Exercises for Neutrino Physics: Theory and Experiment

Teresa Marrodán Undagoitia
Werner Rodejohann

Submission Date: Tuesday, 22. June 2021 before 11:00

Tutors:
Janine Hempfling: janine.hempfling@mpi-hd.mpg.de
Oliver Scholer: scholer@mpi-hd.mpg.de

Sheet 10: Experiment

1. **GZK Cut-Off [2 Points]**

   Extragalactic cosmic rays with high energies above a certain limit are suppressed due to the so-called GZK cut-off. For this reason very distant sources can not be observed by cosmic rays but with high energy neutrinos. Estimate the mean free path of protons with an energy of about $10^{20}\,\mathrm{eV}$. The cross section at this energy for Δ^+-resonance with photons from the cosmic microwave background is $\sigma \sim 10^{-28}\,\mathrm{cm}^2$ and the number density of photons is $n_\gamma \sim 400\,\mathrm{cm}^{-3}$. Which location in our universe does this correspond to?

2. **High Energy Neutrinos in IceCube [8 Points]**

   IceCube is measuring neutrinos in the ice of Antarctica. They detected a neutrino with a high energy of about $290\,\mathrm{TeV}$. Read the paper *Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A* from the IceCube Collaboration (https://science.sciencemag.org/content/sci/361/6398/eaat1378.full.pdf) and work through the following tasks:

   (a) Describe which muon neutrino interaction in ice could generate a muon. Are these neutral current or charged current interactions?

   (b) A muon neutrino interaction was discovered in IceCube with energy $290\,\mathrm{TeV}$ pointing towards the Blazar TXS 0506+056. Describe how the energy can be deduced from the measurement of the muon track and how the direction is extracted. Discuss which effect could reduce the precision of obtaining the direction from which the muon neutrino is coming.

   (c) An electromagnetic counterpart for the neutrino emission was searched with several other observatories. List the experiments which have searched for the EM radiation from Blazar TXS 0506+056 including the corresponding energy range.

   (d) Try to estimate the luminosity of the source of the neutrino by knowing the information that one neutrino of energy $290\,\mathrm{TeV}$ was detected over a time period of 6 months in $1\,\mathrm{km}^3$ ice detector. The cross-section of the interaction of a muon neutrino of $E = 290\,\mathrm{TeV}$ in water is $\sigma \sim 10^{-31}\,\mathrm{cm}^2$. Consider that the distance of TXS 0506+056 is about $1.7\,\mathrm{Gpc}$.

3. Radio and Acoustic Neutrinos [3 Points]

As mentioned in the lecture the detection of radio and acoustic signals of neutrinos opens a new window to detect ultra-high energy neutrinos produced by the interaction of ultra-high energy cosmic rays with the CMB.

(a) The radio and acoustic signal of the neutrinos is produced due to the Askaryan effect. Explain this effect for both, radio and acoustic signals, and give the related frequency ranges.

(b) The UHE neutrinos can also be detected by experiments based on the common optical Cherenkov effect like IceCube. What are the advantages of the radio/acoustic neutrino experiments compared to optical ones?

(c) To evaluate the feasibility of the acoustic neutrino detection in ice the South Pole Acoustic Test Setup (SPATS) was built in 2007. Explain the setup and working principle of SPATS.