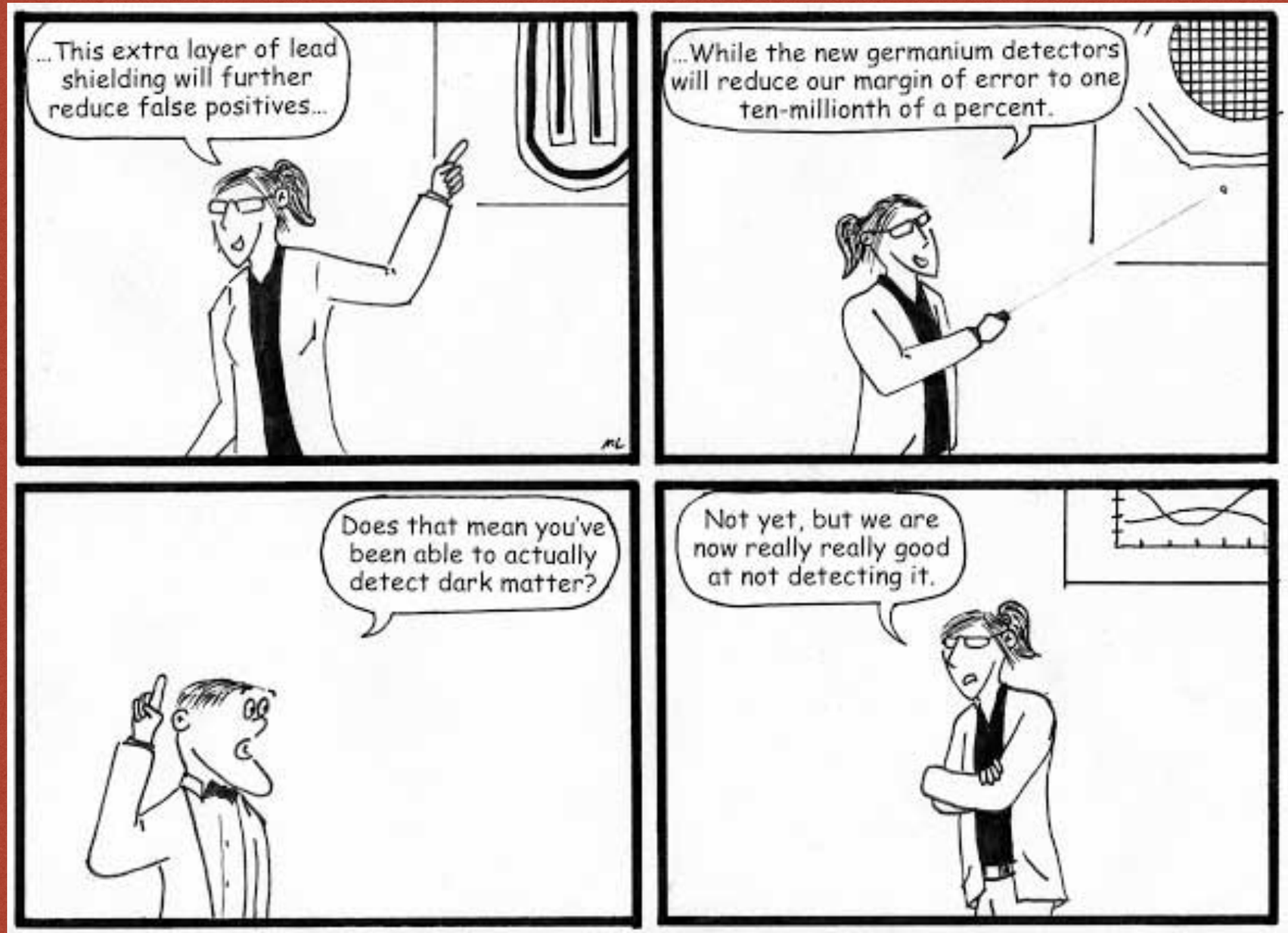


Michael Lucibella 2014, APS.org

Recent Results and Prospects for Direct Dark Matter Detection

Kimberly J. Palladino
University of Wisconsin Madison
June 5, 2018
Blois, France

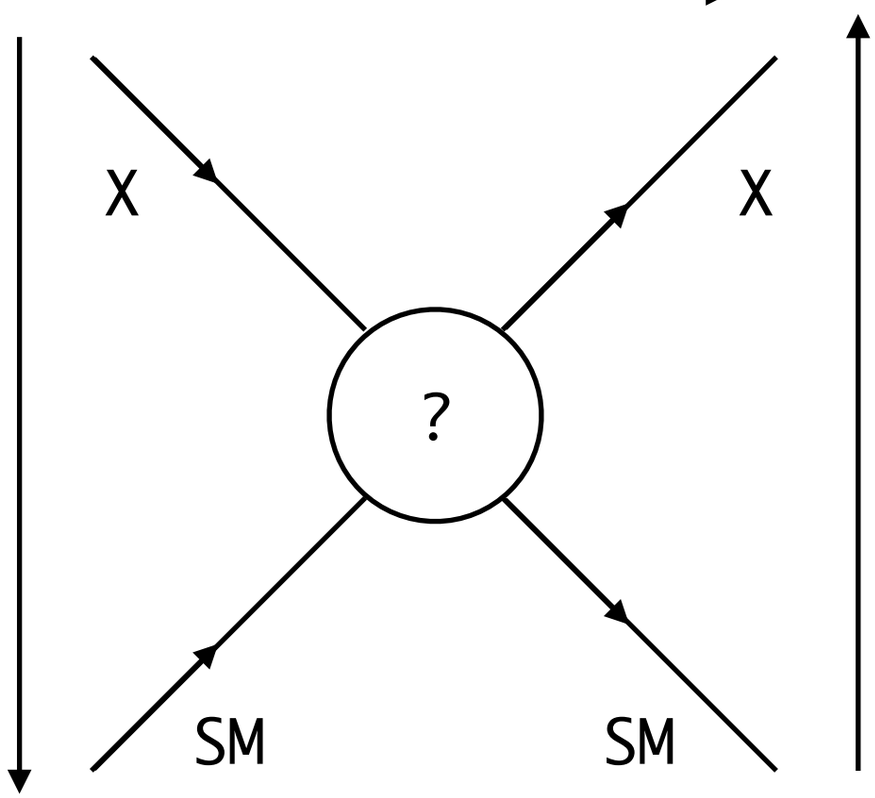
Dark Matter Searches

Shake It!

Direct (Scattering)

Break It!

Indirect
(Annihilation)



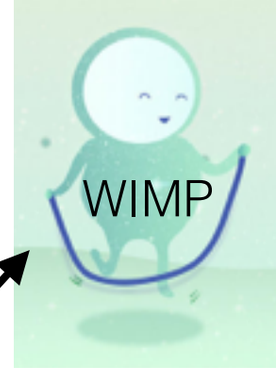
Make It!

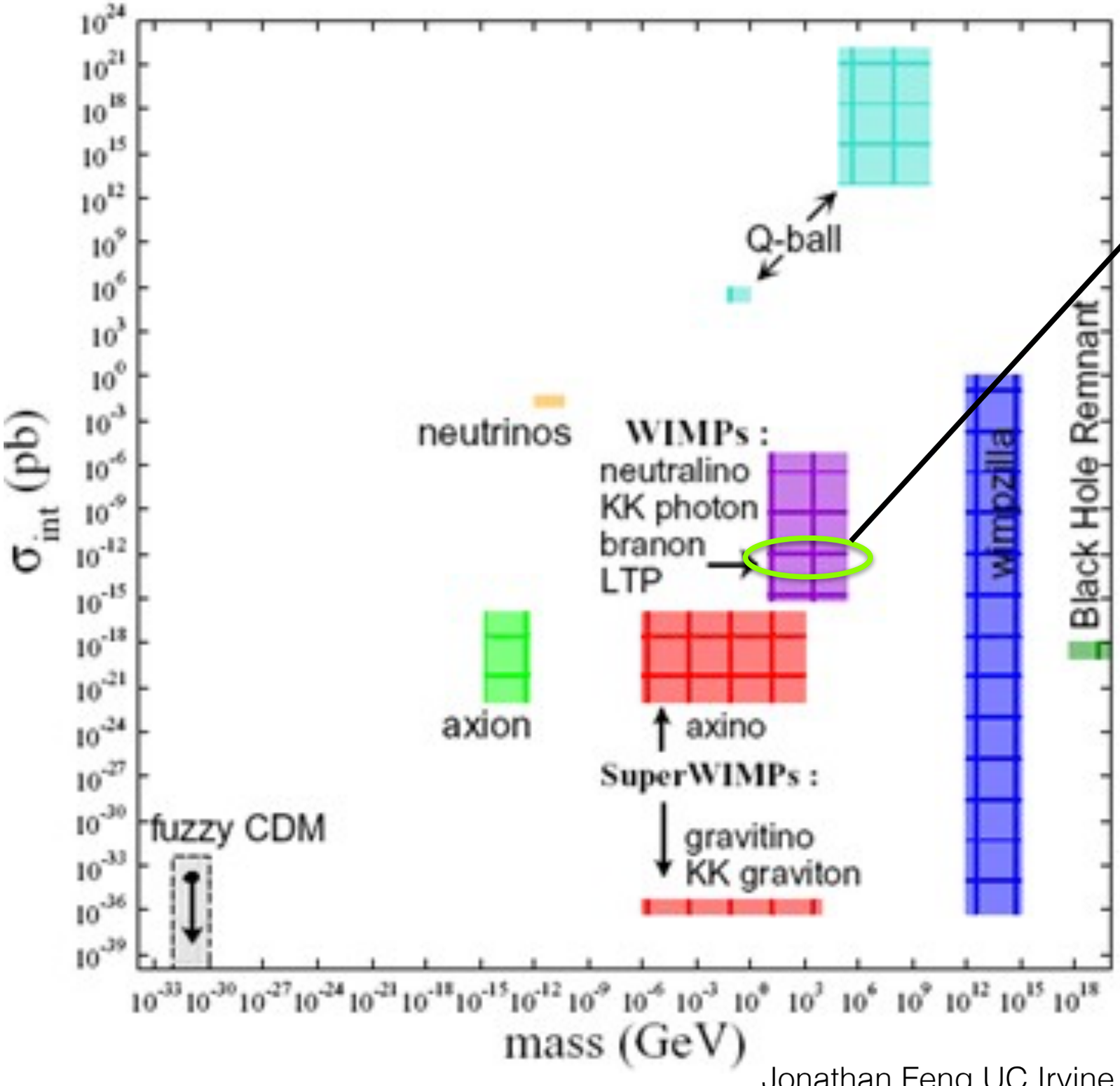
Collider
(Production)

Bake It!

Theorists
(Models)

Dark Matter Parameter Space (out of date)





Jonathan Feng UC Irvine

Direct WIMP Detection needs

- Ability to see low energy WIMP induced recoils
  - Radiogenically pure
  - Low threshold
- Ability to distinguish nuclear recoils
  - Difference between electronic recoils & nuclear recoils
  - Difference between alphas and nuclear recoils
- Shielding from radiogenic and cosmogenic backgrounds
  - Position reconstruction and fiducialization
- Detector stability for annual and diurnal modulation

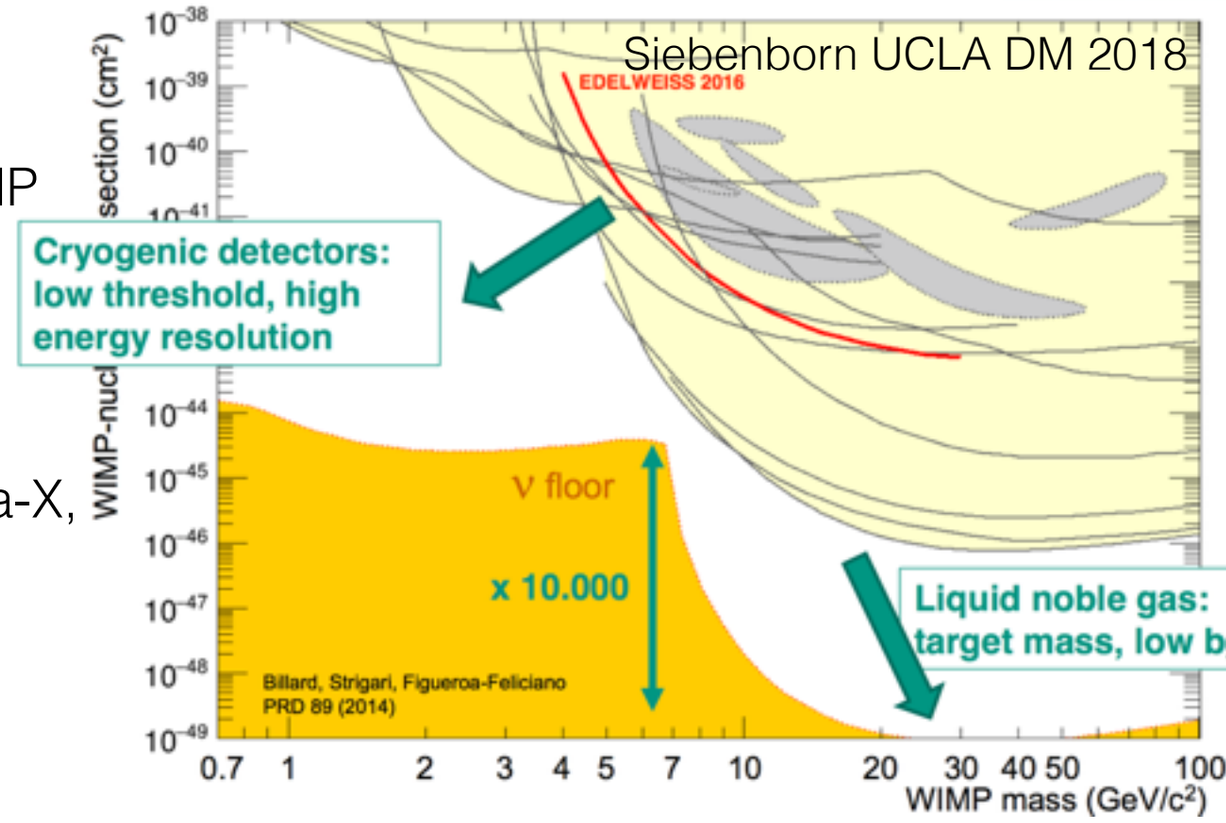
An analogy to the Big 5 Tech Firms

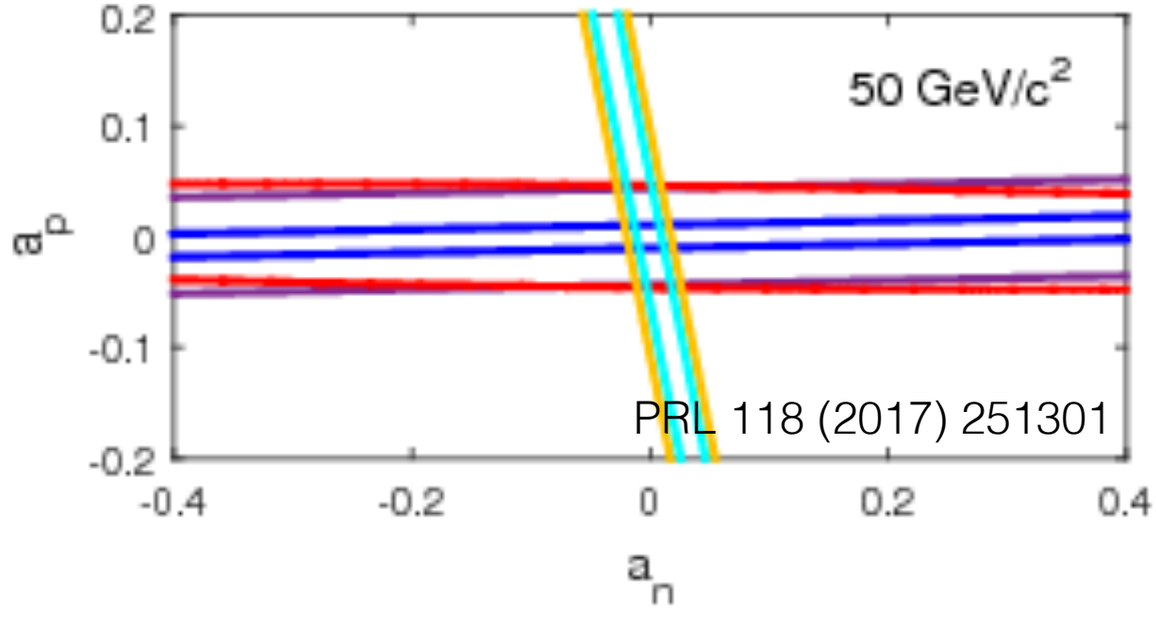
What criteria help set which experiments to cover in this talk?

- Canonical: First to come to mind
  - Establishment, Behemoths
- Big: larger collaborations, more established projects, largest detectors that can lead in sensitivity
- Dark Matter: WIMP mass range 1 - few 100 GeV/c^2 Generally less innovation, but leading the field

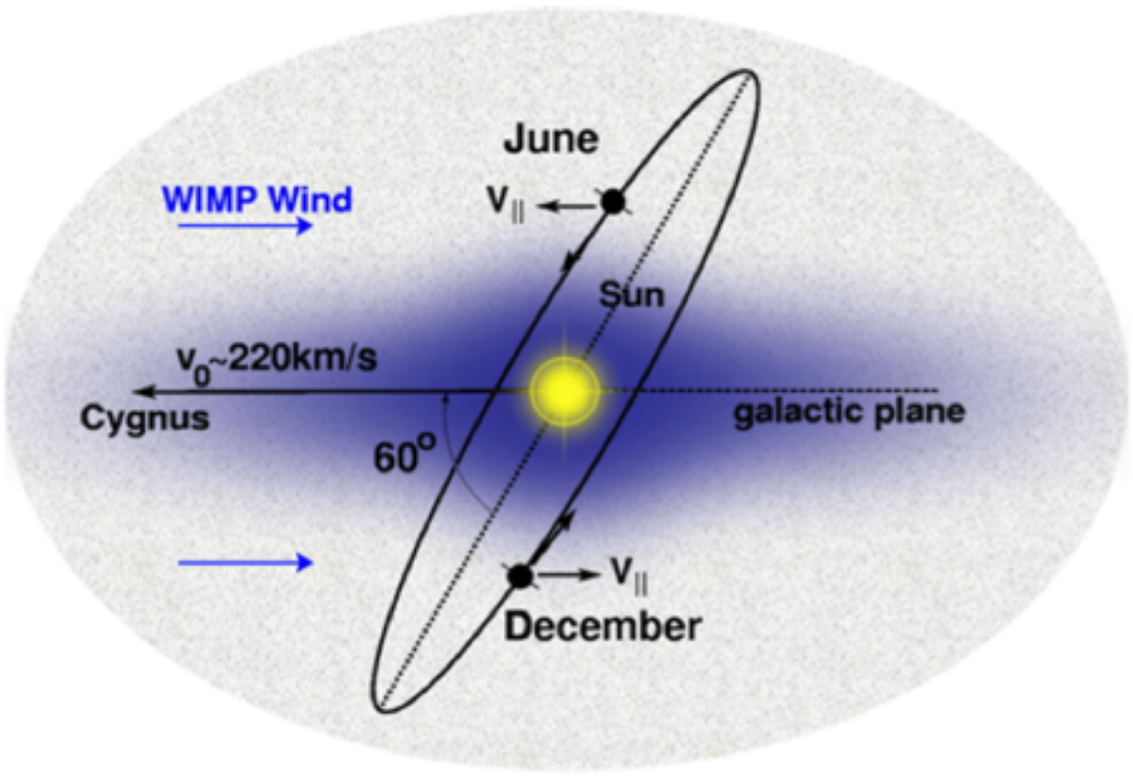
Three Divisions to Explore

- **Liquid Noble targets**
  - Largest and most sensitive over the widest WIMP range
  - 5 GeV-1 TeV WIMP masses probed
  - Darkside, DARWIN, DEAP3600, LUX, LZ, Panda-X, XENON1T, XENONnT
- **Cryogenic crystal targets**
  - Oldest technology, with new innovations
  - 1-10 GeV WIMP masses probed
  - CRESST, EDELWEISS, SuperCDMS,
- **Alternate targets with unique properties**
  - NaI crystals, bubble chambers
  - ANAIS, COSINE, DAMA/LIBRA, SABRE, PICO





What's not on that list?

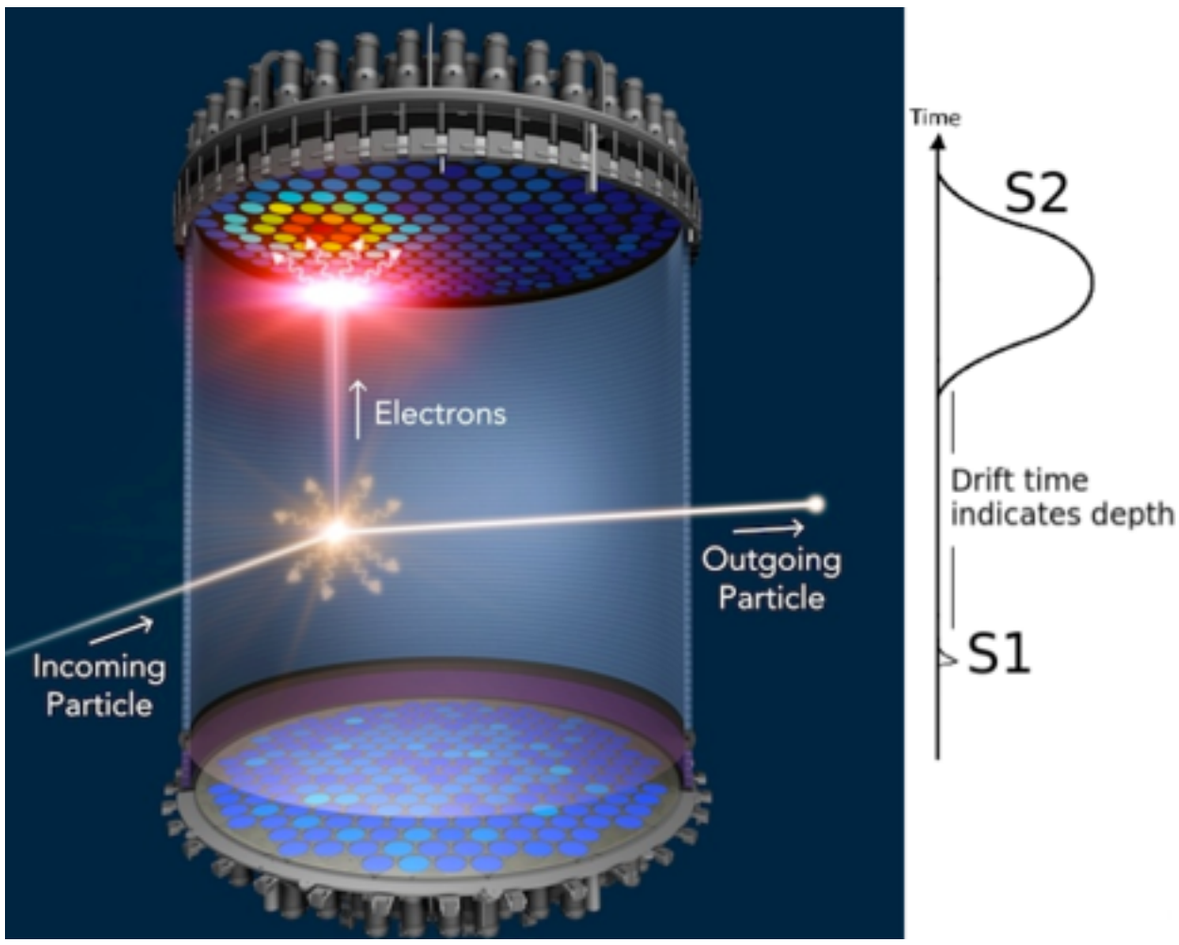


- Directional Detectors
  - Most established techniques are gaseous time projection chambers, very active research area
  - Naka and Gerbier talks today and tomorrow

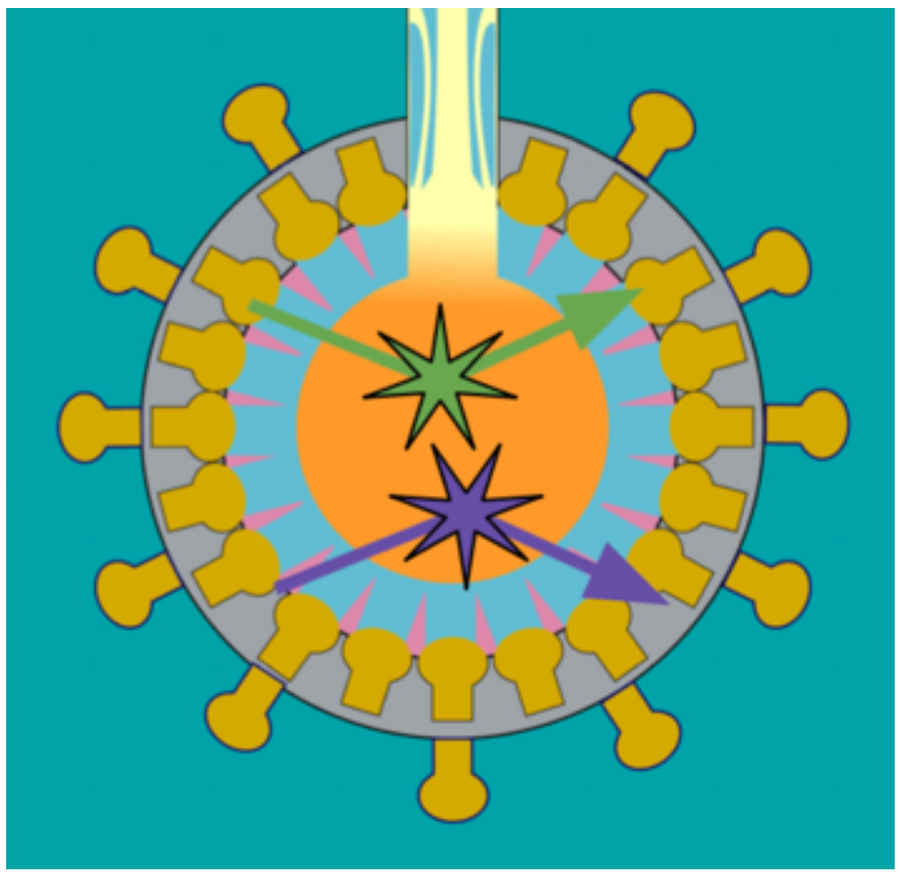
- Axion Detectors
  - A very different dark matter candidate, with a very different direct detection signal

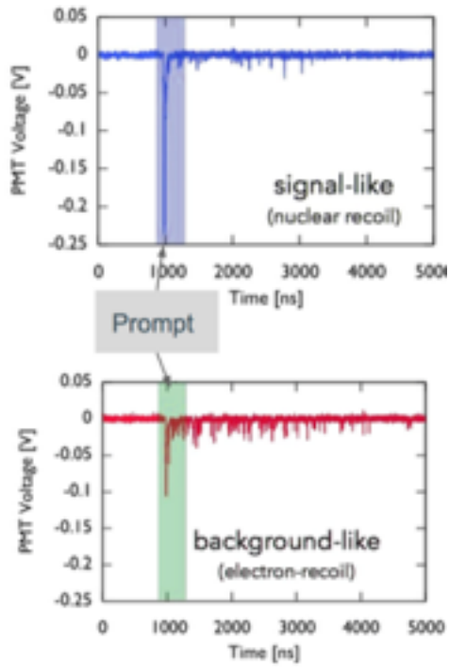
Characteristic liquid noble detectors

Dual Phase

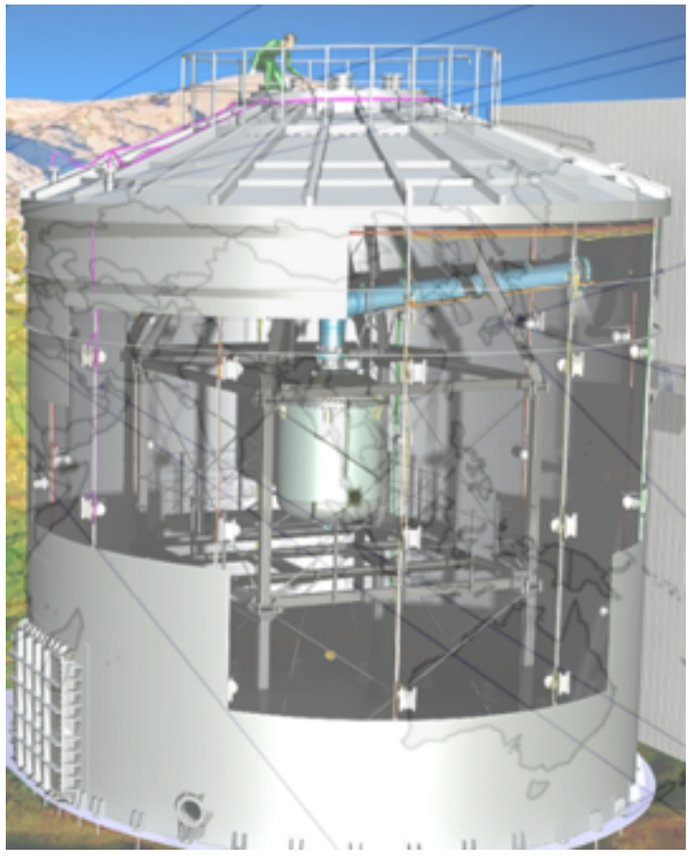


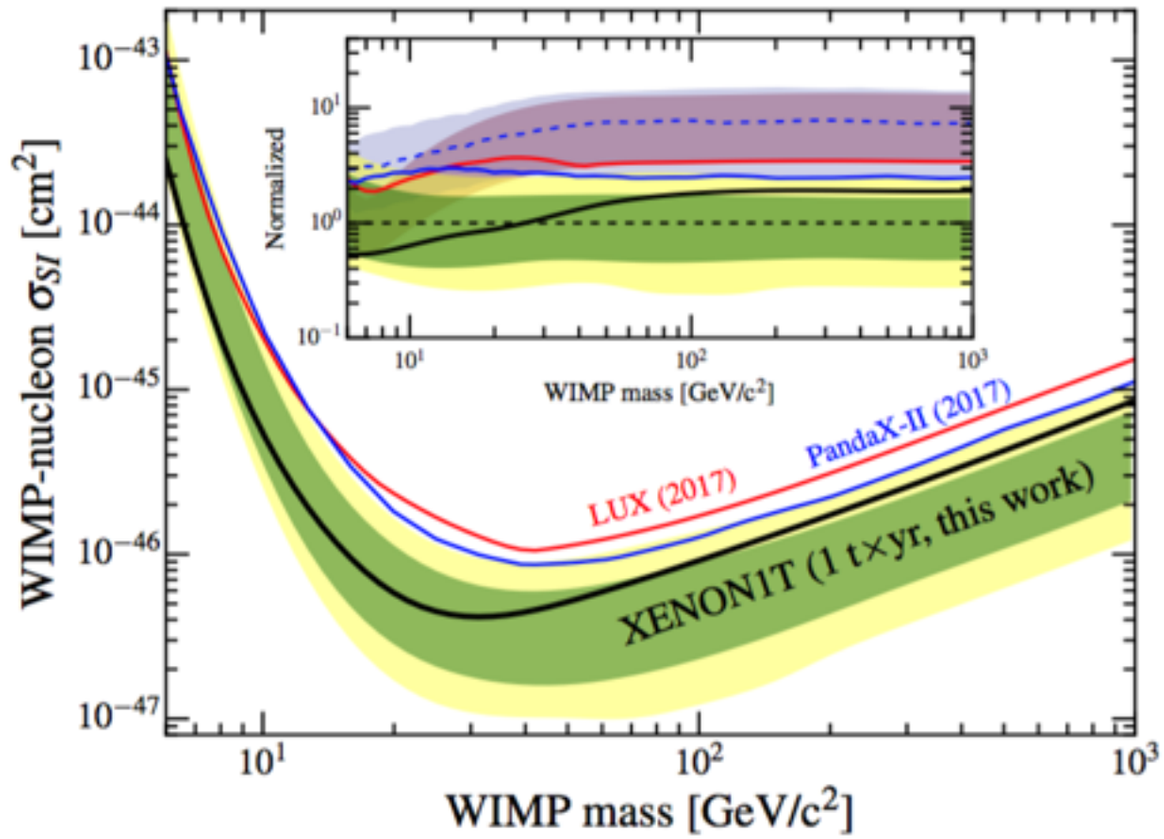
Single Phase





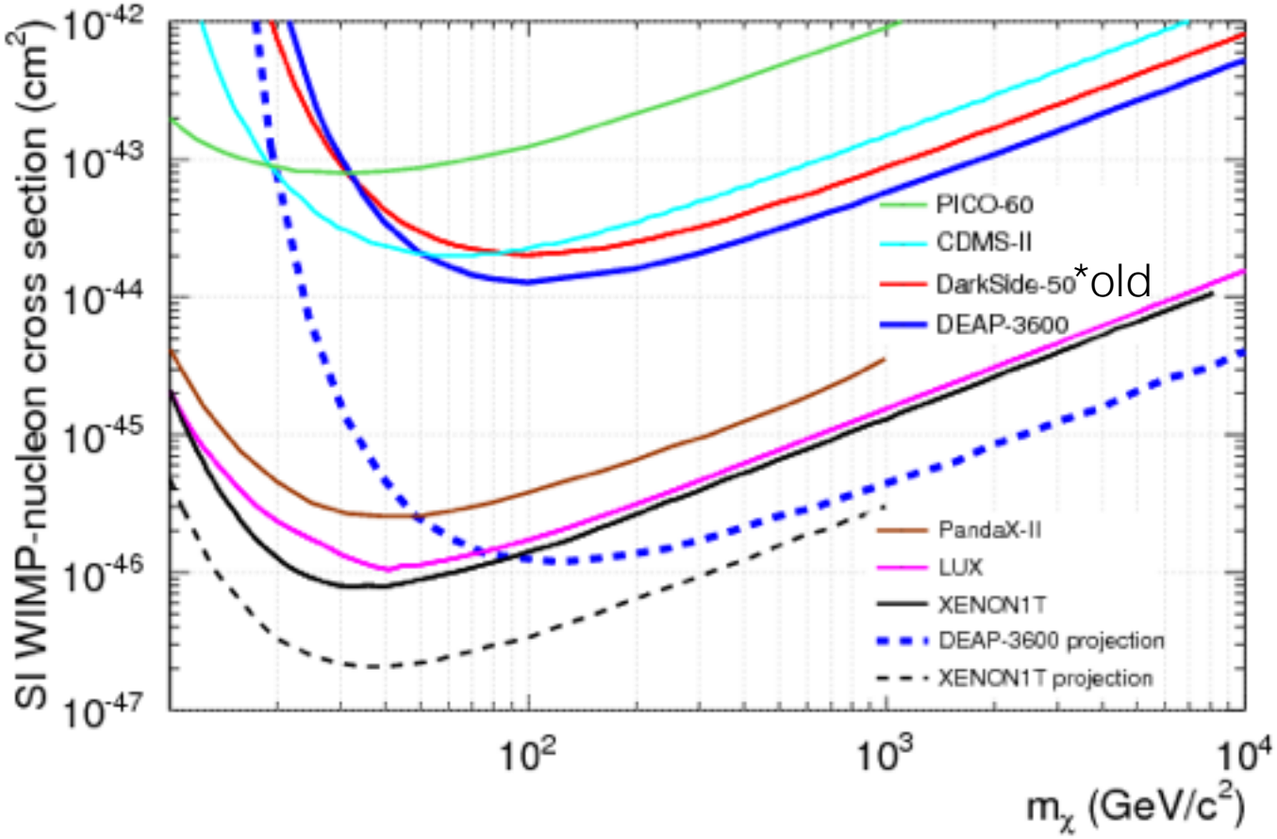
New results in xenon





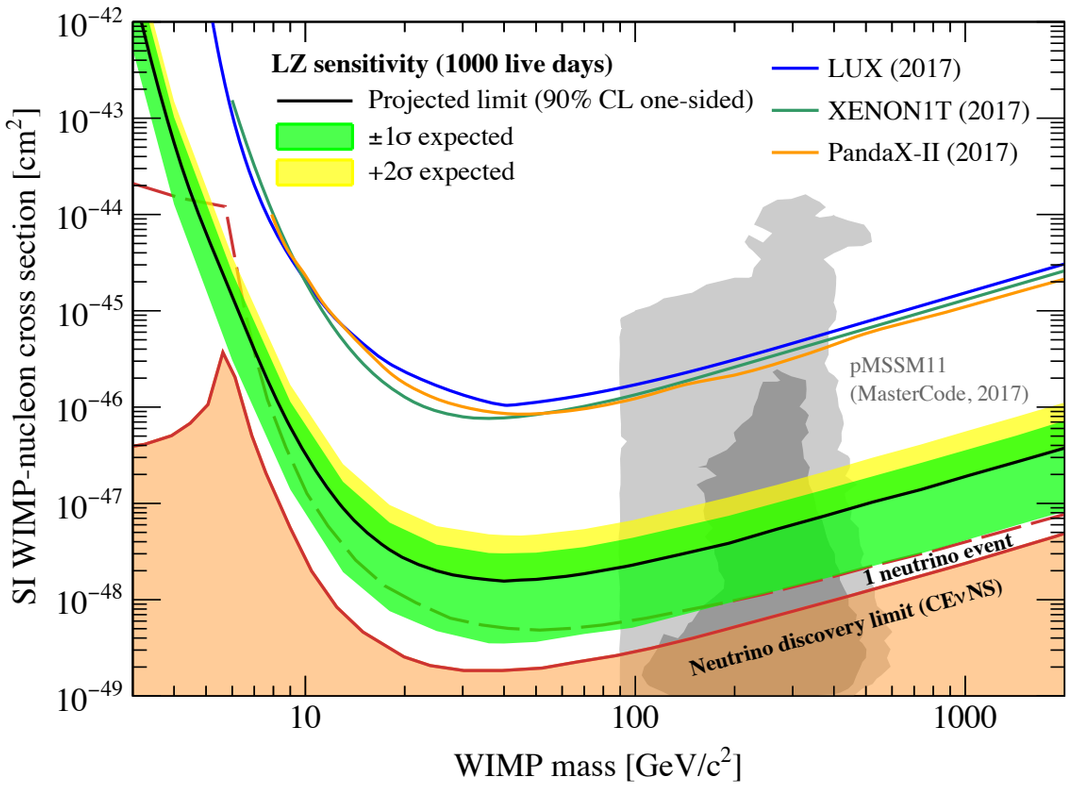
- XENON1T: May 28, presented results from 1 tonne-year
  - arXiv:1805.12562 world leading limit
  - Di Gangi talk this afternoon
- PandaX, LUX and XENON100 still rolling out secondary analyses: ALP, EFT, PSD, detector effects

Recent argon experimental results

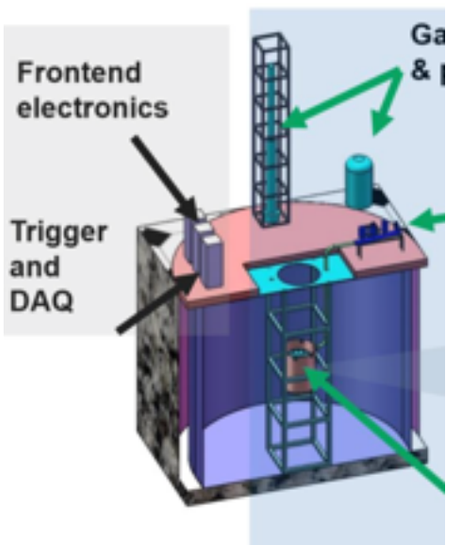


- DEAP3600 4.4 day result from initial run arXiv: 1707.08042
- DarkSide-50 numerous results this winter (Giganti talk later today)
  - arXiv:1802.07198 Primary result 532 day search
  - arXiv:1802.01427 Pulse shape and diffusion
  - arXiv:1802.06998 DM-electron scattering limit
  - arXiv:1802.06994 low mass search

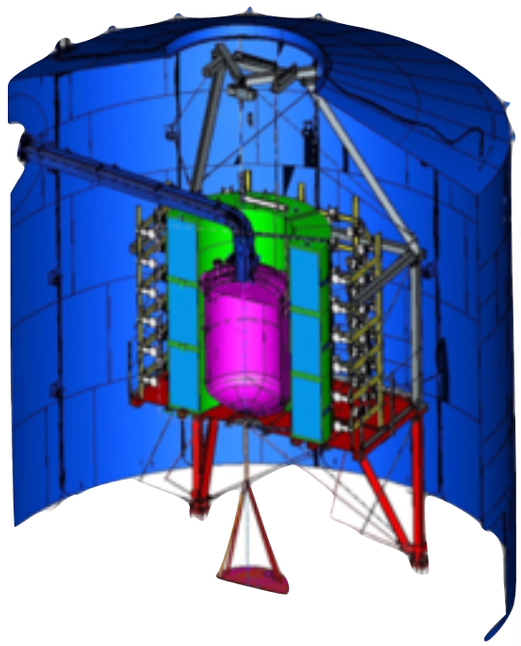
Future in xenon



- Results from running experiments and secondary results from completed ones
- XENONnT: 2019 8t, 4t fiducial
- PandaX-4T: 2020 4t
- LZ:2020 10t, 5.6t fiducial
- DARWIN:2024 50t

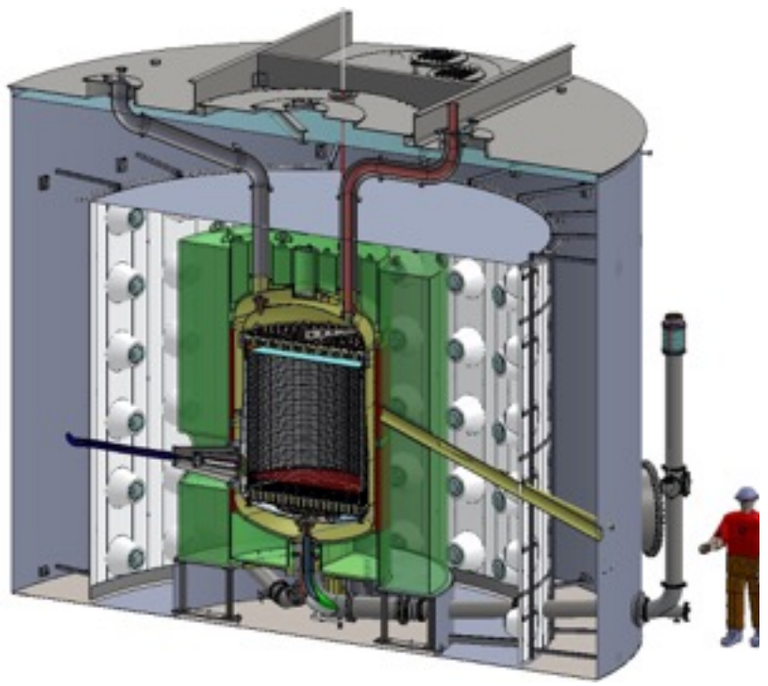


PandaX-4T

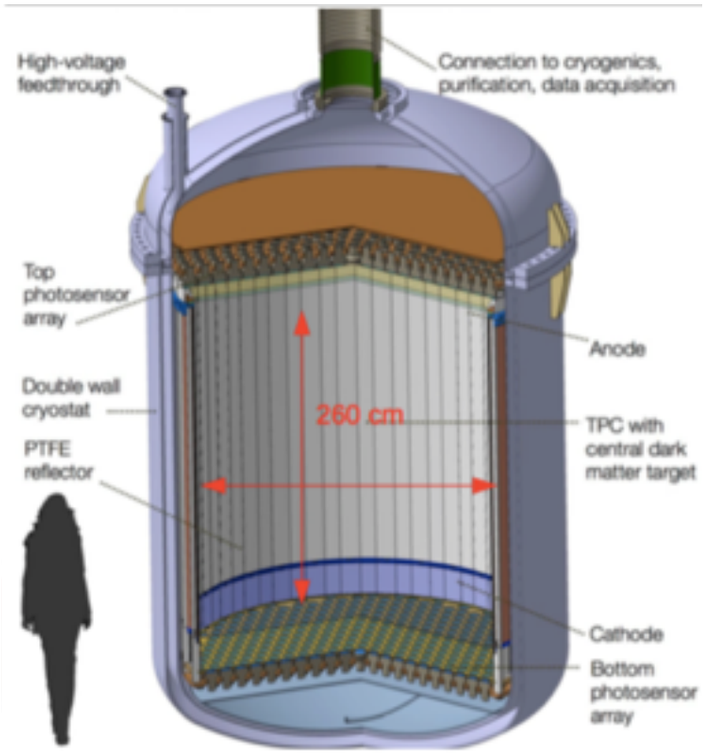


XENONnT

LZ

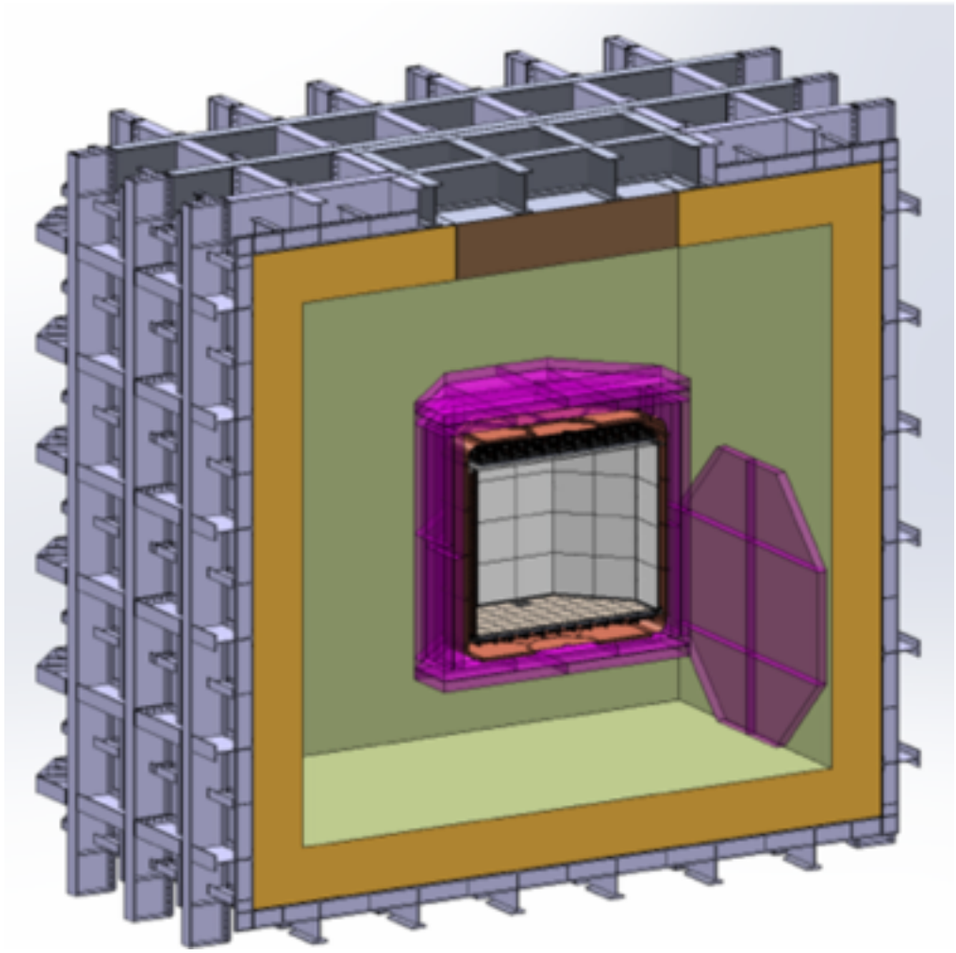


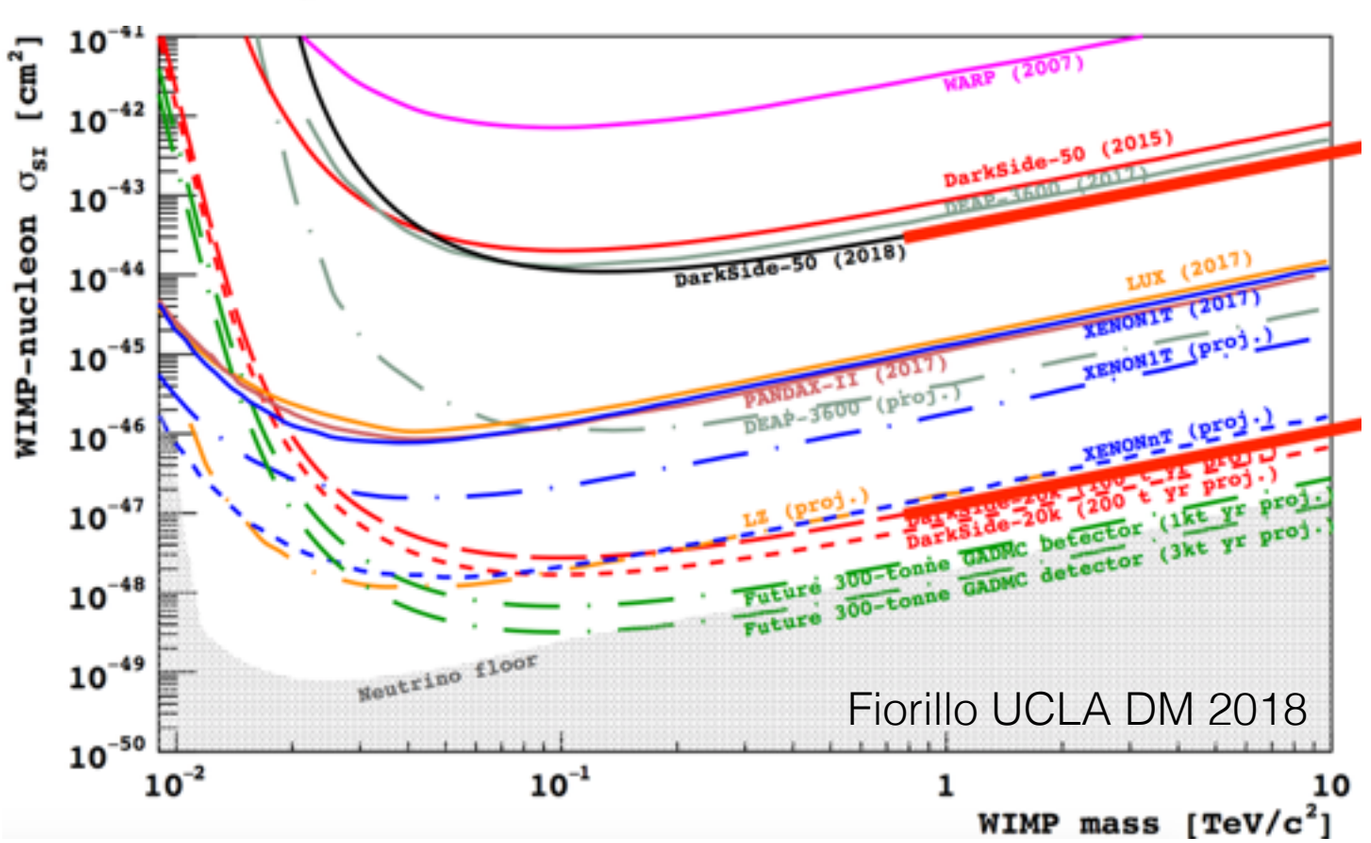
DARWIN



Future in argon

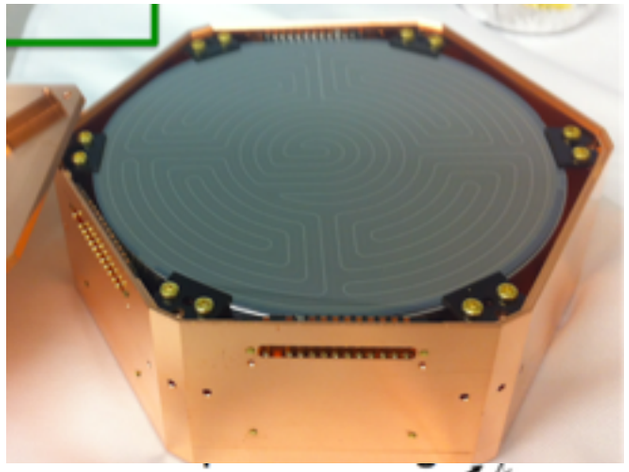
- DEAP-3600 Full year of data should be published this summer
  - blinding since Jan 2018
  - aims to run for 3 tonne-yr
- DarkSide-20k
  - Scheduled for 2021
  - Utilizing underground argon
  - Atmospheric LAr veto, DUNE style cryostat possible
  - Background free
- Global Argon Dark Matter Collaboration
  - 300 t in 2027

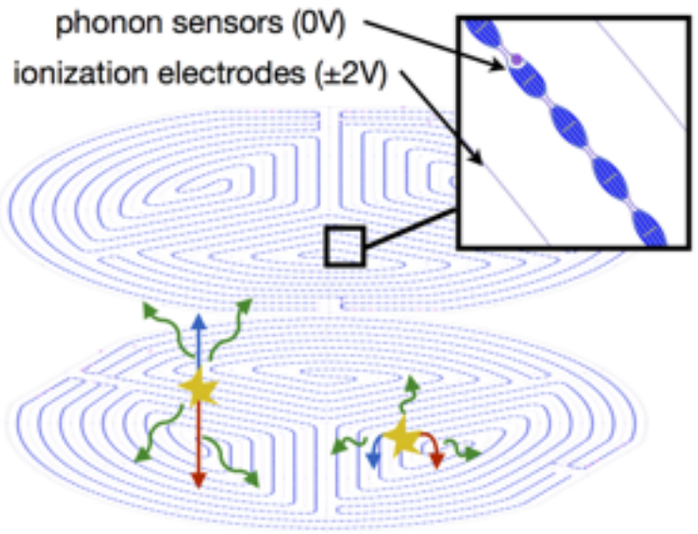


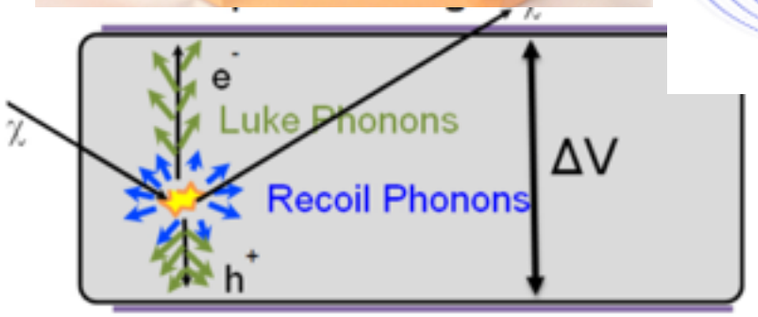


Fiorillo UCLA DM 2018

Cryogenic crystals technology

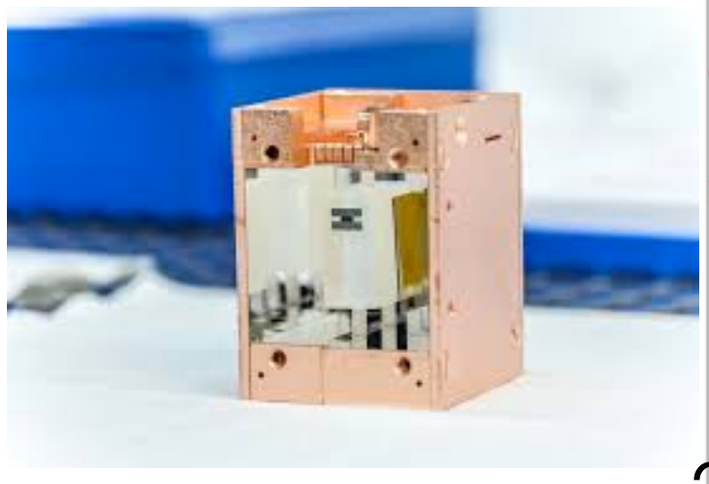


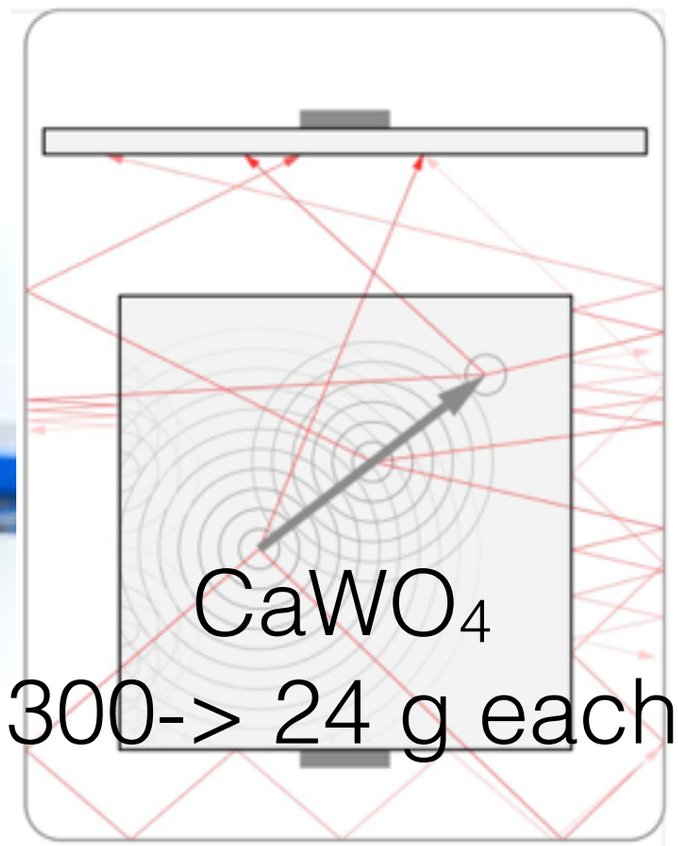




Ge, Si ~1 kg each

- SuperCDMS/EDELWEISS 2 techniques
  - HV (CDMSlite): Luke phonons: low threshold, but no discrimination
  - iZIP/FID: ionization and phonon signals with interleaved sensors discriminate against electronic recoils and surface events

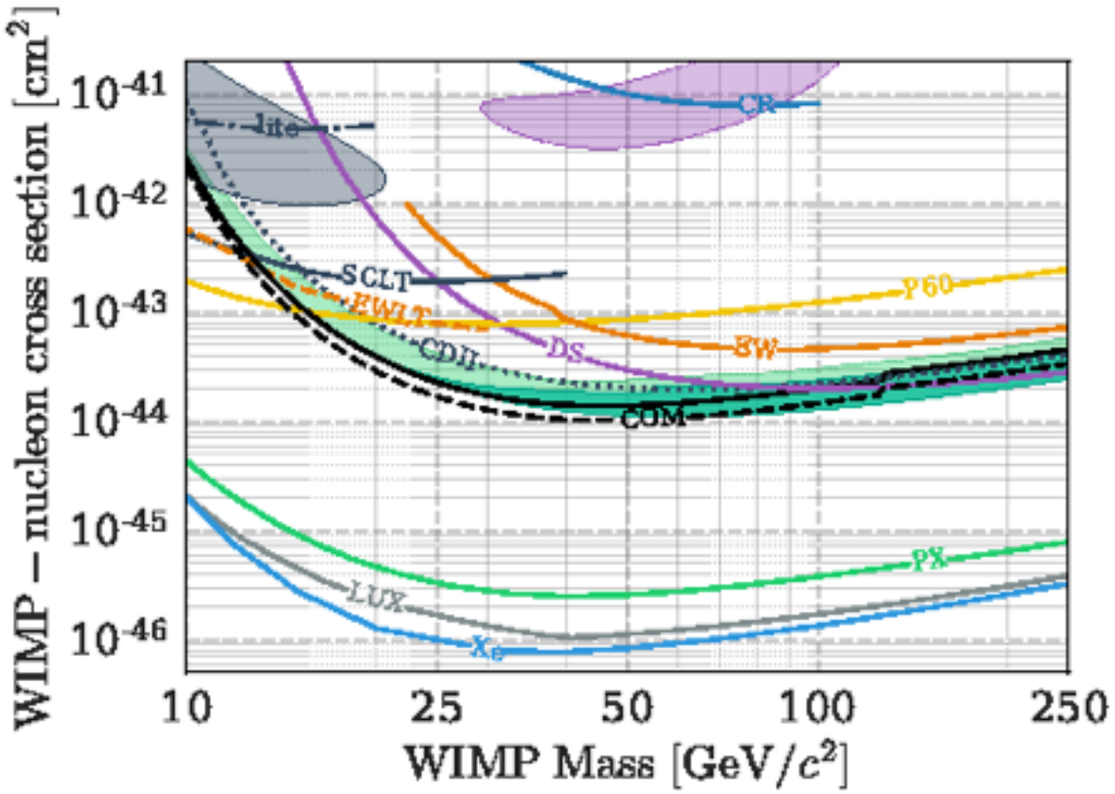


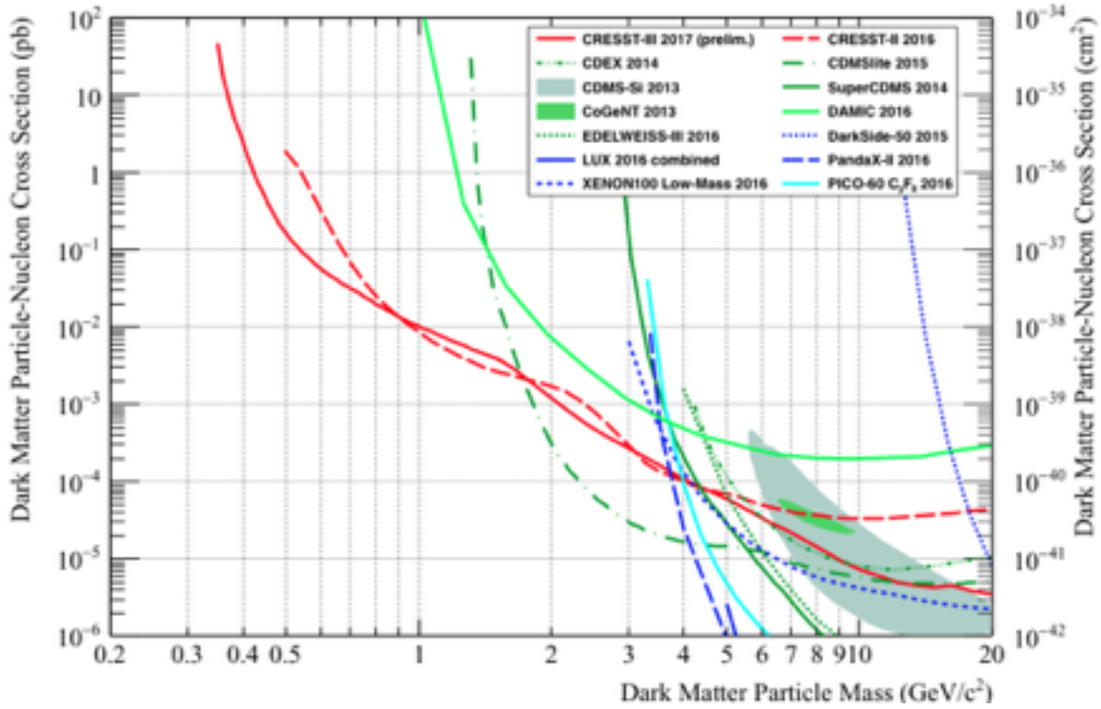


- CRESST
  - $CaWO_4$ crystals for phonons and scintillation
- DAMIC
  - Si CCD

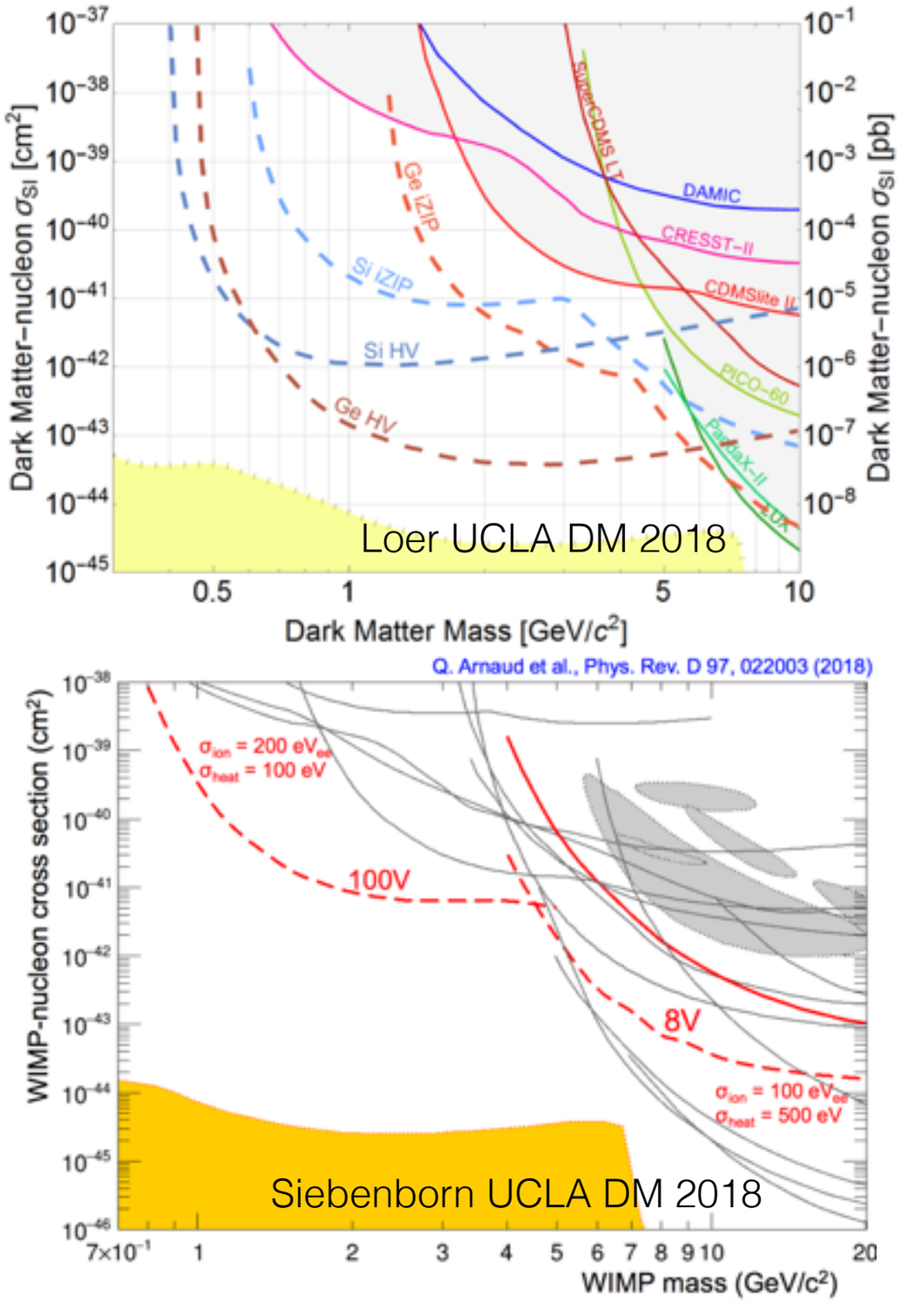
Recent news in cryogenic crystals

- SuperCDMS Sudan halted in 2016, but results still coming out, PRL 120 (2018) 061802
  - High threshold, 1 background on expectation of 0.33
- CRESST-III
  - Preliminary look at 2.39 kgd and conservative threshold of 100 eV arXiv:1711.07692





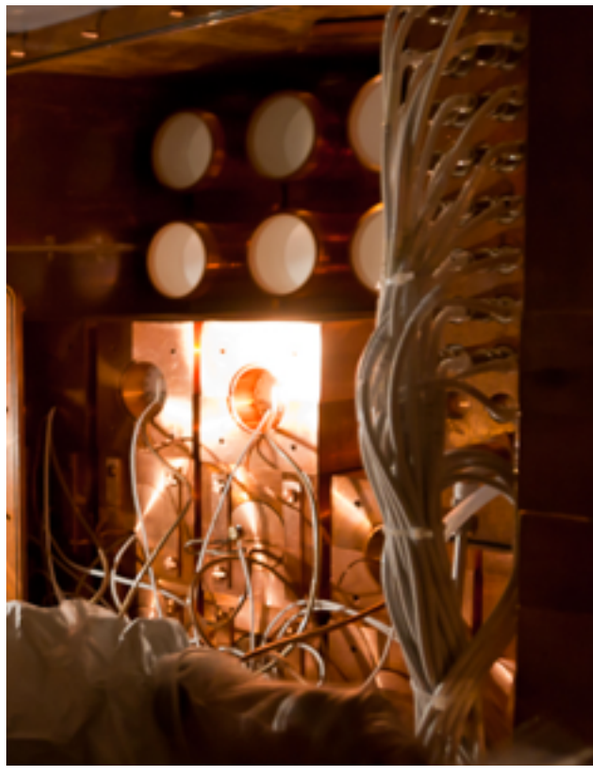
Future in cryogenic crystals

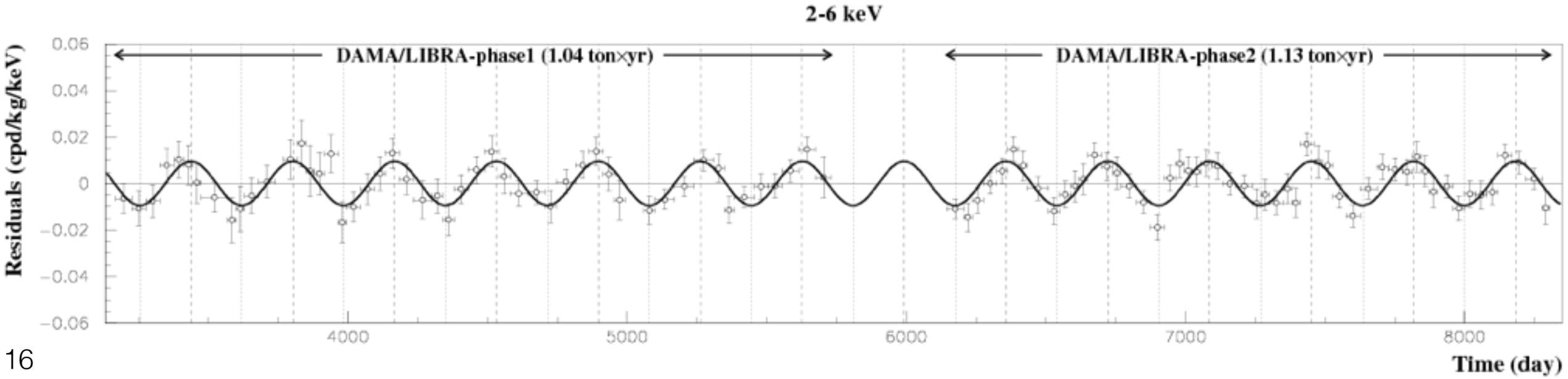


- SuperCDMS SNOLAB passed DOE CD-3, scheduled to begin data taking in 2020
  - 8 GE HV, 4 Si HV, 10 GE iZIP, 2 Si iZIP planned
- EDELWEISS-III goals for 2019 with 50 kgd
- EDELWEISS aiming for 100 kg detector in future with other R&D based improvements
- Further CRESST-III Results

DAMA/LIBRA results

- DAMA and DAMA/LIBRA phase 1
  - 250-kg high-purity NaI(Tl) array collected data for 14 solar cycles
  - observed ~0.01 cpd/kg/keV modulation in 2 - 6 keV energy range
  - over 9 σ stat. significant; WIMP signal interpretation in tension with other experiments
- DAMA/LIBRA phase 2 arXiv:1805.10486
  - 250-kg high-purity NaI(Tl) array collected data for 6 solar cycles
  - 2-6 keV range combined now gives 12.9 σ stat. significant
  - Modulation clearly evident in lowest energy bins now too (1-3 keV)

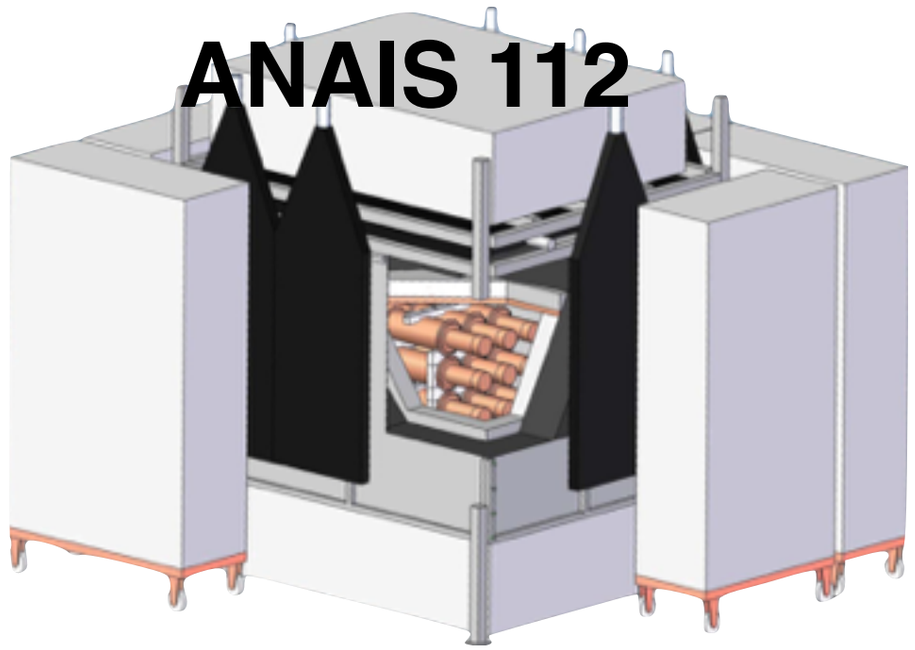


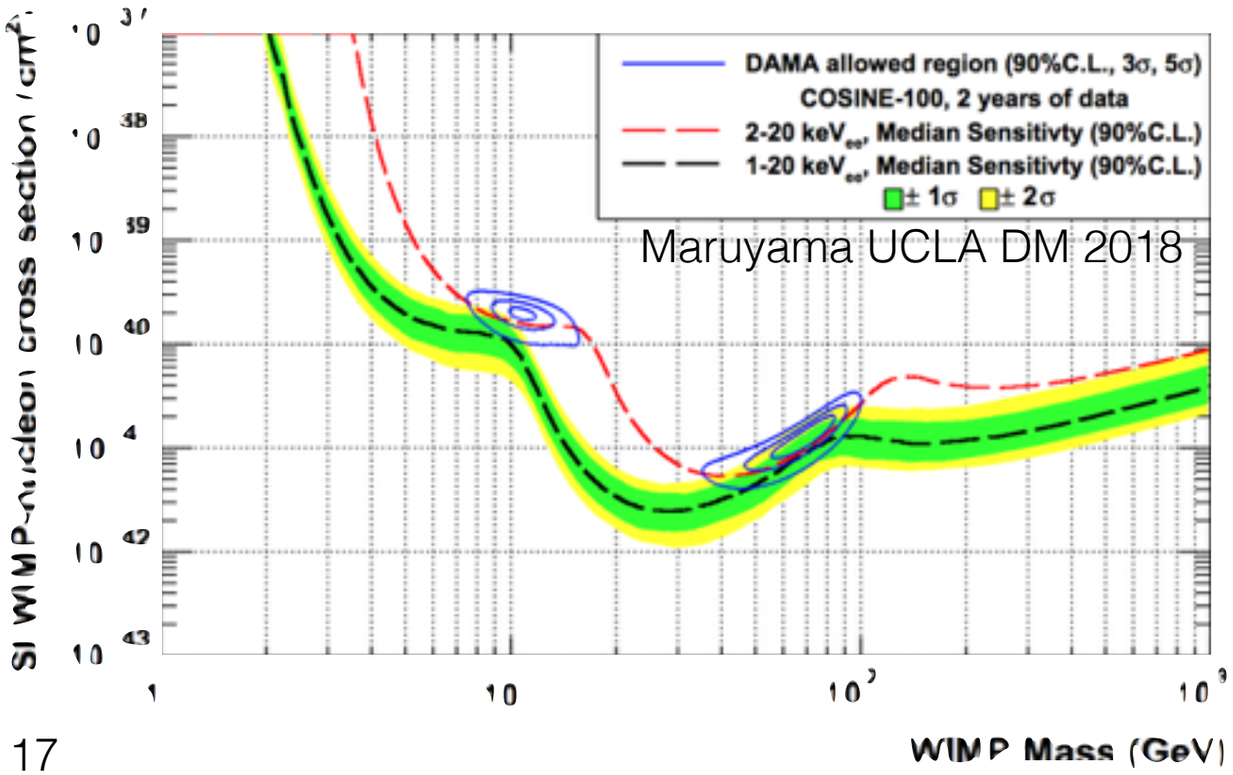


Future in NaI

- COSINE 10 running since September 2016

- ANAIS 112 started operations in August 2017 and will have 3 σ significance after 5 years



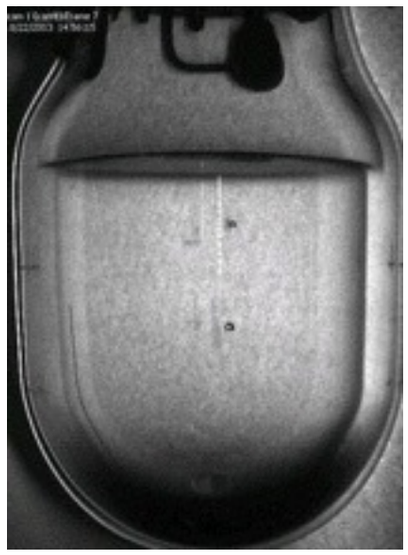


- SABRE 5 kg proof of principle starts this year(2018)

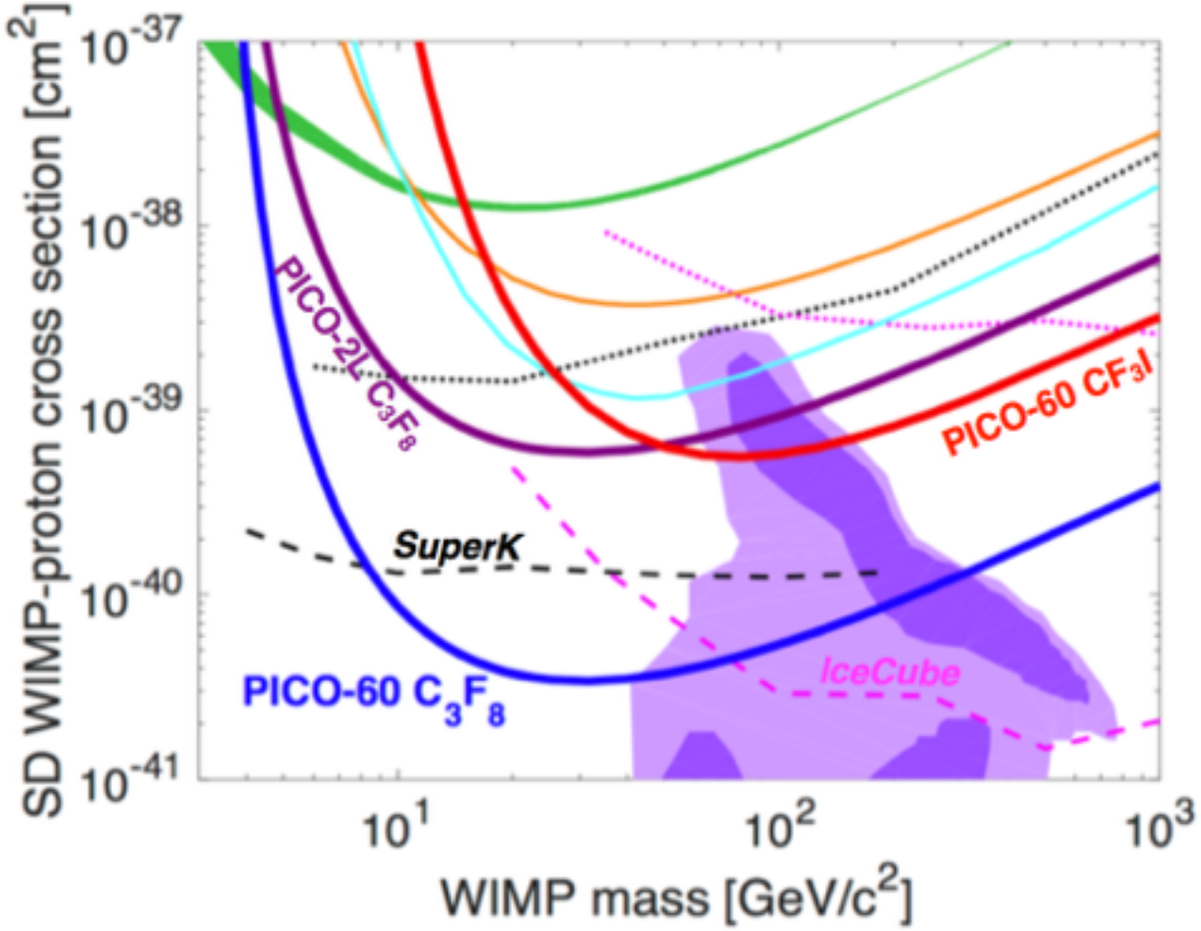
- SABRE South (50 kg in Australia) scheduled to start in 2019

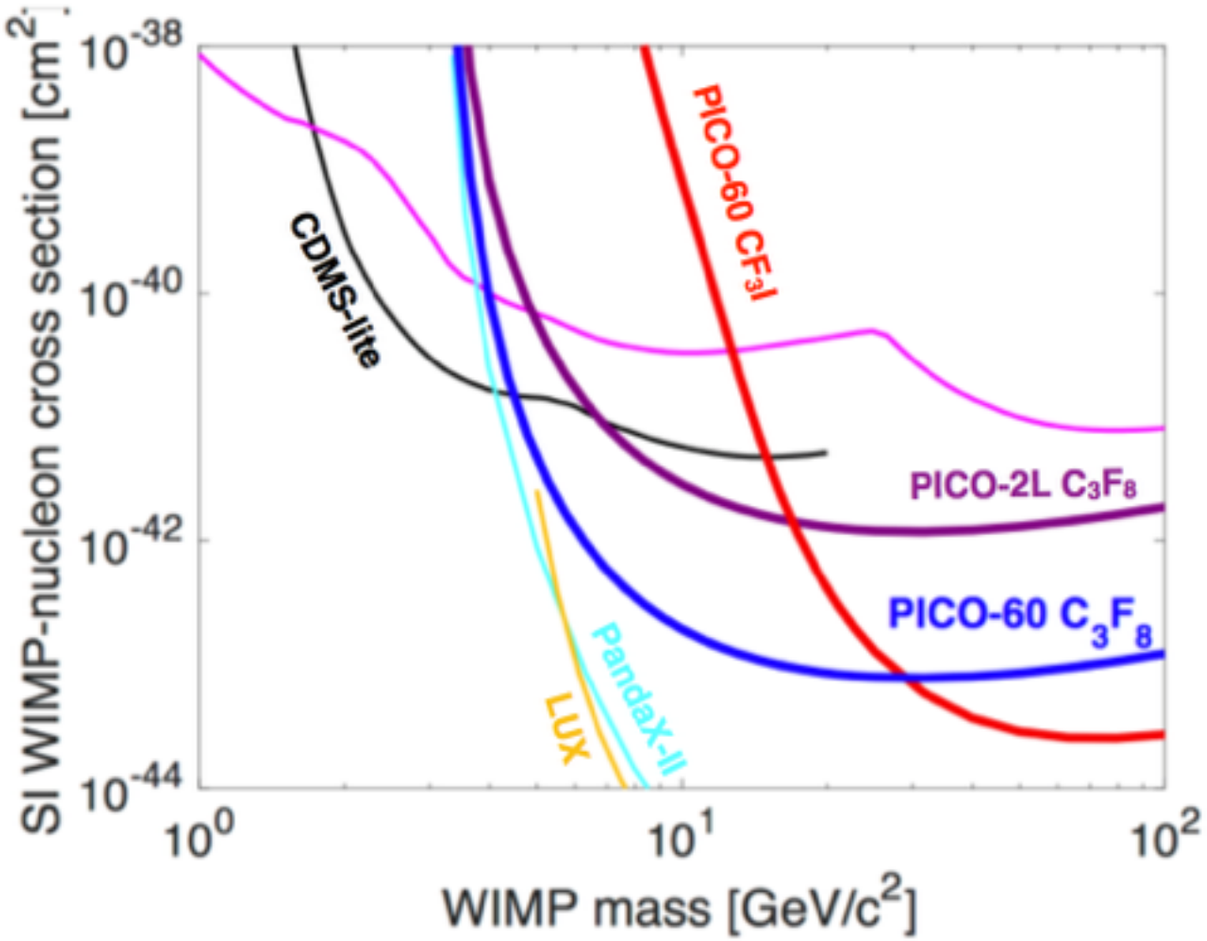
- DAMA/LIBRA phase 3 (1 ton) R&D underway

Bubble chamber operations



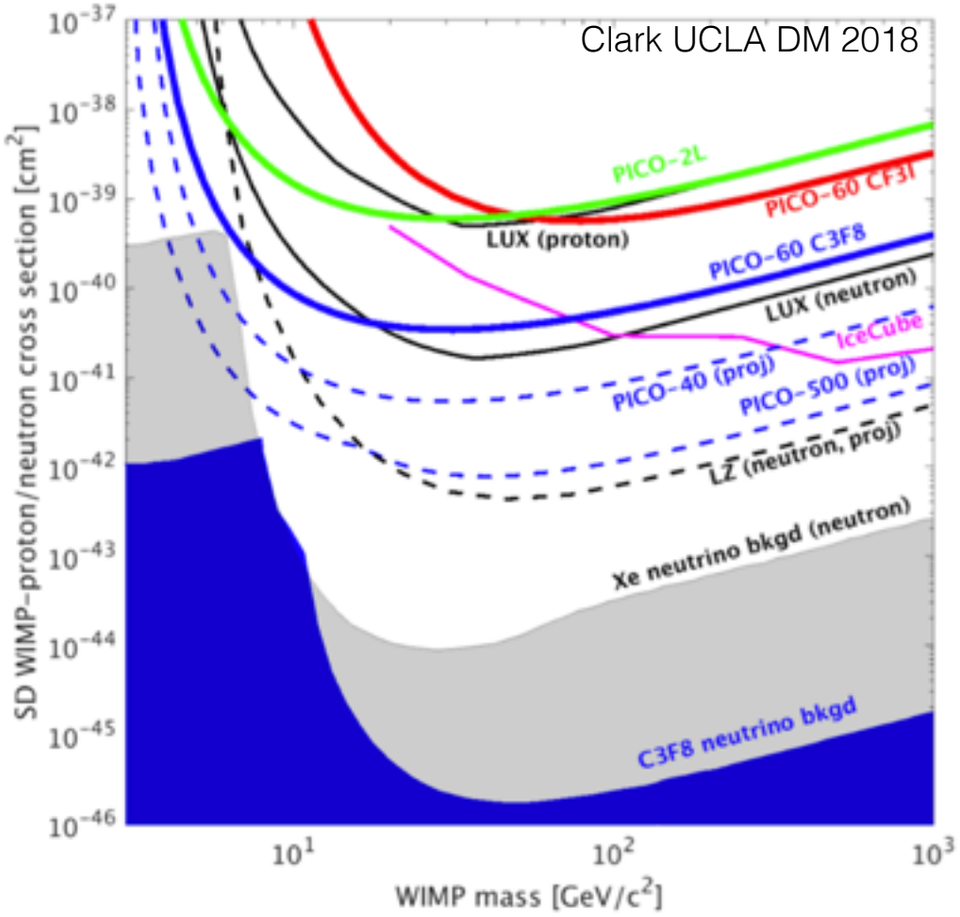
- Bubble nucleation in superheated liquids, target can include spin-dependent proton targets (F)
- Gammas and betas do not cause bubbles, alphas discriminated with acoustic signal
- PICO 60 6-2017 run 201results with 52 kg active, 30 days at 3.3 keV threshold, then background limited



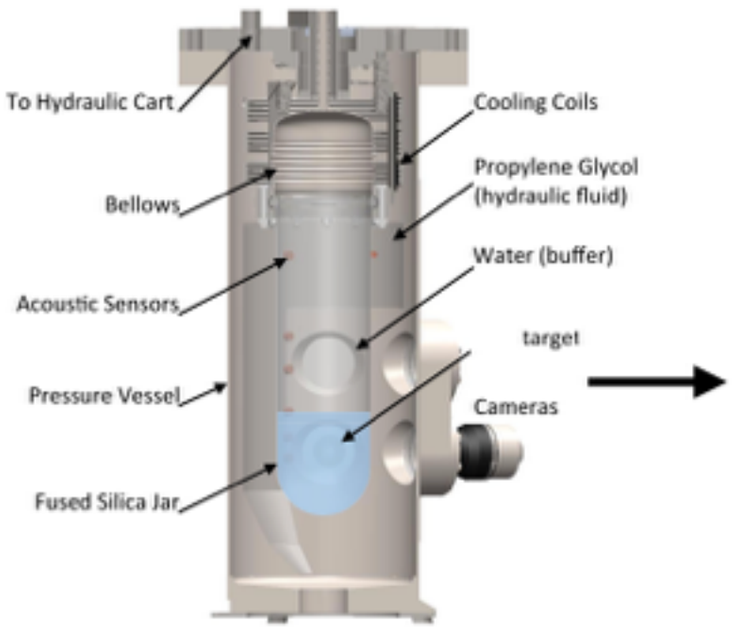


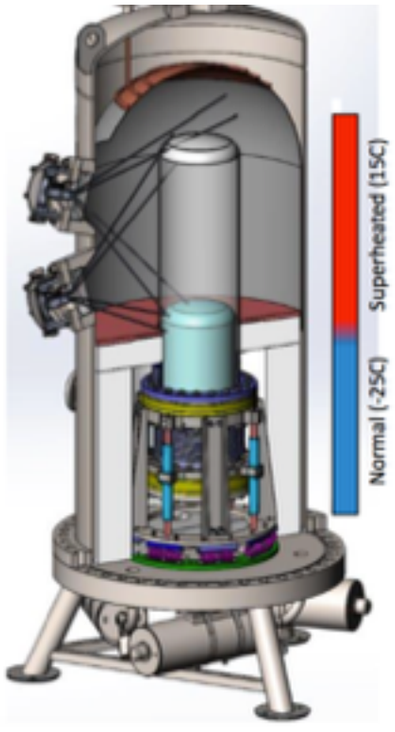
Phys. Rev. Lett. **118**, 251301 (2017)

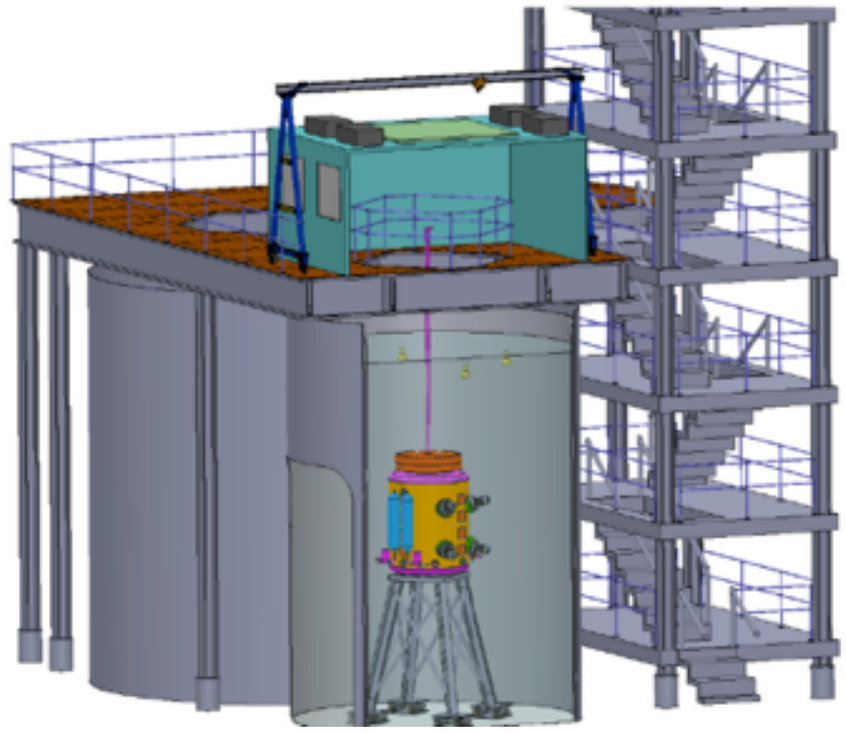
Future in PICO



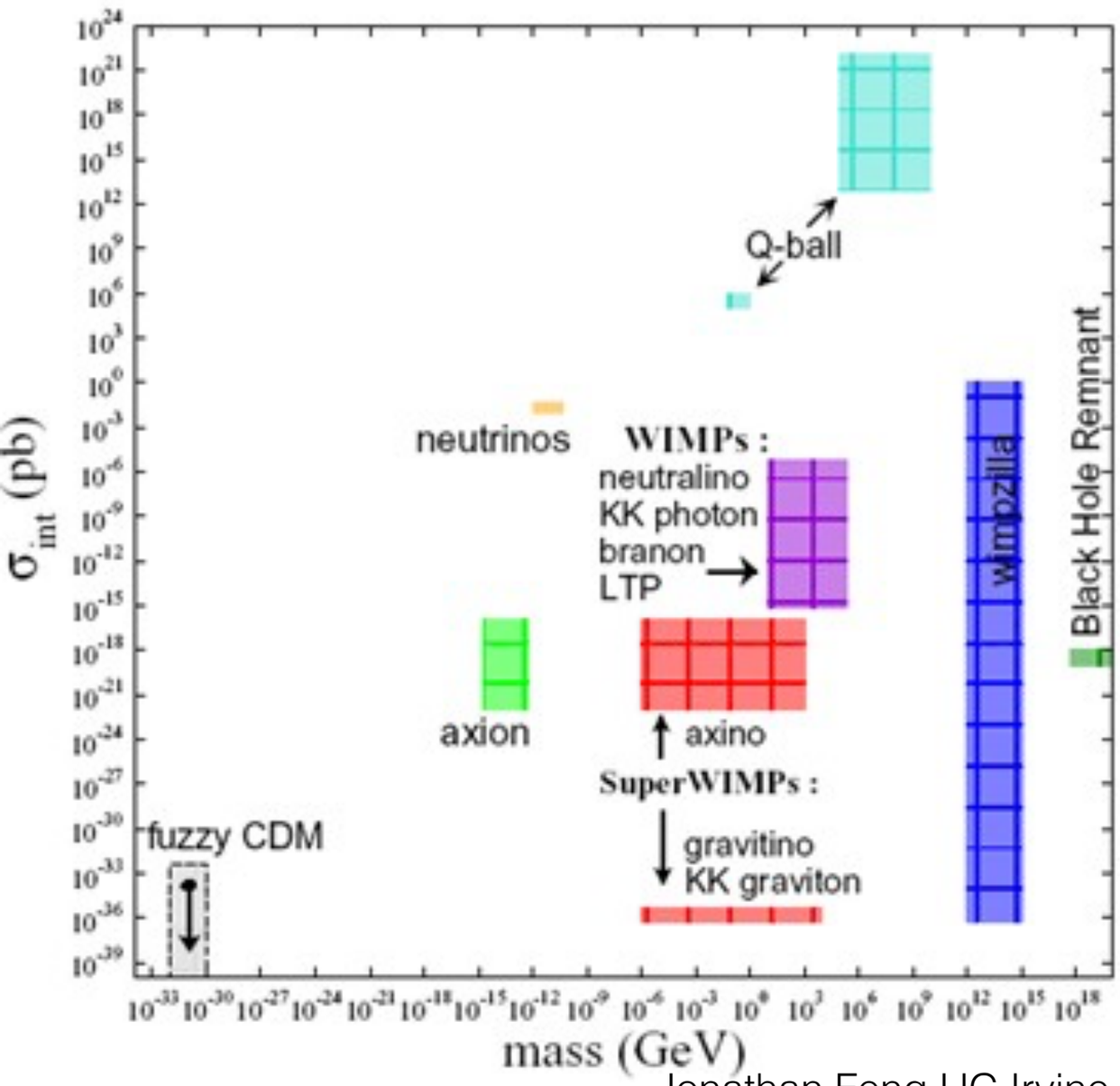
- Additional PICO 60 analyses forthcoming
- PICO 40L coming online this summer (2018) with C_3F_8 target and inverted vessel
- PICO 500 scheduled to begin construction in 2019







WIMP Detection Prospects

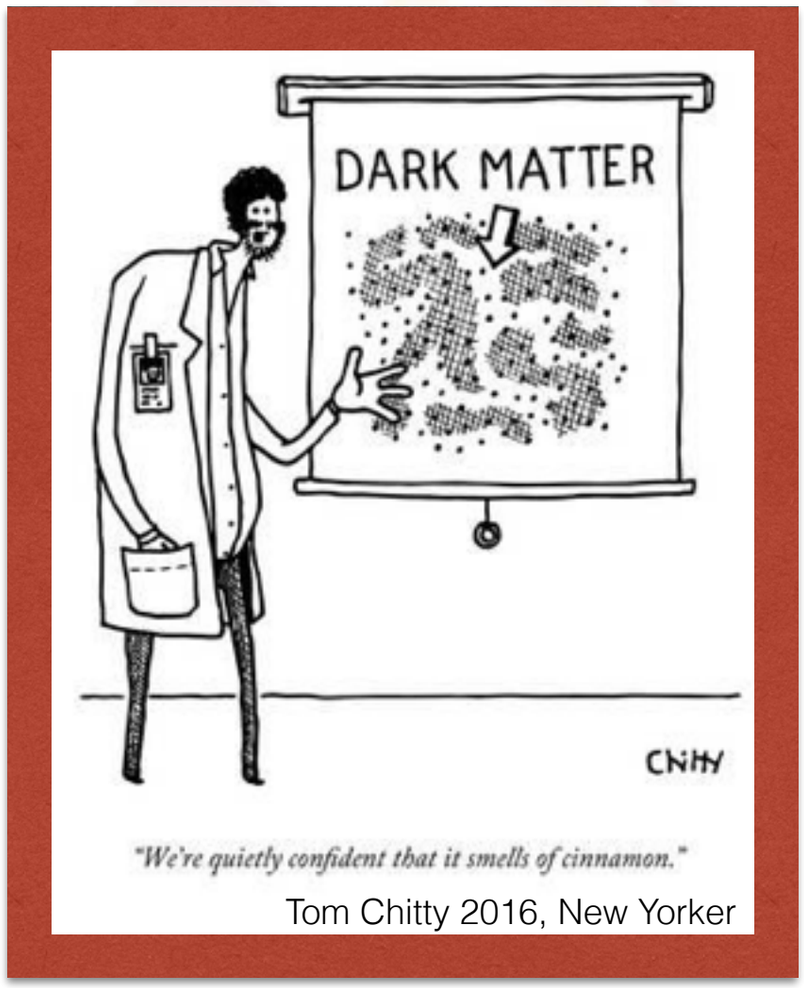


Jonathan Feng UC Irvine

- WIMPs are 16% of the parameter space
  - New experiments only probe a new 2%
- Word usage in theory papers
  - 27% WIMP (Inspire)
  - 22% WIMP arXiv
  - 49% WIMP Google Scholar
- Combining new probe parameter space with weighting ~3% chance we see dark matter in next generation experiments
  - Many poor statistical assumptions here!

Hope and Resignation in Direct Detection

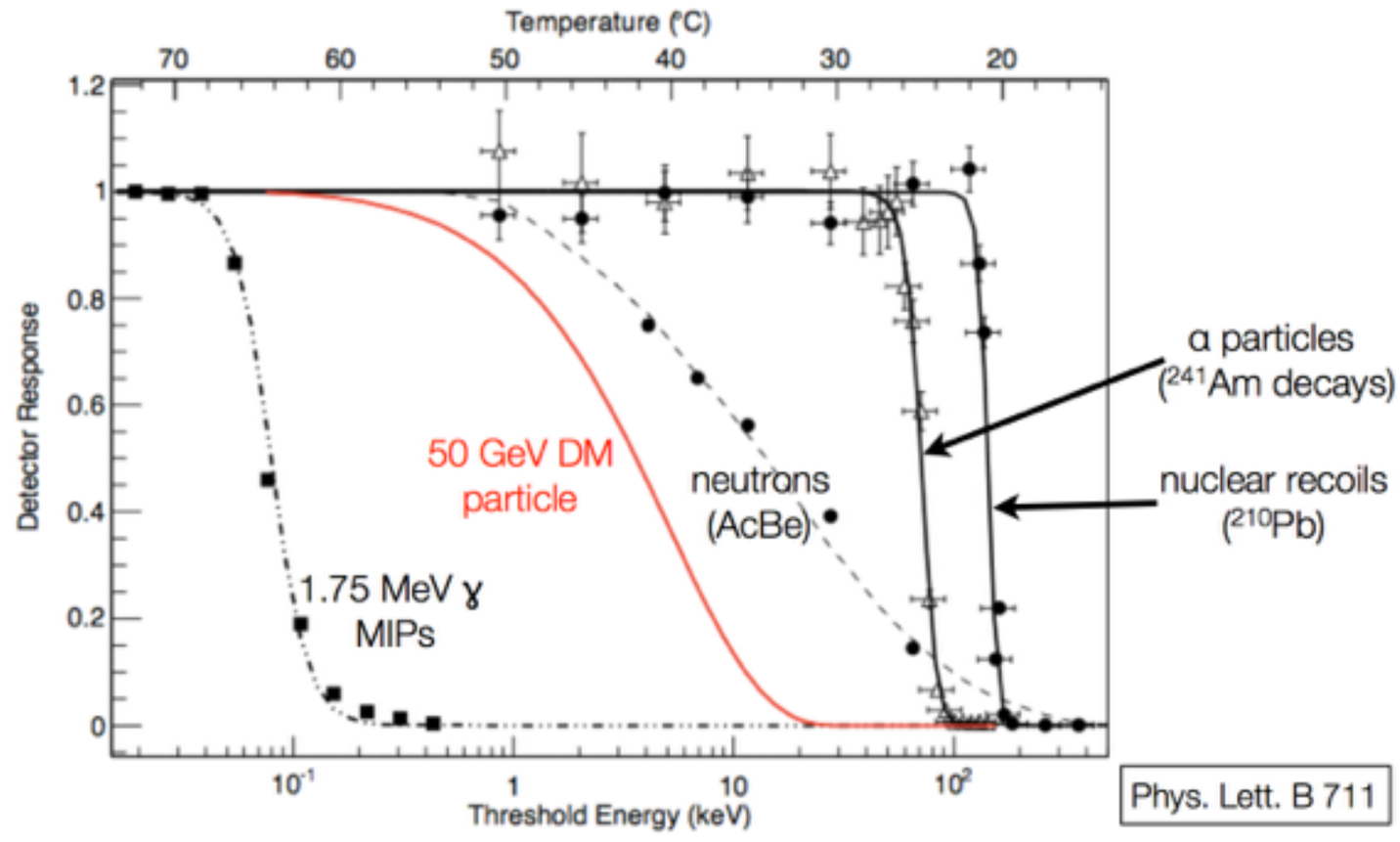
- Getting close to coherent neutrino signals, and no dark matter signal
- Experiments take time
- Mature technologies pursuing multiple fronts
- Best detectors we've made
- Ongoing rollout of results from running/ recently completed experiments
- Many new experiments turning on 2019-2021



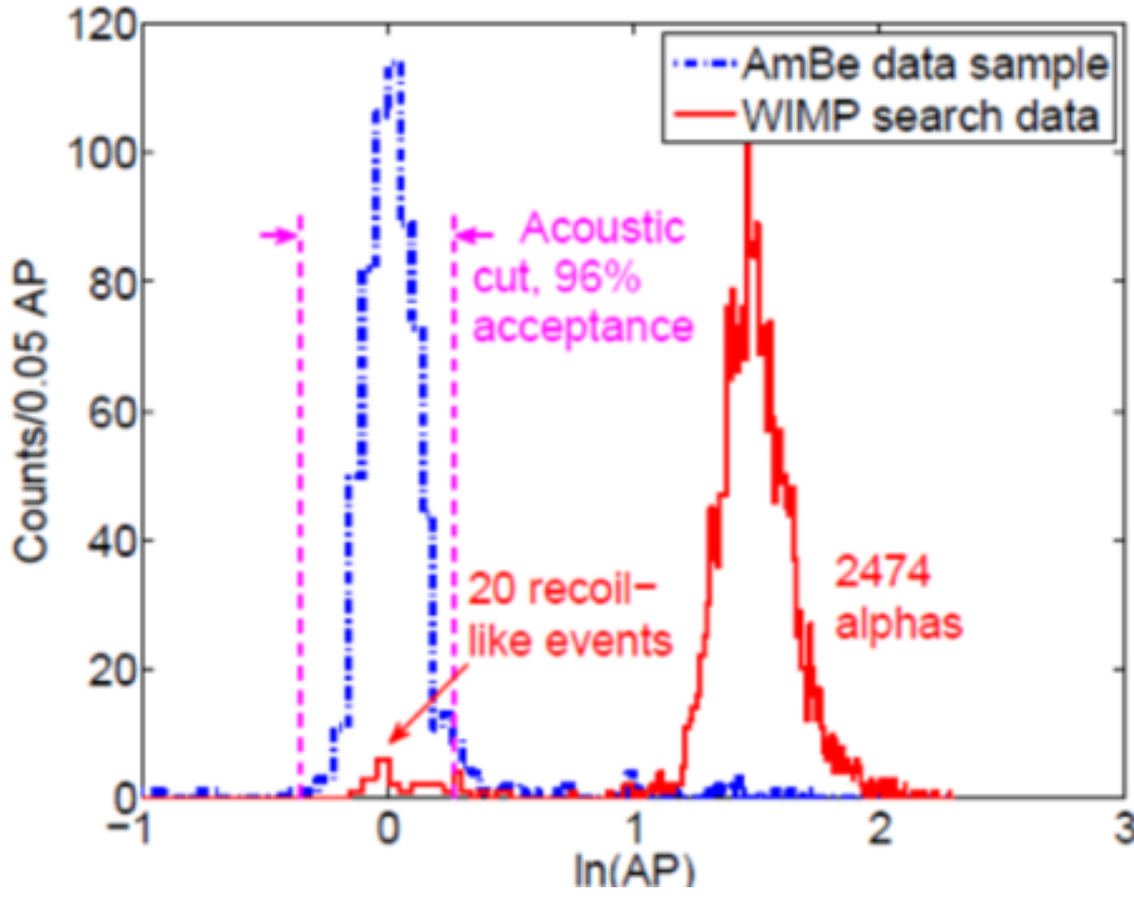
Tom Chitty 2016, New Yorker

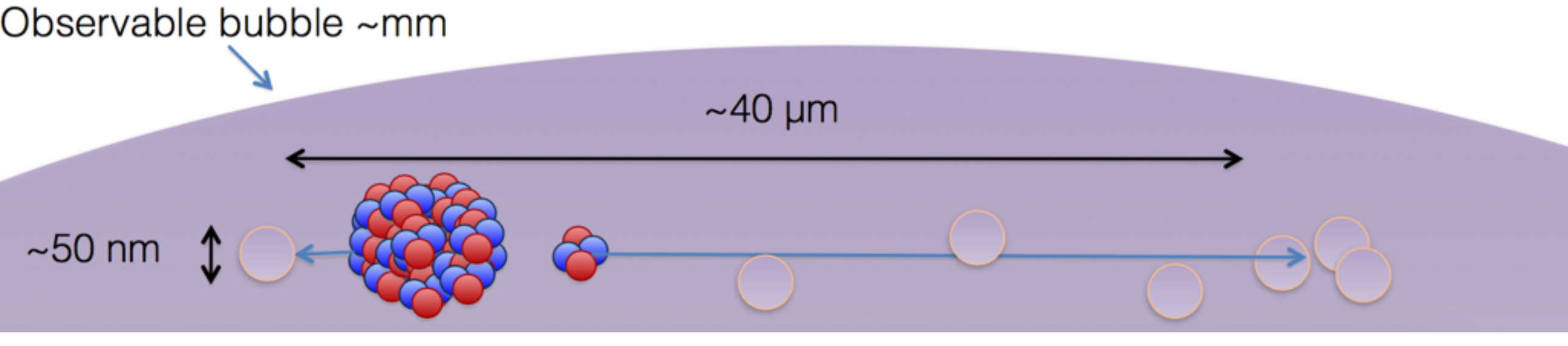
Backup Slides

PICO discrimination



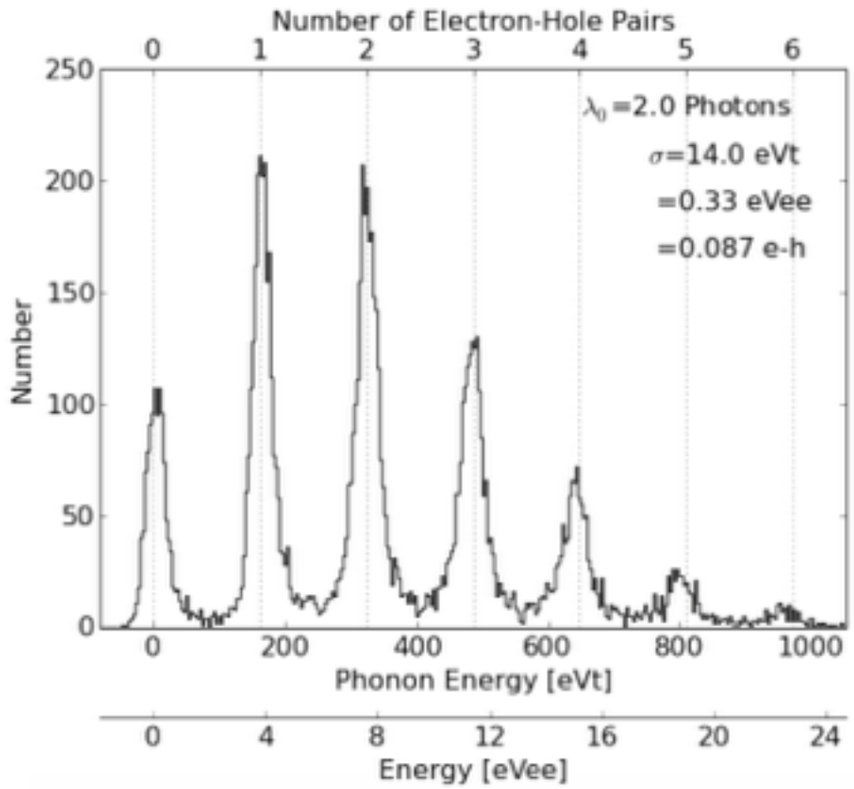
Phys. Lett. B 711





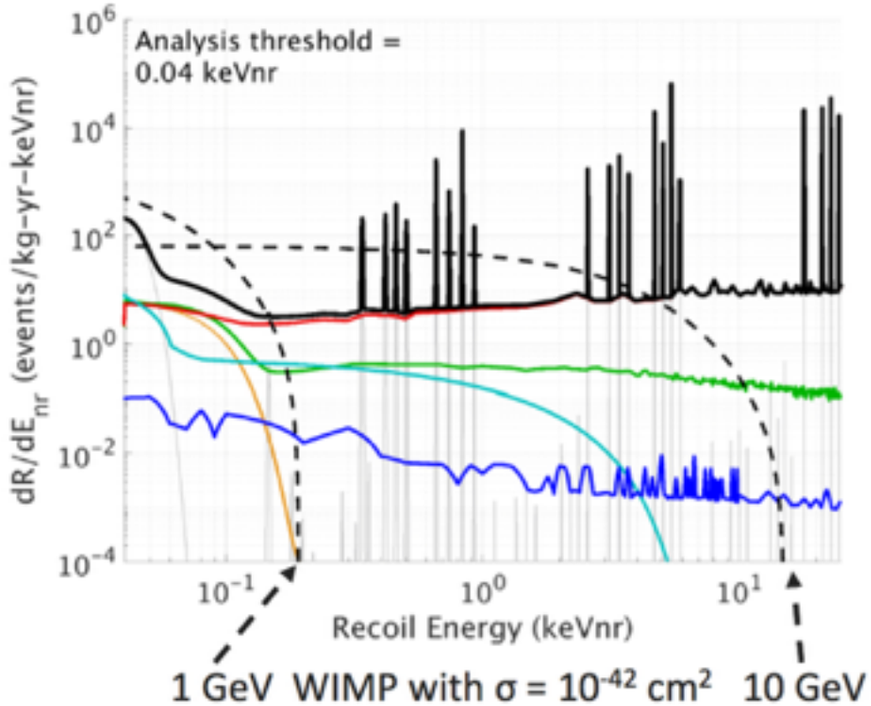
SuperCDMS Goals

	Soudan	SNOLAB
Phonon resolution, eVt	~250	10 HV, 50 iZIP
HV Bias Voltage, V	70	100
iZIP Charge resolution, eVee	~400	160
HV Threshold, eVnr	300	40



[Appl. Phys. Lett. **112**, 043501 (2018)](#)

1 cm^2 x 4 nm Si test device with 160V bias demonstrating single e/h pair measurement with <10% resolution



Total

^{3}H and Comptons

neutrons

Ge activation

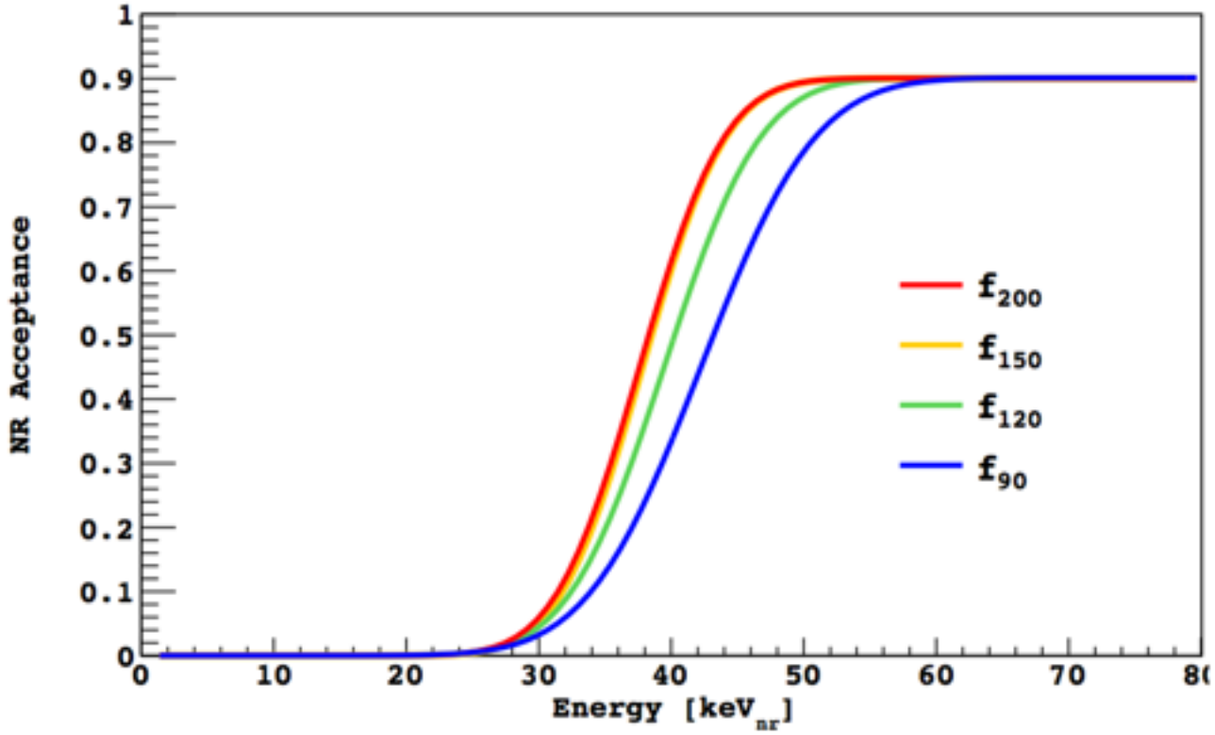
Coherent neutrinos

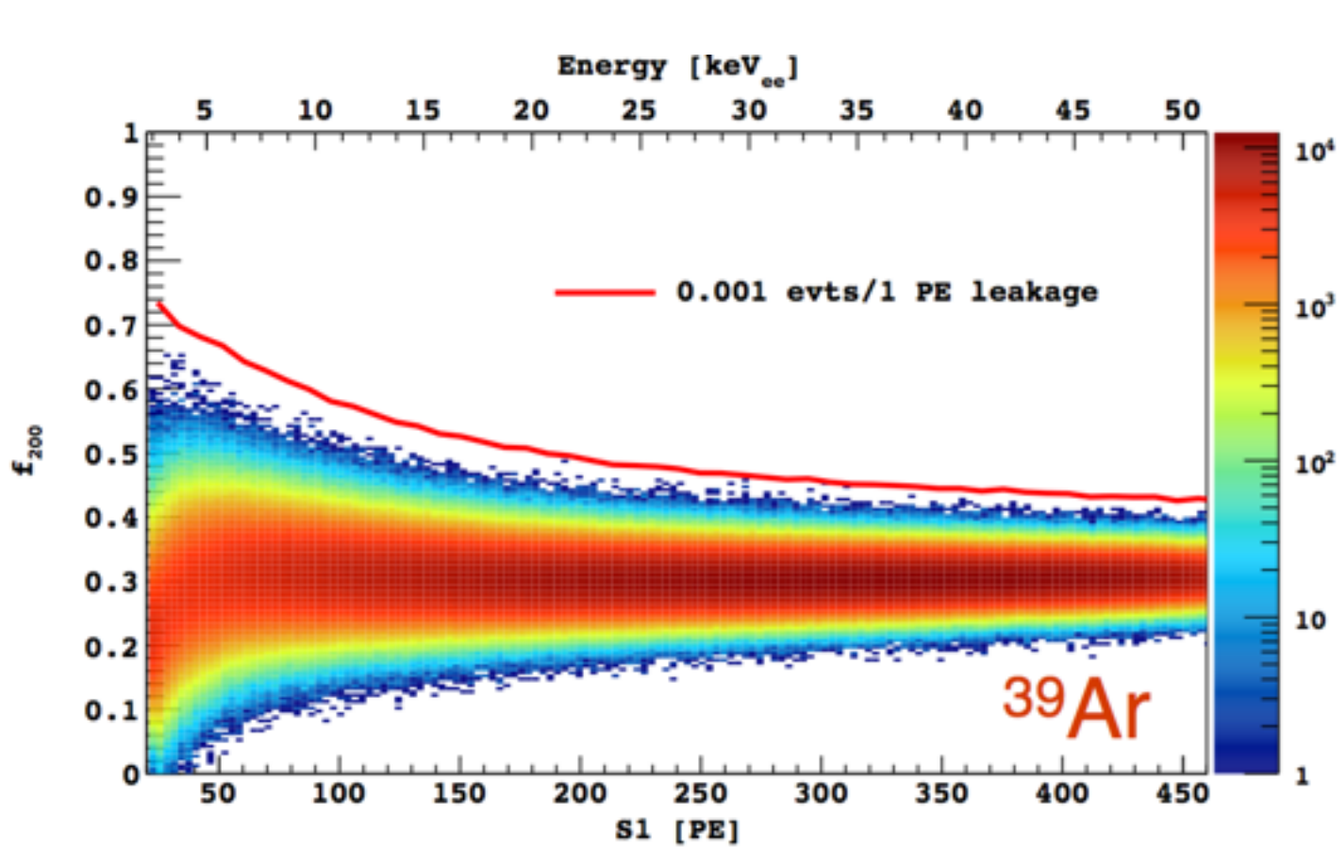
Surface betas

Surface ^{206}Pb

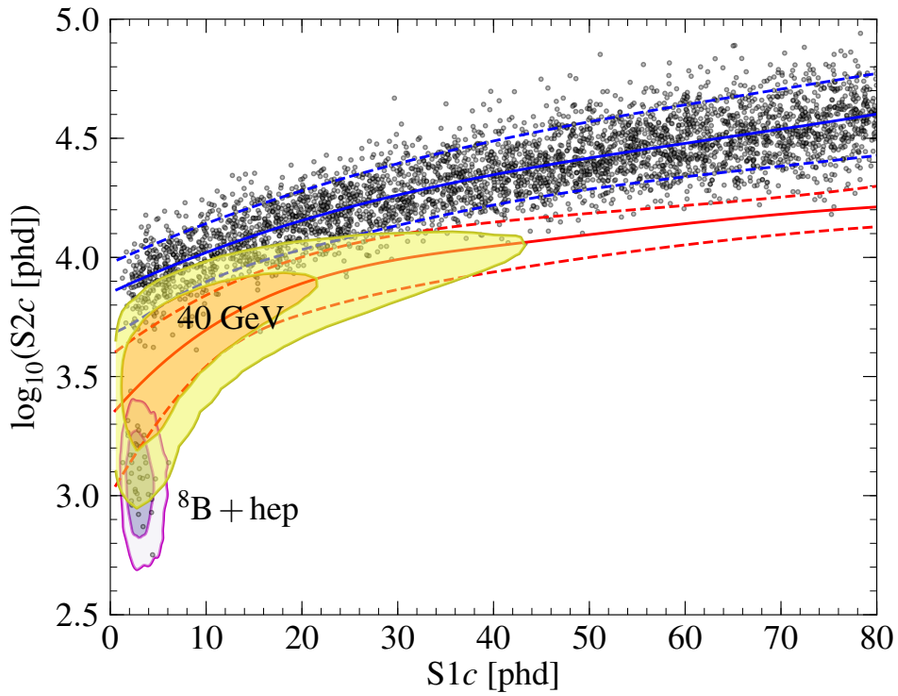
DarkSide-20k

arXiv:1707.08145

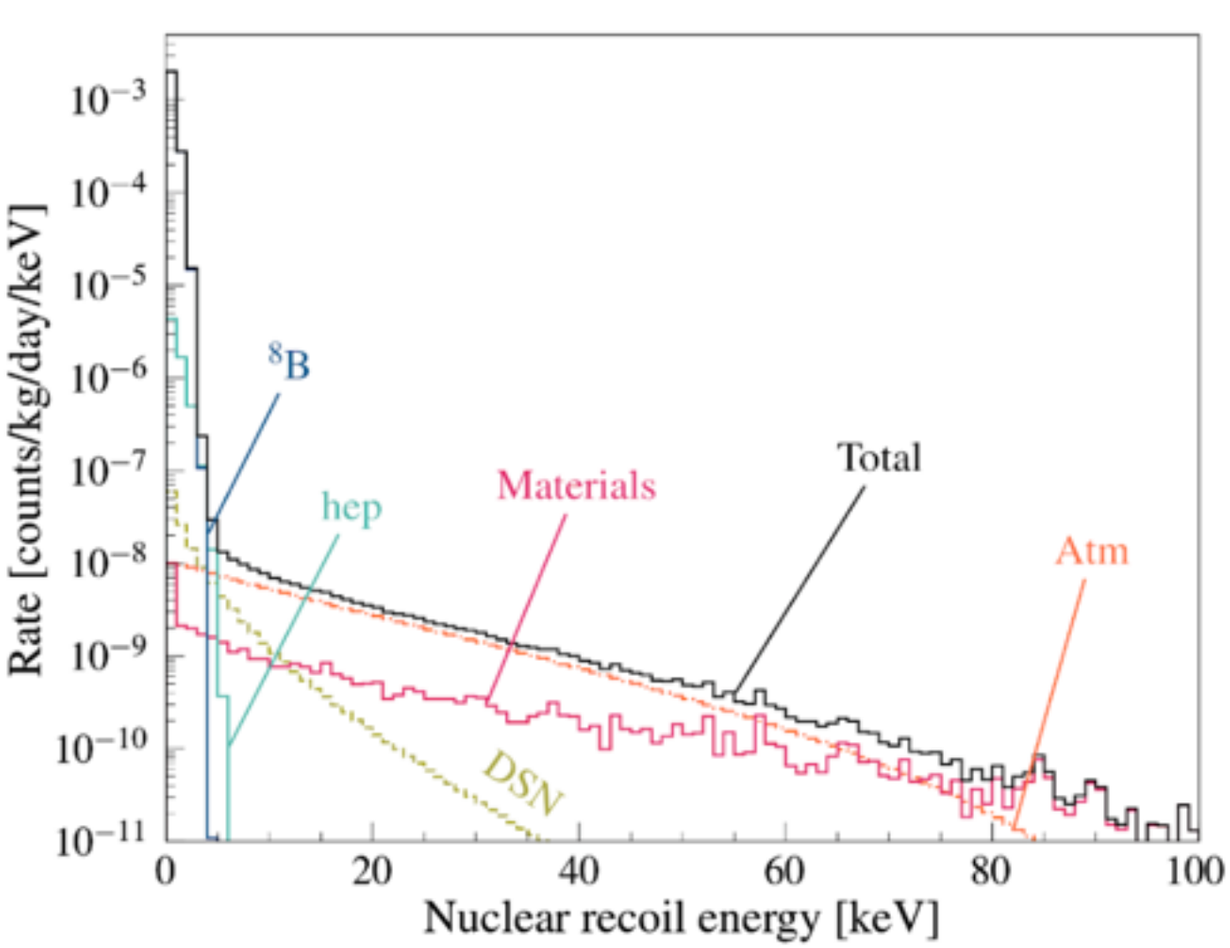




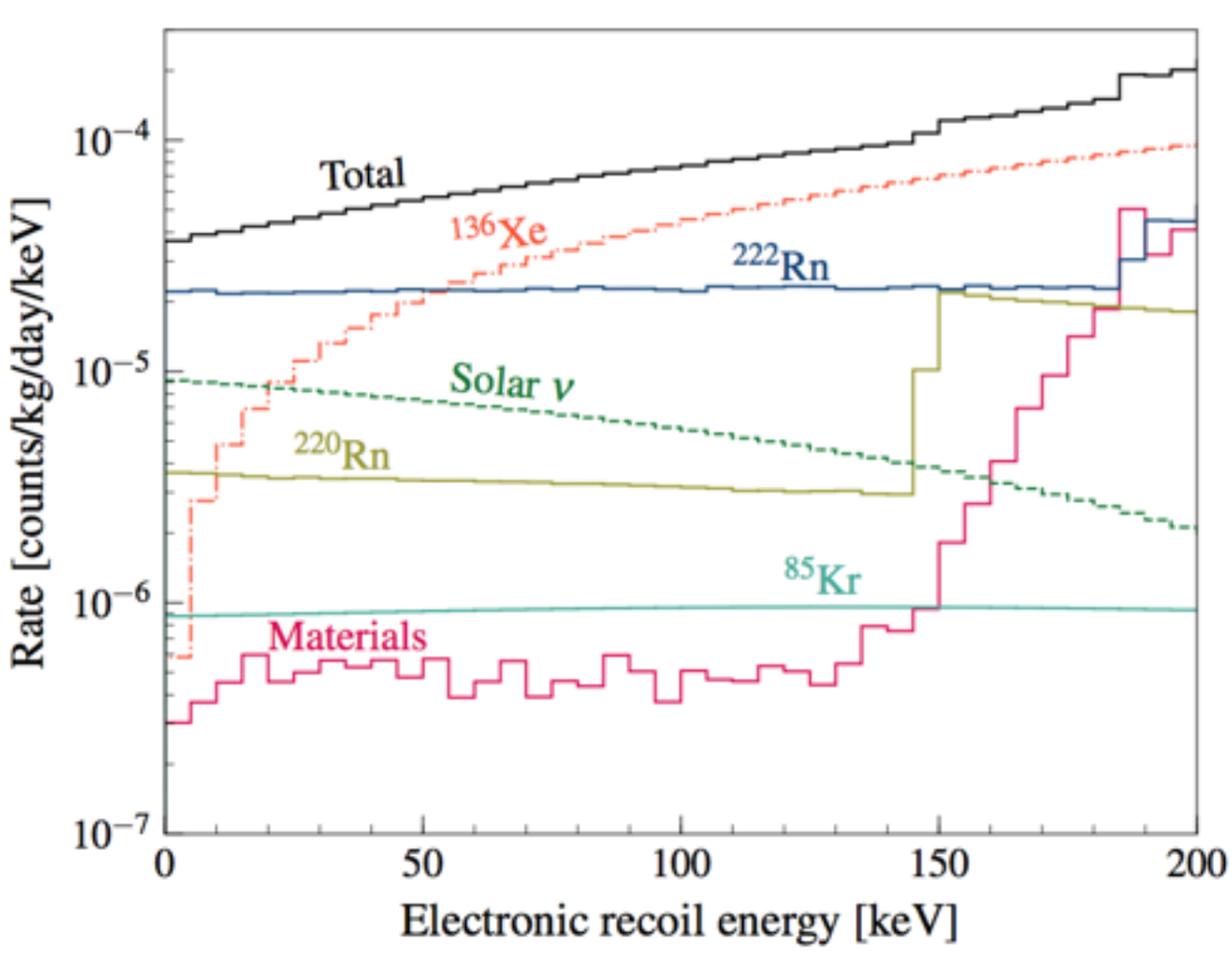
LZ Extras



Nuclear recoils



Electron recoils



XENON1T Extras