

Machine learning in radiation metrology

ML in radiation metrology:

Application of Gamma-ray spectrometry



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Contents

Introduction

**Overview of our ML application
in radiation metrology**

**Example of application
Fast Gemma-ray spectrometry**

Summary



Contents

Introduction

**Overview of our ML application
in radiation metrology**

**Example of application
Fast Gemma-ray spectrometry**

Summary

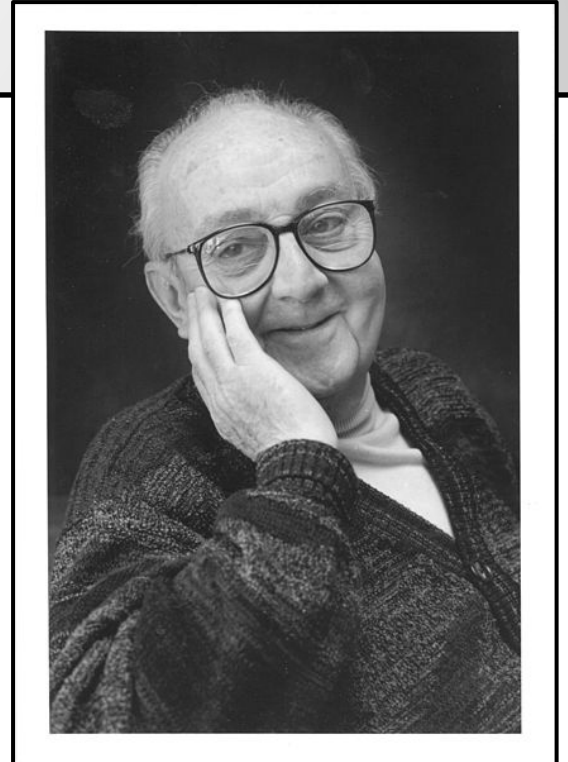
Introduction

ML approach promising for what?

George E. P. Box (1919-2013) said...

**“All models are wrong;
but some are useful”**

As an example, he shown “gas state equation,” and claimed “the equation is wrong for any real gas”.

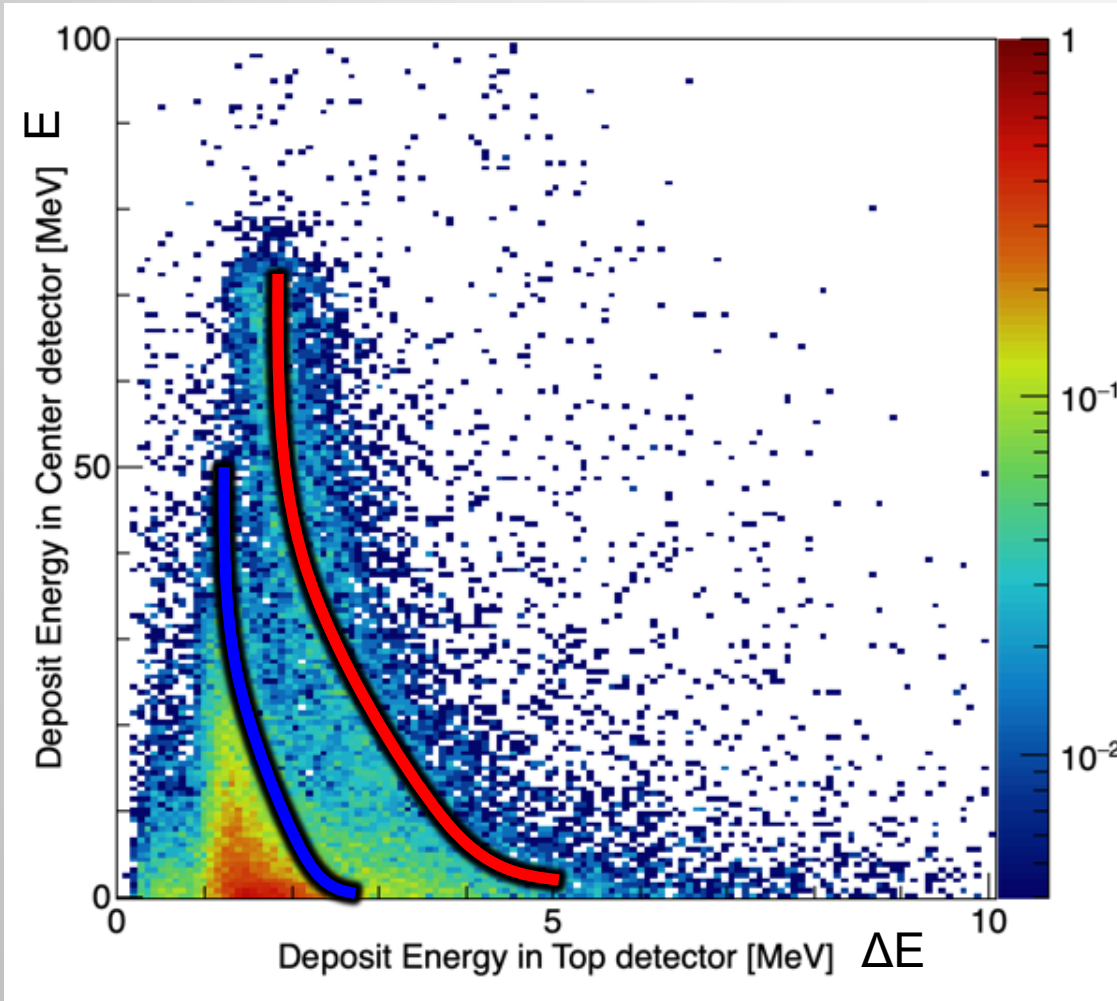


In my opinion, experiment procedures or principles are based on physics, we can use machine learning models in a lot of data analysis process.

ML model proposed in viewpoint from physics is also attractive.

Introduction

Radiation metrology requires models!



Example: Cosmic-ray muon and electron identification by means of ΔE - E method.

This method is based on physics

Mean function for muons and electrons can be analytically derive.

However, any model is okay for separation, double gaussian fitting, Landau, and **ML (classification)!!**



Contents

Introduction

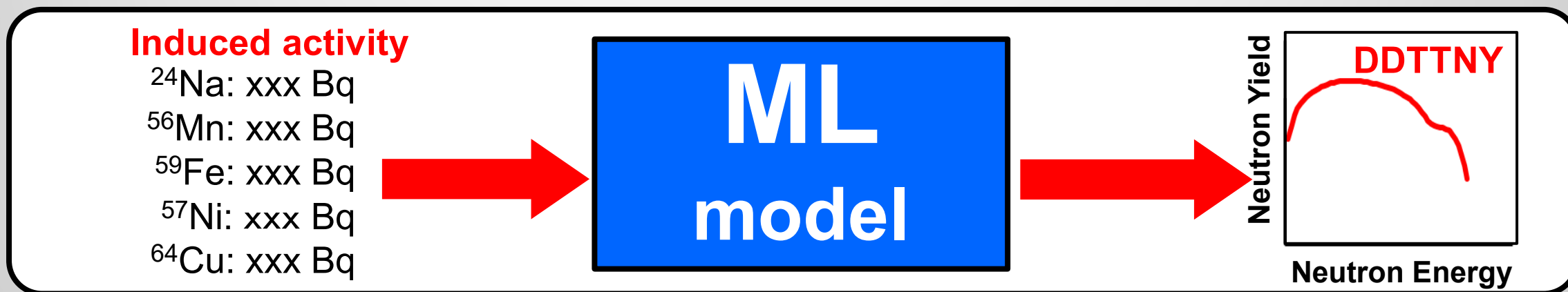
**Overview of our ML application
in radiation metrology**

**Example of application
Fast Gemma-ray spectrometry**

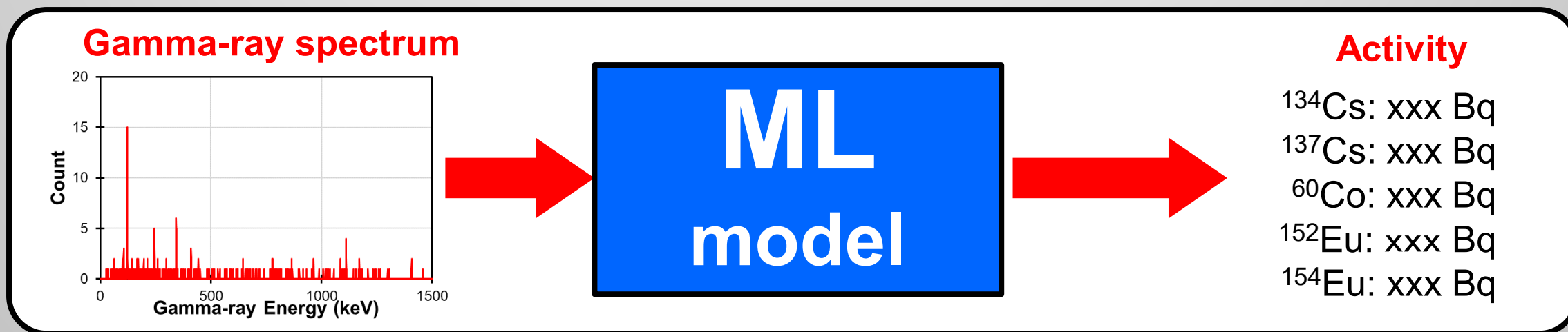
Summary

Introduction: Our history of ML application

1. Neutron spectrum unfolding of multiple-foils activation method



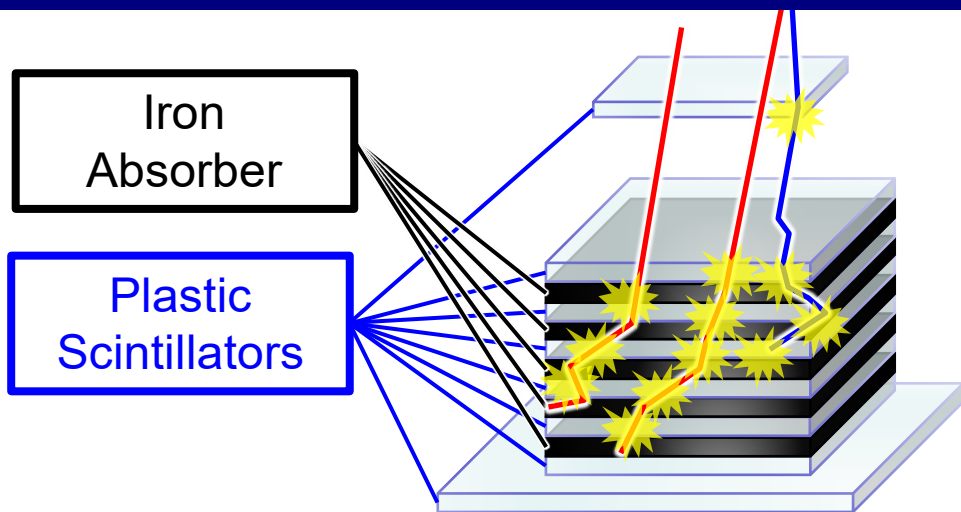
2. Gamma-ray spectrometry



Introduction: Our history of ML application

3. Measurement of terrestrial cosmic-ray muon spectrum around low energy range

Full-Absorption Muon Energy Spectrometer+ (FAMES+)



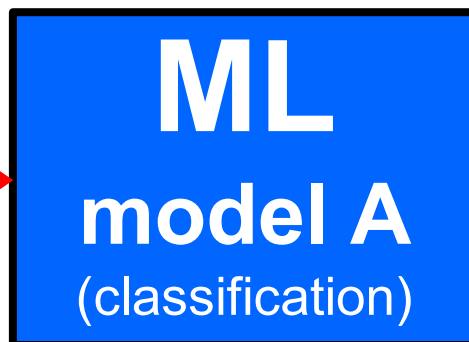
Single event deposit energies

1st layer: xxx MeV
2nd layer: xxx MeV
3rd layer: xxx MeV
⋮

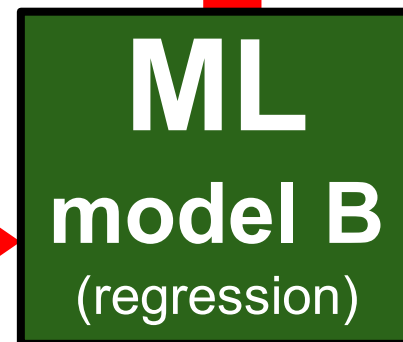
Deposit energy pattern is dependent to particle type and its energy.

Kinetic energy: yyy MeV

Application of Japanese Patent
特願2019-160460 (Sep. 3, 2019)



discard
(20% of total events)





Contents

Introduction

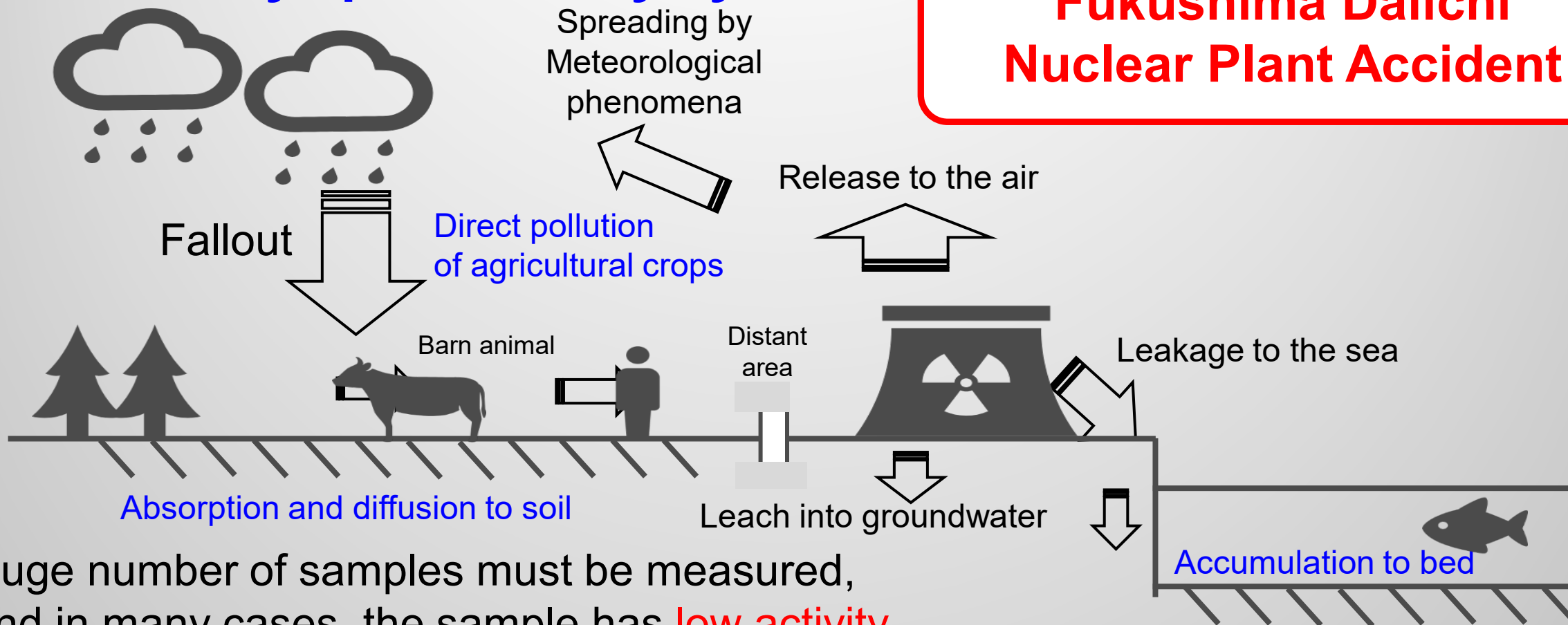
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Summary

Gamma-ray Spectrometry: Background

Gamma-ray spectrometry by ML



Huge number of samples must be measured, and in many cases, the sample has **low activity**.

→ To confirm “ND,” long measurement time is required.

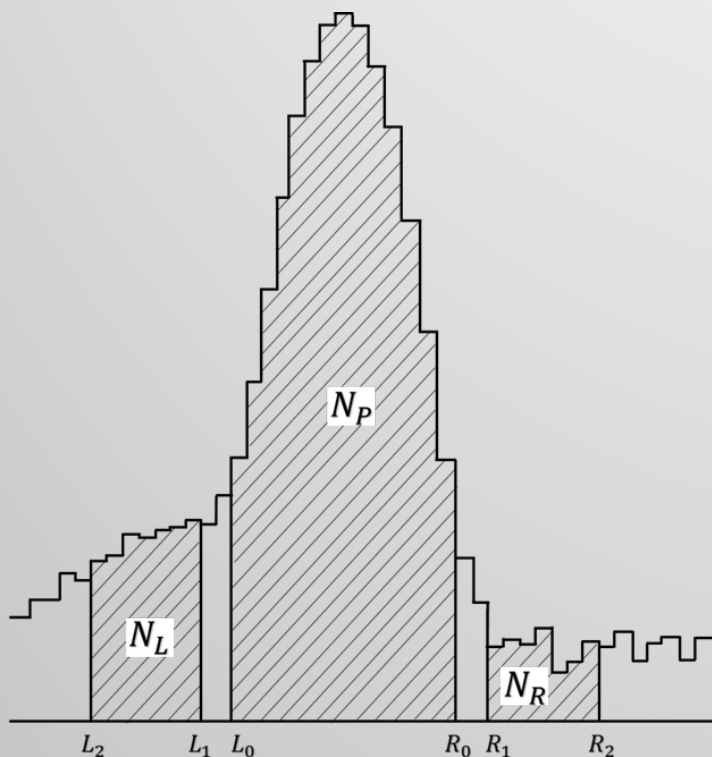
Key is “automation “ and “rapidity.” ... ML has potential.

Gamma-ray Spectrometry: Methods

■ Conventional Method: Covell Method

Simple linear estimation method to subtract background component under an interested photo peak

→ implemented on all gamma-ray spectrometry software.



$$N_{net} = N_P - \beta_L N_L - \beta_R N_R$$

$$\beta_R = \frac{(L_0 + R_0 - L_1 - L_2)(R_0 - L_0 + 1)}{(R_2 - R_1 + 1)(R_1 + R_2 - L_2 - L_1)}$$

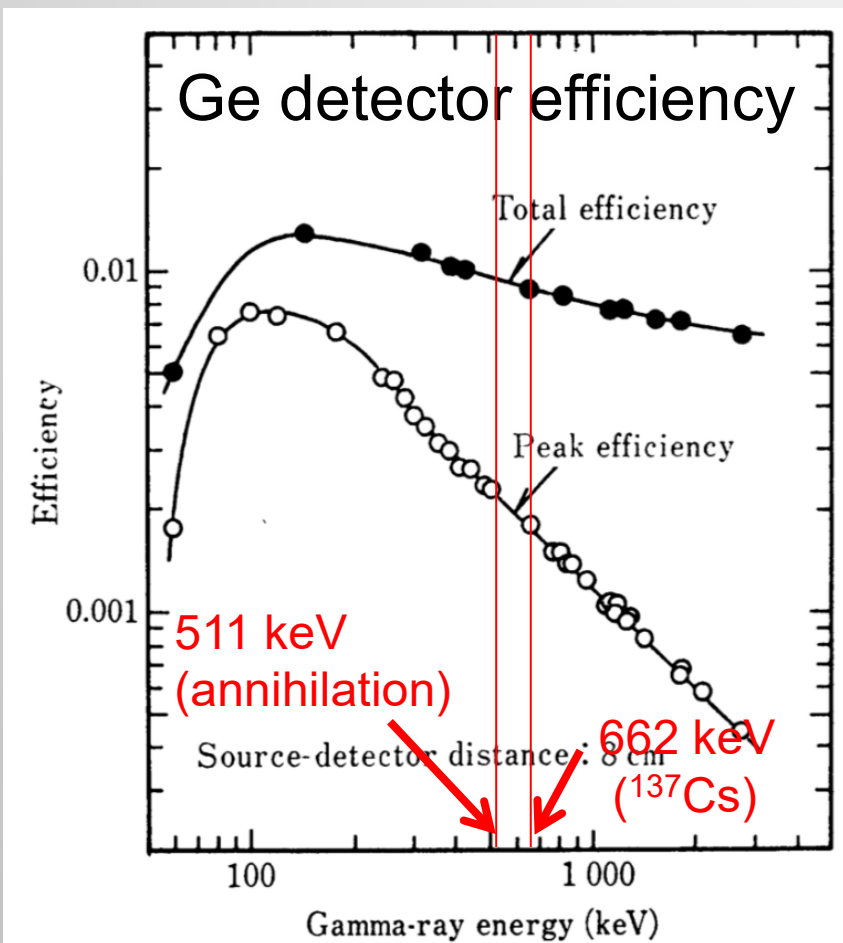
$$\beta_L = \frac{(R_1 + R_2 - L_0 - R_0)(R_0 - L_0 + 1)}{(L_1 - L_2 + 1)(R_1 + R_2 - L_2 - L_1)}$$

$$N_P = \sum_{i=L_0}^{R_0} n_i \quad N_L = \sum_{i=L_2}^{L_1} n_i \quad N_R = \sum_{i=R_1}^{R_2} n_i$$

Gamma-ray Spectrometry: Methods

■ How can we reduce measurement time?

As long as using only photo peak, no method drastically improve measurement time of Covell method.



If discarded events, i.e., Compton component, in Covell method can be taken into account, 3 times faster measurement is possible (ideally).



UNFOLDING!!

- ✓ Once we achieved around 10 times faster measurement of NaI(Tl) gamma-ray spectrometry by the iterative unfolding method (awarded by Minister of the environment of Japan in 2015)
- ✓ Any codes are okay, but we have experience of successful unfolding by ML model.

Gamma-ray Spectrometry: Methods

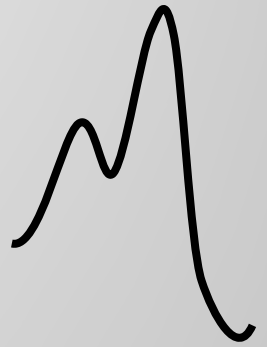
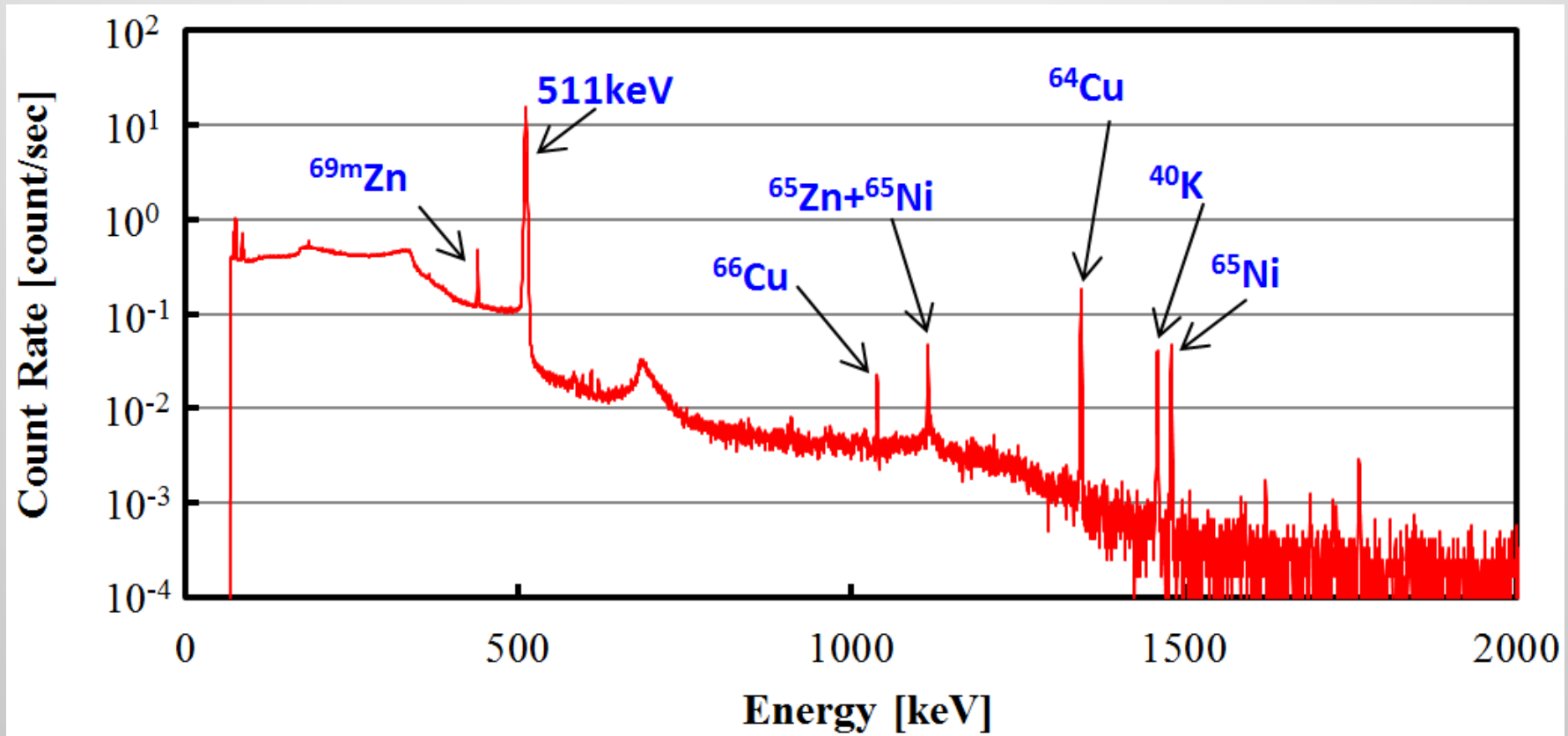
■ Spectrum “shape” has information

→ Convolutional Neural Network (CNN) is promising.



Compton component ends

Photo peak



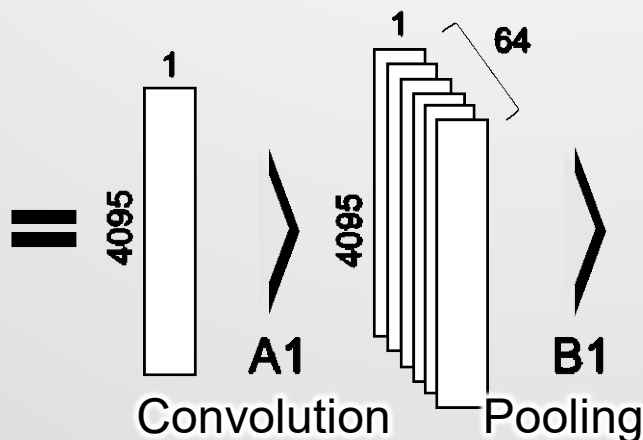
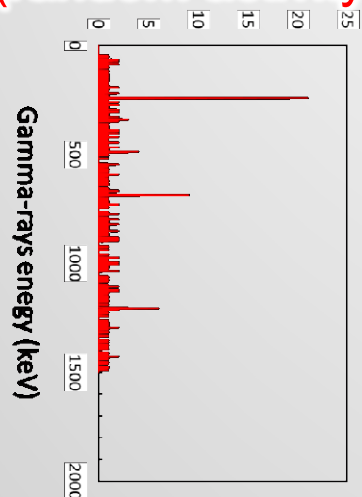
Doublet

Gamma-ray Spectrometry: Methods

R. Takahashi (M1 student) coded everything last year for his bachelor thesis

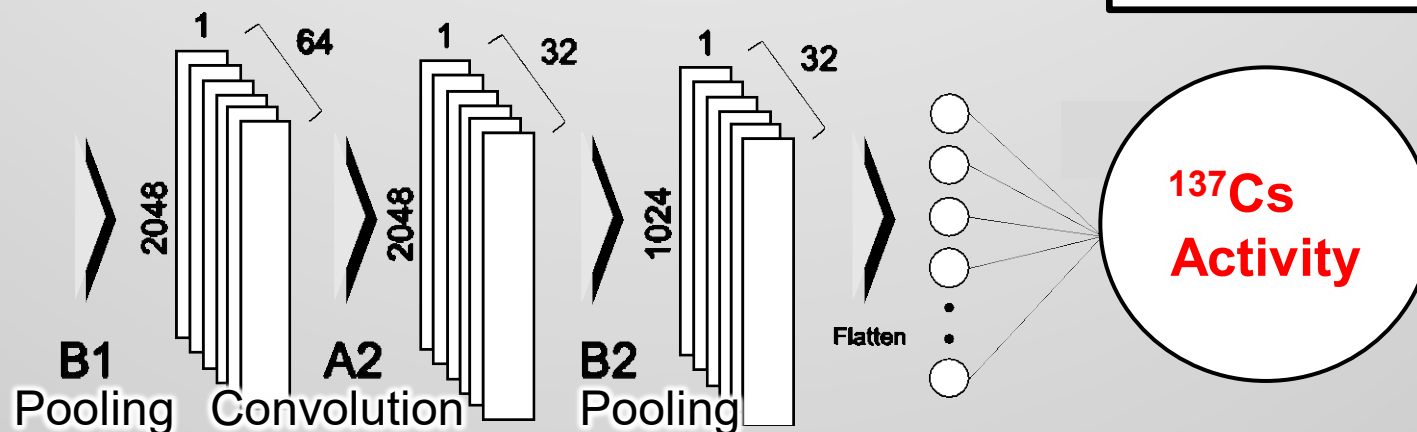
Activity prediction of ^{137}Cs including ^{134}Cs and ^{40}K

(random activity for each nuclide, fixed measurement time 60s)



Tensorflow + keras
to develop the ML model

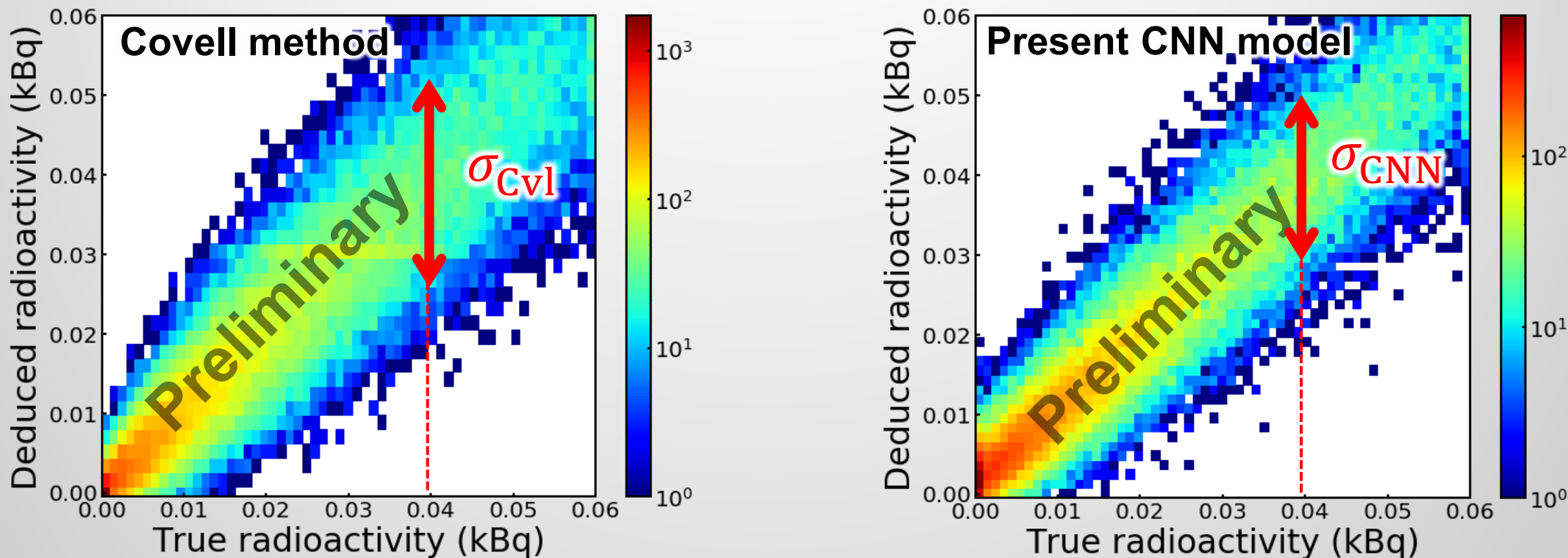
Using GPU server machine
having **2 boards** of
Geforce RTX 3020



Loss: MSE

Training and validation data
sets were prepared by
Geant4 simulation

Results and discussion: ^{137}Cs



How to estimate the measurement time reduction factor, while we have only 60 sec. dataset.

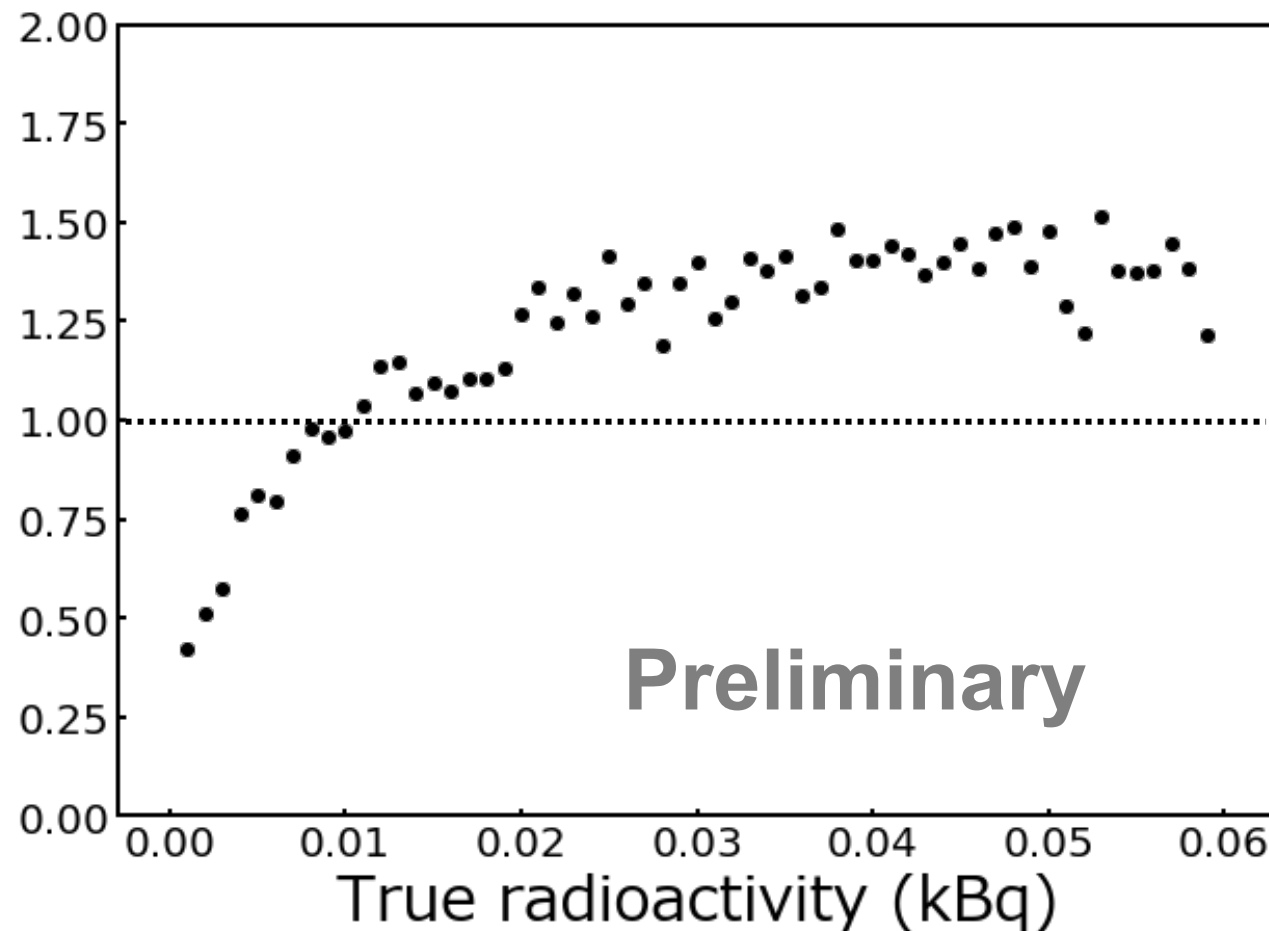
Squared ratio of SDs: $\left(\frac{\sigma_{\text{Cv1}}}{\sigma_{\text{CNN}}}\right)^2 \equiv c$ gives sensible estimation;
as a measurement time multiplication factor.

Results and discussion: ^{137}Cs activity

What does “ c ” express?

- By analyzing with Covell method,
“ c ” times longer measurement time is necessary to obtain the same for the ML model.
- Larger than 1 for c is expected and higher activity range (~1.5), we achieved. However lower range did not...
→ Cost (loss) function trials has continued... At this moment, we have flatter c .

$$c = \left(\frac{\sigma_{\text{Cv1}}}{\sigma_{\text{CNN}}} \right)^2$$





Contents

Introduction

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Summary

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- ML model of 1D CNN is promising for Gamma-ray spectrometry to reduce measurement time

Convolutional Neural Network

- ✓ may use also **non-photo peak events** for higher activity samples,
- ✓ may **not directly count photo-peak events**, considering the worse performance around lower activity sample.

