2. S2 yield and liquid xenon purity

The proportional scintillation light S2 is proportional to the number of electrons liberated in the liquid by an ionizing event. The number of electrons which reach the liquid-gas interface depends strongly on the liquid xenon purity, which can be inferred from a measurement of the electron lifetime τ [48]. The presence of impurities reduces the number of electrons produced in the liquid at time t=0 ($N_e(0)$) according to the relation: $N_e(t) = N_e(0)e^{-t/\tau}$. To determine the electron lifetime, we used the data from ^{137}Cs calibration, measuring the attenuation with drift time of the S2 signal associated with the full energy peak of 662 keV gamma rays. Throughout the dark matter search period an electron lifetime longer than 2 ms was measured, corresponding to $\ll 1$ ppb O_2 equivalent impurity concentration in the LXe. A similar purity level was inferred during a subsequent calibration of XENON10 with gamma rays from neutron-activated Xe gas, carried out shortly after the first dark matter search run was completed. Fig. 21 shows the electron lifetime measurement using S2 from the 164 keV gamma events uniformly distributed in the XENON10 active volume. The electron lifetime inferred from this calibration is 2.2 ± 0.3 ms, confirming the excellent purity level achieved in XENON10 during the dark matter search.

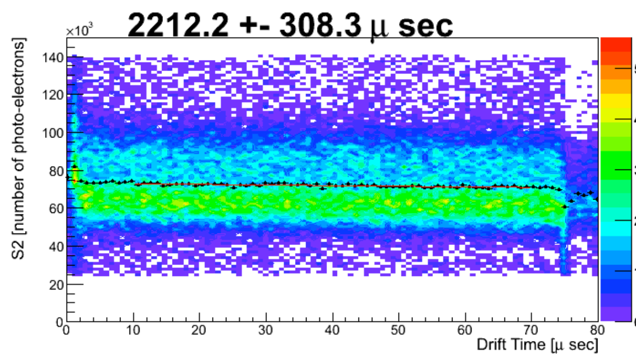

FIG. 21: (Color online) Determination of the electron lifetime from calibration data. The band is the S2 signal measured by the bottom PMT array as a function of drift time for fully-absorbed 164 keV gamma events from the activated Xe calibration of XENON10.

As previously discussed, the amplitude of the S2 signal, for a given number of ionization electrons extracted from the liquid, depends on several factors: the gas pressure p, the gas gap x, the electric field E across the gap, the light collection efficiency of the PMTs, and the quantum efficiency Q_E of the PMTs. The observed number of photoelectrons per electron drifting in the gas can be found from single electron pulses within the data. During the operation of the XENON10 detector, a class of pulses due to single electron emission from the liquid to the gas phase was observed (Fig. 22). From this observation, we estimate that, on average, each electron produces 13.8 p.e. on the top PMT array and 9.9 p.e. on the bottom PMT array respectively.

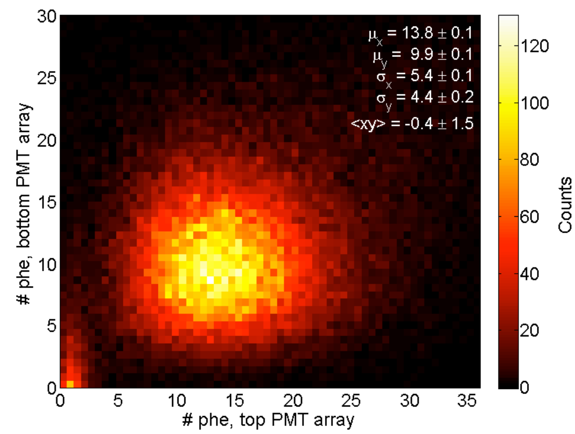

FIG. 22: (Color online) S2 from single electrons seen in the neutron calibration data, with the signal detected by the top PMT array on the x-axis, and bottom PMT array on the y-axis. These events were selected based only on pulse width (full width 0.2 μs - 3.0 μs) plus a requirement that they would be at least 10 μs from the trigger region (either before or after).

3. Position-dependence of $S1$ and $S2$ Signals

The S1 light collection efficiency (LCE) has a strong dependence on the event position, due to the effects of total internal reflection at the liquid-gas interface, the solid angle, the optical transmission of the grids and the teflon reflectivity. In order to obtain an accurate energy calibration, data from both Monte Carlo simulation and internal sources were used to study the position dependence of the signals.

Fig. 23 shows the simulated S1 LCE throughout the XENON10 detector, where we define LCE as the probability of photons released in the detector to hit the photocathode of a PMT; it does not include the QE of the PMTs. Some regions are light- but not charge-sensitive, most notably in the reverse field region between cathode and bottom PMT array. Some light sensitivity also exists in the xenon around and below the bottom PMT array, where stray light enters through openings between the Teflon cylinder and the PMTs. The primary light is predominantly detected by the bottom PMT array, due to total internal reflection at the liquid-gas interface, where the index of refraction changes from 1.61 [49] to 1. The ratio of top to bottom S1 signal ranges from ~ 0.14 to ~ 0.3 from the bottom to the top of the drift region. Some light is absorbed by the meshes, by the PTFE walls, or by the liquid xenon. We calculated 92% transparency of the meshes and assumed 92% reflectivity for PTFE [28]. The absorption length of liquid xenon is taken as 100 cm and the scattering length as 30 cm [50].