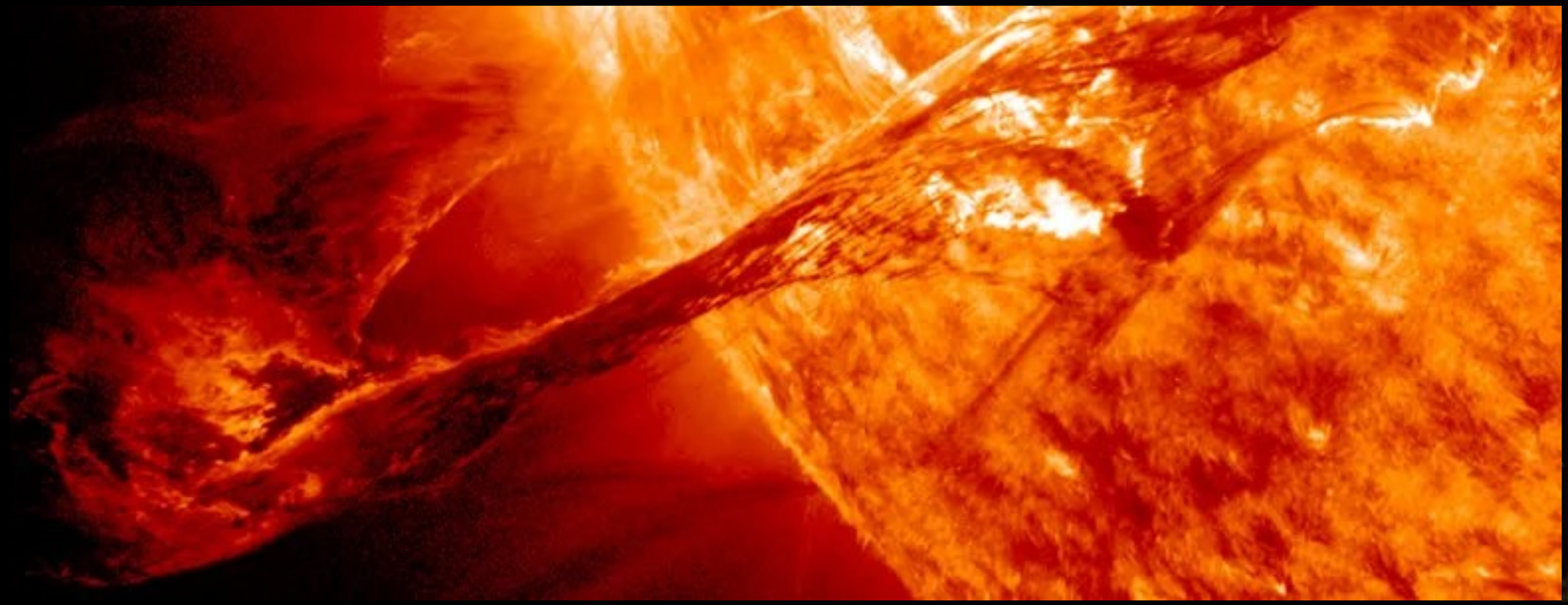
Neutrino Physics in Dark Matter Detectors

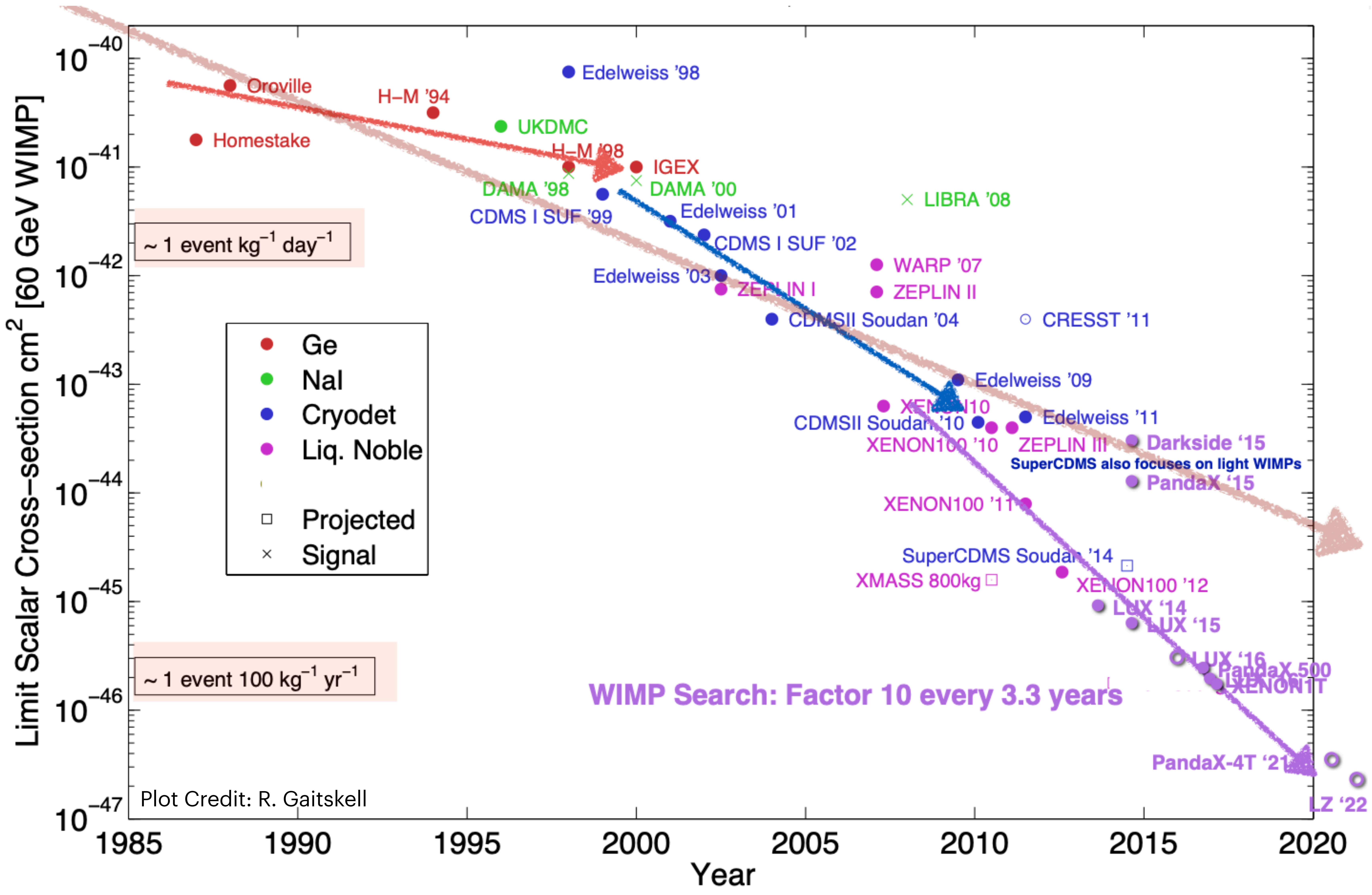


Amy Cottle, University College London

NuPhys Conference, 18th December

UCL

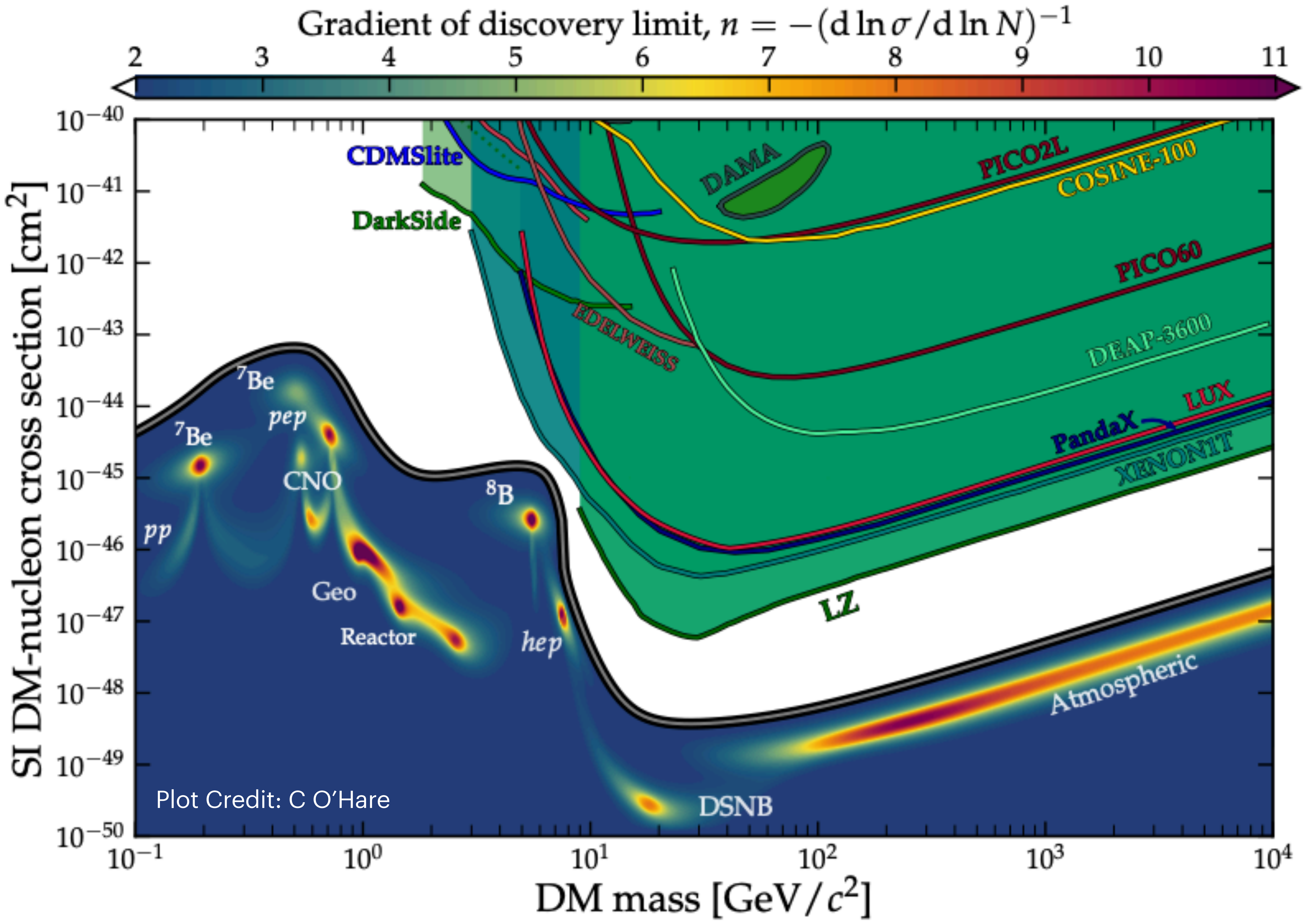
Brief History of WIMP Dark Matter Searches



- Weakly Interacting Massive Particles (WIMPs): compelling cold dark matter candidate
- Aim to directly detect WIMPs through interactions with ordinary matter
- Liquid noble detectors have led the field in the past decade

The Neutrino Floor: Foe.. or Friend?

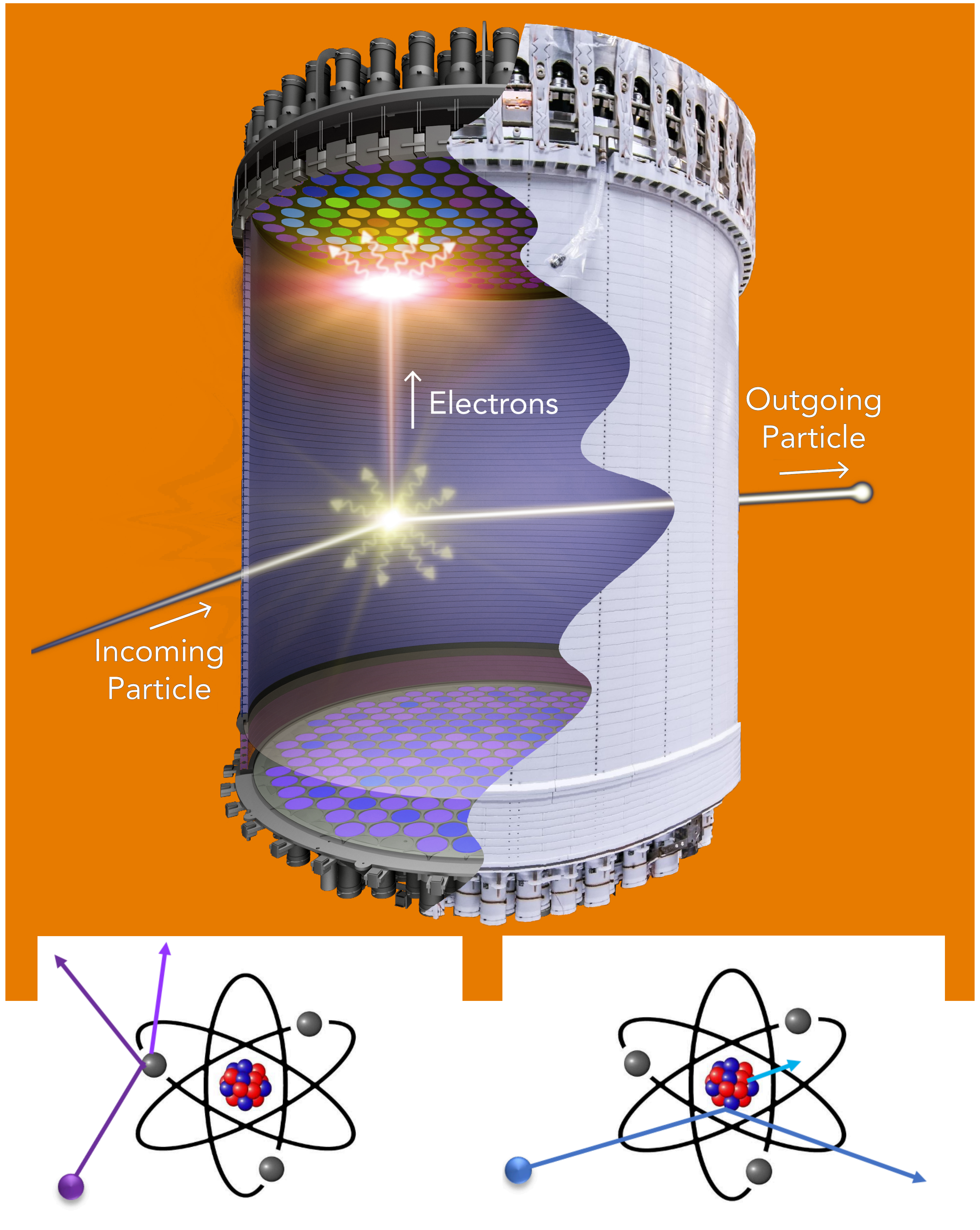
- WIMP limits and sensitivities of current "G2" xenon experiments (LZ, XENONnT, PandaX-4T) approaching the neutrino "floor"
  - Irreducible background from ^8B solar neutrino CEvNS limits low-mass WIMP searches



Neutrinos as background ➡ neutrinos as signal?

Talk will focus on neutrino physics in xenon detectors

Dual-Phase Xenon Detectors



Electron recoil (ER)

Nuclear recoil (NR)

- Detect both scintillation & ionisation from interactions
  - Ratio ➡ **excellent discrimination** of electron recoils (ERs) from nuclear recoils (NRs)
- Highest light and charge yields of all noble elements
  - **Low energy threshold** of ~1 (3) keV for ERs (NRs)
- **Low background** environment
  - Low intrinsic radioactivity; easily purified
  - Excellent 3D position reconstruction (~mm) & self-shielding ➡ fiducialisation
- Monolithic detectors ➡ **scalable target**

Neutrino Reach of Dark Matter Detectors

- Sensitive to neutrinos of energy in the ~MeV-GeV regime
- Natural neutrino sources: the Sun, the atmosphere, supernovae, diffuse supernova background (DSNB)

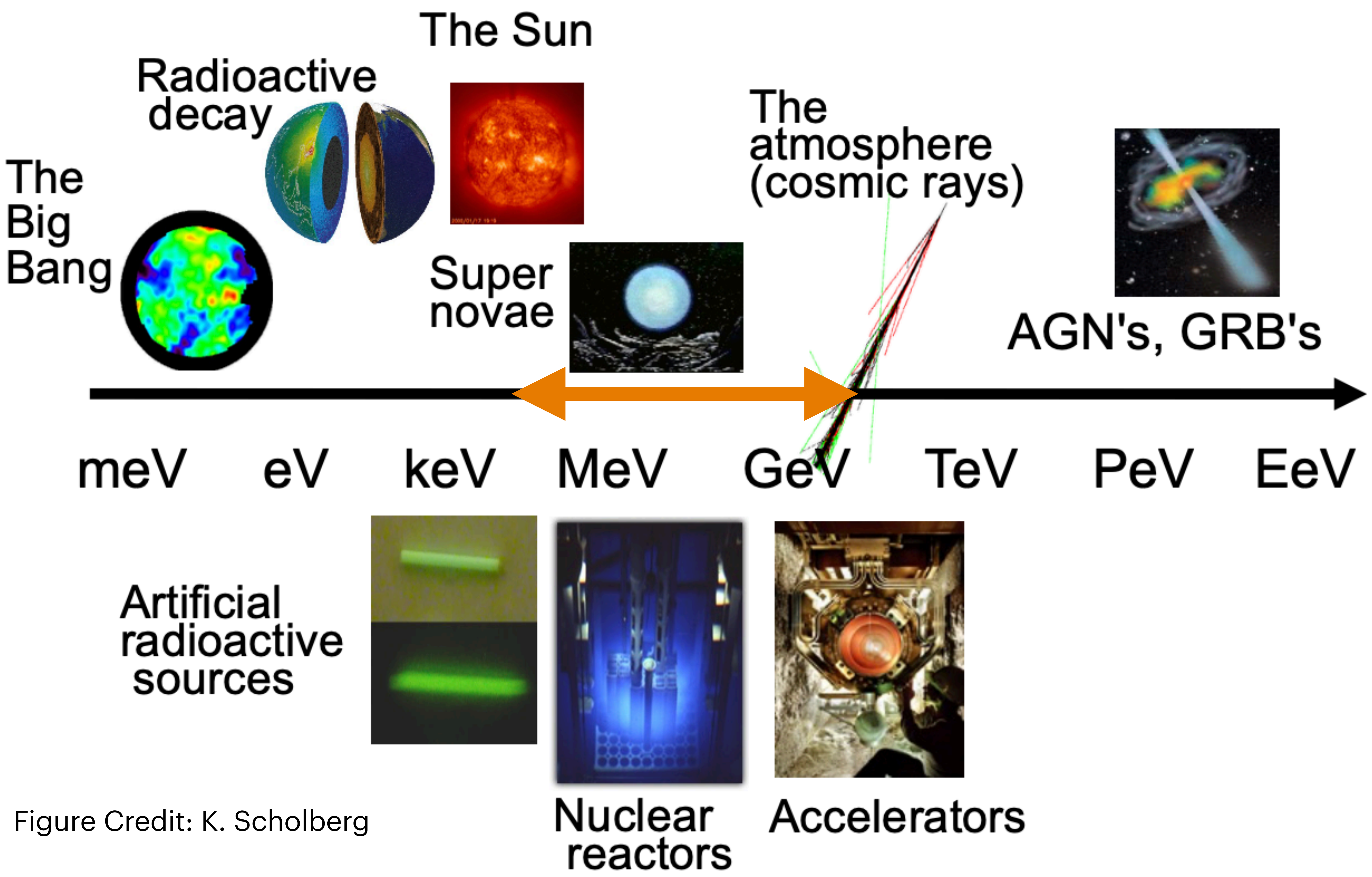
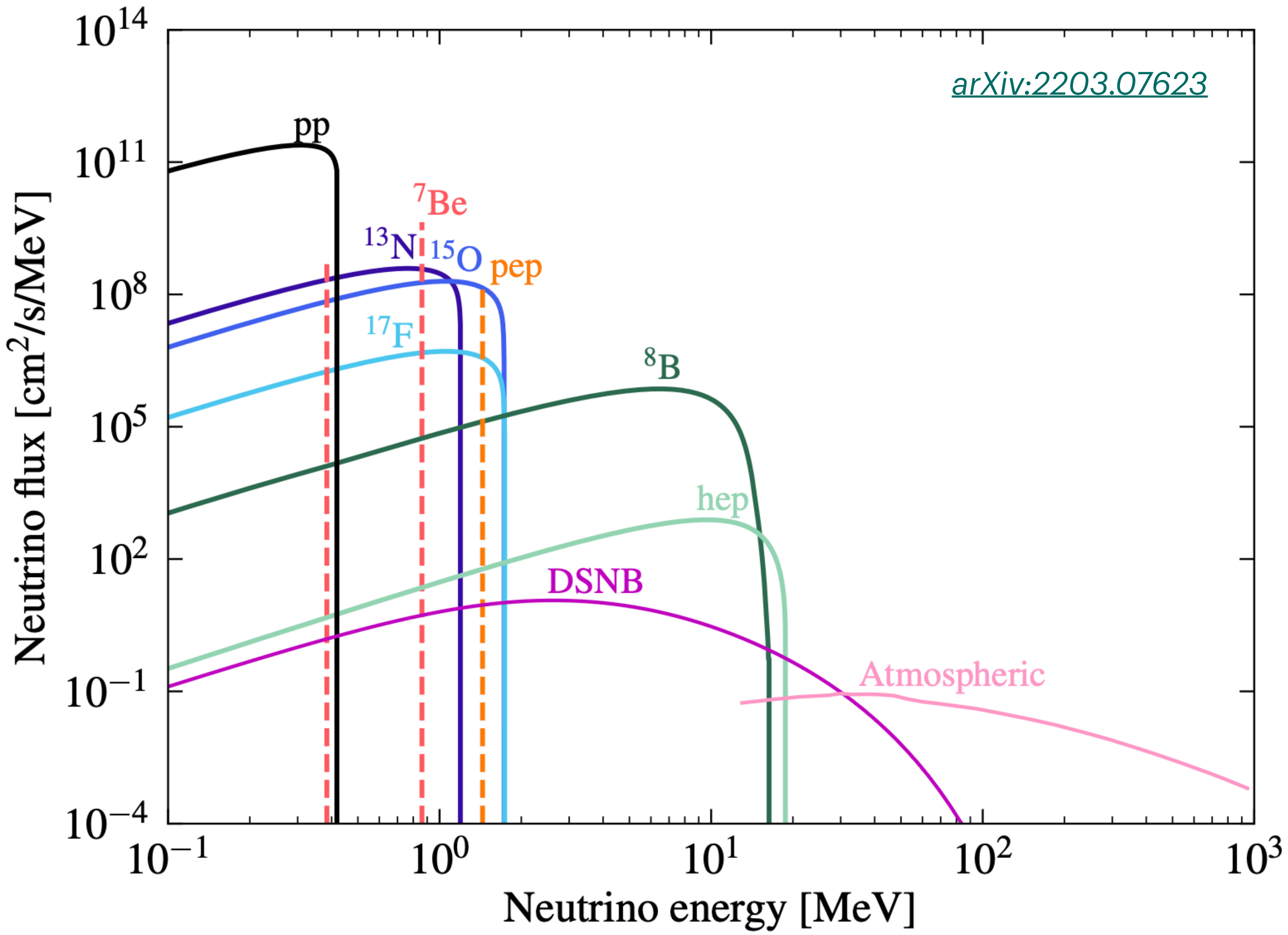
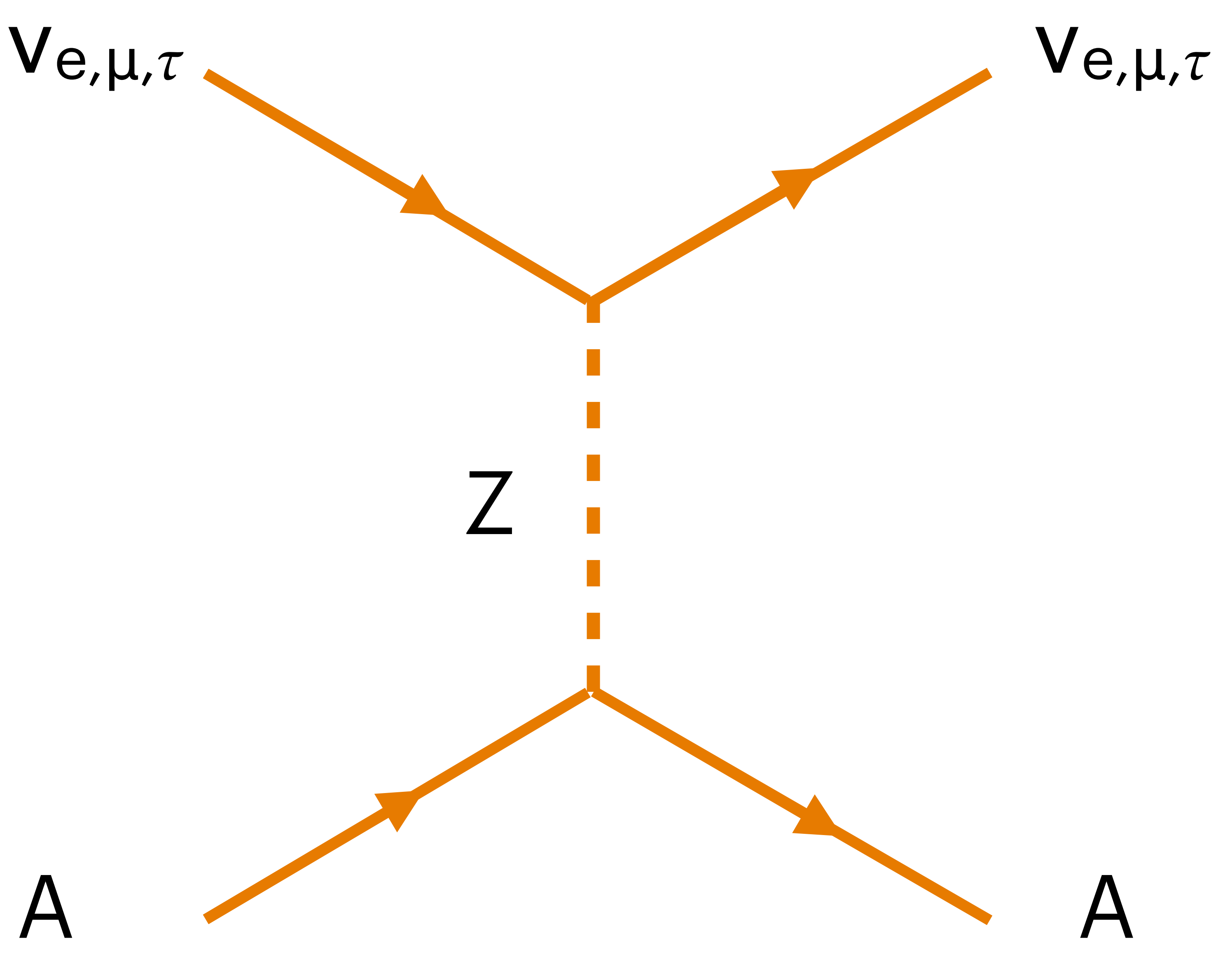


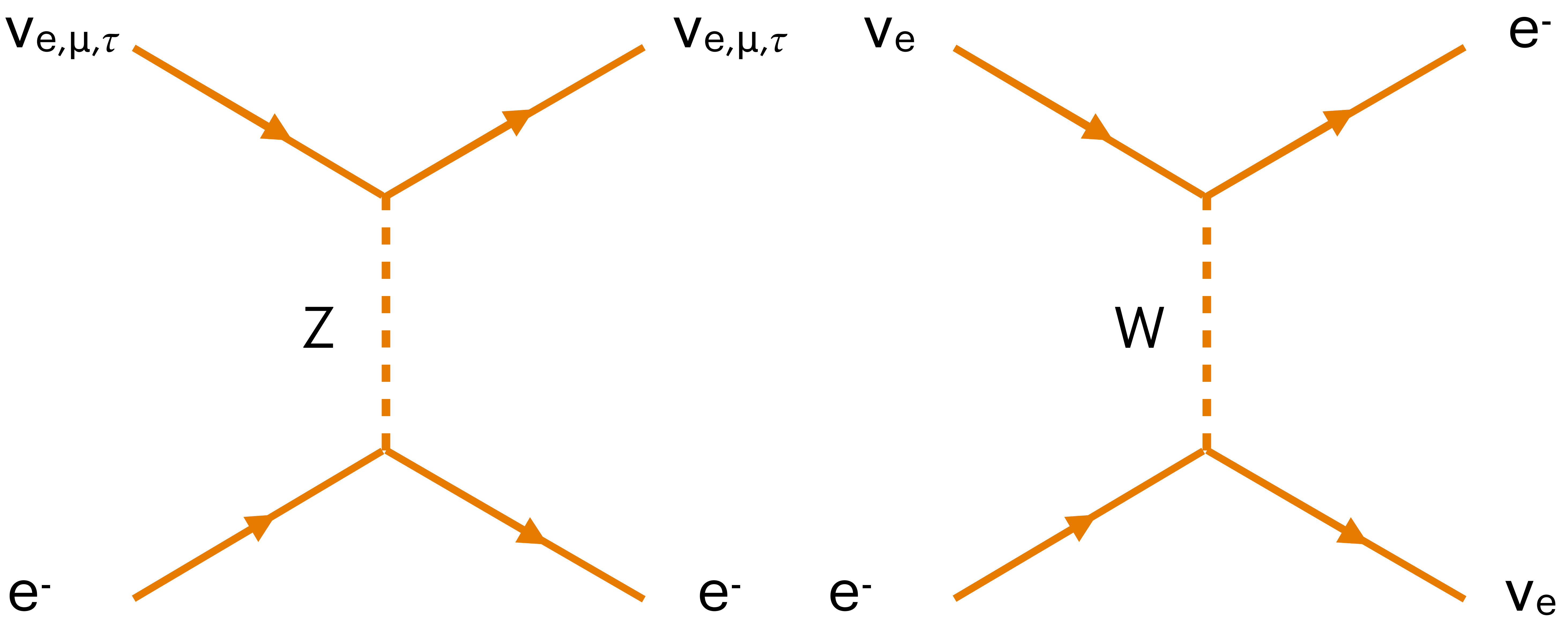
Figure Credit: K. Scholberg



Neutrino Detection Channels



CEνNS

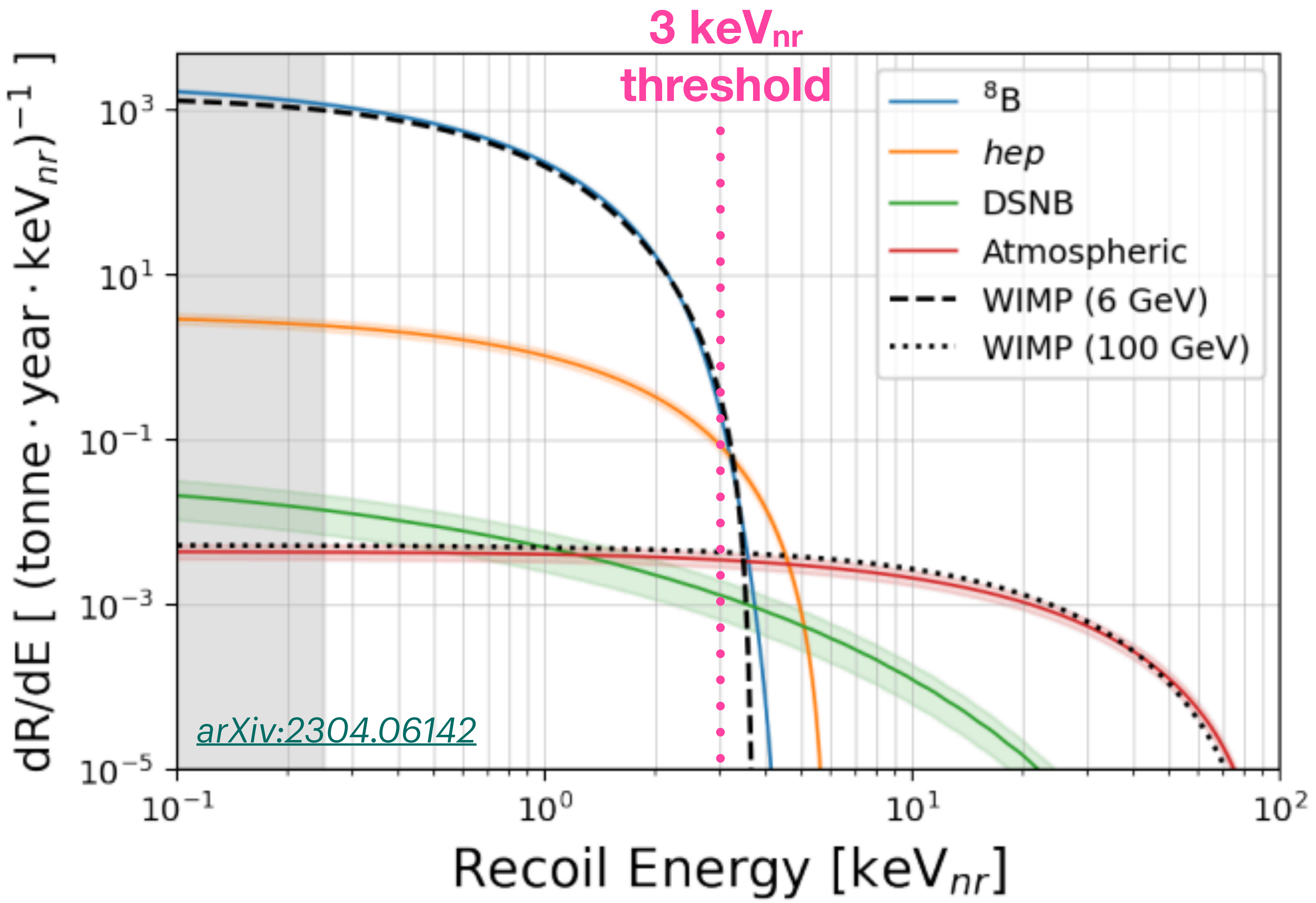


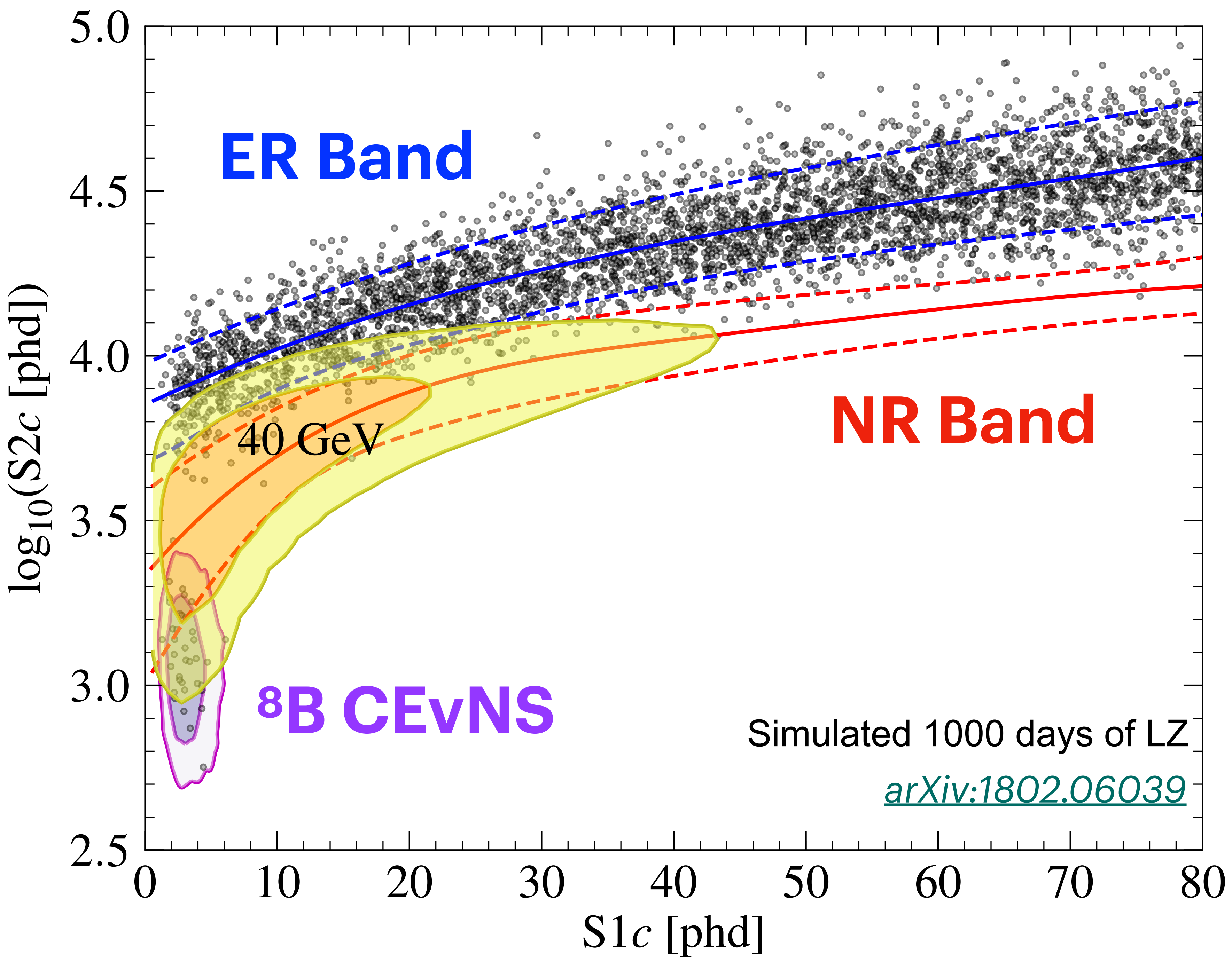
ν-e⁻ scattering

- CEνNS: flavour blind process coherent up to ~50 MeV neutrino energies
- ν-e^- scattering: low-energy regime ➡ only ν_e contributes to CC process
- CC ν-nucleus scattering: not relevant to the present generation of detectors

^{8}B Solar Neutrino CEvNS

- Up to ~15 MeV in energy ➡ all coherent scatters
- ~99% of events expected <3 keV$_{nr}$
  - Find novel method to push experimental threshold e.g. charge-only search
  - Use long exposures and rely on upwards fluctuation of observed signal
    - Expect ~3 events/100 days for typical threshold in a current generation detector (LZ)
- Observation would be first for natural neutrinos **➡ this will happen with a G2 detector**





ν-e⁻ Scattering

- Continuum of ER events, dominated by *pp* solar neutrinos (~2000 events in LZ (7 t) per year)

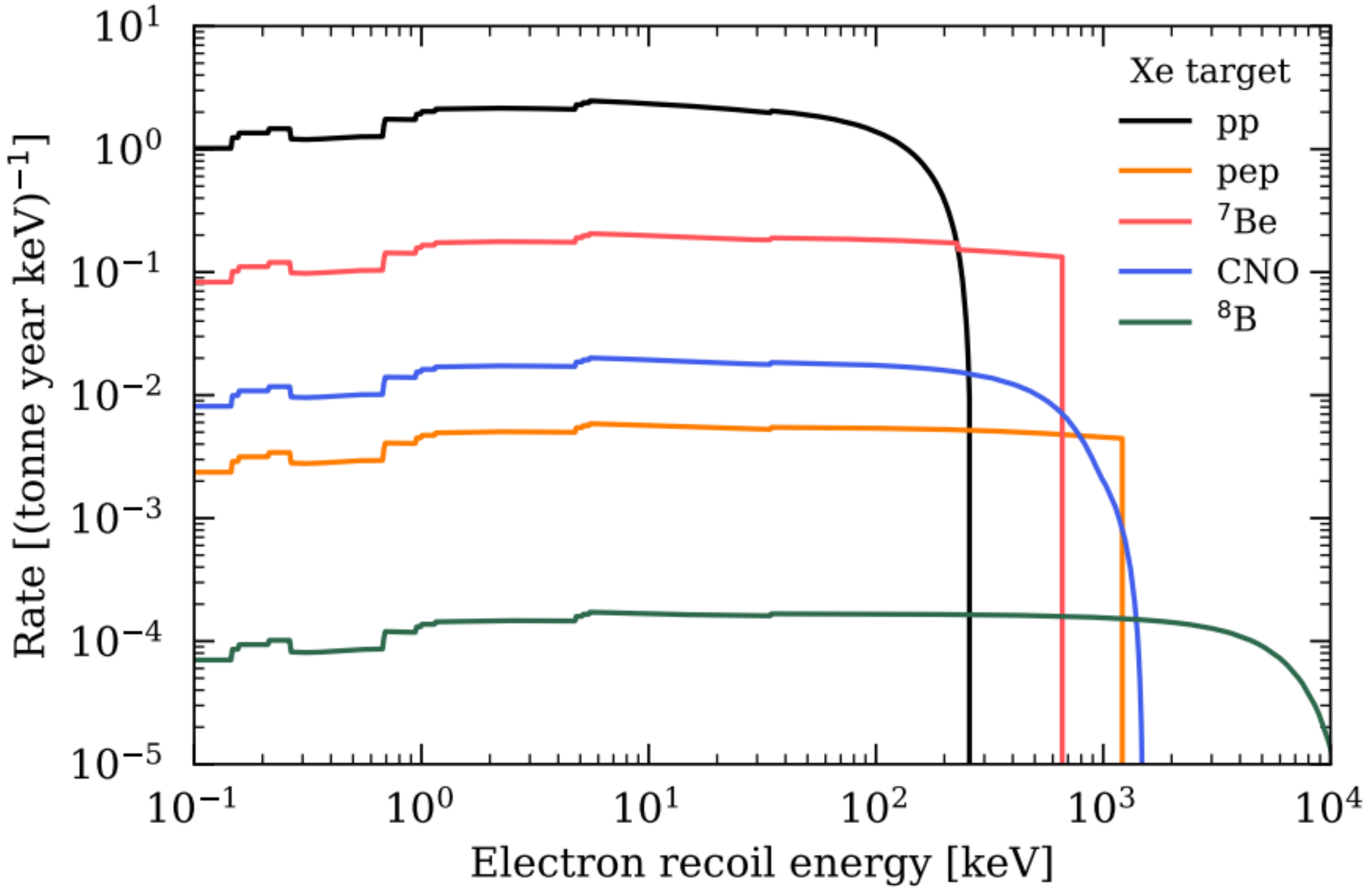
- Swamped by backgrounds from beta decays in the ^{222}Rn chain and ^{136}Xe 2νββ decay

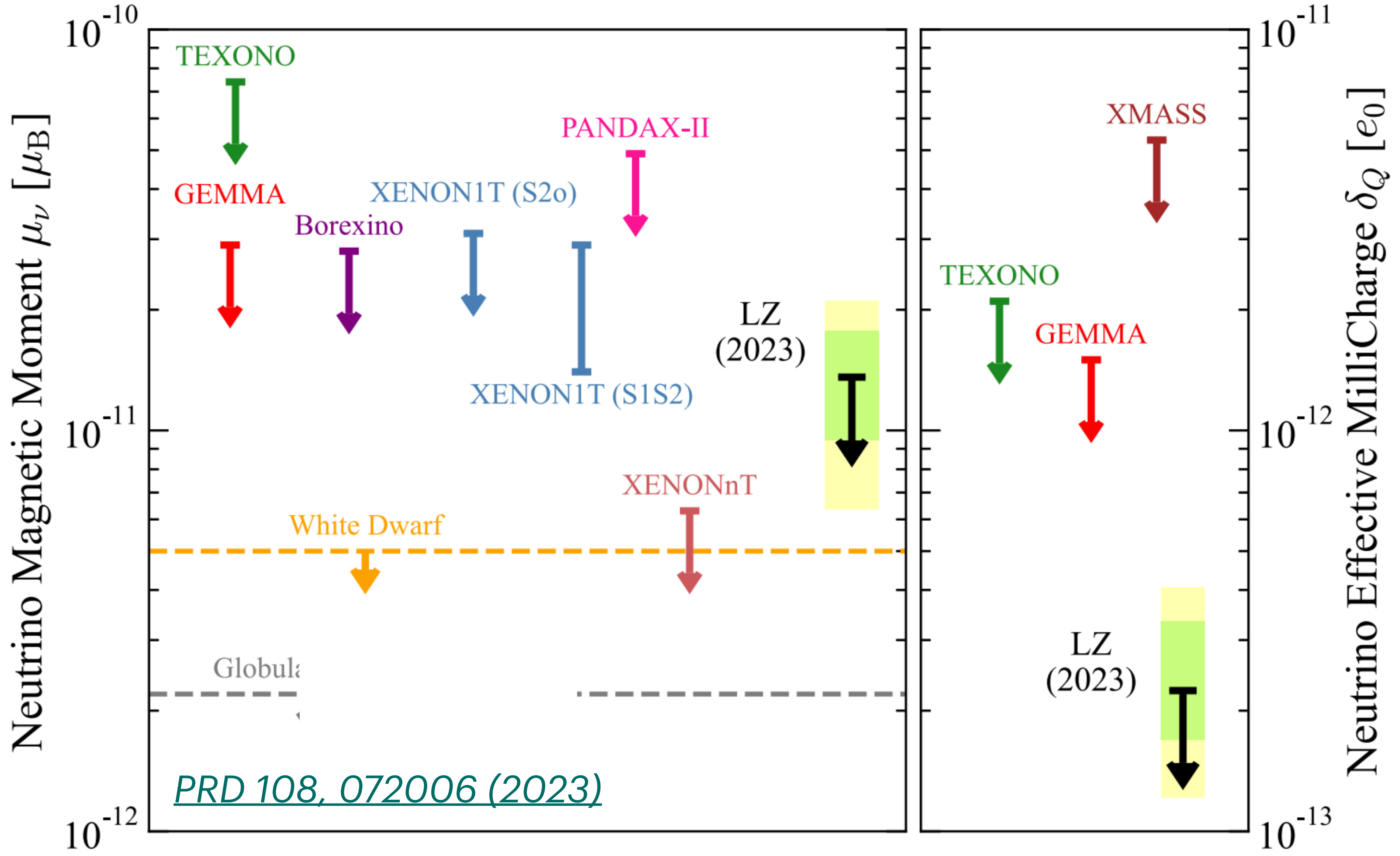
  - XENONnT reached 0.8 μBq/kg of ^{222}Rn
    ➡ 2x *pp* neutrino events in <20 keV_{ee} region

- A 1% accuracy in *pp* measurement would **not** be possible in G2 experiments

- However, sensitive to new neutrino physics e.g. dipole moments & electromagnetic properties

arXiv:2203.07623

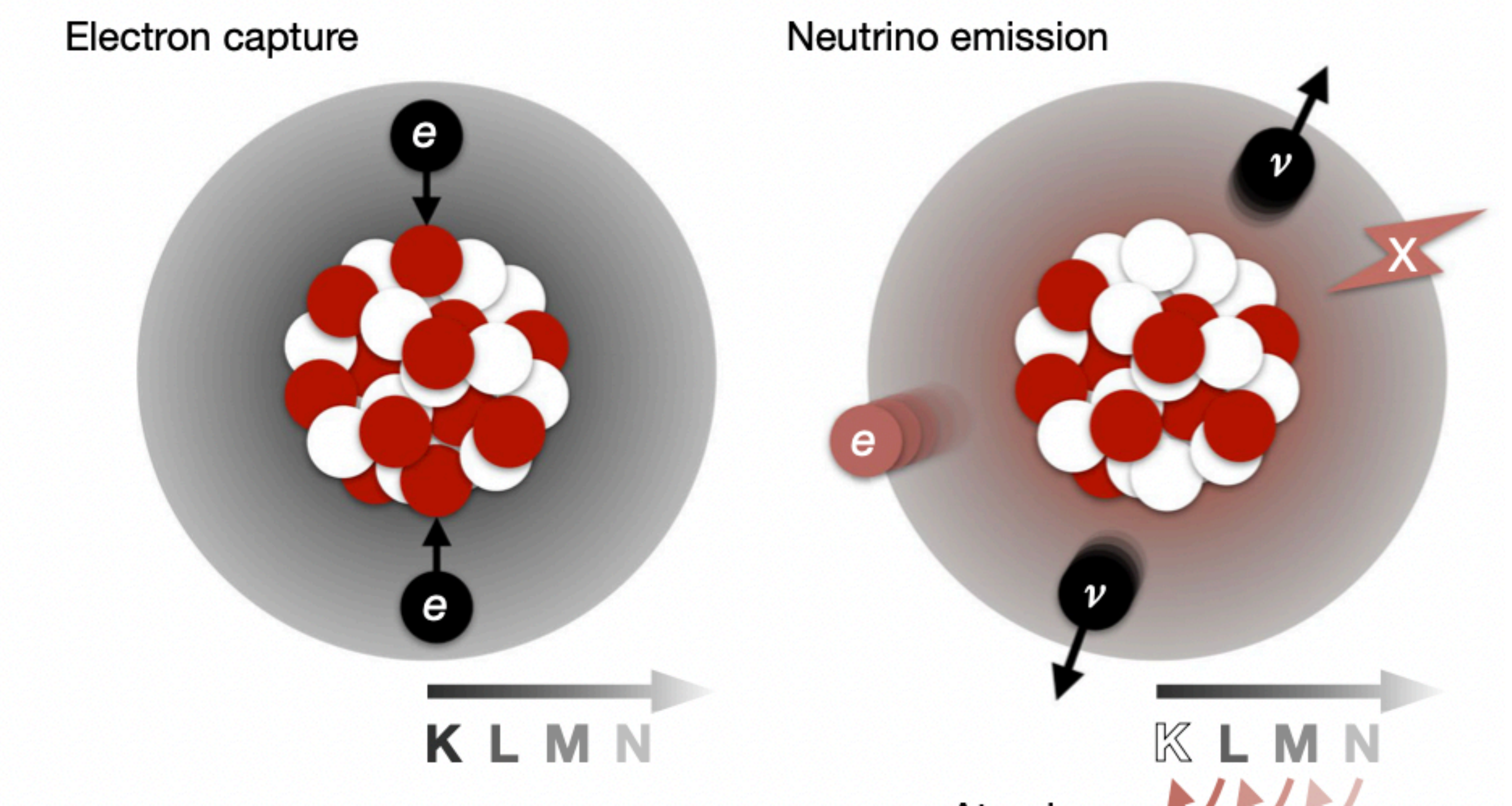




PRD 108, 072006 (2023)

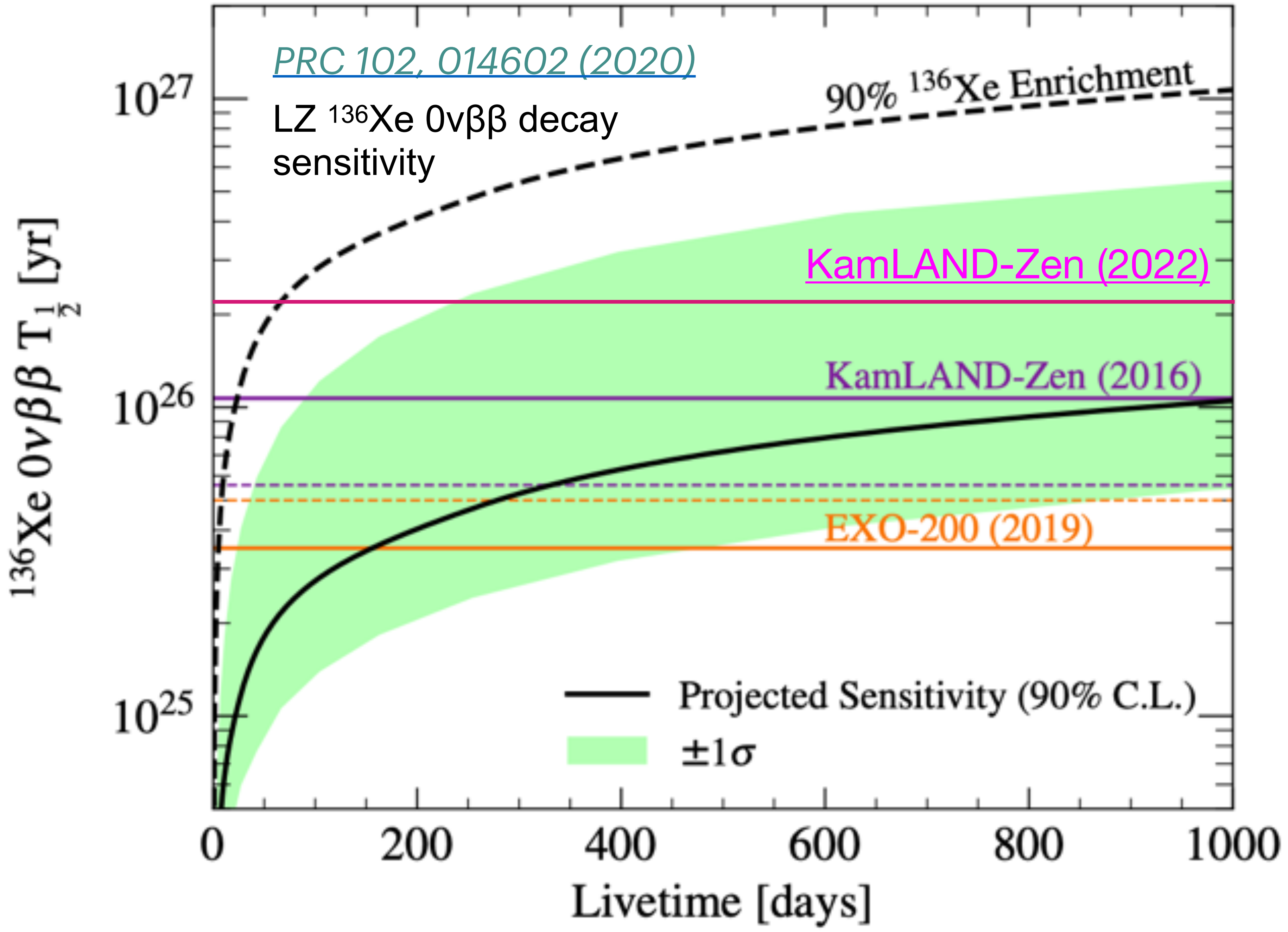
Neutrino Physics Via Xenon Decays

- Searches for second-order weak decays
  - Double beta decay:
    ^{134}Xe (826 keV), ^{136}Xe (2458 keV)
  - Double electron capture (DEC):
    ^{124}Xe (2864 keV), ^{126}Xe (920 keV)
- XENON1T ^{124}Xe 2vDEC discovery*
  ➡ **rarest decay process ever measured**
- ^{136}Xe 0vββ decay sensitivities approaching those of enriched target experiments



^{124}Xe Double Electron Capture (DEC)

Nature 568, 532–535 (2019)

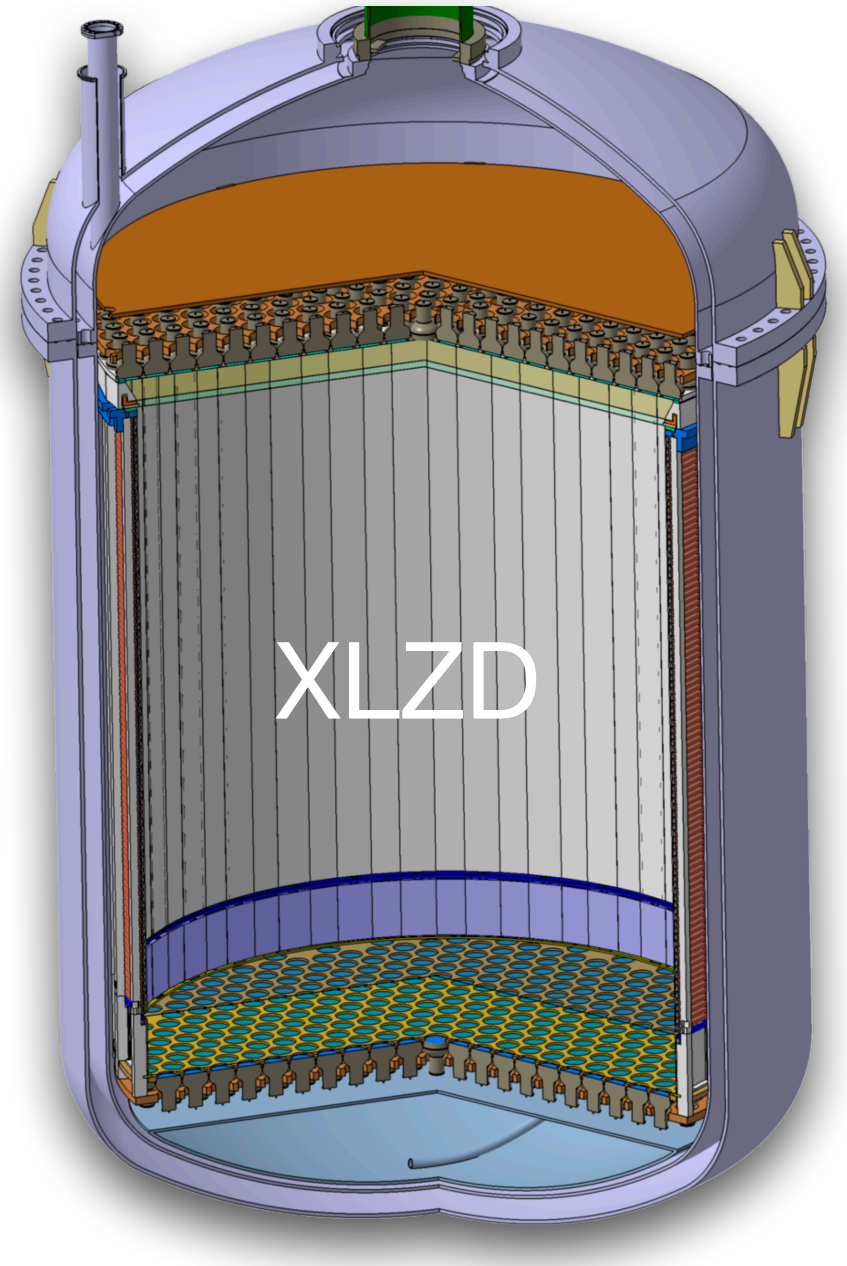


*PRC 106, 024328 (2022)

The Next-Generation Detector - XLZD

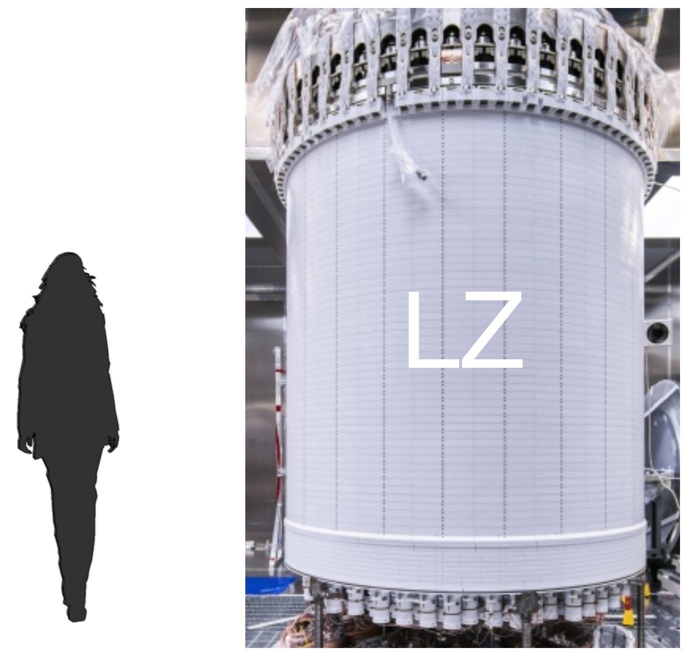
- Consortium of LZ, XENON & DARWIN, foremost xenon-based DM experiments

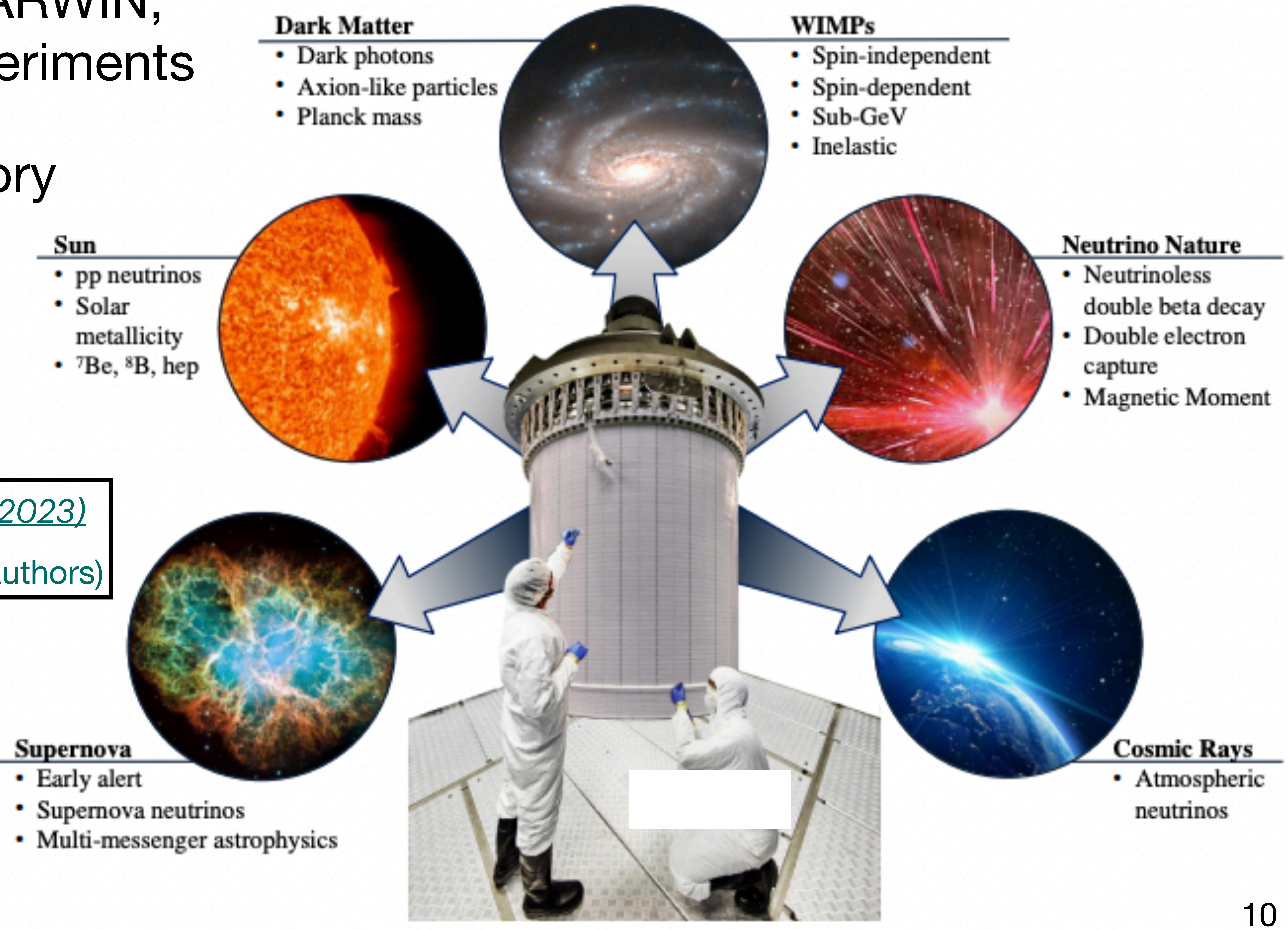
- 60 t xenon rare-event observatory
  ➡ High potential for neutrino astrophysics & double beta processes



[J. Phys. G 50, 013001 (2023)](https://doi.org/)

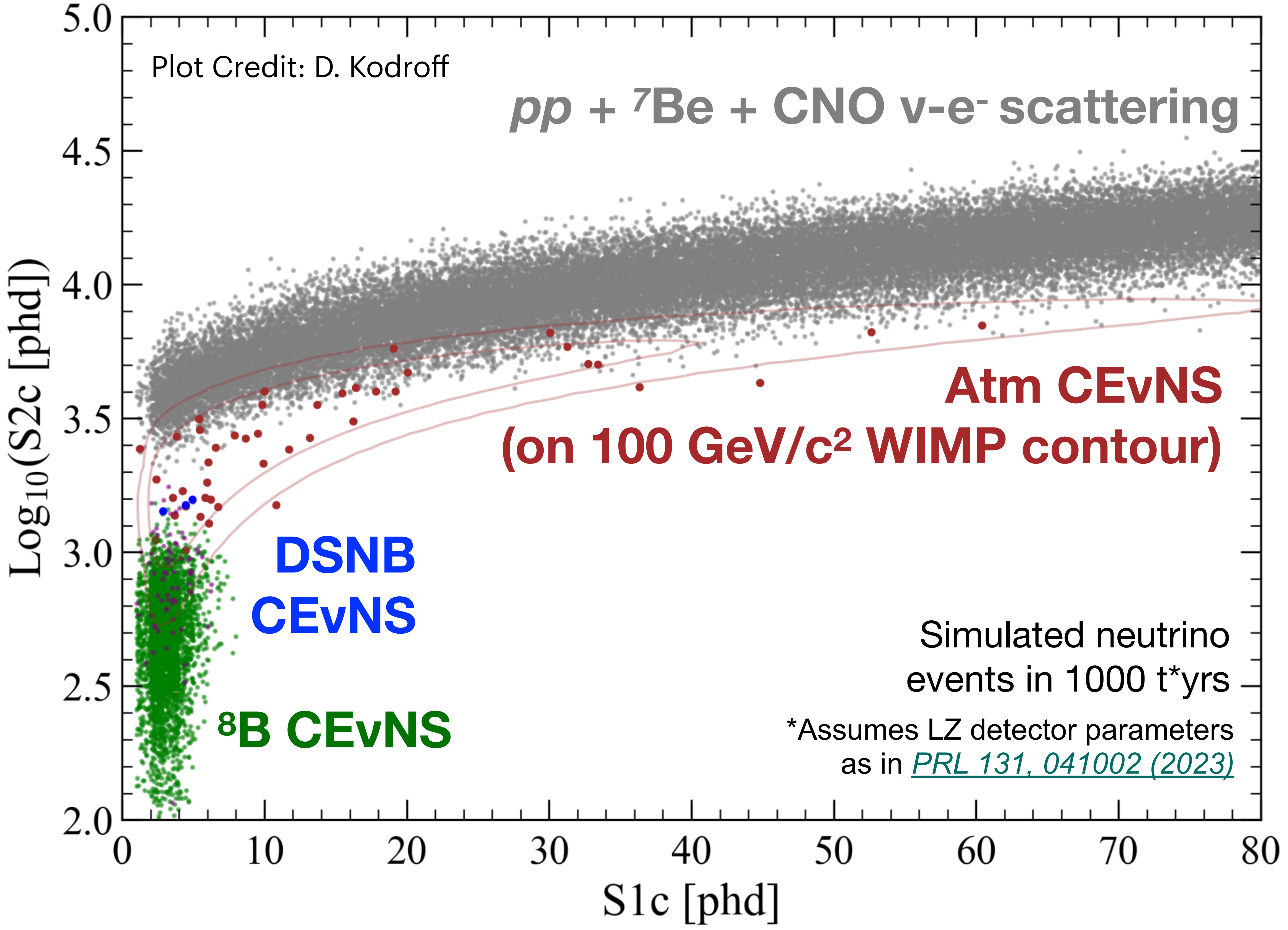
(White paper with ~600 authors)

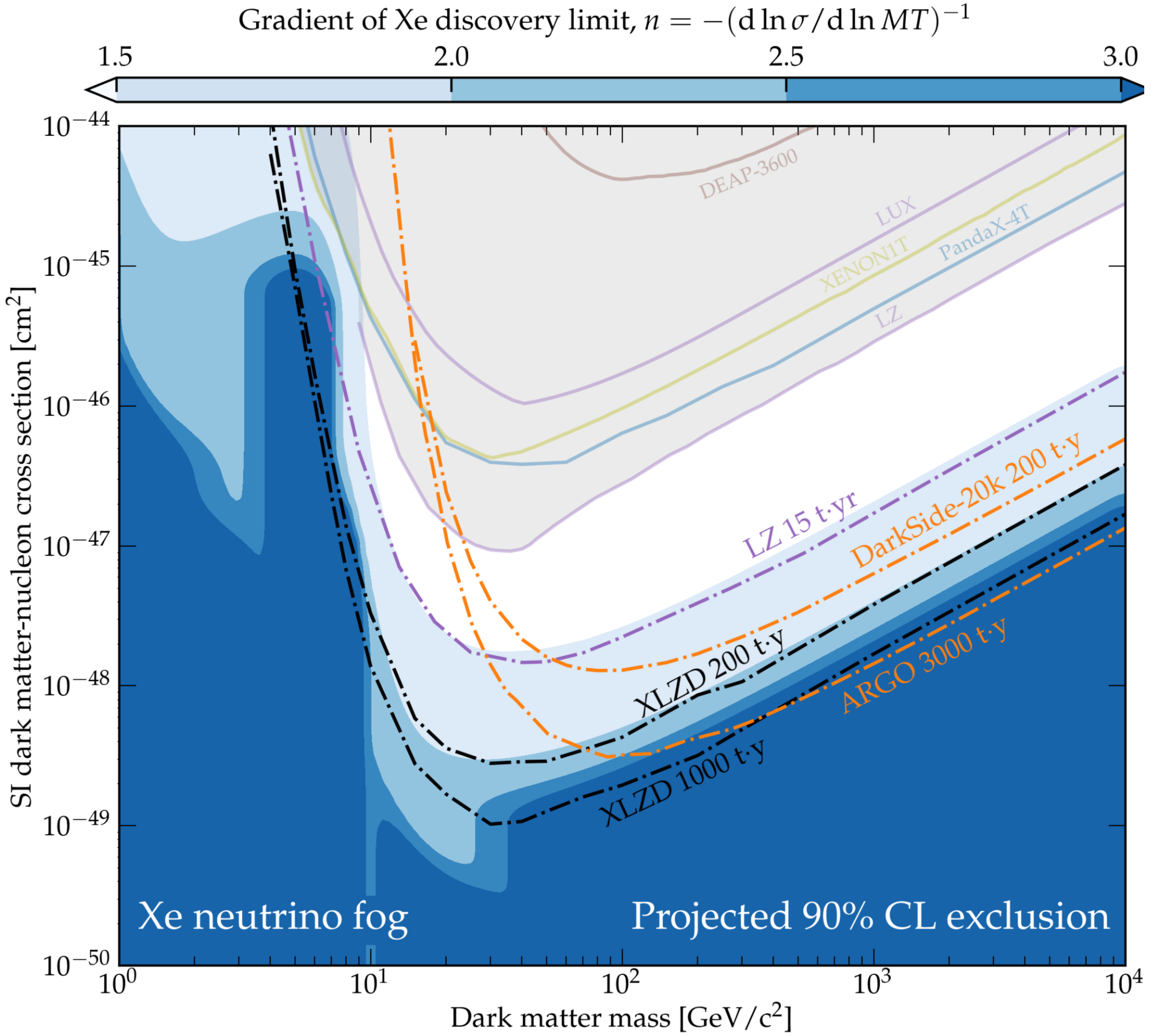




Neutrino Impact in XLZD

J. Phys. G 50, 013001 (2023)





- Atmospheric neutrinos present a new neutrino floor for WIMP searches
  ➡ provide first measurement of low-energy (<100 MeV) flux of these neutrinos
- Will maximise ER channel reach by pushing to sub-*pp* ^{222}Rn levels (~0.1 μBq/kg)

Solar Neutrinos

300 tonne*year exposure would give uncertainties on neutrino fluxes of

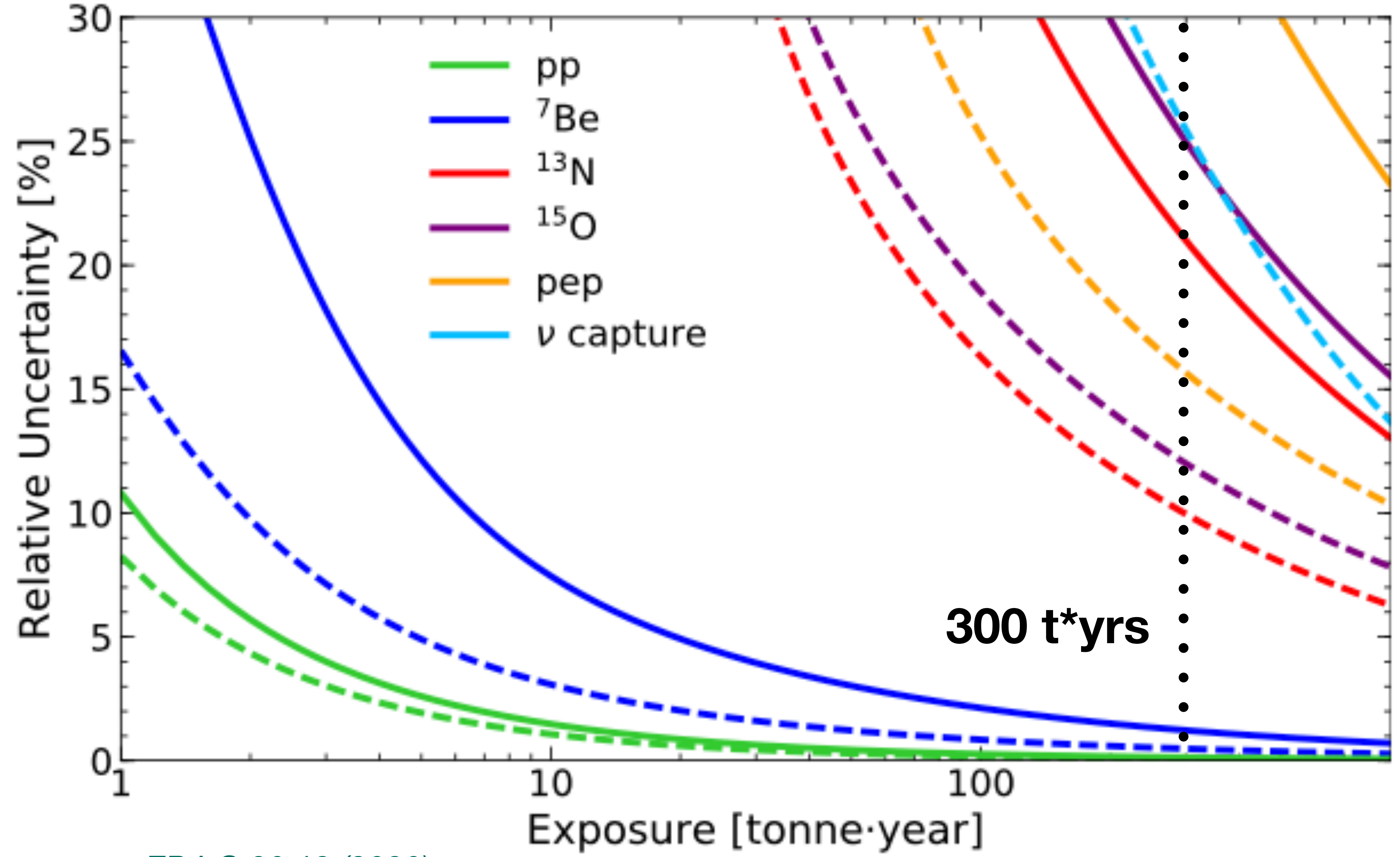
- 0.15% *pp* & 1% on ^{7}Be

➡ Constrain neutrino-inferred solar luminosity to 0.2% uncertainty

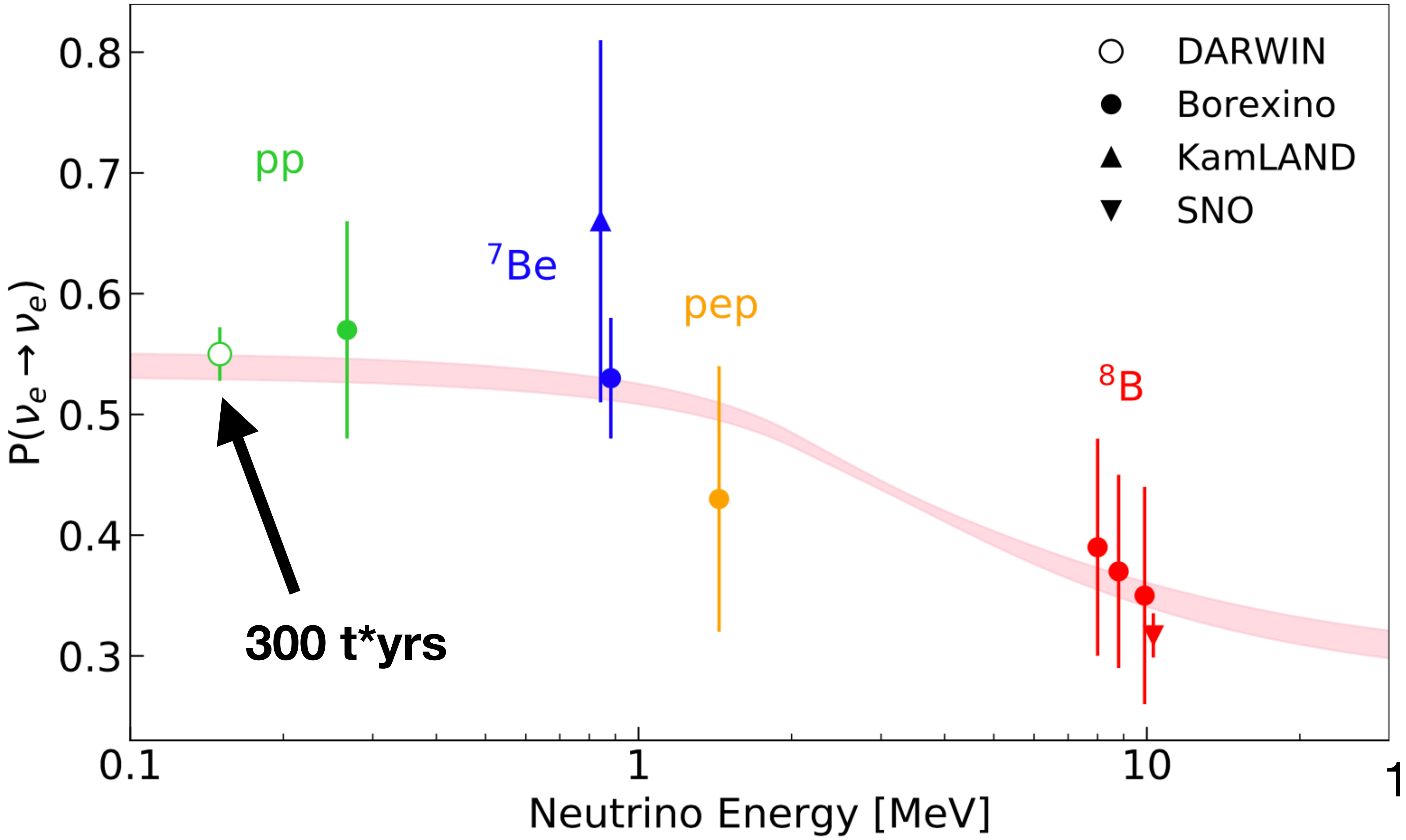
➡ First measurement of P_{ee} ($\sin^2\theta_W$) in <200 keV range to ~4 (5)% precision, testing LMA-MSW oscillation model

- ~25% on both ^{13}N & ^{15}O

➡ Inform solar abundance problem



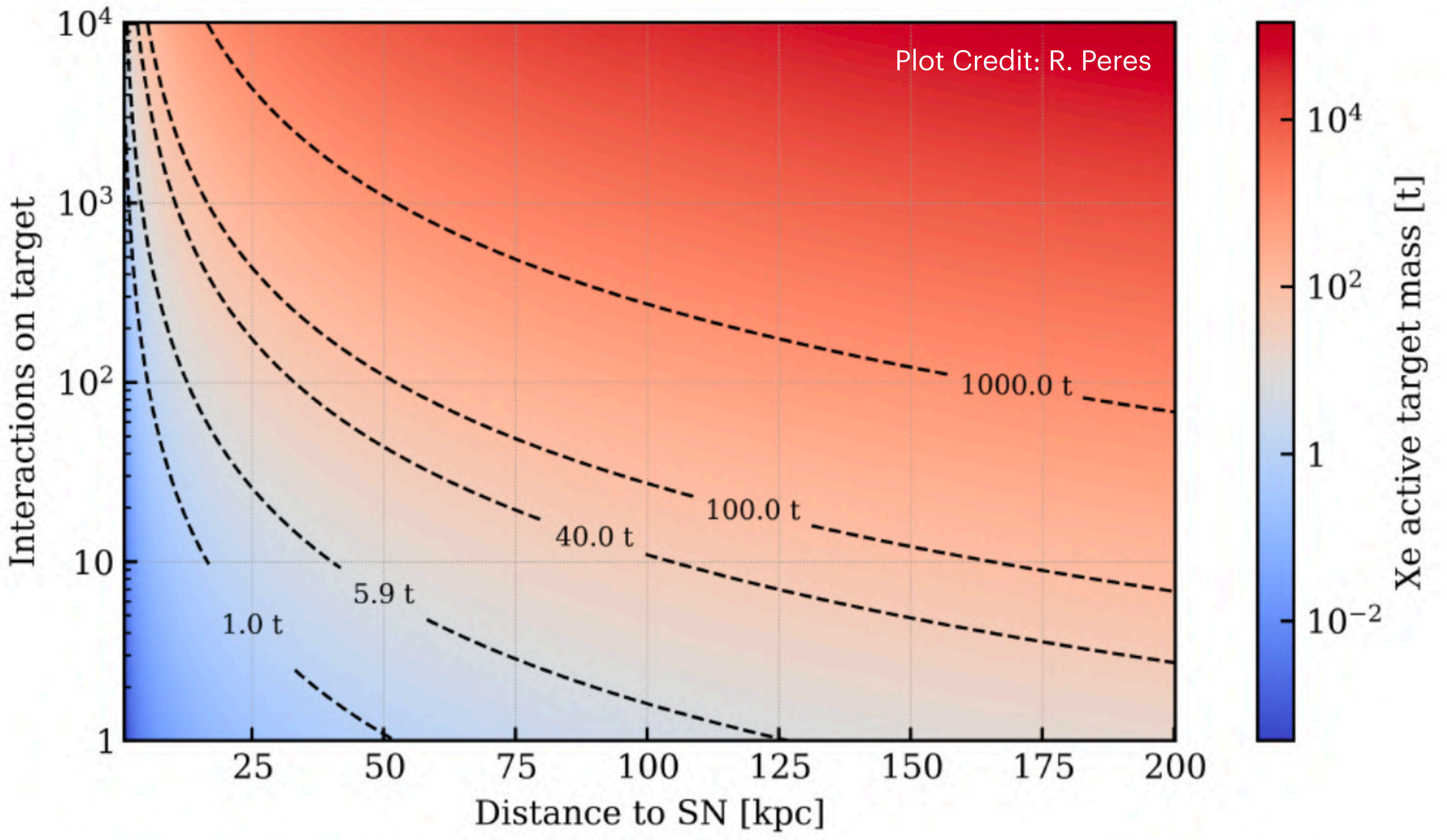
EPJ-C 80 12 (2020)

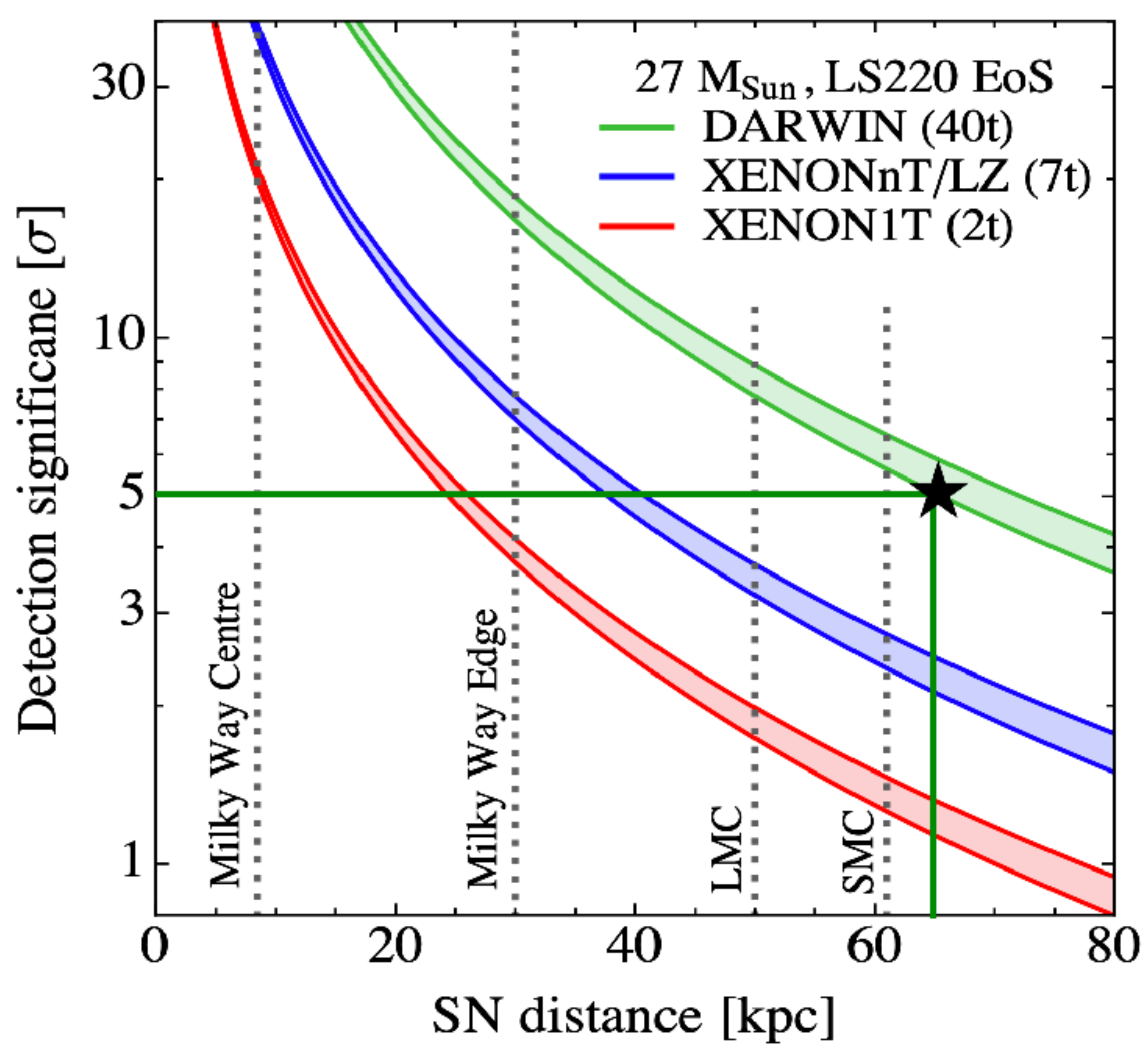


Supernova Neutrinos

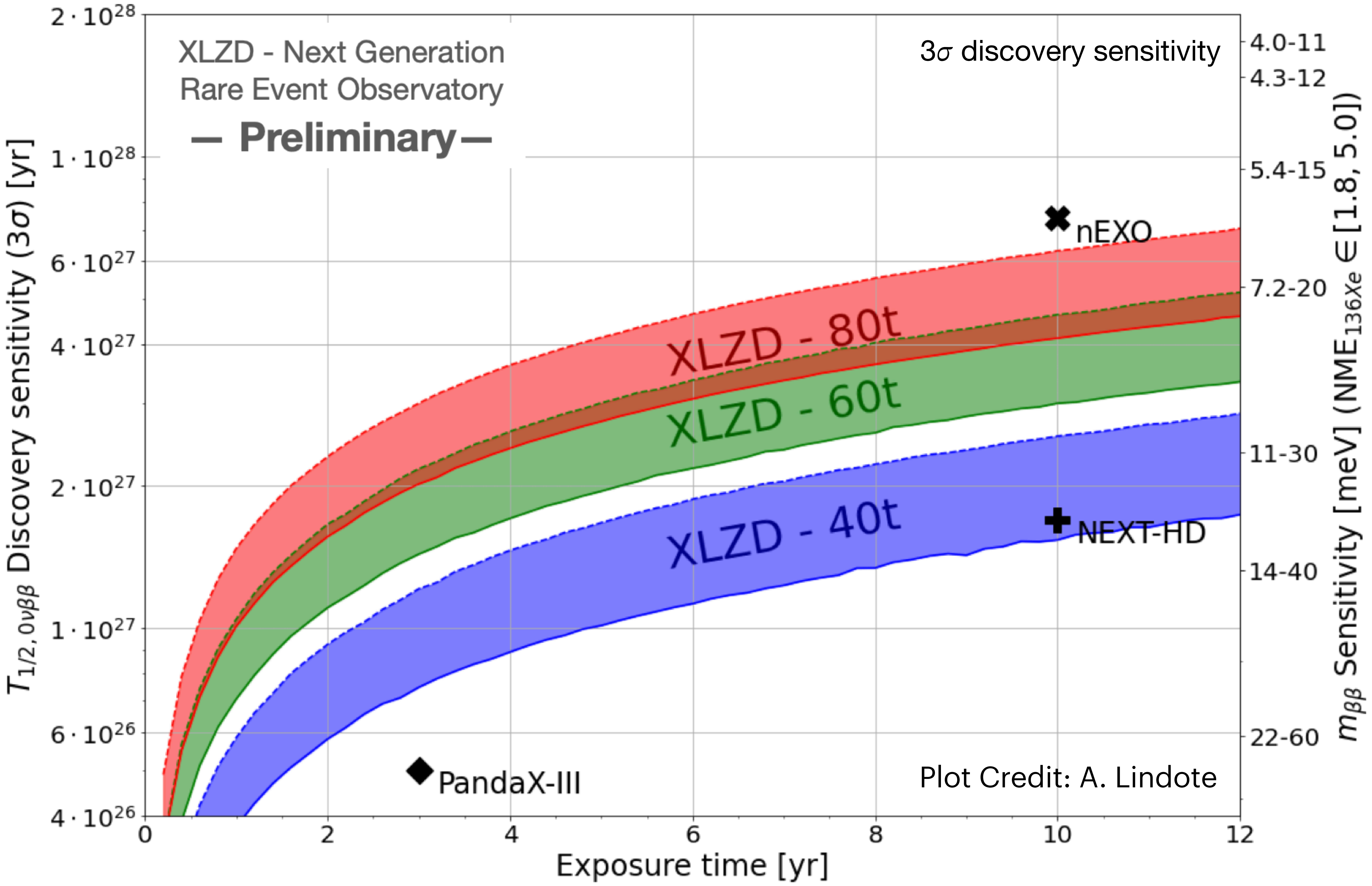
- Typical energy spectrum peaking at ~10 MeV, tail extending >50 MeV ➡ CEvNS
- ~1000 events (in 60 t) from 27 $M_\odot$ supernova at 10 kpc
- Planned participation in Supernova Early Warning System (SNEWS) 2.0

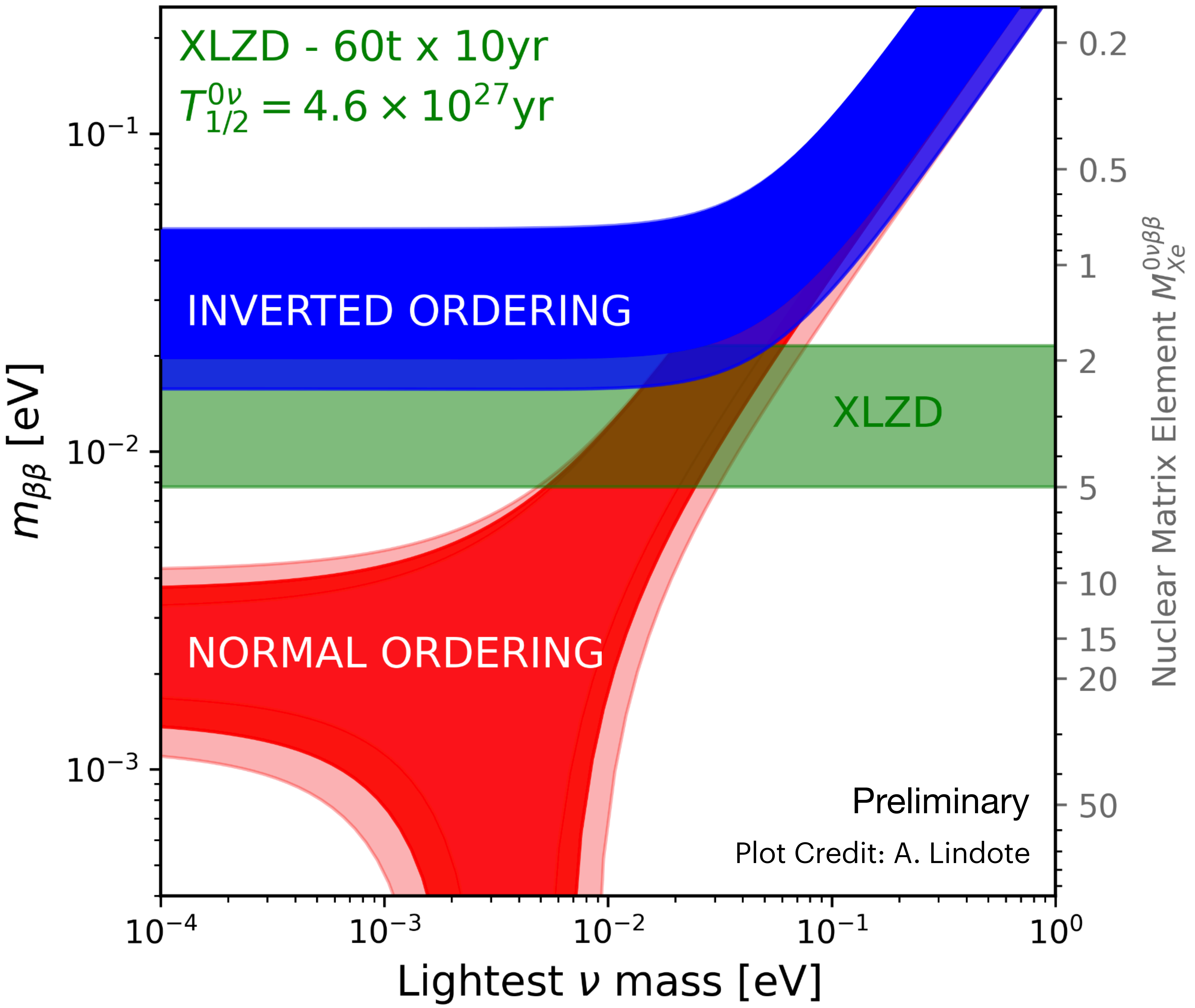
PRD 94, 103009 (2016)





^{136}Xe 0νββ Decay





- Sensitivity driven by mass (5.3 t), energy resolution (<1% at $Q_{\beta\beta}$), background control
- 10 years: probe the inverted hierarchy scenario for a broad range of NME predictions

Conclusions

- DM experiments can provide complementary measurements of solar, atmospheric and supernova neutrinos & their properties in the low-energy regime
  - Experiments approaching the neutrino floor have the potential to detect neutrinos with CEvNS ➡ **expect first ^{8}B CEvNS measurement with G2**
- XLZD, the G3 xenon DM experiment, will be built with neutrino physics in mind
  - Solar ν-e⁻ scattering can give important measures to inform solar neutrino luminosity, solar metallicity and test the LMA-MSW model
  - ^{136}Xe 0νββ decay can be competitively searched for, as can other second-order weak decay processes in other isotopes
- **XLZD could be coming to a place near you!** (Boulby Underground Laboratory)