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COSMIC-RAY INTERACTIONS AND ISR MAGNET SYSTEMS

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INTRODUCTION

This informal report consists of an outline of a talk given at CERN on 7 March, 1969, followed by a set of acceptance tables. The tables were prepared with advice from B.D. Hyams.

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1. COSMIC-RAY INTERACTIONS

Two recent conferences on cosmic rays have given considerable data which are useful in guiding the design of particle-analysis systems for the ISR. We ask the questions: in reactions at the ISR energy, how many product particles are there, what are their momenta, and where do they go?

Data on multiplicity comes from absorption-calorimeter measurements by Dobrotin, and is verified by emulsion-stack measurements done by two groups (Fig. 1). There is evidently an average of about 12 to 13 charged secondaries per collision at $E_{lab.} \sim 1500$ GeV.

The angular distribution can be parametrized by an isobar + fireball model. This does not mean we depend on any uniqueness for such a model. Typically the original nucleons emerge as isobars. In addition, there are 10-11 low-energy particles, mainly pions (Figs. 2 and 3). Dobrotin's experimental method permits the reconstruction of events as seen in the c.m.s. Figure 2 shows 12 such reactions at 500-1500 GeV. In Fig. 3, one of these is plotted in detail. Figure 4 shows plots in $dN/d\Theta$ and $dN/d\Omega$ for these 12 events. $dN/d\Theta$ appears roughly flat. In Fig. 5, $dN/d\Omega$ is plotted for 46 events [this compilation is due to P.R. Murthy (Univ. of Michigan), reprint of talk given at the Symposium on Multiparticle Production in Cosmic Rays, Argonne National Lab., 5 and 6 December, 1968]. With better statistics and a higher average energy, $dN/d\Omega$ is less forward peaked, implying a peak around 90° in a $dN/d\Theta$ plot.

The total momentum distribution for (non-isobar) secondaries is given in Fig. 6. It tends to be confirmed by emulsion-chamber data (Fig. 7), in which a fireball system is defined for which particle production appears to be isotropic. Figure 6 should be (and appears to be) consistent with a fold of Fig. 7 with a fireball γ distribution, shown in Fig. 8. For these emulsion-chamber events, $\bar{E}$ = 1,000 - 3,000 GeV in the lab. A look at the full data of the original report shows that as $\bar{E}$ increases to 10^{14} eV and higher, $\bar{\gamma}$ gradually increases and double-peaked jets become more common (i.e. events with two well-defined fireballs). At the energies of the 34 jets of Fig. 8, the average γ of the fireball as seen in the c.m.s. is only 1.9. To estimate the angle coverage we need, we calculate the lab angle which half the fireball particles exceed; this is 90° in the fireball system:

$$\text{For } \Theta_{FB} = 90°,\ P_T = \langle p\rangle_{FB} = 350 \text{ MeV/c (Fig. 7)}.$$

$$\gamma_{FB} = \bar{\gamma}_{FB} = 1.9. \quad \beta_{FB} = \bar{\beta}_{FB} = 0.85\ .$$

$$P_{L\text{-lab.}} = \gamma_{FB}(0 + \beta_{FB}\, U_{\pi\text{-}FB}) = 1.9\ (0.85)\ (0.38) = 0.62 \text{ GeV/c}\ .$$

$$\Theta_{lab.} = \arctan \frac{0.35}{0.62} = 0.56\ . \quad \Theta_{lab.} = 30° = \Theta_{median.}$$

As a check, the Dobrotin data, from the slightly lower energy range 500 - 1500 GeV, gives Θ_{median} = 39°. This is quite reasonable agreement, and the difference is in the direction we would expect. We must design, therefore, assuming that half the particles will exceed a polar angle of 30° to 40° in the lab.

2. PHYSICS OF THE SMALL-ANGLE REGION

a) For elastic scattering, we know that at P_T = 4 GeV/c the cross-section is reduced by a factor of the order of 10^{12}, for $E_{lab.}$ = 30 GeV. Therefore we must provide an acceptance

$$\Theta_{max} \text{ (accepted)} \sim \frac{3 \text{ GeV/c}}{28 \text{ GeV/c}} \sim 0.1\ .$$

The low angle limit is set by the vertical size of the vacuum chamber, ±3 cm. Therefore

$$\Theta_{min} \text{ (vertical)} \sim \frac{3 \text{ cm}}{400 \text{ cm}} \sim 7.5 \text{ mrad} \rightarrow 210 \text{ MeV/c}\ .$$

b) Typically isobar production is peripheral, the colliding nucleons emerging with altered masses but with their energies and momenta almost unchanged. We sample two extreme cases of isobars, noting that in an isotropic two-particle decay, 60% of the decay products have transverse momenta $p_T > 0.8\ p_{max}$, where p_{max} is the (line) momentum of the decay. Table 1 summarizes the results for the lowest and one of the highest isobars; the case of decay at 90° in the isobar system is chosen.

Table 1

Isobar	Mode	p_{max} GeV/c	90° decay in isobar system	Lab. system
Δ(1236)	N + π	0.231	E_π = 0.23 GeV E_N = 1.0 GeV	E_π = 6 GeV E_N = 22 GeV Θ_π = 38 mrad Θ_N = 10.5 mrad
Δ(2850)	N + π	1.266	E_π = 1.28 GeV E_N = 1.57 GeV	E_π = 13 GeV E_N = 15 GeV $\Theta_N \approx \Theta_\pi \approx \frac{1.27 \times 0.8}{14}$ = 72 mrad for > 60% of all decays.

It appears therefore that an acceptance of ±0.1 radian is adequate for the downstream high-momentum measuring system.

3. ISR BEAM PROPERTIES

The ISR beam momentum uncertainties limit the momentum precision that we can achieve in reconstruction. What are these uncertainties? The horizontal betatron oscillations are ±1 cm. The 20 ampere stack has a 2% momentum spread:

$$\frac{2\% \times 28\ \text{GeV/c}}{4.6\ \text{cm}} = 122\ \frac{\text{MeV/c}}{\text{cm}}\ .$$

Therefore

$$(\text{STACK DISPERSION}) \times (\beta\text{TRON SPREAD}) \times \sqrt{2} \approx 170 \text{ MeV/c} .$$

The $\sqrt{2}$ takes account of the two beams.

In the transverse direction we can do better: the vertical betatron $\lambda\!\!\!^{-}$ is 14 metres.

$$\Theta_v \approx \frac{\pm 0.7 \text{ cm}}{14 \text{ m}} = 1/2000 .$$

Therefore

$$\Delta p_T \approx \frac{28{,}000 \text{ MeV/c}}{2{,}000} \times \sqrt{2} \sim 20 \text{ MeV/c} .$$

4. MEASUREMENT

To equal the errors of the beam, we need not exceed an accuracy of

$$\Delta p_L \sim 200 \text{ MeV/c at } 28 \text{ GeV/c} .$$

We examine what this means in terms of conventional spark-chamber performance.

a) Typically for one gap $\Delta X \sim 0.28$ mm, so for about eight gaps $\Delta X \sim 0.1$ mm. The sagitta error Δs is related to ΔX in a three-point measurement by

$$\Delta s = \Delta X \sqrt{1.5} = 0.12 \text{ mm} .$$

We round this to 0.15 mm to be more conservative. We therefore require a sagitta of

$$s = \frac{0.15 \text{ mm}}{0.7 \times 10^{-2}} = 2 \text{ cm}.$$

For a curvature radius of R, and a track of length 2y in the field,

$$s = \frac{y^2}{2R} \quad \text{and} \quad BR = 33 \frac{\text{kG-m}}{\text{GeV/c}} \times 28 \text{ GeV/c} = 920 \text{ kG-m} .$$

For $B = 14$ kG, $R = 66$ m, so $y = 1.6$ m. We therefore require a track of length $2y = 3.2$ m.

b) For the large-angle region, the momenta are usually much lower than 28 GeV/c, but we recognize the comparative difficulty of spark-chamber construction for large solid angles by doubling the error estimate: $\Delta s = 0.15 \text{ mm} \times 2 = 0.3$ mm.

Then

$$\Delta p = \left(\frac{\Delta p}{p}\right) p = \left(\frac{\Delta s}{s}\right) p . .$$

With

$$\frac{1}{s} = \frac{2R}{y^2} = \frac{2(33)p}{y^2B} ,$$

$$\Delta p = \frac{2(33)\Delta s}{B} \left(\frac{p}{y}\right)^2 = 0.17 \text{ GeV/c} ,$$

to equal the beam momentum errors. Therefore

$$\left(\frac{p}{y}\right)^2 = 85 \left(\frac{\text{GeV/c}}{\text{metre}}\right)^2 .$$

For B = 10 kG and a track length 2y = 1.6 m, we can accept particles up to p = 6.8 GeV/c, or $\Delta p/p$ = 2.5%. Typically, however, a particle of such a momentum will have an angle

$$\Theta(p = 6.8 \text{ GeV/c}) = \frac{0.3}{6.8} = 44 \text{ mrad} ,$$

and so will go into the downstream higher-precision measurement region. We note also that a typical event will have some 10 to 12 large-angle tracks, so that good precision is required even on tracks of only 1 GeV/c so that the compounding of errors will not exceed what we can allow.

5. LATEST DESIGN WORK

Can a system be designed which meets the conditions just set out? We believe so, and illustrate this by Fig. 9. This three-magnet system would run at 6 to 7 MW, and provide a downstream power of about 4 m × 13.5 kG. The return yoke location can be chosen for convenience, to leave the horizontal plane much more open even than in the design of Figs. 9 and 10. The plan shown achieves near-symmetry about the mid-plane of the interaction region, and eliminates all but two modest compensators, by tuning the currents of adjacent ISR magnets by about ±10%. The same magnets could also be used without ISR magnet-current changes by the addition of compensators, as illustrated by Fig. 10. Several other improvements of detail have also been made; these relate mainly to open access horizontally both to the central and downstream magnets.

It is an essential feature of this design that when sufficient confidence in ISR operation has been achieved so that some changes in ISR magnet location can be made, the fields in all three magnets could be made to be in the same direction by a simple reconnection. This would give a system, with high sweeping power, retaining high symmetry and full 4π coverage of the central region.

6. ACCEPTANCE TABLES

In the tables on pages 18-23, the criterion for acceptance is that the combined errors of the beams and of the momentum-measuring system should not exceed twice those of the beams alone. The standard ISR elliptical vacuum chamber is used, because no reduction in the chamber size can be made without superposing momenta in the stacked beam, and thus losing momentum information. No clearance of the detectors from the vacuum chamber has been assumed, because detectors already exist which are usable within 1 cm of the beam pipe, and further progress is not ruled out for any fundamental reason.

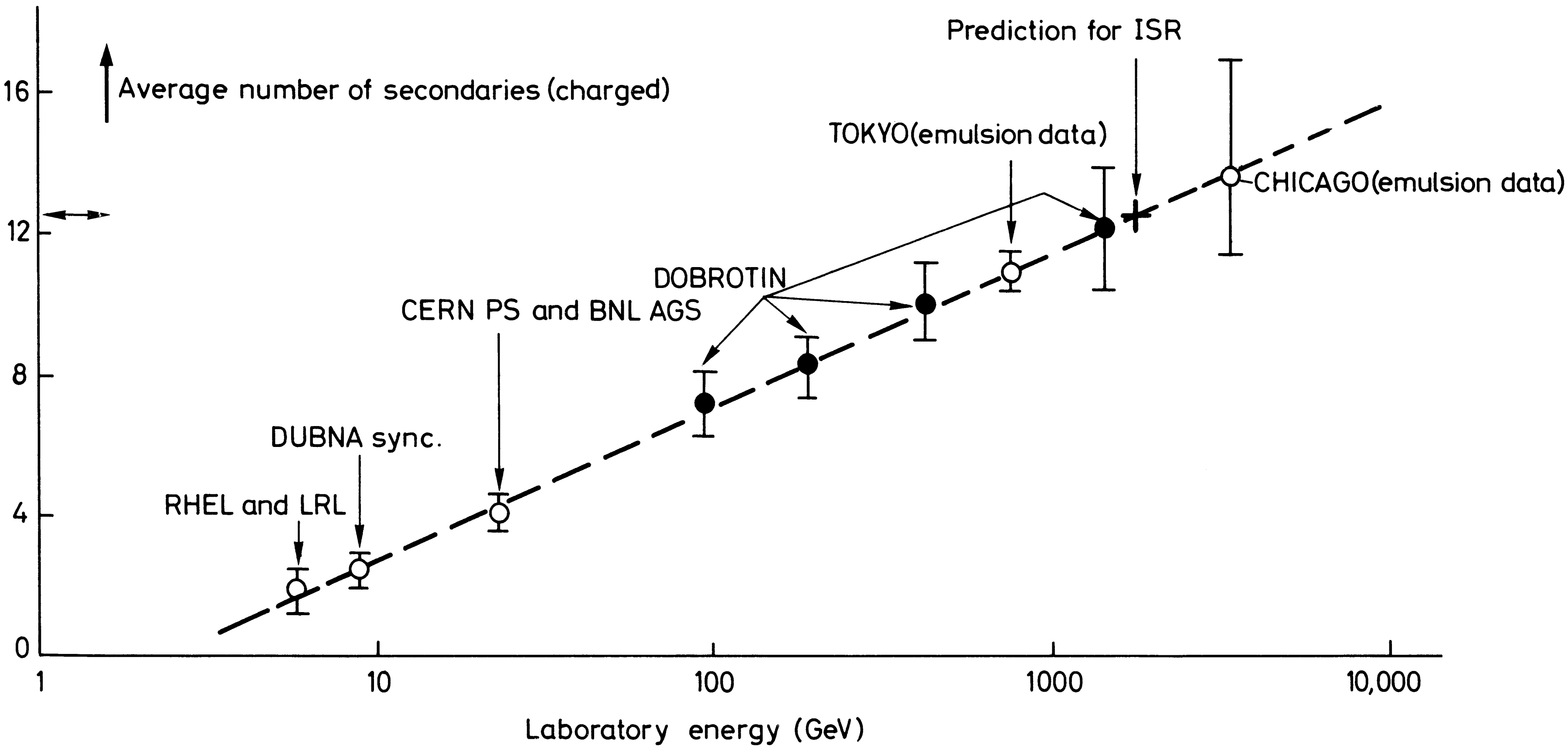
The tables are divided into two groups; pages 18-21 refer to the three-magnet system with alternated fields, which does not require relocating ISR magnets. Pages 22 and 23 refer to the system with all fields in the same direction.

In the first group, pages 18-21, 18 and 19 apply to the isobar (small-angle) region. The transverse momentum distribution was chosen by summing the distributions of several known isobars representing a wide range of masses: the 1236, 1688, and 2850.

Pages 20 and 21 refer to the large-angle region, with a weighting constant in $d\sigma/d\theta$ as indicated by the cosmic-ray data. They apply equally well to the system with a common field direction.

For comparison, on all pages the three-magnet system is compared with the split-field system, which has been chosen as the first large-scale system to be built for the ISR. In general, the acceptances in the forward-angle region appear quite similar for the two systems, the three-magnet becoming slightly superior to the split-field after field reversal. In the large-angle region the three-magnet system appears strongly superior to the split-field under all conditions.

This report is being circulated as part of the input data for the discussion of "ultimate" ISR analysing systems satisfying a wide range of requirements.



(Source: Murthy FIG.'S 5,7; Note definition changes)

FIG.1

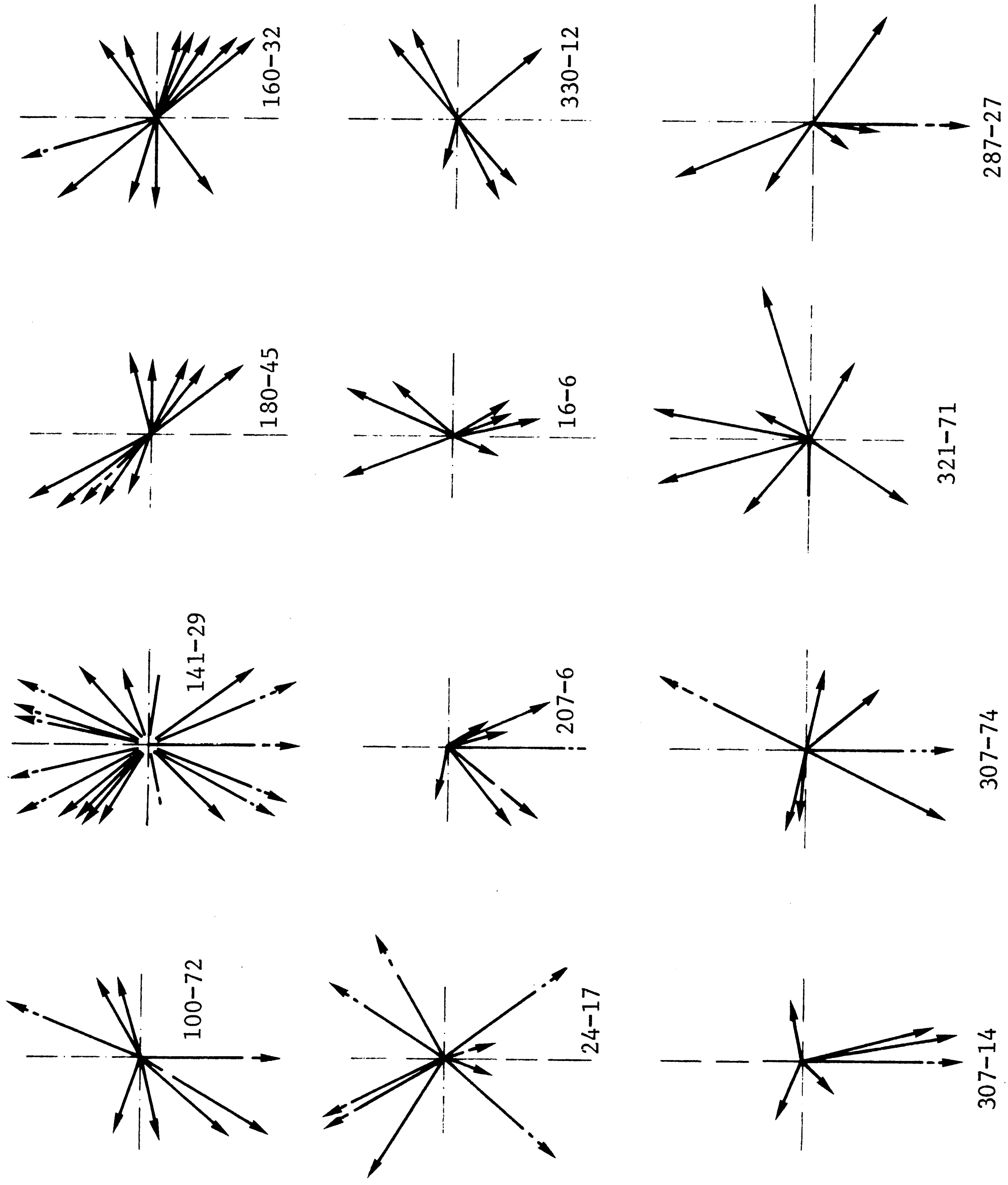

160-32
330-12
287-27
180-45
16-6
321-71
141-29
207-6
307-74
100-72
24-17
307-14

FIG. 2

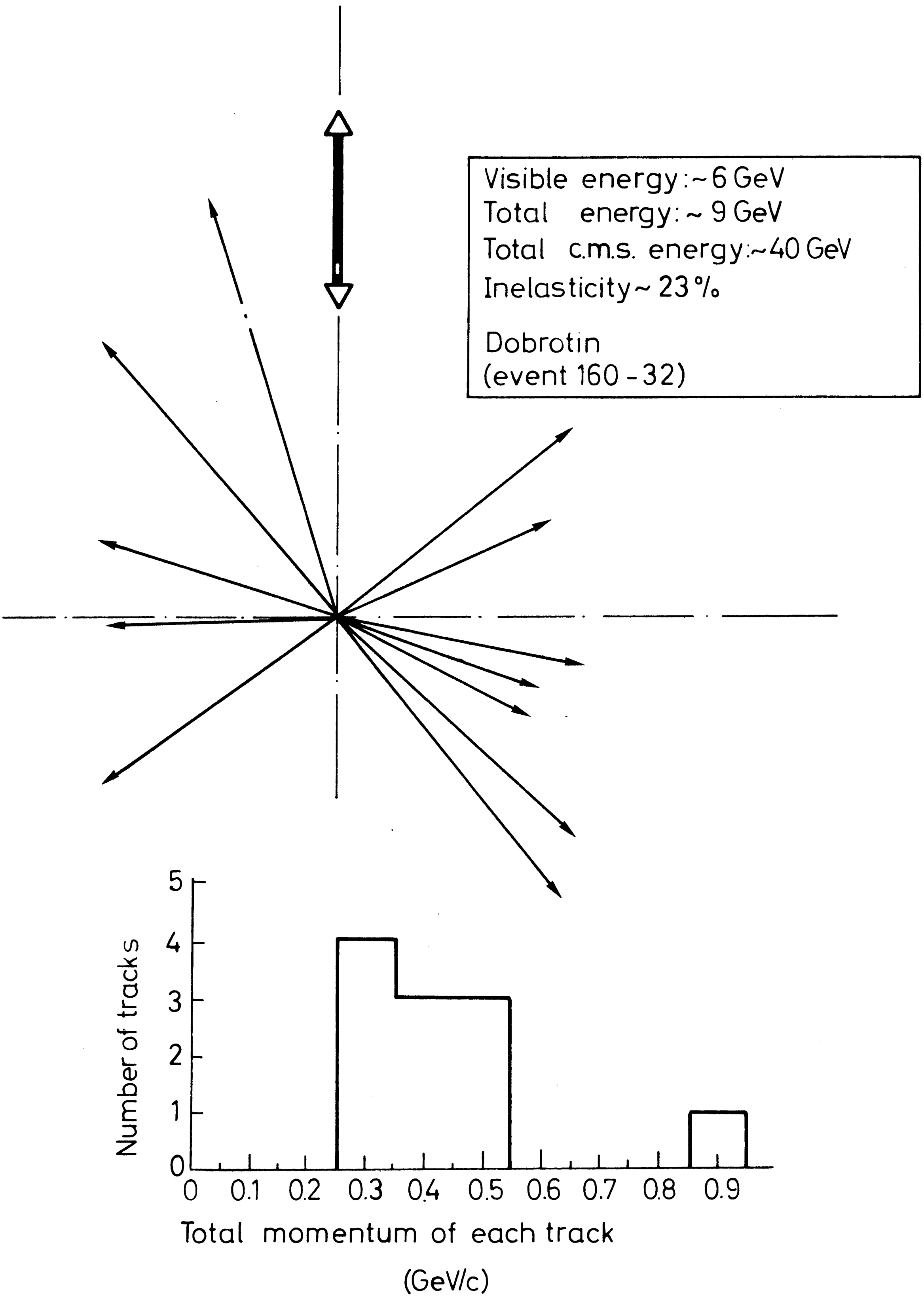

Visible energy:~6 GeV
Total energy: ~ 9 GeV
Total c.m.s. energy:~40 GeV
Inelasticity ~ 23 %
Dobrotin
(event 160 - 32)
Number of tracks
0
1
2
3
4
5
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
Total momentum of each track
(GeV/c)

FIG.3

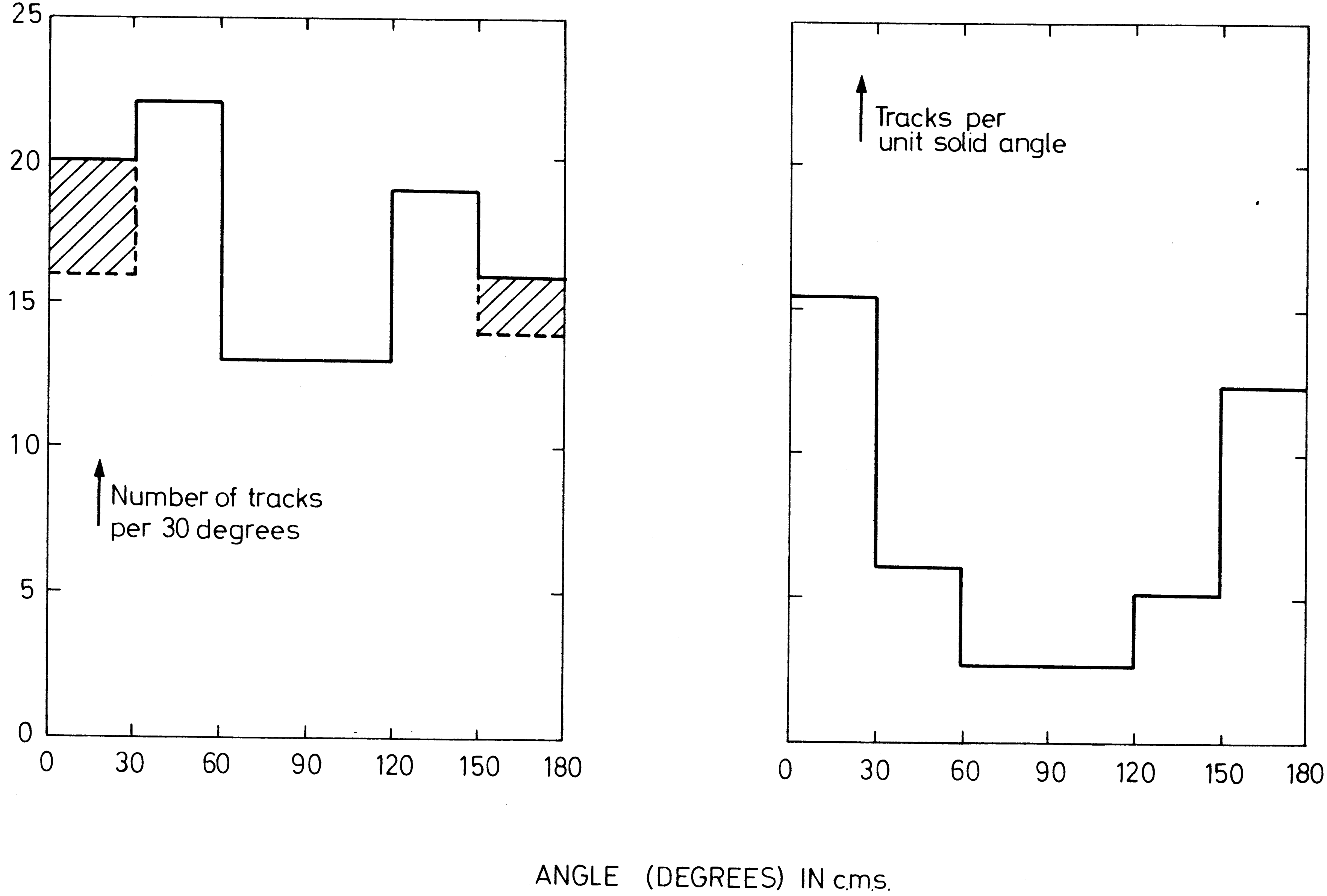
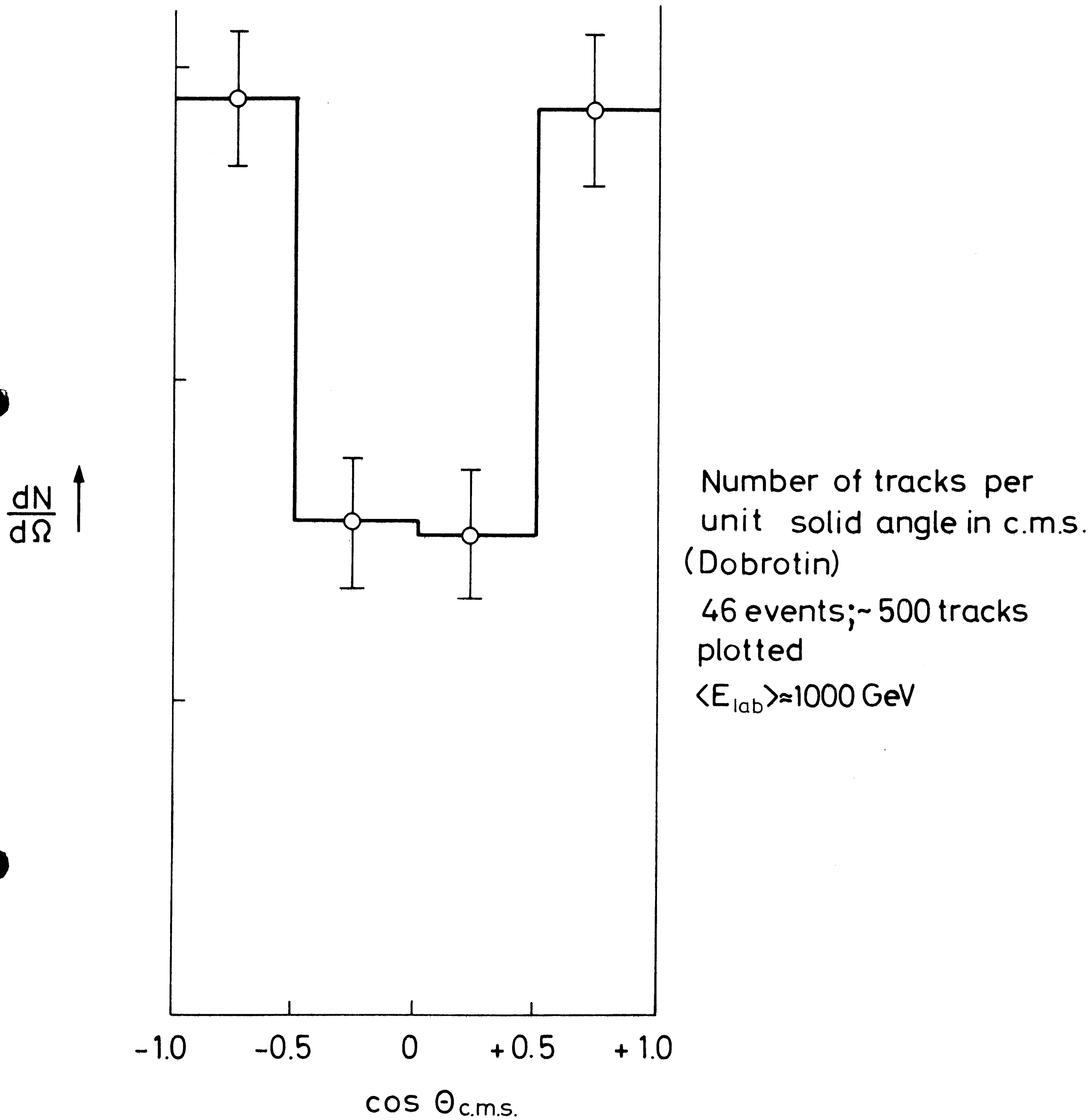
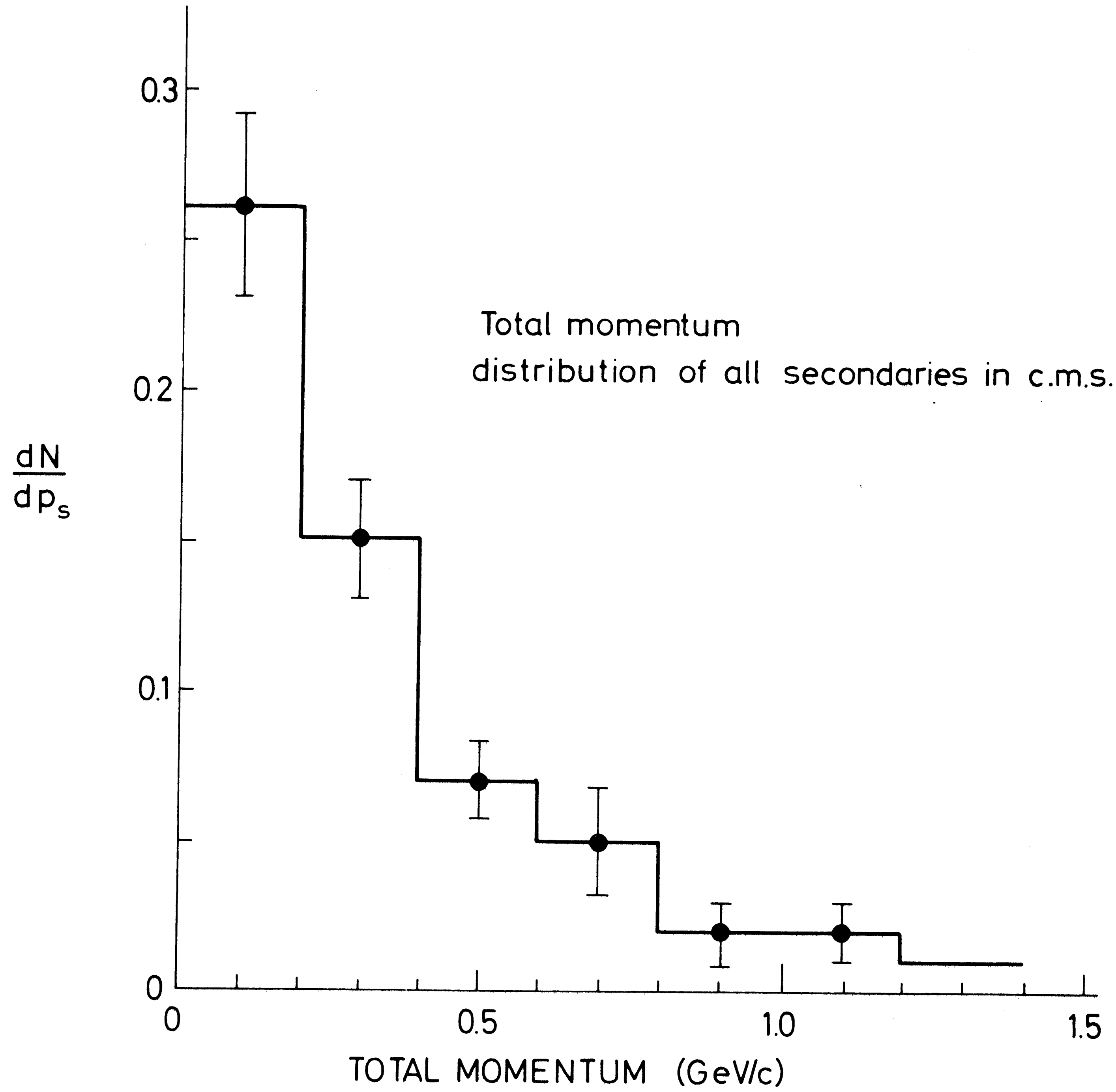

25
20
15
10
5
0
0
30
60
90
120
150
180
Number of tracks per 30 degrees
Tracks per unit solid angle
0
30
60
90
120
150
180
ANGLE (DEGREES) IN c.m.s.

FIG.4



(Murthy, ANL Symp. on multiparticle production, Dec.1968)

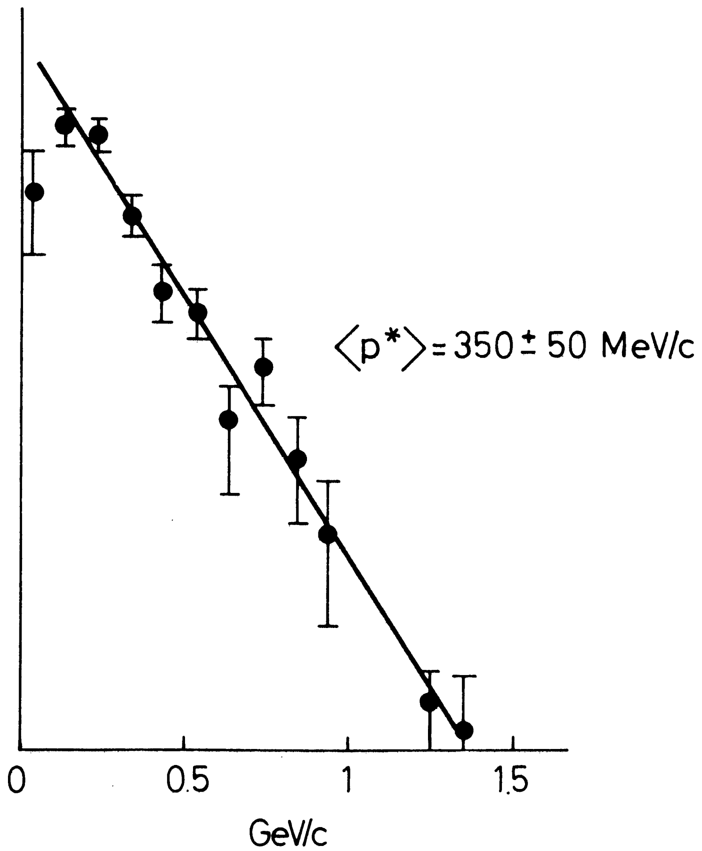
FIG. 5



(Dobrotin data, reconstructed from $\frac{1}{N}\frac{dN}{dp_s}$ plot,

Murthy, ANL Symp., FIG.4)

FIG.6

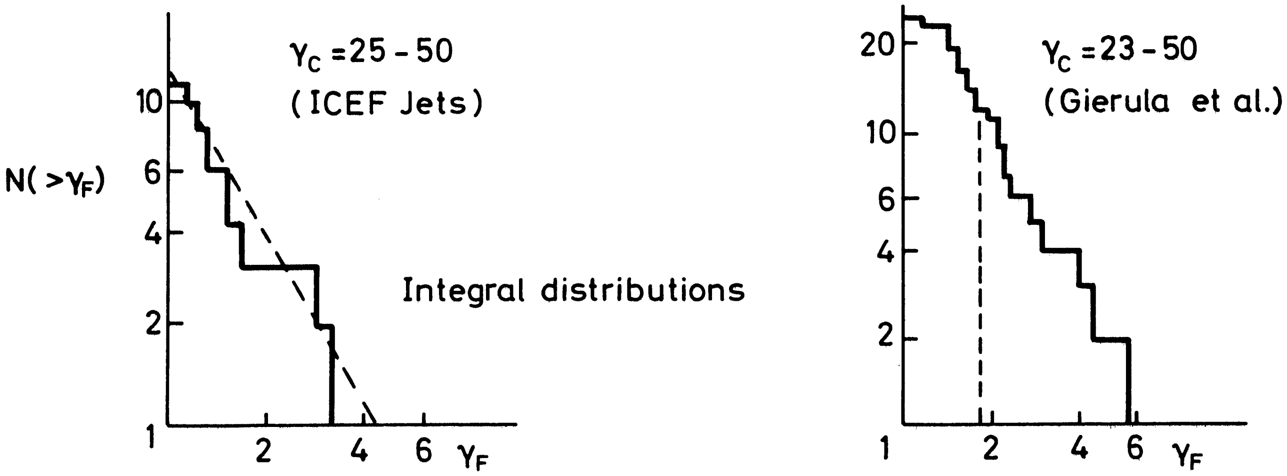


Momentum distribution of π^0 mesons in fireball system

JAPAN - BRASIL - emulsion collaboration

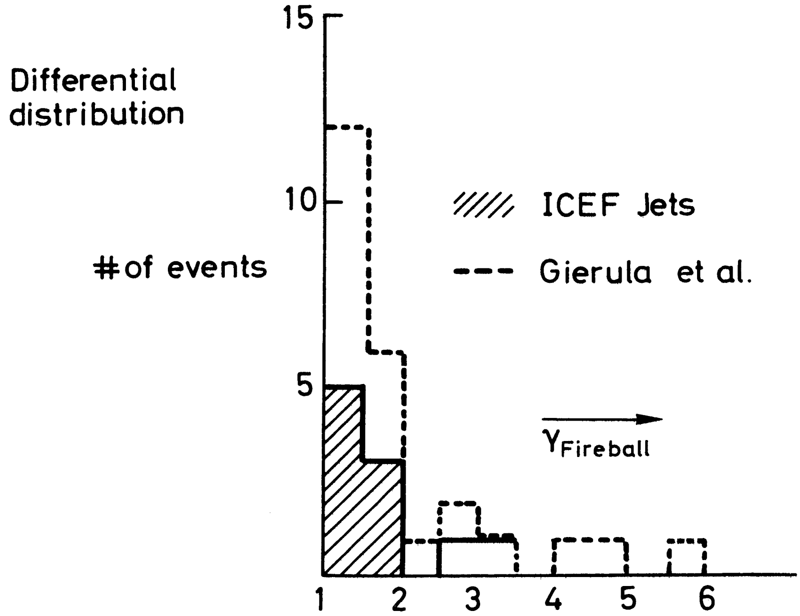
$3,000\ \text{GeV} < E_{lab} < 12,000\ \text{GeV}$

FIG.7



γ of the fireball as seen in the c.m.s.
(from emulsion-chamber measurements)

Reference : K.Imaeda (Dublin Inst. Adv. Study)
Can. J. Phys. 46, #10, pt.3, p.S 722 (1968)



The lower graph summarizes in differential form the integral data of the upper graphs.

FIG. 8

THREE-MAGNET ANALYSING SYSTEM

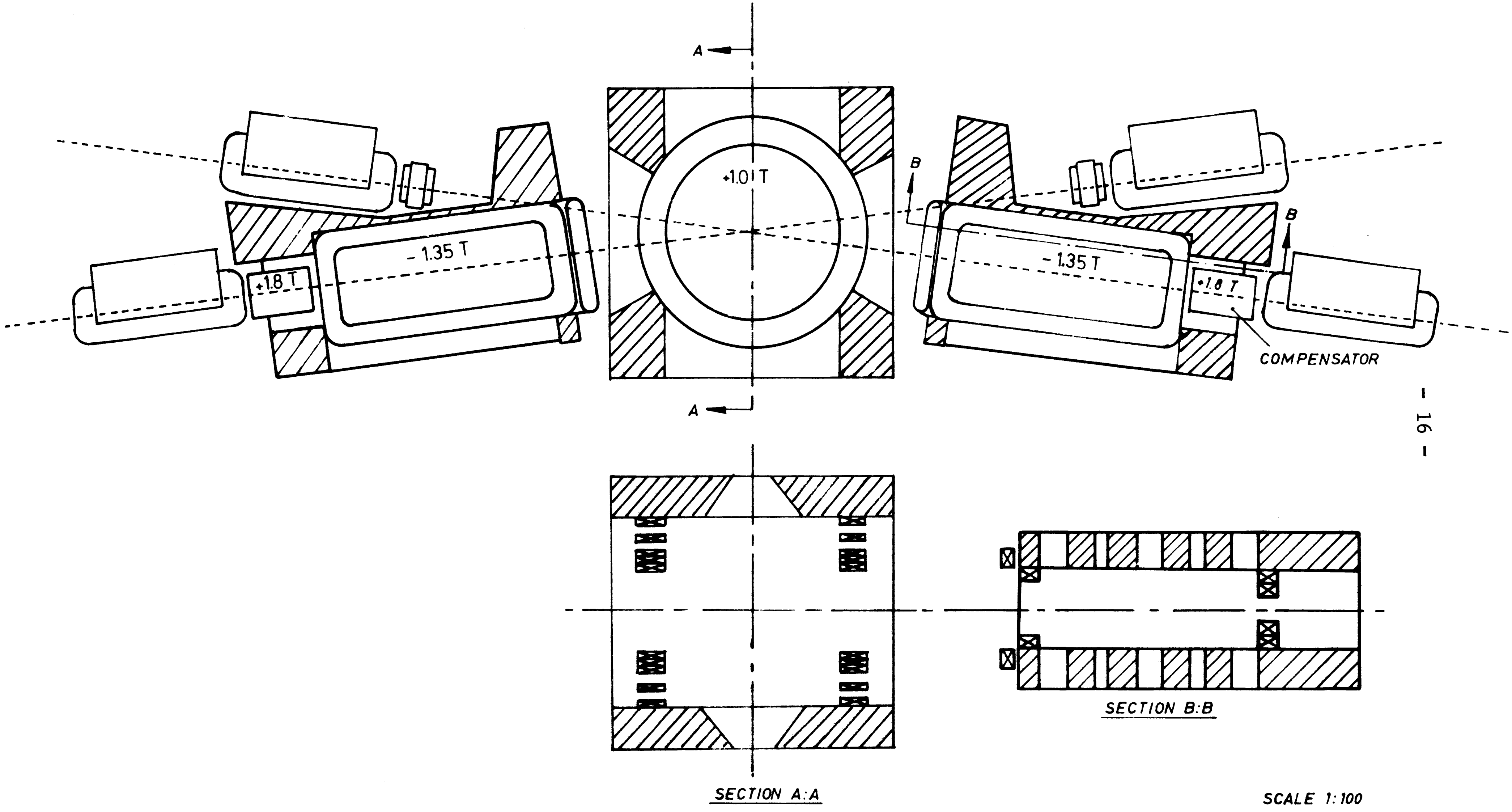


FIG.9

THREE-MAGNET ANALYSING SYSTEM

(Crossing Point has moved right by 50 cm, all compensators shown)

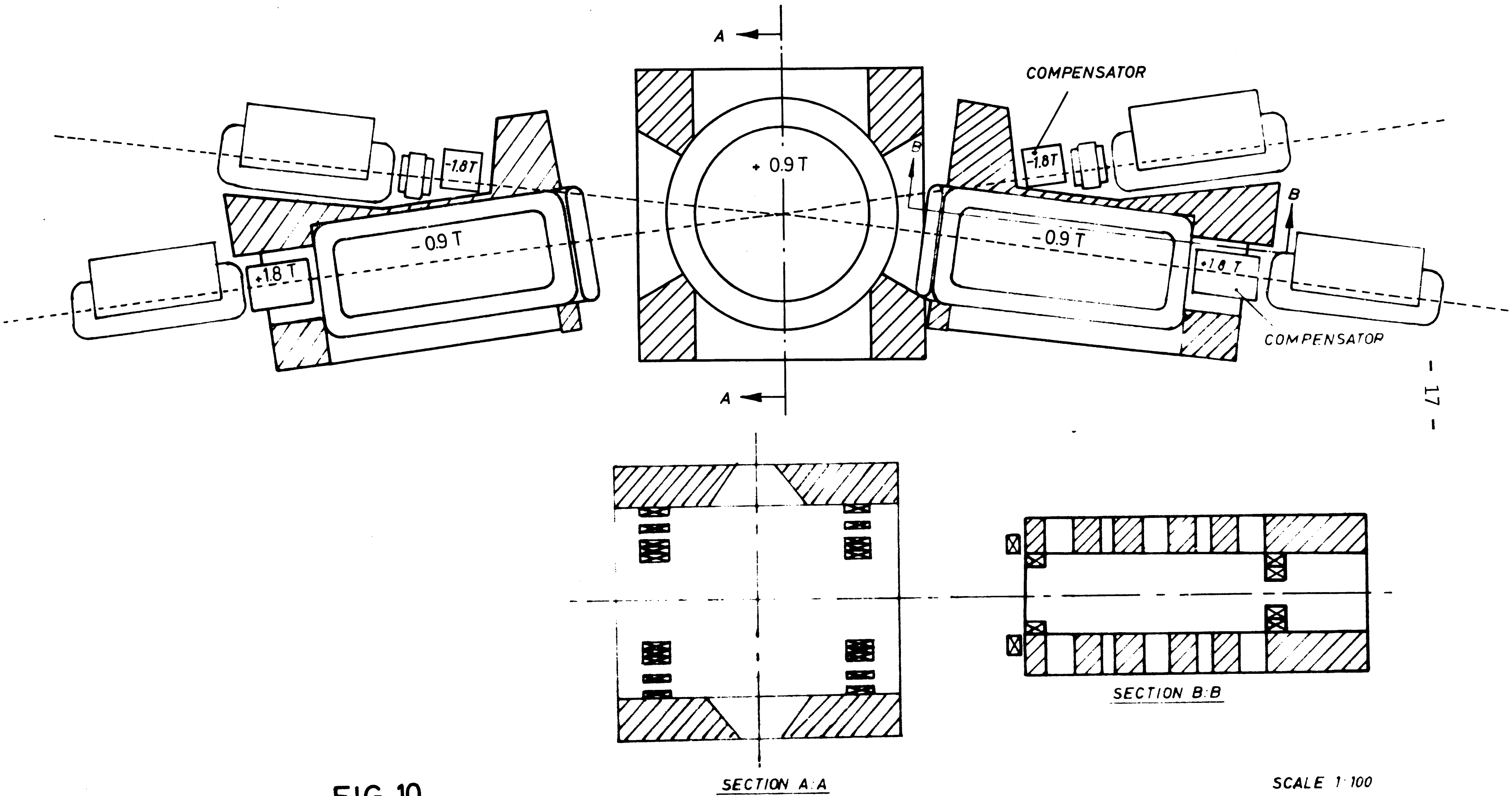


FIG. 10

Fraction of particles accepted by the magnet system using Δp criterion
(elliptical vacuum tube, clearance from magnet surfaces of 5 cm).
Isobar region.

Particles of positive charge

Three-magnet system

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4	1.0	1.0	1.0	1.0	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0
10	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9
12	0.8	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
16	0.4	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	0	0.5	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	0	0.2	0.6	0.7	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	0	0	0.6	0.7	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{\Sigma}$	0.59	0.71	0.88	0.92	0.94	0.98	0.99	1.0	0.99	0.99	1.0	1.0	0.99	0.99	0.99	0.99

Average = 0.94

Split-field system

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.6
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
16	1.0	1.0	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	0	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	0	0.4	0.7	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{\Sigma}$	0.77	0.86	0.92	0.95	0.98	0.98	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.97	0.96

Average = 0.96

Fraction of particles accepted by the magnet system using a Δp criterion (elliptical vacuum tube, clearance from magnet surfaces of 5 cm).
Isobar region

Particles of negative charge

Three-magnet system

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
16	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0
$\overline{\Sigma}$	1.0	1.0	1.0	1.0	1.0	0.99	0.98	0.97	0.97	0.98	0.99	1.0	1.0	1.0	1.0	1.0

Average = 0.992

Split-field system

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.6
4	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1 0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
16	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\overline{\Sigma}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.97	0.96

Average = 0.996

Fraction of particles accepted by the magnet system using Δp criterion (elliptical vacuum tube, clearance from magnet surfaces of 5 cm). Large angle region.

Particles of positive charge

Three-magnet system

Scattering angle (degrees)	Momentum GeV/c										
	0.05	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2	3	4
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9
15	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
45	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
55	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
65	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
75	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.8
85	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.7
$\bar{\Sigma}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.99	0.99	0.93	0.93

Average = 0.99

Split-field system

Scattering angle (degrees	Momentum GeV/c										
	0.05	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2	3	4
5	0.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.7	0.6
45	1.0	1.0	1.0	1.0	0.8	0.7	0.7	0.6	0.5	0.5	0.4
55	1.0	1.0	1.0	1.0	0.8	0.6	0.6	0.5	0.4	0.4	0.4
65	1.0	1.0	0.8	0.8	0.8	0.5	0.5	0.4	0.4	0.3	0.3
75	1.0	0.8	0.7	0.7	0.7	0.5	0.4	0.3	0.3	0.2	0.1
85	1.0	0.7	0.7	0.7	0.7	0.6	0.4	0.4	0.3	0.1	0
$\bar{\Sigma}$	0.89	0.92	0.91	0.91	0.87	0.77	0.73	0.69	0.62	0.58	0.53

Average = 0.77

Fraction of particles accepted by the magnet system using Δp criterion
(elliptical vacuum tube,clearance from magnet surfaces of 5 cm).
Large angle region.

Particles of negative charge

Three magnet system

Scattering angle (degrees)	Momentum GeV/c										
	0.05	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2	3	4
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
45	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
55	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
65	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
75	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.8
85	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.7	0.7
$\bar{\Sigma}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.98	0.94	0.94

Average = 0.99

Split-field system

Scattering angle (degrees)	Momentum GeV/c										
	0.05	0.1	0.2	0.3	0.5	0.8	1.1	1.5	2	3	4
5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
15	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
25	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
35	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.7	0.6
45	1.0	1.0	1.0	1.0	0.8	0.7	0.7	0.6	0.5	0.5	0.4
55	1.0	0.9	1.0	1.0	0.8	0.6	0.6	0.5	0.5	0.4	0.4
65	1.0	0.8	0.7	0.8	0.8	0.5	0.5	0.4	0.4	0.3	0.3
75	1.0	0.7	0.7	0.7	0.7	0.5	0.3	0.3	0.3	0.2	0.1
85	1.0	0.7	0.7	0.7	0.7	0.6	0.4	0.4	0.3	0.1	0
$\bar{\Sigma}$	0.98	0.90	0.90	0.91	0.87	0.77	0.72	0.69	0.63	0.58	0.53

Average = 0.77

Fraction of particles accepted by the magnet system using Δp criterion
(elliptical vacuum tube, clearance from magnet surfaces of 5 cm).
Isobar region

Particles of positive charge

Three-magnet system - all fields in same direction

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	0	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	0	0.2	0.6	0.7	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\overline{\Sigma}$	0.56	0.76	0.88	0.90	0.94	0.98	1.0	1.0	0.98	0.98	1.0	1.0	1.0	1.0	1.0	1.0

Average = 0.94

Split-field system

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.6
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	0	0.4	0.7	0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\overline{\Sigma}$	0.74	0.84	0.90	0.94	0.96	0.98	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.94	0.92

Average = 0.95

Fraction of particles accepted by the magnet system using Δp criterion (elliptical vacuum tube, clearance from magnet surfaces of 5 cm). Isobar region

Particles of negative charge

Three-magnet system - all fields in same direction

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{\Sigma}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Average = 1.0

Split-field system

Momentum GeV/c	Transverse momentum GeV/c															
	0.08	0.14	0.20	0.24	0.28	0.34	0.40	0.46	0.58	0.66	0.76	0.86	0.96	1.06	1.18	1.26
2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.6
6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
20	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
24	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\bar{\Sigma}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.94	0.92

Average = 0.99