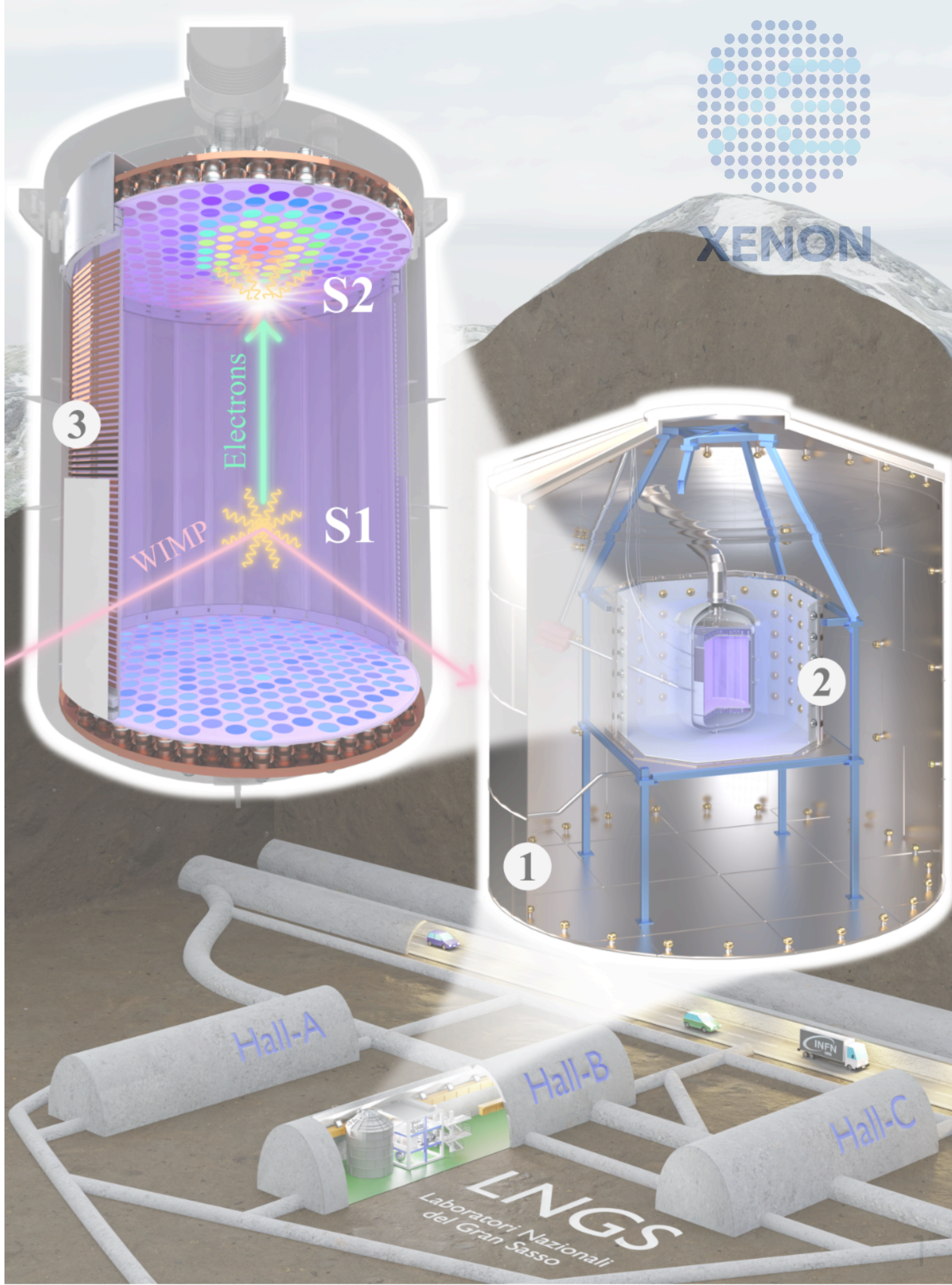
XENON and XLZD

山下雅樹

東京大学カブリIPMU

for the XENON Collaboration
and the XLZD Collaboration



Outline

XENONnT Highlight

- **太陽ニュートリノ8B の観測**
  - First Indication of Solar 8B Neutrinos via Coherent Elastic Neutrino-Nucleus-Scattering with XENONnT
  - PRL 133, 191002 (2024), **Editors' Suggestion** **Featured in Physics**

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- **ニュートリノfogに差し掛かったWIMP探索**
  - First search for light dark matter in the neutrino fog with XENONnT
  - PRL, accepted

XLZD

- 2024 コラボレーションの設立
- XLZDの物理 (WIMP, 二重ベータ崩壊など)

Neutrino detectors and XENONnT

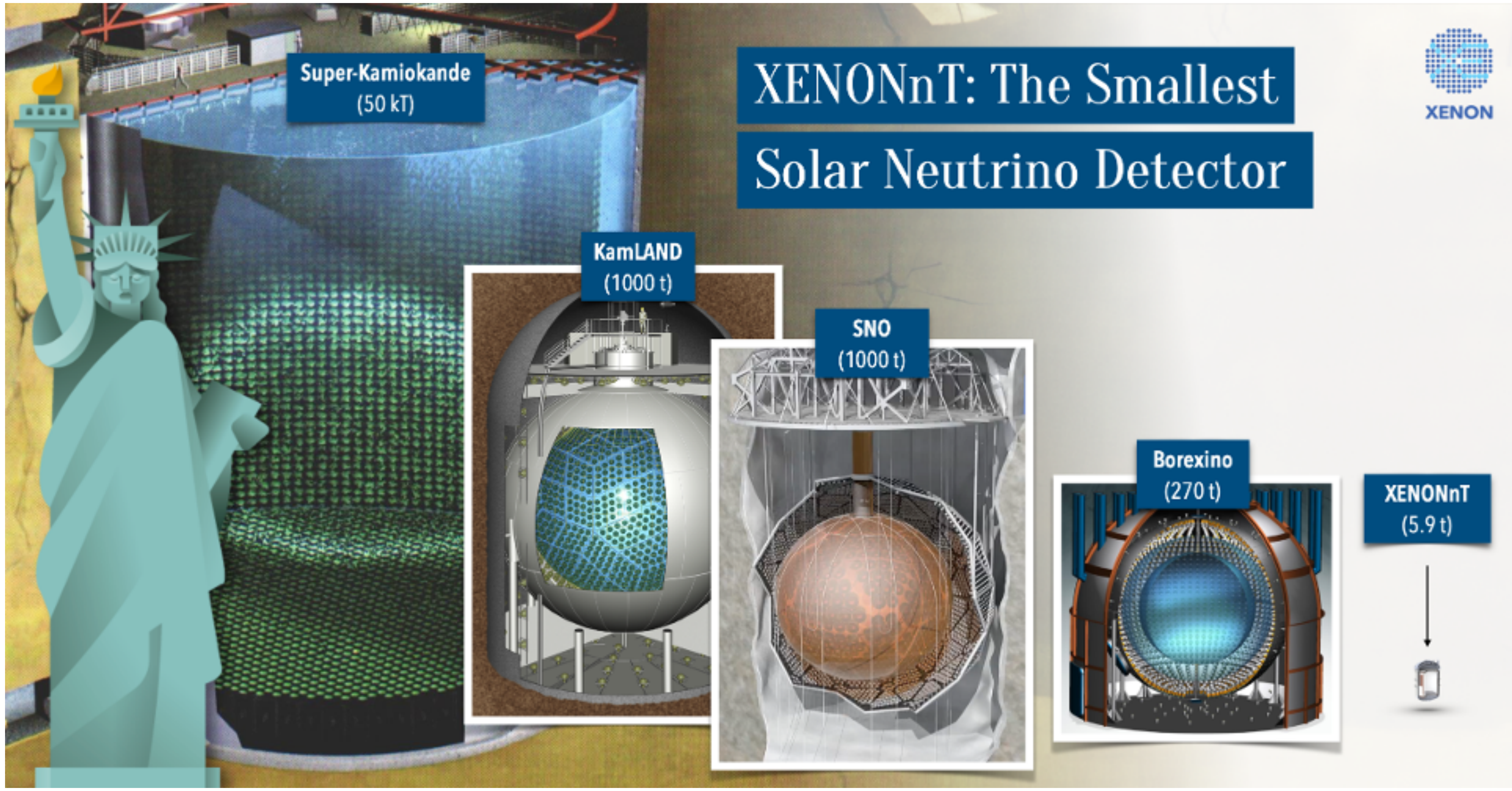
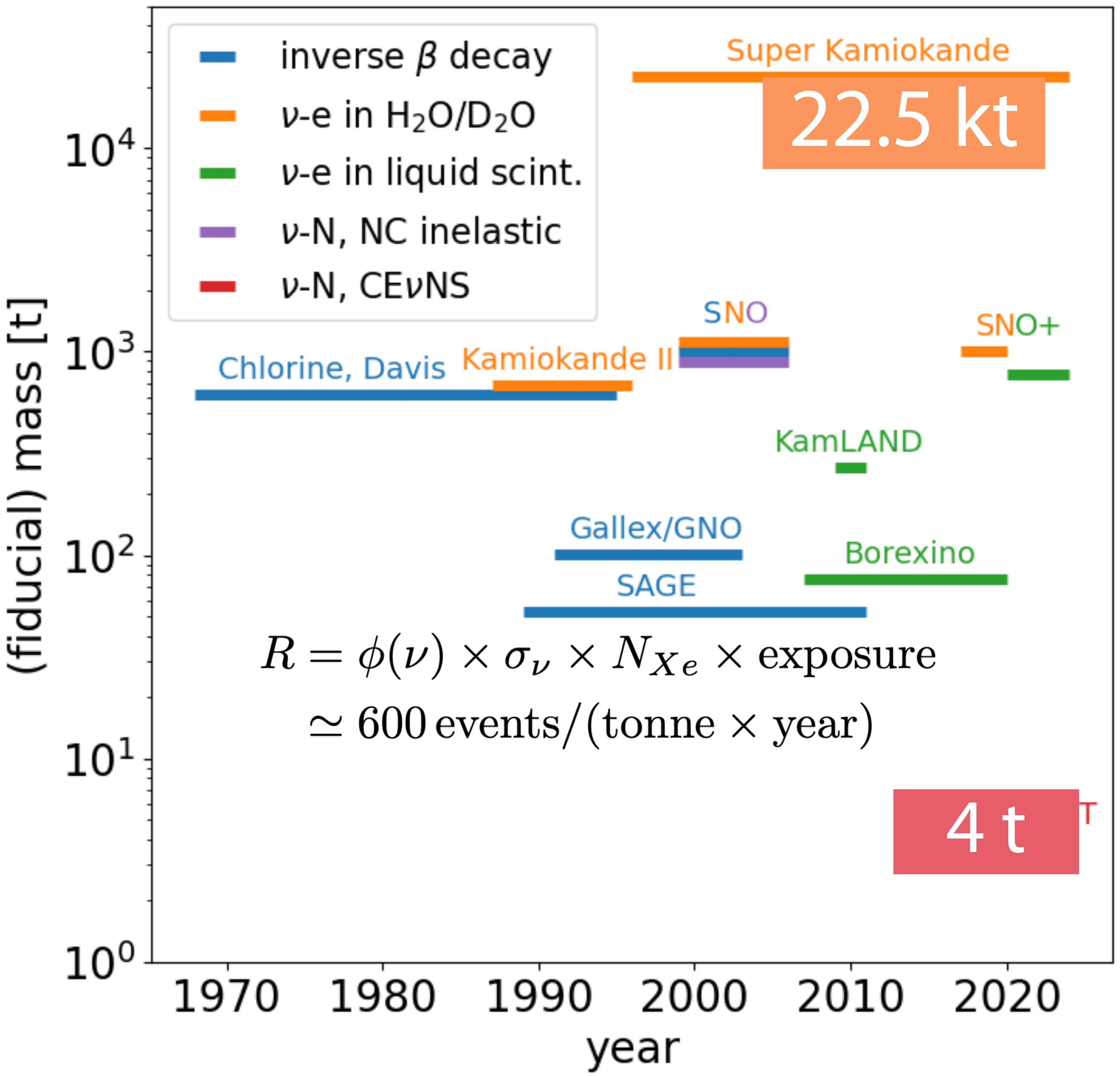


Figure: Detection of solar neutrinos. Compilation courtesy R. Hammann.



Coherent Elastic Neutrino Scattering (CEvNS)

XENON

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

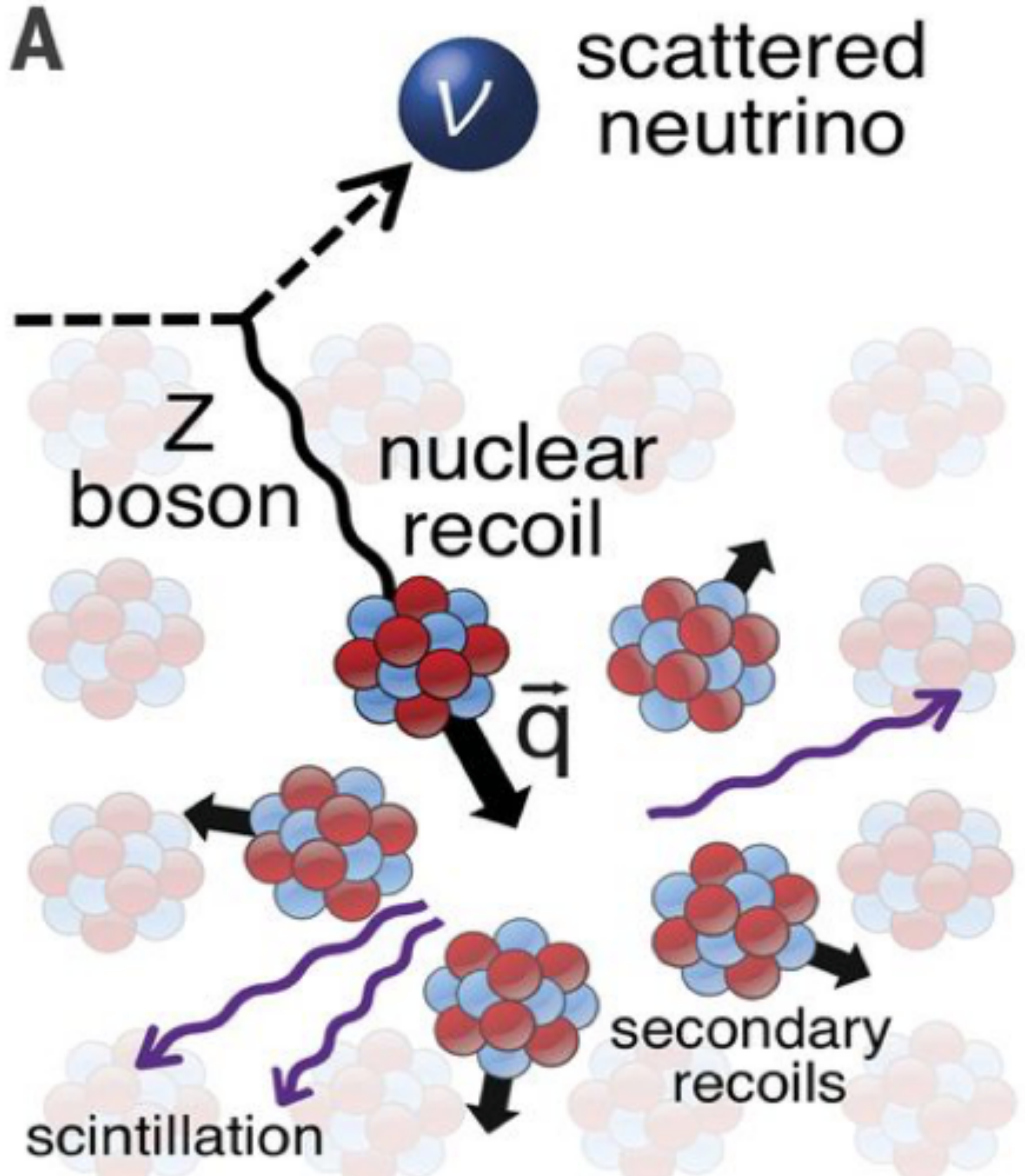
Coherent effects of a weak neutral current

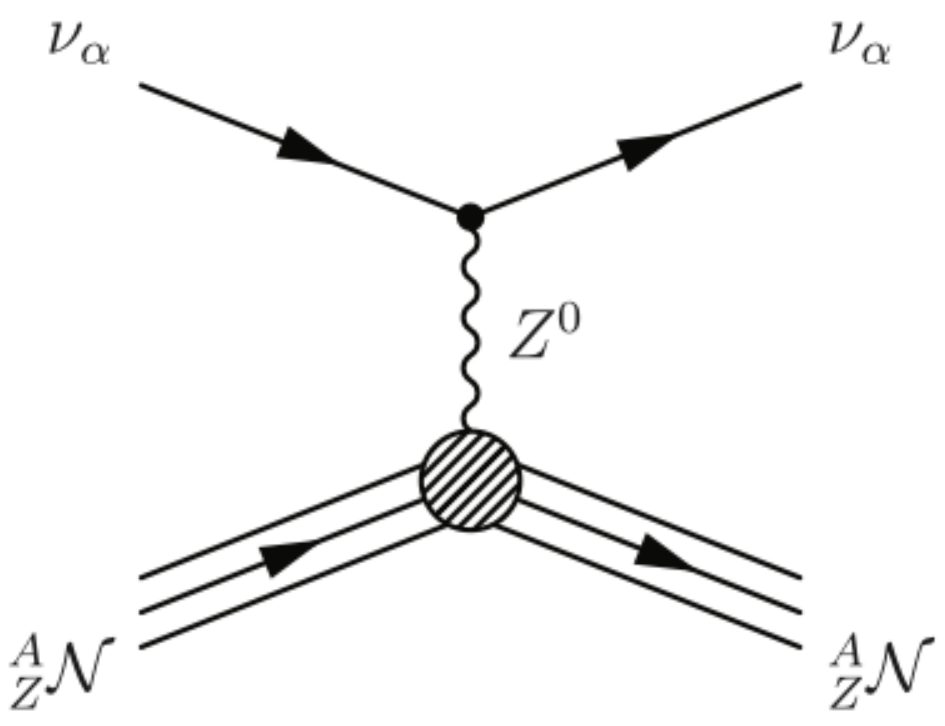
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm^2 on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

ν





D. Akimov et al, Science 357 (2017)

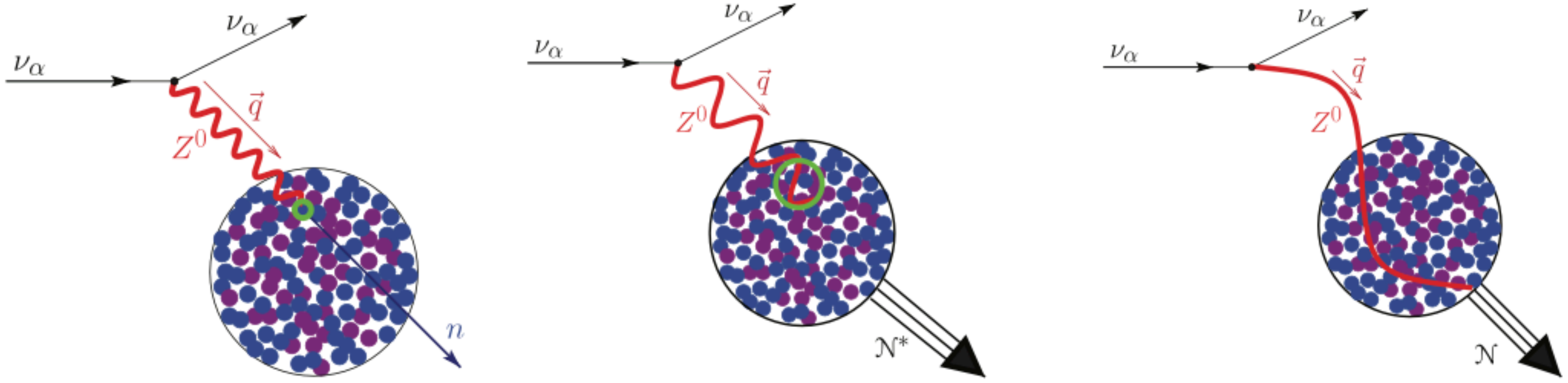
1974 Coherent elastic neutrino-nucleus scattering (CEvNS) was predicted theoretically by D.Z. Freedman.

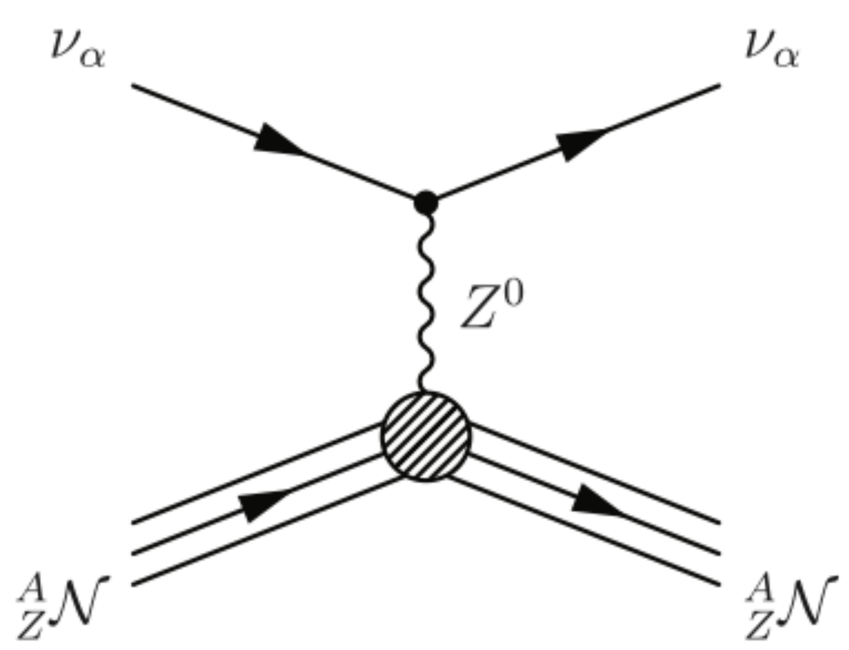
1985 Drukier&Stodolsky and Goodman&Witten showed the possibility for the detection of astrophysical neutrino or dark matter through coherent elastic scattering

2017 It was observed experimentally for the first time only in 2017 in the COHERENT experiment with neutrinos produced by the Spallation Neutron Source.

It took ~40 years to observe it. Why?

Neutrino-Nucleus Interactions



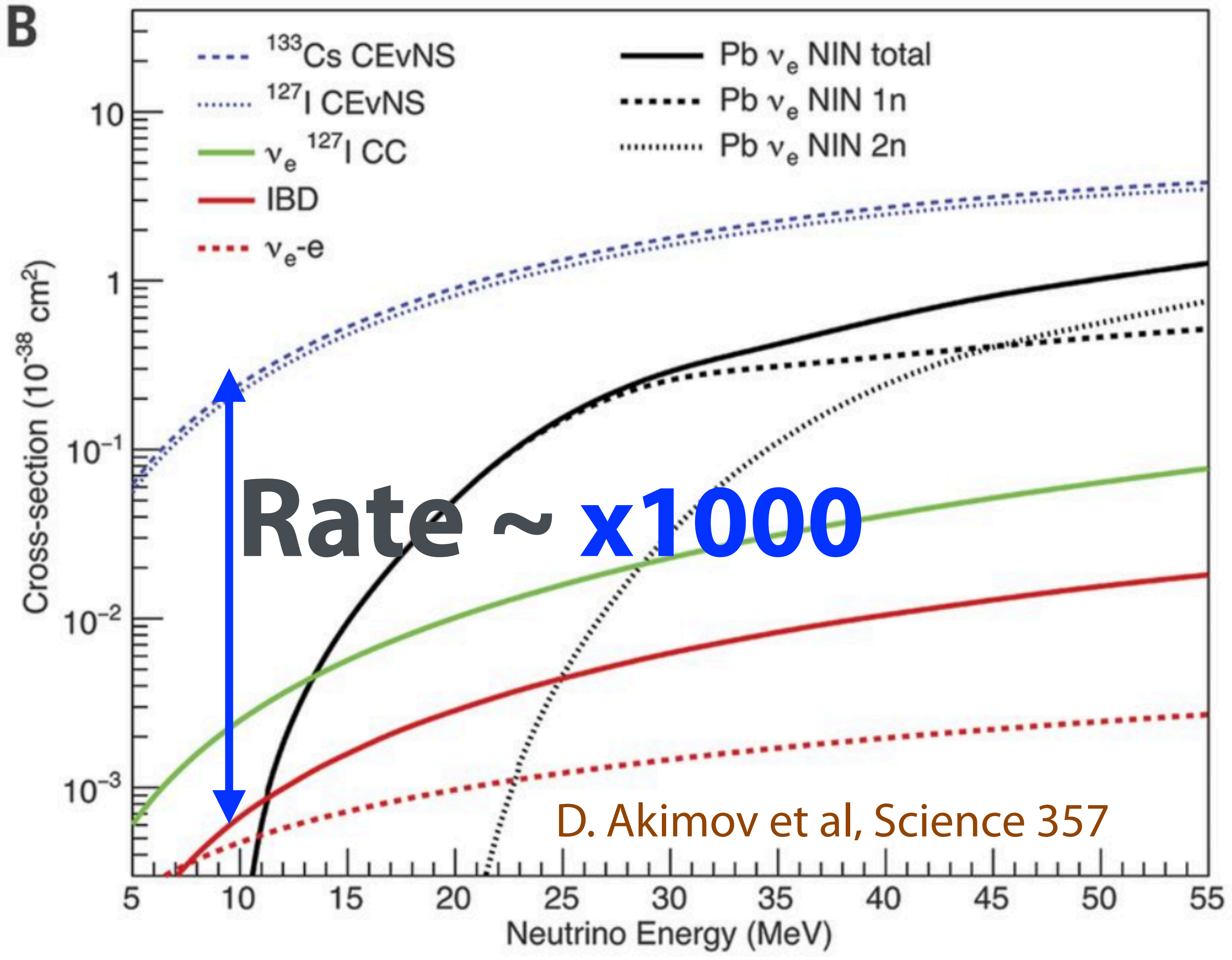


Inelastic incoherent	Elastic incoherent	Elastic coherent (CEνNS)
$\lambda_{Z^0} \ll 2R$	$\lambda_{Z^0} \lesssim 2R$	$\lambda_{Z^0} \gtrsim 2R$
~ 100 GeV	~ GeV	~MeV

M. Cadeddu et al. EPL, 143 (2023) 34001

$\boxed{\lambda \sim R \ (\sim 5\mathrm{fm}), \quad E_\nu \lesssim 50\ \mathrm{MeV},}$

$\boxed{E_{max}: \quad \frac{2E_\nu^2}{M} \sim 1.5\ \mathrm{keV}}$

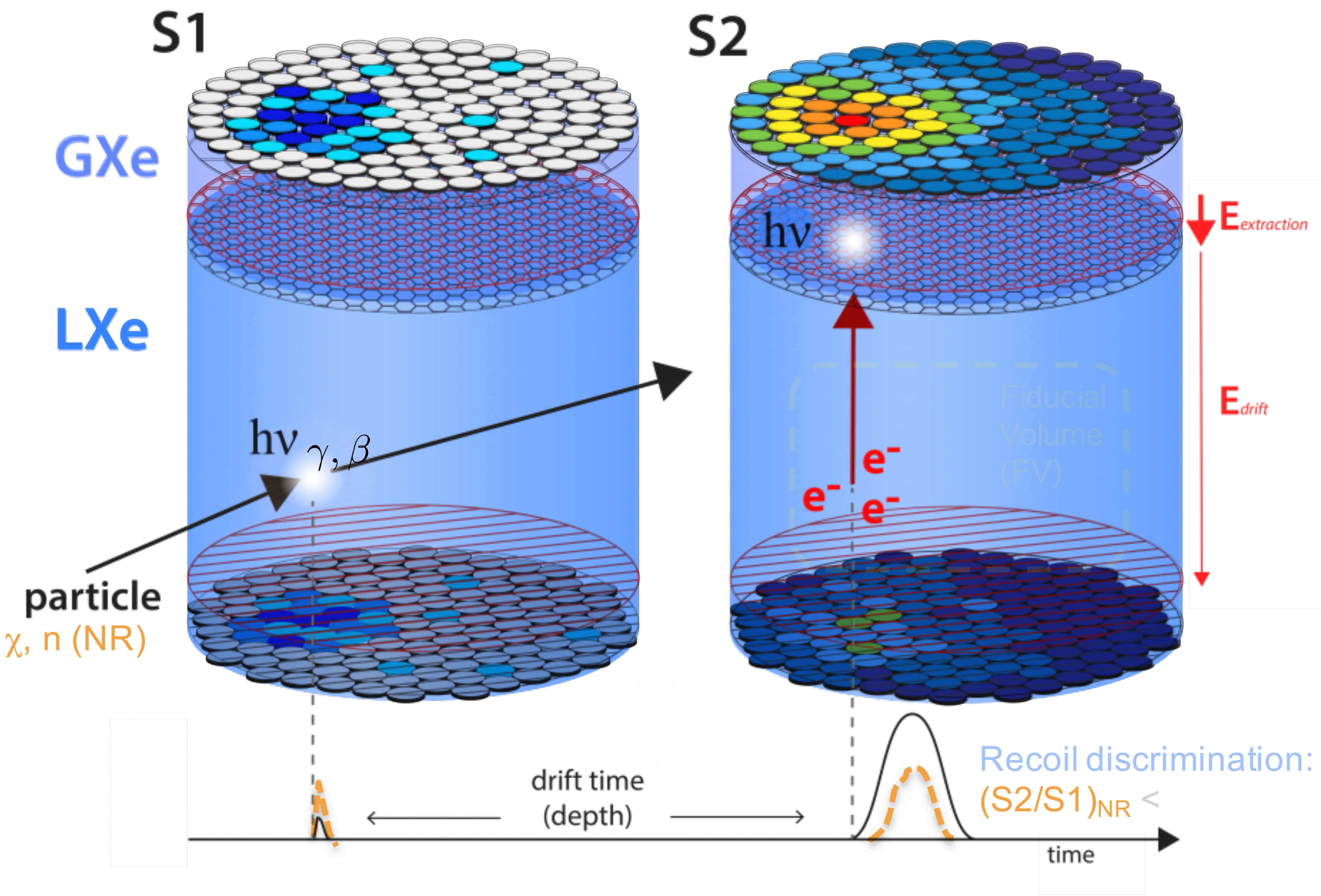


E ~ x 1/1000 w.r.t. neutrino detector

Two-phase Xe Time Projection Chamber

XENON

- **Target Liquid Xenon (-100°C)**
- **S1: Scintillation**
- **S2: electron (->proportional light)**



- simultaneously observe both S1 and S2
- 3D event imaging: x-y (S2) and z (drift time)
- Self-shielding, surface event rejection, single vs multiple scatter events
- Particle identification using S2/S1 ratio (nuclear recoil vs beta, gamma)

one drifted electron produces ~ 200 photon

-> ~30 Photoelectron/electron

Improve Energy threshold by usin S2-only for SN search :

S2 only < 1keV (E threshold)

太陽ニュートリノ(^{8}B) の結果

XENON

PHYSICAL REVIEW LETTERS **133,** 191002 (2024)

Editors' Suggestion **Featured in Physics**

First Indication of Solar ^{8}B Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT

SR0 + SR1

Component	Expectation	Best-fit
AC (SR0)	7.5 ± 0.7	7.4 ± 0.7
AC (SR1)	17.8 ± 1.0	17.9 ± 1.0
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3
Total background	$26.4^{+1.4}_{-1.3}$	26.3 ± 1.4
^{8}B	$11.9^{+4.5}_{-4.2}$	$10.7^{+3.7}_{-4.2}$
Observed	37	

First solar ^{8}B flux measurement via CEvNS as

$(4.7^{+3.6}_{-2.3}) \times 10^6\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ cm^{-2} s^{-1} at 90% C.L.

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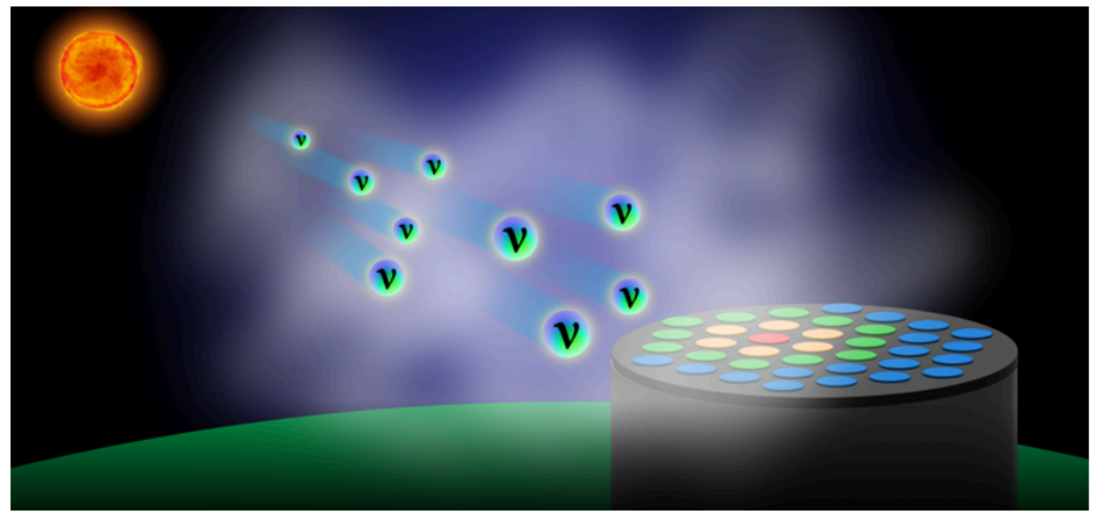

First Indication of Solar ^{8}B Neutrinos via Coherent Elastic Neutrino-Nucleus Scattering with XENONnT

XENON Collaboration

The background-only hypothesis is disfavored at 2.73σ

* Panda-X https://arxiv.org/abs/2407.10892 (2.64σ)

太陽ニュートリノ(^{8}B) の結果

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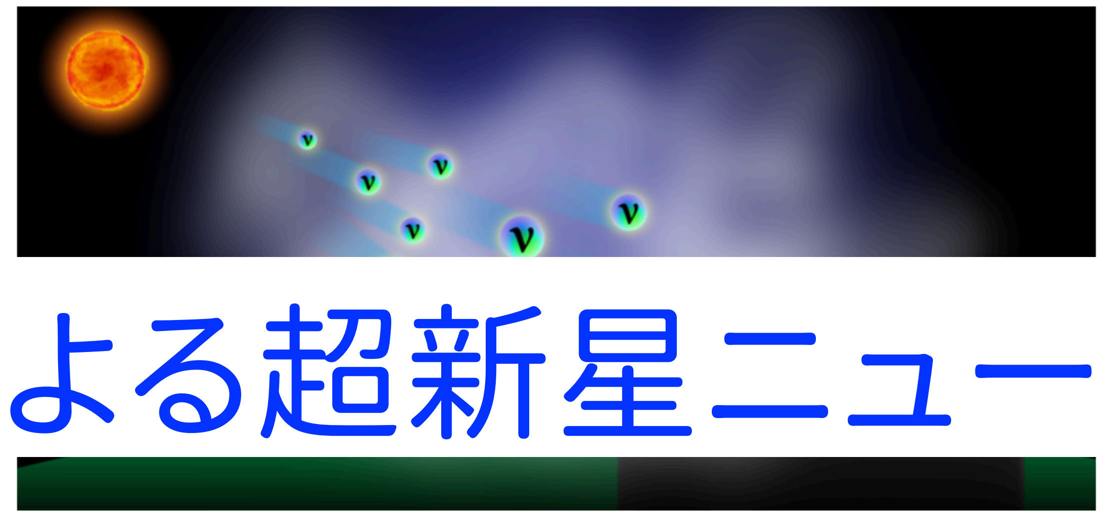

フレーバーによらないコヒーレント散乱による超新星ニュートリノ観測に期待

The background-only hypothesis is disfavored at 2.73σ

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XENON Collaboration

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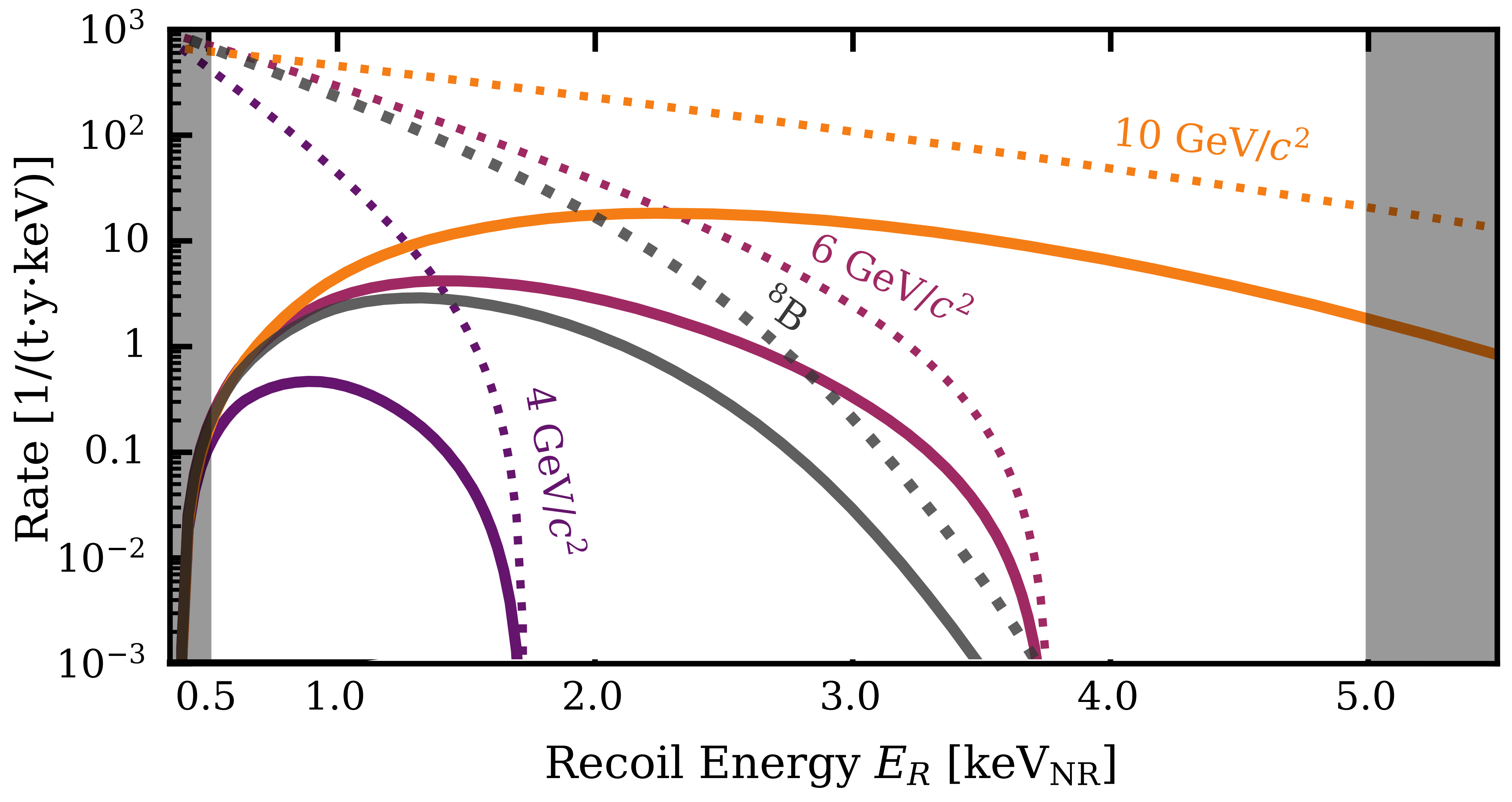
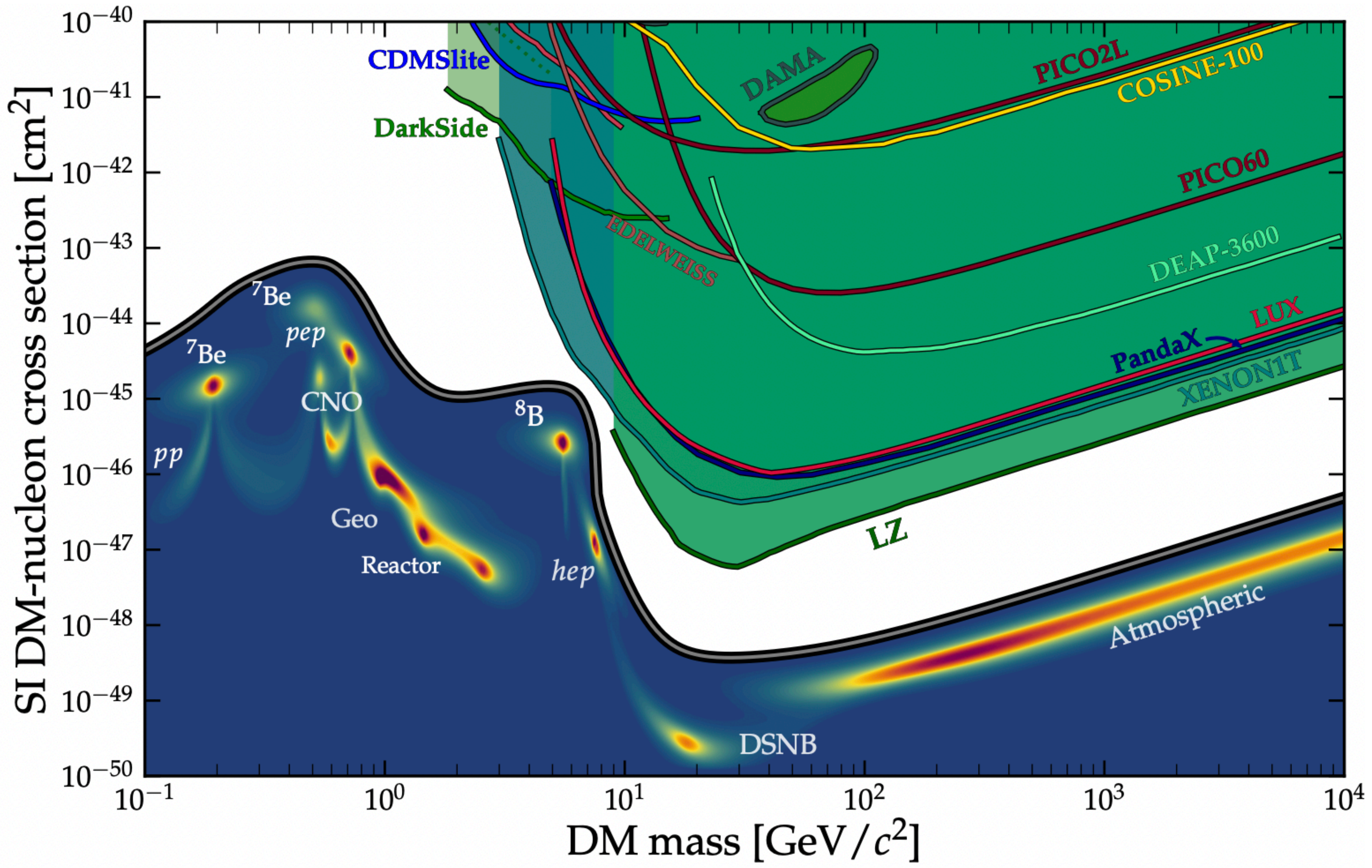
Search for ^{8}B neutrino signal / low mass WIMPs

First search for light dark matter in the neutrino fog with XENONnT (PRL, accepted)

- ^{8}B 太陽ニュートリノによるコヒーレント散乱 は **5.5GeV WIMPsとほぼ同様なエネルギースペクトラム**
- ^{8}B 太陽ニュートリノ解析と同様にWIMP探索
    - **^{8}B 太陽ニュートリノはバックグラウンド**
- “neutrino fog” に差し掛かった**初めて**の WIMP探索
- 12GeV質量以下に上限値を与えた





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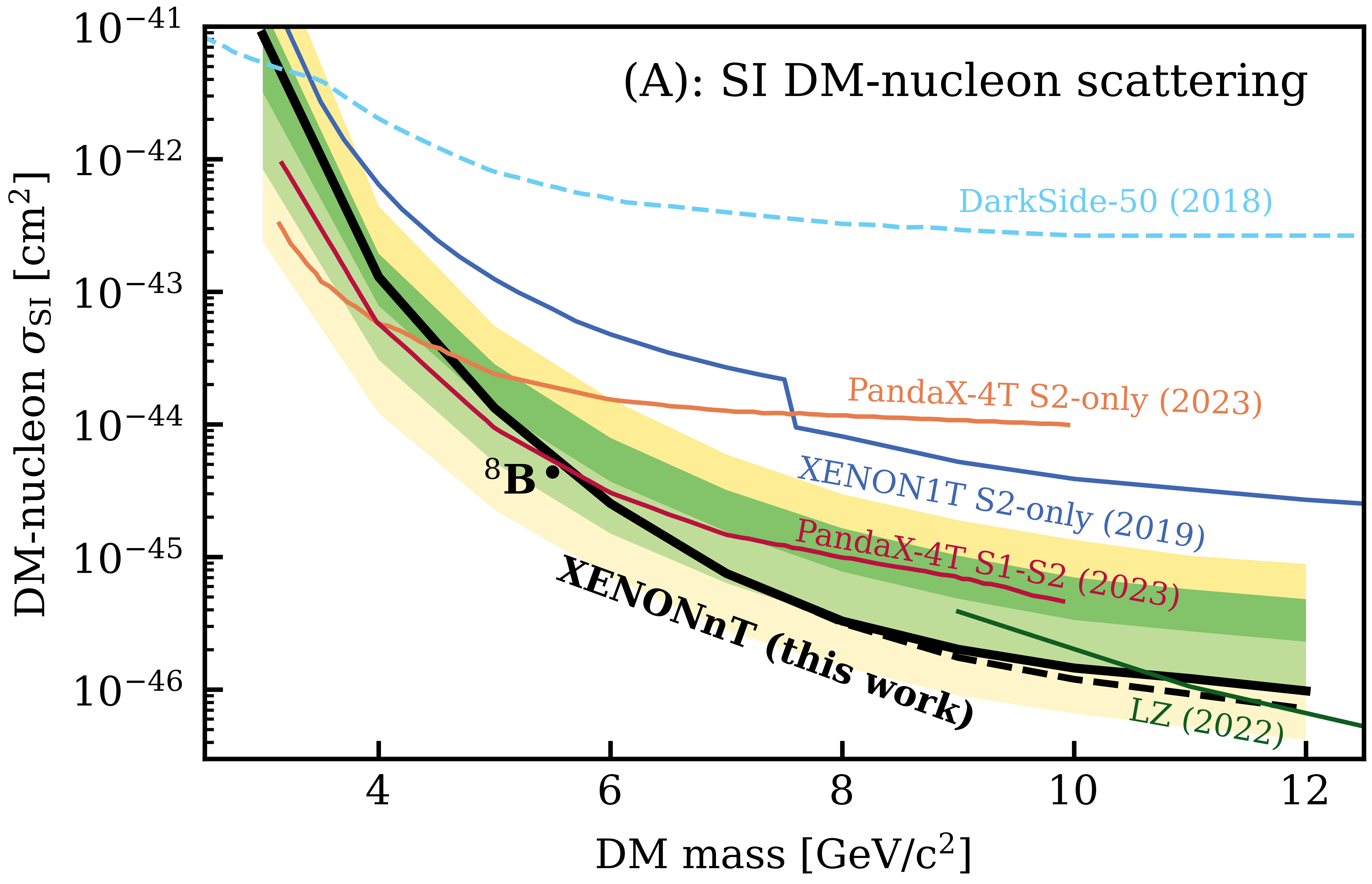

Component	Expectation	Background-only	4 GeV/c^2	6 GeV/c^2
SI DM	–	–	3.2 (1.6)	0.0 (0.0)
^{8}B CEνNS	$11.9^{+4.5}_{-4.2}$	$11.4^{+2.0}_{-3.6}$	10.2 ± 2.7 (2.5 ± 0.7)	$11.4^{+2.7}_{-2.6}$ (6.0 ± 1.4)
AC	25.3 ± 1.2	$25.3^{+1.1}_{-1.3}$	25.1 ± 1.2 (3.7 ± 0.1)	25.3 ± 1.2 (4.1 ± 0.2)
ER	0.7 ± 0.7	$0.5^{+0.7}_{-0.6}$	$0.6^{+0.7}_{-0.6}$ (0.0 ± 0.0)	$0.5^{+0.6}_{-0.5}$ (0.3 ± 0.3)
Neutron	$0.5^{+0.2}_{-0.3}$	0.5 ± 0.3	0.5 ± 0.3 (0.1 ± 0.1)	0.5 ± 0.3 (0.2 ± 0.1)
Total background	$38.3^{+4.7}_{-4.4}$	$37.7^{+2.5}_{-3.9}$	$36.4^{+3.0}_{-3.0}$ $(6.3^{+0.7}_{-0.7})$	$37.7^{+3.0}_{-2.9}$ $(10.6^{+1.5}_{-1.4})$
Observed	–	37	37 (10)	37 (10)

Outline

XENONnT Highlight

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XLZD

- 2024 コラボレーションの設立
- XLZDの物理 (WIMP, 二重ベータ崩壊など)

The XLZD Collaboration

液体キセノンを用いて20年以上に渡り最も良い感度でDM探索を行った実績
50-100トンを用いた次世代の実験に向けて世界で一つの究極のキセノン検出器を
XENON-LZ-DARWIN -> XLZD コンソーシアム -> XLZD Collaboration

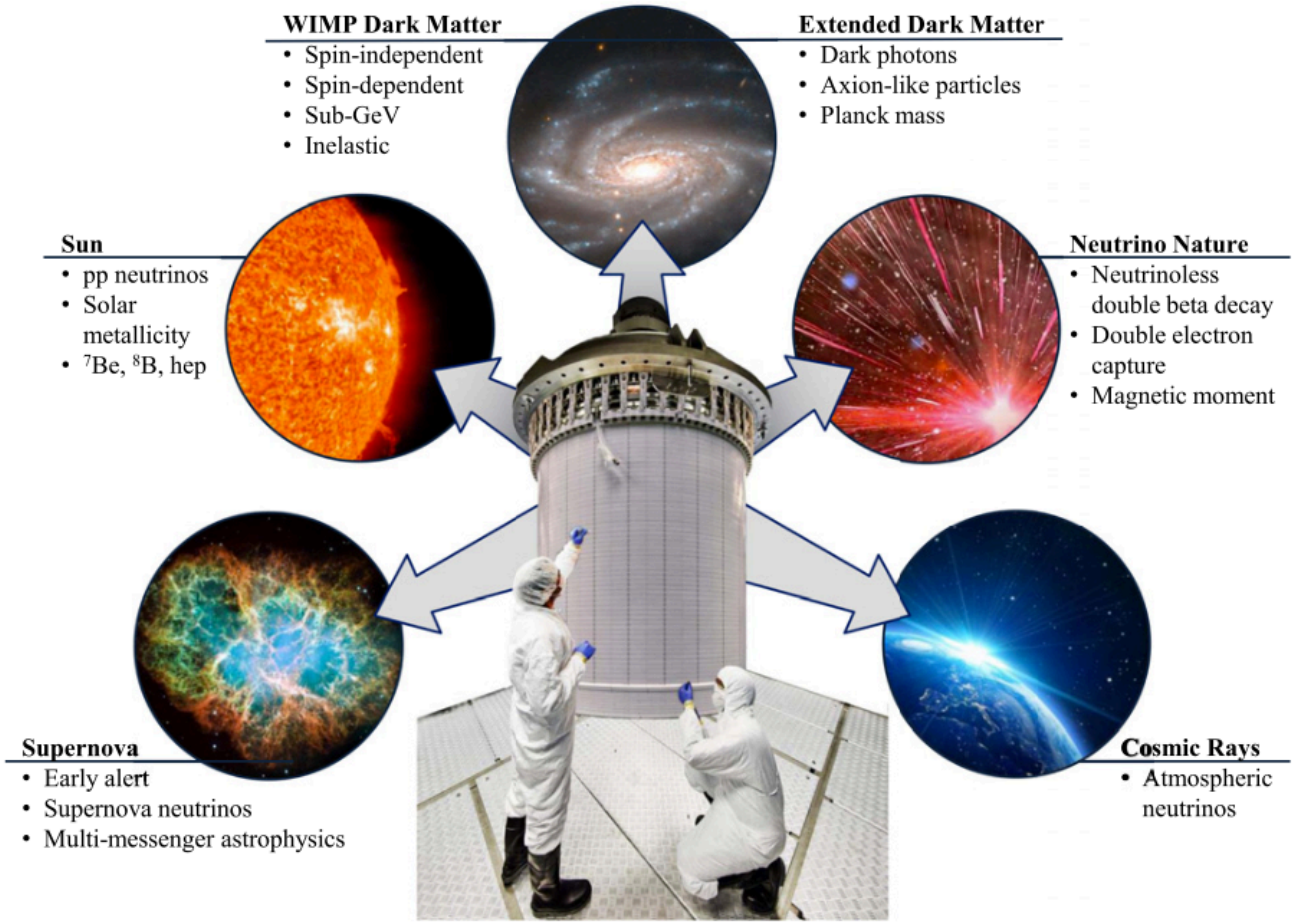
XENON

DARWIN

2021 XENON/DARWIN, LUX-ZEPLIN meeting
https://indico.cern.ch/event/1028794/
2021 **MOU締結** 16カ国 104名が署名 : XENON, DARWIN, LUX-ZEPLIN(米国)
2022 1st Summer Meeting at KIT in Germany
2023 2nd meeting at UCLA
2024 **XLZD collaboration発足** **参加日本グループ**：神戸大学、東京大学、名古屋大学
Spokespersons Dan Akarib (SLAC), Marc Schumann (Freiburg)
Exec board 10名 [Masaki Yamashita (Tokyo)]

- **White Paper: A Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics** arXiv: 2203.02309
- **The XLZD Design Book: Towards the Next-Generation Liquid Xenon Observatory for Dark Matter and Neutrino Physics** arXiv:2410.17137v1

Science: Multi-purpose observatory

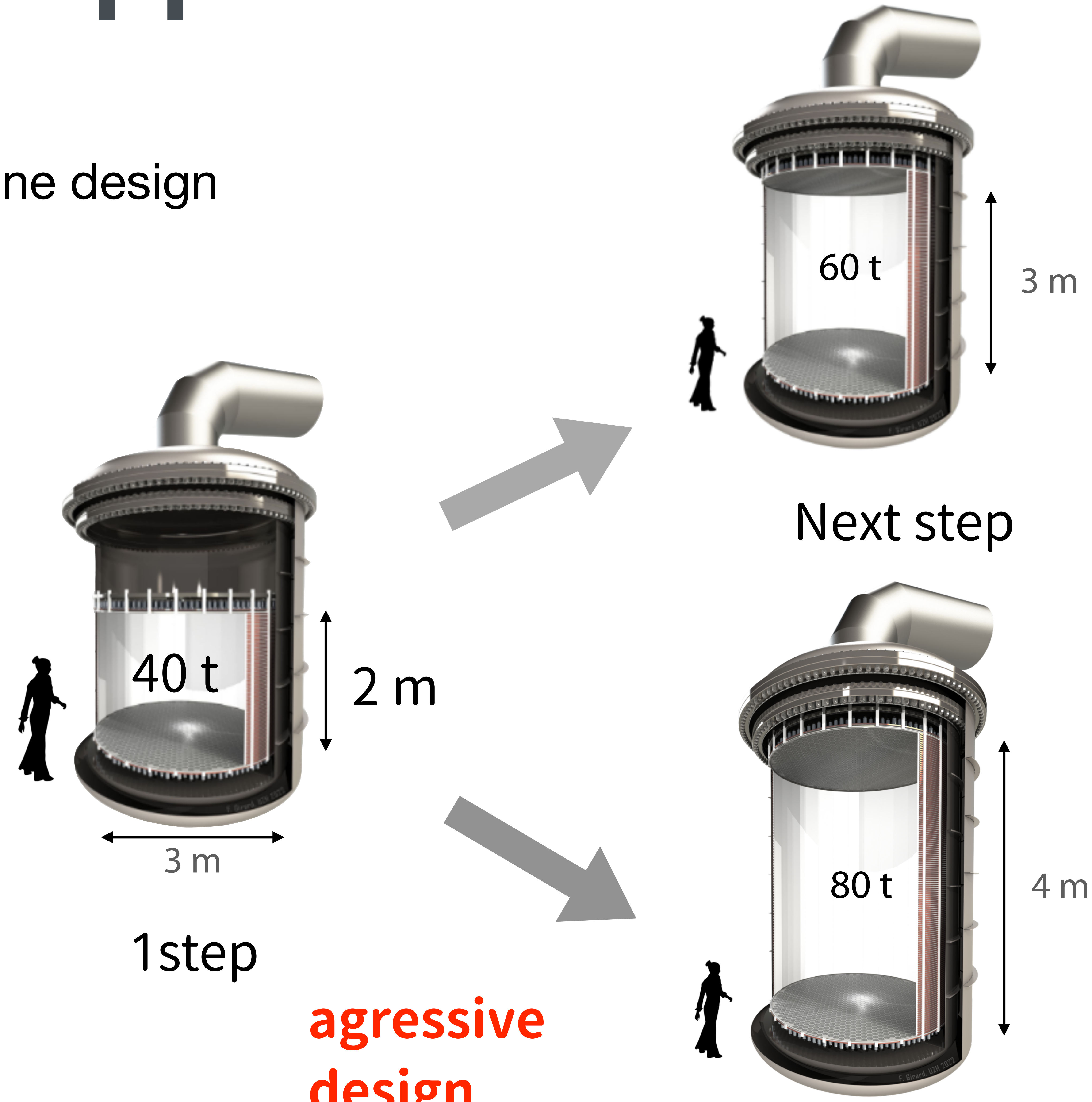


- WIMP暗黒物質探索
- $0\nu\beta\beta$探索
- 他の DM 候補探索

  (Light WIMPs, Axions, ALPs, Dark Photons, etc)
- ニュートリノ
  - Solar neutrinos (model, properties)
  - Supernovae

A staged approach

- Use 60 t diameter (~3 m in 1:1 ratio) as baseline design
- First phase:
  - 40 t, shallow detector
  - Build infrastructure for taller detectors (cryostat, water tank, etc.)
  - 5 years run time
  - **Technical demonstration and early dark matter result**
- Main phase:
  - >10 years operation
  - Full science reach
  - Ultimate size depending on xenon availability
  - **Nominal**, 60 t, 1:1 ratio
  - **Opportunity**, 80 t, tall detector



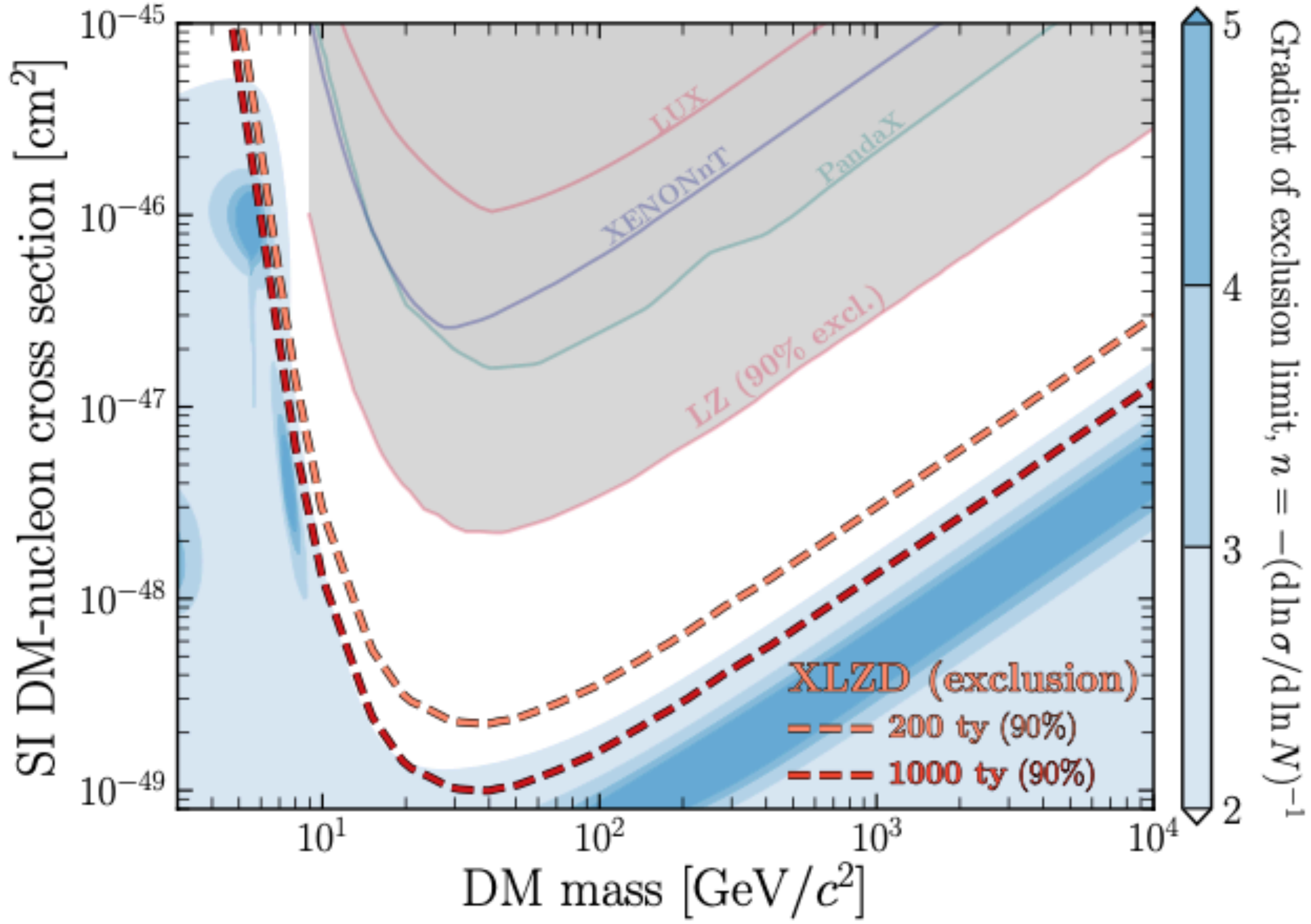
1step

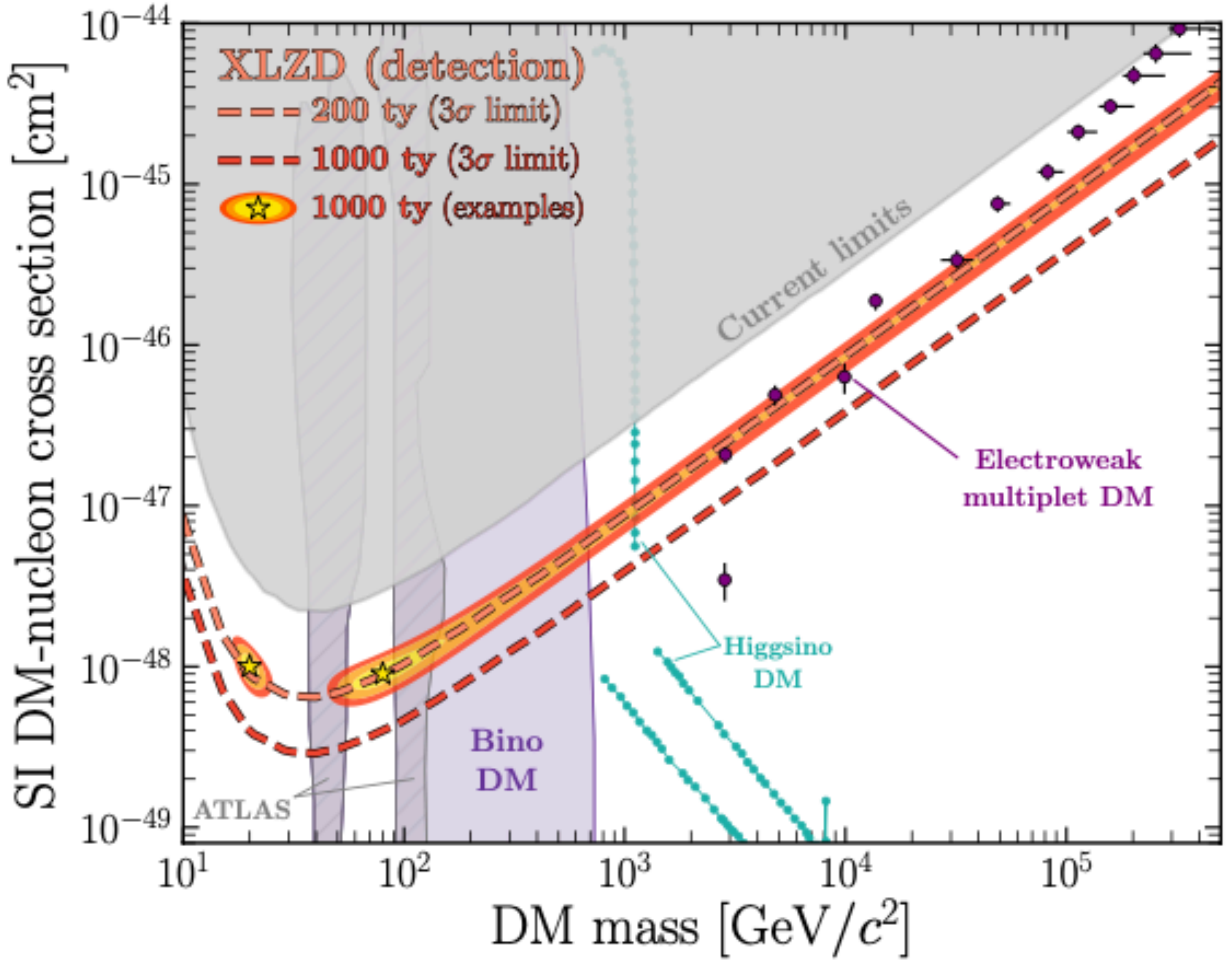
Next step

agressive design

Searching for WIMPs down to the neutrino “fog”

XLZD design book
arXiv:2410.17137v1



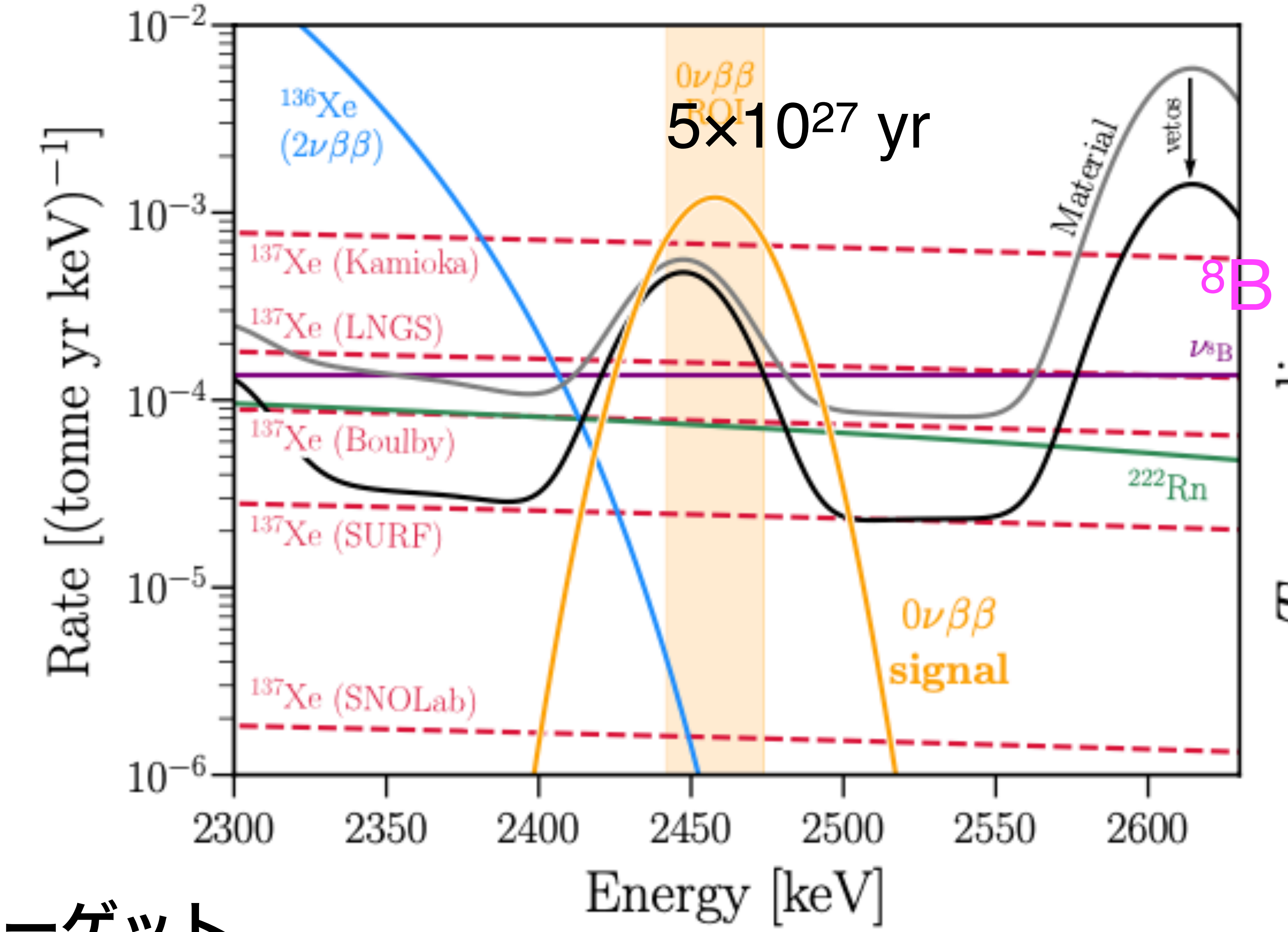


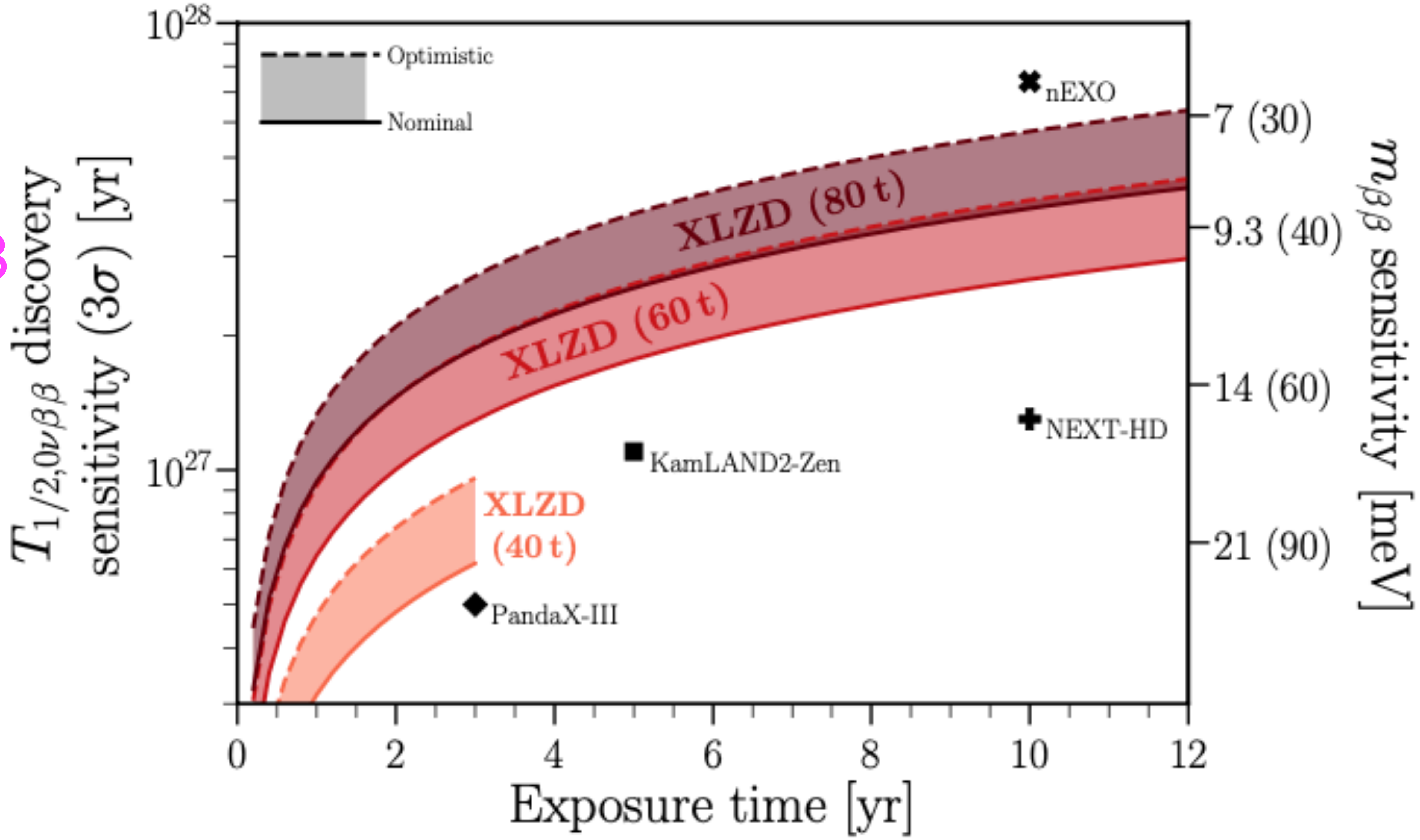
- Indistinguishable background from astrophysical neutrinos
- Limited sensitivity improvement (20% flux uncertainly)
- Systematic uncertainty limit (1000 t·yr)
- 90% C.L. exclusion 2.5x10^{-49} cm^2 (at 40 GeV, 200 t·yr)

- Median evidence potential curves for 3σ for both exposures.
- The example evidence contours for 20 and 80 GeV WIMPs are 1-,2- and 3-sigma (yellow, orange, red)
- Example regions of interest for dark matter candidates

^{136}Xe二重ベータ崩壊

XLZD Double Beta Decay
arXiv:2410.19016v1





ターゲット

- ^{136}Xe $0\nu\beta\beta$ Q値: 2458 keV
- ^{136}Xe は 8.9% の自然同位体
  - 80 t のターゲットに ~ **7 t of ^{136}Xe**

主な内部バックグラウンド

- ^{214}Bi β from ^{222}Rn in the xenon (Q = 3270 keV)
- ^{137}Xe β (Q = 4170 keV), neutron activation of ^{136}Xe
  - Mostly by muon-induced neutrons, depending on the installation site

未来の学術振興構想「学術の中長期研究戦略」に掲載 大型液体キセノンを用いた宇宙暗黒物質直接検出実験 (DARWIN/XLZD実験計画の推進)

XENON

グランドビジョン⑲：自然界の基本法則と宇宙・物質の起源の探求

- **目的　（多目的実験）**
  - **WIMP暗黒物質直接探索実験 10^{-49}cm^2**
  - pp太陽ニュートリノ観測 (~1% 精度)
  - 超新星ニュートリノ
  - ^{136}Xe二重ベータ崩壊 (～10^{27} y)

- **検出器**
  - **60-80トン　キセノン**
  - 液体キセノンTPC
  - 極低バックグラウンド

- **参加者、予算**
  - アジア、欧米
  - **XLZD** (XENONnT + LUX-ZEPLIN + DARWIN)
  - 日本（神戸大、東大、名古屋大）
- 約200億円(国内15億円)
  - 光センサー,キセノン純化装置,中性子反同時検出器など
- 海外情勢
  - 米国P5 Generation3 Direct DM
  - 欧州 APPEC LXe Direct DM

2010's　2020's　2030's　2040'

LUX/XENON1T　LZ/XENONnT　DARWIN/XLZD

Conclusion

XENON

- 太陽ニュートリノ8Bをコヒーレント散乱を通して観測
  - フレーバーによらないコヒーレント散乱による超新星ニュートリノ観測に期待
  - ニュートリノfogに差し掛かり、WIMP探索を行った。

XLZD (XENONnT + LUX-ZEPLIN + DARWIN)

- **2024年にXLZD collaborationを設立**
- WIMP探索だけではなく、(neutrino fog)　太陽ニュートリノ,二重ベータ崩壊, 超新星ニュートリノ観測など多目的実験
- 2030’ 初めに運転開始を目指す