# Direct detection of heavy dark matter particles (> ~1 GeV)

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Dark Wave

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# Outline

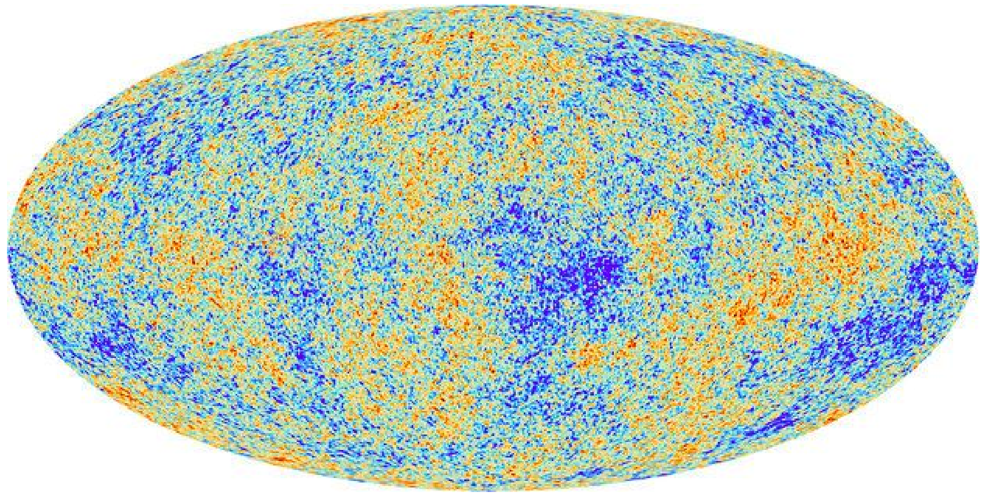
- Introduction
- Historical perspective on direct detection
- WIMP search methodology
- DAMA and new modulation searches
- Low-mass WIMP searches
  - Low energy excess
  - Migdal effect update
- Heavy WIMP searches
- EFT and exotic interactions
- Planck-mass DM
- Towards the neutrino fog
- Directional searches
  - New ReD result
- Paleodetectors
- ECFA Detector R&D
- Summary

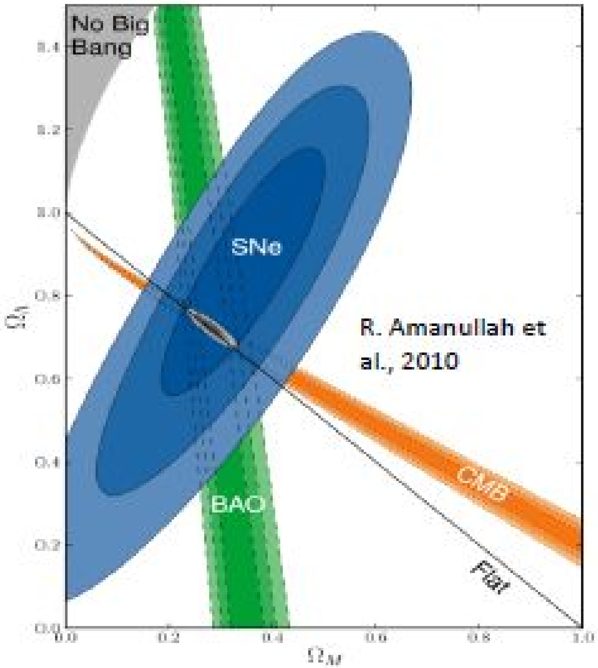
Very rich field

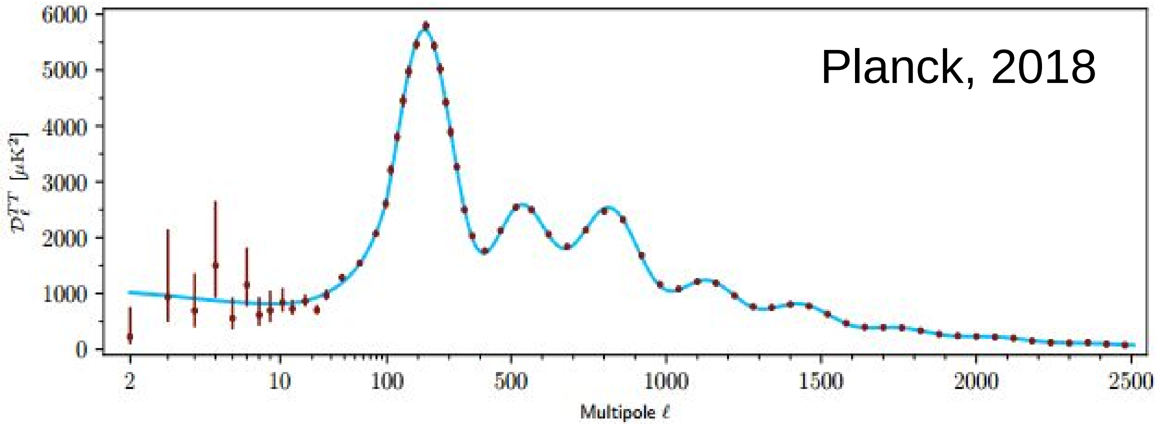
Limited and biased selection of topics in this talk

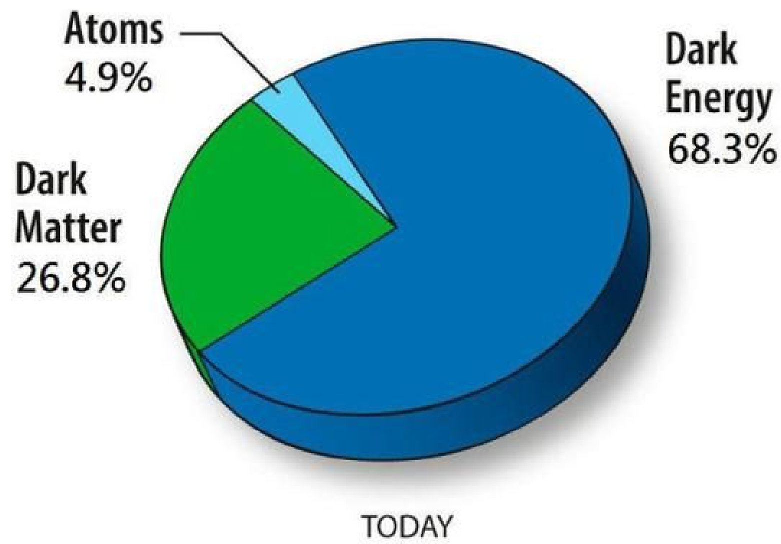
# Evidence for Dark Matter

- Cosmic microwave background (CMB) observations, resulting in precise estimates (WMAP, Planck) supporting $\Lambda$CDM model



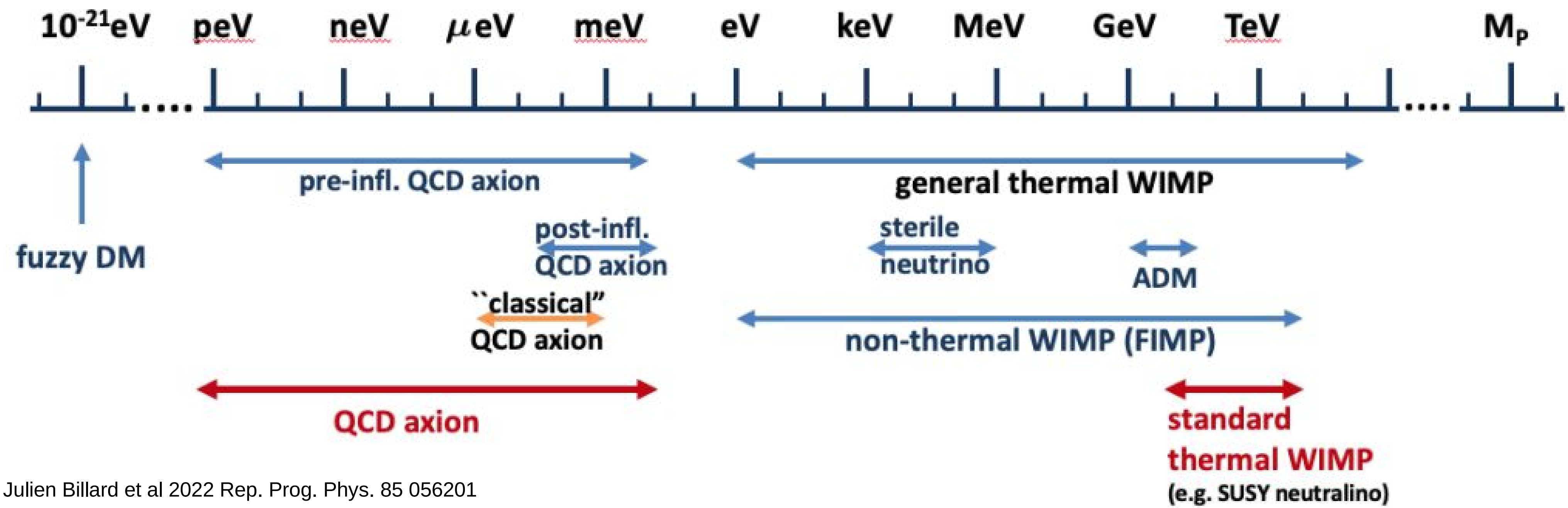


# What is Dark Matter?

- A number of possibilities considered and excluded:
  - Modifications of the gravity law (MOND)
  - Massive compact halo objects (MACHOs)
- Primordial black holes
- New Particles




Julien Billard et al 2022 Rep. Prog. Phys. 85 056201

# What is Dark Matter?

- A number of possibilities considered and excluded:
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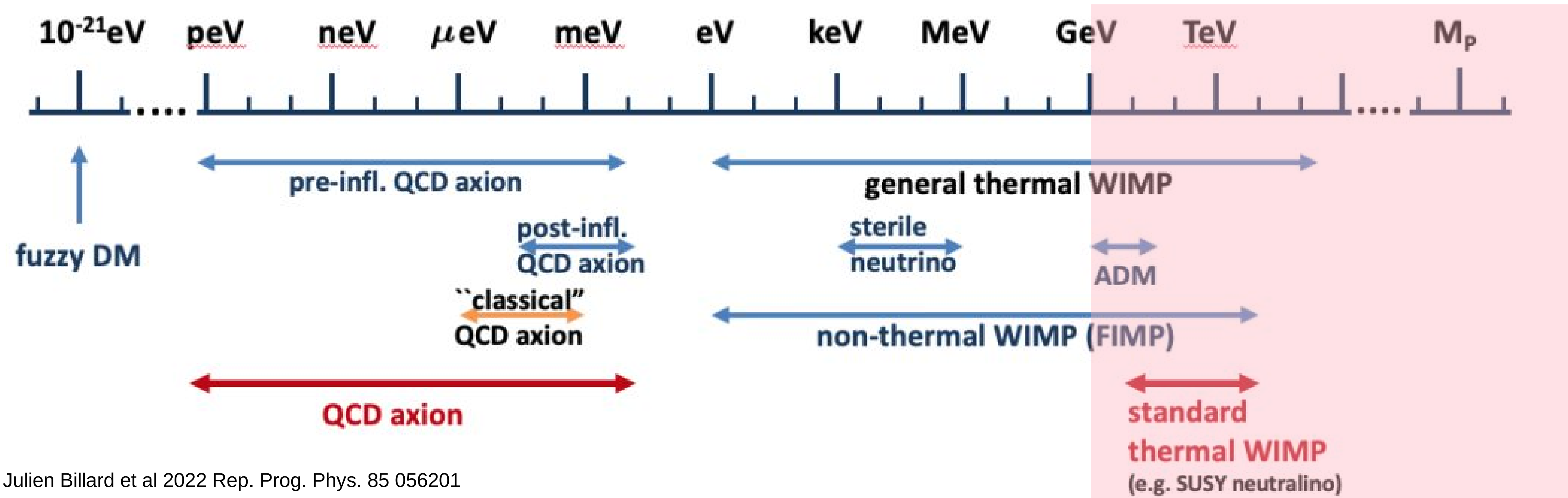
  - Massive compact halo objects (MACHOs)
- Primordial black holes
- New Particles
  - Weakly Interactive Massive Particles (WIMP), Asymmetric DM, Feebly Interacting Massive Particles (FIMP)

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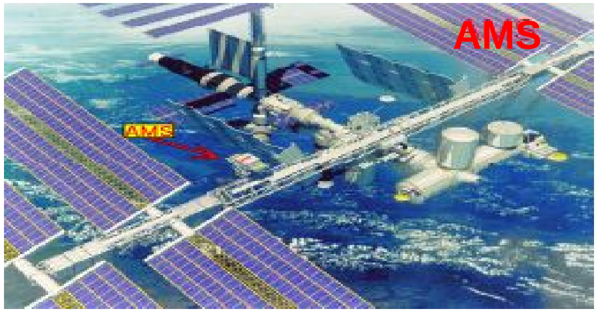
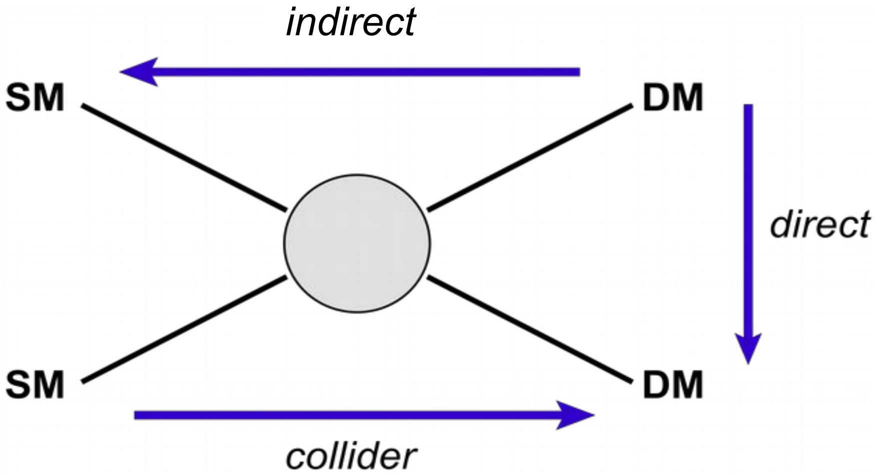
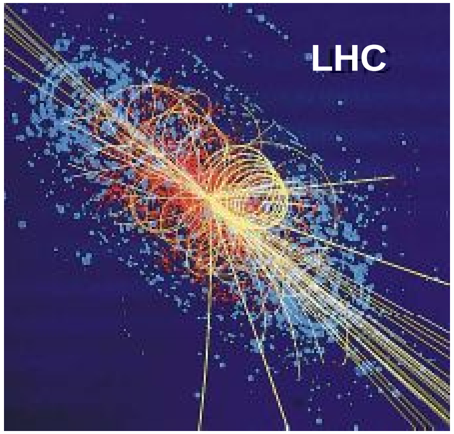
# Ways to look for Dark Matter particles




- Indirectly via their annihilation in Sun, Earth, Galaxy
  - Neutrinos (IceCube, Antares/KM3NeT)
  - Positrons, antiprotons (AMS)
  - $\gamma$-rays (Fermi-LAT, CTA)
- **<u>Direct detection</u>**
- By producing them at accelerators (LHC, beam dump experiments)

# Historical perspective

Direct dark matter detection started nearly 40 years ago from these 2 papers:

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1984

**Principles and applications of a neutral-current detector for neutrino physics and astronomy**

A. Drukier and L. Stodolsky
*Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany*
(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small ($10-10^3$ eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted.

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

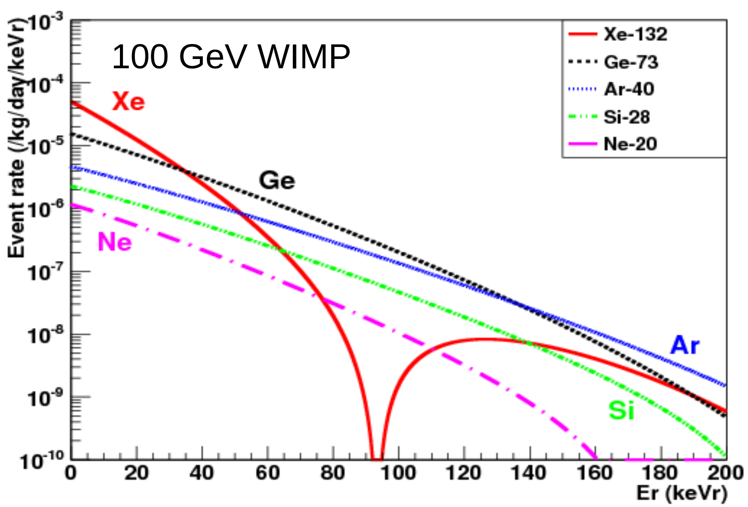
**Detectability of certain dark-matter candidates**

Mark W. Goodman and Edward Witten
*Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544*
(Received 7 January 1985)

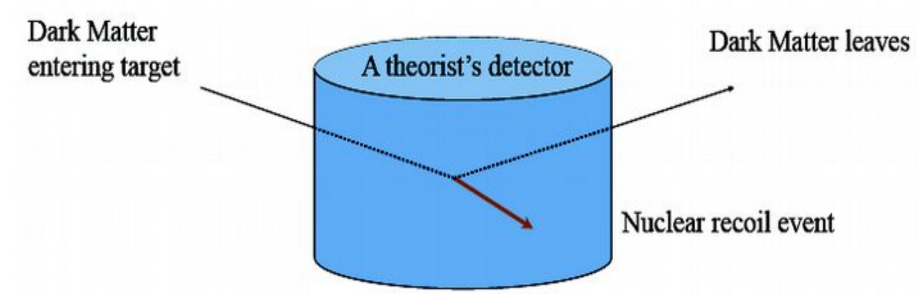
We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

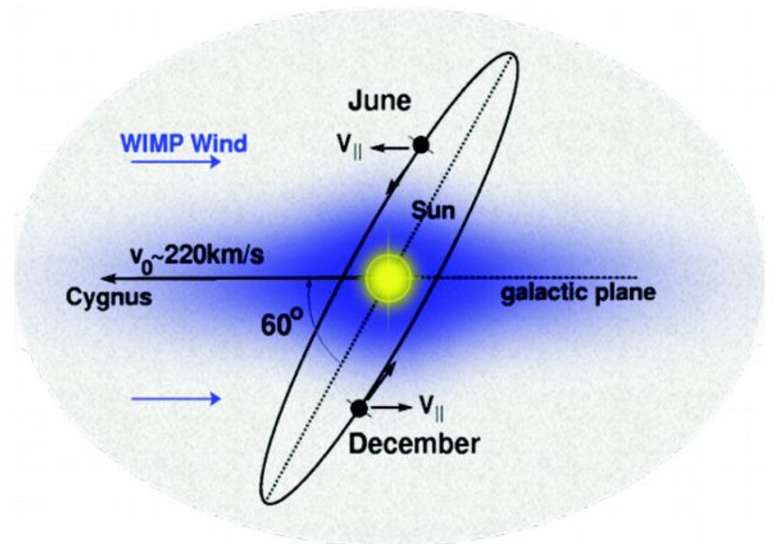
# DM direct detection signature

- Only through rare interactions with ordinary matter
- After the interaction, recoiling nucleus deposits energy in the detector, which is detectable (**heat, light, electric charge, ...**)




**Nuclear recoil spectrum**
- featureless, ~exponential
- lower threshold → more sensitivity
- natural radioactivity is a background




Annual modulations in the event rate should be present!

**Directionality**
→ annual modulation of the signal

astrophysics

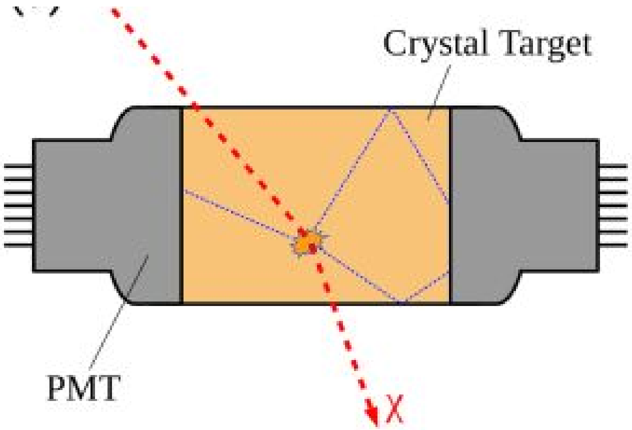
$$\frac{dR}{dE_R} = N_T \int_{v_{min}}^{\infty} dv\, v\, \Phi(v, v_E) \frac{d\sigma}{dE_R} \varepsilon(E_R)$$

detector response

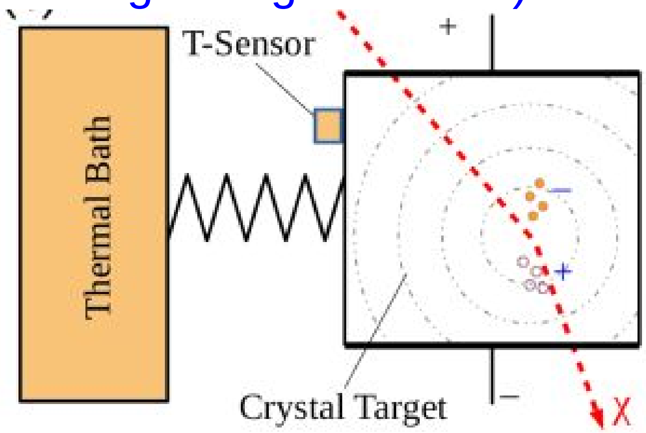
particle/nuclear physics

# Main detection techniques

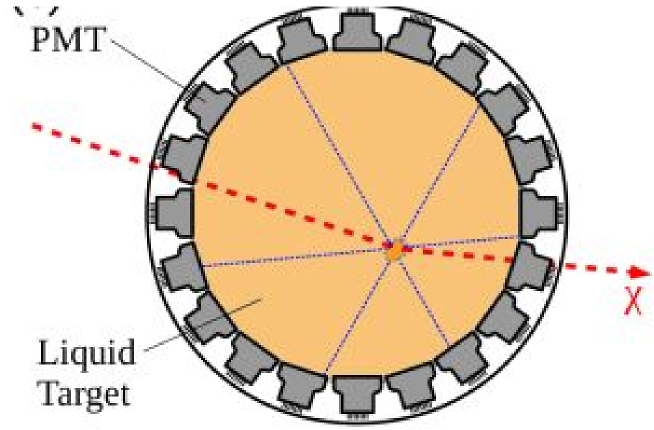
Scintillating crystal



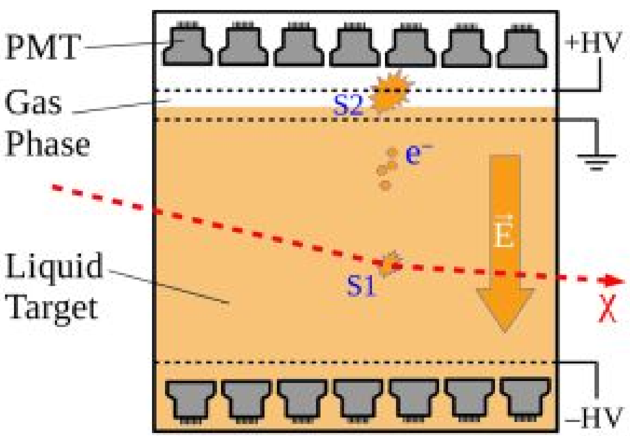

Cryogenic bolometer (with charge or light readout)



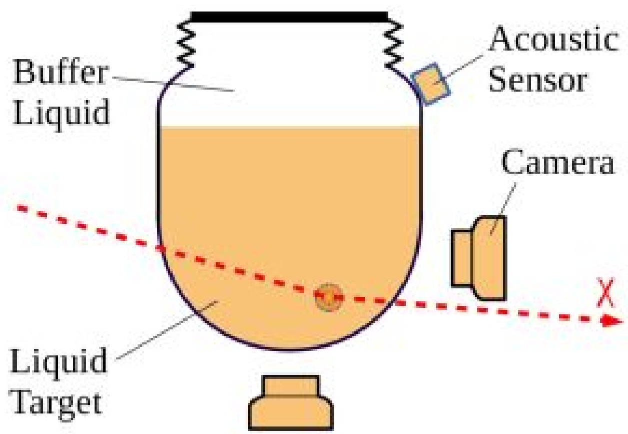

Single-phase noble liquid detector



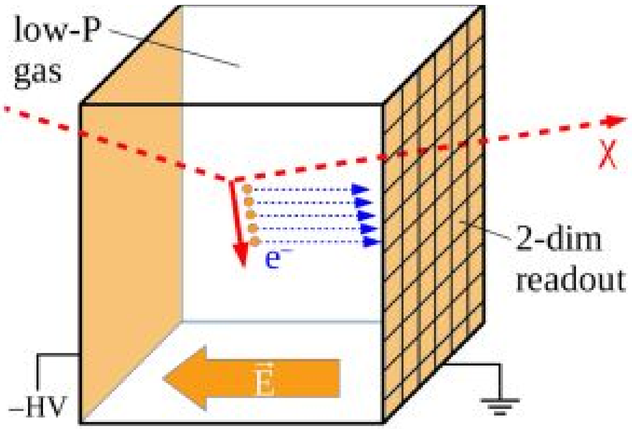

Dual-phase noble liquid detector




Bubble chamber (optionally scintillating)




Directional detector

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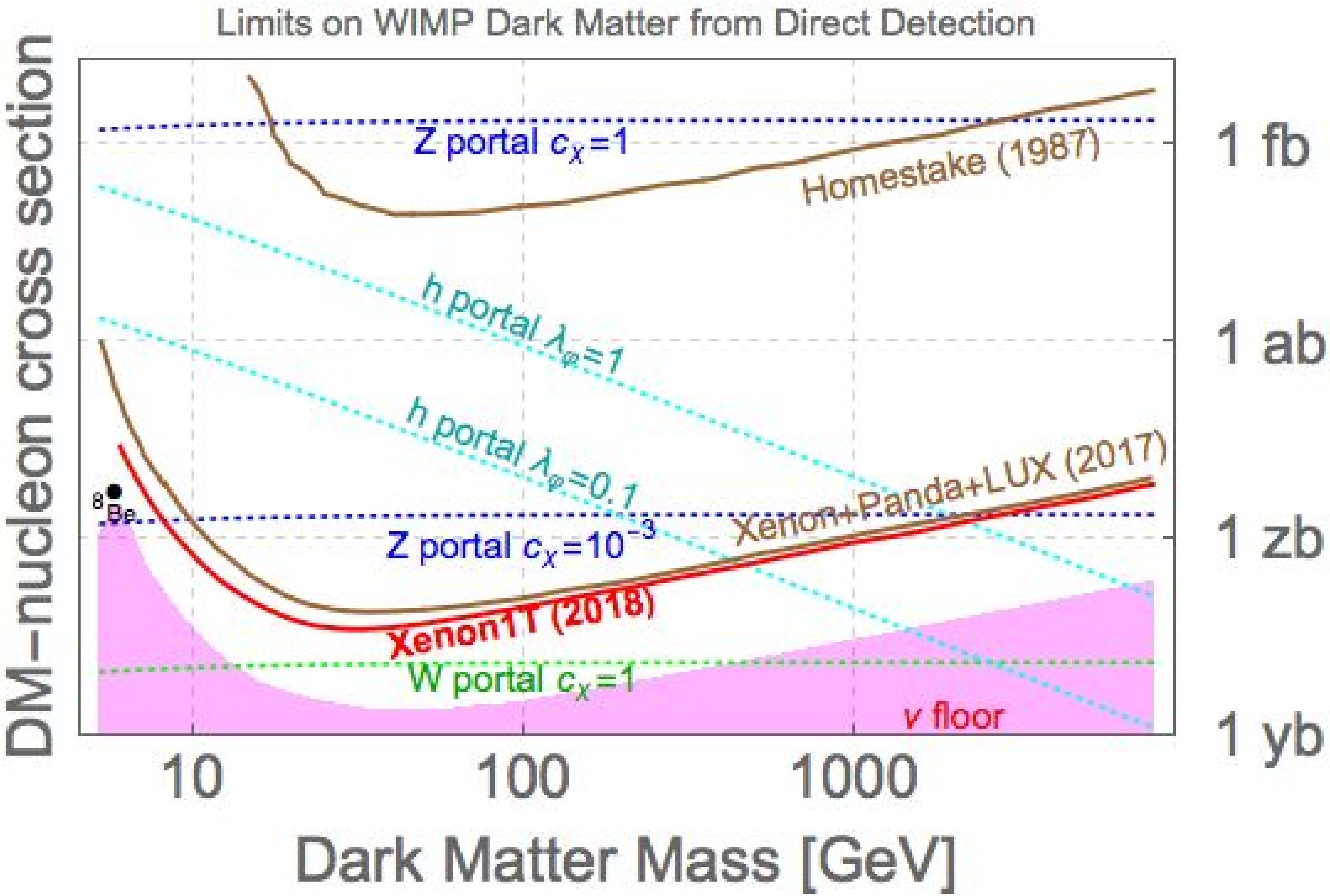
- Bolometers and ionization detectors tend to provide lower energy threshold
- Not all techniques scalable to multi-tonne scales
- Sensitivity to multiple response channels helps to discriminate backgrounds

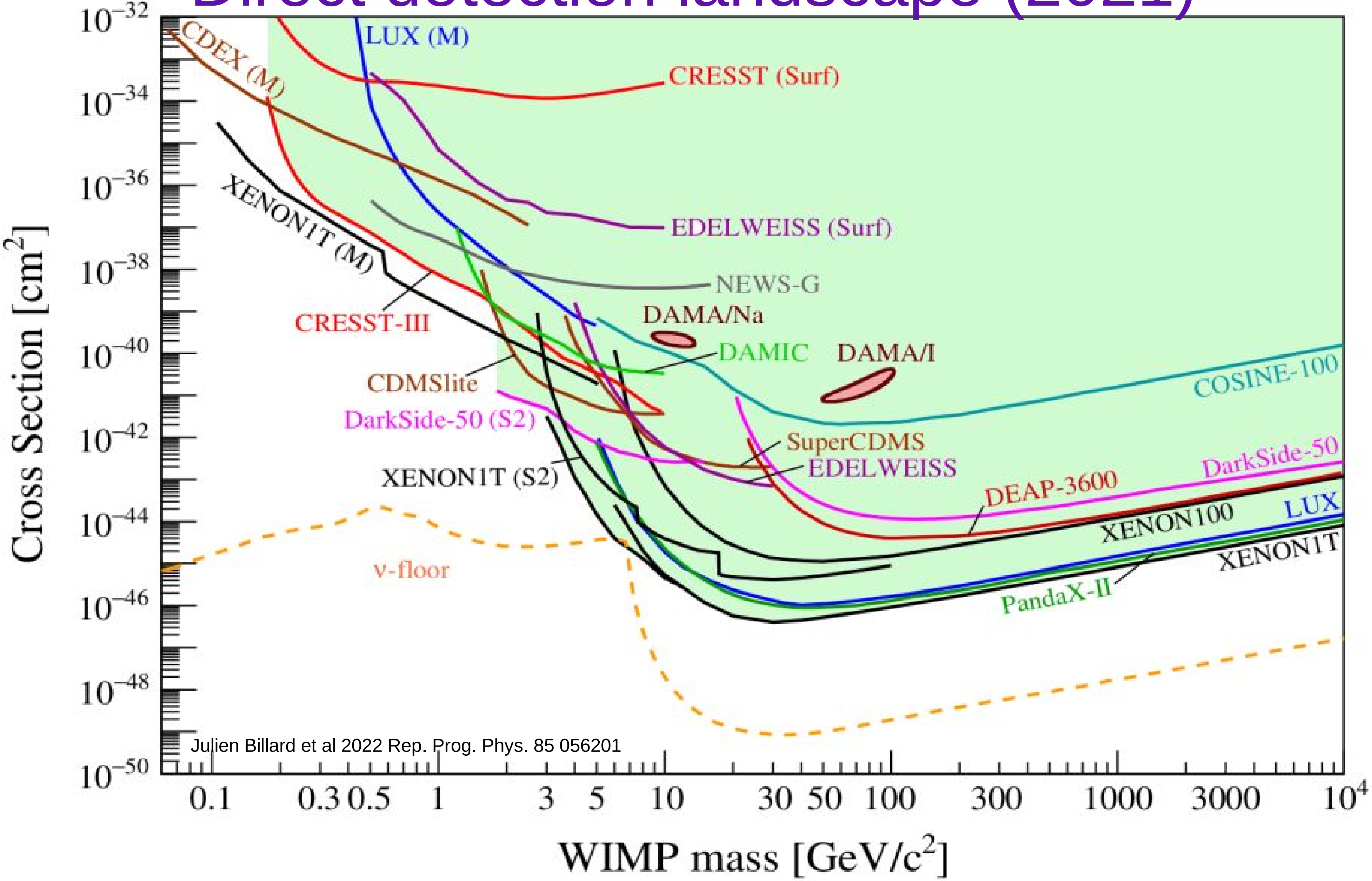
# Explored so far...




Source: http://resonaances.blogspot.com/2018/05/

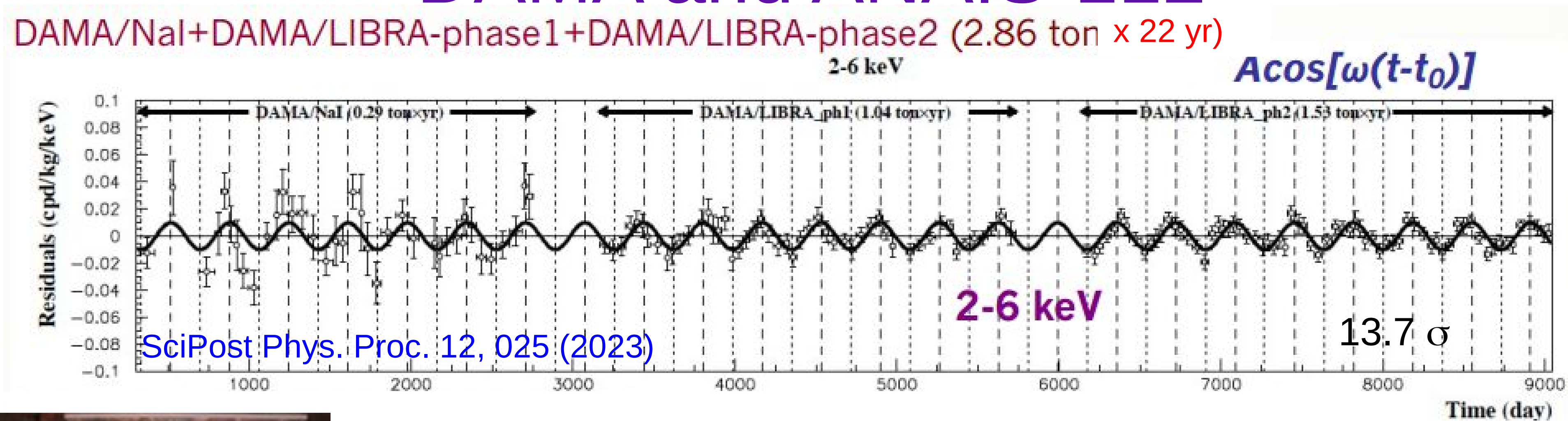
(1 yb = 10^-12 pb = 10^-48 cm^2).

# Direct detection landscape (2021)

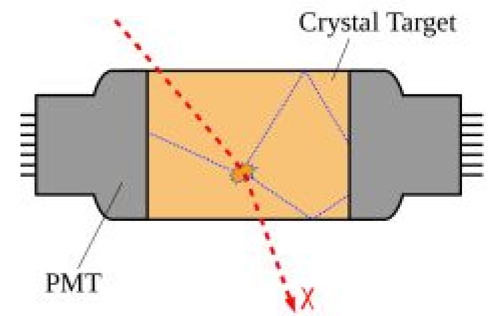



- Spin-independent, with the usual assumptions: Standard Halo Model, isospin parity
- **LAr and LXe dominate searches in the spin-independent sector >~2 GeV/c2**
- Continued search towards the neutrino floor still very well motivated

# DAMA and ANAIS-112

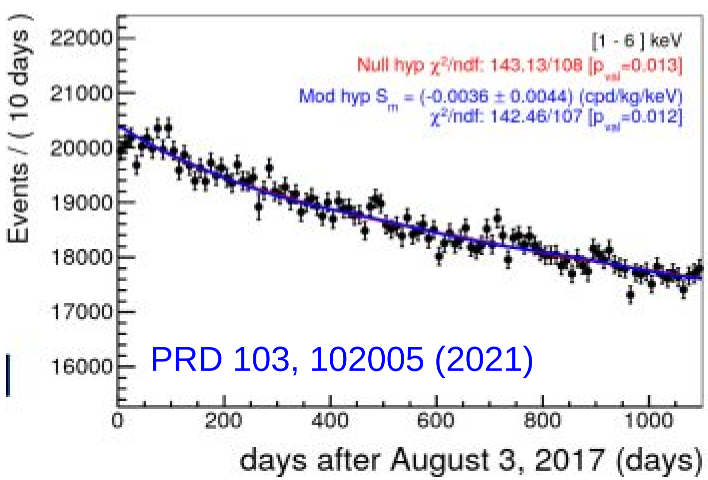


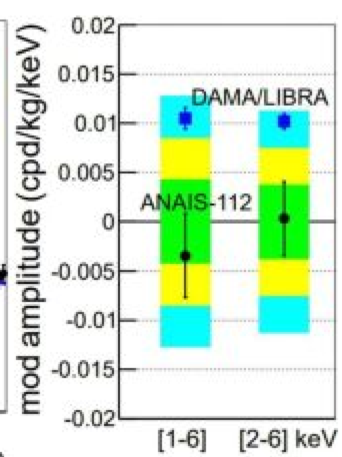

- Annual modulation can be a DM signature DM (or a tricky background)
- DAMA signal in tension with experiments using other target materials
- Several groups attempt to independently verify the claim using a similar NaI(Tl) scintillator technology
- Upgraded DAMA is taking data with reduced thresholc

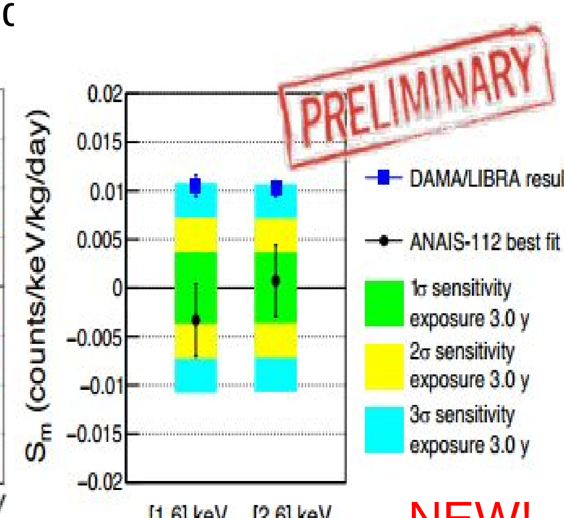



## ANAIS-112:

- First independent result with the same methodology
- Data incompatible with DAMA at >2.5σ, consistent with no modulation
- Ongoing important work on quenching factor systematics



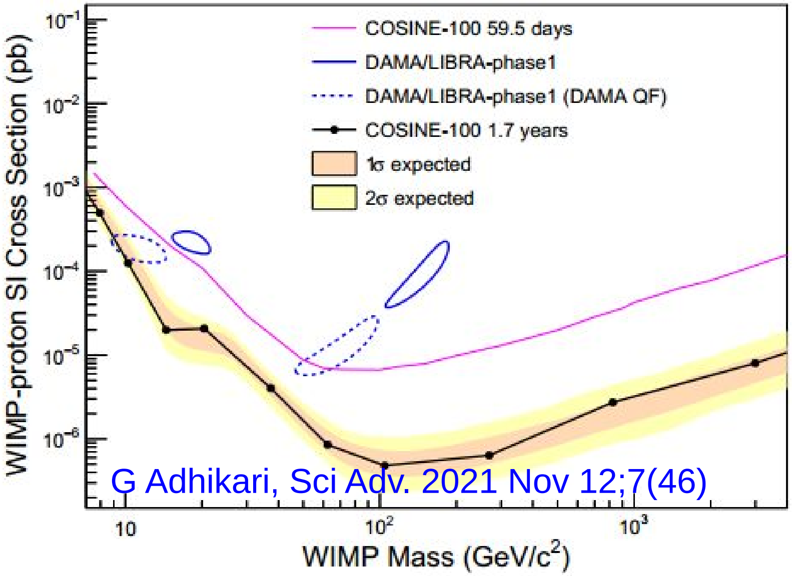




NEW!

# Other DAMA tests

## COSINE-100

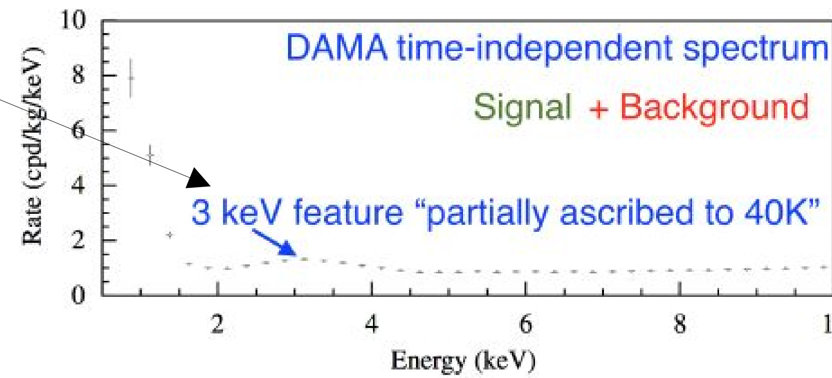



- Modulation search with 2.8 yr of data consistent with both DAMA and no modulation [PRD 106, 052005]
- New result soon (2x exposure and lower threshold)

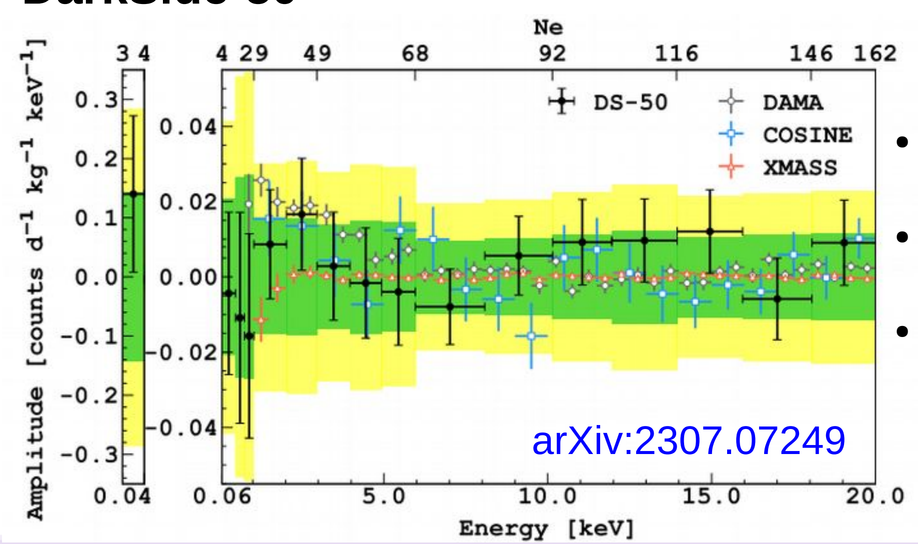
## SABRE

- Same NaI technology as DAMA, independently purified crystals
- 2 detectors planned:
  - North: LNGS
  - South: Australia

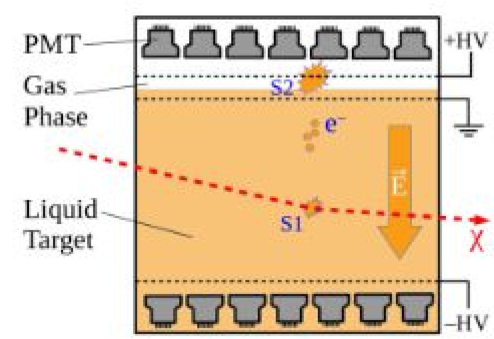
**KDK:** First measurement of direct-to-ground-state EC of $^{40}$K, potential constraint on DM interpretation of DAMA
→ *see M. Stukel's talk (Wednesday)* [PRL 131, 052503 (2023)]



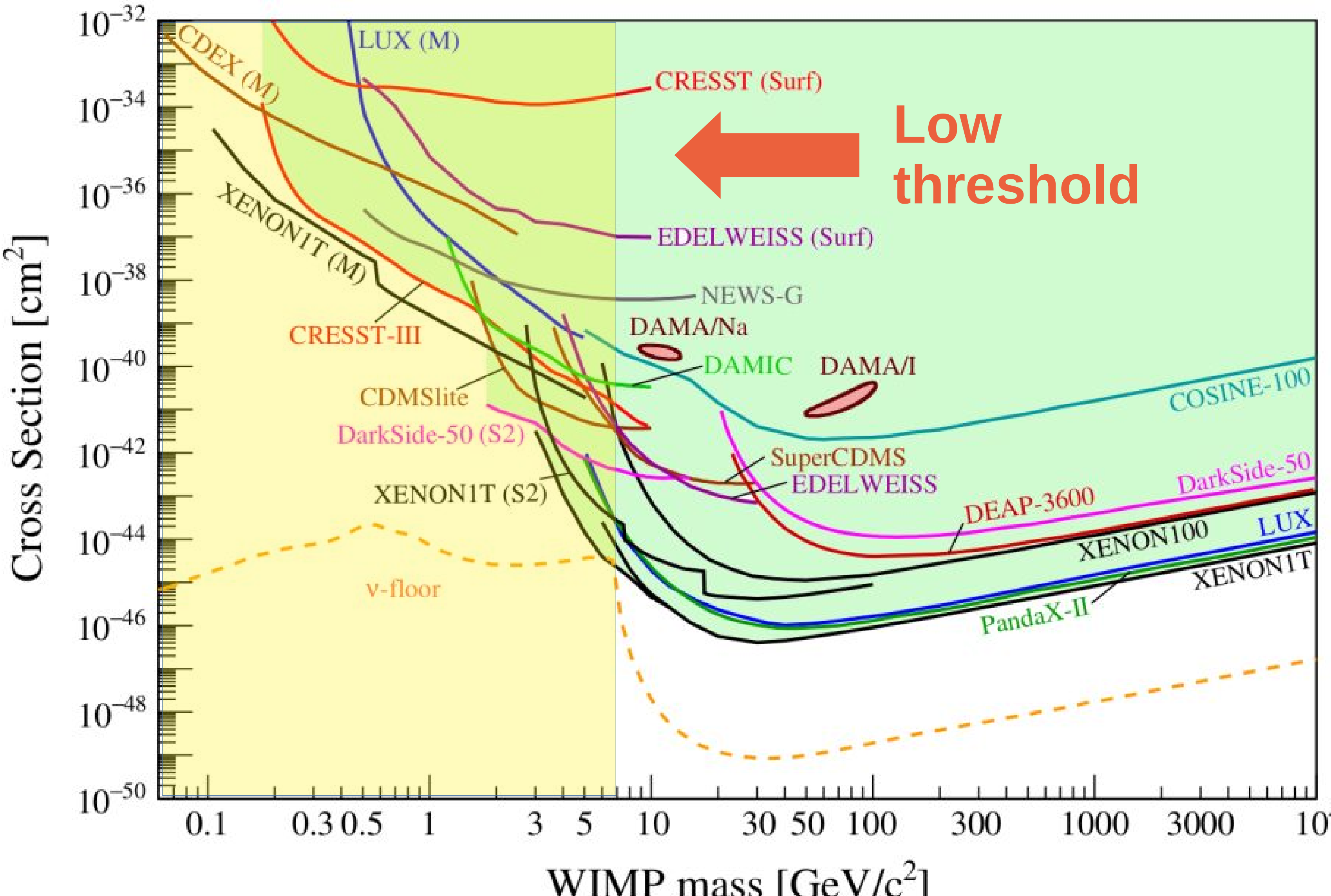

## DarkSide-50




- First annual modulation search using argon
- The lowest energy threshold 0.04 keV
- Neither confirm nor reject DAMA
  → *see T. Hugues' talk (Tuesday)*



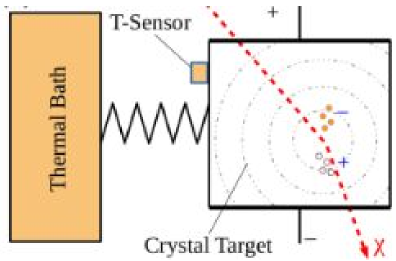
# Status and prospects (1-10 GeV)

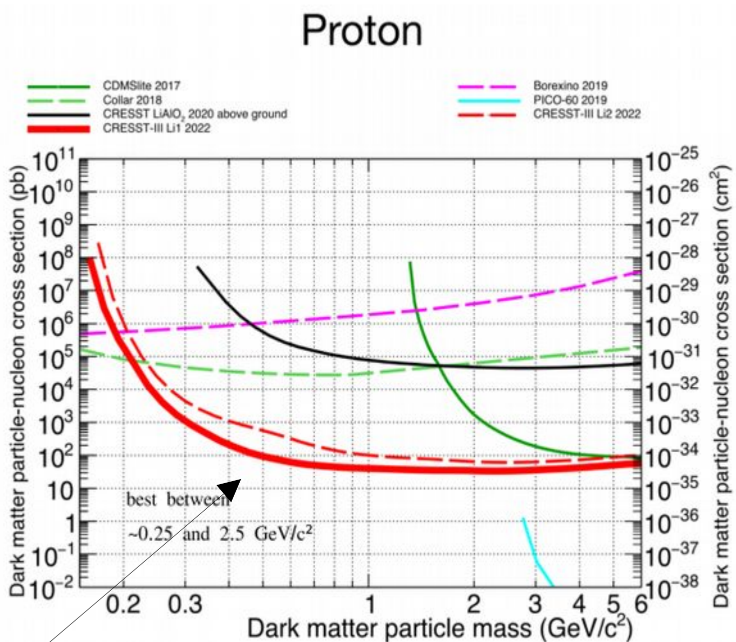


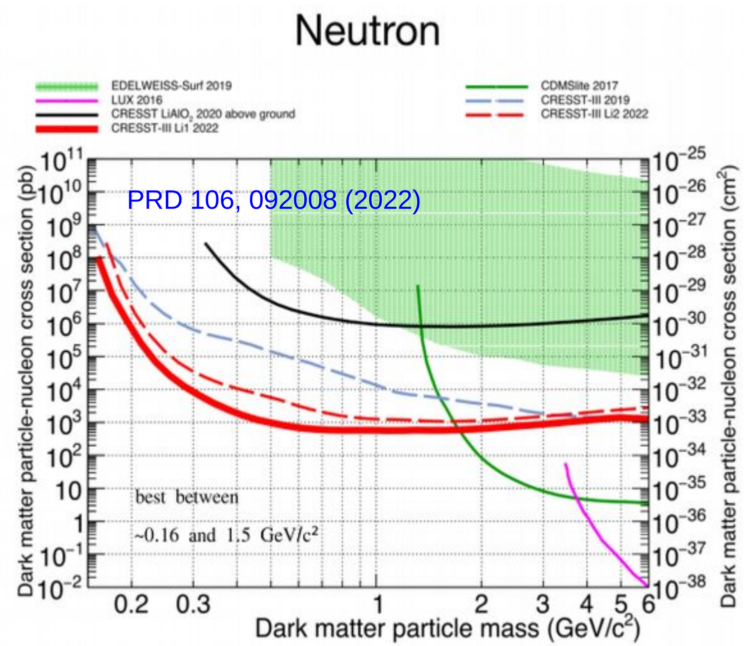

- Leading exclusions from DarkSide-50 and LXe (both S2-only) and CRESST
- Multiple noble liquid-based and other technologies still in play in different parts of the mass spectrum (SuperCDMS, NEWS-G, DAMIC)
- The neutrino floor soon within reach
- Work on low-energy calibration and backgrounds

# Cryogenic bolometers: CRESST

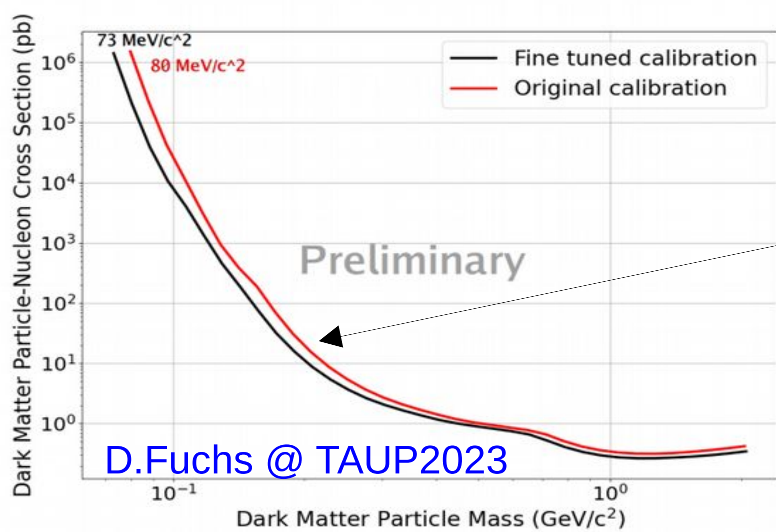
**CRESST-III** (@ LNGS)




- Phonon and light sensitive
- Leading spin-dependent limit
- Ongoing detector upgrade, before resuming data taking

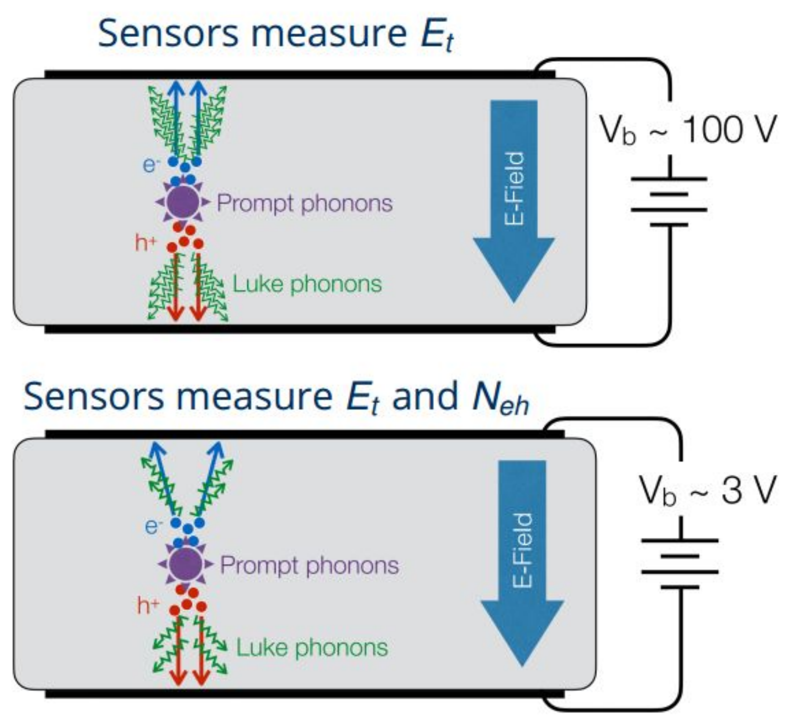


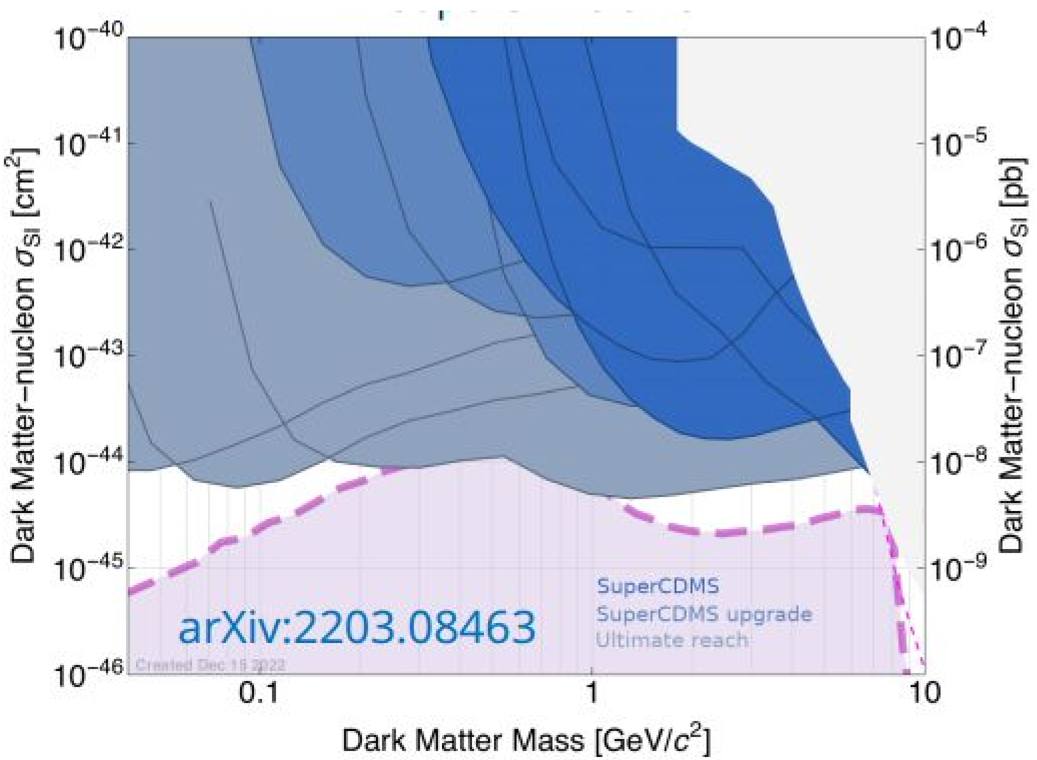

Better exclusion with improved energy calibration (so far demonstrated on one module)

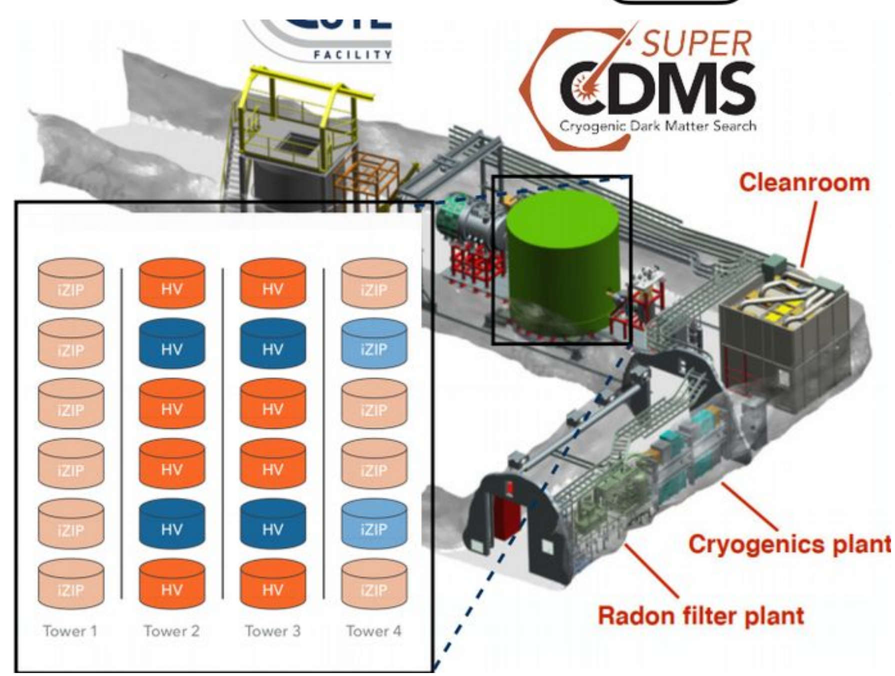
# Cryogenic bolometers: SuperCDMS

**SuperCDMS @ SNOLAB**

- Phonon and ionization sensitive
- Ongoing detector testing and installation at SNOLAB
- 2 types of detectors, optimized either for either low threshold or for background discrimination



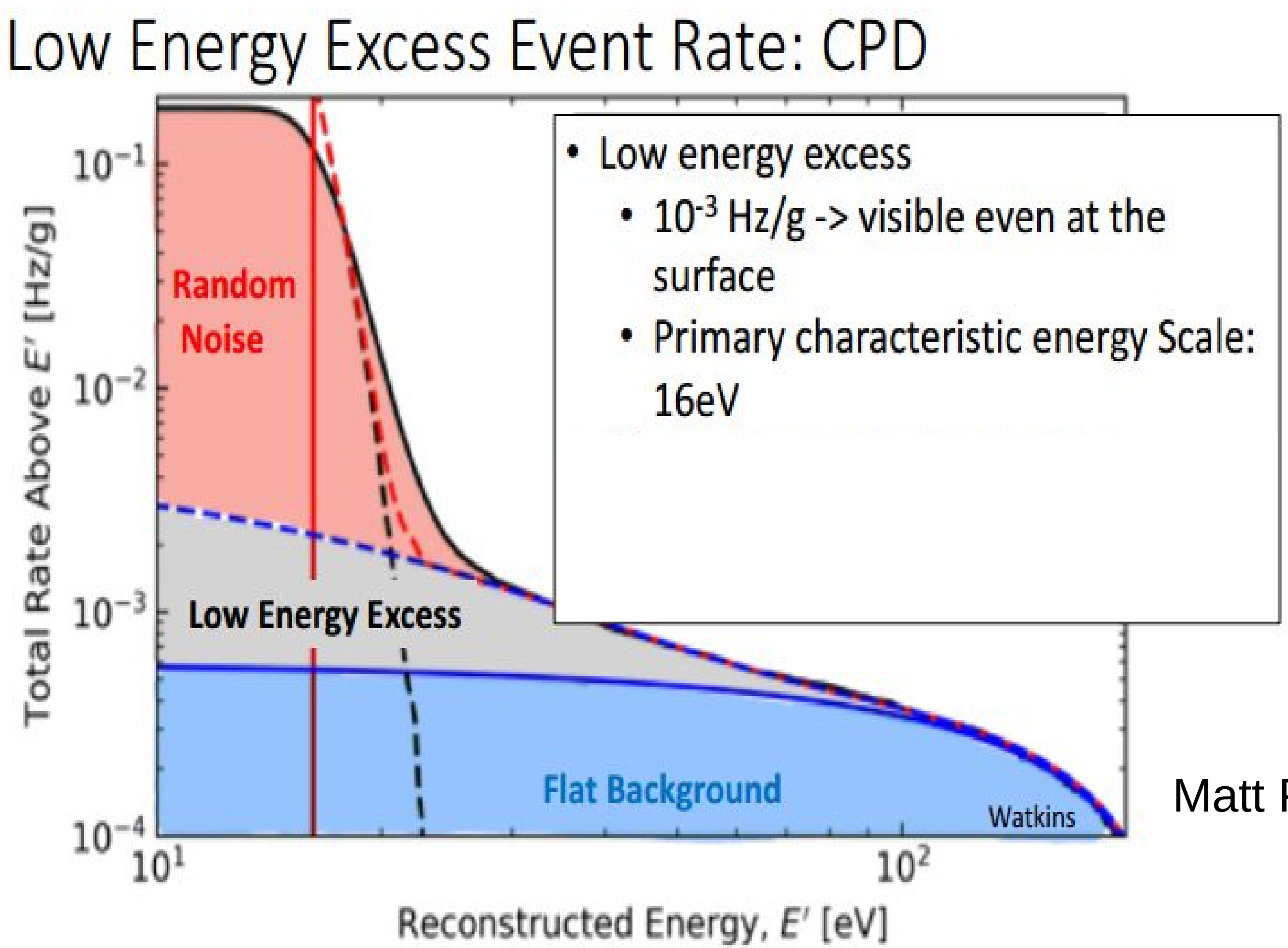




Talk by S. Zatschler at TAUP 2023

# Low energy excess

Observed in Edelweiss, CRESST, SuperCDMS-CPD ...





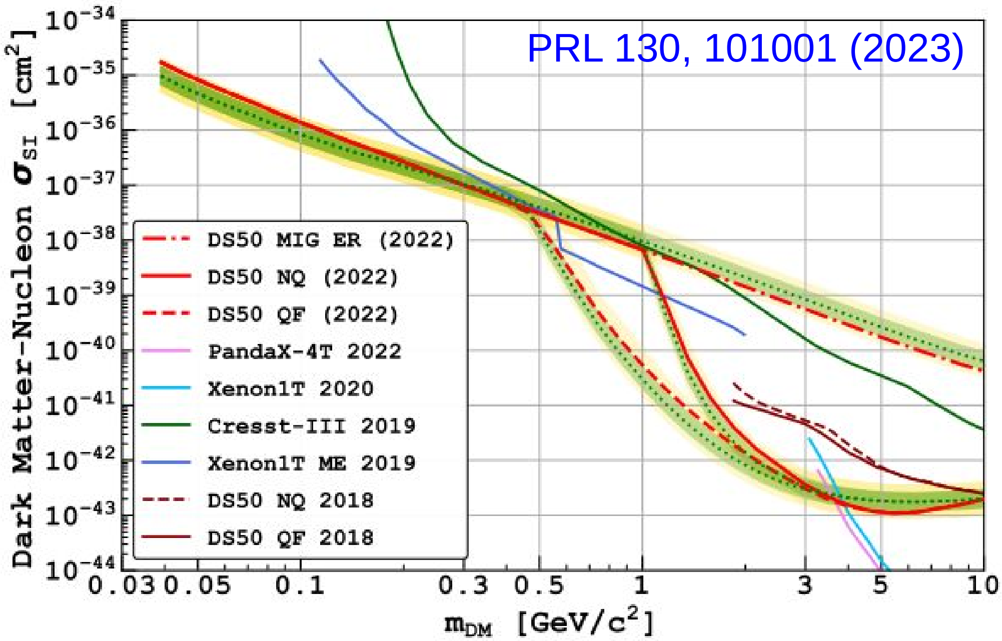
Matt Pyle, EXCESS 22

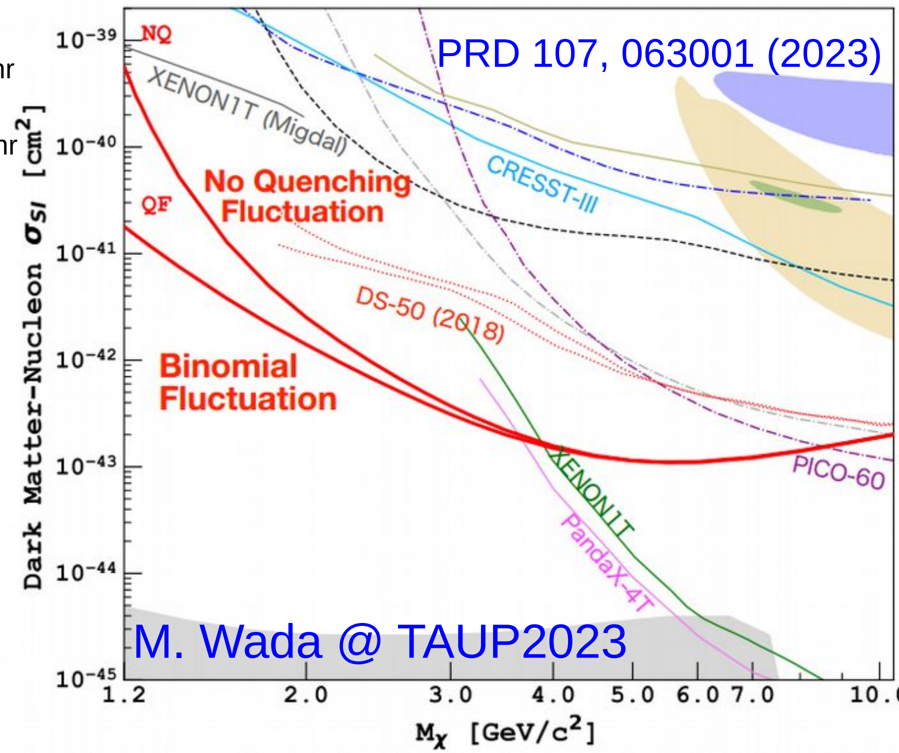
- Frequent cross-collaboration workshops (EXCESS) to tackle this issue, including at TAUP2023
- Great example for the community to follow when dealing with anomalies in the data
- No firm conclusion yet, but... not compatible with WIMPs and most likely not radiogenic

# DarkSide-50 (charge only)

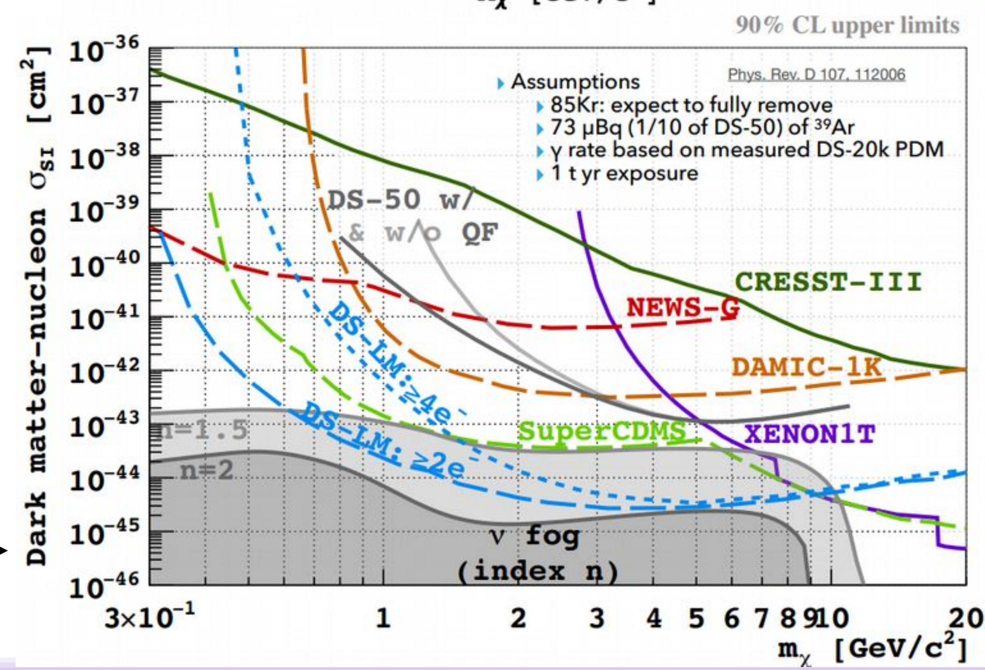
- Scintillation signal (S1): threshold at ~2 $keV_{ee}$ / 6 $keV_{nr}$
- Ionization signal (S2): threshold < 0.1 $keV_{ee}$ / 0.4 $keV_{nr}$

  → With S2 only can achieve lower threshold
- New best limit in this energy window
- Further improved with Migdal effect based limit



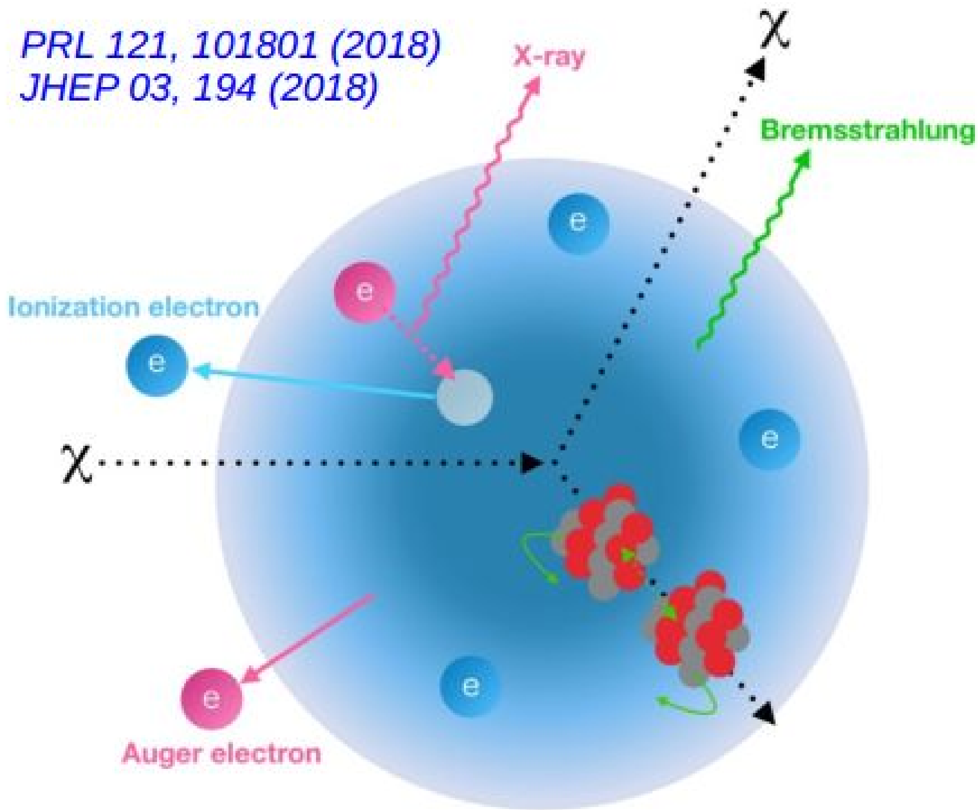

Sensitivity study and proposal for a dedicated 1-tonne scale LAr experiment DarkSide-LowMass to reach the neutrino floor in the 1-10 GeV window.



# Migdal effect

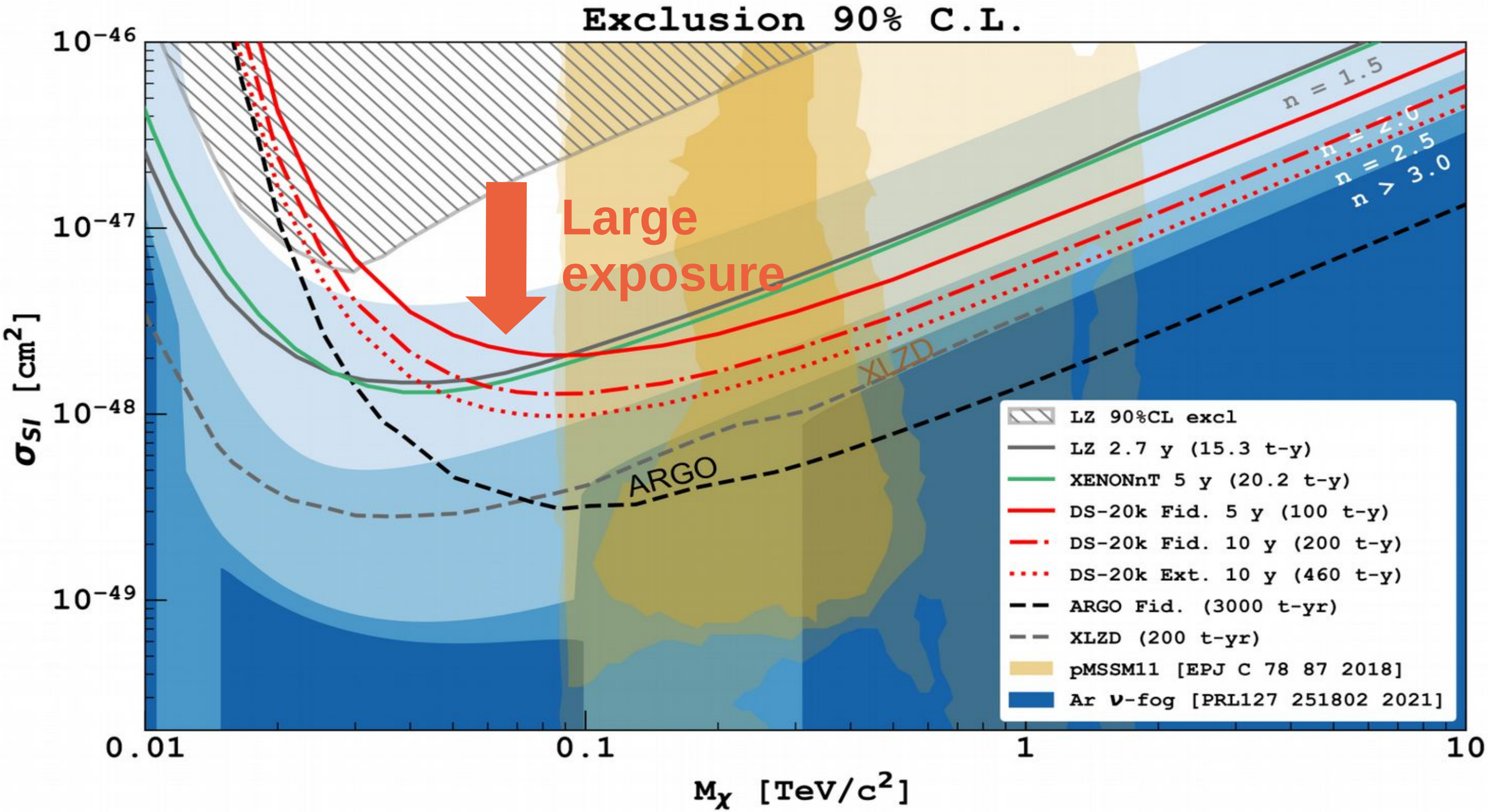
- De-excitation or bremstrahlung from displacement between the electron cloud and nucleus after low energy recoil
- Expected to dominate over ionization at low energies
- Exploited to reduce energy threshold
- Migdal effect not yet observed

PRL 121, 101801 (2018)
JHEP 03, 194 (2018)




- First results from a Migdal effect search in LXe, see Jingke Xu's talk and arXiv:2307.12952 → **lack of Migdal events** at the predicted rate in the expected signal region!
  - Significant implications, if confirmed
  - Possible caveats: enhanced recombination, energy of the events
- Parallel effort by the MIGDAL collaboration; first science run completed (see P. Majewski's talk)

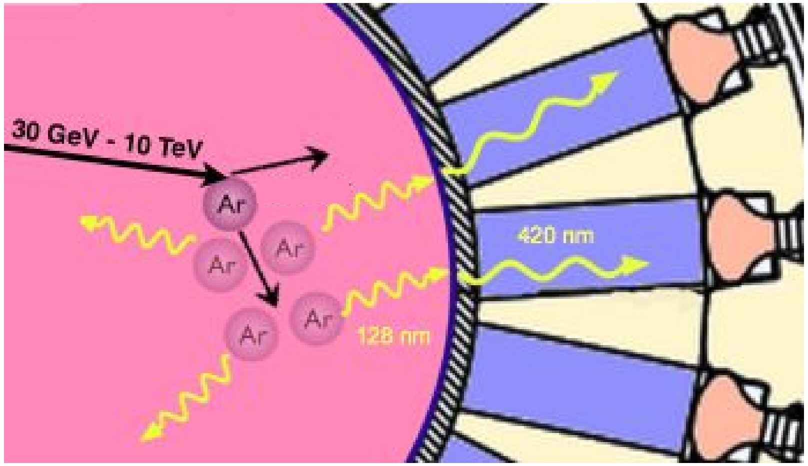
# Status and prospects (>10 GeV)

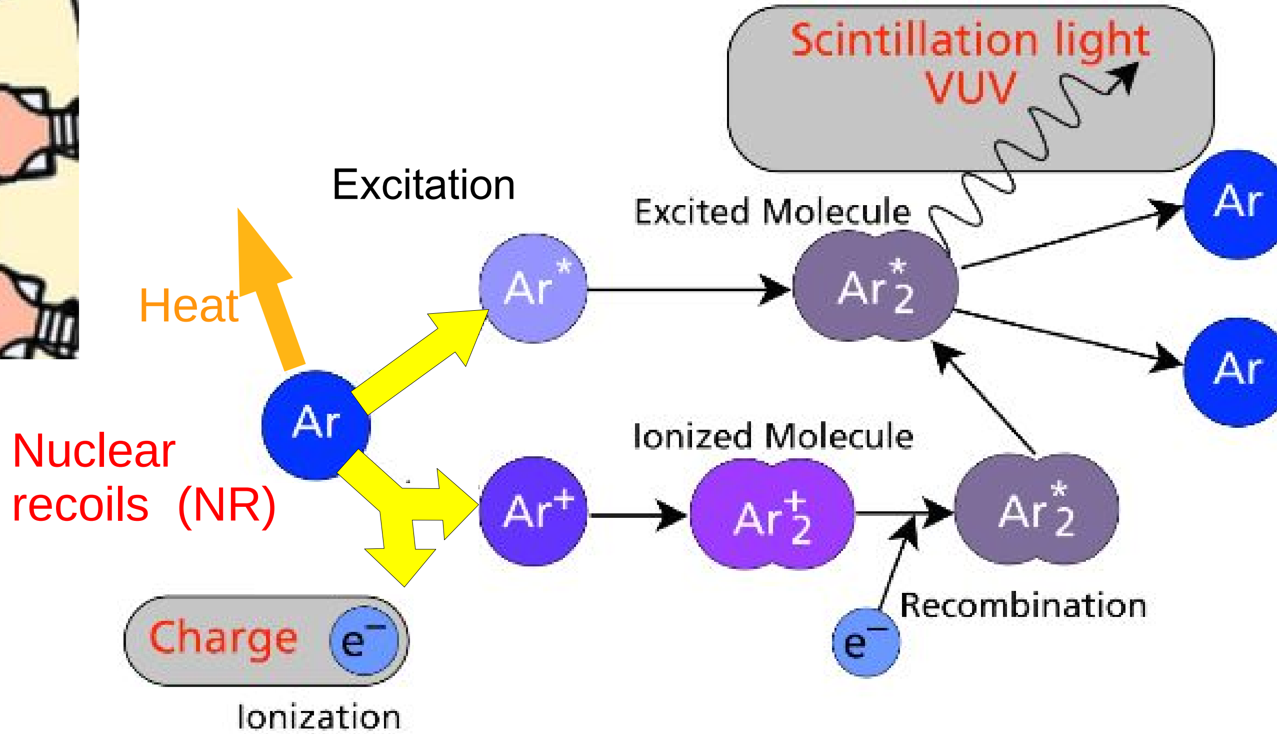



- New results from LZ, XENON-nT and PandaX-4T
- Roadmap in place for reaching the neutrino floor

- **Global consolidation of efforts for the ultimate scale-up:**
  **LAr**: GADMC **LXe**: XENON + LZ + DARWIN = XLZD; PandaX-xT

# Liquid noble detectors




**Ar and Xe are used for WIMP detection.**

- Ar inexpensive and advantageous for purification and background rejection

**Why noble elements?**

- High light yield, transparent to their own scintillation
- Easy to purify and scalable to very high masses
- (At least) two available detection channels: scintillation and ionization

# LXe detectors

2010

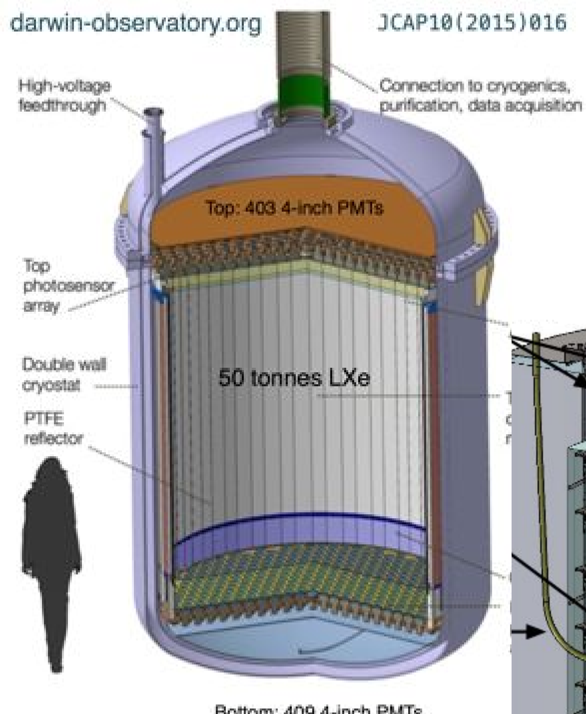
10 kg

**XENON10** (LNGS)
**ZEPLIN II** (Boulby)
**ZEPLIN III** (Boulby)

100 kg

**XENON100** (LNGS)
**LUX** (250 kg, SURF)
**PandaX** (500 kg, CJPL)

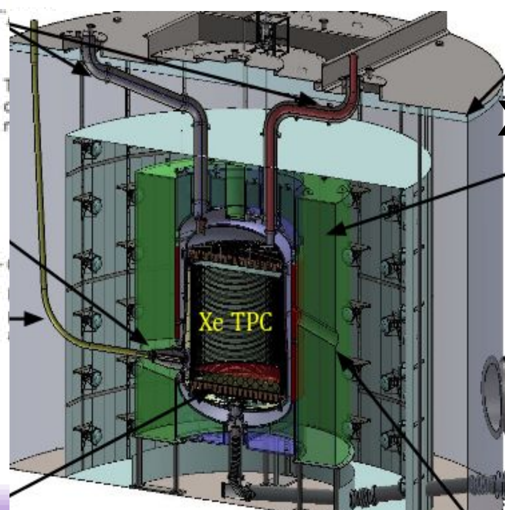
2015




**XMASS** (0.8t, Kamioka)

1000 kg

**XENON1T** (1t, LNGS)




**PandaX-4T** (4t, CJPL)
**XENONnT**: (6t, LNGS)
**LZ**: (7t, SURF)

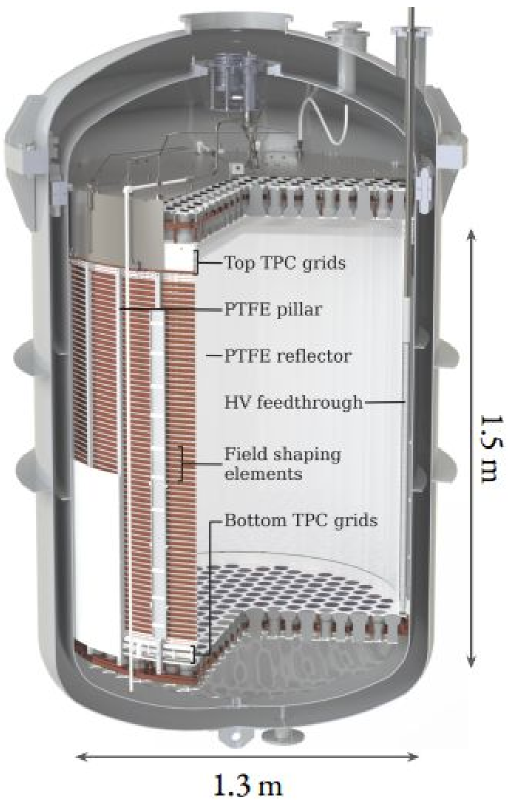
2020

10000 kg

**XLZD**: 40-60 t
**PandaX-xT**: >30 t

Slide courtesy J. Monroe

# Spin-independent limit: XENONnT




**Xe target mass** (×3 XENON1T)

~ 6 tonne in active volume

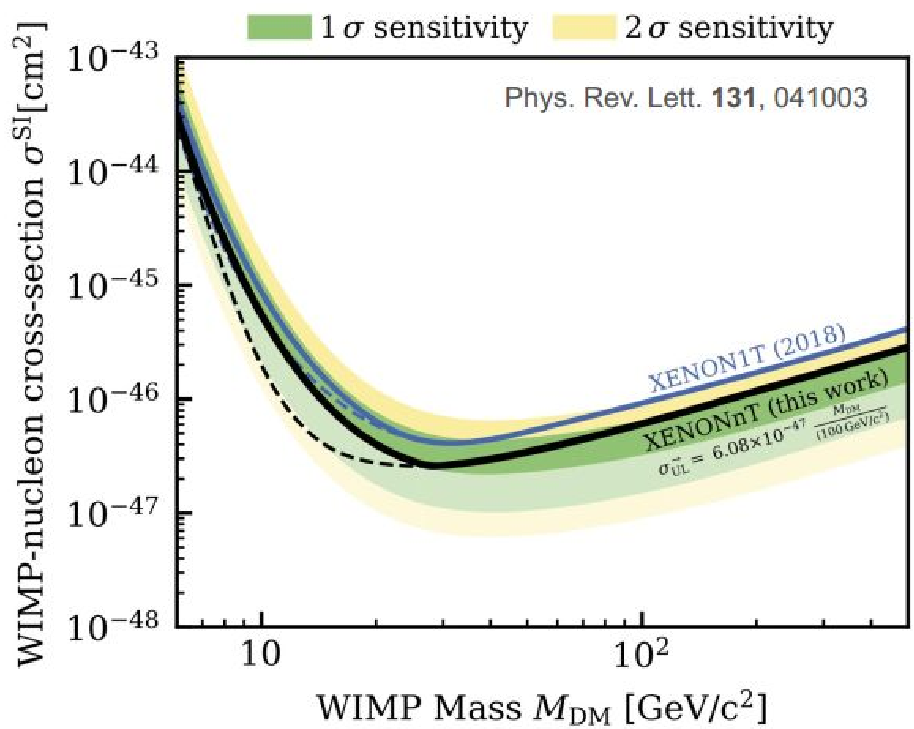
~ 4 tonne in SR0 WIMP fiducial volume

**Electric fields**

Drift field = 23 V/cm

Extraction field = 2.9 kV/cm

(extraction efficiency ~ 50%)

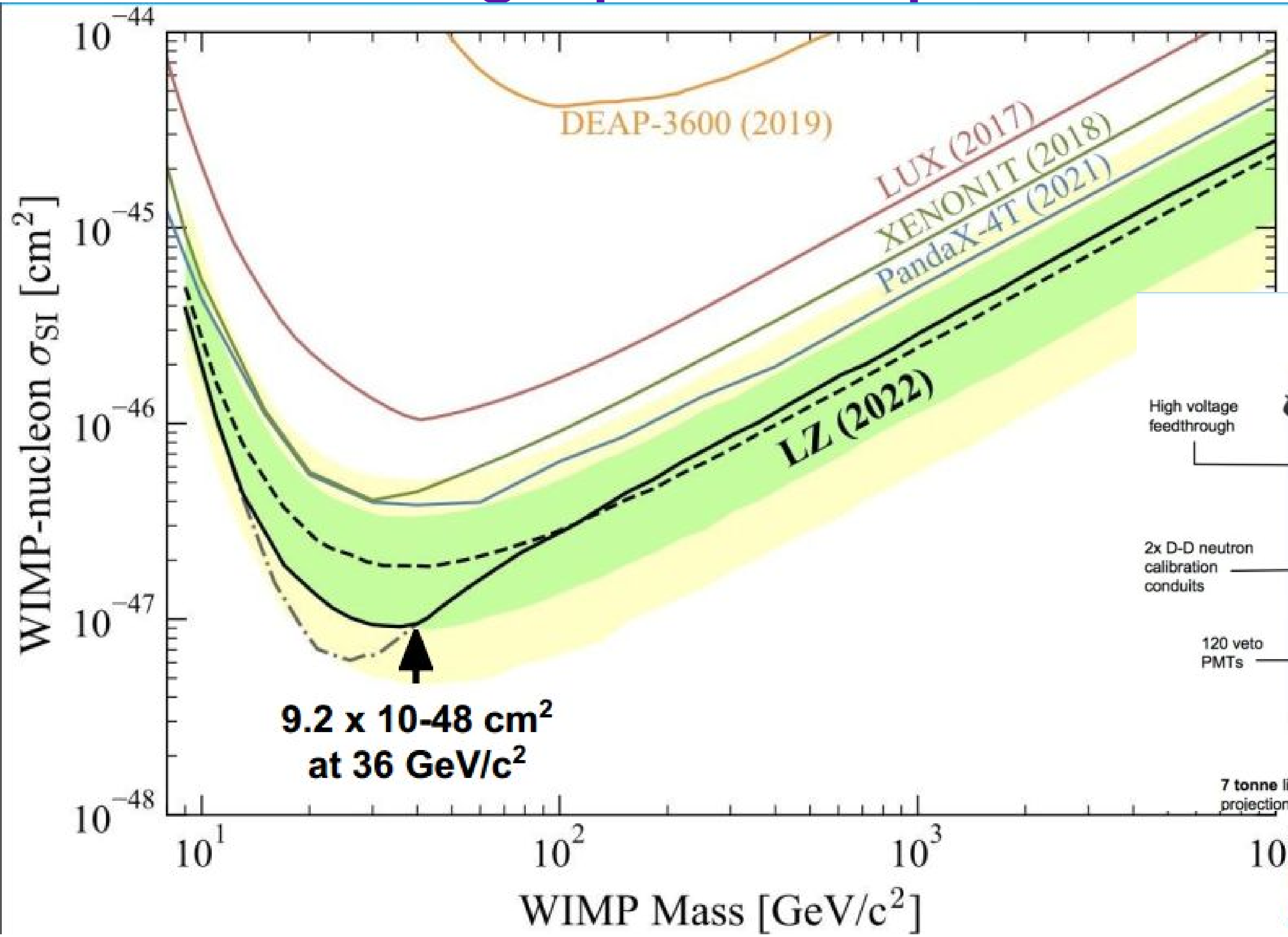


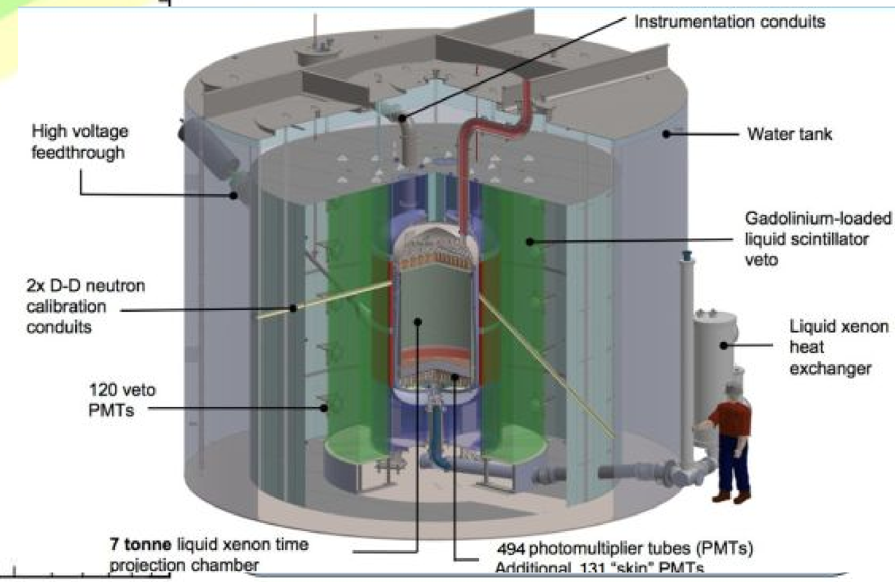

**XENONnT TPC**

- Exposure = 4.2 tonne $\times$ 95 days ~ total XENON1T exposure
- Backgrounds within expectations
- No significant excess is observed
- Minimal upper limit is 2.58 $\times$ $10^{-47}$ cm2 for 28 GeV / $c^2$ WIMP
- Continued data taking ongoing; combined blind analysis on the way

Zihao Xu @ TAUP2023

# Leading spin-independent limit from LZ



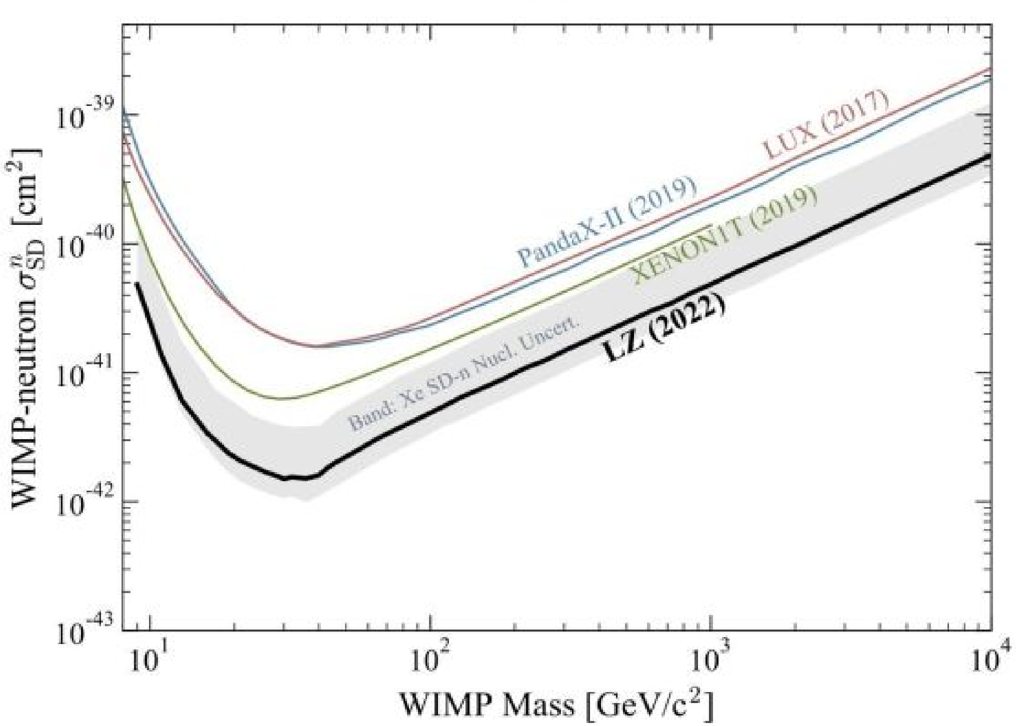

First dark matter search result from the LZ Experiment
Phys. Rev. Lett. 131, 041002 (2023)

- Exposure = 5.5 tonne ╳ 60 days
- Backgrounds within expectations
- Planning for a total 1000 live days (x 17 more exposure)

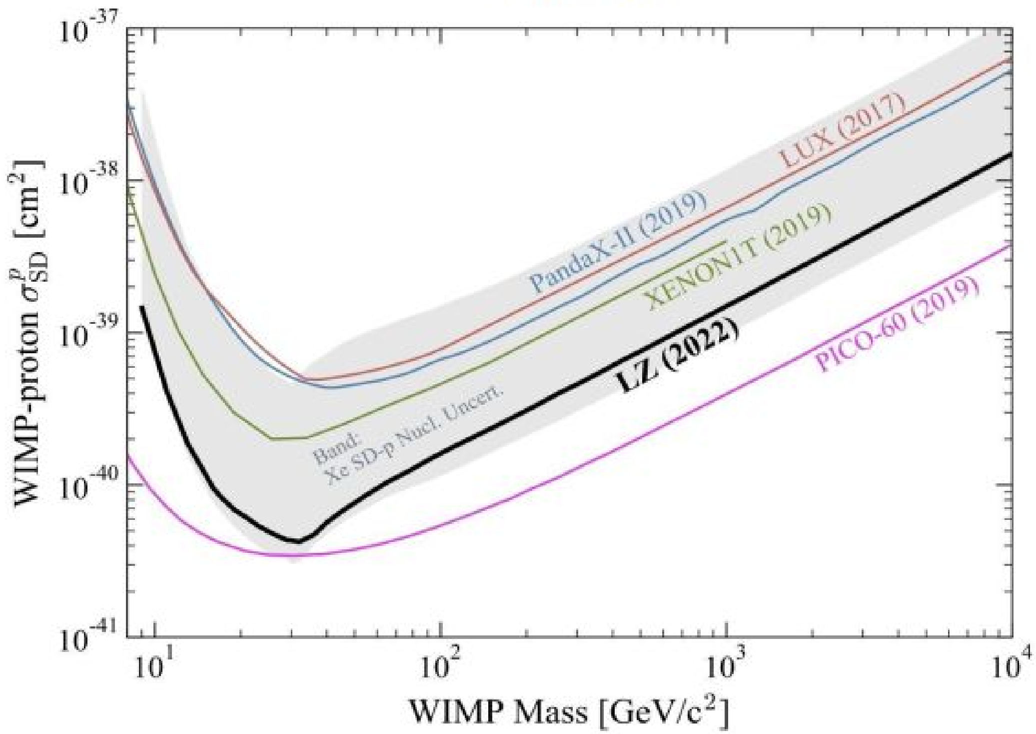
Billy Boxer @ TAUP2023

# Spin-dependent limits

Spin-dependent WIMP-neutron scattering




Spin-dependent WIMP-proton scattering




B. Boxer @ TAUP 2023;   PRL 131, 041002 (2023)

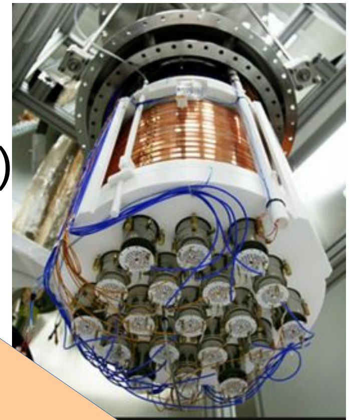
- Coupling of WIMP to unpaired nucleon spins
- Fluorine based target (PICO-60) remain on the lead for WIMP-proton cross-section
- LXe detectors dominate the WIMP-neutron sector
- Same parameter space explored by indirect and collider searches

# Liquid argon detectors

2010

10 kg

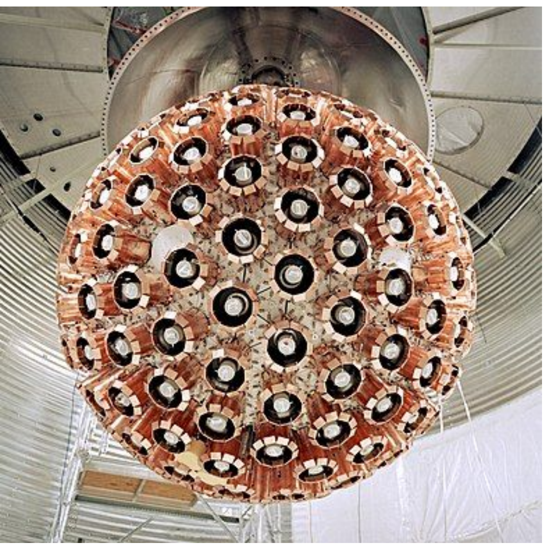
**DarkSide-50**
(50 kg, LNGS)



100 kg

- More than 300 scientists from 15 countries and 60 institutions
- Officially supported by underground labs: LNGS, LSC, and SNOLAB

**ArDM** (1t, LSC)

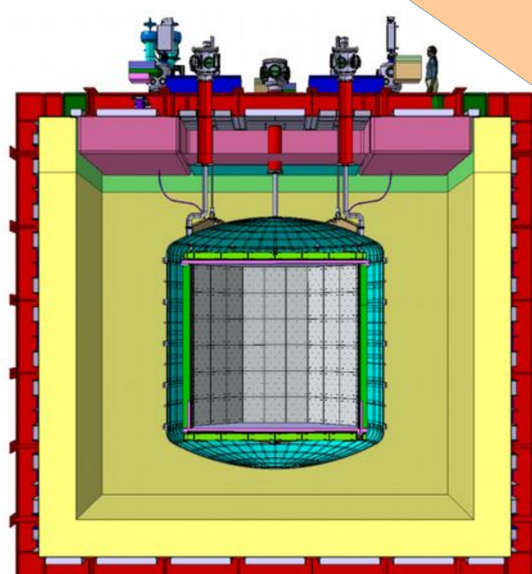


1000 kg

2015

**DEAP-3600** (3.3t, SNOLAB)

**Global Argon Dark Matter Collaboration formed**



2020

**DarkSide-20k**
(50t, LNGS)

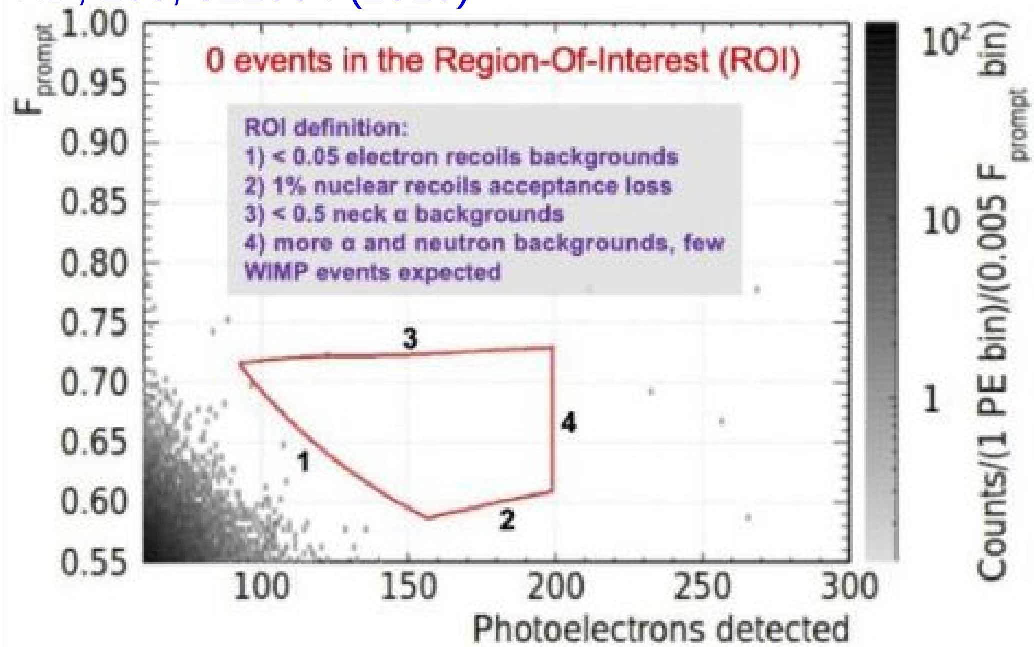
100000 kg

**ARGO**: 400 t

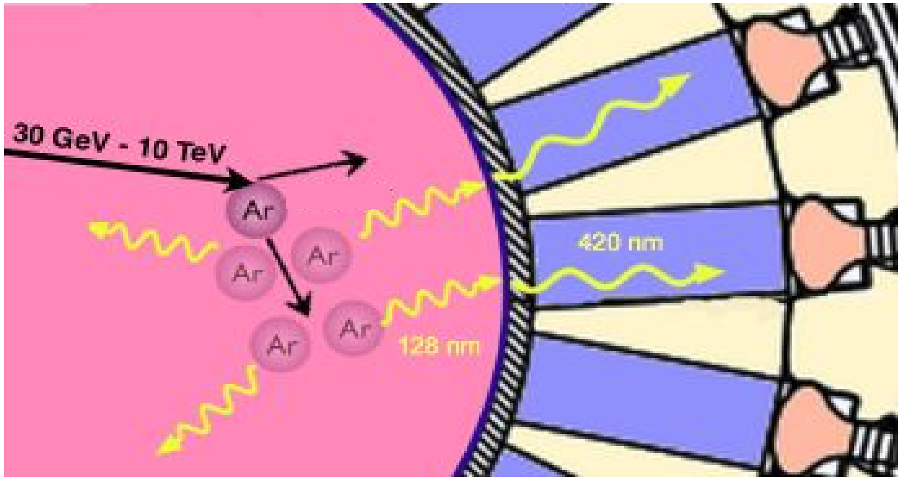
Slide courtesy J. Monroe

# DEAP-3600 status

PRD, 100, 022004 (2019)




Single-phase, scintillation only, LAr target




- Zero observed backgrounds, leading exclusion with LAr
- Excellent control over main background types, leading edge among other experiments:
  - $^{222}$Rn: 0.153(5) µBq/kg
  - $^{220}$Rn: 4.3(1.0) nBq/kg,
- Further sensitivity improvements **limited by backgrounds from alpha activity in the neck of the detector**: ongoing hardware fix to the alpha backgrounds problem
- Analysis on 388 live-days of open data almost ready to publish! Open+Blind analysis results based on 813 live-days of data will follow
- **Other DM searches and physics analyses**

| | Source | $N^{CR}$ | $N^{ROI}$ |
|---|---|---|---|
| β/γ's | ERs | $2.44 \times 10^9$ | $0.03 \pm 0.01$ |
| | Cherenkov | $< 3.3 \times 10^5$ | $< 0.14$ |
| n's | Radiogenic | $6 \pm 4$ | $0.10^{+0.10}_{-0.09}$ |
| | Cosmogenic | $<0.2$ | $<0.11$ |
| α's | AV surface | $<3600$ | $< 0.08$ |
| | Neck FG | $28^{+13}_{-10}$ | $0.49^{+0.27}_{-0.26}$ |
| | **Total** | N/A | $0.62^{+0.31}_{-0.28}$ |

Backgrounds budget

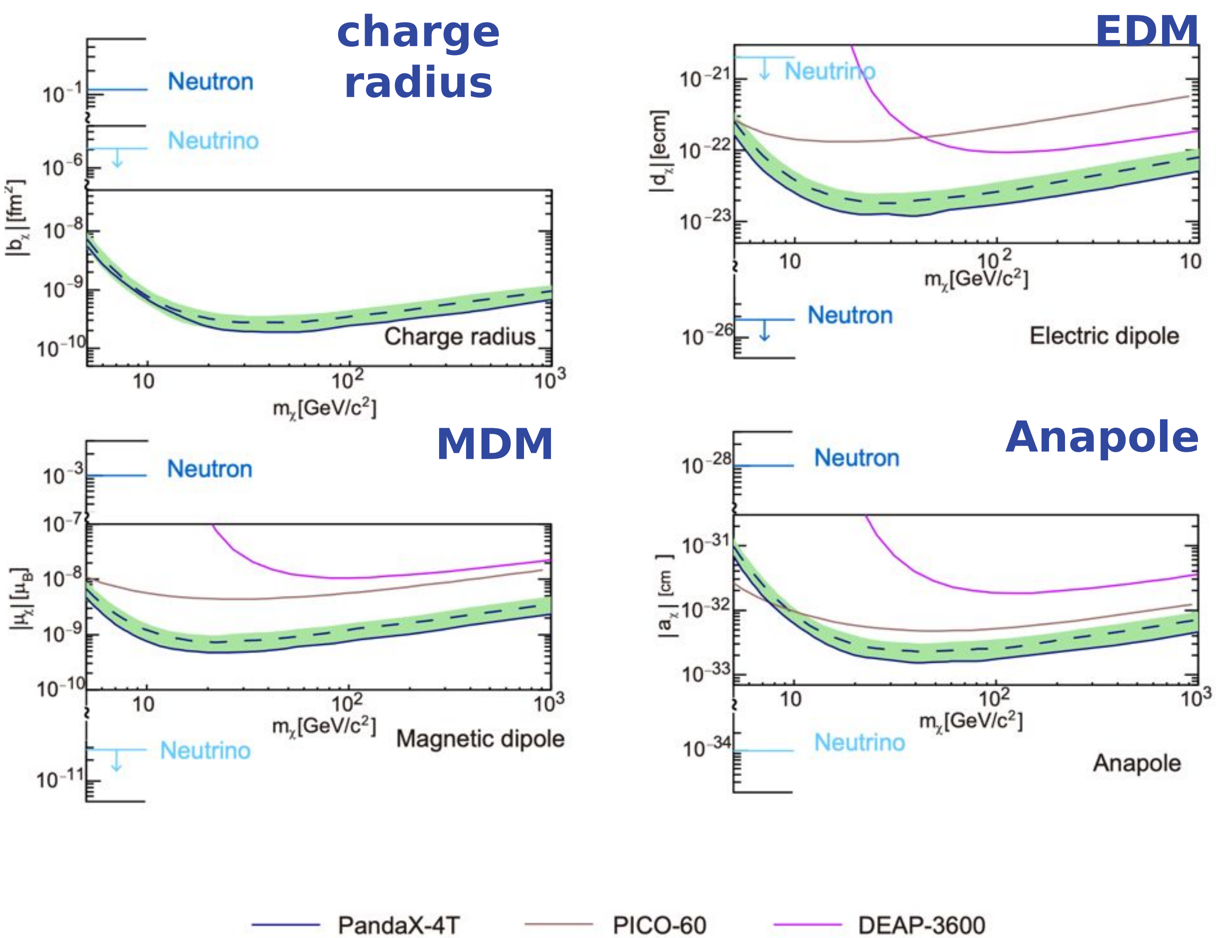
see Simon Viel @ TAUP 2023

# EFT and exotic interactions: PandaX-4T, LZ

Framework mapping and allowing to test all possible interactions of DM with nucleons.

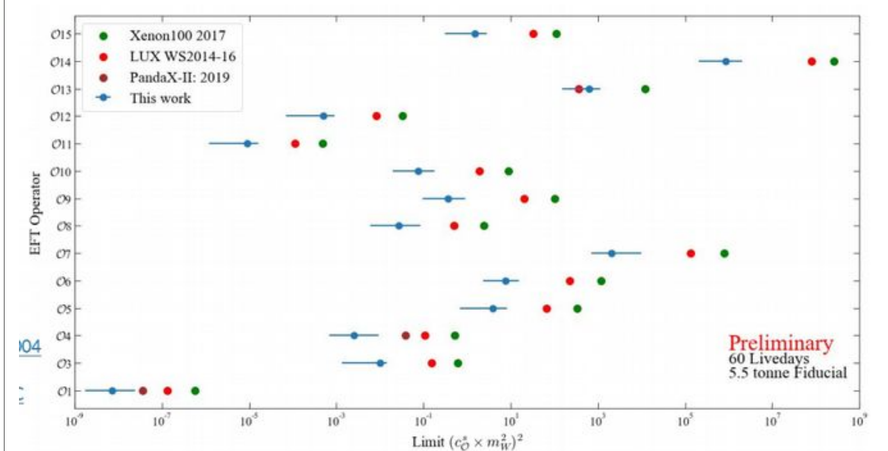
- **PandaX-4T:** First experimental constraints on DM charge radius from PandaX
  - 4 orders of magnitude smaller than neutrino

X. Ning et al. Nature 618, 47-50 (2023)




→ see Ning Zhou's talk on Monday

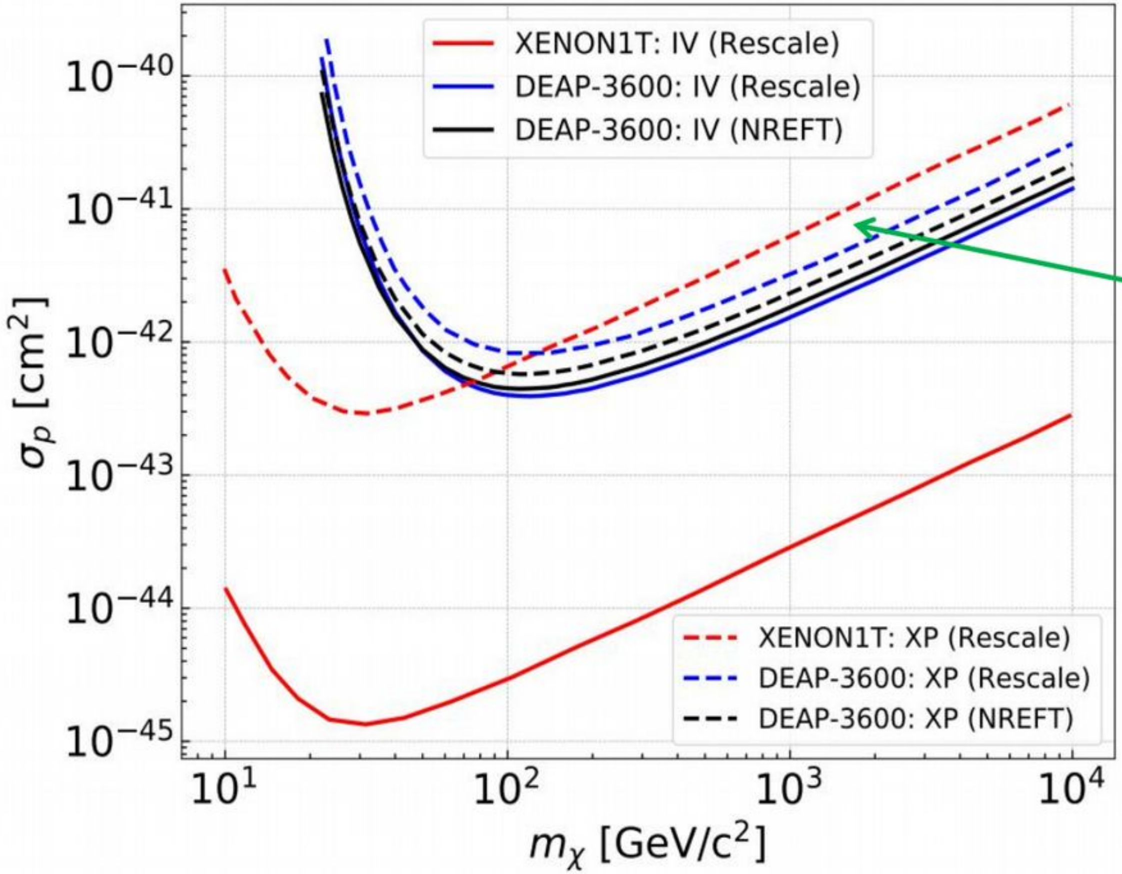
**LZ:**
60 livedays LZ limits on elastic and inelastic operators, comparison with PandaX-II, LUX and XENON100




→ see Michael Williams' talk (Monday)

# Effects of isospin parity breaking

P. Adhikari et al. (DEAP-3600 Collaboration), Phys. Rev. D **102**, 082001 (2020)

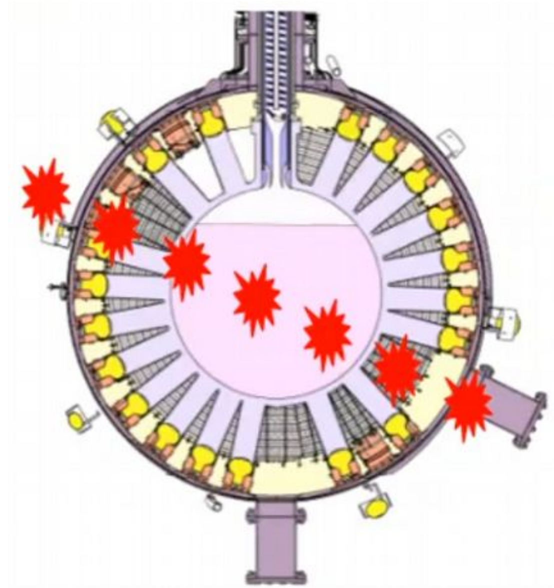


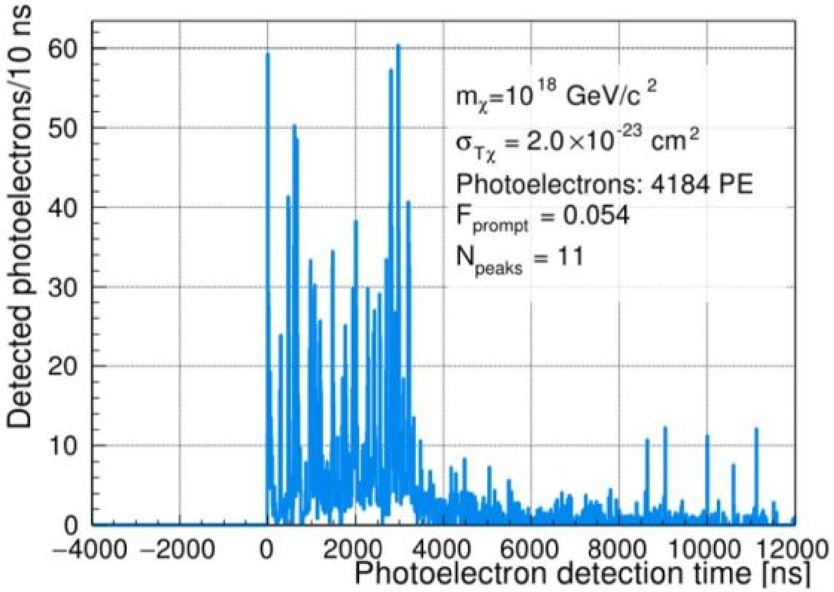

Region where DEAP-3600 sets stronger limits than XENON1T by considering the XP scenario.

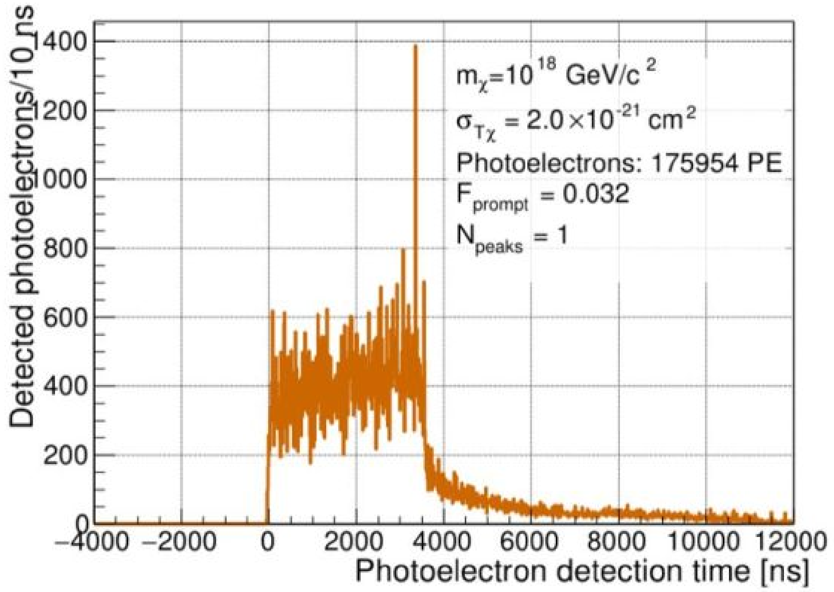
Using NREFT + XP (black dash line), the region increases. While the Helm form factor doesn't change assuming $c_n \neq c_p$, in the NREFT formalism the form factor does.

# Planck-scale mass multi-scattering dark matter

- a.k.a multiply-interacting massive particles (MIMPs)
- DM candidates above $\sigma_{\chi\text{-}n} \cong 10^{-25}$ cm$^2$ and $m_\chi \gtrsim 10^{12}$ GeV lose a negligible amount of energy in the scatterings with the Earth nuclei and can reach underground detectors designed for WIMP search.
- Event signature:
  - Contains multiple nuclear recoil scatters
  - In LAr apparent electronic recoil-like event

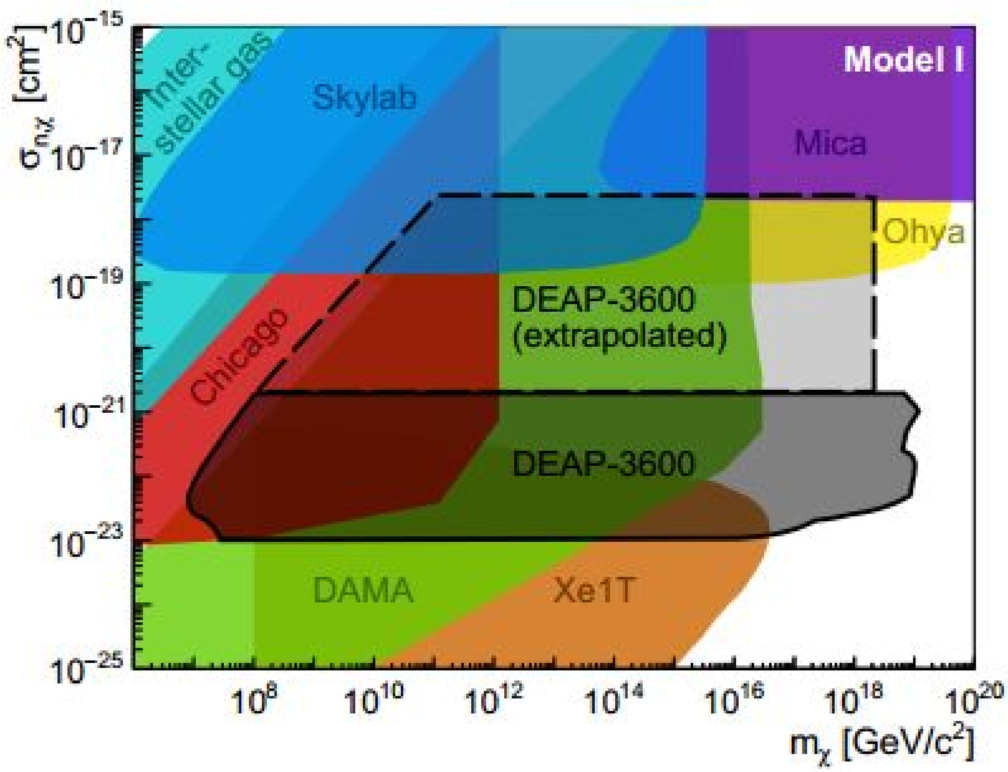


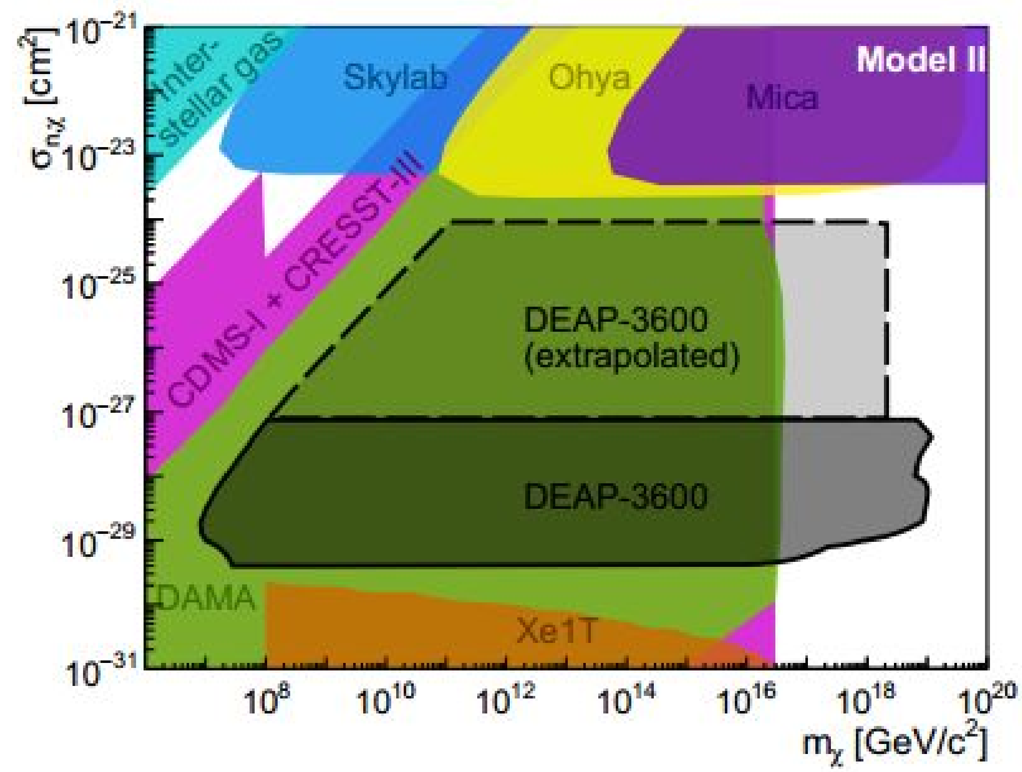


# Planck-scale mass DM exclusion

- P. Adhikari et al. (DEAP Collaboration), Phys. Rev. Lett. 128, 011801 (2022)
- 813 live-days, blind analysis
- TAUP2021 exclusion for candidates at Planck-scale masses




$$\sigma_{T\chi} = \sigma_{n\chi} |F_T(q)|^2$$

(relevant for composite DM models)

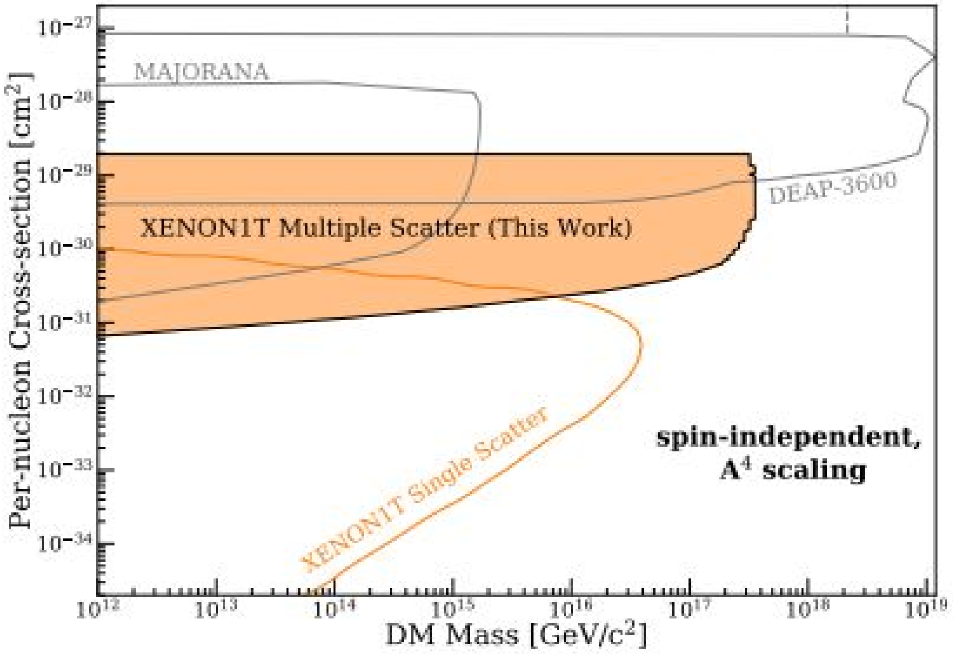
$$\sigma_{T\chi} \simeq \sigma_{n\chi} A^4 |F_T(q)|^2$$

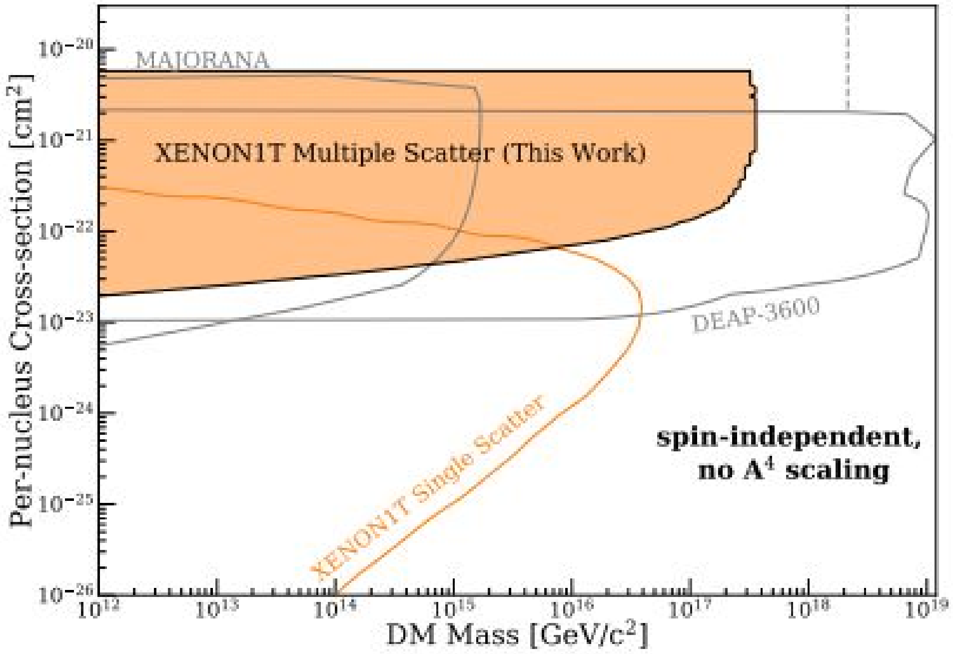
# New Planck-scale DM result from XENON1T

Spin-independent:

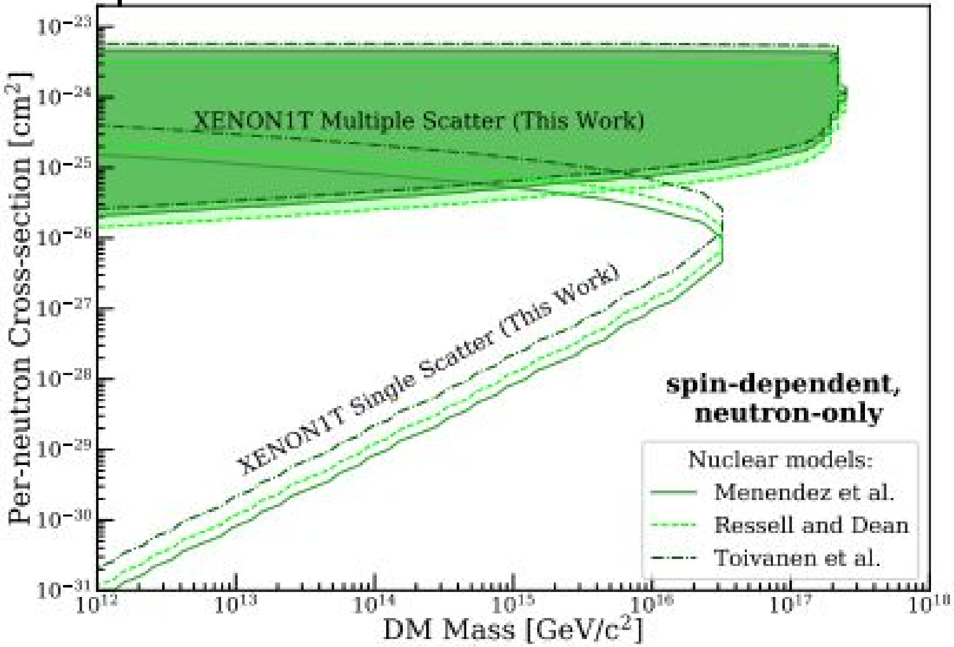
Talk by Shengchao Li at TAUP 2023

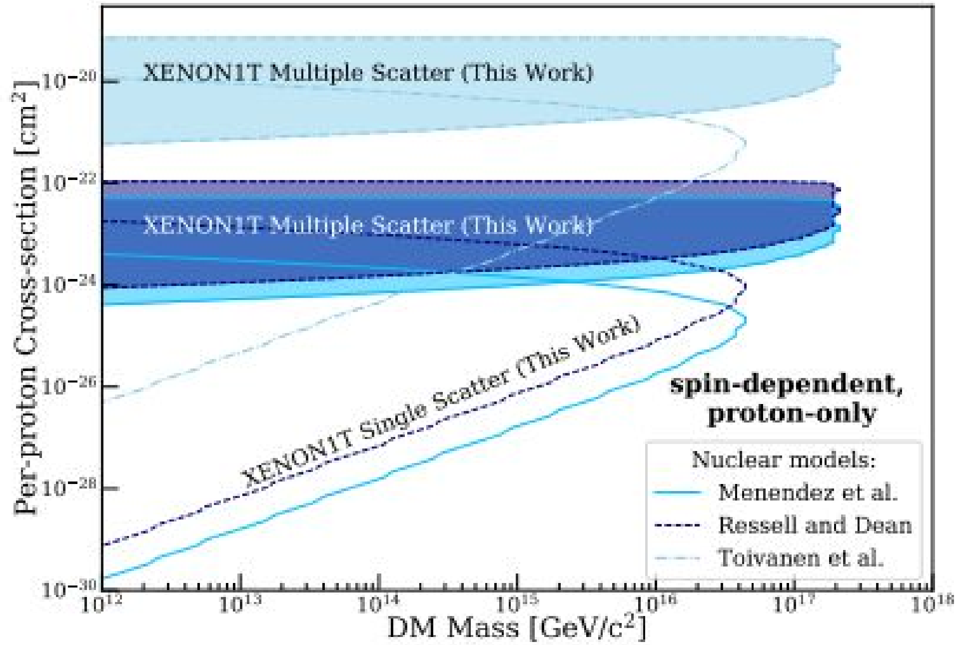
Phys. Rev. Lett. 130, 261002 (2023)



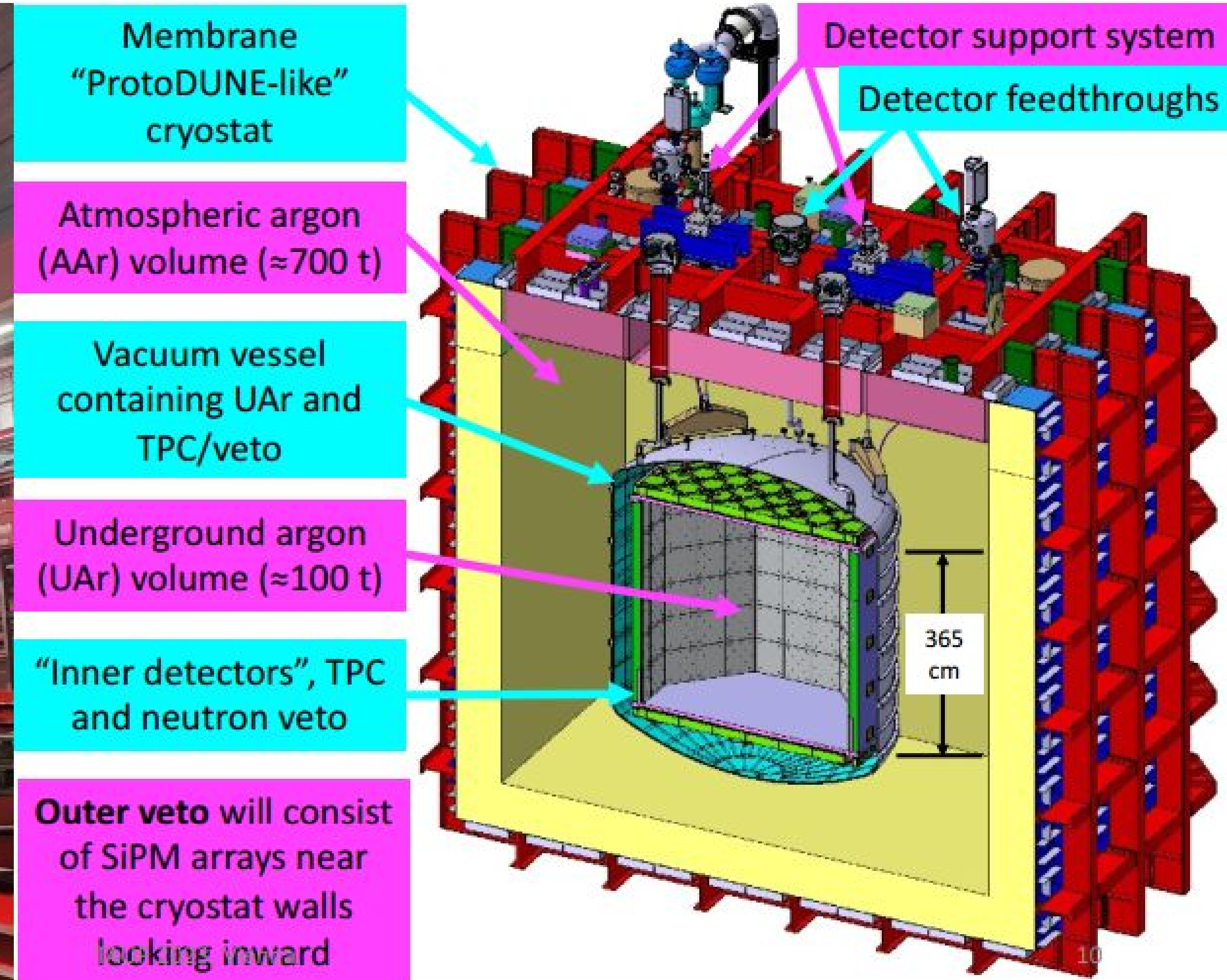




Spin-dependent:



# DarkSide-20k status

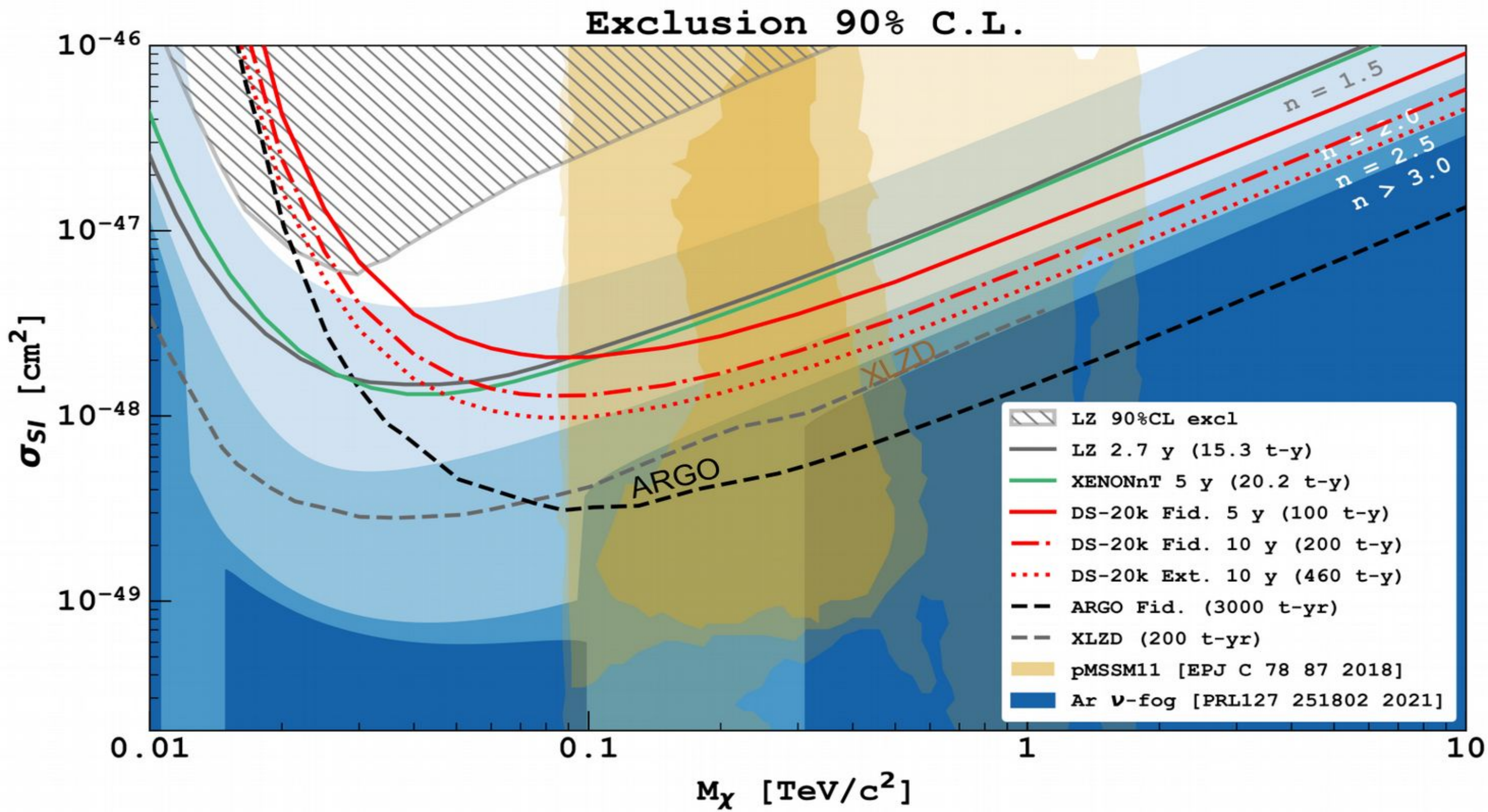

TPC + neutron veto:

- Octagonal shape dual phase argon TPC:
  - Active UAr mass: 49.7 tonnes;
  - Fiducial UAr mass: 20.2 tonnes;
- Neutron veto:
  - Active UAr mass: 32 tonnes

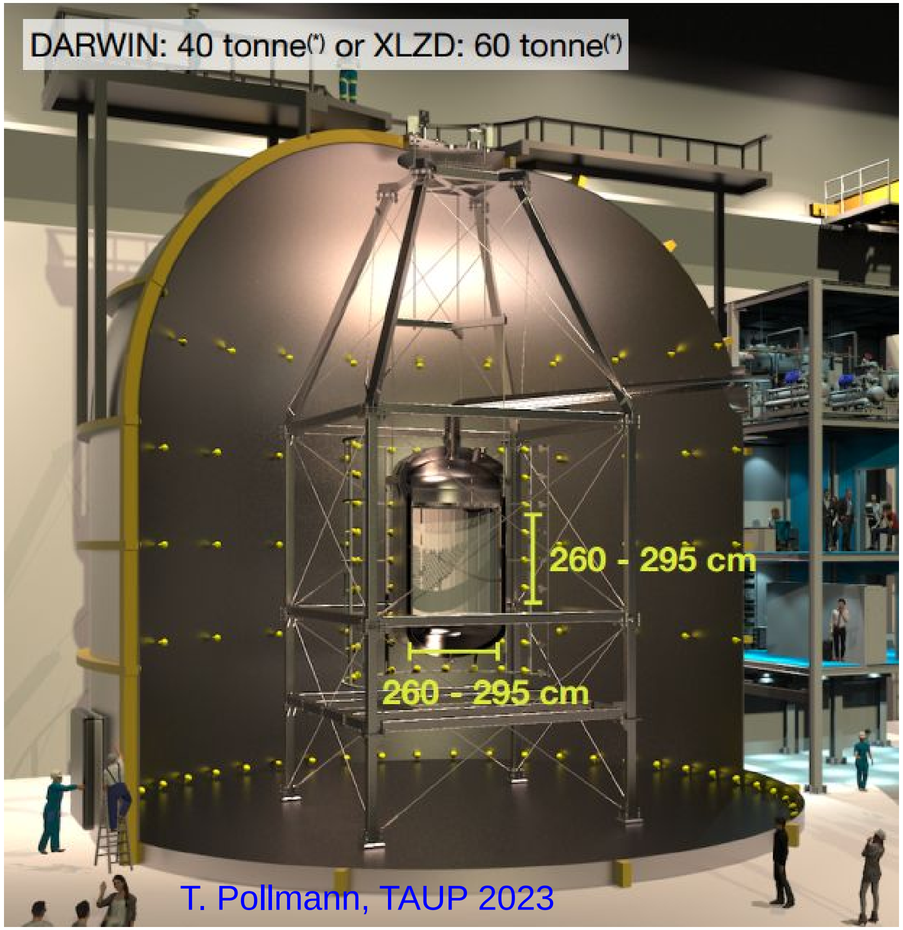
- DarkSide uses dual-phase argon TPC
- Underground Argon with reduced 39Ar contamination
- DarkSide-20k is entering the construction phase;
- Will start filling the detector by the end of 2026

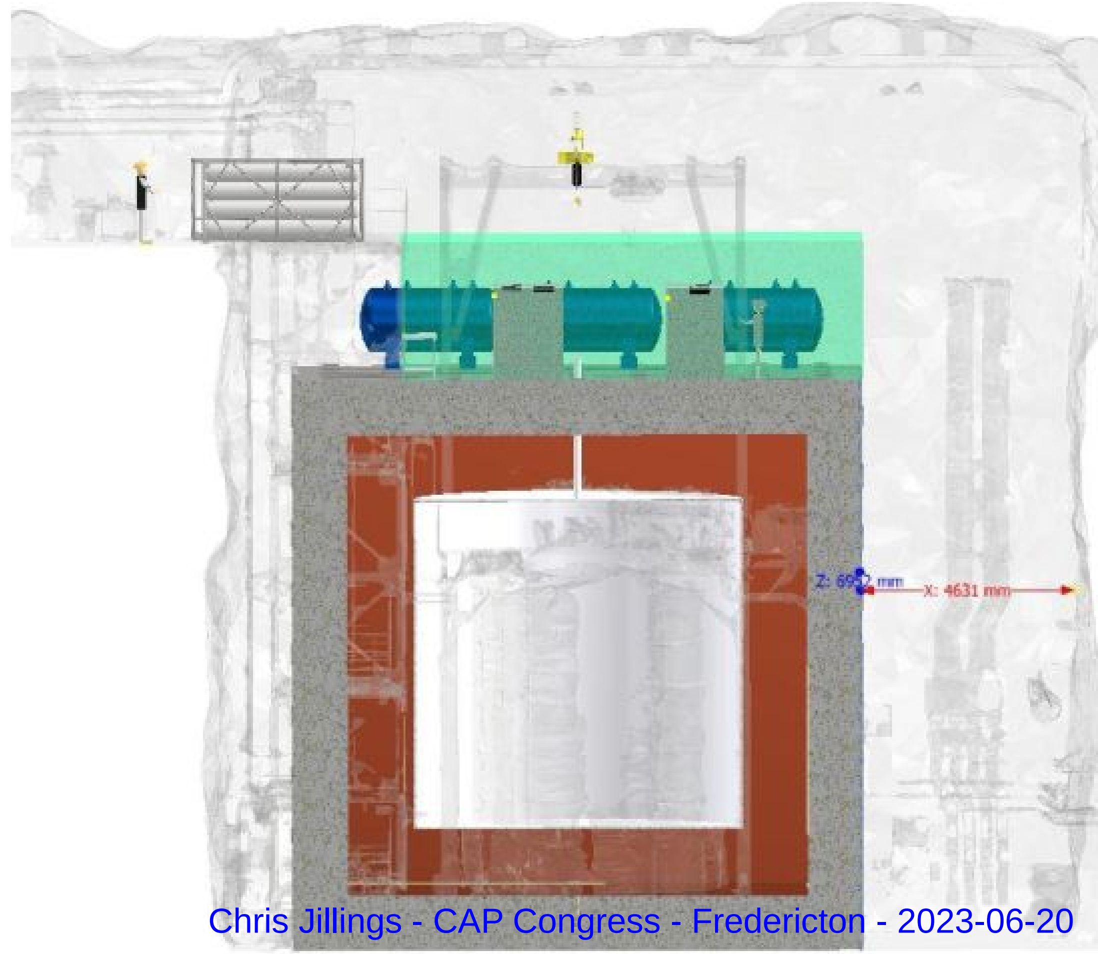
Yi Wang's talk at TAUP 2023

# DarkSide-20k sensitivity projections



# Ultimate detectors




**XLZD:**
If funding can be secured, DARWIN+LZ+XENON will form XLZD, which would enable a 60-tonne detector (instead of the 40 tonne option)

**ARGO:**
- 7 m diameter x 7m high acrylic vessel
- Underground argon
- Surrounded by atmospheric argon
- In a Proto-Dune style cryostat
- SNOLAB as the preferred site

# Pulse shape discrimination (PSD)

Ar singlet and triplet excited states have well separated lifetimes (6ns vs. ~1.5μs)

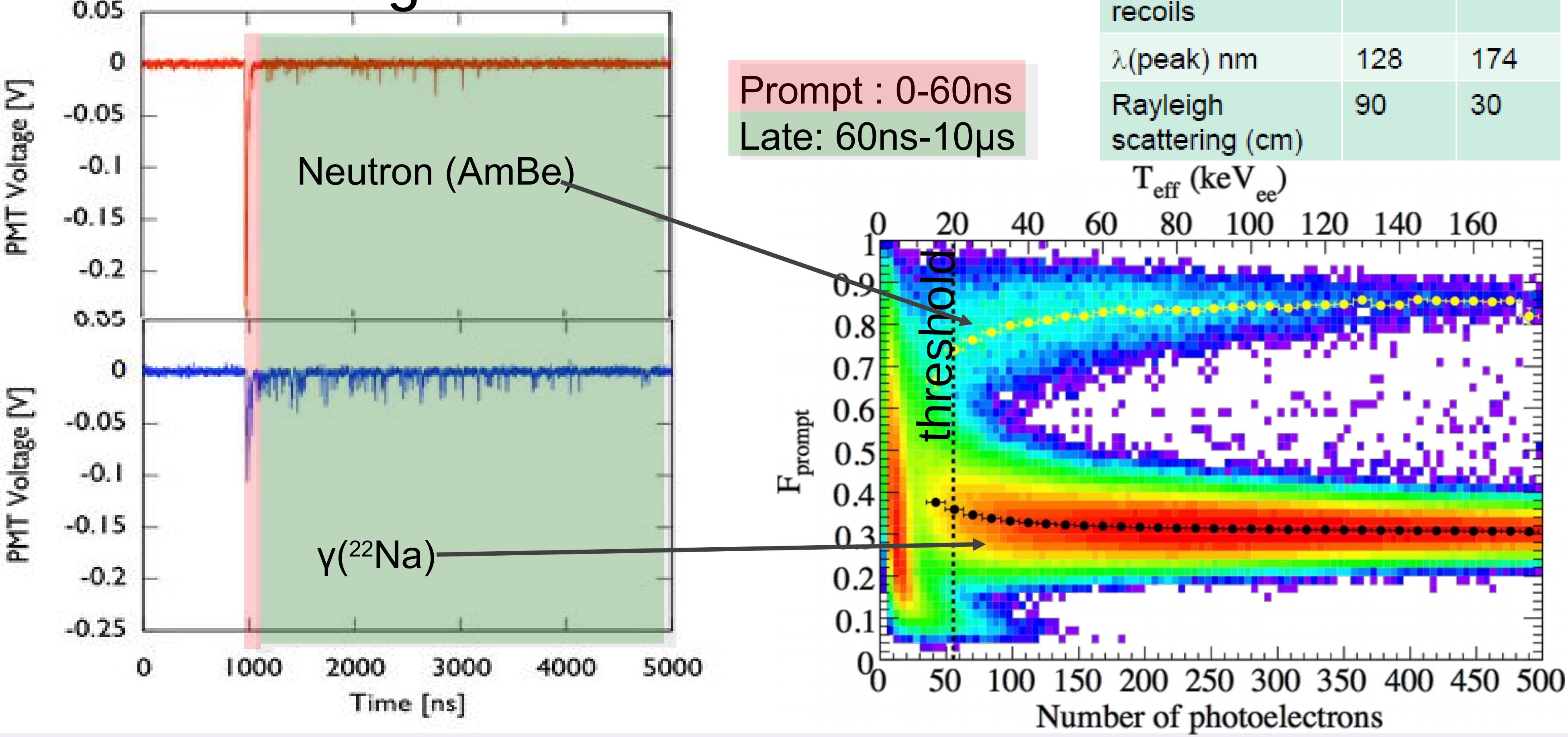
**Single phase LAr:**
scintillation channel is sufficient for β/γ rejection
no need for the ionization channel

| Parameter | Ar | Xe |
|---|---|---|
| Yield (x10$^4$ photons/MeV) | 4 | 4.2 |
| Prompt time constant $\tau_1$ | 6 ns | 2 ns |
| Late time constant $\tau_3$ | 1.5 μs | 21 ns |
| $I_1/I_3$ for electrons | 0.3 | 0.3 |
| $I_1/I_3$ for nuclear recoils | 3 | 1.6 |
| λ(peak) nm | 128 | 174 |
| Rayleigh scattering (cm) | 90 | 30 |

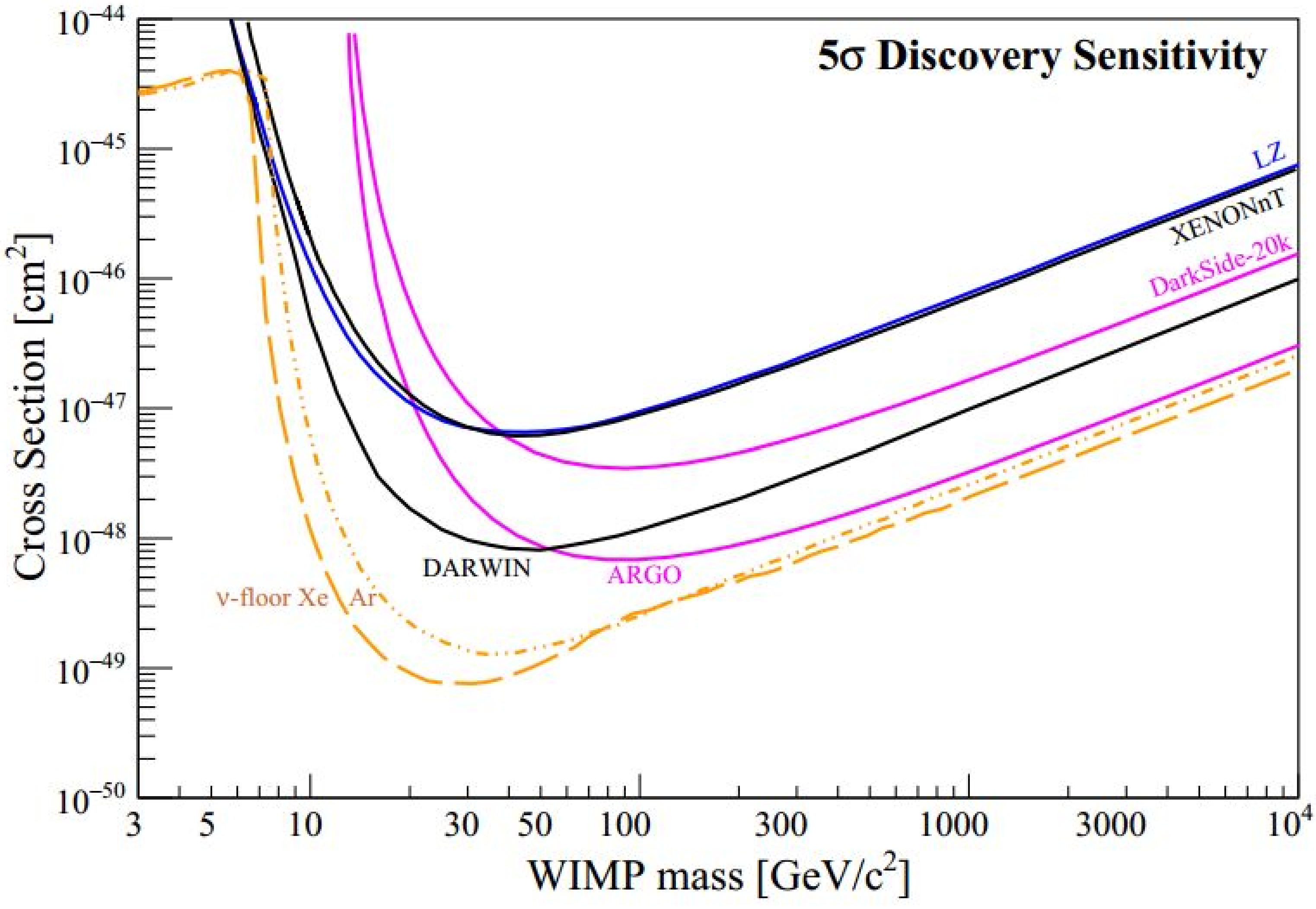
$$\mathrm{FPrompt} = \frac{N_{prompt}}{N_{prompt} + N_{Late}}$$

Prompt : 0-60ns
Late: 60ns-10μs

PMT signal:



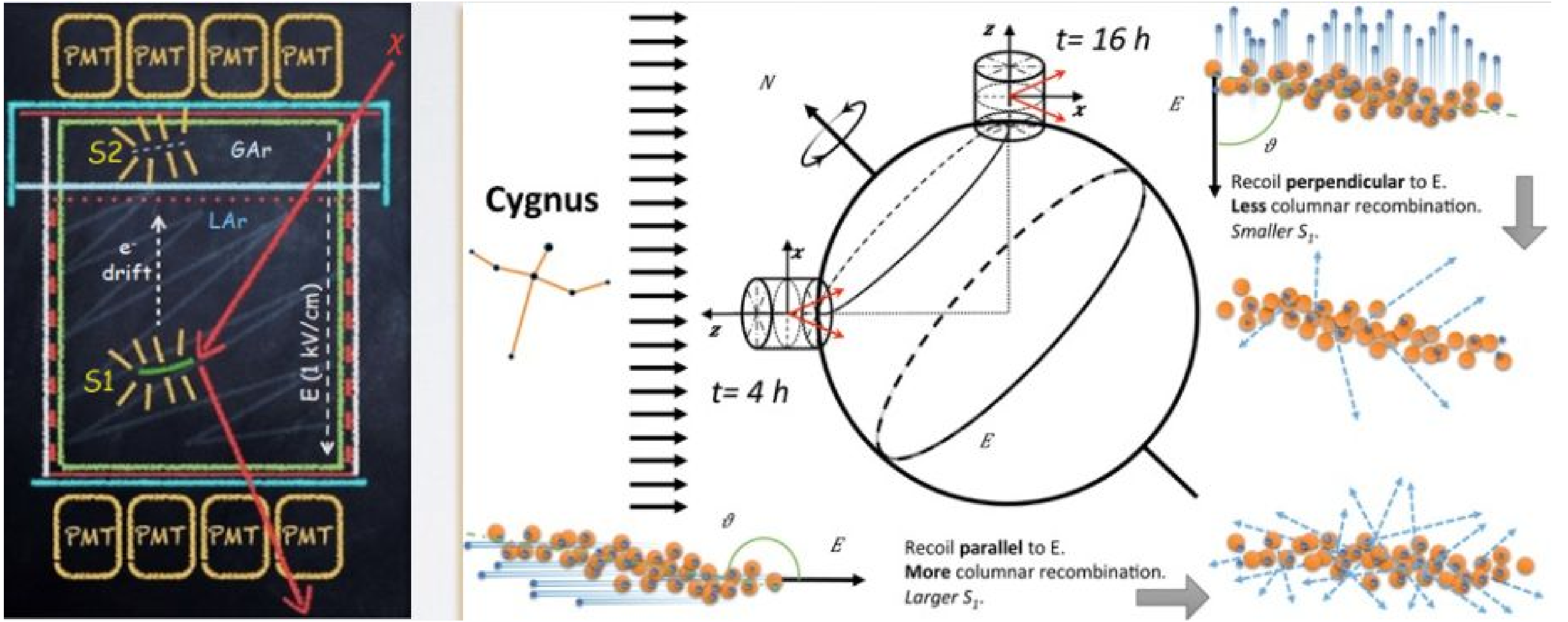
# Discovery potential




- Superior ER rejection in LAr (with PSD) allows to suppress background from elastic scattering of solar neutrinos on electrons
- Zero background paradigm results translate to better 5-σ discovery sensitivity
- **Need for both programs recognized by APPEC, P5, ESPPU**

# Directional detection with LAr

- Powerful means to mitigate backgrounds and reach beyond the neutrino fog
- Hopes to find columnarity effect in LAr (informed by hints from 2015 SCENE measurement)



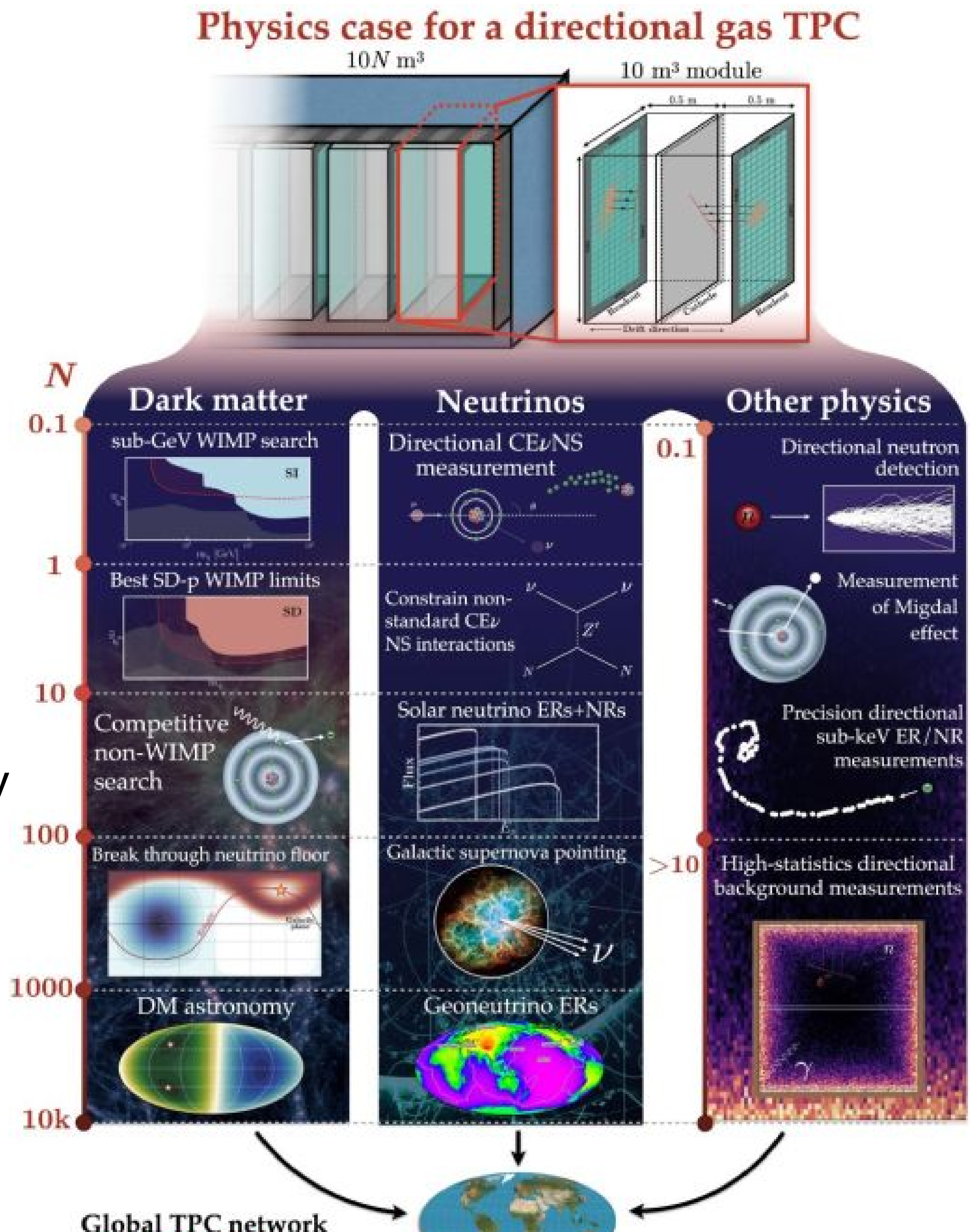


Recent result from ReD (Recoil Directionality) experiment finds **no significant directional effect** in LAr:
DarkSide-20k Collaboration, arXiv:2307.15454 (2023)

No other technology allowing for large target masses on the horizon.

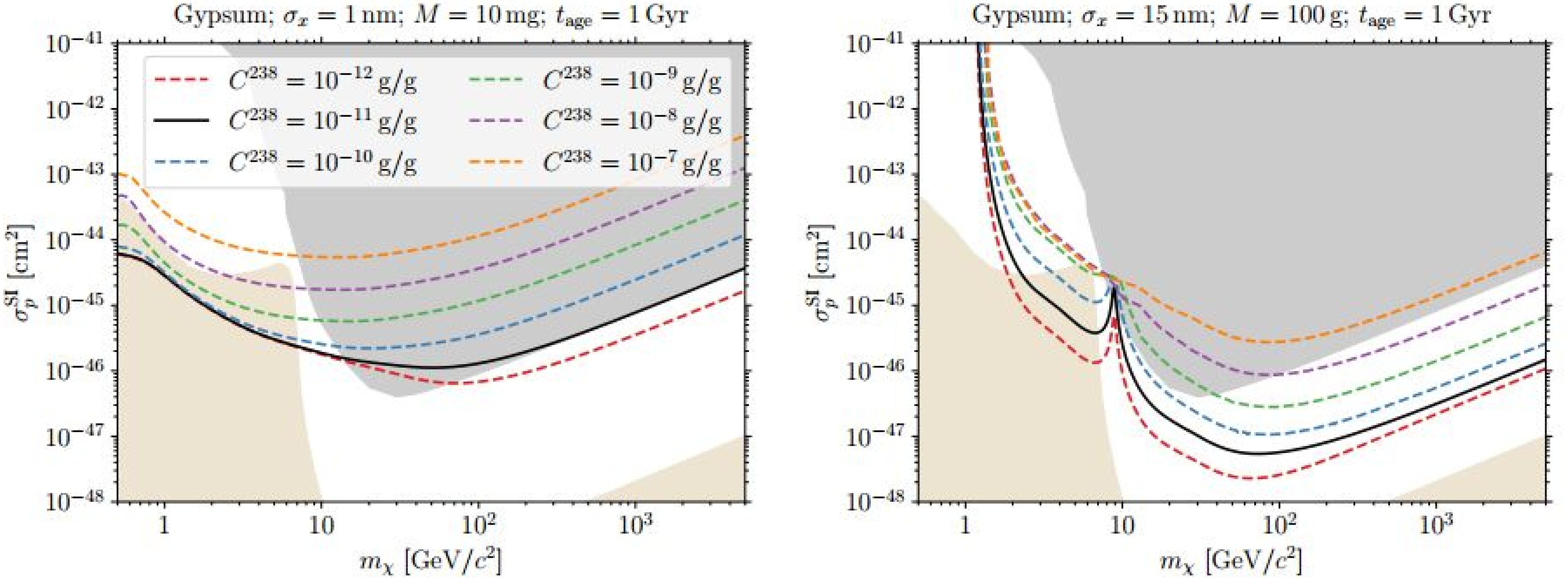
# Directional detectors

- Mainly gaseous detectors or emulsions
- Global consolidation of efforts
- While scale-up challenging, in some scenarios (spin-dependent, low mass) competitive sensitivities are feasible
- Dedicated TAUP 2023 session on Friday




Arxiv: 2102.04596

# Paleodetectors




Searching for Dark Matter with Paleo-Detectors, Sebastian Baum, Andrzej K. Drukier, Katherine Freese, Maciej Górski, Patrick Stengel, Phys.Lett. B803 (2020) 135325

S. Baum et al., Instruments 2021, 5(2), 21

A completely different approach to direct detection:

- Look for damage from nuclear recoils in minerals
- Modest mass, extreme livetime -> competitive exposure
- Some potential for directionality

see S. Baum talk @ TAUP 2023

Why the Best Place to Find Dark Matter May Be in a Rock | Quanta Magazine

# ECFA Detector R&D initiative

- Scale-up to ultimate detectors is a technological challenge
- Community driven process to plan essential R&D for the coming years
- Direct detection mostly represented in TF1 (gaseous detectors) and TF2 (liquid detectors) subgroups
- Detector R&D proposals prepared with community feedback and currently under review

ECFA
European Committee for Future Accelerators

ECFA Detector R&D Roadmap

24 March 2021 to 30 July 2023
Europe/Zurich timezone

Enter your search term

- Overview
- Implementation of the ECFA Detector R&D Roadmap
- Mandate for the Preparation of the Roadmap
- The Roadmap Document
- Panel members and Task Forces
- Input from future facilities
- Symposia
- Registration to the symposia
- ECFA Detector R&D

## Implementation of the ECFA Detector R&D Roadmap

**After the publication of the ECFA Detector R&D Roadmap, CERN Council requested ECFA to develop the plan for its implementation.**

The document approved by the SPC and CERN Council in September 2022 can be found at https://indico.cern.ch/event/1197445/contributions/5034860/attachments/2517863/4329123/spc-e-1190-c-e-3679-Implementation_Detector_Roadmap.pdf.

**As proposed in the document, topic specific community meetings will now be held in the course of the coming months. To sign up for these and to register your interest in participating on the corresponding R&D Collaborations being developed please see the links below.**

- TF1 Gaseous Detectors https://indico.cern.ch/event/1214405/
- TF2 Liquid Detectors https://indico.cern.ch/event/1214404/
- TF3 Solid State Detectors https://indico.cern.ch/event/1214410/
- TF4 Photon Detectors and PID https://indico.cern.ch/event/1214407/
- TF5 Quantum and Emerging Technologies https://indico.cern.ch/event/1214411/
- TF6 Calorimetry https://indico.cern.ch/event/1213733/
- TF7 Electronics and On-detector Processing https://indico.cern.ch/event/1214423/
- TF8 Integration https://indico.cern.ch/event/1214428/
- TF9 Training https://indico.cern.ch/event/1214429/

# Summary

- Conclusive verification of DAMA result finally on the horizon
- Otherwise, no discovery or new detection claims. However...
- Many interesting new results and ideas over the last couple of years
  - Steady progress
  - Low-mass region (1-10 GeV/c2) increasingly competitive (LXe S2 only, LAr S2 only, LAr SBC, SuperCDMS)
  - Planck-mass scale
  - EFT result interpretations becoming a standard
- General paradigm change: leave no stone unturned
- Consolidation of efforts for high-mass WIMP searches towards to neutrino floor
  - ECFA detector R&D roadmap
  - Low energy excess workshops
  - Consolidation of directional search collaborations
  - LAr:
    - Global consolidation of efforts towards DarkSide-20k and the ultimate detector, Argo
    - Fruitful synergy with ProtoDUNE/DUNE
    - Novel materials to facilitate scale-up
    - Rapid growth of the SiPM technology
  - LXe:
    - XLZD
    - Successful progression of 2 phase LXe TPCs
    - Ongoing R&D for DARWIN

# Backup

# Main challenges moving beyond LZ/XENONnT/DS-20k

**LXe**

- Securing enough Xenon
- Rn mitigation
- ER rejection
- HV scalability/stability
- Other backgrounds

**LAr**

- Very large, highly efficient, photosensitive surface area
- UAr extraction/storage
- Scalable and robust wavelength shifter/light collection approach
- Backgrounds

# Ar-Xe complementarity

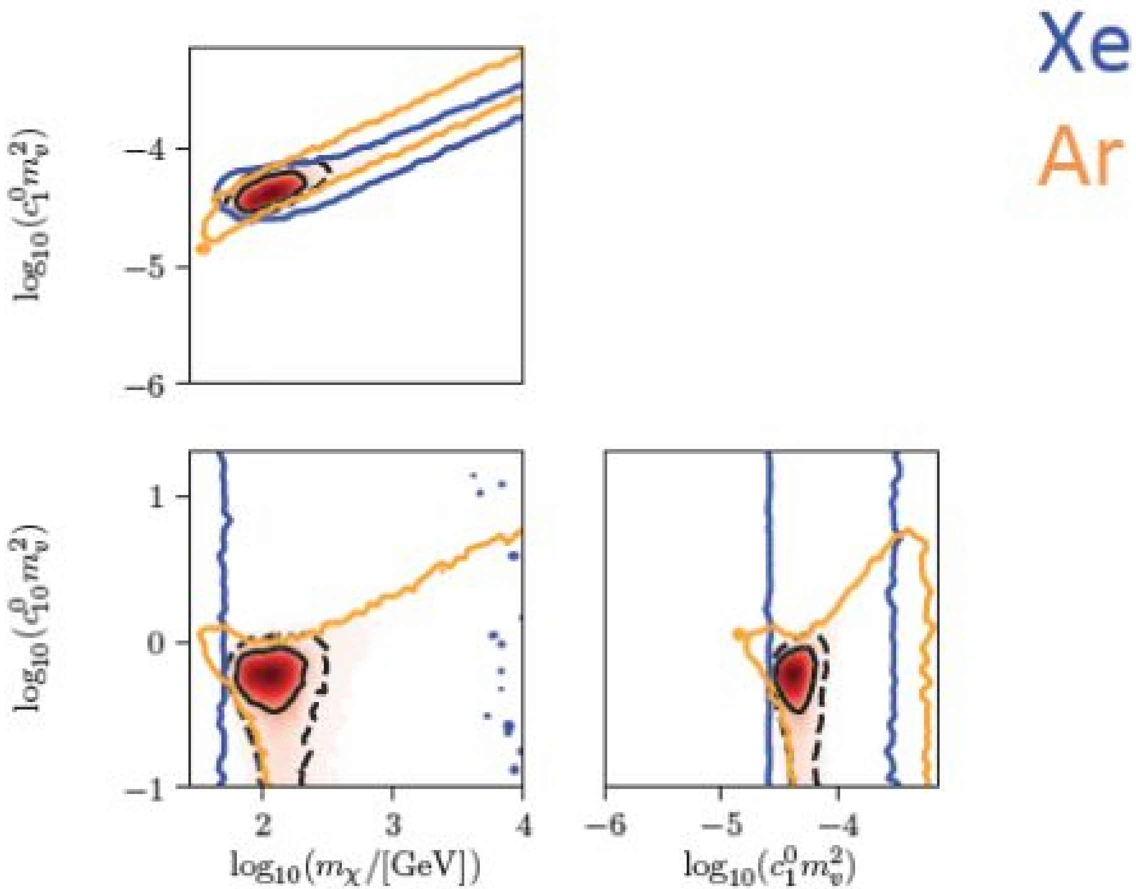
Example: Scalar DM – Scalar Mediator
m = 100 GeV

Newstead et al., PRD D 88, 076011 (2013)
DARWIN, JCAP 10 (2015) 016

A single target cannot determine the DM mass and couplings

The experimental response is very sensitive to the target

Combining data some degeneracies can be removed




D. Cerdeno, IPPP April 2018