ICALEPCS2017
Barcelona · Spain, October 8-13 · Palau de Congressos de Catalunya

Development of an Expert System for the High Intensity Neutrino Beam Facility at J-PARC

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for J-PARC Neutrino Facility Group

KEK/J-PARC

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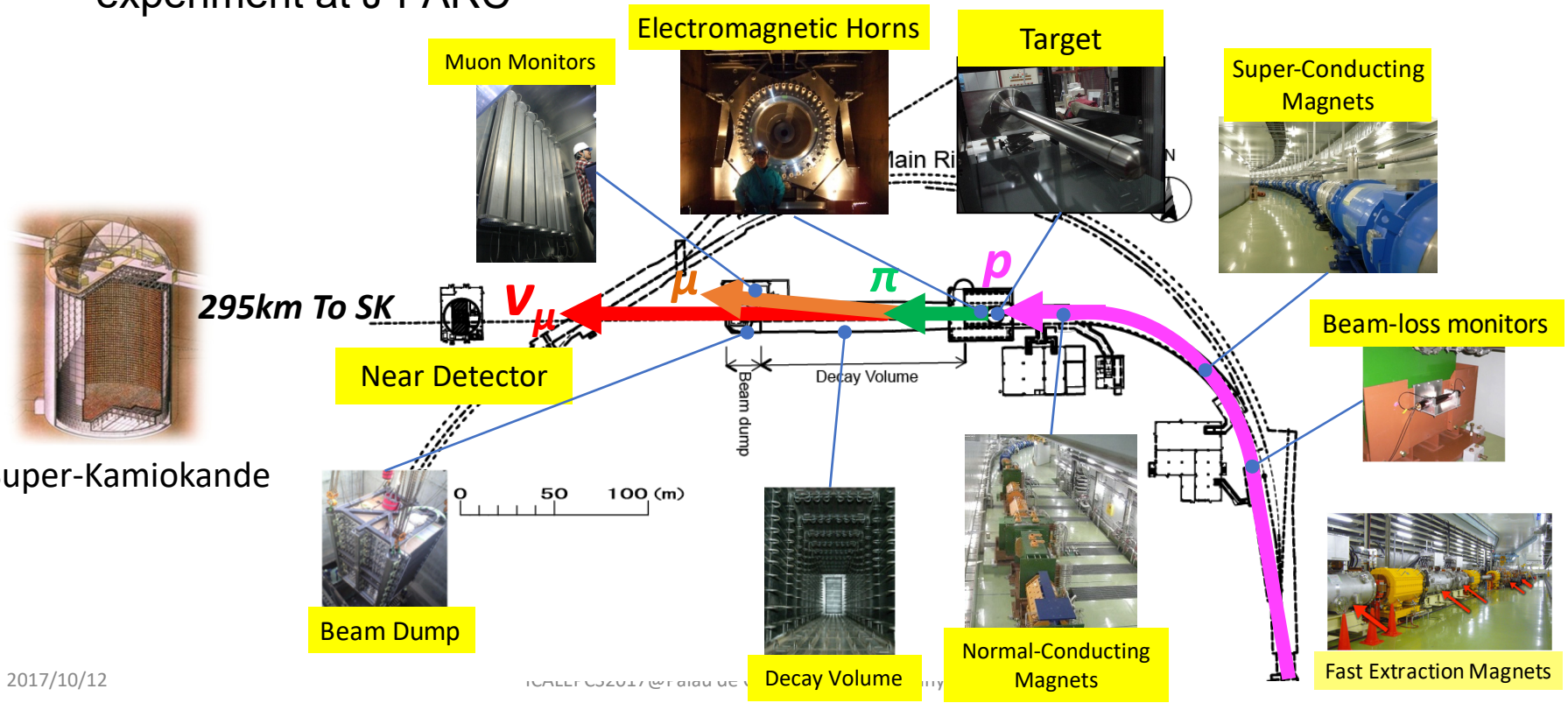
- Beamline expert system based on machine learning method and its initial evaluation
- Summary and prospect

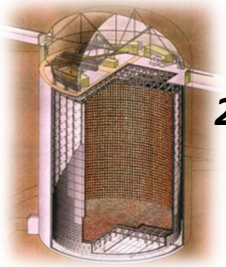
Introduction

We are producing high intensity neutrino beam for T2K neutrino oscillation experiment at J-PARC

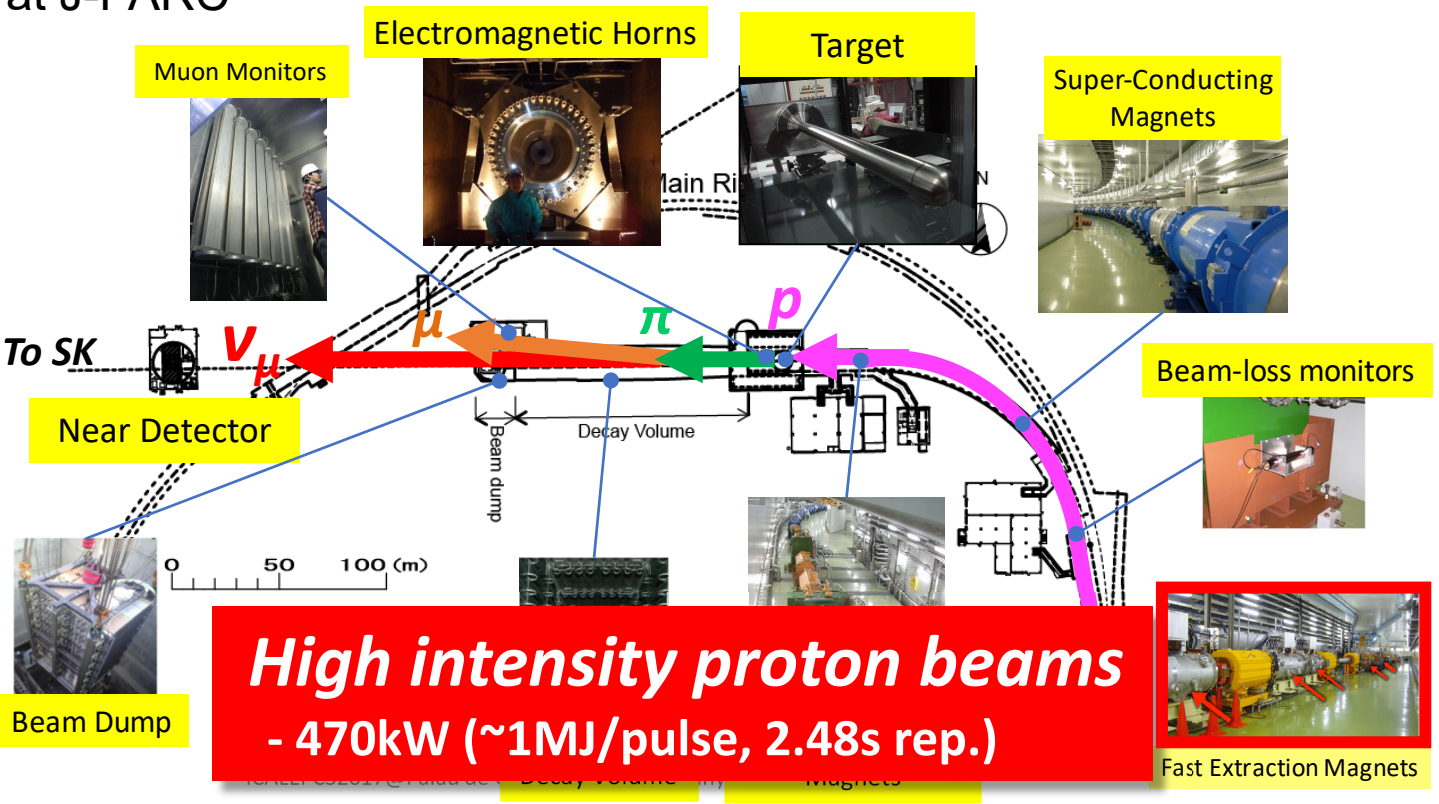


Introduction

We are producing high intensity neutrino beam for T2K neutrino oscillation experiment at J-PARC



Super-Kamiokande

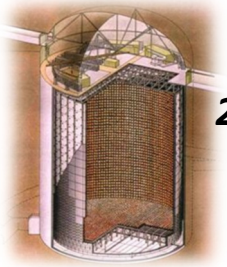


High intensity proton beams

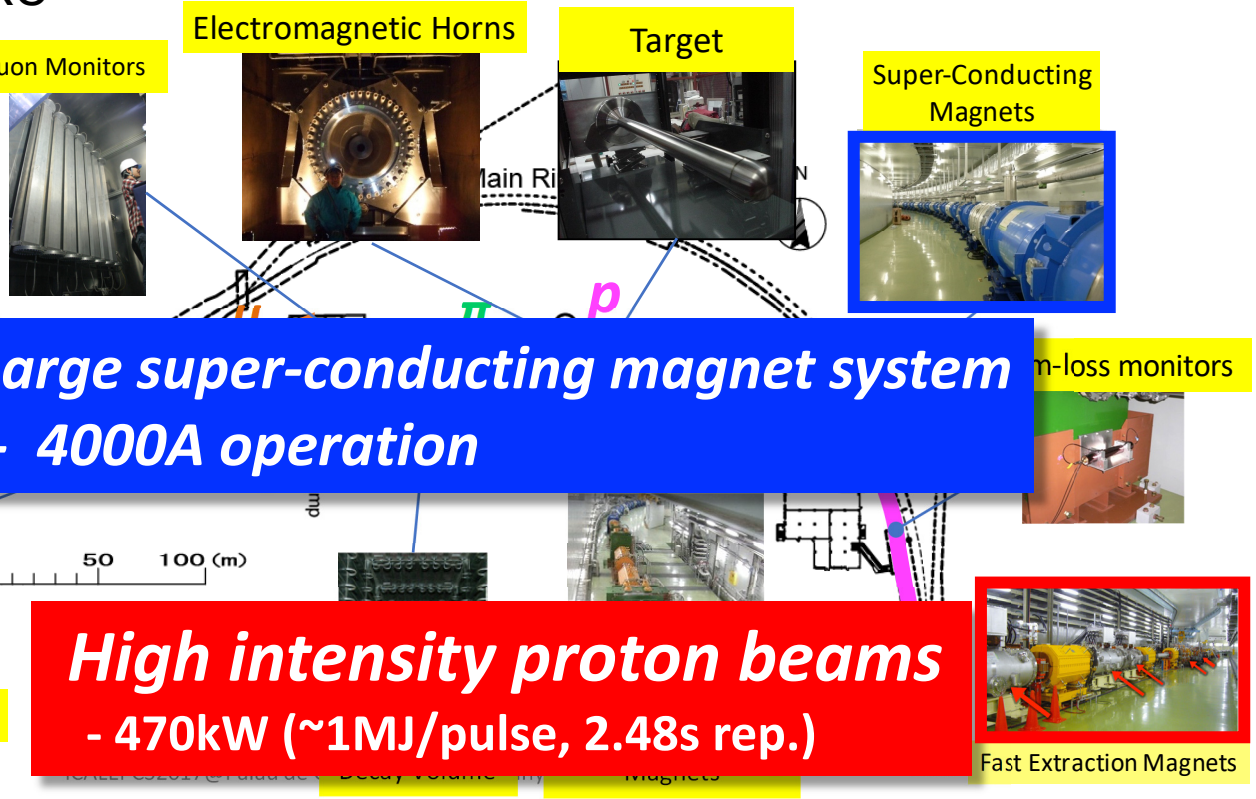
- 470kW (~1MJ/pulse, 2.48s rep.)

Introduction

We are producing high intensity neutrino beam for T2K neutrino oscillation experiment at J-PARC



Super-Kamiokande



Introduction

We are producing high intensity neutrino beam for T2K neutrino oscillation experiment at J-PARC

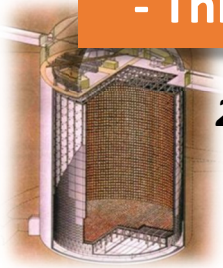
Electromagnetic Horns

Target

Muon Monitors

Super-Conducting Magnets

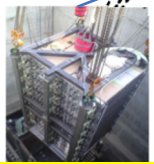
Large pulse current
- Three horns with 250kA



295km To SK

Large super-conducting magnet system
- 4000A operation

Super-Kamiokande



Beam Dump

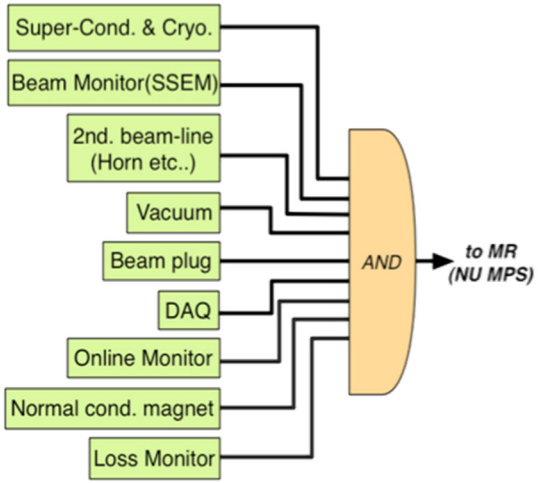
High intensity proton beams
- 470kW (~1MJ/pulse, 2.48s rep.)

Fast Extraction Magnets

Motivation

Prompt and proper error handling is important

- A wide variety of equipment at beamline
- There are **784** of interlock (MPS) sources
- Multiple sources of the interlock happened at the same time

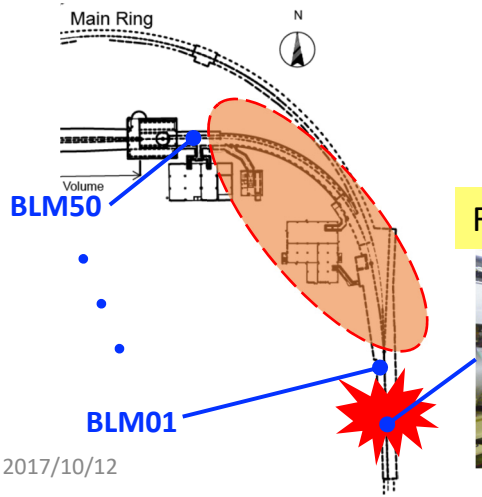


We develop "beamline expert system" in order to prevent beam time loss and wrong operation

Actual examples of MPS event

MPS activated
Normal

The failure of the fast extraction magnets (septum and kicker) cause simultaneous BLM(Beam-loss monitor) MPS events



Fast Extraction Magnets

MPS Event#1

BLM01

BLM#1 - #50

BLM50

	2016/2/11
	SEPTUM
BLMP01	1
BLMP02	1
BLMP03	1
BLMP04	1
BLMP05	1
BLMP06	1
BLMP07	1
BLMP08	1
BLMP09	1
BLMP10	1
BLMP11	1
BLMP12	1
BLMP13	1
BLMP14	1
BLMP15	1
BLMP16	1
BLMP17	1
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BLMP22	1
BLMP23	1
BLMP24	1
BLMP25	1
BLMP26	1
BLMP27	1
BLMP28	1
BLMP29	1
BLMP30	0
BLMP31	1
BLMP32	1
BLMP33	1
BLMP34	0
BLMP35	0
BLMP36	0
BLMP37	0
BLMP38	0
BLMP39	0
BLMP40	0
BLMP41	0
BLMP42	0
BLMP43	0
BLMP44	0
BLMP45	0
BLMP46	0
BLMP47	0
BLMP48	0
BLMP49	0
BLMP50	0

Actual examples of MPS event

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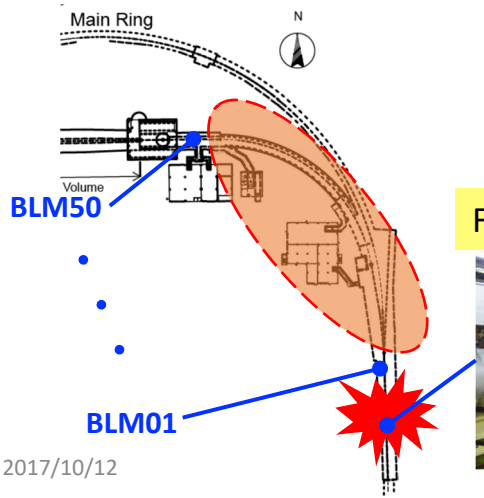

Fast Extraction Magnets

MPS Event#1 . . . MPS Event#10

BLM01

BLM#1 - #50

BLM50

	2016/2/11	2016/2/17	2016/2/23	2016/2/25	2016/5/15	2016/11/14	2016/12/11	2016/12/25	2017/2/27	2017/3/20
	SEPTUM	SEPTUM	SEPTUM	SEPTUM	FXKM	FXKM	FXKM	FXKM	FXKM	FXKM
BLMP01	1	1	1	1	1	0	1	1	1	1
BLMP02	1	1	1	1	1	0	1	1	1	1
BLMP03	1	1	1	1	1	0	1	1	1	1
BLMP04	1	1	1	1	1	0	1	1	1	1
BLMP05	1	1	1	1	1	1	1	1	1	1
BLMP06	1	1	1	1	1	1	1	1	1	1
BLMP07	1	1	1	1	1	1	1	1	1	1
BLMP08	1	1	1	1	1	1	1	1	1	1
BLMP09	1	1	1	1	1	1	1	1	1	1
BLMP10	1	1	1	1	1	1	1	1	1	1
BLMP11	1	1	1	1	1	1	1	1	1	1
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BLMP14	1	1	1	1	1	1	1	1	1	1
BLMP15	1	1	1	1	1	1	1	1	1	1
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BLMP17	1	1	1	1	1	1	1	1	1	1
BLMP18	1	1	1	1	1	1	1	1	1	1
BLMP19	1	1	1	1	0	1	0	1	0	1
BLMP20	1	1	1	1	1	1	1	1	1	1
BLMP21	1	1	1	1	1	1	1	1	1	1
BLMP22	1	1	1	1	1	1	1	1	1	1
BLMP23	1	1	1	1	1	1	1	1	1	1
BLMP24	1	1	1	1	1	1	1	1	1	1
BLMP25	1	1	1	1	1	1	1	1	1	1
BLMP26	1	1	1	1	1	1	1	1	1	1
BLMP27	1	1	1	1	1	1	1	1	1	1
BLMP28	1	1	1	1	0	1	0	1	0	1
BLMP29	1	1	1	1	0	1	0	1	0	1
BLMP30	0	1	1	1	0	1	0	1	0	1
BLMP31	1	1	1	1	0	1	0	1	0	1
BLMP32	1	1	0	0	0	1	0	1	0	1
BLMP33	1	1	1	0	0	1	0	0	0	0
BLMP34	0	0	0	0	0	1	0	1	0	1
BLMP35	0	0	0	0	0	0	0	0	0	1
BLMP36	0	0	0	0	0	1	0	1	0	1
BLMP37	0	0	0	0	0	1	0	0	0	0
BLMP38	0	0	0	0	0	1	0	1	0	1
BLMP39	0	0	0	0	0	1	0	0	0	1
BLMP40	0	0	0	0	0	1	0	1	0	1
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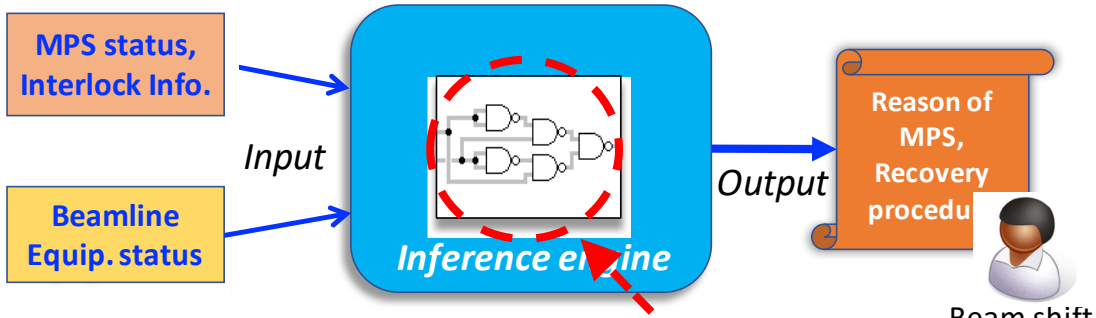
BLMP44	0	0	0	0	0	0	0	0	0	0
BLMP45	0	0	0	0	0	1	0	0	0	0
BLMP46	0	0	0	0	0	1	0	0	0	0
BLMP47	0	0	0	0	0	0	0	0	0	0
BLMP48	0	0	0	0	0	1	0	0	0	1
BLMP49	0	0	0	0	0	1	0	1	0	1
BLMP50	0	0	0	0	0	1	0	1	0	1

Beamline expert system based on machine learning method and its initial evaluation

Development of expert system with a machine-learning scheme

- Our idea of **the beamline expert system** is continuously collecting the MPS status (and other data) and then infers the MPS reason and presents recovery procedure
- "**Inference engine**" is a key component of the expert system. It infers the reason of MPS and equipment failure from input data
- Although typical Inference engine of the expert system is rule-based, we adapt a ***Machine-Learning (ML)*** based inference engine in the expert system



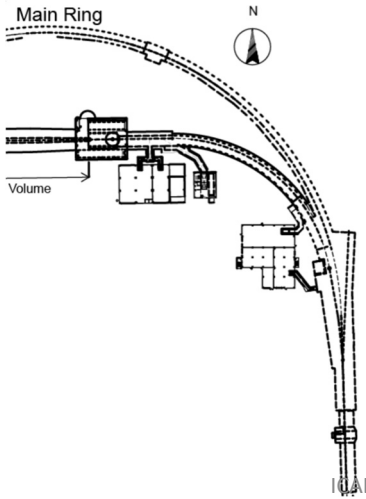
In this talk, we will discuss on initial evaluation of the ML-based inference engine

Method of the initial evaluation

MPS activated
Normal

Evaluating the ML-based inference engine considering the case of events where many BLM MPS were happened

- right table is the list of many BLM MPS events caused by FX septum or kicker



Septum | Kicker

BLM#1 - #50

	2016/2/11	2016/2/17	2016/2/23	2016/2/25	2016/5/15	2016/11/14	2016/12/11	2016/12/25	2017/2/27	2017/3/20
	SEPTUM	SEPTUM	SEPTUM	SEPTUM	FXKM	FXKM	FXKM	FXKM	FXKM	FXKM
BLMP01	1	1	1	1	1	0	1	1	1	1
BLMP02	1	1	1	1	1	0	1	1	1	1
BLMP03	1	1	1	1	1	0	1	1	1	1
BLMP04	1	1	1	1	1	0	1	1	1	1
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BLMP06	1	1	1	1	1	1	1	1	1	1
BLMP07	1	1	1	1	1	1	1	1	1	1
BLMP08	1	1	1	1	1	1	1	1	1	1
BLMP09	1	1	1	1	1	1	1	1	1	1
BLMP10	1	1	1	1	1	1	1	1	1	1
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BLMP16	1	1	1	0	0	1	0	1	0	1
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BLMP21	1	1	1	1	1	1	1	1	1	1
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BLMP25	1	1	1	1	1	1	1	1	1	1
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BLMP28	1	1	1	1	0	1	0	1	0	1
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BLMP32	1	1	0	0	0	1	0	1	0	1
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BLMP34	0	0	0	0	0	1	0	1	0	1
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BLMP36	0	0	0	0	0	1	0	1	0	1
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BLMP38	0	0	0	0	0	1	0	1	0	1
BLMP39	0	0	0	0	0	1	0	0	0	1
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BLMP48	0	0	0	0	0	1	0	0	0	1
BLMP49	0	0	0	0	0	1	0	1	0	1
BLMP50	0	0	0	0	0	1	0	1	0	1

BLM MPS patterns of FX Septum/Kicker

Method of the initial evaluation

MPS activated
Normal

Evaluating the ML-based inference engine considering the case of events where many BLM MPS were happened

- right table is the list of many BLM MPS events caused by FX septum or kicker

Can our ML-based expert system classify those events into FX septum and kicker ?

Septum | Kicker

BLM#1 - #50

	2016/2/11	2016/2/17	2016/2/23	2016/2/25	2016/5/15	2016/11/14	2016/12/11	2016/12/25	2017/2/27	2017/3/20
	SEPTUM	SEPTUM	SEPTUM	SEPTUM	FXKM	FXKM	FXKM	FXKM	FXKM	FXKM
BLMP01	1	1	1	1	1	0	1	1	1	1
BLMP02	1	1	1	1	1	0	1	1	1	1
BLMP03	1	1	1	1	1	0	1	1	1	1
BLMP04	1	1	1	1	1	0	1	1	1	1
BLMP05	1	1	1	1	1	1	1	1	1	1
BLMP06	1	1	1	1	1	1	1	1	1	1
BLMP07	1	1	1	1	1	1	1	1	1	1
BLMP08	1	1	1	1	1	1	1	1	1	1
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BLMP10	1	1	1	1	1	1	1	1	1	1
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BLMP12	1	1	1	1	1	1	1	1	1	1
BLMP13	1	1	1	1	1	1	1	1	1	1
BLMP14	1	1	1	1	1	1	1	1	1	1
BLMP15	1	1	1	1	1	1	1	1	1	1
BLMP16	1	1	1	0	0	1	0	1	0	1
BLMP17	1	1	1	1	1	1	1	1	1	1
BLMP18	1	1	1	1	1	1	1	1	1	1
BLMP19	1	1	1	1	0	1	0	1	0	1
BLMP20	1	1	1	1	1	1	1	1	1	1
BLMP21	1	1	1	1	1	1	1	1	1	1
BLMP22	1	1	1	1	1	1	1	1	1	1
BLMP23	1	1	1	1	1	1	1	1	1	1
BLMP24	1	1	1	1	1	1	1	1	1	1
BLMP25	1	1	1	1	1	1	1	1	1	1
BLMP26	1	1	1	1	1	1	1	1	1	1
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BLMP31	1	1	1	1	0	1	0	1	0	1
BLMP32	1	1	0	0	0	1	0	1	0	1
BLMP33	1	1	1	0	0	1	0	0	0	0
BLMP34	0	0	0	0	0	1	0	1	0	1
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BLMP37	0	0	0	0	0	1	0	0	0	0
BLMP38	0	0	0	0	0	1	0	1	0	1
BLMP39	0	0	0	0	0	1	0	0	0	1
BLMP40	0	0	0	0	0	1	0	1	0	1
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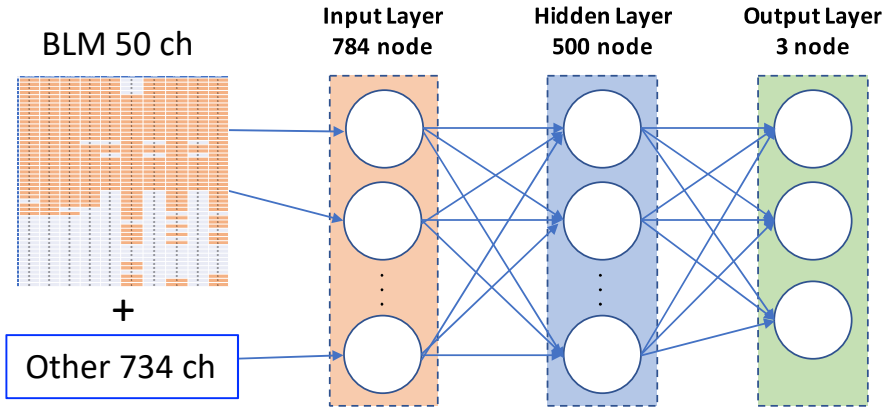
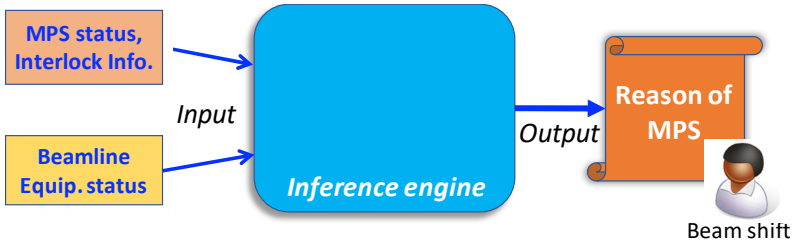
BLMP42	0	0	0	0	0	0	0	0	0	0
BLMP43	0	0	0	0	0	0	0	0	0	0
BLMP44	0	0	0	0	0	0	0	0	0	0
BLMP45	0	0	0	0	0	1	0	0	0	0
BLMP46	0	0	0	0	0	1	0	0	0	0
BLMP47	0	0	0	0	0	0	0	0	0	0
BLMP48	0	0	0	0	0	1	0	0	0	1
BLMP49	0	0	0	0	0	1	0	1	0	1
BLMP50	0	0	0	0	0	1	0	1	0	1

BLM MPS patterns of FX Septum/Kicker

A model for the initial evaluation

- We used a 2-layer model for the initial evaluation at this time
  - Input is an array data of the 784 interlock sources (1 or 0)
  - Output is three labels such as FX septum, FX kicker and others





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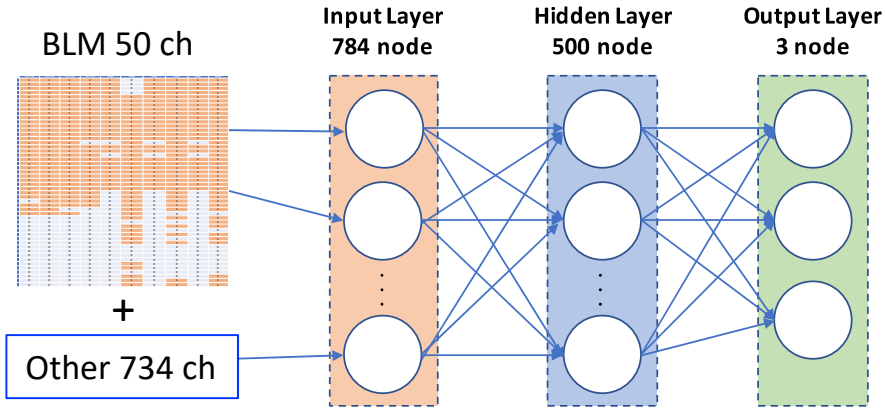
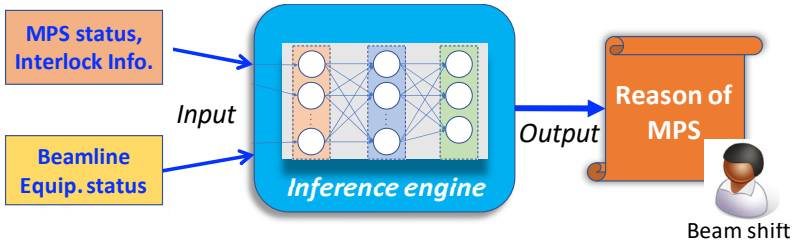
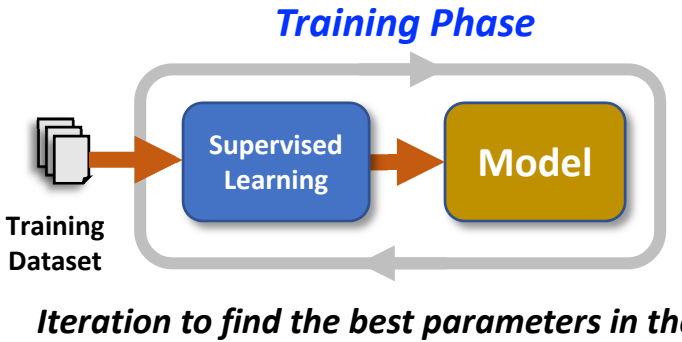




Supervised training of the model

We performed a supervised training

- First, we prepared a simulated training data which consists of an input data and its correct label and 30000 of the training data (10000 of each label) were generated based on the actual past MPS events
- Then, we performed a training to optimize the model to get the correct label



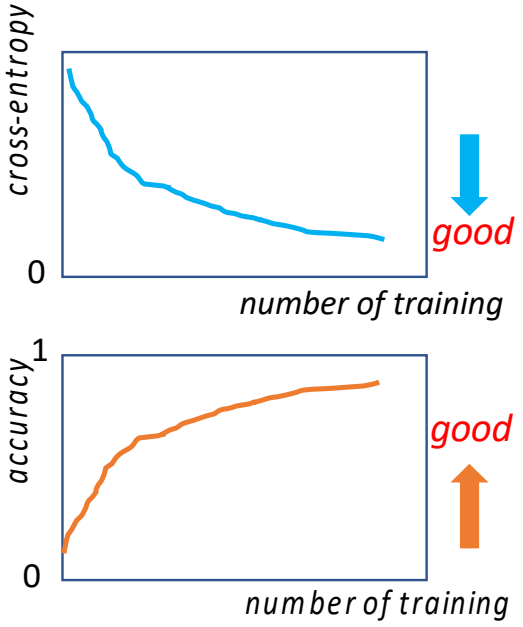
Our testbed: tensorflow 1.2.0, MacBook Pro(2.7GHz Core i5)

Evaluation method during the training

We evaluate our model based on following two values

- **The cross-entropy** is an entropy of the model. It tends toward small value as the model getting better during the training.
- **The accuracy** is the correct answer rate of the prediction from the model

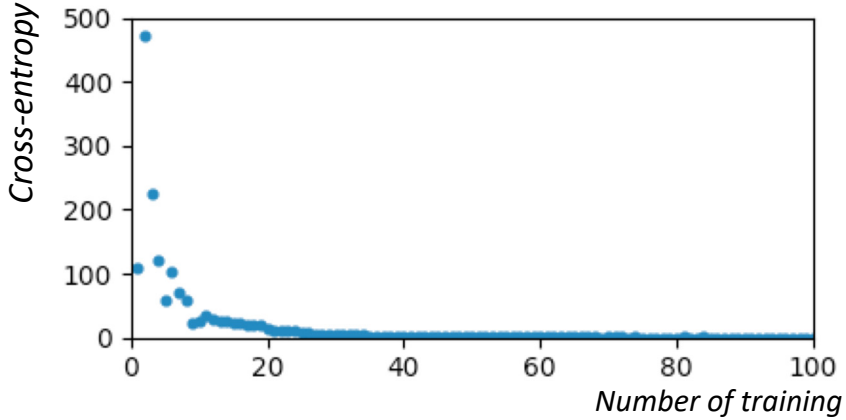
$$Accuracy = \frac{Num\ of\ correct\ prediction}{Num\ of\ training\ data}$$



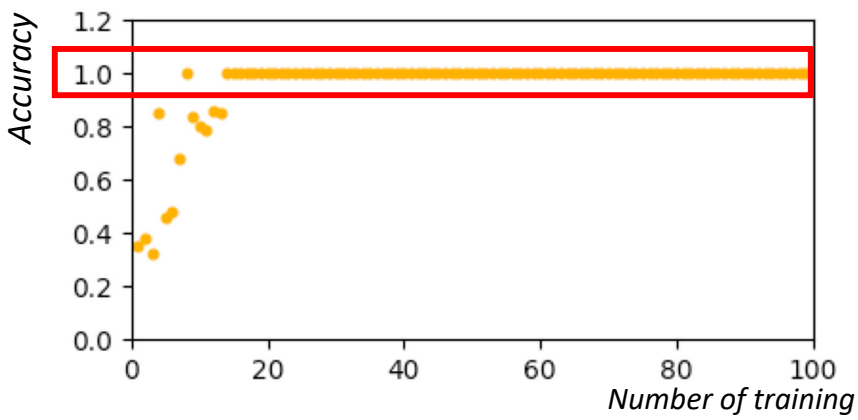
If we get an accuracy of 1, the model can classify the events into three labels. In our case, it is possible if the input data of each event have individual features with its label.

Results of initial evaluation

Cross-entropy vs. Num of training



Accuracy vs. Num of training

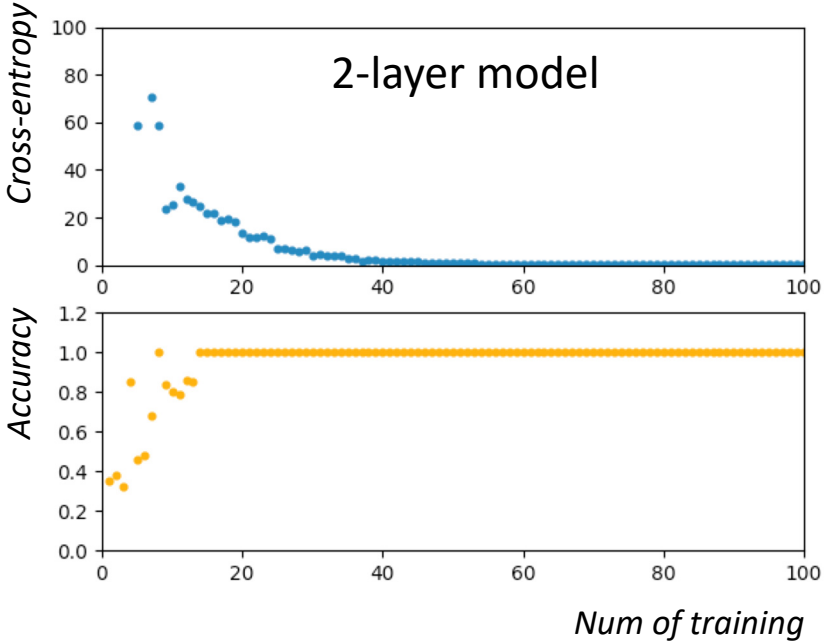


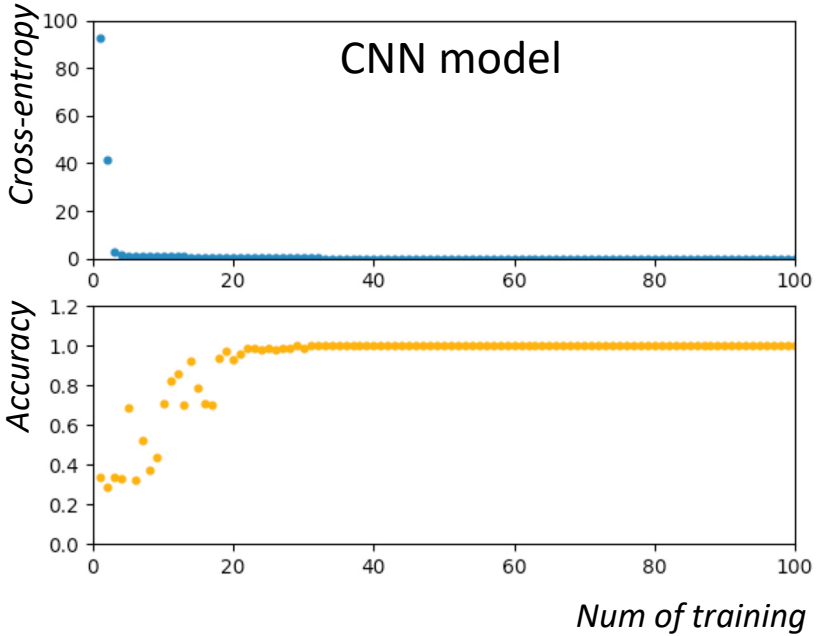
- *The cross-entropy was rapidly reduced and became flat in the training.*
- *The accuracy became 100% after 20 times training.*

Our ML-based expert system can classify the MPS events into FX septum, kicker and one other correctly.

Comparison with other model case

We also performed a study with other model case, which CNN (Convolution Neural Network) is a model which is particularly well-adapted to classify images.





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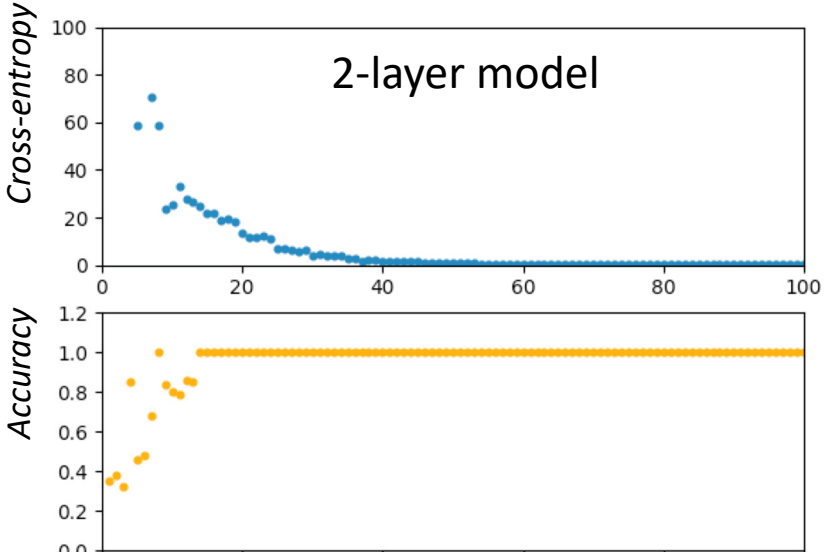

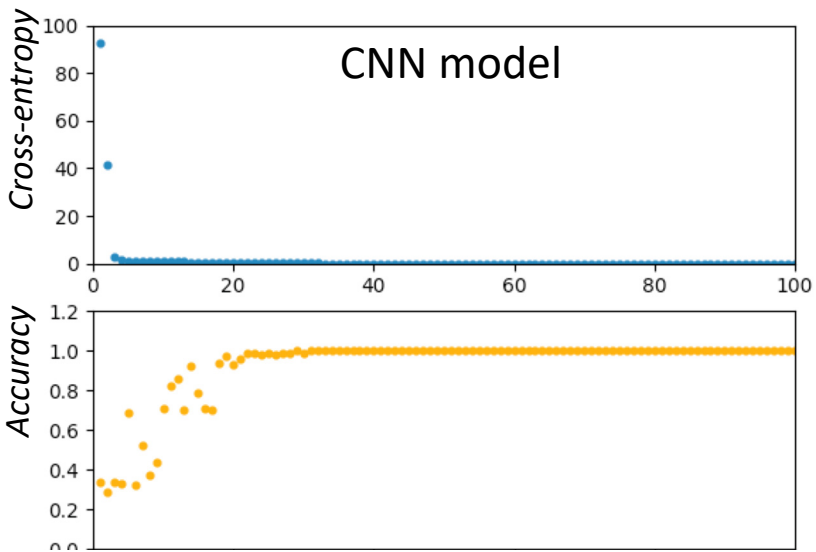

From the initial study, it is found that the CNN based model also shows 100% of accuracy while the learning speed seems faster than the 2-layer model

Summary and prospect

- We are developing machine-learning(ML) based beamline expert system for neutrino facility at the J-PARC
- We performed an initial evaluation. The results indicate that ML-based inference engine is promising
- We also evaluated other model scheme (e.g. Convolution Neural Network) . We plan to perform further studies (model dependence, etc.)
- We plan to study further details on the ML-based inference engine and evaluate with future actual interlock events during next beam operation (from middle October)