EUROPEAN
SPALLATION
SOURCE

# ESS SRF vacuum project: design and assembling plans

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ESS Vacuum Group Leader

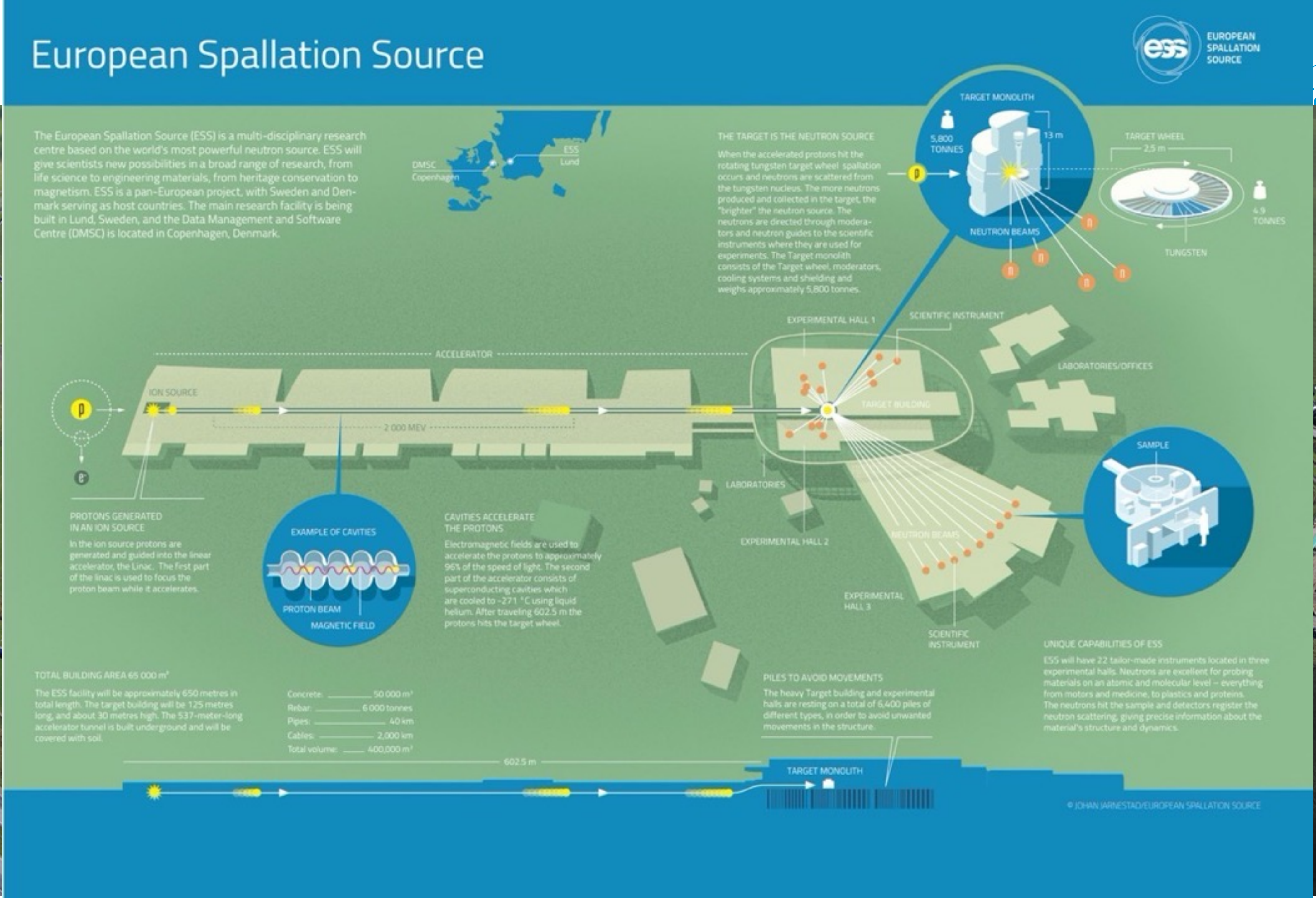
2022-07-04

# Agenda

1

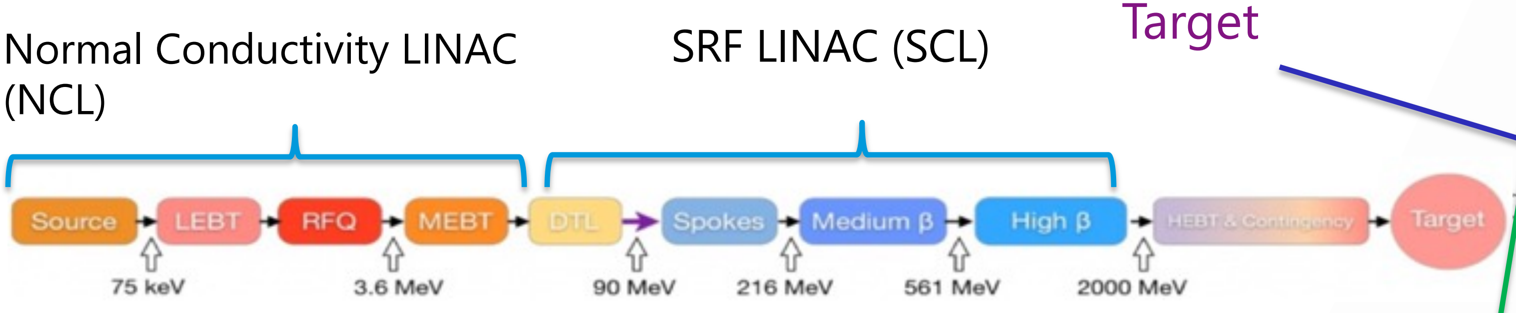
# Introduction: ESS

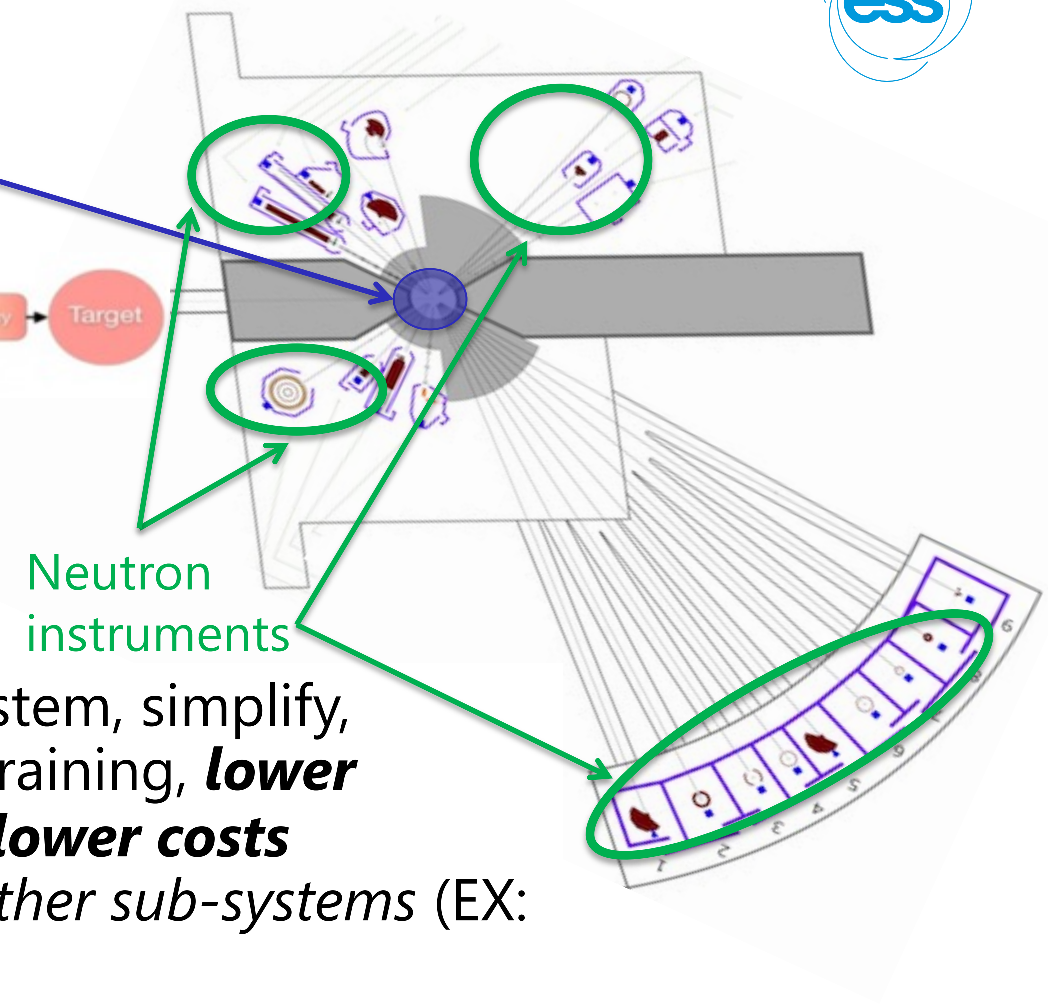
# Accelerator Collaboration



European Spallation Source
EUROPEAN SPALLATION SOURCE
The European Spallation Source (ESS) is a multi-disciplinary research centre based on the world's most powerful neutron source. ESS will give scientists new possibilities in a broad range of research, from life science to engineering materials, from heritage conservation to magnetism. ESS is a pan-European project, with Sweden and Denmark serving as host countries. The main research facility is being built in Lund, Sweden, and the Data Management and Software Centre (DMSC) is located in Copenhagen, Denmark.
DMSC
Copenhagen
ESS
Lund
THE TARGET IS THE NEUTRON SOURCE
When the accelerated protons hit the rotating tungsten target wheel spallation occurs and neutrons are scattered from the tungsten nucleus. The more neutrons produced and collected in the target, the "brighter" the neutron source. The neutrons are directed through moderators and neutron guides to the scientific instruments where they are used for experiments. The Target monolith consists of the Target wheel, moderators, cooling systems and shielding and weighs approximately 5,800 tonnes.
TARGET MONOLITH
5,800 TONNES
13 m
NEUTRON BEAMS
TARGET WHEEL
2,5 m
4.9 TONNES
TUNGSTEN
EXPERIMENTAL HALL 1
SCIENTIFIC INSTRUMENT
LABORATORIES/OFFICES
ACCELERATOR
ION SOURCE
2 000 MEV
TARGET BUILDING
LABORATORIES
SAMPLE
PROTONS GENERATED IN AN ION SOURCE
In the ion source protons are generated and guided into the linear accelerator, the Linac. The first part of the linac is used to focus the proton beam while it accelerates.
EXAMPLE OF CAVITIES
PROTON BEAM
MAGNETIC FIELD
CAVITIES ACCELERATE THE PROTONS
Electromagnetic fields are used to accelerate the protons to approximately 96% of the speed of light. The second part of the accelerator consists of superconducting cavities which are cooled to -271 °C using liquid helium. After traveling 602.5 m the protons hits the target wheel.
EXPERIMENTAL HALL 2
NEUTRON BEAMS
EXPERIMENTAL HALL 3
SCIENTIFIC INSTRUMENT
UNIQUE CAPABILITIES OF ESS
ESS will have 22 tailor-made instruments located in three experimental halls. Neutrons are excellent for probing materials on an atomic and molecular level – everything from motors and medicine, to plastics and proteins. The neutrons hit the sample and detectors register the neutron scattering, giving precise information about the material's structure and dynamics.
TOTAL BUILDING AREA 65 000 m²
The ESS facility will be approximately 650 metres in total length. The target building will be 125 metres long, and about 30 metres high. The 537-meter-long accelerator tunnel is built underground and will be covered with soil.
Concrete: 50 000 m³
Rebar: 6 000 tonnes
Pipes: 40 km
Cables: 2,000 km
Total volume: 400,000 m³
PILES TO AVOID MOVEMENTS
The heavy Target building and experimental halls are resting on a total of 6,400 piles of different types, in order to avoid unwanted movements in the structure.
602.5 m
TARGET MONOLITH
© JOHAN JARNESTAD/EUROPEAN SPALLATION SOURCE

# Introduction:




The ESS organization charges the ESS Vacuum Group (VG) with the responsibility for all ESS vacuum systems (vacuum instruments and

**Justification: *integrated design*** of the vacuum system, simplify, ***common components***, ***reduce maintenance*** and training, ***lower number of hardware spare parts***, create ***scale to lower costs*** (Framework Agreements), *simplify interfaces with other sub-systems* (EX: ICS, MPS, PSS interface).

It means, support the collaborations on Neutron Instrument to work on their specific needs looking from the ESS long term operation in a most cost effective way.

# Vacuum Standardization
# an Integrated Approach

Working closely with our partners across the project, one of our primary goals was to **promote** the use of **common vacuum equipment and standards**. As a result a Vacuum Standardization meeting was held in February 2014 where equipment suitable for Standardization was agreed and reflected in the **ESS Vacuum Handbook**.

An important element of this **standardization** is the Vacuum Procurement Policy. The primary objective of the program is to develop a list of standard vacuum equipment through a **Vacuum Framework Agreement** (**VFA**) for use project wide to minimize project costs, reduce spares holdings, training and achieve other benefits of standardization. The **VFA** was made in conjunction with **UK** and **France**.

https://europeanspallationsource.se/vacuum

**Description: ESS Vacuum Handbook Part 1**
Document No 0.
Date 23 May 2014

**1. INTRODUCTION**

The European Spallation Source (ESS) is an accelerator-driven neutron spallation source. The linear accelerator (LINAC) of which is a critical component. The role of the accelerator is to create protons at the ion source, accelerates them to an appropriate energy, and steers them onto the target to create neutrons via the spallation process for use by a suite of research instruments.

**2. SCOPE**

The ESS Vacuum Handbook comprises four (4) parts:

ESS Vacuum Handbook Part 1 – General Requirements for the ESS Technical Vacuum Systems,

ESS Vacuum Handbook Part 2 – Vacuum Equipment Standardization,

ESS Vacuum Handbook Part 3 – Vacuum Design & Fabrication, and

ESS Vacuum Handbook Part 4 – Vacuum Test Manual

This Vacuum Handbook (VH) part 1 provides guidelines, and imposes requirements where necessary, for the definition of equipment and processes associated with the vacuum systems of the Accelerator, Target and Neutron Instruments. The VH is applicable to all vacuum components and systems exposed to a technical vacuum environment.

This VH, a level 2 requirement, is to ensure that consistent standards are employed throughout all the accelerator, target and neutron instrument vacuum systems and hardware.

This VH will be periodically updated throughout the life of the ESS project.

All queries or additional information concerning the contents of this handbook should be addressed to the ESS Vacuum Group Section Leader (VGL).

**3. REPONSABILITIES**

The ESS vacuum team has overall responsibility for all technical vacuum systems used on the Accelerator, Target and Neutron Scattering Instrument Systems and has

# Highlights

Selected accomplishments (vacuum and cryo-modules):

- IS to DTL1 vacuum conditioned completed, Beam commissioning up to DTL FC started,
- Three elliptical CM passed acceptance test at ESS TS 2 (vacuum/RF/Cryo)
- All normal vacuum chambers received 100% particle-free pass SAT, 75% non-particle free pass SAT (include vacuum/BI/Magnets), vacuum in kind finished!
- Eight spoke CM produced (out of 13) with more under assembly - IJCLAB
- Five spoke CMs passed acceptance test at the FREIA LAB in Uppsala – FREIA
- Five MB elliptical CMs produced with first HB under final assembly - CEA

# Progress in tunnel for Cryo-distribution

- All parts of spoke LINAC cryogenic distribution system delivered and and welding of header units under way
- Elliptical cryogenic system completed
- Cool-down planned for Q3 2022

# Original discussion on gate valves

## Discussion between 2012-2017

2012-2014 Discussion ESS-CEA-INPO on the best options for the gate valve

Main goals of the design for ESS were: **highest reliability** on the vacuum system (including power failure), **less particle generation possible**, **avoid** materials with **short life in radiation** (< 25 y), **redundant equipment** in case of **low reliability**. (pumps/controller related).

**Ion Pumps**: source of particle generation since the design works by **sputtering process**,

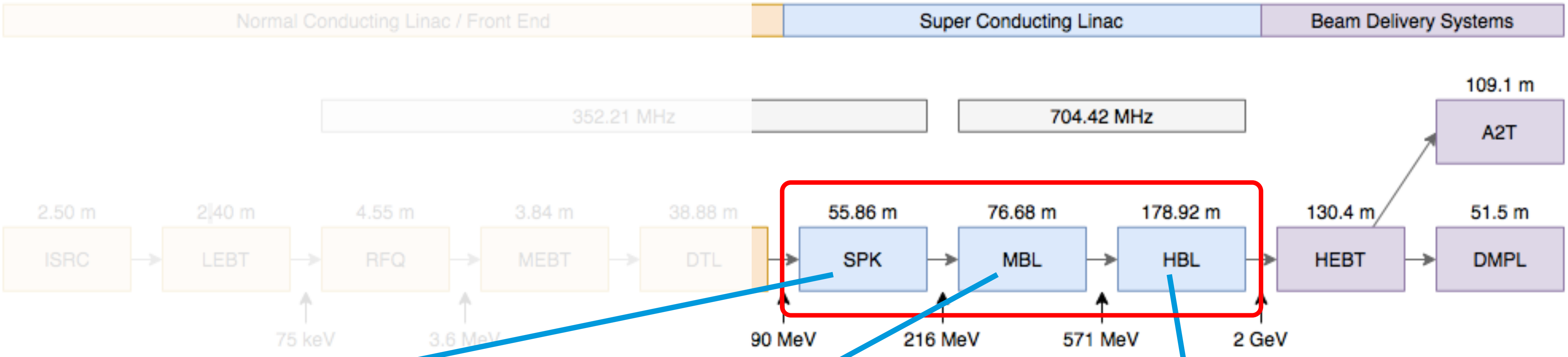
Gate valves: **VAT didn't have better product for low particle generation (series 64 O’ring) until 2017 (!!)** and the EPDM material was discarded after ESS test/research. **VAT developed all metal valves for particle free for semiconductor industry!**

Decision came as an **integrated approach**:

- ZAO NEG alloy as main vacuum pump for all accelerator,
- All-metal gate valves as the lowest particle generation and high life time in radiation (mix environment gamma/neutrons),
- decrease as much as possible any BI to generate particles, from the design perspective for any movable part, should pass the same requirements as LWU.

# Super Conducting RF (SRF) LINAC

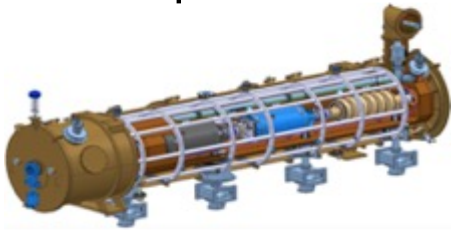
## Cryo-Module (CM) and LINAC Warm Unit (LWU)




x13 Spoke CMs

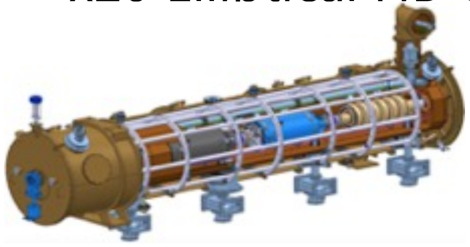
x1 Low Energy DP
x12 Spokes LWUs

x9 Elliptical MB CMs



x9 Elliptical
Medium β LWU's

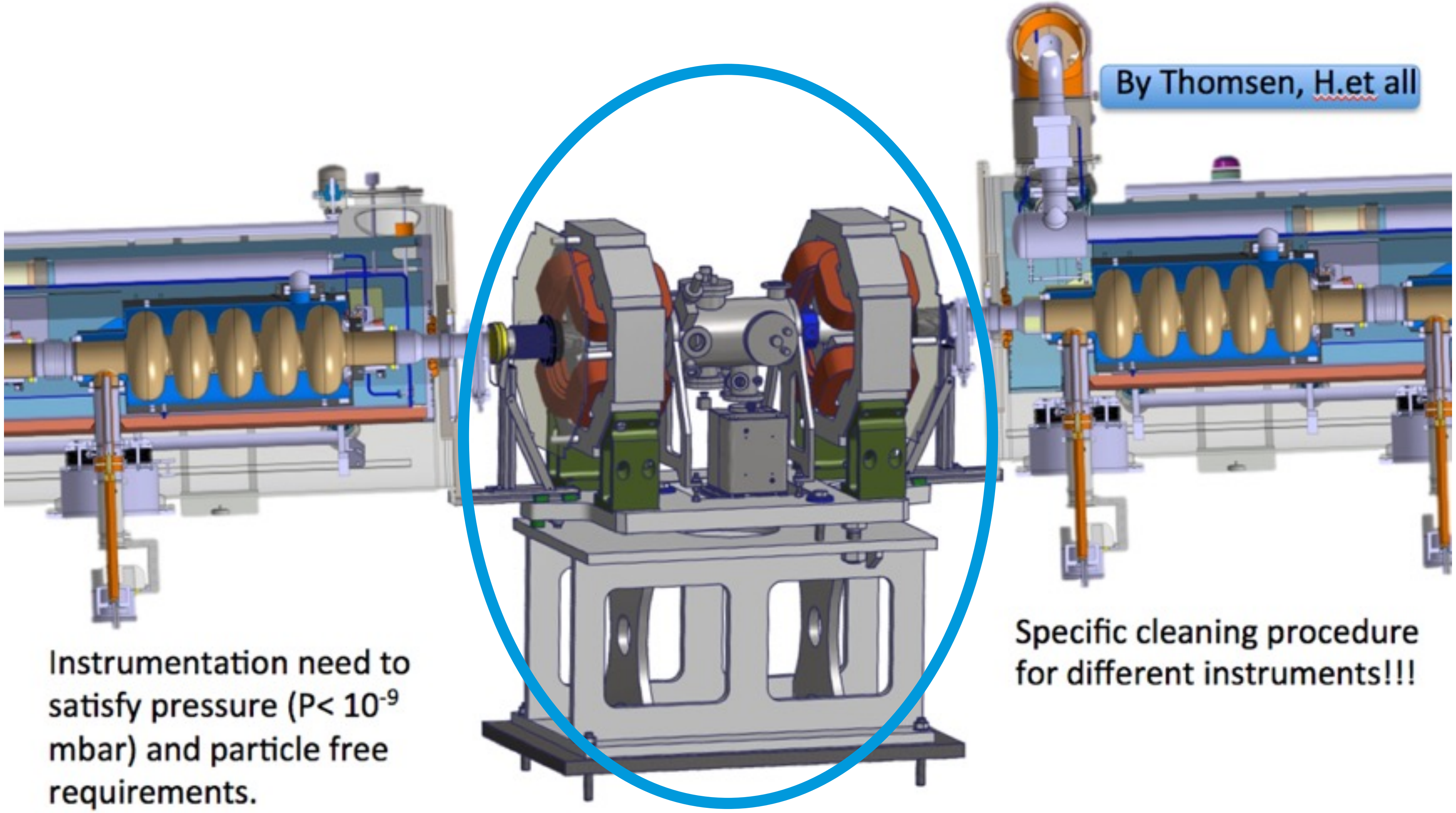
x20 Elliptical HB CMs



x20 Elliptical High β
LWUs x1High Energy DP

# LINAC Warm Unit (LWU)

## Vacuum in kind from STFC/DL (UK)



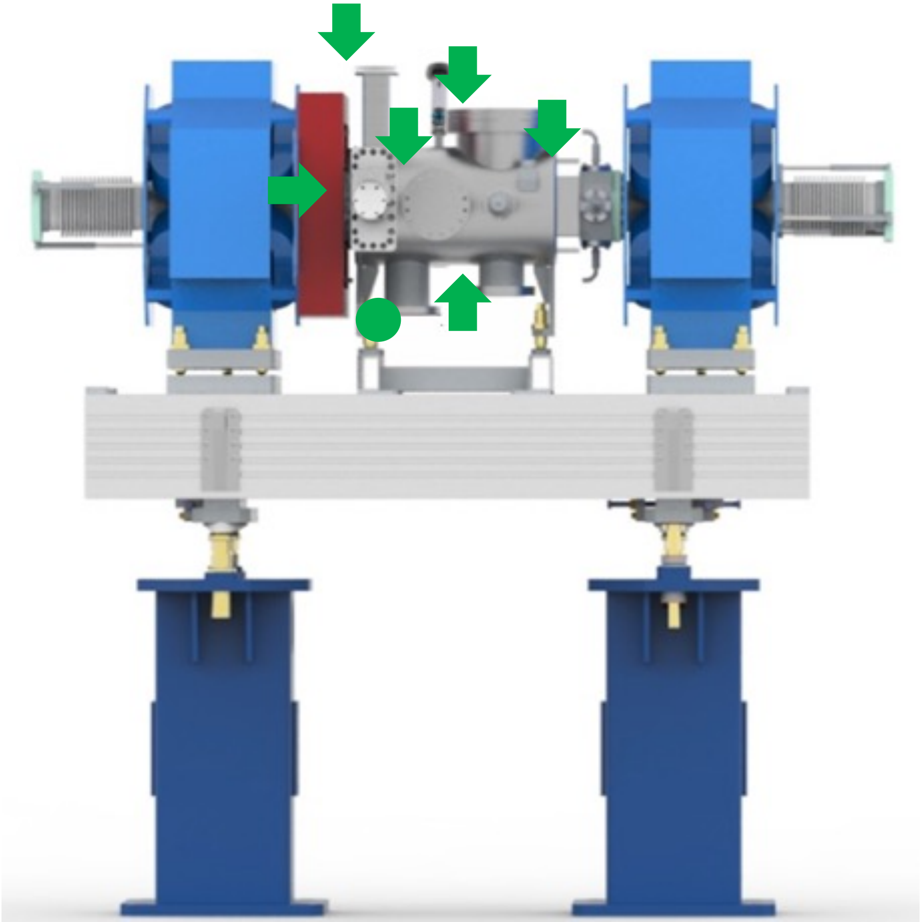

Instrumentation need to satisfy pressure (P< $10^{-9}$ mbar) and particle free requirements.

Specific cleaning procedure for different instruments!!!

Two families: 13 x Spoke LWU (SWU) & 51 x Elliptical LWU (EWU)

# LINAC Warm Unit (LWU)

## Vacuum in kind from STFC/DL (UK)



LWU's provide vacuum continuations between cryo-modules and host beam diagnostic and magnets. Designed, built and processed for UHV and particle free operation (base pressure $5*10^{-9}$ mbar, without beam).

Equipped with **DN100 flange** for UHV pump, DN40 manual valve, Pirani and cold cathode, burst disk.

LWU's integrate **quadrupoles** and **correctors.**

Various **flanges** dedicated to diagnostics (e.g. Wire Scanners, BPM, BCM, Faraday Cup, Bunch Shape Monitor).

Adjustment **fixtures** for the alignment of the girder, the chamber and the quadrupoles.

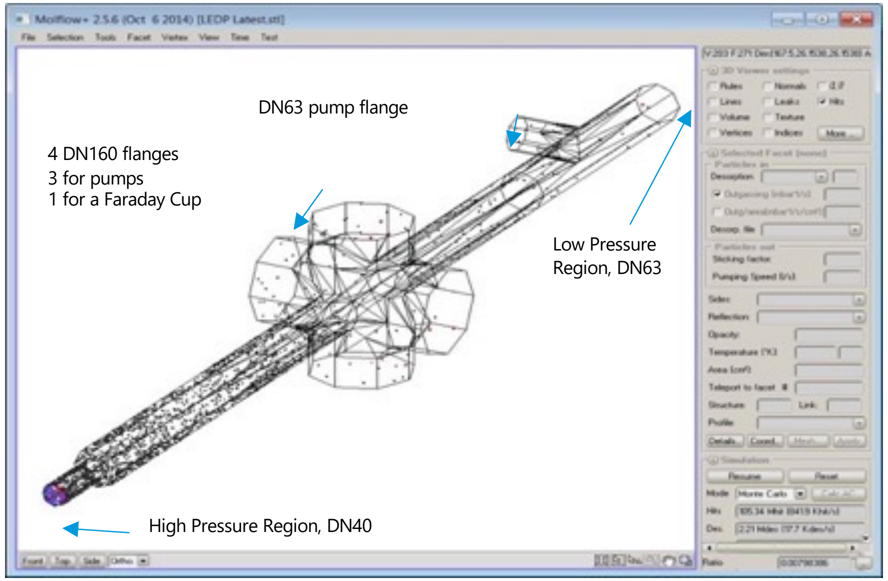
# Low/High Energy Differential Pump

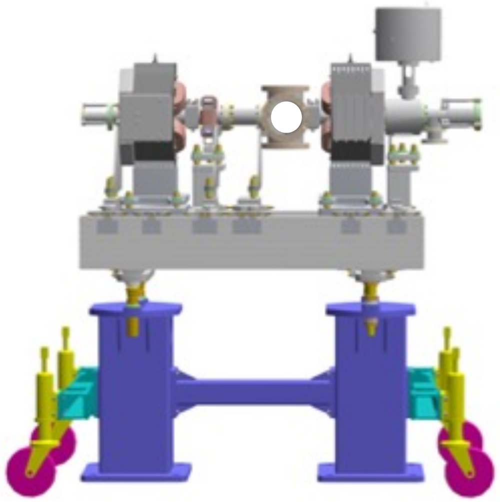
## Vacuum in kind from STFC/DL (UK)

**Requirement of the differential pumping sections**:

- High pressure / Low pressure = 100 to protect superconducting RF cavity
- Molflow+ simulation with the following parameter set:
  - HPR facet desorption = 1
  - HPR facet sticking coefficient S = 1
  - LPR sticking coefficient S = 1
  - All simulations were run for mass 28
  - The pressure ratio is calculated as the ratio between the adsorbed particles on LPR facet and the total desorbed particles

<u>Simulation result</u>: a 100:1 ratio across the section requires approximately 2000 l/s ($N_2$).

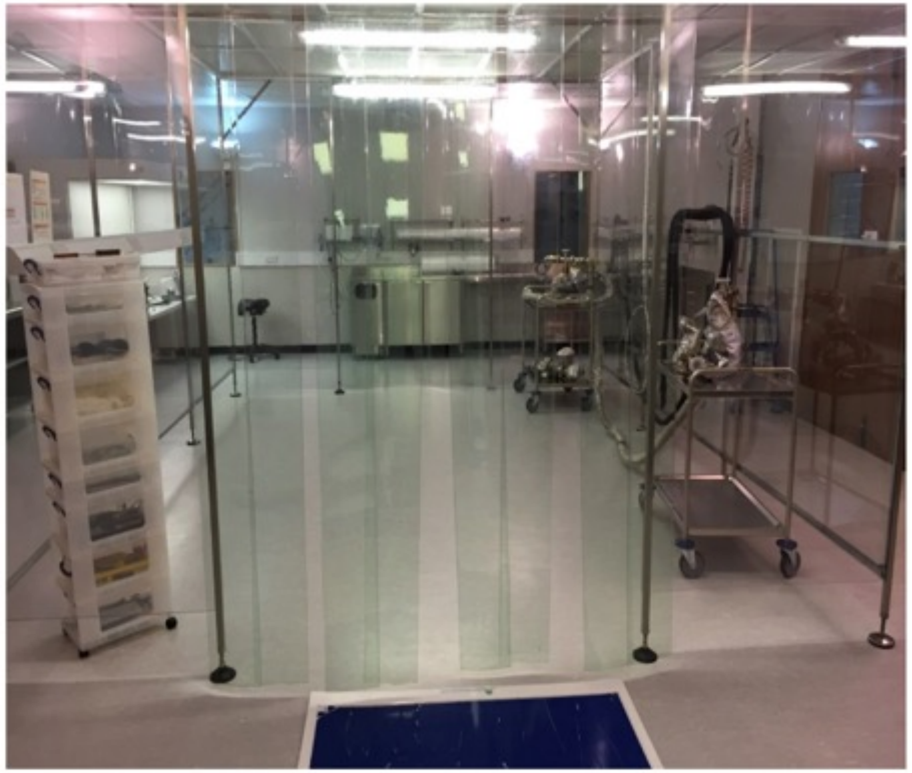


LEDP/HEDP approximately 2 m long

# Cleanroom Upgrade

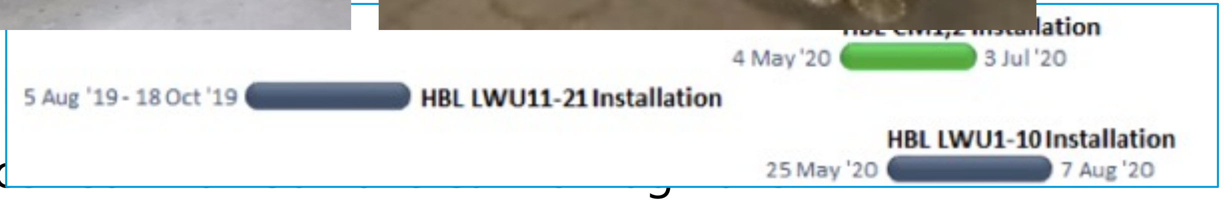
From: **System Review of the Particle Free LWU Installation,** 2017
By Dr. K. Middlemann (STFC/DL)



- Change area $6m^2$ - ISO 7
- Outer area $80m^2$ - ISO 6
- Inner area $12m^2$ ISO 4 at rest
- ISO 5 with 2 people

# HBeta Section Installation Schedule

EUROPEAN SPALLATION SOURCE

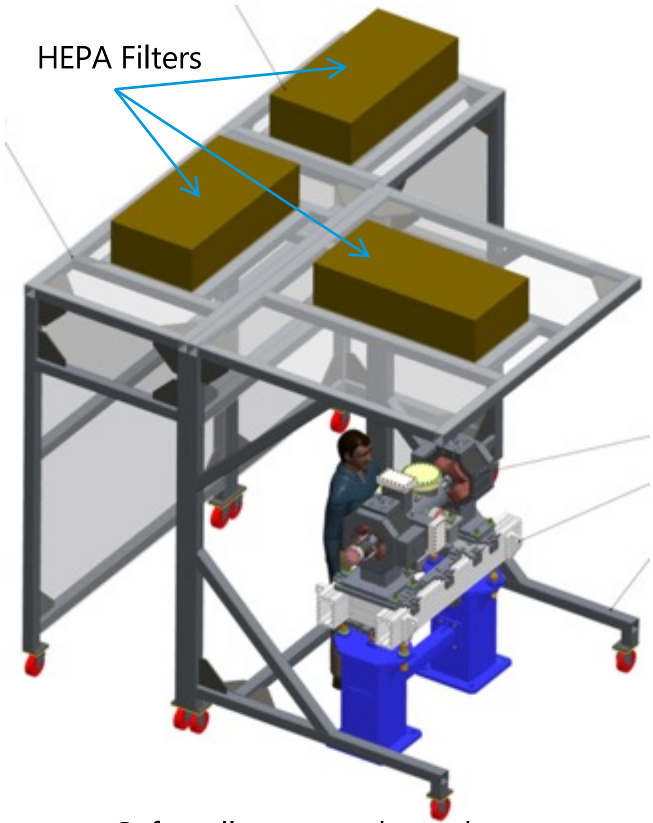



From: **System Review of the Particle Free LWU Installation,** 2017
By F. Ravelli (ESS)

- All DCM's are rec
- Install all DCM's in Q2-Q4 2018, TBC with Ciprian
- LWU HEBT-010LWU & HEDP install in Oct 2018 - Jan 2019, TBC with Ciprian
- Same LWU install rule for DCM's as CM's, so CM's first and LWU's later
- HBL-011LWU to HBL-021LWU install in time slot 5 Aug – 18 Oct 2019, 7 days per LWU
- HBL-001LWU to HBL-010LWU install in time slot 25 May – 7 Aug 2020, 7 days per LWU

# LINAC Warm Unit (LWU)

## Vacuum in kind from STFC/DL (UK)

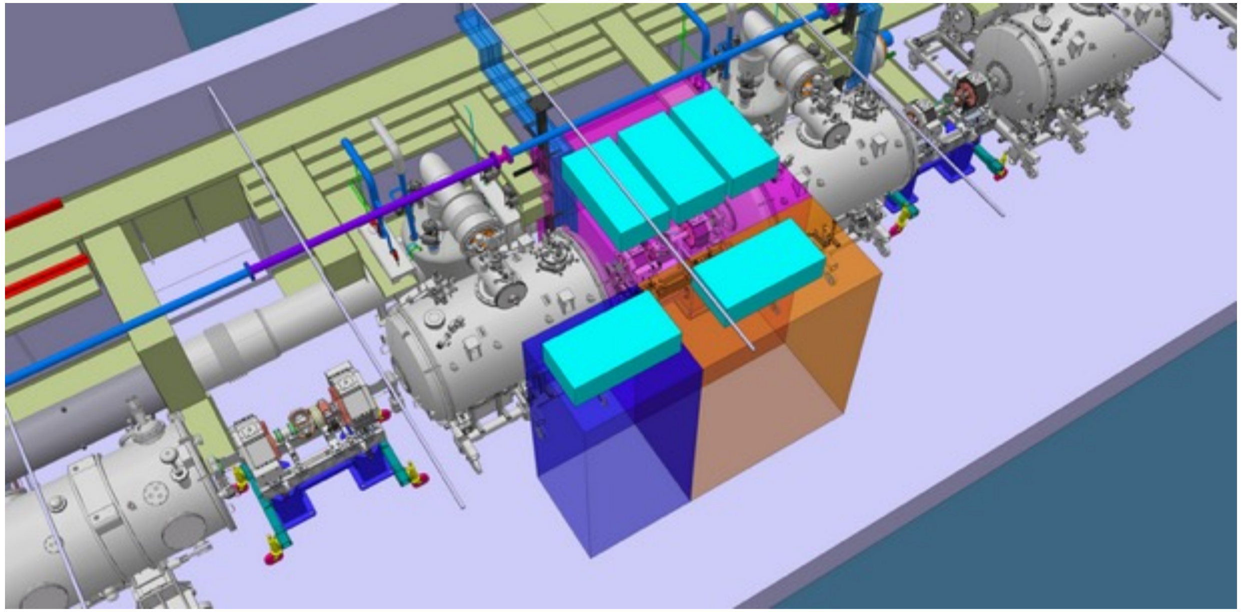



Soft-walls are not showed

Installation of LWU to the cryo-modules require a **particle free environment**; portable modular clean rooms are designed by STFC/Daresbury for in-tunnel installation.

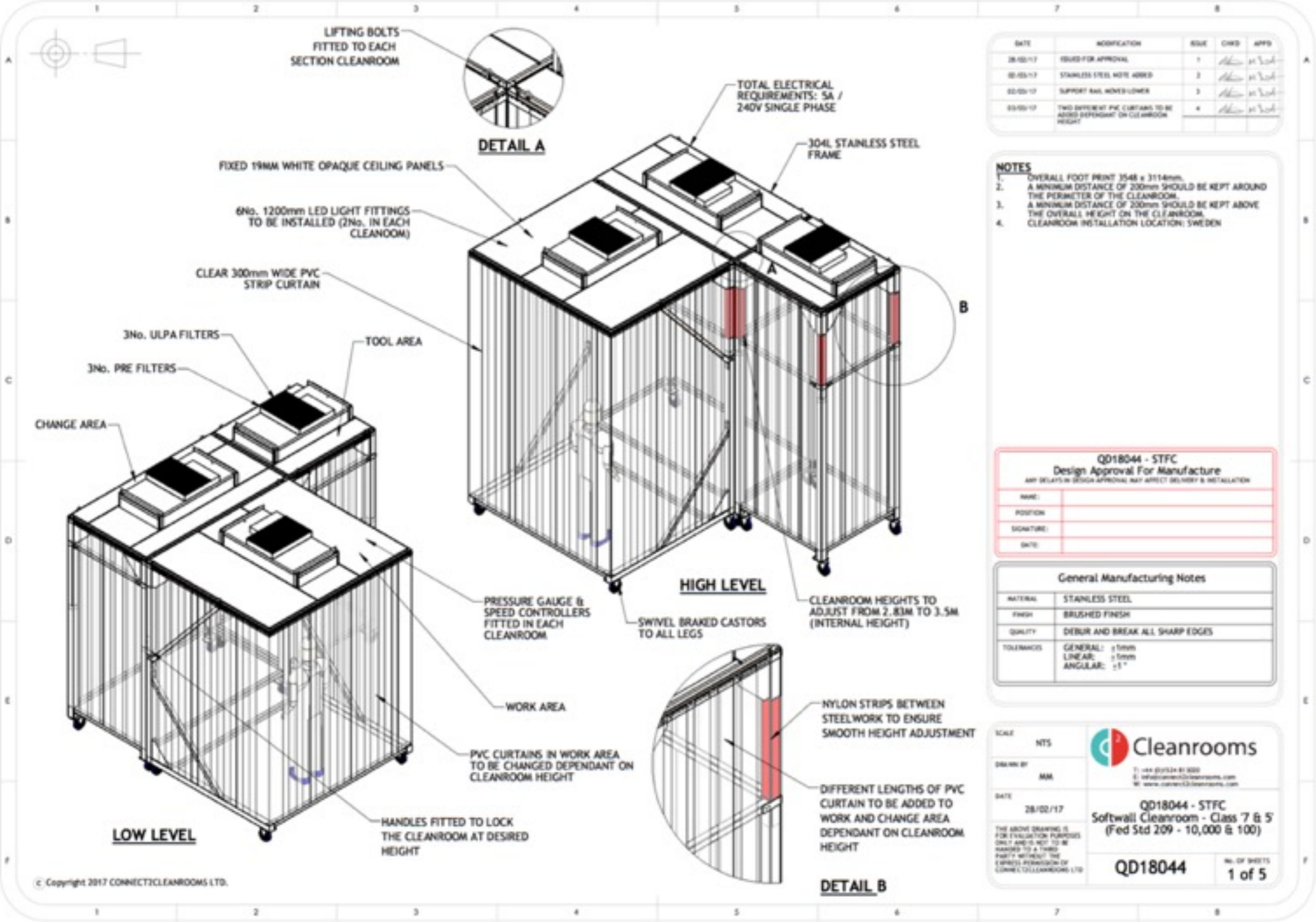
Three independent units with specific functions: gowning room, stock room for tools and components and working unit (ISO class 5 standard).

Prototype version installed at RATS for testing



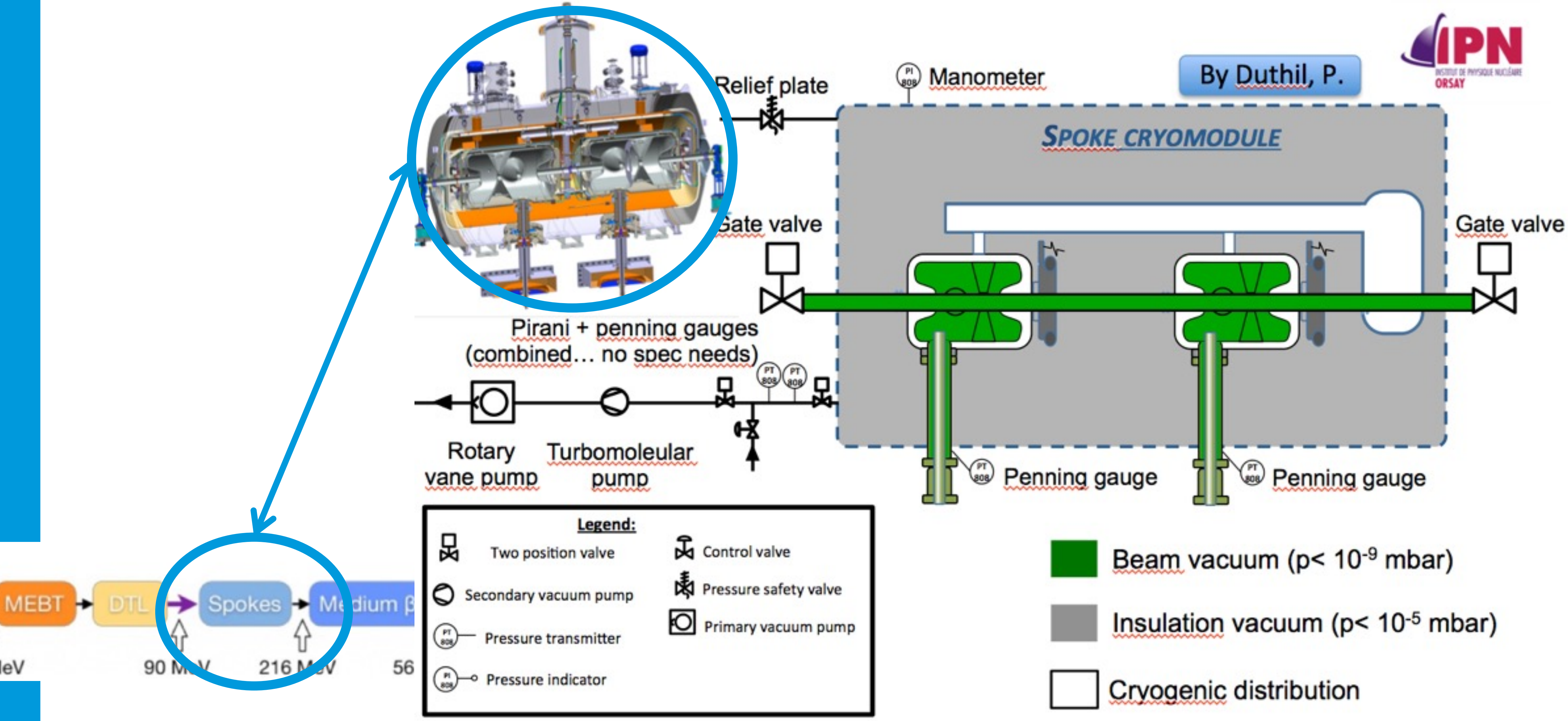
# Mobile Clean room

## Vacuum in kind from STFC/DL (UK)

# LINAC Spokes

## In kind from France, IJC-Lab (IPN)



# Spoke Cryomdoule testing in Uppsala/FREIA well under way

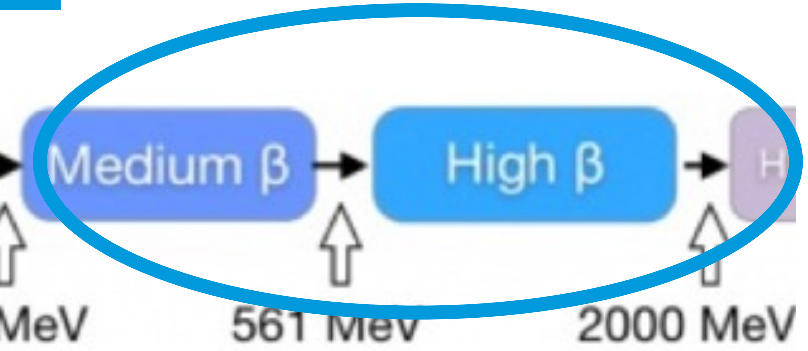
# Elliptical cavity (medium/high β)

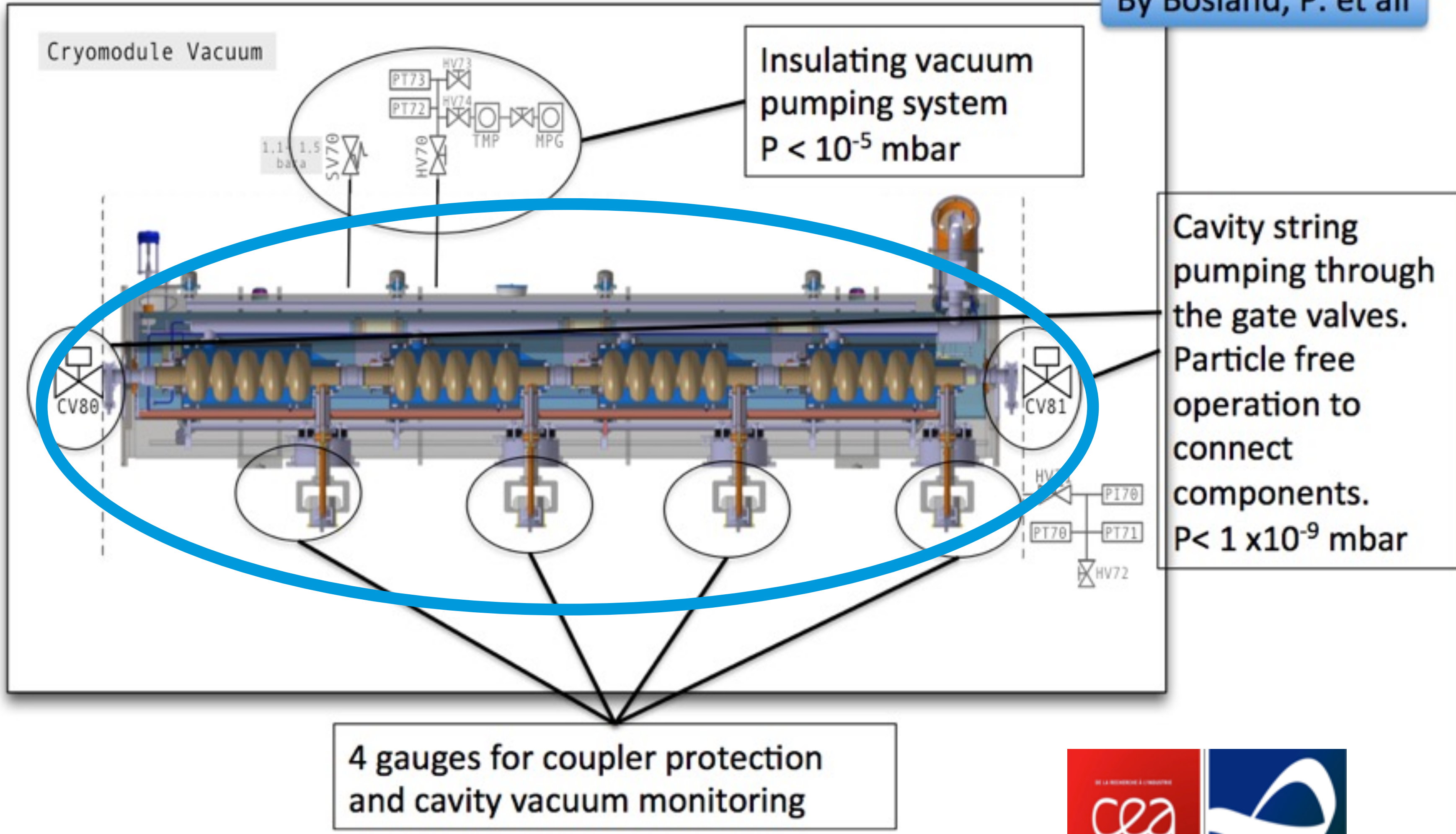
## In kind from France, CEA - Saclay

By Bosland, P. et all

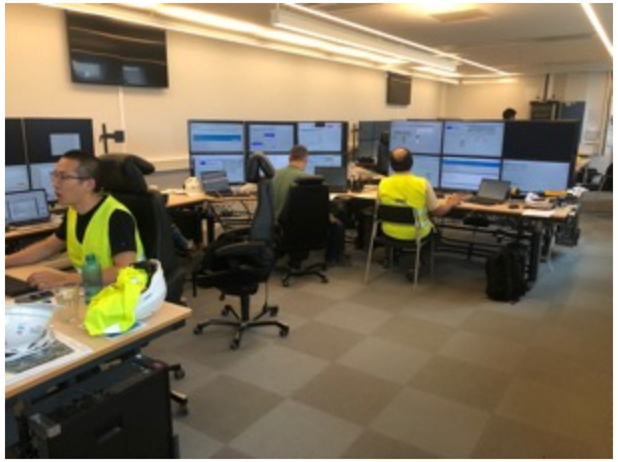
x9 Mediumβ cryomodules increasing beam energy from 216 to 561 MeV

x21 Highβ cryomodules increasing beam energy from 561 to 2000 MeV



# Cryomodule Testing under way at ESS



- Two first medium beta elliptical cryomodules tested
- Vacuum gauge replacement on one coupler done at ESS by CEA followed by a new cool-down and high-power test to verify the repair

# LINAC Warm Unit (LWU)

## Vacuum in kind from STFC/DL (UK)

Full producti

Acceptance
for Beam
installation on
particle free (ISO Class 5) 2020

# Vacuum installation in the tunnel

## Particle free connections

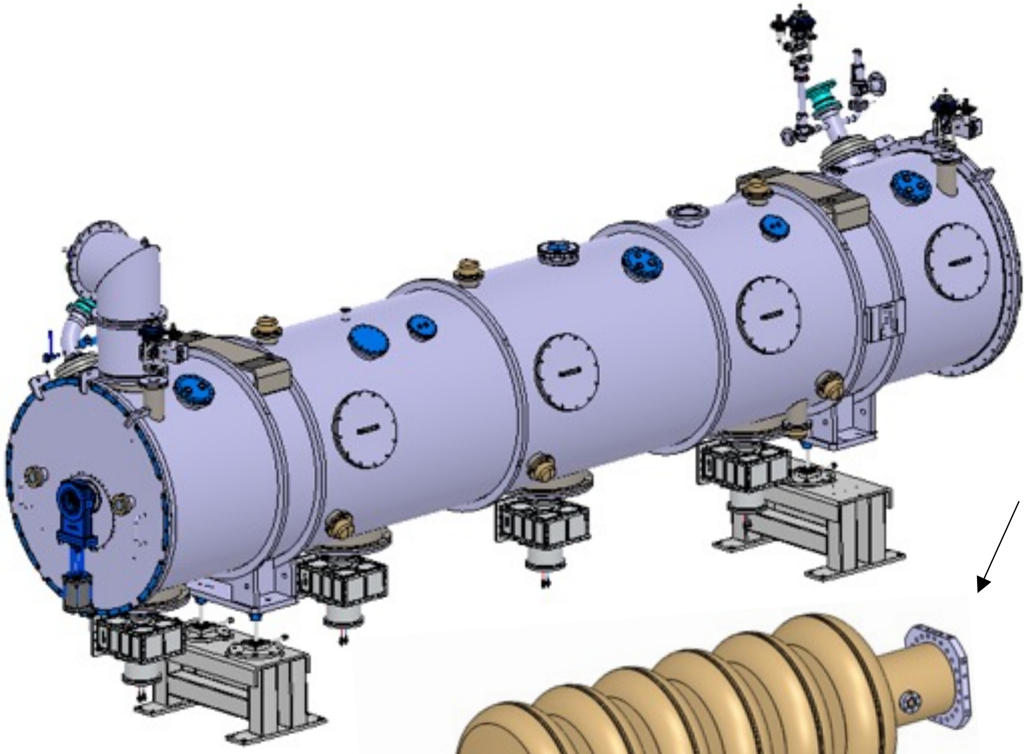
2

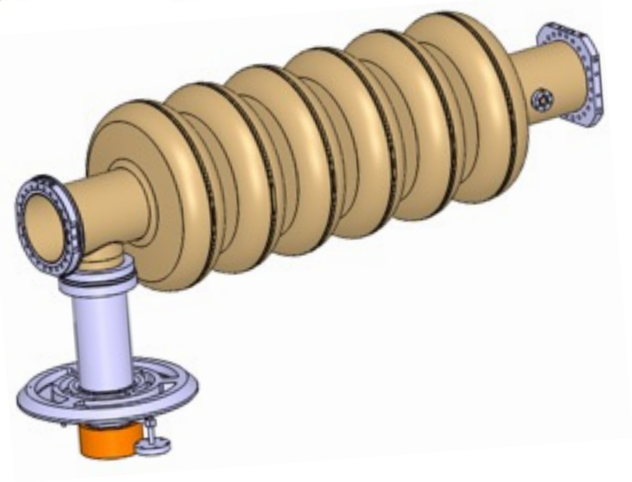
# Vacuum assembling learned lessons (by Artur Gevorgyan)

# ESS SCL particle-~~free~~less vacuum system

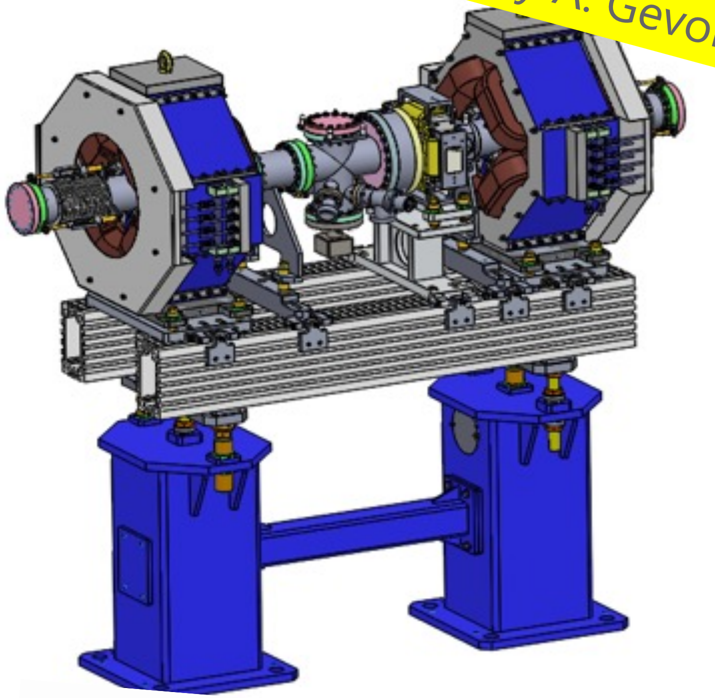
## Elliptical section

By A. Gevorgyan (ESS)

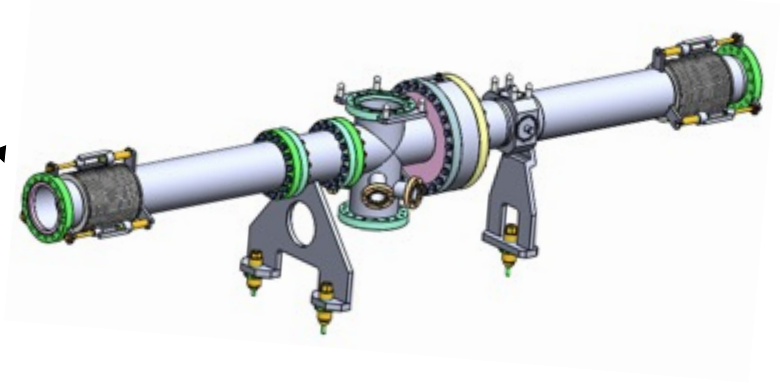




Cleaning and assembly in ISO 4 clean room!



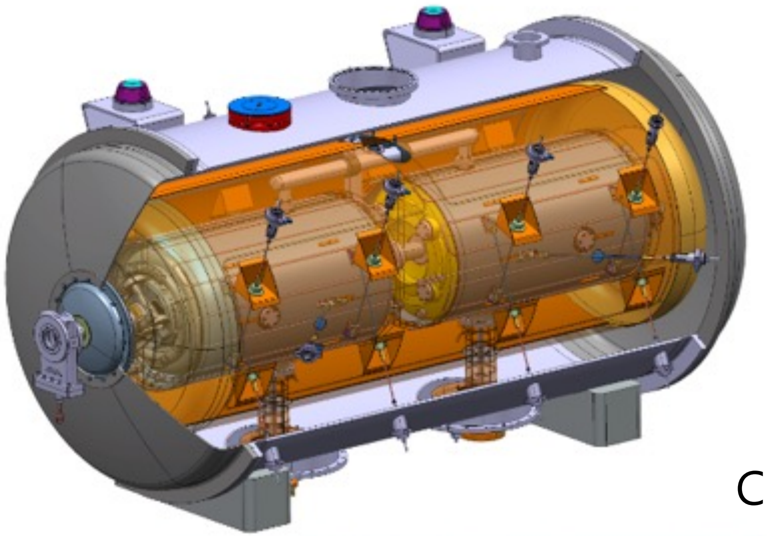
Cleaning and assembly in ISO 5 clean room!

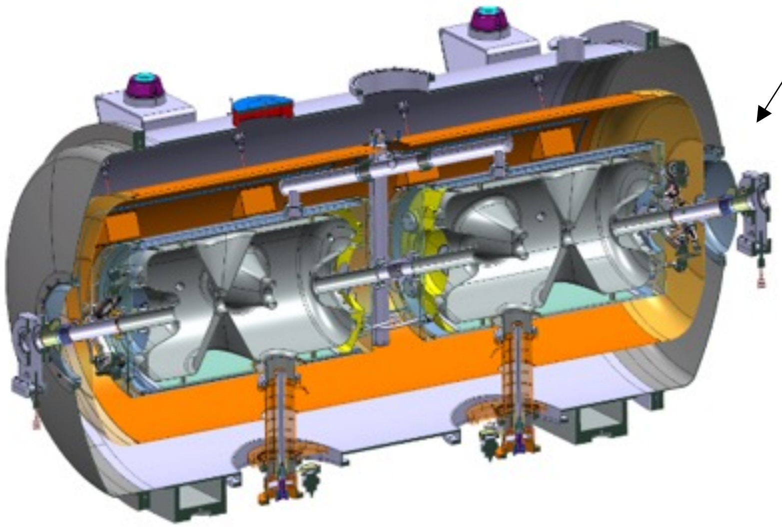


# ESS SCL particle-~~free~~less vacuum system

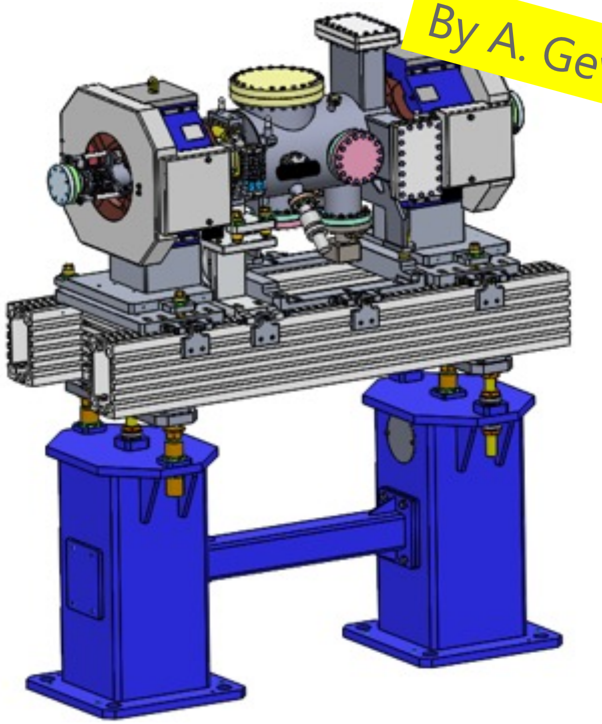
## Spoke section

By A. Gevorgyan (ESS)

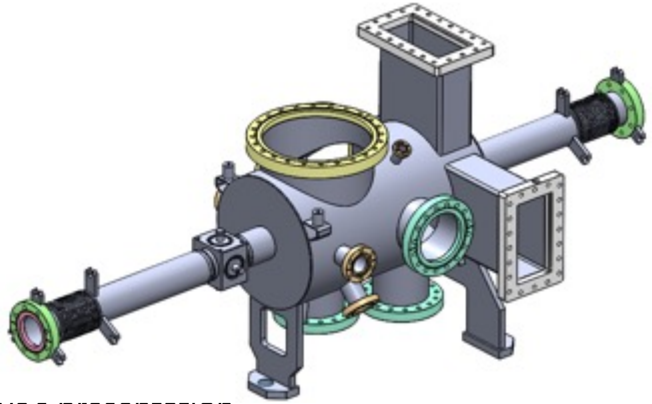




Cleaning and
assembly in ISO
4 clean room!



Cleaning and
assembly in ISO
5 clean room!



SPK CR images copied from Christine Drave s presentation.
(https://indico.cern.ch/event/234471/contributions/495949/attachments/391968/545107/Darve.pdf)

# ESS SCL particle-~~free~~ less vacuum system

By A. Gevorgyan (ESS)

## Reliability.

Vacuum leaks as a source of possible particle contamination/air inrush?

| Diameter | Leak rate in $\frac{mbar \cdot \ell}{s}$ | |
|---|---|---|
| $10^{-2}$ m= 1,0 cm | $10^{4}$ | |
| $10^{-3}$ m= 1,0 mm | $10^{2}$ | |
| $10^{-4}$ m= 0,1 mm | $10^{0}$ | (= 1) |
| $10^{-5}$ m= 0,01 mm | $10^{-2}$ | |
| $10^{-6}$ m= 1,0 µm | $10^{-4}$ | |
| $10^{-7}$ m= 0,1 µm | $10^{-6}$ | |
| $10^{-8}$ m= 0,01 µm | $10^{-8}$ | |
| $10^{-9}$ m= 1,0 nm | $10^{-10}$ | |
| $10^{-10}$ m= 1,0 Angström | $10^{-12}$ | |

| ISO Class number (N) ISO 14644-1 | Maximum allowable concentrations (particles/m3) for particles equal to and greater than the considered sizes, shown below[a] | | | | | |
|---|---|---|---|---|---|---|
| | 0,1 µm | 0,2 µm | 0,3 µm | 0,5 µm | 1 µm | 5 µm |
| **1** | 10[b] | d | d | d | d | e |
| **2** | 100 | 24[b] | 10[b] | d | d | e |
| **3** | 1 000 | 237 | 102 | 35[b] | d | e |
| **4** | 10 000 | 2 370 | 1 020 | 352 | 83[b] | e |
| **5** | 100 000 | 23 700 | 10 200 | 3 520 | 832 | d ,e, f |
| **6** | 1 000 000 | 237 000 | 102 000 | 35 200 | 8 320 | 293 |
| **7** | c | c | c | 352 000 | 83 200 | 2 930 |
| **8** | c | c | c | 3 520 000 | 832 000 | 29 300 |
| **9g** | c | c | c | 35 200 000 | 8 320 000 | 293 000 |

Table regarding leak rate correlation from: https://www.leyboldproducts.com/media/pdf/90/c7/87/Fundamentals_of_Leak_Detection_EN.pdf

# ESS SCL particle-~~free~~ less vacuum system

By A. Gevorgyan (ESS)

## Reliability.

What can impact?

- Corrosion of vacuum components, like bellows from Radiation and Humidity,
- Mechanical design, vibrations, moving parts (instruments),static and dynamic friction coefficients in/out vacuum,
- Beam impact and radiation induced degradation,
- Material selection, roughness, surface treatment,
- Cleaning,
- Vacuum pumps, gauges, fast and normal closing valves,
- Venting, pumping,
- Pressure stabilization,
- Thermal treatment: In-situ bake outs of complex instruments,
- Particle transport with charged beam,
- Adjustment component cleanliness and buffer zones,
- Transport.
- Assembly zone preparation and segmentation.
- Parallel activities,
- Sensitive instrumentsAccessibility.

….

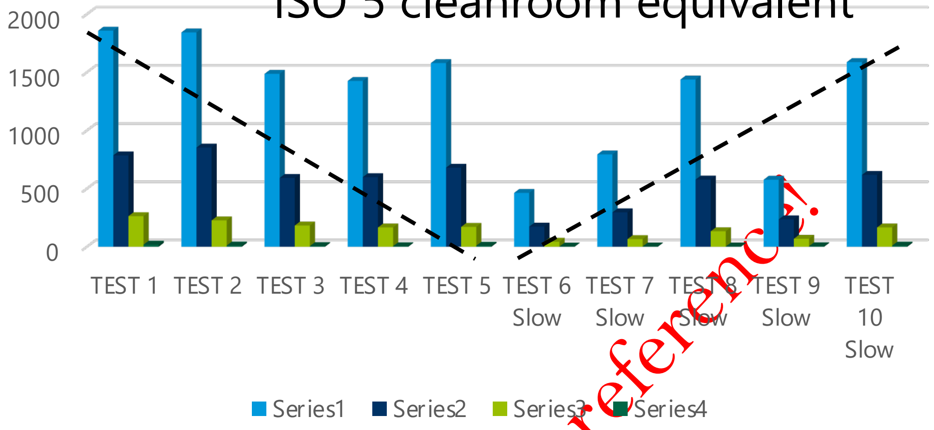
# ESS SCL particle-~~free~~less vacuum system

## Reliability.

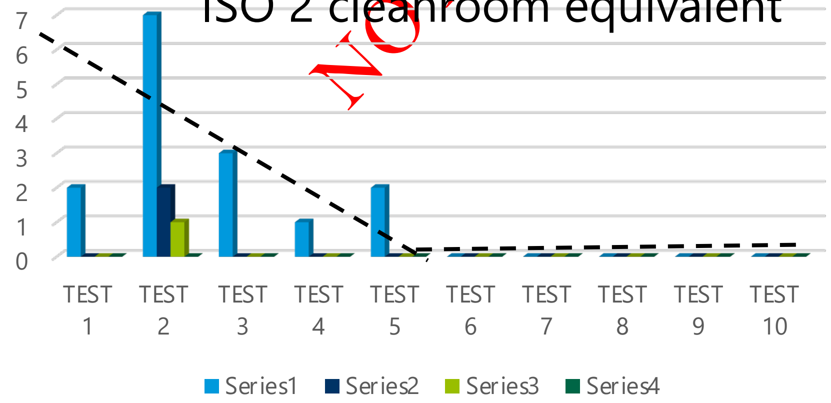
By A. Gevorgyan (ESS)

Normal closing all-metal valves.

fast and slow opening




fast closing




| Material pair | Friction coefficient |
|---|---|
| Stainless vs. stainless | 0.80 |
| Titanium vs. titanium | 1.00 |
| Hardened steel vs. itself | 0.35 |
| Cadmium plate vs. steel | 0.20 |
| Silver vs. stainless or Ti | 0.18 |

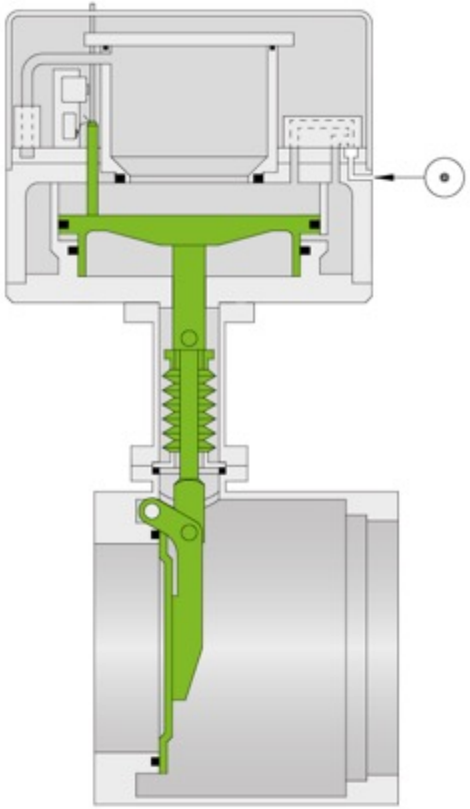
Table from: https://eprints.arums.ac.ir/9308/1/Scanning21212.pdf

# ESS SCL particle-~~free~~ less vacuum system

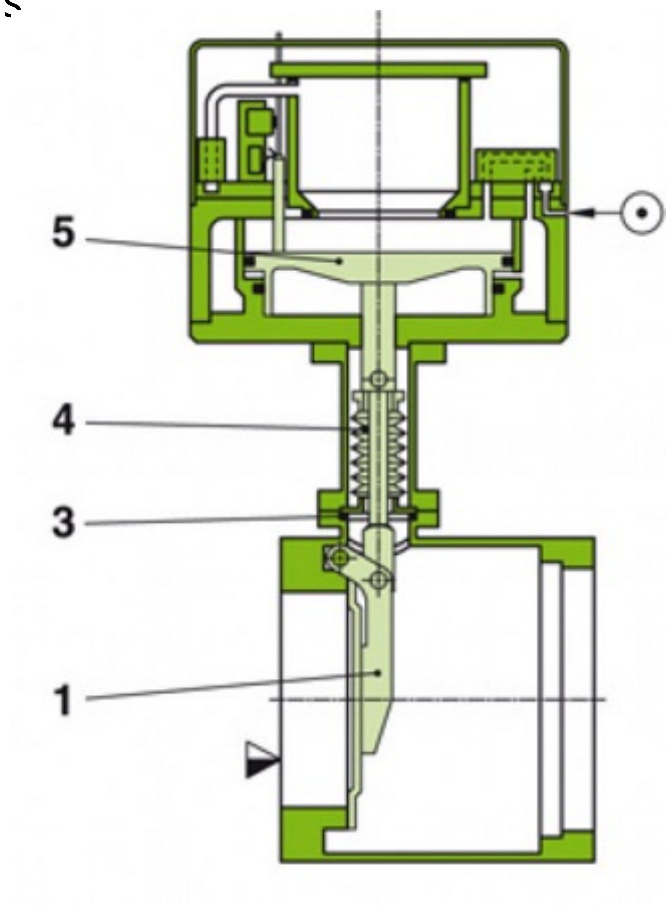
By A. Gevorgyan (ESS)

## Reliability.

Fast closing valves and shutters



Fast valve




Fast shutter

### Fast valve

| | | |
|---|---|---|
| Leak rate | – Valve body | $< 1 \cdot 10^{-10}$ mbar ls$^{-1}$ |
| | – Valve seat | $< 1 \cdot 10^{-9}$ mbar ls$^{-1}$ |

### Fast shutter

Leak rate

| | |
|---|---|
| - To the outside | $< 1 \cdot 10^{-10}$ mbar ls$^{-1}$ |
| - Seat | $< 30$ mbar ls$^{-1}$ (air, 1 bar) |

Leak tightness is better than contaminated cryomodule.

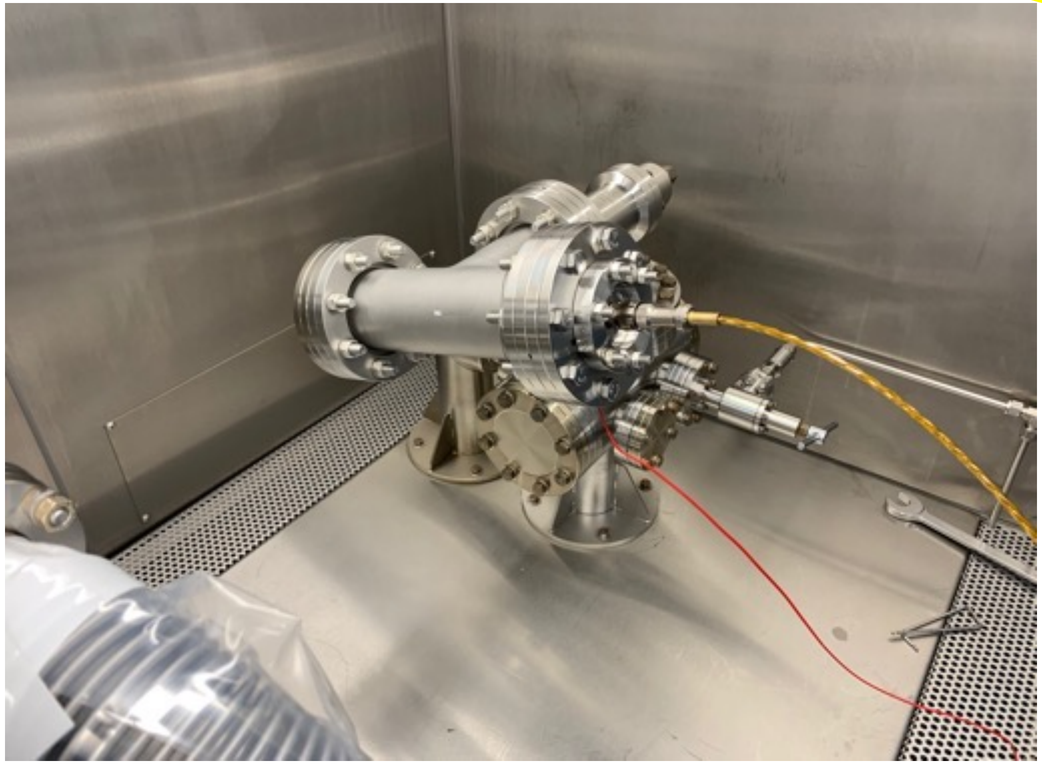
Information and images from: https://www.vatvalve.com/series/ultra-high-vacuum-fast-closing-valve-flap-valve-version/75040-CE44
https://www.vatvalve.com/series/ultra-high-vacuum-fast-closing-flap-shutter/77140-CE44

# ESS SCL particle-~~free~~-less vacuum system

By A. Gevorgyan (ESS)

## Reliability.

NEG pumps. ZAO alloy.



Cleaned and assembled in ISO 4 room.

Images by Delphine Hardion and Thomas Cornes. ESS.

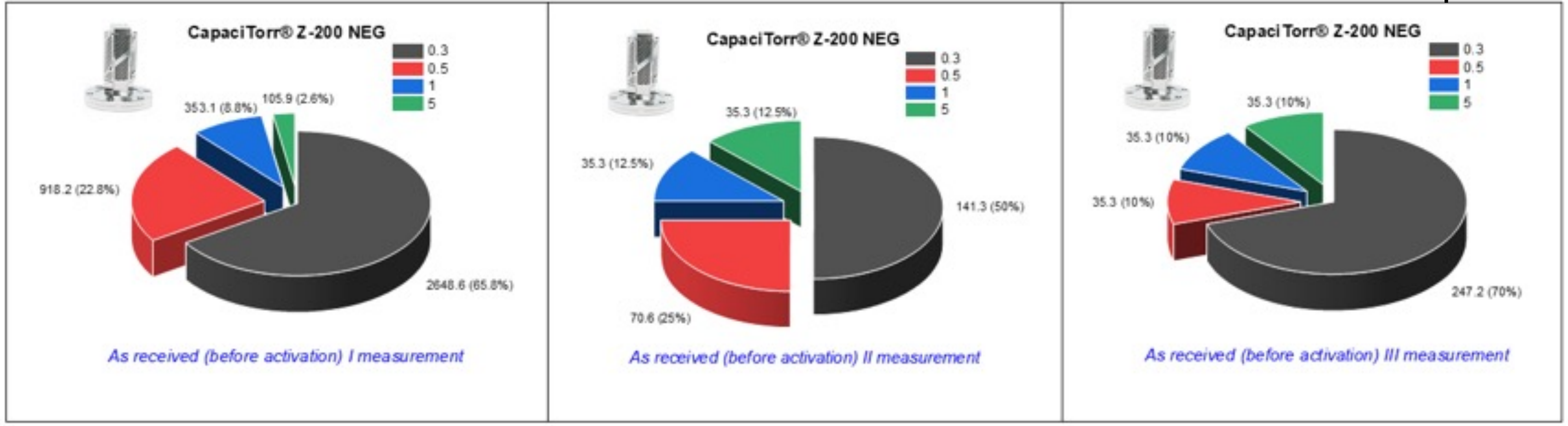
# ESS SCL particle-~~free~~less vacuum system

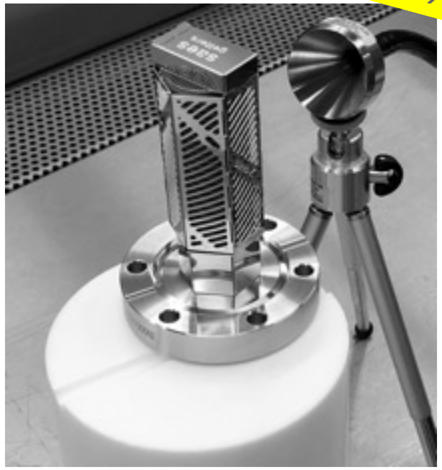
By A. Gevorgyan (ESS)

## Reliability.

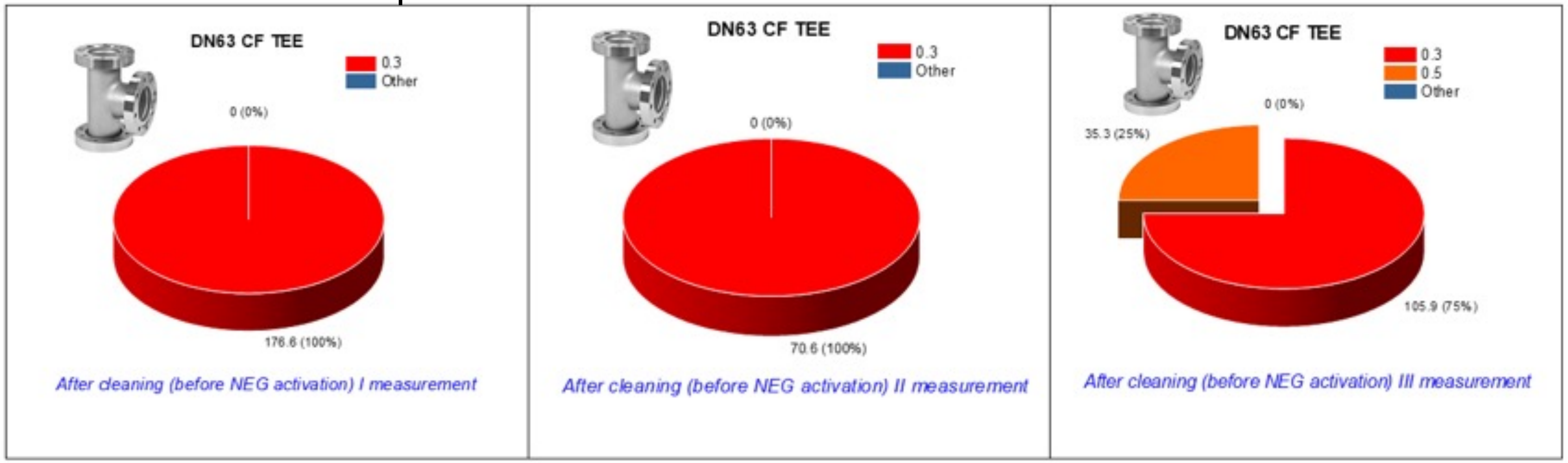
NEG pumps. ZAO alloy. Particle counting before activation (as-received).

ISO 6 clean room equivalent!



ISO 3 clean room equivalent!




Images by Delphine Hardion and Thomas Cornes. ESS.

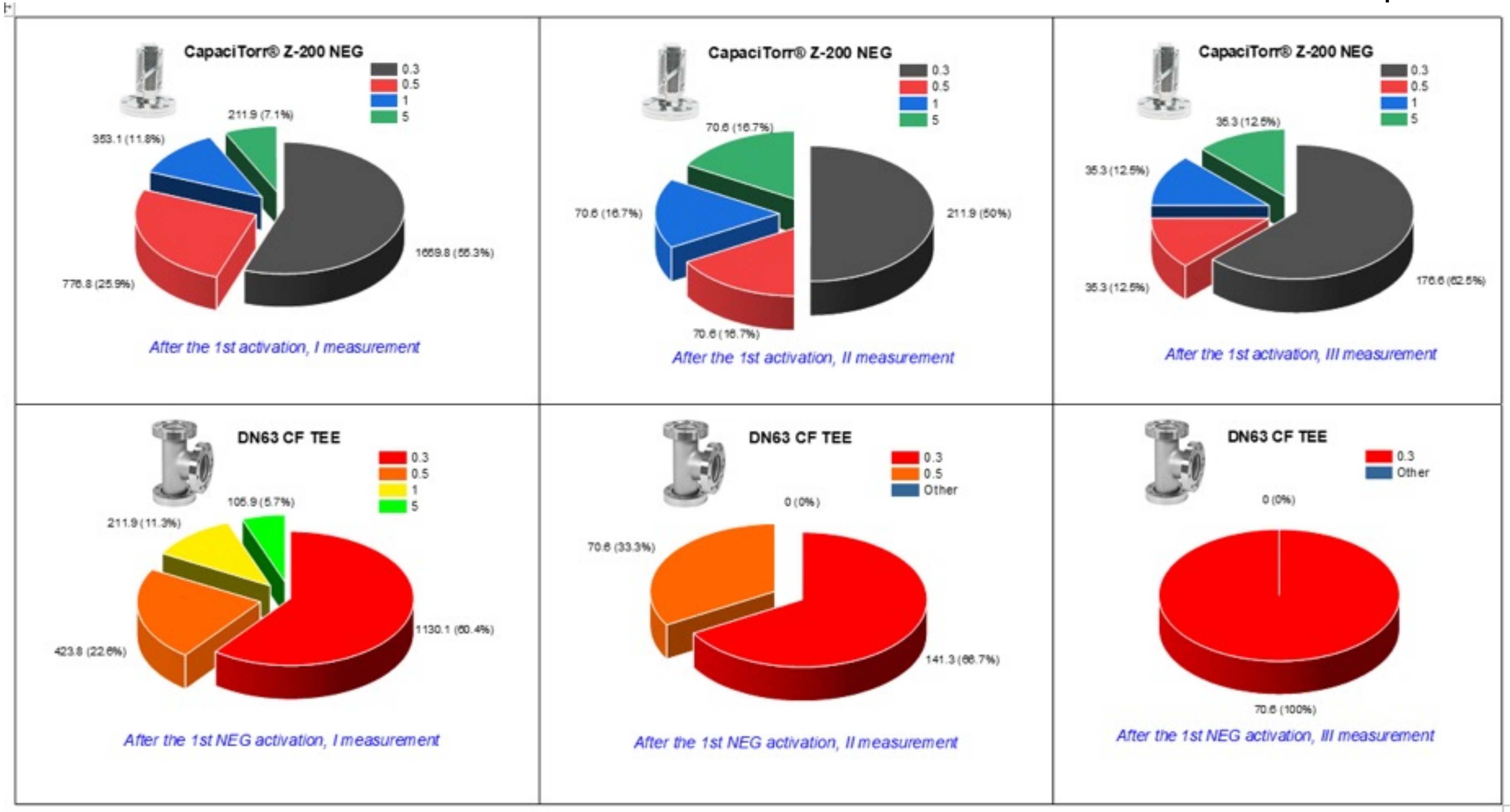
# ESS SCL particle-~~free~~ less vacuum system

By A. Gevorgyan (ESS)

## Reliability.

NEG pumps. ZAO alloy. Particle counting after 1st activation.

Both ISO 6 clean room equivalent!



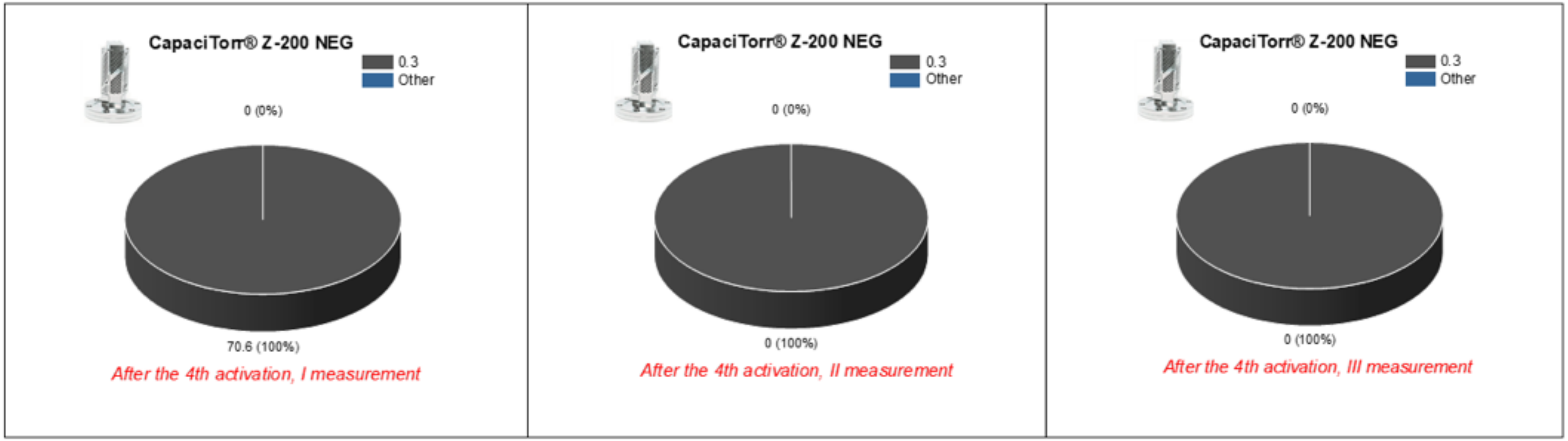
# ESS SCL particle-~~free~~less vacuum system

By A. Gevorgyan (ESS)

## Reliability.

NEG pumps. ZAO alloy. Particle counting after 4th activation.

ISO 3 clean room equivalent!



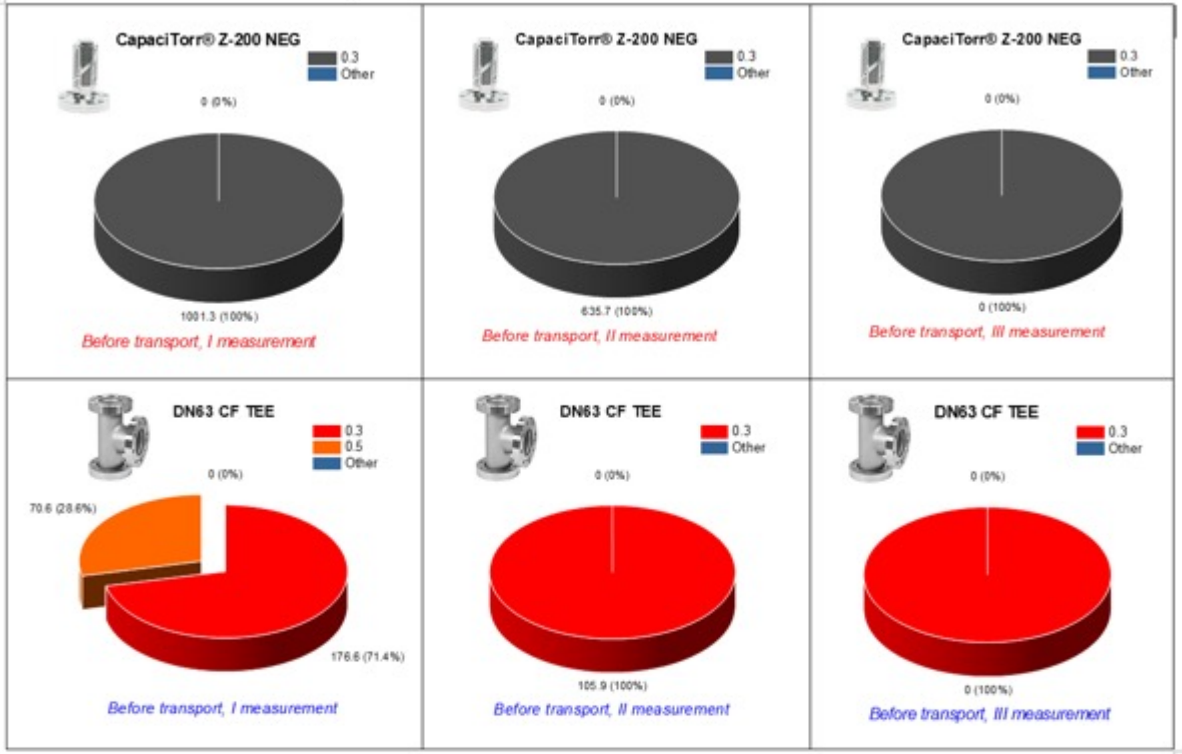

2nd and 3rd activation show ISO 6 compatibility.

# ESS SCL particle-~~free~~less vacuum system

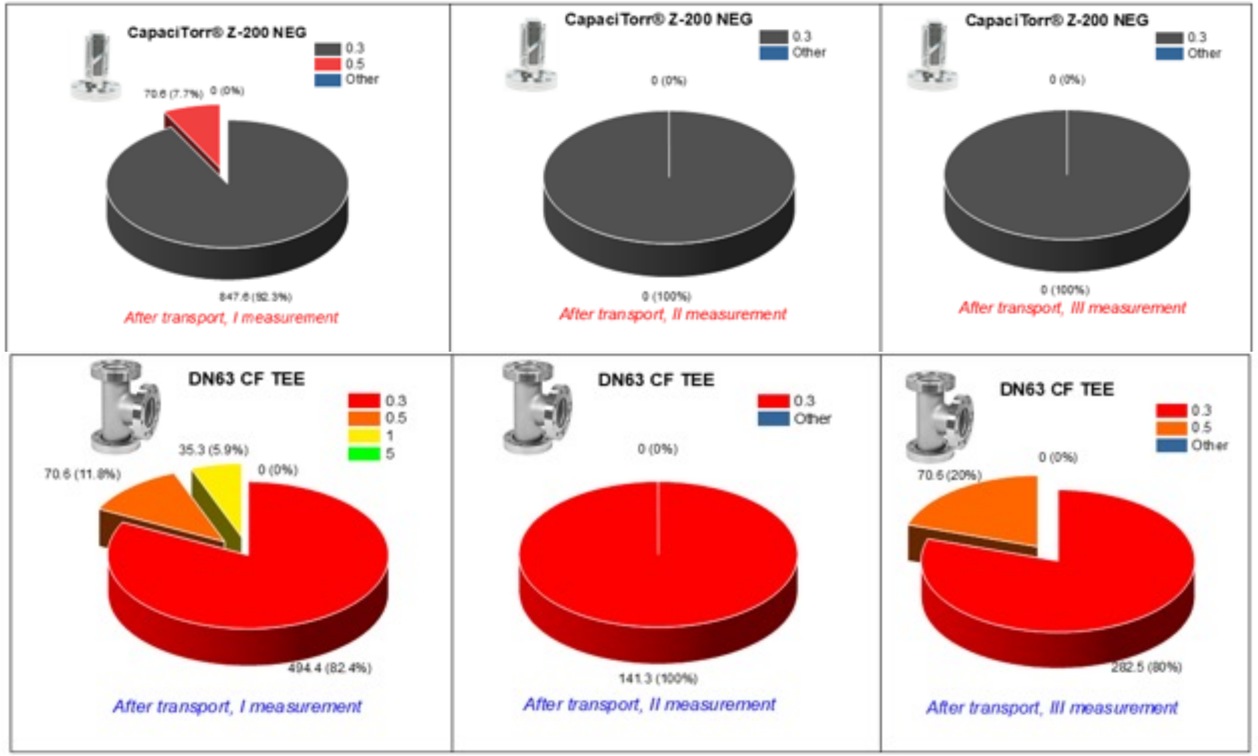
By A. Gevorgyan (ESS)

## Reliability.

NEG pumps. ZAO alloy. Particle counting after an uncontrolled transport (Lund-Malmo)




Before transport test, cleaned for ISO 4.



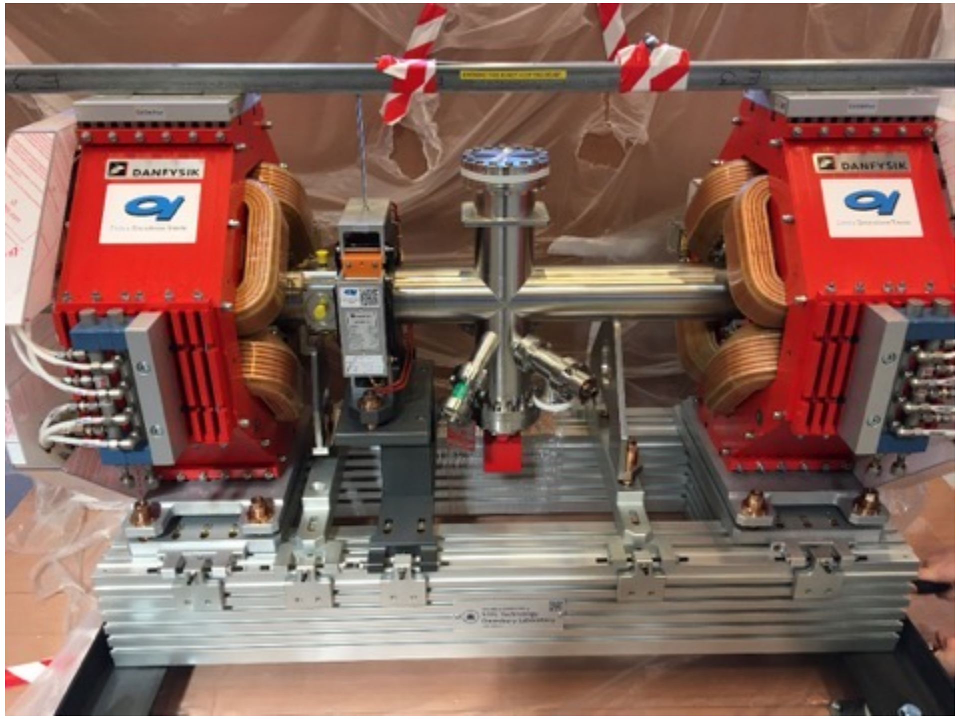

After transport test ISO 4.

# ESS SCL particle-~~free~~-less vacuum system

By A. Gevorgyan (ESS)

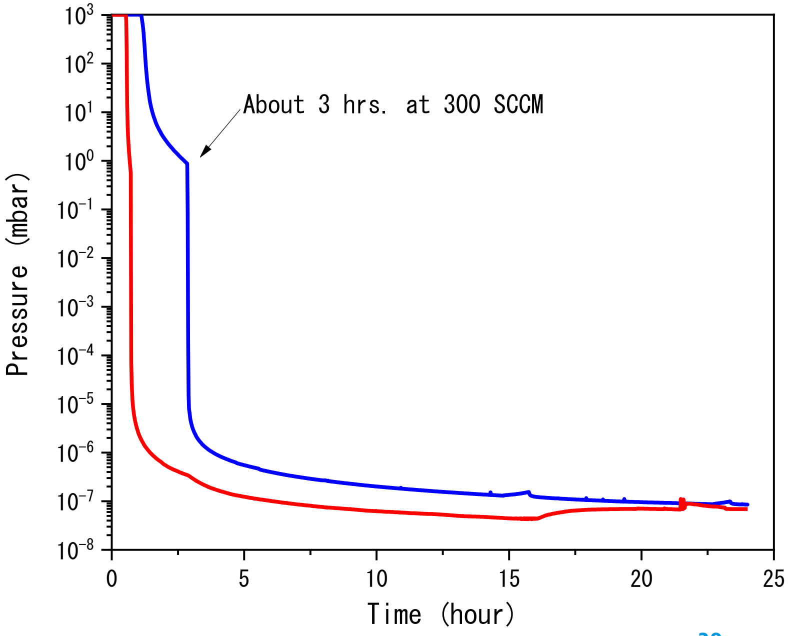
## Reliability.

NEG pumps. ZAO alloy. Conclusion.



In-vacuum transport is better than N2. Van der Waals forces help. Even though the NEG pump generates particles, in vacuum, they will fall down (gravity) and do not move …orientation and location of pump is important. Note: severe vibration is still a problem.

Only laminar gas flow whilst venting or pumping vacuum systems. Maximum flow 3l/min. Δ P=1mbar.




Pumping cart image from: https://doi.org/10.17563/rbav.v37i3.1114

# ESS SCL particle-~~free~~-less vacuum system

## Assembly zone preparation/segmentation and impact of parallel activi

By A. Gevorgyan (ESS)

# ESS SCL particle-~~free~~less vacuum system

## Assembly zone preparation/segmentation and impact of parallel activities

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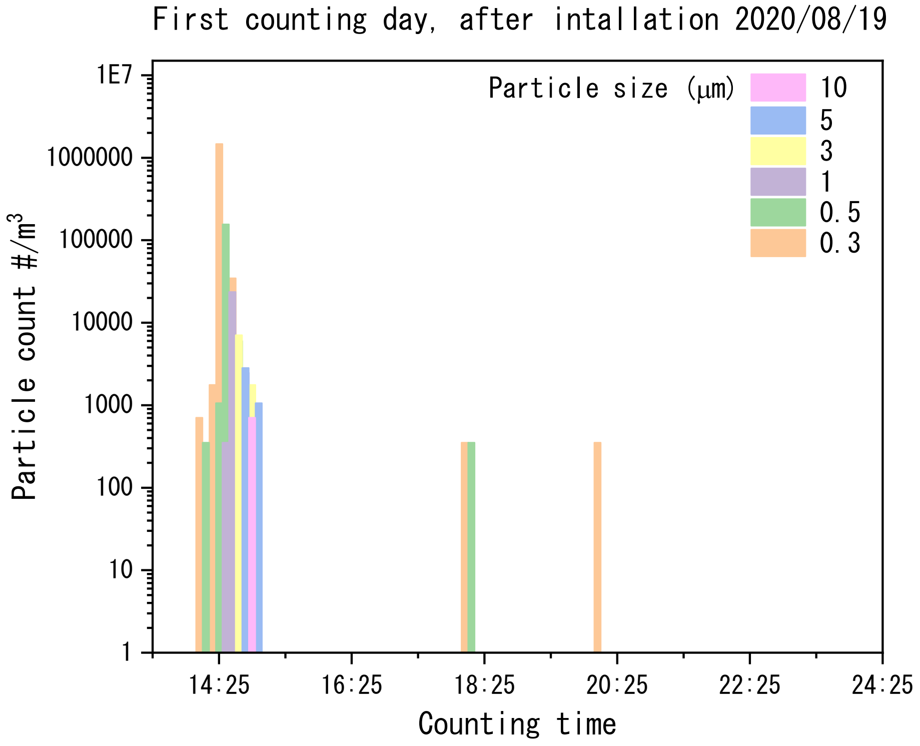


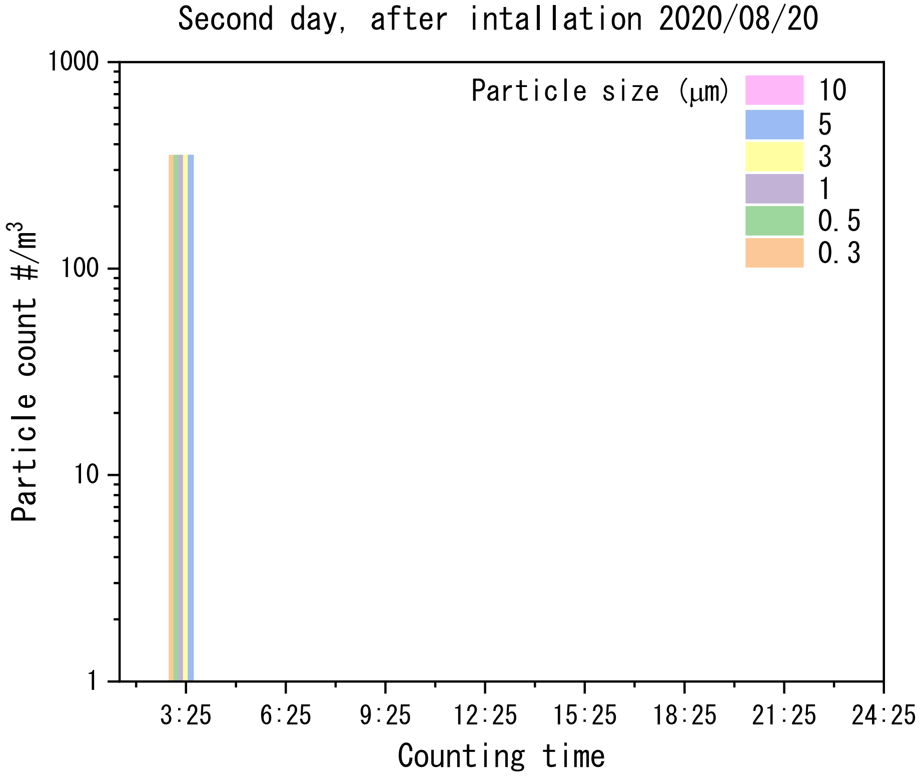


High numbers of particles are due to the counter installation (multiple entering/exiting the room).

Particles settling slowly ...yes, a day or two is needed!

# ESS SCL particle-~~free~~ less vacuum system

## Assembly zone preparation/segmentation and impact of parallel activities

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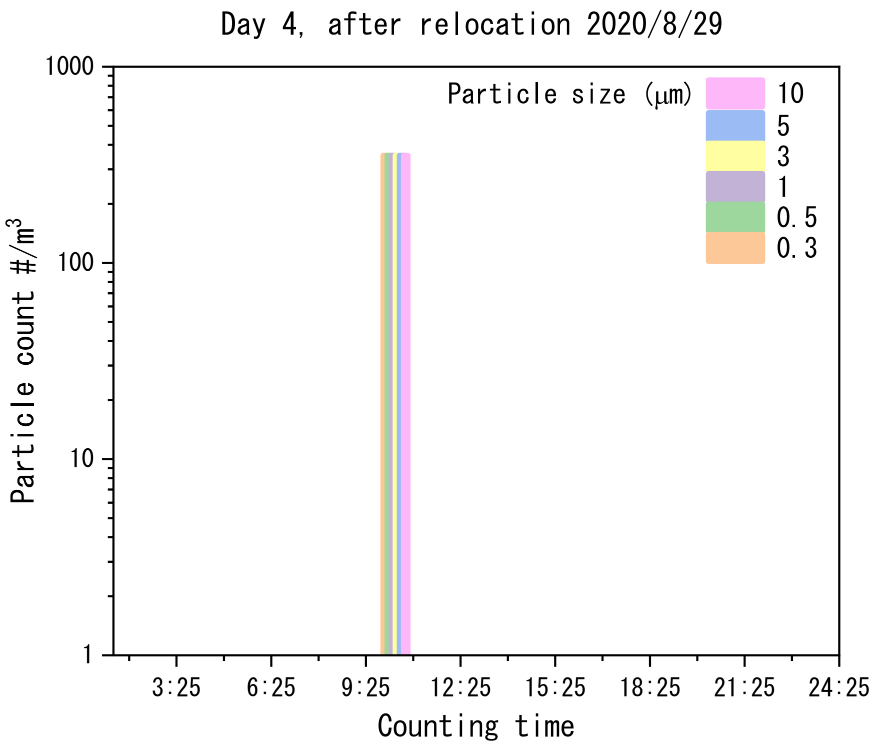


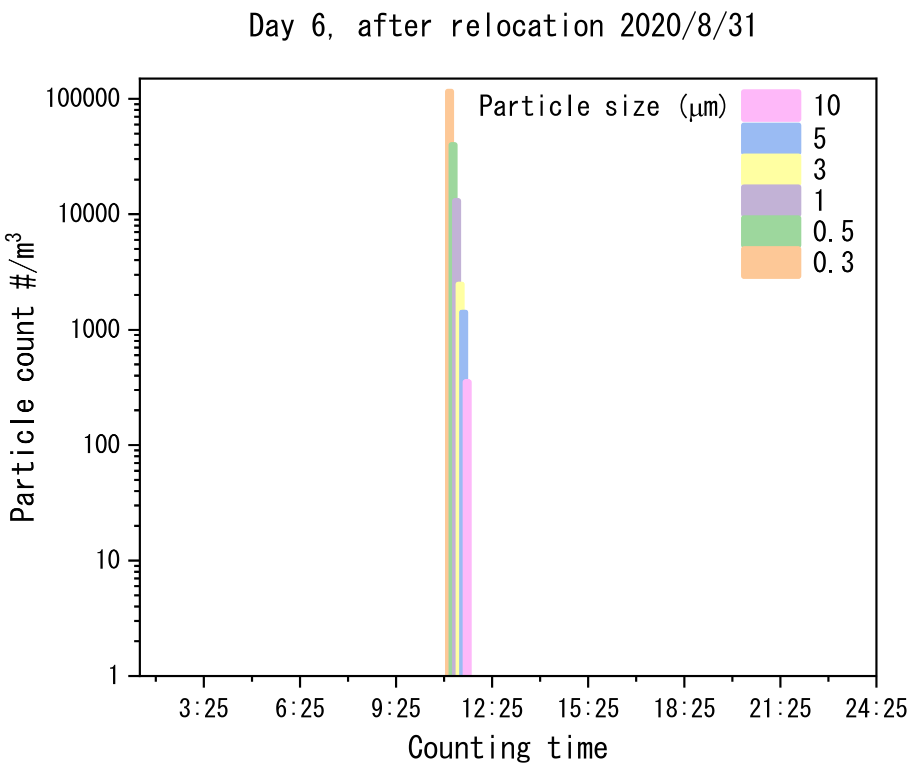


…back from a coffee brake?

Major impact, due to welding, grinding, cutting activities.
Source is 5-8 meter far from the clean room.

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## Assembly zone preparation/segmentation and impact of parallel activ

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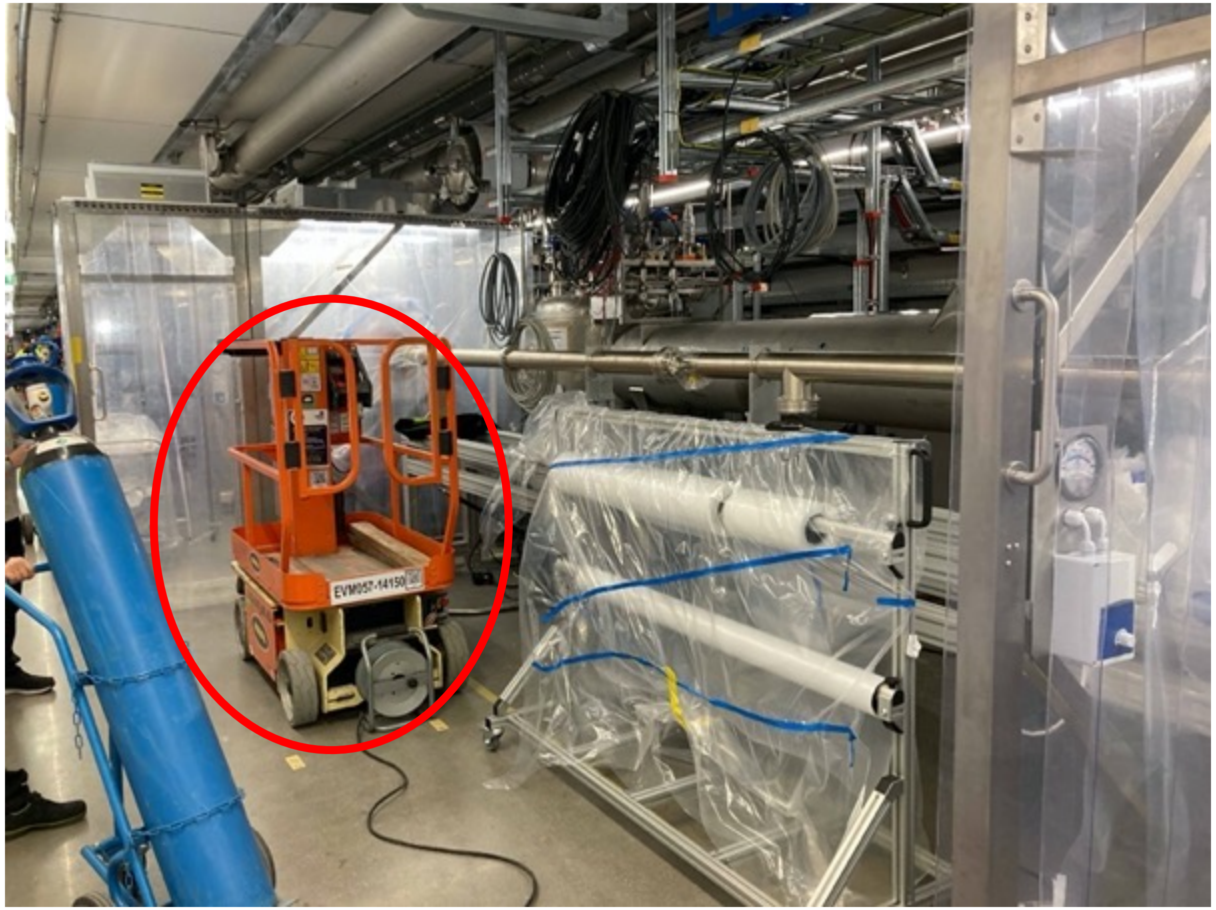
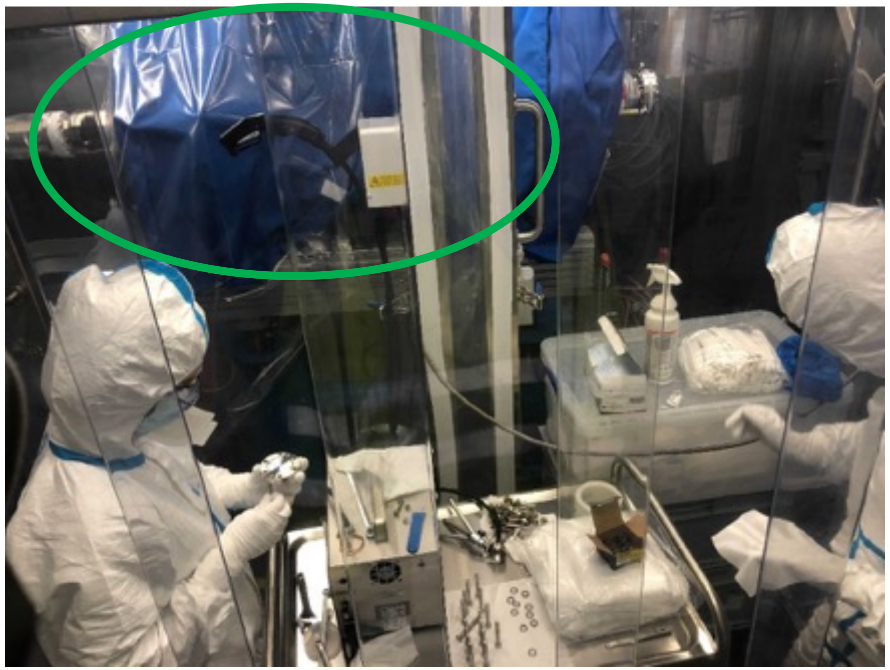



Barrier off the zone at least a day before…

Running cleanroom is important… to maintain the cleanliness

Cover with plastic dirty parts.



# 3

# Conclusion

# Conclusions

- ESS cryo modules under **full RF test at UU and ESS** for spokes and MB,
- Assembling and tests until now showed **failures and special events are more than expected during initial assumptions at the design phase**,
- Any **tunnel installation impact vacuum particle-less installation** in the tunnel,
- Particle-less process/pumps/instruments/valves should be handle as a **vacuum integrated perspective** by all in kind interfaces to **maximize learning experience** on all interfaces,


Thank you for your attention!