New Ideas in Conventional Detectors

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SLAC

16th Rencontres du Vietnam
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Conventional, in this talk

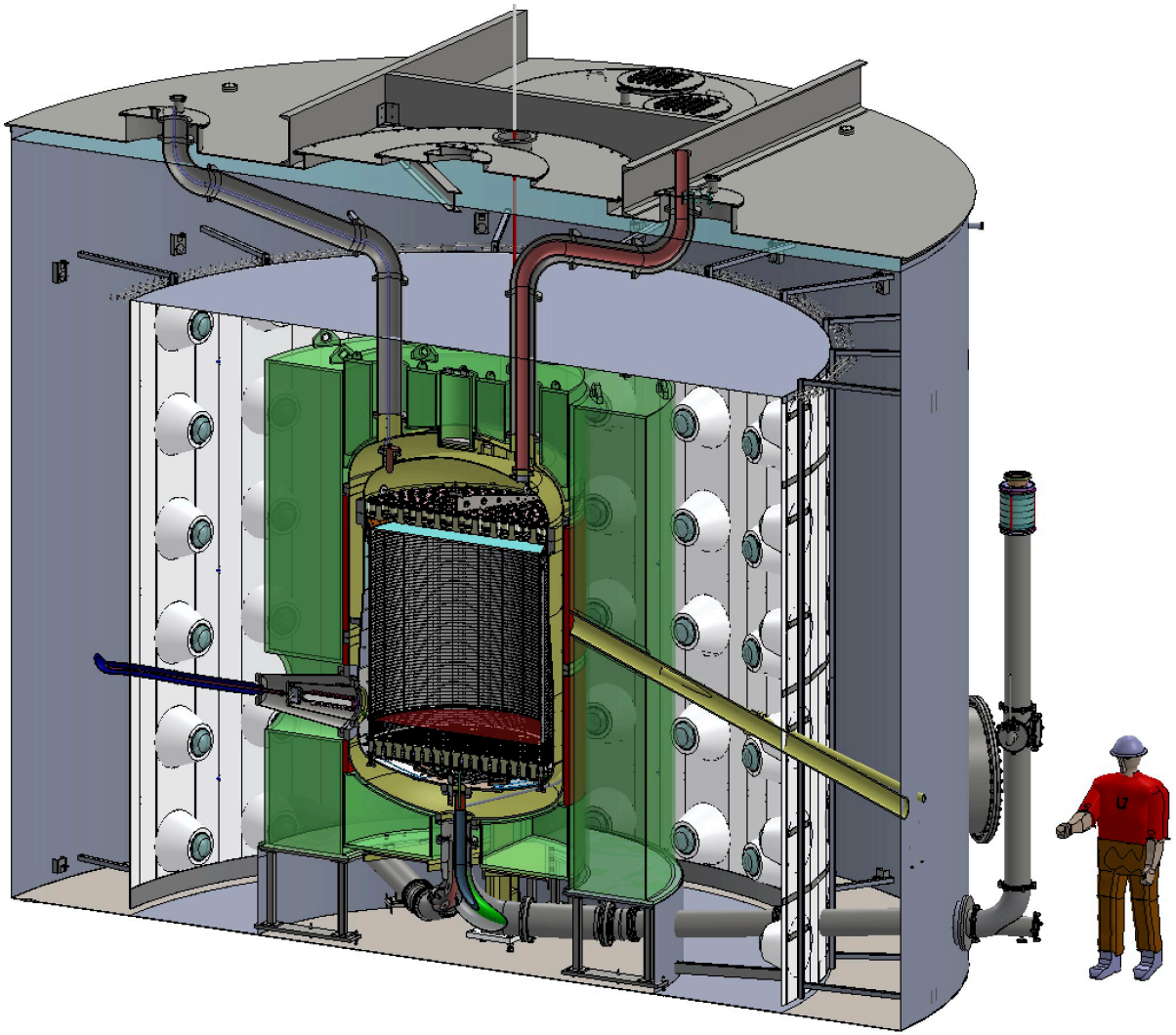
- Dark matter acts like a particle

- Detectors
  - Liquid noble TPCs
  - Next generation cryogenic. (Current: J. Gascon talk)

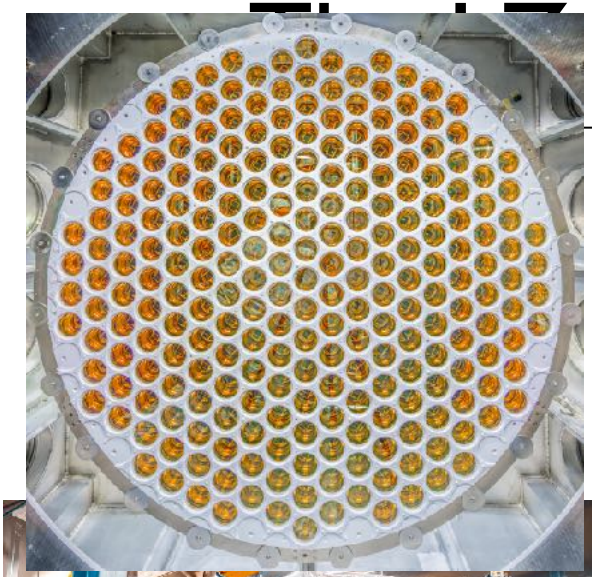
- Not in this talk
  - DM acts like a wave - axions etc., talks by H. Liu, K.J. Bae on Thursday
  - CCDs (DAMIC) + other semiconductors, bubble chambers

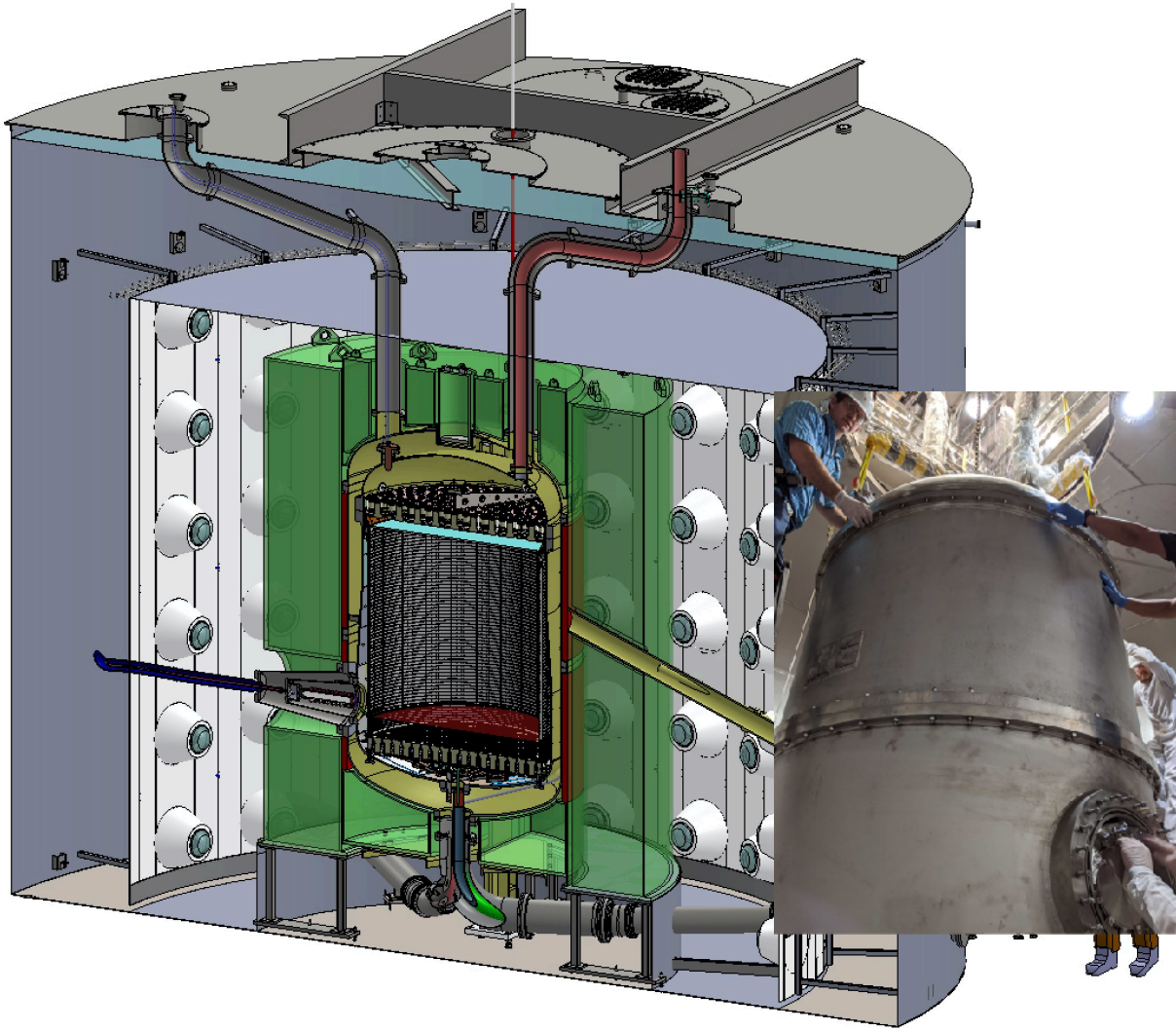
The LZ Dark Matter Experiment

- LXe TPC - 7 tons
- Nested veto: LXe skin + Gd-loaded scintillator



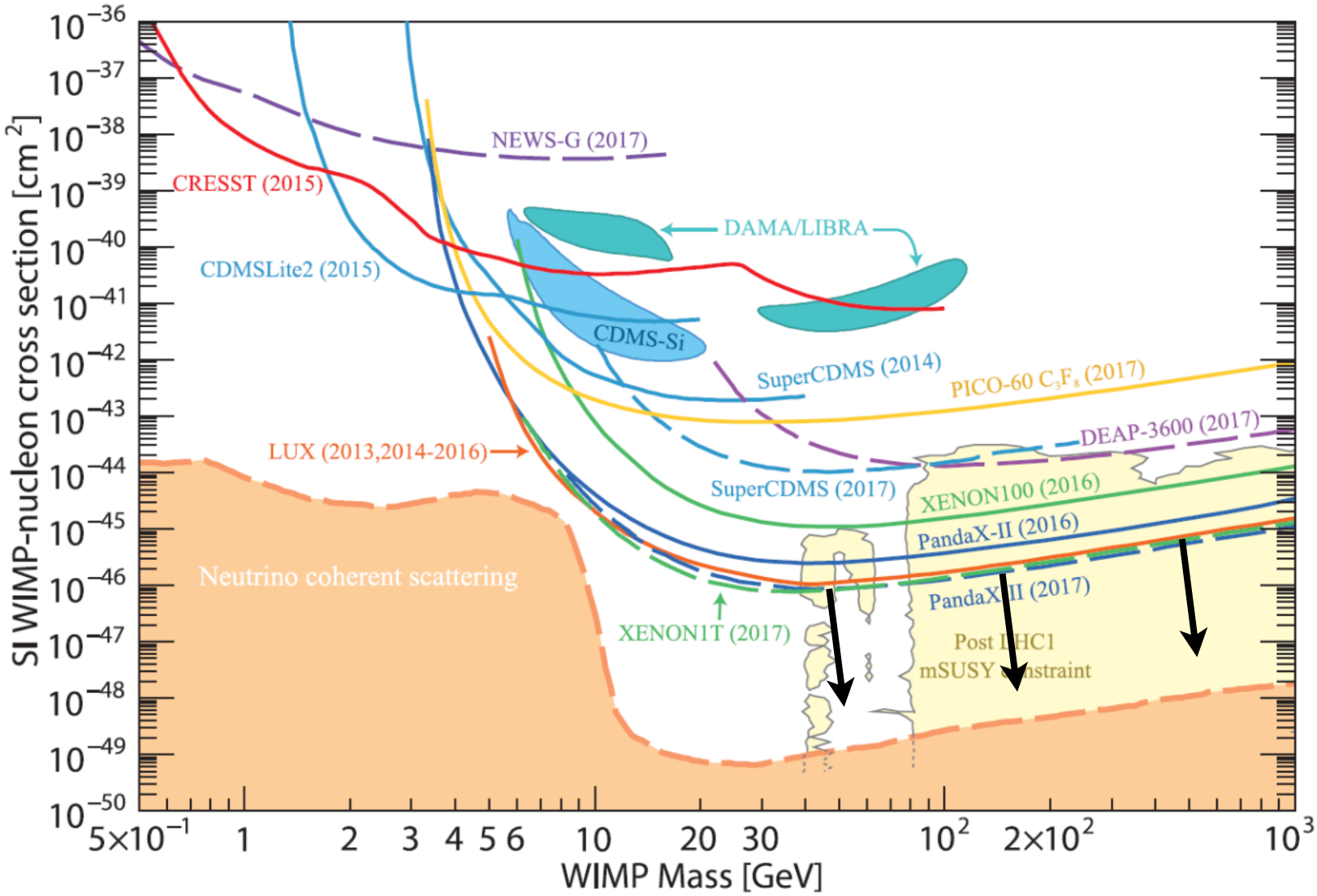
Dark Matter Experiment



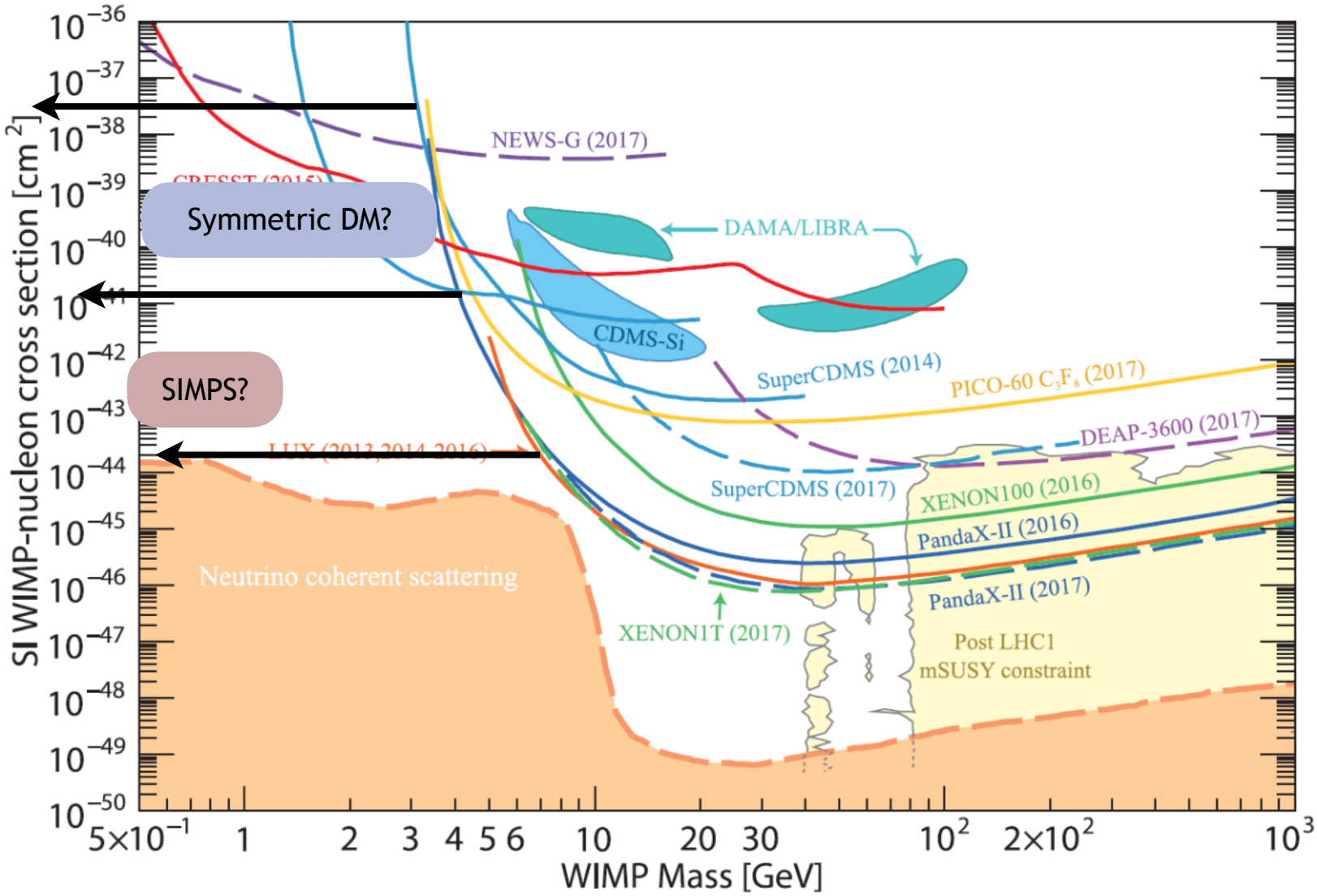


LXe filling this year, first physics in 2021

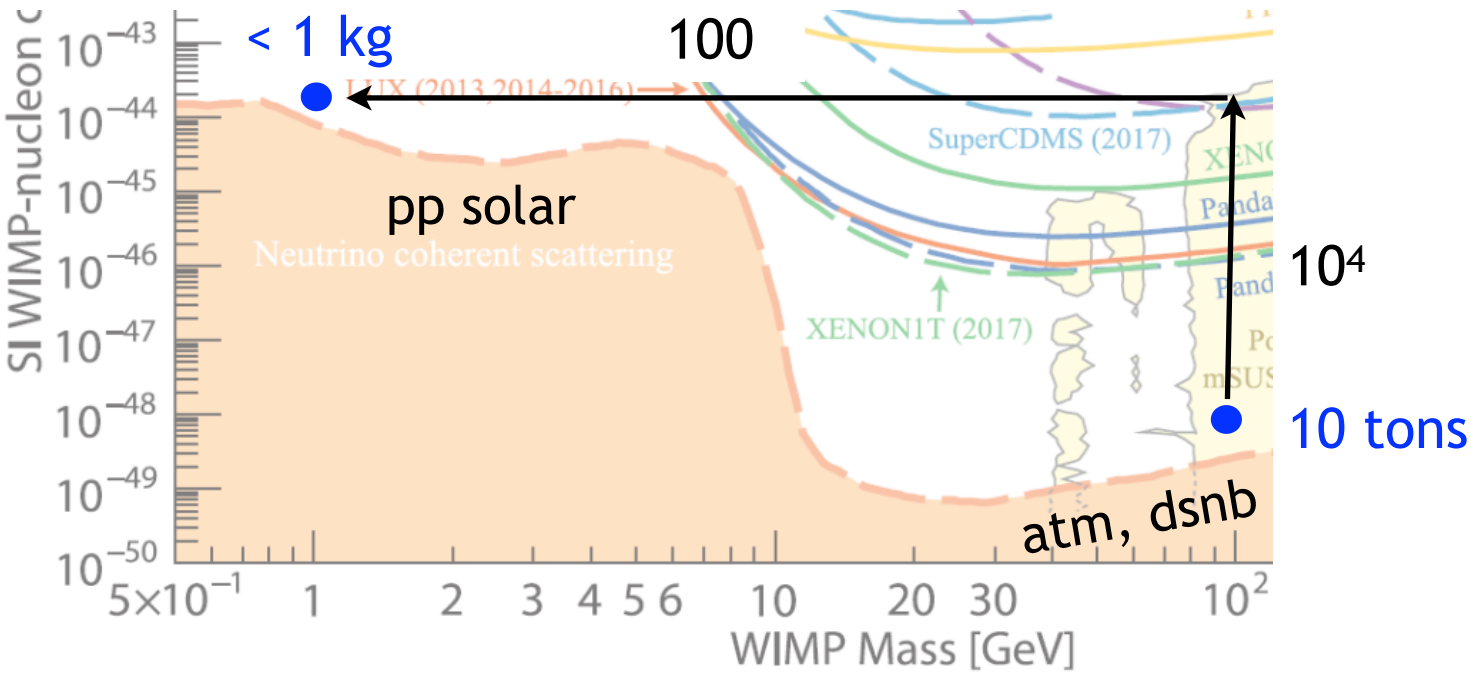
Current focus: neutrino floor



New Idea: Also Look Left



How to look left



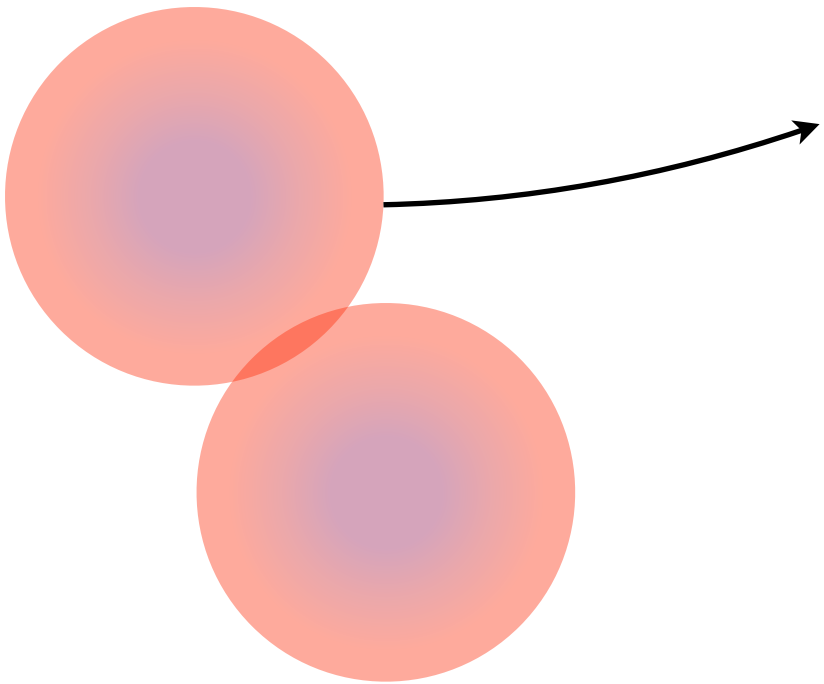
- Low energy threshold, light target

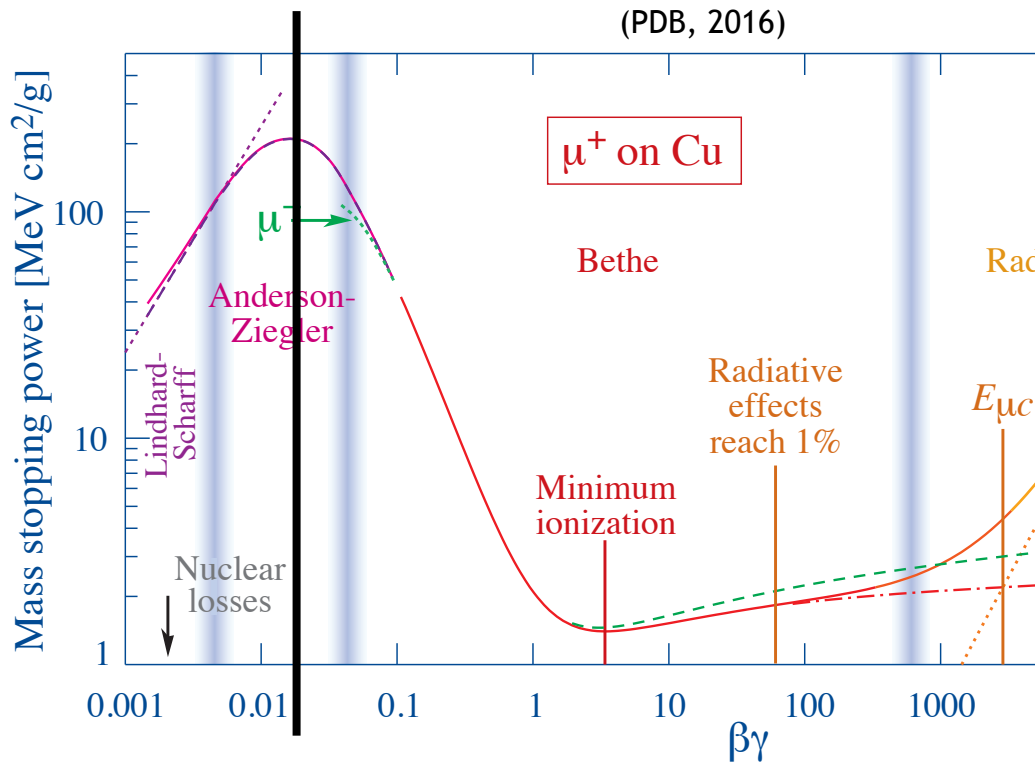
$$m_\chi = 500\ \text{MeV} \times \left[\frac{E_{nr-max}}{0.19\ \text{keV}} \times \frac{M_N}{16\ \text{GeV}}\right]^2$$

- Small detector

Low energy "Nuclear" Recoils

- Lindhard - adiabatic overlap of electron shells
- Most energy goes to heat
- Bigger effect at low energy

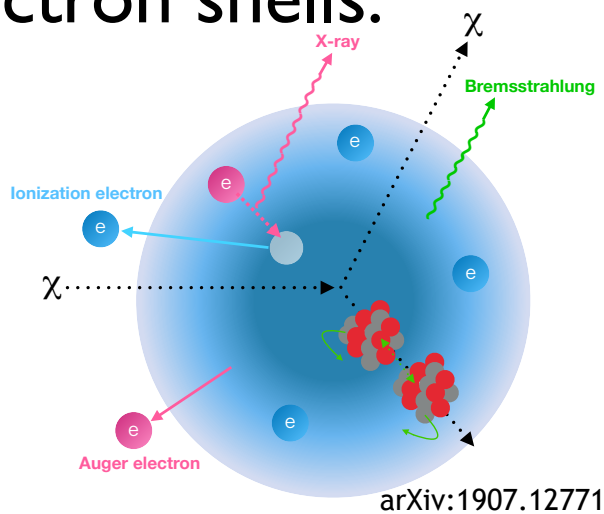




Electron velocity in target atoms

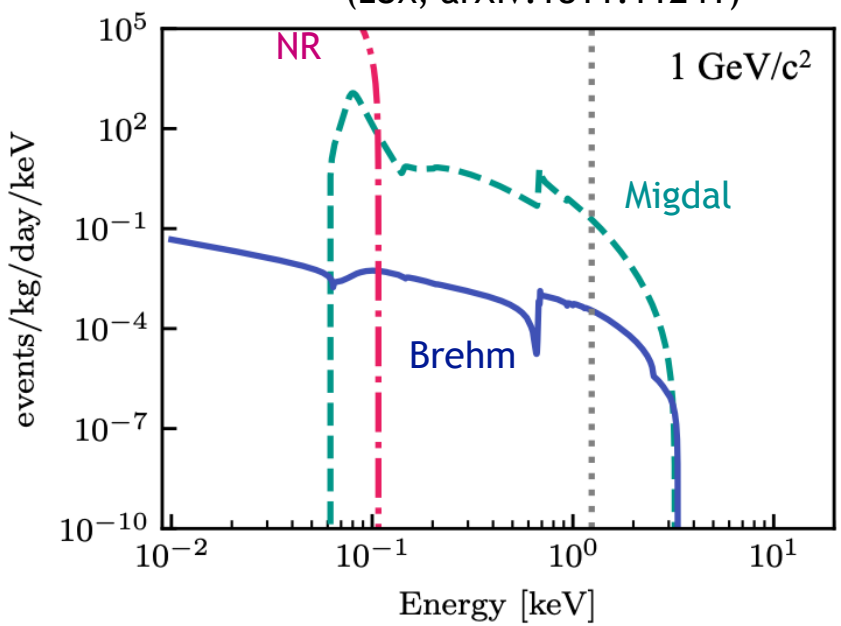
New Idea: different channel

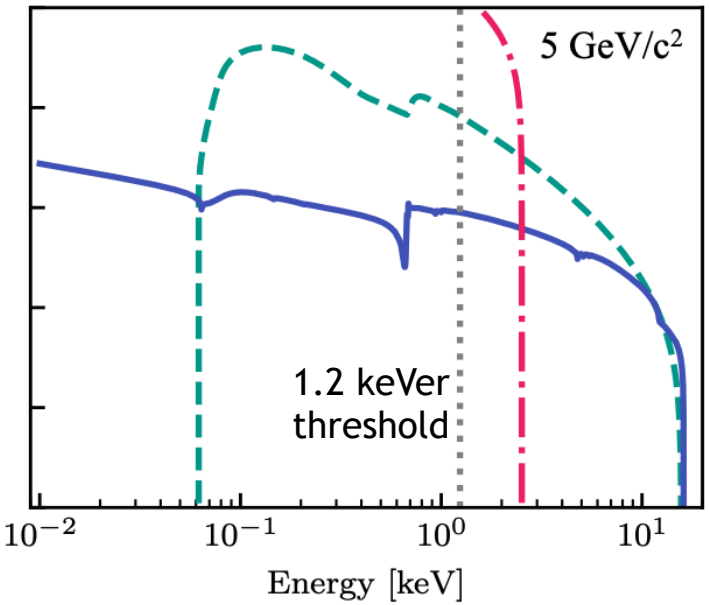
- Migdal: initial nuclear kick excites electron shells. (Ibe, et al., arXiv:1707.07258)
  - Small probability, depends on shells
  - Boosted energy in ER channel
  - Also "Bremsstrahlung" (Kouvaris, Pradler, arXiv: 1607.01789)



arXiv:1907.12771

(LUX, arXiv:1811.11241)





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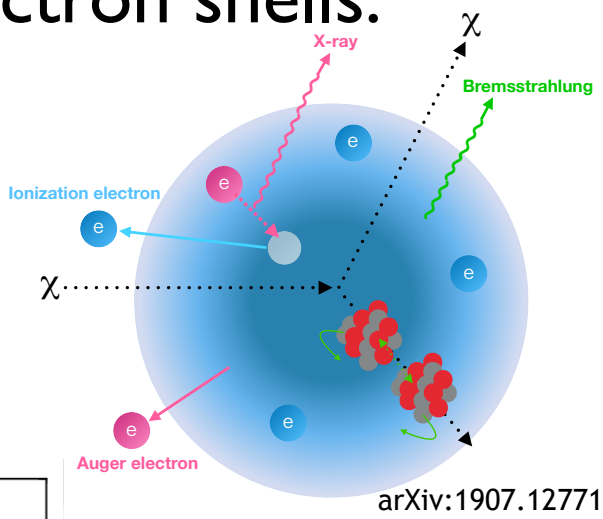

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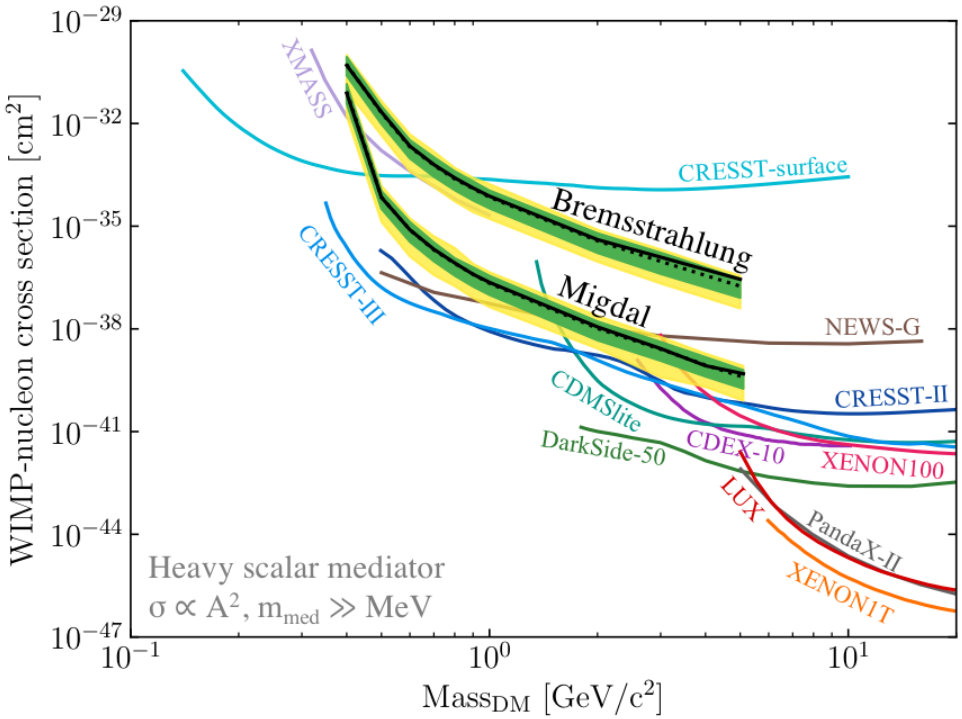
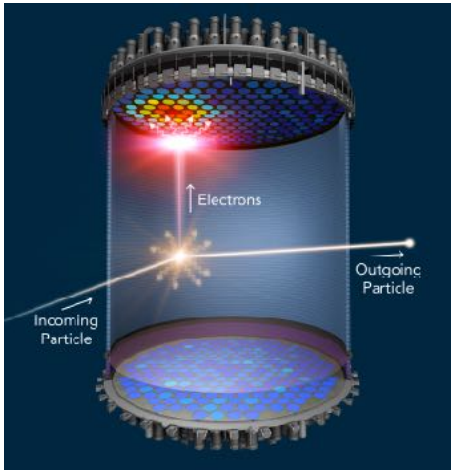
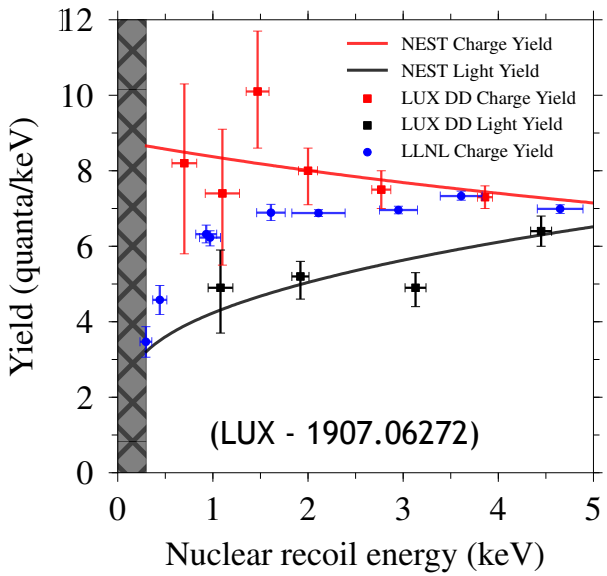


Big penalty in rate

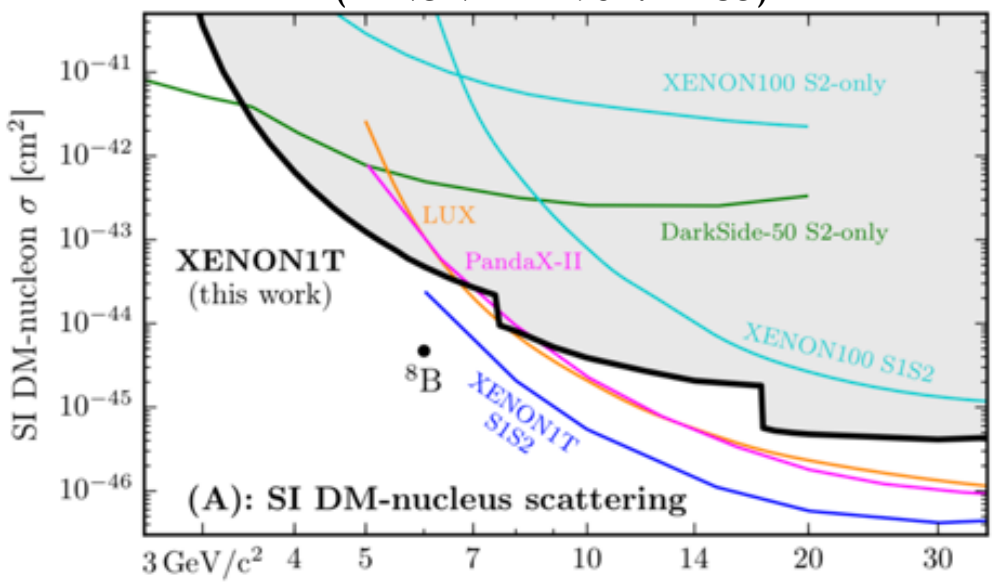
Newish Idea: S2 only in LXe/Ar TPCs

- # electrons, photons comparable
- Light collection ~10%,
  e^- collection ~100%
- Substantially reduce *E* threshold
- ~~Time Projection~~ Chamber



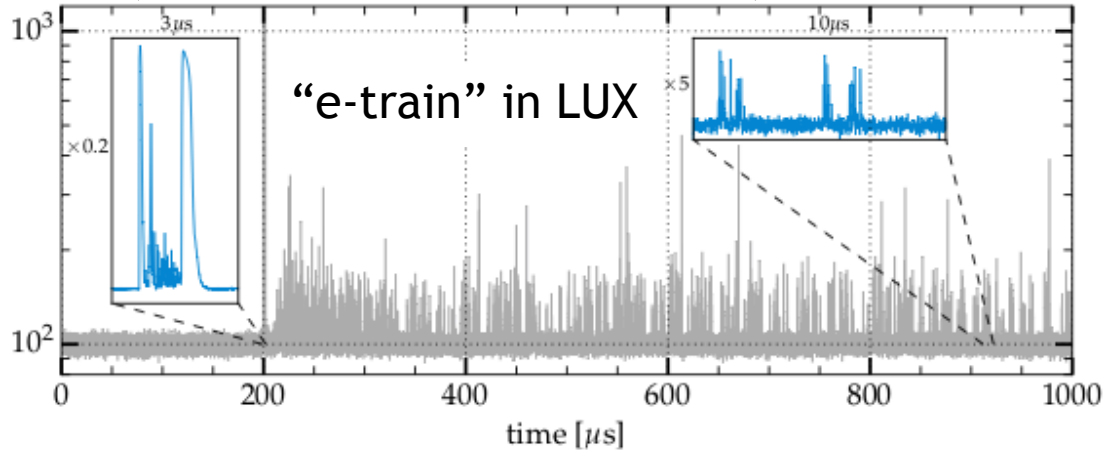


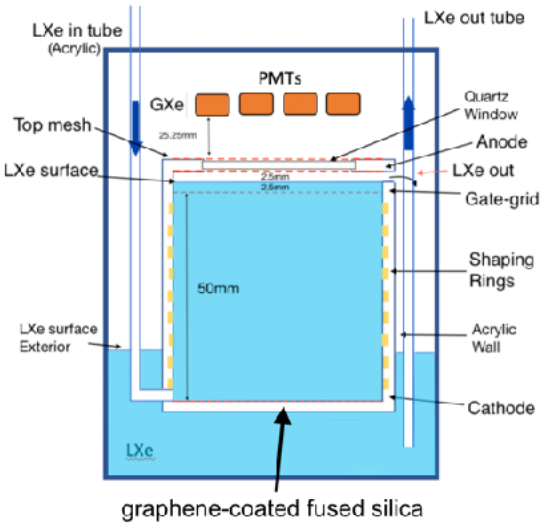
(XENON1T - 1907.11485)



S2 only electron background

(Sorensen, Kamdin, arXiv:1711.07025)



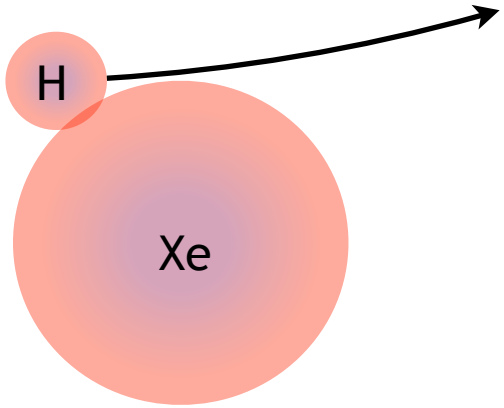


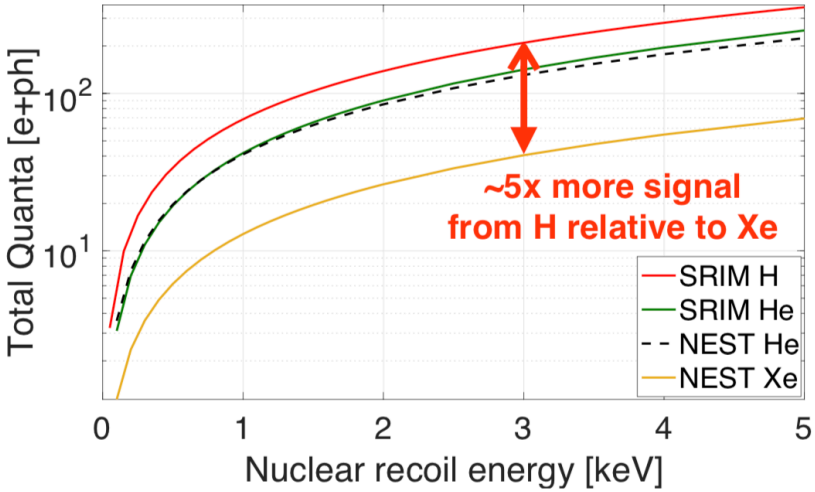
LBECA prototype - sealed chamber with high chemical purity

- Several sources of electrons
- LBECA: dedicated S2 only experiment
  - Electron reduction methods under study
  - 100 kg LXe detector proposed
- LZ: major program to reduce emission from grids
  - electron signal ~4 times larger than LUX

Very new idea: doping

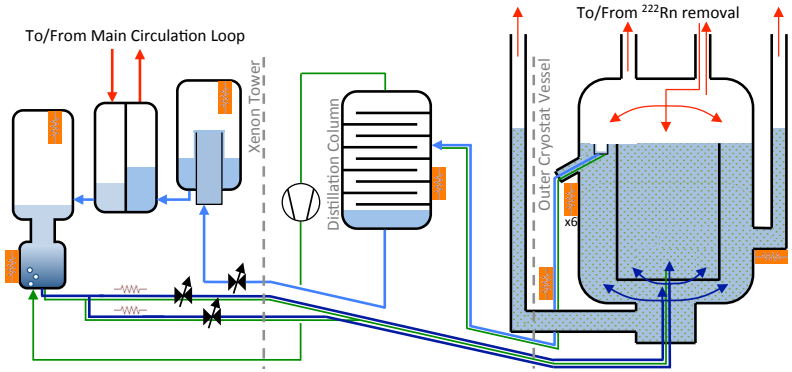
- Dissolve H2 (or He) in LXe TPC
- Proton is *best* low mass target
  - 3 e^- E_{nr}~100 eV: m_x~100 MeV
- Lindhard nullified by m_H, m_{Xe} imbalance
- H2 and D2: odd n and p
  - or He, if ok with PMTs
- HydroX - new experiment, currently LZ-based



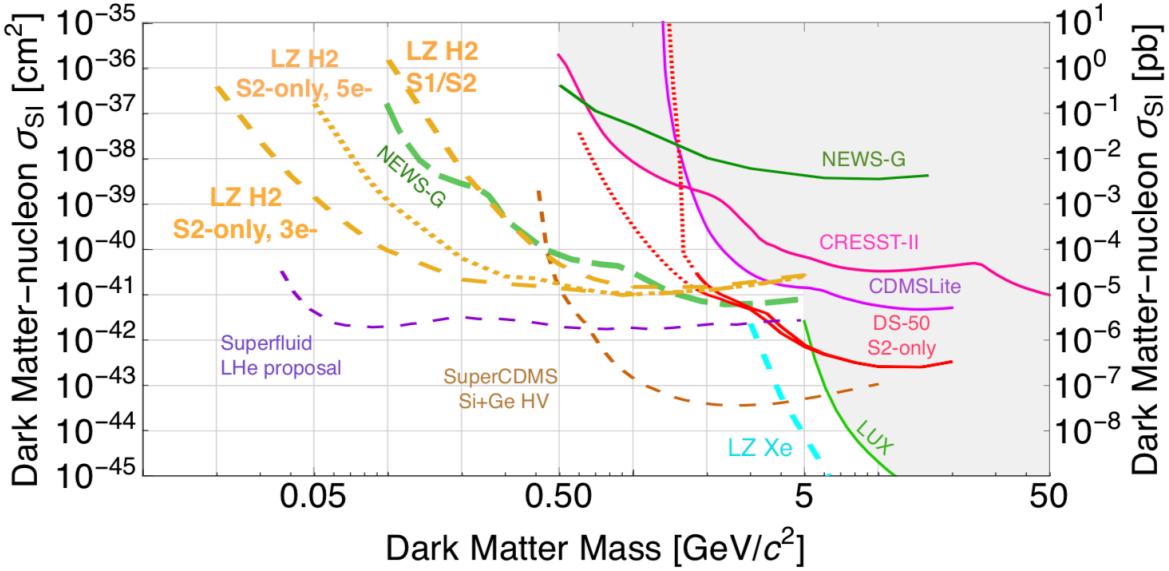


HydroX

- *LZ fiducial becomes shield*
- Modify purification to cope with H2
- Need to check
  - H2 solubility
  - charge yield
  - effect of H2 on S2



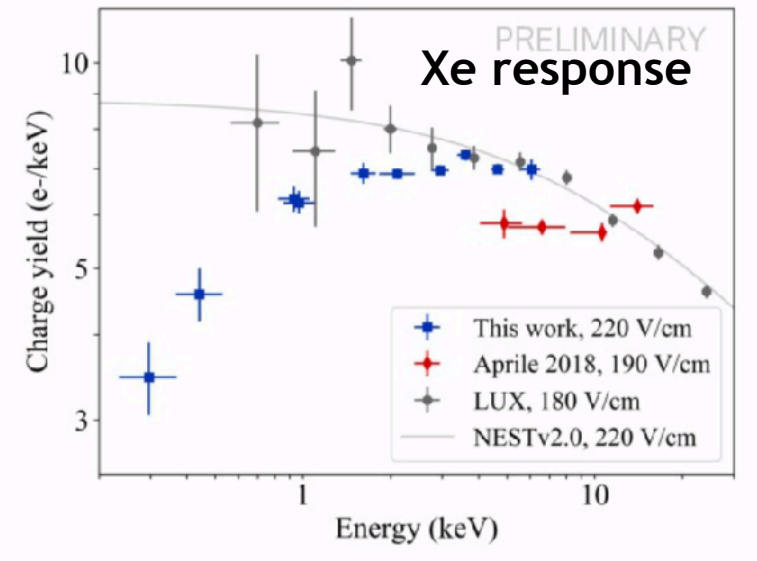
Preliminary Projections



Calibrating Nuclear Recoils

- Lindhard - successful at high energies
  - But recent lower yields in Si, Xe. Generic?
- Must calibrate below threshold
- Increasingly active area
  - Beams with variety of reactions
  - Photo-nuclear sources + gamma shield
  - Notch filters
  - In-situ calibration ideal
- Need keV neutrons to calibrate H!

B. Lenardo, April APIS, 2019



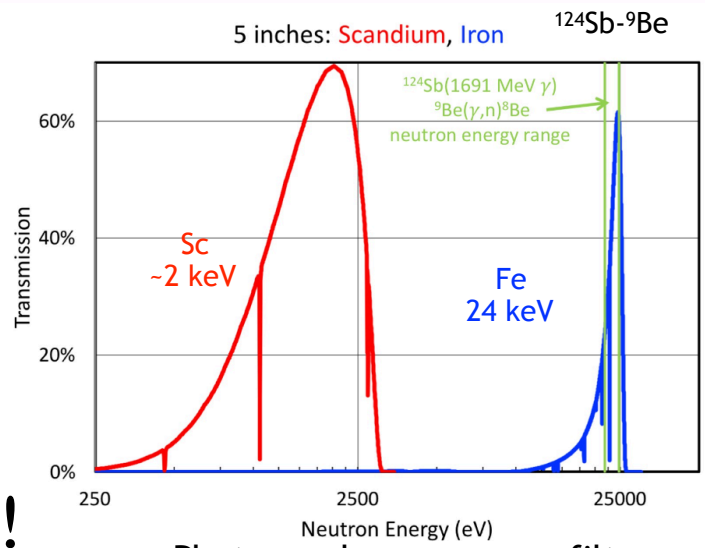
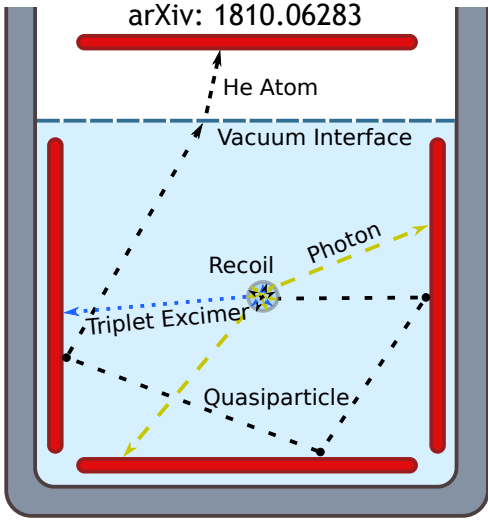


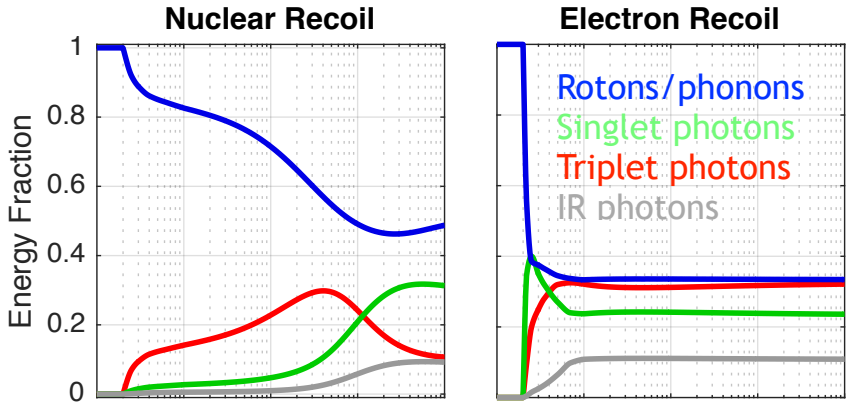
Photo-nuclear source + filters (HydroX, unpublished)

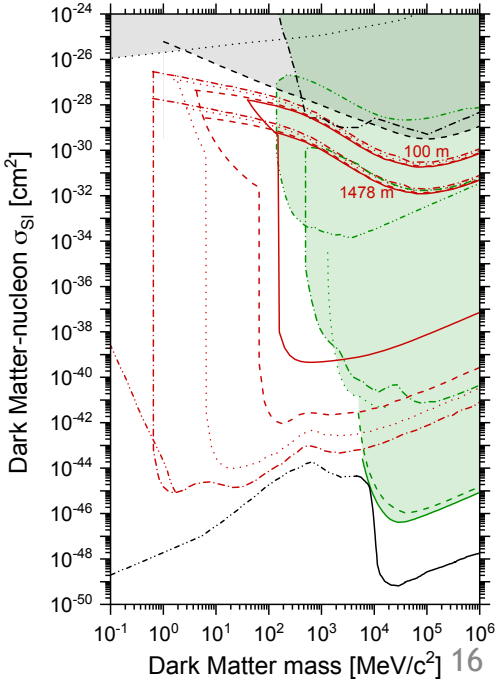
Superfluid ^{4}He

- Low mass target
- Complex set of excitations
  - Excimers, singlet ~ns, triplet 13 s
  - IR light
  - Phonons / Rotons
  - Should provide discrimination
- Early work on HERON, proposed solar ν exp.
  - *Significant advances in sensors and cryogenic technology since then*

HERALD, Hertel et al., arXiv: 1810.06283







Superfluid ^{4}He

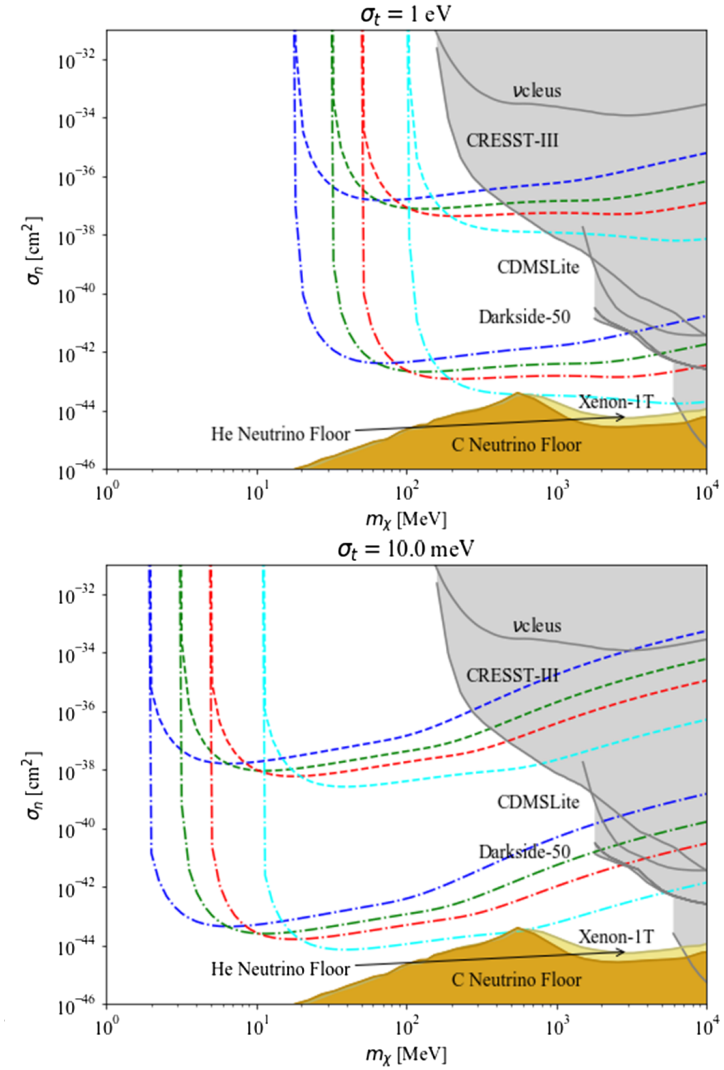
- Field ionization to measure ejected He atom. (Osterman, et. al, TAUP 2019)
- Response is complicated: recent EFT approach (Esposito, TAUP 2019)
- Beyond this: collective modes in He approaches m_{DM} ~ keV (Schutz, Zurek, arXiiv:1604.08206)

"Channeltron" with field ionization tip

Cryogenic Wild West

- Energy measured to ~meV
  - Superconductors+TES (Hochberg, Zhao, Zurek arxiV:1504.07237)
  - Magnetic bubble chambers (Bunting et al., arXiv:1701.06566)
  - Optical phonons (Knapen et al., arXiv:1712.06598)
  - Diamond (Kurinsky, et al., PRD 2019)
  - Absorption in superconductor (Hochberg et al., arXiv:1604.06800)
  - 3D Dirac materials (Hochberg et al., arXiv:1708.08929)
- For electron recoils: m_{DM} ~ keV

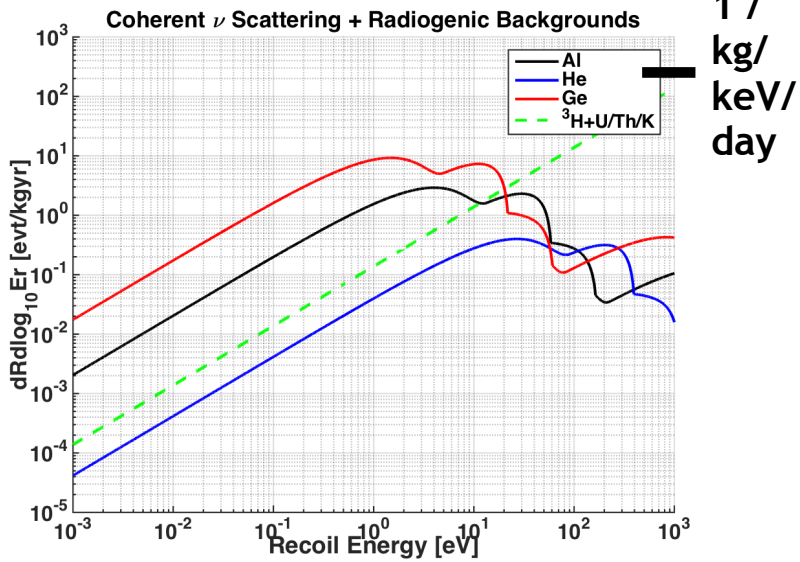
PhysRev D 99, 123005 (2019)



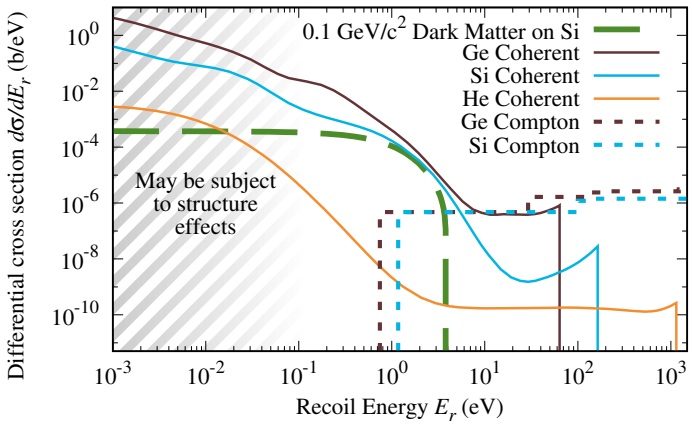
Backgrounds

- Backgrounds below ~keV are *terra incognita*
- Little self shielding at ~kg mass
  - Rates better than 1/kg/keV/day only with enormous effort
- Robinson: coherent Compton scattering *rises at low energy*
- Non particle 'backgrounds"
  - PICO particles
  - CRESST crackophonics ~ca. 2000
  - Will these proliferate at low energy?

Hochberg et al., arXiv:1512.04533



Robinson, arVix:1610.07656



Summary

- As we approach neutrino floor for WIMPs, new frontier has opened at low mass
- Wide variety of new ideas building on existing technologies
- Exciting time for hunting dark matter