OSAKA CITY UNIVERSITY

強化学習を用いたKEK Linac運転調整のための準備研究

R&D of the KEK Linac accelerator tuning based on reinforcement study

Osaka City University

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Abstracts

In this study, we have developed an accelerator operation tuning system using machine learning.

We have developed the tuning of the e^-/e^+ injector linear particle accelerator (Linac) at KEK.

Outline

1. **Introduction**
2. Correlation between operating and environmental parameters in KEK Linac
3. Preparatory studies for the accelerator tunning based on the environment driven ML
4. Summary

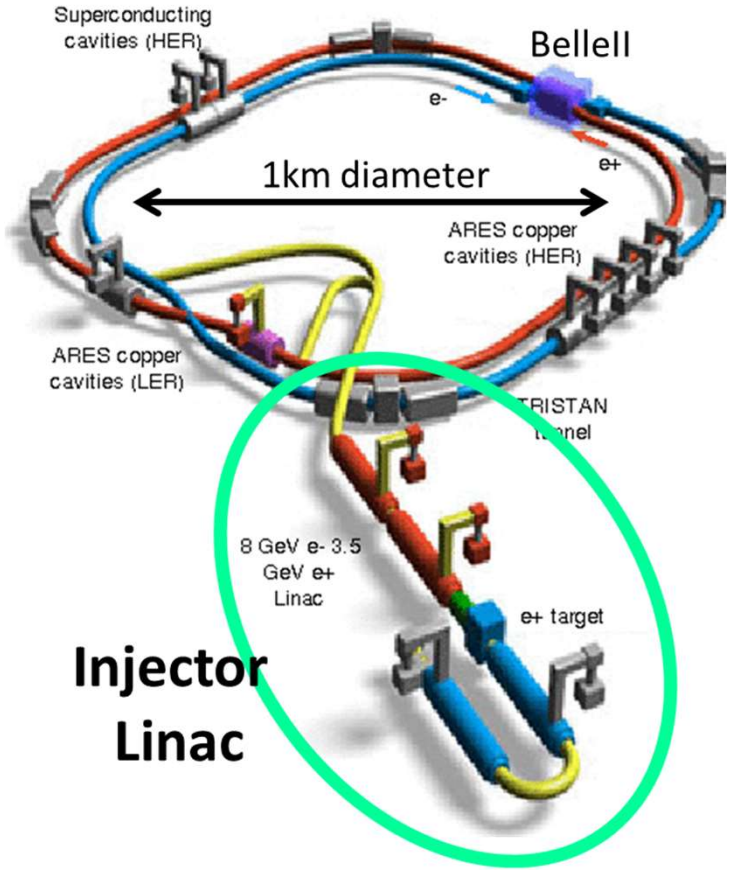
1. Introduction

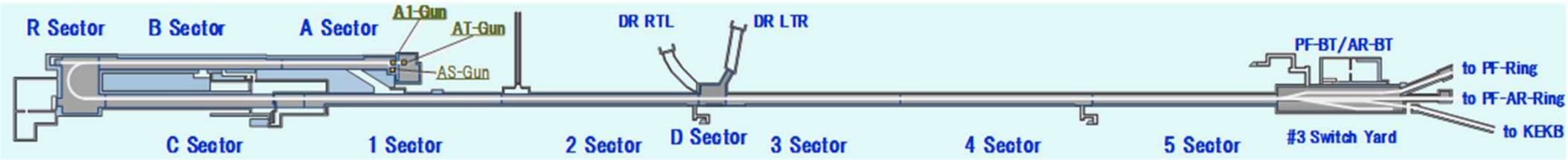
What is Linac?

Linac : 600-meter-long e^-/e^+ injector linear particle accelerator at KEK

The energy of the beam is controlled by RF and the position of the beam is controlled by electromagnets.

- **100 Beam Position Monitors (BPM)**
- **200 Steering Magnets**
- **60 RF monitors**

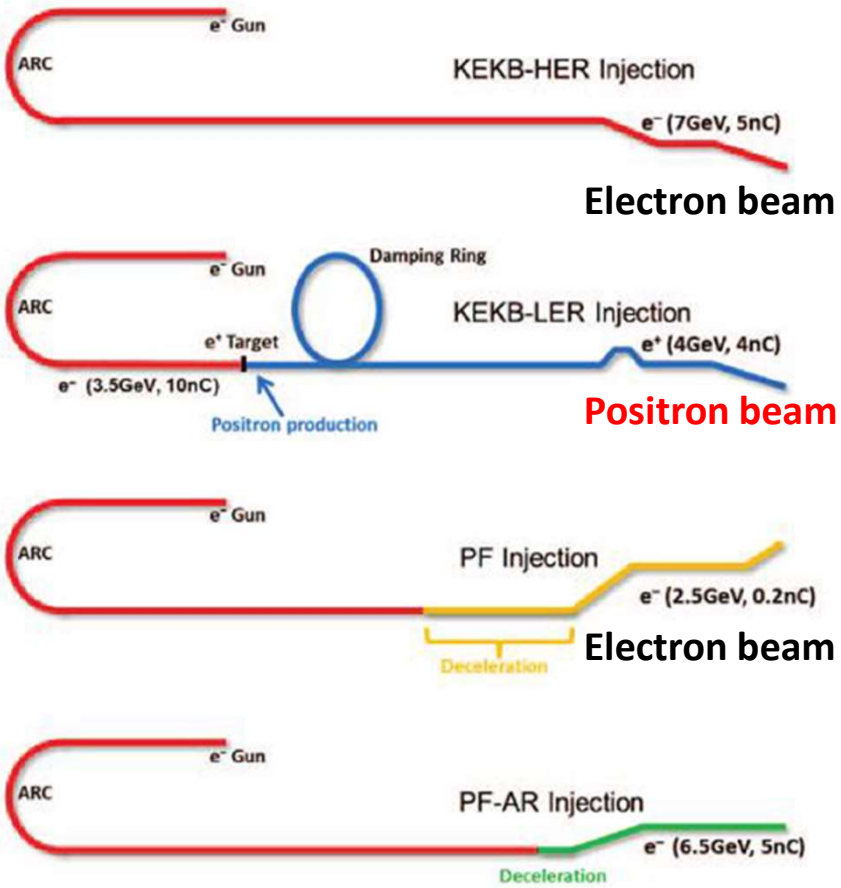




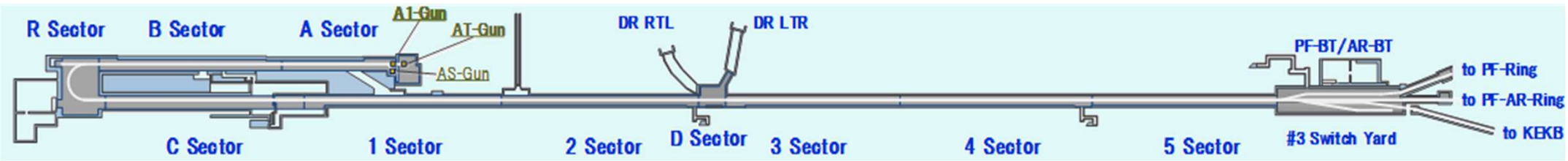
1. Introduction

What is Linac?

Injector Linac is for SuperKEKB, PF and PF-AR



In this study, we use the KEK Linac operation data accumulated in
2018 Nov. – 2019 Nov. (1,806,000 shot)
2020 Mar. – 2020 May (18,053 shot)



1. Introduction

Linac operation tuning

In the Linac operation tuning, various operating parameters are optimized :

1. So that beams can go through the accelerator from top to end (@ starting up)
2. To increase the beam injection efficiency.

Continuously optimized during the operations.

We have developed the acc. tuning scheme for the purpose 2.

Problems on the operation tuning

1. A lot of parameters (~1000) should be tuned, and these parameters are intricately correlated with each other.
2. Continuous environmental change affects to the operation tuning.

Machine Learning (DNN) , which is good at pattern recognition btw multiple params, is expected to be powerful tool for the acc. tuning.

1. Introduction

We have developed the acc. tuning based on DNN

1. Visualization of distribution trend/correlation of acc. params by two-dimensional mapping using DNN (VAE) to solve :

Problem 1. A lot of parameters (~1000) should be tuned, and these parameters are intricately correlated with each other.

2. Parameter optimization using the environment driven DNN (reinforcement ML) based on the most recent data training to solve :

Problem 2. Continuous environmental change affects to the operation tuning.

Outline

1. Introduction
2. **<u>Correlation between operating and environmental parameters in KEK Linac</u>**
3. Preparatory studies for the accelerator tunning based on the environment driven ML
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2. Correlation between operating and environmental parameters in KEK Linac

Visualization of the current "Accelerator Status"

Acc. tuning depends on the "Accelerator Status" which is determined by environmental parameters (component temperature, room temperature, etc.) and operating parameters.

In KEK Linac,

~500 Environmental parameters

~300 Operating parameters (Steering magnet)

Visualization of the "Accelerator Status" and correlation btw the "Accelerator Status" and "good" operating params to get the high injection ε.

Visualization of the "Accelerator Status" by VAE(Variational Auto Encoder).

Input

Environmental and operational parameters of the accelerator

Total ~800

DNN Encoder

A DNN to acquire latent variables of any dimension representing the input data.

Dimensionality reduction

Latent variables Z

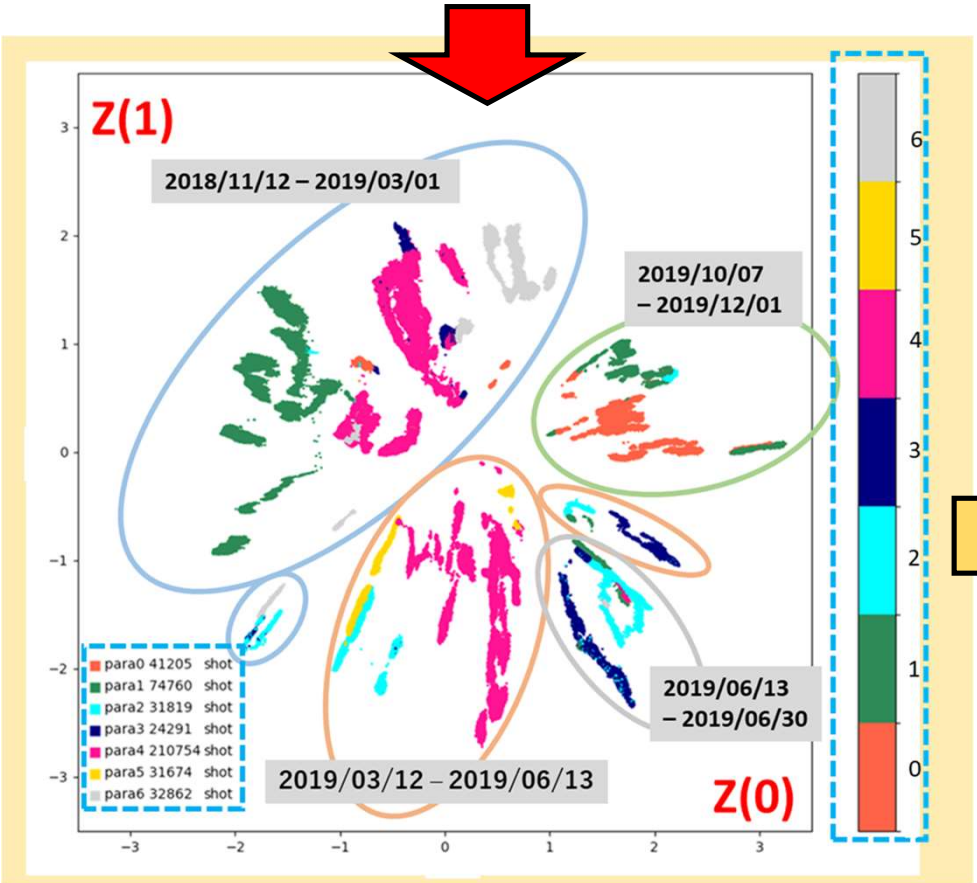
Designated to get 2-D parameters Z(0), Z(1) for mapping

2. Correlation between operating and environmental parameters in KEK Linac

For Linac operational data (2018 Nov. - 2019 Nov.)

Input data : 320 steering magnet params and
495 Environmental params (total 815 params),

acquiring 2-D latent variables Z(0),Z(1) using VAE.



Coloring by category

The value of steering magnet (second of 3 sectors) in case of high injection efficiency.

Classified into 7 categories according to setting values.

Para0 :	$x < -0.6$
para1 :	$-0.6 \leqq x < -0.4$
para2 :	$-0.4 \leqq x < 0$
para3 :	$0 \leqq x < 0.2$
para4 :	$0.2 \leqq x < 0.4$
para5 :	$0.4 \leqq x < 0.6$
para6 :	$0.6 \leqq x$

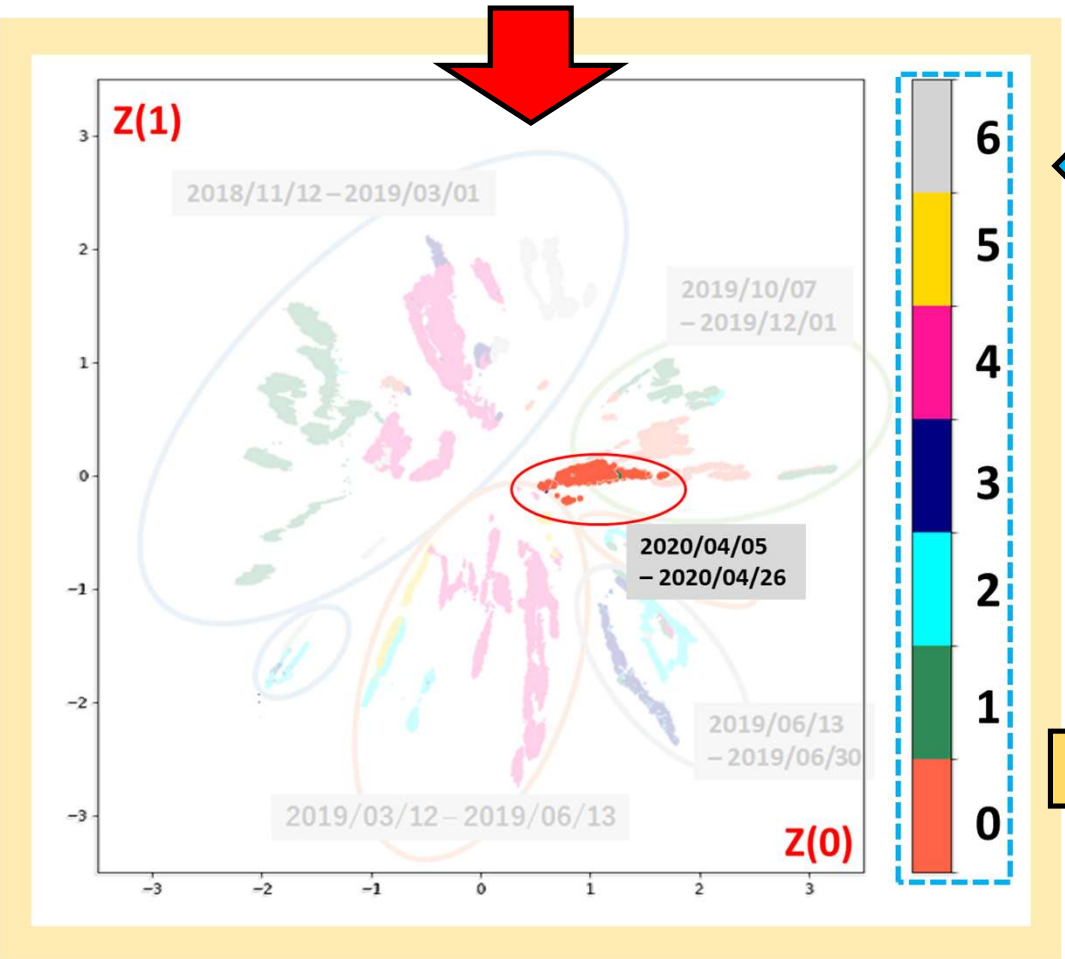
We get a visual on the "Accelerator Status"

The correlation between the Accelerator Status and the optimal operating parameters is obtained.

Validate with 2020 data.

2. Correlation between operating and environmental parameters in KEK Linac

For Linac operational data (2020 Apr.),
Using VAE trained with the 2018-2019 data,
acquiring 2-D latent variables Z(0),Z(1).



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Using VAE trained on the 2018-2019 data,

We described correlation between accelerator state and optimal adjustment of operation parameters for 2020 data.

Outline

1. Introduction
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3. **Preparatory studies for the accelerator tunning based on the environment driven ML**
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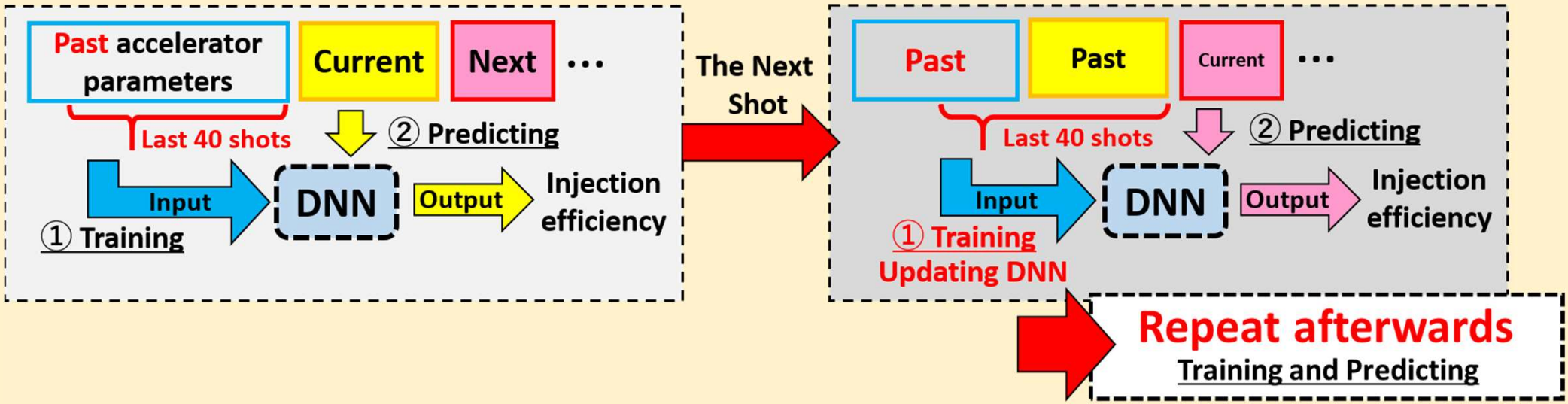
3. Preparatory studies for the accelerator tunning based on the environment driven ML

Injection eff. prediction based on the reinforcement ML

As the accelerator environmental parameters (components temperature, room temperature, etc.) vary, the acc. tuning must continuously done during operations. → Tunning based on the environment driven ML is effective.

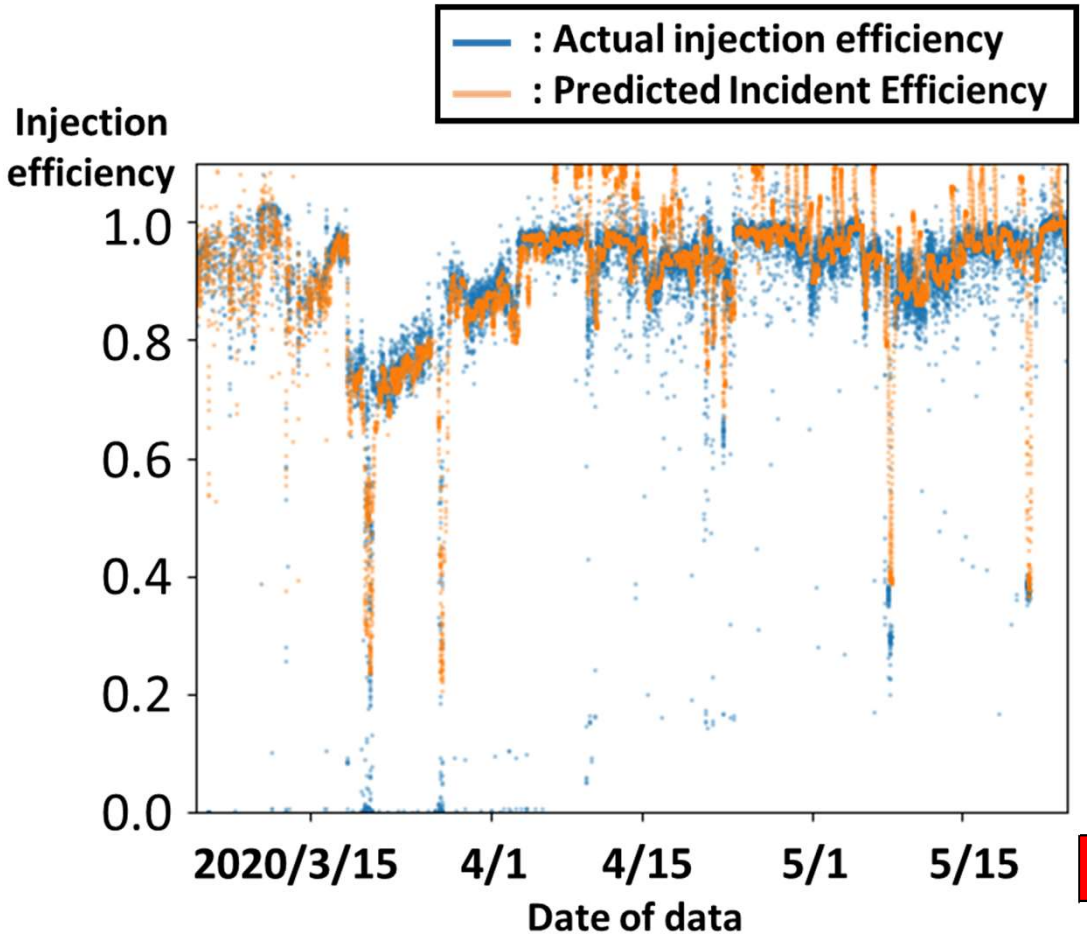
As preparatory studies for the acc. tuning based on the reinforcement ML, we have studied the injection eff. prediction based on the reinforcement ML using the most recent data.

Injection eff. Prediction based on the training/updating DNN with the most recent data

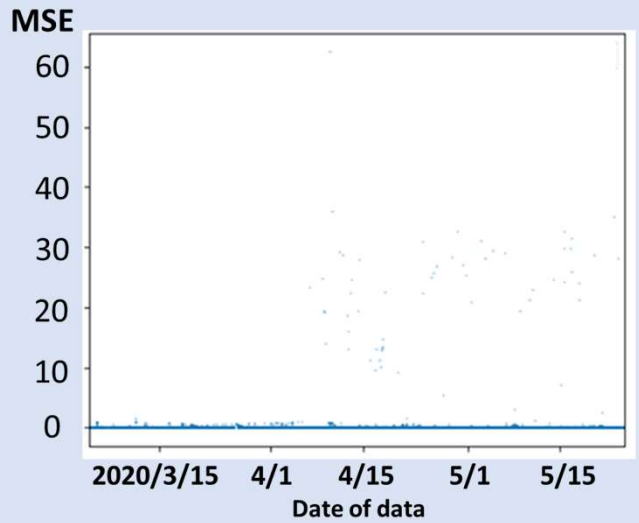


3. Preparatory studies for the accelerator tunning based on the environment driven ML

Results: Predicted injection eff. with the reinforcement ML



For Linac operational data (2020 Mar. - 2020 May),
Input data is 320 steering magnet parameters and 495 Environmental parameters (total 815 parameters).
Learning in recent 40 shots data



Mean Square Error (MSE) between the predicted and actual injection efficiency Ave: 0.0964

By updating the DNN training with the most recent data, the injection eff. can be predicted!

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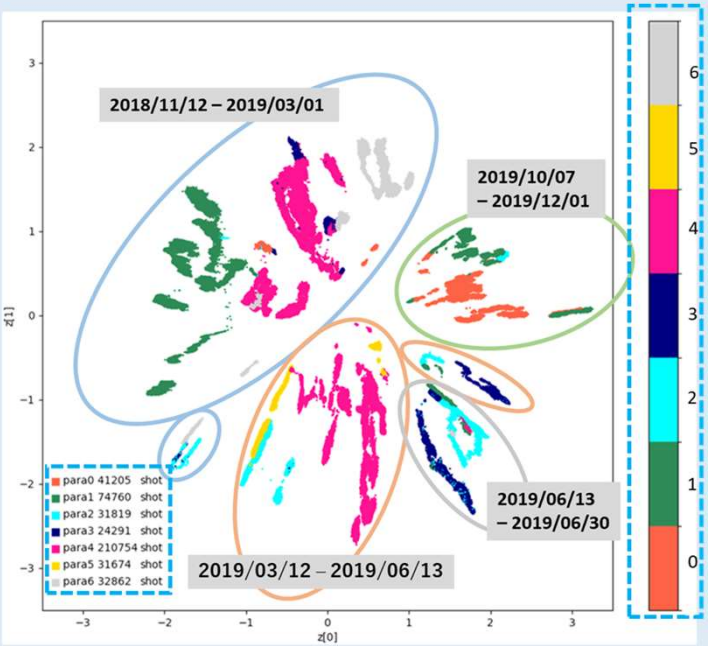
4. Summary

We have developed the accelerator operation tuning system using machine learning

Visualization of distribution trend/correlation of acc. params by two-dimensional mapping using DNN

"Accelerator Status" is visualized using VAE

In addition, the correlation btw the "Accelerator Status" and the optimal operating parameters is expressed / obtained



Preparatory studies for the accelerator tunning based on the environment driven ML

We designed the DNN predicting the injection efficiency using the reinforcement ML with the most recent data.

By updating / training the DNN with the most recent data, injection efficiency can be predicted.

Based on the studies, we will further improve the acc. tuning with ML.

Acknowledgment

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