

# THE HIGH ENERGY SEPARATED BEAM AND THE RF-SEPARATOR FOR IHEP (Serpukhov)

N. GALJAËV, V. KOTOV, A. SAMOILOV and V. VAGHIN

*IHEP, Serpukhov,*

P. BERNARD, D. LAZARD, P. LAZEYRAS and H. LENGELER

*CERN, Geneva, Switzerland*

*Presented by H. Lengeler*

In the framework of the scientific collaboration between IHEP (Serpukhov) and CERN (Geneva) the design of an RF-separated beam and the construction of an RF-separator is under way.

They will provide high energy particles for bubble chamber experiments. Due to the short pulse duration of the RF-separator the separated beam can only work in conjunction with a fast ejection for the primary protons<sup>[1]</sup>.

## 1. Beam-layout

The beam is designed to transport kaons and antiprotons up to 40 GeV/c, pions up to 60 GeV/c and protons up to 70 GeV/c.

The layout is similar to the RF-separator beams already in use at CERN[2-3] and at BNL[4] which work in the energy range of 10—20 GeV/c. It can be divided in three sections (cf. Fig. 1 and Table 1).

### 1. 1. Targetting and momentum analysis.

The beam collects particles from the target under  $0^\circ$  and a first set of 4 quadrupoles (Q1—Q4) arranged in a triplet focuses the beam in the horizontal plane. The triplet (together with the collimators C1, C2) provides a horizontal acceptance  $\alpha_h = \pm 5$  mrad and a vertical acceptance  $\alpha_v = \pm 3,8$  mrad. Normally  $\alpha_v$  has to be reduced in order to fulfill the requirements for a good separation (cf. chapter 2.3). The triplet is followed by 2 bending magnets BM1, BM2 of 6m length each. By using a target with 2 mm horizontal width the minimum relative momentum bite obtained at the collimator C4 is  $\Delta p/p = \pm 0,25\%$ .

The following quadrupole Q5 acts as a field lens which together with the two bending magnets BM3, BM4 and the doublet Q6, Q7 gives a dispersion-free image and focuses the beam in both planes to the centre of the first deflector RF1.

### 1.2. Separation stage

As we are using a "Schnell-type" [5] separator the intercavity optics must have in the separation (vertical) plane a transfer matrix of the form.

$$\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$$

Following calculations done by E. Regenstreif, [6] an optic realizing this matrix in both planes has been adopted for the intercavity distance between RF2 and RF3, whereas for the distance RF1, RF2 this matrix is only obtained in the vertical plane. At 9,75 m behind the centre of the third cavity FR3, the beam stopper (BS) is located. It's position is fixed by the place of the image (across the whole intermediate optics) of a source slit C3 placed in front of the momentum slit C4. Behind the beam-stopper a vertical collimator (C5) is placed in order to reduce the muon background.

### 1.3. Cleaning-and final beam shaping-stage

Behind the beam-stopper 4 quadrupoles Q16—Q20 acting as a triplet refocus the beam on a horizontal (C6) and a vertical collimator (C7) which redefine the target. The next objective (Q20—Q22) together with two 6m-bending magnets (BM5, BM6) provide a second momentum analysis of  $\pm 1\%$ . The corresponding horizontal focus lies inside a 6 m long collimator (C8) made of lead and iron which reduces the muon background. Finally a quadrupole Q23 focuses the beam horizontally in the bubble chamber and spreads it out in the vertical plane.

Table 1

#### Some beam parameters

Target (copper) cross-section	1,5(v)×2(h) mm <sup>2</sup>
Production angle	0°
Collection angles at target $\left\{ \begin{array}{l} \alpha_h \\ \alpha_v \end{array} \right.$	$\pm 5$ mrad $\leq \pm 3,8$ mrad
Solid angle $\Delta\Omega$	$76 \cdot 10^{-6}$ sterad
Relative momentum bite $\Delta p/p$	$\pm 0,25$ %
Number of quadrupoles	23 (2 m long)
Number of bending magnets	6 (6 m long)
Number of collimators	8

Magnifications:	horizontally	vertically
first momentum slit (C4)	1,67	—
centre of deflectors	2,88	5,72
target redefinition (C6, C7)	2,15	5,34
second momentum slit (C8)	11,1	—
<b>Intercavity distances</b>		
$L_{12}$		88 m
$L_{23}$		164,6 m
$L_{13}$		252,6 m
total beam length		511,5 m

#### 1.4. Muon background

Some estimations on the muon background were made for kaons by using the program "Llurch" written by J. Lloyd and D. Stork. Using results of production experiments performed at IHEP[7] we get the following results:

at 22,7 GeV/c	85% K <sup>-</sup> and 15% $\mu^-$
at 32,2 GeV/c	90% K <sup>-</sup> and 10% $\mu^-$

for K<sup>+</sup> assuming a ratio  $K^+/\pi^+=0,1$  at the target one gets for the same energy range 95% K<sup>+</sup> and 5%  $\mu^+$ .

## 2. RF-separator

### 2.1. General layout

Among the various possible RF-separator schemes[8] we have chosen a **three-cavity** separator with linear polarisation of the deflecting fields ("Schnell-type" separator) [5] and a central beamstopper behind the last cavity. This type has been chosen not only because the layout of the separator and the associated beam is relatively simple and because of the high particle intensities which can be obtained, but also because since 1967 a similar type of separator is working successfully at CERN [3].

The well-known working principle of a three-cavity separator as well as its different possibilities for separation has been described in detail in ref. 3 and will not be repeated here.

It was decided to extend the separation range well above 30 GeV/c where there is still enough kaon and antiproton-intensity for a bubble-chamber available. This requirement together with the total intercavity distance available ( $\sim 250$  m) fixed the range of the frequency of the separator. It has been chosen to

$$f=2855,2 \text{ MHz } (\lambda=10,5 \text{ cm})$$

For some definite separation momenta it is very convenient to run the separator as a two-cavity separator (with three possible intercavity distances). In order to have many different separation momenta the three distances were chosen widely different (cf. Table 1).

## 2. 2. Separation momenta

Defining  $D_a$ ,  $D_b$ ,  $D_w$  the final deflection of the unwanted particles (a, b) and the wanted ones, the conditions for separation can be written:

$$D_a \equiv 0 \text{ (one-particle rejection)} \quad (1)$$

$$D_a = D_b \equiv 0 \text{ (Two-particle rejection)}$$

These conditions fix  $D_w$  and it has to be checked that the value of  $D_w$  (which is related directly to the vertical angular acceptance of the separator) doesn't become too small.

### 2. 2. 1. Two cavity separator

If the separator is used as a two cavity separator one can separate **one** kind of unwanted particles from the wanted particles over large momentum ranges (one-particle rejection e. g.  $\pi^+$  from protons) whereas rejection of **two** kinds of unwanted particles is possible only near some definite momenta.

In Table 2 the momenta for two-particle rejection are given for the three intercavity distances and for  $\pi^+$ ,  $K^\pm$  and  $\bar{p}$ . By relaxing somewhat the conditions (1) the separation can be extended around the momenta given in Table 2, but one can show (cf. chapter 2. 3.) that the vertical angular acceptance of the separator has to be strongly reduced. If a reduction of wanted particle intensity by a factor 3 to 4 can be tolerated, separation is possible in the following momenta regions:

$K^+$ : nearly continuous separation from 17-35 GeV/c

$\bar{p}$ : 16,5—18 GeV/c; 21—66 GeV/c

### 2. 2. 2. Three-cavity separator

In a three-cavity separator it is always possible to fulfill the conditions (1) for two particle rejection but the deflection of wanted particles  $D_w$  again is fixed. In Fig. 3, the corresponding vertical angular acceptance which can be handled by the separator (cf. Table 3, first line) is plotted as a function of momentum for  $K^\pm$ ,  $\bar{p}$  and  $\pi^+$ .

It follows from this plot that two particle rejection is possible over large momentum ranges.

Table 2

Two cavity separator momenta for two-particle rejection

Particle	Momentum GeV/c			$\frac{\tau_{ab}}{2\pi}$	$D_w/A$
	$L_{12}=88$ m	$L_{23}=164,6$ m	$L_{13}=252,6$ m		
$K^\pm$	18,99	25,97	32,17	1	1,46
	13,42	18,36	22,75	2	2,00
	10,96	14,99	18,57	3	1,26
$\bar{p}$	9,69	13,26	16,43	1	1,00
$\pi^\pm$	16,32	22,33	27,66	1	1,79
	11,54	15,78	19,56	2	1,60

$\tau_{ab}$  : dephasing between the two unwanted particles over the distance  $L$ .

$A$  : deflection given to the particles in one cavity.

However, one should keep in mind that if enough particle intensity is available it is often more convenient to use the two cavity-operation even if the conditions  $D_a=D_b=0$  are not fulfilled. The much more complicated tuning of a three cavity separator and its more stringent tolerances often favour this solution.

Separation of deuterons (or anti-deuterons) presents a special problem. Generally their production cross-section is so low that for separation three kinds of particles have to be rejected. It can be shown [3] that this is possible with a two cavity separator (under rather poor conditions) near 20,2; 24,2; 27,7; 30 and 34,4 GeV/c. In a three cavity separator deuteron separation is possible around 16, 18,6 GeV/c and above 50 GeV/c.

### 2. 3. Separation conditions and particle intensities

The optimum working conditions with respect to beam stopper thickness and deflection  $D_w$  have determined experimentally at CERN and discussed in detail in reference [3], Appendix II. Some results are given in Table 3.

Table 3

Working conditions for the separator

Deflection of unwanted particles	$\delta_{BS}/\delta_v$	$D_w/\delta_v$	$n_{BS}$	Wanted particle Intensity (relative)
$D_a=D_b=0$	2,5	4	56%	1
$D_b=D_w/4$	4	$\sim 6$	43%	0,55
$D_b=D_w/2$	6,5	$\sim 6$	28%	0,29

$\delta_v$  : angular half-opening in the centre of the deflectors and in the separation plane for the undeflected beam,

$\delta_{BS}$  : half-angle subtended by the beam-stopper in the centre of the last deflector,

$n_{BS}$  : percentage of wanted particles passing the beam stopper (beam stopper transmission).

The last column of Table 3 gives the reduction in wanted particle intensity for the different conditions of separation and shows how rapidly this intensity decreases if the condition  $D_a = D_b = 0$  is relaxed.

In Fig. 3 the expected wanted particle intensities at the bubble chamber are plotted as a function of momentum. The following assumptions are made:

$10^{12}$  circulating protons in the accelerator at 70 GeV/c

10% of protons (3 bunches out of 30) ejected on external target

10% of ejected protons interacting in the target

$\Delta p/p = \pm 0,25\%$

$\Delta\Omega \leq 40 \mu\text{sterad}$ . Towards higher momenta this acceptance

is reduced according to the values of

$\delta_v$  (or  $\alpha_v$ ) obtained from Fig. 2

$n_{BS} = 50\%$

total beam length: 511,5 m

The cross-sections for  $K^-$  and  $P^-$  are taken from the latest results on production cross-sections with 70 GeV/c protons at IHEP [7]. The cross-sections for  $K^+$  are obtained from the Hagedorn-Ranft theory [9].

The limits of separation are not only determined by the maximum particle momentum which can be handled by the separator and the beam but also by the particle intensities, and the ratio of unwanted to wanted particles at the bubble-chamber (Fig. 4). At GERN separation of ratios up to 1500 were successfully achieved. It might be possible to separate even with higher ratios but this will depend strongly on the absolute value of the separation angles and on the fact whether scattering of primary protons and unwanted particles on the vacuum pipe and on the beam elements can be kept sufficiently low\*.

By assuming that about 20 wanted particles should reach the bubble-chamber and that the contamination with unwanted hadrons should lie below a few per cent the following limits for separation seems feasible:

$\pi^+$  : up to 60 GeV/c : limitation from the beam transport system and the separation angles

$K^+$  : up to 40 GeV/c : limitation from separation angles

$K^-, P^-$  : up to 35 GeV/c : limitation from intensity.

The lower limit of separation is influenced by muon contamination, by image broadenings due to the finite momentum bite and by the de-

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\* There seems little hope to separate anti-deuterons because the rate of production [7] is about 1000 times smaller than for  $\bar{p}$ .

cay of  $K^\pm$  giving rise to very high ratios between wanted and unwanted particles. We expect it to lie around 17 GeV/c.

#### 2. 4. Choice of deflector

The parameters of the disc-loaded wave guides foreseen as deflectors have been chosen along the lines discussed in detail in ref. [10].

This choice takes into account:

I) beam properties (size of images in the vertical plane and in the last deflector including chromatic aberrations and scattering:  $h_v = \pm 8$  mm)

II) the separation conditions given in the first line of Table 3

III) the acceptance curves given in Fig. 2

IV) the maximum spill-out time of the 70 GeV-accelerator with a fast ejection system ( $T = 5,2$   $\mu$ sec)

V) the maximum RF-power to be delivered by the klystron amplifiers (20 MW)

VI) the maximum electric field tolerable on the surface ( $E_p = 522$  kV/cm for 1  $\mu$ sec-pulses).

By optimizing for kaon-separation between 25 and 35 GeV/c and by taking also into account problems of mechanical tolerances and machining, we were led to choose a deflector operated in a  $\frac{2\pi}{3}$ -mode with an opening  $2a = 45$  mm. We note that the vertical angle  $\delta_v$  to be accepted in the separator can be limited either by the geometrical acceptance of the deflectors (mainly at lower momenta) or by the deflection that can be given by the deflector to the particles (at higher momenta). A compromise between these two contradictory requirements has to be found which fixes the length  $l$  of the deflector. We have chosen  $l = 6$  m giving a transverse momentum (at 20 MW) of 35 MeV/c and a geometrical angular acceptance for the deflectors of  $\pm 0,526$  mrad. This acceptance is smaller than the one that can be obtained in the beam ( $\delta_v \leq \pm 0,66$  mrad) and, below 24 GeV/c, also smaller than the acceptance that could be reached with the deflections available (cf. Fig 2). One thus favors with this choice of  $l$  the separation at momenta above 24 GeV. This is particularly useful towards the upper limit of separation where for  $K^-$  and  $\bar{p}$  one gets short in intensity.

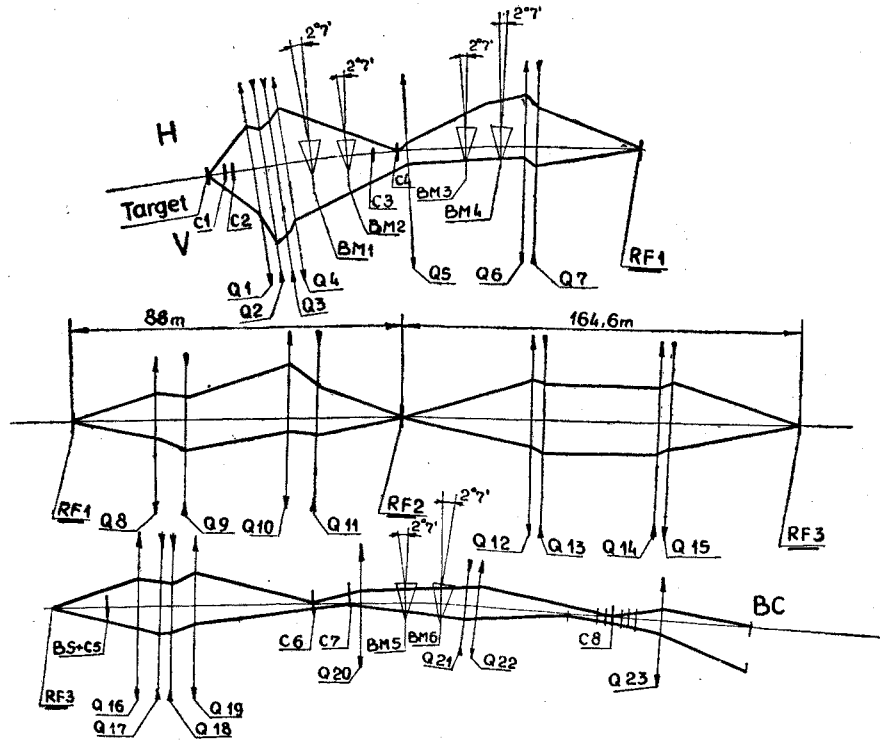


Fig. 1. RF-separated beam: Ray diagram for undeflected particles in the horizontal (H) and vertical (V) plane (zero transverse dimensions of target)

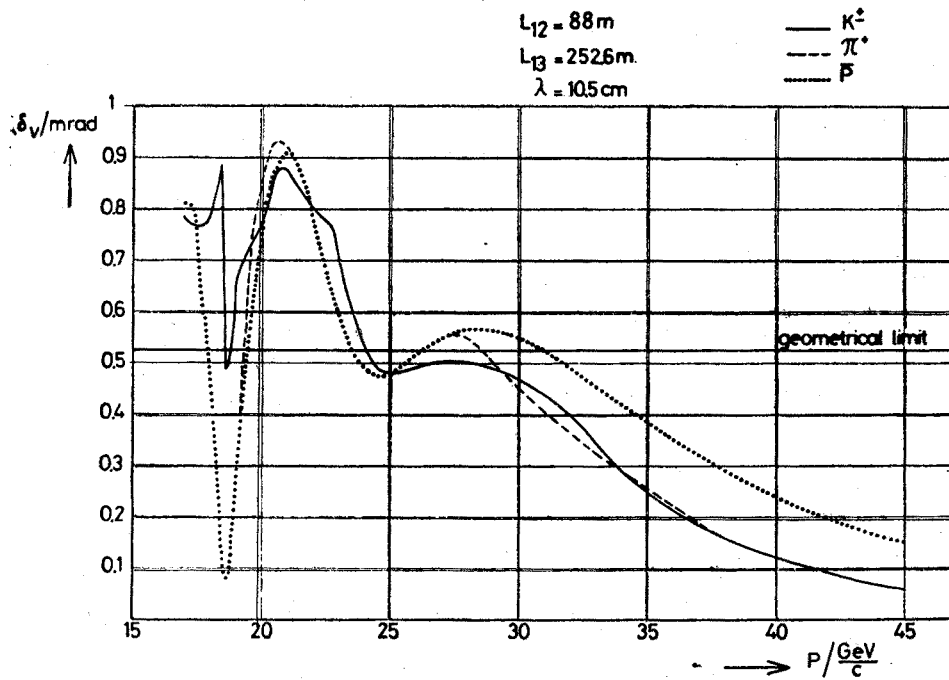


Fig. 2. Thre-Cavity separator.

Vertical angular half-opening  $\delta_v$  that can be accepted by the separator as a function of momentum for  $K^\pm$ , and  $\pi^+$ ,  $\bar{p}$ . The following relations hold:  $D_a = D_b \equiv 0$ ;  $D_w = 4\delta_v$ ;  $\alpha_v = 5.72 \delta_v$ ; straight line: geometrical limit for the deflectors: above this line the acceptance is limited by the deflector geometry, below by the deflection  $D_w$  available.



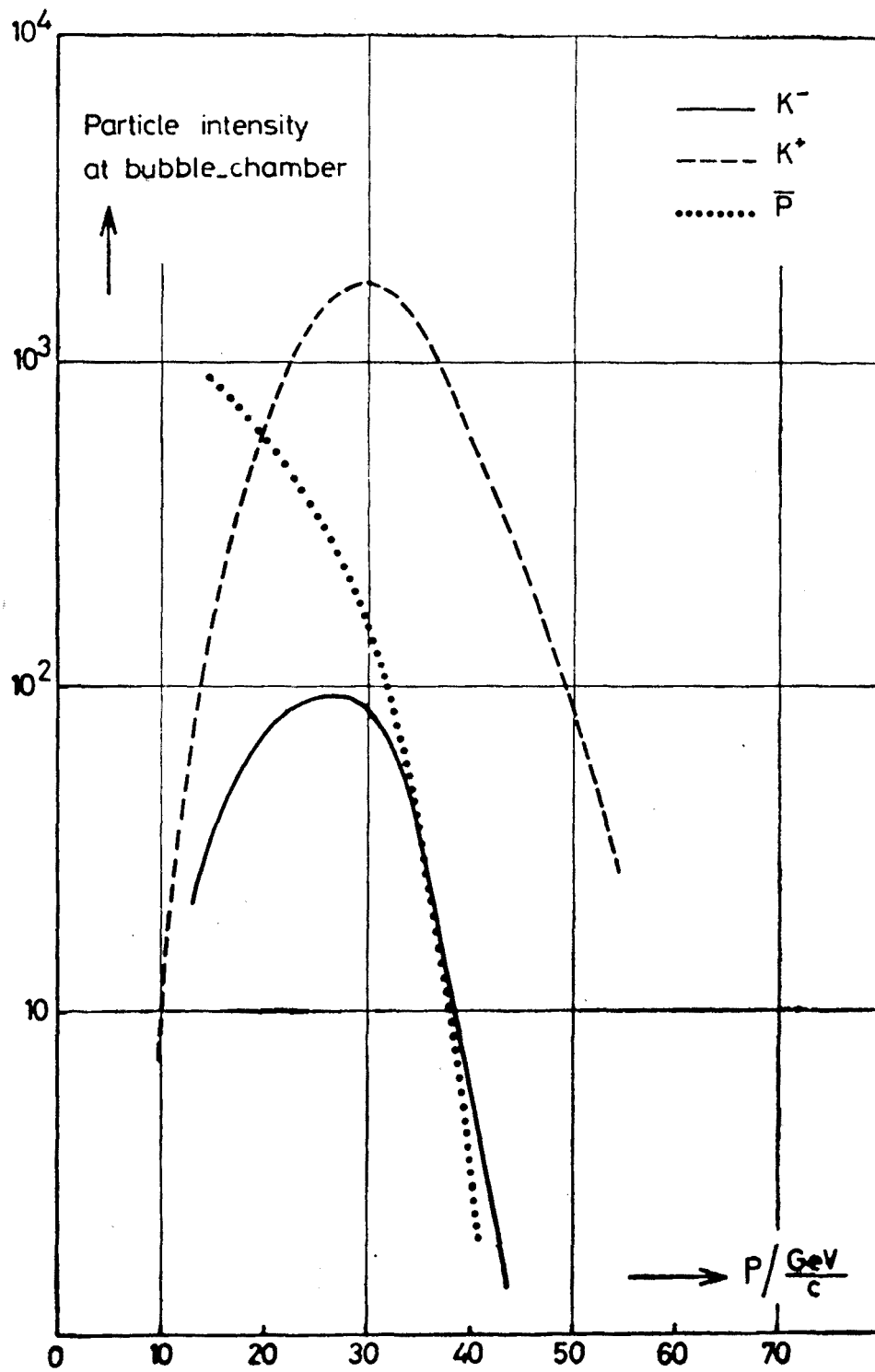


Fig. 3. Expected particle intensity at bubble-chamber. Assumptions cf. texte.

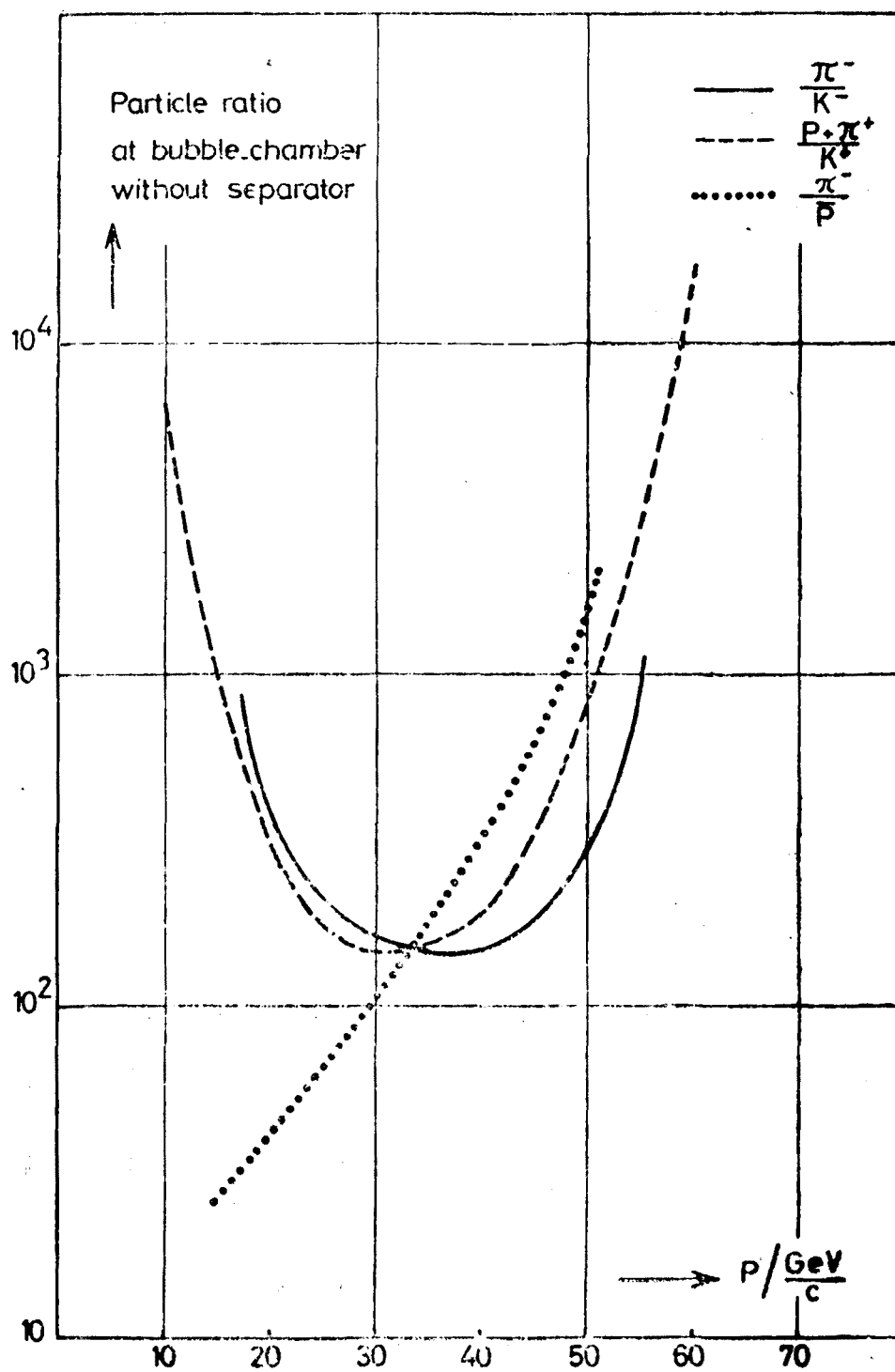


Fig. 4. Ratio of unwanted to wanted particles at the bubble-chamber (without separator). Assumptions like in Fig. 3

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## ДИСКУССИЯ

**Neale:** Is there any difference in principle between the beam you have just described and the three cavity beam in operation at CERN?

**Lengeler:** There is no basic difference between this beam layout and the layout used at CERN for the three-cavity separator ( $V_4$  and  $V_5$  beams).

**Carne:** Is the dispersion curve double-valued with this value of beam aperture?

**Lengeler:** The dispersion curve is not double-valued and the group velocity is  $\beta = 0.0244$ .

**Глазков:** Как выбирается соотношение амплитуд в сепараторе с тремя секциями?

**Lengeler:** The ratio of amplitudes of the deflecting fields in a three cavity separator are fixed by the conditions  $D_a - D_b = 0$  (i. e. the final deflection of unwanted particles must be zero).

**Hahn:** In what type of structure did you measure the values for the peak field

**Lengeler:** We measured it in the old  $\frac{\pi}{2}$ -structure (55 mm opening) of CERN, both in an electroformed and in a vacuum brazed one. The values found for  $E_p$  were about equal  $\left( E_p > 522 \frac{\text{KV}}{\text{cm}} \text{ at } 1 \mu \text{ sec RF-pulse length} \right)$ .

**Lundy:** I would like to make a short comment related to the preceding talk. Some work\* of Dawson and Kustom of Argonne which demonstrated that dielectric-loaded wave guides may be very useful as low-momentum traveling wave separators, has led Sandweiss to propose an application of such structures at the 200 GeV machine. The pertinent point is that such structures can be made quite long due to their low losses compared to iris-loaded structures. This length can give adequate deflections to allow operation in a continuous mode with present power sources. It may be that this will prove to be more economical than an equivalent continuous operation super-conducting separator.

**Вагин:** Предлагаемые Вами отклоняющие структуры имеют в наших условиях и для выбранной нами частоты очень малый акцептанс.

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\* Proceedings of the Particle Conference, Washington, D. C., March 1969.