Machine Learning in MPE

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On behalf of the MPE group

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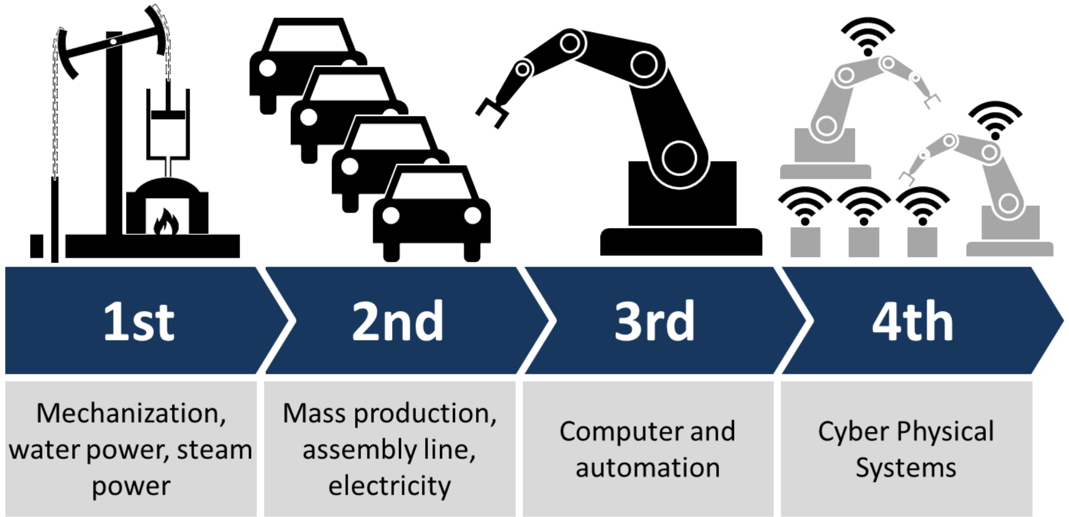
Introduction

New paradigms in industry and engineering:

- Big data analytics
- Data-driven models and decisions
- Internet of Things and Industry 4.0



The particle accelerators context:

- Lots of data from experiments, infrastructures, accelerator equipment, beam measurements
- Advanced modelling of physics phenomena (beam loss mechanisms, quench behavior,…)
- Integrated environment with operators, system experts, hardware systems, lots of software applications
- Complexity: challenging to explore large data sets and find correlations without a systematic and automated approach
- Today most of the observed issues are coming from unknown/unexpected processes and complex system dependencies (UFOs, 10 Hz instabilities,…)

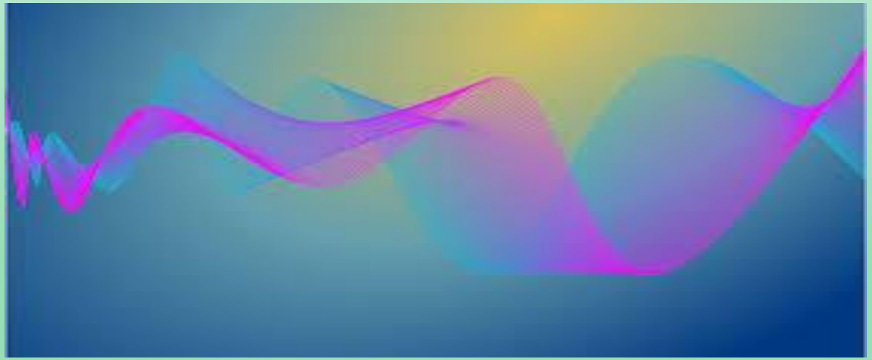
Use Cases in MPE

Health Monitoring and Failure Prognostics

Applications:
- Magnet Circuits → Signal Monitoring Project
- MPE equipment (QPS, BIS,…)
- Failure prognostics for accelerator equipment

Advanced Signal Processing

Applications:
- Filtering
- Quench detection



Health Monitoring and Failure Prognostics

Now

Start HL-LHC

HL-LHC lifetime

Beyond

Report alarms and error messages

Data mining techniques, deep neural networks

Enhanced anomaly detection

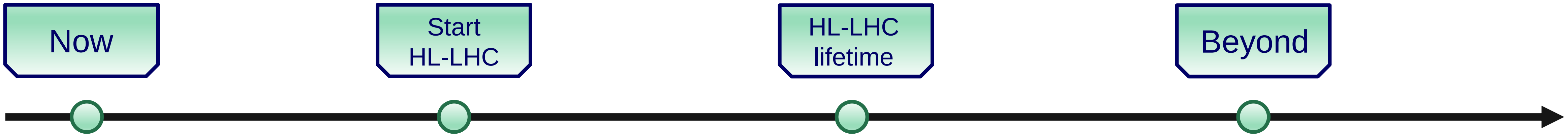
Online ML, (semi)supervised learning

Adaptive condition-based maintenance

Online ML, direct interaction with equipment

Automate intervention planning and system recovery

Signal Processing



Edge processing, basic filtering

Deep neural networks, implementation in MCUs and FPGAs

Advanced filtering, suppression of unwanted signal features, increased bandwidth

Centralized processing

Enhanced filtering and suppression

Diverse redundancy in QDS

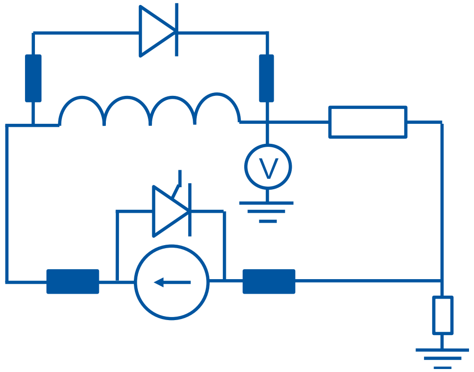
Precursor analysis, circuit correlations

LHC Signal Monitoring Project

We foresee the use different types of models for performing on-line monitoring of LHC superconducting circuits

Physical Models

+ Provide access to non-measurable states
+ High numerical precision
- As accurate as available measurements



Data-Driven Models

Threshold-Based

+ Embed expert knowledge
+ Give a clear answer
- Require adjustments

Probabilistic

+ Distribution of features
+ Do not give a clear answer
- As good as input features

Machine Learning

+ Encode non-obvious relations
+ Find patterns, correlations
- Do not give a clear answer
- As good as input features

Hybrid Methods

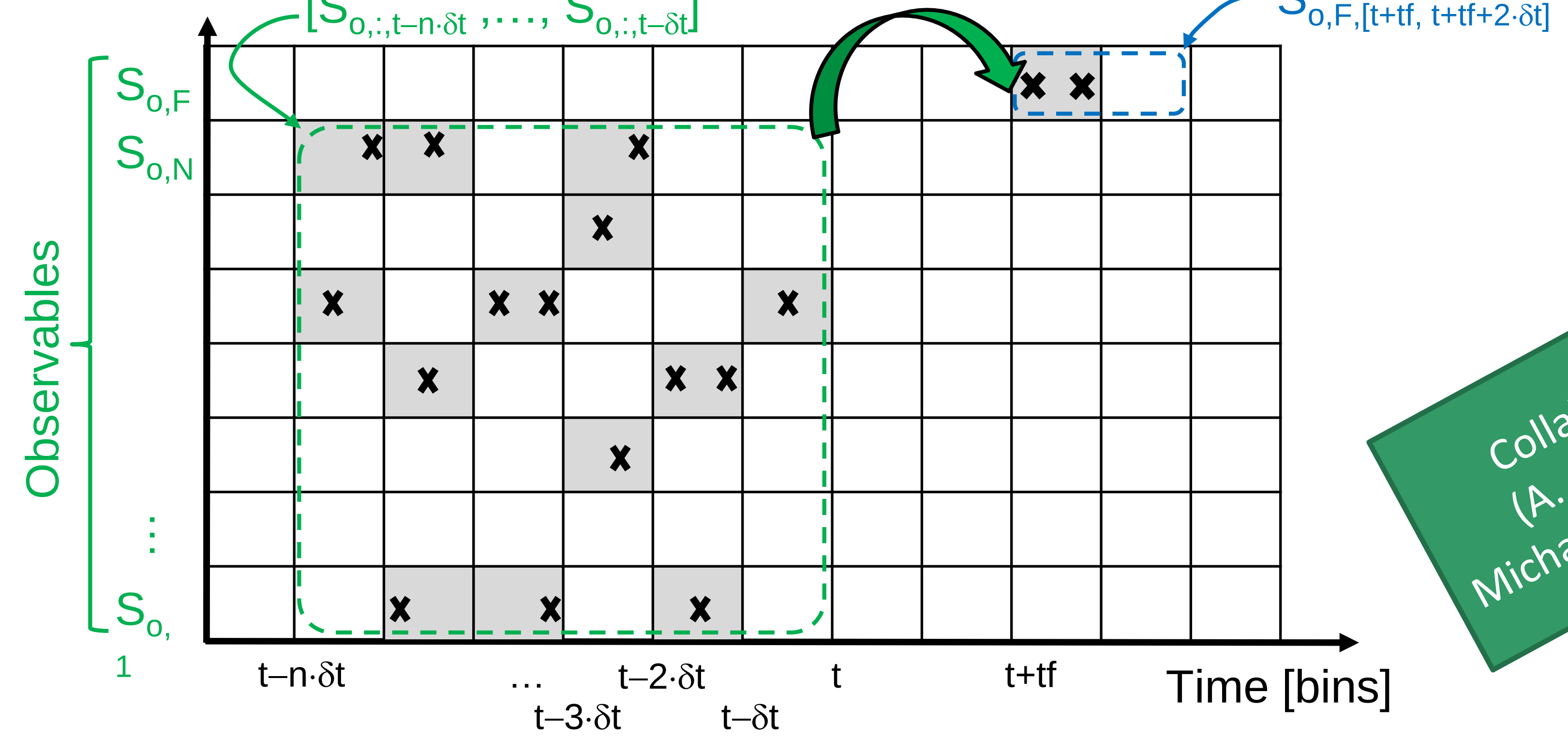
+ Keep fixed threshold and learn deviations as an expert would do
- More complicated analysis

→ **Generic** API to query logging databases and execute analysis on the **NXCALS** cluster.
→ Intuitive notebooks for LHC circuit Hardware Commissioning **analysis** and **reporting**.
→ **Environment** to develop data-driven models (statistical analysis and machine learning with Apache Spark).

“Extension of signal monitoring applications with machine learning”, C. Obermair, CERN thesis, 2020.

Failure Prognostics – PSB Power Converters

$$S_{o,F,[t+tf,\, t+tf+2\cdot\delta t]} \approx \Phi([S_{o,t-n\cdot\delta t}, \dots, S_{o,t-\delta t}])$$



Collaboration MPE/EPC (A. Apollonio, T. Cartier-Michaud, L. Felsberger, B. Todd)

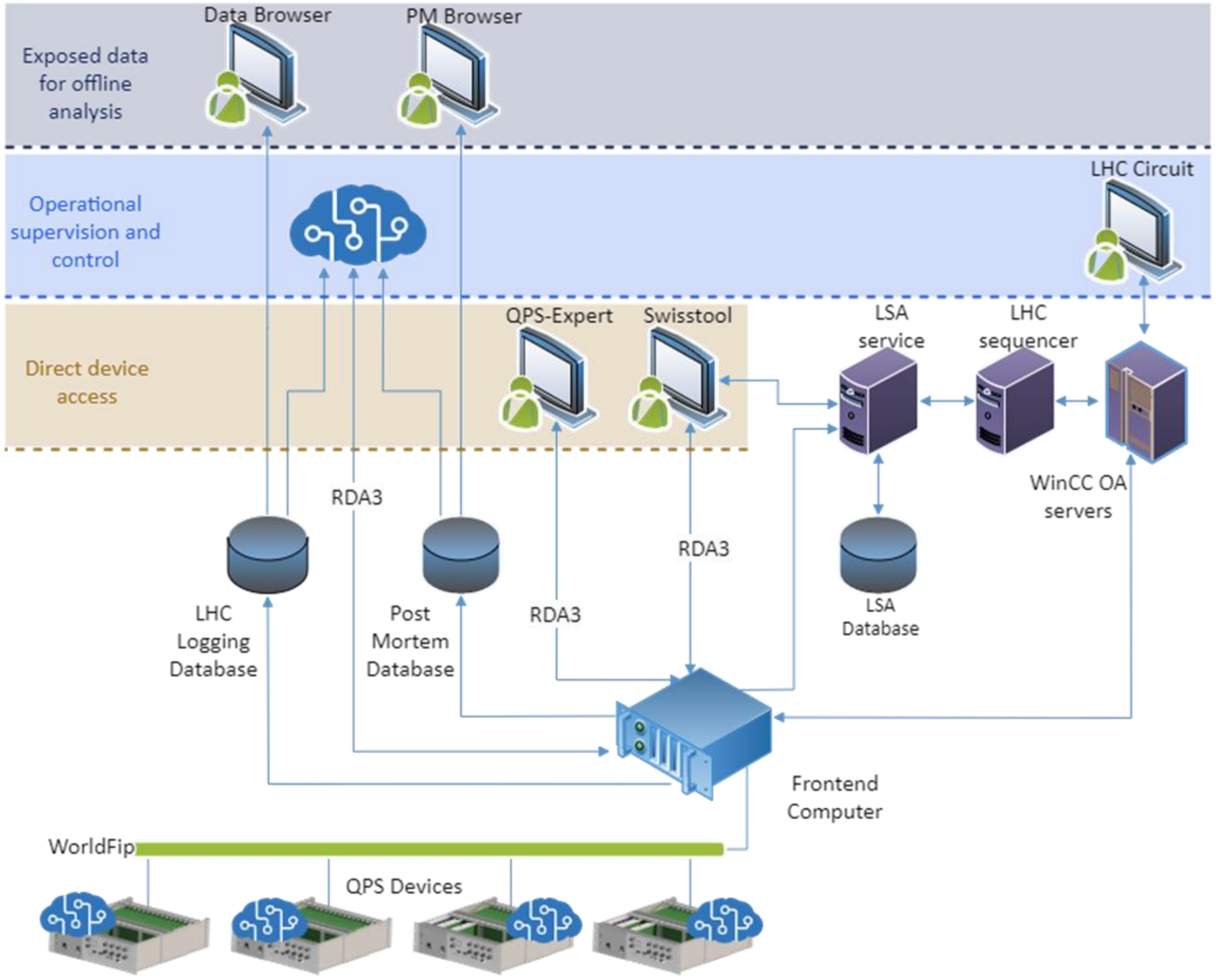
- Many data sources (LASER, NXCALS, AFT,…)
- High number of hyper-parameter combinations
- Challenging due to strong data imbalance (PhD topic, see later)

“Machine learning for early fault detection in accelerator systems”, A. Apollonio, T. Cartier-Michaud, L. Felsberger, A. Mueller, B. Todd, ATS note, 2020.
“Analyzing failure mechanisms in complex infrastructures”, L. Felsberger, A. Apollonio, T. Cartier-Michaud, D. Kranzmueller, A. Mueller, B. Todd, in publication.

First Ideas – QPS

- Maintenance of the system
  - Health and alarms monitoring
  - Condition-based maintenance
  - Semi-automatic maintenance

- Device level applications
  - Signal processing for new superconductor Technologies (Nb3Sn, HTS)
  - Redundant - diverse - quench detection (complementing existing methods), possibly Leading to identification of failure precursors (Slow Power Abort)



MPE Resources

	FTE (already committed)	FTE (proposed)
QPS health monitoring and signal processing	0.2 STAFF (no ML)	+ 1 TECH
Signal monitoring project	2 STAFF (MP3 – no ML) 0.2 FELL 1 PhD (20 months, Austria) 1 STAG	(keep same resources)
Failure prognostics for accelerator equipment	0.1 STAFF 0.2 FELL	(keep same resources)

Conclusions

Is machine learning a revolution?
Yes and no → alternative method to perform tasks that we are already doing, but in a much more coherent and thorough way

Is there a direct application of ML to the accelerator domain?
Definitely yes, several use cases were already explored successfully

Is ML learning expertise available at CERN?
Mostly no, compared to other domains, but there are many ongoing initiatives, growing fast

Would TE (and ATS) benefit from a common framework to share experience and knowledge? (tools, methods, computing infrastructures)
Definitely yes, many similar initiatives are ongoing in different CERN groups

MPE would like to continue its activities in this domain, in order to develop expertise and follow modern trends in the industrial world

Is machine learning requiring (dedicated) high resource investments?
No, a large part of the tasks is performed anyways (data extraction, processing, display, follow-up of issues), strong domain knowledge available

Thanks for your attention!