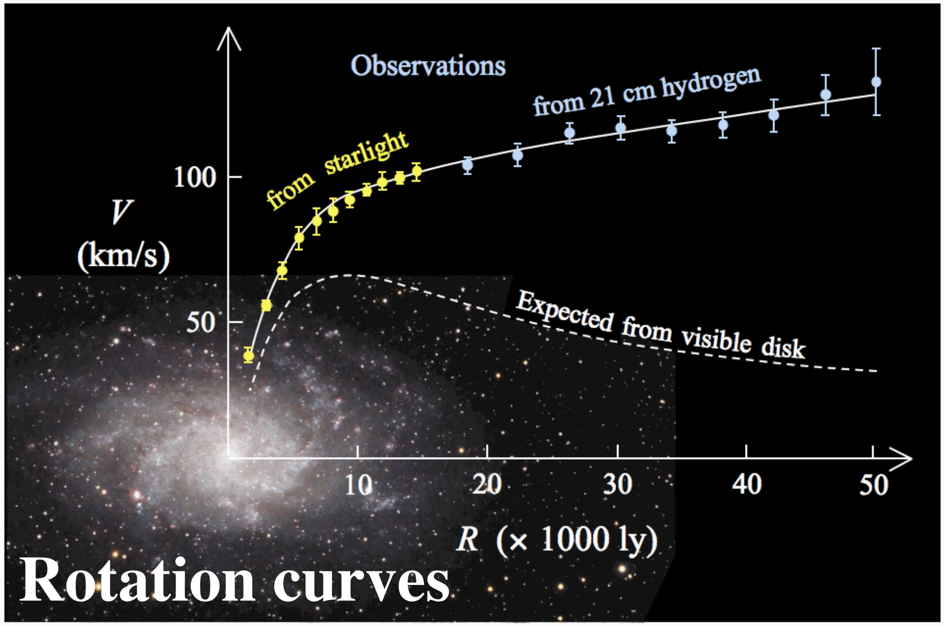
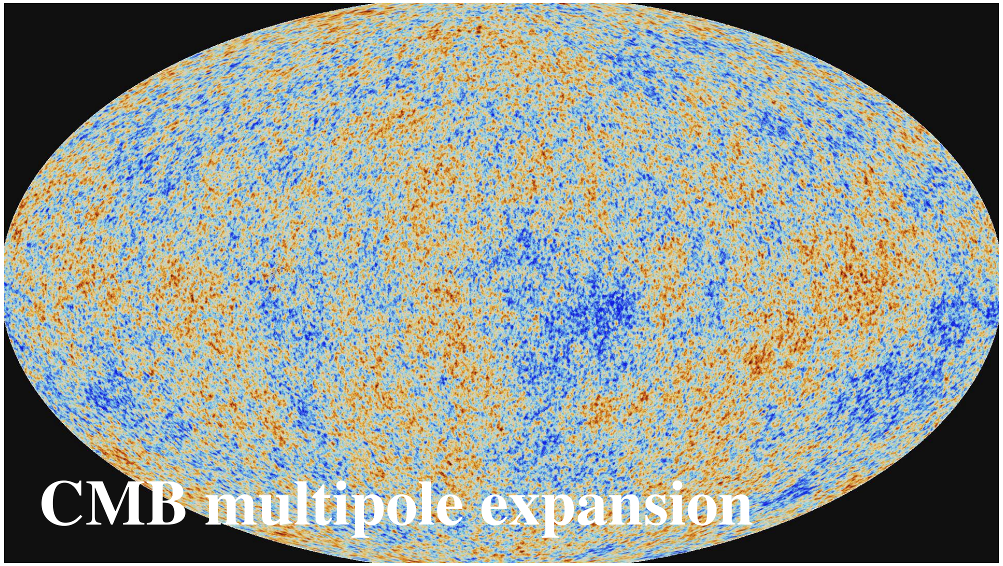
Status of the LUX and LZ dark matter searches

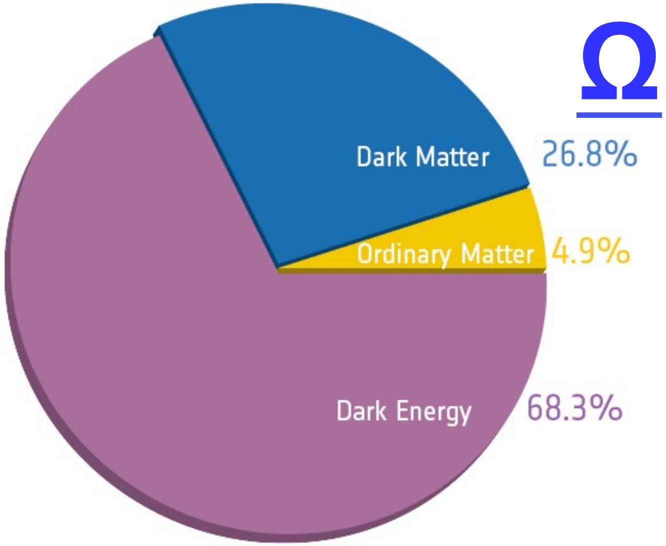
Carter Hall, Univ. of Maryland

September 9, 2015

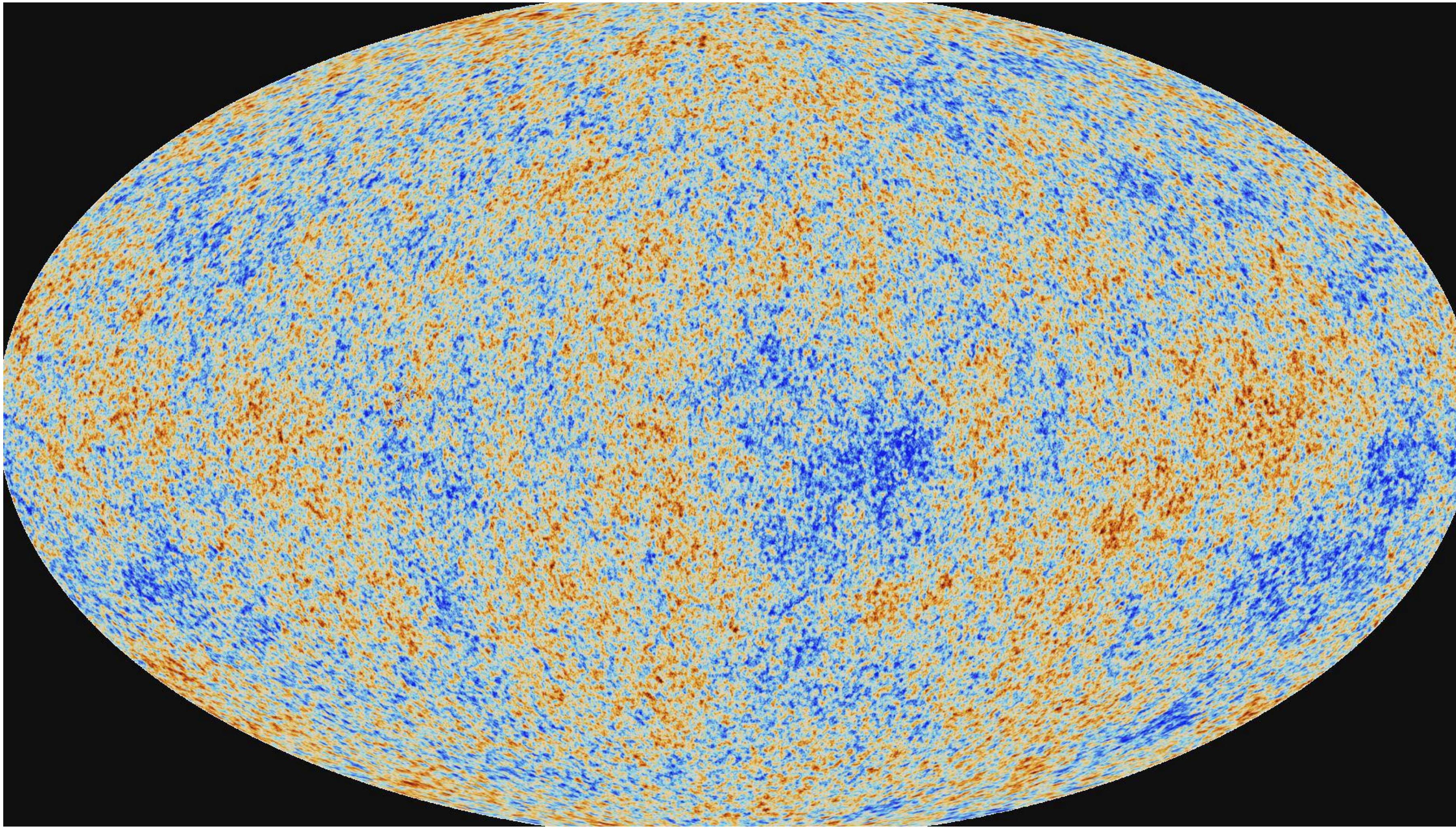
Astrophysical evidence for dark matter





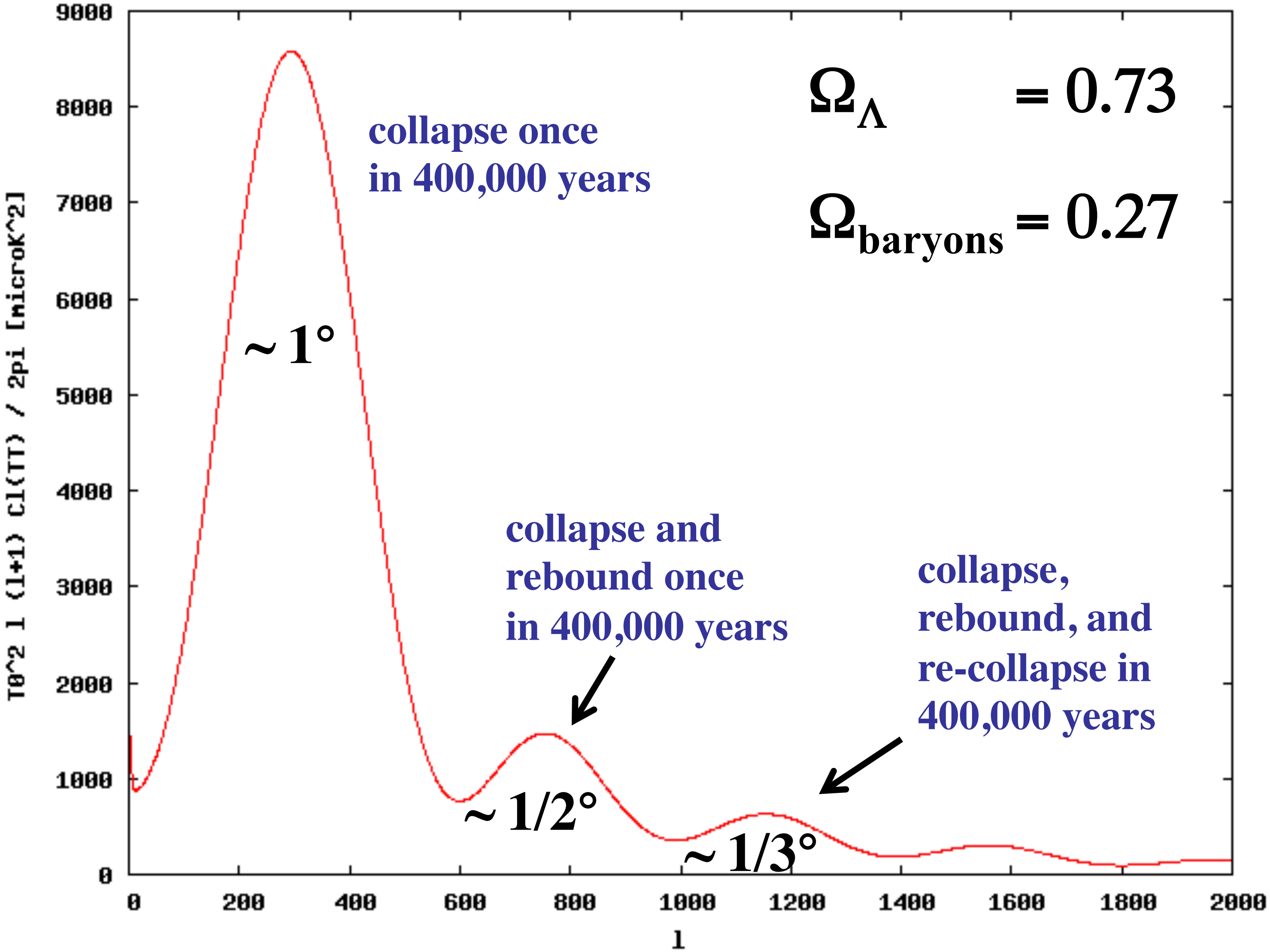


A picture of the universe 400,000 years after the big bang

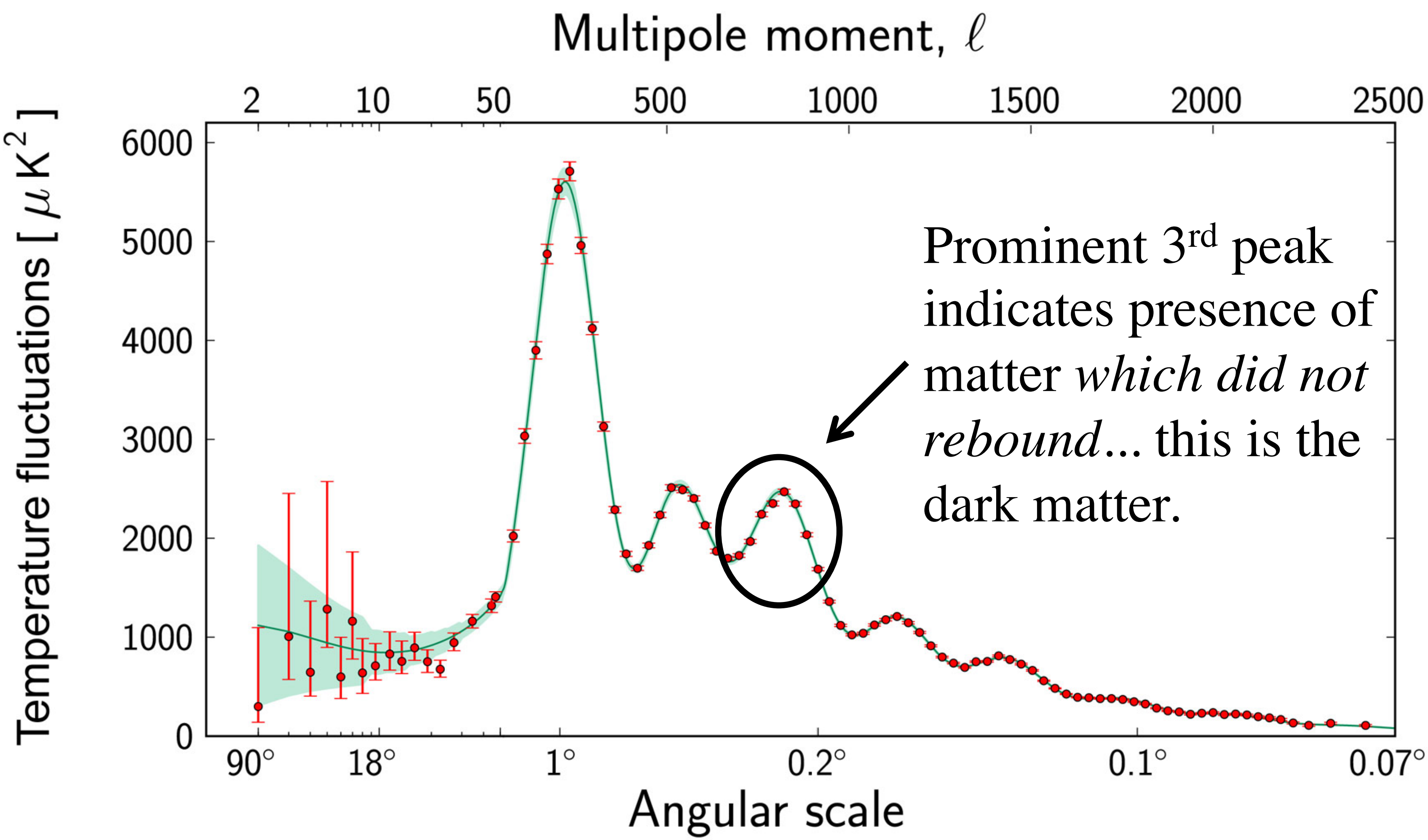


The cosmic microwave background anisotropy as seen by Planck.

In a universe with no dark matter – CMB multipole expansion



CMB multipole expansion as measured by Planck



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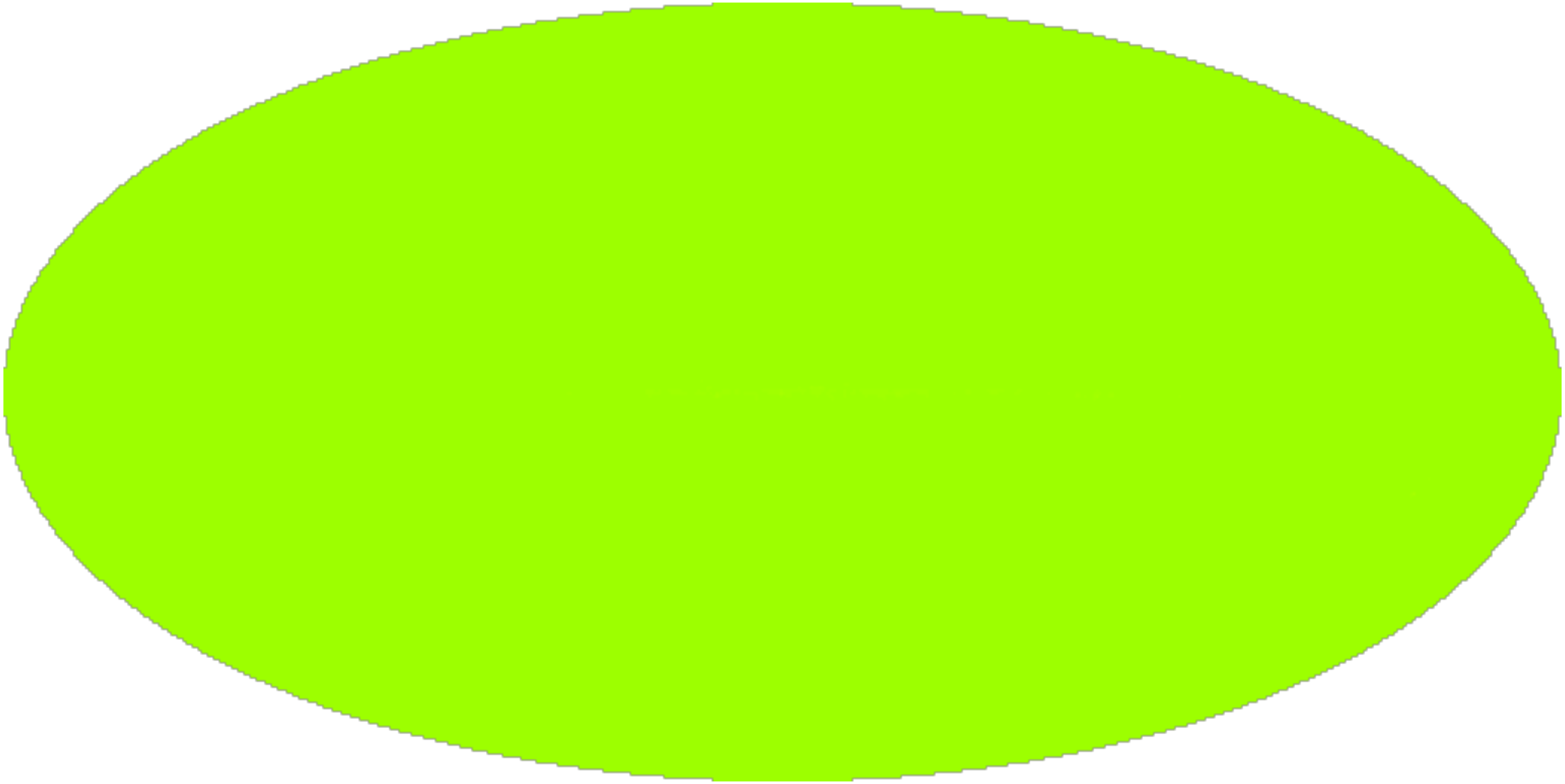
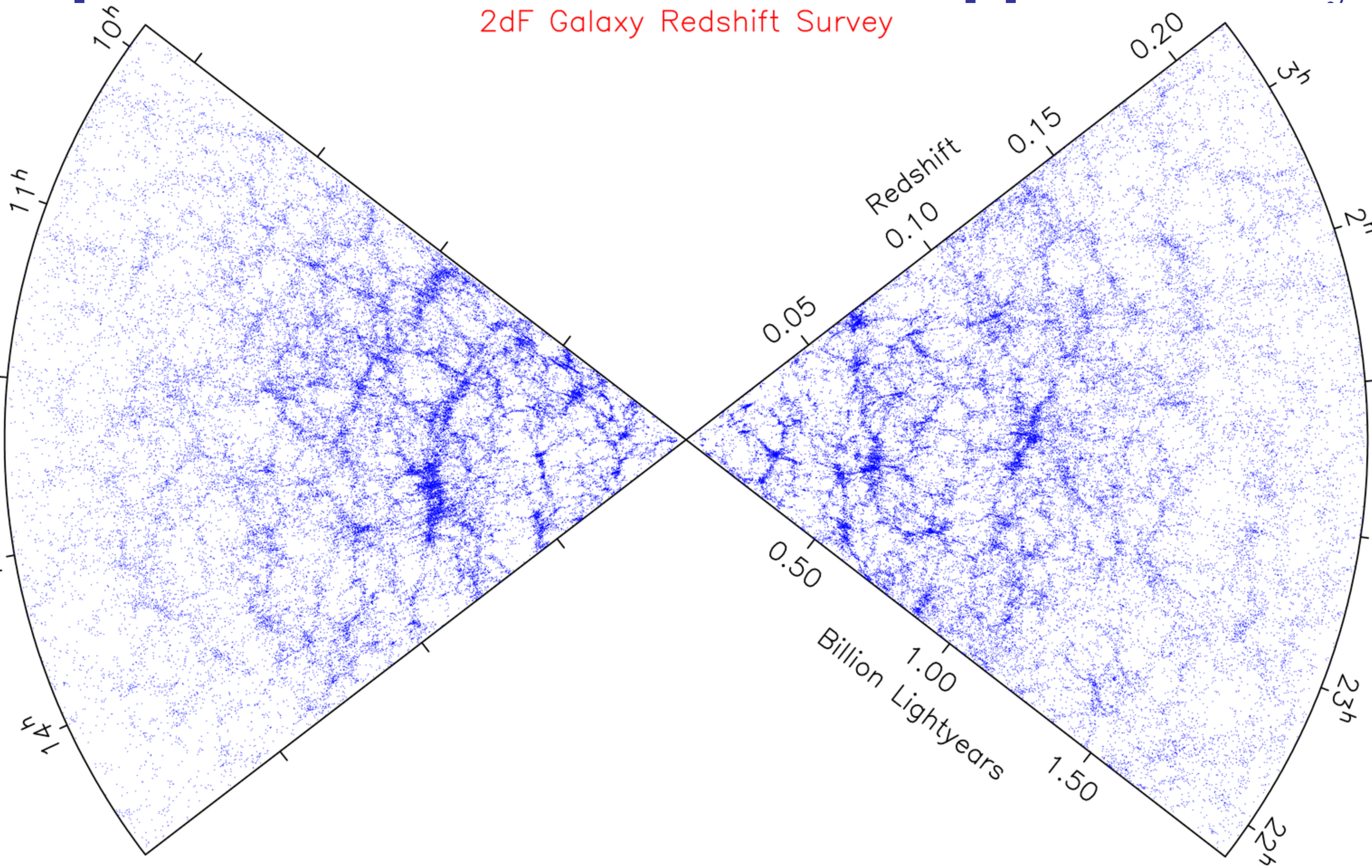
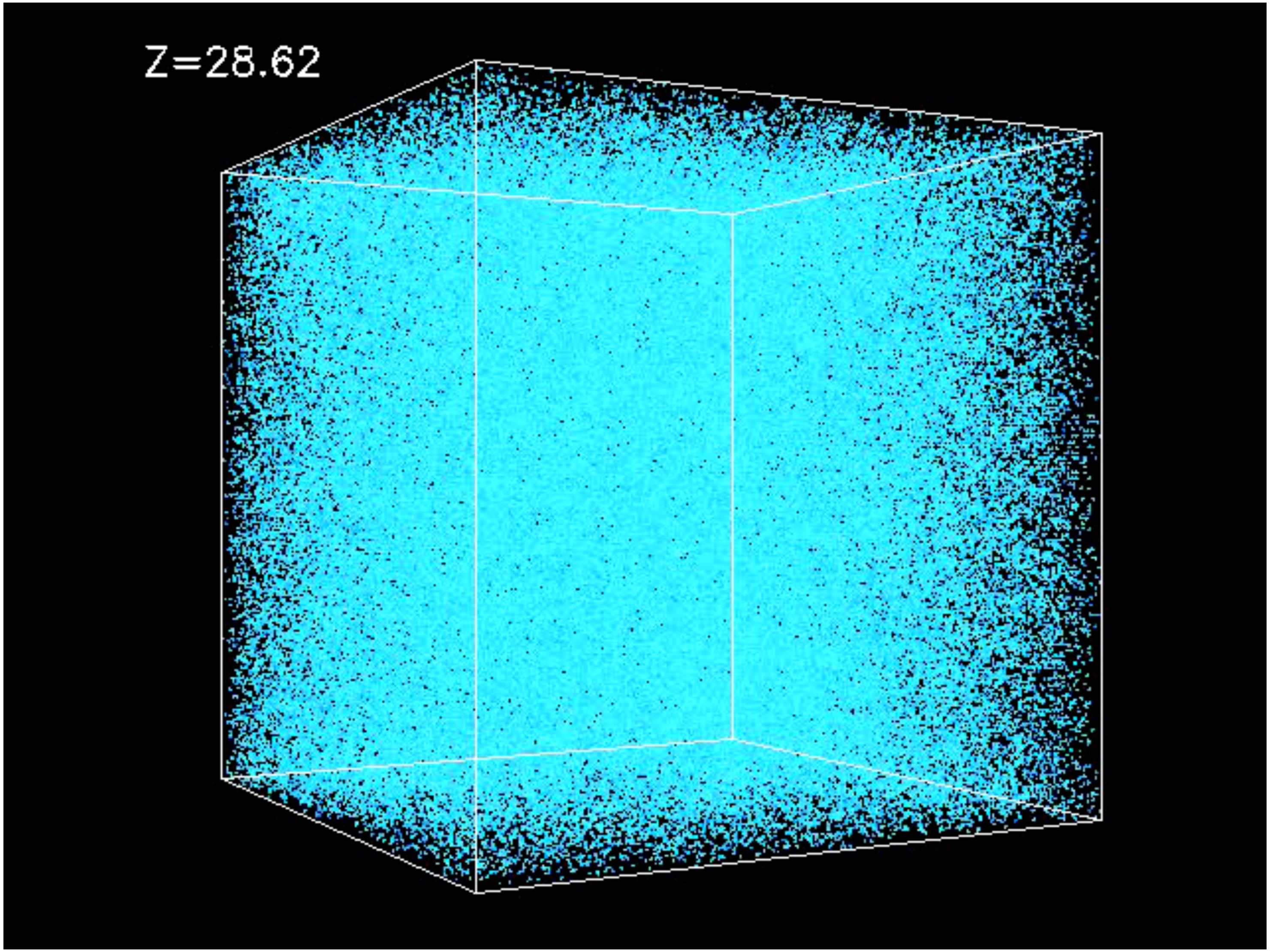


The cosmic microwave background isotropy as seen by WMAP
(no contrast enhancement).

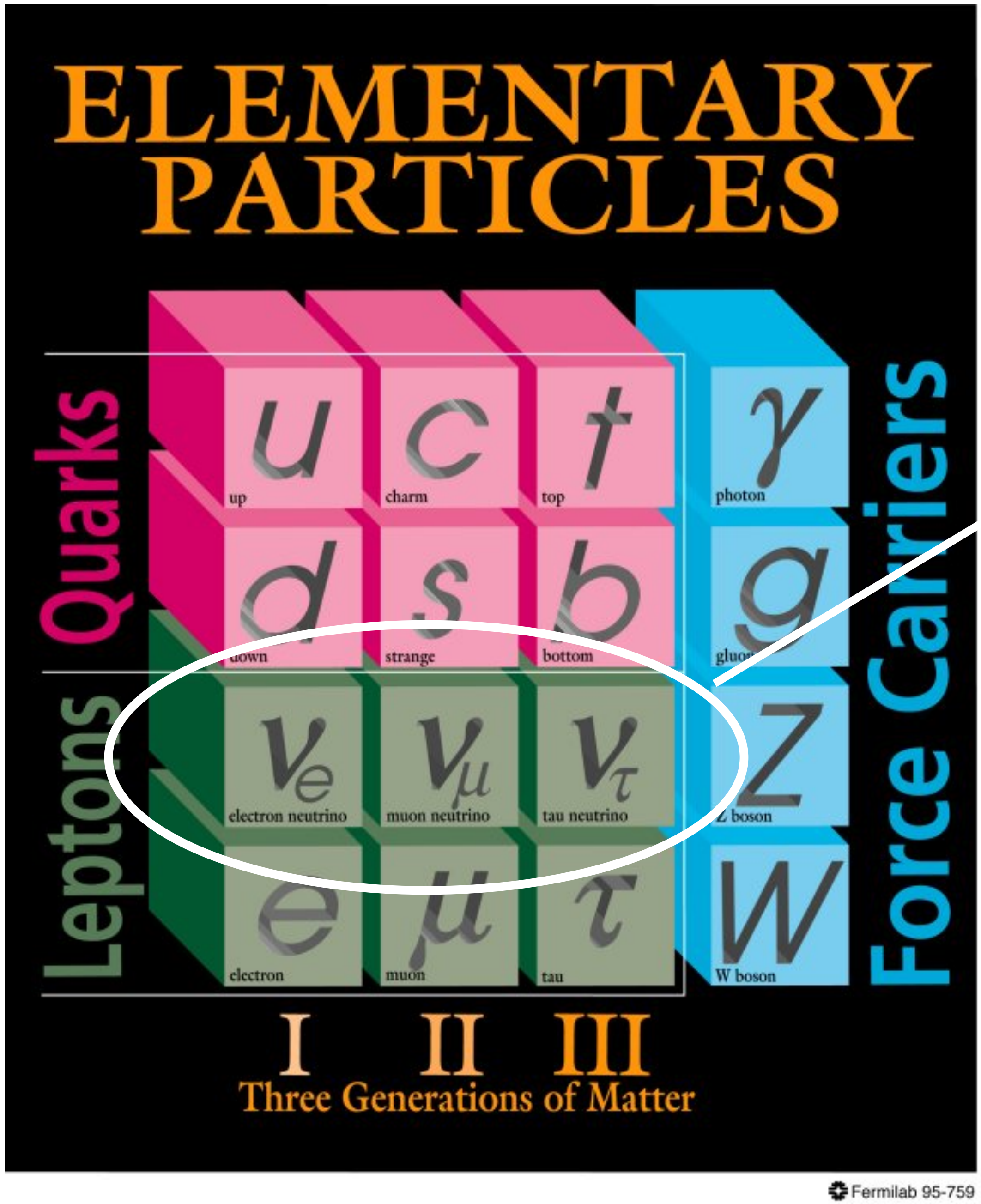
A picture of the universe as it appears today.



Each dot is a galaxy with hundreds of billions of stars.



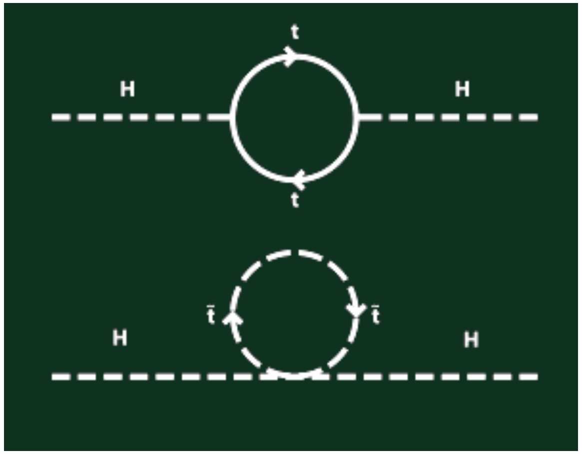
Credit: Andrey Kravtsov, KICP, U. Chicago

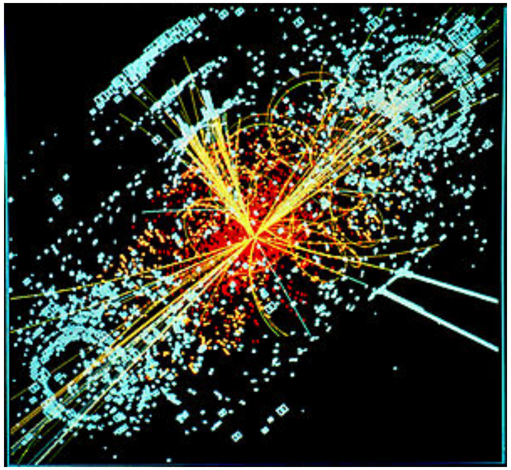


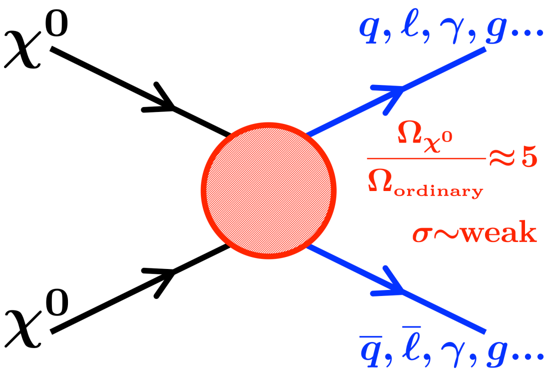
Neutrinos? – Seem to be too light

Two problems from particle physics

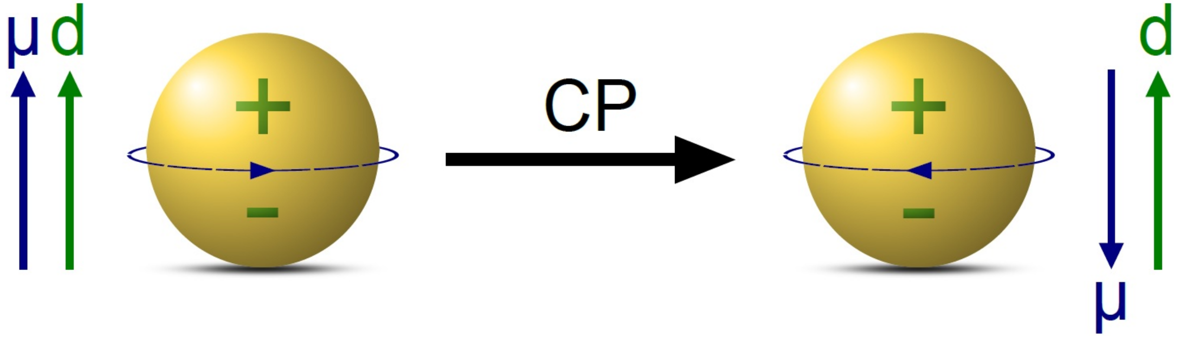
1) Why is the weak scale so light? ➔ New weak physics? ➔ WIMPs

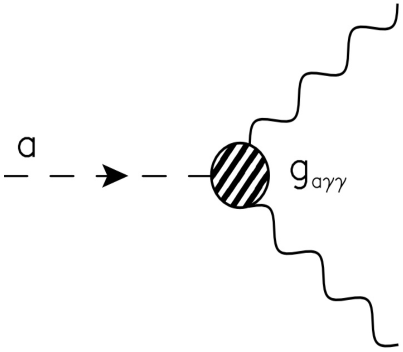






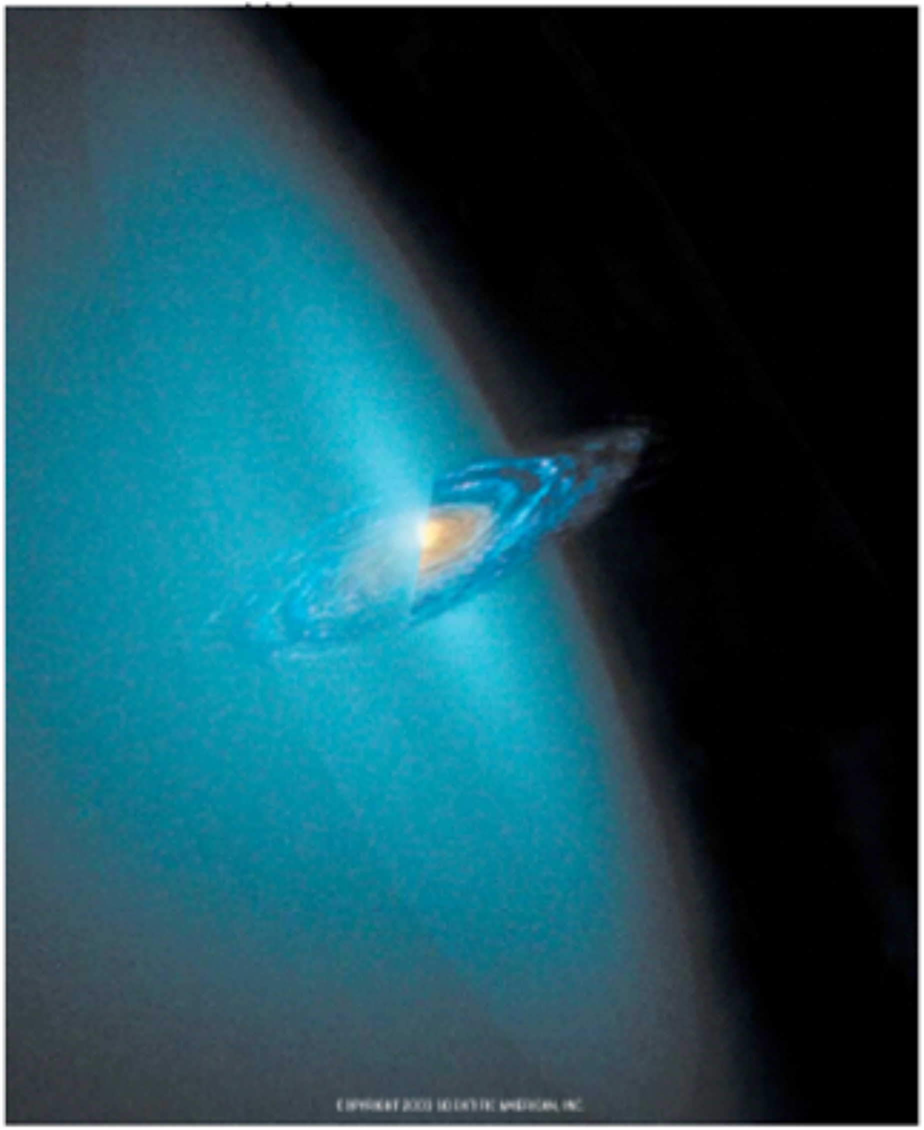
2) Why no CP violation in QCD ? ➔ Pececi-Quinn symmetry?➔ Axions

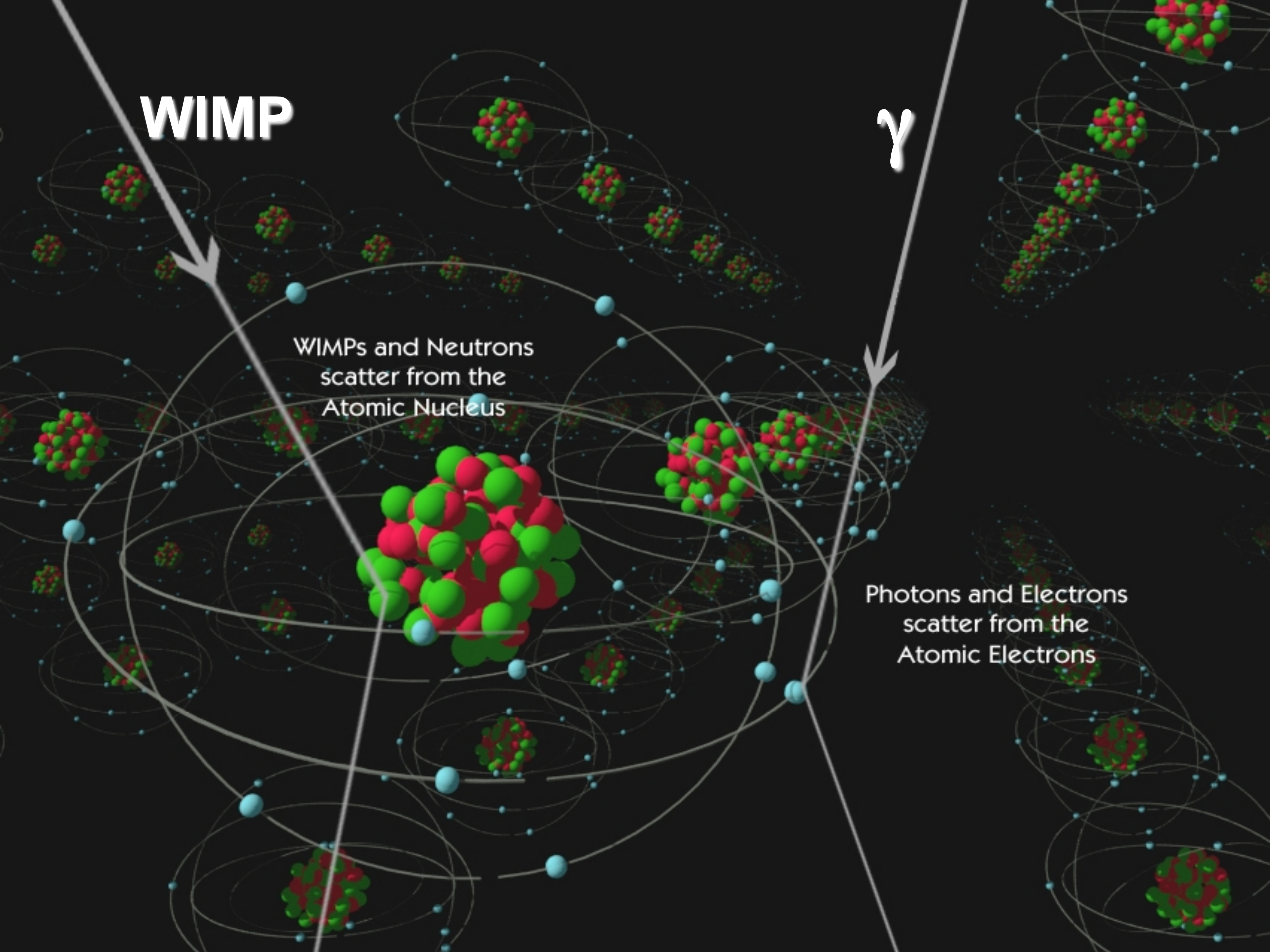




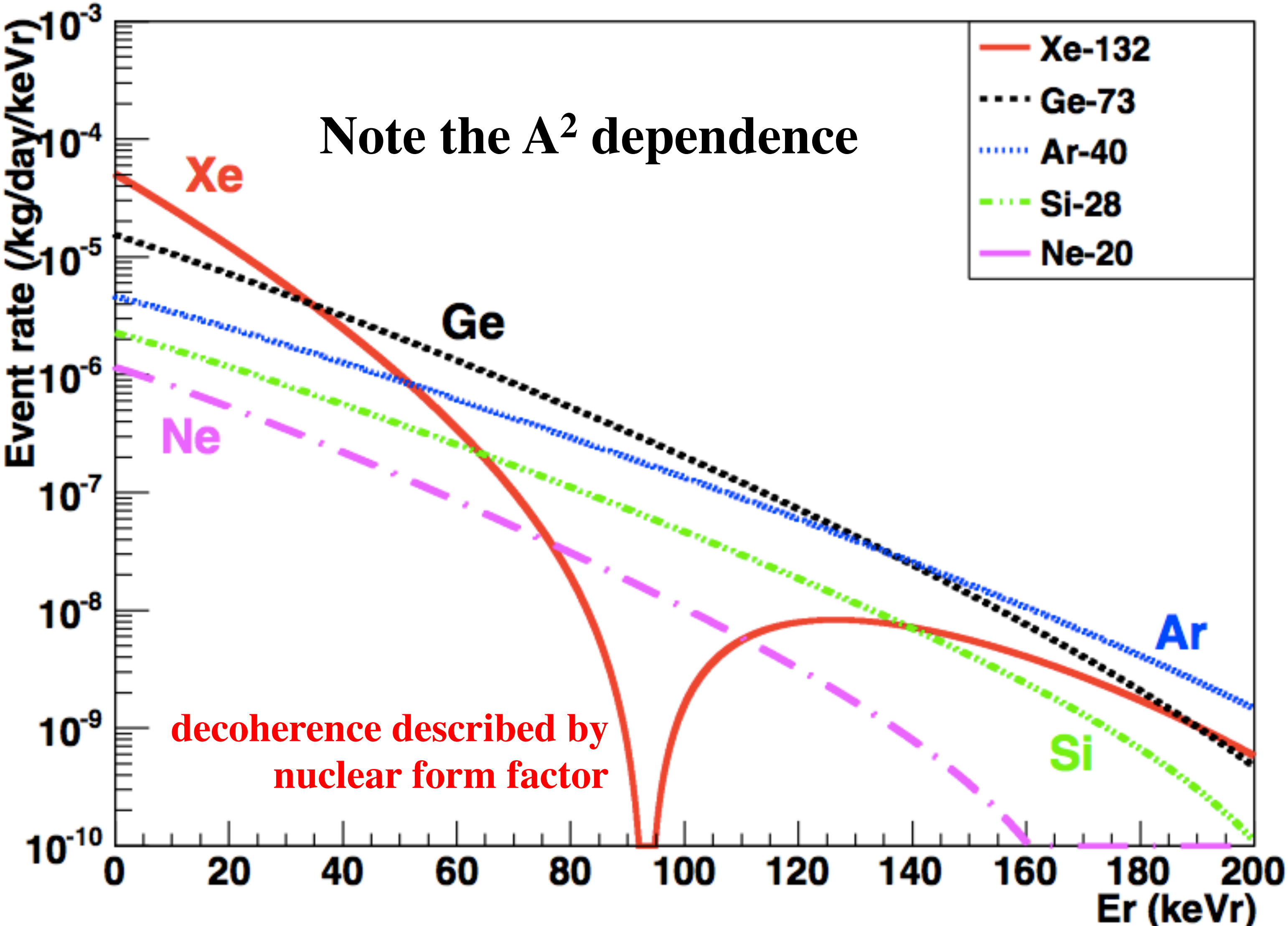
The Milky Way's dark matter halo

- **Typical orbital vel.** = 230 km/sec
  ~ 0.1% speed of light
- Density: ~ 300 m_{proton} / liter
  - **WIMPs** (~100 GeV): 3 per liter
  - **Axions** (~3 μeV): 10^{17} per liter
- deBroglie wavelength:
  - **WIMPs**: larger than a nucleus. Coherent scalar scattering on ordinary nuclear matter, $\sigma \sim A^2$
  - **Axions**: ~100 m, larger than a laboratory. Behaves like a classical field. Resonant conversion in a cavity.
- Production:
  - **WIMPs**: thermal
  - **Axions**: athermal



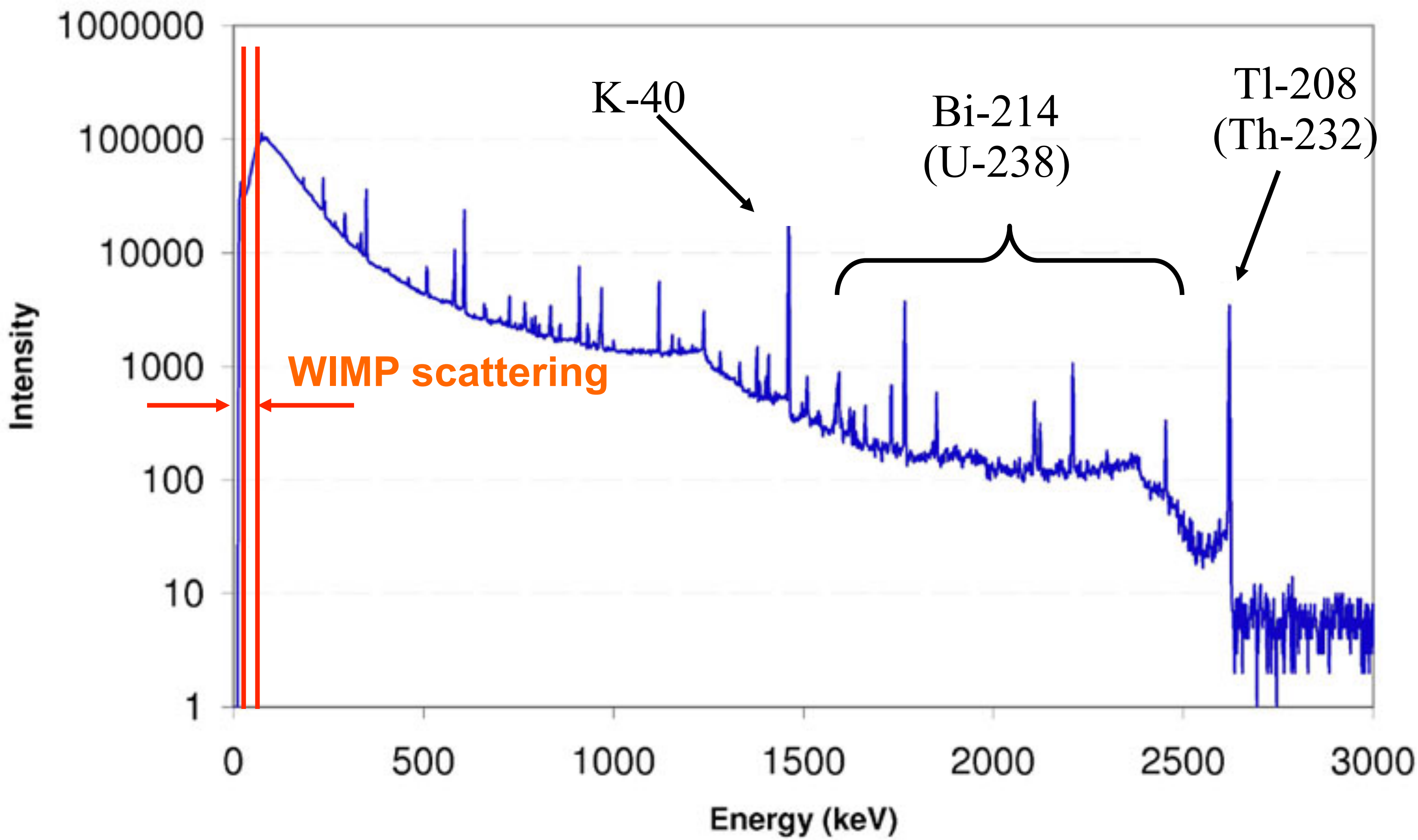

WIMP
γ
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons

Nuclear recoil spectra for various targets

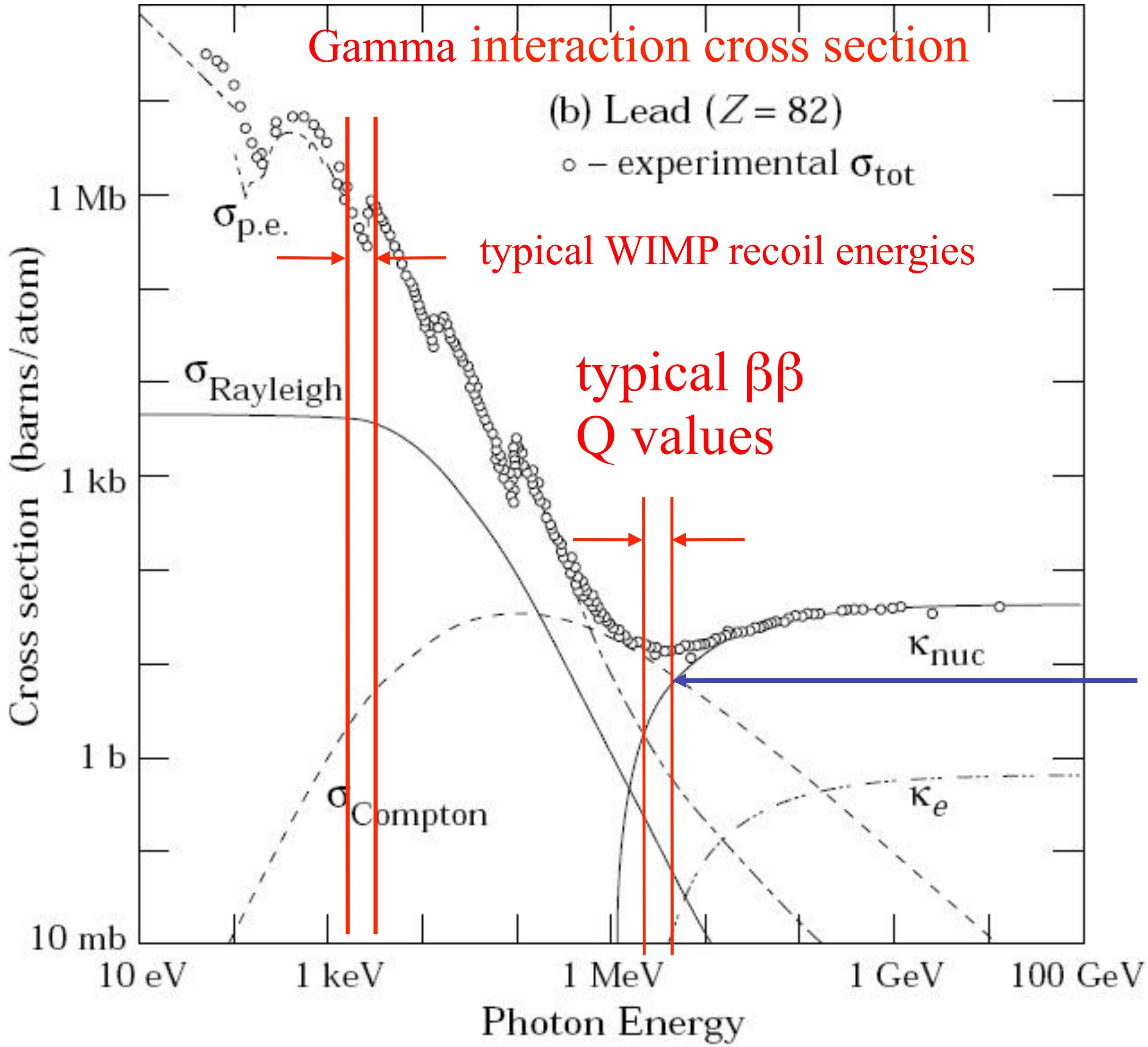


From: arXiv:1107.1295

Common radioactive decay here on earth



Shielding is not difficult @ 5 keV

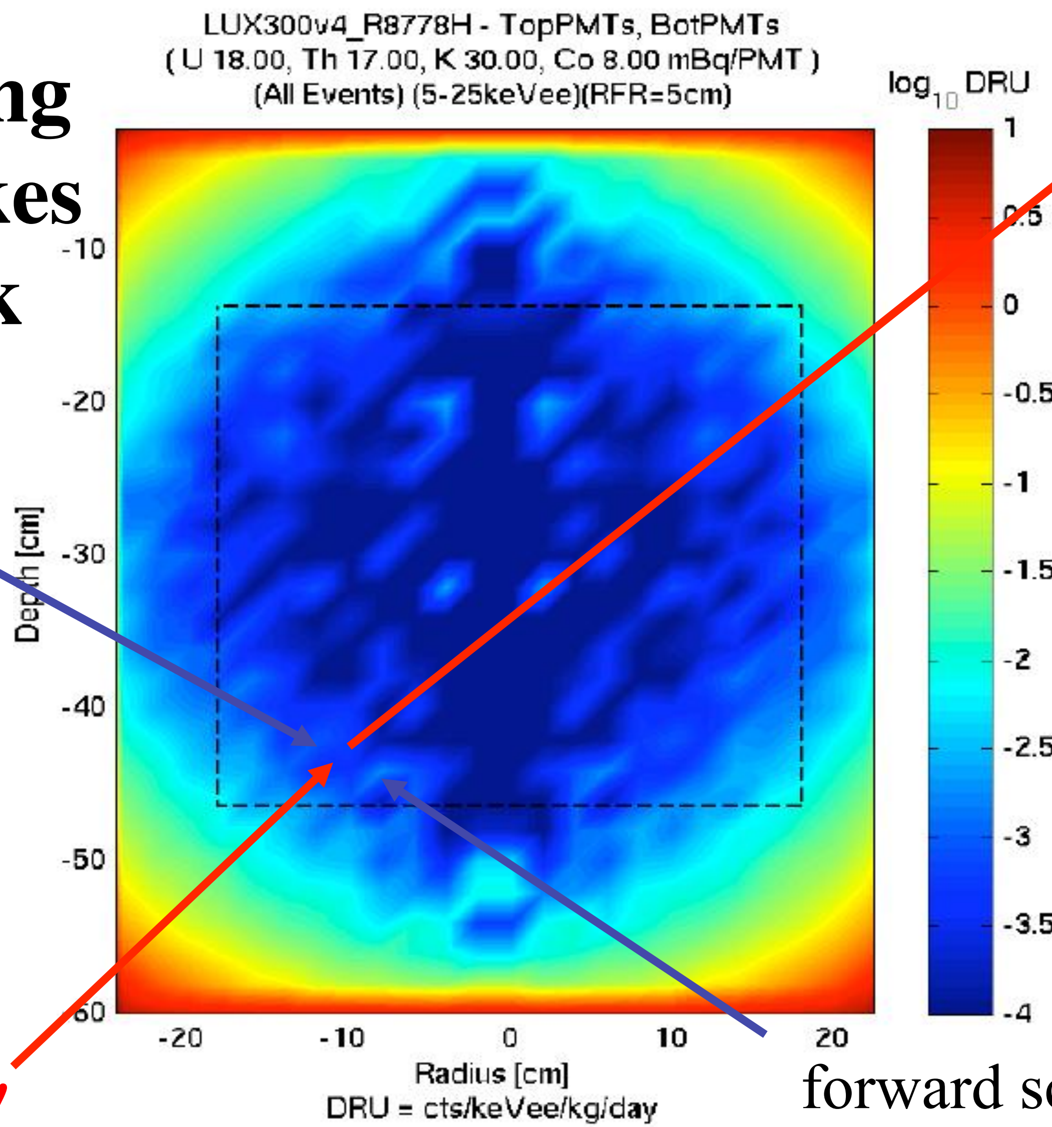


gammas travel about 2 cm before scattering in lead

Kinematics provides strong rejection

Self-shielding is what makes LUX work

~ keV deposition

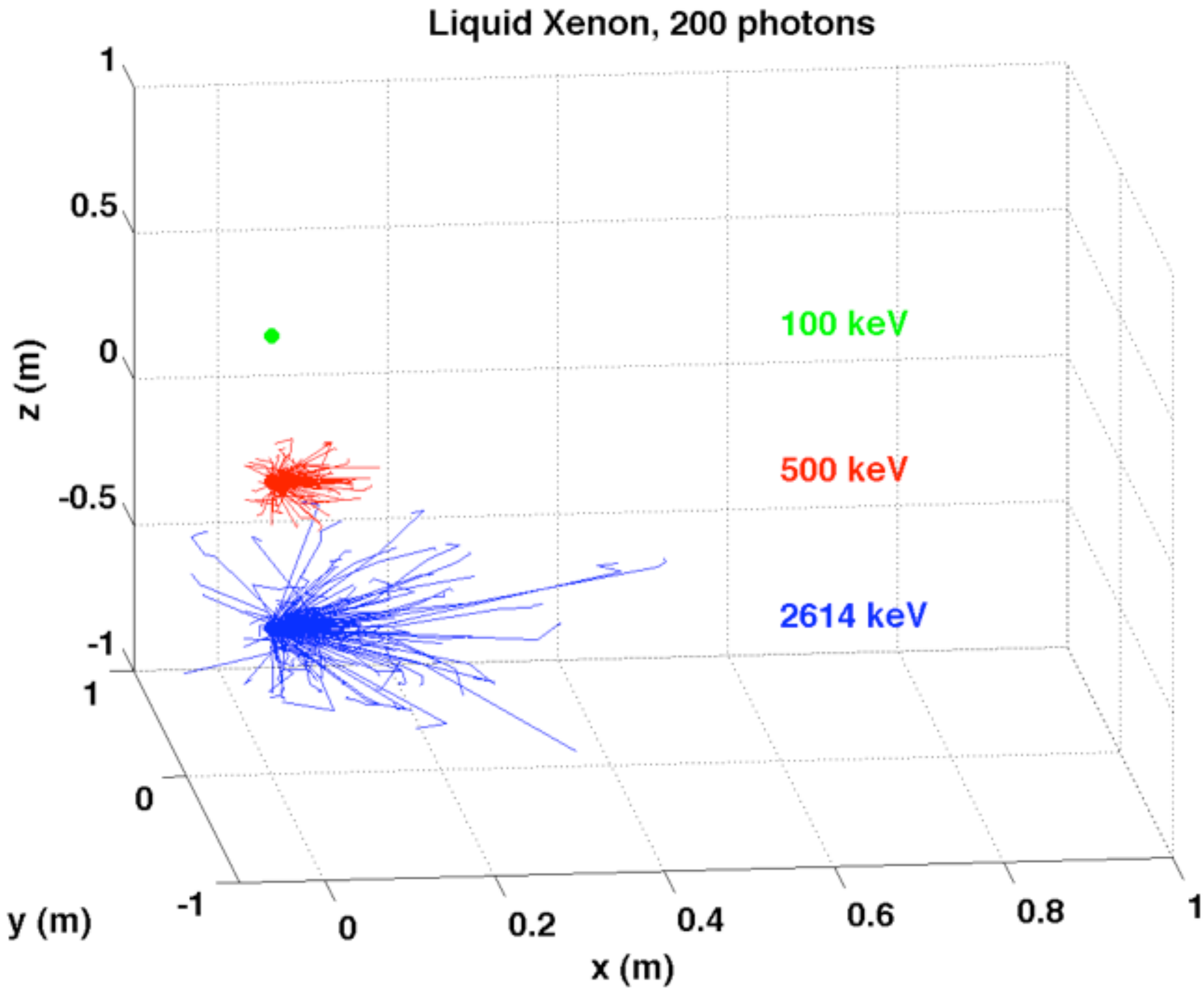


must cross full volume without interacting again

~ MeV γ

forward scattering

Simulation of self-shielding in liquid xenon



Low energy gammas can't travel far –
Fiducial volume cut rejects most backgrounds

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

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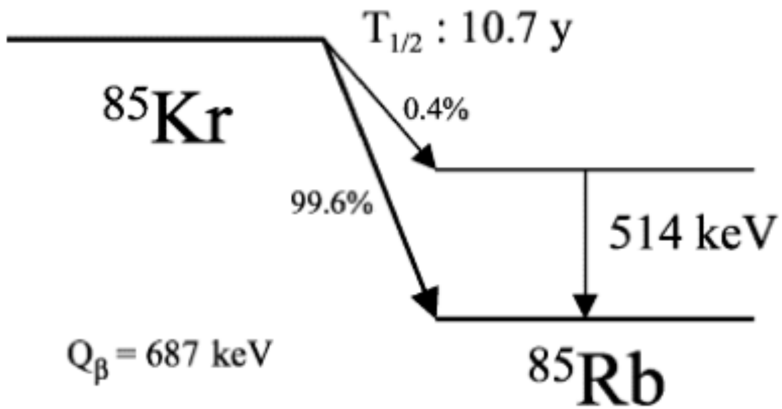
Clean titanium cryostat

**Type 304 stainless steel used in electric field grids

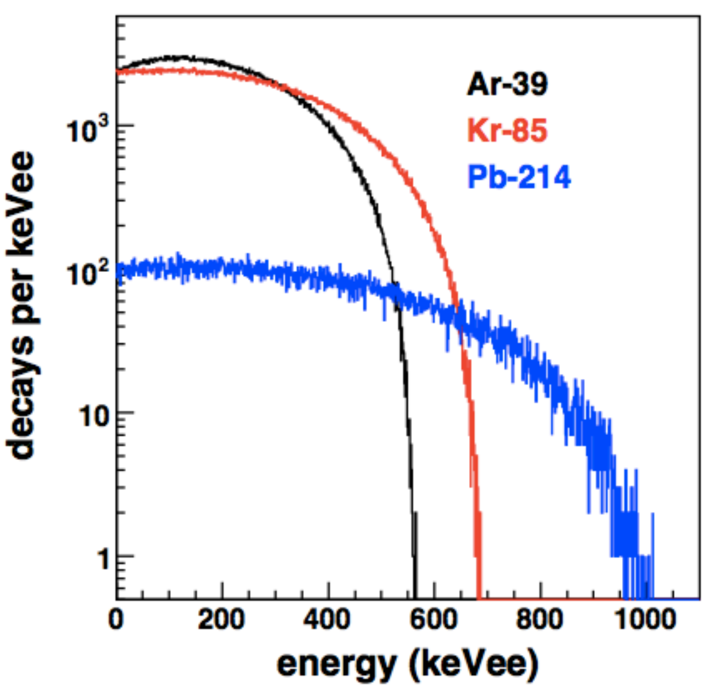
*Cosmogenic equilibrium at 1 mile above SL; decays below ground

Radioactive isotopes dissolved in the liquid xenon would defeat self-shielding

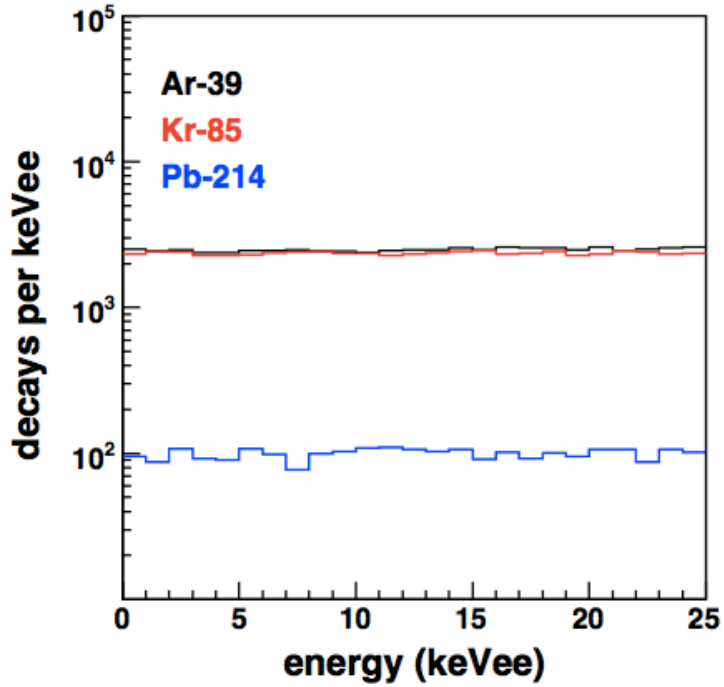


- Krypton-85 is the most important source of internal radioactivity
- Vendor-supplied xenon contains residual krypton at a relative concentration of $\sim 10^{-7}$
- LUX goal: reduce Krypton concentration to $\sim 5 \times 10^{-12}$

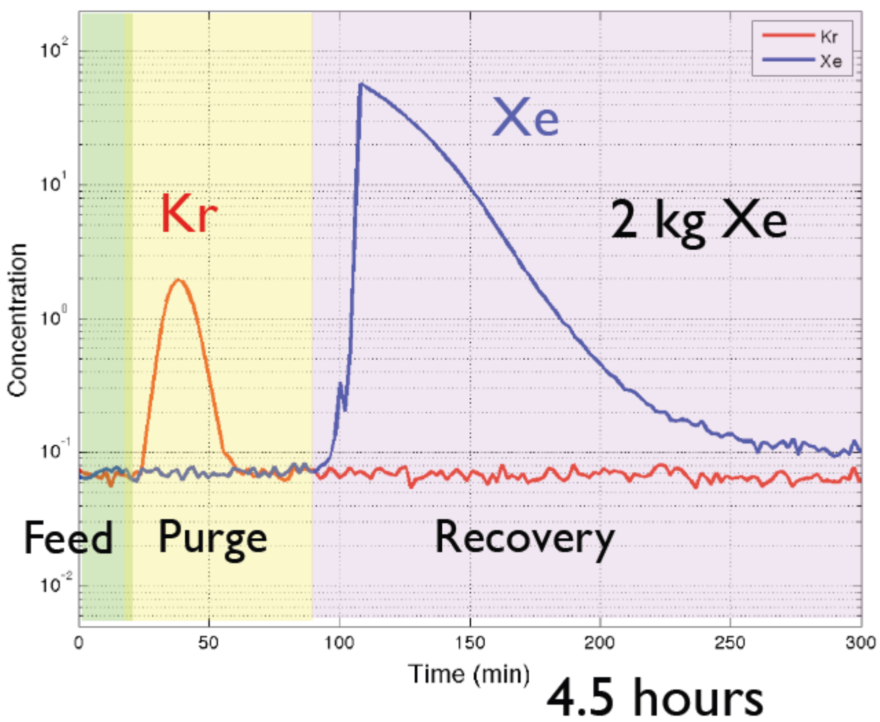
complete spectra

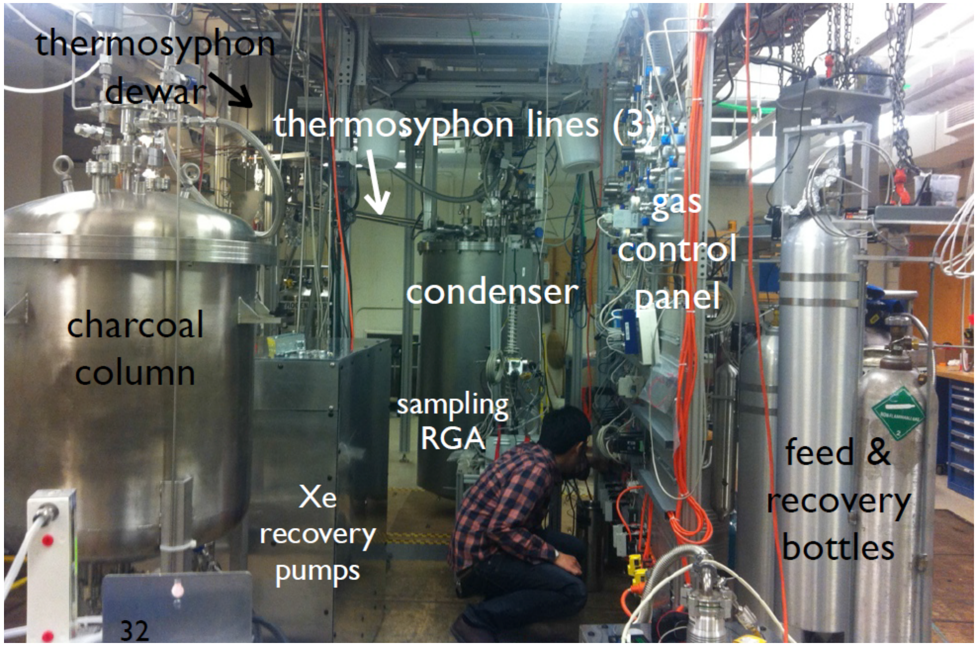


low energy zoom



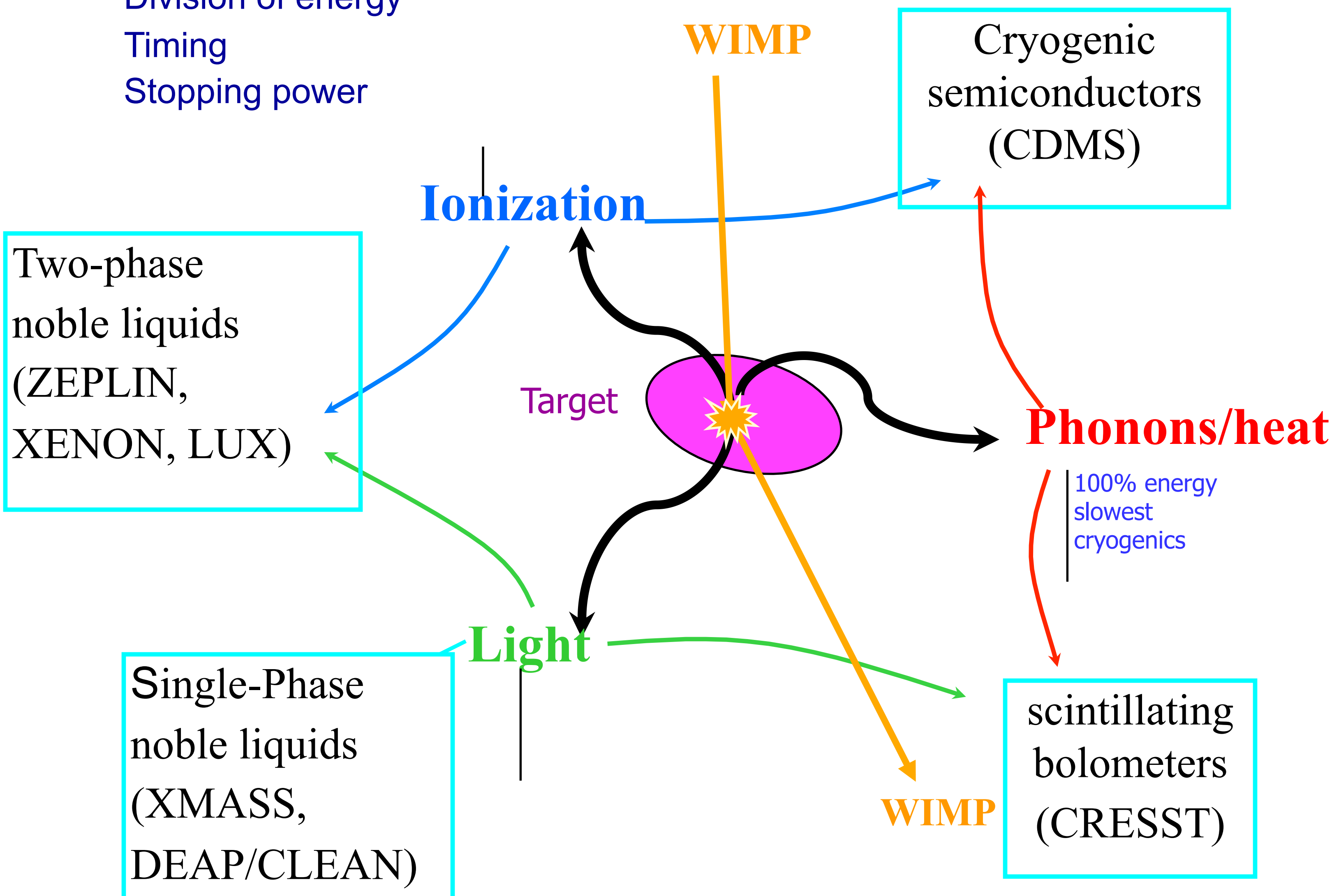
Chromatographic Krypton Removal System @ Case Western (Aug. – Dec. 2012)

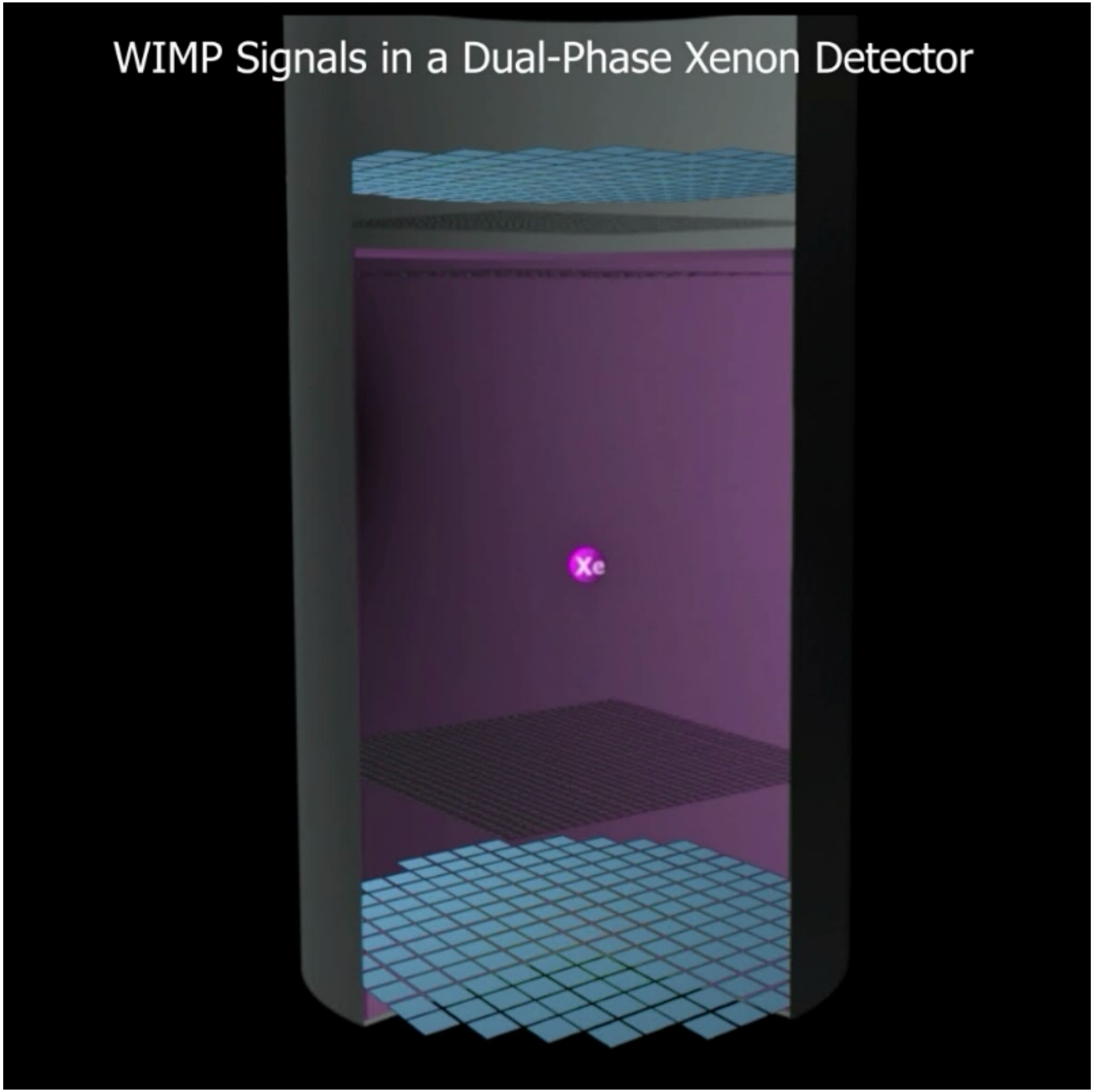




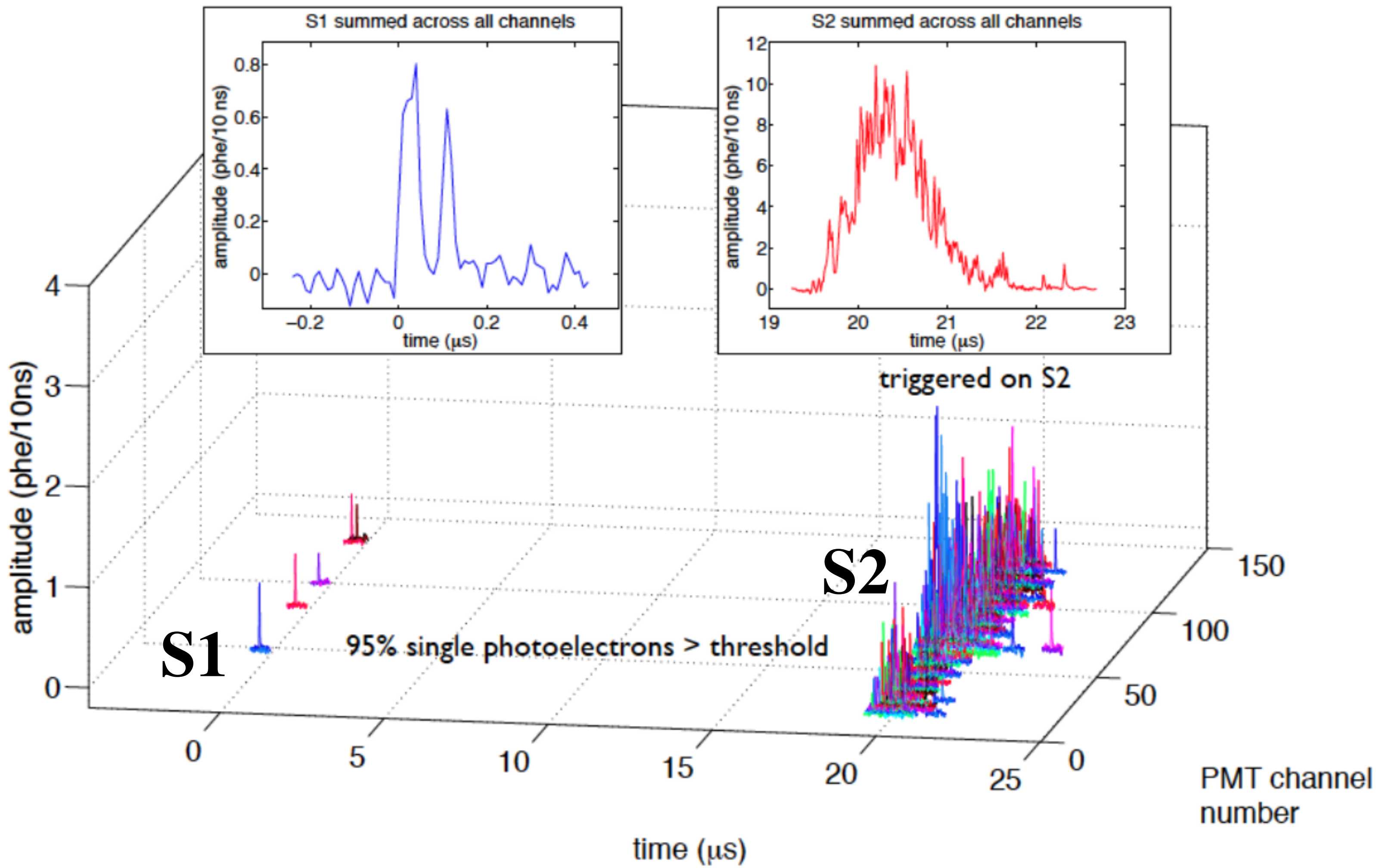
Background rejection through nuclear recoil discrimination

- Nuclear recoils vs. electron recoils
  - Division of energy
  - Timing
  - Stopping power

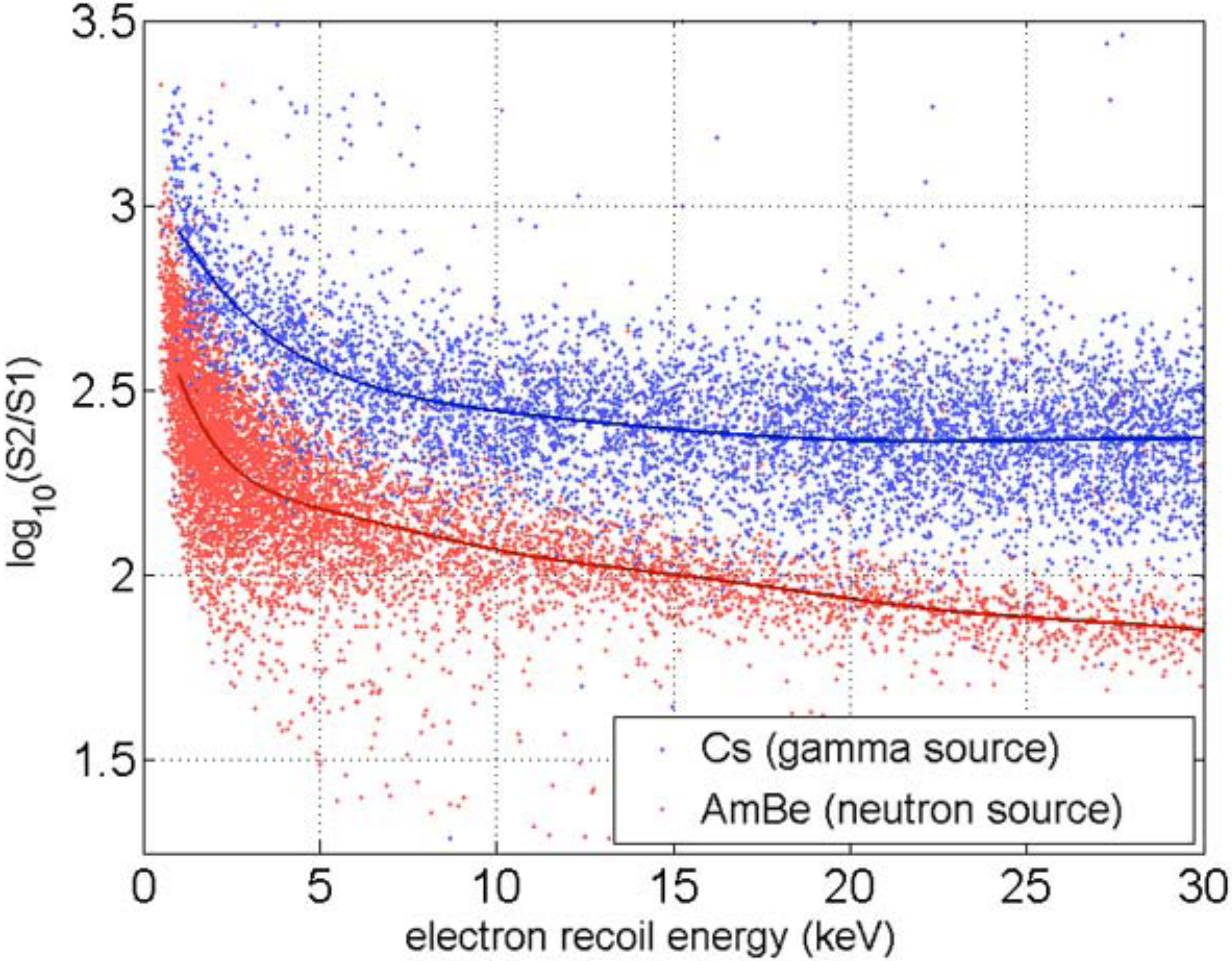



WIMP Signals in a Dual-Phase Xenon Detector
Xe

Typical Event in LUX

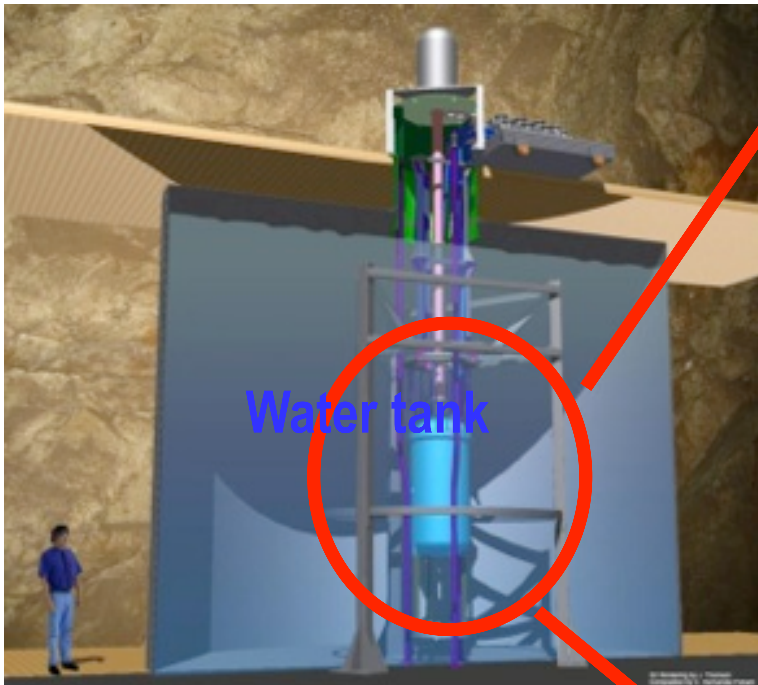


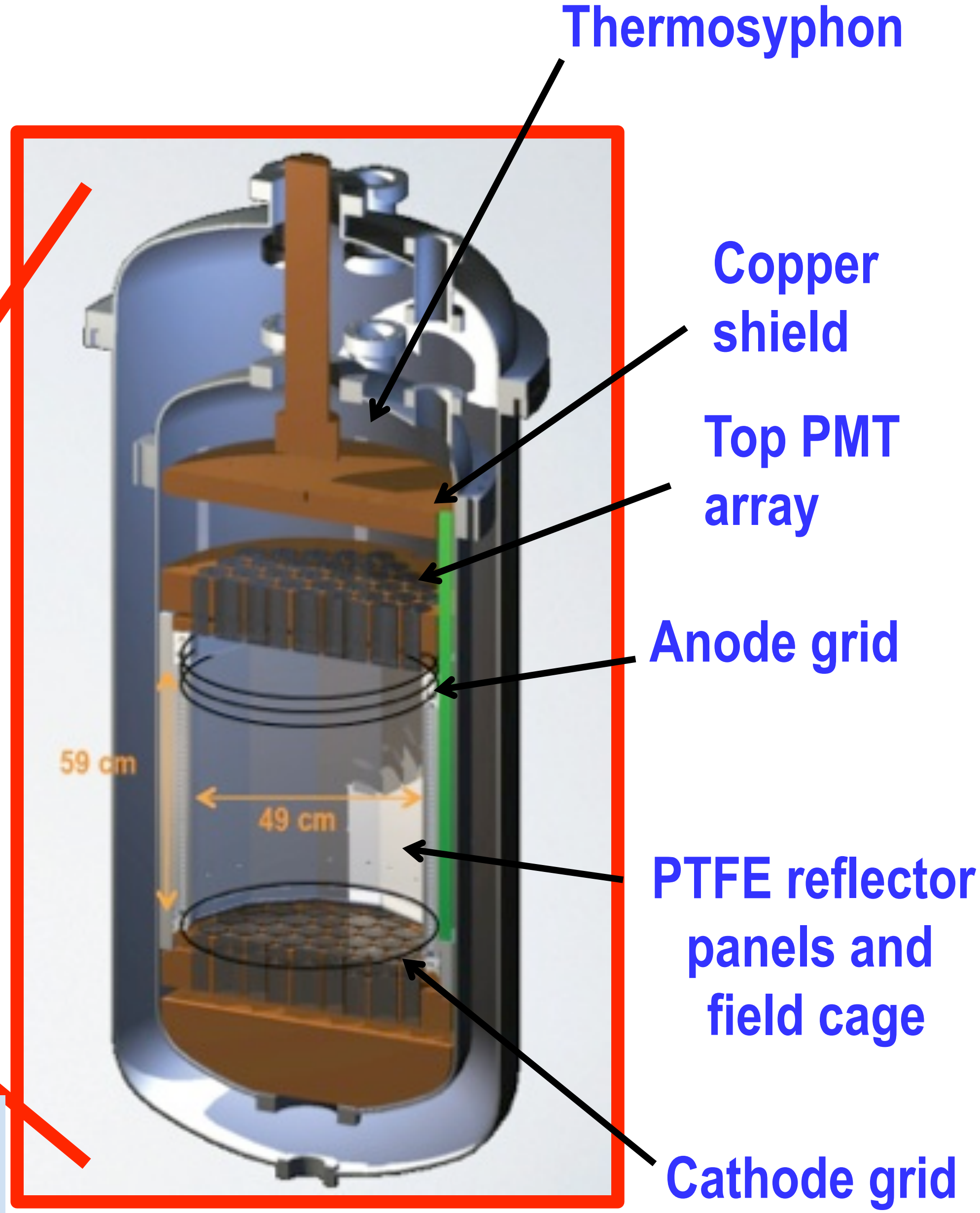
Charge/Light (S2/S1) recoil discrimination in Liquid Xenon



Data from bench-top demonstration experiment at Case Western.

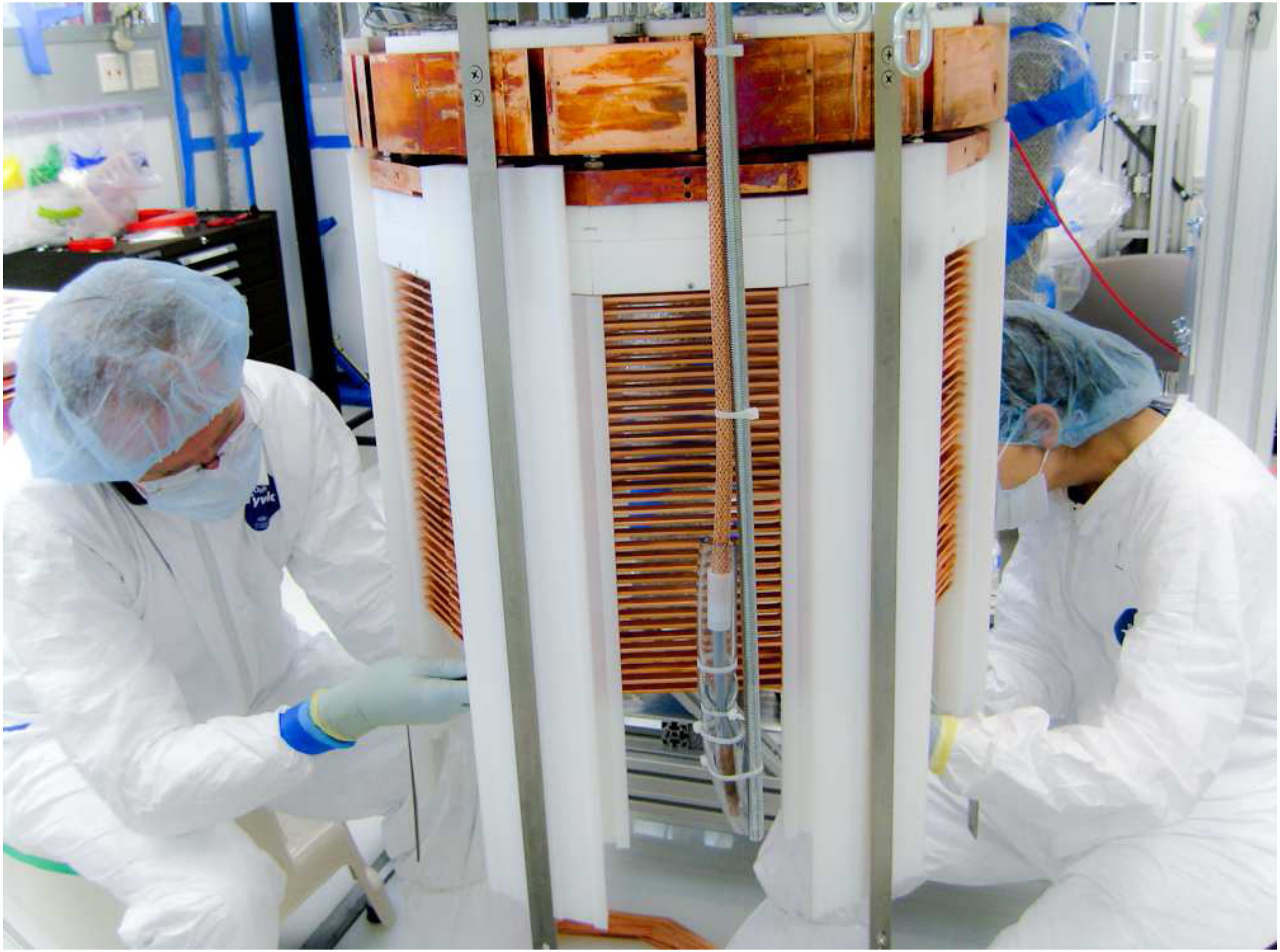
The LUX Detector





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

LUX assembly – 2010 - 2011



370 kg of liquid xenon

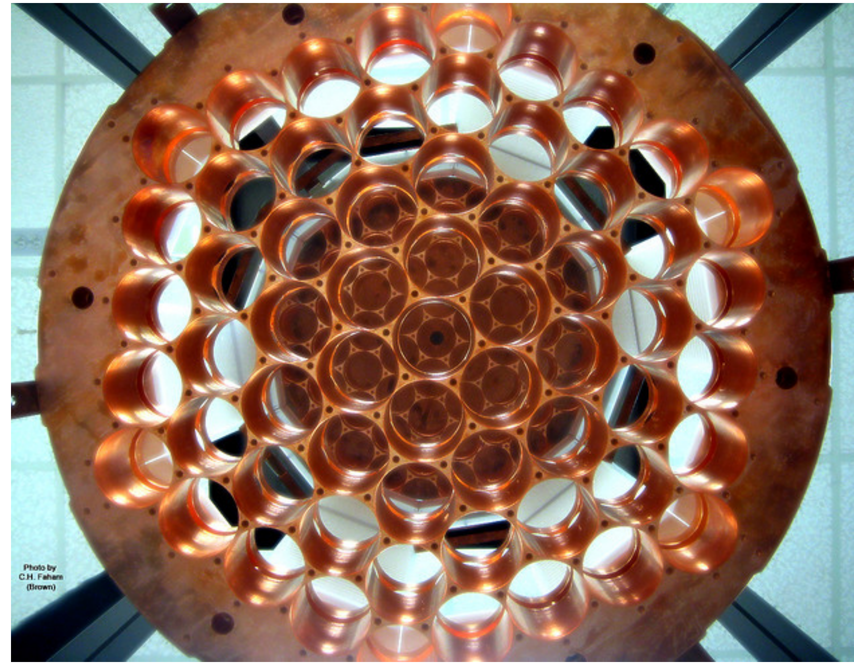
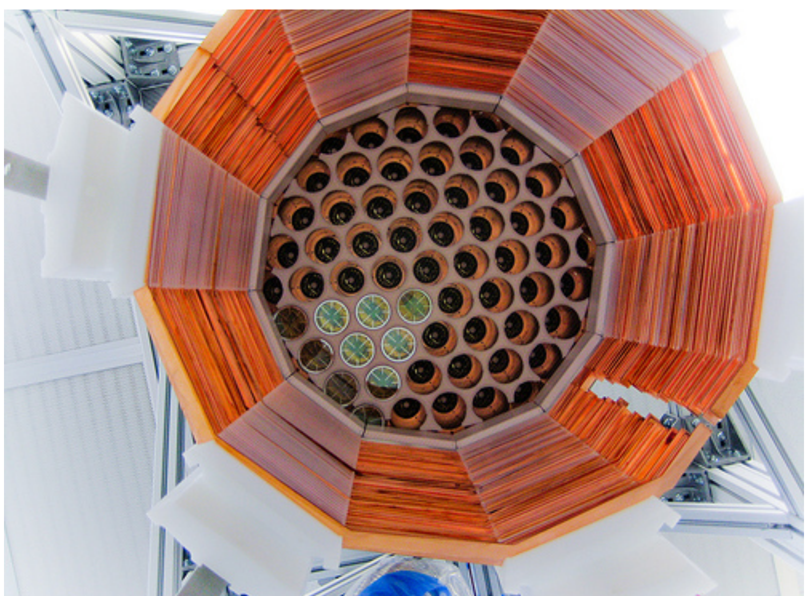
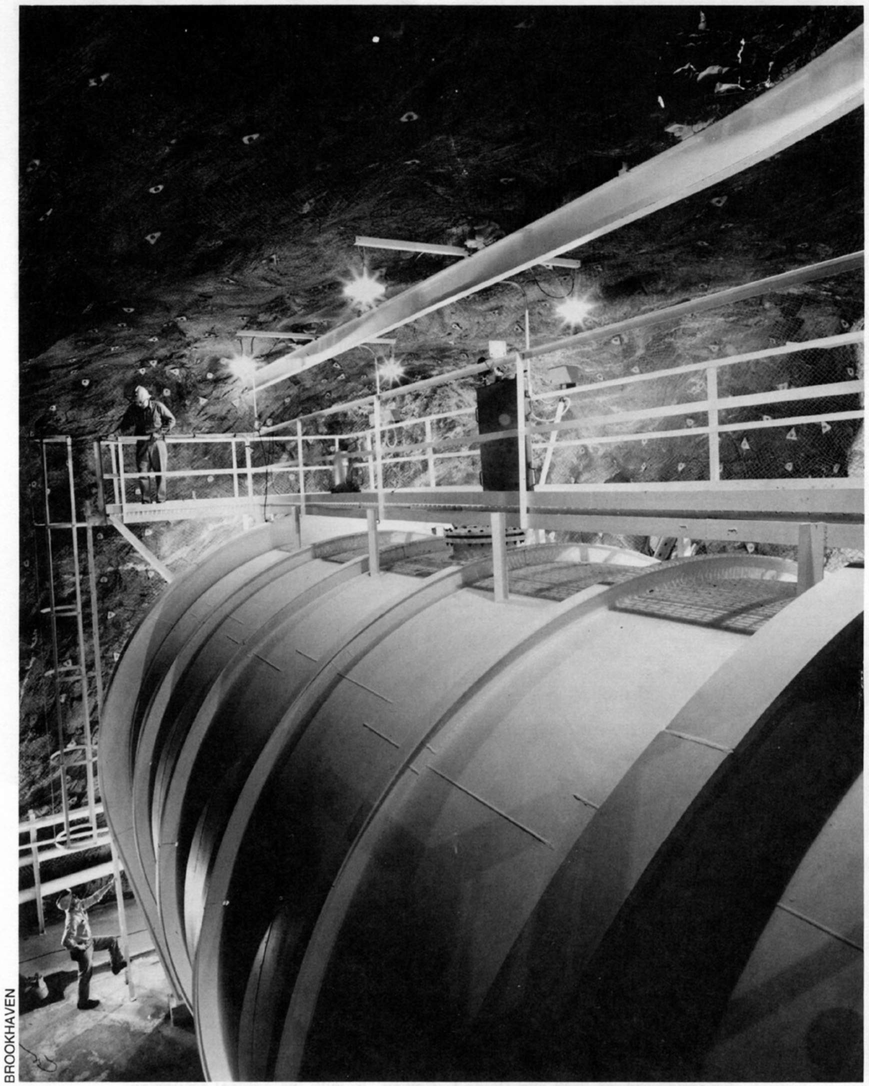


Photo by
C.H. Faham
(Brown)



Sanford Underground Research Facility, Lead, South Dakota

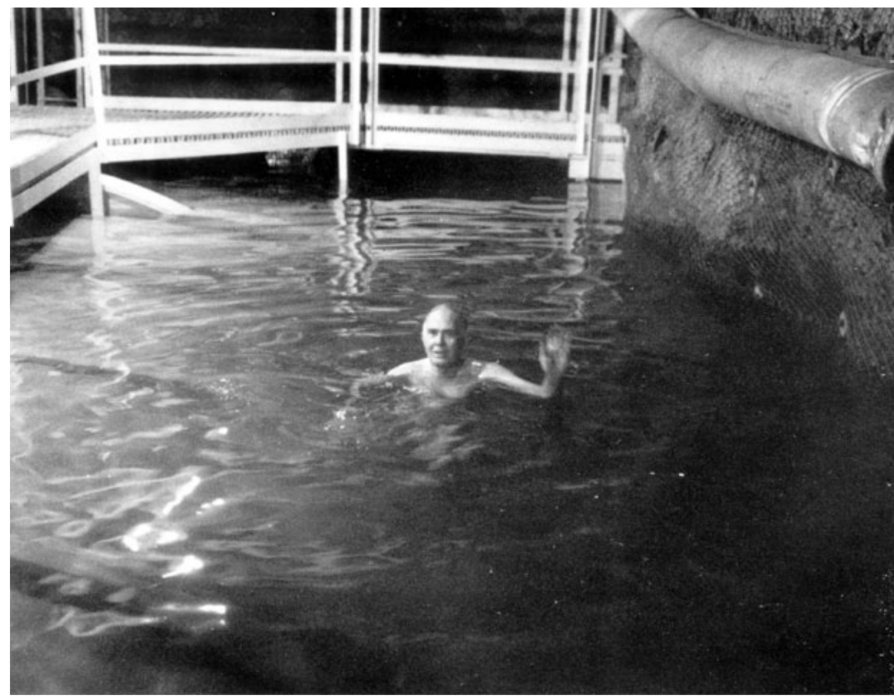
Ray Davis – Homestake Solar Neutrino Experiment



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

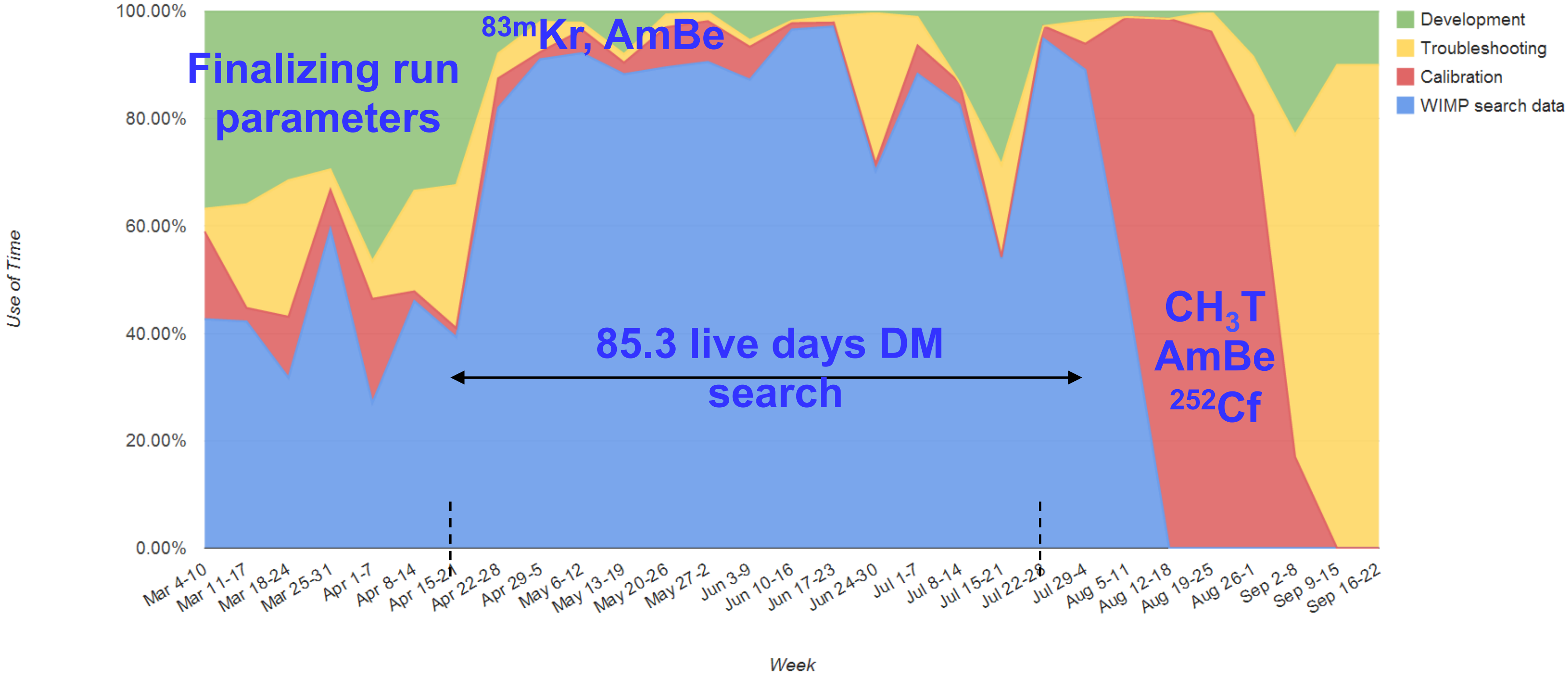
Davis Cavern @ SURF, Spring 2012

LUX received beneficial occupancy on July 1st, 2012

On top of the water shield, Sept. 2012

LUX installed in the water tank, Sept. 2012

LUX Run 3 Operations

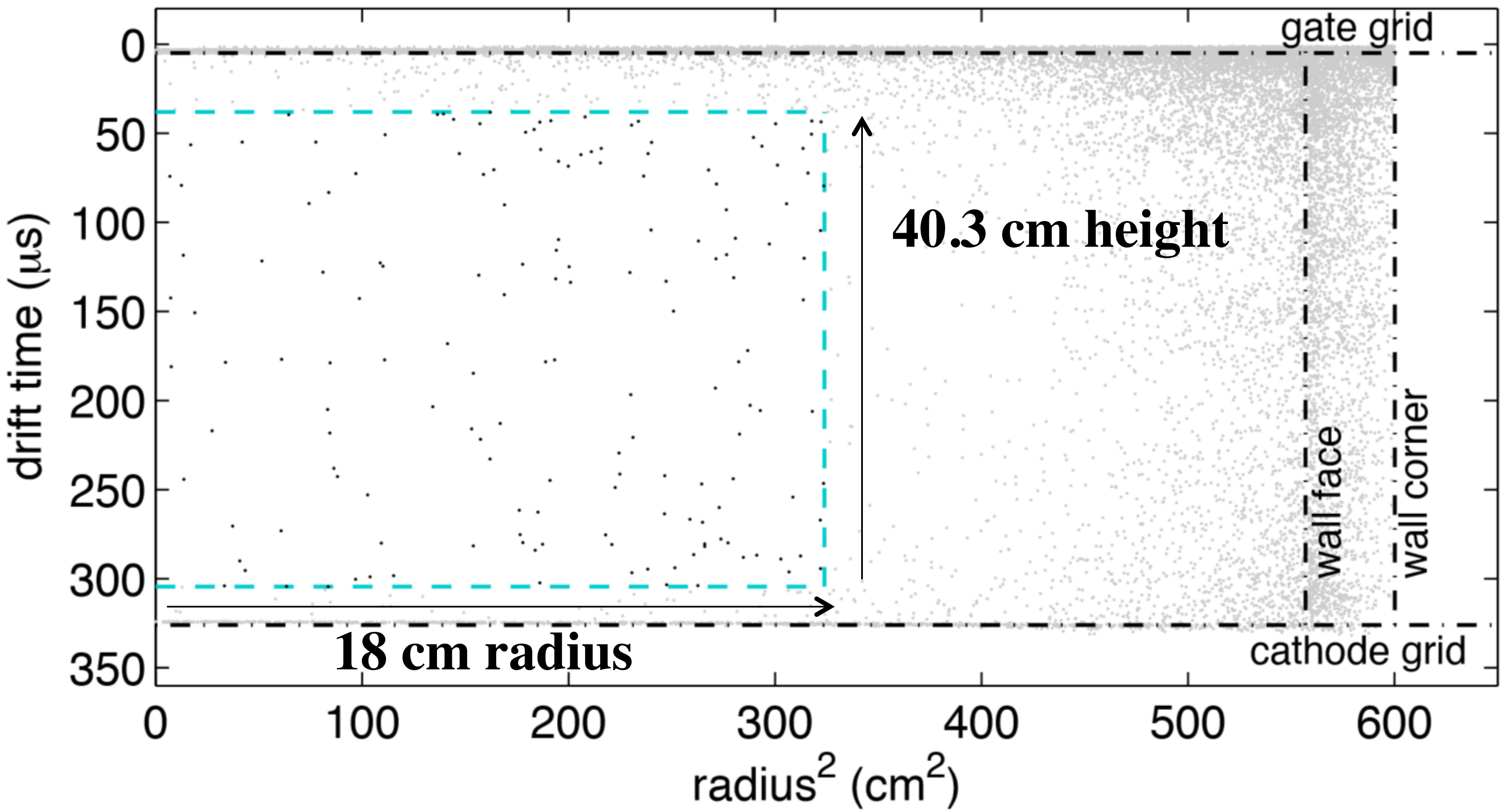


- Detector cool-down Jan. 2013, Xe condensed mid-Feb. 2013
- 95% Data taking efficiency during WIMP search period (minus storms)
- Waited until after WIMP search data was in-hand before performing the precision tritium calibration

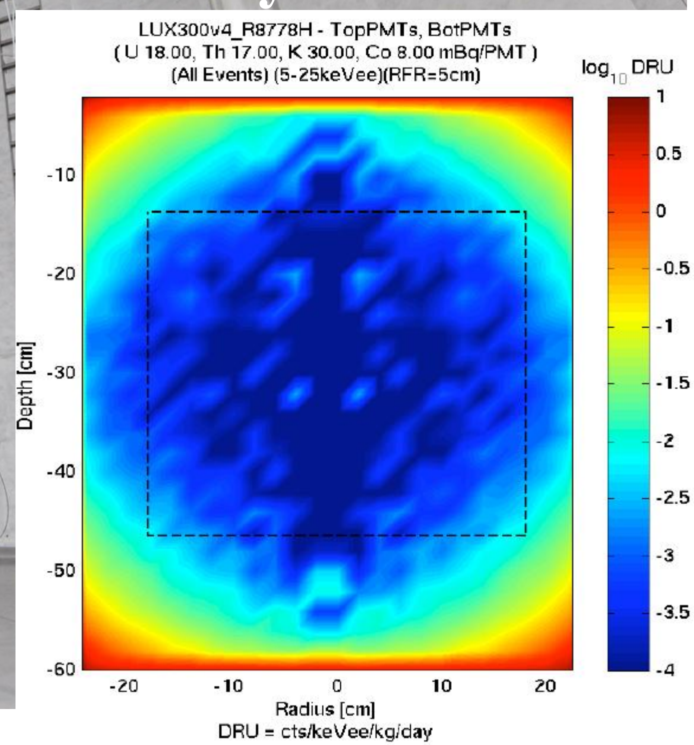
LUX Run 3 – Data Selection

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

LUX fiducial volume cut – 118 kg

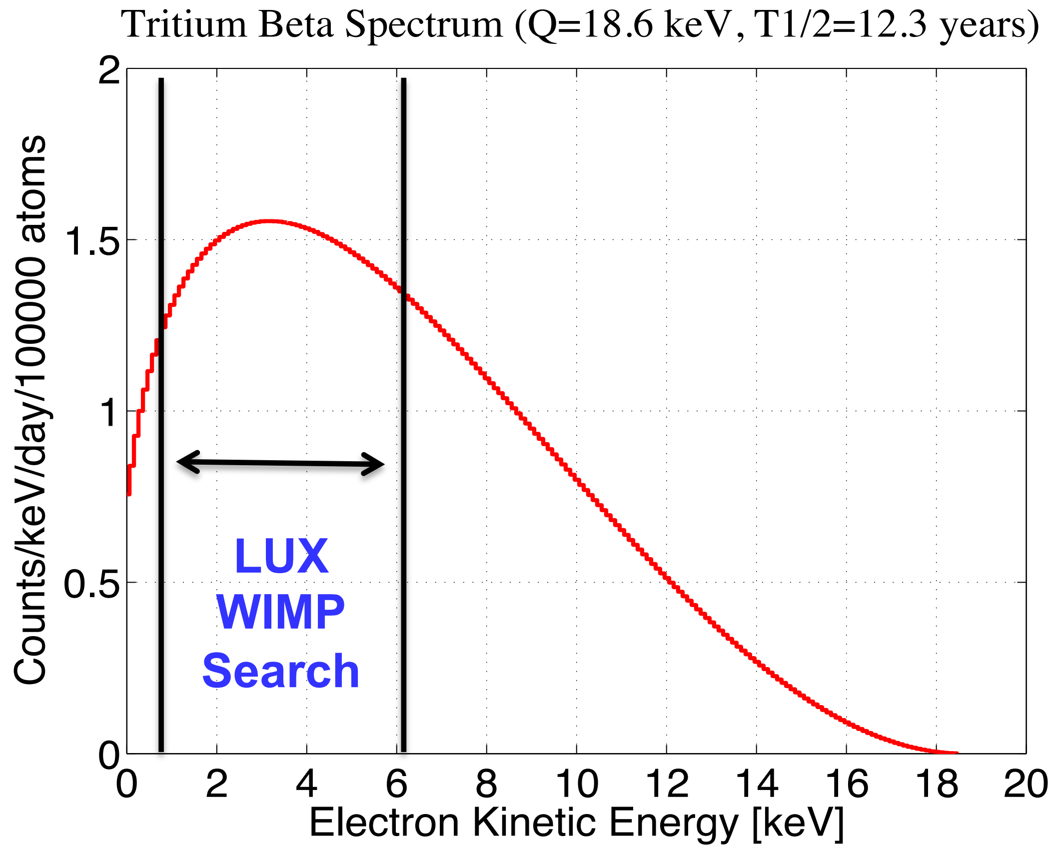


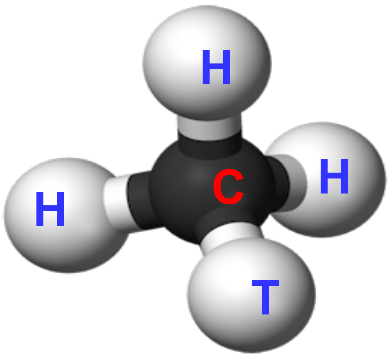
External calibration sources: ^{137}Cs & neutrons (AmBe & ^{252}Cf)



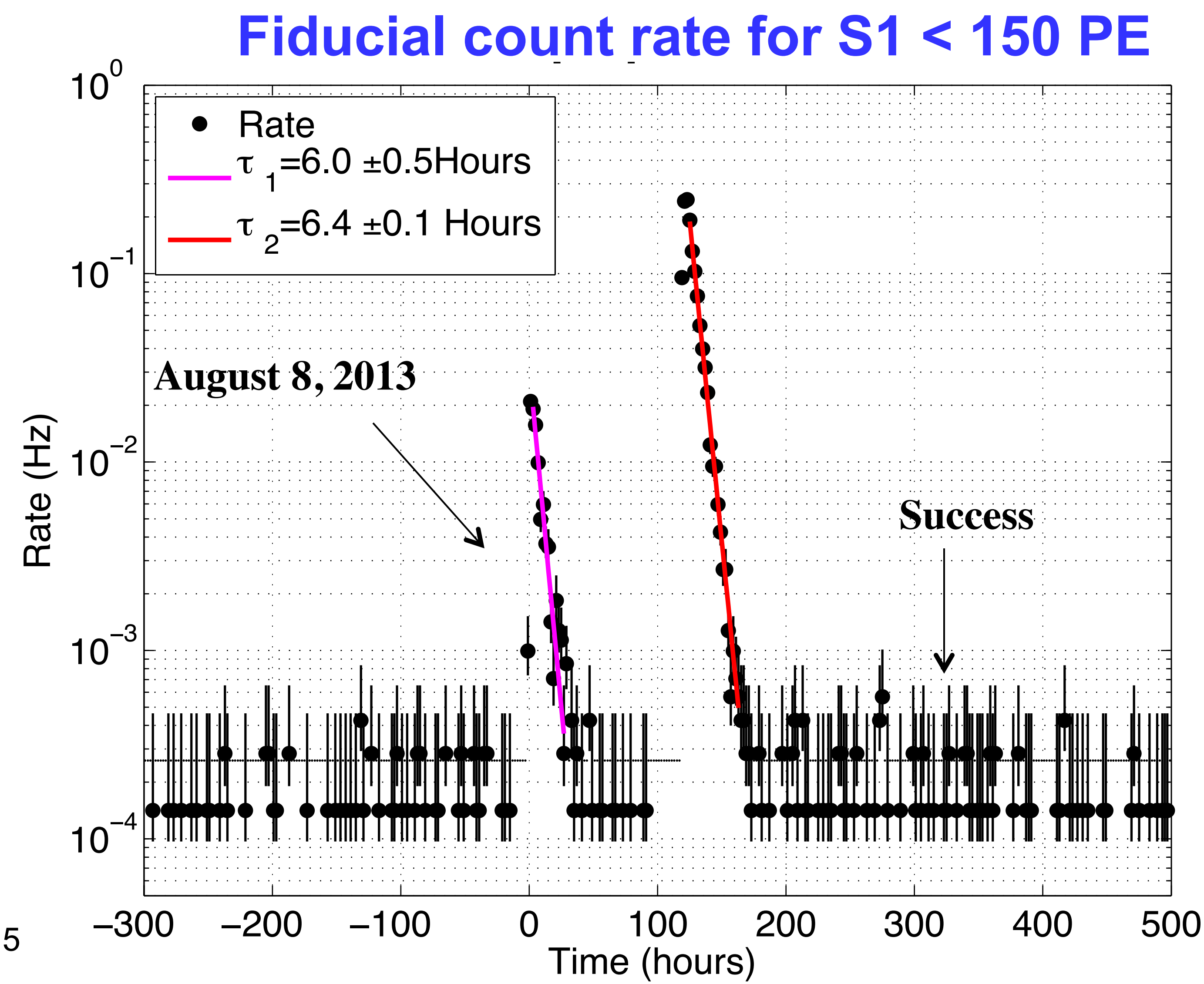
Tritium: an ideal electron-recoil band calibration source

- **Single Scatter events**
- **Q = 18.6 keV**
- **Mean energy: 5 keV**
- **Peak energy: 3 keV**
- **Bare tritium diffuses quickly into detector components.**
- **Use tritiated methane instead.**

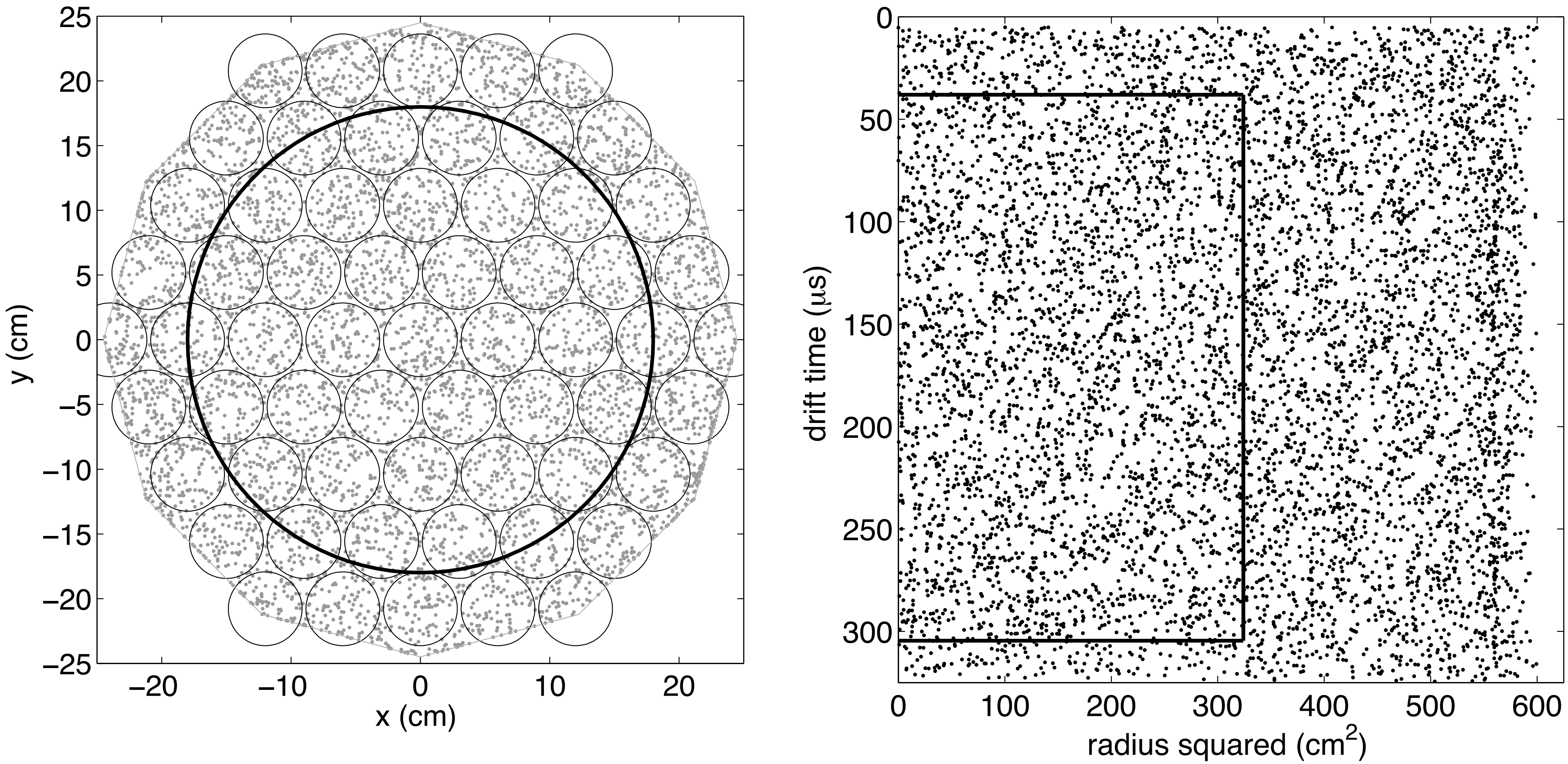




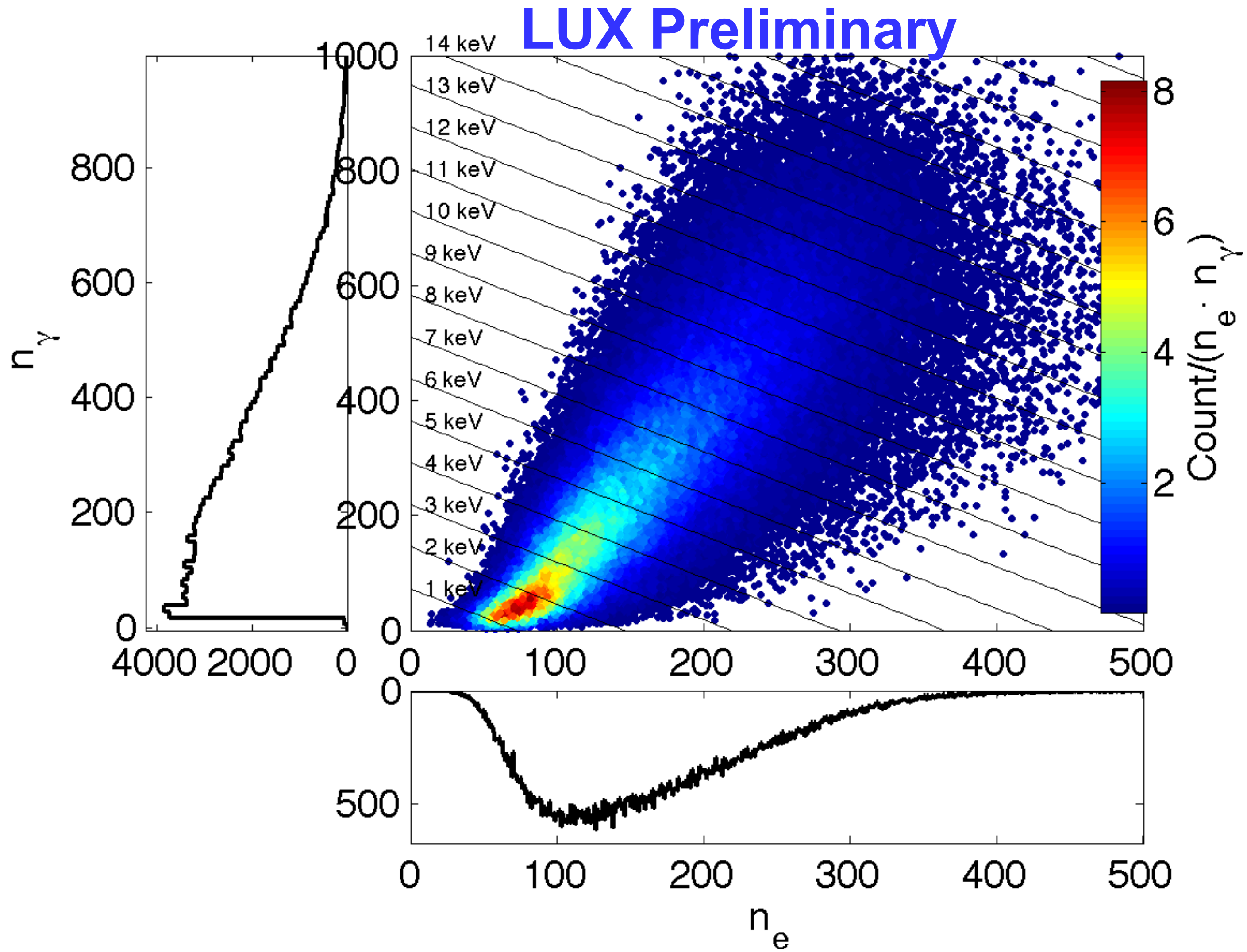
Injection and removal of tritium from LUX, August 2013



Tritium event locations in LUX – August 2013

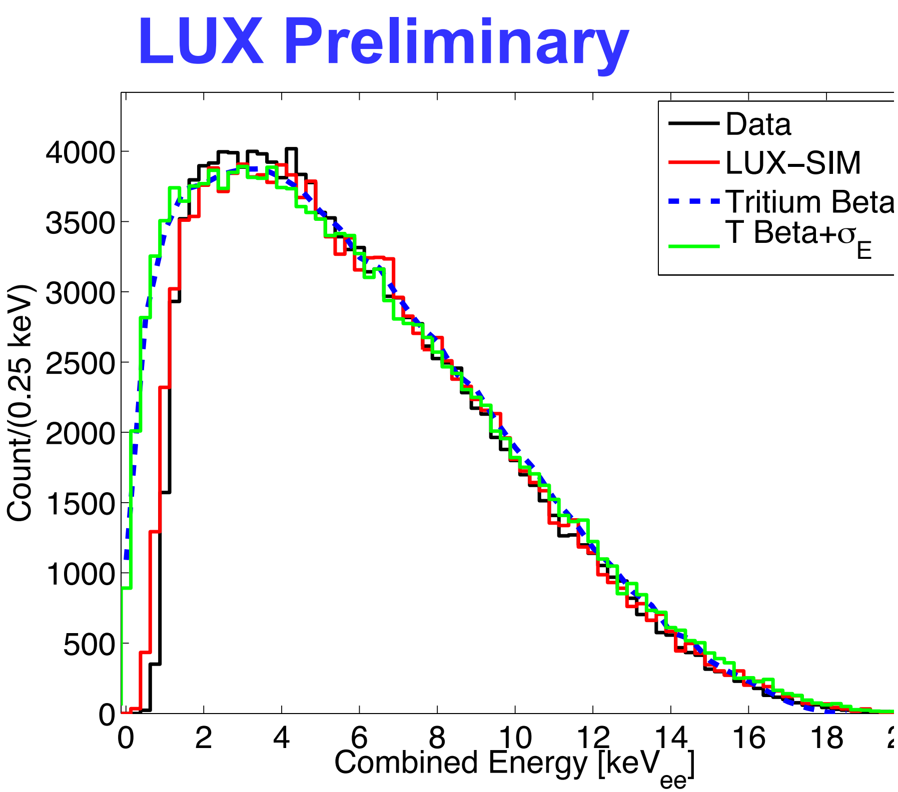


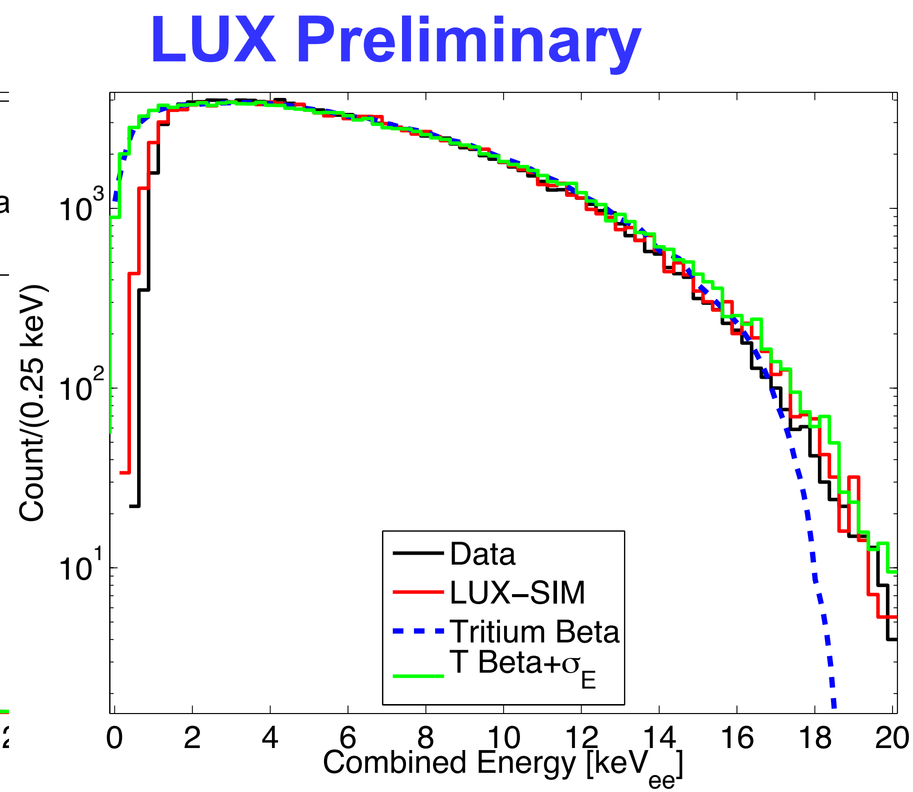
Charge vs Light from tritium in LUX at 170 V/cm



115,000 fiducial tritium events
December 2013 tritium injection

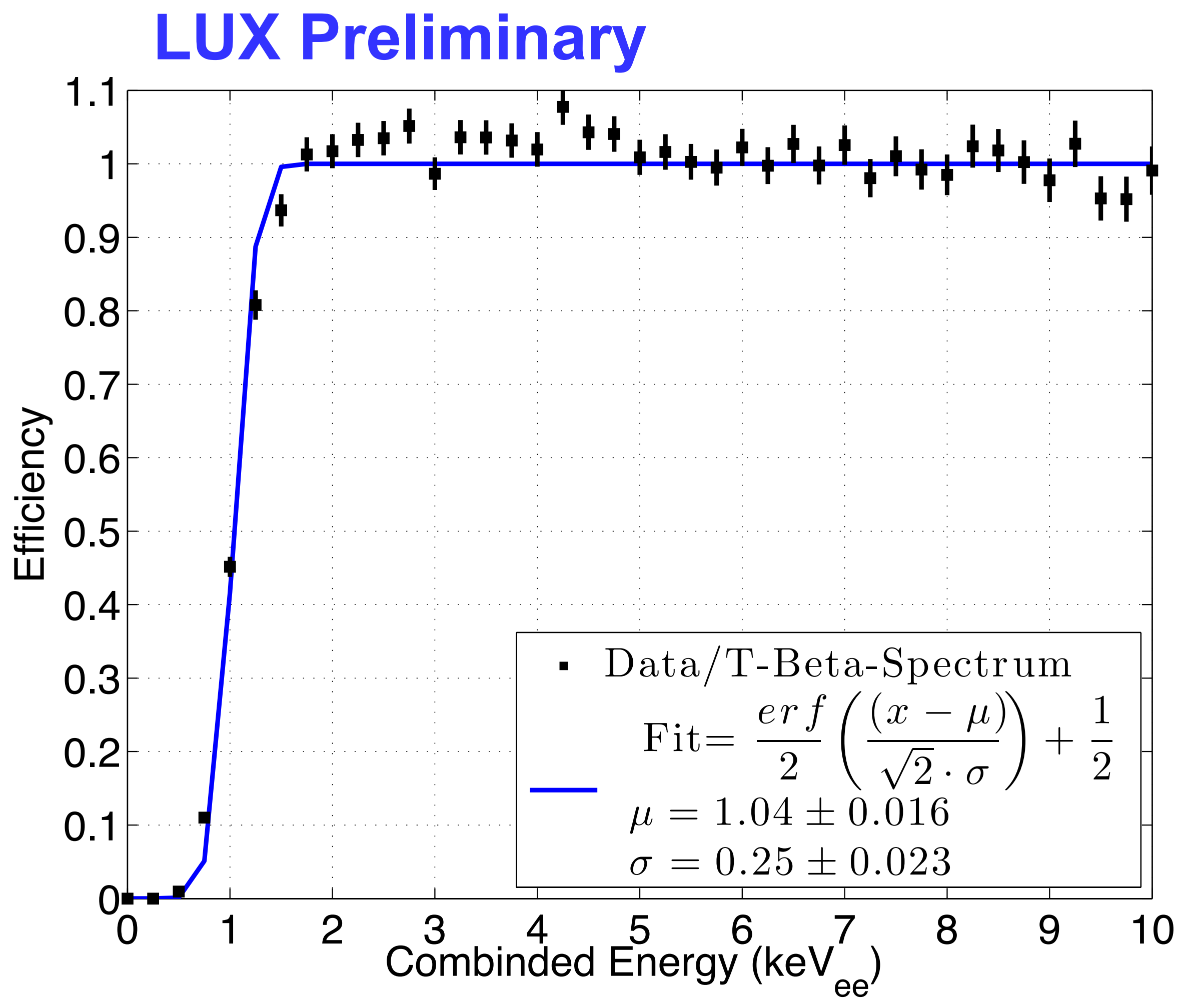
Tritium combined energy spectrum



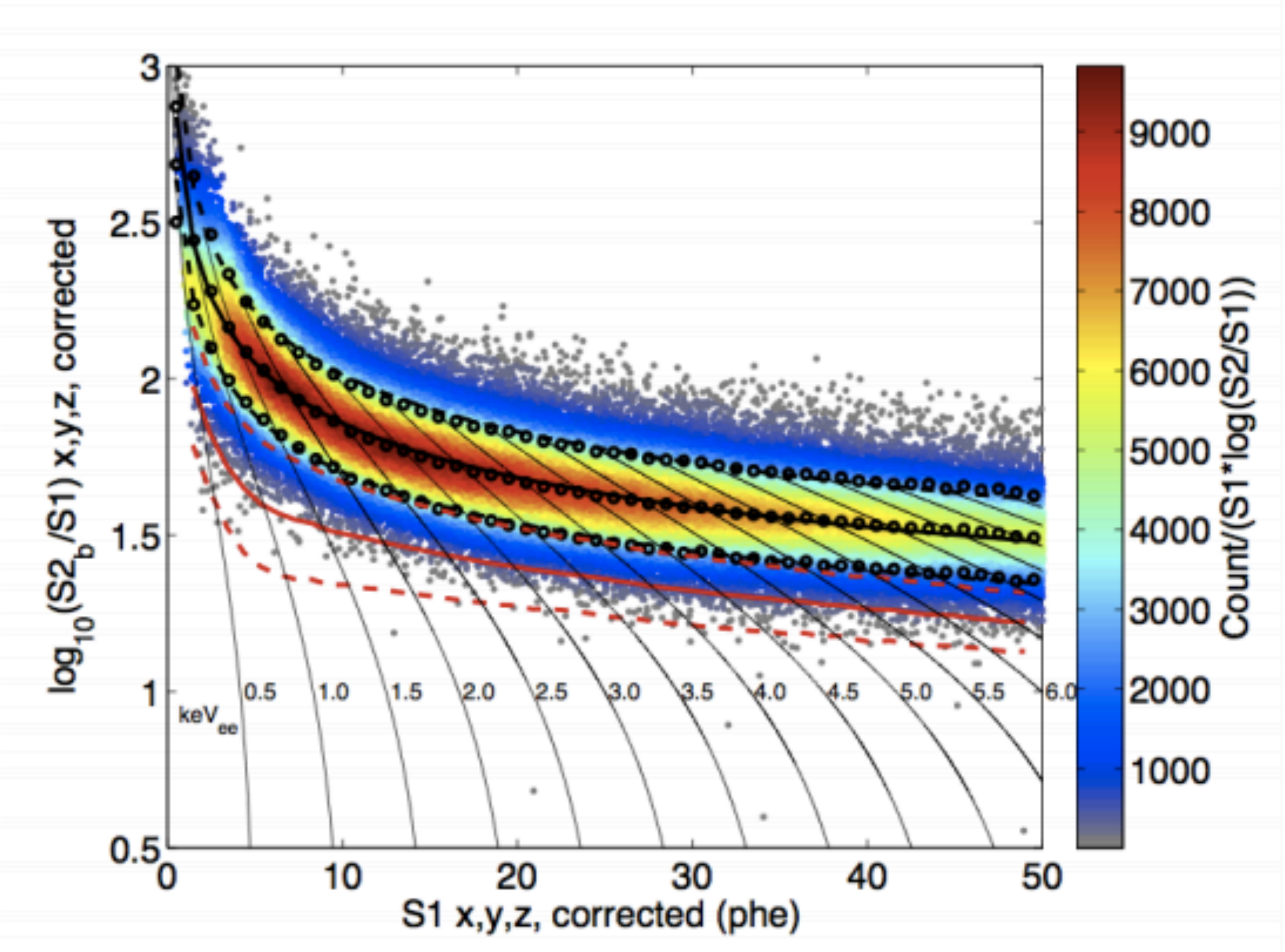


115,000 fiducial tritium events
December 2013 tritium injection

LUX detector threshold from tritium

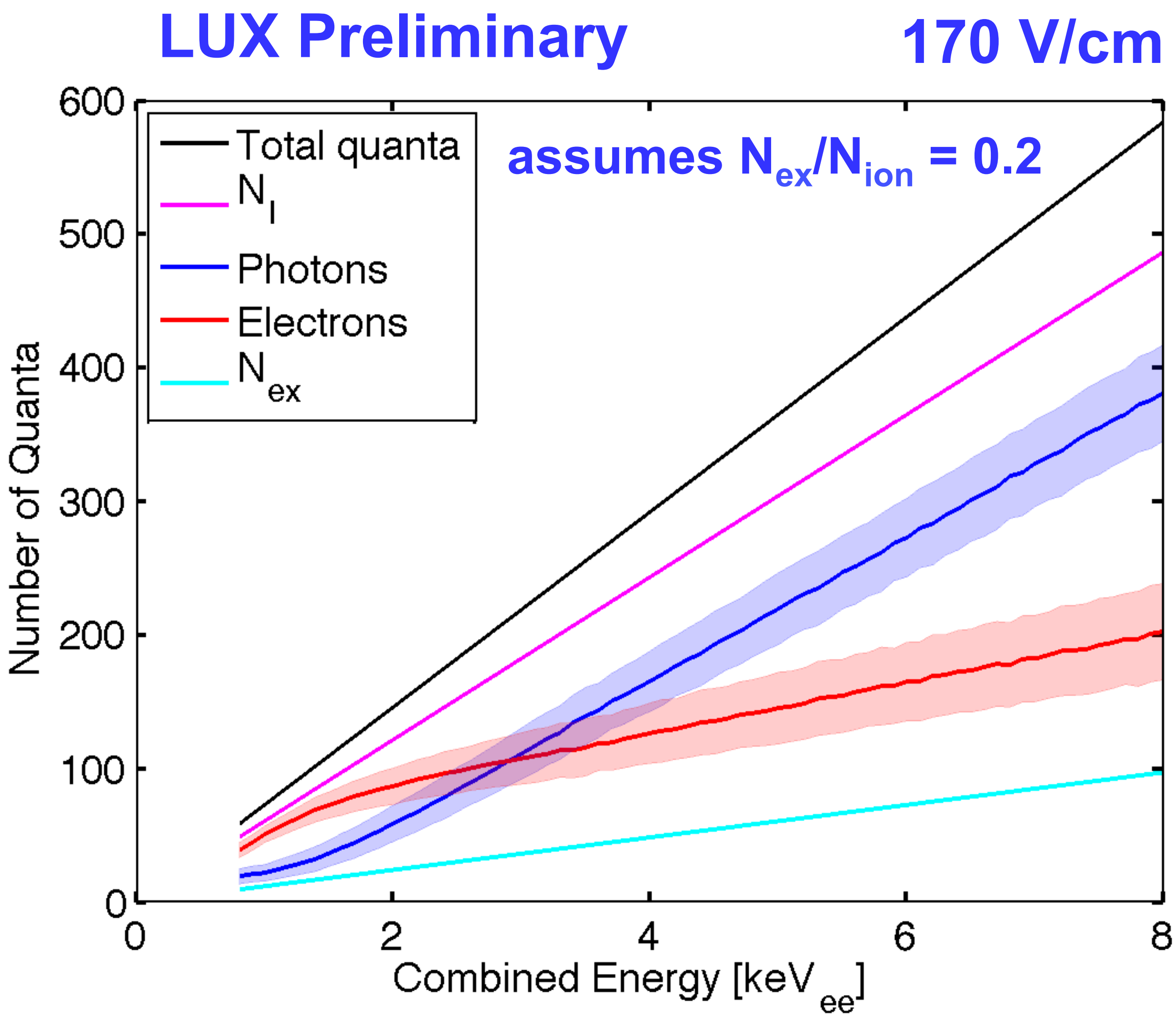


LUX electron recoil band from tritium

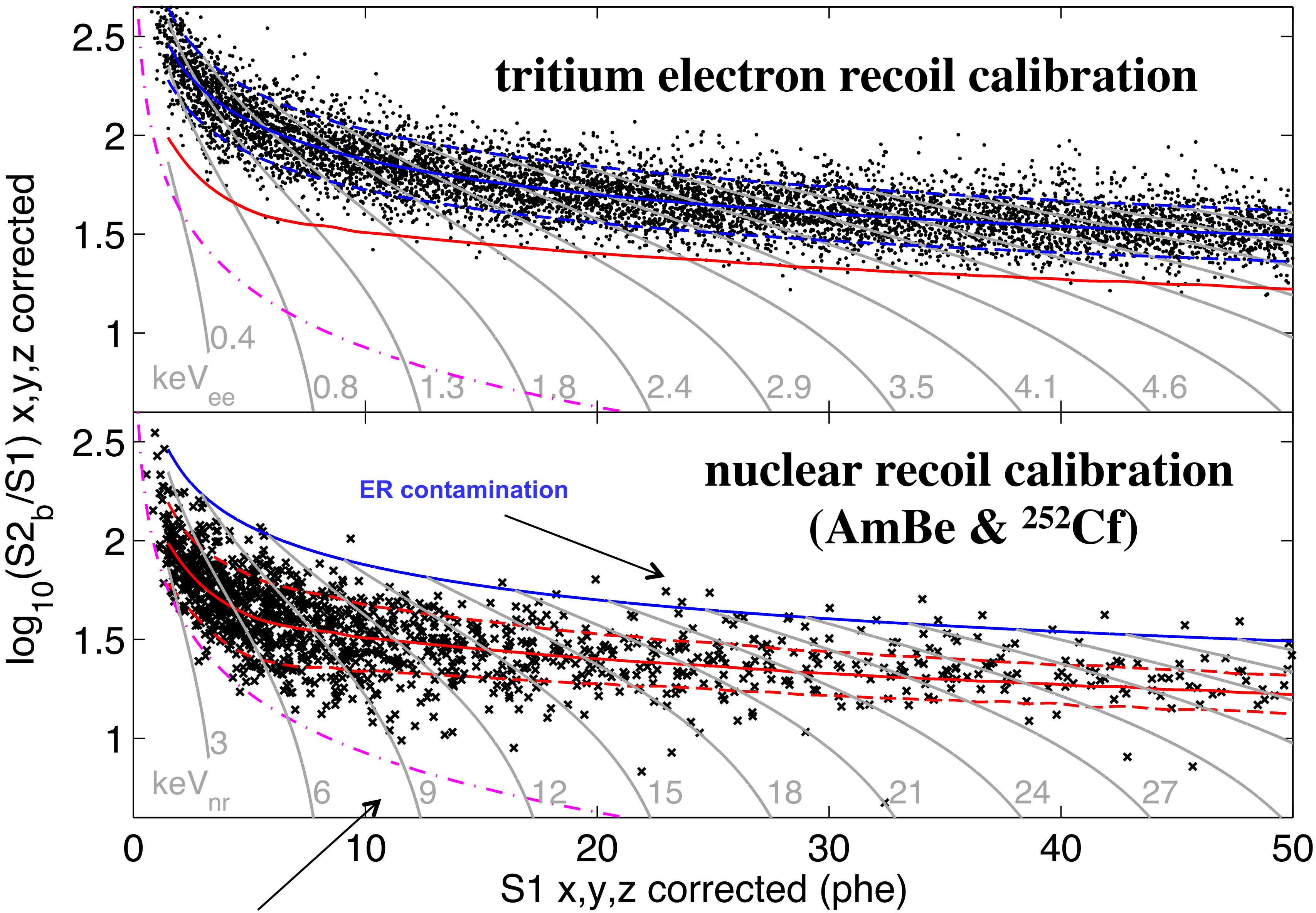


115,000 fiducial tritium events
December 2013 tritium injection

Liquid xenon charge and light yields vs energy

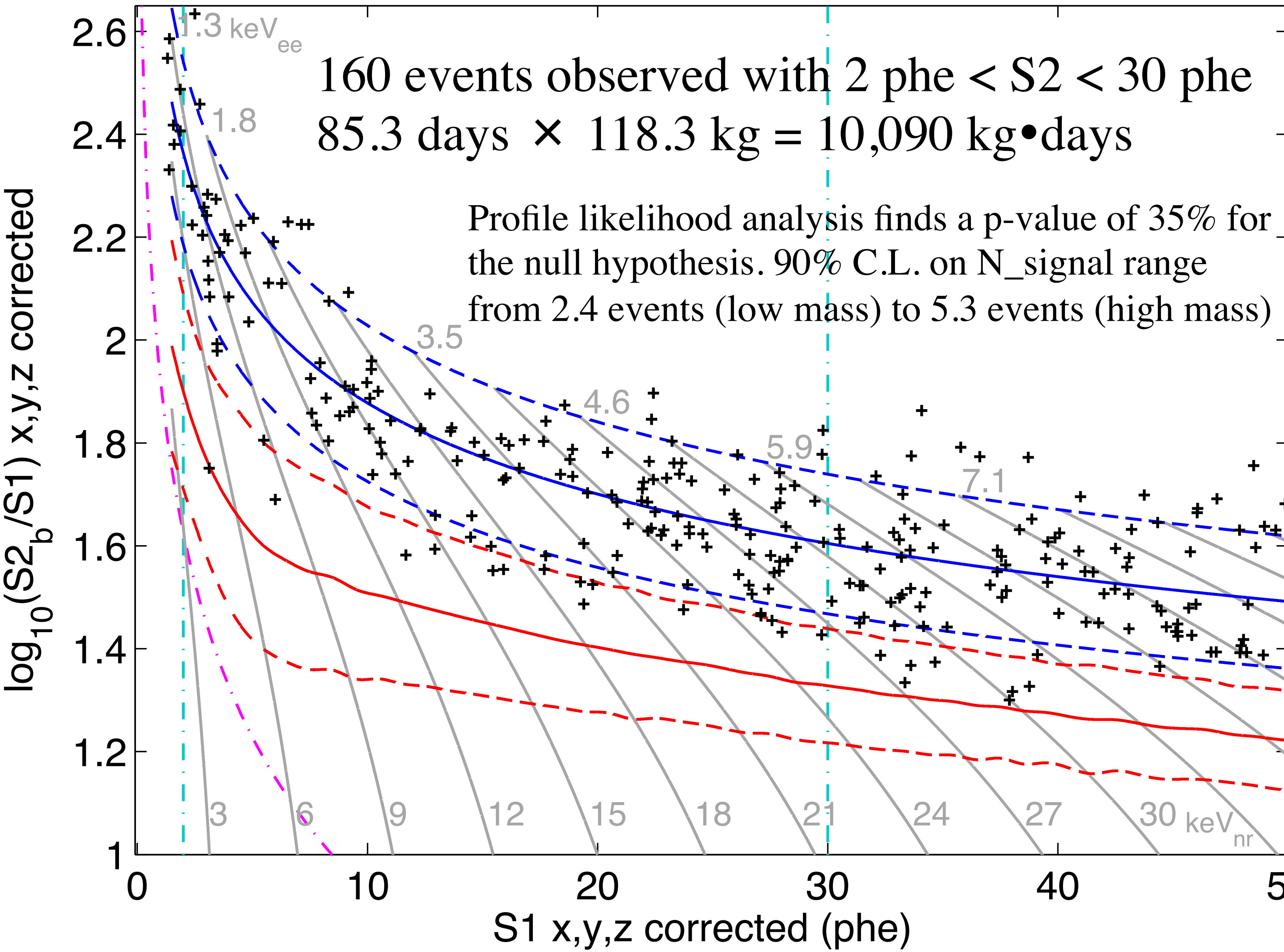


Electron-recoil and nuclear-recoil calibration data

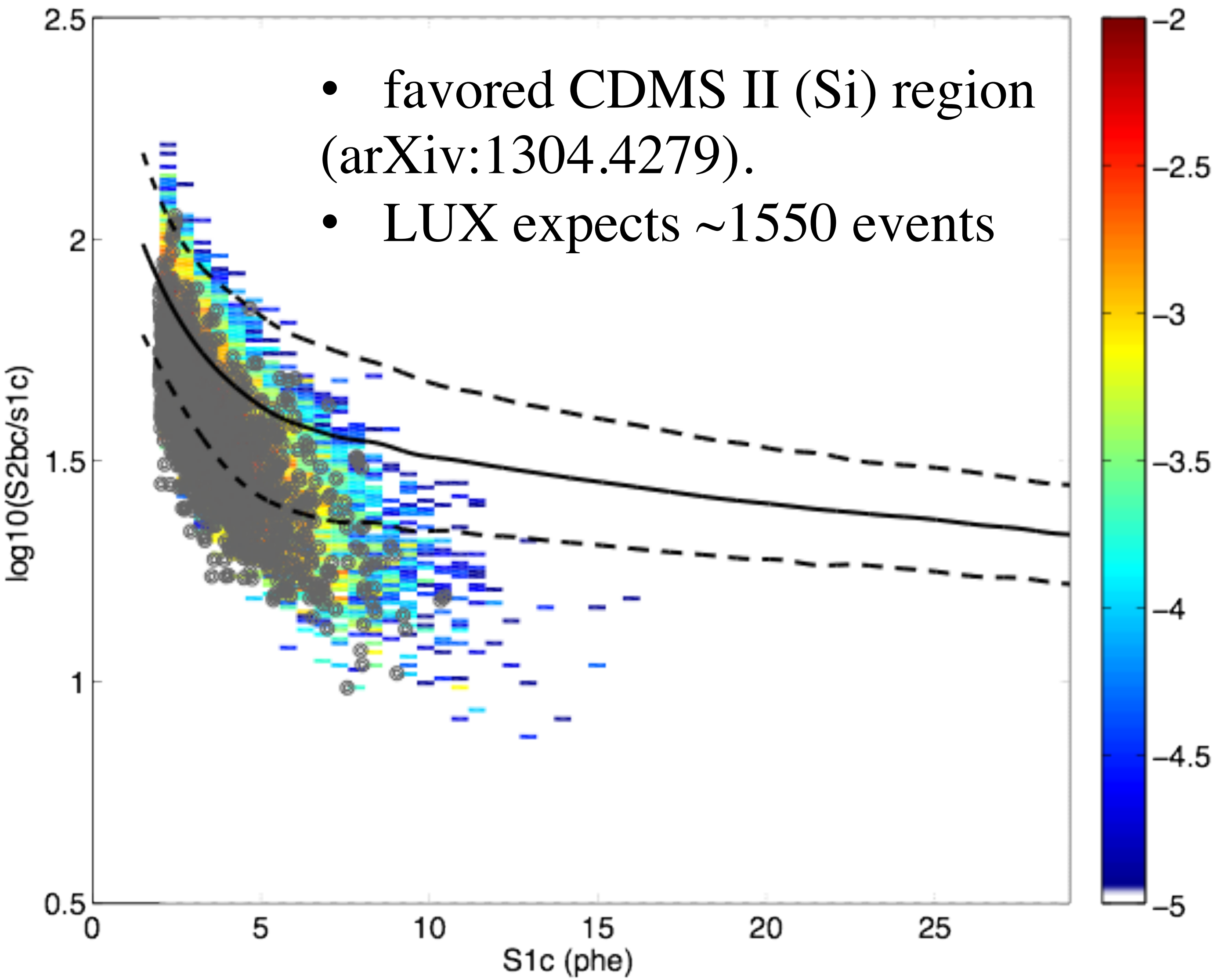


Neutron-X events and multiple scatters with low S2s

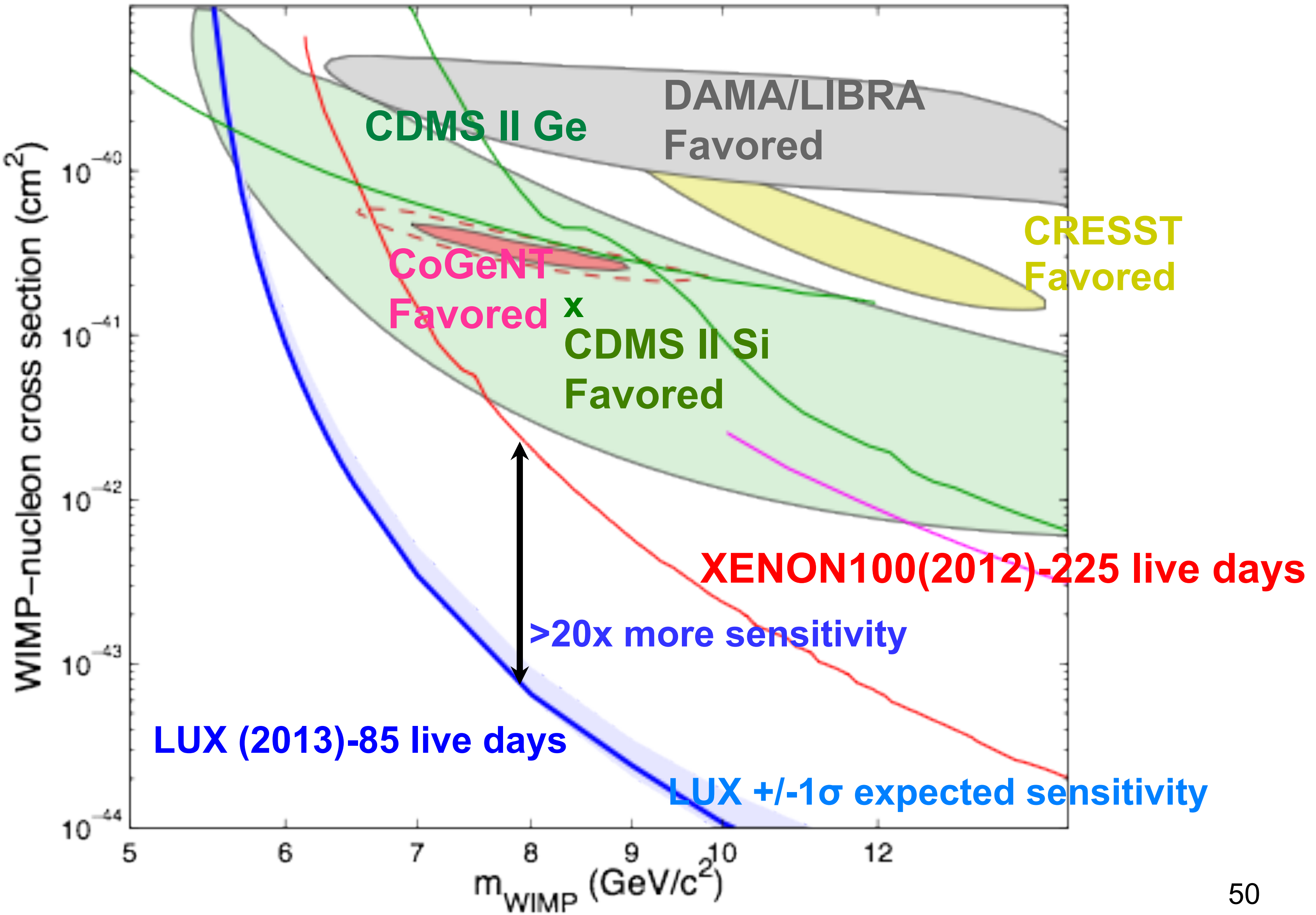
LUX WIMP search data



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



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



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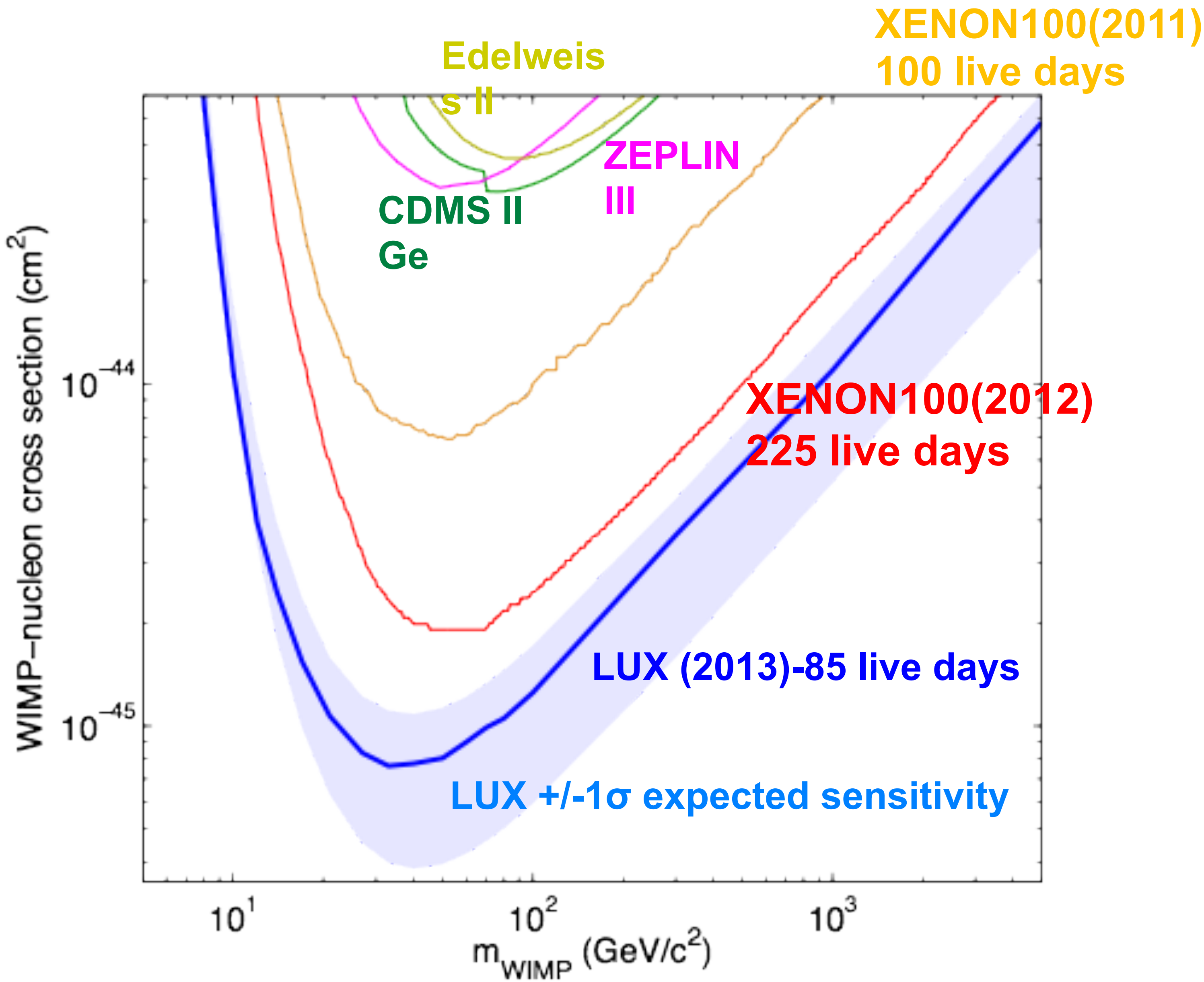


Scale-up LUX fiducial mass by 50

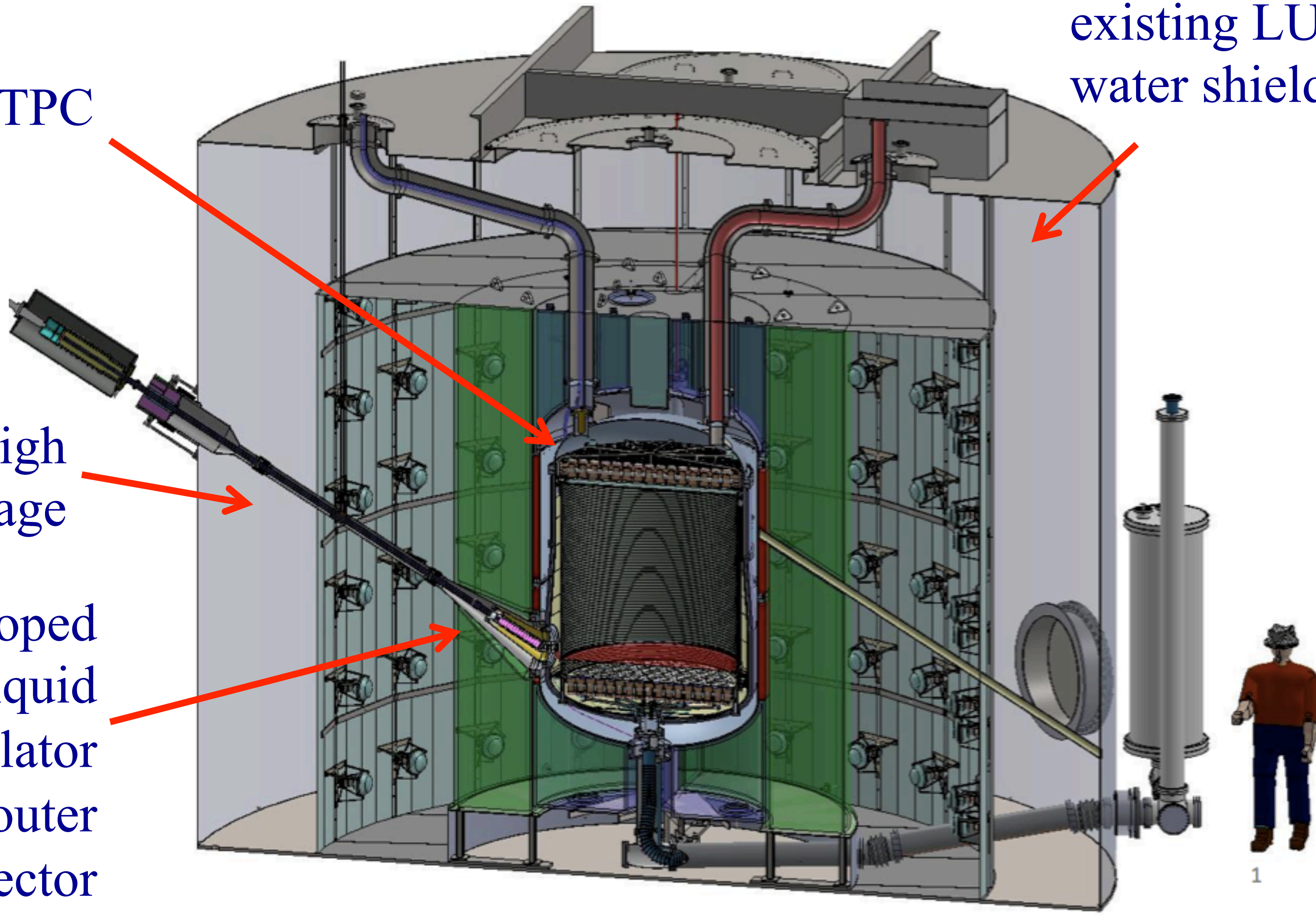
LZ = LUX + ZEPLIN

31 institutions currently
About 180 people
Continuing to expand collaboration

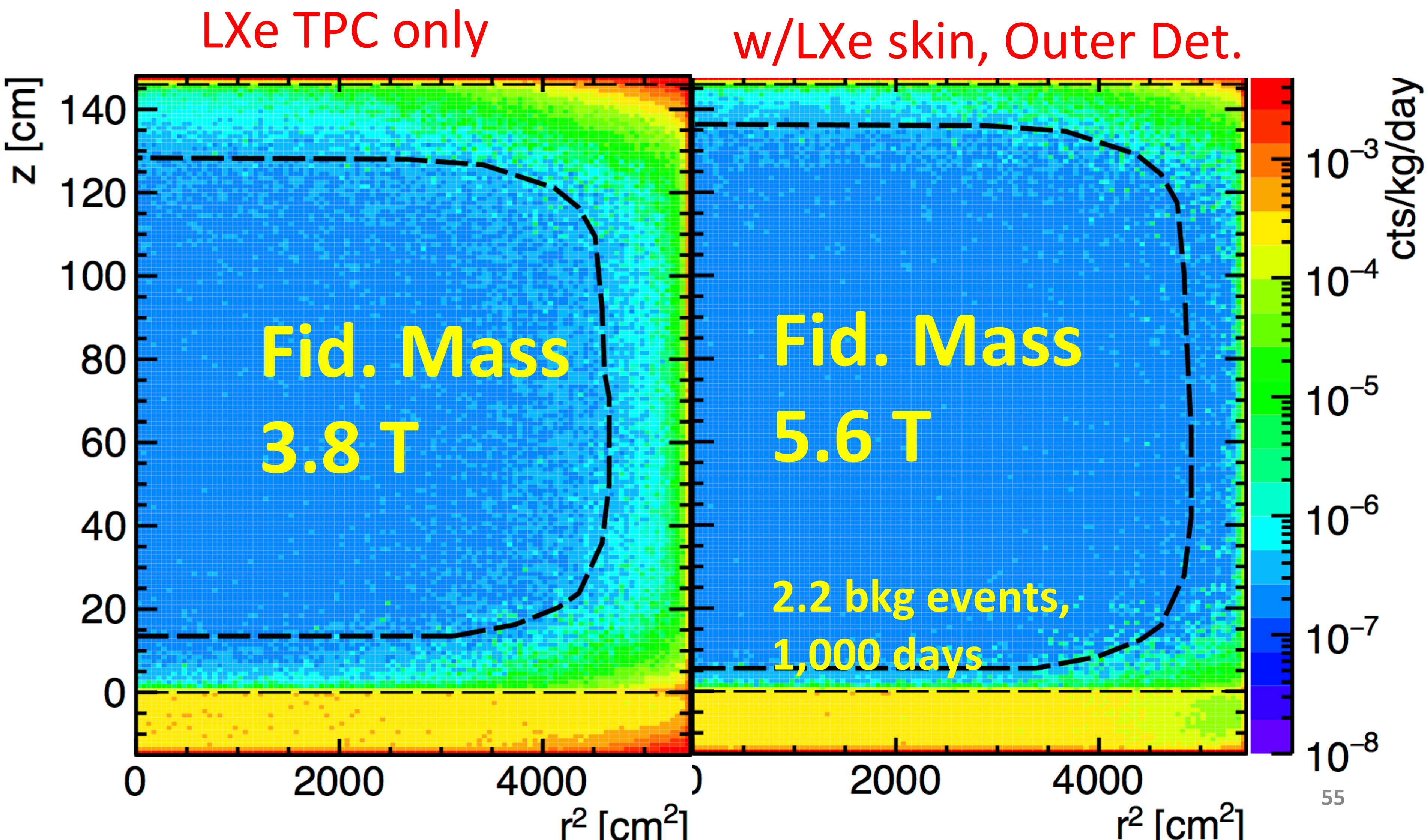
LIP Coimbra (Portugal)
MEPhI (Russia)
Edinburgh University (UK)
University of Liverpool (UK)
Imperial College London (UK)
University College London (UK)
University of Oxford (UK)
STFC Rutherford Appleton Laboratories (UK)
University of Sheffield (UK)

University of Alabama
University at Albany SUNY
Berkeley Lab (LBNL)
University of California, Berkeley
Brookhaven National Laboratory
Brown University
University of California, Davis
Fermi National Accelerator Laboratory
Kavli Institute for Particle Astrophysics & Cosmology
Lawrence Livermore National Laboratory
University of Maryland
University of Michigan
Northwestern University
University of Rochester
University of California, Santa Barbara
University of South Dakota
South Dakota School of Mines & Technology
South Dakota Science and Technology Authority
SLAC National Accelerator Laboratory
Texas A&M
Washington University
University of Wisconsin
Yale University

LZ Overview

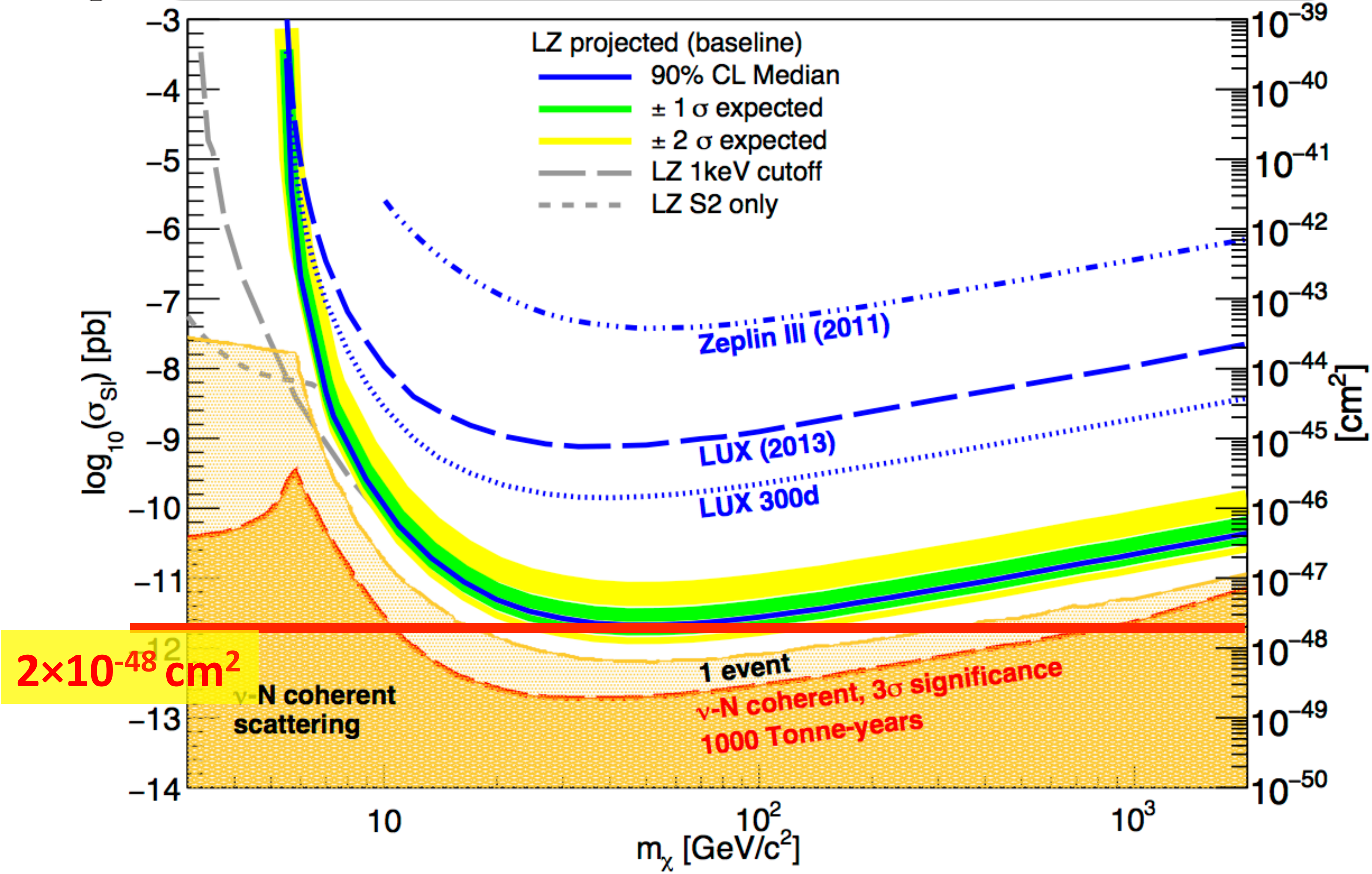

Xe TPC
existing LUX water shield
100 kV high voltage
Gd-doped liquid scintillator outer detector

Backgrounds with and without outer detector

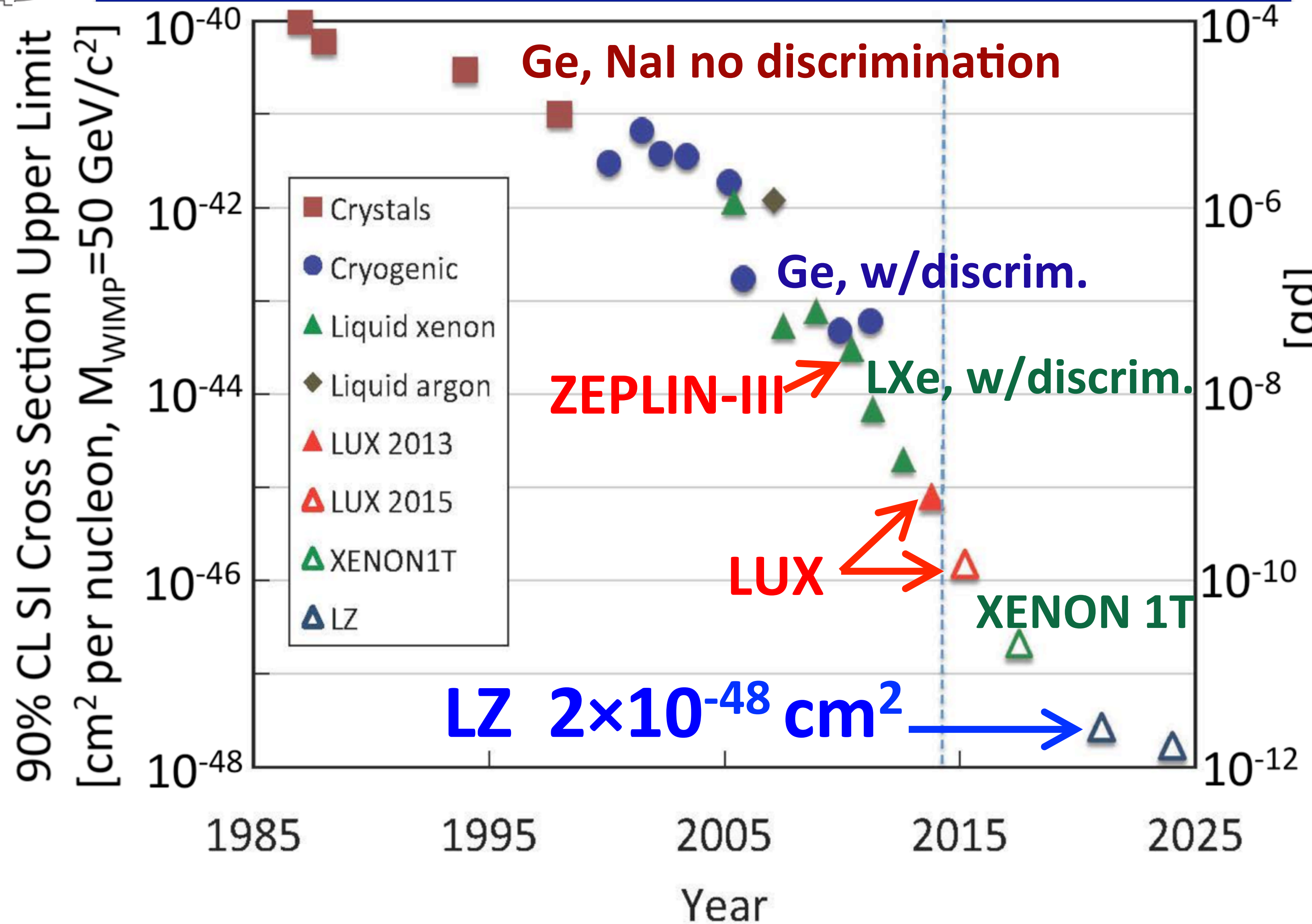


LZ Sensitivity

(5.6 Tonnes, 1000 live days)



Time Evolution



Timeline

Year	Month	Activity
2012	March	LZ (LUX-ZEPLIN) collaboration formed
	May	First Collaboration Meeting
	September	DOE CD-0 for G2 dark matter experiments
2013	November	LZ R&D report submitted
2014	July	LZ Project selected in US and UK
2015	April	DOE CD-1/3a approval, similar in UK Begin long-lead procurements(Xe, PMT, cryostat)
2016	April	DOE CD-2/3b approval, baseline, all fab starts
2017	June	Begin preparations for surface assembly @ SURF
2018	July	Begin underground installation
2019	Feb	Begin commissioning

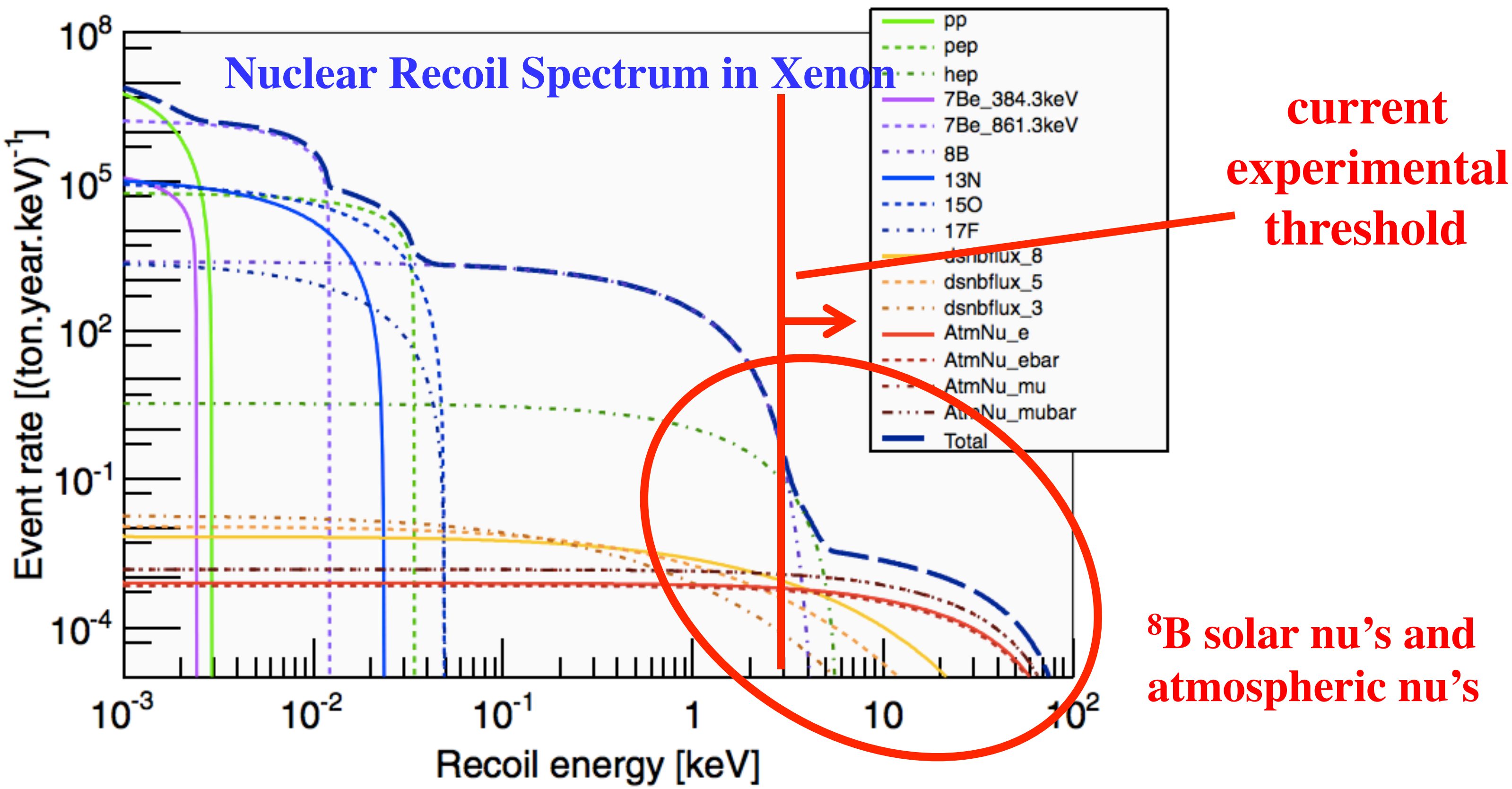
WIMP discovery limits – How low can we go?

WIMP discovery limits – How low can we go?

Coherent neutrino scattering sets fundamental constraints due to:

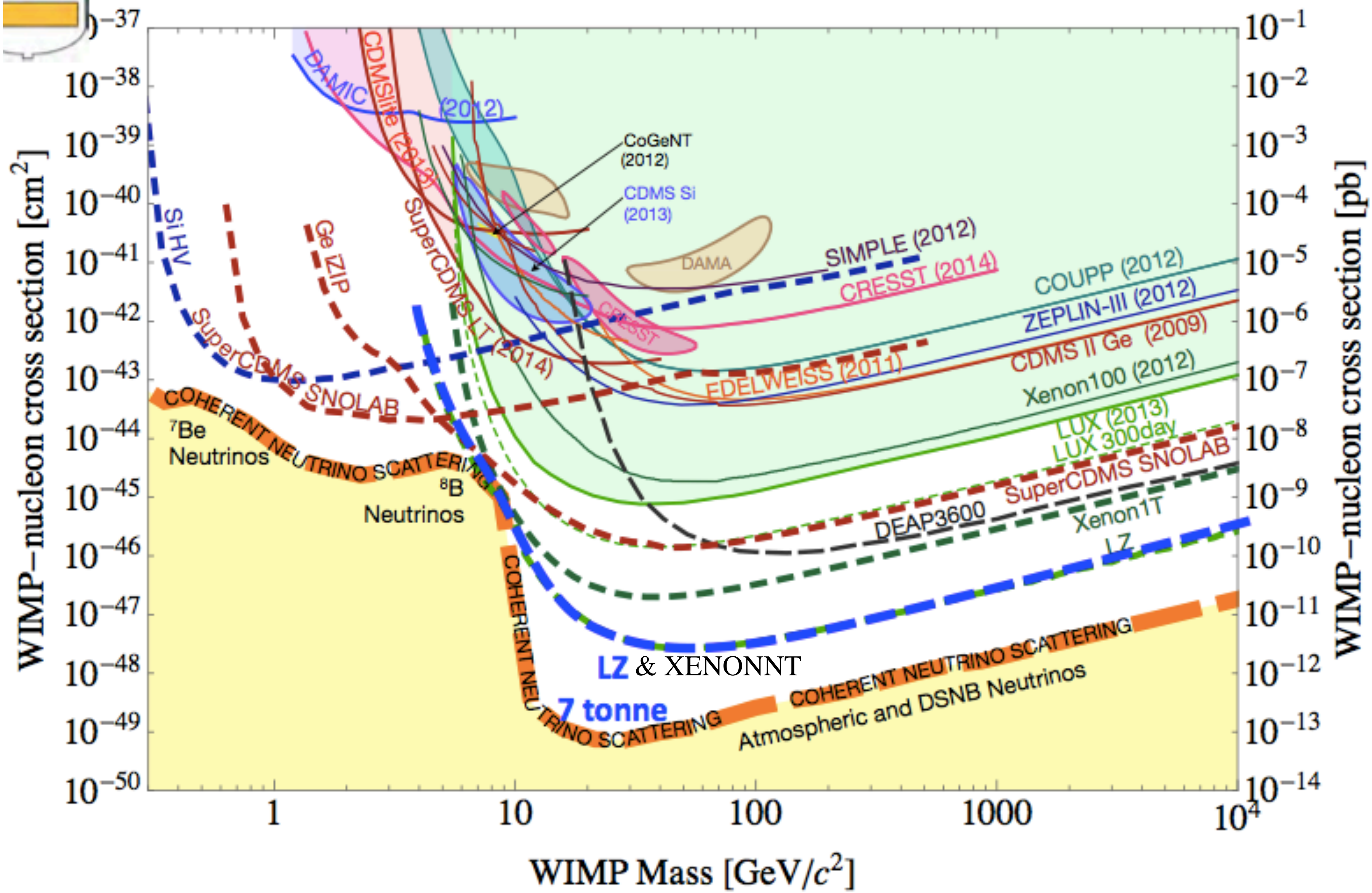
- statistical fluctuations
- theoretical uncertainty on rates

PHYSICAL REVIEW D **89**, 023524 (2014)



From Billard, Strigari, Figueroa-Feliciano, arXiv:1307.5458

Status and outlook for WIMP detection

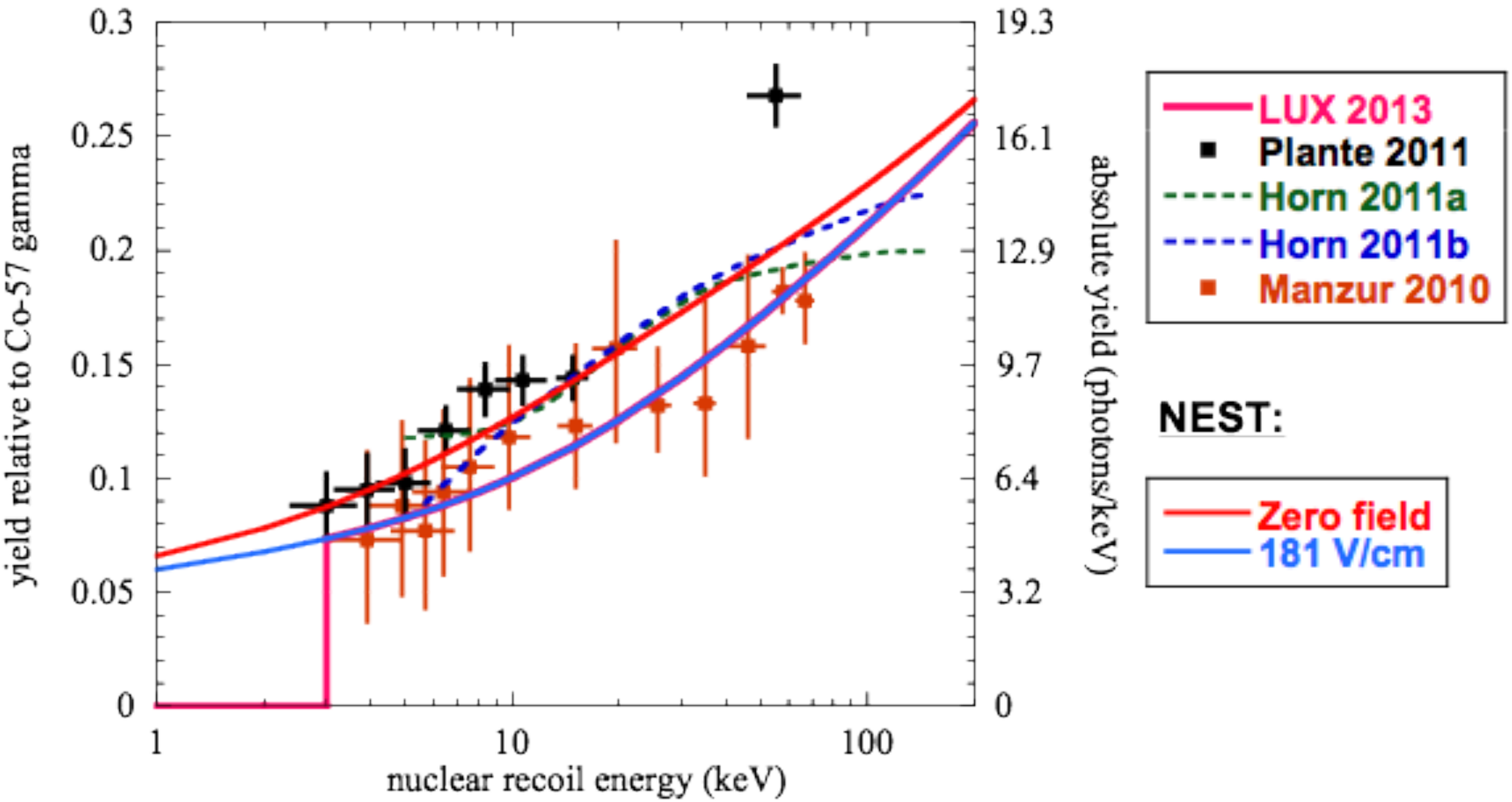


The LZ collaboration

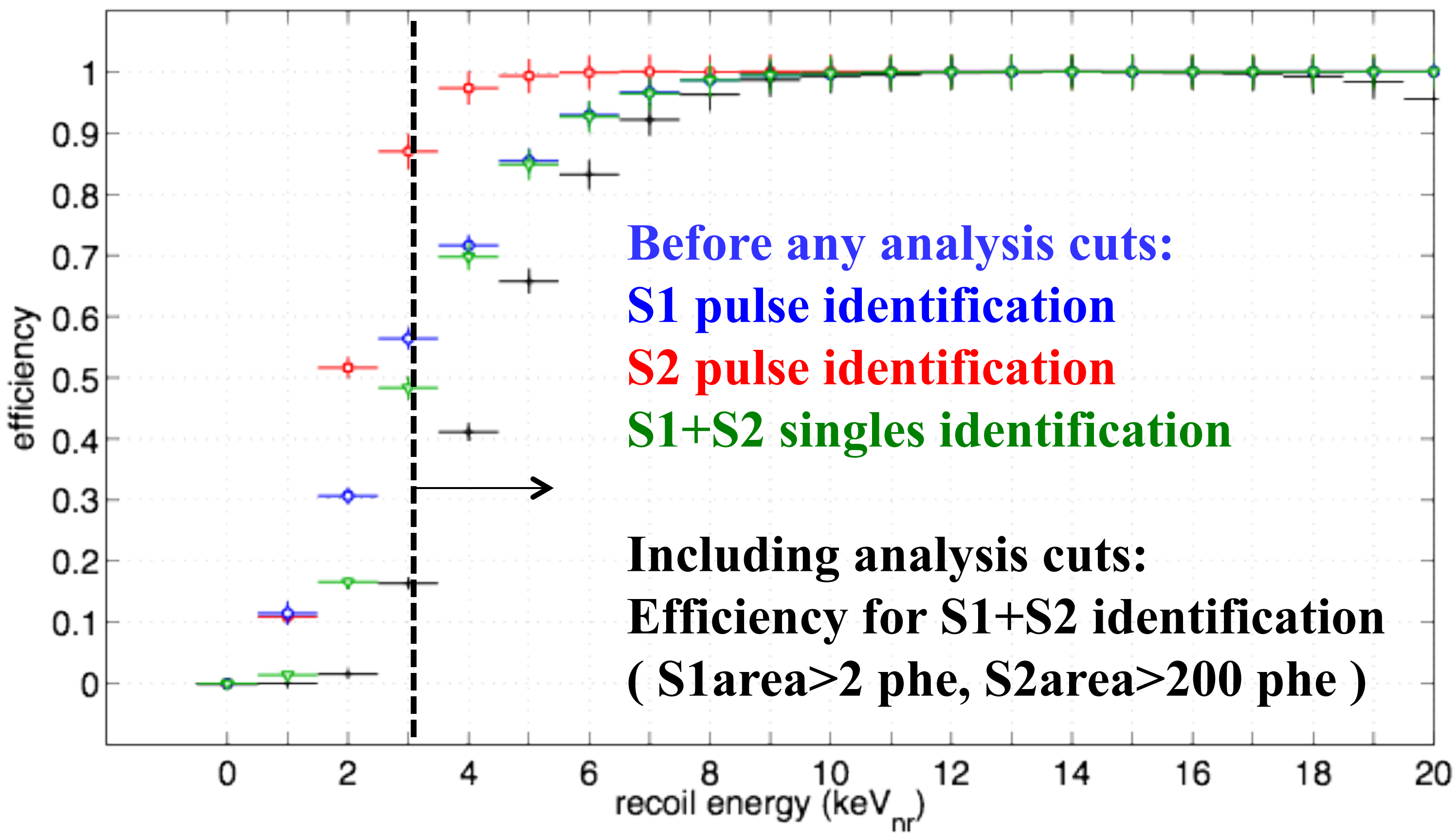
Thank you!

Light and Charge Yields

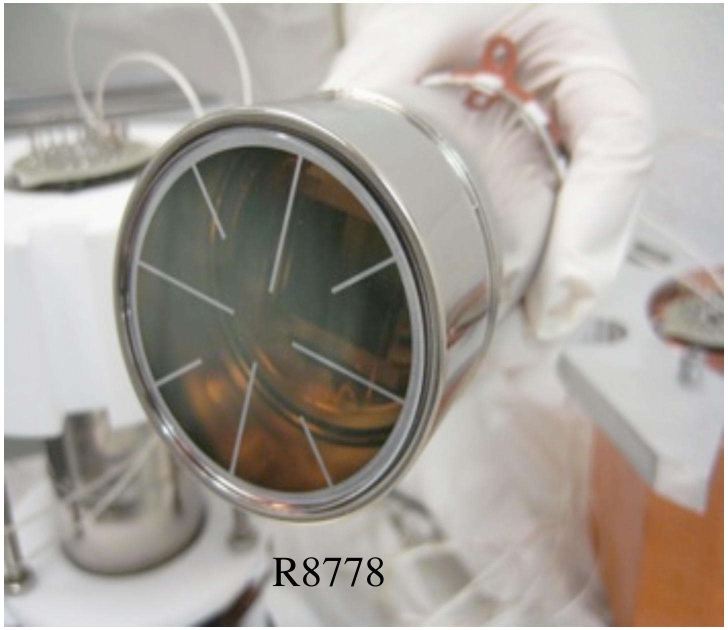
- Modeled using the Noble Element Simulation Technique (NEST), based on the canon of existing experimental data.
- **Artificial cutoff in light and charge yields assumed below 3 keVnr, to be conservative.**
- **Includes** E field quenching of light signal (77-82% compared to zero field)
- Charge yield: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

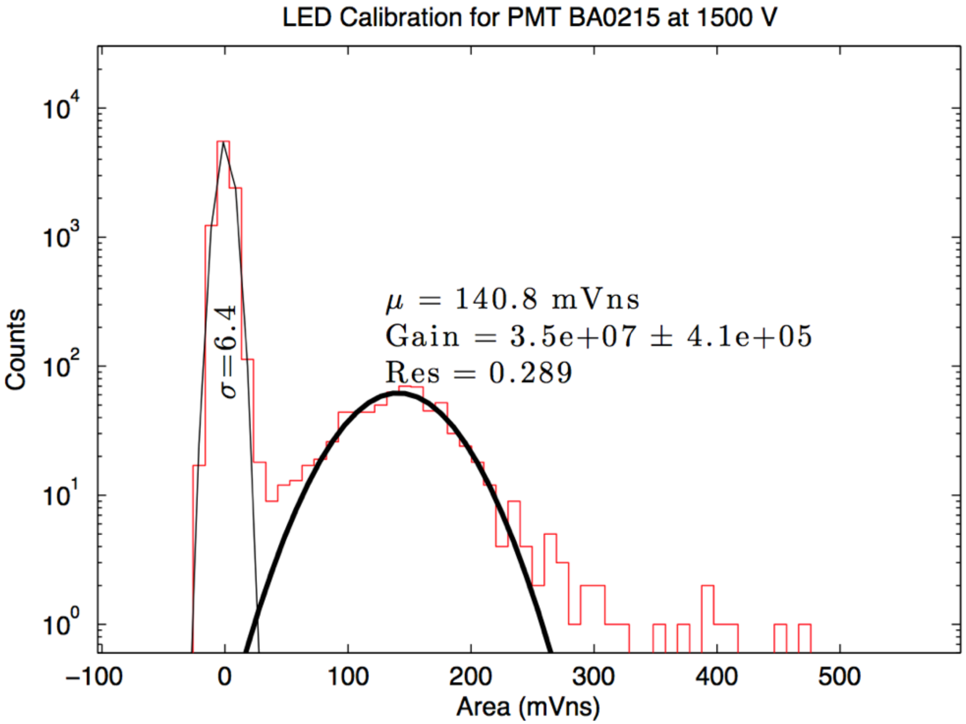


LUX detector threshold translated to recoil energy



LUX PMTs

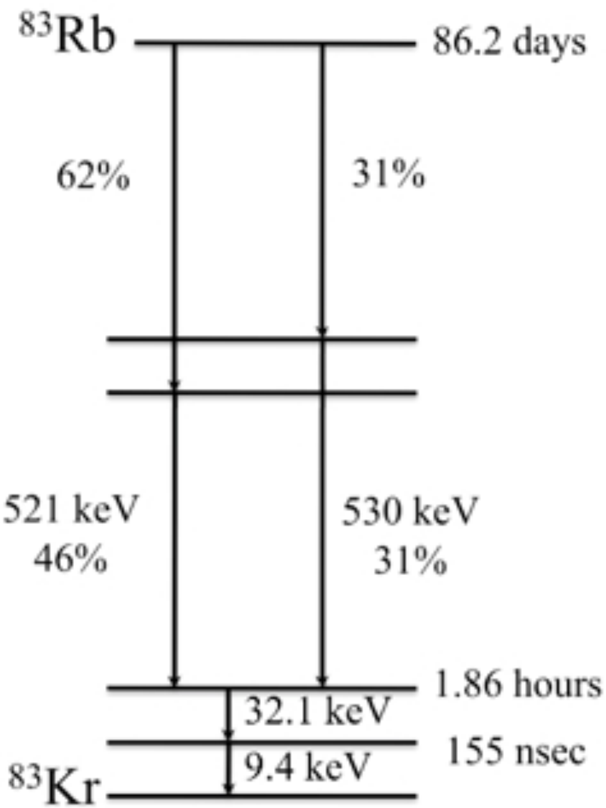




- 122 x 2” diameter R8778 Hamamatsu
- U/Th 10/2 mBq/PMT
- Demonstrated QE: average=33%, max 39% at 175 nm
- U/Th content ~ 9/3 mBq/PMT

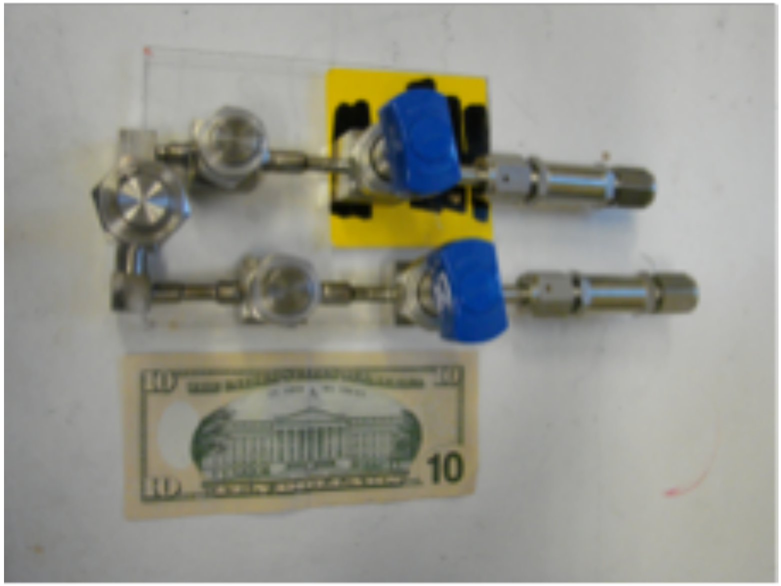
LUX Calibrations – ^{83m}Kr

- ^{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.

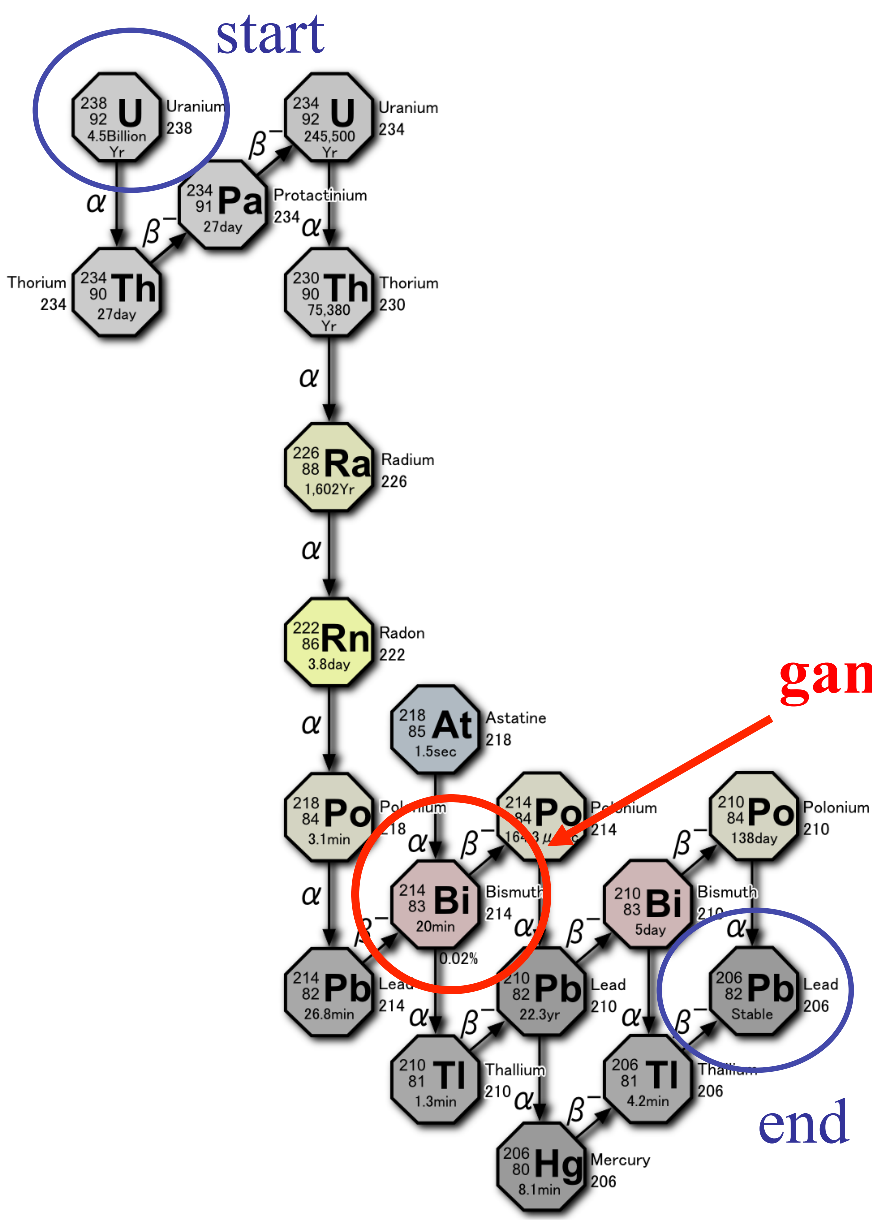


- Bonus: tomography of Xe flow

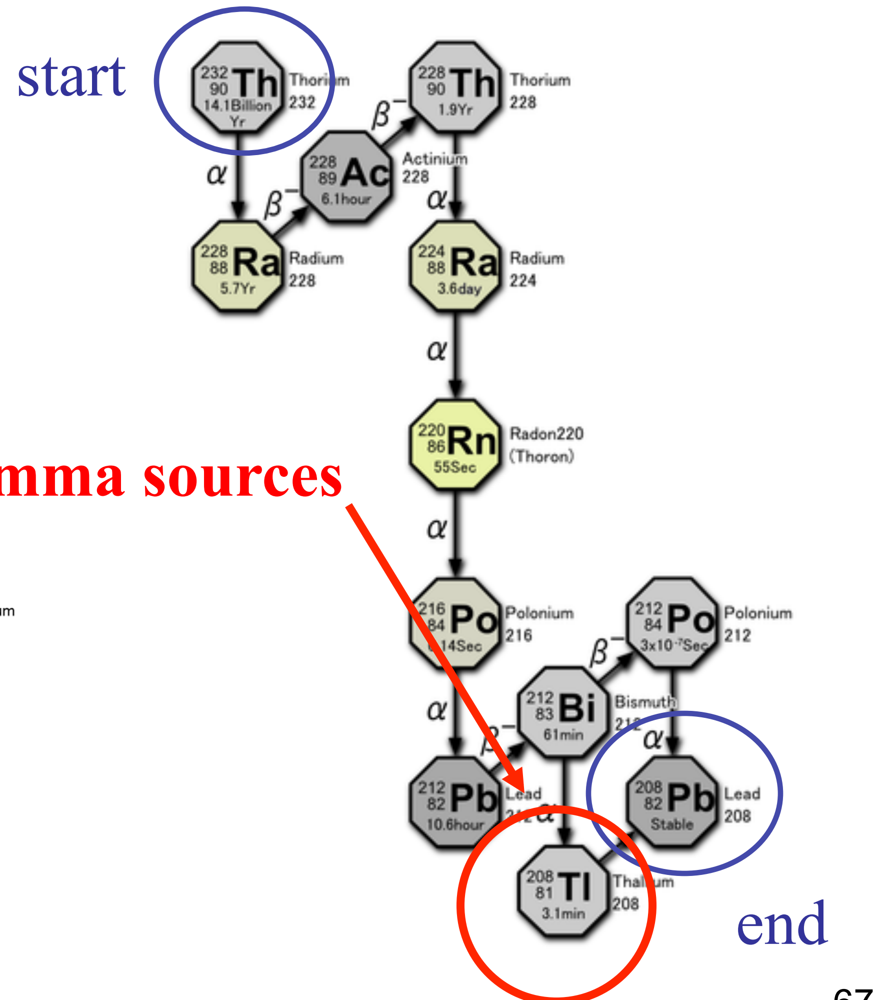
^{83m}Kr source (^{83}Rb coated on charcoal, within xenon gas plumbing)



Uranium-238 decay chain



Thorium-232 decay chain

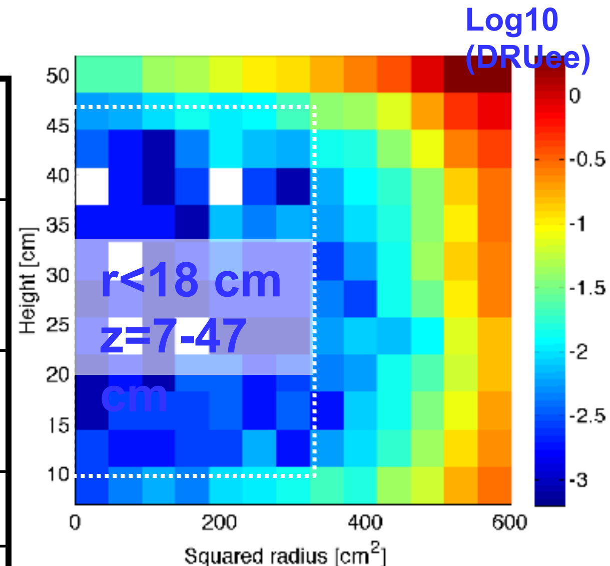


LUX Run 3 – Background Levels

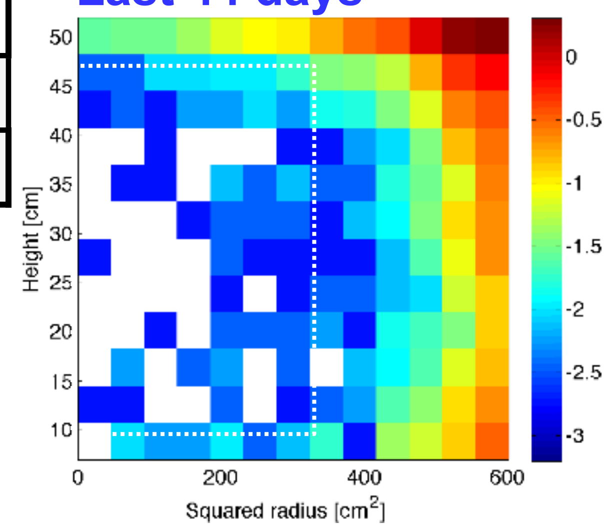
Background Component	Source	10^{-3} x evts/keVee/kg/day
Gamma-rays	Internal Components including PMTS (80%), Cryostat, Teflon	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe (36.4 day half-life)	Cosmogenic 0.87 -> 0.28 during run	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	^{222}Rn	$0.11\text{-}0.22_{(90\%\ CL)}$
^{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	$3.1 \pm 0.2_{stat}$

- Dedicated publication is coming

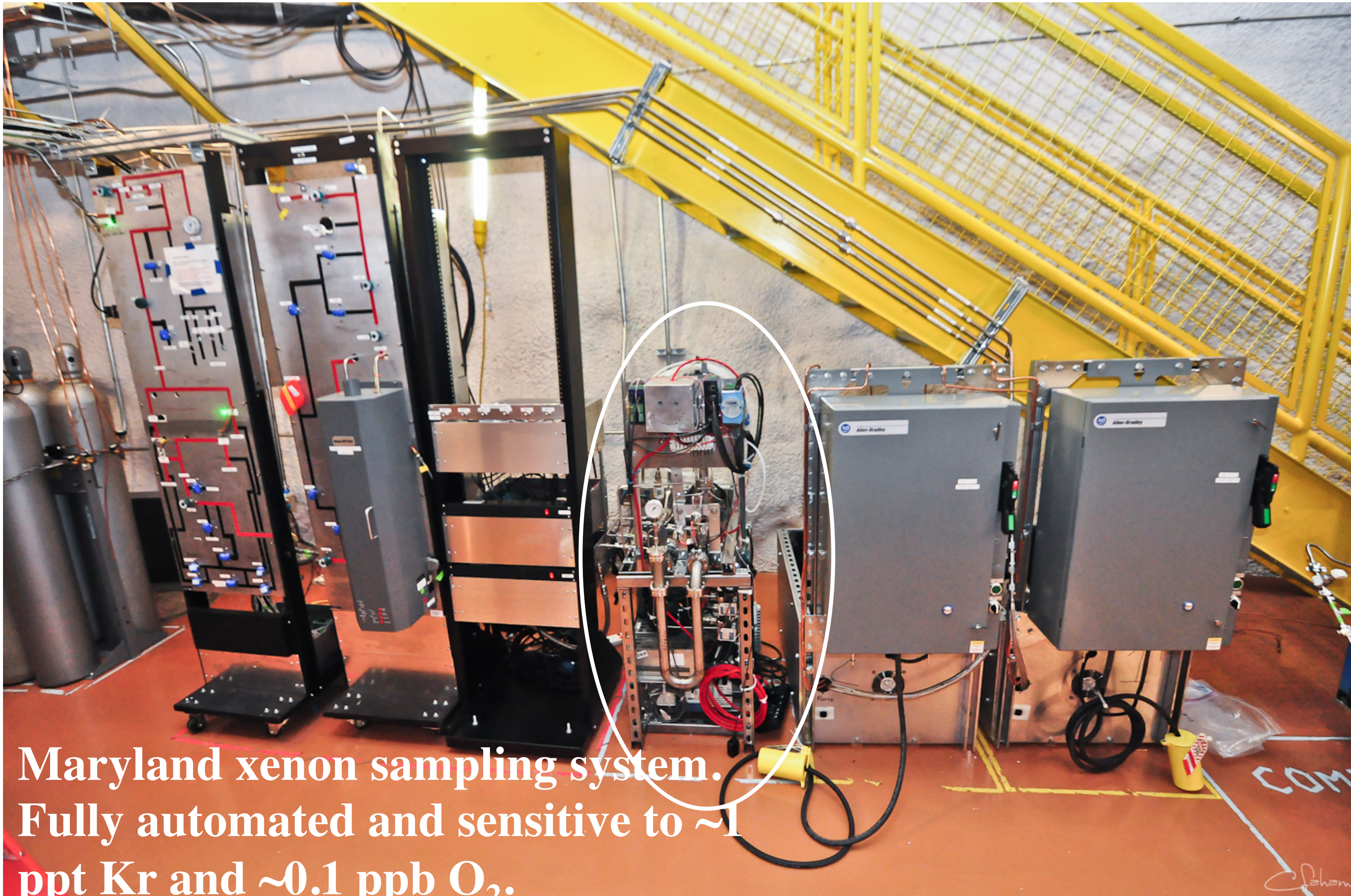
ER < 5 keVee in 118 kg



Last 44 days



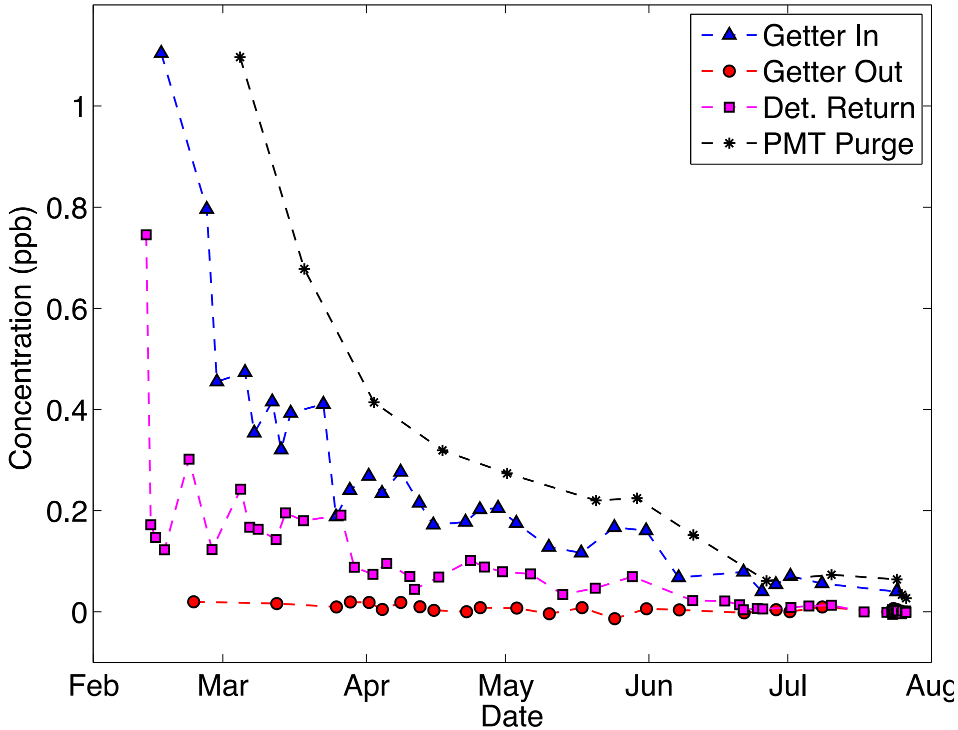
Xenon purification system and impurity monitoring



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

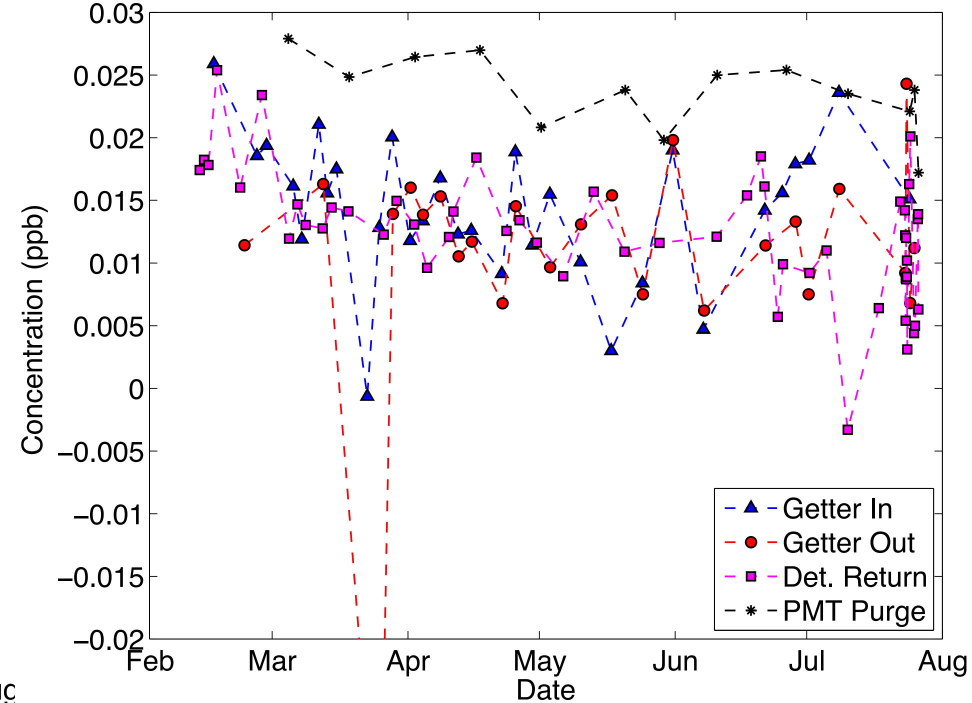
Monitoring of impurities in the LUX xenon with the Maryland sampling system

O_2 Run 03 Sampling



2013

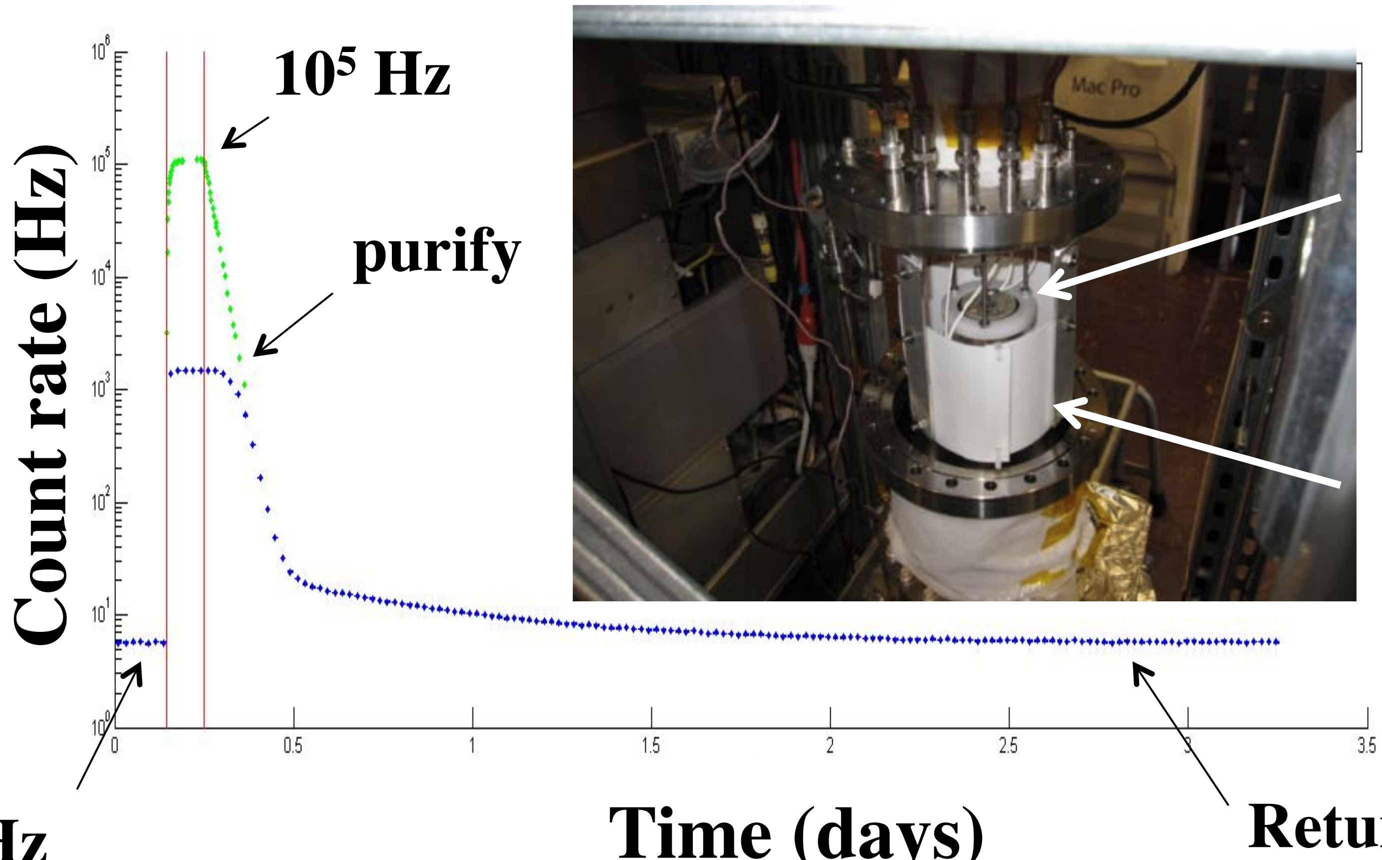
Kr Run 03 Sampling



2013

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

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



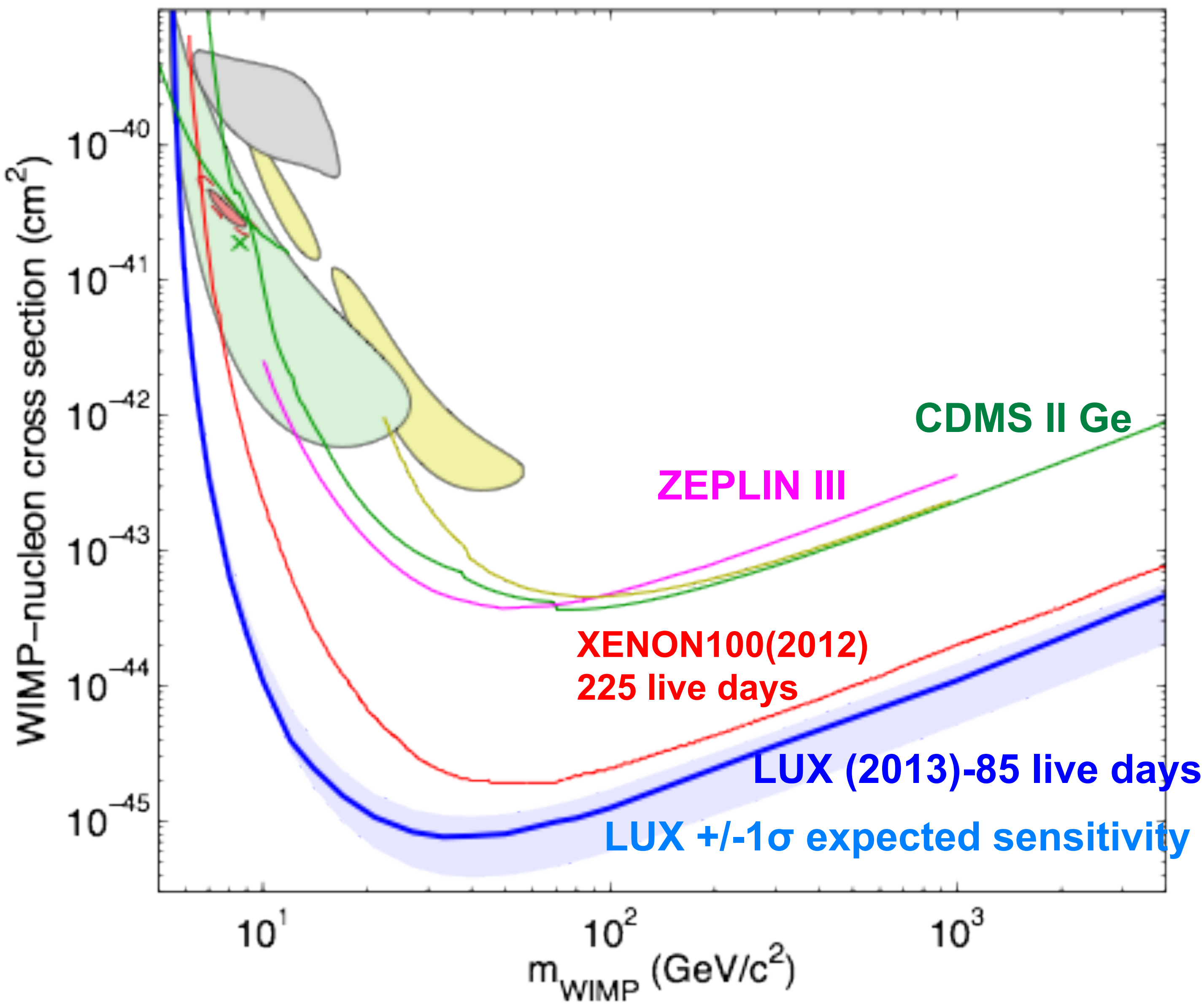
2 PMTs immersed in liquid xenon, and surrounded by samples of plastics used in LUX

5 Hz (cosmic ray rate)

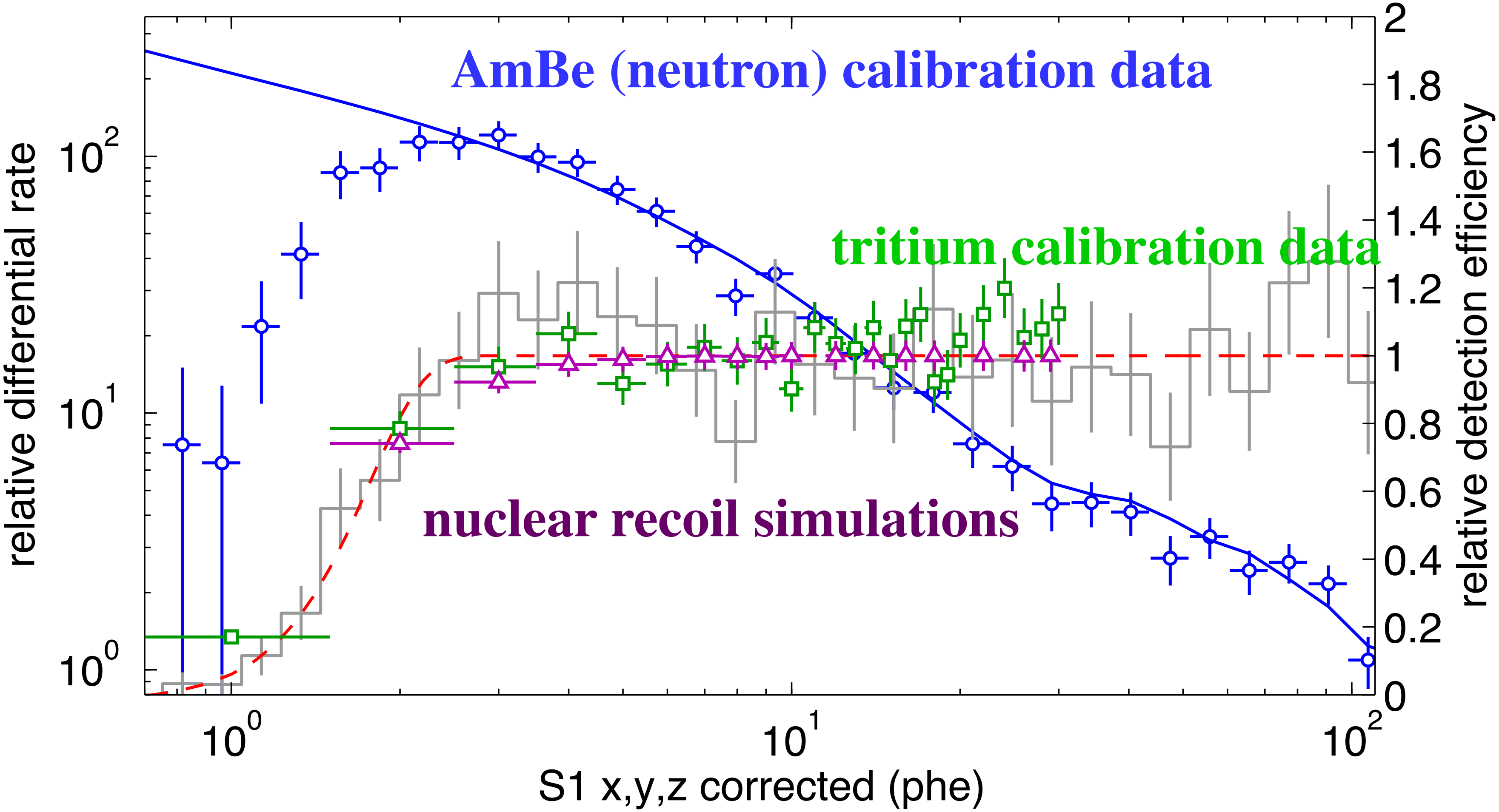
Return to 5 Hz

Maryland students Richard Knoche and Jon Balajthy.

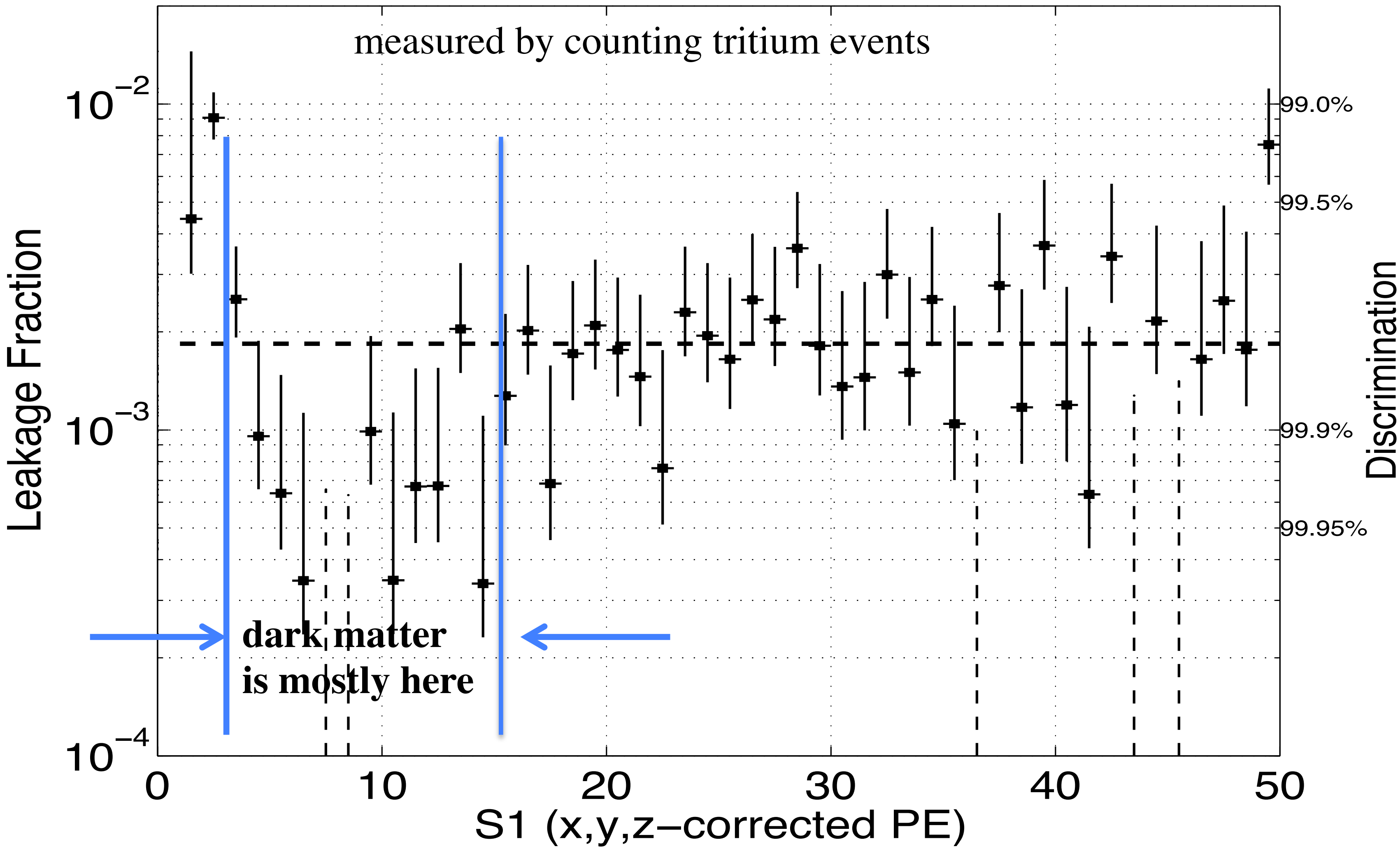
LUX 90% C.L. exclusion limits



LUX detector threshold vs S1



LUX electron recoil discrimination



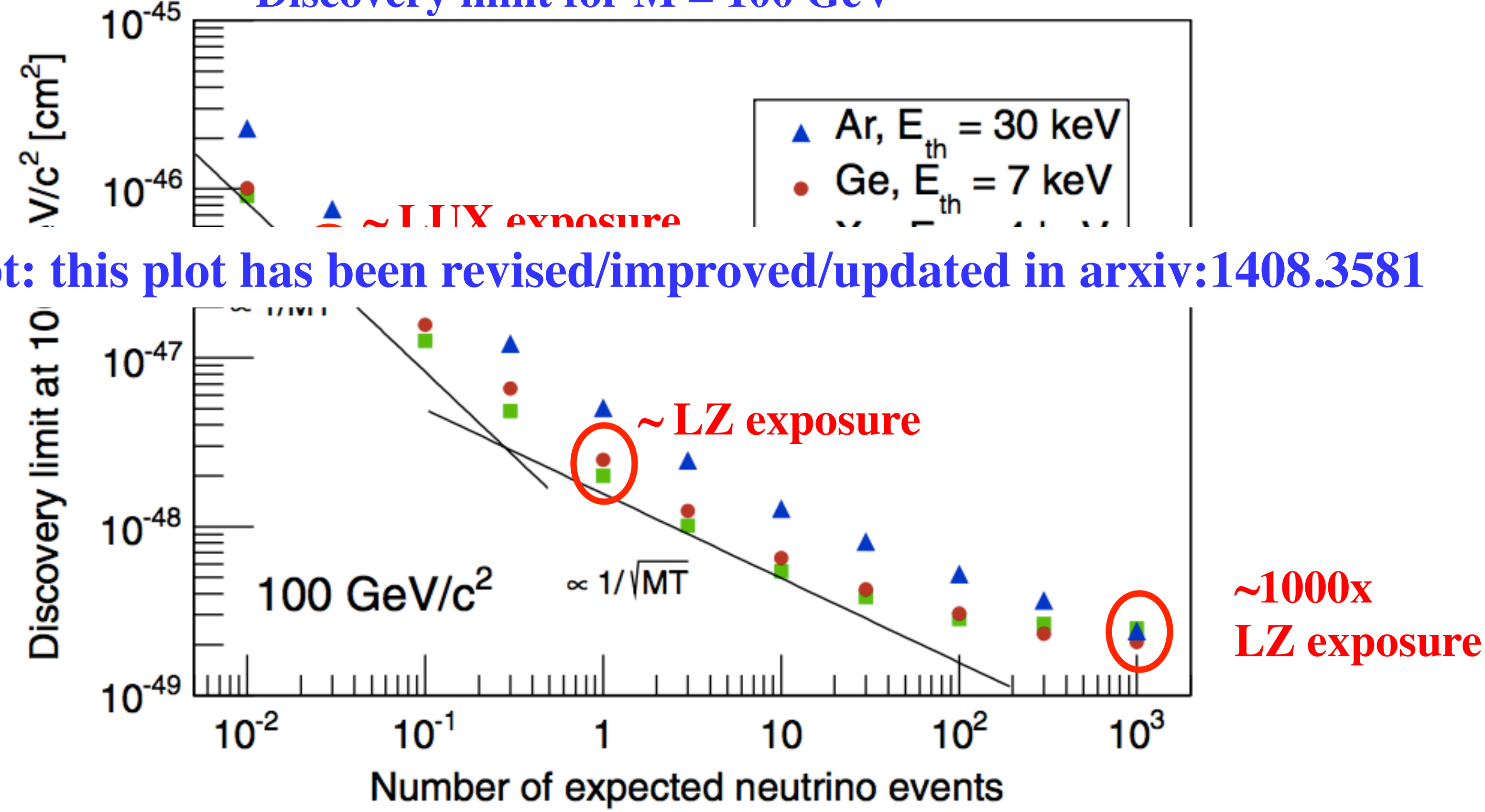
115,000 fiducial tritium events
December 2013 tritium injection

WIMP discovery limits – How low can we go?

Coherent neutrino scattering sets constraints due to:

- statistical fluctuations
- theoretical uncertainty on rates

Discovery limit for M = 100 GeV

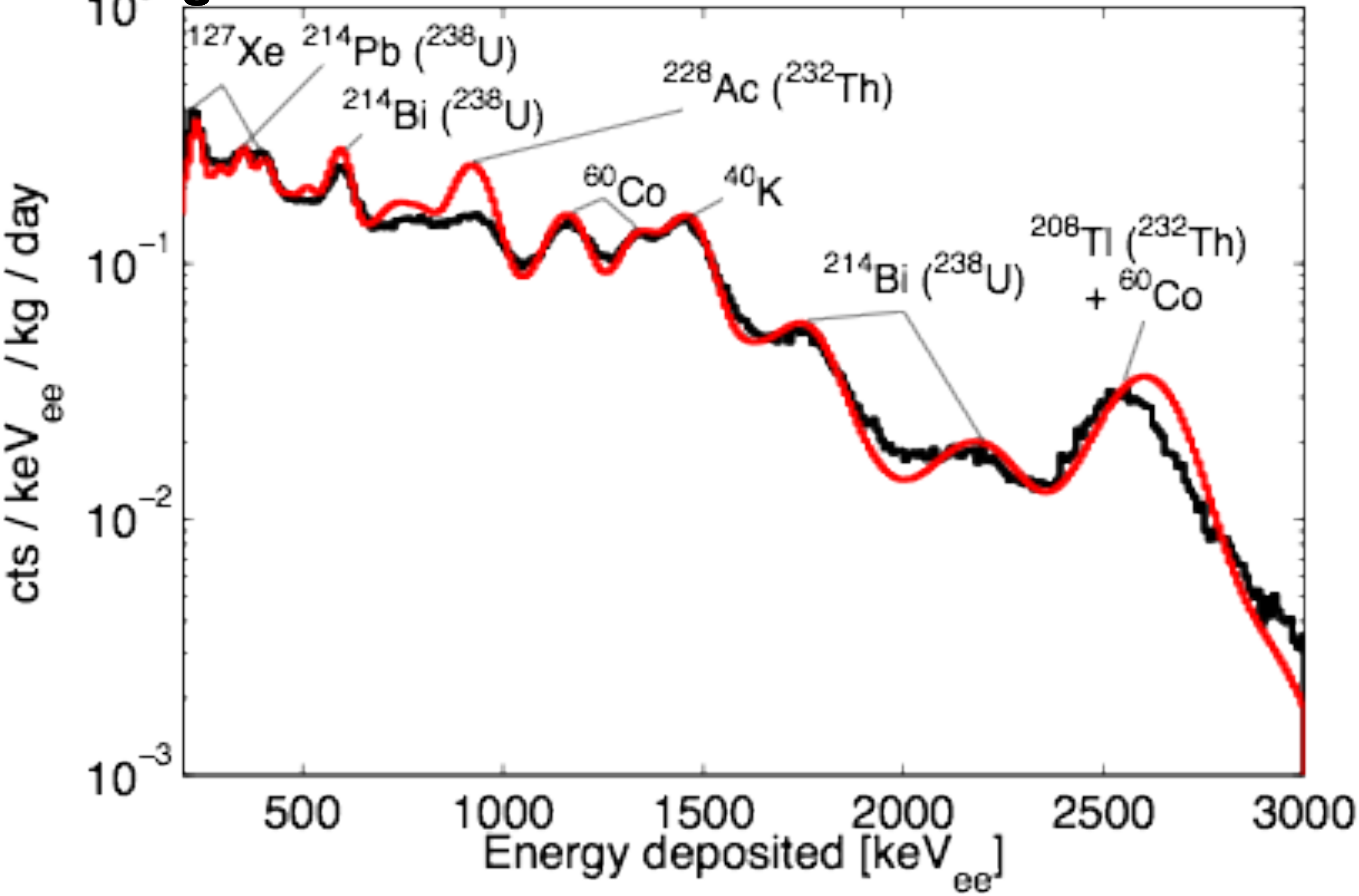


Postscript: this plot has been revised/improved/updated in arxiv:1408.3581

From Billard, Strigari, Figueroa-Feliciano, arXiv:1307.5458

LUX Run 3 – Background Levels

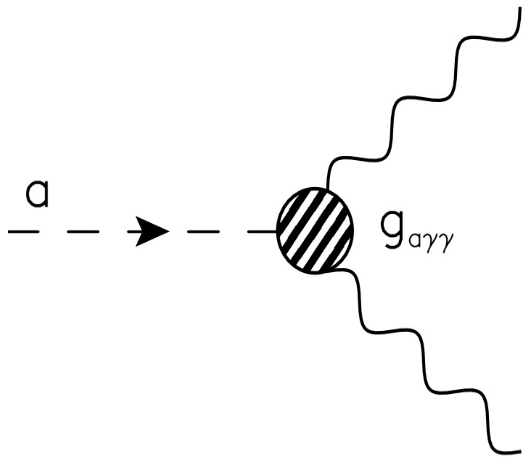
- Full gamma spectrum, excluding region ±2 cm from top/ bottom grids

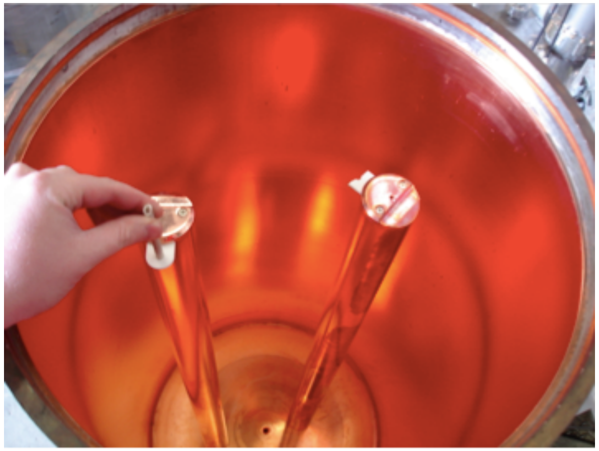


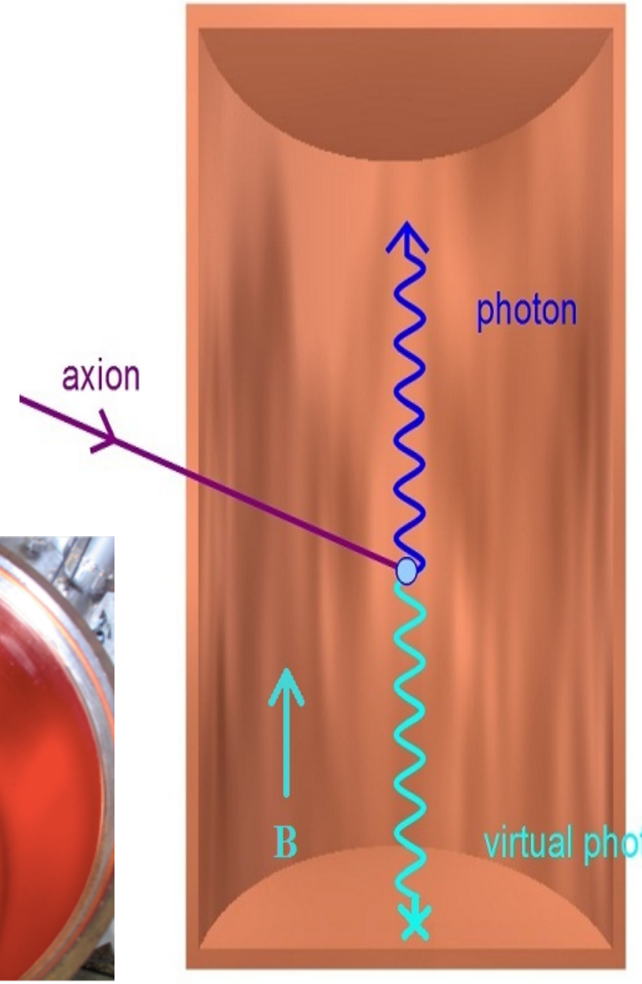
ADMX - The Axion Dark Matter eXperiment

- Conversion of axions into EM radiation via the inverse Primakoff effect
- Use strong static magnetic field to induce a→γ.
- Microwave cavity has a tunable resonant frequency. $Q \sim 10^5$
- Axion conversion is resonantly enhanced when $m_a \sim h\nu$ of cavity.
- Measure total microwave power with RF receiver.

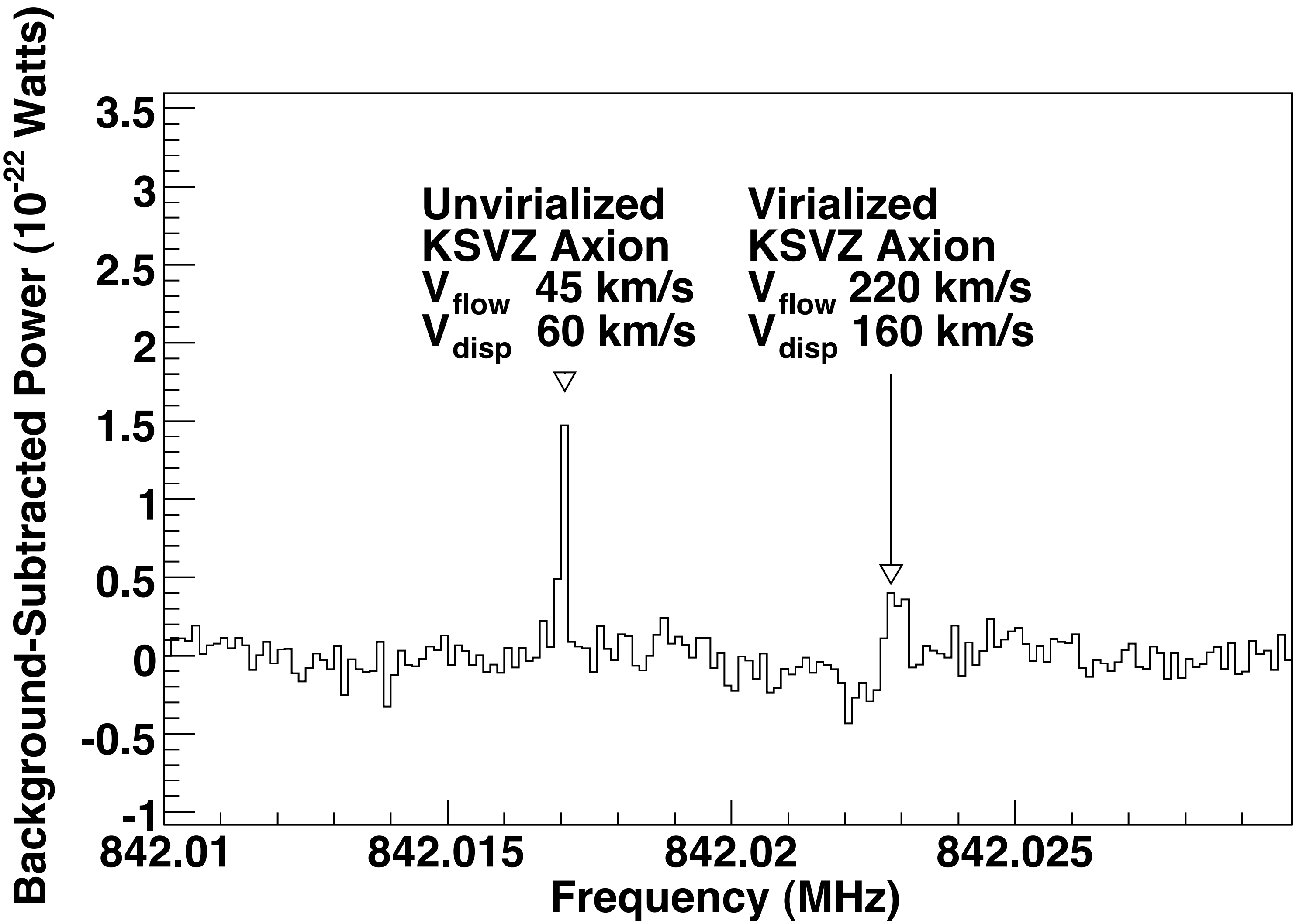
Microwave cavity, ~ 0.5 m x 1.5 m



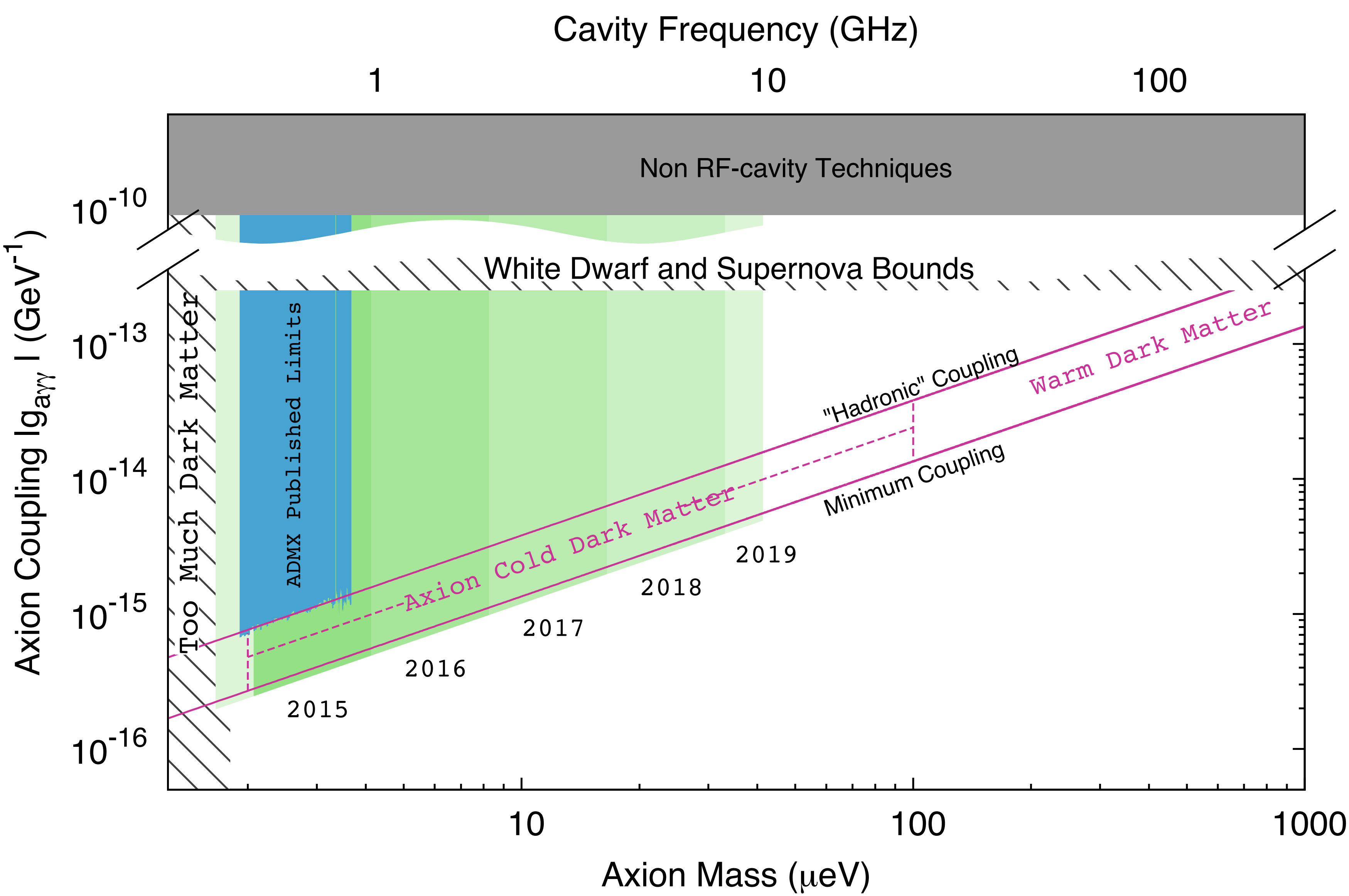




What would an axion look like in ADMX?



Gen 2 ADMX Projected Sensitivity



JV Sloan 12 April, 2015

Jim Sloan (U Washington) – Session J2: Dark Matter IV