4 Search for Cold Dark Matter Particles with XENON

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The goal of the XENON (1) program is to detect Weakly Interactive Massive Particles (WIMPs), which may be responsible for the dark matter in our galaxy, via their collision with Xe nuclei. The current phase, XENON100, is a 161 kg liquid xenon time projection chamber (TPC) operated in the interferometer tunnel at LNGS in an improved XENON10 shield (2). It uses two arrays of low-radioactivity, UV-sensitive photomultipliers (Hamamatsu R8520-06-Al 1″ square PMTs) to detect simultaneously the prompt (S1) and proportional (S2) light signals induced by particles interacting in the sensitive xenon volume, containing 62 kg of ultra pure liquid xenon (LXe). The remaining 99 kg of LXe are used as an active veto shield against background events; the LXe scintillation in the veto region is detected by additional PMTs of the same type. While the fiducial mass of XENON100 was increased by a factor of 10 with respect to the XENON10 experiment, the background has been demonstrated to be lower by a factor of 100 (Fig. 4.1). This was achieved through careful selection of ultra-low background materials, by placing the cryogenic system and high-voltage feedthroughs outside of the shield, by using the self-shielding power of xenon as well as the active LXe shield, by purifying the LXe for the radioactive ^{85}Kr with a dedicated column at LNGS, and by an improved passive shield.

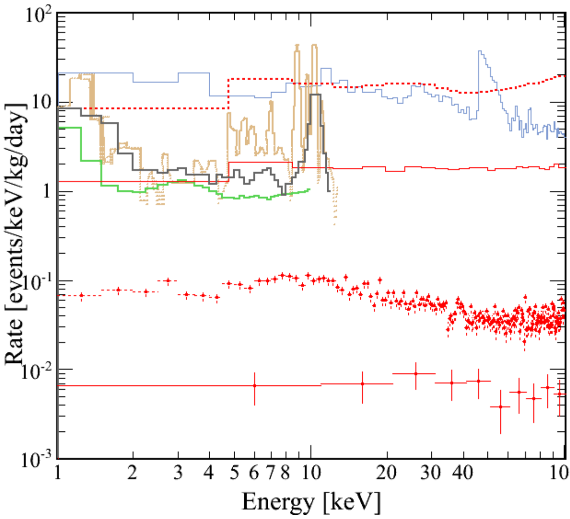

Figure 4.1: Raw event rate in the XENON100 experiment before (62 kg of LXe) and after (40 kg of LXe) a fiducial volume cut (lowest two red curves). This background rate is compared to the ones of XENON10 (before, and after a fiducial volume cut, upper two red curves), CRESST (blue), CoGeNT (brown), CDMS (grey) and DAMA (green).

The aim of XENON100 is to probe WIMP-nucleon cross sections down to $\sim 2\times10^{-45}$ cm^2 at a 100 GeV WIMP mass, after a life-exposure of 6000 kg days (200 days with 30 kg fiducial mass, taking into account the detector's acceptance). The dark matter search run started in January 2010, and the current raw exposure (with the data in the signal region being masked) is about 5000 kg days. The optimization of data analysis tools necessary to unveil this large data set is ongoing. The XENON100 experiment will continue running throughout 2010 and will either detect WIMPs, or set strong constrains on theoretical WIMP models. In either case, a larger scale experiment is needed and we have proposed the XENON1T detector (2.4 t of LXe in total, 1.1 t in the fiducial volume) (3) with the construction and the dark matter search phases to start by mid 2011 and 2014, respectively.

The current activities of our group focus on calibrations and stability monitoring of the XENON100 PMTs, position reconstruction algorithms based on neural networks, material screening with the Gator HPGe detector, Monte Carlo simulations of backgrounds and light-collection efficiencies, energy calibrations with various sources, as well as operations, data processing and analysis (along with Columbia, we are leading the analysis effort). We are also involved in R&D activities for XENON1T (3) and are leading the DARWIN (4) project. In the following, we can only highlight a small subset of our XENON related activities during the past year.

We have performed a first dark matter analysis on 11.2 live days of background data, taken during the commissioning of the detector in the period of October-November 2009. For this analysis, we have chosen a nuclear recoil energy interval between 9.7 – 31.6 keV (corresponding to 4 – 20 photoelectrons in S1, as determined in extensive detector calibration measurements) and a fiducial mass of 40 kg. We have applied simple data selection criteria, which were developed and tested on low-energy nuclear and electronics recoils from ^{241}AmBe and ^{60}Co sources, respectively. In particular, we require a two-fold PMT coincidence in a 20 ns window for the S1 signal and discard events which contain more than a single S1-pulse. For the S2 signal, we set a lower threshold of 300 photoelectrons, corresponding to about 15 ionization electrons, and require that events contain only one S2 pulse above this threshold, as WIMPs are expected to interact only once. We also discard events with energy deposits in the veto volume of the TPC and require that the width of the S2 pulse be consistent with what is expected from the inferred drift time due to the diffusion of the electron cloud (5).

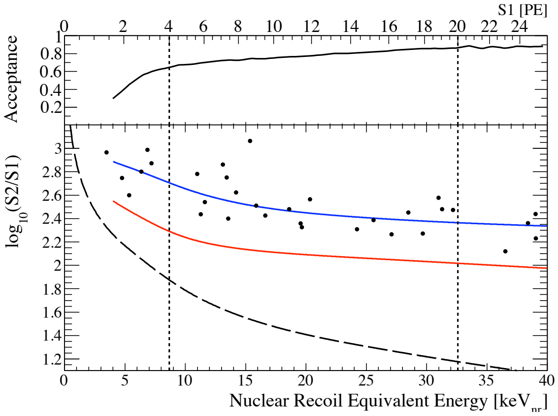

Figure 4.2: log$_{10}$(S2/S1) (bottom) and cut acceptance (top) as functions of nuclear recoil energy. A total of 22 events are observed in the electron recoil band (the median is shown as the blue curve) in the energy region between 9.7 – 31.6 keV (inside the two vertical dotted lines) and no events are observed in the pre-defined signal acceptance region below the nuclear recoil median (red line) and above the S2 threshold (dashed line).

The distribution of events in log$_{10}$(S2/S1) versus nuclear recoils energy is shown in Fig. 4.2. While a total of 22 electronic recoil events are observed, no WIMP candidates are seen in the pre-defined signal region.

Based on this null observation of signal candidate events and on standard dark matter halo assumptions, we derive an upper limit on the WIMP-nucleon elastic scattering cross section, taking into account the S1 resolution dominated by Poisson fluctuation. The resulting 90% confidence upper limit is shown in Fig. 4.3. This limit has a minimum at a cross section of 3.4×10^{-44}cm^2 for a WIMP mass of 55 GeV/c^2 for a spectrum-averaged exposure 170 kg·days. It excludes all parameter space for the interpretation of the CoGeNT and DAMA signals as being due to light mass WIMPs at 90% confidence (12). This initial results of XENON100, which uses only a short exposure, demonstrates the potential of this de

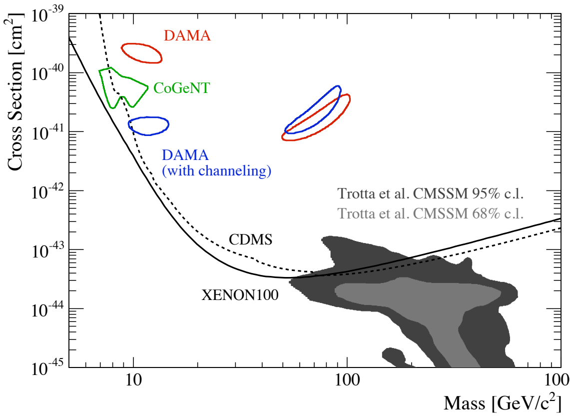

Figure 4.3:
90% confidence limit on the spin-independent elastic WIMP-nucleon cross section (solid line), together with the best limit to date from CDMS (dashed) [6], expectations from a theoretical model [7], and the areas favored by CoGeNT (green) [8] and DAMA (blue/red) (3σ, 90%) [9].

tector to discover Galactic WIMP dark matter.

Using our small liquid xenon time projection chamber (Xürich) located in the Physik Institut, we have tested a new method for calibrating liquid xenon detectors based on a short-lived ($T_{1/2}$ = 1.8 h) ^{83m}Kr source. The ^{83m}Kr source has transitions at 9.4 keV and 32.1 keV, and, being a noble gas like xenon, it disperses uniformly in all regions of the detector. Even for low source activities, the existence of the two transitions separated by 154 ns provides a method of identifying the decays that is free of background. We found that at decreasing energies, the LXe light yield increases, while the amount of electric field quenching is diminished. Figure 4.4 shows the light yield as a function of the applied field, normalized to the zero field value, of the two ^{83m}Kr transitions and of the ^{57}Co 122 keV line.

We plan to use this method for a uniform calibration of the XENON100 detector at low energies at the end of the dark matter run. For the near future, we plan to use the Xürich prototype to measure the light and ionization yields of nuclear recoils at low energies.

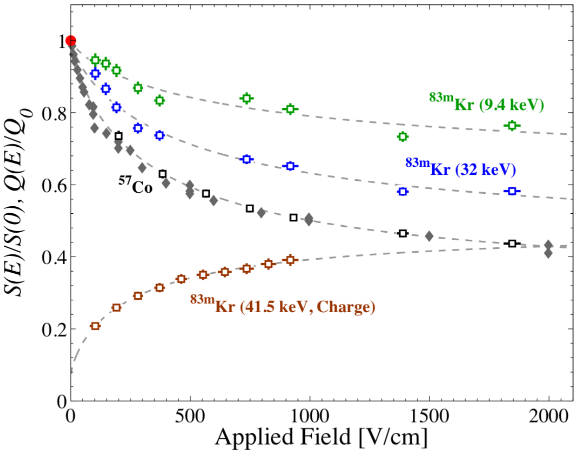

Figure 4.4: Field quenching of the scintillation light of ^{57}Co (black) and the two lines of ^{83m}Kr (9.4 keV and 32.1 keV, in green and blue, respectively). The bronw line shows the charge quenching for the sum of both ^{83m}Kr lines. The data from the literature [11] is shown as grey points.

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