

Using Machine learning to segregate cosmic muons from background gammas

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Introduction

Cosmic muons are high-energy charged particles originating from cosmic rays in the upper atmosphere and reaches the Earth surface. These cosmic muons has the mean energy of $\sim 3\text{-}4$ GeV, which make them a particularly useful probe for applications like Muon Tomography, and can also be used as a probe to calibrate particle detectors. In addition to cosmic muons there is several order of magnitude more cosmic background is also available in our environment. Hence, these cosmic muons need to be segregated from background, in-order to be used for any muon based application. In the current we will present a Machine Learning based approach to segregate these cosmic muon from background gamma using the plastic scintillator detector.

Detector Setup

The detector setup consist of a plastic scintillator bar ($10\text{ cm} \times 10\text{ cm} \times 100\text{ cm}$) coupled to the Photo Multiplier Tube (PMT) at both ends, which are used to get the timing and the integrated charge. The geometric mean of these integrated charges correspond to the energy deposited in the scintillator by the incident radiation, and is key to segregate the cosmic muon from background γ rays, as it is seen from the GEANT4 [1] simulation that cosmic muons deposit $\sim 2\text{ MeV/cm}$ for the material used in the scintillator bar which is much more than the energy deposited by background γ rays.

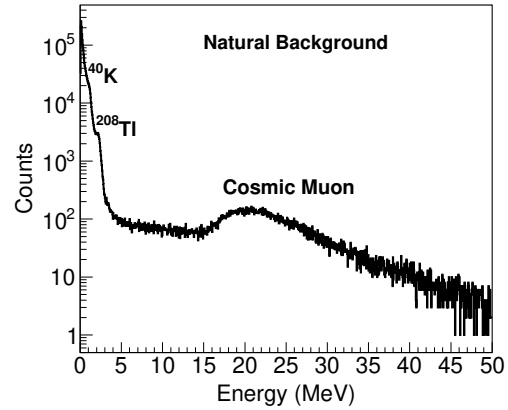


FIG. 1: Spectrum of energy calibrated background γ and cosmic muons

Conventional energy deposition based cosmic muon segregation

The energy calibration of these detectors are conventionally done using different radioactive sources of known energies to get a parameterization to map the integrated charge to energy. The parameterization will then be applied on the experimental data to get the energy deposited by incident radiation. Fig. 1 shows the plot of energy deposited by cosmic particles after the application of energy calibration. From here one can see that the energy deposited by cosmic muons peaked at $\sim 20\text{ MeV}$, which is also verified using GEANT4 simulation [2]. Hence, an energy threshold of 10 MeV is chosen to segregate the cosmic muons from the background γ rays.

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Machine learning based cosmic muon segregation

The conventional approach needs energy calibration procedure to be applied on individual event and in the second step takes the decision based on the selected threshold. This makes the job computation intensive as background γ rays events are the orders of magnitude more than muon events. This problem can be seen as the binary classification problem in machine learning which can be solved by building a classification model, that can quickly discriminate background γ and muon events without applying any energy calibration. Calibrated data is required only in the initial phase to label the individual events as muon event or background γ event, which is required for building the classification model.

Data Sets

As mentioned above, the data from experiment consist of timing and integrated charge, where the geometric mean of the integrated charge is proportional to the energy deposited. In the present work, only the energy is used for the segregation of cosmic muon, hence in the learning phase of the model, the integrated charge obtained from both the PMTs are used as the input features, and the event is labelled as muon event if the calibrated energy deposited is more than 10 MeV, otherwise it is labelled as background γ event. The labelled data set is used to train and test the classification model and the results are shown below.

Results

After building the labelled dataset, a regression based classification model is trained using 3×10^5 events of labelled data. To evaluate the performance of the classification model, another labelled dataset of 3×10^5 events is used, and muon classification performance of the model is found to be $\sim 99\%$. Later on the same model is applied on raw data using only the two input feature i.e. integrated charge from both the PMTs and without applying

any energy calibration. Once the classification is over, the energy calibration is applied only on those events which are classified as muons,

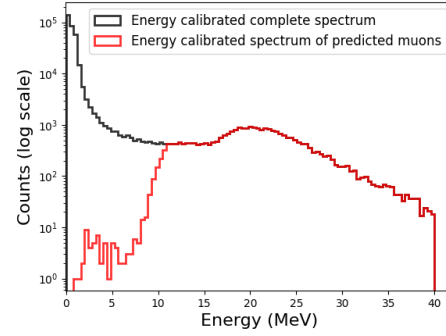


FIG. 2: Muons segregation using Machine learning classification algorithm

and the data is compared with the calibrated data of the complete spectrum, as show in Fig. 2. Here one can see in the red plot, that there very few events of low energy cosmic background which are classified as muons, but from 10 MeV (energy threshold used to label the data) onwards we are able to correctly classify them as muons, which we had previously verified by GEANT4 simulations.

Conclusion

By harnessing the power of advanced machine learning classification algorithms, a successful segregation between cosmic muons and background γ -rays is obtained based on their distinct energy deposition patterns. This has yielded the promising results with significant implications for applications like Muon Tomography.

References

- [1] S. Agostinelli et al., *GEANT4*, *NIM-A* **506**, (2003) 250
- [2] R. Sehgal et al., *JINST* **17** P02036, September **2022**