#242

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Analysis of 303 GeV/c Proton Interactions* Tagged by High Energy γ rays.

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Two emulsion chambers of sandwich type of nuclear emulsion and thin lead plates were exposed to 303 GeV/c proton beams at the Fermi National Accelerator Laboratory. 70 jet showers tagged by high energy γ rays were analysed and correlations between high energy γ rays and charged particles with large transverse momenta were studied. Strong correlation was observed between these components and a possible explanation for this effect may be the formation of a forward excited baryon and its decay. A special event with a direct electron was also observed.

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* Exposure of Emulsion Chambers was carried out at the Fermi National Accelerator Laboratory as FNAL proposal #242, in Oct, 1974.

§1. Introduction

In order to study in detail proton nucleus interactions, two emulsion chambers consisting of nuclear emulsion plates and thin lead plates were exposed to 303 GeV/c proton beams at the Fermi National Accelerator Laboratory. In the present study, main attention is focussed on high energy γ rays and charged particles with large transverse momenta emitted in forward fragmentation region and their correlations in each interaction.

Secondary γ rays with energy higher than 30 GeV were scanned in the lead emulsion sandwich layers. 70 jet showers tagged by those γ rays were analysed making use of the cascade shower method for γ rays and the relative scattering method for charged particles.

Distribution of transverse momenta of charged particles and γ rays, their azimuthal distributions and correlations between both components were studied and reported in this paper.

§2. Experimental Procedure

Two emulsion chambers with the size of 12cm×9.5cm×7cm were exposed to 303 GeV/c proton beams at the Fermi National Accelerator Laboratory. The construction of the chamber is shown in the Figure 1. It is a sandwich pile of 24 nuclear emulsion plates coated on both sides of the acrylic base whose thickness is 800μm, 4 thin lead plates with thickness of 500μm and 18 of 1mm. Each emulsion plate is separated from lead plates by thin papers of 90μm thick. This type of chambers were exposed to the beams vertically as illustrated in the Figure 1. The beam density was regulated to be about $1.5 \cdot 10^3$ particles/cm^2.

Scanning for nuclear interactions with a high energy γ ray or γ rays due to beam protons was made on the emulsion plates which were inserted in at the depth of about 3 cascade units from the top surface of the chamber. Those cascade showers which had been multiplied up to more than 6 electrons in a circle with radius of 25μm at the scanning layer were picked up in this procedure.

Properties of thus tagged cascade showers were analysed later and it was revealed that energy of γ rays iniciated these cascade showers distributed in a region between 30 GeV and 130 GeV and that emitting angle distributed in an interval from 10^{-3} to $2 \cdot 10^{-2}$ radians.

Following back tagged cascade showers successively into the upper layers of emulsion plates, origins of nuclear interactions produced by incident protons were detected. In total 70 jet showers were found following 80 cascade showers picked up from scanned area of $25cm^2$. 10 cascade showers were from outside origins.

Then, the behaviour of the secondary charged and neutral particles were analysed. In order to estimate the energy of γ rays, transitions of number of electrons in a circle with radius of 25μm and 50μm were observed along each shower axis to the bottom of the chamber and they are compared with theoretical transition curves modified Nishimura's one[1] to fit actual design of our chamber. Calibration of this method was done finding a π^0 peak in the invariant mass distribution of any two γ rays in the same event. Error of estimated energy by this method is the order of 20% for γ rays with energy higher than 20 GeV. Momenta of charged particles were estimated by means of the relative scattering method which was calibrated making use of the beam ptotons[2].

Errors involved in this method were estimated as $10\sim30\%$ in our case.

§3. Characteristics of the observed events.

In the present study, properties of the following nuclear interactions with high energy γ rays are discussed.

$$P + \text{nucleus} \rightarrow \gamma' + \gamma + \text{charged particles} + \text{anything}$$

where γ' is the tagged γ ray. Nature of the target nucleus of the observed events is tabulated in the Table 1.

Table 1.

Target		No. of events
Lead	Pb	46
Emulsion	Ag, Br	4
Acryl	C,H,O,	16
Paper	C,H,O,	4
total		70

As was mentioned before, main substance of our chamber is lead, therfore, proton-lead interactions were dominant in our sample. In total 70 interactions were analysed, in which 45 were jet showers occured within 0.6 cascade units from the top surface. Expected total number of nuclear interactions due to beam protons occuring within top layers is 3000. Therefore, we are dealing with only 1.5% of the total interactions biased by tagged high energy γ rays.

Scatter plots of the energy or momentum against the tangent of emission angle for γ rays and charged particles are shown in the Figure 2a and 2b respectively. Eenrgy of 147 γ rays from 70 interactions were measured, and observations were extended up to 2×10^{-2} radians in angles and down to 10 GeV in energy in this angular range. As for charged components, 179 particles were analysed. Observation of charged particles extended up to 1.5×10^{-1} radians, but measurment of momenta was restricted only for those with emission angle up to 5×10^{-2} radians.

§4. Distributions of transverse moments.

Figure 3a and 3b show transverse momentum distributions of γ rays and charged particles respectively. Distributions extend up to 1.5 GeV/c for γ rays and 1.7 GeV/c for charged particles, and discrepancies between e^{-6P_T} law and experimental one are conspicuously observed at higher ends of both distributions.

§5. Azimuthal Distributions.

Azimuthal distributions of γ rays and charged particles for observed angular intervals are shown in Figure 5. In this case azimuthal angles are measured relatively to the direction of charged particle with highest transverse moemntum in each event. Definition of azimuthal angle is shown in the Figure 4.

Figure 5a shows the azimuthal distribution of number of γ rays in each 40° interval which were emitted in 2×10^{-2} radians in 13 events in which charged particle with transverse momentum higher than 1 GeV/c were involved. Remarkable peak in oppisite side is seen in this figure.

This is in contrast with that of charged particles which is shown in Figure 5b for different angular intervals. In the Figure 5c and 5d azimuthal distribution of γ rays and charged particles respectively are shown for 54 events without charged particle of high transverse momentum higher than 1 GeV/c. In these cases also there is no peak similar to that in the Figure 5a.

Figure 6 shows correlation between γ rays and charged particles with the highest transverse momentum in each event. Nomalized mean number of γ rays in the same and opposite sides with the charged particle are plotted to the transverse momentum of the charged particle with the highest one in each event. Strong correlation is observed in the highest region of the transverse momentum.

§6. Summary and Discussions.

We have studied inthe present analysis proton nucleus interactions tagged by high energy γ rays with energy higher than 30 GeV. Analyses of secondary particles were limitted in the forward cone of jet showers. Distribution of transverse momenta for γ rays and charged particles show marked discrepancies from e^{-6P_T} law at both higher parts.

In most of the cases, charged particle with the highest transverse momentum in each event has also the highest longitudinal momentum. This suggests that charged particle with the highest transverse momentum belongs to a fragment of incident protons. Remarkable peak in the azimuthal distribution of γ rays emitted in the most forward part was observed in opposite side to the charged particle with transverse momentum higher than 1 GeV/c. No correlation, however, was observed in the azimuthal distribution of γ rays in those event without charged particle of high transverse momentum. No correlation was also observed in the azimuthal distribution of charged particles in any case.

The above situation suggests that local correlation in fragmentation region is strong between a charged particle with the highest transverse momentum and high energy γ rays for those events in which a charged particle with transverse momentum higher than 1 GeV/c is emitted. A possible explanation for this effect is the formation of a forward excited baryon emitted with a certain transverse momentum and decaying into a large transverse momentum charged baryon and γ rays from a neutral meson.

Assuming that the charged particle with the highest transverse momentum is a proton, invariant mass of assumed proton and a neutral pion emitted mostly in opposite side of it were calculated. In Figure 7 scattered plot of invariant masses against transverse momenta for assumed excited baryons is shown. Apeak at arround 1.7 GeV in invariant mass distribution is in quantitative agreement with a N^* origin of observed phenomena. Transverse momentum of excited baryon distributes rather widely and its mean value is calculated to be 0.79 GeV/c. Though the statistics is still poor, it seems likely to have weak positive correlation between the mass and transverse momentum of excited baryons.

During the course of this analysis, Event 303-Pb-1-27 attracted our notices because of emittion of a direct electron and a charged particle with large transverse momentum. Whole data now available for this event is given in Figure 8.

One of charged particle, No.10, initiates a low energy cascade shower in lead emulsion sandwich after 0.4 cascade unit traversal from the origin. This particle was, therfore, identified as an electron with energy of 13 GeV. This electron has relatively high transverse momentum, 0.59 GeV/c, and is isolated on θ-ϕ plot in the Figure 8. One charged particle, No.2, emitted with the highest momentum into away side to the above electron has large transverse momentum of 1.14 GeV/c. Similar events to ours were already reported by Soviet group[3]. Details of this event will be reported in near future.

Acknowledgement.

The authors would like to express their gratitude to the members of the Fermi National Accelerator Laboratory for making saccessful exposure of emulsions to accelerator beams.

References.

1) J.Nishimura; Supplement Prog. Theor. Phys. 32, (1964), 72

2) K.Hoshino et al.; Proceedings of International Cosmic Ray Symposium on High Energy Phenomena, CRL, Univ. of Tokyo, (1974), 155

3) A.A.Komar et al.; J.E.T.P.Letters 21, (1975), 239

Figure Captions

Figure 1. Design of the chamber exposed to 303 GeV/c protons.

Figure 2a. Energy versus $\tan\theta^{LAB}$ distribution of γ rays.

2b. Momentum versus $\tan\theta^{LAB}$ distribution of charged particles.

Figure 3a. Transverse momentum distribution of charged particles.

3b. Transverse momentum distribution of γ rays.

Figure 4. Definitions of emission angle θ^{LAB} and azimuthal angle ϕ.

Figure 5. Azimuthal distributions of γ rays and charged particles in the events with and without the highest transverse momentum higher than 1 GeV/c.

a) γ rays $\theta^{LAB} < 2\cdot10^{-2}$ radians in the events $P_{T\ max}^{ch} > 1$ GeV/c.

b) charged particles ——— $\theta^{LAB} < 8\cdot10^{-2}$ radians

- - - $\theta^{LAB} < 2\cdot10^{-2}$ radians

in the events $P_{T\ max}^{ch} > 1$ GeV/c.

c) γ rays $\theta^{LAB} < 2\cdot10^{-2}$ radians in the events $P_{T\ max}^{ch} < 1$ GeV/c.

d) charged particles ——— $\theta^{LAB} < 8\cdot10^{-2}$ radians

- - - $\theta^{LAB} < 2\cdot10^{-2}$ radians

in the events $P_{T\ max}^{ch} < 1$ GeV/c.

Figure 6. Correlation of γ rays and charged particle with the highest transverse momentum. Mean number of γ rays in one event is plotted against the transverse momentum of the charged particle with the highest value.

○ same side to the highest P_T charged particle.

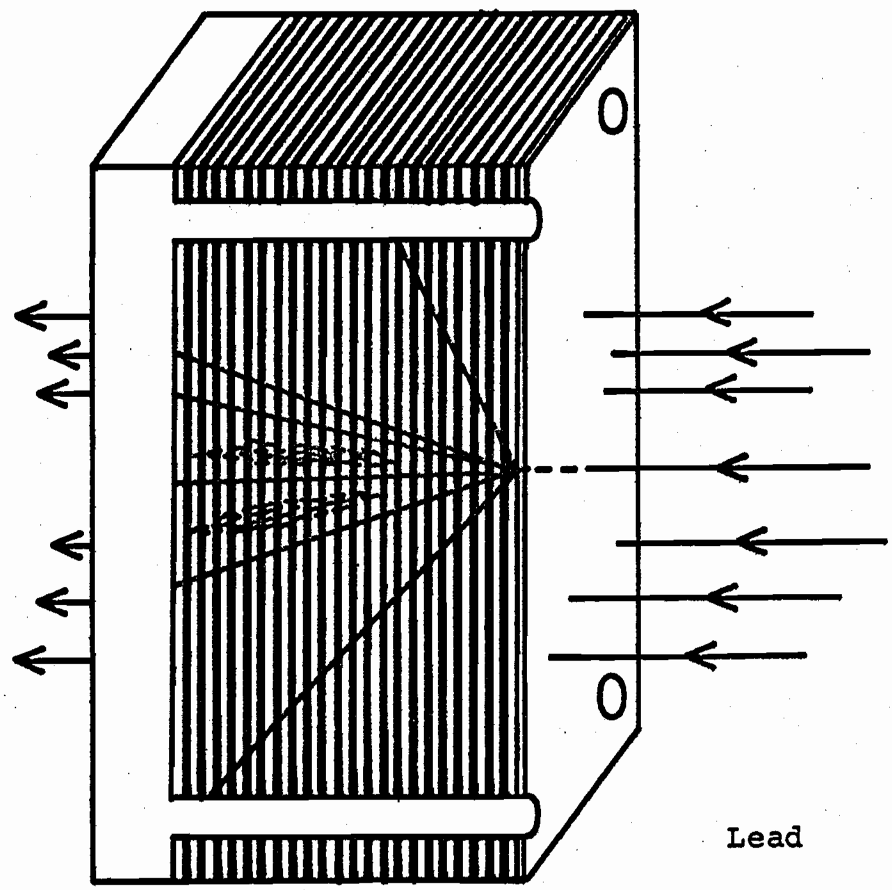
● opposite side to the highest P_T charged particle.

Figure 7. Scatter plot of transverse momentum against invariant mass of excited baryons.

Figure 8. Data sheet of the Event Pb-1-27.

Fig. 1

Design of the chamber



Lead	0.5 mm thick	× 4
	1.0 mm thick	× 18
Emulsion plate	0.96mm thick	× 24

Fig. 2a

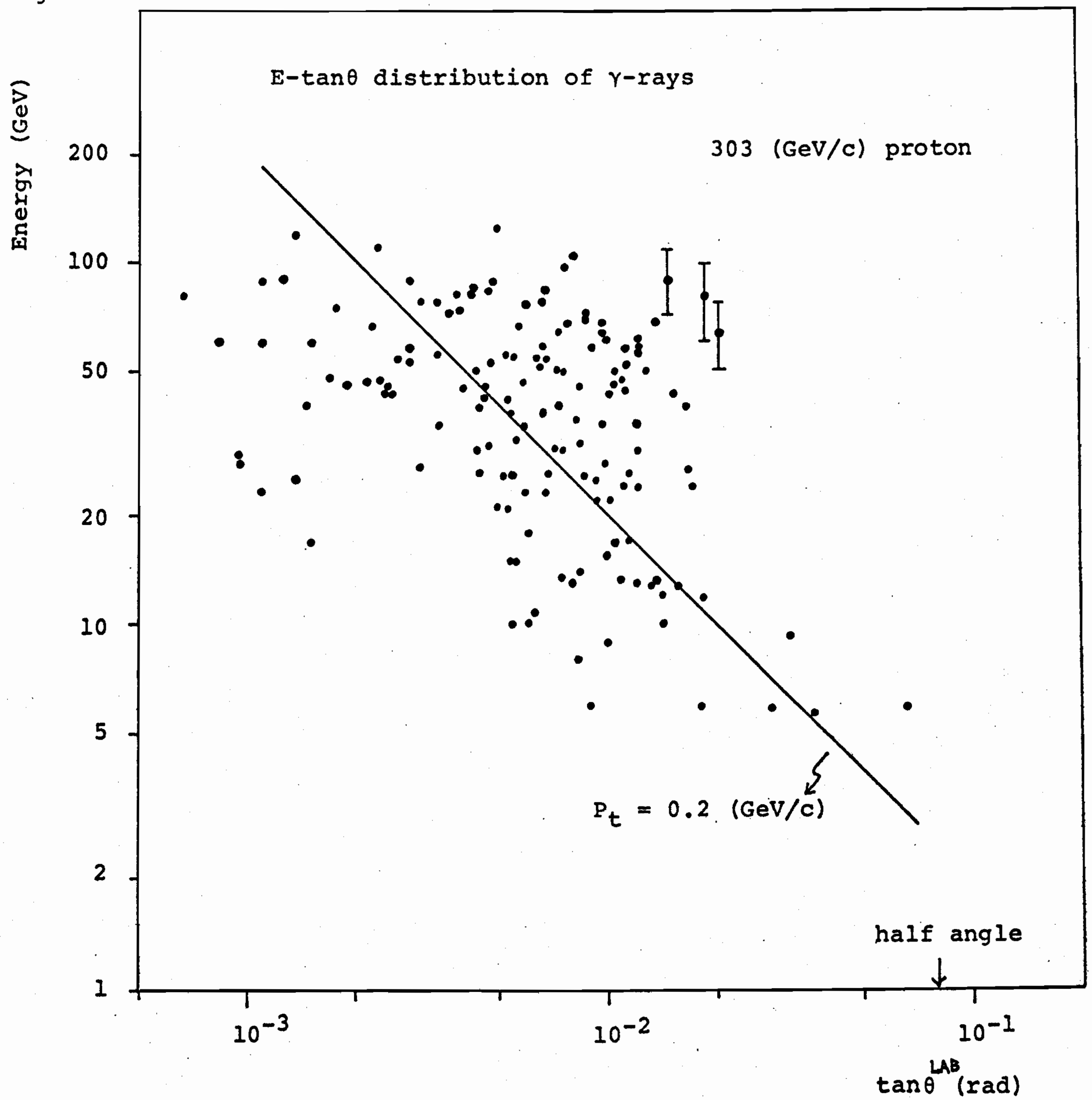
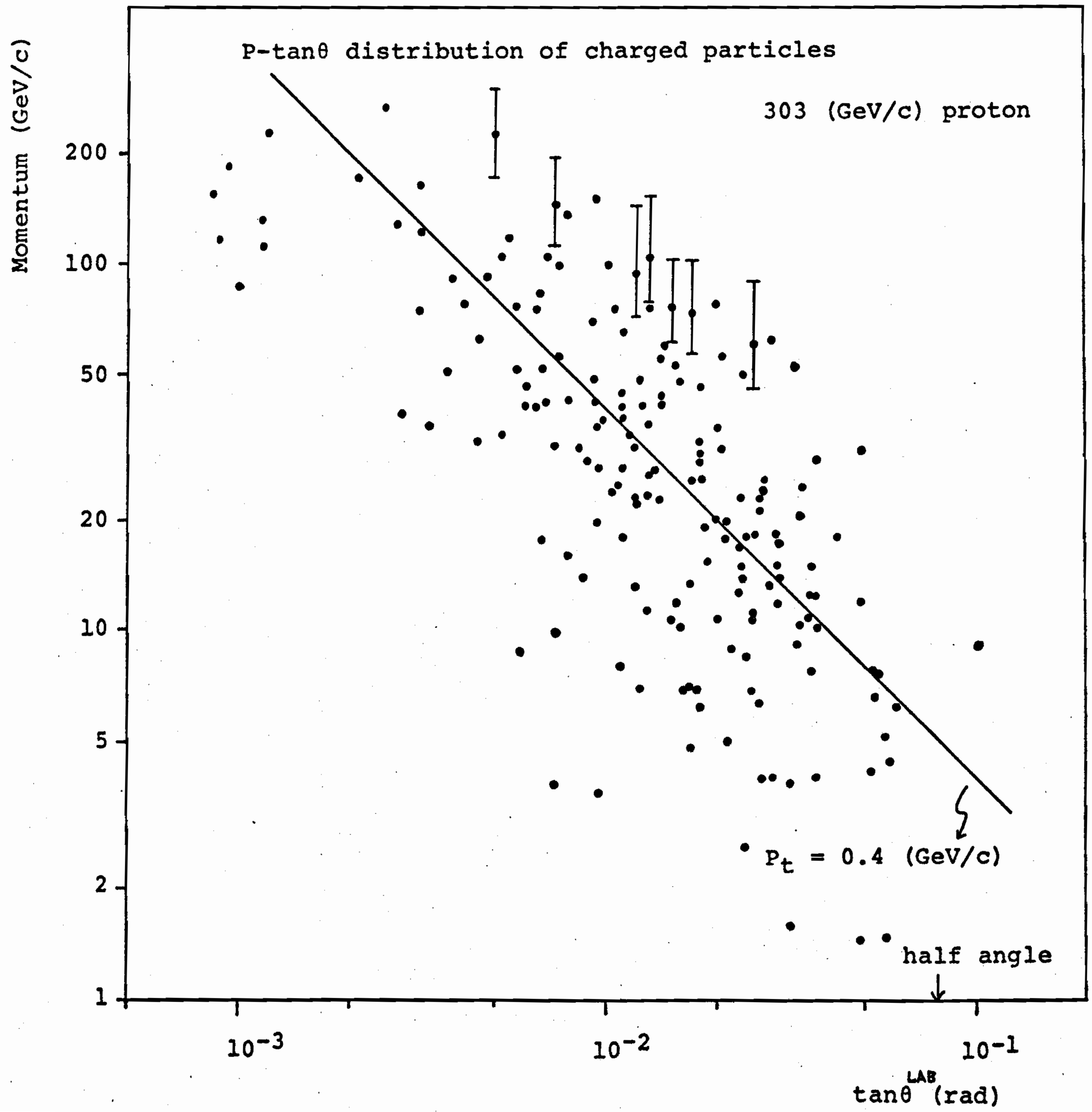
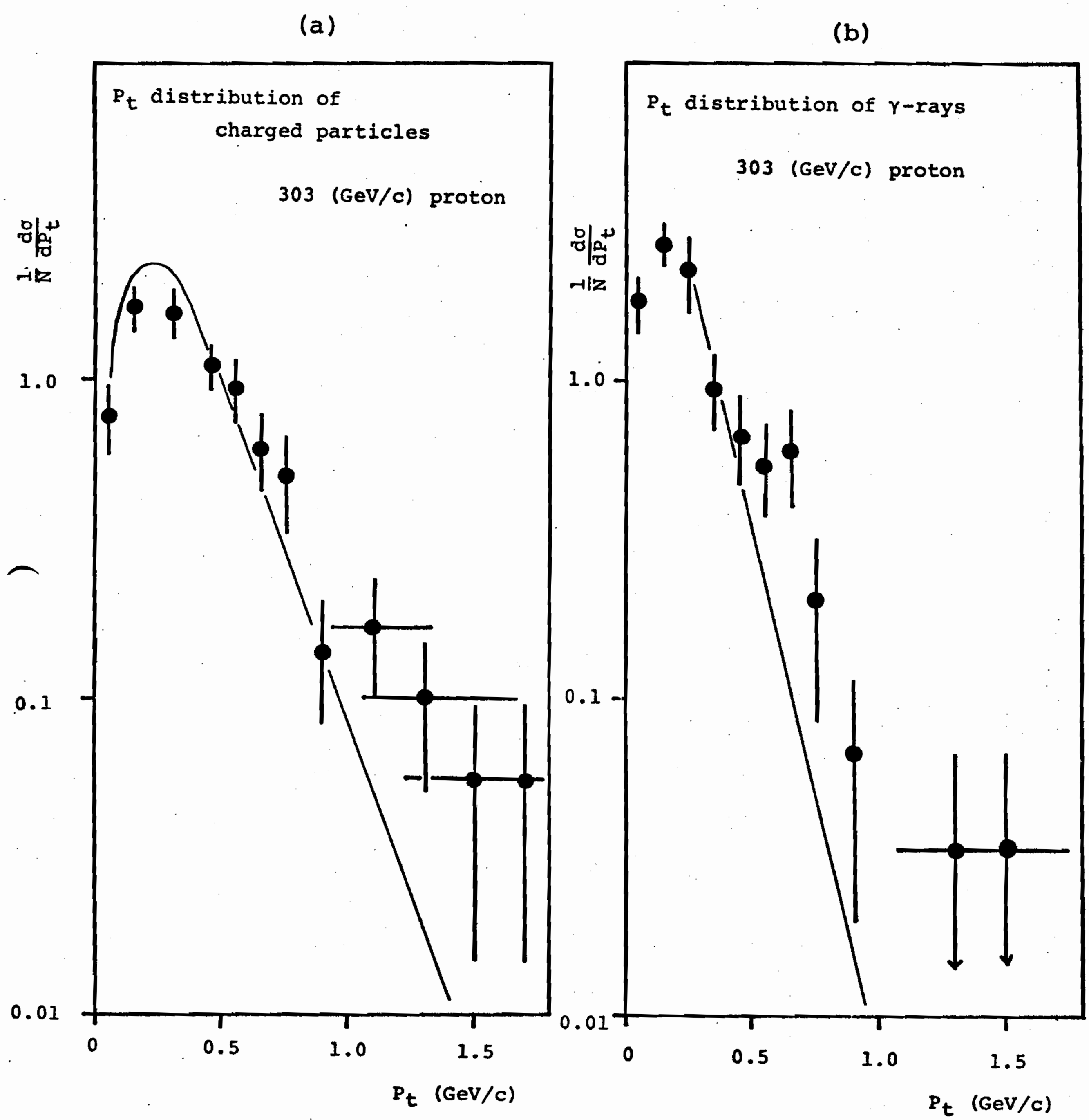

E-tanθ distribution of γ-rays
303 (GeV/c) proton
Energy (GeV)
200
100
50
20
10
5
2
1
P_t = 0.2 (GeV/c)
half angle
10^{-3}
10^{-2}
10^{-1}
$\tan\theta^{LAB}$ (rad)

Fig. 2b



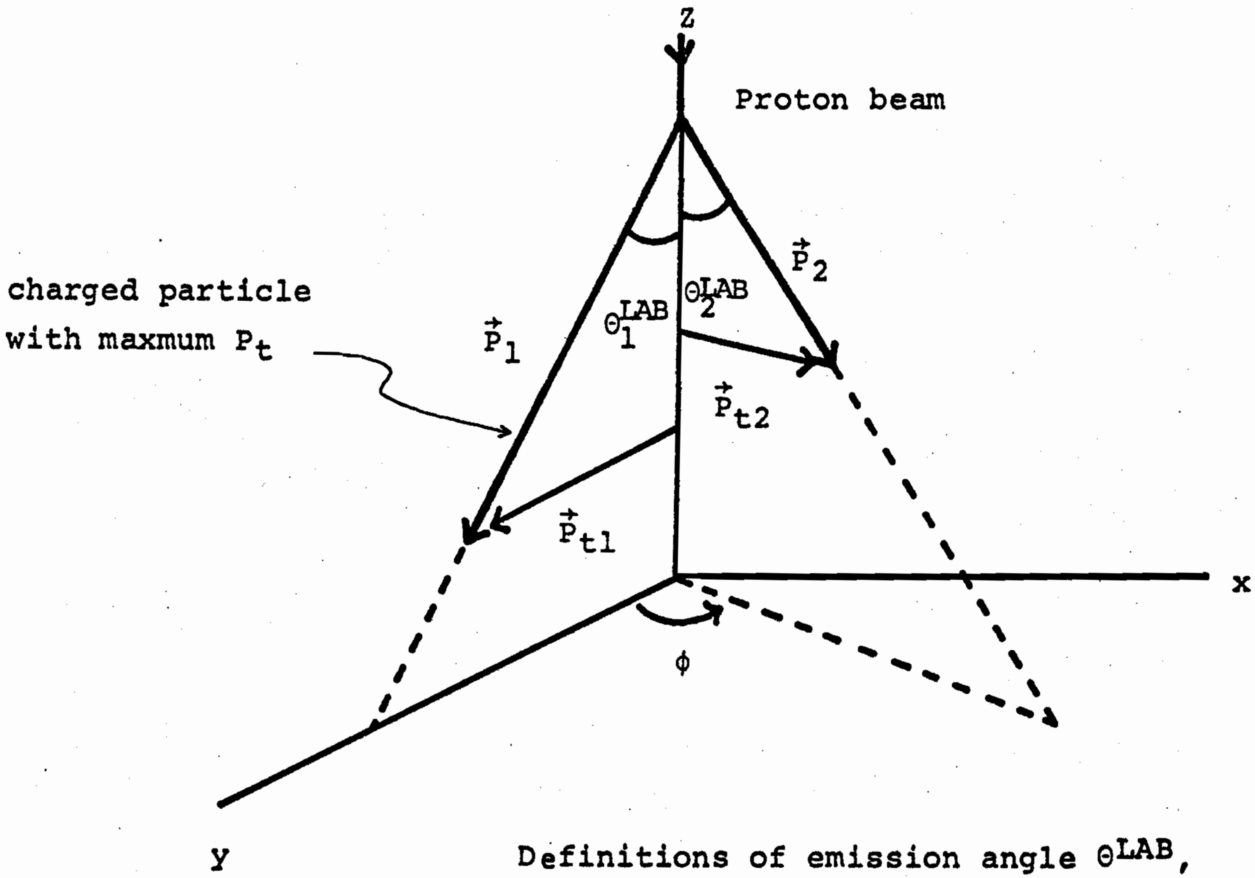
P-tanθ distribution of charged particles
303 (GeV/c) proton
Momentum (GeV/c)
200
100
50
20
10
5
2
1
P_t = 0.4 (GeV/c)
half angle
10^{-3}
10^{-2}
10^{-1}
$\tan\theta^{LAB}$ (rad)

Fig. 3



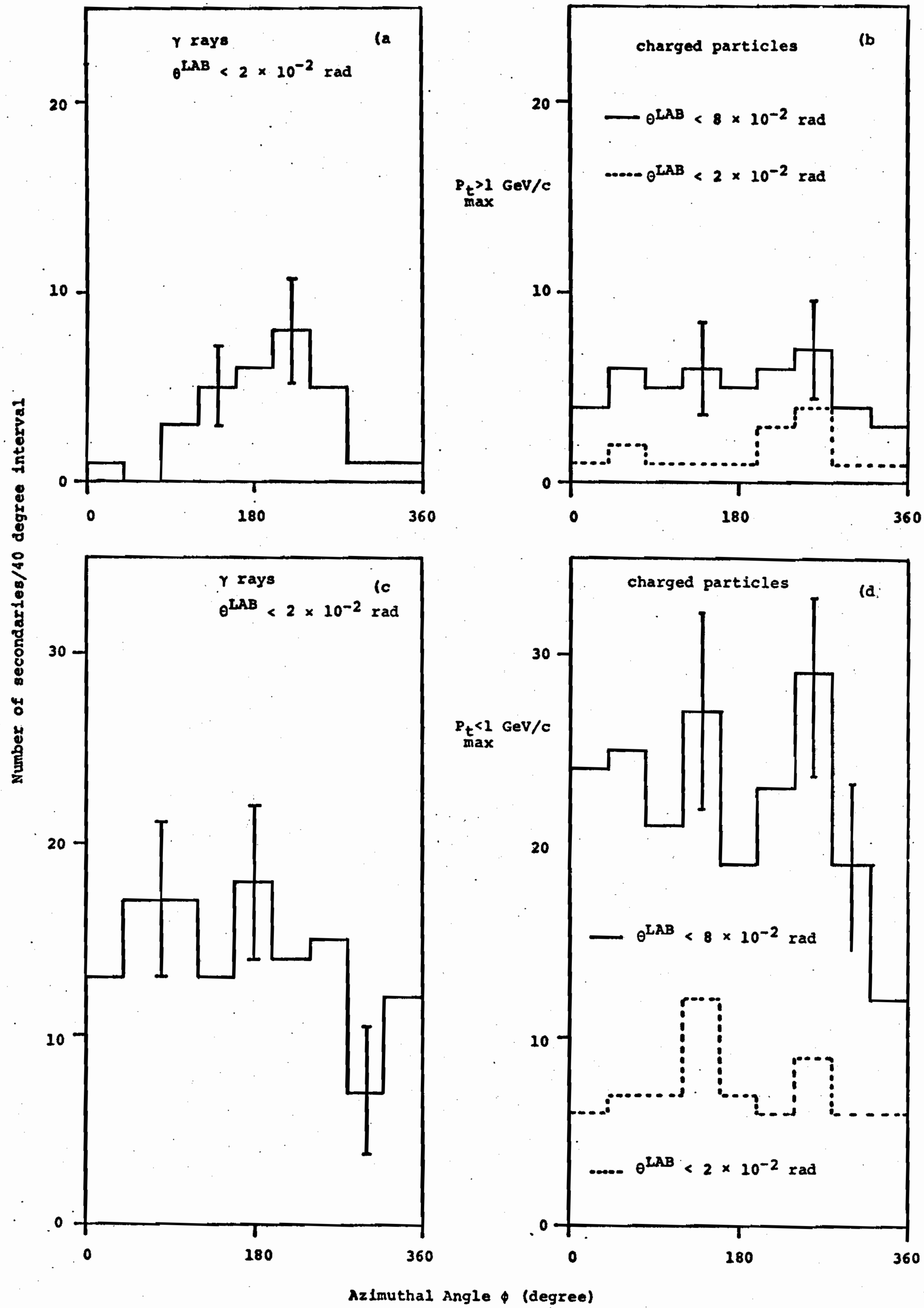
(a)
P_t distribution of
charged particles
303 (GeV/c) proton
$\frac{1}{N}\frac{d\sigma}{dP_t}$
1.0
0.1
0.01
0
0.5
1.0
1.5
P_t (GeV/c)
(b)
P_t distribution of γ-rays
303 (GeV/c) proton
$\frac{1}{N}\frac{d\sigma}{dP_t}$
1.0
0.1
0.01
0
0.5
1.0
1.5
P_t (GeV/c)

Fig. 4



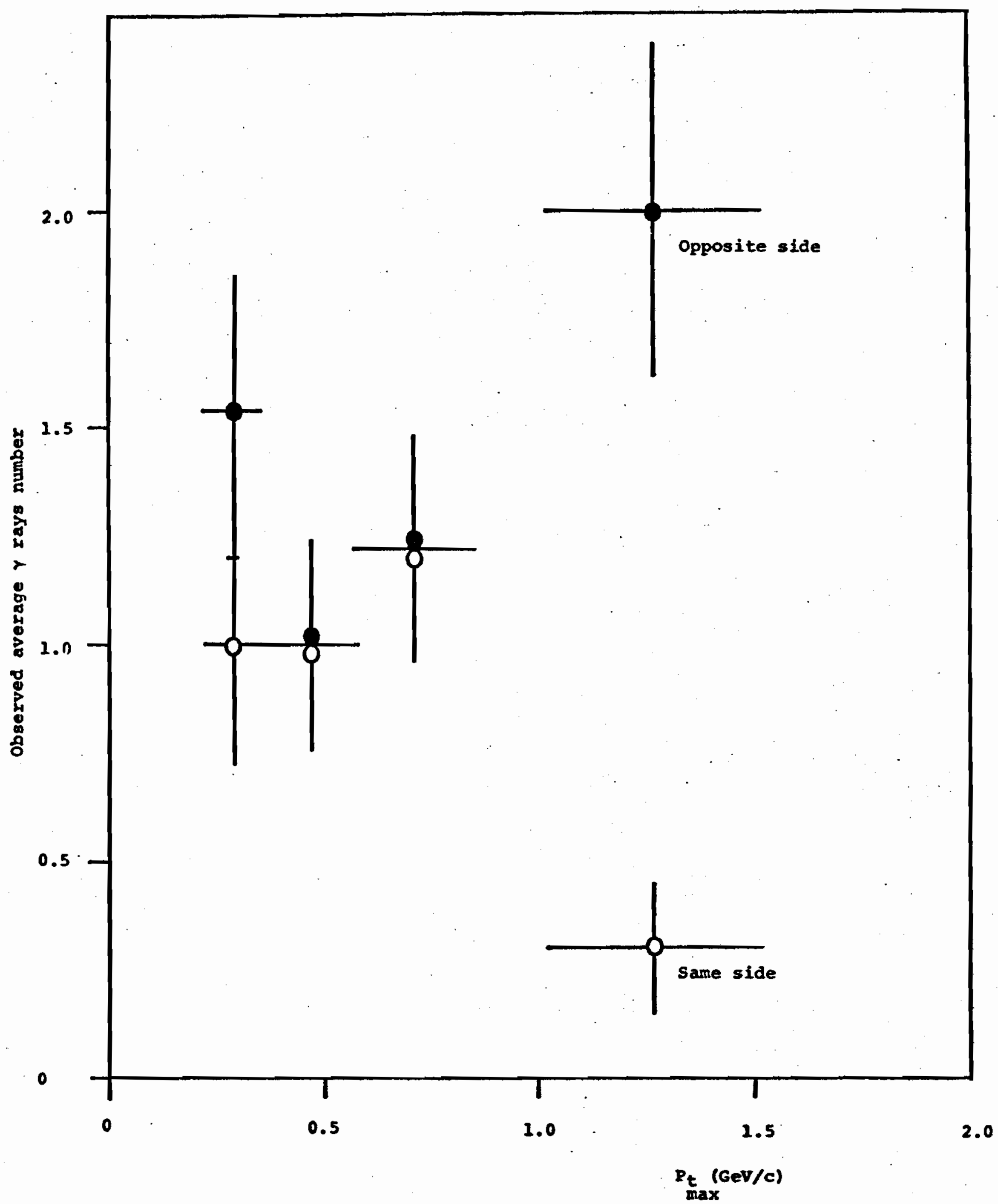
Definitions of emission angle Θ^{LAB}, azimuthal angle ϕ.

Fig. 5



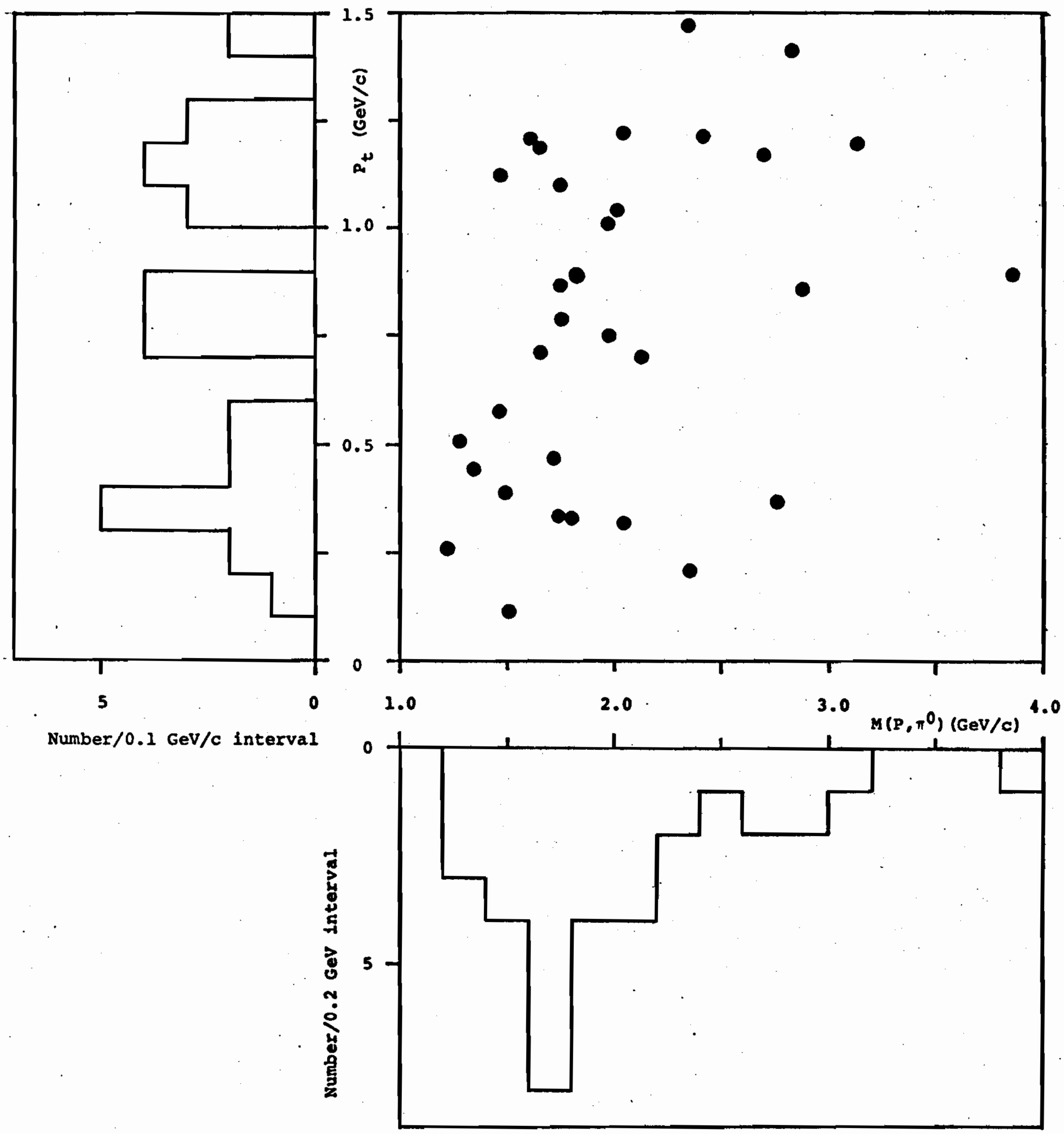
γ rays
θLAB < 2 × 10-2 rad
(a
charged particles
(b
θLAB < 8 × 10-2 rad
θLAB < 2 × 10-2 rad
Pt>1 GeV/c
max
γ rays
(c
θLAB < 2 × 10-2 rad
charged particles
(d
Pt<1 GeV/c
max
θLAB < 8 × 10-2 rad
θLAB < 2 × 10-2 rad
Number of secondaries/40 degree interval
0
10
20
30
180
360
Azimuthal Angle ϕ (degree)

Fig. 6



Observed average γ rays number
2.0
1.5
1.0
0.5
0
0
0.5
1.0
1.5
2.0
$P_{t\,max}$ (GeV/c)
Opposite side
Same side

Fig. 7



1.5
1.0
0.5
0
P_t (GeV/c)
5
0
Number/0.1 GeV/c interval
1.0
2.0
3.0
4.0
M(P,π^0) (GeV/c)
Number/0.2 GeV interval

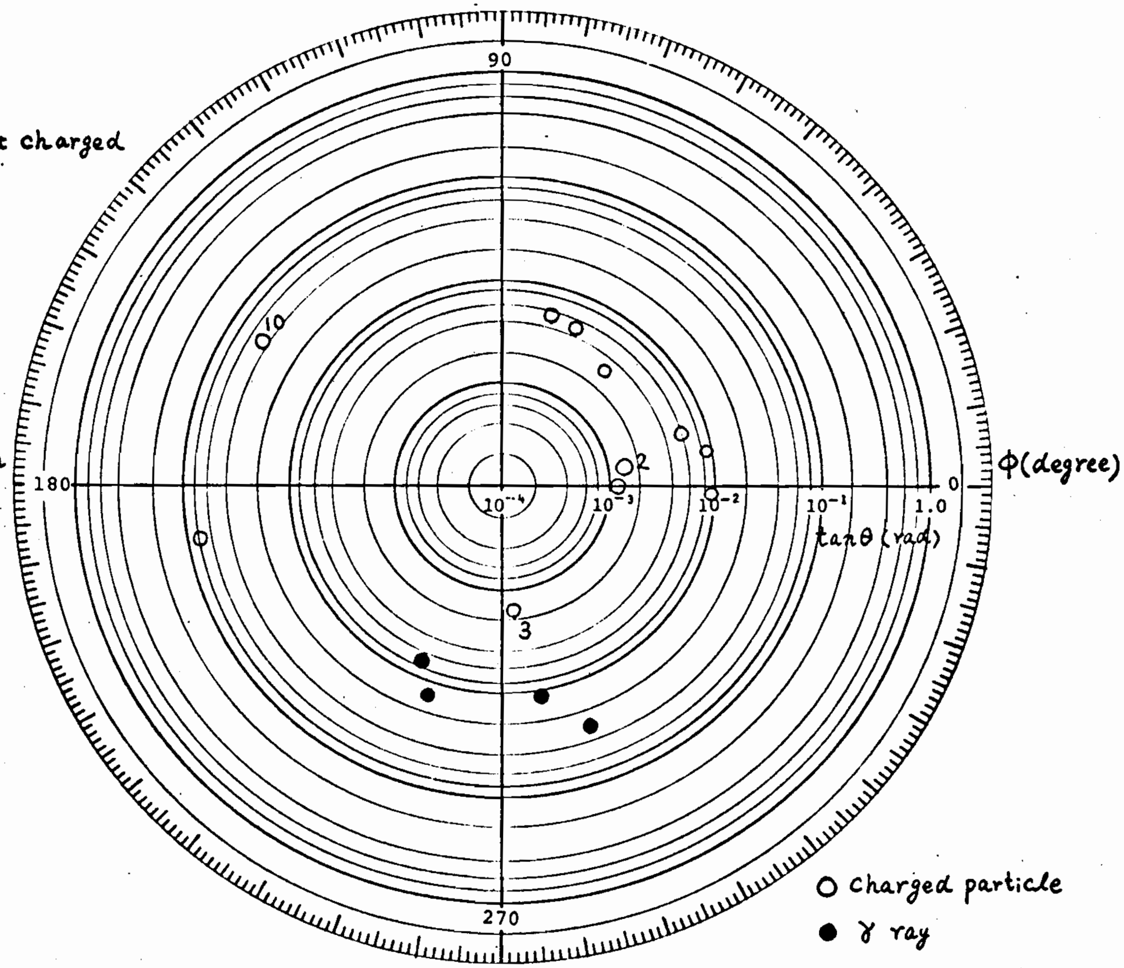
Fig. 8

Beam Energy	Event No.
303	Pb — 1 — 27

Type n_s	N_h	n_γ	First Plate No.	Grid Print	Target	Height	Observer	No.
11	—	— 4	16 up (down)		base	700 μm		

Track No.	tan θ (rad)	φ (deg)	P (GeV/c)	P_t (GeV/c)	
1	1.3 -2	0	27	0.35	
2	1.5 -2	8	76	1.14	large Pt charged
3	1.6 -2	275	> 10	> 0.16	
4	2.6 -2	49	23	0.60	
5	4.9 -2	66	1.5	0.07	
6	5.6 -2	74	11	0.61	
7	5.9 -2	17	4.5	0.27	
8	9.0 -2	10	5.4	0.49	
9	9.0 -2	358	3.6	0.32	
10	4.5 -2	148	13	0.59	electron
11	7.9 -2	190			
a	1.2 -2	280	30	0.36	
b	7.1 -3	246	50	0.36	
c	1.4 -2	251	12	0.17	
d	3.0 -2	290	~ 1	0.03	
π^0 (ac)	1.2 -2	272	42	0.50	

Remarks $E_{visible}$ = 269 (GeV)



No.1 ~ 11 charged secondaries, No. a ~ d γ rays.

Log tanθ-Plot