BTW S-Band High-Gradient Acceleration Cavity Studies

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Abstract

High gradient accelerating cavities are one of the main research lines in the development of compact linear colliders. However, the operation of such cavities is currently limited by non-linear effects that are intensified at high electric fields, such as dark currents and radiation emission or RF breakdowns. A new **normal-conducting High-Gradient S-band Backward Travelling Wave accelerating cavity** for medical application (v=0.38c) designed and constructed at CERN is being tested at IFIC. Heavy particles deposit its dose in a more localized way than photons which makes them an ideal option for more precise cancer treatments where the healthy surrounded tissues are very sensitive to radiation damage. However, it is necessary to develop accelerators efficient enough for these particles.

In this poster, we present experimental measurements and simulation results on breakdown analysis and dark current and radiation studies, in order to improve our understanding in such effects. The final objective consists of studying the viability of using this techniques in linear accelerators for **hadrontherapy** treatments in hospitals.

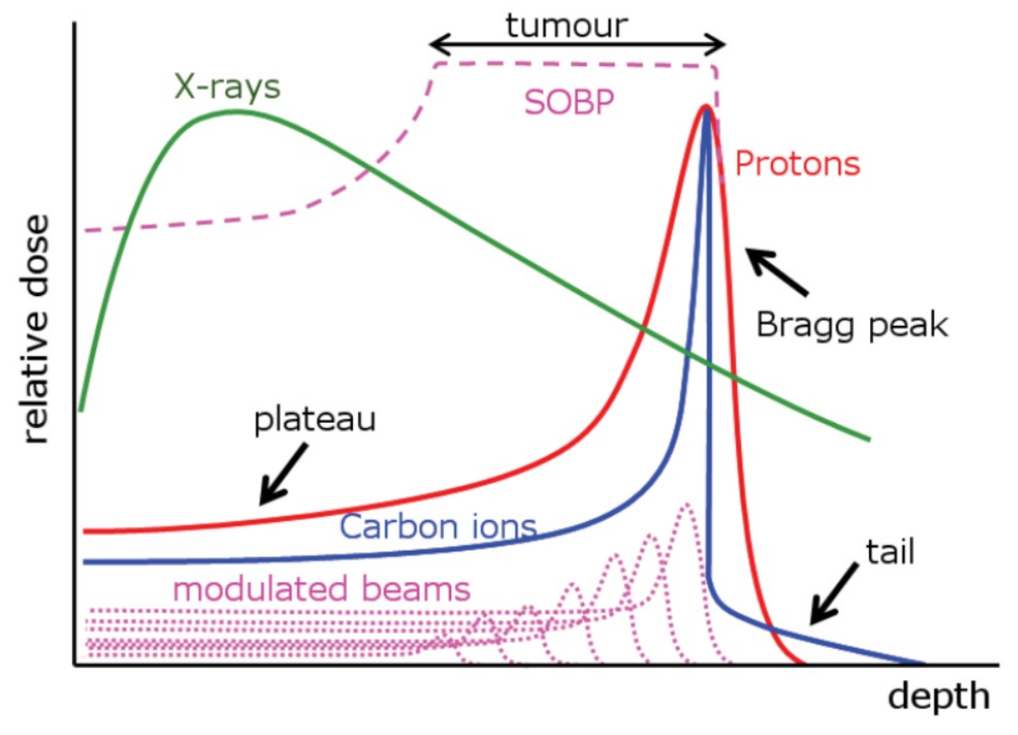
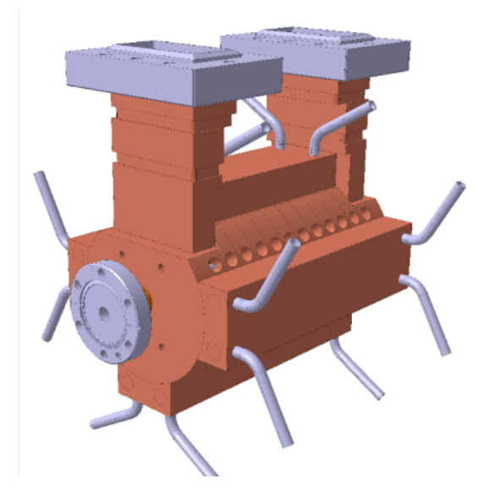
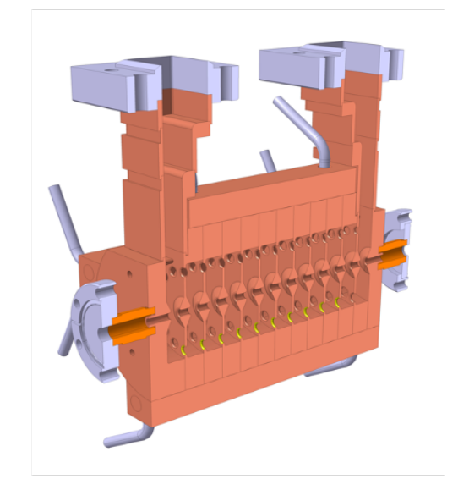


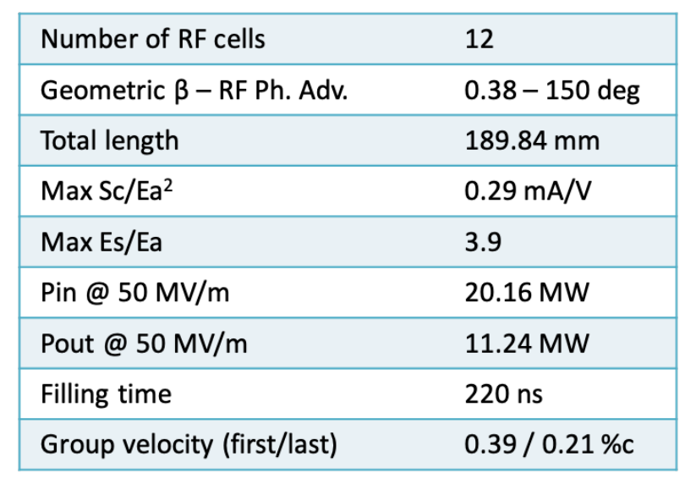
Fig. 1: Dose deposited vs penetration depth

BTW S-Band Cavity

We are studying the electromagnetic behaviour of a Backward Traveling Wave (BTW) S-Band ($f = 2.9985$ GHz) High-Gradient accelerating cavity designed at CERN. This cavity can be the main seed in the development of compact high power linear accelerators for protons treatments in hospitals







Number of RF cells	12
Geometric β – RF Ph. Adv.	0.38 – 150 deg
Total length	189.84 mm
Max Sc/Ea^2	0.29 mA/V
Max Es/Ea	3.9
Pin @ 50 MV/m	20.16 MW
Pout @ 50 MV/m	11.24 MW
Filling time	220 ns
Group velocity (first/last)	0.39 / 0.21 %c

Fig. 3: Parameters of BTW cavity

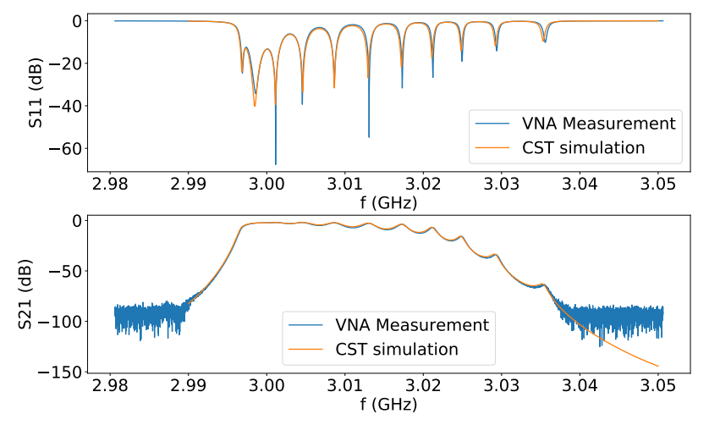


Fig. 5: S-parameters of the acceleration cavity. Measurements and simulation

High-power RF Laboratory at IFIC

In our lab, we have the capacity of studying **two** high-power devices at the same time at very high rate:

- 3 GHz of RF frequency.
- 6 μs RF pulses.
- 15 MW of RF power
- 200 Hz pulse rate.
- Ultra-high vacuum level.

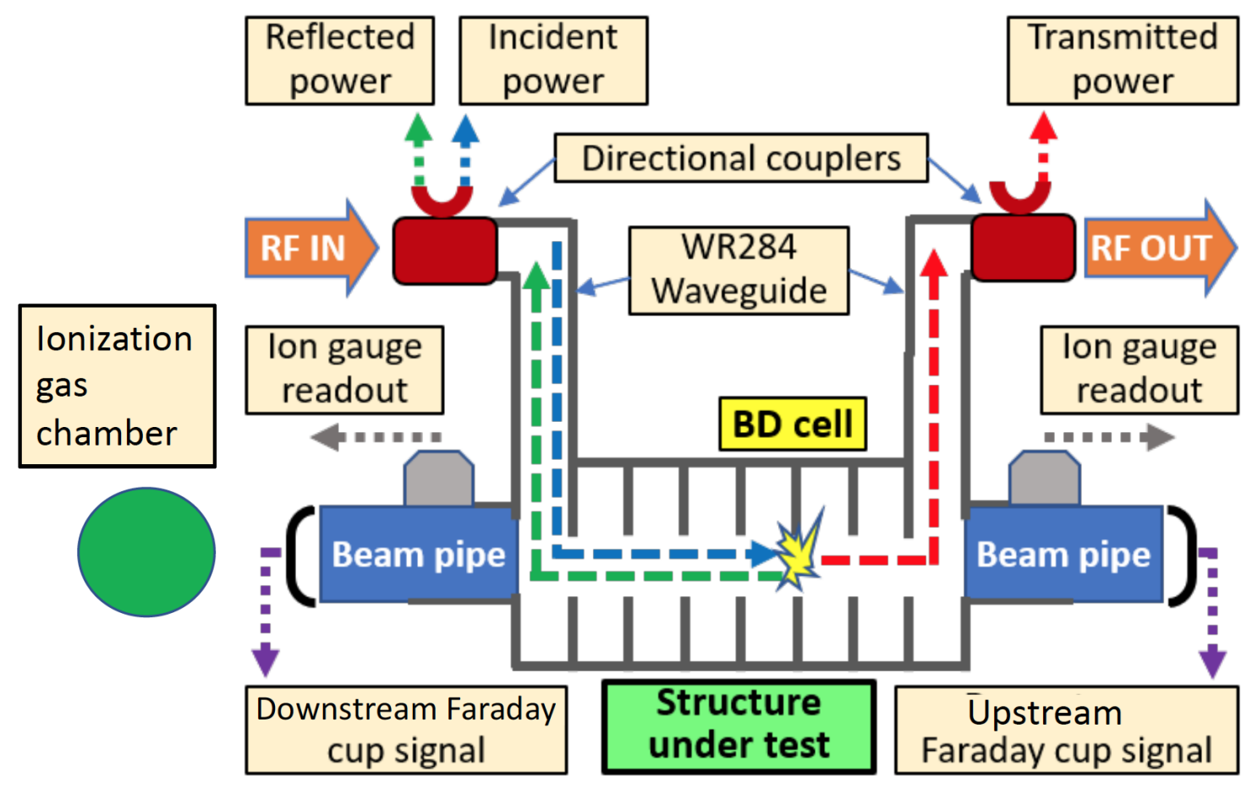


Fig. 7: Cavity set up

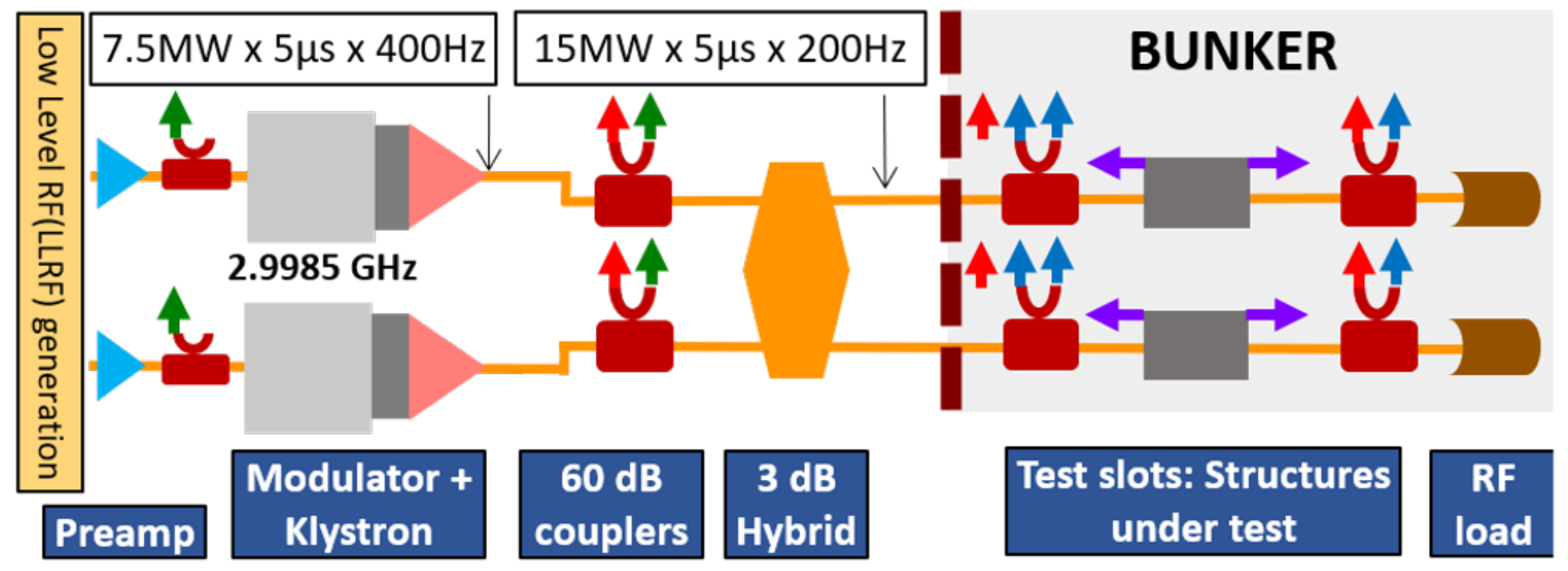


Fig. 6: Laboratory set up

Besides, thanks to our acquisition system, we are able to measure the principal signals during the conditioning process:

- **Incident, reflected and transmitted power and phases** through directional coupler localized at the entrance and exit of the cavities. These signals pass through a downmixer and an IQ demodulation in order to extract this information
- **Electron currents** emitted by field emission (dark currents) are collected in the Faraday Cups.

Conditioning process and RF breakdowns

High-Gradient accelerator cavities need to follow a **conditioning process** before they are able to reach such a high RF power. This process is known as RF conditioning and usually takes several months.

The mechanism consists of introducing RF pulses in the cavity and **increasing slowly the power** of these pulses in such a manner that **controlled RF breakdowns** are produced. These breakdowns must be detected by the real time acquisition system, so that the RF power can be stopped when this process takes place, otherwise, the cavity can be **damaged irreversibly**.

There are several clues that can be used as interlocks for RF breakdown detection:

- High dark currents.
- Abrupt increase in the reflected power and/or decrease in the transmitted power.
- Sudden increase in vacuum levels.

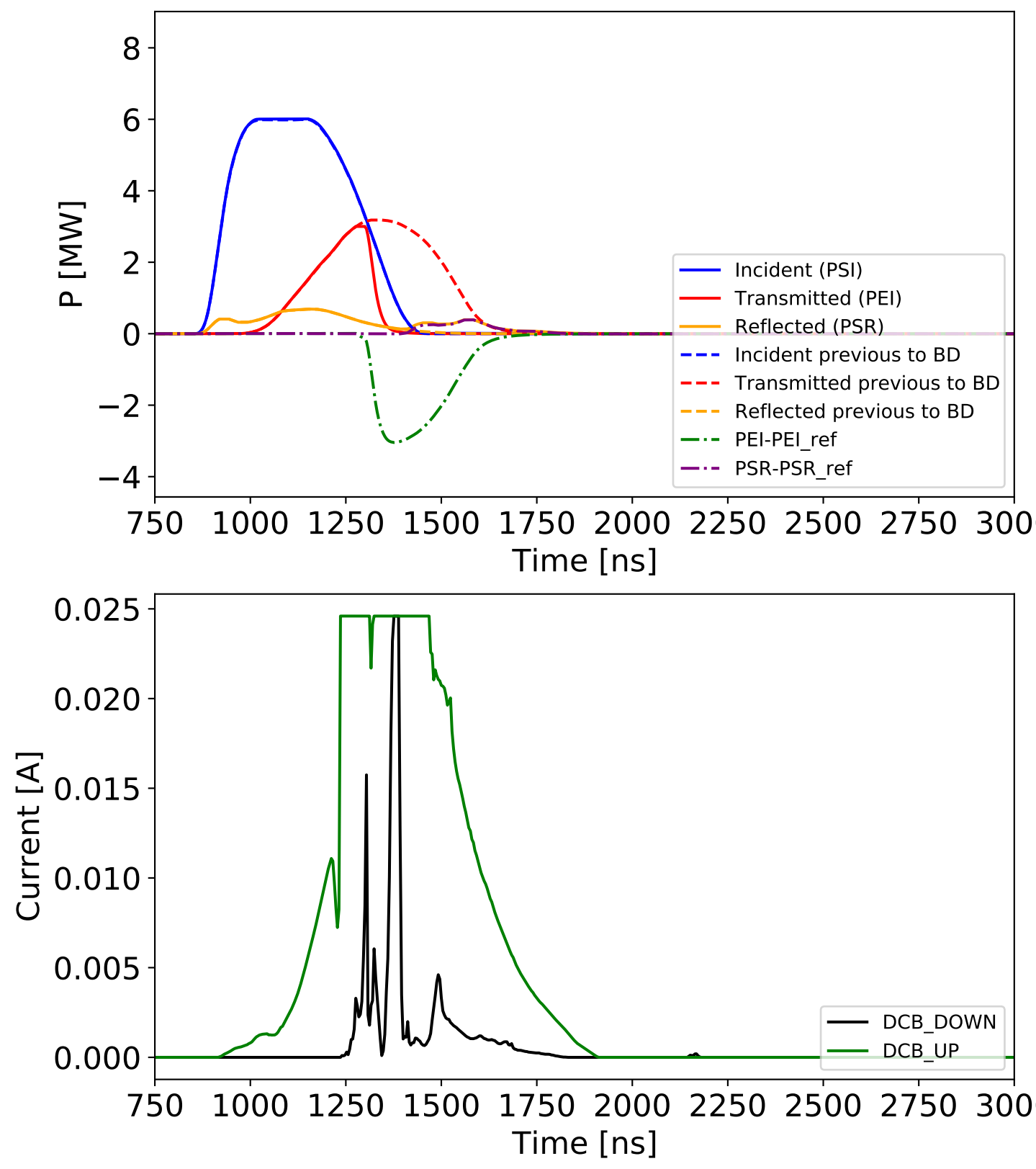


Fig. 8: RF breakdown pulse type

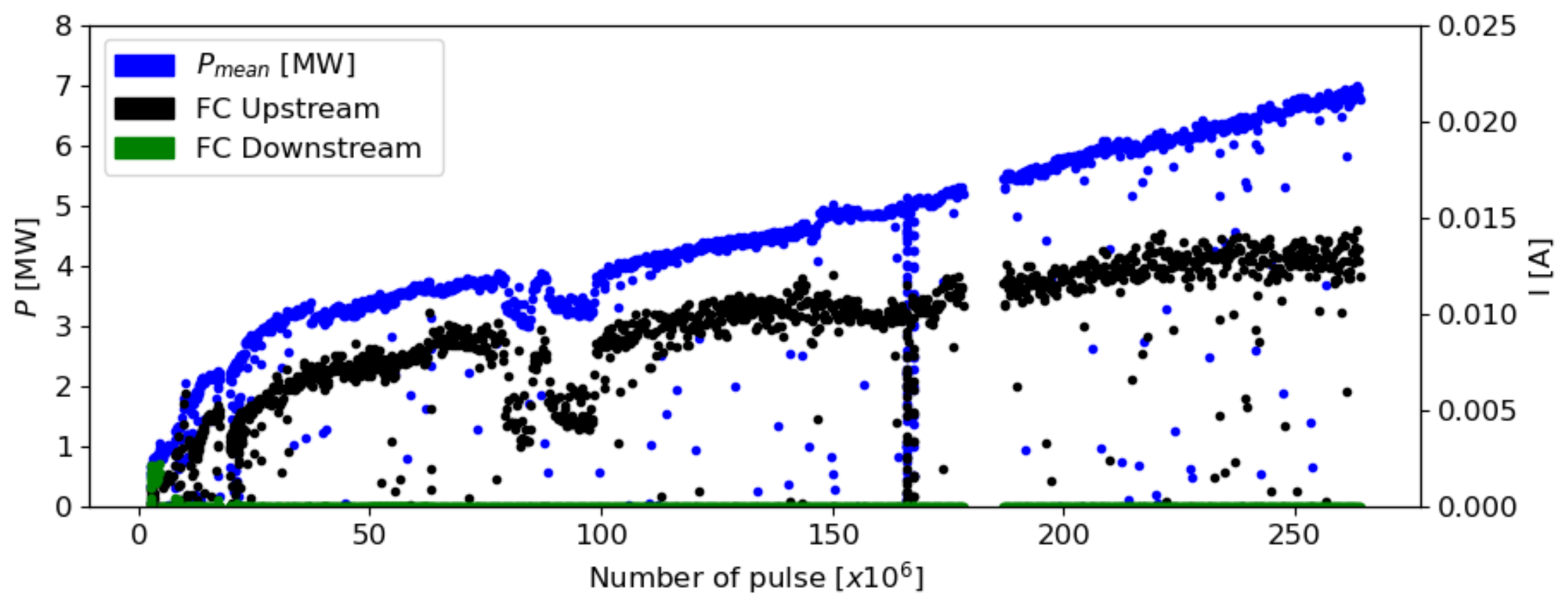


Fig. 9: Conditioning progress

Multiple studies shown evidence that conditioning process is proportional to the number of pulses stimulated in the cavities, which leads to the conclusion that the conditioning time only depends on the **pulse rate** of the laboratory.

Moreover, it has been proved that the **Breakdown Rate** (BDR), defined as the number of RF breakdowns per pulse and meter, follows the behaviour:

$$BDR \propto E_{acc}^{30} \cdot \tau_p^5, \tag{1}$$

where E_{acc} is the acceleration field and τ_p is the pulse length.

Non-linear effects: Dark currents and radiation

Electrons are emitted from **microscopical protrusions** in the internal walls of High-Gradient cavities due to the high surface electric fields. These electrons are known as dark currents and its emission follows the **Fowler-Nordheim equation**:

$$J_{FN} = A(\beta E)^2 \exp\left(-\frac{B}{\beta E}\right), \tag{2}$$

where A, B are constants that depend on the material, β is the enhancement factor and E is the electric field.

As we move forward in the conditioning process, dark currents and radiation dose levels decrease for the same acceleration gradient, which translate into a decrease on the breakdown rate.

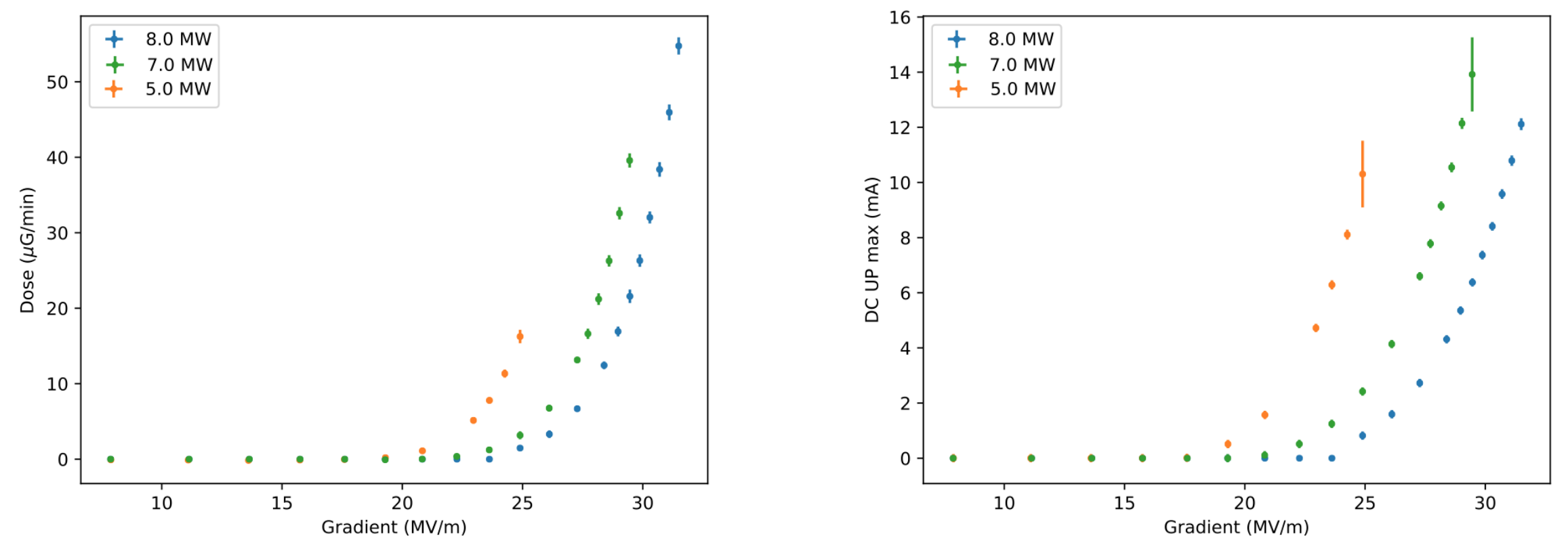


Fig. 10: Dose (left) and dark current (right) vs acceleration gradient for different times of the conditioning

However, as a higher electric field is needed in order to reach the same amount of dark current, these electrons will have higher energy. As a consequence, for the same amount of dark current emitted, the radiation dose will be higher as we move on in the conditioning process.

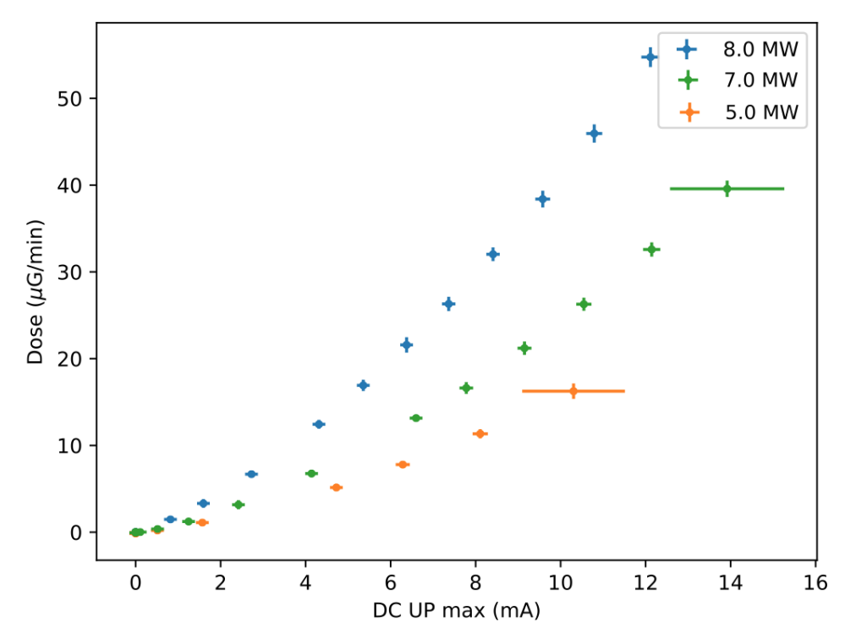


Fig. 11: Dose vs dark current for different times of the conditioning

Conclusions and perspectives

Even though high-gradient acceleration cavities can be a possible solution to build compact linear accelerators, the high electric fields generated produce some undesired effects that must be understood in order to make this type of technology realizable.

Several investigations are being done in different research centres so that this knowledge could be reached. However, due to the complexity of these phenomena, definitive conclusions are not yet available.

Our research try to find out the viability of these type of cavities in medical centres, where it is necessary not only to ensure the beam stability, but also the safety of the stuff and equipment surrounding these devices. As a consequence, the **radiation levels** produced by these structures must be **below the limits** stipulated by these kind of buildings, which imply that it is important to know how this radiation is produced and how it will evolve during the conditioning process.

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