4 Cold Dark Matter Search with XENON

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The XENON program is focussed on the direct detection of Weakly Interacting Massive Particles (WIMPs) [1], which are candidates for the dark matter in the Milky Way. XENON employs time projection chambers (TPCs) which are filled with cryogenic liquid xenon (at about $-90°$C) as target material. Operated in two-phase (liquid/gas) mode, simultaneously reading light and charge signals from scintillation and ionization, respectively, the TPC provides 3-dimensional interaction vertex reconstruction on an even-by-event basis and efficient discrimination against background signals from γ or β decays in the detector materials or the experiment's surroundings.

The XENON100 detector is taking data at the Gran Sasso Underground Laboratory (LNGS) since 2009. First results from data recorded during an early 11.2 days commissioning run have revealed that XENON100 suffers hundred times less background than any other direct dark matter detection experiment [4]. No event candidates were observed in the WIMP region and the derived upper limits on spin-independent WIMP-nucleon cross sections were the lowest obtained so far [3]. Figure 4.1 compares the measured background spectrum with a simulated spectrum accounting for the known intrinsic radioactive contaminations of all materials used for the detector. Most background measurements have been performed with the low background germanium spectrometer (HPGe) Gator [4], which is operated at LNGS by our group.

The background of this instrument, shown in Fig. 4.2, is very low and comparable to the best HPGe detectors available. Gator, however, provides a larger sample cavity, a necessary requirement to measure tiny radioactive contamination in raw materials for detector construction, such as copper, titanium, stainless steel, and PTFE (Teflon). In the bottom part, Fig. 4.2 shows the deconvolution of the background spectrum into the contribution from different materials, derived by a best fit method from the measured data [4].

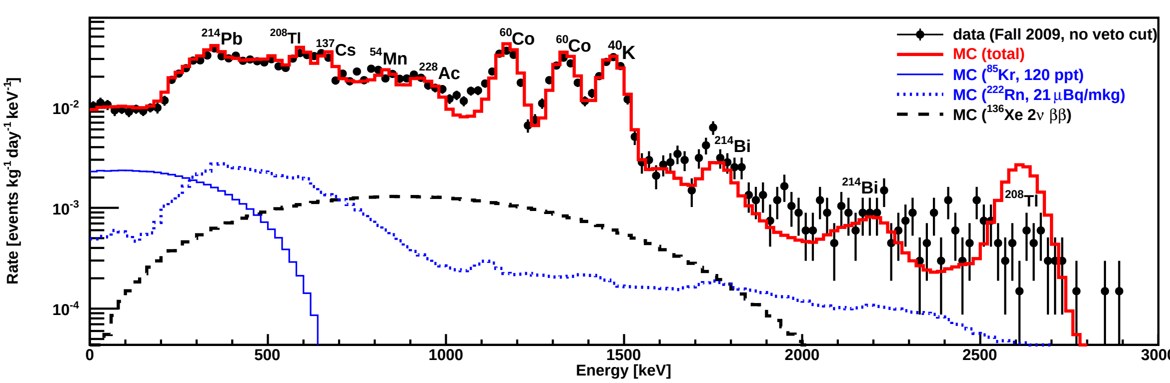

Fig. 4.1 – Measured background spectrum of XENON100 during the comissioning run [3] nicely reproduced by a detailed Monte Carlo study of the detector and shield.

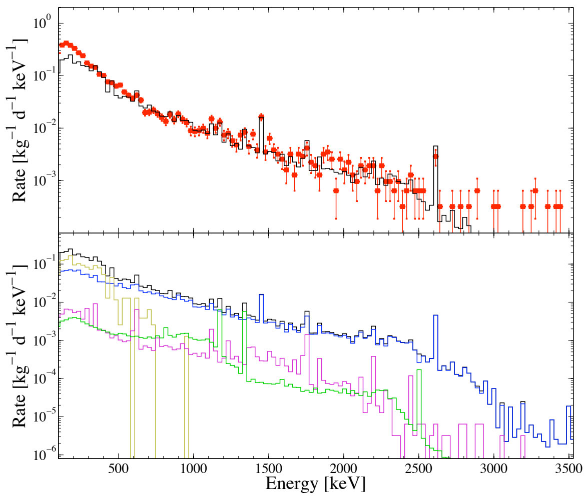

Fig. 4.2 – Top: background spectrum of the low background germanium spectrometer Gator, together with a best fit from a Monte Carlo study. Bottom: Decomposition into the contributions from various materials: natural radioactivity in Cu (blue), cosmogenic radio-nuclides in Ge and Cu (green), ^{222}Rn decays inside the shield (magenta), and ^{210}Pb in the Pb shield (yellow).

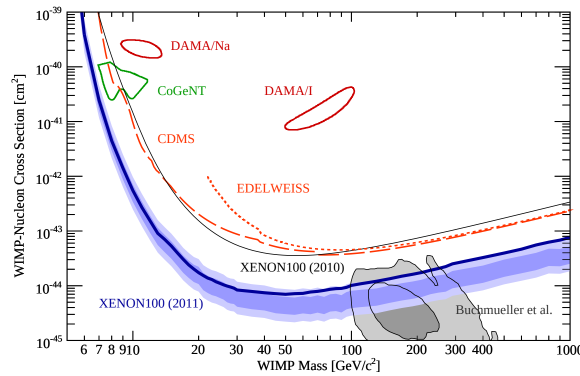

Fig. 4.3 – Thick blue line: 90% CL upper limit on the spin-independent WIMP-nucleon scattering cross section from 100.9 days of XENON100 data [3]. Blue shaded region: expected sensitivity for the exposure in absence of a WIMP signal. Thin black curve: XENON100 limit from the comissioning run [3].

The increased sensitivity of XENON100 and all future detectors requires improved analysis techniques. For the first time in dark matter searches, the Profile Likelihood method, commonly used in high energy physics, has been applied [5]. The method properly accounts for known systematic uncertainties and makes a quantitative statement about the likelihood of the observation to be just background or to include a signal.

The results of a much larger data set of 100.9 life days, taken in the first half of 2010, have been published recently [3]. Three events were observed in the pre-defined WIMP search region between 8.4 keV and 44.6 keV for the nuclear recoil energy with an expected background of (1.8 ± 0.6) events. The resulting upper limit on the spin-independent WIMP-nucleon scattering cross section is well below all previous results which severely constrains the interpretation of the DAMA and CoGeNT results [7] as being due to light mass WIMPs (Fig. 4.3). Moreover, it enters the sensitivity region for supersymmetric WIMP dark matter accessible at the LHC [8].

XENON100 is in continuous operation at LNGS with a new dark matter run that started in March 2011. The next phase, XENON1T, is expected to enter its construction phase in Fall 2011. Our group is responsible for data acquisition and electronics and for the design and manufacturing of the inner detector structure. We also test new low-radioactive light sensors.

Besides the R&D activities for XENON1T and within the DARWIN project [9], the research performed in our laboratory is focused on understanding the properties of liquid xenon as dark matter target, in particular at lowest energies. The neutral WIMPs would interact with the xenon nuclei, resulting in nuclear recoils. The dominant γ and β backgrounds involve electromagnetic interactions with the atomic electrons, generating electron recoils. The energy range for all these processes will be extended towards lower energies in the XÜRICH detector [10] which is filled with about 3 kg of xenon. The measurement of the electronic recoil scale, which is completely unknown below 9.4 keV, is ongoing. The study of the nuclear recoil scale will follow as soon as the new neutron facility at UZH becomes available.

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