Deployment and Management of Mechanical Engineering Services at the European Spallation Source ESS

https://indico.cern.ch/event/1259184/

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www.europeanspallationsource.se

Agenda

1 Introduction to ESS

2 Mechanical Design

3 Requirements & Engineering Workflow

4 Simulation, FEA & Engineering Analysis

5 Mechanical Measurements Lab (MML)

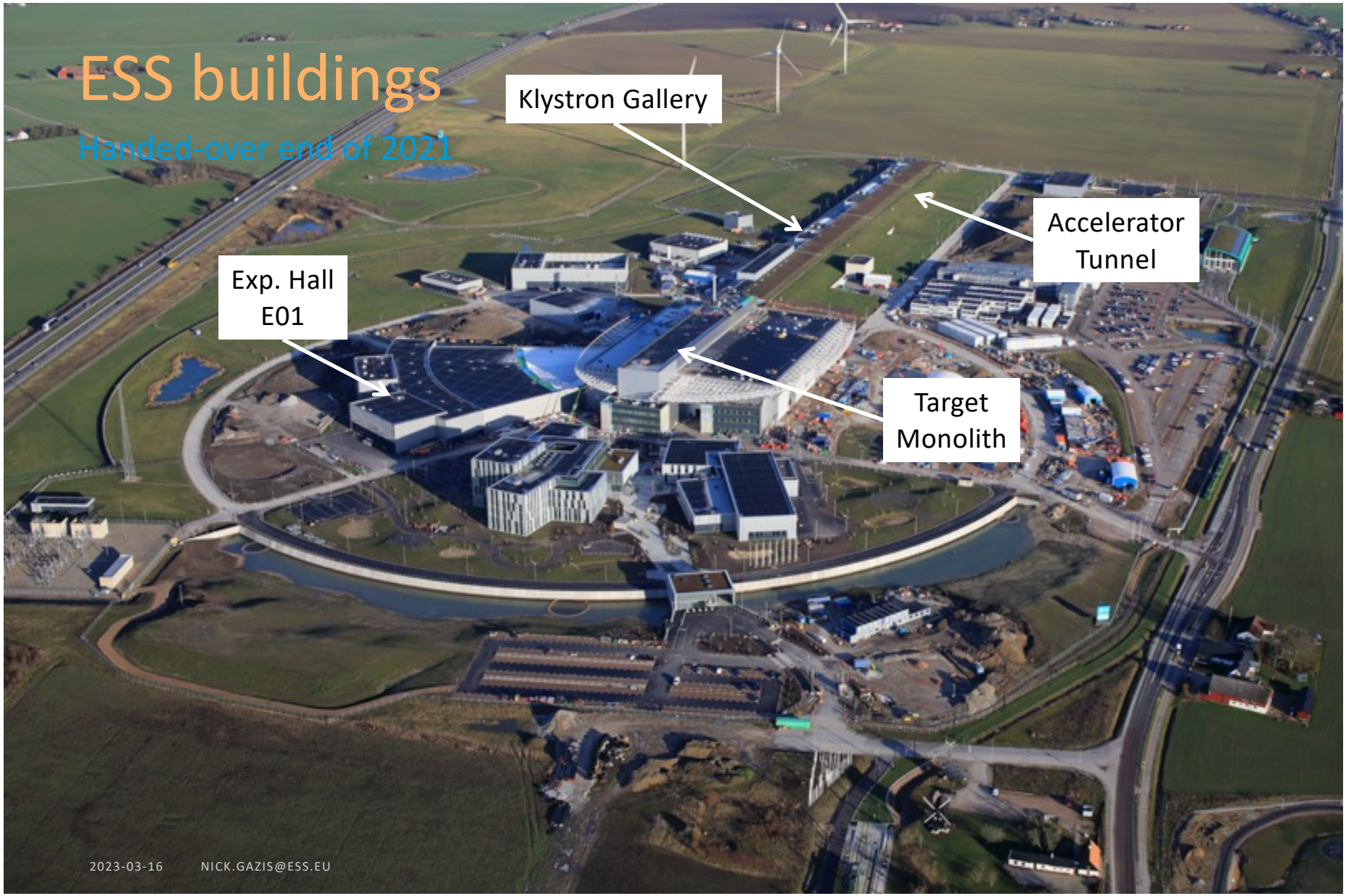
6 Future upgrades & Summary

1

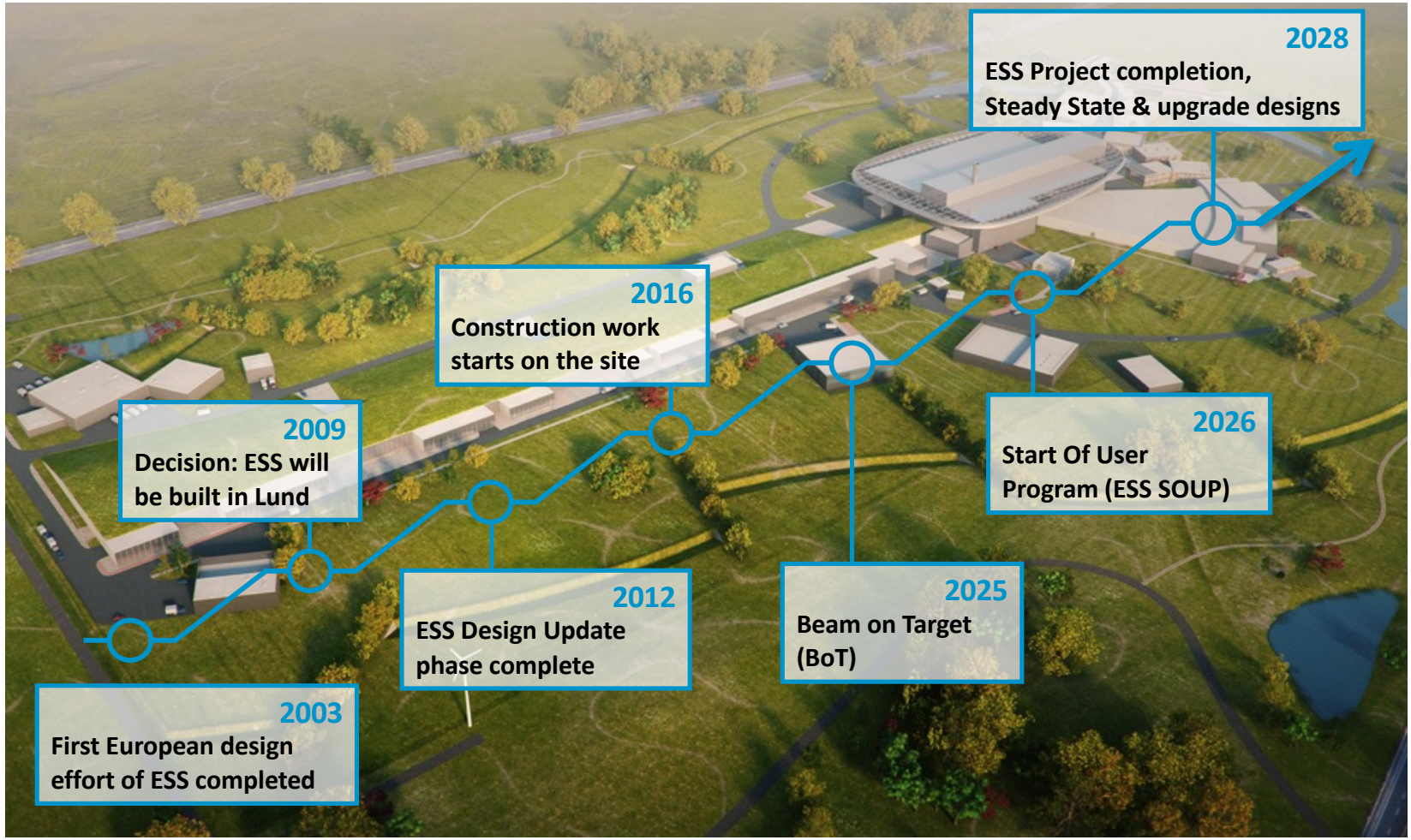
Introduction to ESS

ESS buildings

Handed-over end of 2021



ESS timeline



Contributions building ESS

In-Cash and In-Kind

Host Countries of Sweden and Denmark

47,5% Construction

15% Operations

In-kind Deliverables ~ 3%

Cash Investment ~ 97%

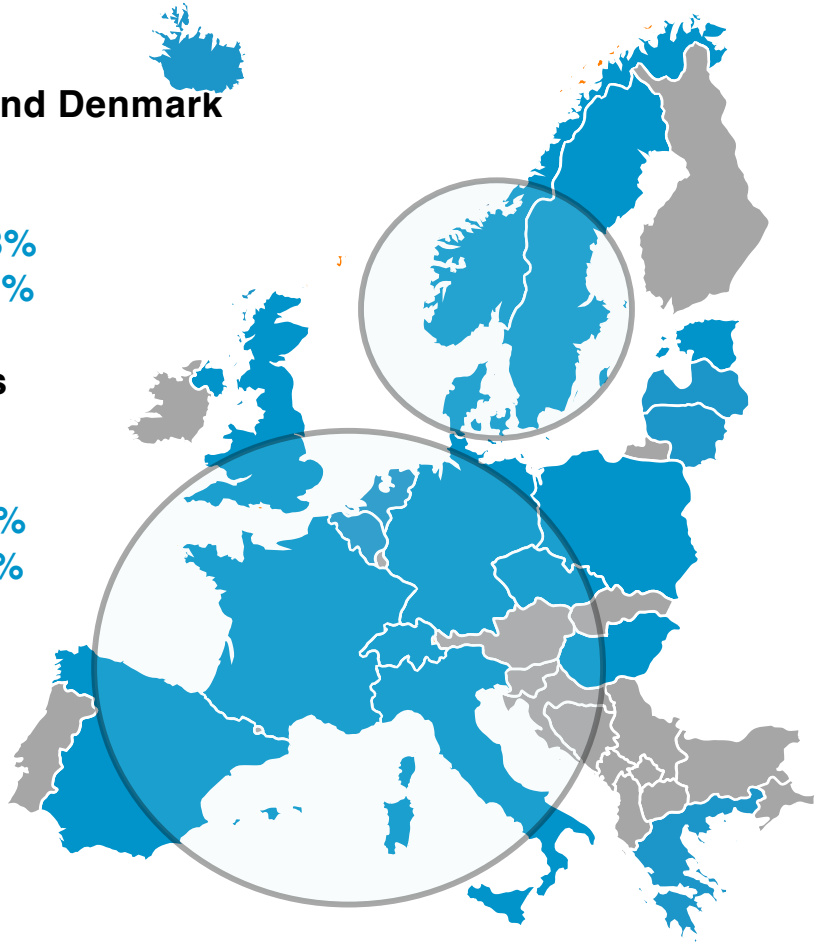
Non Host Member Countries

52,5% Construction

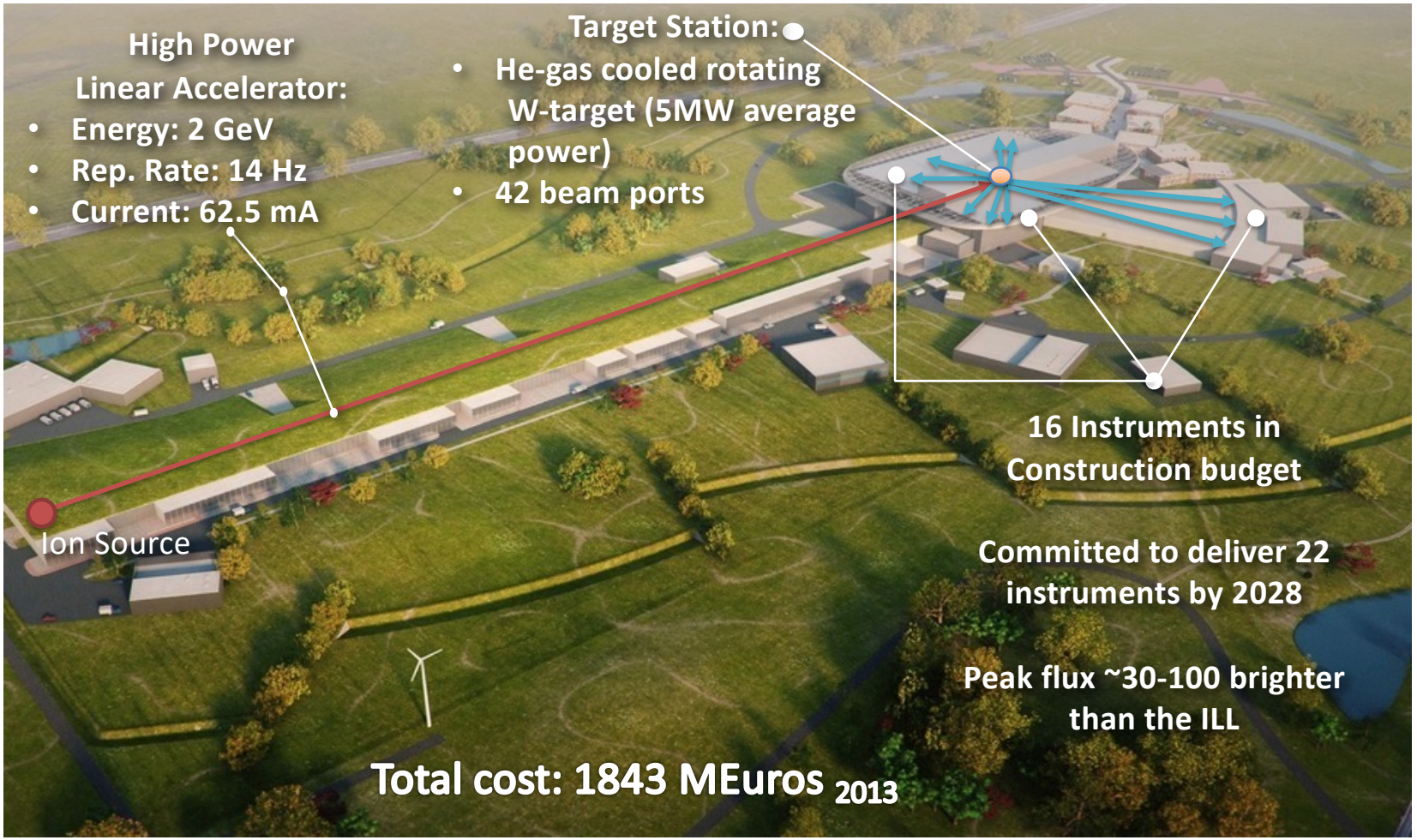
85% Operations

In-kind Deliverables ~ 70%

Cash Investment ~ 30%



ESS layout


High Power
Linear Accelerator:
• Energy: 2 GeV
• Rep. Rate: 14 Hz
• Current: 62.5 mA
Target Station:
• He-gas cooled rotating W-target (5MW average power)
• 42 beam ports
Ion Source
16 Instruments in Construction budget
Committed to deliver 22 instruments by 2028
Peak flux ~30-100 brighter than the ILL
Total cost: 1843 MEuros 2013

2

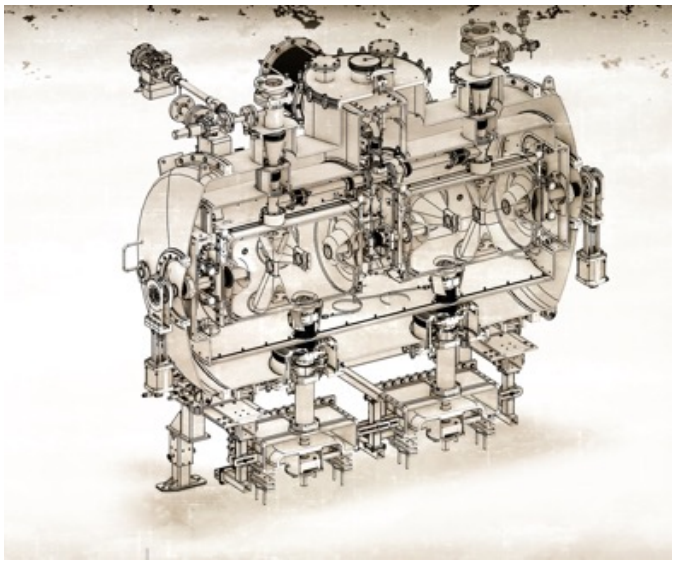
Mechanical Design

Strategy statement

for Mechanical Design & Engineering

The Mechanical Engineering Function is responsible to deliver ESS-wide services that lay mainly within the following axes (ESS-1537394):

- Centralization of Mechanical Design & Engineering
- Centralization of Simulations, FEA & Engineering Calculations
- Operate Mechanical Measurements Lab (MML)
- Execute Mechanical Standardization & ISO-GPS Training
- Provide Mechanical Expertise & Reviewing
- Organize the MECH Forum & IKC MECH Forum



Cross section of a Spoke Cryomodule

Mechanical Engineering

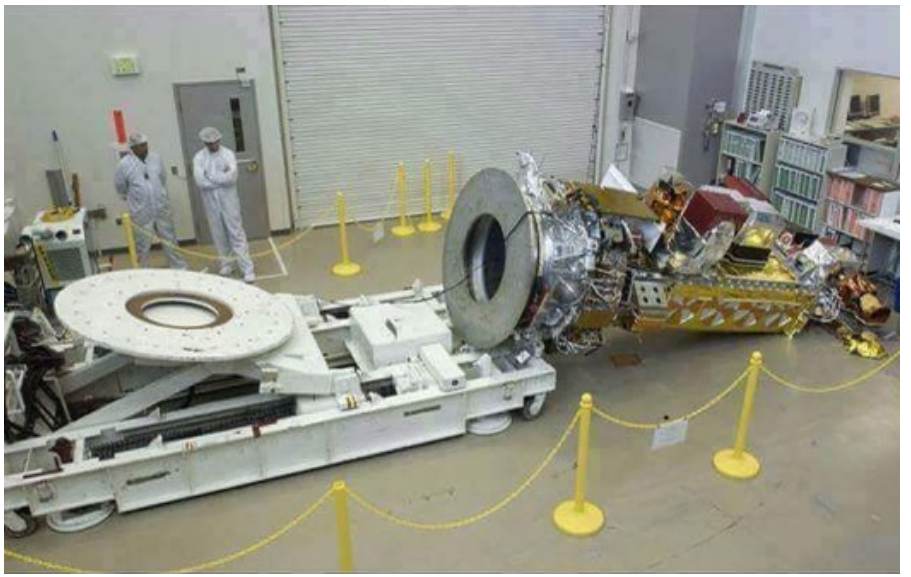
ESS WoW

Several engineering plans & processes have been developed at ESS.

Facility-wide level implementation can be slow, with legacy issues causing quality and other considerations.

Therefore, a ***pragmatic***, ***holistic*** and ***maintainable*** plan for engineering is developed in order to:

- deliver with reduced delays
- Eliminate reworks
- Improve quality of deliverables
- Kick-off operations
- and have a long-term sustainable way of doing things
  (also called ESS Ways of Working – WoW).



To learn this lesson, we shouldn't need to drop MEUR equipment (again)..

Mechanical Engineering

Graded Approach

We implement a *Graded Approach:*

1. Most systems need to be built according to design standards with precision & tolerances
   [so-called *ISO-GPS* or *GD&T* rules]
   to eliminate:
   - **ambiguity**
     (due to lack of quality or engineering ways)
   - **delays**
     (due to mistakes and known-unknowns)
   - additional **costs**
     (repairs, reworks, orphan scopes)

ESS Target

Our work may not be rocket science but can be considered comparable in terms of engineering complexity and modularity in its design.

Mechanical Engineering

Graded Approach

We implement a *Graded Approach.*

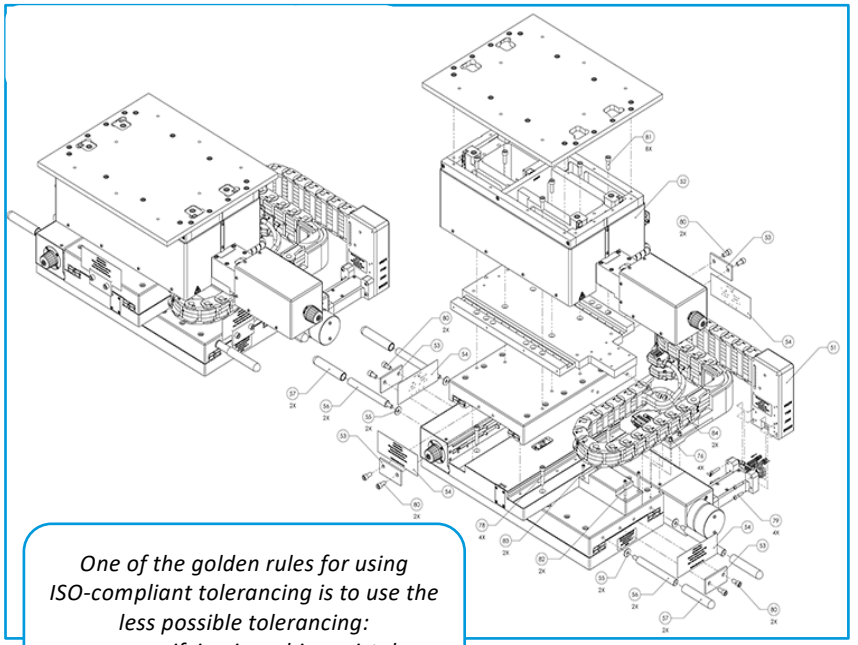
2. Some systems need to be built simpler:

   In specific cases, if you can motivate why you don't need to do it, you can omit parts of the framework

   - e.g. The ***Granularity*** of your systems' models can be coarse, depending on your assembly and installation requirements (predominantly)

3. However, there are few things you can't exclude:

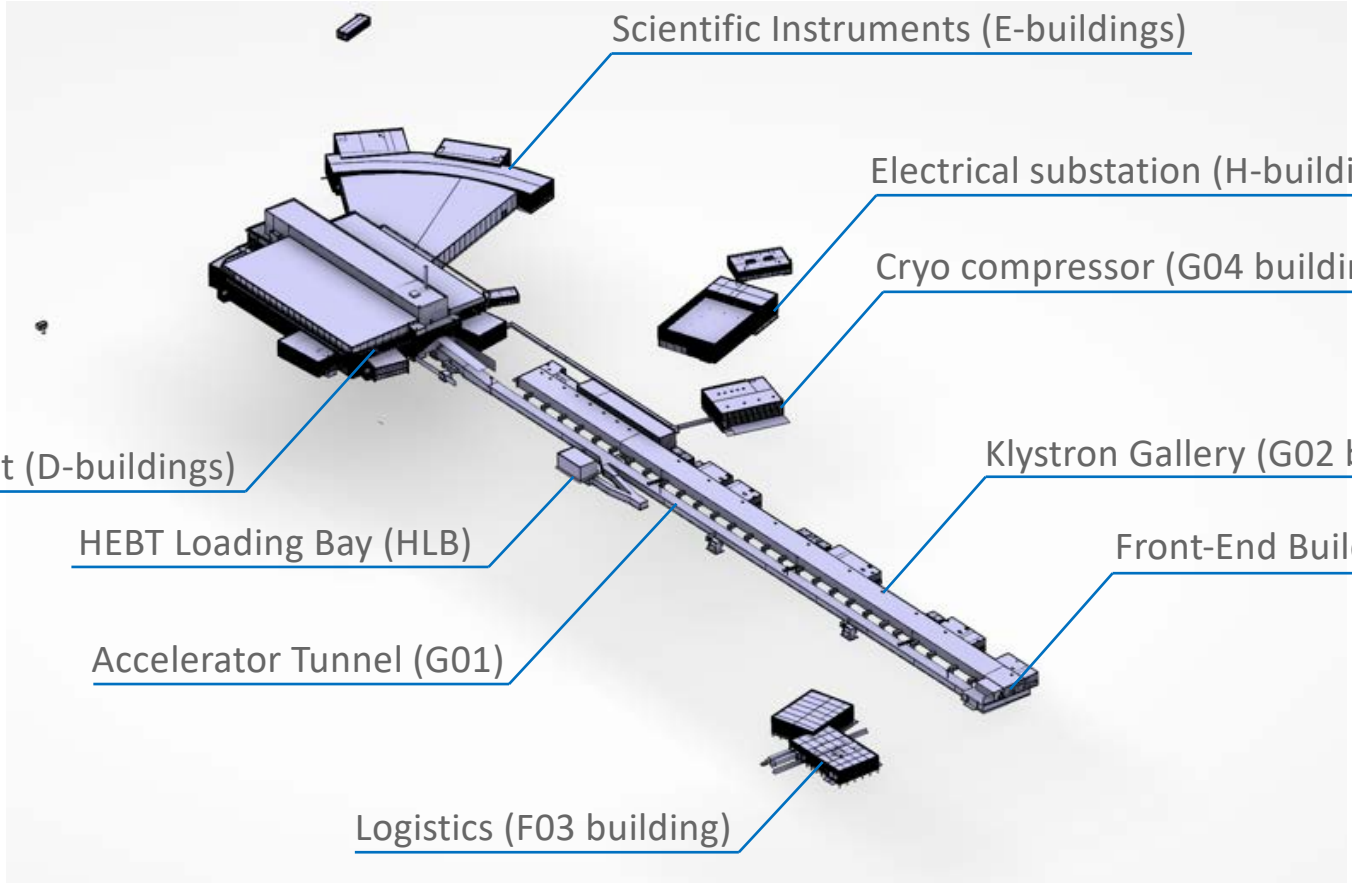
   - e.g. ***Release*** designs & documents



One of the golden rules for using ISO-compliant tolerancing is to use the less possible tolerancing: over-specifying is a –big– mistake

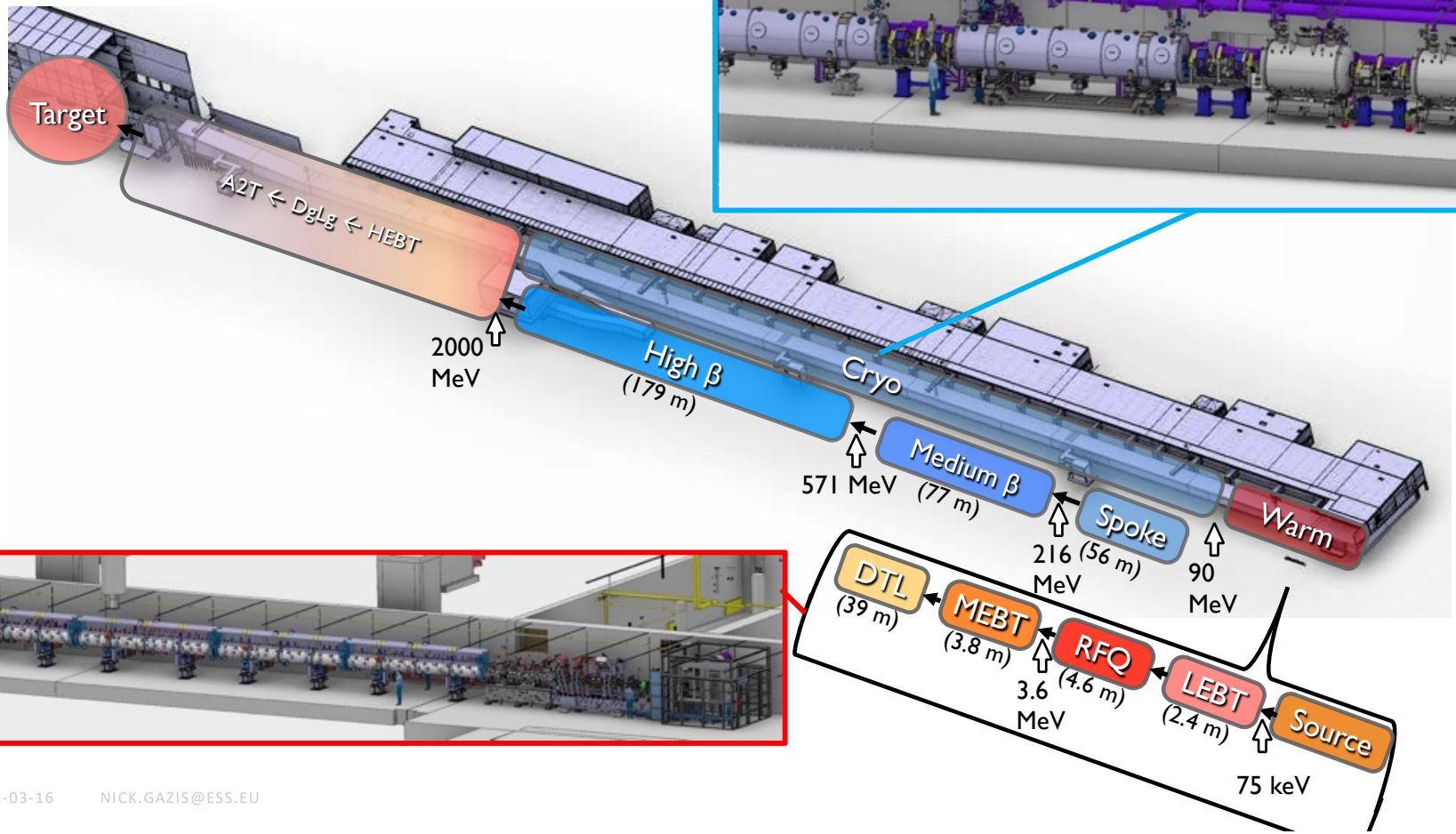
ESS facility

Map of buildings



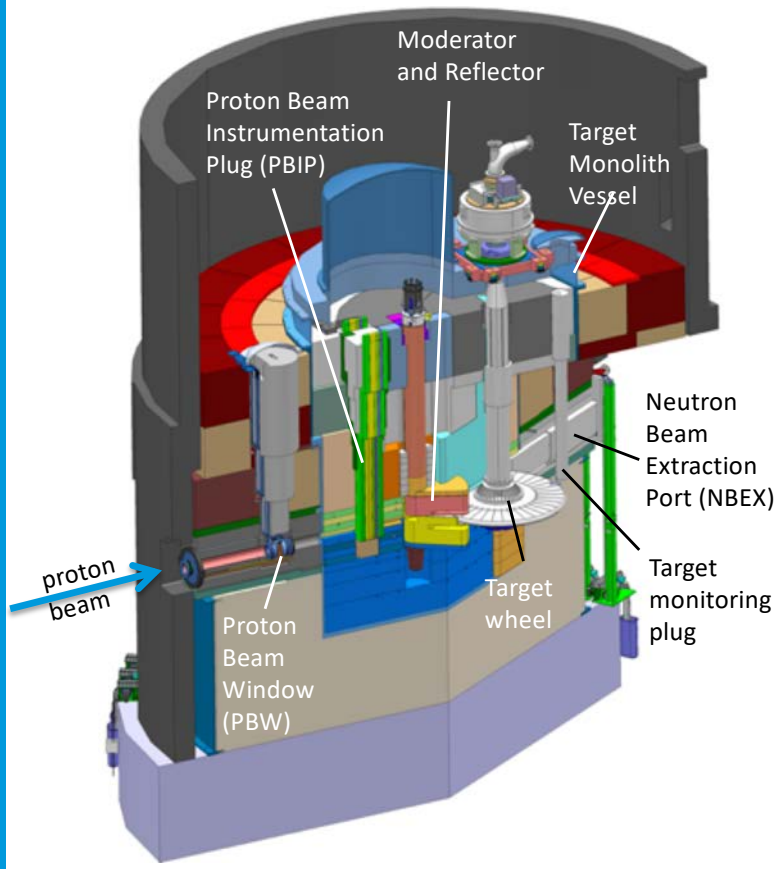
ESS accelerator

High level overview



ESS target

Key features



Target Safety System

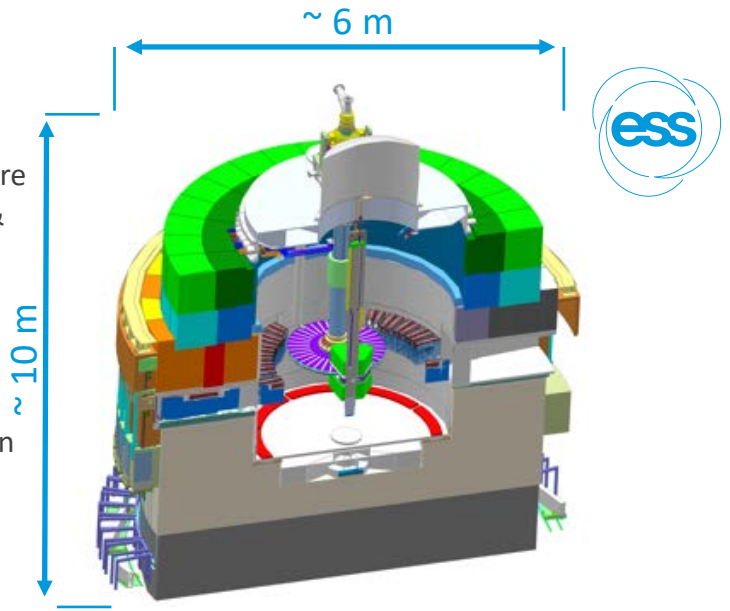
- Monitors target coolant flow, pressure & temperature, monolith pressure & target rotation

Rotating solid tungsten target

- 36 sectors
- Total mass: 11 tn (3 tn of W)
- Rotatation: 23.3 rpm (synchronized with the pulsed proton beam at 14 Hz)

Helium cooling of target material

- Mass flow: 3 kg/s
- Pressure: 11 bar
- Temperature inlet/outlet: 40°C/240°C



Moderators

- Locations of moderators above and beneath of the target wheel, i.e. monolith centre
- 1st MR plug exploits the upper space, offering:
  - Cold, 30 mm high, liquid H_2 moderators, 17 K
  - Thermal, 30 mm high, H_2O moderator, 300 K

Diagnostics and instrumentation

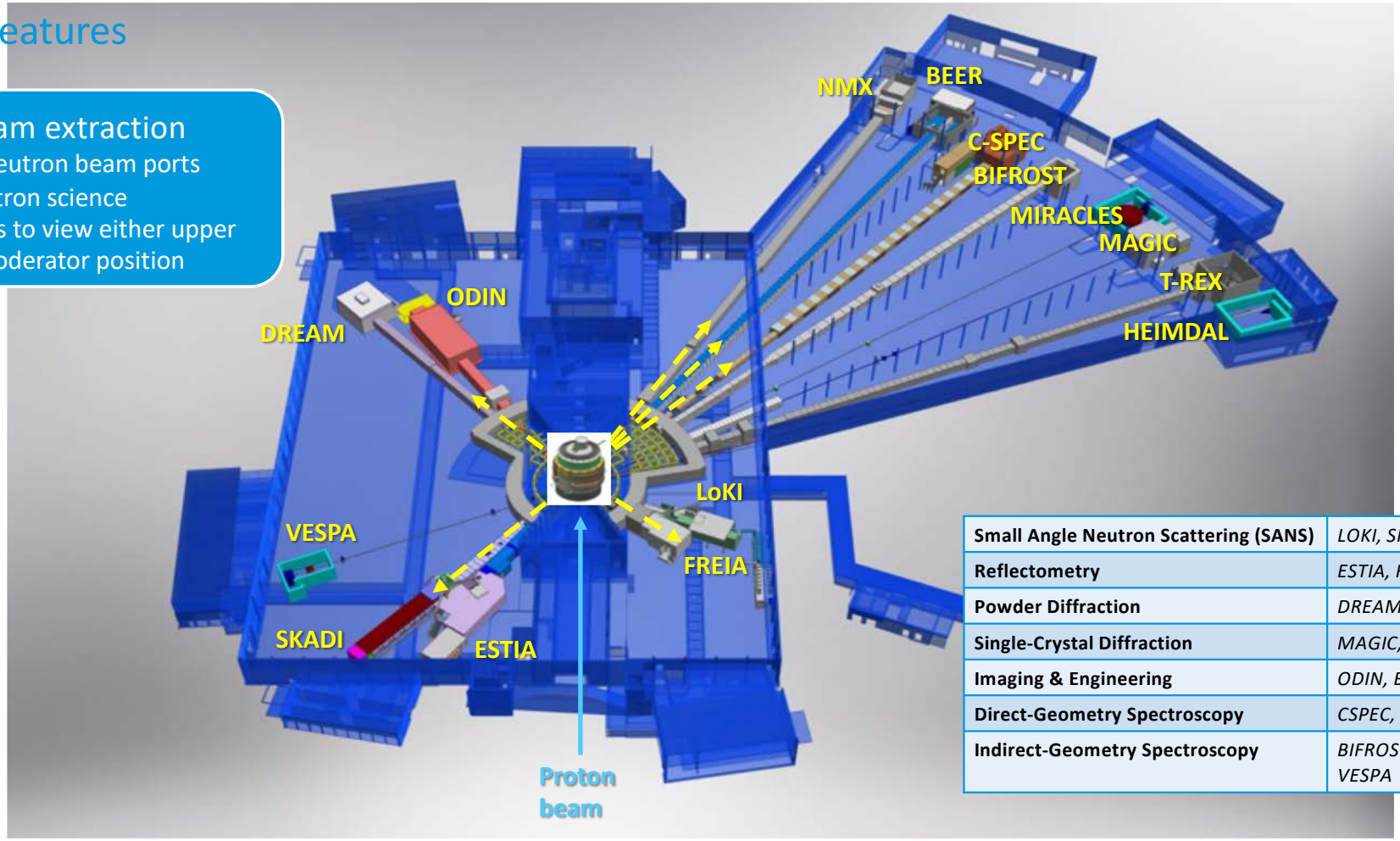
- Fluorescent coating of PBW and target front face
- Wheel monitoring including position, temperature, vibration, as well as internal structure

ESS Neutron Instruments

Key features

Neutron beam extraction

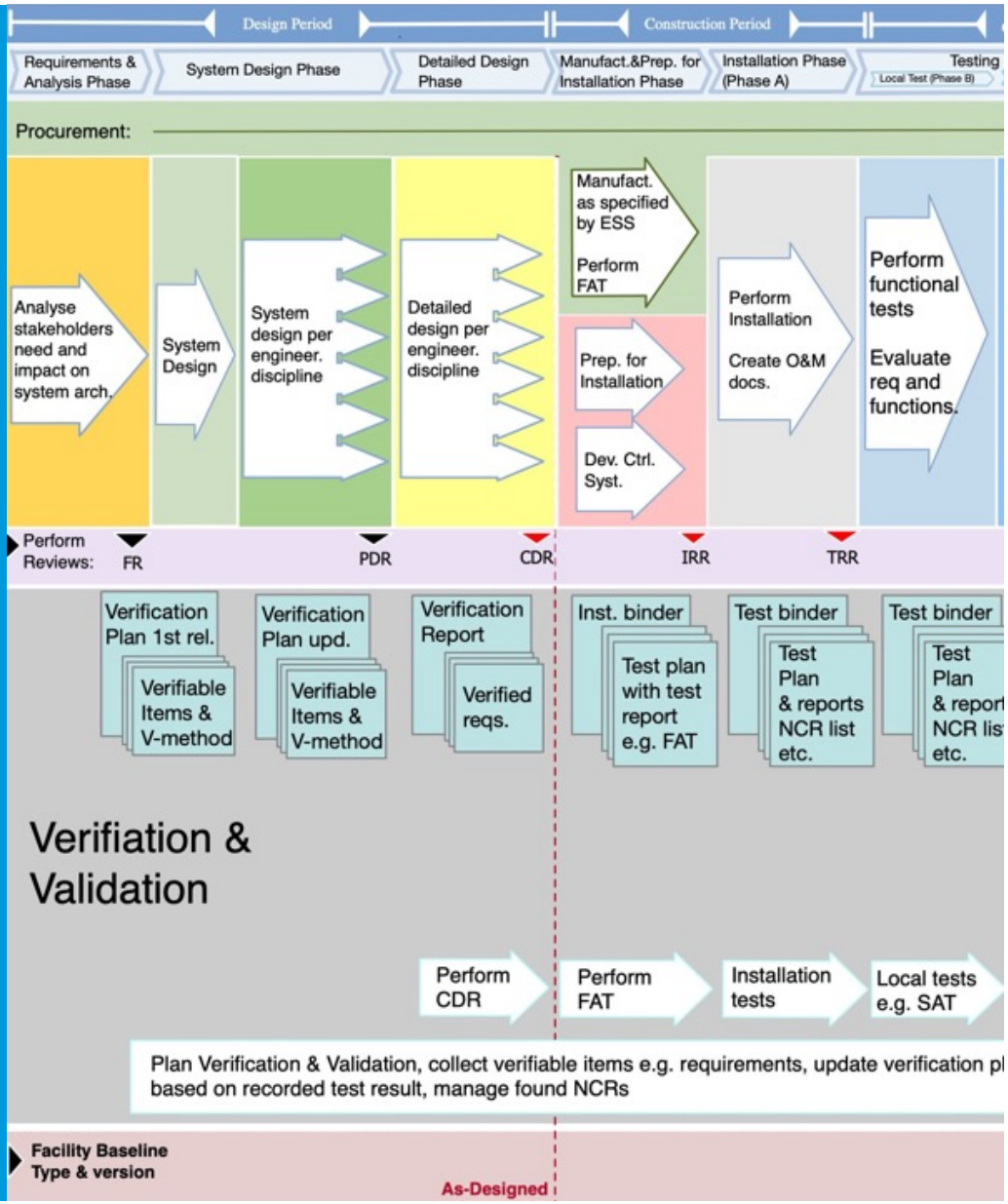
- Offers 42 neutron beam ports
- Allows neutron science instruments to view either upper or lower moderator position



Small Angle Neutron Scattering (SANS)	*LOKI, SKADI*
Reflectometry	*ESTIA, FREIA*
Powder Diffraction	*DREAM, HEIMDAL*
Single-Crystal Diffraction	*MAGIC, NMX*
Imaging & Engineering	*ODIN, BEER*
Direct-Geometry Spectroscopy	*CSPEC, T-REX*
Indirect-Geometry Spectroscopy	*BIFROST, MIRACLES, VESPA*

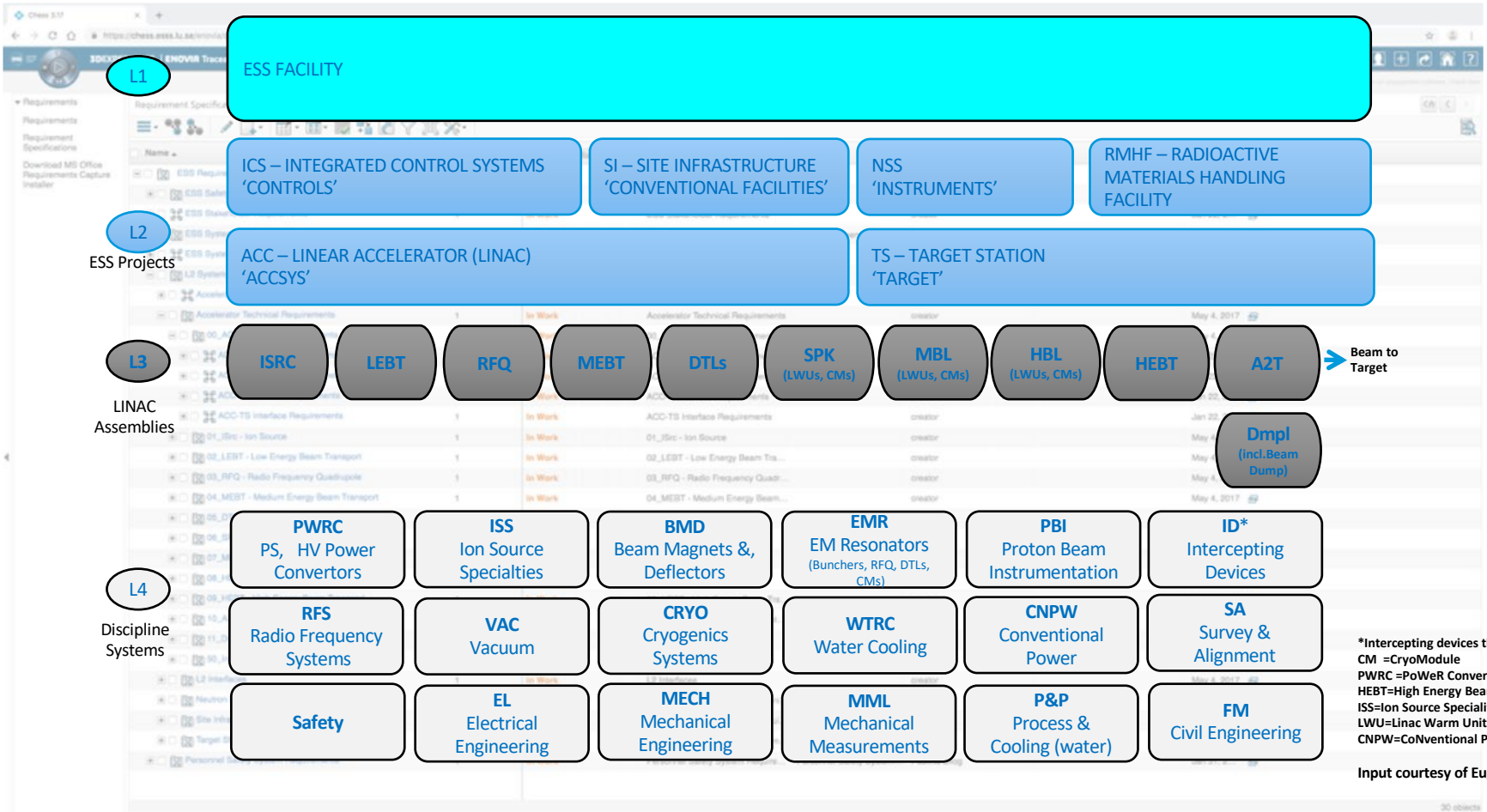
3

Requirements & Engineering Workflow



Different levels of Requirements

Specification flow

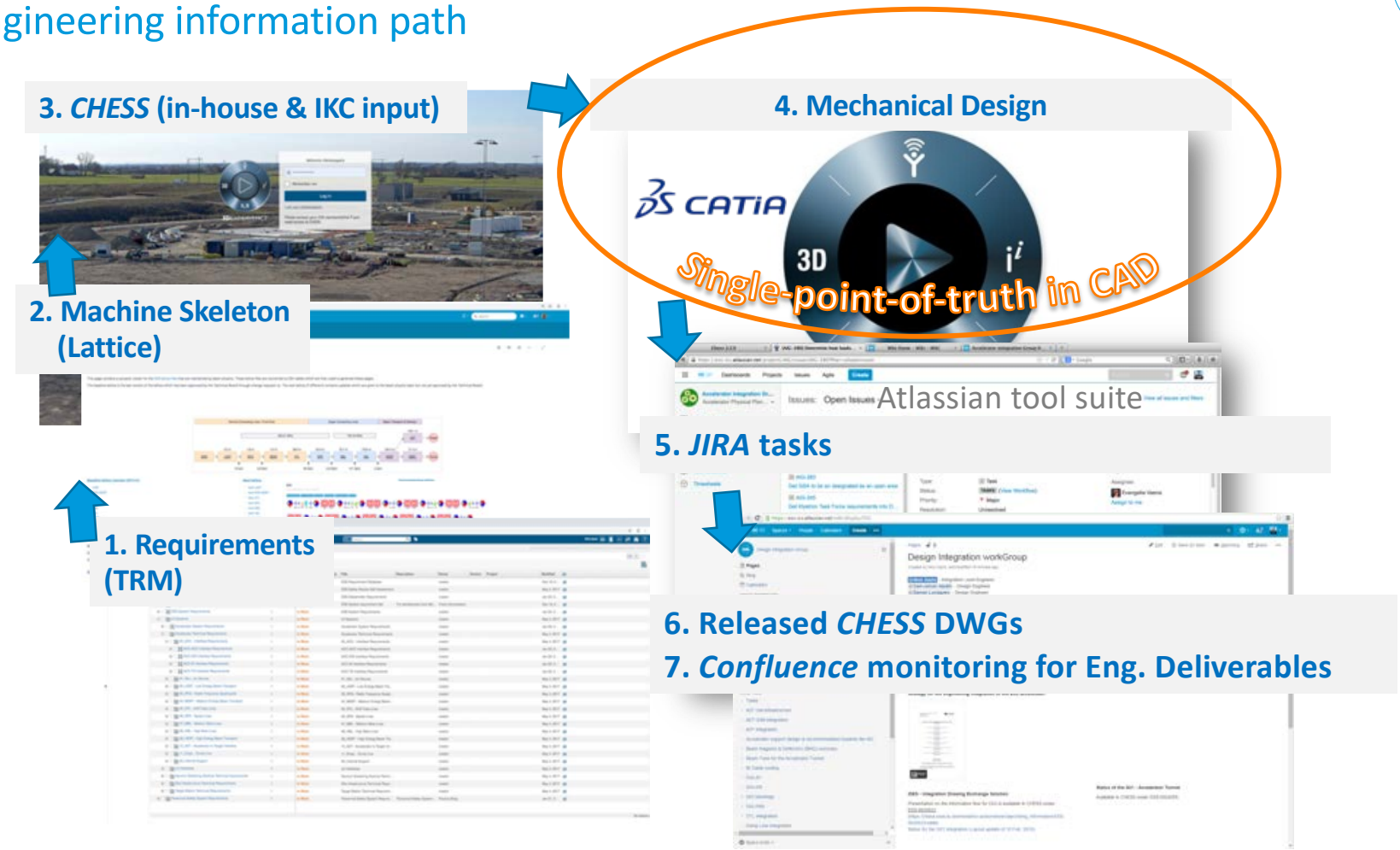


*Intercepting devices that are not part of VAC & PBI
CM =CryoModule
PWRC =PoWeR Convertors
HEBT=High Energy Beam Transport
ISS=Ion Source Specialities
LWU=Linac Warm Unit
CNPW=CoNventional PoWer

Input courtesy of Eugene Tanke (ESS-0008904)

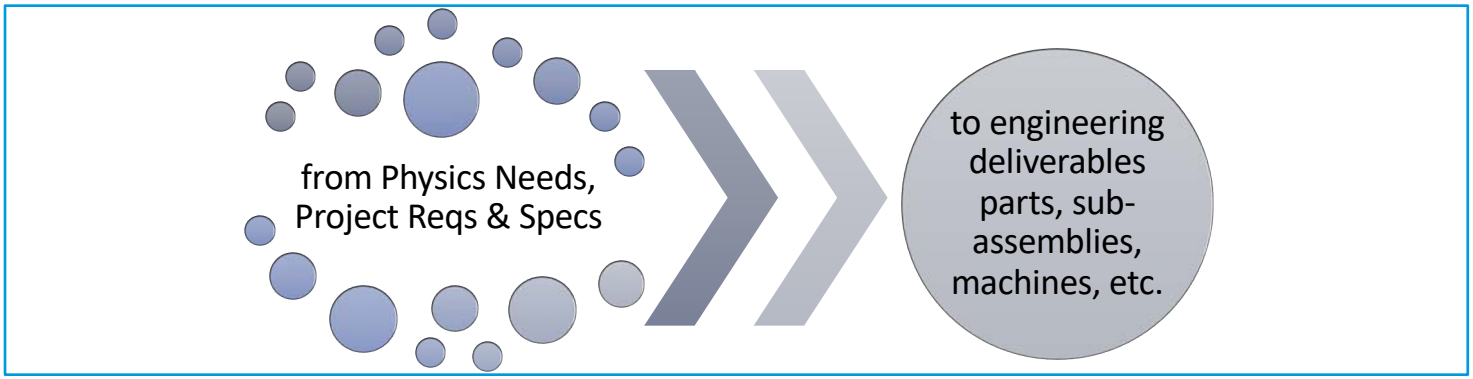
Digital Mock-Up

ESS engineering information path



Mech Eng Task Exec Coord - mETEC

"We need a quick design in CATIA…" means



Open a JIRA task
(define deliverable expectations)

jira.esss.lu.se/projects/MET/issues/

Conceptual design CATIA
(3D checklist ESS-1778194)

Check Spatial Integration

Analysis ANSYS etc
(when/if)

Drawing Review
(centrally offered)

no cost for the projects & 2D checklist ESS-1789580

Inspection Plan CHESS
(draft)

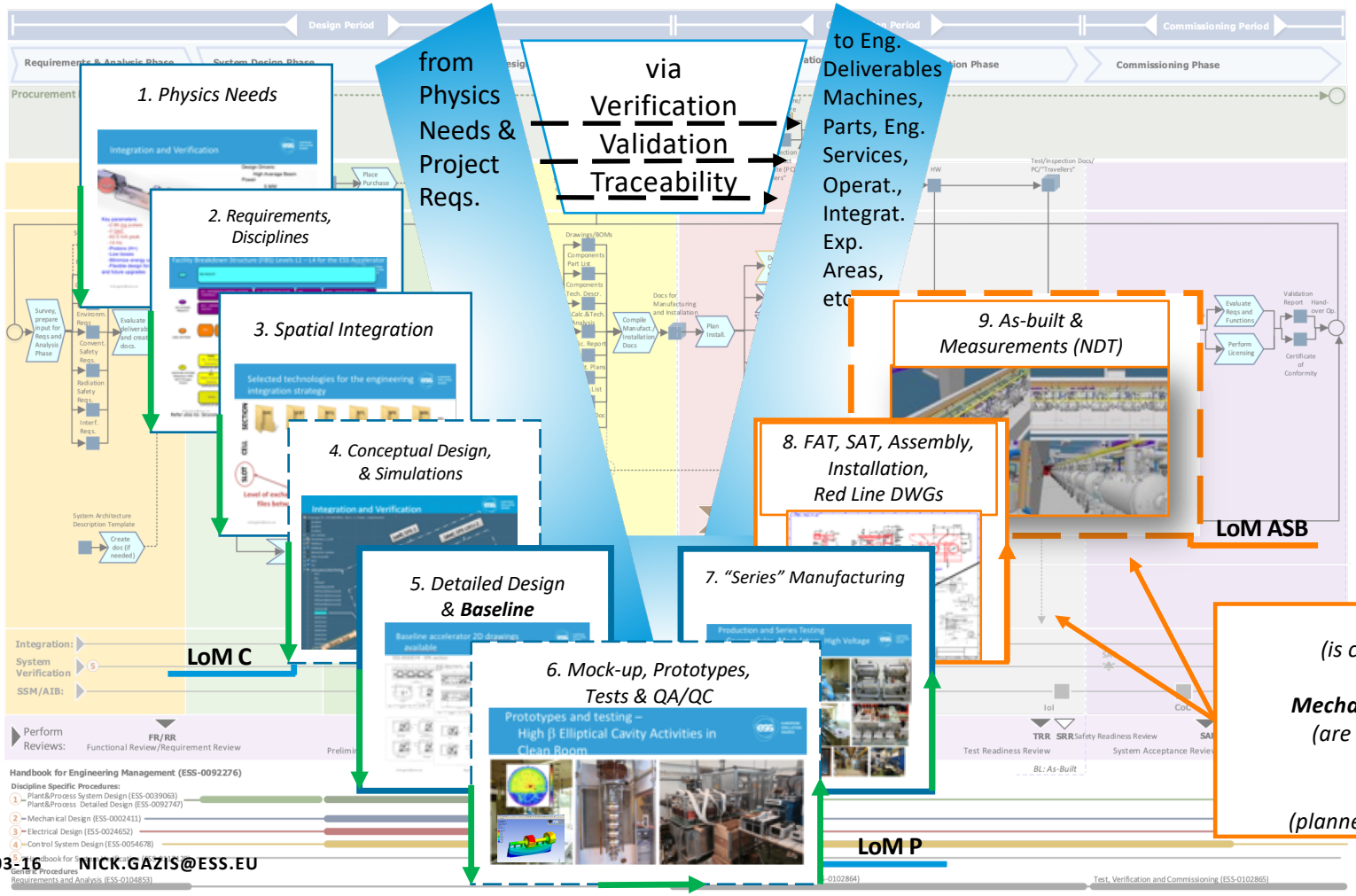
ISO GPS requirement for DWGs manufacturing

e.g.1 BOM is a prerequisite for manufacturing, not optional

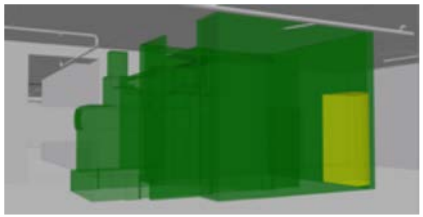
e.g.2 Releasing drawings is a prerequisite as well

Systematic flow with design milestones

Mechanical Engineering & Design (ESS-0002411)

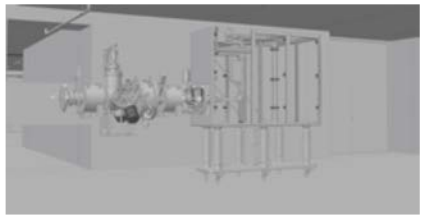


Machine design cycle

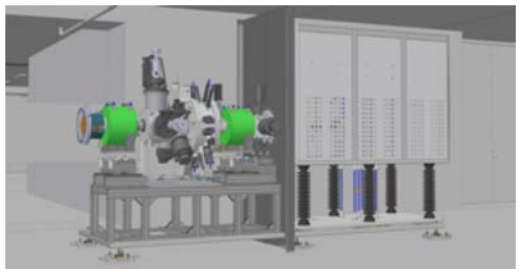


1. Space reservation

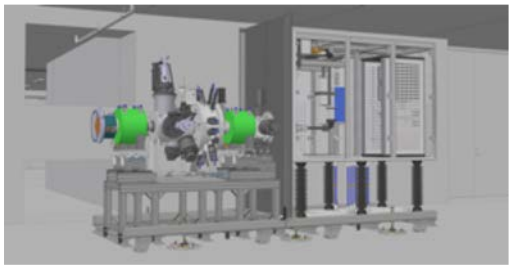
2. Preliminary Design



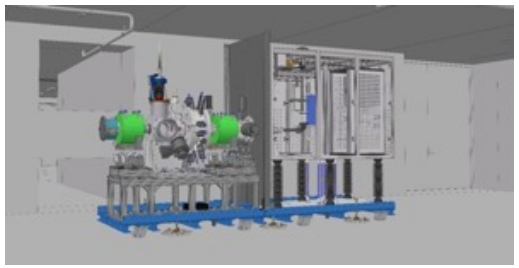
3. Detailed Design



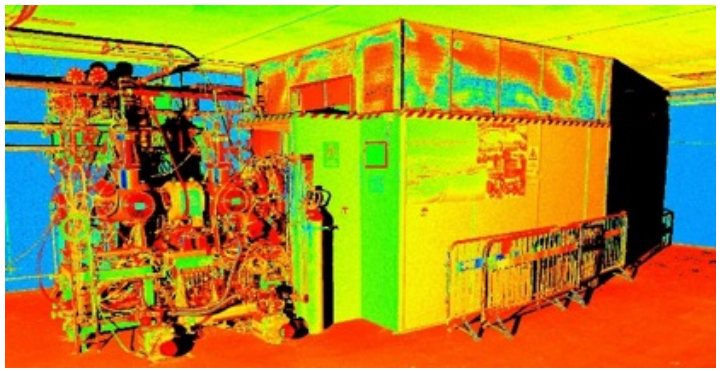
4. Manufacturing



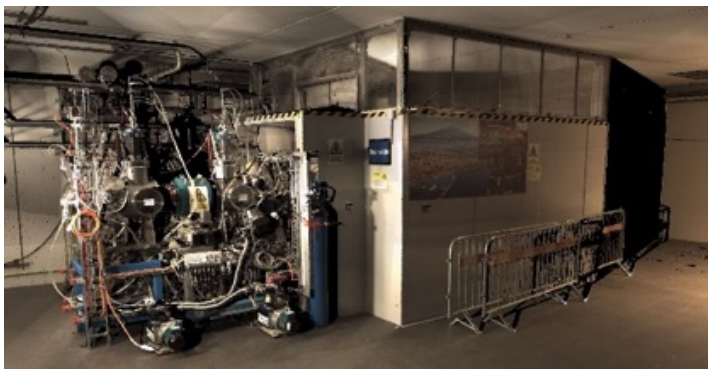
5. Tests & Installation



6. Commissioning



7. As-Scanned

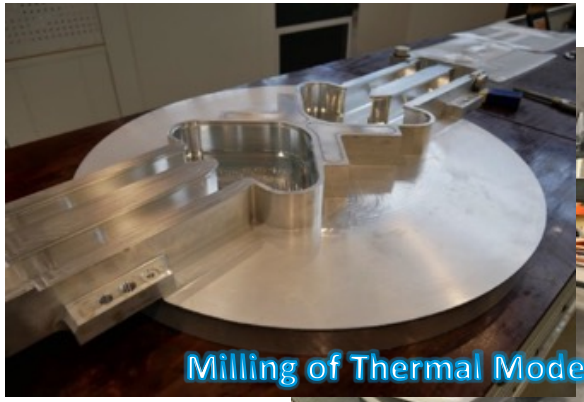


8. Ready for Operation

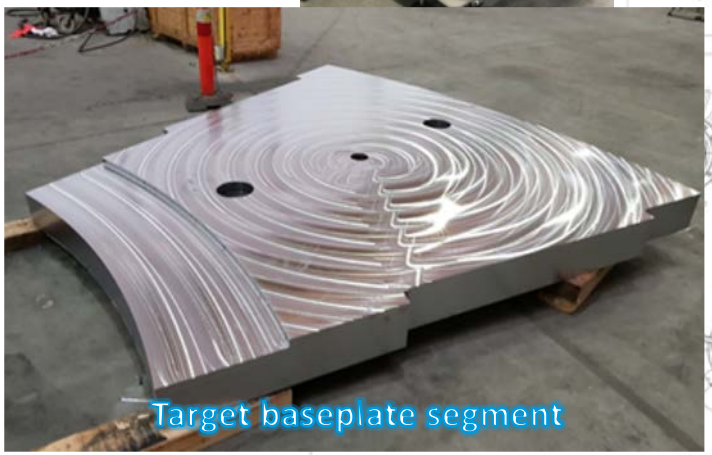
Courtesy of Fabien Ray

Parts & Prototypes Design

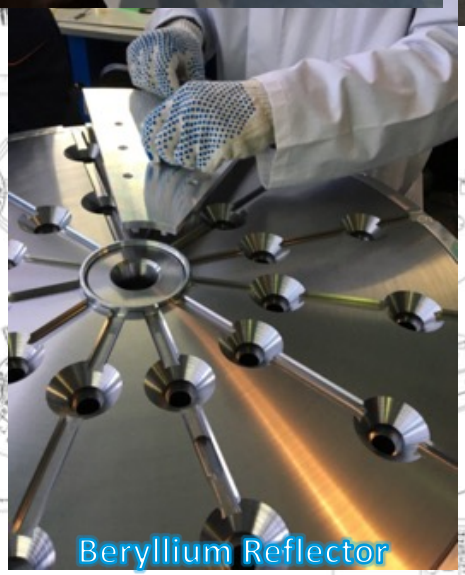
Manufacturing, Repairs & Modifications



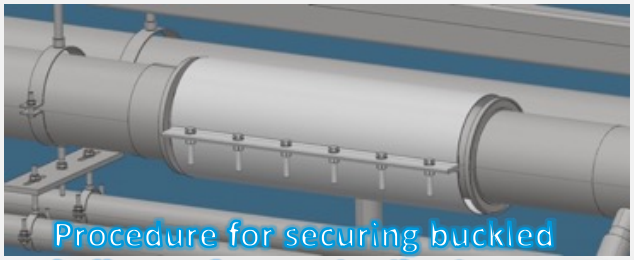
Milling of Thermal Moderator



Target baseplate segment



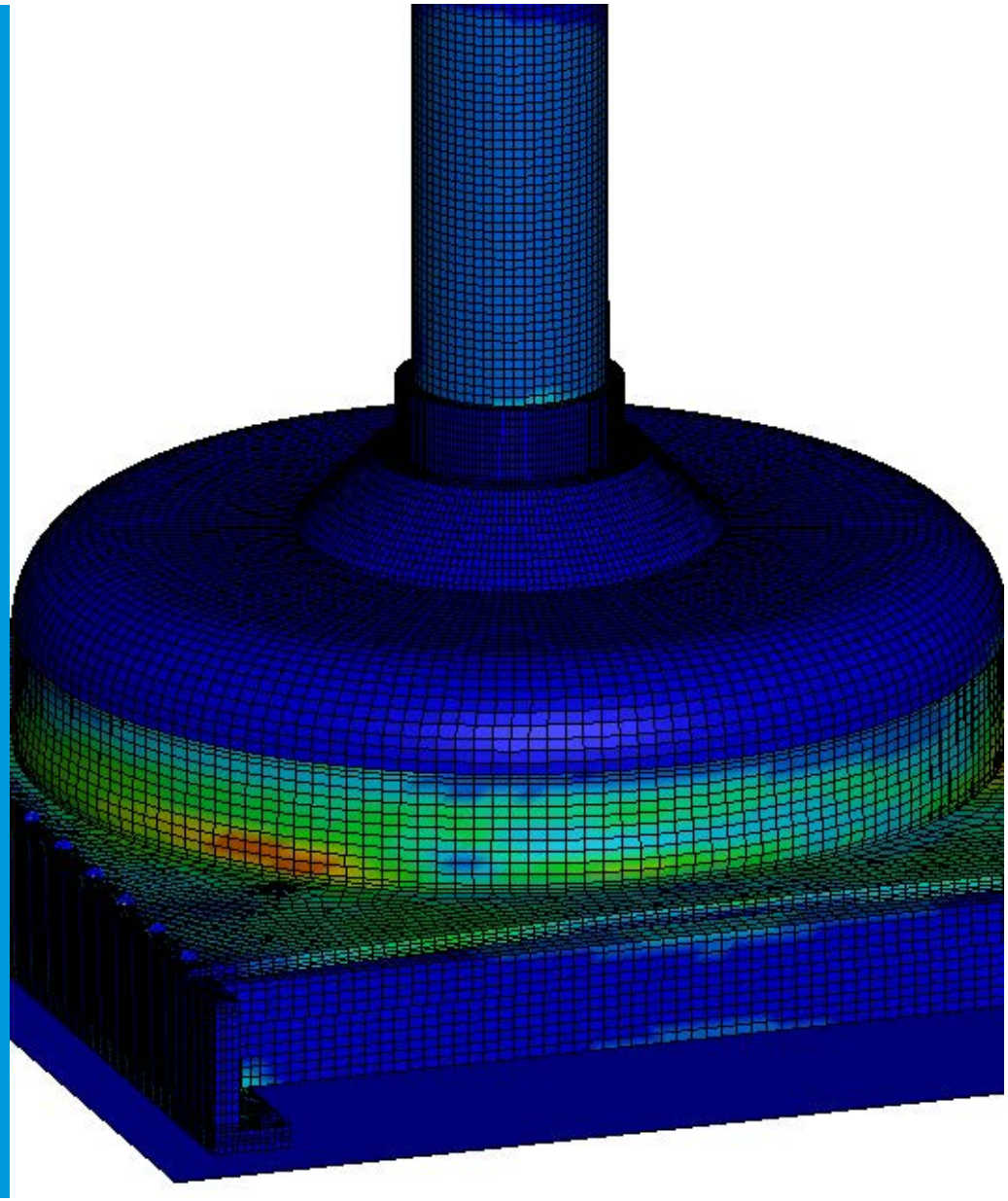
Beryllium Reflector



Procedure for securing buckled bellows of Cryo Distribution System –(CDS-SPK) failed auxiliary line

4

Simulation, FEA & Engineering Analysis



Simulation, FEA & Engineering Analysis

Different types of analyses:

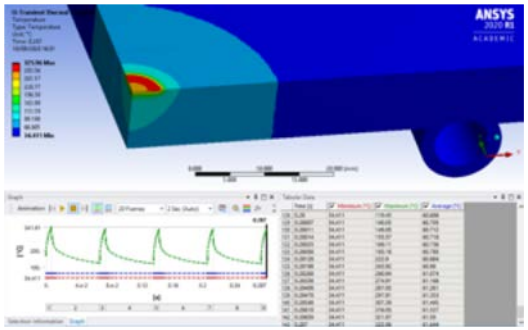
- Structural strength calculations
- Fluid dynamics (CFD)
- Thermal calculations and thermodynamics
- Seismic and vibrations
- Pipe and support calculations
- Explicit simulations (impact analyses)
- Accident analyses
- Process simulations
- Root cause analysis (RCA)

Tools

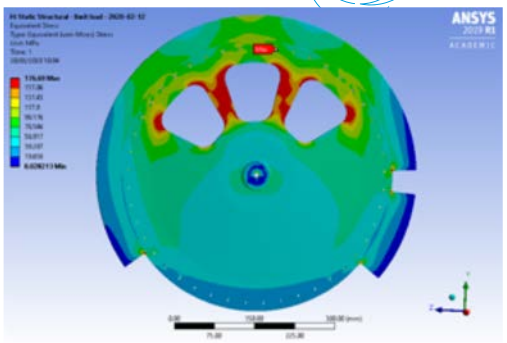
- ANSYS
- ROHR2
- LS-DYNA
- DYMOLA
- Analytical calculations

Tools

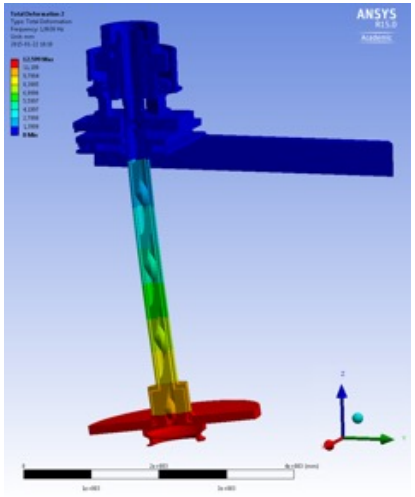
- EN/Eurocodes
- RCC-MRx



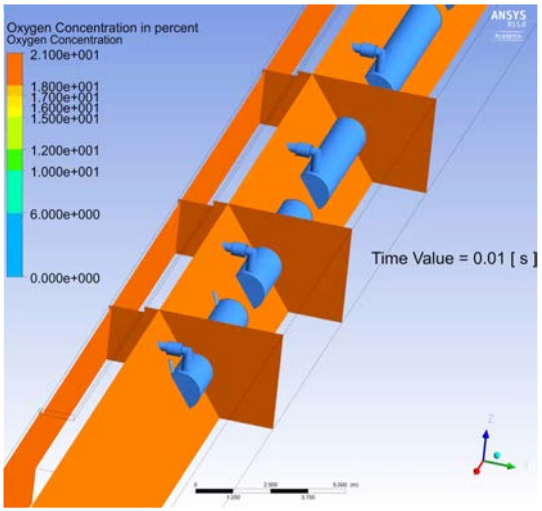
Thermal transient - Proton beam impact



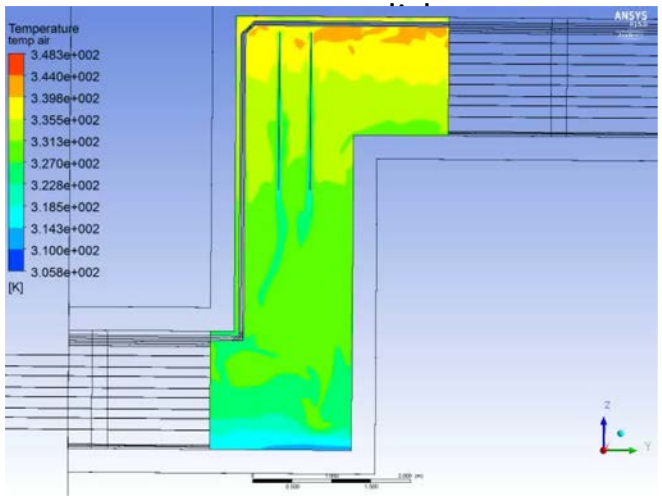
Rotordynamics – chopper



Eigenfrequency



CFD of ODH (CM burst discs)



CFD of Stub cooling concept

Input courtesy of Emil Lundh

5

Mechanical Measurements Lab (MML)

Mechanical Measurements Lab (MML)

ESS-internal measurements

- Finite Elements Analysis (FEA) for tests
- Resonant Ultrasound Spectroscopy (RUS)
- Transient Grating Spectroscopy (TGS)
- Modal Measurements & Vibrations monitoring
- Seismic Measurements & Monitoring

NDT & SHM Methods

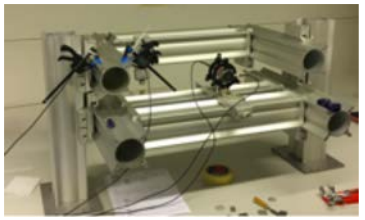
- ANSYS simulations
- Results validation (experimental)

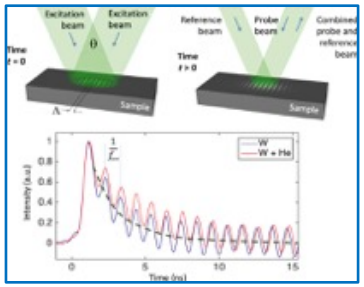
- Non-Destructive Testing (NDT)
- DUT Ultrasound excitation
- Elastic constants calculation
- Structural Health Monitoring (SHM) for machines with duty cycles under radiation background

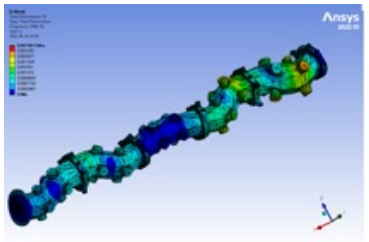
Study & MML implementation of a TGS bench :
- characterisation of accelerator materials
- impact assessment on material properties from beam operations

Non-Destructive Testing (NDT)
Structural Health Monitoring (SHM)
Vibrational profiles & mode patterns

- Geophones for vibration background measurements
- Transfer function analysis.







Vibration control & modal measurements

Transportation of different types of ESS Cryomodules is monitored with accelerometers.

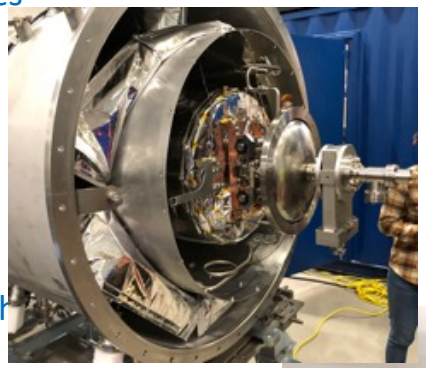
Recording of given acceleration and respective frequency response for validation.

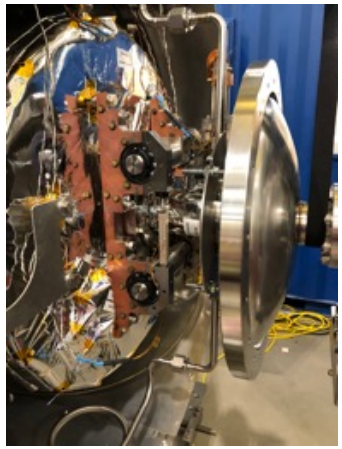
The results in the time domain allow us to spot the critical steps during transportation procedure (usually, intermediate stages of crane operation with excitation forces > 3G)

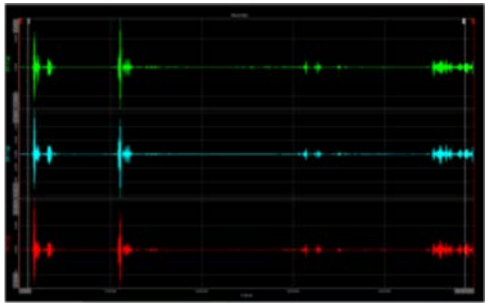
Potentially dangerous excitations for the integrity of the sub-assemblies are identified and apply specialized damping during the procedure.

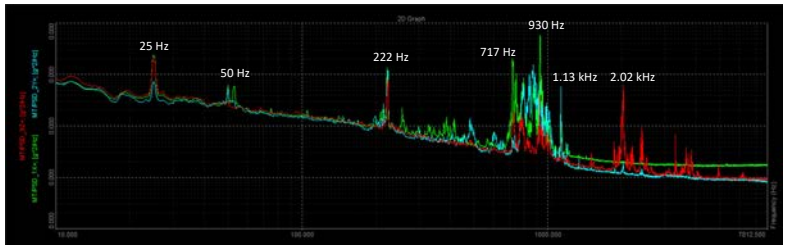
Additional related activities :

- Maintenance, modifications and repairs
  - e.g. replacement of CM-internal step motor for the SPK CM cavity tuner
- Testing & validation of the design and manufacturing of new/upgraded components
  - e.g. new CM micro-adjustable feet, coupler installation tooling









Input courtesy of Andrea Bignami

Resonant Ultrasound Spectroscopy (RUS)

”Derivation of elasticity matrix through excitation of natural vibration modes using ultrasound acoustic waves.”

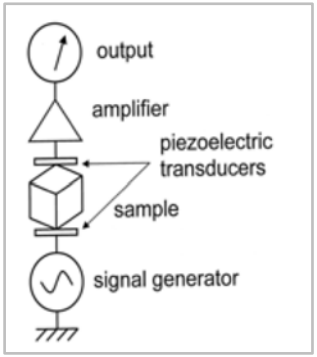
In-situ SHM for component aging mechanisms

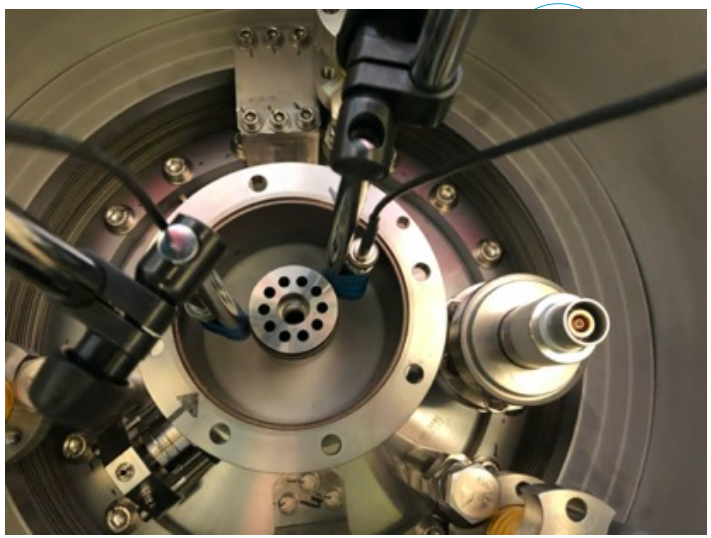
Analysis of accelerator structural materials (Cu, Nb, SS, Al)

Finite Elements Analysis (FEA) benchmarking

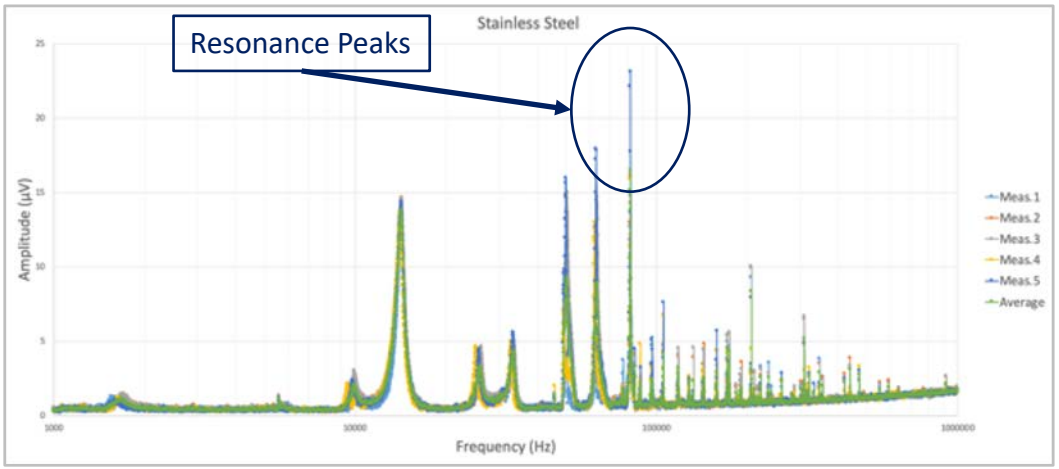
Portable measurement apparatus

Different sensor types, tailored to the needs of the component and measurements conditions (i.e. radioactive background, thermal deltas, high-vacuum/pressure profiles)

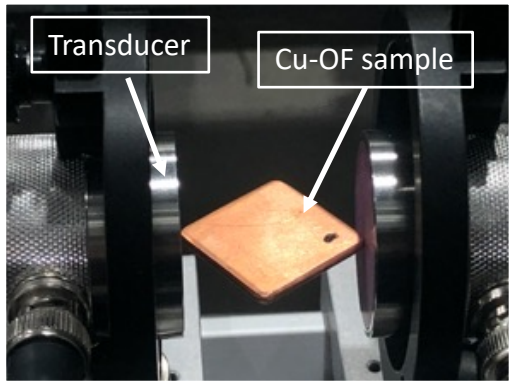




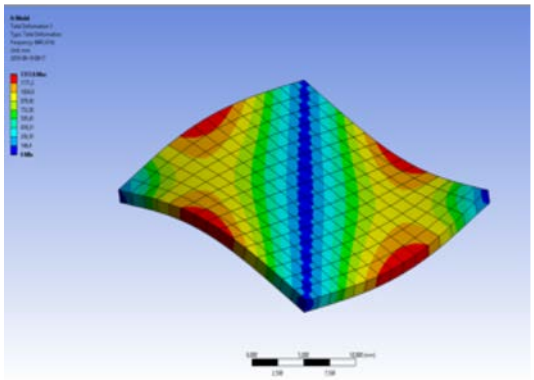
RUS measurement on high-β cryomodule coupler ceramic window



Resulted Spectrum of SS-316L RUS measurement (1kHz-1MHz)



RUS measurement



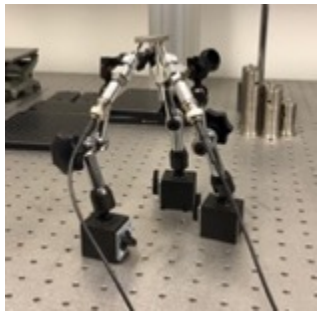
Sample’s FEA

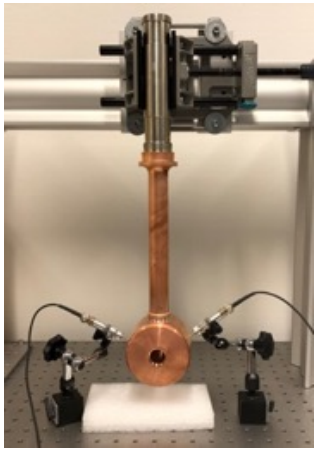
Input courtesy of Andrea Bignami

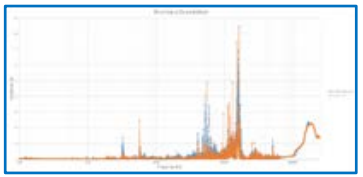
MML in a nutshell

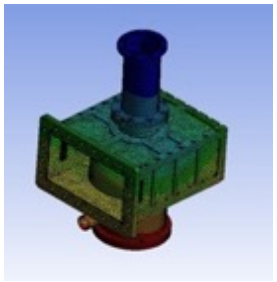
Measurements & Tests

- NDT (SHM, RUS, TGS, FOS*, modal characterization, duty cycles, measuring extensions, acoustic, ground vibration, pressures etc.)
- DMT (UCT, 3PB, 4PB, BrDT)









List of active lab collaborations with:

CERN

OAK RIDGE National Laboratory

Massachusetts Institute of Technology

Mizzou University of Missouri

MURR® Matters...

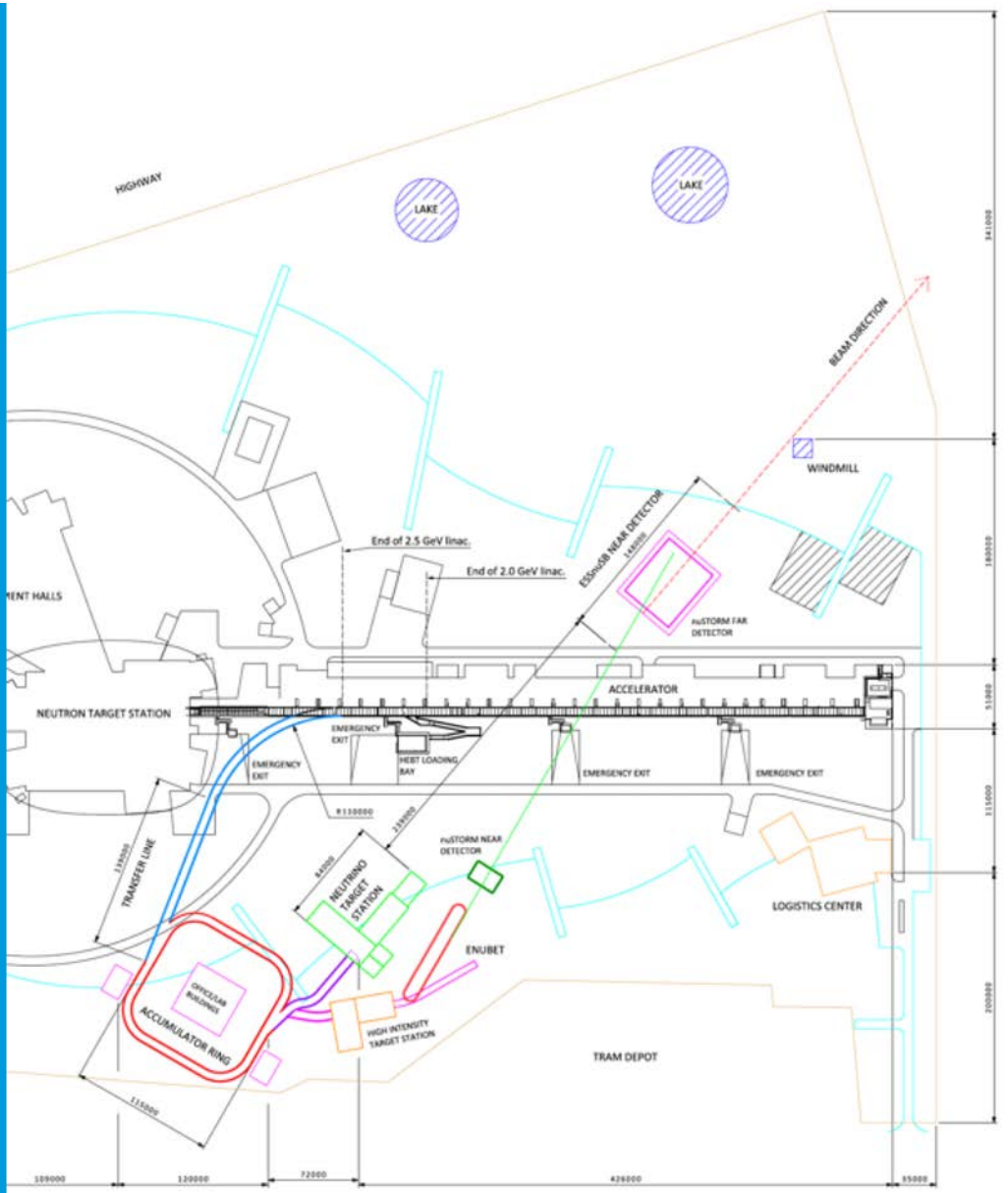
Elettra Sincrotrone Trieste

INFN

IASA

6

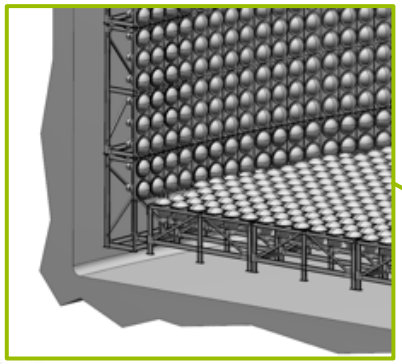
Future upgrades & Summary

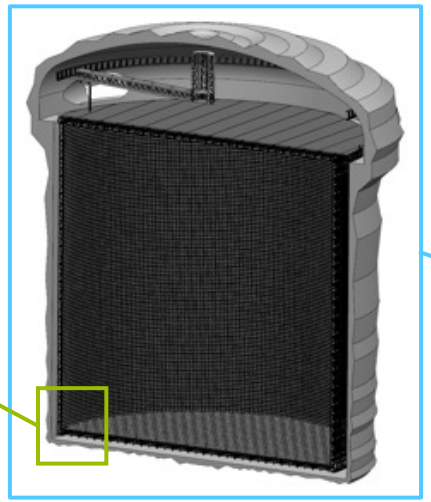


ESSnuSB+

WP2 – Engineering & Infrastructure

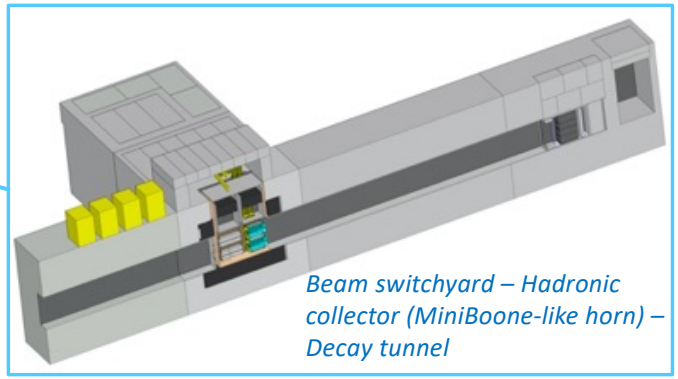
ESS NEUTRINO SUPER BEAM





Far Detector (FD): photomultiplier-based detector for neutrinos, D = 78 m ; H = 75 m

Proton Beam (Ep=2.5 GeV, 14 Hz)

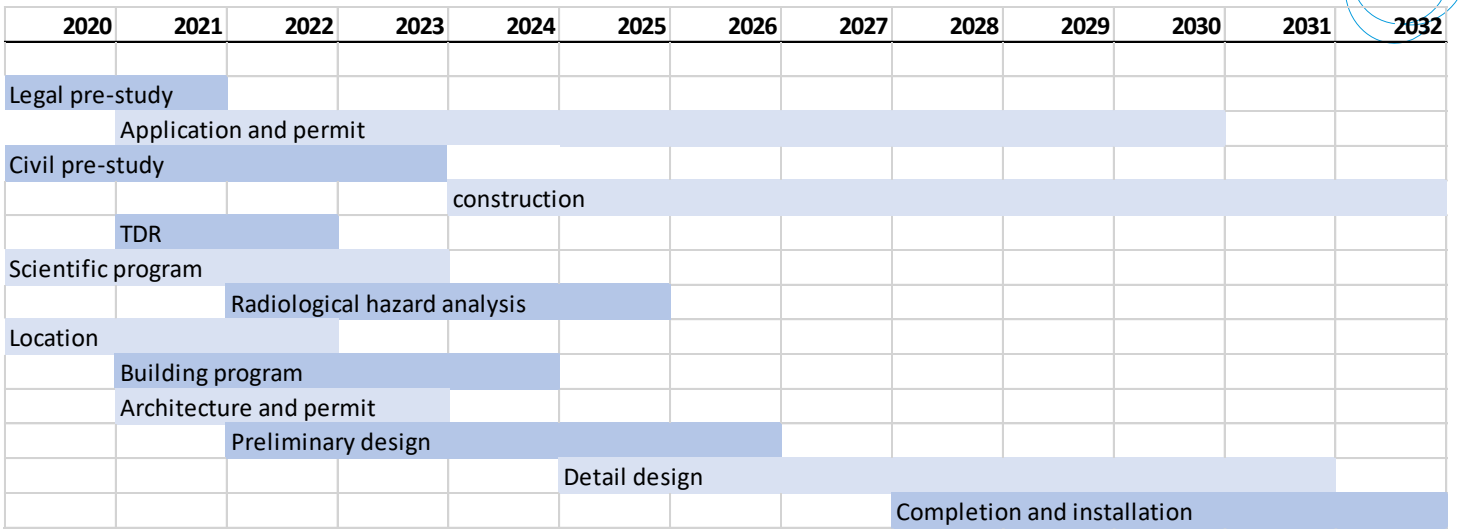


Beam switchyard – Hadronic collector (MiniBoone-like horn) – Decay tunnel

Design & technological solutions under exploration in order to support the proposal of installing the ESSnuSB+ at ESS site and its FD cavern 450 km in the north, in an old repurposed mine.

ESSnuSB+ WP2

Task 2.4:
High-level planning & timeline



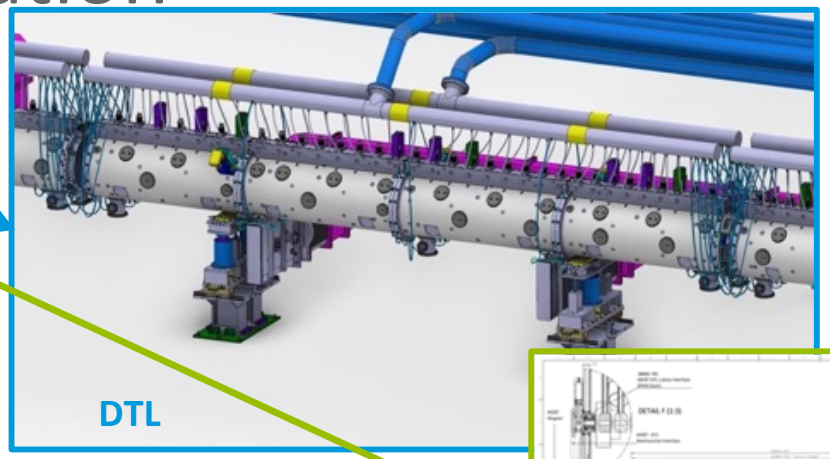
INDICATIVE TASKS

- **Legal process, preparation and pre-studies** *Estimated time aspect 4-10 years*
  - Concretize technical design to a level suitable for starting permit process
  - Swedish environmental code process
- **Conceptual design of civil structures and geology** *Estimated time aspect 2-4 years*
  - Desk Pre-study and planning
  - Geological investigation on site drilling and radar
  - Bedrock investigation with drilling and deformation analysis
- **Site planning and local issues** *Estimated time aspect 2 years*
  - Contracts or agreements for land
  - Architectural competition or parallel assignments
  - Building permit

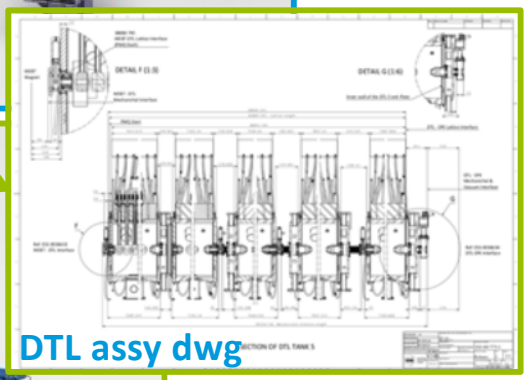
An example for consideration

More than meets the eye..

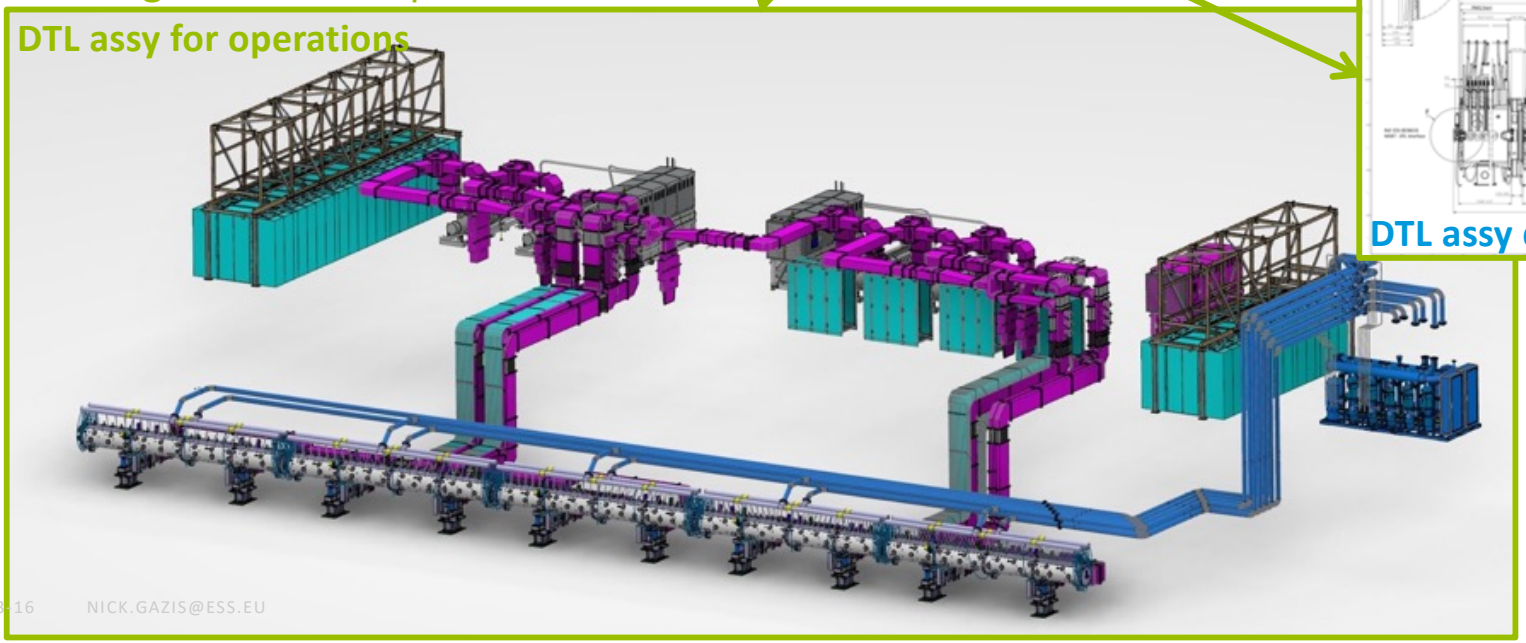
A linac does contain the **accelerator parts**
but also the power sources, electronics, controls, waveguides, cooling sources etc
and accessiblity for side-operations such as assembly, installation, maintenace etc,
that need also design effort and space to fit in.



DTL



DTL assy dwg



DTL assy for operations

Last slide

Kids can teach us good lessons, for instance:

Tasks are **not linear**,

they **CAN be** linear, but they **seldomly are**..

Tasks can *look simple*,

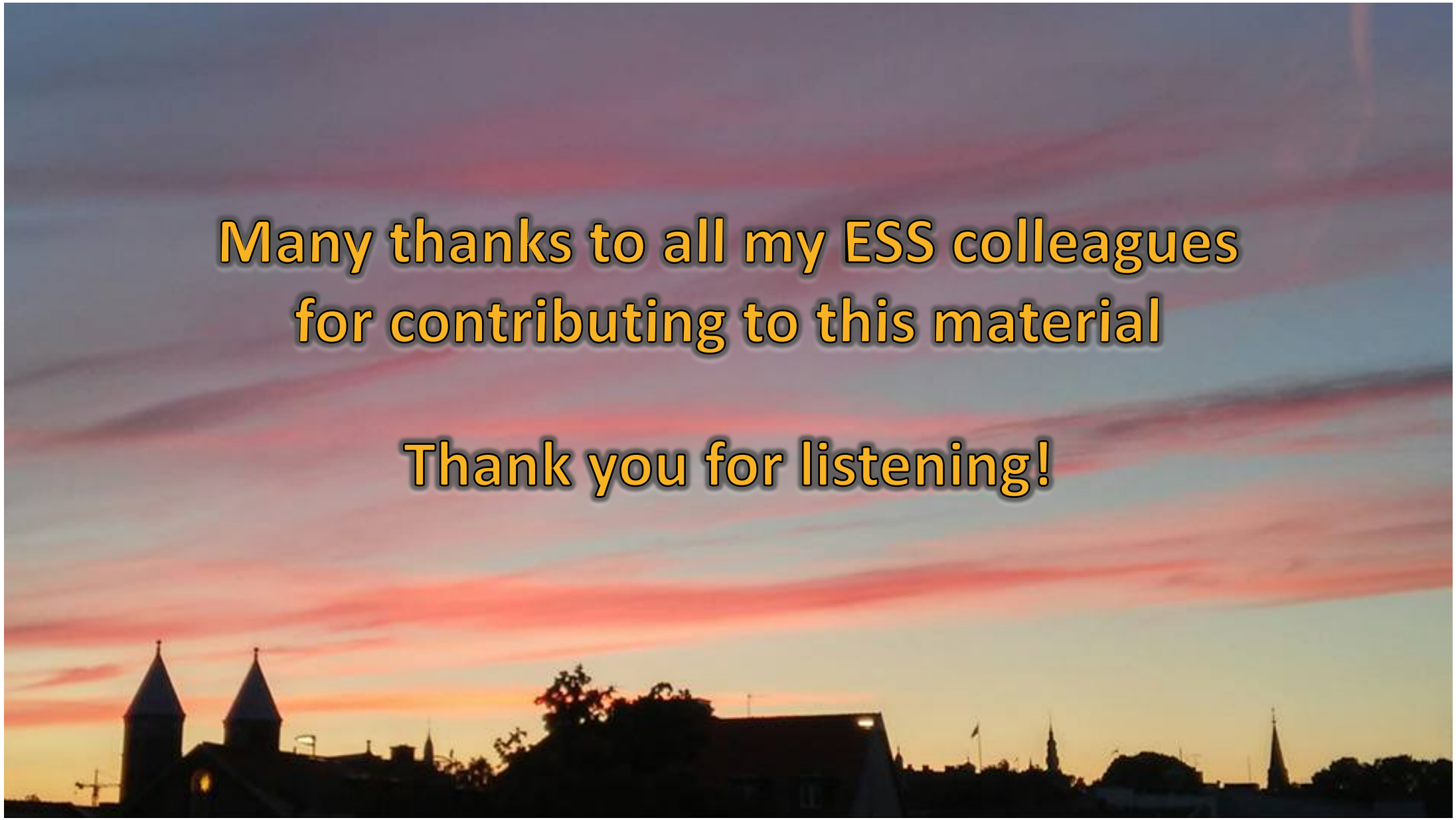
or they can *simply look* like:

- an ambulance..
- with 2 space satellite antennas on the roof..
- that is driven by an astronaut..
- who holds a medieval axe!!

The engineering approach has to focus on

efficiency, simplification, quality, problem solving

and avoid **complexifying** things.


Many thanks to all my ESS colleagues
for contributing to this material
Thank you for listening!

EUROPEAN
SPALLATION
SOURCE