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MODERNIZATION AND OPERATION OF IONIZATION-PROPORTIONAL GAS COUNTER AT INR RAS PROTON LINAC

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Abstract

Multianode gas counter is used as a detector for low intensity proton beam diagnostics at INR RAS linac. The device consists of ionization chamber to measure beam current and two proportional chambers, based on stripe geometry, to measure beam profiles. The data is processed with Labview software. The models and methods predicting operational characteristics of the counter in ionization and proportional mode are presented. An analytical model of recombination was tested to predict the saturation voltage for ionization mode. Beam test results and operational characteristics of the counter are presented as well as results of investigations of counter degradation under the beam. A new design of a gas filled counter is also discussed.

MGC: Operation Principles

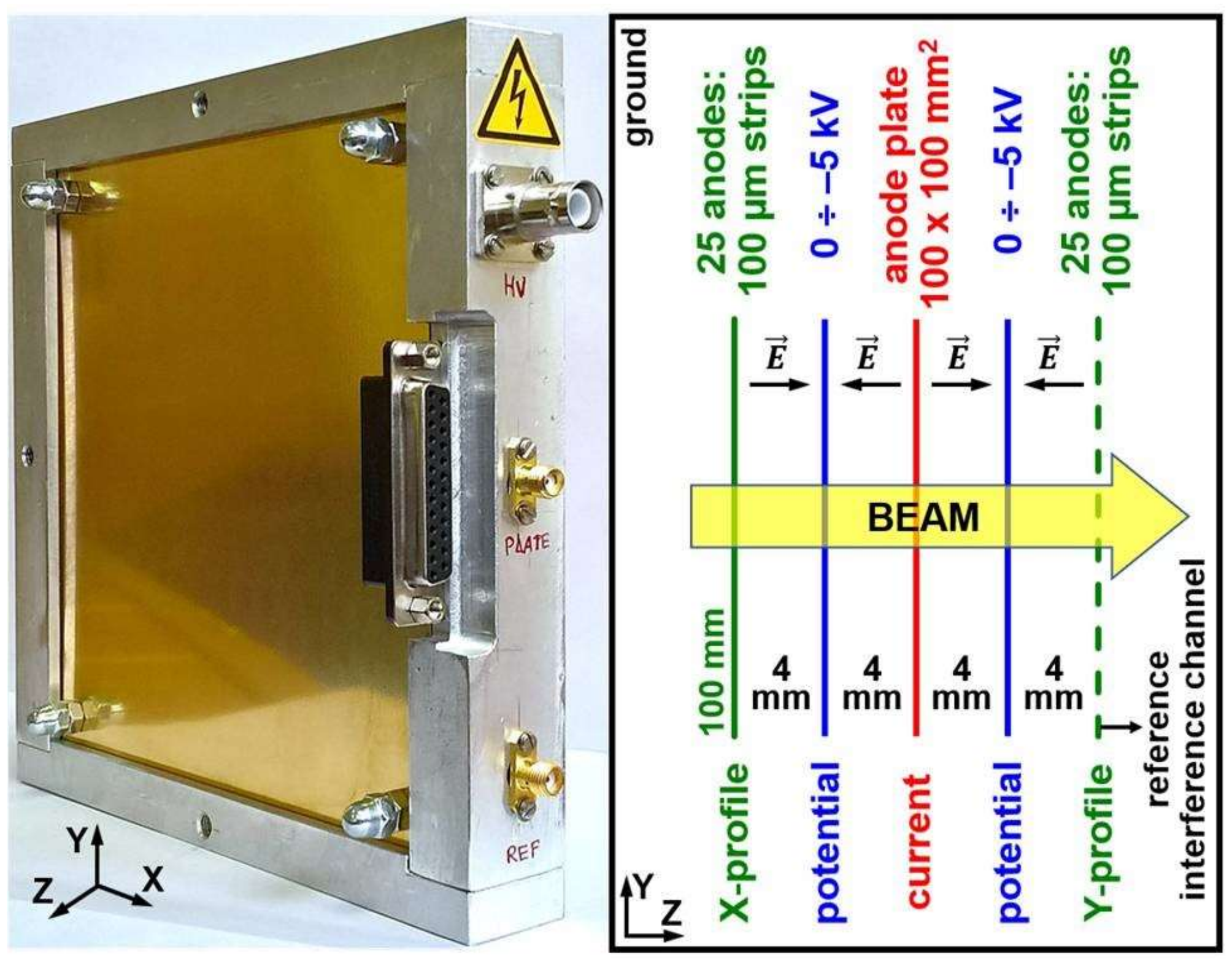

Fig. 1: MGC photo and layout.

Multianode gas counter (MGC) consists of 5 plates (Fig. 1) which are printed-circuit boards made of FR4 with 0.5 mm width. The metal covering is 18 μm nickel, plated with 0.05 μm immersive gold.

Three central plates form a dual gap ionization chamber. Electrons of primary ionization are collected at the middle anode plate by a quasi-uniform electrostatic field. This part of the detector allows to measure beam current in an ionization mode.

Lateral regions are proportional chambers for beam position and profile measurements. Electrons are collected at the multichannel anode structure, which consists of 25 stripes with 100 μm width, 100 mm length and 4 mm spacing. Strong nonuniform field around stripes leads to electron avalanches, increasing the signal.

MGC Operating Modes:

1. Recombination Mode

Charge collection efficiency $f(\xi)$ is:

$$f = \frac{2}{1+\sqrt{1+\frac{2}{3}\,\xi^2}}\,,$$

$$\xi = \frac{md^2\sqrt{q}}{V}\,,$$

where d is electrode spacing, $q\,[C/m^3s]$ is ionization density, m is a constant depending on gas properties, V- applied voltage. The experimental results are in Fig. 2. The upper picture is to find parameter m from fitting.

The theoretical scaling of saturation voltage:

$$V_{sat} = const * d^2 * \sqrt{q}.$$

In the experiment the dependence of V_{sat} on beam current proportional to q was tested. The result is:

$$log(V_{sat}) \sim log(q) * 0.38 \pm 0.01.$$

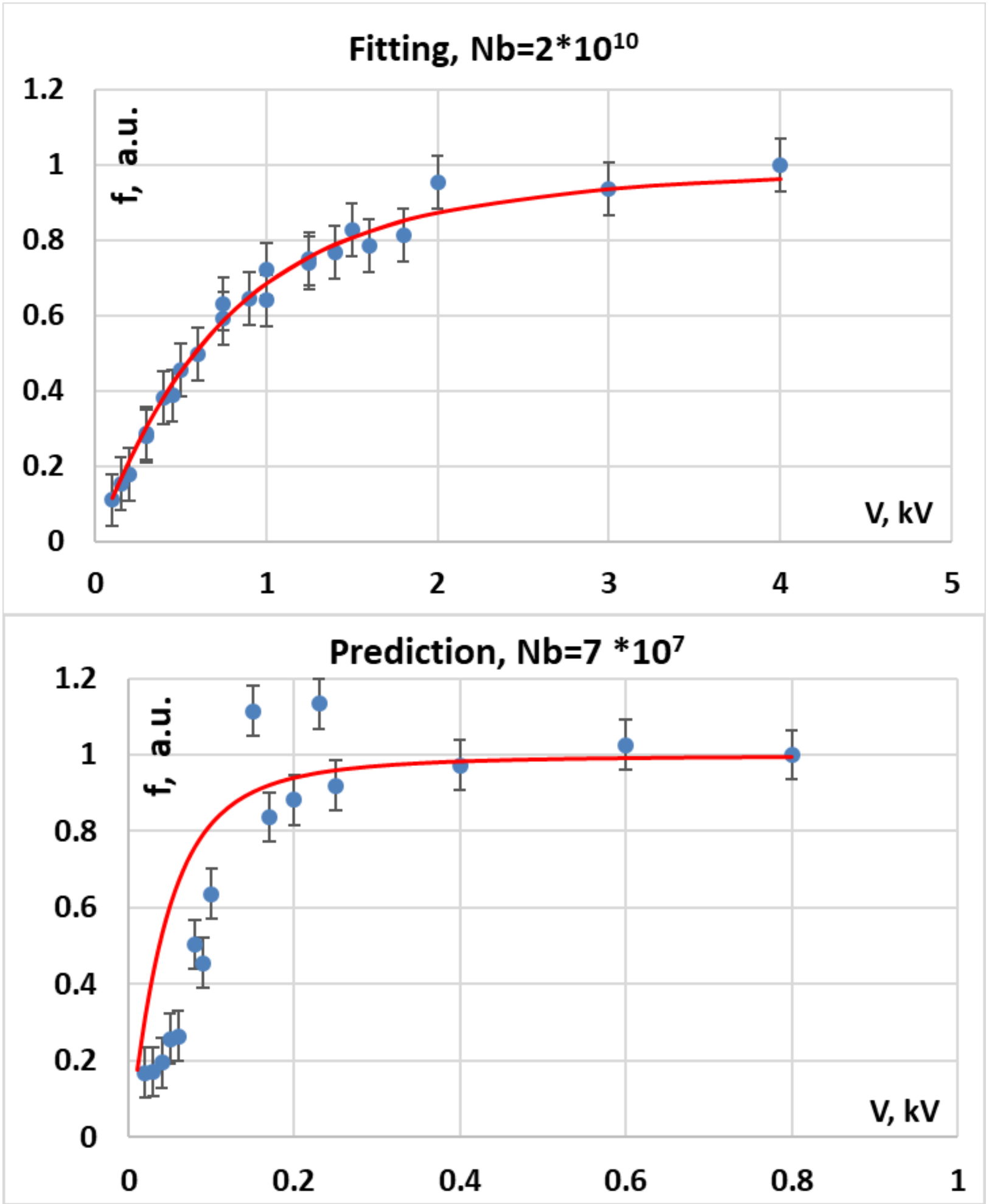

Fig. 2: Experimental (blue circles) signal from the ionization chamber and theoretical model (red line).

2. Ionization Mode

The computed ionization signal level based on dE/dx agrees with experimental results with 10% precision. The gas composition was assumed as 80% N_2 and 20% O_2 molecules at standard conditions.

The measured signal from ionization chamber electrodes is caused by induced currents due to the moving electrons and ions: $i^{e,+,-}$, where Q_0 is a total charge of primary particles, $t_{de,+,-}$ is the drift time of electrons or ions of corresponding sign, T_a is an attachment time (Fig. 3).

$$i^e(t) = \frac{Q_0}{t_{de}}\left(1-\frac{t}{t_{de}}\right)exp\left(-\frac{t}{T_a}\right).$$

$$i^+(t) = \frac{Q_0}{t_{d+}}\left(1-\frac{t}{t_{d+}}\right).$$

$$i^-(t) = \frac{Q_0}{t_{d-}}\left[1-\frac{t}{t_{d-}}- -\frac{T_a}{t_{de}}\left\{1-exp\left(-\frac{t_{de}}{T_a}\left(1-\frac{t}{t_{d-}}\right)\right)\right\}\right].$$

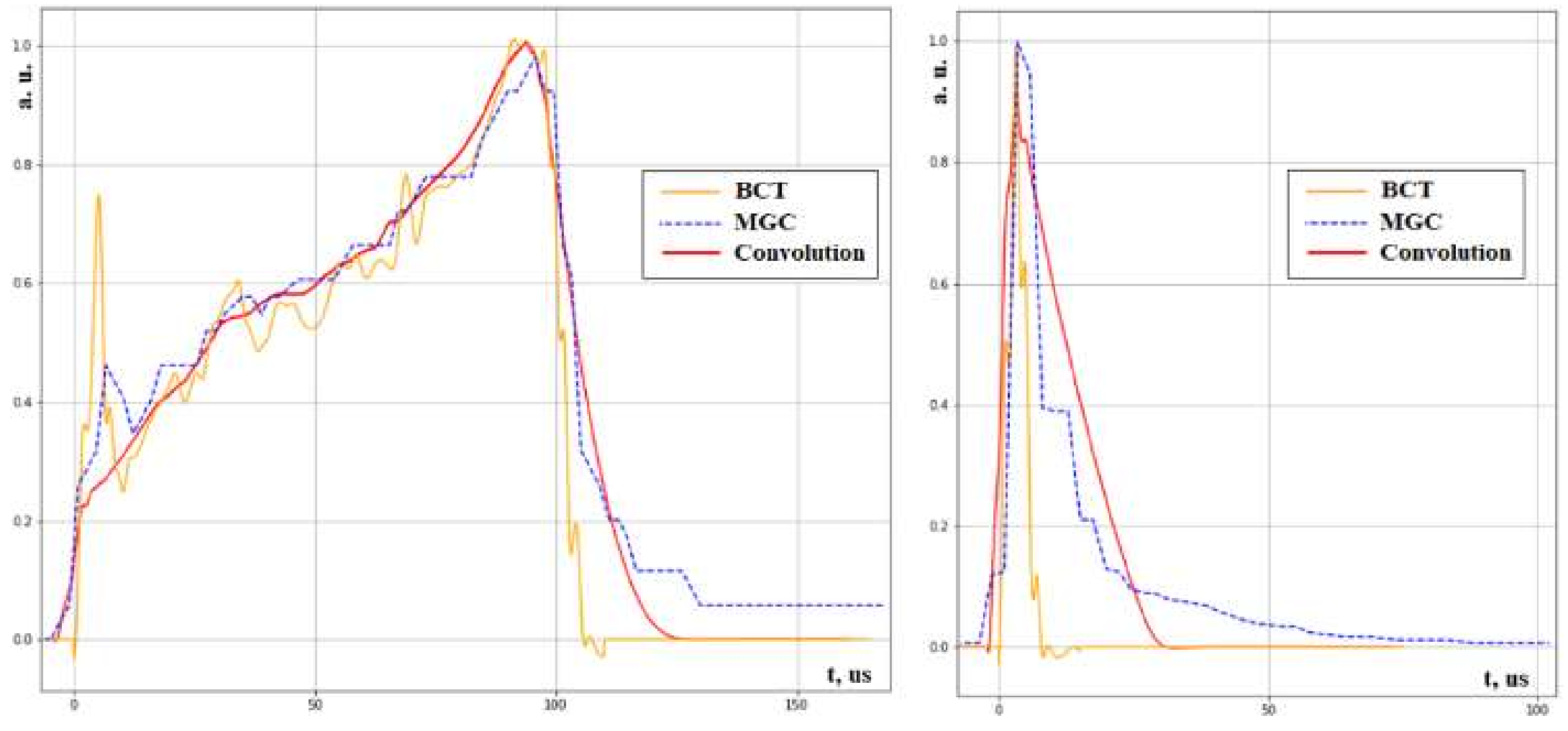

Fig. 3: BCT measured signals from a proton macropulse, MGC measured signals from stripes in ionization mode and reconstructed signals with convolution method.

3. Proportional Mode

The electric field distribution around the stripes was calculated in COMSOL (Fig. 4). The black line is for obtaining $E(s)$.

The change in electron (n) and positive ion (m) concentration after passage of ds is:

$$dn = (\alpha - \eta)\;n\;ds.$$

$$dm = \alpha\;n\;ds,$$

where α and η are townsend ionization and attachment coefficients. A simple integration can be done to get the avalanche plus primary ionization gain. After substitution of $E(s)$, $\alpha(E)$ and $\eta(E)$ in the derived formula one can obtain gain-voltage properties of a proportional chamber (Fig. 5).

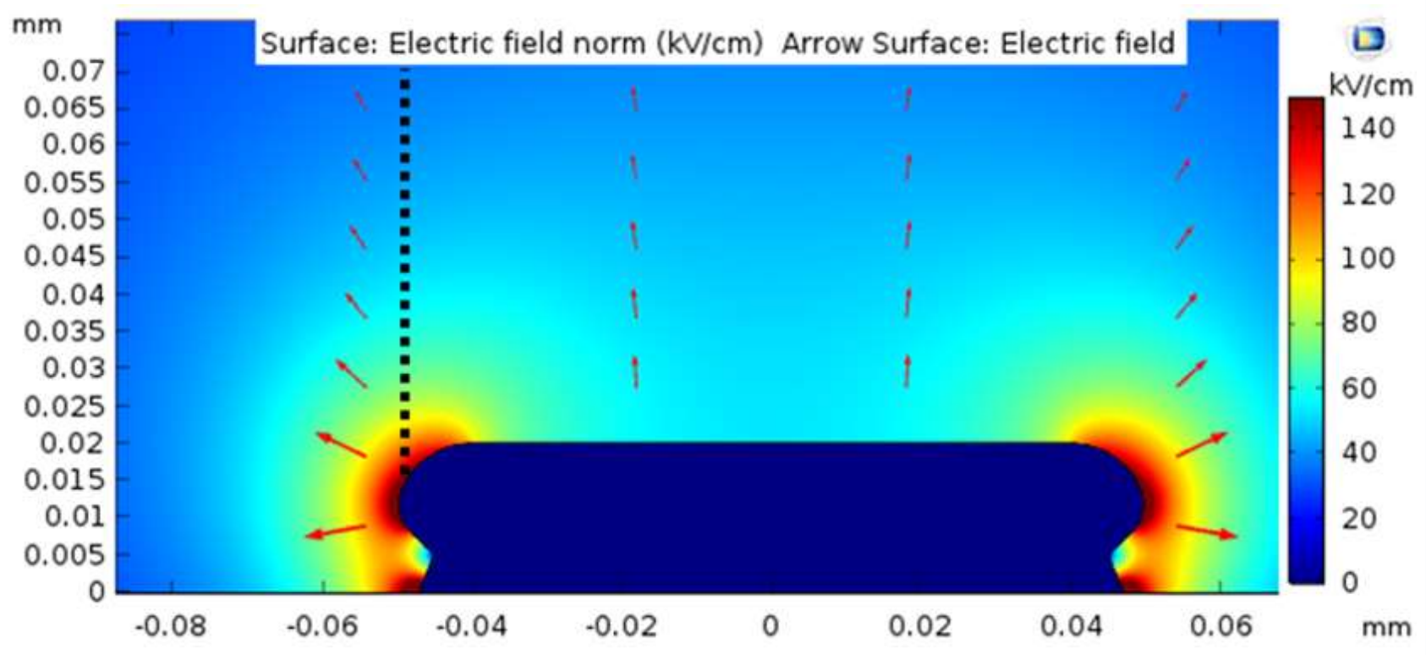

Fig. 4: Distribution of electric field near a stripe for 4 kV voltage.

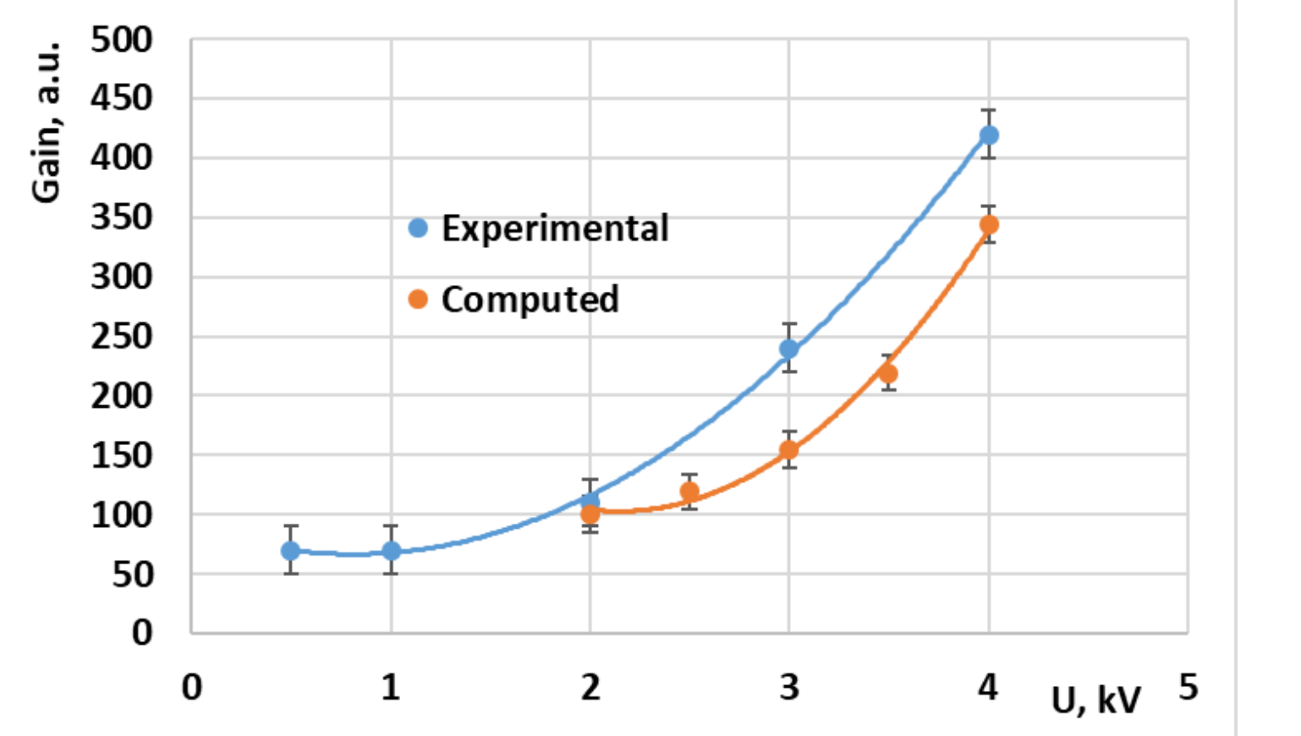

Fig. 5: Experimental and computed gain-voltage curves for proportional chamber.

MGC Exploitation and Degradation Effects

The experimental operational range of MGC is $10^7 \div 10^{11}$ p/pulse with pulse duration about 130 μs. Usage of beams less intensive than 10^7 p/pulse decreases the signal below the sensitivity threshold of MGC electronics.

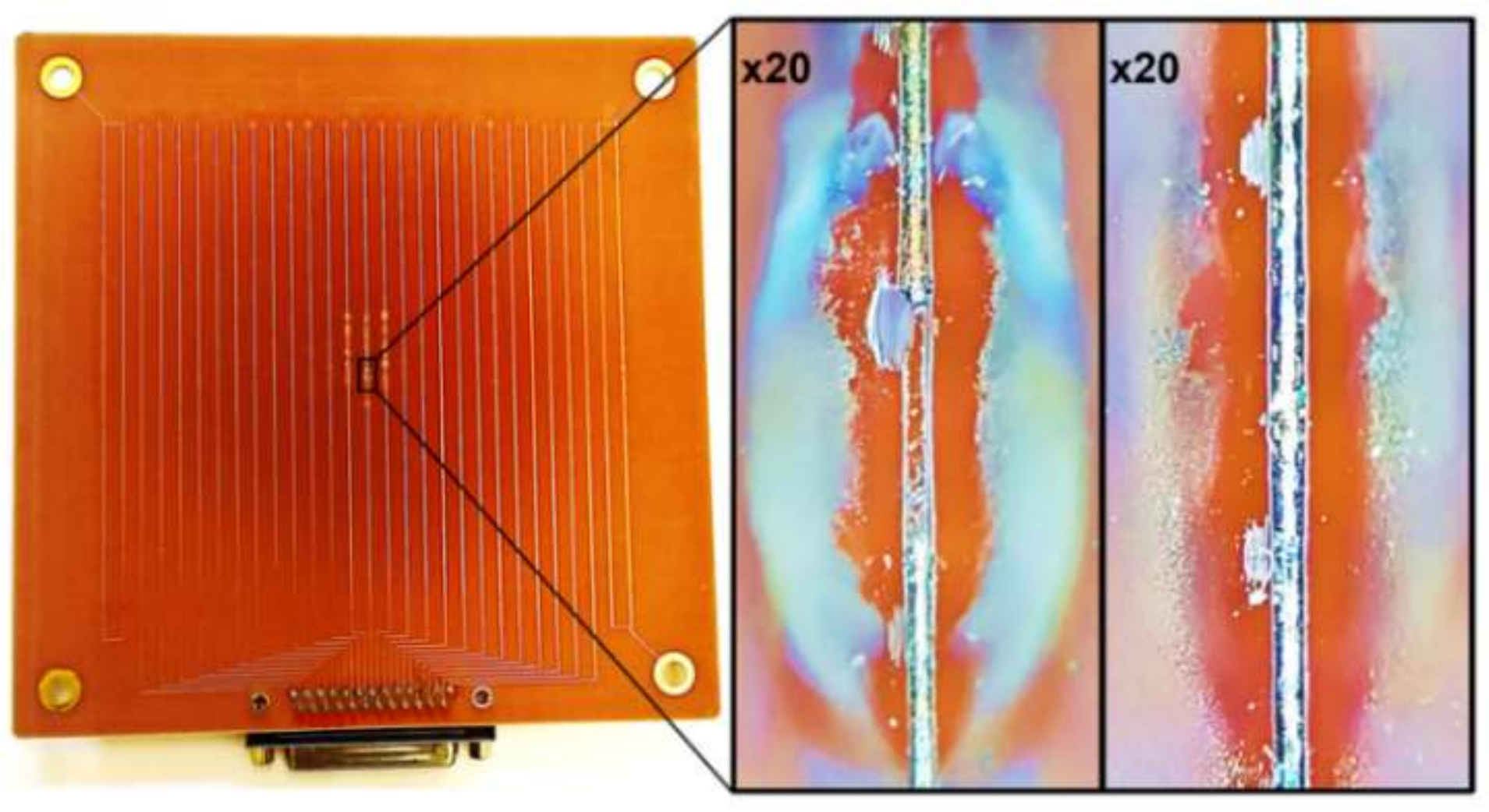

Fig. 6: Ageing effects: stripe destruction and oxidation.

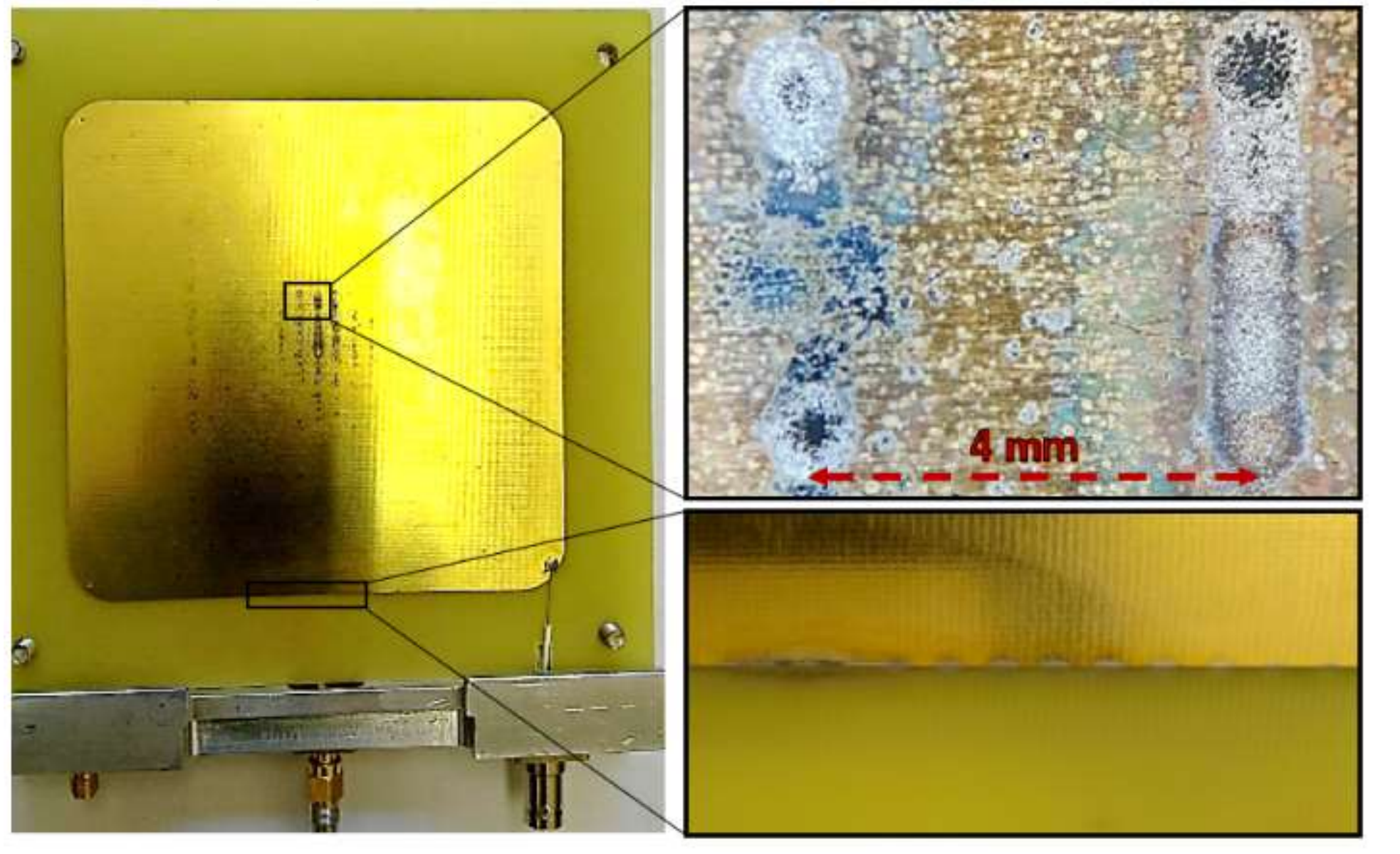

Fig. 7: Degraded plane electrodes of proportional chamber.

It was found out, that intensive beams (density >10^{10} p/cm²) lead to oxidation of MGC stripes. Temper colors are visible in Fig. 6.

Cathode deposits on plane electrodes are also visible (Fig. 7). They cause positive charge build-up and electron emission - Malter effect.

Dielectric oxide film reduces the field strength exerted on particles near stripes and decreases the signal. Profile signal amplitudes in Fig. 8 are almost identical after an irradiation.

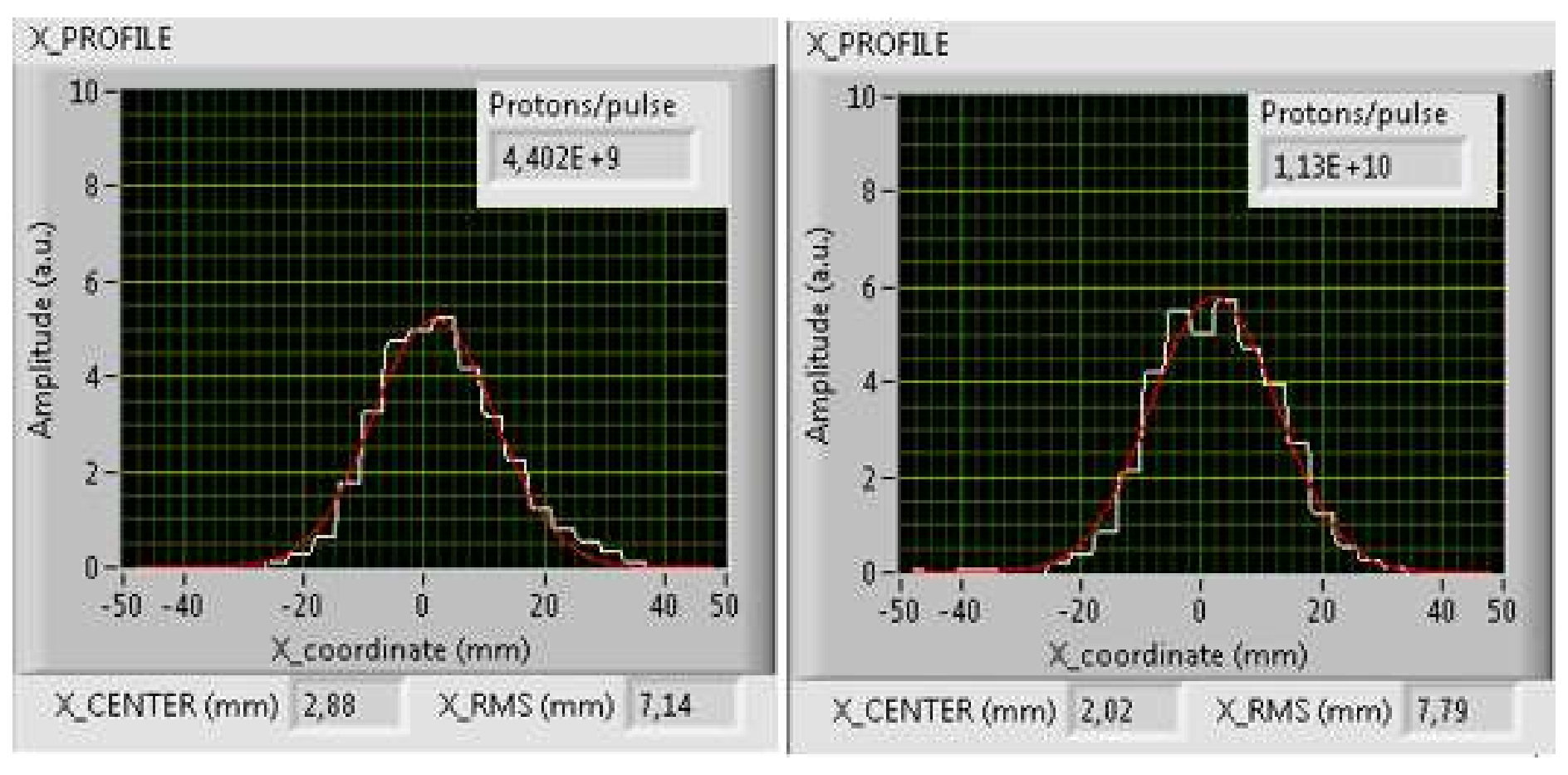

Fig. 8: X profiles for a symmetric beam after 2.5*10^15 protons passed through the counter.

New Design of a Gas Counter

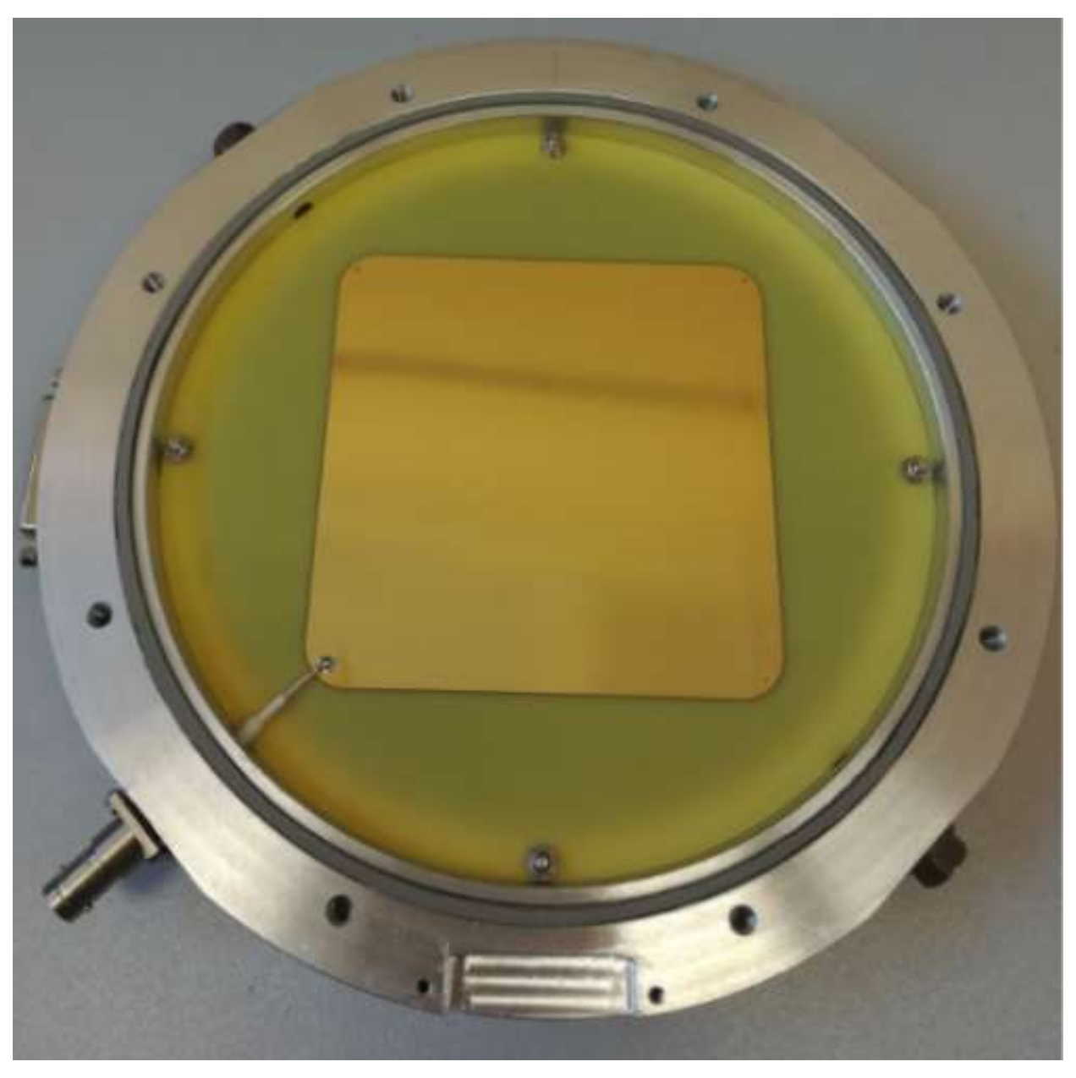

Fig. 9: Shell with HV plate.

The new design of MGC consists of only 3 printed-circuit boards instead of 5. The total volume is divided in two parts: segmented ionization chambers, measuring beam current and X, Y profiles in ionization mode. Beam current is obtained by summing the profile signals from stripes in the software. The profile plates in combination with metal coverings serve as caps to make the total assembly sealed. (Fig. 9, 10, 11). Two screw ports for gas pumping are also visible. The supposed gas filling is N_2.

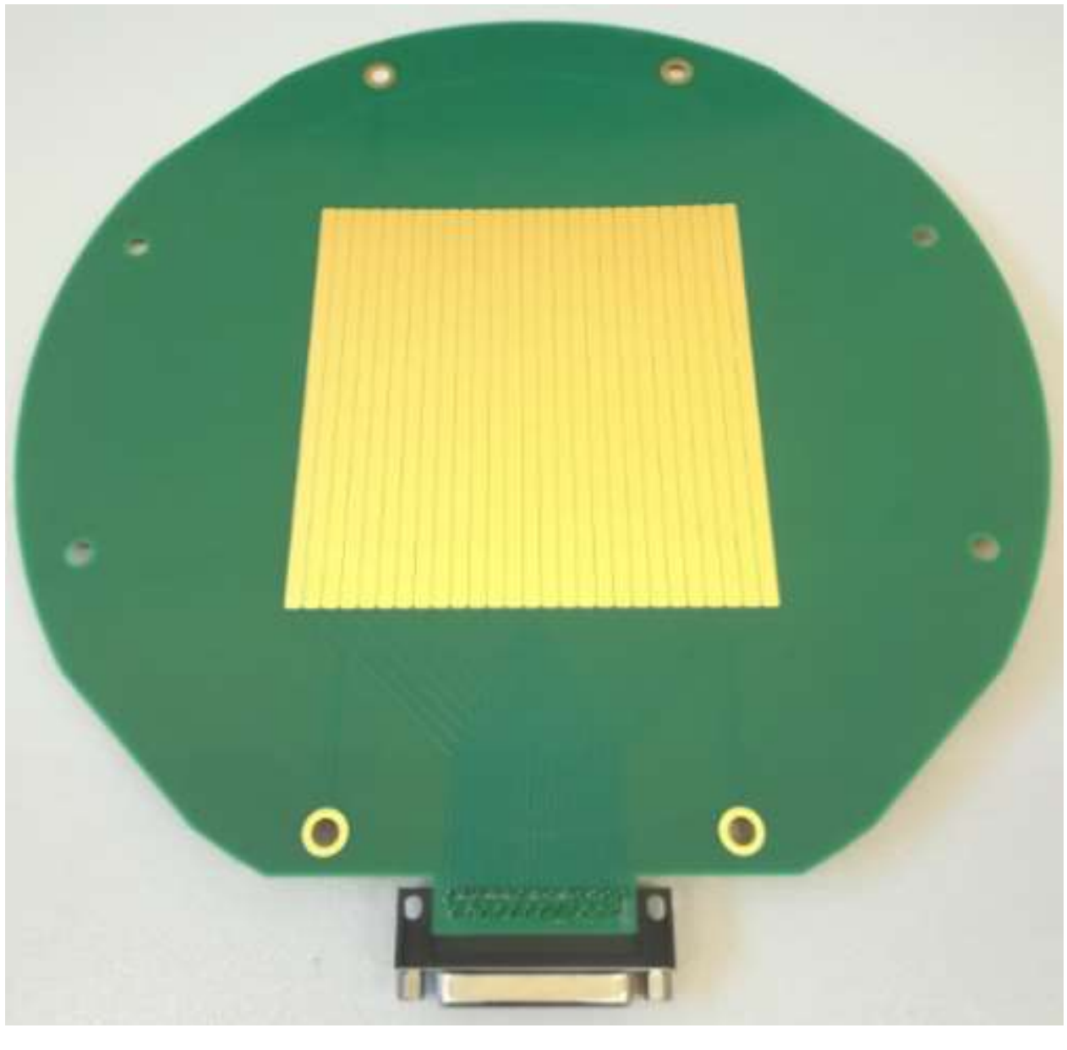

Fig. 10: Multichannel plate.

Fig. 11: Total assembly.

O_2-free gas filling prevents oxidation of stripes. Working in ionization mode helps to avoid intense avalanches near thin stripes and their destruction.