The DARWIN Observatory for Dark Matter and Neutrino Physics

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for the DARWIN Collaboration
University of Zurich

Annual Meeting of the Swiss Physical Society
University of Fribourg
27 June 2022

DARWIN

University of Zurich[UZH]

European Research Council
Established by the European Commission

WIMP direct detection landscape

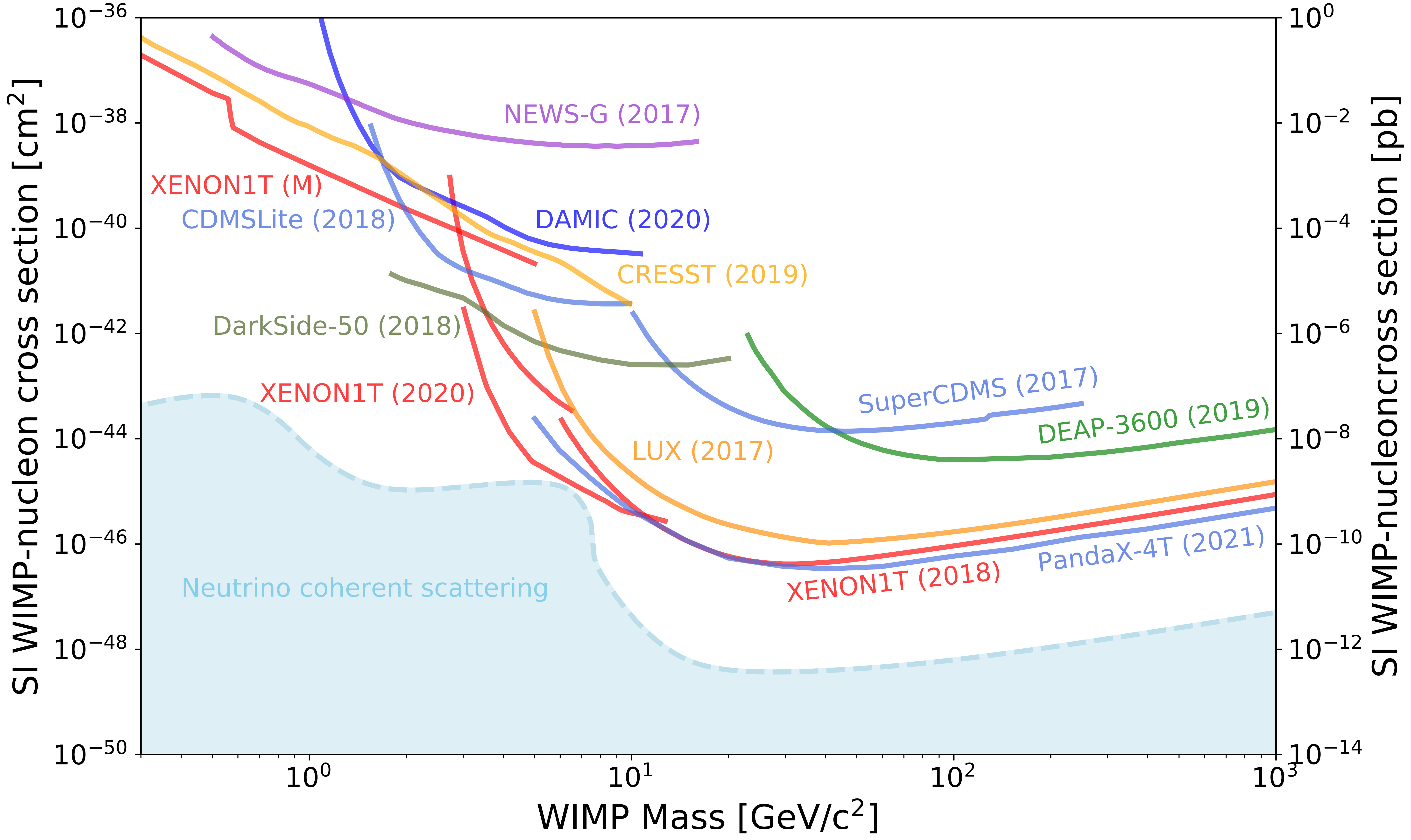

Figure adapted from P.A. Zyla et al. (Particle Data Group) (2020)

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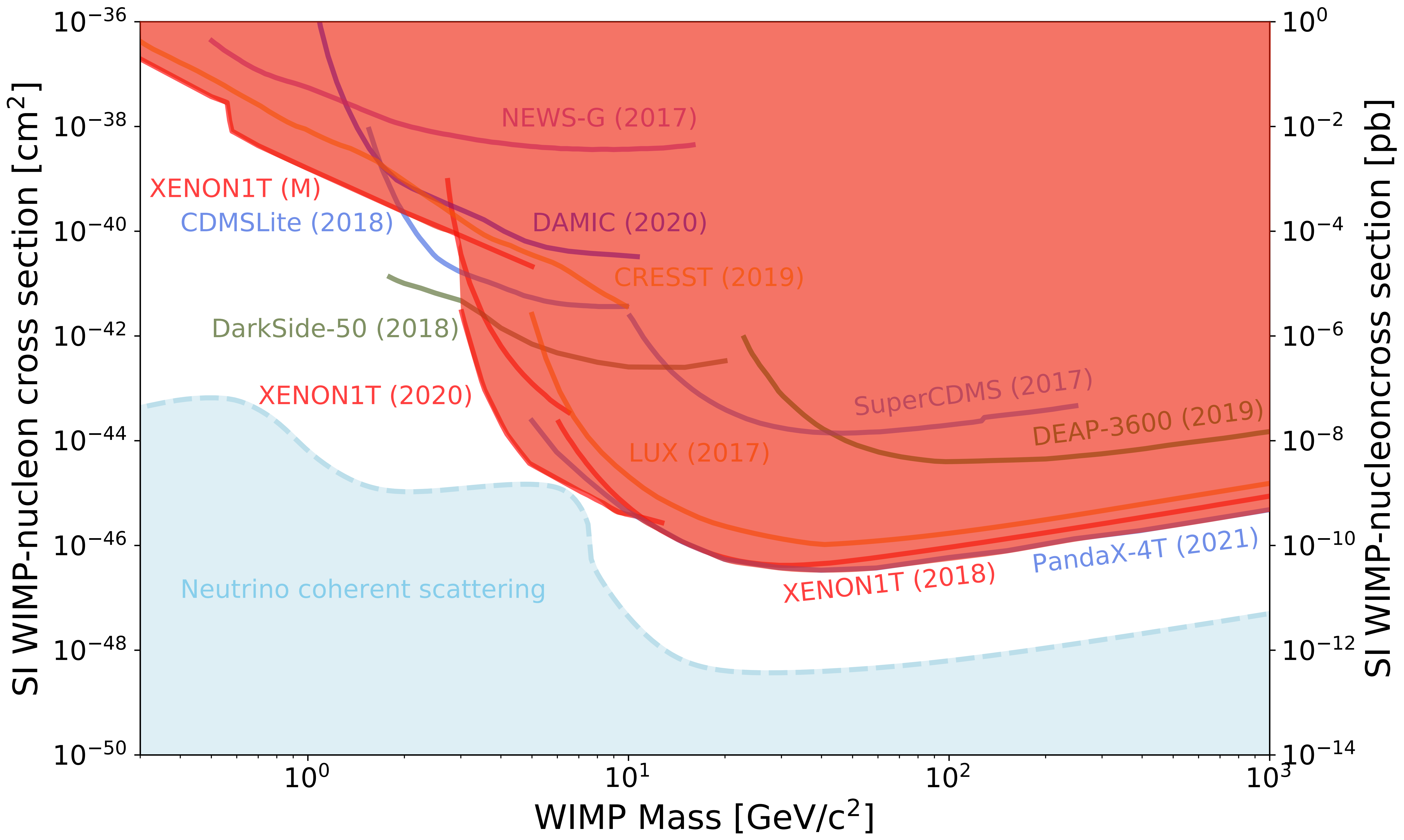

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Limits from two-phase xenon-based experiments

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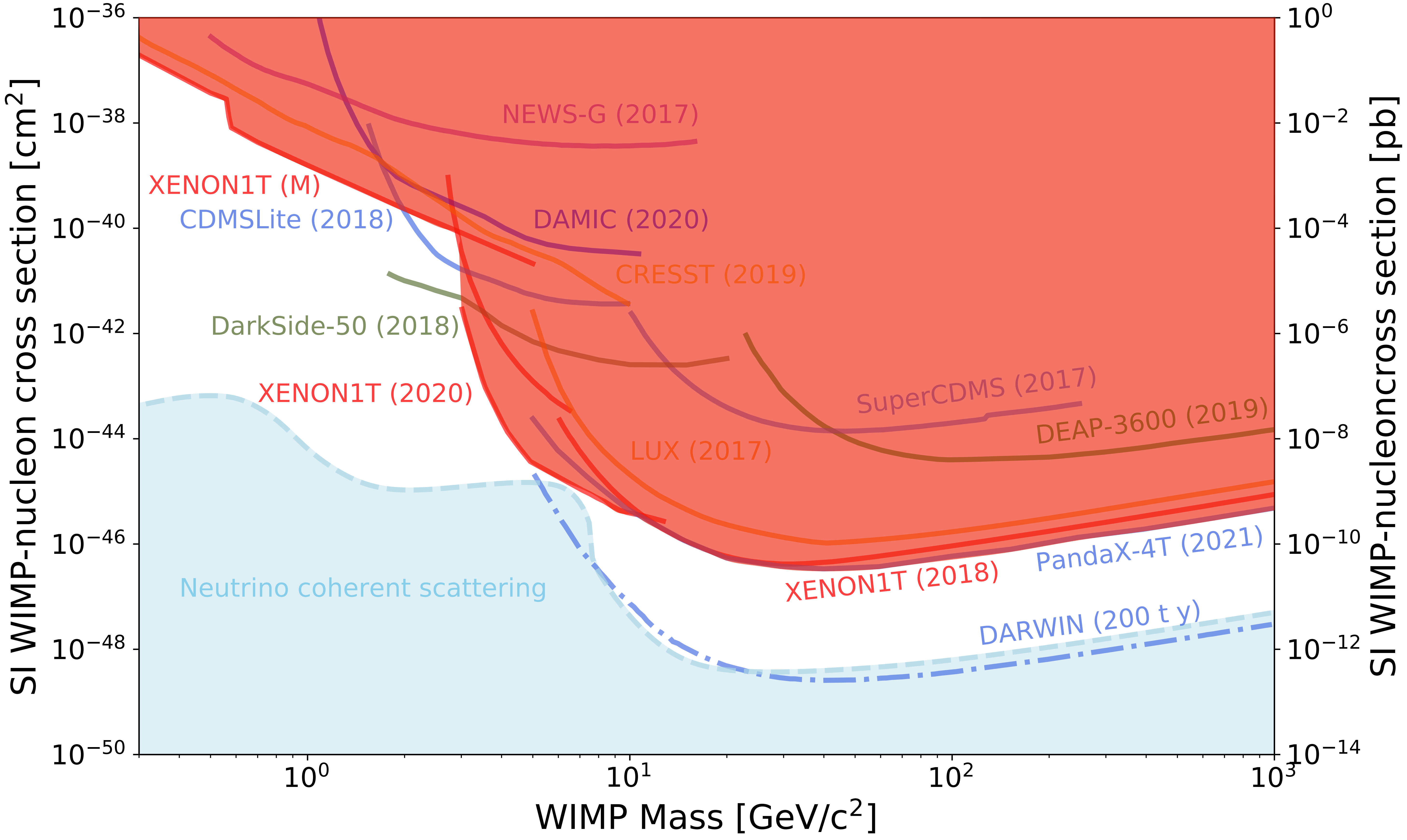
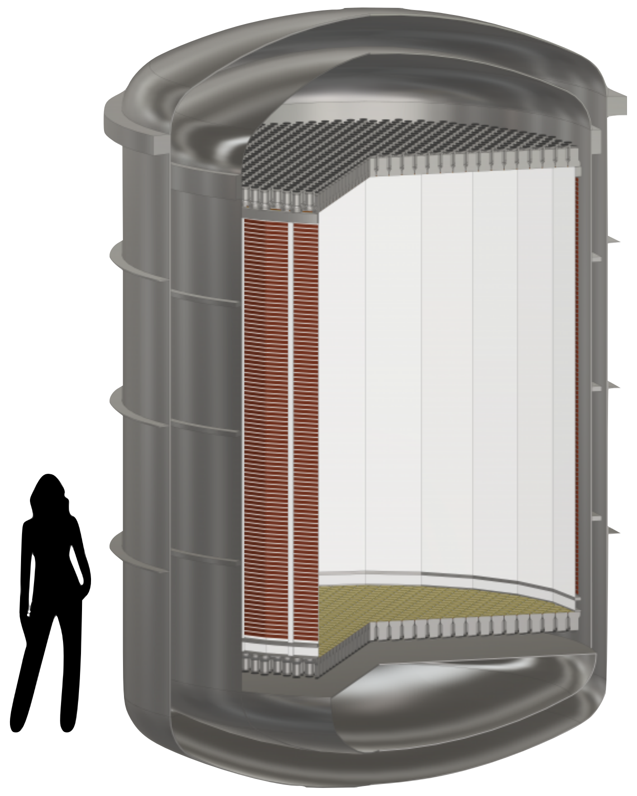


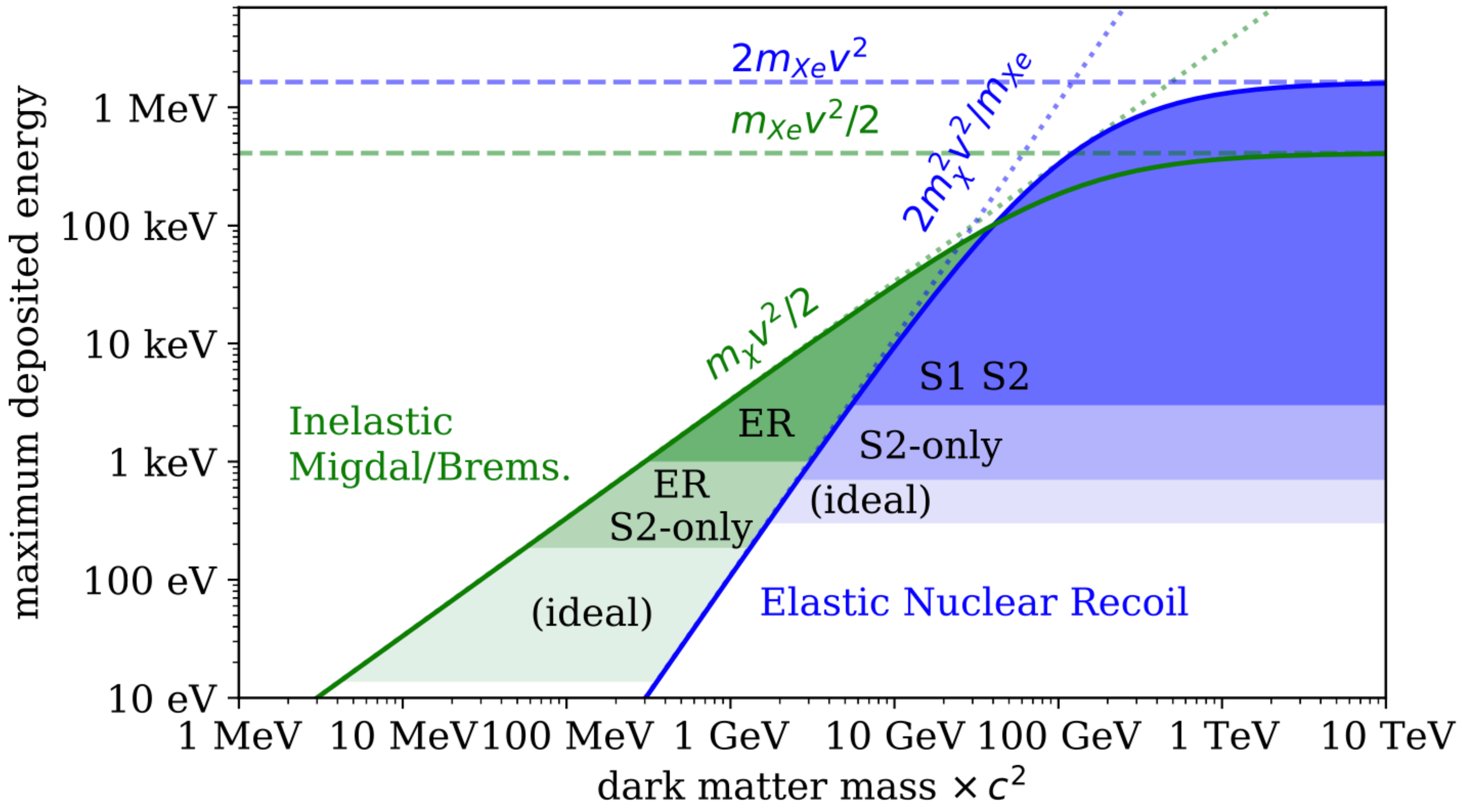
Figure adapted from P.A. Zyla et al. (Particle Data Group) (2020)

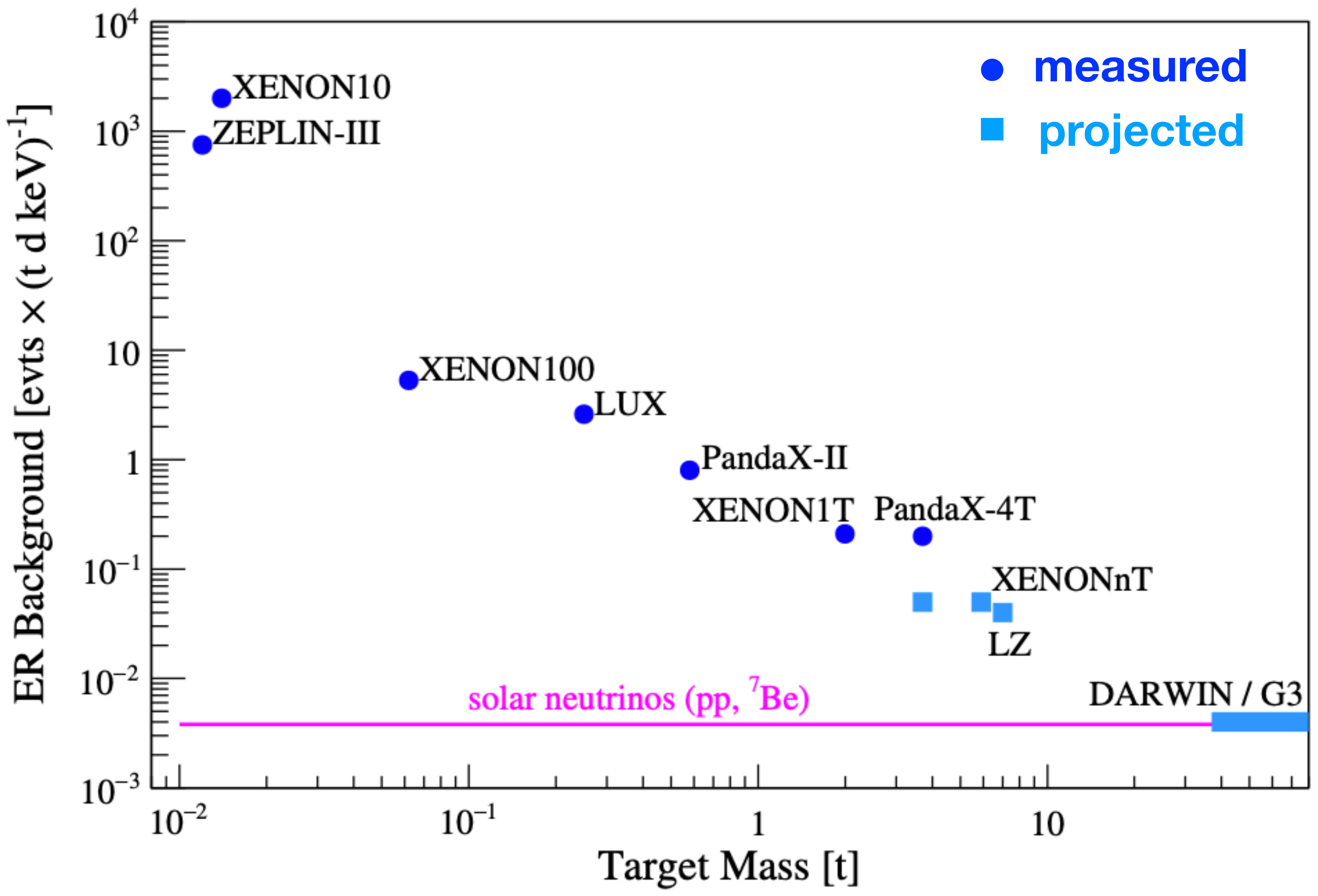
Limits from two-phase xenon-based experiments

DARWIN -
the next generation



Towards higher sensitivity



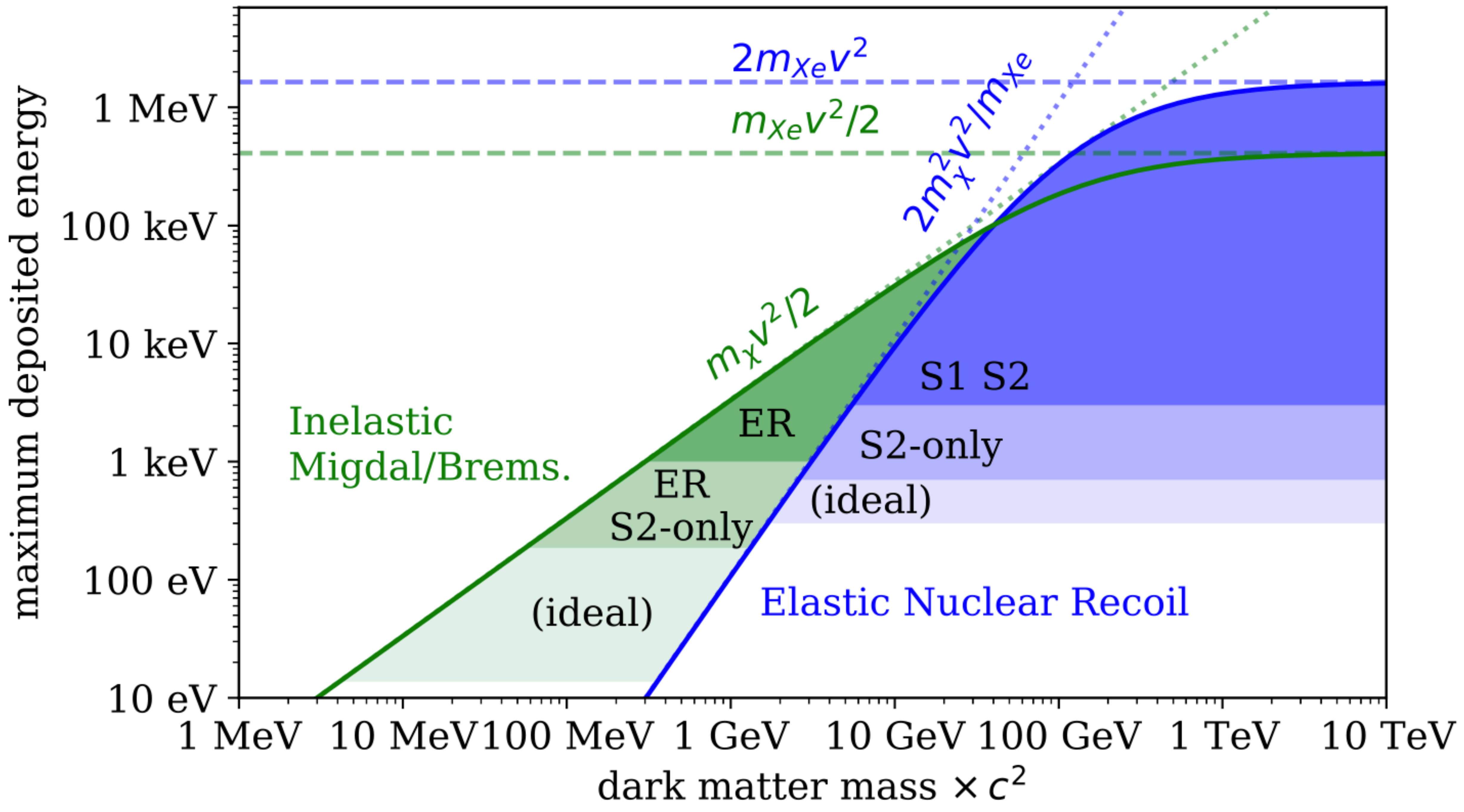


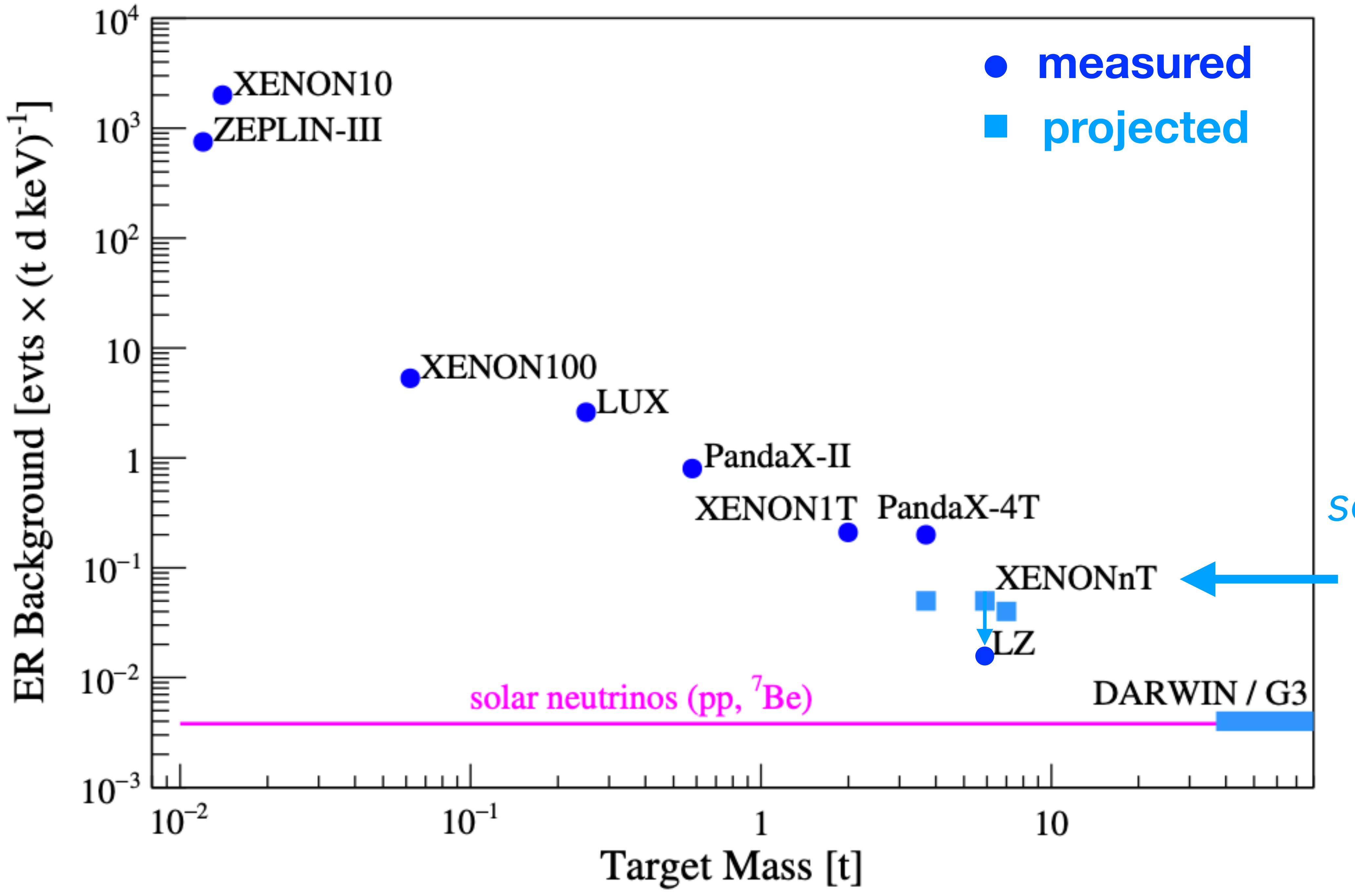
Interaction kinematics -
lowering the threshold

Lower backgrounds and larger mass
extending the physics reach

Community Whitepaper: arXiv:2203.02309 (2022)

Towards higher sensitivity





see talk by G. Volta

Interaction kinematics - lowering the threshold

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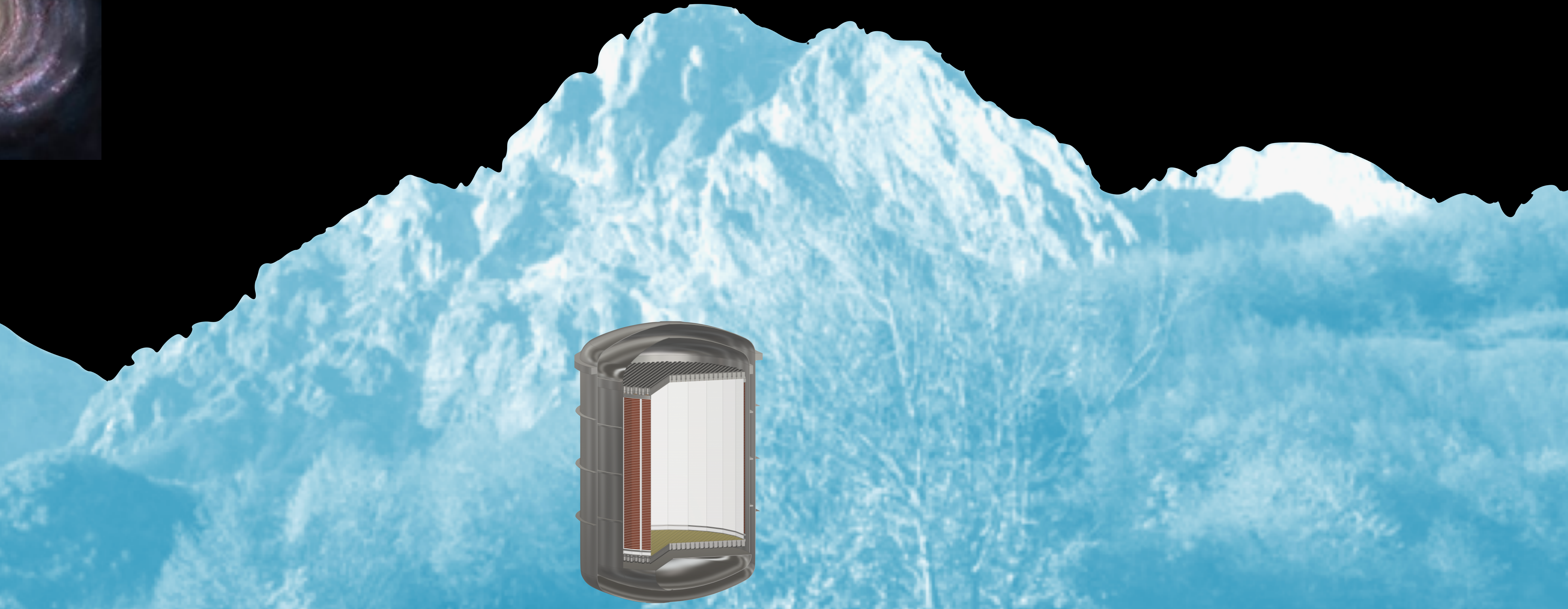
Dark Matter
WIMPs (sub-GeV - TeV scale)
ALPs/dark photons (keV scale)



Supernova Neutrinos
Early alert
Multi-messenger

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Solar Neutrinos
pp neutrino flux, $\sin^2\theta_w$
Solar Axions

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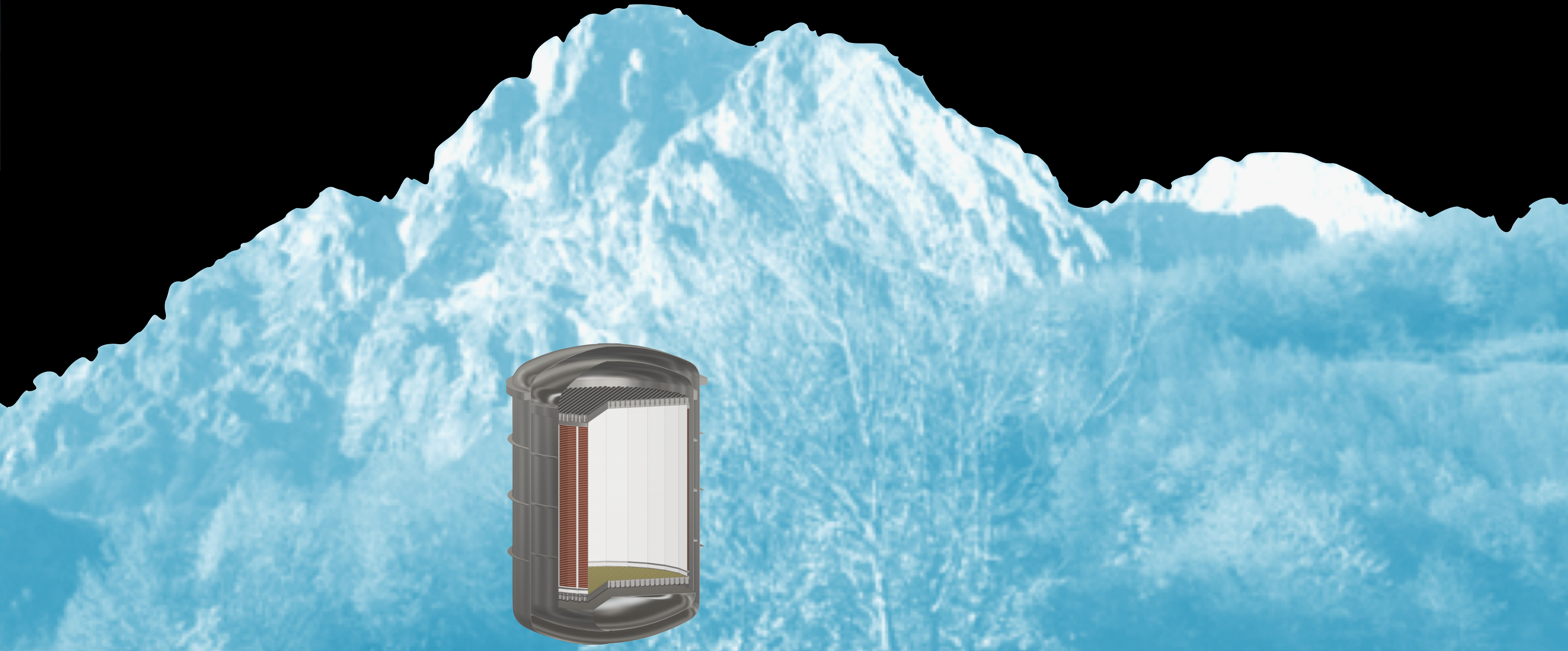

Supernova Neutrinos
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Dark Matter
WIMPs (sub-GeV - TeV scale)
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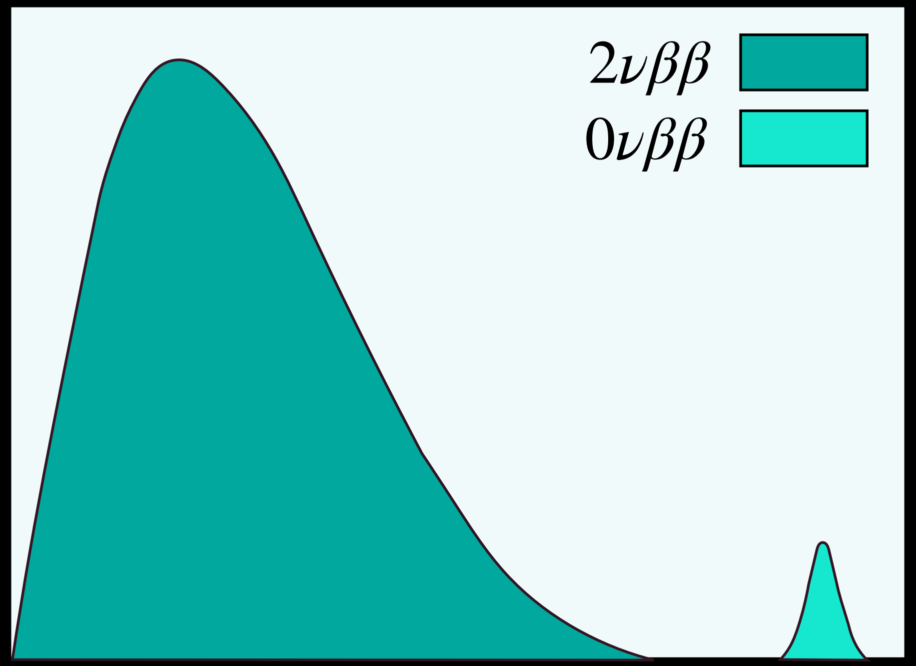
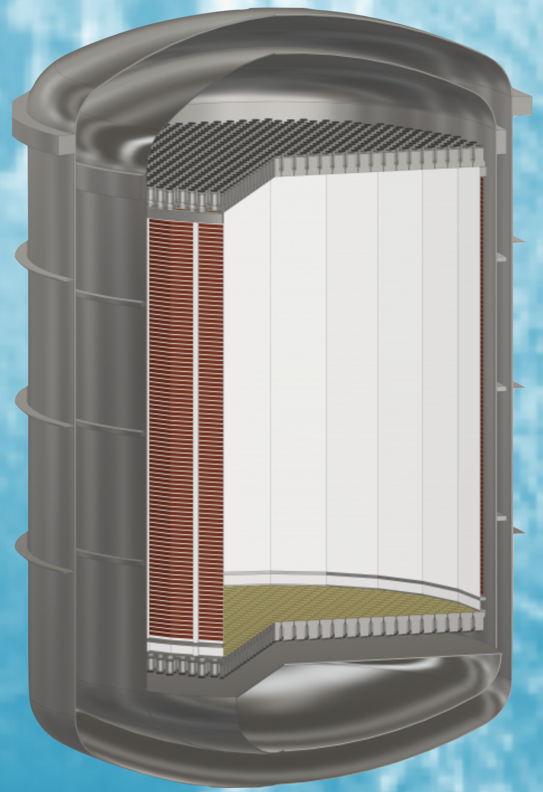
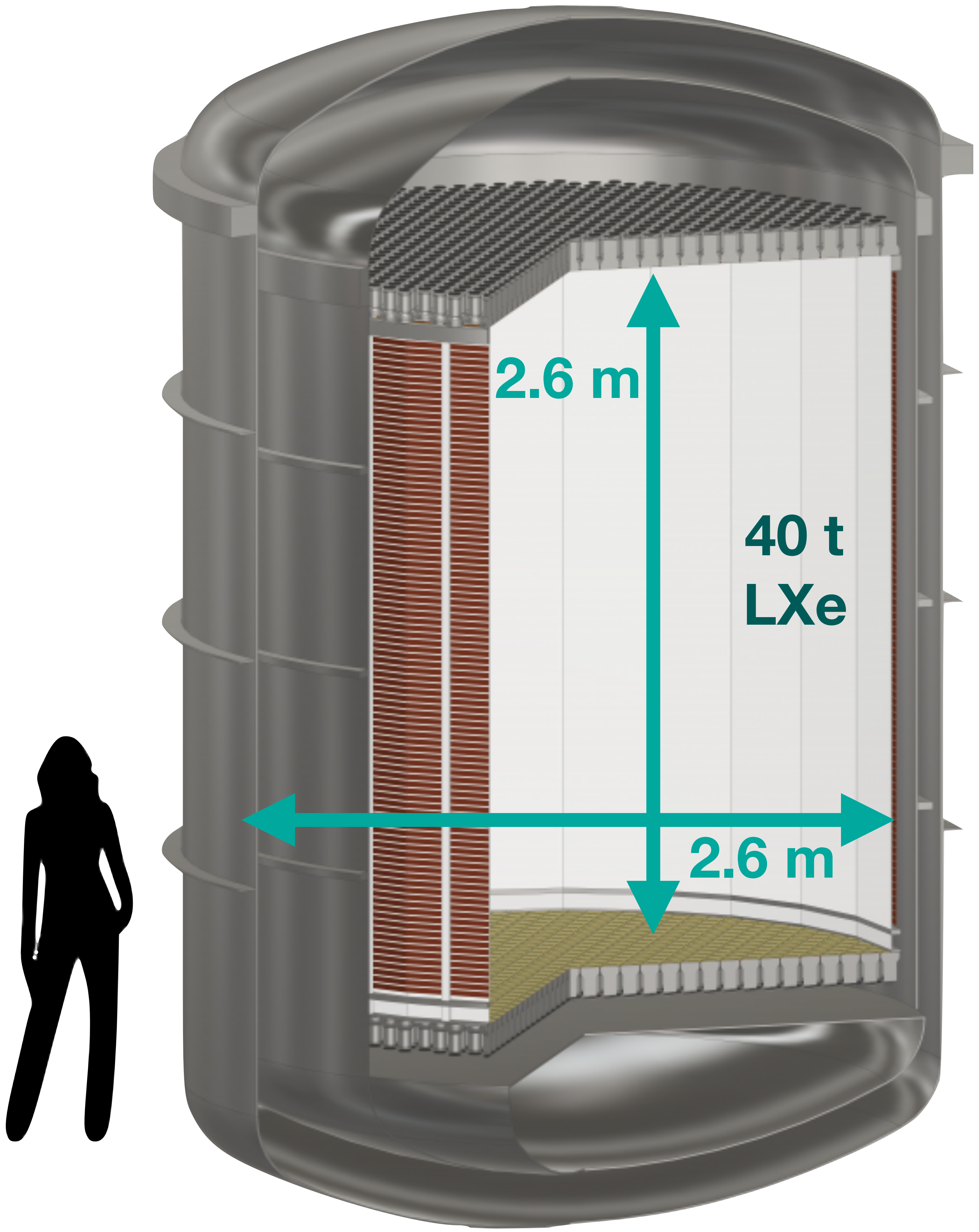
Fundamental Physics
Neutrinoless double beta decay of ^{136}Xe
Rare decays



Detector as source

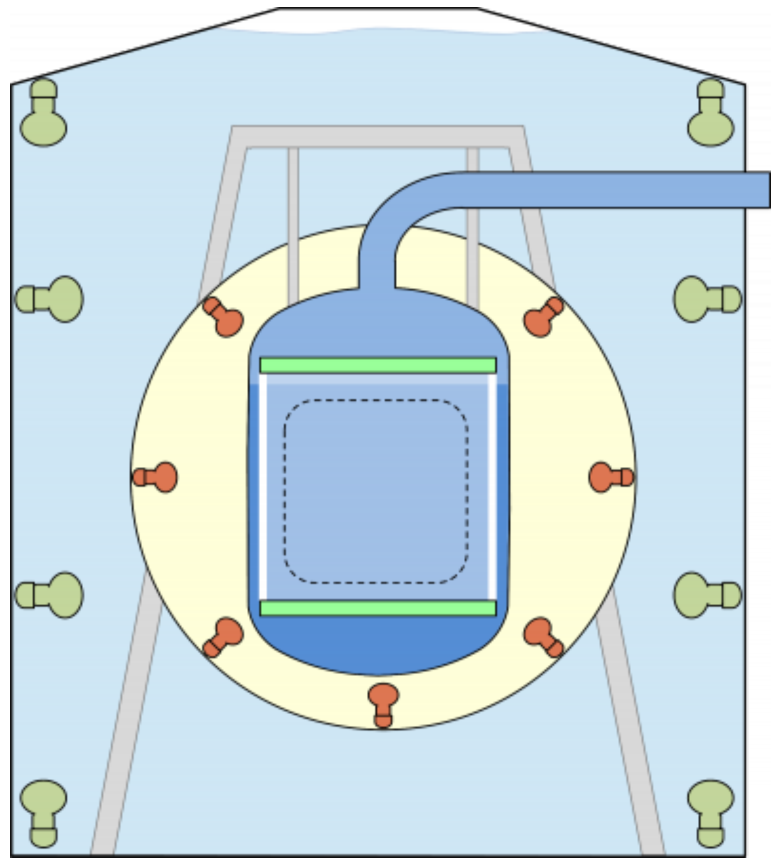


The DARWIN baseline design



DARk matter WImp search with liquid xenoN

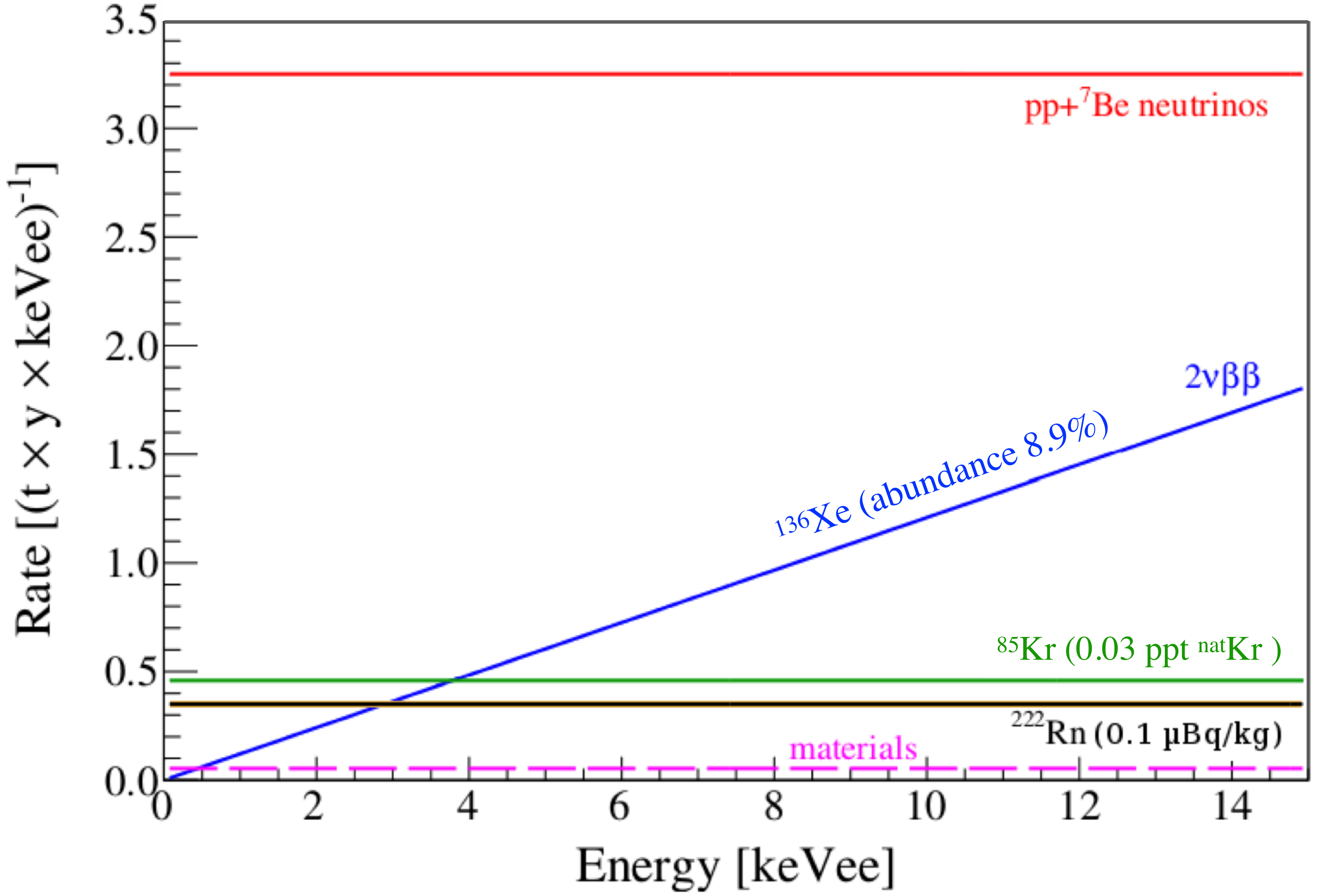
- Two-phase LXe/GXe TPC; aspect ratio 1
- **50 t total** LXe (40 t target)
- Top and bottom photosensors (~1800 3″ XENON PMTs)
- PTFE reflectors and Cu field-shaping rings
- In-situ purification plus krypton and radon distillation (background mitigation)
- Veto detectors: water Cerenkov for muons with Gd doping for neutrons



DARWIN Collaboration, JCAP 1611 (2016) 017

Background goals

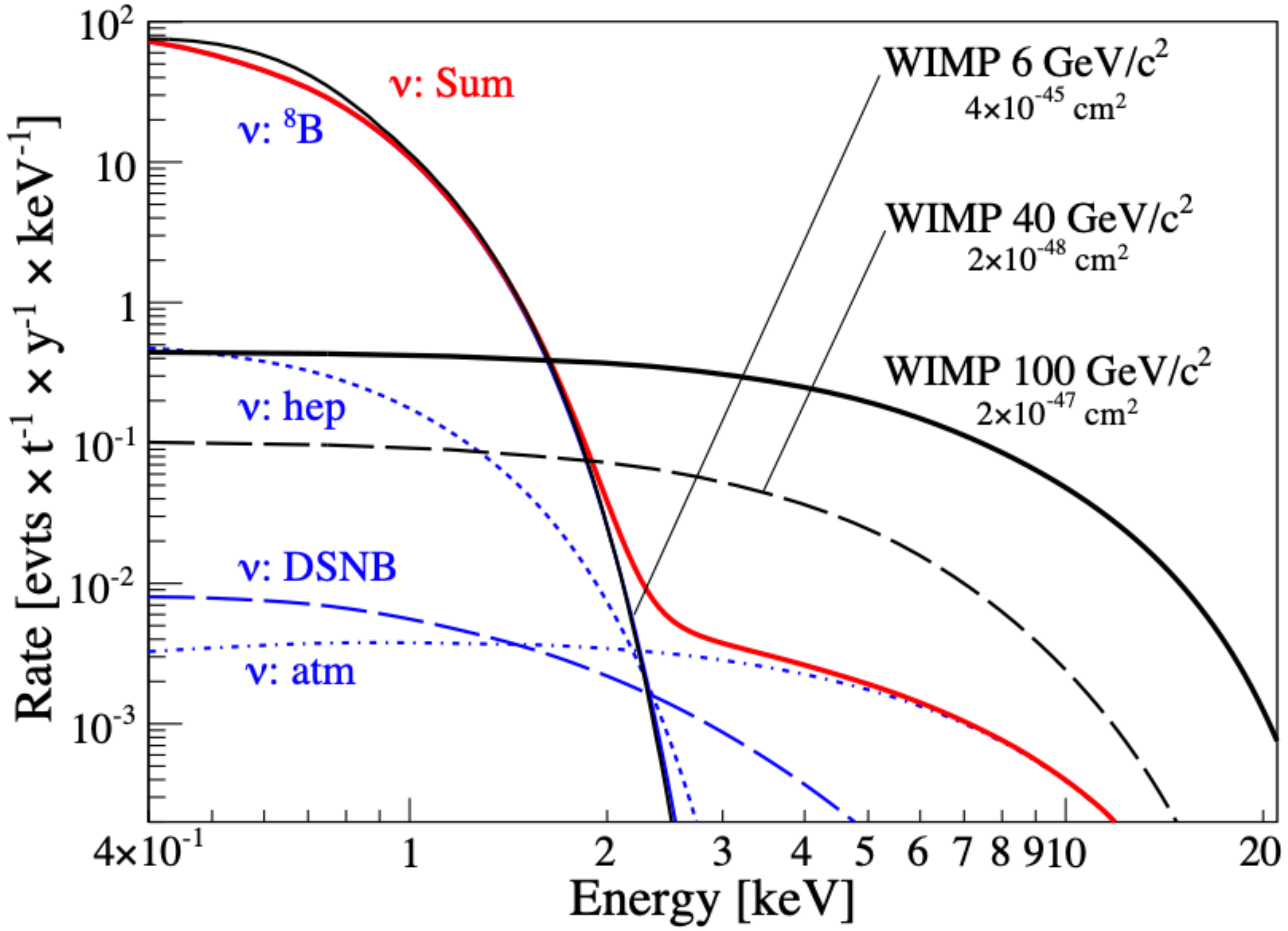
Electronic recoil (ER) background



- Intrinsic goal: ~one order of magnitude lower **^{222}Rn**, **^{85}Kr** than currently achieved by XENON
- Expected **neutrino**-dominated ER background

Figure updated from Schumann et al., JCAP 1510 (2015) 016

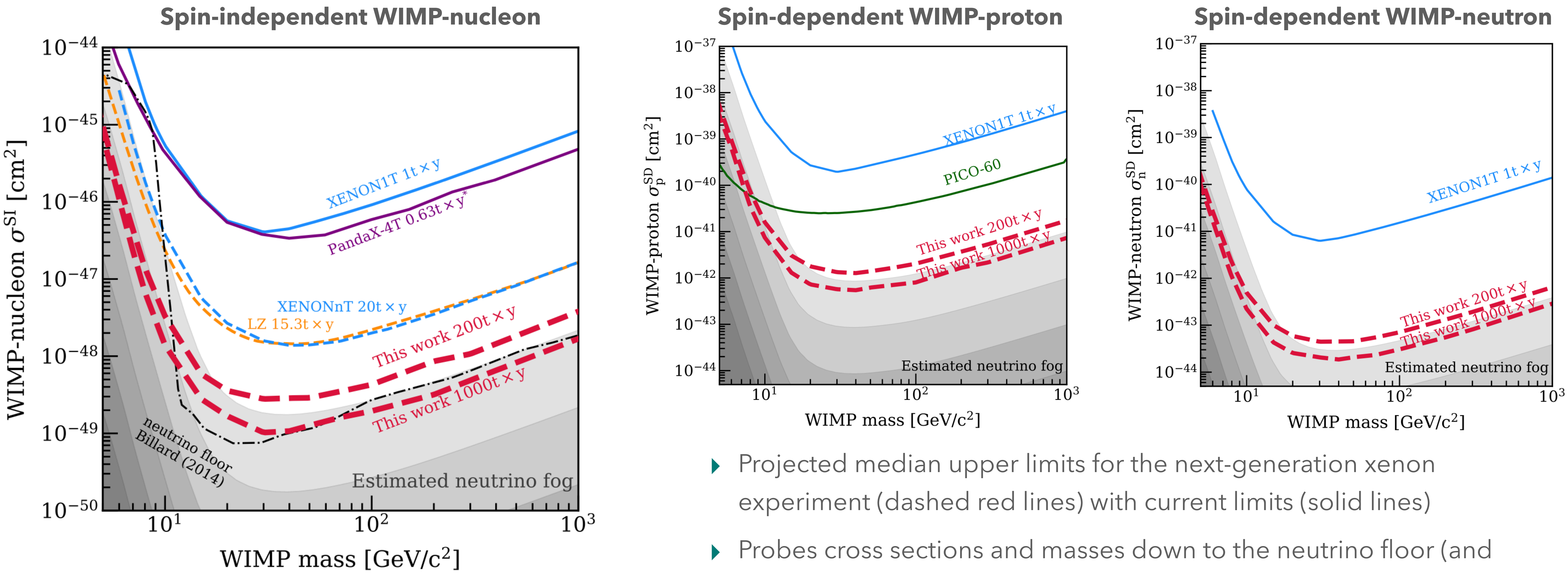
Nuclear recoil (NR) background



- NR background dominated by coherent elastic neutrino-nucleus scattering (**CEνNS**)
- Radiogenic neutrons: ~2 events/ 200 t yr (**materials**)
- **muon-induced neutrons**: ~0.4 events/ 200 t yr (12 m diameter water tank at LNGS)

DARWIN Collaboration, JCAP 1611 (2016) 017

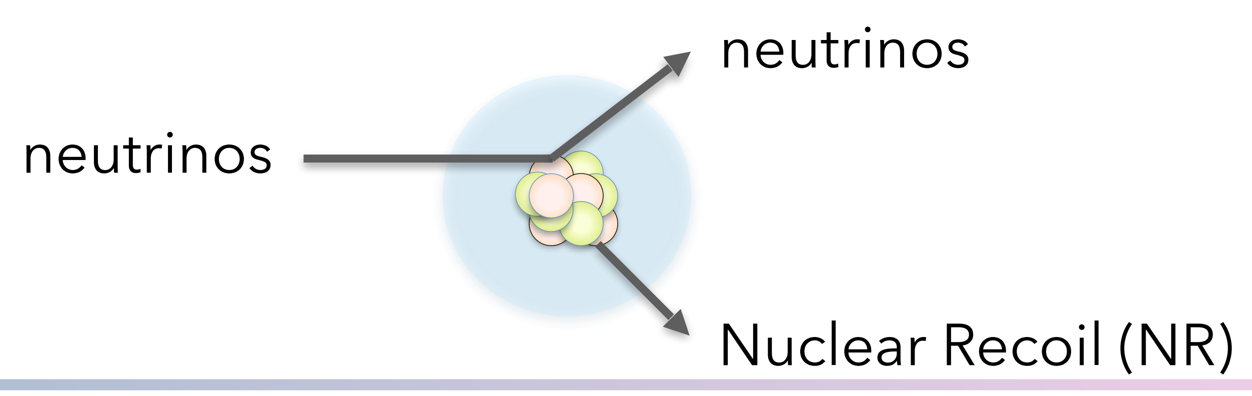
WIMP sensitivity projections



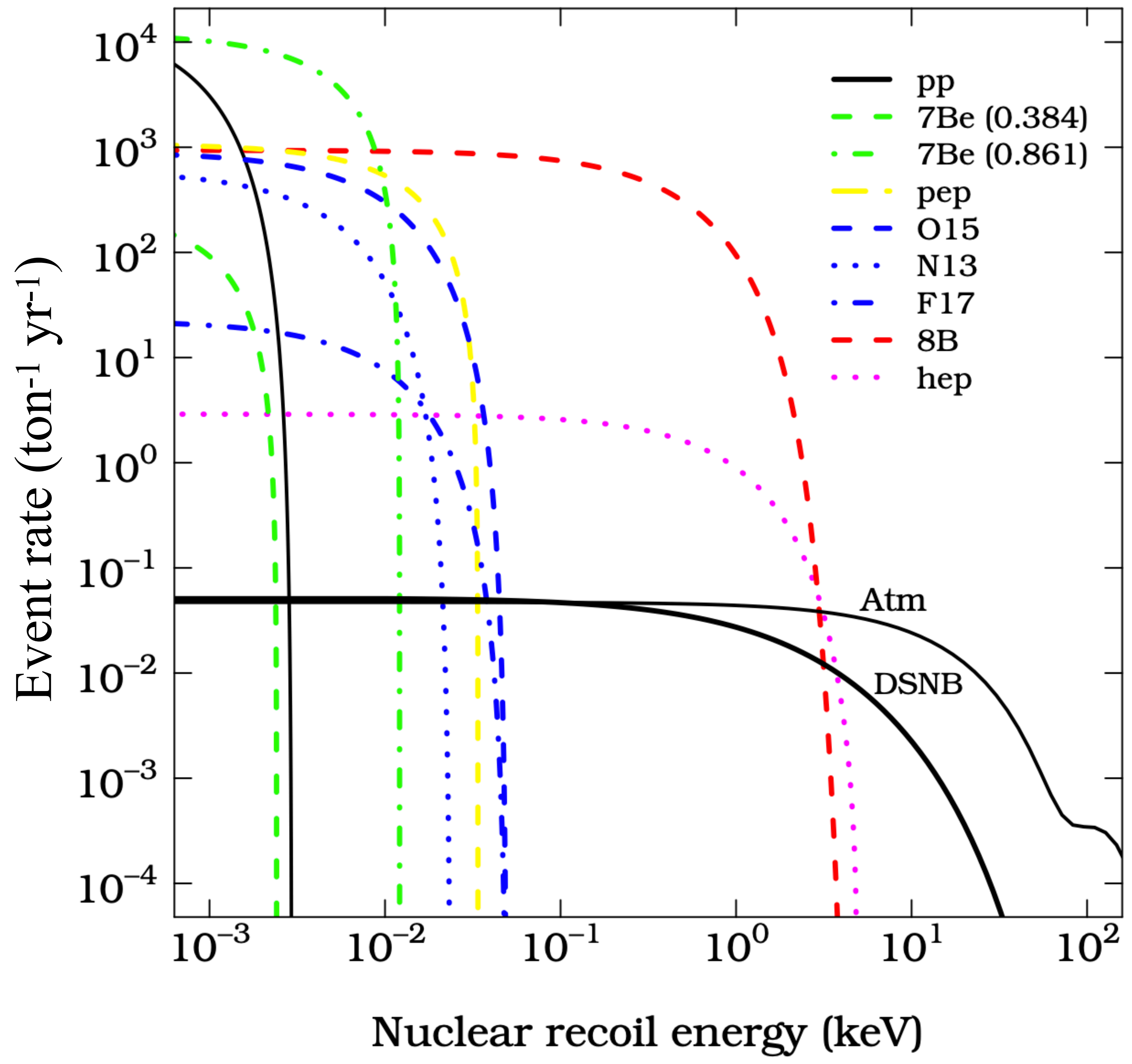
- Projected median upper limits for the next-generation xenon experiment (dashed red lines) with current limits (solid lines)
- Probes cross sections and masses down to the neutrino floor (and into the neutrino fog)
- Grey bands indicate >1, 10, 100, etc. expected neutrino events in the 50% signal-like region

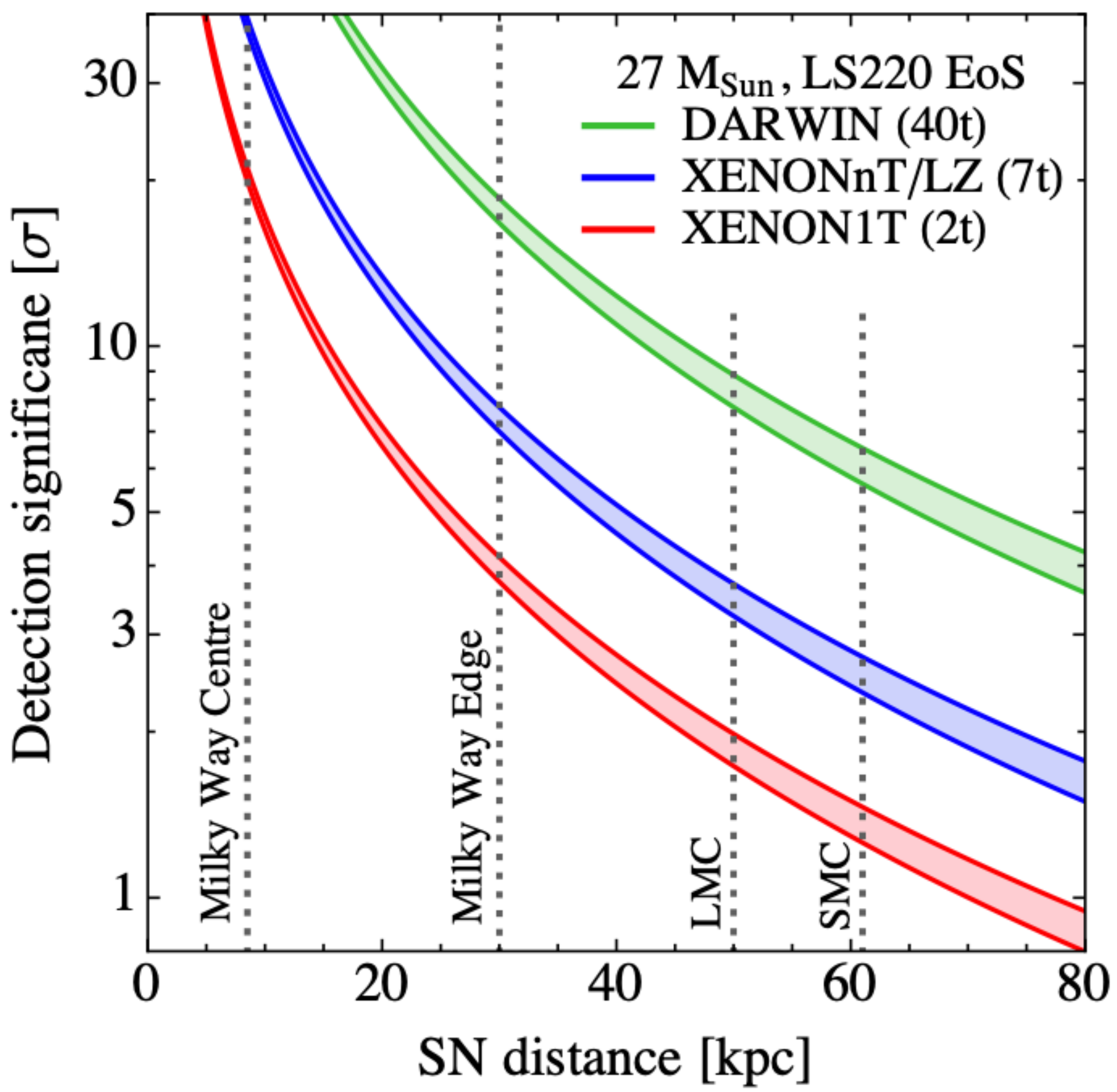
Community (DARWIN/LZ) Whitepaper: arXiv:2203.02309 (2022)

Solar and Supernova neutrinos



Coherent elastic neutrino-nucleus scattering (CEνNS)





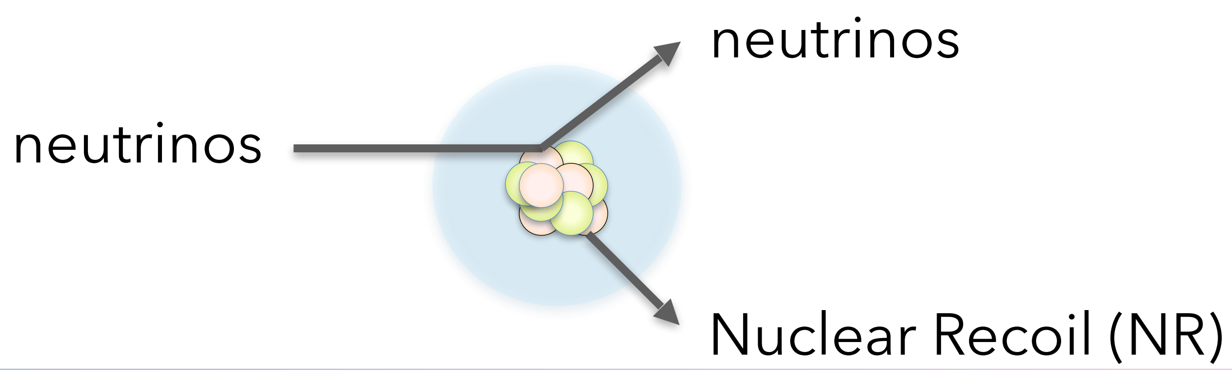
- Detect solar and atmospheric neutrinos via CeνNS interactions

Community (DARWIN/LZ) Whitepaper: arXiv:2203.02309 (2022)

- Flavour-insensitive detection of supernovae neutrinos
- Participation in SNEWS network

R. Lang et al, PRD 94, 103009)

Solar and Supernova neutrinos



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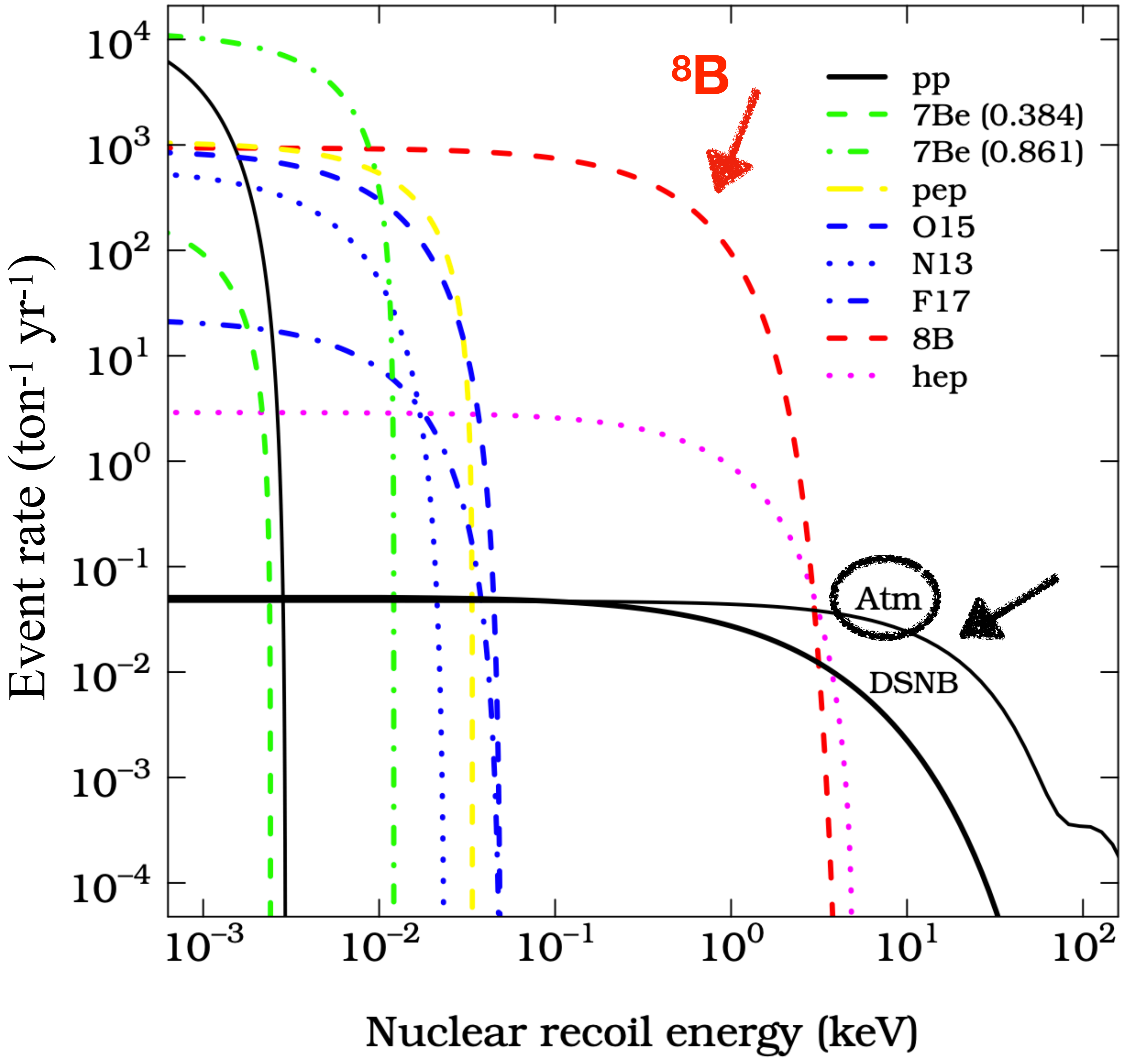

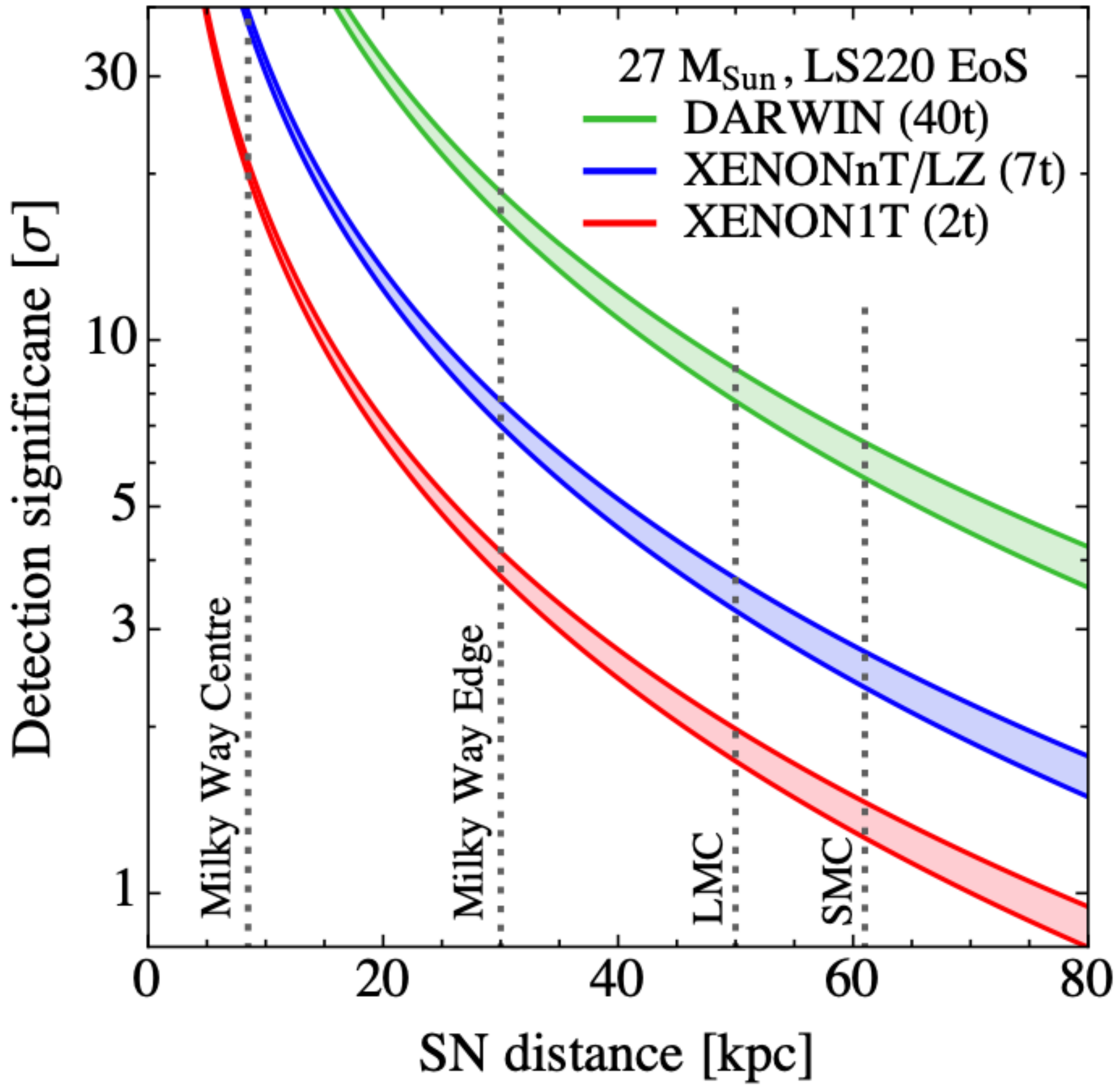

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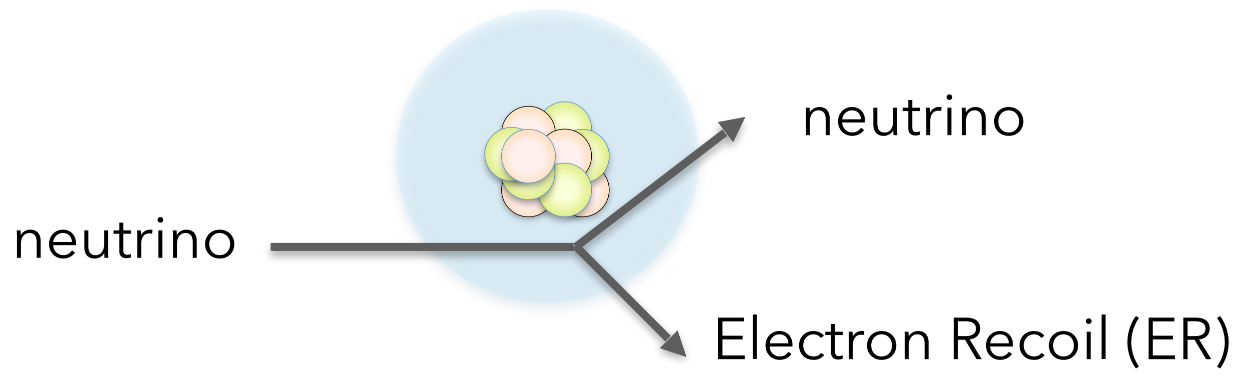
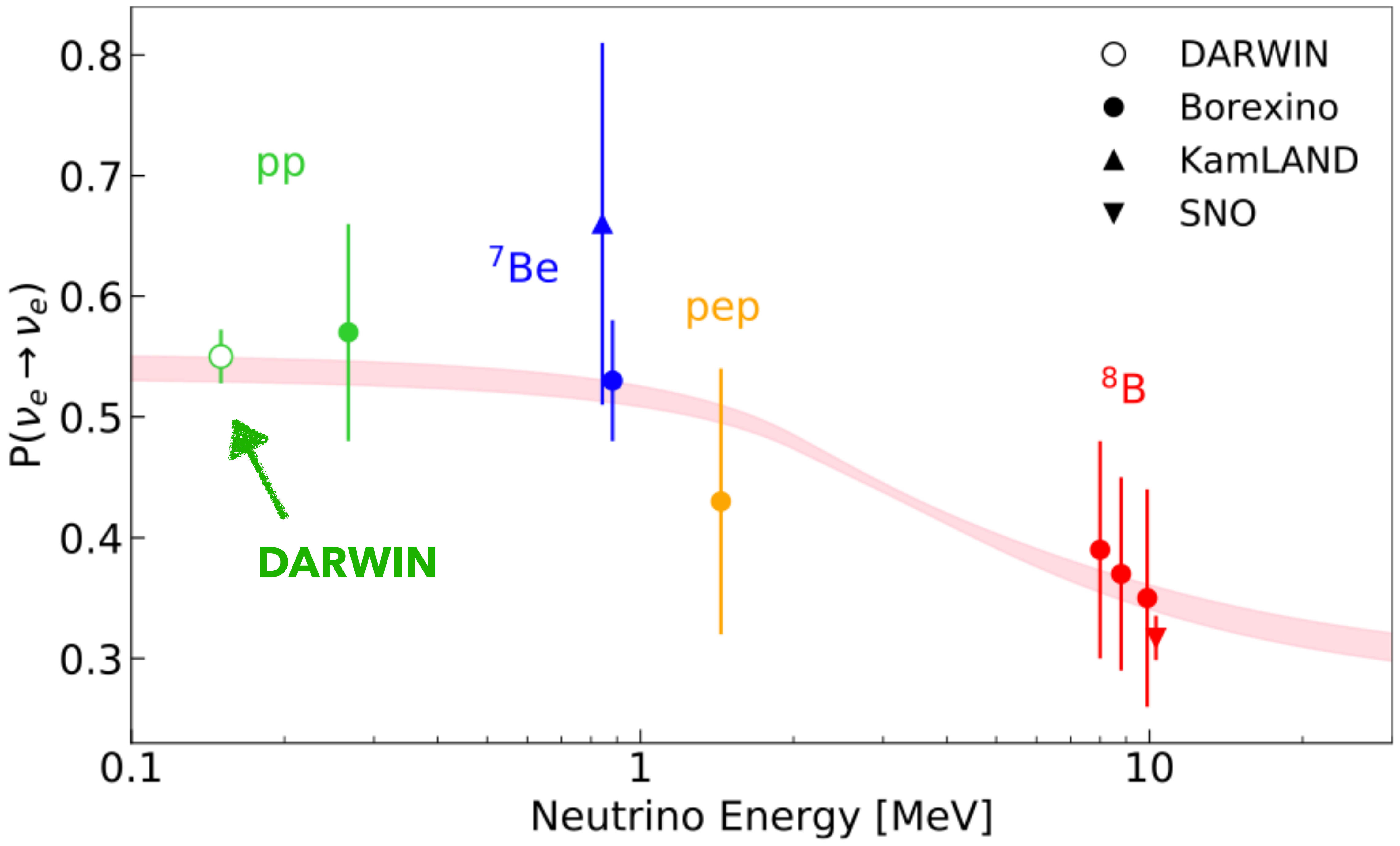
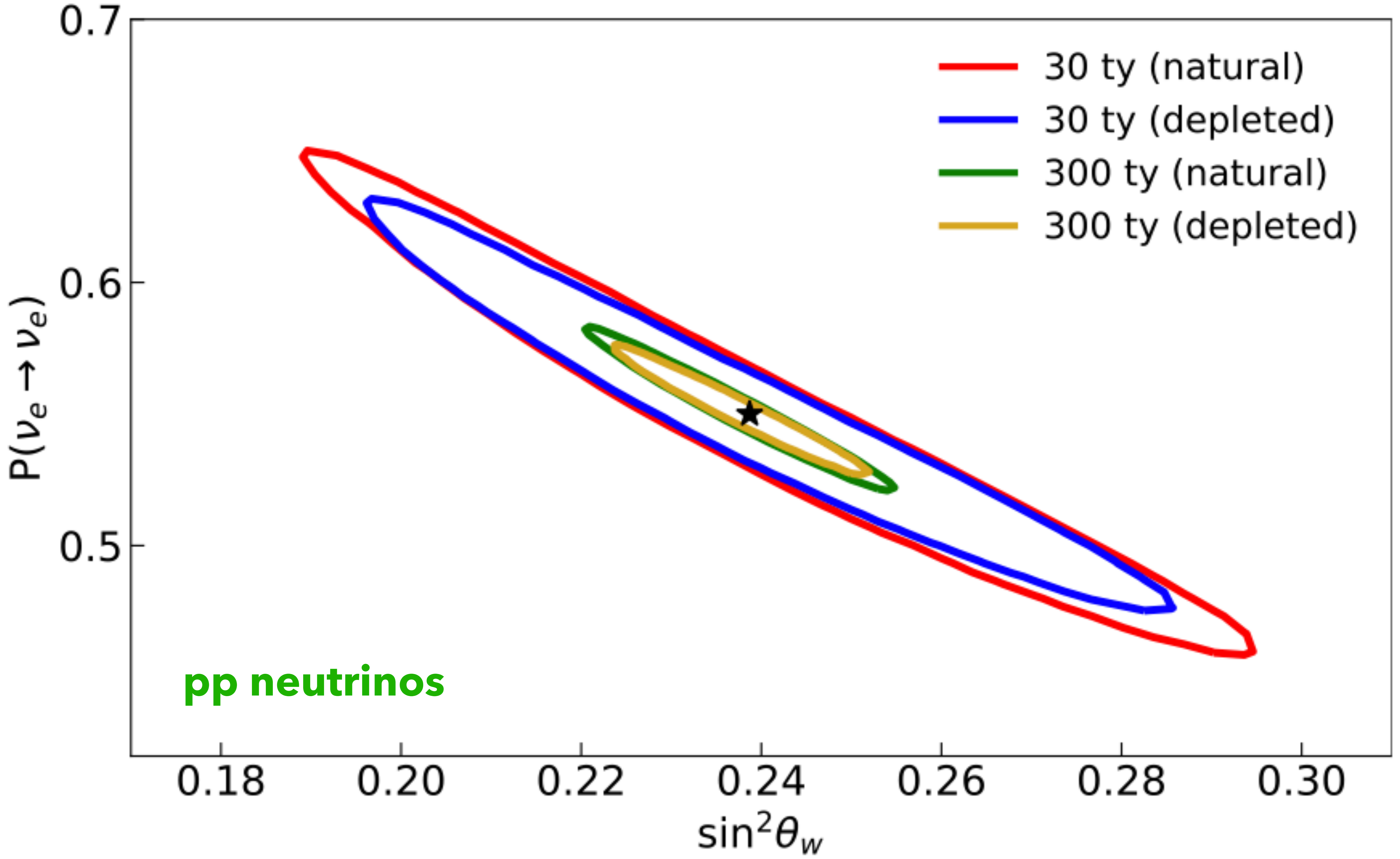
Solar neutrinos



Elastic neutrino-electron interactions



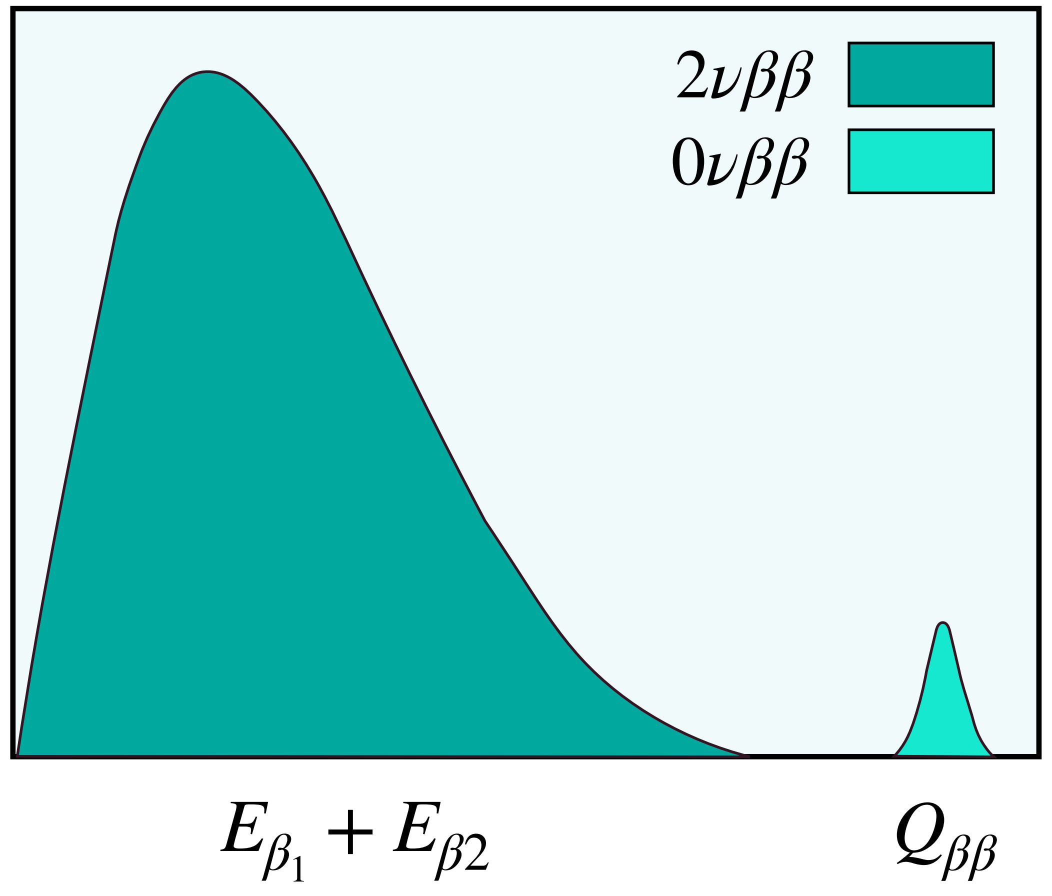


- 1 pp neutrino event/t day [1 keV_{ee} threshold]
- Measurement of pp-neutrino flux with 0.15% statistical precision (300 t yr exposure)

- Inferred electron neutrino survival probability and weak mixing angle

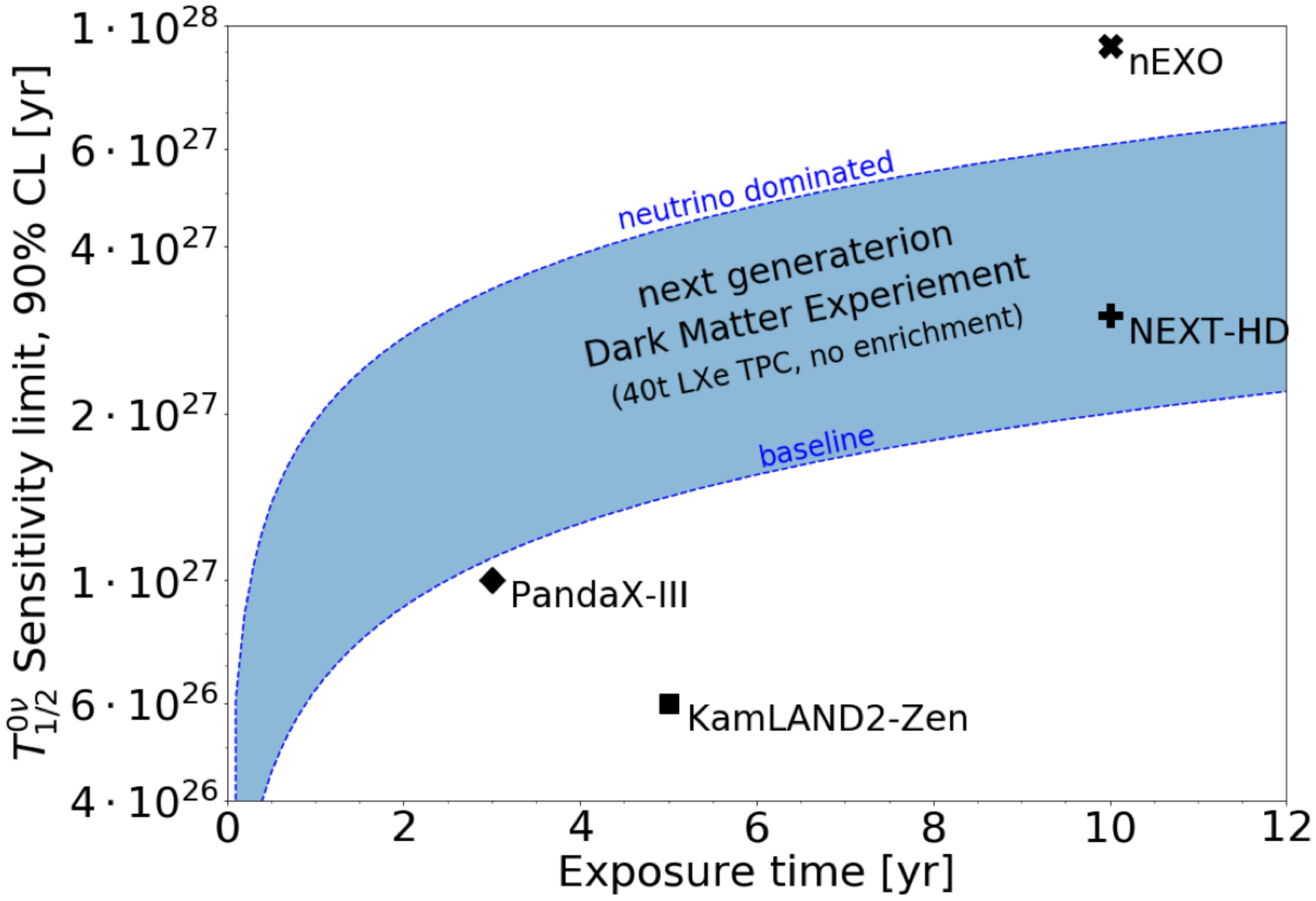
DARWIN Collaboration, Eur. Phys. J. C 80 (2020) 12

Neutrinoless double beta decay of ^{136}Xe



- Test of lepton number conservation
- Majorana neutrino nature

- ^{136}Xe is a neutrinoless double beta decay candidate (8.9% natural abundance ~ 3.6 t in 40 t DARWIN)
- $Q_{\beta\beta}$ peak at 2.458 MeV with 0.8% energy resolution (XENON, EPJ C 80 (2020) 8).
- Half-life measurement (constraint); can also probe the mass hierarchy



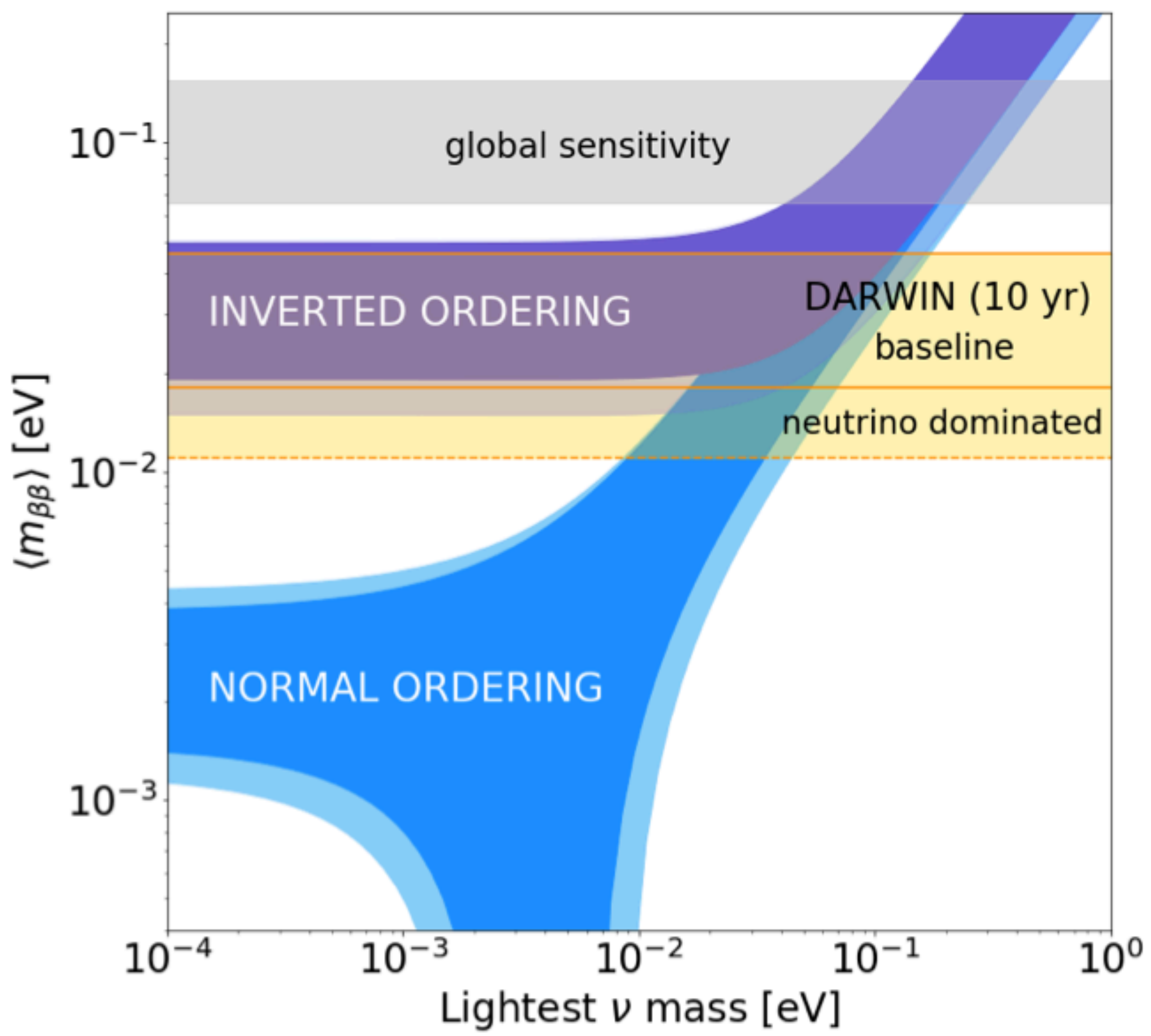
$$T^{0\nu}_{1/2} \propto \sqrt{\frac{Mt}{B}}$$

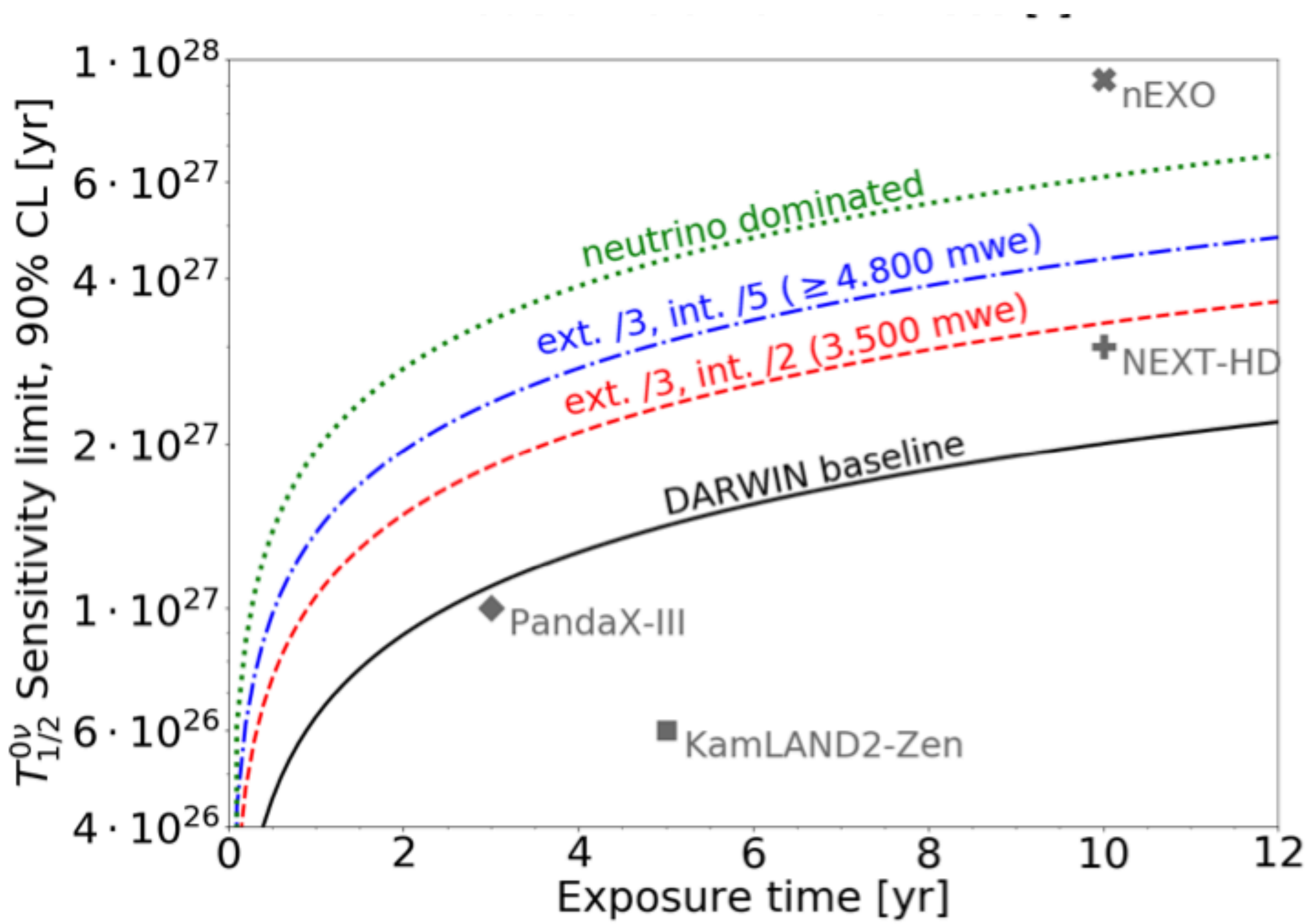
Projected sensitivity

$T_{1/2} = 2.4 \times 10^{27}$ yrs in 50 t yr

DARWIN Collaboration, Eur. Phys. J. C 80 (2020) 9

Neutrinoless double beta decay of ^{136}Xe



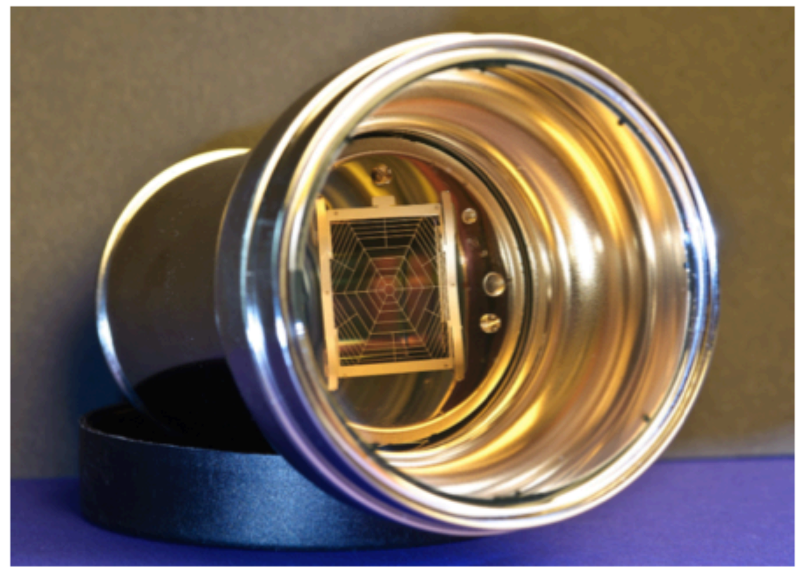
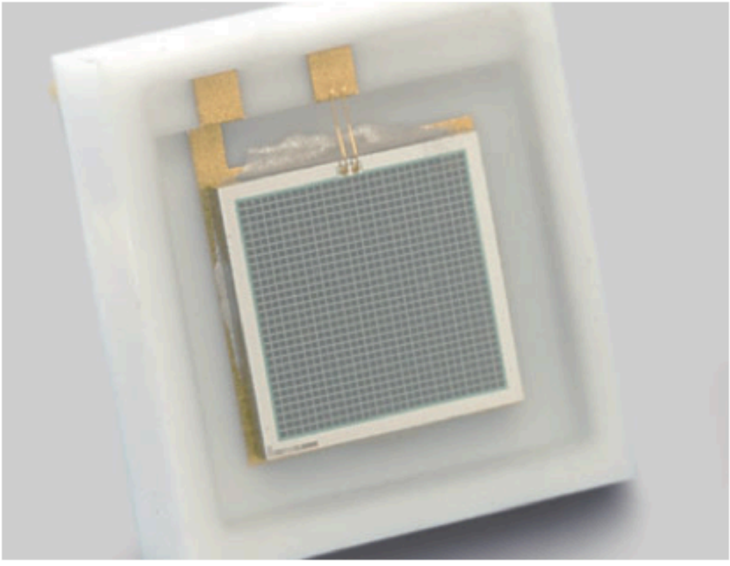
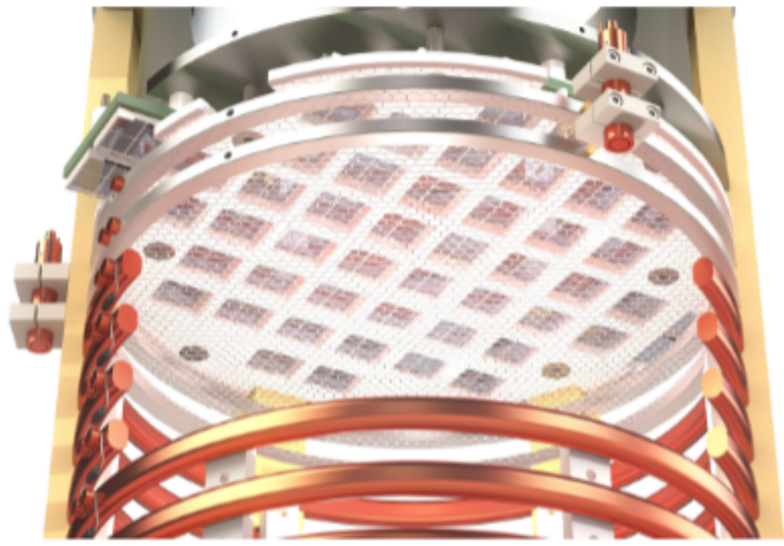
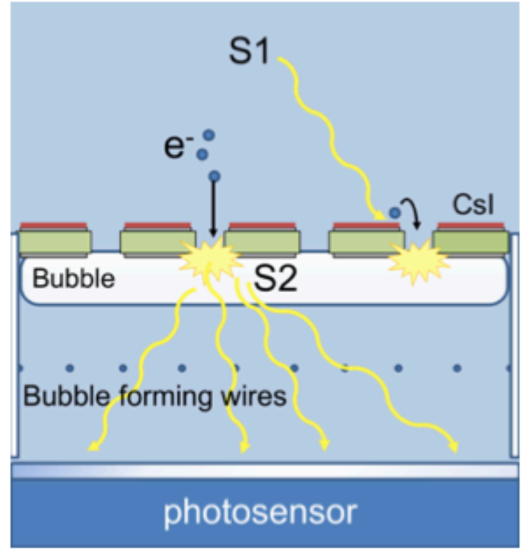


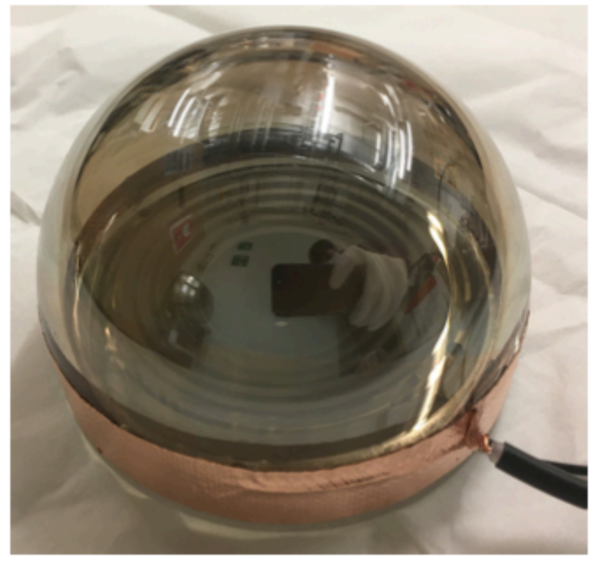
- Probe the neutrino mass heirarchy
- Background rate assumption 0.2 events/(t yr); dominated by materials (fiducial volume dependent), plus cosmogenic ^{137}Xe (site dependent), intrinsic ^{222}Rn, and ^{8}B solar neutrinos.
- Active area of R&D aimed at reducing $0\nu\beta\beta$ backgrounds.

DARWIN Collaboration, Eur. Phys. J. C 80 (2020) 9

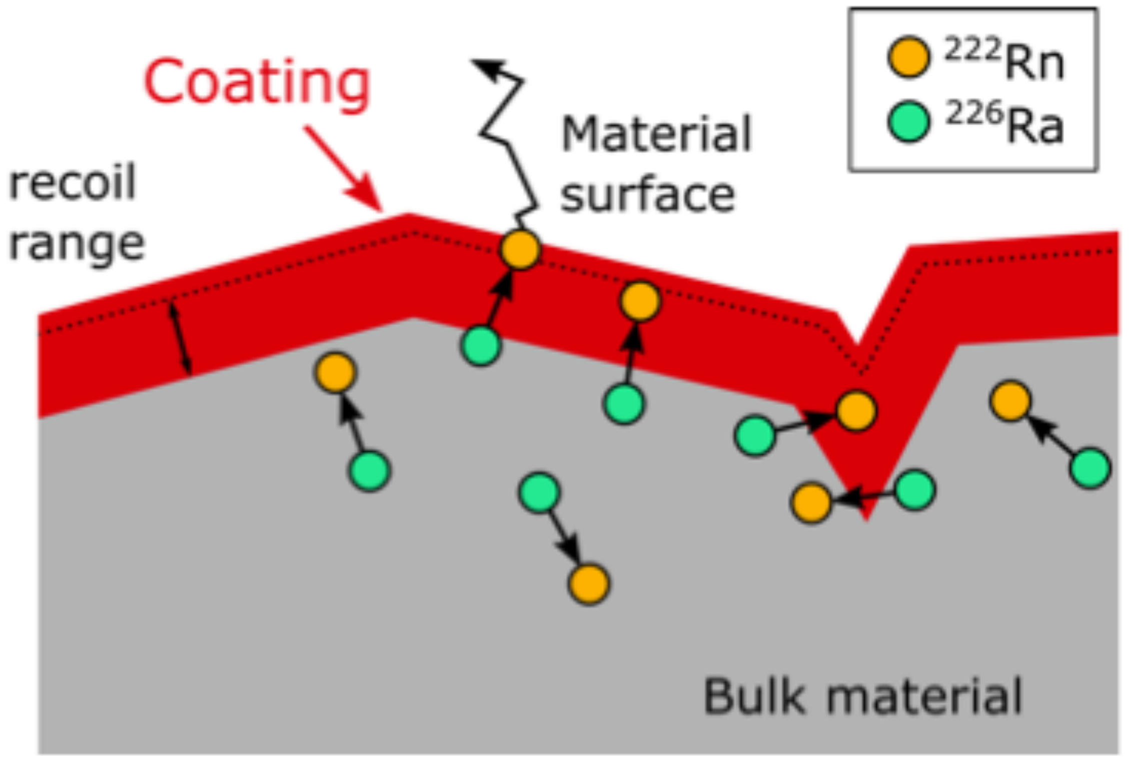
DARWIN R&D

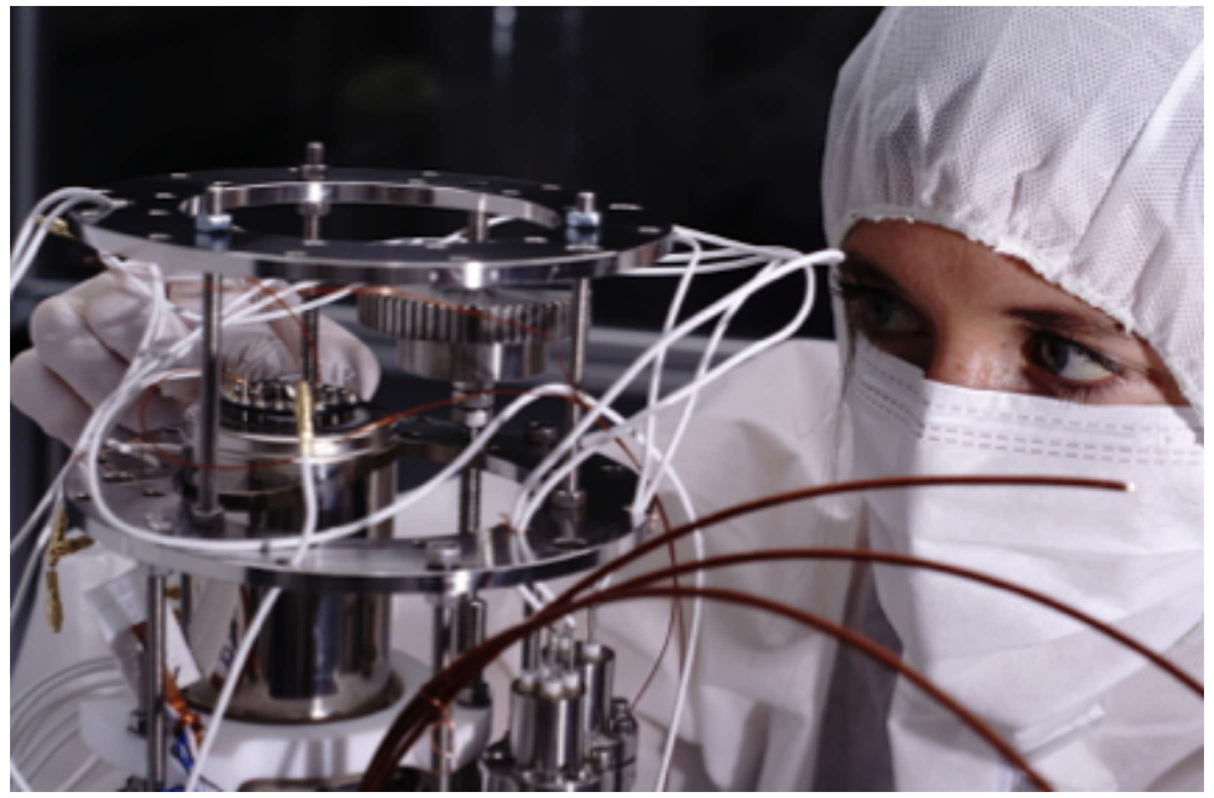
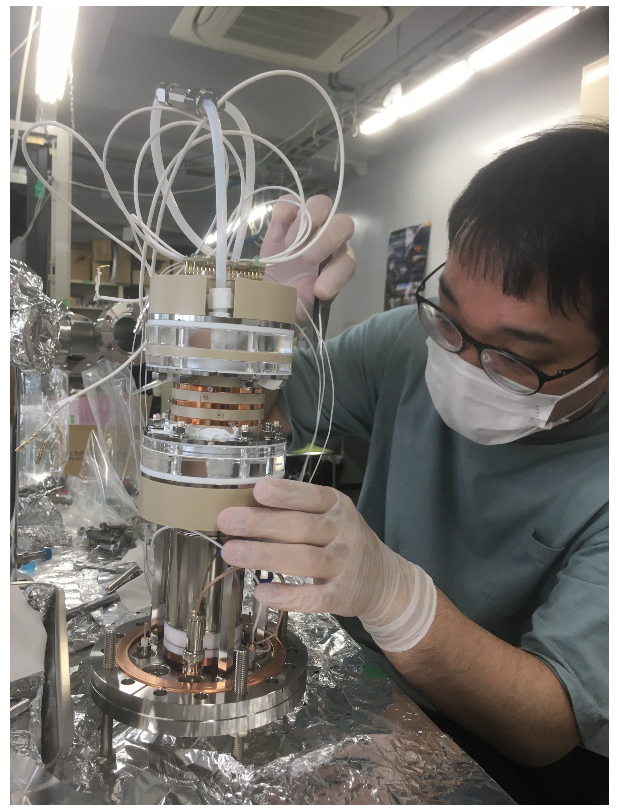
- **Photosensors**: Lower radioactivity PMTs, high position resolution SiPMs, hybrid photosensors for improved light collection, etc.
- **Background mitigation**: materials screening and site studies for muon-induced backgrounds, liquid xenon purifi cation, distillation, Rn mitigating coatings and detector designs
- **Detector design**: sealed/hermetic TPCs, single-phase TPCs, aspect ratio optimisation



Photosensors



Background mitigation

Detector design

XENON TPC R&D

R&D facilities and prototypes

- Two large-scale demonstrators (in z & in x-y) supported by ERC grants: demonstrate electron drift over 2.6 m, operate 2.6 m ø electrodes
- Study of high-voltage application; typically limited by light emission from electrodes, xenon purity.

Test electron drift over 2.6 m (purification, high-voltage): U. Zurich

Test electrodes with 2.6 m diameter: U. Freiburg

see talk by A. Bismark

The DARWIN Collaboration

Columbia · RPI · London · Nikhef · Muenster · Darmstadt · Stockholm · Mainz · Dresden · MPIK, Heidelberg · Heidelberg · KIT · Freiburg

Chicago

Purdue

UCSD

ORIGINS

Alabama

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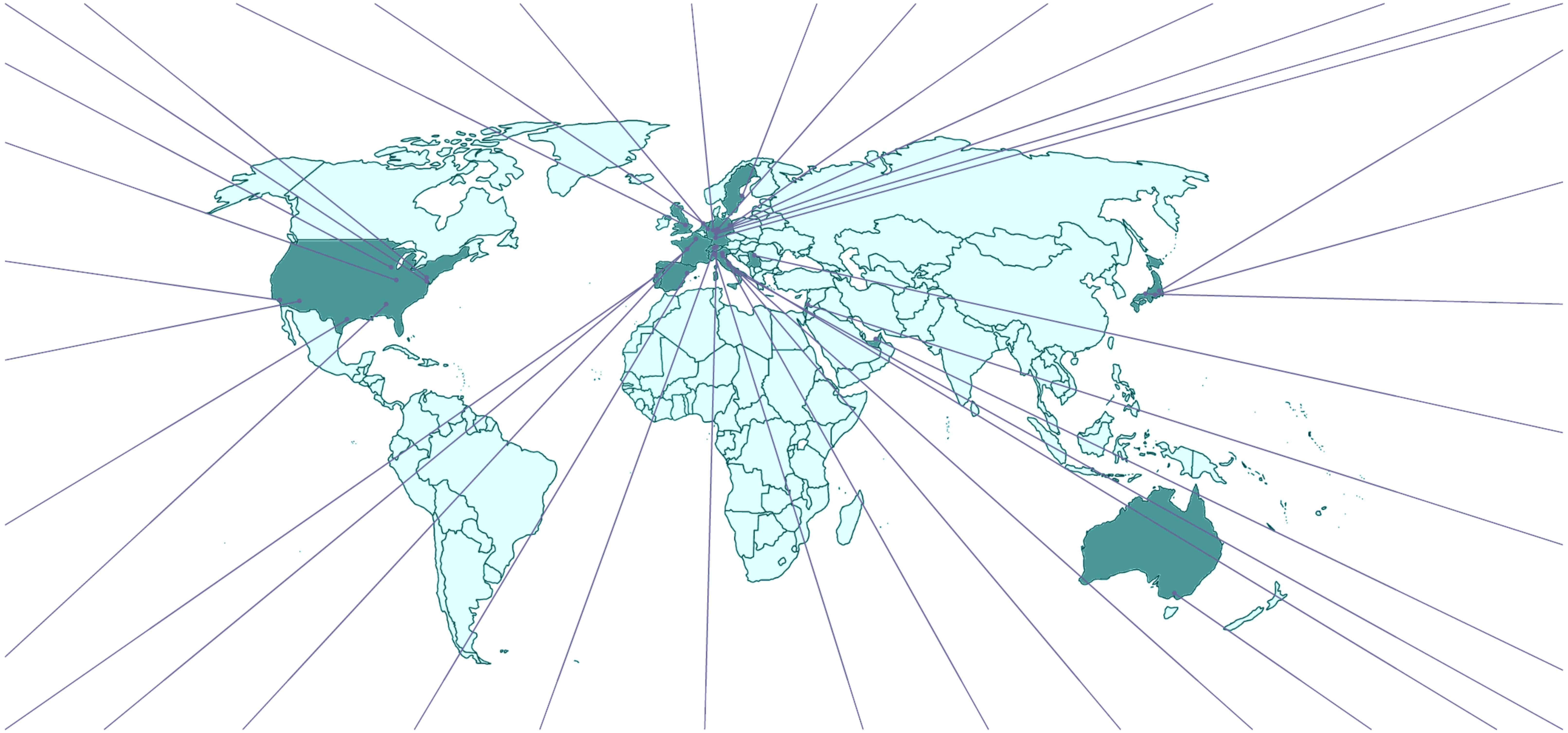

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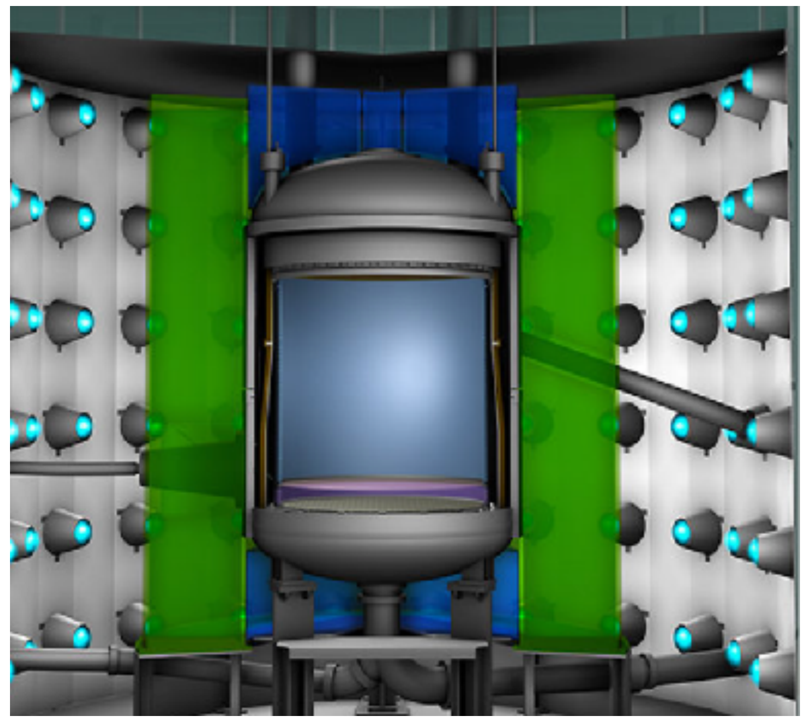
>170 members from 33 institutions and 11 countries

The future

Current generation

XENONnT: 8.6 t LXe
Data taking 2021



LUX-ZEPLIN (LZ): 10 t LXe
Data taking 2021

Merger of leading collaborations for a
future DARWIN/G3 xenon-based experiment

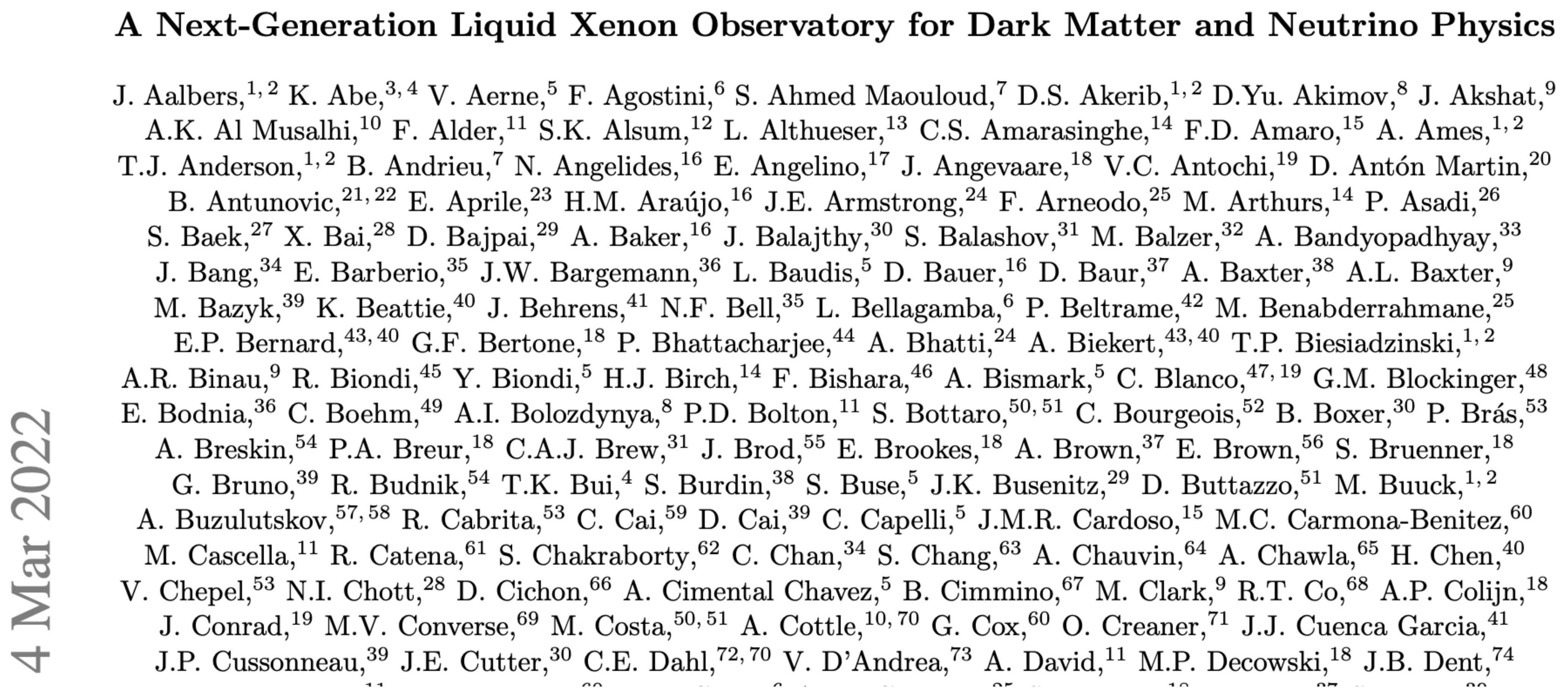
XENON

DARWIN

LZ

Data taking 2027/28

- **Memorandum of Understanding** signed July 6, 2021 by 106 research group leaders from 16 countries
- International collaboration with complementary areas of expertise
- First joint meeting April 26-27, 2021; second meeting now ongoing (hosted by Karlsruhe Institute of Technology)
- **Community whitepaper** with combined science goals, background considerations, priorities - posted March 2022.



4 Mar 2022

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

J. Aalbers,[1,2] K. Abe,[3,4] V. Aerne,[5] F. Agostini,[6] S. Ahmed Maouloud,[7] D.S. Akerib,[1,2] D.Yu. Akimov,[8] J. Akshat,[9] A.K. Al Musalhi,[10] F. Alder,[11] S.K. Alsum,[12] L. Althueser,[13] C.S. Amarasinghe,[14] F.D. Amaro,[15] A. Ames,[1,2] T.J. Anderson,[1,2] B. Andrieu,[7] N. Angelides,[16] E. Angelino,[17] J. Angevaare,[18] V.C. Antochi,[19] D. Antón Martin,[20] B. Antunovic,[21,22] E. Aprile,[23] H.M. Araújo,[16] J.E. Armstrong,[24] F. Arneodo,[25] M. Arthurs,[14] P. Asadi,[26] S. Baek,[27] X. Bai,[28] D. Bajpai,[29] A. Baker,[16] J. Balajthy,[30] S. Balashov,[31] M. Balzer,[32] A. Bandyopadhyay,[33] J. Bang,[34] E. Barberio,[35] J.W. Bargemann,[36] L. Baudis,[5] D. Bauer,[16] D. Baur,[37] A. Baxter,[38] A.L. Baxter,[9] M. Bazyk,[39] K. Beattie,[40] J. Behrens,[41] N.F. Bell,[35] L. Bellagamba,[6] P. Beltrame,[42] M. Benabderrahmane,[25] E.P. Bernard,[43,40] G.F. Bertone,[18] P. Bhattacharjee,[44] A. Bhatti,[24] A. Biekert,[43,40] T.P. Biesiadzinski,[1,2] A.R. Binau,[9] R. Biondi,[45] Y. Biondi,[5] H.J. Birch,[14] F. Bishara,[46] A. Bismark,[5] C. Blanco,[47,19] G.M. Blockinger,[48] E. Bodnia,[36] C. Boehm,[49] A.I. Bolozdynya,[8] P.D. Bolton,[11] S. Bottaro,[50,51] C. Bourgeois,[52] B. Boxer,[30] P. Brás,[53] A. Breskin,[54] P.A. Breur,[18] C.A.J. Brew,[31] J. Brod,[55] E. Brookes,[18] A. Brown,[37] E. Brown,[56] S. Bruenner,[18] G. Bruno,[39] R. Budnik,[54] T.K. Bui,[4] S. Burdin,[38] S. Buse,[5] J.K. Busenitz,[29] D. Buttazzo,[51] M. Buuck,[1,2] A. Buzulutskov,[57,58] R. Cabrita,[53] C. Cai,[59] D. Cai,[39] C. Capelli,[5] J.M.R. Cardoso,[15] M.C. Carmona-Benitez,[60] M. Cascella,[11] R. Catena,[61] S. Chakraborty,[62] C. Chan,[34] S. Chang,[63] A. Chauvin,[64] A. Chawla,[65] H. Chen,[40] V. Chepel,[53] N.I. Chott,[28] D. Cichon,[66] A. Cimental Chavez,[5] B. Cimmino,[67] M. Clark,[9] R.T. Co,[68] A.P. Colijn,[18] J. Conrad,[19] M.V. Converse,[69] M. Costa,[50,51] A. Cottle,[10,70] G. Cox,[60] O. Creaner,[71] J.J. Cuenca Garcia,[41] J.P. Cussonneau,[39] J.E. Cutter,[30] C.E. Dahl,[72,70] V. D'Andrea,[73] A. David,[11] M.P. Decowski,[18] J.B. Dent,[74]

Community Whitepaper: arXiv:2203.02309 (2022)

Summary

- The DARWIN observatory will be the next-generation xenon-based TPC, following the legacy of the leading WIMP search experiments.
- The large-mass, low-background experiment enables a broad physics program beyond WIMPs, including:
  - Low-mass dark matter (sub-GeV down to keV)
  - Precision measurement of the solar neutrino pp-flux
  - Early detection of supernova neutrinos; synchronisation with the global multi-messenger community
  - Competitive search for neutrinoless double beta decay using intrinsic ^{136}Xe.
- Diverse, international R&D efforts are currently ongoing to address the technical and background requirements for the next generation.
- A new global consortium with the LZ dark matter collaboration is underway.

DARWIN

www.darwin-observatory.org

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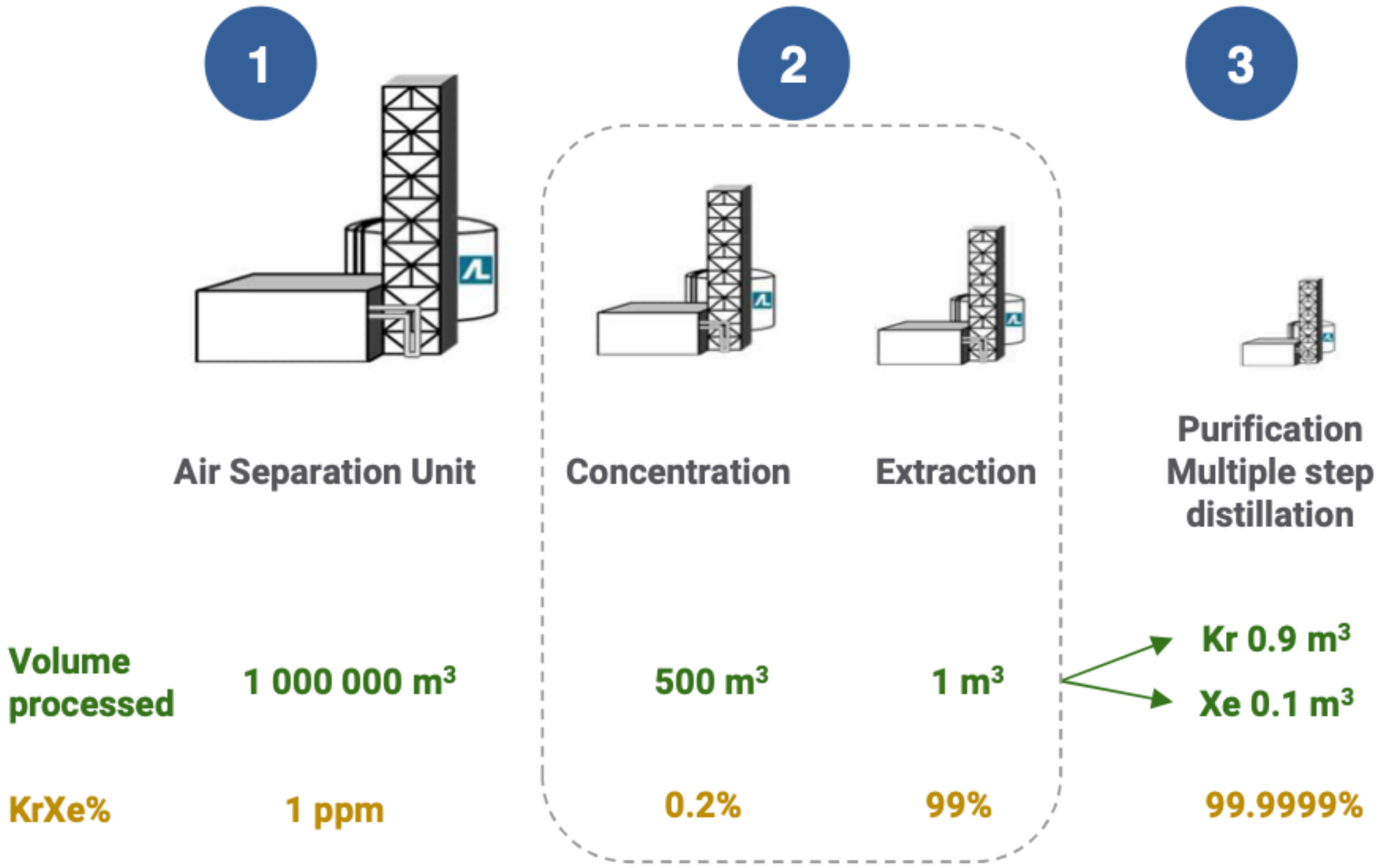
European Research Council

Established by the European Commission

XENON availability

- Xenon has an abundance of 0.087 ppm in the Earth's atmosphere
- Extraction from air requires multiple steps
- Electronics demand expected to continue until 2030
- Space demand is booming (recent developments + private investment)
- Long-term supply may be affected by geopolitical crises



Key facts:

- Only very large air separation units (ASUs) can justify extraction of Kr and Xe
- Even large ASUs can only produce a small amount of Kr and Xe
- Increasing Kr/Xe capacity requires investments in very large ASUs which are Kr/Xe ready

⇒ Production of Kr and Xe is managed globally in order to maximize reliability of supply

> Such demand provoked a shortage situation that is meant to continue over the next few years despite the different investments made by industrial players.

Reference: Air Liquide, Gaffet, XeSAT 2022