



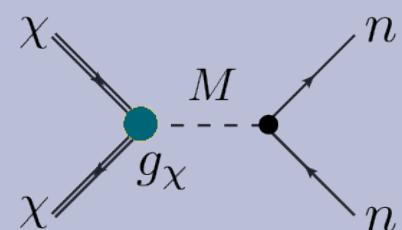
Towards the Neutrino Floor – Generation-3 Experiments

Marc Schumann *University of Freiburg*

2nd DMNet Symposium, 15.09.2022

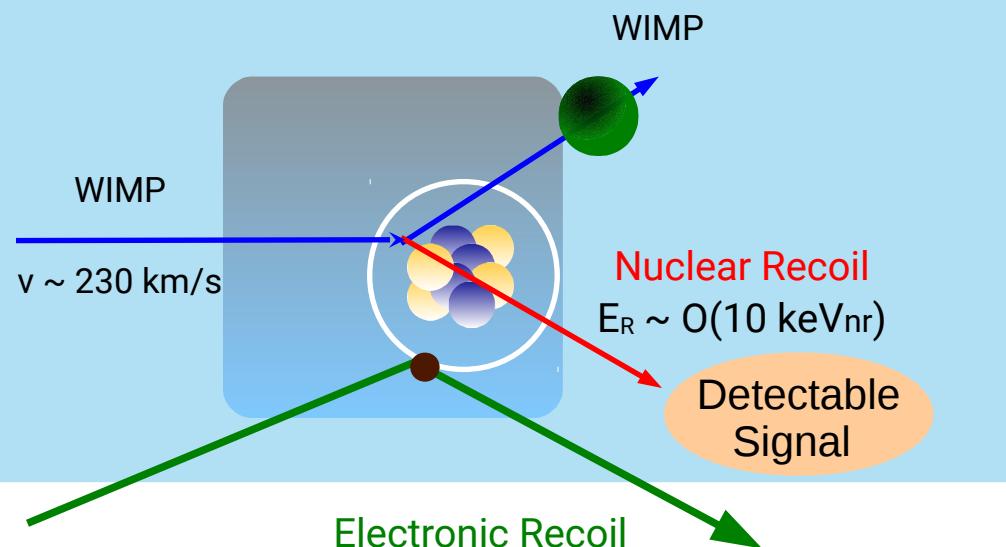
www.app.uni-freiburg.de



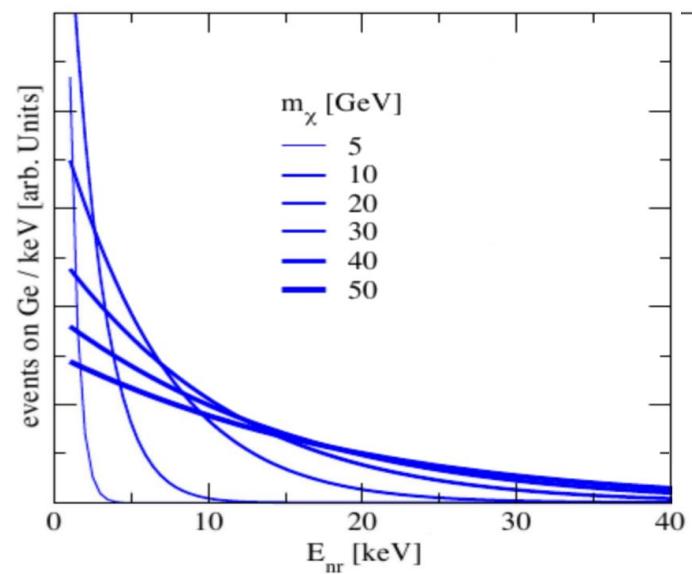
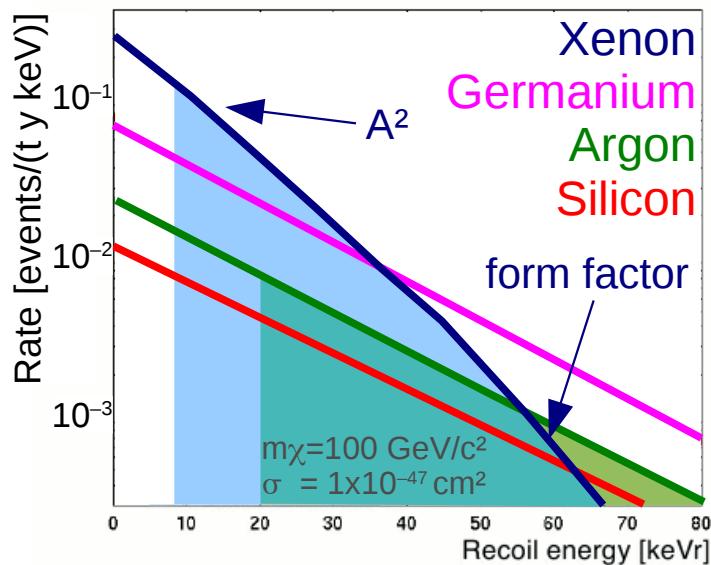


Direct WIMP Search

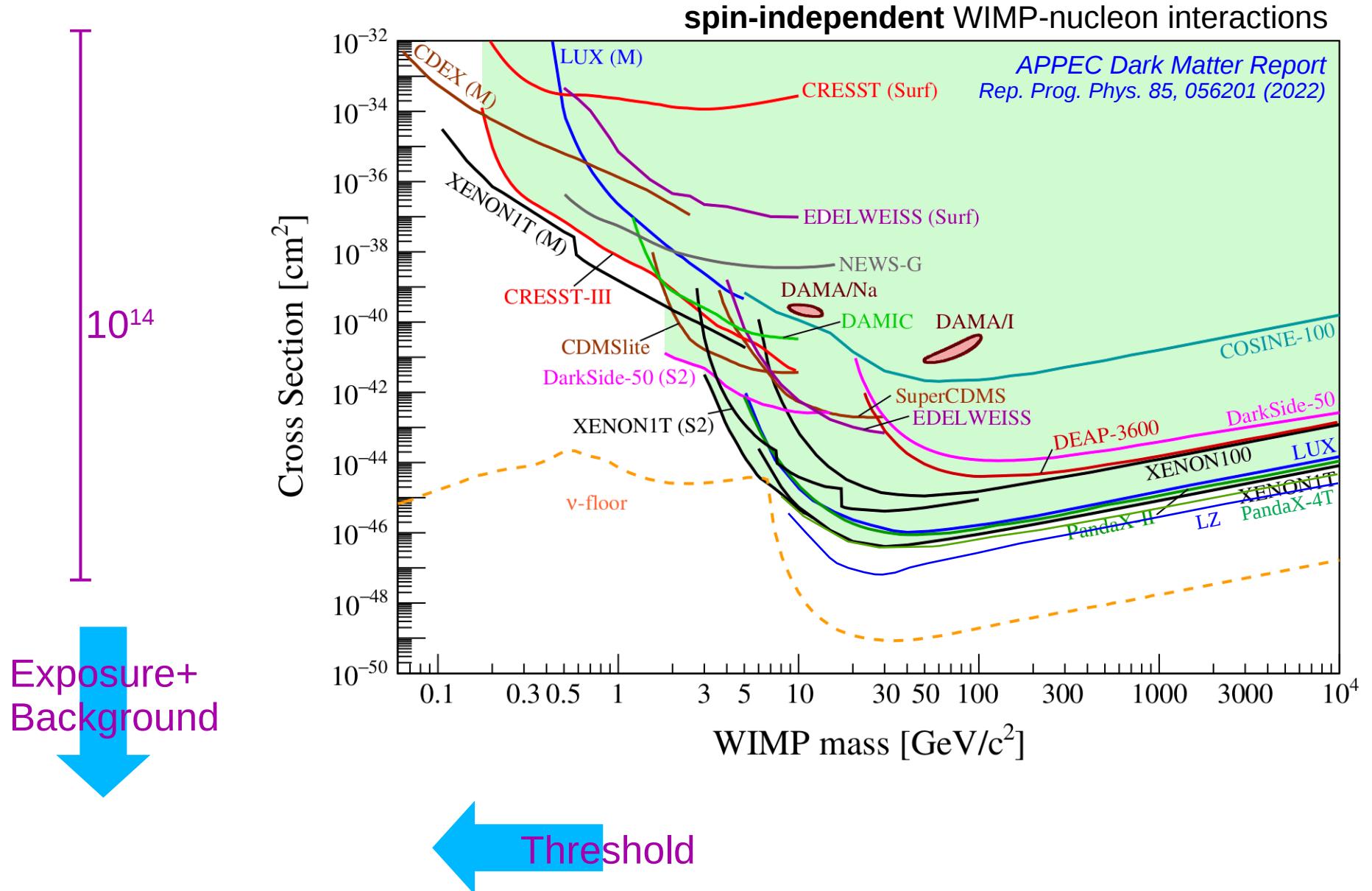
Elastic Scattering of WIMPs off target nuclei
 → nuclear recoil



Recoil Spectra:



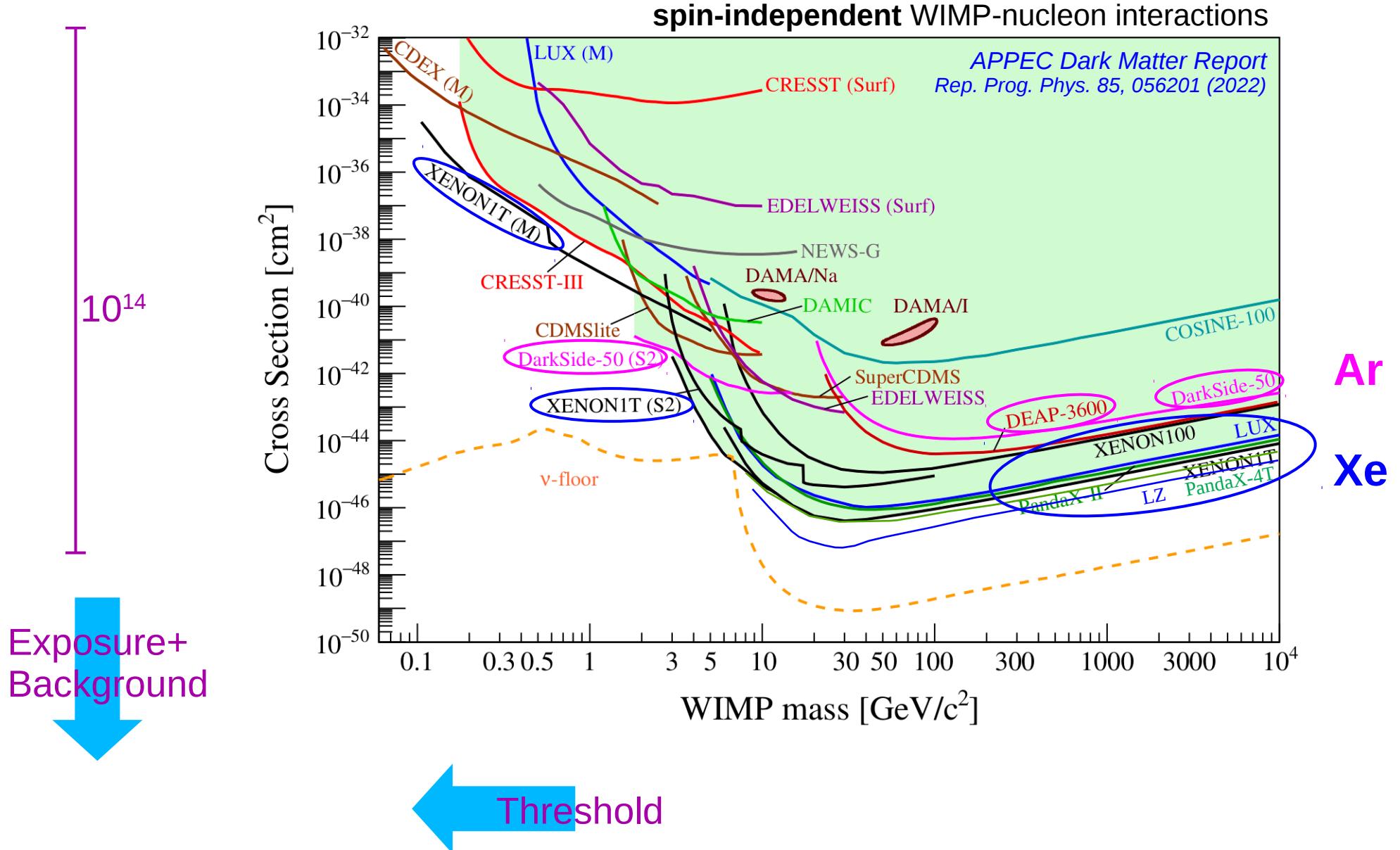
Current Status



Exposure+
Background

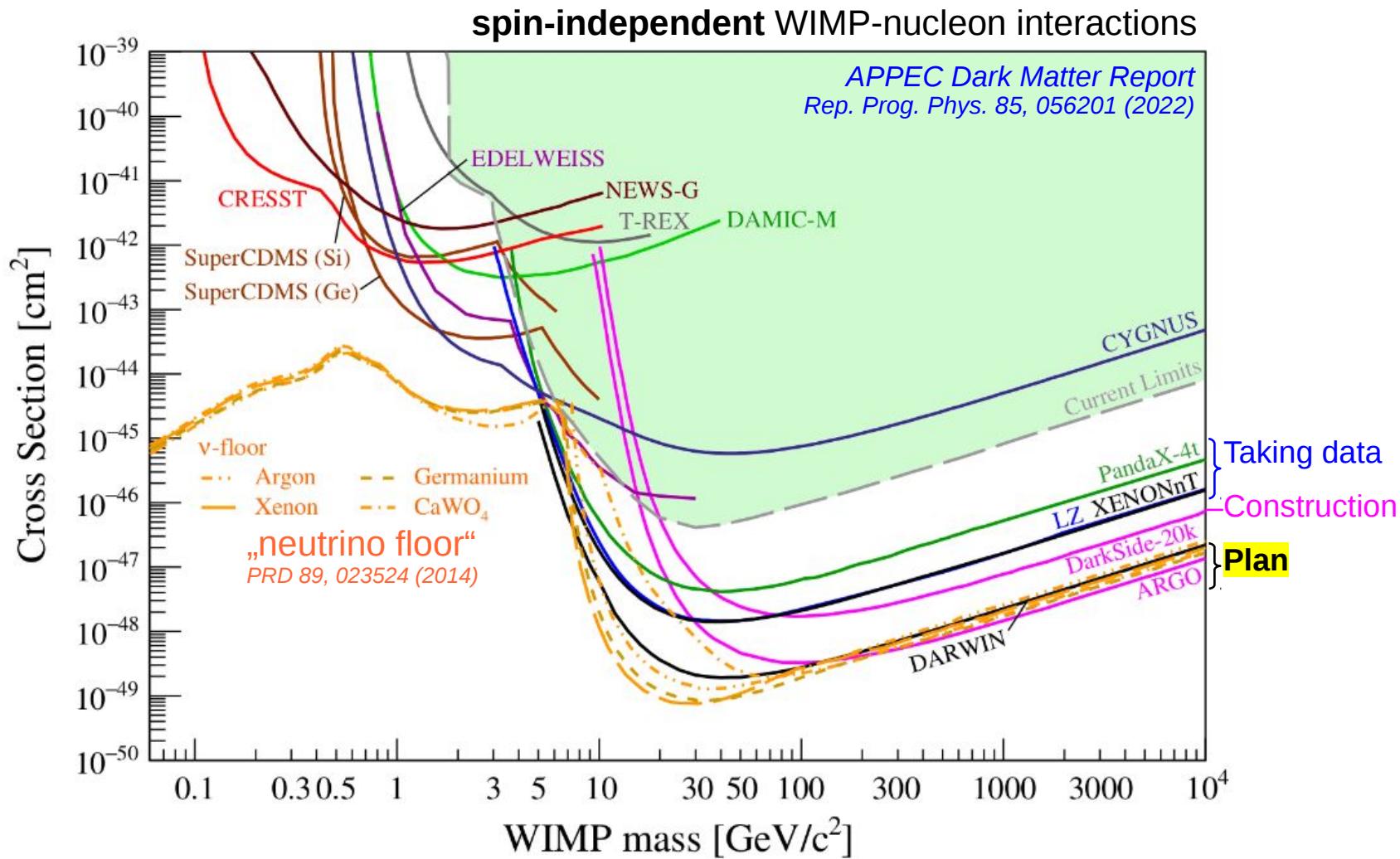
Threshold

Current Status

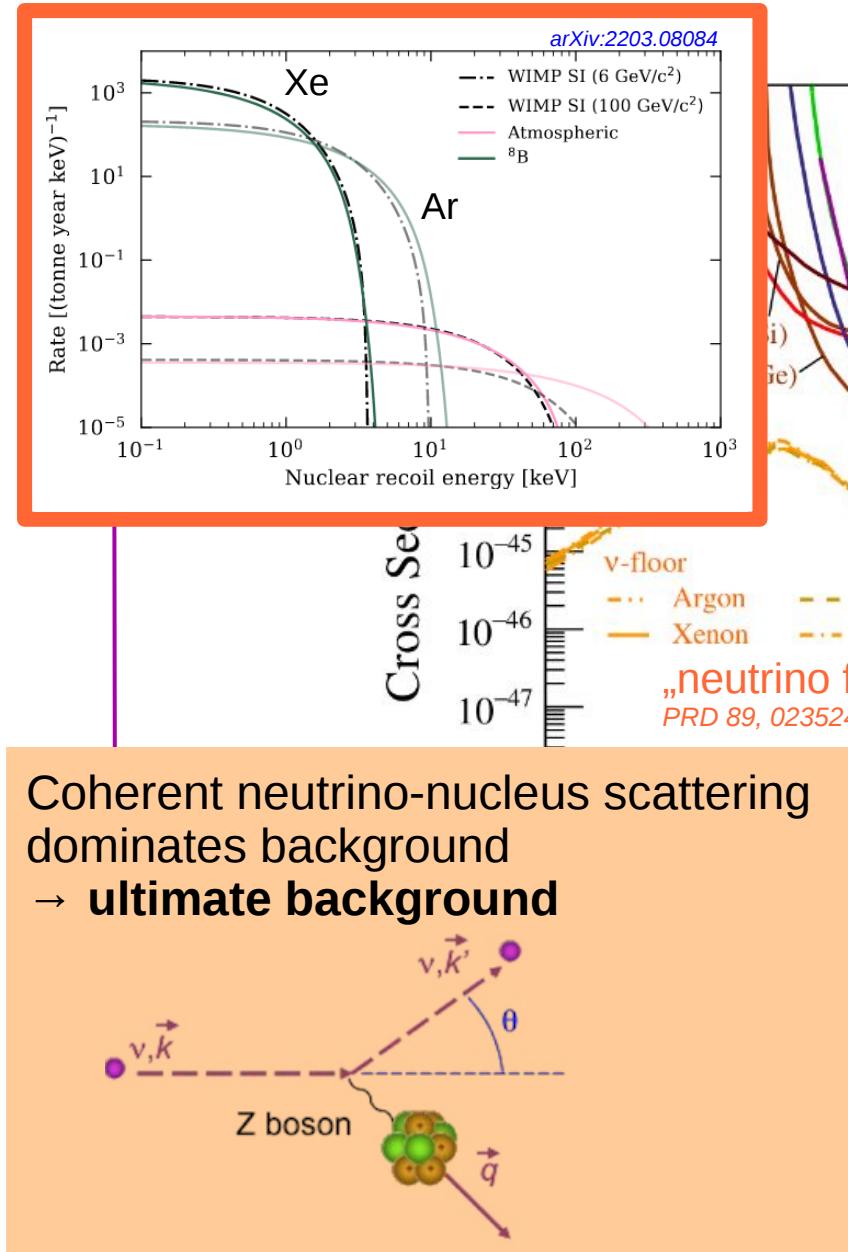


The Future

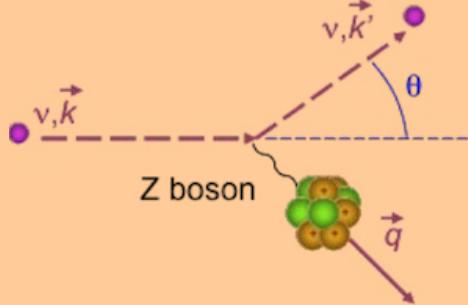
Exposure+
Background

The Neutrino Floor

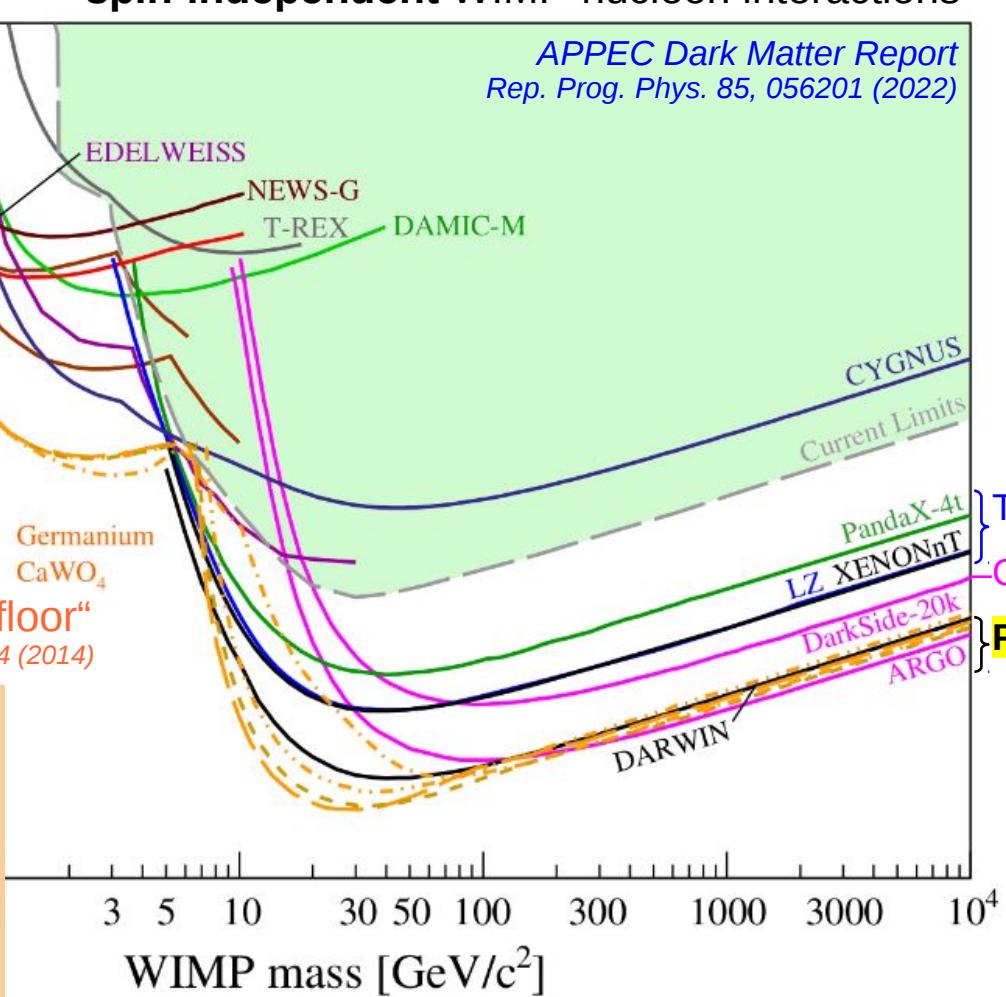


Coherent neutrino-nucleus scattering
dominates background
→ **ultimate background**



spin-independent WIMP-nucleon interactions

APPEC Dark Matter Report
Rep. Prog. Phys. 85, 056201 (2022)



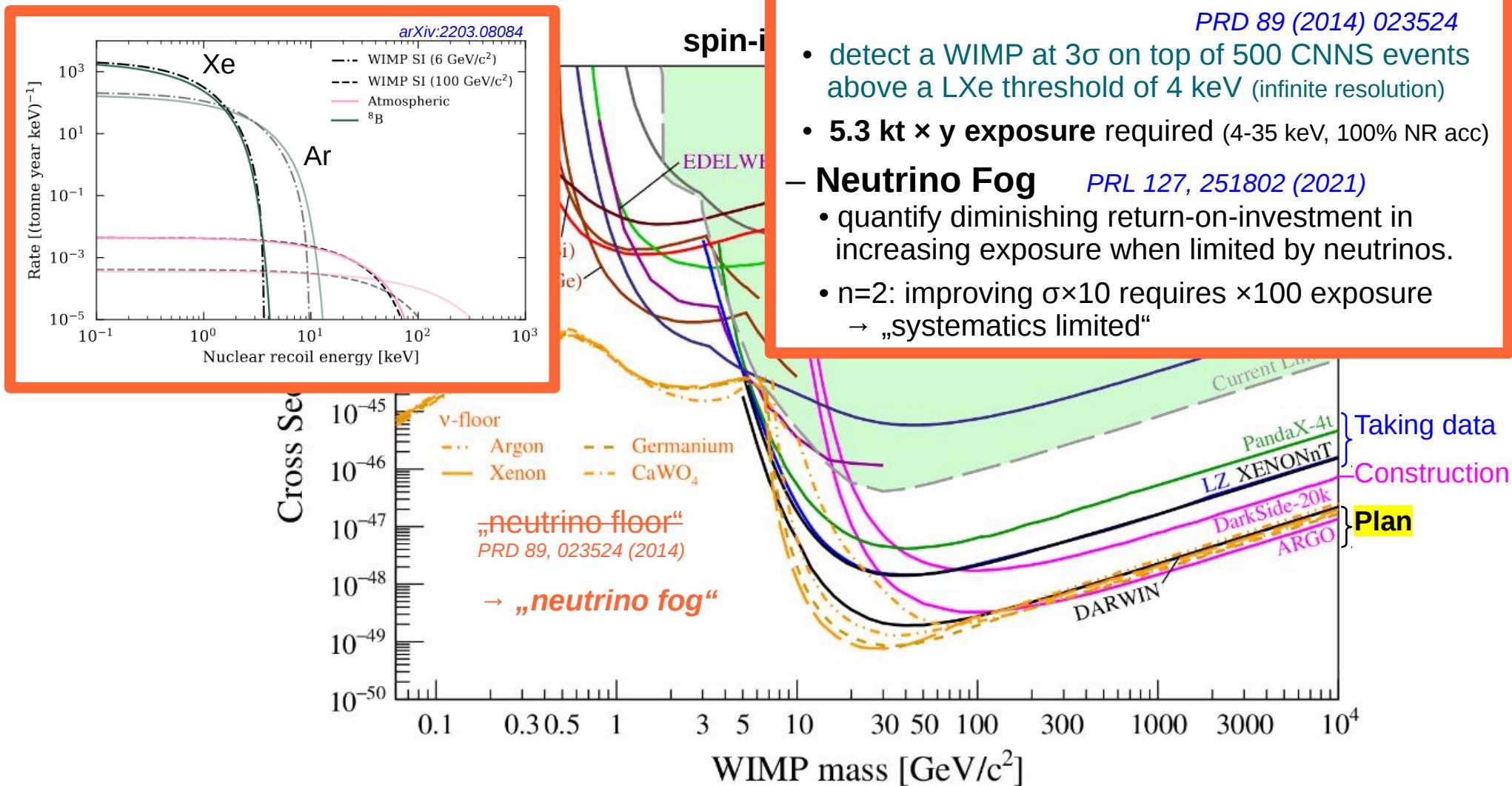
The Neutrino

Be aware of the **definition**

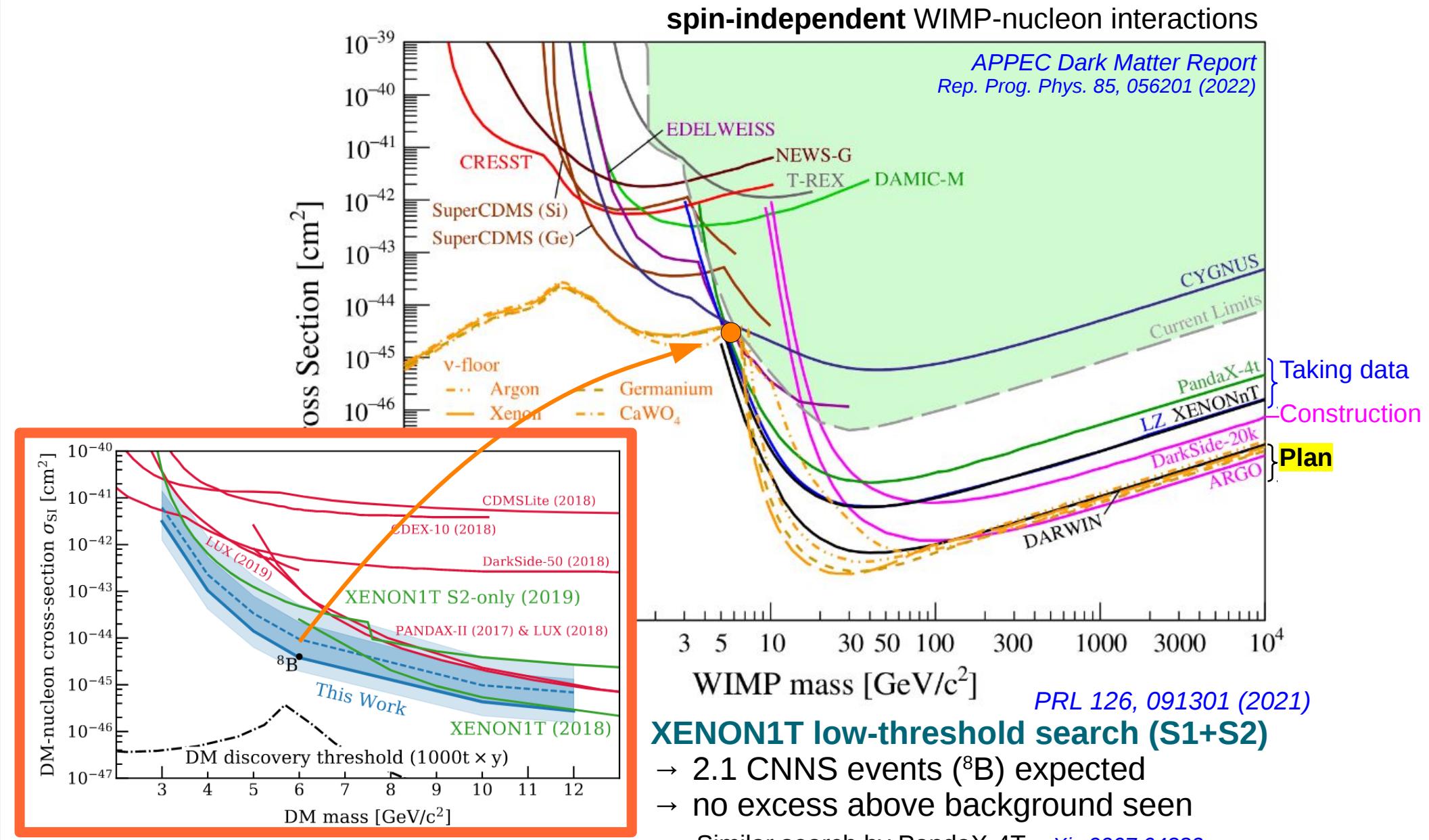
- „1 CNNS event“ line is well above „ ν -floor“
- **ν -floor = „WIMP discovery limit“**

PRD 89 (2014) 023524

- detect a WIMP at 3σ on top of 500 CNNS events above a LXe threshold of 4 keV (infinite resolution)
- **5.3 kt \times y exposure** required (4-35 keV, 100% NR acc)
- **Neutrino Fog** *PRL 127, 251802 (2021)*
 - quantify diminishing return-on-investment in increasing exposure when limited by neutrinos.
 - $n=2$: improving $\sigma \times 10$ requires $\times 100$ exposure
→ „systematics limited“

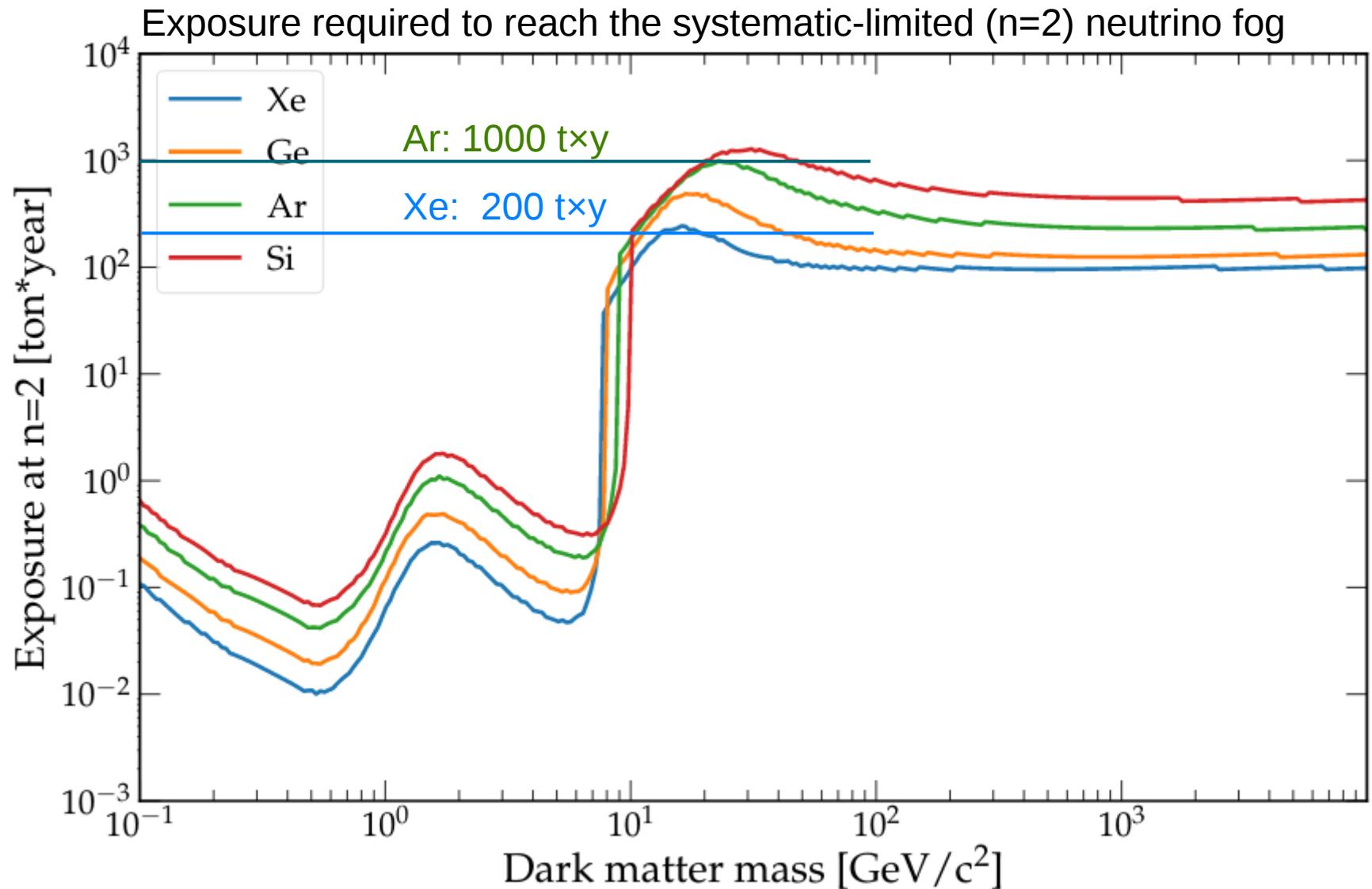


Almost there...



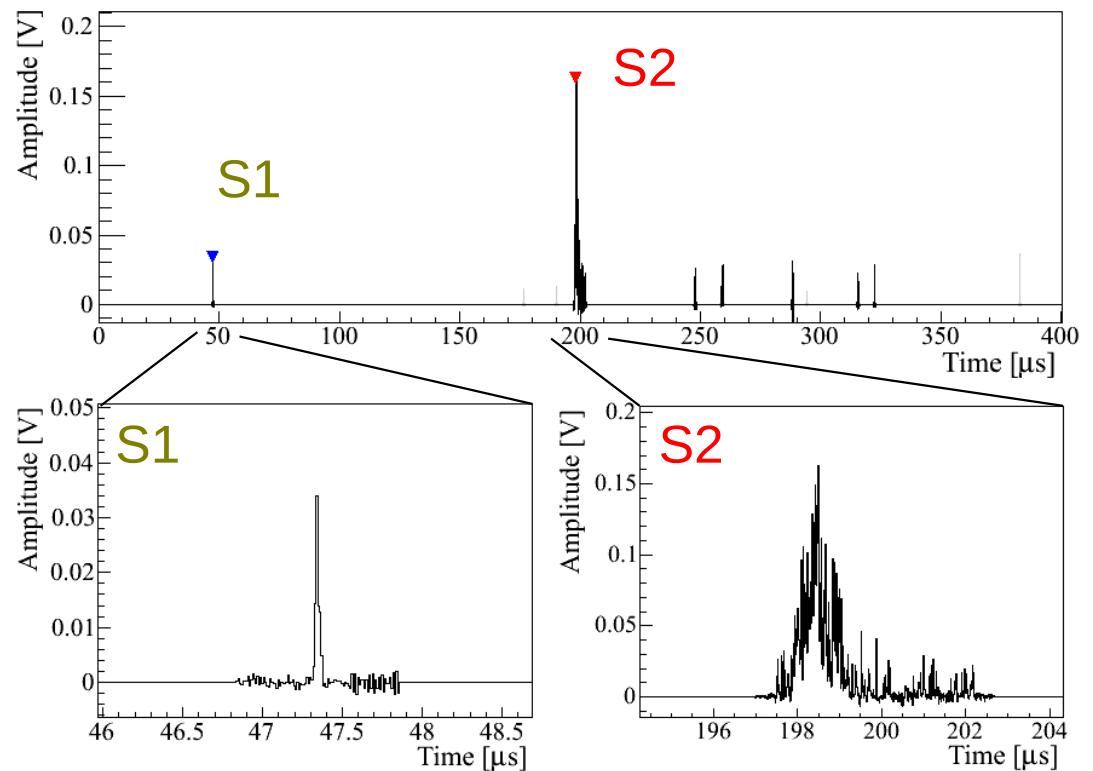
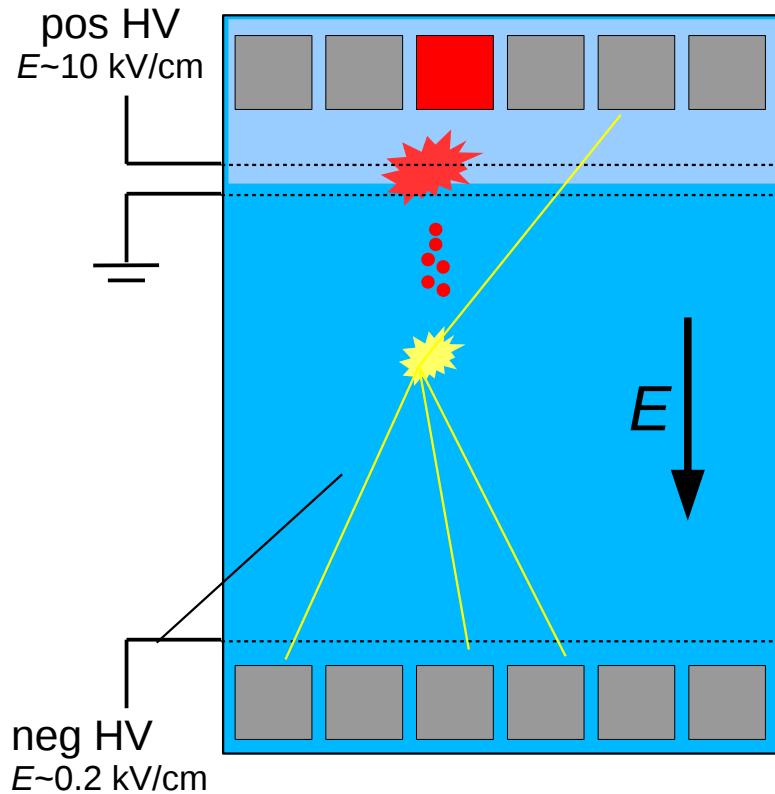
Reaching the Neutrino Fog

arXiv:2203.08084



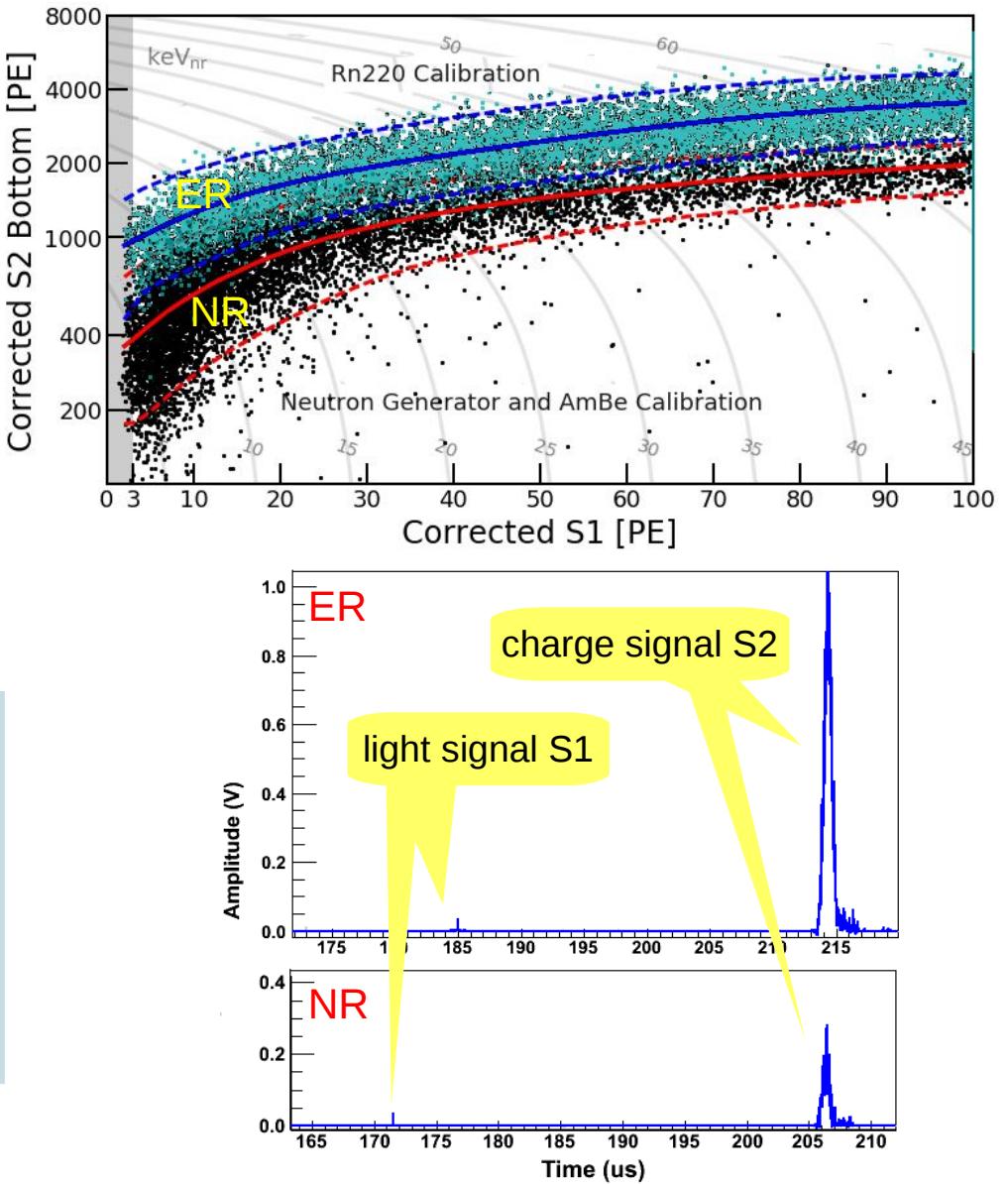
Dual Phase TPC

Dolgoshein, Lebedenko, Rodionov, JETP Lett. 11, 513 (1970)



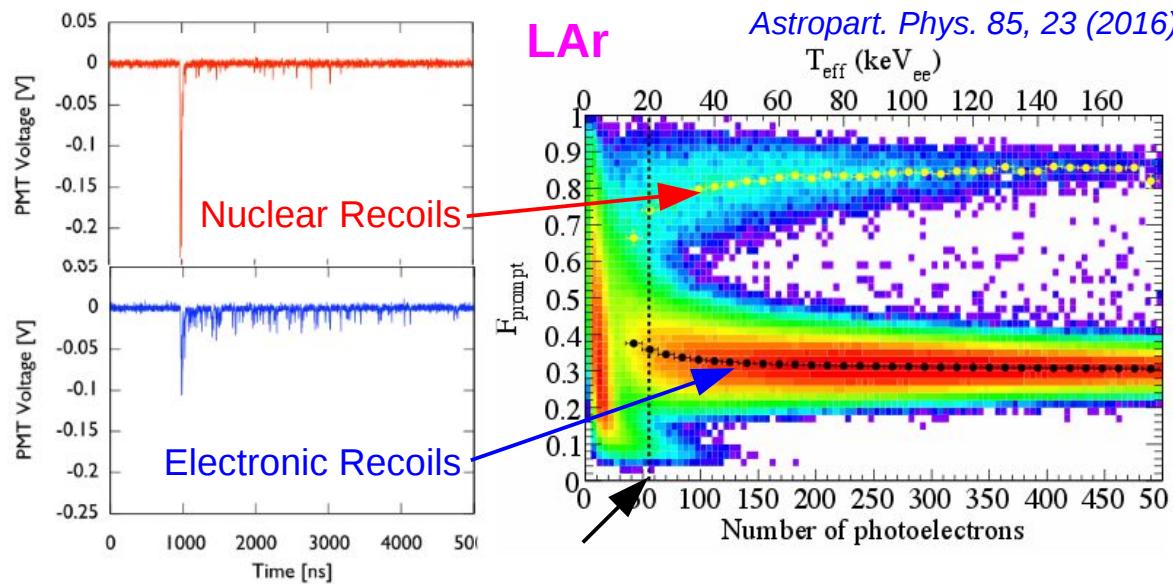
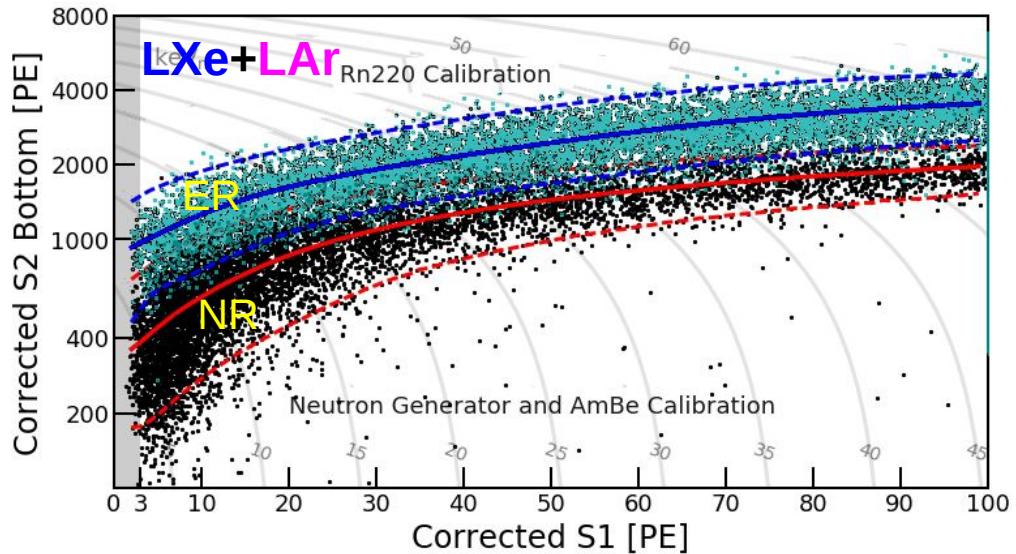
LXe TPC Features

- 3dim vertex reconstruction
→ **fiducialization**
- multi-scatter rejection
- energy measurement ($S_1 + S_2$)
- **Charge-Light-Ratio (S_2/S_1):**
Particle ID
 - ER background rejection (WIMP search)
 - selection of ER channels
- very low background (ER + NR)
- low threshold
(light: ~2-3 PE, charge: few electrons)
- large target mass → high exposure



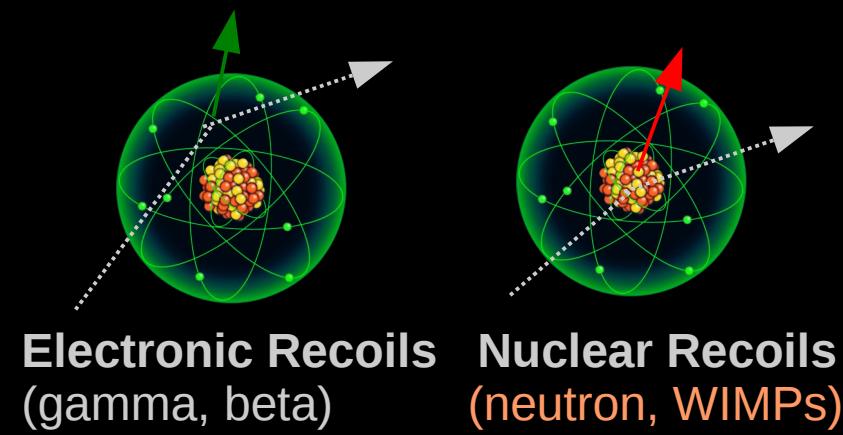
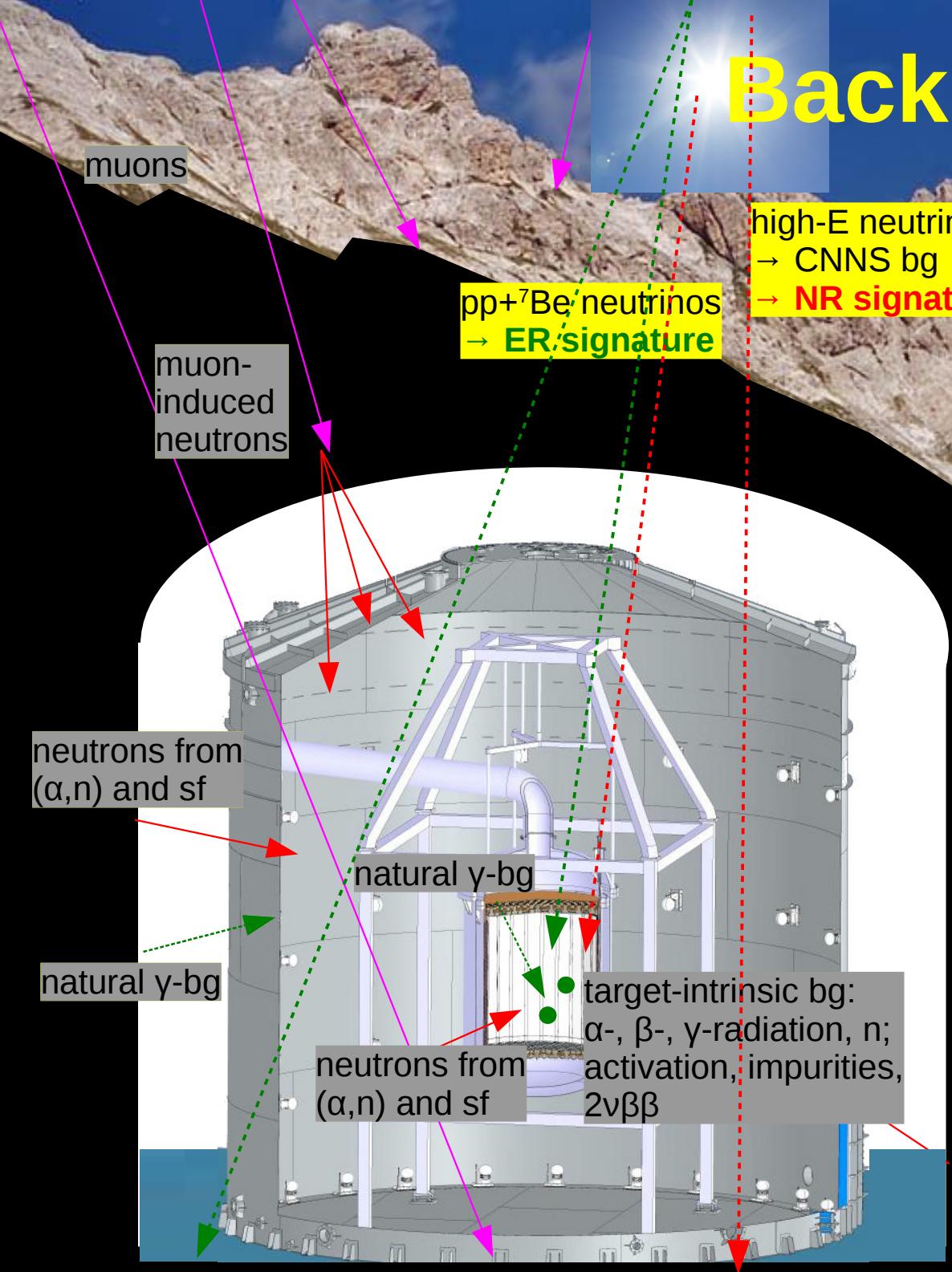
LAr TPC Features

- 3dim vertex reconstruction
→ **fiducialization**
- multi-scatter rejection
- energy measurement (S1+S2)
- **Charge-Light-Ratio (S2/S1):**
Particle ID
 - ER background rejection (WIMP search)
 - selection of ER channels
- extremely low background (NR)
ER rejection @ 10^{-8} level via
pulse shape discrimination (PSD)
- 20+ keV threshold
to exploit PSD
- large target mass → high exposure



Background Sources

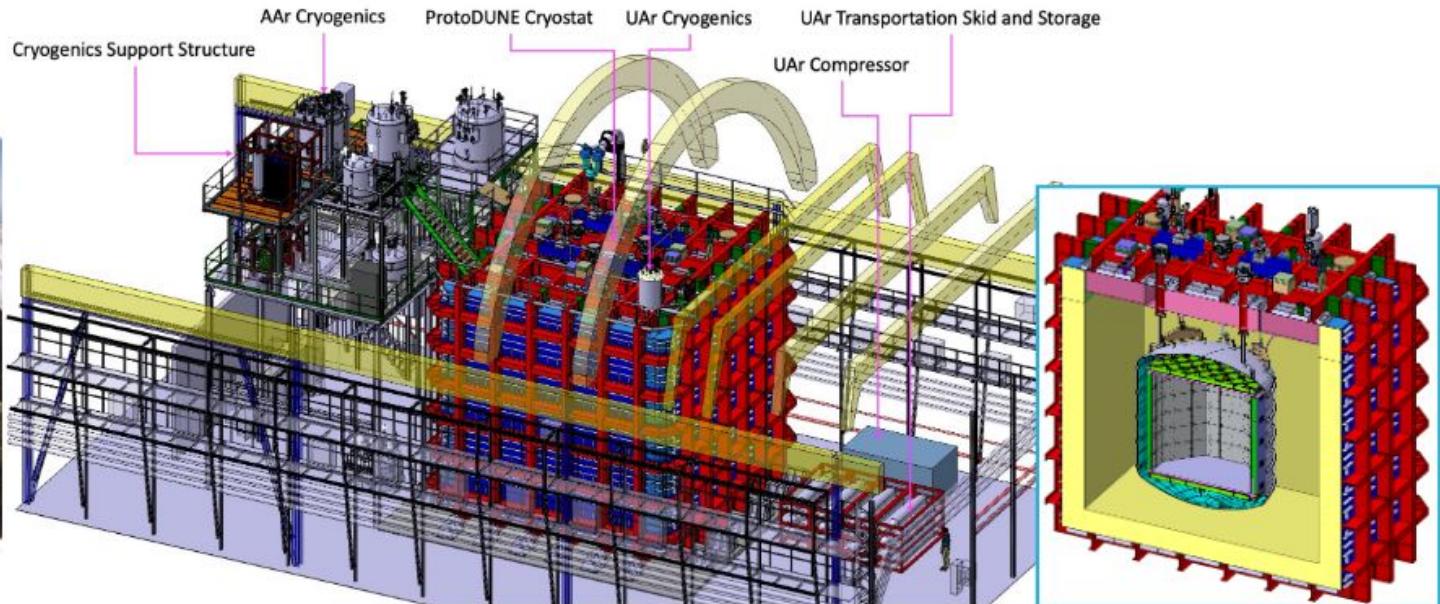
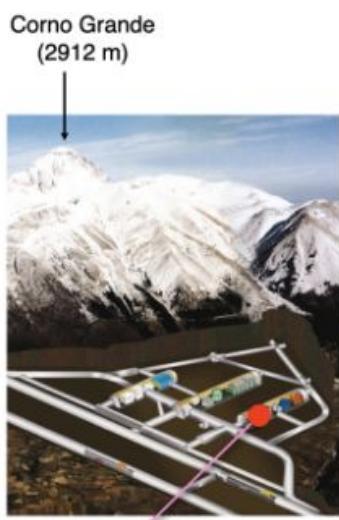
(for G3-scale detectors)



DarkSide-20k ... even though still G2

DarkSide-20k detector

Slide from M. Haranczyk, PATRAS 2022



INFN-CERN agreement finalised

The installation will start later this year in the hall C at the Gran Sasso National Laboratory, in Italy.

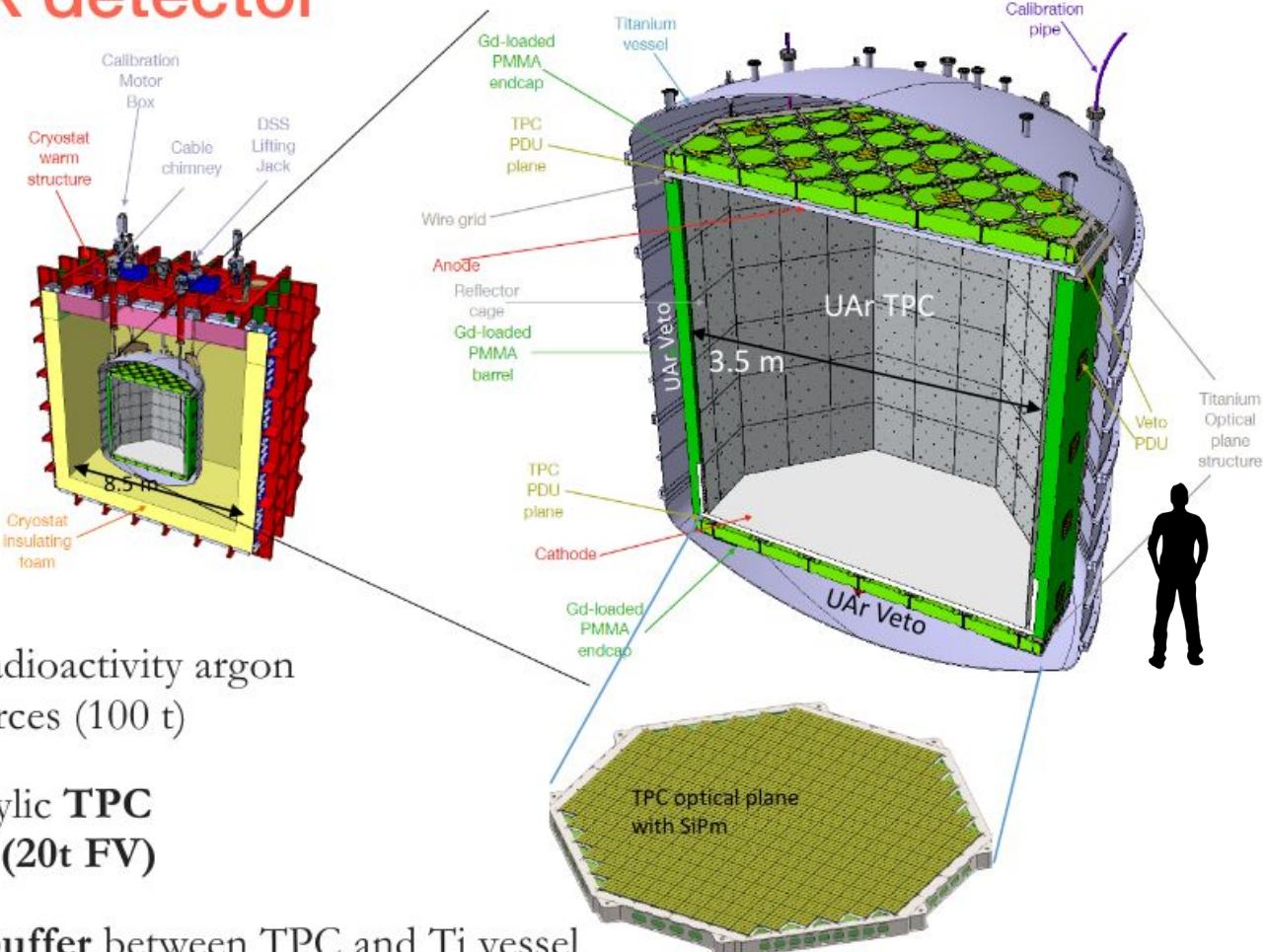
Data taking with nominal run time: 10 years. → 2026 – 2036

Nested structure of the detector with innovative technologies

DarkSide-20k ... even though still G2

DarkSide-20k detector

Slide from M. Haranczyk, PATRAS 2022



Titanium Vessel

containing liquid low radioactivity argon
from underground sources (100 t)

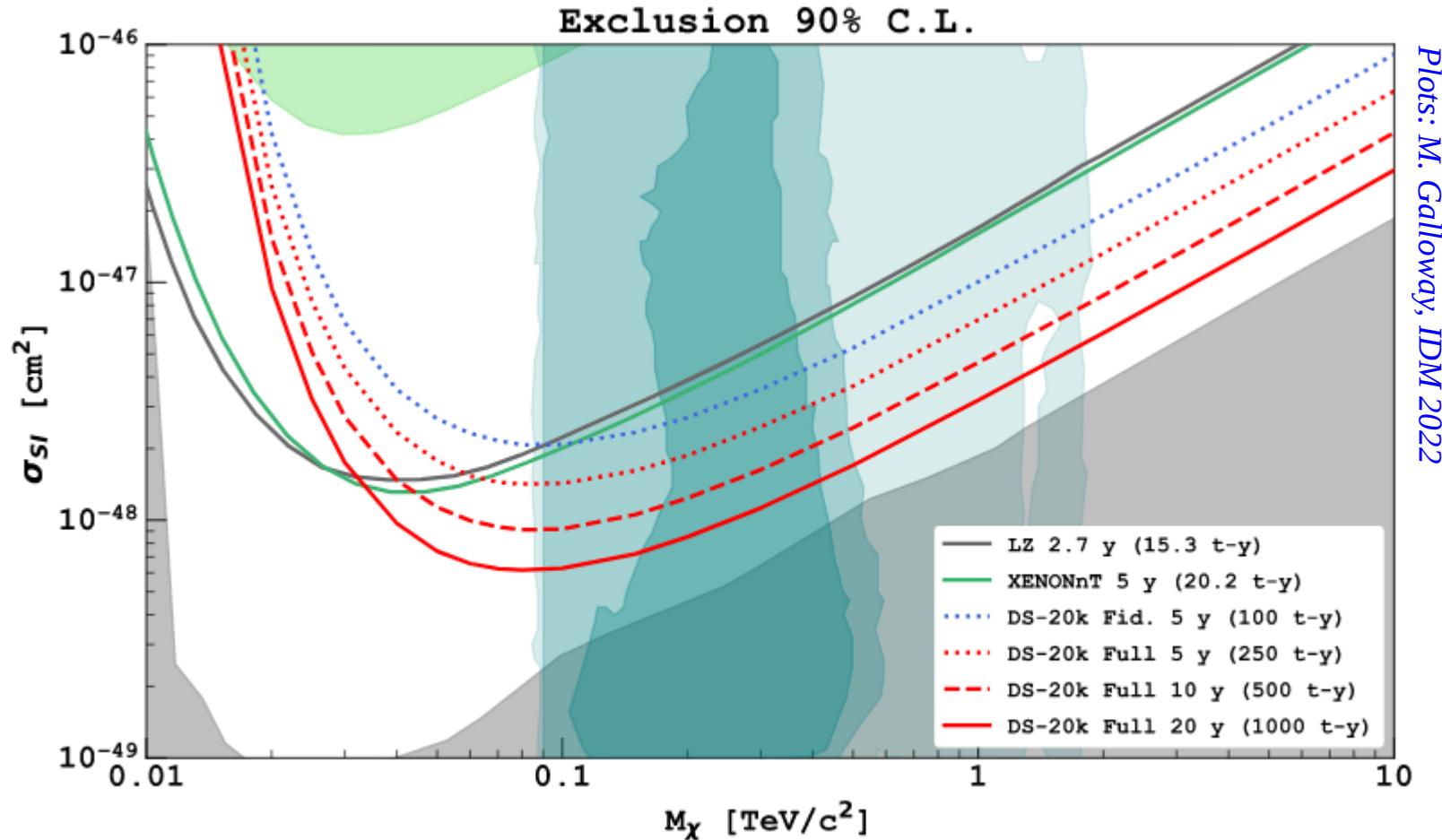
Gadolinium loaded acrylic **TPC**
filled with **50 t of UAr (20t FV)**

Neutron active veto buffer between TPC and Ti vessel

21 m² of **Cryogenic Silicon Photo-Multipliers** as light detectors

Membrane cryostat made in a ProtoDune-like technology

DarkSide-20k: WIMP Sensitivity



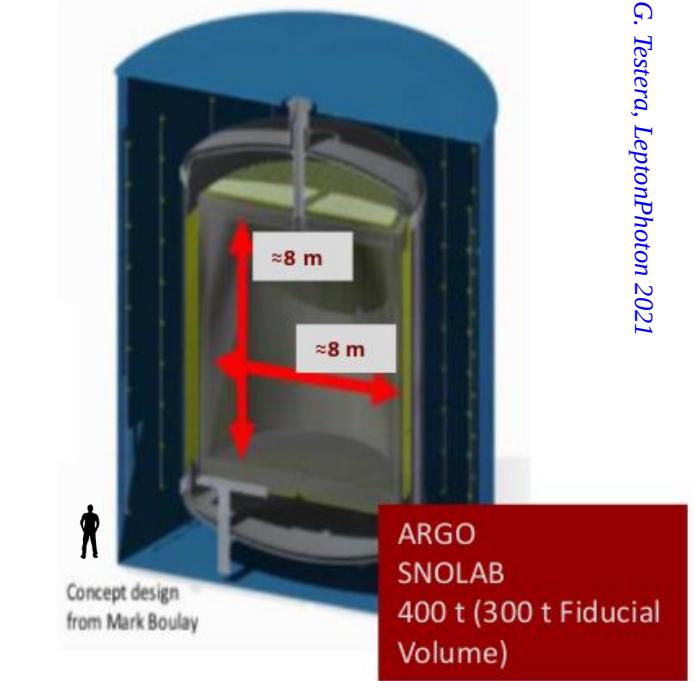
Background expectation/assumption:

- 3 events from CNNs in 200 t·y
- neutrons <0.1 events in full exposure (same as in DS-50)

ARGO @ SNOLAB

[arXiv:2203.08084](https://arxiv.org/abs/2203.08084)

- follows DarkSide-20k
- GADMC Collaboration:
DarkSide + DEAP + MiniCLEAN + ArDM
- 300 t UAr fiducial target
→ aim for $3 \text{ kt} \times \text{y}$ exposure
- Site: SNOLAB
- Technology: TPC?
Single-phase?
- Future goal: ARGO@SNOLAB



Conceptual studies in progress
Nominal run time: 10 years ($3 \text{ kt} \times \text{year}$)

- Requirements:
 - 400 t UAr → 5y operation of Urania+Aria
 - 100 m^2 photosensors → (digital?) SiPMs
- Immune to ERs at higher recoil energies thanks to PSD

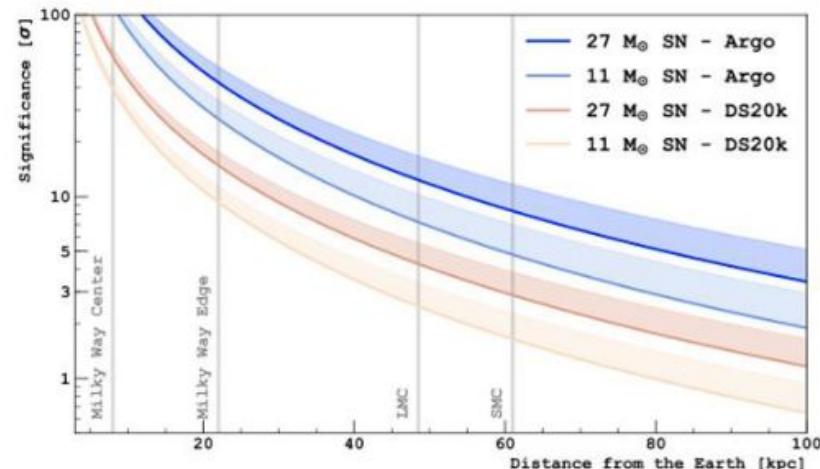
LAr: Supernova Detection

JCAP 2021, 043 (2021)



Image: G. Testera, LeptonPhoton 2021

- Detection based on the ionization signal only (S2)
- Threshold down to 0.4 keV_{nr}
- Coherent scattering:
 - neutrino flavor insensitive
 - highest neutrino cross section
- Advantages of CENvS in LAr TPC:
 - Sensitive to the entire unoscillated neutrino flux
 - Sensitive to the neutronization burst (the electronic flavor is highly suppressed by oscillations)



Supernova detection in LXe

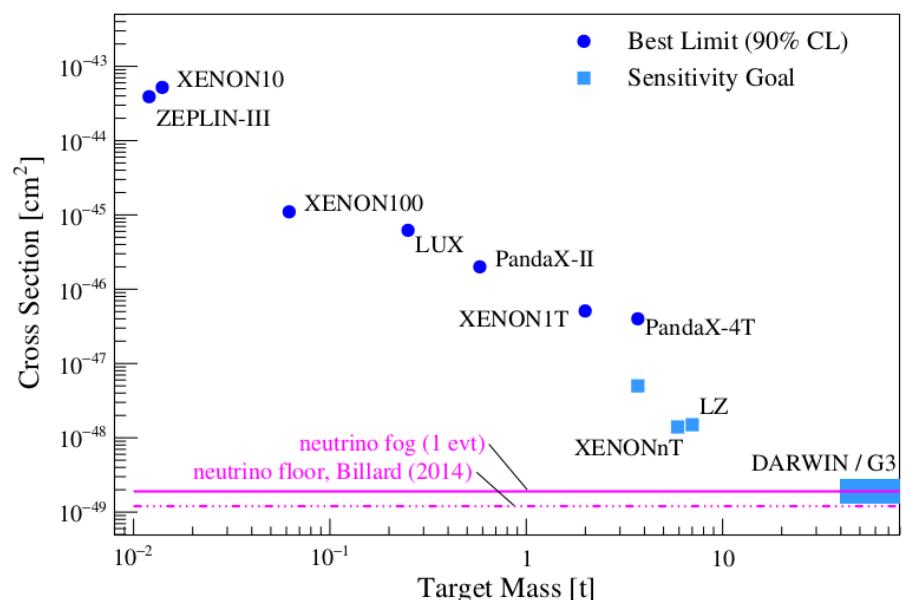
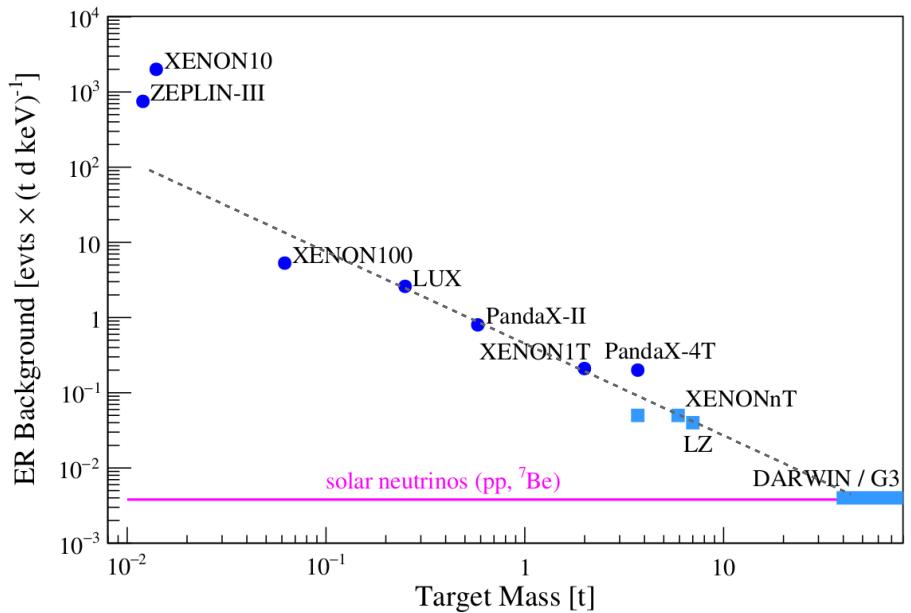
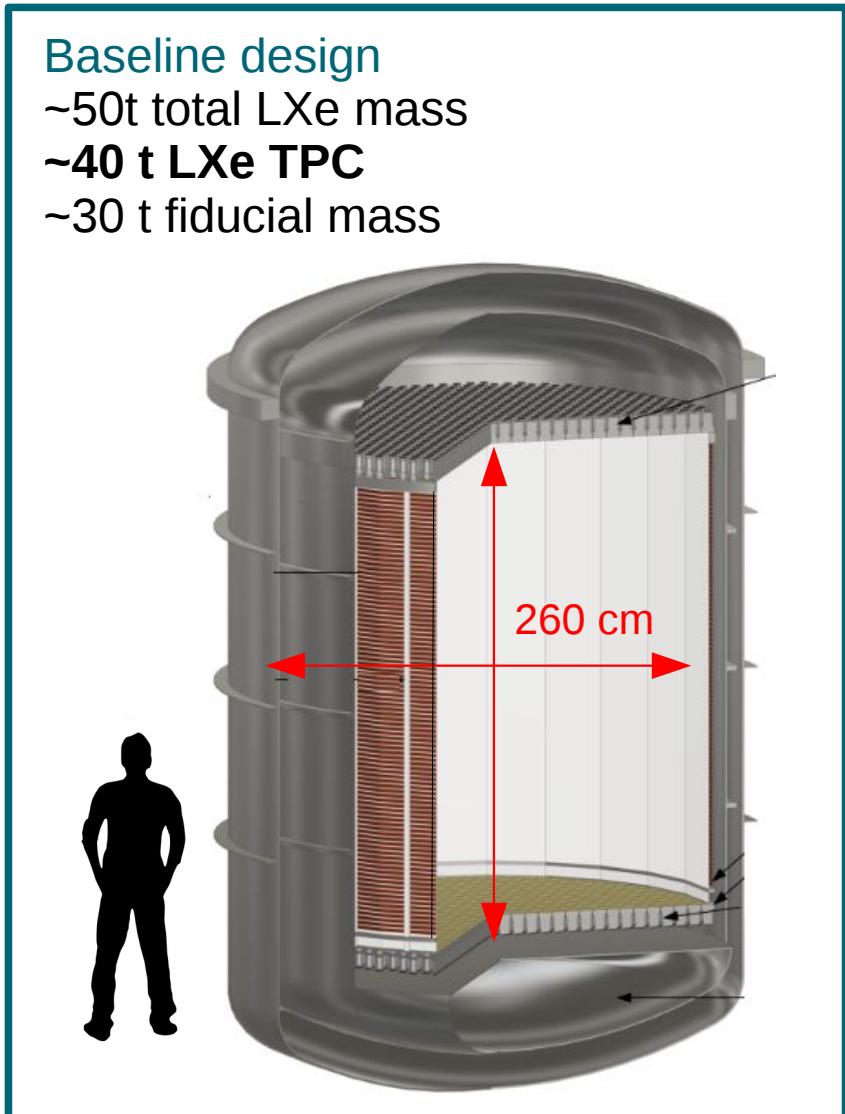
PRD 89, 013011 (2014)

PRD 94, 103009 (2016)

DARWIN: The ultimate LXe WIMP Detector

darwin-observatory.org JCAP 11, 017 (2016)

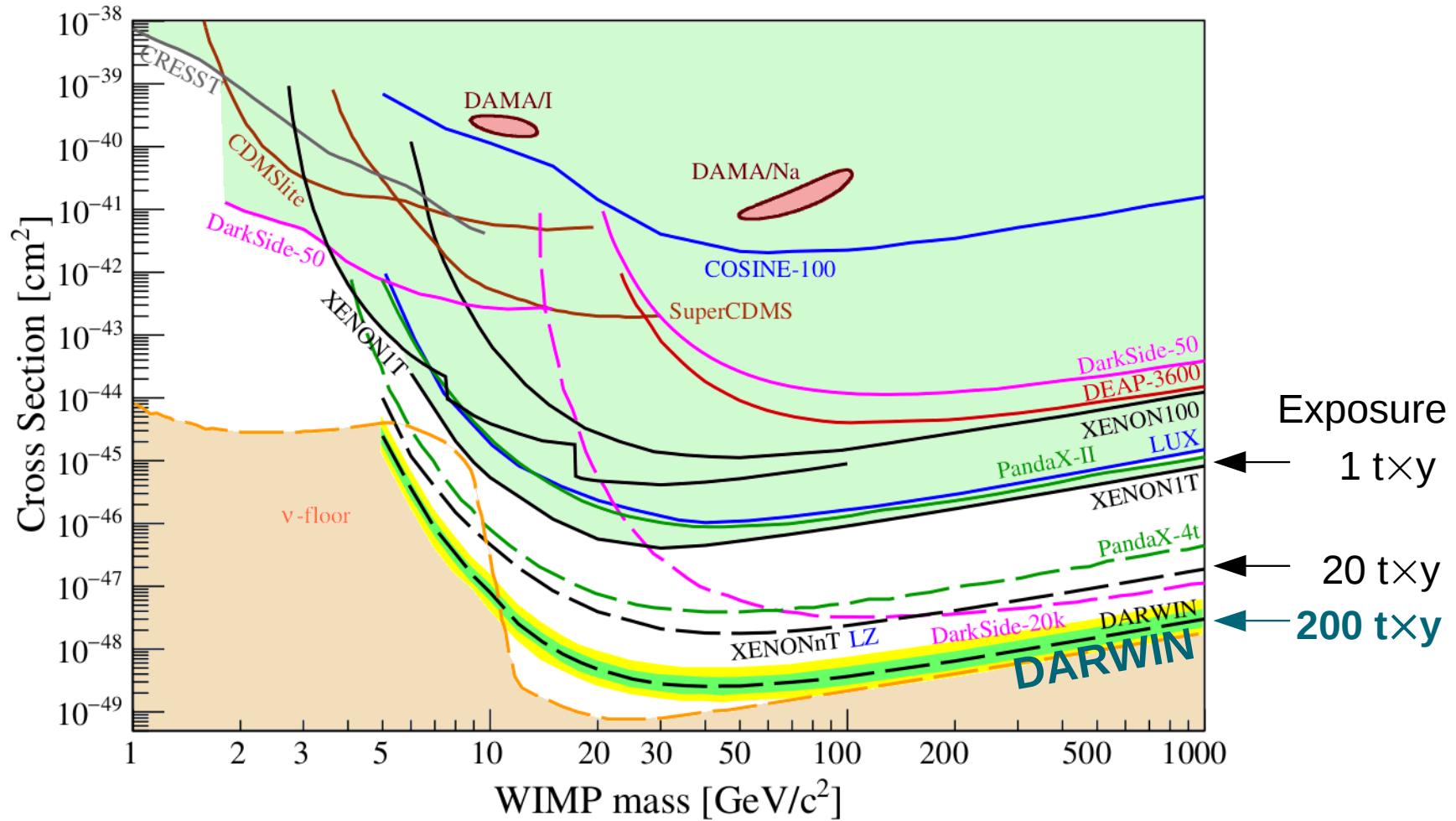
Background dominated by irreducible neutrinos



DARWIN: The ultimate LXe WIMP Detector

DARWIN

darwin-observatory.org
 JCAP 11, 017 (2016)



Spin-Dependent Couplings

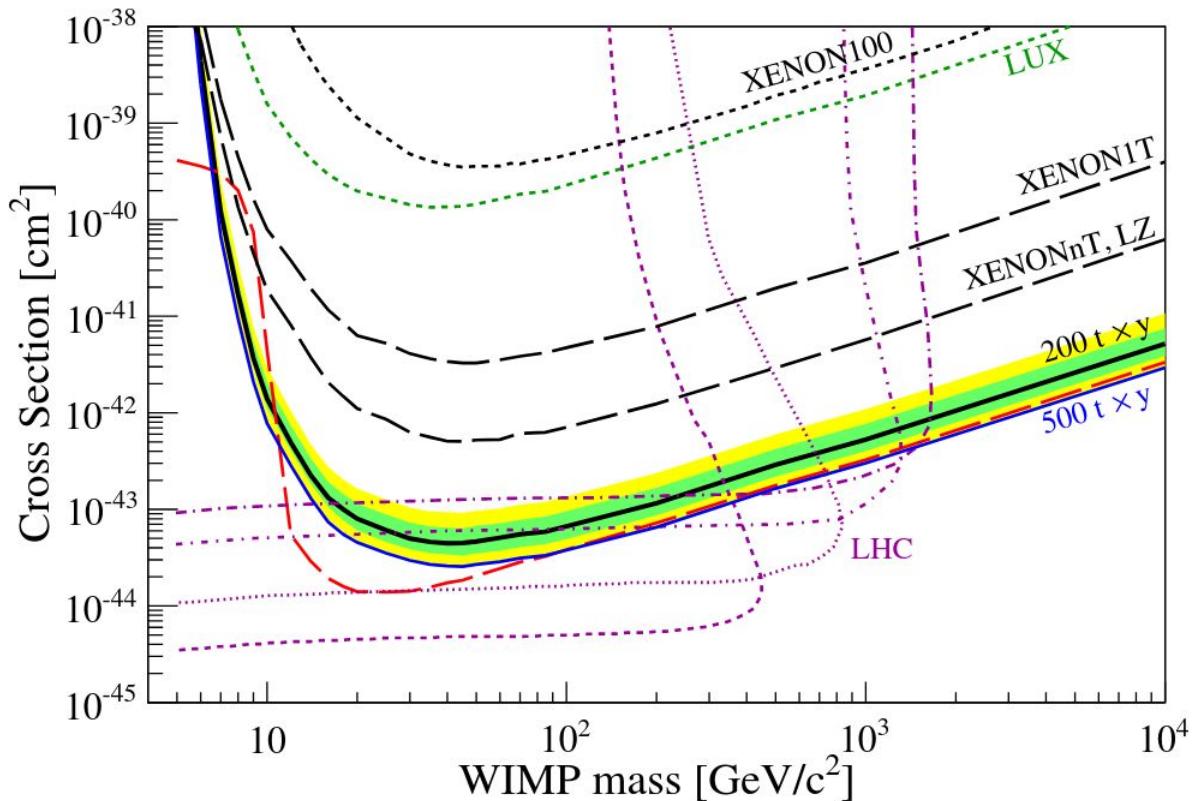
JCAP 10, 016 (2015)



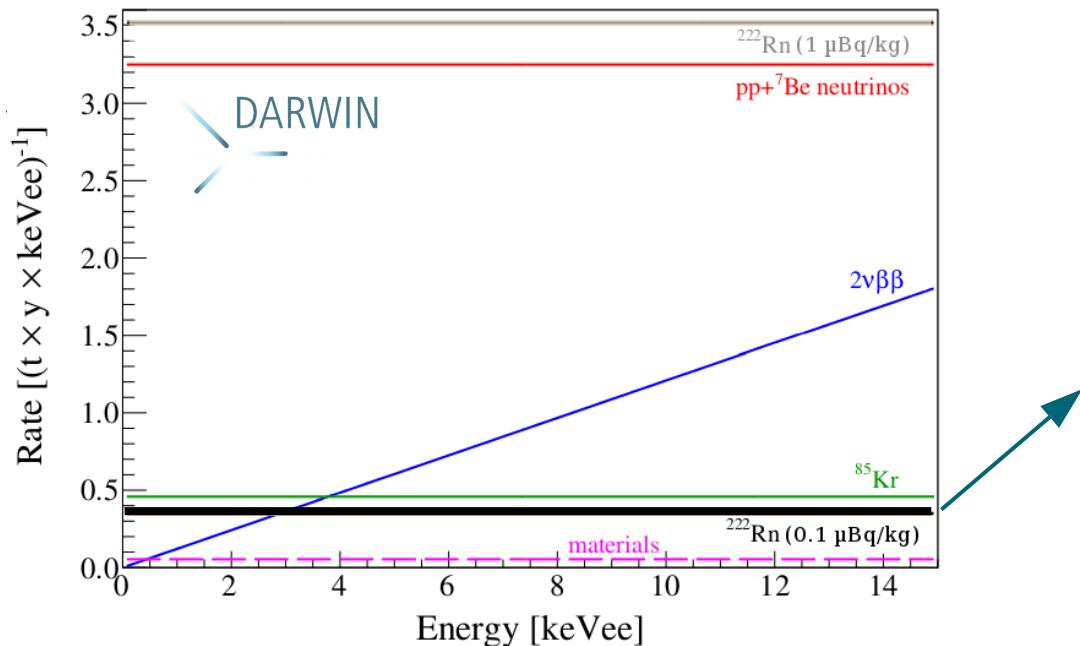
- coupling of WIMP to unpaired nucleon spins
→ **Xenon very favoured target**
- traditionally separated in proton-only and neutron-only
- same parameter space explored by indirect and collider searches**

Isotope	Abundance	Spin	Unpaired Nucleon	Relative Strength
⁷ Li	92.6%	3/2	proton	12.8
¹⁹ F	100.0%	1/2	proton	100.0
²³ Na	100.0%	3/2	proton	1.3
²⁹ Si	4.7%	1/2	neutron	9.7
⁷³ Ge	7.7%	9/2	neutron	0.3
¹²⁷ I	100.0%	5/2	proton	0.3
¹³¹ Xe	21.3%	3/2	neutron	1.7

WIMP-neutron
scattering



DARWIN: Radon Background



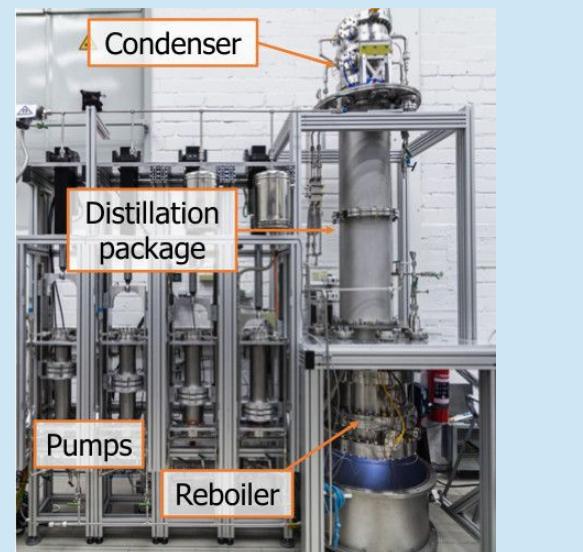
DARWIN goal:
ER background dominated
by solar neutrinos

**^{222}Rn emanated from all
detector surfaces.**
Need concentration
factor ~ 50 below XENON1T
factor ~ 10 below XENONnT

→ **main background challenge**

Strategy DARWIN

- **active Rn removal via cryogenic distillation**
 - column developed for XENONnT is R&D for DARWIN
- avoid Rn emanation by
 - optimal material production
 - **material selection**
 - surface treatment
 - **optimized detector design**



Size challenge: PANCAKE Detector Platform



DARWIN LXe test platform in Freiburg:

- 2.7 m inner diameter
- up to ~15 cm height (~5 cm LXe)
 - ~400 kg Xe gas
 - test horizontal components, real-scale electrodes etc.

Size challenge: PANCAKE Detector Platform



DARWIN LXe test platform in Freiburg:

- 2.7 m inner diameter
- up to ~15 cm height (~5 cm LXe)
 - ~400 kg Xe gas
 - test horizontal components, real-scale electrodes etc.



DFG

Deutsche
Forschungsgemeinschaft

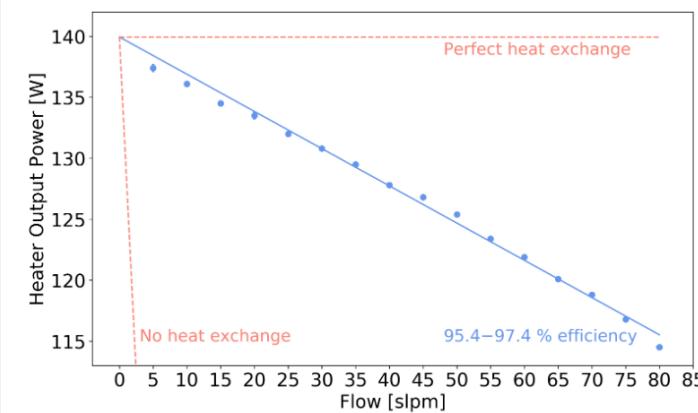


Size challenge: Xenoscope Detector Platform

JINST 16 P08052 (2021)

DARWIN Testplatform
in Zürich:

- 16 cm inner diameter
- up to 2.6 m LXe height



M. Schumann (Freiburg)

XENON + LZ + DARWIN = XLZD

www.xlzd.org



- Future merger of DARWIN / XENON + LZ collaborations to build and operate the next-generation liquid xenon observatory
 - new, stronger collaboration
 - will come once XENONnT and LZ are in routine operation
- Now: paving the way with XLZD Consortium
 - MoU 2021: 104 group leaders from 16 countries
 - joint whitepaper on science published
 - first joint workshops

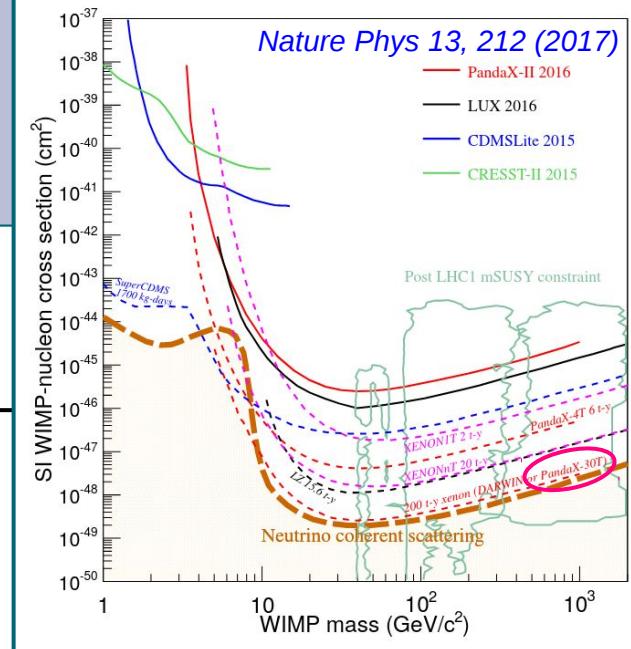


PandaX

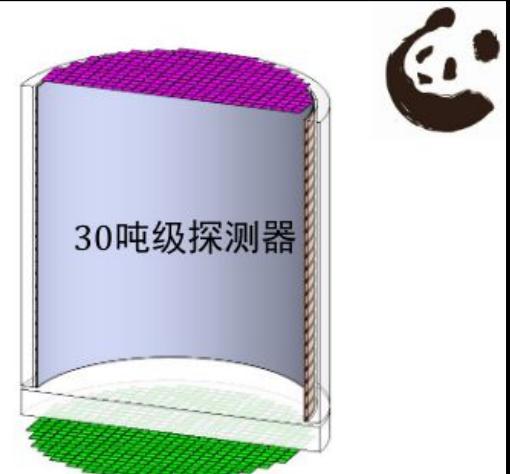
Proposal of PandaX-30T in CJPL-II
Nature Phys 13, 212 (2017)
JINST 16 T12015 (2021)

R&D of PandaX-xT

- Low background PMT
- Large size TPC
- Xenon isotope separation

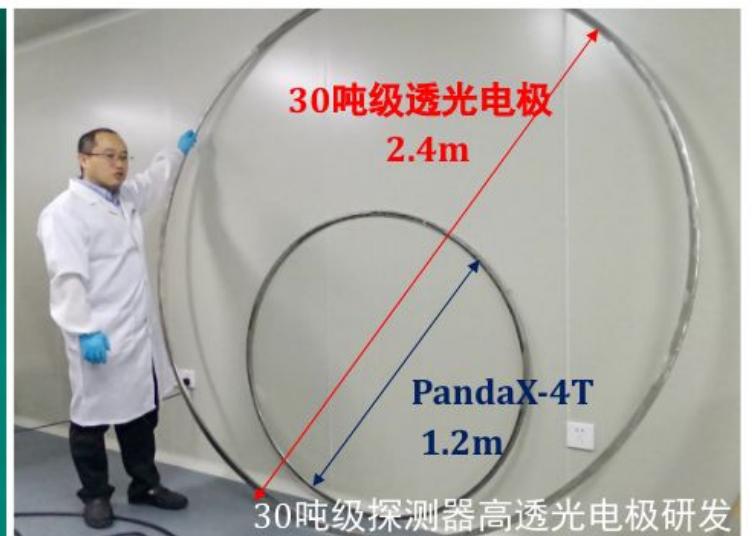
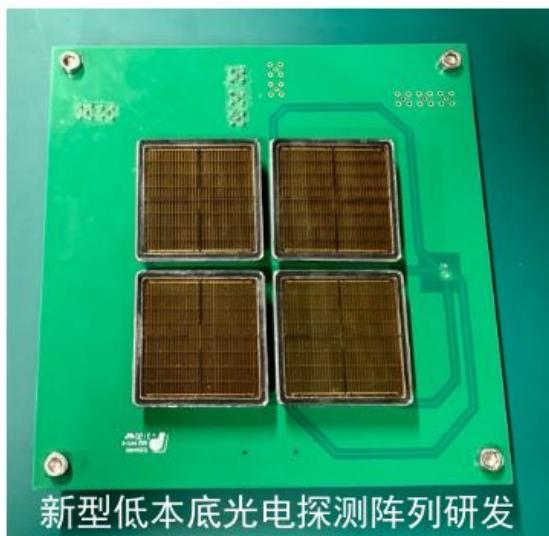


slide: PandaX (Nov 2021)



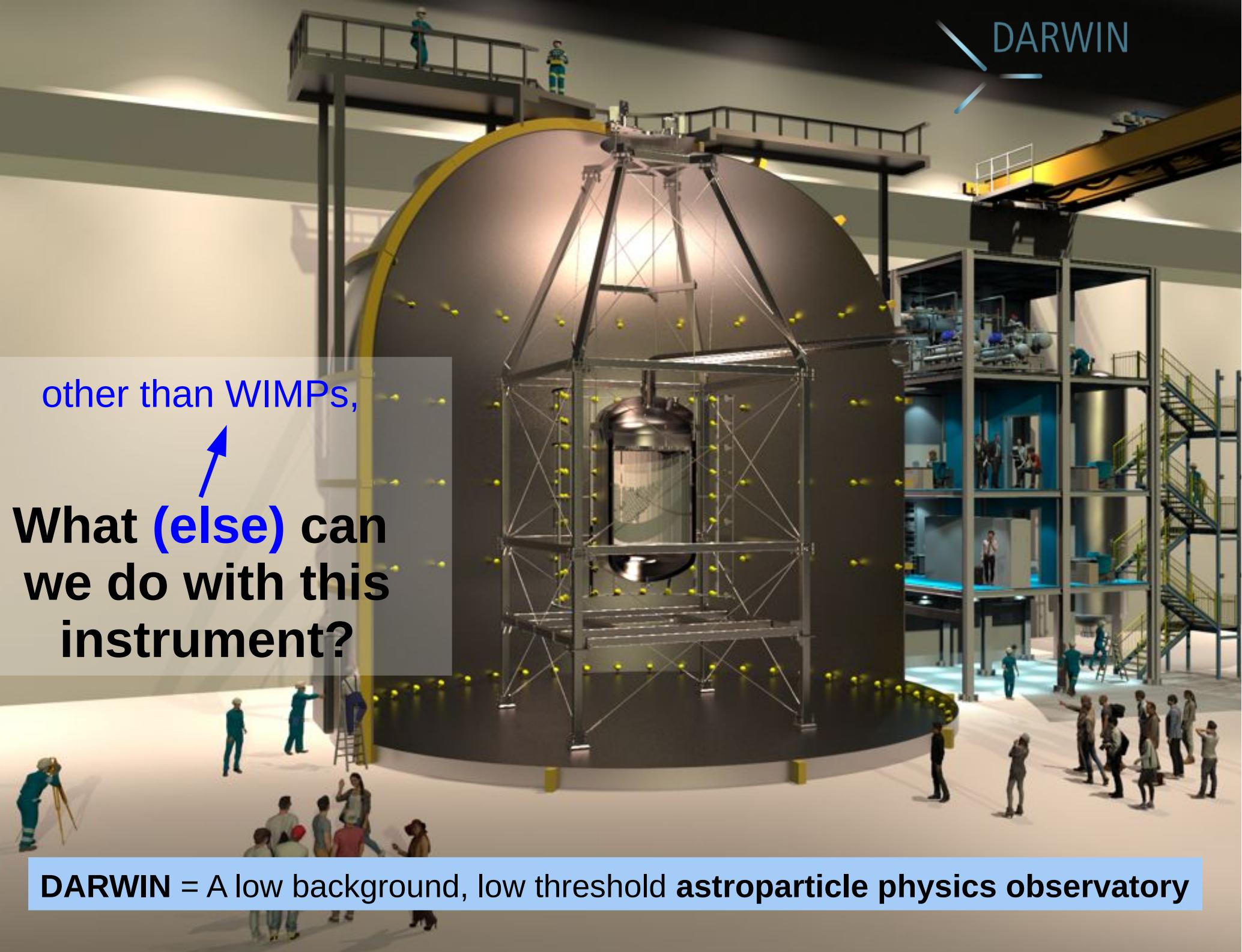
Hamamatsu R12699-406-M4

Unit: mBq/pc	R12699 (30T)	R11410 (4T)
Co-60	0.05±0.06 <0.15	1.16±0.72 <2.34
Cs-137	0.12±0.08 <0.25	0.52±0.81 <1.85
K-40	36.91±2.45	8.37±8.47 <22.31
Th-232(early)	0.35±0.35 <0.92	4.33±2.16 <7.88
Th-232(late)	0.80±0.29 <1.28	1.50±0.96 <3.08
U-235	0.00±0.17 <0.28	13.13±8.53 <27.16
U-238(early)	2.26±4.36 <9.44	26.29±16.90 <54.09
U-238(late)	0.63±0.26 <1.07	2.05±1.18 <3.99



DARWIN

other than WIMPs,
What (else) can
we do with this
instrument?



DARWIN = A low background, low threshold **astroparticle physics observatory**

LXe Whitepaper

[arXiv:2203.02309](https://arxiv.org/abs/2203.02309), accepted by *J. Phys. G*

A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics

D. S. Akerib,^{2,3} D. Yu. Akimov,⁴ J. Akshat,¹ M. Alfonsi,⁵ S. J. Andaloro,⁶ E. Angelino,⁷ J. Angevaare,⁸ H. M. Araújo,⁹ S. Baek,¹⁰ D. Bajpai,¹¹ A. Bandyopadhyay,¹² L. Baudis,¹³ A. L. Baxter,¹ N. F. Bell,¹⁴ P. Bhattacharjee,¹⁵ F. Bishara,¹⁶ C. Blanco,¹⁷ C. Boehm,¹⁸ P. D. Bolton,¹⁹ A. I. Bolozdynya,⁴ B. Boxer,²⁰

•••

⁹⁷*Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany*

⁹⁸*Department of Physics and Astronomy, University of California, Riverside, CA 92521, USA*

⁹⁹*School of Physics, Beihang University, Beijing, 100083, P.R.China*

¹⁰⁰*Technische Universität Dresden, 01069 Dresden, Germany*

~600 authors
from XLZD
+ others
+ theory

~100 institutions

The nature of dark matter and properties of neutrinos are most pressing issues in contemporary particle physics. The dual-phase xenon time-projection chamber is the leading technology to cover the available parameter space for Weakly Interacting Massive Particles (WIMPs) while featuring extensive sensitivity to many alternative dark matter candidates as well. The same detectors can study neutrinos through a variety of astrophysical sources and through neutrinoless double-beta decay. A next-generation xenon-based detector will therefore be a true multi-purpose machine to significantly advance particle physics, astrophysics, nuclear physics, and cosmology. This review article presents the science cases for such a detector.

Keywords: Dark Matter, Neutrinoless Double-Beta Decay, Neutrinos, Supernova, Direct Detection, Astroparticle Physics, Xenon

- [1075] A. Giuliani, J. J. Gomez Cadenas, S. Pascoli, E. Previtali, R. Saakyan, K. Schäffner, and S. Schönert (APPEC Committee) (2019), 1910.04688.
- [1076] T. Panesor, *A Review of UK Astroparticle Physics Research* (2015).
- [1077] N. Tyurin, *PARTICLE PHYSICS IN RUSSIA* (2012).
- [1078] T. Nakada et al., *The European Strategy for Particle Physics Update 2013* (2013).
- [1079] C. Bai et al., *Neutrinoless Double Beta Decay: A Study of Strategic Development by Chinese Academy of Sciences, in Chinese* (2020).

>1000 references

LXe Whitepaper

arXiv:2203.02309, accepted by J. Phys. G



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		L. Data-Intensive and Computational Sciences	47
		IX. Research Community: Priority	48

Covers (probably) all science channels you can think of...

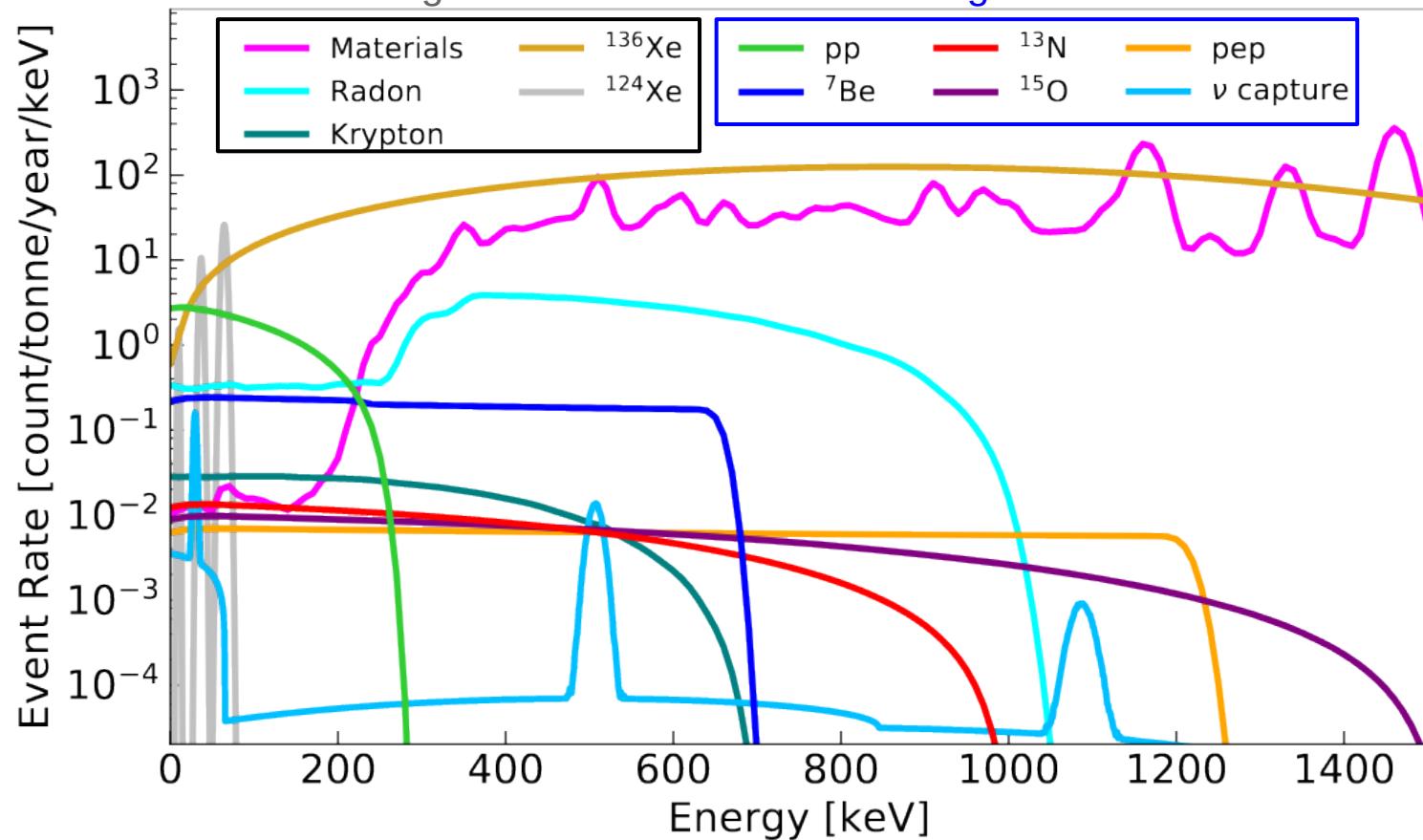
Solar Neutrinos

ER Spectrum in Xe

Backgrounds

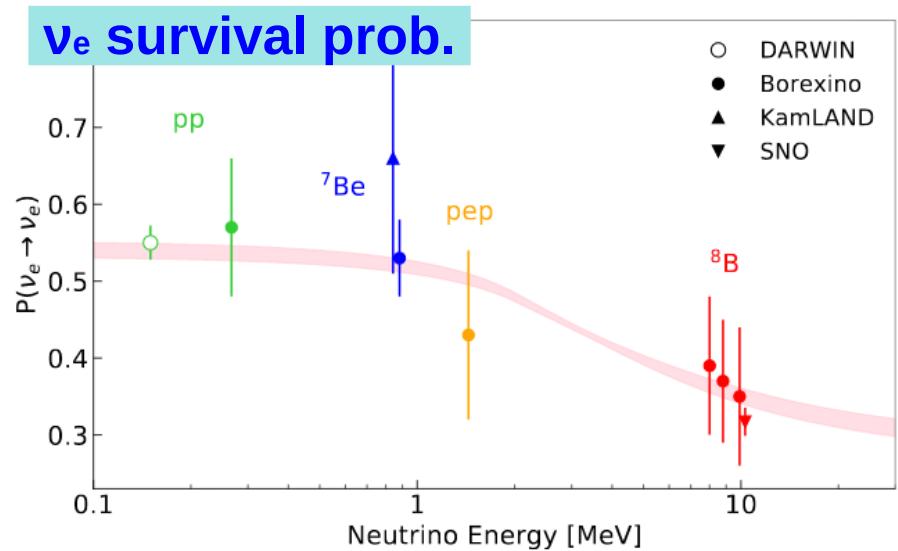
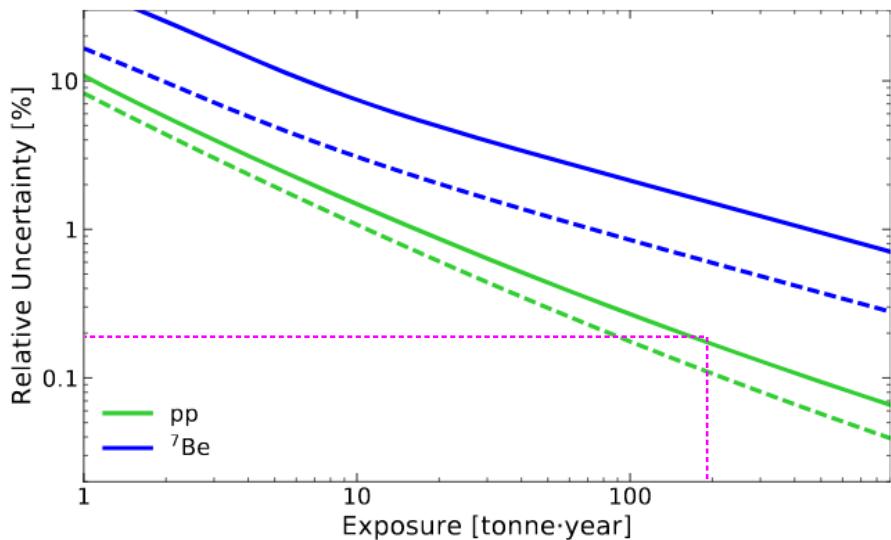
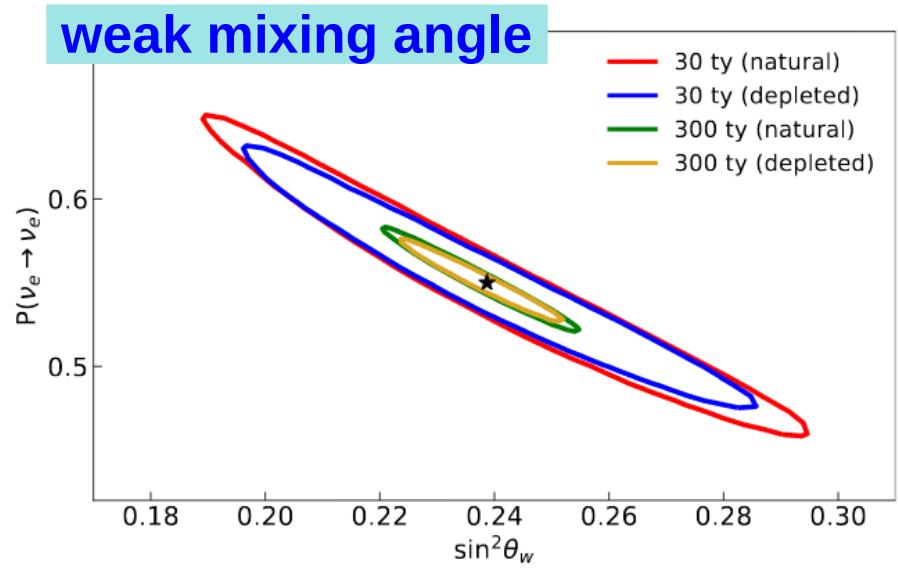
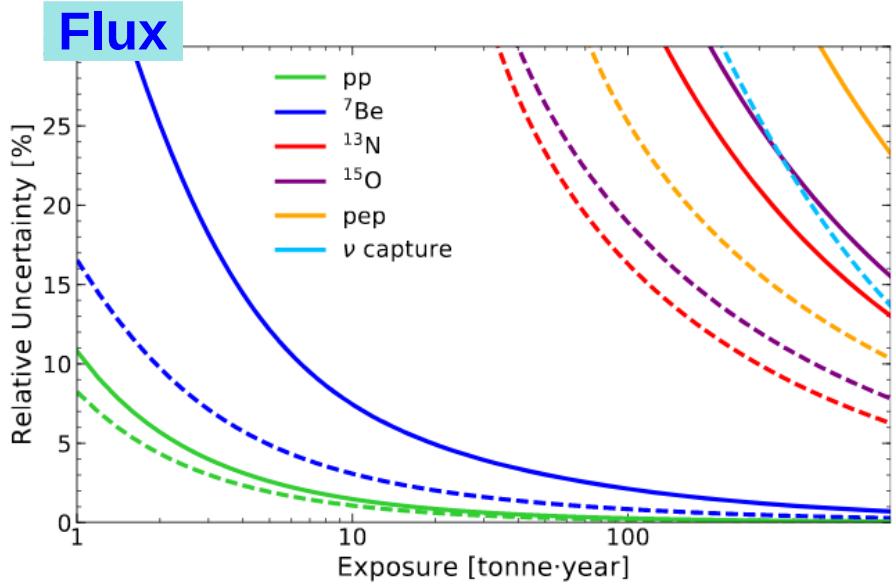
Signals

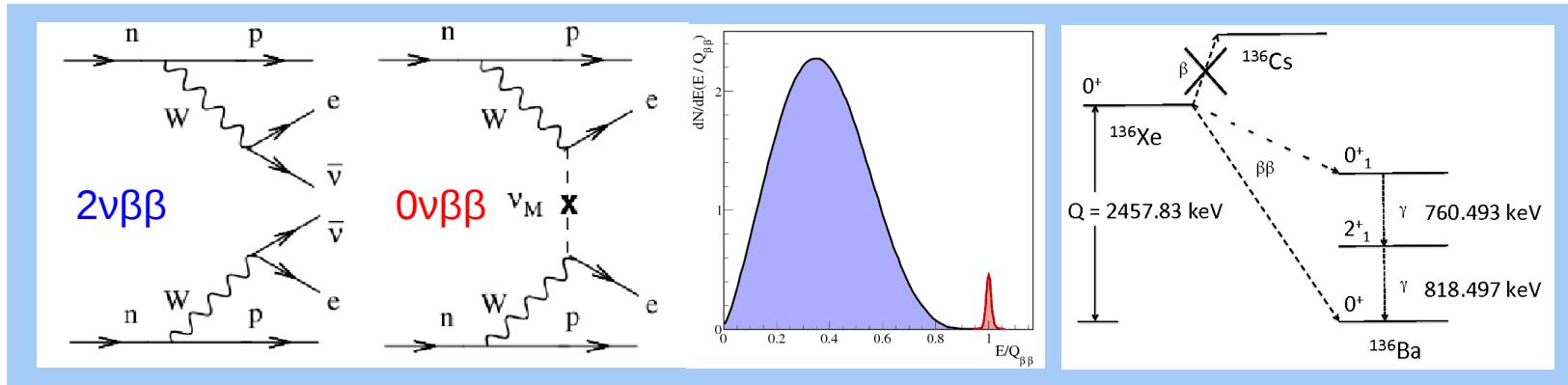
JCAP 01, 044 (2014)
 EPJ C 80, 1133 (2020)



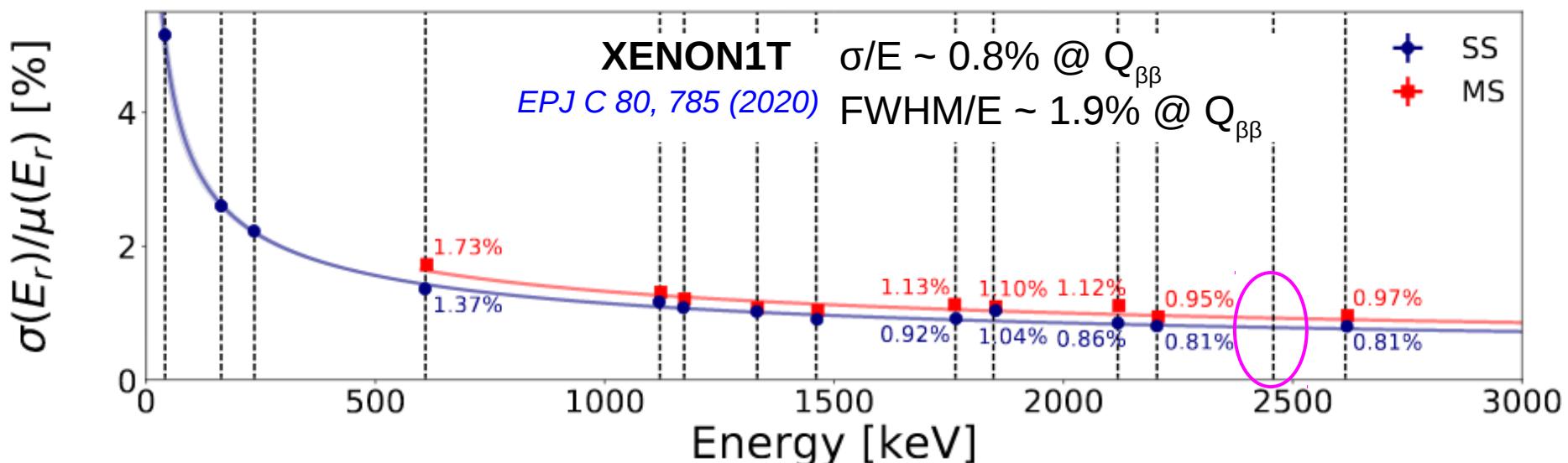
- DARWIN's low-E ER spectrum dominated by pp neutrinos (and $2\nu\text{DEC}+2\nu\beta\beta$)
- distinct features in ν spectra allow extracting neutrino fluxes
 → full spectral fit of all components up to 3 MeV
 (possibility to enhance sensitivity by more sophisticated analysis)

pp-Neutrinos in real time

EPJ C 80, 1133 (2020)



 $\Delta L \neq 0$

- 0 $\nu\beta\beta$ candidate with $Q_{\beta\beta} = 2.46$ MeV
- 40t DARWIN LXe target contains 3.5t of ^{136}Xe **without any enrichment!**

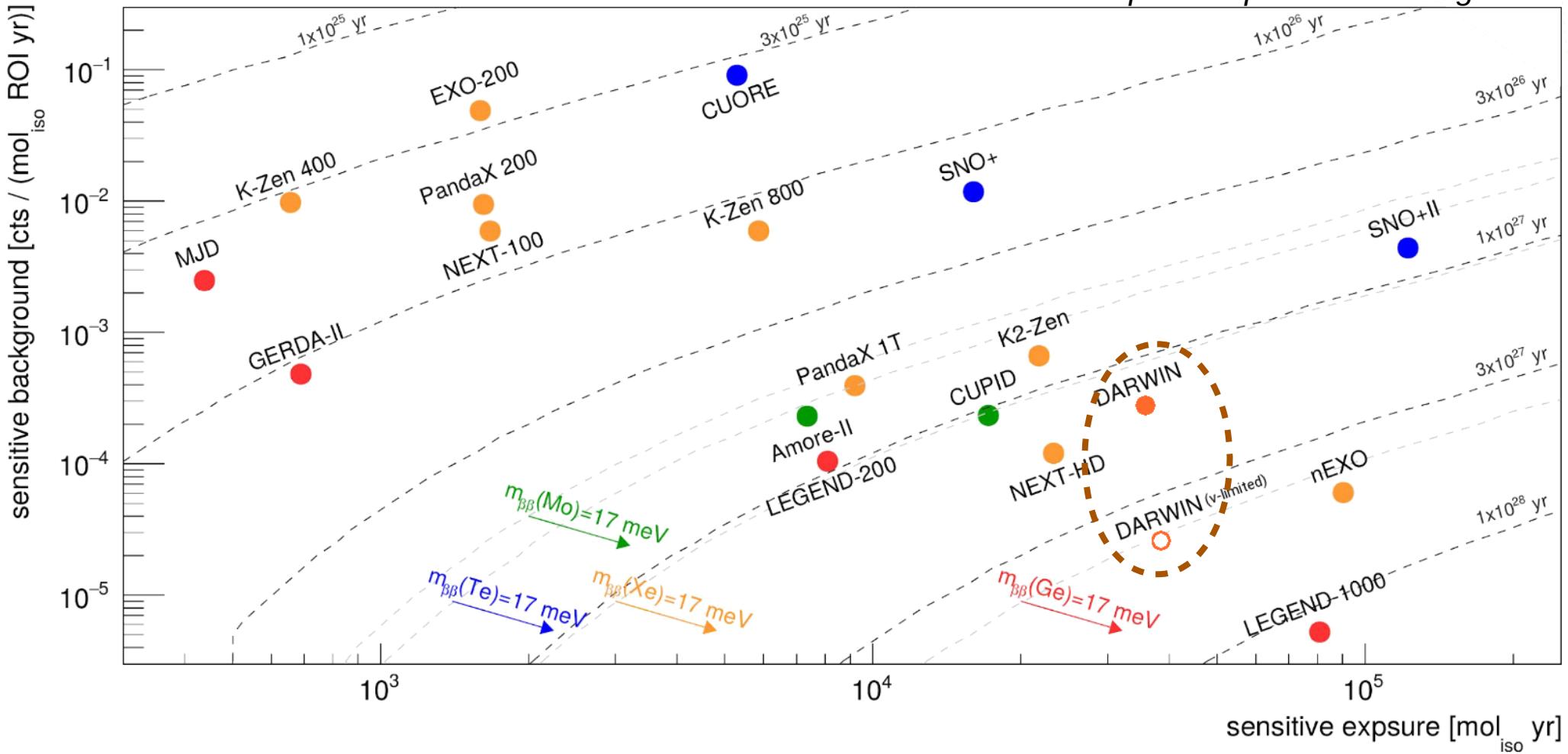


^{136}Xe : 0 ν double-beta Decay

EPJ C 80, 808 (2020)



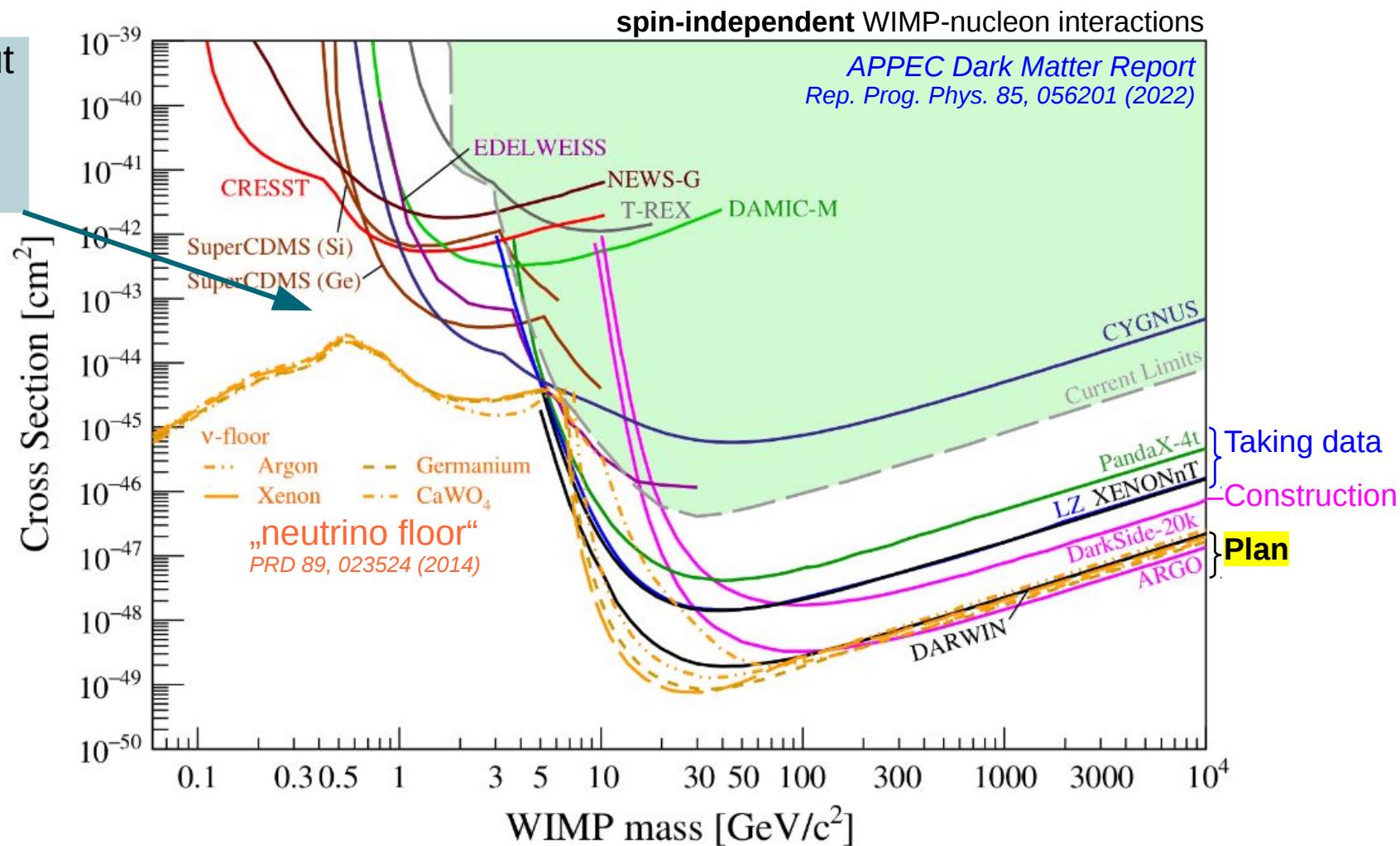
plot adapted from M. Agostini



half-life sensitivity: $2.4 \times 10^{27} \text{ y}$

Summary

I did not talk about projects probing exclusively low-mass WIMPs



- We will hit the neutrino floor soon (@ ~6 GeV)
- very large exposures ($\rightarrow \nu$ -limited detectors) required to reach neutrino floor
- proposals for LXe and LAr targets \rightarrow exciting non-WIMP physics as well