One year into the Control System Machine Learning Project

Karin Rathsman

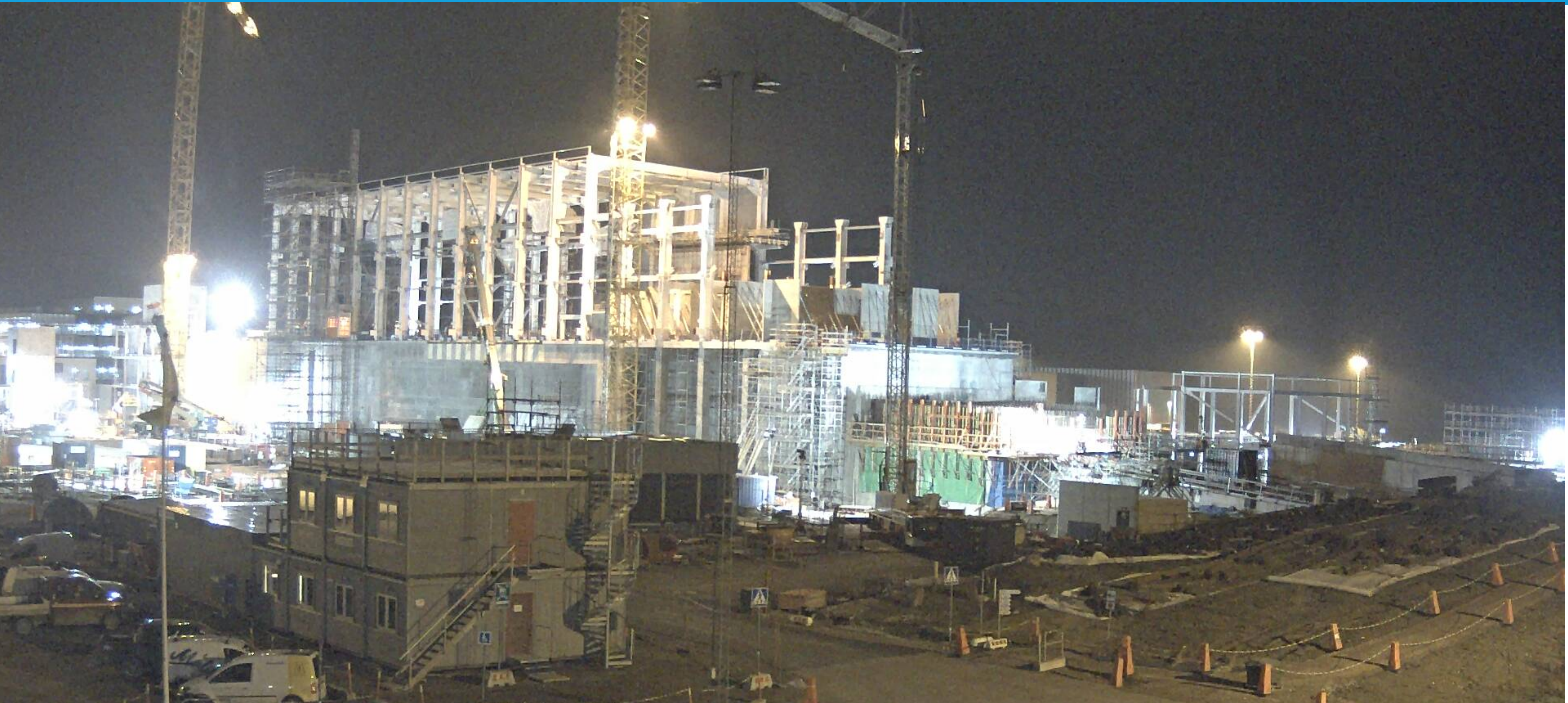
Integrated Control System Division
European Spallation Source ERIC

ESS Mission

Design, build, and operate the world's leading research facility using neutrons in Lund

November 2019

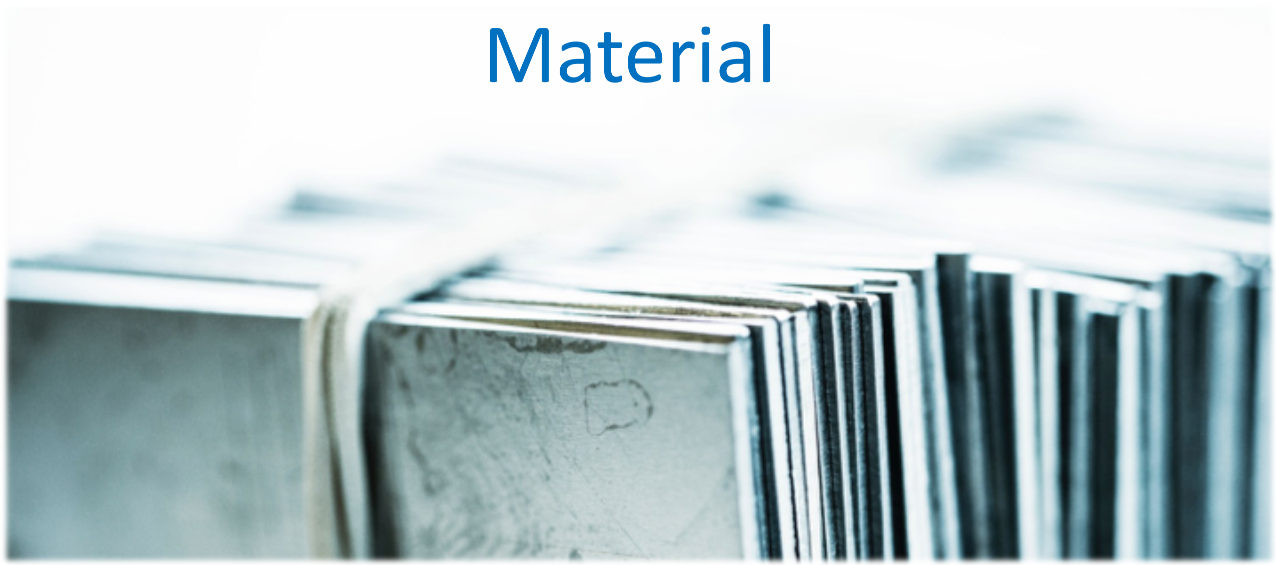
EUROPEAN SPALLATION SOURCE



Why neutrons?

- Probe structure and motion
- High penetration
- A precise tool
- High sensitivity and selectivity
- Probe for magnetism
- A probe of fundamental properties

Applications



European Collaboration

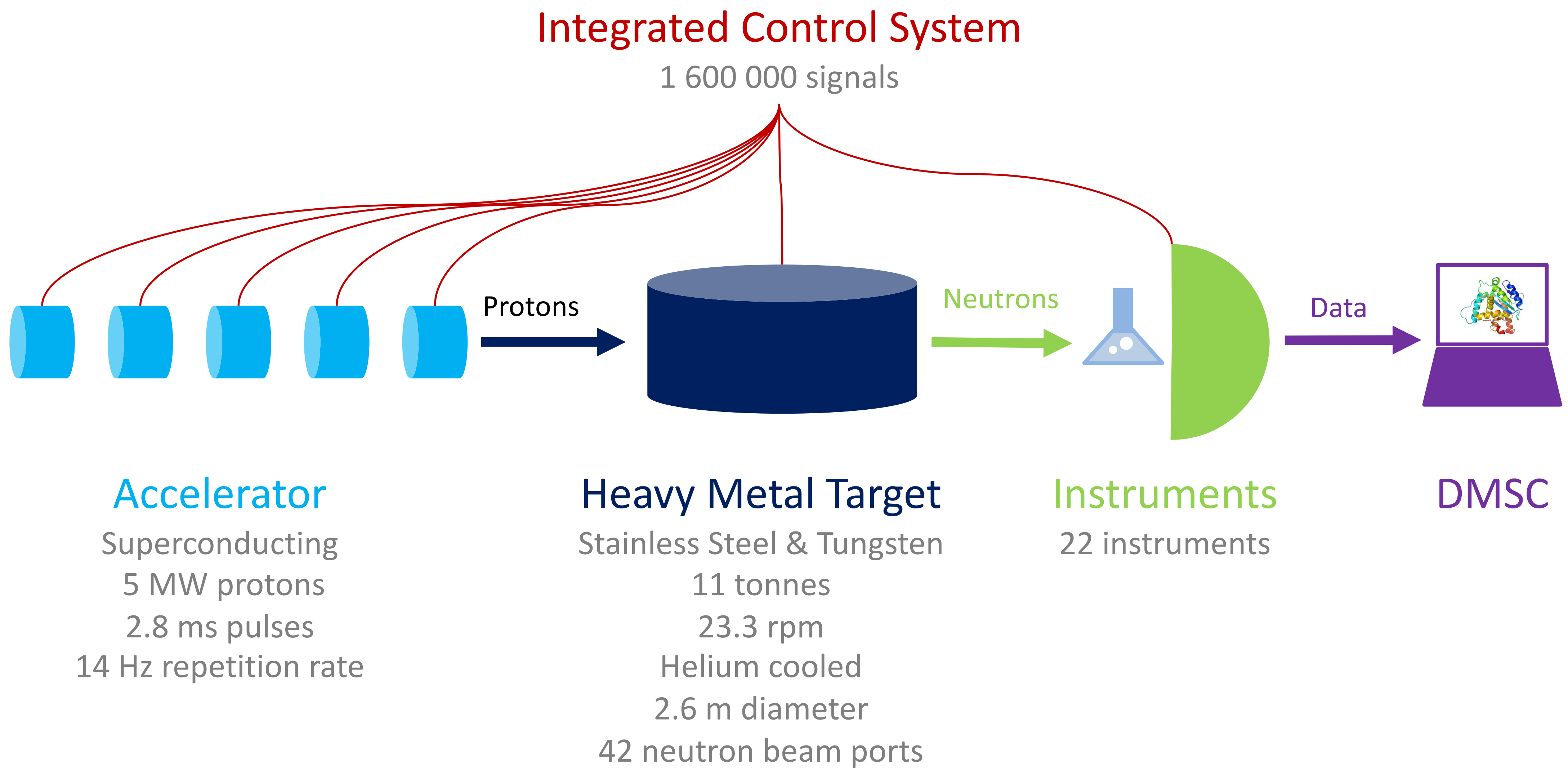
- Total project cost €1,843$_{M2013}$
- Host Countries Sweden and Denmark
  - Construction 47.5%
  - Cash Investment ~ 97%
- Non Host Member Countries
  - Construction 52.5%
  - In-kind Deliverables ~ 70%

People

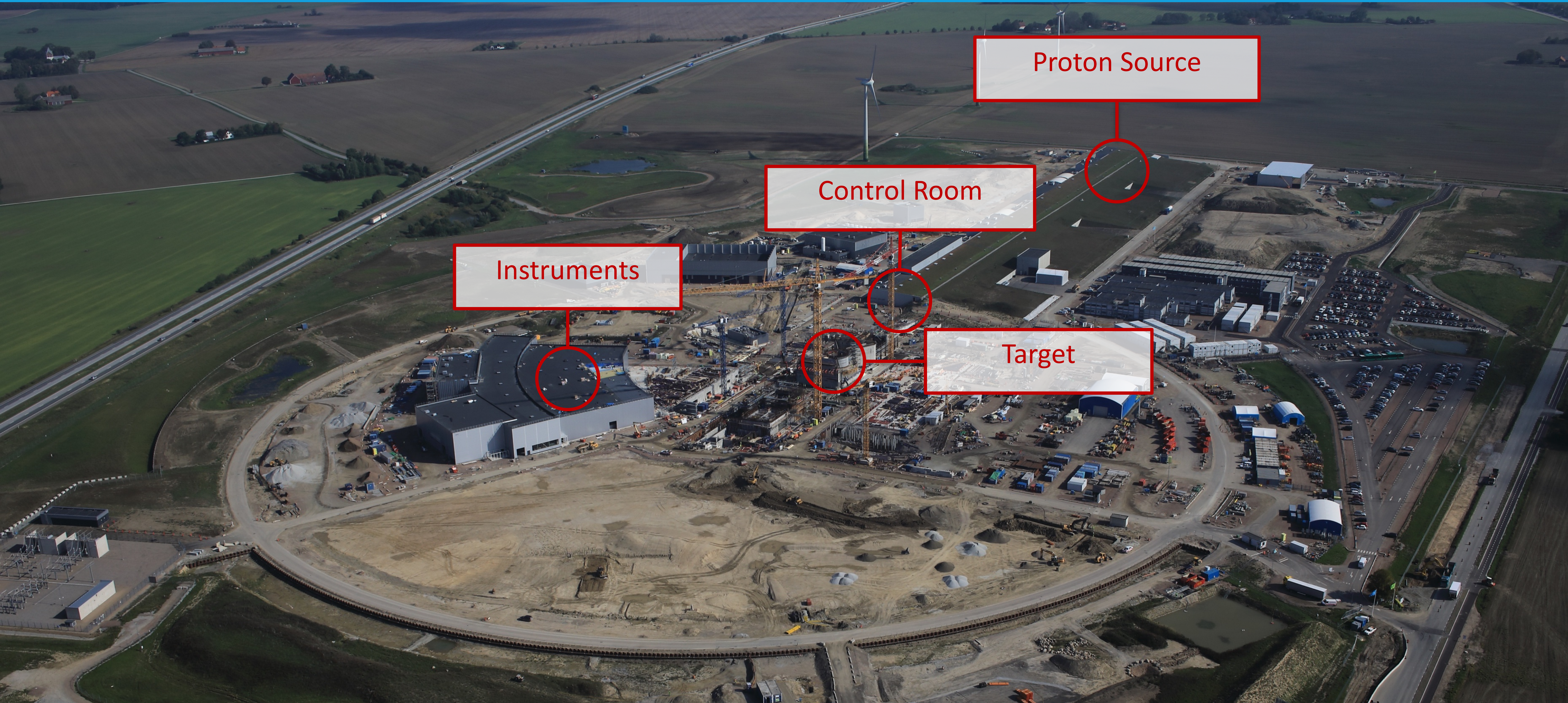
EUROPEAN SPALLATION SOURCE

- 481 Employees
- 53 Nationalities
- >100 Collaborating Institutions

How Spallation Works

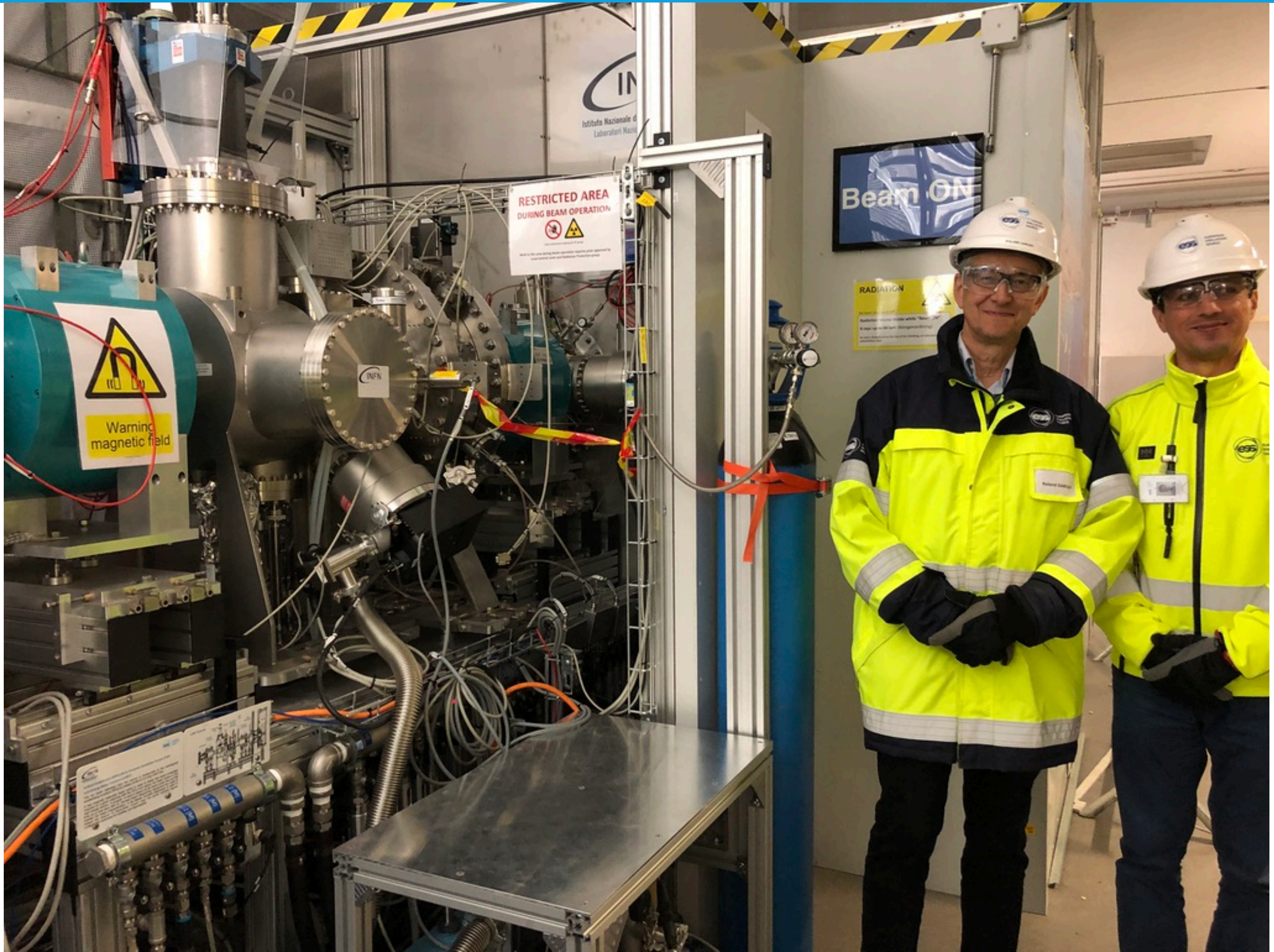


Site September 2018



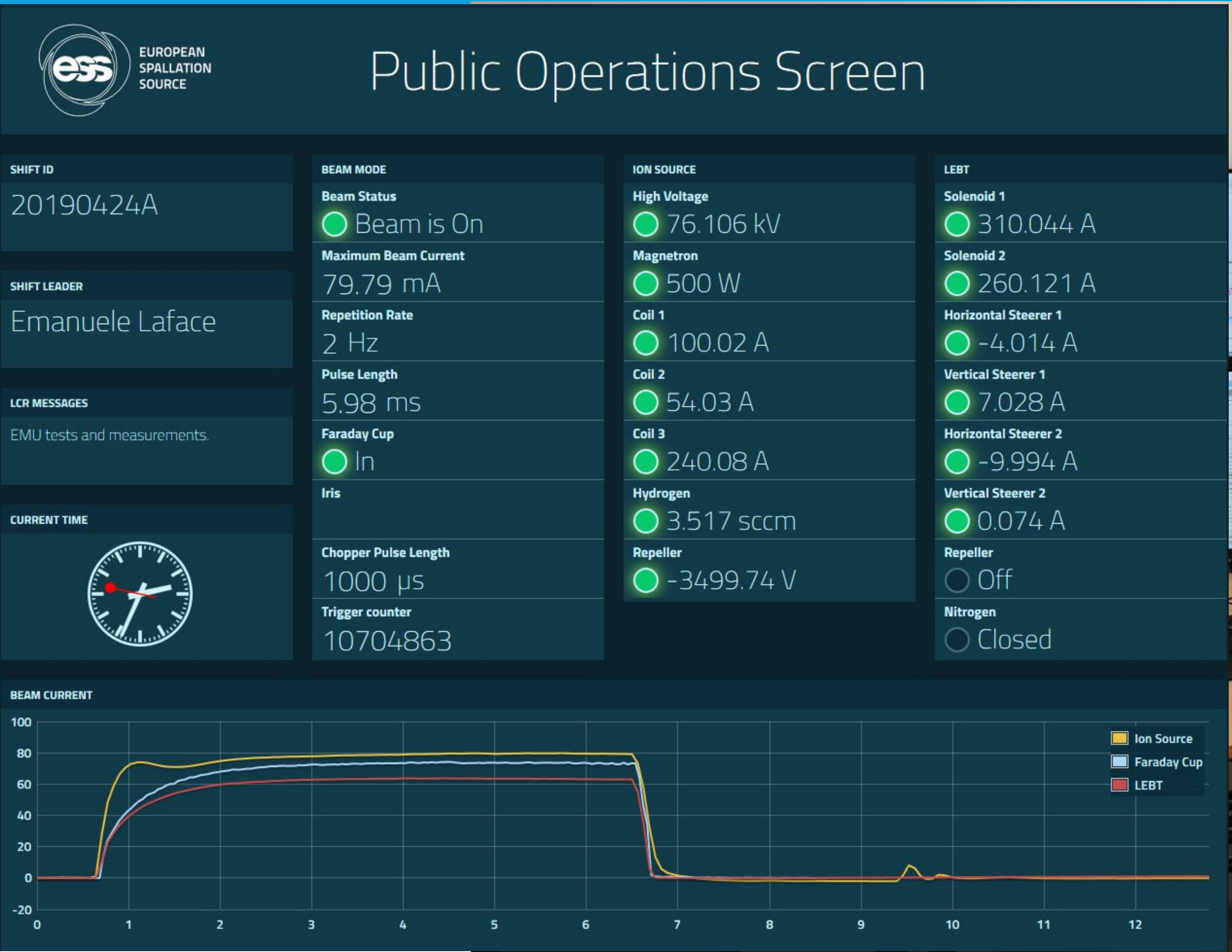
The Proton Source

In the accelerator tunnel



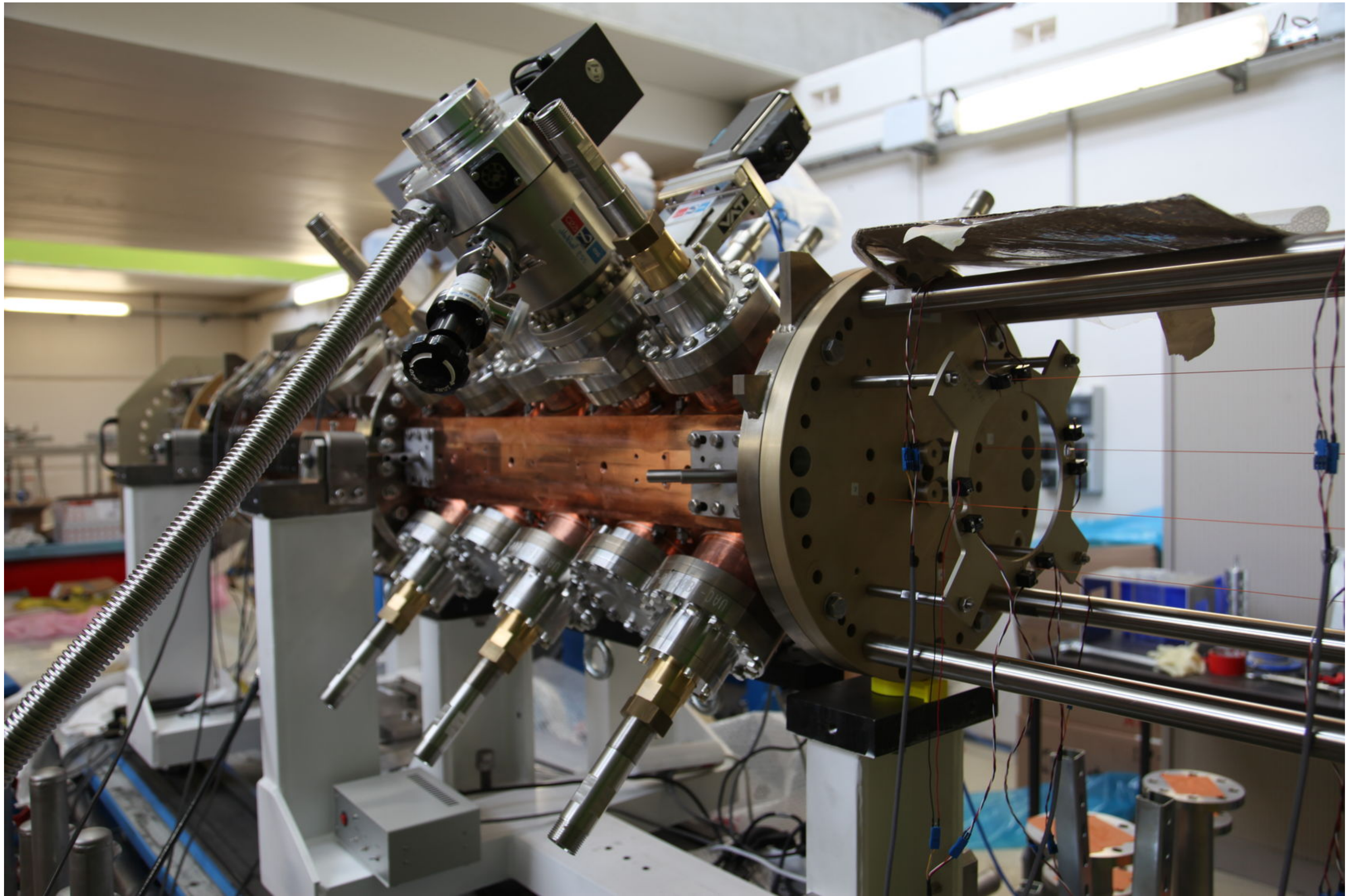
Beam Is On!

https://pos.esss.lu.se/

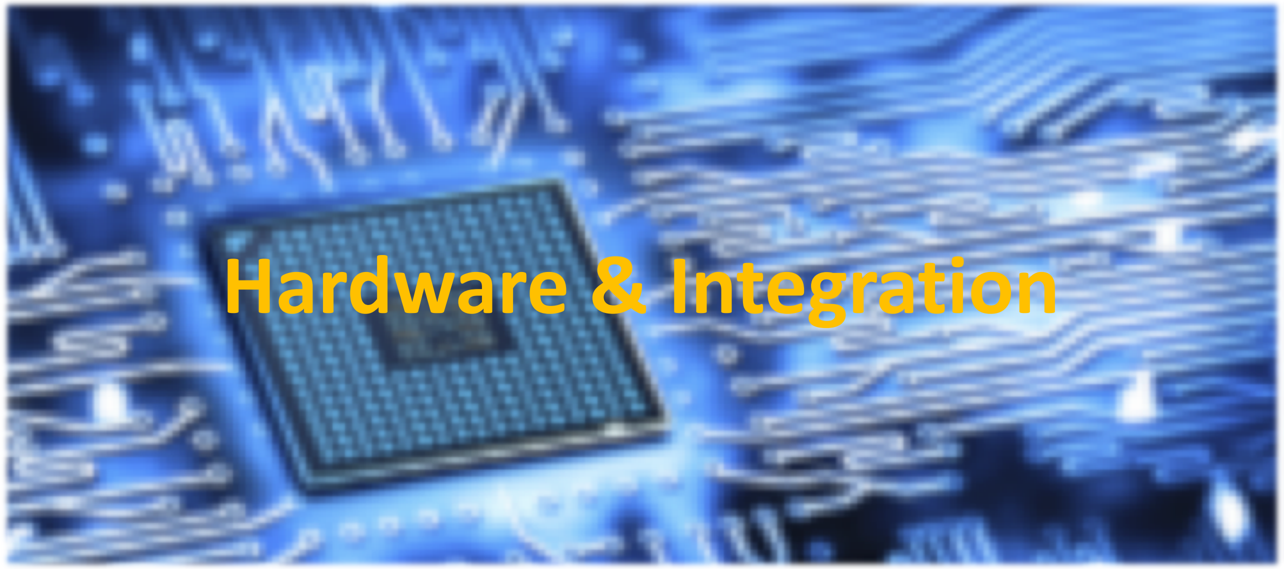


RFQ installation

EUROPEAN SPALLATION SOURCE

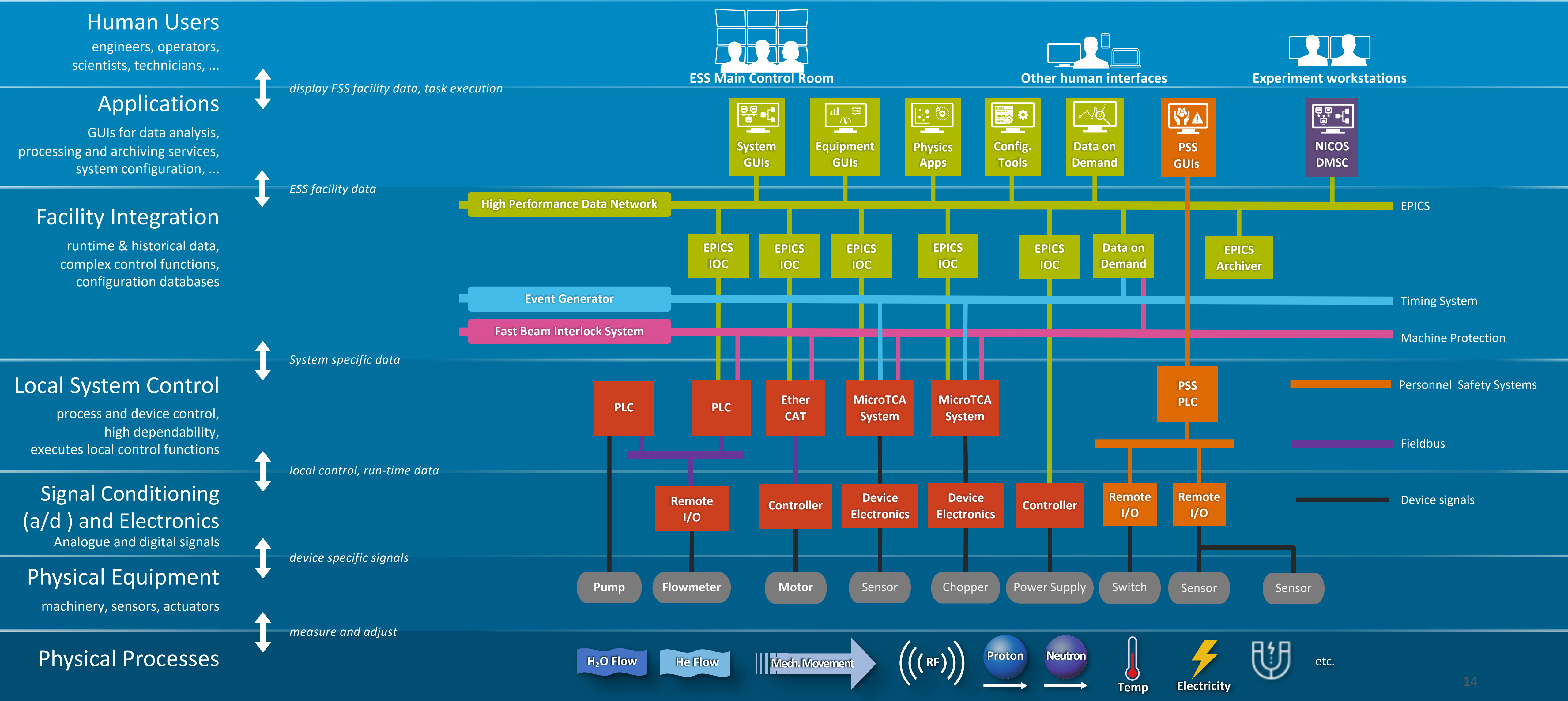


Integrated Control System Division



Layer Architecture of the ESS Control System

EUROPEAN SPALLATION SOURCE



Challenges

- The ESS machine is very complex
  - Accelerator – based facilities are the worlds most complex systems
  - Large variety of systems, both advanced and non-advanced.
  - About 1 600 000 control signals.
- ESS is a user facility with a 95% availability goal
  - High availability requirements on equipment
- The control system plays a key role for the availability of the facility

Control System Machine Learning Project

We want to explore if artificial intelligence can be applied to the control system in order to

- Increase facility availability
- Increase efficiency of operation
- Improve human/machine interaction
- Lower operational and maintenance costs
- Decrease commissioning time and effort

In a Nutshell…

…the integrated control system is the brain of the ESS Machine.

ESS/ICS is ideal for ML & AI research

- Research facility
- Build on scientific collaborations
- Skilled staff
- Belongs to a rich community of research facilities
- Has a large variety of systems to control
- Complexity
- Open data, open software, open mindset
- Will have lots of data for training and validation
- Takes an active part in the EPICS development.

Benefits for society

- Industrial plants, emergency rooms, dairies, aeroplanes and other systems are becoming more complex as more sensors, controllers and software are implemented.
- Traditional industry will within the near future encounter the same issues as advanced system such as ESS have today.
- AI, in particular ML, has the potential to address key problems, relating to environmental impact, energy efficiency, traceability and accident avoidance.
- As the number of control points grow and the time window from process malfunction to required, correct remedial action shrinks the burden on human operators will exceed their capabilities unless proper support is provided.

Systems

- Acceleration
- Beam Instrumentation
- Beam Intercepting Devices
- Beam Optics
- Controls
- Conventional Power
- Cryogenics
- Heating, Ventilation and Air Conditioning
- Ion Source Specialties
- Machine Protection
- Mechanics
- Motion Control
- Network
- Neutron Chopper
- Oxygen Deficiency Hazard
- Operations
- Personnel Safety
- Power Convertors
- Radiation Monitoring
- RF
- Sample Environment
- Target Safety
- Timing
- Vacuum
- Water Cooling

Early Spinoff from ESS

”This initiative now shows that we can already see the possibilities and harvest the benefits of the investment in ESS - we don’t need to wait for scientific results”

Leif Ericsson

Swedish Research Council

AI workshop Big Science Sweden and ESS in August 2018

CSML 4 year project scope

EUROPEAN SPALLATION SOURCE

- Create a research collaboration between ESS, industry and universities to develop AI/ML 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/ML is feasible
- Select framework and software platform and integrate with EPICS
- Create a portfolio of project proposals

Benefits

CSML 4 year project scope

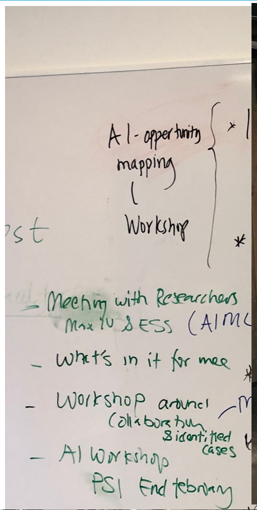
- Build up AI competence within ESS and industry
- Host interesting applied AI research topics for master and Ph.D. students and their supervisors
- Make applications work in an industrial environment
- Extend collaborations between university, ESS, and industry

Resources

CSML 4 year project scope

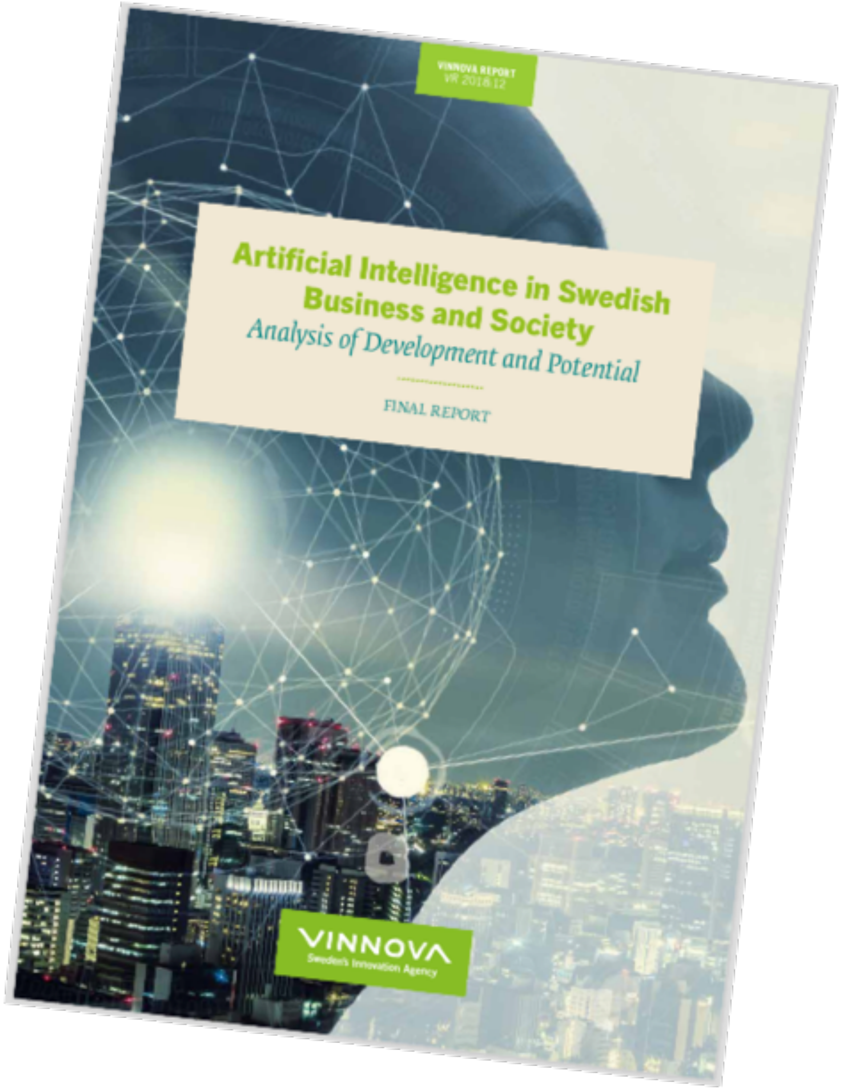
- 100% Me 2019-2023
  - Good start given that ESS is in a very constraint and busy construction phase. AI will become important in the next phase.
  - Lots of interests from other colleagues.
  - Other initiatives at ESS have already started that are not part of this project
- External Collaboration and funds

First Stakeholder’s Meeting



Collaboration

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



Project proposal portfolio

Under construction

1. Data Lab (Proposal written)
2. Intelligent Alarm Handling (Proposal written)
3. Hardware Architecture for Machine Learning in Large Real-time Systems (first ideas)
4. Software Development Ecosystem for Machine Learning (first ideas)
5. Optimisation of Machine Performance with Machine Learning (first ideas)
6. Validation and verification (TBD)
7. Benefits of Machine Learning and other AI methods in the ESS control system.
8. Education (TBD)
9. Transient Beam Loading Based Method for Online Beam phase measurement (first ideas, as case study)

1. Data Lab for AI
Motivation

- In all ML projects, it is critical to have access to large amounts of well-organized data to feed the learning process.
  - The ESS control systems will generate at least an order of magnitude larger volumes of control system and automation related data than typical existing, large industries.
  - This rich mix of data will range from typical industrial process control systems to state-of-the-art control and data acquisition systems.
- It is well known that data is the oil in machine learning. We would also like to emphasise that data is the lubricant in the collaboration.
  - Work on the same problems using the same data.

1. Data for AI

Data Sharing and Quality

- Develop Licence and explore Open Collaborative Data (OCD) in respect to
  - technical infrastructure,
  - licence models for data,
  - governance models,
  - privacy.
- Investigate means to reduce the data set and to optimize it for machine learning.
- Study how to share large volumes of structured data, with both low maintenance and investment costs.
- Share problem formulations packaged together with sets of data that we would like to apply machine learning on.

1. Data Lab for AI

Benefits

- Community of Accelerator-based research facilities
  - Work on the same problems using the same data.
  - Enhance development of common standards for annotating and sharing data.
- University:
  - Access to real, high quality data for research and education in machine learning.
  - Ideal for the planed masters program “Machine Learning, Systems and Control” at Lund University.
- Industry
  - Develop and test new algorithms. Cross-check and benchmark results.
  - Learn machine learning on relevant data and problems.

2. Intelligent Alarm Handling

Motivation

- Alarms are important for process-understanding, availability, reliability and maintainability.
  - Critical alarm (e.g. security and safety emergency alarms) are handled by separate safety and protection systems and are not included in this scope.
- ESS has an established alarm philosophy that form the basic strategies to mitigate alarm problems.
  - This is the basis for alarm management to mitigate alarm problem.
- Advanced alarm suppression techniques will be important in order to meet the required availability and reliability goals.

2. Intelligent Alarm Handling
Common alarm problems

- Many alarms are simply unnecessary
  – System owners tend to define alarm that are relevant to them, but are not necessary relevant for operators.
- Some alarms are missing
  – Missing sensors or forgotten
- Many alarms have badly tuned parameters
  – Correct limits not known during the design.
- Some alarms has a higher priority than others.
  – Need a faster response or has a higher criticality.
- Many alarms are only relevant in certain operational states
  – Appears as irrelevant alarms in other situations.
- A fault often leads to several consequences
  – Causes alarm cascades.

2. Intelligent Alarm Handling

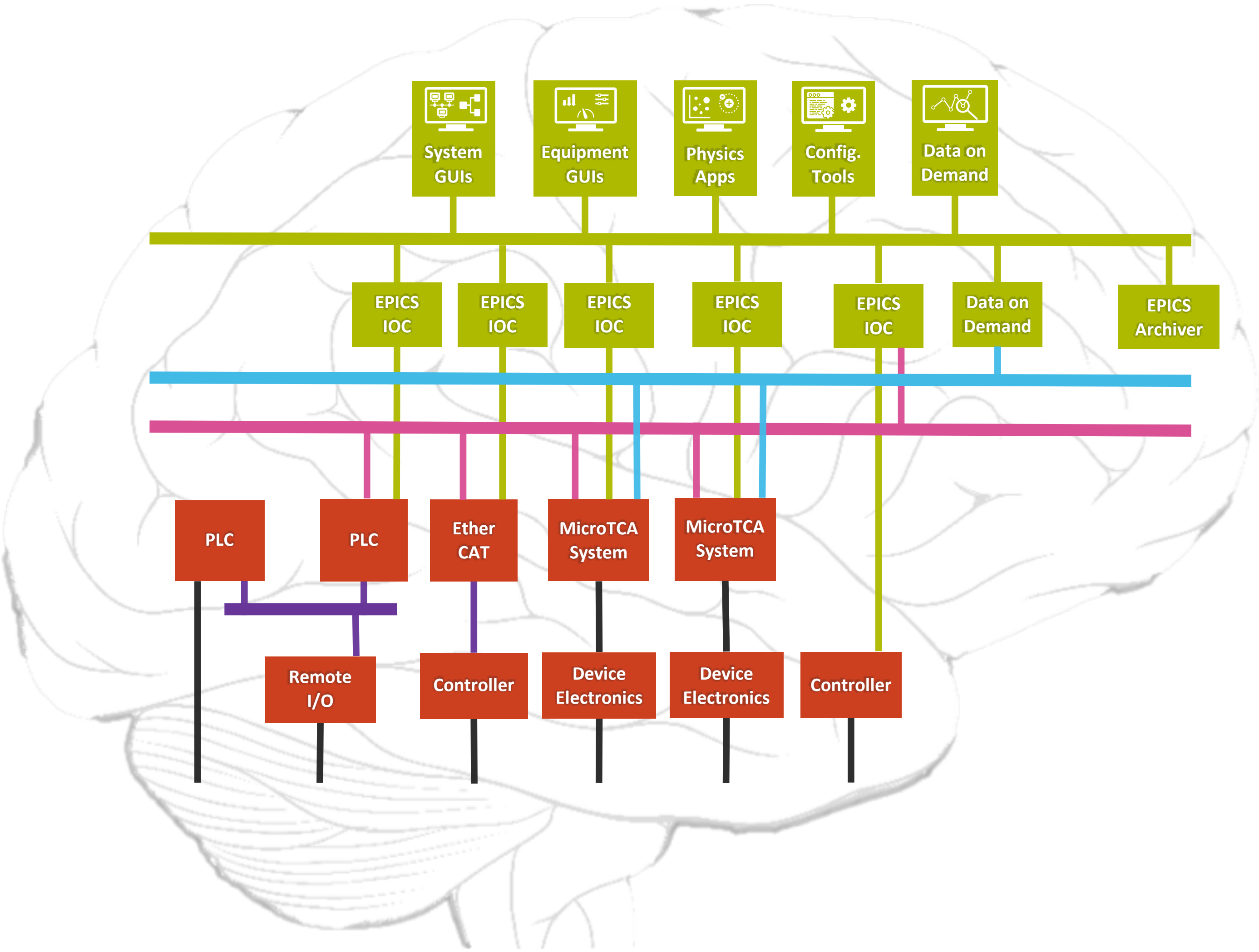
Scope

Develop new methods for alarm management, based on AI and ML technologies to

- Identify unnecessary alarms
- Adjust alarm limits
- Classify alarms according to state.
  - Suppress alarms that can be predicted by the operational state or mode.
- Classify alarms according to root cause.
  - Supress alarms that are consequences of other alarms.

3. Hardware Architecture for ML in Large Real-time Systems

Question



- Where are the intelligent agents?
  - In the cloud?
  - In the software applications?
  - In the EPICS IOC?
  - In the electronic circuits?
- How to decide where to deploy them?
  - Maintainability,
  - Speed,
  - Power,
  - Latency
  - Communication bandwidth
- How to do this in practice?
  - In particular machine learning on high performance micro TCA
  - Co-optimization between ML algorithm and hardware.

4. Software Development Ecosystem for Machine Learning

Motivation

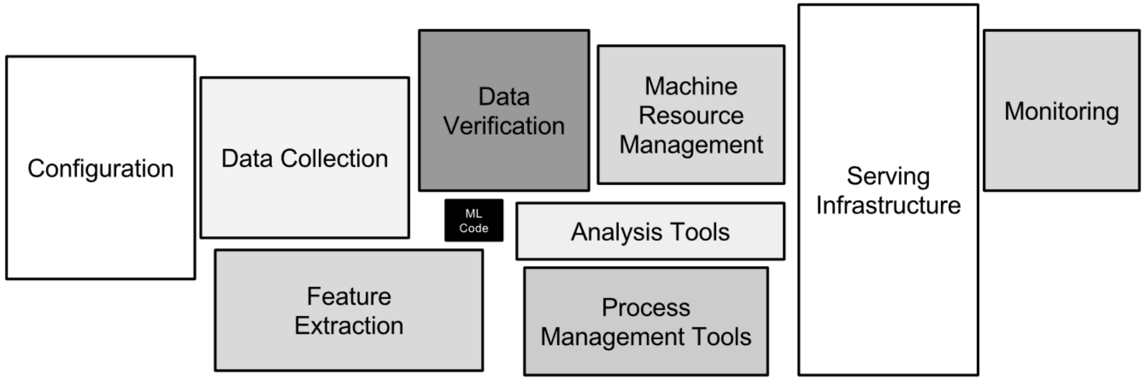
- Accelerators are continuously being developed, upgraded and maintained.
- Applied intelligent agents (IA) therefore needs to be updated from time to time.
- To keep a large number of applied IA in a highly complex facility up to date will require structure, processes and tools.
- Intelligent agents will be developed by many teams in the organisation. We therefore need a common mindset (philosophy), platform and tools to keep track of them.

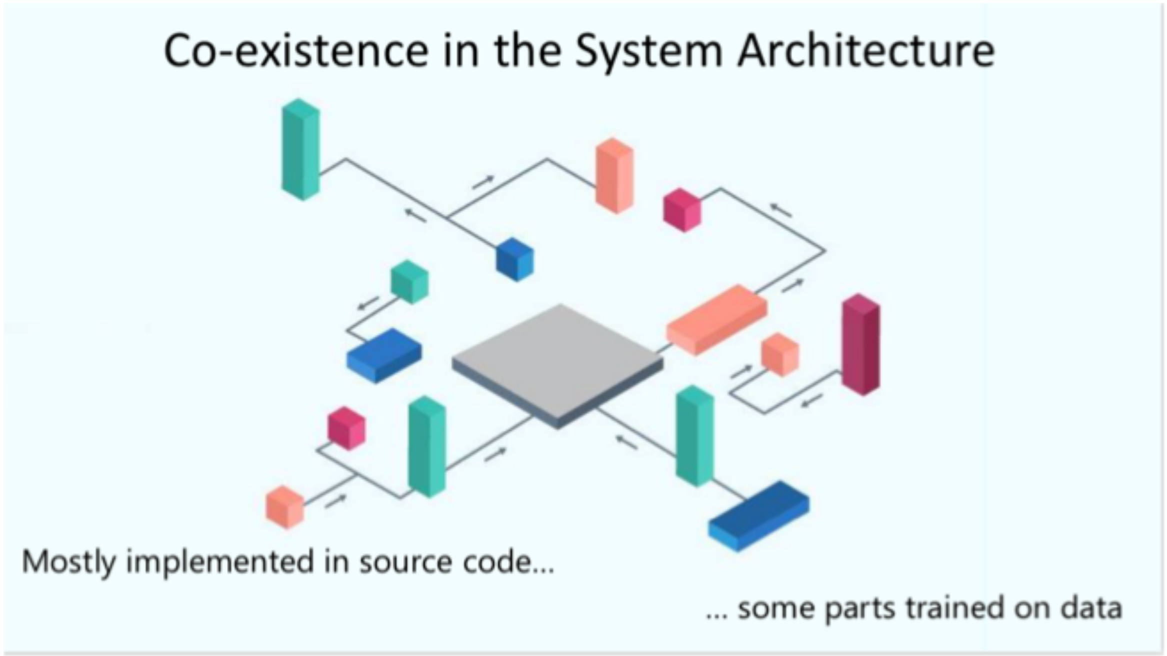
Workshop at Lund University in June

4. Software Development Ecosystem for Machine Learning

Questions

- How much of this infrastructure do we already have?
- Do we need additional infrastructure?
- How to combine models based on machine learning with theoretical models that are implemented in source code and specific for ESS?
- Are there existing standards industry we can implement or do we need to investigate the wheel for the first time?





5. Optimisation of Machine Performance with Machine Learning
Motivation

- Changes in the environment can have large impact on performance. Examples:
  - Mechanical deviations
  - Cable length changes as a consequence of temperature variations.
  - Other metrological changes
  - Disturbances in power distribution
  - Calibration
- To start up a large accelerator after down time takes time.
  - Despite theoretical models, well calibrated devices and a high degree of systems engineering applied, the reality is more complex than any model can predict.
  - In the end you spend lots of time adjusting many parameters randomly. With many different devices and far many more parameters this can be very tedious.

Thank You!

Contact: karin.rathsman@esss.se

EUROPEAN
SPALLATION
SOURCE