Review of neural network methods for the Baikal-GVD experiment

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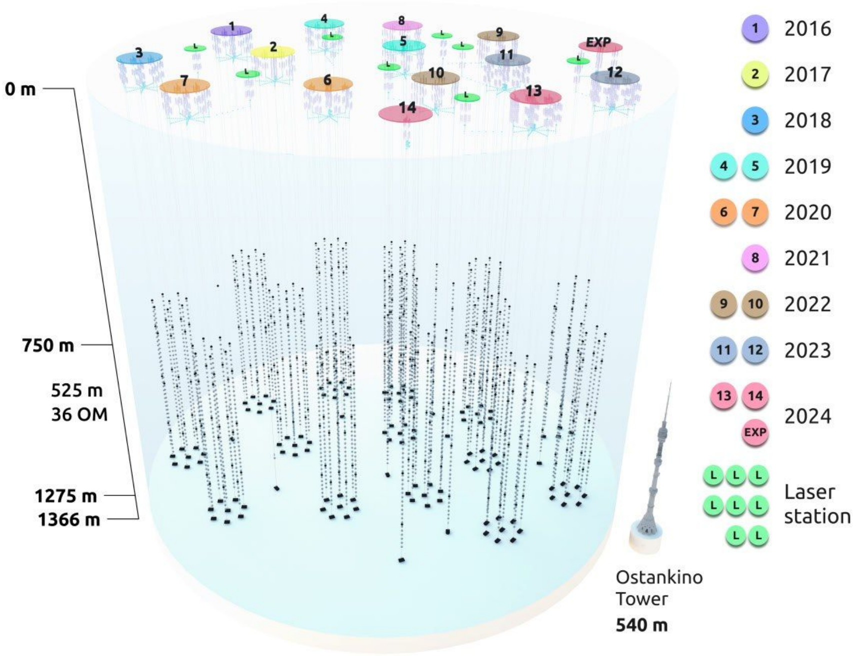
Agenda

1. About Baikal-GVD experiment
2. Monte Carlo simulations
3. Noise suppression
4. Track-cascade separation
5. Identification of ν_μ induced events
6. Energy reconstruction

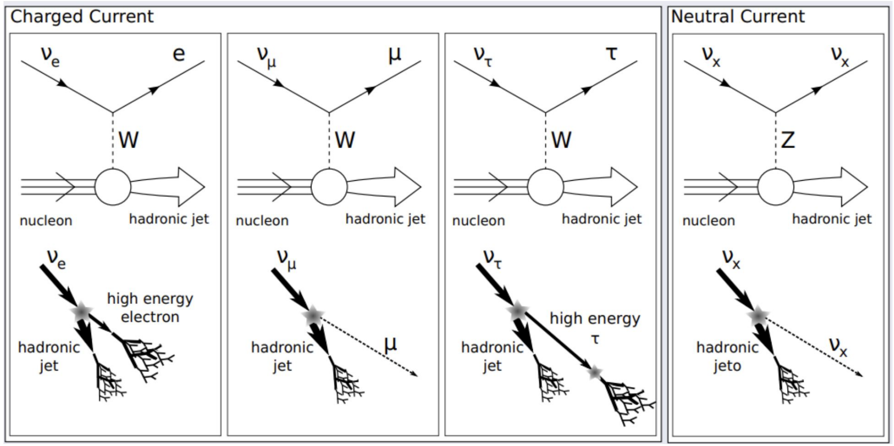
Baikal-GVD

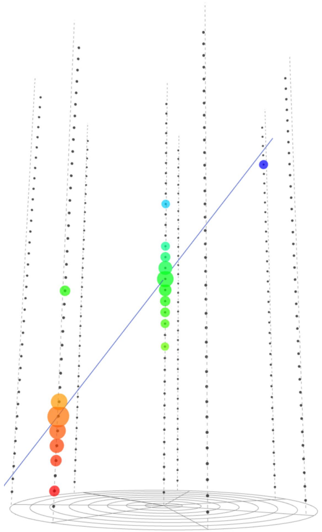
- Largest in northern hemisphere neutrino telescope
- Effective volume - 0.6km^3
- 14 clusters, containing strings equipped with spherical optical modules
- ~20 cm accuracy of modules positions
- Time resolution ~2ns

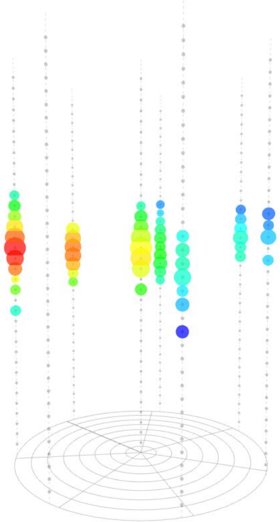


Baikal-GVD

Optical modules detect Cherenkov light from muons (track) or other secondary-induced particles (cascade)







Monte Carlo simulation

Simulation includes:

1. Muons from cosmic rays (μ) (top)
2. ν_μ-induced events (bottom)

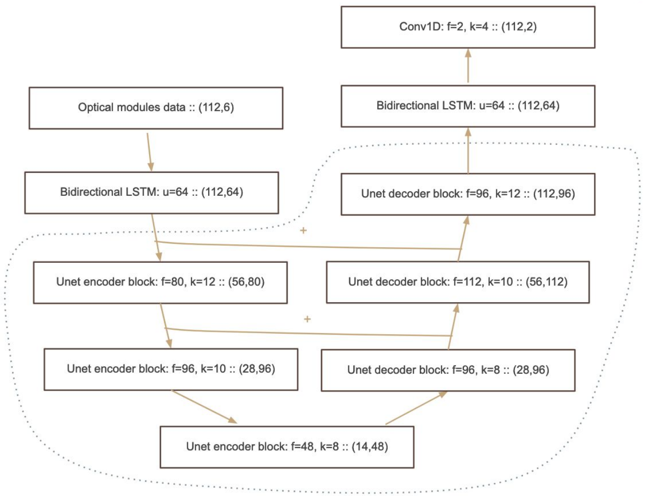
- Comprehensive simulation of Extensive Air Showers (EAS), with parametric evolution of showers in water.
- The spectrum of Monte Carlo events follows the experimental expectations.

As input data to neural networks we use:

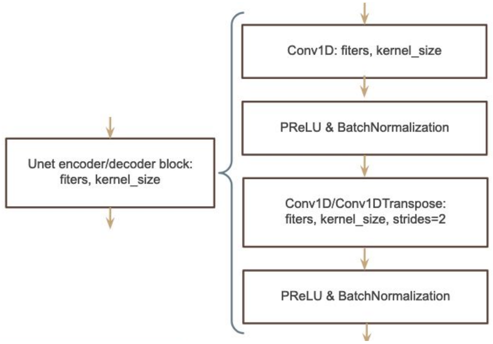
- Data from one cluster
- For each hit - 5 features: x, y, z, registered signal, time of activation

Noise suppresion

- Goal: Suppress all noise-related activation of optical modules (due to natural water luminescence)

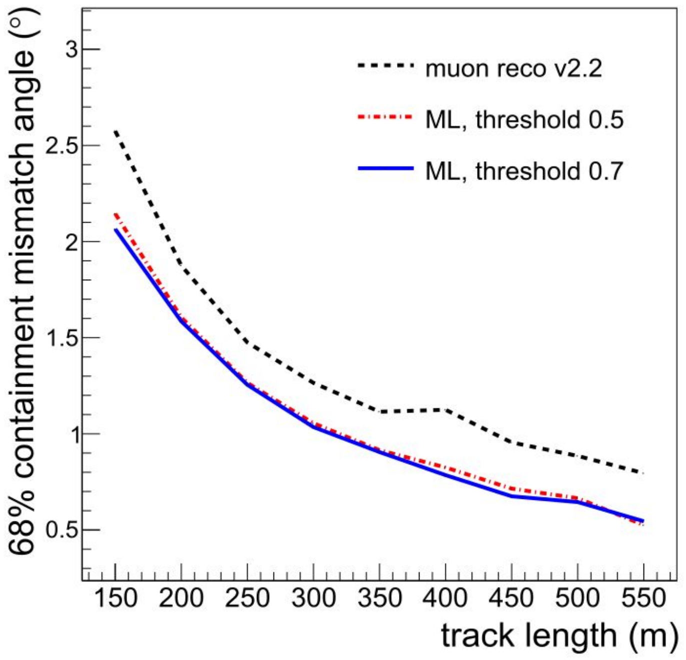


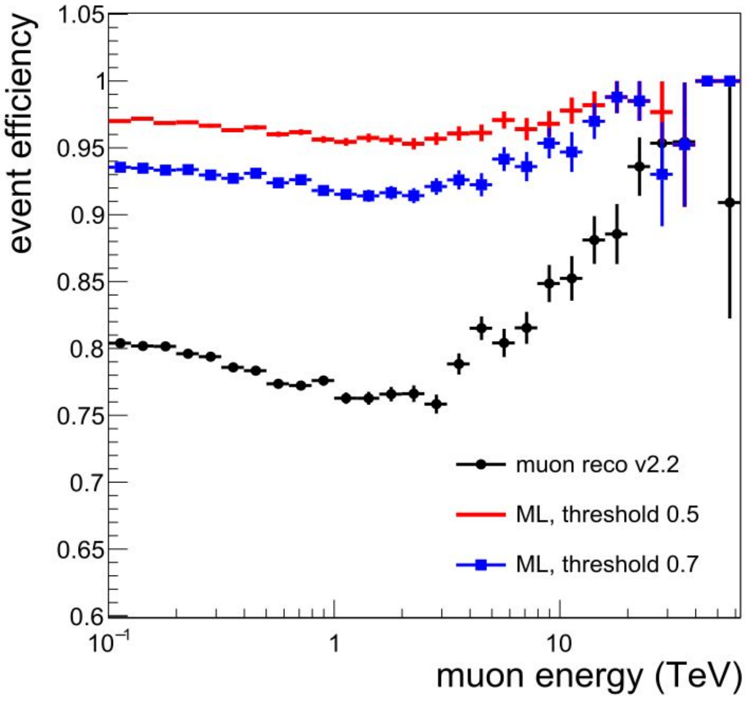
- Architecture used: Encoder and Unet. They allow to capture local and global features of events.



Noise suppression: Results

arXiv:2210.04653
JINST 18 (2023)

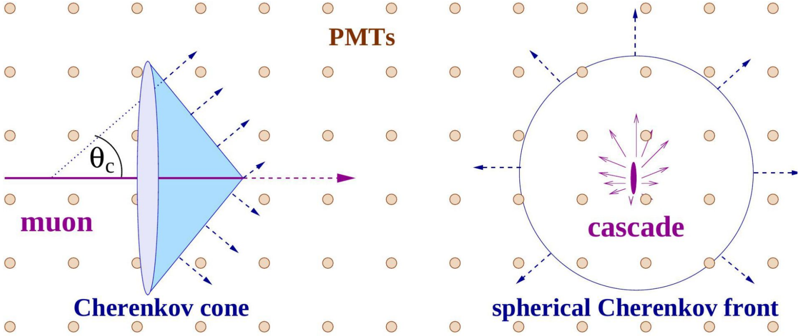


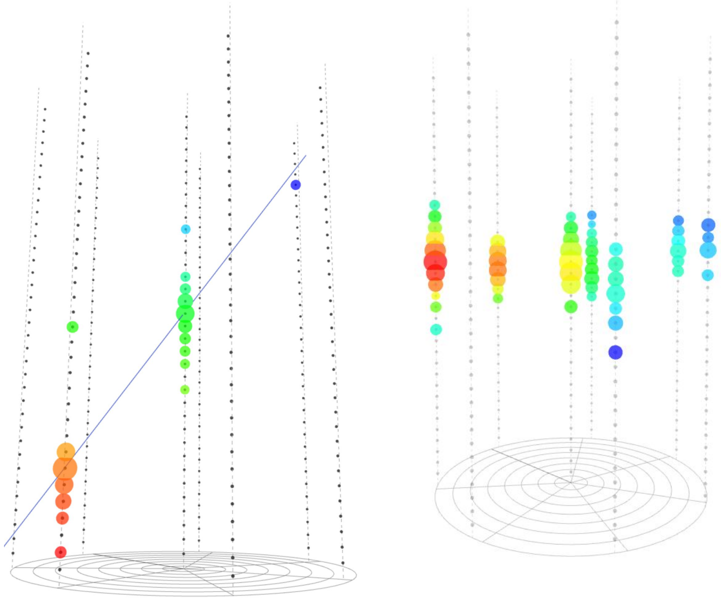


Track-cascade separation

Motivation: improve energy and angle reconstruction (track - for angle, cascade - for energy)

Encoder model is used

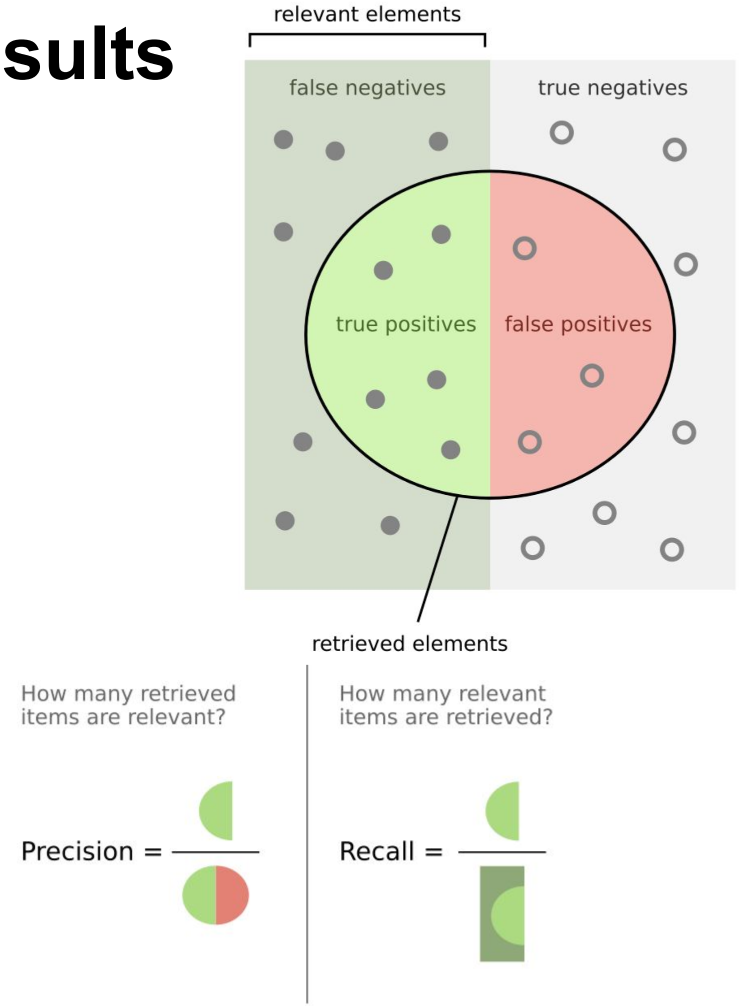




Track-cascade separation: results

Cascade: Recall - 85% Precision - 86%

Track: Recall - 97% Precision - 97%*



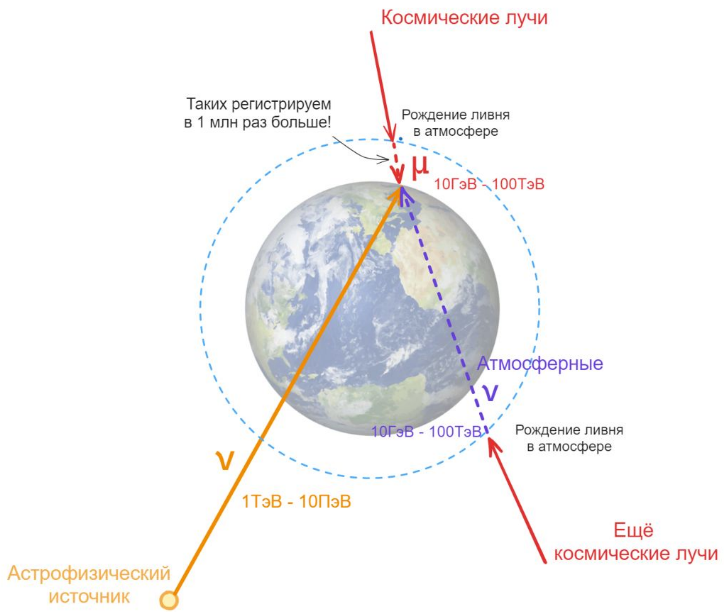
$$\text{Precision} = \frac{\text{Relevant retrieved instances}}{\text{All retrieved instances}}$$

$$\text{Recall} = \frac{\text{Relevant retrieved instances}}{\text{All relevant instances}}$$

*metrics when cascade hits with small |t_residual| are labeled as track

Identification of ν_μ induced events

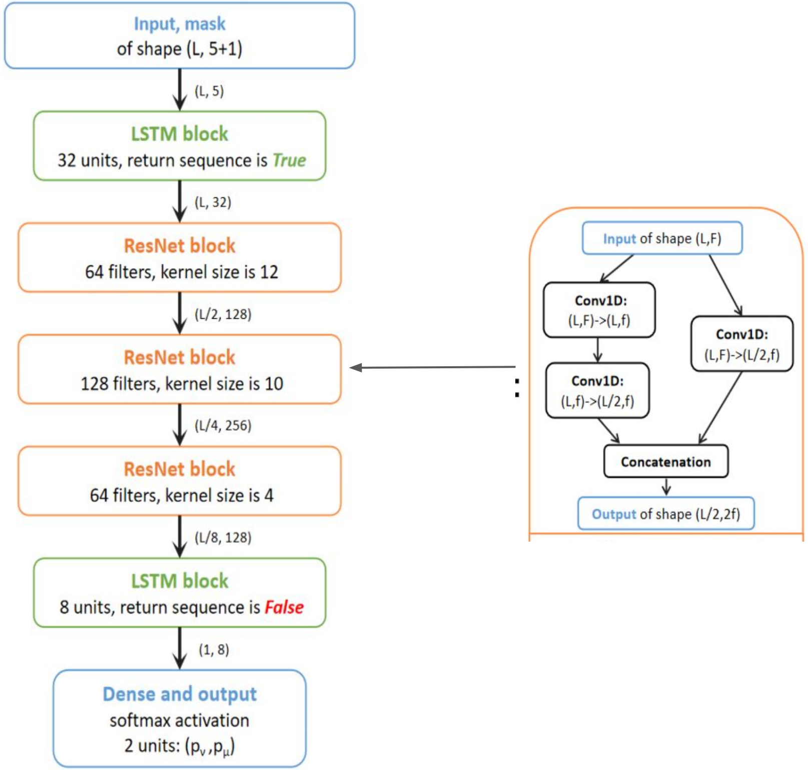
- $N\mu / N\nu_\mu$ ~ 10^6-10^7
- Classic algorithm: filter by reconstructed angle, slow
- ML model can filter faster
- Can be also used for ν flux estimation



Identification of ν_μ induced events: Results

- With ~99% of neutrinos being retained, ~80% of extensive air showers μ are suppressed

- Architecture: Convolutions+LSTM



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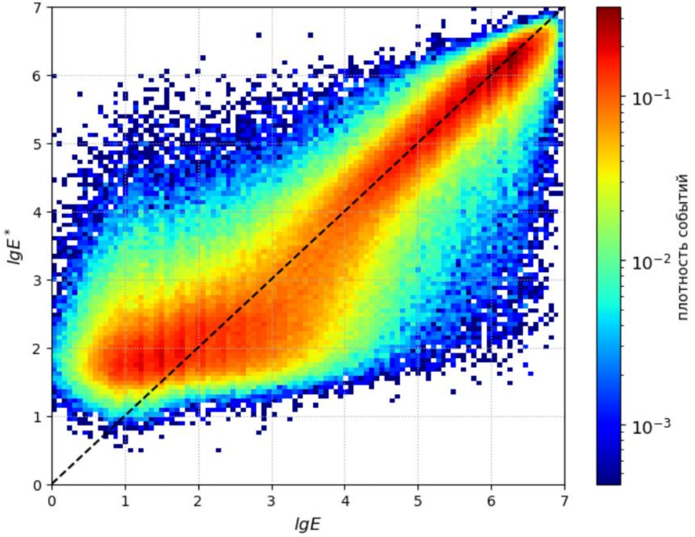
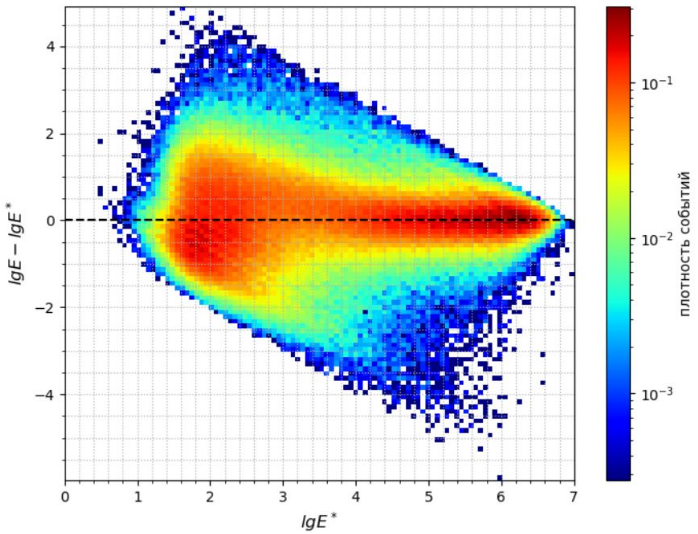
Energy reconstruction

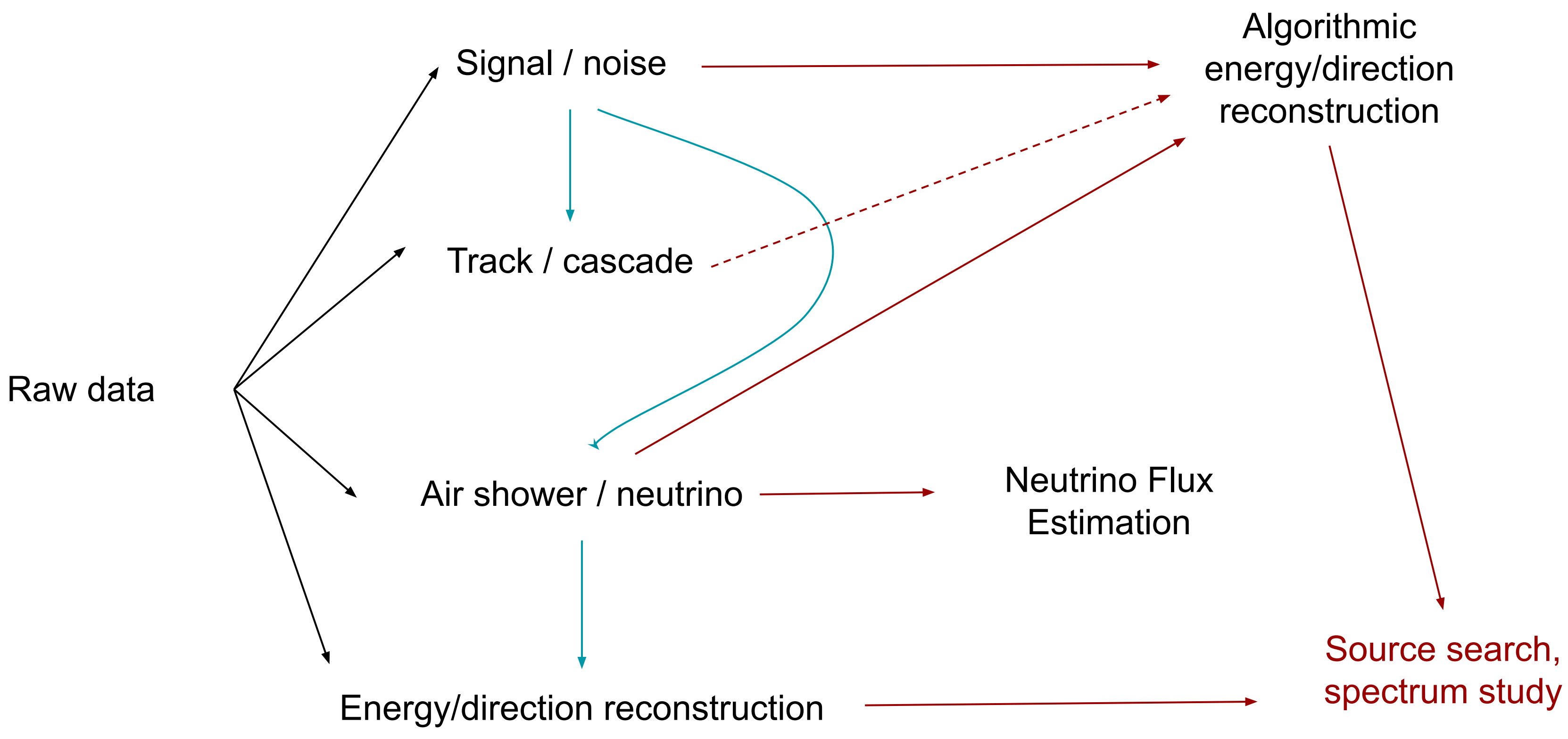
- Only track events. Reconstruct initial μ energy
- Network also estimates prediction uncertainty





E* - model prediction, E - ground truth

Role of ML in Baikal-GVD



Conclusion

- The benefits of applying ML methods in the experiment demonstrated
- We are working on enhancing the quality of the models
- We are planning to deploy ML methods into the standard data analysis chain of the experiment