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PRELIMINARY VACUUM SIMULATION RESULTS ON ELI C-BAND ACCELERATING STRUCTURE

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Abstract
A C-band accelerating structure has a higher accelerating gradient than that of the S-band structure. It provides a good advantage of a shorter machine length. In order to effectively use RF power and for cost reduction, the accelerating structure should be as long as possible.
We propose a 2 meter long structure, although a longer accelerating structure has worse vacuum performance than a shorter accelerating structure. Thus, the vacuum conductance of two meters long structure has to be checked. We simulate vacuum performance of the accelerating structure by 1-D analytical method.
From simulations, it is shown that the vacuum performance for the two m long accelerating structure is safe enough; vacuum tests are in progress in order to confirm these simulations.

Introduction

For main linac of the ELI-NP, C-band accelerating structures have a benefit of a shorter machine length. We propose a two meters accelerating structure. Extending the column length, the number of RF modules can be reduced, also if, a longer accelerating column has a lower vacuum conductance and then there is a high possibility of the RF breakdowns, a shorter beam lifetime and emittance blow-up.
For vacuum calculations, there are several methods available: analytically solving the gas flow equation [1], the finite element method (FEM) [2], the equivalent circuit analysis [3], the Monte Carlo [4] and commercial codes [5]. We adopt analytically solving the gas flow equation (1-D).

Vacuum analysis

In general, the pressure distribution in a vacuum system is determined by the load, flow, and pumping-out of gases.
For a simple analysis, we assume that the vacuum pressure is a steady state, and there are no intermolecular collisions in the accelerating column. The relation between the gas throughput Q and the vacuum pressure P is given by [2]:

$$Q = PS + C\Delta P \tag{1}$$

Where, S is the pumping speed, C is the vacuum conductance and ΔP is the pressure difference between cavities. Q is given by a product of the out gassing rate of the inner surface area of the cavity.
The cross section of the C-band cavity is shown in Fig. 1. The cavity is divided by three parts: the main cavity, four damping channels, and iris. The vacuum conductance is dominantly determined by the iris, since the entrance of damping channel is larger enough than the iris.

Therefore, in analytic calculations, we simplify the vacuum model as composed by two parts: the main cavity including the damping channels and the iris. The vacuum conductance of iris is calculated by the small cylindrical tube model [2].

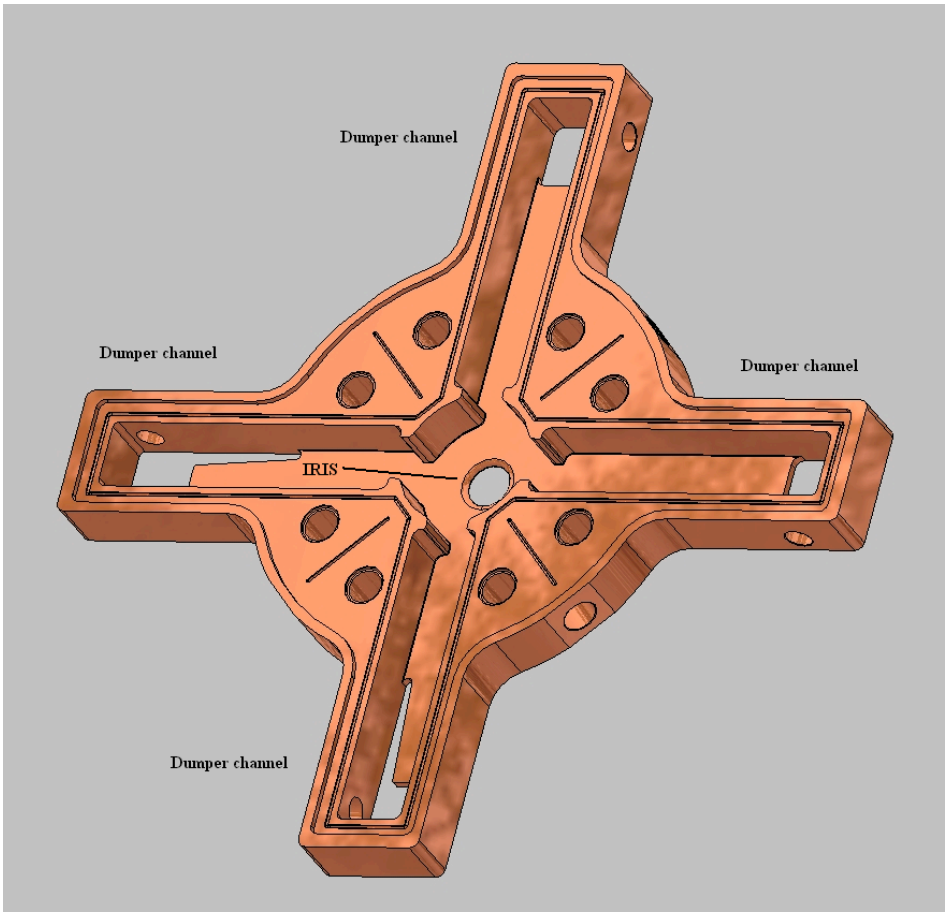

Fig. 1: A cross-sectional view of the vacuum volume in the C-band accelerating cavity.

The out-gassing rate of the copper inner surface is assumed as $10^{-12}\, mbar \cdot liter \cdot \sec^{-1} \cdot cm^{-2}$. The gas molecular mass is assumed as 28, equivalent to nitrogen. The dumpers are made of silicon carbide, with an out gassing rate assumed similar to the copper one (from literature). An experiment is in progress in order to confirm this statement, the results will be provided in a forthcoming paper.
Using different out-gassing rates only change linearly the vacuum levels limits of the graphs.
Eq. (1) becomes:

$$Q = P_n S_n + C_{n-1}(P_n - P_{n-1}) + C_n(P_n - P_{n+1}) \tag{2}$$

where, P_n is the vacuum pressure at the nth cavity, S_n is the pumping speed at the nth cavity, C_n is the vacuum conductance between nth and n+1th cavity. Since the vacuum pumps are connected at the both end of the cavity, S_n is zero except for the first and last cavity or in the middle in the case with three vacuum pumps. The coupled equations of Eq. (2) for every cavity are solved by using an iterative calculation, a software program made by Labview and the results are also checked using a most popular code VAKTRAK [6].

Calculation results

Simulations were performed in two different conditions; the first with three vacuum pumps and the second only with two. The net pumping speed is assumed to be about 40 l/s for the pumps at the ends while 20 l/s for the case in the middle.

The vacuum pressure along the accelerating structure for the three pumps is shown in Fig. 2. The vacuum pressure in the middle of the cavity is a factor about 15 times better than the case simulated with two pumps, as shown in Fig. 3.

No other significant differences are highlighted in the rest of the cavity, due to the fact that the pressure profiles didn't change significantly by the pumping speeds. The reason is that the effective pumping speed S_{eff}, which is defined by

$$S_{eff} = \frac{1}{S_0} + \frac{1}{C}$$

where, S_0, is the pumping speed and C is the vacuum conductance, is limited by C although S_0 becomes higher.

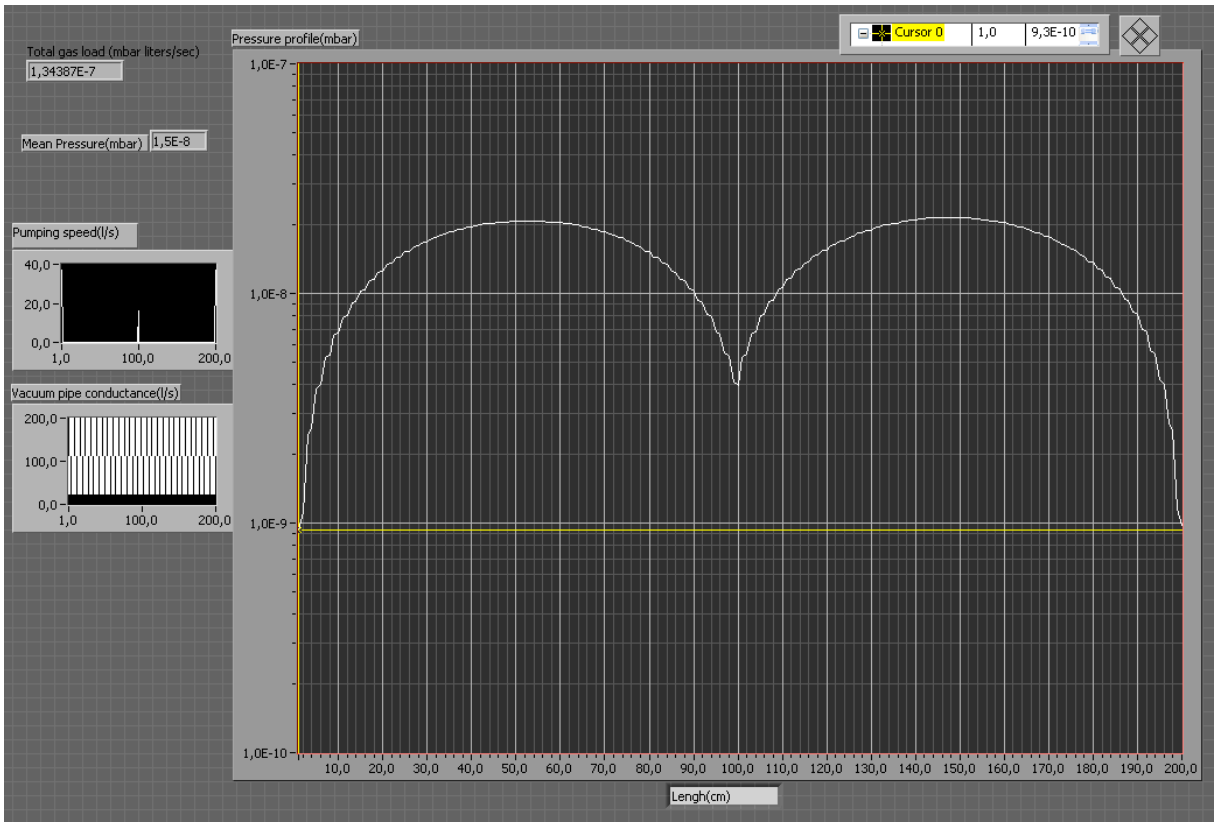

Fig. 2: Distribution of the on-axis vacuum pressures along the accelerating structure (three vacuum pumps).

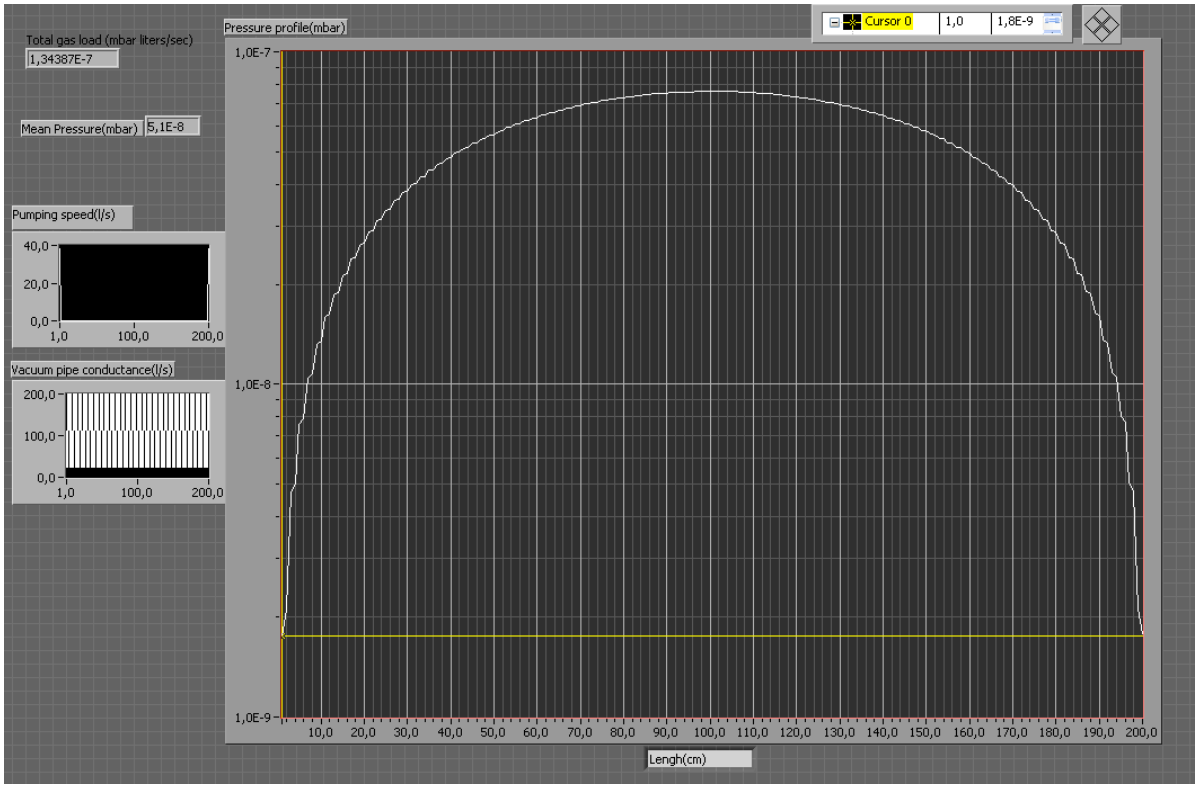

Fig. 3: Distribution of the on-axis vacuum pressures along the accelerating structure (two vacuum pumps).

Performing the simulations using VAKTRAK code the graphs are shown in Fig. 4.

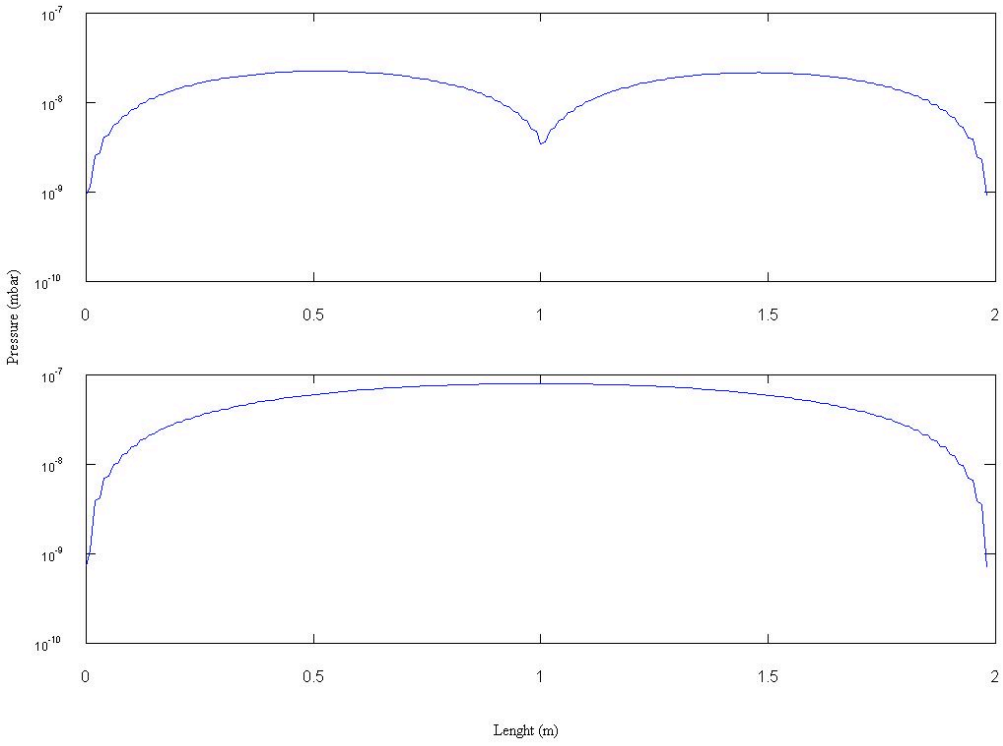

Fig. 4: Distribution of the on-axis vacuum pressures along the accelerating structure (three or two vacuum pumps).

These simulations are computed using a specific out-gassing rate of about $10^{-12}\, mbar \cdot liter \cdot \sec^{-1} \cdot cm^{-2}$ both for copper and silicon carbide. These values are conservative for materials without bake-out treatment. Adopting a particular thermal procedure, called Vacuum Firing, that consists in keeping the structure at 550 Celsius degrees in a vacuum oven for three days at a pressure better than 10^{-7} mbar, and consequently baking-out in situ at 180 Celsius degrees for at least 24 hours, an out-gassing value for copper of about $2*10^{-14}\, mbar \cdot liter \cdot \sec^{-1} \cdot cm^{-2}$ and $5*10^{-13}\, mbar \cdot liter \cdot \sec^{-1} \cdot cm^{-2}$ for silicon carbide could be reached [7, 8]. Table 1 summarizes data.

Table 1: Some measured out gassing rates at room temperature.

Material	**Surface treatment**	**Out-gassing rate** $mbar \cdot liter \cdot \sec^{-1} \cdot cm^{-2}$
Copper OFHC	Vacuum fired at 550°C/3 days +baked 180°C/24h	$2*10^{-14}$
Silicon Carbide	Vacuum fired at 550°C/3 days +baked 180°C/24h	$5*10^{-13}$
Copper OFHC	No thermal treatment	$1*10^{-12}$
Silicon Carbide	No thermal treatment	$2*10^{-12}$

Performing vacuum simulation with these data, the following graph is obtained:

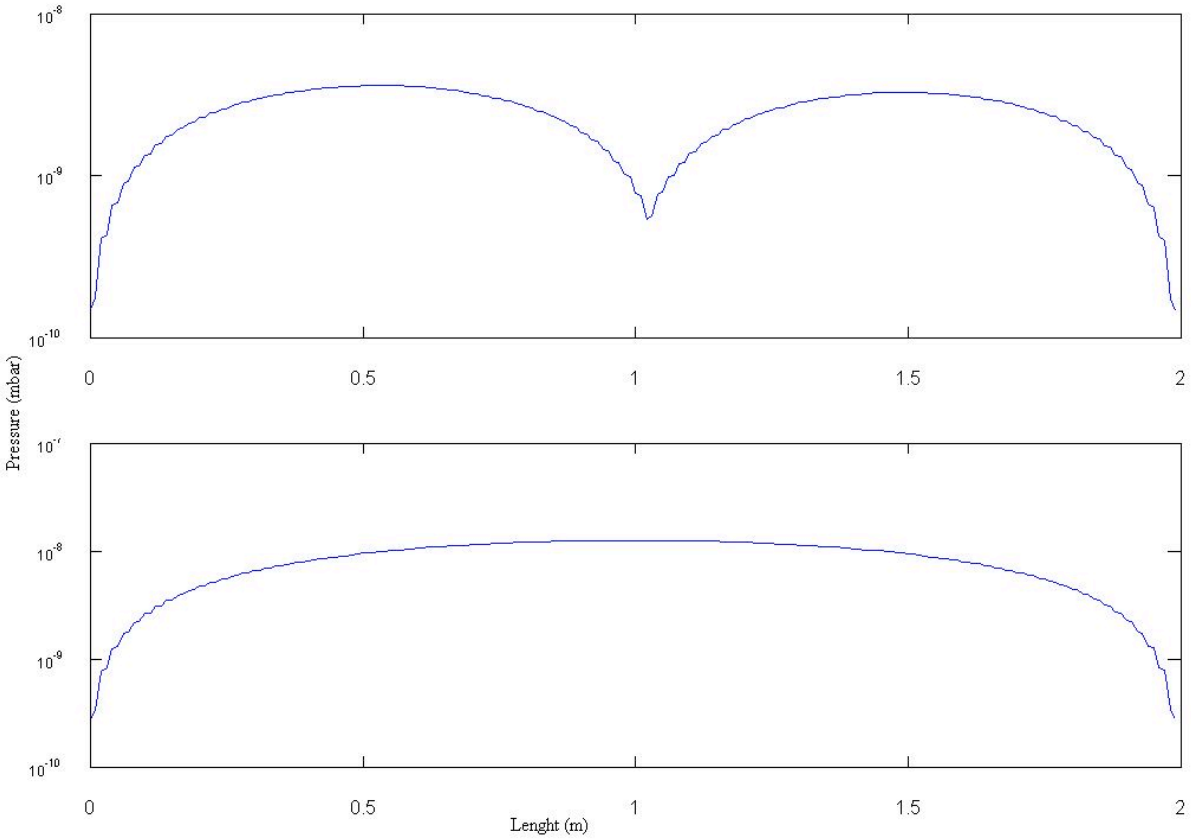

Fig. 5: Distribution of the on-axis vacuum pressures along the accelerating structure (three or two vacuum pumps).

Results and conclusions

The vacuum pressure is simulated for a 2 meter C-band accelerating structure, considering two cases: three or two vacuum pumps. The vacuum pressure in the middle of the cavity is better in the case with three pumps obviously, but there are no significant differences in the rest of the cavity, because the vacuum behavior is dominated by vacuum conductance and not by the net pumping speed. However, in the case of two vacuum pumps, the maximum pressure is about 10^{-7} mbar with pumping speed of 40 l/s each, also in the worst case (material without thermal treatment) and it is safe enough to be used in the proposed ELI–NP linac. For this case, considering also practical question, the solution adopted is that with only two vacuum pumps, head and tail ones, as shown in Fig. 4. Using different out-gassing rates for copper and silicon carbide only change linearly the vacuum levels limits of the graphs, but the shape of the graphs remain the same.

These are preliminary results; vacuum tests are in progress in order to verify these simulations, the definitive results will be provided in a forthcoming paper.

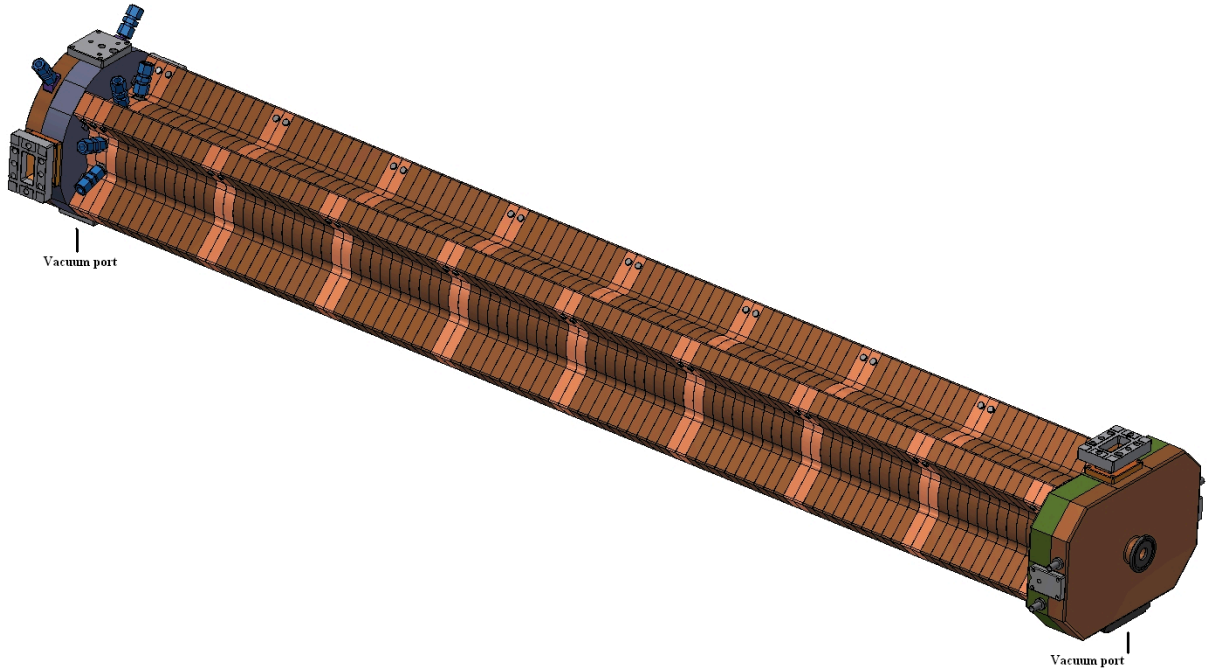

Fig. 6: ELI C-band 3D model.

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