Dark Matter (WS 2018/19) - Problem sheet 7

Tutorials: Florian Jörg (florian.joerg@mpi-hd.mpg.de)

Deadline for this sheet: 12.12.2018

Direct detection of dark matter

7.1 Liquid xenon (LXe) time projection chambers (TPCs) *5.5 Points*

As an example of a liquid noble gas direct detection experiment, we will look at the XENON1T experiment. Read `https://arxiv.org/pdf/1708.07051.pdf` and answer the following questions (do not get lost in the technical parts of the paper):

a) Which kinds of interaction with the xenon target can incoming particles have? Which one of these are WIMPs expected to typically undergo?

b) What are S1/S2 signals, and how are they generated? Is all of the energy deposited by a particle accessible for read out using these signals? Name possible processes that lead to losses of the signal strength.

c) Which information can one extract from the S1 signal of an interaction in conjunction with the S2 signal to which it belongs? What is this information used for? State 3 examples.

d) Why does the xenon need to be continuously purified?

e) What is "self-shielding"? Why does one need to use radioactive sources which mix with the xenon target itself to calibrate the entire detector volume instead of using sources outside of the TPC?

7.2 Background sources for liquid xenon experiments *4.5 Points*

a) Why is the detector located deep underground?

b) Why is not the entire volume of the TPC used for WIMP searching? What could be done to allow for usage of a larger volume?

c) Why is the xenon being distilled? Why cannot the rare-gas purifiers of the purification system be used instead of relying on distillation?

d) Which background source (for a nuclear recoil energy region from 4 to 50 keV and a fiducial target of 1.0 t) is dominant after applying electronic recoil background rejection (with a typical discrimination fraction as stated in the paper), and what is the expected rate of background events caused by it then?

7.3 Calculating a limit on the WIMP-interaction rate *2 Bonus Points*

Let us reconsider the case that was presented on last week's exercise sheet (exercise 6.2). Assume that over the whole run time ($T = 100\,\text{days}$), the xenon detector (active mass $M = 35\,\text{kg}$) has observed a total of $n_0 = 3$ events. From which $b = 1$ event is expected to be induced due to the background of that detector (e.g. from radioactive impurities). Use the below table to derive 90% confidence intervals on the WIMP interaction rate R for this case.
(*Hint: Remember that the number of WIMP scattering events N is connected to the interaction rate R by $N = R \cdot M \cdot T$*)

7.4 Visit to the MPIK

On 13th December 2018 there will be no exercise class, but a small tour in our labs at the Max-Planck-Institut für Kernphysik. Therefore we will meet at Bismarckplatz and from there we will take the 39 bus (Königstuhl) leaving at 9.00 am.

$n_0 \backslash b$	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0	0.00, 2.44	0.00, 1.94	0.00, 1.61	0.00, 1.33	0.00, 1.26	0.00, 1.18	0.00, 1.08	0.00, 1.06	0.00, 1.01	*0.00, 0.98*
1	0.11, 4.36	0.00, 3.86	0.00, 3.36	0.00, 2.91	0.00, 2.53	0.00, 2.19	0.00, 1.88	0.00, 1.59	0.00, 1.39	0.00, 1.22
2	0.53, 5.91	0.03, 5.41	0.00, 4.91	0.00, 4.41	0.00, 3.91	0.00, 3.45	0.00, 3.04	0.00, 2.67	0.00, 2.33	0.00, 1.73
3	1.10, 7.42	0.60, 6.92	0.10, 6.42	0.00, 5.92	0.00, 5.42	0.00, 4.92	0.00, 4.42	0.00, 3.95	0.00, 3.53	0.00, 2.78
4	1.47, 8.60	1.17, 8.10	0.74, 7.60	0.24, 7.10	0.00, 6.60	0.00, 6.10	0.00, 5.60	0.00, 5.10	0.00, 4.60	0.00, 3.60
5	1.84, 9.99	1.53, 9.49	1.25, 8.99	0.93, 8.49	0.43, 7.99	0.00, 7.49	0.00, 6.99	0.00, 6.49	0.00, 5.99	0.00, 4.99
6	2.21,11.47	1.90,10.97	1.61,10.47	1.33, 9.97	1.08, 9.47	0.65, 8.97	0.15, 8.47	0.00, 7.97	0.00, 7.47	0.00, 6.47
7	3.56,12.53	3.06,12.03	2.56,11.53	2.09,11.03	1.59,10.53	1.18,10.03	0.89, 9.53	0.39, 9.03	0.00, 8.53	0.00, 7.53
8	3.96,13.99	3.46,13.49	2.96,12.99	2.51,12.49	2.14,11.99	1.81,11.49	1.51,10.99	1.06,10.49	0.66, 9.99	0.00, 8.99
9	4.36,15.30	3.86,14.80	3.36,14.30	2.91,13.80	2.53,13.30	2.19,12.80	1.88,12.30	1.59,11.80	1.33,11.30	0.43,10.30
10	5.50,16.50	5.00,16.00	4.50,15.50	4.00,15.00	3.50,14.50	3.04,14.00	2.63,13.50	2.27,13.00	1.94,12.50	1.19,11.50
11	5.91,17.81	5.41,17.31	4.91,16.81	4.41,16.31	3.91,15.81	3.45,15.31	3.04,14.81	2.67,14.31	2.33,13.81	1.73,12.81
12	7.01,19.00	6.51,18.50	6.01,18.00	5.51,17.50	5.01,17.00	4.51,16.50	4.01,16.00	3.54,15.50	3.12,15.00	2.38,14.00
13	7.42,20.05	6.92,19.55	6.42,19.05	5.92,18.55	5.42,18.05	4.92,17.55	4.42,17.05	3.95,16.55	3.53,16.05	2.78,15.05
14	8.50,21.50	8.00,21.00	7.50,20.50	7.00,20.00	6.50,19.50	6.00,19.00	5.50,18.50	5.00,18.00	4.50,17.50	3.59,16.50
15	9.48,22.52	8.98,22.02	8.48,21.52	7.98,21.02	7.48,20.52	6.98,20.02	6.48,19.52	5.98,19.02	5.48,18.52	4.48,17.52
16	9.99,23.99	9.49,23.49	8.99,22.99	8.49,22.49	7.99,21.99	7.49,21.49	6.99,20.99	6.49,20.49	5.99,19.99	4.99,18.99
17	11.04,25.02	10.54,24.52	10.04,24.02	9.54,23.52	9.04,23.02	8.54,22.52	8.04,22.02	7.54,21.52	7.04,21.02	6.04,20.02
18	11.47,26.16	10.97,25.66	10.47,25.16	9.97,24.66	9.47,24.16	8.97,23.66	8.47,23.16	7.97,22.66	7.47,22.16	6.47,21.16
19	12.51,27.51	12.01,27.01	11.51,26.51	11.01,26.01	10.51,25.51	10.01,25.01	9.51,24.51	9.01,24.01	8.51,23.51	7.51,22.51
20	13.55,28.52	13.05,28.02	12.55,27.52	12.05,27.02	11.55,26.52	11.05,26.02	10.55,25.52	10.05,25.02	9.55,24.52	8.55,23.52

Figure 1: 90 % confidence level intervals for Poisson signal mean μ, for totals events observed n_0, for known background b (Feldman and Cousins 1999).