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CHARGE ASYMMETRY

IN CMS BARREL TRACKER

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Charge Asymmetry in CMS Barrel Tracker

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Abstract

The charge asymmetry in CMS barrel tracker has been preliminarilly investigated. Its origin has been identified, and its possible effect on some physics results has been addressed. Further studies are foreseen to assess its impact in detail.

1, Introduction.

The new design (i.e. silicon and MSGC modules are arranged in an over-all spiral structure [1]) of the CMS barrel tracker causes an apparent asymmetry when detecting positive and negative particles (at the same transverse momentum) (Fig.1). How serious is the asymmetry? What is its origin? How would it affect the physics results? Some preliminary works have been done to address these questions. The investigations may be extended by using precise track and vertex reconstruction.

In this note, Section 2 discusses results for the tracks originating from a primary vertex at the beam position, and a comparison between the new spiral design and the old superlayer baseline design [2]. Section 3 focuses on decay products of the long-lived particles (e.g. $K_0 \rightarrow \pi^+\pi^-$) which decay at the positions quite far from the beam position. Finally, conclusions are presented and perspectives are outlined in Section 4.

2, Charge asymmetry for tracks originating at beam position.

For an initial study, it is sufficient to use simplified simulation of the detector, i.e. to only consider the sensitive parts of detector neglecting the electronics and other materials which cause multiple scattering. The MSGCs are tilted by 18° (a total of 16 layers outside), and the silicon-strip detectors by 9° (a total of 9 layers close to the beam). This is to compensate the Lorentz drift angles in order to optimise detector resolution. The MSGC and silicon modules are arranged in an overall spiral

configuration. Tracks with fixed momentum are generated at (x,y)=(0,0) with random ϕ angles in a 4 Tesla magnetic field. From distributions of the number of hits per track (e.g. Fig.2), one gets Table 1. From the number of hits per track, the momentum resolution can be roughly calculated using analytical formulae [3]; they are listed in Table 2.

For comparison, the same analysis is also done for the old baseline design (Fig.3) which consists of 3 superlayers (4 layers per superlayer). The silicon and MSGC modules are also tilted as in the spiral case. The results are also given in Table 1.

Table 1, (Number of hits)/track with (statistical errors in hits)

P_t (GeV/c)		0.5	1	2	5	10
Spiral	+	7.15 (0.07)	11.39 (0.08)	12.76 (0.09)	13.36 (0.11)	13.72 (0.09)
	-	13.87 (0.08)	16.08 (0.10)	14.85 (0.11)	14.34 (0.13)	14.14 (0.09)
Base line	+	5.26 (0.10)	9.86 (0.14)	11.04 (0.10)	11.64 (0.06)	11.84 (0.04)
	-	10.66 (0.09)	14.10 (0.10)	13.09 (0.11)	12.36 (0.07)	12.18 (0.04)
No tilting		8	12	12	12	12

Table 2, Momentum resolution dp/p (including multiple scatterings)

P_t (GeV/c)		0.5	1	2	5	10
Spiral	+	0.42%	0.34%	0.36%	0.38%	0.41%
	-	0.56%	0.42%	0.39%	0.39%	0.42%
Base line	+	0.35%	0.31%	0.33%	0.35%	0.39%
	-	0.49%	0.38%	0.36%	0.36%	0.40%
No tilting		0.43%	0.35%	0.35%	0.36%	0.39%

Table 3, Degrees of asymmetry

P_t (GeV/c)		0.5	1	2	5	10
Spiral	-/+	1.94 ±0.02	1.41 ±0.01	1.16 ±0.01	1.07 ±0.01	1.03 ±0.01
Base line	-/+	2.03 ±0.05	1.43 ±0.02	1.19 ±0.01	1.06 ±0.01	1.03 ±0.01

Though the (number of hits)/track are different for the new and the old design, the **degree of asymmetry** (≡ (number of hits on a negative track)/(number of hits on a positive track)) turns out to be nearly the same (Table 3). When some parameters of the detector are fine-tuned, e.g. by varying the distance between the layers, changing the overlap between detector elements within one layer or between two layers (as shown in

Fig.4), the degrees of asymmetry vary only little, never exceeding 5%. Without detector tilting, all asymmetries disappear. Therefore, one may conclude that the intrinsic reason of the +/– charge asymmetry is the Lorentz angle tilting, and not the new spiral structure as may have been suspected. Actually, one can see that the spiral structure is just a special arrangement of the superlayer structure, i.e. the distances between layers are somehow equalized and detector elements are laid along curves of the spiral legs.

From Tables 1 and 3, one can see that, for $P_t \geq 5$ GeV/c the difference between positive and negative tracks is less than 1 hit per track (or smaller than 7%); for the tracks with $P_t \geq 10$ GeV/c, the difference is diminishing (less than 3%).

As shown in the Fig.5 [1], detector efficiencies and resolutions are strongly correlated with the track incident angle. It is instructive to impose restrictions on the incident angle associated with each accepted hit: i.e. a hit is accepted only when the incident angle is smaller than a certain value (say 10° or 30°); the other disqualified hits are discarded. Asymmetries for the tracks with the restriction are listed in Table 4. As all hits on the tracks with $P_t \geq 5$ GeV/c have incident angles less than 10°, only results for low P_t tracks are presented.

Table 4, Charge asymmetry when imposing a restriction on incident angle

P_t (GeV/c)		0.5			1			2		
Restriction		30°	20°	10°	30°	20°	10°	30°	20°	10°
Spiral (hits/track)	+	3.99	2.36	0	8.45	5.93	2.57	12.76	12.00	6.35
	-	4.75	2.74	0	10.59	6.70	2.76	14.85	13.84	6.71
Base line (hits/track)	+	3.69	3.69	0	7.20	3.90	3.90	11.04	10.03	3.93
	-	4.32	4.32	0	9.06	4.13	4.13	13.09	11.68	4.11
Spiral	-/+	1.19	[0]	[0]*	1.25	1.13	[0]	1.16	1.15	1.06
Base line	-/+	1.17	1.17	[0]	1.26	1.06	1.06	1.19	1.16	1.05

*) [0] means that either there is no qualified hit left on the track (e.g. for the case of 0.5 GeV/c), or the number of qualified hits are less than 3 which is the least number for reconstructing a track (e.g. for 1 GeV/c).

Again, there is almost no difference between the spiral and the baseline designs from the degree of asymmetry's point of view. Comparing with Table 1, the degree of asymmetry is smaller for the tracks with incident angle restrictions. However, application of tight restriction (e.g. 10°) may eliminate the track at all.

3, Effect of the charge asymmetry on decay products of the long-lived particles (K_0 as an example).

Apparently, the charge asymmetry is more significant when tracks originating from the positions other than (x,y)=(0,0). This may affect the reconstruction of long-lived particles (e.g. K_0's) through their decay products. Though the transverse momentum (with respect to the direction of the parent-particle) of the decay products may be not too large to lead to the worst case (namely one track in a charged particle pair (i.e. the positive track in our convention) may be totally lost if it is emitted from the position between two spiral legs and goes somehow parallelly along the leg), the P_t spectrum and the secondary vertices distribution need to be examined to see what is the real situation.

The PYTHIA7.3 package is used (for the pp collision at $\sqrt{s}$ = 14 TeV) to produce LHC events, then K_0 final states are selected and their charged decay products (i.e. π^+ and π^-) are collected. The 2-D distribution about P_t of pions vs. r_v is shown in Fig.6(a), where r_v is the distance between the secondary vertex and the beam, the sign of P_t reflects the charge of particle. From its projections (Fig.6(b)), it can be seen that P_t of the pions are peaked around 0.35 GeV/c, the mean value of r_v is about 9 cm and about 12% of K_0's decay in the sensitive range of the barrel tracker (i.e. r_v = 20-120 cm). Fig.7(b) plots the decay products' direction (i.e. the angle β between pions and the radial direction at the decay location in x-y projection, see Fig.7(a)) vs. r_v. It can be seen that, in the tracker's sensitive region, the maximum β is about 45°; the larger r_v the smaller maximum β. This is expected, since a more energetic K_0 travels longer (i.e. decays at larger r_v) and its decay products have more thrust (i.e. are more parallel with the K_0 path). It is also noticed (from Fig.8) that β distribution of π^+ (or π^-) is symmetric with respect to β=0°; so the cases with negative β also have to be examined.

Once having this general picture, we can generate the tracks at various locations with different P_t and β, within the maximum $\pm\beta$ limits. Tables 5 and 6 are the results. The numbers corresponding to the "with restriction on track incident angle" are also listed in Table 6. From the

tables, it can be observed that, when vertices are not at (x,y)=(0,0),

(1) the degrees of asymmetry increase as the initial angles β of decay products; even for the high P_t (≥ 10 GeV/c) tracks, the asymmetry is still not vanishing;

(2) again, the degrees of asymmetry decrease when restricting the track incident angle on accepted points; however, a too much restriction may cause the loss of the track at all; therefore, a compromise among the efficiency, the resolution and the asymmetry may have to be further studied.

Table 5, Hits/track for tracks generating at different r_v and β

r_v (cm)	β	P_t = 1 GeV/c		P_t = 3 GeV/c		P_t = 10 GeV/c	
		+	-	+	-	+	-
0	-	11.4	16.1	13.1	14.5	13.7	14.1
20	-30°	13.1	14.8	14.1	13.7	14.4	13.4
	0°	12.2	15.3	13.5	14.3	13.7	14.0
	30°	11.3	16.4	12.6	14.8	13.1	14.7
40	-20°	9.0	10.0	9.9	9.4	10.0	9.1
	0°	8.5	10.7	9.2	9.9	9.4	9.6
	20°	7.6	11.3	8.6	10.3	8.9	10.2
70	-10°	5.5	6.0	5.9	5.8	6.0	5.7
	0°	5.3	6.3	5.7	5.9	5.78	5.82
	10°	5.1	6.6	5.4	6.1	5.5	6.1

*) The statistical errors for all numbers are less than 2%.

Table 6, Degrees of asymmetry

r_v (cm)	β	P_t = 1 GeV/c			P_t = 3 GeV/c			P_t = 10 GeV/c		
		no Restri	30° Restri	10° Restri	no Restri	30° Restri	10° Restri	no Restri	30° Restri	10° Restri
0	-	1.41	1.25	[0]	1.11	1.11	1.09		1.03	
20	-30°	1.13	1.12	1.03	0.97	0.97	1.00	0.93	0.93	0.94
	0°	1.25	1.14	1.04	1.06	1.06	1.04		1.02	
	30°	1.45	1.29	[0]	1.17	1.17	[0]		1.12	
40	-20°	1.11	1.04	0.98	0.95	0.95	0.98	0.90	0.90	0.93
	0°	1.26	1.18	[0]	1.08	1.08	1.06		1.02	
	20°	1.49	1.30	[0]	1.21	1.21	[0]**	1.14	1.14	[0]
70	-10°	1.08	1.08	1.01		0.98*			0.96	
	0°	1.19	1.19	[0]		1.05			1.01	
	10°	1.30	1.24	[0]	1.13	1.13	[0]		1.09	

*) only one number in a box means that all three numbers are the same.
**) the [0] has the same meaning as in Table 4.
• the statistical errors for all numbers are less than 4%.

3, Conclusions and comments.

Due to the detector tilting (for compensating the Lorentz drift angles in order to obtain the best resolution), an asymmetry between positive and negative charged tracks appears in the CMS barrel tracker. The asymmetry is more significant for the low P_t tracks and for the tracks originating not at the primary vertex. Some physics issues (e.g. the ones related with K_0 and other long-lived particles) may be affected. Though the degree of asymmetry is not large for high P_t tracks or after imposing a restriction on the track incident angle, it is still not negligible in some

circumstances. An indirect impact could be that the momentum resolution (as shown in Table 2) will be different for different charges, this may lead to a systematic error on the evaluation of invariance mass from secondary particles. If further studies would show the difference on the invariance mass between the tilted detector and the untilted one, this systematic error may have to be added in some physics analysis related with the tracker.

Acknowledgement

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References

[1] CMS Collaboration, "Status Report and Milestones", CERN/LHCC 93-48 (1993).

[2] CMS Collaboration, "Letter of Intent", CERN/LHCC 92-03 (1992).

[3] R. Bock et al., "Data Analysis Techniques for High-Energy Physics Experiments", ed. M. Regler, CUP (1990).

Figure captions

Figure 1: Spiral structure of the CMS barrel tracker and illustration of the charge asymmetry problem.

Figure 2: Distributions of the hits per track for $P_t = 0.5$ GeV/c.

Figure 3: Baseline design of the CMS barrel tracker.

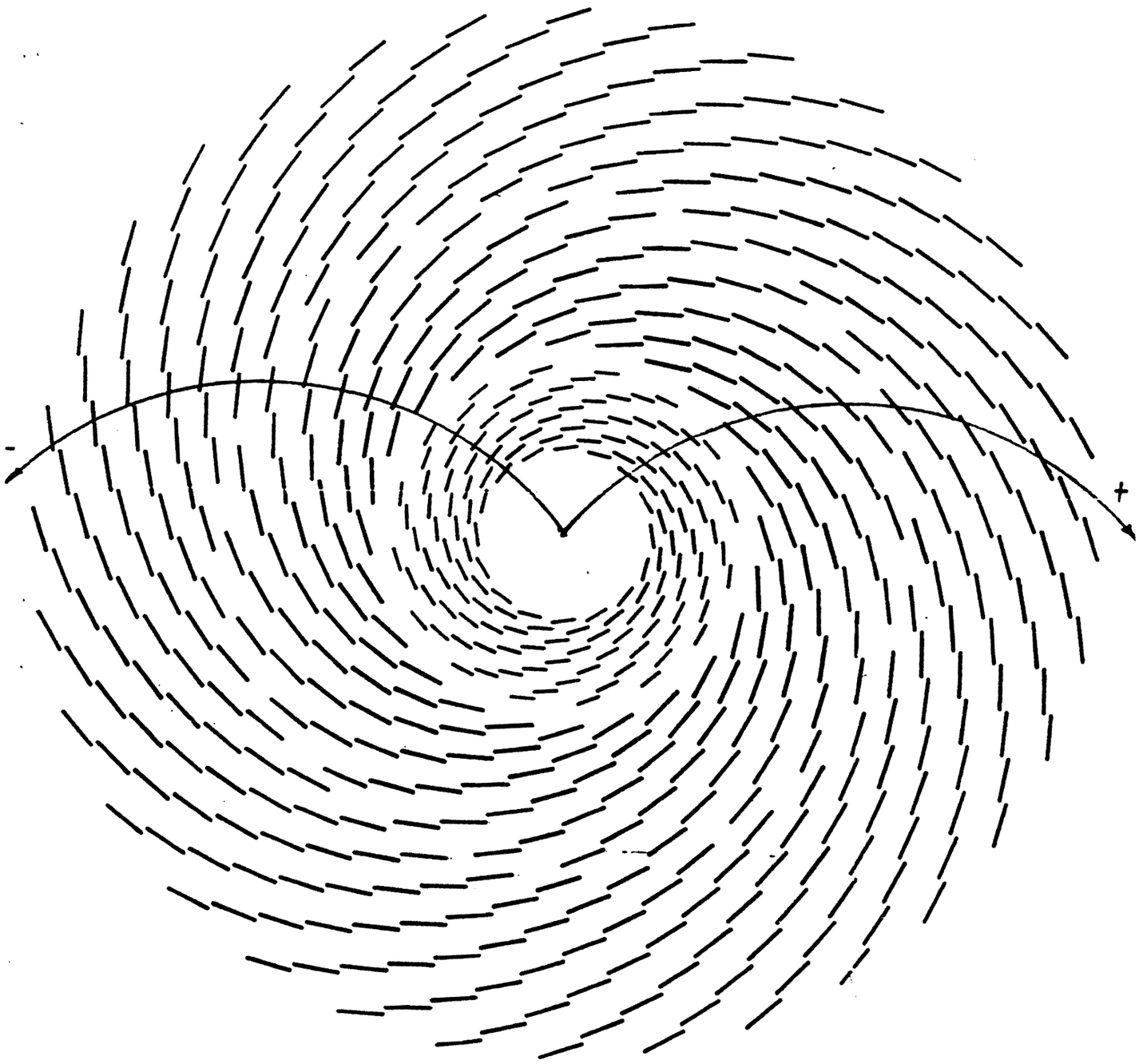
Figure 4: Illustration of some fine-tunings on tracker's parameters;

Figure 5: Efficiencies and resolutions vs. track incident angles (cited from [1]); N.B. $\tan(0.2) \cong 11.3°$, $\tan(0.4) \cong 21.8°$, $\tan(0.6) \cong 31.0°$.

Figure 6: (a) 2-D distribution about P_t of pions vs. r_v, where r_v is the distance between the secondary vertex and the beam;
(b) Its two projections.

Figure 7: (a) Definition of β angle; (b) Direction of pions vs. r_v.

Figure 8: β angle distributions of π^+ and π^-.



– 1 GeV/c : 17 hits
+ 1 GeV/c : 12 hits

Figure 1

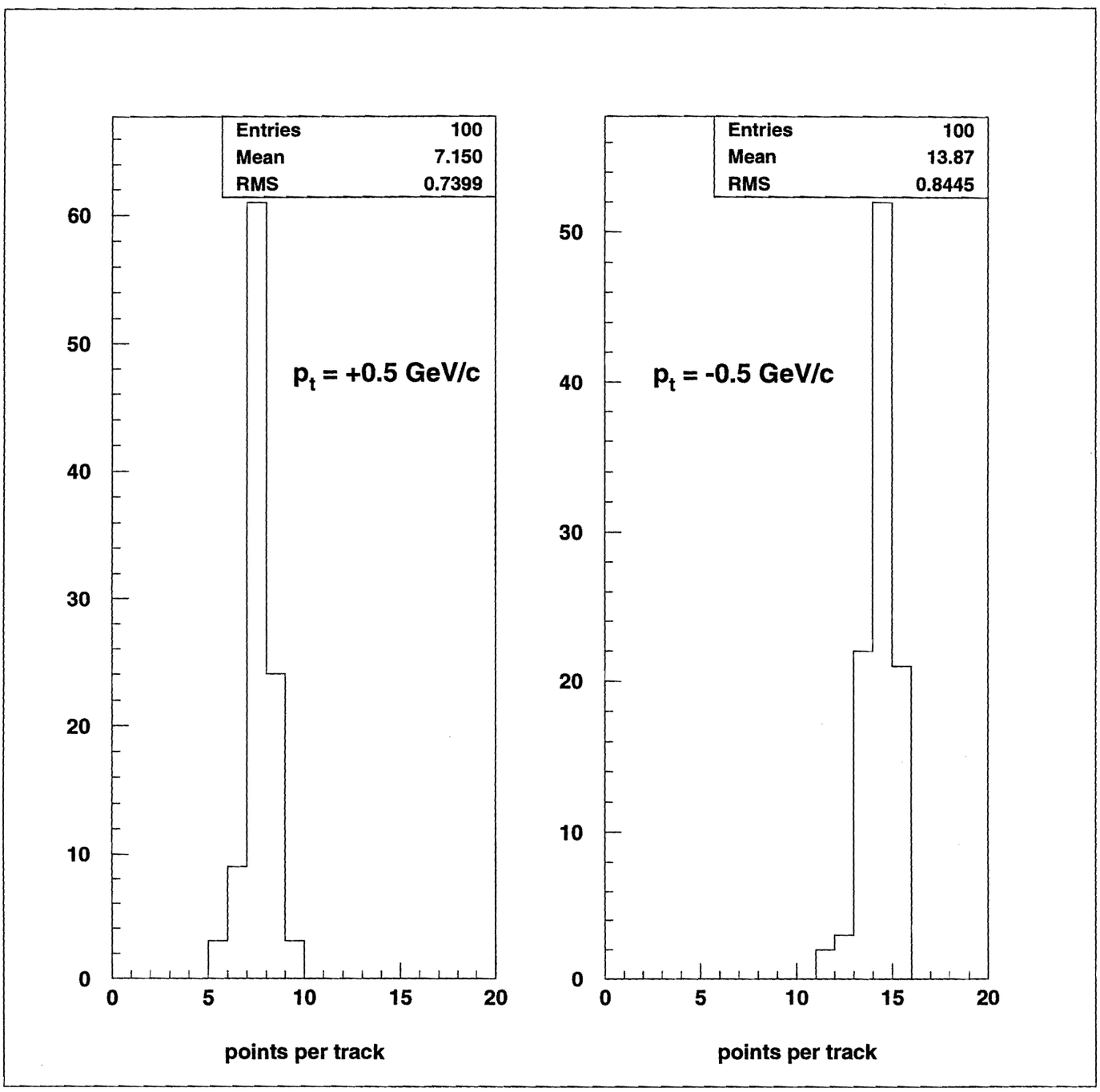
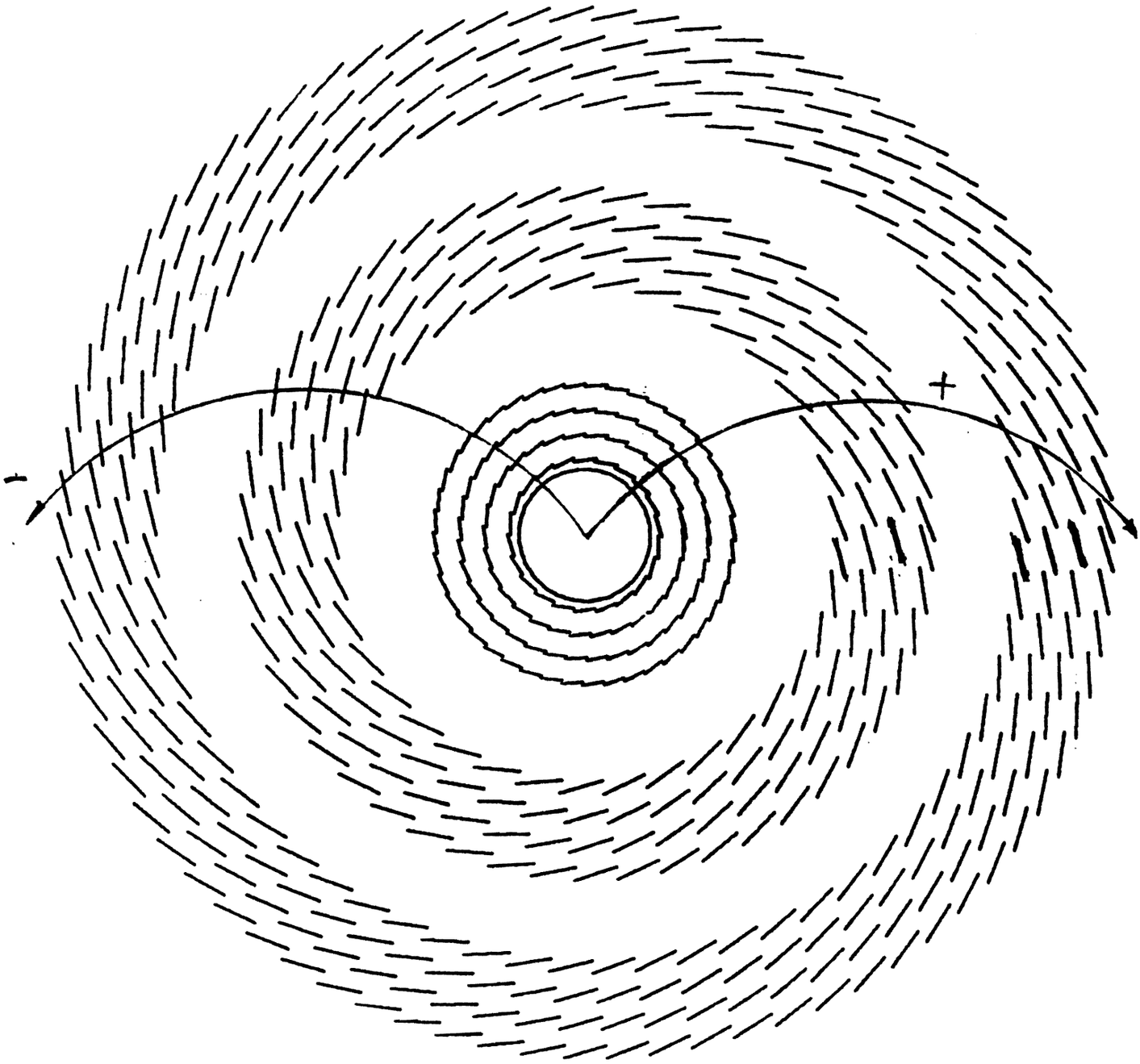

Entries 100
Mean 7.150
RMS 0.7399
p_t = +0.5 GeV/c
points per track
Entries 100
Mean 13.87
RMS 0.8445
p_t = -0.5 GeV/c
points per track

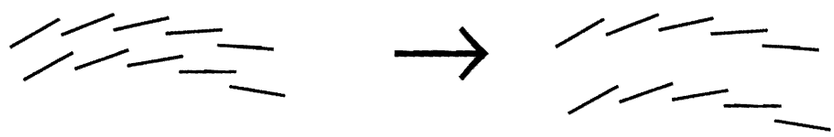
Figure 2



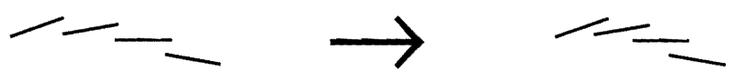
– 1 GeV/c : 15 hits
+ 1 GeV/c : 10 hits

Figure 3

(1) To change the distance between layers, e.g.



(2) To change the overlapping between modules within one layer, e.g.



(3) To change the overlapping between two layers, e.g.

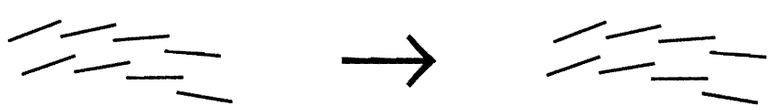
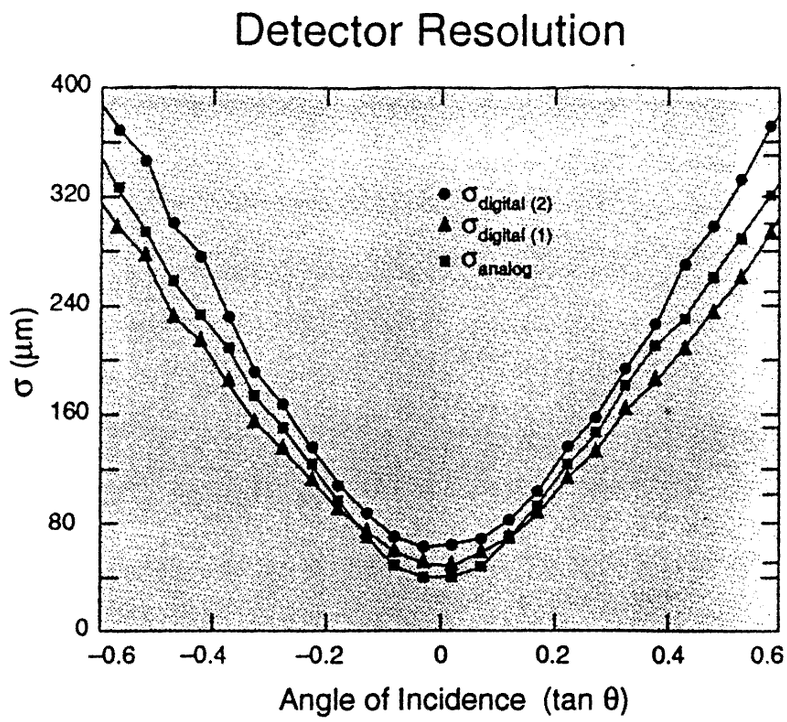
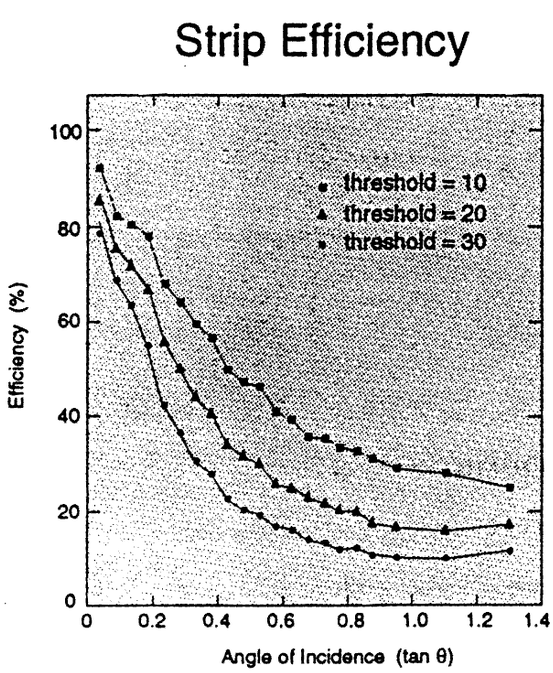


Figure 4

MSGC: Angular Effects





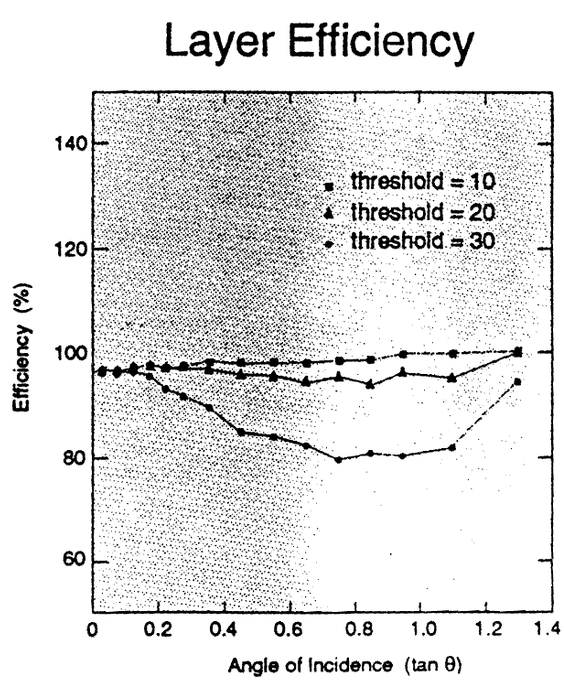


Figure 5

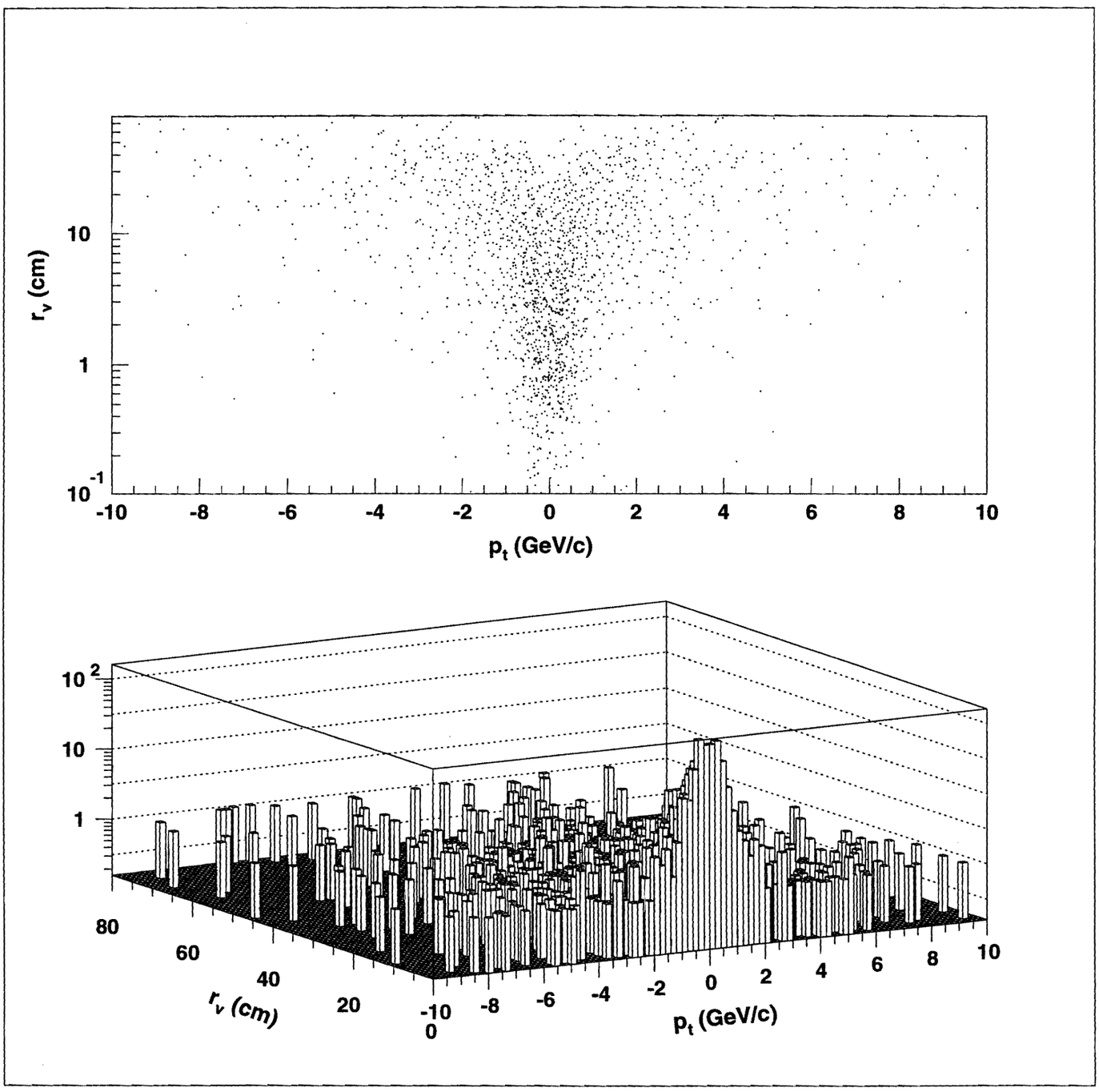

r_v (cm)
10
1
10^{-1}
-10
-8
-6
-4
-2
0
2
4
6
8
10
p_t (GeV/c)
10^2
10
1
80
60
40
20
0
r_v (cm)
-10
-8
-6
-4
-2
0
2
4
6
8
10
p_t (GeV/c)

Figure 6(a)

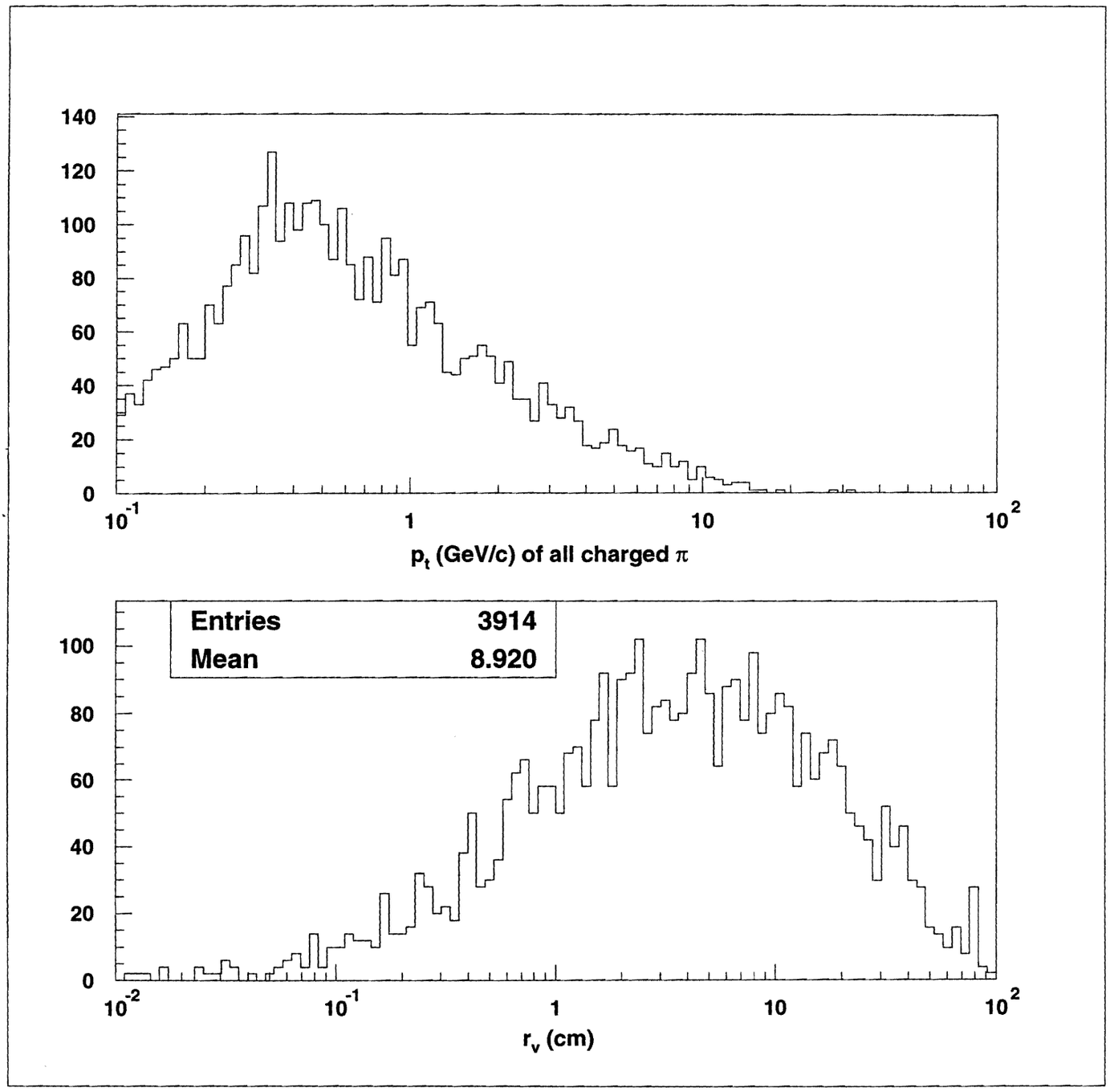

140
120
100
80
60
40
20
0
10^{-1}
1
10
10^{2}
p_t (GeV/c) of all charged π
Entries 3914
Mean 8.920
100
80
60
40
20
0
10^{-2}
10^{-1}
1
10
10^{2}
r_v (cm)

Figure 6(b)

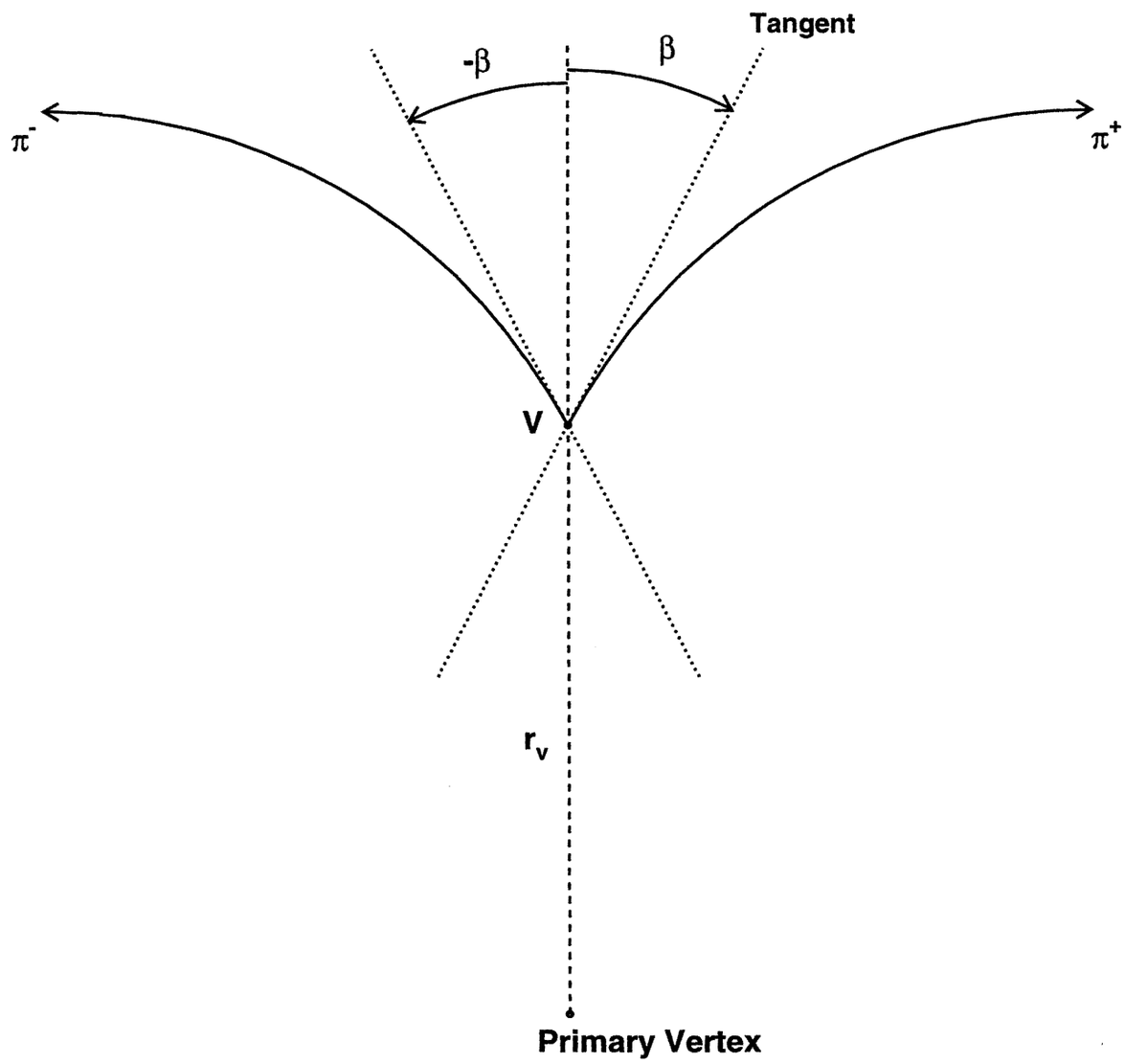
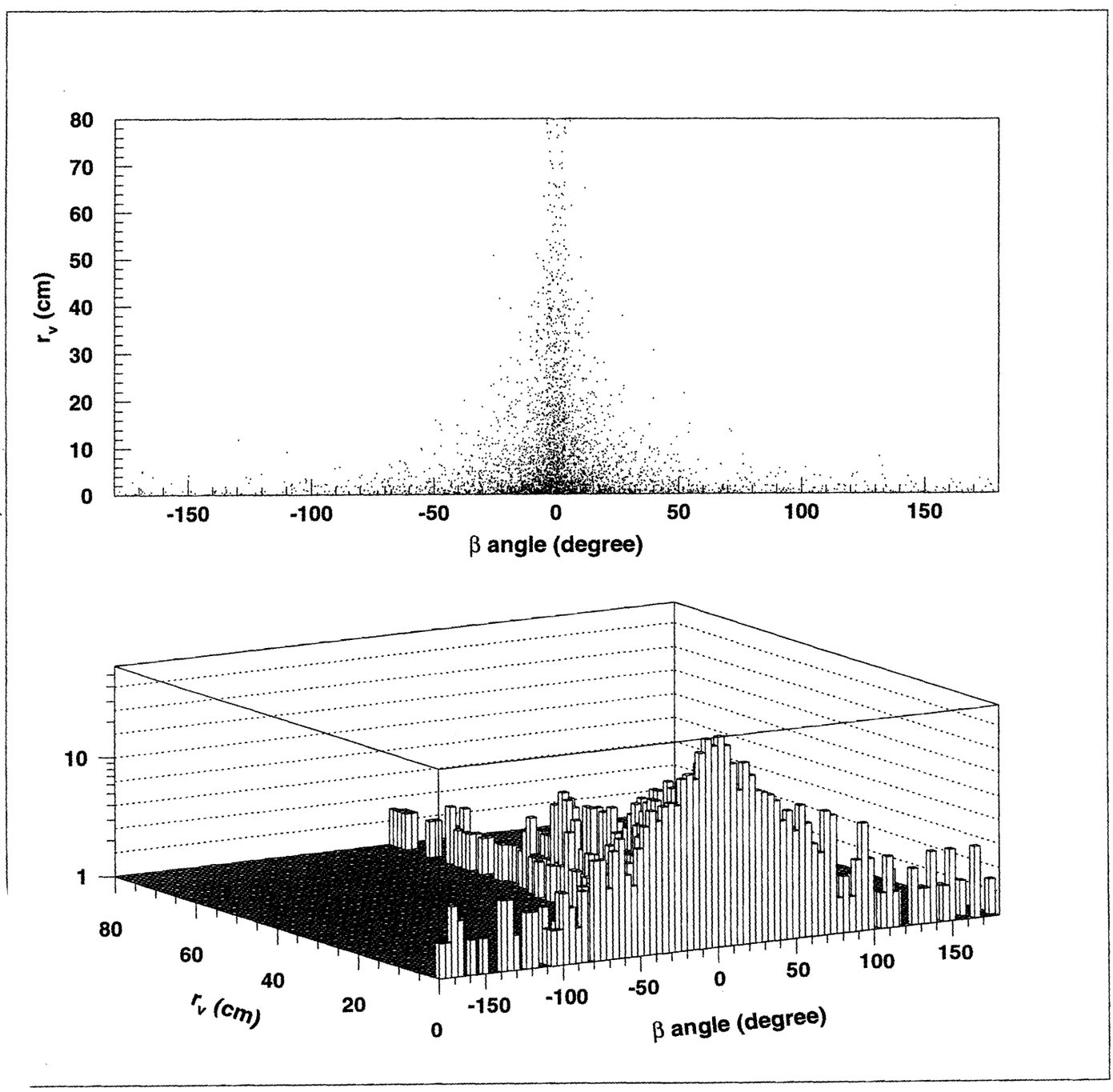


Figure 7(a)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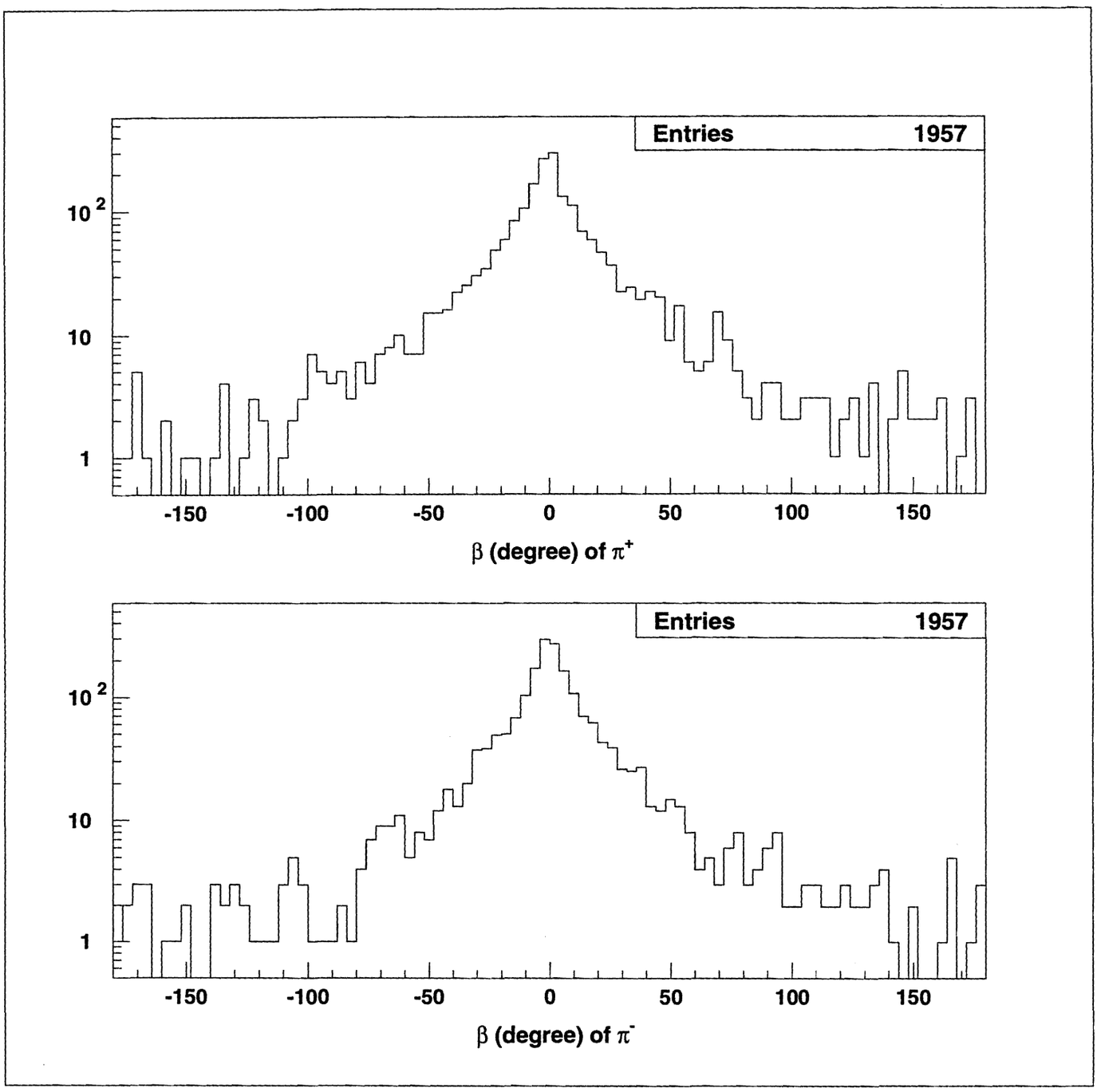
70
60
50
40
30
20
10
0
r_v (cm)
-150
-100
-50
0
50
100
150
β angle (degree)
10
1
80
60
40
20
0
r_v (cm)
-150
-100
-50
0
50
100
150
β angle (degree)

Figure 7(b)


Entries 1957
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10
1
-150
-100
-50
0
50
100
150
β (degree) of π+
Entries 1957
10 2
10
1
-150
-100
-50
0
50
100
150
β (degree) of π-

Figure 8