Advanced optimization algorithms and neural networks for accelerators control

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OUTLINE

Introduction

ML activity at Accelerator Division at IJCLab

Study program for SuperKEKB linac

A-RD-21 Project status

2020 – blanc year

2021 – resubmit, new participant

ID[1]:	Title: Advanced optimization algorithms and neural networks for accelerators control					
	French Group			**Japanese Group**		
	Name	**Title**	**Lab./Organis.[2]**	**Name**	**Title**	**Lab/Organis.[3]**
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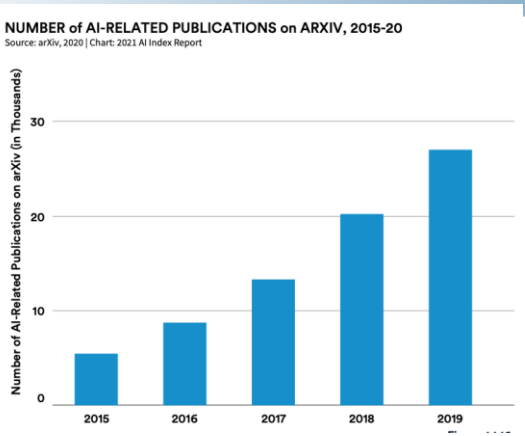
	E.Goutiere	PhD student	IJCLab/LRI	K. Furukawa	Prof.	Accelerator Lab/KEK

Trends in AI



Active research subject in application to accelerators

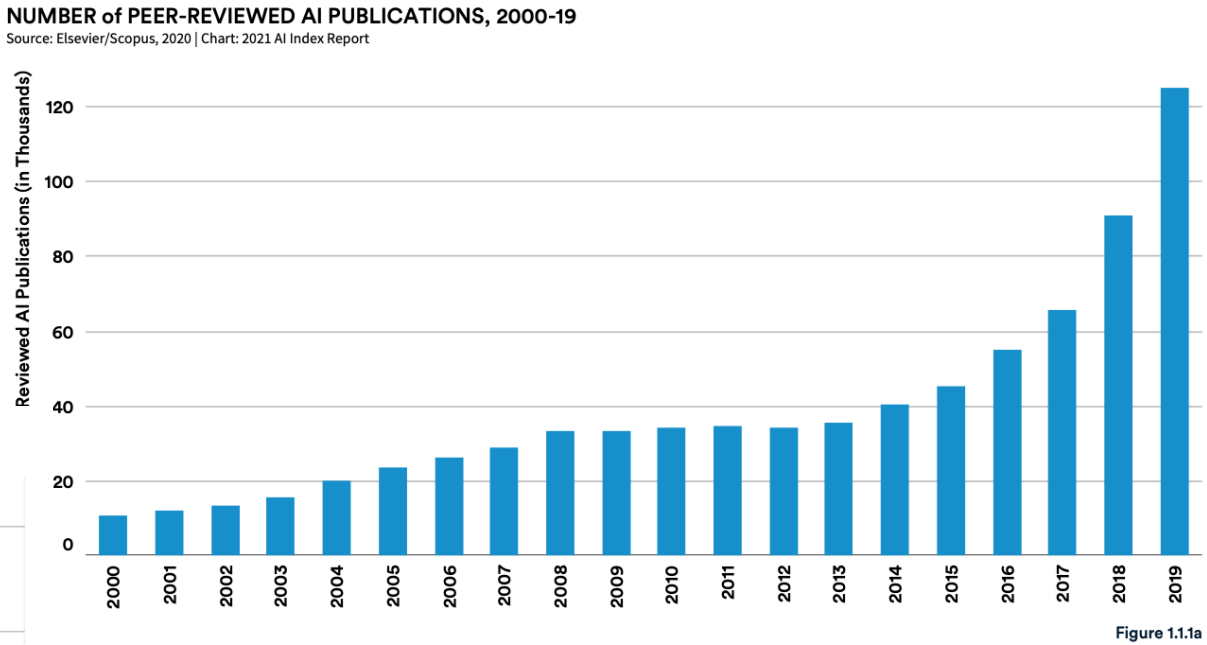


Figure 1.1.1a

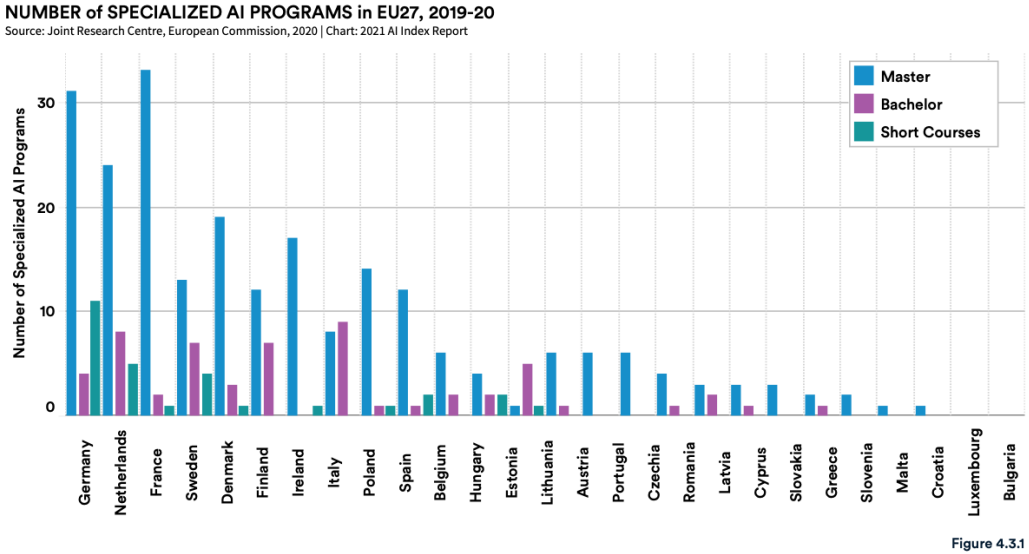


Figure 4.3.1

https://aiindex.stanford.edu/

Artificial Intelligence Index Report 2021

ML for Accelerators

IN2P3/IRFU ML workshop, CERN ML workshop, OWLE seminars, online trainings, European projects (I.FAST) and many more.

<u>Current ML studies at IJCLab Accelerators division:</u>

Linac and Ring (THOMX), FJPPL, HIGH power laser (ML-COLA), positron sources, laser- plasma injector design.

For the moment not much of experimental DATA.

HIGH intensity laser optimsation (ML-COLA)

Proof of the principle experiment of Machine Learning based online Characterization and Optimisation of a high intensity LAser pulse (ML-COLA)

Integrated phase measurement single shot

A(x,y,omega) in single snapshot!

Step 1: USE both diags

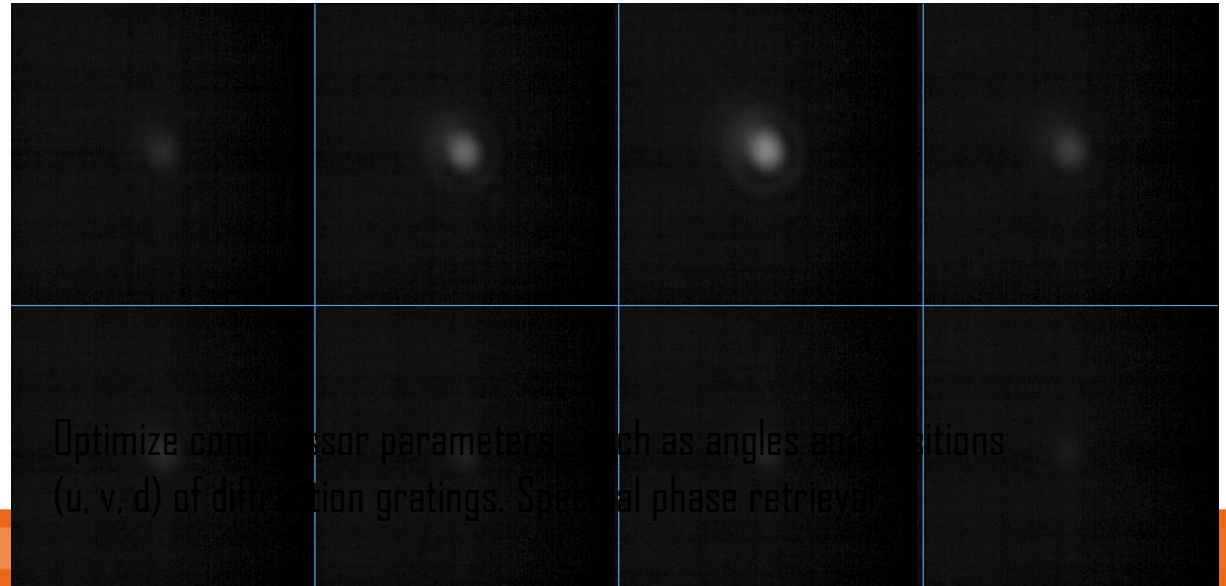
Step 2: USE only CAMERA

Very precise but, not single shot (scan)

Time consuming: 10min on powerful workstation

Amplitude TECHNOLOGIES → TERMITES

SourceLAB → INSIGHT

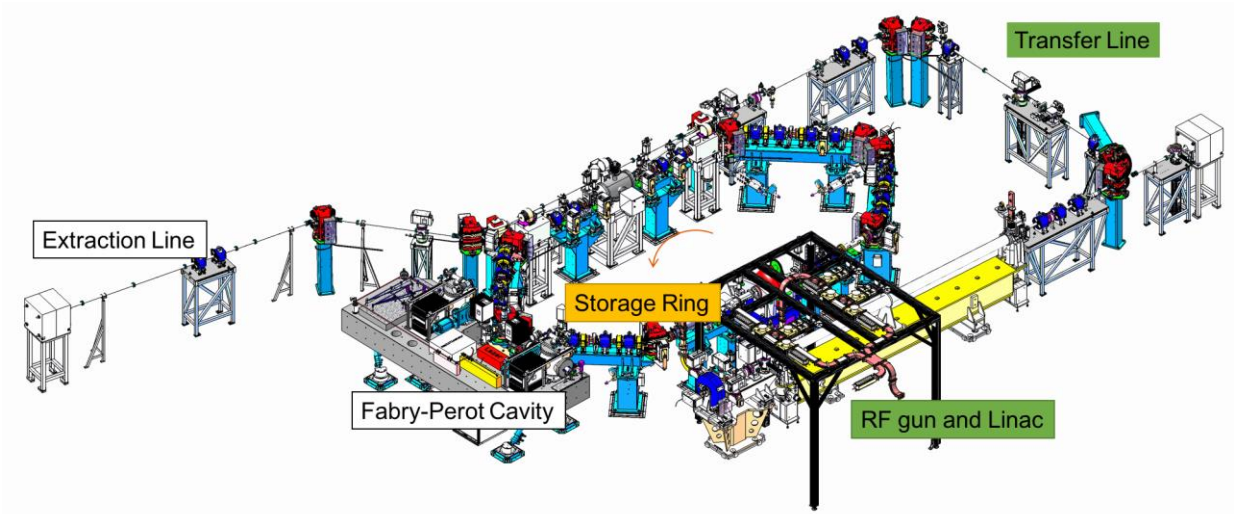


Optimize compressor parameters , such as angles and positions
(u, v, d) of diffraction gratings. Spectral phase retrieval.

THOMX project at IJCLAB

ThomX - Compact source of X-rays

Producing a compact source of directional X-rays, with high performance, very bright, monochromatic and with adjustable energy for application to the field of medical science (imaging and therapy) and social science (artistic heritage), technology and industry.



- **Linac and transfer line:** find day to day repeatable beam conditions
  is challenging task (temperature conditions, laser jitter, …).
  Reproducible beam dynamics. Injection matching with Ring.

- **Ring:** Need to stabilize machine, find stable orbit.
  First turns – need to match several parameters.
  There are empirical ways. Machine expert can do (experience).
  We search for automatization/ guiding. Study case.

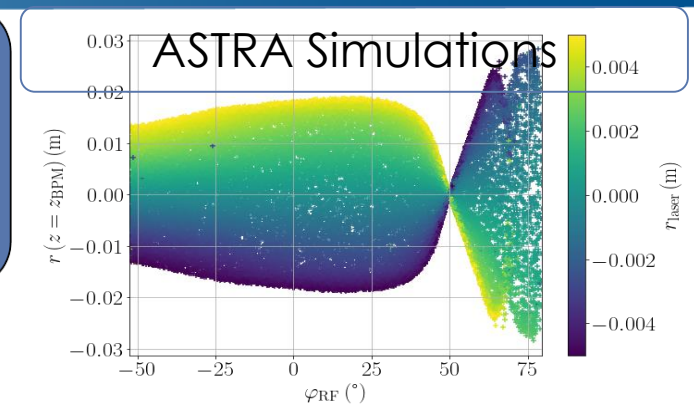
Waiting for ASN (Nuclear Safety Authority) permission to start

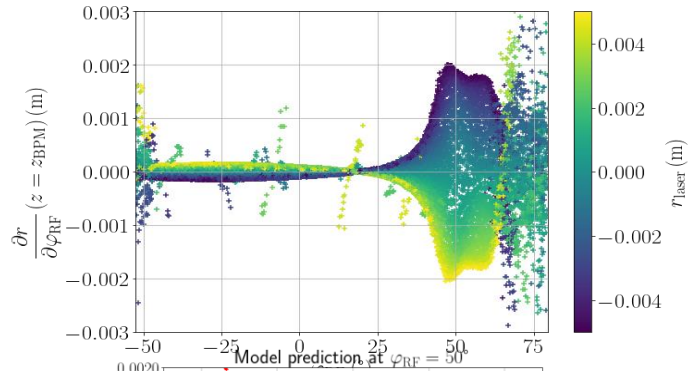
THOMX LINAC TUNING WITH LEARNING METHODS

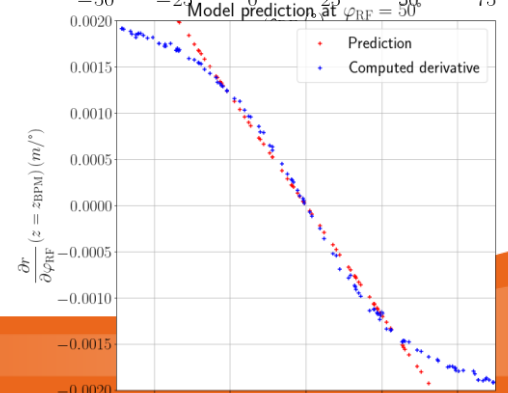
Tuning and Diagnostics Objectives

Photocathode alignment
Solenoid alignment
Accelerator section misalignment detection

ASTRA Simulations







Problematics

One observation of the sensors does not give a value of the various misalignments

Goal

Using a minimal number of actions to tune the Linac

Model Calculation

- Establishment of an analytical model
- Validation of these models on simulator

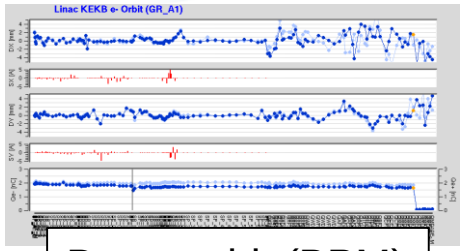
Validation

- Works for the laser & solenoid alignment
- Probably too complicated for a more complicated task

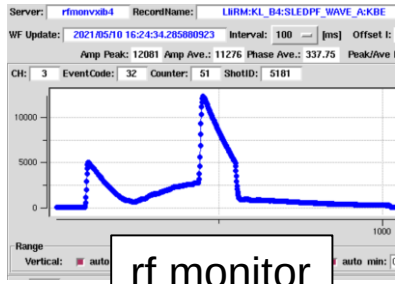
SuperKEKB linac

Pulse-to-pulse measurement up to 50 Hz (all data have been stored)

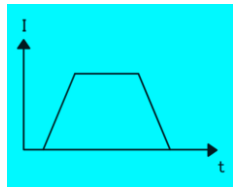
(BPM: x100, rf monitor: x60, pulsed magnet: x100)



Beam orbit (BPM)



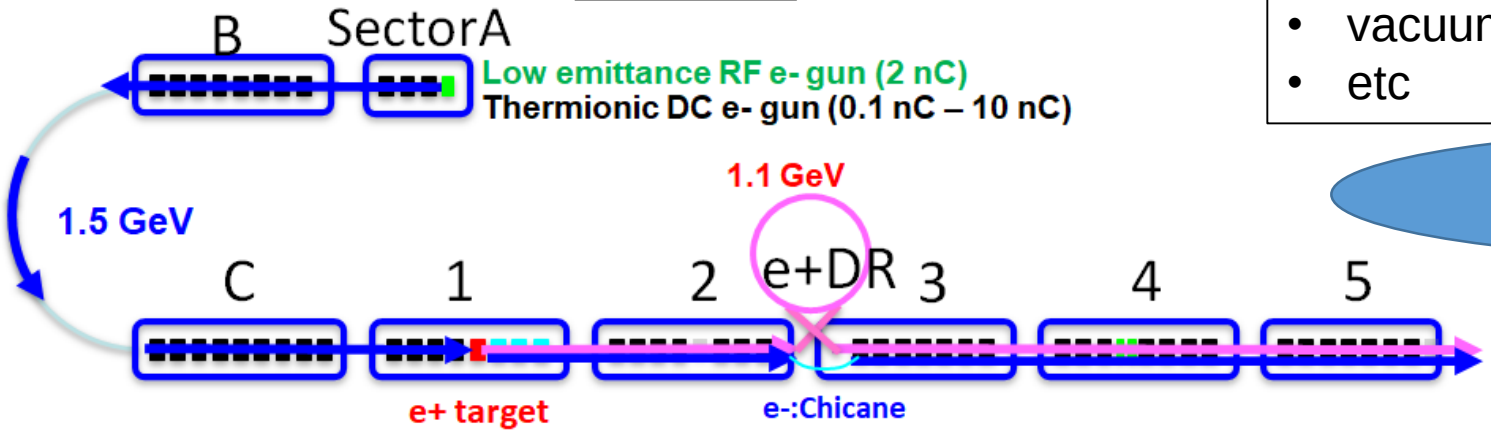
rf monitor



pulsed magnet

All other data (～ 80,000) have been recorded (1 s to 10 s sampling period)

- DC magnet
- cooling water/room temperature
- rf gun laser power, phase
- vacuum pressure
- etc



600-m-long injector linac

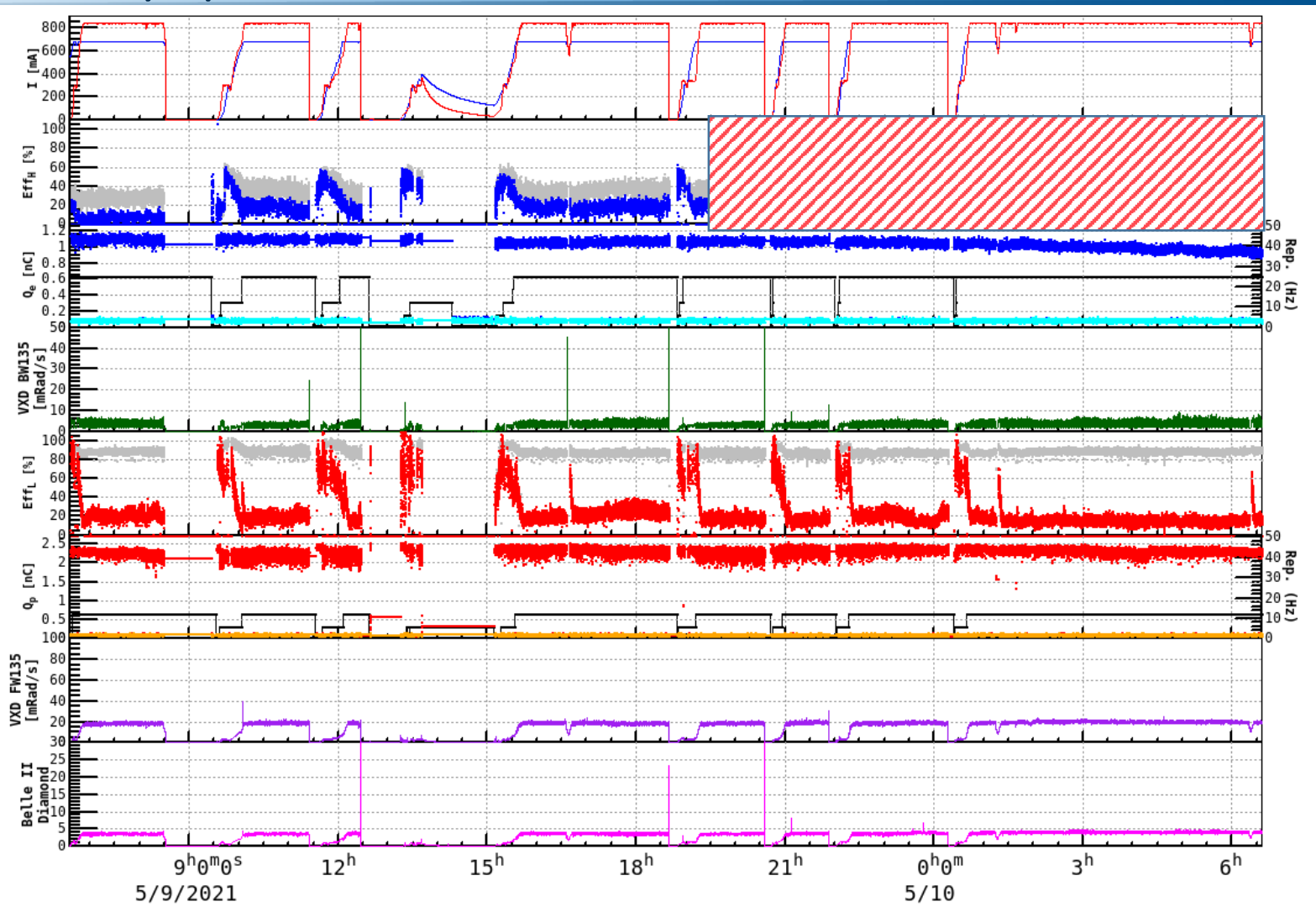
Simultaneous top up injection

- Super KEKB
  HER 7 GeV e-
  LER 4 GeV e+
- Light sources
  PF 2.5 GeV e-
  PF-AR 5 or 6.5 GeV e-

LINAC daily operation

Top level view on the **SuperKEKB 24-Hour Injection Summary**

A lot of DATA!
Japanese team:
Experts with good understanding of machine and DATA



Linac tuning goals and ML methodology

Goal: Optimal LINAC parameters for low emittance electron beam and for low injection noise background to BELLE2 detector.

Could we predict/improve emittance of SUPERKEKB e- beam, injection efficiency?

Linac must operate, destructive measurements are not possible

1. DATASET from EPICS PVs data:

collection, processing, alignment, understanding and labelling of the raw data (machine parameters, beam parameters, magnets, diagnostics, BPMs, pulsed elements, transport parameters, vacuum, temperatures, BELLE2 background). A lot of diagnostics can work at 50 Hz

Work is ongoing.

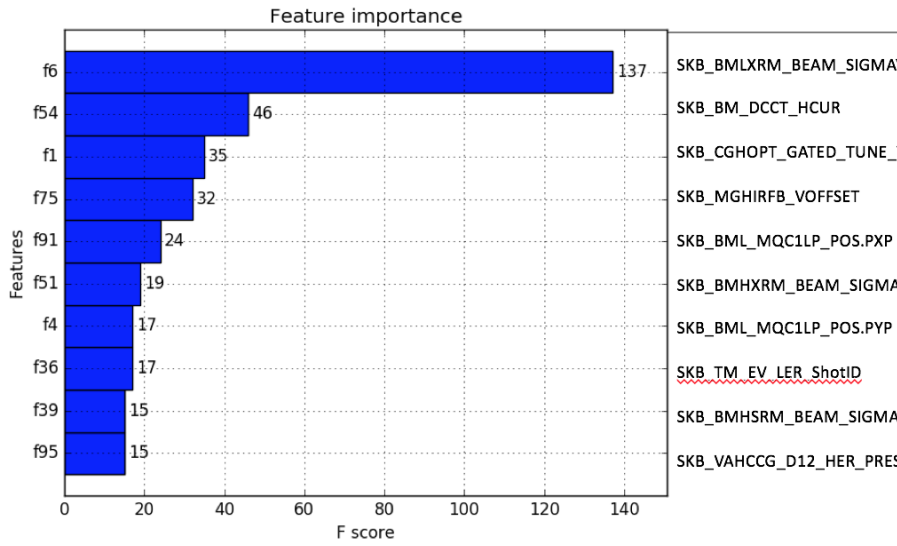
Example of PVs list

```
+++
# BEAM CURRENT
'SKB:BM_DCCT:HCUR'
'SKB:BM_DCCT:LCUR'
# BEAM SIZE MONITOR MEASUREMENT
'SKB:BMHSRM:BEAM:SIGMAY'
'SKB:BMHXRM:BEAM:SIGMAY'
'SKB:BMLSRM:BEAM:SIGMAY'
'SKB:BMLXRM:BEAM:SIGMAY'
# HER (E) and LER (P) INJECTION CHA
'SKB:CG_BTE:BPM:CHARGE_AVE'
'SKB:CG_BTP:BPM:CHARGE_AVE'
+++
+++
+++
```

Model Training and Inference

2. Development of the ML models, training, test and validation.

Determine principal parameters. Tests of different approaches: XGBoost, Neural Networks, LSTMs, Reinforcement learning.
Control of the overfit.
At this stage we will need to understand our data.
Multiple interaction with machine experts.
Answer many questions: 50Hz, how to train models, data normalization, which assumptions and limits of applicability.
How well we generalize the model? How much data we need?
Do we need use advanced ML: ensemble methods, stacking?



3. Model tests on live data.

Nvidia Jetson nano (or eqivalent) for production and integration to EPICS channel.

Summary

- Work on project started in 2021. Dataset preparation is ongoing. Progress meetings are previewed.

- Our aim is to learn/predict new useful knowledge from the linac data by applying existing ML techniques.

- At the beginning start from very simple model.