Australian Government

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Machine learning and Accelerator Physics at the Australian Synchrotron

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Accelerator Technology Forum 2020

Science. Ingenuity. Sustainability.

What do we mean by Machine Learning?

- AI is the ability to think and learn from data (mimicking human cognition)
  - Interpret external data correctly
  - Learn from the data
  - Achieve specific goals/aims using the insights from the data
  - Adapt to changing situations on the fly
- Machine learning (ML) can be thought of as the generation of algorithms that can learn from data without being explicitly programmed
  - Using sample data, learn and predict based on that data

Difficulties with modelling and control

- Complex systems:
  - Nonlinear phenomena
  - Large parameter space
  - Interacting systems and subsystems
  - Diagnostics may not exist
  - Non-Static time variant behaviour – drift over time
- Strong need to improve, control and understand
  - User demand – this will increase and need to switch operation mode
  - Downtime – bad! User output, scientific output
  - Changing landscape for science needs – need to adapt beam setups

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Challenges in the future when we push toward more extreme beam parameters and requirements (ultra low emittance, high gradient, X-FEL, electron guns etc.)

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Examples

Some examples of ML at ANSTO

- Instrumentation design and optimization (Surrogate modelling)
  - Compact Light Bunch Compressor Optimization

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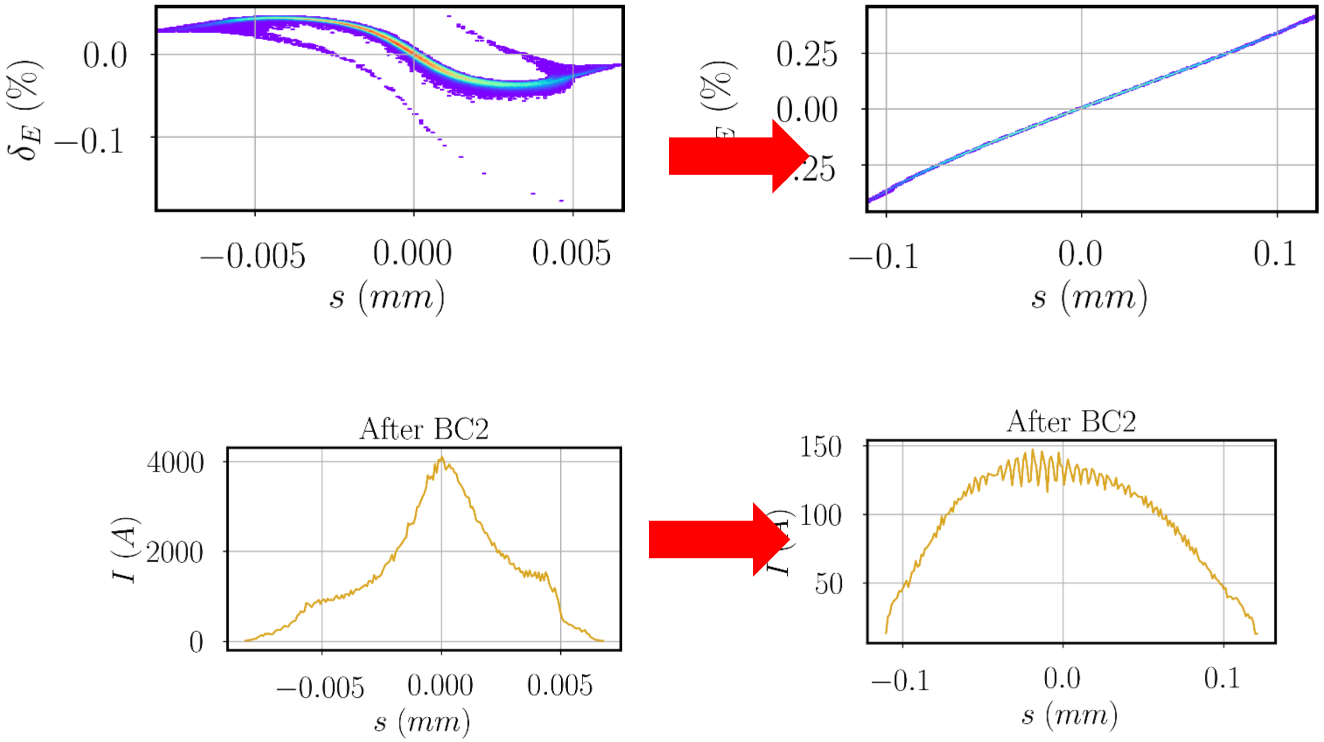

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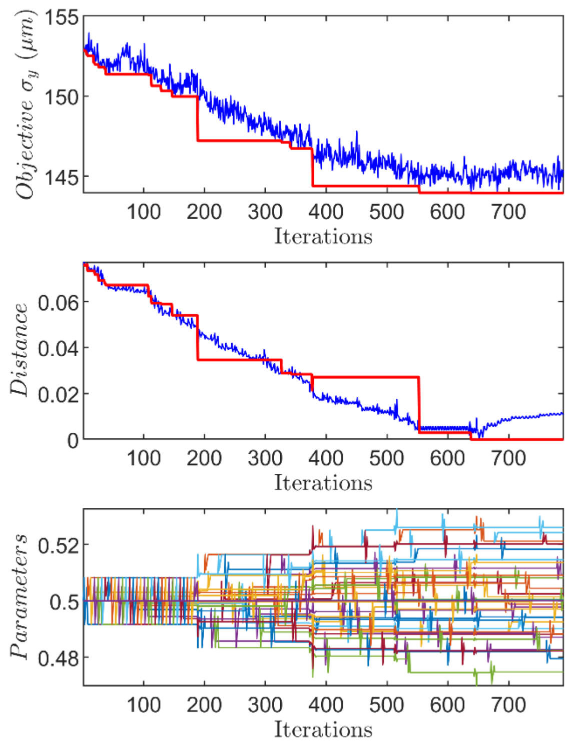
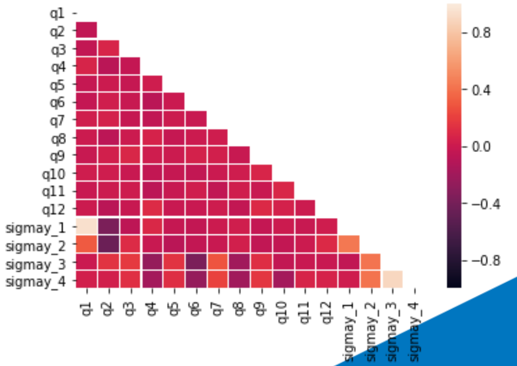
Some examples of ML at ANSTO

- Instrumentation design and optimization (Surrogate modelling)
  - Compact Light Bunch Compressor Optimization
  - Next generation facility designs (see Dr Rohan Dowd's presentation)
  - Nonlinear kicker design
- Online optimization tuning of the machine
- Prediction of unwanted changes and failures for prevention (anomaly detection)

Online Optimization using RCDS

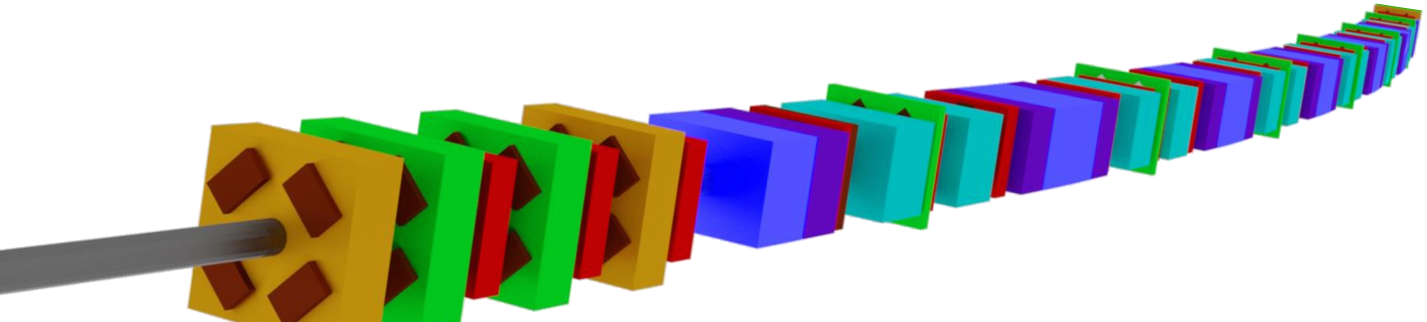
- Traditionally, we have used manual optimization to tune the machine
- Rather than optimize 1000 variables, do a sensitivity analysis
  - Determine the most sensitive parameters that have a distinct impact on the target
- Deploy online optimisation algorithms
  - Robust Conjugative Directional Search (like RCDS) to tune the machine in real-time using the variables selected from the sensitivity analysis
  - E.g. optimise the injection kicker bump of the current injection system

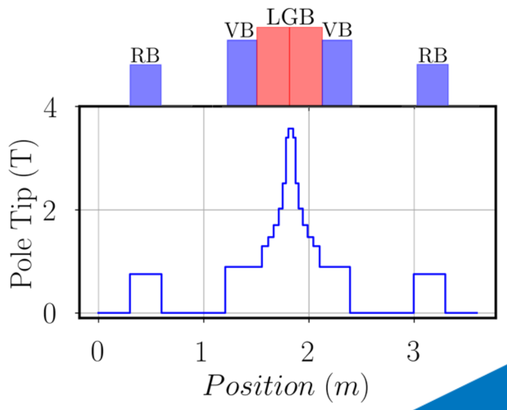




Design optimization

- Challenge: design a next generation reverse bend longitudinal gradient bend ultra low emittance (pm) lattice that could fit into the existing infrastructure
- Fixed constraints make manual optimization hard
- Computationally expensive to explore full parameter space
- Future work: speed up by combining genetic algorithm with neural network





Beam Dump Diagnosis

- Predictive algorithms to diagnose beam dumps
- We lose approximately 50 hours of scheduled beam operators per year due to accelerator faults
- Project aims to reduce user beam downtime by automatically classifying fault cause
- Operators can immediately recover the machine without searching for the cause using various diagnostic tools


APPLICATIONS OF ONLINE OPTIMIZATION ALGORITHMS FOR INJECTION AT THE AUSTRALIAN SYNCHROTRON

THE ONLINE OPTIMIZATION SOLUTION

THE RCDS ALGORITHM

THE CHALLENGES TO THE OPTIMIZATION OF ACCELERATORS

[7] M. C. Chalmers, "Machine Learning Algorithms for a Predictive Tool to Reduce Beam Down Time", presented at the 10th Int. Particle Accelerator Conf. (IPAC'19), Melbourne, Australia, May 2019, paper THPRB003, this conference.

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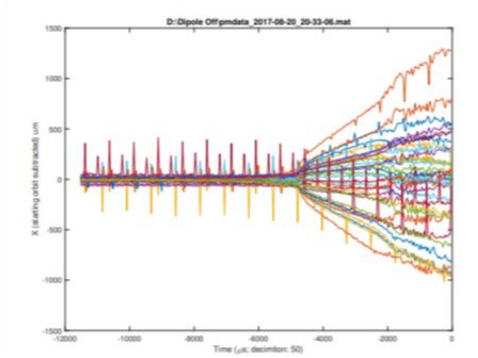
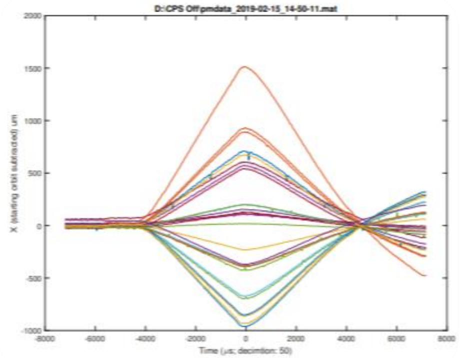
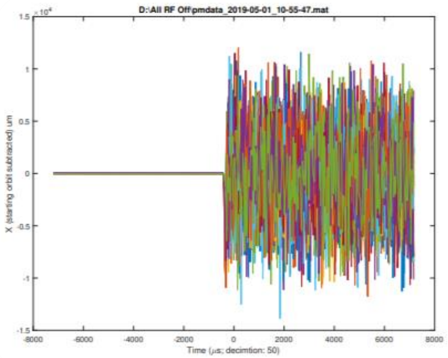
Beam Dump Diagnosis

- Most common failures are visually characteristic of the fault
  - e.g. magnet power supply failure, RF inhibition by EPS
- Project manually classifies the most common faults using logistic regression - accuracy currently at 87%
- Accuracy could be improved using feature engineering







Feature selection of unknown faults

- A fault can have no one obvious characteristic that allows immediate classification and identification
- First steps: data cleaning of post mortem archival data and then exploratory data analysis to analyse hundreds of features to classify as-yet unknown faults
- The model will be used to proactively predict beam dumps before they occur so operators can intervene

Areas for mutual collaboration

- Fault detection, anomaly detection and end of life prediction:
  - Identify bad BPMs, magnet power supplies etc.
  - Predict machine faults before they occur
  - Classification of trips/faults
  - Instrumentation end of life prediction
- Optimization:
  - Different operational modes for machines
  - Treatment delivery for electron radiotherapy (VHEE)
  - Accelerating structure design and optimization
  - Magnet designs

Thank you

We welcome collaborations!

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