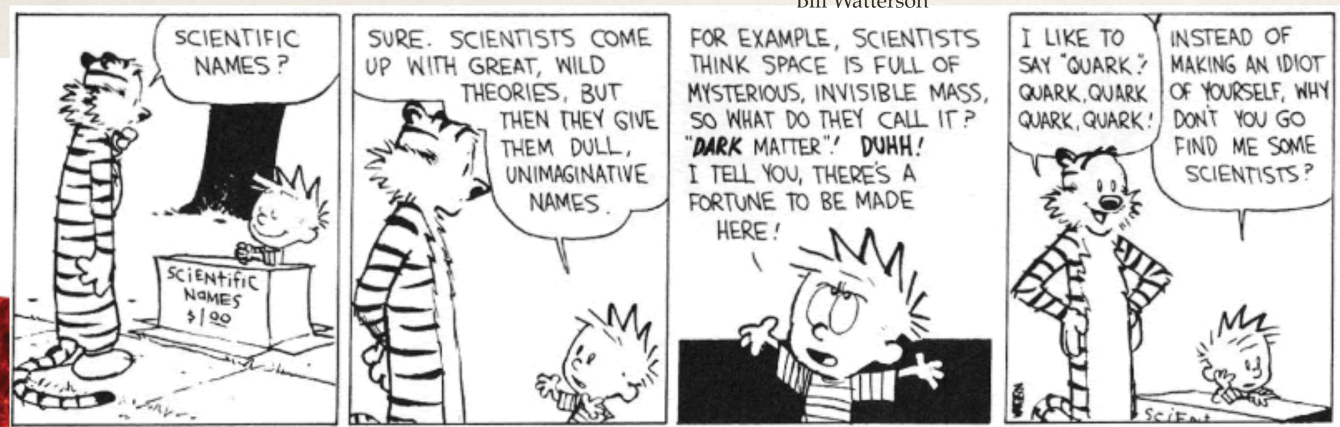
LUX, and the Combatting of the WIMP Lamppost Effect

Matthew Szydagis, the TeVPA Conference at OSU, August 8, 2017

v2.7

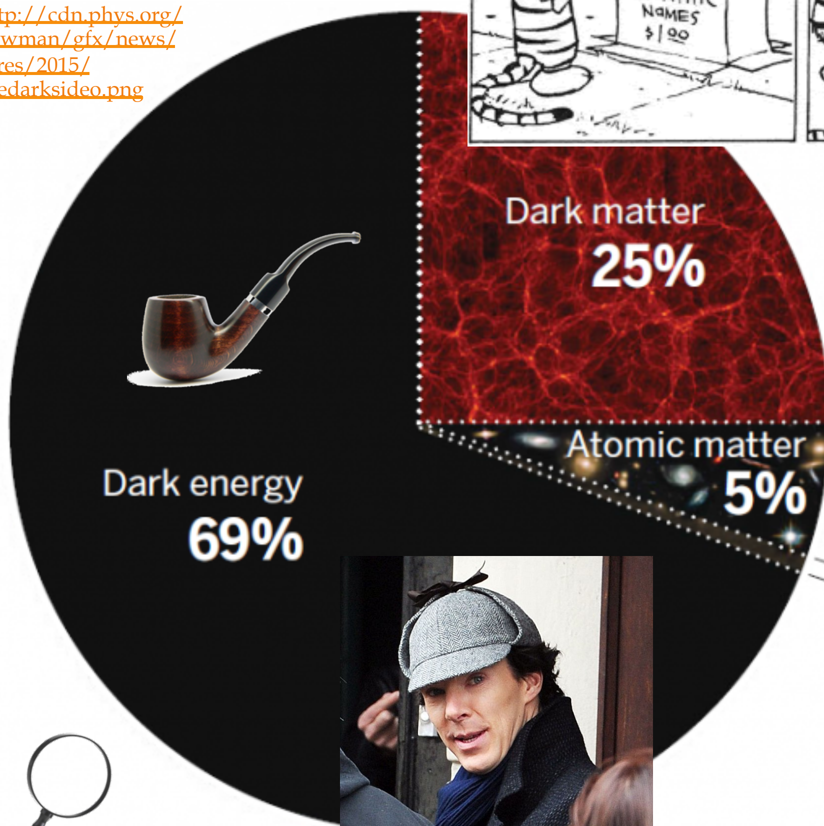
A Big Hole in Our Knowledge

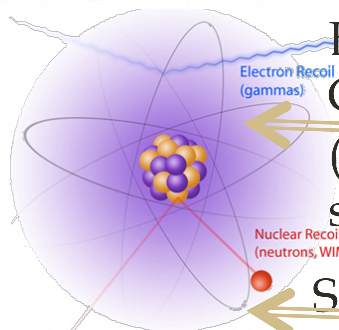
Bill Watterson



What is this **dark matter?**

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

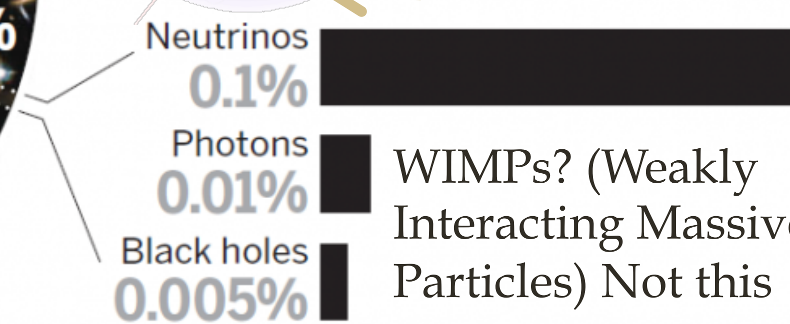




BACK-GROUND (also signal?)

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.



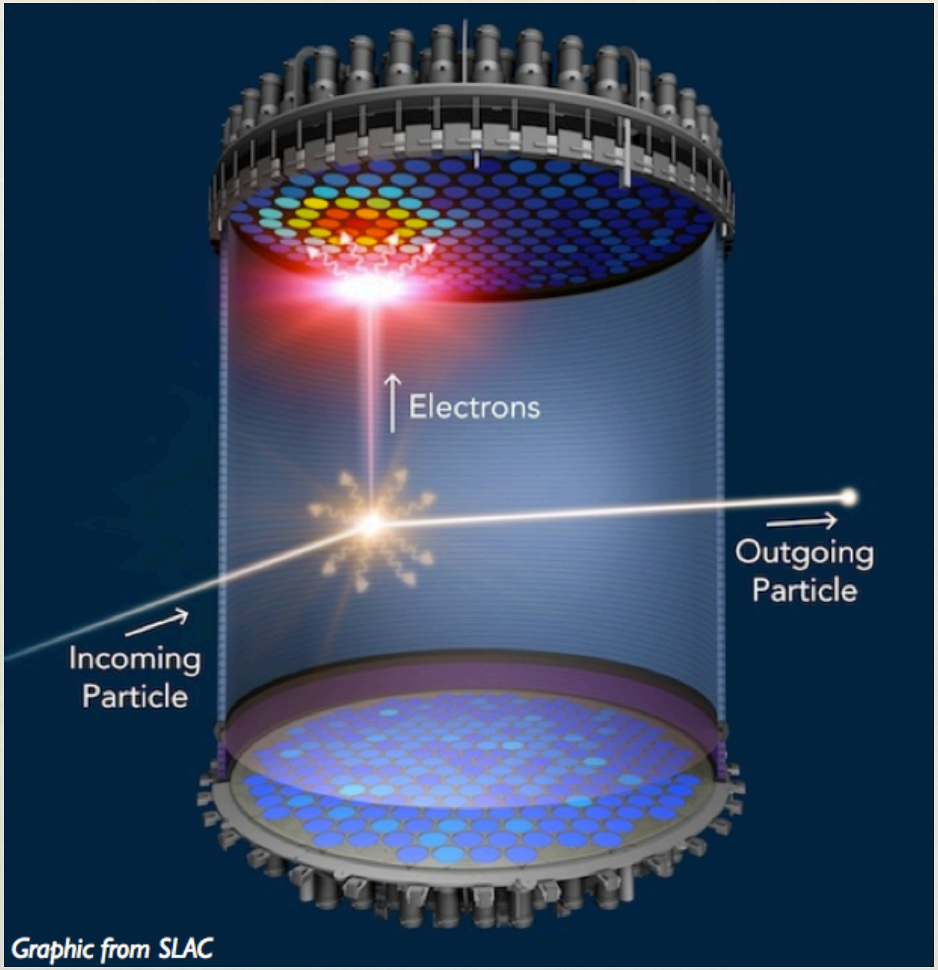
WIMPs? (Weakly Interacting Massive Particles) Not this

Large Underground Xenon

- 2-phase xenon detector deployed (was recently decommissioned) underground in SD with 122 photo-multiplier tubes
- Why element Xe?
  - Dense (good self-shielding)
  - Gets excited and scintillates, and can get ionized easily
- Why deep underground?
  - Cosmic rays -> bad
- Why PMTs not low BG Si?
  - PMT: 1-photon, large area
  - SiPM unavailable in past

photos by Jack Genovesi, UAlbany

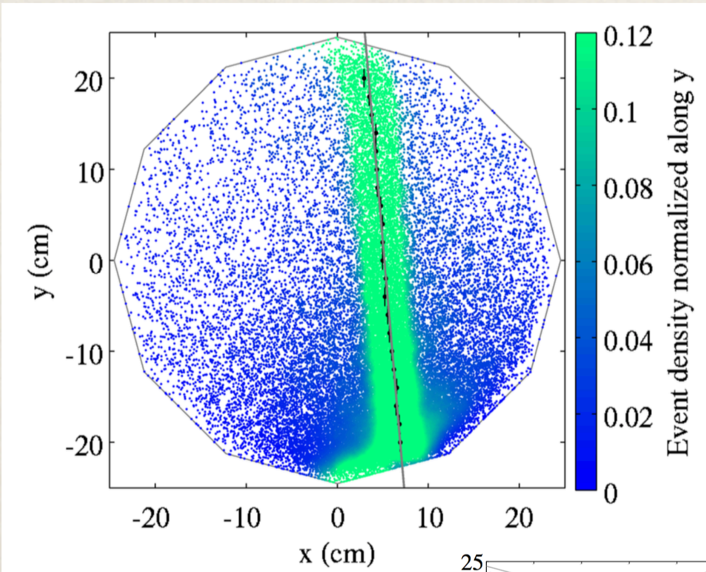
How It Functions

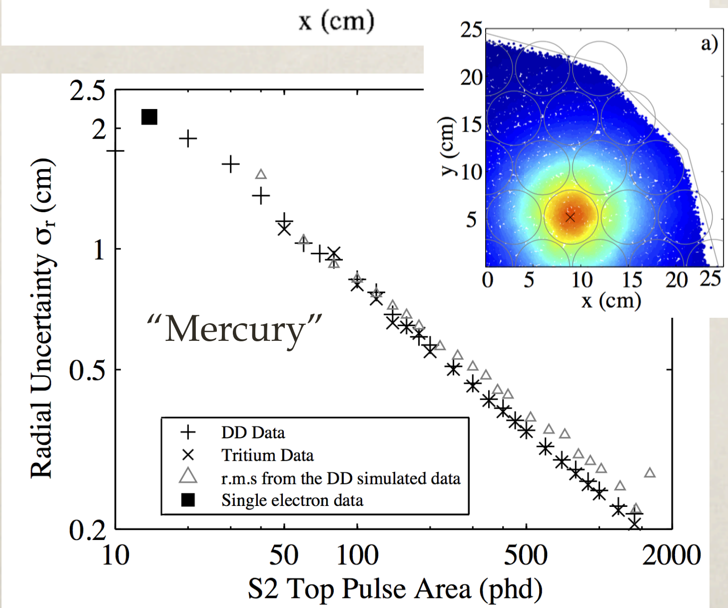


S2/S1 ratio gives particle ID, and S2-S1 drift time gives depth

- 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 Reconstruction

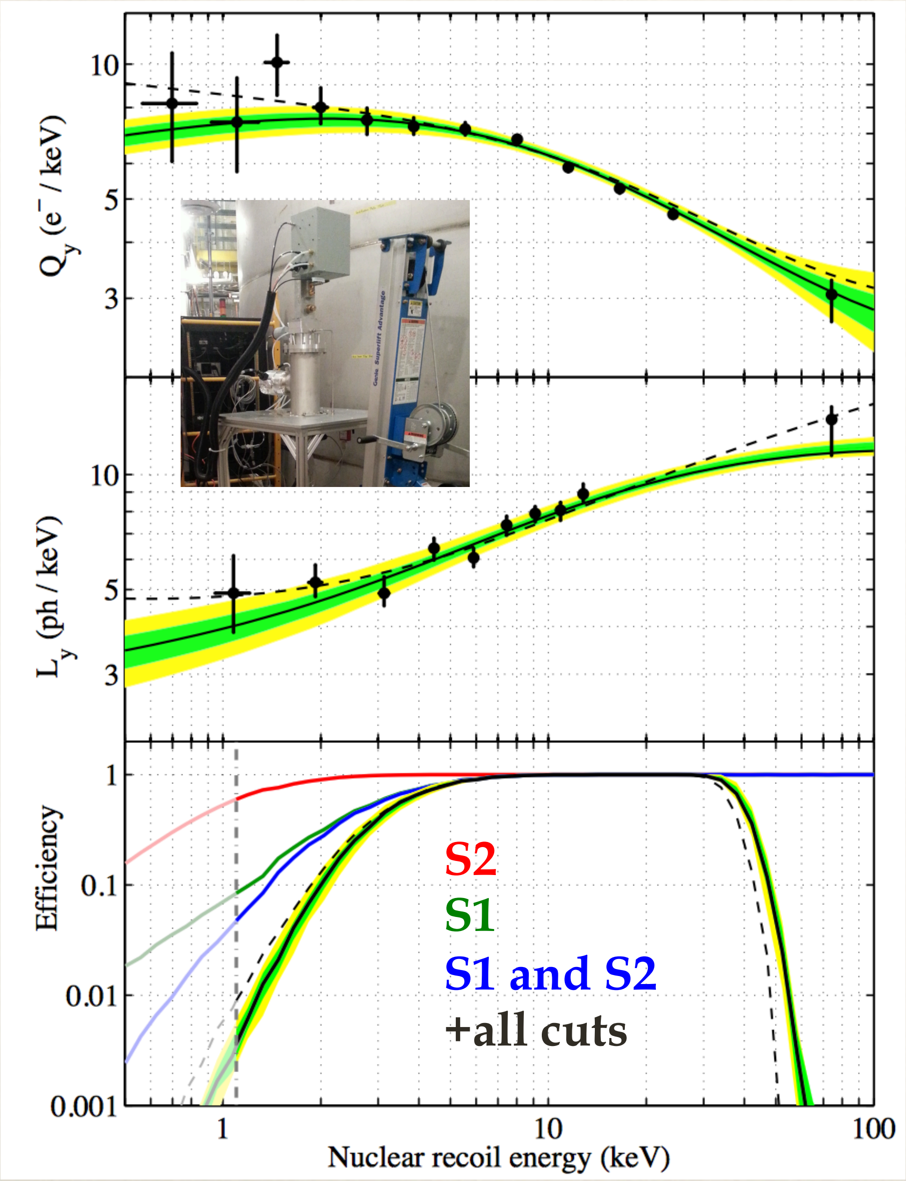




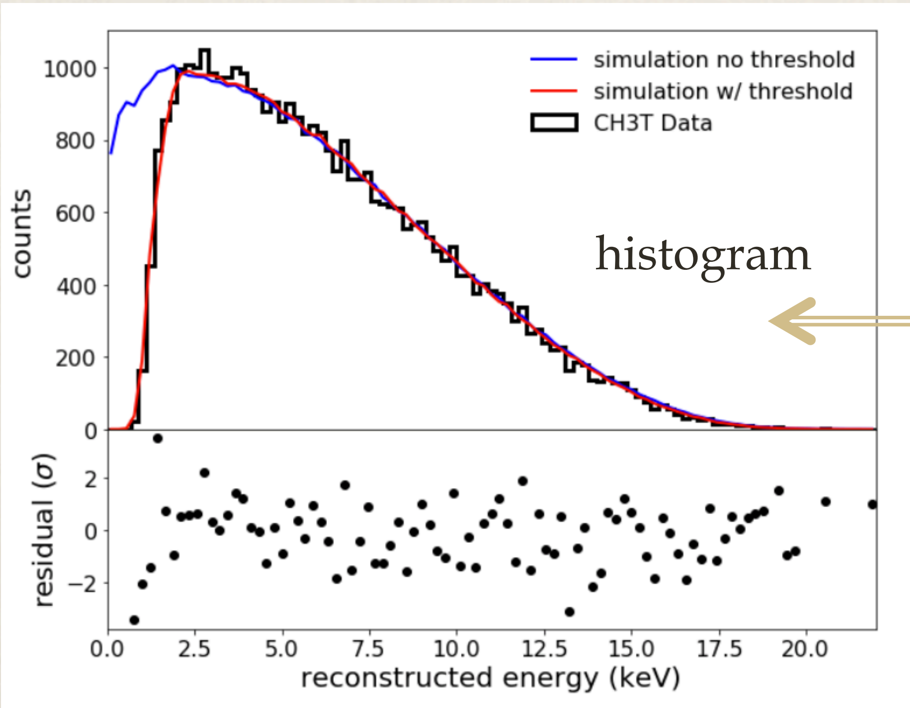
- Even a single drift electron from an ionization is visible using the S2!
- X-Y position is reconstructed at 2-20 mm accuracy using top PMTs
  - Depends on S2 size, and on radius
  - Detector was 50x50cm dia x depth
- Possible to reconstruct positions of neutron elastic scatters from D-D gun, and isotropic internal sources
  - Neutrons like dark matter WIMP signal in theory, therefore used for the calibrations
  - CH_3T, ^{83m}Kr, ^{127}Xe calibrate the BGs
- Many more technical publications forthcoming (and physics results!)

Calibration: NR With D-D Gun

* Lowest absolute calibration of light yield (180 V/cm)
  * 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! (from Manzur et al., 2010)
* Air-filled conduit in water shield is neutron guide

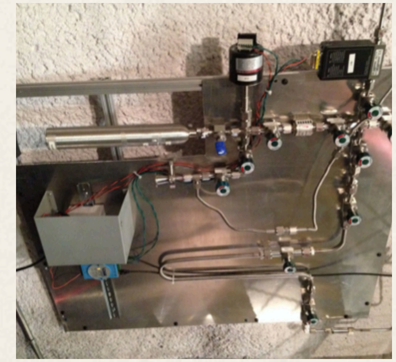


Calibrations: ER, Old and New

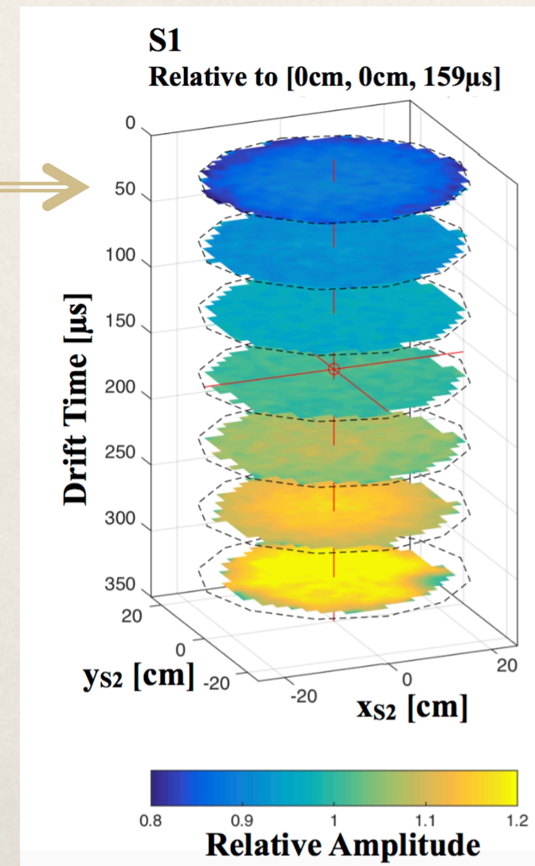


histogram

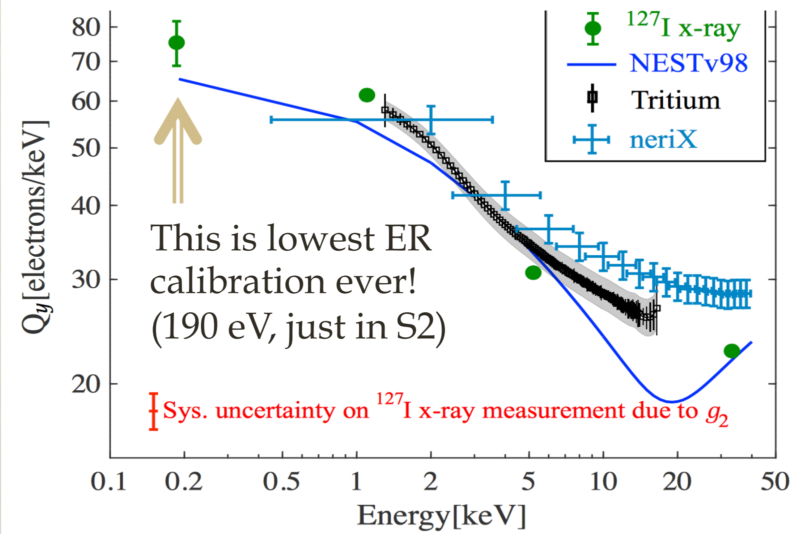
tritium (i.e., tritiated methane)



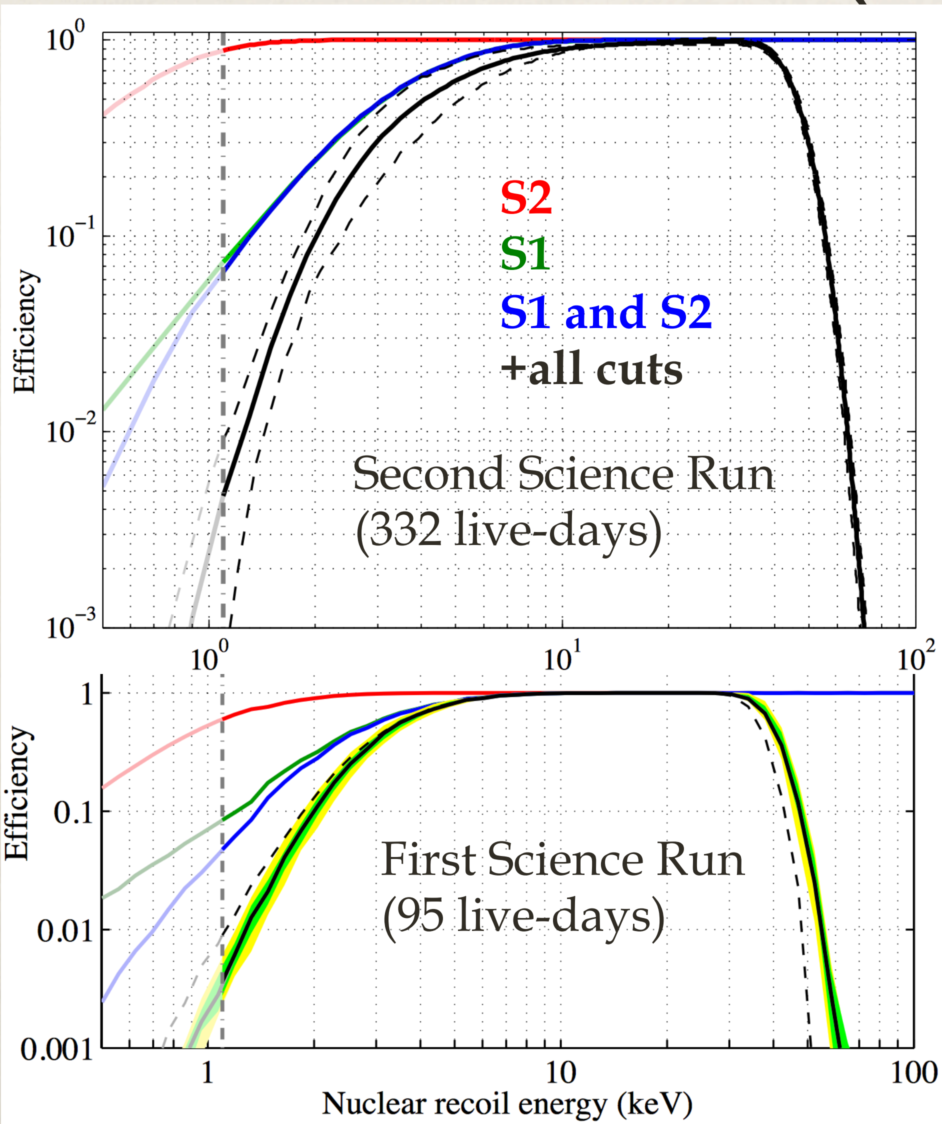
^{83m}Kr

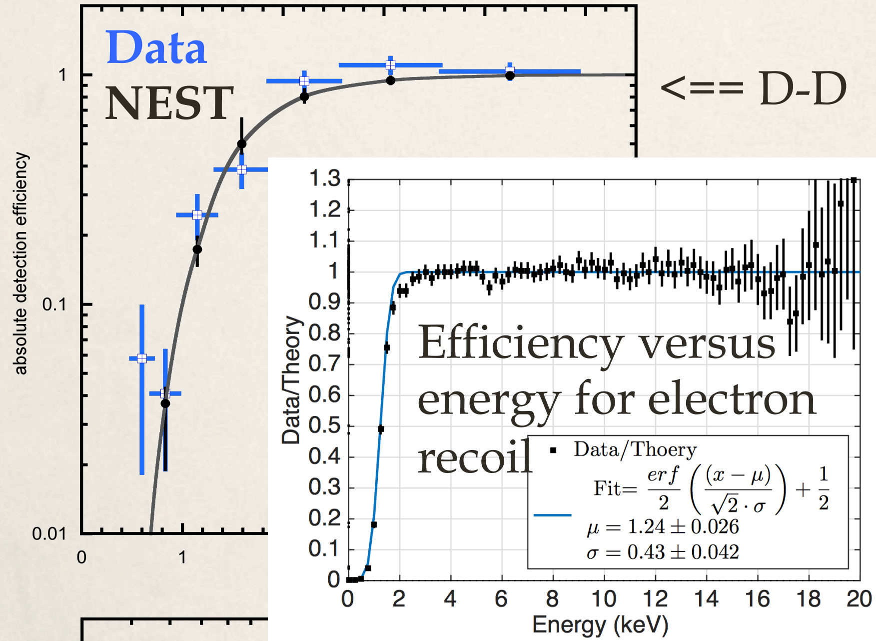


low energy x-rays and electron capture or internal conversion events

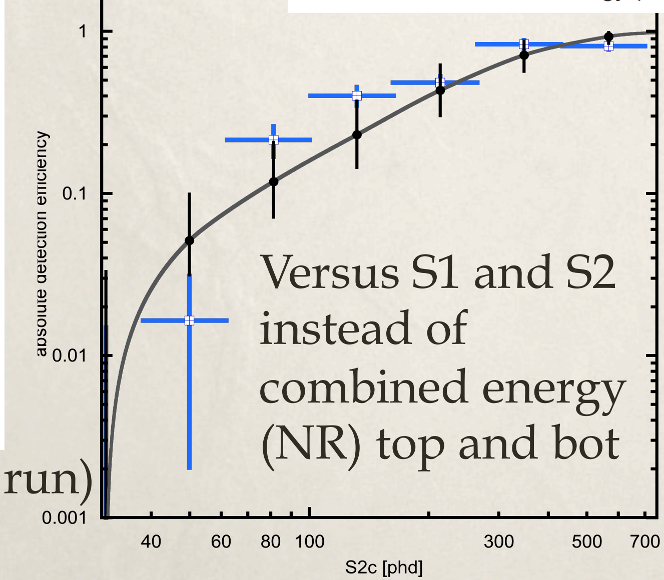


Efficiencies (Analysis, NR)





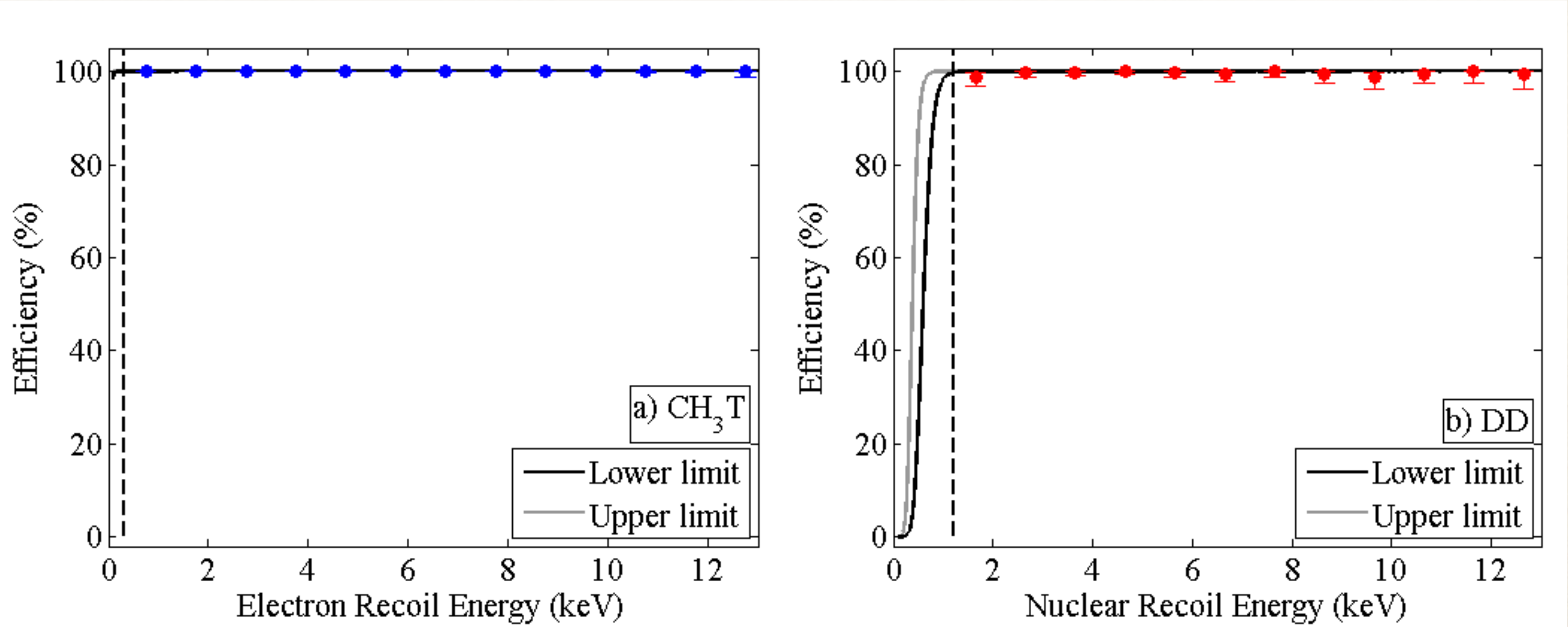
<== D-D



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

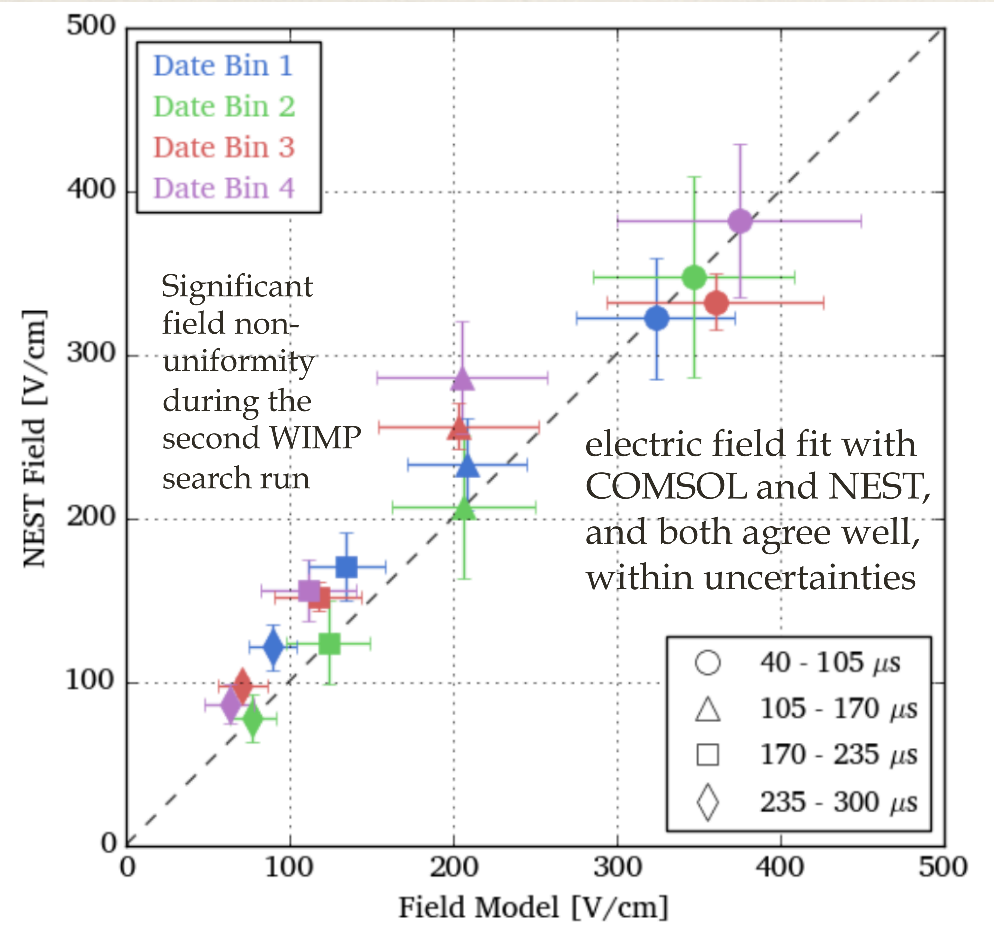
- 50% efficient @3-4 keVnr (depending on run)
- Below 1.1 keV (L_y un-calibrated) set to 0

Efficiencies (Trigger, ER & NR)



The trigger thresholds are of course well below the analysis thresholds

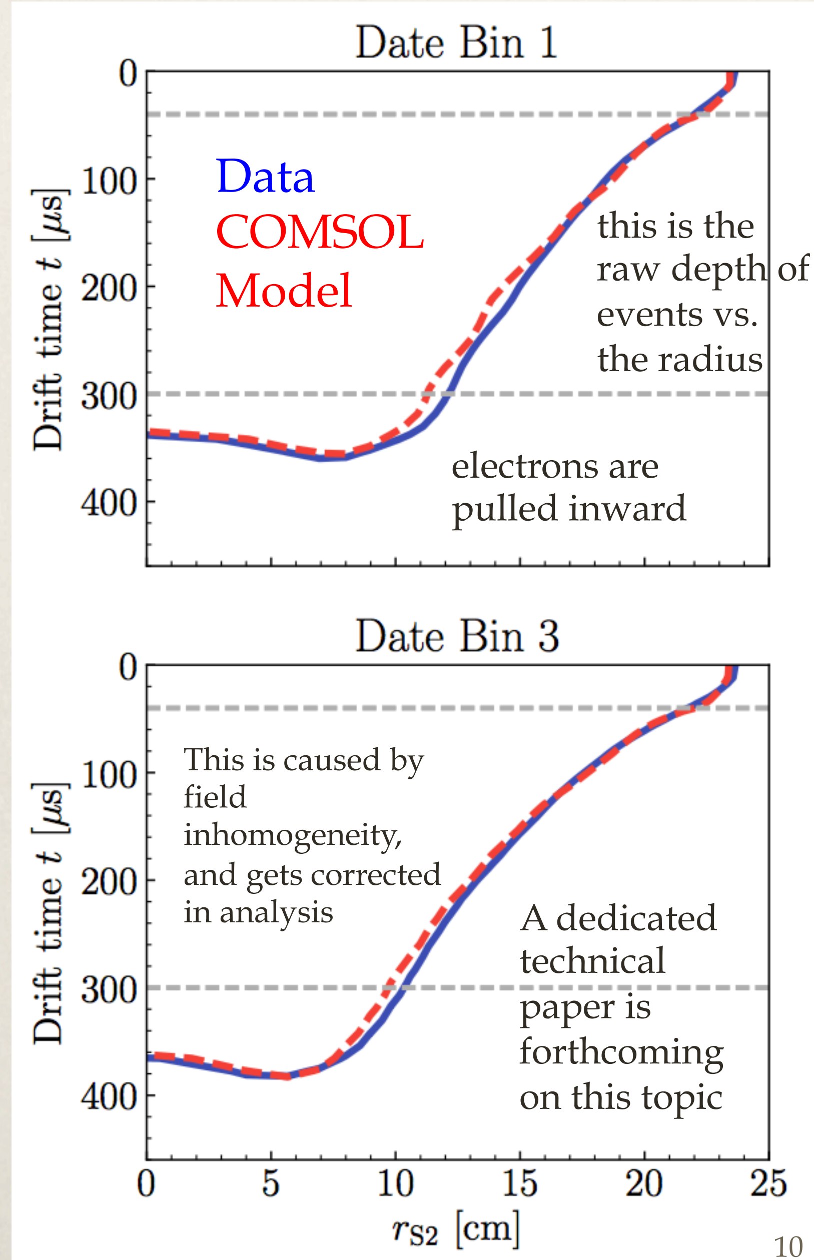
E-Field Modeling



Significant field non-uniformity during the second WIMP search run

electric field fit with COMSOL and NEST, and both agree well, within uncertainties

Wall Position: 2 Examples



this is the raw depth of events vs. the radius

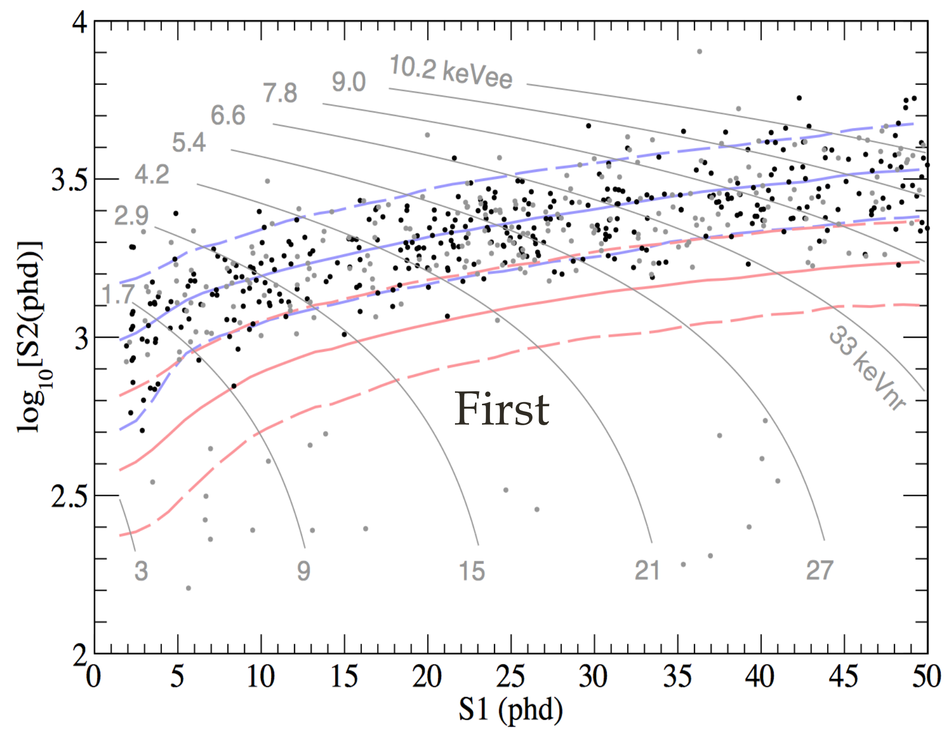
electrons are pulled inward

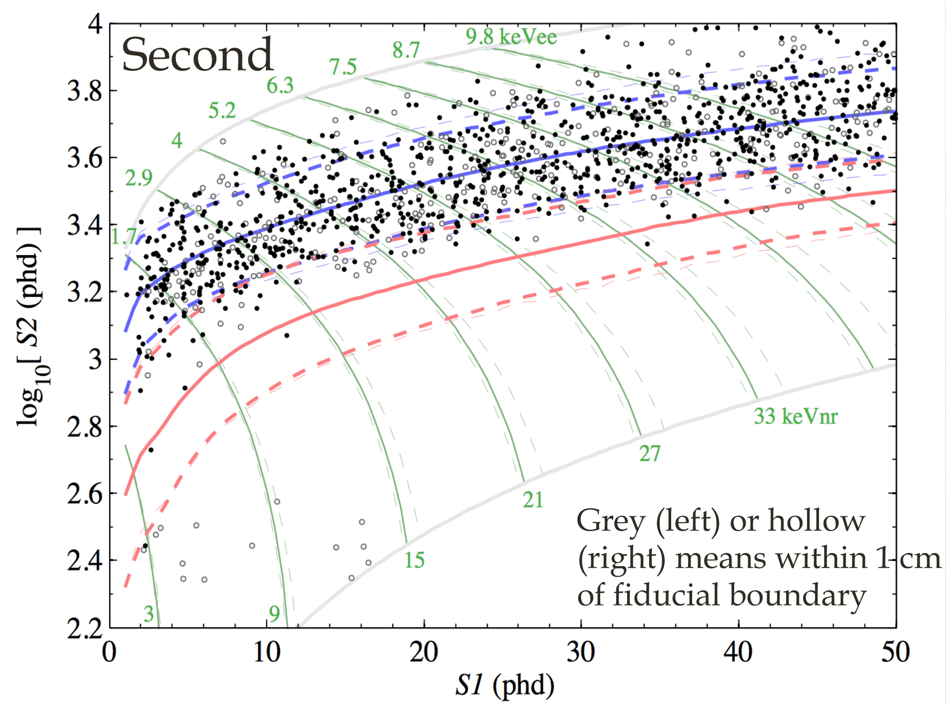
This is caused by field inhomogeneity, and gets corrected in analysis

A dedicated technical paper is forthcoming on this topic

SI WIMP Search Final Results

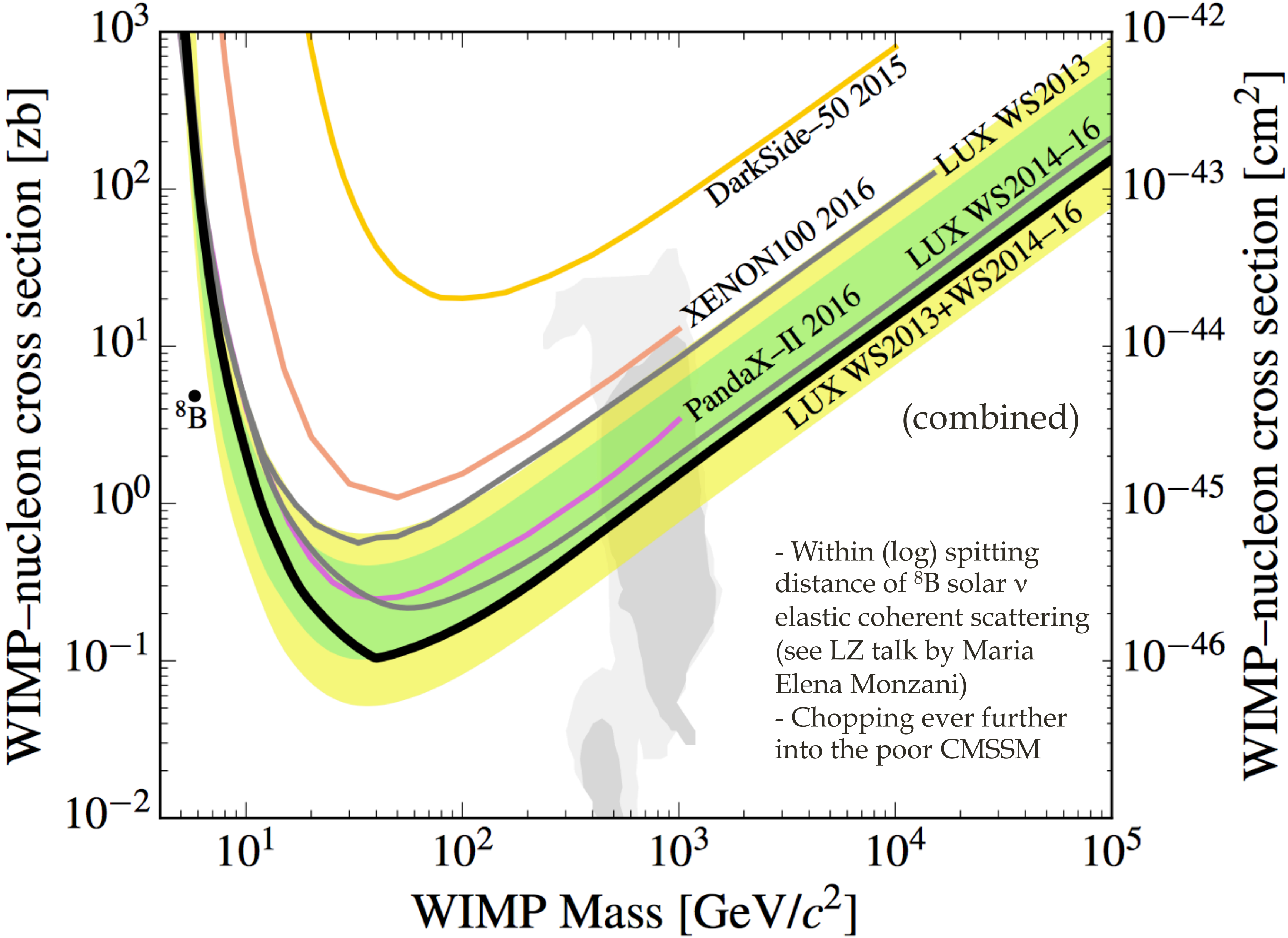
(in S2/S1 space; limit on next slide)





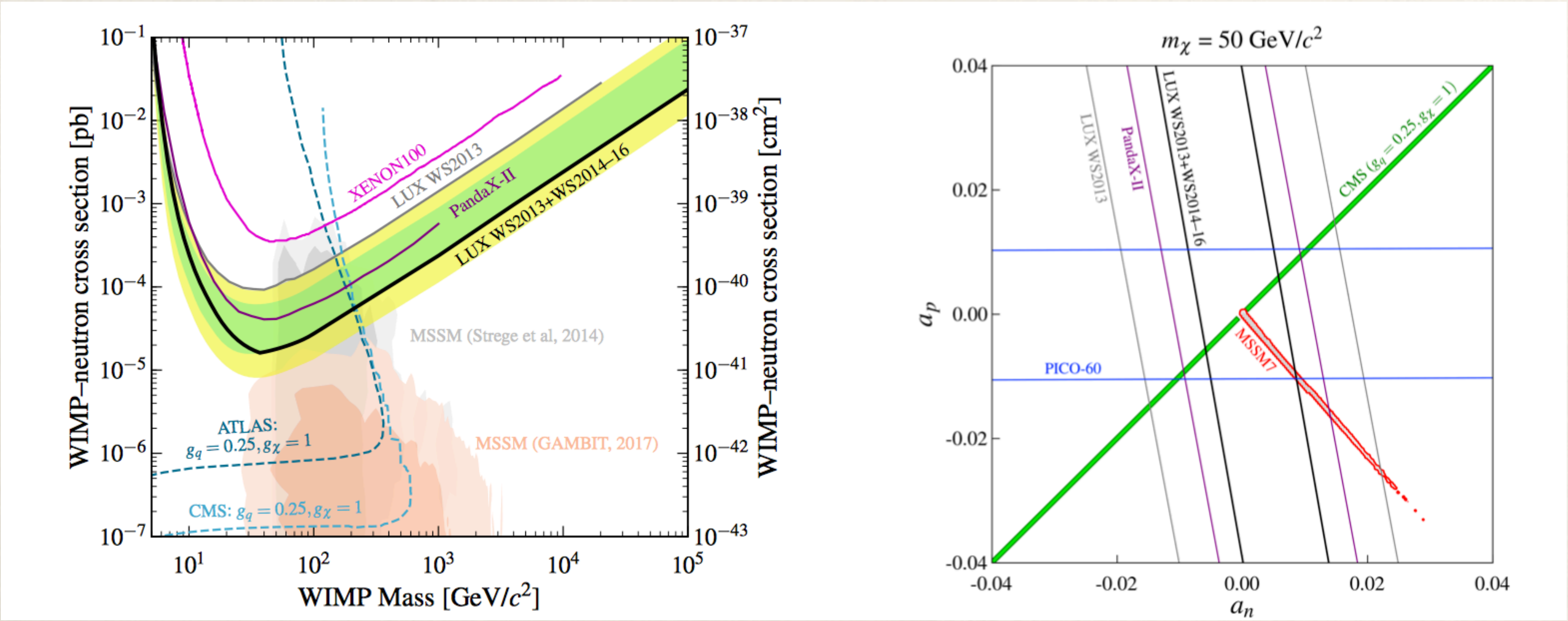
Phys. Rev. Lett. 116, 161301 (2016), re-analysis of Phys. Rev. Lett. 112, 091303 (2014)

Phys. Rev. Lett. 118, 021303 (2017)


WIMP–nucleon cross section [zb]
WIMP–nucleon cross section [cm^2]
WIMP Mass [GeV/c^2]
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^1
10^2
10^3
10^4
10^5
^{8}B
DarkSide–50 2015
LUX WS2013
XENON100 2016
LUX WS2014–16
PandaX–II 2016
LUX WS2013+WS2014–16
(combined)
- Within (log) spitting distance of ^{8}B solar ν elastic coherent scattering (see LZ talk by Maria Elena Monzani)
- Chopping ever further into the poor CMSSM

Spin-dependent Limits

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



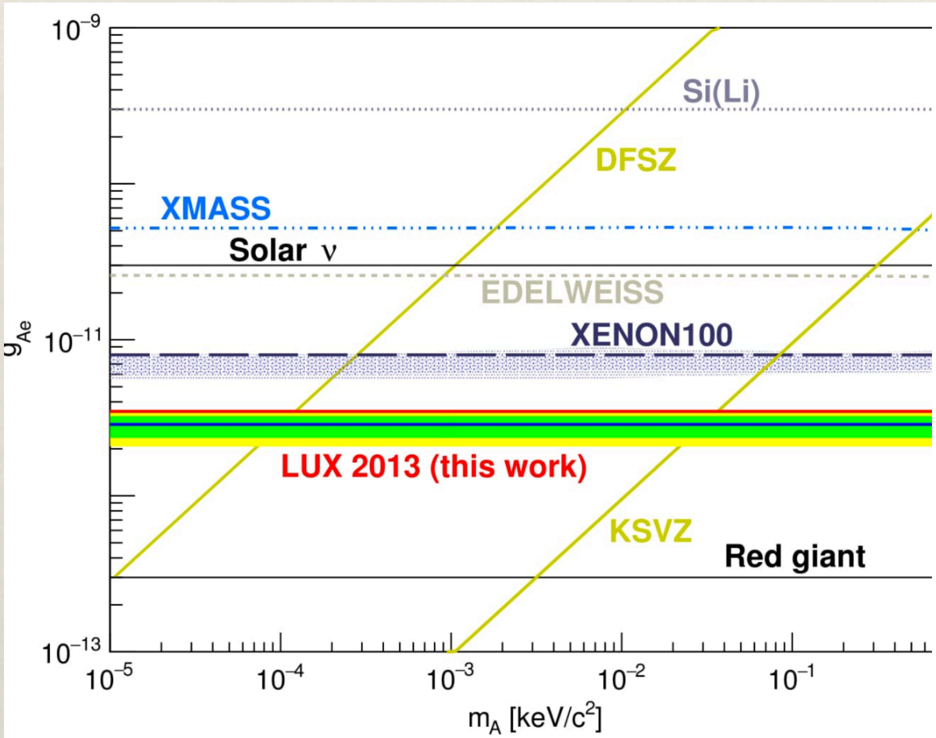
- Left plot is neutron coupling vs. mass, while right is proton interaction strength vs. neutron, at a fixed example mass near the strictest point in the limit curve (50 GeV)
- Xe is even Z, but some isotopes are odd-N, allowing for SD interactions to be probed, especially WIMP-neutron: LHC dark matter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

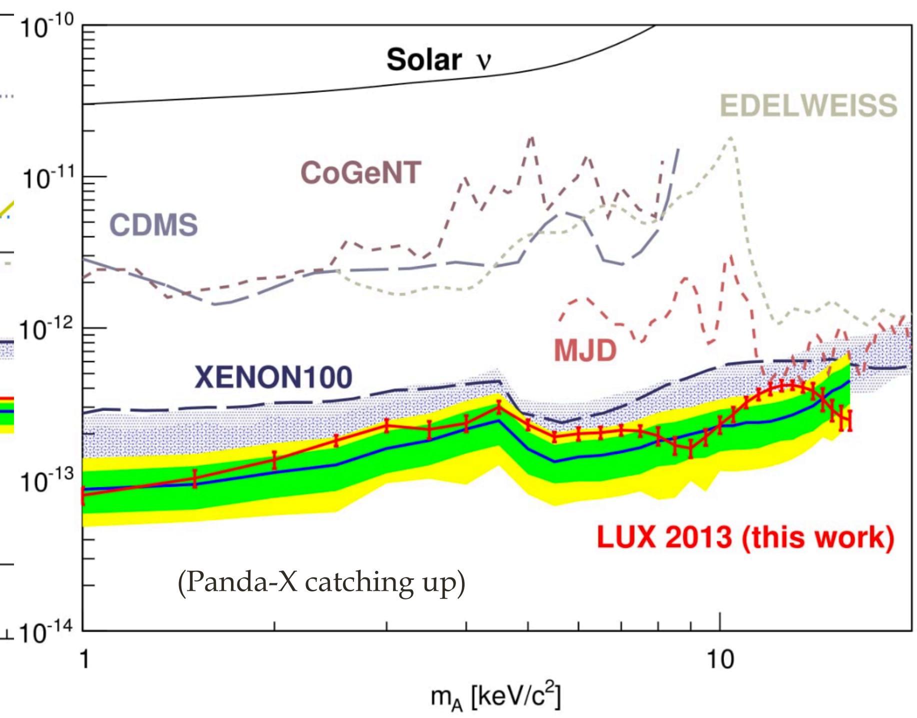
No WIMPs, So Trying Axions

First Run Only

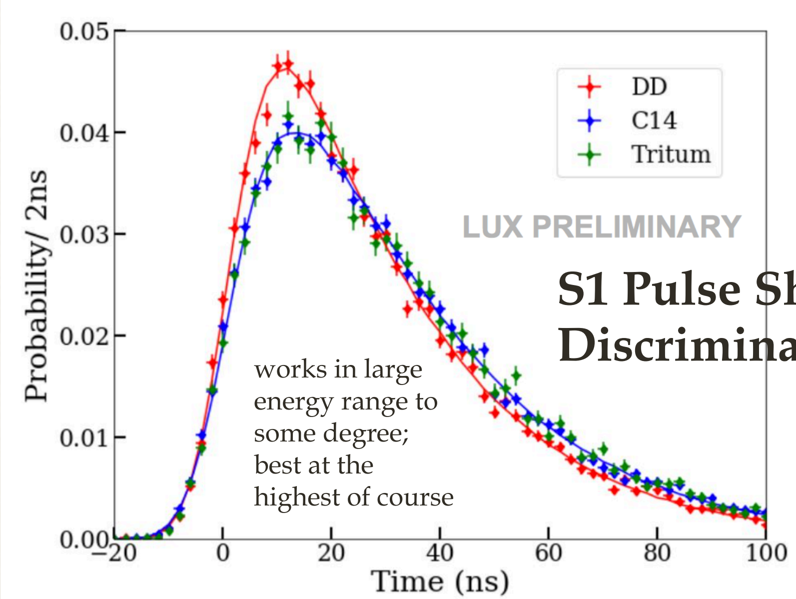
Solar Axions

Galactic ALPs

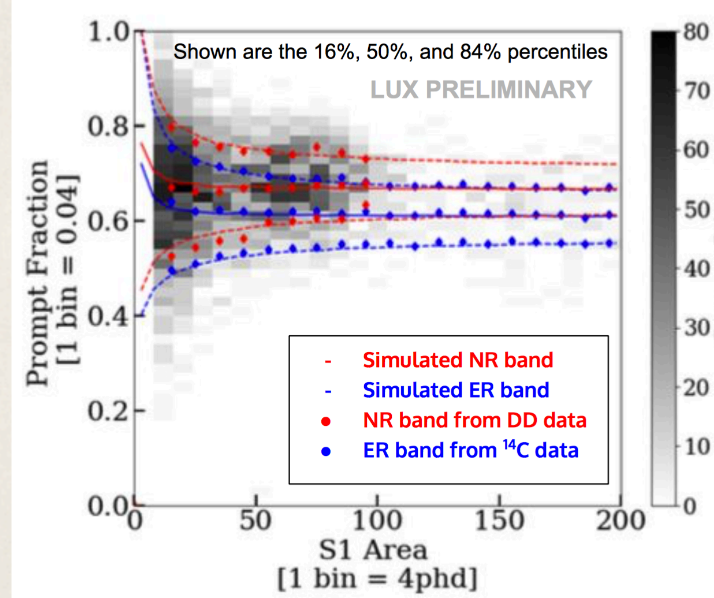




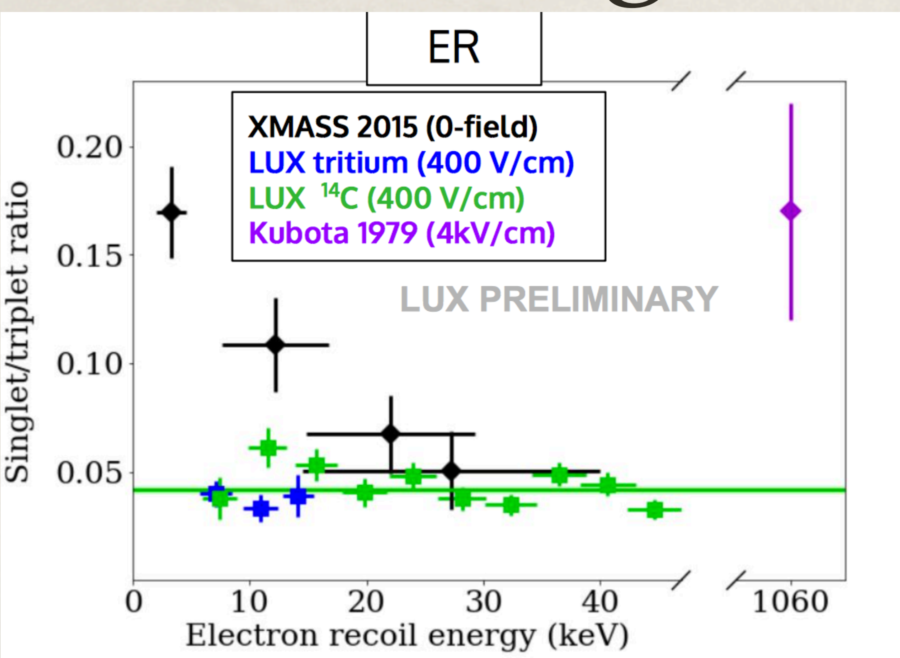
Phys. Rev. Lett. 118, 261301 (2017)

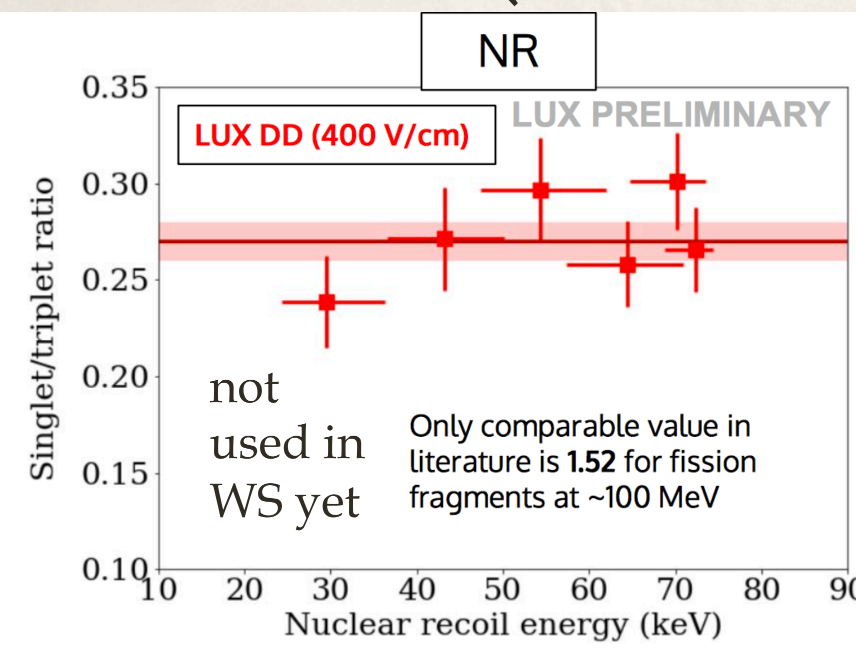


S1 Pulse Shape Discrimination



Push to High-E WIMPs (for *EFT*)





Conclusions

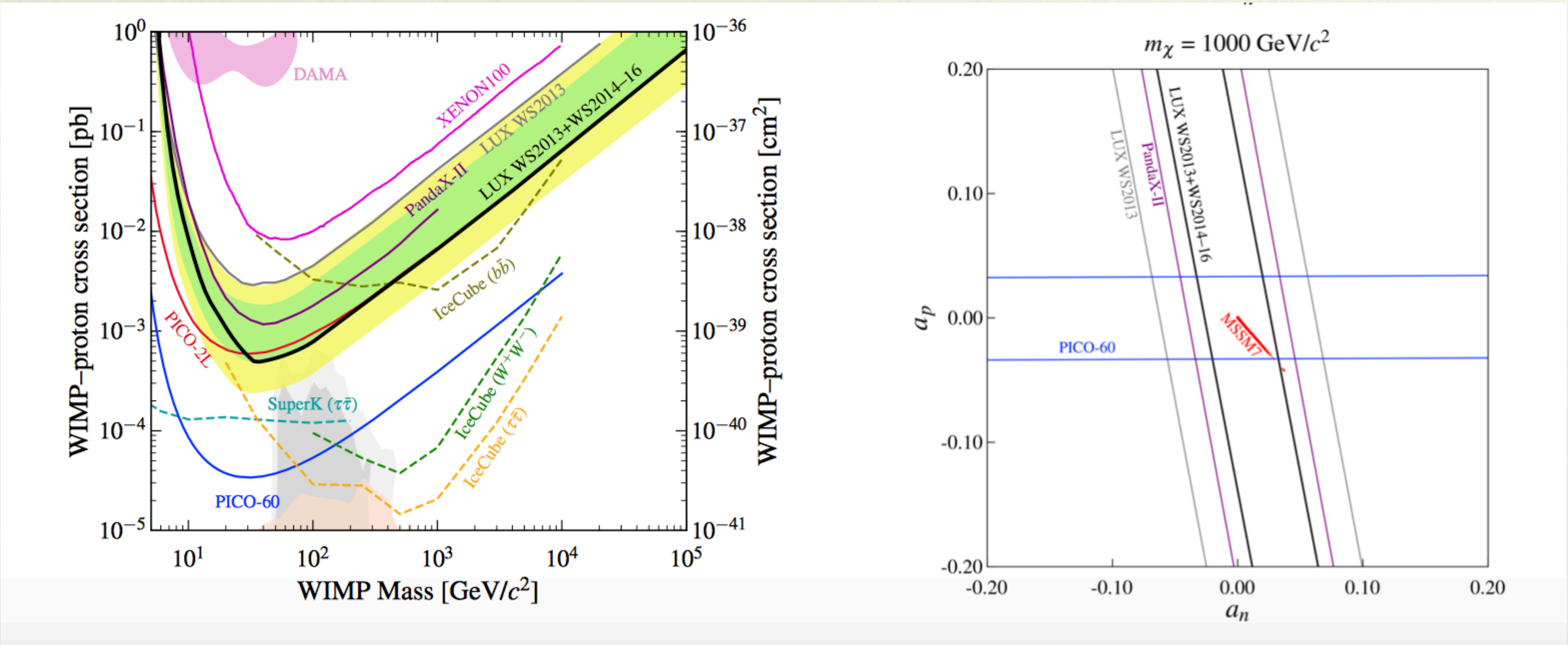
- The LUX spin-independent WIMP limit led the field for 3 years (2013-2016). Only now are the larger XeTPCs catching up (XENON1T, Panda-X) ☺ arXiv:1705.06655, arXiv:1707.07921
- LUX ultimately delivered *4* times better sensitivity in 427 live-days than projected 300 live-day sensitivity for design in the original LUX proposal
  - This is nearly unheard of, especially in direct WIMP dark matter searches!
- Spin-dependent limit still best in world for neutrons
- Strictest constraints on axions and axion-like particles 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 analysis 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!
  - There is a great deal more science yet to come. Be on the look out

Hopefully we are looking for dark matter in ALL the right places !

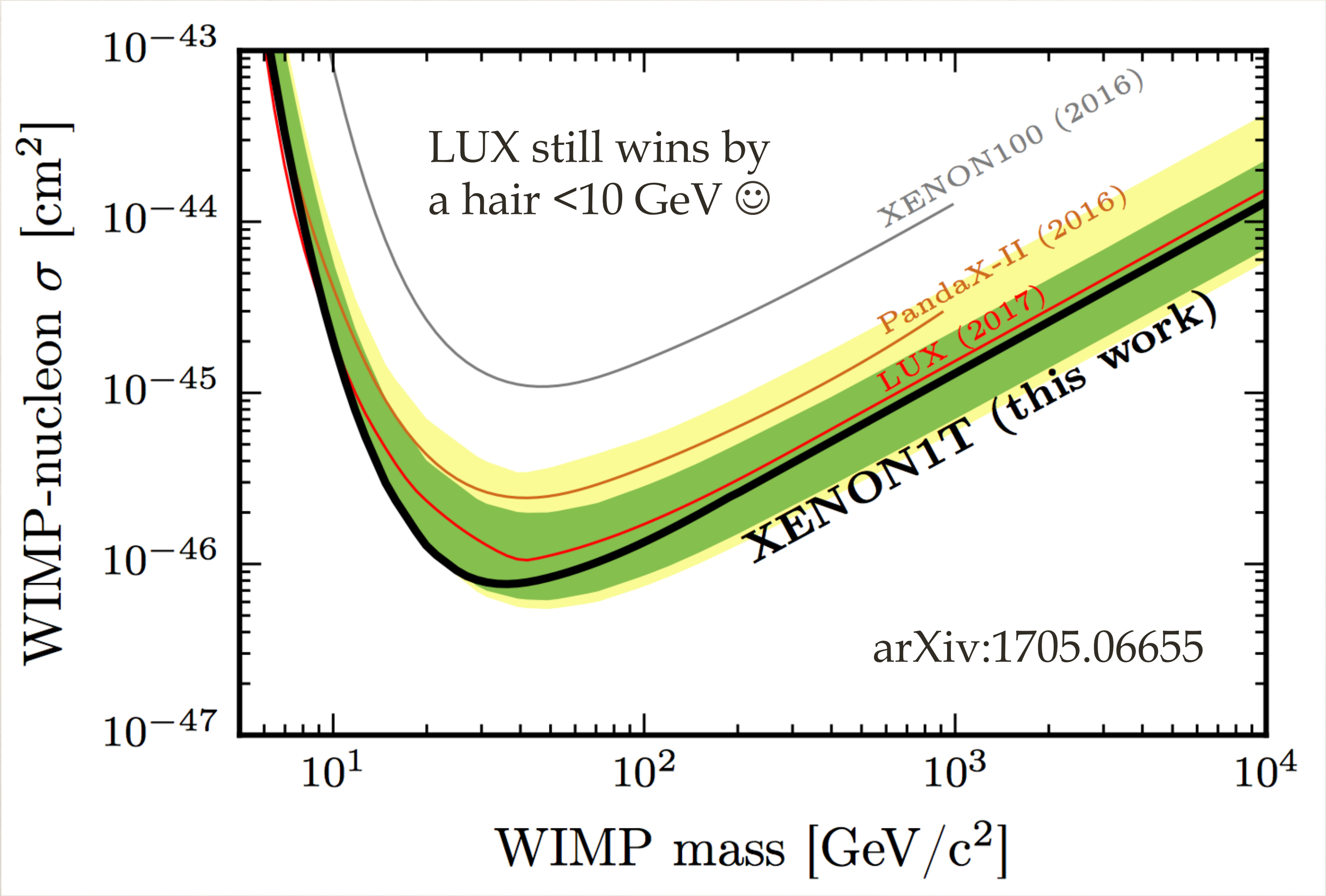
Thank You!
Questions??

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

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



Nod to XENON1T's First



Primordial BHs as DM???

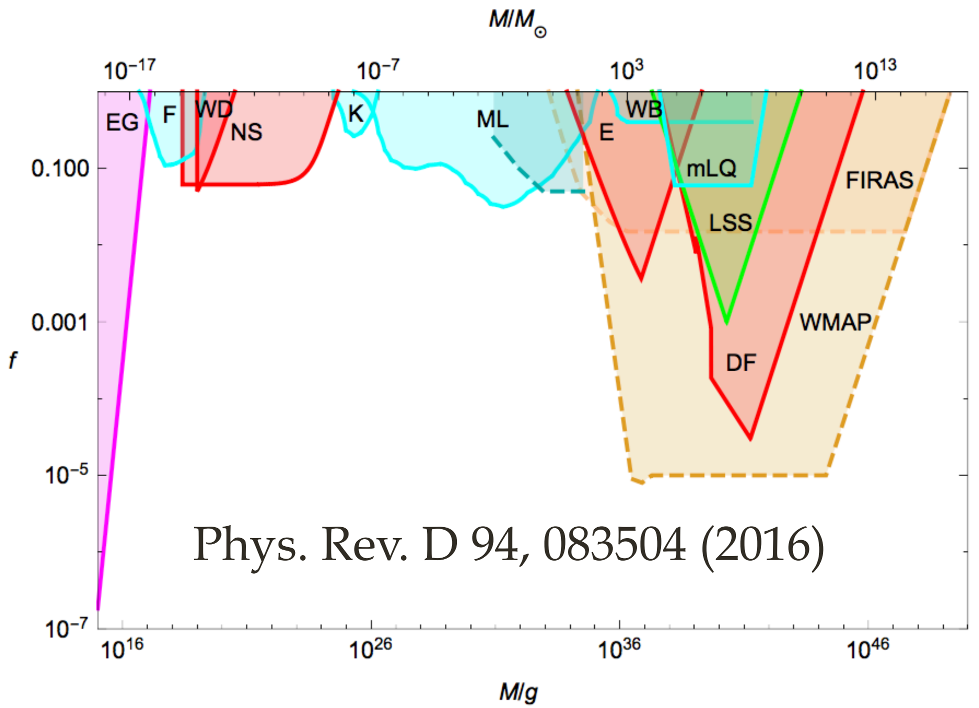


FIG. 3: Constraints on $f(M)$ for a variety of evaporation (magenta), dynamical (red), lensing (cyan), large-scale structure (green) and accretion (orange) effects associated with PBHs. The effects are extragalactic γ-rays from evaporation (EG) [11], femtolensing of γ-ray bursts (F) [187], white-dwarf explosions (WD) [188], neutron-star capture (NS) [36], Kepler microlensing of stars (K) [189], MACHO/EROS/OGLE microlensing of stars (ML) [27, 190] and quasar microlensing (broken line) (ML) [191], survival of a star cluster in Eridanus II (E) [192], wide-binary disruption (WB) [37], dynamical friction on halo objects (DF) [33], millilensing of quasars (mLQ) [32], generation of large-scale structure through Poisson fluctuations (LSS) [14], and accretion effects (WMAP, FIRAS) [15]. Only the strongest constraint is usually included in each mass range, but the accretion limits are shown with broken lines since they are are highly model-dependent. Where a constraint depends on some extra parameter which is not well-known, we use a typical value. Most constraints cut off at high M due to the incredulity limit. See the original references for more accurate forms of these constraints.

Pathologies