(A) Install a root precompiled version

https://root.cern/install/

ROOT is an open source (free) software package from CERN written in C++. It is used by all high energy physics experiments to store and analyzer data.

One can find a lot of information at the ROOT. web page below:

https://root.cern/

One can find more general instruction on how to get started here:

https://root.cern/get_started/

as well as info on installing the pre-complied version, which is very simple:

https://root.cern/install/

(B) Find scientific publications

https://inspirehep.net/literature?sort=mostrecent&size=25&page=1

Example of search : Search by title and for the MINOS Collaboration (cn keyword below), type in the search box:

find title observation and title seasonal and title variation and cn MINOS

(C) Get basic info on Particle Physics (PDG)

https://pdg.lbl.gov/

You can find intros, history plots, constants, Units, Mathematical tools and many more!

https://pdg.lbl.gov/2022/reviews/contents_sports.html

(E) Get info on the Monte Carlo in general

Mathematical tools section in PDG:

https://pdg.lbl.gov/2022/reviews/contents_sports.html

and specifically, Monte Calro Techniques:

https://pdg.lbl.gov/2022/web/viewer.html?file=../reviews/rpp2022-rev-monte-carlo-techniques.pdf

(F) Statistical Compatibility between two histograms with ROOT

Chi2Test()
https://root.cern/doc/master/classTH1.html#a6c281eebc0c0a848e7a0d620425090a5
AndresonDarlingTest()
https://root.cern/doc/master/classTH1.html#aa395c473ea9693359a74189fbe0ee0db
KolmogorovTest()
https://root.cern/doc/master/classTH1.html#aeadcf087afe6ba203bcde124cfabbee4

And references therein.

Project A

Open the root file with the number of cosmic muons per event for different runs:

Day of Year	Runs
14	6314
101	7559
141	7941
198	8902
326	10418
327	10431
330	10444
336	10529
348	6201

i) Create a TGraph with asymmetric errors (you can use the template)
ii) Give the values of the flux and the errors as you can estimate them from the Mean and the Error on the Mean.
iii) Add a 2% systematic uncertainty for each measurement, uncorrelated point by point.
iv) Fit with the hypothesis of the function :

$$F(t)=C(1+B*\cos(2\pi(t- t0)/T)) ,T =365 \text{ (days of the year)}$$

What do you observe in terms of a seasonal variation of the Cosmic muon rate?
How do these results compare with bibliography?

[0] The ProtoDUNE Single-Phase Detector, DUNE Collaboration (J. Stewart, Argonne for the Collaboration), 10.1109/NSSMIC.2017.8532623 Proceedings, 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference and 24th international Symposium on Room-Temperature Semiconductor X-Ray & Gamma-Ray Detectors (NSS/MIC 2017) : Atlanta, Georgia, USA, October 21-28, 2017
[1] MINOS collaboration, Observation of Seasonal Variation of Atmospheric Multiple-Muon Events in the MINOS Near and Far Detectors, Phys. Rev. D 91 (2015) 112006 [1503.09104].

[2] Rostislav Kokoulin. Seasonal variations in the intensity of muon bundles detected at the ground level . PoS, ICRC2015:367, 2016.
[3] NOVA collaboration, Seasonal variation of multiple-muon cosmic ray air showers observed in the NOvA detector on the surface, Phys. Rev. D 104 (2021) 012014 [2105.03848].
[4] NOVA collaboration, Observation of seasonal variation of atmospheric multiple-muon events in the nova near detector. Phys. Rev. D, 99:122004, Jun 2019.
[5] N. Agafonova et al. Measurement of the cosmic ray muon flux seasonal variation with the OPERA detector. JCAP, 10:003, 2019.

Books

Cosmic Rays and Particle Physics: Thomas Gaisser

Project B

Open the data and the simulated (MC) files and

i) Superimpose the number of tracks, track length, azimuth and zenith angles and compare data with simulation.
ii) Create the ratio (with the proper error) of data to simulation.
iii) Compare data for the different months, study their stability and judge how stable the data are as a function of time. You can use mean values of distributions or other metrics (i.e . ratios).

What do you observe and what can you conclude from the above comparisons? Are data of high quality? Is the MC describing the data well? Use a statistical metric (like the Kolmogorov Smirnov test) to quantify the data/MC agreement.

Are data stable as a function of time concerning the track length, azimuth and zenith angle distributions? If not can there be an explanation?

[0] The ProtoDUNE Single-Phase Detector, DUNE Collaboration (J. Stewart, Argonne for the Collaboration), 10.1109/NSSMIC.2017.8532623 Proceedings, 2017 IEEE Nuclear Science Symposium and Medical Imaging Conference and 24th international Symposium on Room-Temperature Semiconductor X-Ray & Gamma-Ray Detectors (NSS/MIC 2017) : Atlanta, Georgia, USA, October 21-28, 2017
[1] MINOS collaboration, Observation of Seasonal Variation of Atmospheric Multiple-Muon Events in the MINOS Near and Far Detectors, Phys. Rev. D 91 (2015) 112006 [1503.09104].
[2] Rostislav Kokoulin. Seasonal variations in the intensity of muon bundles detected at the ground level . PoS, ICRC2015:367, 2016.
[3] NOVA collaboration, Seasonal variation of multiple-muon cosmic ray air showers observed in the NOvA detector on the surface, Phys. Rev. D 104 (2021) 012014 [2105.03848].

[4] NOVA collaboration, Observation of seasonal variation of atmospheric multiple-muon events in the nova near detector. Phys. Rev. D, 99:122004, Jun 2019.
[5] N. Agafonova et al. Measurement of the cosmic ray muon flux seasonal variation with the OPERA detector. JCAP, 10:003, 2019.