Future liquid xenon-based dark matter searches Marc Schumann University of Freiburg

Nagoya workshop on future liquid noble gas detectors, 14.02.2024

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The indirect evidence for the existence of dark matter is a clear indication for physics beyond the Standard Model

We are here ... "We" are here ... moving through the Dark Matter Halo

made of ???





Direct WIMP Search





Direct WIMP Search





Direct WIMP Search





The WIMP Parameter Space



Reaching the neutrino fog



Exclusion vs. Detection



1000 t×y: probe entire mass range ≥10 GeV at 3σ evidence universitätfreiburg M. Schumann – Future LXe-based DM searches

Background Requirements



Backgrounds must be dominated by irreducible neutrinos ER: pp, ⁷Be NR: ⁸B, atmospheric

The LXe Family Tree



General Features of current Designs

- dual-phase TPC
 - → rely on experience from smaller "demonstrators"
- Target mass and background level aimed at neutrino floor
- Cylindrical target, light readout on top and bottom
- PMTs as light sensors
- Drift field >100 V/cm (ideal: 250-290 V/cm) LUX: PRD 102, 112002 (2020)
 - \rightarrow 30-100 kV on cathode for 3 m drift
- Staged approach in line with Xe procurement
- Neutron veto





DARWIN Dark matter WImp search with liquid xenoN



DARWIN



PandaX-xT

arXiv:2402.03596

Proposal to upgrade PandaX-4T at CJPL



43t LXe in target, 34.2t fiducial

XENON + LZ + DARWIN =

- Preparation of merger of DARWIN / XENON + LZ collaborations to build and operate the next-generation LXe observatory
 - \rightarrow new, stronger collaboration
 - \rightarrow P5 recommendations for G3 detector positive (US)
- Currently: paving the way with XLZD Consortium
 - → MoU 2021: 104 group leaders from 16 countries
 - → joint whitepaper, workshops (2022 KIT, 2023 UCLA, 2024 RAL)
 - → common WGs, regular SteCo meetings
 - \rightarrow preparing documents (detector, siting, etc)
- Preparing to form full collaboration









XLZD Strategy



Low-background dual-phase LXe TPC with nominal 60t target (54t fiducial mass)

System can be readily upgraded to 80t target if LXe market allows for faster acquisition rate

Siting decision currently being prepared. Five labs expressed interest: Boulby, Kamioka, LNGS, SNOLab, SURF



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DARWIN/PandaX ↔ XLZD: Science Reach



Common Challenges

- Sufficiently high drift field
- Dual-phase S2 electrodes
- Backgrounds
 - Rn emanation
 - neutrons (materials, veto)
 - avoid contaminations
 - accidental coincidences
- Size
 - mass (\rightarrow background) vs. stability
 - Thermal contraction
- Photosensors
 - background
 - low DC rate
- Xenon procurement





What can we do with such an amazing Instrument?

nb: I often show results from smaller LXe detectors for illustration. In general, all channels explored by smaller detectors can also be studied with larger instruments. And I have easier access to XENON results...

LXe Whitepaper



~600 authors

from DARWIN.

XENON, LZ

+ theory

~100 institutions

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

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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

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LXe Whitepaper

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

Spin-Dependent WIMP Couplings JCAP 10, 016 (2015)

Isotope 7 Li

Abundance

92.6%

Spin

3/2

Unpaired Nucleon

proton

Relative Strength

12.8

100.0

1.3

9.7

0.3

0.3

1.7



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coupling of WIMP to unpaired nucleon spins

Standard Analysis



Charge-Only Analysis





Charge-Only Analysis PRL 123, 251801 (2019)

spin-independent WIMP-nucleon interactions 10^{-32} LUX (M) 10^{-34} 10⁻³⁶ ENONIT (M) EDELWEISS (Surf) with Migdal 10^{-38} Cross Section [cm] NEWS-G effect CRESST-III DAMA/I 10⁻⁴⁰ DAMIC DAMA/Na COSINE-100 **CDMSlite** DarkSide-50 (S2) 10⁻⁴² SuperCDMS DarkSide-DEAP-3600 **EDELWEISS** XENON1T (S2 XENON100 10^{-44} 10⁻⁴⁶ 10^{-48} 10-50 日 0.1 0.30.5 10 30 50 100 300 10^{4} 1 3 5 1000 3000 WIMP mass $[GeV/c^2]$ some results are missing...

WIMP-e⁻ Scattering



Very light DM scatters off electrons

Detectors with single-e⁻ sensitivity required \rightarrow LXe TPCs have it!





Supernova Neutrinos

Chakraborty et al., PRD 89, 013011 (2014) Lang et al., PRD 94, 103009 (2016)

- $\bullet\,\nu$ from supernovae could be detected via CNNS as well
- signal fom accretion phase of a ~18 Msun supernova
 @ 10 kpc is visible in a 10t-LXe detector (<future dets)
- signal: NRs plus precise time information
- challenge: theshold





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DARWIN



Low-E Electronic Recoils

PRL 129, 161805 (2022)

Current Status



pp-Neutrinos in real time

EPJ C 80, 1133 (2020)



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Limits on New Physics

PRL 129, 161805 (2022)



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XENON

¹³⁶Xe: 0v double-beta Decay

EPJ C 80, 808 (2020)



ΔL ≠ **0**

DARWIN

• $0\nu\beta\beta$ candidate with $Q_{\beta\beta}$ =2.46 MeV



DARWIN Sensitivity

- optimize sensitivity by fiducialization
- background from decays of neutron-activated ¹³⁷Xe irrelevant at LNGS depth
- half-life sensitivity: 3 × 10²⁷ y (5t fiducial volume, 10y operation)

¹³⁶Xe: 0v double-beta Decay





An updated study for XLZD is currently under preparation

An exciting future ahead of us

PANDAX

Dark Matter (NR) WIMPs (SI, SD, EFT) low-mass NR S2-only, Migdal Planck-scale DM

Dark Matter (ER) WIMP-e scattering Annual Modulation ALPs Dark Photons

Neutrinos

CNNS supernova neutrinos solar neutrinos neutrino magn. moment

Rare nuclear decays 0vbb ¹³⁶Xe 0v / 2vECEC ¹²⁴Xe

Solar Axions

... and even more: J. Phys. G 50, 013001 (2023)