A SURF Low Background Module for Enhanced Dark Matter and Neutrino Physics Searches

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at Lead/Deadwood Middle School

THE INSTITUTE

For Underground Science at SURF

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Acknowledgements

Snowmass2021 Whitepaper (e-Print: [2203.08821](2203.08821) [physics.ins-det]**)**

J.Phys.G 50 (2023) 6, 060502 (e-Print: [2301.11878](2301.11878) [hep-ex]**)**

Large Low Background kTon-Scale Liquid Argon Time Projection Chambers

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Overview

- **Concept of SLoMo as described in**
  Snowmass2021 Whitepaper (e-Print: 2203.08821 [physics.ins-det]**) and in**
  J.Phys.G 50 (2023) 6, 060502 (e-Print: 2301.11878 [hep-ex]**)**

- **Key idea: Radiopure underground argon (UAr) at kton scale from prospective commercial source**

- **Use outer large regular argon volume as shield and as a combined target for undisturbed long-baseline neutrino physics**

- **Better supernova detection efficiency (incl. 'CEvNS glow')**

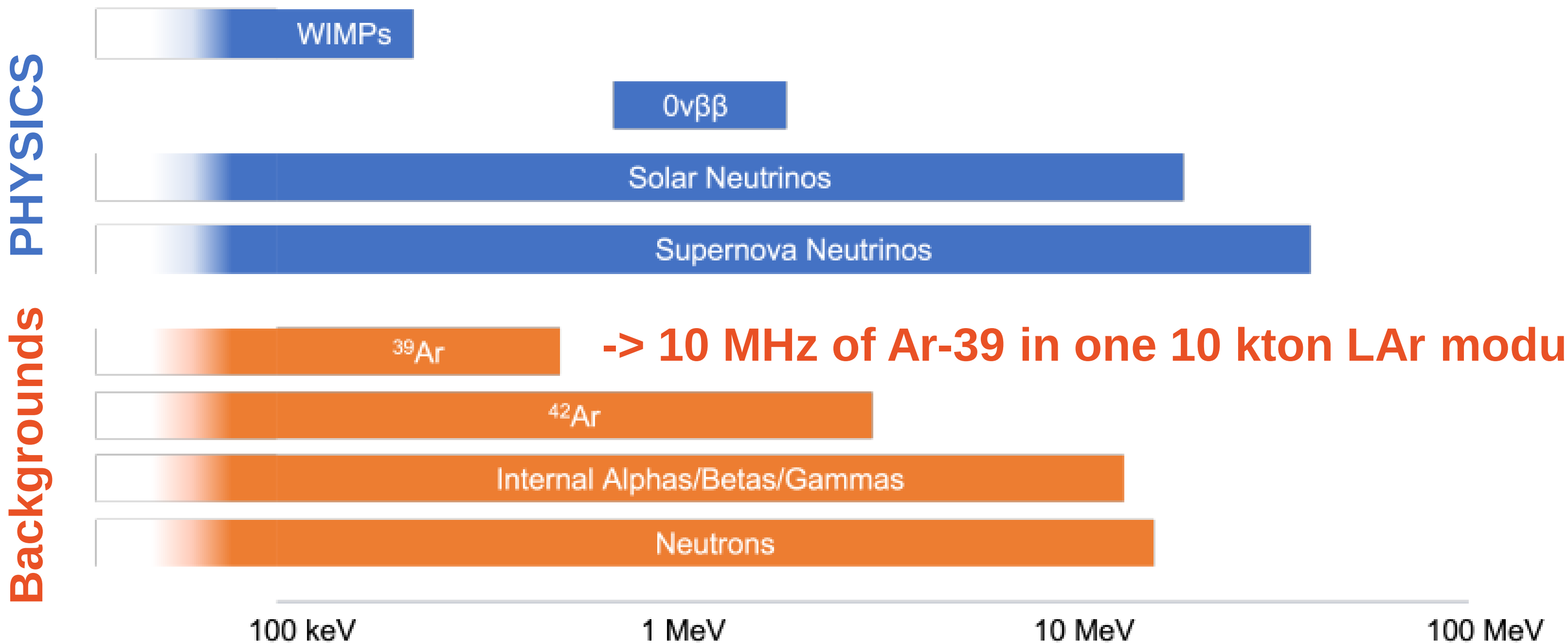
- **Precision solar neutrino physics possible (incl. NSI searches and resolve high- or low-metallicity)**

- **Competitive Dark Matter searches allowing for probing seasonal variation of galactic WIMPs (potential smoking gun for WIMP nature)**

- **Potentially 0nuBB searches at later stage with xenon doping**

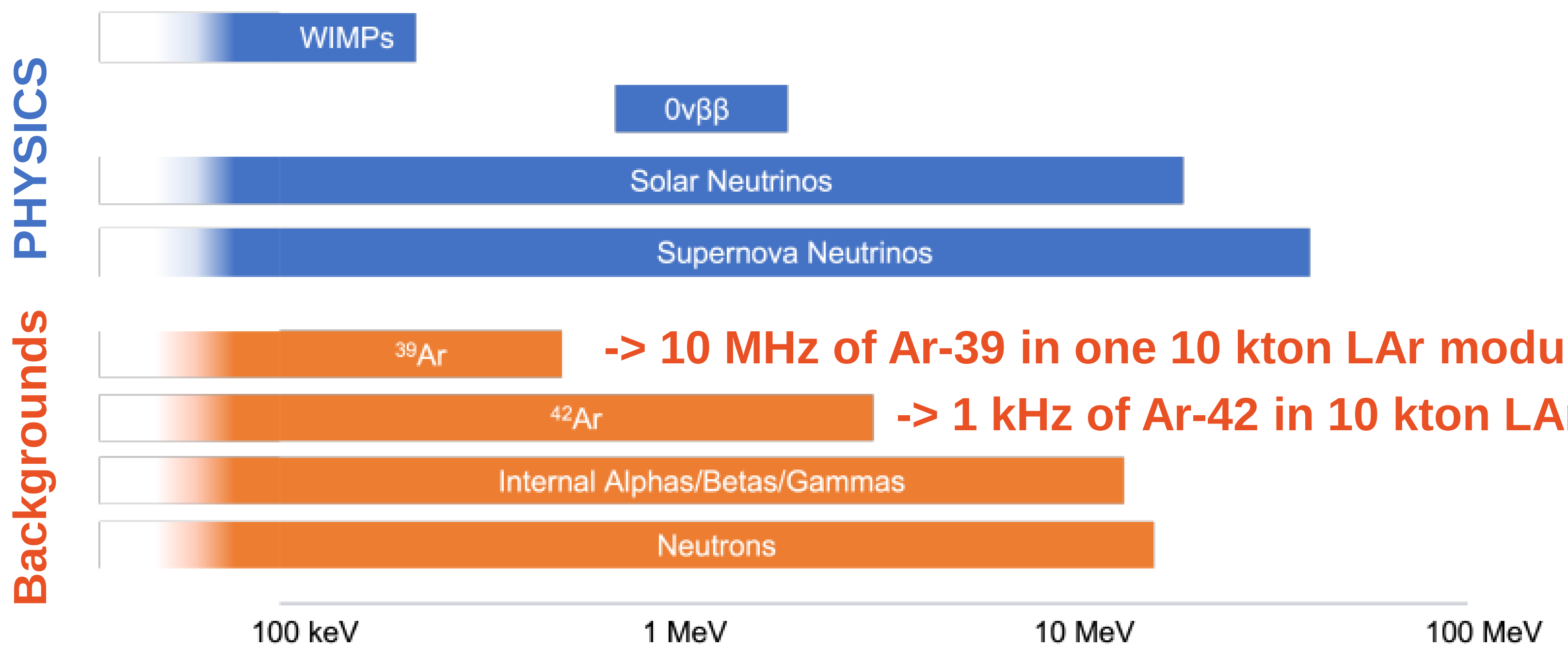
- **Additional Topics**

Key idea:
Radiopure underground argon (UAr) at kton scale



-> 10 MHz of Ar-39 in one 10 kton LAr module

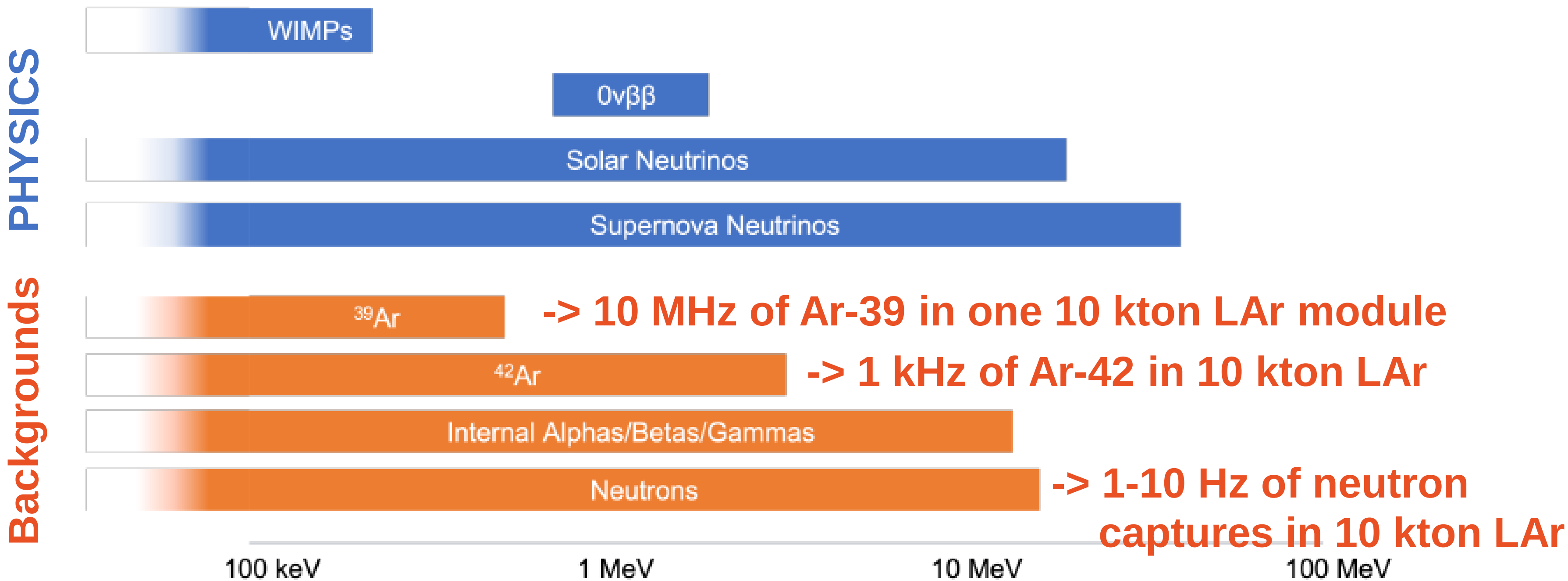
Key idea:
Radiopure underground argon (UAr) at kton scale



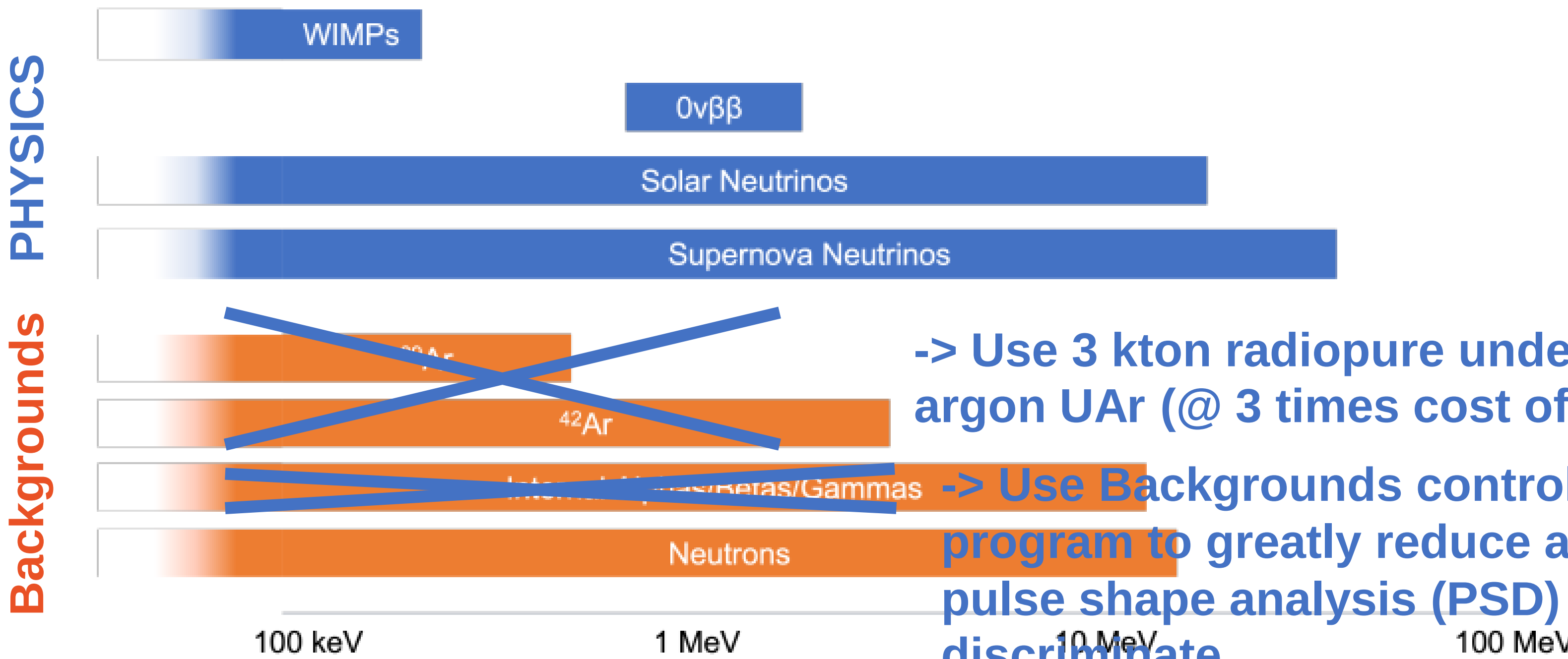
-> 10 MHz of Ar-39 in one 10 kton LAr module

-> 1 kHz of Ar-42 in 10 kton LAr

Key idea:
Radiopure underground argon (UAr) at kton scale



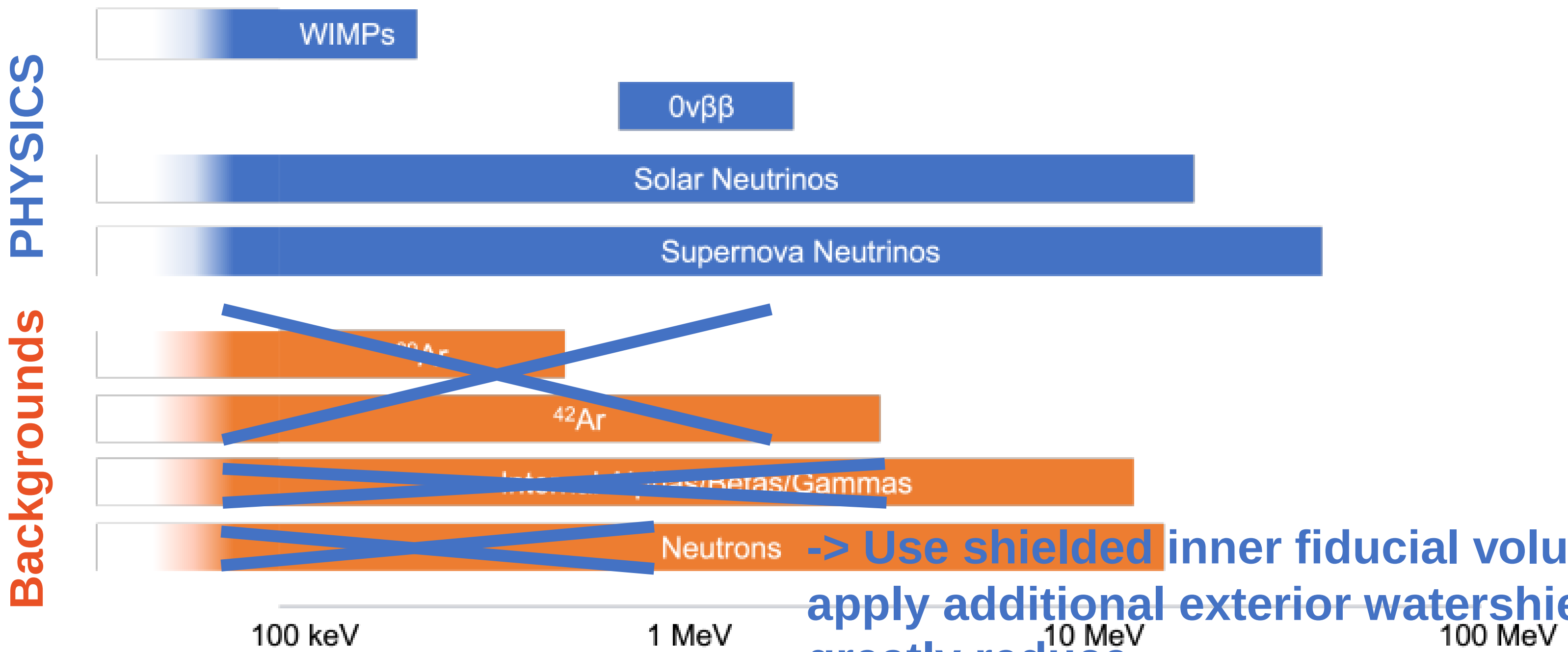
Key idea:
Radiopure underground argon (UAr) at kton scale



-> Use 3 kton radiopure underground argon UAr (@ 3 times cost of LAr only)

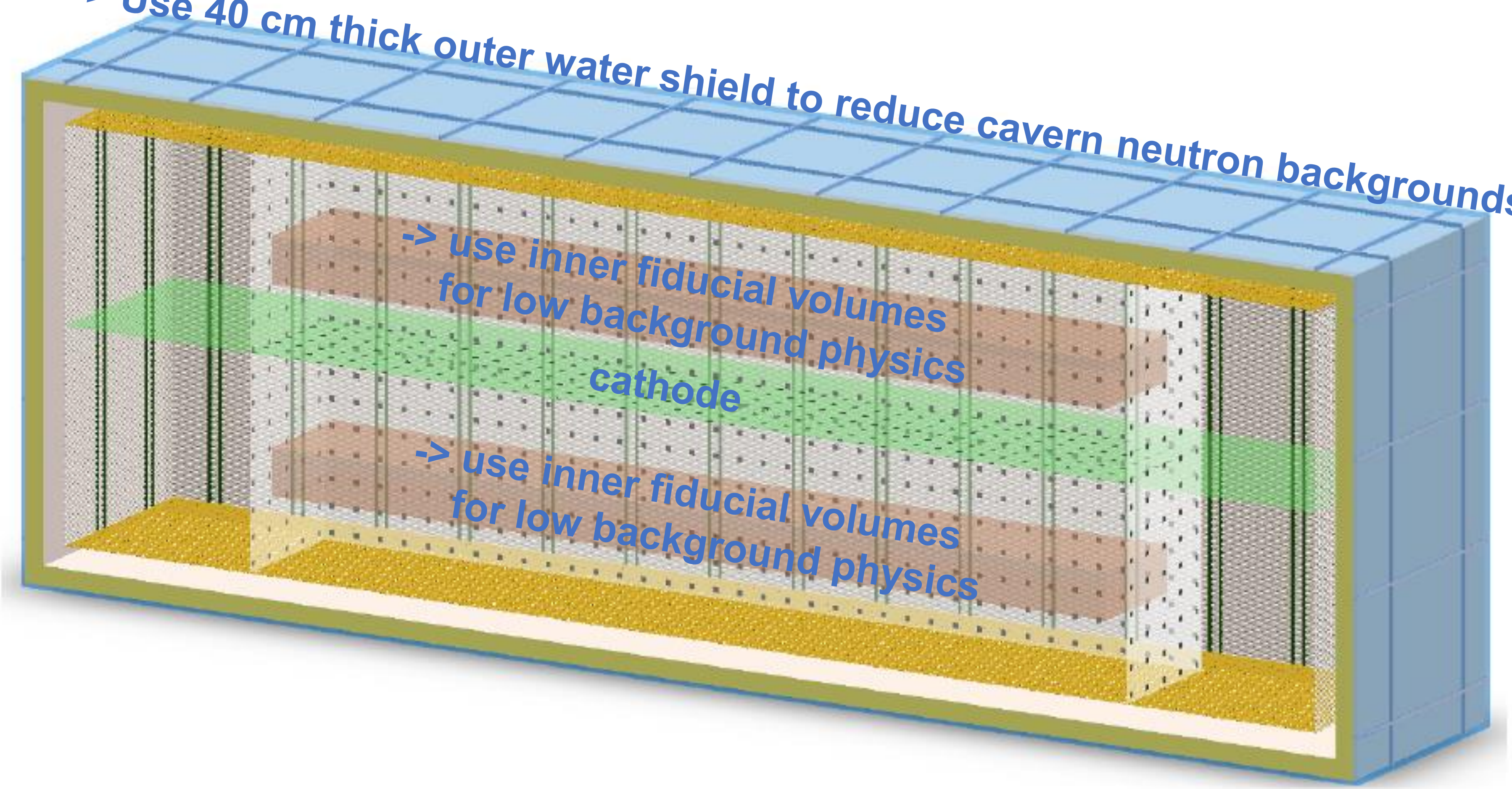
-> Use Backgrounds control program to greatly reduce and pulse shape analysis (PSD) to discriminate

Key idea:
Radiopure underground argon (UAr) at kton scale



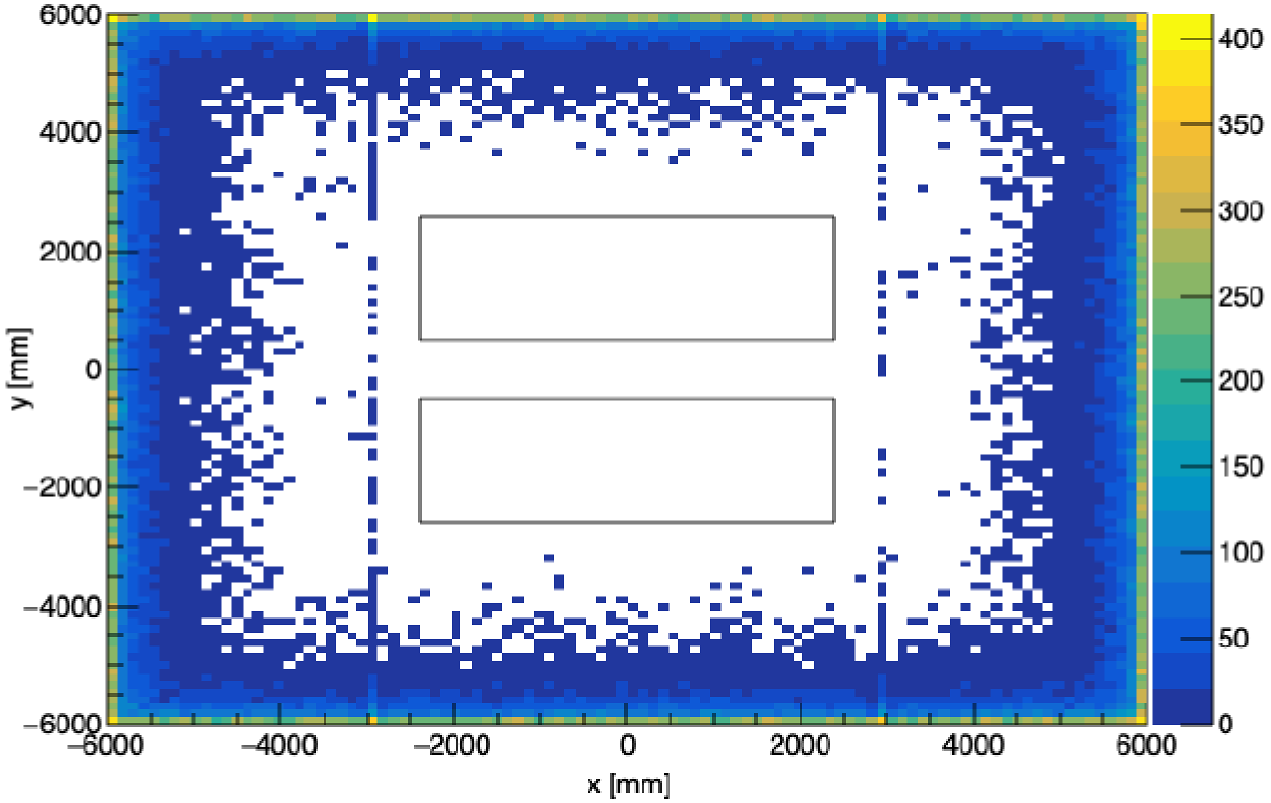
-> Use shielded inner fiducial volume and apply additional exterior watershield to greatly reduce

SLoMo Detector Concept
(DUNE-Like Vertical Drift w/ Cathode at Half-Height)



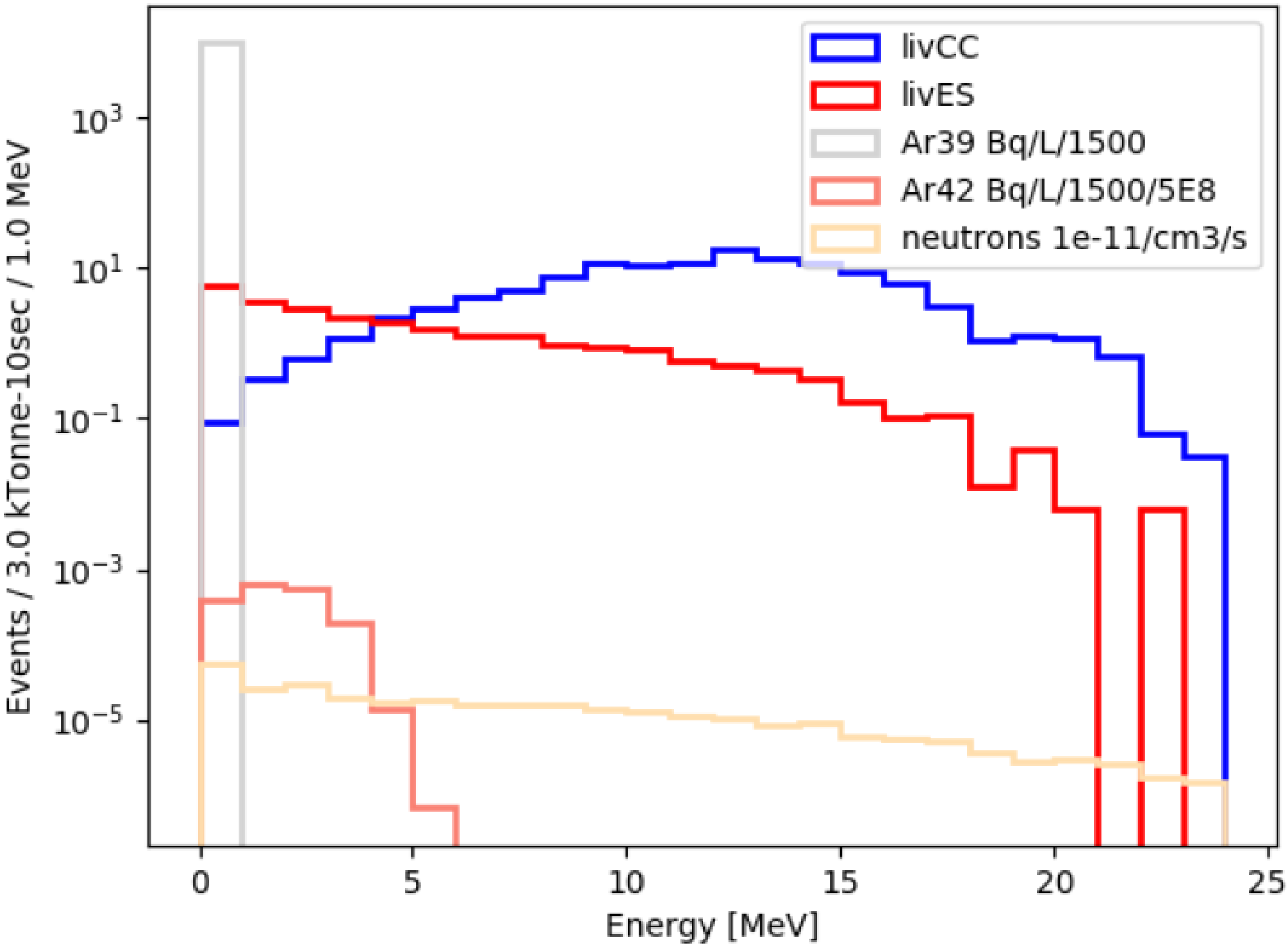
-> Use 3 kton radiopure underground argon UAr (@ 3 times cost of LAr only)
-> Use high light yield detection 100 pe/MeV
(SiPMs on optically segmented UAr volume walls)

Use Outer Large Regular Argon Volume as Shield and as a Combined Target for Undisturbed Long-Baseline Neutrino Physics



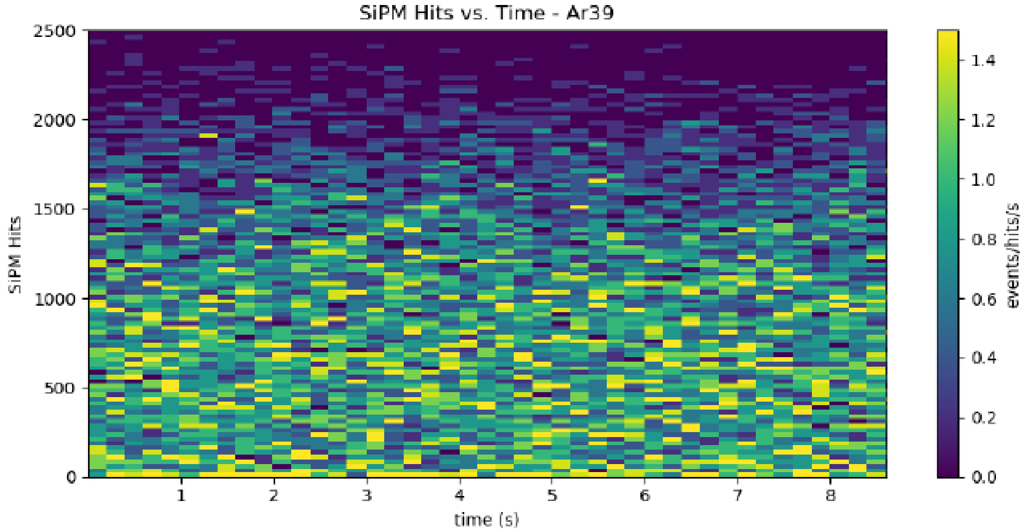
-> Use shielded inner fiducial volume and apply additional exterior watershield to greatly reduce exterior backgrounds (cavern/cryostat neutrons and γ's)

Galactic Supernova Detection in Shielded 3 kton UAr



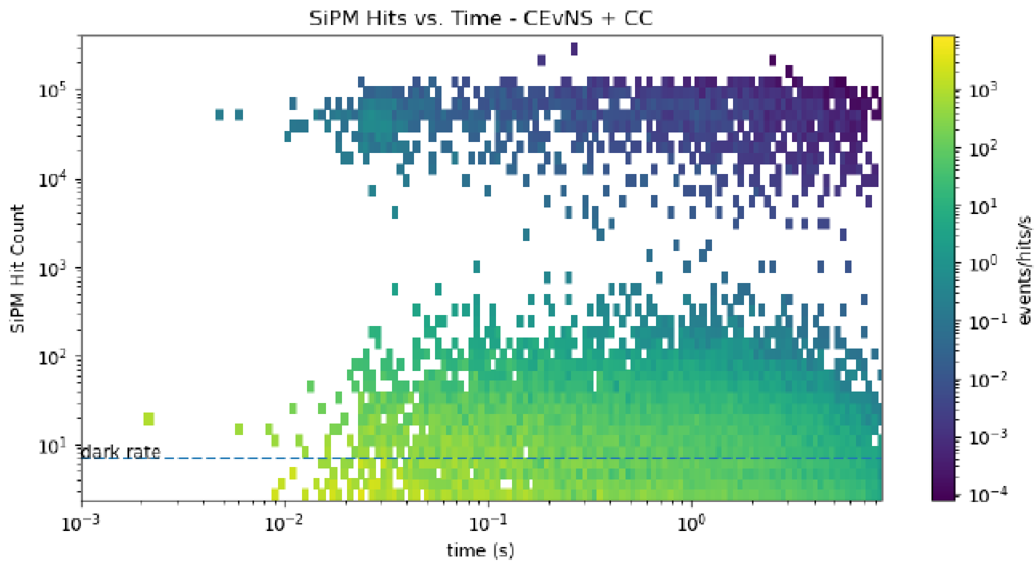
CEvNS Glow from Galactic Supernova Detection

atmospheric LAr



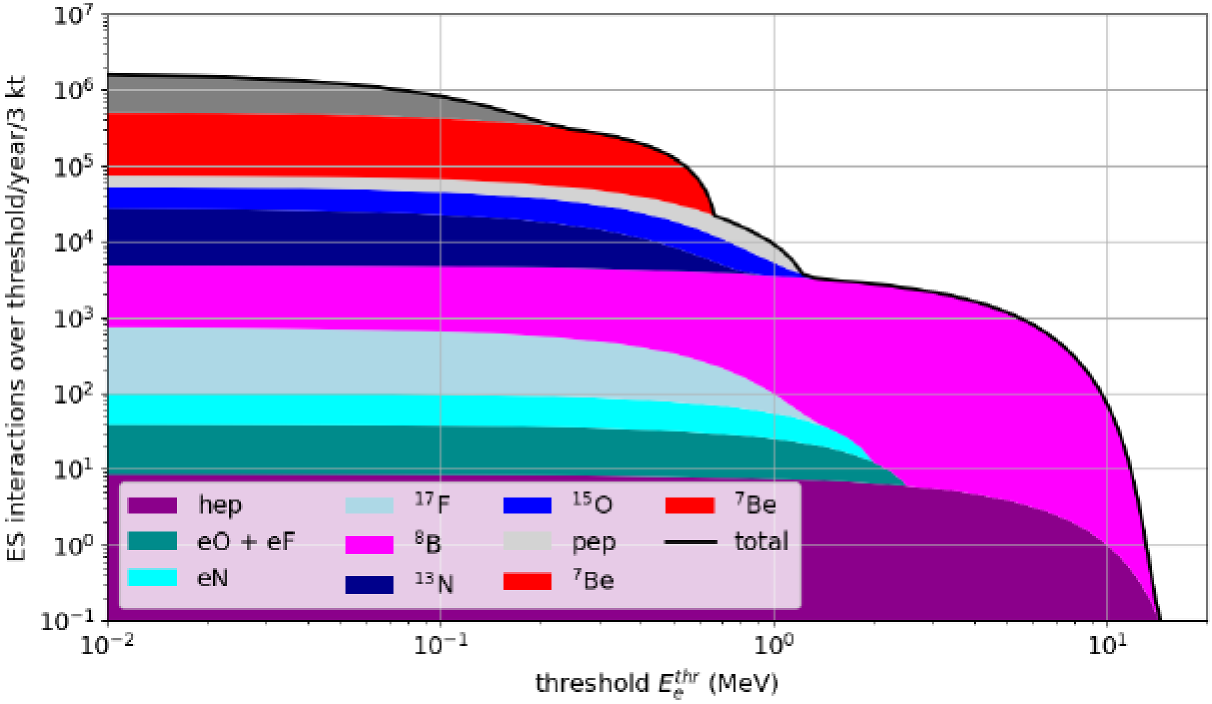
(a)

UAr allows to see CEvNS Glow!

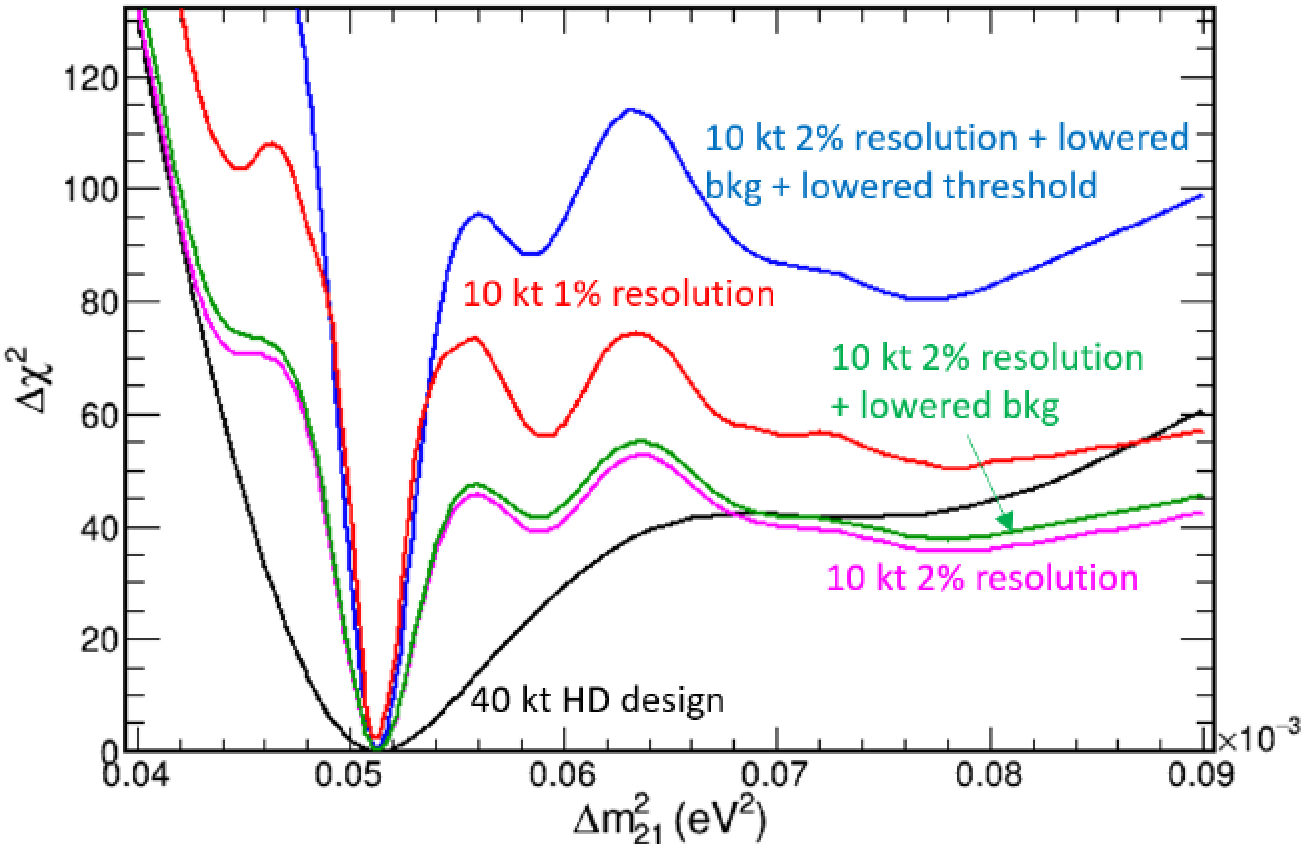


(b)

Solar Neutrino Physics: Spectral Rates in 3 kton as Function of Threshold



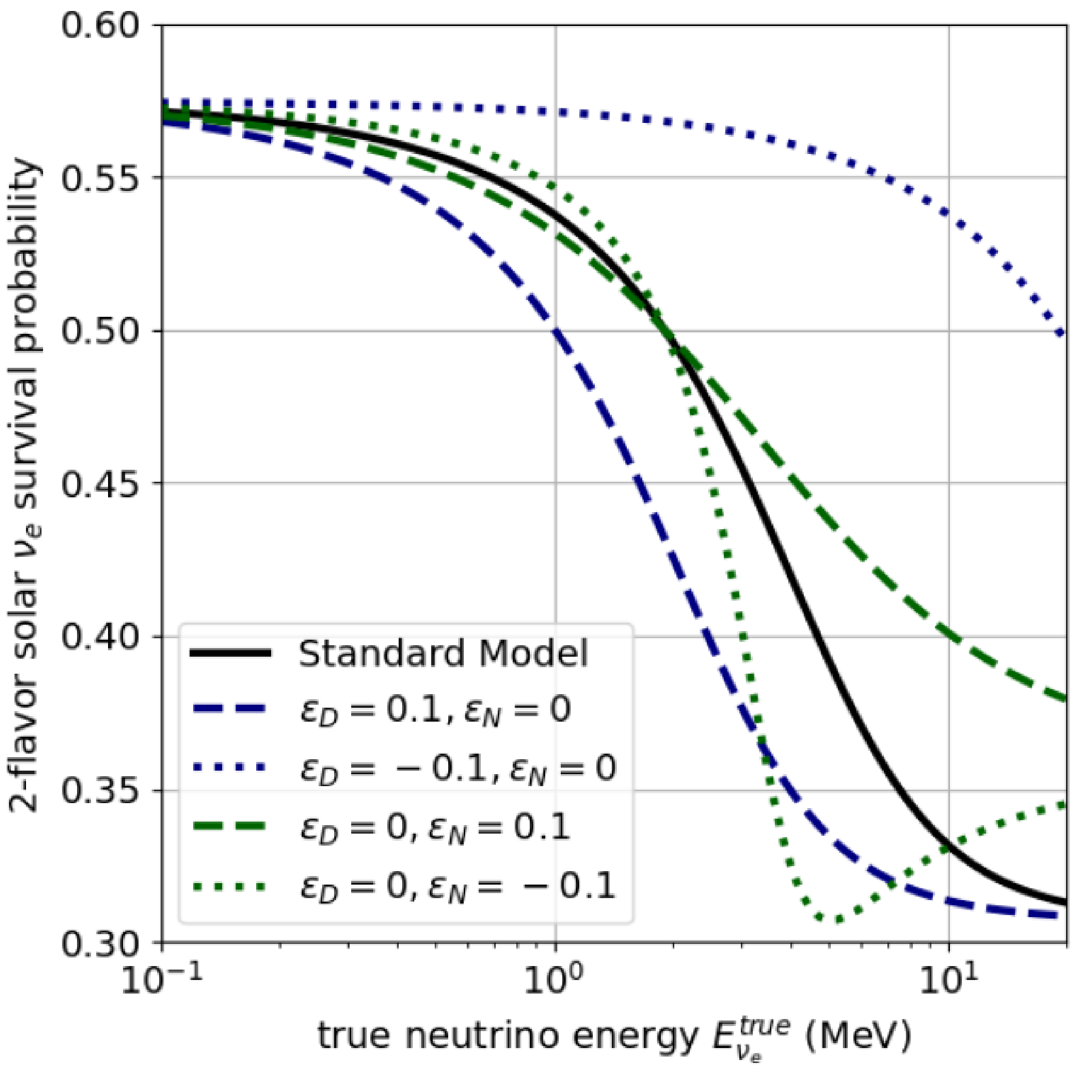
Precision Solar Neutrino Physics Possible



Improved Δm_{21}^2 measurements possible!

-> Interesting to compare to JUNO reactor neutrino results in future

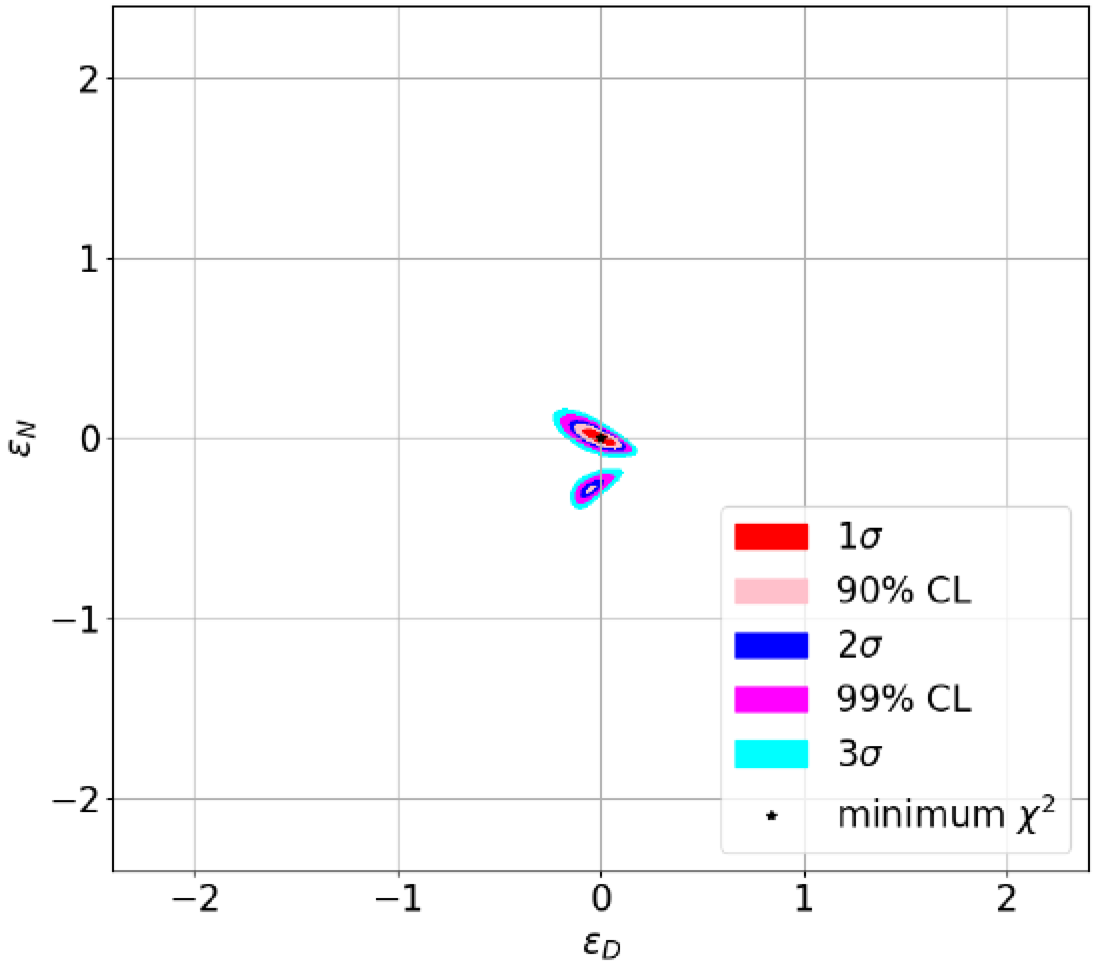
NSI Searches (NC) with Solar Neutrinos Possible (Resolution to Solar Neutrino Anomaly?)



$$H_\nu^{NSI} = \sqrt{2} G_F (n_u + n_d) \begin{pmatrix} -\epsilon_D & \epsilon_N \\ \epsilon_N^* & \epsilon_D \end{pmatrix}$$

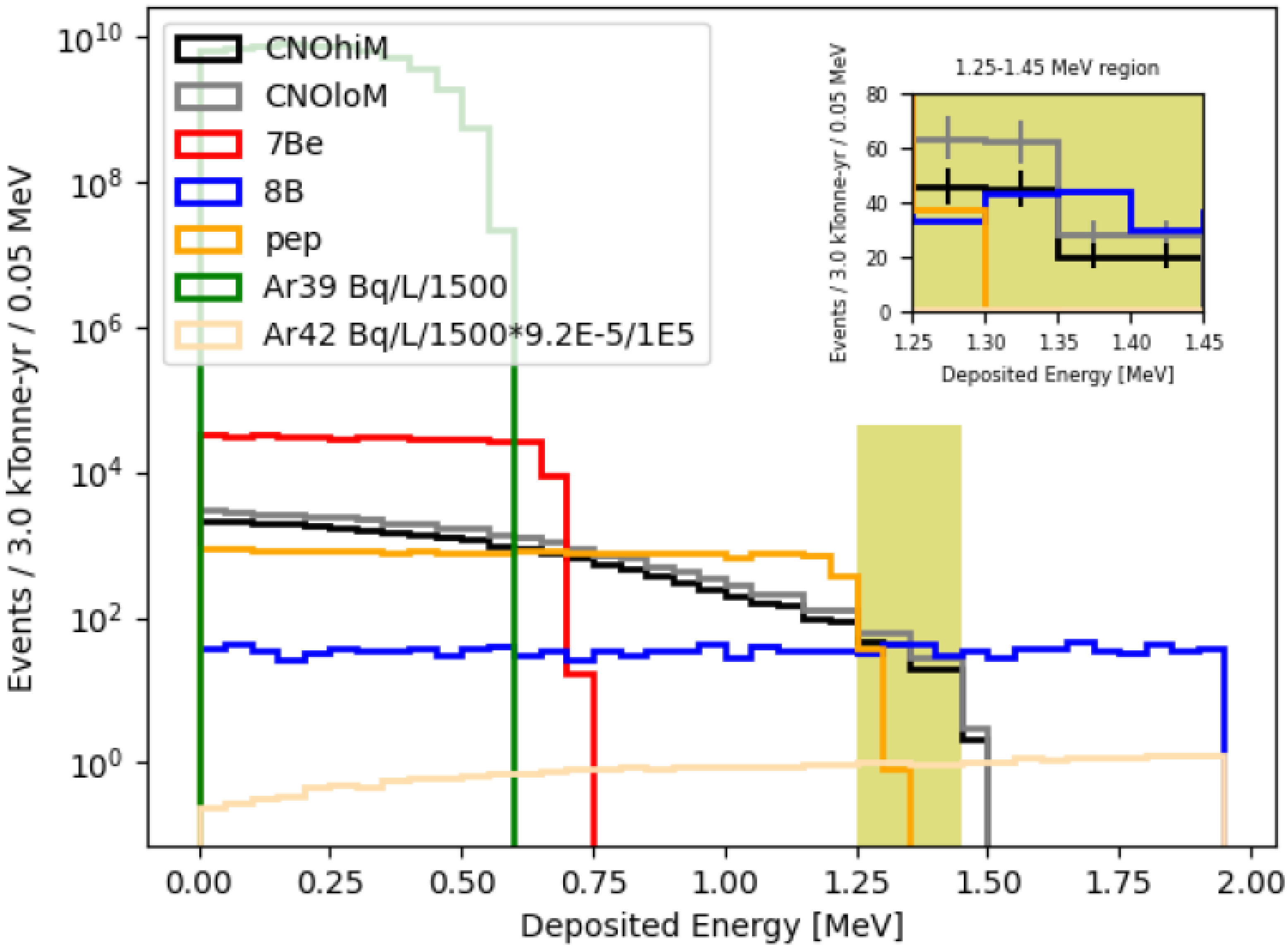
-> can replicate w/ good agreement KamLAND curve (reactor nu's)

Improve Constraints on NSI Parameters with Solar Neutrinos Detected in 3 kton X years UAr



$$H_\nu^{NSI} = \sqrt{2} G_F (n_u + n_d) \begin{pmatrix} -\epsilon_D & \epsilon_N \\ \epsilon_N^* & \epsilon_D \end{pmatrix}$$

Resolve High- or Low-Metallicity in Sun



Great Sensitivity for High Mass WIMPs:

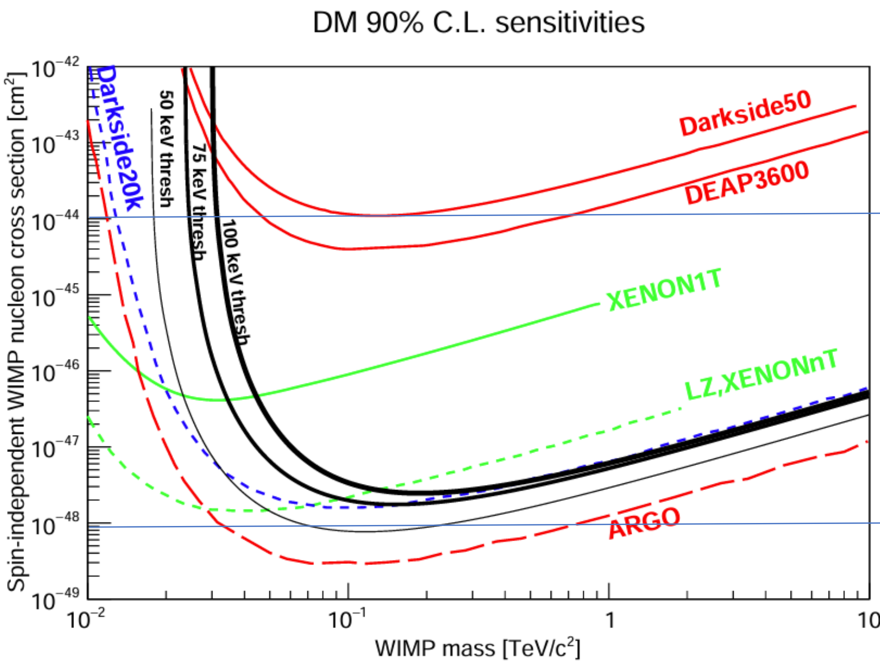
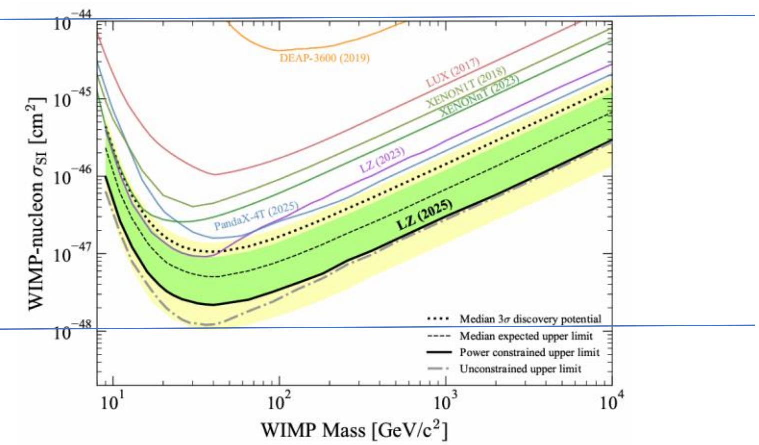


Figure 6. Shown are the achieved 90% c.l. sensitivities in solid colored lines for various experiments for WIMP Dark Matter searches [6, 12, 17]. Dashed lines for proposed argon [5] and xenon [21, 22] experiments are overlaid. The DarkSide-20k exposure is 20 tons over a planned 10 years for a total of 200 ton-yrs, while our proposal for a DUNE-like module is 3 years of a 1 kt mass for a 3 kt-yr exposure. The ARGO exposure is a planned 300 tons over ten years for a total of 3 kt-yr. Two possibilities for a DUNE-like module 4 for two thresholds and expected backgrounds, as discussed in the text, are shown in black lines. A third, aspirational, DUNE module 4 sensitivity for a 50 keV threshold is also drawn as a thinner line.

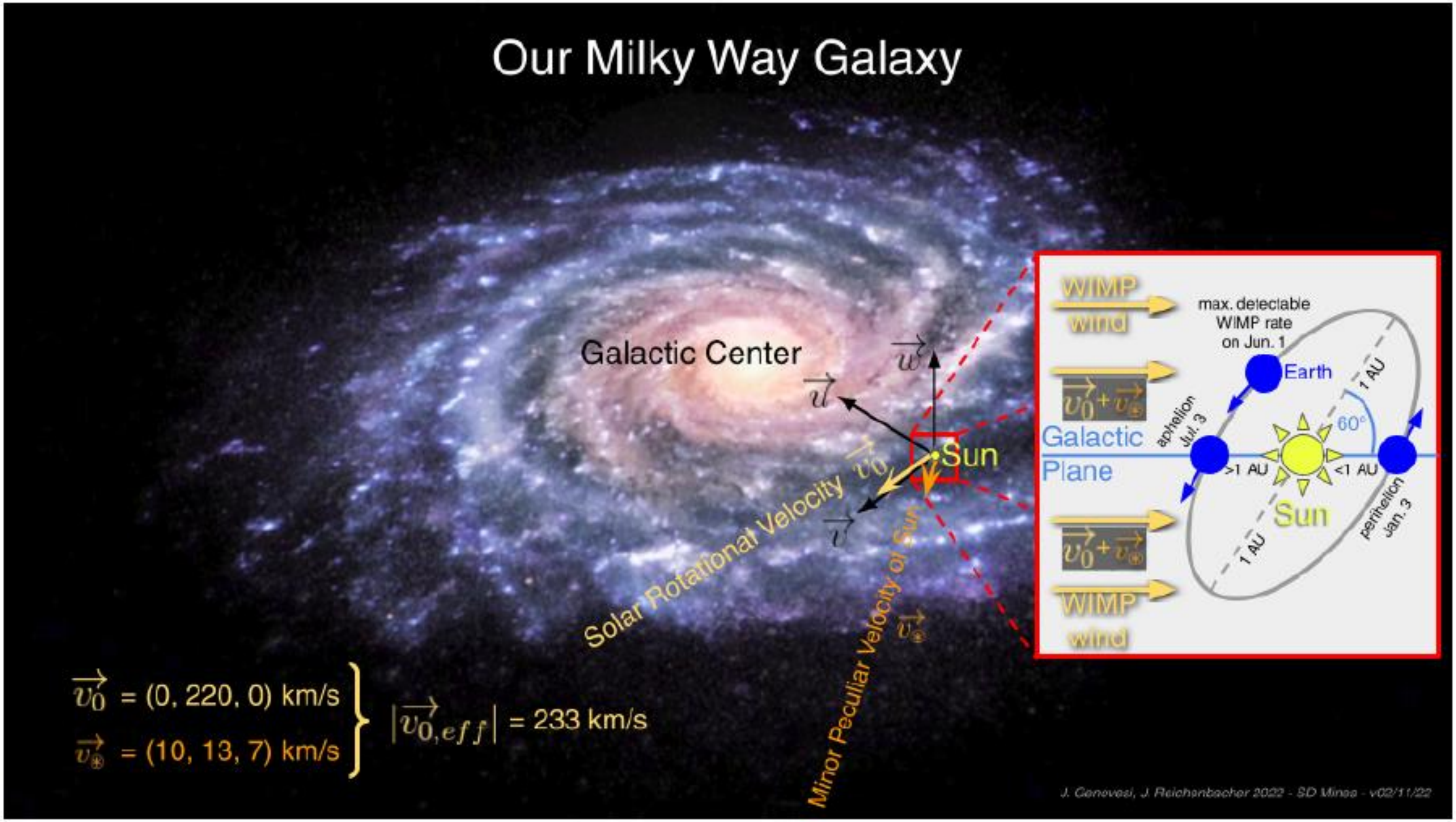


[Dark Matter Search Results from 4.2 Tonne-Years of Exposure of the LUX-ZEPLIN (LZ) Experiment](https://arxiv.org/pdf/2410.17036)
LZ Collaboration, Phys. Rev. Letters 2025-07-01,
https://arxiv.org/pdf/2410.17036

E. Church, C.M. Jackson, and R. Saldanha.
'Dark matter detection capabilities of a large multipurpose liquid argon time projection chamber'.
Journal of Instrumentation, 15(09):P09026, Sep 2020

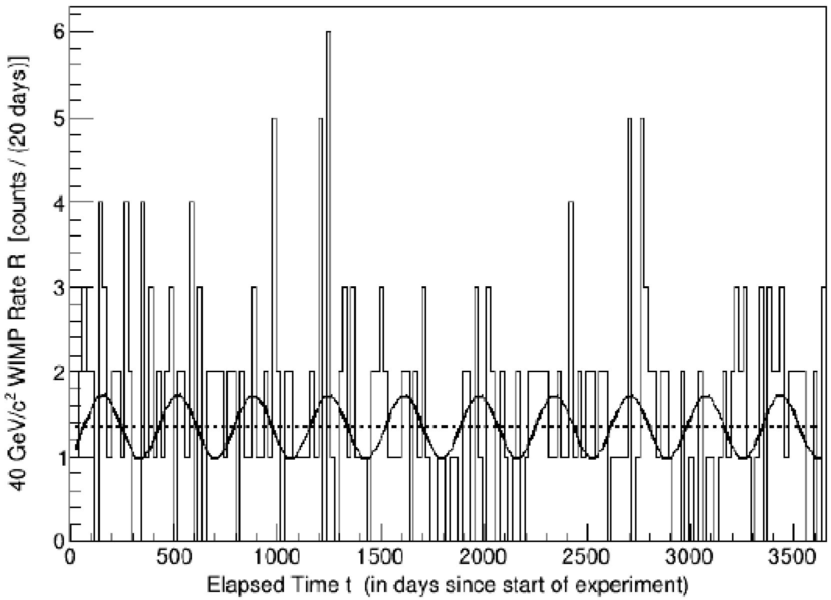
https://iopscience.iop.org/article/10.1088/1748-0221/15/09/P09026/pdf

Competitive Dark Matter Searches Allowing for Probing Seasonal Variation of Galactic WIMPs



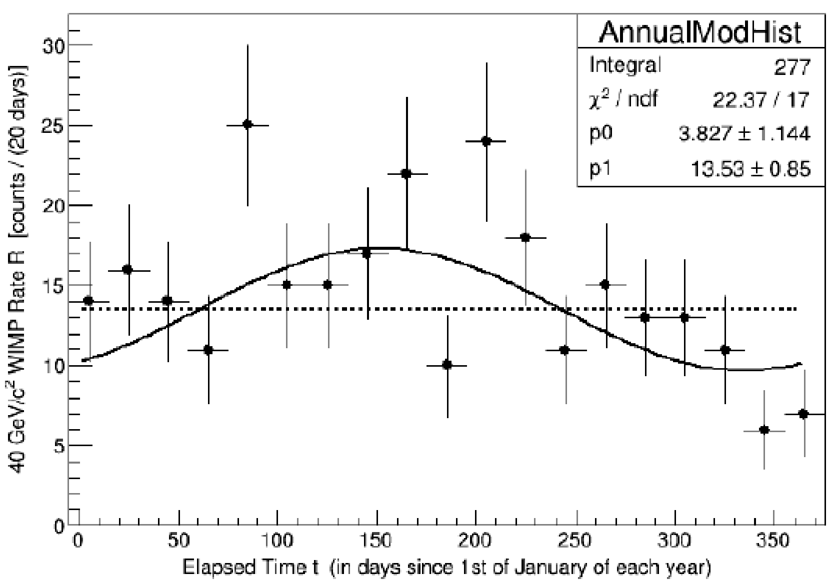
-> Rate can e.g. go up when going faster into galactic WIMP wind or vice versa (depends also on WIMP mass, form factor, and E_NR threshold of 50 keV)

Potential Smoking Gun for Galactic WIMP Nature:



$$\frac{dR}{dE_R} = \sigma_N^{SI} \frac{A^2 m_A N_T \rho_\chi}{2 m_\chi \mu_N^2} F^2(E_R) \int_{\nu_{min}(E_R)}^{\infty} \frac{d^3\vec{\nu}}{\nu} f_\oplus(\vec{\nu}, \vec{\nu_{obs}})$$

$$R(\,[d^{-1}]\,) = A\,[d^{-1}] \times \cos\left(\frac{2\pi}{T[d]} \times (\,t[d] - t_{June1}[d]\,)\right) + R_{avg}\,[d^{-1}]$$

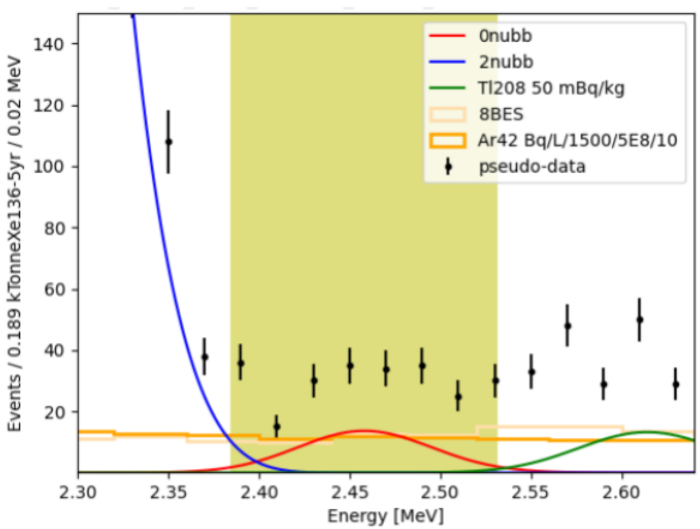


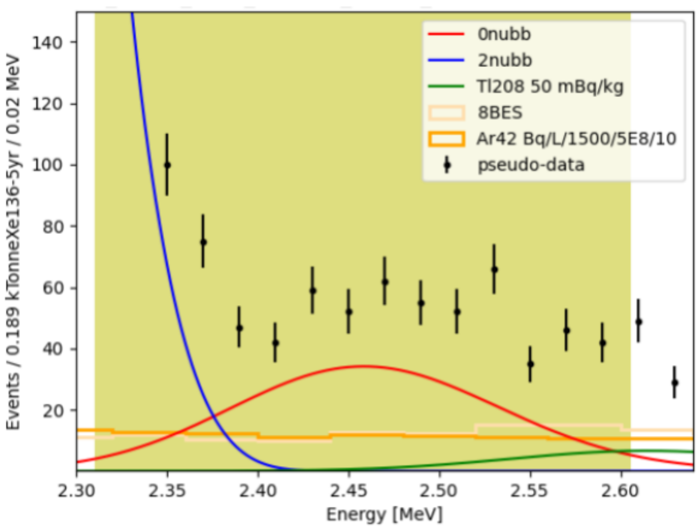
-> need with x-section of 4x10^-48 cm^2 and 40 GeV WIMPS already ~kton targets to be able to observe potentially the annual modulation after a decade!

-> argon with lower mass enhances effect compared to xenon

-> assumes E_NR threshold of 50 keV and no backgrounds (perfect PSD)

Potentially 0nuBB Searches at Later Stage with Xenon Doping





-> xenon in argon forfeits PSD of backgrounds

-> no DM search possible anymore

-> use xenon doping only in later stage (takes cumulative world production of xenon also a long time to get to kton target mass ;-)

Additional Topics

- **CEvNS detection of atmospheric neutrinos (background check for dark matter experiments)**
- **Strangelets (potential cleaner signature for search in LAr with UAr)**
- **Charged micro-black holes and Superheavy dark matter**

Acknowledgements

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