Improved WIMP scattering limits from the LUX experiment

Wing To
LUX Collaboration
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Outline

- Large Underground Xenon (LUX)
- First Run3 Analysis (90 live-days)
- Improved Analysis of Run3 Data arxiv:1512.03506
- Preparation for Run4 (300 live-days) Data

Improved WIMP scattering limits from the LUX experiment

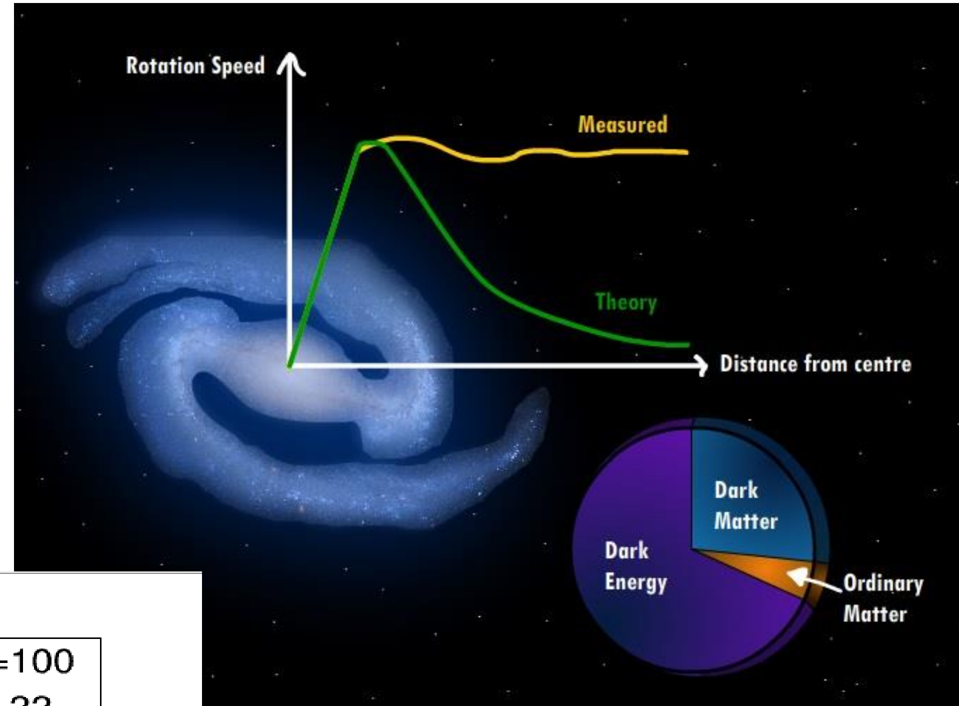
D.S. Akerib,[1,2,3] H.M. Araújo,[4] X. Bai,[5] A.J. Bailey,[4] J. Balajthy,[6] P. Beltrame,[7] E.P. Bernard,[8] A. Bernstein,[9] T.P. Biesiadzinski,[1,2,3] E.M. Boulton,[8] A. Bradley,[1] R. Bramante,[1,2,3] S.B. Cahn,[8] M.C. Carmona-Benitez,[10] C. Chan,[11] J.J. Chapman,[11] A.A. Chiller,[12] C. Chiller,[12] A. Currie,[4,*] J.E. Cutter,[13] T.J.R. Davison,[7] L. de Viveiros,[14] A. Dobi,[15] J.E.Y. Dobson,[16] E. Druszkiewicz,[17] B.N. Edwards,[8] C.H. Faham,[15] S. Fiorucci,[11] R.J. Gaitskell,[11] V.M. Gehman,[15] C. Ghag,[16] K.R. Gibson,[1] M.G.D. Gilchriese,[15] C.R. Hall,[6] M. Hanhardt,[5,18] S.J. Haselschwardt,[10] S.A. Hertel,[19,8,15] D.P. Hogan,[19] M. Horn,[19,8,15] D.Q. Huang,[11] C.M. Ignarra,[2,3] M. Ihm,[19,15] R.G. Jacobsen,[19,15] W. Ji,[1,2,3] K. Kazkaz,[9] D. Khaitan,[17] R. Knoche,[6] N.A. Larsen,[8] C. Lee,[1,2,3] B.G. Lenardo,[13,9] K.T. Lesko,[15] A. Lindote,[14] M.I. Lopes,[14] D.C. Malling,[11] A. Manalaysay,[13] R.L. Mannino,[20] M.F. Marzioni,[7] D.N. McKinsey,[19,8,15] D.-M. Mei,[12] J. Mock,[21] M. Moongweluwan,[17] J.A. Morad,[13] A.St.J. Murphy,[7] C. Nehrkorn,[10] H.N. Nelson,[10] F. Neves,[14] K. O'Sullivan,[15,19,8] K.C. Oliver-Mallory,[19,15] R.A. Ott,[13] K.J. Palladino,[22,2,3] M. Pangilinan,[11] E.K. Pease,[19,8,15] P. Phelps,[1] L. Reichhart,[16] C. Rhyne,[11] S. Shaw,[16] T.A. Shutt,[1,2,3] C. Silva,[14] V.N. Solovov,[14] P. Sorensen,[15] S. Stephenson,[13] T.J. Sumner,[4] M. Szydagis,[21] D.J. Taylor,[18] W. Taylor,[11] B.P. Tennyson,[8] P.A. Terman,[20] D.R. Tiedt,[5] W.H. To,[1,2,3] M. Tripathi,[13] L. Tvrznikova,[19,8,15] S. Uvarov,[13] J.R. Verbus,[11] R.C. Webb,[20] J.T. White,[20] T.J. Whitis,[1,2,3] M.S. Witherell,[10] F.L.H. Wolfs,[17] K. Yazdani,[4] S.K. Young,[21] and C. Zhang[12]
(LUX Collaboration)

[1] *Case Western Reserve University, Department of Physics, 10900 Euclid Ave, Cleveland, OH 44106, USA*
[2] *SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94205, USA*

Dark Matter Detection

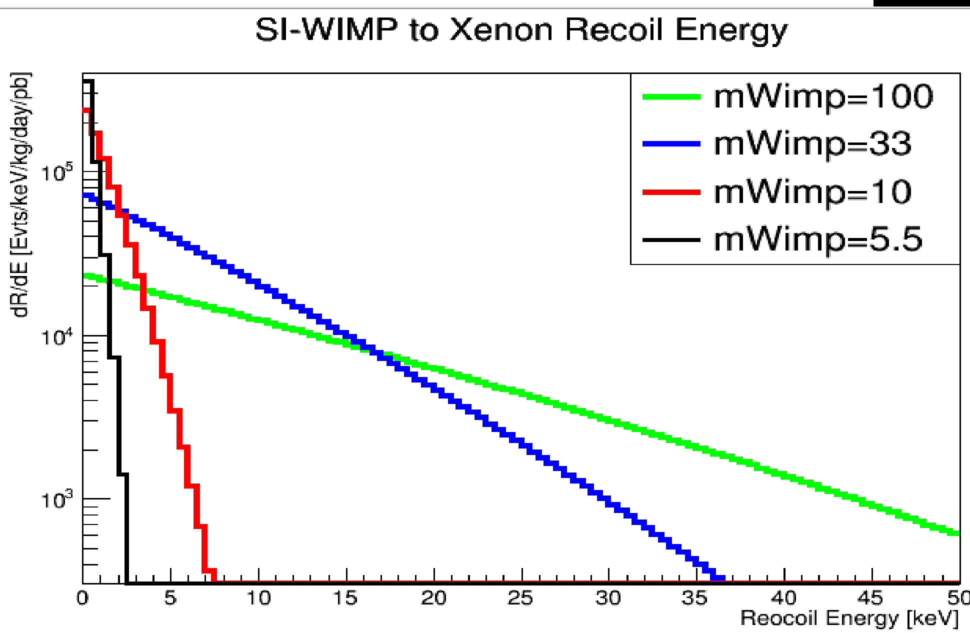
Our Universe

- 4.9% Visible Matter
- 26.8% Dark Matter
- 68.3% Dark Energy



Weakly Interacting Massive Particles

- Weak! Interaction cross-section
  $\sigma < 10^{-45} cm^2$ @ 33 GeV mass
- Massive ~ 100 GeV range



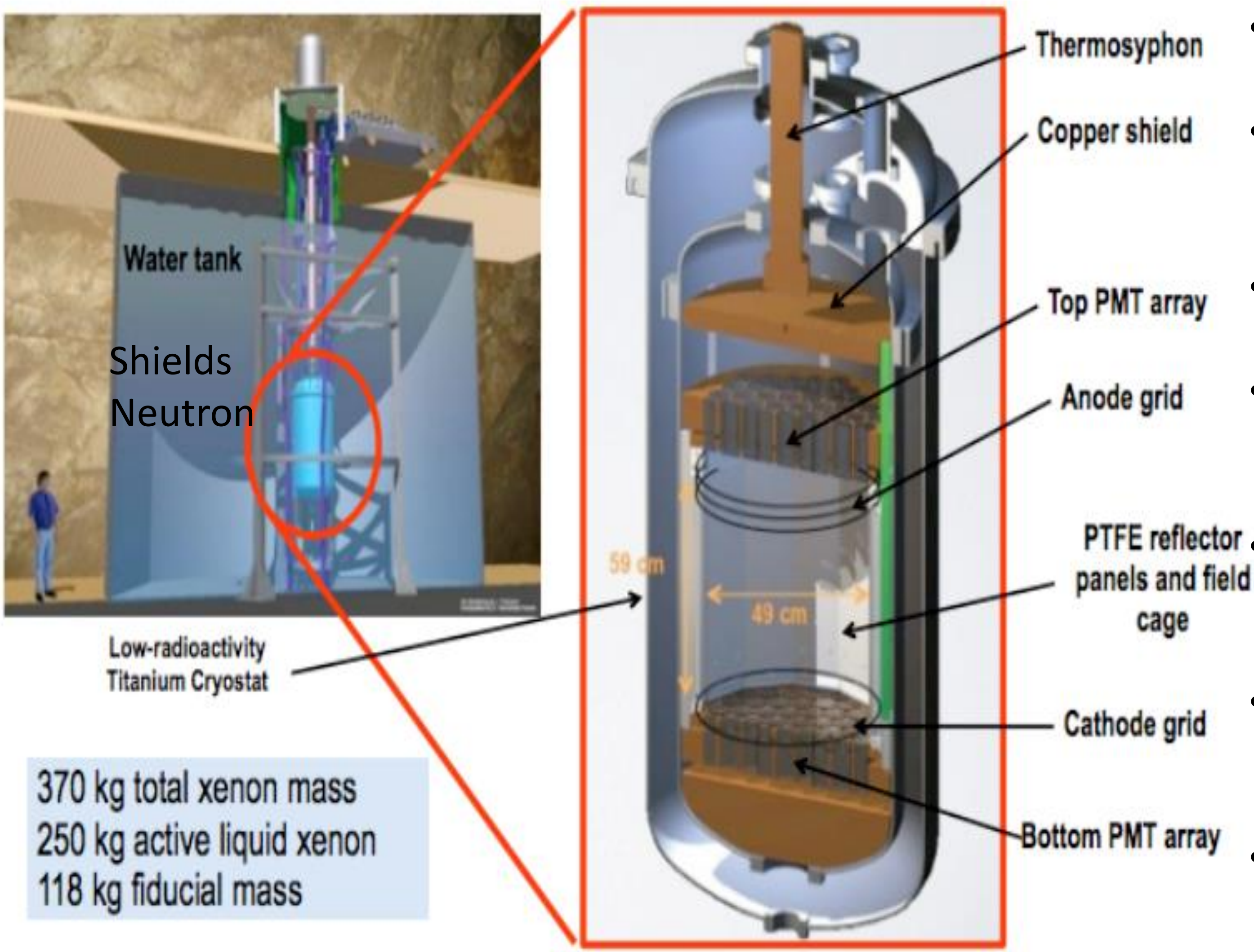
WIMP – Xenon interaction

- WIMPs scatters off normal matter and imparts small amount of energy
- Excited atom releases this energy
  - Heat (Loss)
  - Scintillation Light (S1)
  - Ionization (S2)

LUX Collaboration

LUX Detector

Located 4850 ft (1.5km) underground in the Davis Cavern in Lead South Dakota



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

- Xenon at 165K
- Thermo Isotropy
- S2/S1 Reconstruct
- Extracts Electrons
- ~99% reflectivity VUV light
- Applied 180 V/cm drift field
- S1 Reconstruction

LUX Detector

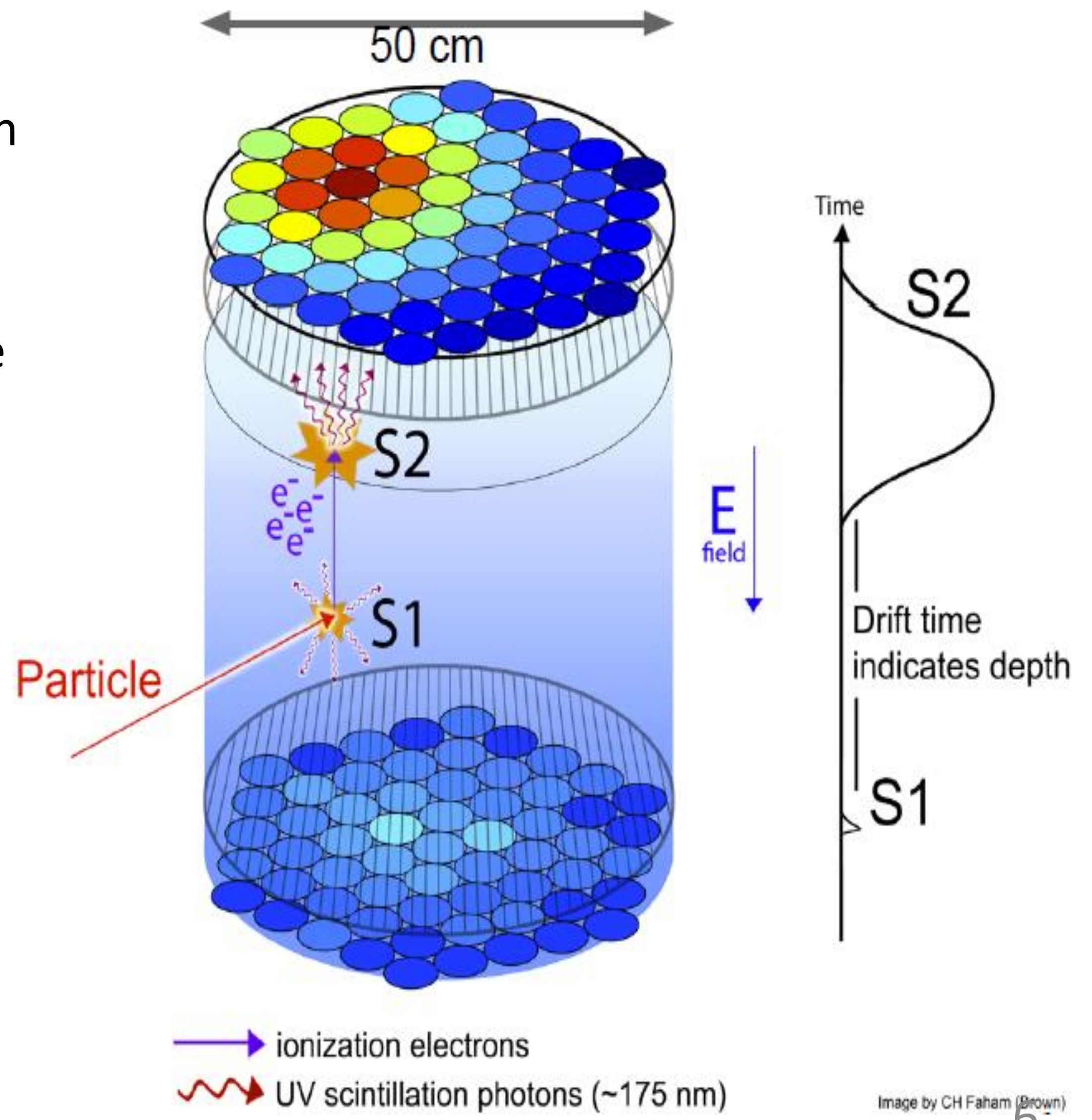
Dual Phase Xenon TPC

- Particle interacts with the Xenon and deposites ~ keV of Energy
- Prompt Scintillation Light (S1)
- Delay & Localized Charge on the top PMT array (S2)
- Drift time of the electrons

$$E = \frac{1}{\mathcal{L}(E)} \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right) \cdot W.$$

- W = 13.7 eV
- g1 = Light Collection
- g2 = Extraction Eff, Light
- L(E) = Lindhard Factor

  Fraction of Energy Loss to Heat

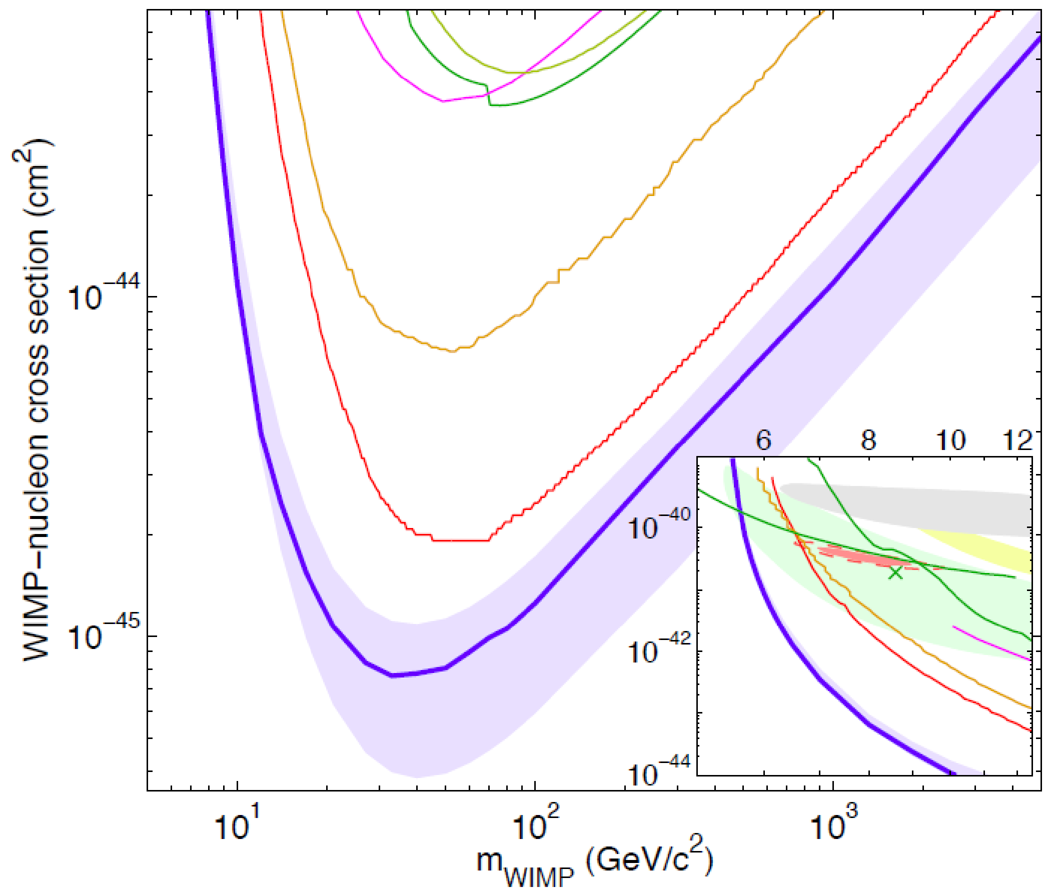


Notes Original Analysis

Original Run3 Analysis

- Exclusion down ~ 6 GeV
- Energy threshold: 3 keV (slide2)
- 85.3 Live-days with 118 kg of fiducial mass (10k kg-days)
- 2 ≤ S1 ≤ 30 Phe
- S2 > 200 Phe
- Event Radius < 18 cm
- 160 Events observed in data after selection cuts

First LUX Run3 Exclusion Limits



- LUX
- Xenon100 (225 days)
- Xenon100 (100 days)
- Edelweiss II
- ZEPLIN III
- CDMS II

Reanalysis: The List

PMT Pulses

- Vacuum UV correction between liquid and gas (A.Currie)
- Spike Counting for S1 Improved Pulse classification (S.Shaw)
- Fixed biases in pulse area measurements (T. Biesiadzinski,S.Shaw)
- Improved XY position Reconstruction (C.Silva)
- S2 energy from both Top and Bottom Array (C.Silva)
- Energy Calibration for Electronic Recoil Events (A.Dobi)
- Inclusion of low energy Nuclear Recoil Events (J.Verbus)
- Improve background models (B.Tennyson, C.Lee)
- Improved signal model full Energy -> S1 / S2 simulation (W.To)
- Created a new sensitivity and limits framework using Profile Likelihood Ratio (W.To)

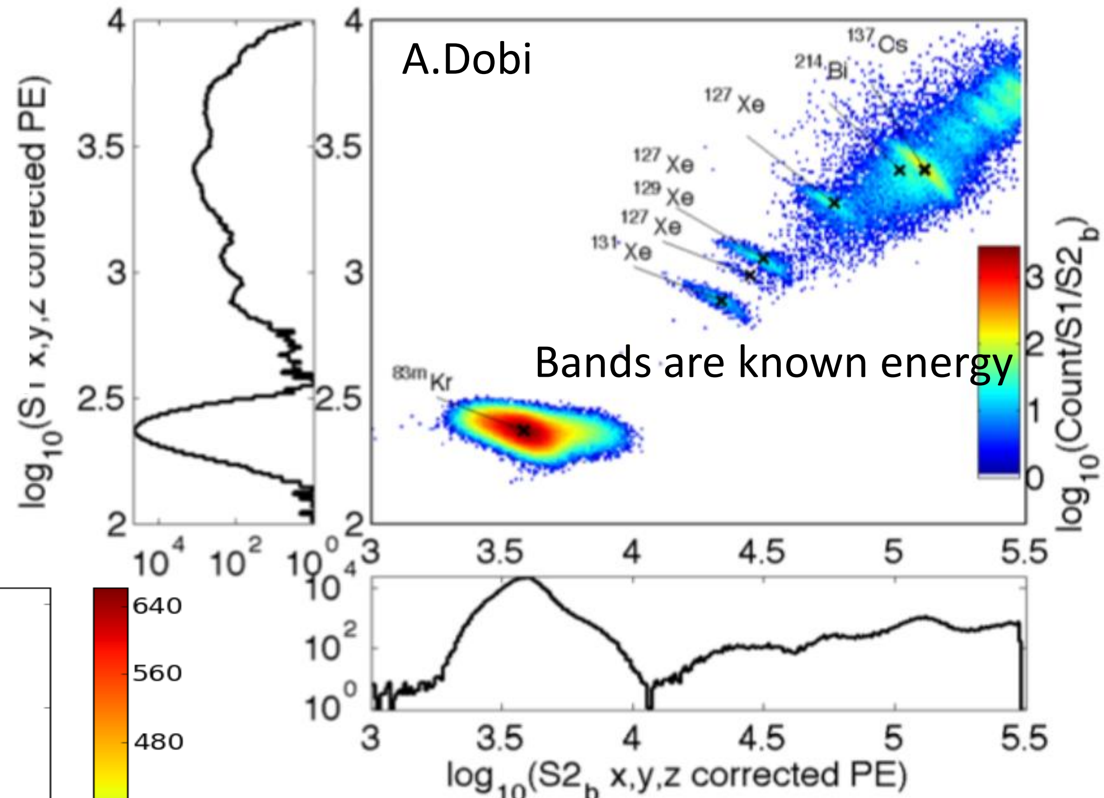
Exclusion Curves

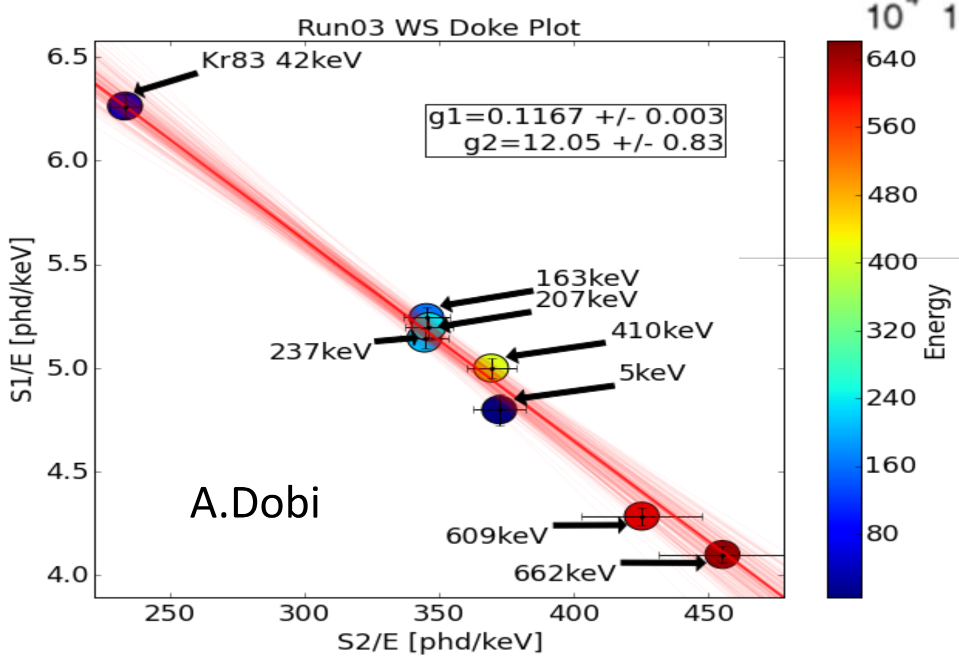
Data-Driven Energy Calibration

$$E = \frac{1}{\mathcal{L}(E)} \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right) \cdot W.$$

$$S2/E = \frac{n_e}{(n_e + n_\gamma)} \cdot \frac{g_2}{W} \text{ and}$$

$$S1/E = \frac{n_\gamma}{(n_e + n_\gamma)} \cdot \frac{g_1}{W},$$





x-intercept

- $n_\gamma \rightarrow 0$; S2/E = g2/W

Y-intercept

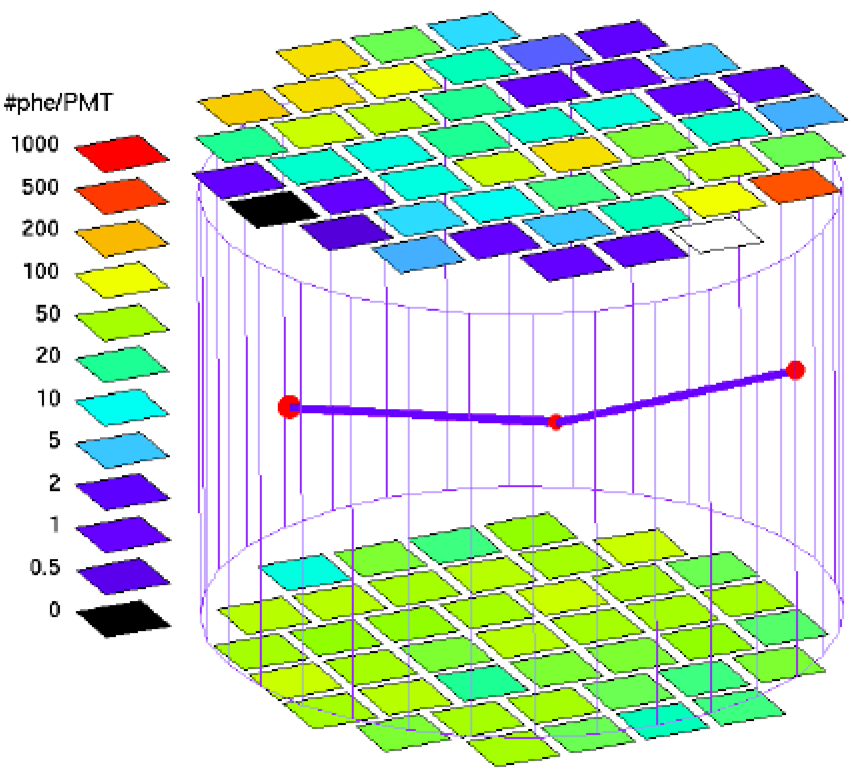
- $n_e \rightarrow 0$; S1/E = g1/W

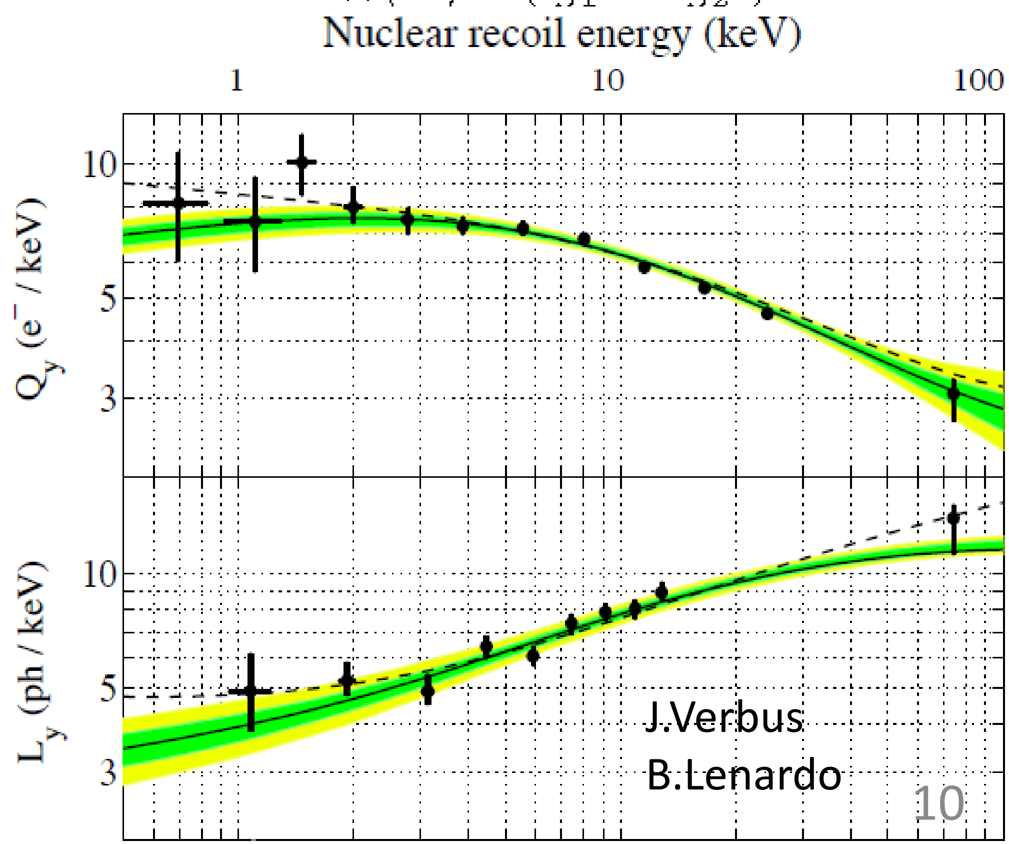
Neutron DD Calibration

- Mono-energetic: 2.45 MeV fired into LUX
- Two line segments so the energy of the middle scatter is known

- Qy = Charge Yield (S2 Size/ E)
- Ly = Light Yield (S1 Count /E)
- Fit to Lindhard/Berzukov model to get L(E)

$$E = \frac{1}{\mathcal{L}(E)} \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right) \cdot W.$$



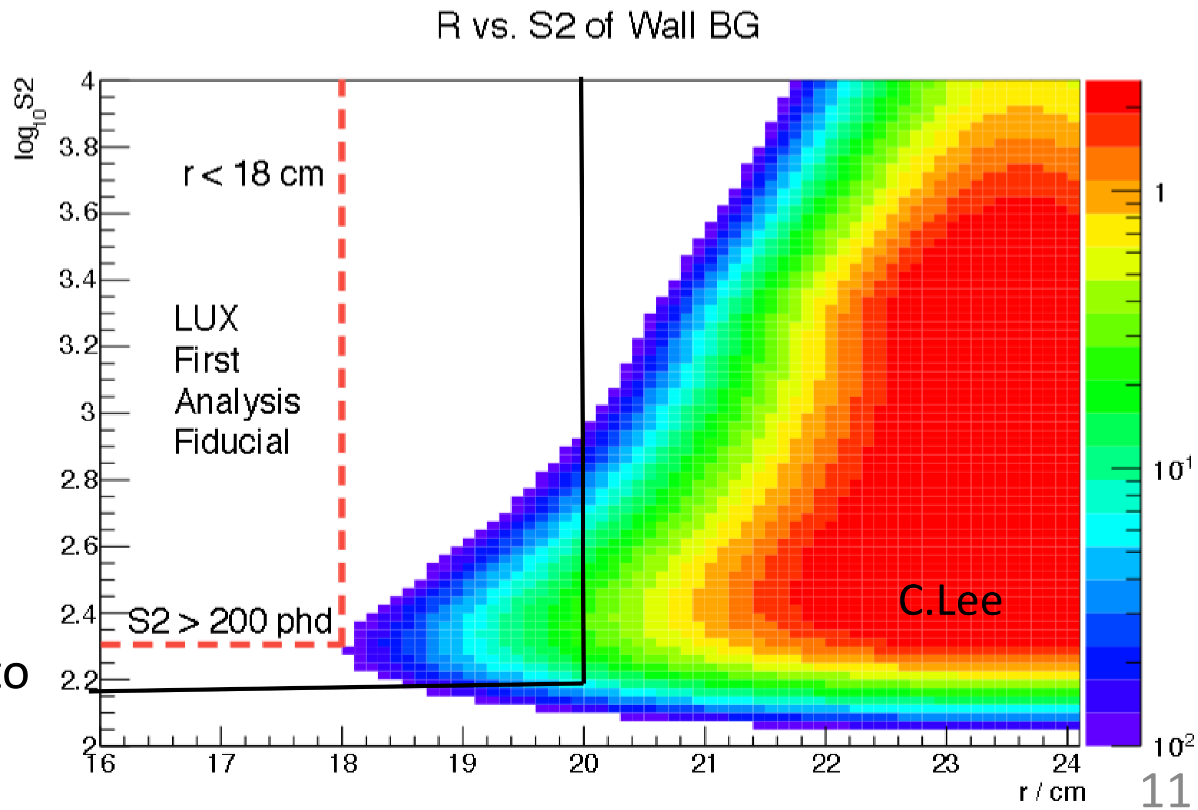


Background Model

- Detector Material: Gamma rays from Co-60, K-40, Tl-208, Bi-214
  - Global Fit to 3 MeV
  - Asymmetric source from top and bottom
- Internal Background (in Xenon): Ar-37, Kr-85m, Xe-127

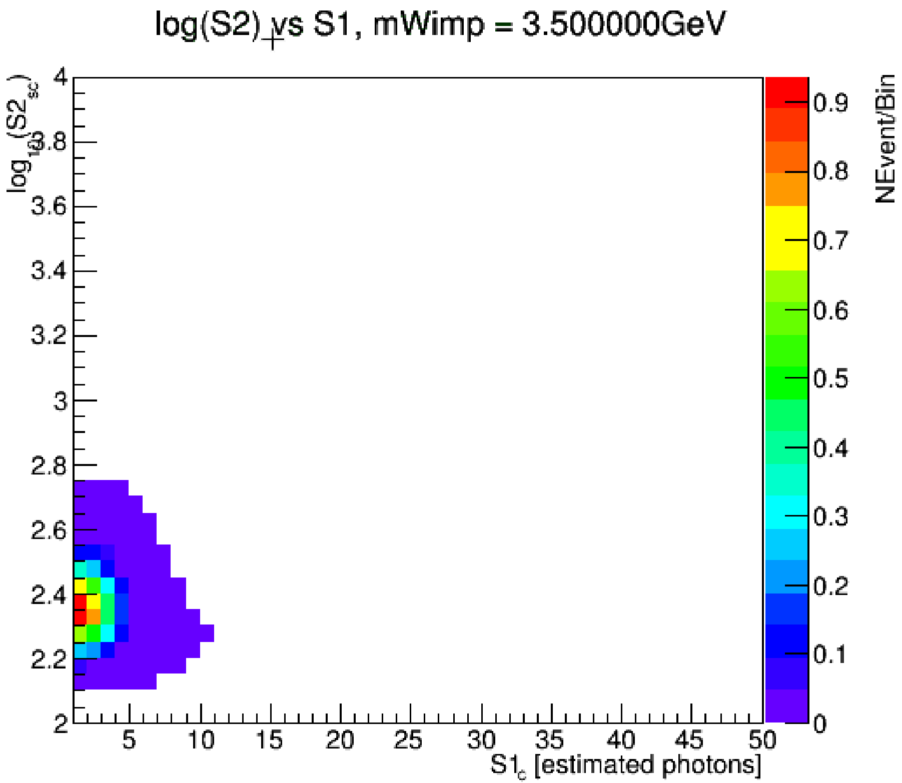
Wall Background:

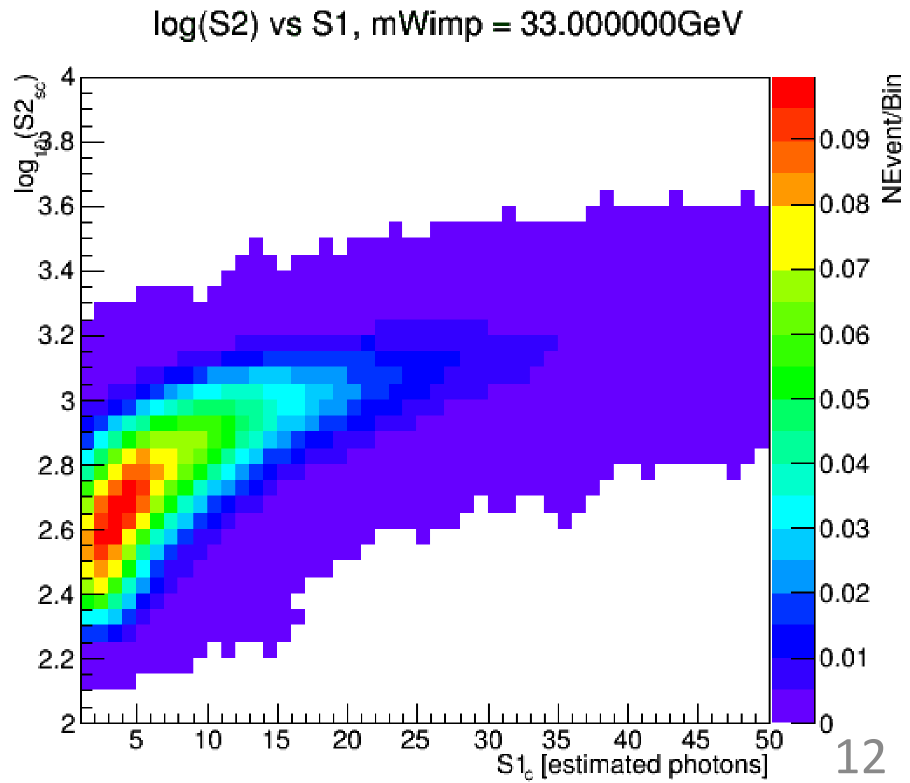
- Rn222-Pb206
- Occurs on the wall at 24.2-5 cm
- Resolution Leaks into below 18 cm
- Charge Loss
- Inclusion of Wall Bkg increase Fidicial Radius to 20 cm



Signal Model and Limits

- First Result used S1 as a proxy for Energy { E(S1) = 6th Degree Poly }
- Noble Element Simulation Technique, M.Sydagzis et al, arxiv:1106.1613
- Implement full NEST simulation in the sensitivity calculation
- NEST parameter are derived from DD-data
- All parameters including g1 , g2 and L(E) are allow to vary in fits



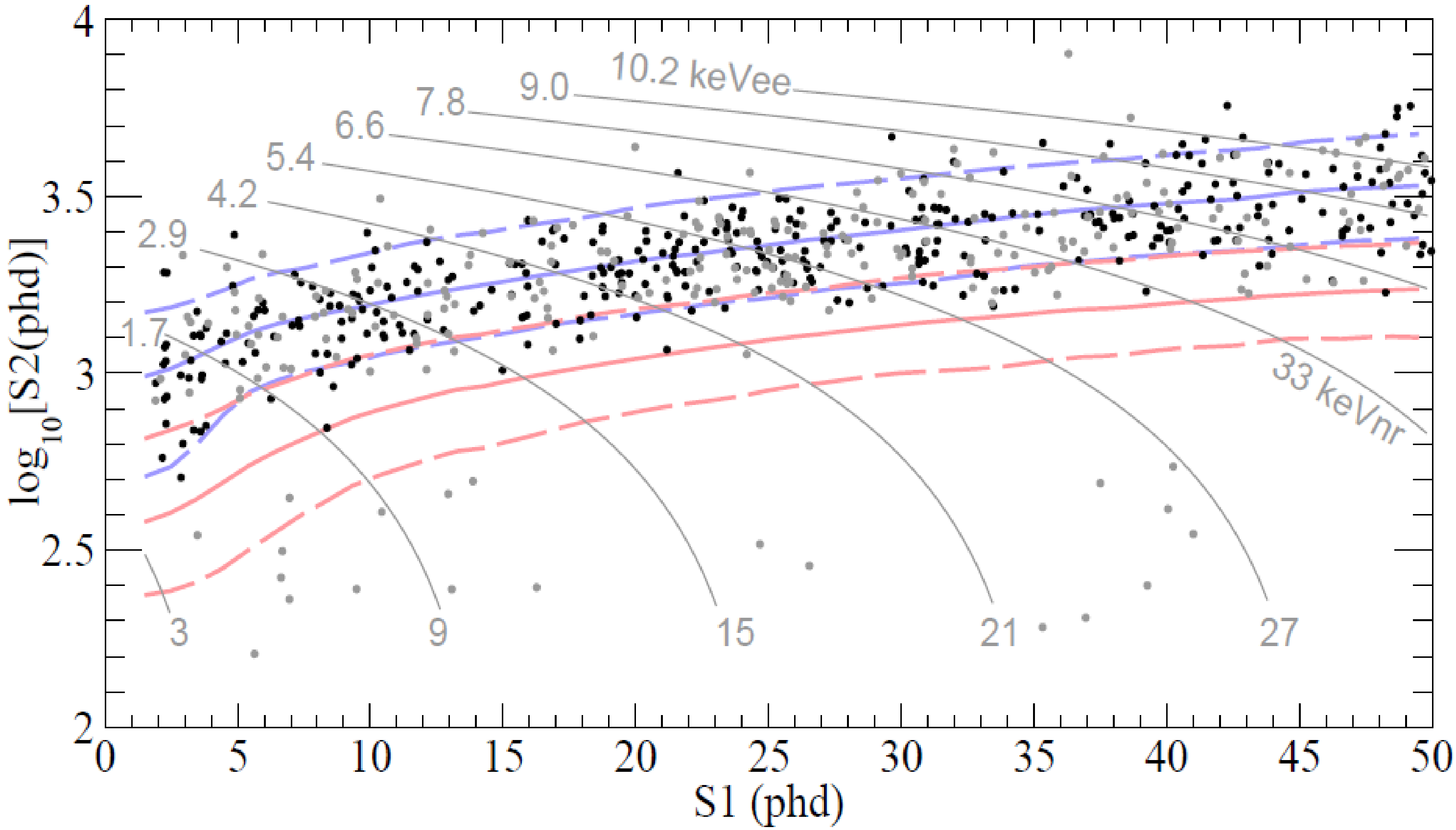


Sensitivity Exclusion Calc

- Limits calculation switched to physical quantity of cross-section instead of number of events
- Signal Model is generated on the fly
  - Parameters can be varied during fits
  - Profile over parameter space
- Nuisance Parameters
  - Both Signal Strength and Shape could be changed by the NPs
  - The kappa factor in L(E) is found to be dominated in Signal Strength
  - g2 is found to dominated in Signal Shape.
  - kappa is allowed to for all mass points
  - g2 only floats above 4 GeV (huge increase in computing time)
  - Each individual background contribution also have a NP
  - The likelihood ratio is calculated with all NPs variation so we get a profile of the model parameters (PLR)
- “Goodness-Of-Fit” between Data and Background Model

Re-Analysis Dataset

- 1 ≤ S1 ≤ 50 Phd   S2 > 150 Phd   Energy Threshold = 1.1 keV
- 10 additional days from dataset with tiny amount of Kr-83 from calibration
- 95 Live-days x 145 kg = 13800 kg-days (increase of 40%)
- Total of 591 events



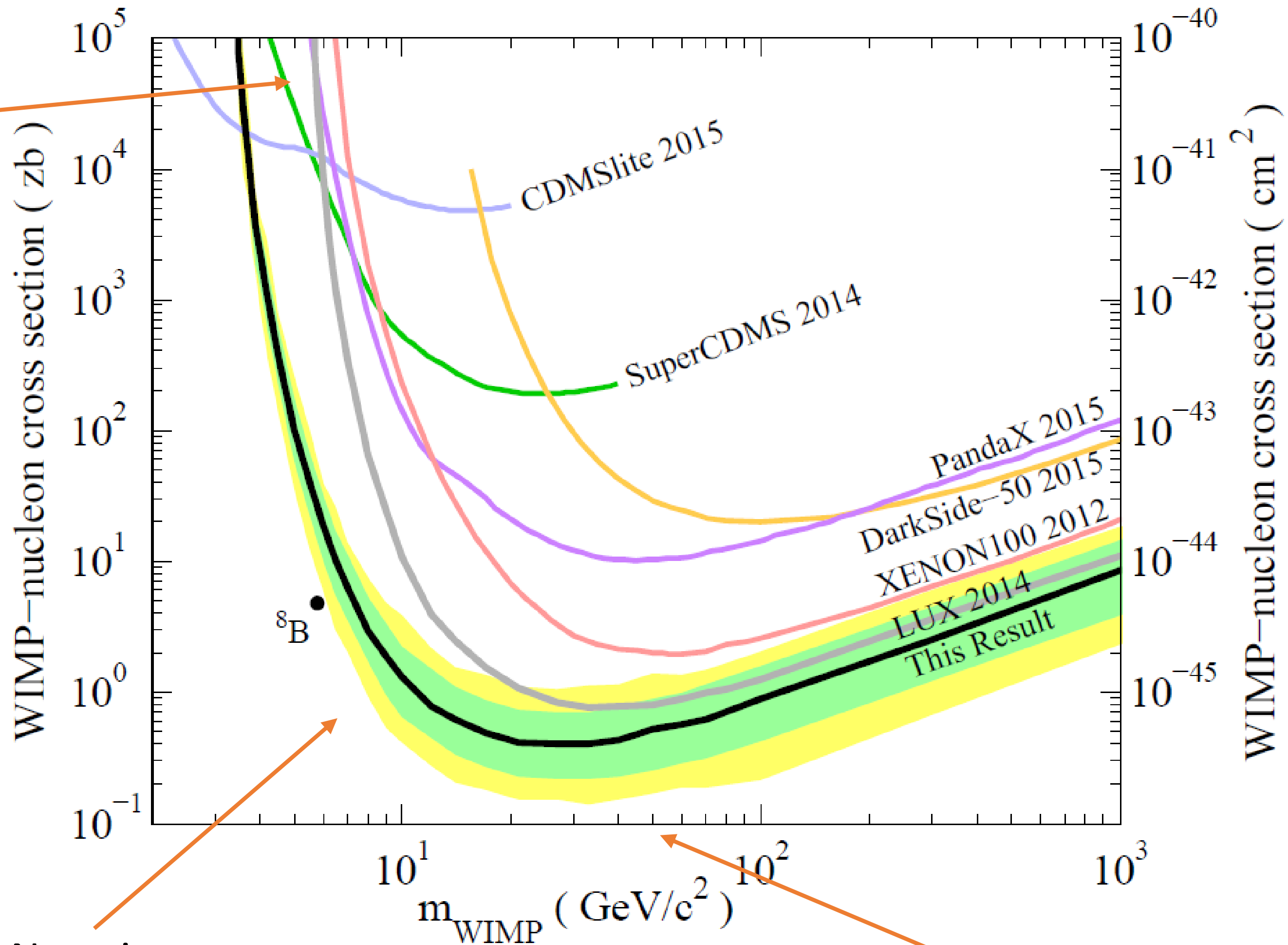
Maximum Likelihood Fit

- 95 Live days * 145 kg of Exposure
- Observed 591 Events
- Background Model Predicted: 589 Events
- Signal Model of various masses are included into the fit with Lindhard k and g2 allowed to float
- cross-section for all masses fit to < 1e-4 zb

Parameter	Constraint	Fit value
Lindhard k	0.174 ± 0.006	-
S2 gain ratio: $g_{2,\mathrm{DD}}/g_{2,\mathrm{WS}}$	0.94 ± 0.04	-
Low-z-origin γ counts: $\mu_{\gamma,\mathrm{bottom}}$	172 ± 74	165 ± 16
Other γ counts: $\mu_{\gamma,\mathrm{rest}}$	247 ± 106	228 ± 19
β counts: μ_{β}	55 ± 22	84 ± 15
^{127}Xe counts: $\mu_{\mathrm{Xe\text{-}127}}$	91 ± 27	78 ± 12
^{37}Ar counts: $\mu_{\mathrm{Ar\text{-}37}}$	-	12 ± 8
Wall counts: μ_{wall}	24 ± 7	22 ± 4

New Exclusion Limits

Improved Low Mass Threshold lowered to 1.1keV



Boron-8 Solar Neutrino. Currently contributes to 0.1 Evt to our Bkg

33 GeV σ = 4 x 10^{-46} cm^2

Increased exposure of 40% and better background / signal models

LUX Run4 Data

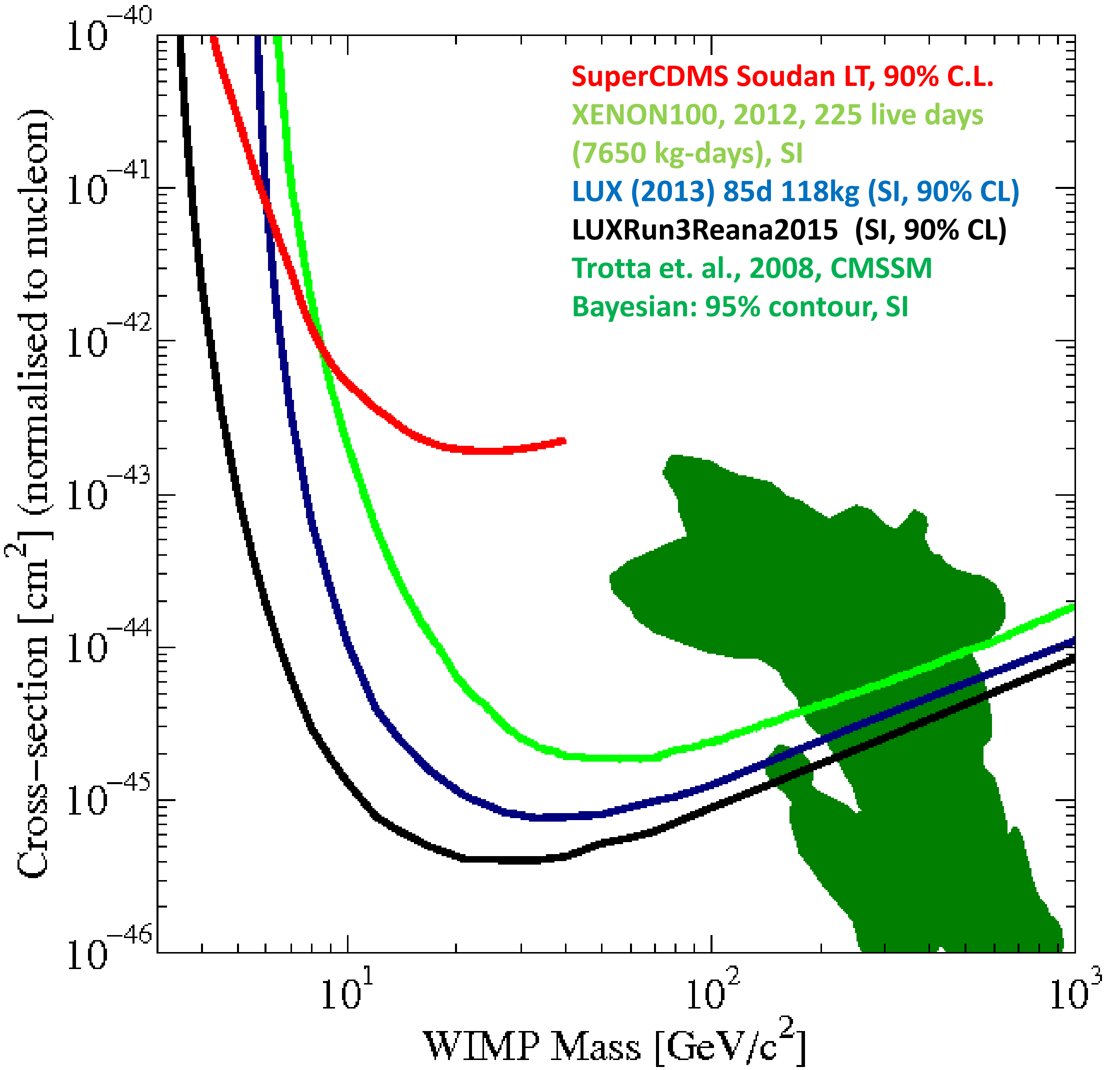
- LUX is currently taking data until the end of 2016
- Additional 300+ live-days of data
- Increase exposure by a factor of 4
- Preliminary estimate approximately factor of 2 improvement in WIMP sensitivity
- Improved Modeling of the E-field in LUX
- Better background models with full 3D information (ϕ)
- Improve treatments of nuisance parameters in order to allow variation at low masses
  - Large number of events needs to be generated currently
  - Avoid this by parameterizing s1 and s2

Conclusion

- Reanalysis of LUX first 90 live-days of data improved the sensitivity by factor of 2 at 33 GeV
- Pushed lowest mass limits from 6 GeV to 3.4 GeV
- Improvement s from PMT Pulses to Final Limits calculation were implemented
- Additional calibration sources allowed us to use data drive methods for background and signal modeling
- Work is meant to be carried over to 300+90 live-days of data being collected until end of 2016
- PRD with analysis detail coming soon.
- SD and Axion limits are also coming out

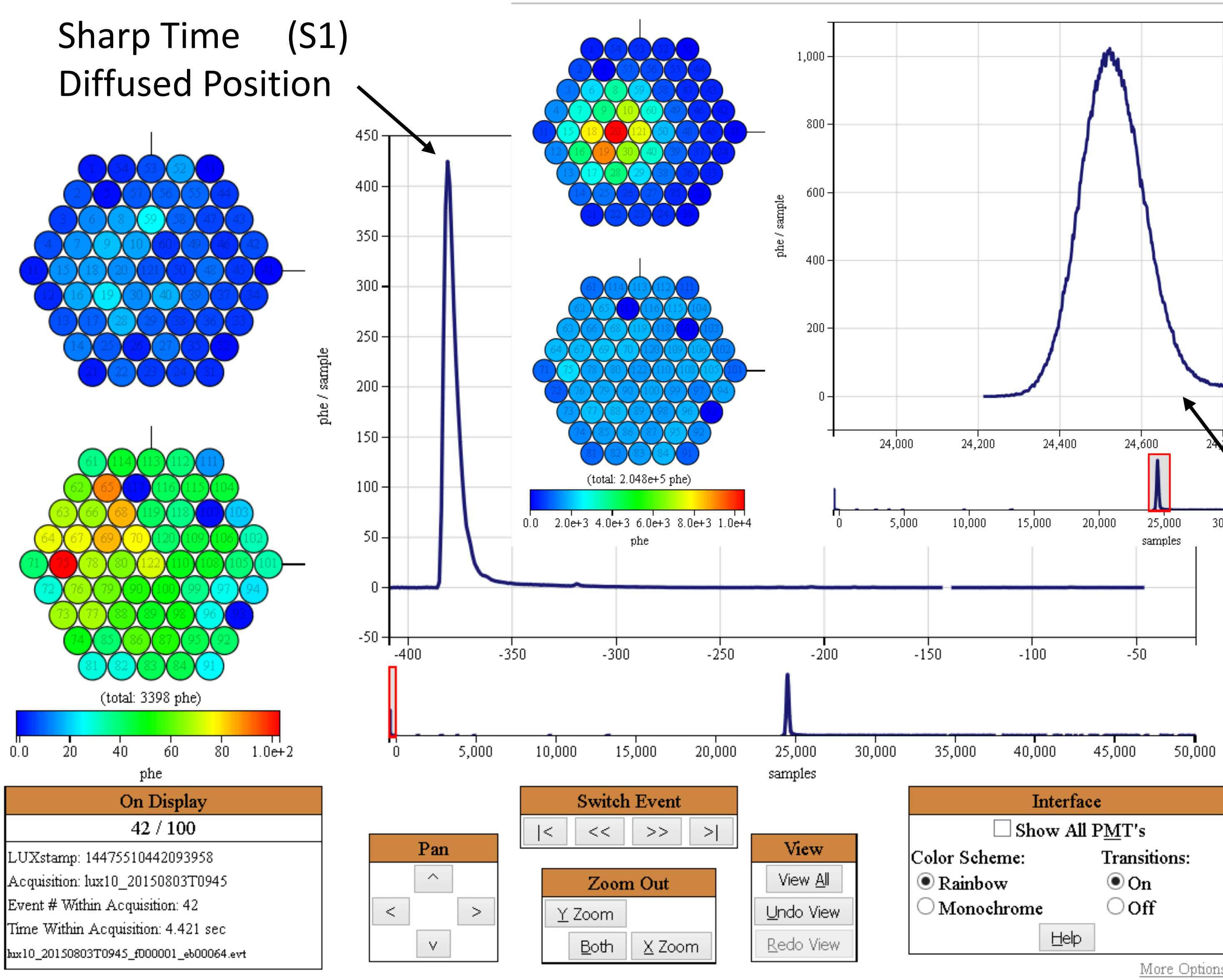
Back Up Slides (BUS)

Exclusion of CMSSM



VisuaLUX Event Display

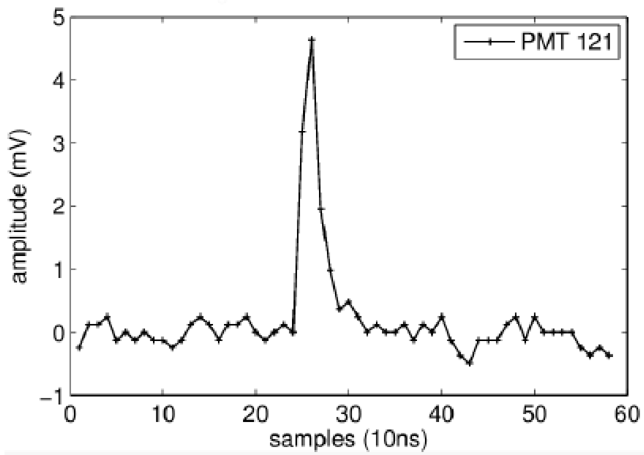
Sharp Time (S1)
Diffused Position



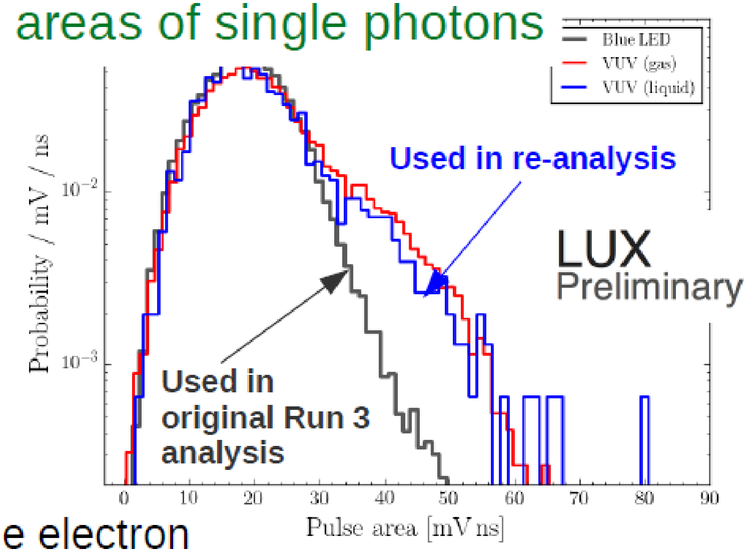
Diffused Time ~ 4 us
Sharp Position (S2)

More On VUV Photons

Single Photo-electron



Distribution of pulse areas of single photons

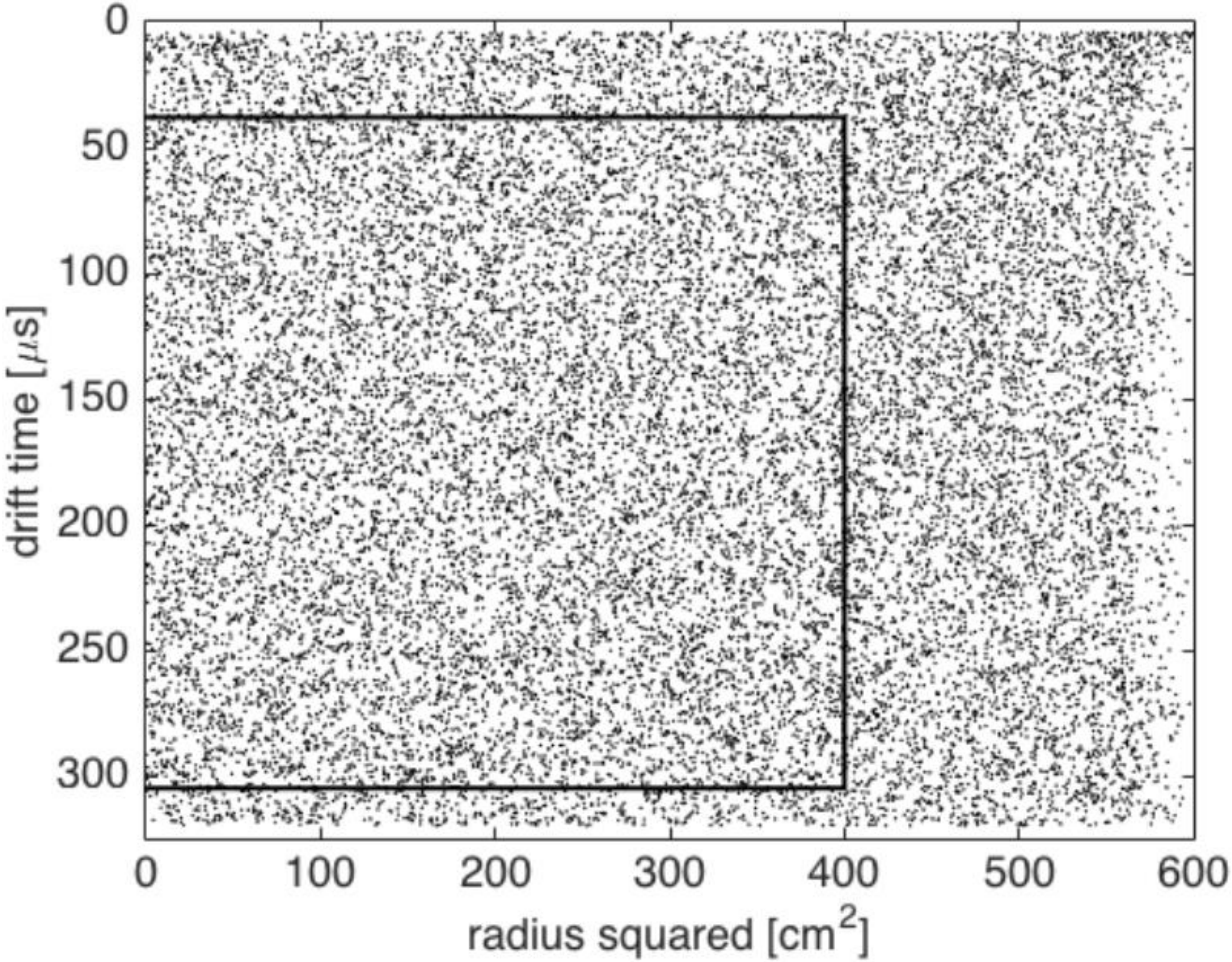


- Photon → PMT photocathode → single electron

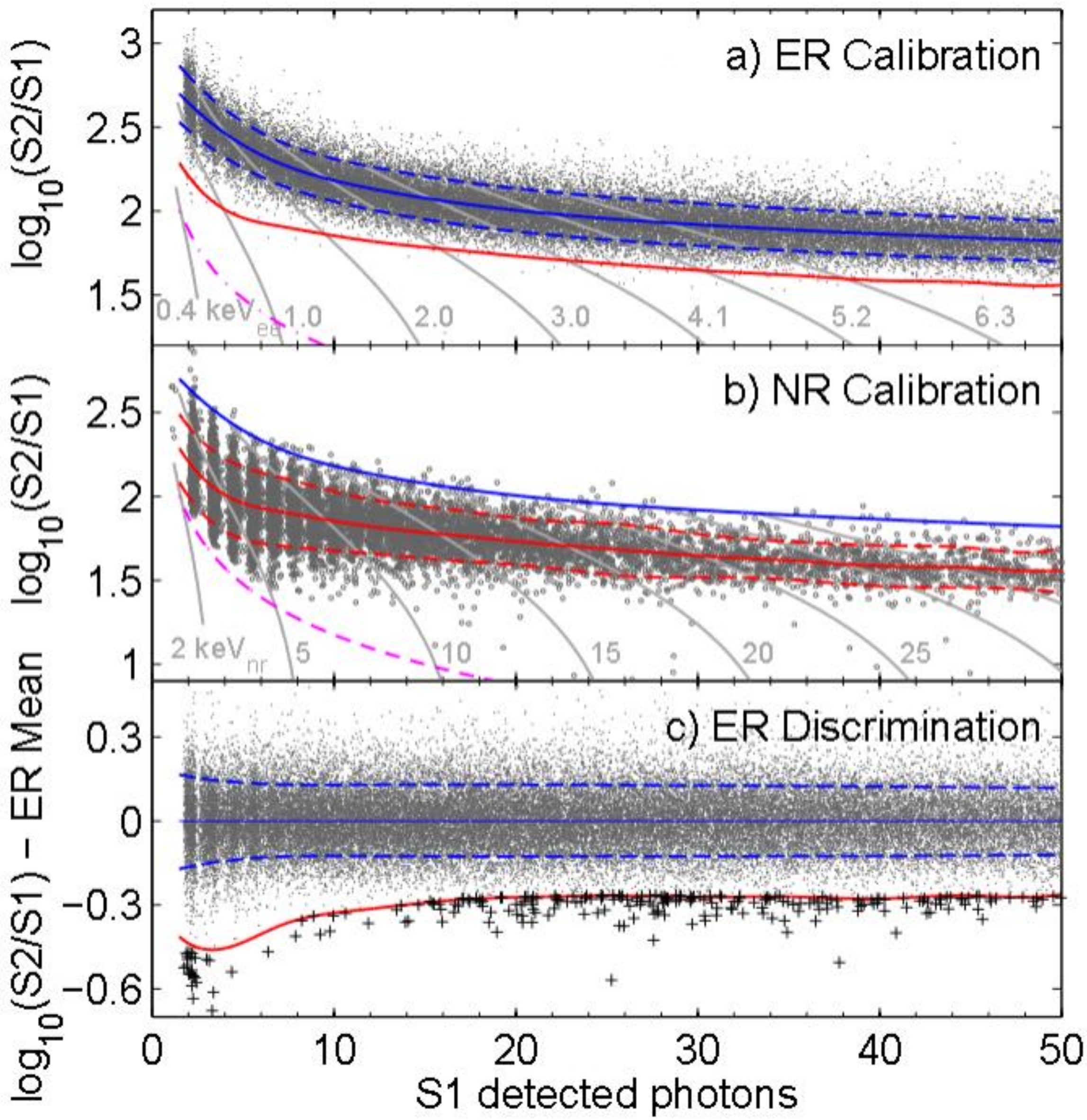
  Except...
  - Xe scintillation: 175 nm (7.1 eV). Callibration LEDs: 470 nm (2.6 eV)
- Two photo-electrons about 20% of the time in Xe
  - phe (photoelectrons) → phd (detected photons)

Tritium BUS

Spatial Uniformity

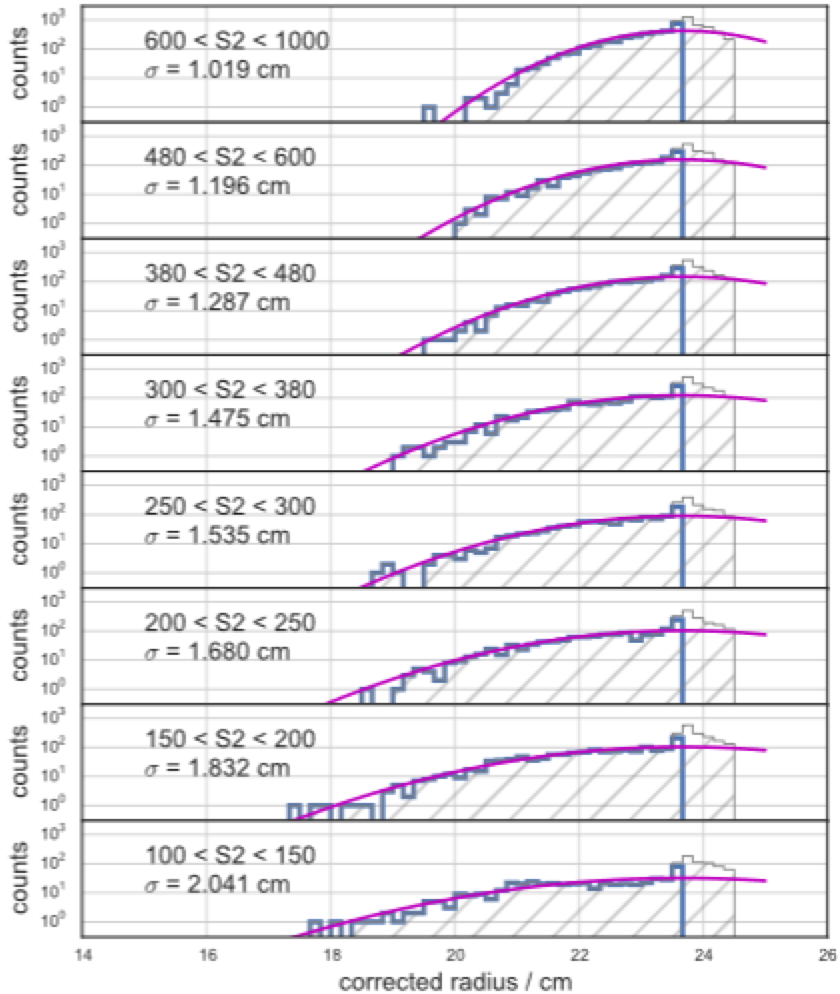


Discriminator ER/NR

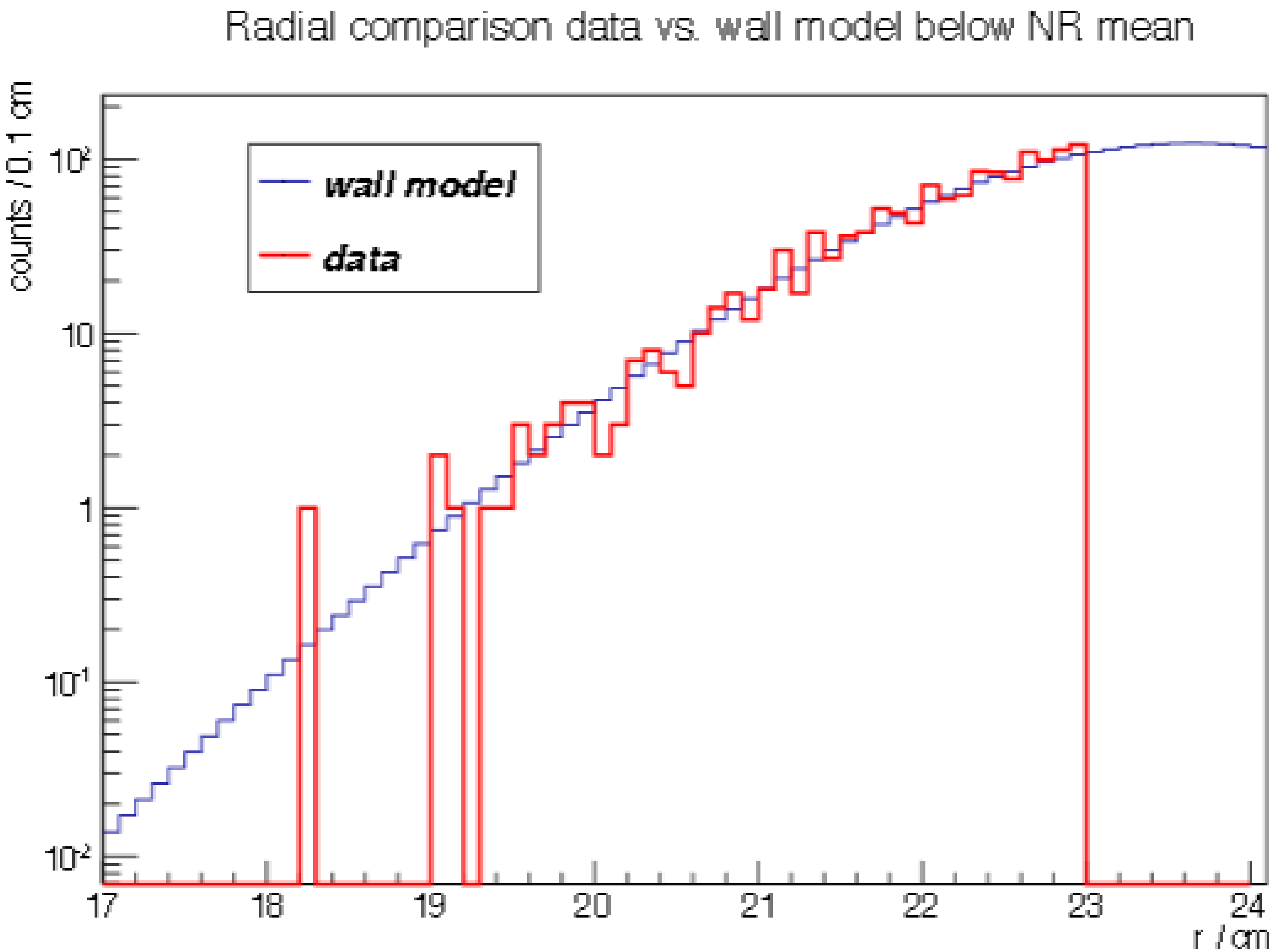


Wall BUS

- Radial parametrization of the corrected Mercury radius vs. S2 size

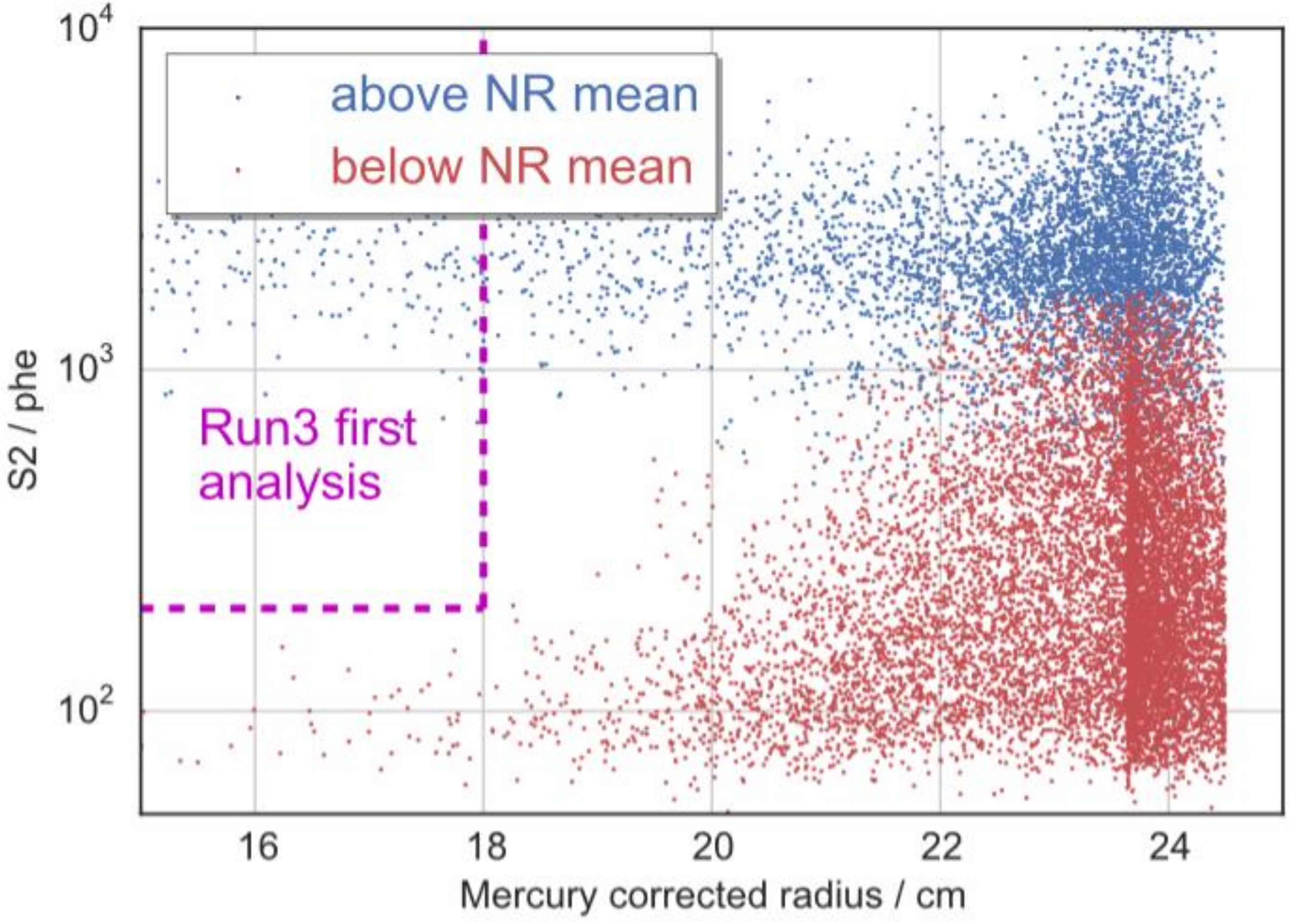


Wall BUS



Radial comparison data vs. wall model below NR mean
counts / 0.1 cm
wall model
data
10^2
10
1
10^{-1}
10^{-2}
17
18
19
20
21
22
23
24
r / cm

Wall BUS



above NR mean
below NR mean
Run3 first analysis
S2 / phe
10^4
10^3
10^2
16
18
20
22
24
Mercury corrected radius / cm

Wall BUS

- ^{222}Rn, 3.8 days, alpha decaying to...
- ^{218}Po, 3.10 minutes, alpha decaying to...
- ^{214}Pb, 26.8 minutes, beta decaying to...
- ^{214}Bi, 19.9 minutes, beta decaying to...
- ^{214}Po, 0.1643 ms, alpha decaying to...
- ^{210}Pb, which has a much longer half-life of 22.3 years, beta decaying to...
- ^{210}Bi, 5.013 days, beta decaying to...
- ^{210}Po, 138.376 days, alpha decaying to...
- ^{206}Pb, stable.