LINAC-4 Ion Source Review
Pumping Systems

Paolo Chiggiato, Chiara Pasquino,
Giovanna Vandoni

Technology Department

Vacuum, Surfaces and Coatings Group

Workpackage Activities

3MeV test stand upgrades:

- LEBT gas density regulation
- Study of differential pumping effectiveness

357-Plasma Generator test stand: Modification.

357-Cs-Oven test stand:

- Cs compatible vacuum system

357-Ion-source test stand:

- LEBT gas density regulation
- Differential pumping effectiveness

Control's rack & cabling

Operation and maintenance of the 357 test stands and Linac4 components

- Spare parts: 10% + at least 1 unit of each item.
- Gauges calibration for H_2
- Monitoring and storage in database of pressure and density measurements.

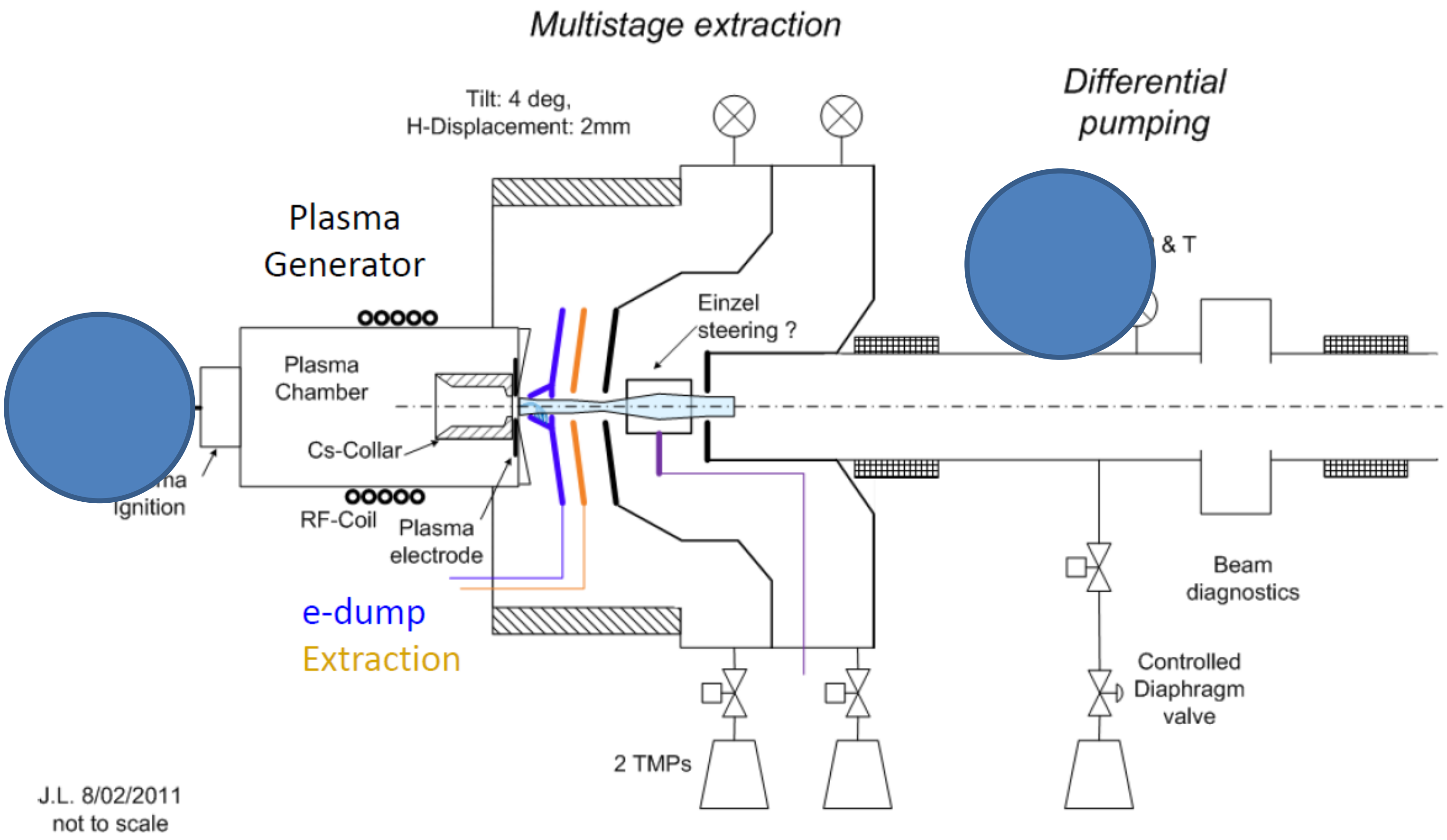
RGA in the L4 tunnel:

- Remote control and logging of the RGA data 8 light gases + 1-100 u scans at 15' intervals.
- Operation of the RGA as He-leak detection during IS exchange ?

High distributed pumping for H_2

IS Pumping System

The IS's vacuum system aims mainly at controlling the pressure at the beginning of the beam line despite the heavy gas injection at the level of the source and LEBT.



J. Lettry, IEFC workshop, March 2011

IS Pumping System

The pumping systems of the 3 MeV test stand and the 357 setups are based on standard components:

- Pumping:
    - ➢ 500 l s^{-1} turbomolecular pumping (TMP) stations backed by dry roughing pumps

-Measurement:
    - ➢ Penning-Pirani gauges powered by TPG 300 (Pfeiffer)

-Valves:
    - ➢ Viton seal gate valves to isolate vacuum sectors and TMP

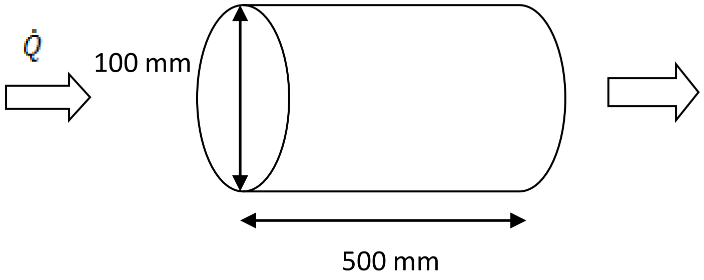
The effectiveness of the pumping configuration has been verified introducing the vacuum system's electrical equivalent network.

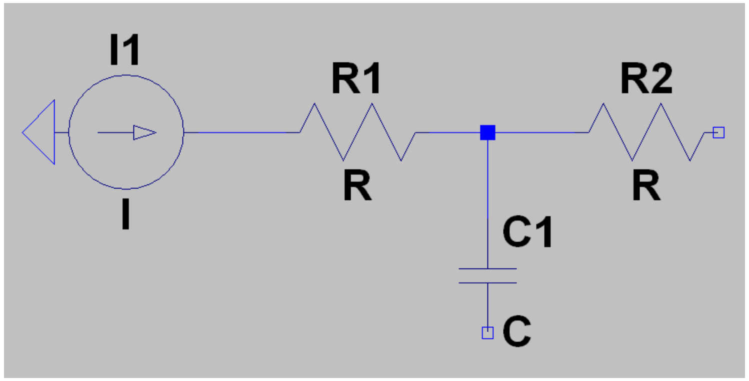
IS Pumping System: Electrical Network – Vacuum Analogy

To any vacuum system corresponds an equivalent electrical circuit where gas flow and pressure are replaced by electrical current and voltage.

VACUUM	ELECTRICAL NETWORK
Volume	Capacitance
Conductance	Resistance
Flow	Current
Pressure	Voltage

This approach allows the evaluation of dynamic pressure profiles of complex vacuum systems using programs dedicated to electrical networks (for example PSpice)



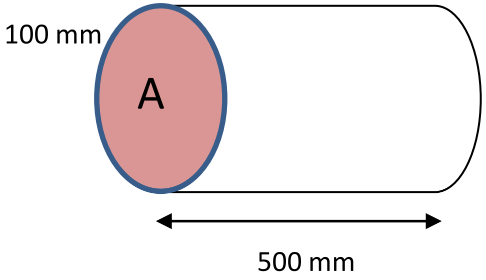


IS Pumping System: Gas Conductance Calculation

The conductance of a vacuum component can be easily calculate by analytical formulas whenever the geometry of the component is rather simple (tube, bellows, orifices..).

For more complex geometry, Monte Carlo simulations are carried out by computing the transmission probability

$$C = \alpha \cdot C_a \qquad C_a = A\sqrt{\frac{R \cdot T}{2\pi \cdot m}}$$

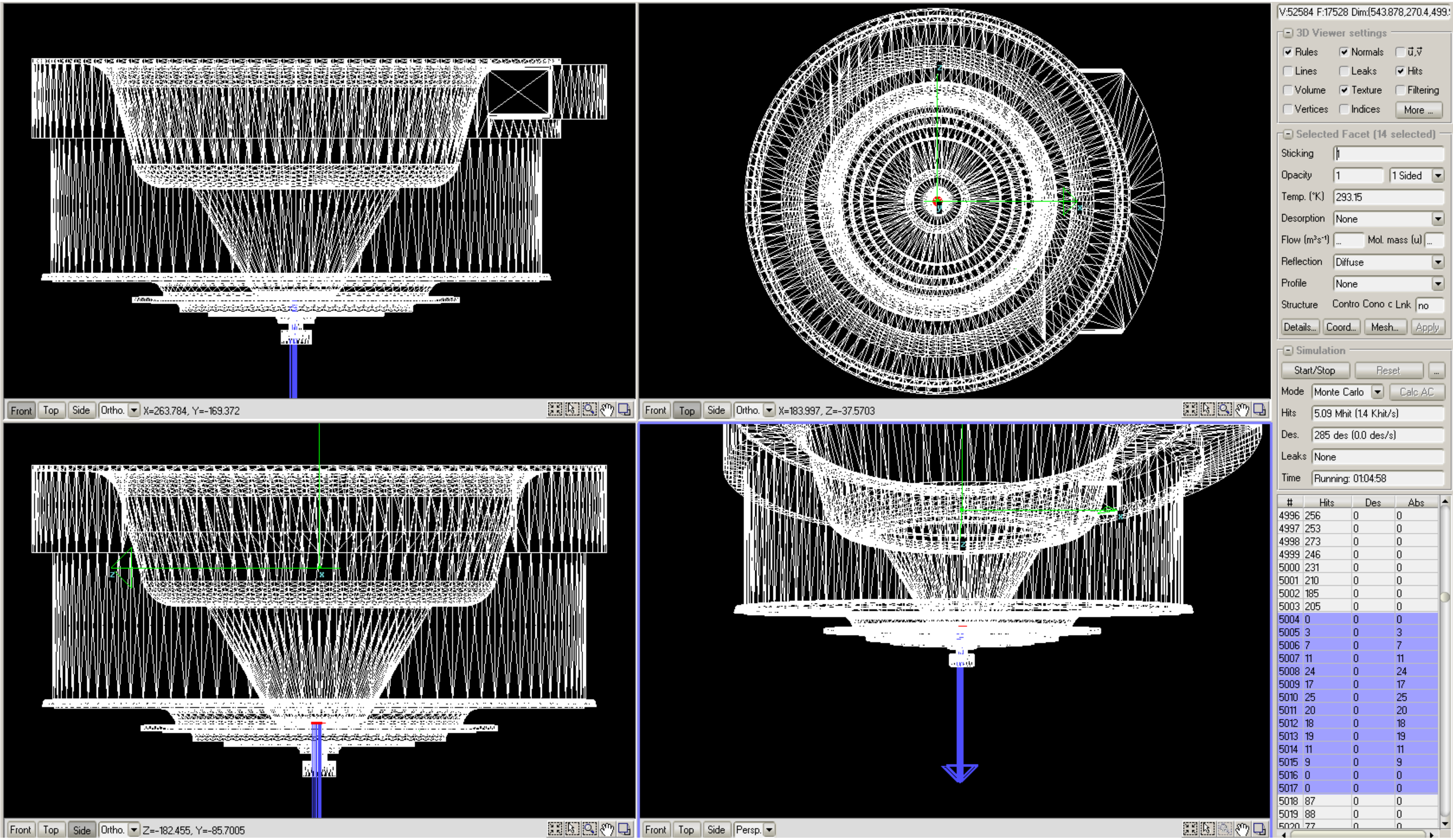


- ✓ T temperature.
- ✓ R gas constant.
- ✓ m molecular mass.
- ✓ Area of the entrance surface.
- ✓ α transmission probability.

The simulation programme is Molflow written by Roberto Kersevan.

IS Pumping System: Gas Conductance Calculation

Complex components can be simulated giving directly their 3-D drawing files as an input.



V:52584 F:17528 Dim:(543.878,270.4,499.

3D Viewer settings

☑ Rules ☑ Normals ☐ u⃗,v⃗
☐ Lines ☐ Leaks ☑ Hits
☐ Volume ☑ Texture ☐ Filtering
☐ Vertices ☐ Indices More ...

Selected Facet (14 selected)

Sticking: 1
Opacity: 1 — 1 Sided
Temp. (°K): 293.15
Desorption: None
Flow (m³s⁻¹): ... Mol. mass (u): ...
Reflection: Diffuse
Profile: None
Structure: Contro Cono c Lnk: no

Details... Coord... Mesh... Apply

Simulation

Start/Stop Reset ...
Mode: Monte Carlo — Calc AC
Hits: 5.09 Mhit (1.4 Khit/s)
Des.: 285 des (0.0 des/s)
Leaks: None
Time: Running: 01:04:58

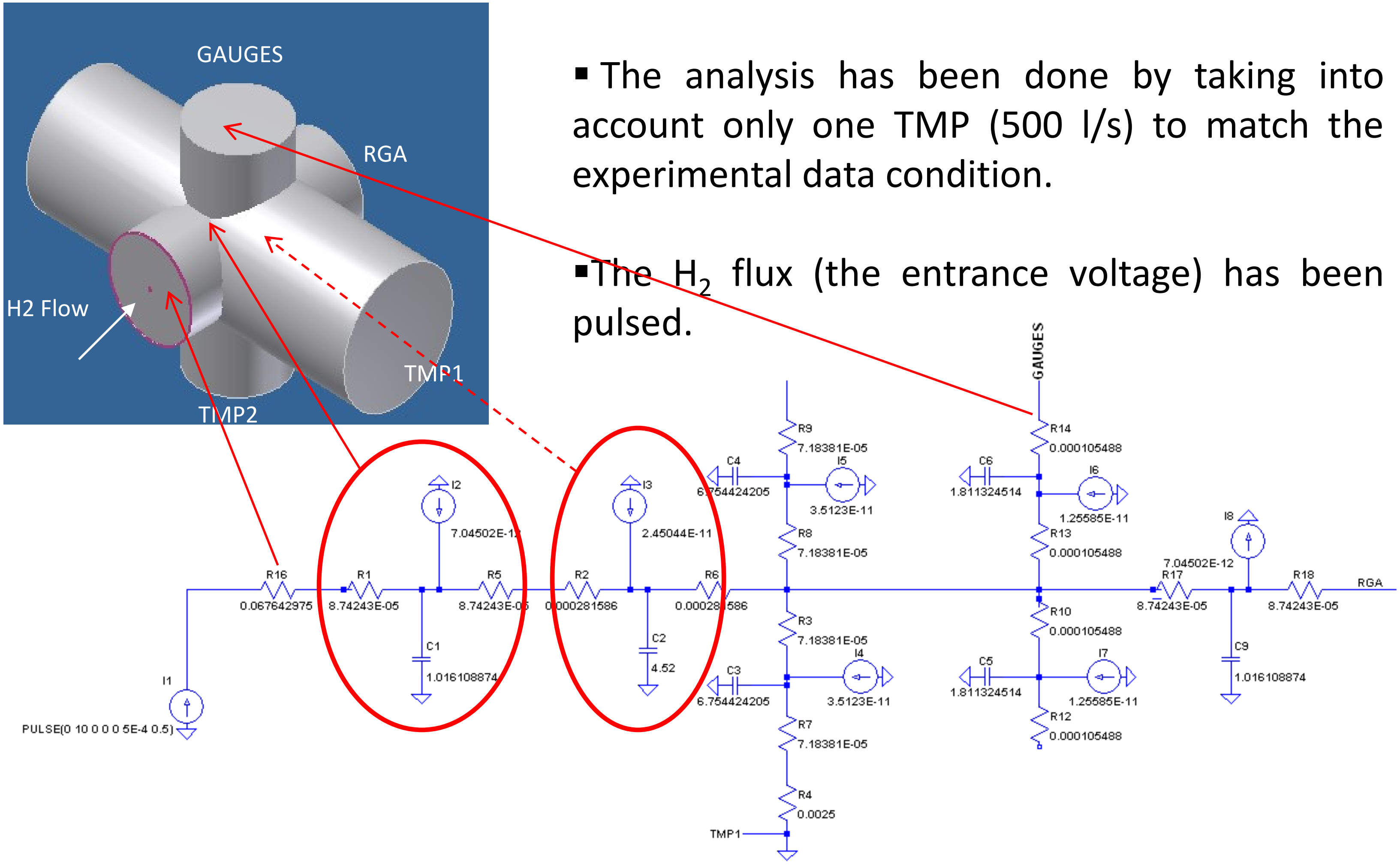
#	Hits	Des	Abs
4996	256	0	0
4997	253	0	0
4998	273	0	0
4999	246	0	0
5000	231	0	0
5001	210	0	0
5002	185	0	0
5003	205	0	0
5004	0	0	0
5005	3	0	3
5006	7	0	7
5007	11	0	11
5008	24	0	24
5009	17	0	17
5010	25	0	25
5011	20	0	20
5012	18	0	18
5013	19	0	19
5014	11	0	11
5015	9	0	9
5016	0	0	0
5017	0	0	0
5018	87	0	0
5019	88	0	0
5020	77	0	0

IS Pumping System: Simulation of the 357 Test Stand

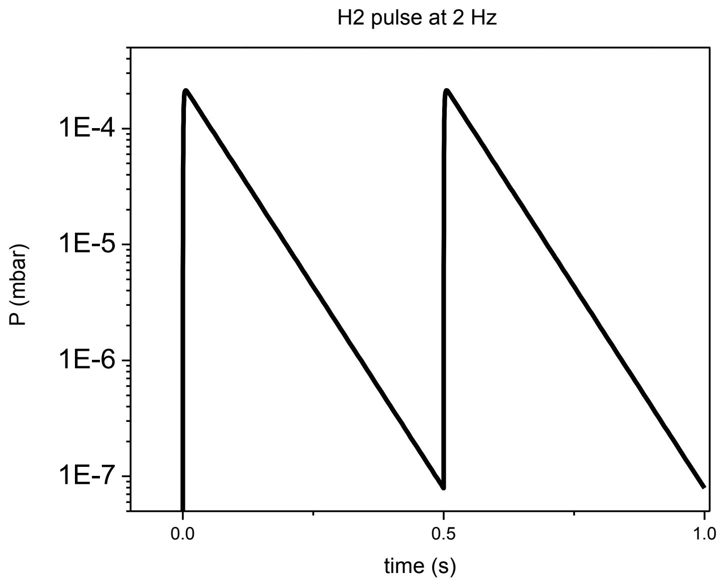
- The equivalent electrical network for the six-arm cross vacuum chamber has been drawn.

- The analysis has been done by taking into account only one TMP (500 l/s) to match the experimental data condition.

- The H_2 flux (the entrance voltage) has been pulsed.



IS Pumping System: Simulation of the 357 Test Stand

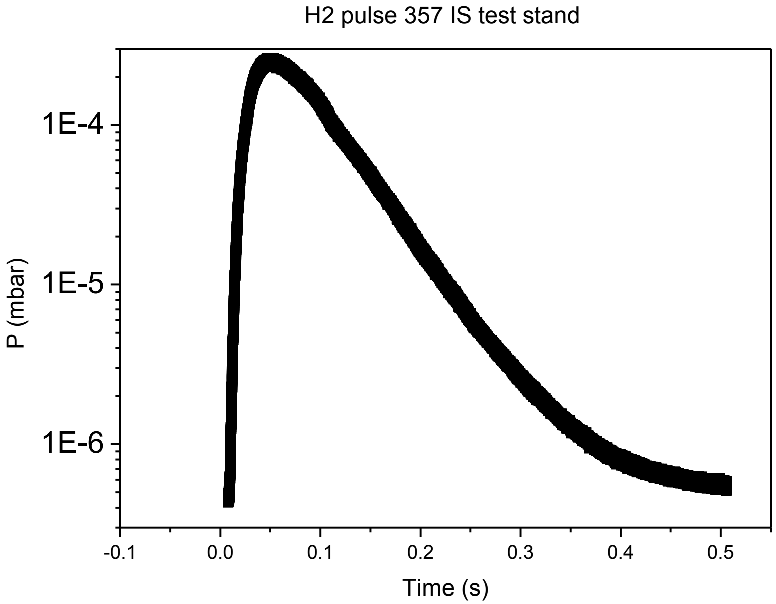


- ✓ Flow:5x10^{-3} mbar l/pulse;
- ✓ Pulse: 5x10^{-4} s;
- ✓ Frequency: 2Hz;
- ✓ Thermal outgassing not taken into account.

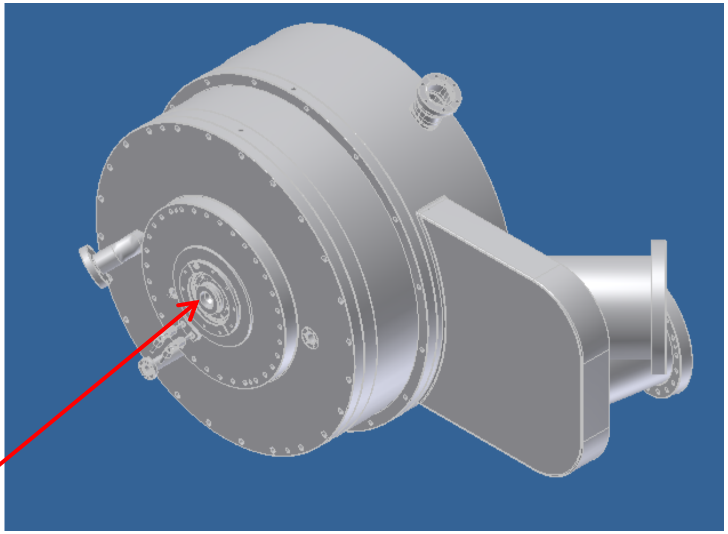
Good matching with the experimental data. The difference in the pressure value at the end of the pulse can be ascribed to:

- No thermal outgassing input in the calculation.

- Temporary memory effect of the Penning gauge.

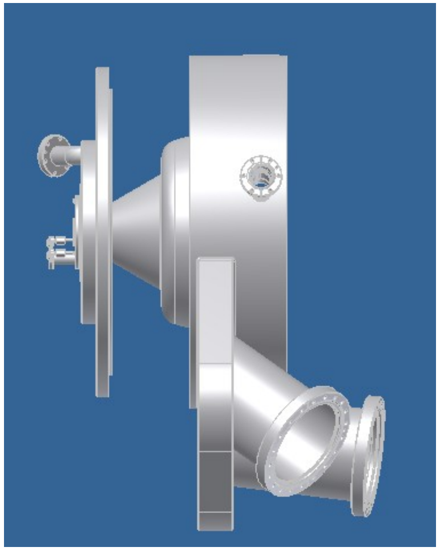


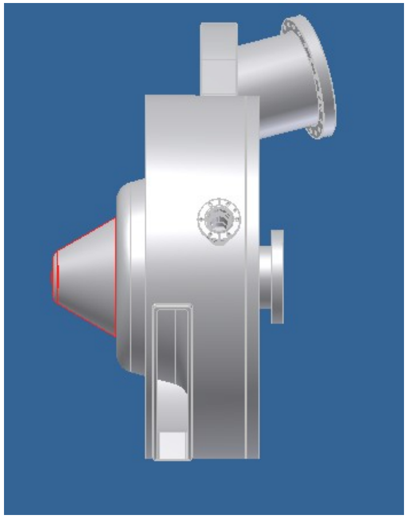
IS Pumping System: Simulation of LINAC4's IS + LEBT



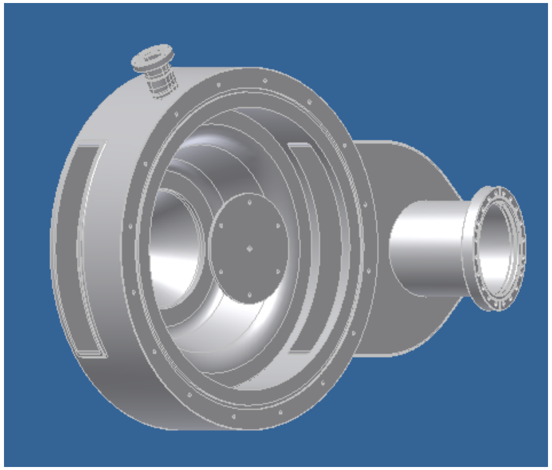
H_2 injection

FIRST VOLUME

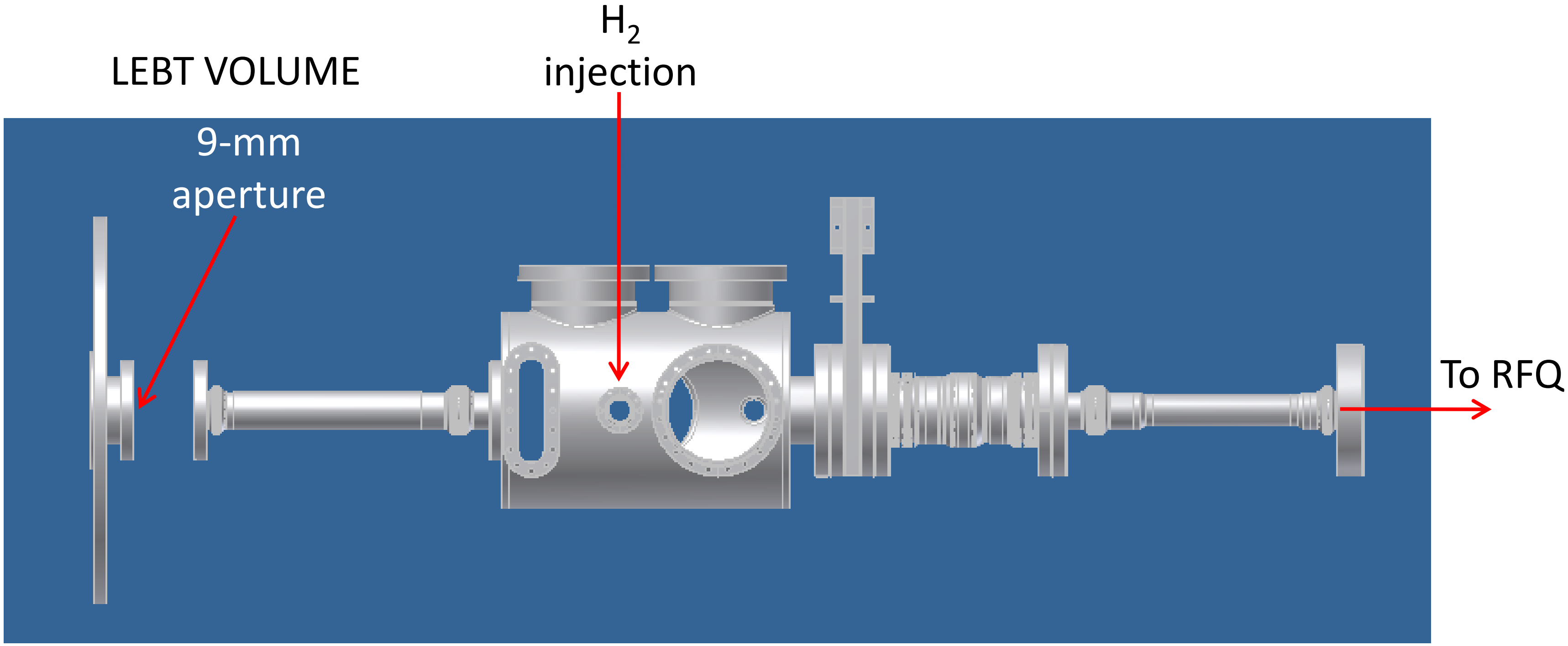




SECOND VOLUME

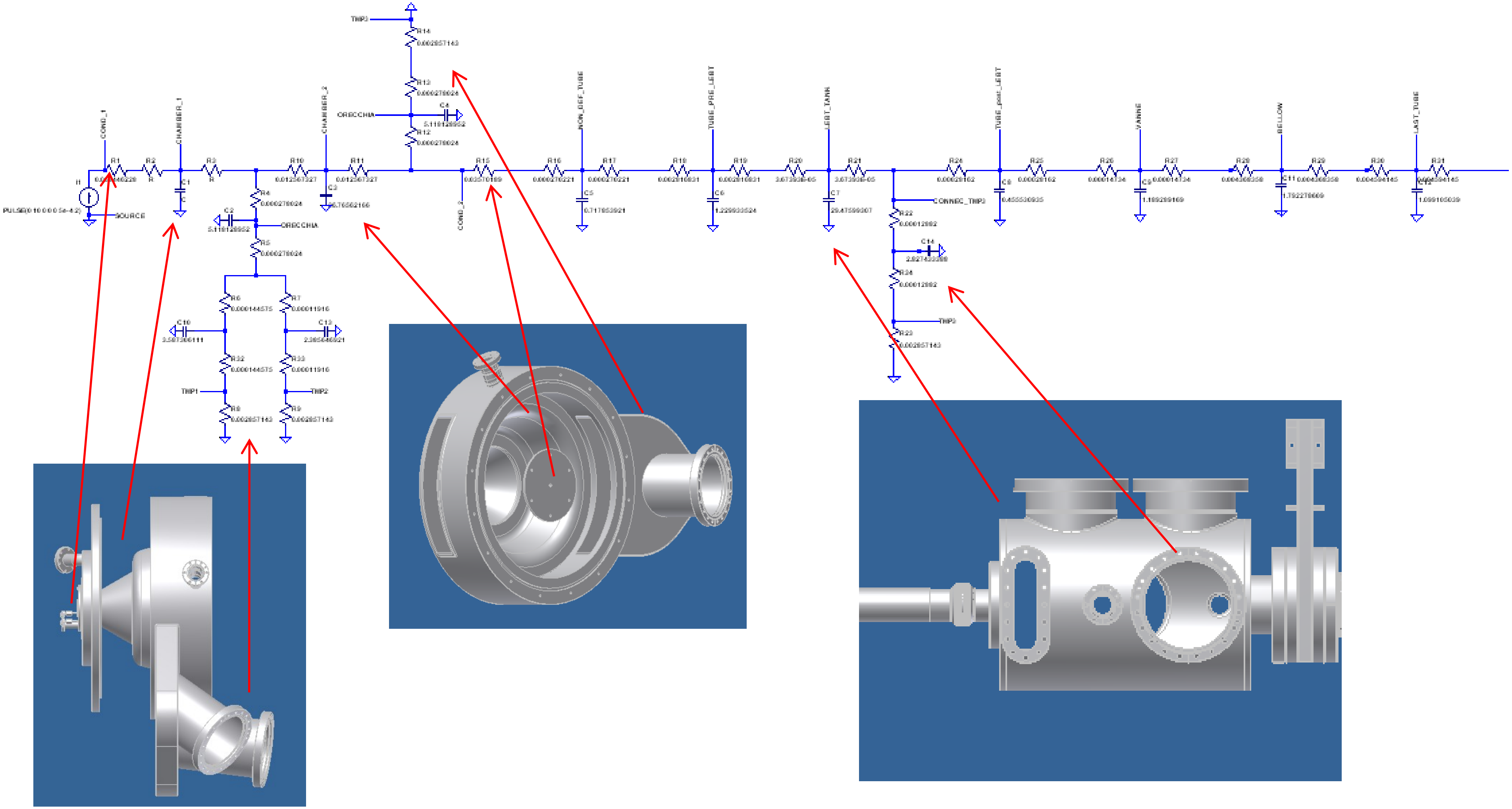


IS Pumping System: Simulation of LINAC4’s IS + LEBT



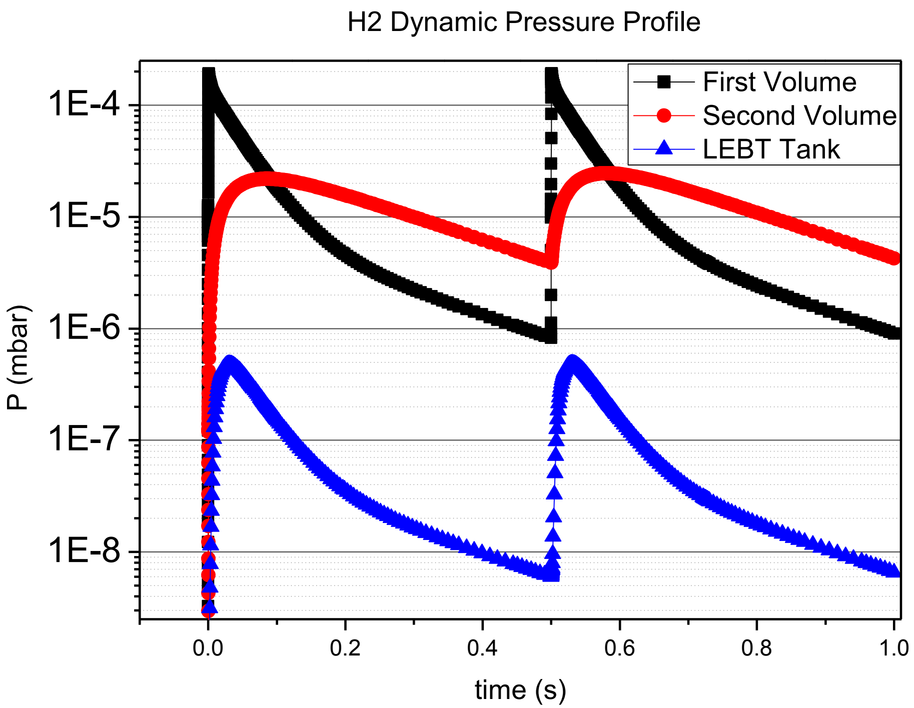
- TMP connected 500 l/s.
- No injection in the LEBT taken into account yet.
- No degassing taken into account yet.

IS Pumping System: Simulation of LINAC4’s IS + LEBT



IS Pumping System: Simulation of LINAC4’s IS + LEBT

RESULTS @ 2Hz

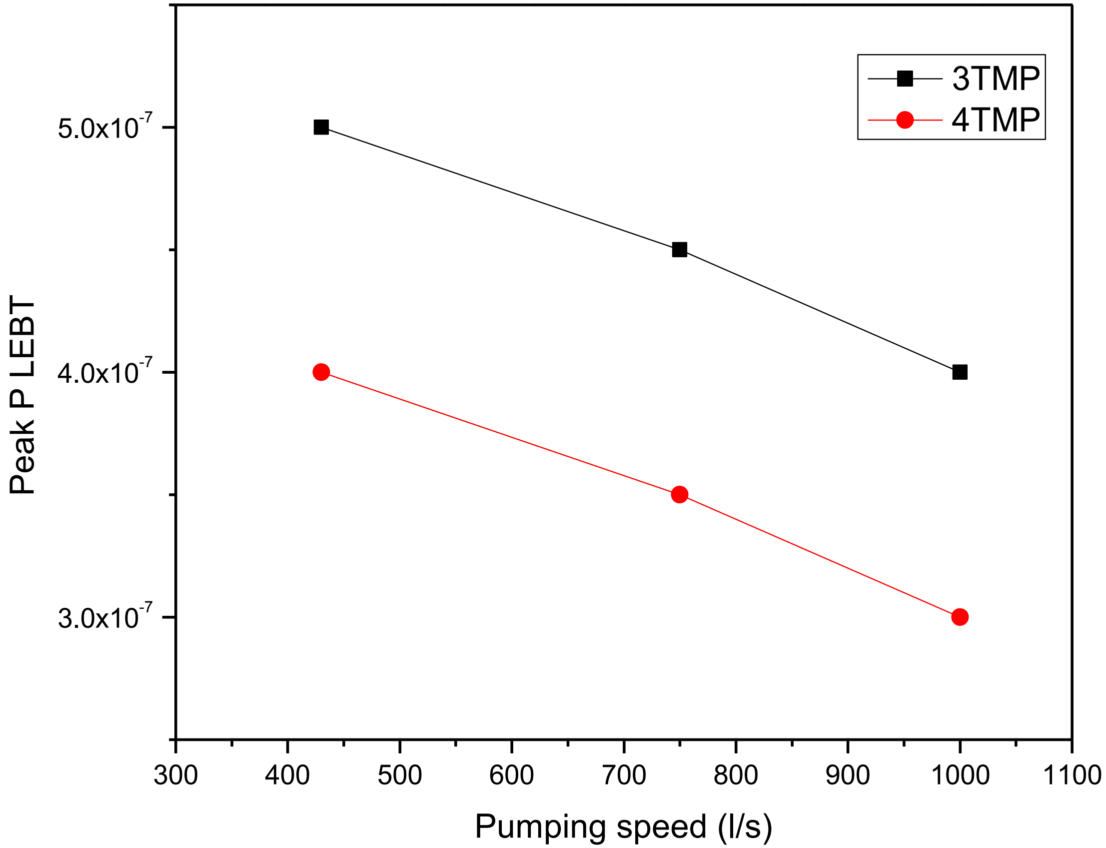


- 2 TMPs are connected to the first volume.
- 1 TMP to the second volume.
- 1 TMP connected to the LEBT tank.
- No direct injection in the LEBT tank taken into account yet

- The pressure in the LEBT tank oscillates between about 1x10^{-8} and 5x10^{-7} mbar during the source injection cycle.
- About 0.1 s after the gas pulse, the pressures in the system are led by the gas stored in the second volume (lower pumping speed than in the first volume).

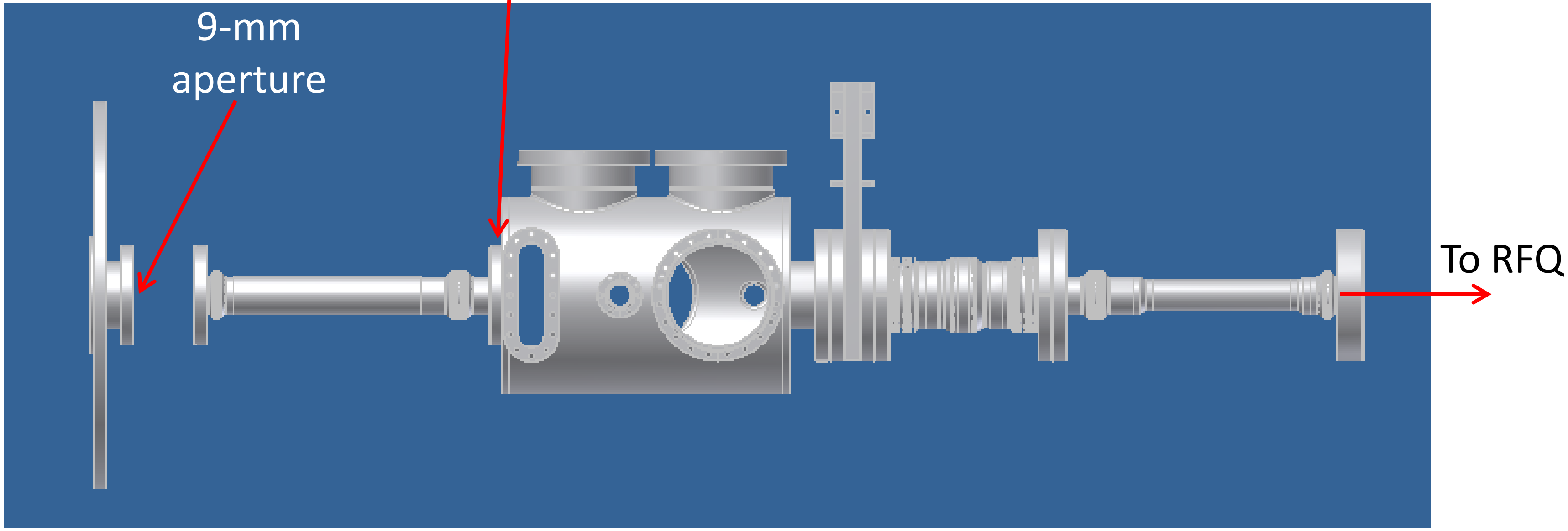
IS Pumping System: Simulation of LINAC4's IS + LEBT

- The pressure peak in the LEBT can be reduced by increasing the TMP pumping speed in first and second volume, and adding a second pump in the second volume.
- However the reduction is limited to only 40%.



- Another approach to reduce the LEBT pressure would consist in reducing the beam pipe aperture at the entrance of the LEBT tank (can we do that?).

IS Pumping System: Simulation of LINAC4's IS + LEBT



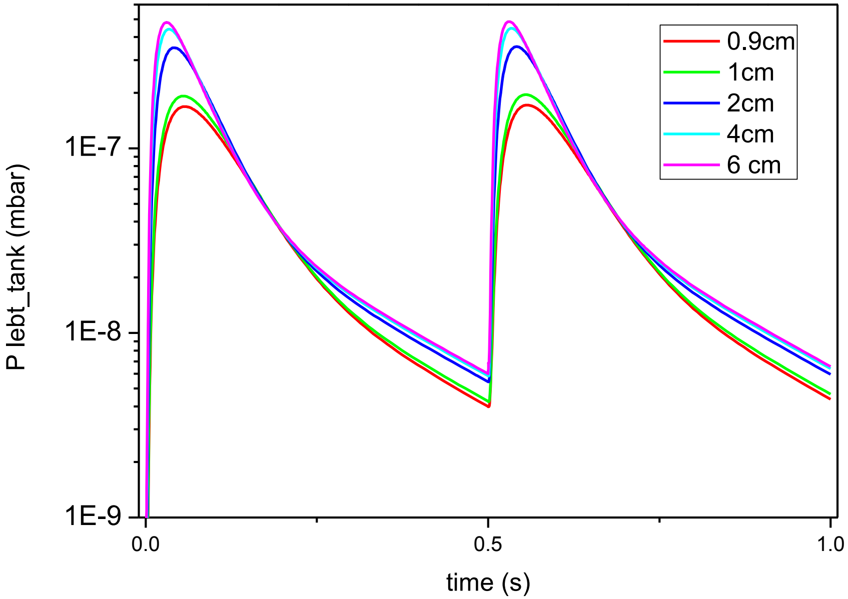
Additional restriction

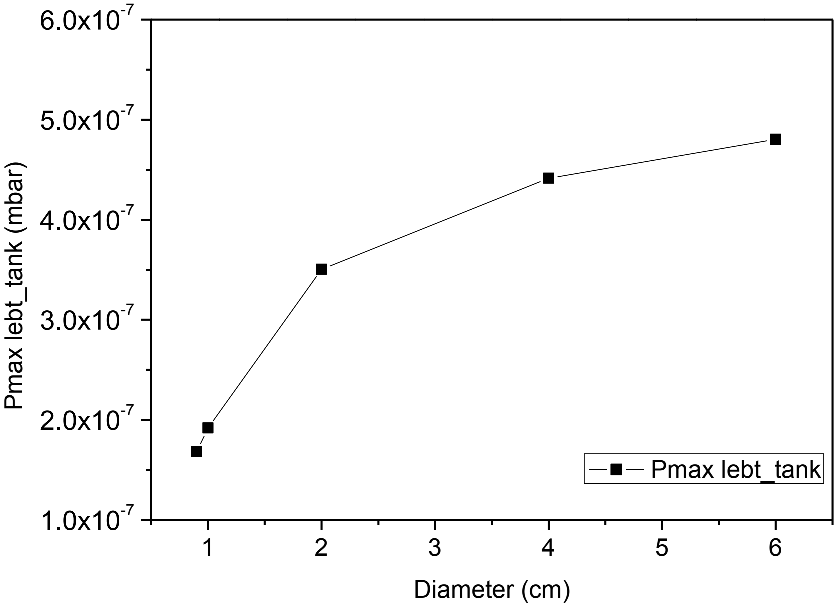
9-mm aperture

To RFQ

IS Pumping System: Simulation of LINAC4’s IS + LEBT

- Decreasing the LEBT entrance aperture from 6 cm down to 9 mm, the pressure peak can be reduce by about 60% .

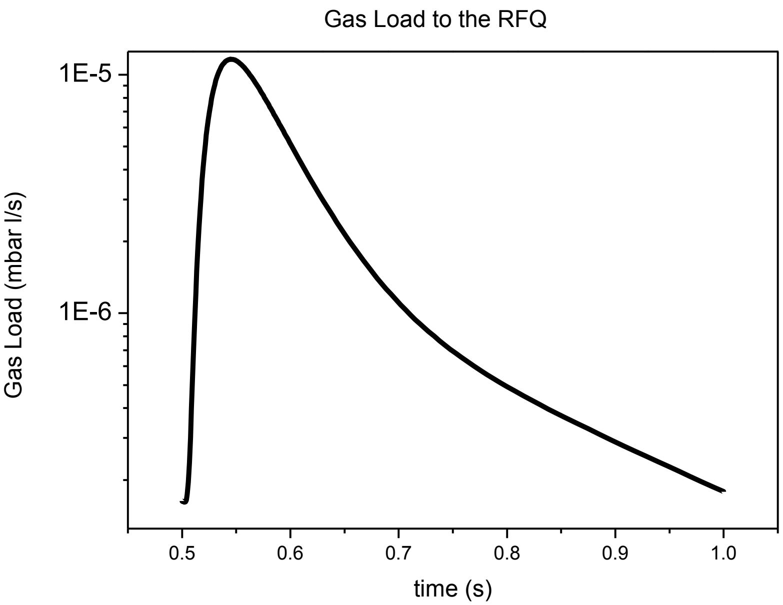


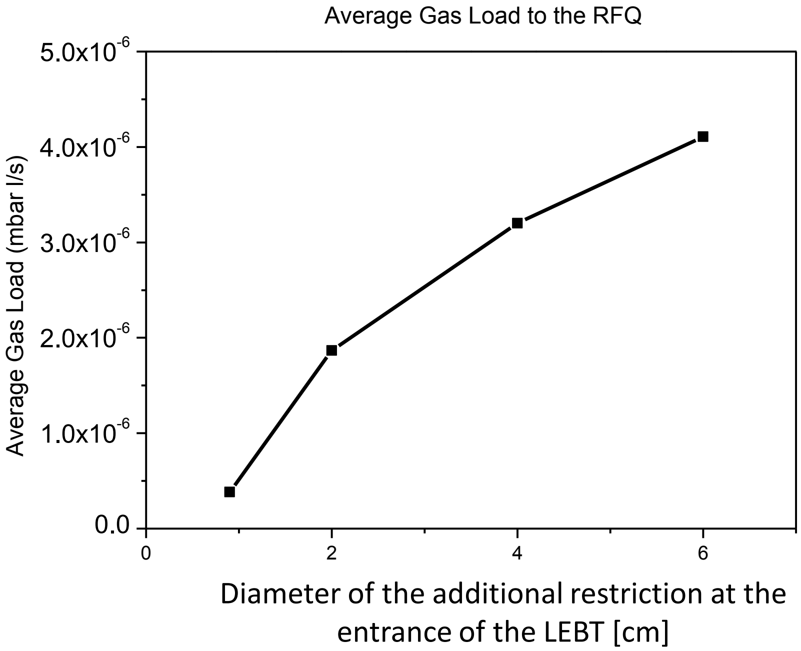


- Another important result of the computation is the evaluation of the H_2 flux that enters into the RFQ volume, either when the local H_2 injection in the LEBT is considered or not.

IS Pumping System: Simulation of the gas load in the RFQ

No local injection in the LEBT





Pumping speed installed in the RFQ: 1500 l s^{-1}.

The maximum pressure variation in the RFQ, due to the pulsed gas injection in the IS, is in the high 10^{-9} mbar.

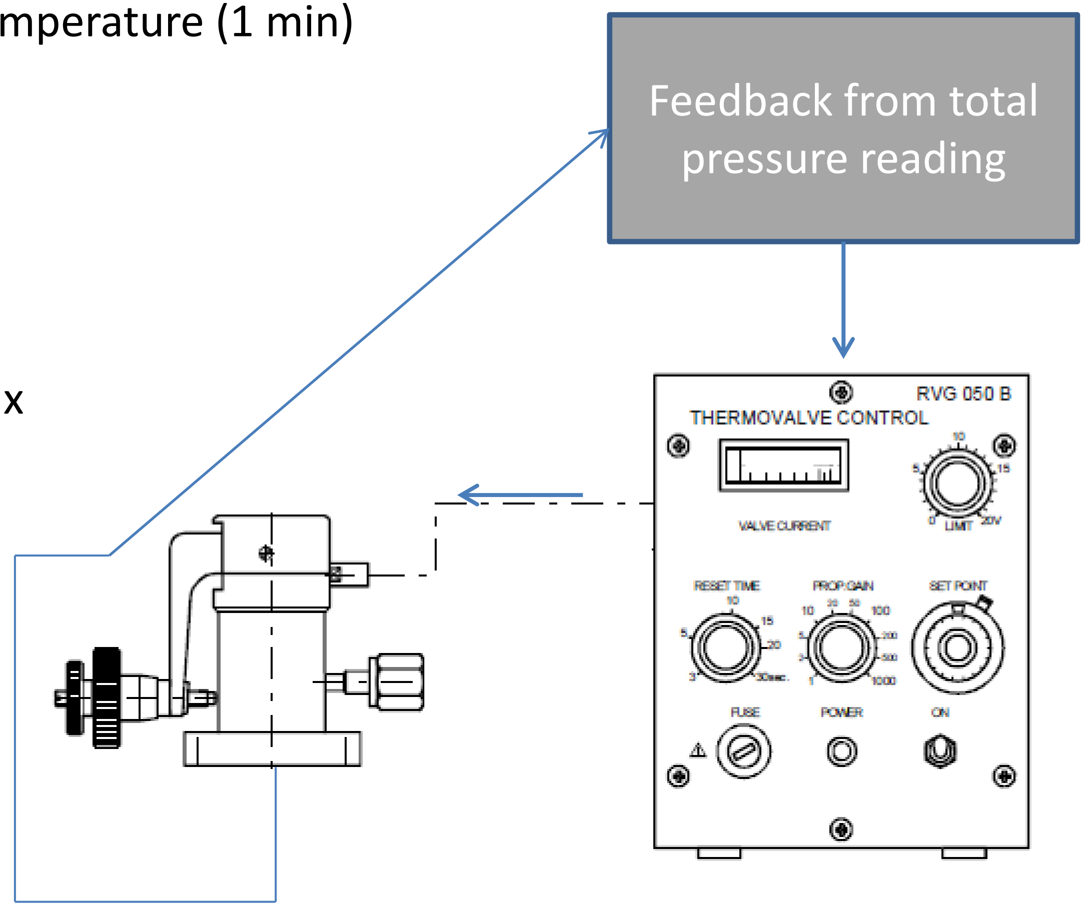
LEBT Gas Density Regulation

- Density regulation (2-5%):
  - **10^{-8} (10^{-7})**÷10^{-4} mbar at 25 °C,
  - measurement integration time > 1s
  - regulation loop time constant > 1 min
  - time resolved pressure (5ms) temperature (1 min)
  - monitoring for failure analysis

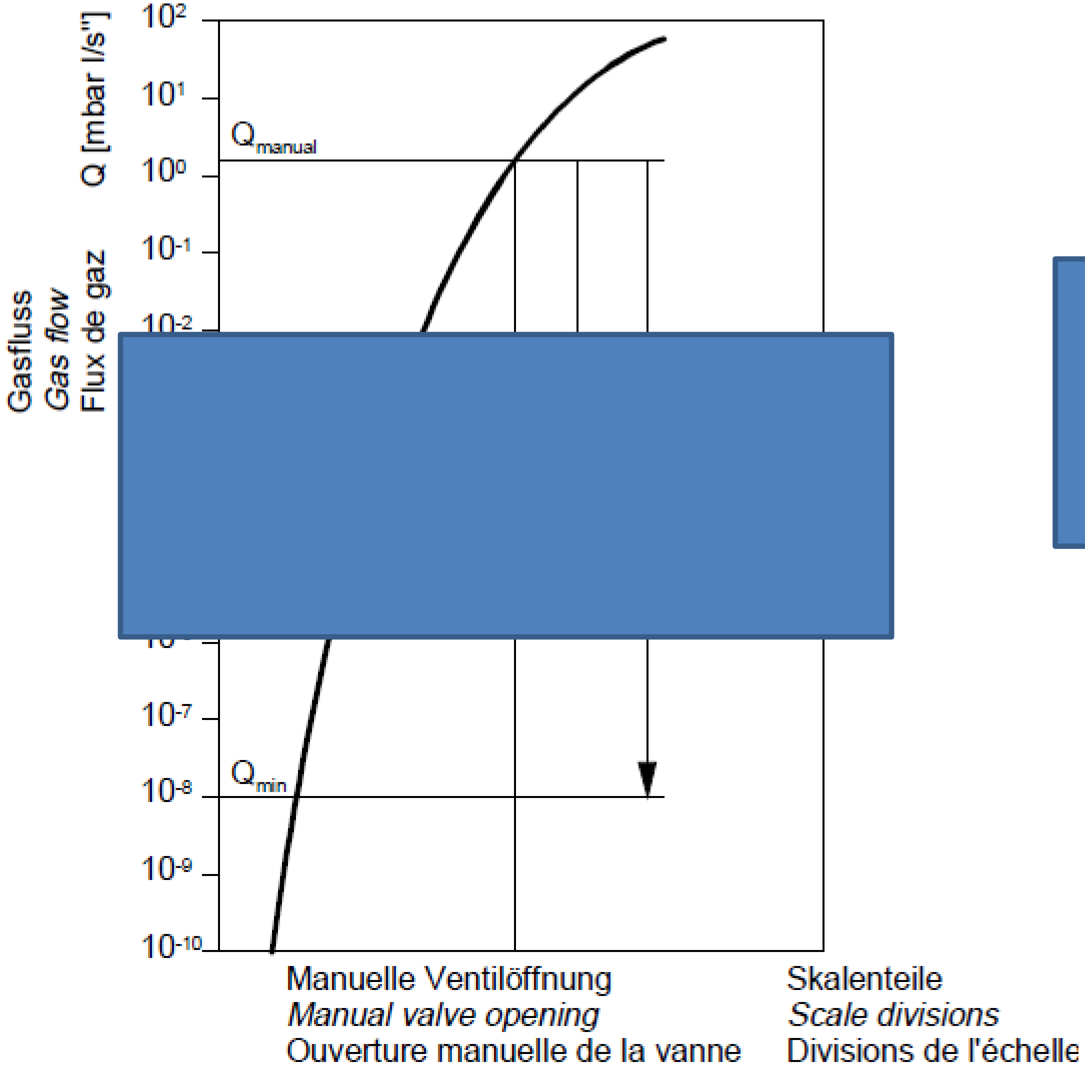
- Flux regulation:
  - **10^{-5}÷**10^{-2} mbar l s^{-1} at 25 °C

- UDV 140 by Pfeiffer: the variable flux is obtained by controlling the thermal expansion of a bolt.

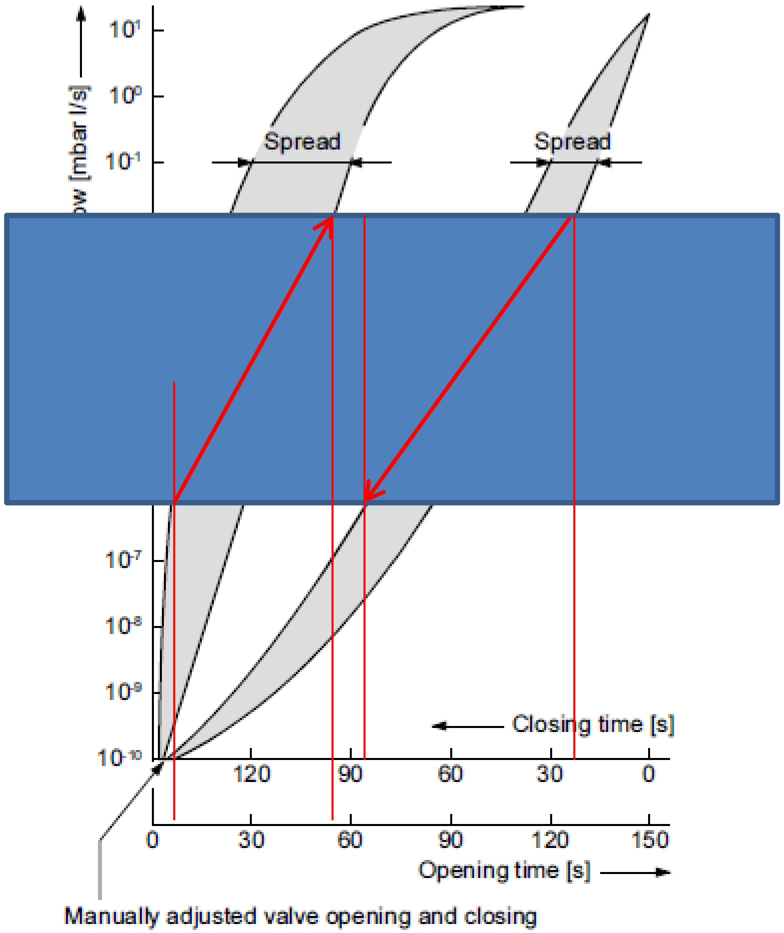
- The maximum flux is pre-set manually. As a consequence an additional ‘normally-closed’ valve is needed to stop the flux in case of power cut.


Feedback from total pressure reading

LEBT Gas Density Regulation



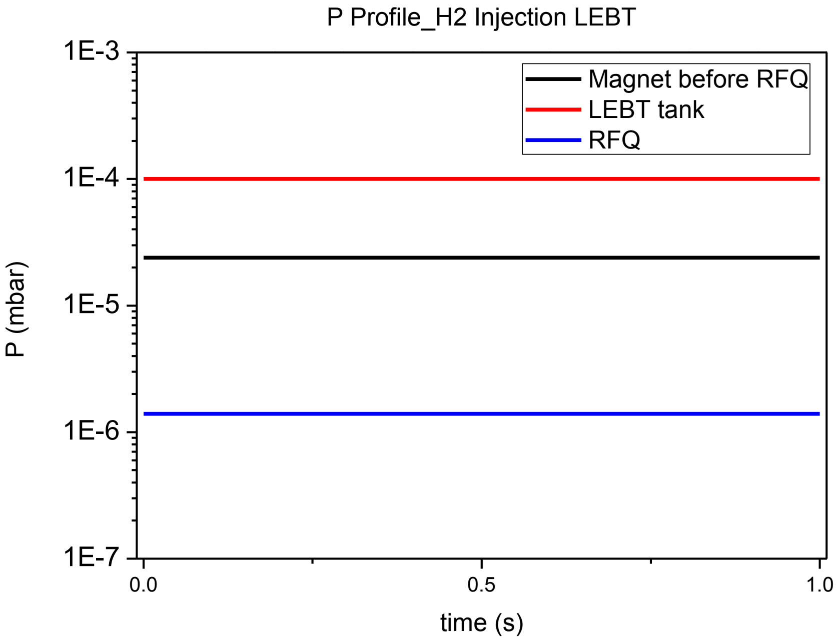
Example of the gas throughput characteristic of a UDV 146 used in conjunction with the RVG 050 C at maximum power.



The spread is a function of the mechanical tolerances of the valve.

Source: Pfeiffer Operating Instruction of RVG 050 C and UDV 140

LEBT Gas Density Regulation: Impact on the RFQ



Pumping speed installed in the RFQ: 1500 l s^{-1}.

Pulsed source and local injection to the maximum design pressure (10^{-4} mbar).

Of course the pressure in the RFQ is dominated by the gas injection in the LEBT

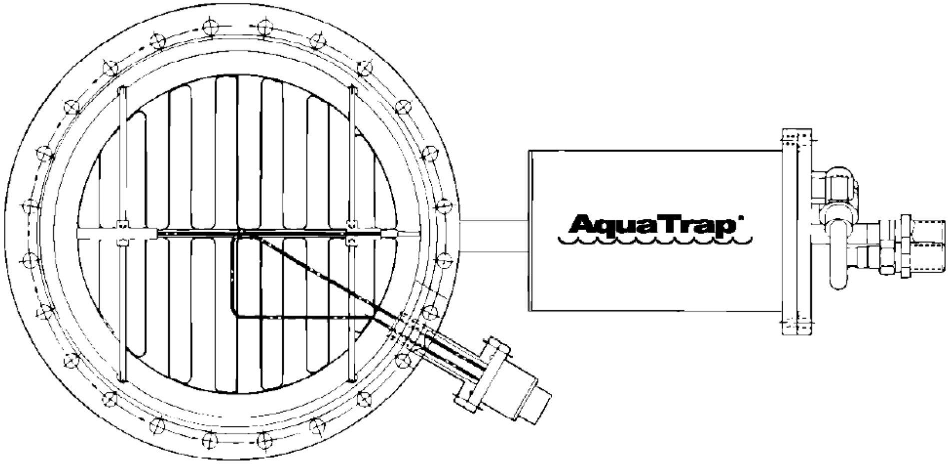
In this condition the H_2 load in the RFQ is **2.6×10^{-3} mbar l s^{-1}**

TMP and Cs Compatibility

- Cs atoms can be efficiently stopped before reaching the TMP blades by a cooled stage placed in between the pump and the Cs source.

- These intermediate pumping stages are already available to increase pumping speeds for water vapour.

- They reach a temperature of about -100 °C and can be easily adapted to the LINAC4-IS need.



Remote Control of RGA in L4 Tunnel

- The RGA remote control in the LINAC4 tunnel is of course feasible. At present we are controlling MKS and Pfeiffer quadrupole gas analyzers in CTF and SPS.

- The Pfeiffer analyzer installed in CTF is now controlled by PVSS. This could be implemented in LINAC4 but is not part of the Vacuum WP.

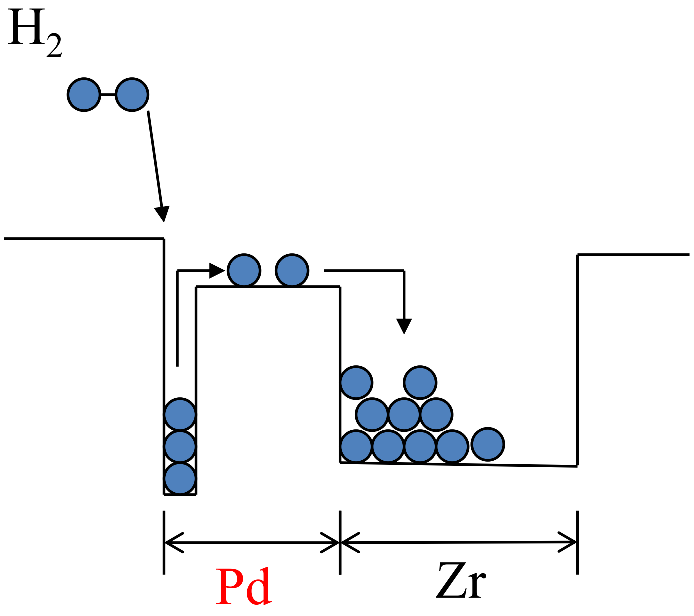
- RGA are frequently used for He leak detection by monitoring mass 4 signal as a function of time. The sensitivity of the detection is not an issue.

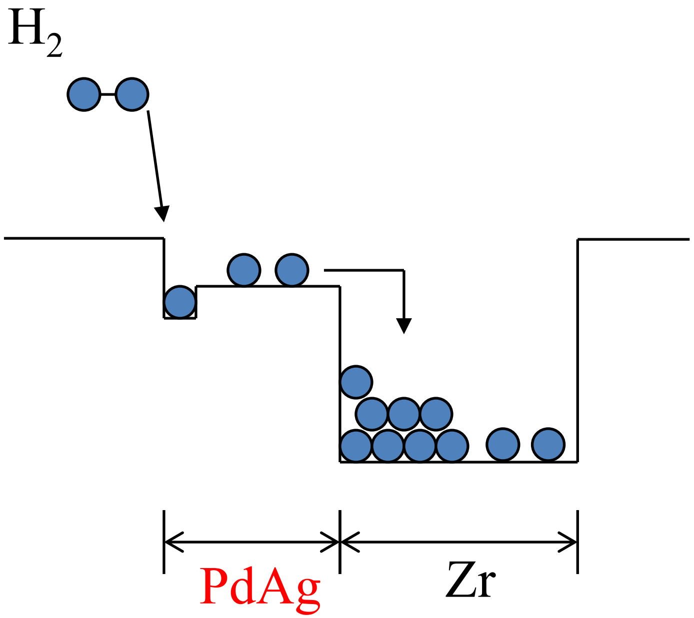
Distributed Hydrogen Pumping Speed with High Gas Capacity

A distributed H_2 pumping would be very effective in blocking the transmission of gas from the LEBT to the RFQ.

We are studying metallic multilayers for the pumping of H_2 based on Pd alloy coated Zr sheets.

The materials (wires for thin film coating and sheets) have just arrived. The first test are planned from June to September.





Vacuum Control of the Test Stands

Pressures and temperatures will be acquired by a local computer. The data monitoring will be used for failure analysis and online testing.

At present the TE-VSC group has not enough resources to adapt a specific control system based on PLC and interfaced by PVSS to the test stands.

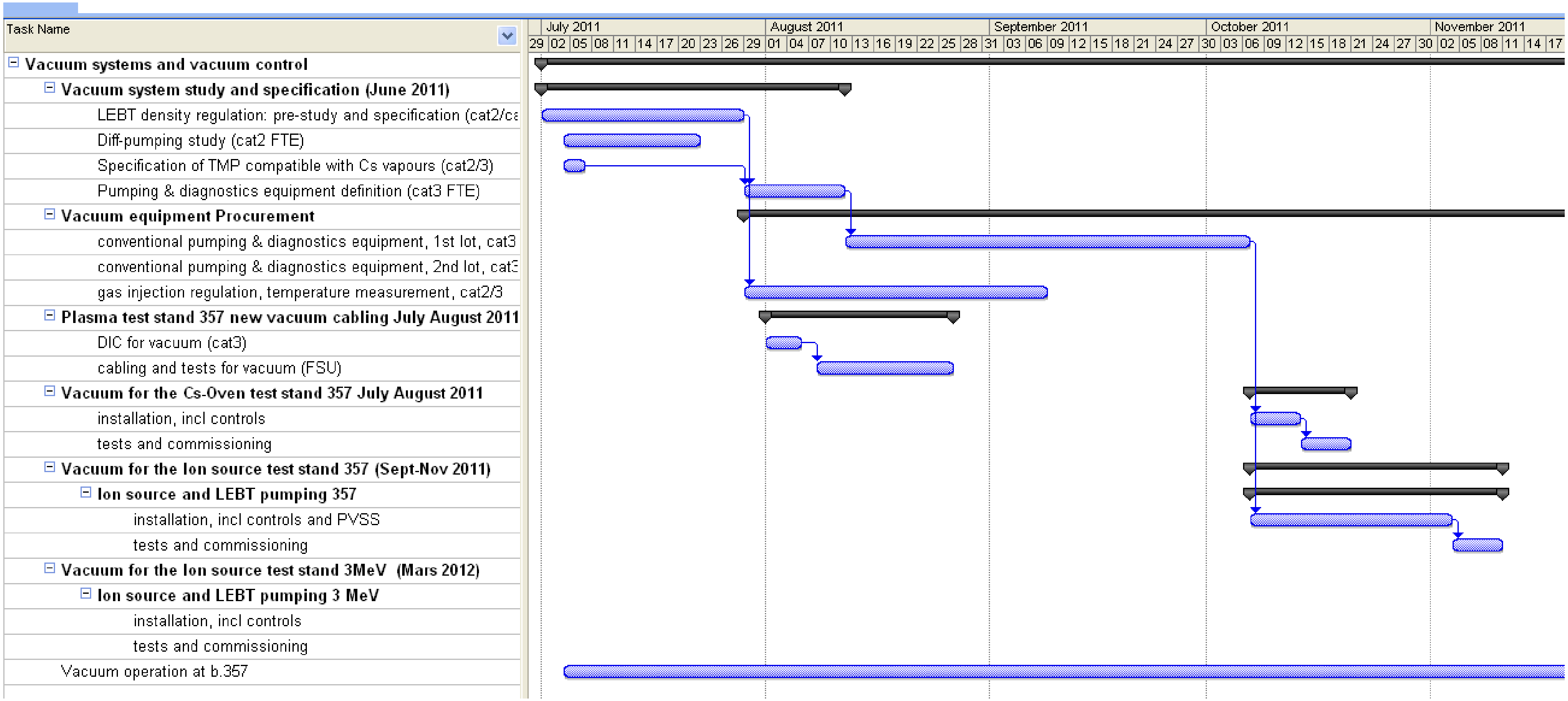
LINAC4 Test Stands are not considered for TE-VSC stand-by duty support.

Budget and Manpower

System	Contents of the vacuum WP	Start	Work breakdown	Who	FTE [days]	Budget [kCHF]
357- Ion source test stand	*Vacuum for the IS test stand:* *a) Pumping of Ion Source +LEBT* *b) LEBT density regulation* *c) Differential pumping system*	Sept-Nov 2011	Differential pumping: study	cat2	15	0
			LEBT density regulation: pre-study and specification	cat2	20	0
			LEBT density regulation: equipment/controls	cat2	20	7
			Vacuum equipment (4TMP, 2VGR/VGP, spare TMP)	cat3	5	157
			Vacuum controls	cat3	10	7
			Installation, tests and commissioning	cat3	15	8
3MeV test stand Ion Source	*Upgrade of the 3MeV ion source with the development done in b.357 on the ion source:* *b) LEBT density regulation* *c) Differential pumping system*	March 2012	LEBT density regulation: equipment/controls	cat3	2	7
			Differential pumping: equipment/controls	cat3	2	122
			Installation, tests and commissioning	cat3	15	8
357-Plasma test stand	*new vacuum cabling campaign, following the modification of the test stand*	July August 2011	"Demande d'installation de cables" for vacuum	cat3	2	0
			cabling and tests for vacuum (FSU)	cat3	5	2
357-Cesium oven test stand	*Selection, purchasing and installation of a new turbopump compatible with Cs vapours*	July August 2011	1 TMP + baffle for Cs	cat3	5	35
			installation, incl controls	cat3	3	2
			tests and commissioning	cat3	3	3
357-Vacuum operation	*Vacuum support to operation of the b.357 test stands*			cat3	365(5%)	16

373 kCHF

Schedule



Task Name

- Vacuum systems and vacuum control
  - Vacuum system study and specification (June 2011)
    - LEBT density regulation: pre-study and specification (cat2/ca
    - Diff-pumping study (cat2 FTE)
    - Specification of TMP compatible with Cs vapours (cat2/3)
    - Pumping & diagnostics equipment definition (cat3 FTE)
  - Vacuum equipment Procurement
    - conventional pumping & diagnostics equipment, 1st lot, cat3
    - conventional pumping & diagnostics equipment, 2nd lot, cat3
    - gas injection regulation, temperature measurement, cat2/3
  - Plasma test stand 357 new vacuum cabling July August 2011
    - DIC for vacuum (cat3)
    - cabling and tests for vacuum (FSU)
  - Vacuum for the Cs-Oven test stand 357 July August 2011
    - installation, incl controls
    - tests and commissioning
  - Vacuum for the Ion source test stand 357 (Sept-Nov 2011)
    - Ion source and LEBT pumping 357
      - installation, incl controls and PVSS
      - tests and commissioning
  - Vacuum for the Ion source test stand 3MeV (Mars 2012)
    - Ion source and LEBT pumping 3 MeV
      - installation, incl controls
      - tests and commissioning
  - Vacuum operation at b.357

Conclusions

- The vacuum system layout is almost fixed. By the electrical model we can simulate any effect in the pressure distribution due to changes in the mechanical design and modifications of the pumps' layout .

- The H_2 injection system for the LEBT can be made of standard components.

- A cold trap could be considered for the pumping of the Cs source.

- Despite the fact that the LINAC4 ion source is considered one of the most important tasks in the TE-VSC group, the vacuum control manpower is not enough to pursue the present requests for the test stands, i.e. a complete control of all vacuum variables with PVSS interface. A simpler and less time consuming approach is proposed, namely a data acquisition and storage for online and failure analysis.

- 3MeV test stand upgrades:
  1)LEBT Density regulation (2-5%), 10^{-8}-10^{-4} mbar at 25 deg.C, measurement integration time > 1s, regulation loop time constant > 1 min). time resolved pressure (5ms) temperature (1 min) monitoring for failure analysis.
  2)Based on pulsed IS flow 1-5 10^{-3} mbar l/s per pulse and apertures size (5-20 mm), pre study of the differential pumping effectiveness.
  3)Beam extraction chamber's Differential pumping system (2+1 TMP).
- 357-Plasma Generator test stand: Modification.
- 357-Cs-Oven test stand: design, produce and commissioning of pumping system (1 TMP compatible with Cs vapours)
- 357-Ion-source test stand: identical to linac4's source +LEBT
  1)LEBT: produce and commissioning of pumping system (1 TMP+ diaphragm + H2 injection)
  2)LEBT Density regulation, 10^{-8}-10^{-4} mbar at 25 deg.C, measurement integration time > 1s, regulation loop time constant > 1 min)
  3)Beam extraction chamber's Differential pumping system (2+1 TMP).
- Control's rack, cabling, Operation and maintenance of the 357 test stands and Linac4 components
- Spare parts: 10% + at least 1 unit of each item. The gauges shall be calibrated for H2, the pressure and density measurements shall be monitored in a database and accessible.
- RGA in the L4 tunnel:
  1)Remote control and logging of the RGA data 8 ligh gases + 1-100 amu scans at 15' intervals.
  2)Operation of the RGA as He-leak detection during IS exchange ?
- High pumping speed getter surfaces