Artificial Neural Networks as a FPGA Trigger for a Detection of Very Inclined „Young" Showers

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ABSTRACT

Neutrinos play a fundamental role in the understanding of the origin of ultrahigh-energy cosmic rays. They interact through charged and neutral currents in the atmosphere generating extensive air showers. However, the very low rate of events potentially generated by neutrinos is a significant challenge for detection techniques and requires both sophisticated algorithms and high-resolution hardware. Air showers initiated by protons and muon neutrinos at various altitudes, angles and energies were simulated in CORSIKA and the Auger OffLine event reconstruction platforms, giving analog-to-digital (ADC) patterns in Auger water Cherenkov detectors on the ground. The proton interaction cross section is high, so proton „old" showers start their development early in the atmosphere. In contrast to this, neutrinos can generate „young" showers deeply in the atmosphere relatively close to the detectors. Differences between „old" proton and „young" neutrino showers are visible in attenuation factors of ADC waveforms. For the separation of ``old'' proton and „young" neutrino ADC traces many three-layer artificial neural networks (ANNs) were tested. They were trained in MATLAB (in a dedicated way - only „old'' proton and „young" neutrino showers as patterns) by simulated ADC traces according the Levenberg-Marquardt algorithm. Unexpectedly, the recognition efficiency is found to be almost independent of the size of the networks. The ANN trigger based on a selected 8-6-1 network was tested in the Cyclone$®V E FPGA 5CEFA9F31I7, the heart of prototype Front-End boards developed for testing new algorithms in the Pierre Auger surface detectors.

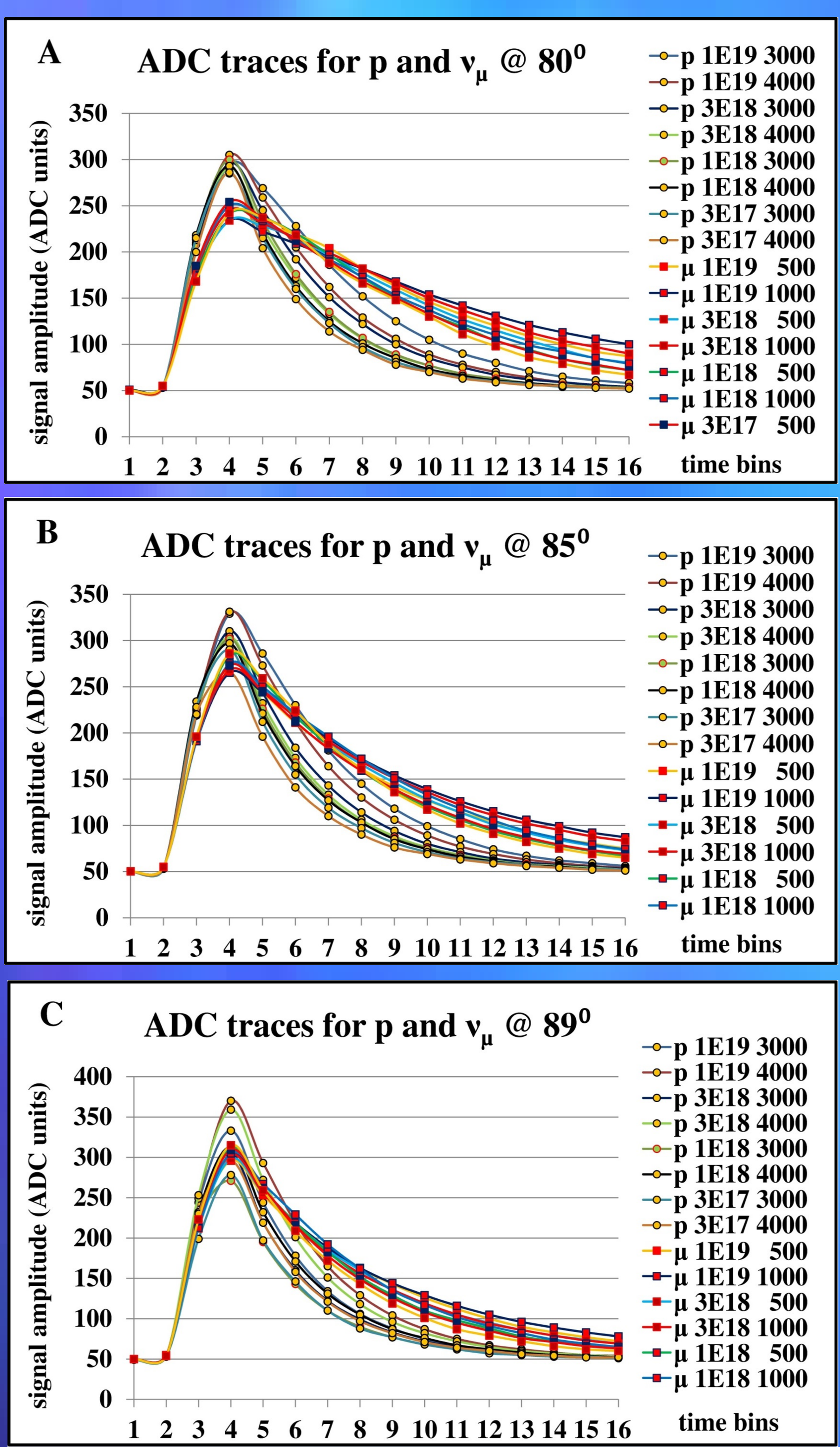

Fig. 1 – Traces produced by ``old'' proton showers (circle markers) and ``young'' neutrino showers (square markers). Traces can be classified using exponential attenuation factors especially for relatively low angles (80°-89°). Graphs show that for large zenith angles and very wide energy ranges „old" proton showers are attenuated faster than „young" neutrino showers.

		500	1000	2000	3000	4000	5000	10000
80°	p			+	+	+		
80°	ν	+	+	+	+	+		
85°	p			+	+	+	+	
85°	ν	+	+	+	+	+	+	
89°	p			+	+	+	+	+
89°	ν	+	+	+	+	+	+	+

Table 1 – Distances used in simulations from the first interaction to detector location for protons and muon neutrinos as a function of zenith angle. All the distances are in g/cm^2. Because of the geometry not all the distances are available from every angle

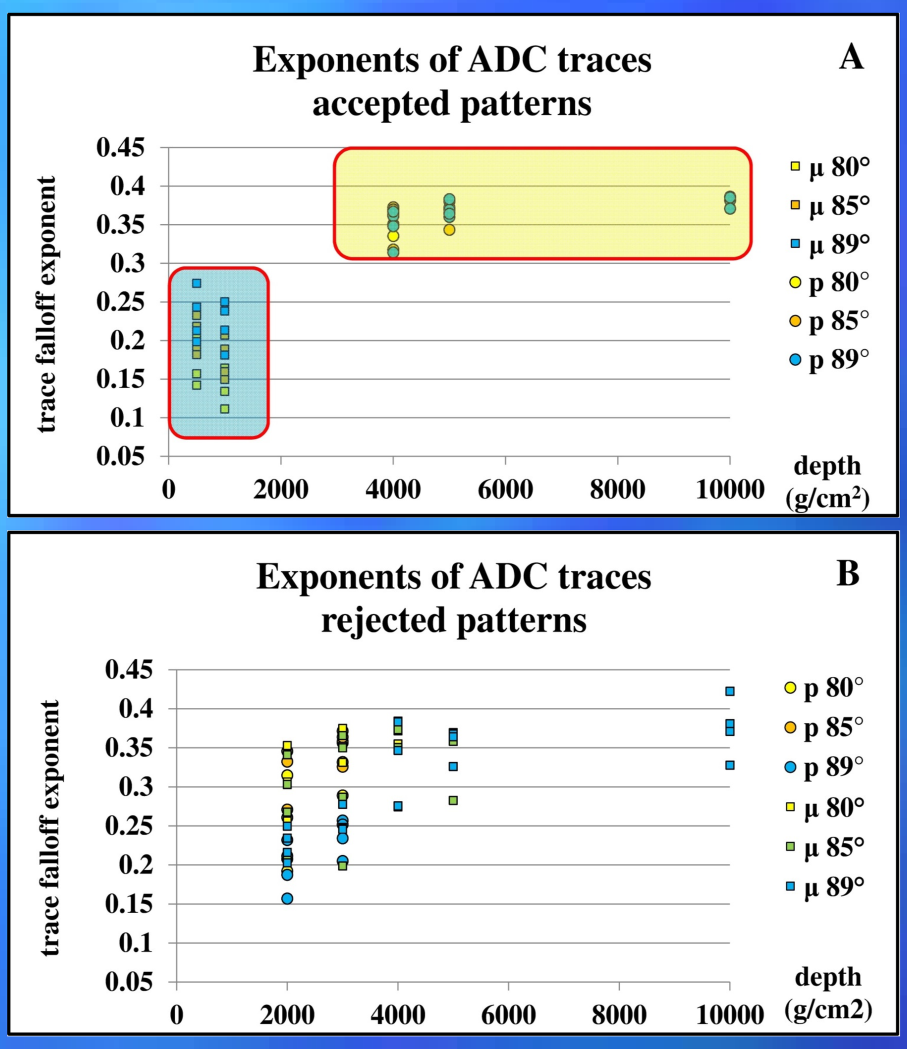

Fig. 2 – Exponents of accepted and rejected traces for protons and neutrinos. Exponents of accepted neutrino and proton traces are well separated from each other (A). Nevertheless, training by patterns for only „old" proton and „young" neutrino showers seems to be justified as protons start their interactions just at the beginning of the atmosphere while the probability of neutrino interactions high in the atmosphere is negligible.

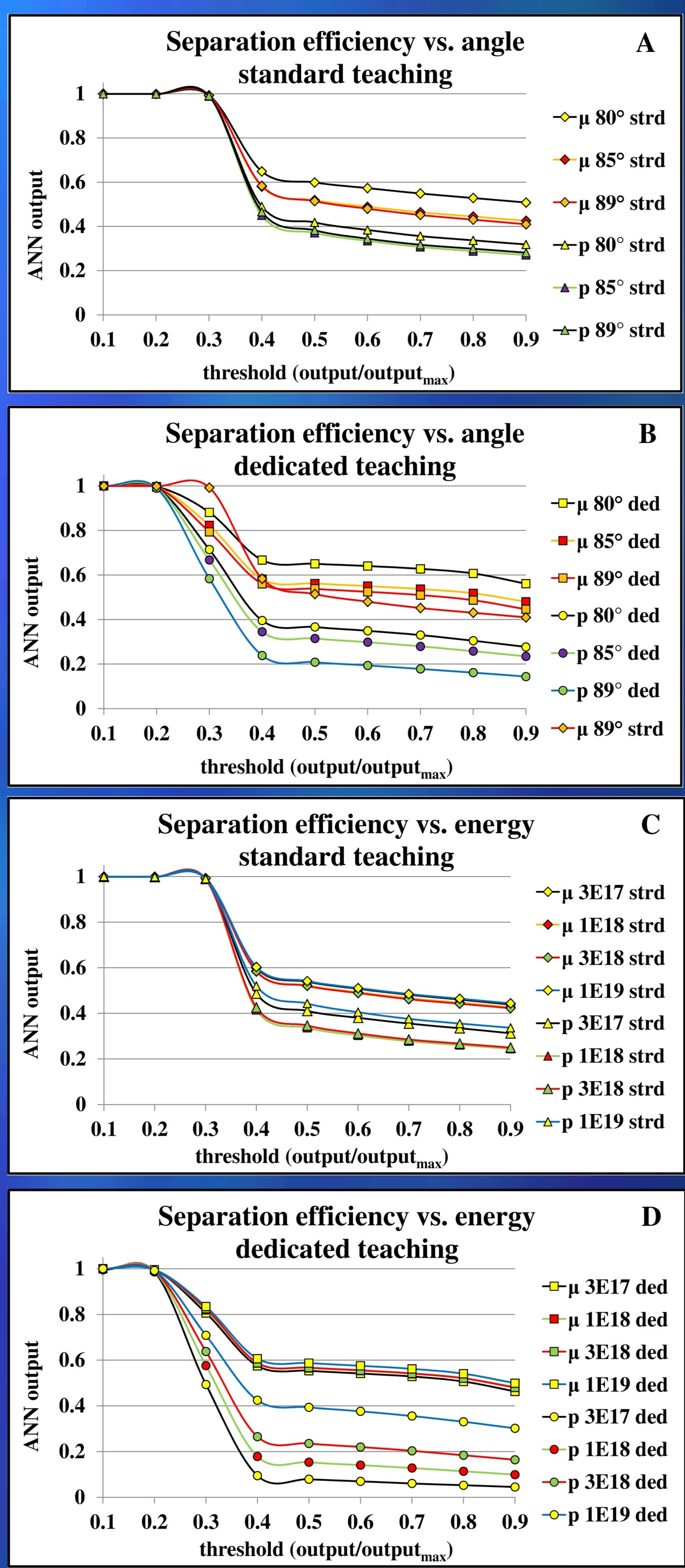

Fig. 3 – Efficiency of separation of the neutrino events from the proton background as a function of the threshold for various angles and energies of the muon neutrinos and protons. The graphs denoted as „standard" (strd) show the efficiency for network training on the basis of a wide range of initial points of the first interaction. The graphs denoted as „dedicated" (ded) show the efficiency when the network is trained by patterns corresponding to „young" neutrino events and „old" proton ones. A higher level of proton background (spuriously recognized) for lower angles (80°) comes with a higher probability of significant EM contribution in a shower (for a slant depth at the level of 3000 - 4000 g/cm²)

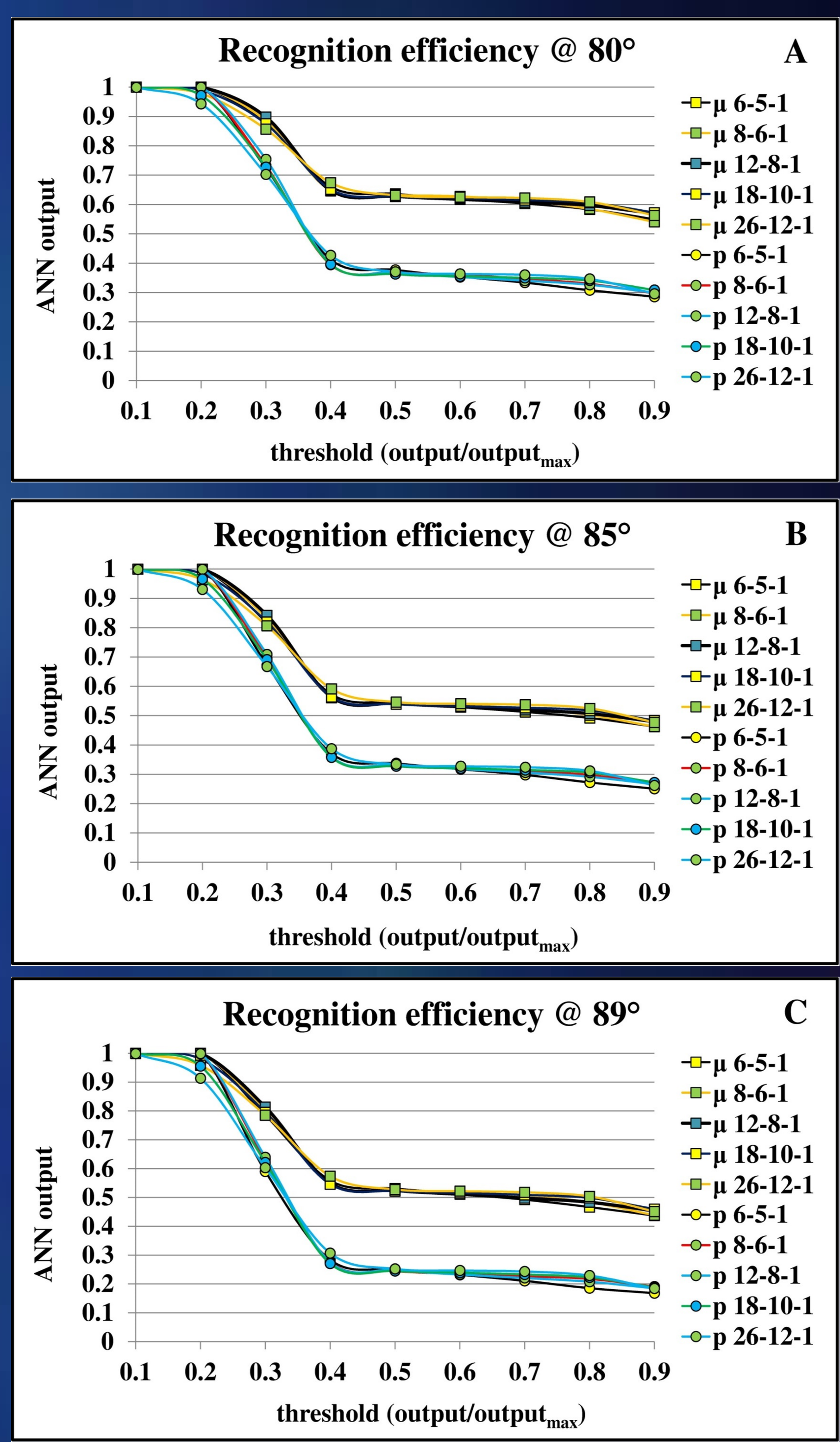

Fig. 6 – Efficiency of neutrino-proton separation for various neural networks.

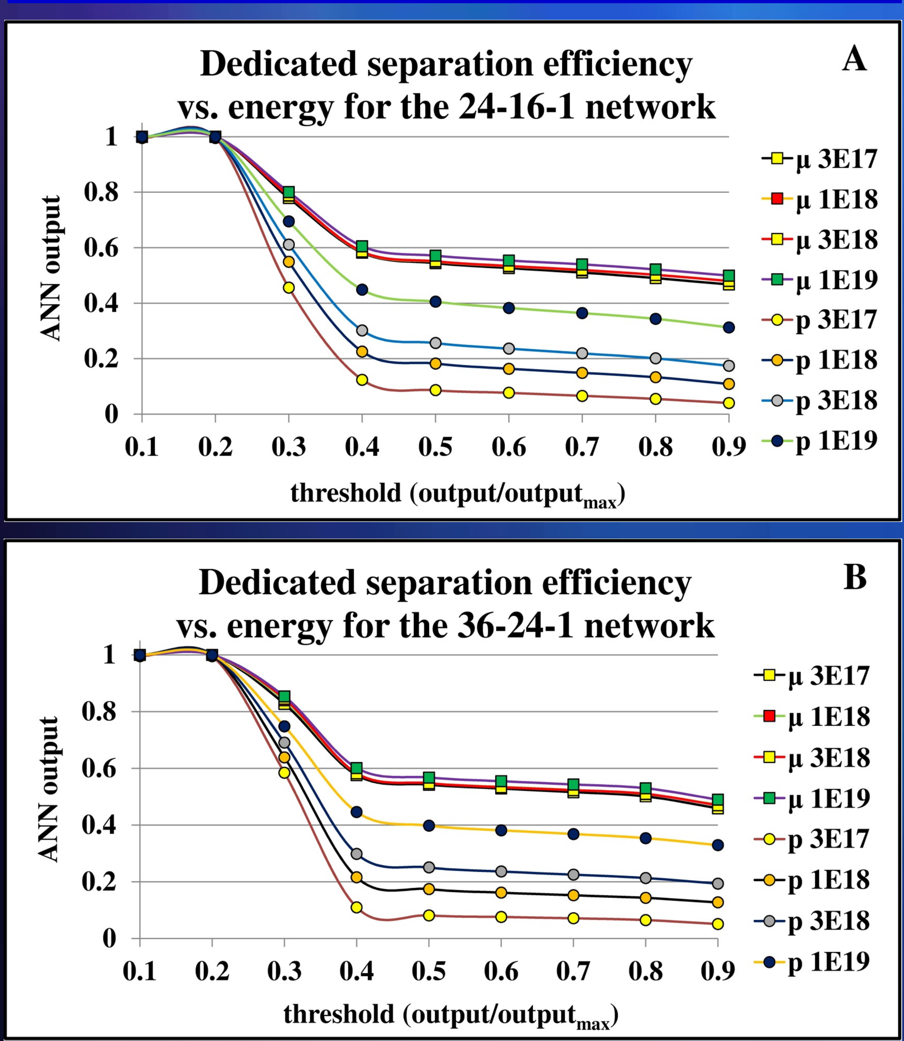

Fig. 4 – Efficiency of neutrino-proton separation for 24-16-1 and 36 24-1 neural networks

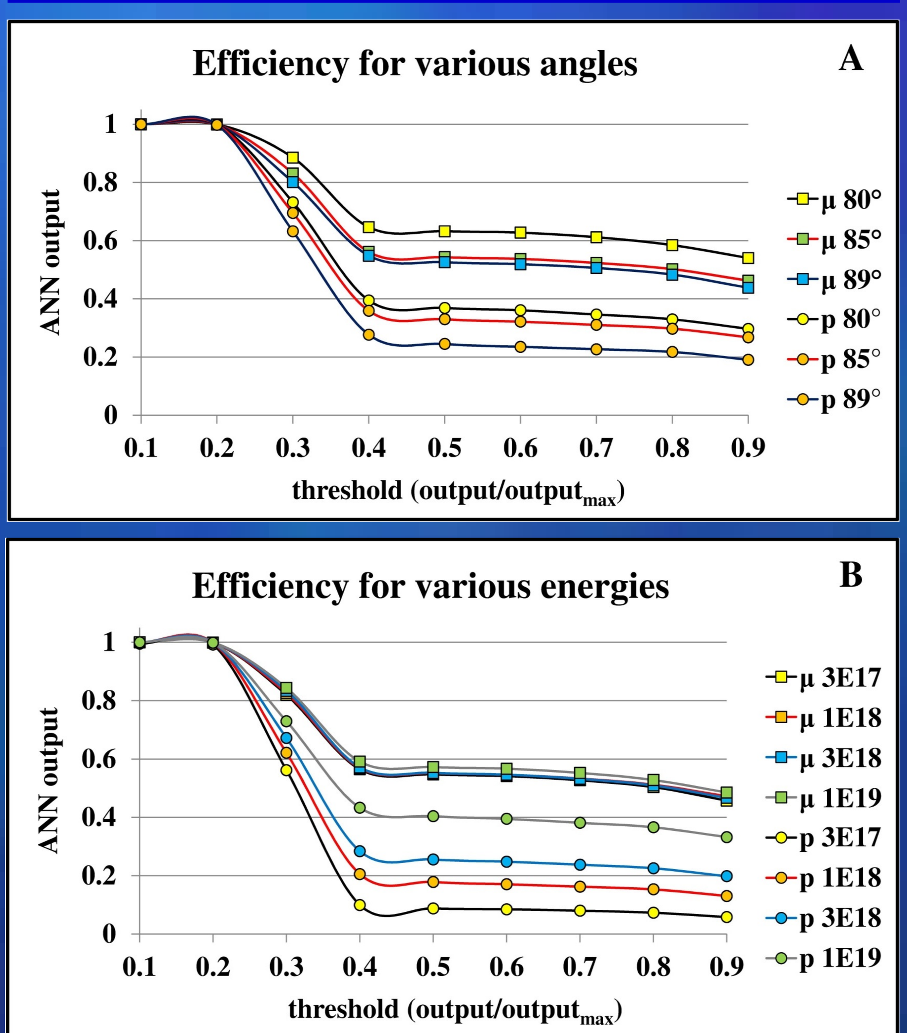

Fig. 5 – The recognition efficiencies for various angles and energies for selected 8-6-1 network.

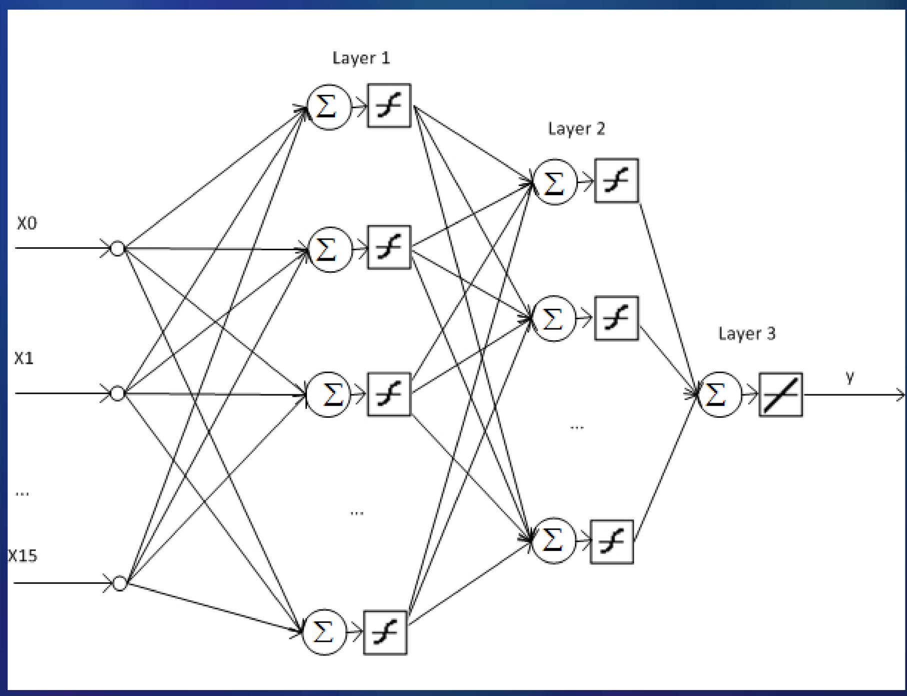

Fig. 6 – Internal structure of an FPGA neural network.

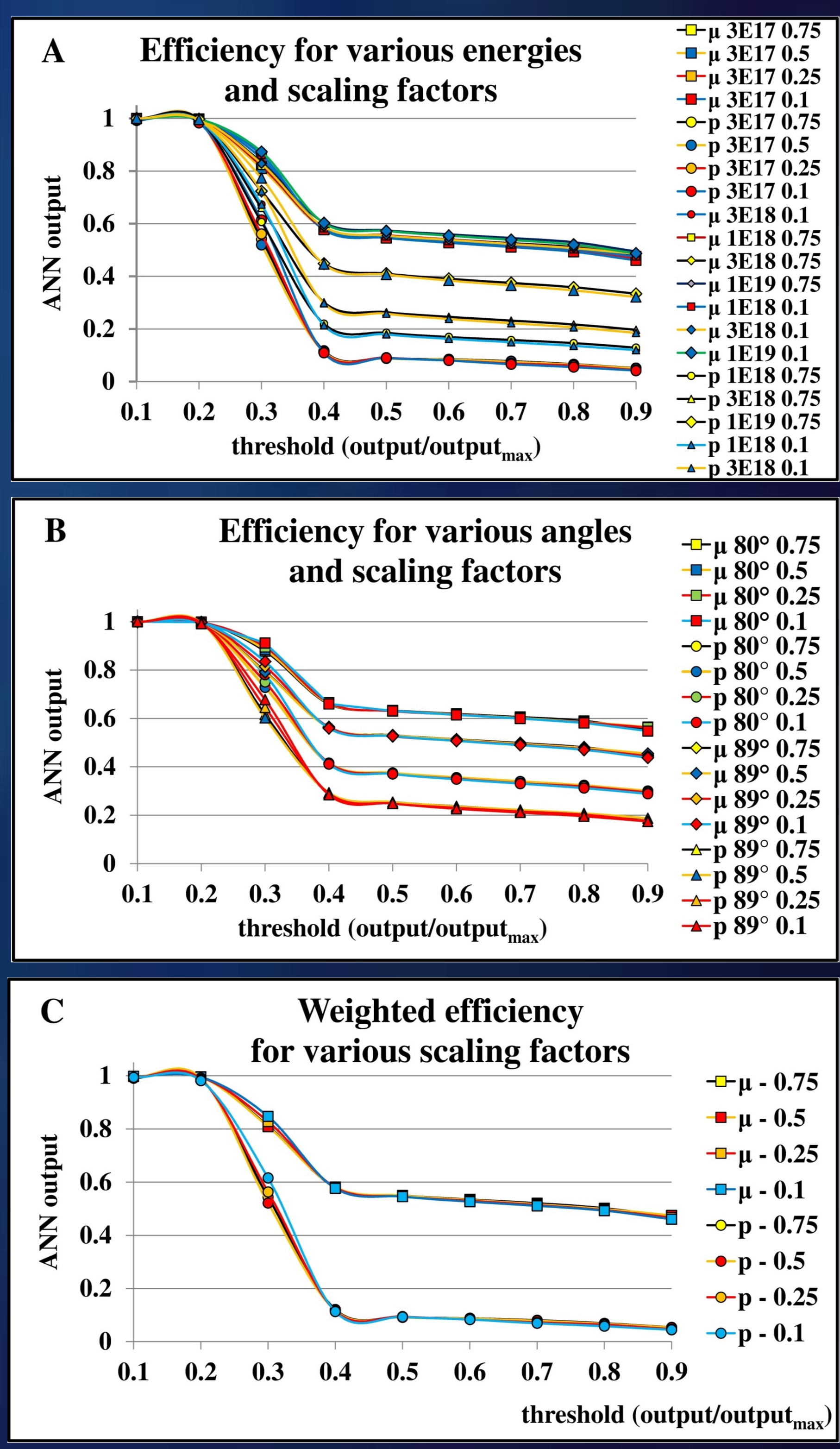

Fig. 7 – Identification efficiencies for the selected 8-6-1 network.

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CONCLUSIONS

We ran CORSIKA simulations for proton and ν_μ primaries. Output data collected at 1450 m a.s.l. (the level of the Pierre Auger Observatory) was an input for OffLine reconstruction providing the ADC response in the WCDs. The ADC obtained traces were thus used to train the 8-6-1 neural network which was tested next in the 5CEFA9F31I7 FPGA Cyclone®V E on the prototype Front-End Board developed for the Pierre Auger surface detector. Preliminary results show that the ANN algorithm can detect neutrino events that are currently neglected by the standard Auger triggers. The recognition efficiency of the neutrino traces by the ANN algorithm strongly depends on the differences between the data used for the ANN training. If we train the ANN with the data containing only traces produced by ``young" neutrino and ``old" proton-induced air showers we can reach an acceptable level of recognition. Moreover, we can distinguish between proton and neutrino events, which means that the ANN algorithm is a very promising approach for future neutrino event searches.

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