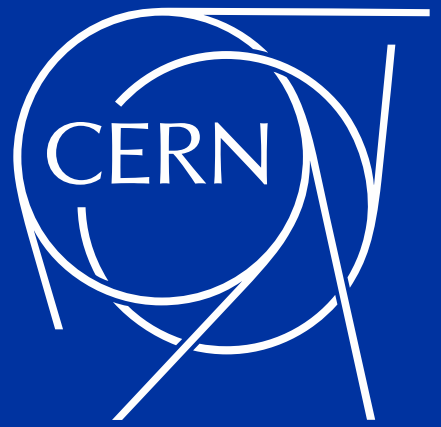


Predicting the LINAC3 Beam Current

Summary of work done by BE-ICS

Max Mihailescu

22.07.2020

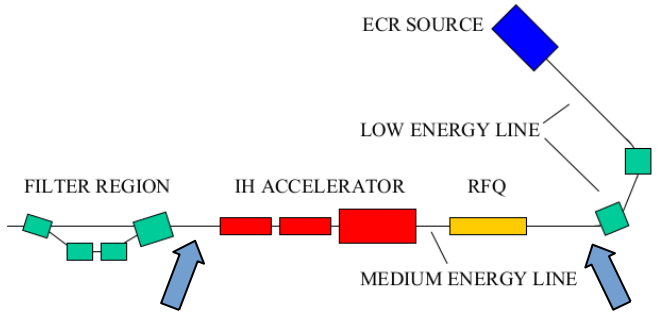
Overview of the Cooperation

- Three year old cooperation with BE-ICS/Siemens
- Develop a Machine Learning Model supporting LINAC3 operation
- Since October: Filip Široký and Marc Bengulescu
- Presented multiple times at ML-coffee (informal CO plattform on machine learning)

- **Goal:** Predicting the Beam current of the LINAC3 using Neural Networks

Thank you to Filip and Marc as everything presented here is their work.

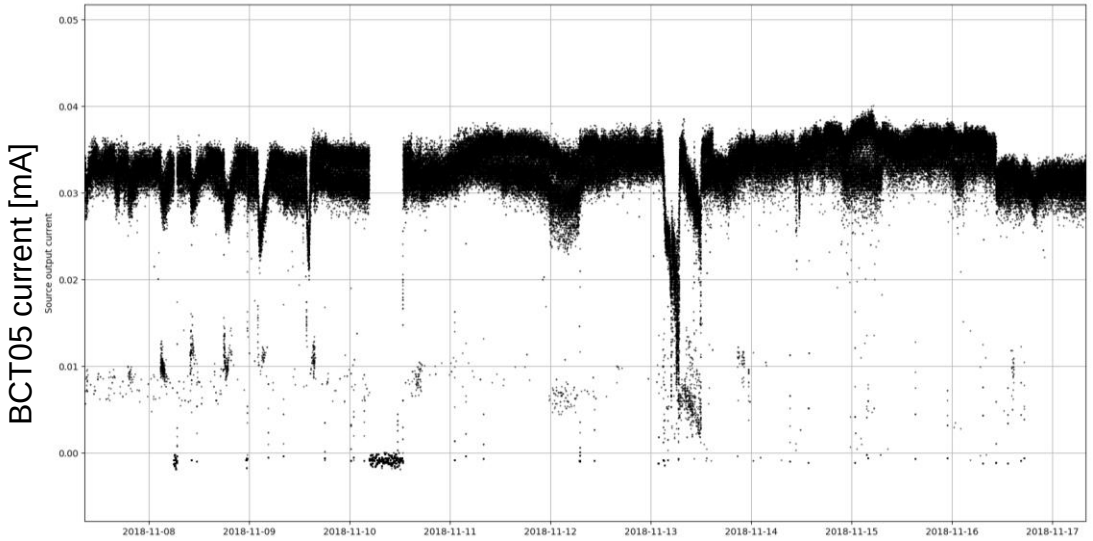
Layout of LINAC3 and the objective



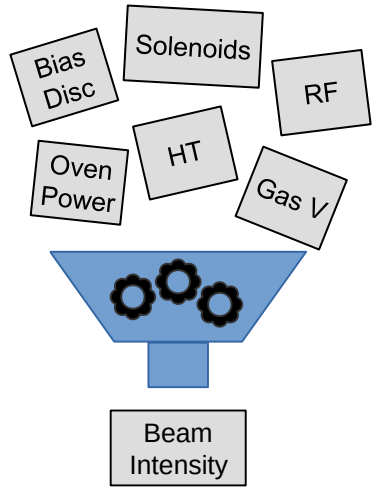
ITF.BCT.15:CURRENT *ITL.BCT.05:CURRENT*

Objective:

Using all source Aquisitions, can we predict what the intensity of the beam will be in the near future?



Dates (08.11.2018 – 17.11.2018)



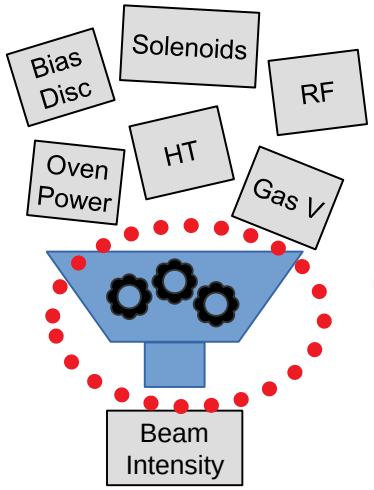
Numerous possible applications

- **During operation:**
  - Automatically correct (small) instabilities
  - Have a pre-warn system that alerts operators if the current is about to degrade
    - Will the beam intensity drop over the next 30min?
    - Are there going to be many bad shots in the next hour?

- **Offline analysis:**
  - Study how certain source settings might influence the current (simulation)
  - Understand what variables cause the beam intensity to change

Machine learning crash course

How do you train a (supervised) model?



This is what we call a model

At the begining, the model knows nothing.

Take all your data and split it up

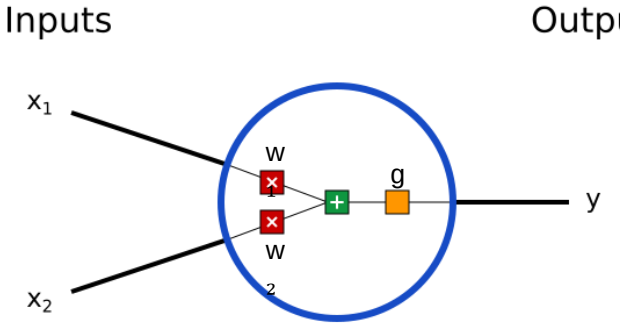
1. Present it a lot of (input, expected output) pairs and adjust model to minimize an error function

1. Measure performance on **unseen** data

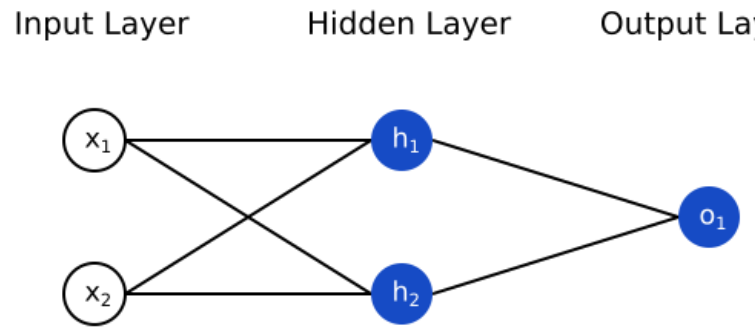
1. Test behaviour in real application

Machine learning crash course

Neural network basics

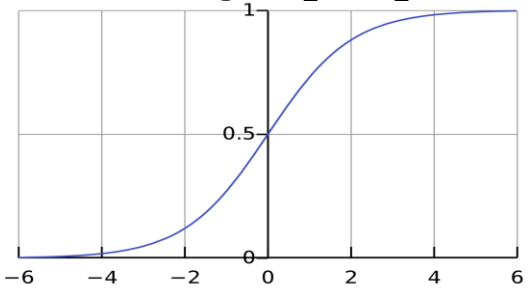


Building Blocks: Neurons



Combine units to get a neural net

$$y = g(w_1 * x_1$$



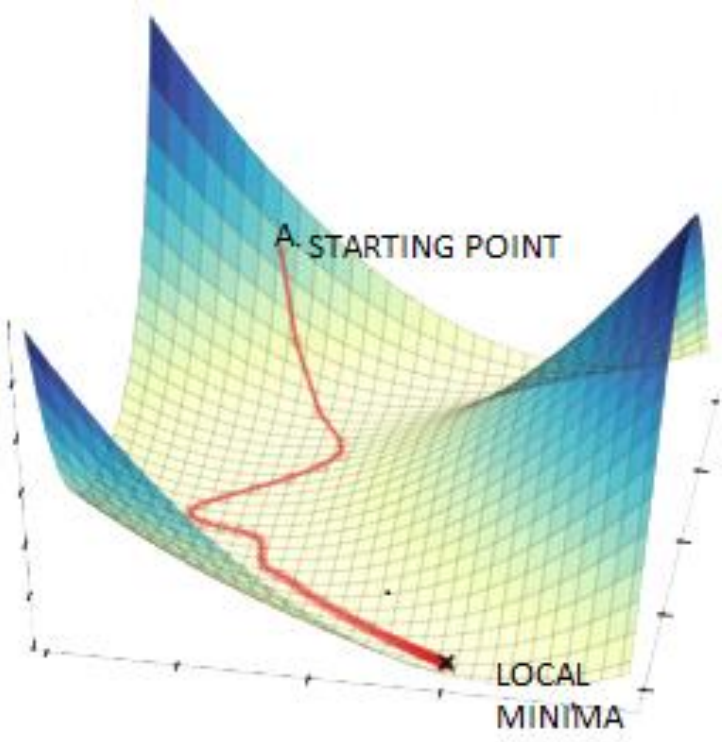
A typical activation function

You need this, to model non-linear functions!

Images from https://towardsdatascience.com/machine-learning-for-beginners-an-introduction-to-neural-networks-d49f22d238f9 (03.07.2020)

Machine learning crash course

Neural network basics



The most common error function is

$$\sum_{(x,y)\in Training} (f(x)$$

In our case we have

$$f(x) \equiv f(x, w_1, \ldots, w_n)$$

Partial derivatives of error function with respect to *w_i* give the direction you have to move *w_i* to decrease the error.

➡ Can in theory approximate any function

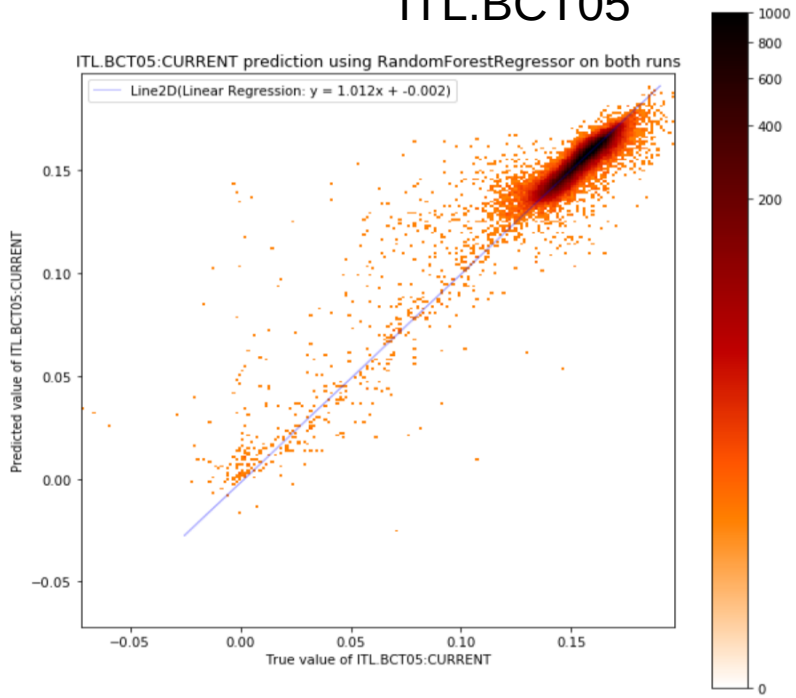
Images from https://towardsdatascience.com/machine-learning-for-beginners-an-introduction-to-neural-networks-d49f22d238f9 (03.07.2020)

A first, promising result

Testing on two weeks of training data

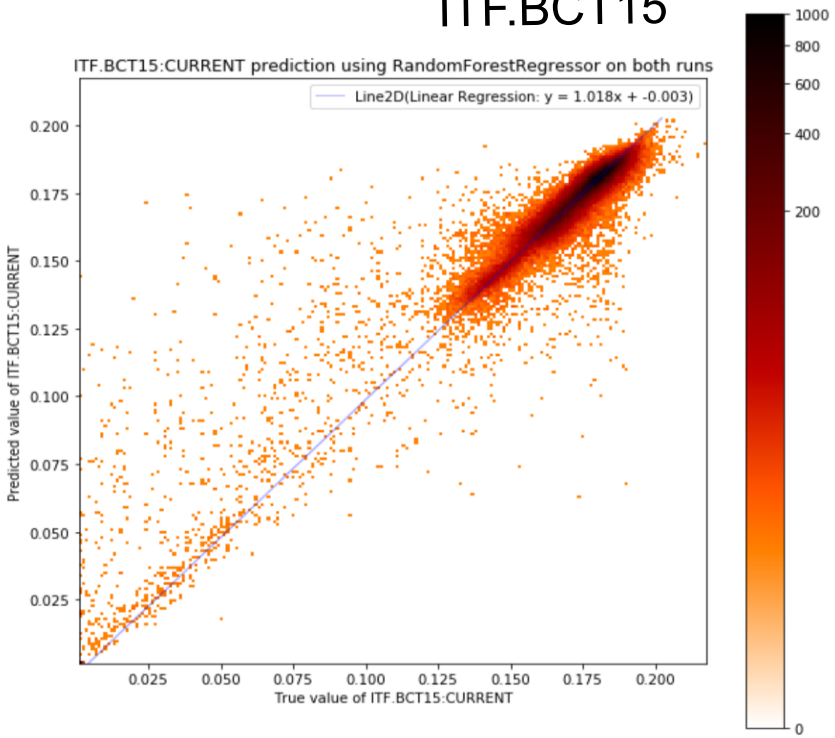
Pearson correlation squared: 0.88
MSE of NN: 1.7e-05

ITL.BCT05



Pearson correlation squared: 0.92
MSE of NN: 3.2e-05

ITF.BCT15



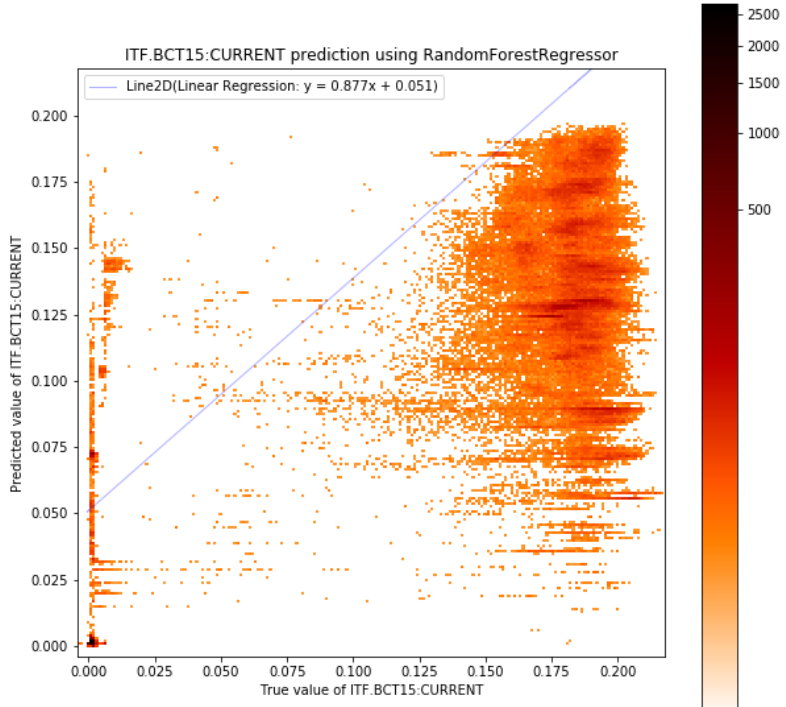
- True ion current on x-axis
- Predicted current on y-axis

➡ Almost perfect prediction

Plots by Filip Široký

However, it generalizes poorly

Applying the previous model to new data



True BCT15 current (x-axis): constant ~180 uA

Predicted BCT15 current (yaxis): full range 25 uA - 200uA

Plots by Filip Široký

Why?

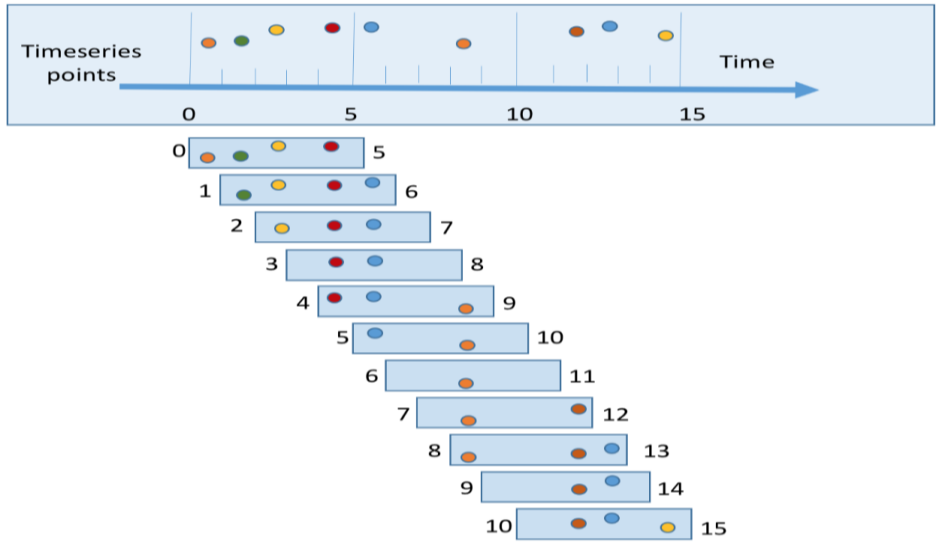
- Training data of only two weeks
- No time component included

A surprise?

- Supports Cluster Analysis that showed no direct link between used setting and source performance
- Many settings used throughout a year,
- test data might be from unknown regime

⇒ Need to model **time series**

Modeling the next instant



Classical training approach

Time series training

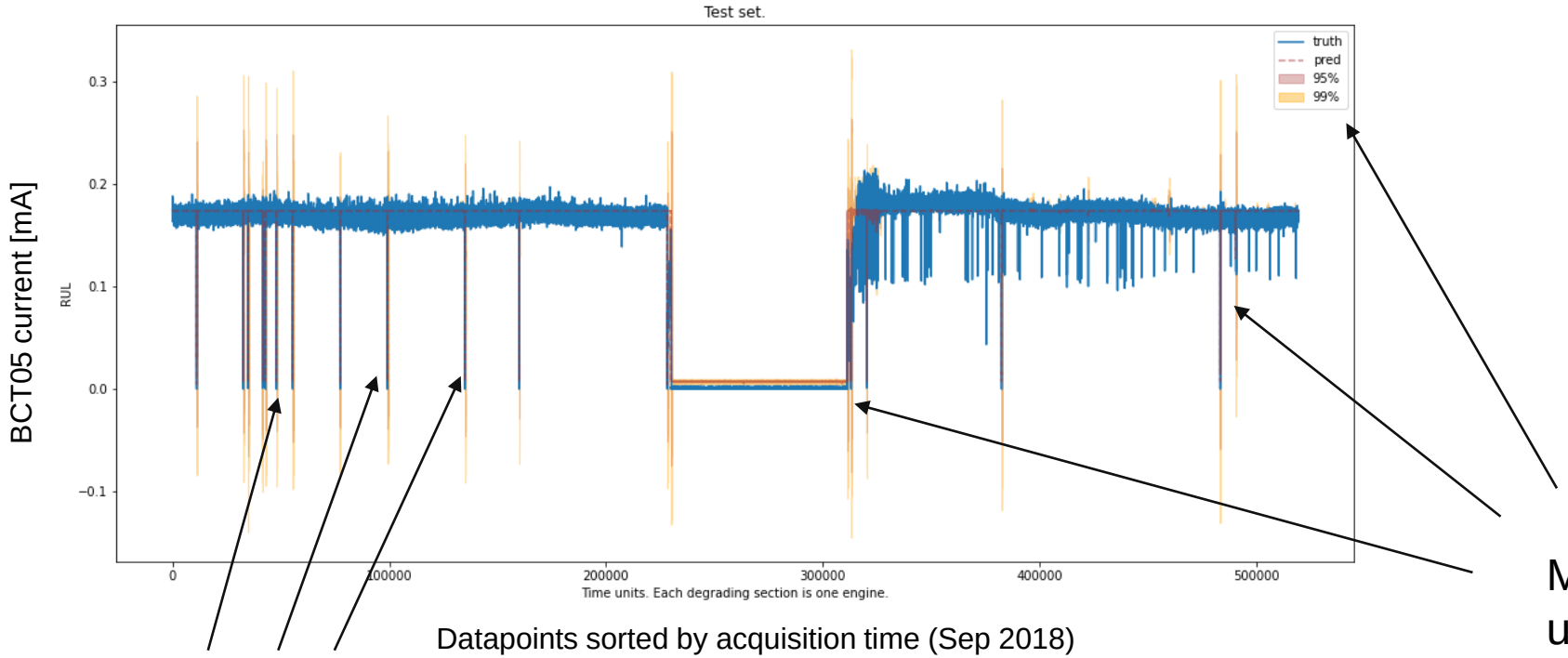
Given the data from *n* points, what will the *n+1* point look like*?*

- Model should learn the near future
- Can be viewed as a real-time simulation
- Input data can be multidimensional (HT current, Bias Disc Voltage, Oven Power, ...)

➡ **In our case:** Given all information from the last *60s*, what will the beam intensity be in the next few shots (*1s*).

Predictions of a temporal model

Results of a model trained on periods of September 2018



Model outputs uncertainties

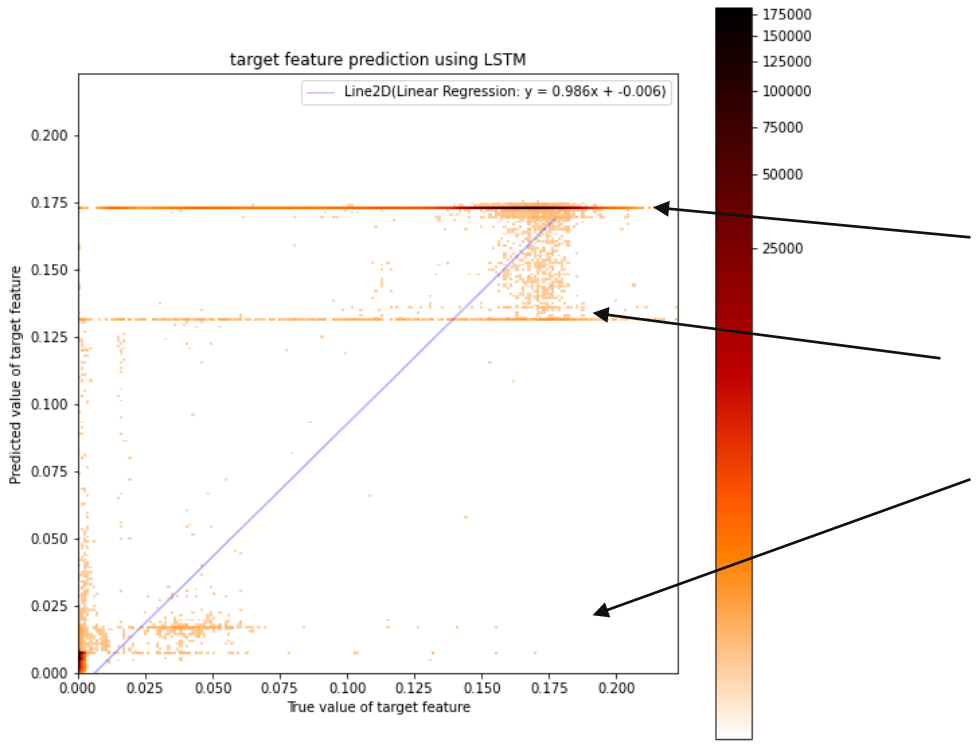
Model learns HT voltage breakdown artifacts

➡ There is potential to learn (stable) source operation

Plots by Filip Široký

Predictions of a temporal model

Results of a model trained on periods of September 2018



Training and predicting Sep 2018

Model learns to predict three distinct levels

Average Beam current

Average value of bad shots

Source was off

} Possible Interpretation?

➡ Some Key features of interest for operation could not yet be represented

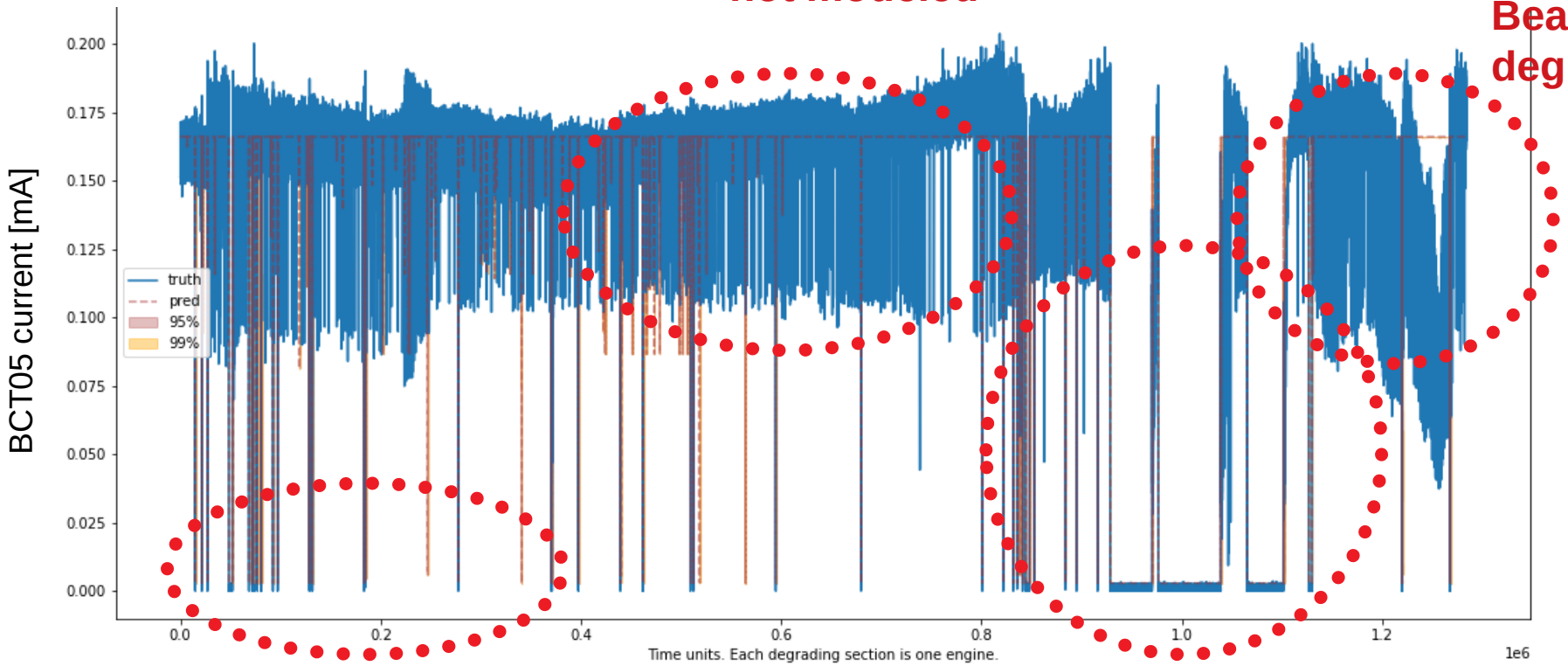
Plots by Filip Široký

Forcasting new horizons

Previous model predicting October 2018

Instability regions not modeled

Beam degradation



HT voltage breakdowns identified, but with lag

Source-off phase correct

Plots by Filip Široký

Conclusion and next steps

- Promising time series models that already learned very basic current features
- Improvement over randomly shuffled data (without time component)
- Output of uncertainity can be of very great interest to indicate degradation of the beam

- Predict Longer future (e.g. next 30min instead of next second)
- Understand lag and prediction of discrete states
- Try out different ML approaches
- Have a different representation of the target (Wavelet/FFT Transform of current)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