Search for supernova relic neutrinos using neural network in KamLAND

Minori Eizuka for KamLAND collaboration (Email:minori@awa.tohoku.ac.jp), Research Center for Neutrino Science, Tohoku University

1. Introduction

Supernova relic neutrino (SRN) is the integration of past supernova neutrinos.

Motivation

$$\frac{d\phi(E_{\nu_i})}{dE_{\nu_i}} = c\int R_{ccSN}(z)\frac{dN(E'_{\nu_i})}{dE'_{\nu_i}}(1+z)\left|\frac{dt}{dz}\right|dz$$

ϕ: SRN flux z: Red shift
E_ν: Neutrino energy

Supernova rate → **Star formation history**

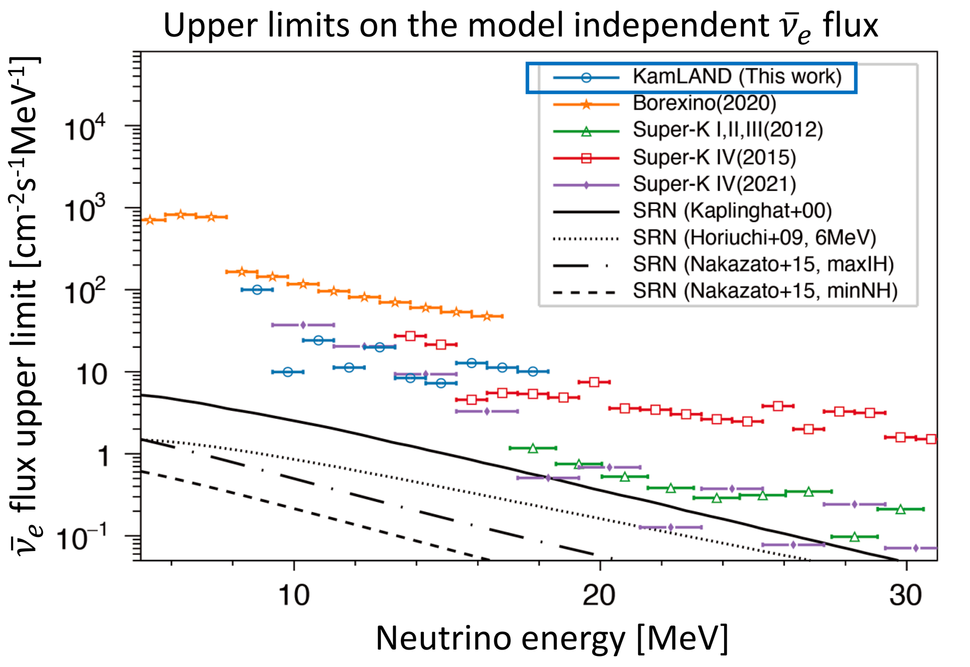
Neutrino spectrum from each supernovae → **Mechanism of supernova**

Previous results

There were no observation of SRN signals.

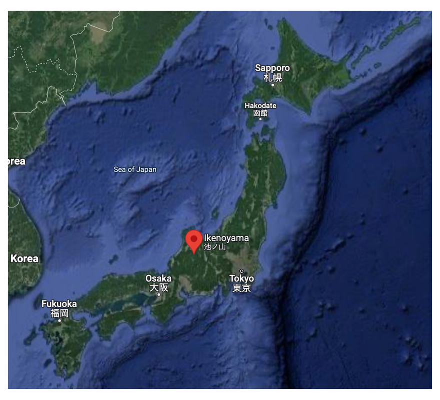
We set upper limits on the model-independent $\bar{\nu}_e$ flux.

×2–10 sensitivity must be achieved to reach SRN models



S. Abe et al, 2022, Apj, 925, 14

2. Kamioka Liquid-scintillator Anti-Neutrino Detector



Data taking from 2002 Mar.

1000 m underground of the Kamioka mine → $\times 10^{-5}$ μ flux

Outer detector

Water-Cherenkov detector for muon veto

- 3.4 kt pure water
- 140 20-inch PMTs

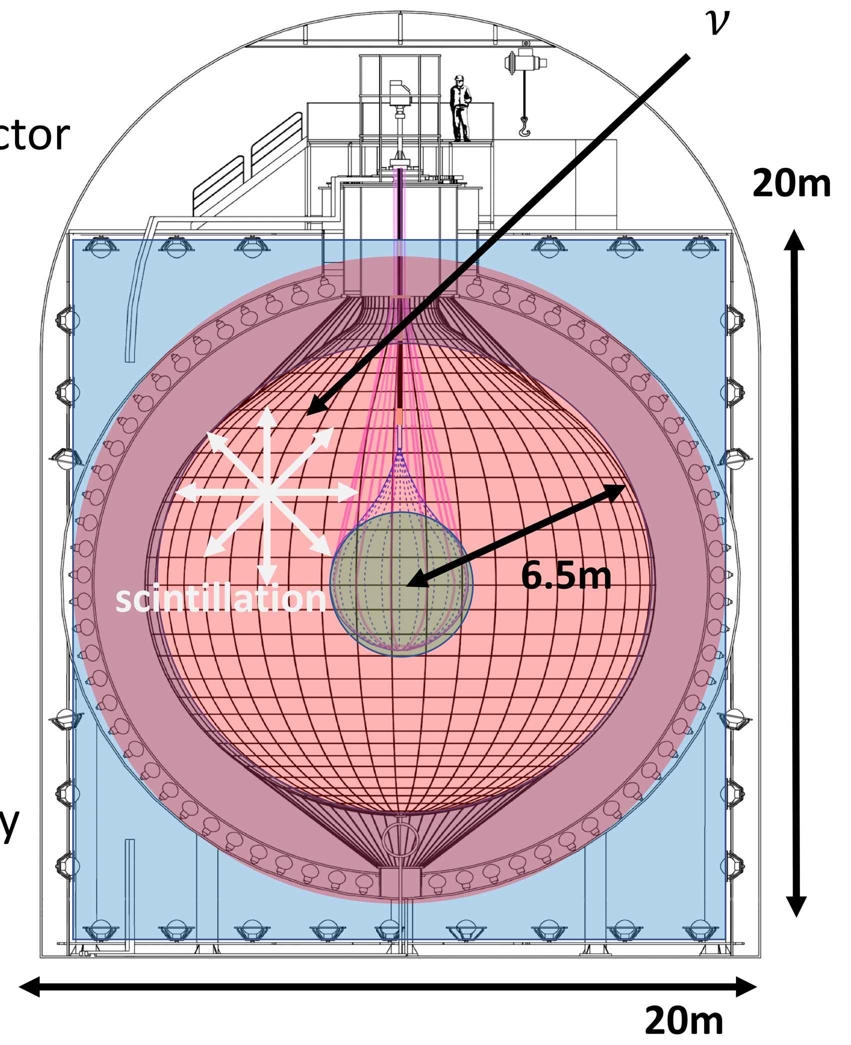
Inner detector

Liquid scintillator for physics event detection

- 1 kt liquid scintillator in large balloon
- Xe-loaded liquid scintillator in mini balloon
- 1325 17-inch PMTs & 554 20-inch PMTs

KamLAND detects $\bar{\nu}_e$ via the inverse beta decay (IBD) using delayed coincidence method.

Sensitivity for MeV-energy neutrinos



3. Atmospheric neutrino background

Atmospheric neutrino neutral current interaction makes sequential events.

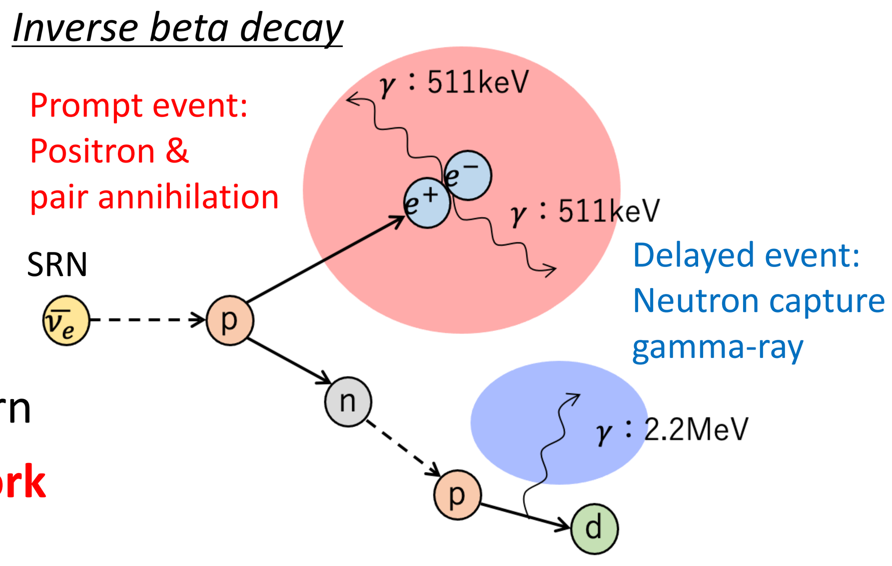
→ "mimic" IBD events

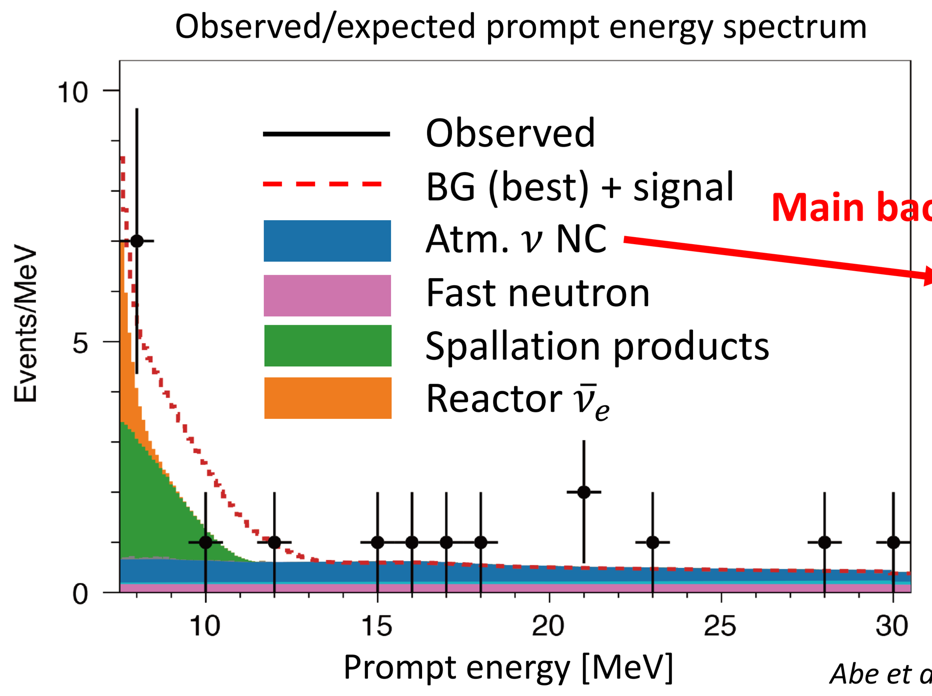
Can not separate by the current analysis

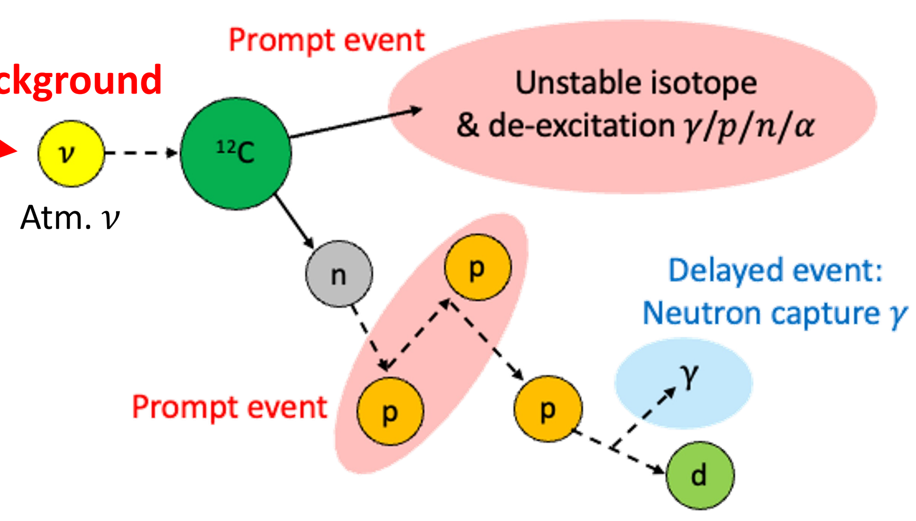
→ Main background of SRN search

Differences appear in prompt event hit pattern

→ Event discrimination using a neural network







Abe et al, 2022, Apj, 925, 14

4. Neural network training strategy

Given the lack of high-energy IBD ($\geq$ 8.5 MeV) and atmospheric neutrino candidates, a well tuned simulation is required.

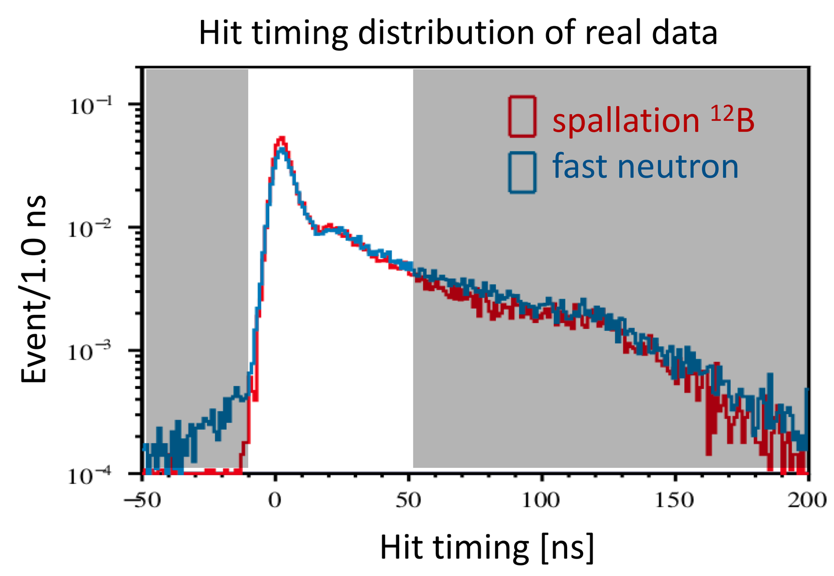
Assumption: ^{12}B (β^- decay) / fast n (p scatter) have similar characteristics

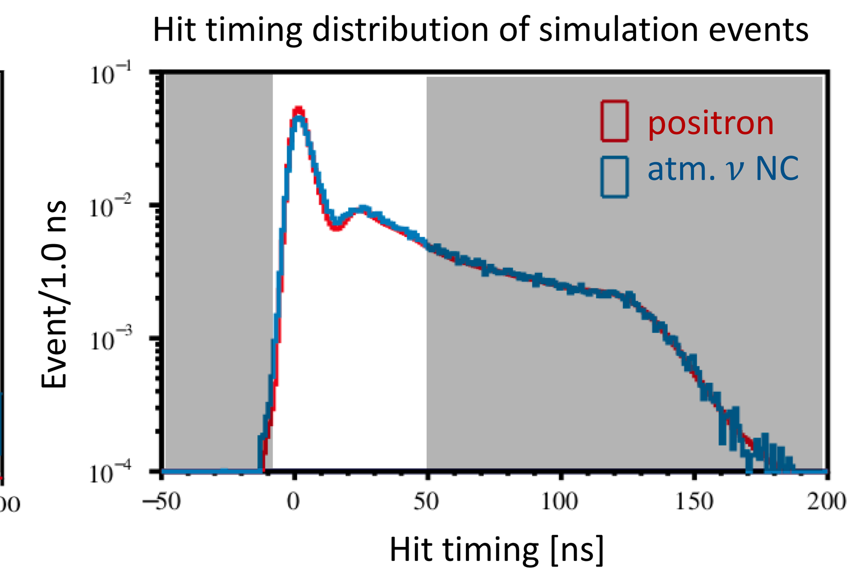
→ Simulation consistency check (section 4)

→ Neural network training with simulation events (section 5)

Our simulation successfully reproduced the hit information of real data.

- Broad background peak
- Two peaks caused by discrete TDC sampling



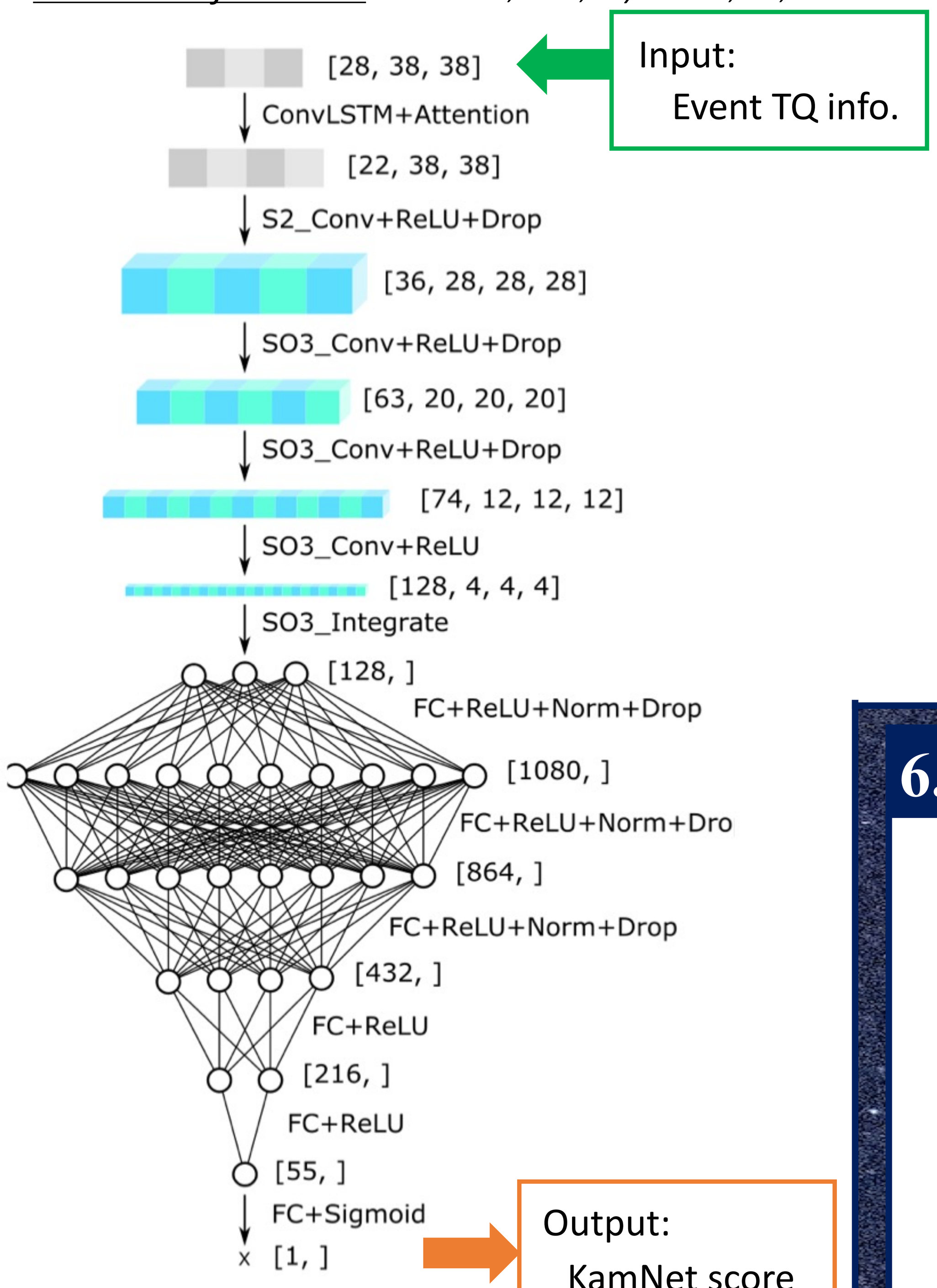


5. Event discrimination using a neural network: KamNet

KamNet is a spatiotemporal neural network developed by KamLAND group.

- **Spherical neural network** to conserve detector's symmetry
- **Convolutional long short-term memory** to incorporate time correlation
- **Dropout** to avoid over training

Structure of KamNet A. Li et al, 2023, Phys. Rev. C,107, 014323



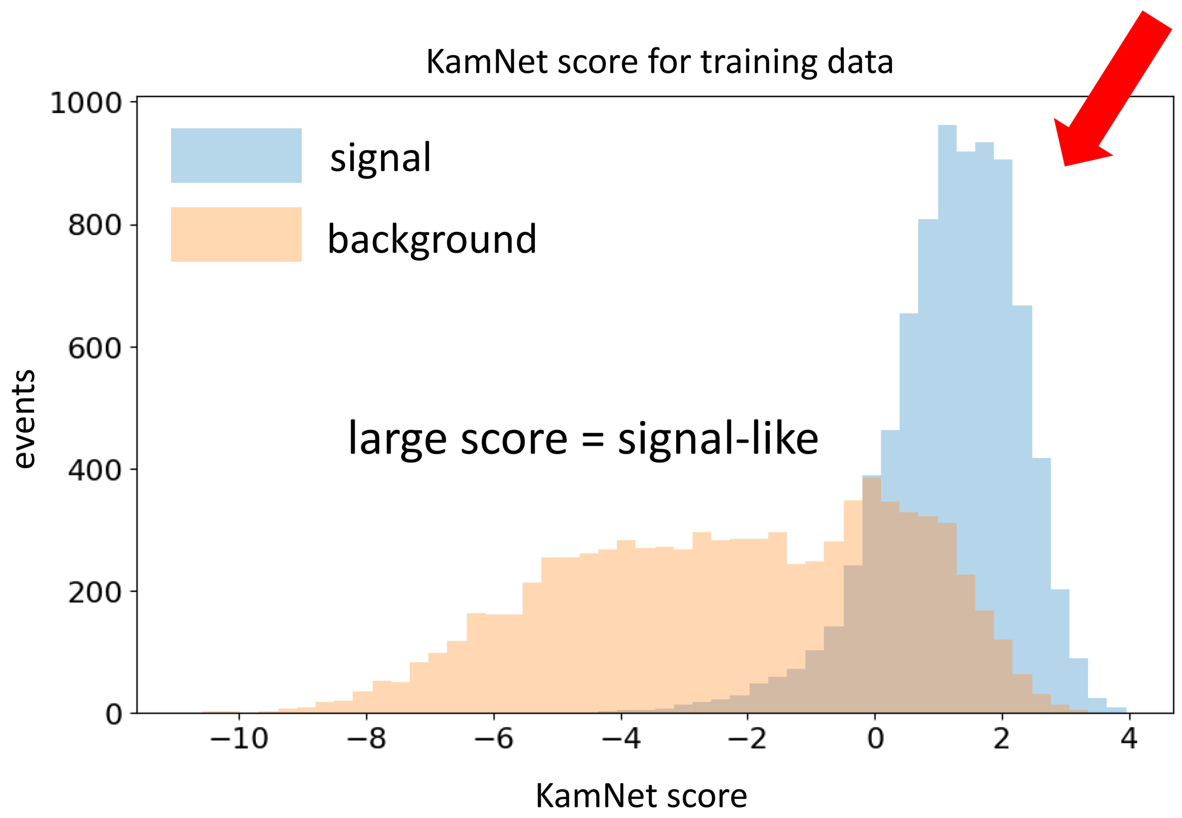
Training and performance check have been done with tuned simulation events.

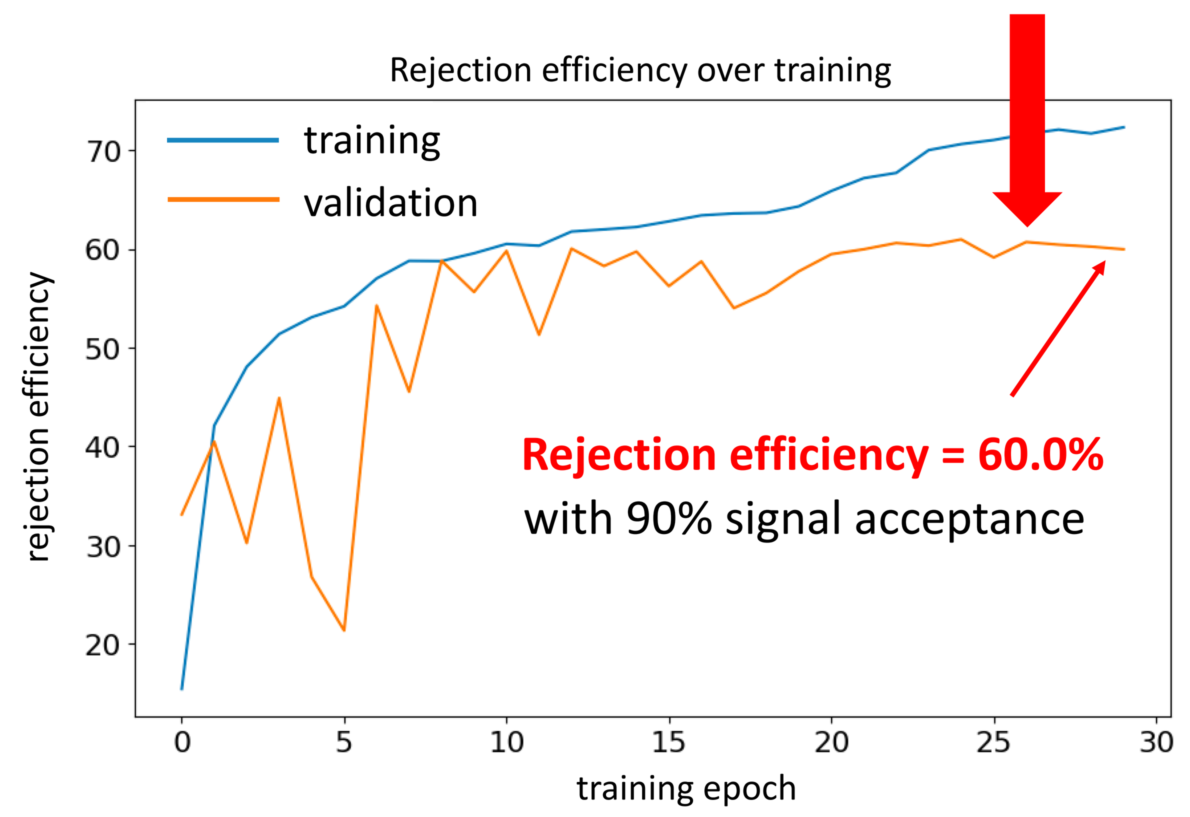
Different score distribution

→ Event discrimination is successful.

Saturation in rejection efficiency

→ Training of KamNet is sufficient.





6. Summary and prospects

Summary

Atm. ν is the largest background for the SRN search in KamLAND.

Our neural network (KamNet) has succeeded to separate signal & BG.

Prospects

We need additional studies to interpret and polish KamNet performance.

- Energy / vertex dependence
- Difference between simulation & real data