Dark Matter Experiments
XENON1T

Nikhef Dark Matter staff members Auke-Pieter Colijn, Patrick Decowski, and postdoc Chris Tunnell in front of the XENON1T detector at the underground laboratory LNGS in Italy.

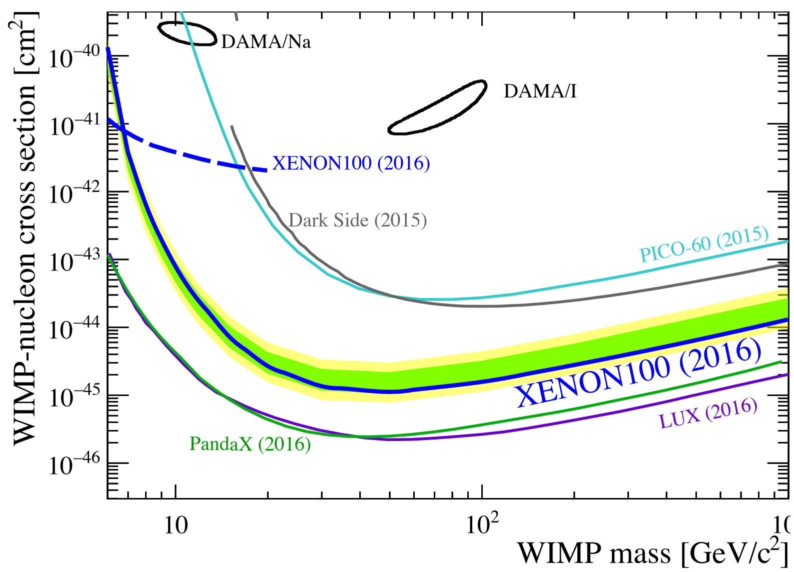

Figure 1. The dark matter landscape before the start of XENON1T. The lines show the present limits for the WIMP-nucleon cross section as a function of WIMP mass for different experiments. The solid blue line is the final result from XENON100 and the dashed blue line shows the XENON100 result for the low-mass WIMP analysis led by Nikhef. XENON1T will have an ultimate sensitivity reach of 1.6×10^{-47} cm^2 at 50 GeV/c^2, *i.e.* below the scale shown on the y-axis.

Management
prof.dr.P. Decowski

The main Nikhef Dark Matter group activity was the preparation for the scientific run of the XENON1T experiment. Construction of the detector was completed at the end of 2015 and most of 2016 was devoted to commissioning of the subsystems and calibration of the detector. The first XENON1T dark matter science run started at the end of 2016. While these activities were ongoing, we also analysed data from the XENON1T predecessor, XENON100. The XENON collaboration has also commenced the design of the future XENONnT detector, an upgrade of XENON1T.

XENON1T: Starting the Dark Matter Science Run

The XENON1T detector (see Fig. 1), with 3.5 tons of liquid xenon, has become the world's most sensitive running direct detection dark matter experiment. Most of 2016 was devoted to commissioning the subsystems, calibrating the detector and purifying xenon. The cryostat with the time-projection chamber (TPC), hanging in the middle of a 10-meter diameter water tank, was filled with liquid xenon in April and has remained full of xenon since. Nevertheless, a number of operations still had to be done inside the water tank, which shields the detector from external radioactivity and acts as a water Cherenkov muon veto. The water tank was finally filled in July and the muon veto system commissioned. The fall was spent performing calibrations, with radioactive sources deployed into the water tank but outside of the cryostat (*e.g.* with ^{228}Th and neutrons) and using internal sources, with short-lived isotopes ^{83m}Kr and ^{220}Rn mixed into the liquid xenon. These calibrations were necessary to fully characterise the detector. Simultaneously, we also purified the detector by circulating liquid xenon through the getter and distillation systems. The getter system removes electronegative impurities and improved the electron lifetime from 1 µs to about 500 µs, sufficient for the first dark matter run. The distillation system was used to remove the isotope ^{85}Kr from the liquid xenon, and reducing it by roughly three orders of magnitude. This decreased the ^{85}Kr background contribution to the dark matter search from being the largest background to being almost negligible. All these activities were necessary to prepare XENON1T for the dark matter science run. The dark matter run started at the end of December.

The Nikhef group was heavily involved with almost all aspects of XENON1T commissioning. The flexibility of the Nikhef-designed trigger and event-building system allowed adjustments throughout the year to adapt to changing detector conditions. We also spent a significant effort improving the XENON1T data reconstruction software that also originated in our group and is now the official data reconstruction software of the collaboration. To support the analysis and the adoption of our reconstruction, we organised two collaboration-wide analysis workshops. All these efforts put the Nikhef group in an excellent position to play a leading role in the analysis of the first XENON1T dark matter data.

XENON100: Final Data Analysis

While the commissioning of XENON1T was ongoing, the collaboration also finalised the analysis of the scientific data from XENON100. The Nikhef team led an analysis focusing on low-mass weakly interacting massive particles (WIMPs) by looking only at the charge-related signal ('S2-only'), allowing for a lower energy threshold. This provides better sensitivity than the main WIMP search analysis technique below 8 GeV/c^2 WIMP mass. The other two significant XENON100 analyses were the combination of all three dark matter science runs to obtain the final XENON100 WIMP exclusion plot (see Fig. 1) and a search for annual modulations of the dark matter signal spanning more than four years. We anticipate a few more publications from XENON100, especially on various R&D efforts related to XENON1T and calibrations.

After eight years of almost continuous operation, XENON100 was turned off in July 2016 and the 160 kg of xenon recuperated.

Future Experiments: XENONnT and DARWIN

Even though the scientific exploitation of XENON1T only started, the Nikhef dark matter group is already planning future experiments. The XENON collaboration aims to upgrade XENON1T to about 8 tons of xenon, with a commensurately larger cryostat, time-projection chamber and more photomultiplier tubes. This phase of the experiment is called XENONnT. Most of the other XENON1T infrastructure will remain, and in fact has been designed with the XENONnT upgrade in mind. With the larger xenon target mass and lower backgrounds, XENONnT will have ten times better sensitivity than XENON1T. Installation in the XENON1T water tank is planned for 2019, after XENON1T reaches its final sensitivity. The collaboration has already purchased a large fraction of the additional xenon required.

We also continued studying the 'ultimate' dark matter detector, DARWIN with 50 tons of xenon. This detector, to be operational in 2025, will cover the remaining sensitivity space, up to the point when neutrinos from the Sun and the atmosphere become a difficult to reduce background. Apart from operating as the ultimate dark matter detector, the large xenon mass and extremely low backgrounds would also allow the study of a wide-range of other physics topics. Our group contributed to a long publication summarizing the DARWIN physics programme.

Auke Pieter Colijn appointed professor

Auke Pieter Colijn was appointed special professor of 'Experimental Astroparticle Physics' at the Institute for Subatomic Physics of the University Utrecht with effect from 1 November 2016. Colijn is researcher in the Dark Matter group at Nikhef.

Auke Pieter Colijn