Measurement of the Low-energy Muon Spectra with the Rotatable NEWCUT Spectrometer

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A Rotatable Muon Spectrometer

Motivation:

- Measurement of the energy dependent muon fluxes, called spectra, has numerous applications
- High-energy spectra (well beyond the few tens of GeV): studying of particle generation beyond accelerator energies, improve the understanding of extensive air showers, estimating of atmospheric neutrino fluxes, etc.
- Low-energy spectra (upto a few tens of GeV): investigating of the physical properties of the atmosphere, the effects of Earth's magnetic field, studying neutrino decays, etc.
- Muographic imaging utilizes the muon spectra to determine the density-lengths through the investigated targets
- The spectra data are scarce at low-energies that limits the muography of few-meter-sized targets

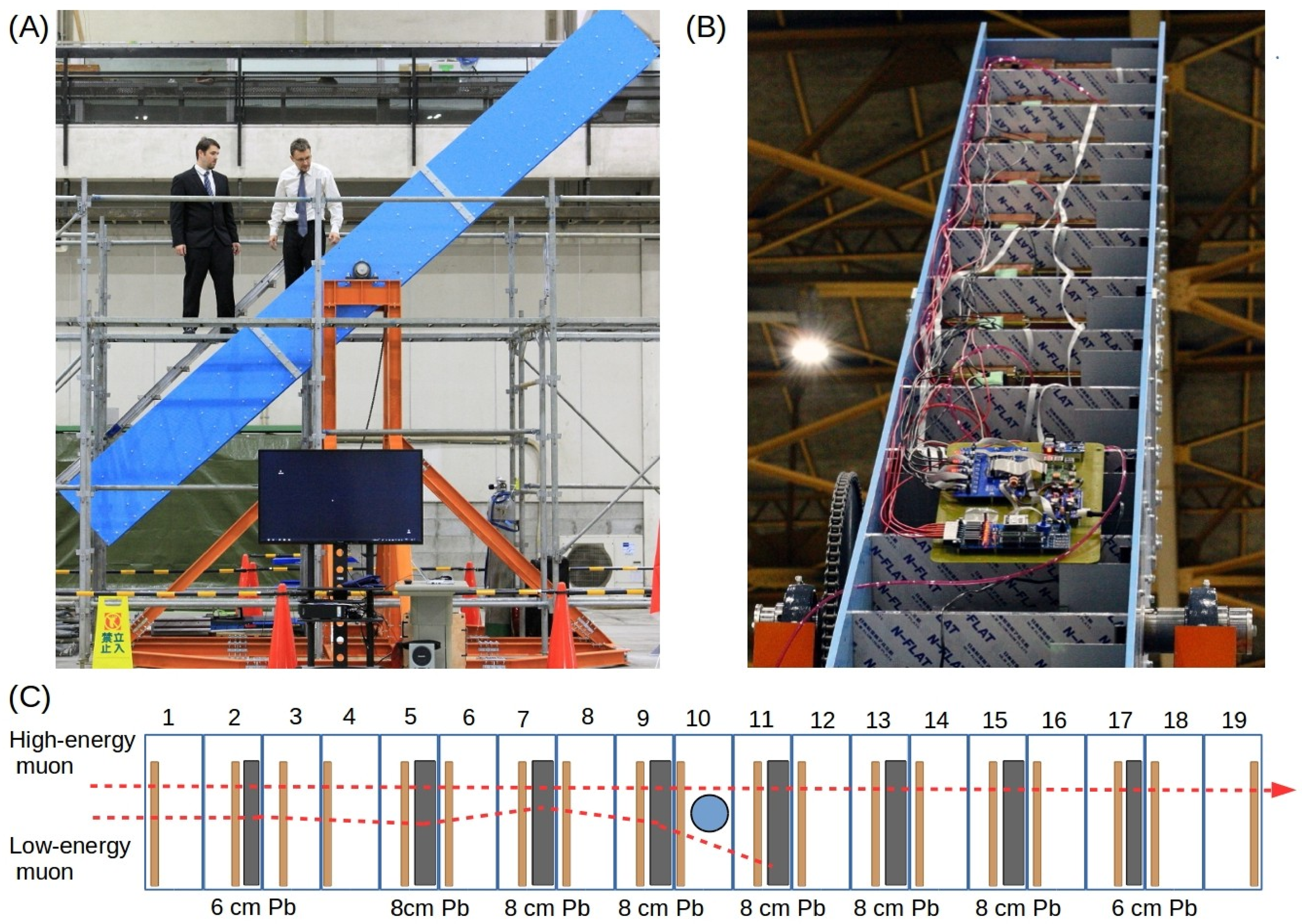


Figure 1. Photographs about the spectrometer from side (A) and front (B) views. (C) Schematic drawing of the arrangement of 19 detectors and 8 lead walls.

Experimental apparatus:

- 6 m long rotatable tracking system consists of 19 Multi-wire-proportional chambers (MWPCs) + 8 lead walls (Figure 1)
- The MWPCs provide positional resolution of 4 mm in 1+1 dimension
- Non-flammable, non-toxic Ar-CO_2 (80%-20%) gas mixture is flushed across MWPCs with the typical flow of 1 L/h.
- The high-voltage of 1750 V applied on the anode wires to achieve the reasonable detection efficiency of above 98 %.
- Data collection triggered by the triple coincidence of MWPCs
- Data acquisition controlled by a microcomputer
- High energy physics data analysis methods (cluster reconstruction, combinatorial tracking algorithm) are applied for track reconstruction

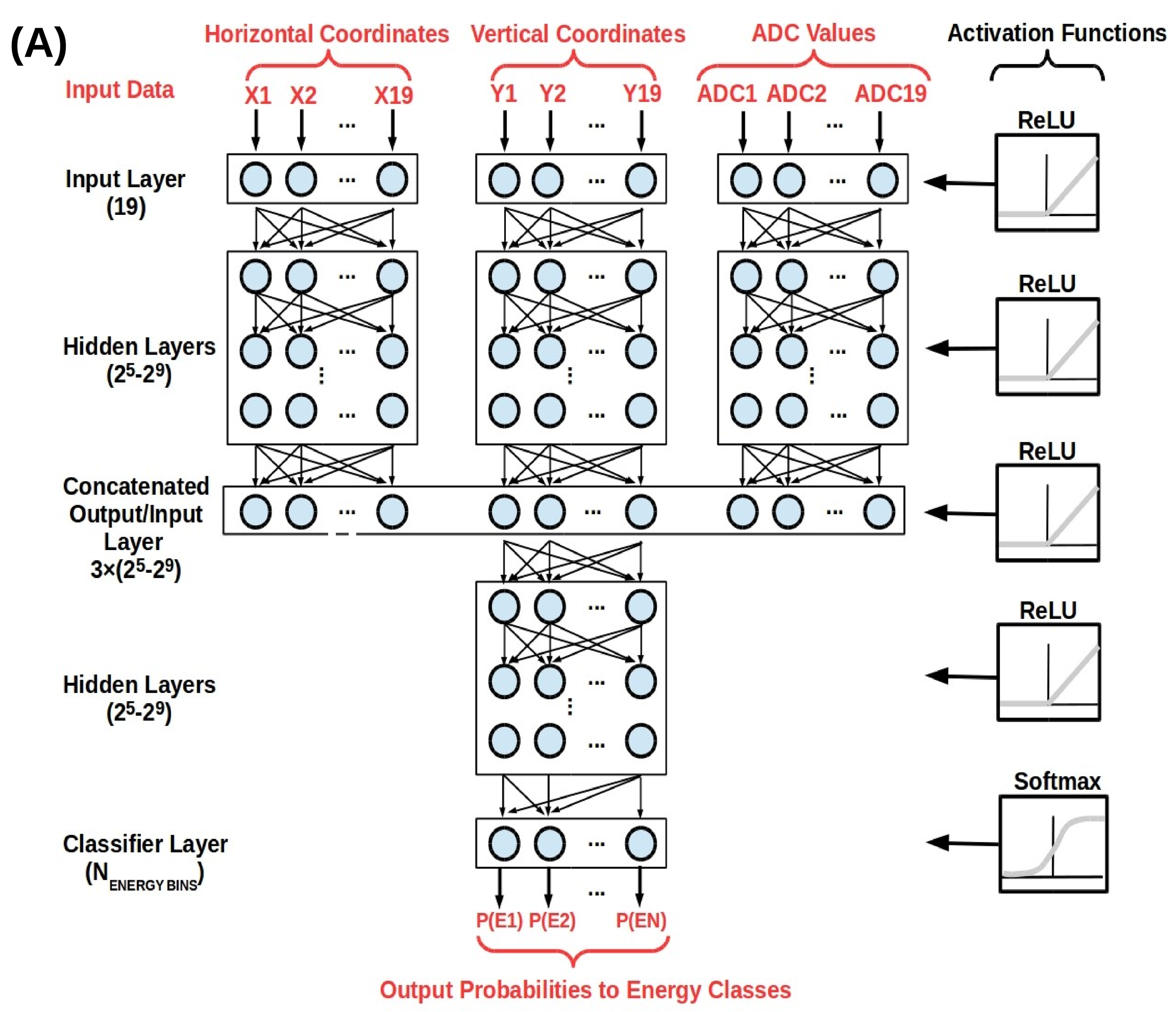
A Neural Network-based Muon Spectra Analyzer

GEANT4 simulation:

- The spectrometer was constructed in GEANT4 framework
- 200,000 muons were injected into the setup with a uniform energy distribution up to 10 GeV
- All relevant electromagnetic physics processes were involved
- Coordinates and energy depositions were reconstructed in each detector layer

Data preparation to machine learning:

- Event-by-event analysis were applied
- Horizontal and vertical coordinates were transformed to detector system
- Energy depositions were summed for each track within an event.
- Total energy deposition distributions were scaled with a×E+b functions to accurately approximate the measured ADC distributions for each detectors

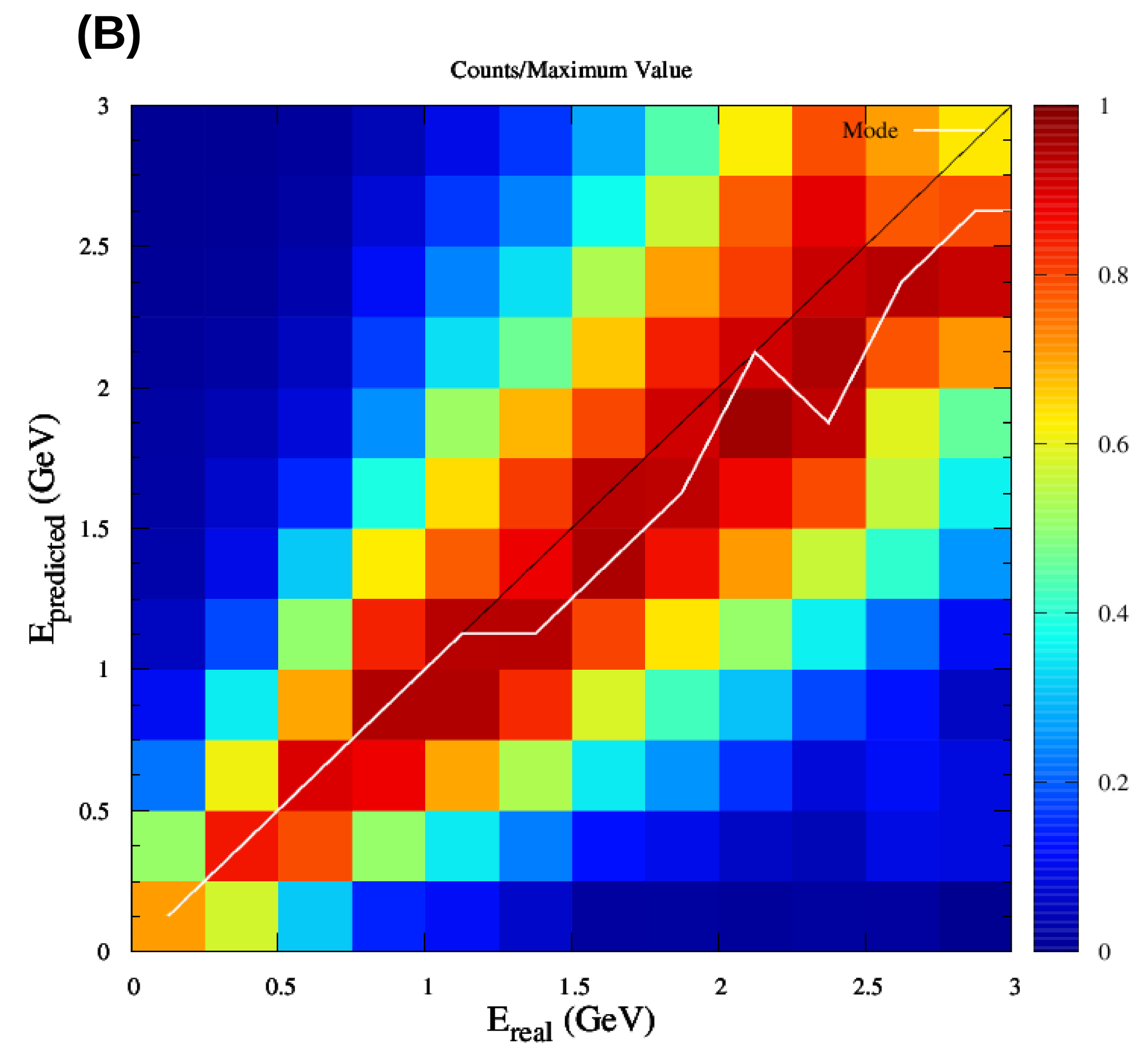


Neural Network:

- 19 horizontal coordinates, 19 vertical coordinates and 19 scaled energy deposits (ADCs) were parallelly read into inputs of neural network (Figure 2A)
- The output layers of three neural networks were concatenated further layers were added with ReLU activation functions
- A classification layer were added with Softmax activation function → bin size of 0.25 GeV was used (Figure 2B)
- Model were optimized to minimize the relative difference between the simulated spectra and results of classification

Preliminary Results:

- Neural network achieved a moderated accuracy of 0.6 and average relative spectra ratios of 0.2 and 0.26 below 2 and 2.5 GeV respectively (Figure 2C)
- The model is planned to be applied on experimental data after its optimization



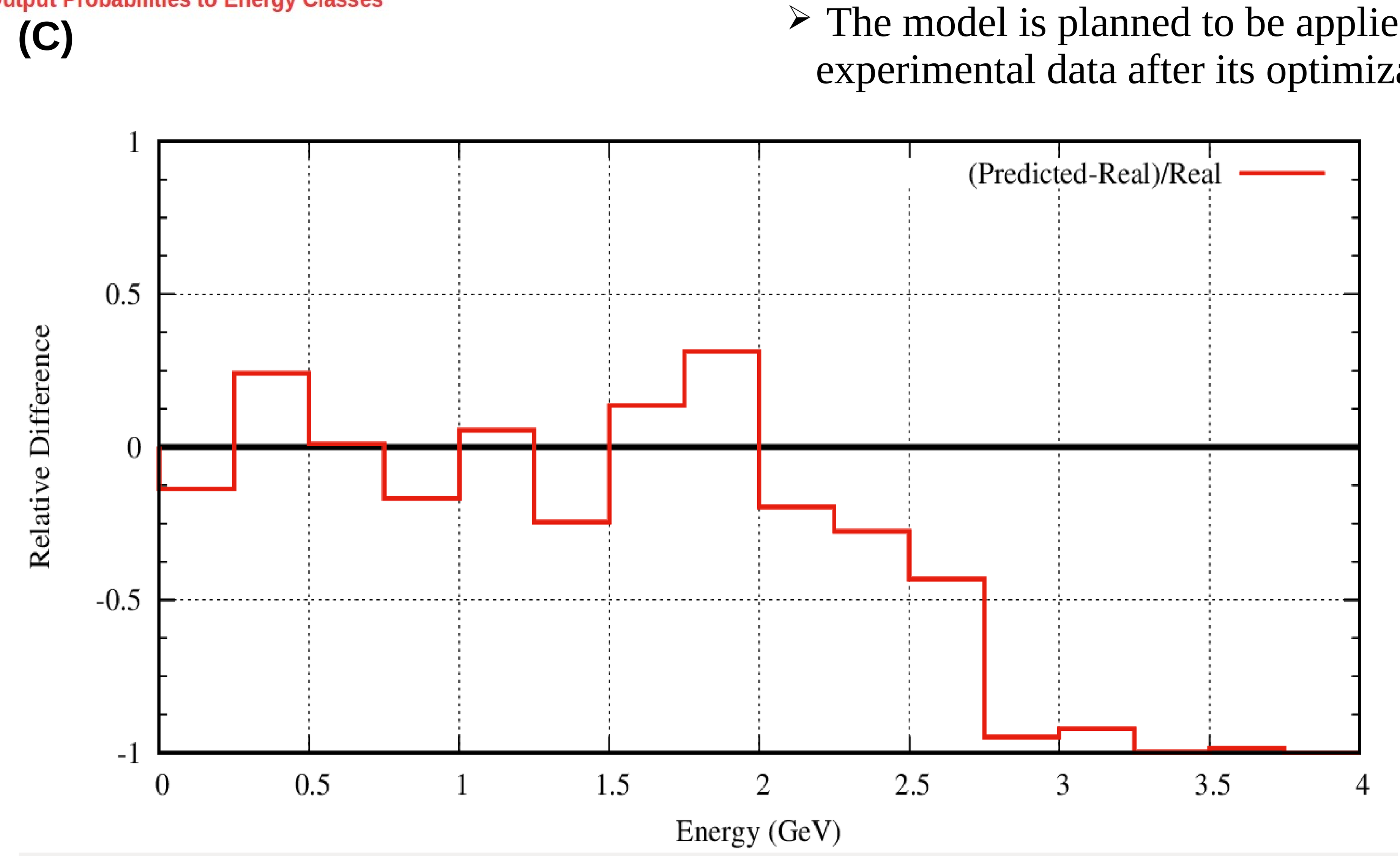


Figure 2. (A) Schematic drawing of neural network applied for muon energy classification. (B) Predicted energy is shown as a function of simulated ("real") energy. (B) Relative spectra ratio, (predicted-real)/real, is shown as a function of energy.