Machine learning for ASTRA simulations

DESY summer student project

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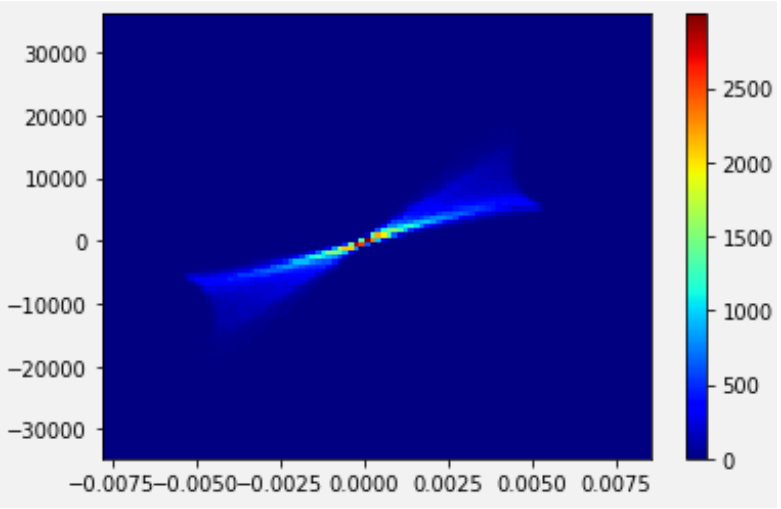
The problem and the goal

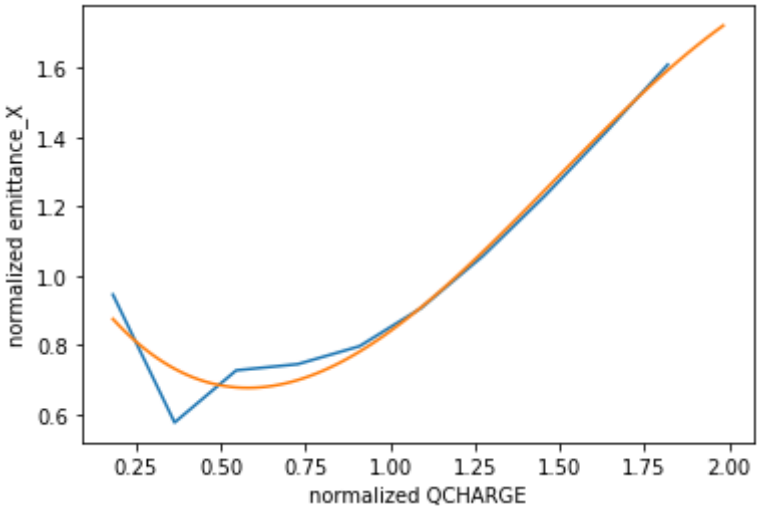
Problem

- Simulations take a lot of time
- Necessity of scanning a wide range of parameters
- Plain simulations slow down the optimization processes
- Precize results can be obtained only by these time-consumung simulations

Goal

- Write a software able to make a decent estimation of the output parameters based on the input parameters in a faster way





The purpose of ML

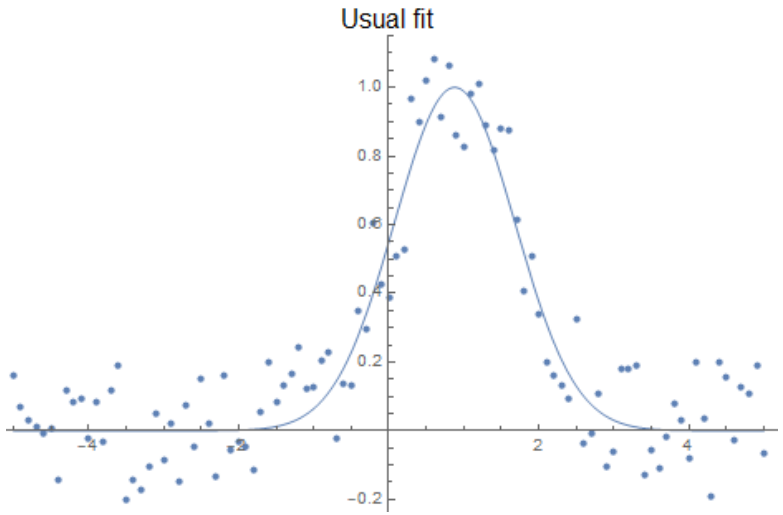
How to fit simulation data?

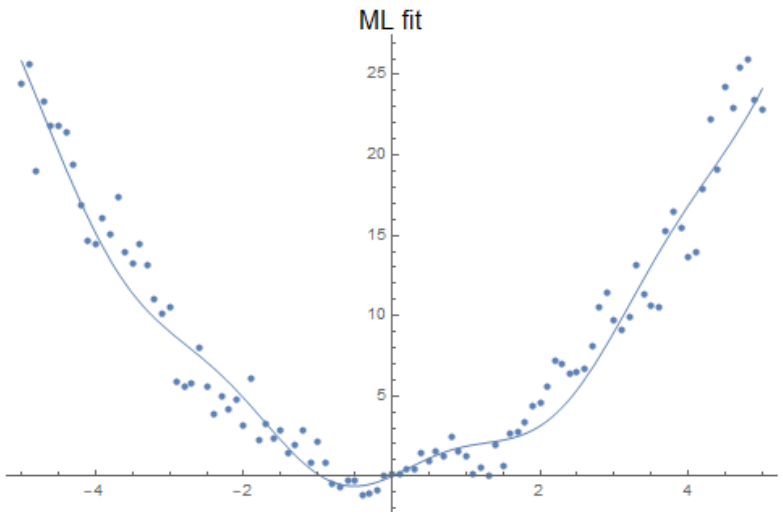
Why ML?

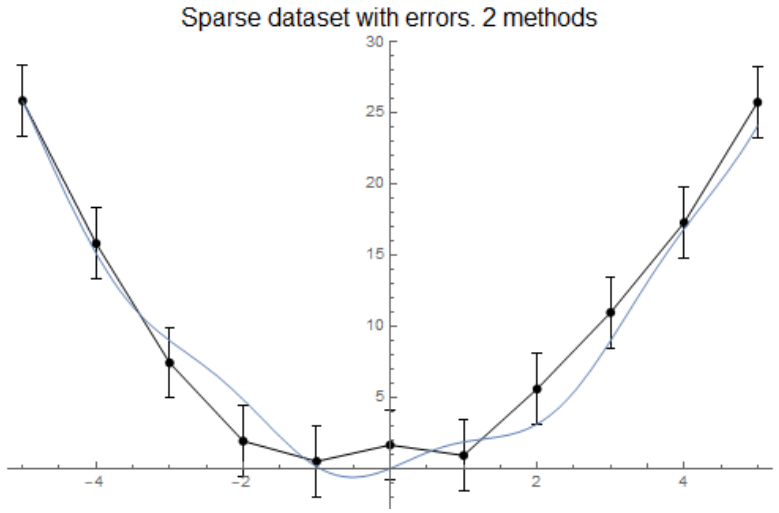
- Usual fit – when we know the function
- ML fit – when we don't know the function

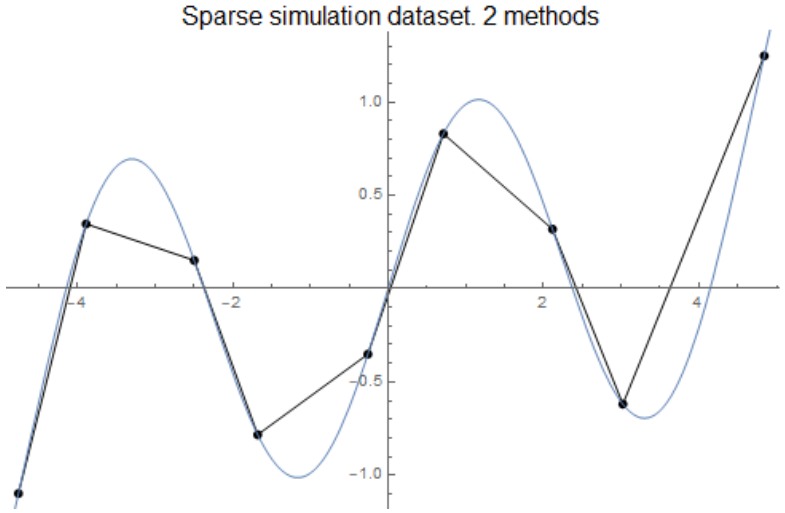
The goal for our ML

- Sparse dataset
- Every point matters
- Small simulation errors





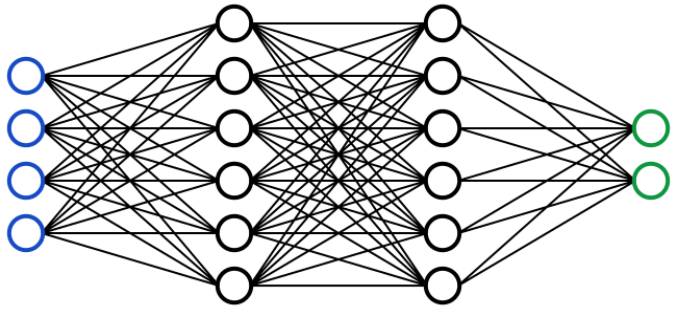




Methods and datasets

Methods:

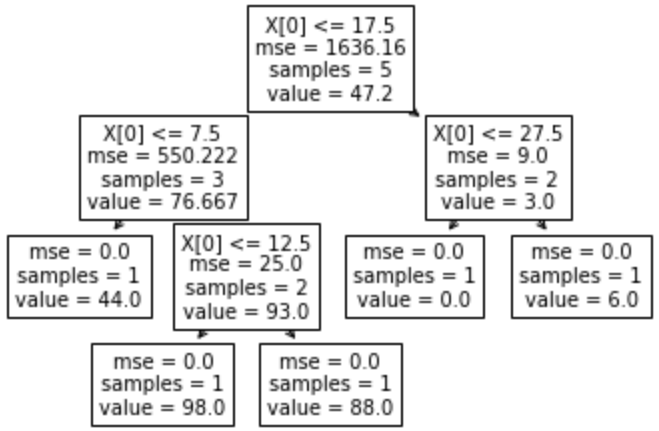
- Neural network
- Decision tree
- Gradient tree boosting
- Kernel ridge, linear models
- Voting (averaging of others)



NN general layout

Datasets

- All are for a simple gun with booster lattice
- 1d initial charge scan
- 2d charge and solenoid field grid-like scan
- 2d random scan
- 3d charge, solenoid and electron gun fields scans



A simple tree model example

Fit results

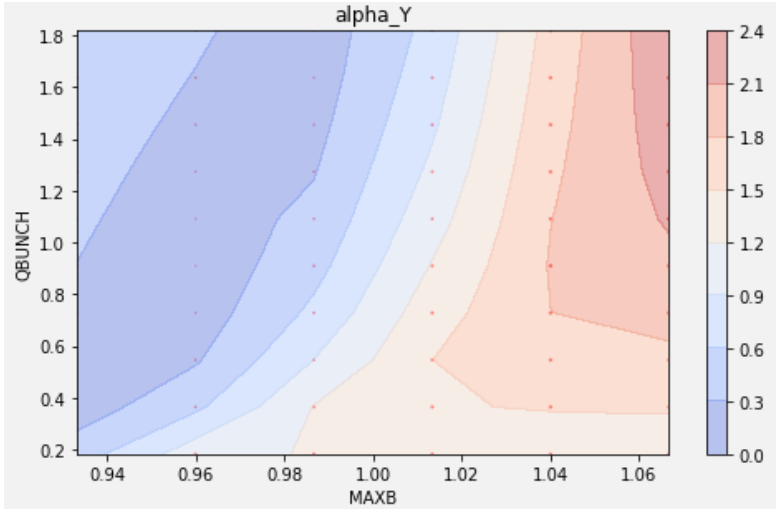
General performance

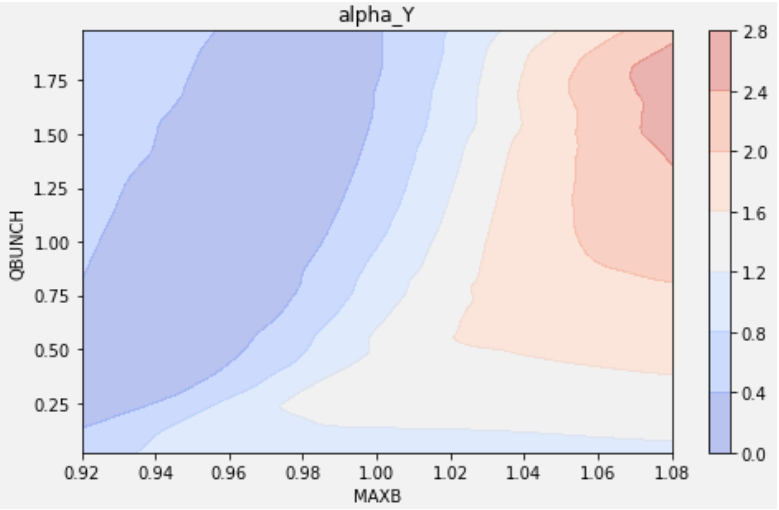
Performance

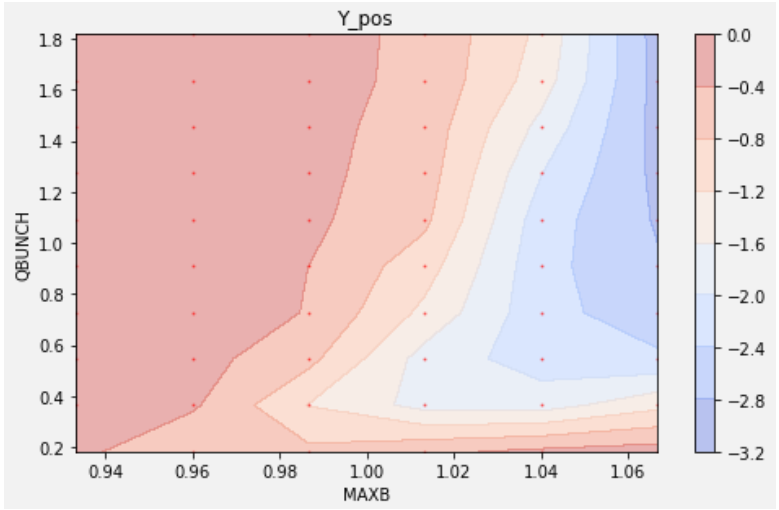
- Qualitative match
- Red dots – simulation scan points
- Can be plotted for each of models

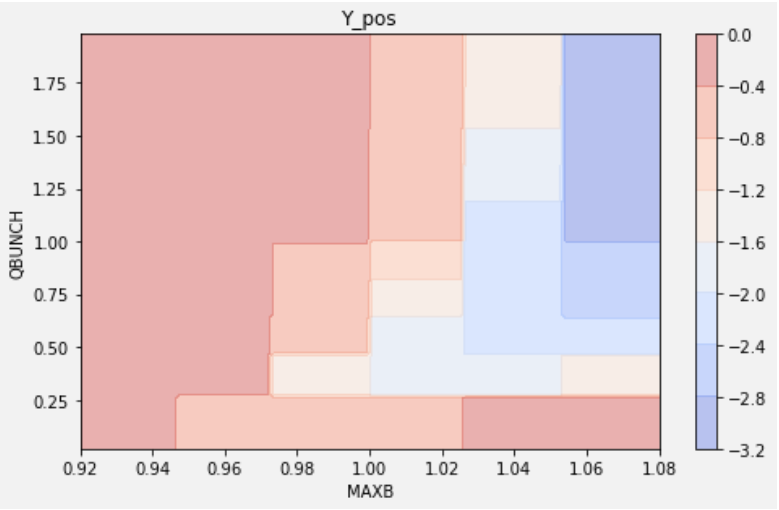
Models

- Linear models and kernel ridge are not implemented for >1 dimension datasets
- NN fit on the top, Tree fit on the bottom







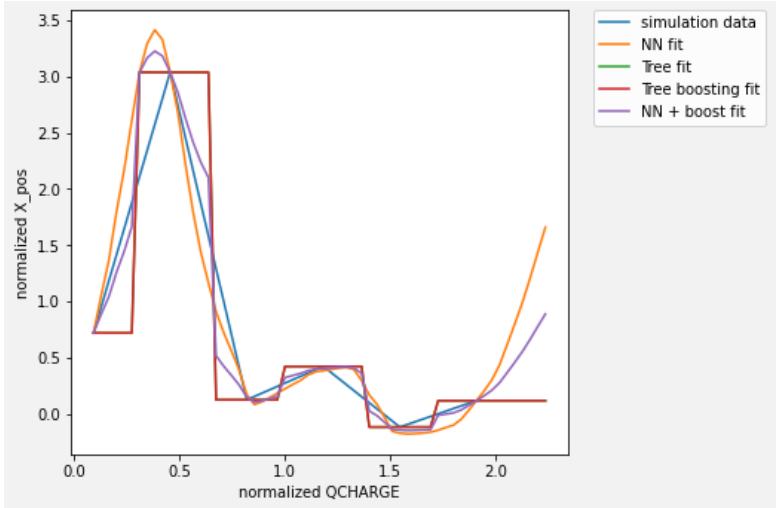


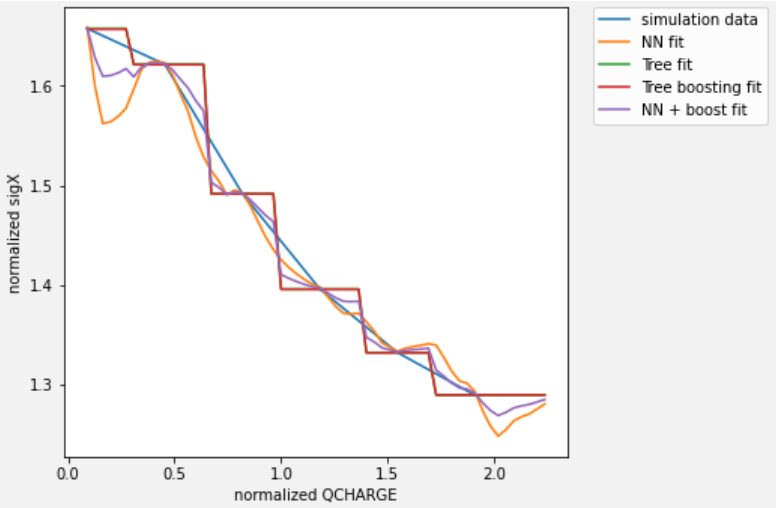
Fit results

Comparison of the models

Fit comparison

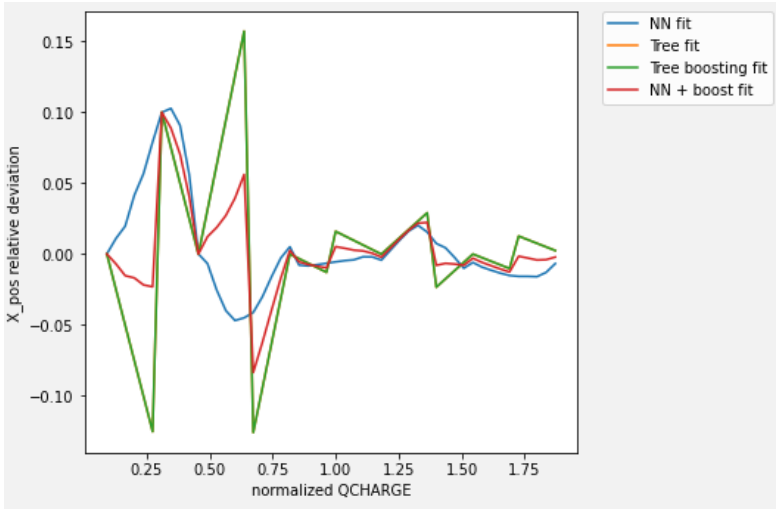
- Training accuracy of all models ~100%*
- Rigidity of the tree models
- NN + Boost – their averaging

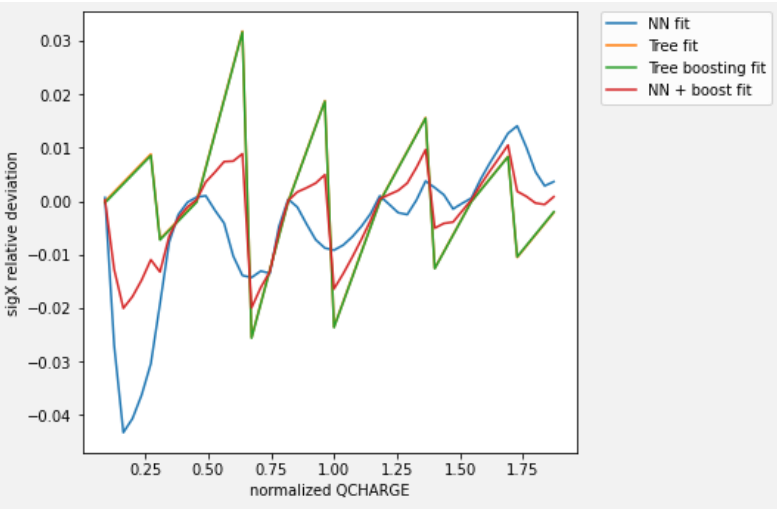




Relative deviation

- Tree errors up to 40%*
- Best model average errors ~5%
- NN + Boost is usually the best choice



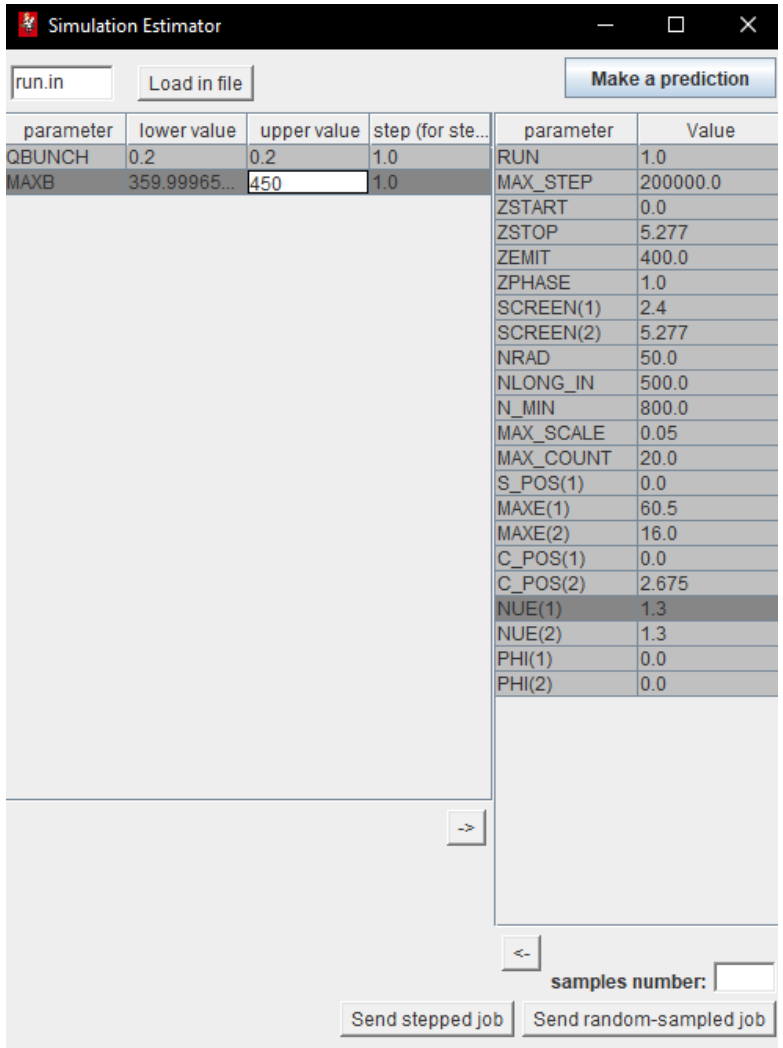


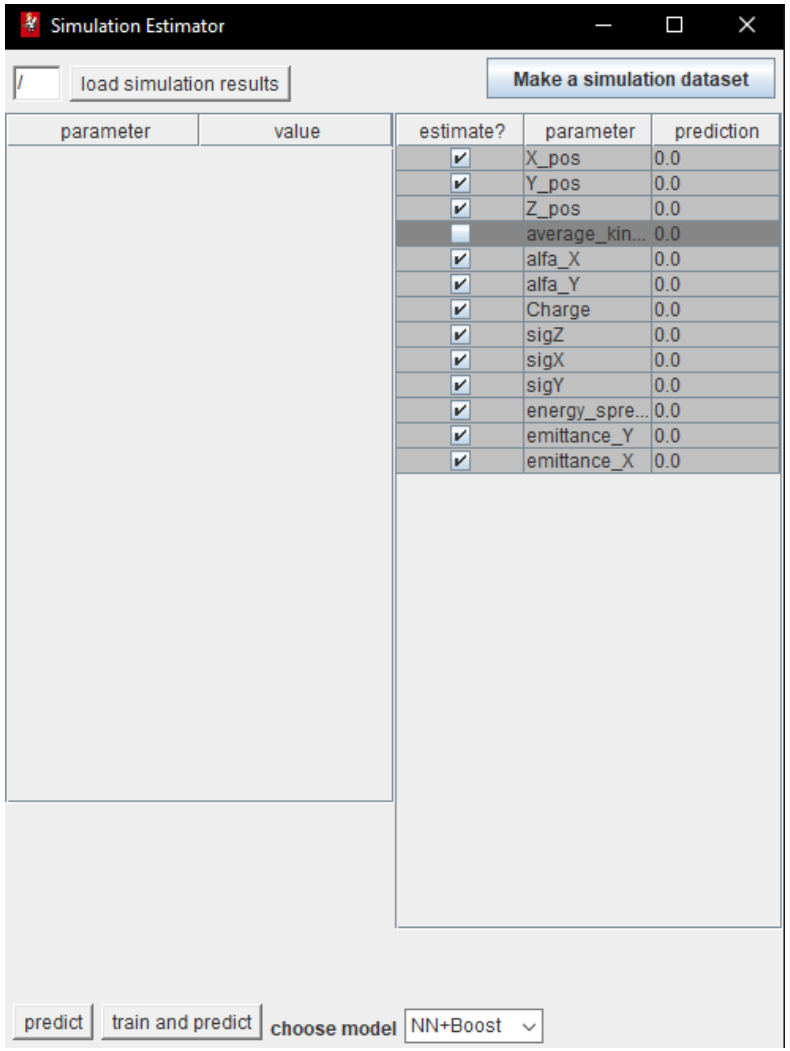
Java automation program

Send a simulation task

- Convenient way to perform ASTRA scans
- Two possible scan mods

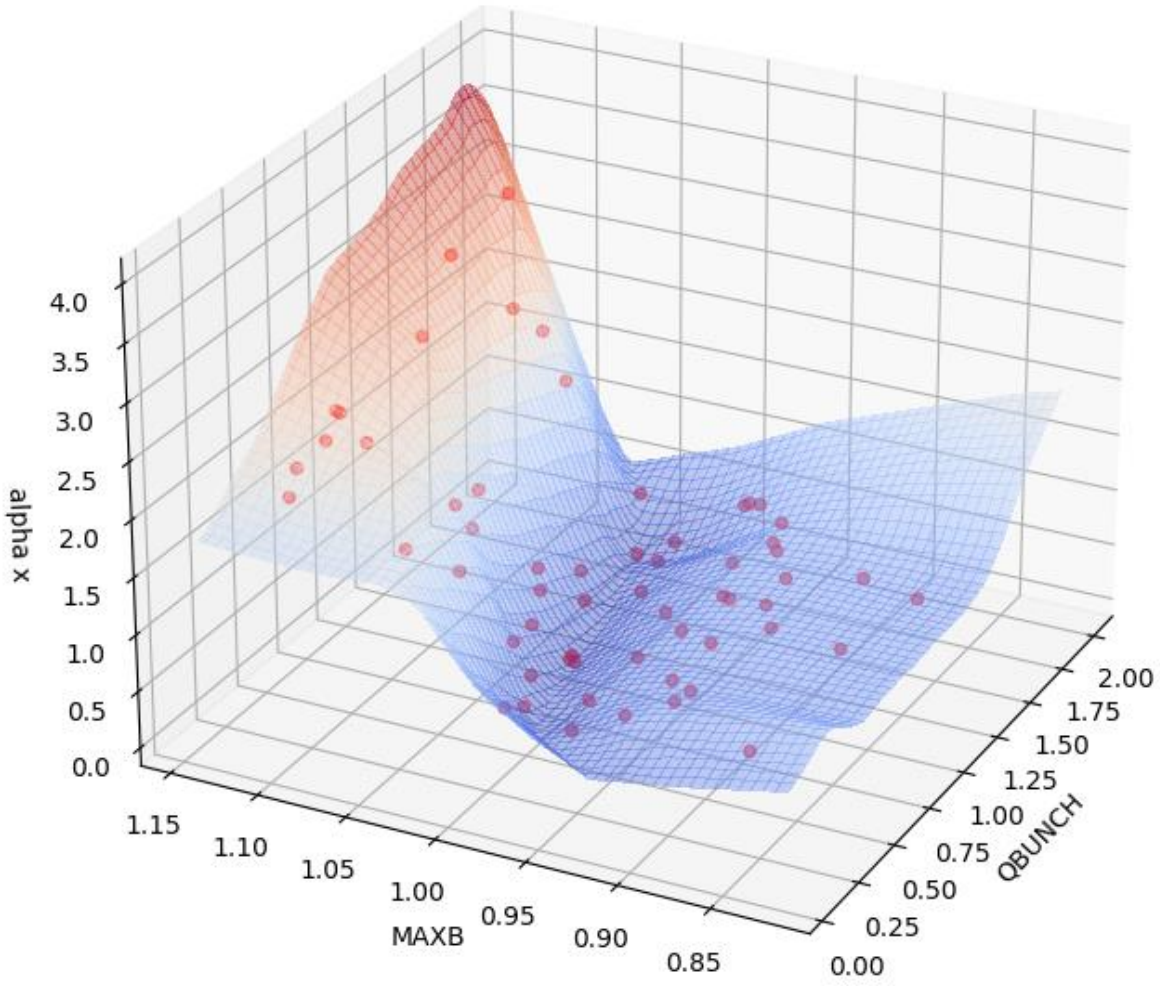
- **Predict**
- Train different models
- Visualize the training results
- Set the input parameters and obtain the estimation

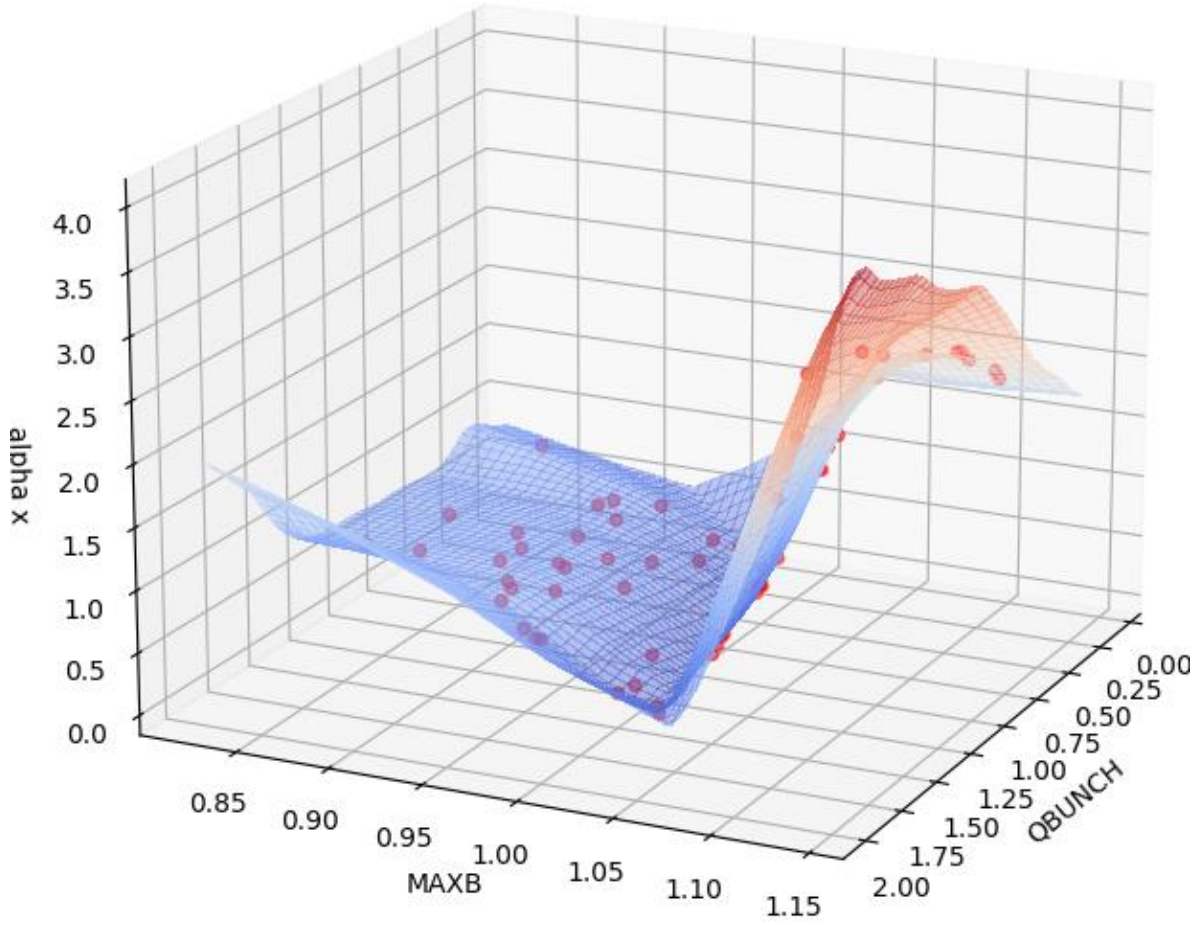




GUI visualization of the trained model

3d plots for 2d datasets (NN fit)





Summary

- Input parameters scan times can be significantly reduced with the usage of ML
- Multiple ML algorithms are implemented
- The models performance is tested on various datasets
- An error in the worst case is ~40%, but the usual relative divergence of the best model is ~5%
- The Java GUI program is written for ease of train, prediction, and scans

Thank you

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