Study of Pair-Monitor for ILC using Deep Learning

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RCNP Project
"*Application of deep learning to accelerator experiments*"

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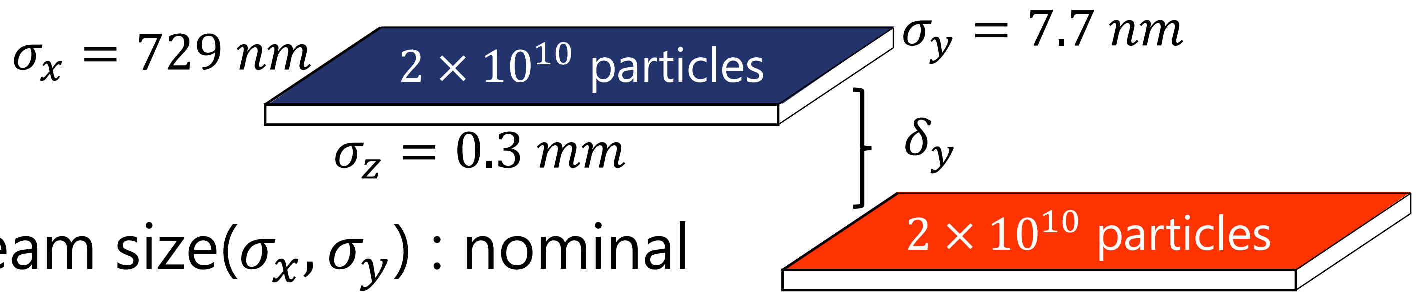
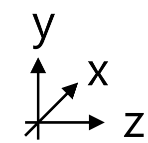
Introduction

1.1 Pair Monitor

- Beam size





beam size(σ_x, σ_y) : nominal

Beam gap(δ_y) : 0.0

Between e$^-$ bunch and e$^+$ bunch

High Luminosity!

$$L = \frac{N^2}{4\pi\sigma_x\sigma_y}$$

N : number of particle per second

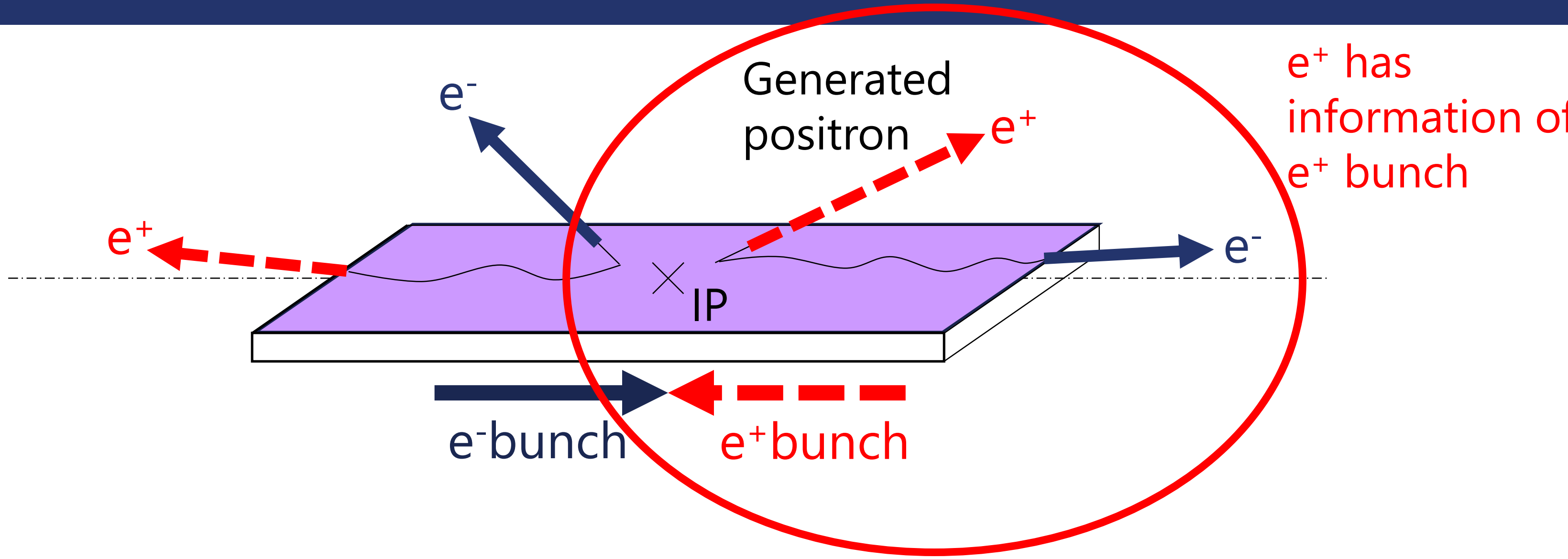
$\sigma_x(\sigma_y)$: horizontal(vertical) beam size

- Importance variable to know luminosity

  $\sigma_x, \sigma_y, \delta_y$

- **Pair monitor**
  - Purpose : **measurement of beam size**
  - Good point : nondestructive measurement

1.2 Measurement method



The intensity of scattering depends on the shape of the bunch

■Measurement principle

1. Photons are generated at the IP
2. The photon reacts with the beam to generate a incoherent pair of ee^-
3. Incoherent pair is scattered by the electric field by the beam
4. Incoherent pair collides with Pair Monitor while spiraling by the magnetic field inside the measuring instrument

Simulation

2.1 Simulation setup

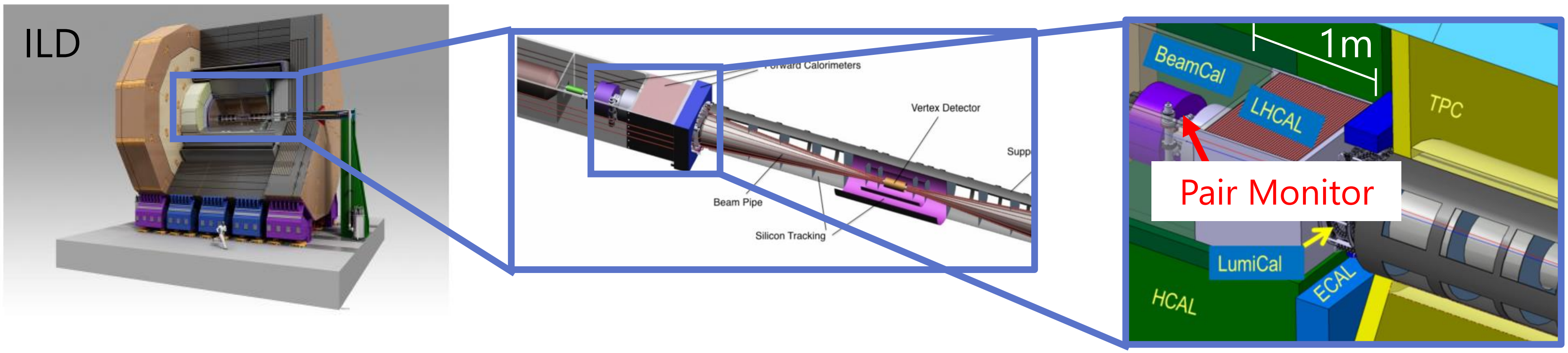
- We calculated the hit distribution of pair monitor.
- parameter as TDR2013
- Center-of-mass energy : 250 GeV

Summary table of the 250 GeV baseline parameter

RMS bunch length	σ_z	mm	0.3
Electron RMS energy spread	$\Delta p/p$	%	0.190
Positron RMS energy spread	$\Delta p/p$	%	0.152
Electron polarisation	P_-	%	80
Positron polarisation	P_+	%	30
Horizontal emittance	$\gamma\epsilon_x$	μm	10
Vertical emittance	$\gamma\epsilon_y$	nm	35
IP horizontal beta function	β_x^*	mm	13.0
IP vertical beta function	β_y^*	mm	0.41
IP RMS horizontal beam size	σ_x^*	nm	729.0
IP RMS veritcal beam size	σ_y^*	nm	7.7

2.2 Forward Instrumentation

- Generator : CAIN
- We assume that magnetic field is 3.5 T to z direction.
- We don't consider other detectors
  - ➢ for the principle condition.

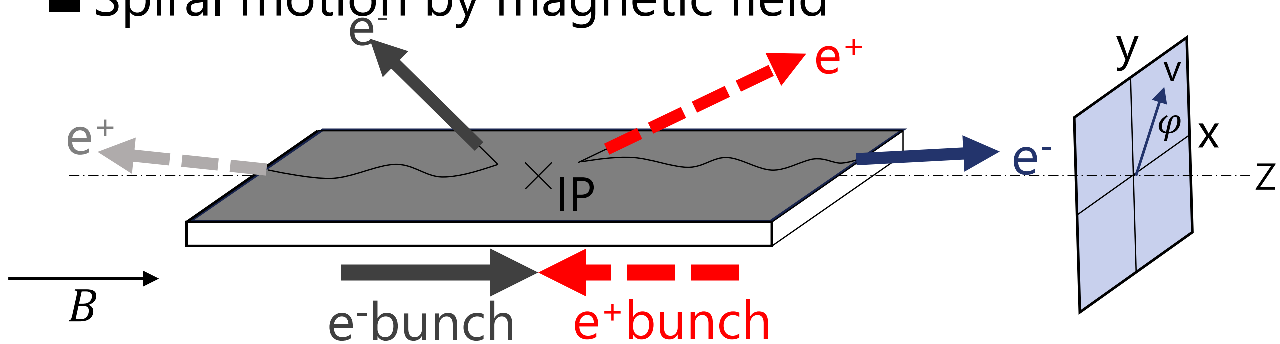


Pair Monitor Design			
Z position with respect to the IP	**~4m**	Pixel size	**400μm ×400μm**
sensitive area	**10cm**	Thickness of sensor	**200μm**

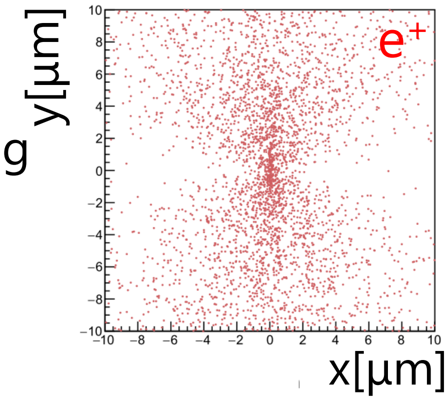
2.3 Characteristic of incoherent Pair

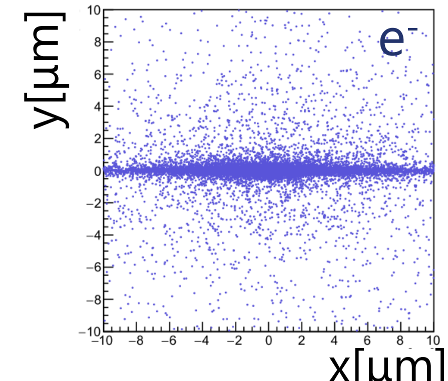
Region that e+ bunch is coming.

- Incoherent pair e^+
  - e^+ is scatted by e^+ bunch.
  - e^+ bunch has a flat shape.
  - The force is strongly up and down
  - Vertical distribution
  - Spiral motion by magnetic field

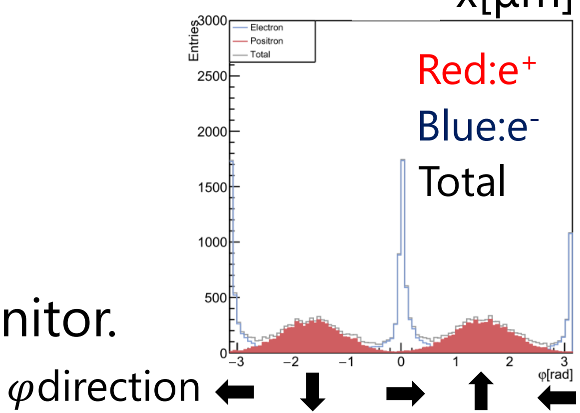


Position of particle after bunch crossing



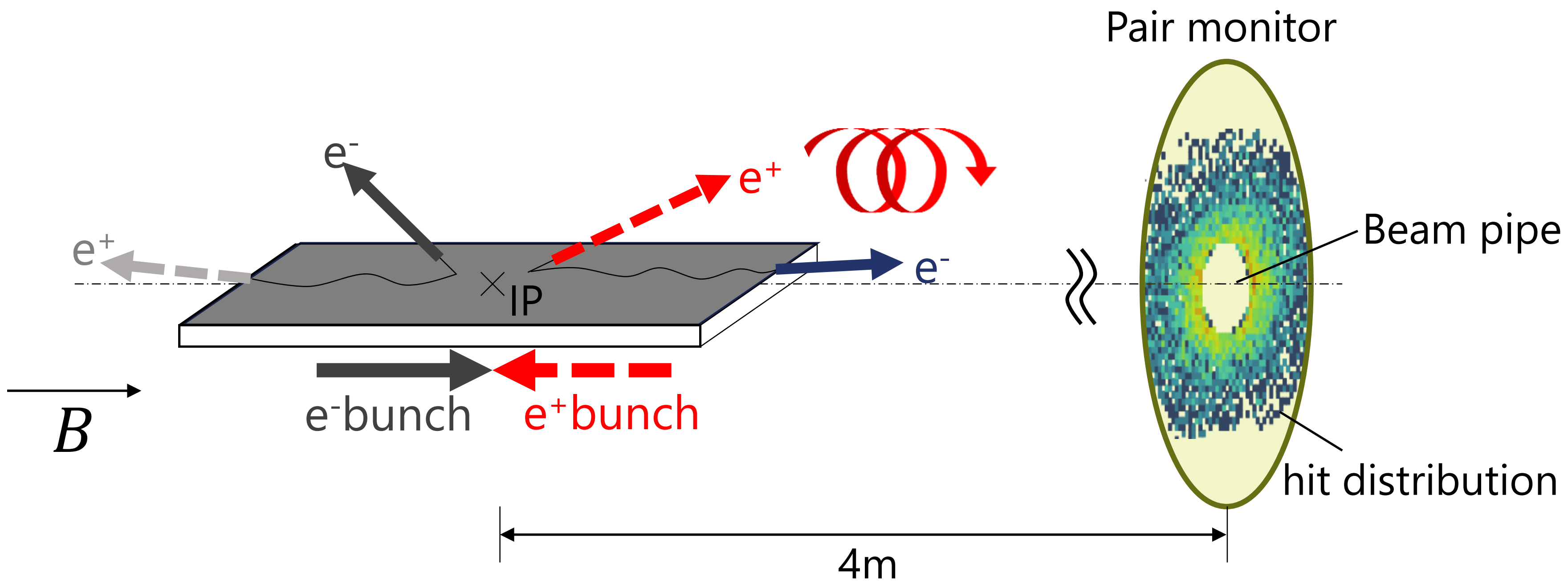


- Incoherent pair e^-
  - e^- is attracted by e^+ bunch.
  - e^- oscillates along the horizontal direction.
  - Horizontal distribution
  - e^- travels near the beam pipe.
  - Therefore, e^- come into beam pipe at pair monitor.



2.4 Calculation in magnetic field

We calculate incoherent pair that motion in uniform magnetic field until 4m.



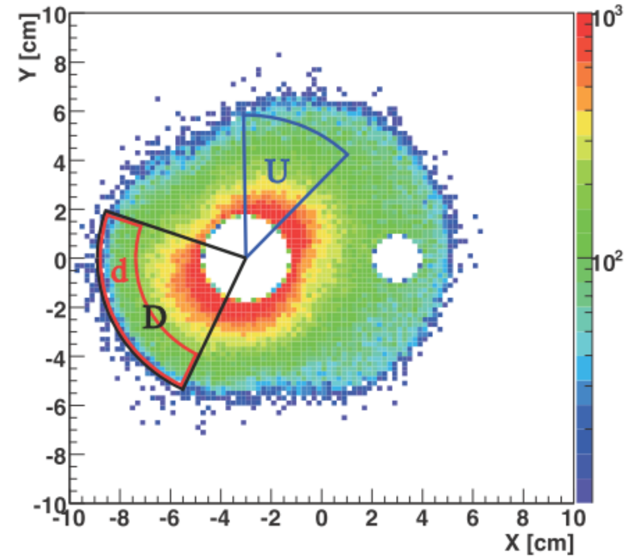
2.5 Previous study

Reference
Y.Sato, Research and development of an interaction-region beam profile monitor for the international linear collider, 2009

- define regions d, D, and U.
- calculate ratio of particles at these regions and all region.
- Beam parameters are reconstructed using the matrix method.
- The result is good value

although

- **Ignore except for regions d, D, and U.**



Regions d, D, U for defining the ratio of hit numbers

Accuracy of beam parameter reconstruction

	Pair monitor	BeamCal	Pair Monitor + BeamCal
σ_x	3.1%	4.7%	2.8%
σ_y	9.9%	17.1%	8.6%
δ_y	9.0%	9.5%	7.4%

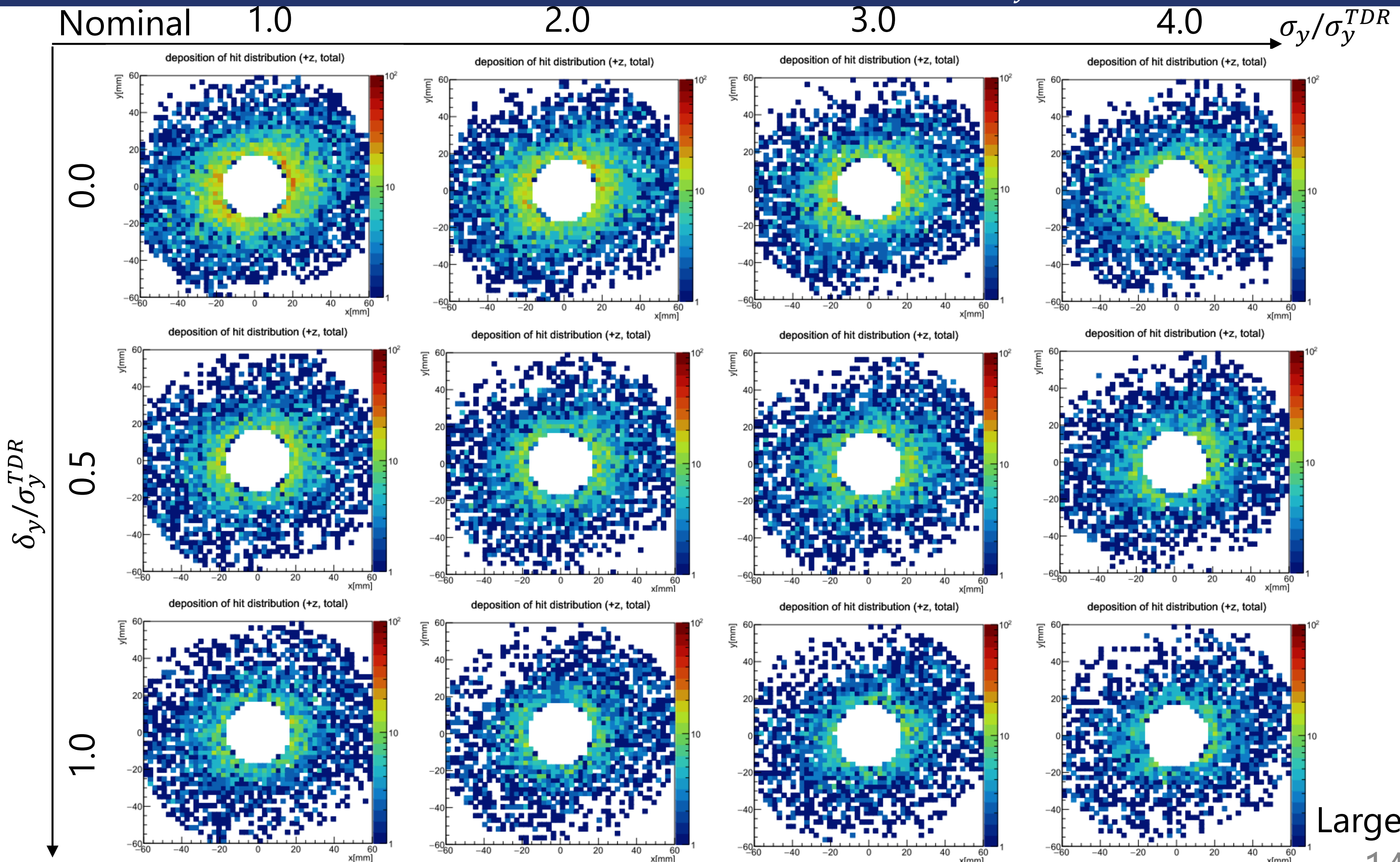
Reconstruction
Using Deep Learning

3.1 Machine learning

- We reconstruct beam parameter using **all hit information.**
- In order to be image recognition, we used machine learning(ML).

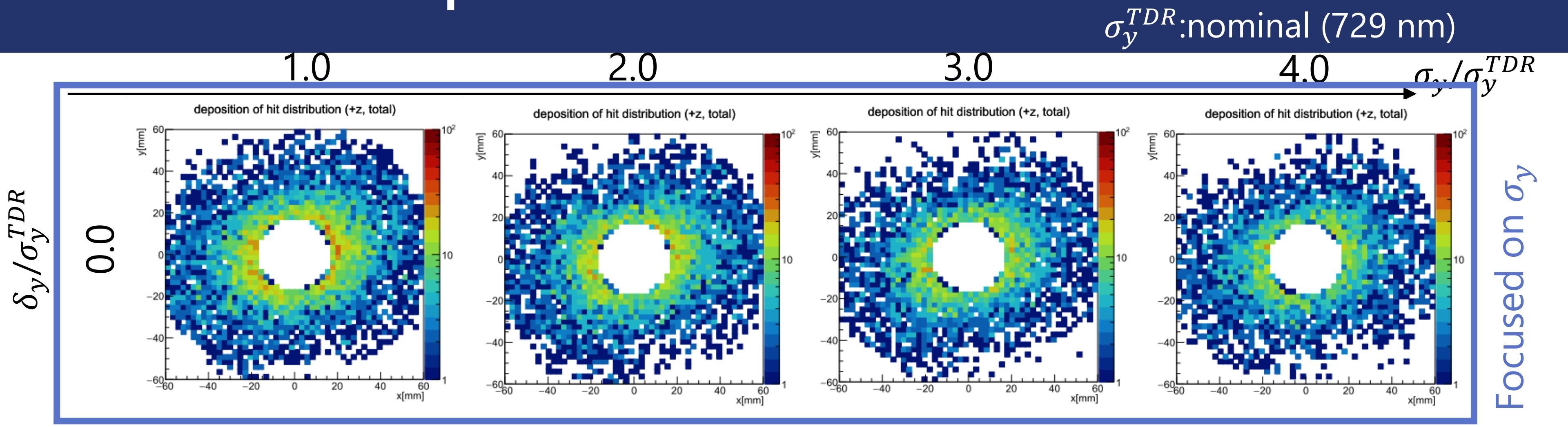
3.2 Comparison of hit distribution

σ_y^{TDR}:nominal (729 nm)



These variables are changed significantly to conform whether available at ML

3.2 Comparison of hit distribution



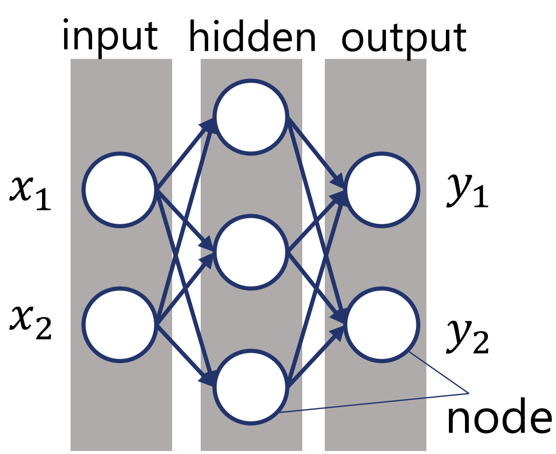
In order to check whether machine learning is effective, 1 parameter was reproduced first.

Machine Learning

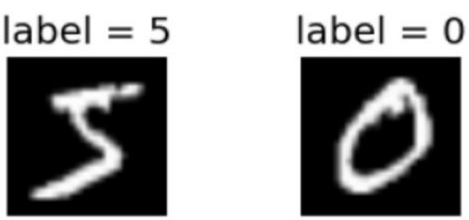
- Algorithm to find rules from a lot of input data.
- An algorithm based on the cellular tissue of an organism is called Neural Network(NN), which consists of input, hidden, and output layer.

Deep learning

- A model with multiple hidden layers is called Deep Neural Network (DNN).



Concept of NN



handwritten digits classification

example

3.4 Software

Tensorflow

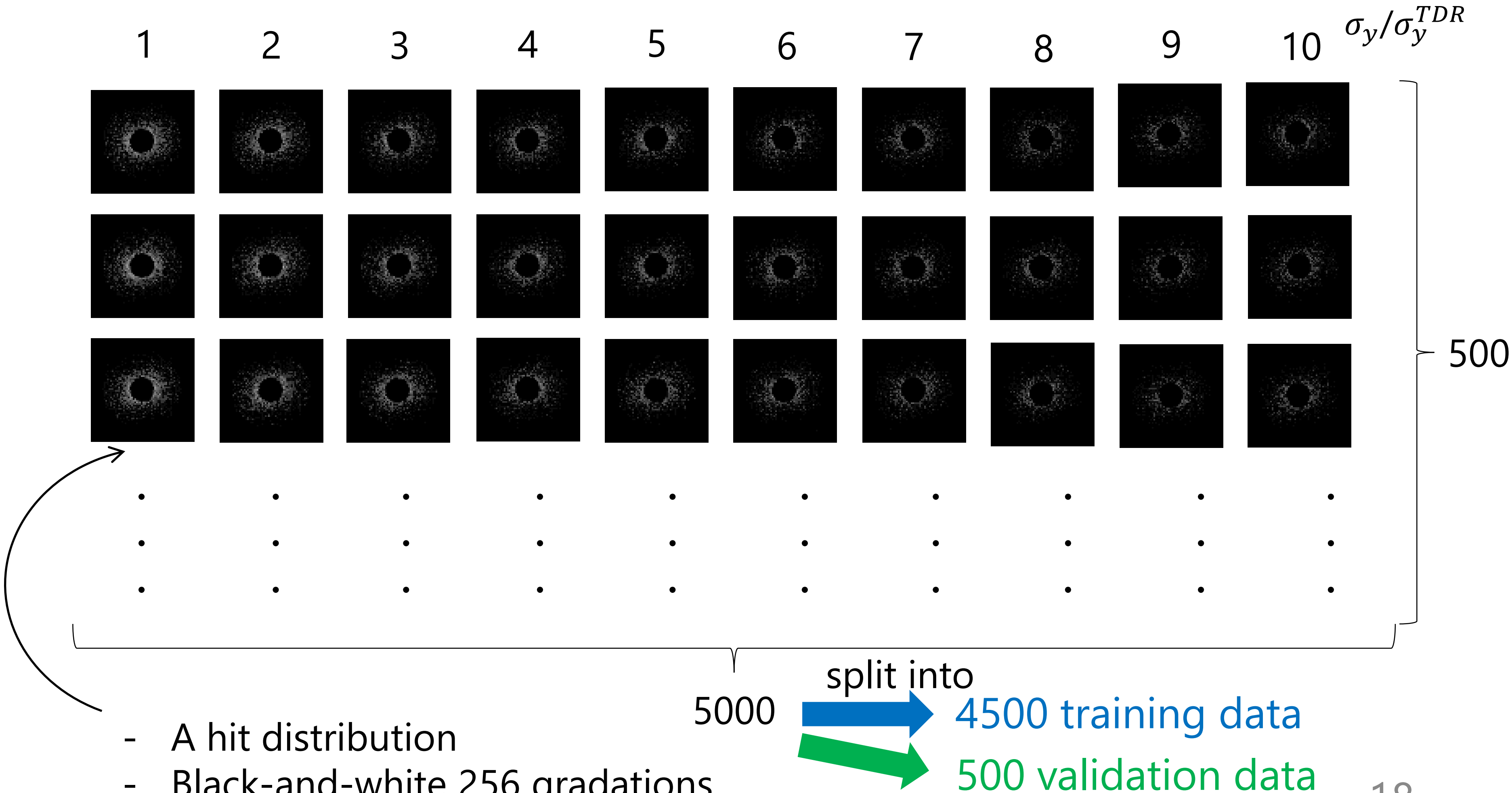
- TensorFlow is an open source software library for high performance numerical computation at Machine learning.
- This library was developed by Google.

Keras

- Keras is a high-level neural network API, written in Python and is wrapper of Tensorflow.

3.5 Training data

- We prepare 500 images for each σ_y .



- A hit distribution
- Black-and-white 256 gradations

3.6 Loss function

Estimate how far the current function deviates from the target.

$$L = -\frac{1}{N}\sum_n \sum_k t_{nk} \log y_{nk}$$

cross entropy function

- Probability value approximates 1.0.
- L goes down
- It is good learning that L is low.

Example($N = 3,\ k = 10$)

Prediction

$$\begin{array}{cc} & \begin{array}{cccc} \text{"}1\sigma_y\text{"} & \text{"}2\sigma_y\text{"} & \dots & \text{"}10\sigma_y\text{"} \end{array} \\ y = & \underbrace{\begin{pmatrix} 0.9 & 0.05 & \dots & 0 \\ 0 & 0.8 & \dots & 0 \\ 0 & 0 & \dots & 0.99 \end{pmatrix}}_{k} \end{array}$$

The row data

N

Truth value

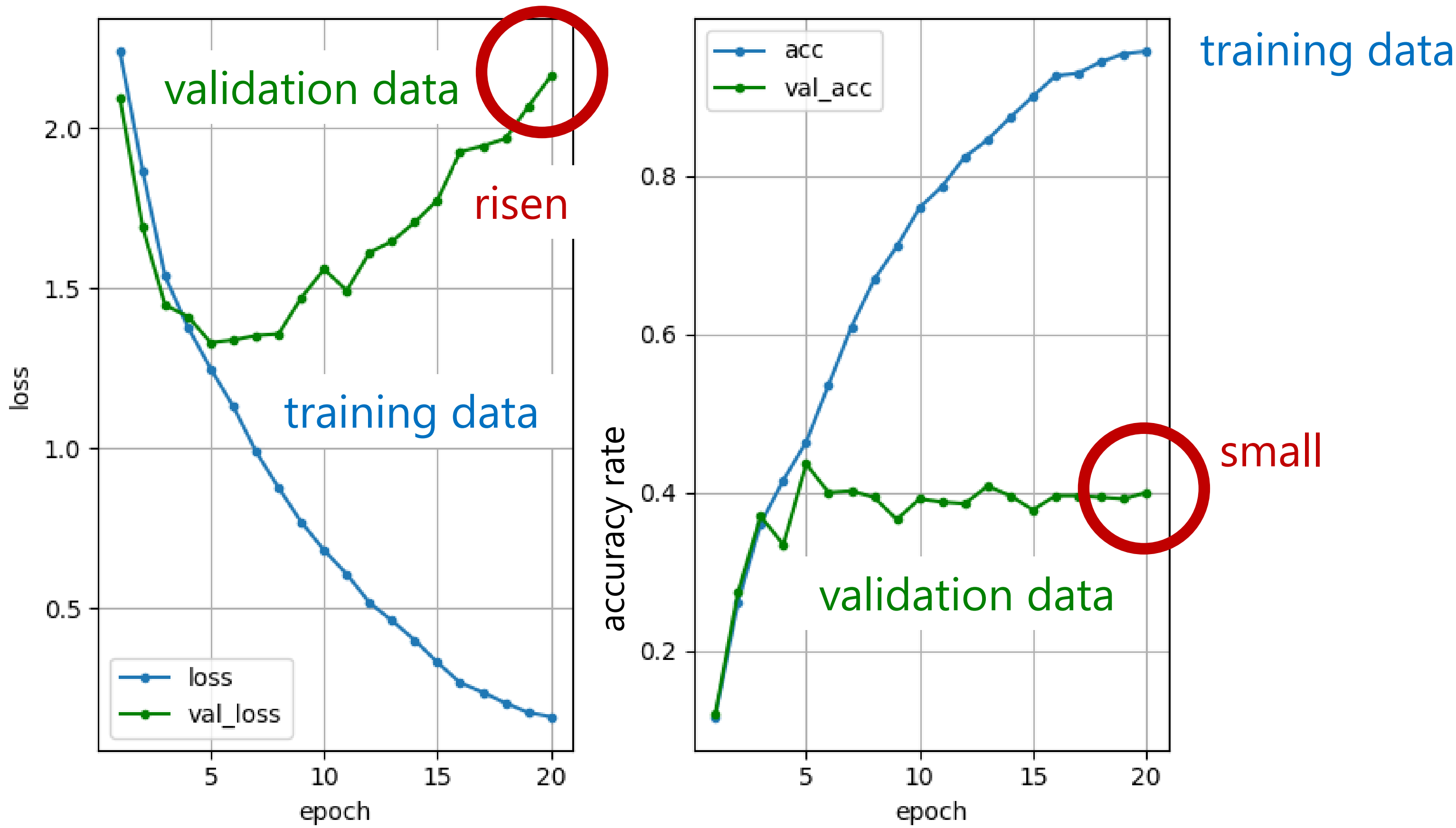
$$\begin{array}{cc} & \begin{array}{cccc} \text{"}1\sigma_y\text{"} & \text{"}2\sigma_y\text{"} & \dots & \text{"}10\sigma_y\text{"} \end{array} \\ t = & \begin{pmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ 0 & 0 & \dots & 1 \end{pmatrix} \end{array}$$

probability of correct answer

$$L = 0.11$$

3.7 Result

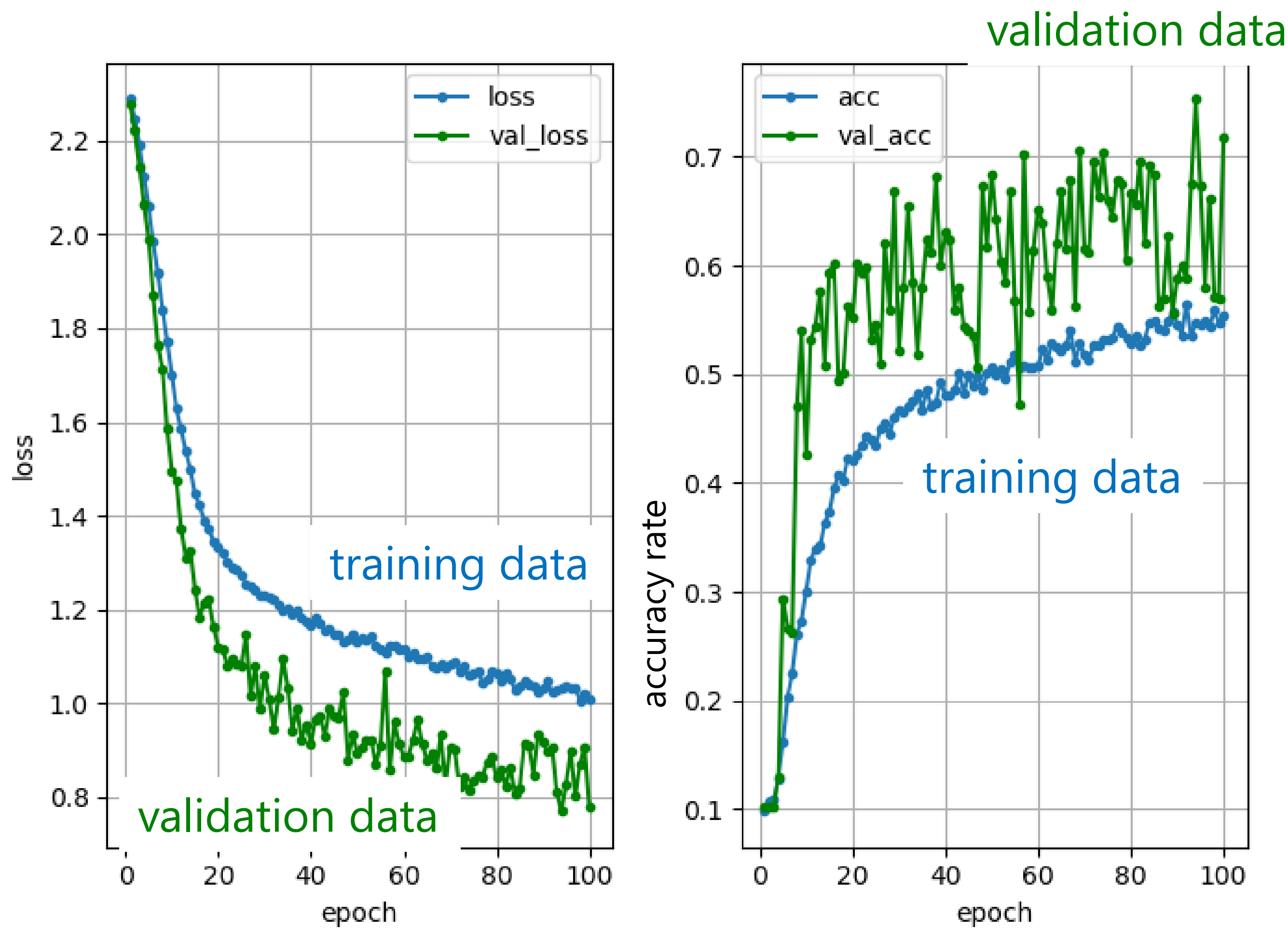
Result of machine learning (neural network)



Neural network learned optimum only training data.

➡ This condition is called Over-fitting

3.8 Result



Result when model is changed to Convolutional Neural Network(CNN).
CNN is kind of DNN. This learning is better than NN.
Accuracy rate is 60% ~ 70%.

4.1 Summary

Consideration

- Deep learning will be probably apply to beam size measurement.
- Adjustment of this learning model is required.
- We need to study machine learning in detail.

Summary

- We reconstruct beam parameter using all hit information.
- we used machine learning.
- Machine learning : NN ← Over-fitting
- Deep learning : CNN ← Accuracy rate is 60% ~ 70%
- Adjustment of these learning model is required.

Backups

Introduction

Purpose of ILC

- measurement of higgs boson and other new particle

Important thing

- Increase the number of reactions per unit time

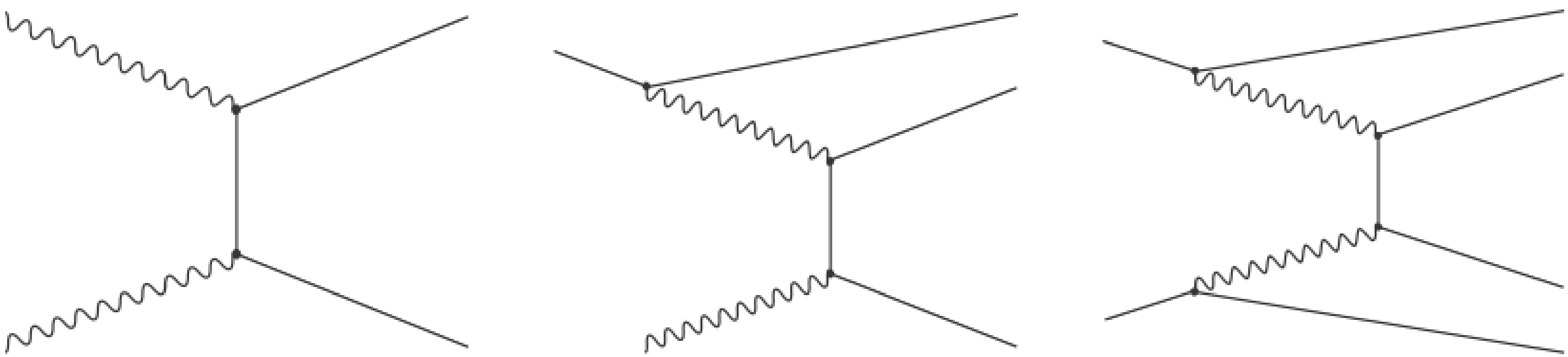
$$N[s^{-1}] = L[cm^{-2}s^{-1}] \times \sigma[cm^{2}]$$

L : Luminosity

σ : Cross section

Increase the number of reactions by high luminosity

beamstrahlung



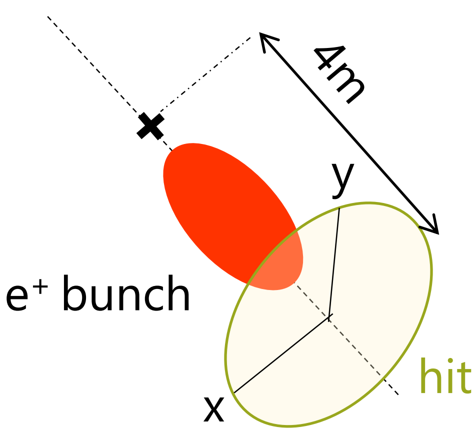
(a) Breit-Wheeler ($\gamma\gamma \rightarrow e^+e^-$)

(b) Bethe-Heitler ($e\gamma\gamma \rightarrow e^{\pm}e^+e^-$)

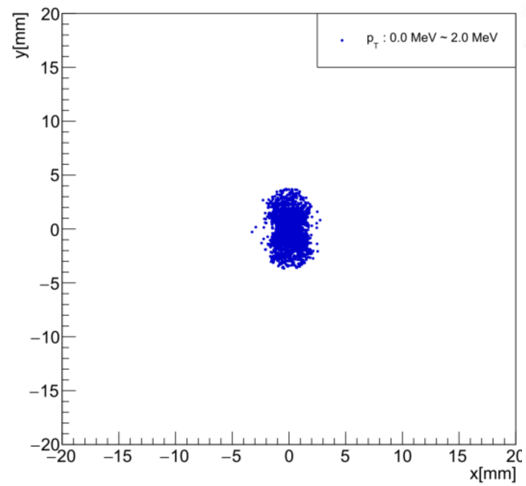
(c) Landau-Lifshitz ($ee\gamma\gamma \rightarrow e^+e^-e^+e^-$)

hit distribution of pair background(e^-)

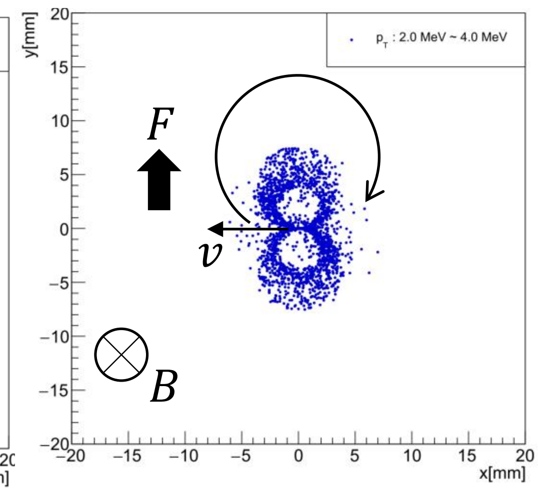
- Since the P_T of the electron is oriented in 0 or π direction, draw circles up and down by the magnetic field.
- Since the particle's turning radius depends on P_T, the distribution widens as P_T increases.
- When the P_T becomes even larger, it collides with the pair monitor before the particle goes round.



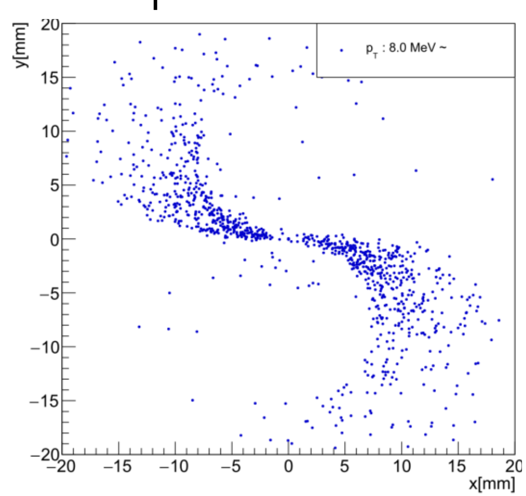
0.0< P_T<2.0 MeV



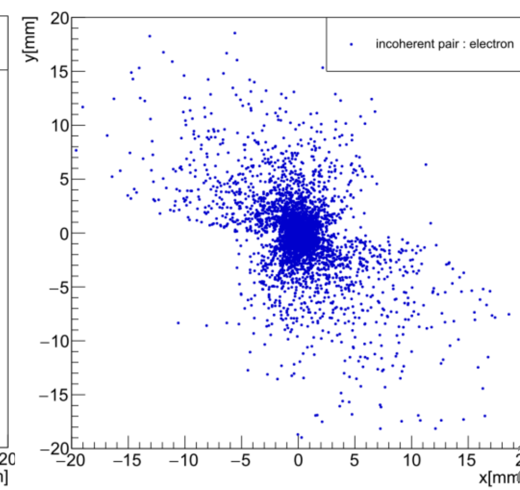
2.0< P_T<4.0 MeV



P_T>8.0 MeV

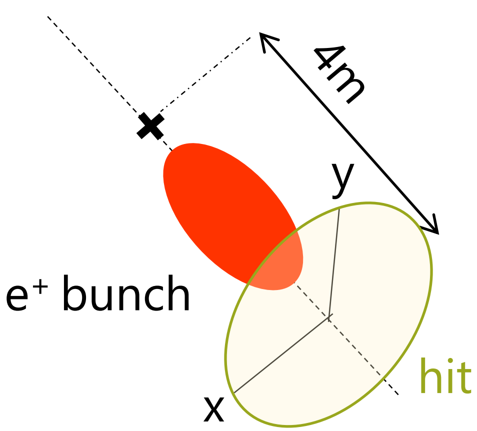


Hit distribution

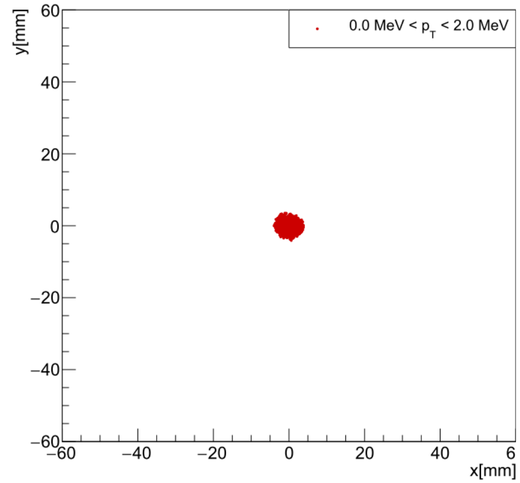


hit distribution of pair background(e^+)

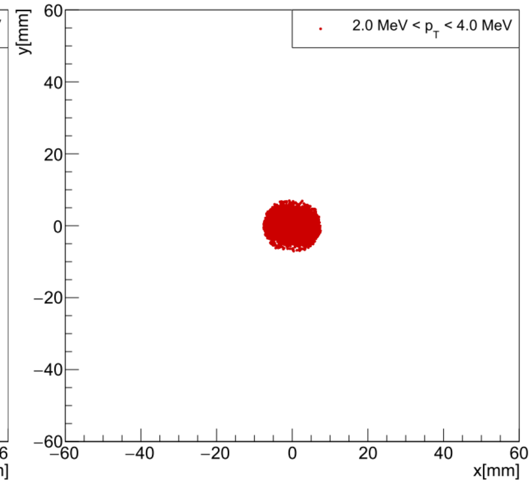
- Positron's P_T is oriented in π/2 or -π/2 direction, that draw a circle on the left or right.
- However, because of the spread of angles, the distribution becomes more uniform as compared with electron's hit distribution.



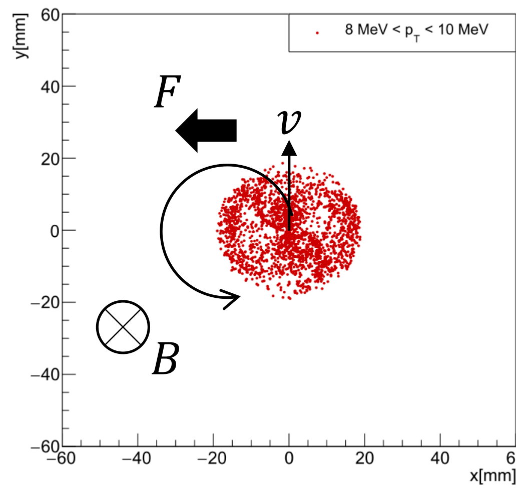
0.0< P_T<2.0 MeV



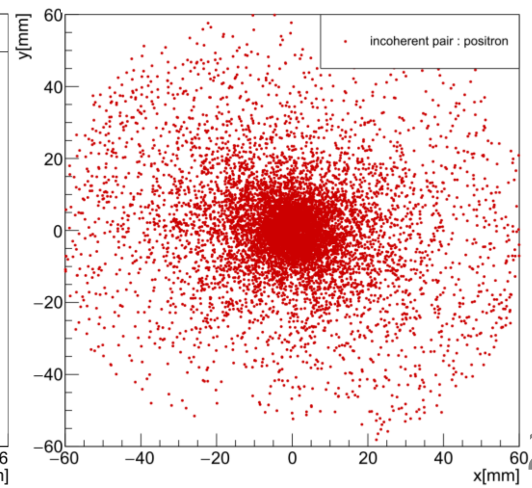
2.0< P_T<4.0 MeV



8.0< P_T<10.0 MeV



Hit distribution



CNN

Convolutional **N**eural **N**etwork

Convolutional and Pooling layer are added to hidden layer of NN.