Input from the DARWIN collaboration to the European Strategy for Particle Physics

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The DARWIN collaboration (www.darwin-observatory.org) is planning to build the ultimate underground-based direct detection dark matter detector, with a dark matter sensitivity limited only by irreducible neutrino backgrounds. The core of the detector will have a 40 ton liquid xenon target instrumented as a dual-phase time projection chamber. The large xenon target, the exquisitely low radioactive backgrounds and the low energy threshold will allow a diversification of the physics program beyond purely the search for dark matter particles: DARWIN will be a true low-background, low-threshold astroparticle physics observatory [1]. The collaboration, formed in 2009, consists of about 150 members from 27 institutions, currently mostly based in Europe. Members of the collaboration play leading roles in xenon-based dark matter experiments. DARWIN is included in the APPEC roadmap and appears on many national roadmaps.

The DARWIN collaboration has gone through an extensive conceptual design phase, which has resulted in several publications. The remaining backgrounds from nuclear recoils as well as from electronic recoils will both be induced by neutrinos. Core physics targets of the DARWIN programme are:

- Sensitivity to $\geq 5\,\mathrm{GeV}$ mass WIMP dark matter down to the neutrino background from coherent neutrino-nucleus scattering. The expected sensitivity for spin-independent couplings is few $\times 10^{-49}\,\mathrm{cm}^2$ for WIMP masses of 50 GeV, a $100\times$ greater sensitivity compared to current state-of-the-art detectors (i.e., XENON1T) [2, 3]. DARWIN will probe dark matter particle masses up to several tens of TeV, and will thus be highly complementary to the HL-LHC.
- Since two xenon isotopes, ^{129}Xe and ^{131}Xe (with a combined abundance of 47.6% in natural xenon) have non-zero total angular momenta, DARWIN will also be sensitive to spin-dependent WIMP-nucleon interactions. For neutron-only couplings, the HL-LHC will cover a similar parameter space and will allow for important cross-verification of possible signals [2].
- DARWINs extremely low electronic recoil background will allow probing several inelastic WIMP-nucleon interaction models, as well as the search for spin-dependent, inelastic WIMP-nucleus scatters

- The ultra-low electronic recoil background will also ensure sensitivity to solar axions, as well as galactic axion-like-particles and dark photons as dark matter candidates through axio-electric couplings and kinetic mixing, respectively.
- The low energy threshold, ultra-low background levels and excellent target fiducialization will allow for a precise measurement of the solar pp-neutrino flux at the 1% level through elastic neutrino-electron scattering. It will provide access to other solar neutrinos as well [4].
- Even without isotopic enrichment, DARWIN will contain more than 3.5 tons of ^{136}Xe, a double beta decaying isotope with a Q-value around 2.46 MeV. This will enable the search for neutrinoless double beta decay in an ultra-low background environment to investigate the Majorana nature of neutrinos, and lepton number violation [4]. Other rare decays accessible to DARWIN are the double electron capture process in ^{124}Xe.
- DARWIN will be a continuous monitor for supernova neutrinos, with sensitivity to all (active) neutrino species. A galactic supernova will generate hundreds of events in the target through coherent scattering off xenon nuclei. Such a measurement would allow the determination of supernovae properties, as well as intrinsic properties of neutrinos [5].

The DARWIN collaboration is currently starting the technical design phase of the experiment, with an expected TDR in 2022/23. The technical design and prototyping is supported by two ERC grants. The experiment is envisioned to be constructed during the data-taking phase of the upcoming XENONnT experiment to be ready to start commissioning after the completion of XENONnT in ∼2025. The location for DARWIN has not yet been selected, however, the collaboration has expressed an interest to install it at the Laboratori Nazionali del Gran Sasso (LNGS) underground laboratory in Italy. It is planned that this new observatory will take data for at least ten years.

The DARWIN experiment is a cornerstone of the European Astroparticle Physics program and should be considered as an essential part of the European Strategy for Particle Physics, especially in light of the complementarity of its dark matter program to the HL-LHC. DARWIN presents a unique opportunity to realize an observatory for low-background, low-threshold astroparticle physics in Europe, under European leadership. On the path towards becoming reality, DARWIN could directly benefit from the unique CERN expertise on cryogenics, large-scale vacuum systems, engineering, electronics, computing, etc. The collaboration would also benefit from interacting with the CERN theory group in designing new potential physics channels for the observatory, and with high-energy experimentalists and phenomenologists for combined data analysis projects.

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References

[1] DARWIN collaboration, J. Aalbers et al., *DARWIN: towards the ultimate dark matter detector*, *JCAP* **1611** (2016) 017, [1606.07001].
[2] M. Schumann et al., *Dark matter sensitivity of multi-ton liquid xenon detectors*, *JCAP* **1510** (2015) 016, [1506.08309].
[3] J. L. Newstead et al., *The Scientific Reach of Multi-Ton Scale Dark Matter Direct Detection Experiments*, *Phys. Rev.* **D88** (2013) 076011, [1306.3244].
[4] L. Baudis et al., *Neutrino physics with multi-ton scale liquid xenon detectors*, *JCAP* **01** (2014) 044, [1309.7024].
[5] R. F. Lang, C. McCabe, S. Reichard, M. Selvi and I. Tamborra, *Supernova neutrino physics with xenon dark matter detectors: A timely perspective*, *Phys. Rev.* **D94** (2016) 103009, [1606.09243].