5 DARWIN: dark matter WIMP search with noble liquids

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DARWIN [1] is an R&D and design study for a facility to detect dark matter induced signals by observing the charge and light produced in multi-ton scale liquid noble gas targets, using techniques which have already been successful in 10 kg-100 kg detectors [2–4], and which soon will be studied at the ton-scale. The goal is to probe the spin-independent WIMP-nucleon cross section well below 10^{-47}cm^2 (10^{-11}pb), which is three orders of magnitude beyond the current best limits. In conjunction with other WIMP targets, with indirect searches and with the LHC, DARWIN should allow us to learn not only about the WIMP properties, but also about their density and velocity distribution in our local vicinity in the Milky Way.

Approved by ASPERA [5] in late 2009, the DARWIN study has officially started in April 2010, and a Technical Design Study is expected to become available by early 2013. The letter of intent and the proposal for the construction of the facility would be submitted by mid and late 2013, respectively, with the construction and commission phases scheduled for 2014-2015. The period of operation and physics data taking is foreseen for 2016-2020.

Recent results from noble liquid detectors have shown that these offer a promising technology to push the sensitivity of direct WIMP searches far beyond existing limits into the regime of favored theoretical predictions. To support the dark matter interpretation, measurements of the interaction cross section for different targets are mandatory [6]. Liquid argon (LAr) and xenon (LXe), having high charge and light yields for nuclear recoils expected from WIMP-nucleus scattering, are excellent WIMP targets. A noble liquid Time Projection Chamber (TPC) is a scalable, large, self-shielding, homogeneous and position sensitive WIMP detector. The relative size of the charge and light signals, as well as their timing allows efficient discrimination against electron recoil events, while good spatial resolution helps to identify the neutron background.

Operating a LAr and a LXe target under similar experimental conditions would allow to better constrain the WIMPs mass (see Fig. 5.1), and to distinguish between spin-independent and spin-dependent couplings (^{40}Ar has no spin, while natural xenon contains 26.4% ^{129}Xe and 21.2% ^{131}Xe with $1/2^+$ and $3/2^+$ ground states, respectively). From a technical point of view, there are many

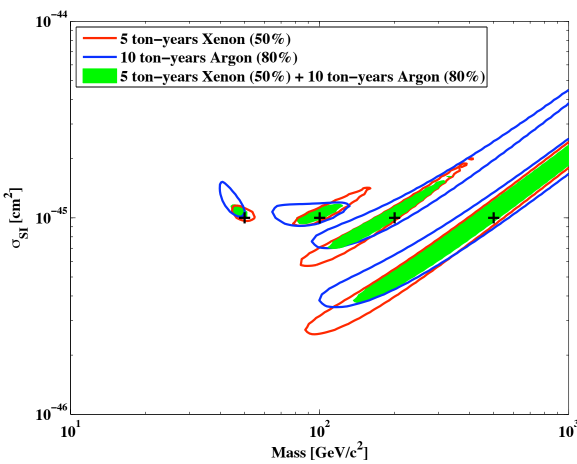

Fig. 5.1 – Spin-independent WIMP-nucleon cross section versus WIMP mass for benchmark scenarios of 10^{-45}cm^2 (10^{-9}pb) and four WIMP masses (+ symbols). Also shown are the 1-σ constraints for exposures of 5 t year in LXe (assuming 50% acceptance of nuclear recoils) and 10 t year in LAr (assuming 80% acceptance of nuclear recoils), as well as the combined result.

common aspects to LAr and LXe dark matter TPCs, such as cryostat design, charge and light readout, purification of noble liquids, HV system for the drift field, field uniformity and charge extraction, use of ultra-low radioactivity materials and shields as well as the underground infrastructure and safety aspects.

DARWIN unites the ample expertise in Europe on liquid noble gas detectors, low-background techniques, cryogenic infrastructures, underground infrastructures and shields as well as on the physics related to the direct detection of WIMPs. Connections among the participating institutions are established through several work packages, such as:

- design of cryostat, inner TPC, high-voltage and cryogenic systems based on the experience gained by existing LAr and LXe experiments,
- study of novel, high quantum-efficiency and low-radioactivity light sensors and UV light collection schemes,
- study of the light and charge yields of electronic and nuclear recoils at low energies,
- study of new concepts to read out the ionization signal, such as large-area thick gas electron multipliers (GEMs), large-area gaseous photomultipliers (GPM) and CMOS pixel detectors coupled to electron multipliers,
- study of low-noise, low-power and cost-effective electronics for light and charge read-out, as well as new DAQ and data processing schemes,
- optimization of noble gas purification procedures concerning water and electronegative impurities and radioactive isotopes such as ^{39}Ar, ^{85}Kr and ^{222}Rn; studies of material outgassing, liquid handling and purity monitoring procedures,
- material selection and process control needed for ultra-low background operation; exploration of optimal underground locations and cost-effective shielding.
- study of the scientific impact and establishment of a framework in which results from indirect dark matter searches, cosmology and the LHC can be combined with direct dark matter searches; asses the impact of potential results on astrophysics.

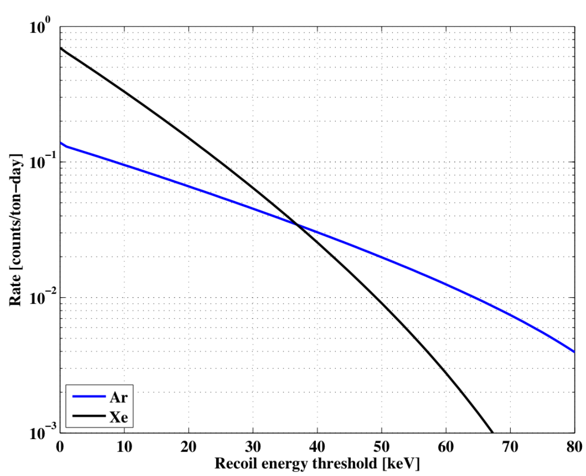

Fig. 5.2 – Event rates in LAr and LXe as a function of energy threshold for a WIMP-nucleon cross section of 10^{-45}cm^2 and a WIMP mass of 100 GeV/c^2.

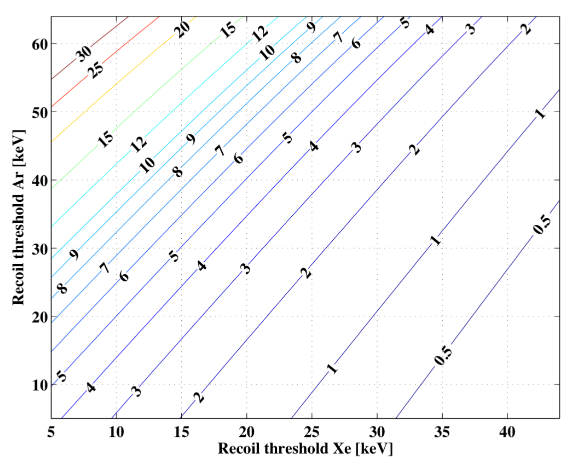

Fig. 5.3 – The detector mass scaling factor between argon and xenon for achieving a similar sensitivity to a standard WIMP as a function of the thresholds on the nuclear recoil energy.

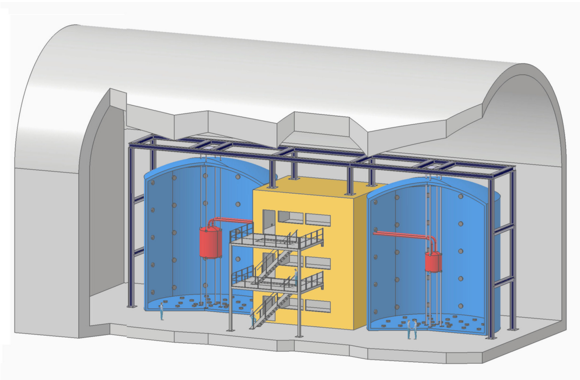

Fig. 5.4 – A preliminary sketch of the DARWIN facility, which would operate 20 t (10 t) and 8 t (5 t) of total (fiducial) argon and xenon mass in double-walled cryostats immersed in large water Cerenkov shields.

The final configuration and the size of DARWIN are under study. The optimal choice of the fiducial mass for the two target materials is a function of detector-dependent quantities such as energy thresholds and WIMP parameters like mass and interaction cross section. Figure 5.2 shows the event rates in LAr and LXe as a function of energy threshold for a WIMP-nucleon cross section of 10^{-45}cm^2 and a WIMP mass of 100 GeV/c^2. Figure 5.3 shows the detector mass scaling factor between the two targets for achieving a similar sensitivity to a standard WIMP that interacts predominantly via coherent scattering on nuclei, as a function of energy thresholds.

To study the physics reach of the facility, we assume as benchmark scenarios fiducial masses of 10 t and 5 t for the LAr and LXe components, respectively, corresponding to roughly 20 t and 8 t of total argon and xenon mass (a preliminary sketch of DARWIN is shown in Fig. 5.4). Figure 5.5 shows the sensitivity to the spin-independent WIMP-nucleon cross section as a function of exposure for a WIMP mass of 100 GeV/c^2 and a nuclear recoil energy window of 30-100 keV and 10-100 keV in LAr and LXe, respectively. It also displays the number of events that would be detected for a WIMP-nucleon cross section of 10^{-44}cm^2 (10^{-8}pb) in the same energy windows. The assumptions for LXe are the following: a raw background of 10^{-4} events kg^{-1}day^{-1} keV^{-1}, which is a factor of 100 below the current XENON100 background [4], a 99.9% rejection of electronic recoils based on the ratio of the charge and light signals, and a 50% acceptance for nuclear recoils. For LAr, the assumptions are: a raw background of 0.45 events kg^{-1}day^{-1} keV^{-1}, with a factor of 10^8 rejection of electronic recoils based on pulse shape analysis and the charge-to-light ratio, a reduction of the ^{39}Ar rate by a factor of 25 relative to atmospheric argon (corresponding to an activity of 40 mBq/kg for ^{39}Ar) and a 80% acceptance for nuclear recoils.

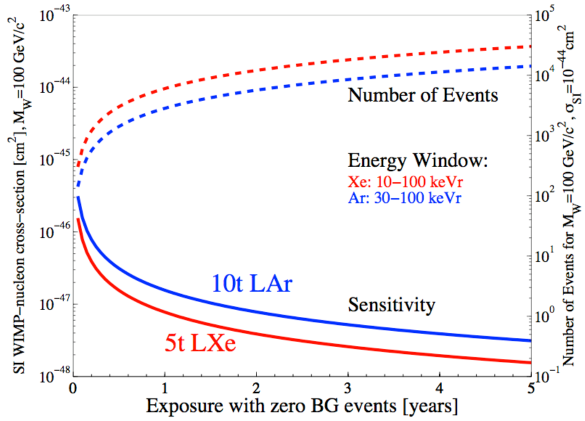

Fig. 5.5 – The sensitivity to the spin-independent WIMP-nucleon cross section as a function of exposure for 10 t LAr and 5 t LXe, for a WIMP mass of 100 GeV/c^2 and zero background events for a given exposure (left y-axis). The dashed lines show the number of events that would be detected for a WIMP-nucleon cross section of 10^{-44}cm^2 (right y-axis).

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