Review of direct Dark Matter searches

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Preparing for Dark Matter discovery, 12th June 2018, Göteborg

Outline

- Review of WIMP kinematics (no Axions in this talk, sorry)
- Generalities on signal and backgrounds
- Most effective detection techniques
- Review of recent results from direct DM detection experiments

* many thanks to
E. Aprile, L. Baudis, G. Fiorillo, T. Marrodan,
K. Palladino, K. Ni, M. Schumann
for useful materials used in this review

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Usual disclaimers of these kinds of review talks:
not complete, biased, personal view, etc

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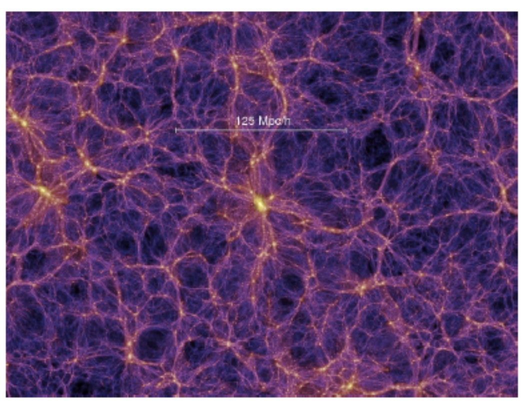
Particle Dark Matter

An elementary particle?

- Massive → explain gravitational effects
- Neutral → no EM interaction & Weakly interacting at most
- Stable or long-lived → not to have decayed by now
- Cold (moving non-relativistically) or warm → structure formation



In the standard model of particle physics:
Neutrino fulfil most
but it is a hot dark matter candidate

→ Models beyond SM typically predict NEW particles

Neutralino in Supersymmetry, gravitino, Axion, LKP in extra dimensions, Sterile neutrino, Super-heavy dark matter and many others

WIMPs

Well motivated theoretical approach:

WIMP

(**W**eakly **I**nteracting **M**assive **P**article)

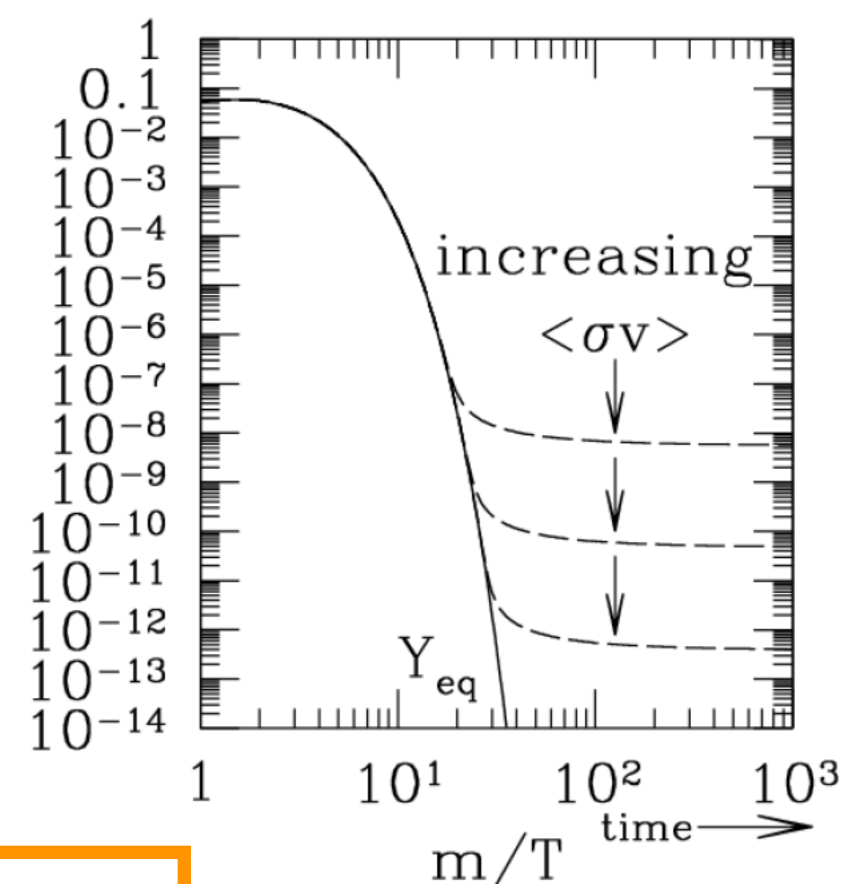
- In the early Universe particles are in thermal equilibrium:

  creation ↔ annihilation

  $\chi\bar{\chi} \leftrightarrow e^+e^-, \mu^+\mu^-, q\bar{q}, W^+W^-, ZZ\ldots$

- When annihilation rate ≪ Universe expansion rate → 'freeze out'

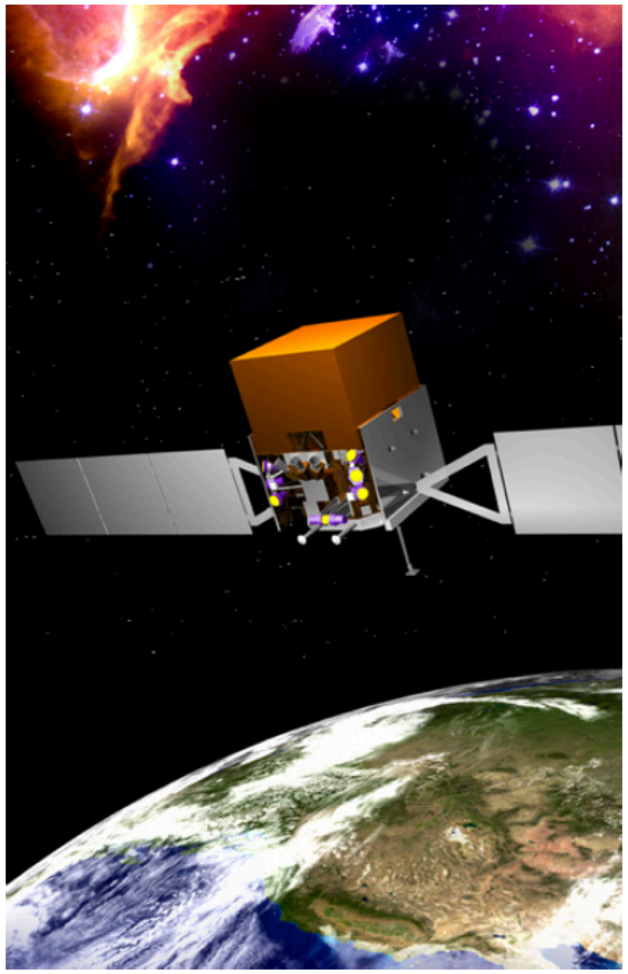
- Correct relic density for an annihilation rate ~ weak scale

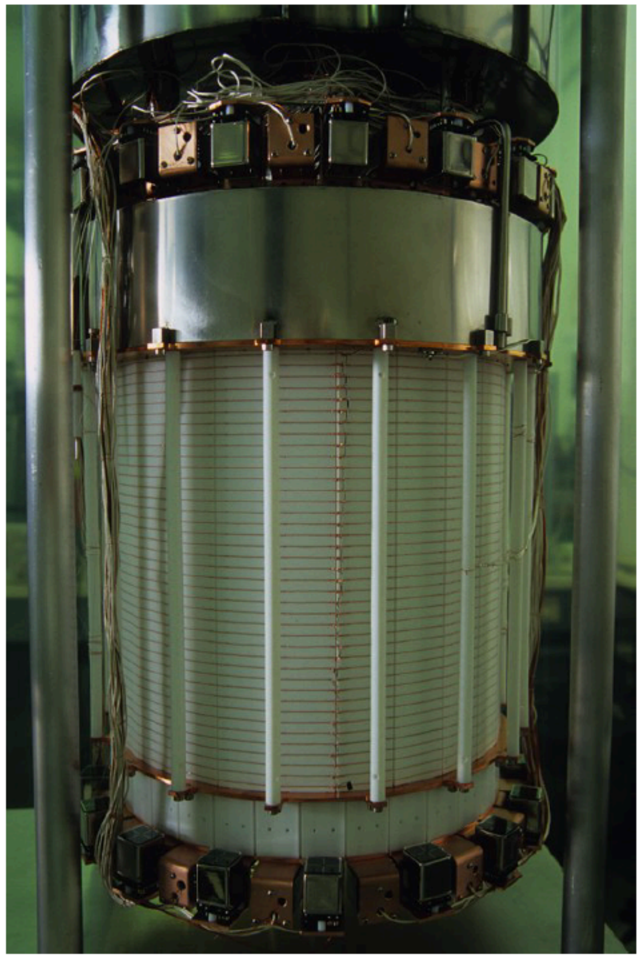


In this talk I will focus mostly on WIMP direct detection

Dark Matter searches

- Production at LHC
- Indirect detection
- Direct detection



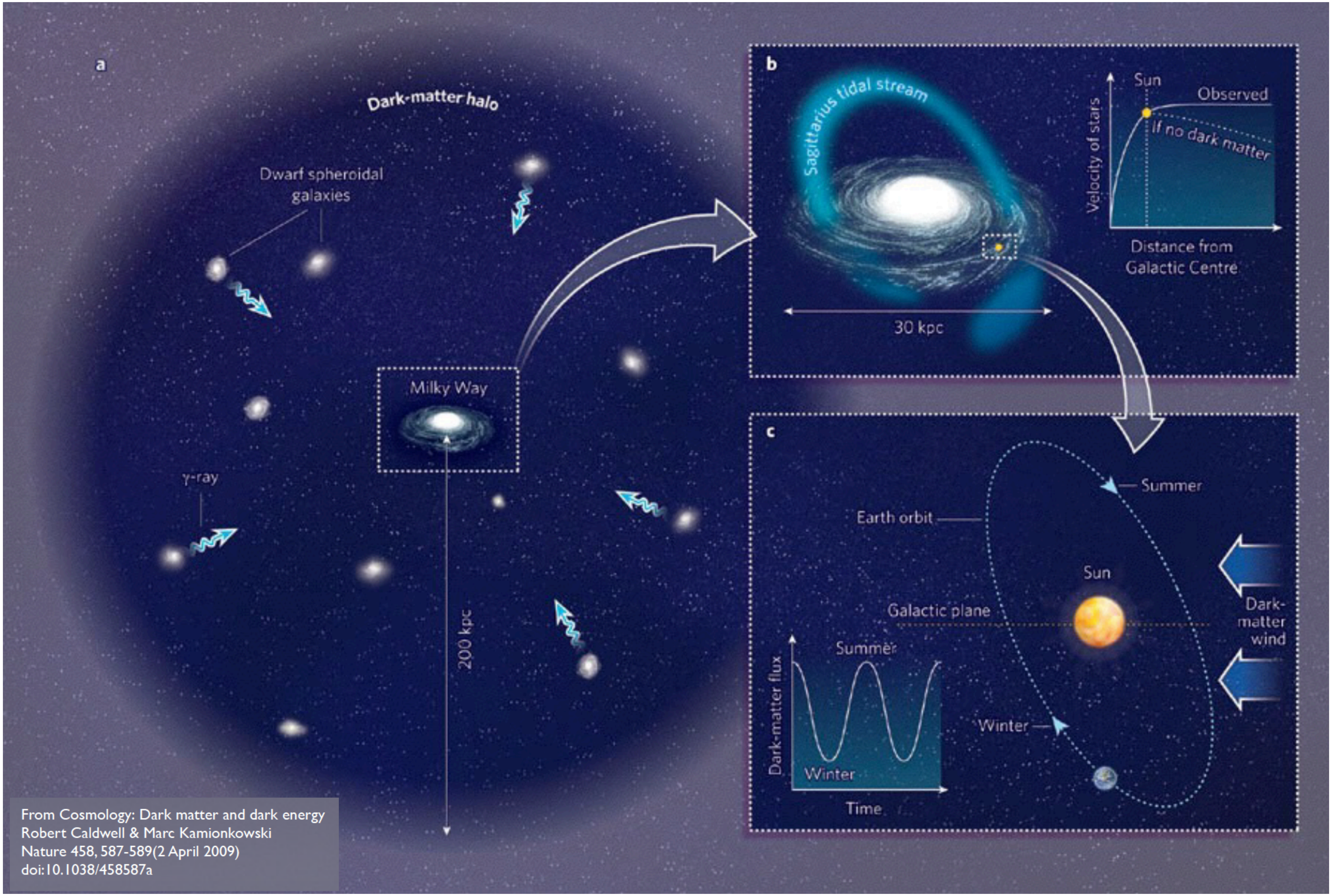


$p + p \rightarrow \chi\bar{\chi}$ + a lot

$\chi\chi \rightarrow \gamma\gamma, q\bar{q}, \ldots$

$\chi N \rightarrow \chi N$

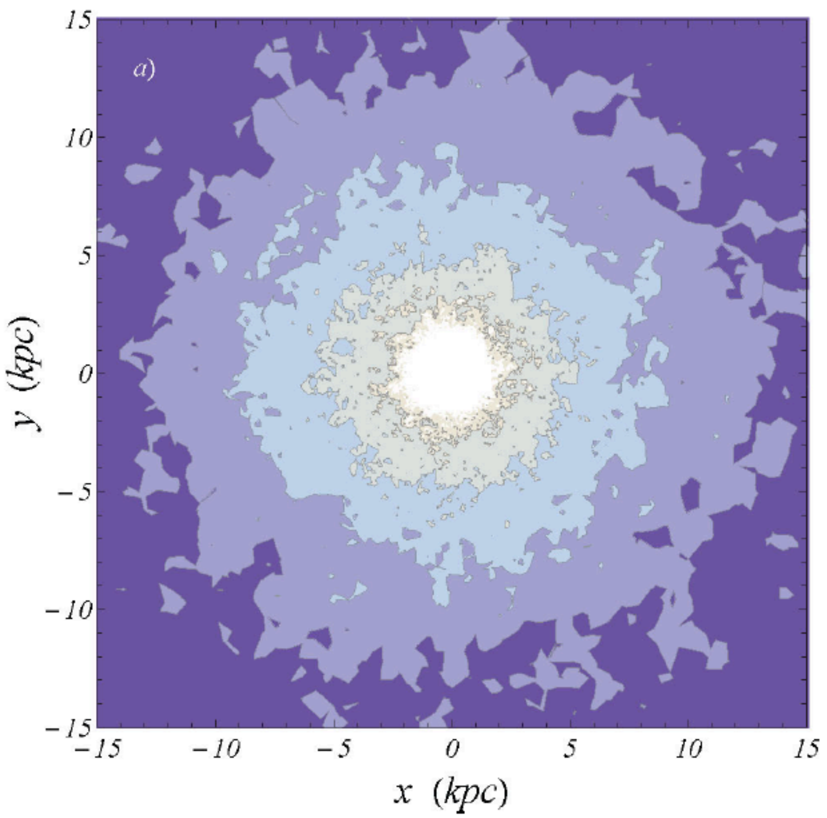
We live in a dark matter halo



WIMP density and velocity distribution

WIMPs in the galactic halo

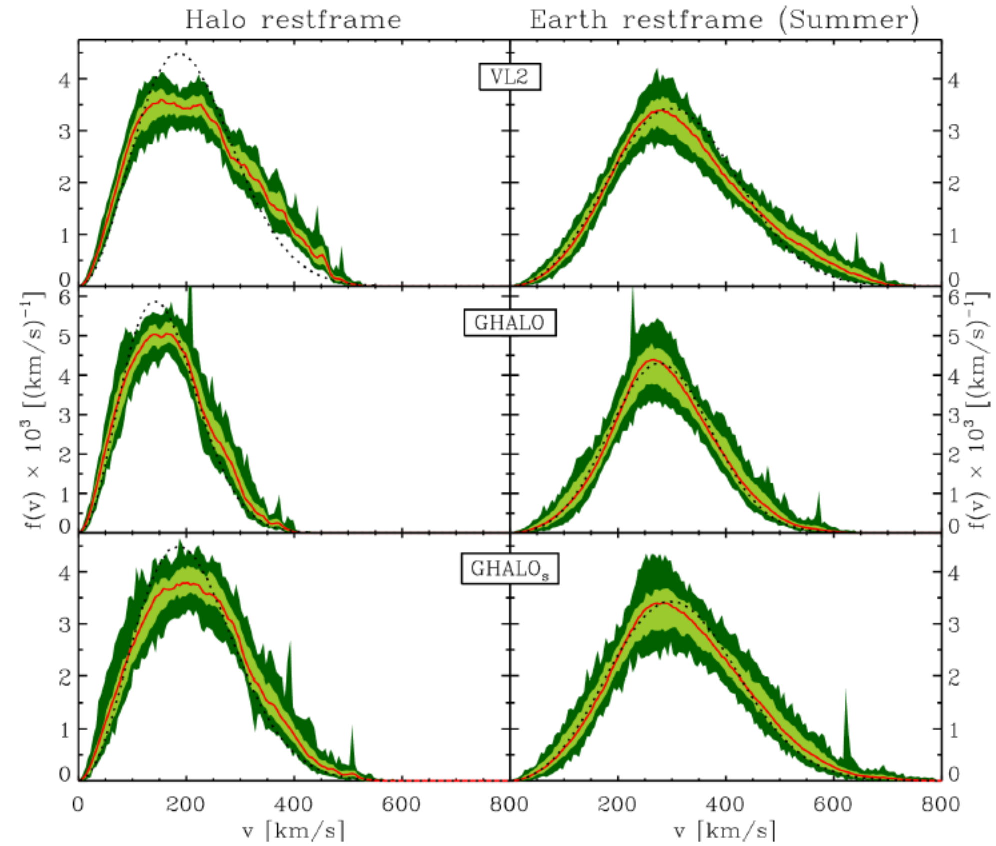
Density map of the dark matter halo
rho = [0.1, 0.3, 1.0, 3.0] GeV cm^{-3}



High-resolution cosmological simulation with baryons: F.S. Ling et al, JCAP02 (2010) 012

$$\rho_{local} \sim 0.3\,\mathrm{GeV} \cdot \mathrm{cm}^{-3}$$

Velocity distribution of WIMPs in the galaxy

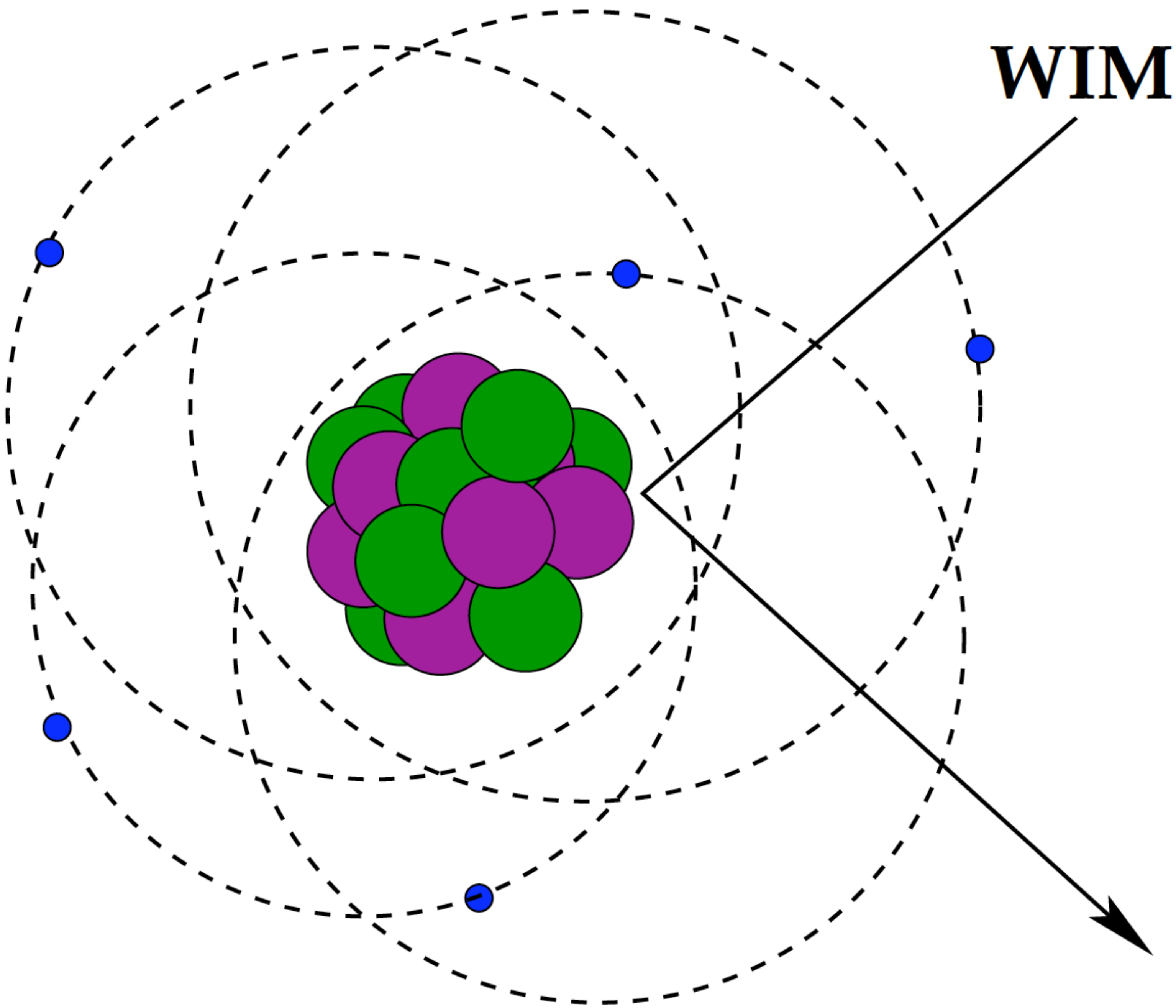


M. Kuhlen et al, JCAP02 (2010) 030

From cosmological simulations of galaxy formation: departures from the simplest case of a Maxwell-Boltzmann distribution

In direct detection experiments, mostly a simple MB distribution, truncated at v_{esc}, is used in the sensitivity calculation

Direct Dark Matter Detection



$$R \propto N_T \frac{\rho_0}{m_X} \sigma \langle v \rangle$$

$E_R \sim \mathcal{O}(10\,\mathrm{keV})$

The standard halo model

Isotropic, isothermal sphere with a Maxwellian velocity distribution

$$f(v) = N \cdot \exp\left(\frac{-3|v|^2}{2\sigma^2}\right)$$

usually truncated $f(v) = 0$ for $|v| > v_{esc}$

Local density $\rho_0 = 0.3\,\mathrm{GeV/cm^3} = 0.008\,M_\odot/pc^3 = 5 \cdot 10^{-23}\,\mathrm{g/cm^3}$
determined via mass modelling of the Milky Way

About 1 WIMP in a coffee cup (assuming $m_\chi \sim 100\,\mathrm{GeV}/c^2$)

Circular velocity $v_c = 220\,\mathrm{km/s}$
with radial dispersion velocity $\sigma_r = v_c/\sqrt{2}$

Escape velocity $v_{esc} = 544\,\mathrm{km/s}$
determined from the speed of high velocity stars (RAVE)

Expected Rates

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v) \, \mathrm{d}^3 v$$

Astrophysical parameters:

- ρ_0 = local density of the dark matter in the Milky Way
- $f(\mathbf{v},t)$ = WIMP velocity distribution

Parameters of interest:

- m_χ = WIMP mass ($\sim 100\,\mathrm{GeV}/c^2$)
- σ = WIMP-nucleus elastic scattering cross section
    - Spin-independent interactions: coupling to nuclear mass
    - Spin-dependent interactions: coupling to nuclear spin

Scattering Cross Section

- In general, interactions leading to WIMP-nucleus scattering are parameterized as:
  - **scalar interactions** (coupling to WIMP mass, from scalar, vector, tensor part of L)

$$\sigma_{SI} \sim \frac{\mu^2}{m_\chi^2}[Zf_p + (A-Z)f_n]^2$$

f_p, f_n: scalar 4-fermion couplings to p and n

=> nuclei with large A favourable (but nuclear form factor corrections)

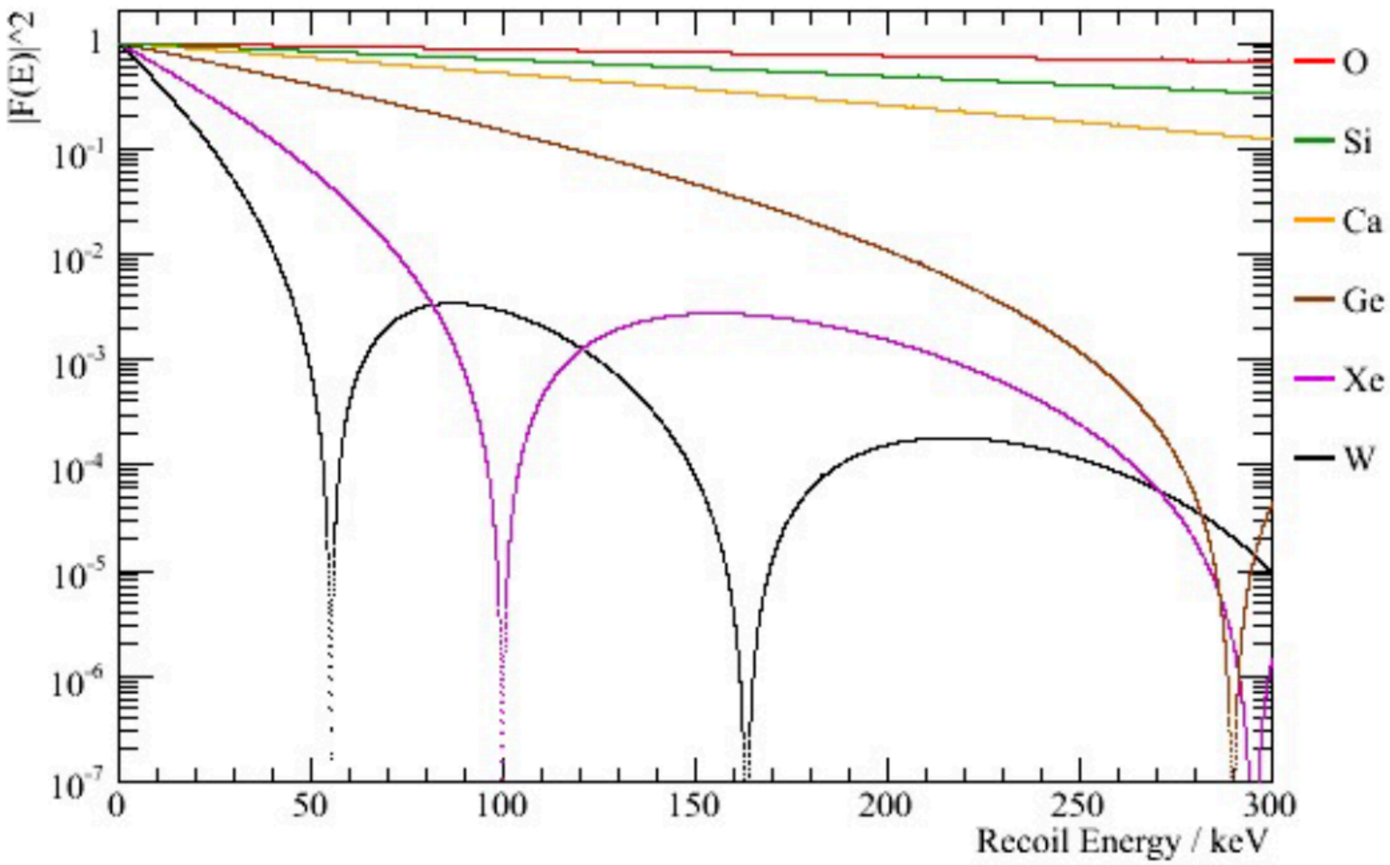
  - **spin-spin interactions** (coupling to the nuclear spin J_N, from axial-vector part of L)

$$\sigma_{SD} \sim \mu^2 \frac{J_N+1}{J_N}(a_p\langle S_p\rangle + a_n\langle S_n\rangle)^2$$

a_p, a_n: effective couplings to p and n; $\langle S_p\rangle$ and $\langle S_n\rangle$ expectation values of the p and n spins within the nucleus

=> nuclei with non-zero angular momentum (corrections due to spin structure functions)

Correction: the Form Factor



With the Helm parametrization for the nuclear density the form factor is

$$F^2(Q) = [\frac{3j_1(qR_1)}{qR_1}]^2 e^{-(qs)^2}$$

J = 1st Bessel function

s = nuclear skin thickness ~1 fm

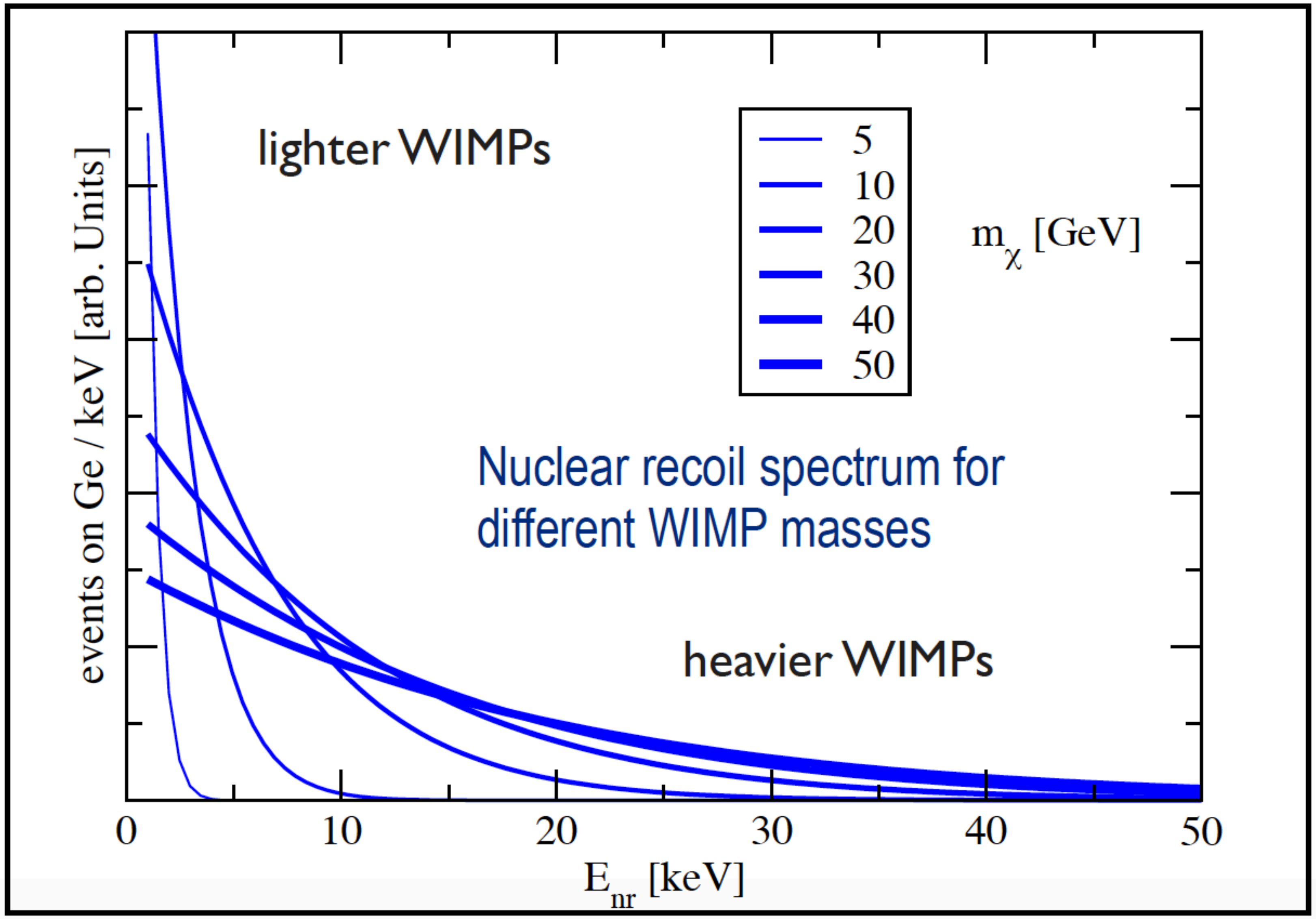
$R_1 \propto 1.14\, A^{1/3} \sim 7A^{1/3}$ GeV^{-1}

Form factor is important for large nuclei, such as Xe, W, etc.
For these targets, a low energy threshold is essential to minimize Form factor suppression of rate
At the same time, the coherence of the scattering favors large nuclei

Nuclear Recoil Energy Spectrum

Rate after integration over WIMP velocity distribution

$$R \sim 0.13 \frac{\text{events}}{\text{kg year}} \left[\frac{A}{100} \times \frac{\sigma_{WN}}{10^{-38}\,\text{cm}^2} \times \frac{\langle v \rangle}{220\,\text{km}\,\text{s}^{-1}} \times \frac{\rho_0}{0.3\,\text{GeV}\text{cm}^{-3}} \right]$$



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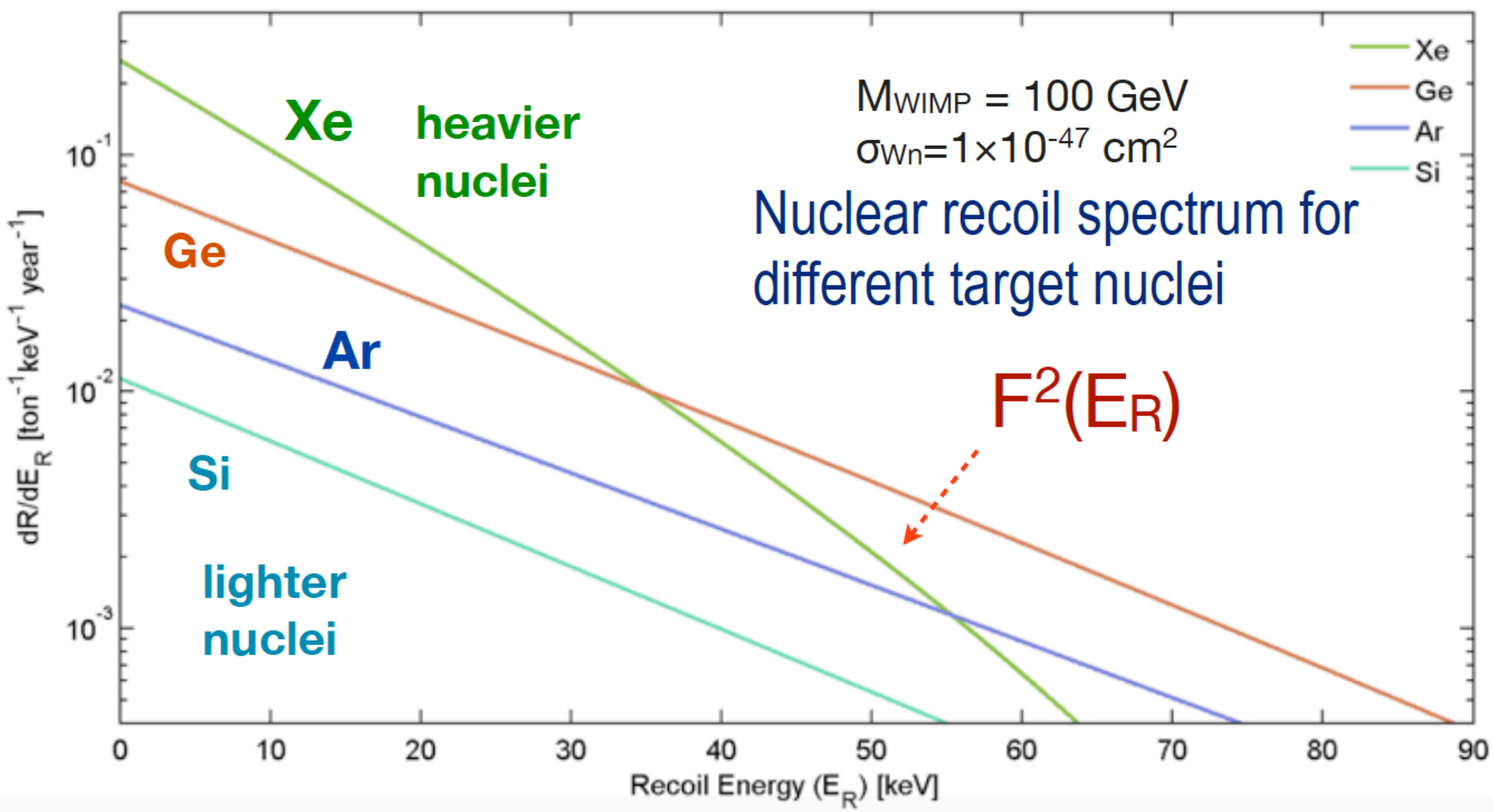
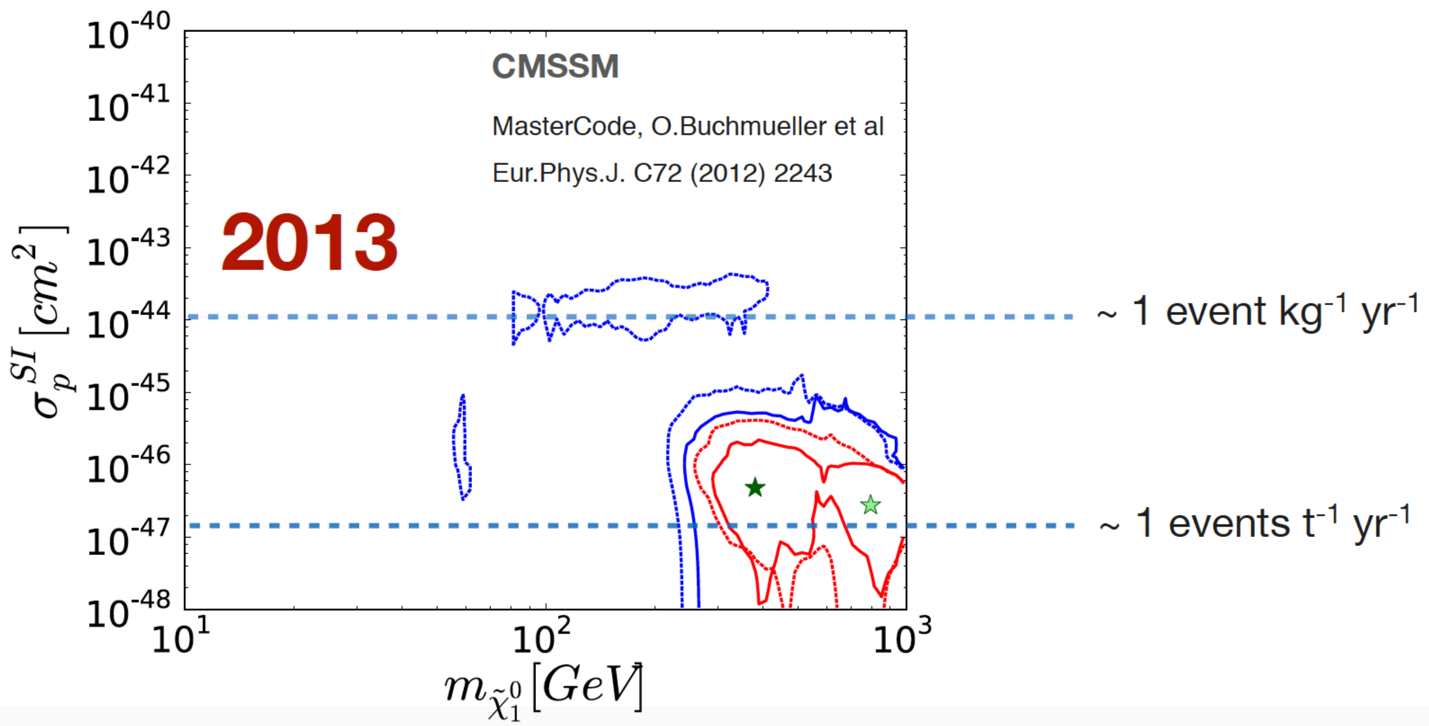


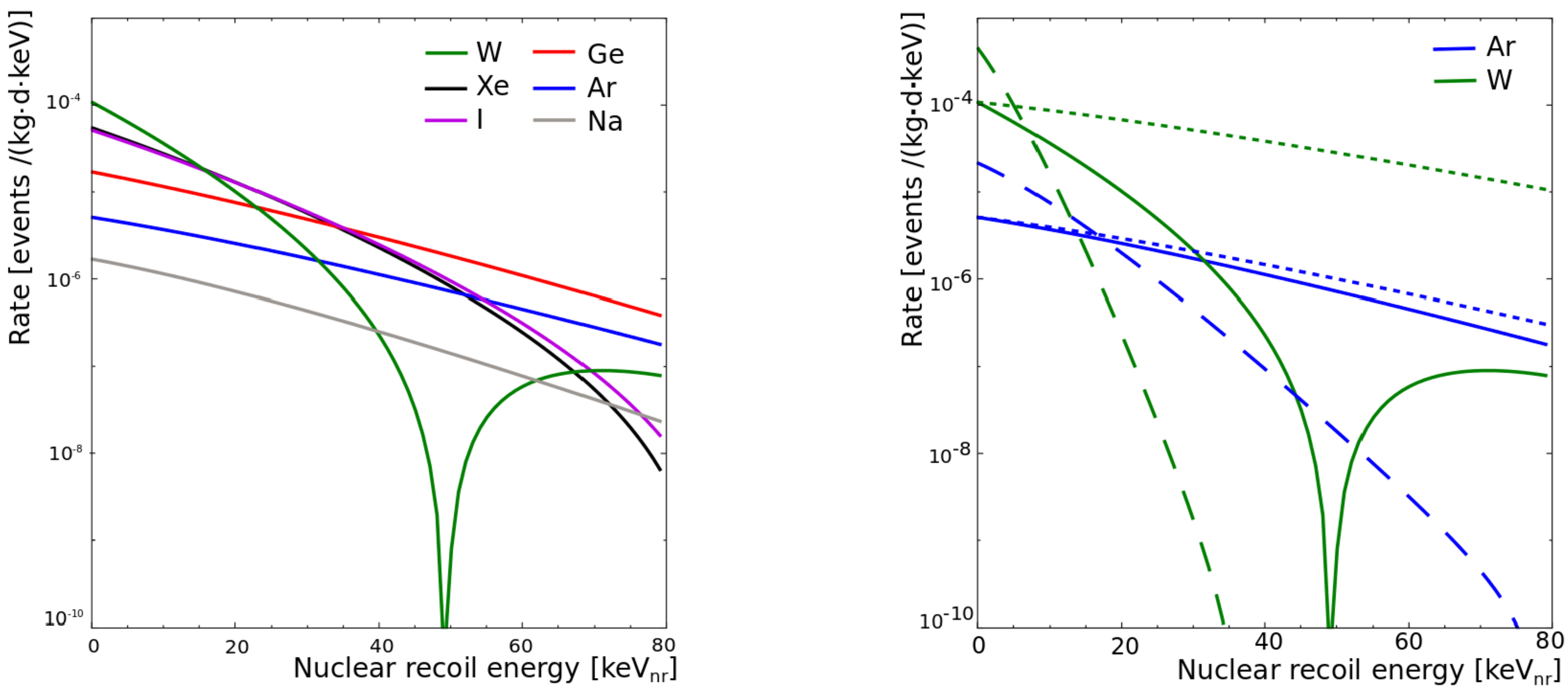
Detector requirements and signatures

- Requirements for a dark matter detector
  - Large detector mass
  - Low energy threshold ~ sub-keV to few keV's
  - Very low background and/or background discrimination
  - Long term stability
- Possible signatures of dark matter
  - Spectral shape of the recoil spectrum
  - Annual modulated rate
  - Directional dependance



Signature: spectral shape

$$\frac{dR}{dE}(E) \approx \left(\frac{dR}{dE}\right)_0 F^2(E)\exp\left(-\frac{E}{E_c}\right)$$



J. Phys. G43 (2016) 1, 013001& arXiv:1509.08767

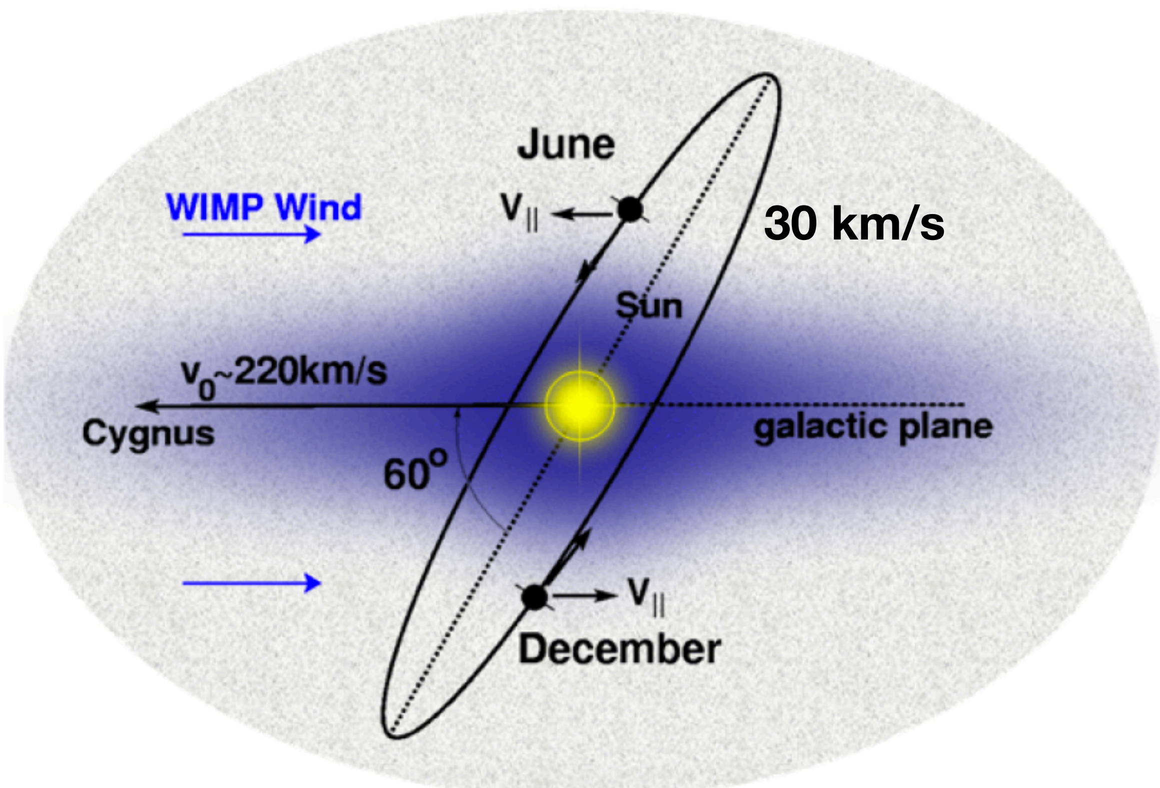
Event rates as function of nuclear recoil energy for different target materials **m_W = 50 GeV**

Dotted line: no form factor correction

Dashed line: for a 25 GeV/c^2 WIMP mass

Signature: annual modulation

$$\frac{dR}{dE}(E,t) \approx S_0(E) + S_m(E)\cdot\cos\left(\frac{2\pi(t-t_0)}{T}\right)$$



- Earth rotation around the Sun
- Relative speed of DM particles larger in summer
- Larger number of nuclear recoils above threshold in summer

Signature: directionality

$$\frac{dR}{dE\, d\cos\gamma} \propto \exp\left[\frac{-[(v_E + v_\odot)\cos\gamma - v_{min}]^2}{v_c^2}\right]$$

γ: NR direction relative to the mean direction of solar motion

v_E and $v_\odot$: the Earth and Sun motions

$v_c = \sqrt{3/2}v_\odot$: halo circular velocity

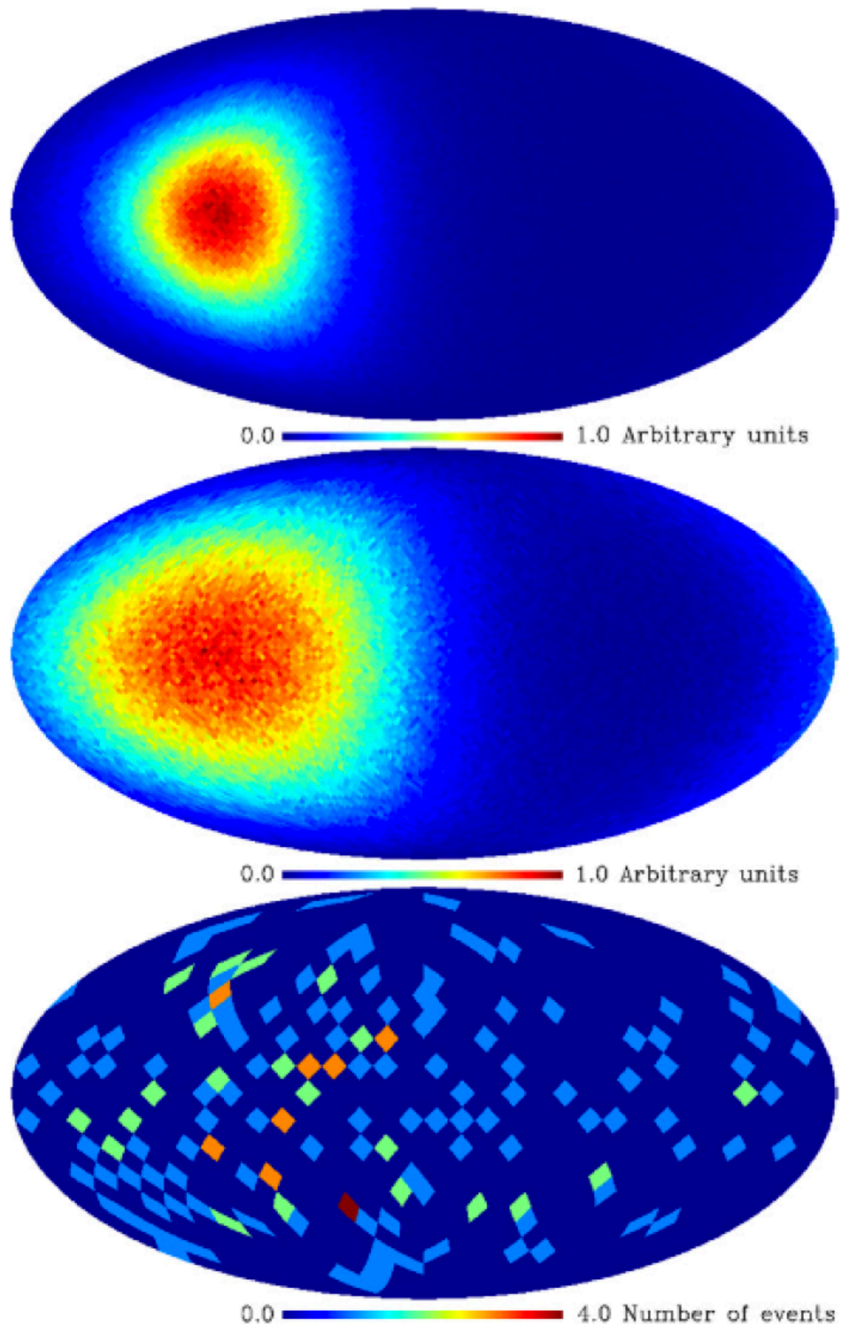
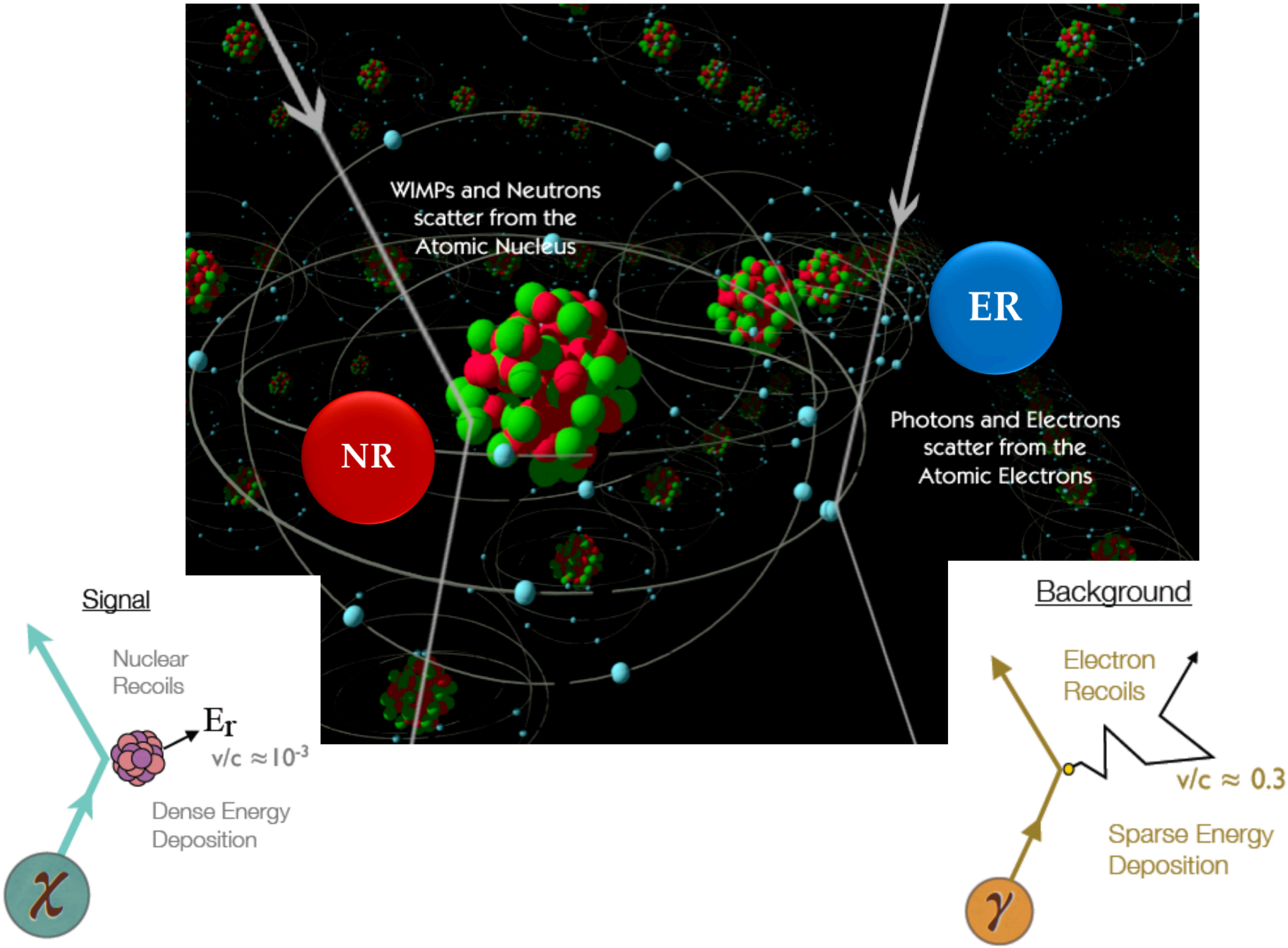


Figure from J. Billard *et al.* 2010

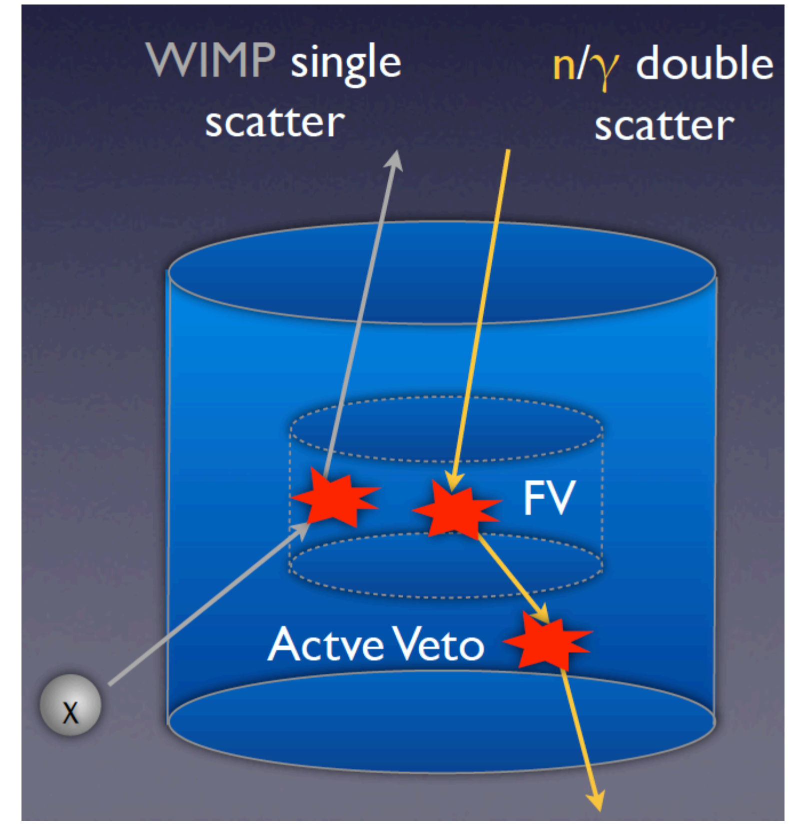
- WIMP flux in the case of an isothermal spherical halo
- WIMP-induced recoil distribution
- A typical simulated measurement:
  100 WIMP recoils and
  100 background events
  (low angular resolution)

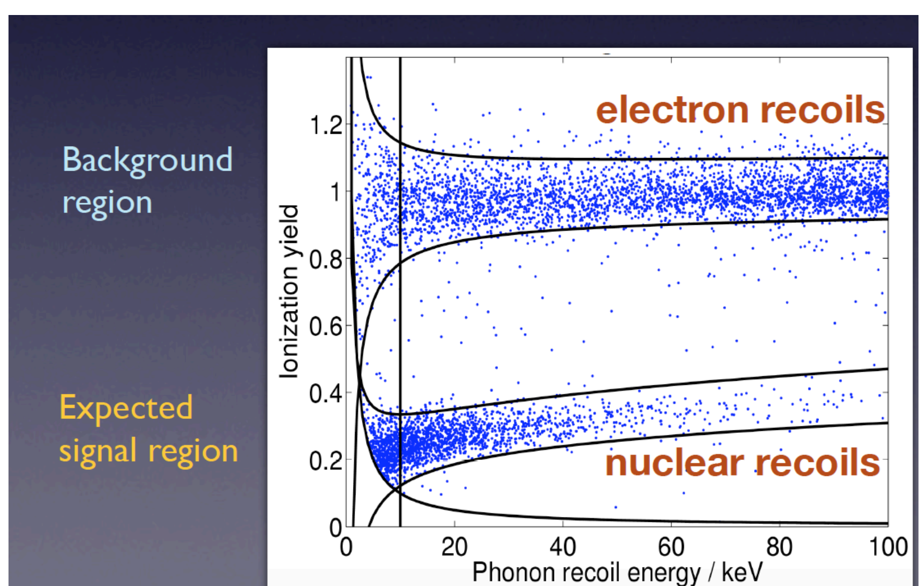
Backgrounds: Electron & Nuclear Recoils

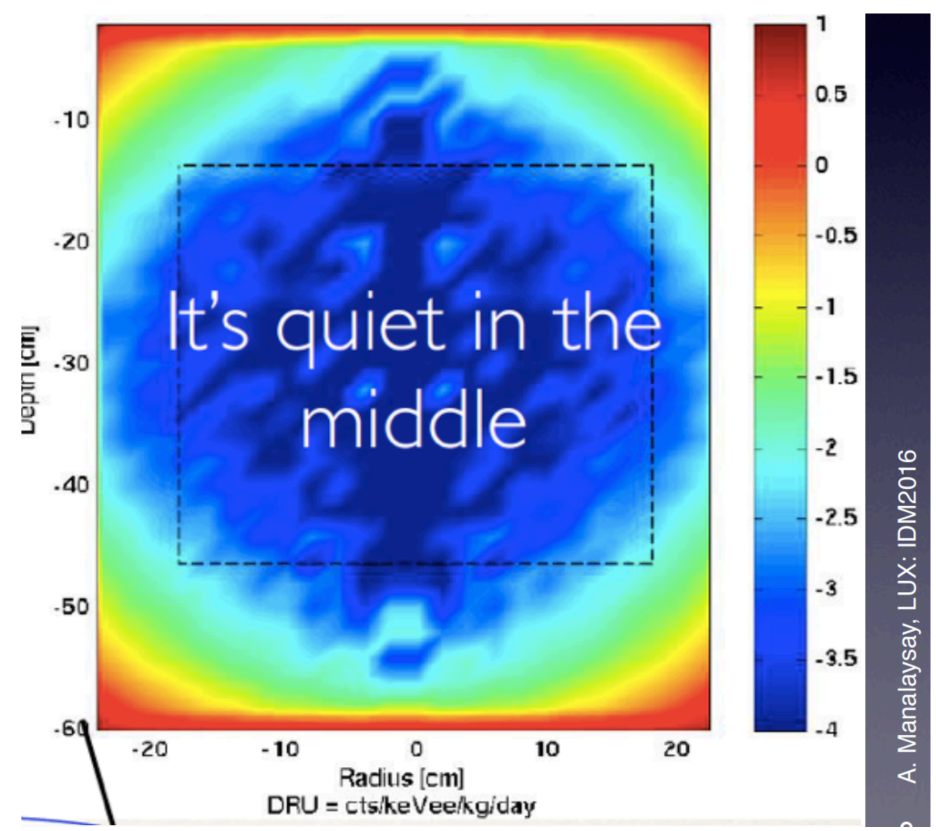


Backgrounds: external sources

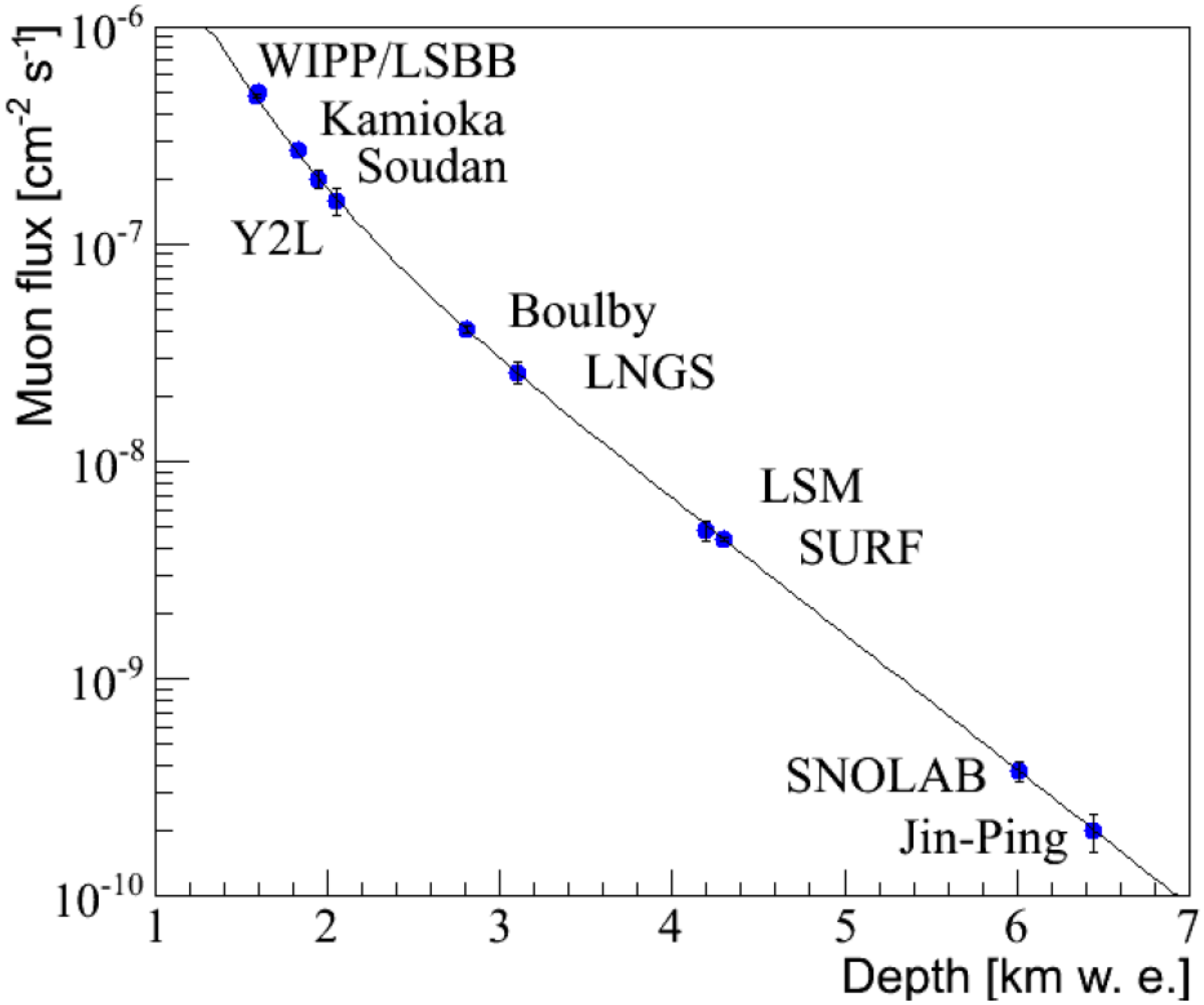
- External γ's from natural radioactivity:
  - Suppression via self-shielding of the target
  - Material screening and selection
  - Rejection of multiple scatters & discrimination
- External neutrons:
  muon-induced, (α, n) and from fission reactions
  - Go underground!
  - Shield: passive (polyethylene) or active (water/scintillator vetoes)
  - material selection for low U and Th contaminations
- Neutrinos:
  from the Sun, atmospheric and from supernovae
  - Elastic neutrino-electron scattering
  - Coherent neutrino-nucleus scattering







Underground laboratories



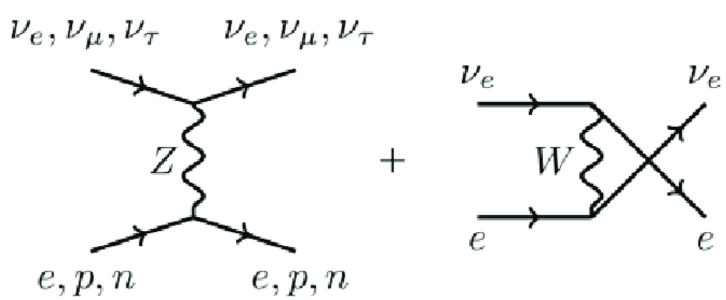
- WIPP in USA (DMTPC)
- LSBB in France (SIMPLE)
- Kamioka in Japan (XMASS, NEWAGE)
- Soudan in USA (SuperCDMS, GoGeNT)
- Y2L in Corea (KIMS)
- Boulby in UK (DRIFT, ZEPLIN)
- LNGS in Italy (XENON, DAMA, Cresst, DarkSide)
- LSM in France (Edelweiss, MIMAC)
- SURF in USA (LUX)
- SNOLAB in Canada (DEAP/CLEAN, PICASSO, COUPP)
- Jin-Ping in China (PandaX, CDEX)

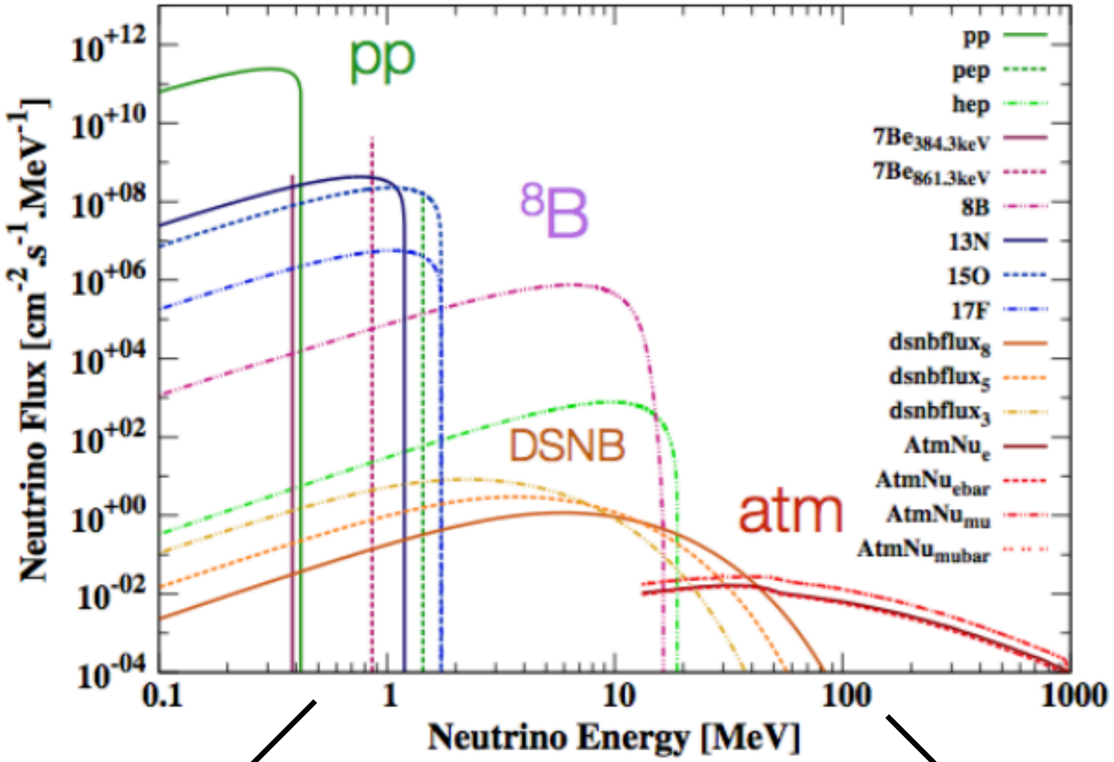
Underground laboratories

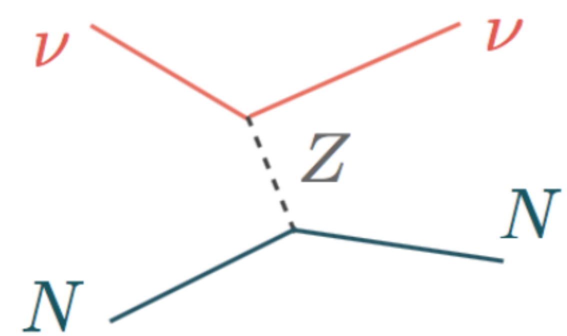
Backgrounds: internal and surface sources

- Internal contamination in liquids:
  - ^{85}Kr: removal by cryogenic distillation/chromatography/centrifuges
  - Rn: removal using activated carbon, distillation, dust removal
  - Argon: ^{39}Ar (565 keV endpoint, 1 Bq/kg), ^{42}Ar
  - Xenon: ^{136}Xe $\beta\beta$ decay ($T_{1/2} = 2.2 \times 10^{21}$ y) *long lifetime!*
- Surface background in solids:
  - Germanium detectors or solid scintillators grown out of high purity powders or melts → low intrinsic background
  - Cosmic activation
  - Surface events from α or β-decays

The ultimate background from neutrinos



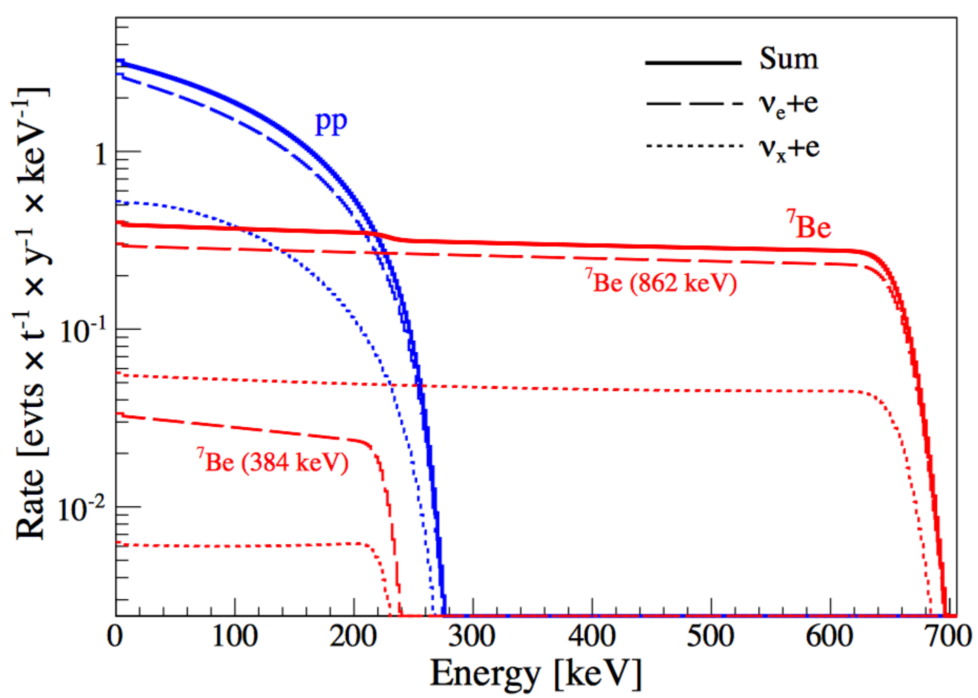


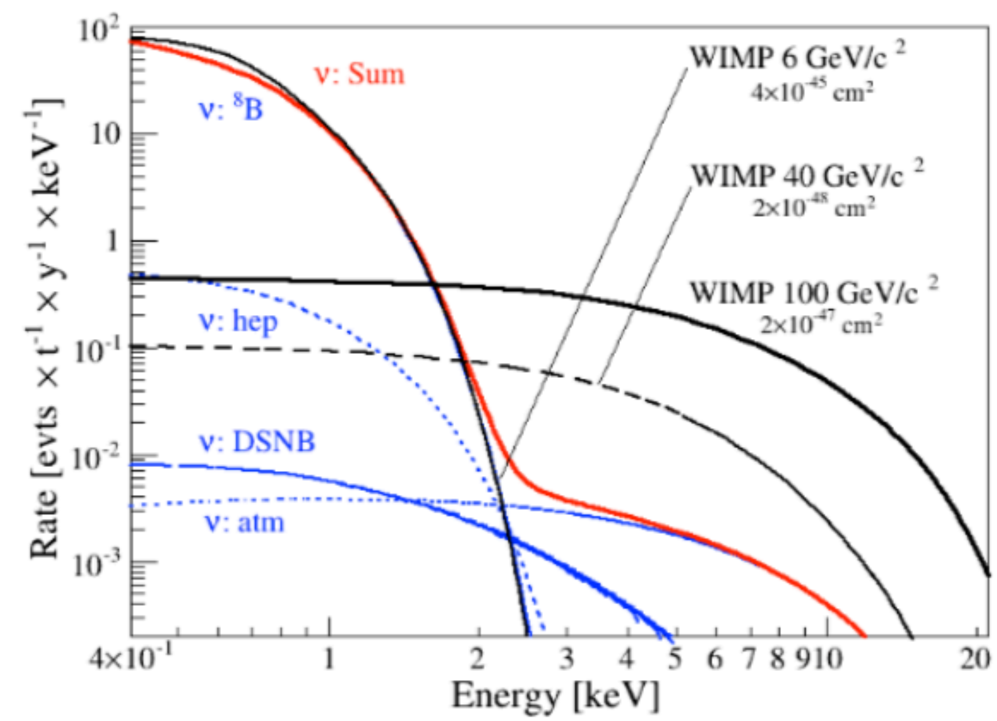


F. Ruppin et al., 1408.

ER

NR $\nu + N \longrightarrow \nu + N$





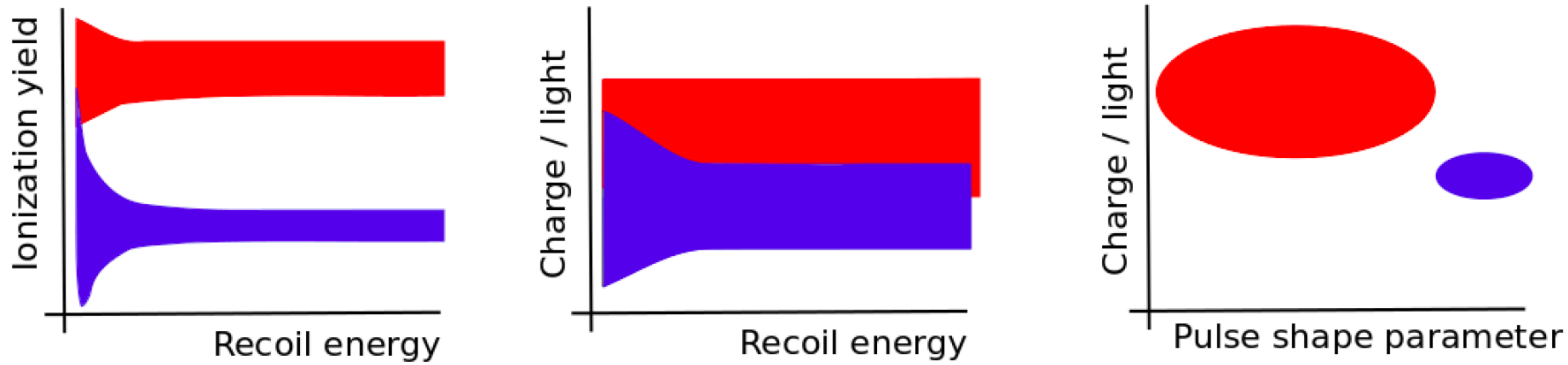
LB et al., JCAP01 (2014) 044

Detector Calibration

Purposes of detector calibration:

- Data stability:
  monitoring of detector parameters (amplification of signals, slow control parameters, ..) and of the related electronics
- Determination of energy scale:
  detector signals are photoelectrons, charges or heat
  → need to convert to keV_{nr}
- Determination of signal and background regions:
  description of nuclear and electronic recoil regions

Detector Calibration: Signal & Background



- Discrimination in a cryogenic germanium detector (left)
  No surface events included!
- Discrimination in a liquid xenon detector (middle)
- Discrimination in a liquid argon detector (right)
  Two parameters available for discrimination

Sensitivity plot in direct DM experiments

→ Statistical significance of signal over expected background?

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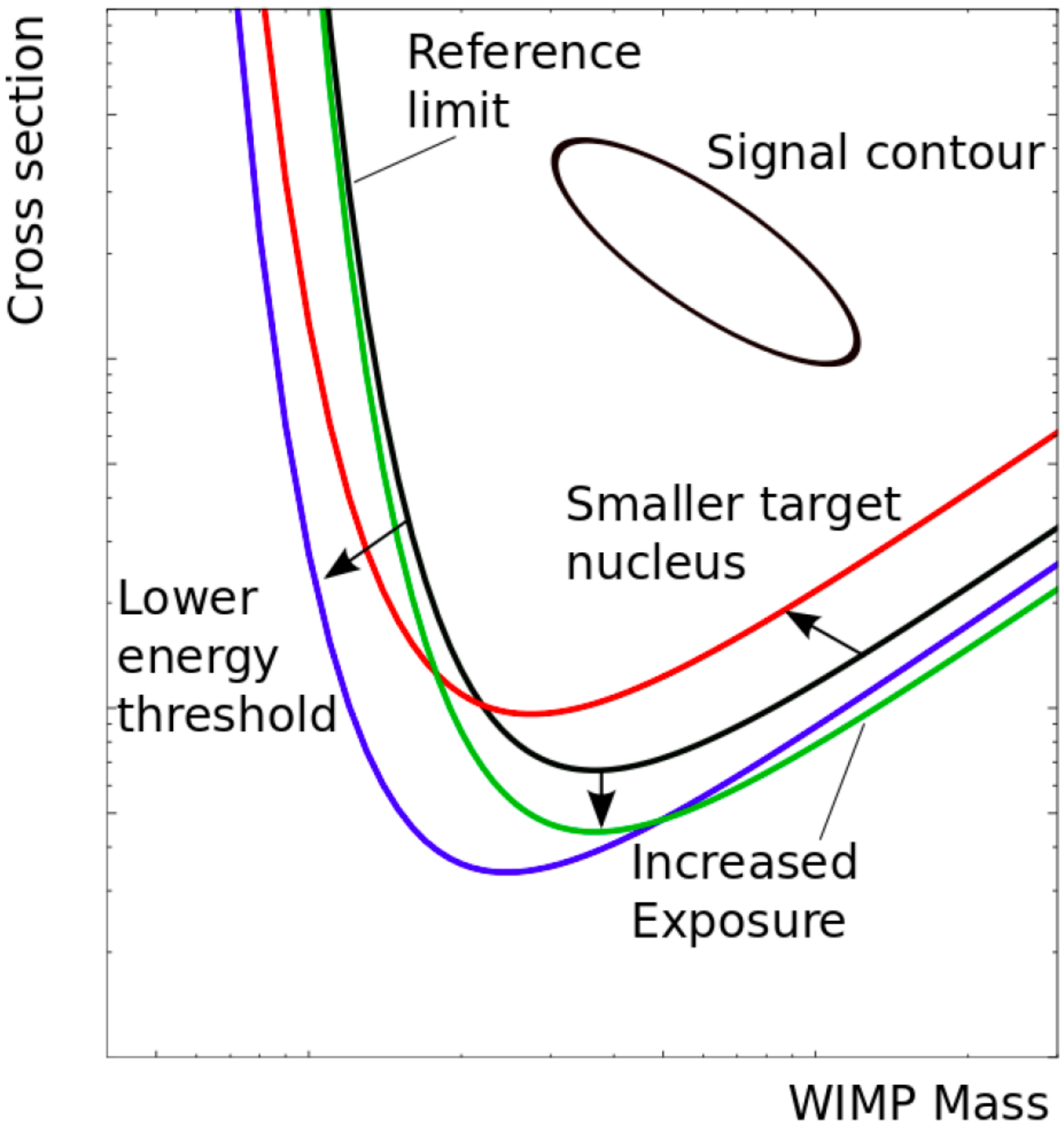
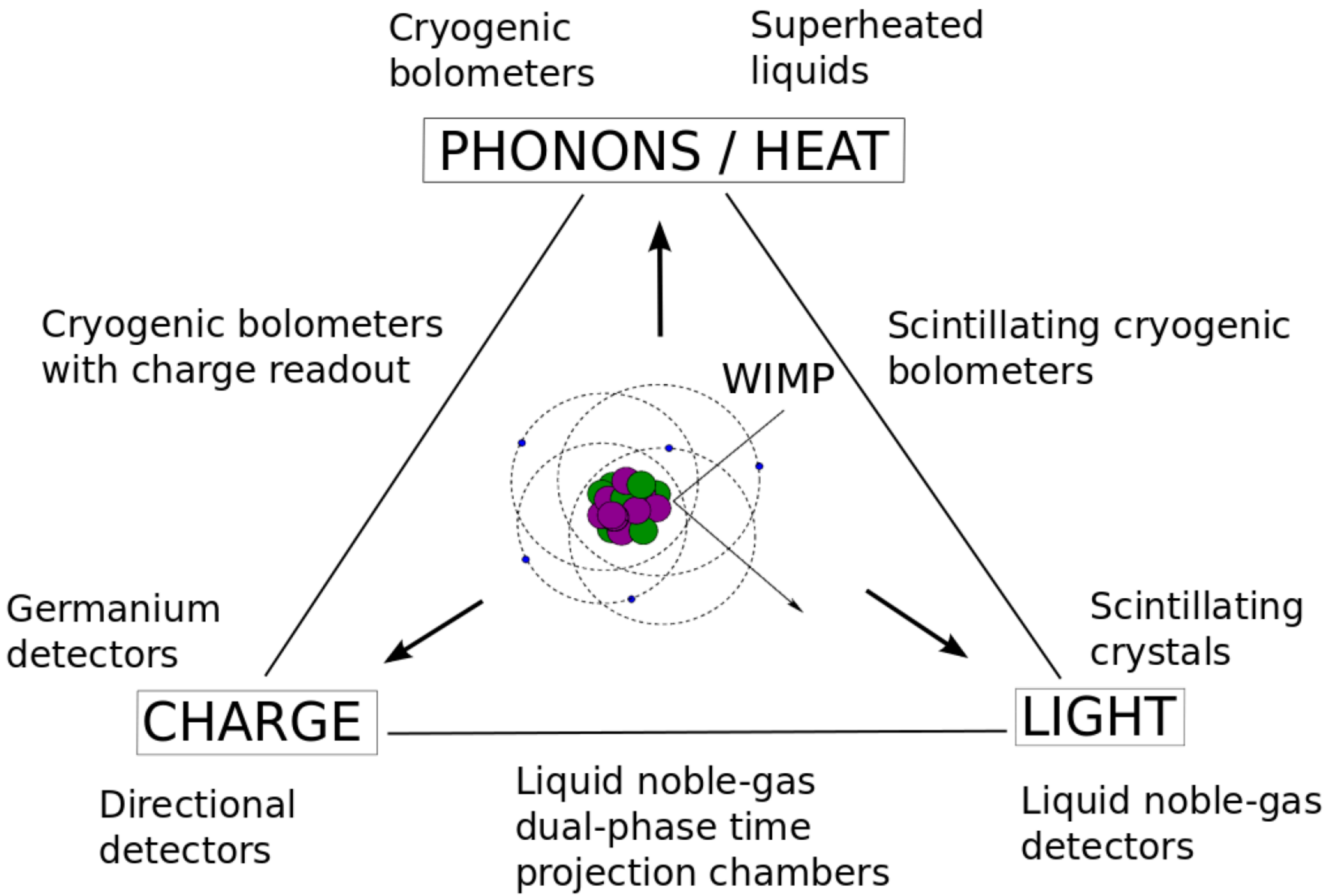


- Positive signal
  - Region in σ_χ versus m_χ
- Zero signal
  - Exclusion of a parameter region

  - Low WIMP masses: detector threshold matters
  - Minimum of the curve: depends on target nuclei
  - High WIMP masses: exposure matters $\epsilon = m \times t$

Direct detection Techniques



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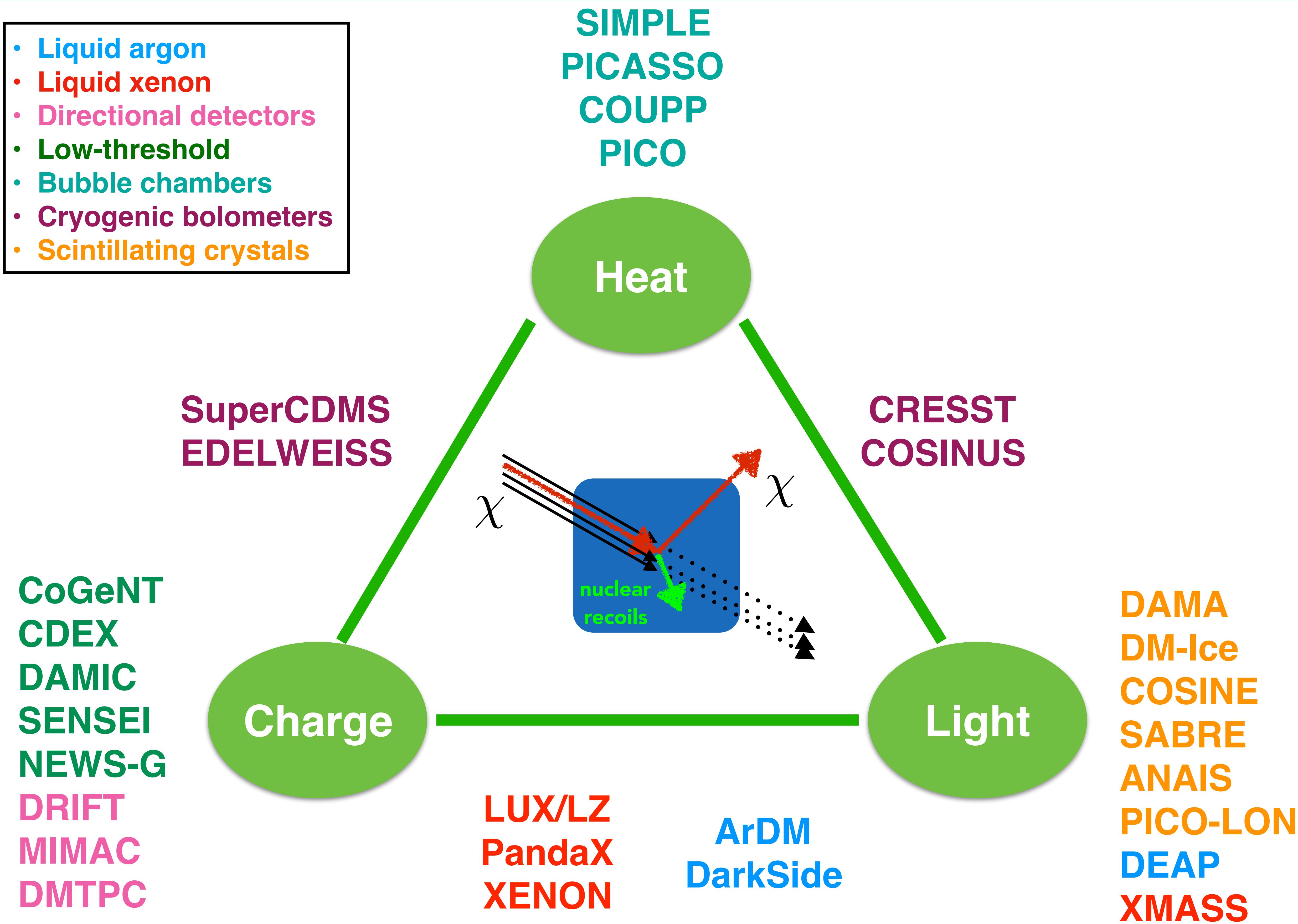
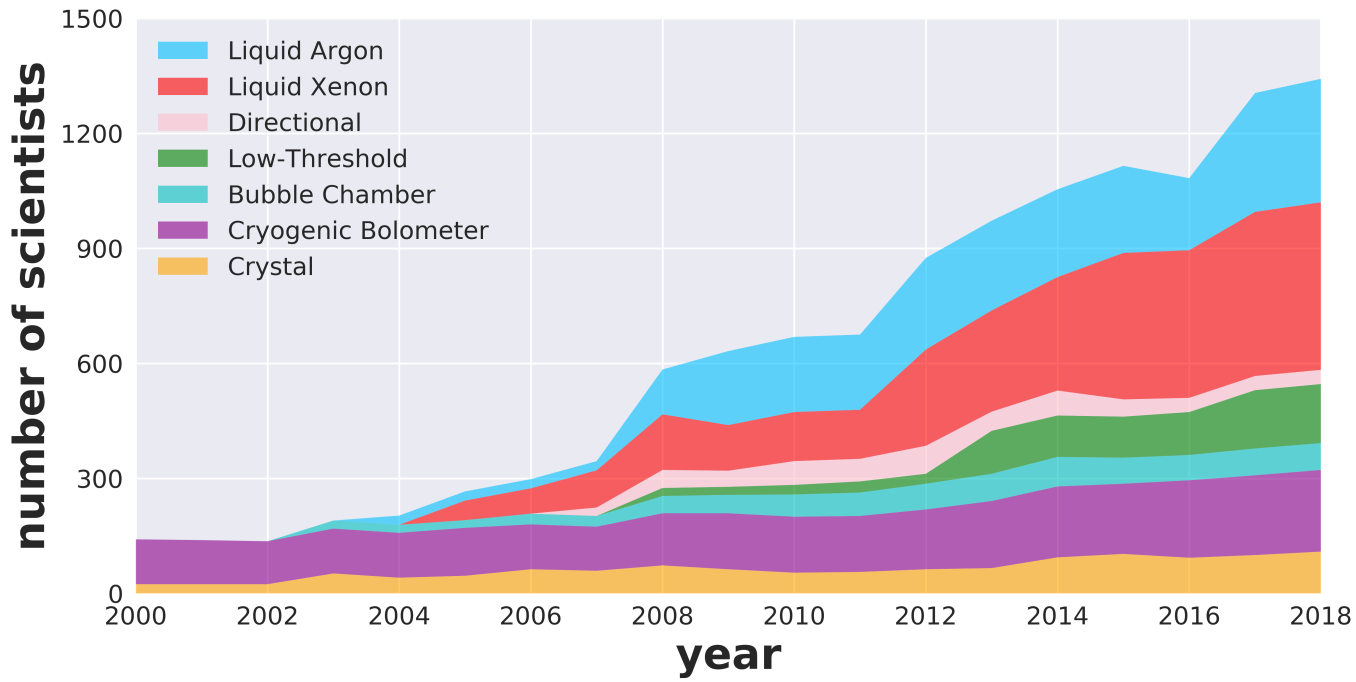
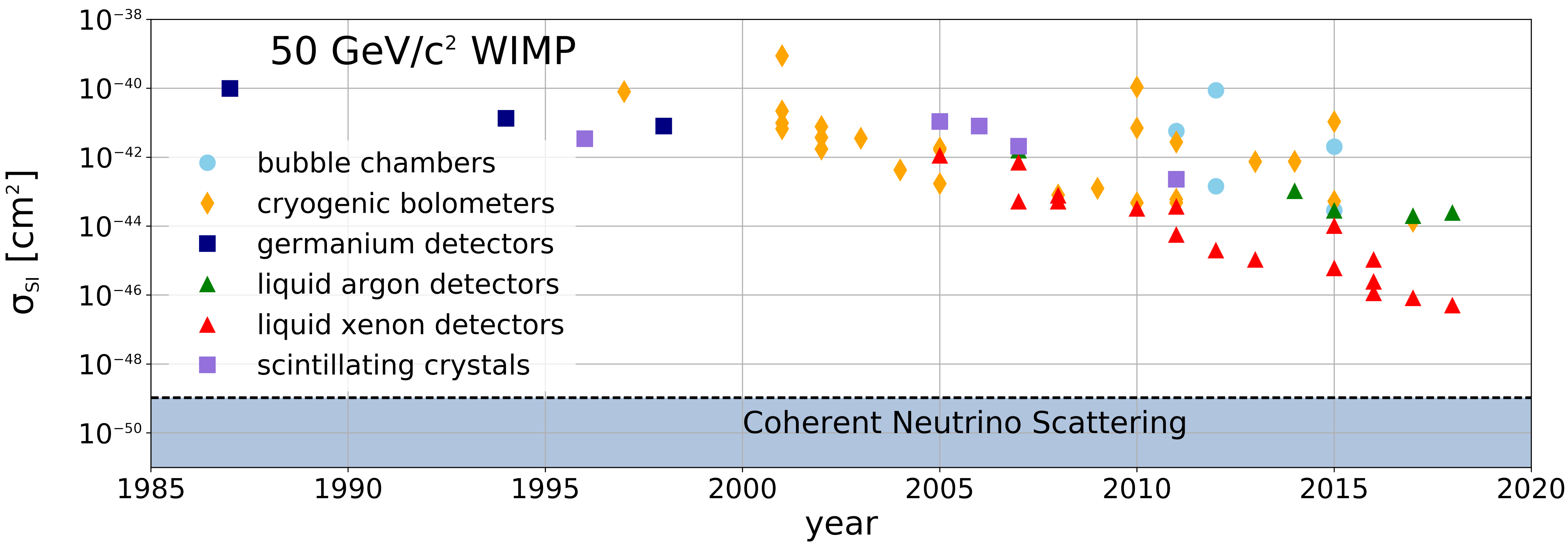
Direct Detection Techniques

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



Competitive field, rapid progress





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

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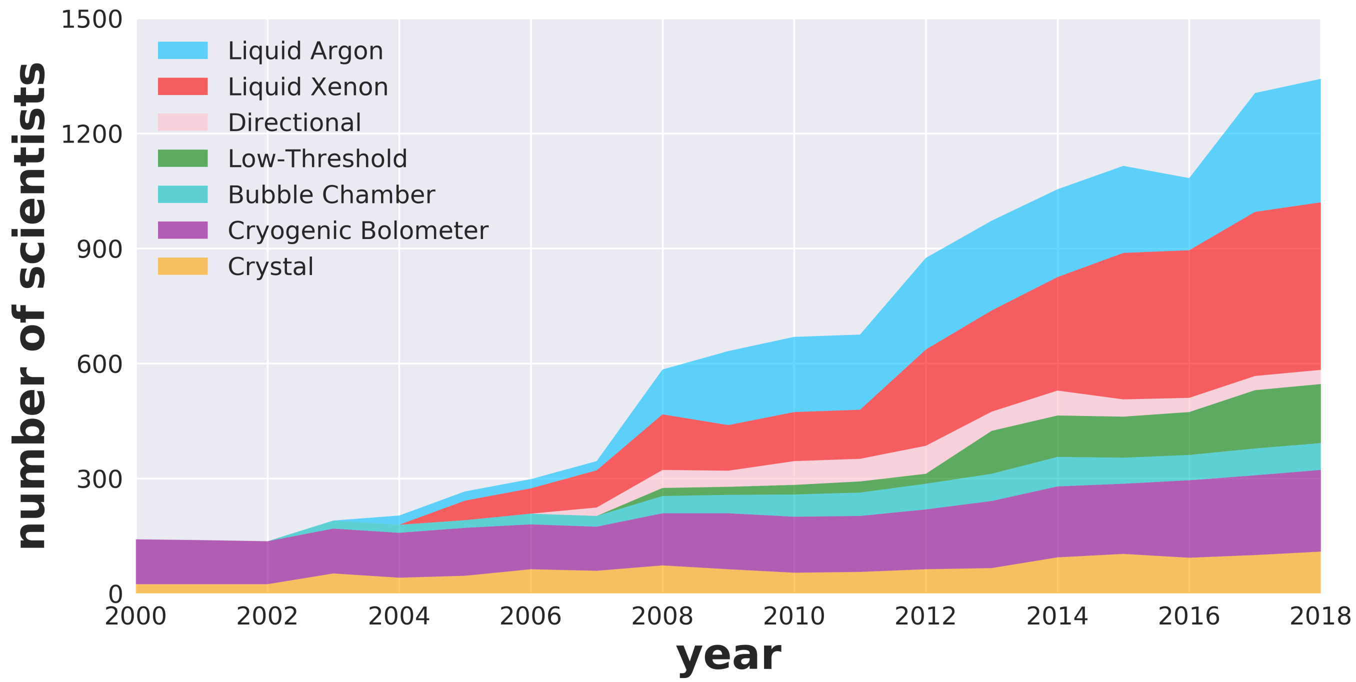

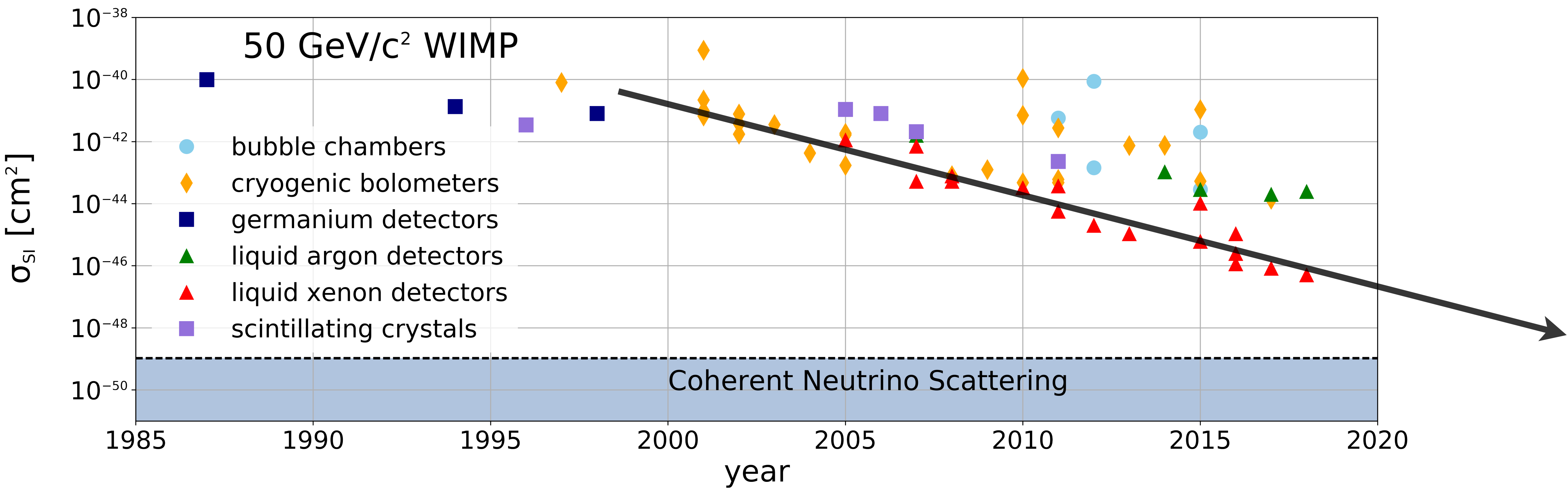

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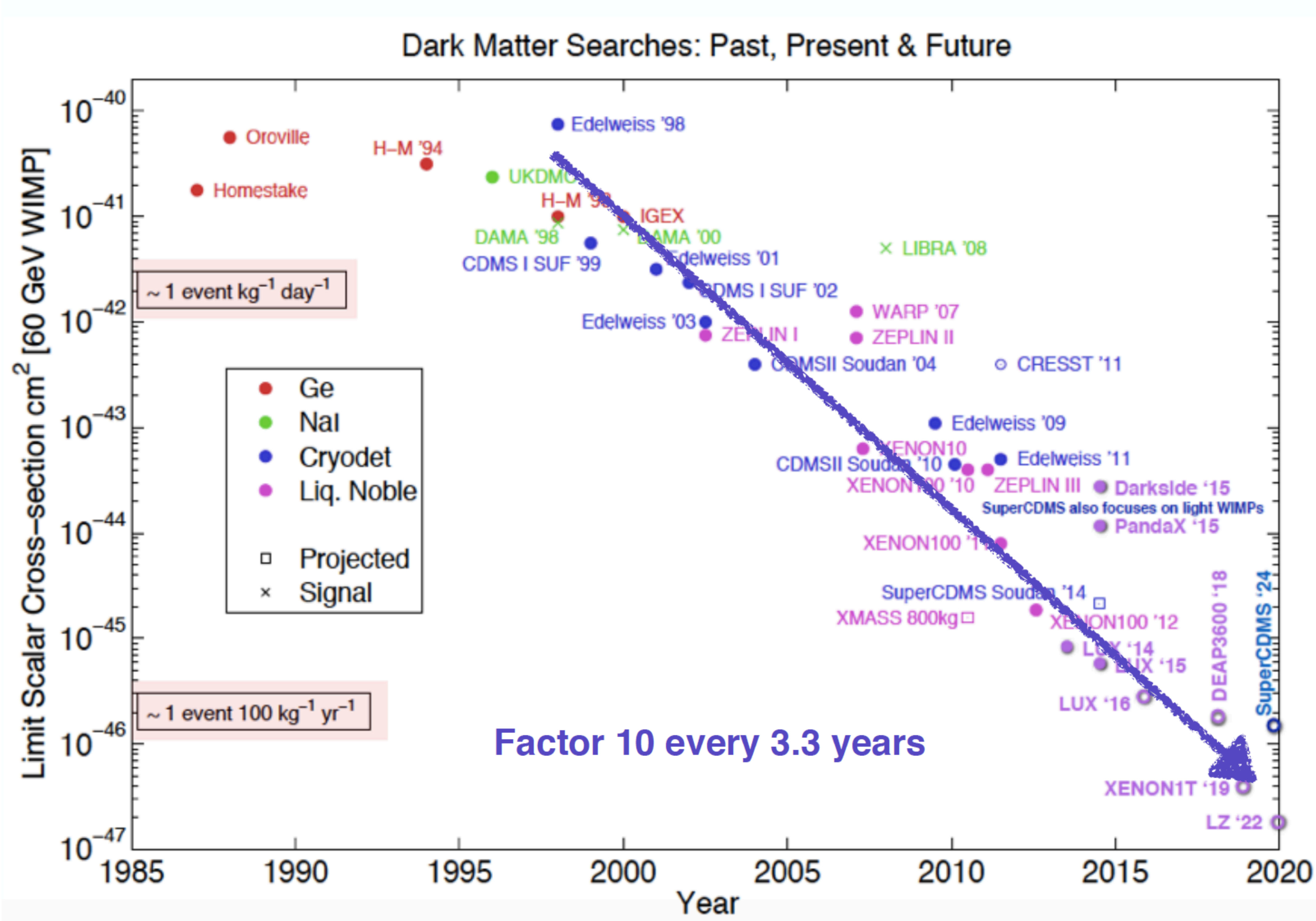
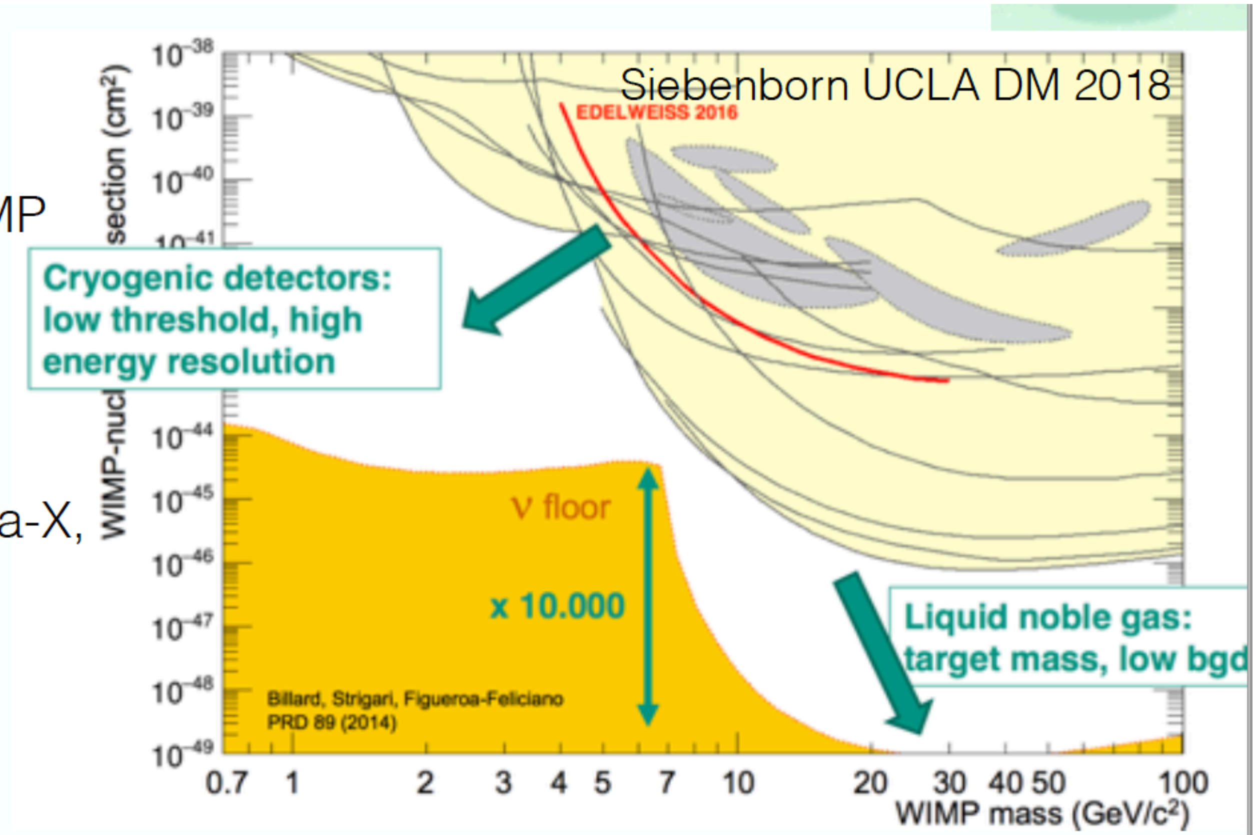
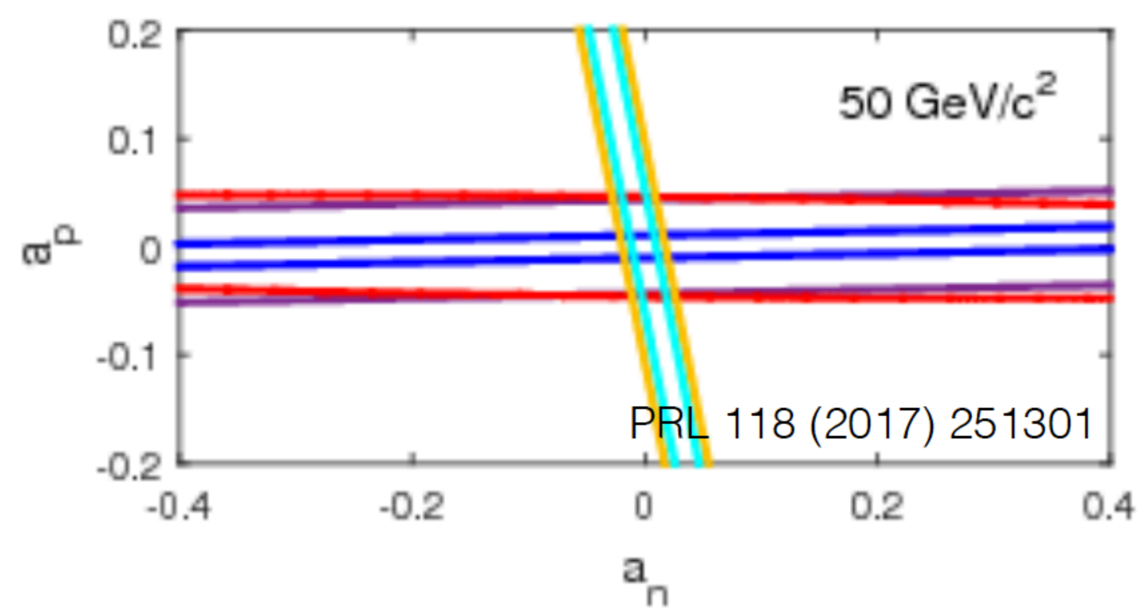


detector sensitivity improved by ~5 orders of magnitude in the last 20 years

Two main lines of improvements (+ others)

- **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



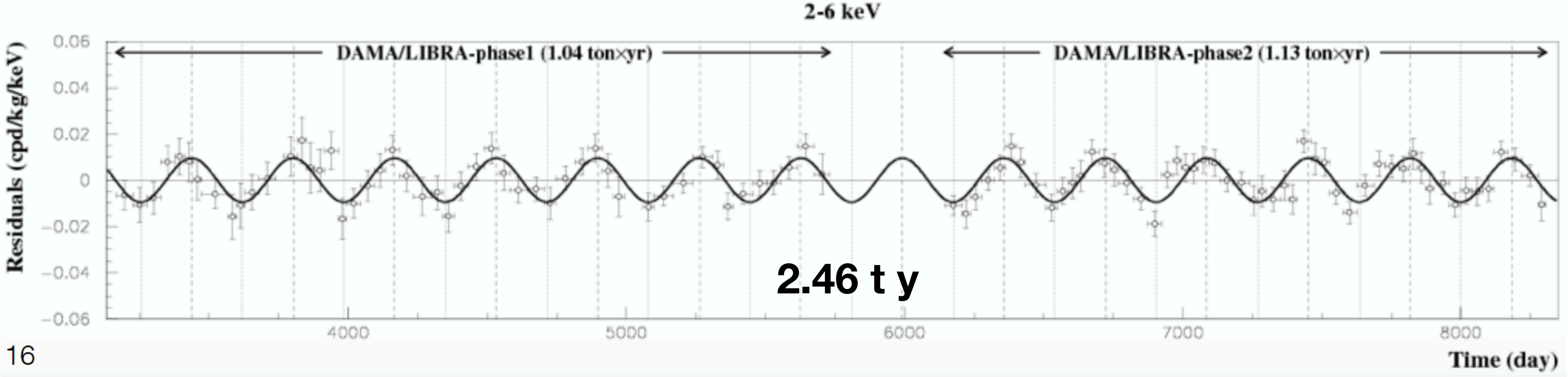


Scintillating crystals

- Mostly NaI (Tl) and CsI (Tl) used in dark matter searches
- Arrays of several crystals at room temperature
  → simple operation, important for long-term stability
- No particle discrimination
  → Low radioactivity of the target material
  → Rejection of multiple scatters in different crystals

DAMA-LIBRA new 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)



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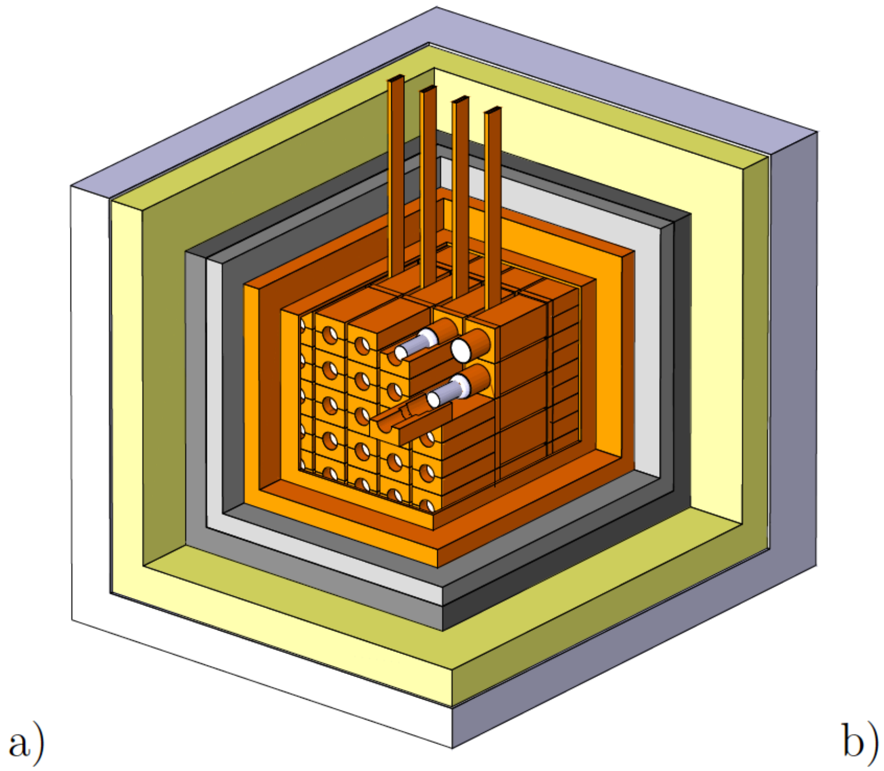
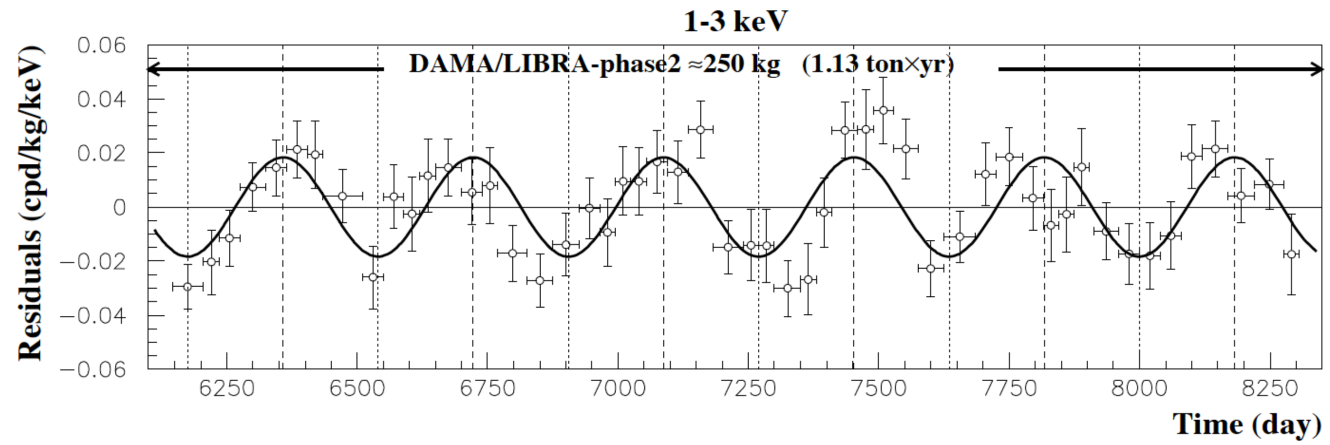
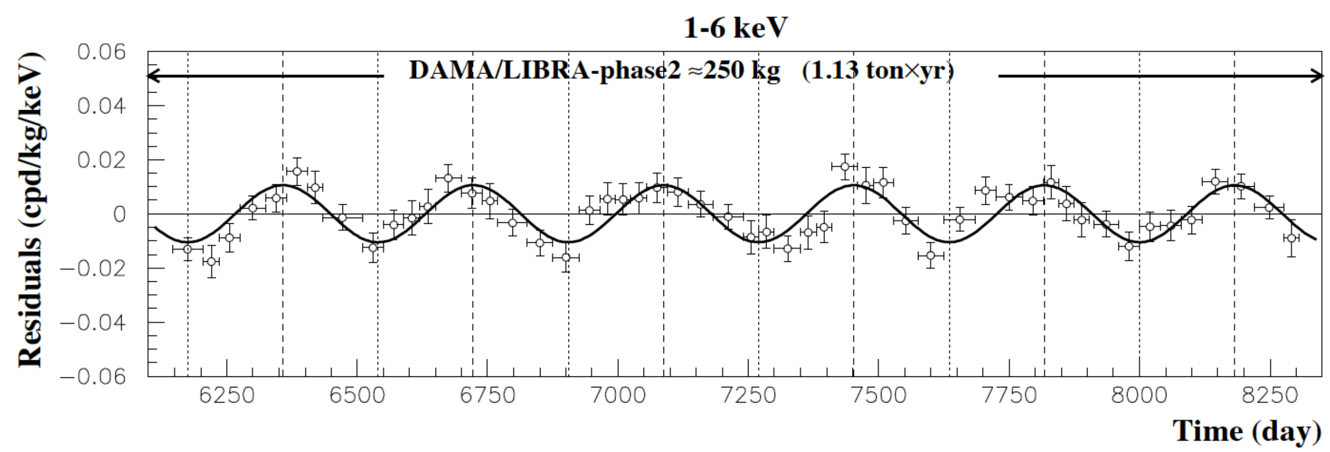
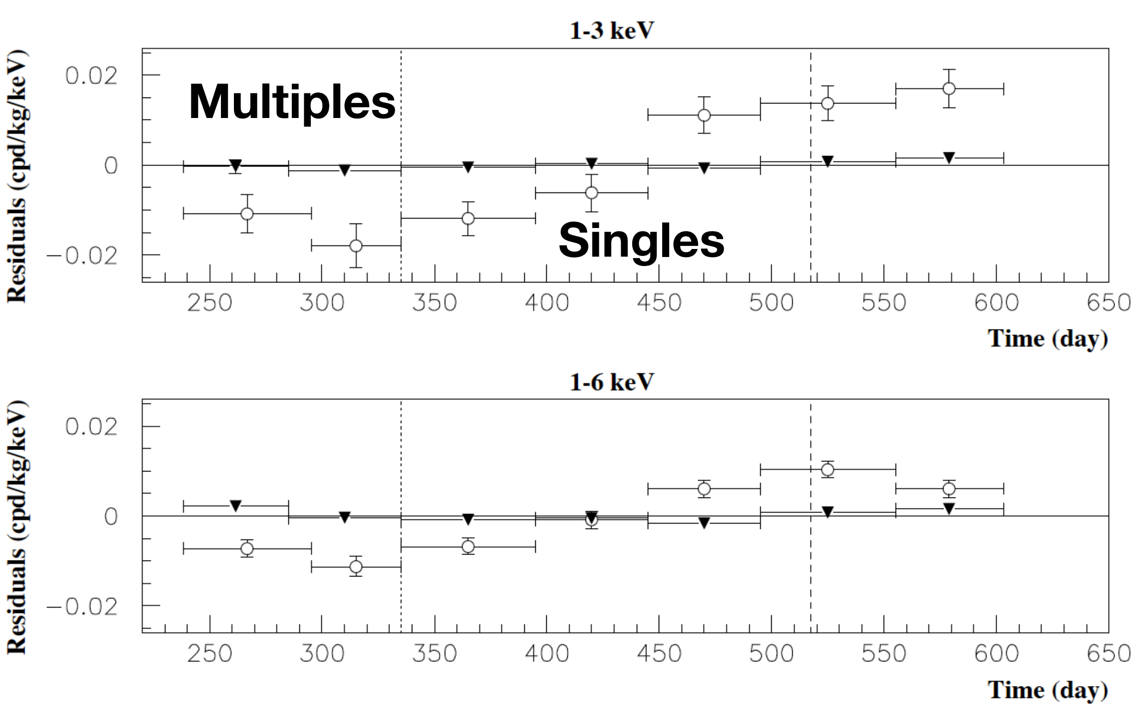
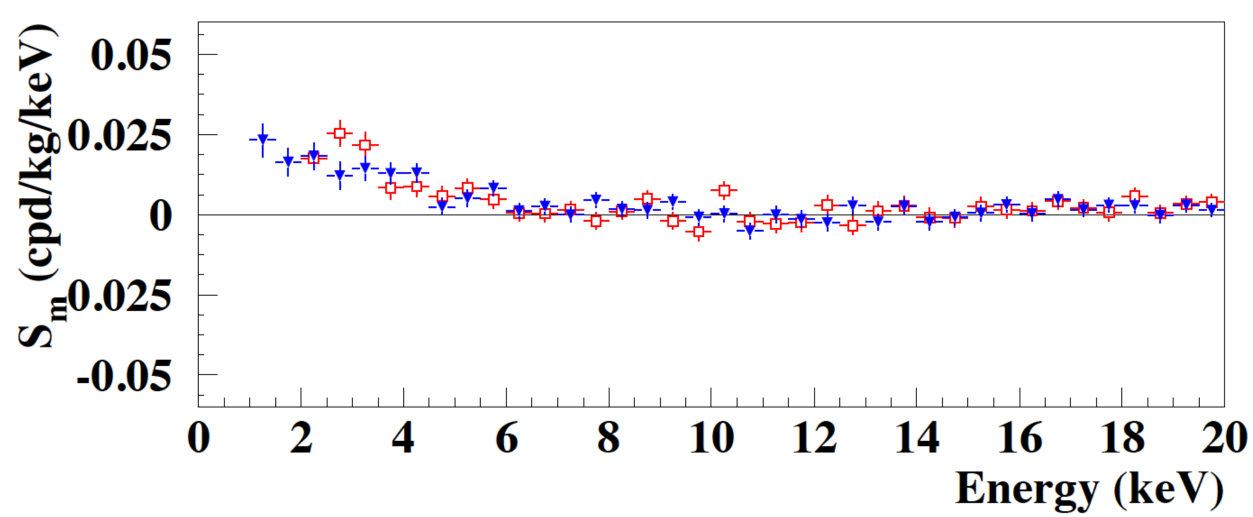






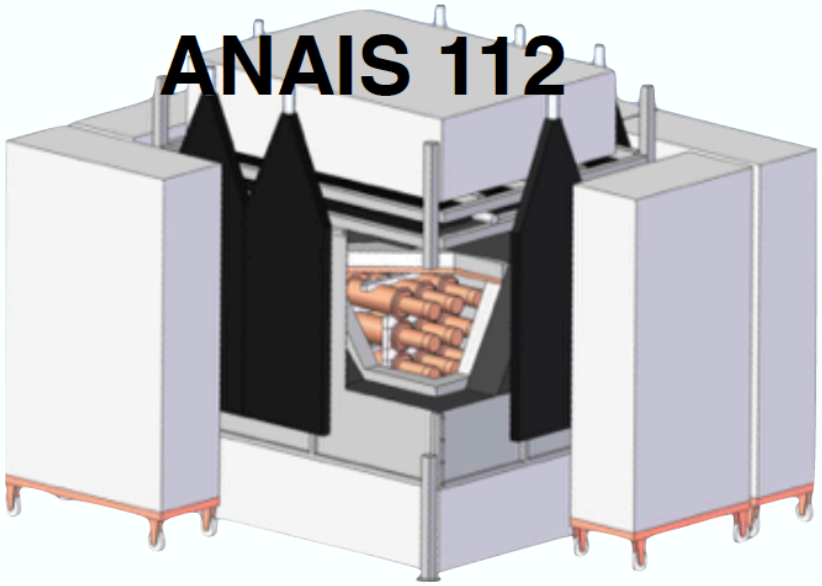


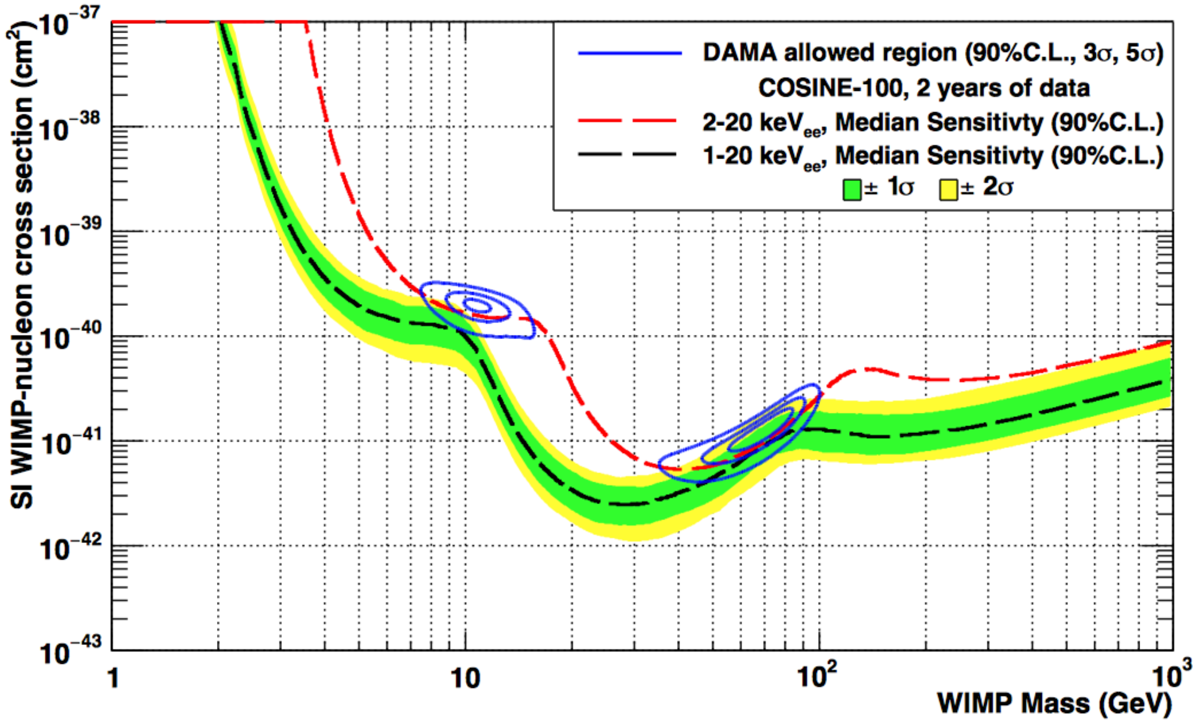


Very hard to attribute it to neutrons, muons, or worst … neutrinos !!!

Future in NaI detectors

- COSINE 100 running since September 2016
- ANAIS 112 started operations in August 2017 and will have 3 σ significance after 5 years

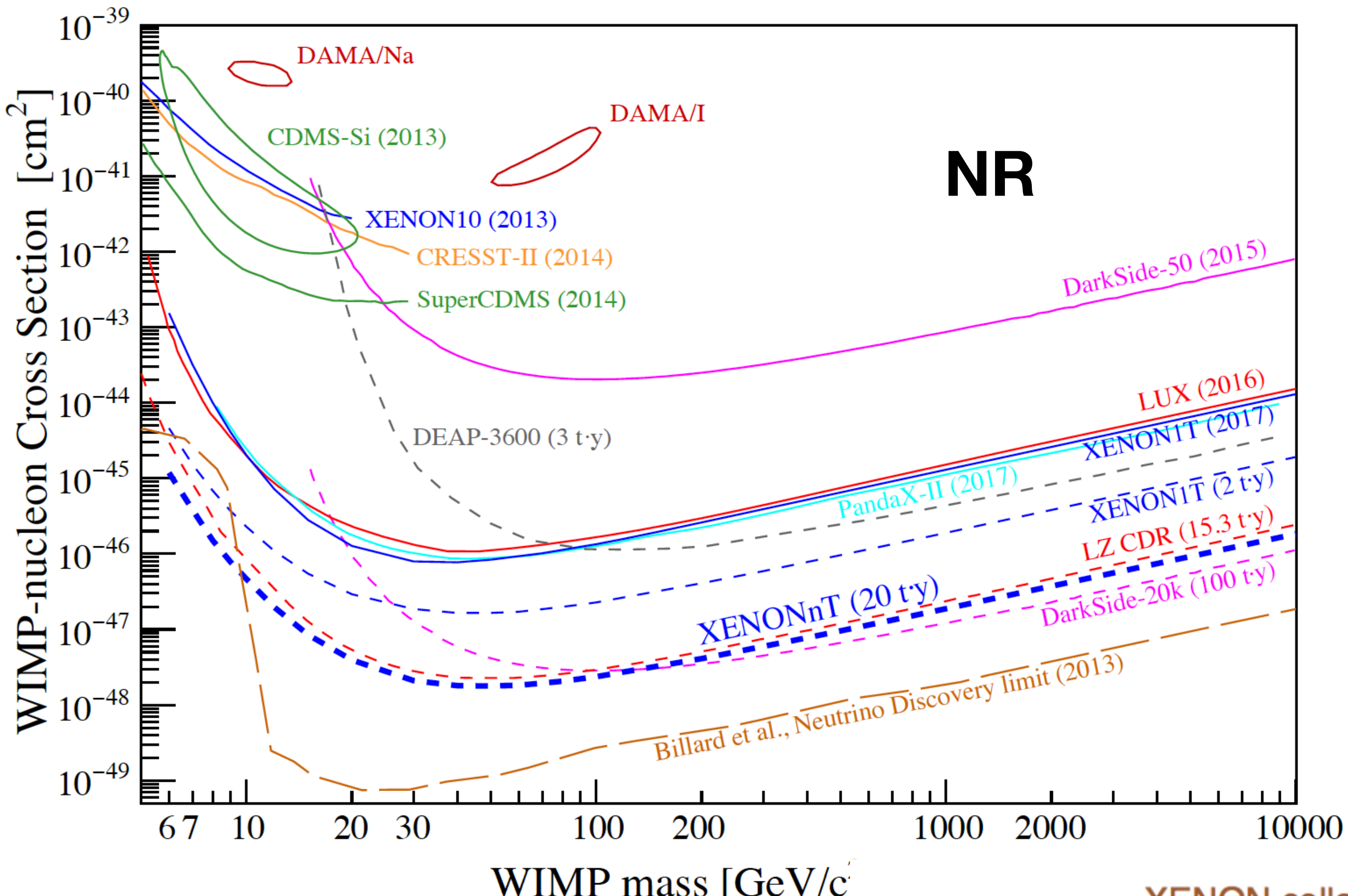




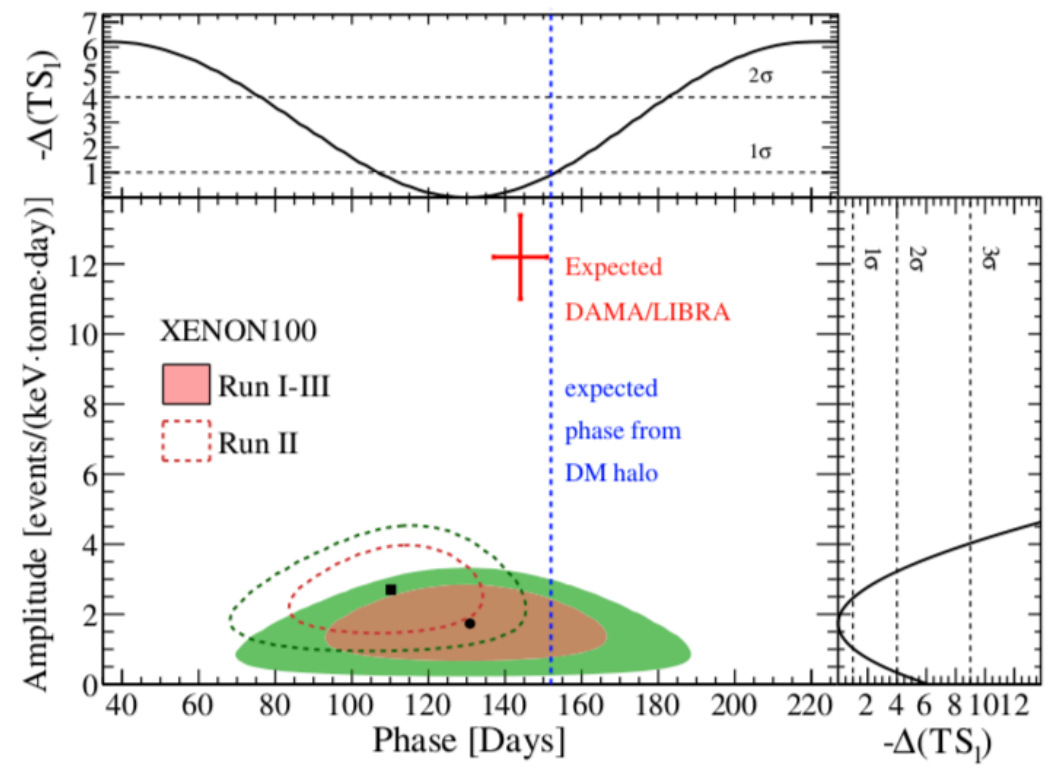
- SABRE 5 kg proof of principle starts this year(2018)
- SABRE South (50 kg in Australia) scheduled to start in 2019
- DAMA/LIBRA phase 3 (1 ton) R&D underway

Comparing DAMA with others

- not compatible with experiments with other targets

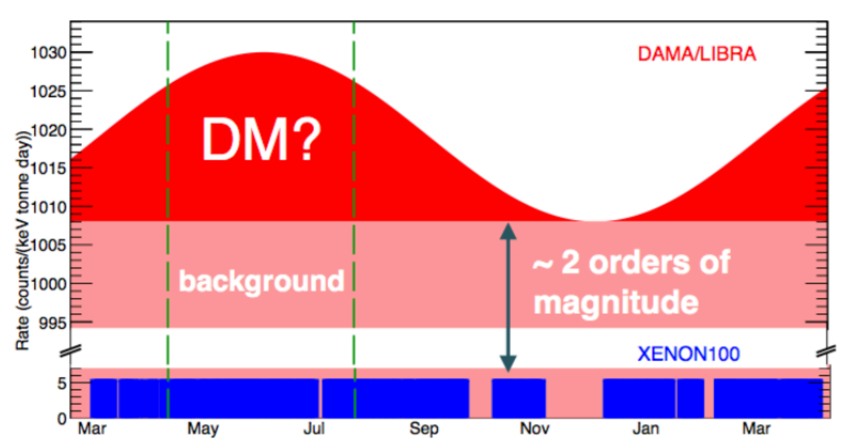


XENON100 4-year ER modulation study, PRL 118, 101101 (2017)

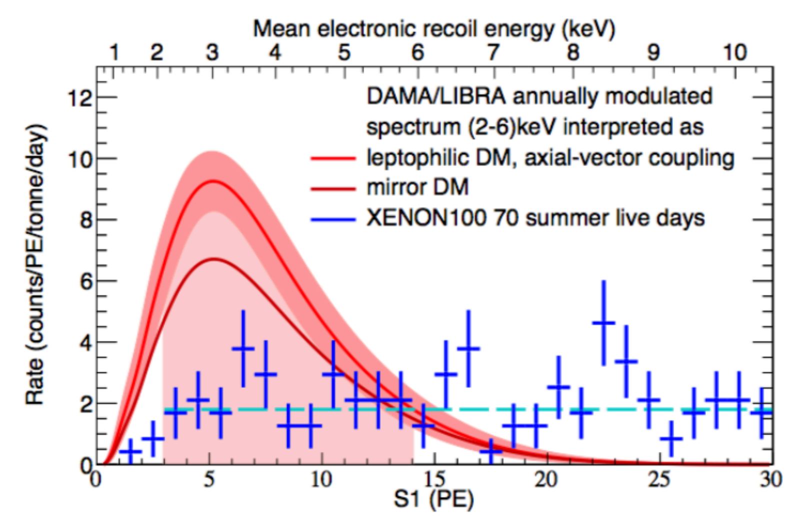


XENON collaboration, arXiv: 1507.07747, Science 349, 2015

...but also with ER models, i.e. leptophilic

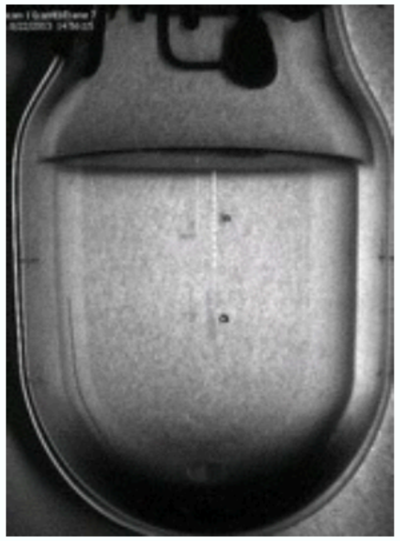


Consider the 70 days with the largest signal

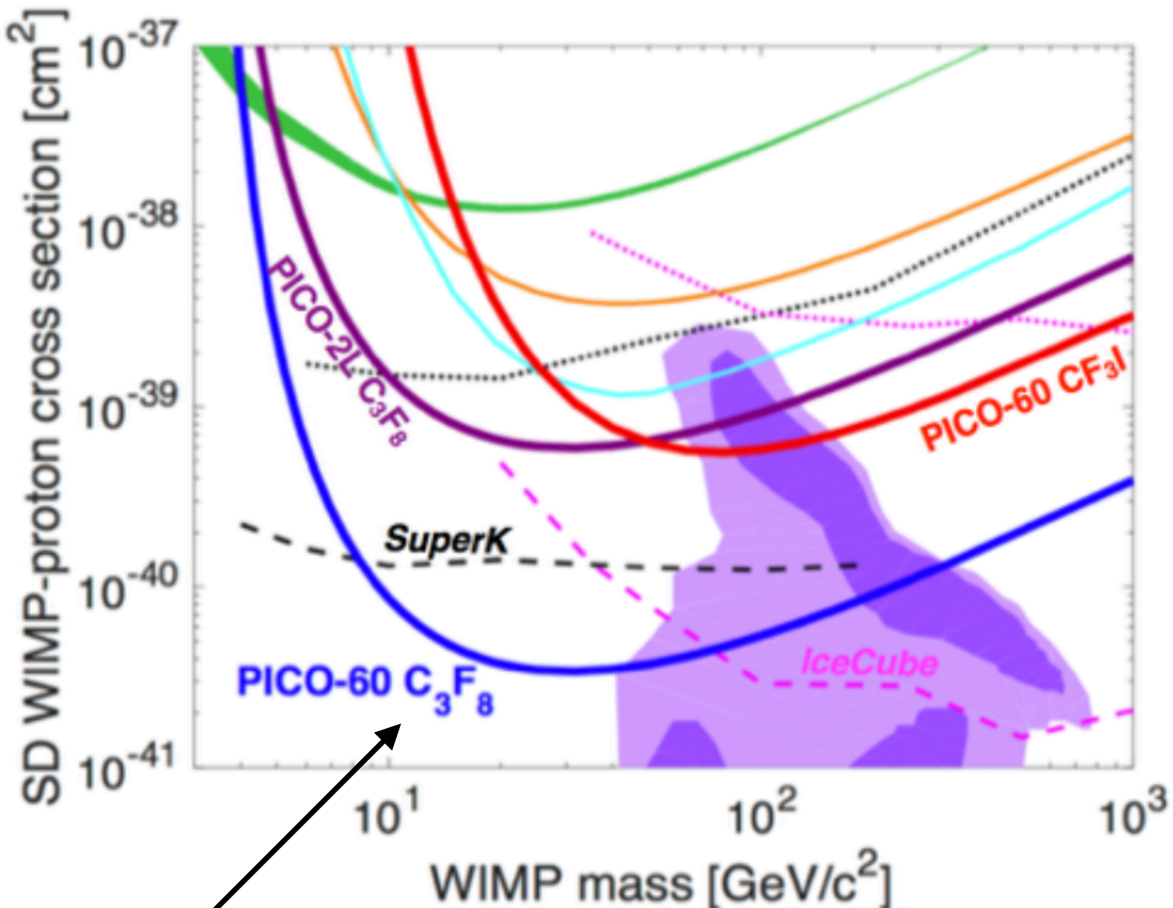


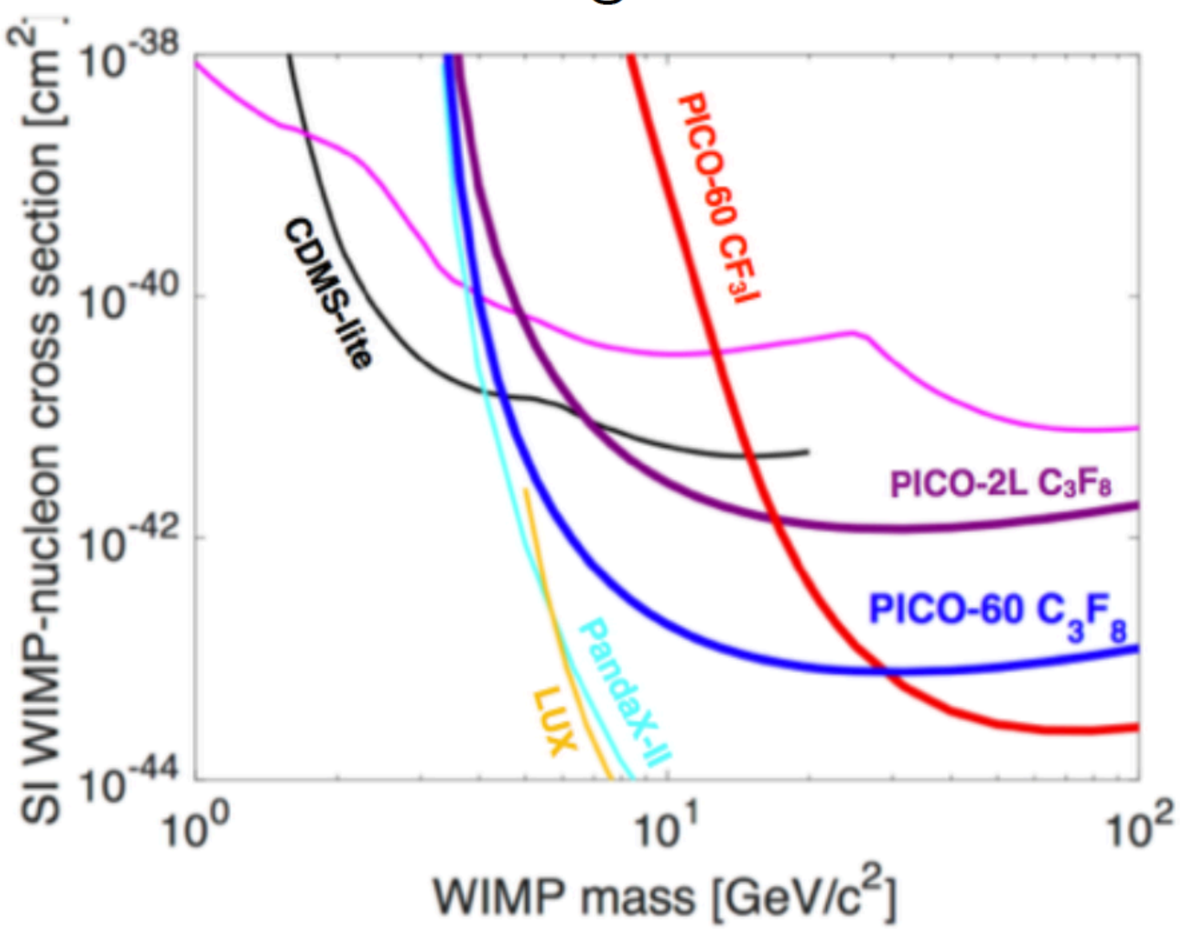
DAMA/LIBRA modulated spectrum as would be seen in XENON100 (for axial-vector WIMP-e⁻ scattering)

Bubble chambers



- 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

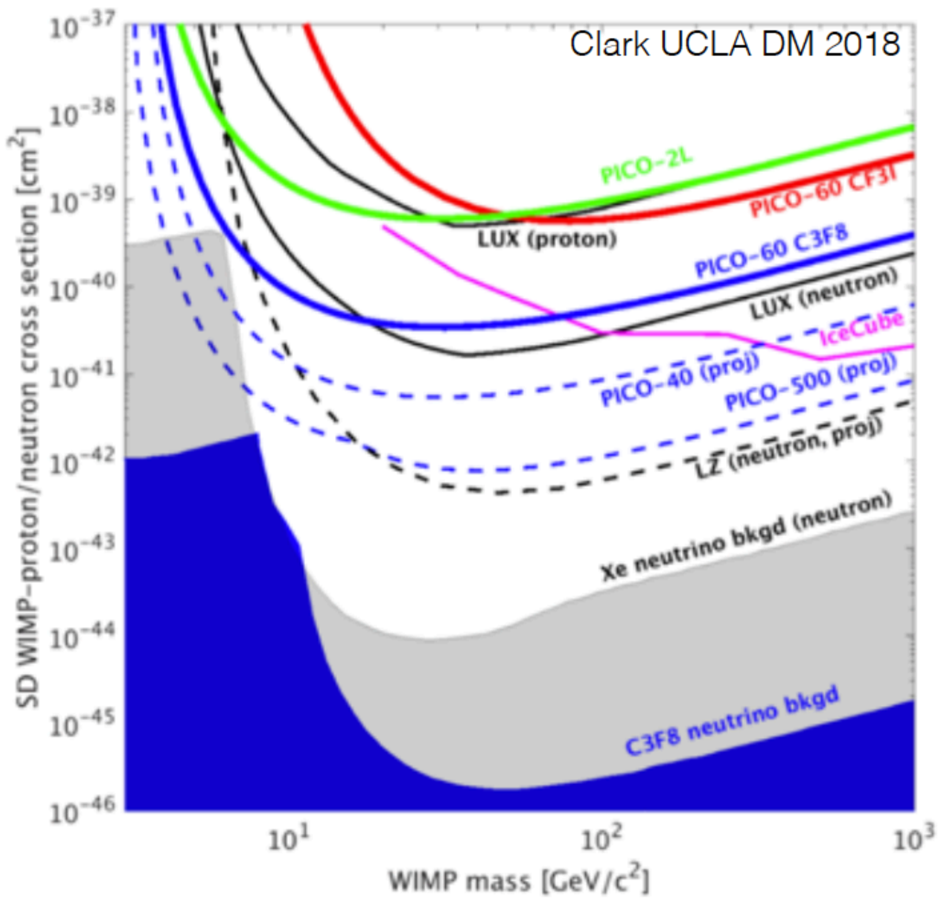




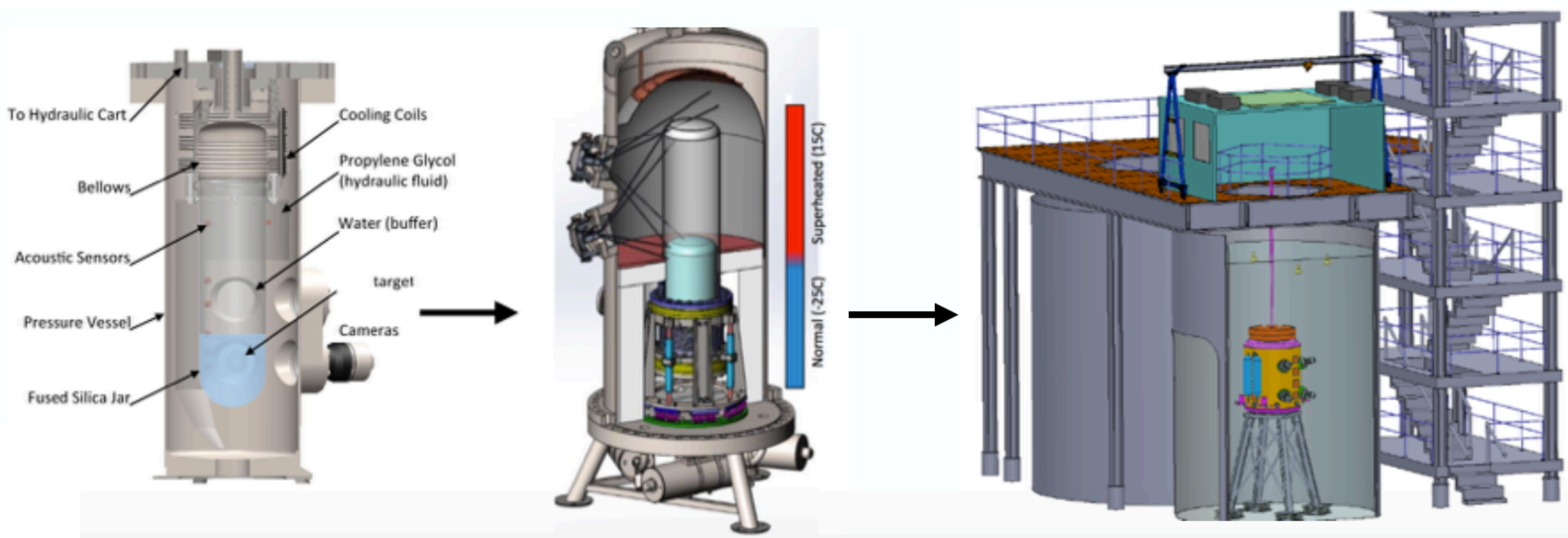
Phys. Rev. Lett. **118**, 251301 (2017)

- best SD WIMP-proton limit: 3.4e-41 cm² at 30 GeV/c²

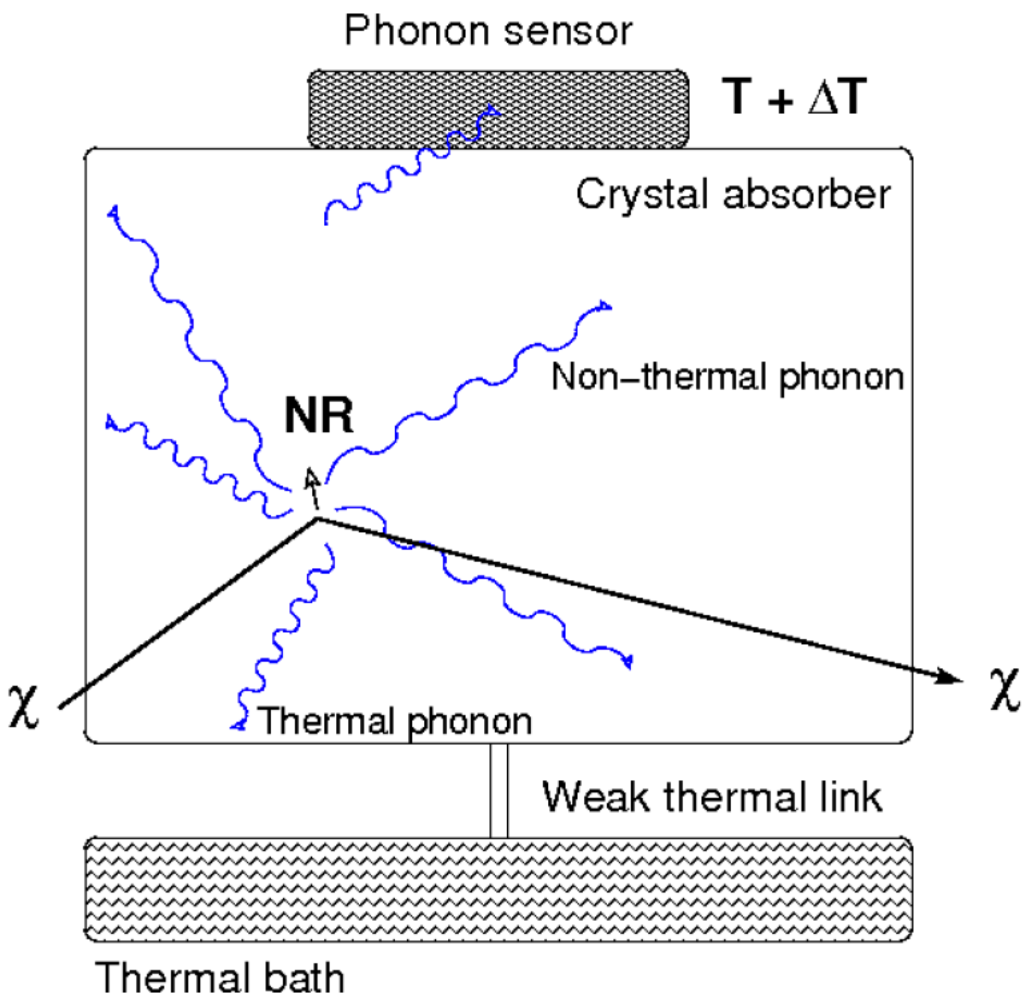
PICO in the future …

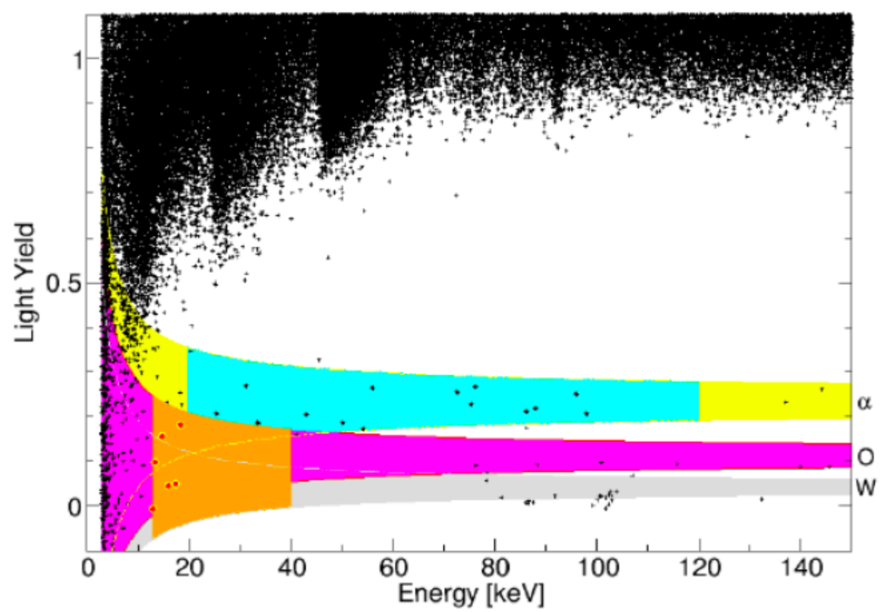


- Additional PICO 60 analyses forthcoming
- PICO 40L coming online this summer (2018) with C_3F_8 target and inverted vessel
- PICO 500 scheduled to begin construction in 2019



Cryogenic bolometers

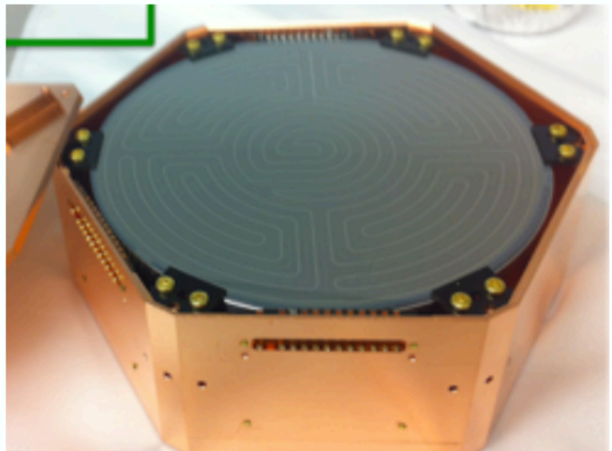


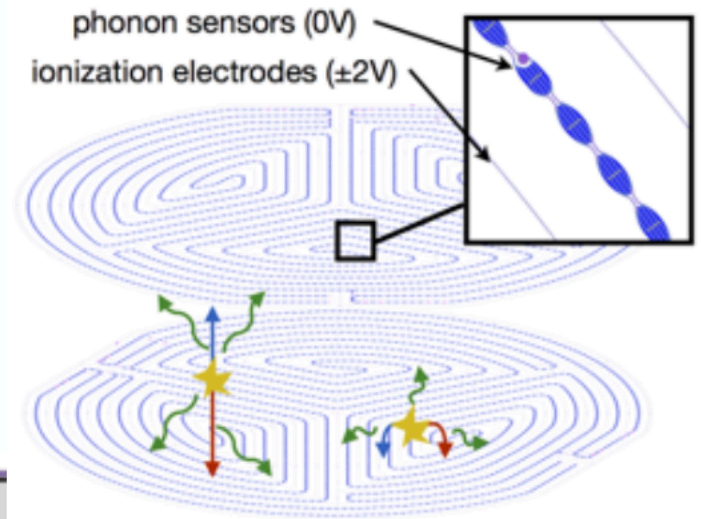


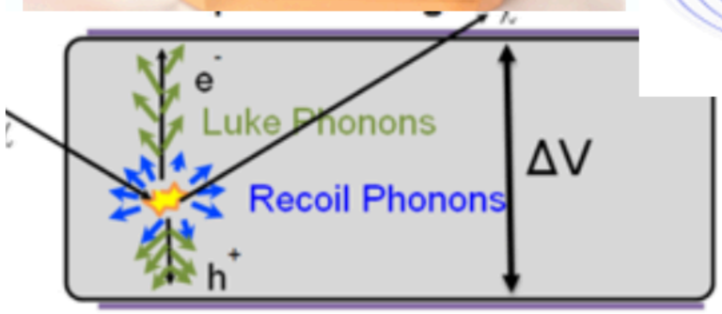
- Crystals at (10 – 100) mK
- Temperature rise:
  $\Delta T = E/C(T)$
  E.g. Ge at 20 mK, $\Delta T = 20\,\mu$K for few keV recoil
- Measurements of ΔT
  NTD: neutron transmutation-doped Ge sensors
  TES: Transition edge sensors
- Discrimination: combination with light or charge read-out
- Large separation of electronic and nuclear recoil bands

Example from CRESST, EPJC 72 (2012) 1971

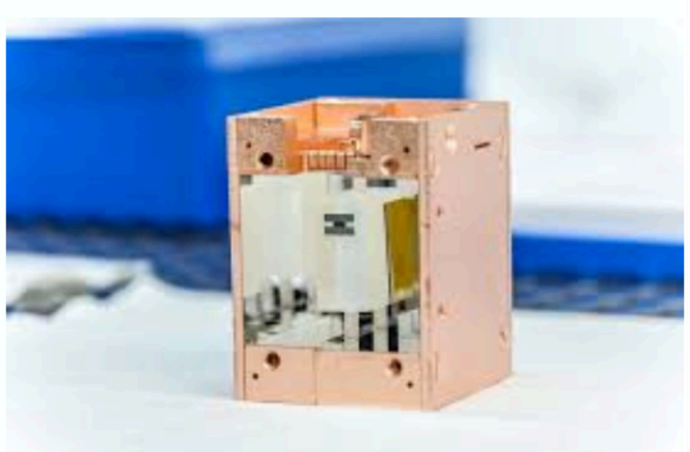
Cryogenic bolometers

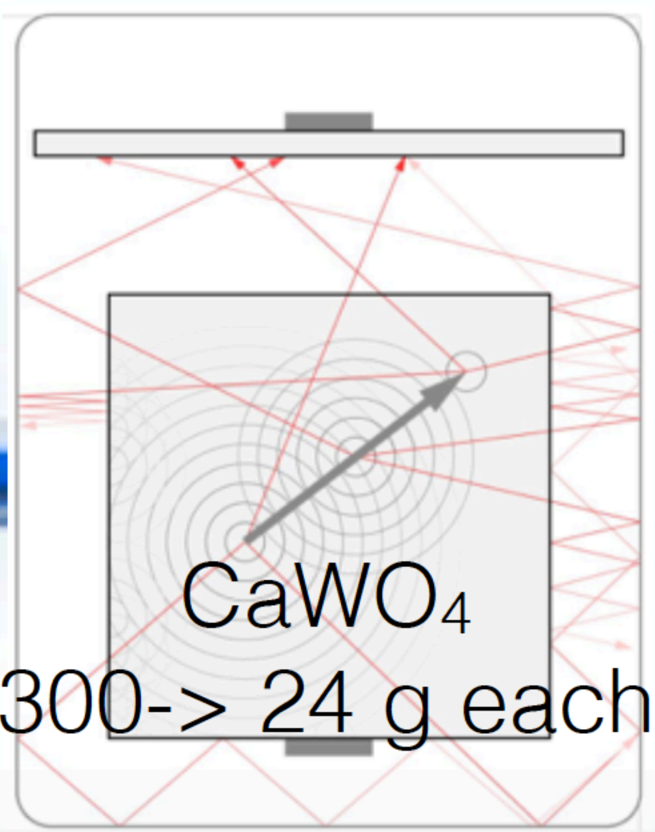






Ge, Si ~1 kg each



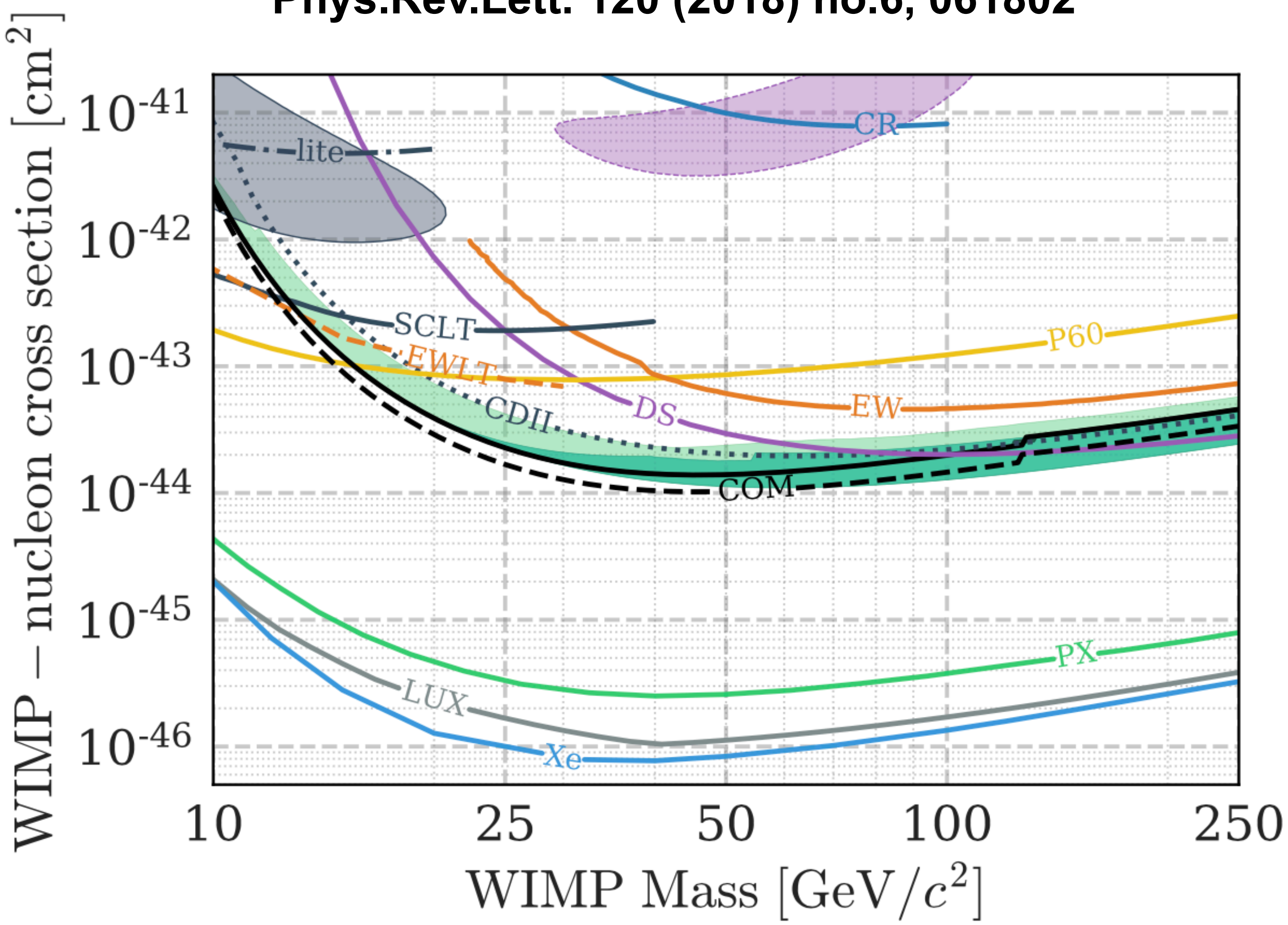


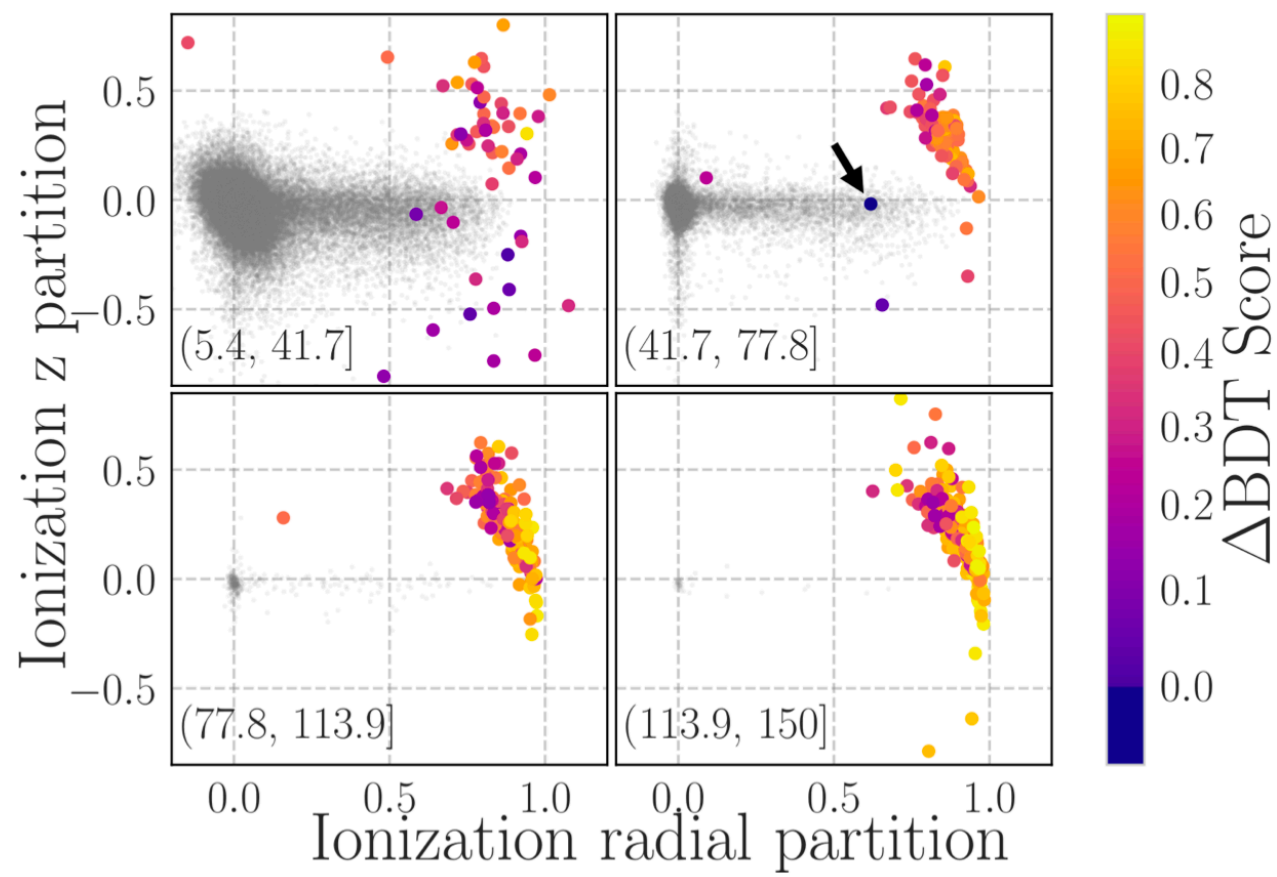
$CaWO_4$
300-> 24 g each

- 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

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**

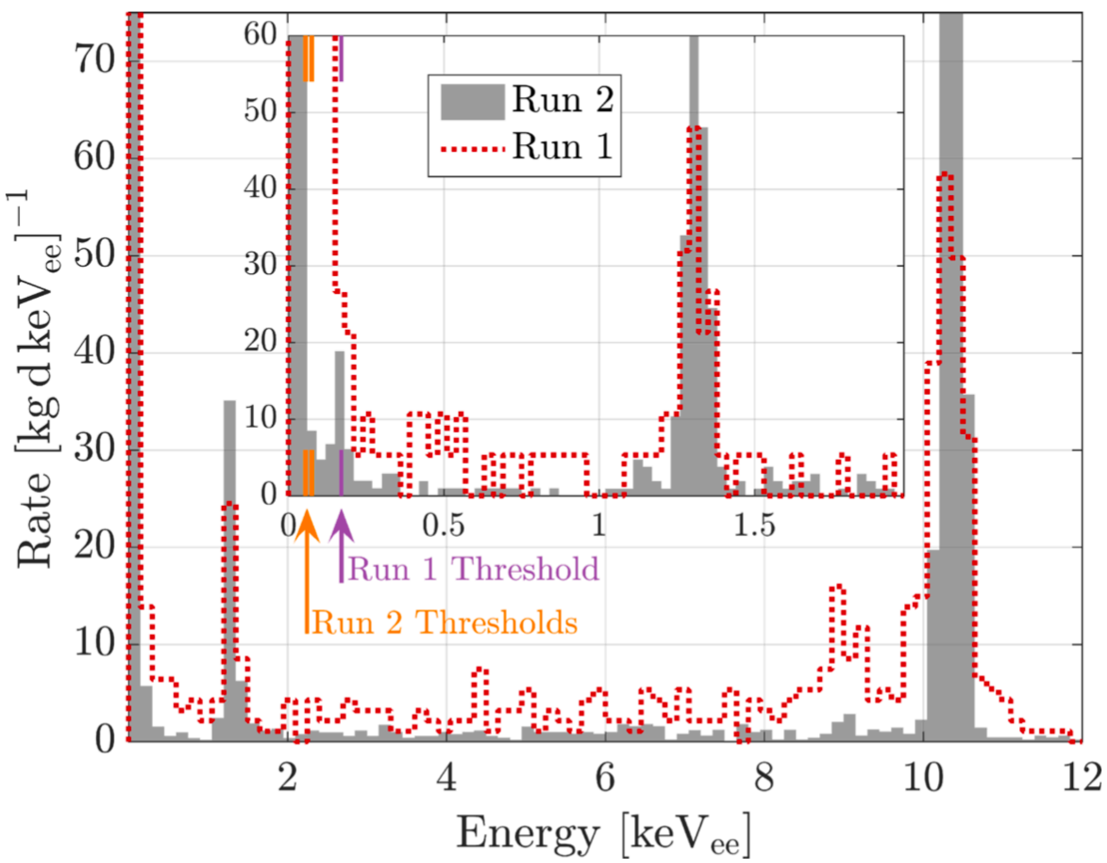
Low-mass (1-10 GeV) dark matter: cryogenic bolometers

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



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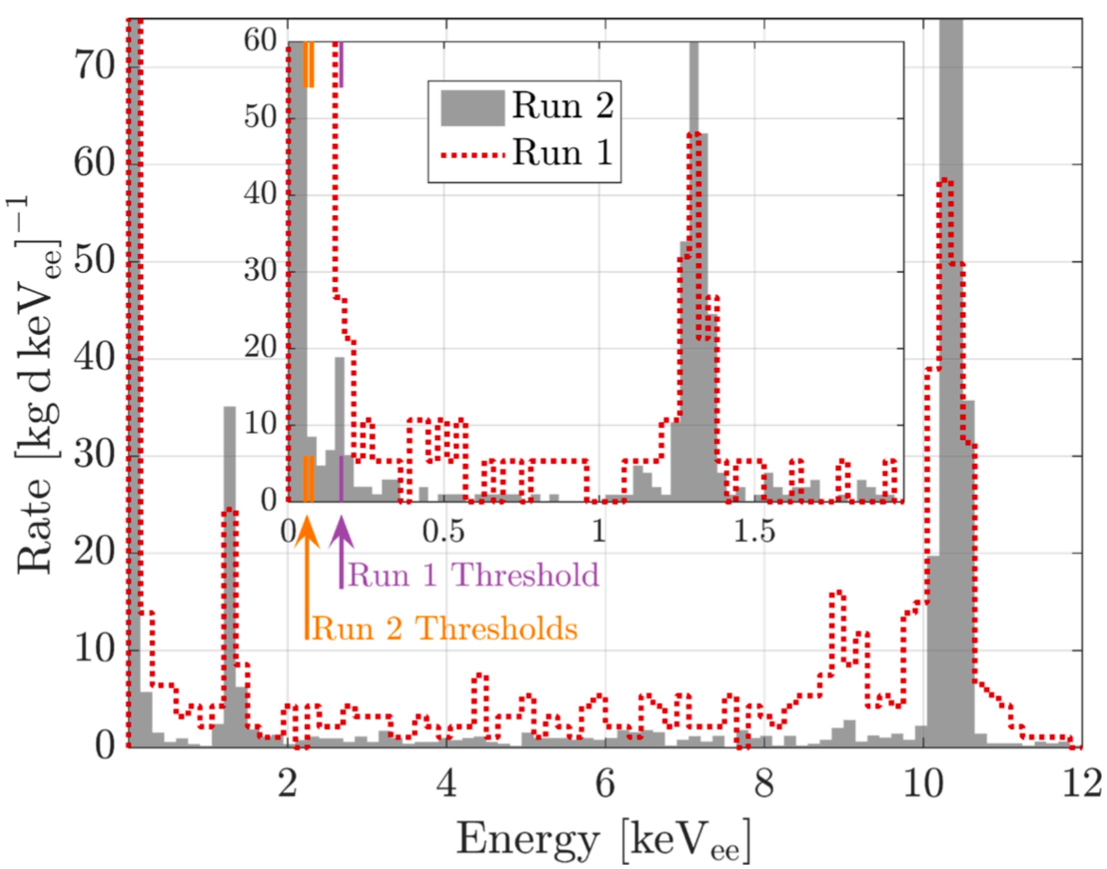
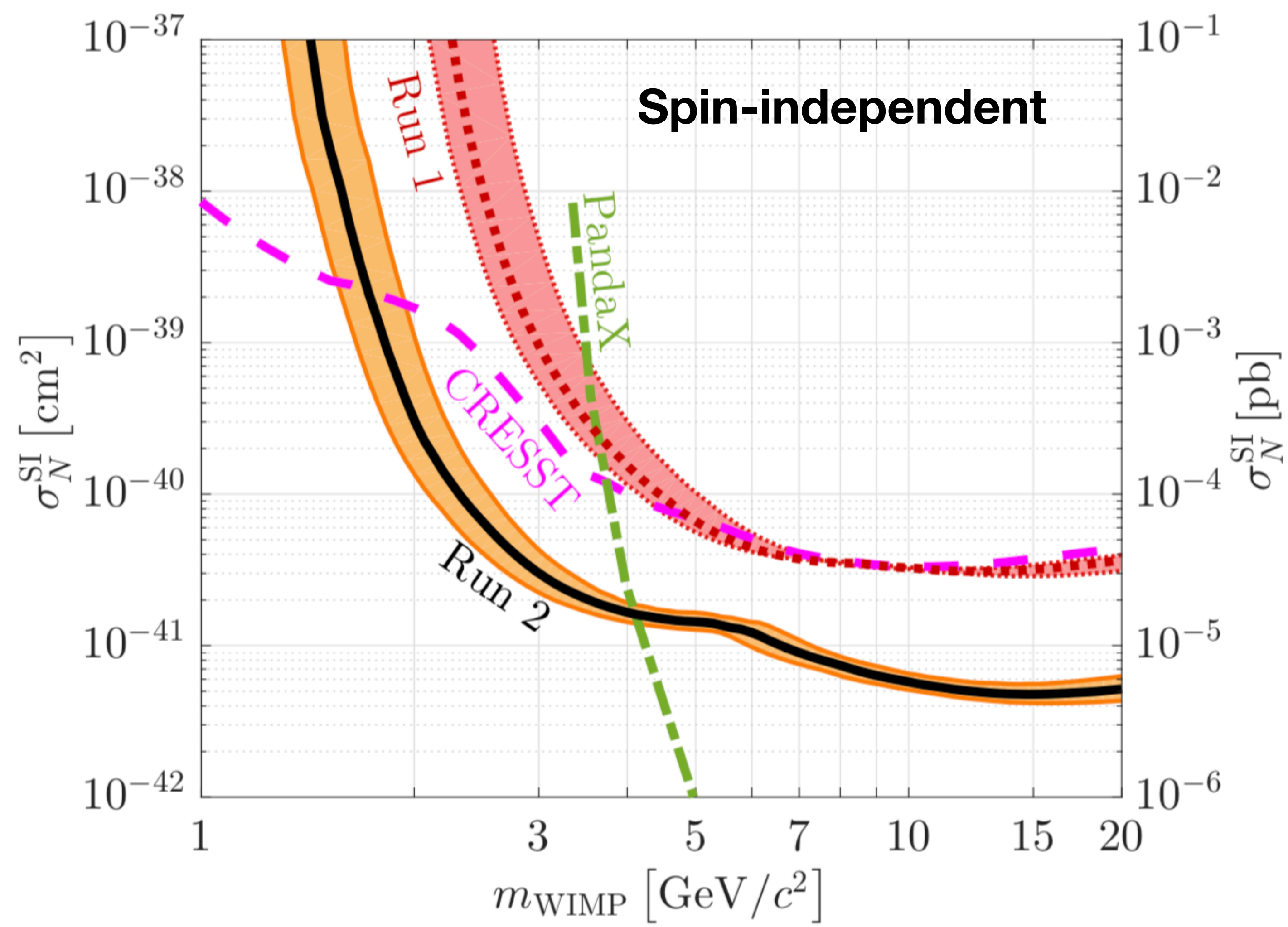




CRESST-III result from arXiv:1711.07692

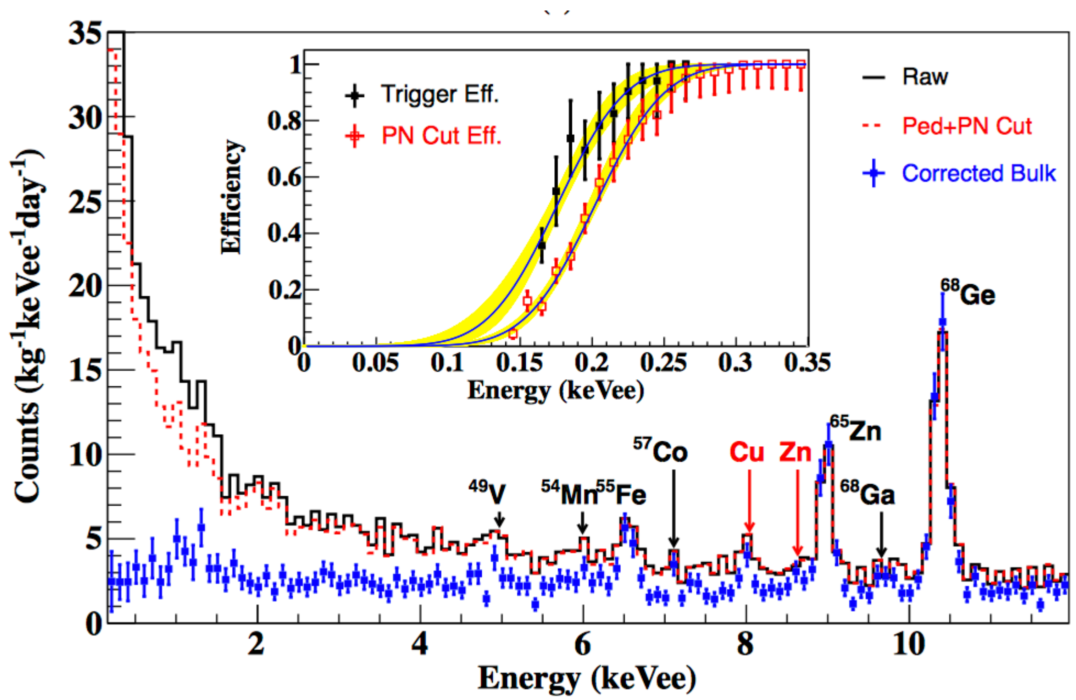
Low-mass (1-10 GeV) dark matter: low-threshold counting

battle between low-threshold and low-background

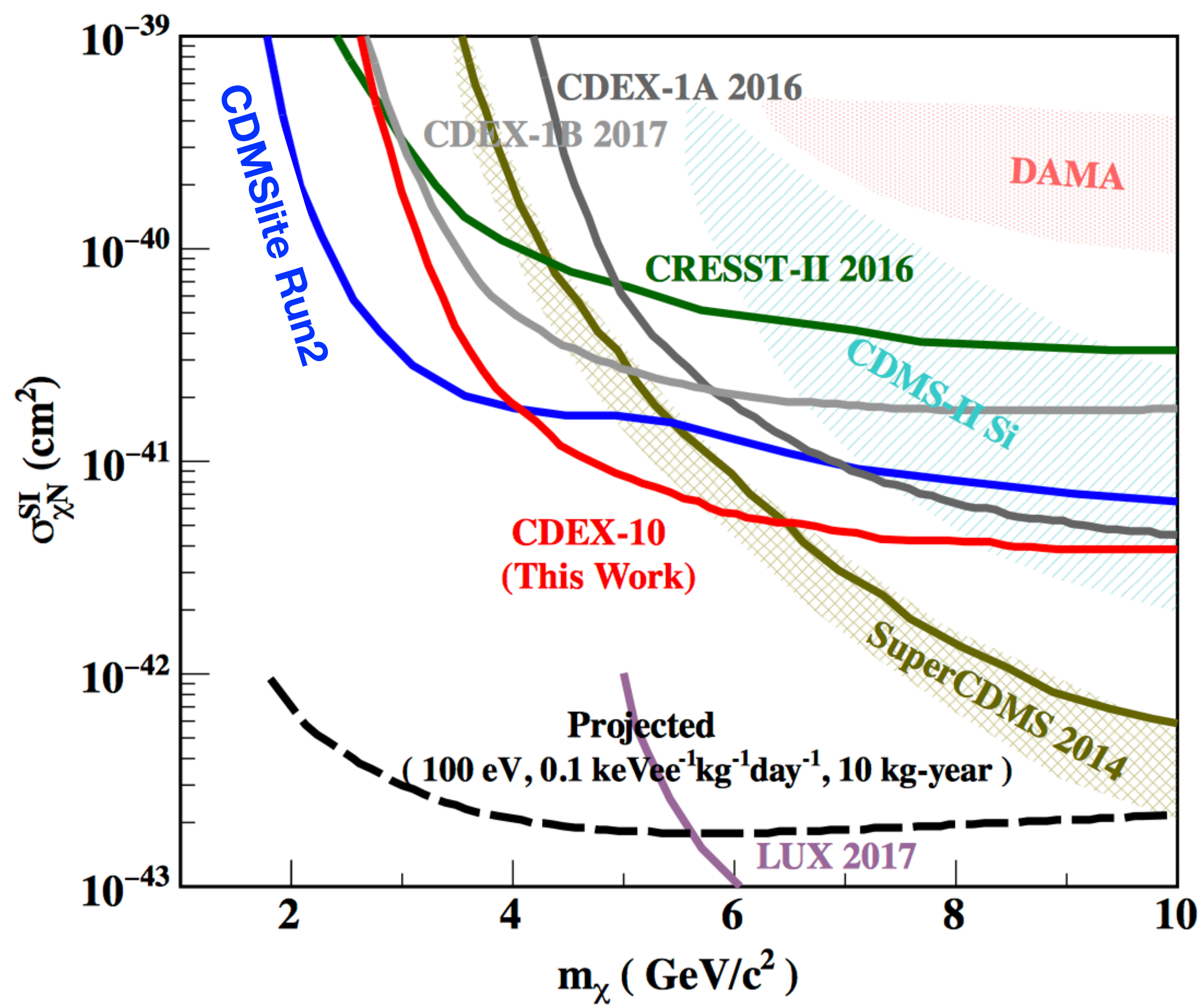
CoGeNT, CDEX: Ge Point Contact detector, low capacitance

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



Liquid Noble Detectors

- Large masses and homegeneous targets (LNe, LAr & LXe)

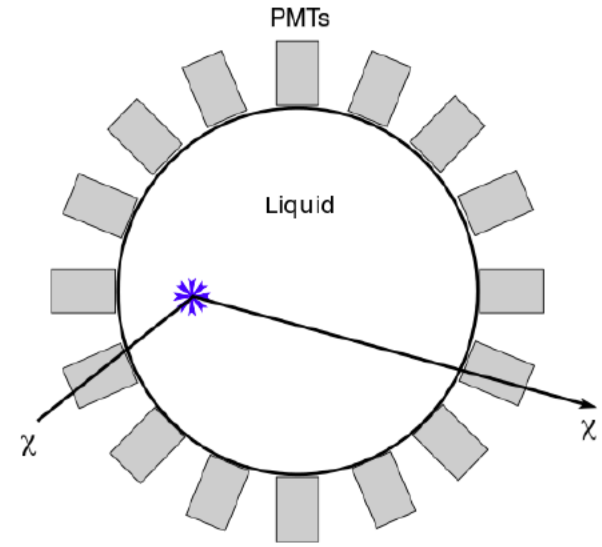
  Two detector concepts: single & double phase
- 3D position reconstruction → fiducialization
- Transparent to their own scintillation light

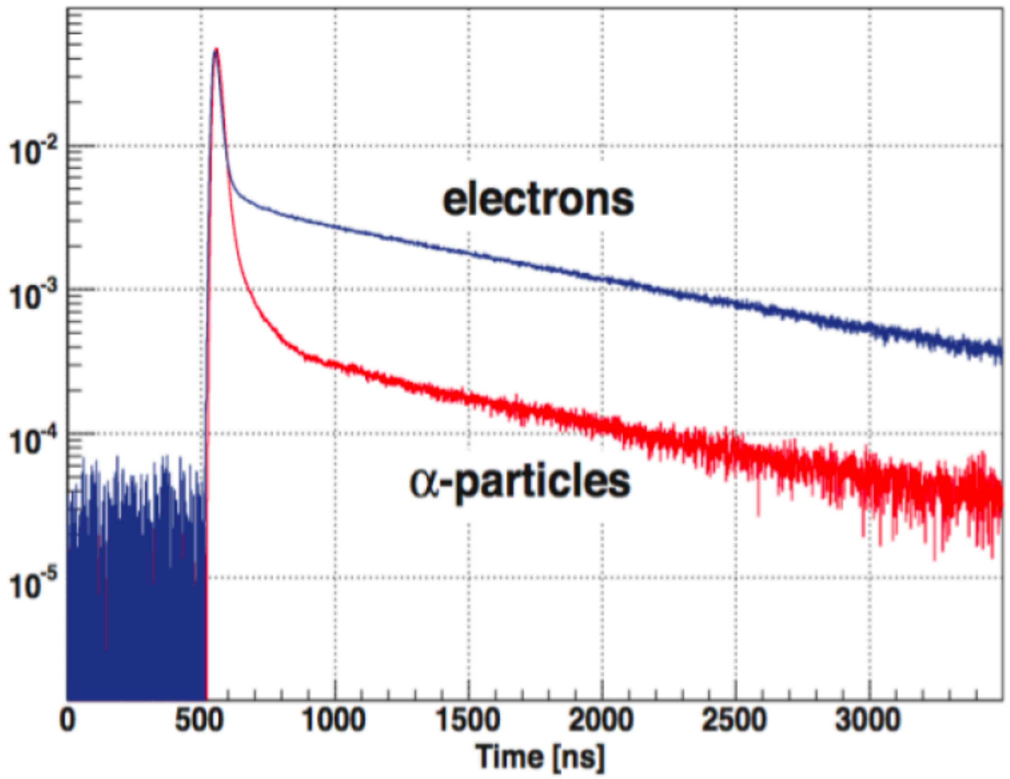
	LNe	LAr	LXe
Z (A)	10 (20)	18 (40)	54 (131)
Density [g/cm^3]	1.2	1.4	3.0
Scintillation λ	78 nm	125 nm	178 nm
BP [K] at 1 atm	27	87	165
Ionization [e$^-$/keV]*	46	42	64
Scintillation [γ/keV]*	7	40	46

* for electronic recoils

Liquid Noble Detectors: Single Phase

- High light yield using 4π photosensor coverage
- Position resolution in the cm range
- Pulse shape discrimination (PSD) from scintillation





Scintillation decay constants of argon measured by ArDM

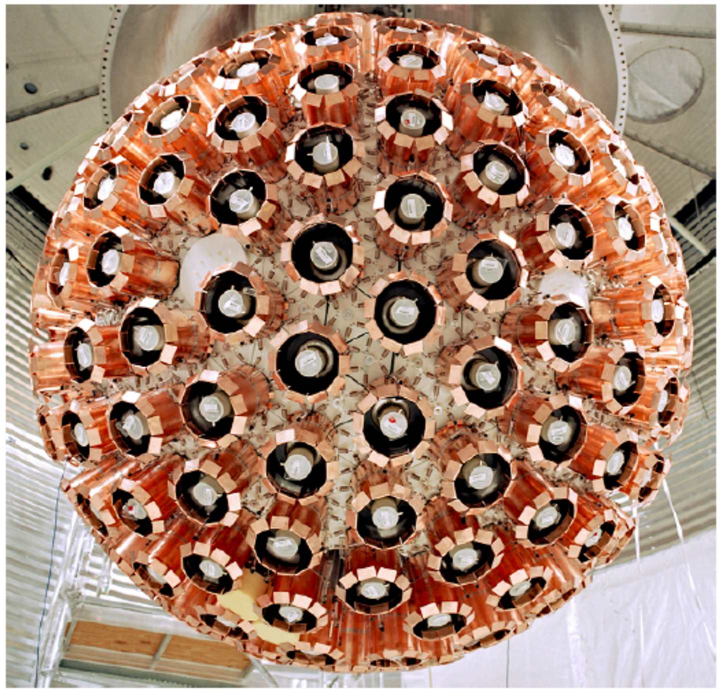
- Very different singlet and triplet lifetimes in argon & neon
- Relative amplitudes depend on particle type → discrimination

DEAP-I obtained 10^{-8} discrimination in LAr above 25 keV_{ee} (50% acceptance)

M. G. Boulay *et al.*, arXiv:0904.2930

→ PSD less powerful in LXe: similar decay constants XMASS, NIM. A659 (2011) 161

Liquid Noble Detectors: Single Phase



DEAP - LAr detector at SNOLAB, Canada
Dark matter **E**xperiment with **A**rgon and **P**ulse shape discrimination

- 3 600 kg total mass & 1 ton FV
- 2-inch thick ultraclean acrylic vessel
- Wavelength-shifter inside the vessel
- Light guides to the PMTs

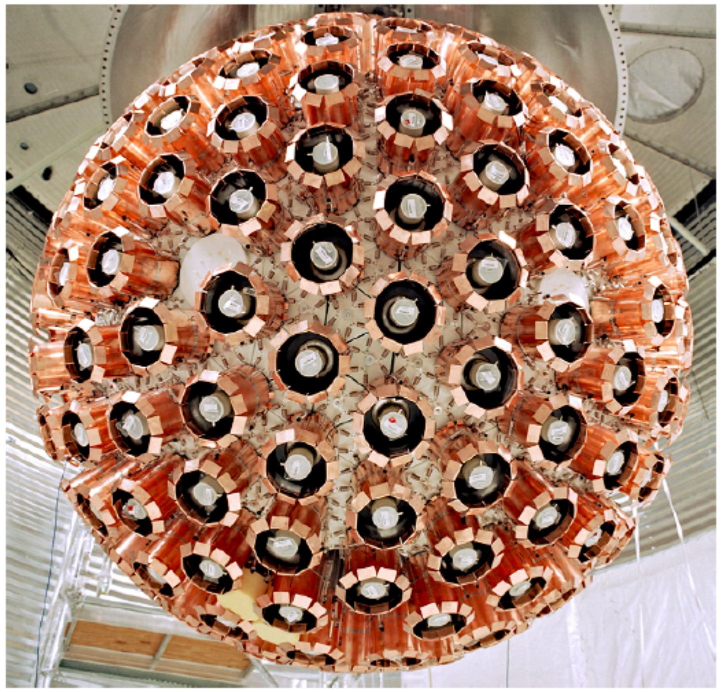
XMASS - LXe detector at Kamioka, Japan

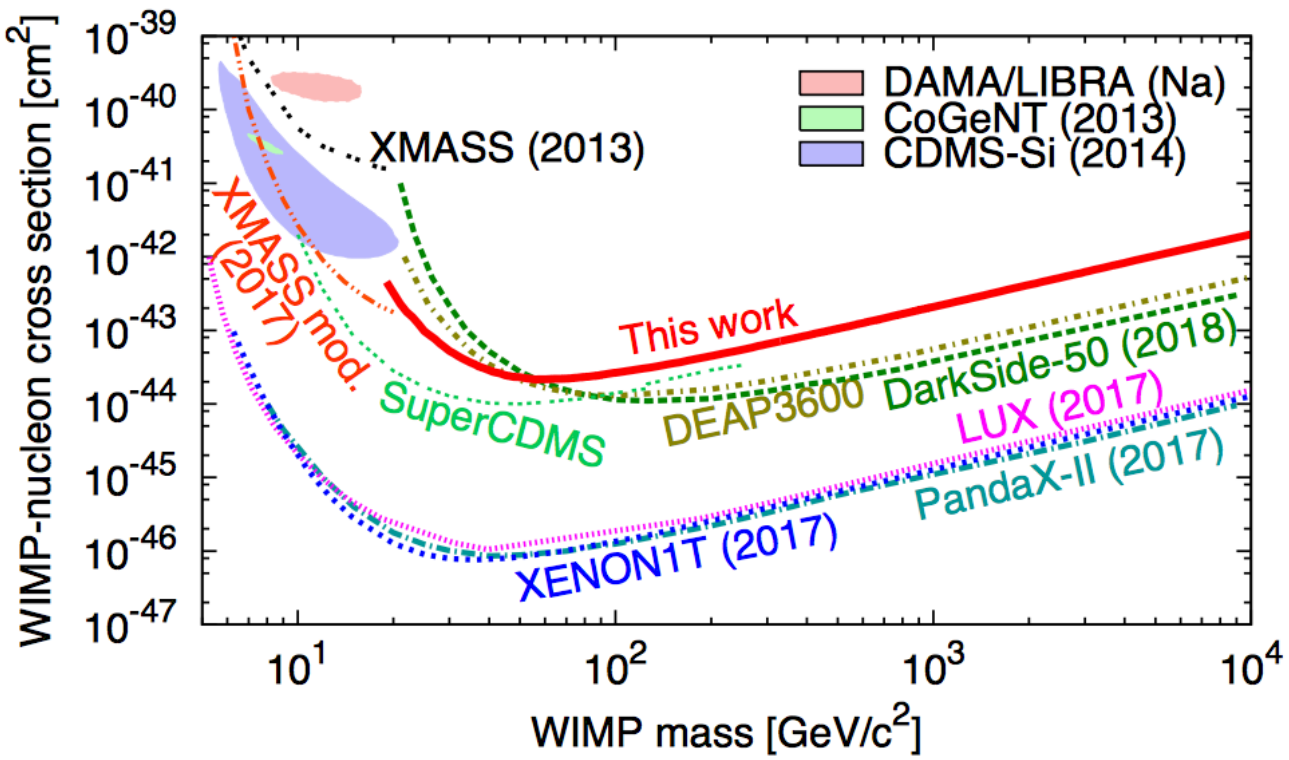
- 1 ton total LXe mass & 800 kg FV
- Ultra-clean PMTs directly in contact with the LXe target
- High light yield measured: 14.7 PE/keVee
  $E_{th} = 0.3\,\mathrm{keV}_{ee}$

Liquid Noble Detectors: Single Phase

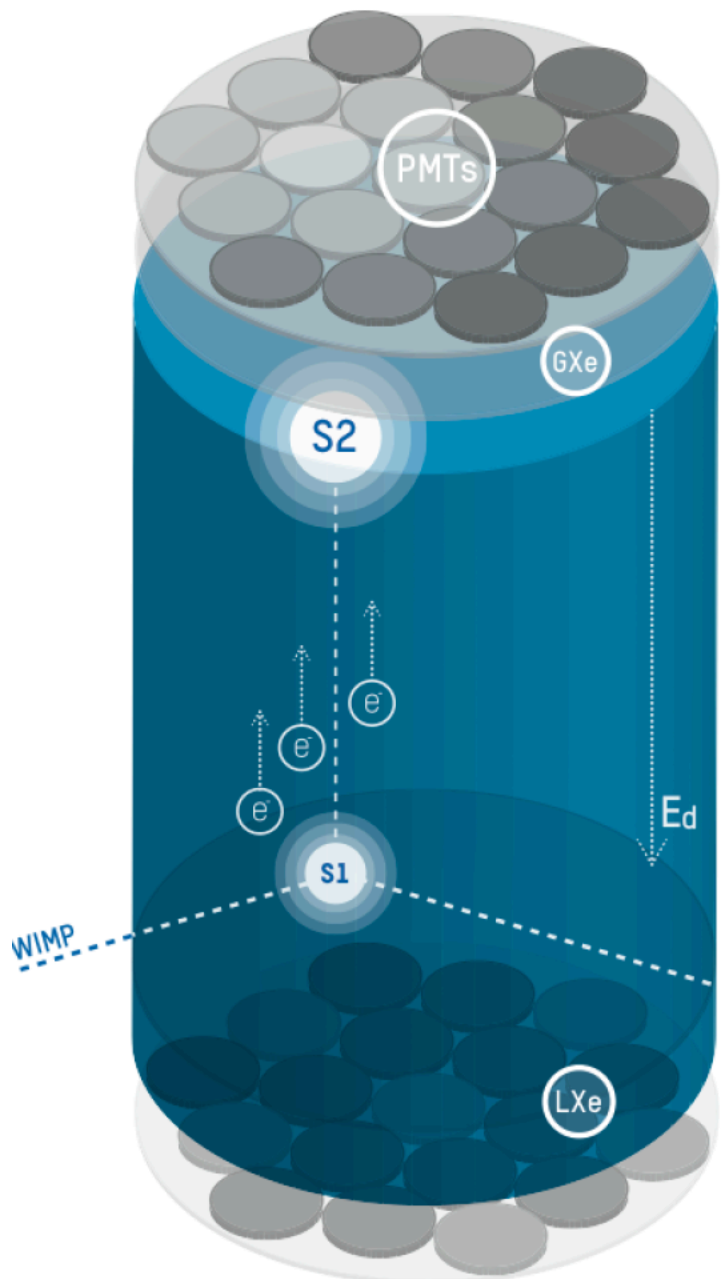
DEAP - LAr detector at SNOLAB, Canada
Dark matter **E**xperiment with **A**rgon and **P**ulse shape discrimination

- 3 600 kg total mass & 1 ton FV
- 2-inch thick ultraclean acrylic vessel
- Wavelength-shifter inside the vessel
- Light guides to the PMTs



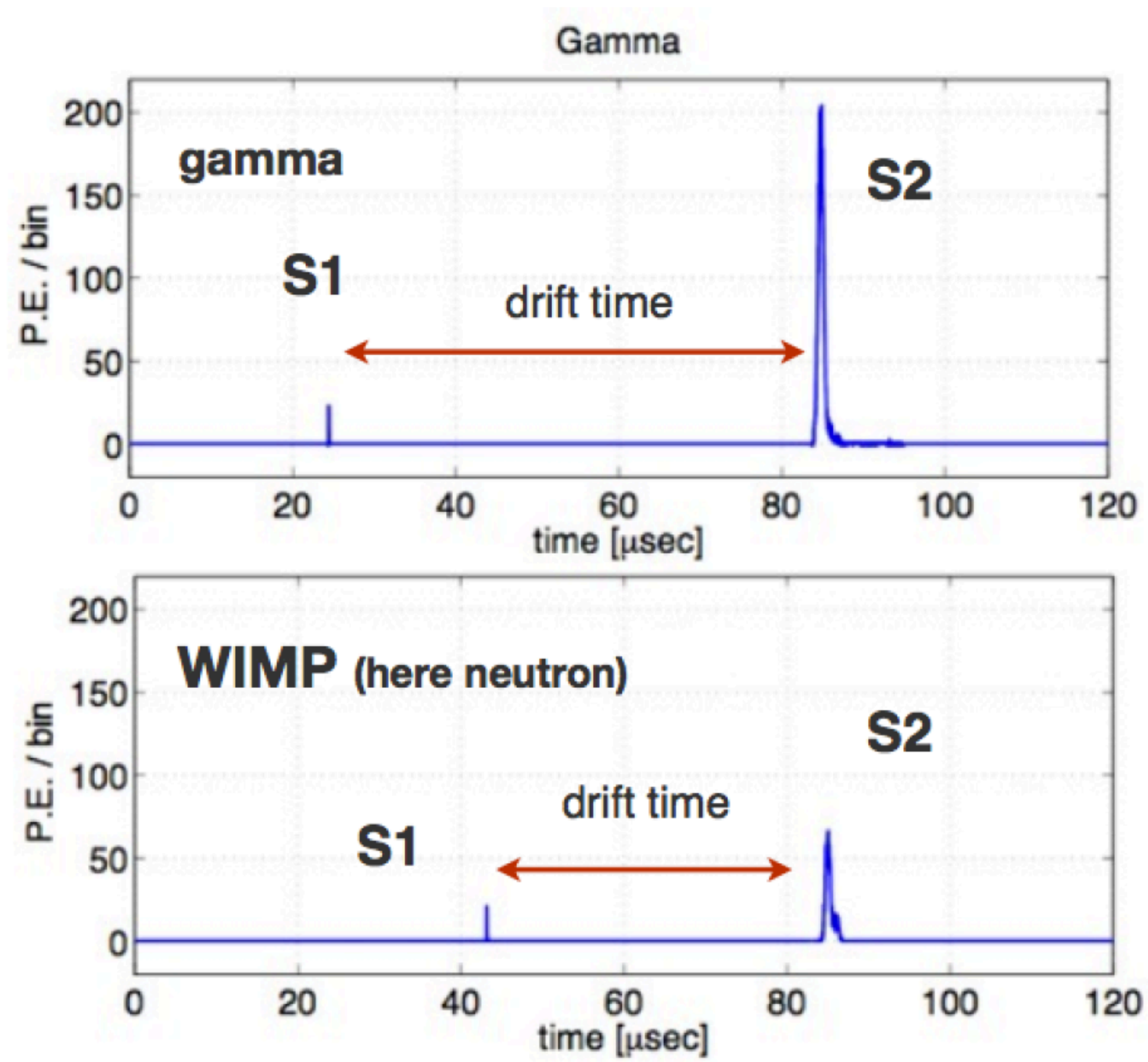


Liquid Noble Detectors: Double Phase TPC



- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)

→ Electron- /nuclear recoil discrimination

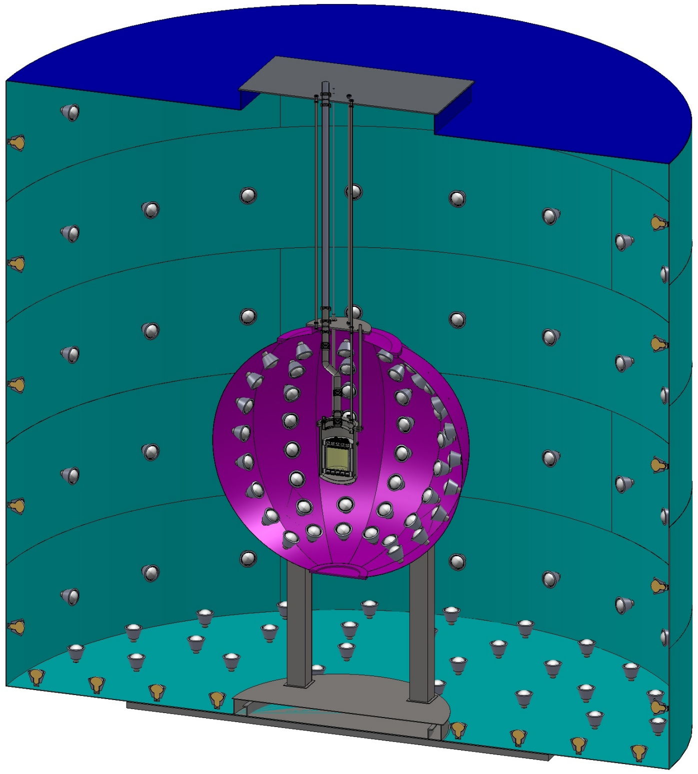


- Drift field
- Electronegative purity
- Position resolution

DarkSide-50 and -20t

- **DarkSide-20t**
  - Scheduled for 2021
  - Utilizing underground argon
  - Atmospheric LAr veto, DUNE style cryostat possible
  - Background free
- Global Argon Dark Matter Collaboration
  - 300 t in 2027

DarkSide-50



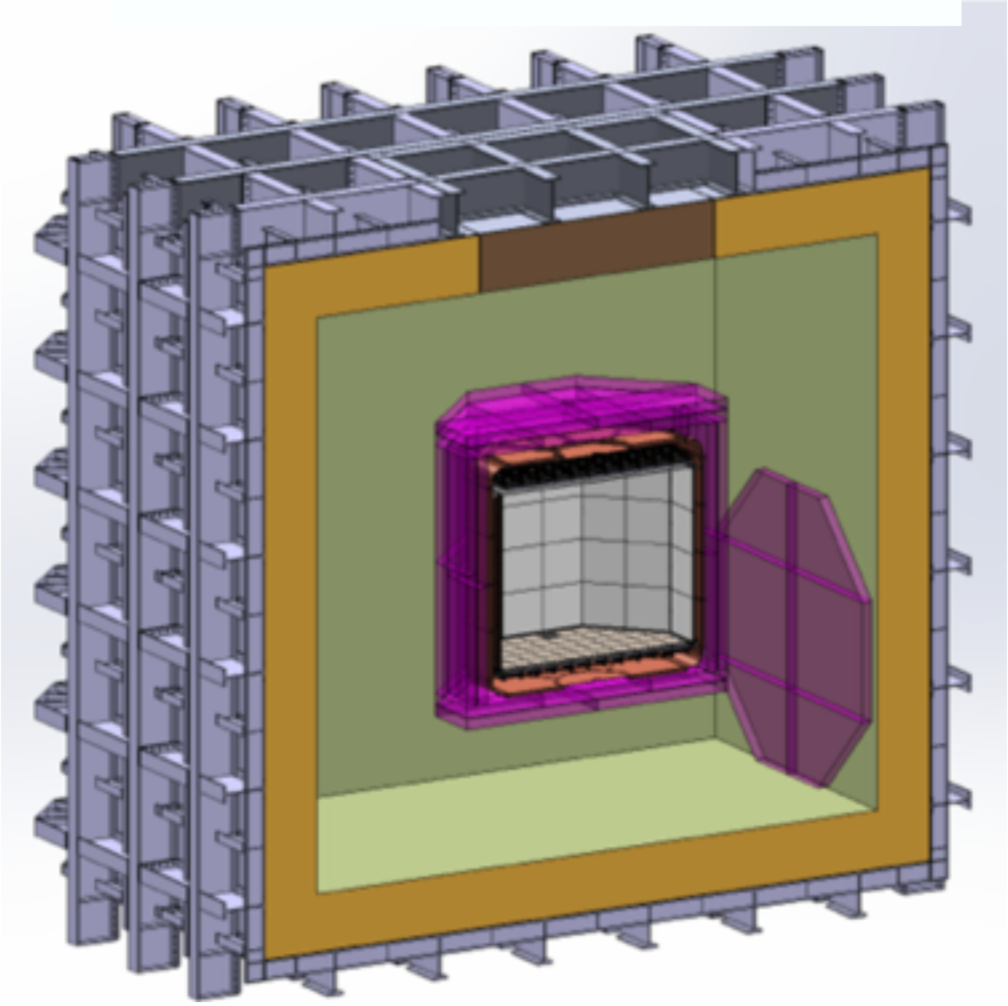
- Detector inside Borexino counting facility at LNGS (Italy)
- 50 kg depleted argon from underground sources

  > 1000 reduction in ^{39}Ar level
- Pulse shape & charge/light ratio for particle discrimination

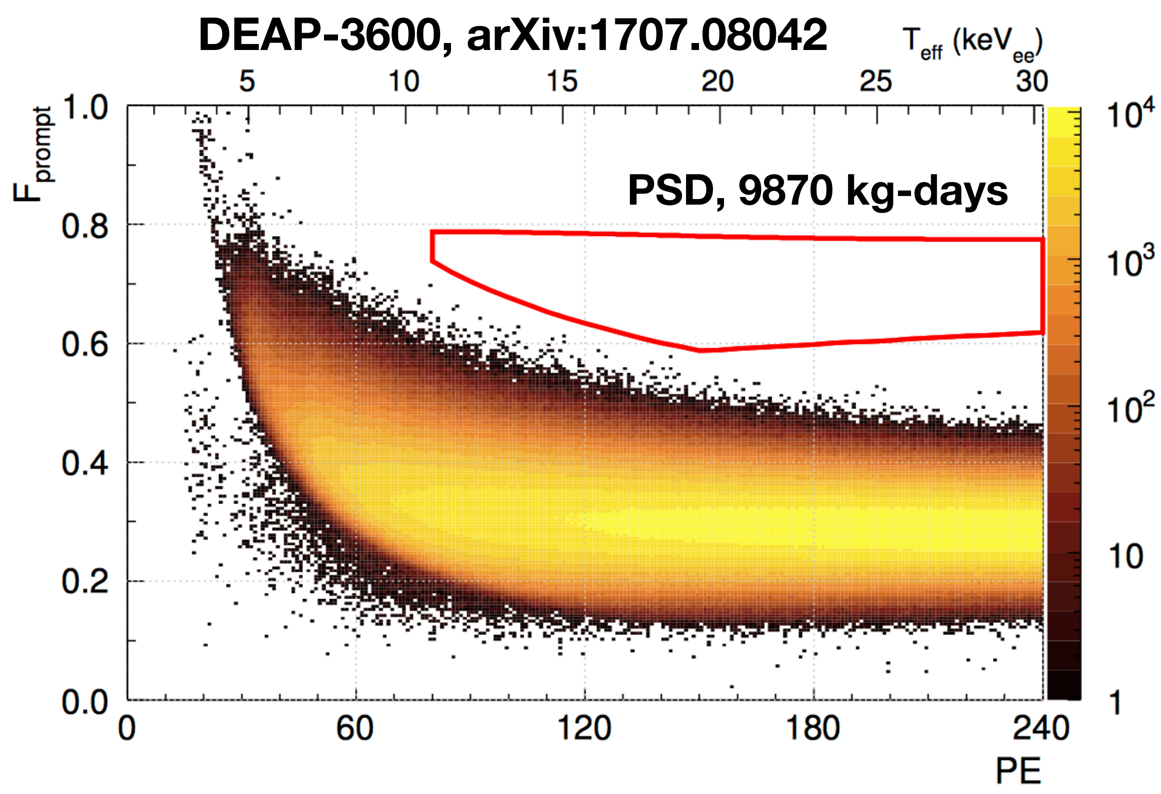
  Pulse-shape separation > 10^7
- Hamamatsu R11065 as photosensor

  Challenge: operation of PMTs at LAr temperatures

  → plan to use SiPMs in the next generation detector



Liquid Argon results: DarkSide-50 & DEAP-3600



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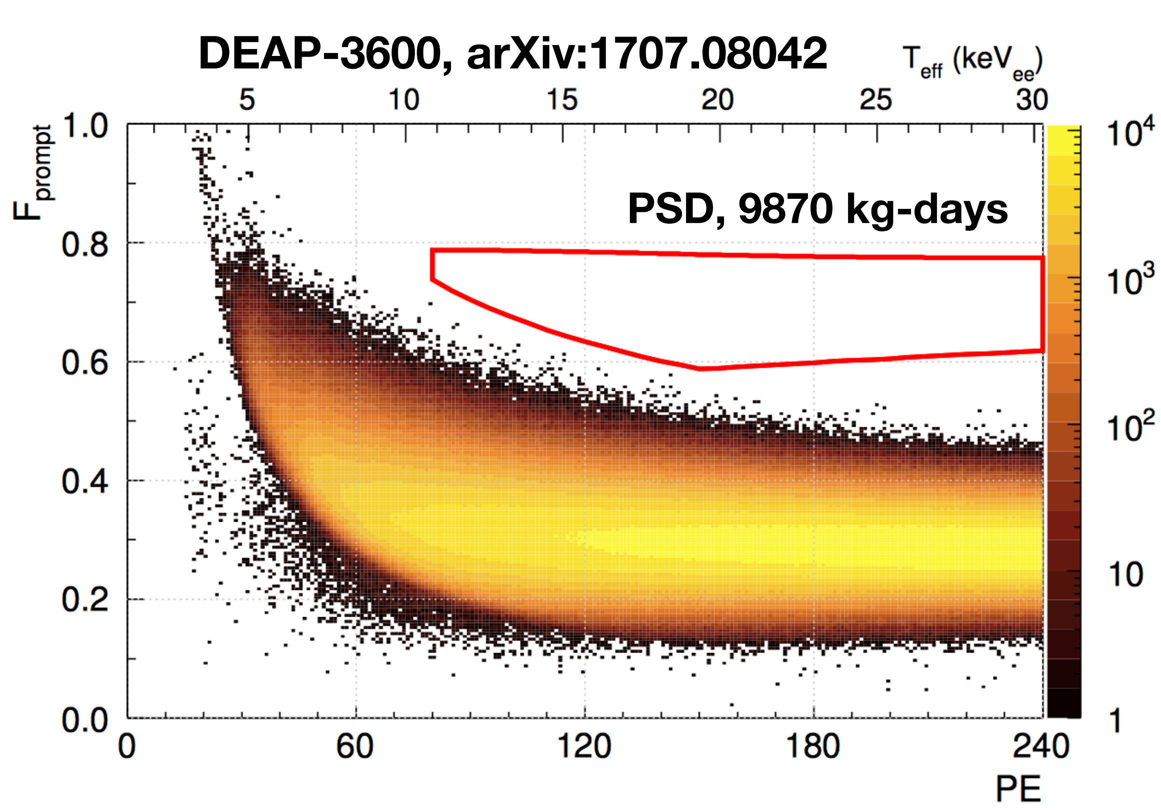
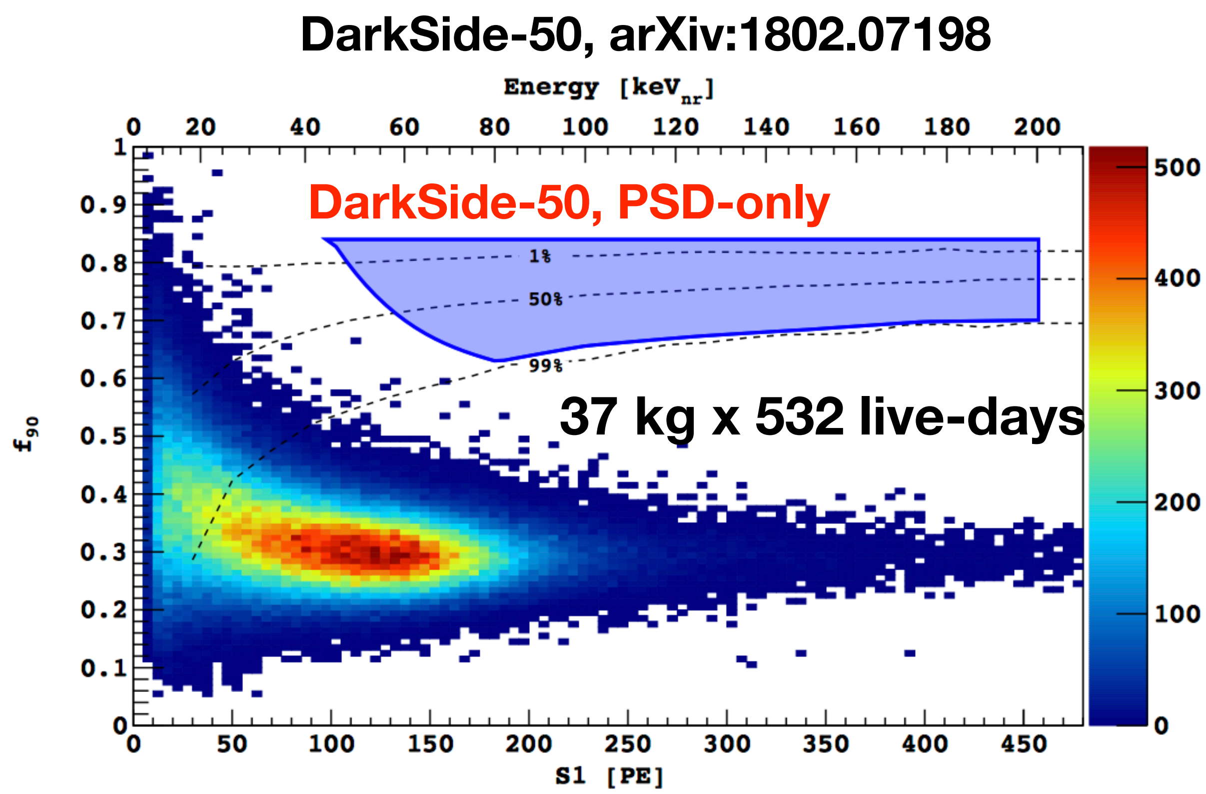
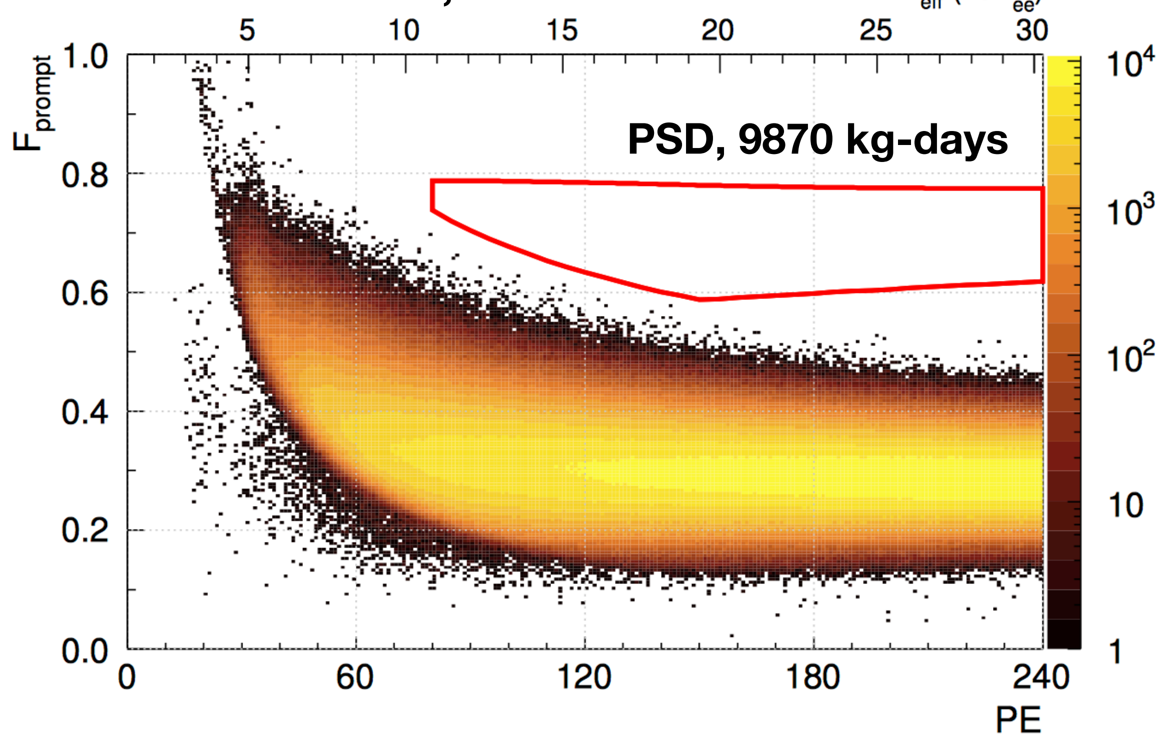


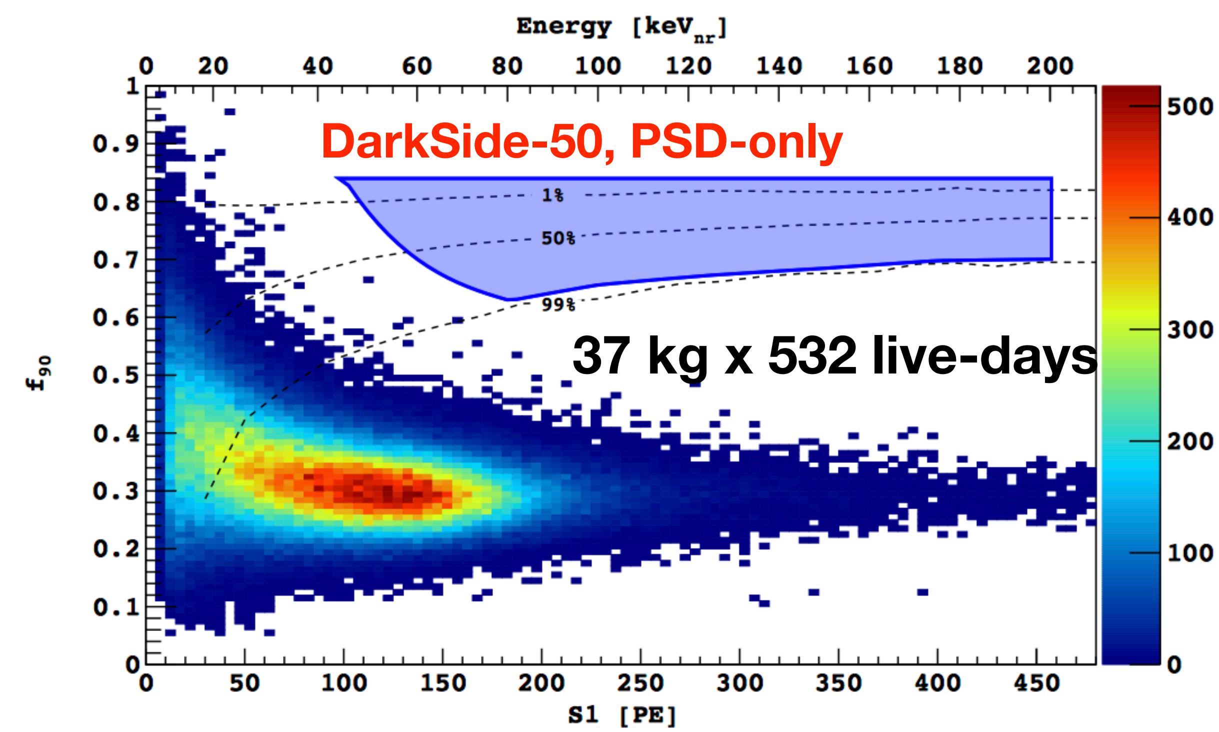


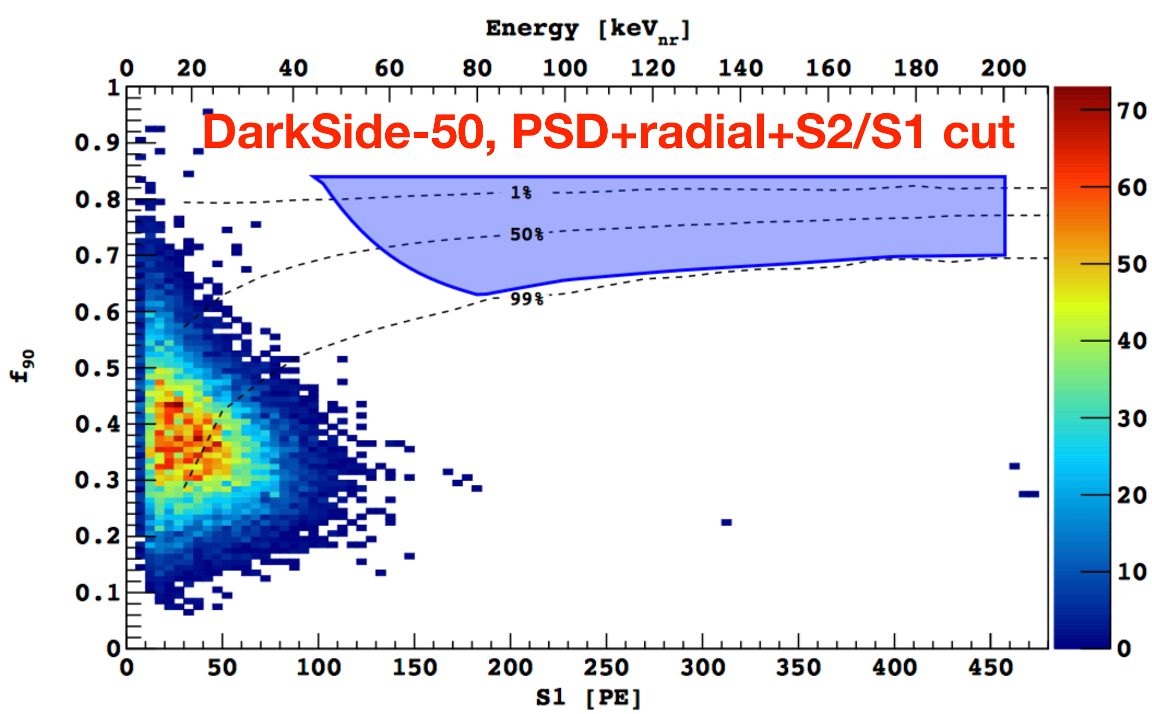
Liquid Argon results: DarkSide-50 & DEAP-3600

DEAP-3600, arXiv:1707.08042

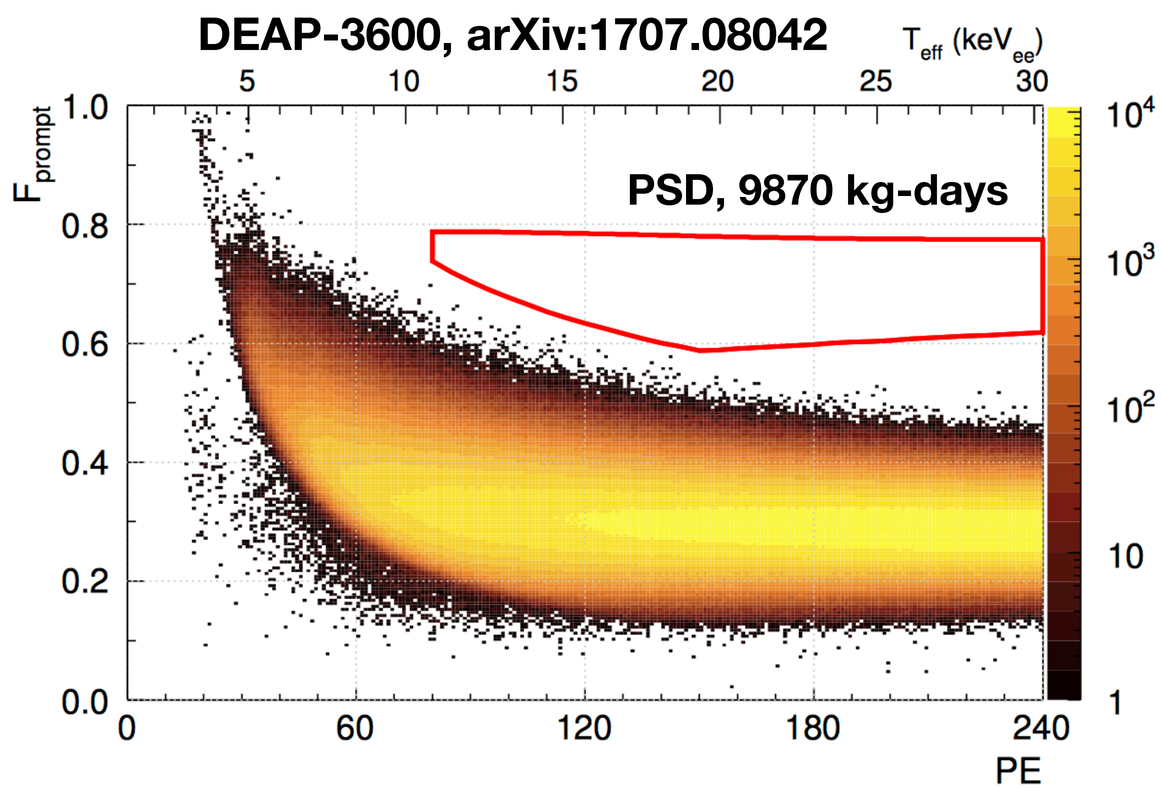


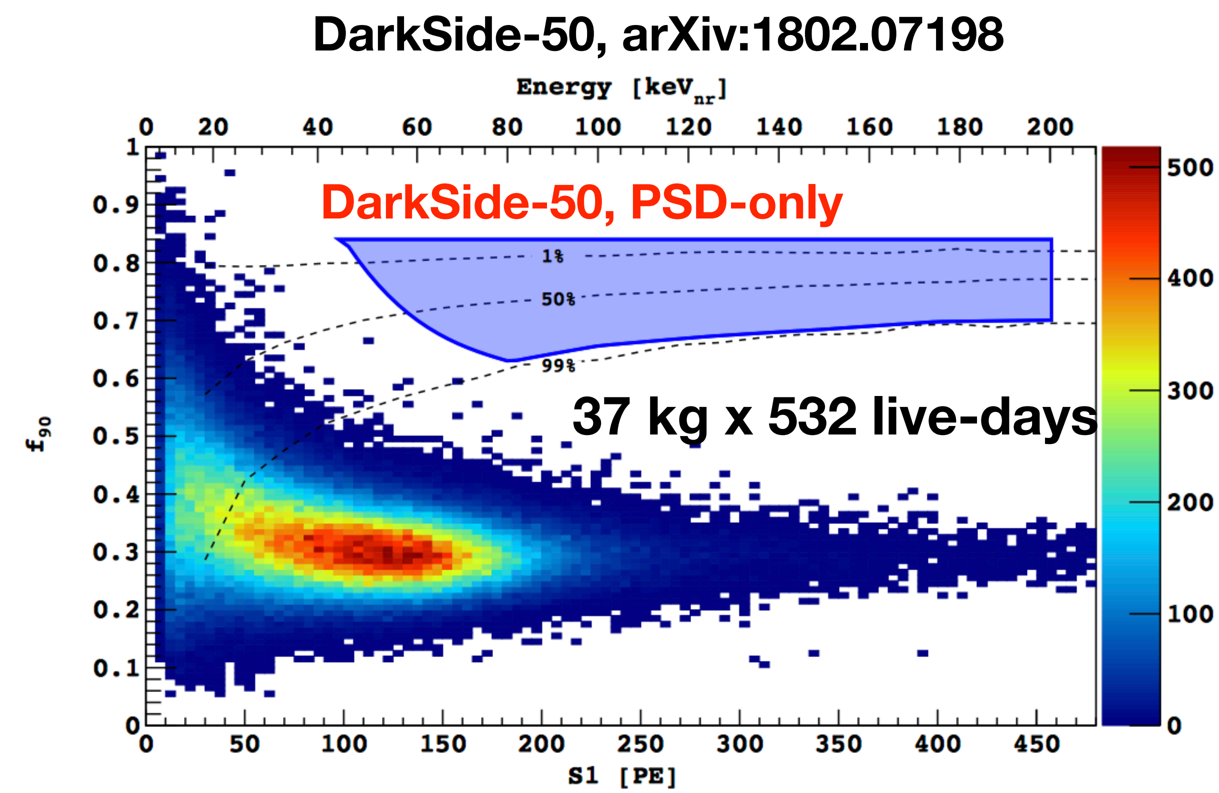
DarkSide-50, arXiv:1802.07198

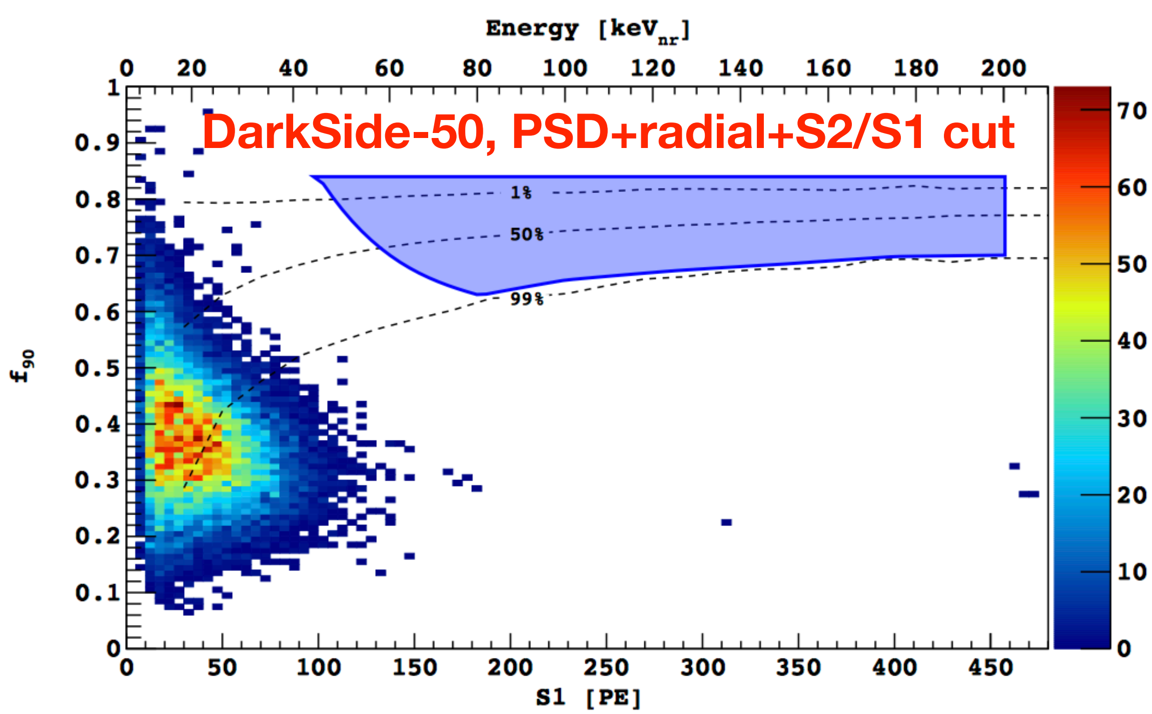


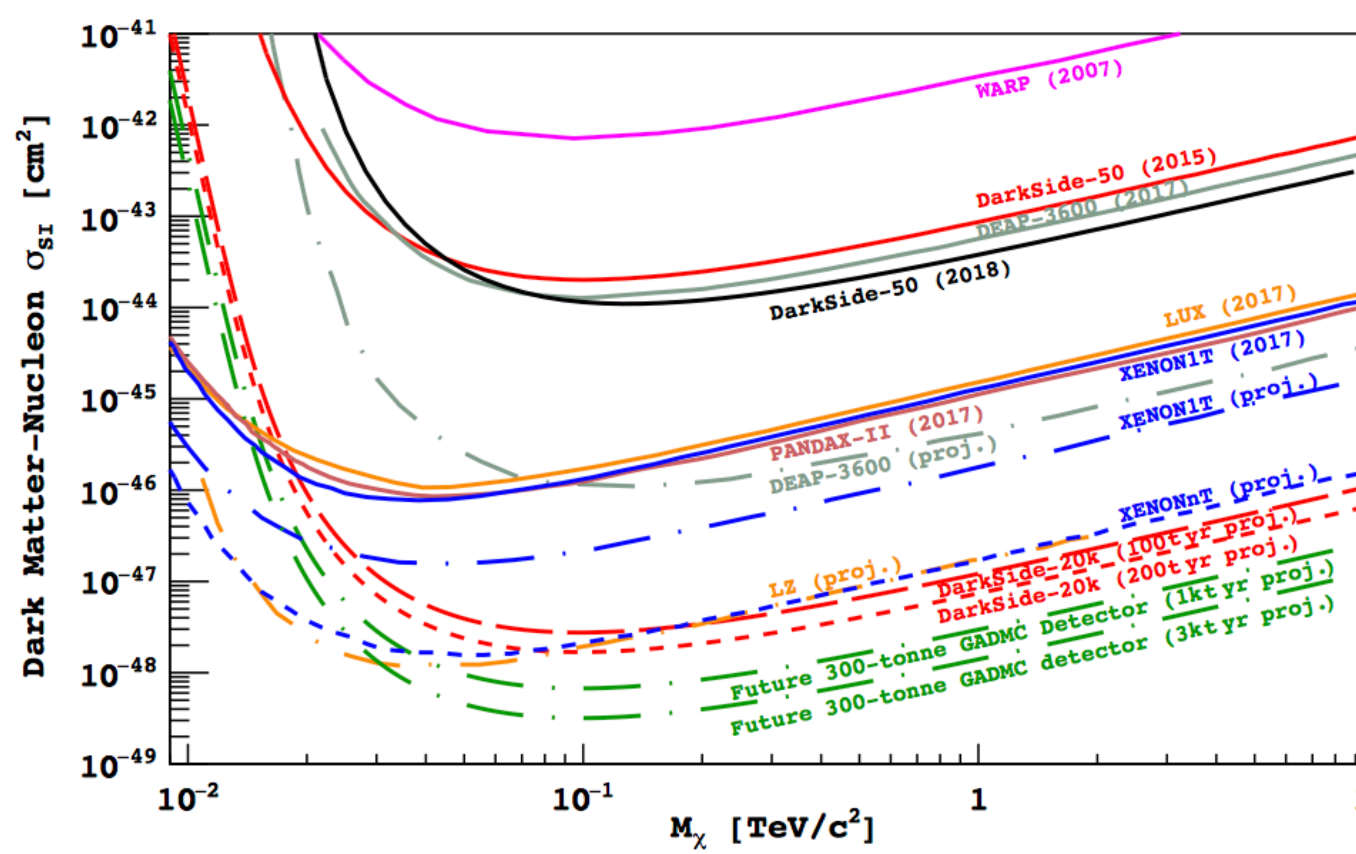


Liquid Argon results: DarkSide-50 & DEAP-3600

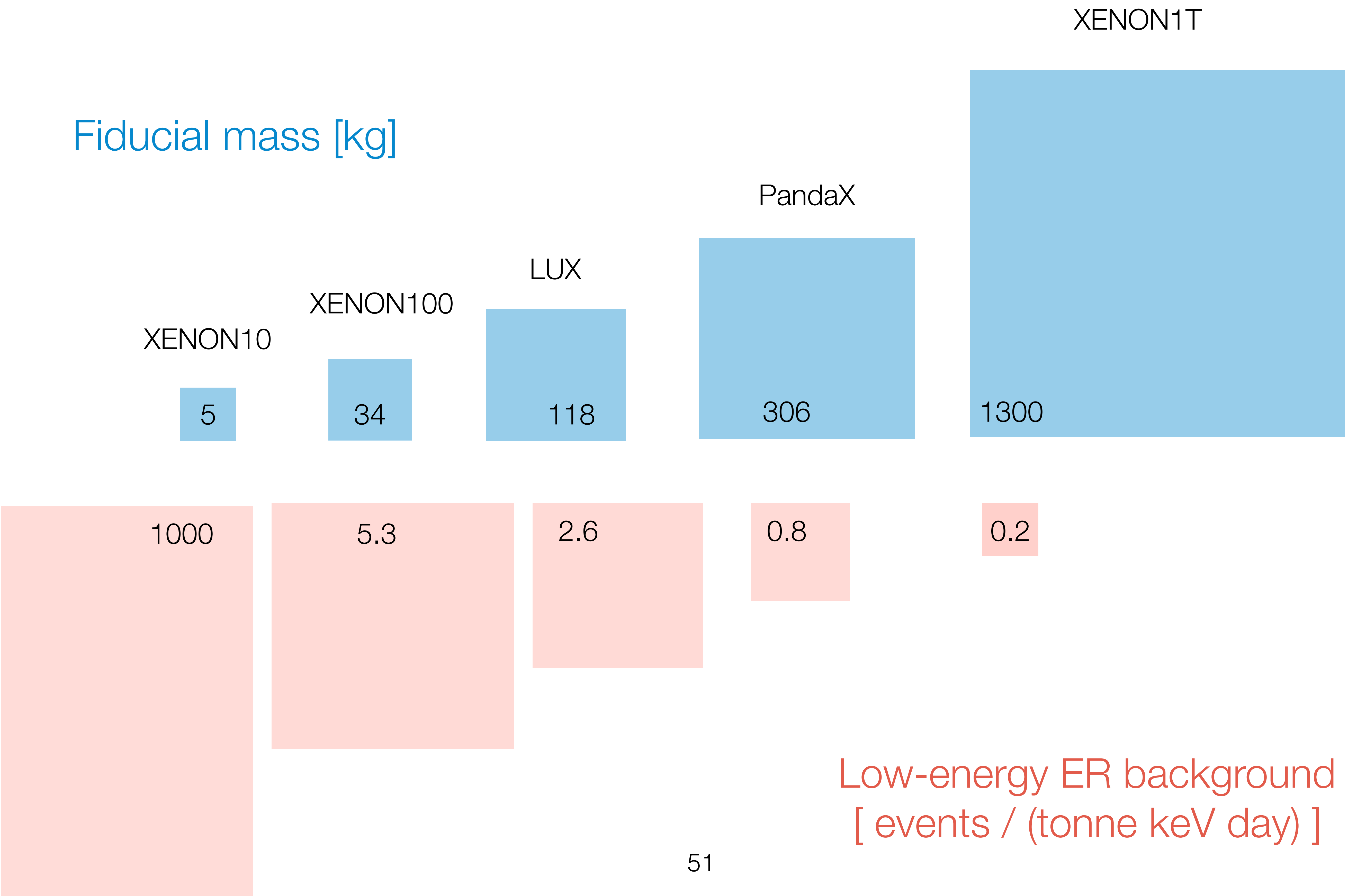






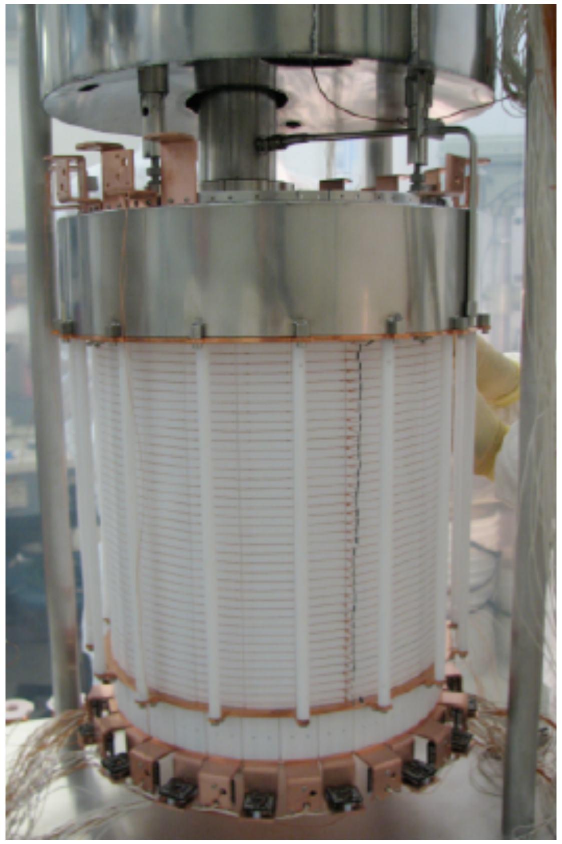
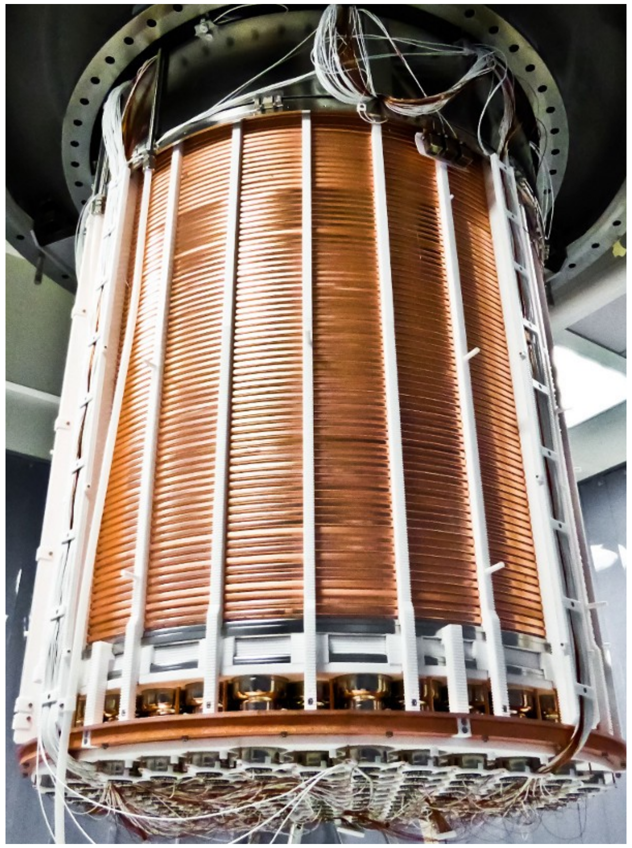
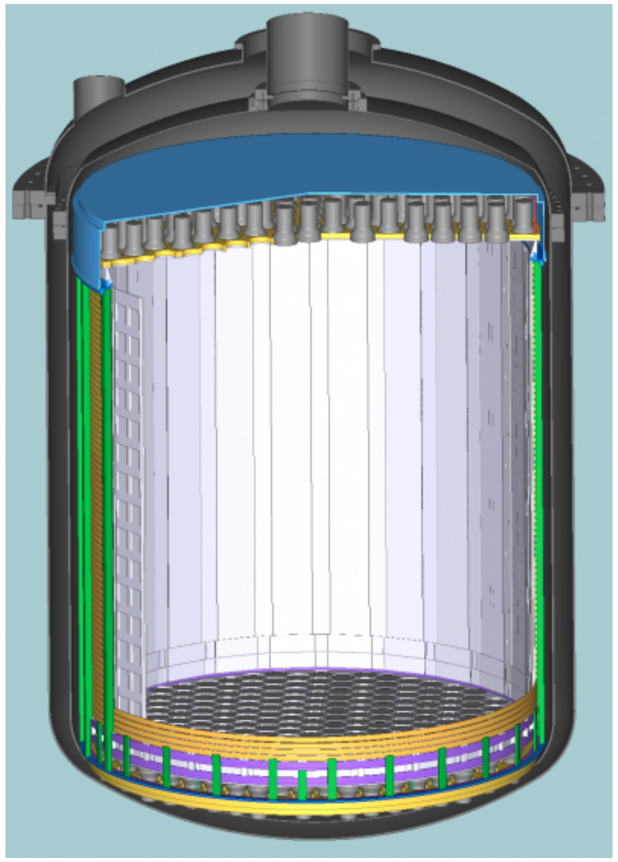


Impressive evolution of LXeTPCs as WIMP detectors



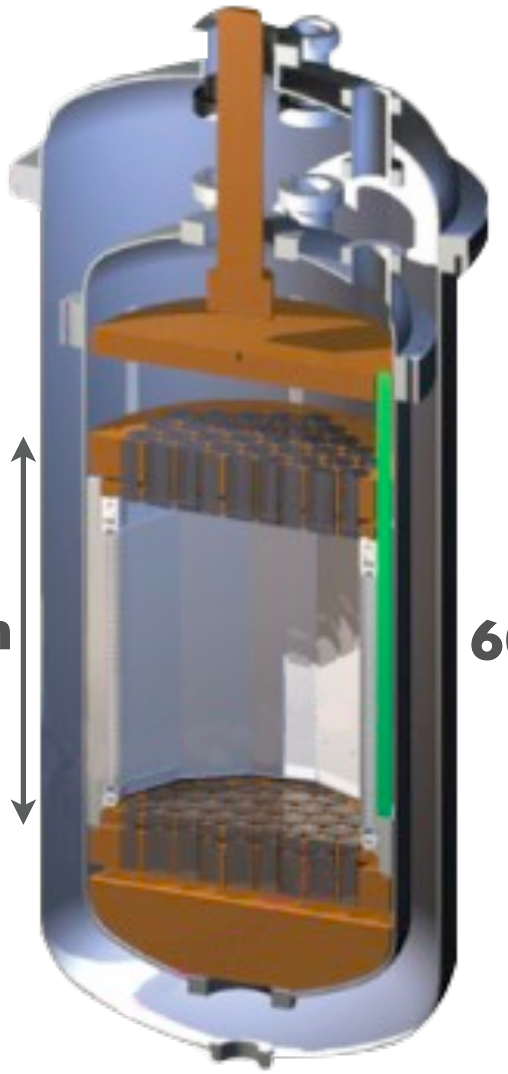
WIMP detectors from the XENON-series

XENON10	XENON100	XENON1T	XENONnT

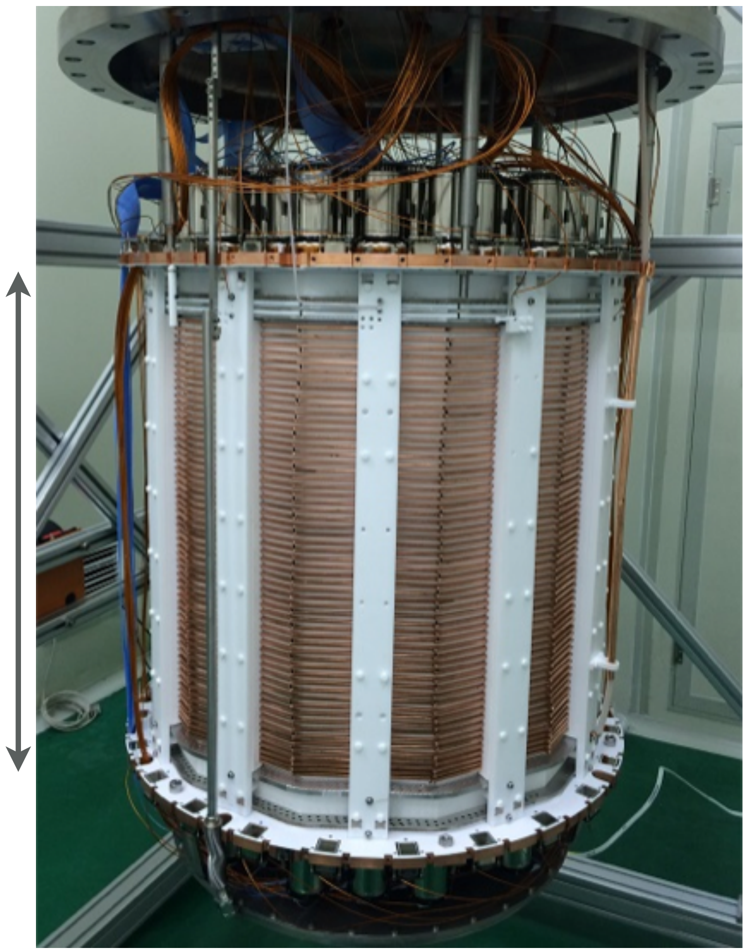
2005-2007	2008-2016	2012-2018	2019-2023
25 kg - 15cm drift	161 kg - 30 cm drift	3.2 ton - 1 m drift	8 ton - 1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

The frontline detectors using the LXeTPC



48 cm

60 cm



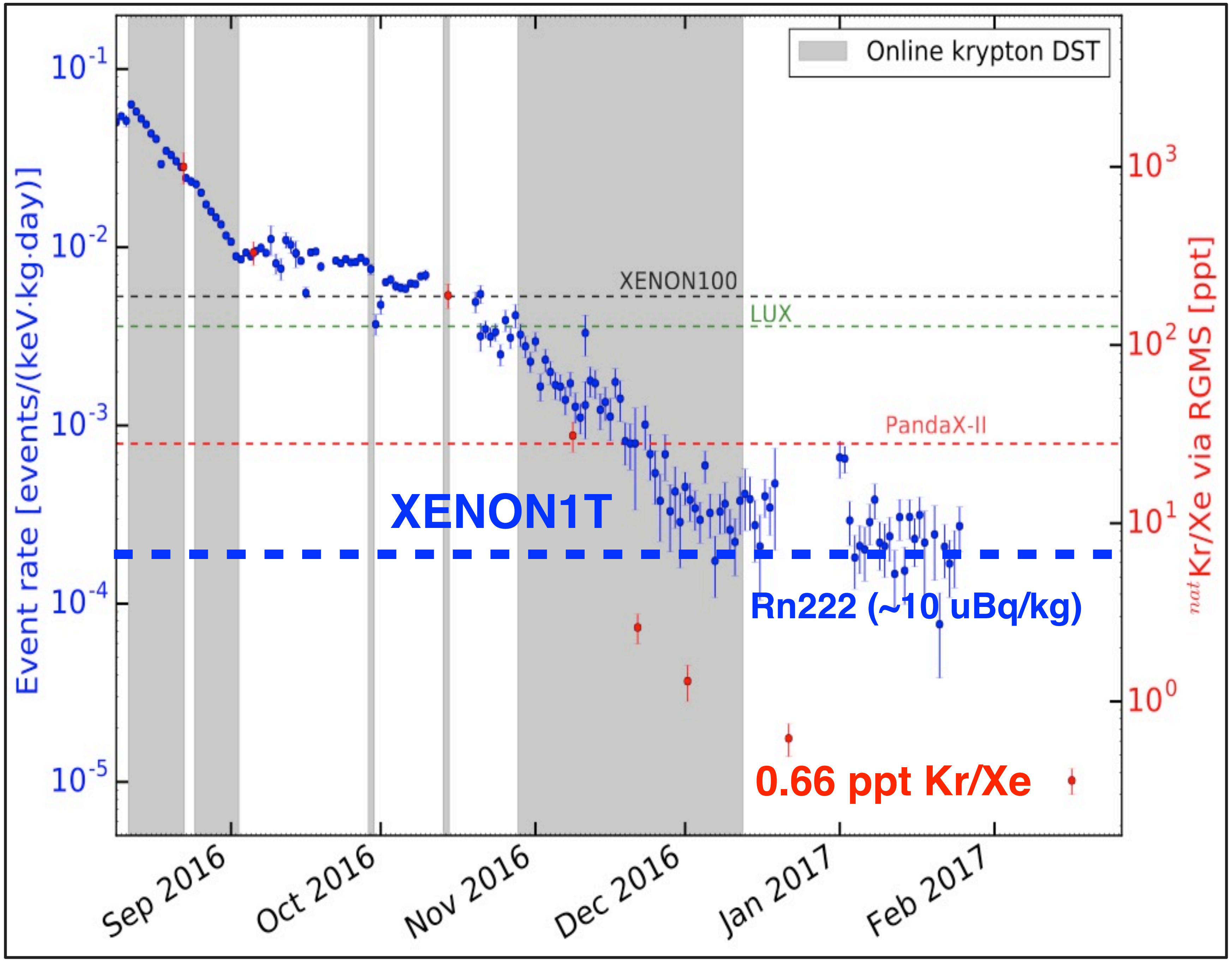
100 cm

LUX
Active Target: ~250 kg
completed

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

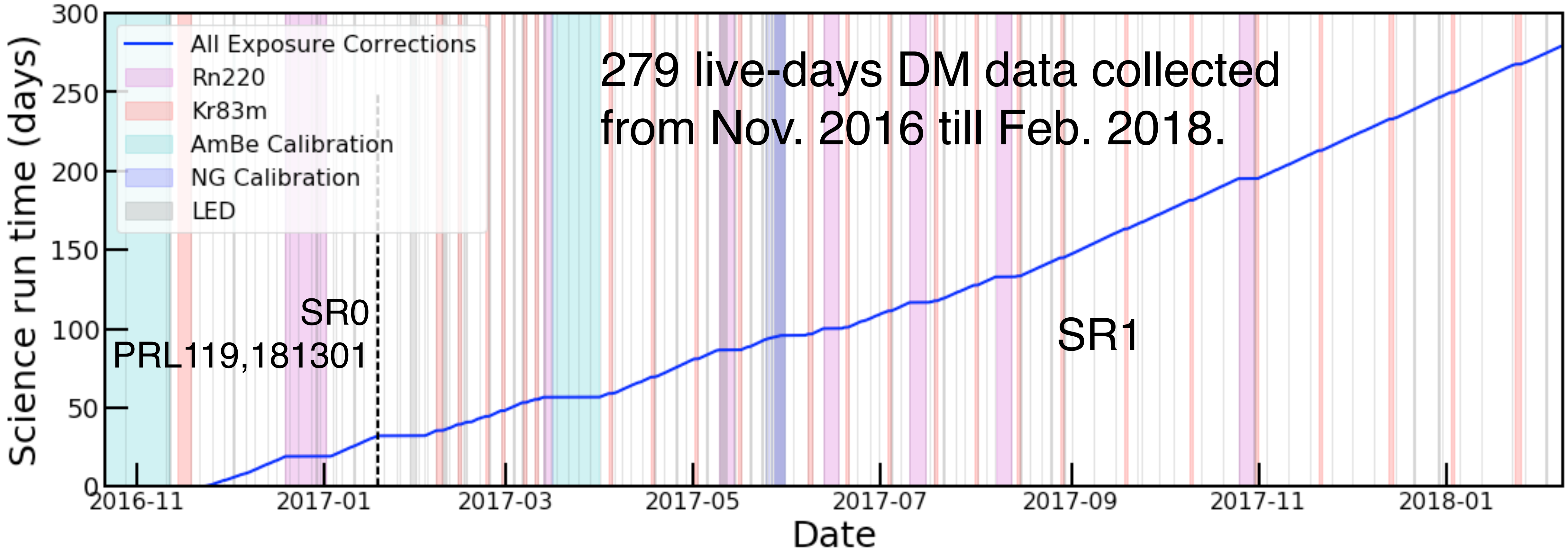
XENON1T
Active Target: 2000 kg
Status: running

Critical issue: reducing the intrinsic radio-contaminants

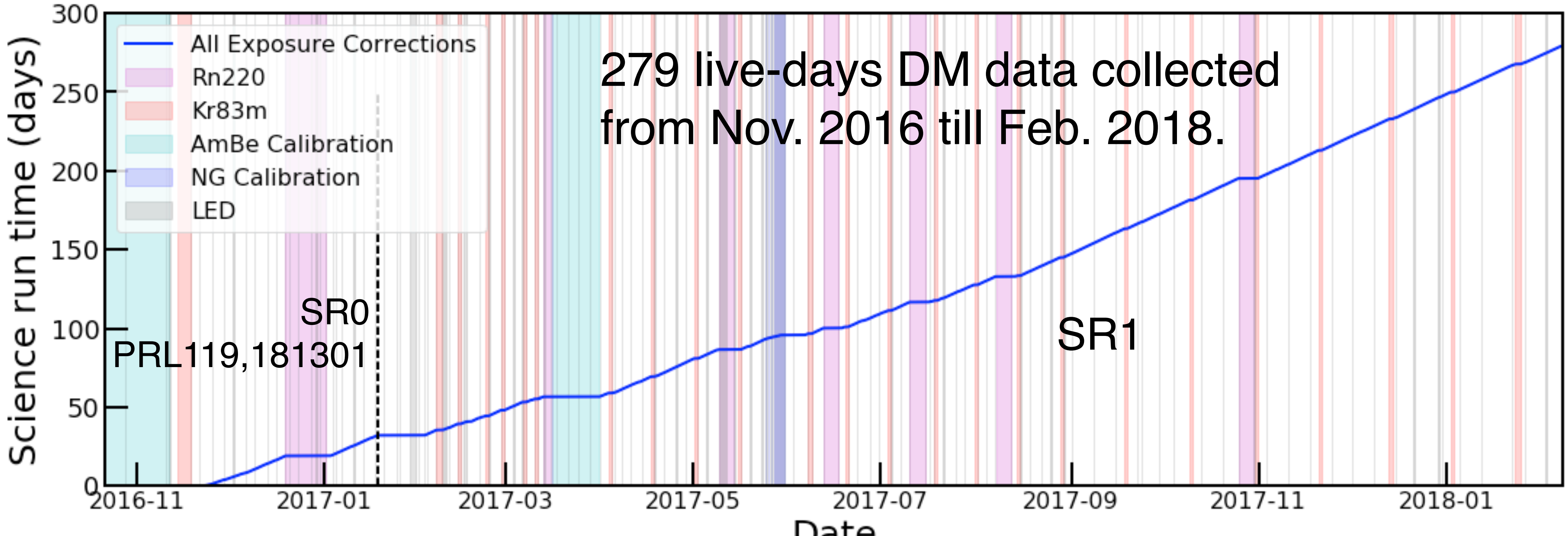


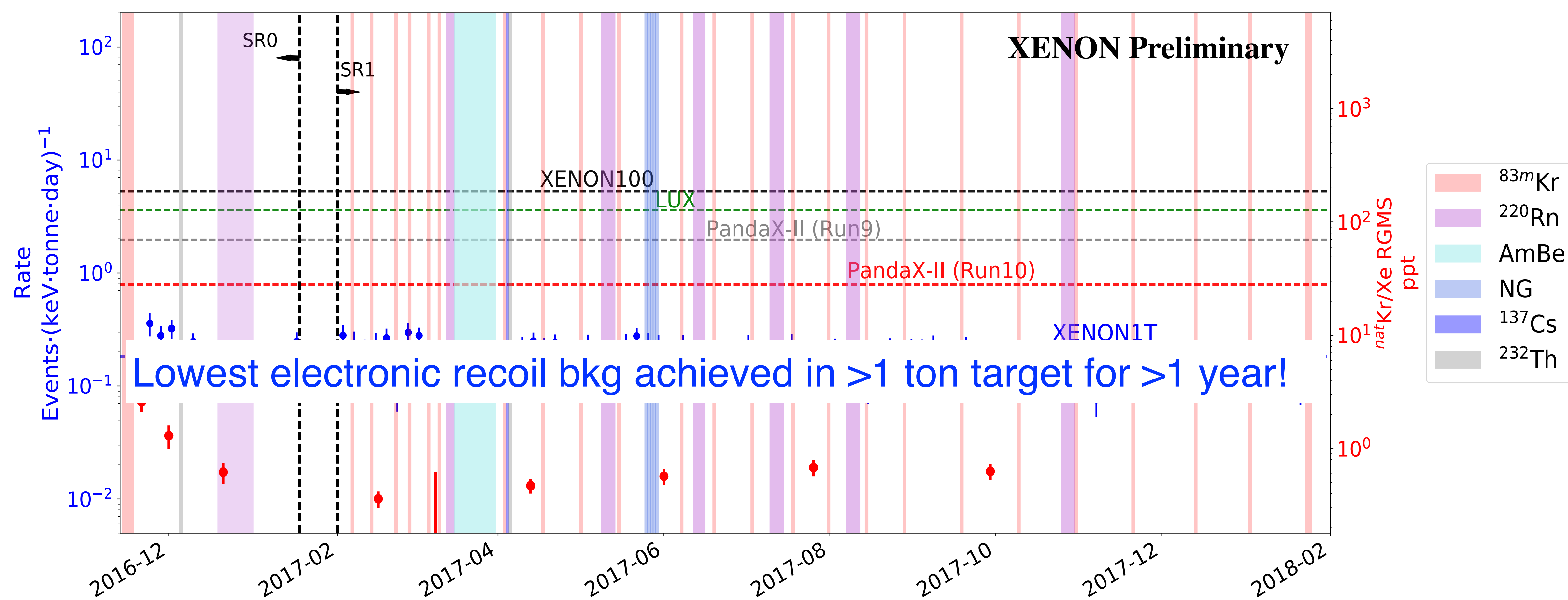
XENON1T Distillation Column

XENON1T Data taking

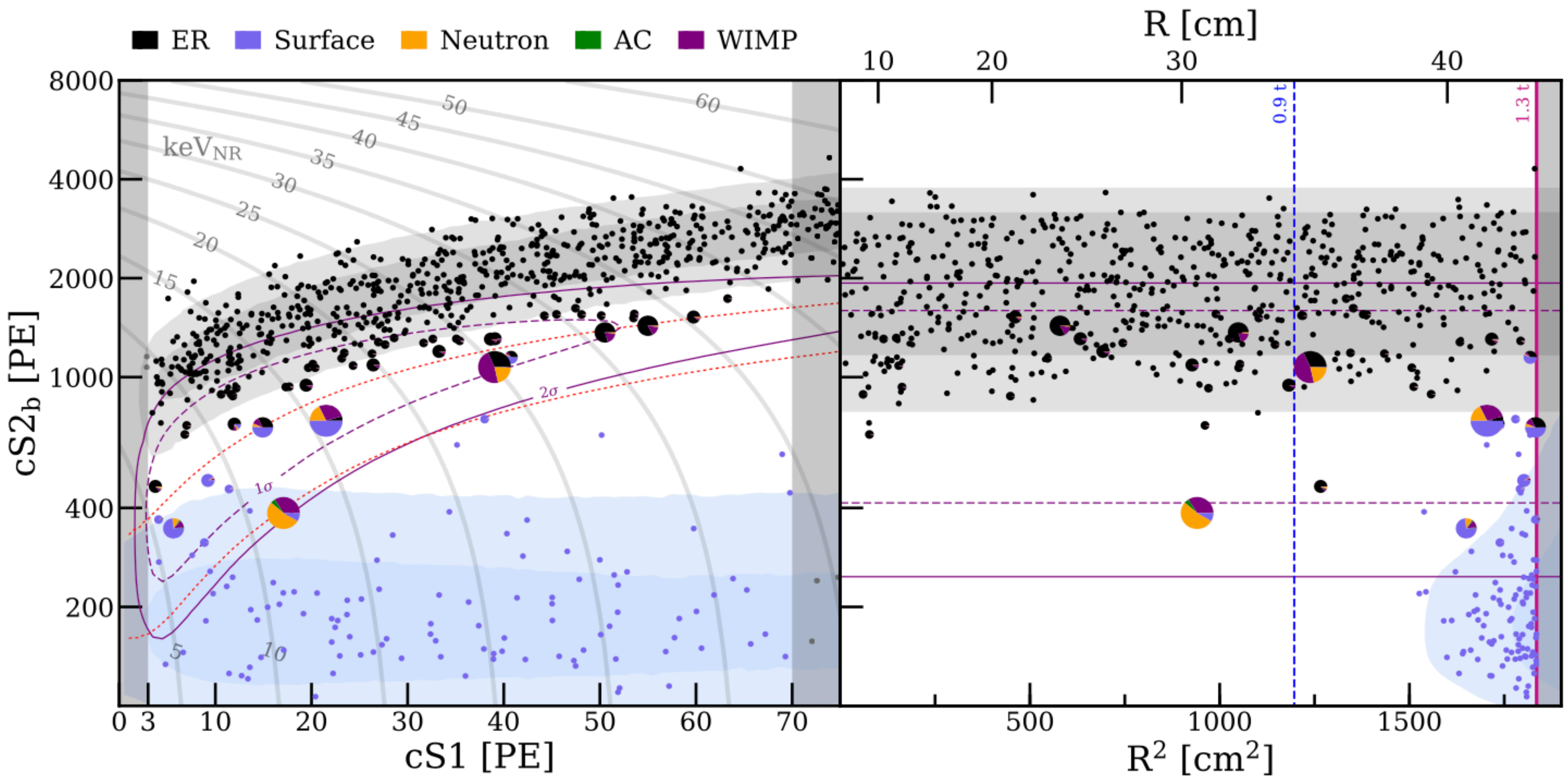


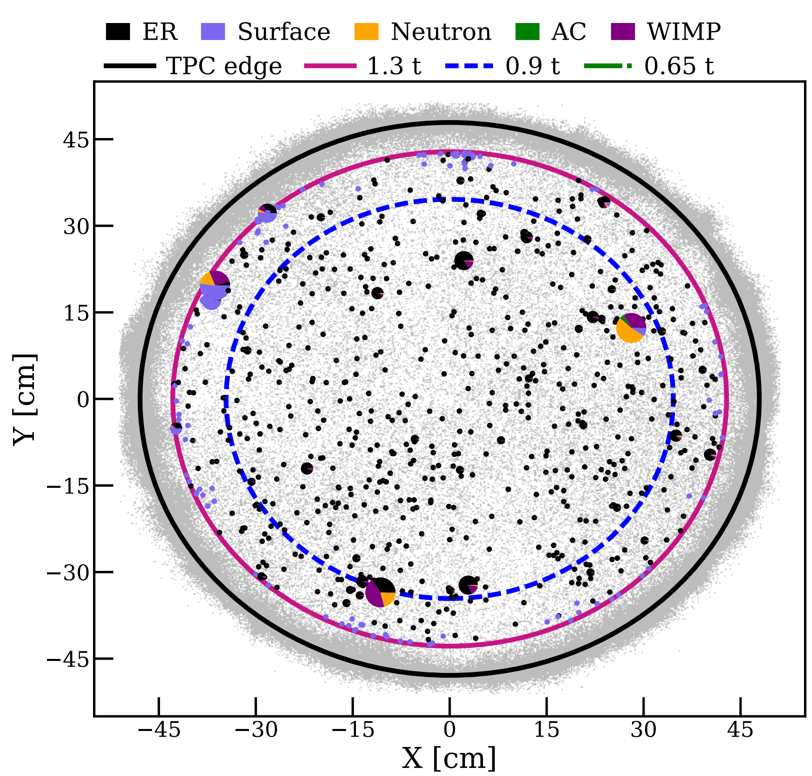
XENON1T Data taking

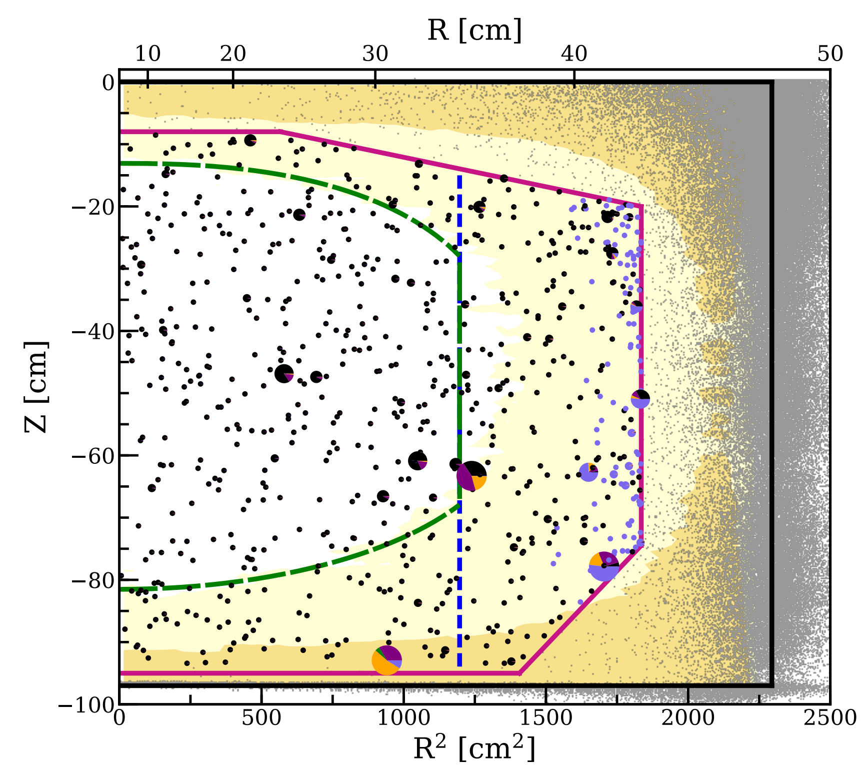




XENON1T results





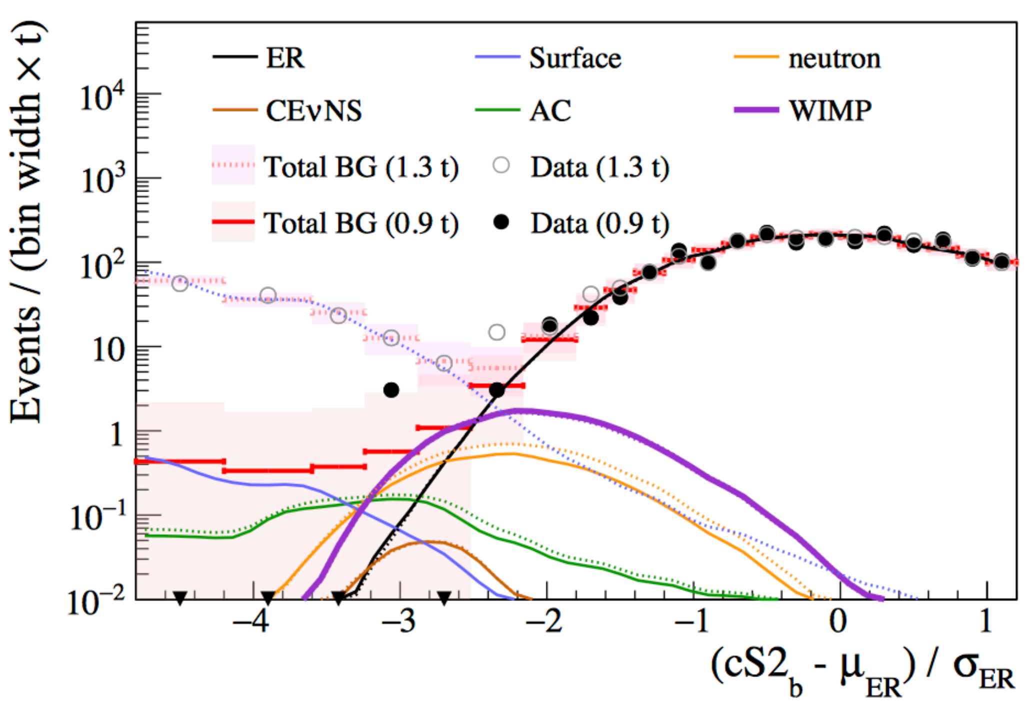


- **Results interpreted with unbinned profile likelihood analysis in cS1, cS2, R space**
- **Piecharts indicate the relative PDF from the best fit (assuming 200 GeV/c^2 WIMPs at cross-section of 4.7x10^{-47} cm^2)**

XENON1T sensitivity & limit

- **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 4.7x10^{-47} cm^2 assuming 200 GeV/c^2 WIMPs**

- **Relevance of a unified statistical approach among direct DM experiments (Neyman construction, unified approach 1,2-sided confidence interval, protection agains under-fluctuations, …)**



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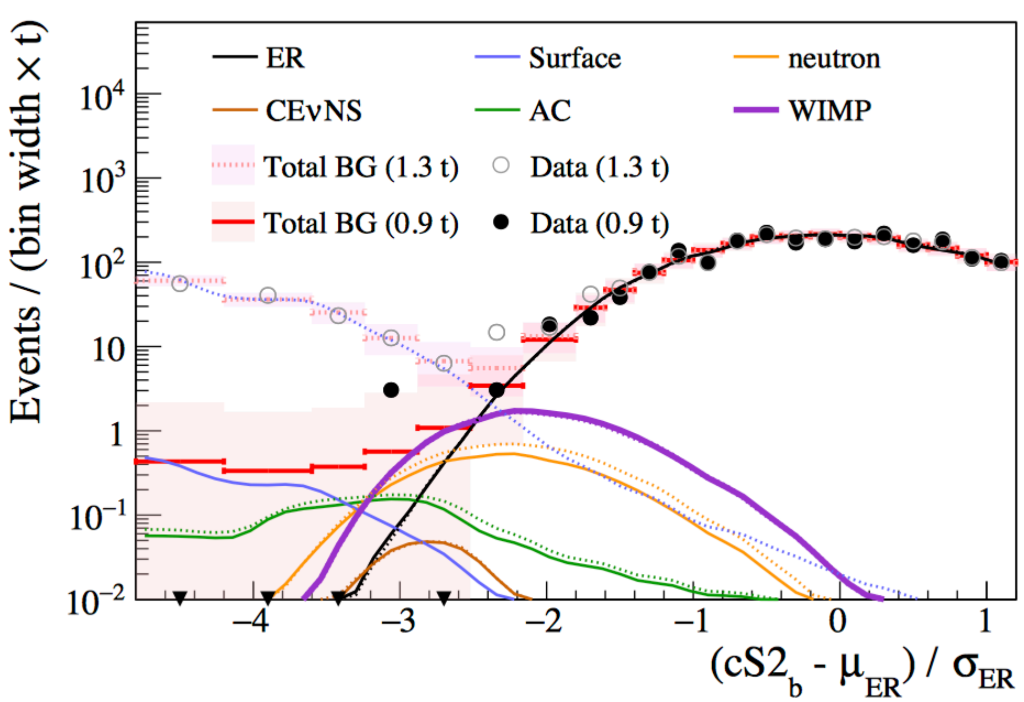
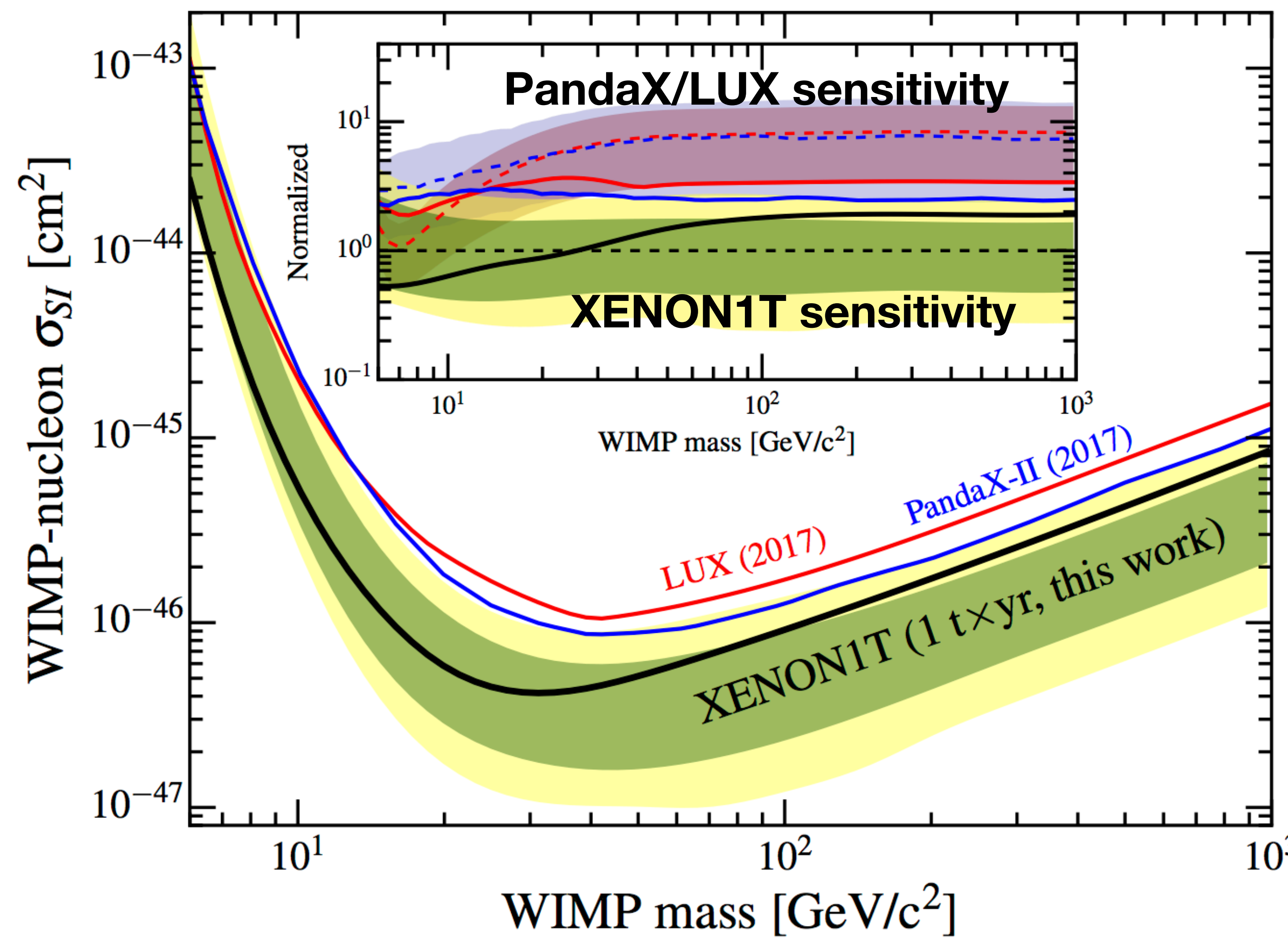
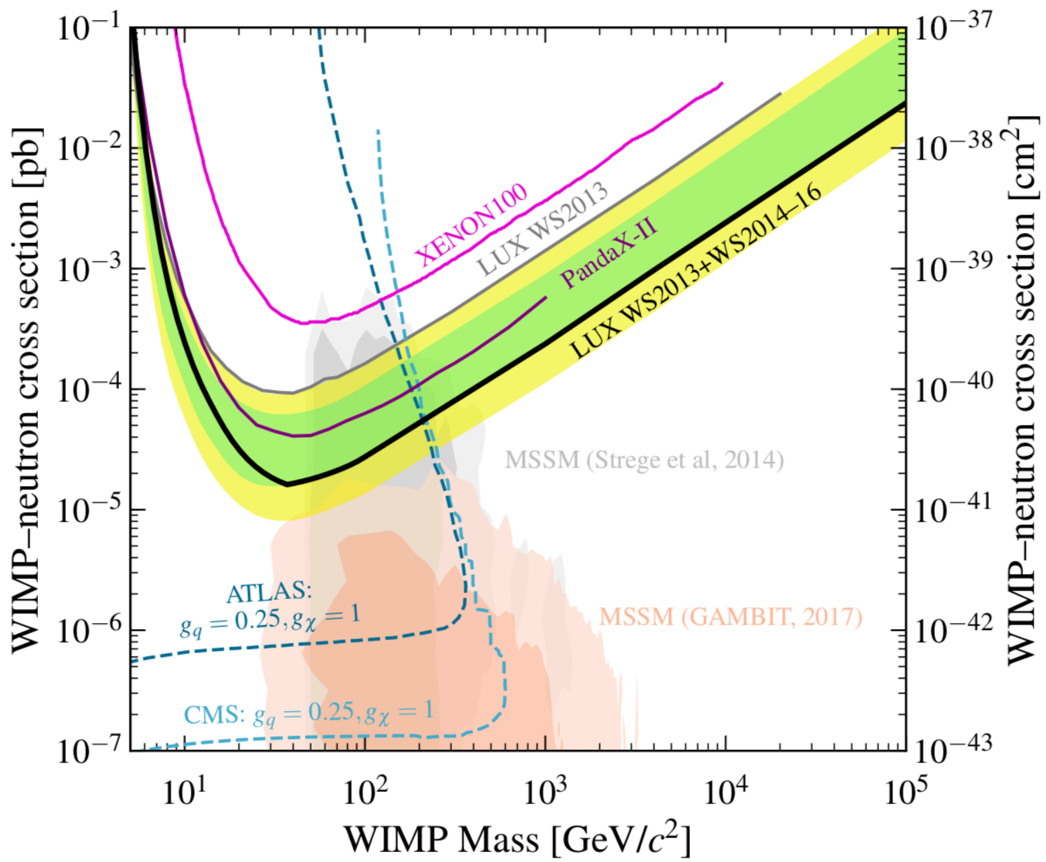
arXiv:1805.12562





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

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



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

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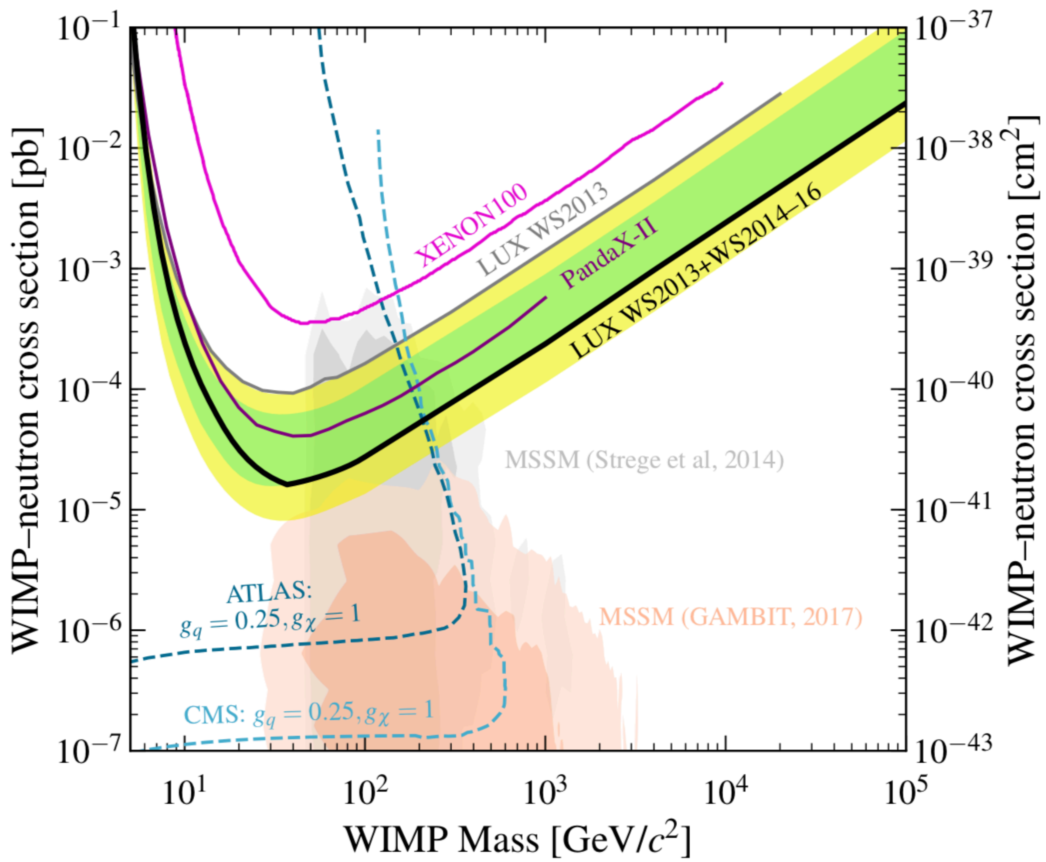
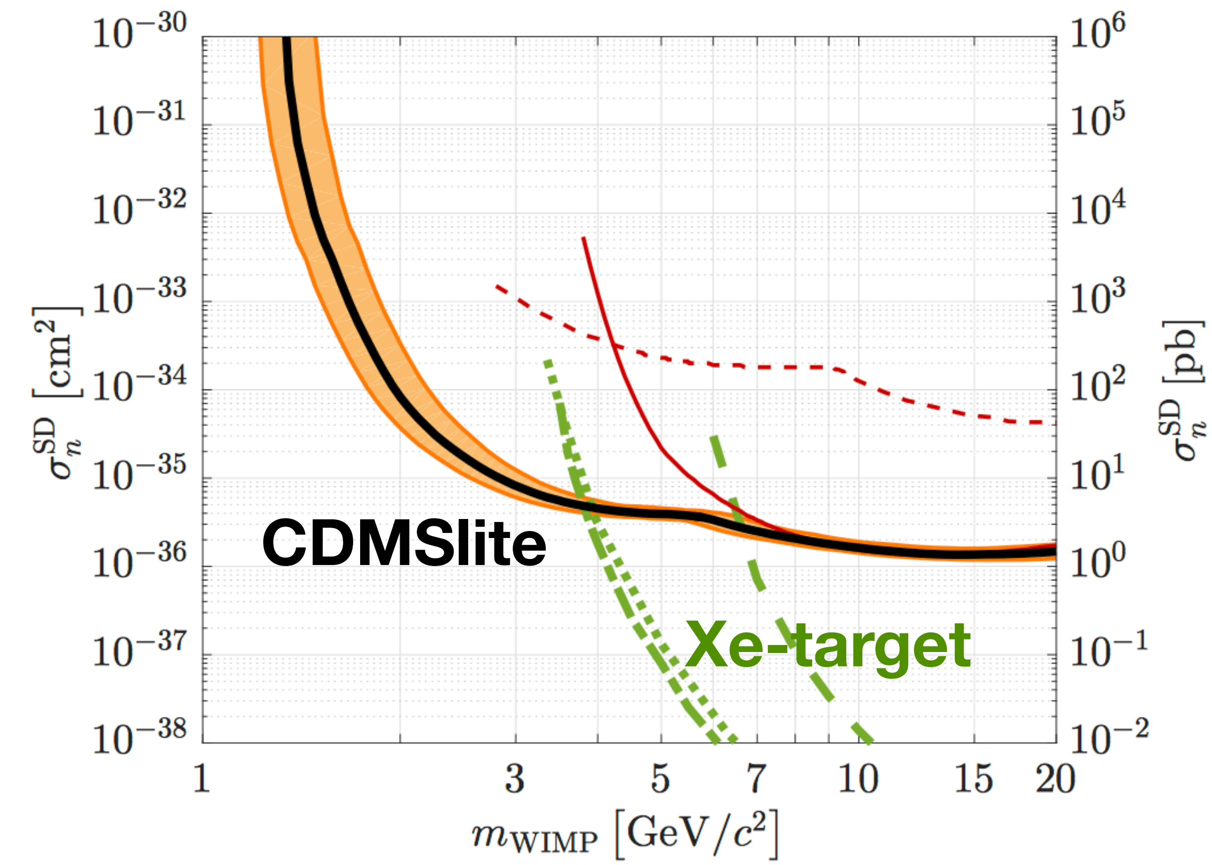


CDMSlite, Phys. Rev. D 97, 022002 (2018)



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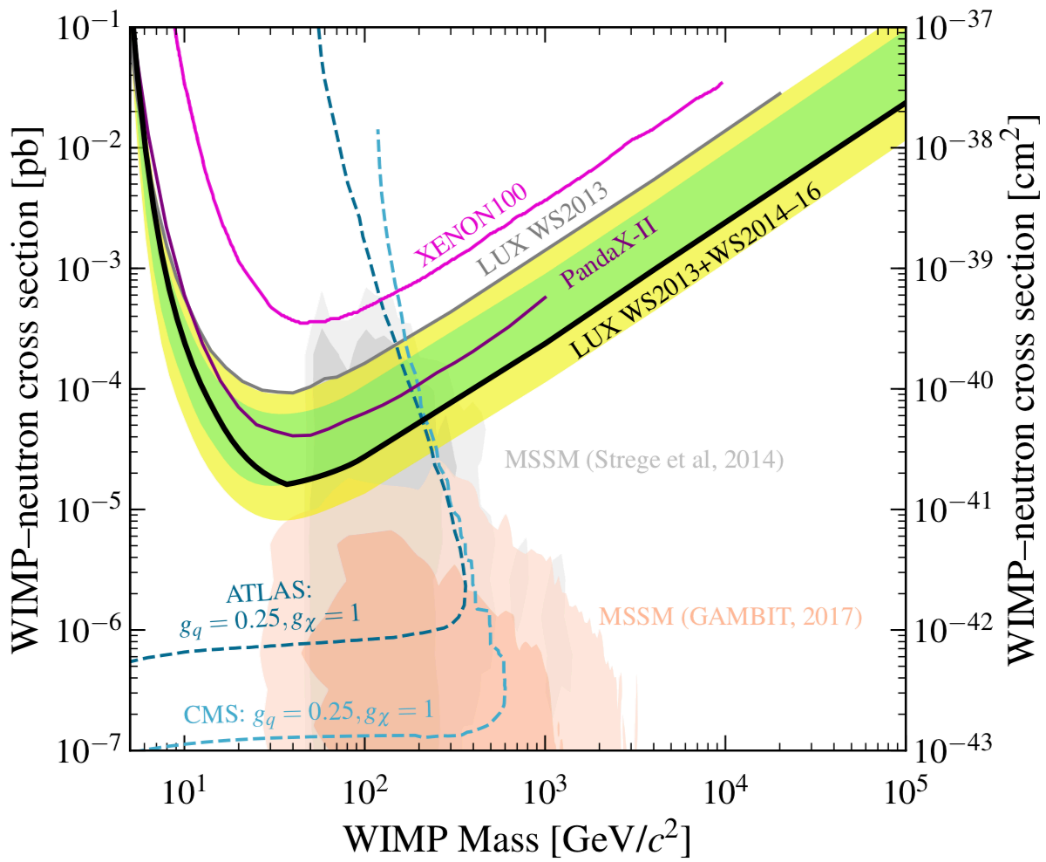
Ge-target (CDMS, CDEX)

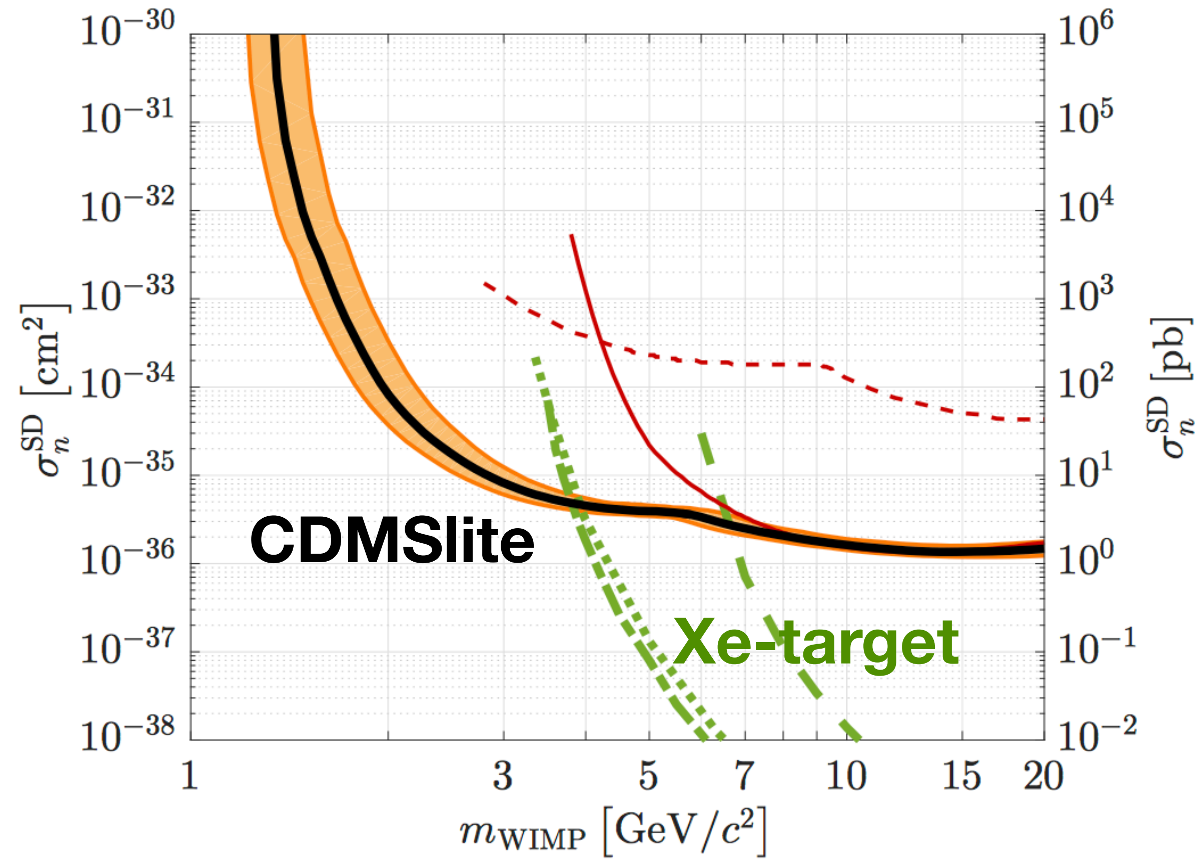
- Ge73 (7.73%)
- best SD-neutron limit below 3 GeV/c^2

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)



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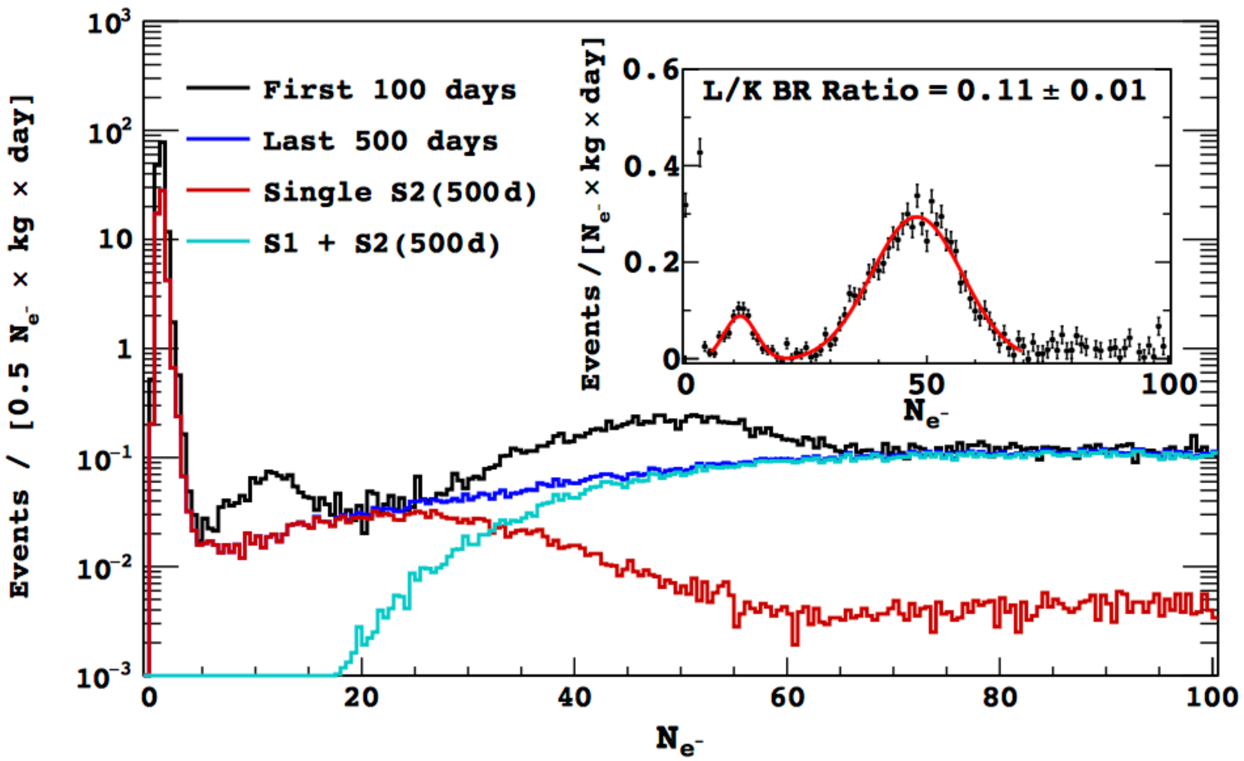
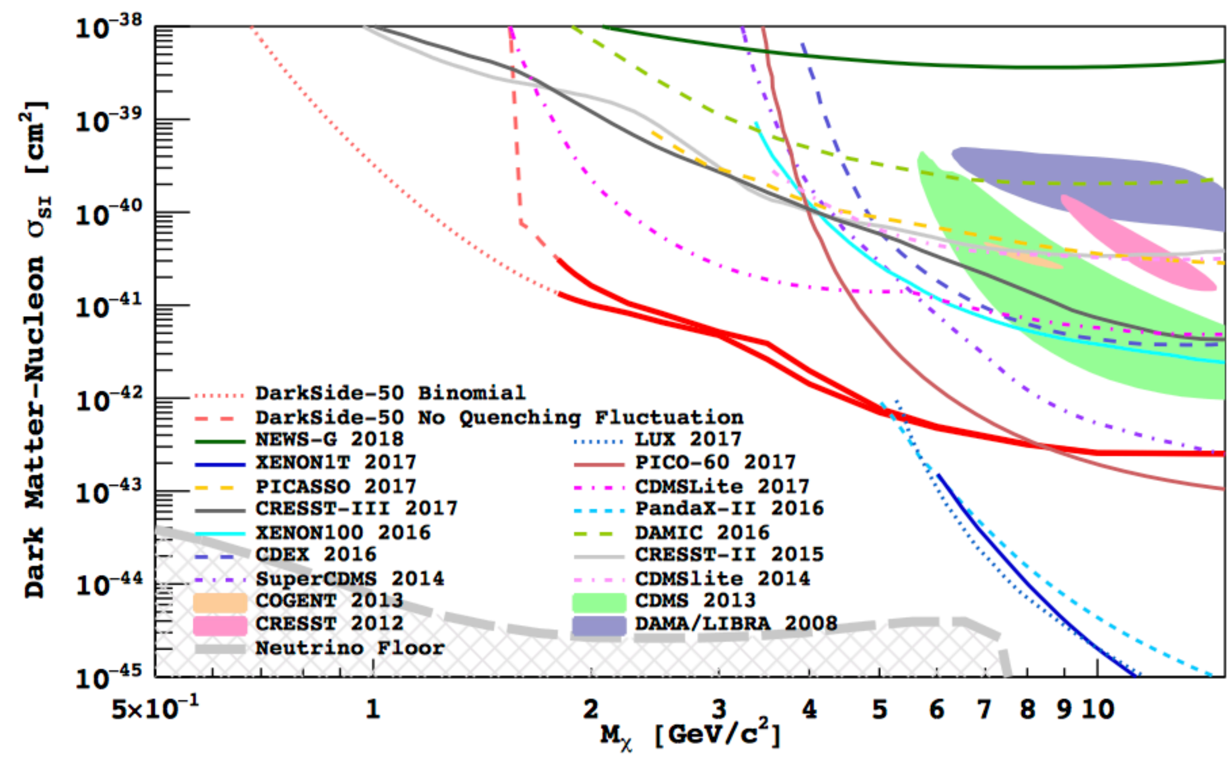
Model-independent Effective field theory (EFT), e.g. XENON100, Phys.Rev. D96 (2017) no.4, 042004

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

big improvement with S2-only search in DarkSide-50



DarkSide-50, arXiv:1802.06994

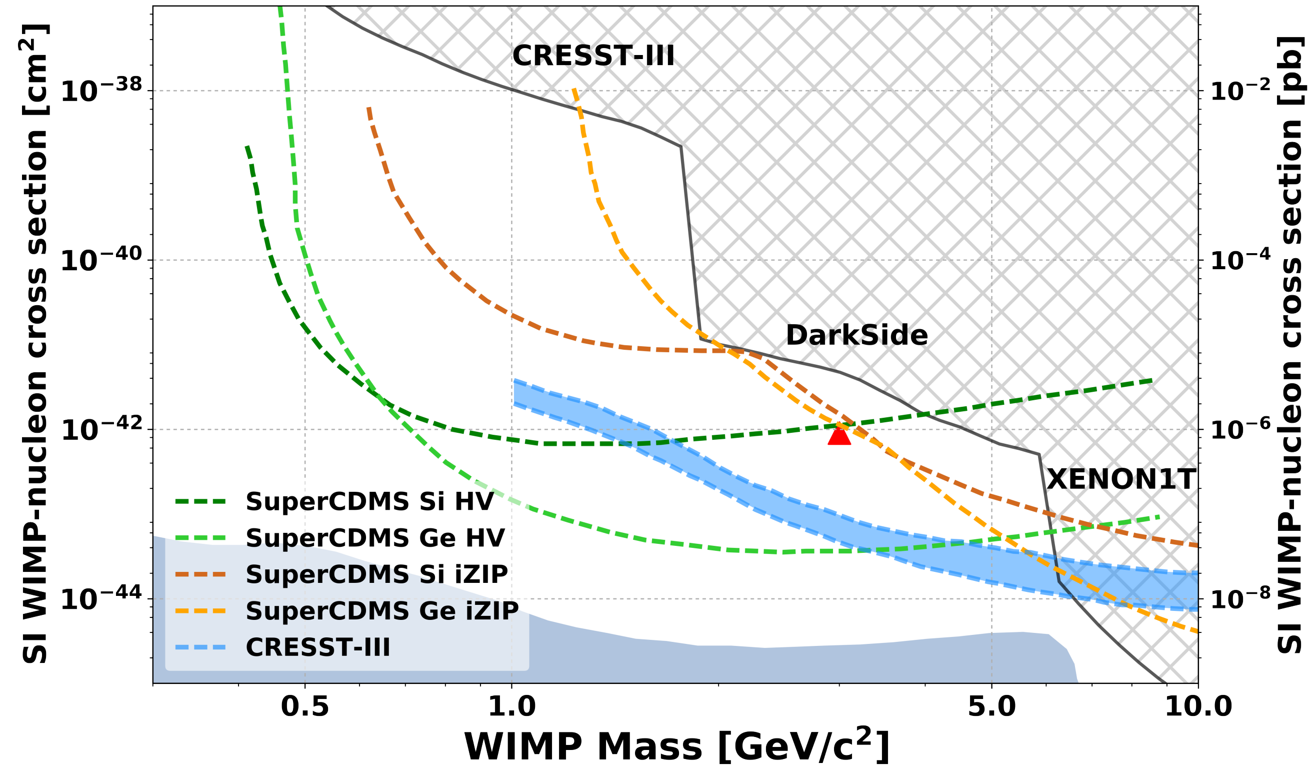


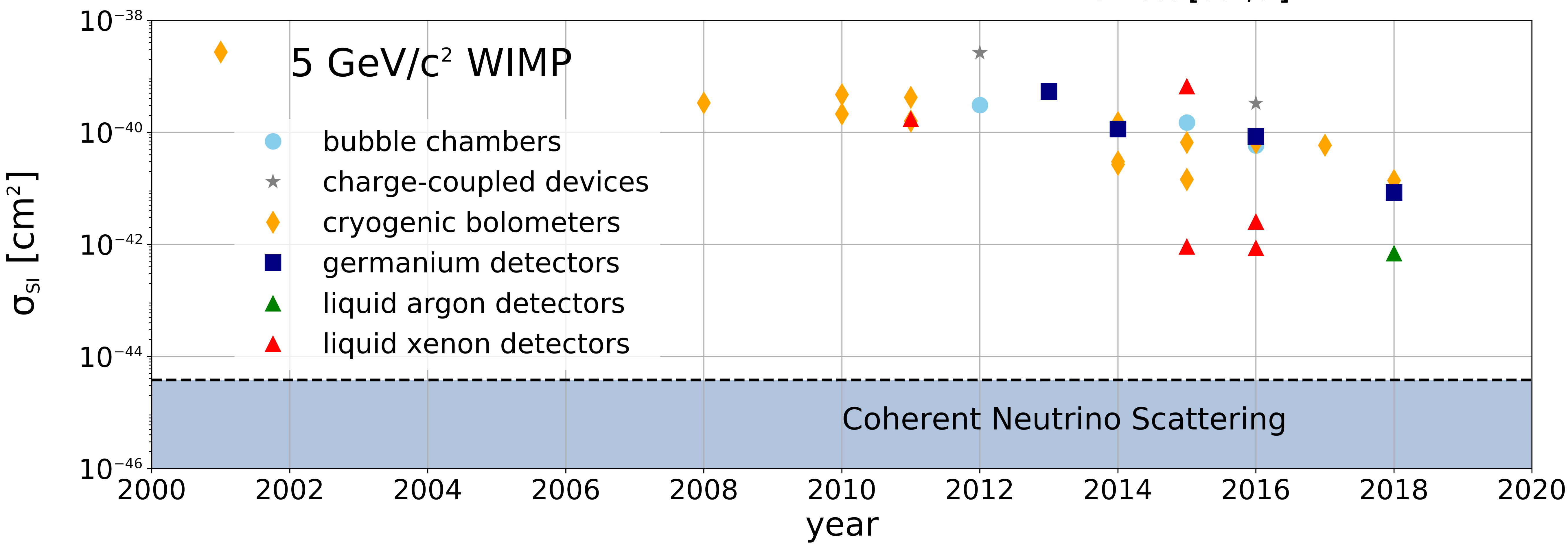
DarkSide-50 S2-only search

- 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**

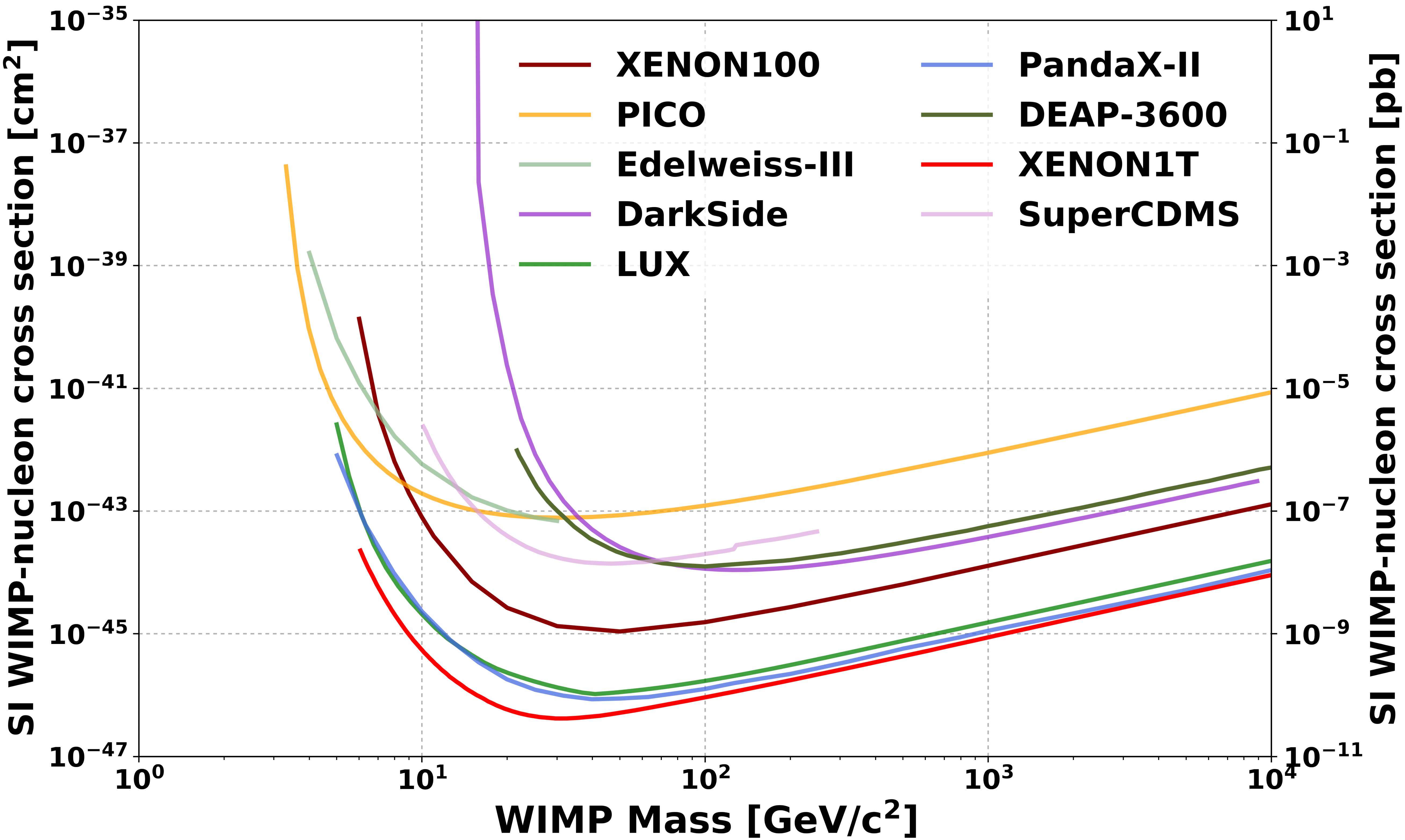
Low-mass dark matter search status

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

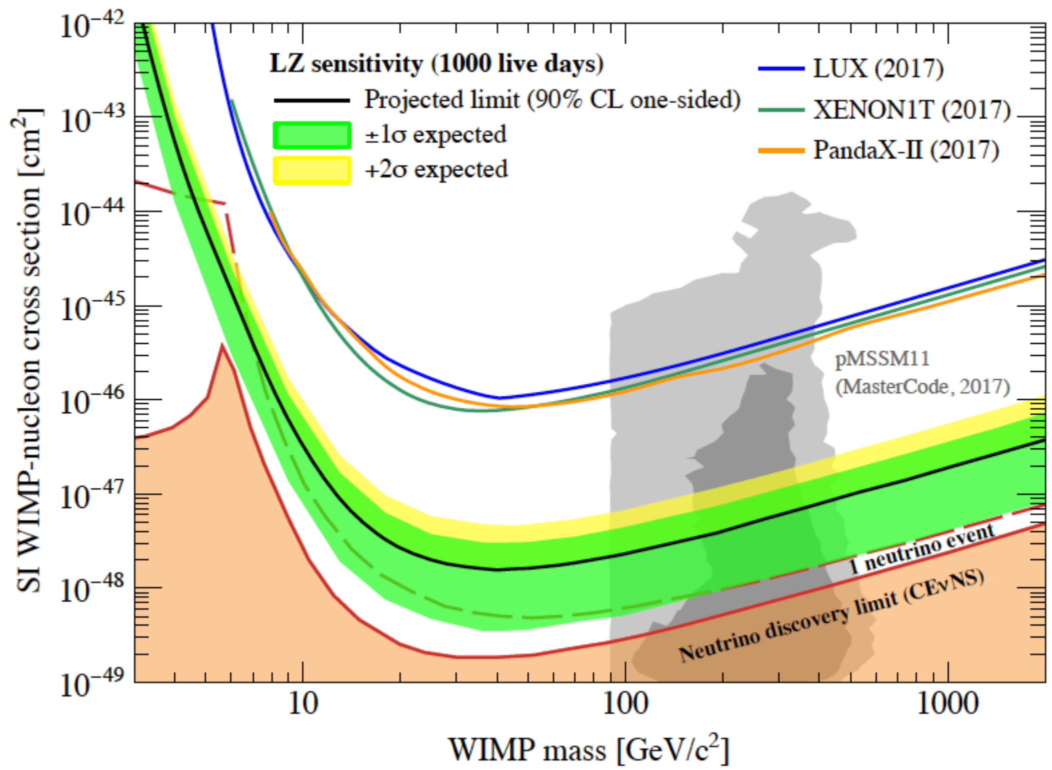




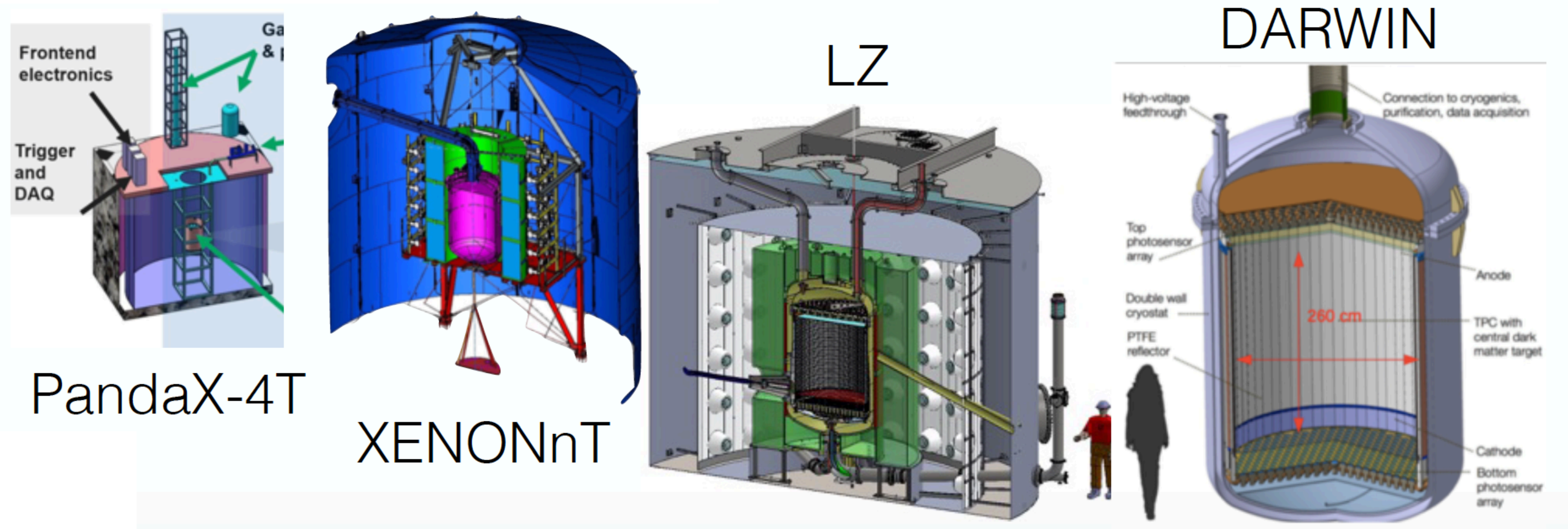
Heavy WIMPs search: current status



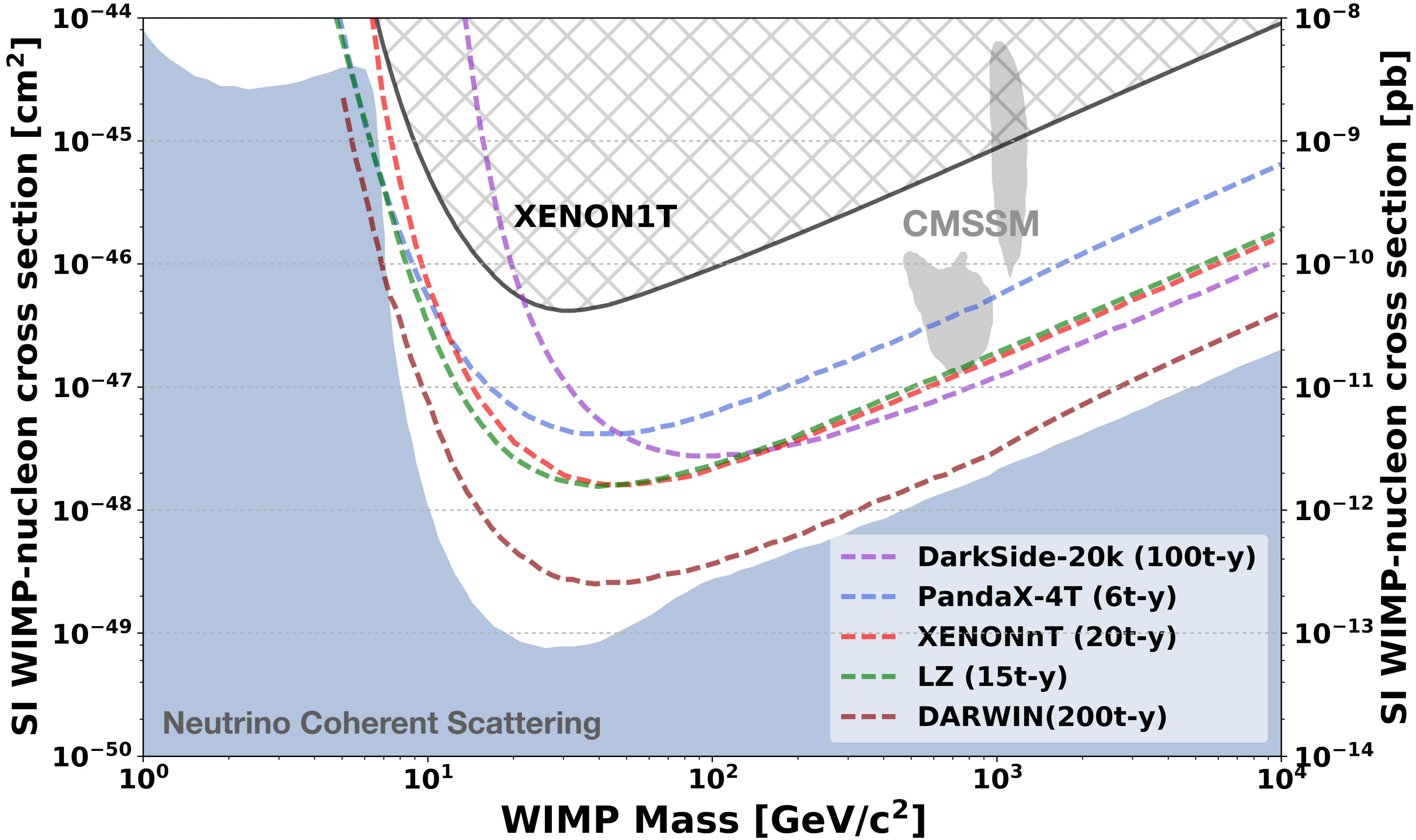
LXe TPCs: the future



- 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



Direct Detection of WIMPs by 2025?



Istituto Nazionale di Fisica Nucleare

Thanks !

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INFN Bologna