EUROPEAN
SPALLATION
SOURCE

ESS Control System Machine Learning Project

…with lessons learned on how to ride a hype without losing control

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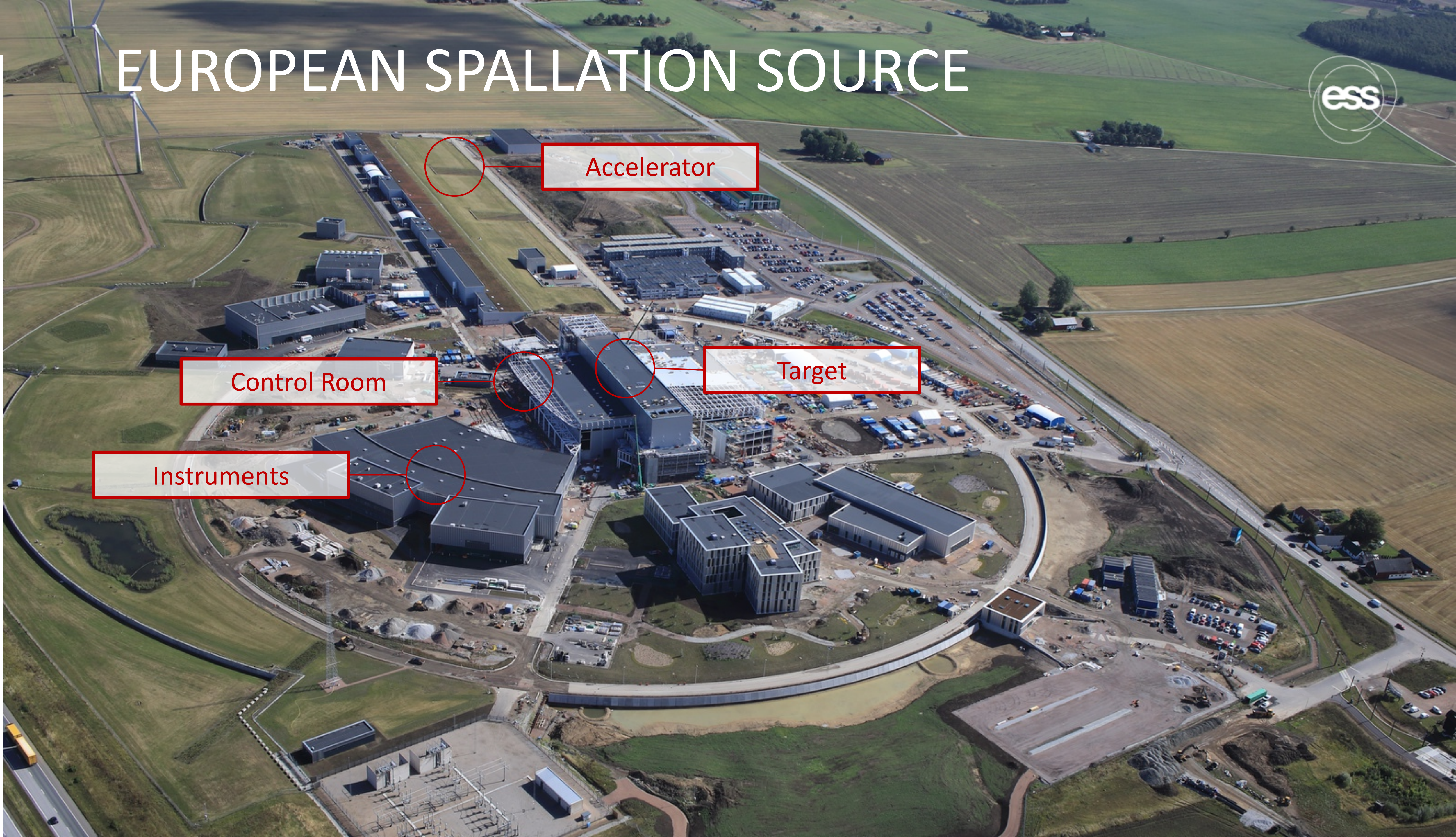
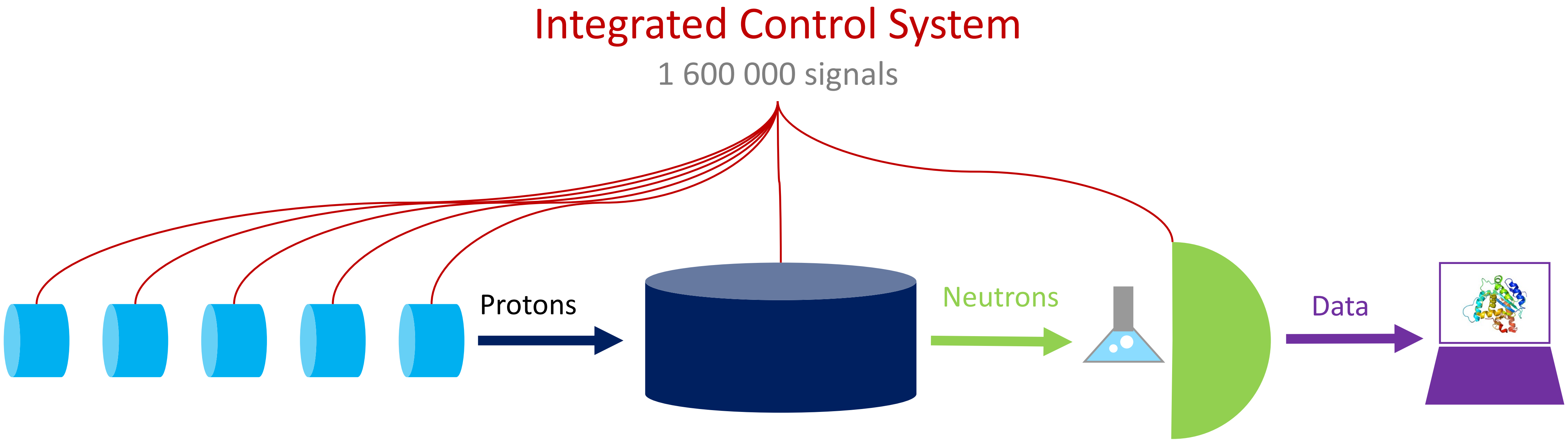
EUROPEAN SPALLATION SOURCE



How Spallation Works



Accelerator

Superconducting
5 MW protons
2.8 ms pulses
14 Hz repetition rate

Heavy Metal Target

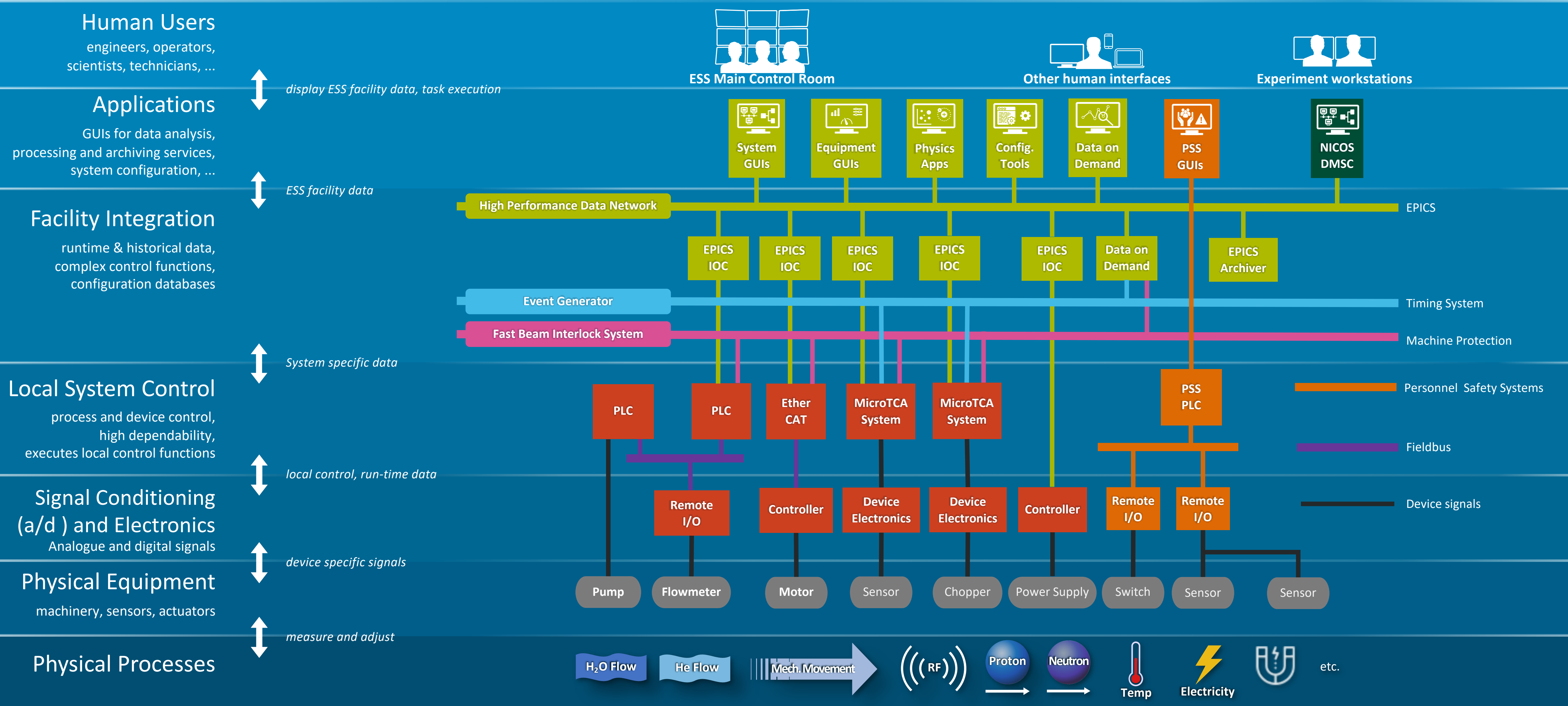
Stainless Steel & Tungsten
11 tonnes
23.3 rpm
Helium cooled
2.6 m diameter
42 neutron beam ports

Instruments

22 instruments

DMSC

Hardware Architecture



Challenges

- Accelerator – based facilities are some of the worlds most complex systems
- ESS is a user facility with a 95% availability goal
- The control system plays a key role for the availability of the facility

Control System Machine Learning Project

Project Charter

Time: 2019-2023

Budget: 4 man-years of effort contributed from the ICS project budget.

Objectives: Explore how artificial intelligence can be used for applications in a large-scale control system such as the ICS of ESS.

Benefits:

- Build up AI competence within ESS and industry
- Host interesting applied AI research topics for master and Ph.D. students and their supervisors
- Make applications work in an industrial environment
- Extend collaborations between university, ESS and industry

Scope:

- Create a research collaboration between ESS, industry and universities to develop AI applications for complex control systems
- Identify research areas, apply for collaborative activity funding and engage students
- Create and take initiative in related conferences and workshops
- Demonstrate the benefits of AI through practical application on a subsystem of the ESS Facility
- Investigate and document guidelines for how to select domains of a control system where AI is feasible
- Select framework and software platform and integrate with EPICS

Constraints:

- Use of Open source software and EPICS framework

Key Stakeholders

Big Science Sweden

- The official Swedish industrial liaison-organisation. Created to promote business opportunities between industry and large-scale research facilities.

AI Lund

- Interdisciplinary network for research, education and innovation in the field of Artificial Intelligence. Coordinated by Lund University and open to members from academia, industry, public sector and other organisations.

MAX IV

- Swedish national laboratory providing scientists with the most brilliant X-rays for research.

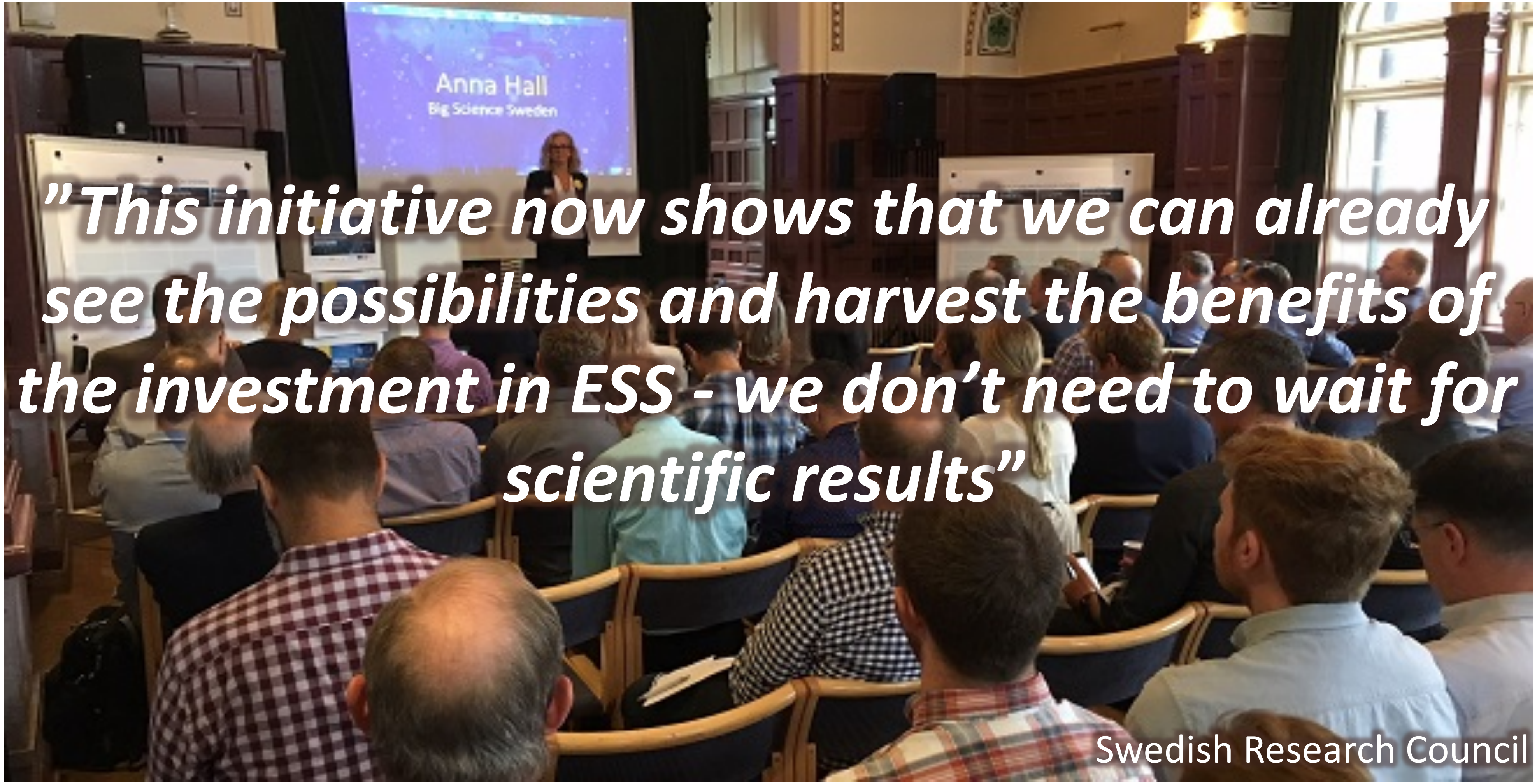
Resources

100% Me 2019-2023:

- Accelerator physicist (beam dynamics, electron cooling, non-linear phenomena, collective instabilities, space charge, vacuum, RF sources)
- Software developer and project manager (Naming convention and tools, alarm management and tools, logbook)
- Sales representative in oncology
- Experience from Innovation in blood analysis

Great Expectations!

AI workshop Big Science Sweden and ESS August 2018



Collaboration

Scope: Create a research collaboration between ESS, industry and universities to develop AI applications for complex control systems

First Stakeholder's Meeting Jan 2019

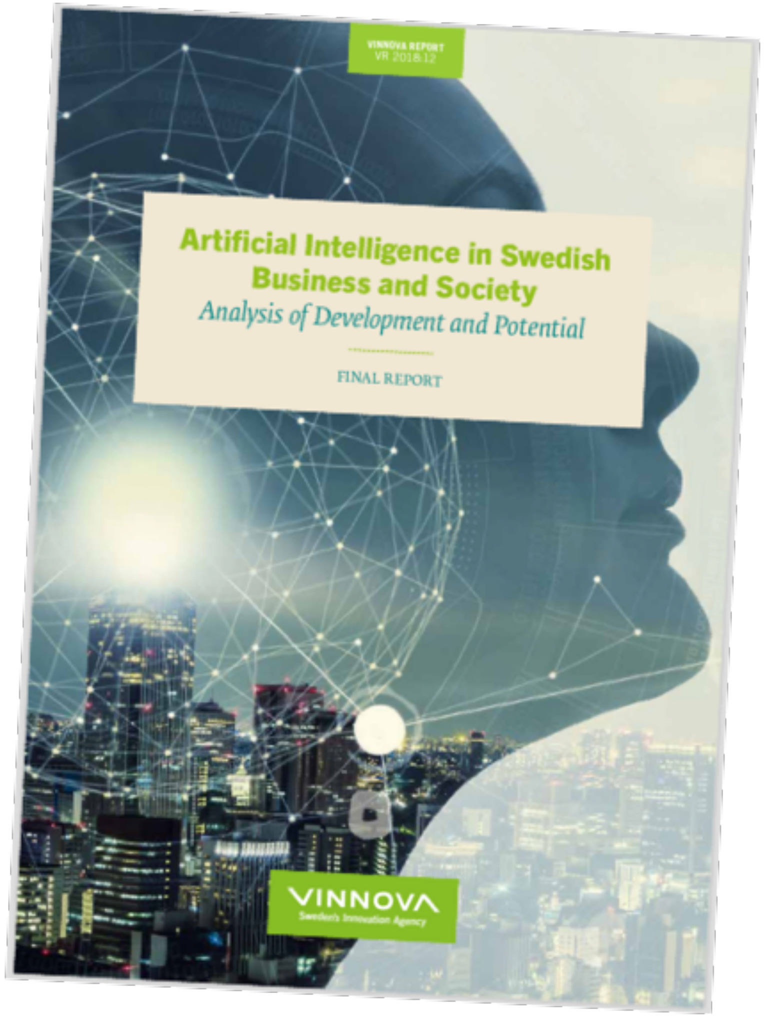
Getting resources

Scope: Identify research areas, apply for collaborative activity funding and engage students

”Collaboration among companies, public operations, research institutes, universities and university colleges will be crucial in realizing Sweden’s AI potential ”

Outcome:

- Two Vinnova projects.
- Postdoc (wrote a recommendation letter)



Workshops and conferences

Scope: Create and take initiative in related conferences and workshops

2nd ICFA Mini-Workshop on Machine Learning for Charged Particle Accelerators 2019

Outcome: Collaboration with DESY!

Conclusions after the first explorative year

Big Science Facilities are ideal for research collaboration in intelligent industrial controls

Applications: Artificial intelligence, in particular machine learning, will change the way big science facilities are operated. Intelligent industrial controls is in its infancy, but many existing machine learning algorithms, which have been developed in other fields, e.g. natural language processing, robotics, image analysis and trading, are directly applicable to industrial control systems.

Brain: Big science facilities have some of world's most technical advanced and complex machines. The machines are made up of a large number of systems that are monitored and controlled by industrial control systems, which acts as the brain of the machines.

Code: Good software development skills, especially in Python are important for machine learning. Big science facilities are multilingual environments where Python is as self-evident as Fortran used to be in the 70's.

Data: A machine learning model can never perform better than the data it is trained on. Big science facilities produce large volumes of control system data. Collecting and managing large quantities of experimental data is routine operation at big science facilities.

Education: University and Big Science Facilities have a common interest in the field. Applying new findings in computer science, automatic controls, electric and information technology and math to challenges in industrial controls is beneficial for both sides.

Freedom: Big science facilities are publicly financed. Consequently, the mindset is open source, open science and giving back to society.

Gain: Reduced costs, increased production, improved quality and enhance safety are strong motivations for incorporating artificial intelligence and machine learning in complex control system.

Hart: Big Science Facilities have been driven to the state of art by the rich collaborations. This includes the control system themselves and suits of software application supporting machine operation.

Industry: Big science facilities are made up of a large number of diverse systems and disciplines, covering for example water cooling, vacuum, power distribution, timing systems, information technology, networking, microwave systems, cryogenics, among others. Although big science facilities have some of world's most technical advanced and complex machines, the underlying systems are mainly made up by conventional industrial components. Equally, processes and methods to operate big science facilities are in essence the same as in any other industrial plant. The difference lies in volume and complexity. On the other hand, industry is at the doorstep of the fourth industrial revolution, with increasing number of sensors, increasing amounts of data and increasing complexity.

Lessons learned after the first explorative year

Maybe too many collaborators

Maybe too many great ideas

Too much invitations, mingle, representation, travel

Too much administration and coordination

Too much outreach, innovation and visibility

Too high expectations

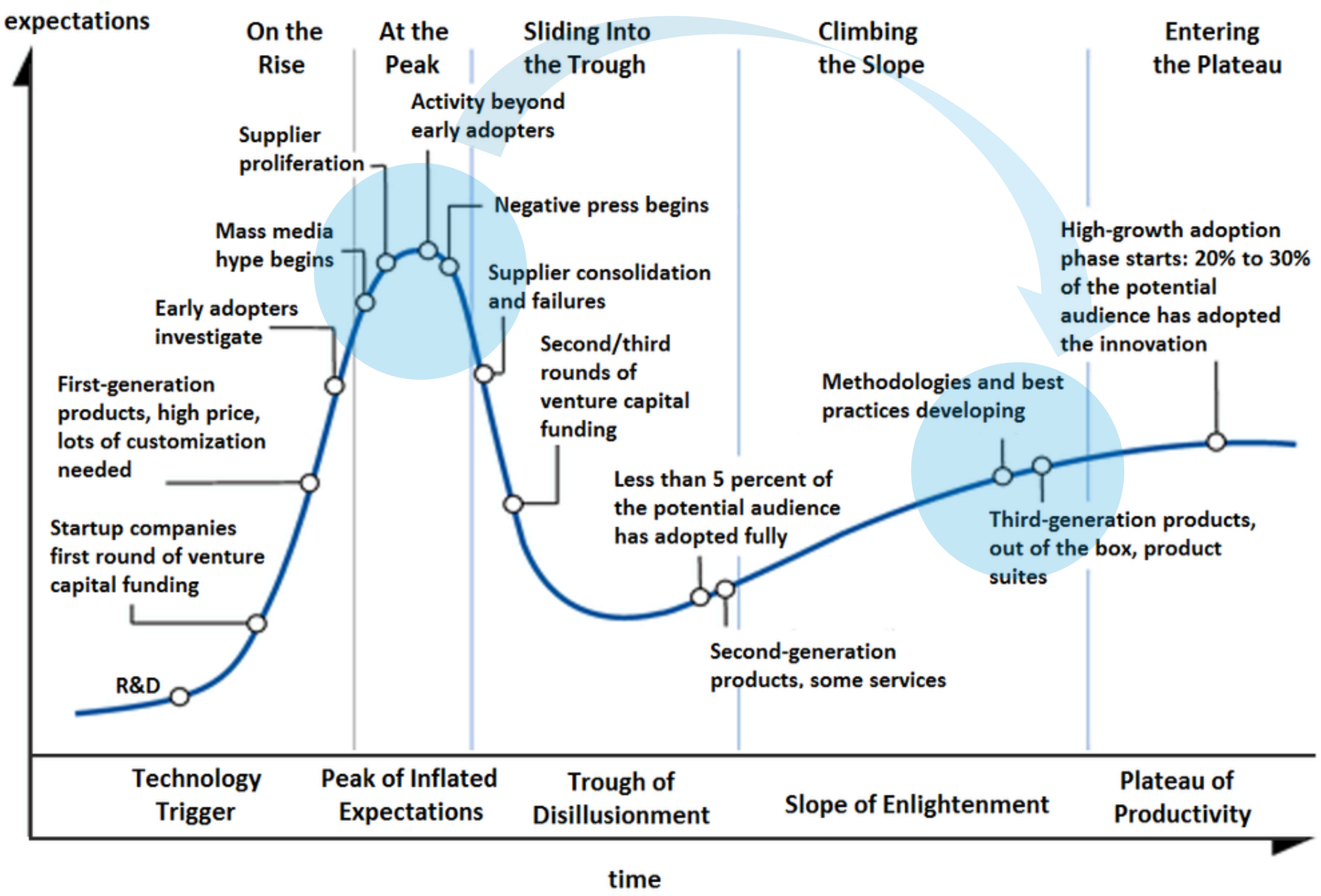
Too much pressure

Too little focus on technical aspects

Too little learning

Gartner Hype Cycle

The catch: To get resources you need to be visible, but visibility kills creativity



How to ride a hype without losing control?

Strategy

Don’t try to control everything

- Continue to share ideas and collaborate!
- Lean towards a big goal but work incrementally towards it.
- Write project descriptions together with collaborators but let industry and academia lead projects and be the visible part. Let them shine!
  - Funding activities
  - Engaging students
  - Project reporting
  - External communications
  - Outreach
  - Workshops, meetings
- Focus on data, problem formulation, integration, implementation. I.e., contribute on the technical work and learn from the collaborators.
- Engage the legal department and write collaboration agreements to maintain control, but avoid other administrative parts.

Project: ESS Control System Data Lab

Scope: Create a research collaboration between ESS, industry and universities to develop AI applications for complex control systems

- A pilot study funded by Vinnova, WASP and IUC Syd
- Collaboration between Lund University (coordinator), Big Science Sweden, GoalArt and ESS
- First kick of meeting Feb 2020 in person, thereafter over Zoom.

Objective

Prestudy report
due January 2021

The objective for this pilot study, is to explore how to collect, store, manage and share data from the integrated control system at ESS to make it available for research and innovation.

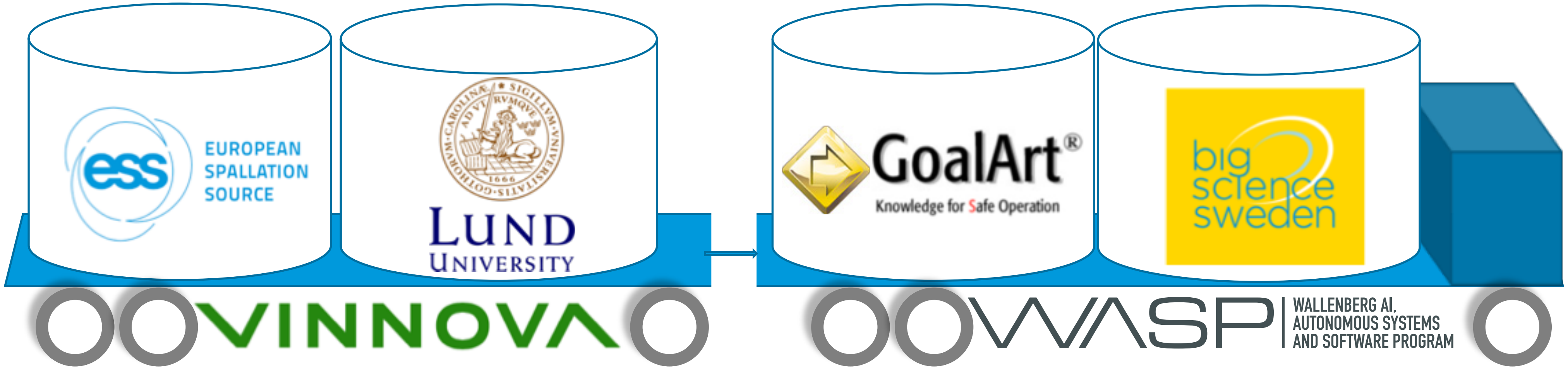
1 Tools and eco-systems for data

2 Meaning of alarm data in context

3 Rights and conditions for data

Open alarm data as a vehicle for collaboration

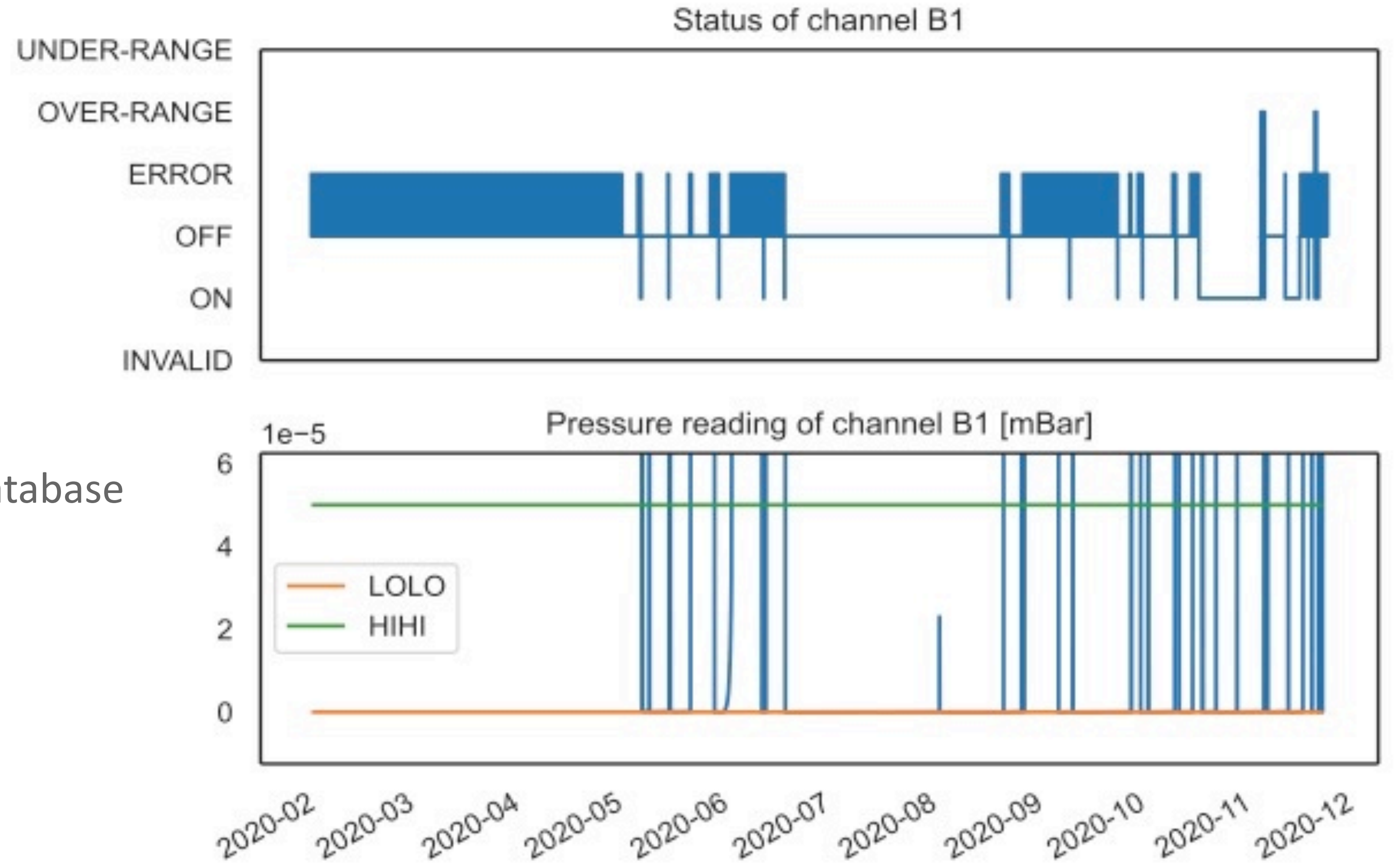
ESS Control System Data Lab – A pre-study project



Alarms are generic across industry domains

Data and meta data

- Archiver
- Naming service
- Configuration database
- Cable database
- Alarm handler
- Logbook



Outreach

Wallenberg Autonomous System and Software Program

WASP | WALLENBERG AI, AUTONOMOUS SYSTEMS AND SOFTWARE PROGRAM

← NEWS

A big machine with lots of data – WASP researchers in a pilot study with ESS

April 28th, 2021

Image: Perry Nordeng/ESS

When finished, the European Spallation Source (ESS) in Lund will have the most complex control system in Sweden, and AI, especially machine learning, is crucial for optimizing its operation. WASP associated researchers Per Runeson and Emma Söderberg, both from Lund University, recently contributed to a pilot study on data sharing for machine learning research from ESS.

In their contribution, they have investigated several issues regarding data sharing. How can data be shared between organizations in order to achieve more and better training data for machine learning models? One useful solution is sharing through data ecosystems with various degrees of openness, where one company shares data, and another annotates it. This could be beneficial in terms of increased knowledge and better prediction models.

"We conclude in our report that by sharing data, ESS can function as a catalyst for Industry 4.0 digitalisation, both in industry and other research facilities," explains Per Runeson, Professor in Software Engineering. "Data sharing fulfills the function of sharing knowledge, and our project shows that it is possible for ESS to be a role model and share relevant data with industry," he adds.

Another topic addressed was how to build long-term reliable data pipelines. They found that agile tools and approaches are needed in order to collect, process and maintain data. Also, data traceability and handling of meta data are important quality factors that needs attention when working with machine learning.

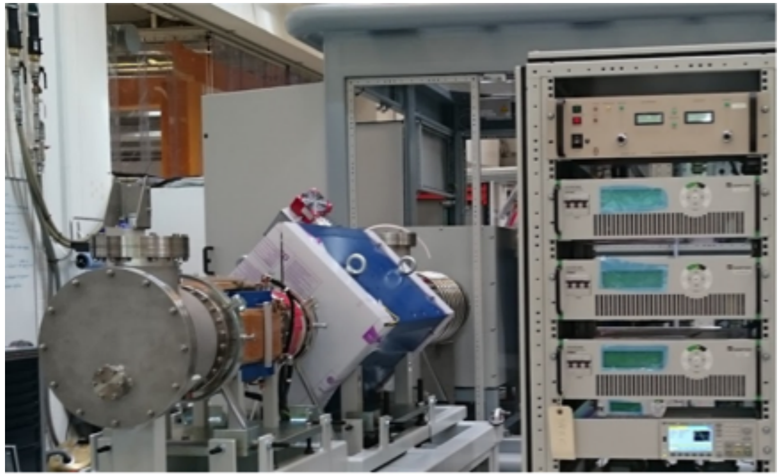
"We found that a lot of the literature cover challenges with Big Data, but in practice for companies in this space the data sets may many times be smaller and there are challenges in how to trace data versions and how to share understanding of the data between developers. We see a potential in further exploring how agile methods and tools from software development can be utilized in management of data," says Emma Söderberg.

Read more about the machine learning project at ESS and what role ESS can play for the development towards Industry 4.0: https://europeanspallationsource.se/article/2021/04/08/machine-learning-ai-enable-brightest-neutron-beams-research

Project: Predict the future with EPICS

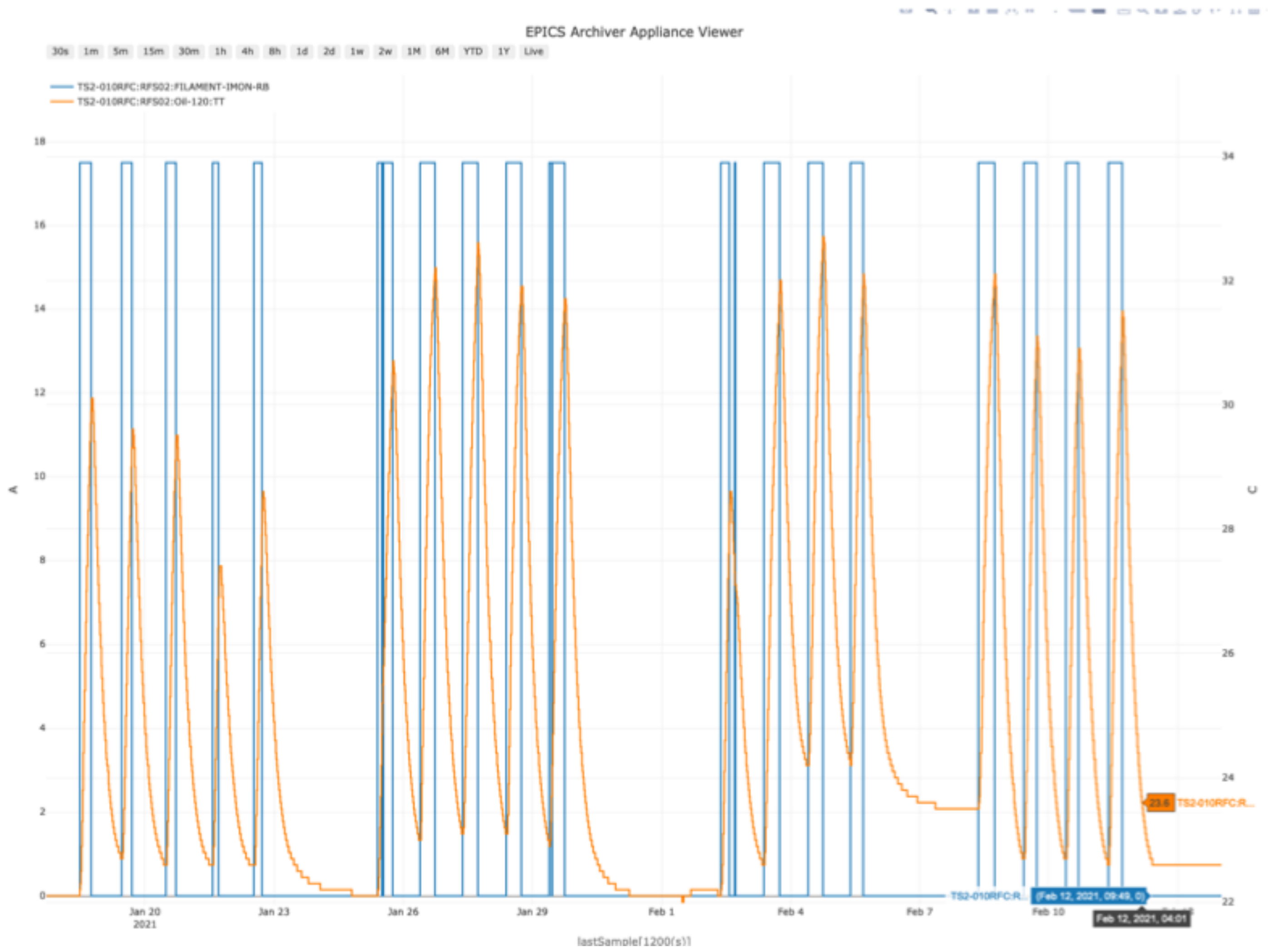
Scope: Demonstrate the benefits of AI through practical application on a subsystem of the ESS Facility
Scope: Select framework and software platform and integrate with EPICS

- Collaboration between DVel (coordinator) and ESS
- Project funded by Sweden's Innovation Agency Vinnova



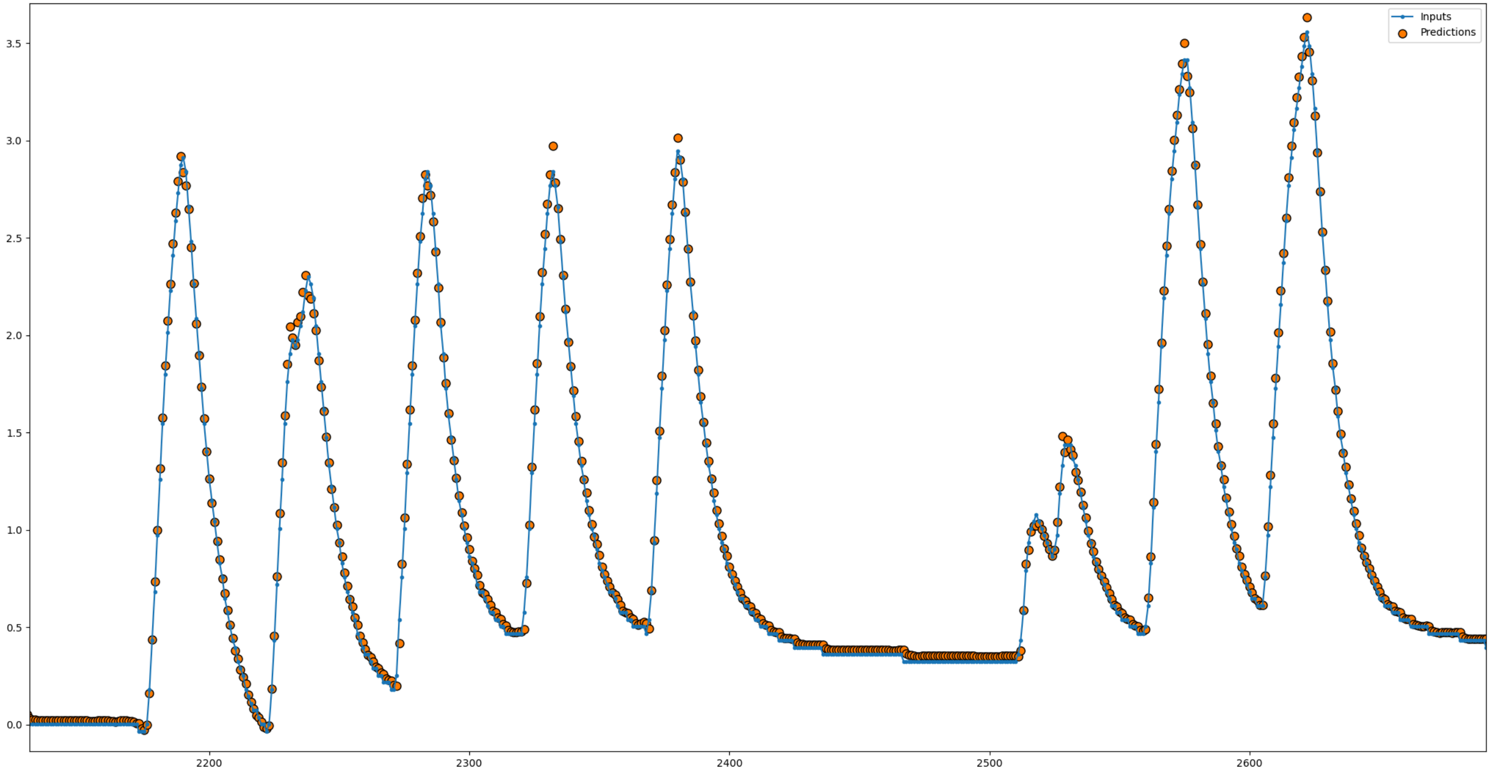
Data from the archiver

Filament current klystron and oil temperature in the tank



LSTM solved the heat equation

Easy compared to natural language processing that LSTM was developed for



Benefits:

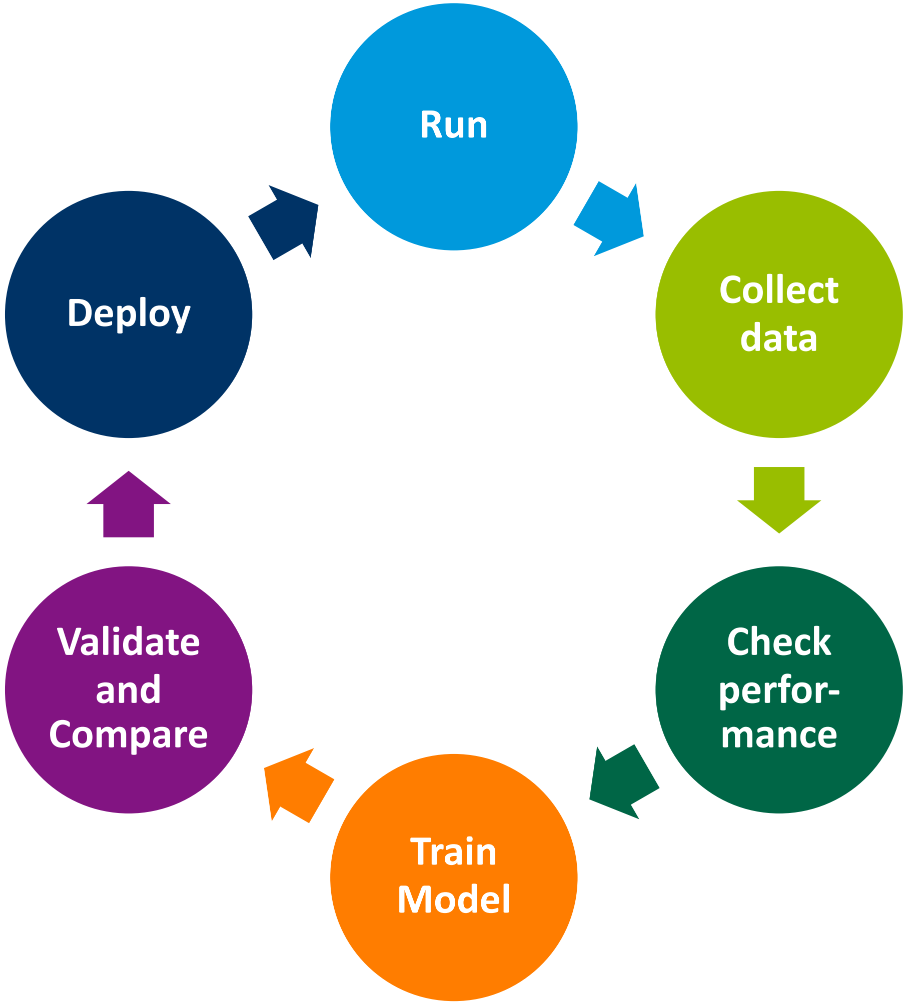
1) Before the oil gets too hot one can automatically adjust the filament current since the model beforehand knows how the temperature will increase with time.

2) Add an alarm that will warn if measured oil temperature does not correspond to the previously predicted temperature. This could either indicate that the model needs to be updated, (calibration) or that the temperature transmitter is broken.

How to adapt to a dynamic machine

Discussions between the collaborators

- Preventing model degradation by adapting to drifting sensors and other slowly varying parameters that we do not control
- Simultaneous prediction and learning with scheduled updates of the latest trained model.



Integration with EPICS

To demonstrate interaction between EPICS and Google Tensorflow

Blue: Simulated chaotic resonator. Signal was intentionally made difficult to predict.

Pink: Machine interlock.

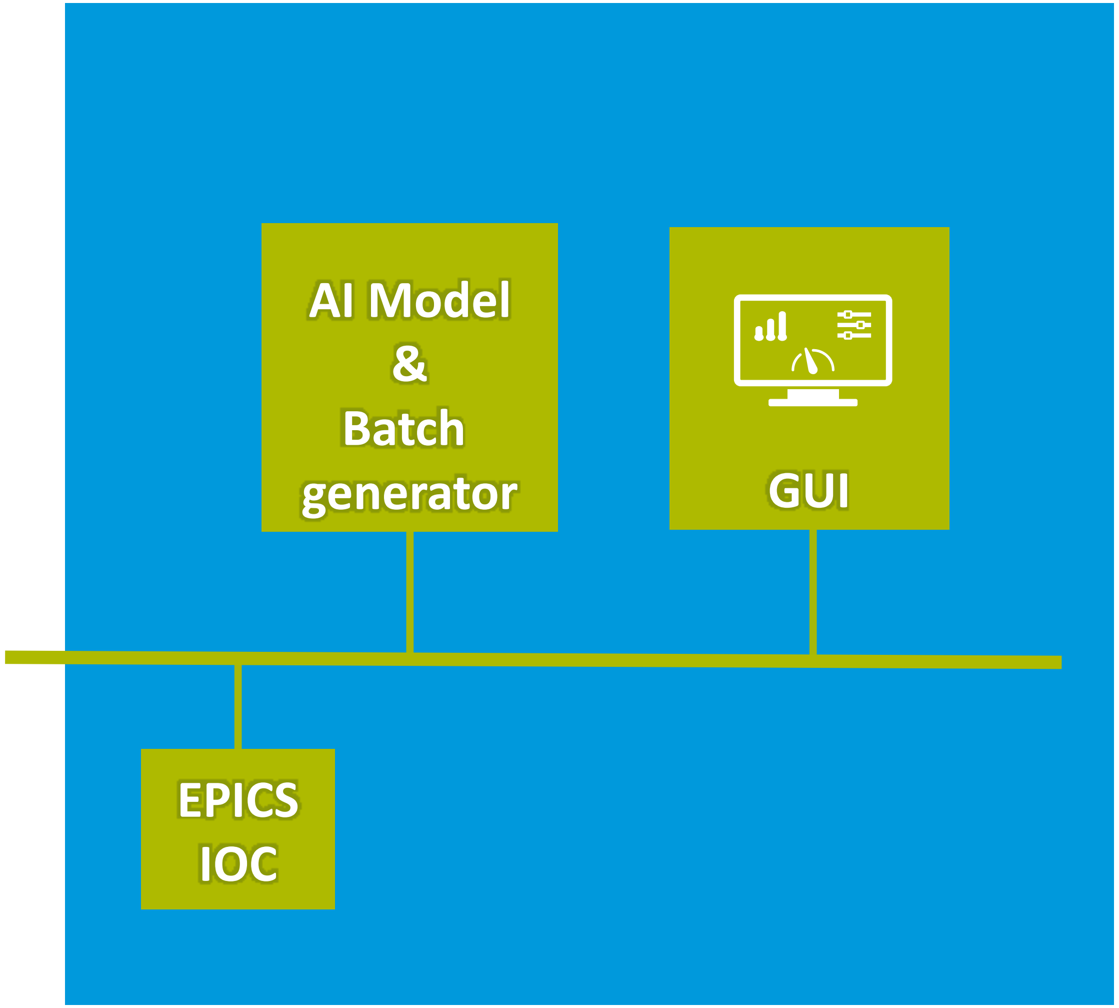
Orange: Alarm limit.

Red: Alarm generated by a machine learning model, which had been trained to alarm during a predefined time interval before interlock.

Outcome:

- LSTM can be used to generate alarms that are more precise in time and with fewer false alarms.
- Integration is straightforward.

Integration and implementation



- EPICS IOC generates the signal
- Batch Generator pre-process the data and package it in a format that can be read by the AI Model.
- Predictions from the trained AI Model, is sent back to the IOC and displayed on GUIs.
- AI Models written in Python, using Tensorflow and Keras and integrated with EPICS using PyEPICS.
- Next steps:
  - Do the predictions in the EPICS IOC.
  - Combine GUI , AI Model and batch generator into a twin.

Next Project: Control racks

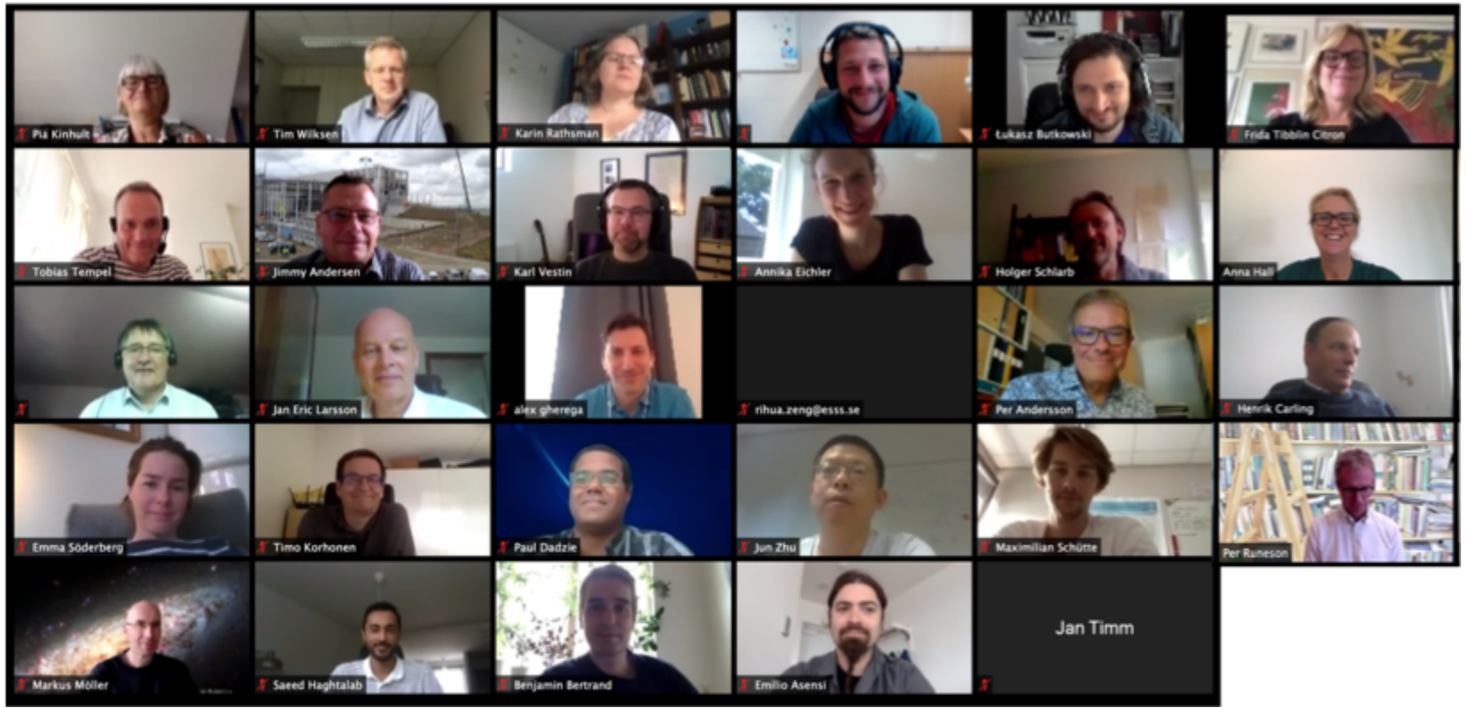
With focus on implementation

Internal ESS project

ESS DESY Intelligent Control System Workshop

September 2, 2020

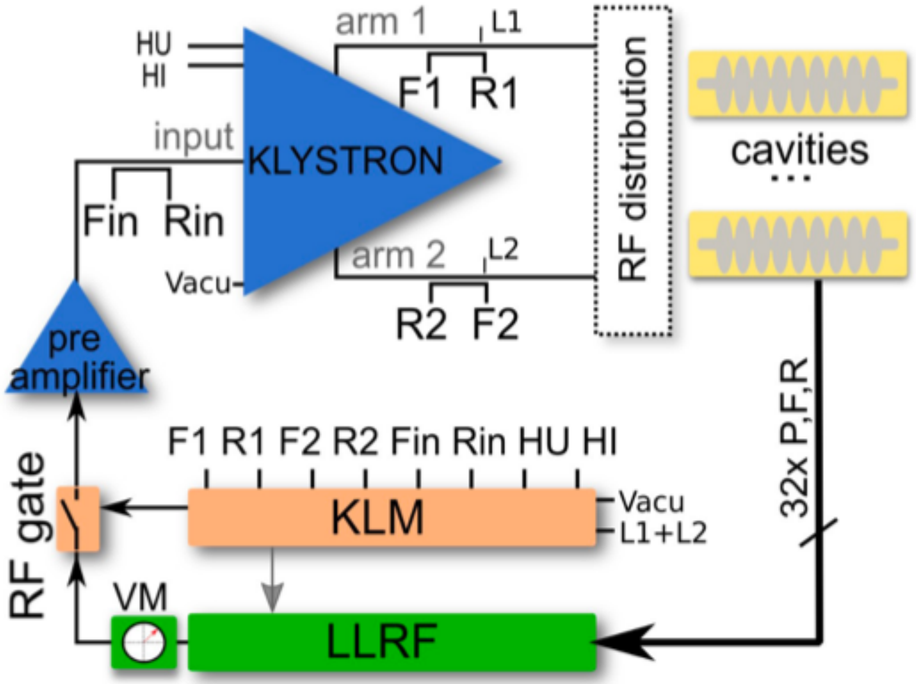
- Focused on failure detection and protection
- Match making sessions on
  - Data
  - Alarms
  - Klystron Protection
  - Quench Detection
- Outcome: Collaboration agreement with short plans and long term visions for the future.

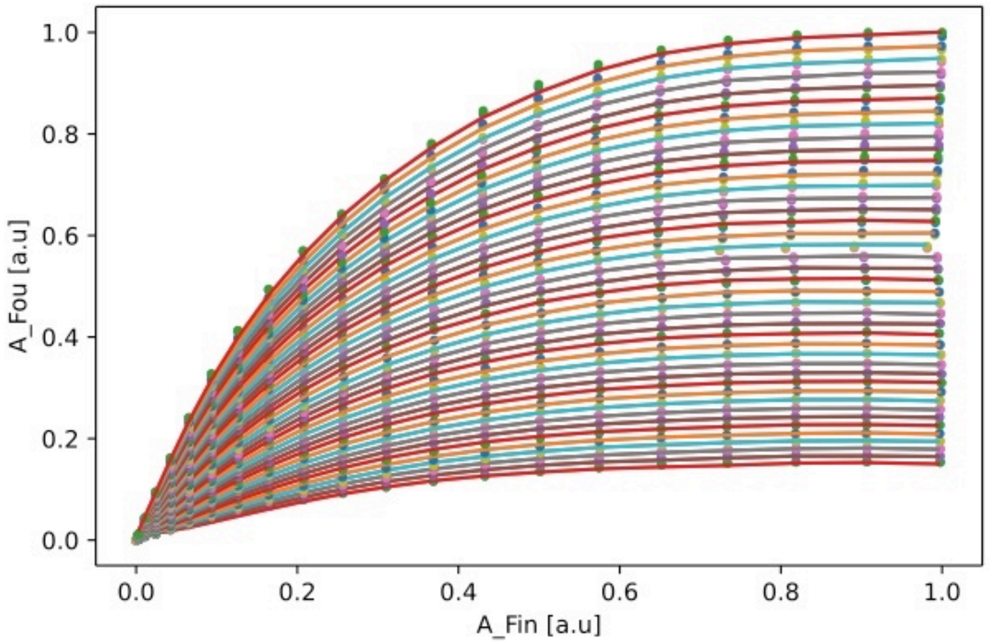


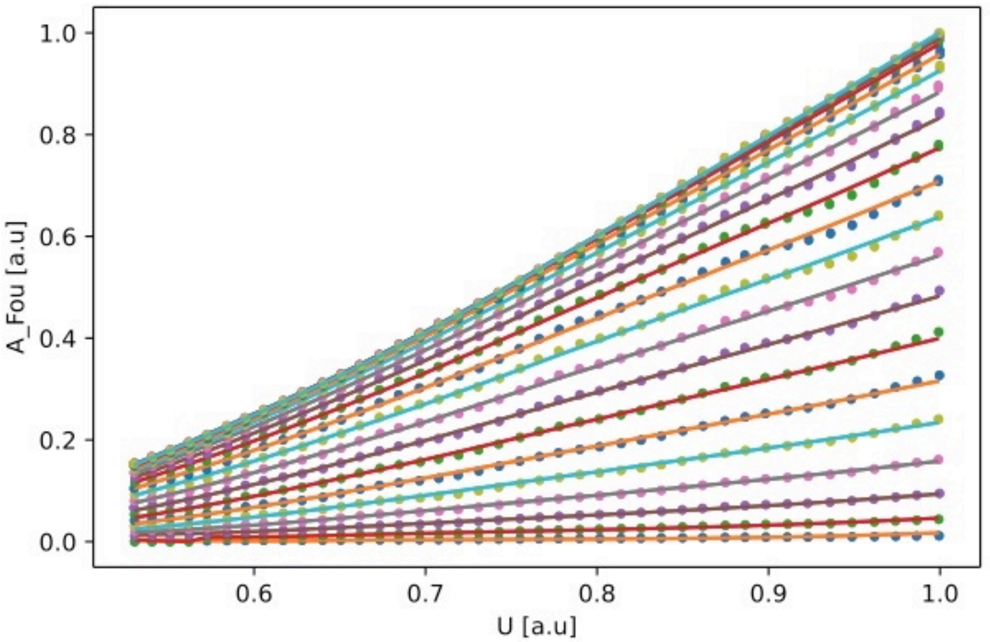
Calibration

Continuation from the ESS DESY workshop

- Klystron Lifetime Management system
- Expensive and critical system
- Collaboration with DESY

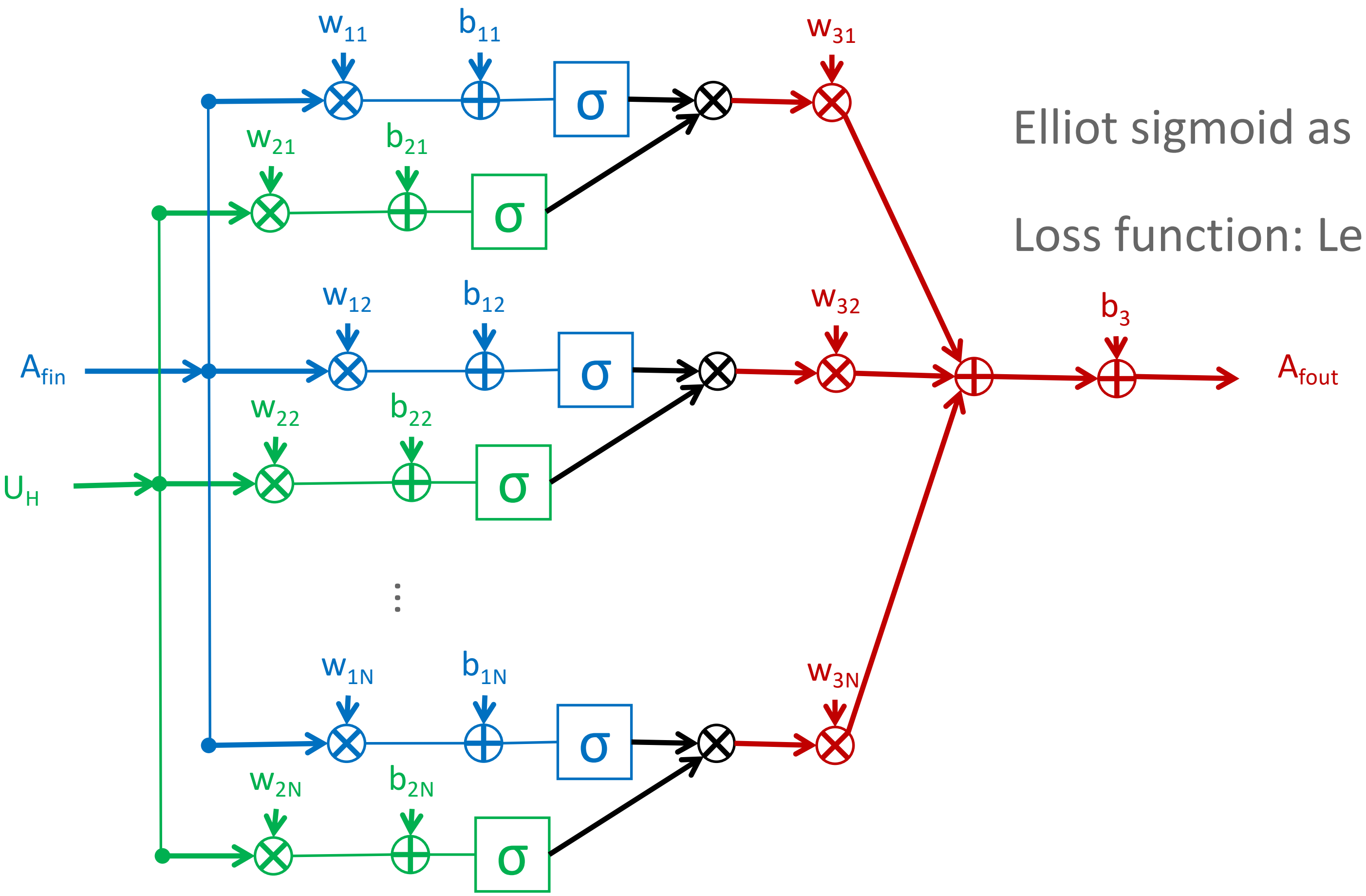






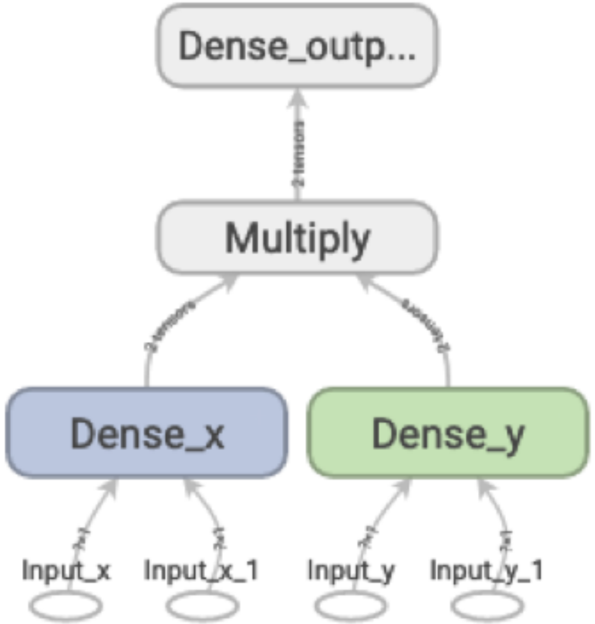
Model

Shallow! A simple model is easier to implement on a FPGA than a complex one.
Next step: Try regression splining.



Elliot sigmoid as activation function: $\sigma(x) = \frac{x}{1+|x|}$

Loss function: Least square err



Next Project: Causality Studies for root cause analysis

Dec 2021-Dec 2023

58 M. Lucke et al. / Journal of Process Control 79 (2019) 56–71

Table 1
Approaches to alarm data analysis.

		Alarm rationalization		Online operator support				Root cause analysis
		Alarm similarity analysis	AF similarity analysis	AF template extraction	Online AF classification	Alarm prediction	Dynamic alarm suppression	Alarm-based RCA
Time series analysis	ACT binary series	[13,14,6]						[15]
	Binary series	[13,16,17]			[4]			[5]
	Multi-valued series							[18]
	Continuous-valued series	[19,14]						
Sequence mining	Set		[20,7]	[9]	[9]		[21]	
	Sequence		[20,7,22]	[8]	[8]	[10,23]		
	Time-stamped sequence	[24]	[3,25,26]	[27]	[28]			
	RTN time-stamped sequence				[29]		[11]	

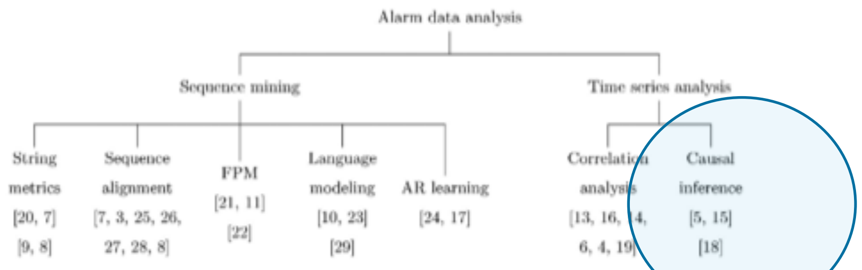


Fig. 1. Family tree of methods for alarm data analysis.

- Collaboration with Automatic Control at Lund University
- Postdoc funded by DFF-International Postdoctoral Grant (grant 0164-00023B) from Independent Research Fund Denmark
- Very interesting topic in machine learning in general.
- Very interesting for alarm management
- Can also be applied to failure detection (quench detection DESY).

Thank You!