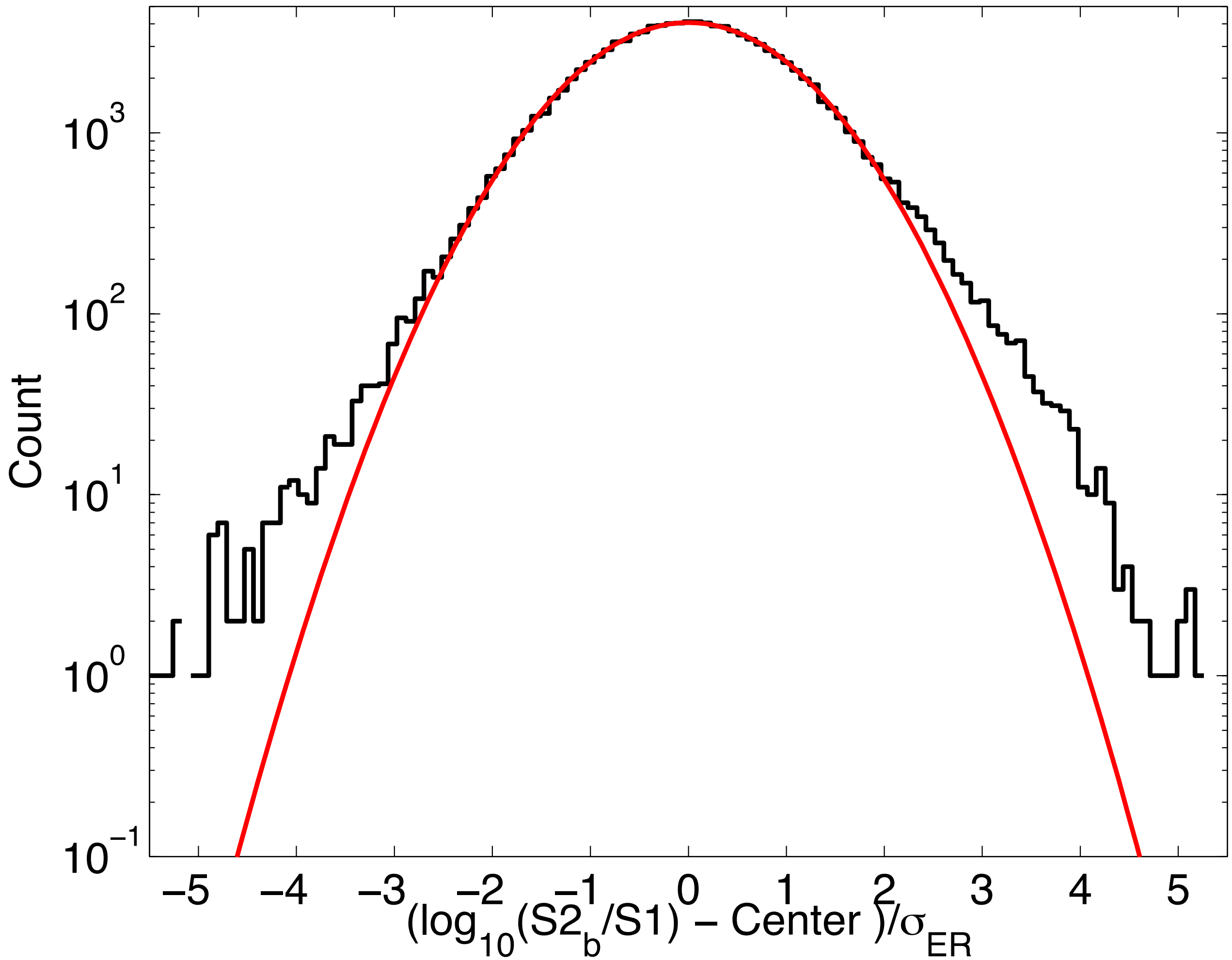


Measurement of the detector response to light.

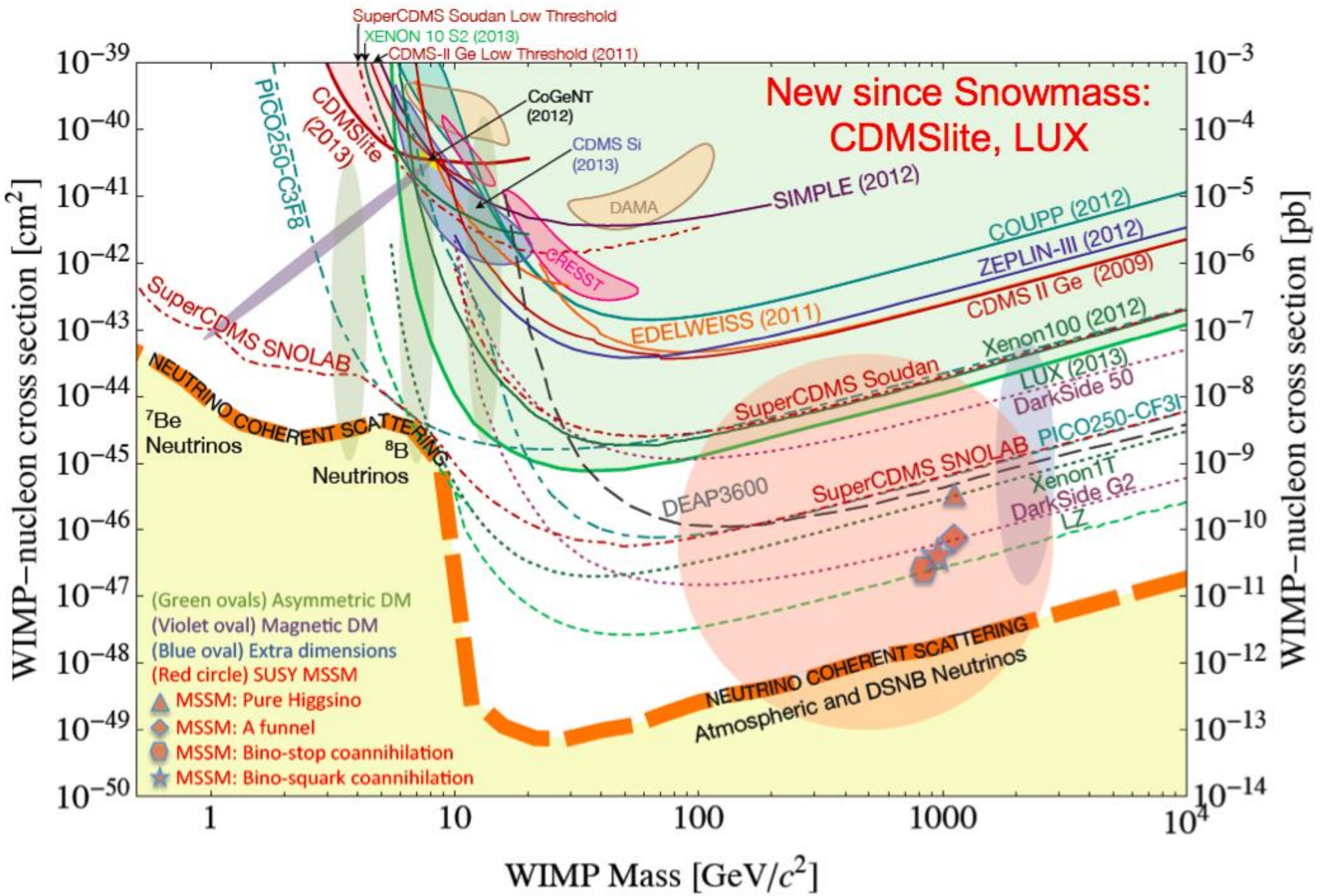
Tritium Uniformity



ER band Gaussianity, Tritium Calibration

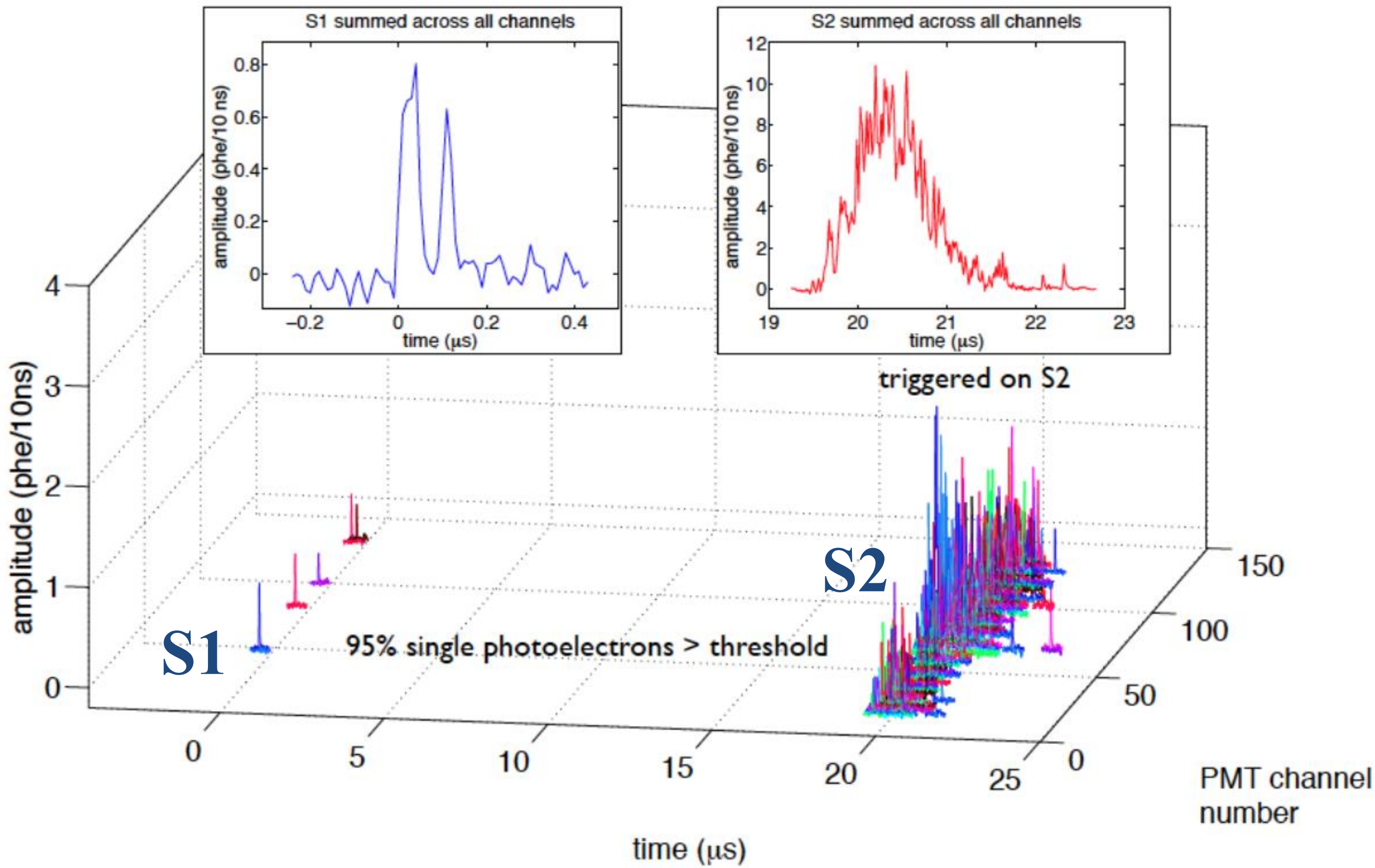


Dark Matter Direct Detection: Current and Future

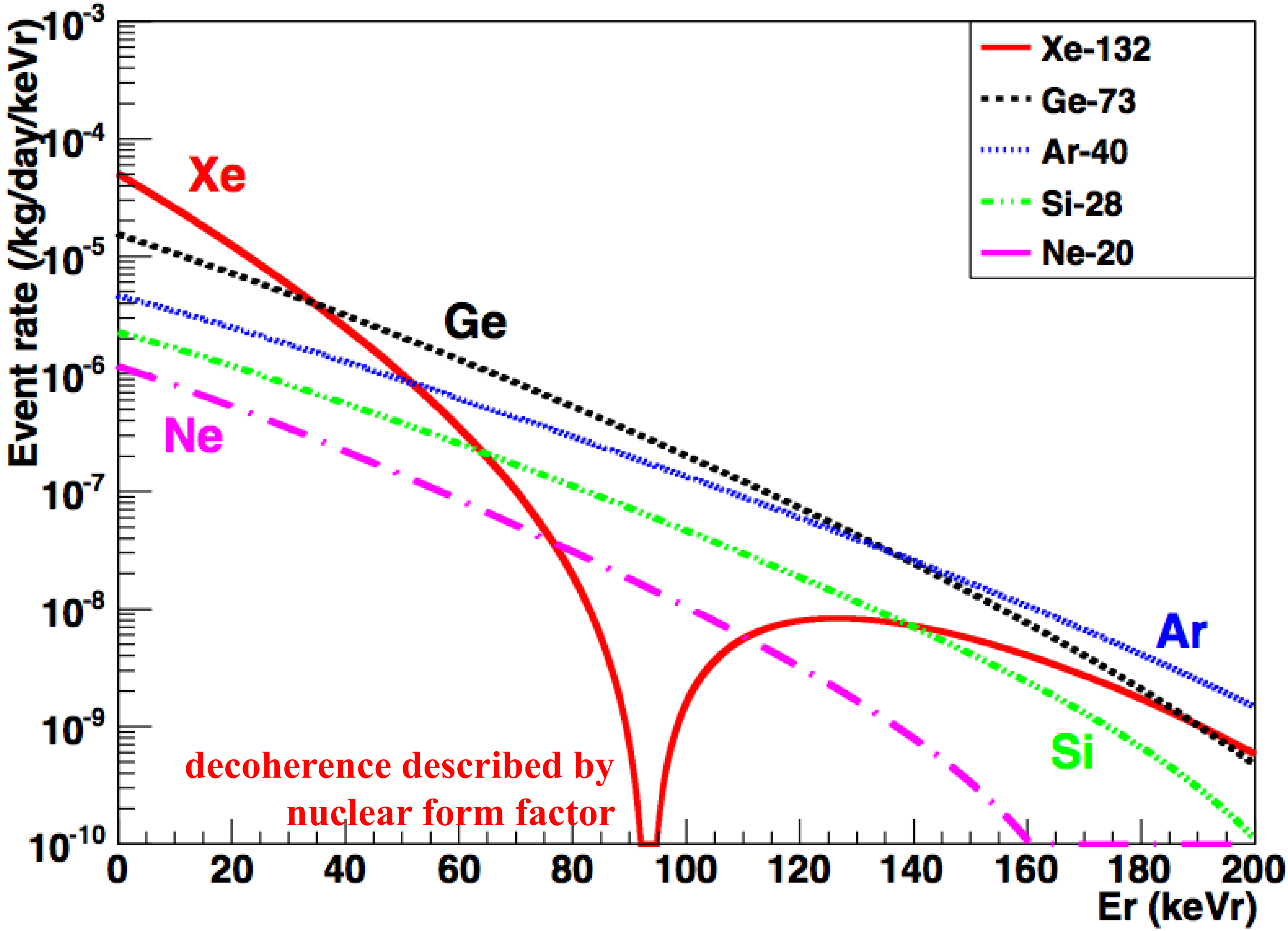


Modified from: "Snowmass CF1 Summary: WIMP Dark Matter Direct Detection", arXiv:1310:8327 (October 2013)

Typical Event in LUX

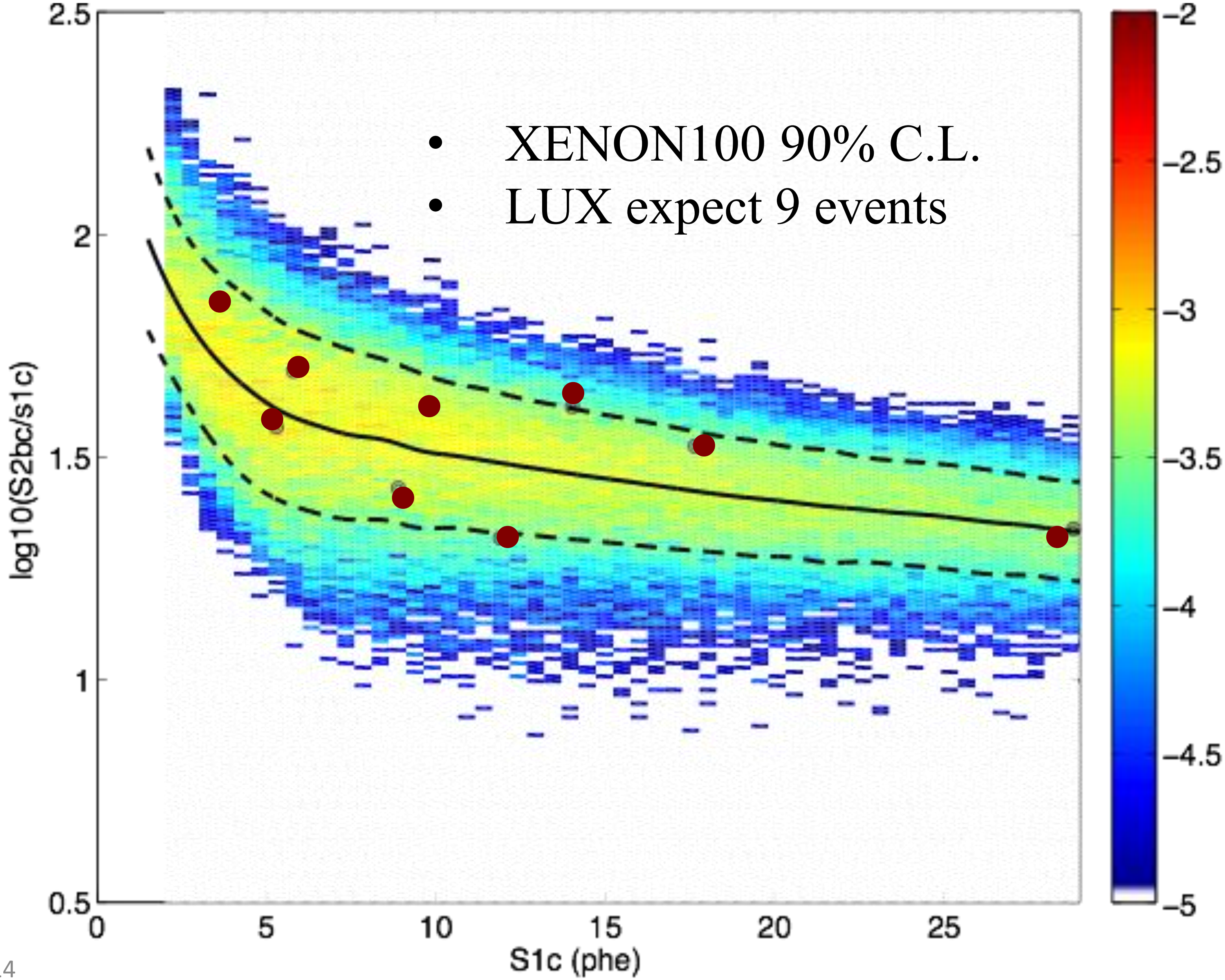


Nuclear Recoil off various targets

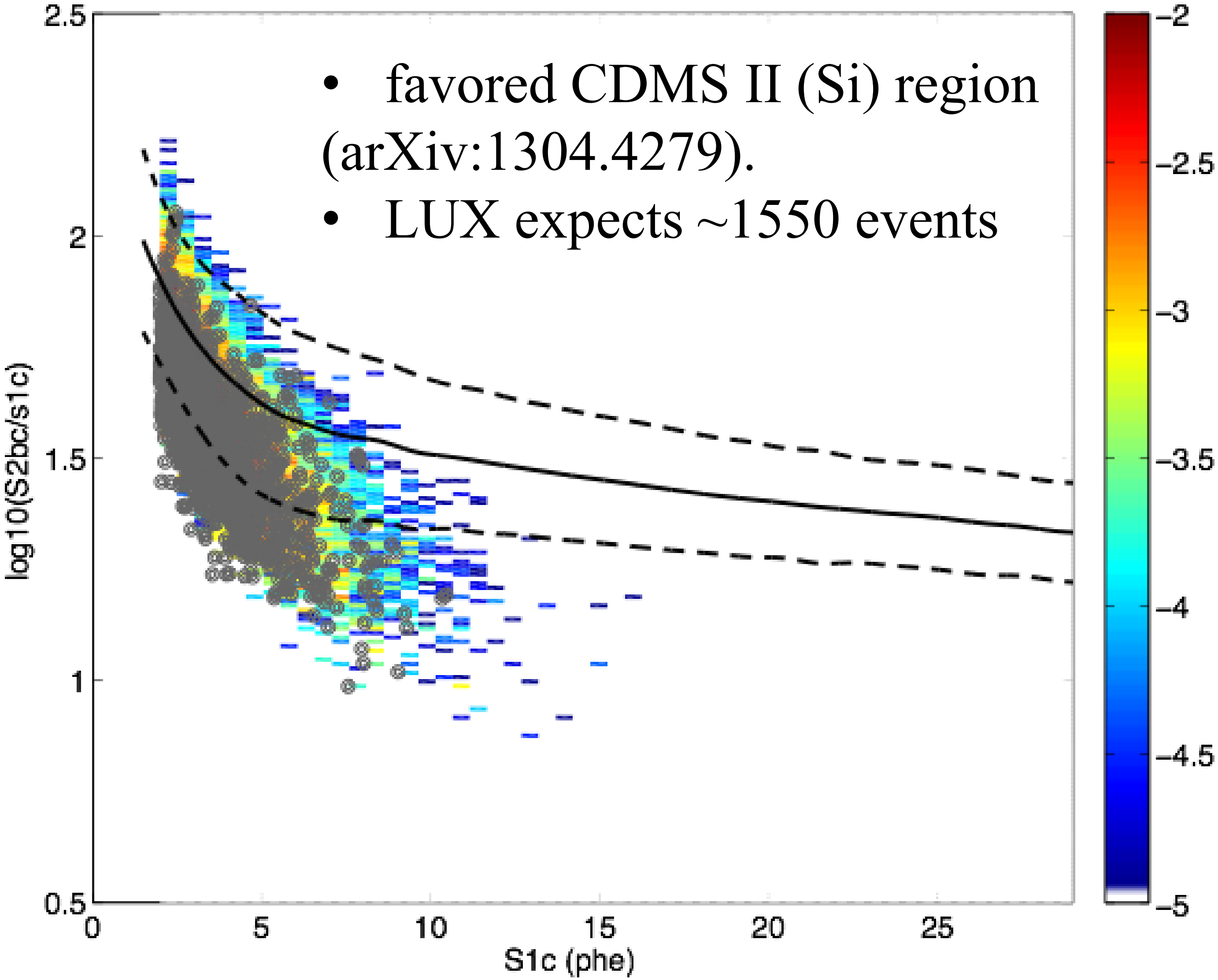


From: arXiv:1107.1295

Simulated 1000 GeV WIMP, $\sigma = 1.9\text{x}10^{-44}$ cm^2



Simulated 8.6 GeV WIMP, $\sigma = 1.9 \times 10^{-41}$ cm^2



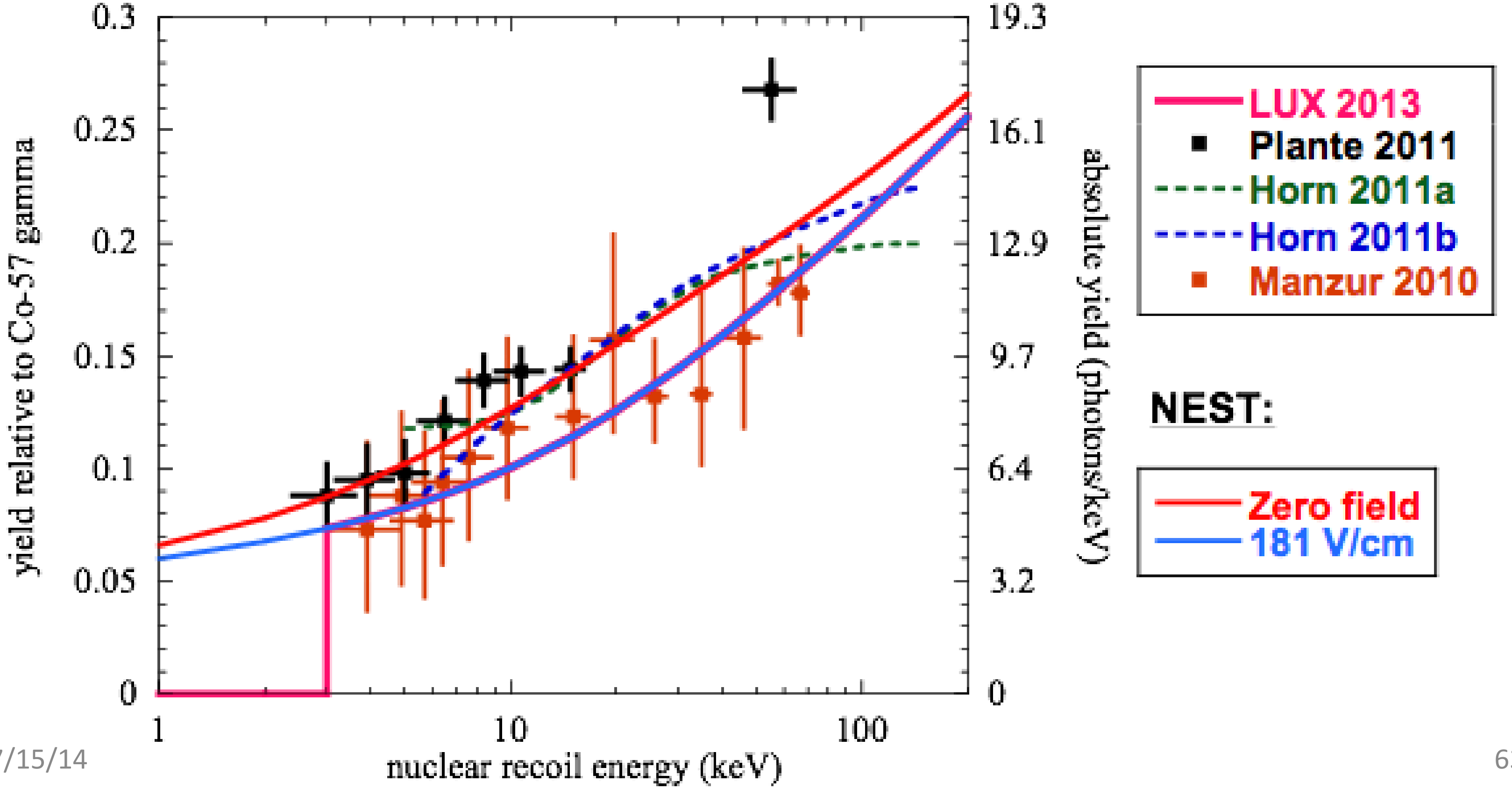
- favored CDMS II (Si) region (arXiv:1304.4279).
- LUX expects ~1550 events

LUX Run 3 – Data Selection

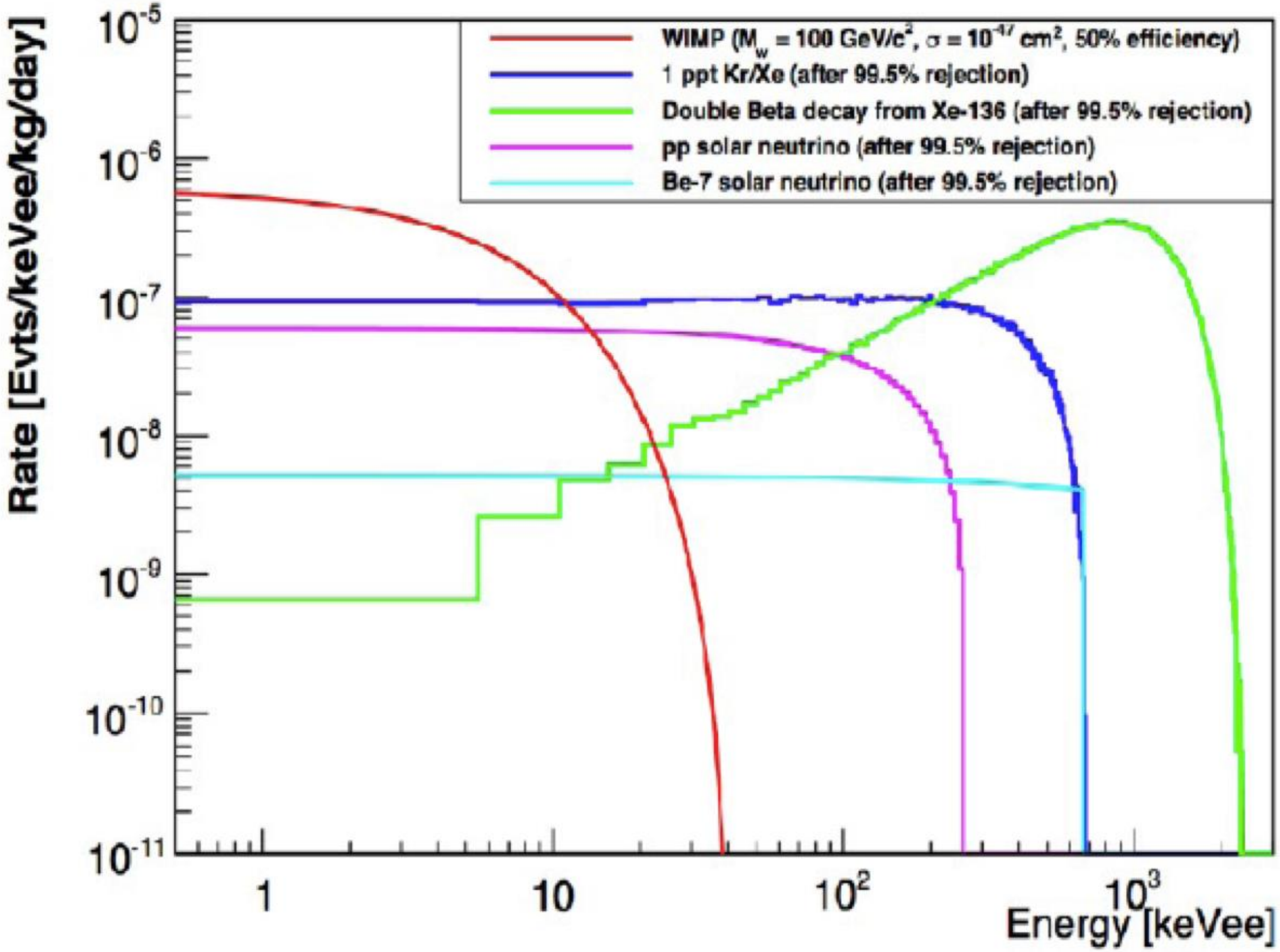
Cut	Explanation	Events Remaining
All Triggers	S2 Trigger >99% for $S2_{raw}$>200 phe	83,673,413
Detector Stability	Cut periods of excursion for Xe Gas Pressure, Xe Liquid Level, Grid Voltages	82,918,901
Single Scatter Events	Identification of S1 and S2. Single Scatter cut.	6,585,686
S1 energy	Accept 2-30 phe (energy ~ 0.9-5.3 keVee, ~3-18 keVnr)	26,824
S2 energy	Accept 200-3300 phe (>8 extracted electrons) Removes single electron / small S2 edge events	20,989
S2 Single Electron Quiet Cut	Cut if >100 phe outside S1+S2 identified +/-0.5 ms around trigger (0.8% drop in livetime)	19,796
Drift Time Cut away from grids	Cutting away from cathode and gate regions, 60 < drift time < 324 us	8731
Fiducial Volume (R,Z)t cut	Radius < 18 cm, 38 < drift time < 305 us, 118 kg fiducial	160

Light and Charge Yields

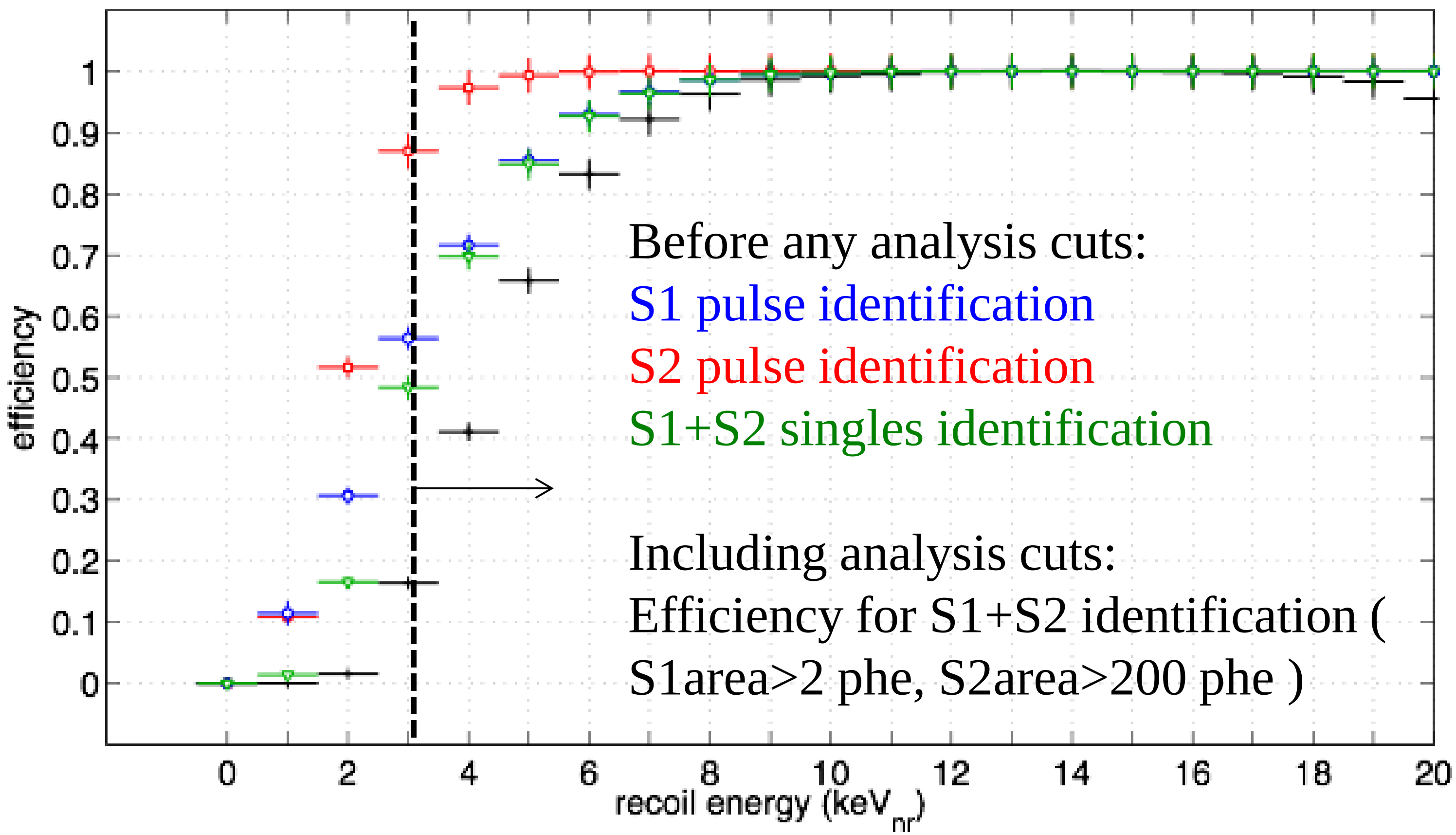
- Modeled using the Noble Element Simulation Technique (NEST), based on the canon of existing experimental data.
- Artificial cutoff in light and charge yields assumed below 3 keVnr, to be conservative.
- Includes E field quenching of light signal (77-82% compared to zero field)
- Charge yield: 26 phe/e-



Internal Backgrounds

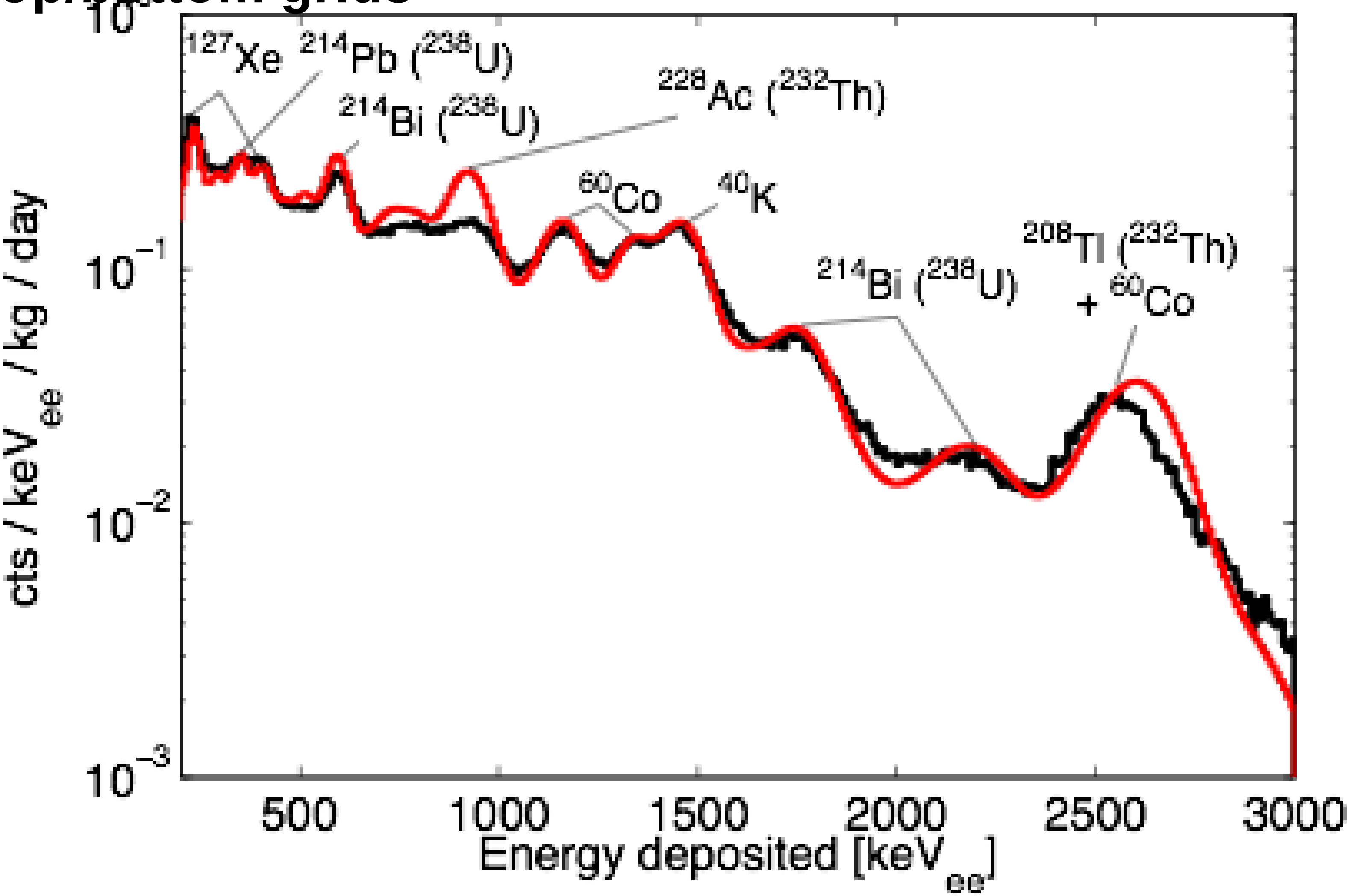


LUX detector threshold translated to recoil energy



LUX Run 3 – Background Levels

- **Full gamma spectrum, excluding region ±2 cm from top/bottom grids**

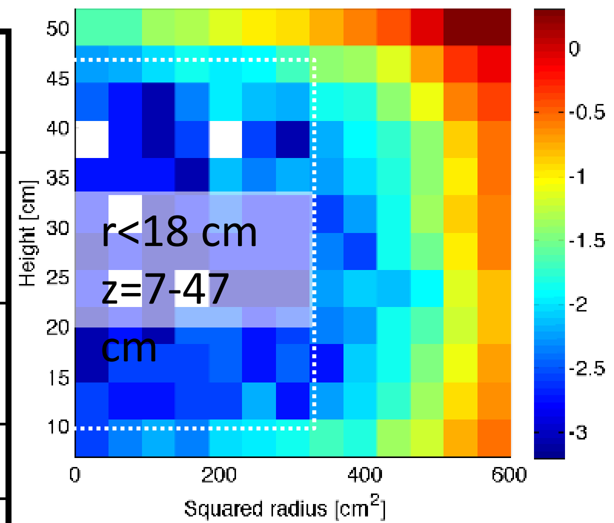


LUX Run 3 – Background Levels

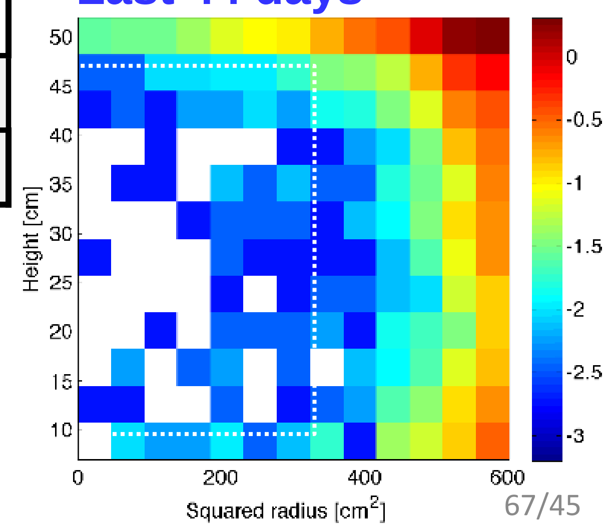
Background Component	Source	10^{-3} x evts/keVee/kg/day
Gamma-rays	Internal Components including PMTS (80%), Cryostat, Teflon	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe (36.4 day half-life)	Cosmogenic 0.87 -> 0.28 during run	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	^{222}Rn	0.11-0.22$_{(90\%\ CL)}$
^{85}Kr	Reduced from 130 ppb to 3.5 ± 1 ppt	$0.13 \pm 0.07_{sys}$
Predicted	Total	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Observed	Total	$3.1 \pm 0.2_{stat}$

ER < 5 keVee in 118 kg

Log10 (DRUee)

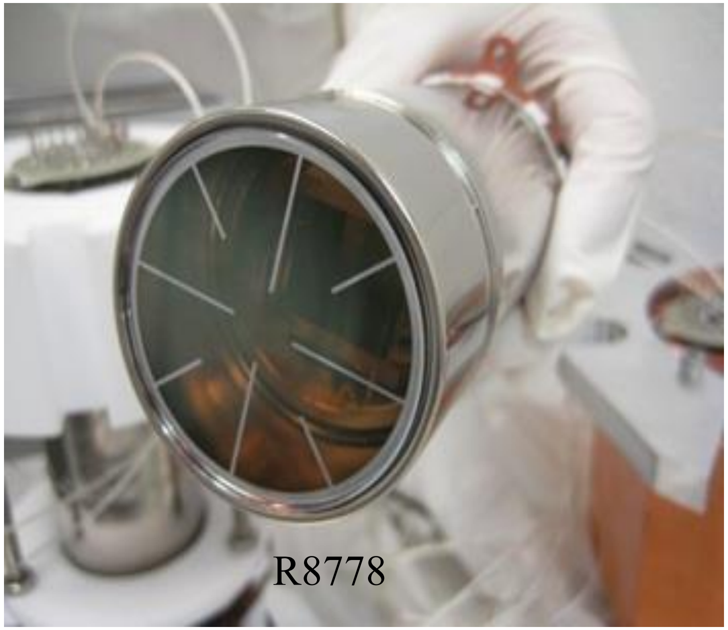


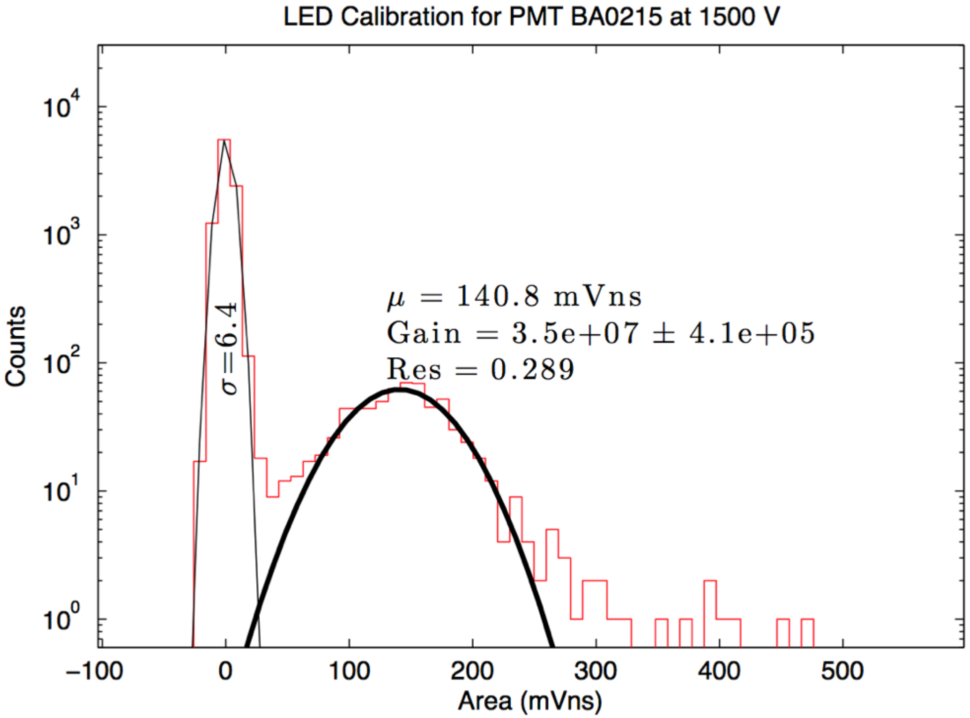
Last 44 days



- Dedicated publication is coming

LUX PMTs

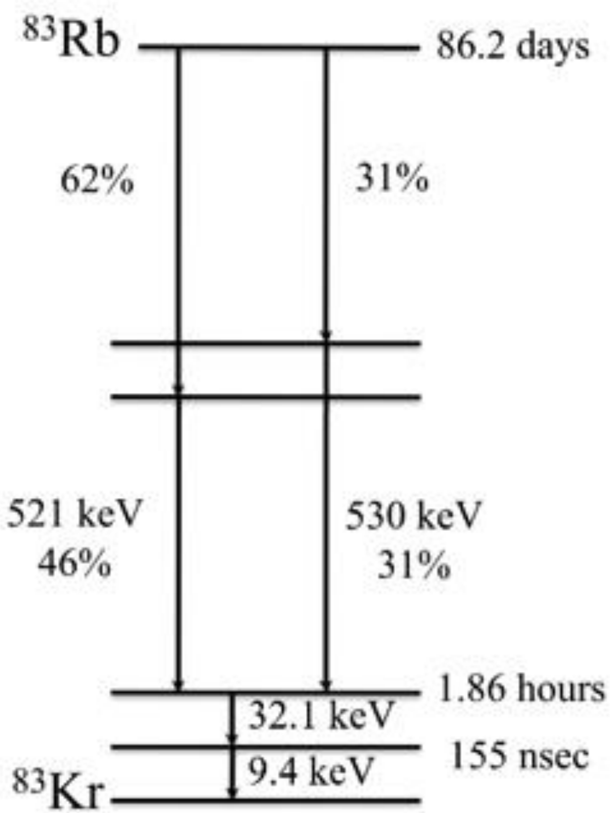




- 122 x 2" diameter R8778 Hamamatsu
- U/Th 10/2 mBq/PMT
- Demonstrated QE: average=33%, max 39% at 175 nm
- U/Th content ~ 9/3 mBq/PMT

LUX Calibrations – ^{83m}Kr

- ^{83}Rb produces ^{83m}Kr when it decays; this krypton gas can then be flushed into the LUX gas system to calibrate the detector as a function of position.
- Provides reliable, efficient, homogeneous calibration of both S1 and S2 signals, which then decays away in a few hours, restoring low-background operation.

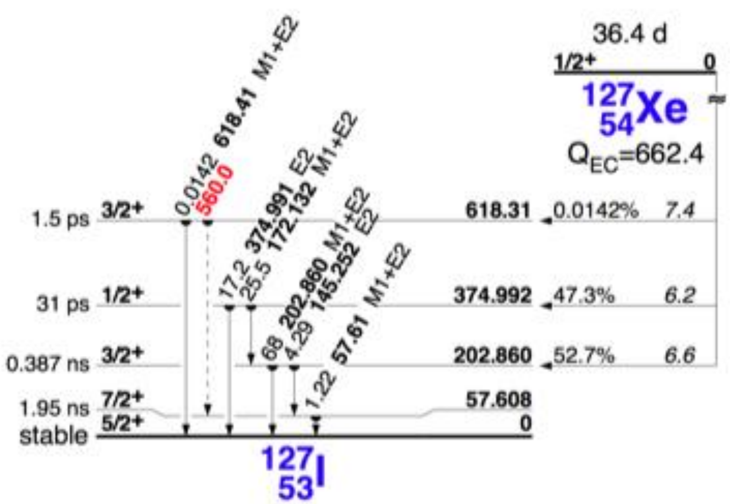


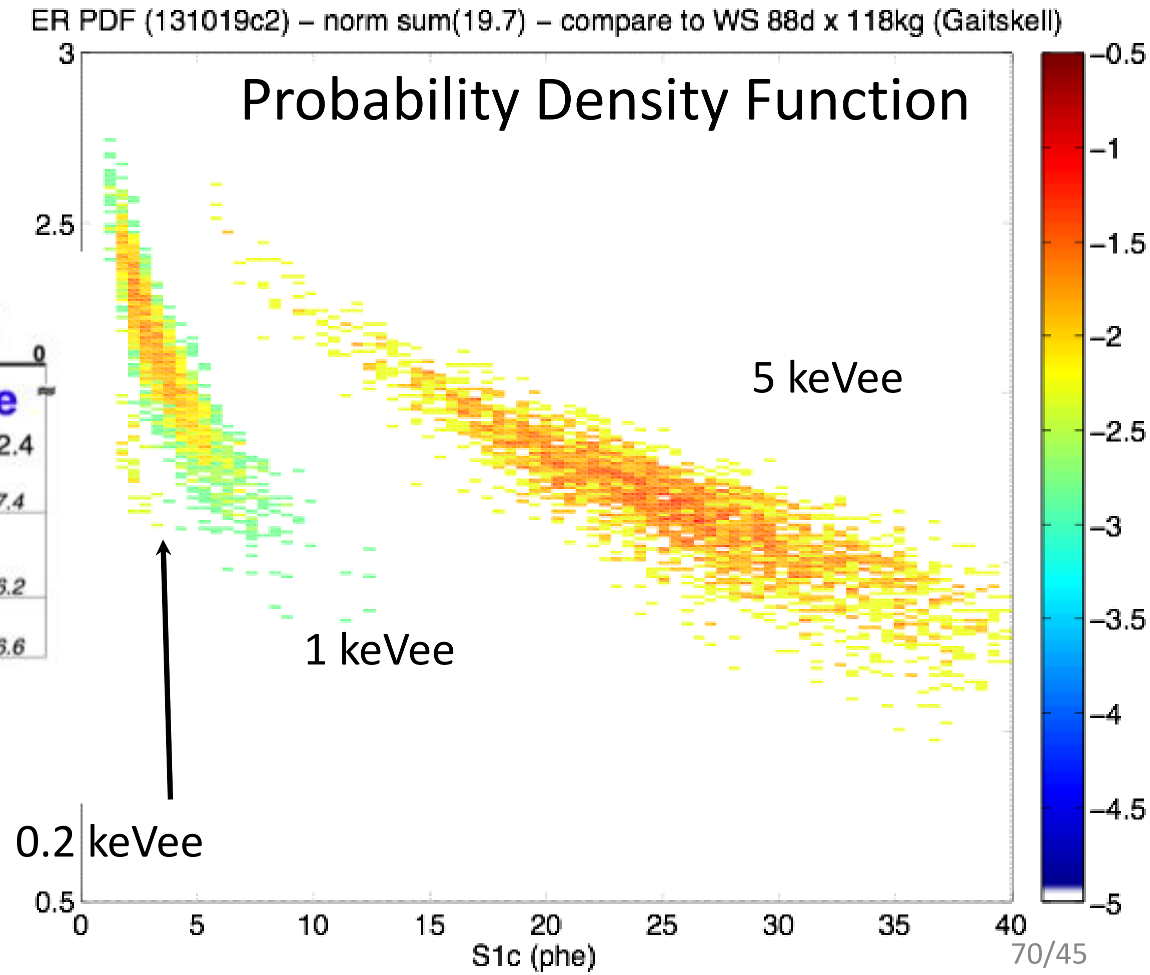
- Bonus: tomography of Xe flow

^{83m}Kr source (^{83}Rb coated on charcoal, within xenon gas plumbing)

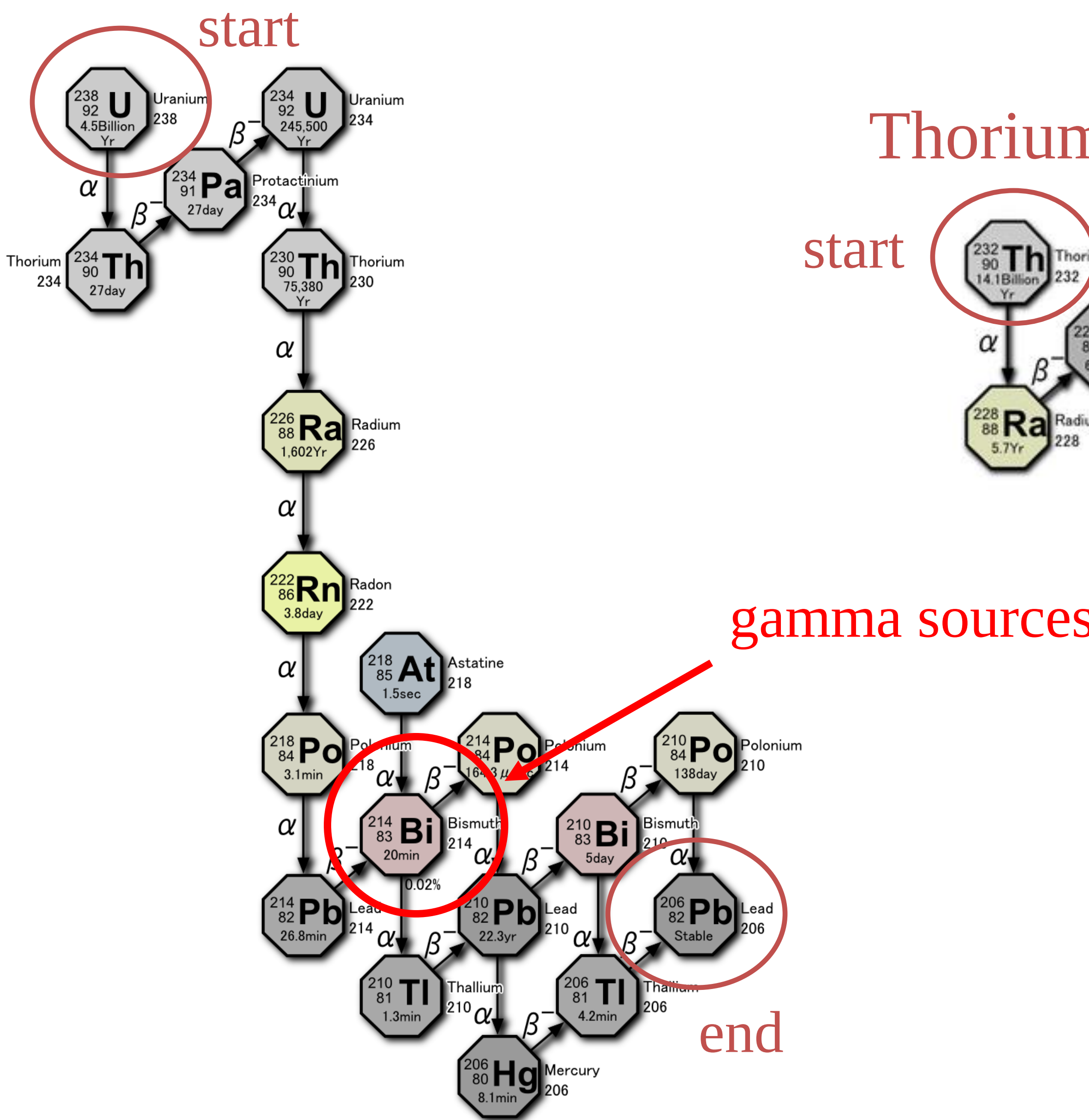
^{127}Xe Electron Capture - Simulation

- x-ray line emission in center of detector following full escape of gamma associated with nuclear excited state

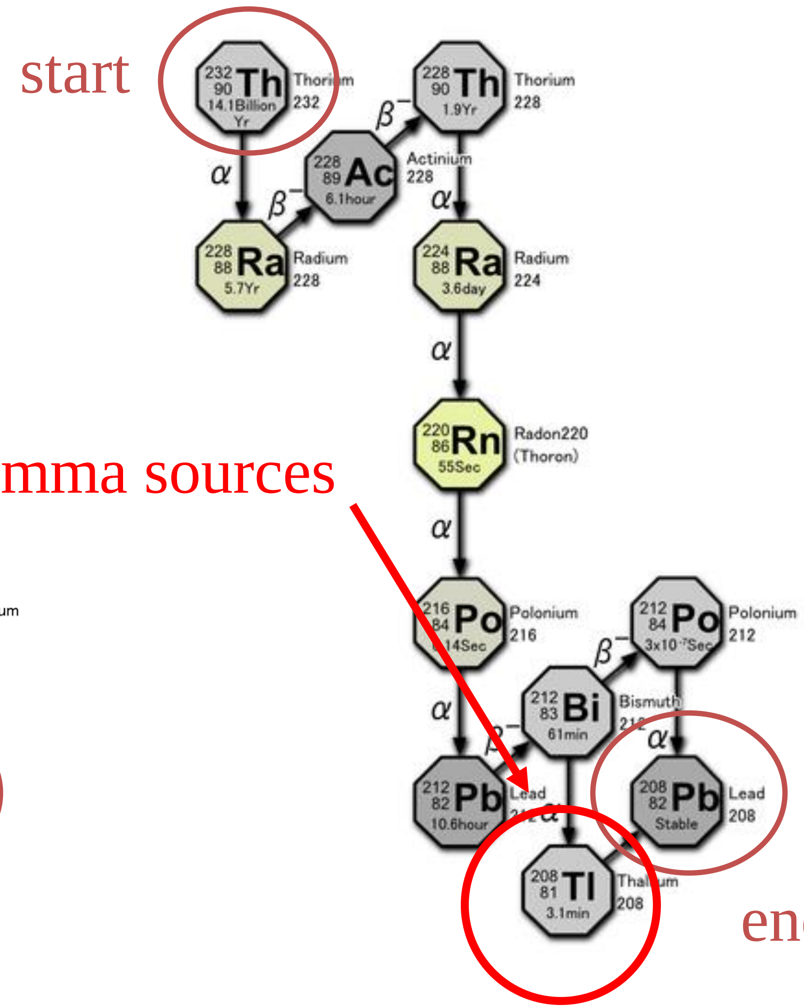




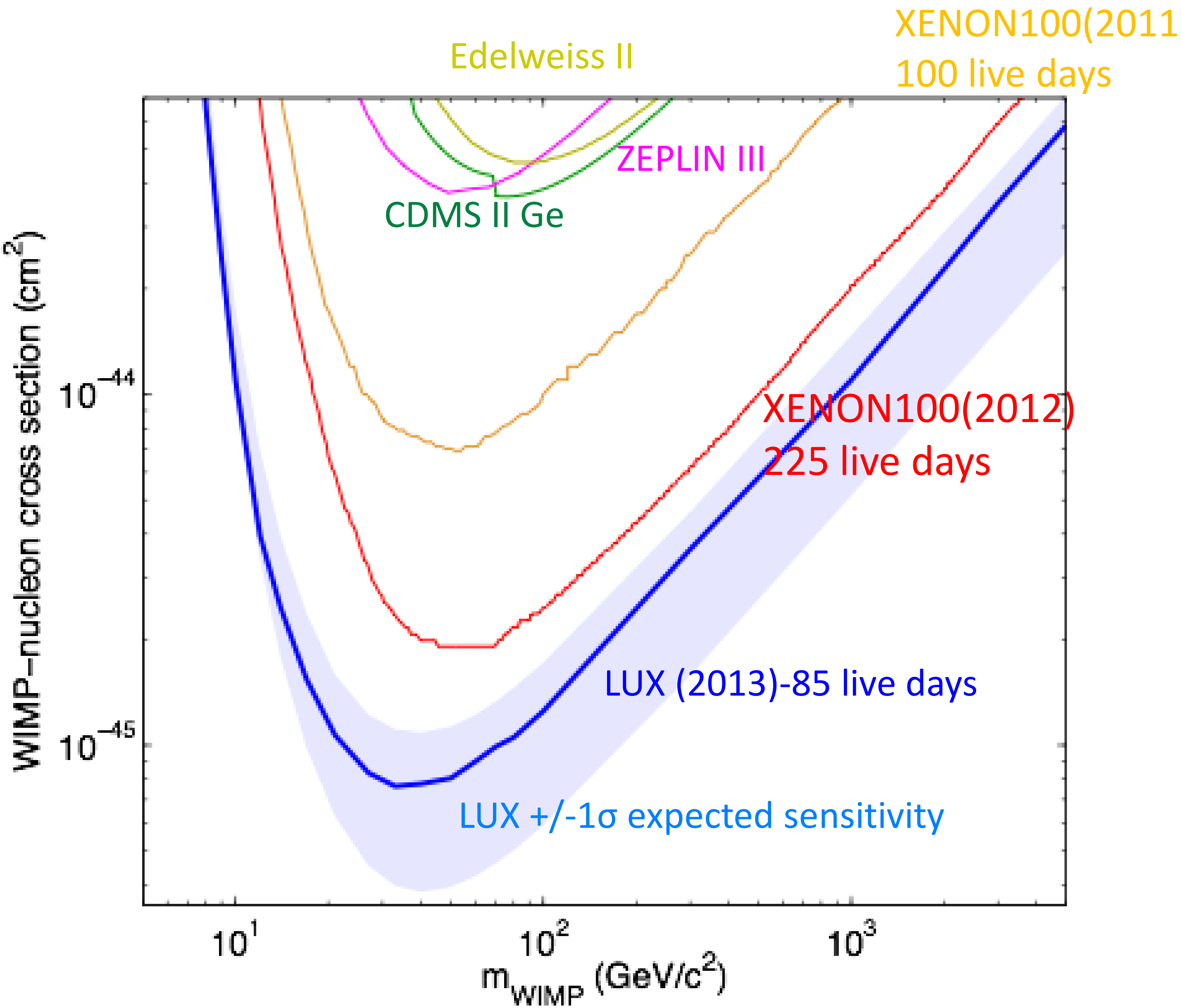
Uranium-238 decay chain



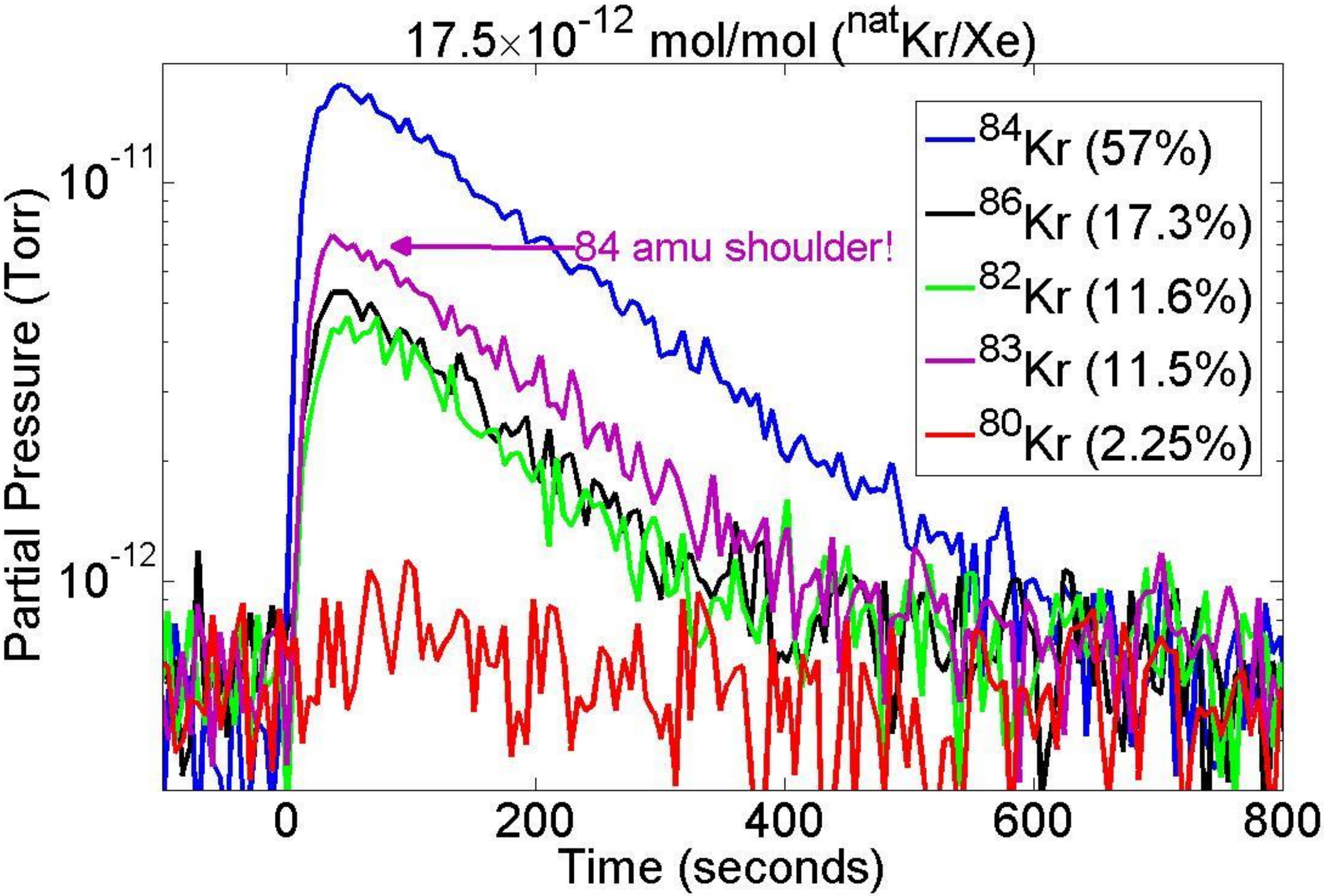
Thorium-232 decay chain



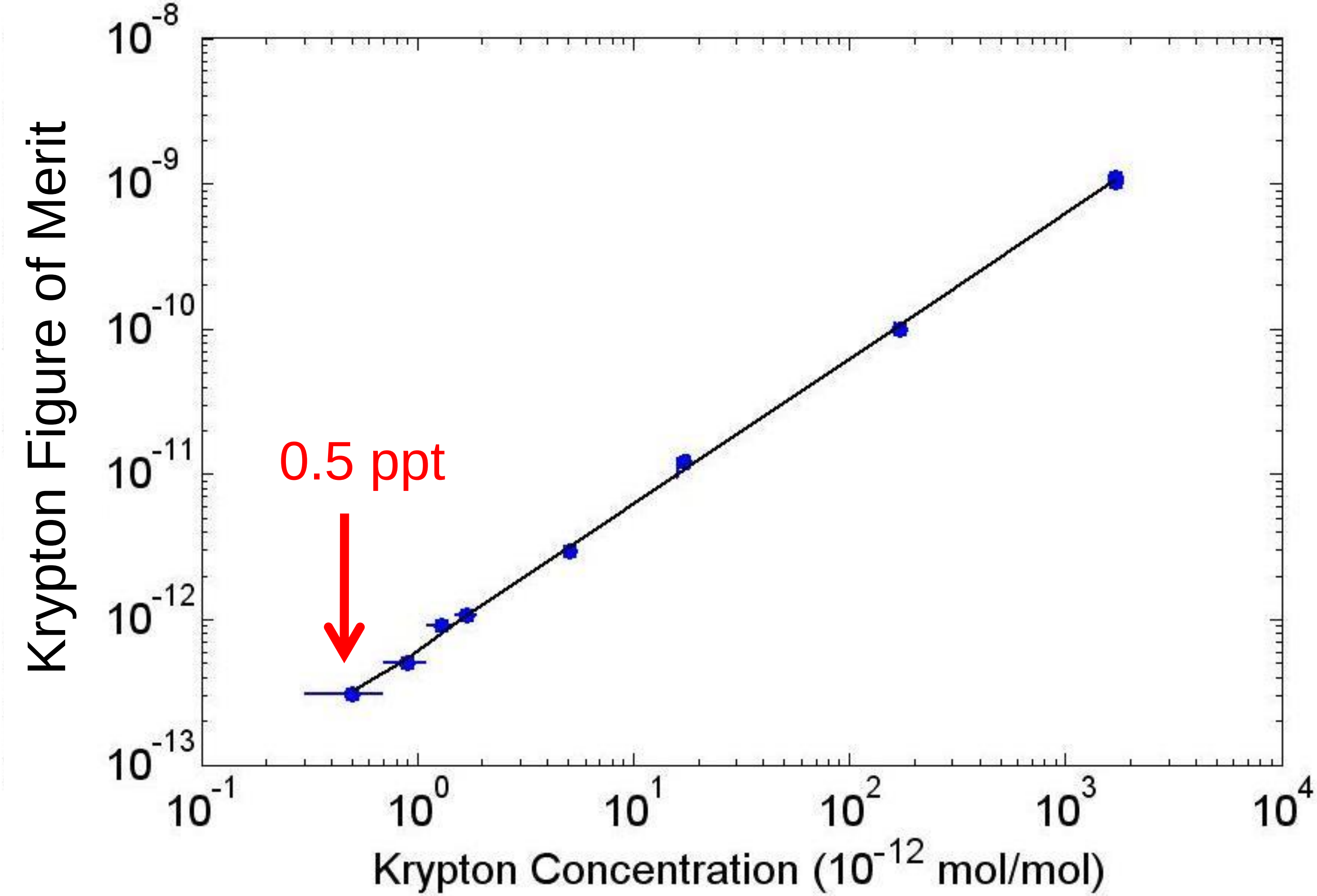
LUX 90% C.L. exclusion limits – high mass



RGA response to 17.5ppt krypton

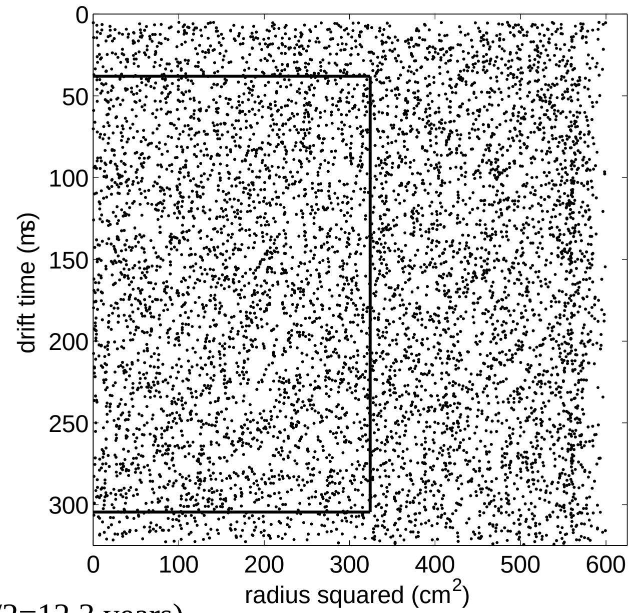


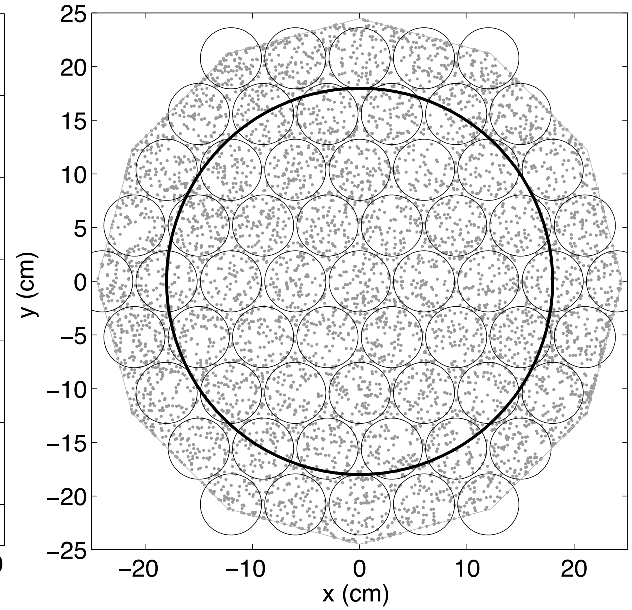
Krypton calibration results

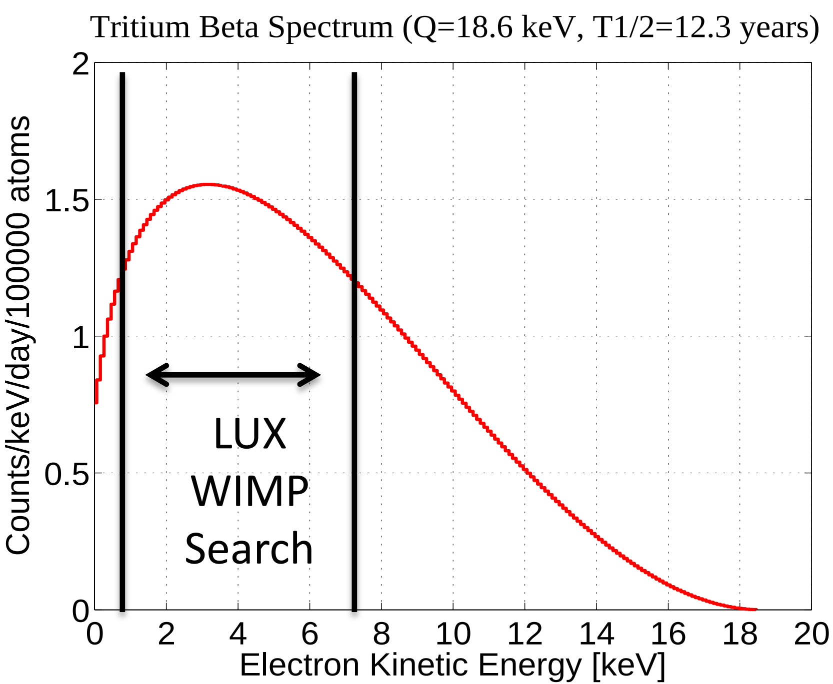


Tritium, The Ideal ER Calibration Source.

- Dissolved uniformly in the xenon, then removed
- Used to calibrate the fiducial volume.
- Calibration of fiducial is impossible with external sources.

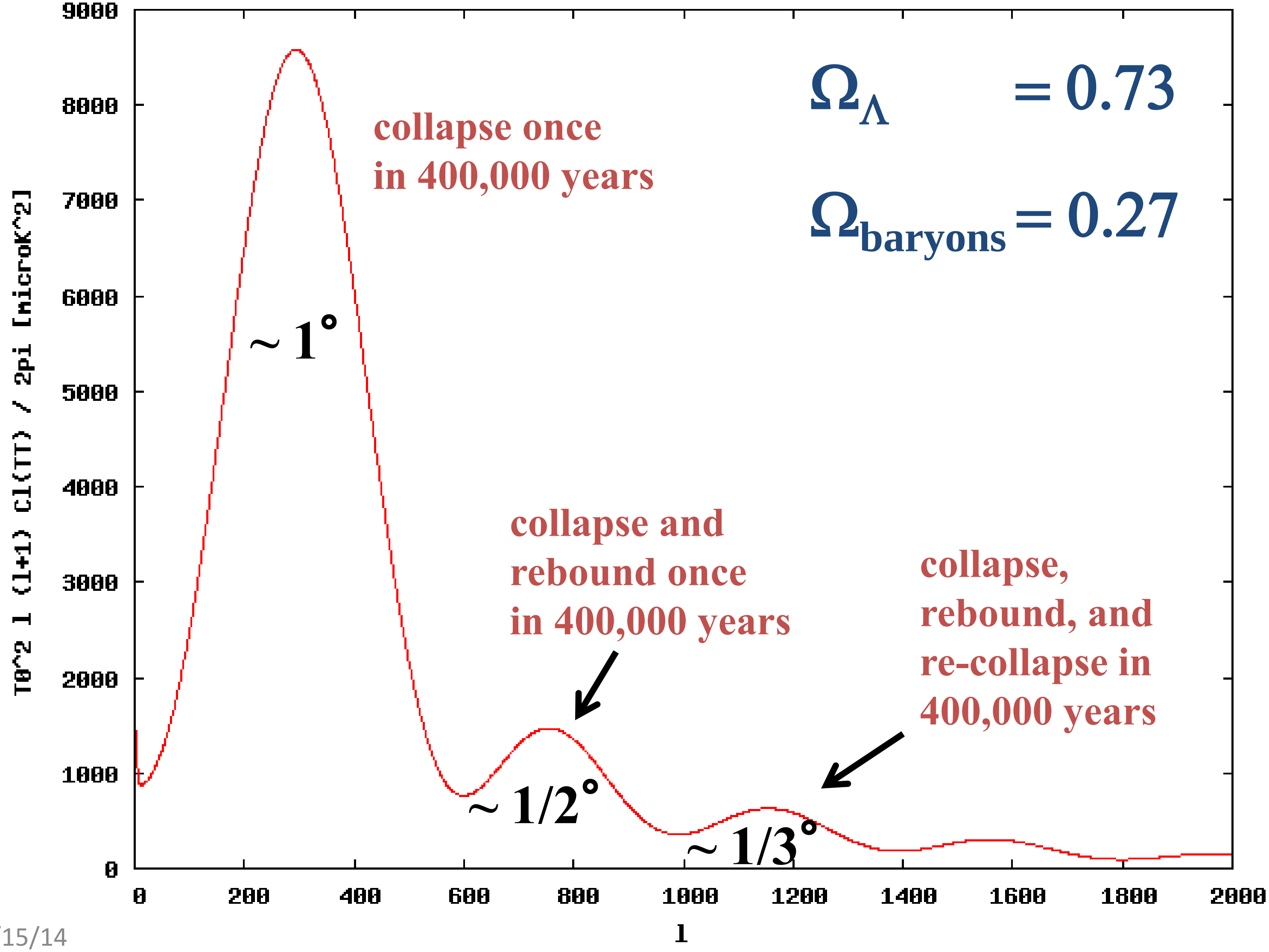




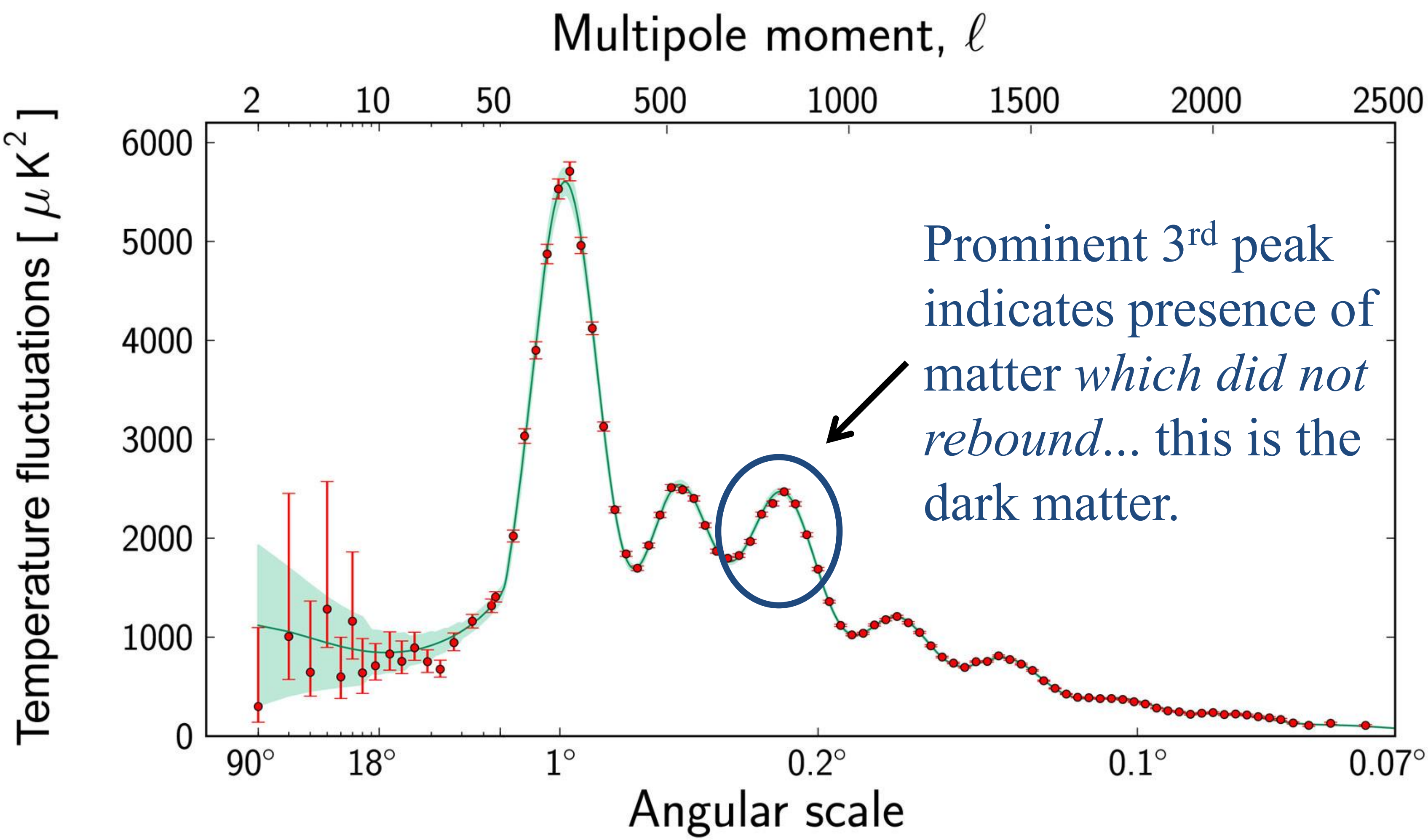


- Single Scatter ER events in energy region of interest: 0.1 keV to 18 keV
- Mean energy: 5 keV
- Peak energy: 3 keV

In a universe with no dark matter – CMB multipole expansion



CMB multipole expansion as measured by Planck



LUX Xe Bottles
Before science run condensation

Name	P&ID Location	Kr (ppt g/g)	Ar (ppb)	He (ppb)	N2(ppb)	O2 (ppb)	CH4 (ppb)
CSB10	SB04	2	0.5	1.1	13	7	0.4
LSB8	SB03	1.3	5.3	5.8	310	84	0.4
LSB1	SB02	<1	1.2	0.8	6.4	3.1	0.4
LSB2	SB01	<1	1.2	2.1	56	17.5	0.2
LSB5	SB05	7.5	0.9	2.7	39	6	0.7
LSB4	SB06	4	0.4	4.8	15	6	4.8
LSB6	SB07	6.6	0.4	5.5	13	6.3	0.7
LSB7	SB08	4.4	0.1	3	7	0.9	0.5
Average		3.5	1.3	3.2	57	16	1.0

Average Krypton concentration of 3.5 ppt

Label	Kr (ppb)	Ar (ppb)	N_2 (ppb)	O_2 (ppb)	He (ppb)
E4 (35kg)	60.1 ± 6.7	1850 ± 850	32200 ± 12500	14300 ± 3190	840 ± 270
E6 (35kg)	85.4 ± 9.5	27.4 ± 12.6	1170 ± 370	<6.5	588 ± 305
E7 (35kg)	25.1 ± 2.8	30.3 ± 13.9	809 ± 256	<1.8	581 ± 301
E2 (35kg)	32.7 ± 3.6	131 ± 60	2490 ± 790	616 ± 138	444 ± 230
E8 (50kg)	20.7 ± 6.6	2.2 ± 0.9	46.9 ± 18.9	<1.9	8.5 ± 4.1
E5 (35kg)	36.4 ± 4.4	2.6 ± 0.6	12.2 ± 2.7	<0.8	<0.1
Stockpile avg.	42.6 ± 5.7	319 ± 146	5720 ± 2180	2320 ± 520	384 ± 173
After recovery	42.9 ± 16.6	256 ± 53	108 ± 25	<0.3	257 ± 83

Sample	Port	Comment	O_2 (ppb)	N_2 (ppb)	Ar (ppb)	He (ppb)	Kr (ppb)	CH_4 (ppb)
Enr-A	S3	Purified TPC gas, before liquefaction.	<0.7	<4.5	128±61	*70±36	<0.4	<1.9
Enr-H[†]	S1	Stockpile mixture, before purification.	<0.4	329±81	8.9±2.0	*42±14	0.0235±0.004	24.9±6.1
Enr-F	S2	Start of liquefaction, after purifier.	<4	<28	9.5±2.0	1.5±0.5	0.0517±0.007	1.3±0.3
Enr-G	S2	During liquefaction, after purifier.	<3	<27	7.6±1.8	1.3±0.4	0.038±0.007	1.7±0.4
Enr-I	S1	Dedicated Kr search, repeat of Enr-H.					0.0274 ± 0.004	

Measuring ^{85}Kr contamination in the natural xenon

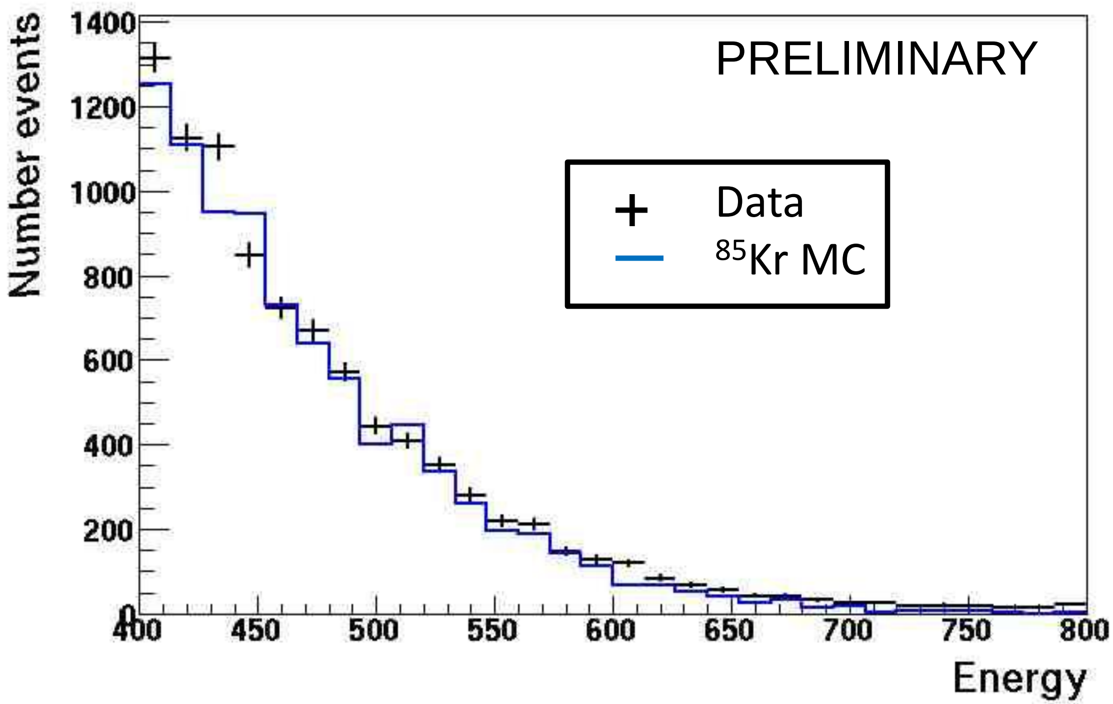
The energy spectrum above 400keV is compared to a MC simulation (including electron lifetime) of the ^{85}Kr β-decay (687 keV end point).

Best fit to the data is 1.1×10^{-18} g/g ^{85}Kr in ^{Nat}Xe.

Total krypton contamination in the ^{Nat}Xe has been separately measured with a cold trap and RGA to be $4.9(3) \times 10^{-8}$ g/g.

Consistent with ^{85}Kr isotopic abundance of 2.2×10^{-11}.

Ionization only energy spectrum
16 hours live time



Bottle Label	Initial Pressure	Note:	He (ppb g/g)	N2 (ppb g/g)	O2 (ppb g/g)	Ar (ppb g/g)	Kr (ppb/ g/g)
Al	800 psi	Xe used in 0.1	136 ± 20	2,600,000 ± 400,000	30.0 ± 4.5	86,000 ± 13,000	87.5 ± 13.1
SB7	820 psi	50kg never used	0.17 ± 0.01	35 ± 2.7	0.80 ± 0.05	2.0 ± 0.2	100 ± 8
SB6	820 psi	50kg never used	0.16 ± 0.01	45 ± 2.3	6.35 ± 0.33	10.0 ± 0.5	155 ± 8
SB5	820 psi	50kg never used	0.26 ± 0.01	70 ± 4	19.5 ± 1	4.3 ± 0.2	52.1 ± 2.7
SB4	820 psi	50kg never used	0.44 ± 0.03	53 ± 3	2.8 ± .14	4.0 ± 0.2	210 ± 13
SB3	820 psi	50kg never used	0.92 ± 0.07	131 ± 9	19.0 ± 1	3.7 ± 0.3	99.6 ± 8.2
SB2	820 psi	50kg never used	0.11 ± 0.01	51 ± 3	1.4 ± 0.1	1.9 ± 0.1	78.0 ± 5.7
SB1-SB7 Average			0.34 ± 0.08	64.3 ± 11.2	8.3 ± 1.5	4.3 ± 0.7	116 ± 20

ppb=1e-9

Control backgrounds with a careful screening program

	Unit	Screening Result				
		U238	Th232	Co60	K40	Sc46
PMTs	mBq/PMT	9.5±0.6	2.7±0.3	2.6±0.1	66±2	
Ti	mBq/kg	<0.18	<0.25			4.4±0.3*
Cu	mBq/kg			2.1±0.19*		
PTFE	mBq/kg	<3	<1			
HDPE	mBq/kg	<0.5	<0.35			
Stainless steel**	mBq/kg			19±1		

~1/3 of LUX design goals

**Type 304 stainless steel used in electric field grids

*Cosmogenic equilibrium at 1 mile above SL; decays below ground

Control backgrounds with a careful screening program

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		U238	**Th232**	**Co60**	**K40**	**Sc46**
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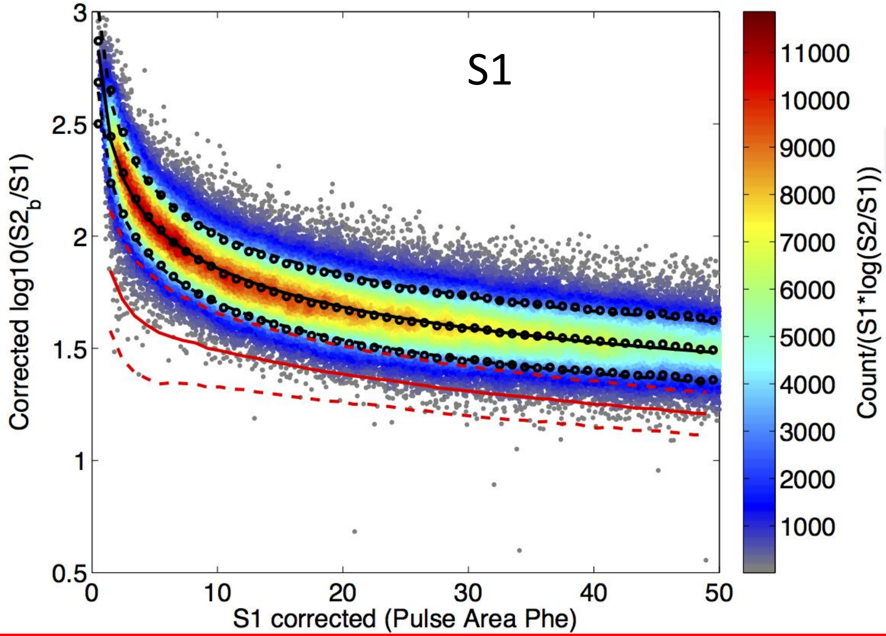
PTFE	mBq/kg	<3	<1			
HDPE	mBq/kg	<0.5	<0.35			
Stainless steel**	mBq/kg			19±1		

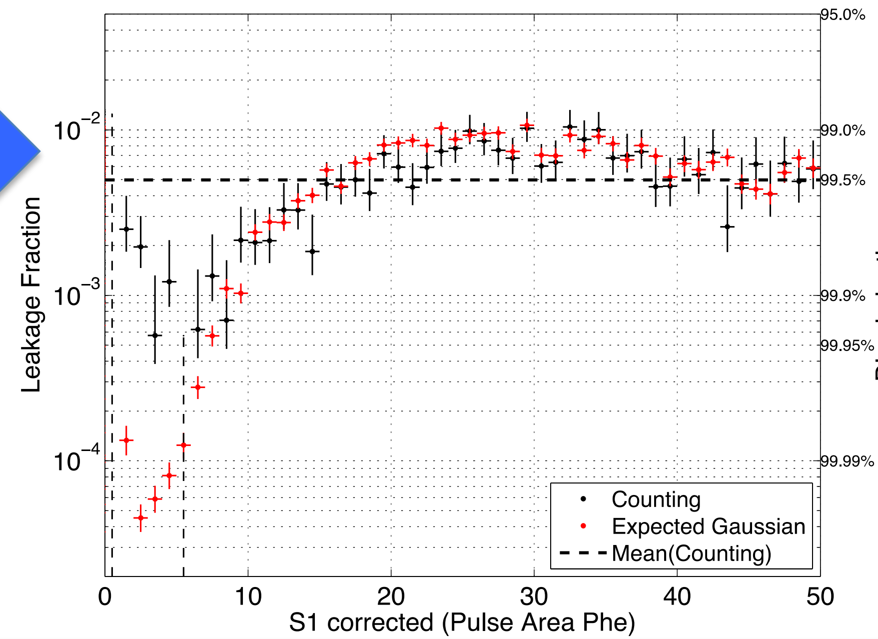
Clean titanium cryostat

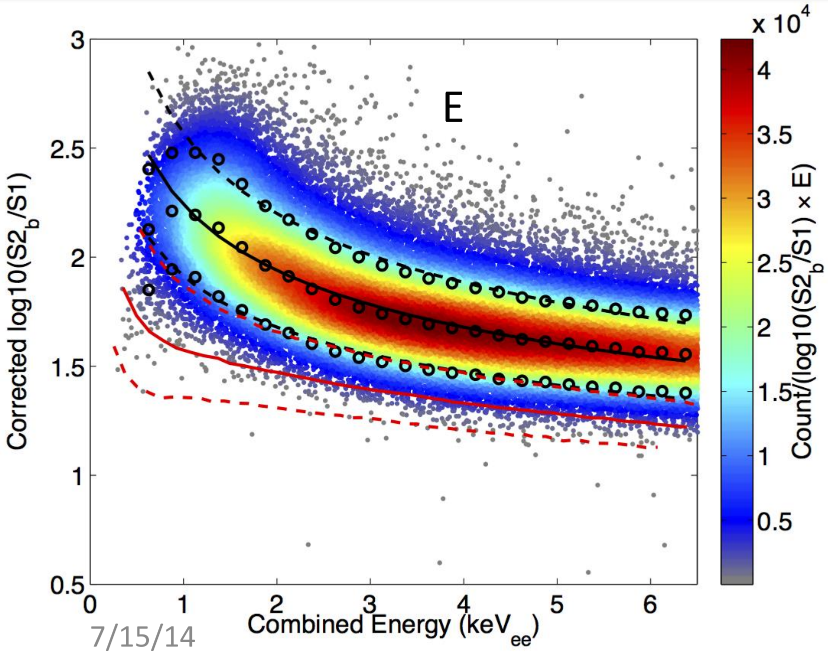
**Type 304 stainless steel used in electric field grids

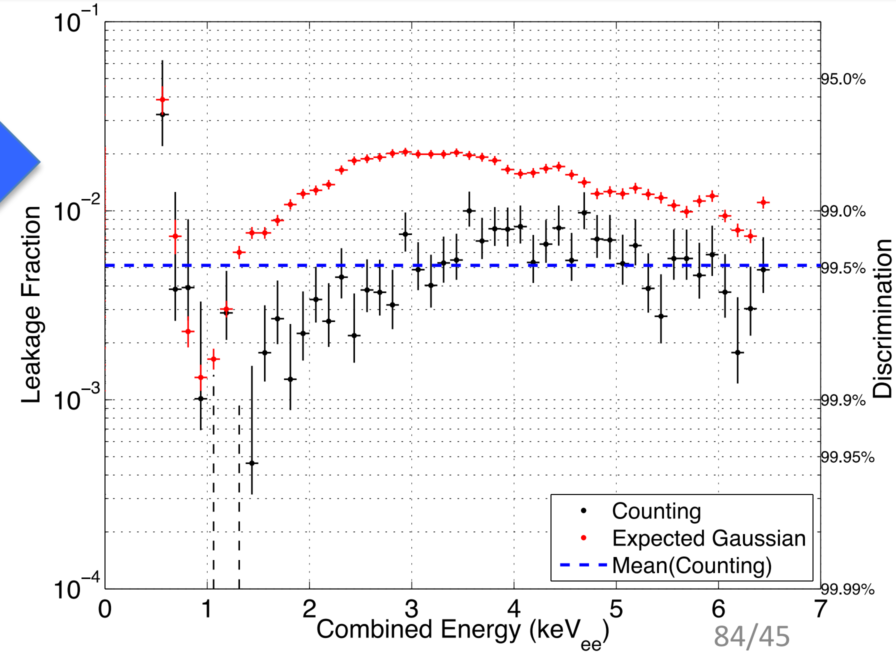
*Cosmogenic equilibrium at 1 mile above SL; decays below ground

ER/NR discrimination vs. S1 & vs. E



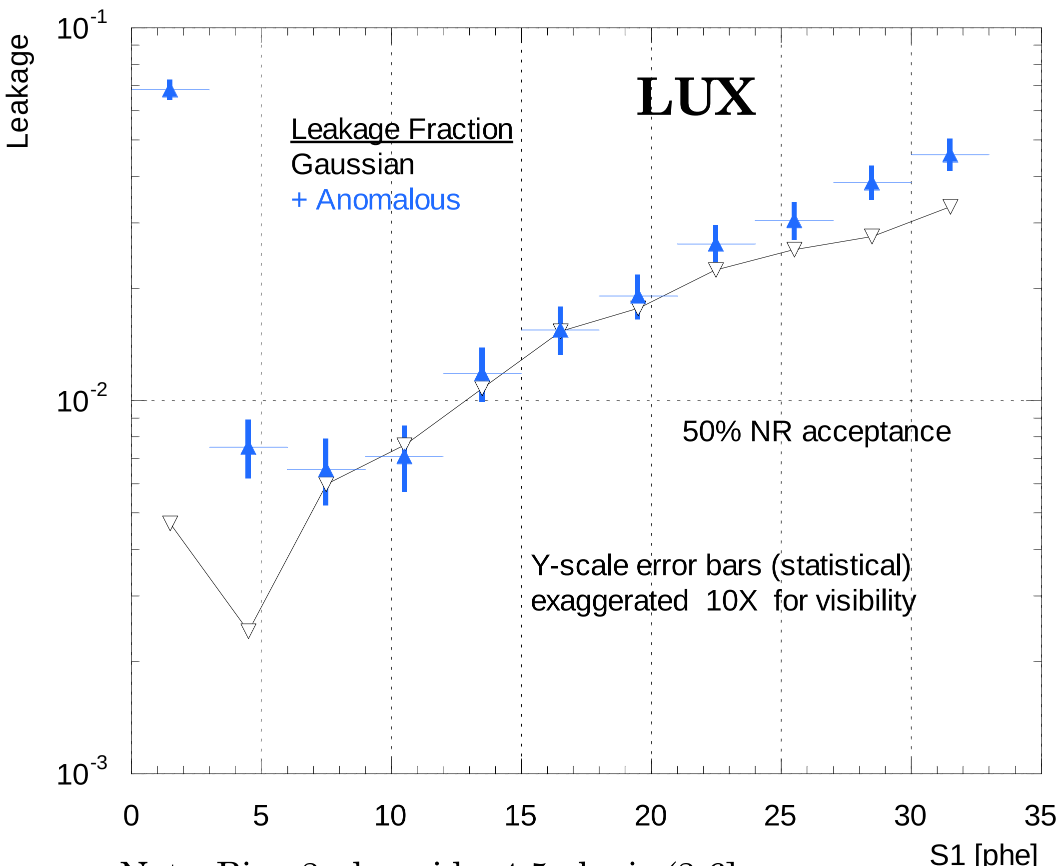






DocDB043 (Matthew)… the check mark shape

NON-GAUSSIAN TAILS

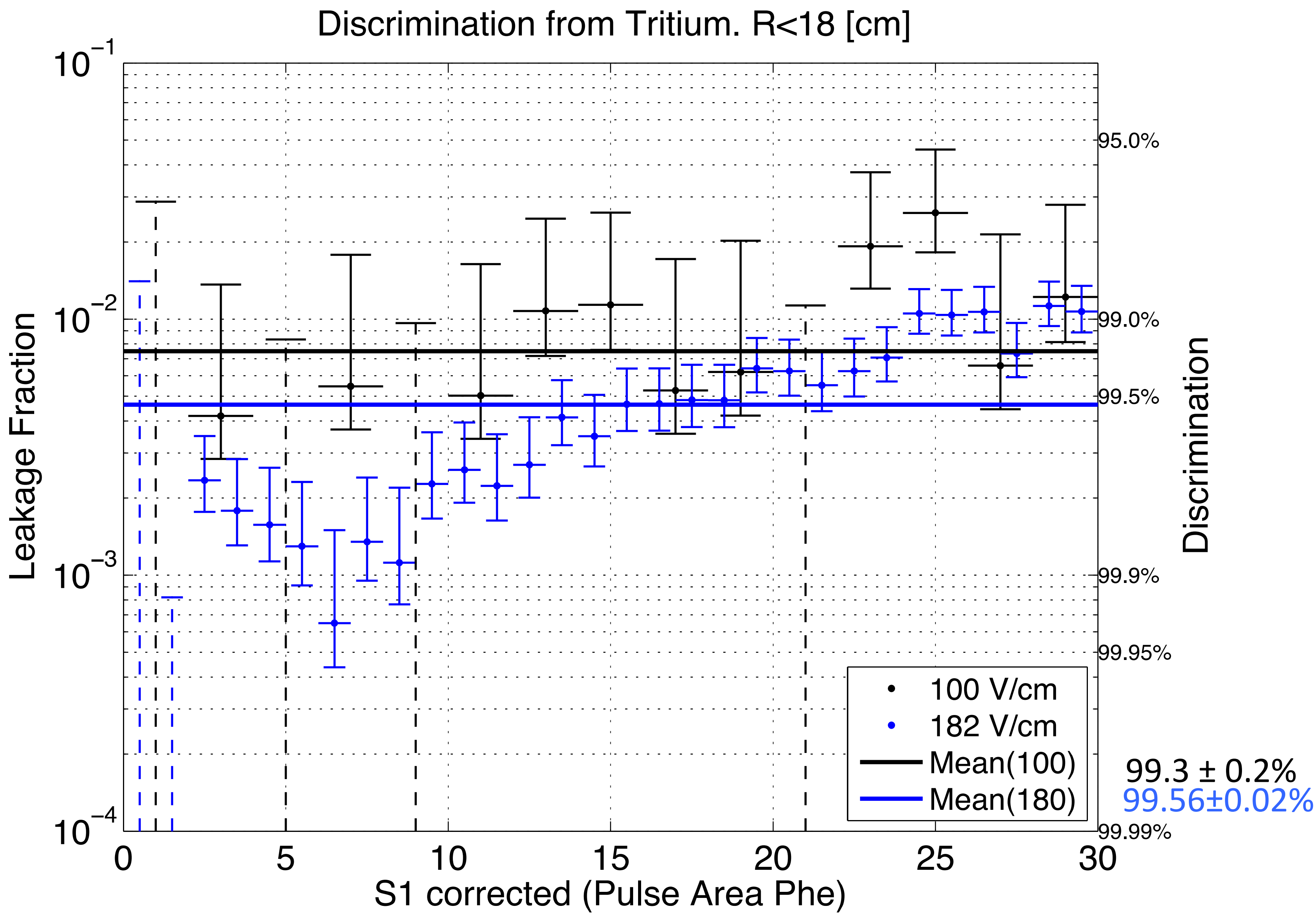


Note: Bins 3-phe-wide. 4.5 phe is (3,6]

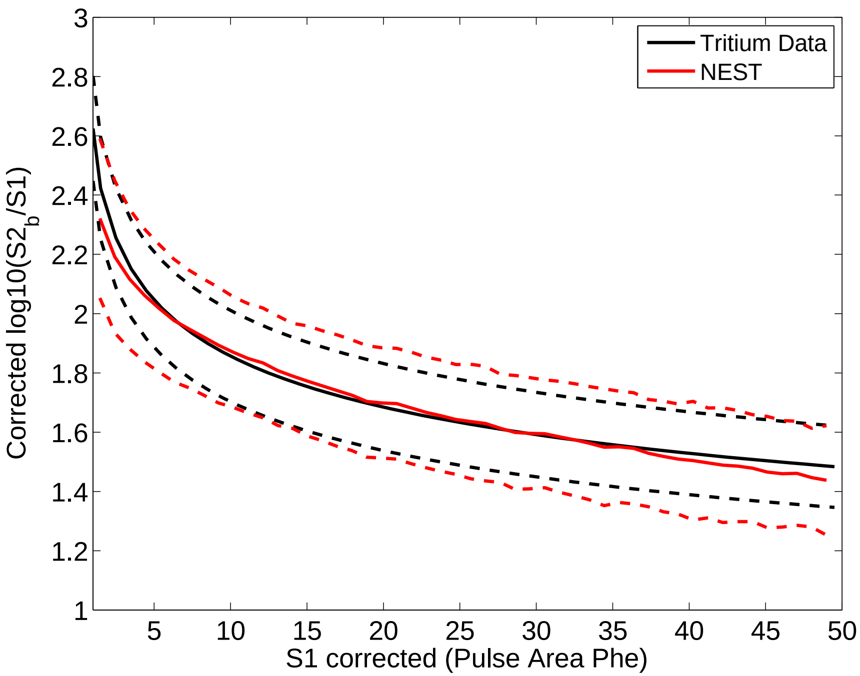
- 182.5 V/cm drift, 14% average photon detection
- "Anomalous" leakage creeps in at low, high S1
  - At low because of the 5 e- threshold and because the bands deform (negative #quanta unphysical): to maintain same acceptance must go above Gaussian mean (raw mean closer to ER band)
  - High: see slide 9

Leakage per S1 bin vs. Field. 100 & 180 V/cm

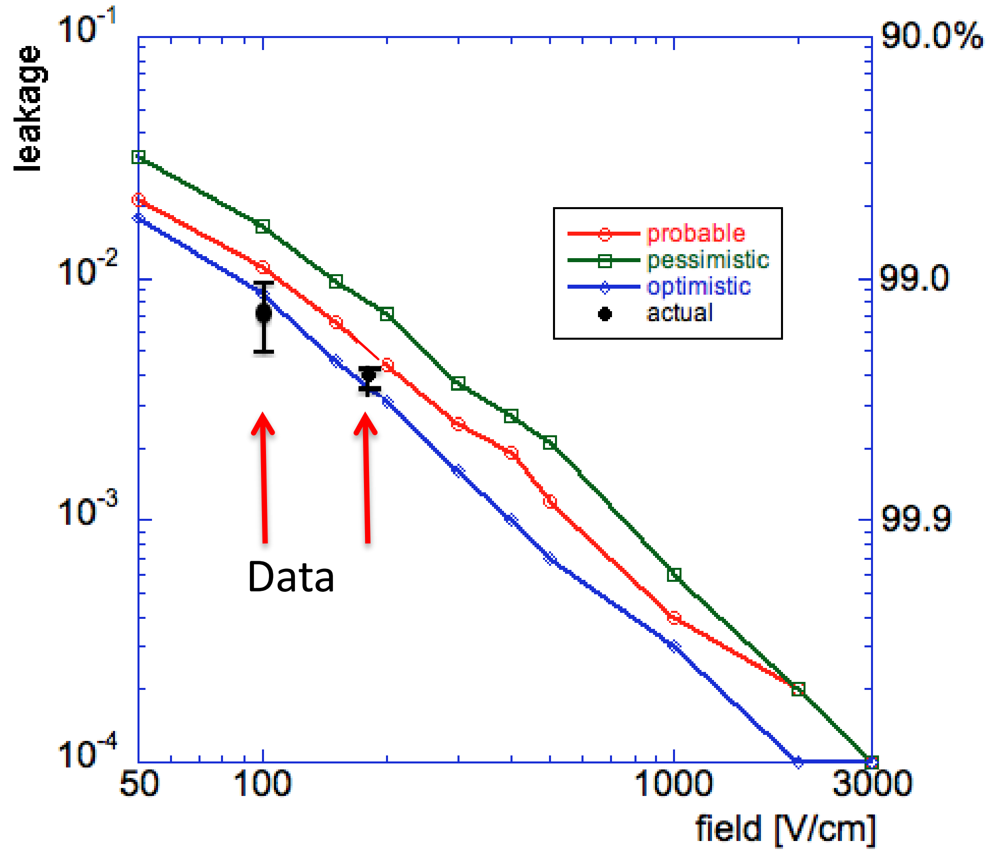
(With S2>200 Phe cut)



NEST Predictions

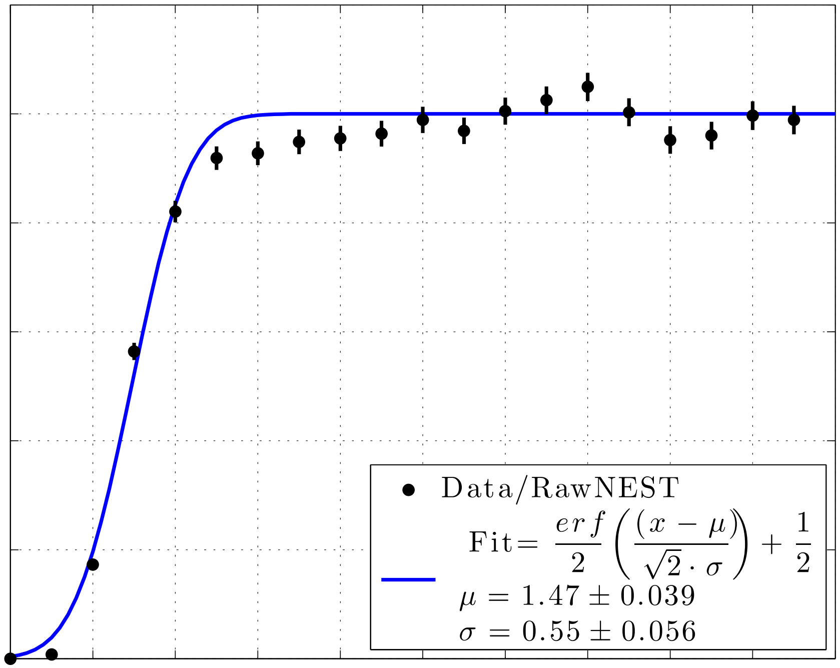


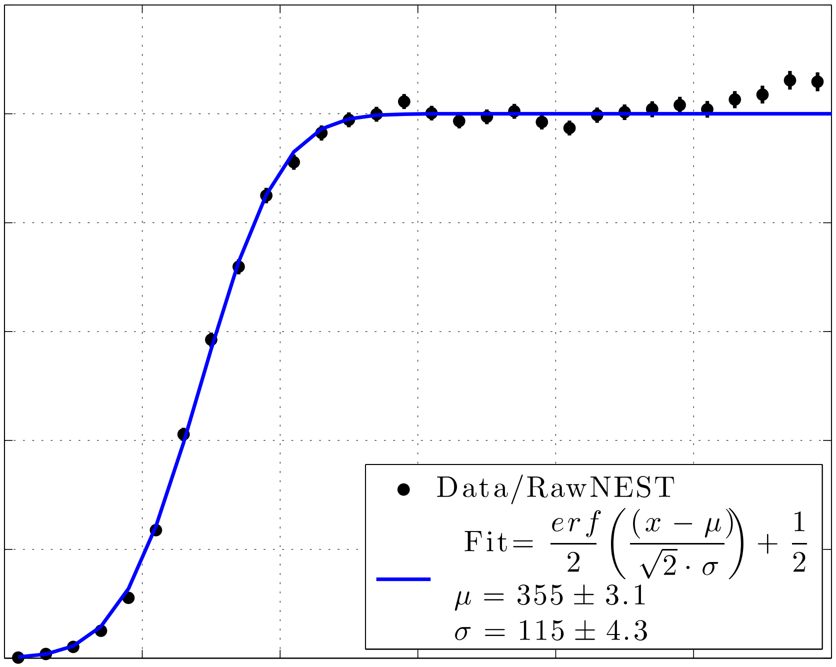
(figure from LUX RUN 04 Sensitivity Study - Matthew)



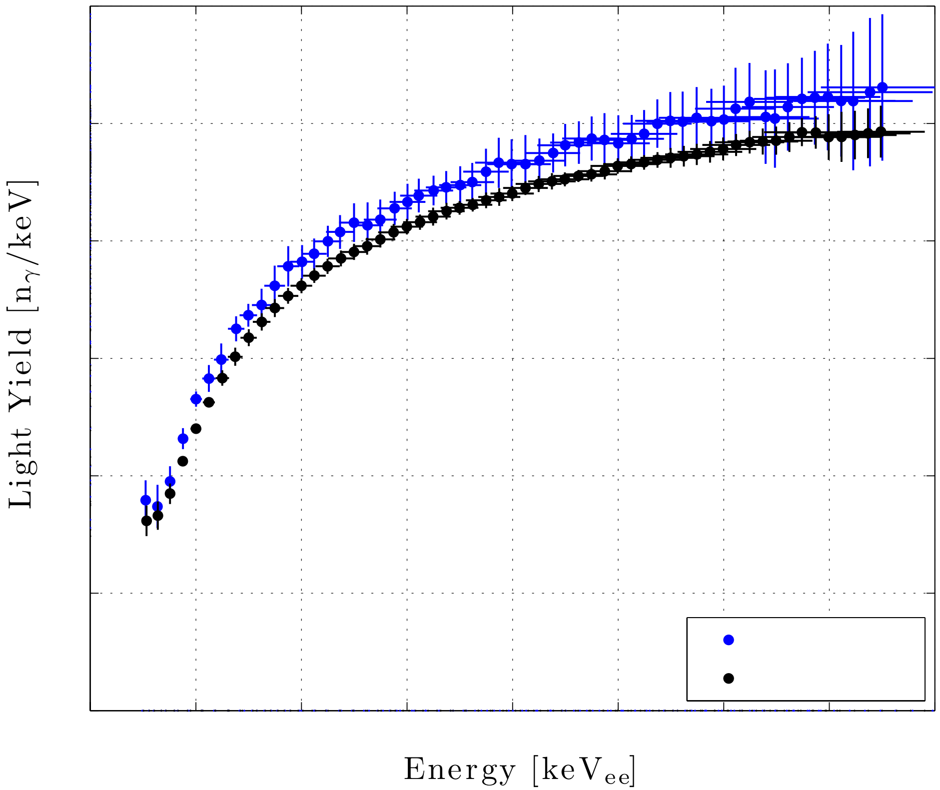
Tritium ER band in good agreement with NEST where vetted (2-8 keV or 7-50 S1 Phe)
Figure on right shows expected improvement in discrimination with field.

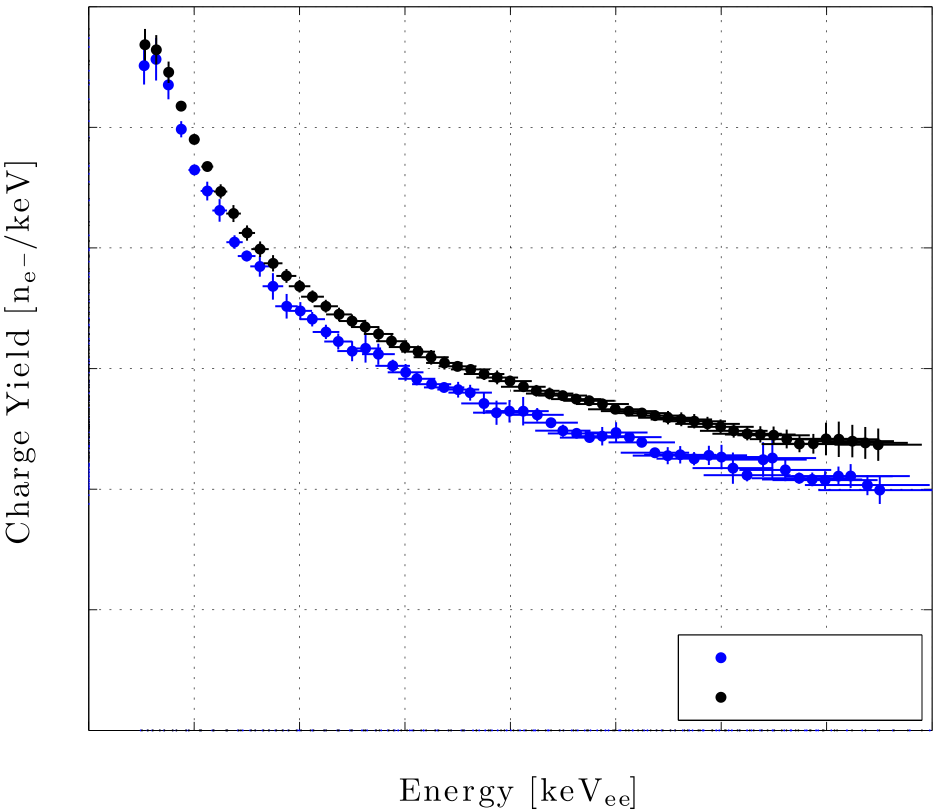
Threshold (golden efficiency)





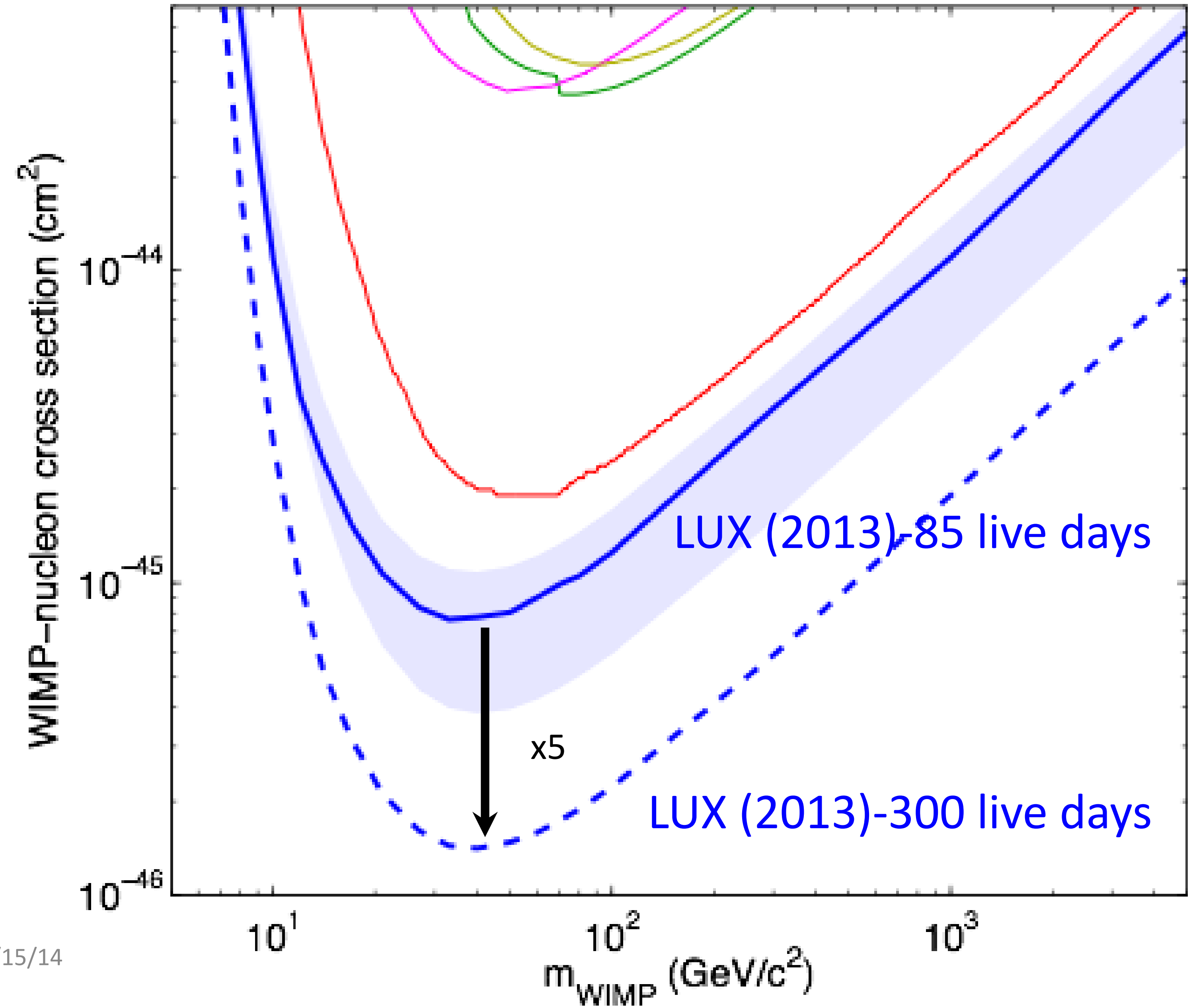
LY, QY measured with Tritium



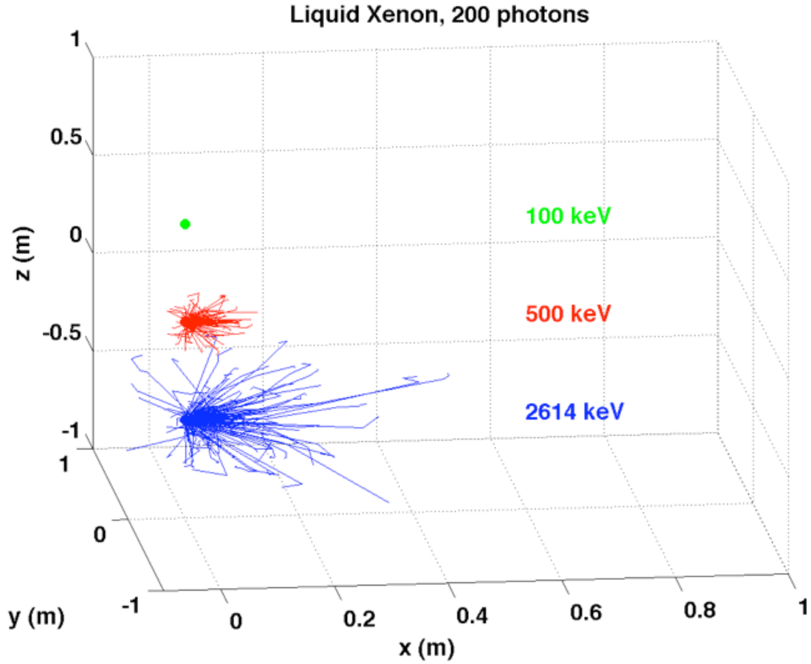


For more info on LY, QY measurement using a beta spectrum see section 2,3 of:
http://teacher.pas.rochester.edu:8080/wiki/pub/Lux/LuxDB00000233/Light_Yield_Tritium.pdf

Projected LUX 300 day WIMP search



Issues with External calibration

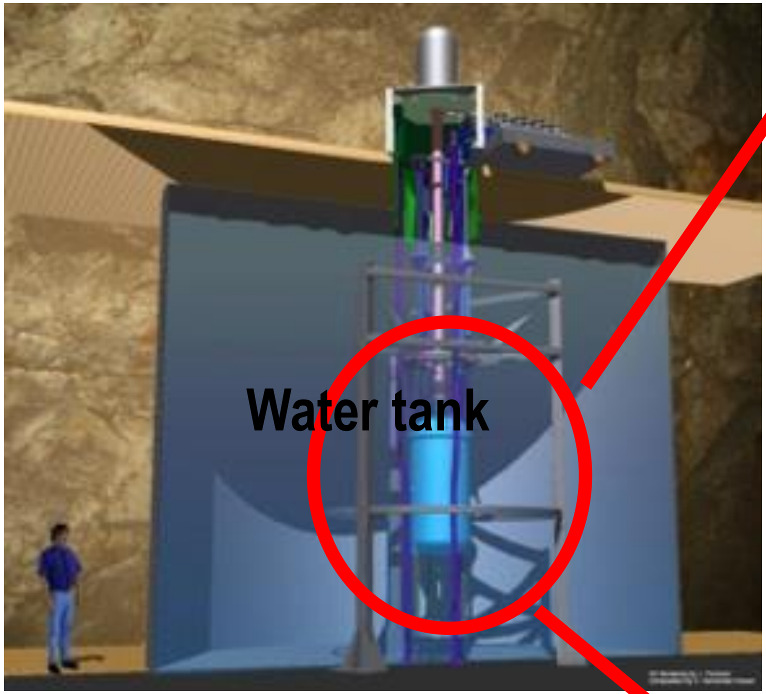


Simulation of self-sheilding in liquid xenon

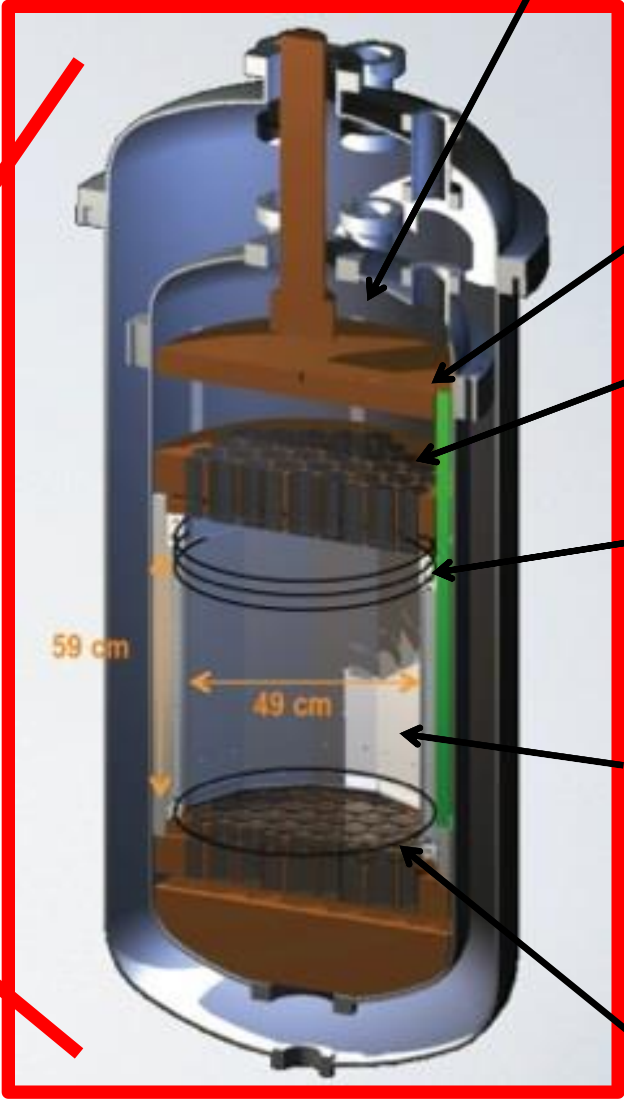
External Source

- Would need a high energy source to perpetrate into fiducial volume
- Probability of forward scatter followed by the gamma escaping the detector is highly suppressed
- Compensating by increasing source rate will overwhelm DAQ and introduce systematics.

The LUX Detector



Low-radioactivity
Titanium Cryostat



370 kg total xenon mass
250 kg active liquid xenon
118 kg fiducial mass

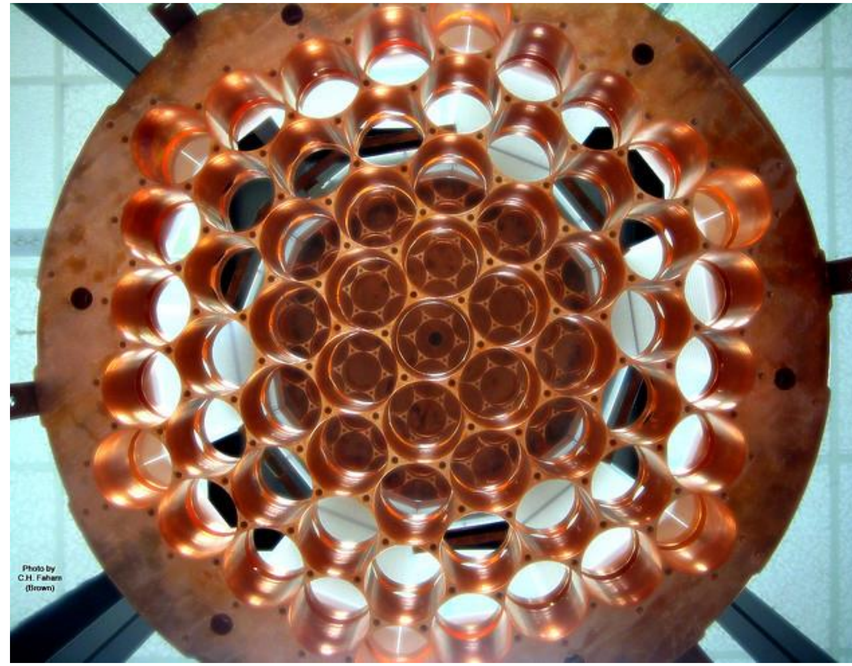
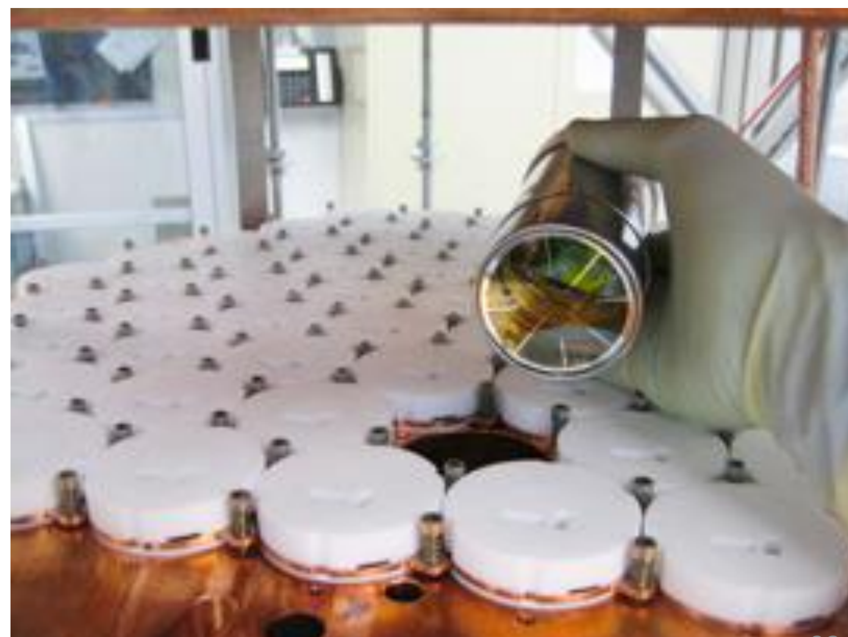
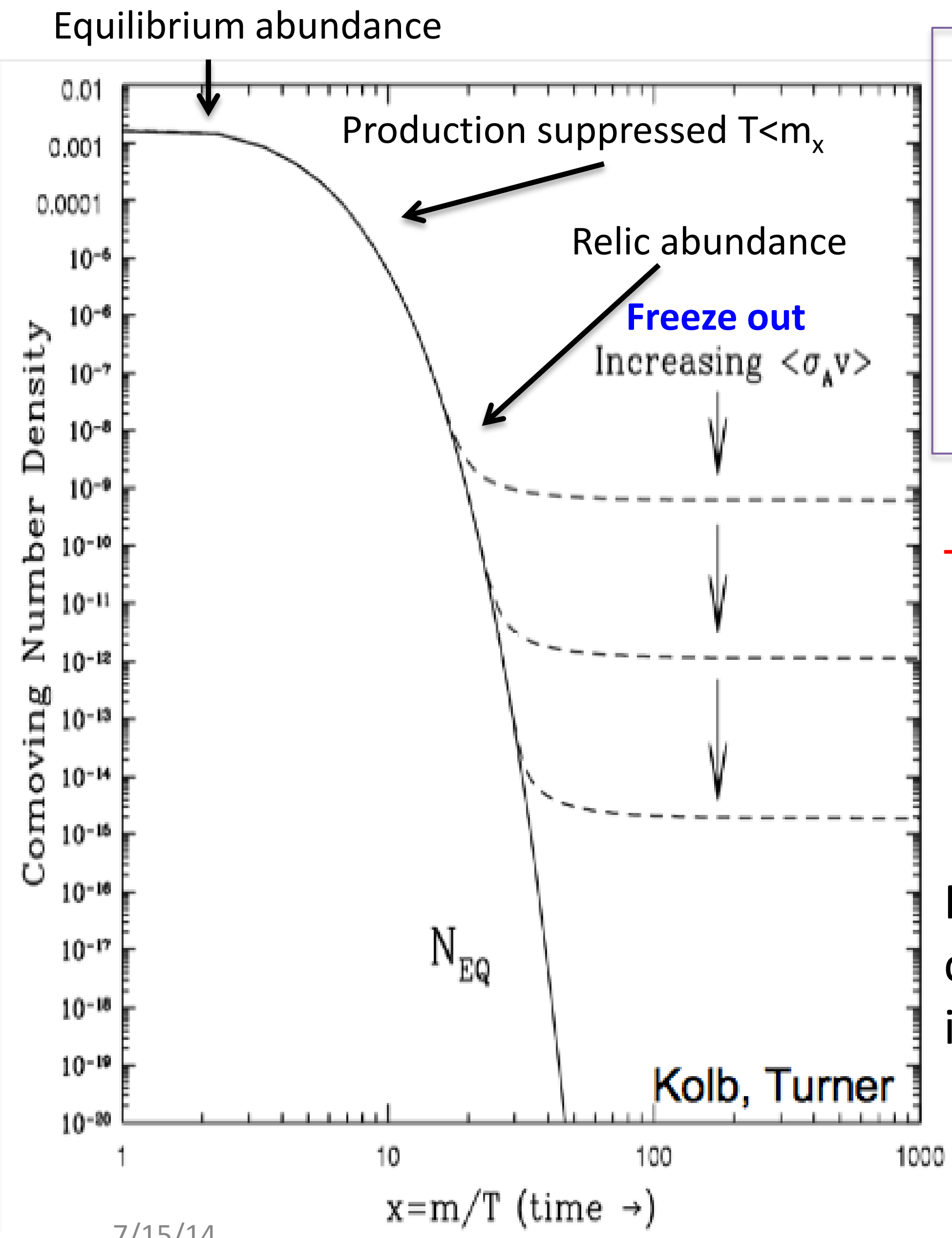


Photo by
C.H. Faham
(Brown)



WIMP Relic Density



Early Hot Universe. Equilibrium	qq ←→ XX
T falls below WIMP mass	qq ← XX
Freeze out (annihilation too slow to keep up with Hubble expansion)	XX

The relic density of such a process is:

$$\Omega \approx 10^{-27}\ \mathrm{cm^3 s^{-1}} / \langle \sigma_{ann} v \rangle$$

Ω_X ~0.1

Remarkably, such a process produces the correct dark matter density with an interaction on the order of the weak scale.

Direct Detection of WIMPs

- Weakly Interacting Massive Particle

A massive particle with weak scale interaction can explain the correct dark matter relic density.

- 300 GeV/liter (about 300 proton masses/liter)
- At 100 GeV, 3 per liter of space
- Average velocity of 230 km/s
- Highly non-relativistic
- Coherent scattering off target nuclei, ~A^2