Neutrino direction and flavor reconstruction using deep neural networks

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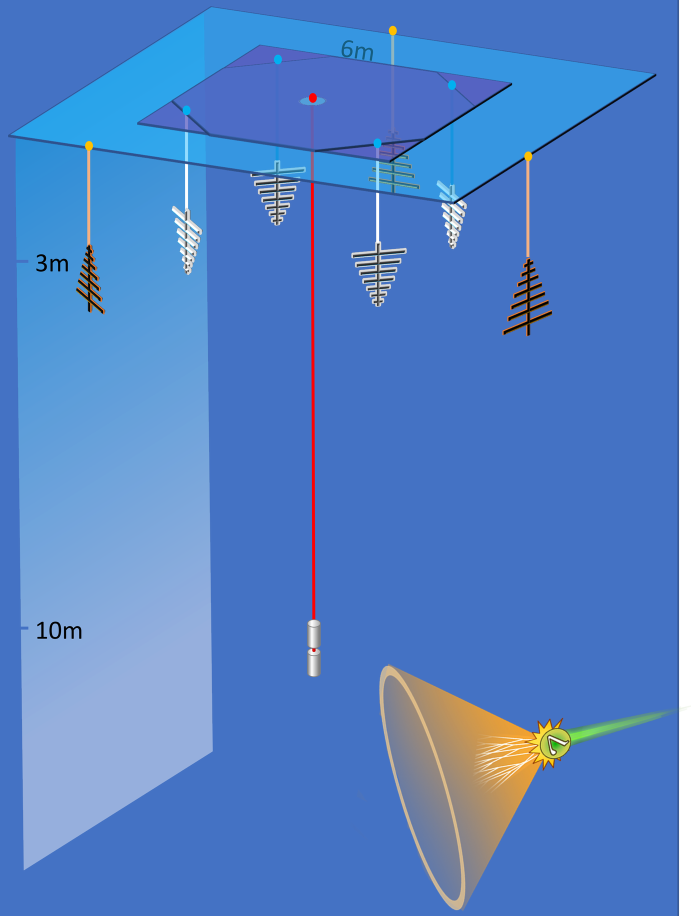
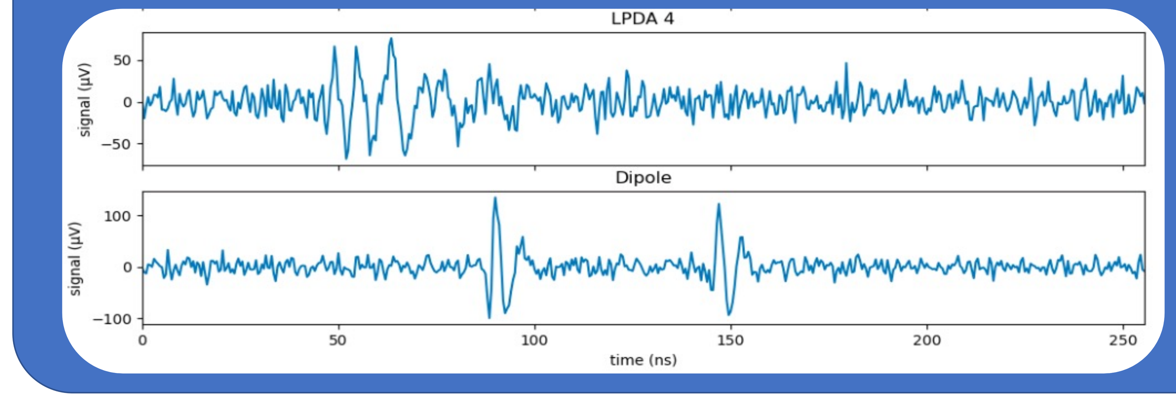
Introduction

- Upcoming detectors on the South Pole & Greenland use the radio technique to detect ultra-high energy neutrinos.
- Reconstructing neutrino properties from data is imperative.
- A deep learning-based approach to direction and flavor is presented.
- NuRadioMC used to generate large realistic training data sets.

Radio technique & Data simulation

- Radio pulses (Askaryan emission) emitted following neutrino-nucleon interactions.
- Signals detected with sparse array of autonomous detector stations.
- NuRadioMC provides large quantities of data.
- Here: shallow detector station with 4 LPDAs and 1 dipole
  - as proposed for ARIANNA-200 and IceCube-Gen2.





Neural network architecture

- VGG inspired neural network.
- Blocks of convolutional layers followed by dense layers.
- Similar networks for flavor and direction recostruction tasks.

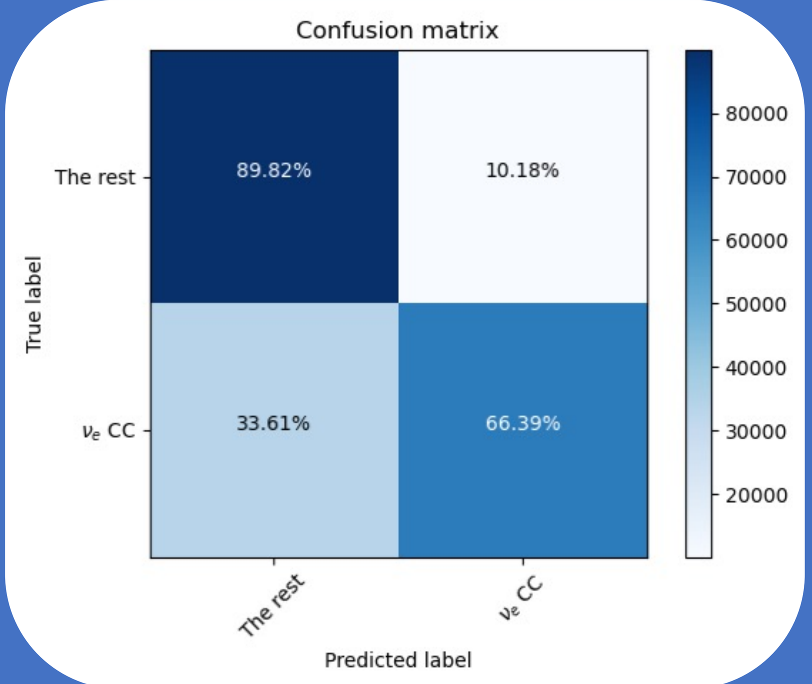
CNN architecture (Flavor)

- **Input layer conv-32 (5x512 input data)**
- Conv-32, (1x5), ReLU
- Conv-32
- Conv-32
- Conv-32
- MaxPooling (1x4)
- Conv-64 (1x5), ReLU
- Conv-64
- Conv-64
- Conv-64
- MaxPooling (1x4)
- Conv-128 (1x5), ReLU
- Conv-128
- Conv-128
- Conv-128
- MaxPooling (1x4)
- Conv-256 (1x5), ReLU
- Conv-256
- Conv-256
- Conv-256
- MaxPooling (1x4)
- BatchNorm + Flatten
- Dense-512, ReLU
- Dense-512
- Dense-2, Softmax (Output layer)

Flavor reconstruction

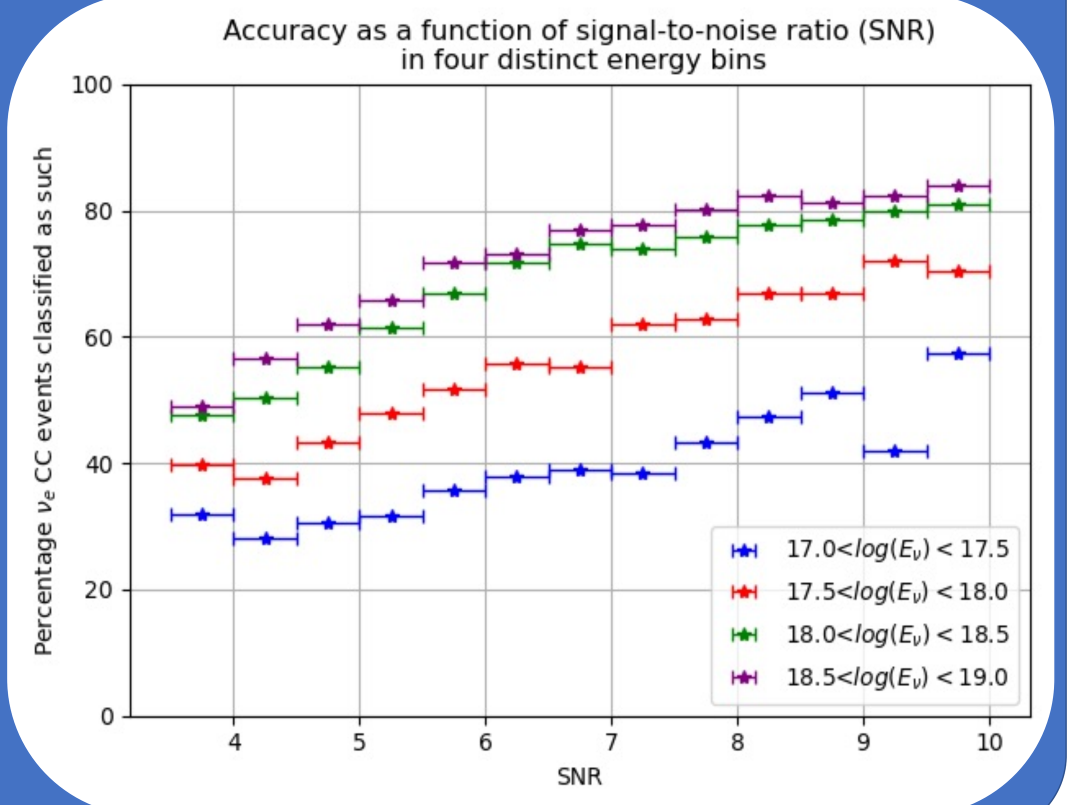
- A first end-to-end reconstruction of neutrino flavor from radio detector data is presented.
- A deep convolutional neural network (CNN) for flavor classification was developed.
- The network distinguishes signals produced in ν_e-CC interactions from those of all other interaction channels.

Flavor reconstruction results



- Events with 10^{17}eV $< E_\nu < 10^{19}$eV were considered.
- ~90% accuracy on non-ν_e-CC events.
- ~66% accuracy on ν_e-CC events.

- Accuracy on ν_e -CC events highly dependent on energy and SNR.
- Poor performance on signals from low E_ν events close to trigger threshold.
- ~85% accuracy at high energy and SNR.
- Performance on non- ν_e -CC events show little energy and SNR dependence.

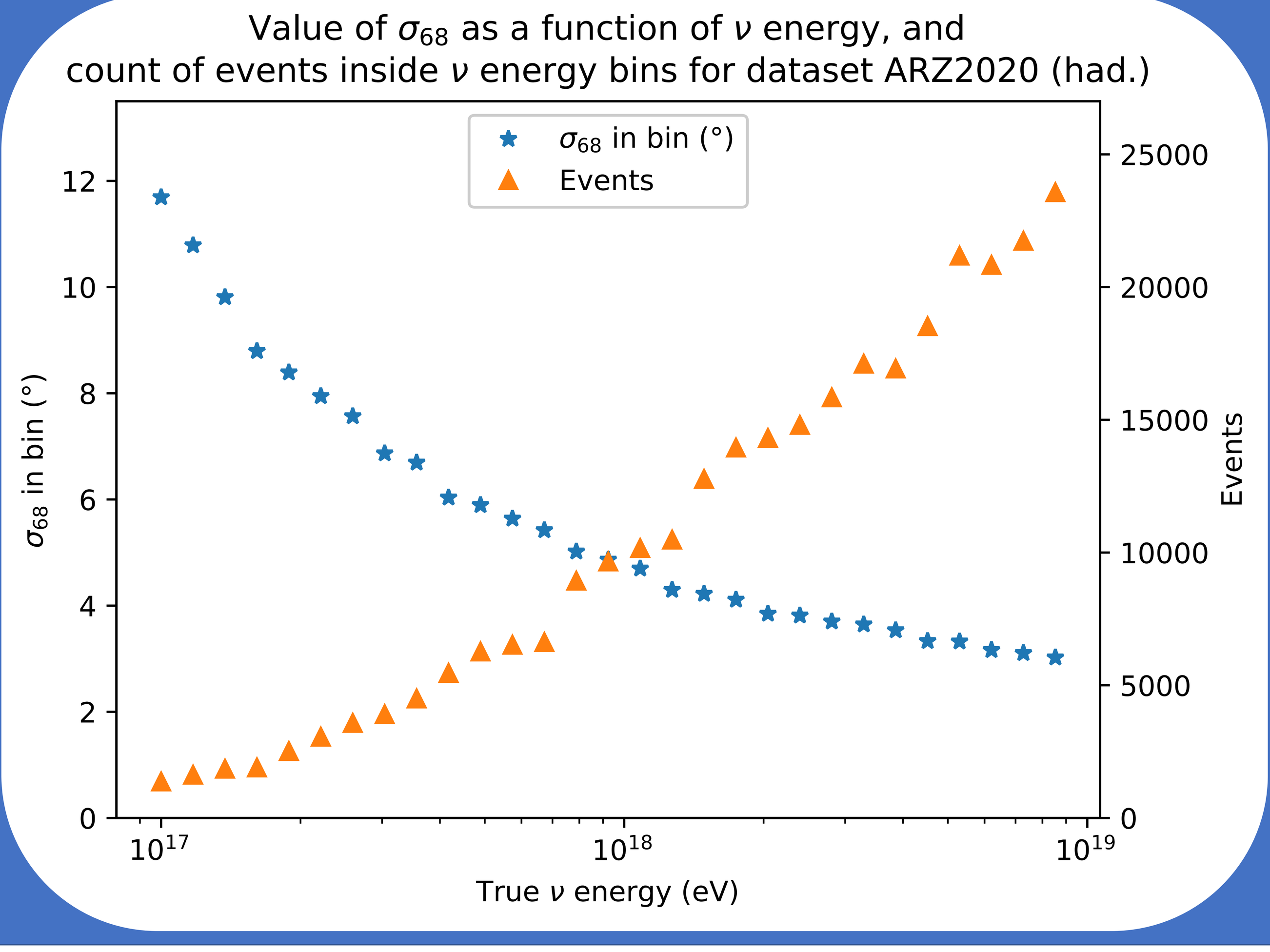


Direction reconstruction

- Precise reconstruction of neutrino direction crucial to identify their sources
- Neural network: very similar as used for flavor reconstruction.
- Space angle difference $\Delta\Psi$: Angle between true and predicted direction.
- Performance quantified by 68 % interval of $\Delta\Psi$, denoted σ_{68}.

Direction reconstruction results

- σ_{68} was 4° for non-ν_e-CC events, 5.5° for ν_e-CC events.
- Reconstruction resolution increases with ν energy.
  - Only partly due to higher signal-to-noise ratios at higher energies.
  - More likely: low energy bins underrepresented in training data set → resolution can be improved with larger data set.



Deep learning is a viable approach to neutrino direction and flavor reconstruction from radio detector data.