From Machine building to Machine Learning

Accelerators with AI

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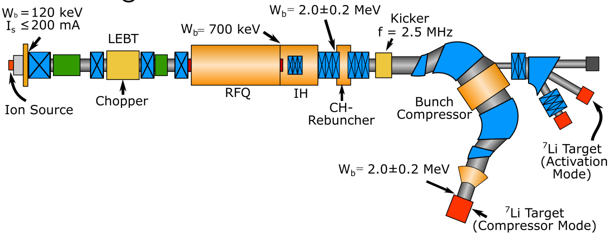
- Accelerator based facilities are growing with higher complexity with Increasing demands for higher intensities, energies and precision.
- It consists of multiple interacting sub systems, long term processes and continual changes in machine component over time.
- Advances in Machine learning (ML) and Artificial Intelligence (AI) can aid Accelerator technology.
- From applications for small *smart* sub systems to optimized operation of the whole facility.

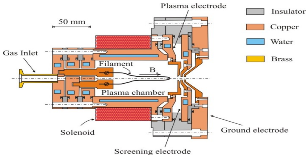
FRANZ Neutron Source

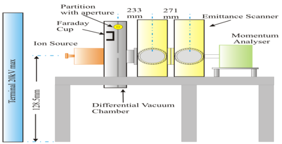
- Neutron production using intense proton beam on *Li* target
- A volume type ion source will deliver a DC beam current of 200 *mA* mA at energy of 120 *keV* with a proton fraction of 90%
- LEBT consisting 4 solenoids and Chopper system that delivers a pulse of 100 *ns* at a repetition rate of up to 250 *kHz* into an RFQ
- A drift tube cavity for the variation of the beam energy in a range from 1.8 to 2.2 *MeV* will be installed downstream of the RFQ
- Bunch compressor of the Mobley type forms a proton pulse length of 1 *ns* at the *Li* target



Ion Source

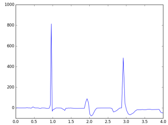
- Requirement of 200 mA proton @ $E = 120\ keV$
- Volume type Ion source for good emittance

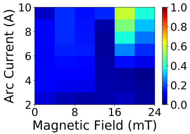


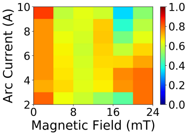


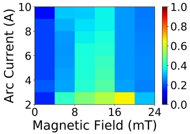
- A separate test bench to investigate plasma properties

- Faraday Cup, Emmitance scanner (Slit-Grid), Mass analyser
- Ion beam composition as a function of plasma parameters





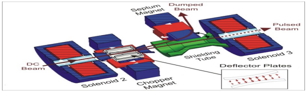


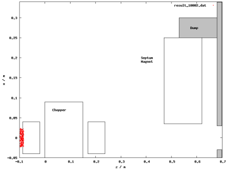


- More than 1000 observations recorded by varying Voltage, Arc current, gas pressure etc.

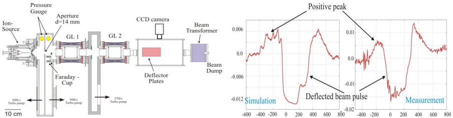
$E \times B$ Chopper

- Input proton beam with $I = 200\ mA$ @ $E = 120\ keV$
- Multispecie transport, Power deposition
- Numerical model includes secondary electron production





- Experiments for proof of principal
- Benchmarking for numerical model
- 20 keV He-beam in pulsed electric field

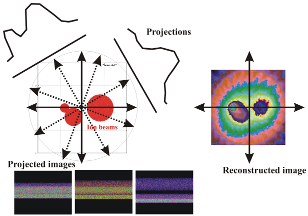


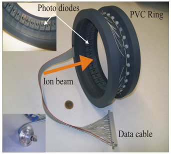
- Studies on vacuum breakdown
- Long term stability

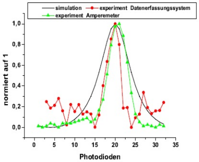
Diagnostics in LEBT

- Non destructive diagnostics at Low energy
- Interaction with buffer gas produces radiation
- Tomographical techniques using rotating camera
- Construction of phase space using 3 profile method

- Non destructive diagnostics using photodiodes
- A ring of photodiodes detects radition from ion beam
- Position and transverse profile
- A railing system gives opportunity of phase space determination



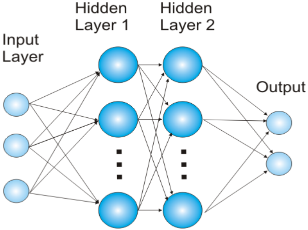




Machine learning is a field of study that gives computers the ability to learn without being explicitly programmed.

- Pattern recognition and learning theory
- Statistics, data analytics for predictive analysis
- Catagorized broadly into Supervised vs Unsupervised
- There exist different approaches Clustering, SVM, Decision tree learning, Artificial Neural Networks, Deep learning, SOM

Artificial neural networks (ANNs), are computing systems inspired by the biological neural networks.



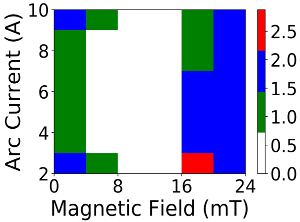
n-dimensional feature vectors from input object

Artificial Neural Network → Non linear activation functions

- Ion sources are designed by simulating EM fields and plasma
- Plasma chemistry is missing
- No direct correlation of ion beam composition and Control Parameters
- Human control is necessary, so do the experience
- Retuning is required after every shutdown
- Any other component can be analyzed with this method

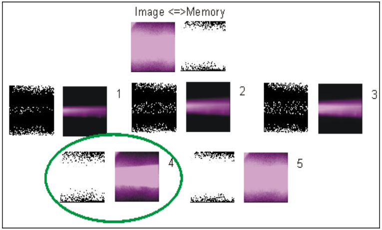
ML $\rightarrow$ Learning from Multi dimensional data

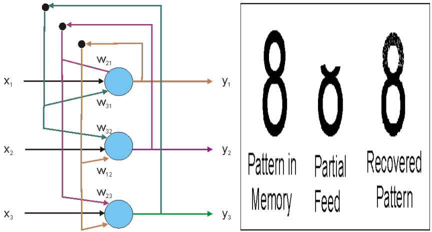
Example: Learning from Ion Source data $\rightarrow$ Control parameters
Extrapolating operating parameters *Voltage*, *Current* to predict beam matching

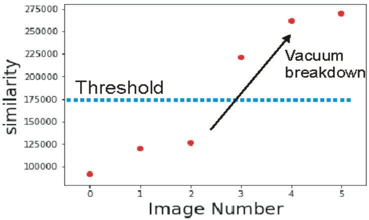


Replacing human experience with Machine learning and automated control system

The Artificial Neural Network of recurrent type can store particular pattern in memory.
This pattern can be recalled from partial information.
Application: Early Event Prediction e.g.vacuum breakdown







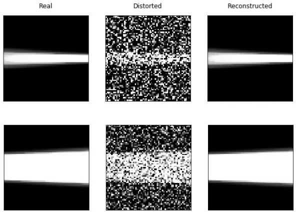
The similarity index is used as a quantitative measure.

Denoising using ANN

- Optical diagnostics using CCD camera was used for profile determination.
- Signal to Noise Ratio can be improved by using various filters.
- Tomography was demonstrated successfully at low energies with hgh current.
- At high energies the reaction cross section decreases for ion beam interaction with buffer gas.

Solution: Application of ANN as autoencoder-decoder.

Simulated images of ion beam with different noise types and level generated. Neural Network is trained with these images to learn to separate signal from noise.
This trained network is then used for real images from experiments for denoising.



Conclusion and Outlook

- Accelerators are being built with heavy dependence on previous experience of scientists in this field.
- Human memory and thinking in multiple dimension has restrictions, machines can do this job better.
- Advanced techniques in Machine learning and Neural Networks for pattern recognition can be applied to various topics in accelerator physics including control systems, diagnostics, design parameters (see list of references)
- One can apply this system to whole facility in order to optimise daily operations for e.g. the feature vectors can consist of human resources, energy consumption etc. and the cost of operations can be optimised.
- This kind of strategy would also provide opportunity for unplanned spontaneous experiments which are otherwise impossible due to strict schedule.

References & Publications

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Thank you ...!

Temporal evolution of proton beam passing through FRANZ chopper with electrons produced at beam dump (space charge included)