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FIRST RESULTS ON A SUPERCONDUCTING 4-CELL CAVITY AT 500 MHz

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SUMMARY

In a first measurement with a superconducting 4-cell cavity at 500 MHz a Q-value $Q_0 = 1.6 \times 10^9$ and a maximum acceleration field $E_{acc} = 2.7 \pm 0.1$ MV/m have been obtained for the π mode at 4.2 K. The field was limited by electron loading. For the π mode no multipacting has been observed. The cavity parts were chemically polished by 100 µm prior to welding. After welding only a degreasing and a rinsing with dust free distilled water was applied.

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In April 1979 a feasibility study for the application of cavities to LEP was started at CERN. The very encouraging results obtained with a single cell 500 MHz cavity of "spherical" shape [1] lead us to proceed with the development and construction of a multicell cavity at the same frequency. The spherical shape was again adopted because of the absence of multipacting, the ease of fabrication and its favourable properties for surface treatments.

1. THE CAVITY

The cavity parameters have been computed by SUPERFISH [2] and a few parameters are listed in table 1. Its main dimensions and the field distributions of the four modes of the fundamental pass band are given in figs 1 and 2 respectively. Initially it was planned to construct a five-cell cavity but because of lack of niobium sheet material only four cells could be fabricated.

A beam tube diameter of 15 cm has been chosen so as to obtain an internal coupling of ∿ 1%. Circular roundings were adopted and as a consequence the cavity body ends with a flat annular region of 3.5 cm width. The cavity has been fabricated out of cross rolled, 2 mm thick Nb sheet material(*) by spinning on a lathe and by applying one intermediate annealing of 1 h in a vacuum furnace at 1050°C and ∿ 10^{-5} mbar. After the final shaping tolerances of about 2/10 mm were obtained. Prior to welding a few material checks [1] and a chemical polishing(**) of 100 µm was applied. Parts were joined by electron beam welding.

After welding the cavity was only degreased, rinsed by 2 x 50 ℓ of dust free distilled water, then dried in a dust free room while in a horizontal position and connected to the cryostat cover and its vacuum system under dust free conditions. No bake out was applied before cooldown.

(*) Kawecki reactor grade niobium, grain size: 40 µm
Ta-contamination < 1000 ppm.

(**) Etching solution: 33% HF, 33% HNO_3, 33% H_3PO_4.

2. EXPERIMENTAL SET-UP

In fig. 3 a photography of the bare cavity and of the cavity mounted below the cryostat cover are shown. The cavity is supported by a tuning system allowing during operation an individual tuning of each cell by a variation of the cell length. The cavity is pumped through the upper beam tube and the pumping line is used for visual inspection. RF power is coupled to the cavity with a fixed coaxial coupling system at the lower beam tube. The cavity is measured inside a vertical cryostat of 4.5 m depth and 1 m diameter. As the first cooldown was considered a technical run no diagnostic systems like temperature and X-ray mappings were foreseen and no magnetic shielding was installed.

3. RESULTS

3.1 Q values and accelerating fields

After cooldown the field level of the cavity in the π mode could be raised immediately to a value well above E_{acc} = 2 MV/m. No sign of multipacting (like characteristic field thresholds or higher mode excitation) was found. This confirms observations of other groups on spherical multicell cavities [3,4]. Electron loading was observed to start at E_{acc} = 1.8 MV/m and led to strong Q-degradation which limited the field increase to E_{acc} = 2.70 MV/m (fig. 4). In this field range excitation of higher modes, light emission and a strong X-ray emission were observed. The X-ray intensity obtained from an ionisation chamber outside the cryostat and the light intensity as observed with a photomultiplier at the viewing port showed the same threshold field and exponential increase. The energy of X-rays was determined at the cryostat cover by a NaI counter followed by a multichannel analyser. At E_{acc} = 2.21 MV/m the X-ray energy shows a maximum of 1.8 ± 0.2 MeV. In table 2 the Q values for the 4 pass band modes are given. By relating these Q-values with the field distributions of fig. 2 according to the method given in ref. [5] one can conclude that losses are concentrated in one of the end cells. It is foreseen to analyze the electron loading and X-ray emission more in detail by using electron trajectory calculations once temperature and X ray mappings [6] have been applied. A first Fowler-Nordheim analysis of the X-ray intensity gives a field enhancement factor $\beta \sim 670$.

We note that while no sign of multipacting was detected for the π mode, at least two thresholds associated with the excitation of other pass band modes were occasionally observed for the three modes $\pi/4$, $2\pi/4$ and $3\pi/4$. They appeared during the raise and decay of the r.f. field and never limited the field values.

After some operation at field levels above 2 MV/m quenches of the cavity field at 1.78, 2.16, 2.54 and 2.64 MV/m were observed. They occurred only a few times and were afterwards no longer seen. They were accompanied by large bursts of X-ray intensity, by the excitation of many higher modes and produced an irreversible Q degradation and an increased electron loading. After this cavity degradation which presumably is due to the appearance of new electron sources [1] the field was limited by electron loading to E_{acc} = 2.34 MV/m and the low field Q value degraded from 1.6×10^9 to $\sim 10^9$ whereas the X ray intensity increased by a factor 5-10.

3.2 Frequency tuning

As pointed out above, the 4-cell cavity can be tuned by independent changes of the 4-cell lengths. In order to avoid excessive length changes of the end cells for obtaining a sufficient field flatness the cavity was designed with diameter corrected (full) end cells (fig. 1). After mounting of the support and tuning system and prior to any tuning the field flatness was checked by a perturbation measurement and a field unflatness of ±14% was observed. The cavity then was tuned with the help of a computer program simulating the cavity by a "lumped circuit" diagram [5] and the field flatness was checked again by a perturbation measurement. In this way the field unflatness was decreased below ±2%. The corresponding frequencies of the 4 fundamental modes are given in table 2. The frequencies obtained at He-temperature are also given in table 2. As may be seen frequency shifts for the different modes of 1.46 MHz ± 29 kHz are obtained. One can estimate from the measured frequency change of the 4 passband modes that a field flatness of a few per cent was maintained at He-temperature. We foresee to retune the cavity during the next measurement at 4.2 K by replacing the usual bead perturbation by a well defined change of length of the individual cells. It has already been demonstrated at room temperature that these two methods give equivalent results [7].

Acknowledgements

The success and rapidity of the fabrication and test of the 4-cell cavity is largely due to the competence and enthusiasm of our engineers and technicians. It would not have been possible without the effort of the SB workshops involved in the spinning, electron beam welding and surface treatments. We also thank the EF workshop and cryogenic group for their help.

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TABLE 1

Some computed parameters(*)

Mode	$f^{(*)}$ [MHz]	$E_p/(\sqrt{P_c Q_0})^{(*)}$ [MV/m/W$^{1/2}$]		
		Iris a	Iris b	Iris c
π	499.78	4.37×10^{-5}	4.59×10^{-5}	4.35×10^{-5}
$3\pi/4$	498.96	2.04×10^{-5}	5.41×10^{-5}	5.17×10^{-5}
$2\pi/4$	497.07	4.33×10^{-5}	3.74×10^{-5}	3.98×10^{-5}
$\pi/4$	495.18	490×10^{-5}	5.05×10^{-5}	2.15×10^{-5}

π-mode

$$E_{acc}[\mathrm{MV/m}] = 1.96 \times 10^{-5} \sqrt{P_c Q_0}^{\;(**)}$$

$$r/Q = \frac{E_{acc}^2}{\omega W/2\lambda} = 462 \left[\frac{\mathrm{Ohm}}{\mathrm{m}}\right]$$

$$E_p/E_{acc} = 2.34$$

$$H_p/E_{acc} = 36.5 \ [\mathrm{Gauss/MV/m}]$$

$$2\,\frac{f\pi - f\pi/4}{f\pi + f\pi/4} = 0.92\%$$

(*) These results have been obtained by SUPERFISH. The electron beam welding caused a deformation of the irises decreasing the iris diameter by ∿ 2 mm and the iris thickness by ∿ 3 mm. The total length of the cavity changed from 150 cm to 148.8 cm. The SUPERFISH calculations take these changes into account. The field flatness is only affected slightly by these deformations.

(**) E_{acc} is defined for a particle with $\beta = 1$

$$E_{acc} = \frac{1}{2\lambda} \int_{\ell_{tot}} E_z(z)\, e^{ikz} dz$$

ℓ_{tot}:	total length of cavity including beam tubes.
P_c:	dissipated power [W].
Q_0:	unloaded Q.
W:	stored energy.

TABLE 2

Some experimental results

Mode	Frequency after tuning in air (MHz)	Frequency at He-temperature (MHz)	Δf (MHz)	Q_0 at low field x 10^9
π	497.33	498.778	1.448	1.2
3π/4	496.46	497.952	1.492	0.65
2π/4	494.67	496.144	1.474	0.8
π/4	492.90	494.333	1.433	1.2

FIGURE CAPTIONS

Fig. 1 Main dimensions of 500 MHz 4-cell cavity.

Fig. 2 Computed field distributions for the four fundamental pass band modes.

Fig. 3 (a) Photography of 4-cell cavity after welding.

(b) Photography of 4-cell cavity mounted with its tuning support.

Fig. 4 Unloaded quality factor for the Q_0 mode as a function of E_{acc}.

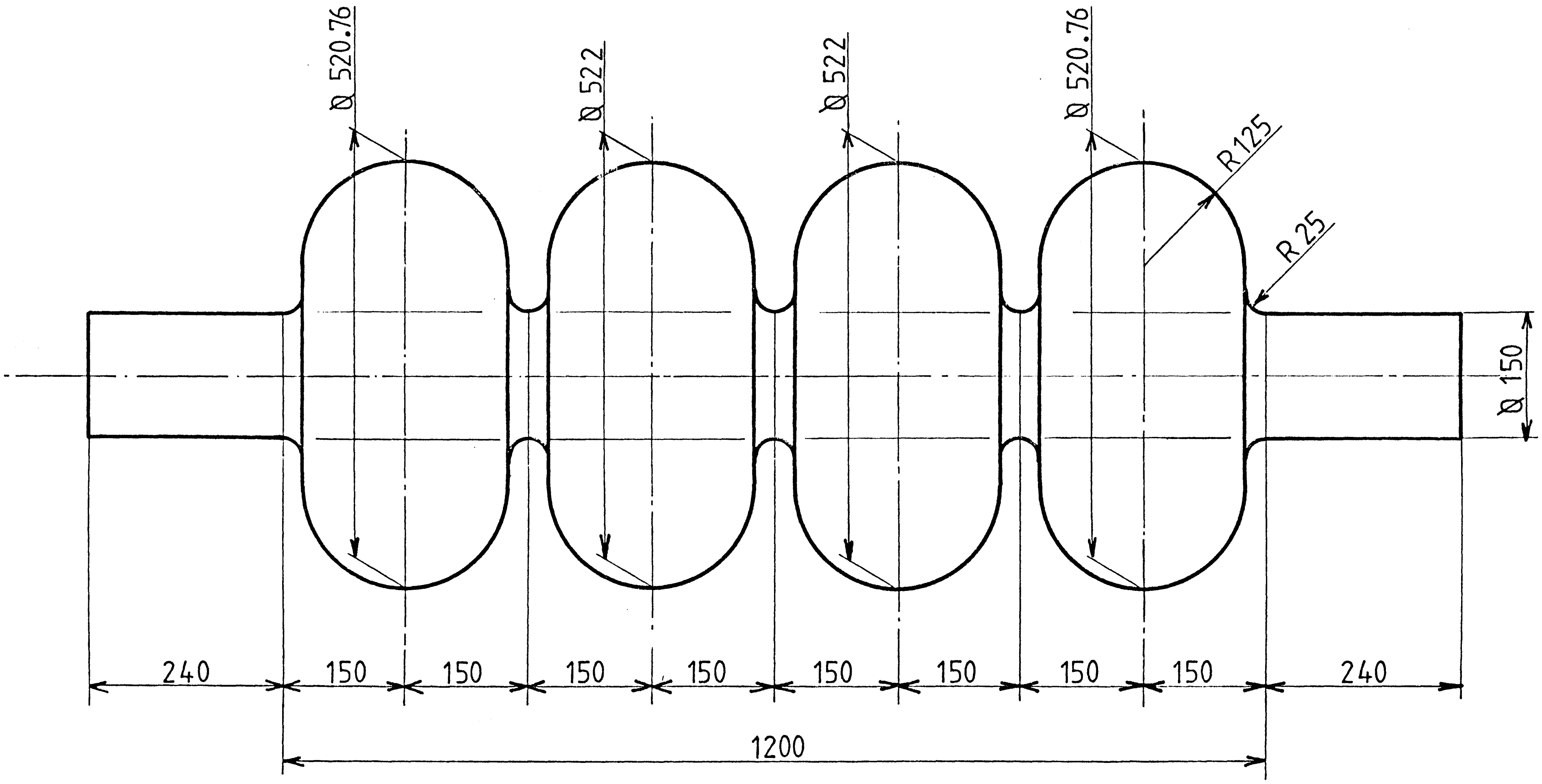
Ø 520.76
Ø 522
Ø 522
Ø 520.76
R125
R 25
Ø 150
240
150
150
150
150
150
150
150
150
240
1200

Fig. 1

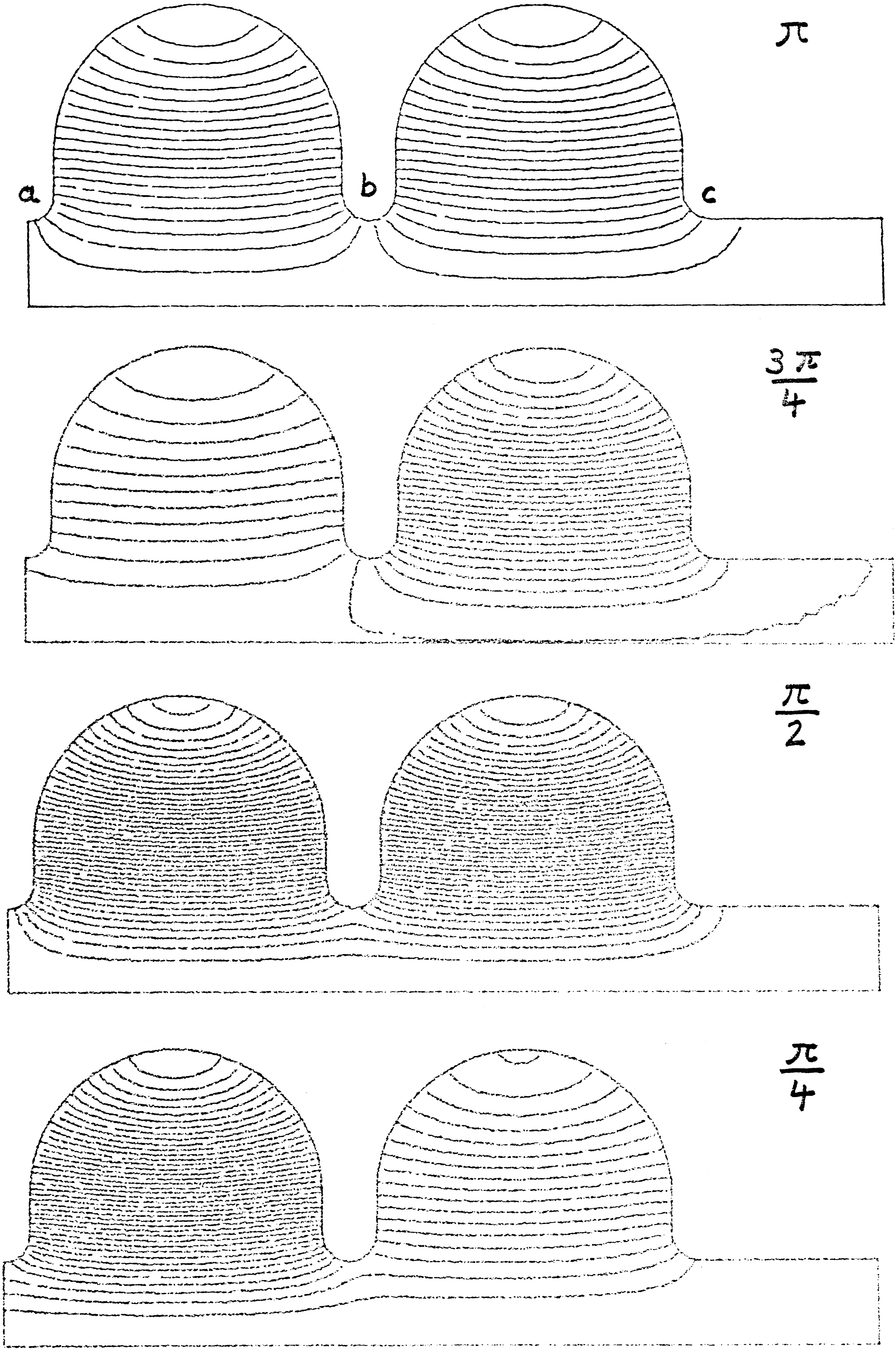

Fig. 2

Fig. 3

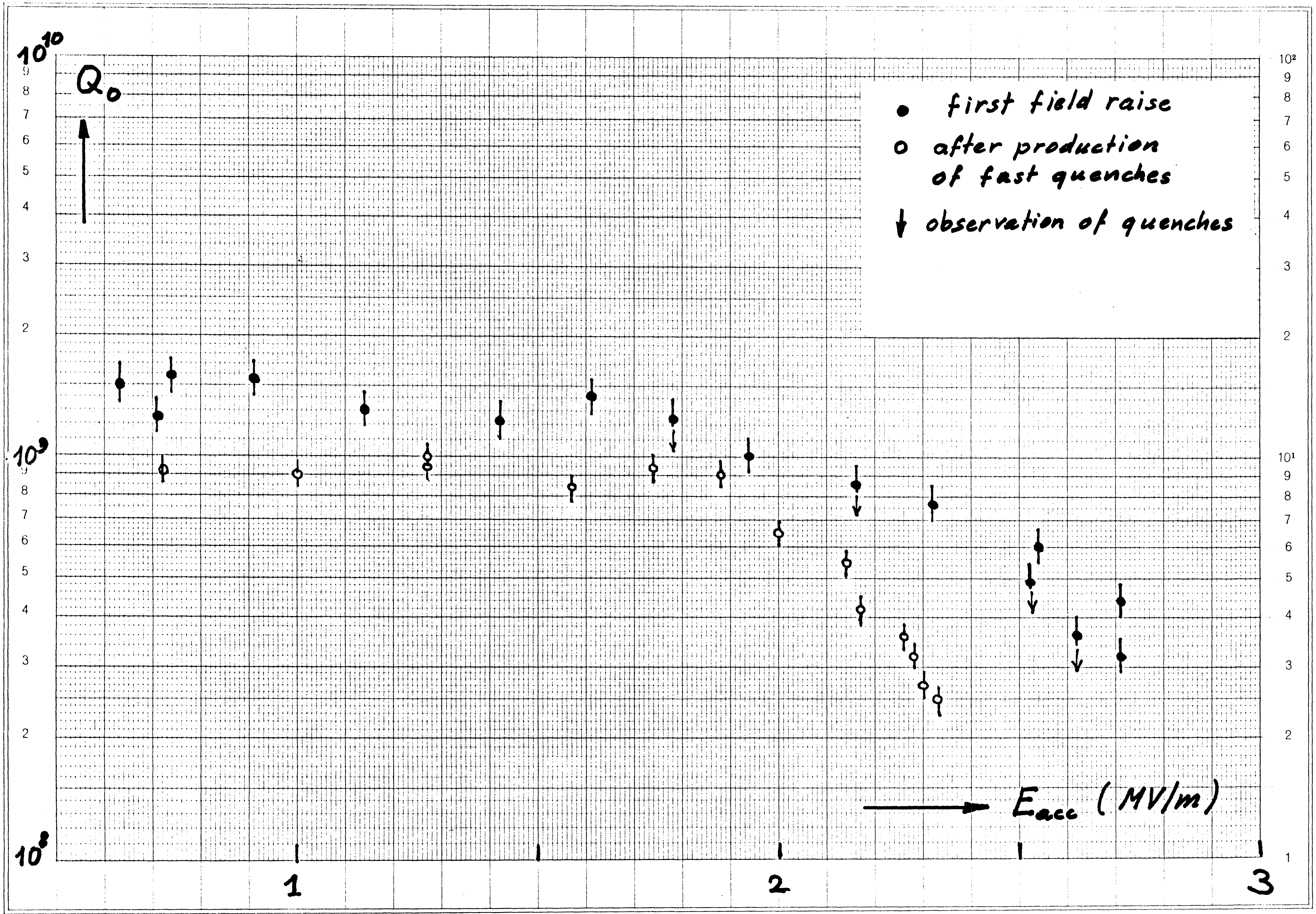
10^{10}
Q_0
10^9
10^8
1
2
3
E_{acc} (MV/m)
● first field raise
○ after production of fast quenches
↓ observation of quenches
10^2
10^1
1

Fig. 4