The Latest Analyses of the LUX Dark Matter Project

Matthew Szydagis, *the CIPANP 2018 Conference, May 31, 2018*

v1.6

The LUX collaboration

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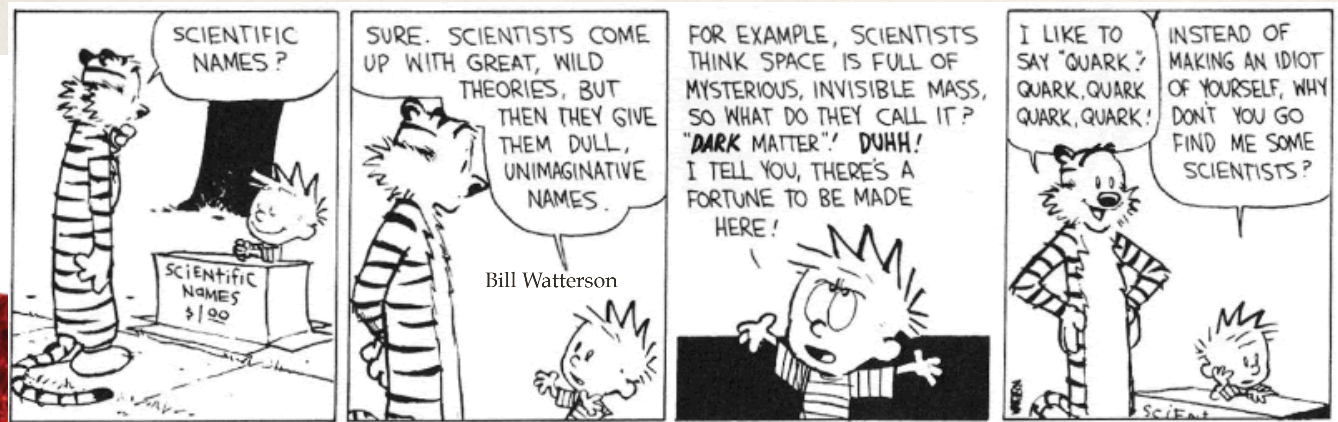
David Woodward	Research Associate
Peter Rossiter	Graduate Student

University of South Dakota

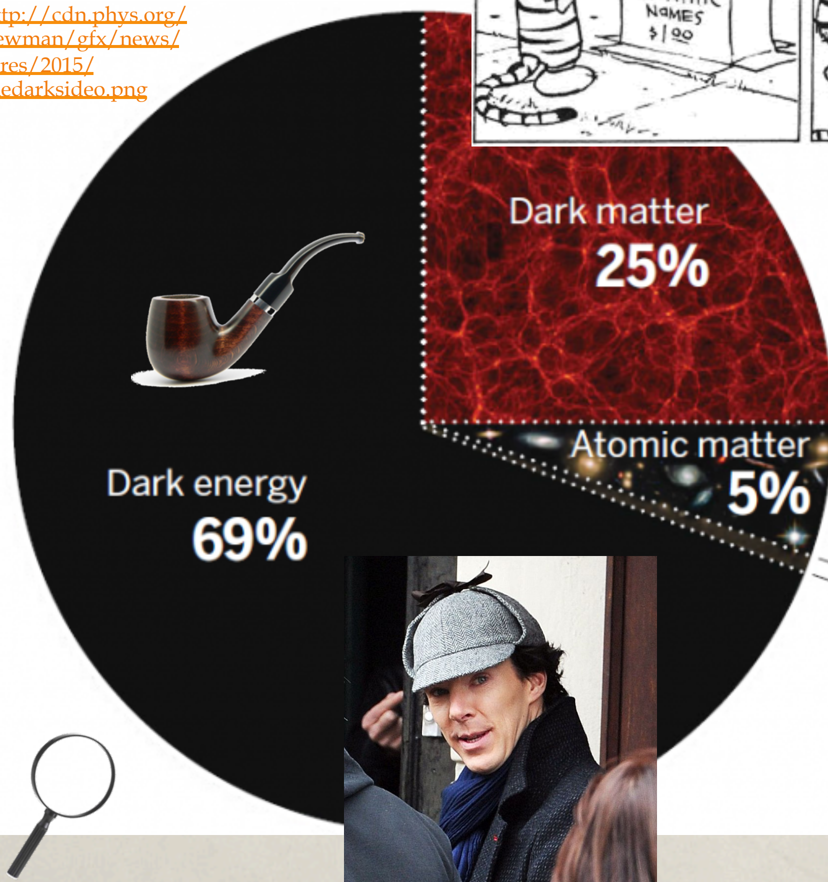
Dongming Mei	PI, Professor

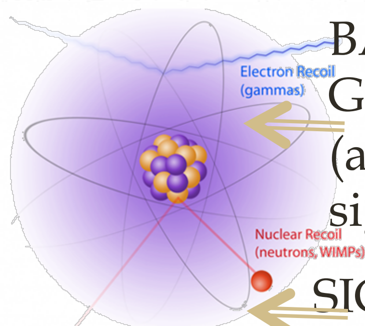
A Big Hole in Our Knowledge



What is this **dark matter?**

http://cdn.phys.org/newman/gfx/news/hires/2015/thedarksideo.png

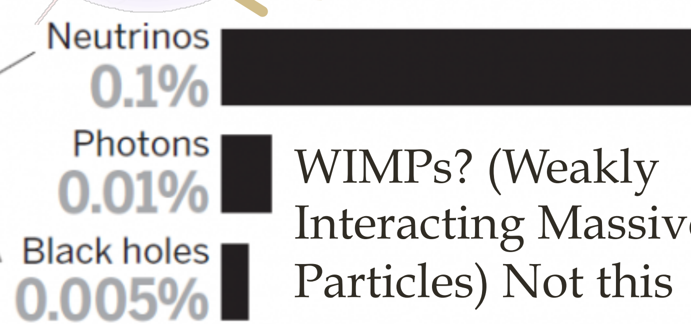




BACK-GROUND (also signal?)

SIGNAL?

Above credit: X-ray: NASA/CXC/CfA/ M. Markevitch et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U. Arizona/ D. Clowe et al.; Optical image: NASA / STScI; Magellan / U. Arizona / D. Clowe et al.; Right: NASA/ ESA/ M. Bradac et al.



except maybe primordial??

WIMPs? (Weakly Interacting Massive Particles) Not this

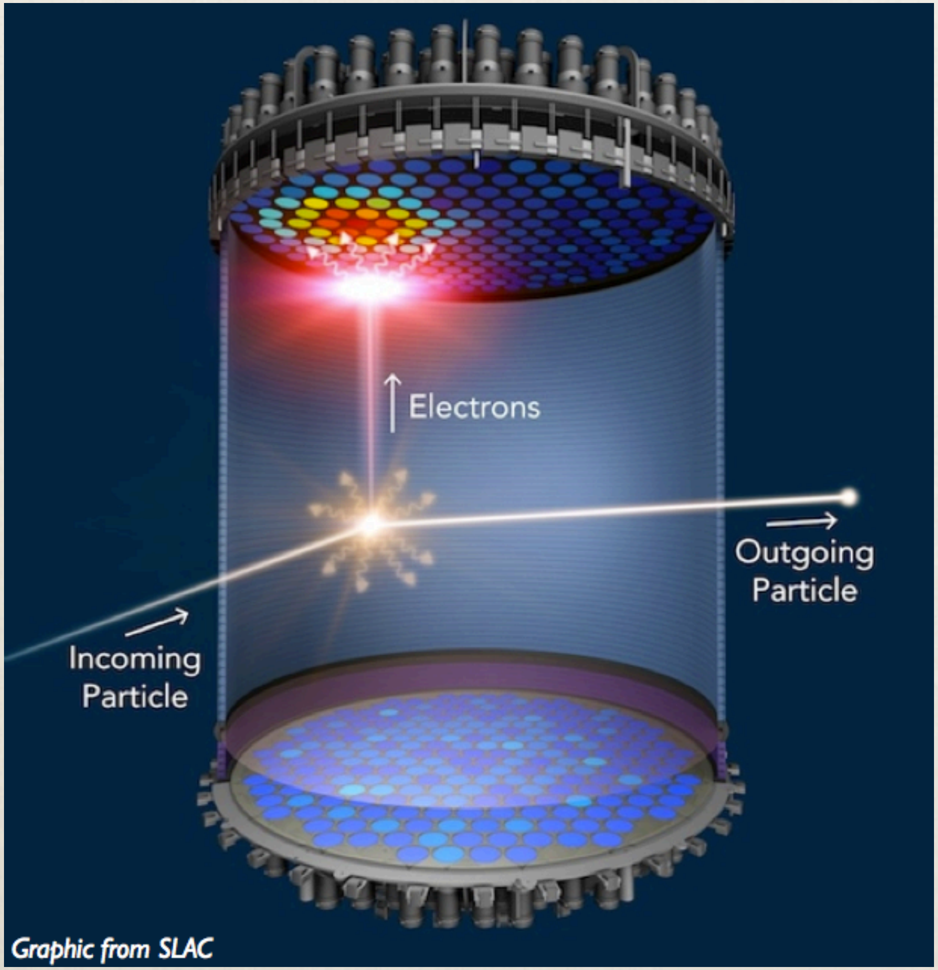
Large Underground Xenon

* 2-phase xenon detector deployed (was recently decommissioned) underground at Homestake with 122 photo-tubes
* Why element Xe?
    * Dense (good self-shielding)
    * Gets excited and scintillates, and can get ionized easily
* Why deep underground?
    * Cosmic rays -> bad
* Properties and statistics
    * ~100-150 kg fiducial mass
    * 95 and 332 live-day runs

LUX

photos by Jack Genovesi, UAlbany

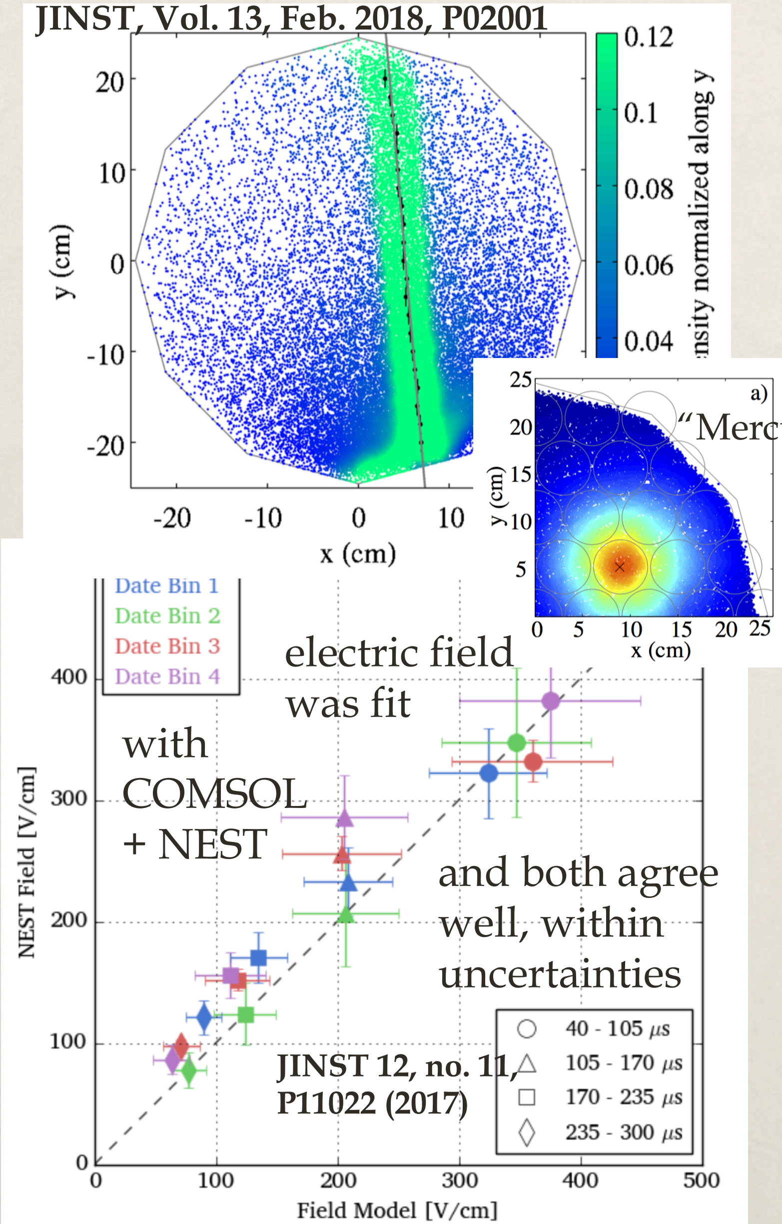
How It Functions



S2/S1 ratio gives particle ID, and S2-S1 drift time gives depth. Detector was 50 x 50 cm dia. x depth

- Two scintillation pulses, S1 and S2 (vacuum-UV)
  - S1 in liquid + S2 in gas
  - S1 O(10-100) ns-wide exponential, S2 O(1 microsec.) Gaussian
  - S1 is direct photon counting, but S2 secondary photons from ionization e^{-}'s
- Why 2 (forms of light)?
  - Better position and energy reconstruction
  - Particle identification
  - Reuse the same PMTs

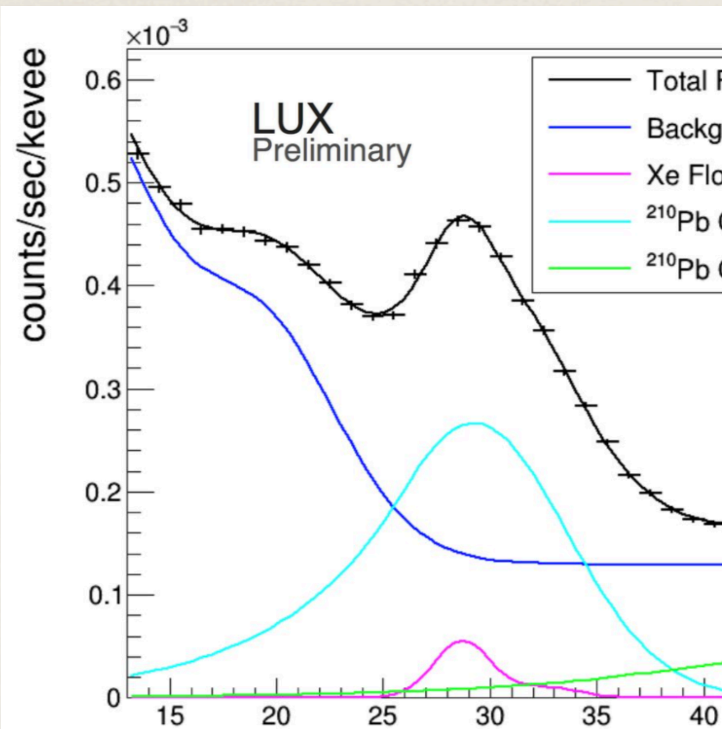
Position and Field Recon



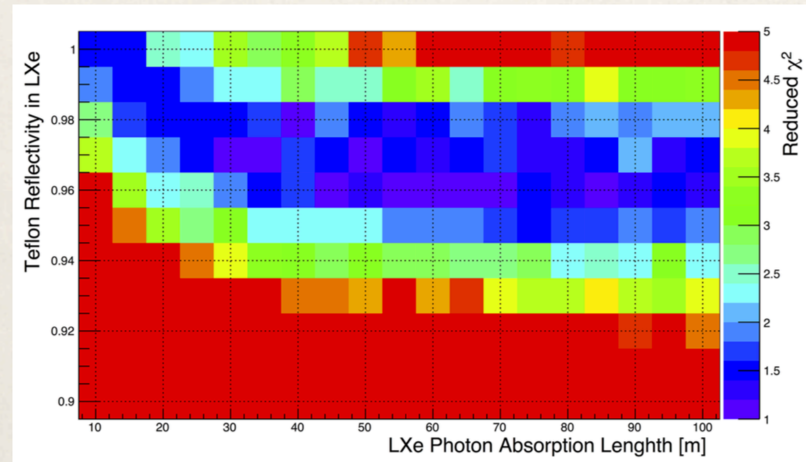
- Even a single drift electron from an ionization is visible using the S2!
- X-Y position is reconstructed at 2-20 mm accuracy using top PMTs
  - Depends on S2 size, and on radius
- Possible to reconstruct positions of neutron elastic scatters from D-D gun, and isotropic internal sources
- Significant field non-uniformity during second WIMP search run
  - Electrons were pulled inward
- Field inhomogeneity was corrected for in final analysis, worked well

Models: Backgrounds, Optical

Adding new BGs to model, going out to higher energies than ever before (e.g for EFT analyses)



keVee



arXiv:1712.05696 (in press at PRD)

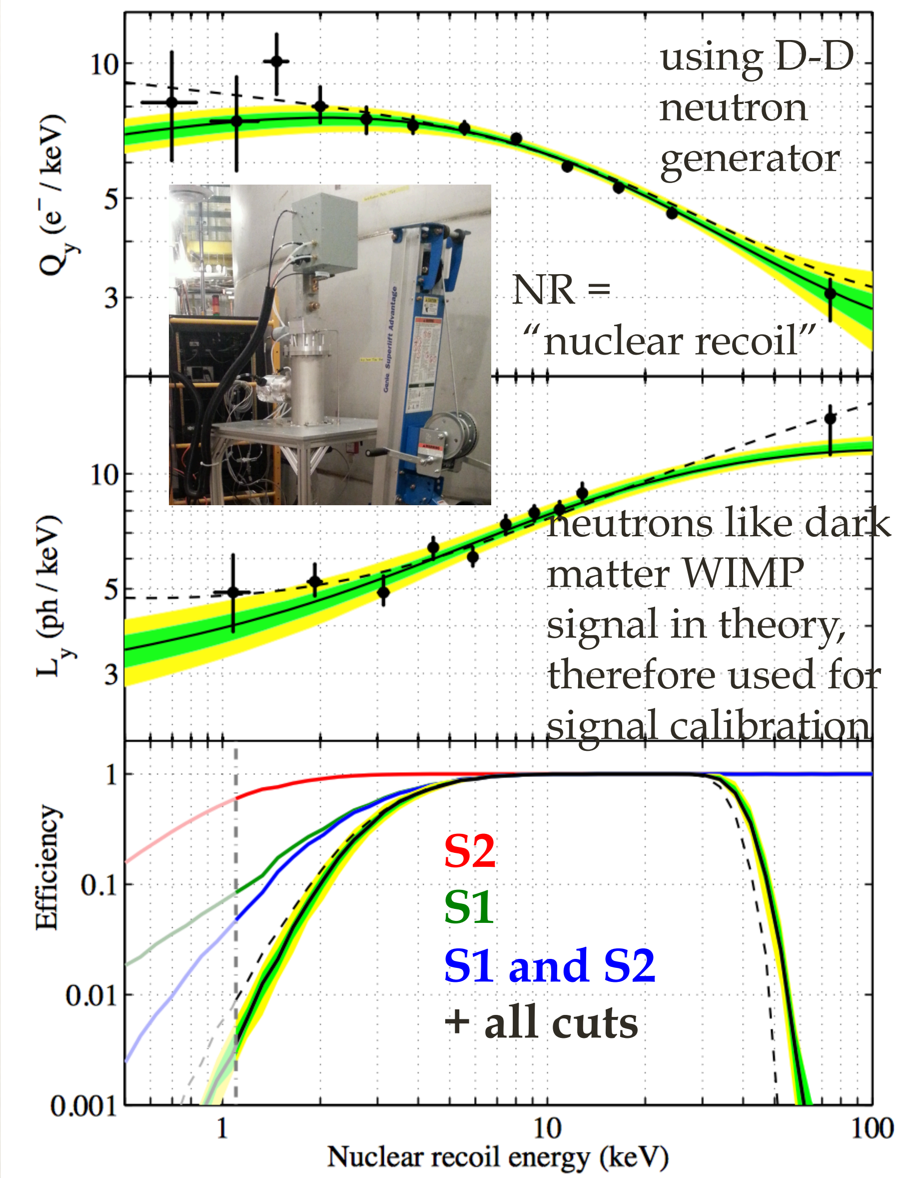
Quantity	Liquid	Gas
PTFE diffuse reflectivity (%)	97^{+3}_{-2}	75^{+10}_{-5}
Stainless steel grid reflectivity (%)	5±5	20 ±5
PMT aluminum reflectivity* (%)	100^{+0}_{-10}	100^{+0}_{-10}
Photon absorption (m)	30^{+40}_{-20}	6 ±3
PMT array QE/predicted	1.024	1.000

* The aluminum is in contact with the PMT quartz window.

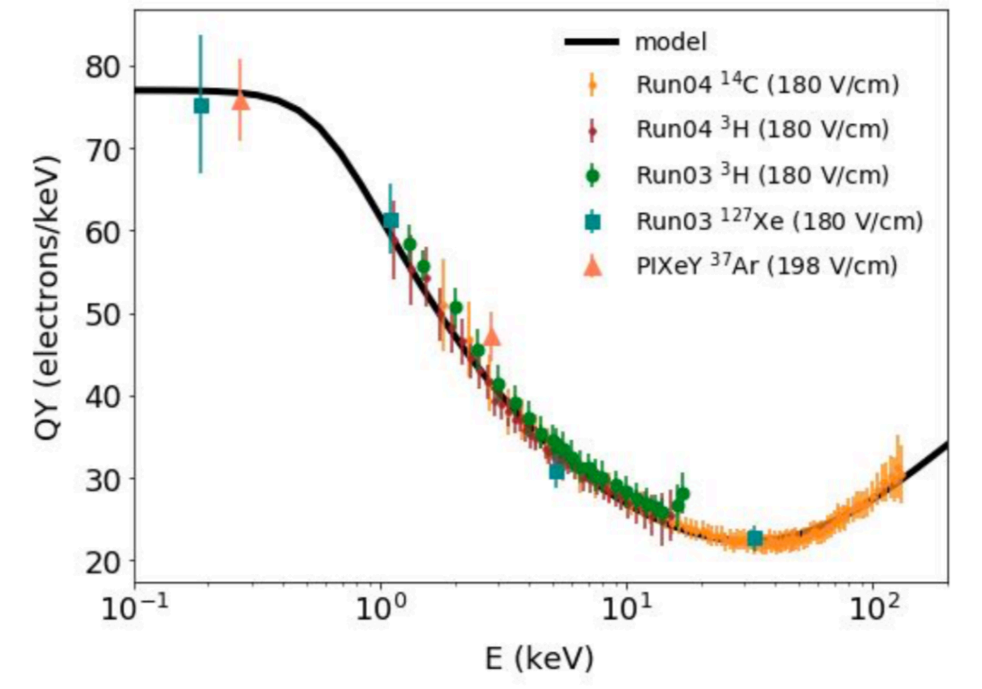
LUX as Calibration Pioneer: NR

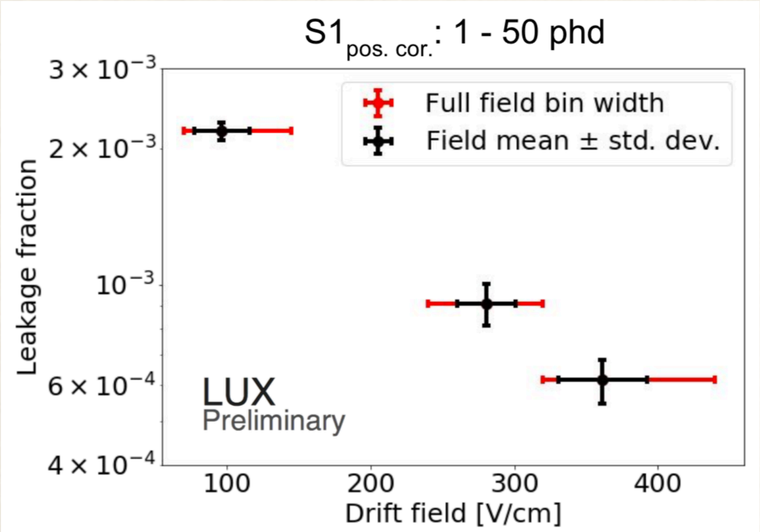
- Lowest absolute calibration of the light yield (180 V/cm) for nuclear recoils in LXe
  - 1.1 keVnr
  - Previous 3 keVnr (from Plante et al., 2011) 0 field
- Lowest absolute, direct calibration of charge yield (180 V/cm)
  - 0.6 keVnr
  - Previous was actually only 4 keVnr! (going back in time to Manzur et al., 2010)
- Air-filled conduit in water shield is n guide, raised into place during data-taking

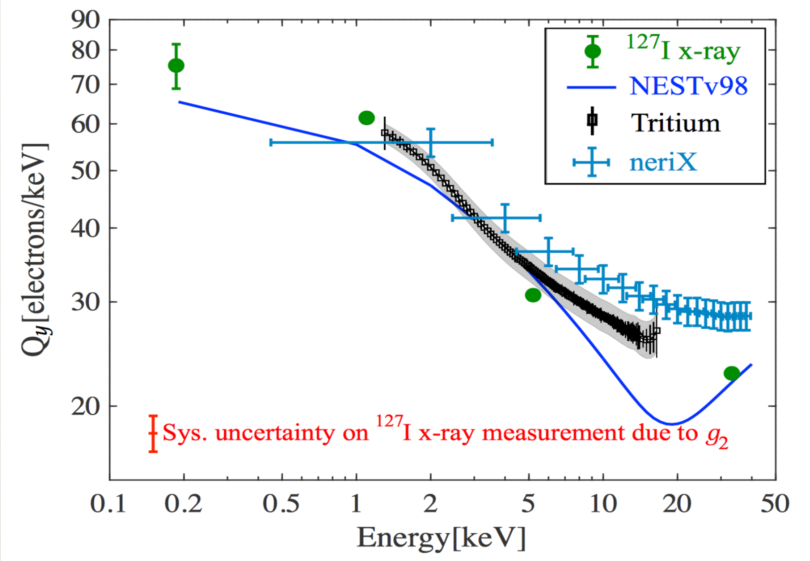
arXiv:1608.05381, submitted to PRC

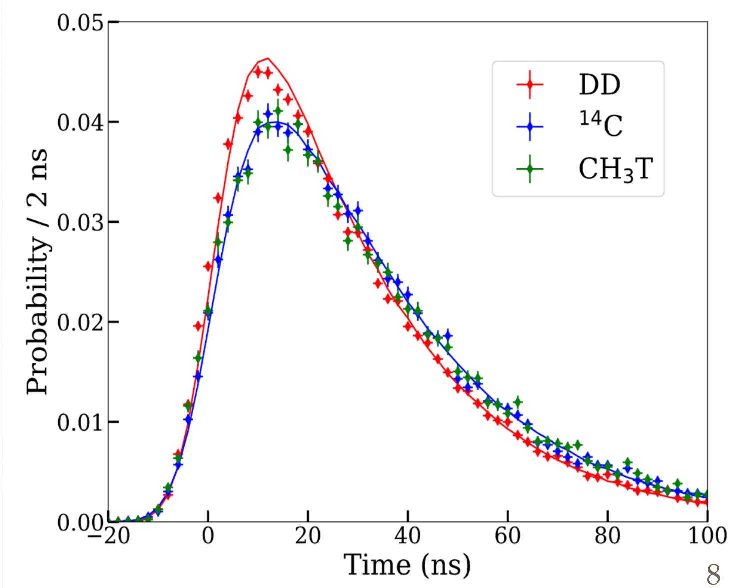


ER for Background: Old & New









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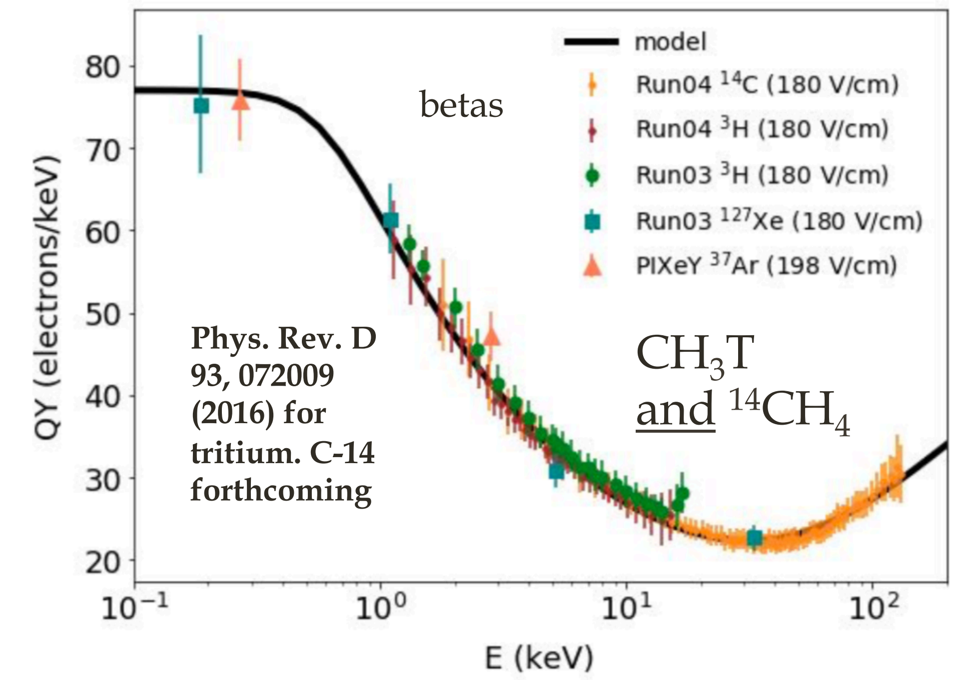

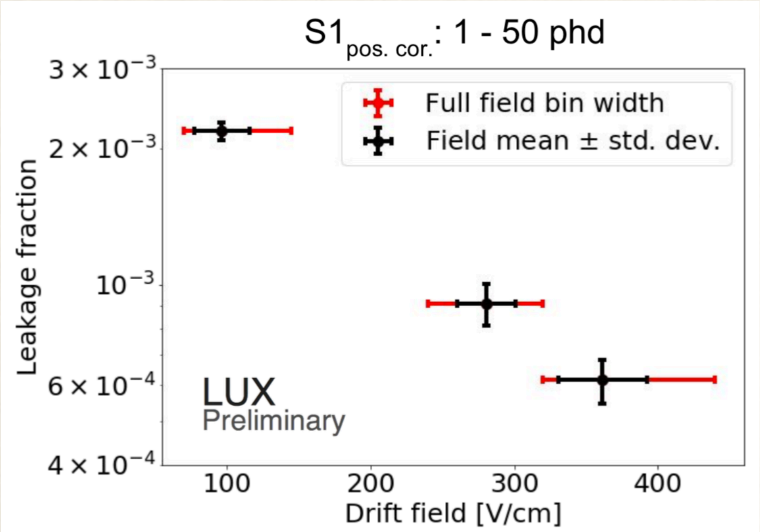

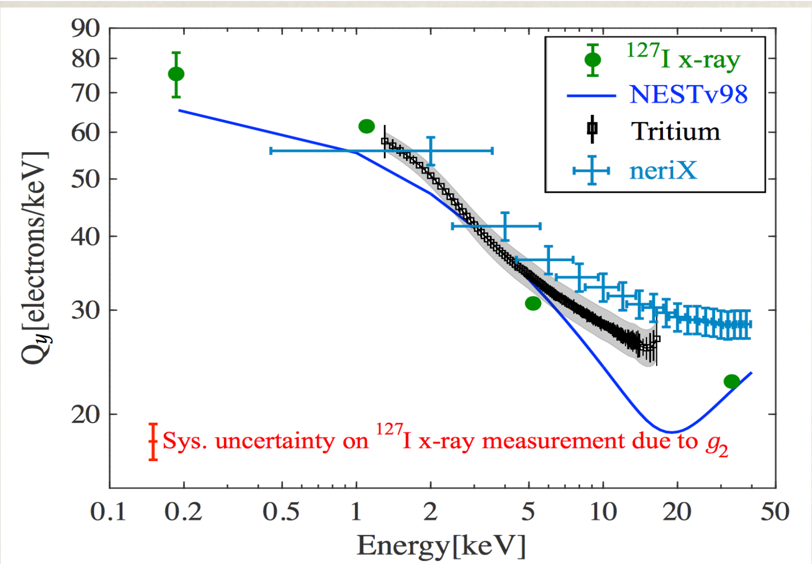

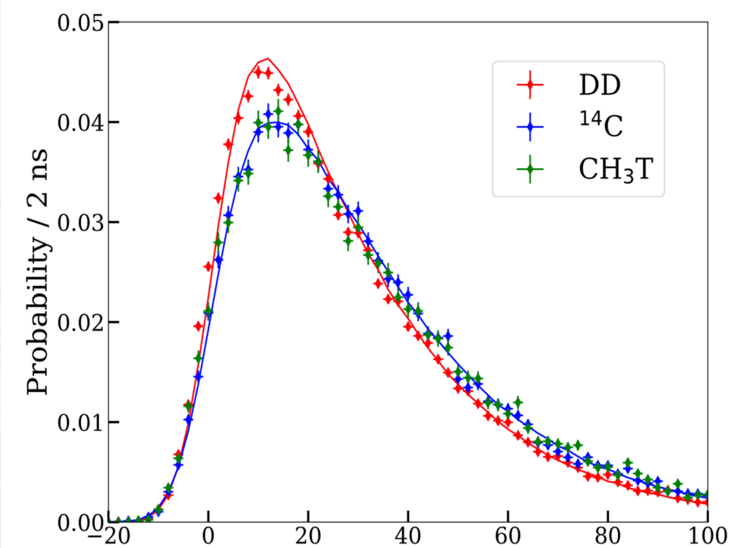

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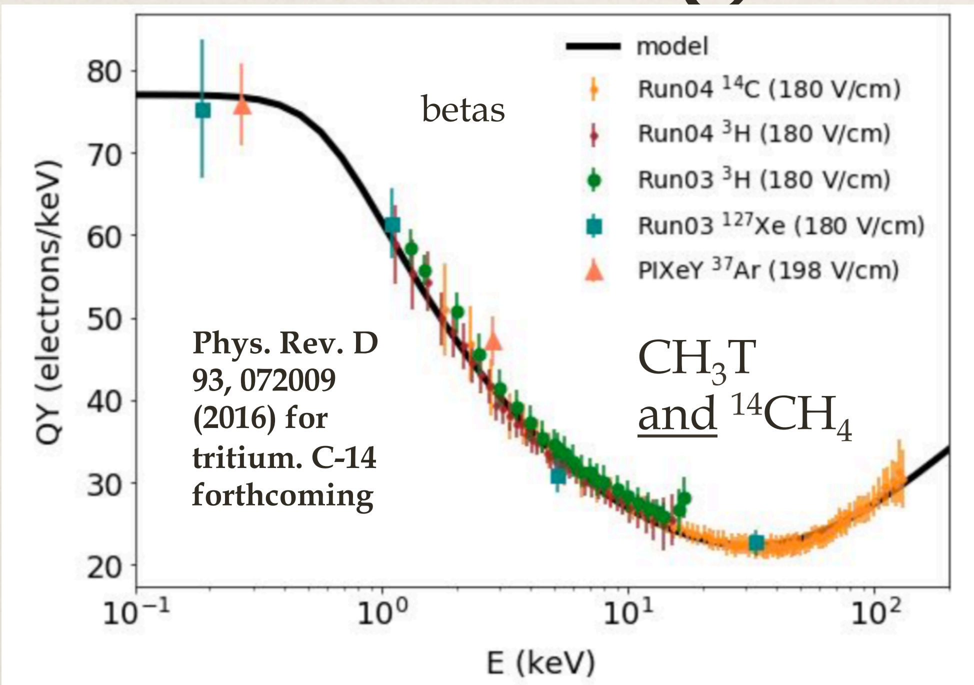
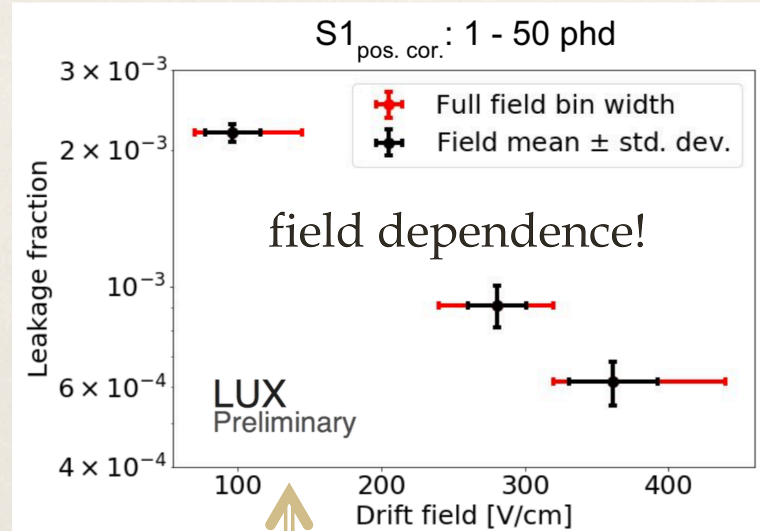
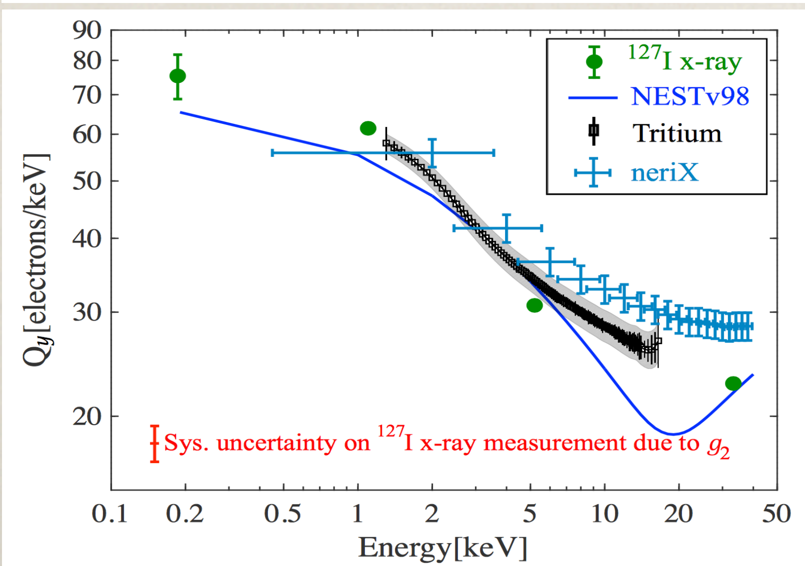
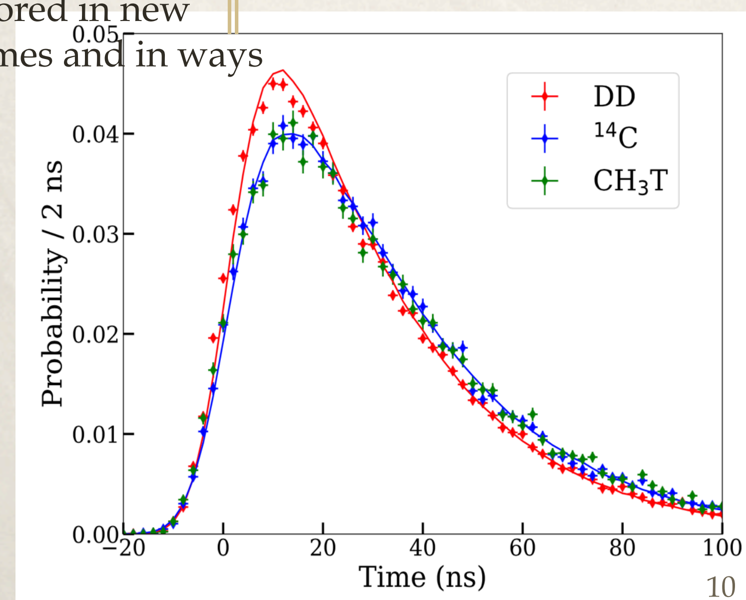


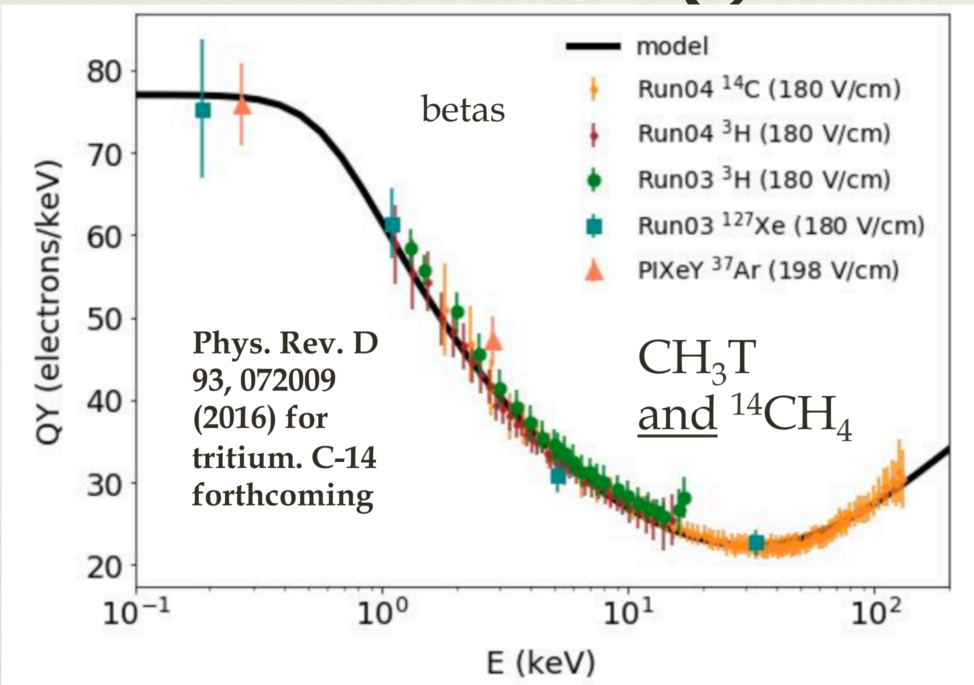


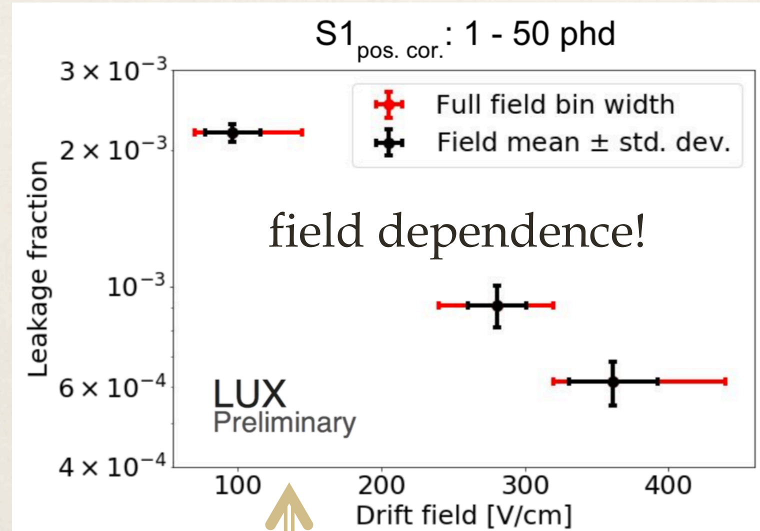
The BG (flat ER) discrimination explored in new regimes and in ways





ER for Background: Old & New





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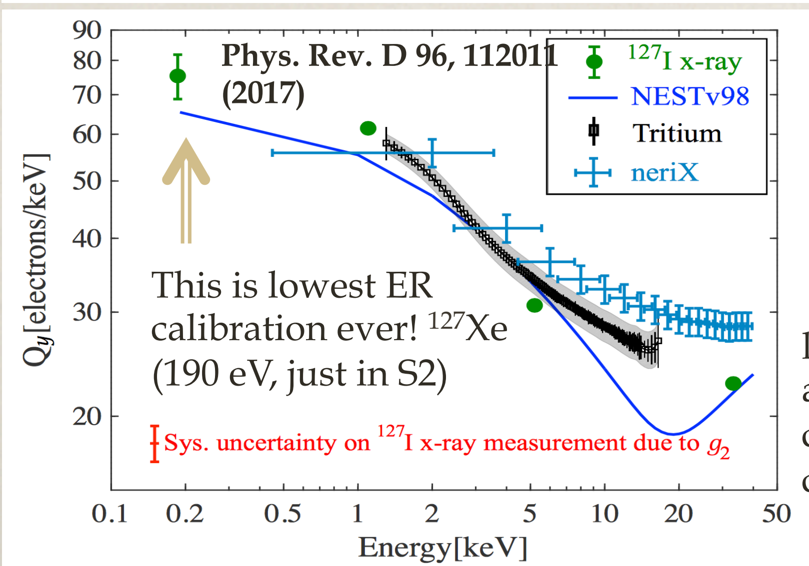
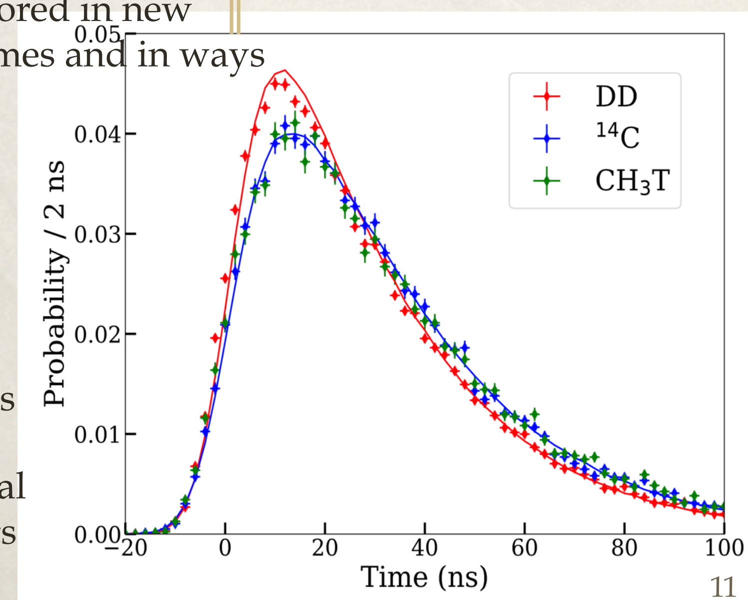
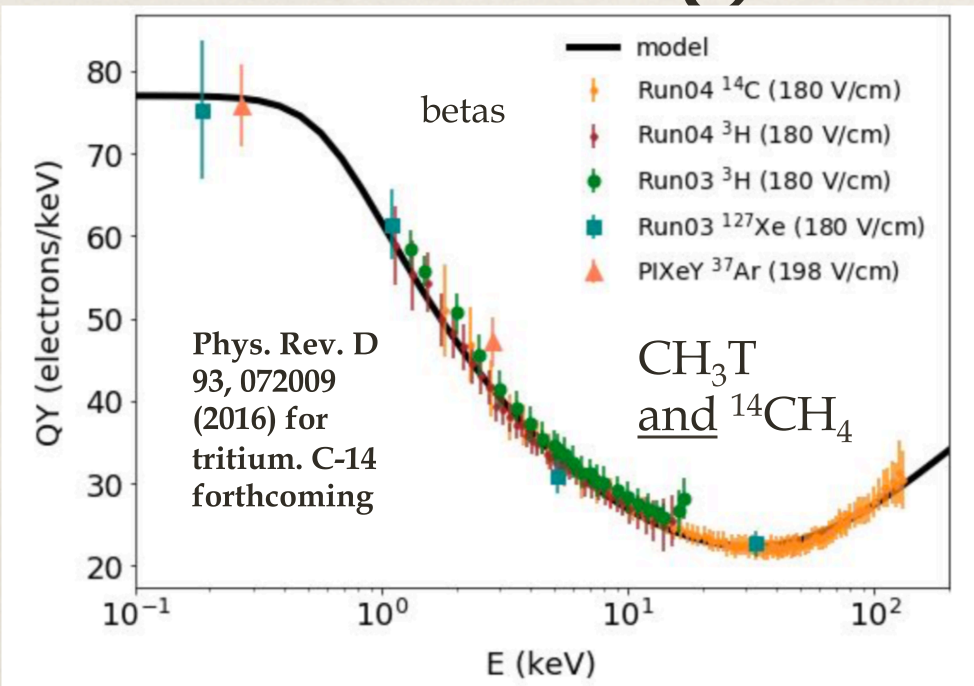
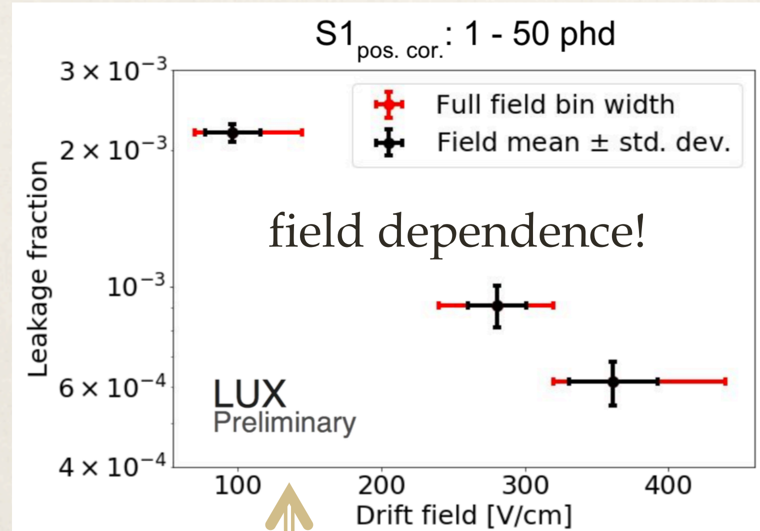


low energy x-rays and electron capture or internal conversion events



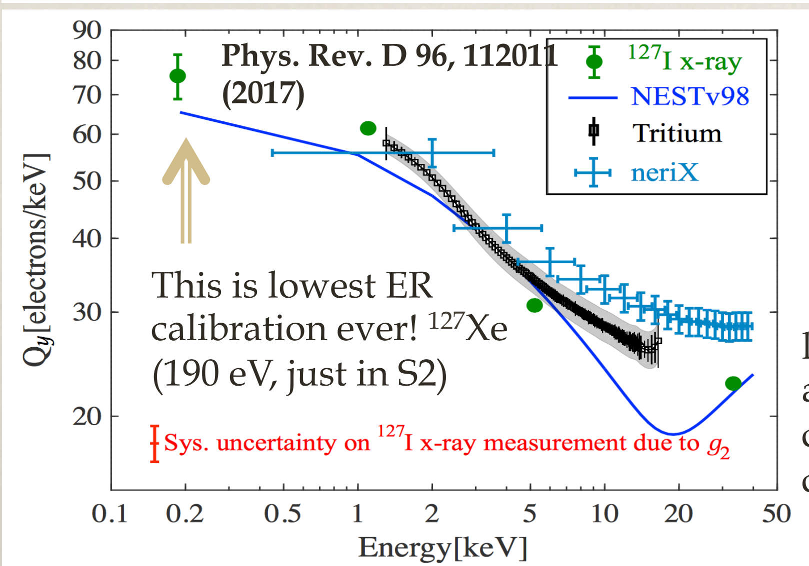
ER for Background: Old & New



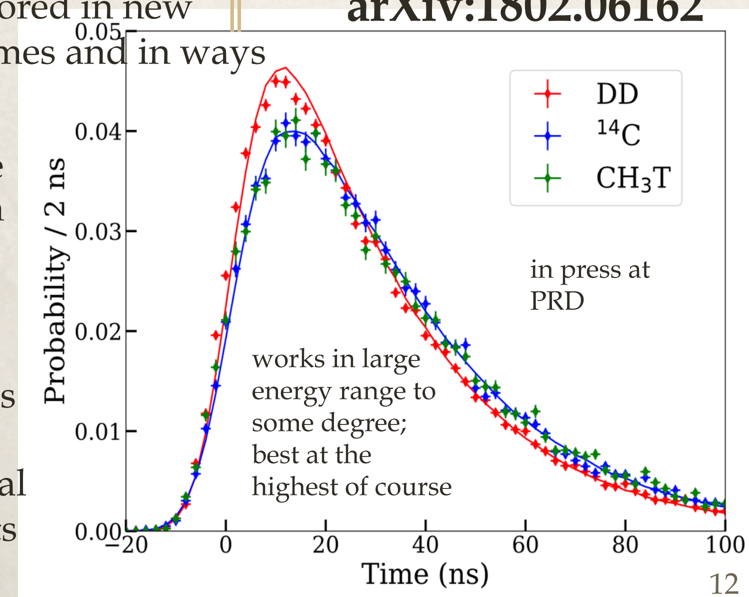


The BG (flat ER) discrimination explored in new regimes and in ways

arXiv:1802.06162



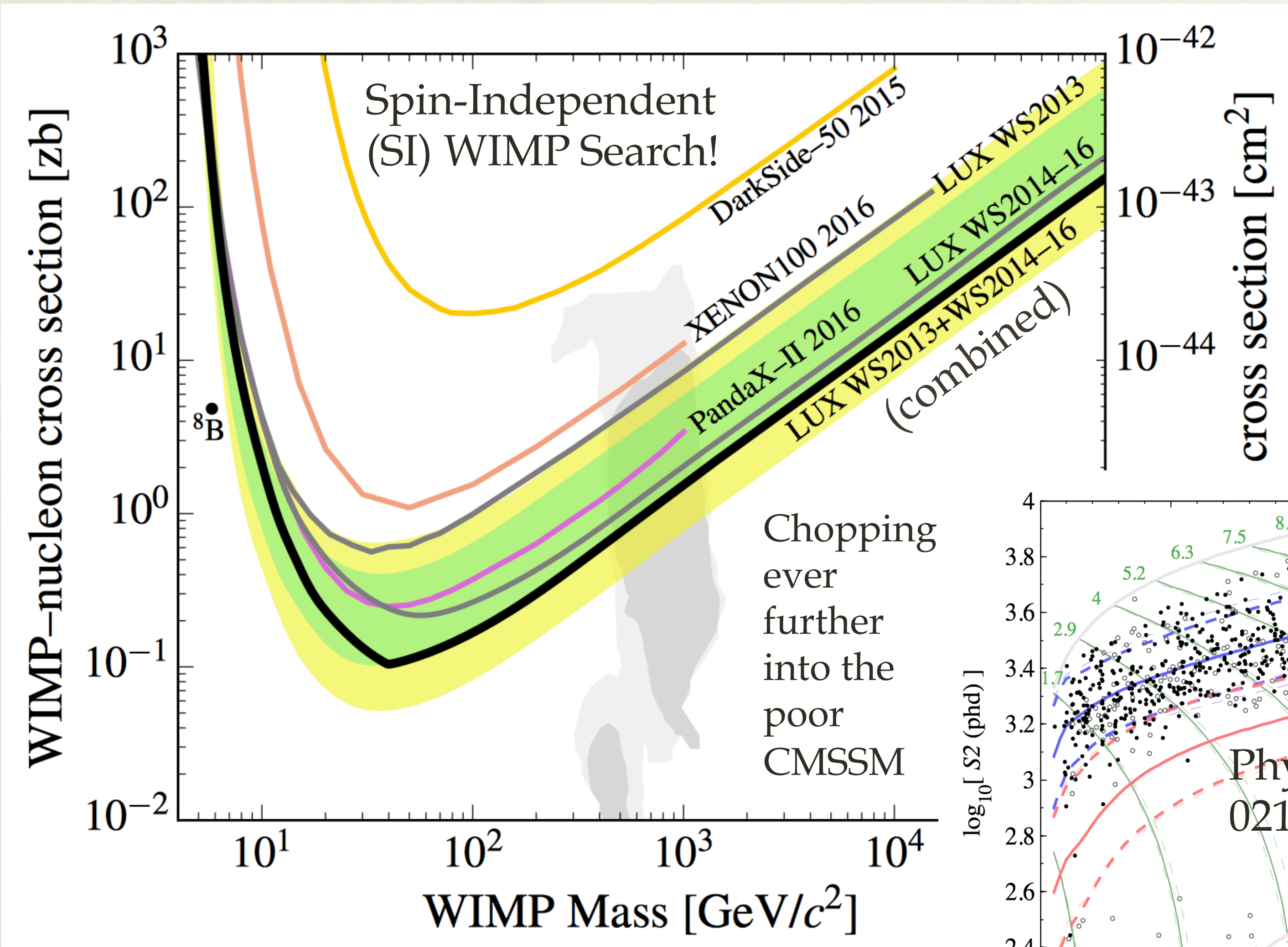
S1 Pulse Shape Discrimination

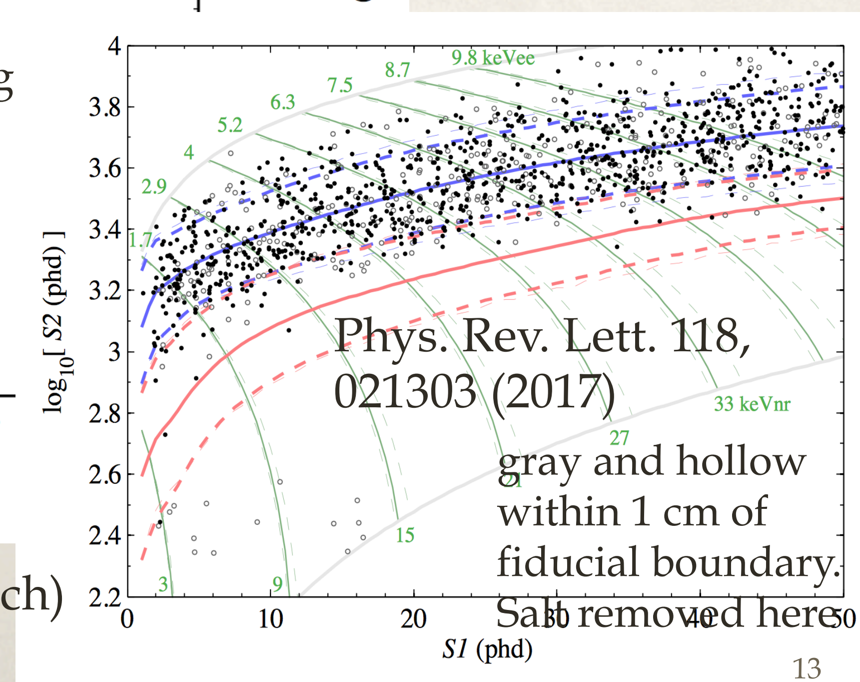


low energy x-rays and electron capture or internal conversion events

Old Headliner Limit

- Within (log) spitting distance of ^{8}B solar ν elastic coherent scattering (LZ coming to get that)
- Since surpassed by PandaX and by XENON1T (latest and greatest, see talk by Kaixuan Ni here)

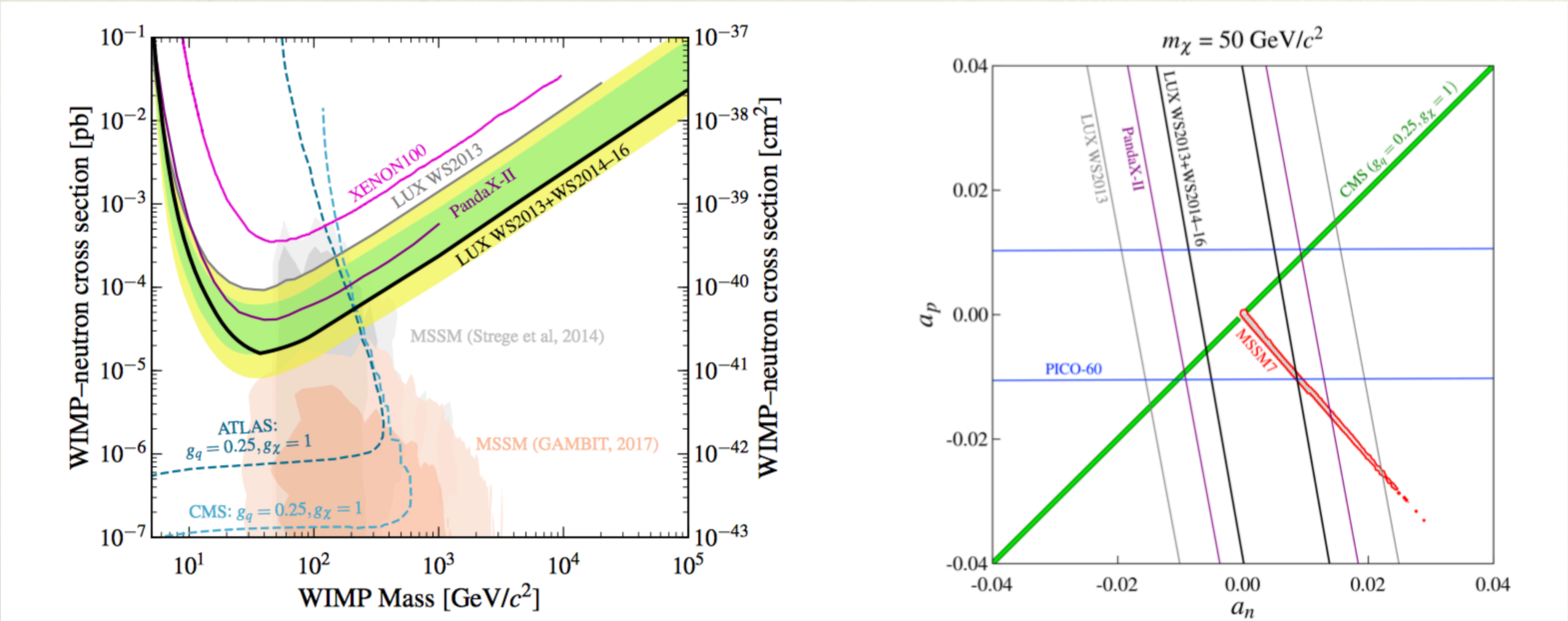




But is that all? NO. SD and axions (2 results each)

Spin-Dependent Exclusions

Phys. Rev. Lett. 118, 251302 (2017)

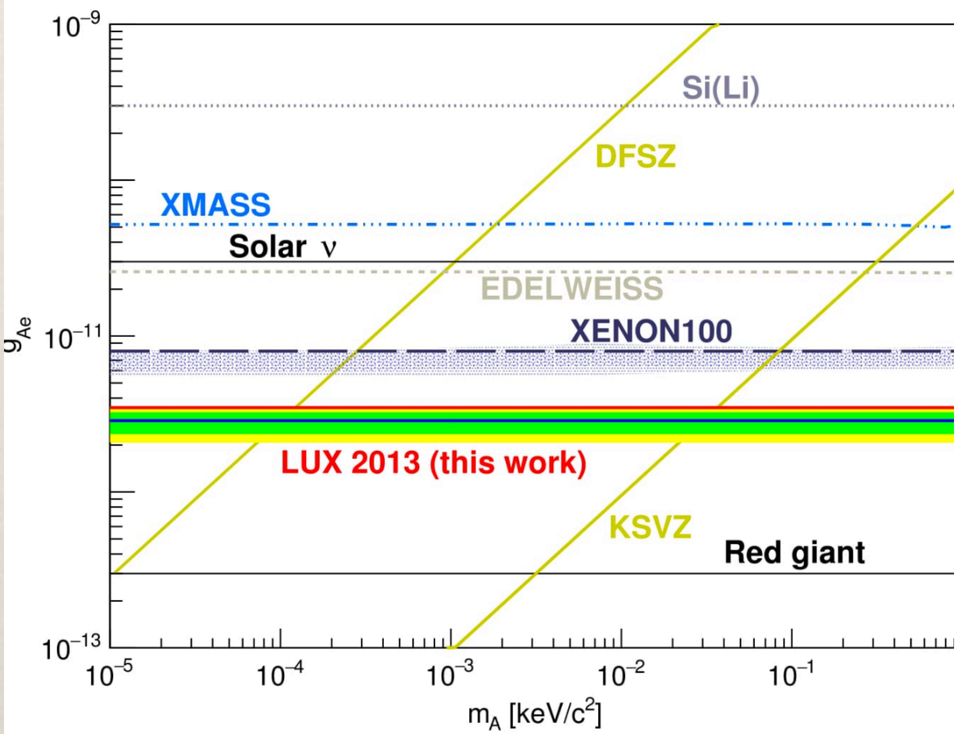


- Left plot is neutron coupling vs. mass, while right is proton interaction strength vs. neutron, at a fixed example mass near the strictest point in the limit curve (50 GeV)
- Xe is even Z, but some isotopes are odd-N, allowing for SD interactions to be probed, especially WIMP-neutron: LHC dark matter limits exceeded at high mass

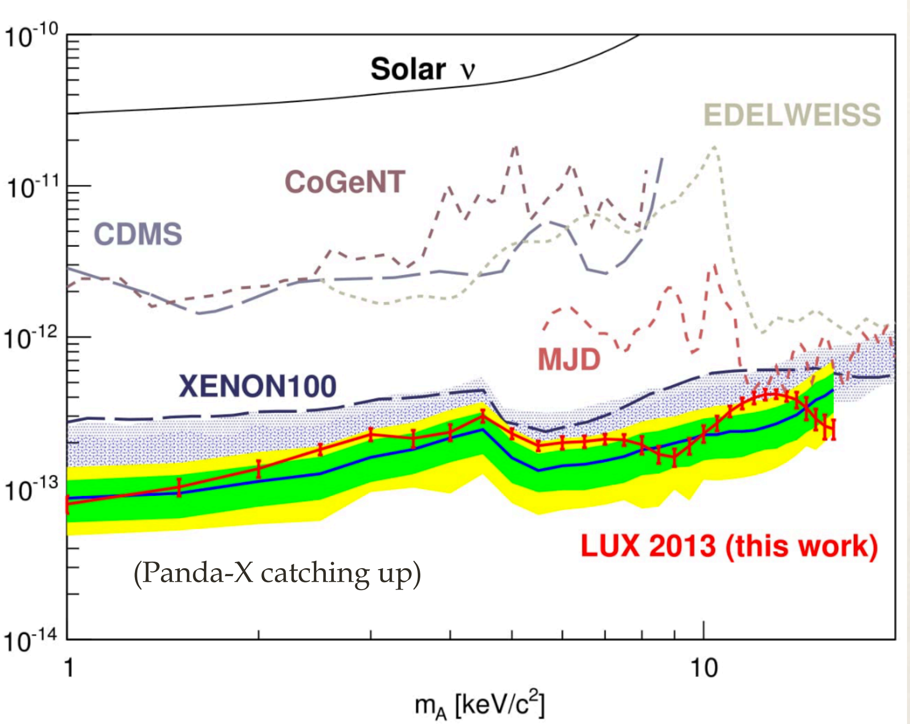
Switching Gears to ER: Axions

Phys. Rev. Lett. 118, 261301 (2017)

Solar Axions



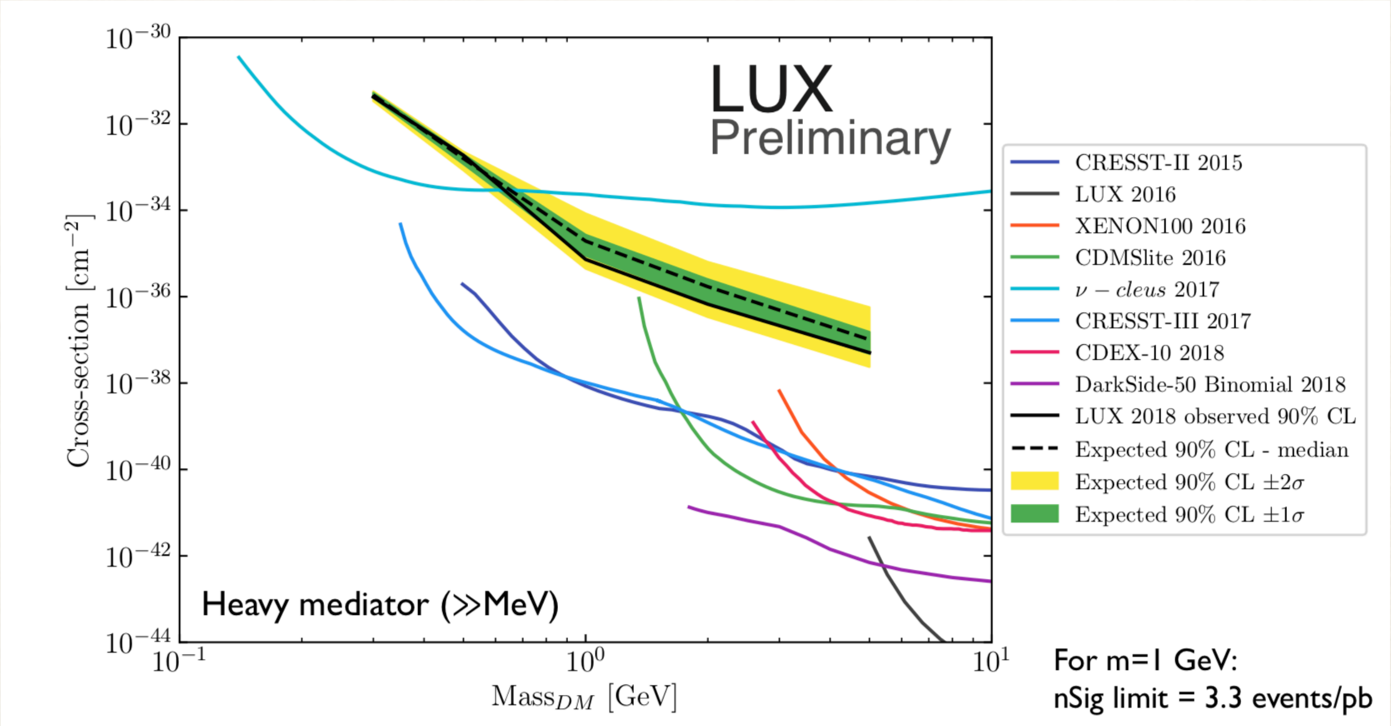
Galactic ALPs



first run only (Run03, 95 live-days)

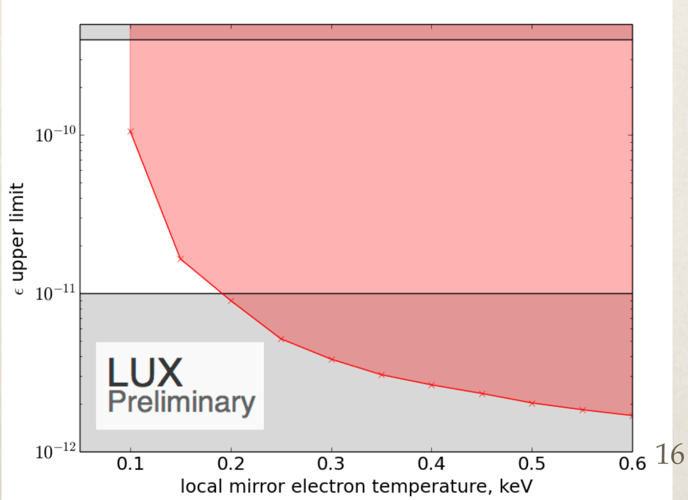
Sub-GeV & Mirror DM

- Bremsstrahlung photon emission from nuclear scattering (C. Kouvaris & J. Pradler)
  - Gain NR sensitivity at low mass, but signal in ER band

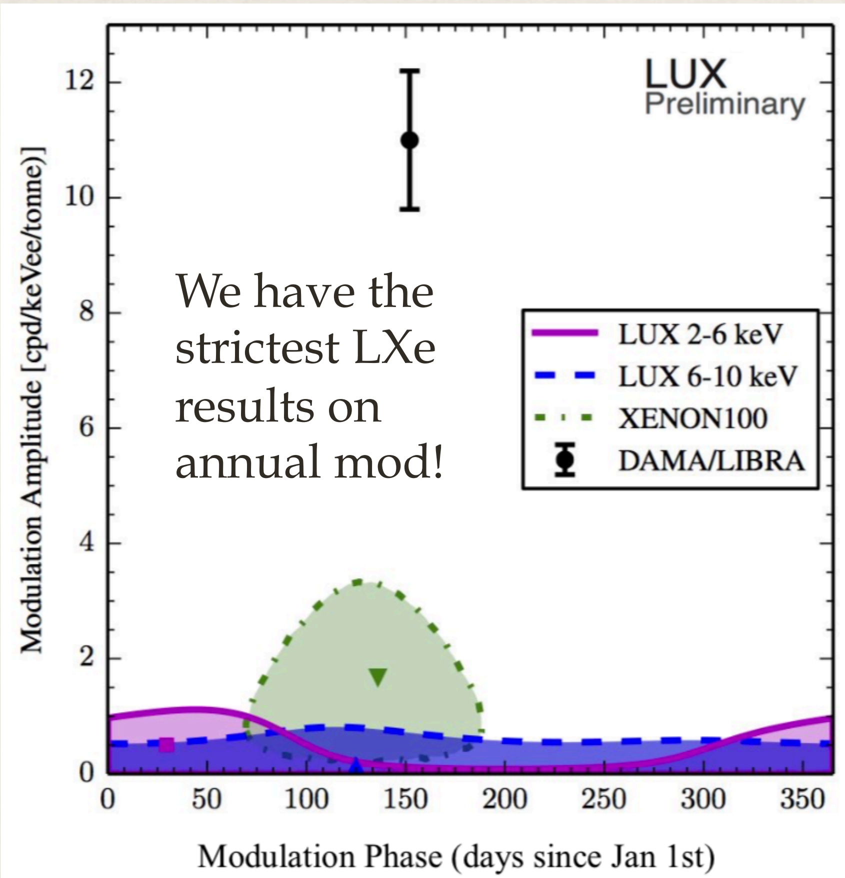


For m=1 GeV:
nSig limit = 3.3 events/pb

- Mirror dark matter (R. Foot et al.)
  - A hidden sector model
  - Copies of all the SM particles in multi-component plasma halo
  - Mirror e's can scatter off Xe atom e-'s

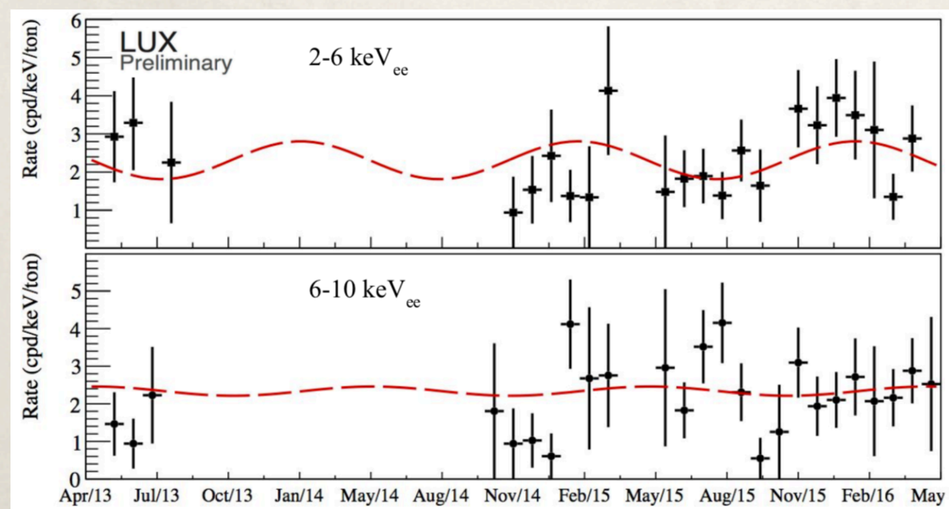


Annual Modulation



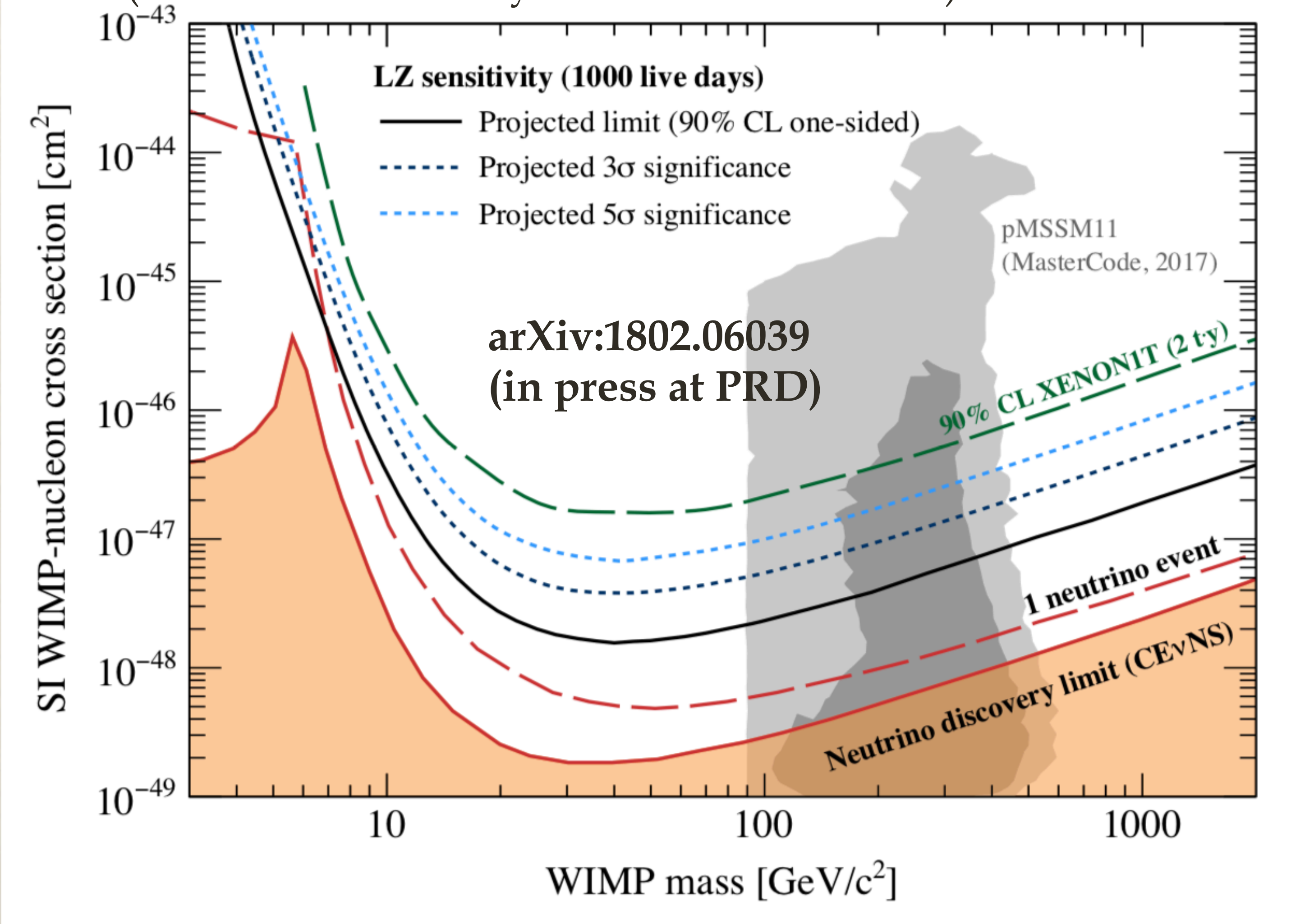
* We carried out modulation analyses with ER events
  * Demonstrated data stability via corrections and cuts
  * No significance evidence was identified of sinusoid

* The DAMA-LIBRA result even *more* ruled out now, again



Future: LZ Coming (2020)

NOTE: Discovery potential not only projected 90% C.L. exclusion limit shown! (Exclusion sensitivity is the solid black line)



Conclusions

- The LUX spin-independent WIMP limit led the field for 3 years (2013-2016). Only recently are the larger XeTPCs catching up
- LUX ultimately delivered better sensitivity in 427 live-days than projected 300 live-day sensitivity for design in original LUX proposal
  - This is nearly unheard of, especially in direct WIMP dark matter searches!
- Strictest constraints on axions and ALPs and mirror dark matter and annual modulation, in terms of coupling to electrons
- Pushing on combining PSD from S1 with S2/S1 discrimination, to use effectively for first time in LXeTPC (Effective Field Theory paper soon)
- LUX yields, efficiencies, and fields well calibrated, simulated, and understood, for all runs
- LUX is not done yet: lot more papers to come out of data! More physics
  - There is a great deal more science yet to come. Be on the look out

hopefully, we are all looking for dark matter in ALL of the right places!

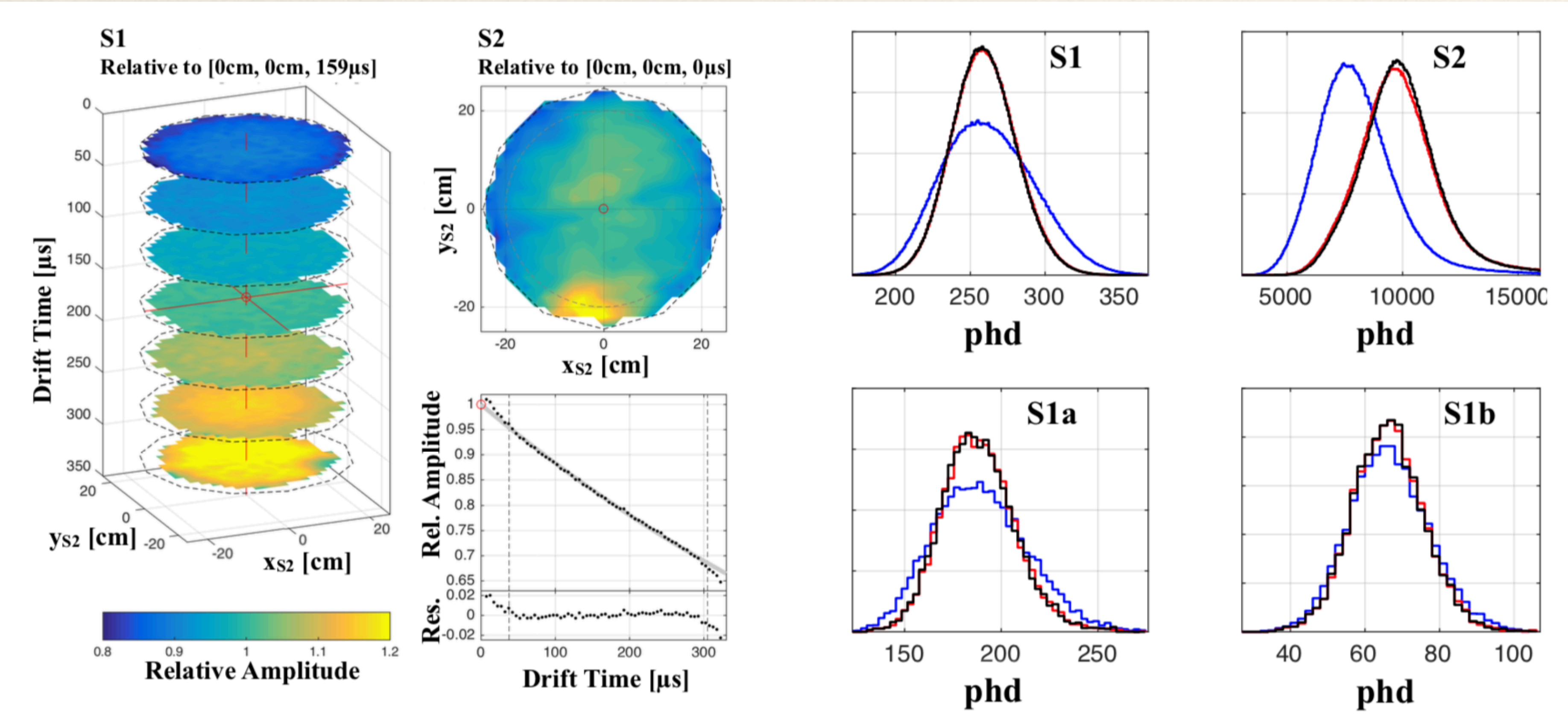
Thank You!
Questions??

Honoré Daumier, "Mr. Babinet, warned by his concierge of the arrival of the comet", illustration for Le Charivari, 22 September 1858

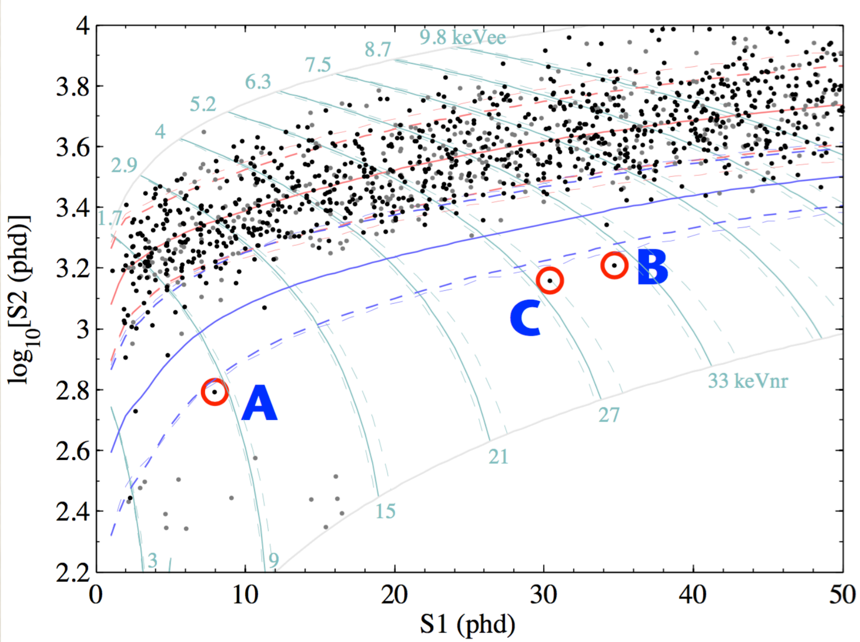
Backup Slides

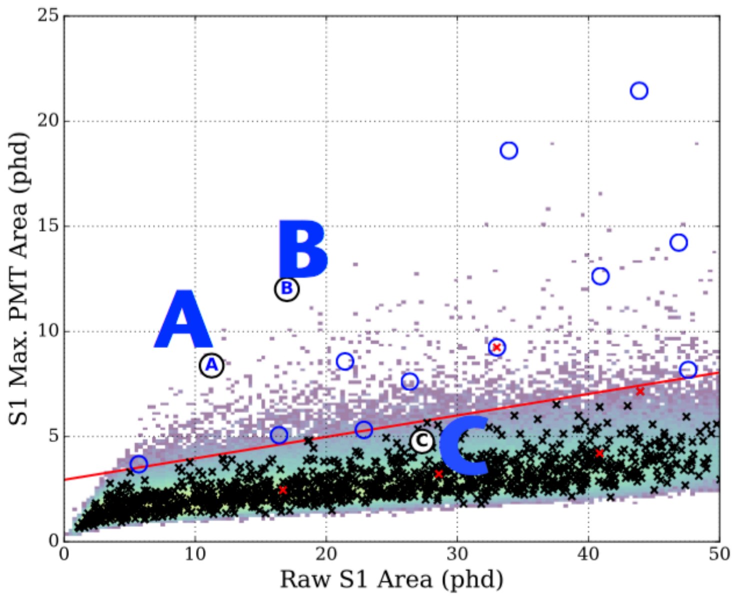
Kr83m Calibration

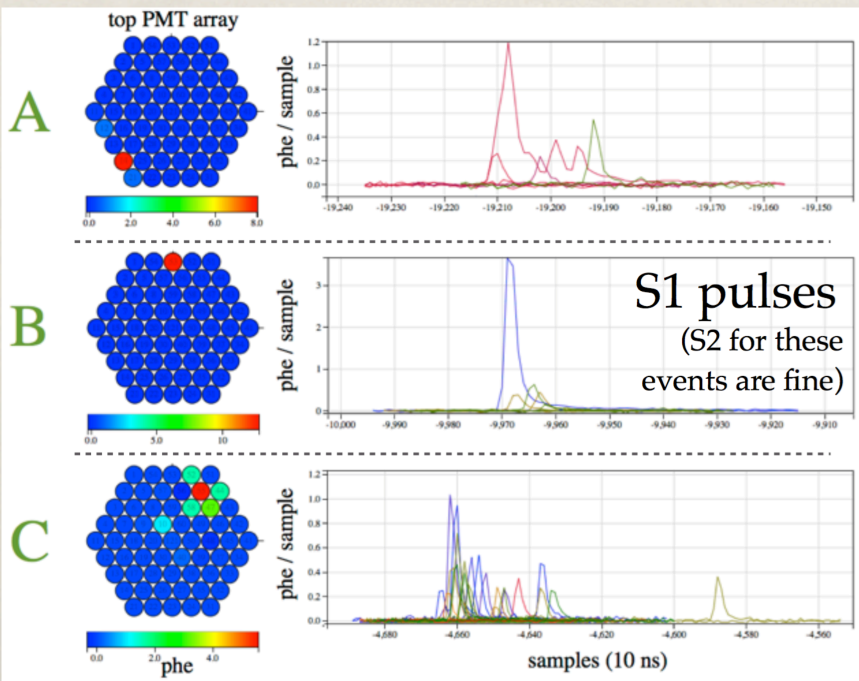
Phys. Rev. D 96, 112009 (2017)

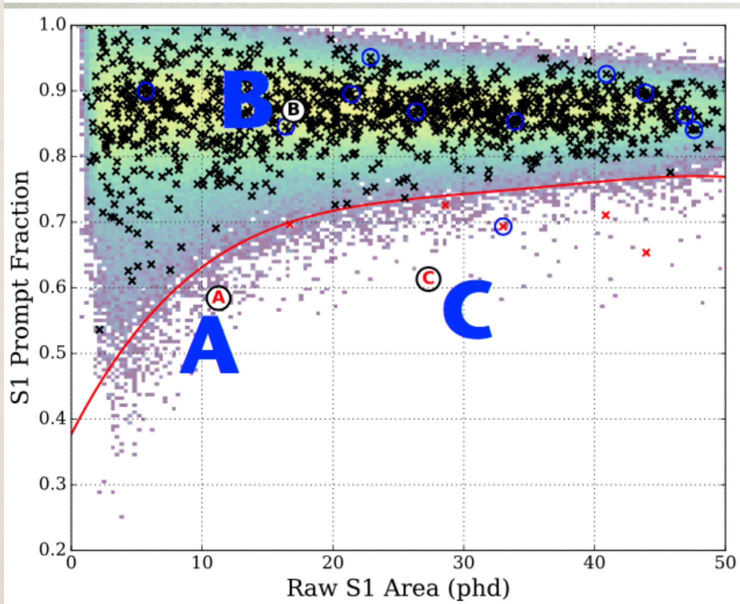


Pathologies

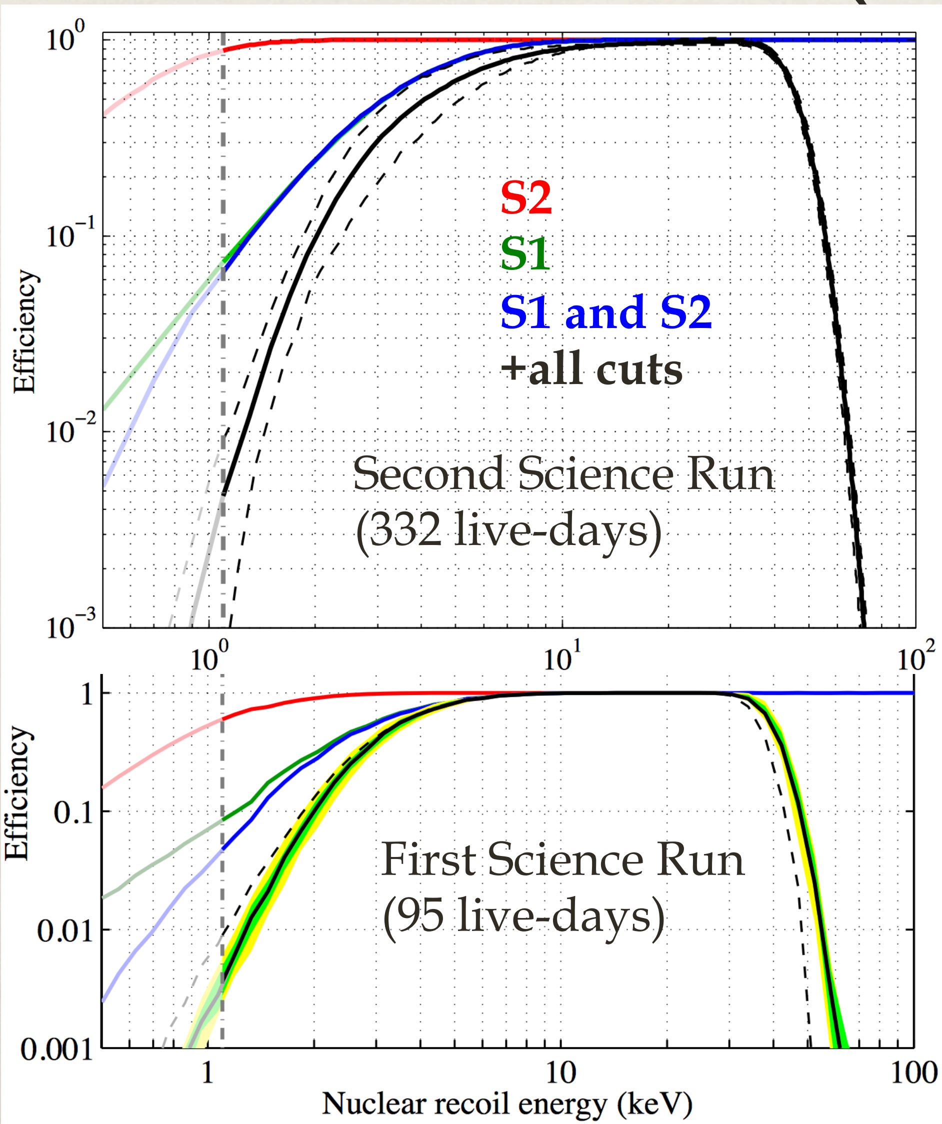


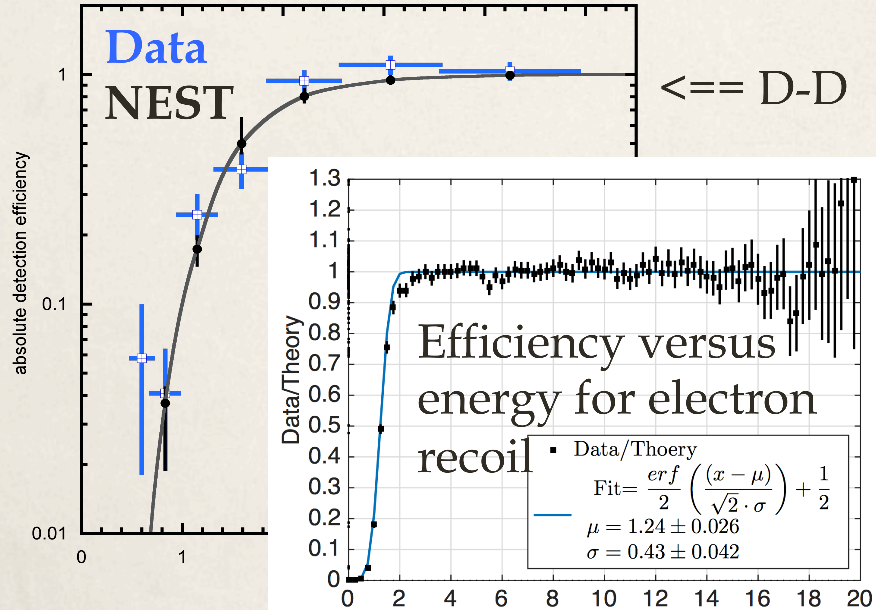






Efficiencies (Analysis, NR)





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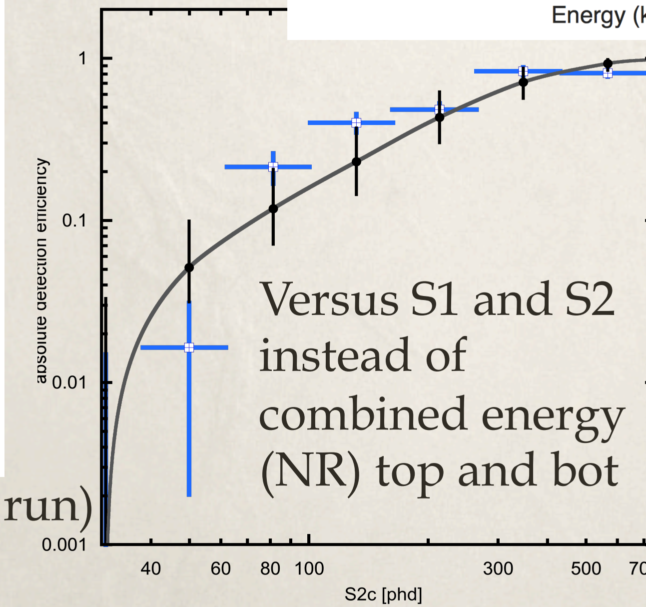
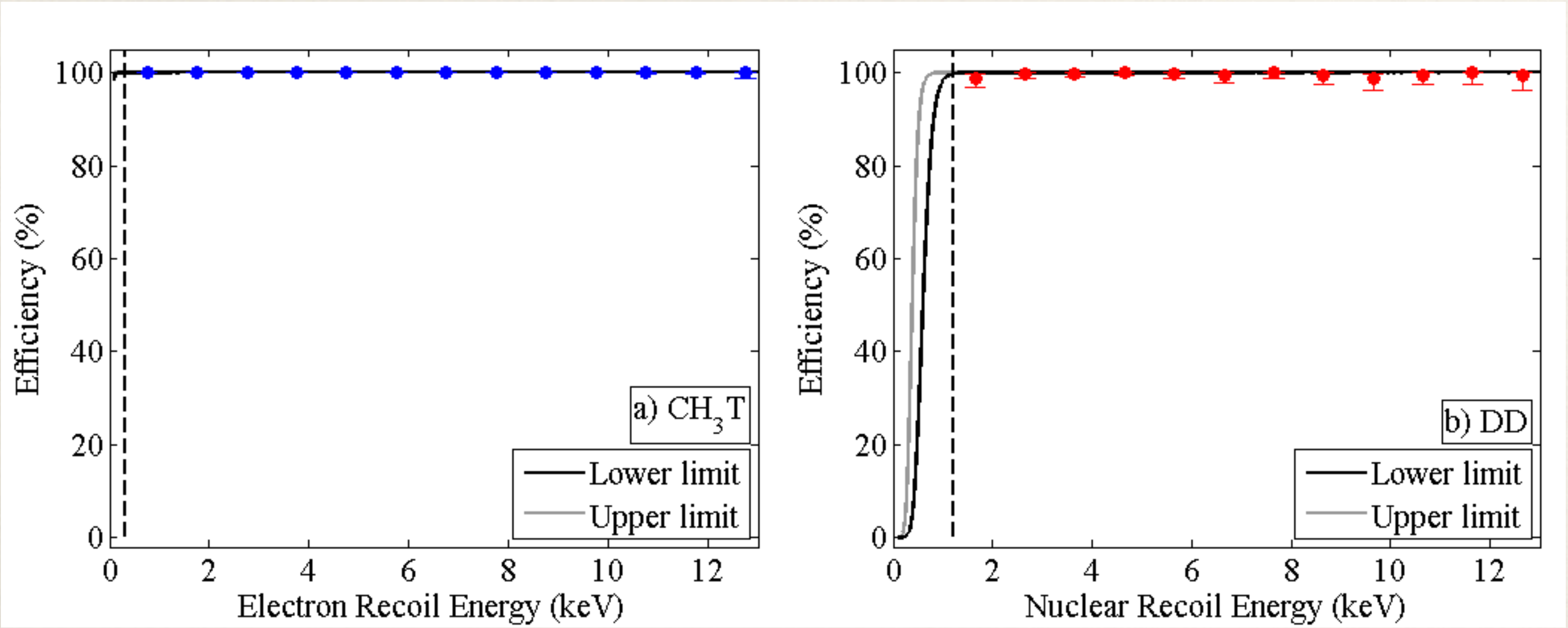


50% efficient at ~1.5 keVee, requiring both an S1 and S2

- 50% efficient @3-4 keVnr (depending on run)
- Below 1.1 keV (L_y un-calibrated) set to 0

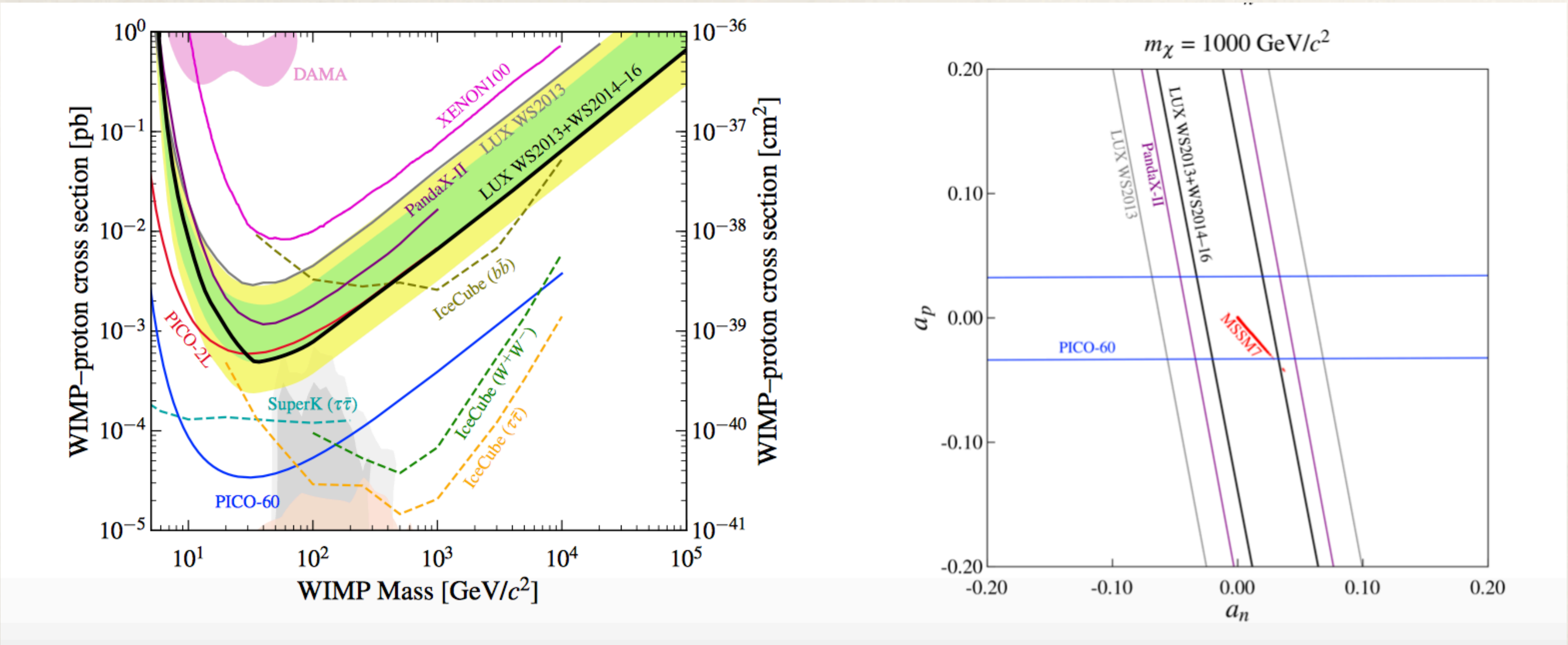
Efficiencies (Trigger, ER & NR)

arXiv:1802.07784



The trigger thresholds are of course well below the analysis thresholds

SD Proton, and Different Example Mass for a_p v. a_n



Diurnal Modulation

- Diurnal NR dark matter modulations are predicted to be very small (<1%)
- Certain ER dark matter models predict diurnal modulation amplitude up to ~10%

Asymmetry factor for the diurnal modulation analysis:

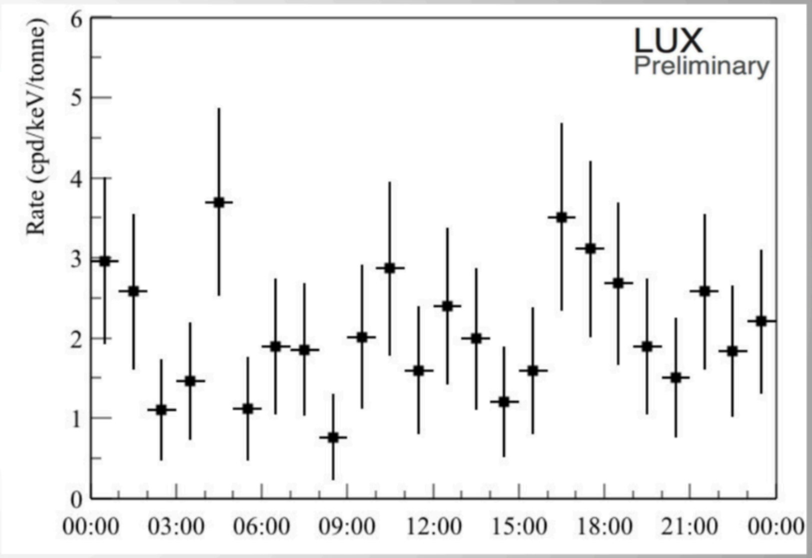
$$\mathcal{A}_t = \frac{R_t - \bar{R}_t}{R_t + \bar{R}_t}$$

Day/night rates: 2.06 / 2.14 cpd/keV/tonne

Asymmetry: -1.6% +/- 8.7% (stats only)

Morning/evening rate: 1.99/2.21 cpd/keV/tonne

Asymmetry: -5.4% +/- 8.7% (stats only)



ER event rate in LUX (2-6 keV_{ee}) as a function of time in the day (local MT w/ DST corrected for).

Muon Veto (Instru-mented Water Shield)