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LOW THRESHOLD-ENERGY ION-CHAMBER SYSTEM FOR PROTON THERAPY MONITORING

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Introduction

A high-quality control of beam parameters is obligatory and most important part of the planning of irradiation in hadron therapy [E. Pedroni ... Med. Phys. 22 (1995) 37]. It is necessary to measure ionization loss with high accuracy and the contribution of various types of radiation and particles to this value before and during irradiation. Ionization chambers are widely used in charged beam monitoring systems and in radiation therapeutic dosimetry [C.Brucasco NIMA, 389 (1997) 499, М.Зельчинский.., Сообщ.ОИЯИ, (1988)]. Attempts have been made to use other instruments to measure ionization but they all have significant drawbacks. A hybrid of an ionization chamber and scintillation screen viewed by television camera does not allow reliable determine the ionization loss maximum depending on the depth at the Bragg peak [4] Semiconductor detectors based on diamond are small in size and very expensive [6]. Chambers filled by an active gas mixture requires the mixing and blowing system [7, 8]. Therefore, the use of environment air as a operative substance is still promising under the condition of small gap between the electrodes in order to reduce the bulk ion recombination [9]. In addition, any substance placed in front of the patient alters the beam composition and properties and results in unwanted irradiation of patient. Earlier, we developed an ionization chamber with electrodes with thickness of 0.4 mg / cm^2 [S.I. Potashev... NIMA, 535 (2004) 115]. However, in order to obtain ionization chamber characteristics and the complete information on the properties of the beam, it is necessary to carry out experiments using several independent ionization chambers with different sensitive gap [5, 10]. A thin-walled narrow-gap air ionization chamber with the following key properties was created:

Magnitude of the gap between the anode and cathode of 1 mm must provide minimizing the ion recombination in the air of the ionization chamber;

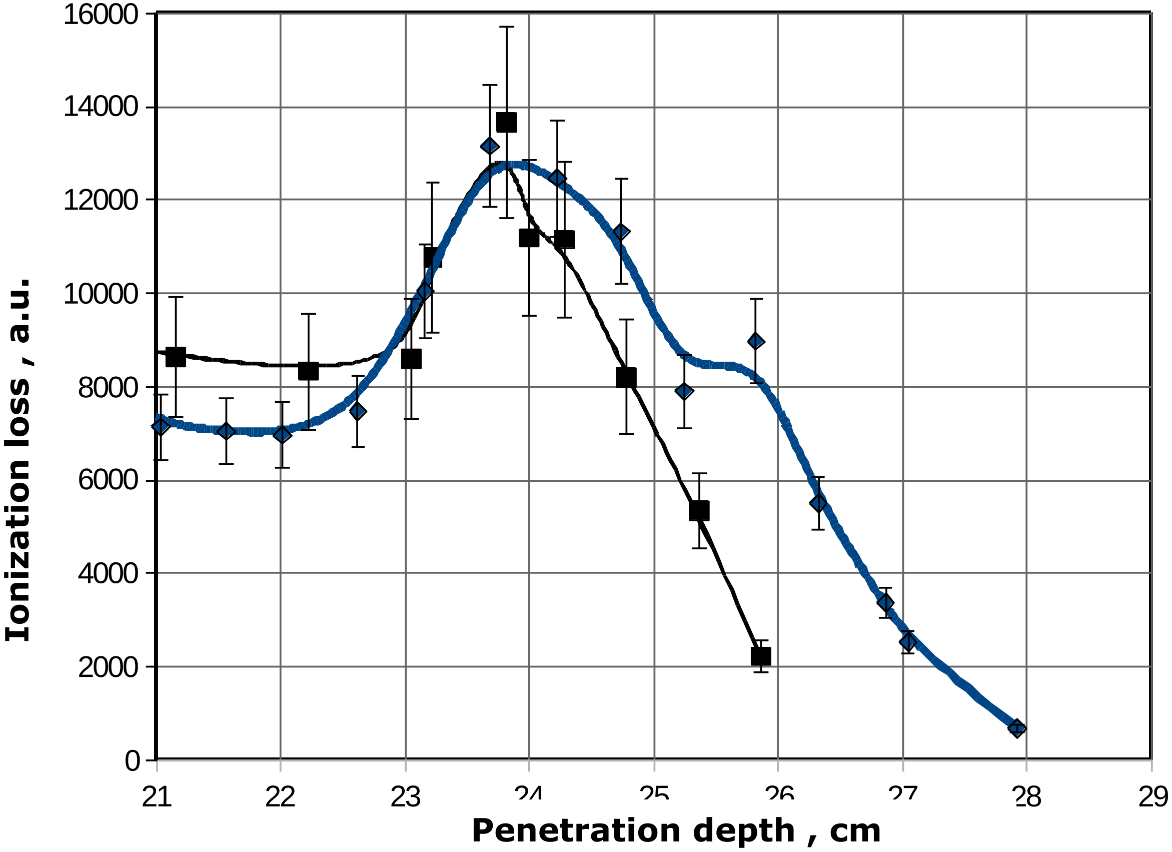
Total thickness is not to be exceed 3 mg/cm^2 in order to minimize scattering & low energy particle generation;

Protons with energies below the Bragg peak energy must penetrate through the anode separating two sensitive gaps to estimate the contribution of the low energy radiation

Image of ionization chambers in the proton therapy beamline

**The multi-channel chamber is on the left,
the narrow-gap chamber is on the right**

Dependence of ionization losses on the proton beam penetration depth



Dependence of ionization losses on the proton beam penetration depth in a water-equivalent fantom at 209 MeV measured by an multichannel ionization chamber developed in the Institute for Nuclear Researches of RAS and by a silicon detector [5].

Relationship between measured charges from multichannel and narrow-gap chambers

Bulk recombination factor

$$f = 2\left(-1 + \sqrt{1+a}\right)/a$$

$$\frac{2\alpha q d^2}{(3ek_1k_2E^2)}$$

$$a = 2\tilde{I}\,\frac{T}{\tau}\,\frac{\alpha}{W}\,\frac{\rho}{S}\,\frac{\mathbf{dE}}{\mathbf{dx}}\,\frac{d^3}{(3k_1k_2E^2)},$$

Bulk ionization density

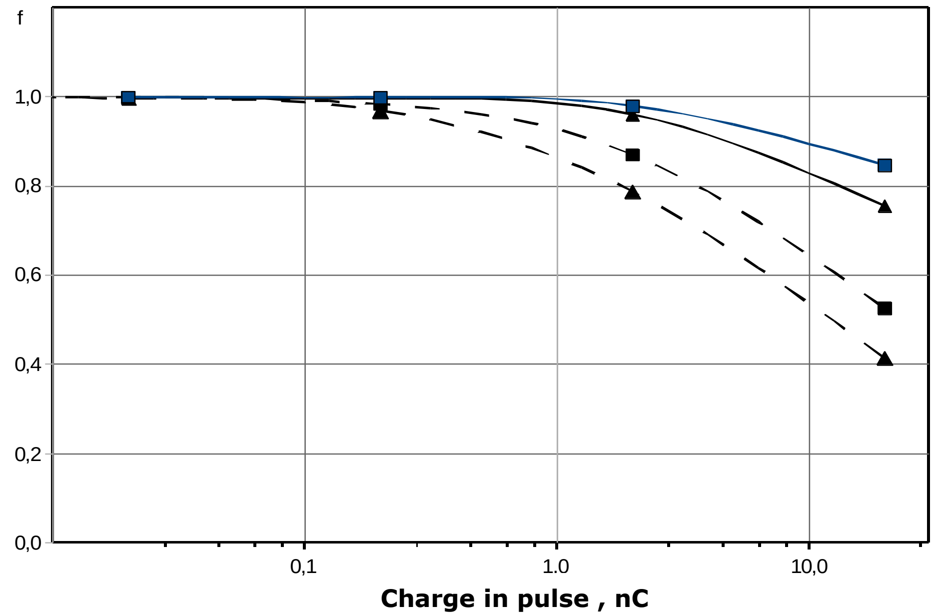
$$q = I\,\frac{\rho}{W}\,\frac{\mathbf{dE}}{\mathbf{dx}}\,\frac{d}{S},$$

Instant current

$$I = \tilde{I}\,\frac{T}{\tau},$$

Ratio of charges measured by multichannel and narrow-gap chambers

$$\frac{(Q_1 f_1)}{(Q_0 f_0)} = \frac{d_1}{d_0}\,\frac{a_0\left(-1 + \sqrt{1 + a_1}\right)}{\left(a_1\left(-1 + \sqrt{1 + a_0}\right)\right)}$$

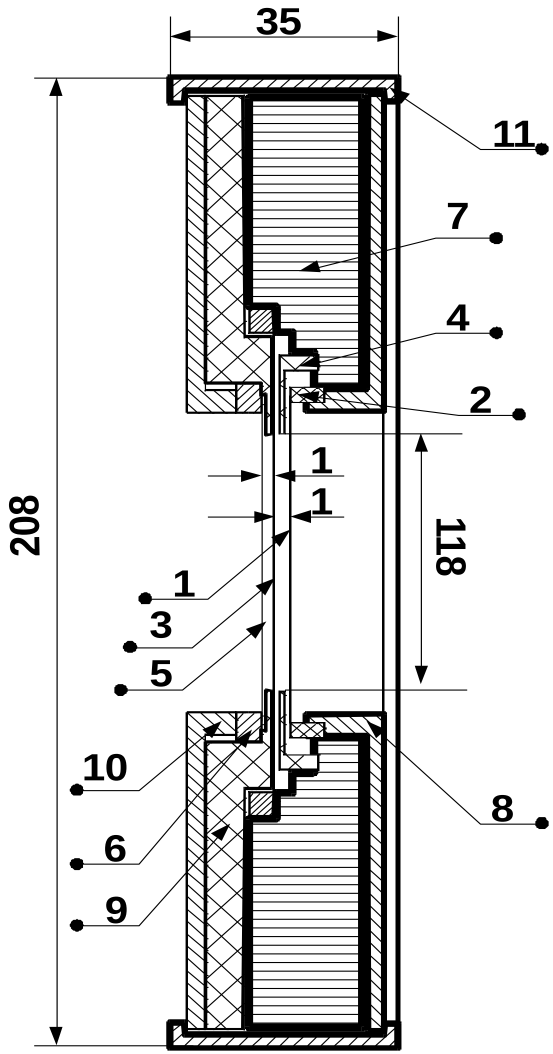


Calculated factor of bulk ion recombination versus the average incident beam current. Solid lines correspond to the ionization chamber with a 1 mm gap, and dashed lines correspond to the chamber with a 2 mm gap. The squares correspond to the accelerator pulse duration of 100 µs, and the triangles correspond to the 50 µs duration.

1-mm gap 120-mm ionization chamber design

- ***1 and 5 – signal cathodes,***
- ***3 - high voltage anode,***
- ***2, 4 and 6 - stainless steel rings,***
- ***7 – lower insulator,***
- ***8 - upper insulator,***
- ***9 и 10 - insulating cheaps,***
- ***11 – metal case.***

Each electrode thickness	3 µm
Internal copper layer thickness	0.15 µm
External layer gold thickness	0.05 µm
The total thickness of anode and cathodes	2.14 mg cm-2
Sensitive air thickness	0.26 mg cm-2
The total thickness including sensitive air	2.4 mg cm-2
Energy threshold for proton penetration through the cathode	0.4 MeV
Energy threshold for proton penetration through the anode	0.5 MeV



Key ionization and beam parameters

Parameter	Value	
Specific ionization loss of proton at 209 MeV	*dE/dx*	3,8 keV mg^{-1} cm^{2}
Energy for ionization single ion pair in air	*W*	34,5 эВ
Number of ion pair produced in 1 mm of air by proton		14,2
Amplifier conversion factor	*K*	12 mV/nA
Amplifier input impedance	*R*	2 Ω
Collimated incident beam area	*S*	7 cm^{2}
Air mass in 1 mm of the collimated incident beam	*dm/dS*	0.91 mg/cm^{2}

Dose calculation

The charge produced in the chamber air gap the during the macro pulse

$$Q = e\frac{U_{exp}}{f}\frac{\tau}{K} = q\ d\ S\ \tau,$$

where K and R - conversion factor and input impedance of the amplifier. Using the parameters given in the table 2 we can calculate the ionization charge in the chamber air gap using the formula

$$Q = Ne\frac{\rho}{W}\frac{dE}{dx}d,$$

where N — number of protons in a single bunch which can be determined from equations (5) and (6) by formula

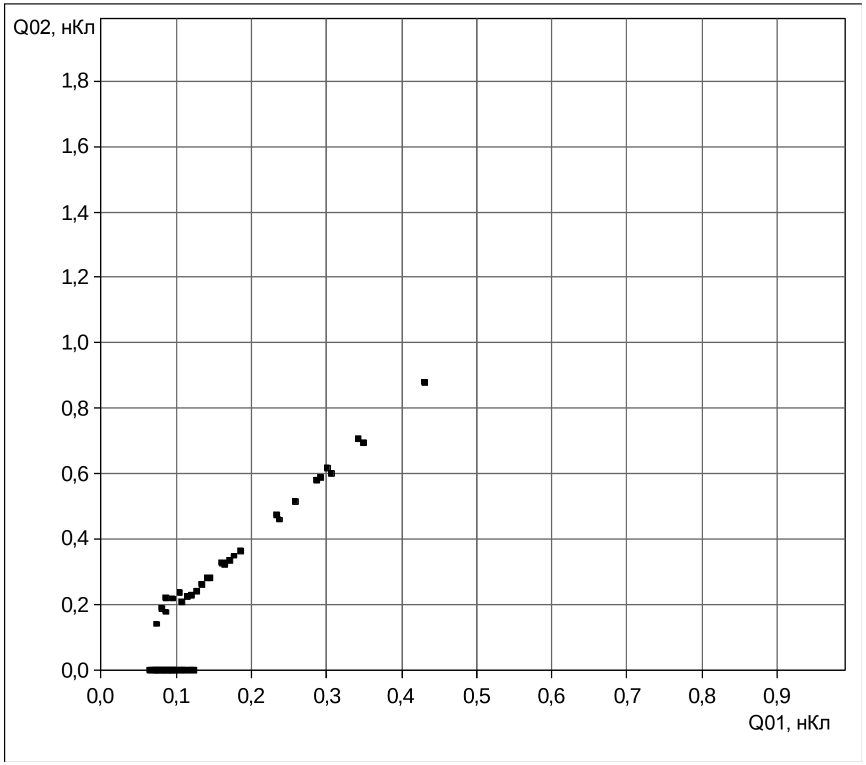
$$N = \frac{U_{exp}}{f}\frac{\tau}{K}\frac{W}{(dE/dx)}\frac{1}{(d\rho)}.$$

Knowing the ionization loss charge in the chamber sensitive gap per a macropulse it is possible to determine the dose per unit of air mass by the formula

$$D[J/kg] = \frac{WQ}{(\rho\ d\ S)}[C] = 3{,}74 \cdot 10^{-11} Q[C]$$

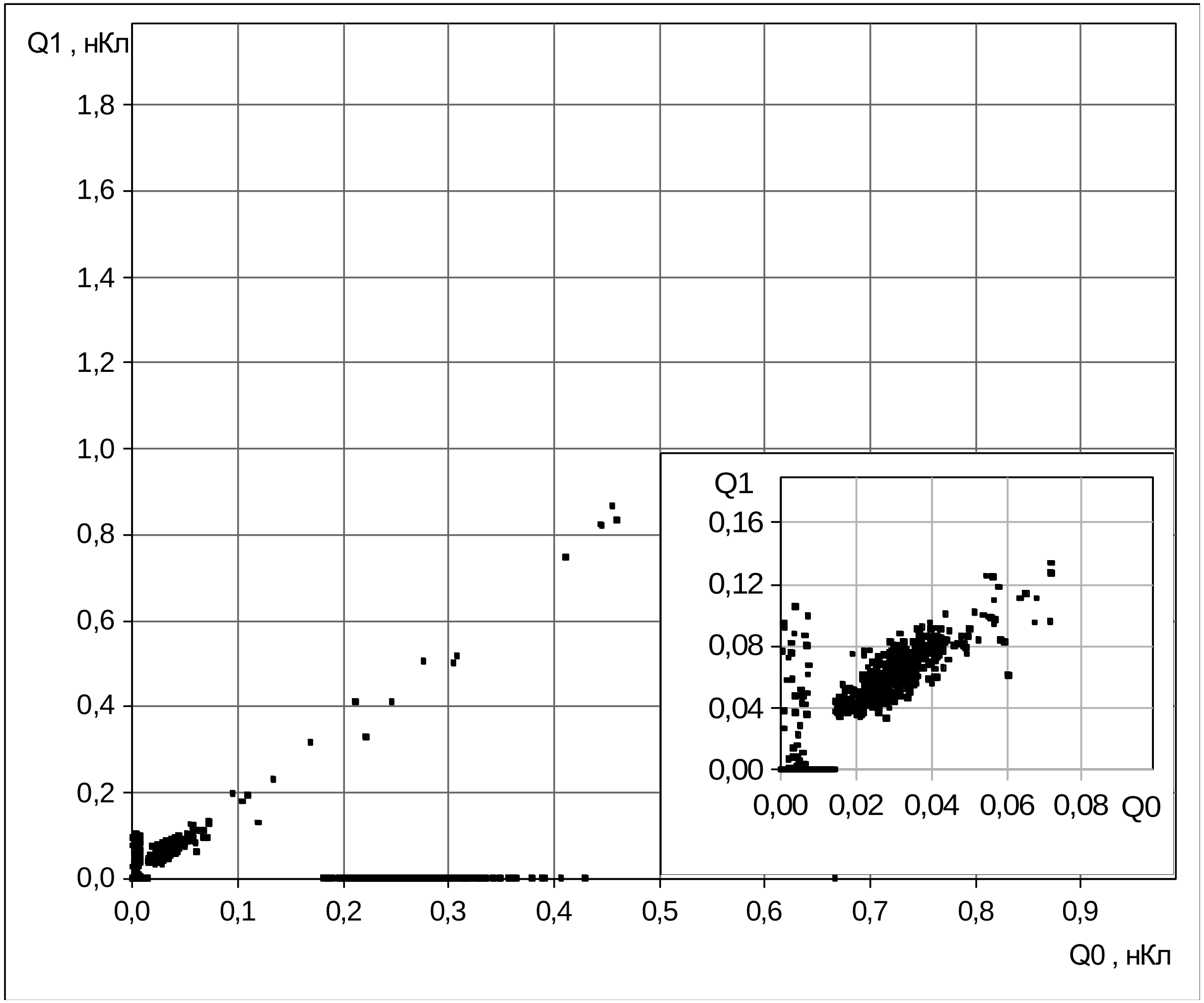
Correlation between charges

Correlation between charges measured by two adjacent cathodes of the narrow-gap chamber with a 1 mm gap between the anode and cathode. The abscissa axis shows the charge values measured by the first gap of the narrow-gap ionization chamber, along the ordinate - the second one.



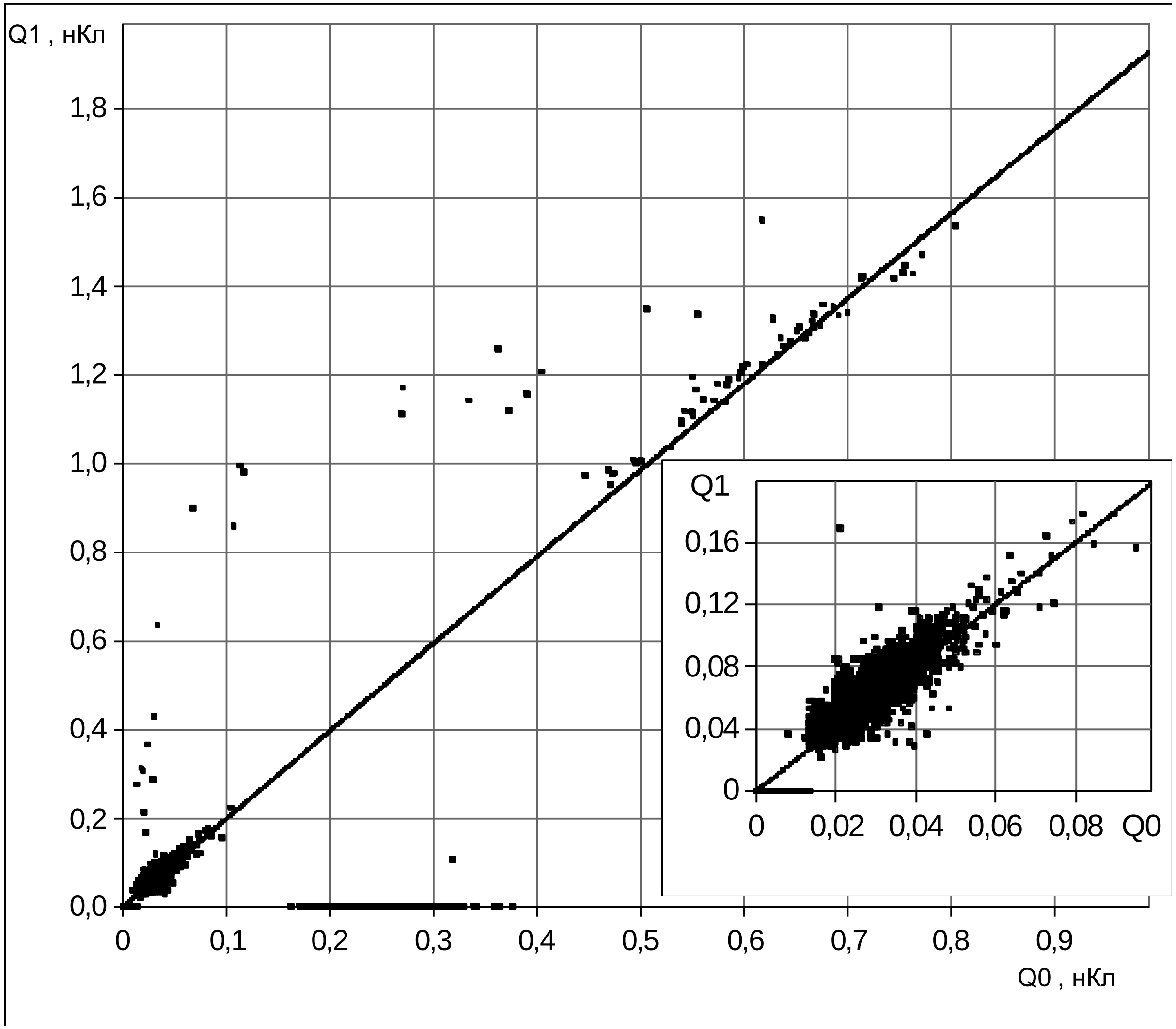
Correlation between charges measured by two chambers. 60 mm in air

Correlation between charges measured by the nearest elements of the narrow-gap (abscissa) and multichannel (ordinate) ionization chambers. The distance in air between chamber electrodes was 60 mm. In the lower right corner in an enlarged scale shows the distribution corresponding to high energy protons.



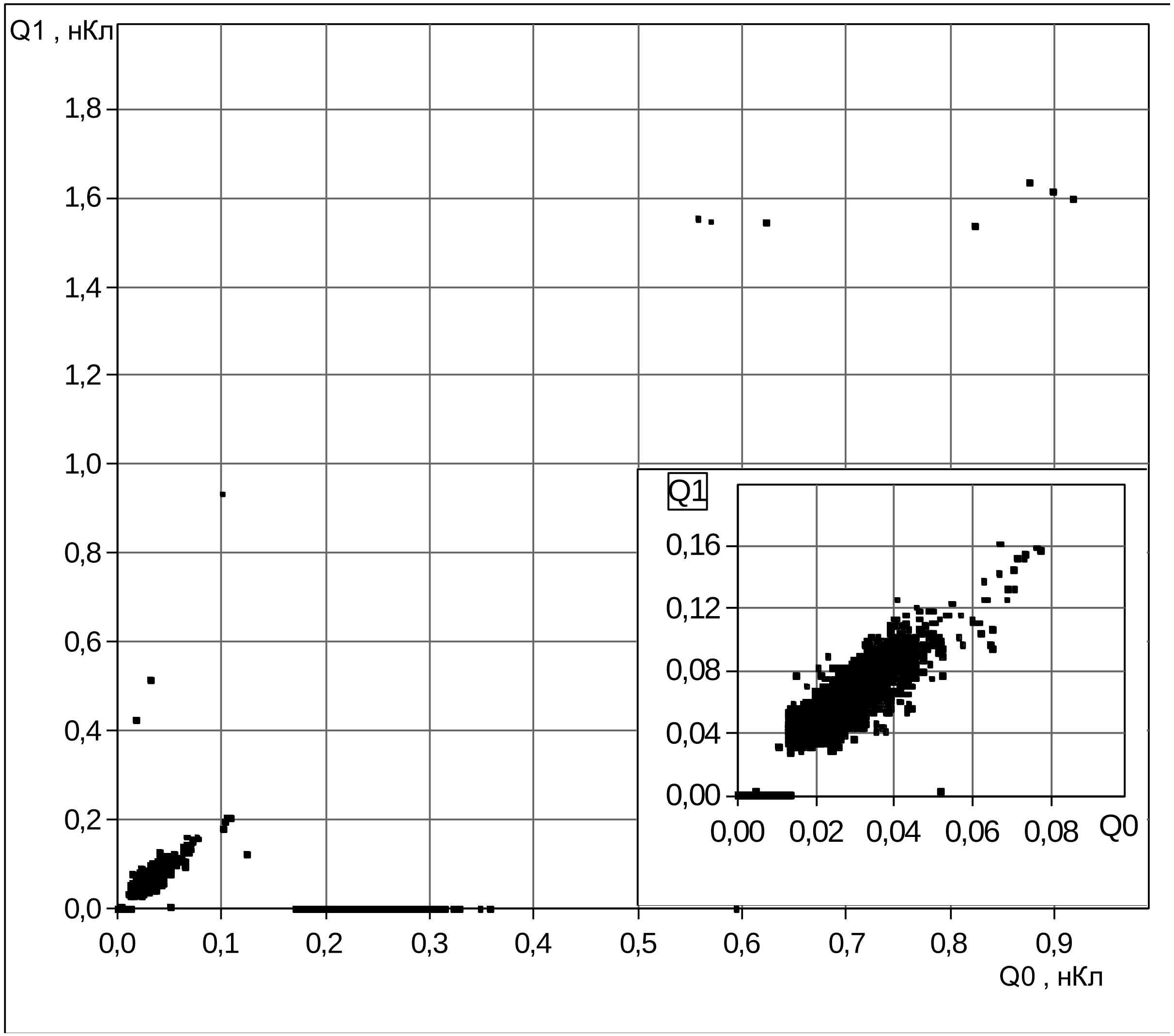
Correlation between charges. 60 mm in air, 1 mm polystyrene

Correlation between charges measured by the nearest elements of the narrow-gap (abscissa) and multichannel (ordinate) chambers.
1 mm thick polystyrene plate is installed between chambers. The air distance was 59 mm. Line - regression according to formula (6) with fitting parameters.



Correlation between charges. 57 mm in air, 3 mm polystyrene

Correlation between charges measured by the nearest elements of the narrow-gap (abscissa) and multichannel (ordinate) chambers, which correspond to ionization losses in air. 3 mm thick polystyrene plate is installed between the chamber electrodes. The air distance was 57 mm.

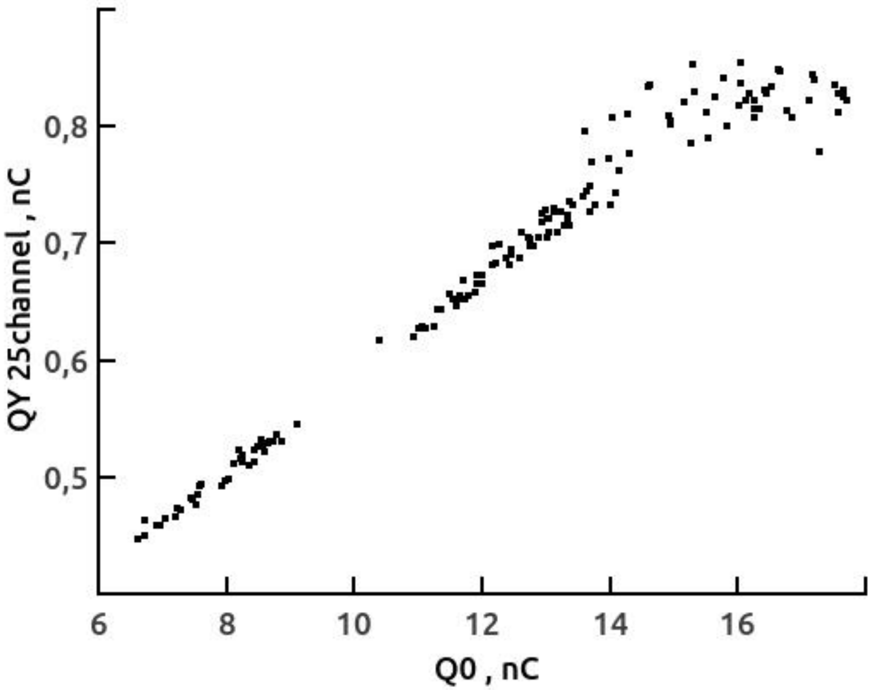


The substance between the sensitive elements of two ionization chambers	Region in Fig.6, 7 and 8	Q0, nC	Q1, nC	N0, events	N1, events
60 mm of air (7.7 mg/cm^2)	Total	88,7	19,9	4152	535
	High energy	14,8	15	479	479
		-17%	-75%		
	Low energy	56,2(63%)	0	210	0
	Scattered background	17,7	4,88	3463	56
		-20%	-25%		
59 mm of air (7.6 mg/cm^2)	Total	193,3	143	4152	3279
1-mm polystyrene (105 mg/cm^2)	High energy	89,2	97,6	3195	3195
Thresholds for electrons and protons		-46%	-68%		
$E_{e,\ thr}$=0.35 MeV $E_{p,\ thr}$=9 MeV	Low energy	60,7	0	247	0
		-31%			
	Scattered background	43,4	45,4	710	84
		-22%	-32%		
57 mm of air (7.5 mg/cm^2)	Total	187,1	106,1	4152	3269
3-mm polystyrene (315 мг/см^2)	High energy	90	98,3	3250	3250
$E_{e,\ thr}$=0.75 MeV		-48%	-93%		
$E_{p,\ thr}$=20 MeV	Low energy	87,9	0	366	0
		-47%			

Correlation between charges measured by multichannel chamber after beam adjustment

Correlation between charges measured the multichannel chamber with a 2 mm gap between the anode and cathode. The abscissa axis shows the charge values measured by the total cathode chamber, along the ordinate – by the 25-th strip in the beam center.

Distortion of chamber response is observed for high ionization density due to bulk ion recombination in air.



Summary and conclusions

- ***The ionization chamber with two sensitive gaps of 1 mm between two cathodes and the anode on the base of 3-μm polyimid films was constructed for measuring the total ionization loss;***
- ***The system of two low threshold-energy ion-chambers, giving new possibilities in proton beam monitoring and analyzing, is considered. The system includes a new double-gap chamber with the gap of 1mm, with polyimid films of 3μm thickness and with the sensitive area 113 cm2 and four-gap ion-chambers with the gap of 2 mm. Stable operation after a proton irradiation of 5 Mrad;***
- ***An analysis of signal correlations from the narrow-gap and the multichannel chambers gives a possibility to make estimation of the contributions of charged particles with high and low energy to total ionization losses.***

List of Publications

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2. C. Brucasco, A. Cattai, R. Cirio, G. Dellacasa, M. Donetti, P.Isoardi, F. Marchetto, C.Peroni, V. Rolando, M. Ruspa, A. Solano, C. Zambernardi, Strip ionization chambers as 3-D detector for hadron therapy, Nuclear Instruments and Methods in Physics Research / A, vol. 389 (1997) pp.499-512.
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7. Н.А. Горяинов, Ю.В. Ефременко, С.Г. Кузнецов, А.В. Смирнитский, Б.Б.Шварцман, "Быстродействующий двухкоординатный профилометр на основе пропорциональной камеры с выводом информации на экран осциллографа", Препринт ИТЭФ-13, 1986, Москва.
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9. С.И. Воробьев, В.Г. Ивочкин, С.В. Косьяненко, "Плоскопараллельная камера", Препринт ПИЯФ-2574, 2004, Гатчина.
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- Thank you!