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Proposal to Study Hadronic Reactions Leading to Multibody Final States with a Particle of Transverse Momentum up to 3 GeV/c at SPS Energies

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1. Introduction and Summary

We propose an experiment to study inelastic hadron reactions in the range of $1.0 < p_T < 3.0$ GeV/c at SPS energies.[1] In particular we are interested in probing the proton with different incident particles like protons, pions and kaons. The reactions we are going to study are of the following type:

$$(\pi, K, p) + p \rightarrow (\pi, K, p, \bar{p}) + MM$$

The aim of the experiment is to analyse the charged particles in the final state as completely as possible. We propose to concentrate our investigations on reactions, in which at least one charged particle has a $p_T > 1.0$ GeV/c. There are strong indications from ISR and FNAL results that for such events, phenomena may be discovered which reveal new insight into the internal structure of the colliding hadrons. The experiment investigates:

- Correlations between the high p_T particle (90° CM and 45° CM) and all the other charged particles in the final state.
- Factorisation by comparing $\pi^\pm p$ collisions with pp collisions.
- Production of neutral strange particles (K^0, Λ^0)
- Search for unknown particles

The proposed apparatus consists of the following parts:

- A vertex detector magnet (1m gap, 2m diameter, 15kG), with a 30 cm long H_2 target inside a large streamer chamber
- A downstream lever arm with a second streamer chamber and a telescope of small proportional chambers
- A trigger spectrometer with 3 standard PS bending magnets, a scintillation counter coincidence matrix, mag-

counters

The apparatus is 35 m long and 10 m wide. It has the following properties:

- 4π acceptance for all charged particles
- easy pattern recognition for high multiplicity events. We believe with present day techniques this can best be done with a streamer chamber
- reasonable momentum resolution allowing the detection of resonant states
- high beam intensities (they are limited to 2 x 10^6/pulse with a 30 cm H_2-target, because of the interaction rate)
- efficient trigger selectivity

The sensitivity with the trigger described below with 10^6 particles per pulse is ∿ 100 events/day for events with p_T ∿ 3GeV/c. Much higher rates are, of course, obtained at lower values of p_T. The shaded area in the Peyrou plot of Fig. 1 represents the acceptance of the trigger spectrometer.

The experiment requires a beam of positive and negative hadrons with moderate momentum resolution (∿1%), a small beam spot (∿ 4mm) and intensity up to 2 · 10^6 particles/pulse at 300 GeV/c. In a running time of about 6 months, we intend to take approximately 150K pictures, which we hope to analyse within a year's time at our institute in Munich.

The proposed apparatus is flexible enough to be adapted to new, interesting physics questions in the future. After the completion of the proposed experiment, the specific trigger suggested here, can be modified to allow continued use of the basic vertex detector.

We feel our experiment should be able to use the highest energy available at the SPS and should therefore be done in the North area. Because of the physics interest, we would like to except for the magnet, can be built and financed by our institute.

We think that at the present time a streamer chamber vertex detector is best suited for the study of multiparticle final states. Being an optical detector, it combines high precision and resolution with maximum pattern recognition capability in many particle events. It can tolerate a high beam intensity and it can be triggered on small cross sections. Walls and gas of the chamber represent little material. Thus, secondary interactions are minimized and downstream detectors can be used without problems. A streamer chamber is cheap to build and operate and for the analysis of the pictures, the existing bubble chamber analysis systems can be used.

2. Physics Motivation

Hadronic reactions at high energies are characterized by the production of many particles. Most of these are emitted with small transverse momenta, characteristic of collisions with large impact parameters. Recent experiments at the ISR[2] and at FNAL[3] have shown that in the pionization region the exponential decrease of the inclusive particle production cross section ($\sim e^{-6p_T}$) does not continue at large p_T. Instead for $p_T \gtrsim 1$ GeV/c the fall off is slower, like p_T^{-n} ($n \sim 8$), the cross section increases with energy and the particle composition changes[4]. These results suggest that a new dynamical mechanism may dominate small impact parameter collisions. Therefore there is great interest in studying such events as completely as possible and in particular to extend our knowledge of the other particles produced.

Up to now only two experiments[5,6], both at the ISR exist which study the final state particles in reactions with a high p_T π^o meson at high energies. While these experiments measured only the production angles of the produced particles in pp collisions, the importance and great interest of the study of the final state particles is illustrated by the following results:

- The average particle multiplicity in events with a $p_T \gtrsim 1$ GeV/c particle is higher than for low p_T events. It increases linearly with p_T in the region around 90^o in the c.m.s. while it decreases in the fragmentation regions.
- The multiplicity increase is mainly in the direction opposite to the large p_T particle.
- Studies of two-particle correlations give qualitative indications of abundant low-mass resonance production.

Although high p_T reactions will be studied intensively at the ISR, these experiments suffer from a number of limitations: only pp collisions can be investigated, the beam pipes limit the observation of the fragmentation regions, momentum measurements in high-multiplicity events and particle identification over a large solid angle ies at conventional accelerators.

The proposed experiment will have the following characteristics:

- use of different beam particles (π, p, possibly K)
- trigger on different secondary particles (π, K, p, $\bar{p}$) with p_T up to 3 GeV/c
- measurement of angles and momenta of all charged particles and of K^0, Λ^0
- identification of a large fraction of the charged particles

With this rather detailed experiment we could help to answer for example the following interesting questions:

- how is the transverse momentum of the large p_T particle compensated: locally or nonlocally, by one or a few particles of larger p_T (jets) or by many particles of small p_T
- how are quantum numbers, like baryon number, strangeness or charge compensated
- does the increase in multiplicity result from the production of high mass resonances or clusters, or from some elementary interactions of constituents
- can multi-particle correlations be explained by well known resonances or are they caused by non resonant clustering
- the 4π acceptance, also for strange particles, could help us to observe new, unexpected particles
- it may be possible to analyze some exclusive channels (4c-fits) with one particle having a large transverse momentum.

Although some of these questions may be answered by the time the proposed experiment can run, we feel that a multiparticle detector covering the full solid angle, triggerable on small cross sections and taking beam intensities up to $\sim 10^6$ particles/pulse can well adapt to a shift in emphasis in the physics questions of interest.

3. Trigger

We trigger our system by selecting a single, charged particle of the desired transverse momentum with a magnetic spectrometer system. For the two spectrometer settings, corresponding to 90° and 45° in the center of mass, we can select particles of transverse momentum larger than 1 GeV/c from the large number of charged particles with smaller transverse momenta.

The spectrometer is shown in Fig. 2 and basically consists of 3 standard PS bending magnets M_1, M_2, M_3 which bend charged particles horizontally, directly followed by two scintillation counter hodoscopes H_2 and H_3 with vertical counter strips to select the desired momenta (see Table I). In addition, a fast coincidence between the horizontal strips of a second set of scintillation counter hodoscopes V_1, V_2, V_3 requires the trigger particle to travel along a straight line in the vertical plane coming from the hydrogen target. This basic trigger-system is supplemented with additional detectors to allow a precise determination of the mass and the momentum of the trigger particle. These additional detectors are 3 threshold Čerenkov counters $\check{C}_1$, $\check{C}_2$ and $\check{C}_3$, 4 magnetostrictive wire spark chambers $MWC_1, MWC_2, MWC_3, MWC_4$ and proportional wire chambers PWC_1 and PWC_4. The dimensions of the various components, like the magnets, hodoscopes and wire chambers are given in Tables I & II.

As shown in Fig. 3, the Čerenkov counters are able to separate π's, K's and protons in the momentum range of 10-80 GeV/c. This momentum range corresponds to the acceptance of the trigger-spectrometer. The parameters of the Čerenkov counters are summarized in Table III.

To select the nth desired transverse momentum interval, the hodoscopes H_2 and H_3 are divided into 10 and 14 elements ($H_2^{1...10}$ and $H_3^{1...14}$) for the 90° setting and into 20 and 24 elements ($H_2^{1...20}$ and $H_3^{1...24}$) for the 45° setting. A fast matrix coincidence system (with 10-20 nsec resolving time) then correlates the elements in H_2 and H_3 (see Fig. 4 for explanation). Thus, for 90° CM and the largest

p_T setting corresponding to $p_T \sim 3$ GeV/c, we require the coincidence

$$(H_2^1 \text{ and } H_3^1) \text{ or } (H_2^2 \text{ and } H_3^2) \text{ or } (H_2^3 \text{ and } H_3^3) \text{ .....} (H_2^{10} \text{ and } H_3^{10})$$

with n = 1. Similarly

$$(H_2^1 \text{ and } H_3^2) \text{ or } (H_2^2 \text{ and } H_3^3) \text{ .....} (H_2^{10} \text{ and } H_3^{11})$$

with n = 2 selects the next band of p_T near 2.4 GeV/c. The selectivity of the matrix combinations is shown in Fig. 5 and 6 for the two spectrometer settings.

This selectivity of the correlation matrix allows us to choose the trigger rate corresponding to various values of n to favour events with large transverse momentum.

The yield of the system can now be calculated for a given p_T interval as defined by the correlation matrix. We calculate the yield per day using

$$Y/\text{day} = N_{inc} \cdot N_T \int \left(E \frac{d^3\sigma}{dp^3}\right) p_T \, dp_T \int \frac{dp}{E} \int d\varphi$$

In the calculation we assume $N_{inc} = \frac{10^6 \text{ particles}}{\text{pulse}} \cdot \frac{10^4 \text{ pulses}}{\text{day}}$

$= 10^{10}$/day, $N_T = 1.26 \cdot 10^{24}$ cm^{-2} as the number of scatterers per cm^2 in the target. The spectrometer acceptance in p, p_T and φ was calculated by tracking particles through the magnet and hodoscope system. For the invariant cross section $E \frac{d^3\sigma}{dp^3}$ we use a parametrisation proposed by D. Carey et. al.[7]

$$E \frac{d^3\sigma}{dp^3} \approx f(X_R) \cdot g(p_T)$$

where $X_R = \frac{2p_{CM}}{\sqrt{S}}$ is a new scaling variable. For yield calculations, we normalize to the measurements of the Chicago-Princeton group at FNAL (3) giving

$$E \frac{d^3\sigma}{dp^3} = 10^{-26} (p_T^2 + 0.86)^{-4.5} (1-X_R)^4 \quad \frac{cm^2}{GeV^2}$$

The rates are calculated assuming that pp collisions at 300 GeV/c are similar to the p-W (Wolfram) collisions observed at FNAL. Relative yields per p_T interval are shown for the various matrix combinations in Fig. 5 and 6 and the integrated yields (events per day) are shown in Table IV. The requirement of recording only events with a single charged particle giving counts in hodoscopes H_2 and H_3 rejects 2% of good events at the 45° CM setting and a negligible fraction at the 90° CM setting.

We are currently considering the possibility of adding a trigger for high $p_\perp$ gammas.

Background

In this section we discuss possible sources of backgrounds and their suppression by our trigger system.

a) Background coming from charged particles with low transverse momentum.

The basic idea of the trigger spectrometer is to sweep low momentum particles with low transverse momentum away before they can form a coincidence in the correlation matrix. Particles with momenta smaller than 20 GeV/c and $p_T \leq 1.0$ GeV/c are outside the acceptance of the 90° CM trigger-spectrometer. In the 45° CM spectrometer setting, some particles with low p_T go through the spectrometer. The particles however will be rejected by the matrix requirement described above.

Low p_T particles, which undergo multiple scattering on their passage through the trigger-spectrometer cannot fake a high p_T event since the multiple scattering angle ($\leq \pm 0.2$ mrad) is small compared to the angular resolution ($\pm$ 5 mrad (90°CM) and $\pm$ 3 mrad

False triggers coming from beam or halo interactions with material outside the H_2 - target are suppressed by the anticoincidence counters A_1 and A_2 in front of the vertex detector. The streamer chamber is constructed such that only a negligible amount of material is seen by the incident beam and the trigger-particle.

The coincidence requirement formed by the horizontal elements in hodoscope V_1, V_2 and V_3 suppresses possible background due to γ rays as described below. It also prevents possible false triggers coming from secondaries of particles, which interact with the collimator walls or polefaces of the spectrometer magnets.

b) Background coming from γ decay of neutral particles.

In the case of the 90^o CM spectrometer setting a collimator C (shown in Fig. 2) prevents γ's coming directly from the H_2-target from being seen by the hodoscope H_3. Only high energy γ's, which convert before entering the trigger-spectrometer, could give a false trigger.

For the 45^o CM setting (shown in Fig. 2) direct γ's will be seen by part of the hodoscope H_2 and the first three elements of the hodoscope H_3. The setting of the collimator C is such that it does not cut the solid angle acceptance of the spectrometer for particles with $p_T > 1$ GeV/c. The background we expect in this case is due to:

- high energy γ's which convert before entering the trigger spectrometer
- two γ's originating either from the same neutral particle or from two different neutral particles with one γ converting in the hodoscope V_1 and the other γ in H_2. This background is suppressed, since we require that the trigger particle travel along a straight line in the vertical plane
- a coincidence of a low momentum charged particle which is counted in hodoscope H_2, but misses H_3, and a γ which converts on its way from H_2 to H_3

The results of these background calculations are summarized at p_T = 3.0 GeV/c in Table V. We find that the background triggers are well below the signal at p_T = 3.0 GeV/c. The small fraction of false triggers will be identified in the off-line analysis.

4. Streamer Chamber Vertex Detector

The arrangement of the streamer chamber detector system in a magnet of 1 m gap and 2 m useful field diameter is shown in Fig. 7.

Streamer Chamber

We intend to build a three-gap streamer chamber (2 x 15 cm and 1 x 30 cm gaps and 100 x 200 x 60 cm^3 sensitive volume). The two high-voltage electrodes are pulsed with voltages of opposite sign. Such a configuration has the advantage that a center electrode is not required. Thus, the region of high particle density is free of material. The electrodes inside the sensitive volume are wire grids with 80% transparency for light. The electrode at the camera side is outside the sensitive volume and is made of single wires with more than 90% transparency for light.

The walls are Rohacell plates (perspex foam) sandwiched with mylar film to reduce gas diffusion. This construction gives enough stability and the wall thickness corresponds to less than 0.5% of a radiation length. The termination resistors are outside the region of high particle flux and outside the acceptance region of the trigger spectrometer.

The liquid H_2- target of 0.3 m length is situated in the center between the high-voltage electrodes. For a pencil beam and 20 mm cell diameter the outer diameter is < 25 mm. Therefore, tracks can be measured close to the vertex which allows a high accuracy of vertex reconstruction, double event recognition, and an elimination of background tracks.

The streamer chamber is mechanically simple, light weight

High-Voltage System

A three gap chamber requires a special HV-pulse system. Because the electric field in the inner gap is the sum of two opposite pulses, the time jitter between them has to be less than 1 nsec. Both pulses will therefore be produced in a single system with only one spark gap(8). The principle of the double Blumlein is shown in Fig. 8. It is charged by a double Marx generator producing a positive and negative voltage of 360 KV. The first stage is common to both the positive and negative polarities. A repetition rate up to 10 pulses/sec is possible.

Optics, Resolution, Accuracy

The optical system is based on standard techniques and will use cameras and image intensifiers. The number of events we will take in the experiment is not limited by the recording system, but by the trigger rate and/or the analysis speed for high multiplicity events.

The streamer chamber will be viewed by 3 cameras equipped with single-stage electrostatic image intensifiers. With a demagnification of 40, a two-track resolution of about 2 mm can be achieved (e.g. image intensifier RCA C 33050, 60 mm). A streamer length of 5-10 mm is required for sufficient brightness. Starting with a measuring accuracy of 4μ on the film, which has been achieved with an HPD measuring machine on streamer chamber film, we get a setting error of 200μ or better in the streamer chamber. Systematic errors from the survey of the fiducial system and from distortions can be corrected to this accuracy.

A possible alternative is a filmless recording system using vidicons. While resolution and accuracy would be comparable to the conventional system described above, the sensitivity is higher. Tubes with a one stage image intensifier in front of a silicon target (e.g. AEG-Telefunken Super Telecon) allow one to operate the streamer chamber in the completely isotropic avalanche mode with streamer lengths of ≤ 2 mm.

Beam Intensity Considerations

When an event has occurred, a time of 0.5 - 1 μsec is required until the HV pulse arrives at the streamer chamber. Therefore, the chamber has to be operated with a time constant for electron attachment of ∿ 0.75 μsec. The streamer density will then be reduced to 1 streamer/cm after 2.5 μsec, corresponding to the disappearance of a track. The maximum tolerable beam intensity is then limited by:

- occurrence of another event during the sensitive time
- δ ray production in the target and the chamber gas
- beam spot size, since a band of beam tracks in the chamber may obscure some of the forward produced particles

For a beam intensity of 10^6 ppp in 0.5 sec, we estimate:

- 15% of the pictures show more than one beam interaction. Most of these can be recognized electronically, the remaining can be eliminated by the observation of 2 vertices
- about 2 δ rays escape from the target and 2 δ rays are produced in the gas for event and beam tracks
- on the average 5 beam tracks, therefore a pencil beam of ± 2 mm width is desirable

Except for the highest r_m interval we will run at lower beam intensities.

5. Lever Arm

A second streamer chamber of 200 x 200 x 60 cm^3 sensitive volume will be placed after the magnet 4 m downstream from the target (see Fig. 2). It is of similar design as the first one in the vertex magnet. The purpose of the second streamer chamber is

- to improve the momentum measuring accuracy for high momentum particles
- to improve recognition of fast tracks near the beam
- to identify particles by means of the relativistic rise of the ionization along the tracks.

In addition, 4 small multiwire proportional chamber modules PWC_1, PWC_2, PWC_3, PWC_4 are placed in the region of the through-going beam and the acceptance of the trigger spectrometer (see Fig. 2). These chambers are required

- to separate additional beam tracks from events in time and thus to recover tracks that get lost in the band of beam tracks in the streamer chambers
- to reconstruct the high p_T trigger particle without measuring pictures. Thus a quick feedback on the functioning of the trigger system is possible.

The parameters of the chamber modules are summarized in Table II. Module PWC_1 will be built with a large frame, such that the frame will be outside the acceptance region of the trigger spectrometer and the second streamer chamber.

6. Particle Identification

The triggering particle will be identified by threshold Čerenkov counters in the trigger spectrometer (see Sec. 3). Other charged particles will be identified where possible in the streamer chambers.

The operation of the streamer chamber in the avalanche mode (streamer length less than 1 cm) allows a good measurement of the primary ionization of charged particles. An accuracy of ± 14% has been achieved in a mixture of 50% neon, 50% helium for tracks perpendicular to the electric field and 25 cm long(9). The measurements were made automatically using a cathode ray tube with a 47 μ spot(10).

For small momenta, the ionization is proportional to β^{-2}. This effect has been used for many years to identify visually slow particles in the streamer chamber. Based on the measuring accuracy of ref. 9, we estimate that in the low momentum region a separation π/K up to 1 GeV/c and π/p or K/p up to 2 GeV is possible with 95% confidence level.

For high momenta ($\gamma \gtrsim 5$) there is a relativistic rise of the ionization in gases. The size of the effect was measured by a Russian group(11) to be about 50%, in agreement with theoretical predictions(12). The particle separation which can be achieved in the relativistic rise region is shown in Fig. 11 (taken from ref. 9) for various track lengths.

Encouraged by the quoted results, we are presently investigating how accurately such ionization measurements can be done in a large scale experiment.

7. Performance

Momentum and Mass Resolution

The momentum measuring accuracy of the apparatus is shown in Fig. 9. The following assumptions were made for the calculation:

- setting error of 200μ in the streamer chambers
- accuracy of 200μ transverse to the beam for the vertex reconstruction
- systematic errors of less than 250μ from alignment, distortions, etc.

The resulting resolution in the invariant mass of typical two-particle systems is plotted against the momentum of the system in Fig. 10.

The momentum accuracy achieved with the described detector is adequate for the proposed experiment.

Track Recognition

In order to investigate the track recognition problems of the detector, we used events from 205 GeV/c pp and π^-p collisions in the 30" NAL bubble chamber.

All tracks of an event were tracked through the vertex detector and the lever arm. We assumed that a track is measurable in the streamer chambers, if for at least 50 cm of its length there is no other track (beam or event track) in a neighbourhood of ± 2 mm (vertex detector) or ± 4 mm (lever arm). We further assume a beam of width ± 2 mm. The pp results are shown in Table VI. Results for the π^-p collisions are similar. It appears that the main problem is the possible confusion of a secondary track with additional beam tracks. This problem will be negligible for beam intensities below $2 \cdot 10^5$ particles/sec. Event tracks can be resolved in time from confusing beam tracks by the proportional wire chambers in the lever arm.

We conclude that the combined streamer chamber and proportional wire chamber detector can solve the track recognition problem in multiparticle events. Since we will investigate large p_T events, it is likely that the pattern recognition problem will be easier than for the events used in the described investigation. Experiments at the ISR have shown that large p_T events contain fewer high momentum particles in the very forward direction.

8. Beam

In order to be able to perform the experiment at the highest energies available, we envision the apparatus to be set up in a high energy hadron beam in the North Area of the SPS.

The product of the memory time of the streamer chamber and the number of interactions per second in the hydrogen target limits our maximum usable beam intensity to a few times 10^6 particles per second (we assumed a $\geq$ 90% duty cycle during a spill length of 1 sec). We would like to have a pencil beam with a ± 2 mm spot size and less than ± 0.5 mrad divergence. The momentum resolution of the beam is not crucial for the experiment and can be of the order of 1-2%. We propose to run with positive and negative incident particles up to 350 GeV/c. Particle identification in the beam would be desirable.

9. Data Acquisition

The experiment requires a small on-line computer to write data on magnetic tape. In addition, the computer performs standard checks on the functioning of the experiment. For a sample of events, the large p_T particle should be reconstructed on-line from the wire chamber information. A computer of the size of a PDP-11/45 is needed.

10. Data Analysis

In the proposed experiment two types of data will be collected, i.e. digital information from the wire chambers and photographs of the streamer chambers.

The wire chamber data will be used to identify the high p_T particle which triggered the apparatus. A preselection of events can be made at this stage if necessary.

We intend to measure the streamer chamber pictures on our HPD system. In a first pass the pictures are digitized on the HPD and the bulk of the tracks will be reconstructed automatically. In a second pass the results are checked by operators on a computer display, where errors can be corrected and tracks not recognized by the automatic program can be recovered. We estimate that this system can handle about 150 K events per year. Standard geometry programs will be used to reconstruct the momenta of the tracks.

11. Cost, Manpower, Timetable

Cost estimates for equipment, excluding the Vertex magnet, are given in Table VII. This equipment will be financed by our Institute.

Ten physicists and two engineers are at present participating in this project. At a later stage, we expect at least 2-3 more physicists from our Institute to join this effort.

For the construction of the equipment, we have available the large capacity and extensive experience of our workshop in designing and building Cerenkov counters, wire chambers, streamer chambers, scintillation counters and electronics.

The equipment can be built and tested within two years.

12. Requirements from CERN

We expect CERN to provide a vertex magnet with $\geq$ 15 KG field 1 m gap and 2 m useful field diameter. In addition, we need 3 standard PS bending magnets for the trigger-spectrometer, each of 2.7 m length, 3.63 Tm and various gap sizes (14 cm, 17 cm, and 20 cm respectively).

The experiment should be set up in a high energy positive and negative hadron beam of the North Area of the SPS. Particle identification in the beam would be desirable.

About 3 months are required for the installation. During this time, some tests with beams are needed. For data taking, we ask about 6 months of running time.

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Appendix: Vertex Magnet

In the following are listed some relevant criteria put by the experiment on the parameters of the vertex magnet.

Geometry

Experience has shown that a dipole field is excellent for optical pattern recognition and momentum resolution. A vertical field provides convenient possibilities for the trigger.

Pattern Recognition

The separation of neighbouring tracks in the magnet and the momentum resolution are proportional to $B \cdot \ell^2$, where ℓ is the track length and B the field in the magnet. For comparison, event recognition is possible in the NAL 30" bubble chamber (B = 30 KG, $\langle \ell \rangle = 0.5$ m, bubble size $\gtrsim 200\mu$) with some difficulty. Since the streamer diameter is $\gtrsim 1$ mm, an equivalent track separation would require $B \cdot \ell^2 \gtrsim 40$ KG m^2, which we consider a lower limit. Apart from confusion with additional beam tracks, which will be resolved by downstream proportional wire chambers, we find with Monte Carlo 8 prong events that 90% can be analyzed completely in a magnet of $B\ell^2 = 60$ KG m^2. This number improves to 94% in a magnet of $B\ell^2 = 120$ KG m^2. Also a factor two would be gained in momentum resolution which would help the analysis of resonance states among the outgoing particles.

Size

To facilitate the pattern recognition, the whole vertex streamer chamber should be visible in a single view. With the proposed optical system, one could go to a chamber size of 3m while still retaining the intrinsic two track resolution of the streamer chamber.

The height of the working space in the magnet must be such as to accomodate the streamer chamber (60 cm) plus mounting rig and counters, which could be installed later to detect, e.g., photons. Thus, the gap height should be at least 1 m. This would be sufficient for the proposed physics, since the particles emitted in the forward c.m.s. hemisphere are contained within a cone of typically 80 mrad half angle in the laboratory system.

Field

A field of about 15 KG can be obtained with a conventional magnet. With a superconducting coil, the technology allows field strengths of up to about 35 KG for a large magnet of 2 m diameter and 1 m gap height.

Accessibility:

A large opening in the top is required to allow photography of the streamer chamber. For flexibility in the choice of the trigger system, a construction with removable return yokes of the type used in the Omega magnet and discussed in the White Book[13] would be desirable.

Shape of Coils

It seems that flat circular coils in a Helmholz-type geometry are easiest and cheapest to build for a superconducting magnet. Moreover, considerable experience exists with such coils for large magnets.

In conclusion, we list a summary of the desired parameters for the vertex-magnet:

- Vertical dipole field
- Helmholz geometry with optical access at the top
- Coil inside diameter = 2 m
- Gap height = 1 m
- Central field strength = 15 KG minimum

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Table I

PS Standard bending magnets (CPS USER'S HANDBOOK Ref: O2 page 1)

magnet	M_1	M_2	M_3
total length m	2.7	2.7	2.7
pole width m (straight poles)	0.52	0.52	
gap height m	0.14	0.17	0.20
bending power Tm	3.63	2.99	2.54

Hodoscopes

	90°CM setting		45°CM setting	
	size	Elements	size	Elements
V_1	0.26x0.14 m^2	10	0.26x0.14 m^2	10
H_2	0.50x0.22 m^2	10	0.50x0.22 m^2	20
V_2	0.50x0.22 m^2	10	0.50x0.22 m^2	10
H_3	1.88x0.45 m^2	14	1.54x0.45 m^2	24
V_3	1.88x0.45 m^2	10	1.54x0.45 m^2	10
Solid angle	$6.5 \cdot 10^{-4}$ sterad		$5.5 \cdot 10^{-4}$ sterad	

Magnetostrictive chambers

	sensitive area	wire orientation
MWC_1	2.0 x 0.5 m^2	0^o, $+7^o$
MWC_2	2.0 x 0.5 m^2	0^o, -7^o
MWC_3	2.0 x 0.5 m^2	0^o, $+7^o$
MWC_4	2.0 x 0.5 m^2	0^o, -7^o

Table II

Proportional wire chambers

	sensitive area	wire spacing	wire orientation
PWC_1	$0.7 \times 0.3\ m^2$	2 mm	0°, $+30^\circ$, -30°, 0° [a]
PWC_2, PWC_3, PWC_4	$0.3 \times 0.3\ m^2$	2 mm	0°, $+30^\circ$, -30°, 0° [a]

[a] second 0° plane shifted horizontally by one 1 mm relative to first 0° plane

Table III

Parameters of Čerenkov Counters

	Č1	Č2	Č3 90°CM	Č3 45°CM
radiator gas	Isobutane	CO_2+N_2	$He + N_2$	He
refractive index	1.00133	1.00031	1.000076	1.000034
radiator length (m)	0.8	1.8	8.5	
threshold (GeV/c)				
π	2.7	5.5	11.3	17.0
K	9.5	19.5	39.8	61.0
P	18.1	37.0	75.5	116.0
99% efficiency				
π	3.0	7.1	13.0	27.0
K	10.7	25.0	49.7	87.0
P	20.5	47.5	82.0	160.0
$\theta_{\check{C}}$ (β=1) mrad	51	24	12	8
number of light quanta (β=1,220-550nm)	327	176	188	72.3
number of photo-electrons (RCA 31000 M)	22	12	13	8
counter length (m)	1.0	2.0	9.0	
mirrors	3	3	3	
multipliers	3	3	3	
L/L_{rad}	$1.2\cdot10^{-2}$	$7\cdot10^{-3}$	$6\cdot10^{-3}$	
L/L_{coll}	$1.0\cdot10^{-2}$	$6\cdot10^{-3}$	$6\cdot10^{-3}$	$8\cdot10^{-3}$

Table IV

Trigger Rates (positive particles)

	matrix combination	yield/day[a]	transverse momentum[b]
	1	100	3.0 ± 0.3
	2	400	2.5 ± 0.3
90° CM	3	1800	2.1 ± 0.3
	4	5500	1.7 ± 0.25
	5	15000	1.4 ± 0.2
	1	160	3.1 ± 0.35
	2	700	2.5 ± 0.3
45°CM	3	3300	2.1 ± 0.22
	4	10000	1.7 ± 0.2
	5	30000	1.4 ± 0.2

a) beam intensity 10^6/pulse, 10^4 pulses/day

b) Central value ± half width at half maximum

Table V

Estimates of Trigger Background at p_T = 3 GeV/c

	90° CM	45° CM
high p_T signal rate per interaction	$2.5 \cdot 10^{-7}$	$5 \cdot 10^{-7}$
one γ ray conversion before trigger spectrometer (a)	$2 \cdot 10^{-10}$	$4 \cdot 10^{-10}$
two γ rays converting, one in V_1, the other in H_2:		
coming from one π^0	-	$3 \cdot 10^{-8}$
coming from two π^0's	-	$4 \cdot 10^{-9}$
one charged particle in H_2, one γ converting in H_3	-	$7 \cdot 10^{-11}$

(a) for other matrix combinations (P_T < 3 GeV/c) the rate per interaction will be larger. However, it will always remain a factor 10^{-3} below the signal.

Table VI

205 GeV/c pp collisions

a) Streamer chamber in vertex magnet

prong	events	confusion with beam	confusion among secondaries
4	1148	273	28
8	674	83	23
12	272	33	13
16	48	11	3

b) Streamer chamber in lever arm

prong	events	confusion with beam	confusion among secondaries
4	1148	37	2
8	674	3	4
12	272	0	1
16	48	0	0

Table VII

Cost estimate (excluding magnets)

Streamer chambers + HV systems	300
Film recording system or	450
Vidicon recording system	900
Proportional wire chambers (3400 wires)	340
Cerenkov counters (mirror cells, multipliers, boxes	150
Magnetostrictive wire chambers	120
Counter hodoscopes (scintillators, multipliers)	250
Fast electronics	800
On-line computer + peripherals	500
	up to 3360 KSFr

Figure Captions

Fig. 1: Acceptance of the trigger spectrometer: the shaded areas are the acceptance regions for trigger particles at the 90° CM and 45° CM settings of the trigger spectrometer.

Fig. 2: Layout of the detector: plan view for the 45° CM (bottom) and 90° CM (center) setting of the trigger spectrometer; cut in the vertical plane (top).

Fig. 3: Cerenkov counters in the trigger spectrometer: momentum regions for particle separation.

Fig. 4: Trigger Matrix for the 90° CM setting of the trigger spectrometer: x denotes the horizontal distance of the particle at hodoscopes H_2 and H_3 from the undeflected beam line. Also indicated are the counter numbers of the hodoscopes H_2, H_3. Particles with fixed values of p_T fall on straight lines as shown. By requiring a coincidence between counters H_2^k of hodoscope H_2 and $H_3^{k+(n-1)}$ of hodoscope H_3 a specific value of p_T is selected.

Figs.5 and 6: Transverse momentum bands selected by the different coincidence requirements n of the trigger matrix. Fig. 5, 6 are for the 90° CM and 45° CM setting of the trigger spectrometer respectively.

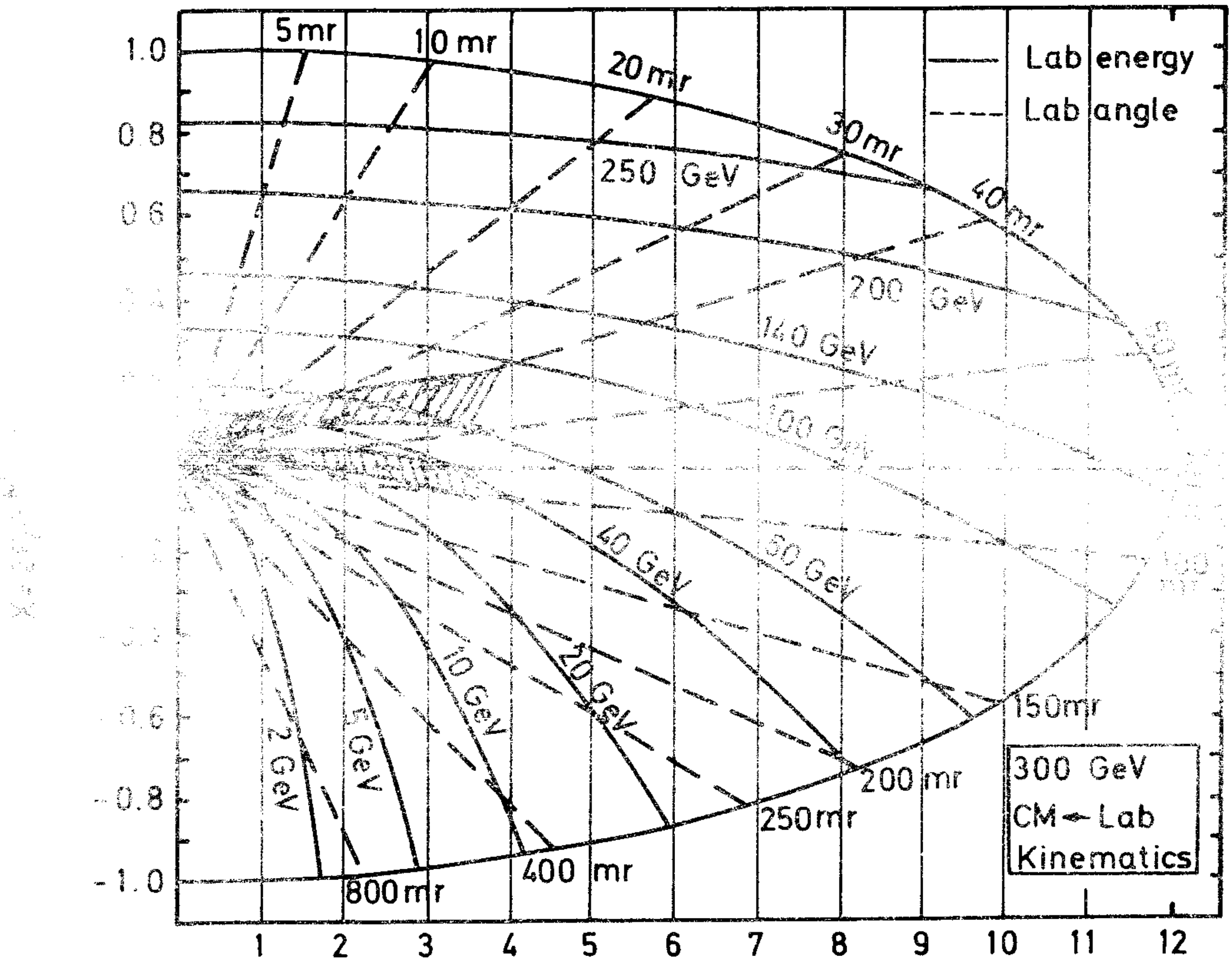
Fig. 7: Schematic view of the streamer chamber in the vertex magnet: (a) horizontal cut, (b) vertical cut.

Fig. 8: Schematic of the Blumlein pulse feeding system.

Fig. 9: Momentum resolution of the detector

Fig. 10: Mass Resolution (RMS) of the detector for various two particle combinations. The abscissa p is the momentum of the two particle system.

Fig. 11: Confidence level for particle separation in the streamer chamber by ionization measurement in the relativistic rise region. Curves for various track lengths are shown (from ref. 9).


1.0
0.8
0.6
-0.6
-0.8
-1.0
5 mr
10 mr
20 mr
30 mr
40 mr
250 GeV
200 GeV
140 GeV
100 GeV
50 GeV
40 GeV
20 GeV
10 GeV
5 GeV
2 GeV
150mr
200 mr
250mr
400 mr
800mr
Lab energy
Lab angle
300 GeV
CM ← Lab
Kinematics
1
2
3
4
5
6
7
8
9
10
11
12

P_T (GeV/c)

Fig.1

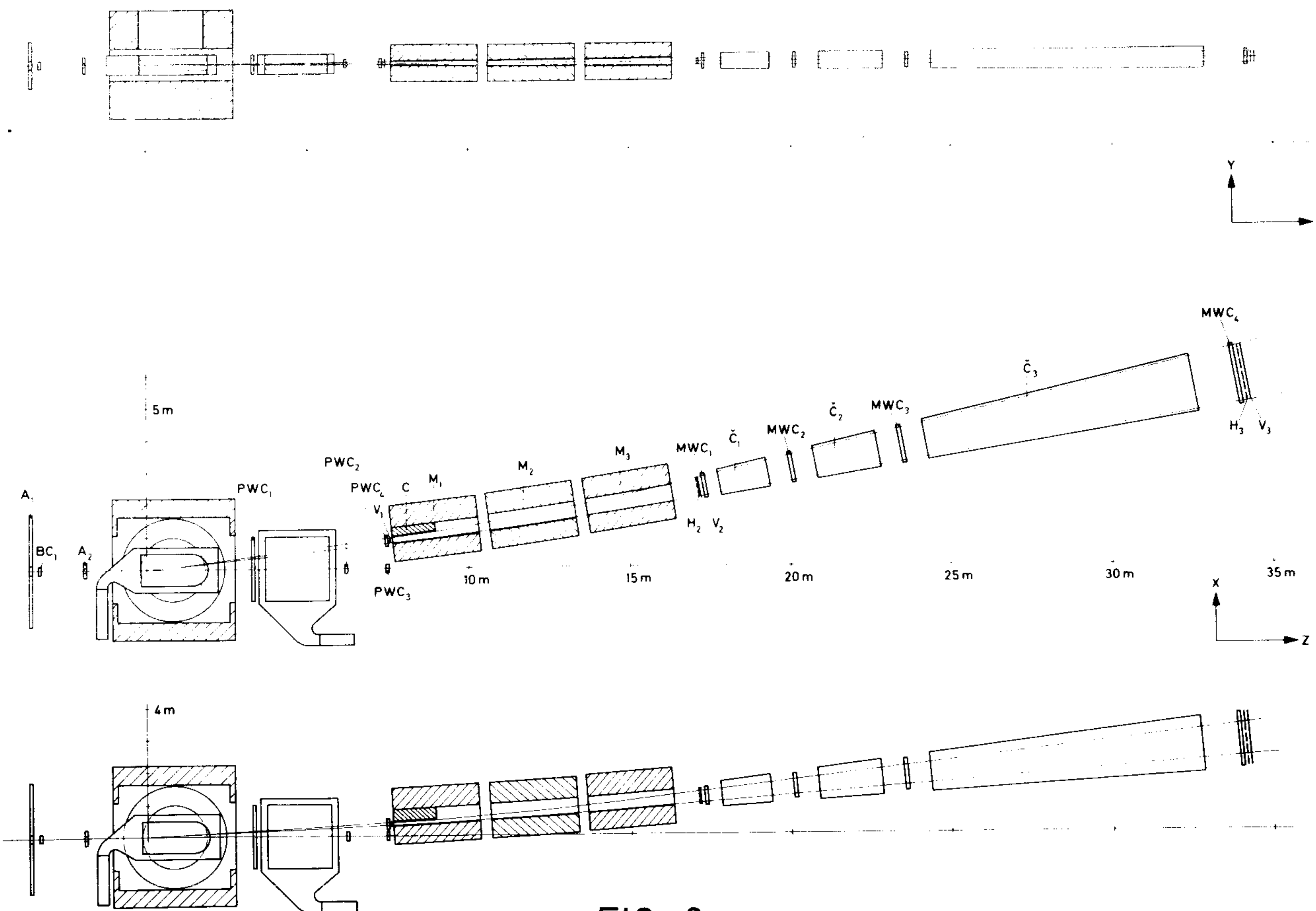
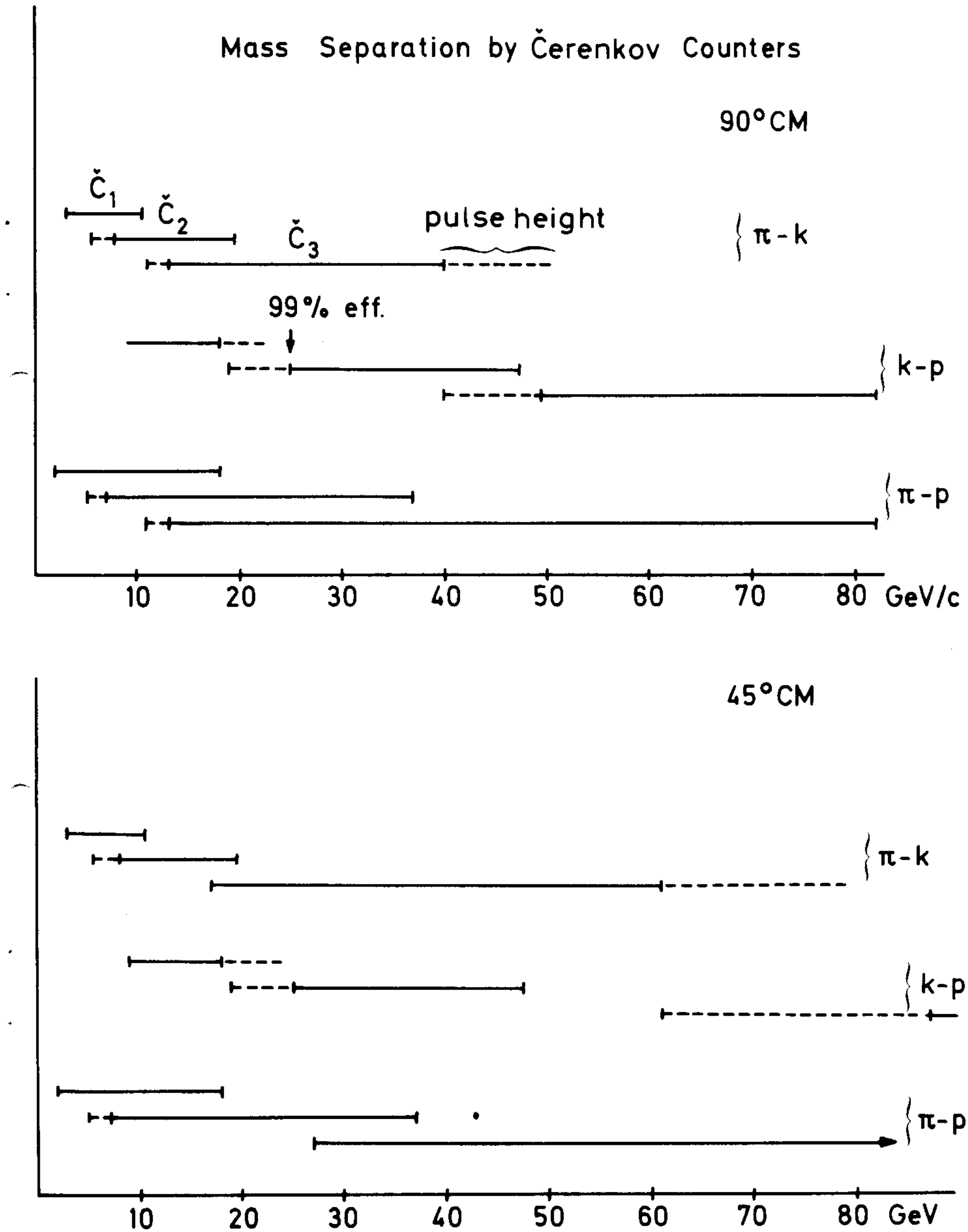

Y
Z
5 m
A
BC1
A2
PWC1
PWC2
PWC4
PWC3
C
V1
M1
M2
M3
MWC1
H2
V2
Č1
MWC2
Č2
MWC3
Č3
MWC4
H3
V3
10 m
15 m
20 m
25 m
30 m
35 m
X
Z
4 m

FIG. 2



Mass Separation by Čerenkov Counters
90° CM
$\check{C}_1$
$\check{C}_2$
$\check{C}_3$
pulse height
π - k
99% eff.
k - p
π - p
10 20 30 40 50 60 70 80 GeV/c
45° CM
π - k
k - p
π - p
10 20 30 40 50 60 70 80 GeV

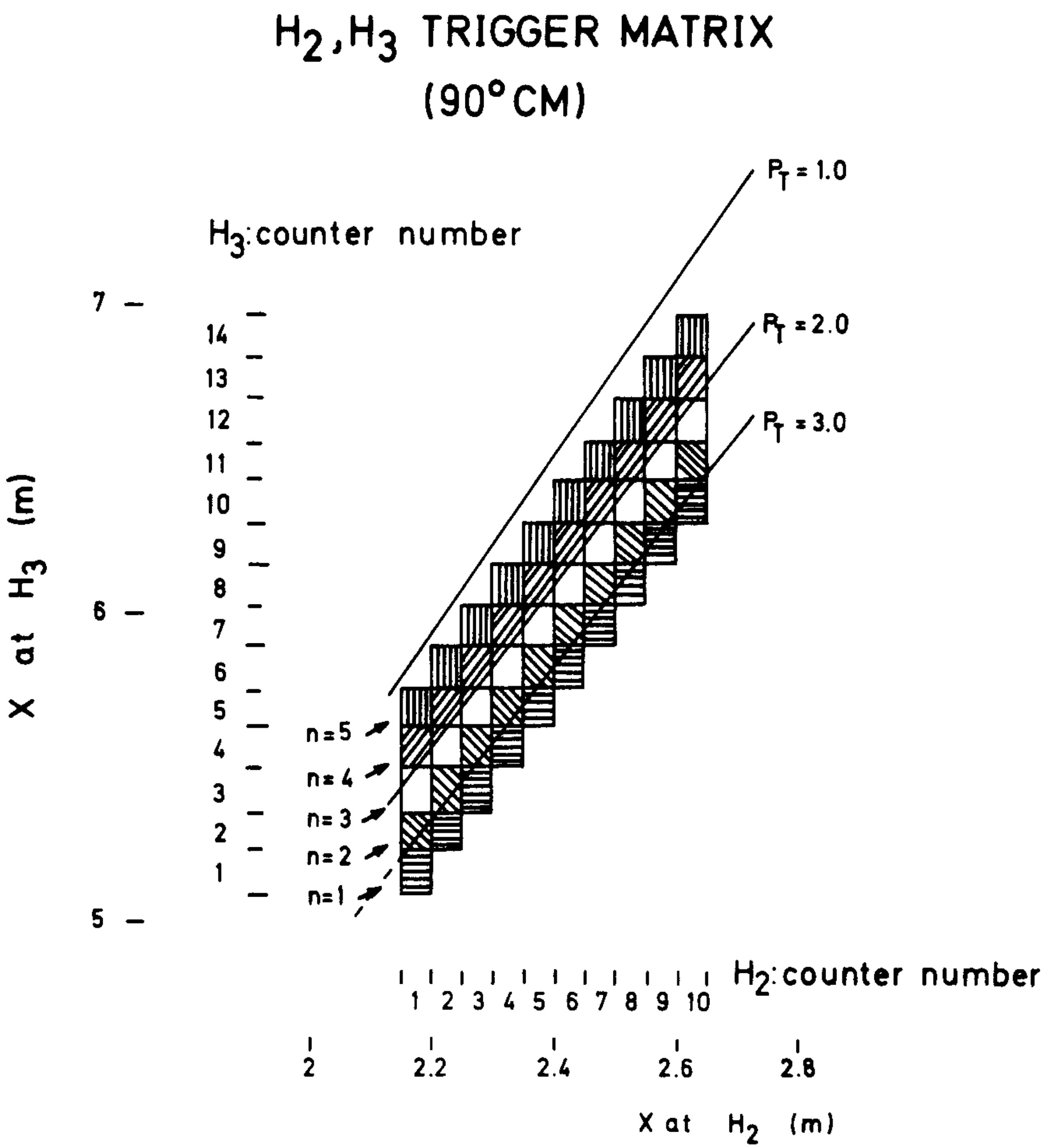

H2,H3 TRIGGER MATRIX
(90° CM)
H3:counter number
X at H3 (m)
7
6
5
14
13
12
11
10
9
8
7
6
5
4
3
2
1
n=5
n=4
n=3
n=2
n=1
PT = 1.0
PT = 2.0
PT = 3.0
H2:counter number
1 2 3 4 5 6 7 8 9 10
2
2.2
2.4
2.6
2.8
X at H2 (m)

Fig. 4

TRIGGER RATE (90°CM)

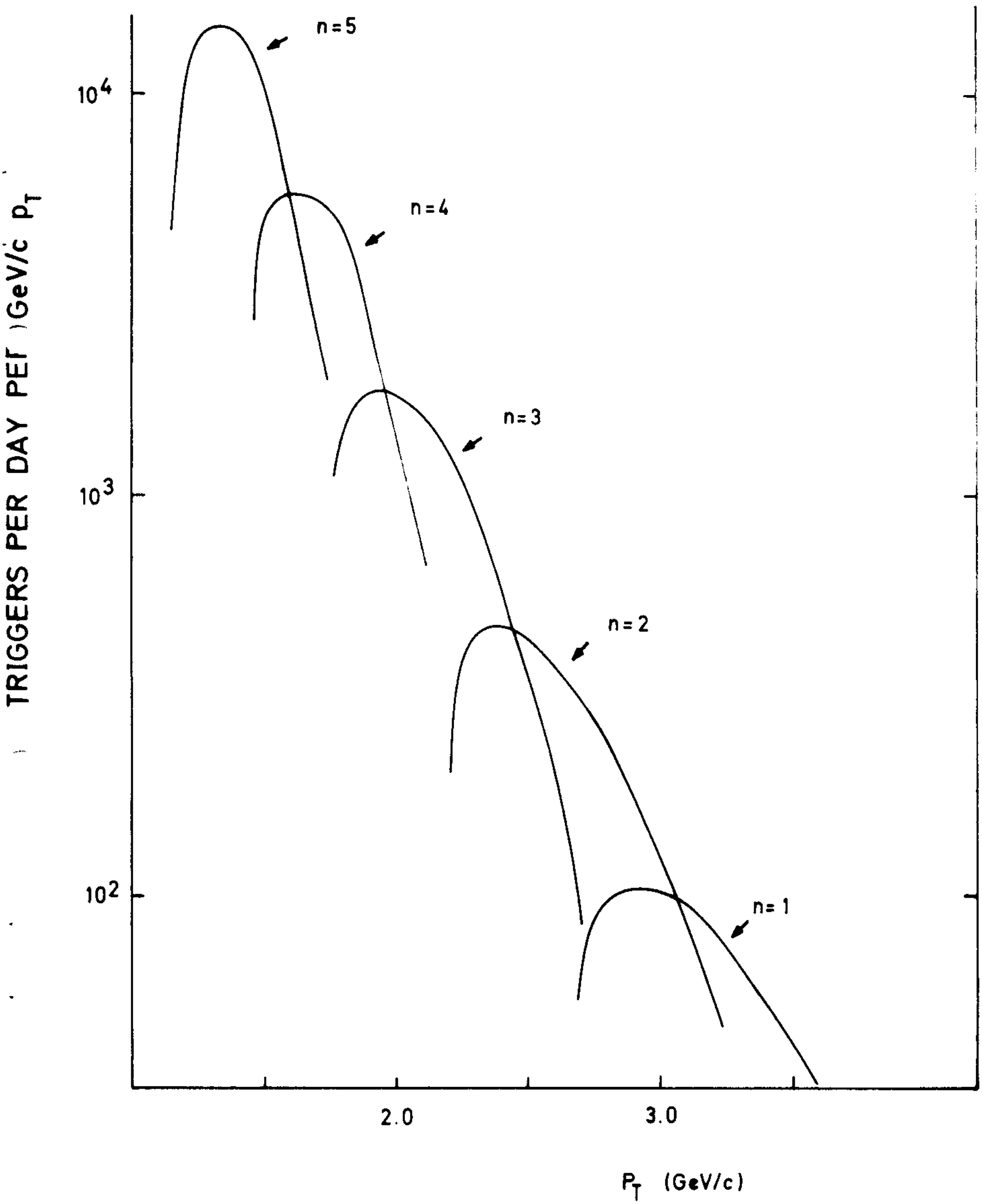
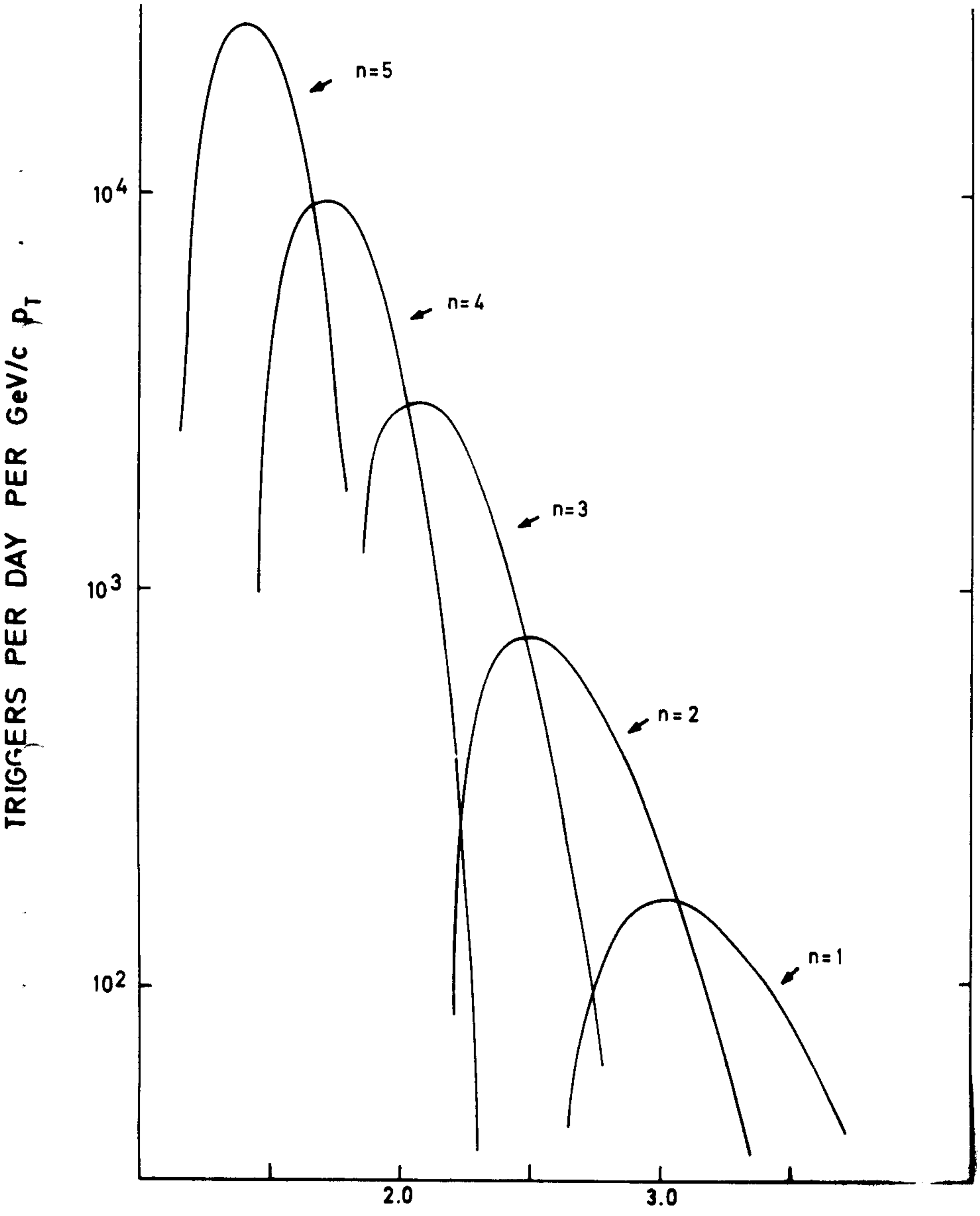


Fig.5

TRIGGER RATE (45°CM)



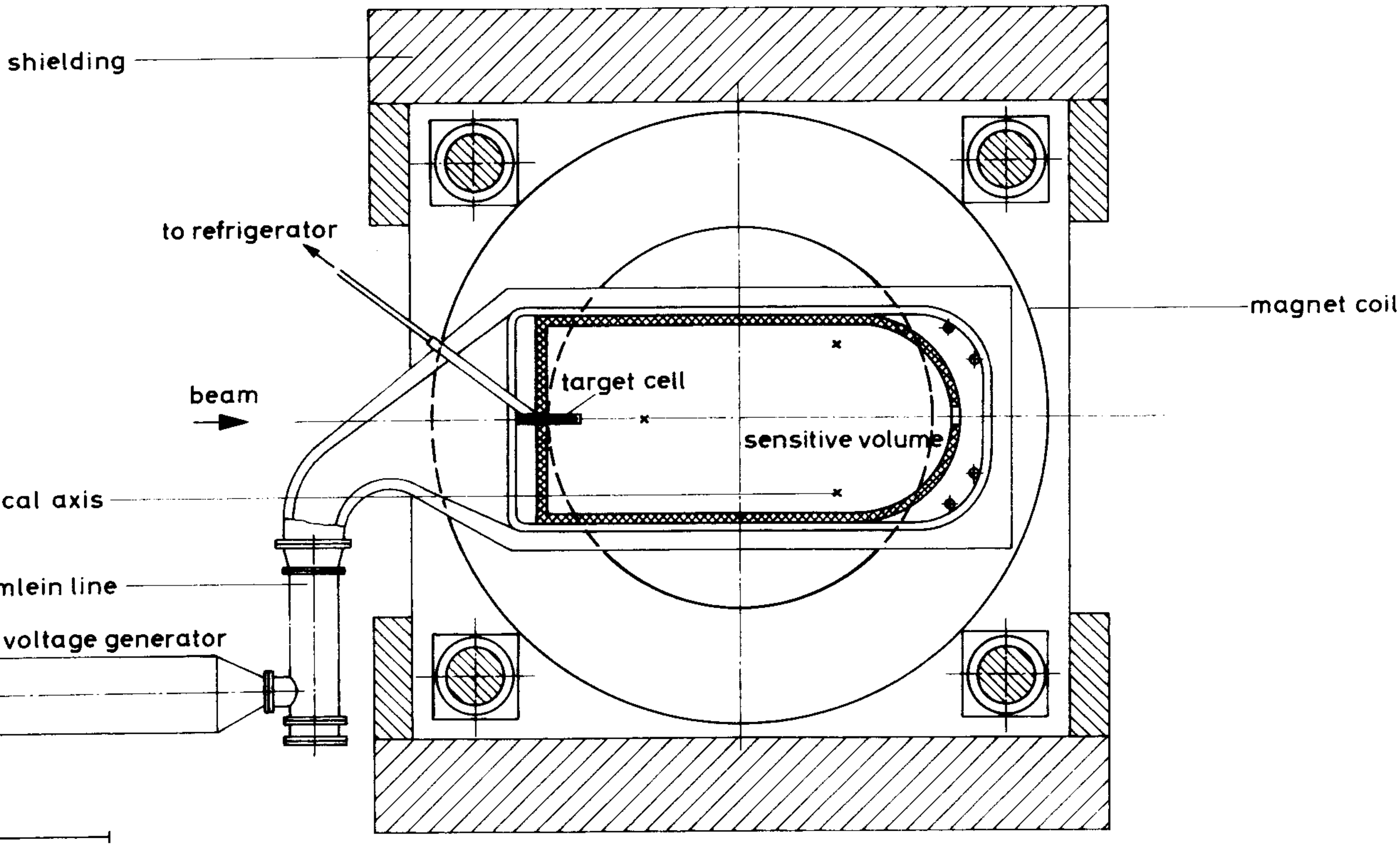

shielding
to refrigerator
magnet coil
target cell
beam
sensitive volume
cal axis
mlein line
voltage generator
m

FIG. 7a

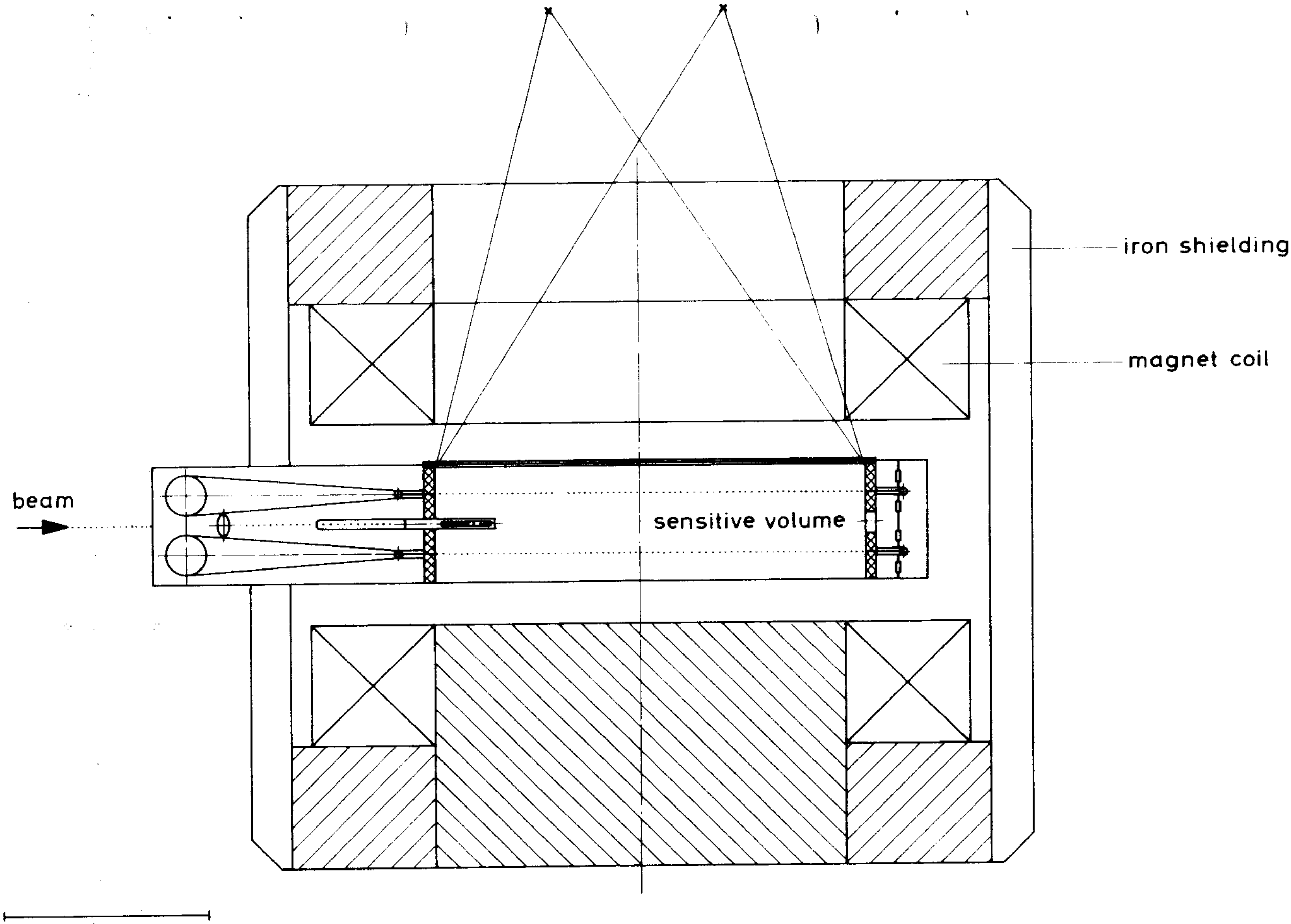


FIG. 7b

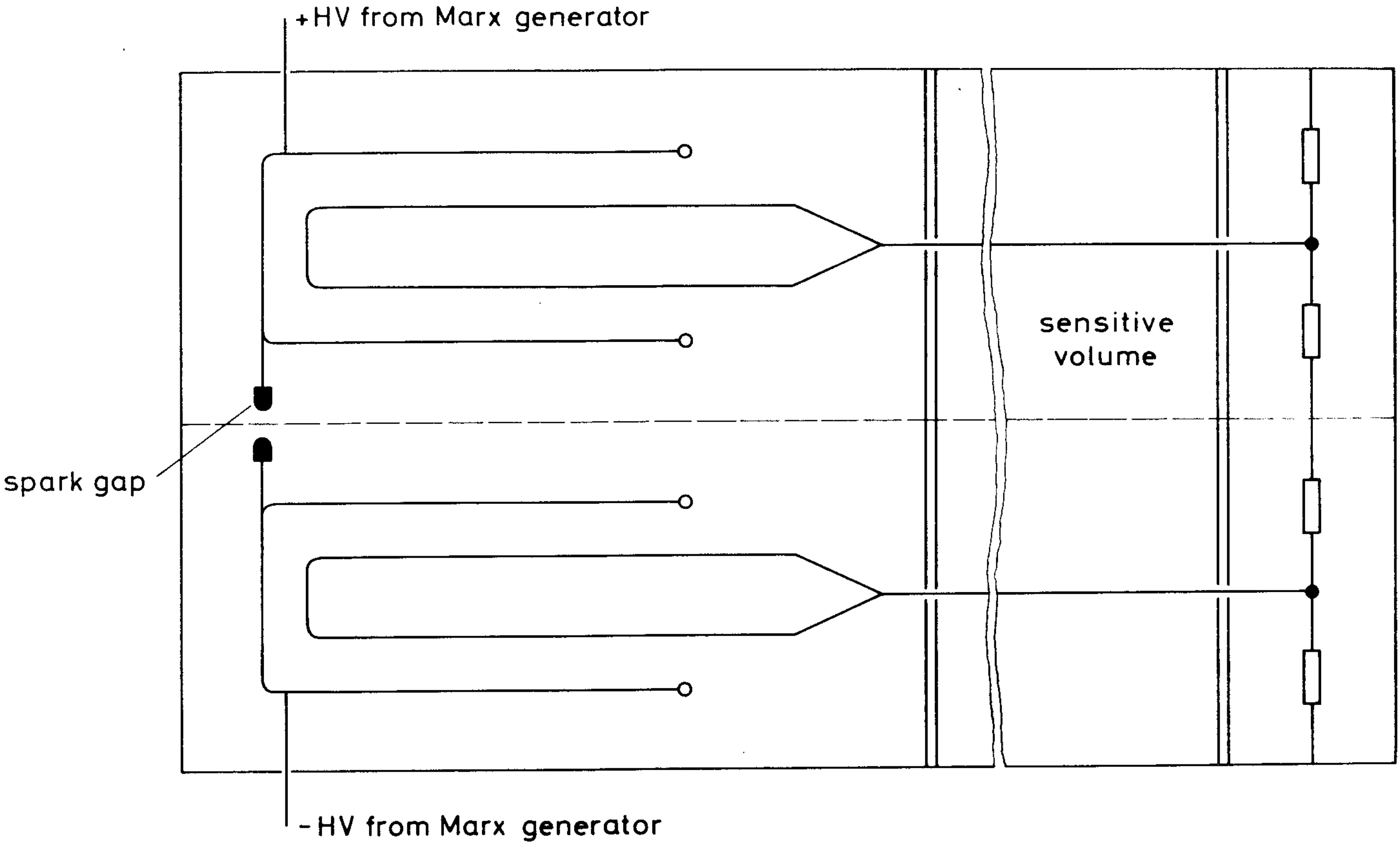
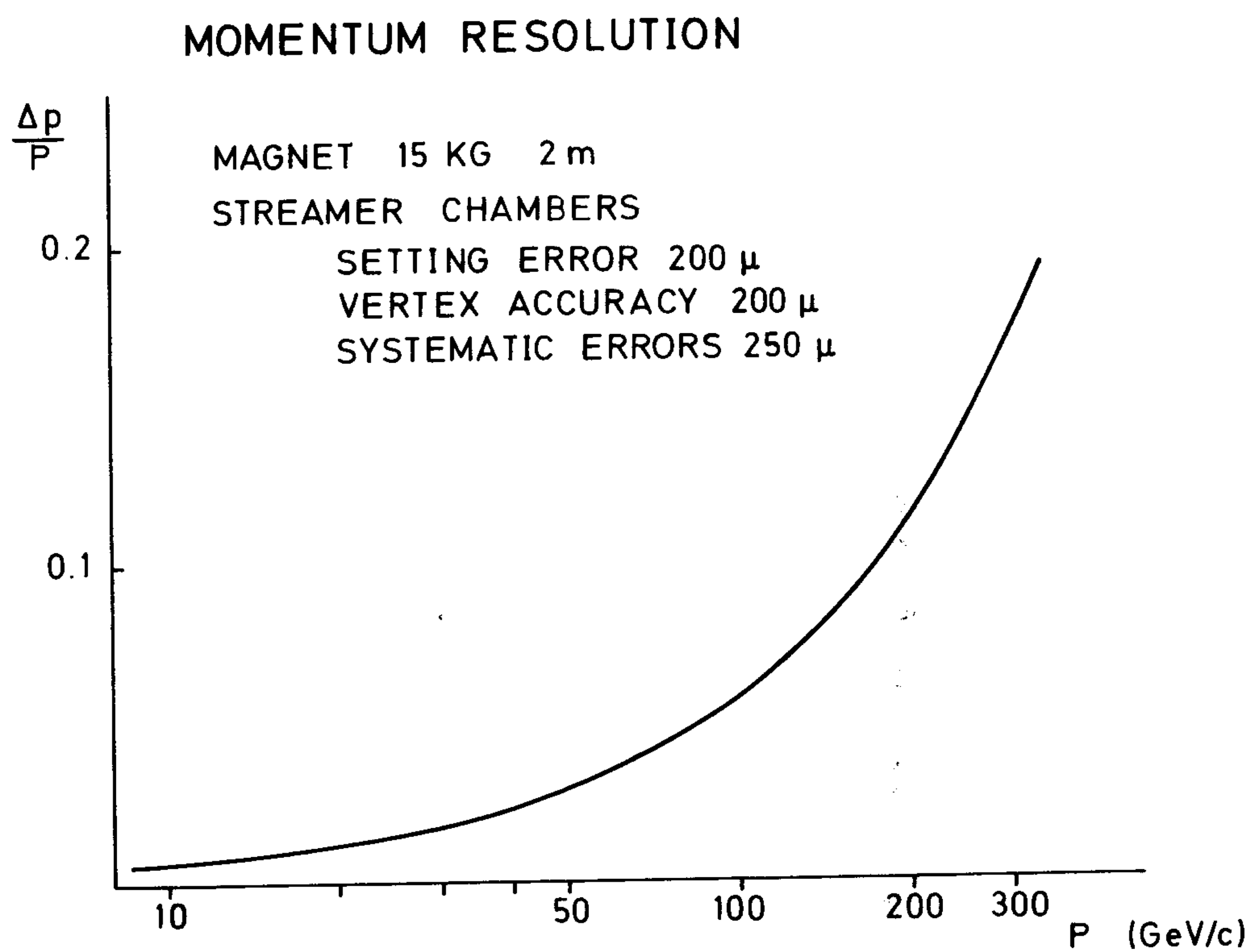
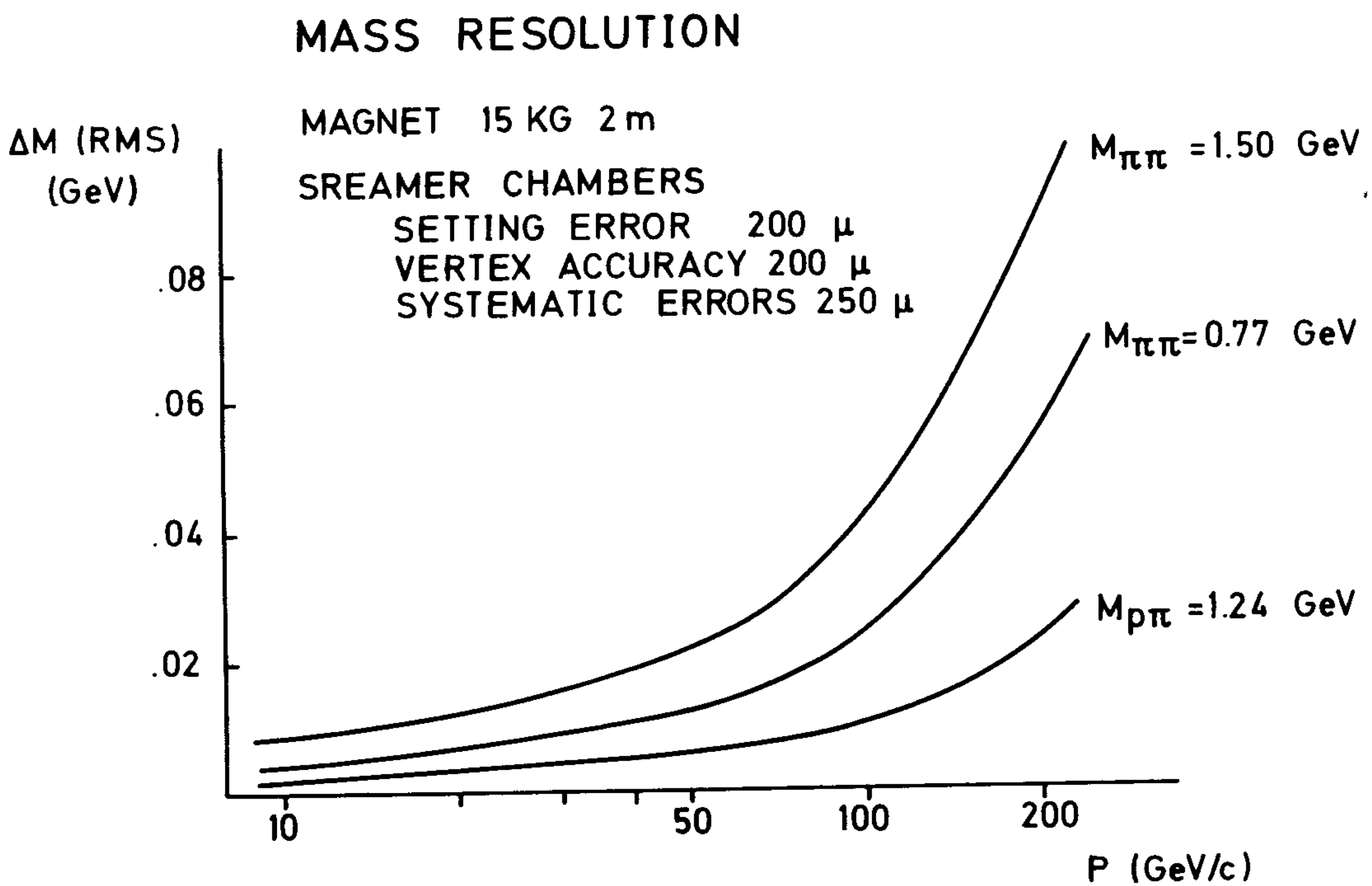

+HV from Marx generator
sensitive volume
spark gap
-HV from Marx generator

FIG. 8



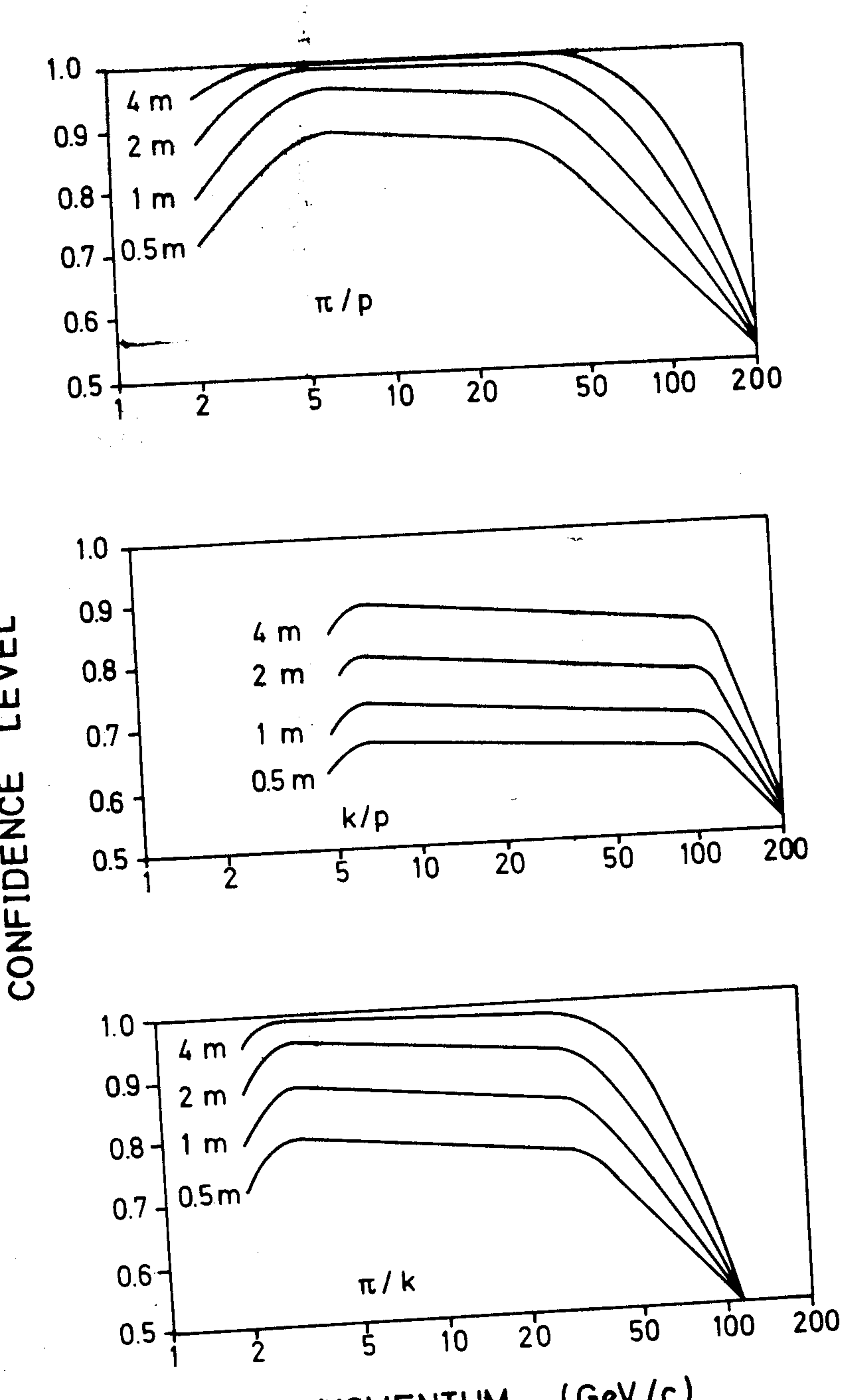
MOMENTUM RESOLUTION
Δp / P
MAGNET 15 KG 2 m
STREAMER CHAMBERS
SETTING ERROR 200 μ
VERTEX ACCURACY 200 μ
SYSTEMATIC ERRORS 250 μ
0.2
0.1
10
50
100
200
300
P (GeV/c)

Fig.9



MASS RESOLUTION
MAGNET 15 KG 2 m
SREAMER CHAMBERS
SETTING ERROR 200 μ
VERTEX ACCURACY 200 μ
SYSTEMATIC ERRORS 250 μ
ΔM (RMS)
(GeV)
.08
.06
.04
.02
10
50
100
200
P (GeV/c)
Mππ =1.50 GeV
Mππ=0.77 GeV
Mpπ =1.24 GeV

Fig. 10


CONFIDENCE LEVEL
1.0
0.9
0.8
0.7
0.6
0.5
4 m
2 m
1 m
0.5m
π / p
1
2
5
10
20
50
100
200
k/p
π / k
MOMENTUM (GeV/c)