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Vaccum Seminar: introduction to vacuum technology and engineering

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Outline

- Introduction,
- Class “0” of vacuum: surface science/material perspective,
- Vacuum for accelerators, Gas regimes and simulations,
- ESS Vacuum System: standardization model, control system,
- ESS examples: RFQ (simulation) and ion source (control system),
- Target vacuum,
- LOKI – instruments,
- Vacuum Laboratory,
- References,
- Conclusions,

Introduction

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Goal: short introduction on the vacuum field (surface science, gas dynamics, simulations, instrumentation...) and the science and engineering for a larger user facility.

Justification: why do we need vacuum?

"the surrounding gas can interfere on the desirable process, it means, it is a requisite part of the process or/and an integral part of a product"

Ex: pressure differential, heat transfer, vaporization, chemical/physical reactions or effects, protection...

Introduction: Vacuum Terms (ISO 3529/1)

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Vacuum range Pa [N/m^2]	Naming
100 kPa - 100 Pa (1000 mbar - 1 mbar)	low (rought) vacuum
100 Pa - 0,1 Pa (1 mbar - 10^{-3} mbar)	medium vacuum
0,1 Pa 10 µPa (10^{-3} mbar - 10^{-7} mbar)	high vacuum (HV)
< 10 µPa (abaixo de 10^{-7} mbar)	ultra-high vacuum (UHV)
< 10^{-10} Pa (abaixo de 10^{-12} mbar)	extreme high vacuum (XHV)*

"A commonly used term to describe the state of a rarefied gas or the environment corresponding to such a state, associated with a pressure or a mass density below the prevailing atmospheric level"

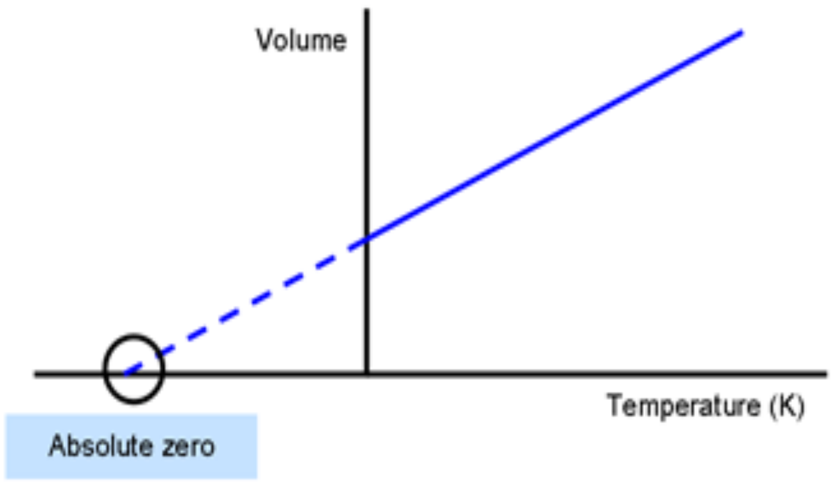
Standard references conditions for gases :

Temperature : 0 °C

Pressure : 101,325 Pa (= 1,013.25 mbar)

Introduction: Ideal Gas Law

$$P \,.\, V = N.\, R.\, T$$



P = pressure [Pa]

V = vomule [m^3]

N = amount of substance [mol]

R = universal gas constant ($k \,.\, N_A$) [8.314 J. $K^{-1}mol^{-1}$]

T = temperature [K]

Class "0" of vacuum : monolayer

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CAS CERN-94
A.G. Mathewson

How many molecules we have at the surface of a cube of 1 liter?

Place one molecule of nitrogem by side another over the cube surface (definition of monolayers).

6 side = 0.010 x 0.010 x 6 = 0.06 m^2

$$\frac{1}{3.7 \,.\, 10^{-10} \times 3.7 \,.\, 10^{-10}} = 7.3 \,.\, 10^{18} \text{ molecule/m}^2$$

0.06 x 7.3 . 10^{18} = **4.38 . 10^{17} molecules**

The molecular diameters are measured in Ångström (1 Å=10^{-10} m).
Diameter of nitrogen molecule : 3.7 Å

Class "0" of vacuum : pressure equivalent

What is one monolayer of gas as pressure equivalent?

Using the ideal gas law at standard references conditions:

$2.69 \cdot 10^{22}$ molecules in 1 liter.

$$\frac{4.38 \cdot 10^{17} \times 101325}{2.69 \cdot 10^{22}}$$ = **1.65 Pa (1.65 mbar) medium vacuum!!!**

Class "0" of vacuum : gas in solid solution

How much gas we have in solid solution (1 liter) on stainless steel (SS) 304?

Typical value (ASTM handbook) for nitrogen on austenitic phase is 150 ppm in weight. SS304 density: $8 \cdot 10^3$ g/liter

$$150 \text{ ppm} = \frac{150}{10^6} \times 8 \cdot 10^3 = 1.20 \text{ g/liter}$$

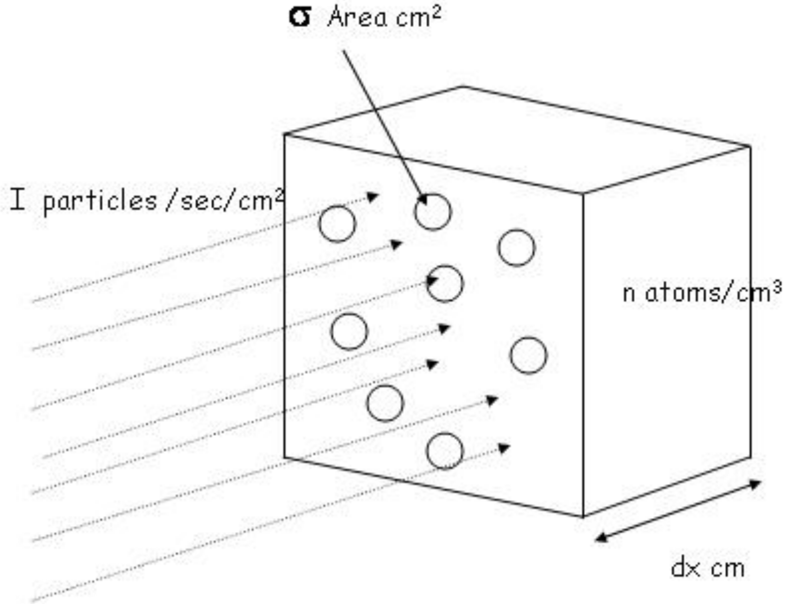
Using the ideal gas law at standard references conditions:
$2.69 \cdot 10^{22}$ molecules in 1 liter => $4.77 \cdot 10^{-23} * 2.69 \cdot 10^{22} = 1.28$ g

Standard references = 1.28 g/l ≈ 1.2 g/l = 150 ppm of nitrogen in SS304!!!

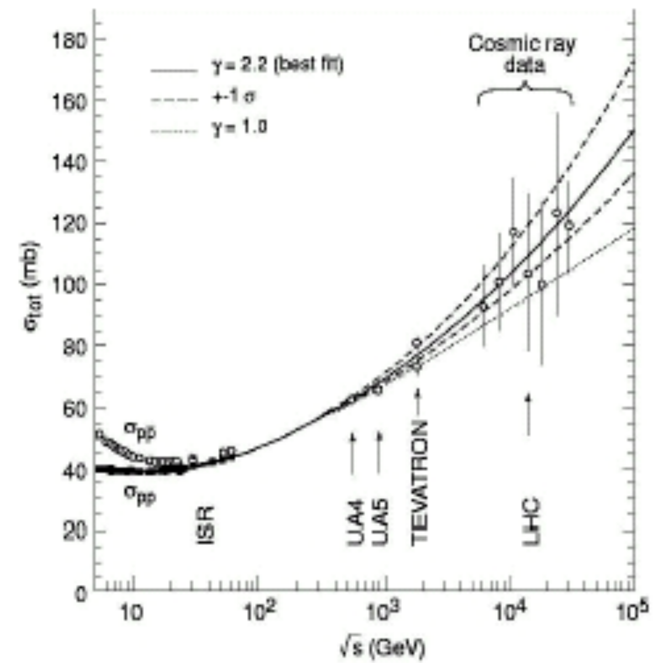
1 molecule of nitrogem weight = $4.77 \cdot 10^{-23}$ g

Vacuum for accelerators: Gas-beam interaction

CAS CERN-2007
P. Grafström



Total cross section



Regimes and simulations

Knudsen number (Kn): is a dimensionless number defined as the ratio of the molecular mean free path length to a representative physical length scale

$$\mathbf{Kn} = \frac{\lambda}{L}$$

λ = mean free path (average distance in between gas-gas

L= representative physical length (Ex: diameter of a pipe)

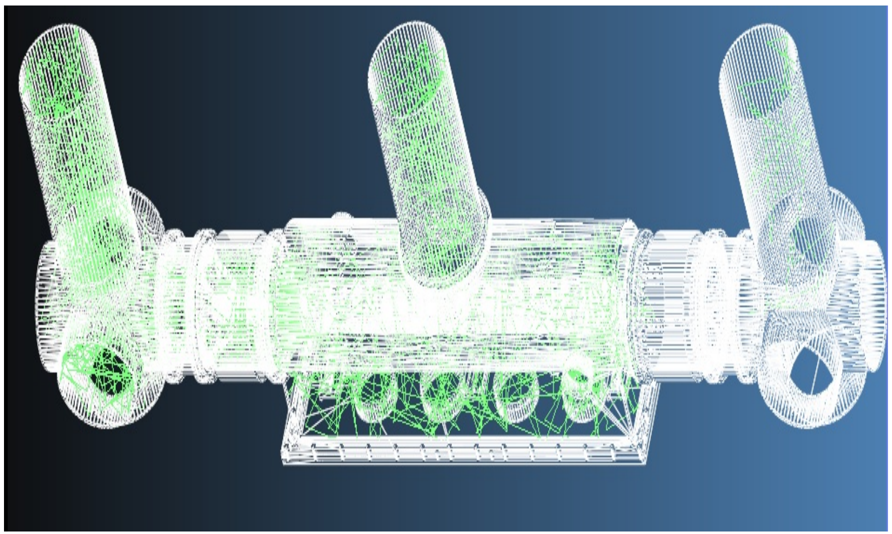
Kn >> 1 hydrodynamics regime (Navies-Stokes commercial softwares)

Kn << 1 free molecular regime (Monte Carlo MOLFLOW + from CERN)

Kn ≈ 1 transitional regime (no commercial or academic software), every model requires a new programing.

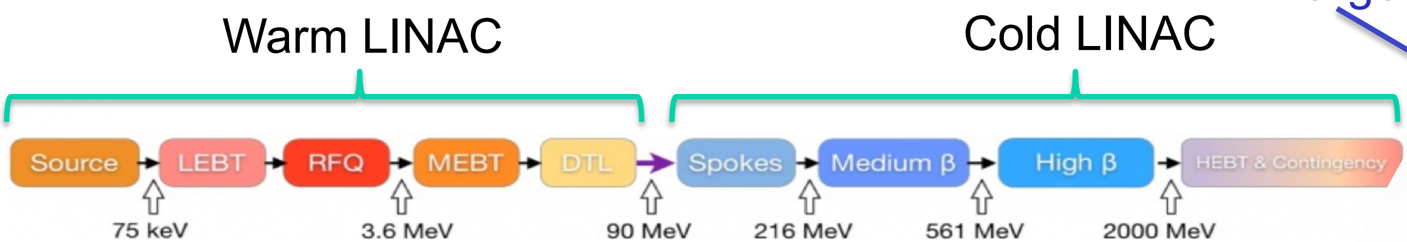
MOLFLOW +

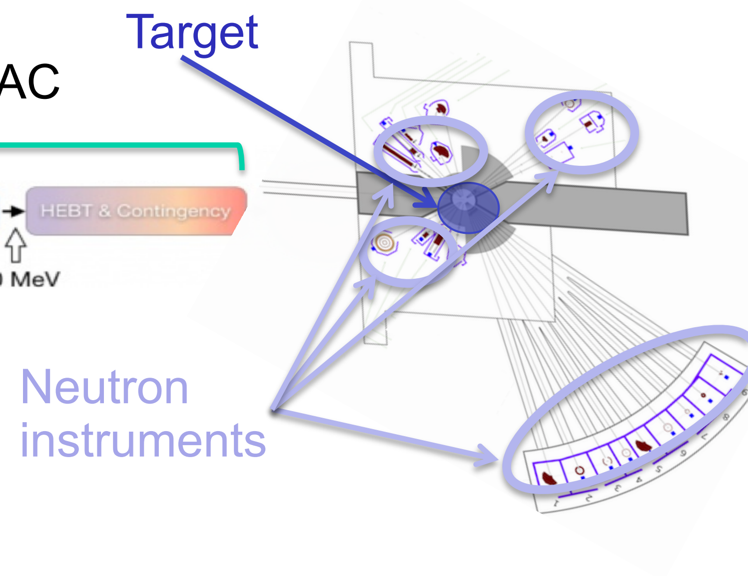
By Roberto Kersevan (CERN), more than 20 years of development.



- steady state and transient,
- only molecular regime,
- temperature,
- accept external files STL,
- possible to couple synchrotron radiation,

ESS Vacuum system





The ESS organization charges the ESS Vacuum Group (VG) with the responsibility for all ESS vacuum systems including not only the Accelerator, but also Instruments and Neutron Beam Lines and the Target.

The main task of the ESS VG is to support the in kind contributions on the vacuum system and the **integrated vacuum design** of the ESS complex.

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 Procurement Policy applied for the procurement of all "major" vacuum equipment. The primary objective of the program is to develop a list of standard vacuum equipment for use project wide to minimize project costs, reduce spares holdings, training and achieve other benefits of standardization.

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.

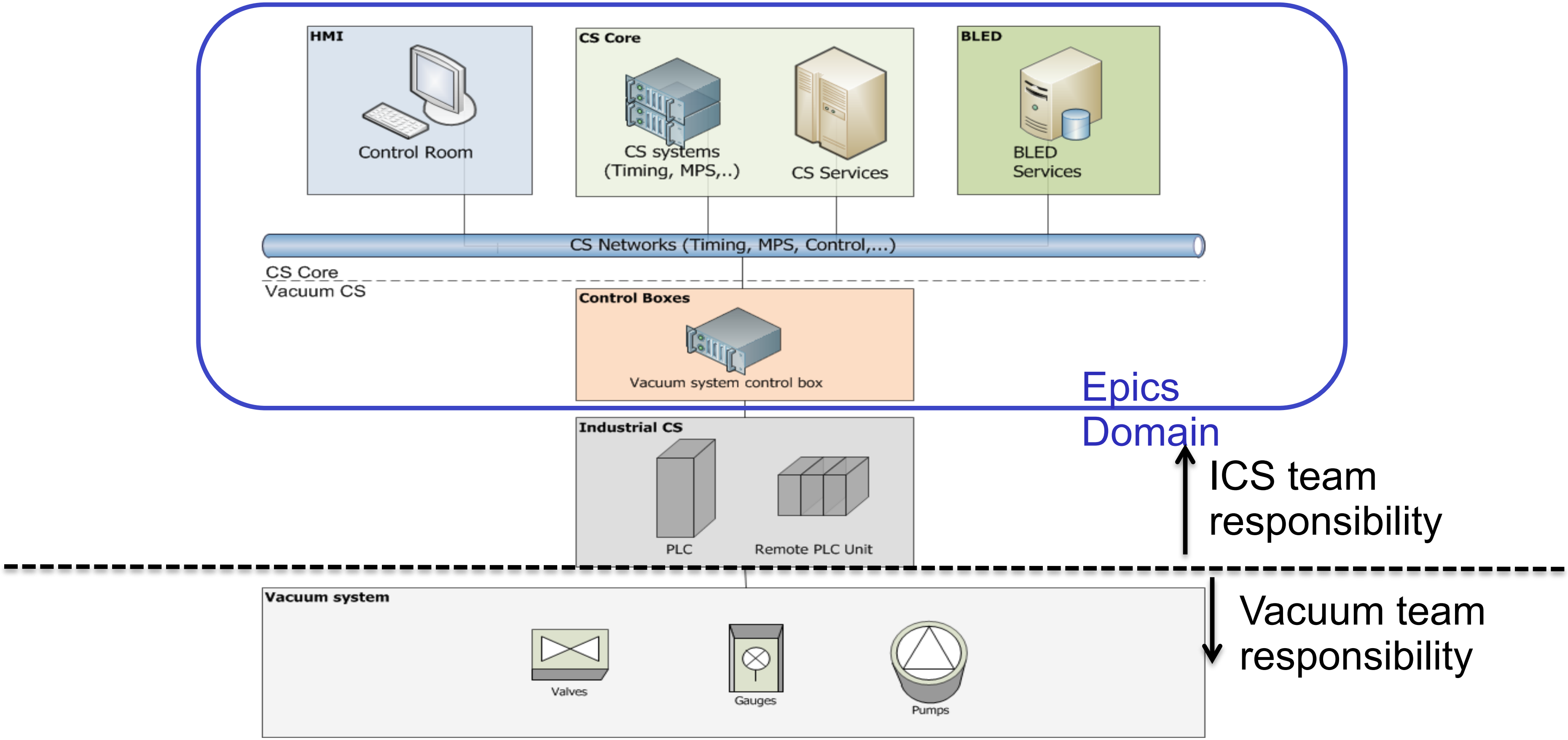
All queries or additional information concerning the contents of this handbook should be addressed to the ESS Vacuum Group Section Leader (VGL).

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

http://europeanspallationsource.se/accelerator-documents

Vacuum Control System



Vacuum Requirements: warm LINAC Radio Frequency Quadrupole (RFQ)

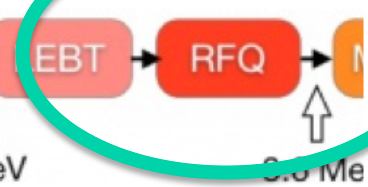
By Poton, A.

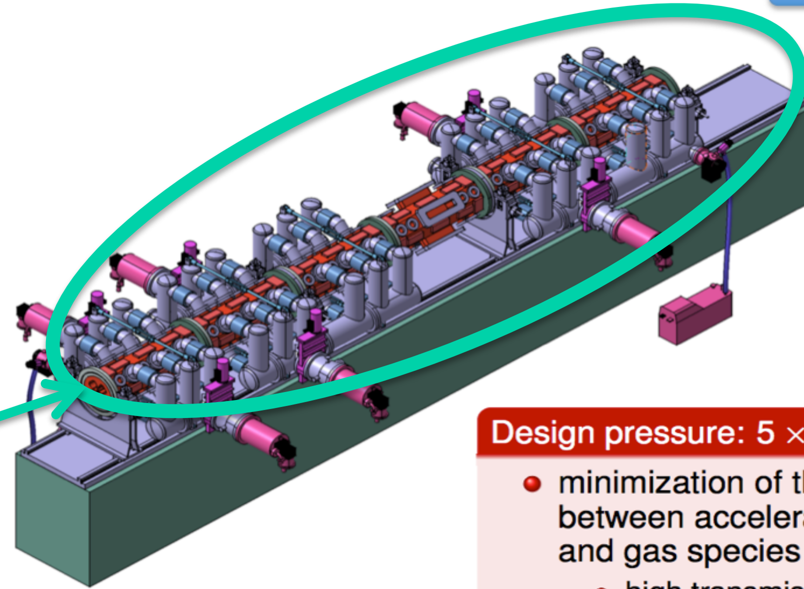
Pumps, gauges and valves

- 2 dry pumps (12.5 m^3/h)
- 6 cryo-pumps 200 L/s
- 2 sets of turbo-pumps 150 L/s
- 26 couples of gauges «Pirani - Penning»
- 14 valves
- 2 gauges Bayard-Alpert

Contributions

- gaz load from LEBT due to differential pressure
  - mainly H_2
  - other gas: *Kr*, *Ar* for SCC…
- out-gassing of copper
  - copper inner surface
  - RF loops due to RF
- desorption due to beam collision
  - depends on the history of the heat treatment
  - only the second half of the RFQ





Design pressure: 5×10^{-7} mbar

- minimization of the scattering between accelerated particles and gas species
  - high transmission
  - high quality beam
- minimization of the probability of discharge between surfaces

ESS RFQ case: Requirement and simulations

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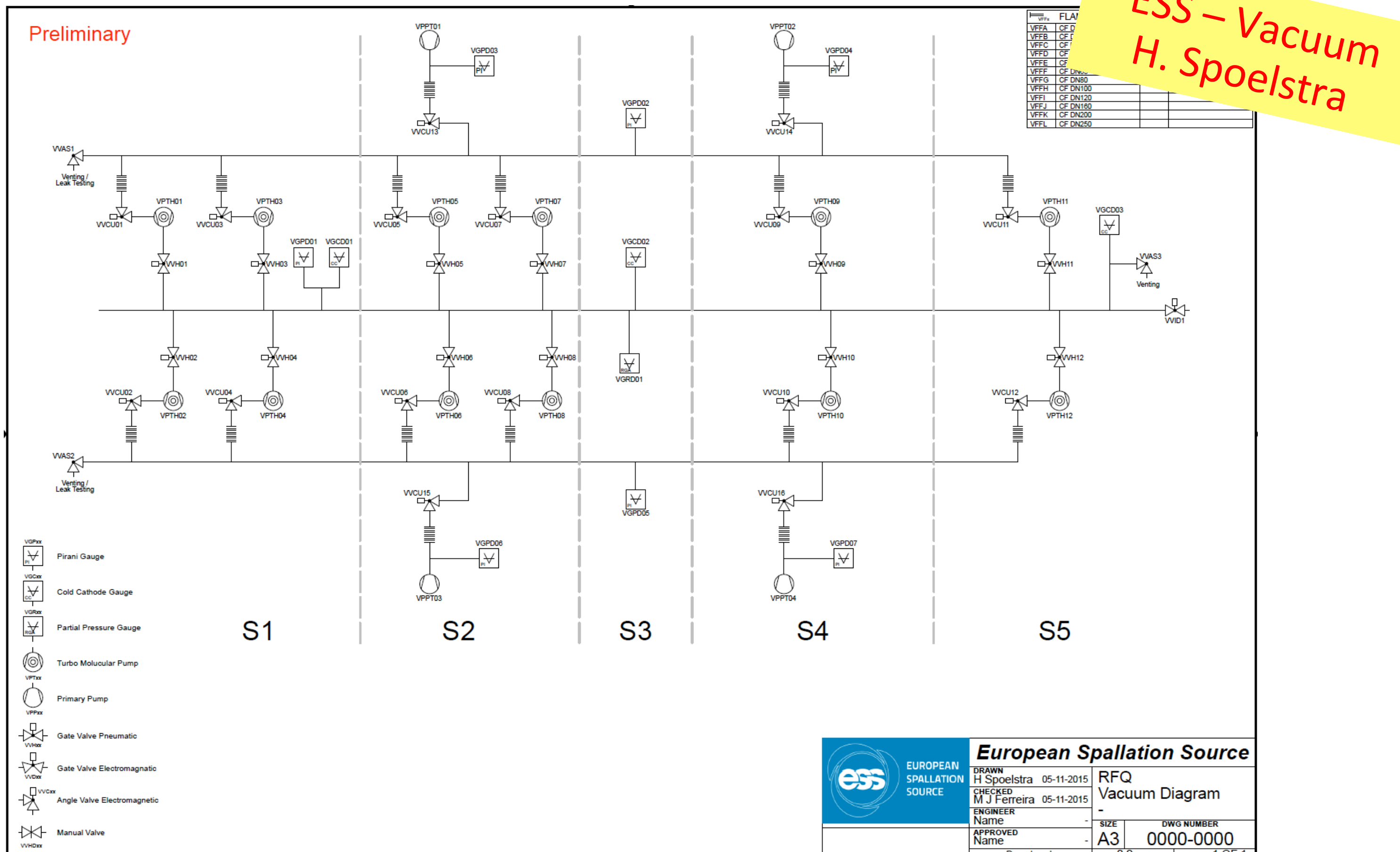
Vacuum diagram



ESS RFQ case: Requirement and simulations

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Operating pressure requirement RFQ.SyR-32 (DOORS Level 3): The maximum operating pressure over 75% of the length of the RFQ shall not exceed 5E-7 mbar for the defined gas throughput from the LEBT to the RFQ.

Interlock requirement (CEA, level 4): P < 2E-6 mbar.

ESS – Vacuum
S. Scollari

Pump-down simulation (1-2 pumps)

Used Software: VacTran

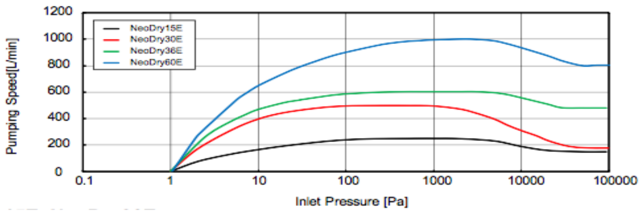
Starting pressure: 1000 mbar

Target pressure: 10^{-2} mbar

Gas composition: Air

Pump: NeoDry 36E

(30 m^3/h @50Hz)



High vacuum simulation (MOLFLOW +)

Operation (8 and 10 TMPs)

Inlet pressure: 6 . 10^{-5} mbar

Outlet pressure: 5 . 10^{-8} mbar

OGV* : 5 . 10^{-10} mbar•l/s/cm^2

Gas**: 50% N_2 and 50% H_2

TMP used: Leybold 361

S***: 231 l/s (N_2) 229 l/s (H_2)

Acceptance cases (TMP)

Inlet: Flanged

Outlet: Flanged

4 different OGV** considered

Gas: 100% N_2

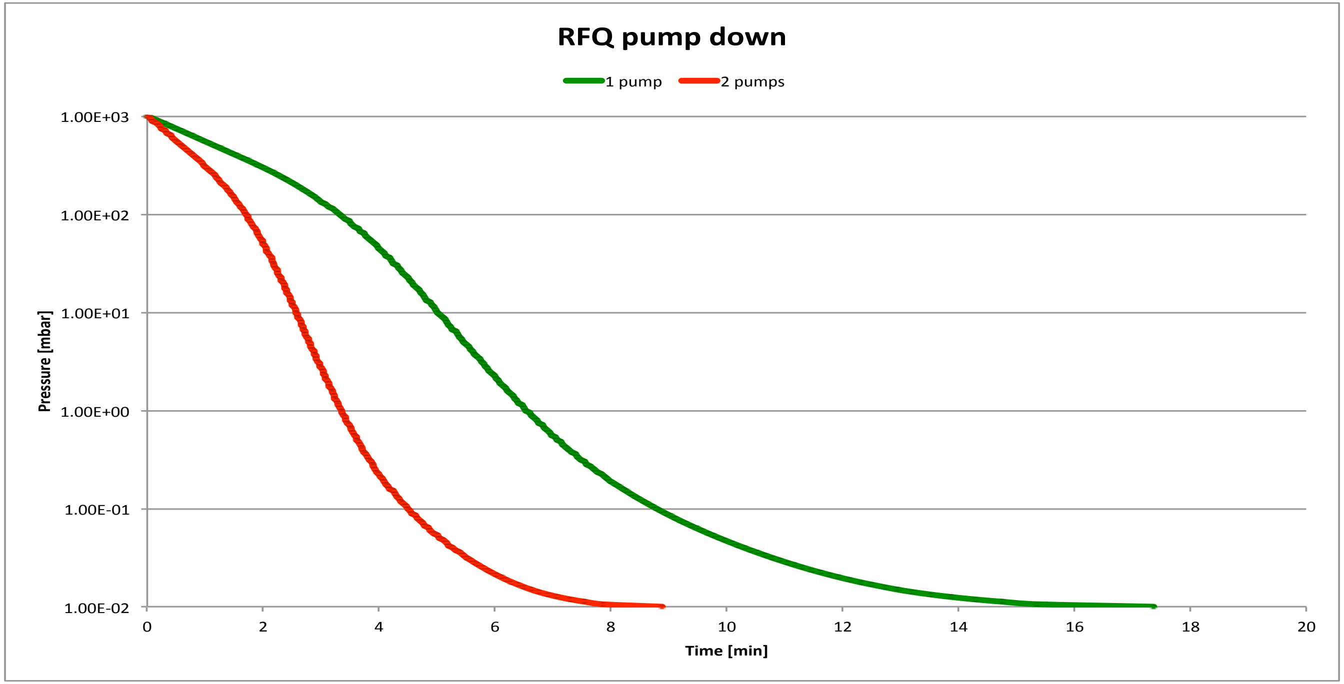
TMP used: Leybold 361

S***: 231 l/s

*OGV = Outgassing Gas in High Vacuum
**Gas composition coming from LEBT
*** Effective pumping speed including the gate valve. Leybold 361 pumping speed are: 345 l/s for N_2 *and* 340 l/s for H_2

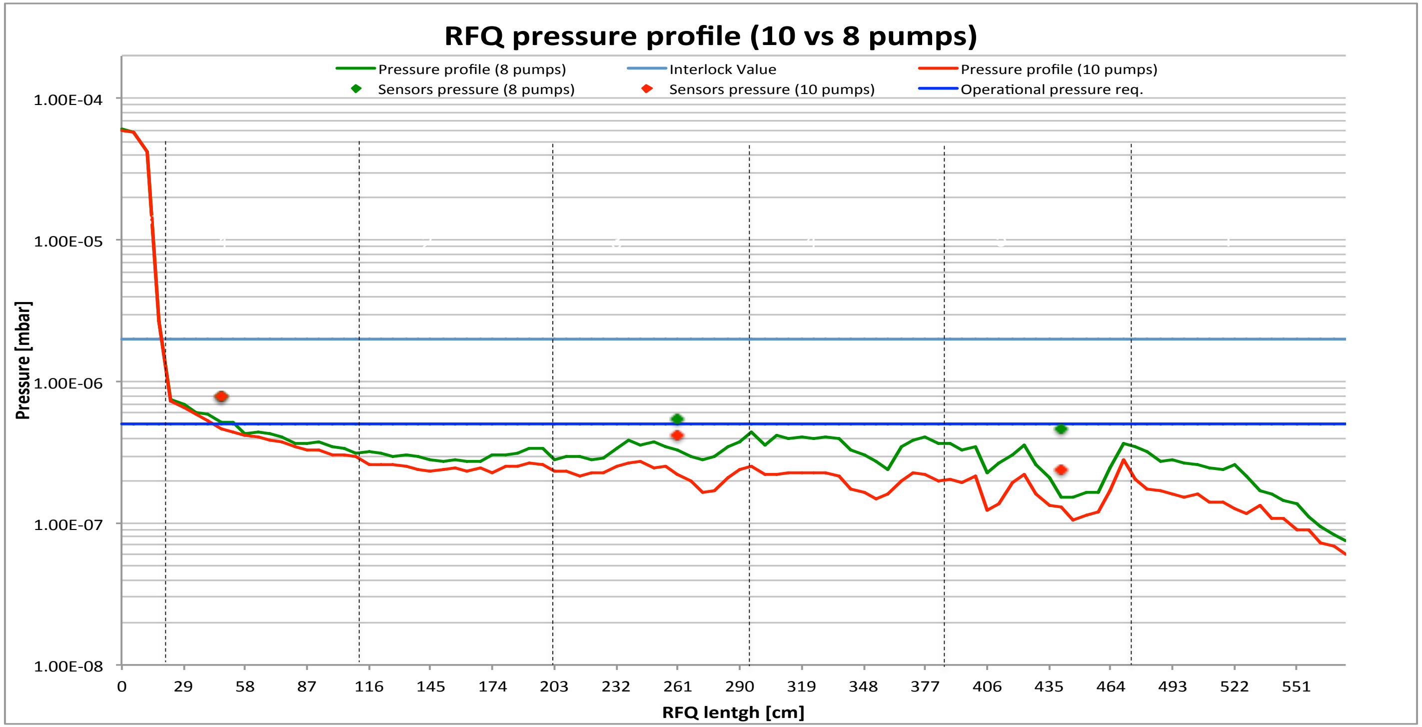
Pump down time (1 and 2 pumps)

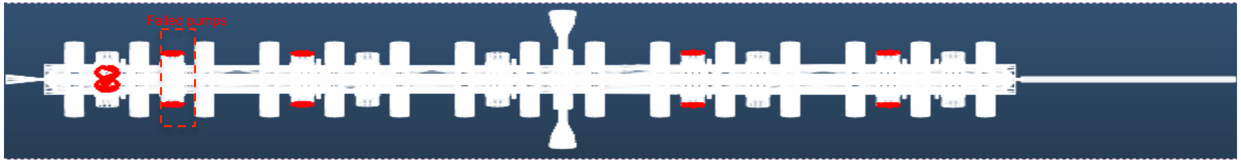
- Simulations with one and two primary pump has been carried out.
- The conductance between each pump and the RFQ has been assumed composed of: the TMP, a DN40 elbow and 4 meters of DN40 bellow.
- The pump down time, in both the cases is < 20 min.



Nominal (10 pumps) vs Failure (8 pumps) case

- A nominal (10 pumps) and a failure (8 pumps) cases have been considered.
- As worst case, the two failed pump have been considered in the first section.
- The operational and interlock requirements are fulfilled in both cases.
- The system is failure tolerant in case of two TMP stops.





Vacuum Requirements: warm LINAC Proton Source (PS) and Low Energy

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By Marletta, S. et all

Present design of P.S. and LEBT:

pumps, gauges and

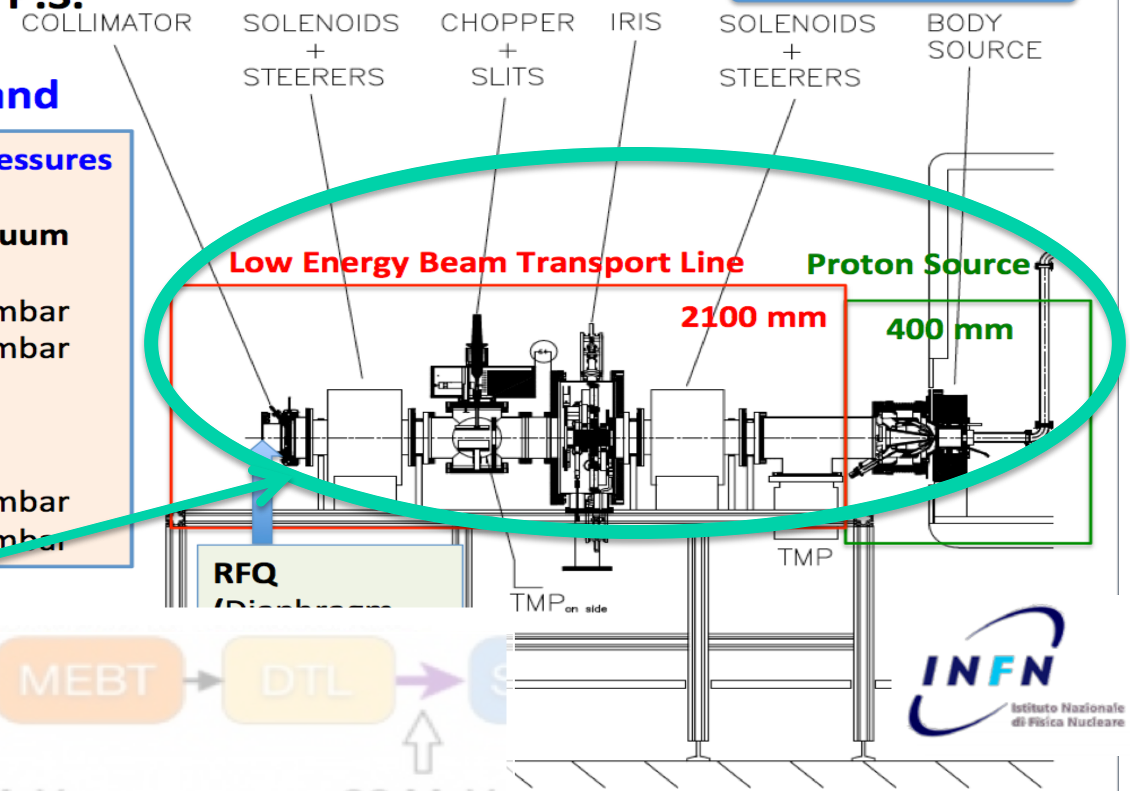
Expected Operative Pressures

BEAM OFF – Static Vacuum

P.S.	range 10E-6 mbar
LEBT	range 10E-7 mbar

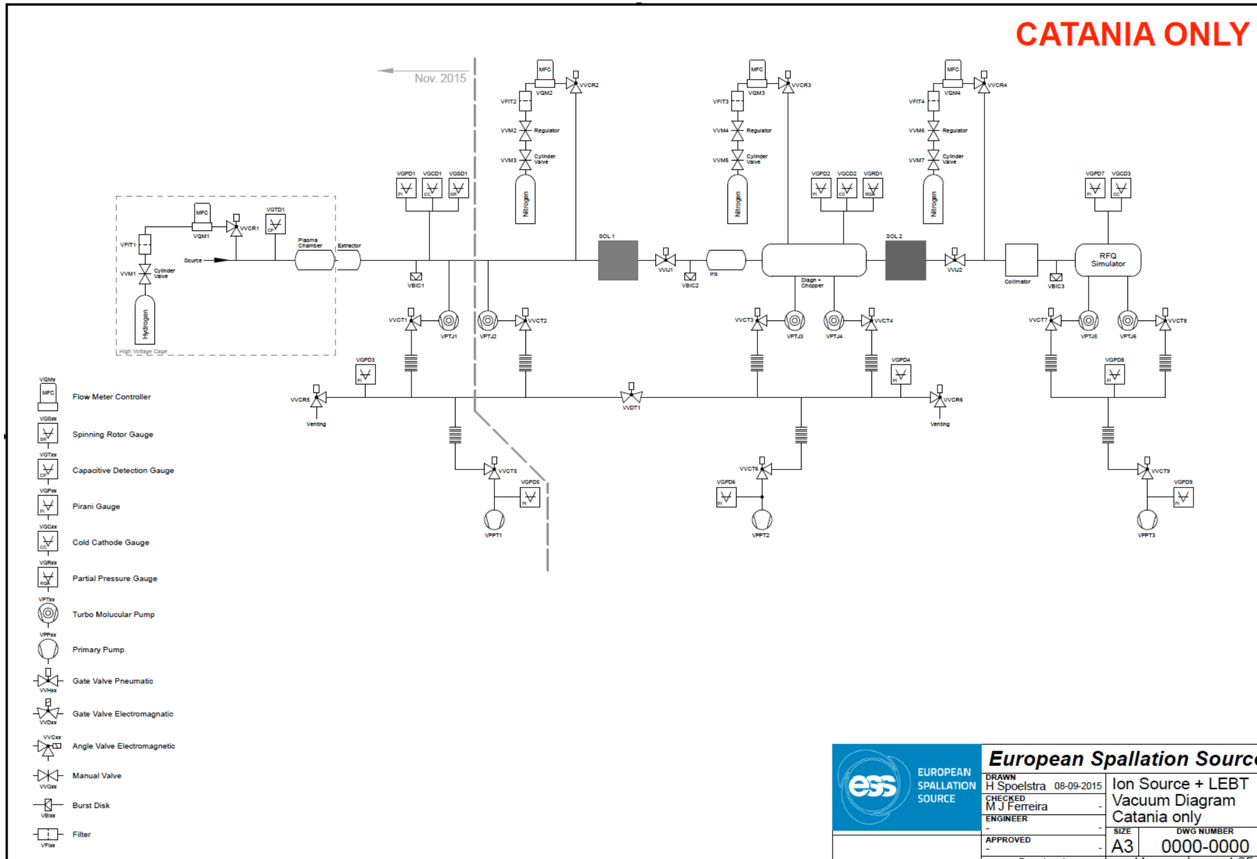
BEAM OFF – Gas IN

P.S.	range 10E-3 mbar
LEBT	range 10E-5 mbar



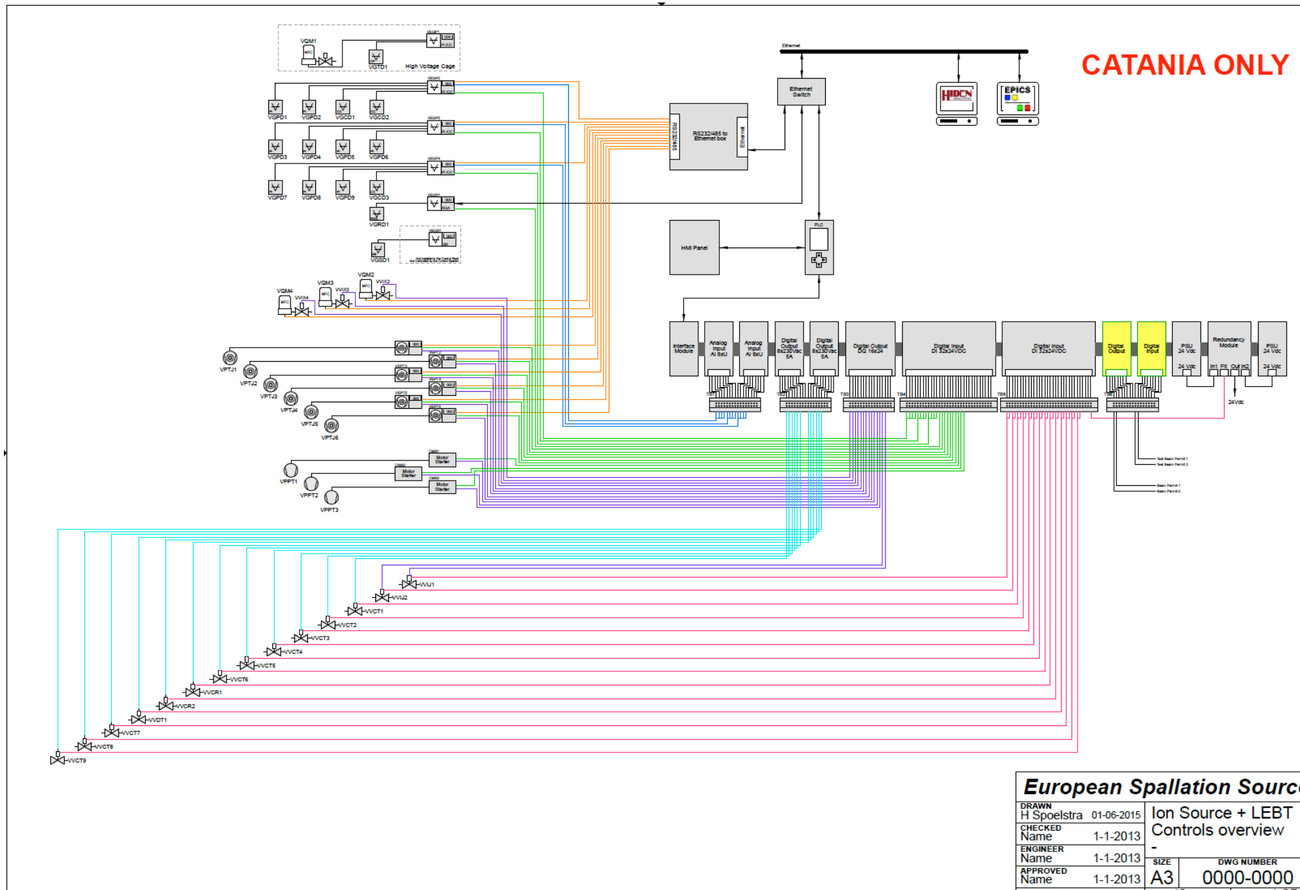
Vacuum Requirements: warm LINAC Proton Source (PS) and Low Energy

Vacuum diagram



Vacuum Requirements: warm LINAC Proton Source (PS) and Low Energy

Vacuum wiring diagram and logic (interlock system)



Proton Source (PS) and Low Energy Beam Transport (LEBT)

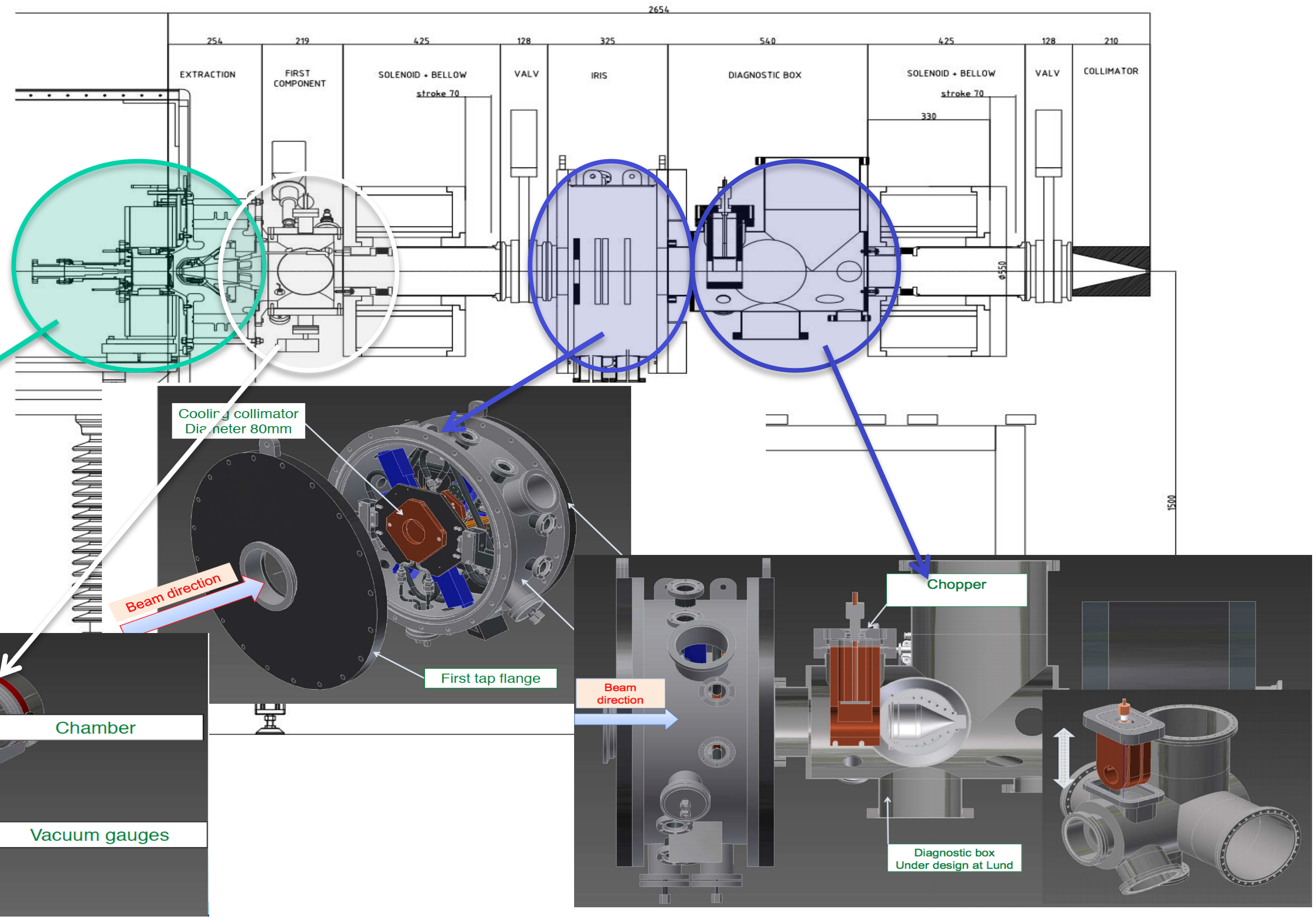
Expected Operative Pressures

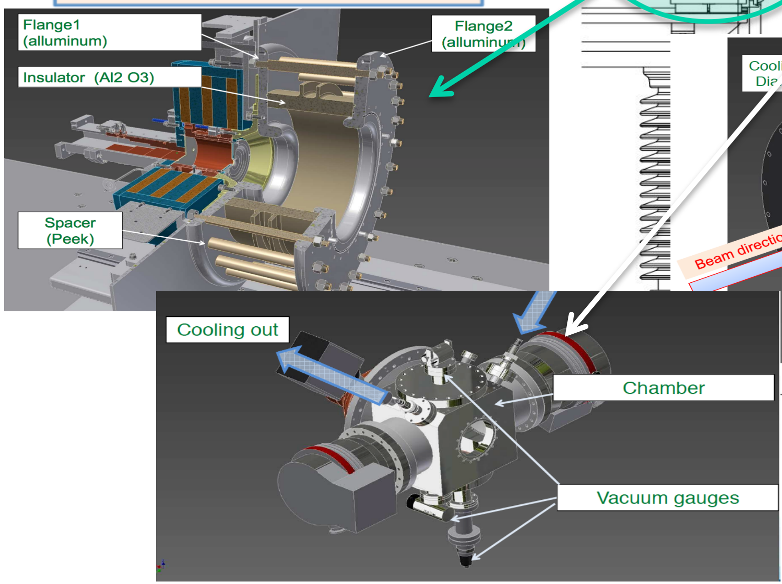
BEAM OFF – Static Vacuum

P.S.	range 10E-6 mbar
LEBT	range 10E-7 mbar

BEAM OFF – Gas IN

P.S.	range 10E-3 mbar
LEBT	range 10E-5 mbar





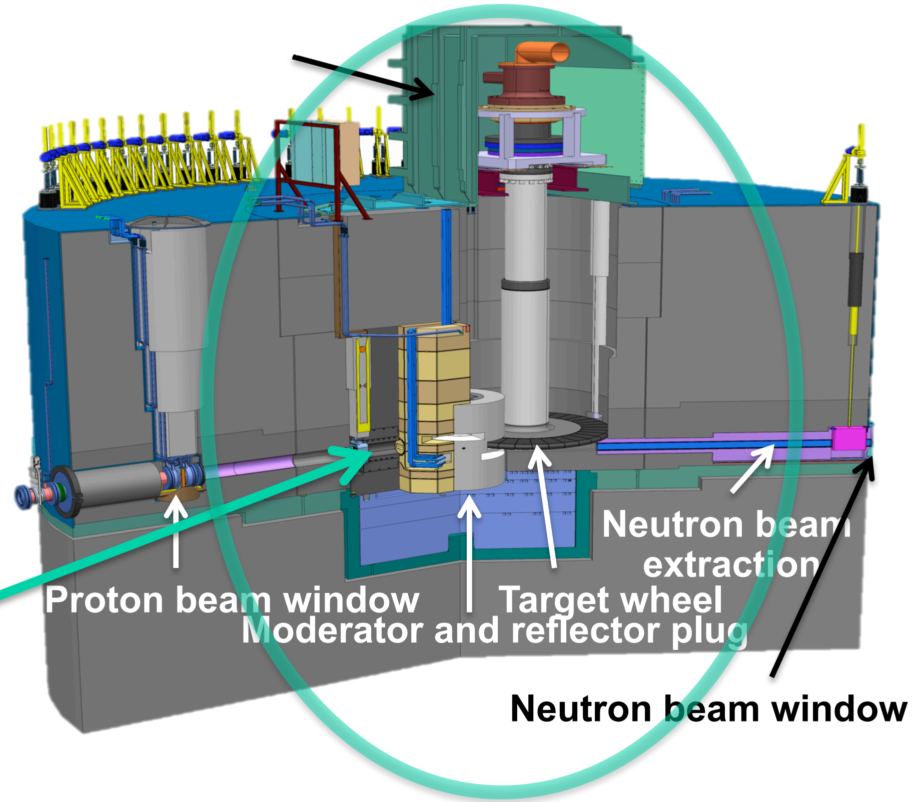
Vacuum Requirements: Target

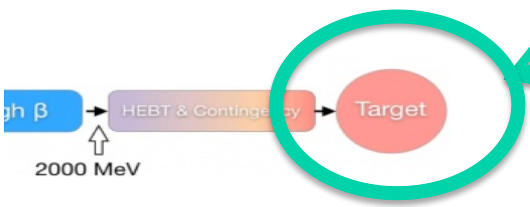
The moderate will operate in either helium or vacuum. In the vacuum mode the BPW will be removed and the monolith connected directly to the accelerator beam line. The monolith will be designed and built to high vacuum standards to ensure that the operation of the accelerator is not compromised, particulates being of major concern. Operating pressure will be 10^{-3} Pa.

The vacuum for insulation will be an active vacuum that will handle both the cryostat vacuum and the piping adjacent to the system. This vacuum might be contaminated by H_2O, H_2 and He .

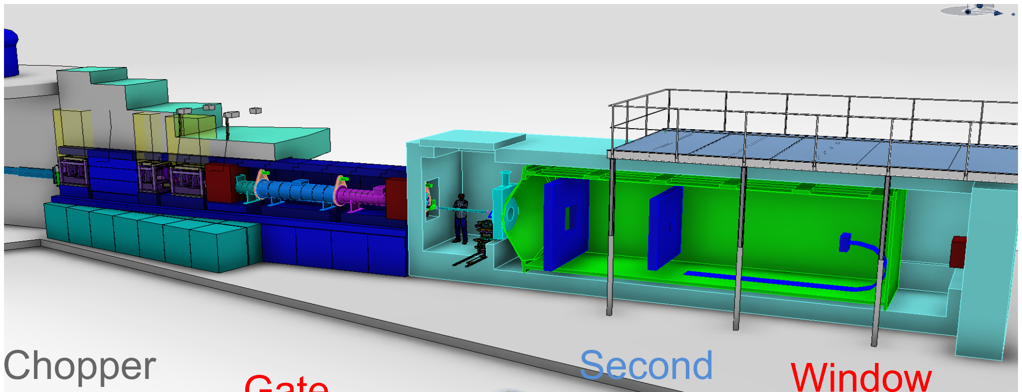
Scope:

The vacuum for insulation, piping, cryostat vacuum and vacuum for purging. Specification for support system, safety system, integration, installation and test.

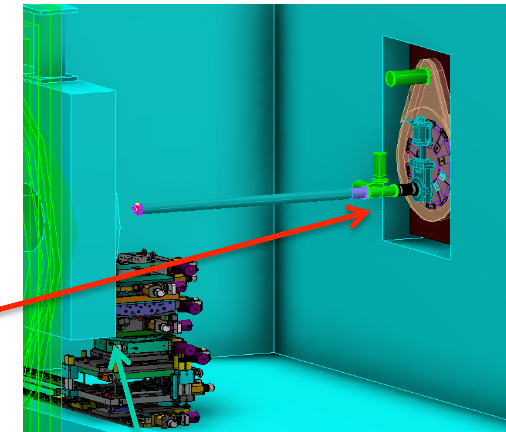


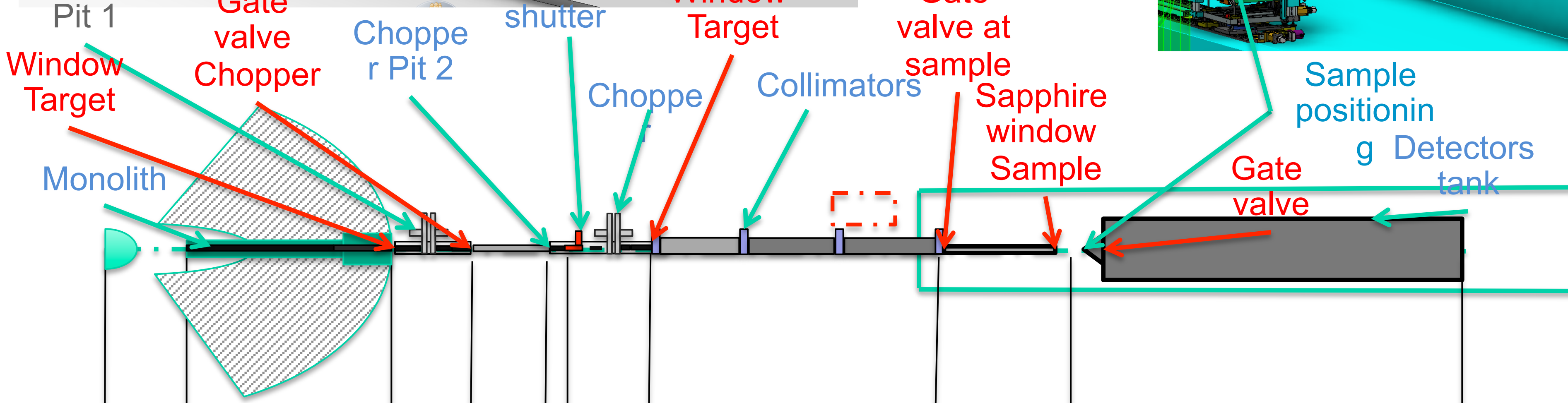


LoKI – SANS Instrument



- Interface document for Instruments already in discussion,
- Standardization model in place.





Vacuum Laboratory

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Vacuum Integration Test Facility (VITF)

This facility will provide the capability for seamless integration of all vacuum systems used on the accelerator, target and neutron instruments with the ICS (ESS Integrated Control System). This allows control logic to be developed and interlocks checked before implementation on the actual systems for which they are designed. EPICS control screens will also be developed together with data acquisition functions using this facility.

The VITF comprises a vacuum vessel that with the installation of vacuum pumps, valves, gauging and any other vacuum equipment can be used to replicate any vacuum subsystem or system used in the accelerator, target or for neutron instruments. While the equipment will be physically different (in most cases smaller), it will operate in the same manner providing a vehicle for the development of the vacuum to ICS interface.

Vacuum Laboratory

Gauge Calibration Facility (GCF)

The GCF will be used to confirm the operation and calibration of all vacuum gauges prior to installation with calibration performed against a secondary standard. All vacuum gauges installed on the accelerator, target and neutron instruments will use this facility. Gauge accuracy is important since gauge readings will be used for set point control and the interlocking and sequencing of the various vacuum system operations.

Vacuum Laboratory

Outgassing Test Facility (MTF)

This facility is designed to support the selection and approval of materials for use in a vacuum environment in accordance with the requirements of the ESS Vacuum Design Handbook (VDH) where materials having vacuum compatible characteristics are listed. The majority of work conducted using this facility will be in support of neutron instrument design where materials used for the neutron filters in the guide tubes can pose specific vacuum issues due to outgassing and in some cases undesirable constituents resulting in the need for preconditioning prior to installation. The selection of vacuum compatible cabling, to minimize the contamination of vacuum spaces from the outgassing of hydrocarbons from plasticizers inherent in cable insulation, will be made using this facility. The selection process will also include a quality control aspect requiring the batch-to-batch monitoring of materials for potential changes as a result of the manufacturing process.

References

- MATHEWSON, A.G. Vacuum System Design. In: TURNER, S. (ed.). Proceedings, CERN Accelerator School: 5th General Accelerator Physics Course. CERN - 94. v. 2. p. 717-729.
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- WUTZ, M.; ADAM, H.; WALCHER, W. Theory and Practice of Vacuum Technology. Braunschweig, Germany: Friedrich Vieweg & Sohn, 1989, 686p. ISBN 3-528-08908-3
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Conclusion

- Vacuum group is responsible for the vacuum requirements of the machine,
- Vacuum Group responsible to over see all related aspect of the vacuum for ESS (including the in kind contributions),
- ESS Vacuum Handbook main point of interface,
- Interface all other subsystem to provide the vacuum signals and logic to the machine control system.

Thank you!

Tack!

Obrigado!

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