# Preliminary Design Review of the Fast Beam Interlock System

Introduction

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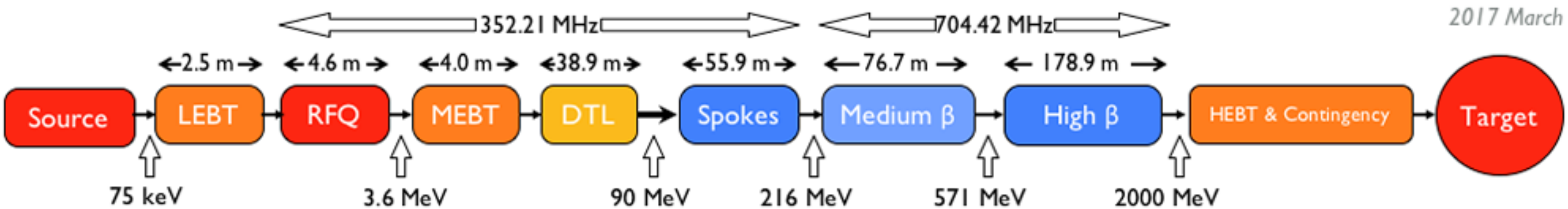
# A BIG WELCOME AND

# THANK YOU FOR ATTENDING THIS REVIEW

# Overview of This Talk

- European Spallation Source, ESS: LINAC, Target and Neutron Instruments
- Damage Potential of ESS Proton Beam
- Machine Protection at ESS
- ESS Fast Beam Interlock System
- Goal of this review

# ESS LINAC




**ESS will be a Neutron Factory!**

Max. average beam power: **5 MW**

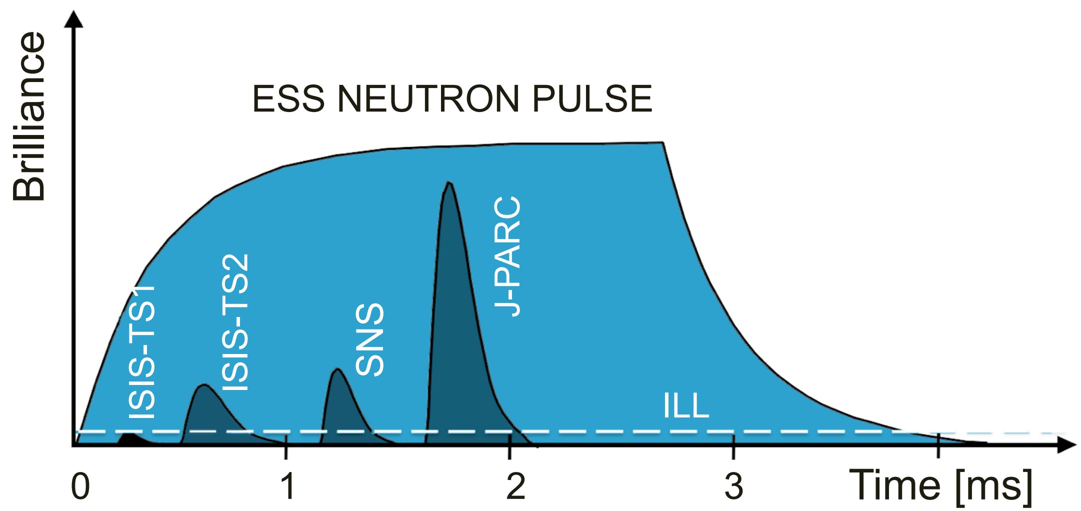
Peak power per pulse: **125 MW**

Average beam current: **62.5 mA**

Max. repetition rate: **14 Hz**

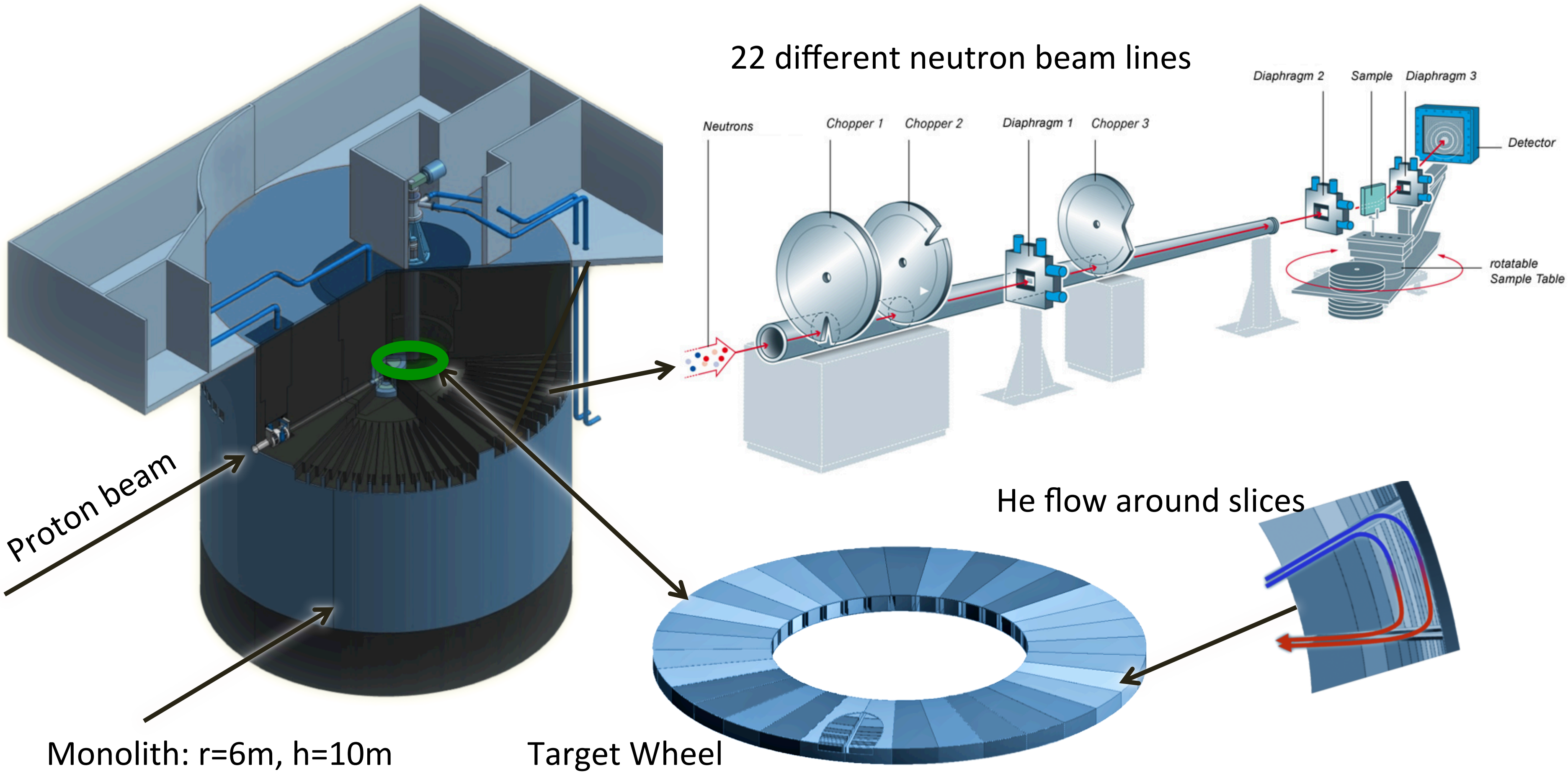
Max. pulse length: **2.86 ms**

Max. proton energy: **2 GeV**



# ESS Target and Neutron Instruments

Rotating tungsten wheel, synchronized to 14 Hz, Helium cooled




Courtesy of ESS Target Division

# Scope of Machine Protection at ESS

**In accordance with** beam and facility related **availability requirements**, Machine Protection (**MP**) **needs to reliably**:

- **protect** the "machine" **from damage**, be it beam-induced or resulting from other sources,
- **protect** the "machine" **from unnecessary beam-induced activation**.

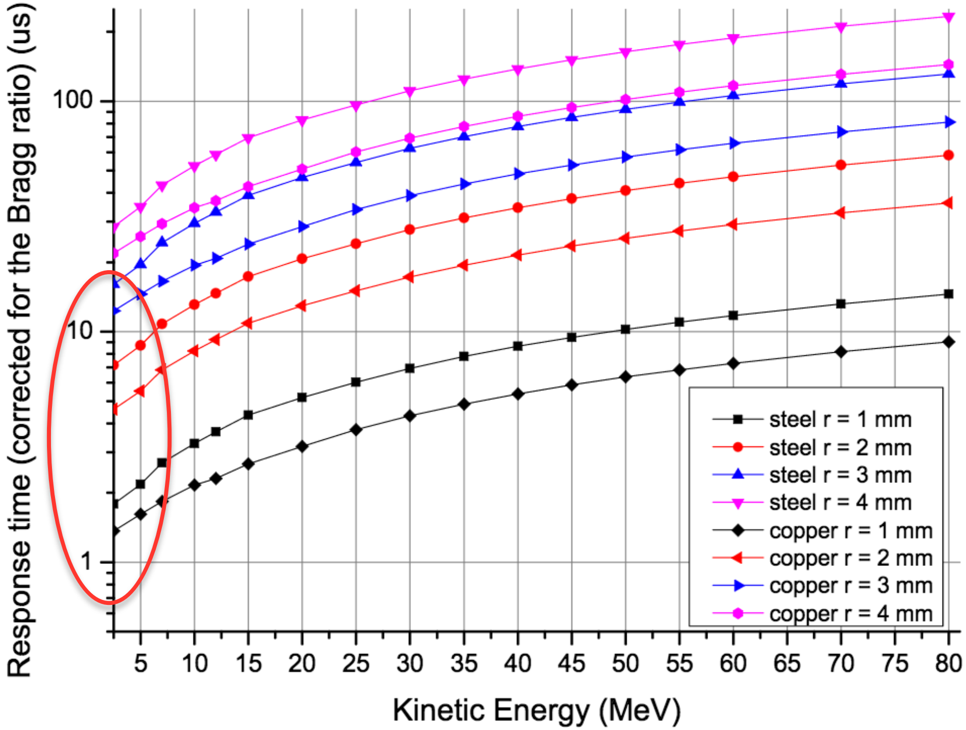
The "**machine**" encompasses the **LINAC**, the **target** station and the **22 neutron instruments**.

Machine protection will be implemented in a way to:

- **minimize** unnecessary downtime due to **spurious trips**,
- provide optimal **support** for **failure localization**,
- **support** all **operational modes** of the facility,
- **avoid wrong configuration** of equipment,
- **support** operation in **degraded mode.**

# Time Needed to Melt Copper or Steel

Assuming perpendicular beam impact, and 1 - 2 mm beam size at 1 MeV, then **melting would start in 1 - 7 μs**!




Courtesy of L. Tchelidze, ESS

**But can it really happen and how?**

# Worst Case Scenarios

More detailed simulations have shown that perpendicular beam impact is possible in the MEBT scrapers.

And the same simulations show that the **fastest possible melting times** are in the order of **5 µs.**

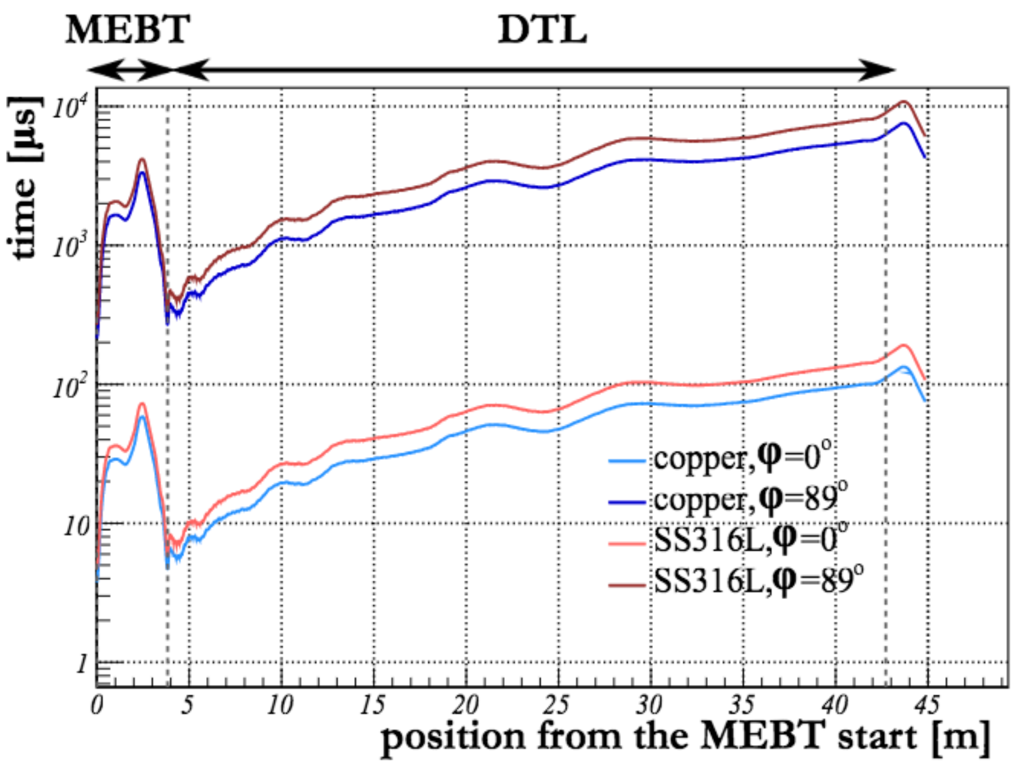



Figure 3: Time to melt a block of copper (blue) or stainless steel (red) under constant irradiation with a proton beam under perpendicular incidence ($\varphi$=0°) or a very shallow angle.

Courtesy of I. Kittelmann/ HB2016 THAM6Y01

# ESS Proton Beam: Damage Potential

Assumptions based on **worst case** scenarios.

Source — LEBT — RFQ — MEBT — DTL — Spokes — Medium ß — High ß — HEBT → Target

| | LEBT, RFQ | MEBT, DTL | Spokes | Medium ß, High ß, HEBT |
|---|---|---|---|---|
| Beam Energy in [MeV] | 1 - 3.6 | 3.6 - 90 | 90 - 216 | 216 - 2000 |
| Melting Time in [μs] | 10 - 20 | 20 - 200 | 200 - 400 | >400 |
| Beam Stop Time in [μs] | 4 - 5 | 5 - 20 | 20 - 40 | >40 |

**Fastest reaction time** required to stop proton beam is **a few μs** (within the first 50m).

This includes detecting, processing and actual stopping of the proton beam.

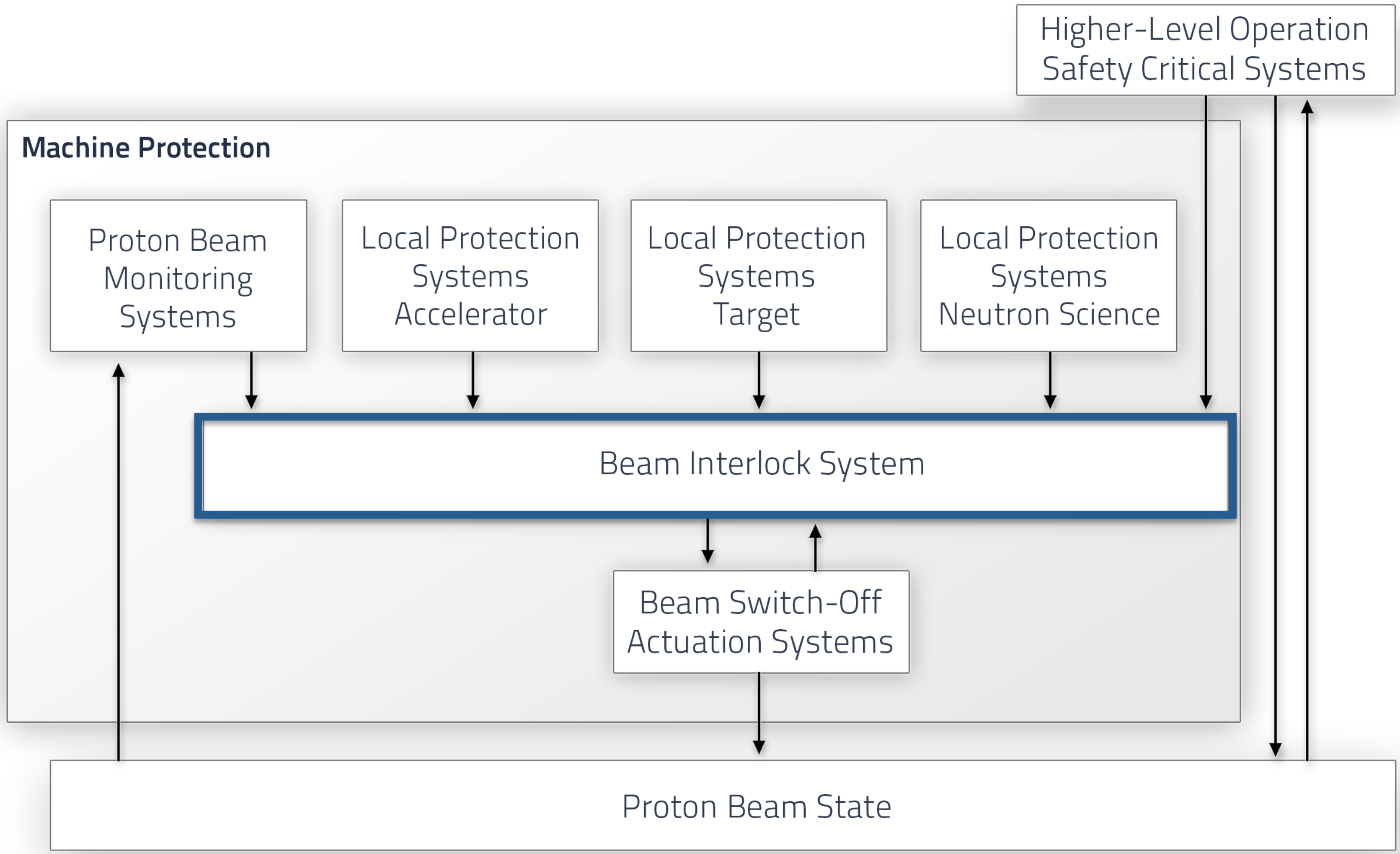
# Experience from SNS/USA

**Equipment operating at high voltage**, like cavities, can be very **sensitive to beam losses** leading to surface quality degradation. Then operation at the same voltage is not possible and probability for arcing increases.

At SNS, errant beam losses in the order of a μs, lead to degraded performance of a superconducting cavity; even a whole **cryo-module had to be exchanged** to fix the problem, causing long downtime.

The energy of **beam losses** in that case is about **100 J**. The damage mechanisms are not fully understood; it is assumed that some beam hitting the cavity desorbs gas or particulates (= small particles) creating an environment for arcing.

# Functional MP-SoS Architecture Concept at ESS

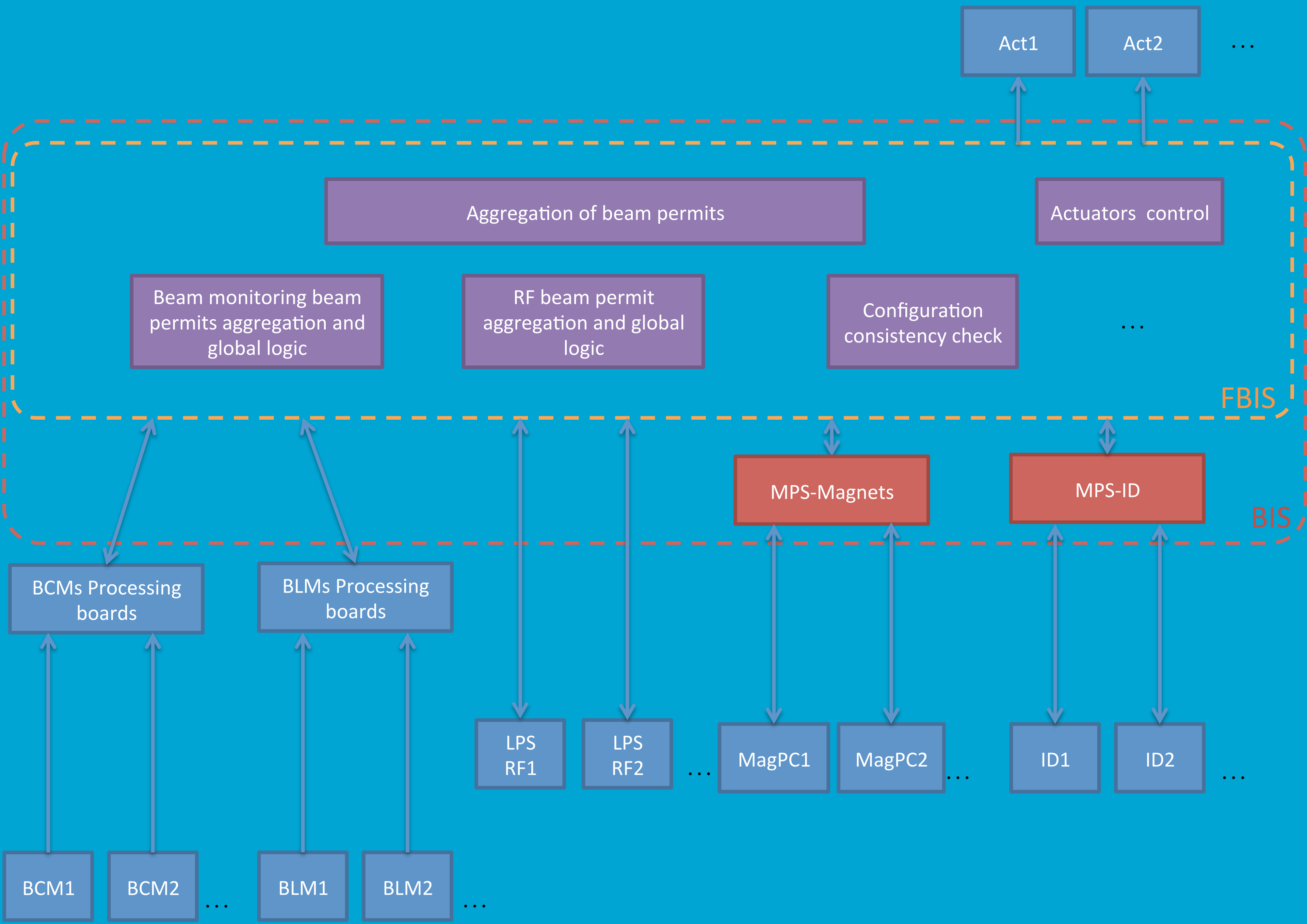


# Functional Concept of the Beam Interlock System

We have defined the **Beam Interlock System (BIS)** to be the **set** of **MP-related Logic systems**. The BIS evaluates all beam permit signals and controls MP-related actuation systems.

**MP-related Logic Systems** evaluate information collected from **MP-related Sensor Systems**. Based on the current operational context of the **Machine**, they control the MP-related Actuation Systems to achieve and maintain a **Protected State**.

The **Fast Beam Interlock System (FBIS)** is the **final** link between the MP-related actuation systems and the other MP-related systems.


Act1
Act2
...
Aggregation of beam permits
Actuators control
Beam monitoring beam permits aggregation and global logic
RF beam permit aggregation and global logic
Configuration consistency check
...
FBIS
MPS-Magnets
MPS-ID
BIS
BCMs Processing boards
BLMs Processing boards
LPS RF1
LPS RF2
...
MagPC1
MagPC2
...
ID1
ID2
...
BCM1
BCM2
...
BLM1
BLM2
...

# In-Kind Contract Between ESS and ZHAW

MEMORANDUM OF UNDERSTANDING

for

Funding of Swiss In-Kind Contributions

between

THE EUROPEAN SPALLATION SOURCE ERIC

and

THE SWISS CONFEDERATION,

REPRESENTED BY THE SWISS STATE SECRETARIAT FOR EDUCATION, RESEARCH AND INNOVATION SERI

European Spallation Source ERIC

Date 2017-02-06

W. J. W

Name (in block letters)
John Womersley

Position
Director General

State Secretariat for Education Research and Innovation SERI

Date 2017-02-06

Mauro Dell'Ambrogio

State Secretary

**Technical Annex** signed in 2015-12

**MoU** ESS-CH signed in 2017-02

**First payment** ESS to ZHAW in 2017-07

**Total value of this IKC**: 2.7 ME

**Value** for **FBIS** contribution: 1.8 ME

# What Does ZHAW Deliver to ESS for the FBIS?

**1) FBIS prototype and engineering documentation documentation set:**

- Prototype
- Functional Safety Management Plan
- System Requirements Specification
- System Architecture Specification
- Verification and Validation Plan
- Verification and Validation Specification
- Verification and Validation Report
- Functional Safety Verification and Validation Report
- Component Requirements Specification
- Component Design Description
- Component Verification and Validation Specifications
- Component Verification and Validation Reports
- Component Functional Safety Analysis Reports

**2) FBIS hardware modules according to FBIS Architecture Specification (PIL2)**

**3) FBIS Verification and Validation System**

- FBIS Verification and Validation System Technical Documentation Set
- Complete FBIS Verification and Validation System including
  - Generic Verification and Validation Hardware Platform
  - FBIS Component specific Test Adapter Hardware
  - Software Implementation and FBIS Component Test Scenario Configuration

# What Does ESS Deliver to ZHAW for the FBIS? How Do We Work Together?

**ESS MP Team focuses on:**

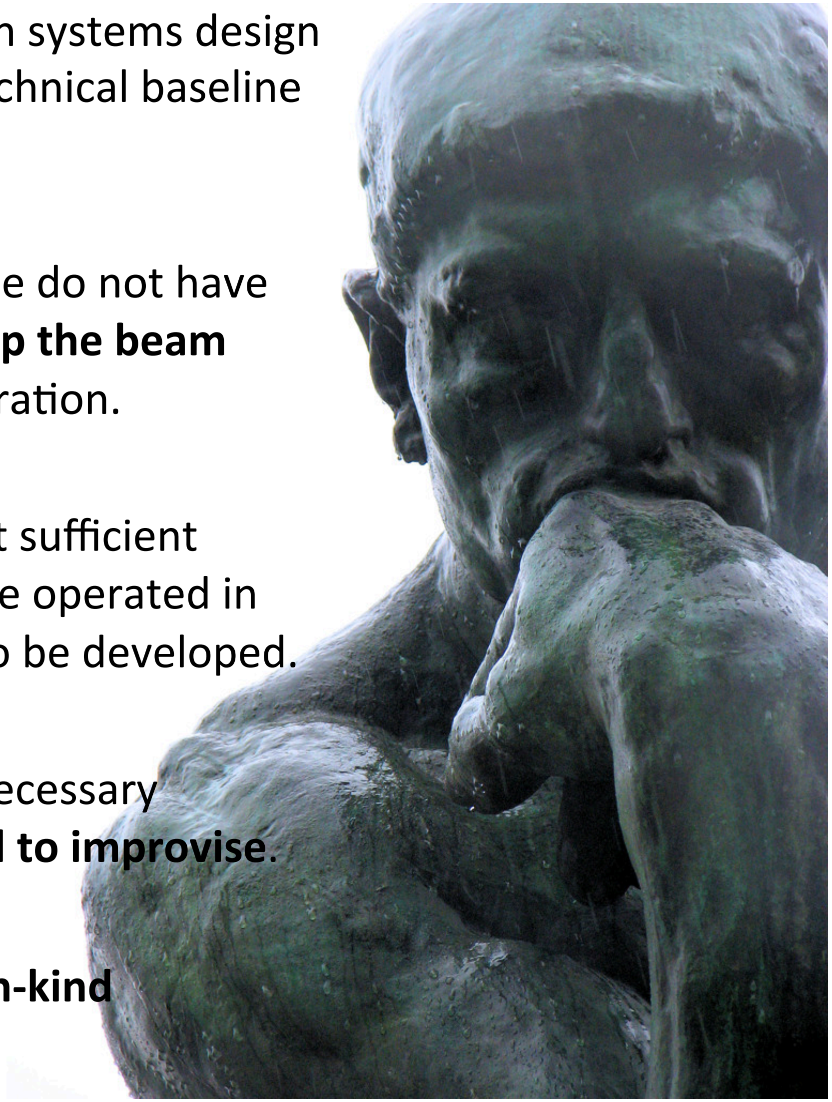
- MP and RAMI **Analyses** of all systems in LINAC, target in neutron instruments, resulting in base-lined protection functions. These functions are also checked by the ZHAW team.

- **Collecting information** related to the **design**, **specifications**, **concept of operation** of the different systems/equipment in the LINAC and target and how to operate the system/equipment in the context of the whole machine.

- Performing **use case workshops** for MP-related systems to establish **detailed interfaces** and to understand how to orchestrate all the systems in a flexible and efficient way.

- **Studying feasibility** related to implementation capability of protection functions (many times to be done across several systems).

# Complex But Inviting Challenges



- Several times there is **not sufficient information** on systems design available, ESS has not yet established a detailed technical baseline to 100%.
- This is very crucial for e.g. the actuator systems. We do not have sufficient information on **how** (reliably) we can **stop the beam** such that there is a painless recovery of beam operation.
- **No mature operations organization at ESS** and not sufficient information on how the machine should and will be operated in detail. Many times operations procedure are yet to be developed.
- This makes it very difficult for ESS to provide the necessary detailed input to ZHAW and several times we **need to improvise**.
- ESS is built on a **green site and relies to >50% on in-kind** contributions.

# FBIS Preliminary Design Review: Goal

- **Several FBIS architectural design concepts** have been analyzed and are summarized in the architectural design options document.
- **One preferred FBIS architectural design** has been developed further and is to be reviewed during the next 2 days.
- The **goal** is to understand whether this **architecture is likely to fulfill the requirements** and whether the ZHAW team can proceed with the detailed design of the FBIS components and the architecture specification.

# NOTE

Please feel free to **interrupt whenever** you have questions or comments or recommendations!

The **discussions** are very **important** and most **interesting** to us. This is also why we have allocated so much time for that.

**We are looking forward to your feedback and fruitful input!**

# Back Up Slides

# Governance of Machine Protection at ESS

**ESS Machine Protection Committee: Take on responsibility and take decisions**

| | |
|---|---|
| **MPC domain/ responsibilities**:<br><br>(Corresponding to analysis part of IEC61508) | Approval of **concept**, overall **scope,**<br>Coordination of **hazard risk analysis,**<br>Approval of overall **machine protection requirements,**<br>Coordination of machine protection **requirements allocation.** |

| | Operations | Accelerator | Controls | Target | CF | NSS | PSS | TSS |
|---|---|---|---|---|---|---|---|---|
| Stakeholder Requirements | - Requirements on work procedures, checklists, training for personnel<br>- … | - Provide systems suitable for allocated machine protection functions<br>- …. | - Provide systems suitable for allocated machine protection functions, | - Provide systems suitable for machine protection functions, | XY,<br>…… | XY,<br>…… | Provide run permit signal according to MP interface specification | Provide run permit signal according to MP interface specification |
| System Requirements | | - Requirements for Proton Source<br>- Requirements for LEBT chopper<br>- …. | - Beam Interlock System<br>- …. | | | | Specification of signal, cable, connector type | Specification of signal, cable, connector type |

# Group Structure / ESS Team

**Machine Protection and Personnel Safety Systems Group**
Annika Nordt: Group Leader, WPM (2012-05)
Denis Paulic: Deputy Group Leader (2017-03)

**Machine Protection ICS/WP14.5:**
**Manuel** Zaera-Sanz (Lead Engineer Slow Interlocks: 2014-08)
**Enric** Bargallo (Lead Analyst for Dependability and MP: 2017-04)
**Szandra** Kövecses (Lead Integrator for MP: 2017-05)
**Ella** Hjertberg (Summer Student: 2017-06)
**Riccard** Andersson (Technical Project Coordinator: 2017-08)
**Stephane** Gabourin (Lead Engineer Fast Interlocks: 2017-08)
**Viktor** Fred (Lead Engineer for El. Installations: 2017-09)
**David** Sanchez Valdepenas (Automation Engineer: 2017-10)

**Vacancies:**
1 Technician

**Personnel Safety Systems ICS/WP14.9:**
**Stuart** Birch (Senior PSS Engineer, WPM: 2014-08)
**Denis** Paulic (PLC IEC61508 Engineer, DGL: 2015-03)
**Morteza** Mansouri (Engineer for Safety Critical Systems: 2015-05)
**Yong Kian** Sin (IEC 61508 Electrical Controls Engineer: 2016-02)
**Alberto** Toral (Technician: 2017-03)
**Manorma** Kumar (Consultant/Senior Analyst: 2017-06)
**Mattias** Eriksson (Technician: 2017-11)

**Vacancies:**
1 Technician

**Goal**: Build a flexible and strong team, sharing & extending the different skill sets,
Everyone has knowledge relevant for both MP and PSS!
Both WPs build systems according to IEC61508.

# European Spallation Source/Timelines

- First proton beam operation (Ion Source + LEBT): 2018-02
- Warm LINAC commissioning start: 2018-09
- Beam on tuning dump: 2019-02
- Beam on target: 2019-12
- Start instrument commissioning: 2021
- User access for science: 2023
- Decommissioning: 2065