The XENON100 Dark Matter Experiment

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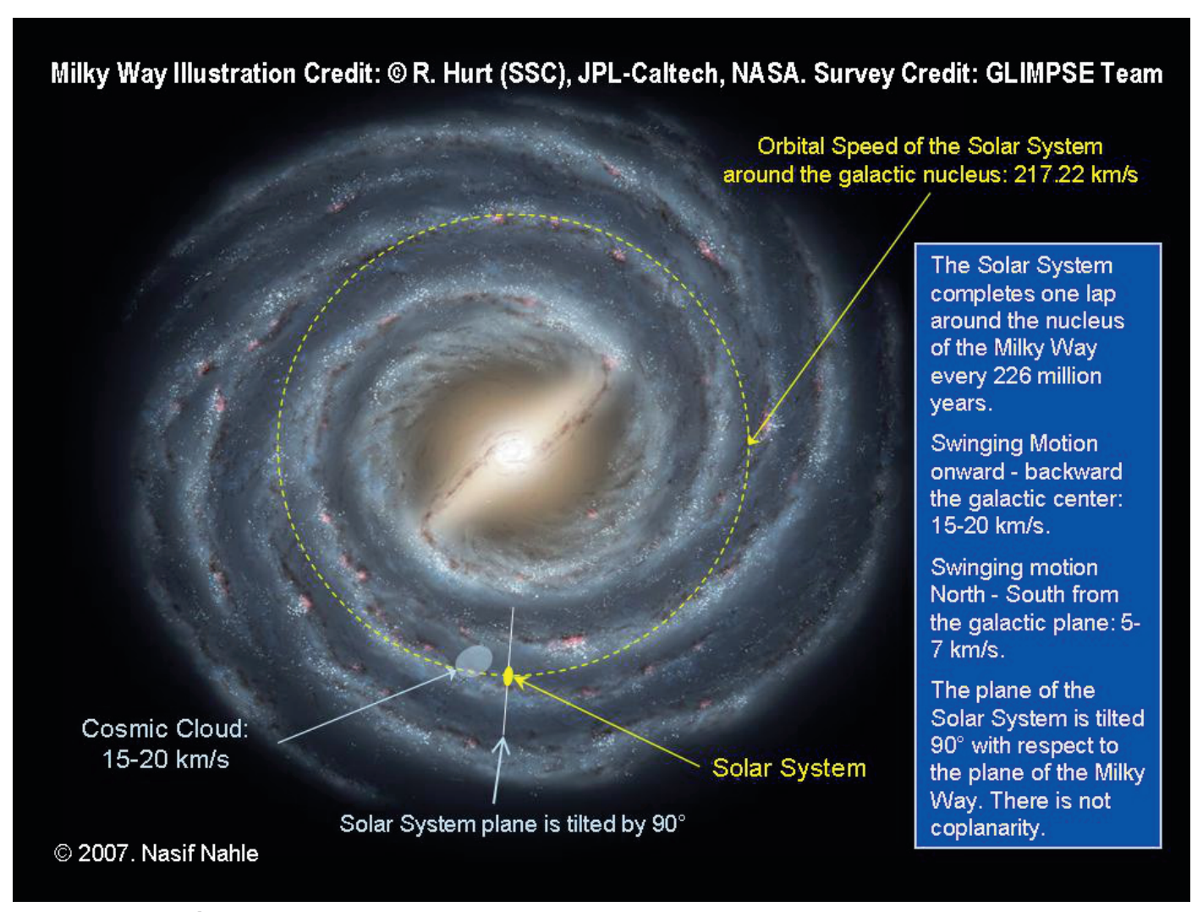
Dark Matter

23% of the universe is made out of Dark Matter, a kind of matter that doesn't emit or absorb electromagnetic waves (light), so that it cannot be directly detected by any telescope on or around earth (dark). It does not interact with ordinary matter that we already know about in any strong fashion that could generate a detectable signature to be picked up by experimental techniques up to date.


Milky Way Illustration Credit: © R. Hurt (SSC), JPL-Caltech, NASA. Survey Credit: GLIMPSE Team

Orbital Speed of the Solar System around the galactic nucleus: 217.22 km/s

The Solar System completes one lap around the nucleus of the Milky Way every 226 million years.

Swinging Motion onward - backward the galactic center: 15-20 km/s.

Swinging motion North - South from the galactic plane: 5-7 km/s.

The plane of the Solar System is tilted 90° with respect to the plane of the Milky Way. There is not coplanarity.

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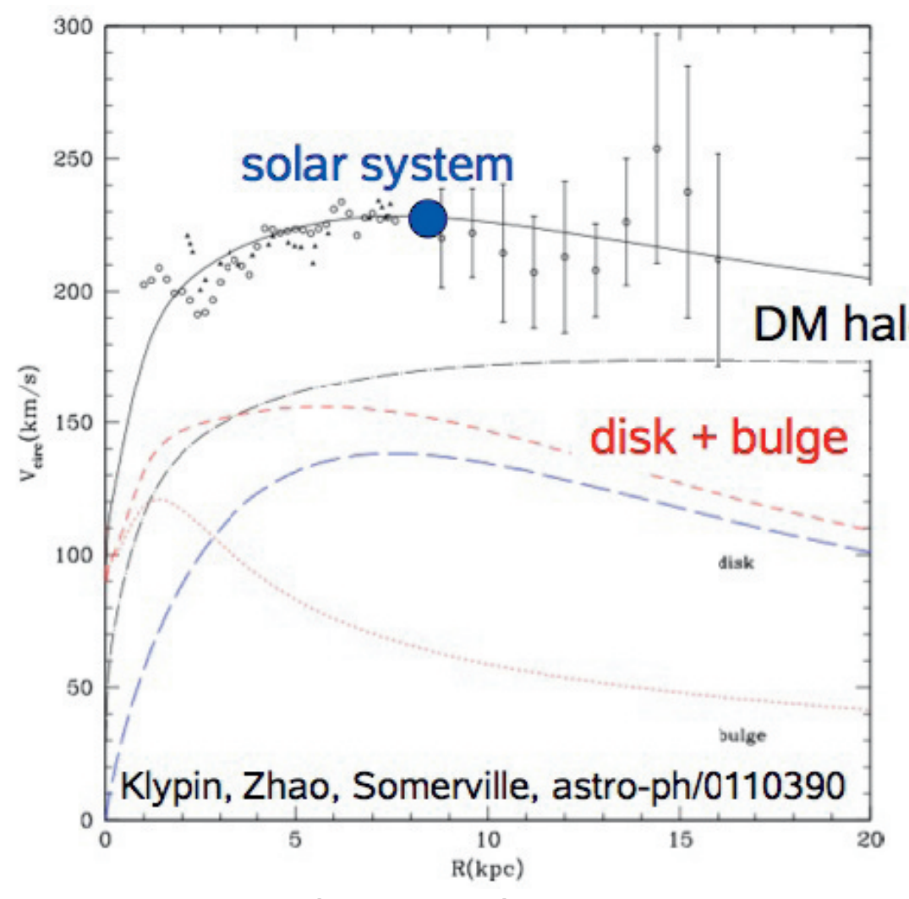


Klypin, Zhao, Somerville, astro-ph/0110390

The existence of Dark Matter in our own Milky Way galaxy is inferred from observing the flatness of the galactic rotation curve at large radii, with a density in the solar neighborhood of about 0.3 GeV/cm^3. Sensitive low-background detectors in underground laboratories are searching for the rare elastic recoils of Weakly Interacting Massive Particles (WIMPs) with the atomic nuclei of the detector, resulting in a steep continuum spectrum of order 10 keV.

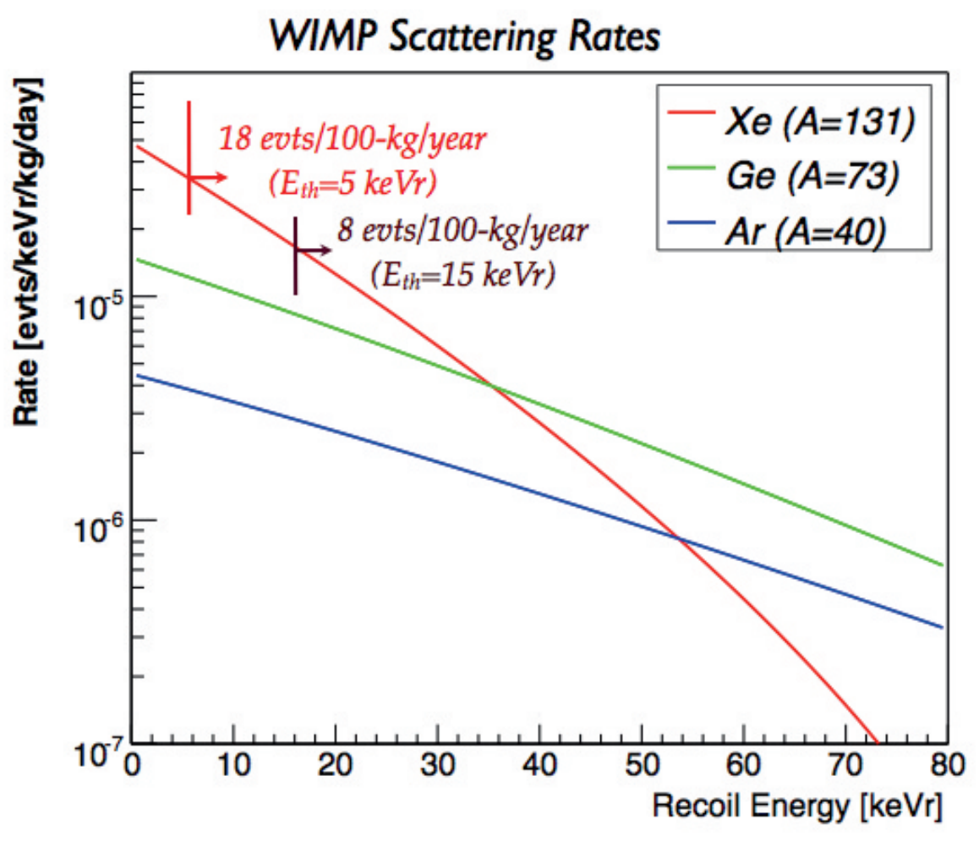
Model: ρ_χ and $f(\mathbf{v},t)$

Measurement: $\frac{dR}{dE}$

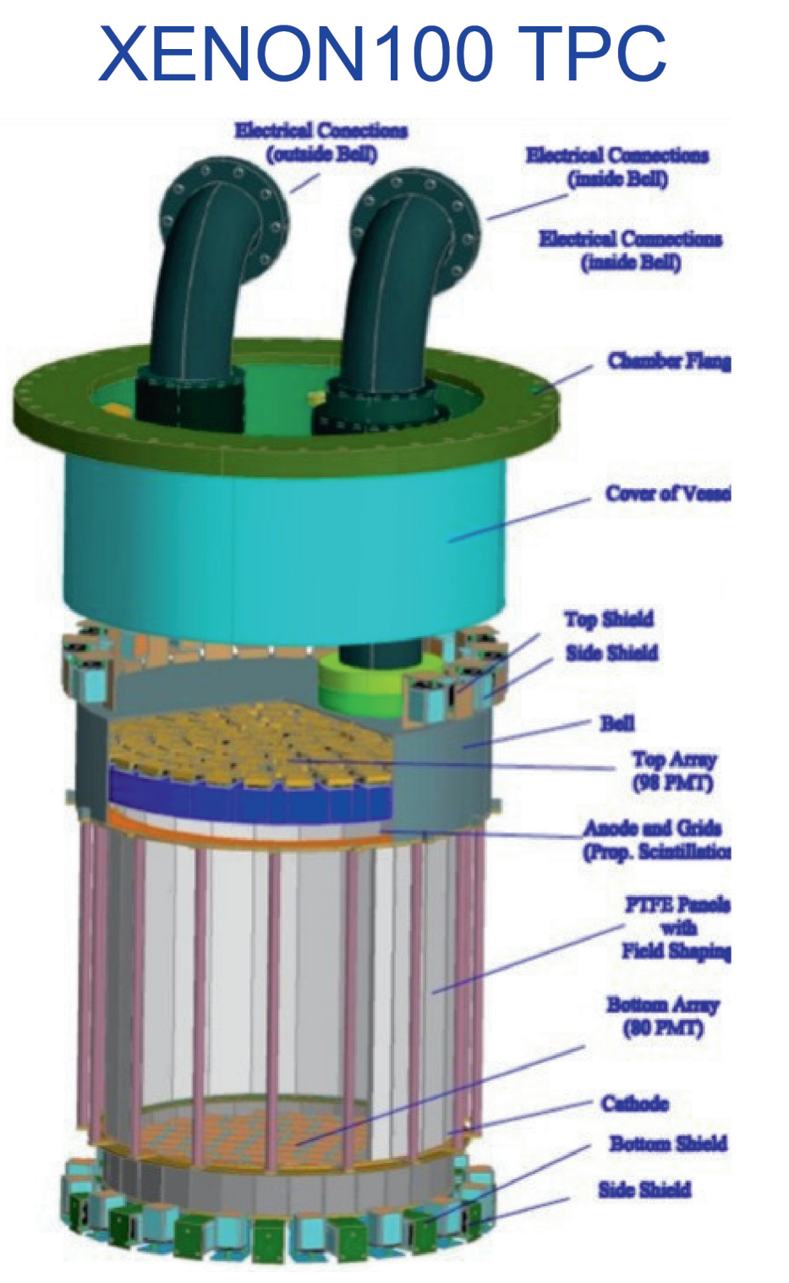
Result: $\sigma_{\chi-p}$–M_χ

$$\frac{dR}{dE} = \frac{\rho_\chi \sigma_{\chi-p}}{2M_\chi \mu^2}|\mathbf{F}(E)|^2 \int_{v_{\min}}^{v_{\max}} \frac{f(\mathbf{v},t)}{v} \mathrm{d}^3 v$$

$$f(\mathbf{v},t) \propto \exp\left(\frac{-(\mathbf{v}+\mathbf{v}_{\oplus}(t))^2}{2\sigma^2}\right)$$

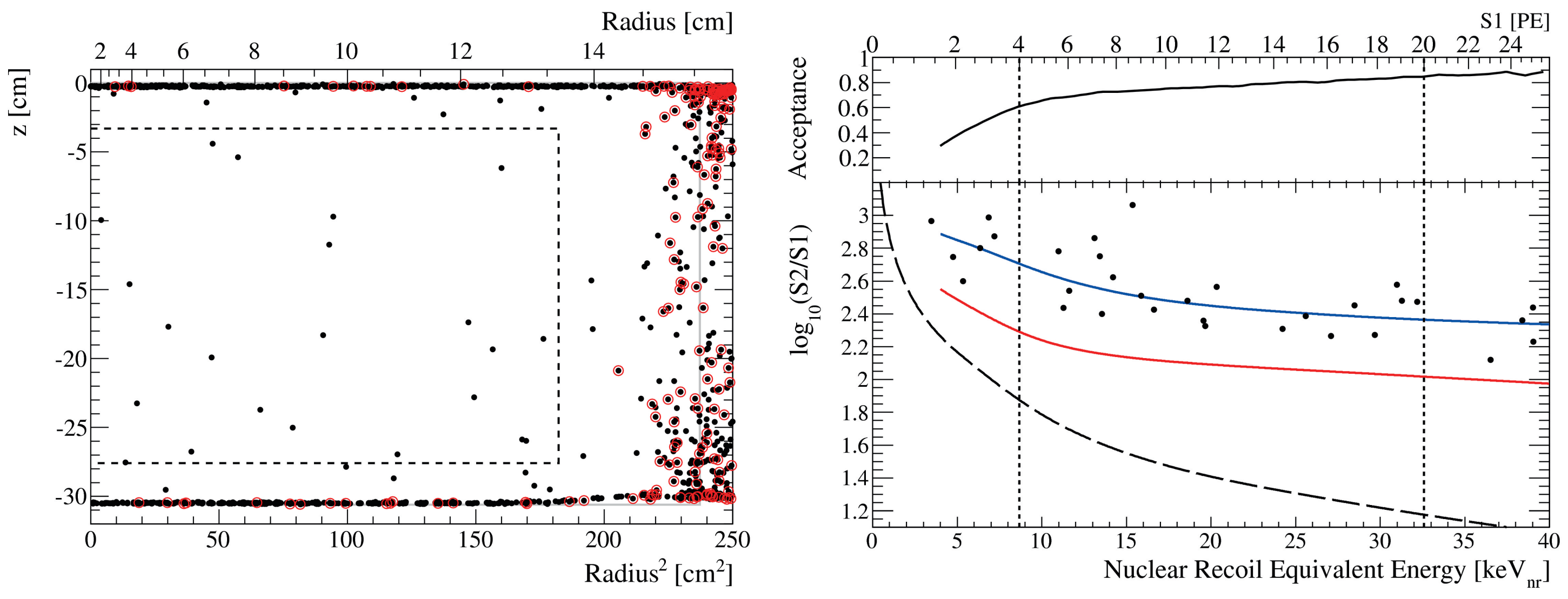


The XENON100 Detector



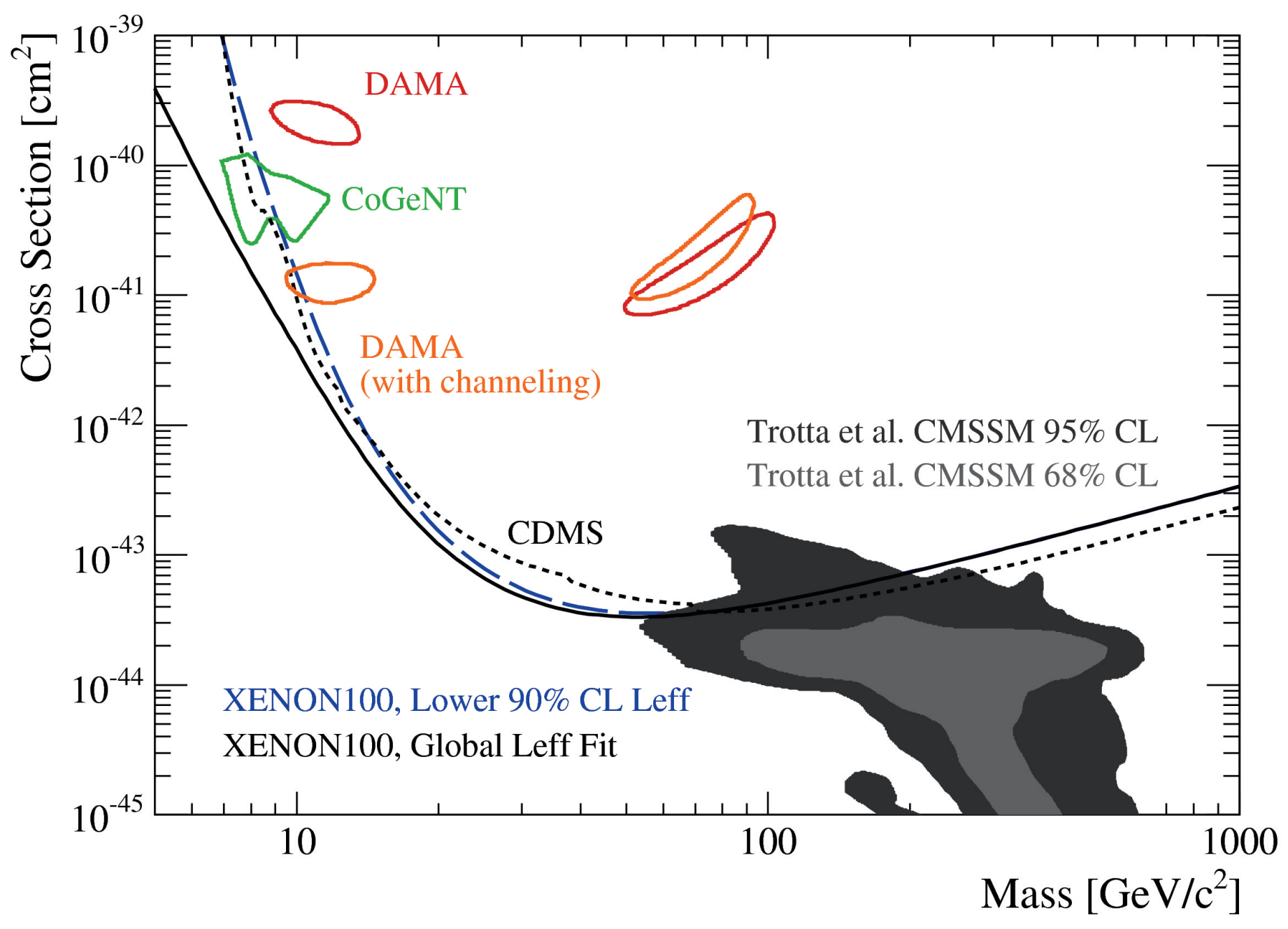
XENON100 is a Dark Matter detector using ~170kg of liquid xenon as its detection medium. The 62kg sensitive volume can detect both scintillation (light) and ionization (charge) signals of particles (both ordinary and WIMP) hitting liquid xenon. The detector is located under the Gran Sasso mountain in central Italy to stay away from cosmic ray backgrounds.
There are 242 1-inch photo-multiplier tubes (PMTs) placed in the detector to count the small number of photons generated at each particle interaction.

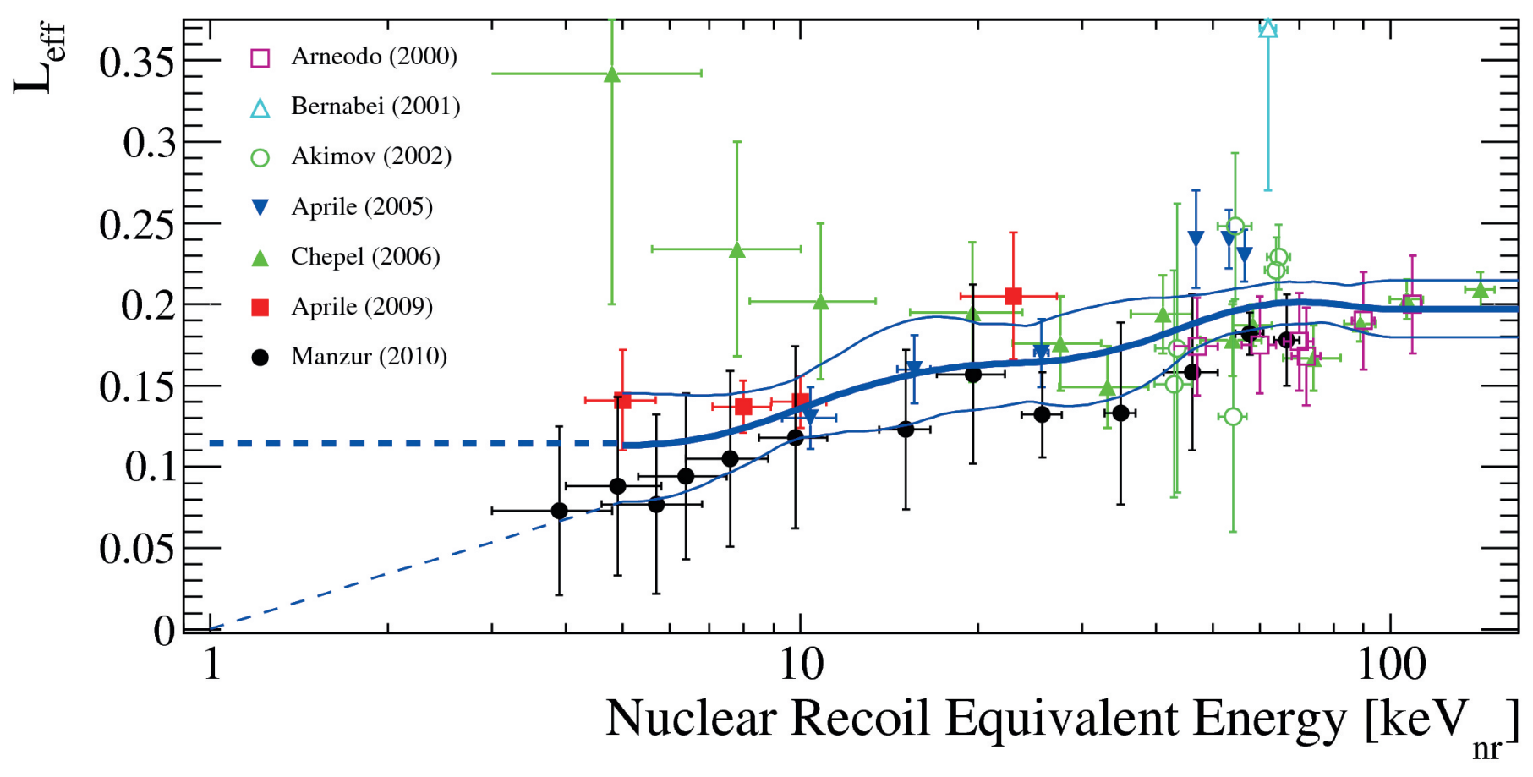
First Results



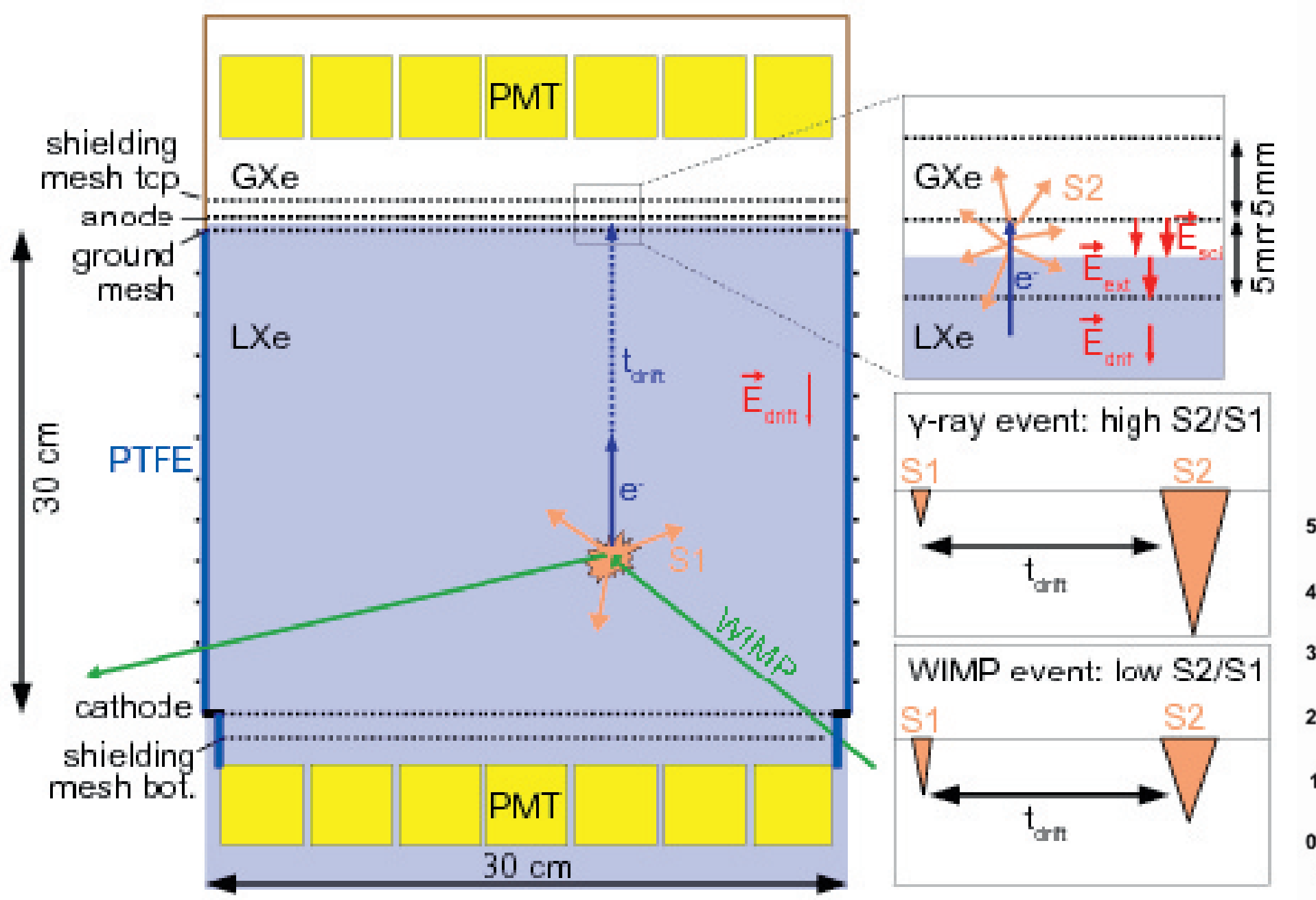
We analyze the first dataset of 11.17 live days acquired in winter 2009 for the first dark matter search results. Remarkably, in the energy window of interest, only 22 events were observed in 11 days, and none of them is a WIMP like nuclear recoil event. Due to the fact that the background rate of XENON100 is 100 times better than any other dark matter experiment, with only 11 days of data in a 40kg target, we already could set the best WIMP-nucleon cross-section limit in the world.

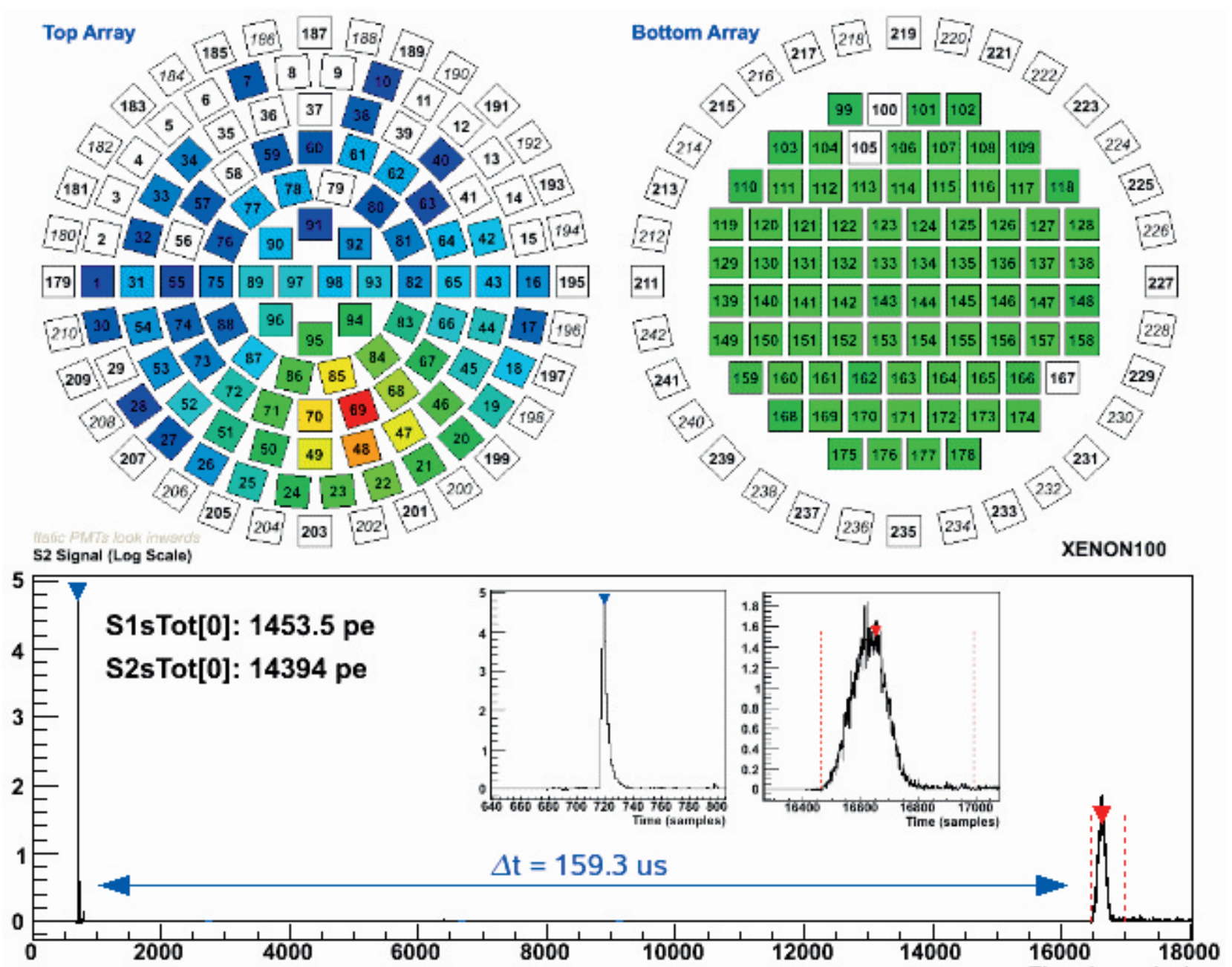
The XENON100 sensitivity limit for low WIMP masses is greatly affected by the scintillation efficiency for nuclear recoils (compared to electronic recoils at 122 keV) L_{eff}. L_{eff} is determined by independent neutron scattering experiments. These measurements have large uncertainty and more importantly there is no direct measurements below 4keVr. A global fit of all existing direct L_{eff} measurements is used to compute the limit. Different extrapolation schemes are used below 4keV. The figure shows the effect of different L_{eff} assumptions on the detector sensitivity.





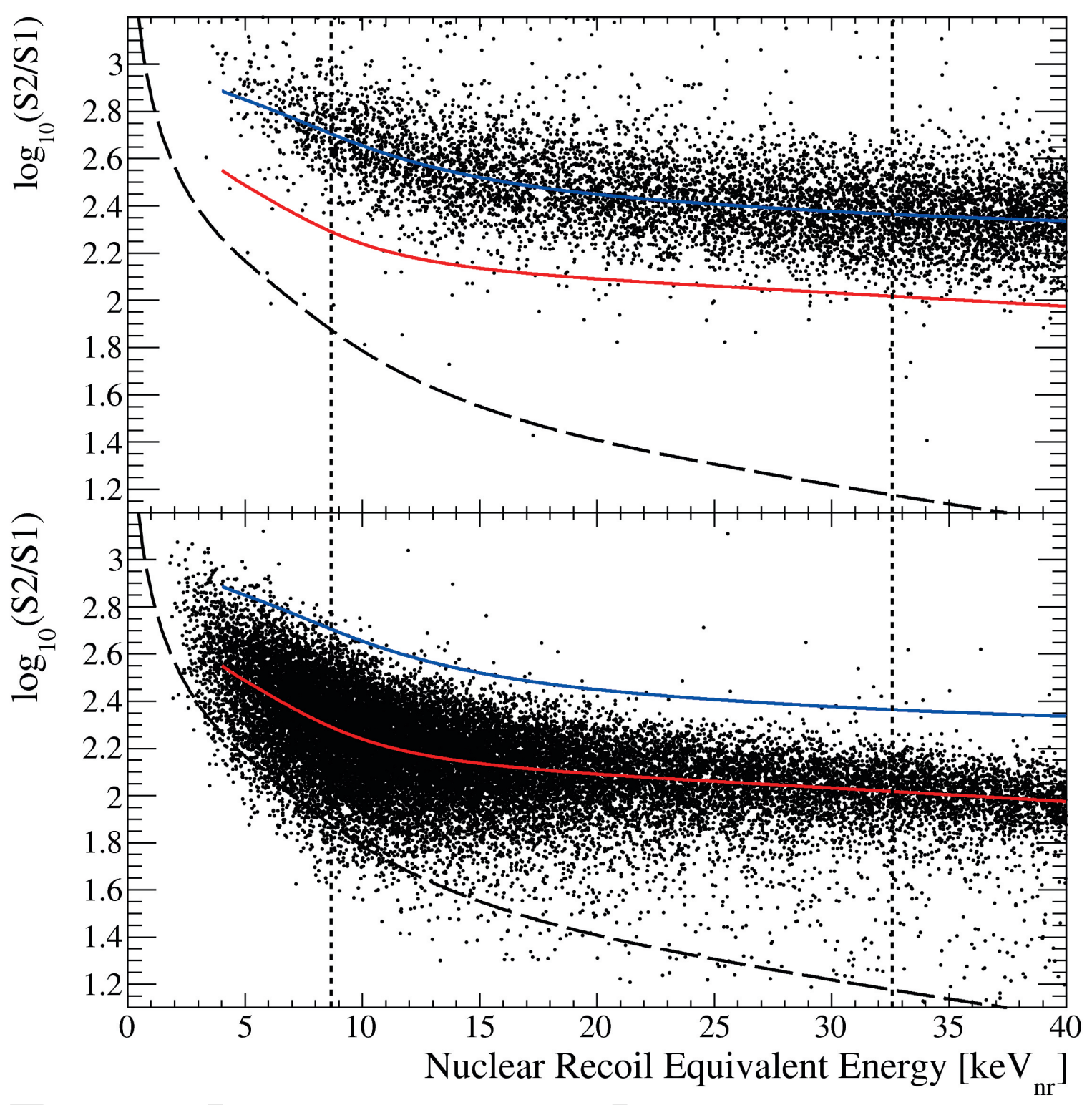
Principle of Operation





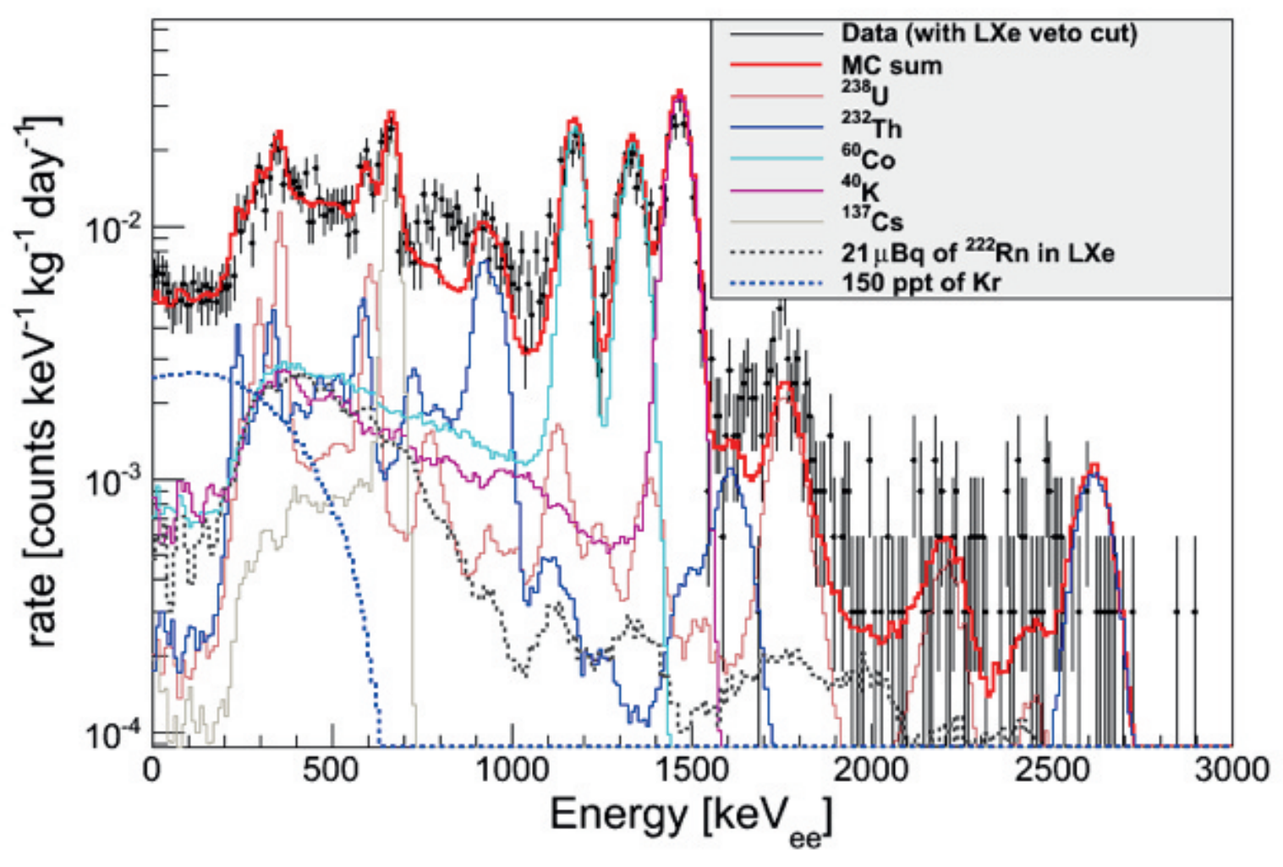
When a particle hits xenon, scintillation light and free electrons are generated at the same time. The light is promptly collected by the PMTs, generating the first peak in the summed waveform (S1). The free electrons are drifted upwards in a 570 V/cm electric field. At the liquid-gas interface, located about halfway between the gate mesh and the anode, a strong electric field of > 4 kV/cm in the liquid extracts the electrons into the gas volume. In the gas, electrons reach sufficient energy to excite xenon atoms and produce scintillation light proportional to the total charge, yielding the second peak in the summed waveform (S2). The signals S1 and S2 not only provide the energy deposition of each interaction, the ratio S2/S1 also gives the type of interaction (electron recoil or nuclear recoil), which is essential to distinguish a WIMP interaction (only nuclear recoil) from background (mostly interactions with the electrons). Together, S1 and S2 enable operation of the detector as a time projection chamber (TPC) with fine 3D position reconstruction. Identification and localisation of single interaction events enables us to select an inner fiducial volume of low background.

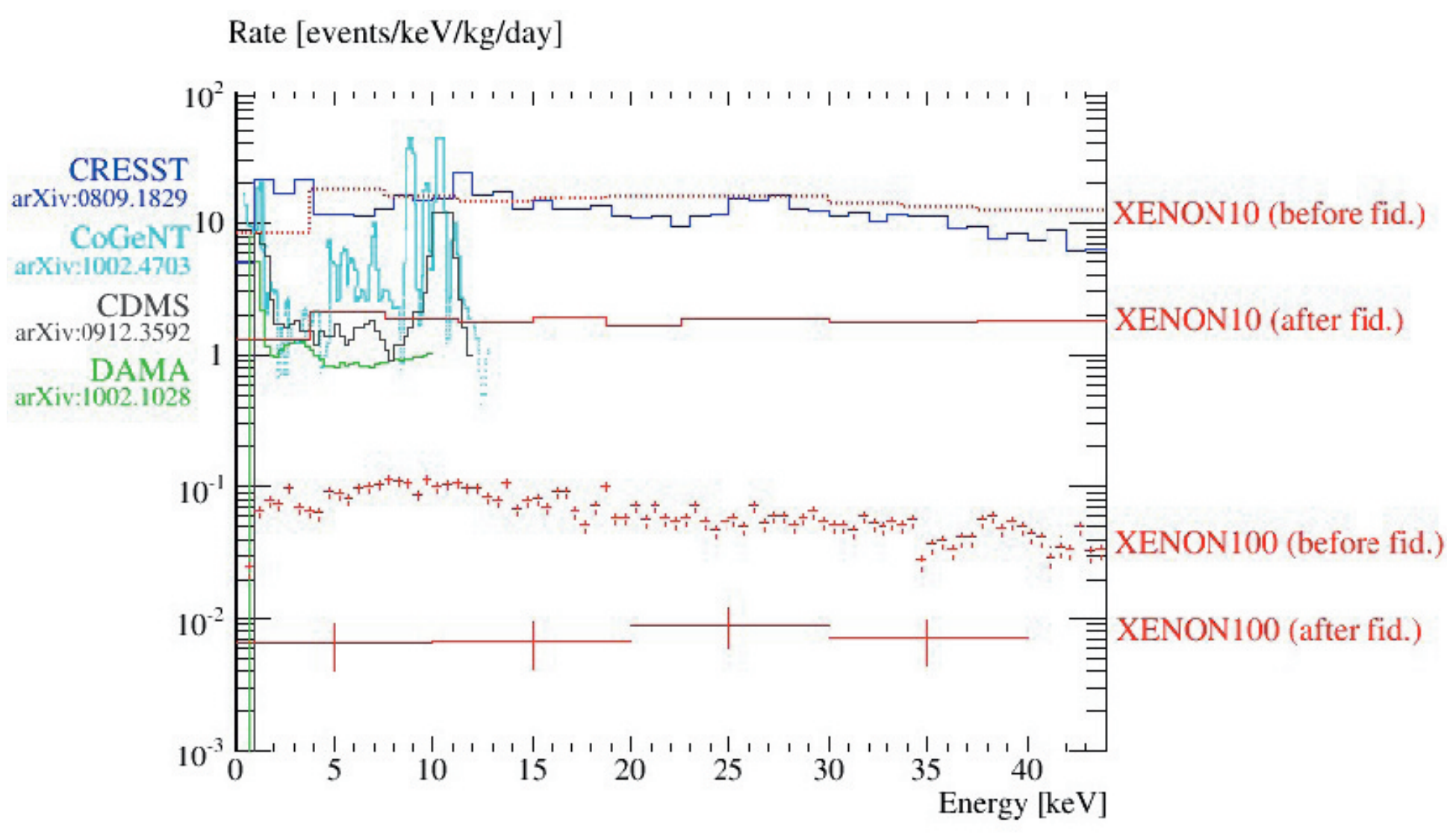
Detector Calibration



The Xenon100 detector response to electron recoils is calibrated with gamma rays from Co-60 sources placed around the detector.
The detector response to nuclear recoils is calibrated with MeV neutrons emmitted from an AmBe source.
The ratio between charge and light produced by electron recoil and nuclear recoil is very different. Therefore, by plotting Log(S2/S1) vs. S1 (or recoil energy), nuclear recoil and electron recoil form two different bands. Dark Matter particles (WIMPs) are expected to behave like neutrons, therefore the dark matter search window is defined below the nuclear recoil band median to minimize background.

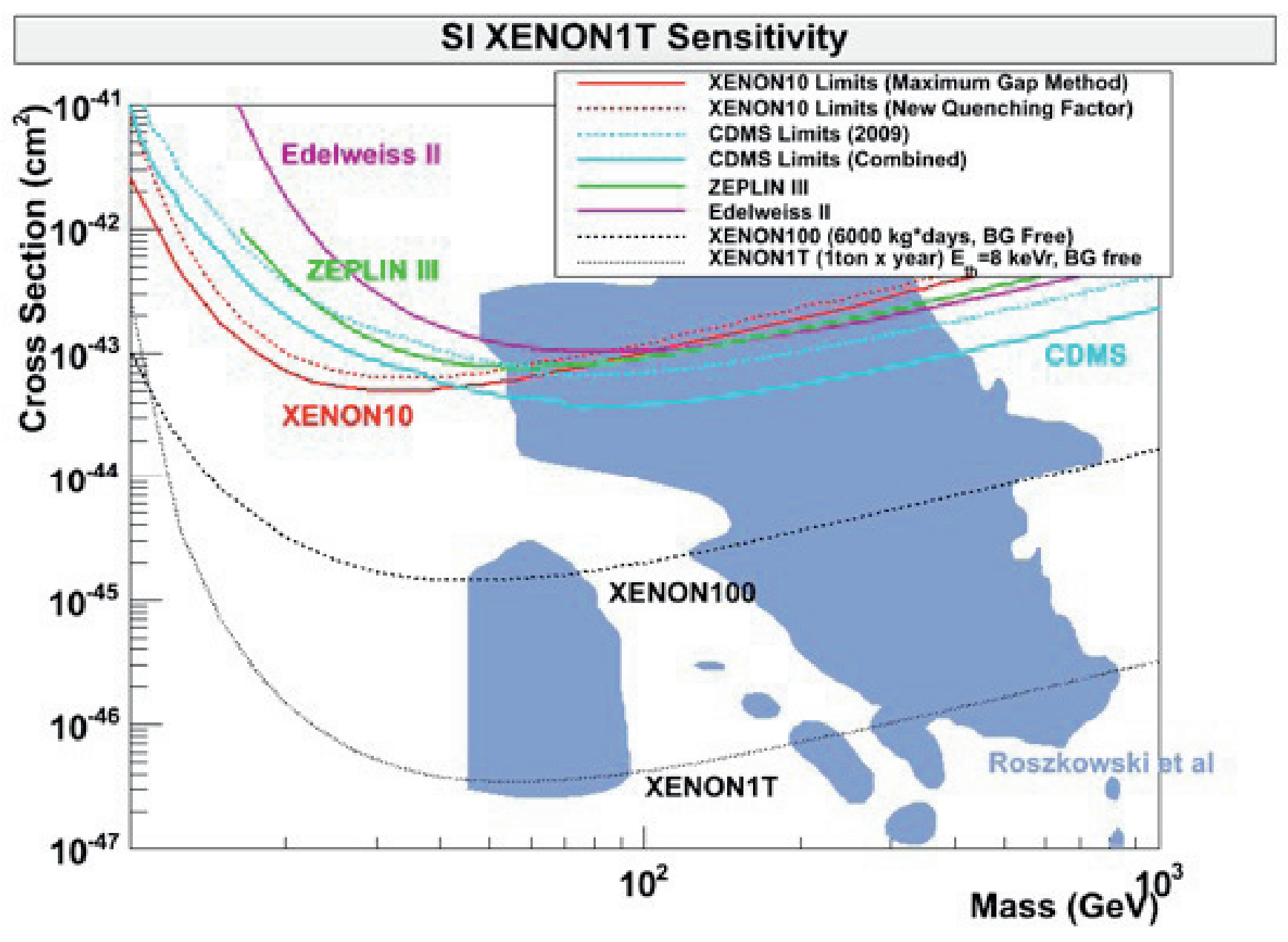
Background





Xenon100 has the lowest background of all current DM experiments. The background contributions are well understod from material screening, Monte Carlo simulations, and background data.

Future



By running XENON100 for longer time, a ~20 times sensitivity improvement is expected.

A bigger detector at 1ton level is being designed, which would gain another two orders of magnitude in sensitivity, covering nearly the entire parameter space of CMSSM models.

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