Dark Matter (WS 2017/18) - Problem sheet 6

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Time: Wd. 09:15 - 11:00

Venue: Philosphenweg 12, kHS

Deadline for this sheet: 20.12.2017

1 Detecting dark matter with colliders

The purpose of this problem sheet is to give a brief, guided introduction to how dark matter candidates are searched for in collider experiments. As an example, we look at a paper from the ATLAS collaboration (arXiv:1411.1559) at the Large Hadron Collider (LHC), in which an analysis looking for physics beyond the Standard Model (SM) is described. "Figures" refer to figures in that paper. For answering the questions, you are encouraged to research information on your own, although almost everything needed to answer the questions on this sheet should be available in the references given.

1.1 Particle detection with ATLAS *3 Points*

To prepare for reading the paper, it is necessary to understand the very basics of how ATLAS is detecting particles. Besides general available resources, the following link might prove to be useful:
`http://atlas.physicsmasterclasses.org/en/zpath_playwithatlas.htm`

1. Describe the purpose of the solenoid magnet, the tracking systems, the two different calorimeter types and the muon spectrometer.
2. Explain how the detector sub-systems respond when a proton/neutron is detected.
3. Explain how the detector sub-systems respond when an electron/muon/photon is detected.
4. What is the transverse missing energy E_T^{miss}? For the "identification" of which particles is it useful? Why is not the total missing energy being used?

1.2 Theoretical treatment and signatures of dark matter *4 Points*

Now is a good point to start reading arXiv:1411.1559. Focus on the key points and try to not get lost in the details! As they play a key role in the paper, a short introduction to effective field theories (EFTs) is provided in the following, with more information being available in arXiv:1008.1783 and arXiv:1307.2253 if needed:
An EFT assumes the SM to describe the low-energy limit of a more complete, higher-order theory. As a consequence, additional effects resulting from this theory show themselves only as small disturbances from the SM, which can be described without knowing the details of this higher-order theory by introducing effective operators into the SM Lagrangian. These ignore, for ex., dependencies on the momenta transferred via mediator particles.

The mass scale M_* is a measure for both the mass M of the mediator particle and the coupling strengths g_i of the higher-order theory which is approximated by the EFT:

$$M_* = M/\sqrt{g_1 g_2}$$

The EFT is considered to be valid as long as the mass of the dark matter particle m_χ is small compared to M. If both are at the same order of magnitude, the EFT cannot be assumed to provide a good approximation any longer. A historical example for an EFT would be Fermi's interaction, which approximates the weak interaction of the SM.

1. What does the grey blob in the Feynman diagram shown in Figure 2 represent?
2. Which dark matter signature is being searched for in the paper?
3. Which Standard Model interaction makes up most of the background? Why? Draw the corresponding Feynman diagram.
4. Which types of the backgrounds mentioned could, in principle, be reduced, and how?
5. What are some of the other signatures one can use to look for dark matter? Name at least two of them and draw the Feynman diagrams of the corresponding interactions.

1.3 Dark matter search results *3 Points*

1. Explain Figure 9. What does it imply for the search for new physics?
2. Figure 13 compares limits from direct detection experiments, where the involved momentum transfers are at the order of $\mathcal{O}(10\ \text{keV})$, to EFT limits derived from the analysis in the paper, where involved momentum transfers can be at $\mathcal{O}(100\ \text{GeV})$ and above. What are potential caveats when doing this?