EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PH I/COM-69/48
20 October, 1969

PHYSICS I

ELECTRONICS EXPERIMENTS COMMITTEE

ADDENDUM

to

PROPOSAL: MEASUREMENT OF THE DIFFERENTIAL CROSS-SECTION for $\bar{p}p \rightarrow \bar{p}p$, $\pi^+\pi^-$, K^+K^-, between 0.6 and 2.0 GeV/c

(PH I/COM-69/33)

by

RHEL/QMC/DNPL/LIVERPOOL

Experimental Background

Since our proposal was submitted in June, 1969, some relevant new data has been published by a BNL/Rochester/Cal. Tech.(10) collaboration.

In the elastic channel they have measured the backward differential cross-section ($\cos\vartheta^* < -0.88$) between 0.7 and 2.2 Gev/c, fig. A1. They see marked structure with a pronounced dip at 0.9 Gev/c but have not explored the region in sufficiently fine mass steps to observe detailed structure of the nature seen by Cline (11) et al.

The data has been interpreted in two ways.

(i) A diffraction model following the parameterisation of Daum (12) et al. is consistent with their data. However the dip in the backward cross-section at 0.9 Gev/c corresponds to a dip at $t \sim -.7$ GeV^2. No such structure appears in the data of Daum et al at 1.73 Gev/c where diffraction minima are evident at $t \sim -0.4$ GeV^2 and ~ -1.5 GeV^2. If a diffraction model fits the data, its parameters must vary with energy. The suggested variation is qualitatively consistent with the shape of the total cross-section.

(ii) A resonance model, where the resonance parameters have been taken from the total cross-section enhancements of Abrams(13) et al. gives a backward cross-section of approximately the correct shape but slightly larger magnitude.

It is extremely difficult to distinguish between these two interpretations with data over this limited angular range.

The same collaboration (14) has studied the di-boson channels ($\pi^+\pi^-$, K^+K^-) in the momentum range 0.7 - 2.4 Gev/c. The angular range covered is $|\cos\vartheta^*| \geq .65$, but the sign of the outgoing meson is measured only in the range $|\cos\vartheta^*| \geq .85$. The data has been combined with that of Fong et al $|\cos\vartheta^*| < .7$, which has no sign determination, in order to produce folded angular distributions. These have been fitted by a series of even Legendre polynomials.

$$\frac{d\sigma}{d\Omega}(\vartheta^*) + \frac{d\sigma}{d\Omega}(\pi - \vartheta^*) = \sum_{\ell=0}^{L} c_\ell P_\ell(\cos\vartheta^*) \qquad \ell\text{-even.}$$

Figure A2 shows the Legendre coefficients obtained for ($\pi^+\pi^-$) and (K^+K^-). The authors have shown that the data in the $\pi^+\pi^-$ channel is consistent with resonances at 2120 MeV (Γ = 249MeV, J = 3) and 2290 MeV (Γ = 165 MeV, J = 5). The relation between these and the T and U resonances of the missing mass experiment(15) is not clear, see table 1 in the original proposal.

The current experimental situation in the elastic and di-boson channels is shown in figure A3. The range of $\cos\vartheta^*$ covered in the elastic channel is indicated by the vertical extent of the symbols representing the work of different groups. The arrows indicate the momenta at which there exists angular distributions for $\pi^-\pi^+$ and K^-K^+, Bizzari(16) et al. have very limited statistics. The S, T and U states from the missing mass experiment are shown along with the total cross-section enhancements and the resonant states proposed by Cline(11) et al and Nicholson(14) et al.

Proposed Experiment

The proposed experiment is now a measurement of all three channels, elastic, $\pi^+\pi^-$ and K^+K^- over the full angular range from 0.6 - 2.0 Gev/c. In the di-boson channels the experiment will have the odd and even Legendre coefficients available for interpretation.

$\pi^+\pi^-$ and K^+K^- Channels

The boson channels are simpler to interpret than the elastic scattering since they have spin = 0. They are also more selective as shown by the quantum numbers listed in table A1.

(i) Parity conservation implies $L = J \pm 1$ (only the $S = 1$, triplet $\bar{p}p$ state contributes).

(ii) G parity implies $J + 1$ is even for $\pi^+\pi^-$, but not for K^+K^- (L = Orbital angular momentum in the $\bar{p}p$ channel, and J = the total angular momentum)

The differential cross-section is given by (17):

$$k^2\frac{d\sigma}{d\Omega} = \left|\sum_J\left(\sqrt{\frac{(J+1)}{(2J-1)}}A_{J-} + \sqrt{\frac{J}{(2J+3)}}A_{J+}\right)Y_J^1\right|^2 + \left|\sum_J\left(\sqrt{\frac{J}{(2J-1)}}A_{J-} - \sqrt{\frac{(J+1)}{(2J+3)}}A_{J+}\right)Y_J^0\right|^2 \quad (1)$$

where A_{J-} is the amplitude for $L = J-1$, A_{J+} the amplitude for $L = J+1$, and Y_J^m are the usual spherical harmonics. Since there is cylindrical symmetry there are no interference terms of the form $Y_J^1\ Y_J^0$.

The expression (1) can be written in terms of any orthogonal set such as the Legendre polynomials:

$$\frac{d\sigma}{d\Omega} = \sum_{n=0}^{2J_{max}} C_n P_n$$

The C_n can be expressed in terms of Re $A^*_J\,A_{J'}$, as shown in table A2 for leading terms for $J \leqslant 6$. It will be seen that:

(i) Even/odd coefficients arise from even/odd parity terms $A^*_J A_{J'}$

(ii) Coefficients for the "unlike" terms $A^*_{J+}\,A_{J'-}$ are generally much larger than the "like" terms $A^*_{J+}\,A_{J'+}$, $A^*_{J-}A_{J'-}$ so that resonance - background interference is likely to dominate resonance-squared terms.

Analysis of $\pi^+\pi^-$ and K^+K^-

There are 2J+1 complex amplitudes and 2J+1 real coefficients fitted to the data at each energy. Some form of energy dependent parametrisation of the amplitudes will be required to obtain a solution, and we could use a method similar to that employed successfully in the low energy $\bar{K}p$ analysis. A resonant amplitude requires 3 parameters (E_R, Γ, and coupling $\sqrt{\Gamma_{\bar{p}p}\,\Gamma_{\pi\pi}}$) and a non-resonant one 4 parameters, for a local linear fit. Assuming we attempt to fit five energies and up to 4 resonant amplitudes we require a total of 8J parameters to be obtained from 10J + 5 Legendre coefficients.

Since (1) is a sum of the squares of two complex terms there will be ambiguities similar to the Minami ambiguities. However it can be seen from table A2 that these are unlikely to affect conclusions about higher spin, only whether the A_{J+} or A_{J-} amplitude is responsible.

We would have twice as many coefficients C_n to fit to partial wave amplitudes as the existing experiments with "folded" angular distributions, and be sensitive to odd parity terms which are absent in the "folded" distributions.

Experimental Set-up.

We have redesigned the experiment using an AEG magnet instead of the double-C arrangement shown in the original proposal. This smaller magnet has a much better field and would be rotated about the hydrogen target. The full angular range in the centre of mass can be covered with the magnet and spark chambers in just two positions (see fig. A4) whereas the fixed double-C arrangement does not cover the full angular range for $\pi^+\pi^-$ and K^+K^-. In addition we have a more flexible system. Acceptance curves using the AEG magent are shown in Figures A5, A6. Table A3 gives an estimate of the data collection time based on running at 15 equally spaced momenta.

For comparison acceptance curves at 1.0 Gev/c for a single C magnet are also presented, see fig. A7. These would imply an increase of a factor 1.6 in running time. There is the serious disadvantage that it would be considerably more difficult to shield our magnetic core spark chamber system from the effects of the large fringe field.

Spark Chambers

With the AEG magnet the largest chamber is now 260 cm x 75 cm. Magnetic shielding studies on the AEG magnet indicate that we can use core, rather than capacity, read out. This is attractive for reasons of cost and a preference for a well-tried system.

REFERENCES

10. Yoh et al., PRL 23,506 (1969)

11. Cline et al., PRL 21,1268 (1968)

12. Daum et al, Nuclear Physics B6, 617 (1968)

13. Abrams et al., PRL 18,1209 (1967)

14. Nicholson et al., PRL 23,603 (1969)

15. Focacci et al., PRL 17,890 (1966)

16. Bizzari et al., Università di Roma Nota Interna n.213

17. Blatt and Biedenham Rev. Mod. Phys. 24,258 (1952)

18. Conforto et al, Nuovo Cimento 54A, 441 (1968)

19. Barish et al., PRL 17,720 (1966)

20. Lys et al., PRL 21,1116 (1968)

TABLE A1

Quantum Numbers for $\bar{p}$ p, $\pi^+\pi^-$ and K^+K^- Systems

Q. N°	$\bar{p}$ p	$\pi^+\pi^-$	K^+K^-
P	$(-1)^{L+1}$	$(-1)^J$	$(-1)^J$
C	$(-1)^{L+S}$	$(-1)^J$	$(-1)^J$
G	$(-1)^{L+S-I}$	$(-1)^{J+I} = +1$	$(-1)^{J+I}$

S = Channel spin

L = Orbital angular momentum of $\bar{p}$ p

J = Total angular momentum

I = Isospin

TABLE A2

Legendre Coefficients for $\bar{p}p \quad \begin{matrix}\pi^+\pi^- \\ K^+K^-\end{matrix}$

$J^\pm$	$J'^\pm$		C8	C9	C10	C11	C12
2+	6+		1.33				
3+	5+		1.17				
3+	6+			1.18			
4+	5+			1.10			
4+	6+		1.58		1.10		
5+	5+		0.76		0.53		
5+	6+			1.51		1.05	
6+	6+		0.88		0.73		0.51
4-	6-		1.77				
5-	5-		0.84				
5-	6-			1.59			
6-	6-		1.07		0.74		
2-	6+		-7.2				
3-	5+		-6.63				
3-	6+			-7.13			
4-	4+		-6.29				
4-	5+			-6.80			
4-	6+		-2.44		-7.26		
5-	4+			-6.53			
5-	5+		-2.41		-7.02		
5-	6+			-2.64		-7.46	
6-	2+		-5.60				
6-	3+			-6.25			
6-	4+		-2.33		-6.79		
6-	5+			-2.59		-7.26	
6-	6+		-1.45		-2.82		-7.69

Hence C11 = 1.05 Re $A^*_{5+} A_{6+}$ - 7.46 Re $A^*_{5-} A_{6+}$ - 7.26 Re $A^*_{6-} A_{5+}$

$Y = \cos\theta^*$

P_{IN} GeV/c	INTERNAL PROTONS $\times 10^{11}$	$\bar{p}$s /PULSE K	RUNNING TIME HRS	$\bar{p}p$ EVENTS $-1<Y<0$	$\bar{p}p$ EVENTS $-.95<Y<-.9$	TOTAL $\pi\pi$ EVENTS
·6	6	·063	120	790	105	252
·7	6	·24	60	1500	195	480
·8	6	·56	60	1390	180	1110
·9	6	1.1	40	1850	242	1480
1.0	6	2.2	20	1880	245	1500
1.1	6	4.0	16	2640	350	1890
1.2	6	7.0	16	4600	608	2800
1.3	6	11.0	16	7250	1030	3960
1.4	6	12.0	16	7930	1040	3800
1.5	3	12.0	16	7930	1040	3160
1.6	3	12.0	16	7930	1040	2520
1.7	3	12.0	16	7930	1040	1900
1.8	3	12.0	16	7930	1040	1640
1.9	3	12.0	16	7930	1040	1520
2.0	3	12.0	16	7930	1040	1260

SUMMARY ① TOTAL DATA TAKING TIME = 460 HRS
② TOTAL $\bar{p}p$ EVENTS = 460 K
③ TOTAL $\pi\pi$ EVENTS = 30 K
④ TOTAL KK EVENTS = 15K

ASSUMPTIONS
① BEAM RATES BASED ON DUBOC ET AL
$\Delta\Omega = 1.5$ msr $\Delta p/p = \pm 2\%$ SPILL = 400 ms
MAX INSTANTANEOUS RATE = 10^5 PARTICLES / SEC
$\pi : p = 3:1$ [1 - 2 GeV/c] [c.f. 1.5 : 1 AT BNL]
② CROSS SECTIONS FROM CLINE, YOH, DAUM, CONFORTO AND INTERPOLATION

TABLE A3

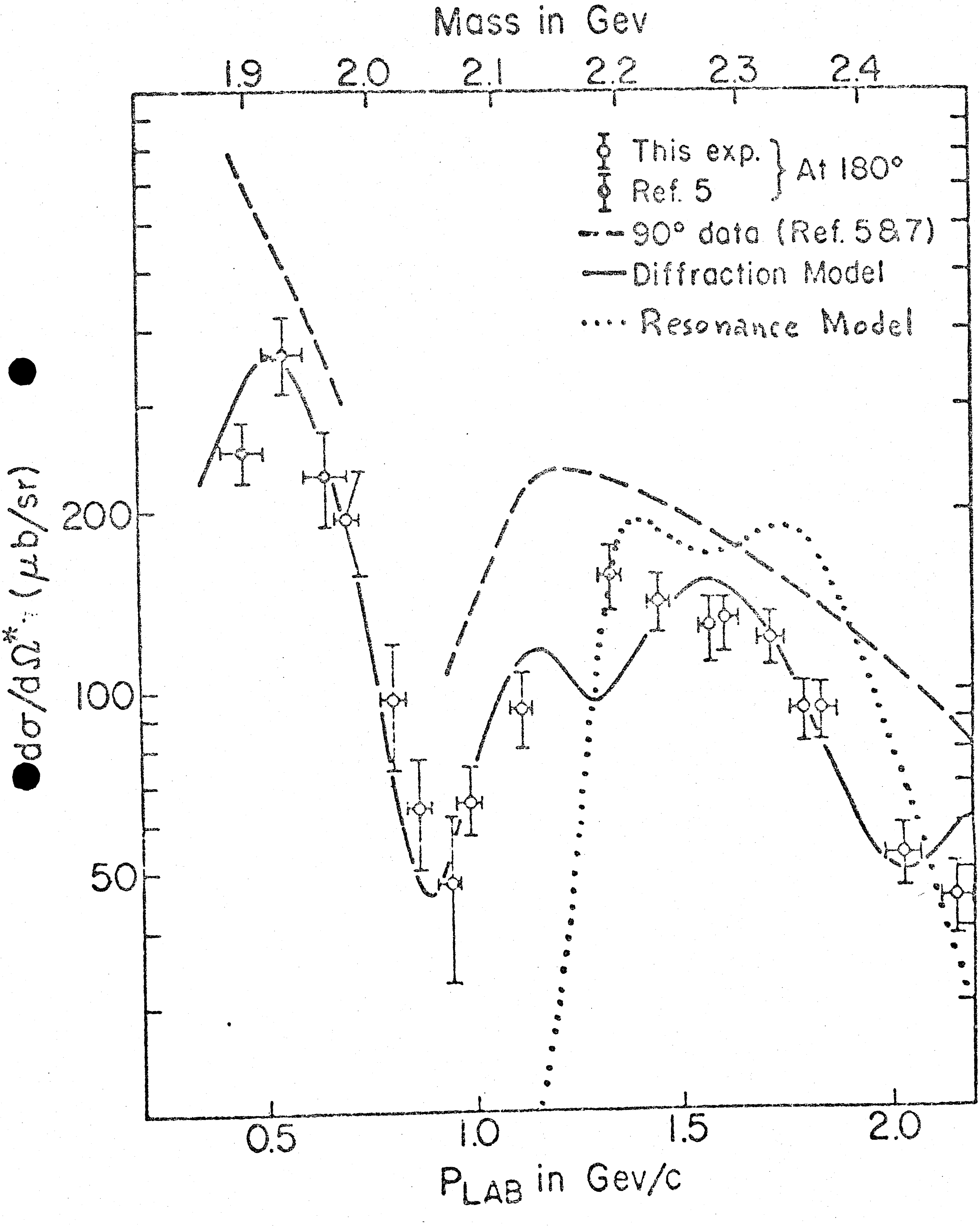
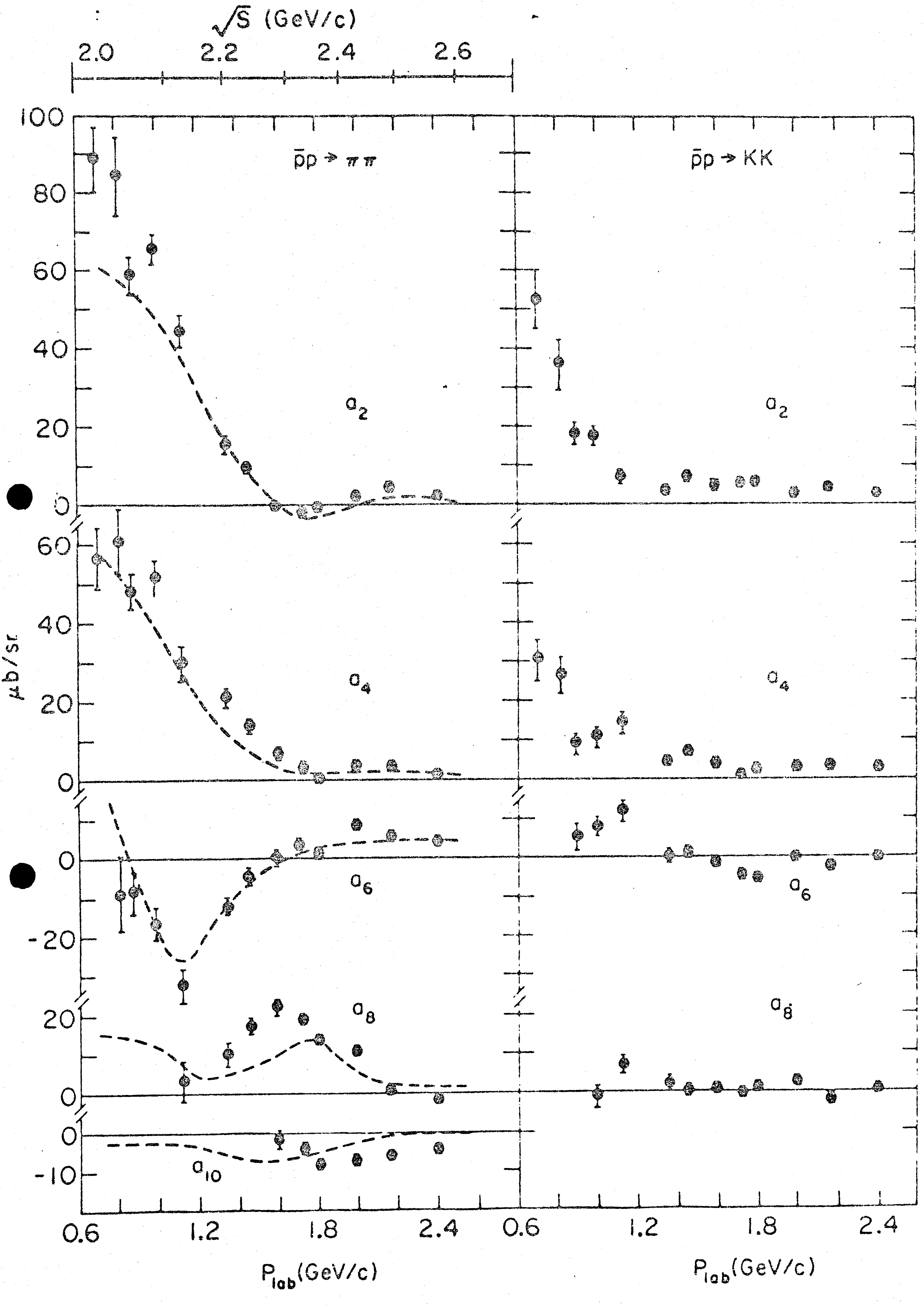
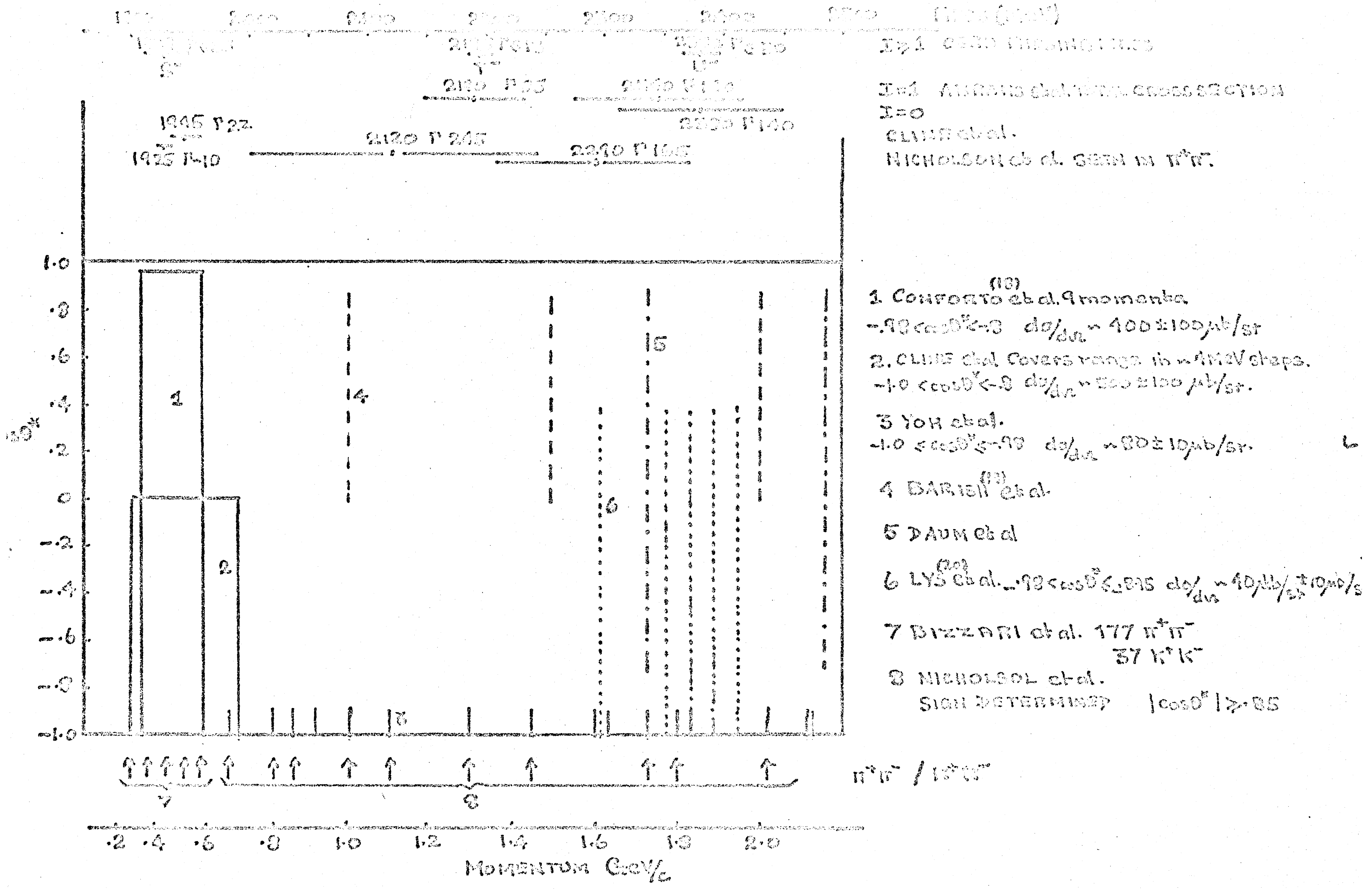

Mass in Gev
1.9
2.0
2.1
2.2
2.3
2.4
This exp.
Ref. 5
At 180°
90° data (Ref. 5&7)
Diffraction Model
Resonance Model
dσ/dΩ* (μb/sr)
200
100
50
0.5
1.0
1.5
2.0
P_LAB in Gev/c

Figure A1



7-267-69)

FIGURE ~~8~~ A2

2000
2100
2200
2300
2400
S*
T*
U*
2190 Γ 35
2360 Γ 140
1945 Γ22
1925 Γ10
2120 Γ 245
2290 Γ 165
I ≥ 1
I=1 ABRAMS et al. TOTAL CROSS SECTION
I=0
CLINE et al.
NICHOLSON et al. SEEN IN π⁺π⁻
1.0
.8
.6
.4
.2
0
-.2
-.4
-.6
-.8
-1.0
cos θ*
1
2
14
5
6
8
π⁺π⁻ / K⁺K⁻
7
8
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
MOMENTUM GeV/c
1. CONFORTO et al. 9 momenta (18)
-.98 < cos θ* < -.8 dσ/dΩ ~ 400 ± 100 μb/st
2. CLINE et al. Covers range in ~ 4 MeV steps.
-1.0 < cos θ* < -.8 dσ/dΩ ~ 500 ± 100 μb/sr.
3 YOH et al.
-1.0 ≤ cos θ* ≤ -.98 dσ/dΩ ~ 80 ± 10 μb/sr.
4 BARISH et al. (19)
5 DAUM et al
6 LYS et al. (20) -.98 < cos θ* ≤ -.875 dσ/dΩ ~ 40 μb/sr ± 10 μb/s
7 BIZZARRI et al. 177 π⁺π⁻
37 K⁺K⁻
8 NICHOLSON et al.
SIGN DETERMINED |cos θ*| ≥ .85

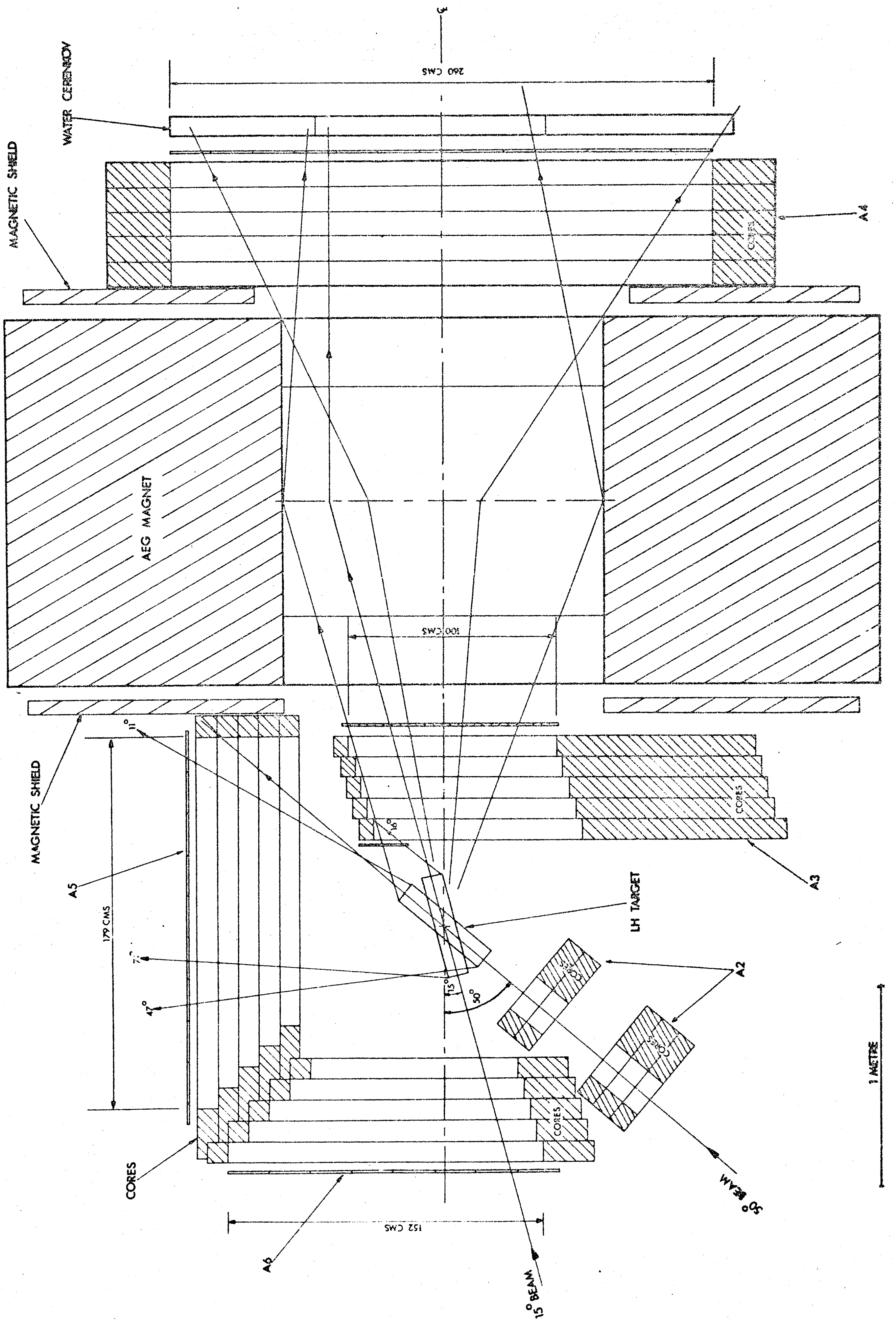
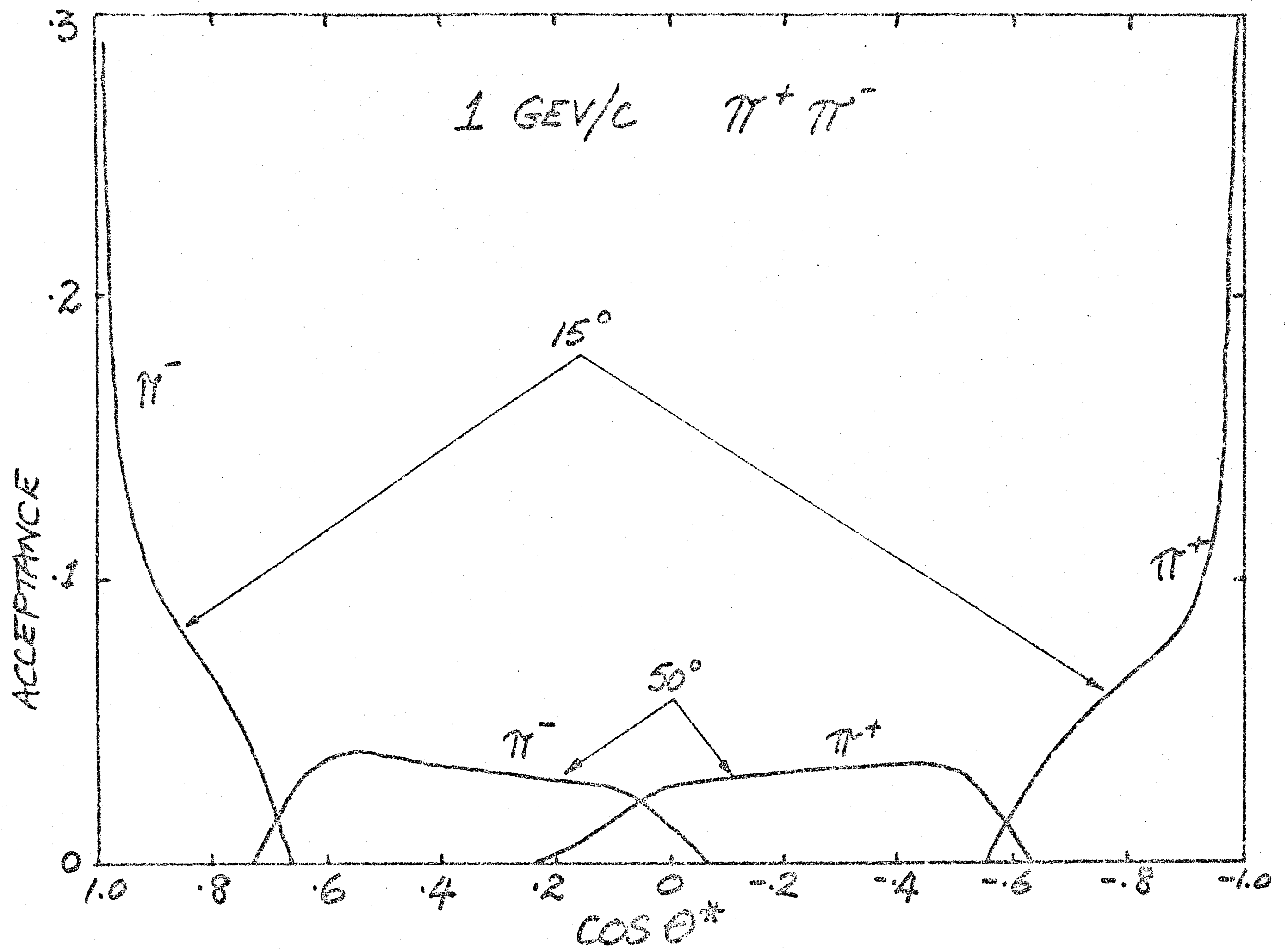
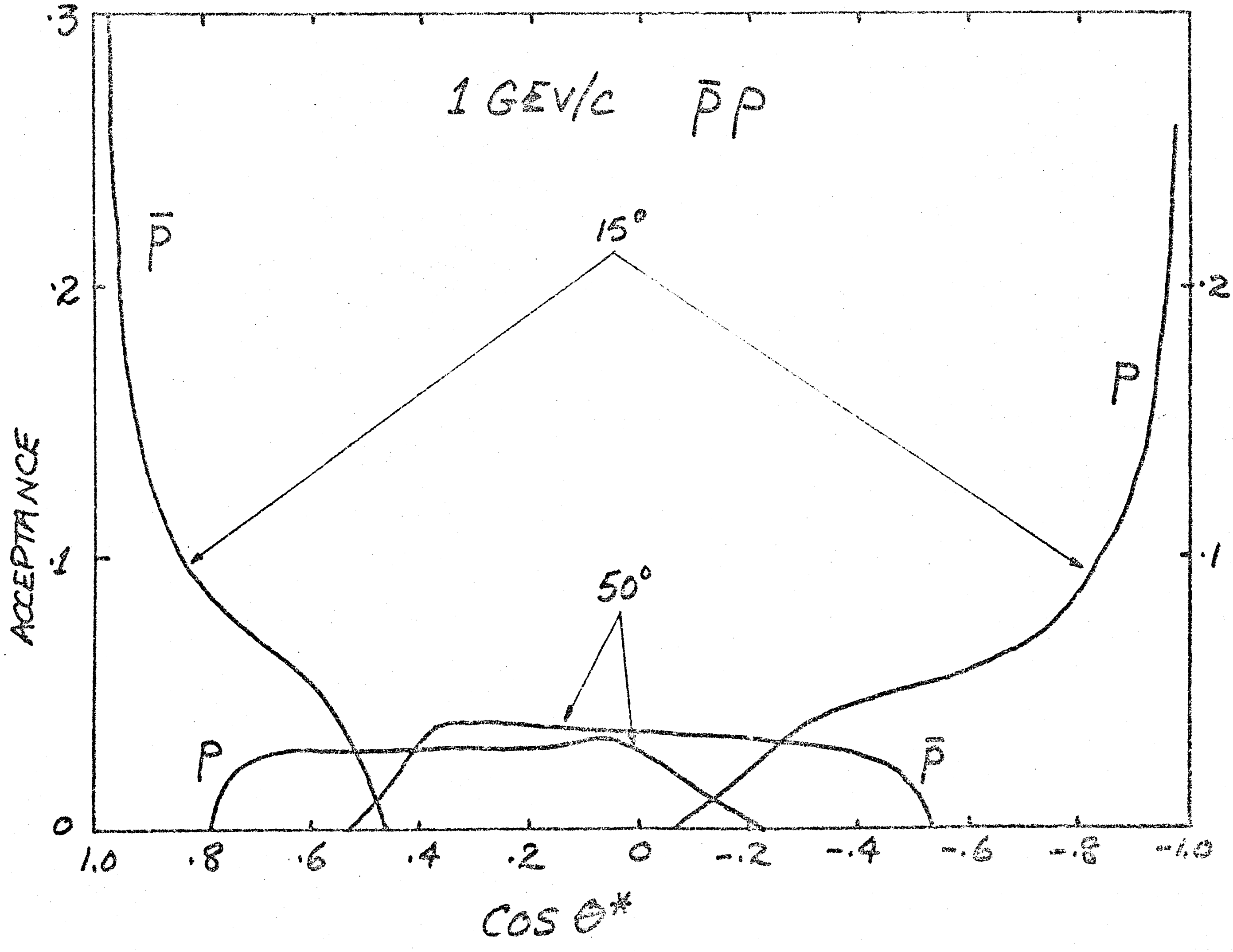

WATER CERENKOV
260 CMS
℄
MAGNETIC SHIELD
A4
CORES
AEG MAGNET
100 CMS
MAGNETIC SHIELD
11°
16°
CORES
A3
A5
179 CMS
LH TARGET
7°
47°
15°
50°
A2
CORES
CORES
CORES
A6
152 CMS
15° BEAM
50° BEAM
1 METRE

Figure A.4


1 GEV/C π+ π−
ACCEPTANCE
·3
·2
·1
0
15°
π−
π+
50°
π−
π+
1.0
·8
·6
·4
·2
0
-·2
-·4
-·6
-·8
-1.0
COS θ*


1 GEV/C P̄ P
ACCEPTANCE
·3
·2
·1
0
·2
·1
15°
P̄
P
50°
P
P̄
1.0
·8
·6
·4
·2
0
-·2
-·4
-·6
-·8
-1.0
COS θ*

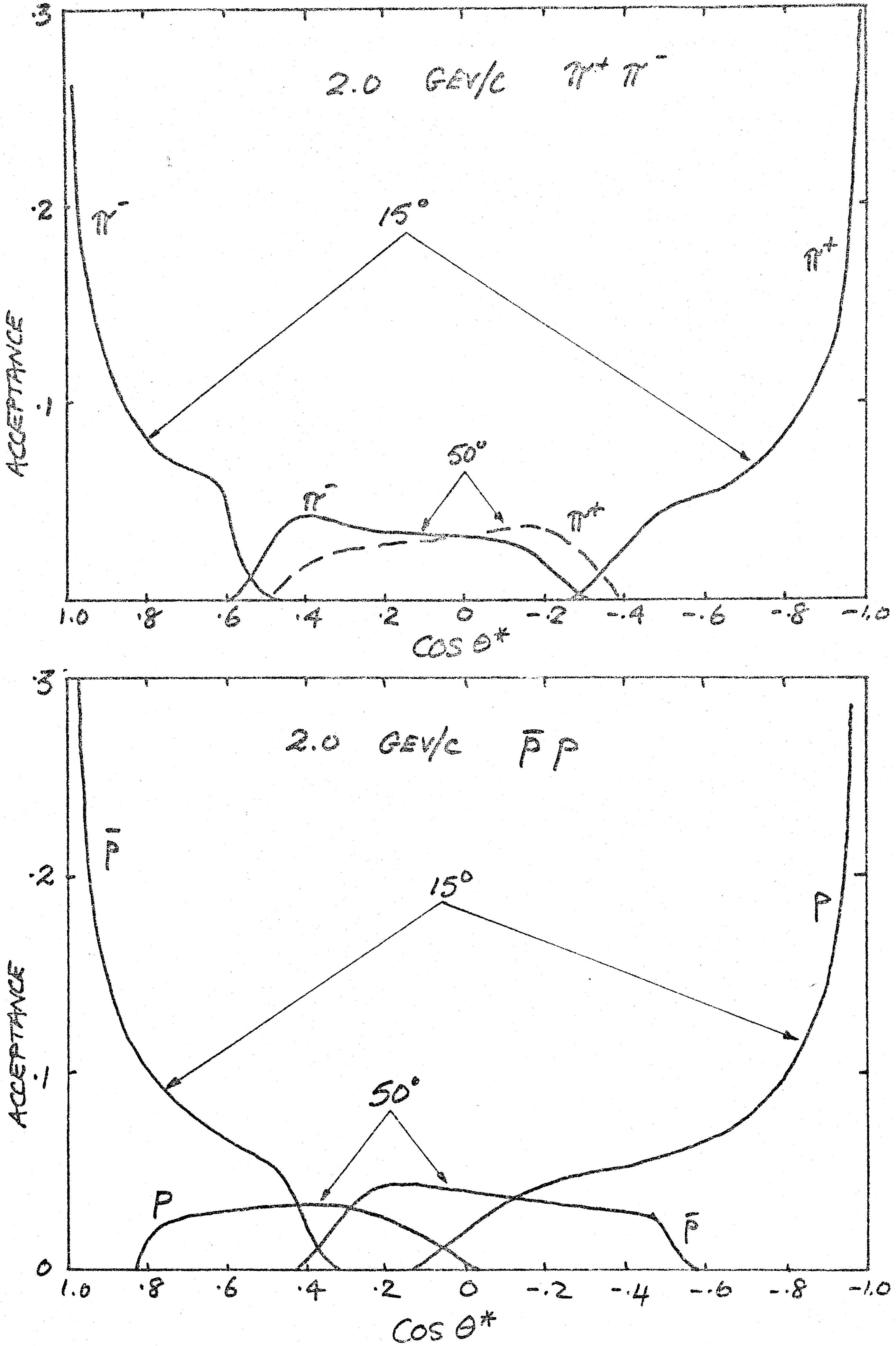

2.0 GEV/C π⁺ π⁻
ACCEPTANCE
3
·2
·1
π⁻
π⁺
15°
50°
1.0
·8
·6
·4
·2
0
-·2
-·4
-·6
-·8
-1.0
COS θ*
2.0 GEV/C P̄ P
ACCEPTANCE
·3
·2
·1
0
P̄
P
15°
50°
P
P̄
1.0
·8
·6
·4
·2
0
-·2
-·4
-·6
-·8
-1.0
COS θ*

FIGURE A6

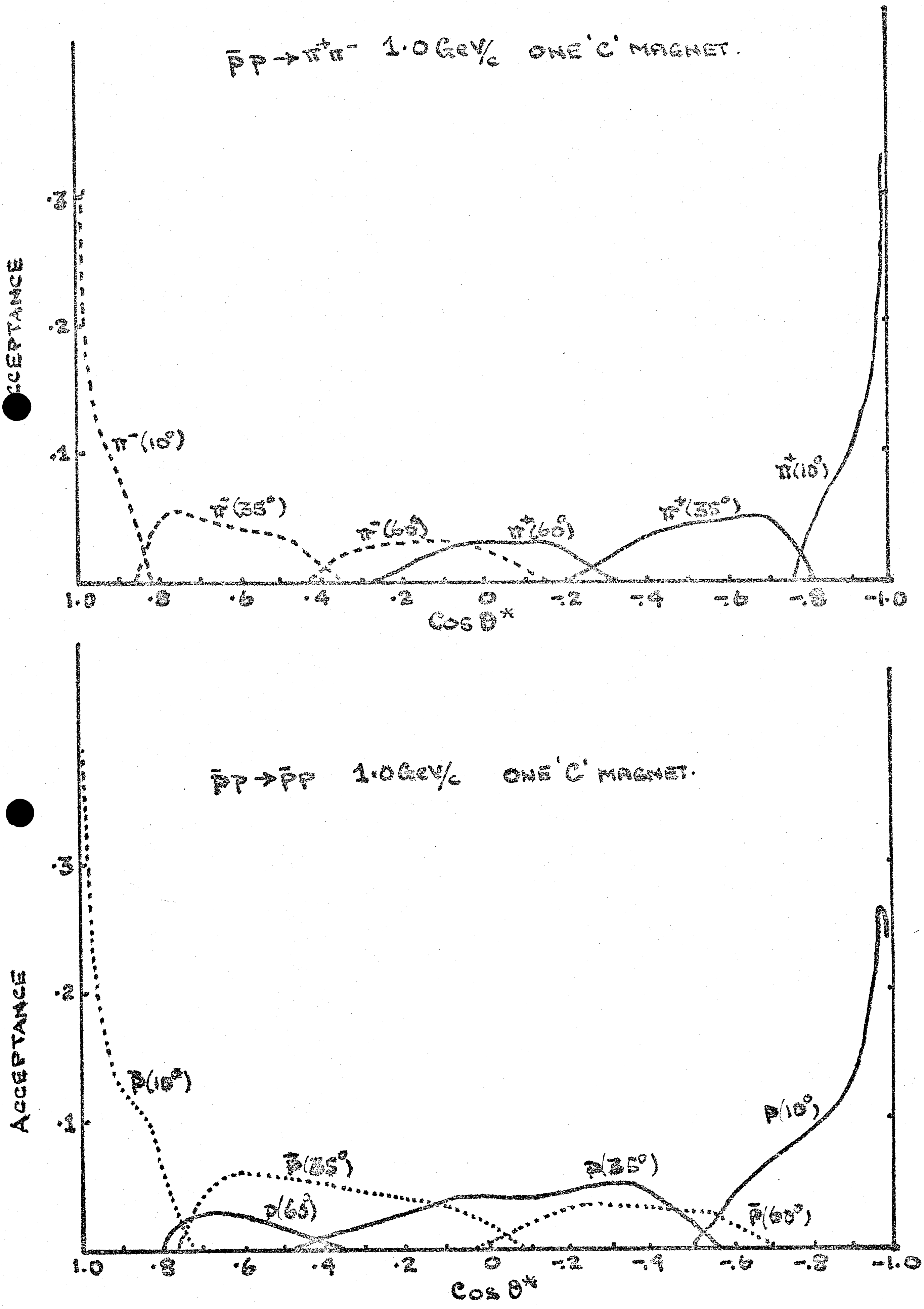

p̄p → π⁺π⁻ 1·0 GeV/c ONE 'C' MAGNET.
ACCEPTANCE
·3
·2
·1
π⁻(10°)
π⁻(35°)
π⁻(60°)
π⁺(60°)
π⁺(35°)
π⁺(10°)
1·0
·8
·6
·4
·2
0
-·2
-·4
-·6
-·8
-1·0
Cos θ*
p̄p → p̄p 1·0 GeV/c ONE 'C' MAGNET.
ACCEPTANCE
·3
·2
·1
p̄(10°)
p̄(35°)
p(60°)
p(35°)
p̄(60°)
p(10°)
1·0
·8
·6
·4
·2
0
-·2
-·4
-·6
-·8
-1·0
Cos θ*

FIGURE A7