Recent Results from Dark Matter Direct Detection Experiments

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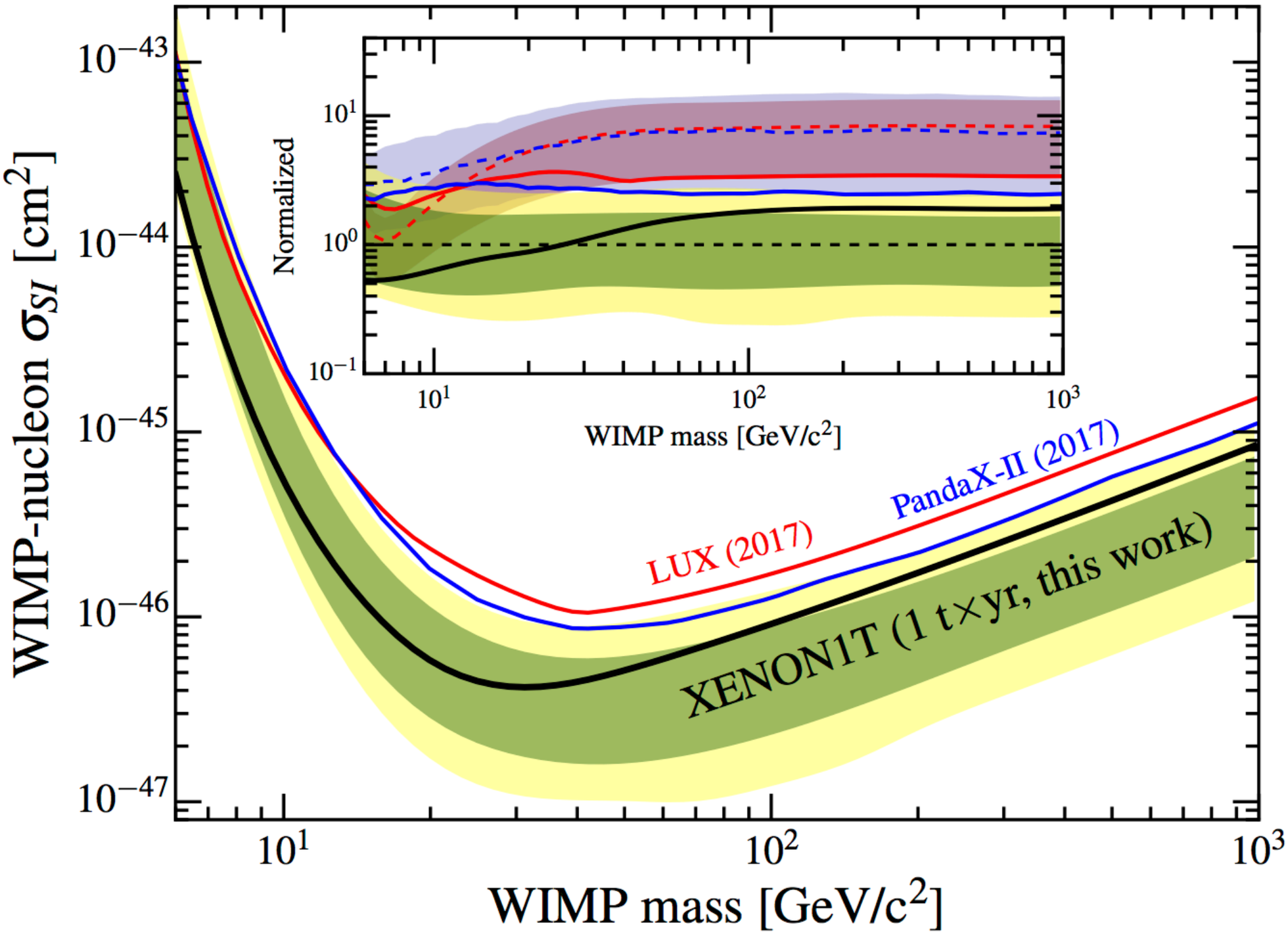
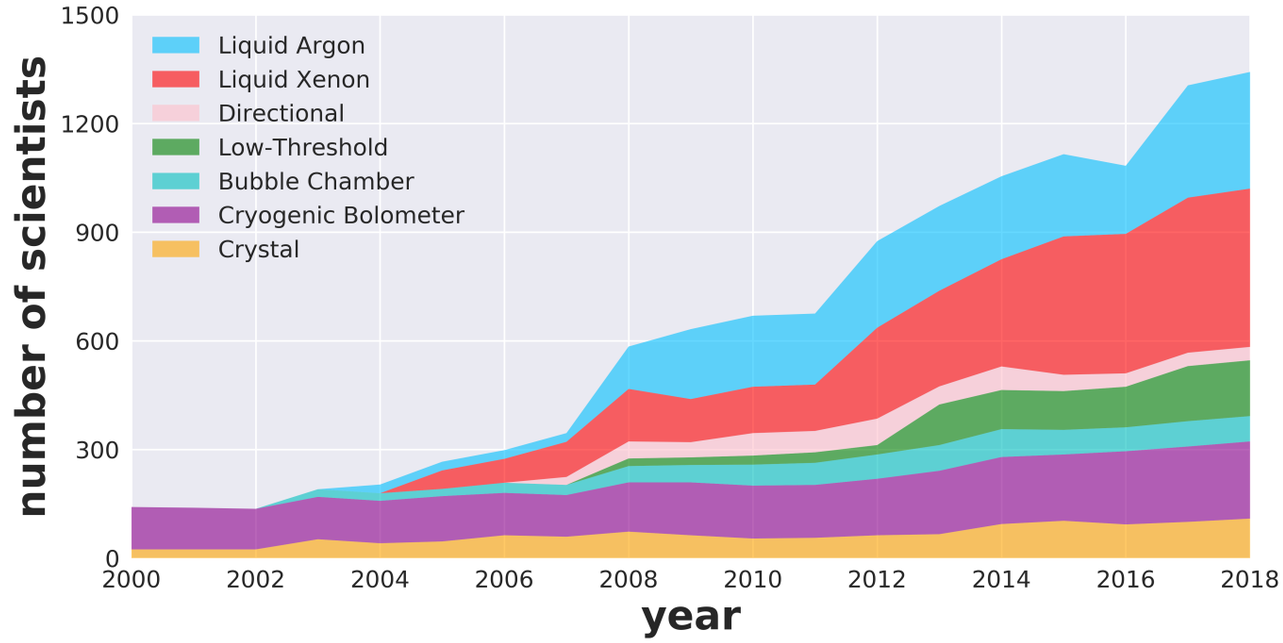
Many recent results, the most recent one from XENON1T

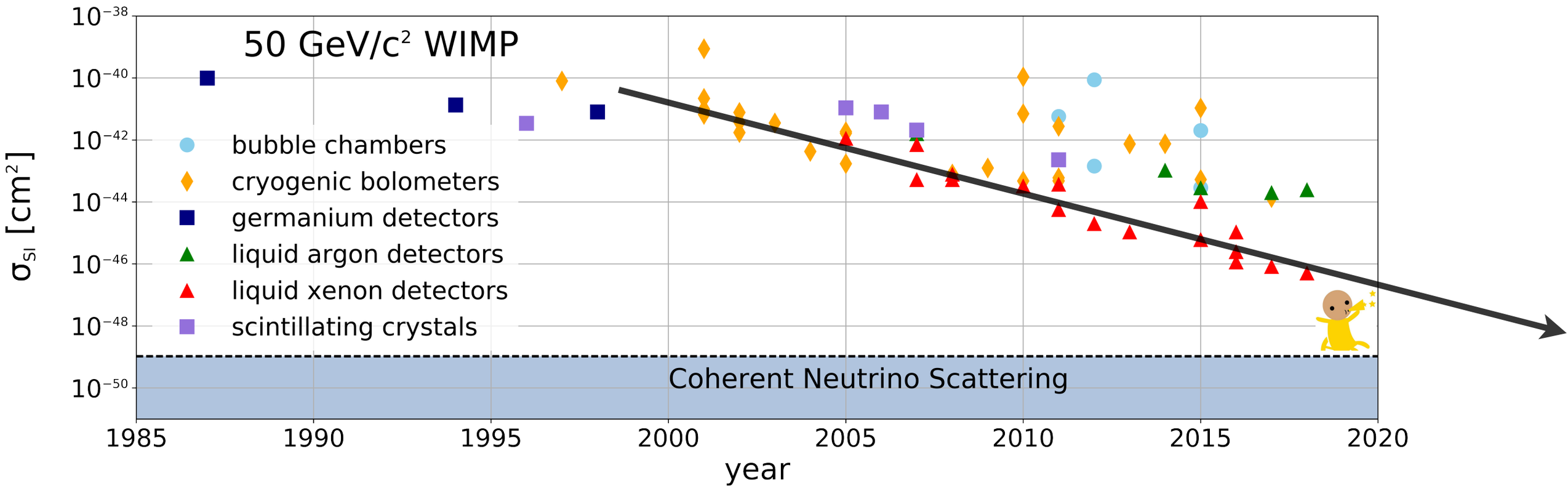
arXiv:1805.12562



This talk: WIMPs (> GeV)
Next talk (Tongyan Lin): light (sub-GeV) and ultra-light DM

Competitive field, rapid progress

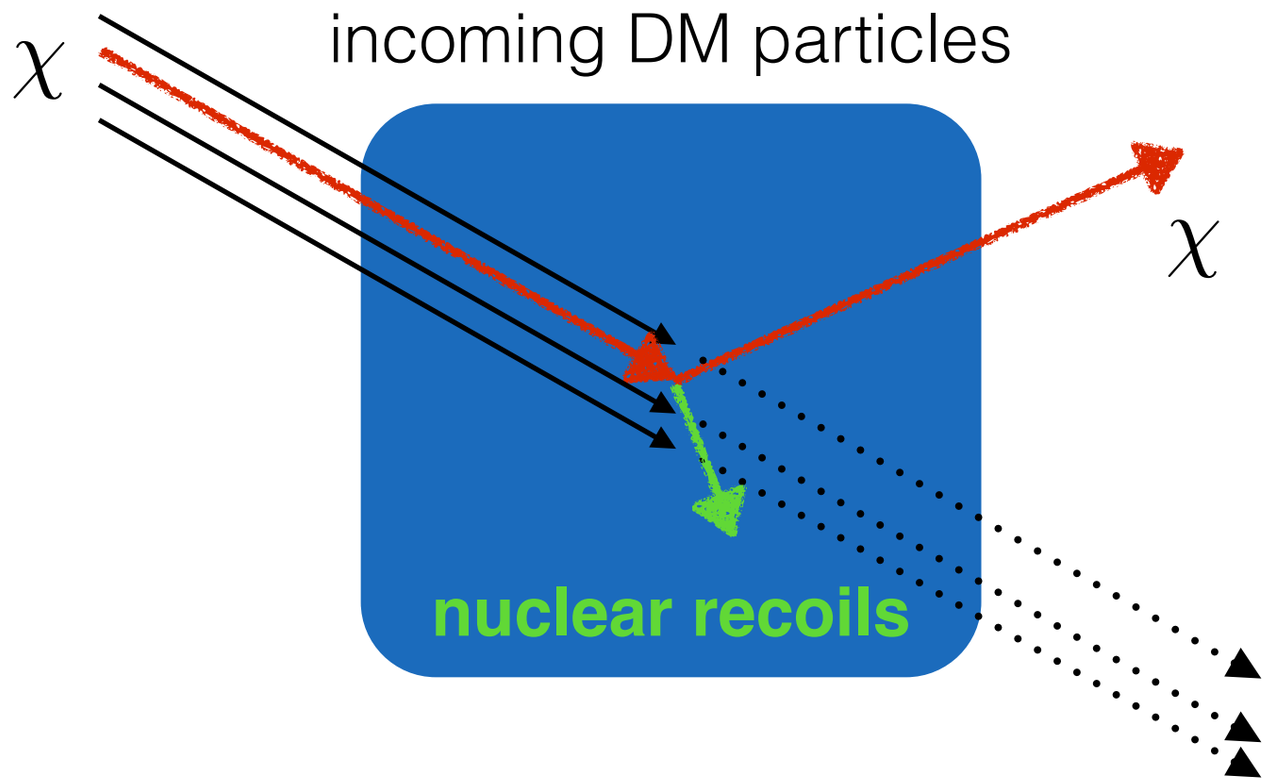




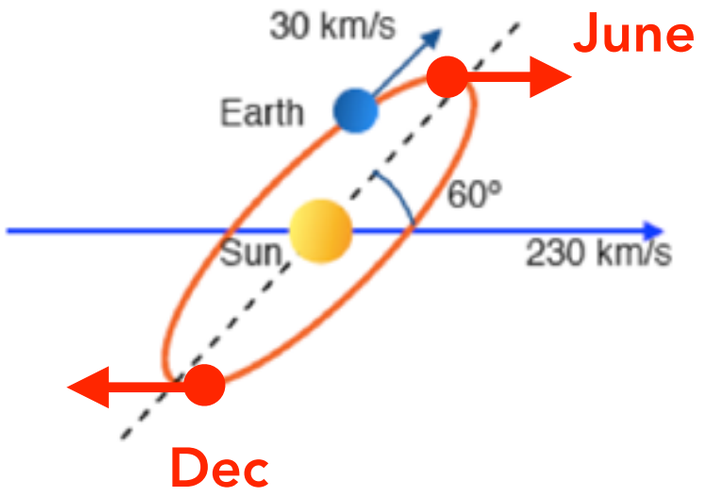
detector sensitivity improved by ~5 orders of magnitude in the last 20 years

Standard Assumptions for Dark Matter Direct Detection

- **DM mass range: GeV~TeV**
- **local WIMP density: 0.3 GeV/cm^3**
- **Isothermal velocity distribution: v_0~220 km/s**
- **WIMP escape velocity ~544 km/s**



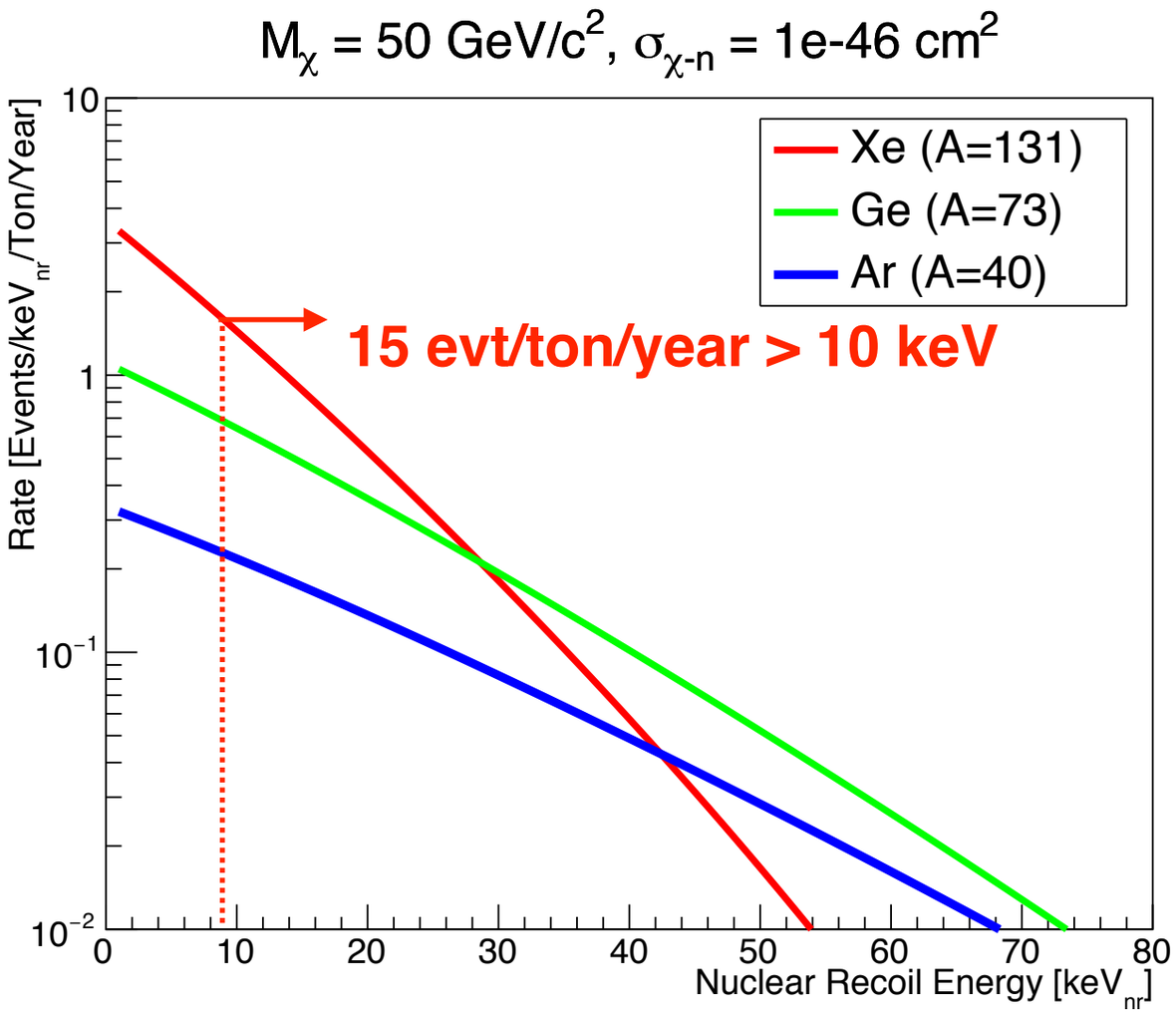
- **Standard channels: SI and SD**



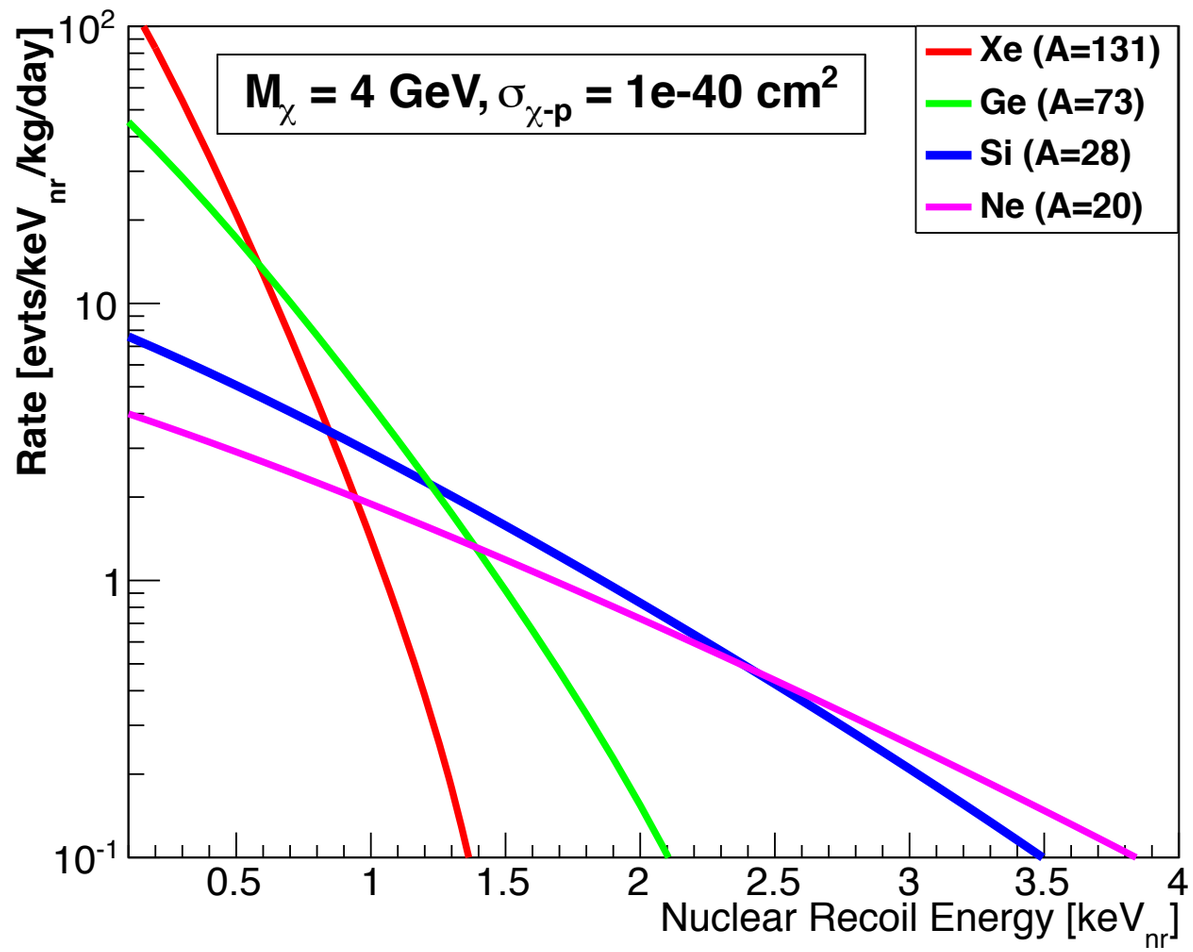
$$\frac{dR}{dE_R} = \frac{\rho_0}{m_\chi m_N} \int_{v_{min}}^{v_{esc}} \frac{d\sigma_{\chi_N}}{dE_R}(v, E_R) v f(v) dv$$

$$\frac{d\sigma_{\chi_N}}{dE_R} = \frac{m_N}{2\mu_N^2 v^2}(\sigma_0^{SI} F_{SI}^2(E_R) + \sigma_0^{SD} F_{SD}^2(E_R))$$

Experimental signature: falling nuclear recoil energy spectrum



Heavy WIMPs

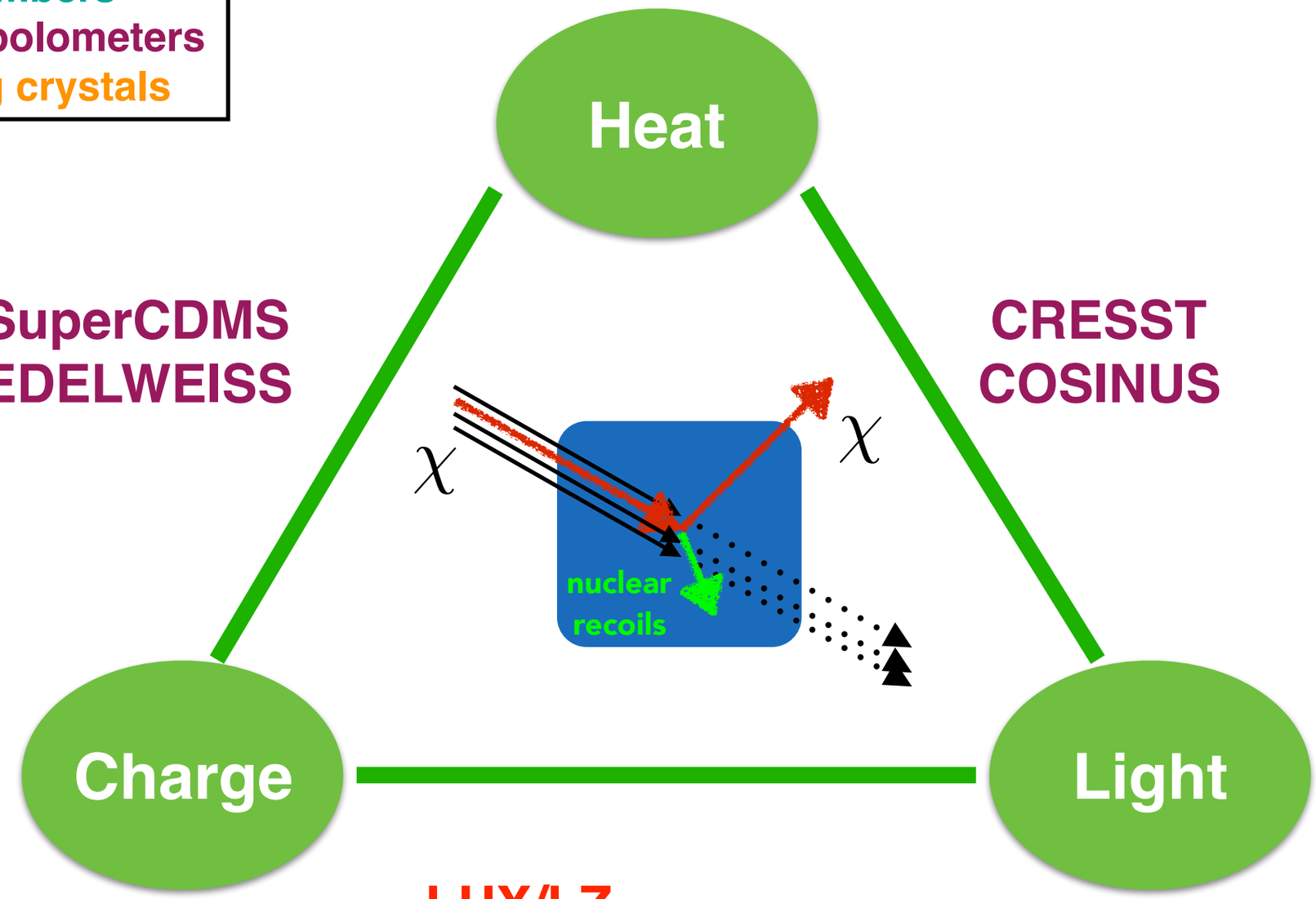


Low-mass WIMPs

Direct Detection Techniques

- Liquid argon
- Liquid xenon
- Directional detectors
- Low-threshold
- Bubble chambers
- Cryogenic bolometers
- Scintillating crystals

SIMPLE
PICASSO
COUPP
PICO



SuperCDMS
EDELWEISS

CRESST
COSINUS

CoGeNT
CDEX
DAMIC
SENSEI
NEWS-G
DRIFT
MIMAC
DMTPC

LUX/LZ
PandaX
XENON

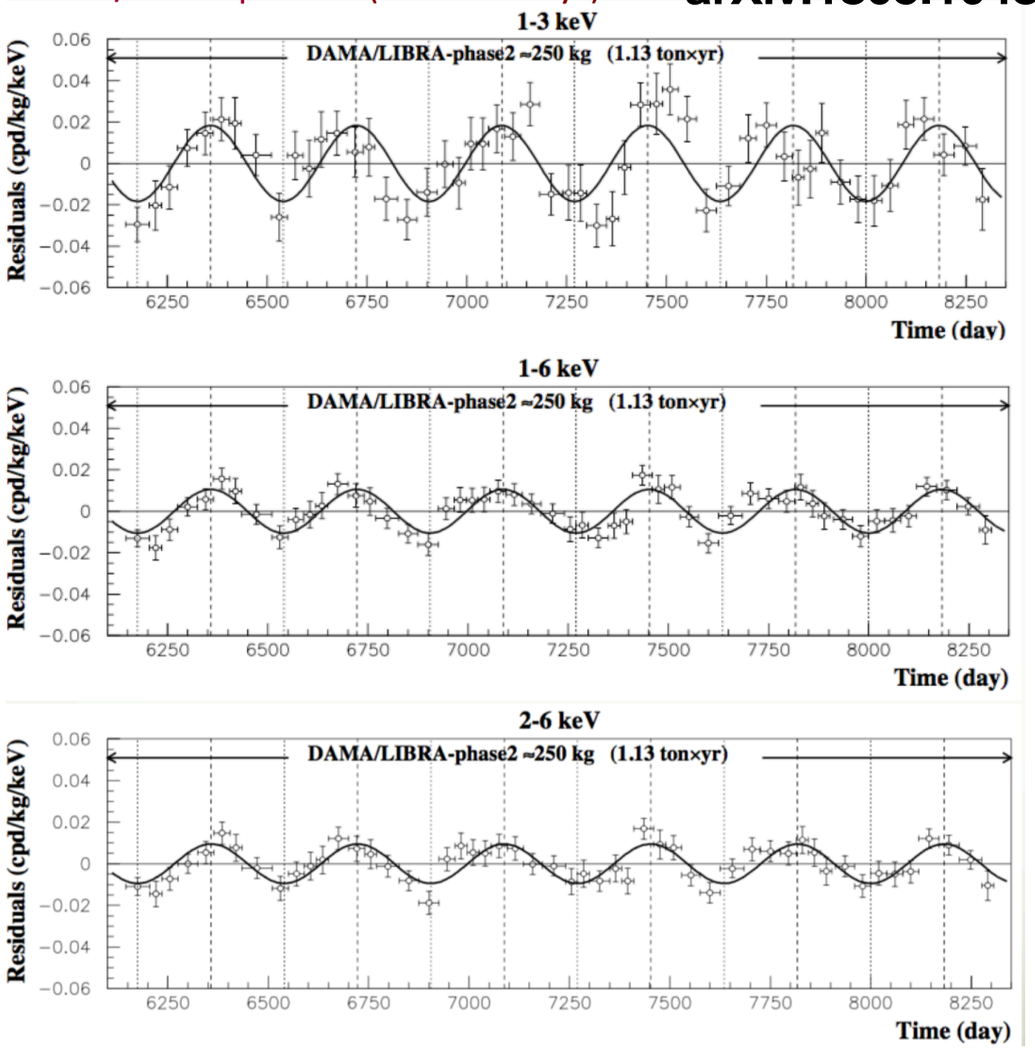
ArDM
DarkSide

DAMA
DM-Ice
COSINE
SABRE
ANAIS
PICO-LON
DEAP
XMASS

DAMA: so far the only experiment detected "dark matter" with >>5 sigma C.L.

from R. Bernabei talk, Mar. 26, 2018, LNGS

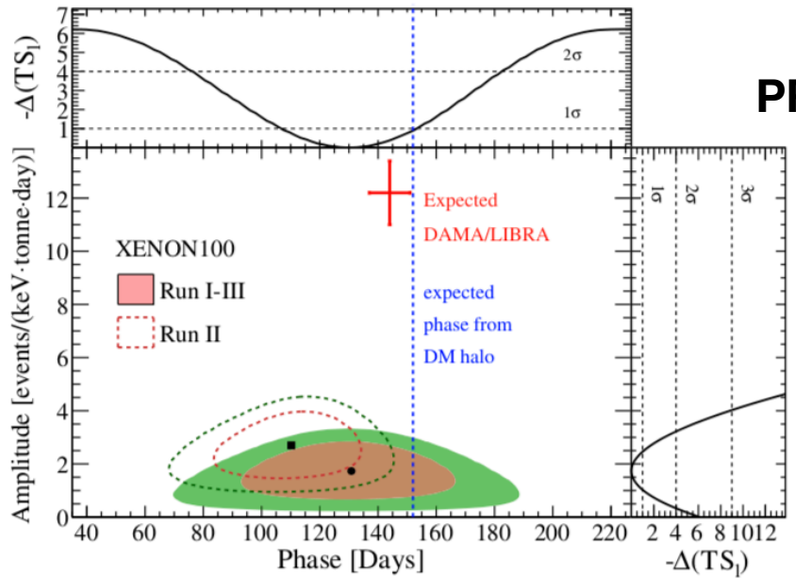
DAMA/LIBRA-phase2 (1.13 ton × yr) **arXiv:1805.10486**



see talk by Reina Maruyama on COSINE-100 at DM session this afternoon

- certainly not compatible with experiments with other targets

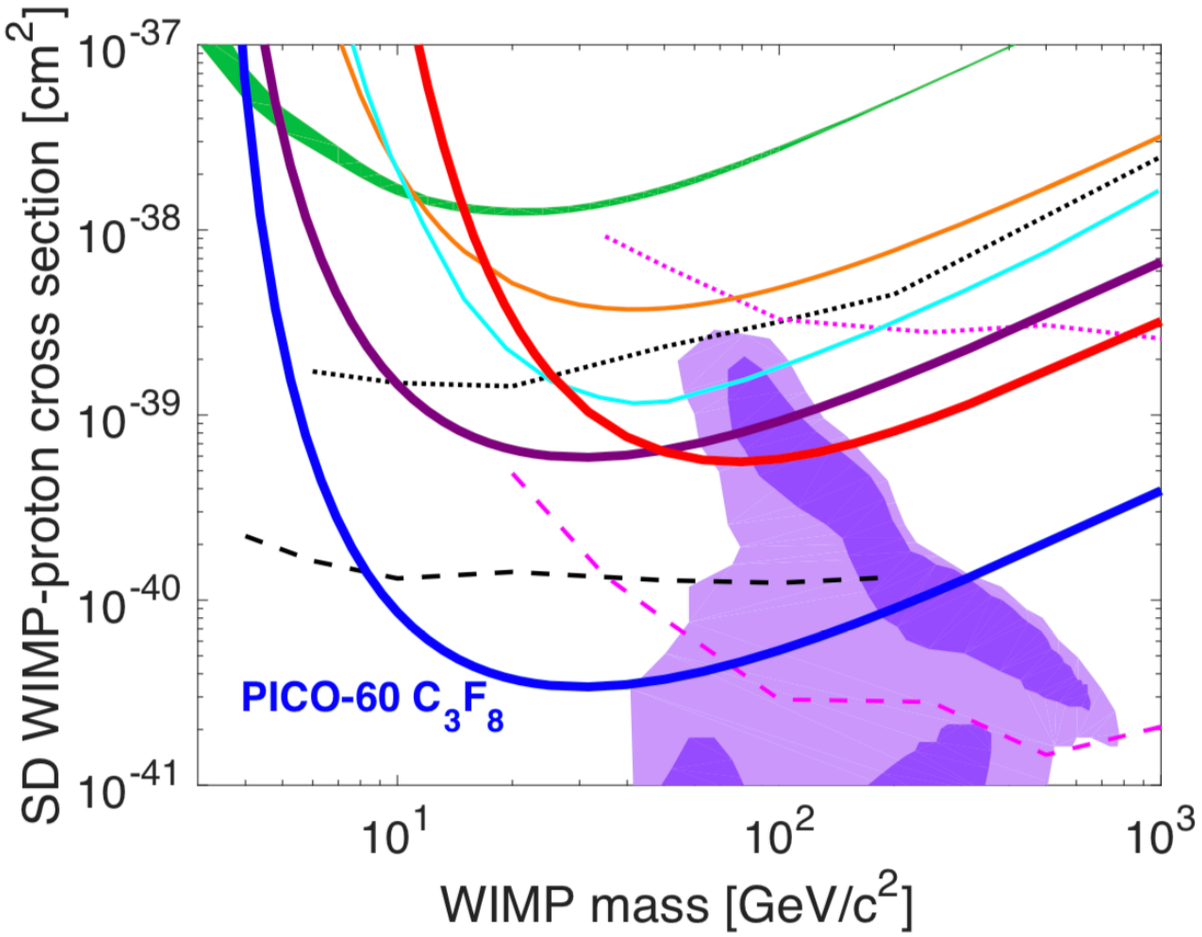
XENON100 4-year ER modulation study, PRL 118, 101101 (2017)



- could be unidentified background, e.g. Dan McKinsey, Is DAMA bathing in a sea of radioactive argon? (arXiv:1803.10110)
- need other NaI experiments:
  - COSINE/ANAIS/SABRE/PICO-LON
  - COSINUS

SD WIMP-proton constraints: F-target leads

PICO, Phys.Rev.Lett. 118 (2017) no.25, 251301

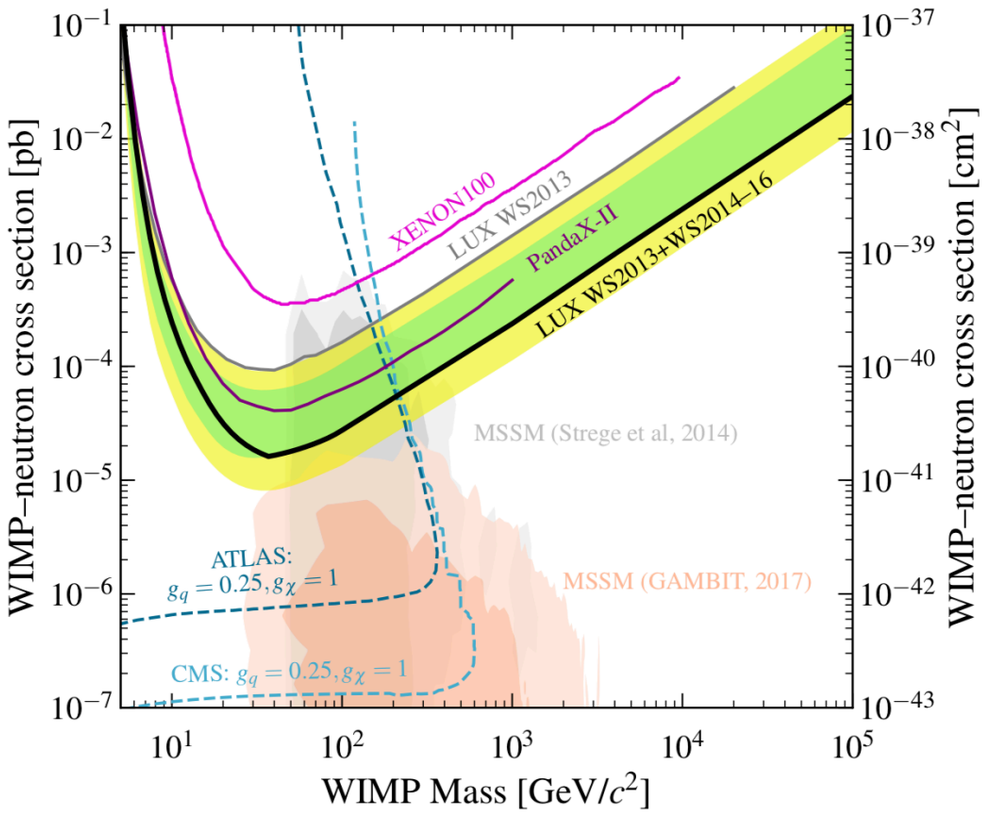


- bubble chamber: 52 kg C_3F_8
- excellent electron recoil and alpha rejection
- 1167-kg-day exposure
- 3.3 keV threshold
- no single-scatter NR candidate
- best SD WIMP-proton limit: 3.4e-41 cm² at 30 GeV/c²

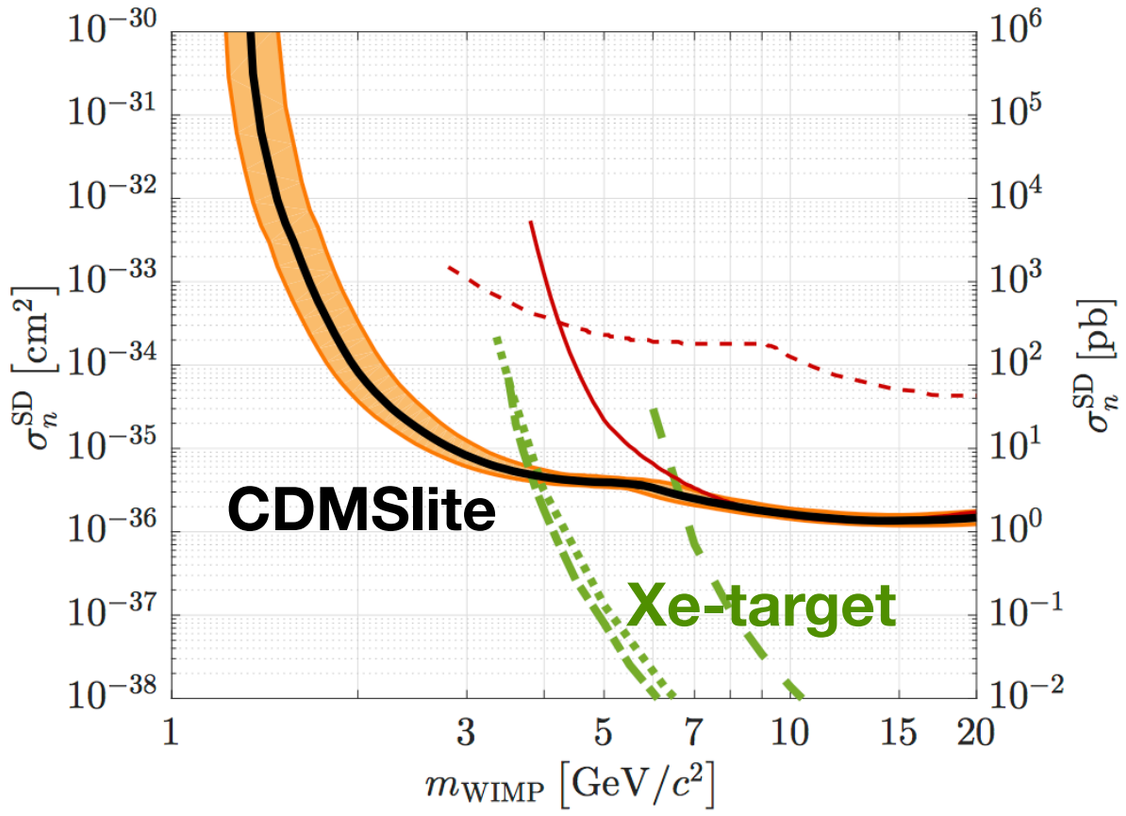
see talk by *Anthony Noble* on PICO at DM session this afternoon

SD WIMP-neutron constraints: Xe-target leads, Ge-target good at low-mass

LUX, Phys.Rev.Lett. 118 (2017) no.25, 251302



CDMSlite, Phys. Rev. D 97, 022002 (2018)



Xe-target (LUX, PandaX, XENON)

- Xe129 (29.5%), Xe131 (23.7%)
- best published SD-neutron limit: 1.6e-41 cm^2 at 35 GeV/c^2
- new lower-bkg data from PandaX-II, XENON1T should give stronger constraints

Ge-target (CDMS, CDEX)

- Ge73 (7.73%)
- best SD-neutron limit below 3 GeV/c^2

Model-independent Effective field theory (EFT), e.g. XENON100, Phys.Rev. D96 (2017) no.4, 042004
see also talk by *Nicole Larsen* on LUX EFT searches at DM session this afternoon

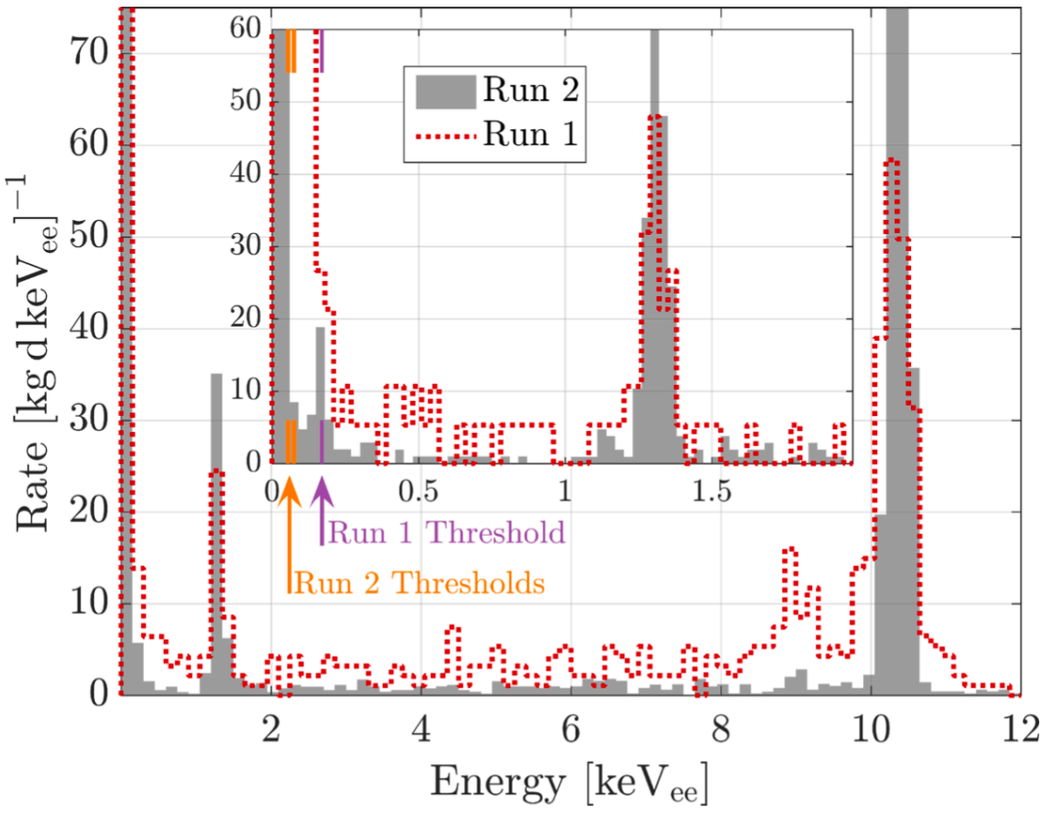
Low-mass (1-10 GeV) dark matter: cryogenic bolometers

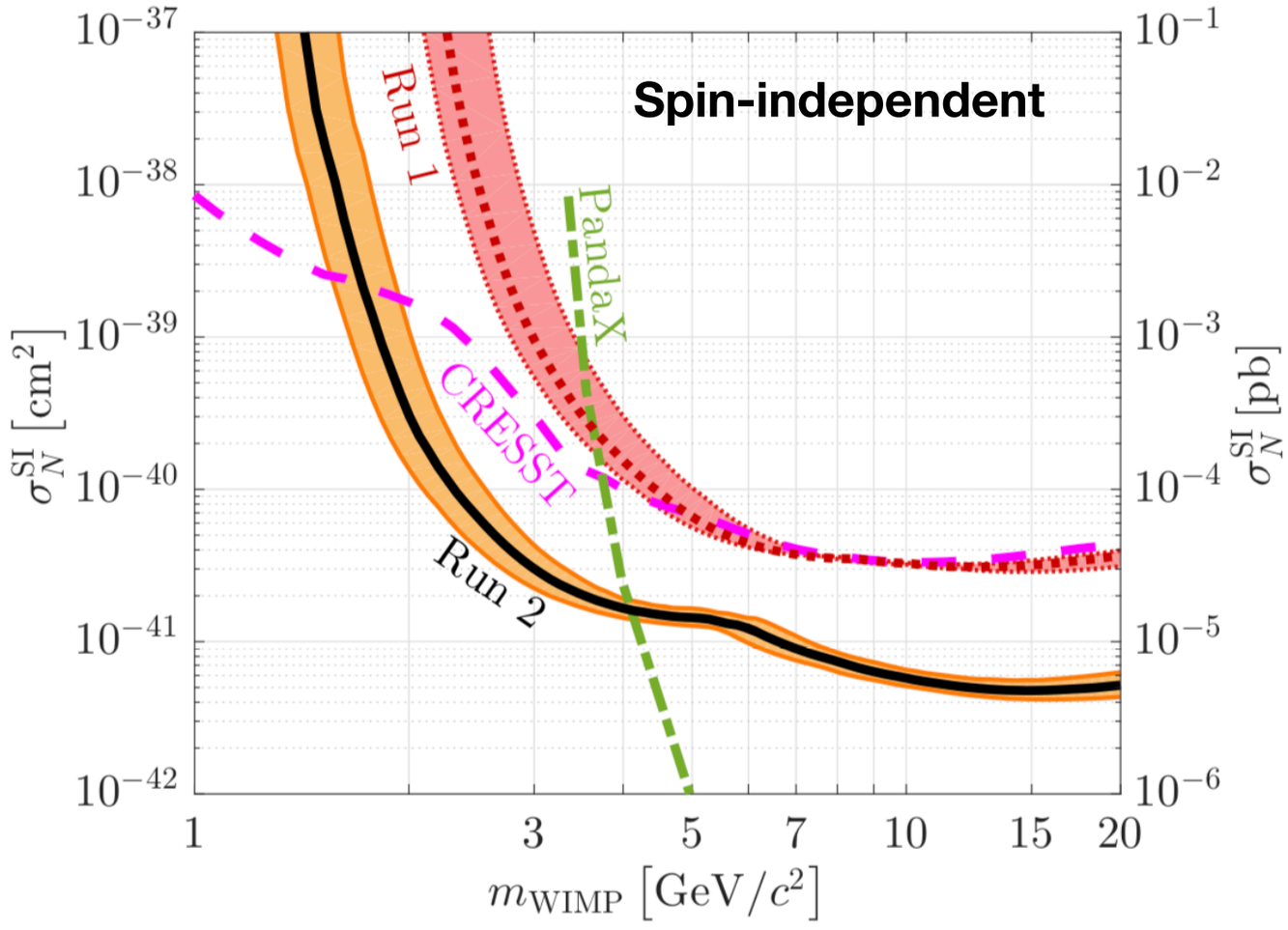
battle between low-threshold and low-background

CDMSlite, Phys. Rev. D 97, 022002 (2018)

CDMSlite: HV operation

- no ER/NR discrimination: higher bkg
- but lowering the threshold: <100 eVee
- gain sensitivity for low-mass WIMPs





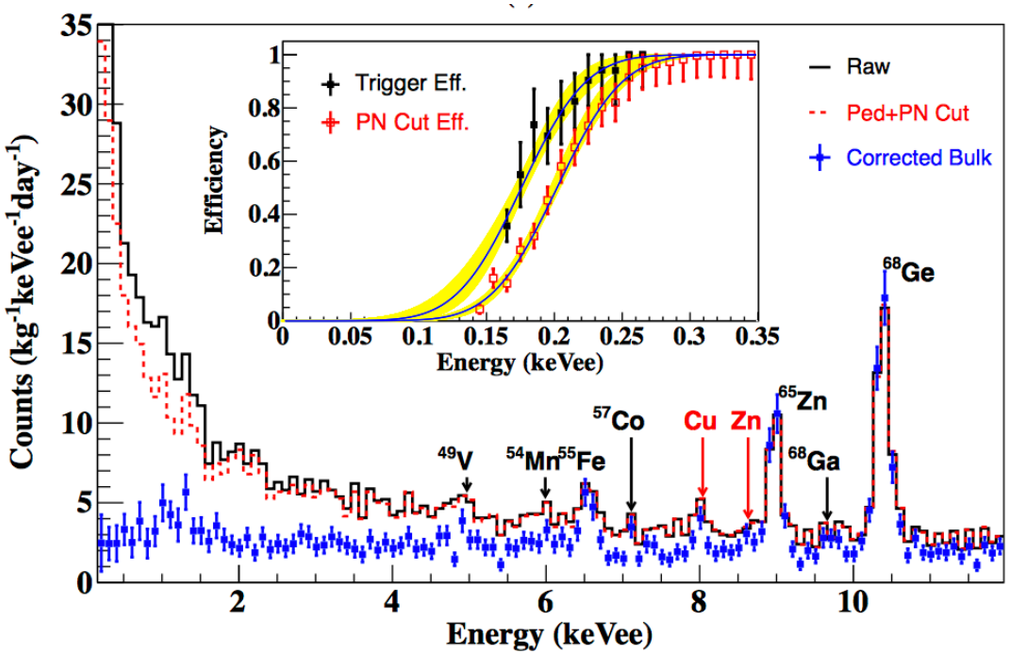
CRESST-III result from arXiv:1711.07692

Low-mass (1-10 GeV) dark matter: low-threshold counting

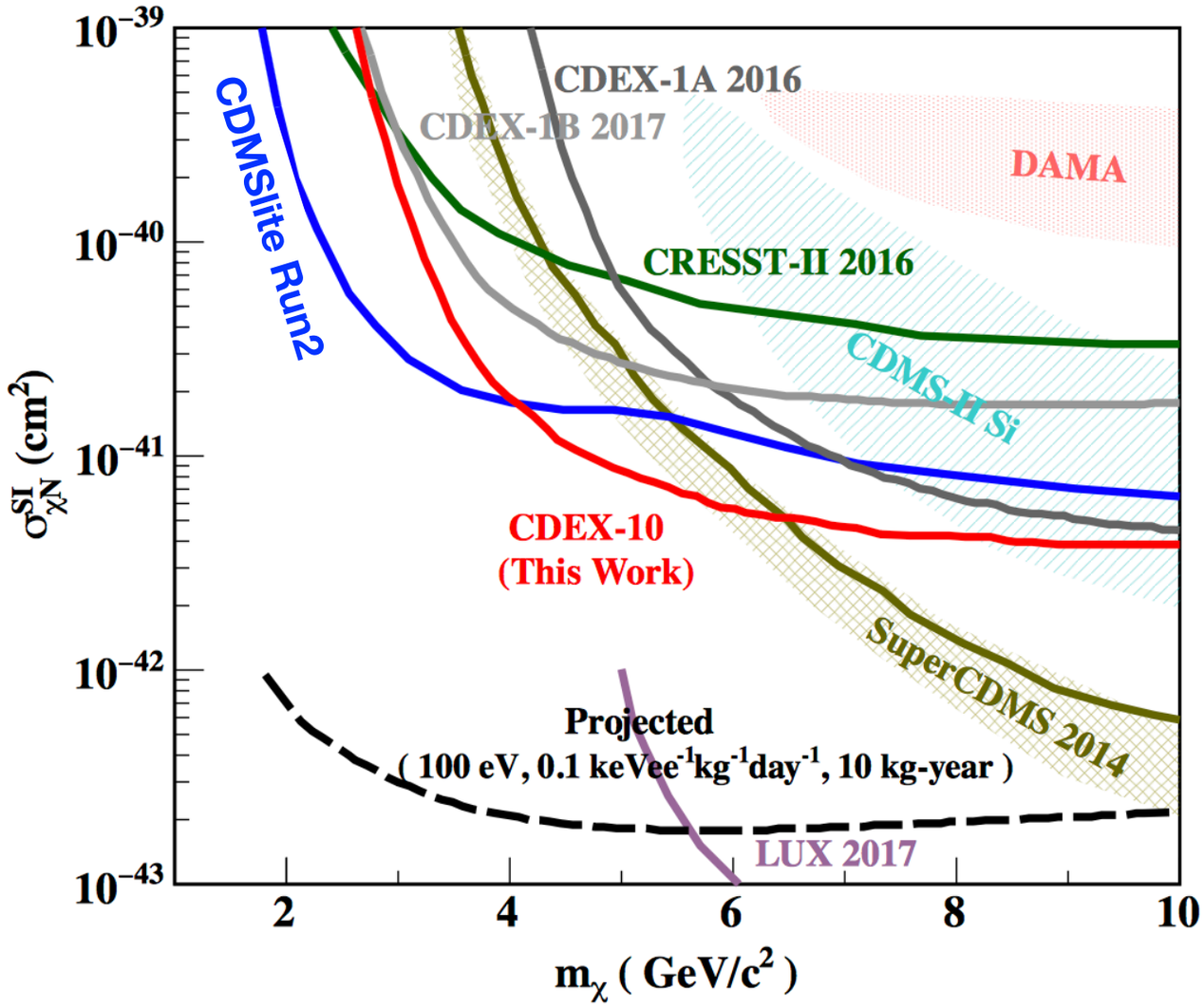
battle between low-threshold and low-background

CDEX-10 at CJPL

- 10kg Ge detector in liquid nitrogen
- 102.8 kg-days exposure
- analysis threshold: 160 eVee
- residual bkg rate: ~2.5 evt/keVee/kg/day
- improved SI & SD-n limits at 5 GeV/c^2



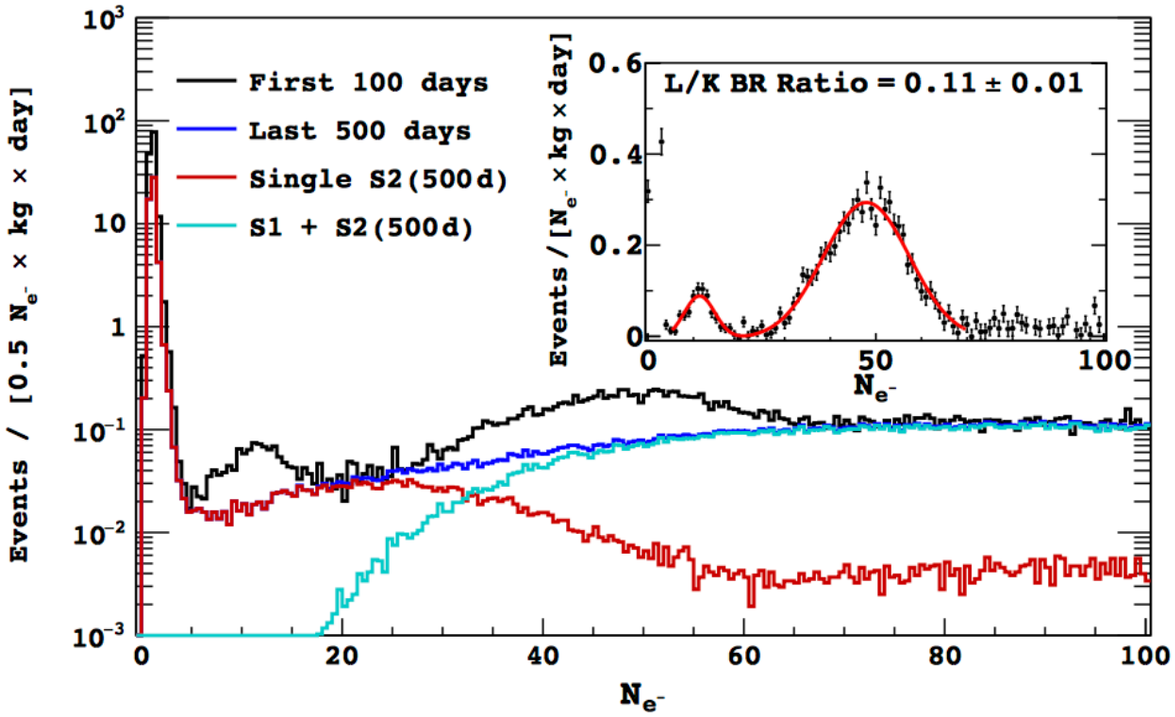
CDEX, arXiv:1802.09016



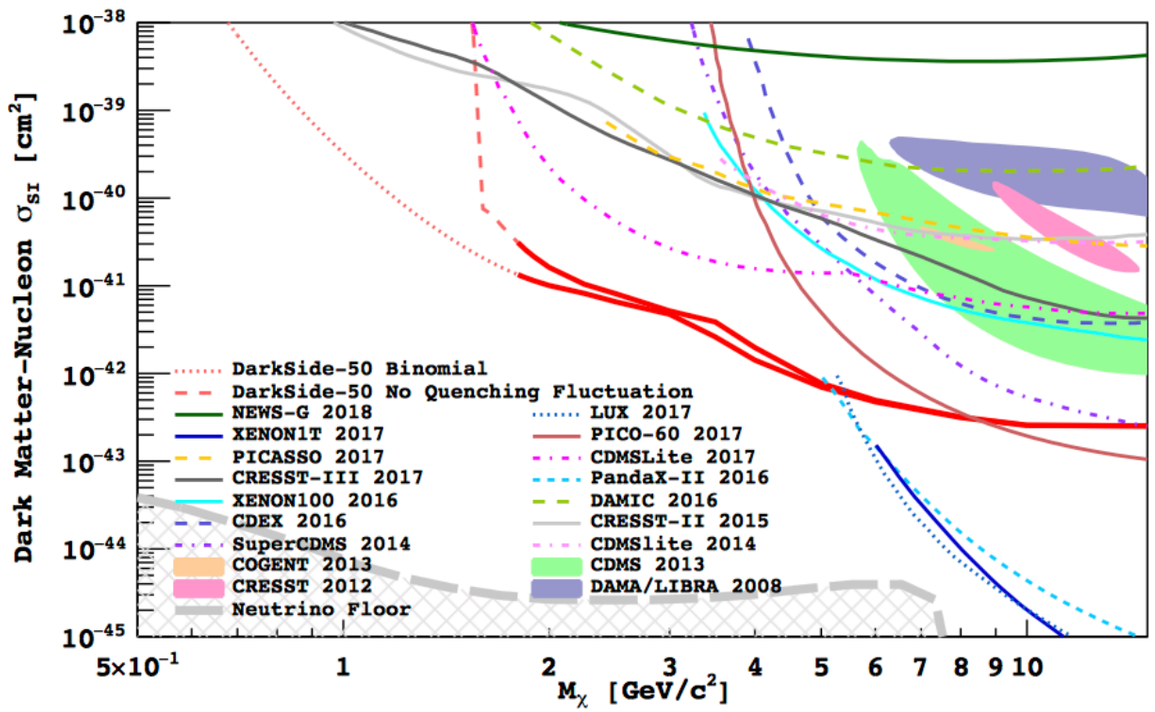
see talk by *Qian Yue* on CDEX at DM session this afternoon

Low-mass (1-10 GeV) dark matter: liquid argon

big improvement with S2-only search in DarkSide-50



DarkSide-50, arXiv:1802.06994



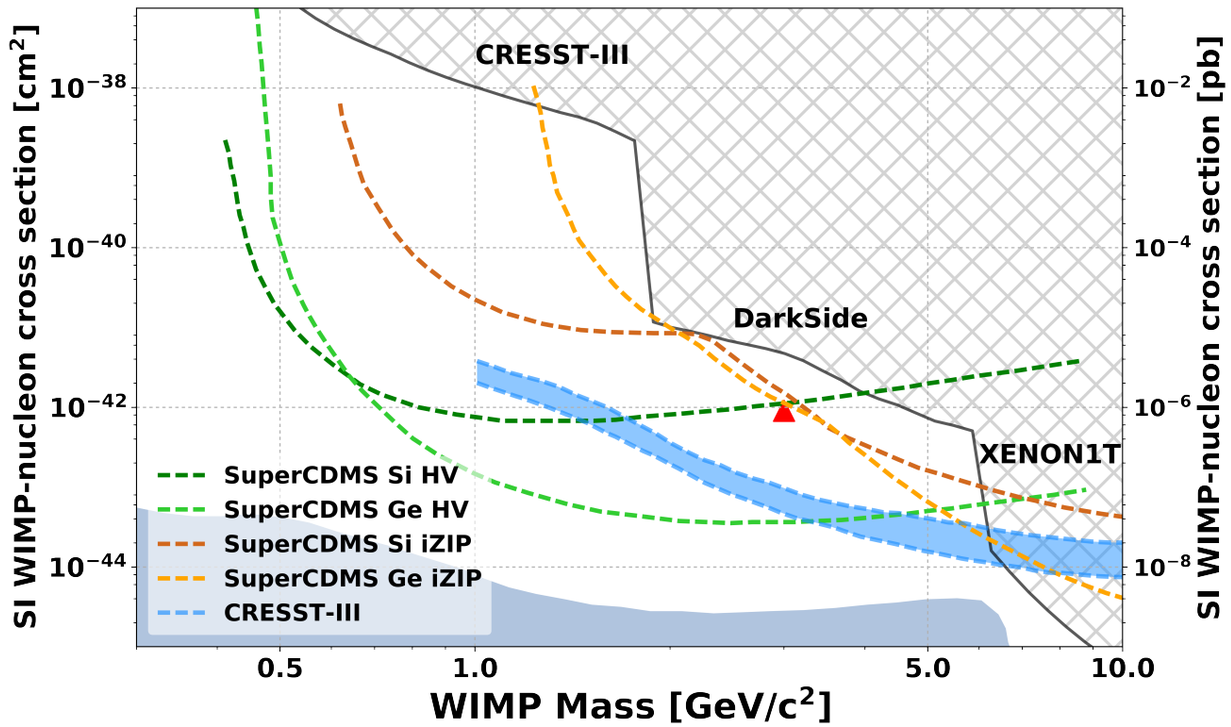
DarkSide-50 S2-only search

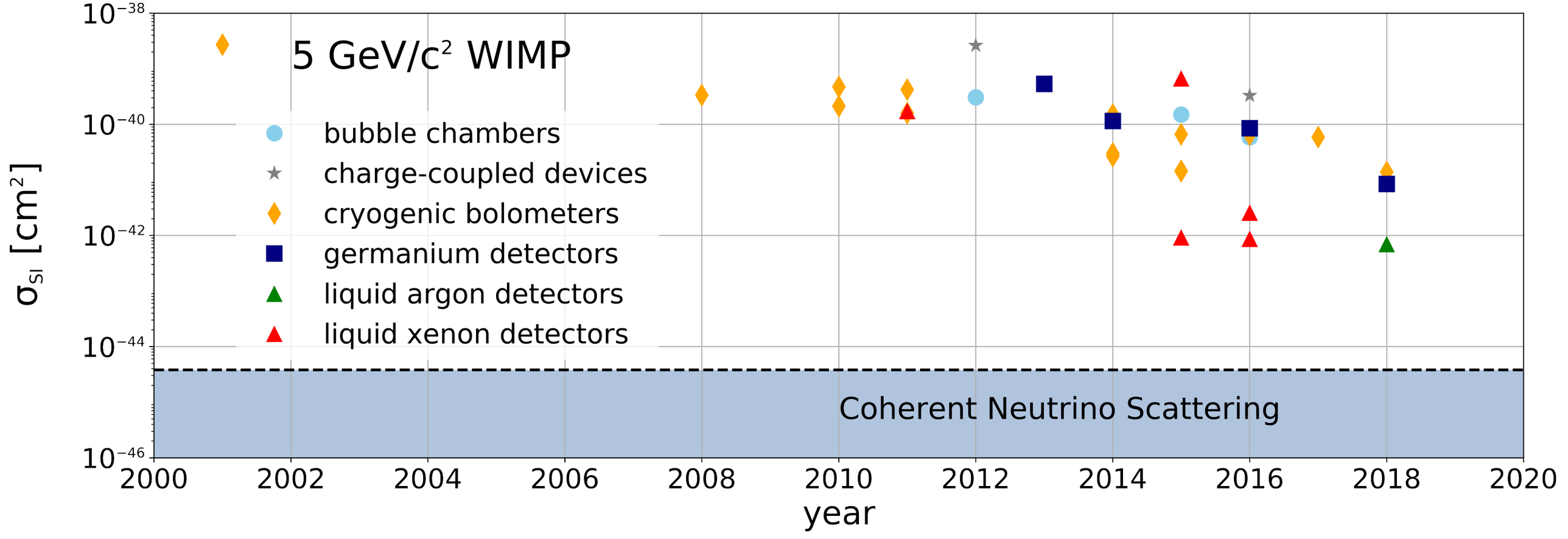
- no ER/NR discrimination
- low threshold: ~100 eVee
- bkg: ~1.5 event/keVee/kg/d at 0.5 keVee
- spectrum consistent with known background
- **Liquid argon now gives the best limits for low-mass DM between 2-5 GeV/c²**

see talk by *Luca Pagani* on DarkSide at DM session this afternoon

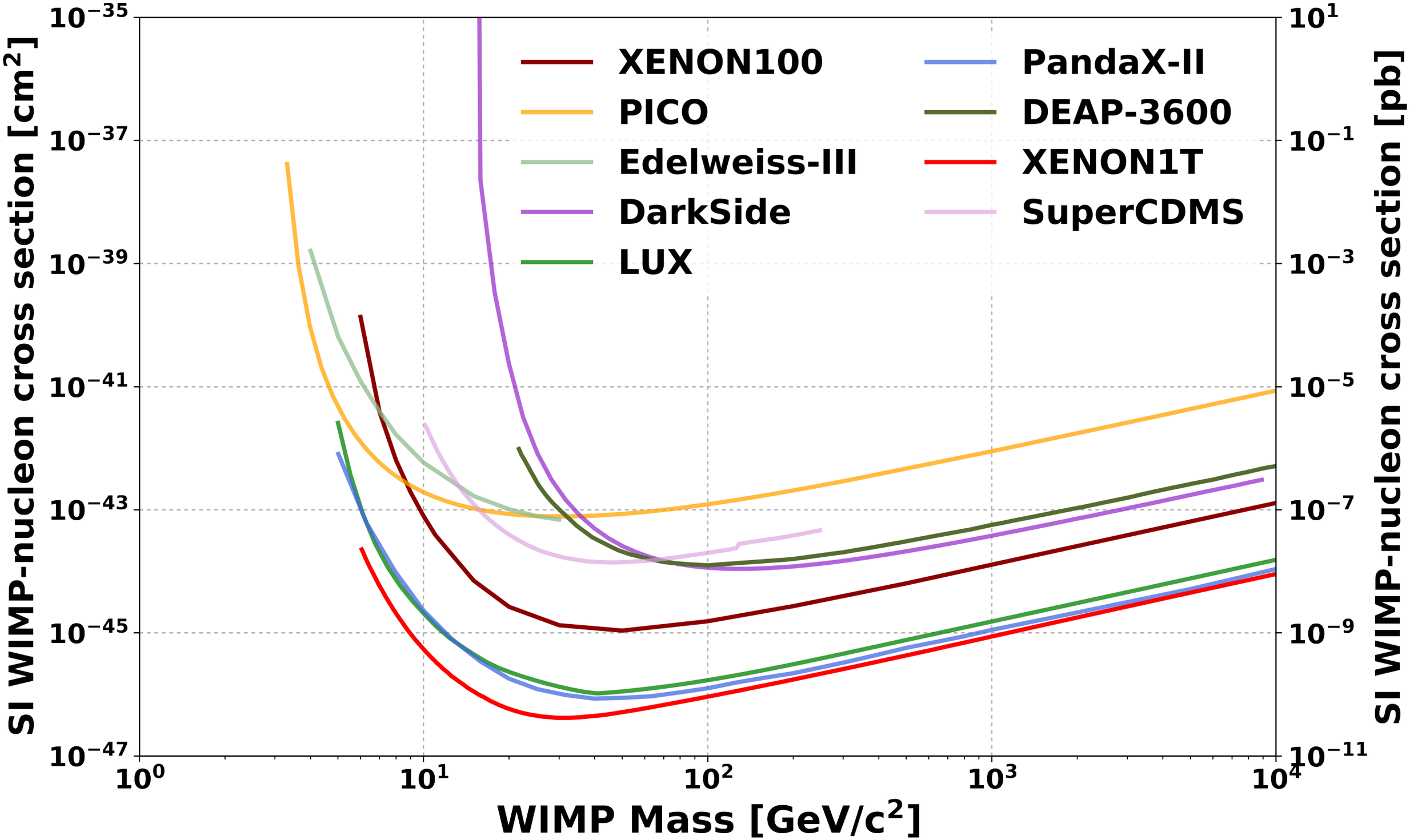
Low-mass dark matter search status

- 2~3 orders of magnitude above the “neutrino floor”
- challenges: background reduction/discrimination at the lowest threshold



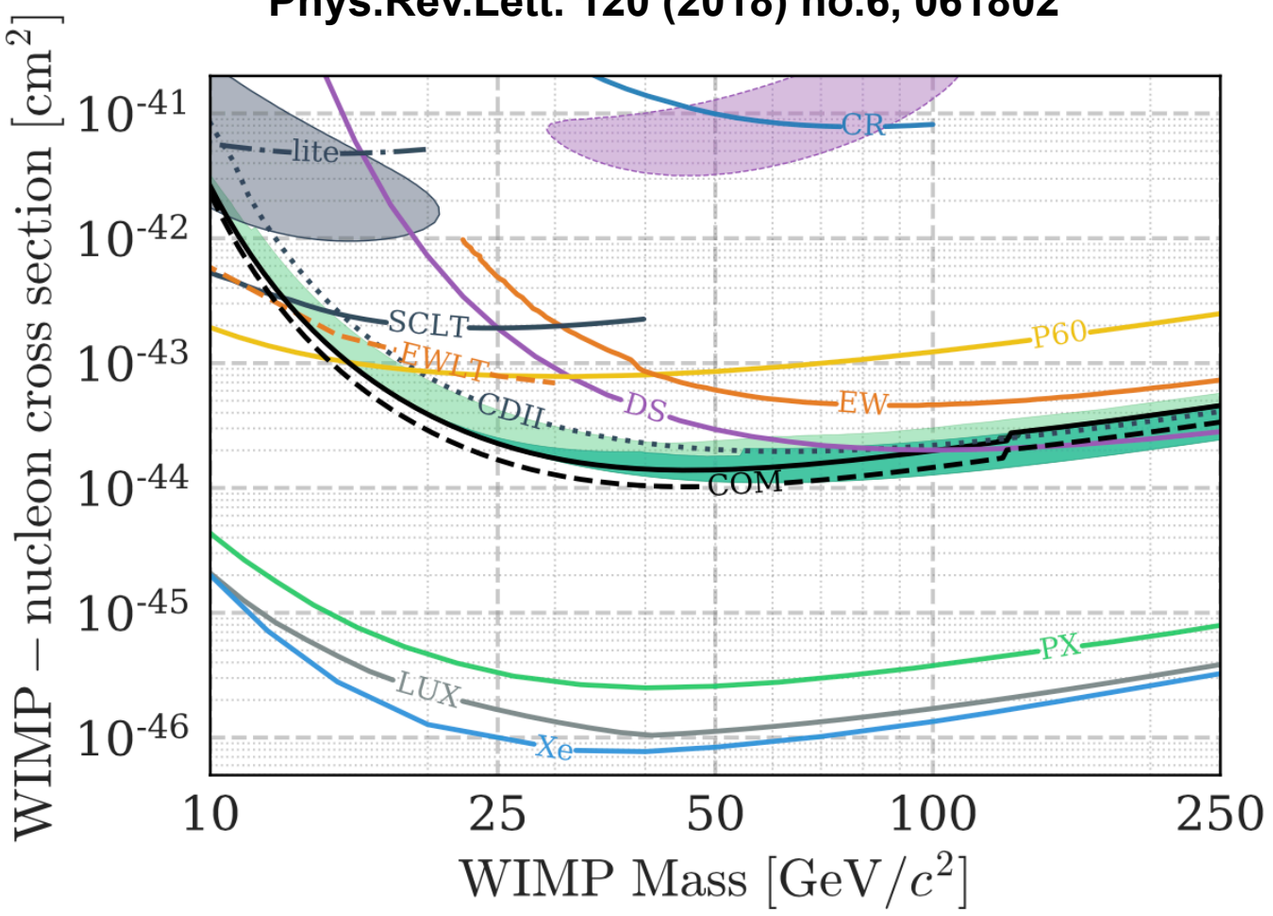


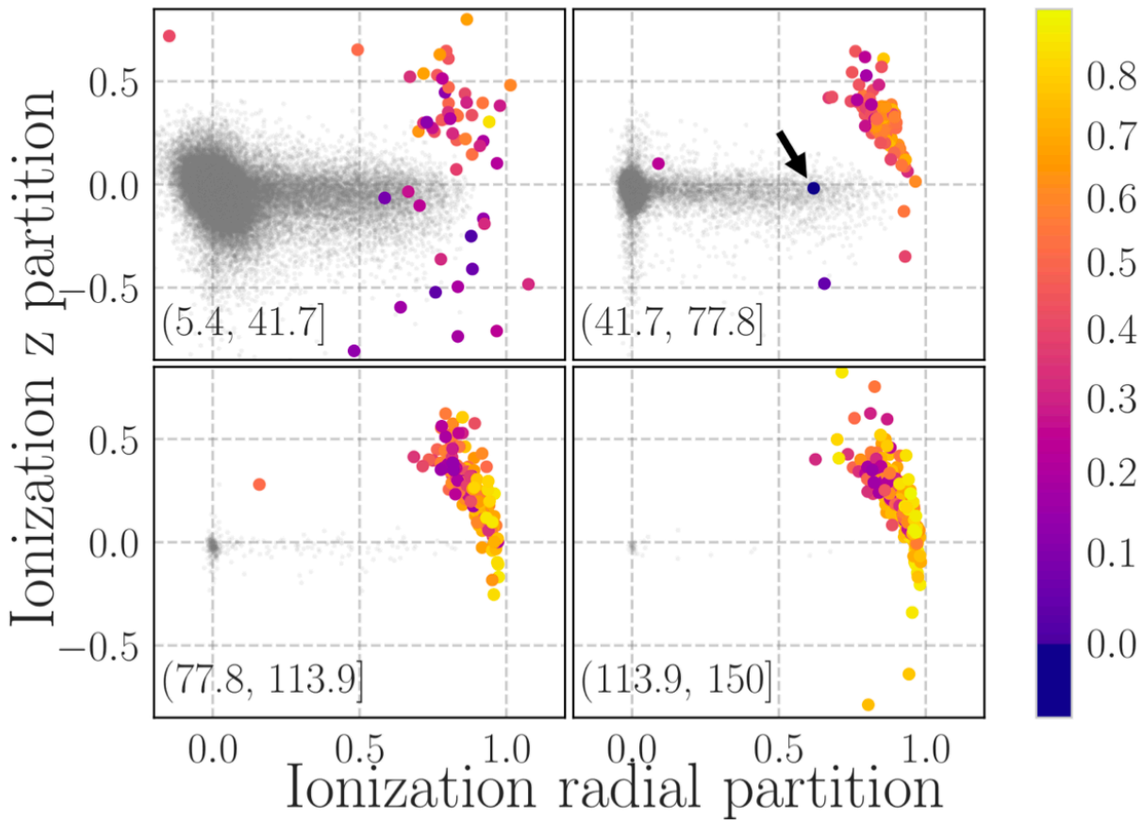
“the battlefield”: heavy WIMPs search



SuperCDMS at Soudan

Phys.Rev.Lett. 120 (2018) no.6, 061802

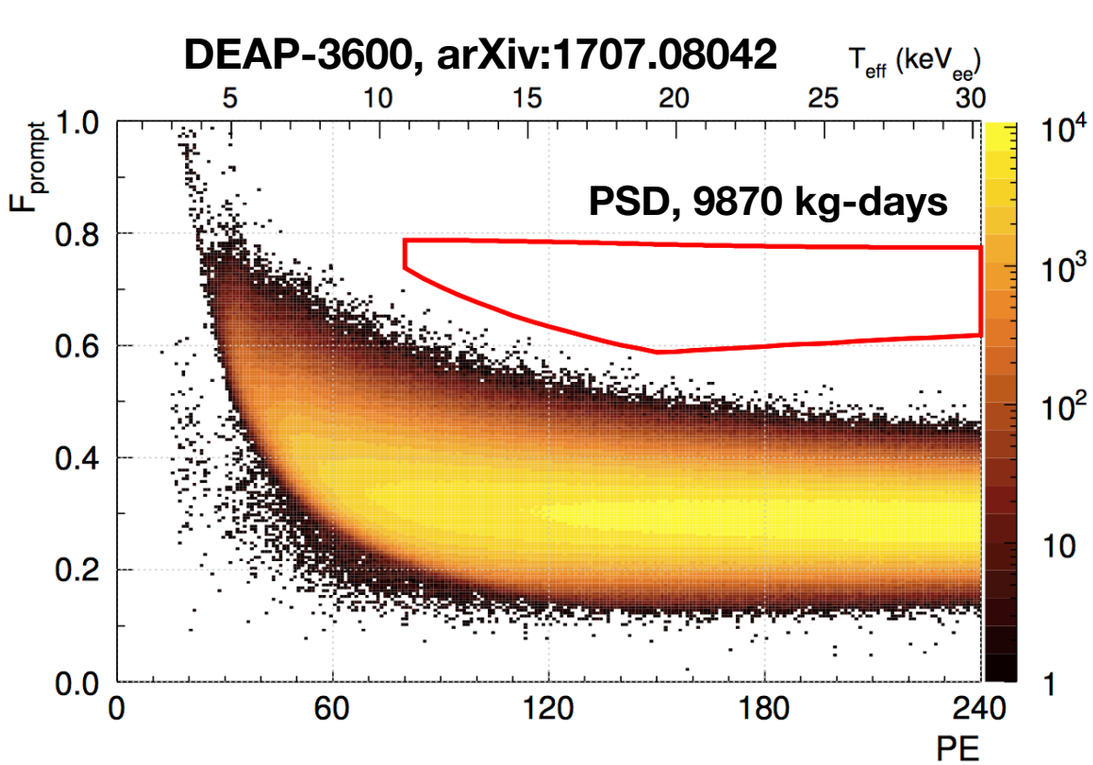


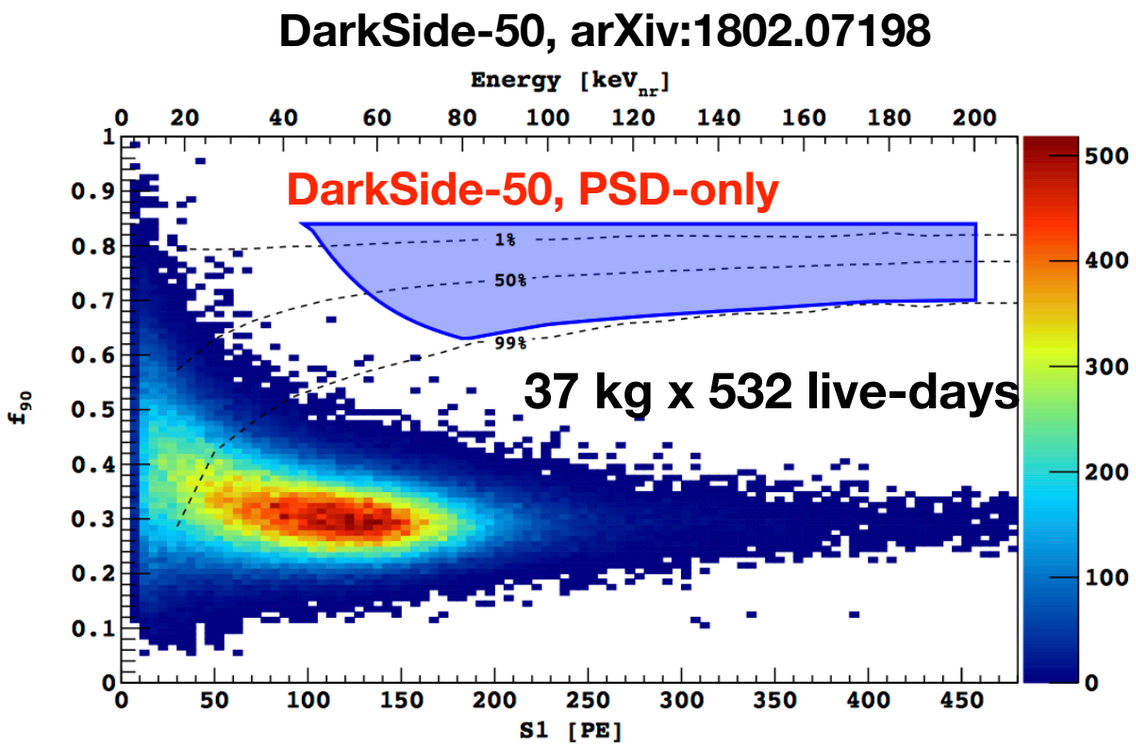


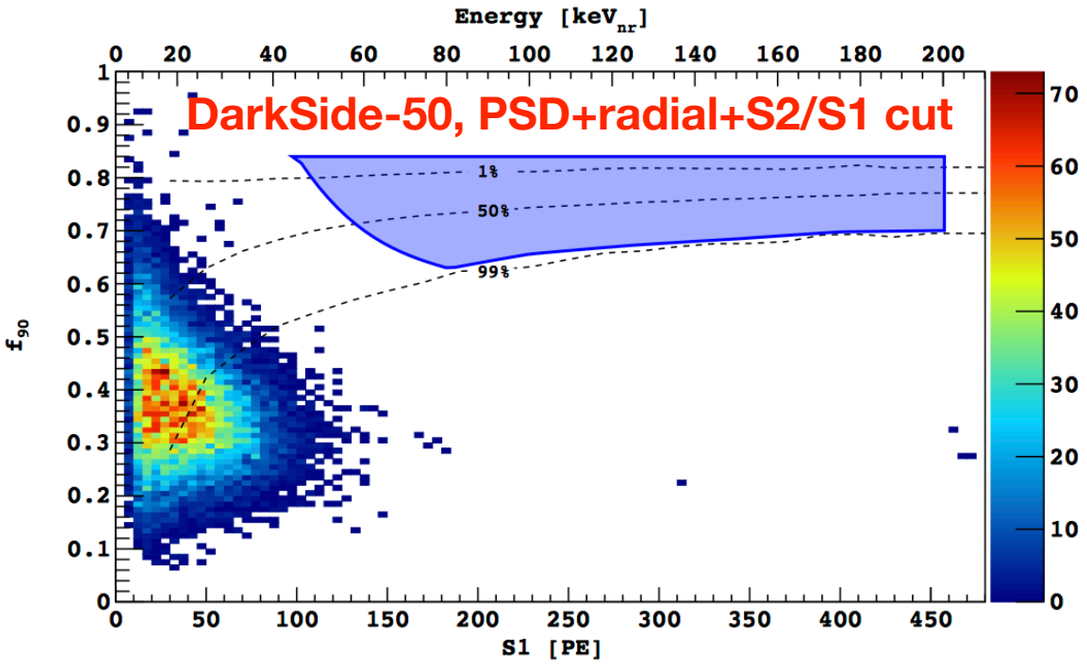
- iZIP detectors
- 1690 kg days exposure
- single candidate observed, consistent with bkg
- **best limits for WIMP-germanium-nucleus interaction > 12 GeV/c²**

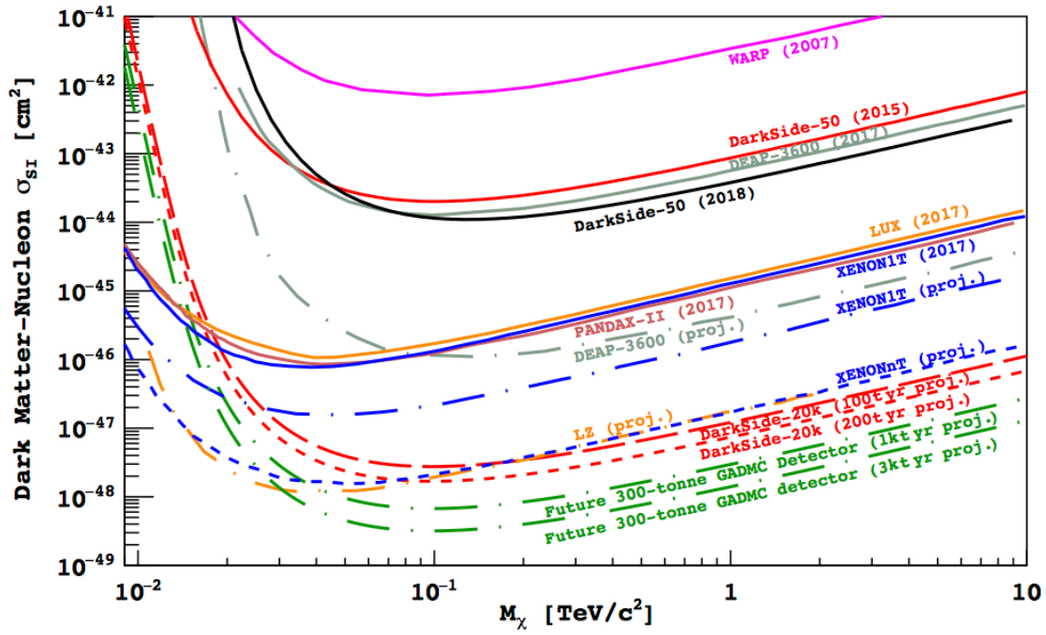
see talk by *Francisco Ponce* on SuperCDMS at DM session this afternoon

Liquid Argon results: DarkSide-50 & DEAP-3600



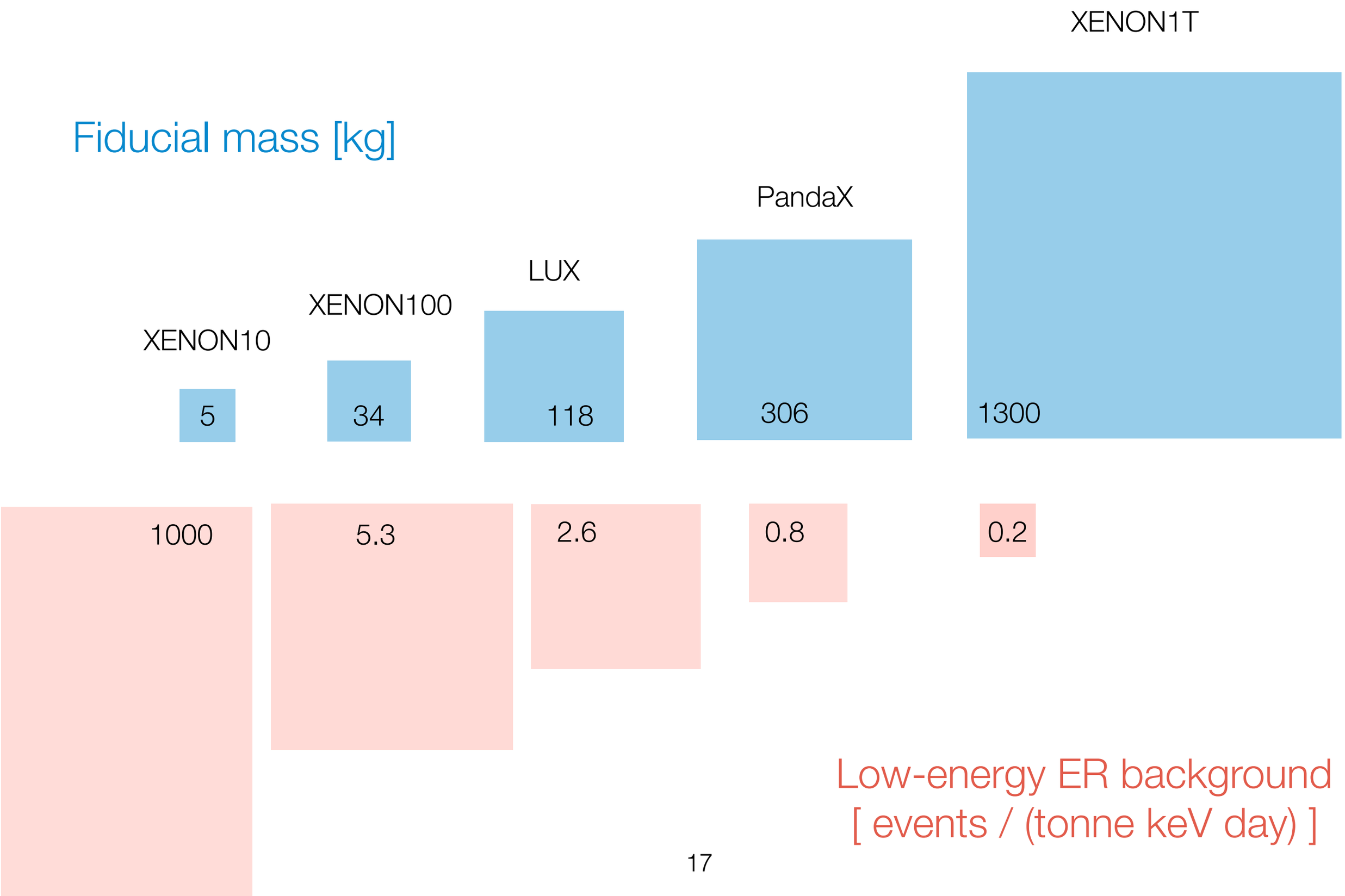




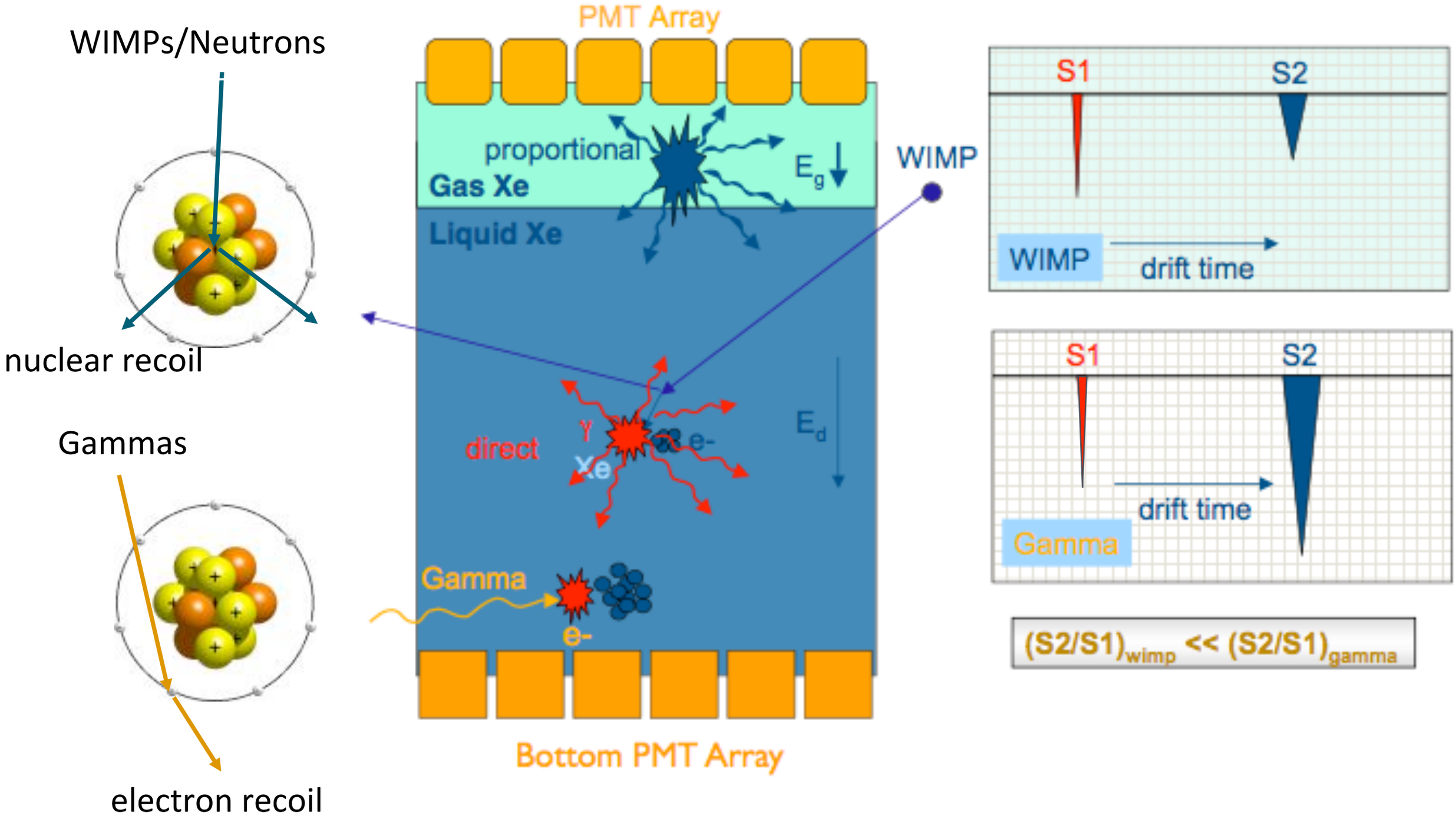


see more by *Luca Pagani* (DarkSide) and *Yu Chen* (DEAP-3600) at DM session this afternoon

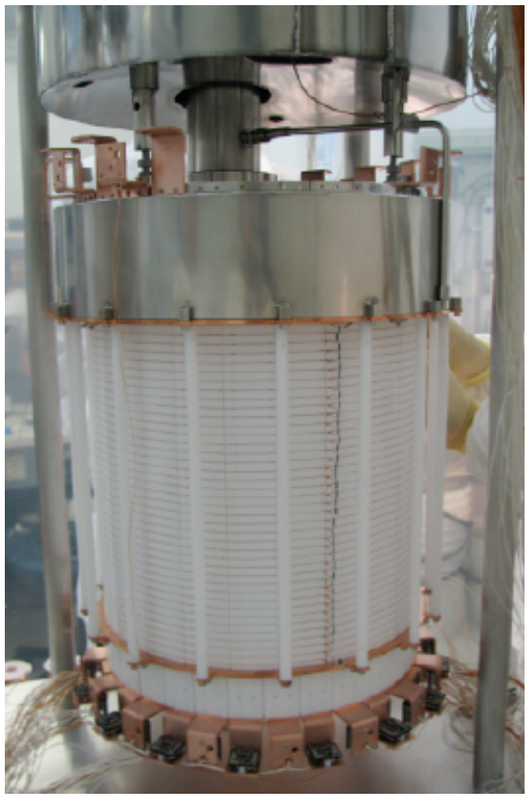
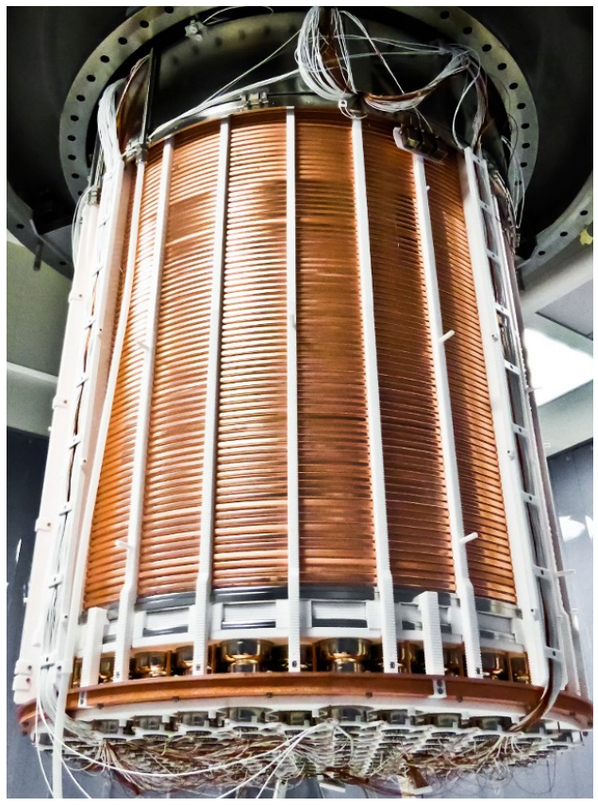
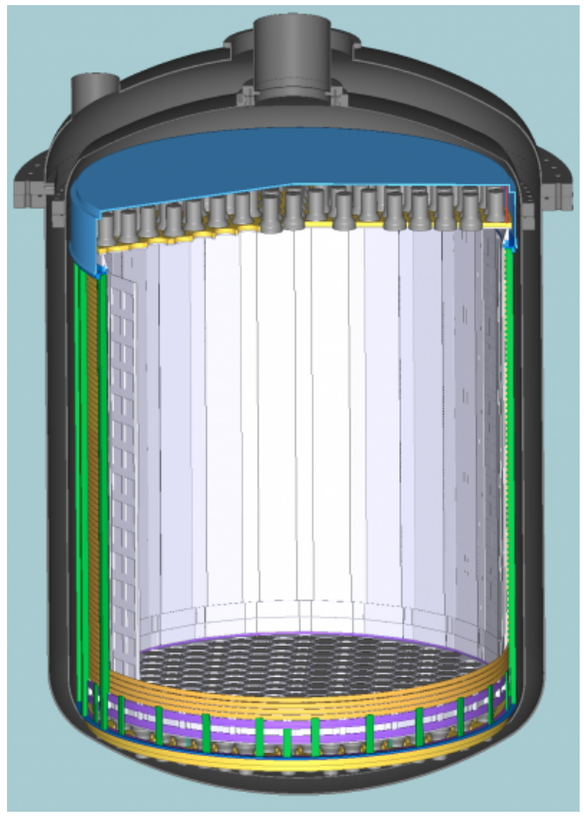
Impressive evolution of LXeTPCs as WIMP detectors



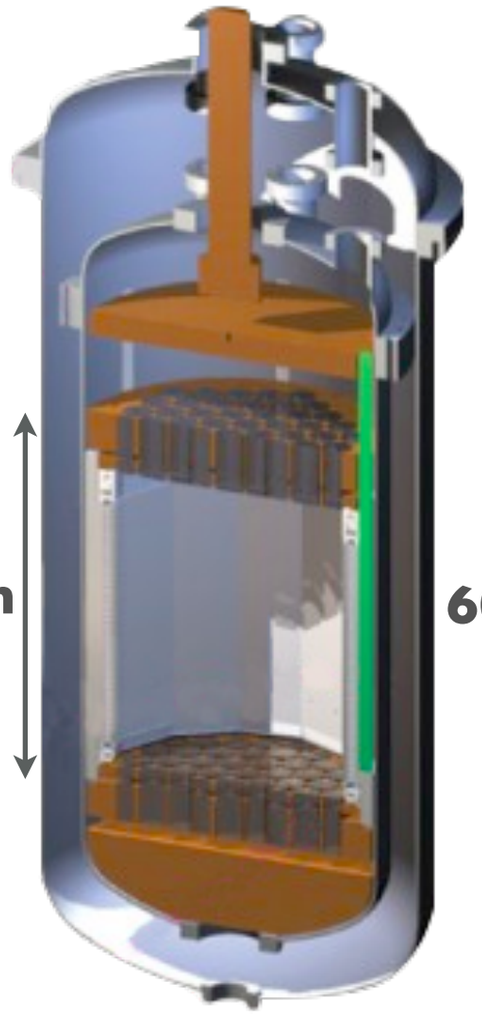
Hunting for WIMPs with Liquid Xenon



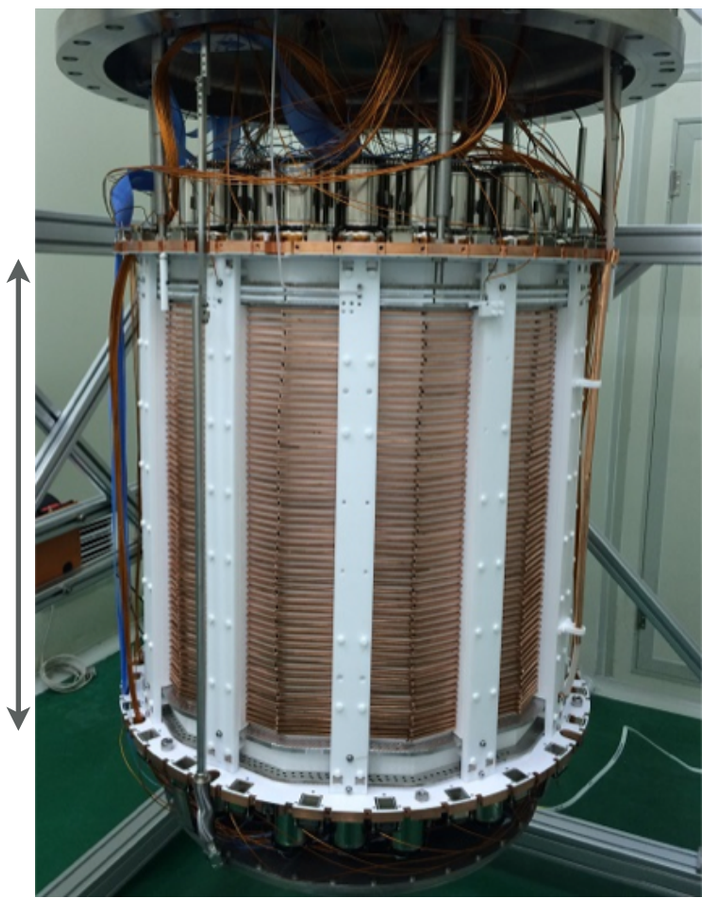
WIMP detectors from the XENON-series

XENON10	XENON100	XENON1T	XENONnT
			
2005-2007	2008-2016	2012-2018	2019-2023
25 kg - 15cm drift	161 kg - 30 cm drift	3.2 ton - 1 m drift	8 ton - 1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

The frontline detectors using the LXeTPC



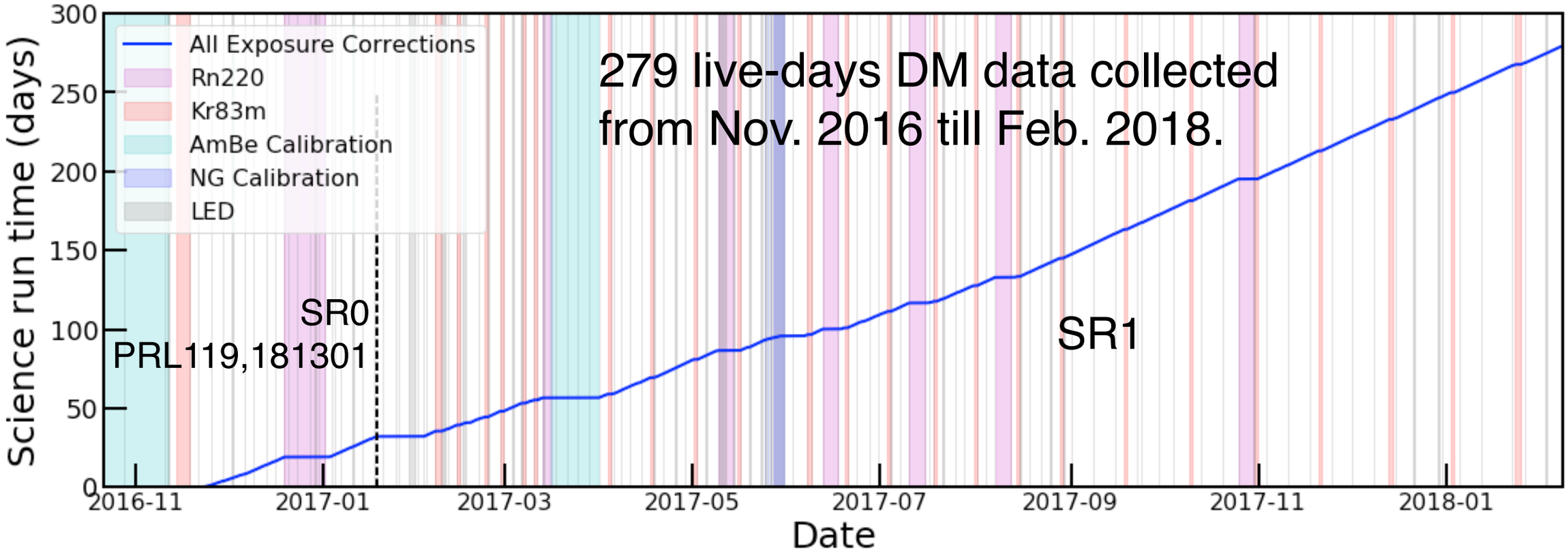
LUX
Active Target: ~250 kg
completed



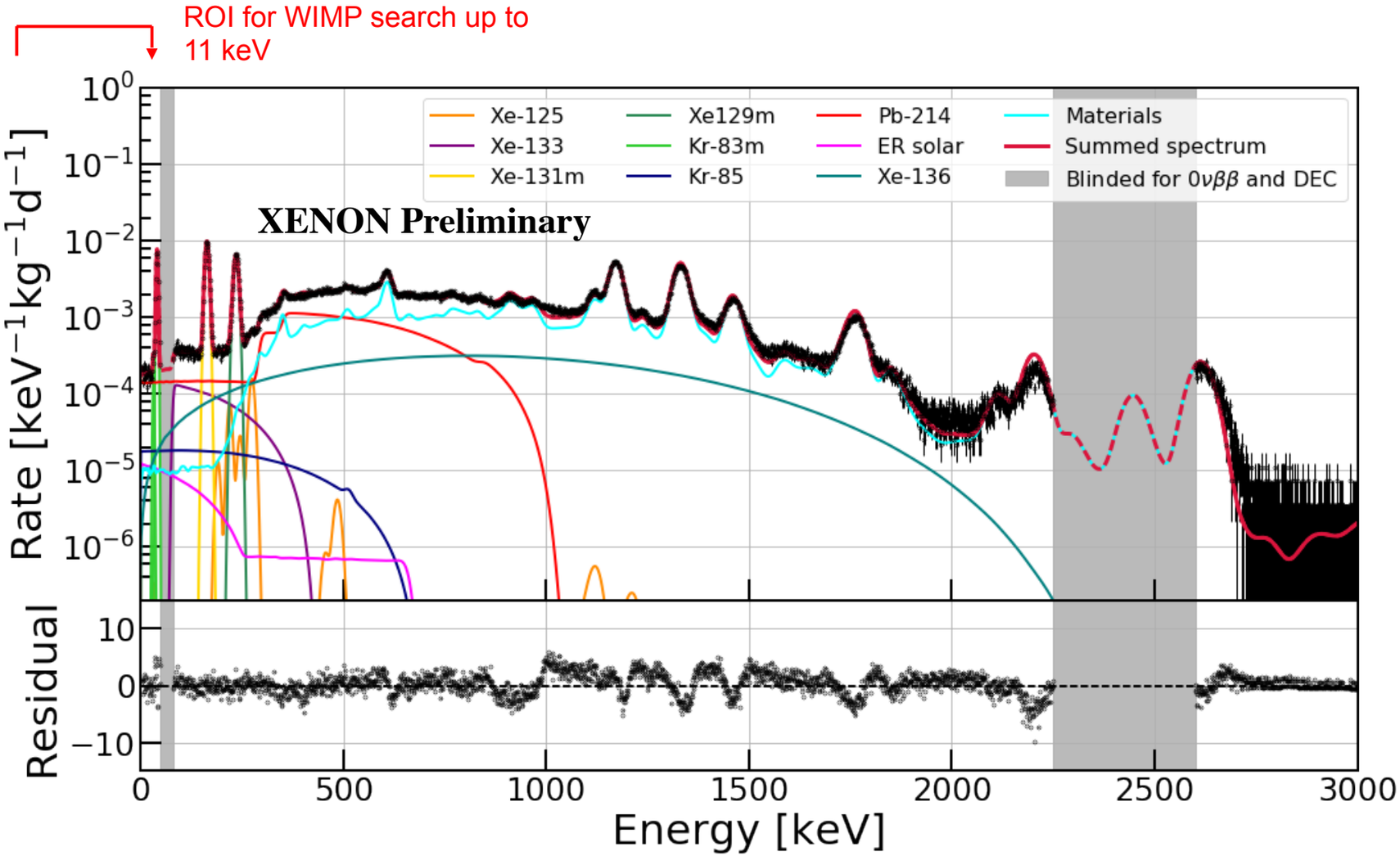
PandaX-II
Active Target: ~580 kg
Status: running

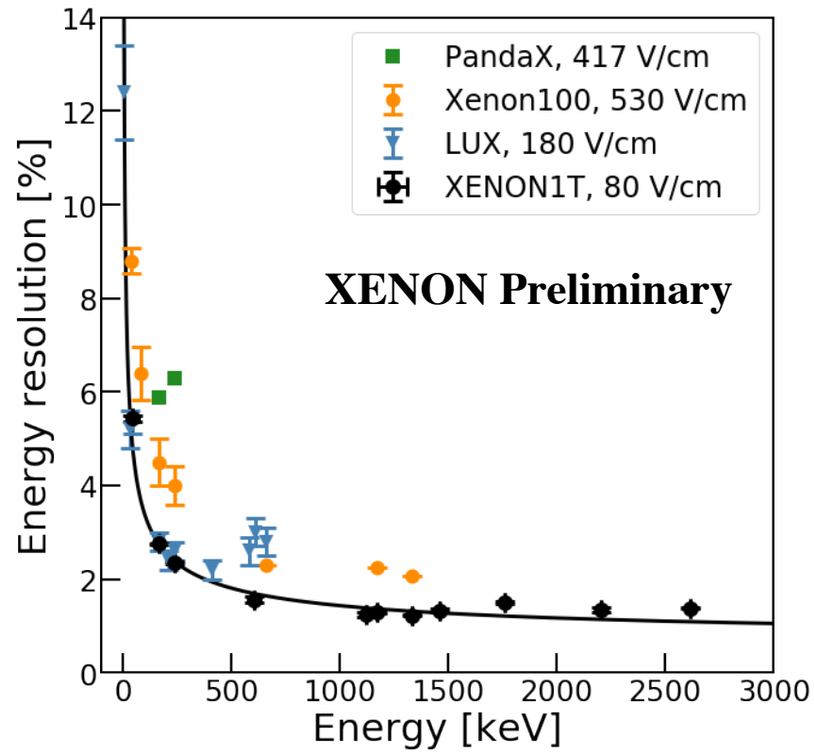
XENONIT
Active Target: 2000 kg
Status: running

XENON1T Data taking

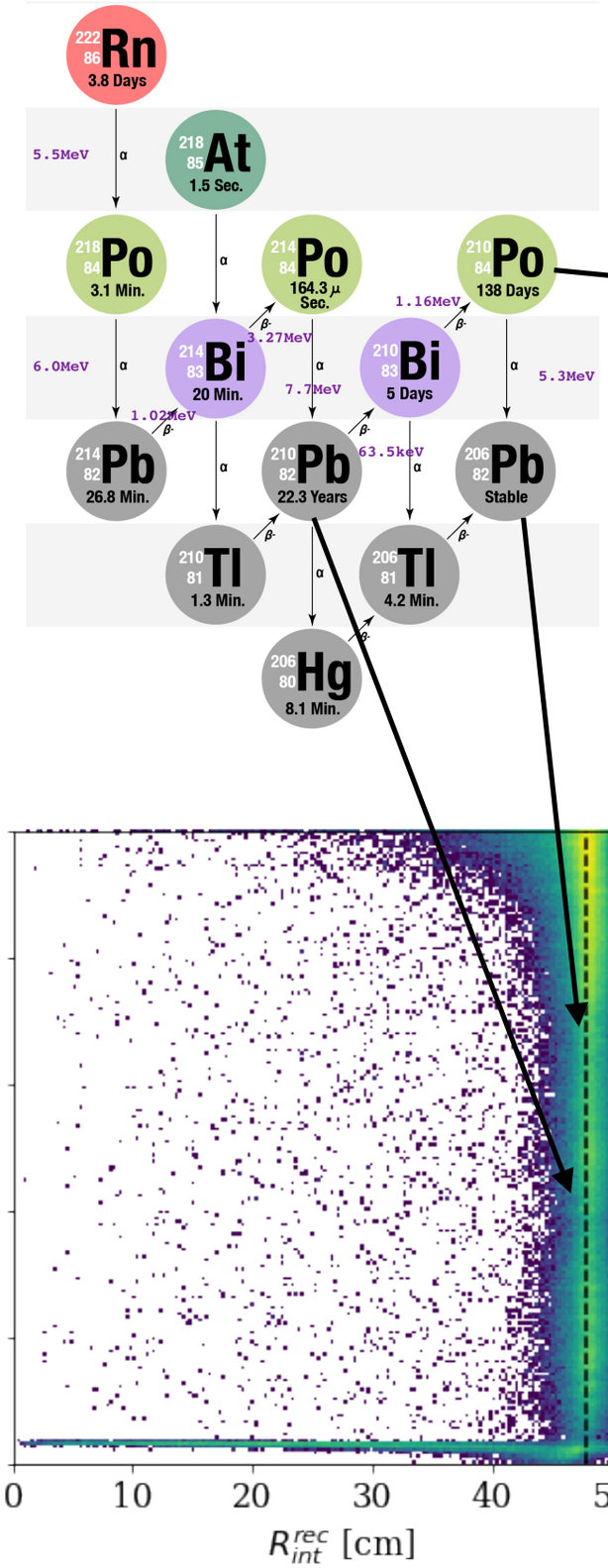


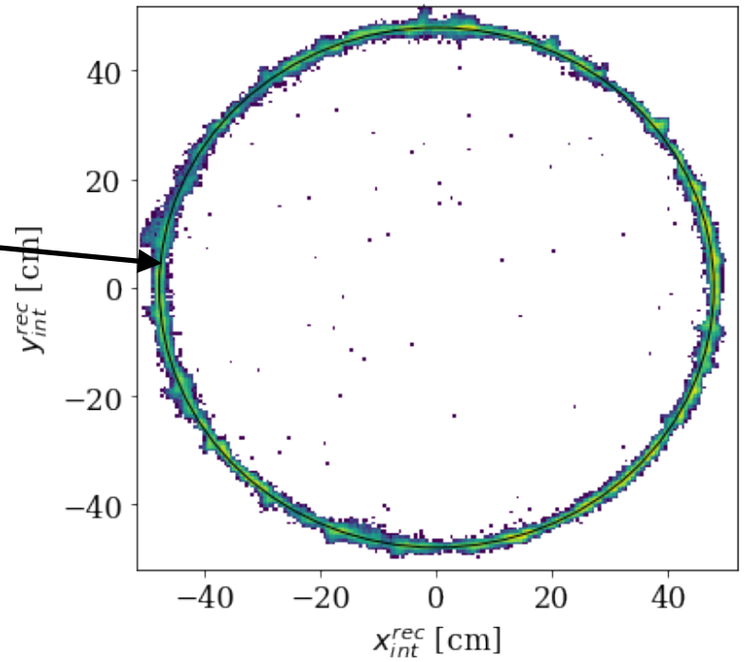
XENON1T: search for dark matter and other rare events

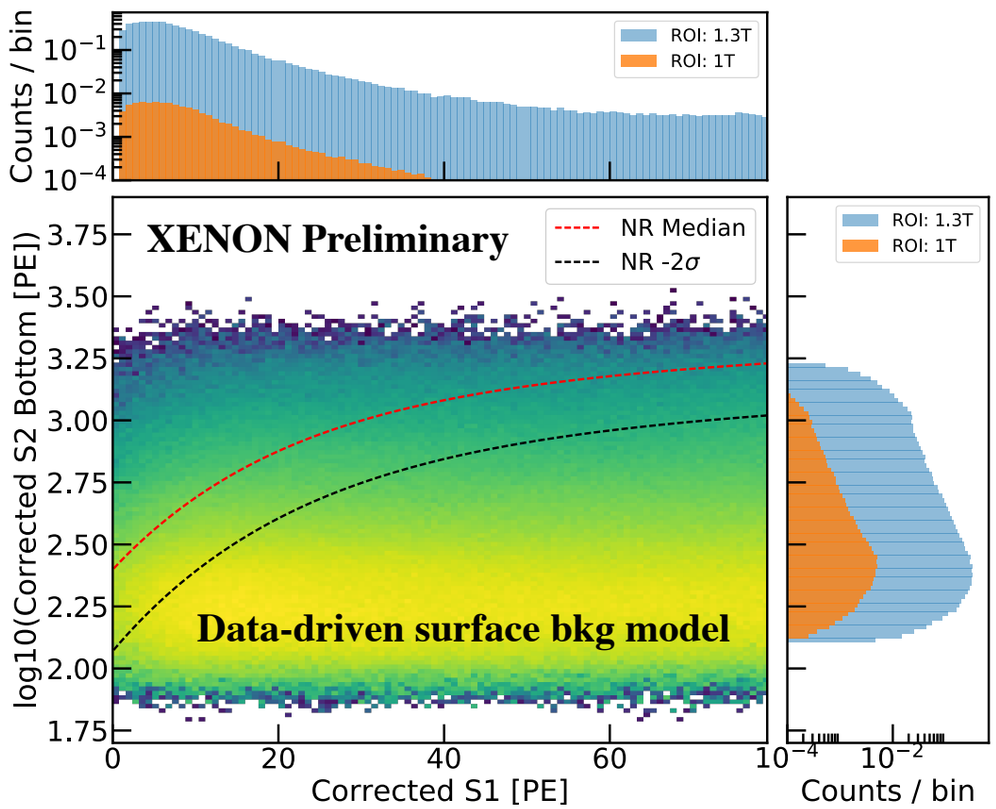




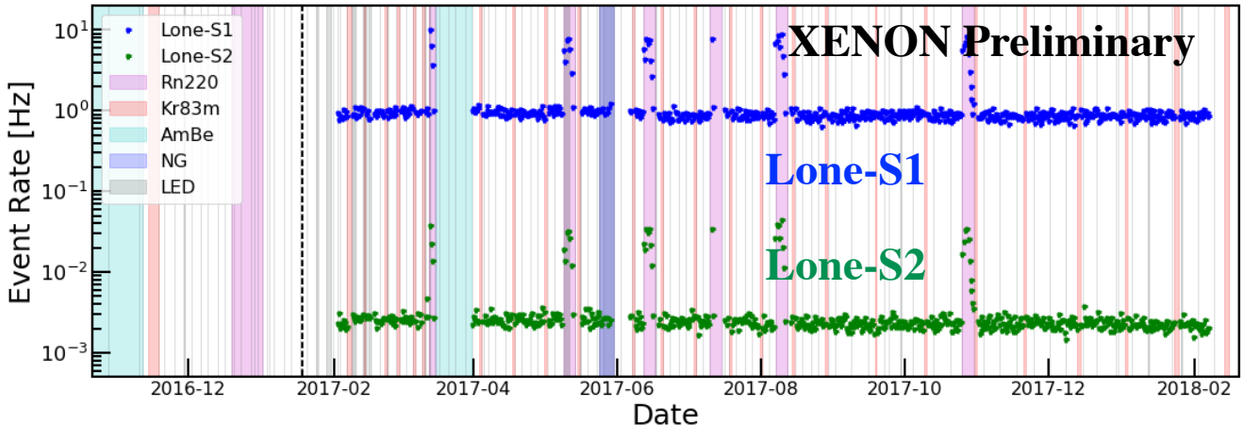
Surface background: from reduced-S2 events from Rn-daughters on the PTFE surface







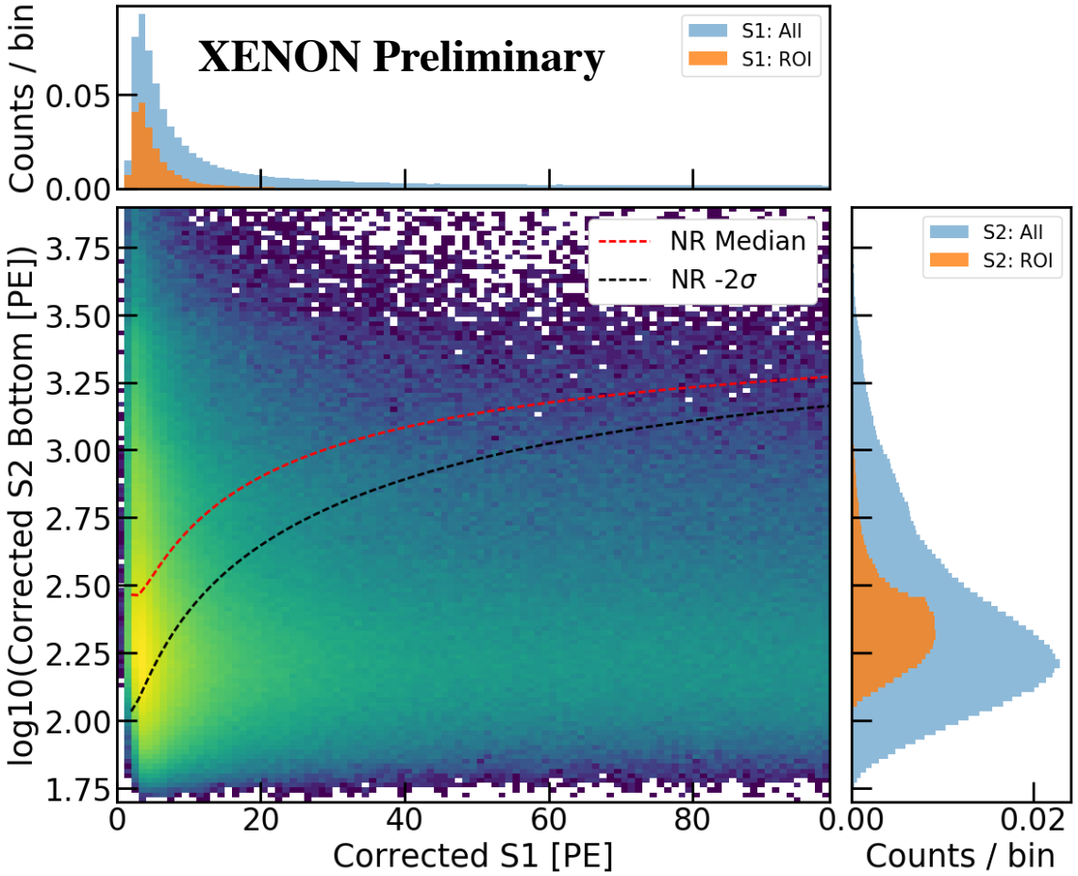
Accidental Coincidence (AC) and Radiogenic neutron background

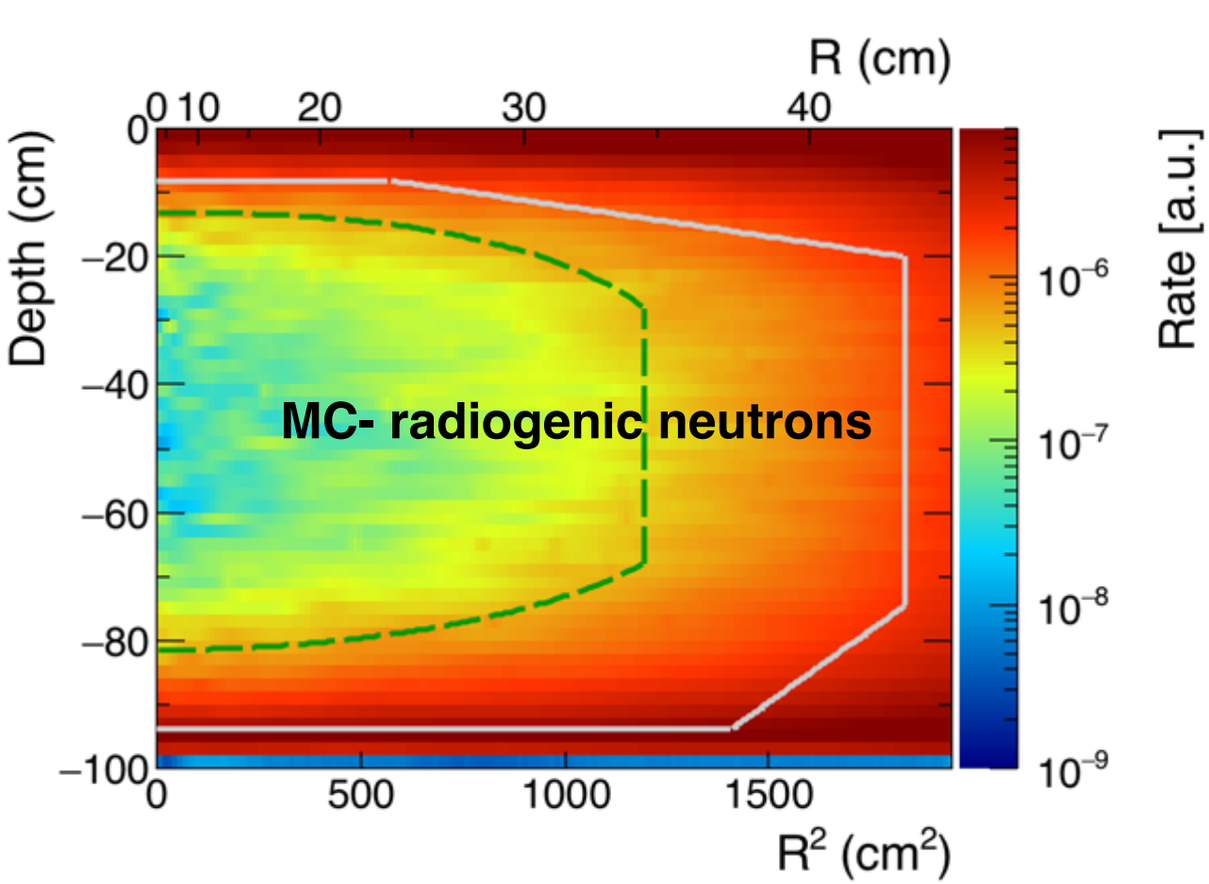


Source	Rate [t^{-1} y^{-1}]	Fraction [%]
Radiogenic n	0.6 ± 0.1	96.5
CEνNS	0.012	2.0
Cosmogenic n	< 0.01	< 2.0

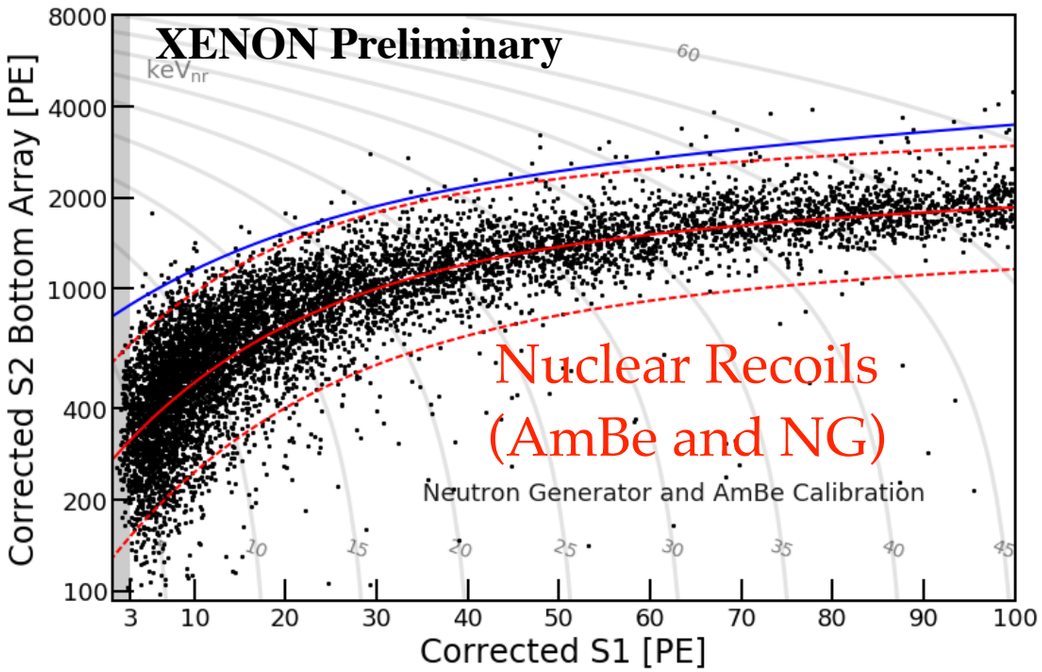
(Expectations in 4-50 keV search window, 1t FV, single scatters)

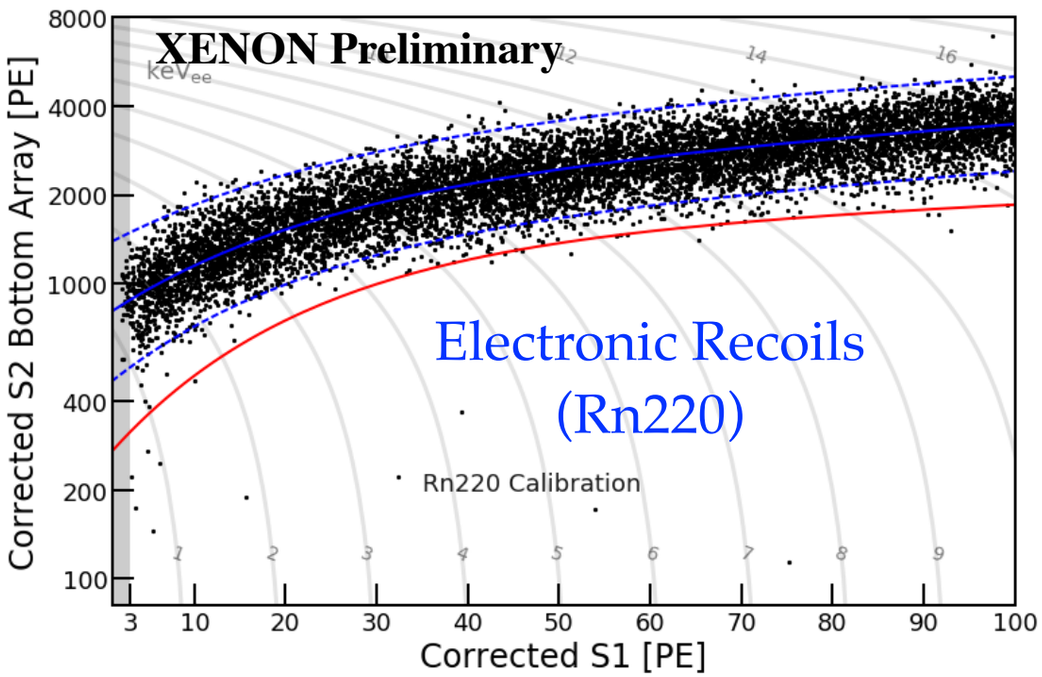
JCAP04 (2016) 027

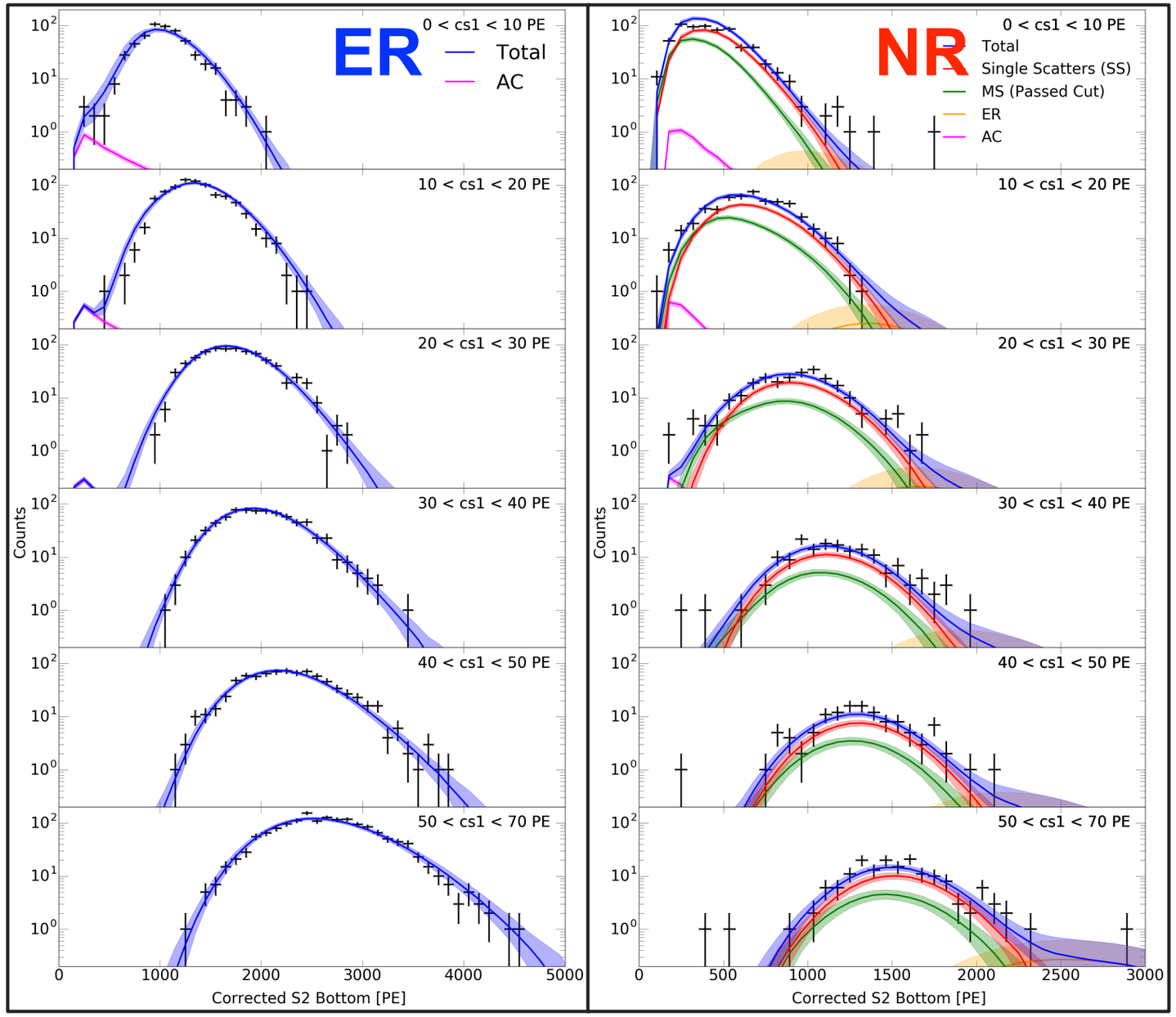




ER and NR modeling from in-situ calibration data



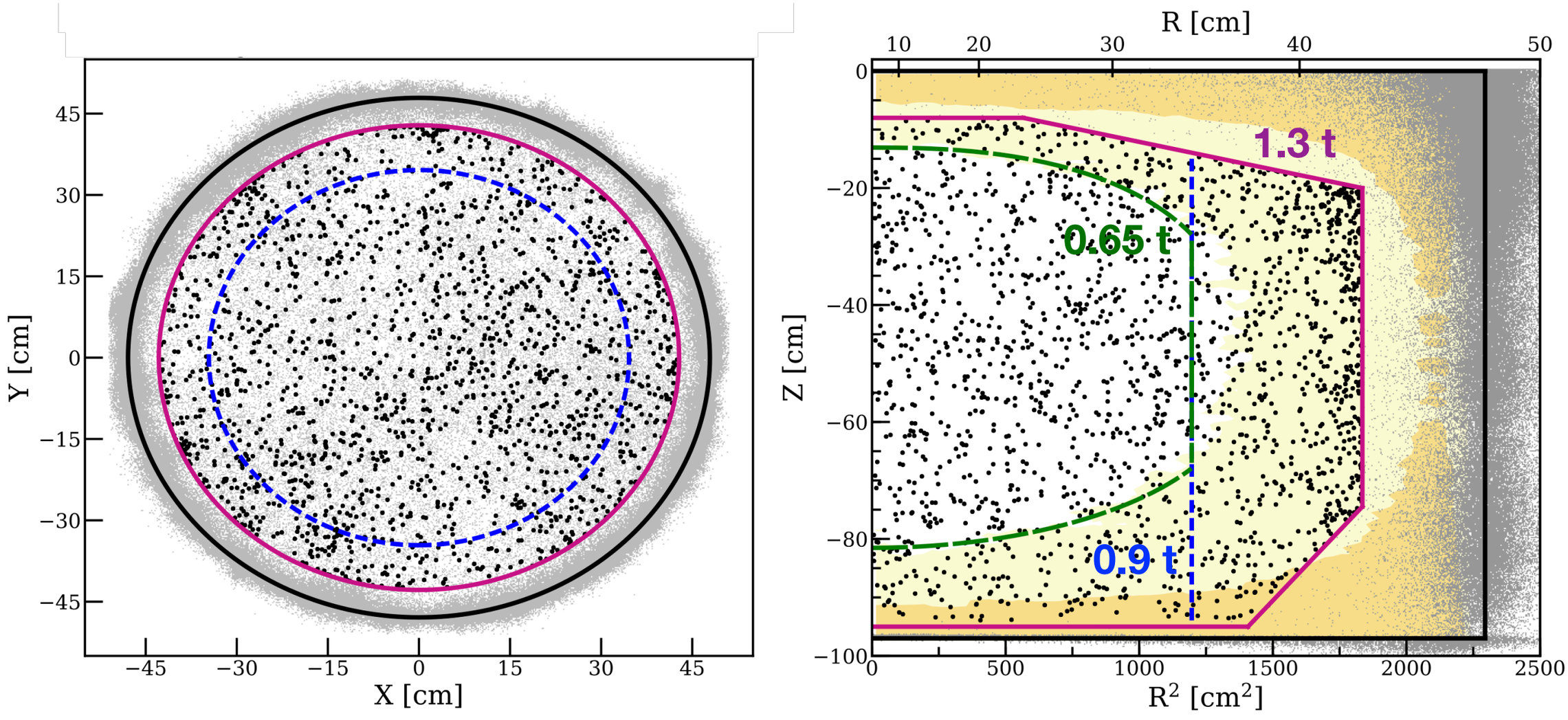




ER rejection: ~99.7% in the reference region with NR acceptance [-2σ, median]

Fiducial volume optimization

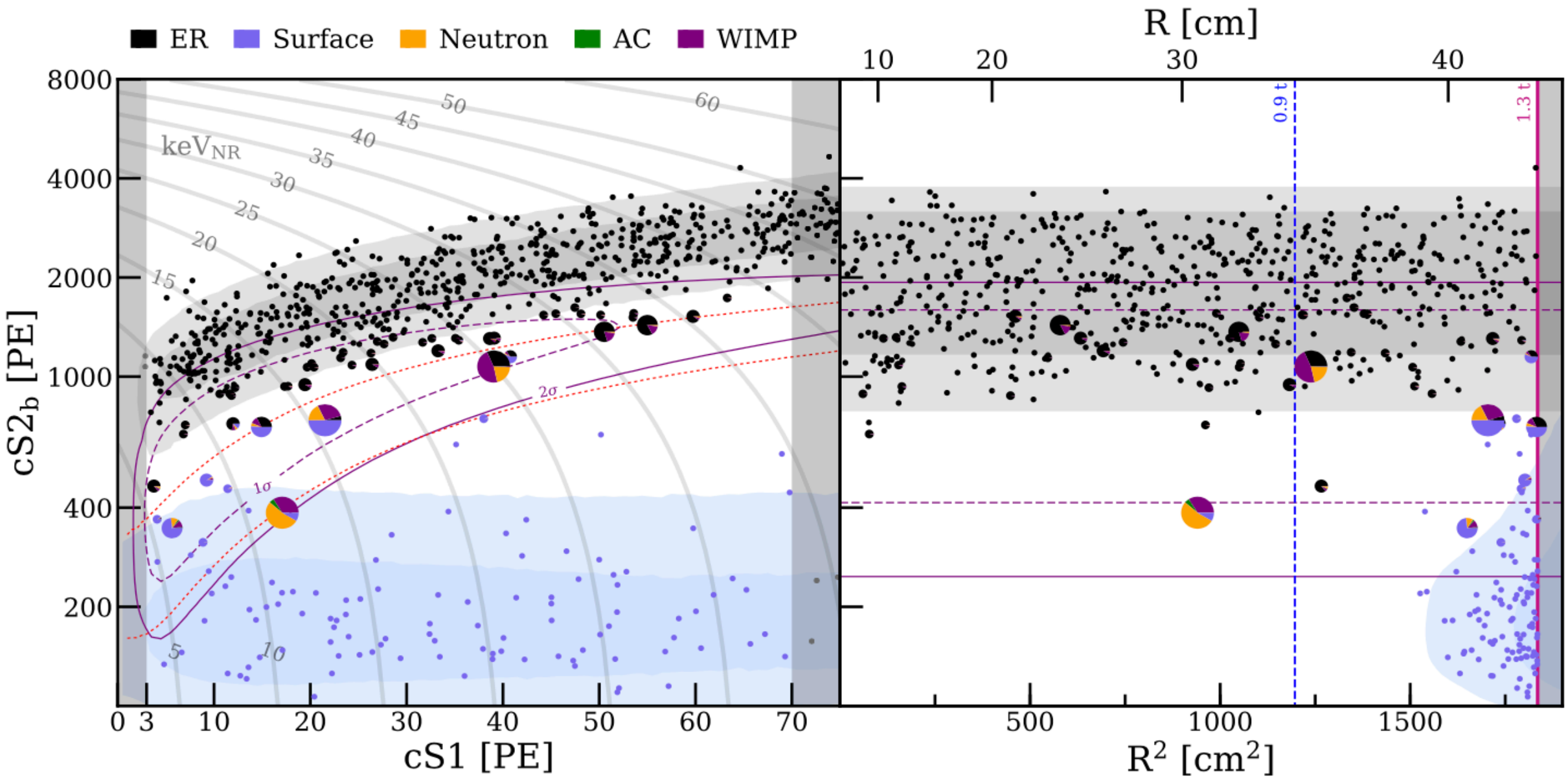
- **new surface background model allowed inclusion of radius, R, in statistical inference to maximize useful volume. Analysis space became cS1, cS2b, R and Z**



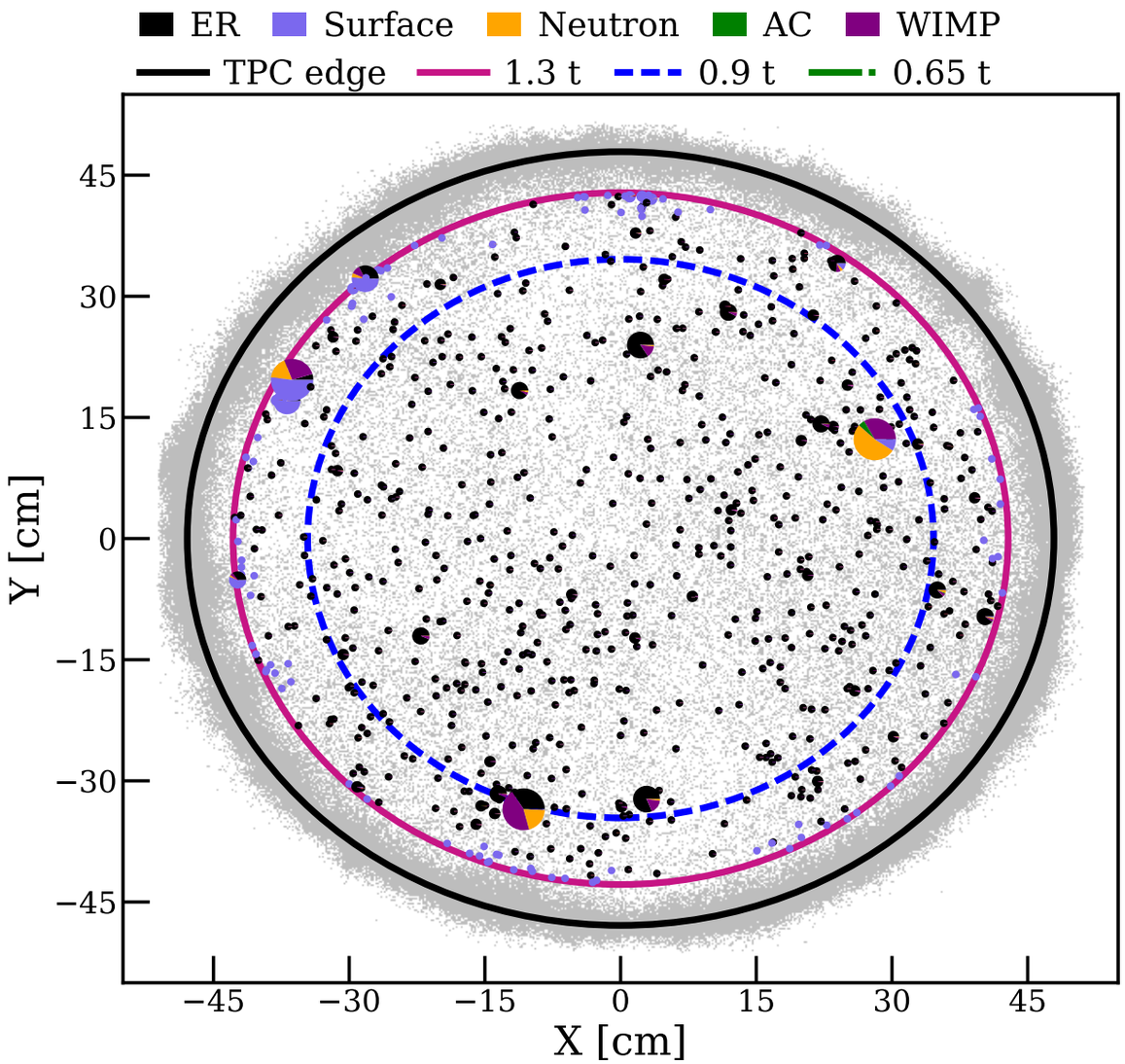
Event reconstruction and data selections were fixed before unblinding.

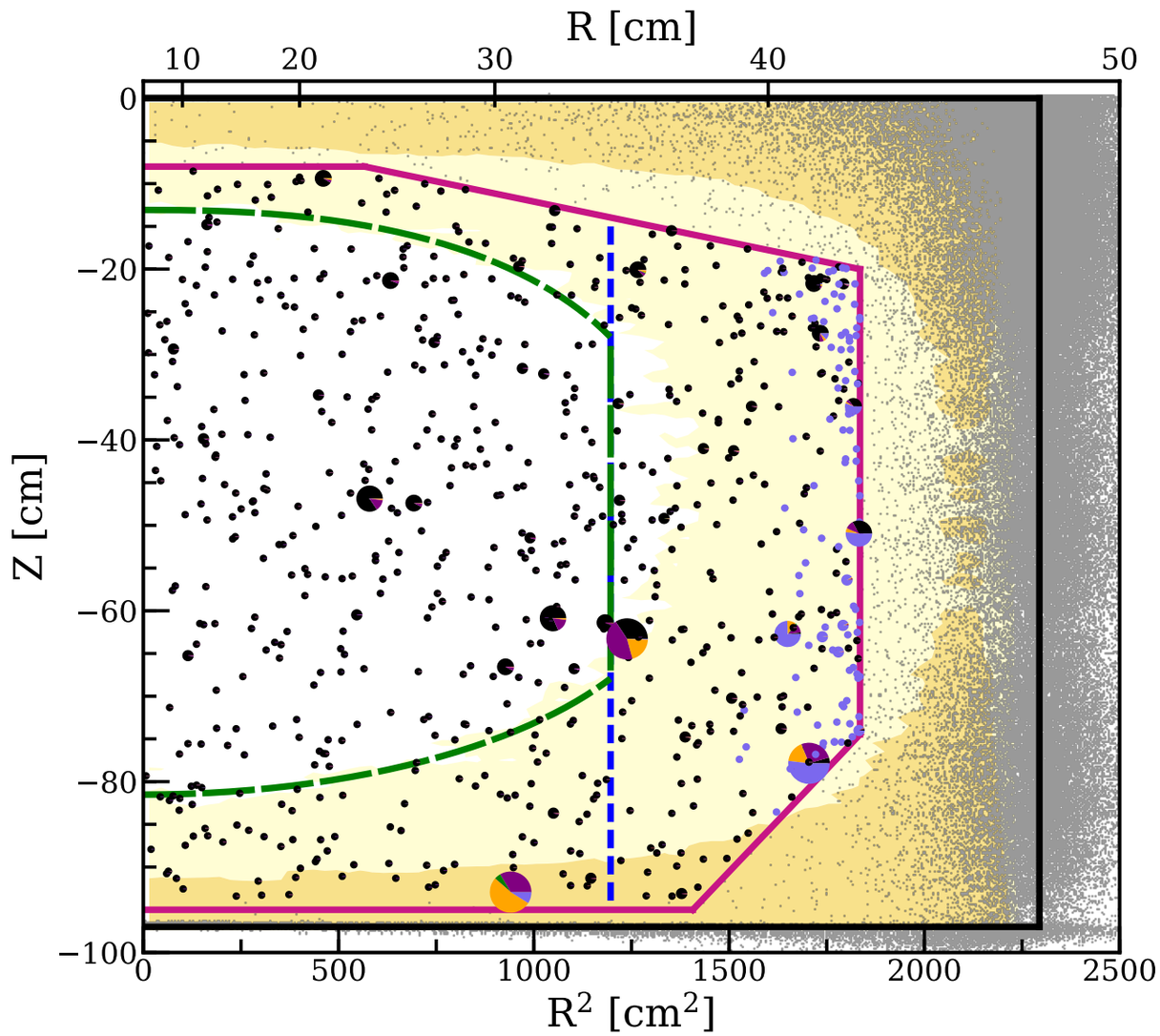
Dark Matter Search Results

- **Results interpreted with unbinned profile likelihood analysis in cS1, cS2, R space**
- **Piecharts indicate the relative PDF from the best fit (assuming 200 GeV/c² WIMPs at cross-section of 4.7×10^{-47} cm²)**



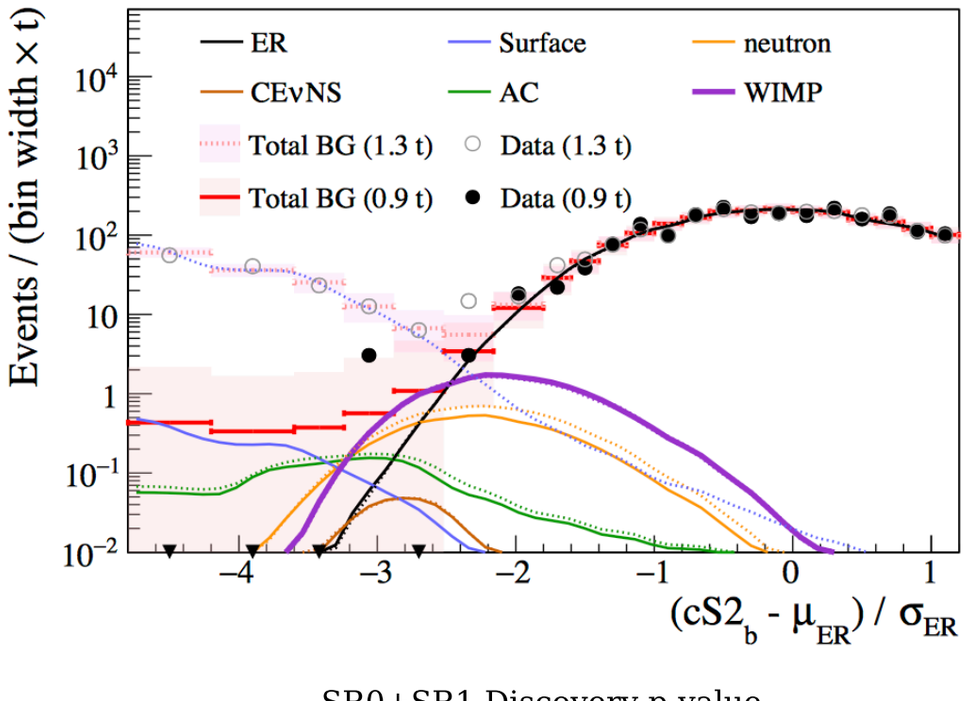
Event spatial distribution

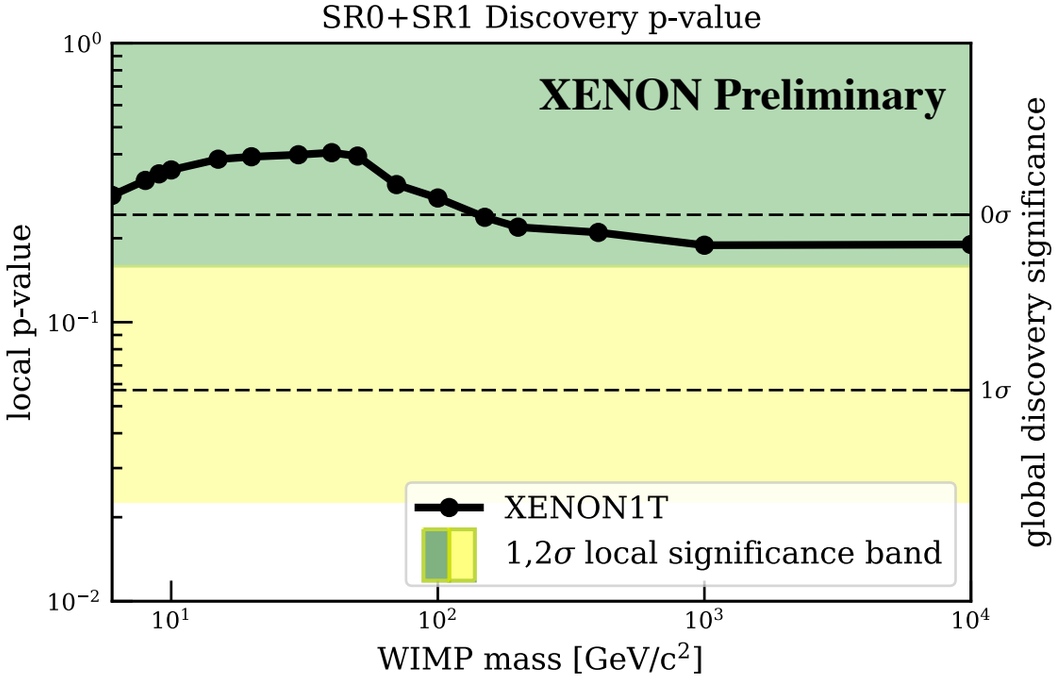


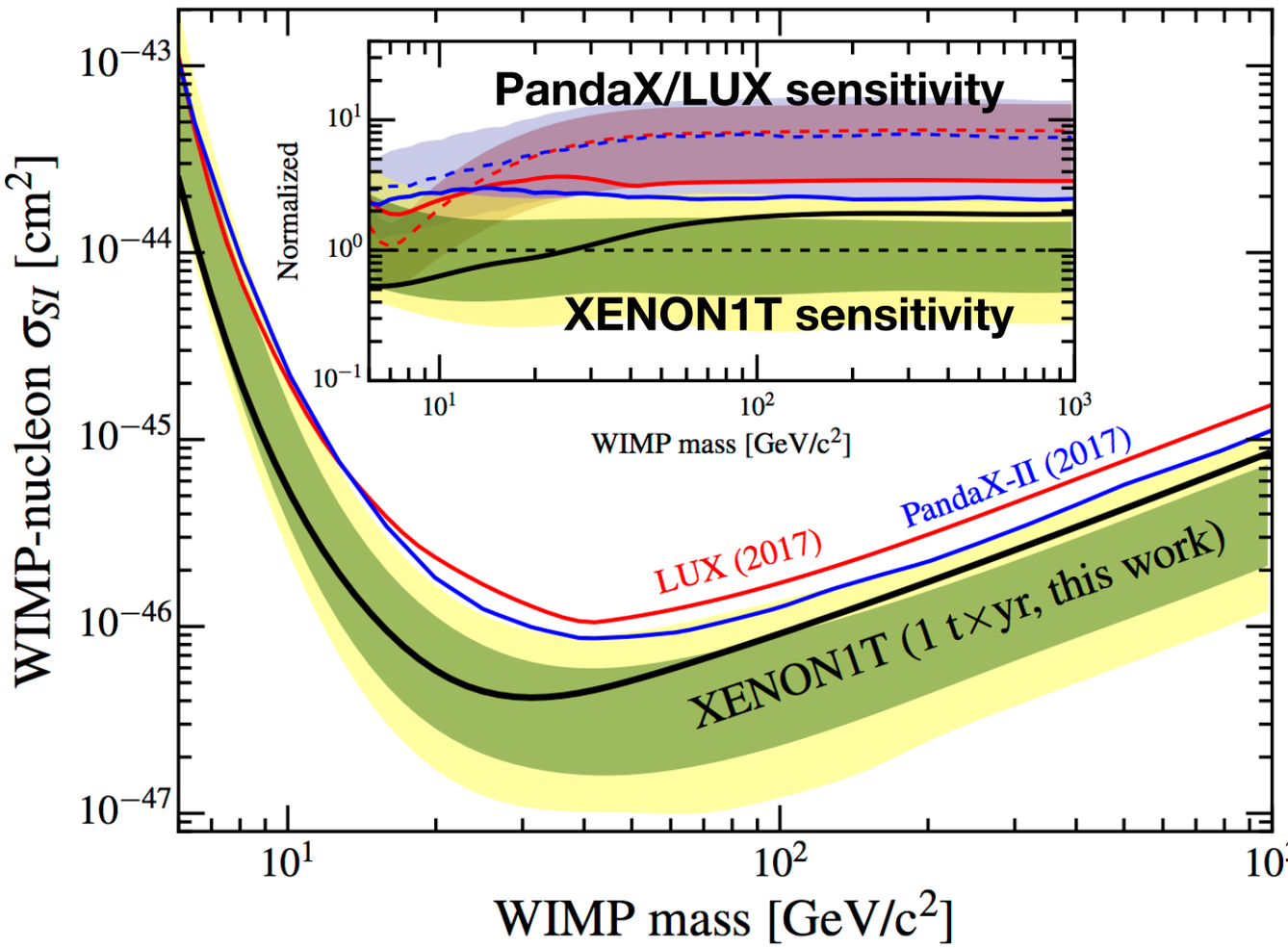


Statistical Interpretation

- **No significant (>3 sigma) excess at any scanned WIMP mass**
- **p-value for background-only hypothesis: ~0.2 at high WIMP mass**
- **Rate plot shows best-fit cross-section of 4.7×10^{-47} cm^2 assuming 200 GeV/c^2 WIMPs**







arXiv:1805.12562

Direct Detection of WIMPs by 2025?