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Hypernuclear & Strange Particle Physics

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Hyperon Resonances in Coupled Channels and Crystal Ball Data

- Introduction
- Kaon Scattering at BNL
- Analysis Details
- Preliminary Results
- Summary

Introduction

- Precise data on $\pi^- p$ and $K^- p$ interactions to various neutral final states were measured in 1998 with the Crystal Ball multi-photon spectrometer.
- The measurements were carried out for beam momenta up to $\sim$760 MeV/c at the C6 beam line of the BNL AGS.

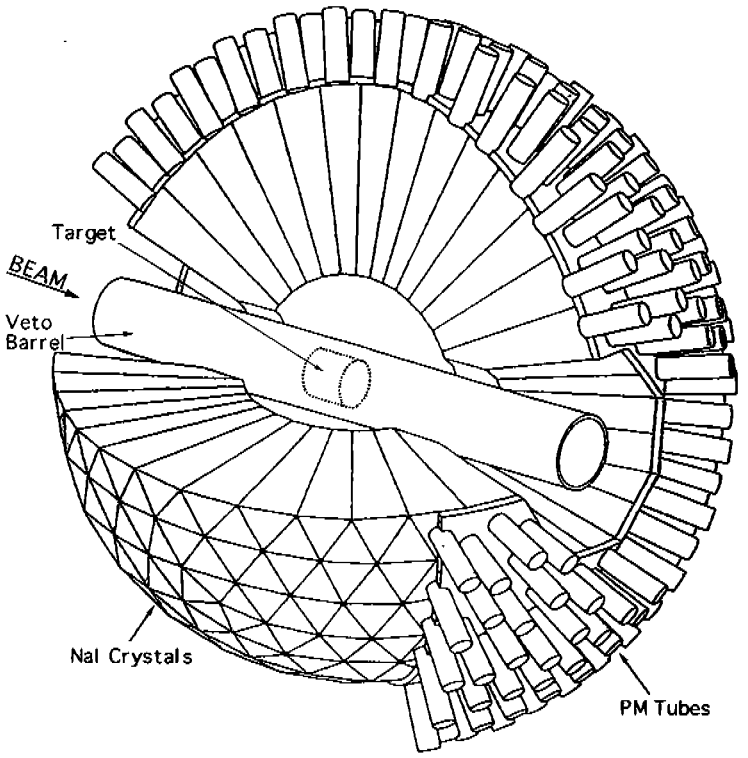


Figure 1: The Crystal Ball multi-photon spectrometer.

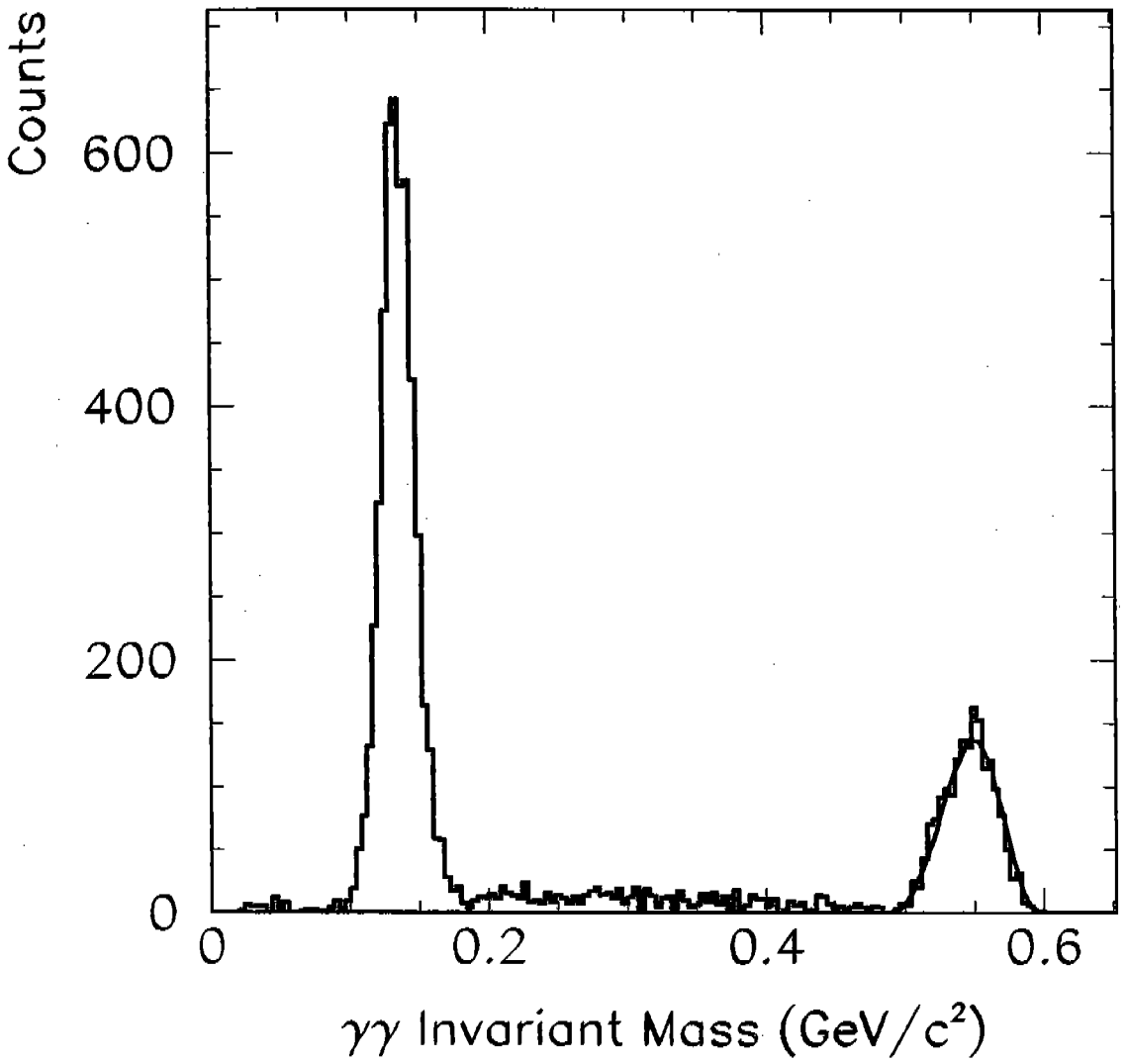
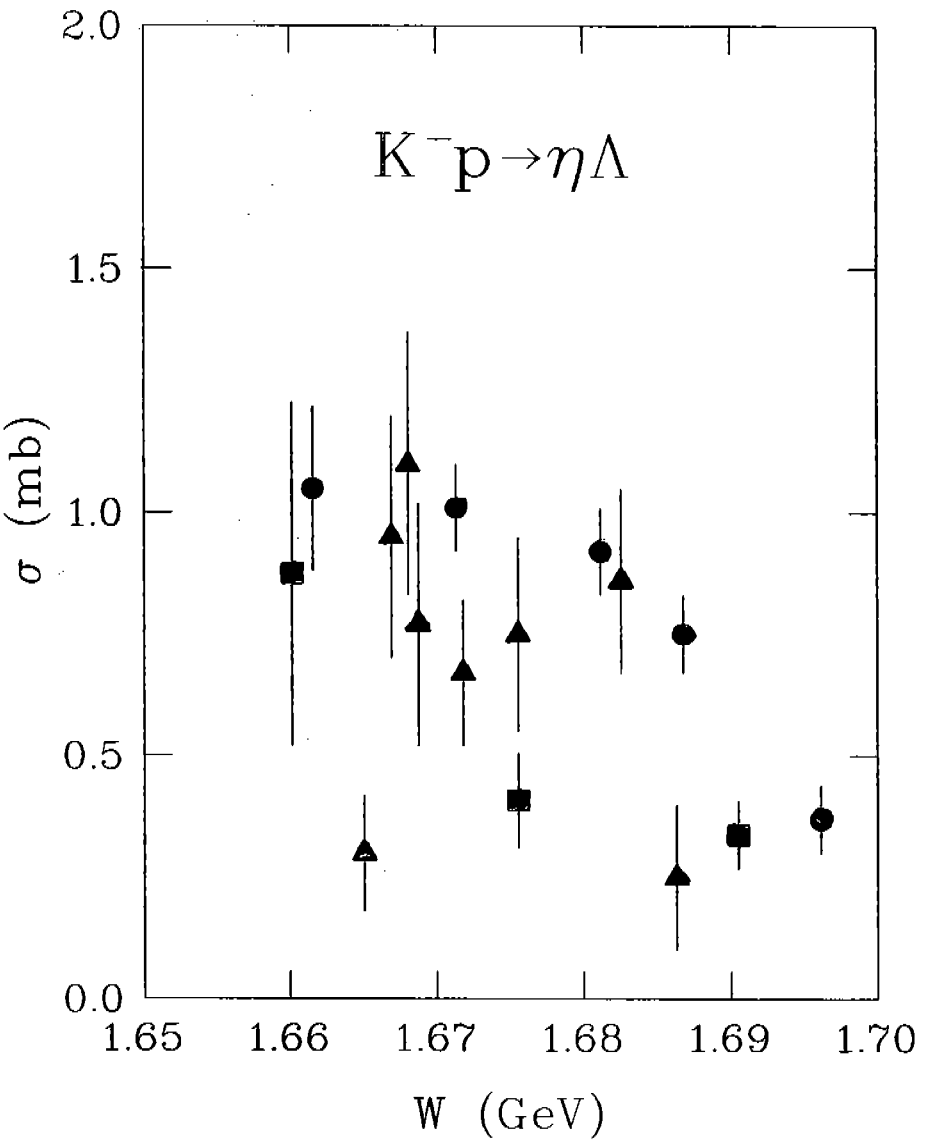
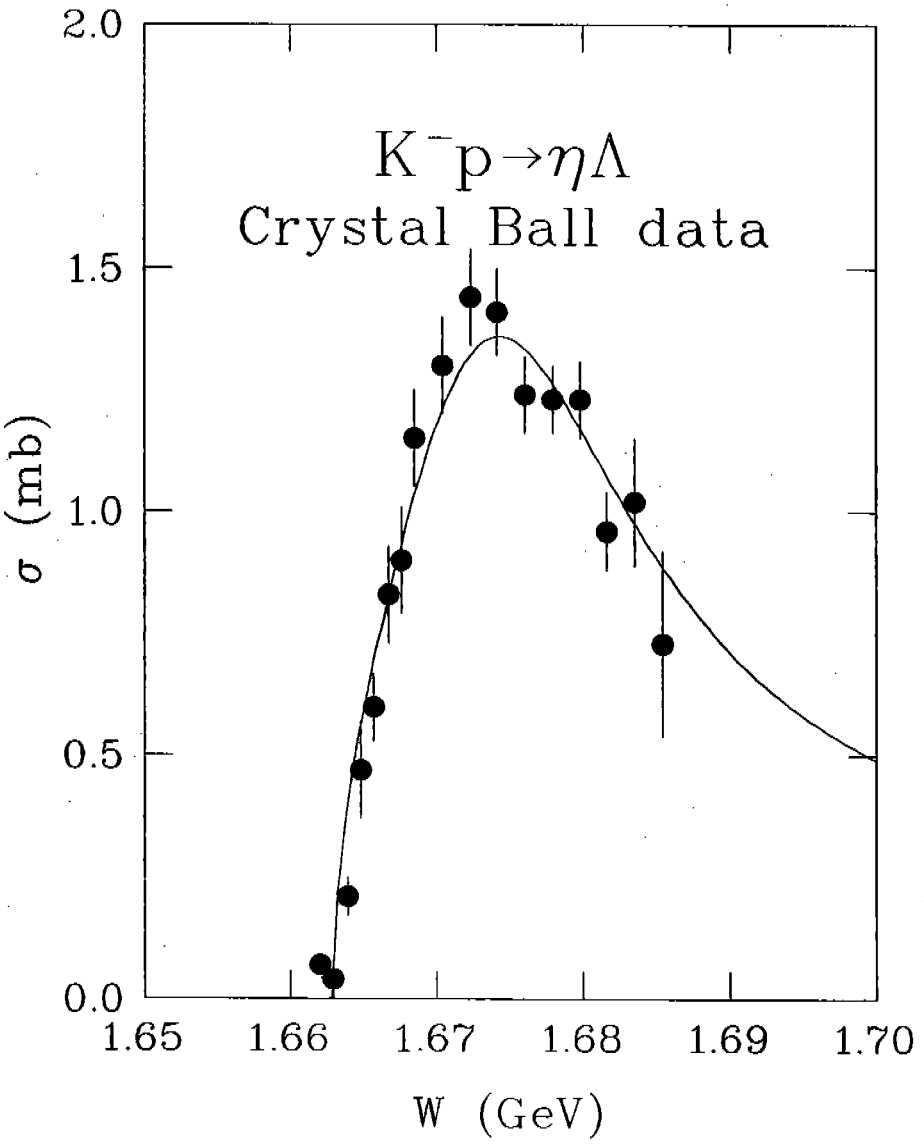


FIG. 11. The invariant mass of two photons in $K^- p \to \gamma\gamma\Lambda$ obtained with the high momentum beam. The normalized empty target spectrum has been subtracted. The results of the Monte Carlo simulation are shown by the smooth solid line. The first peak is due to $K^- p \to \pi^0\Lambda$ and the second one to $K^- p \to \eta\Lambda$.

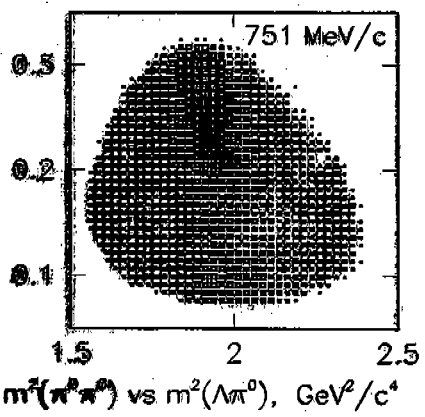


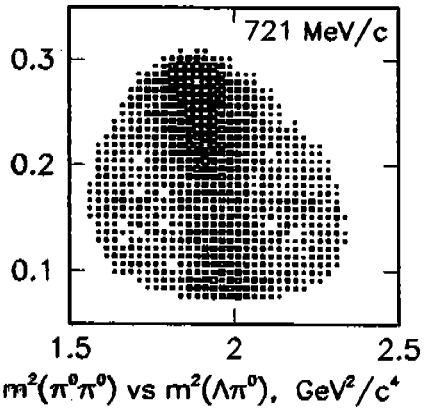
Total cross section for the $K^-p \to \eta\Lambda$ from selected older experiments. Triangles are from D. Berley *et al.*, Phys. Rev. Lett. **15**, 641 (1965); circles are from R. Armenteros *et al.*, Nucl. Phys. **B21**, 15 (1970); and squares are from G. W. London *et al.*, Nucl. Phys. **B85**, 289 (1975).

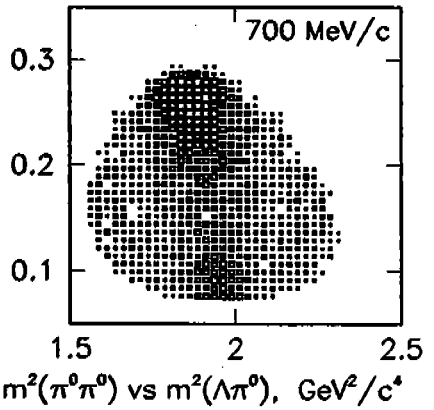


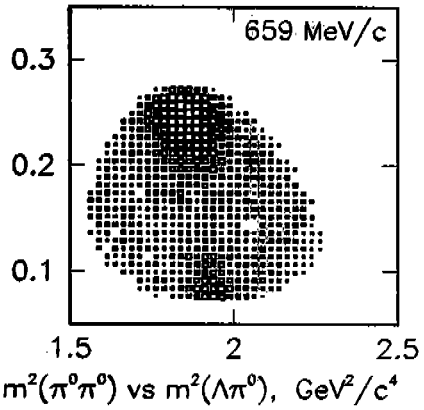
Total cross section for the $K^-p \to \eta\Lambda$ as measured by the Crystal Ball Collaboration. The curve shows the result of a unitary six-channel fit assuming S-wave dominance.

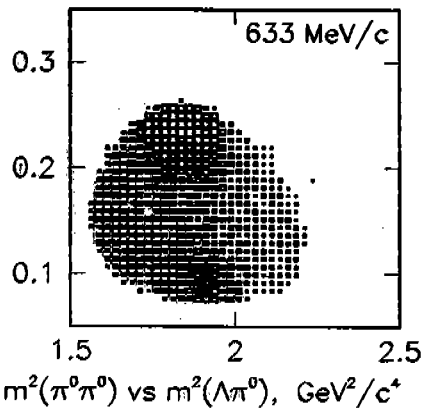
$K^- p \rightarrow \Lambda \pi^0 \pi^0$

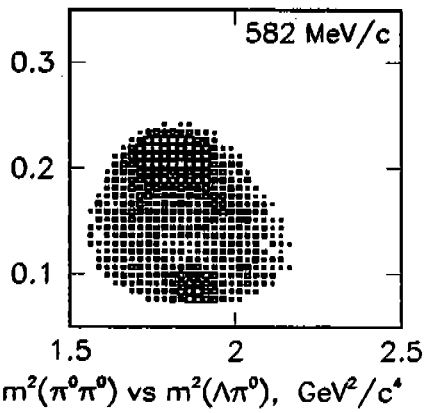


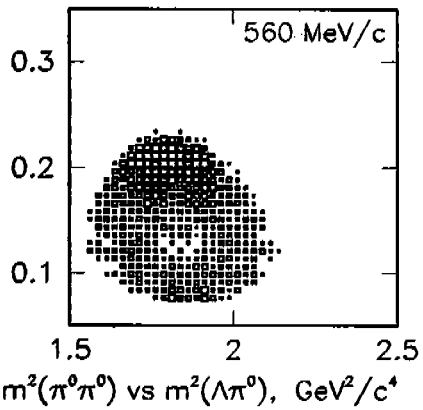


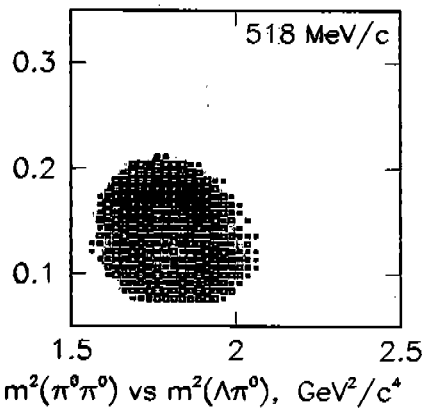




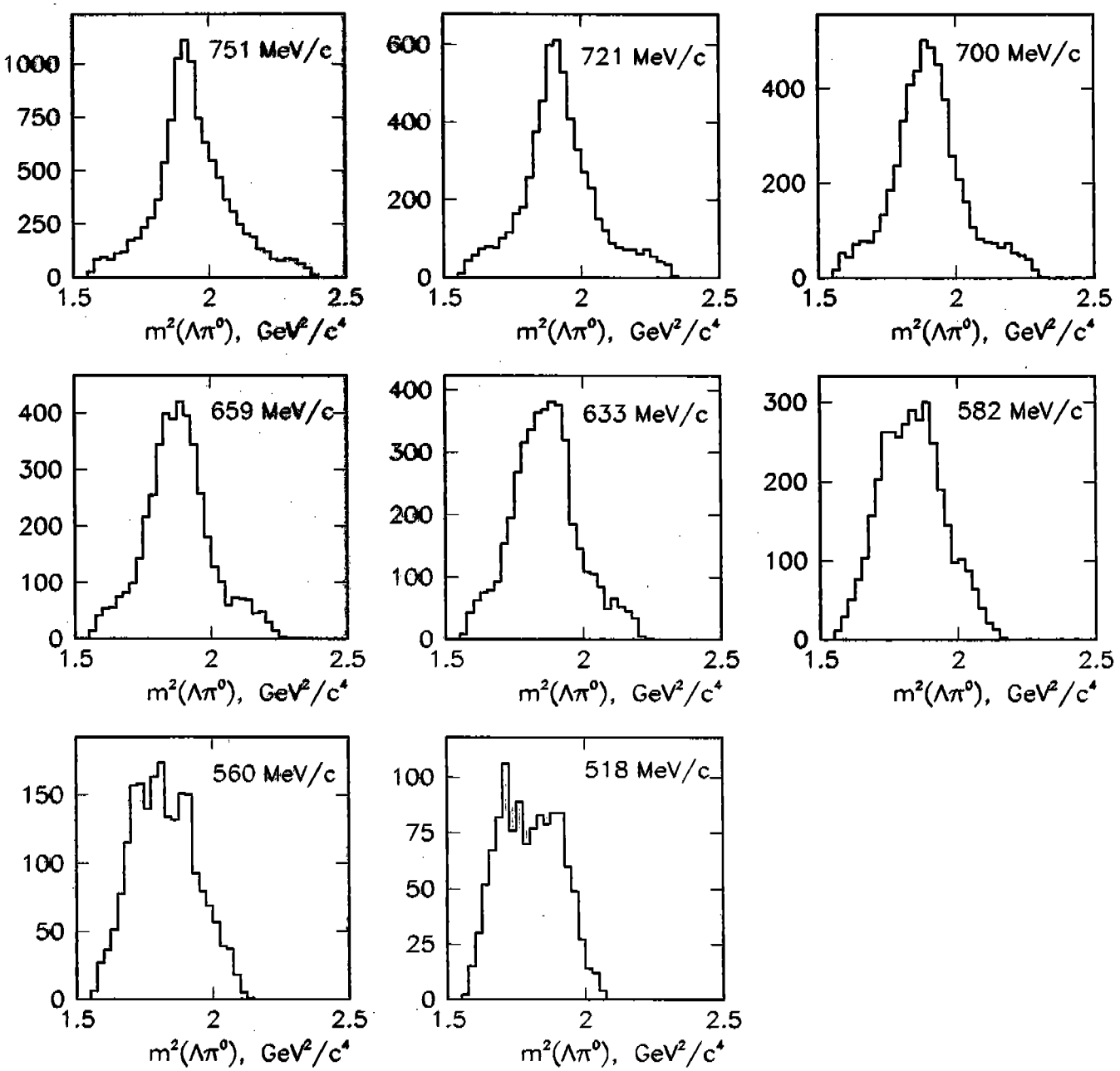








$K^- p \rightarrow \Lambda \pi^0 \pi^0$



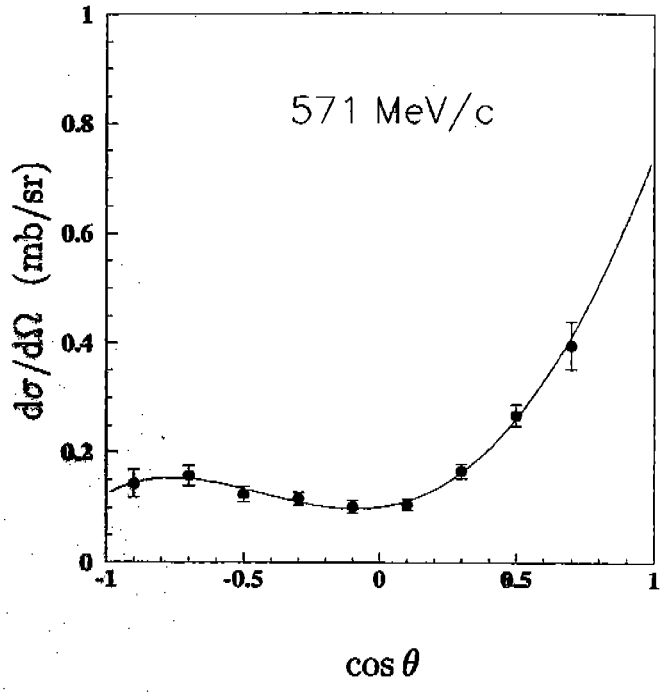


Fig. 4-44: Differential cross section for the reaction $K^- p \to \pi^0 \Lambda$ at 732 MeV/c from this analysis.

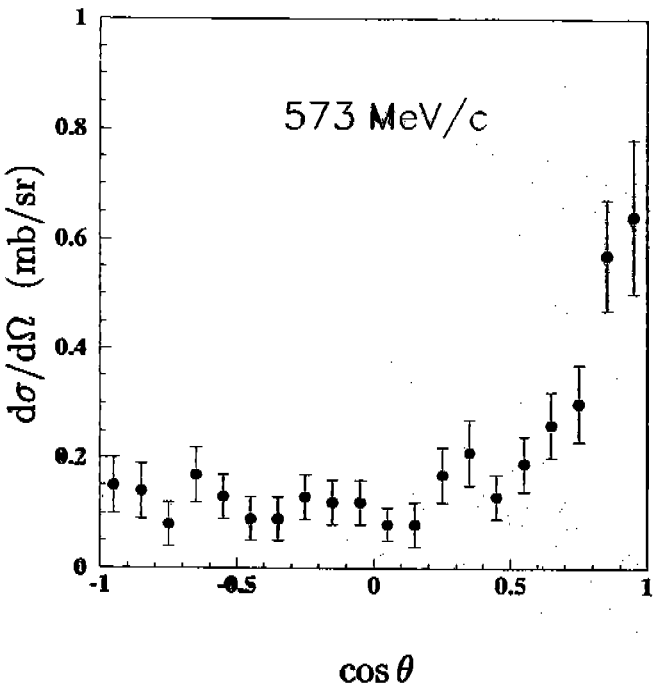


Fig. 4-45: Differential cross section for the reaction $K^- p \to \pi^0 \Lambda$ at 736 MeV/c from Armenteros *et al.*

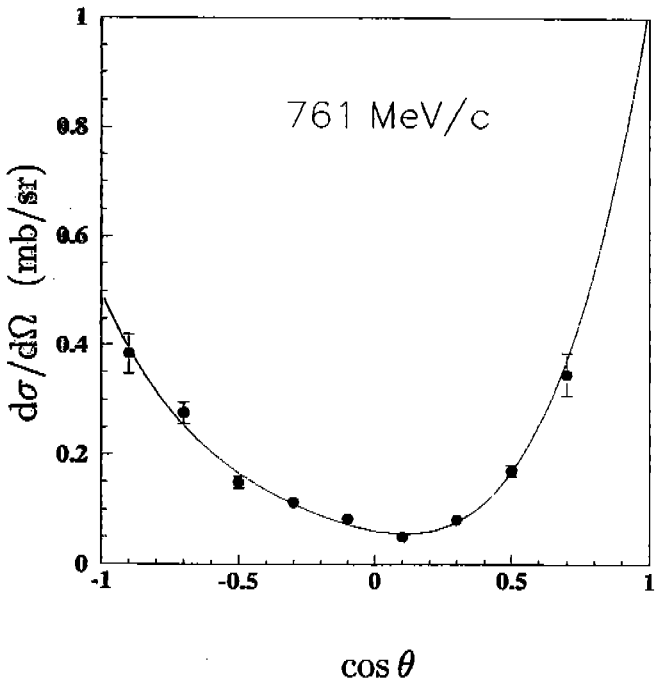


Fig. 4-46: Differential cross section for the reaction $K^- p \to \pi^0 \Lambda$ at 750 MeV/c from this analysis.

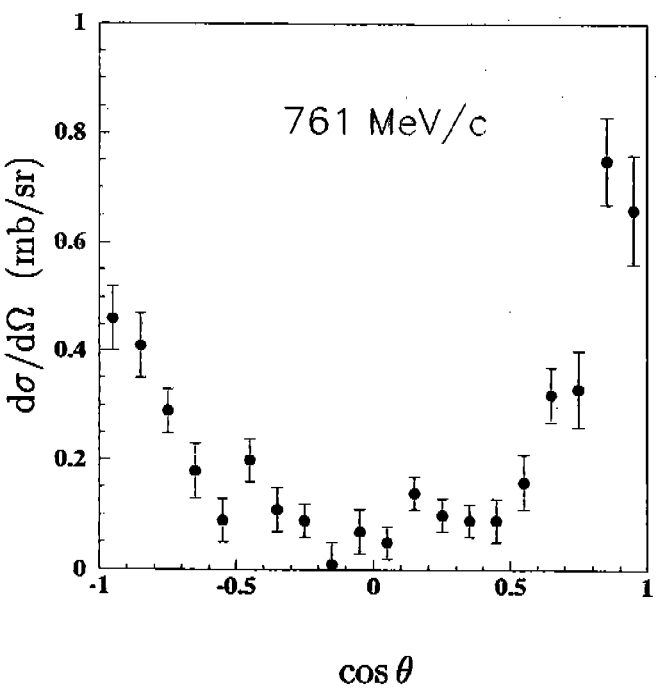


Fig. 4-47: Differential cross section for the reaction $K^- p \to \pi^0 \Lambda$ at 761 MeV/c from Armenteros *et al.*

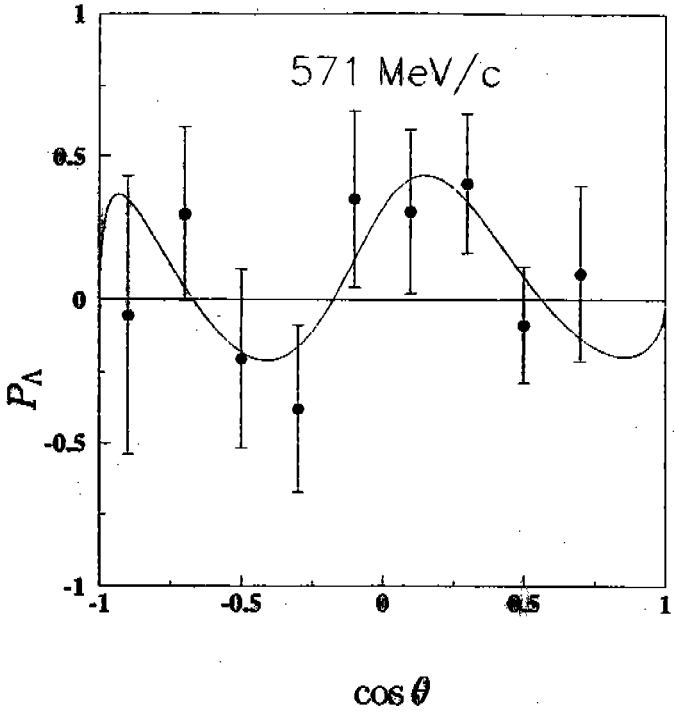


Fig. 4-48: Λ polarization at 732 MeV/c from this analysis.

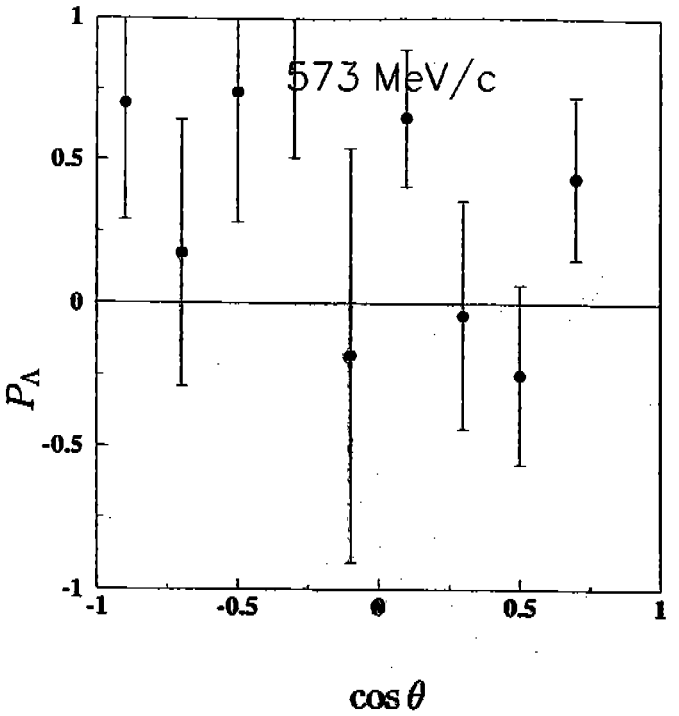


Fig. 4-49: Λ polarization at 736 MeV/c from Armenteros *et al.*

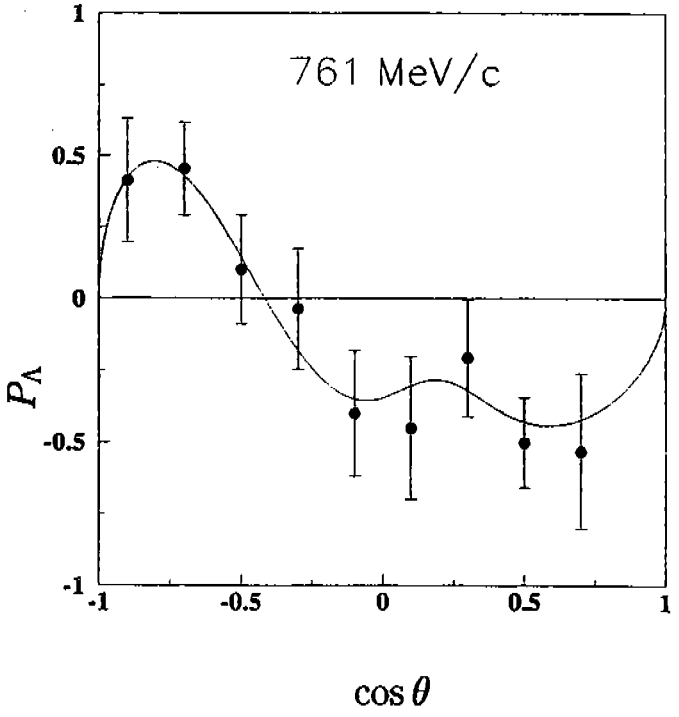


Fig. 4-50: Λ polarization 750 MeV/c from this analysis.

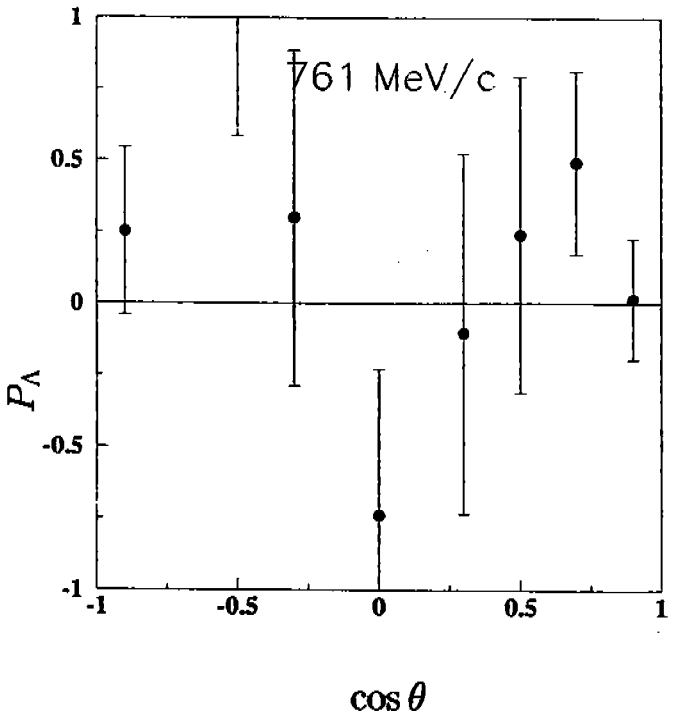
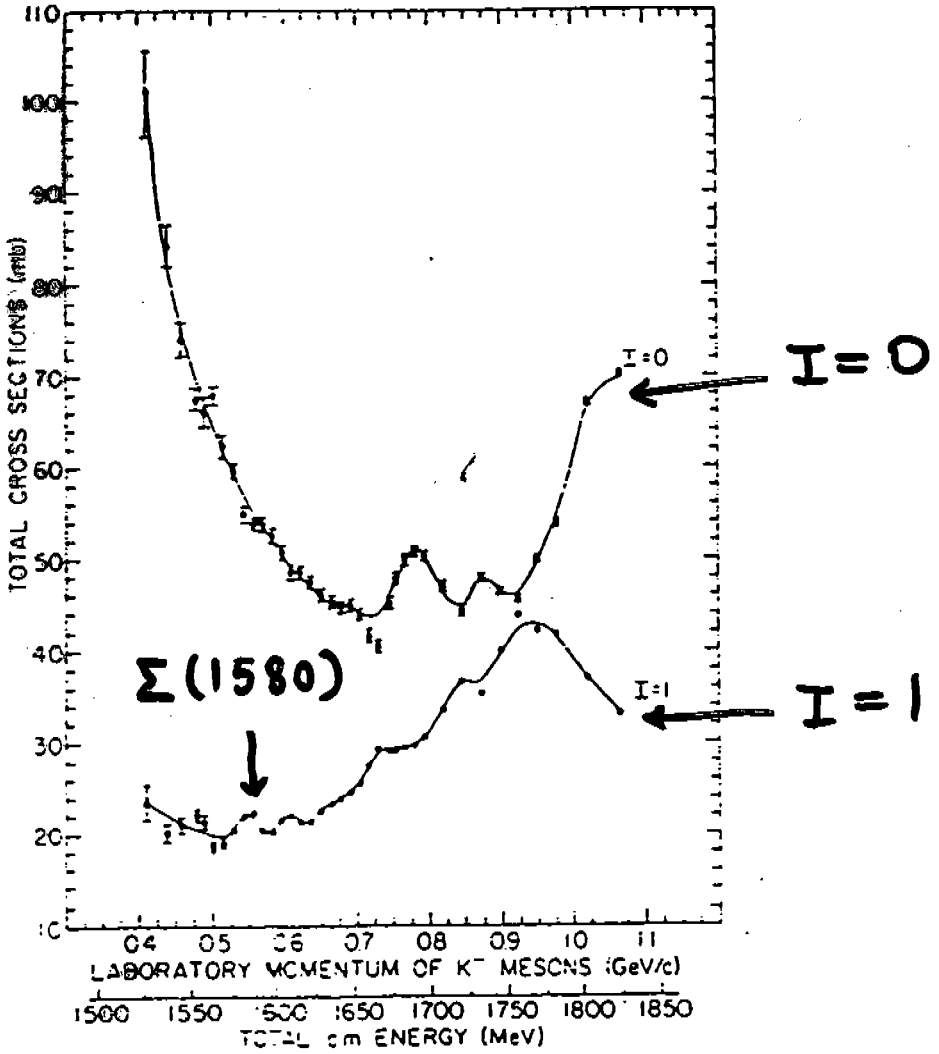
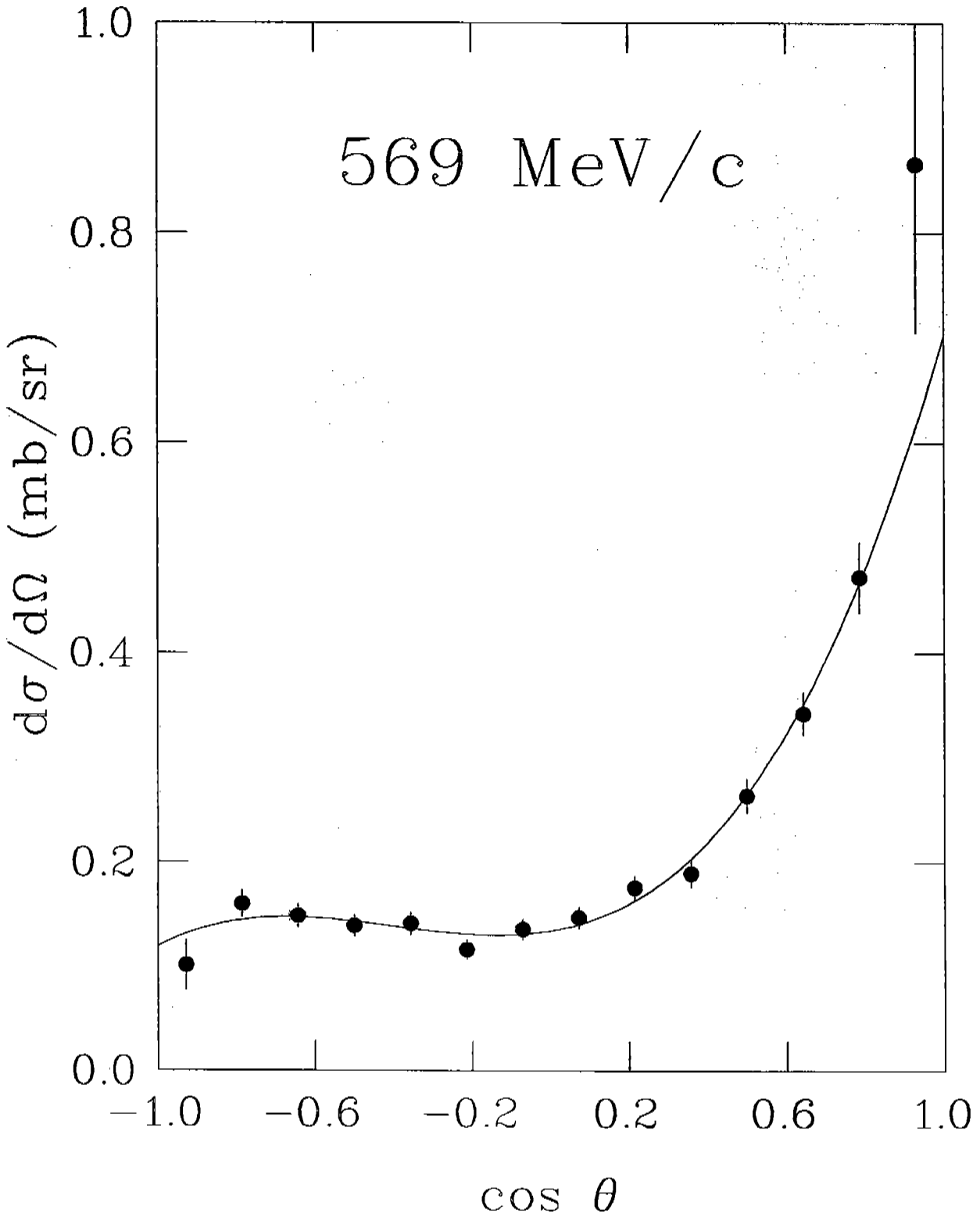


Fig. 4-51: Λ polarization at 761 MeV/c from Armenteros *et al.*

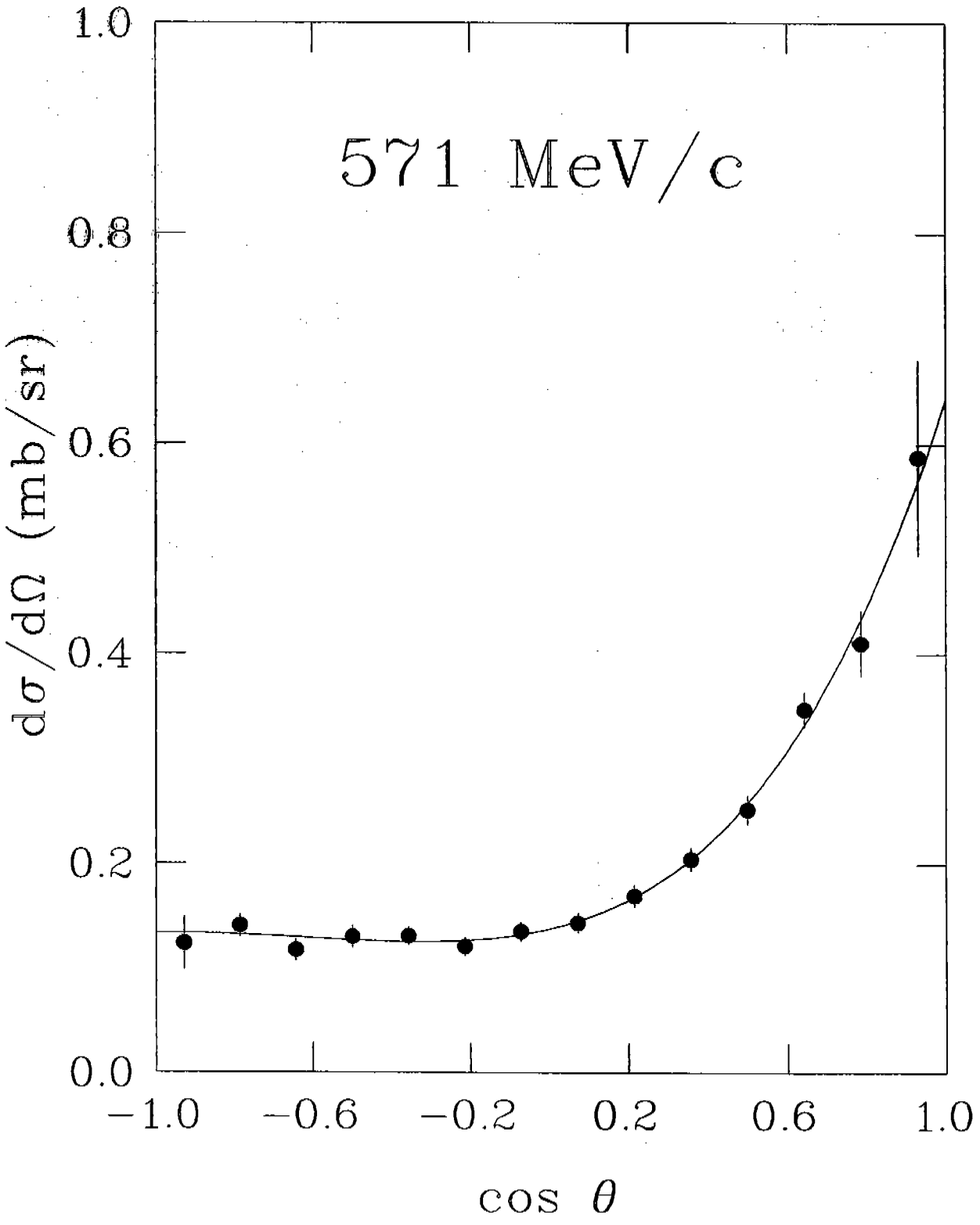
Total $\bar{K}N$ Cross Sections



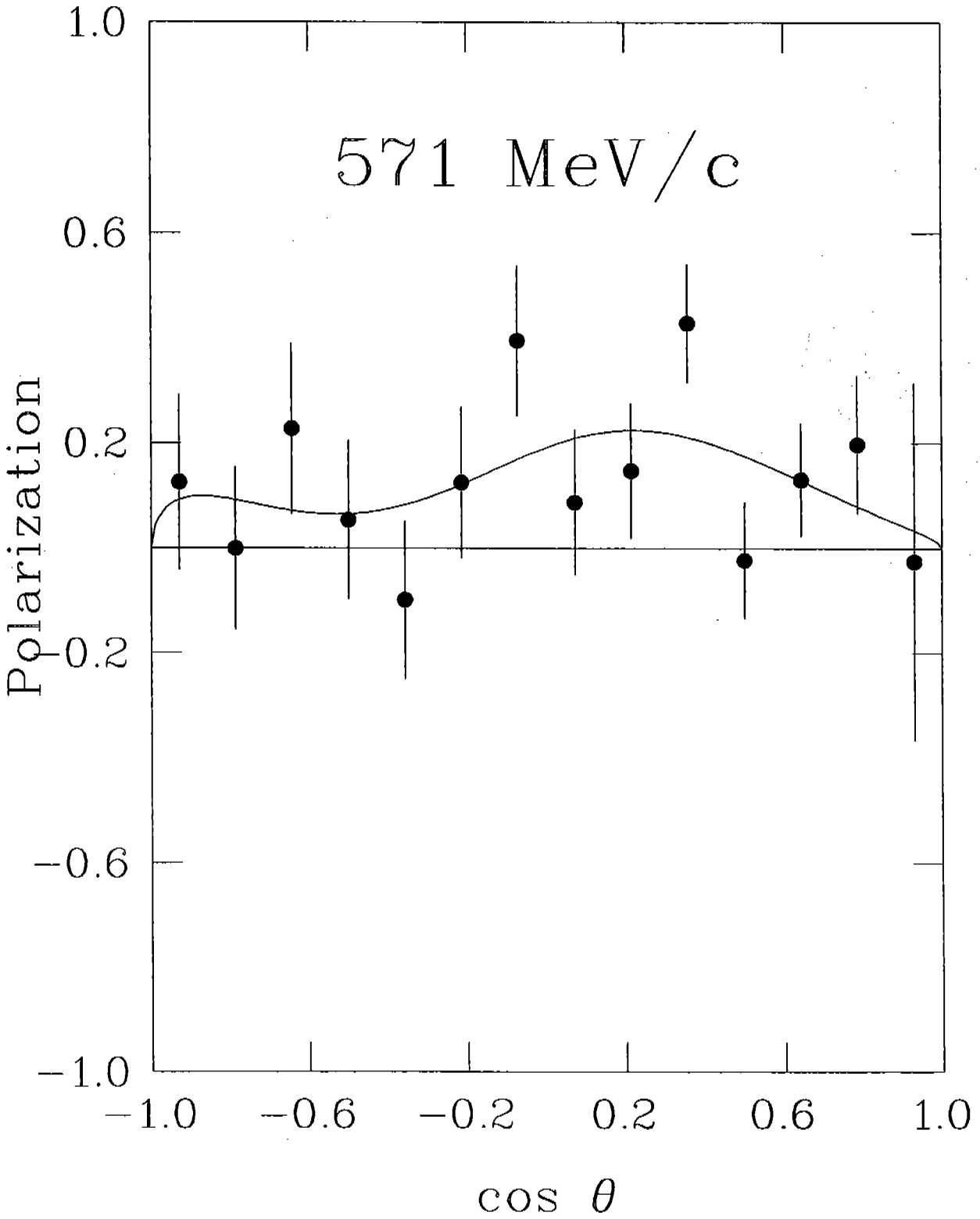
$K^- p \rightarrow \pi^0 \Lambda$



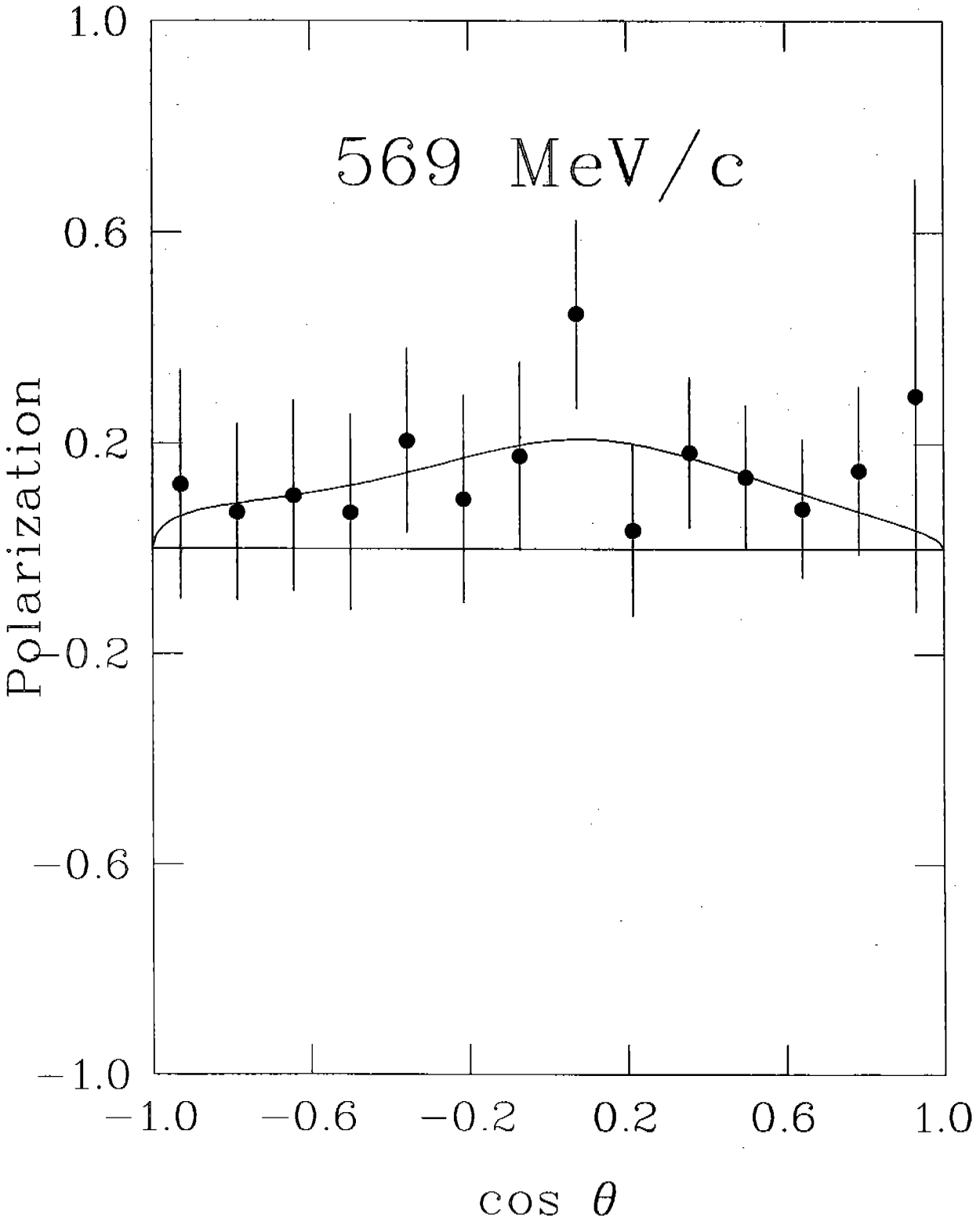
$K^- p \rightarrow \pi^0 \Lambda$



$\bar{K}p \to \pi^0 \Lambda$



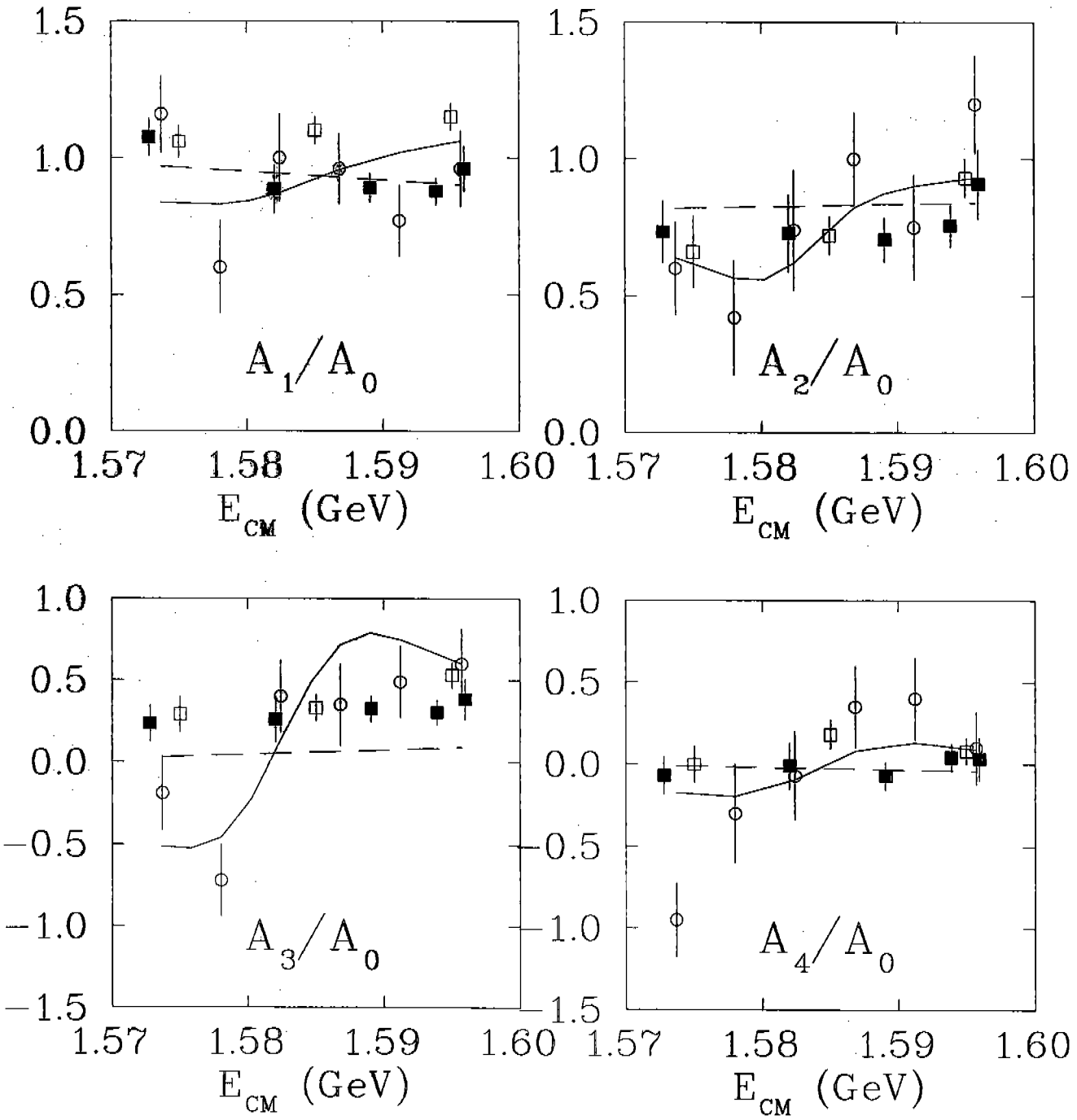
$\bar{K}P \to \pi^0 \Lambda$



Legendre Expansion

$$\frac{d\sigma}{d\Omega} = \lambda^2 A_0 \sum_{L=0}^{4} \left(\frac{A_L}{A_0}\right) P_L(\cos\theta)$$

$$P\frac{d\sigma}{d\Omega} = \lambda^2 A_0 \sum_{L=1}^{4} \left(\frac{B_L}{A_0}\right) P_L'(\cos\theta)$$

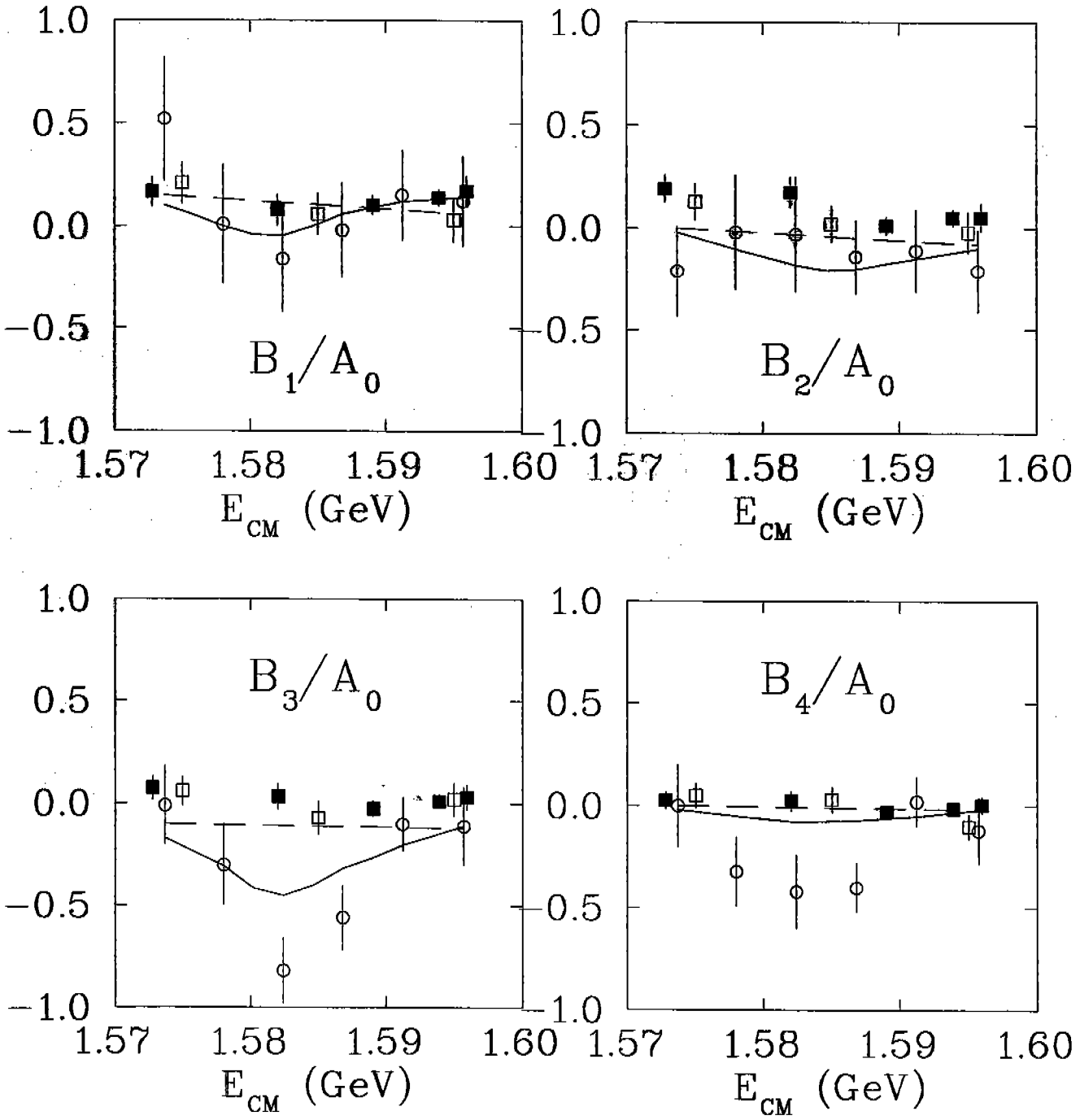


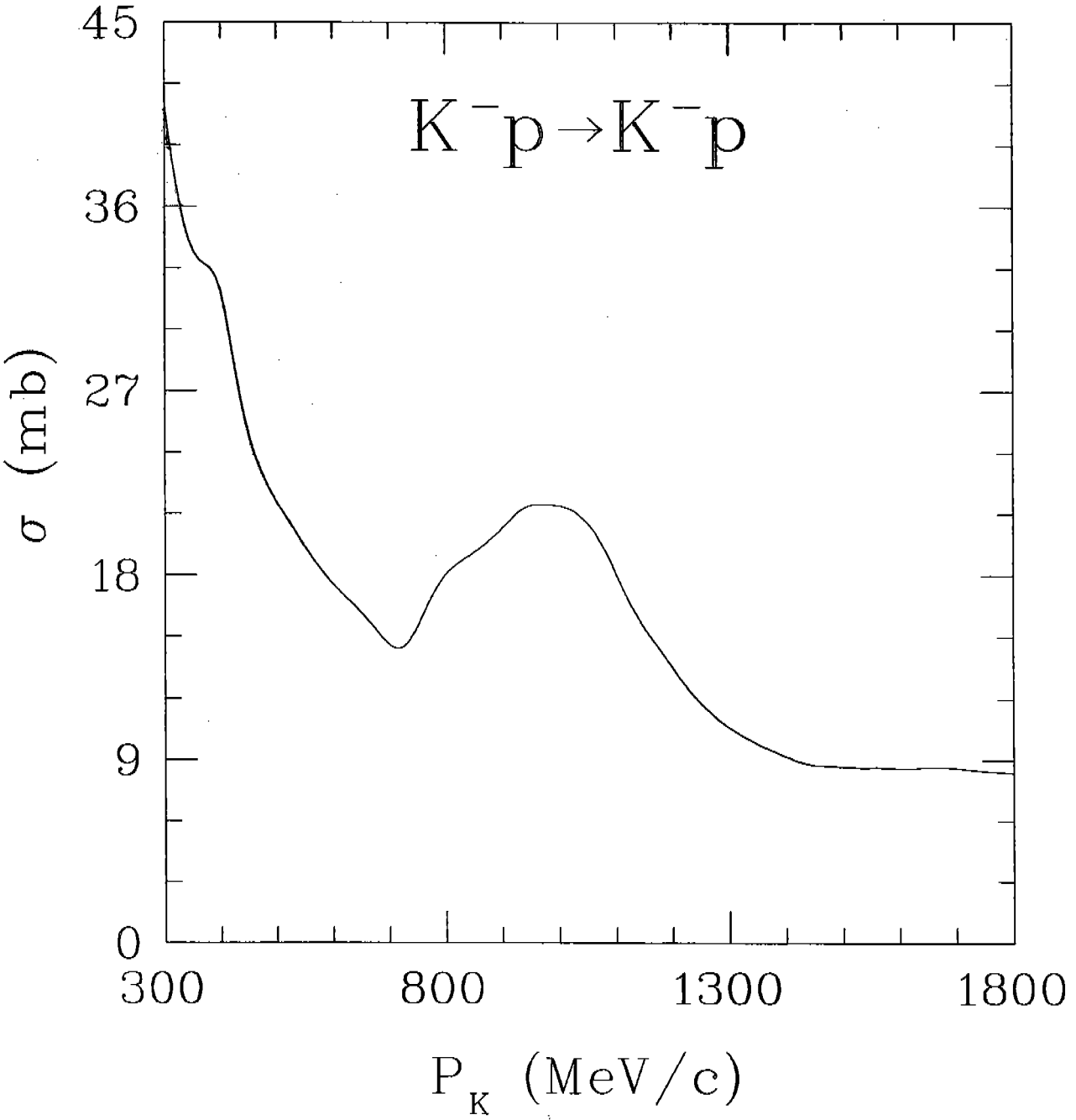
■ This work

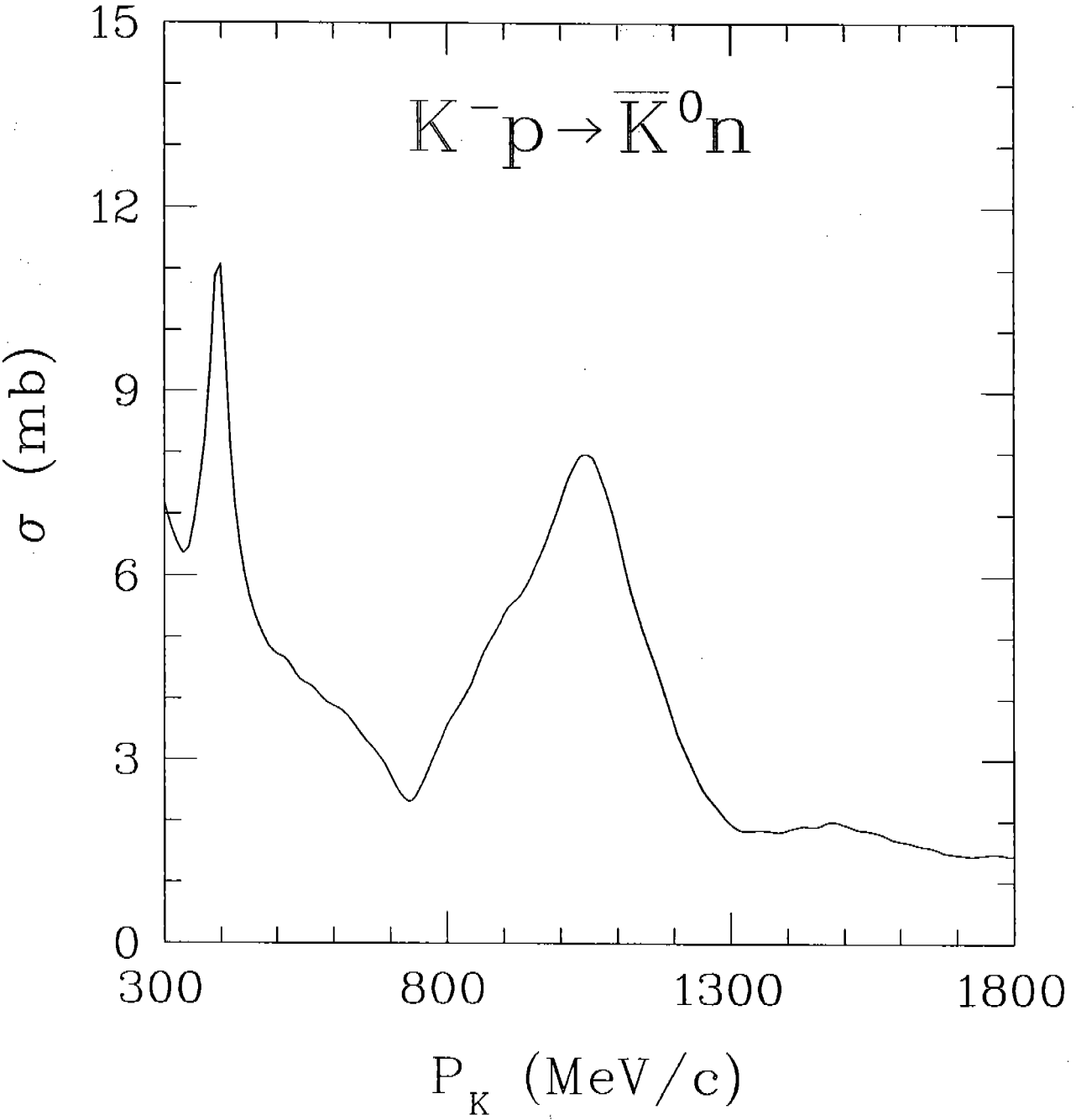
○ □ } Prior work

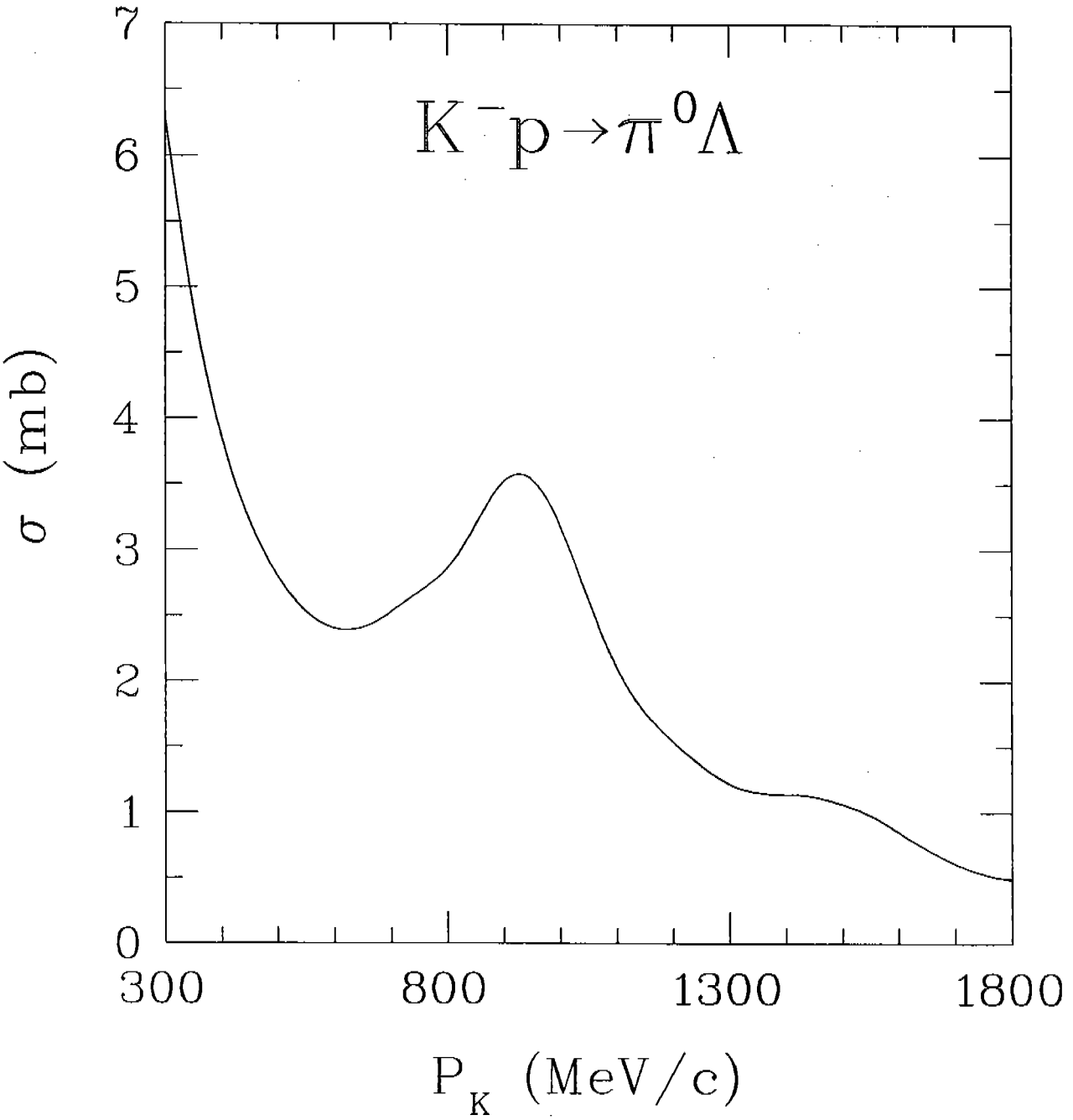
——— w/ Σ(1580)

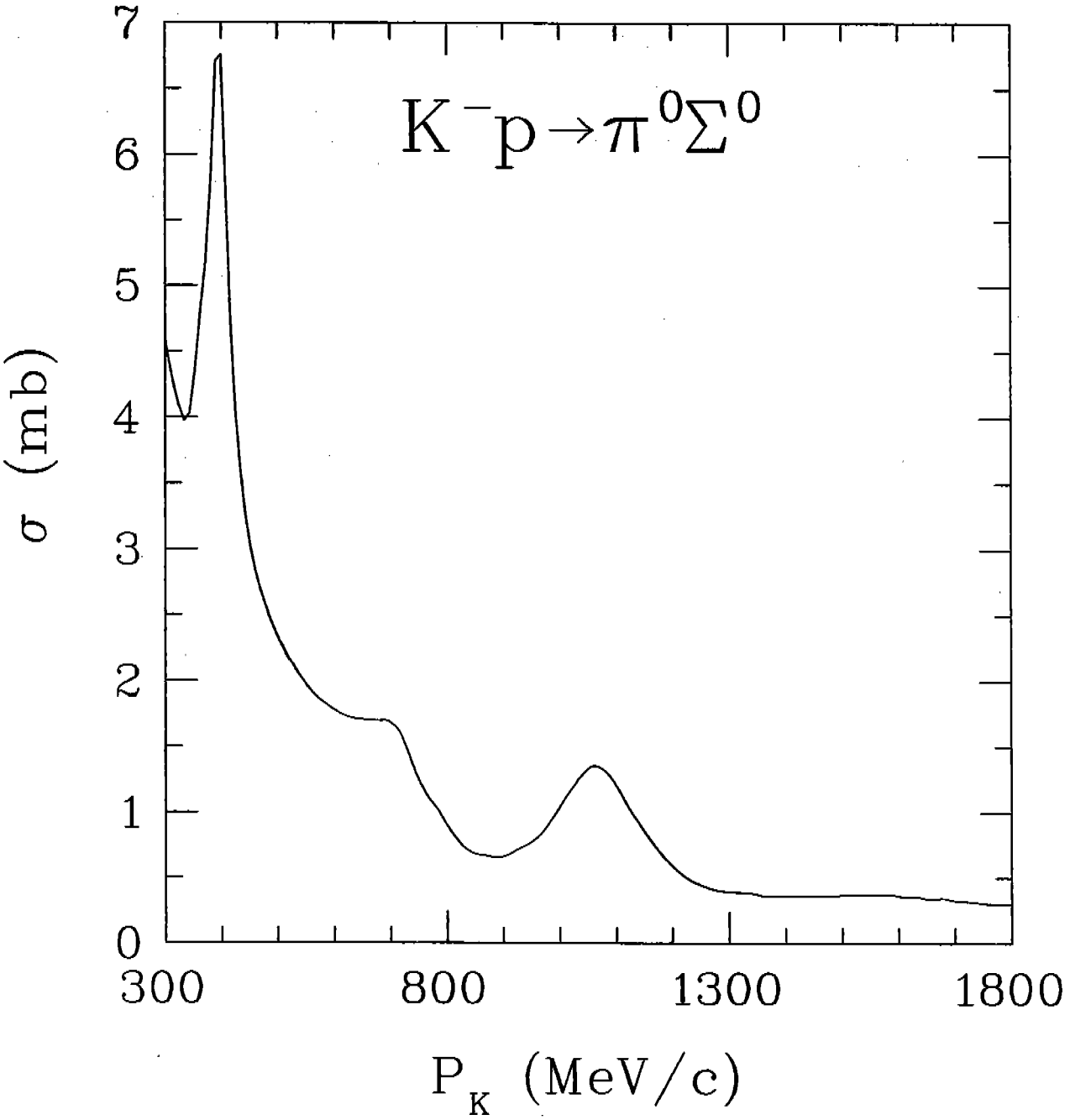
- - - - - w/o Σ(1580)

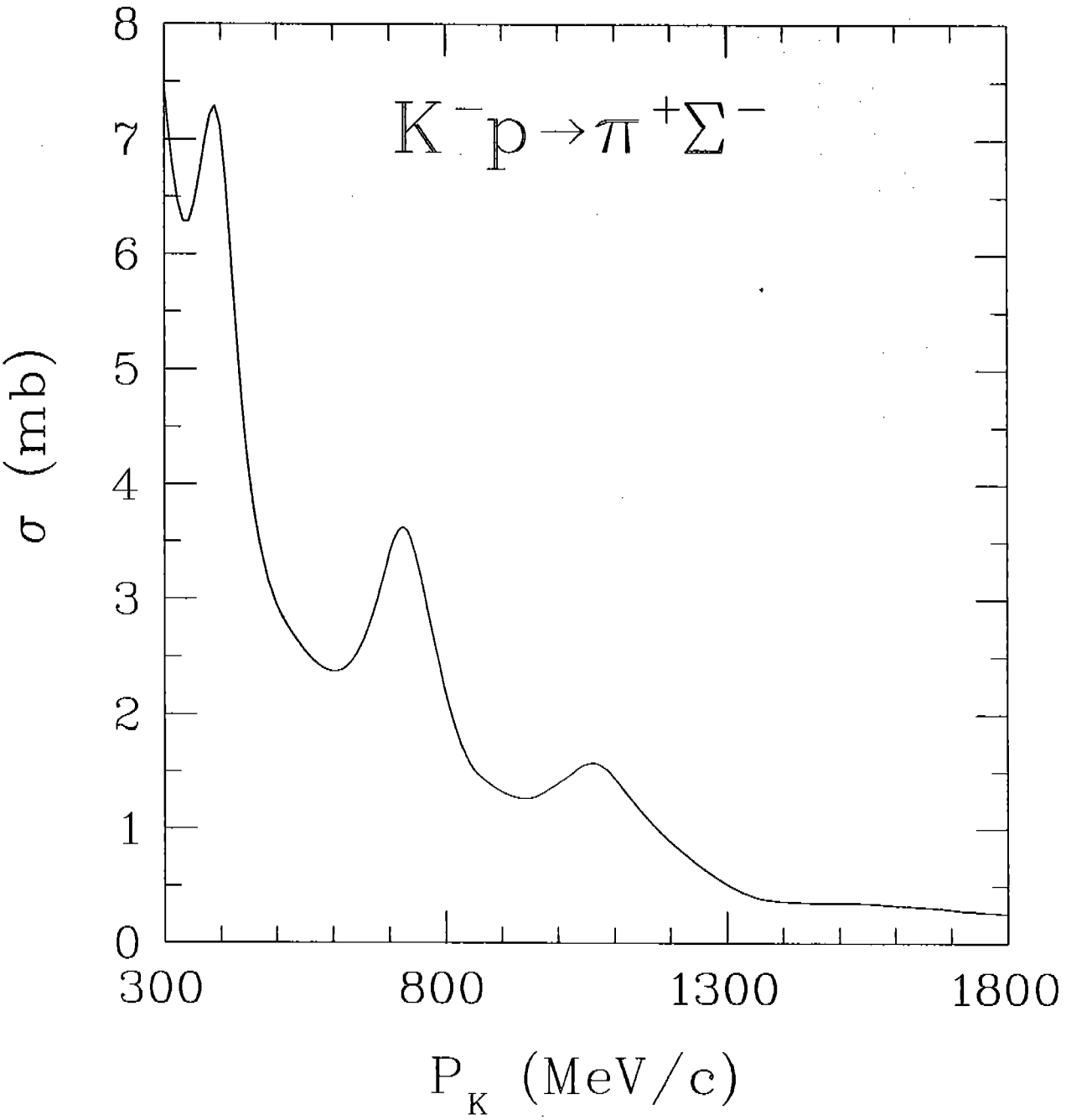

1.0
0.5
0.0
−0.5
−1.0
B_1/A_0
B_2/A_0
B_3/A_0
B_4/A_0
1.57
1.58
1.59
1.60
E_{CM} (GeV)

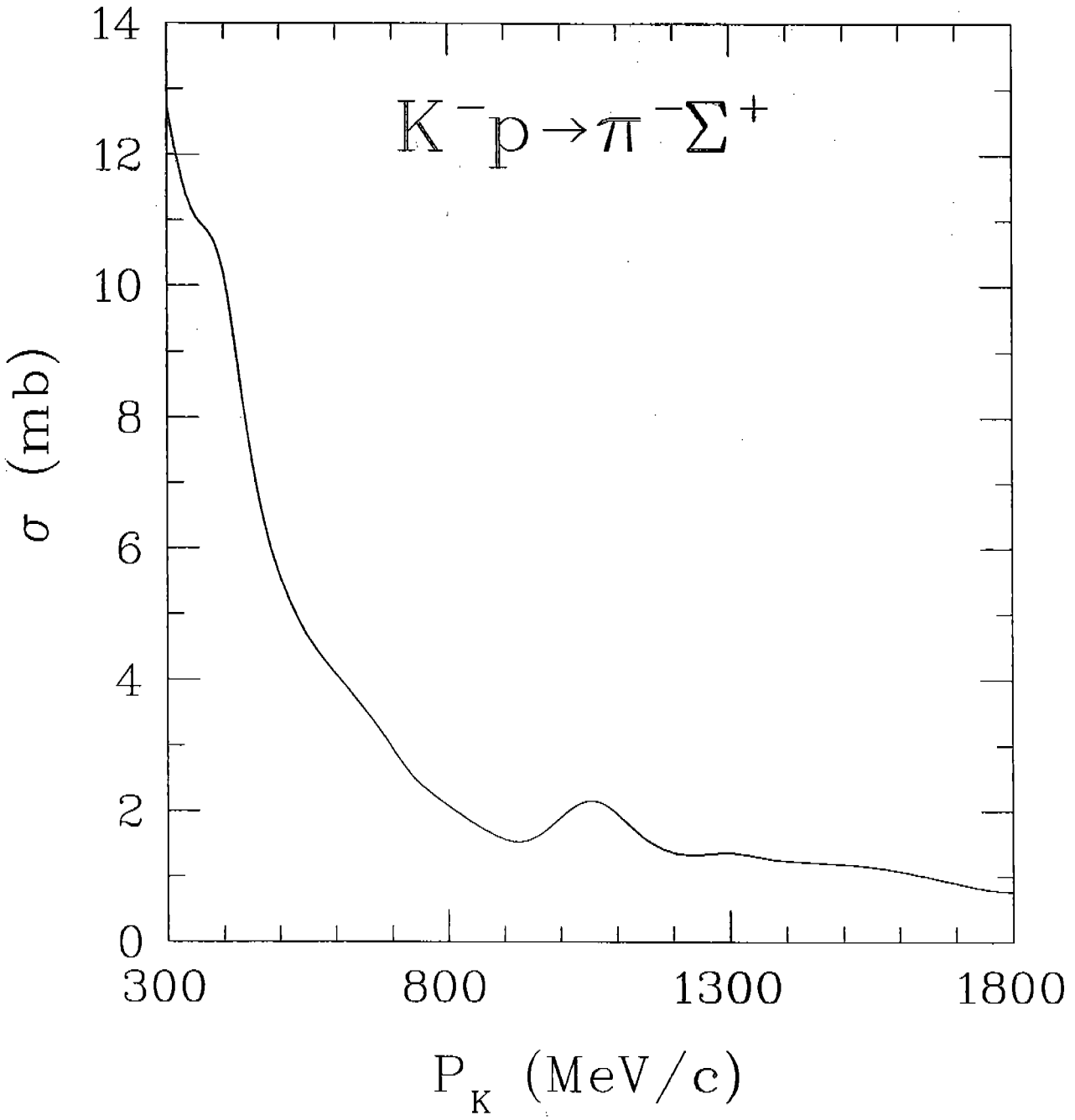

45
36
27
18
9
0
σ (mb)
$K^-p \rightarrow K^-p$
300
800
1300
1800
P_K (MeV/c)


$K^- p \to \bar{K}^0 n$
15
12
9
6
3
0
σ (mb)
300
800
1300
1800
P_K (MeV/c)


$K^- p \to \pi^0 \Lambda$
σ (mb)
0
1
2
3
4
5
6
7
300
800
1300
1800
P_K (MeV/c)


$K^- p \to \pi^0 \Sigma^0$
σ (mb)
0
1
2
3
4
5
6
7
300
800
1300
1800
P_K (MeV/c)


$K^- p \to \pi^+ \Sigma^-$
σ (mb)
0
1
2
3
4
5
6
7
8
300
800
1300
1800
P_K (MeV/c)


$K^- p \to \pi^- \Sigma^+$
σ (mb)
0
2
4
6
8
10
12
14
300
800
1300
1800
P_K (MeV/c)

Unitarity : $S^\dagger S = 1$

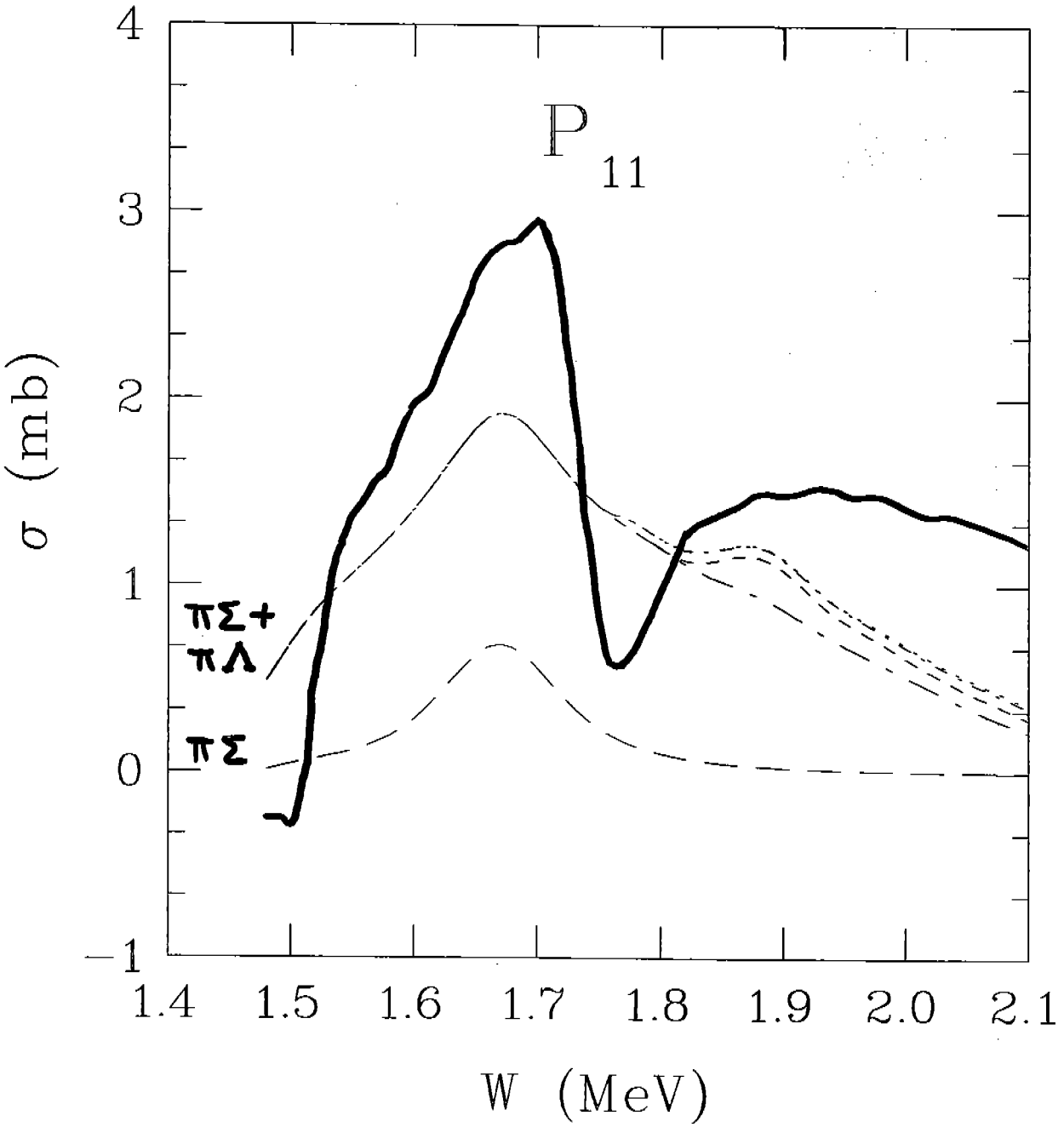
Time-Reversal : $S^T = S$

$$S = 1 + 2i\,T$$

$$T^\dagger T = \frac{T - T^\dagger}{2i}$$

$$\sum_j |T_{ij}|^2 = \mathrm{Im}\, T_{ii}$$

$$\sigma_{i\to j} = 4\pi \lambda^2 (J+\tfrac{1}{2}) |T_{ij}|^2$$


4
3
2
1
0
−1
σ (mb)
P11
πΣ+
πΛ
πΣ
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
W (MeV)

Parametrization of Amplitudes

My parametrization of partial-wave amplitudes satisfies unitarity and time-reversal invariance. The total partial-wave S-matrix has the form

$$\mathbf{S} = \mathbf{B}^{\mathrm{T}}\mathbf{R}\mathbf{B} \ ,$$

where the background matrix $\mathbf{B}$ is unitary but not generally symmetric, and the matrix $\mathbf{R}$ is both unitary and symmetric. The matrix $\mathbf{R}$ is a generalization of the multichannel Breit-Wigner form to include multiple resonances. It is constructed from a resonant K-matrix:

$$\mathbf{R} = \mathbf{I} + 2\mathrm{i}\mathbf{K}(1 - \mathrm{i}\mathbf{K})^{-1} \ .$$

Channels Included in Fits

$\overline{K}N$

$\pi\Lambda$

$\pi\Sigma$

$\pi\Sigma^*(1385)$

$\pi\Lambda^*(1520)$

$\overline{K}\Delta$

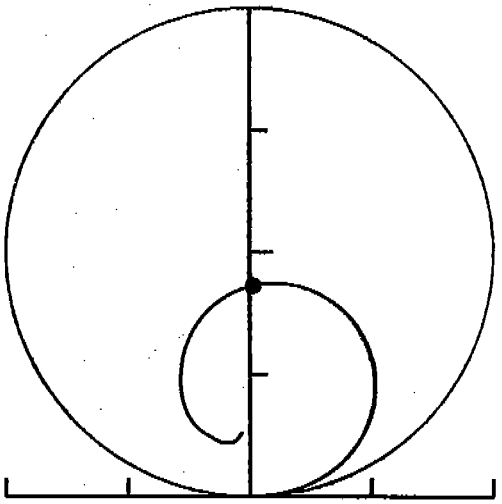
$\overline{K}^*N$

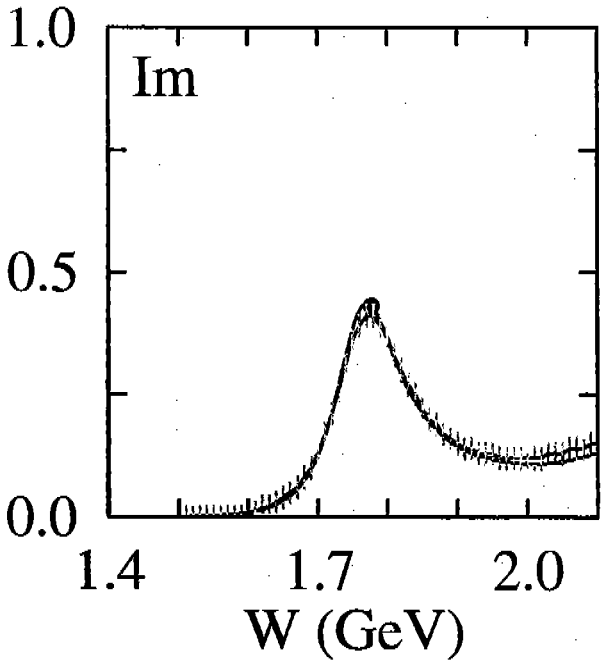
$\eta\Lambda$ (S_{01} waves only)

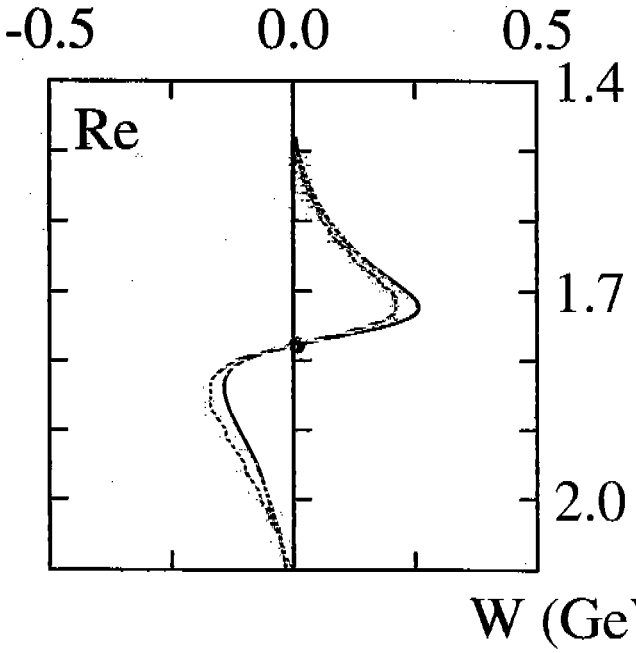
$(\pi\pi)_s\Lambda$ (to satisfy unitarity)

$(\pi\pi)_s\Sigma$ (to satisfy unitarity)

$\eta\Sigma$ (S_{11} waves only – to satisfy unitary)

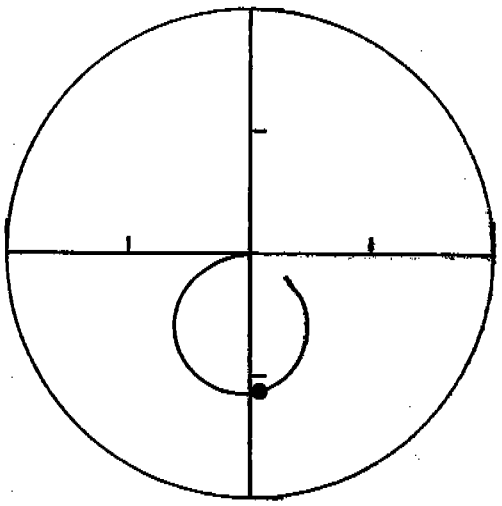


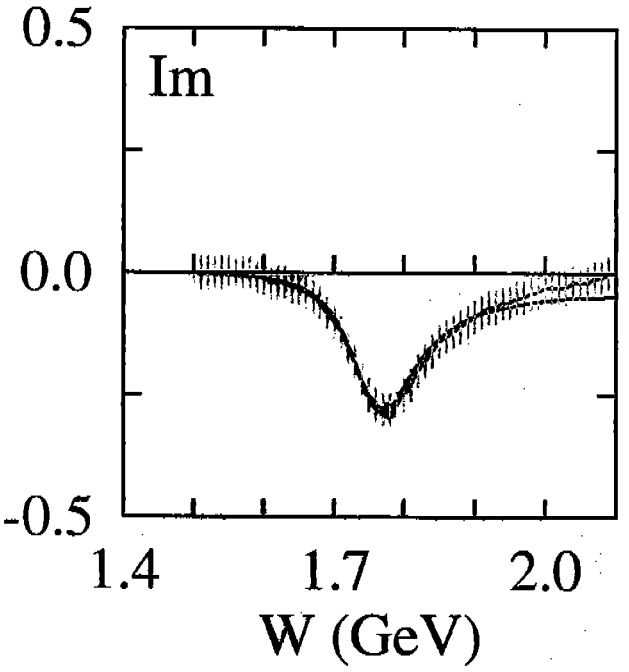


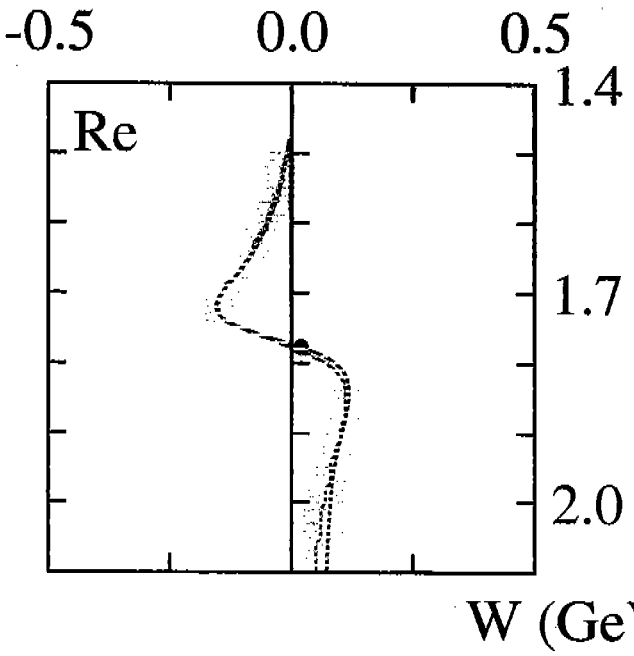


$\bar{K}N \rightarrow \bar{K}N$

D_{15}

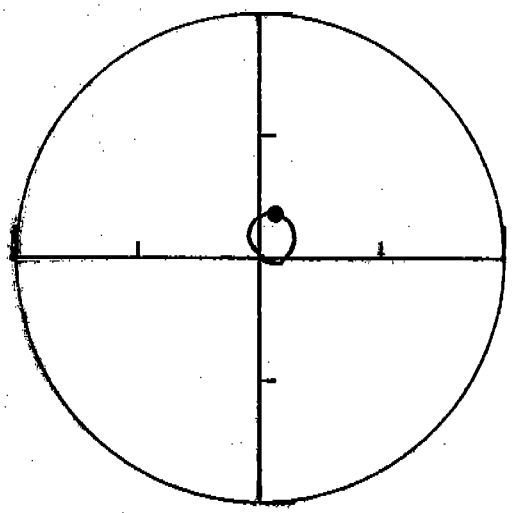


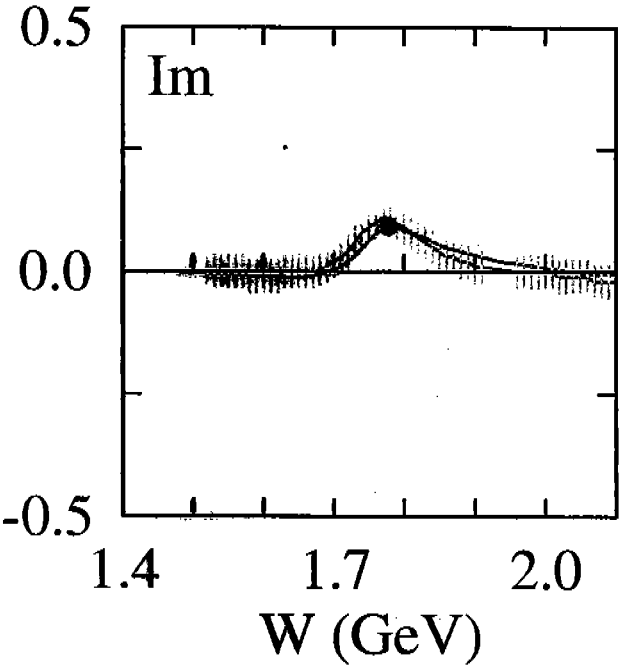


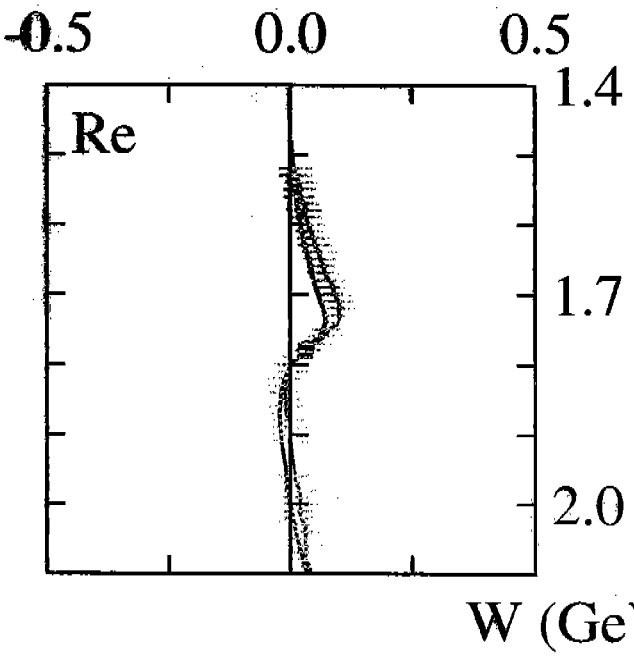


$\bar{K}N \rightarrow \pi \Lambda$

DD15

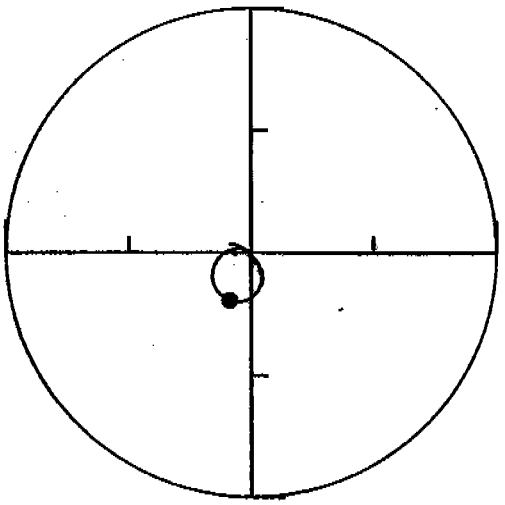


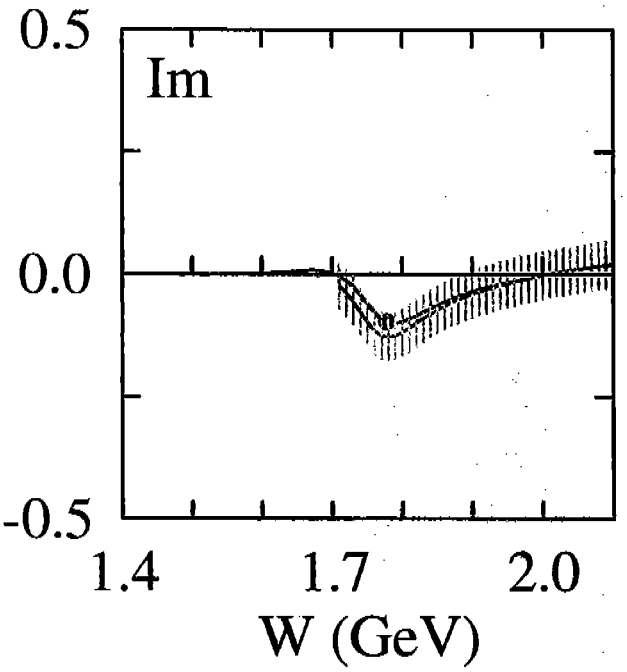


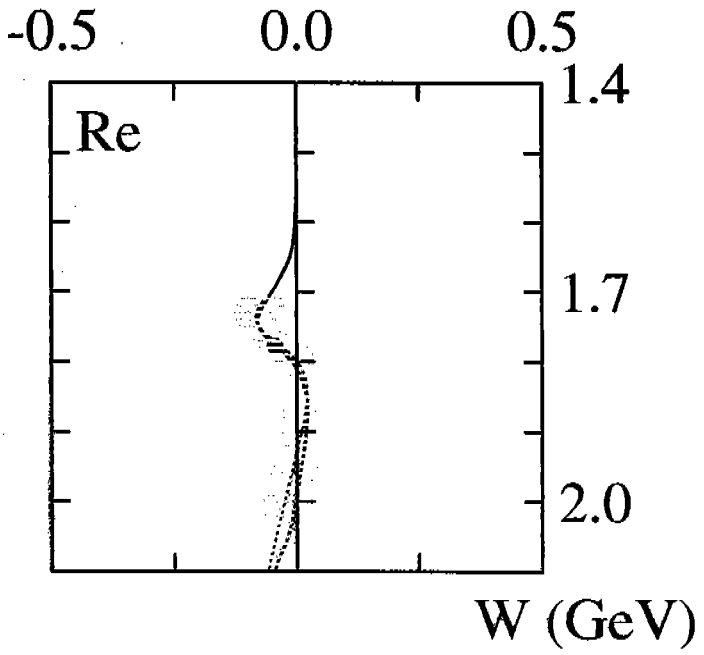


$\bar{K}N \rightarrow \pi \Sigma$

DD15

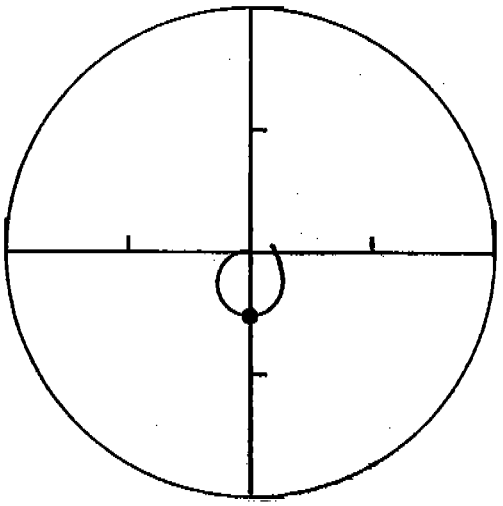


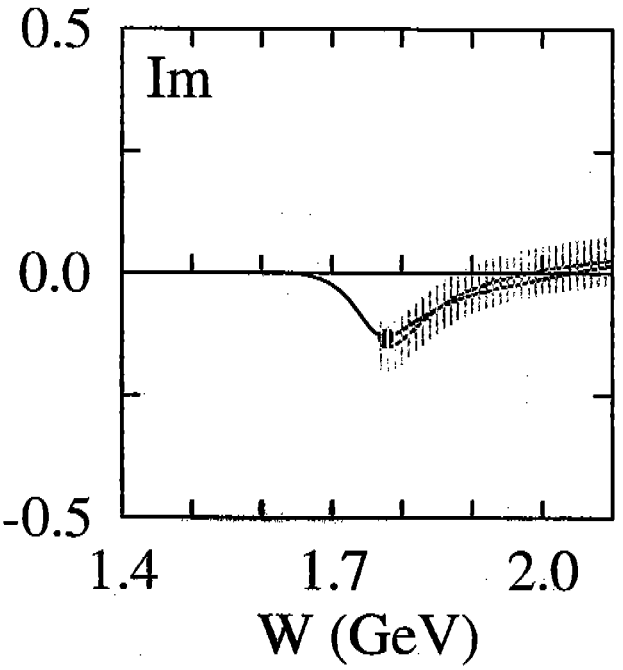


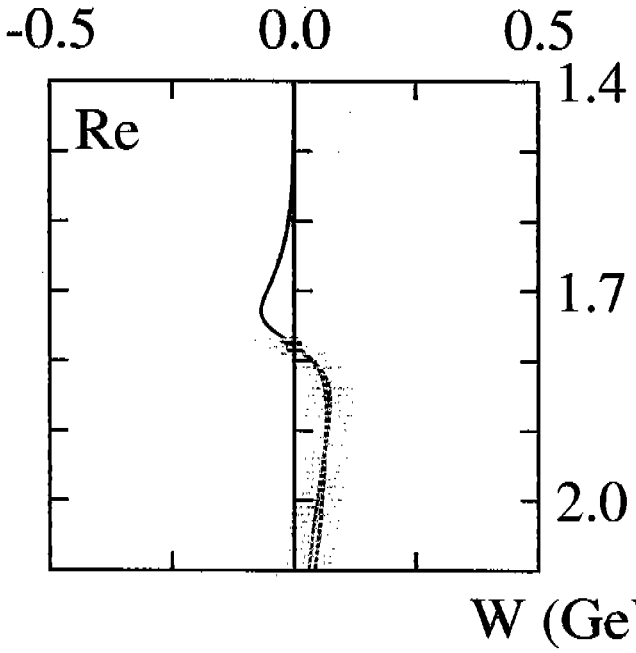


$\bar{K}N \rightarrow \pi \Lambda^*$

DP15







$\bar{K}N \rightarrow \pi \Sigma^*$

DD15

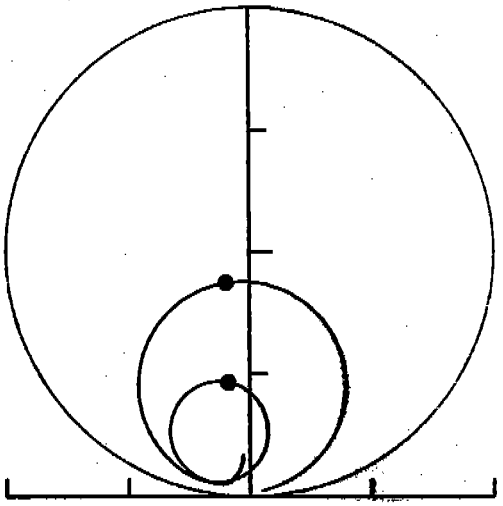
$$\Lambda(1775)\frac{5}{2}^{-}$$

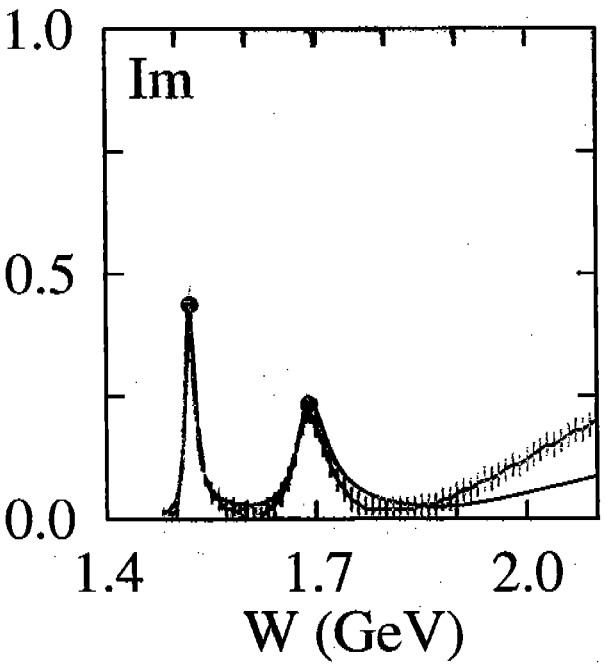
Parameter	This Work	PDG Estimate
Mass	1777(1)	1770-1780
Width	131(4)	105–135
$\Gamma(\overline{K}N)/\Gamma_{\text{total}}$	0.430(8)	0.37–0.43
$\frac{\sqrt{\Gamma(\overline{K}N)\Gamma(\pi\Lambda)}}{\Gamma_{\text{total}}}$	$-0.29(1)$	
$\frac{\sqrt{\Gamma(\overline{K}N)\Gamma(\pi\Sigma)}}{\Gamma_{\text{total}}}$	0.068(12)	

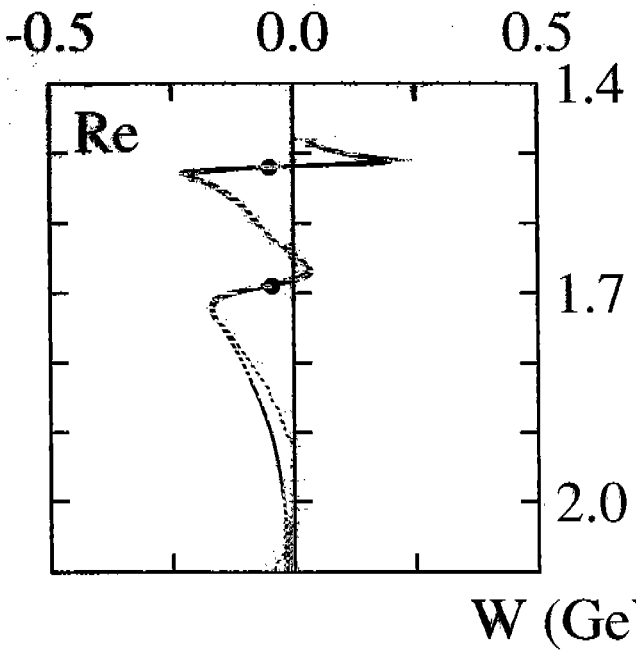
Pole Position: $M - i\frac{\Gamma}{2}$

$M = 1757$ MeV

$\Gamma = 117$ MeV

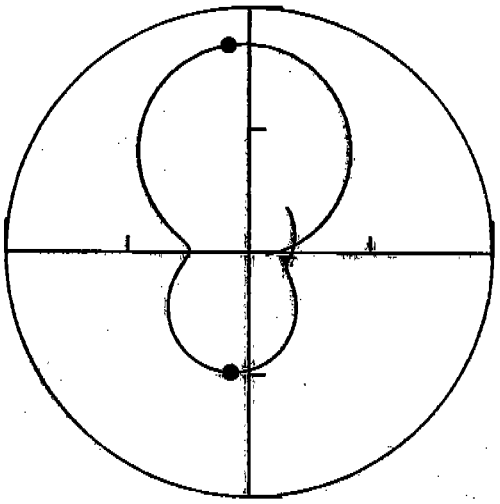


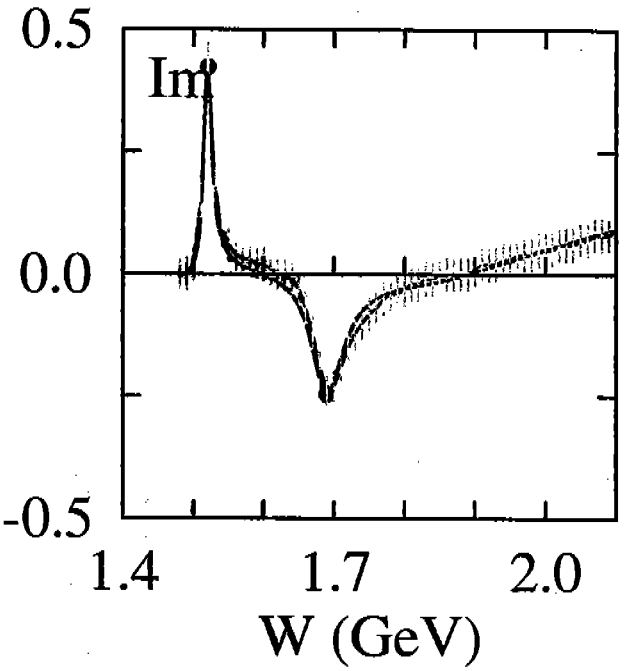


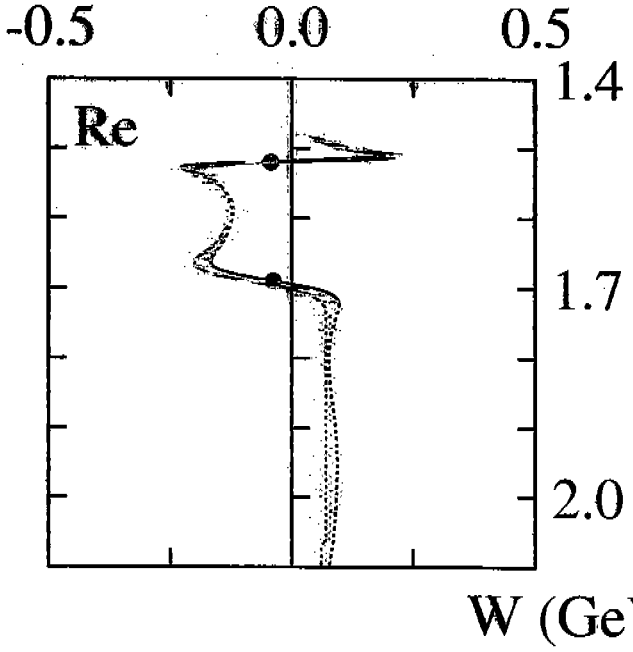


$\bar{K}N \rightarrow \bar{K}N$

D_{03}

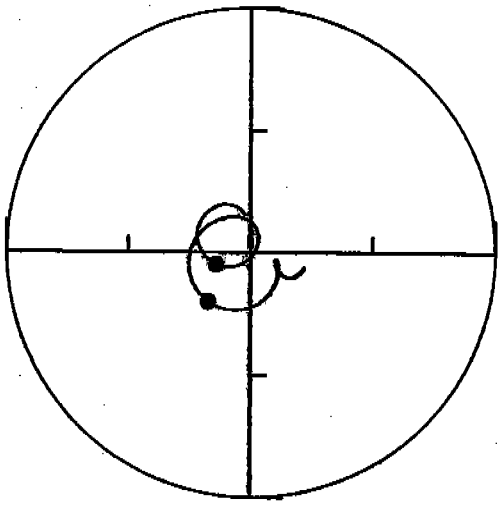


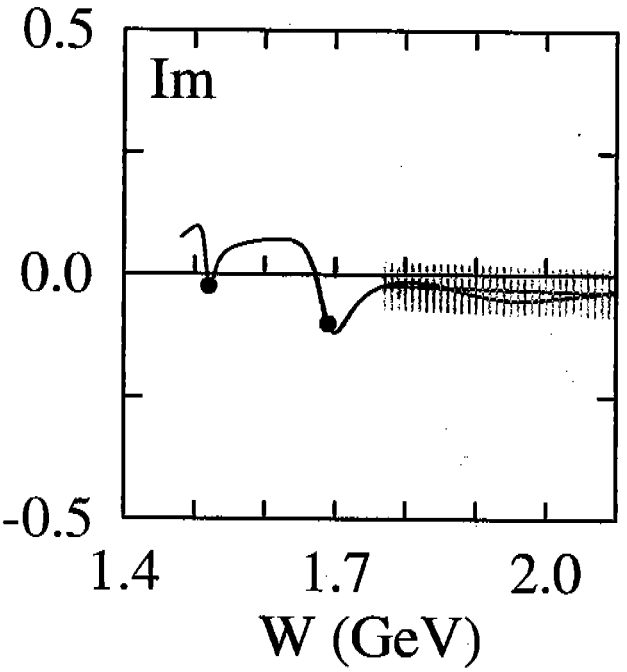


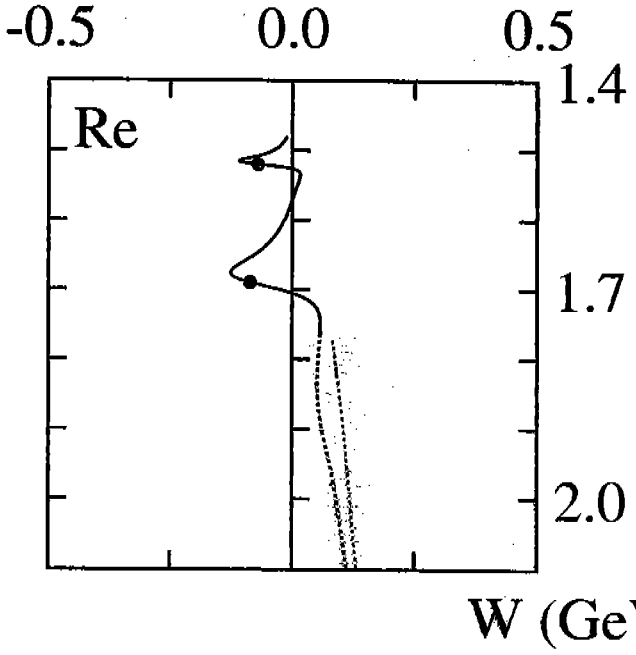


$\bar{K}N \rightarrow \pi\Sigma$

DD03







$\bar{K}N \rightarrow \pi \Sigma^*$

DS03

$\Lambda(1520)\frac{3}{2}^-$

Parameter	This Work	PDG Estimate
Mass	1520.0 ± 0.7	1519.5 ± 1.0
Width	15.5 ± 1.5	15.6 ± 1.0
$\Gamma(\overline{K}N)/\Gamma_{\text{total}}$	0.45(4)	0.45(1)
$\Gamma(\pi\Sigma)/\Gamma_{\text{total}}$	0.43(7)	0.42(1)
$\Gamma(\pi\pi\Lambda)/\Gamma_{\text{total}}$	0.12(7)	0.10(1)

Pole Position: $M - i\frac{\Gamma}{2}$

$M = 1519$ MeV

$\Gamma = 15$ MeV

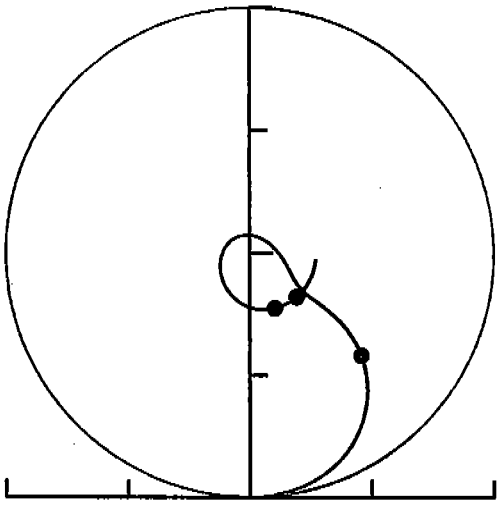
$\Lambda(1690)\frac{3}{2}^-$

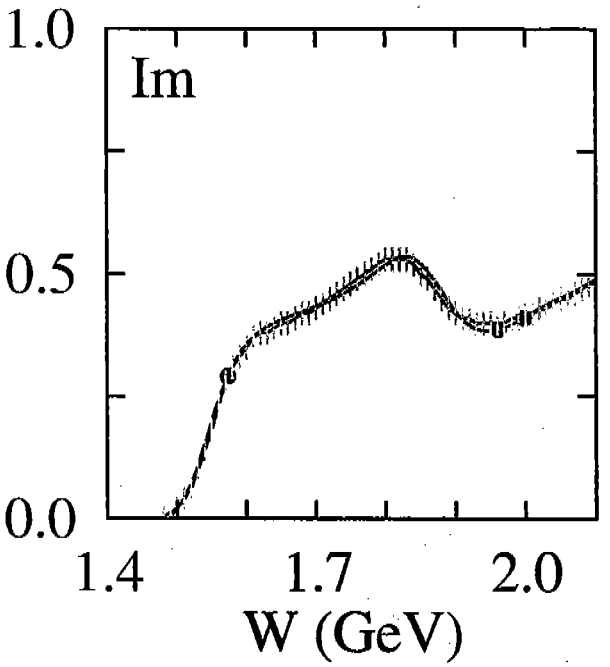
Parameter	This Work	PDG Estimate
Mass	1690(3)	1685–1695
Width	54.1 ± 5.5	50–70
$\Gamma(\overline{K}N)/\Gamma_{\text{total}}$	0.25(4)	0.2–0.3
$\frac{\sqrt{\Gamma(\overline{K}N)\Gamma(\pi\Sigma)}}{\Gamma_{\text{total}}}$	$-0.26(3)$	

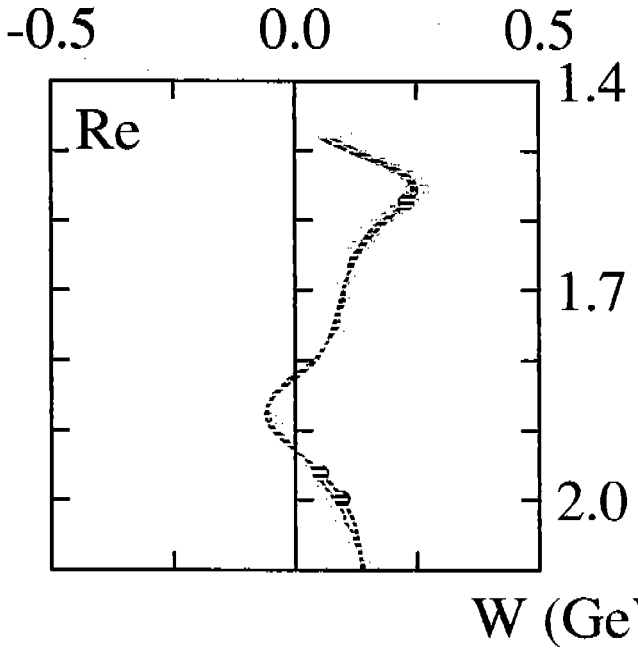
Pole Position: $M - i\frac{\Gamma}{2}$

$M = 1687$ MeV

$\Gamma = 53$ MeV

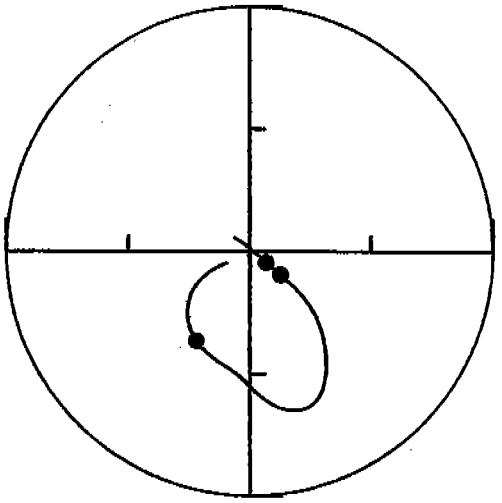


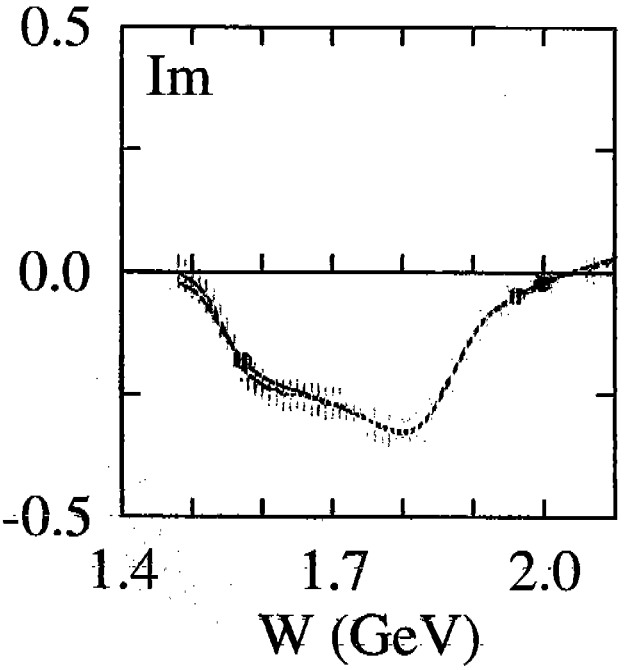


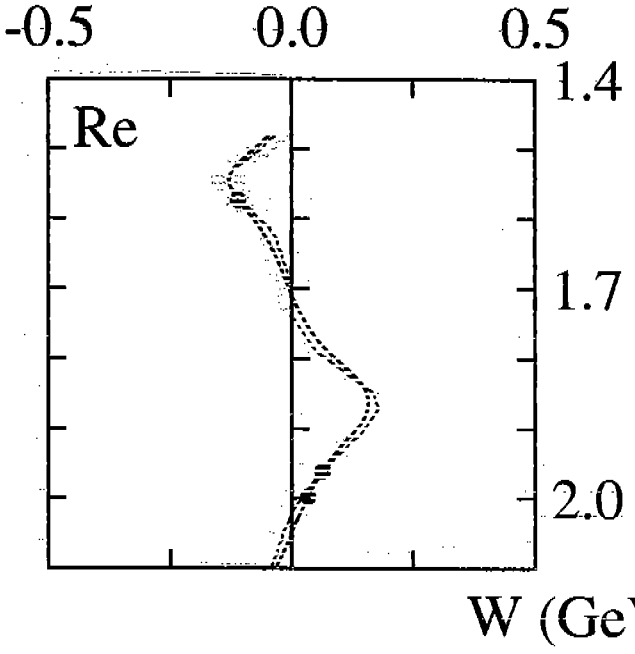


$\bar{K}N \rightarrow \bar{K}N$

P_{01}

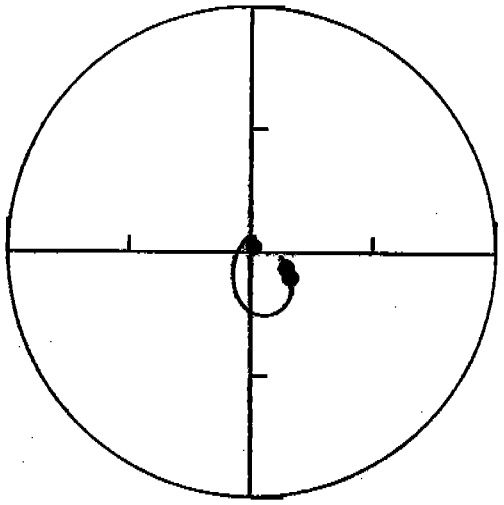


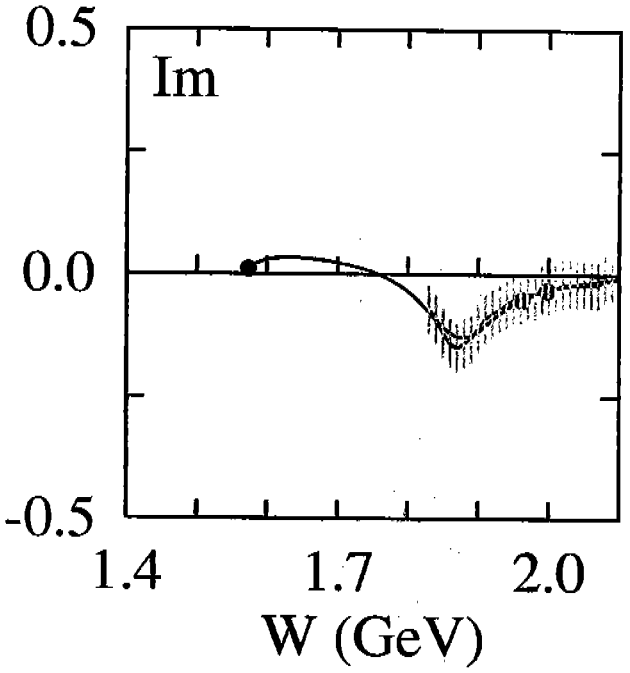


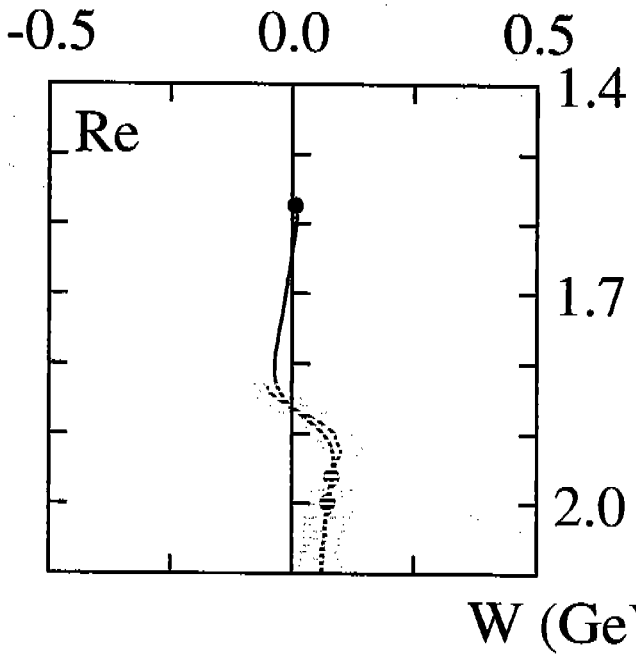


$\bar{K}N \rightarrow \pi\Sigma$

PP01

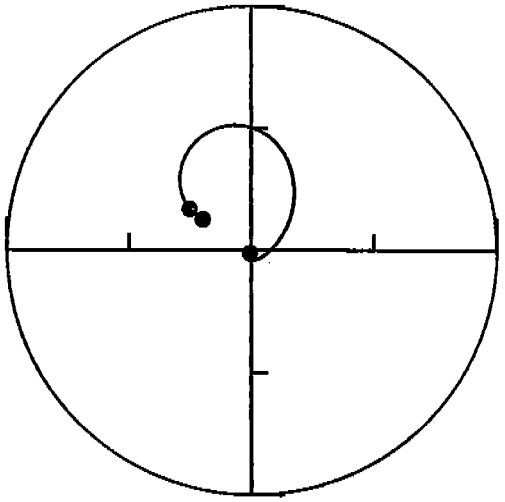


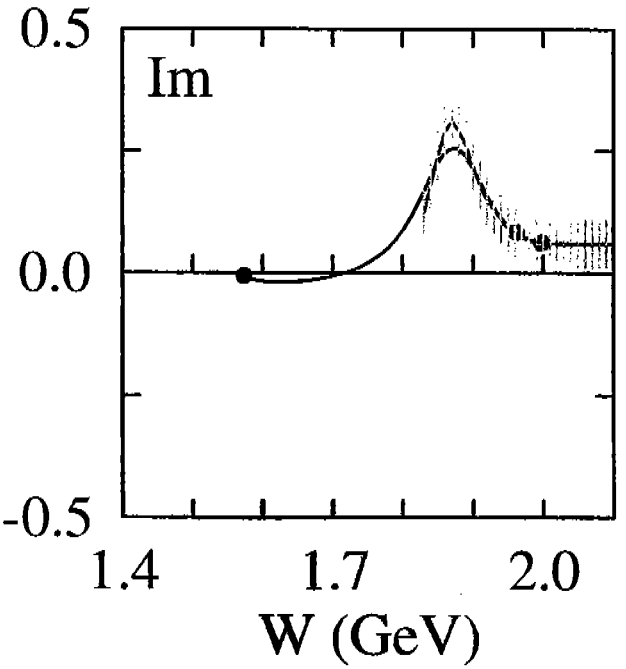


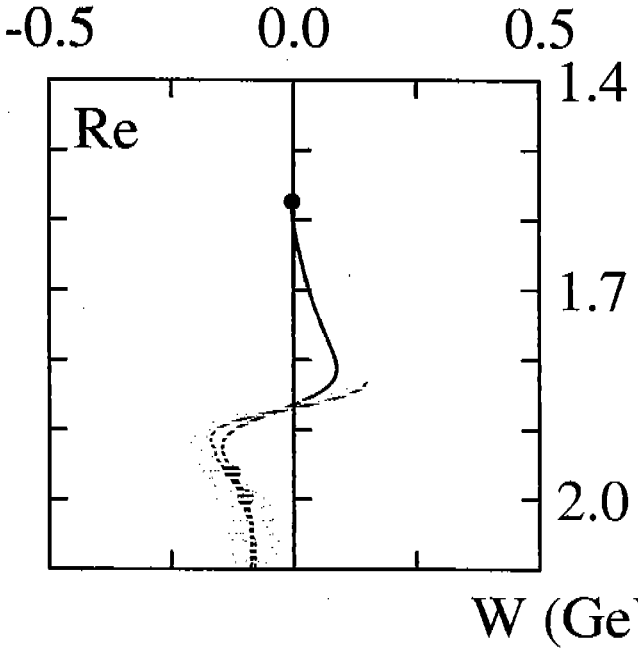


$\bar{K}N \rightarrow \bar{K}_1^* N$

PP01







$\bar{K}N \rightarrow \bar{K}_3^* N$

PP01

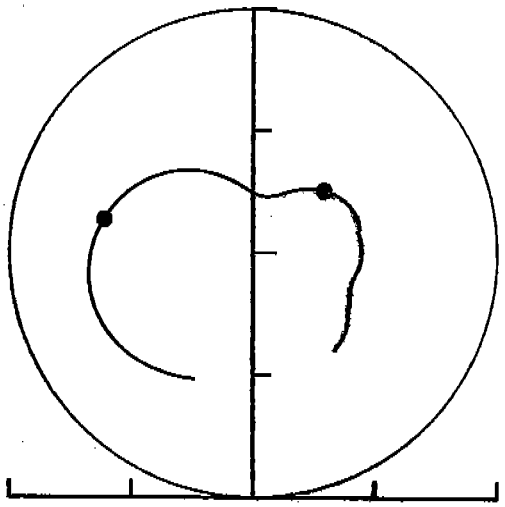
$\Lambda(1600)\frac{1}{2}^+$

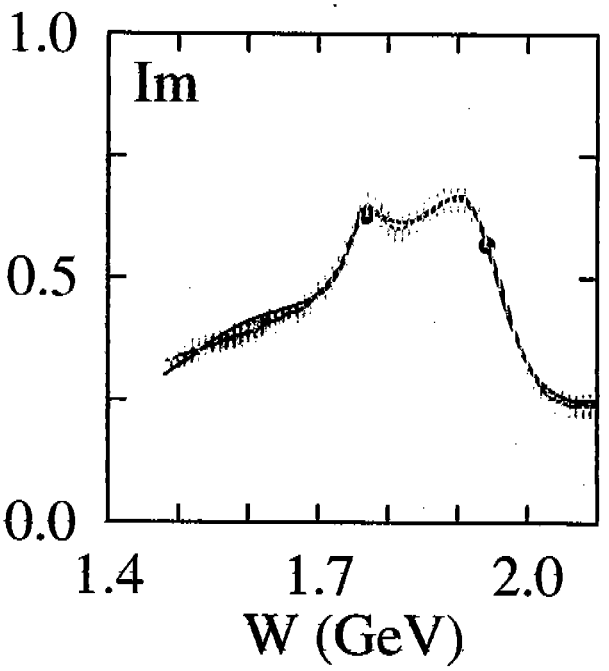
Parameter	This Work	PDG Estimate
Mass	1574(8)	1560–1700
Width	197(21)	50–200
$\Gamma(\overline{K}N)/\Gamma_{\text{total}}$	0.40(2)	0.15–0.30
$\frac{\sqrt{\Gamma(\overline{K}N)\Gamma(\pi\Sigma)}}{\Gamma_{\text{total}}}$	$-0.19(5)$	
$\frac{\sqrt{\Gamma(\overline{K}N)\Gamma(\pi\Sigma^*)}}{\Gamma_{\text{total}}}$	0.15(5)	

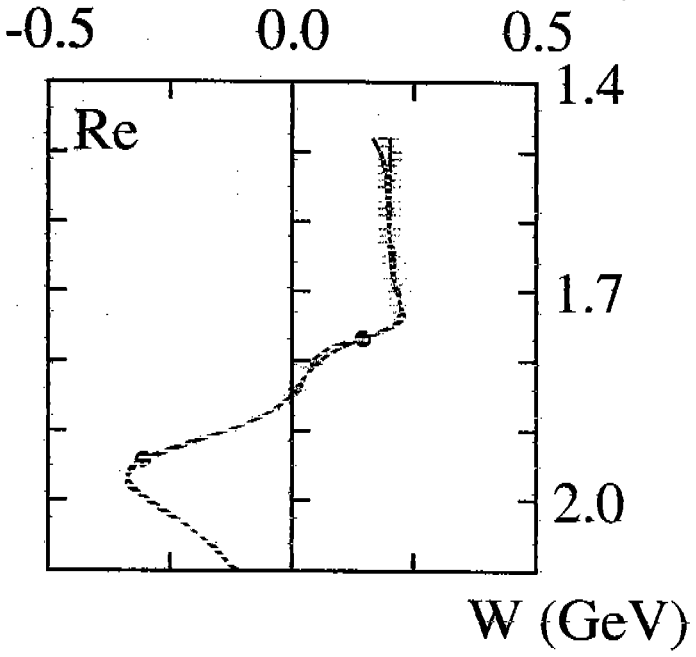
Pole Position: $M - i\frac{\Gamma}{2}$

$M = 1534$ MeV

$\Gamma = 157$ MeV

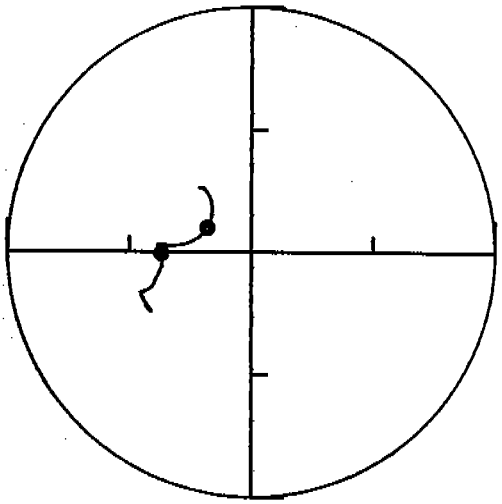


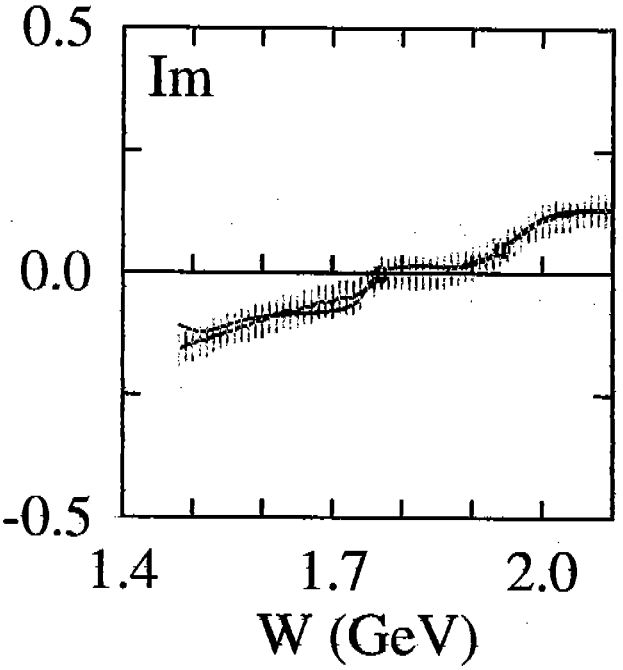


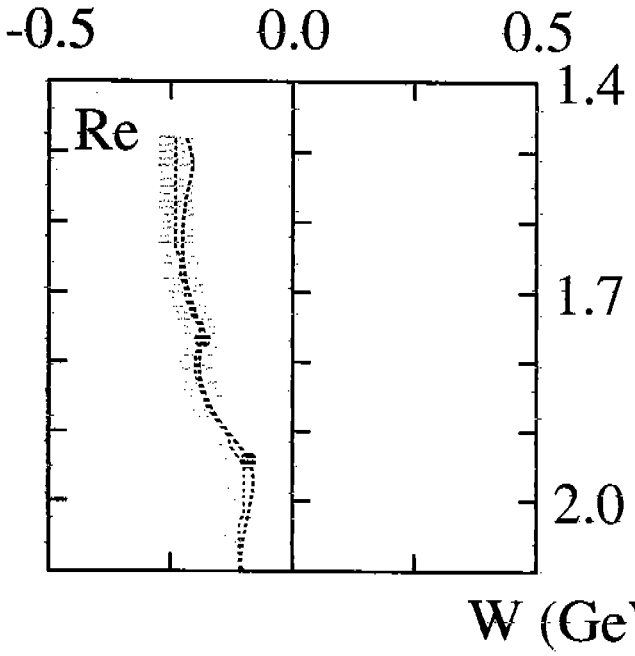


$\bar{K}N \rightarrow \bar{K}N$

S_{11}

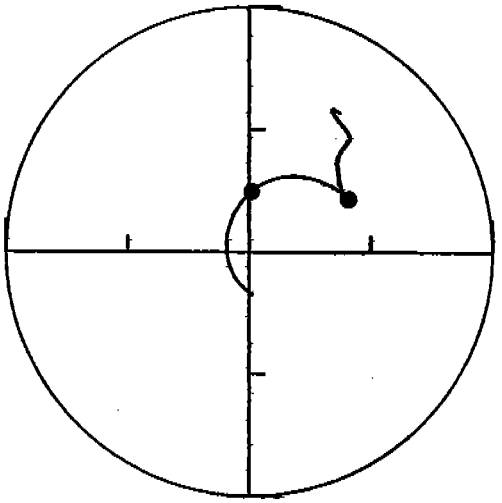


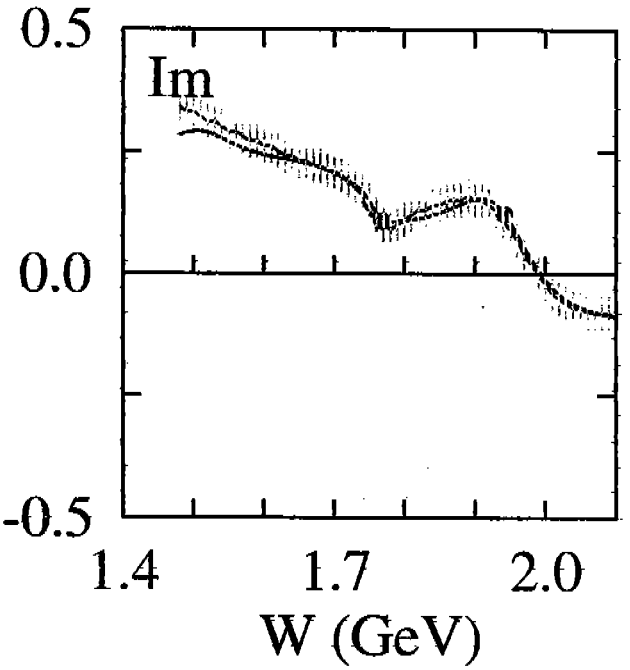


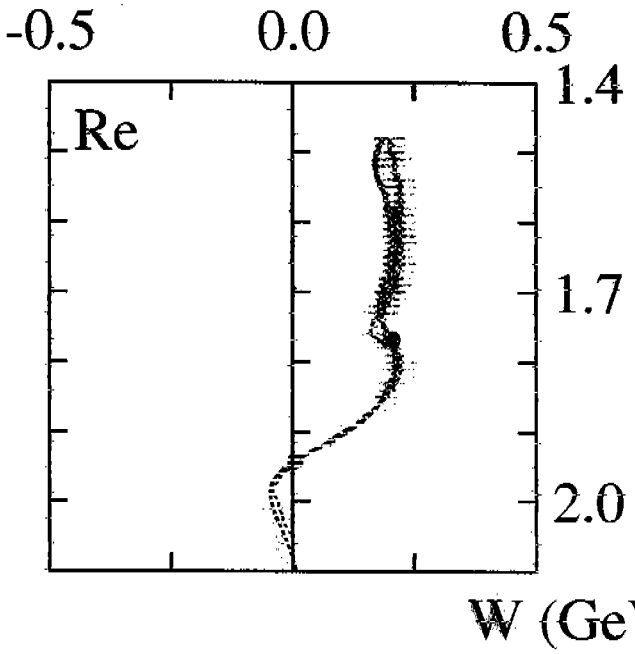


$\bar{K}N \rightarrow \pi \Lambda$

SS11

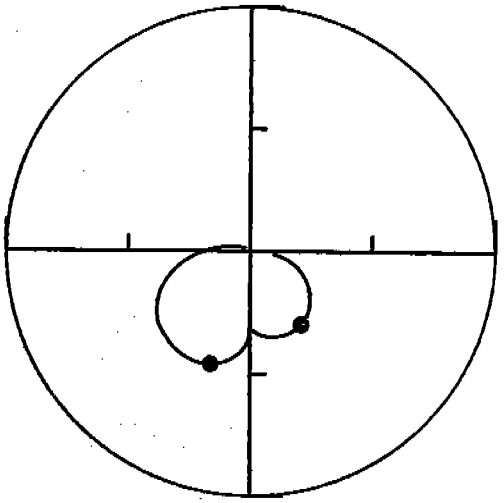


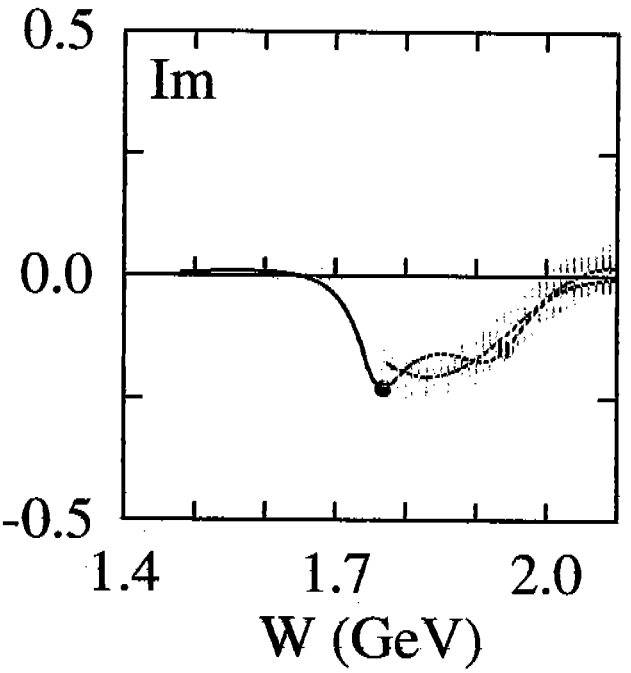


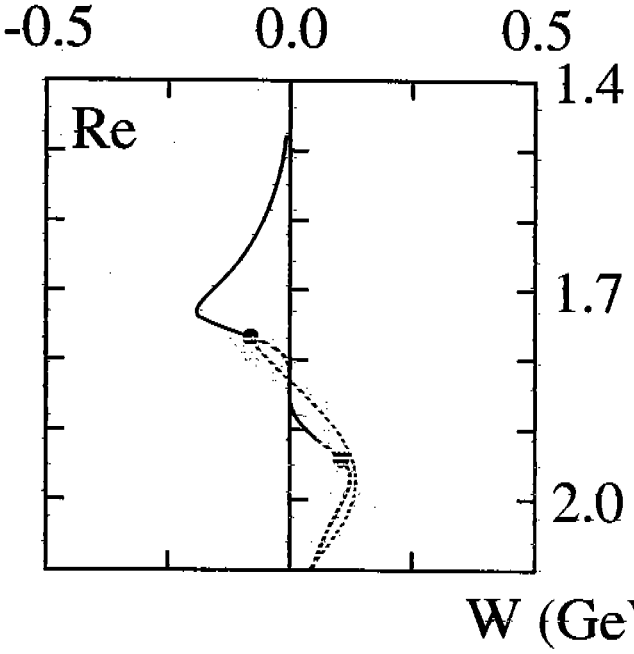


$\bar{K}N \rightarrow \pi\Sigma$

SS11

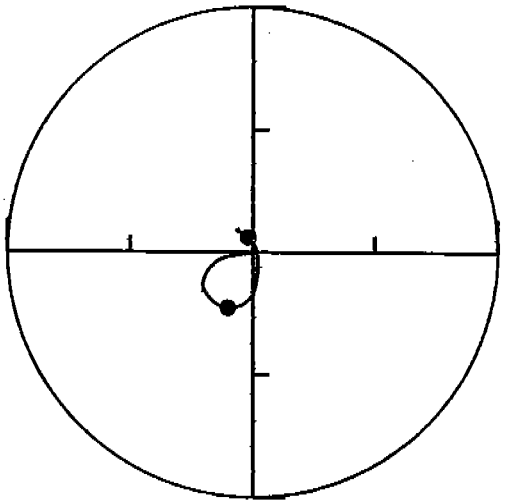


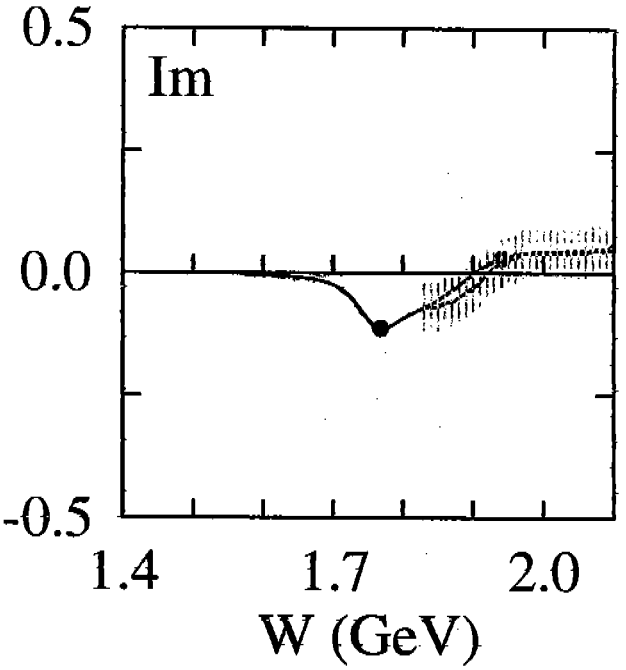


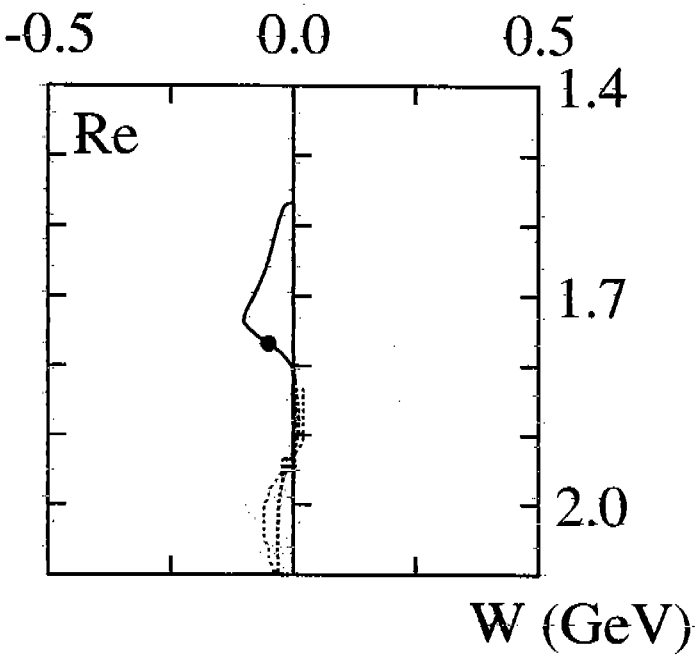


$\bar{K}N \rightarrow \pi \Sigma^*$

SD11







$\bar{K}N \rightarrow \bar{K}_1^* N$

SS11

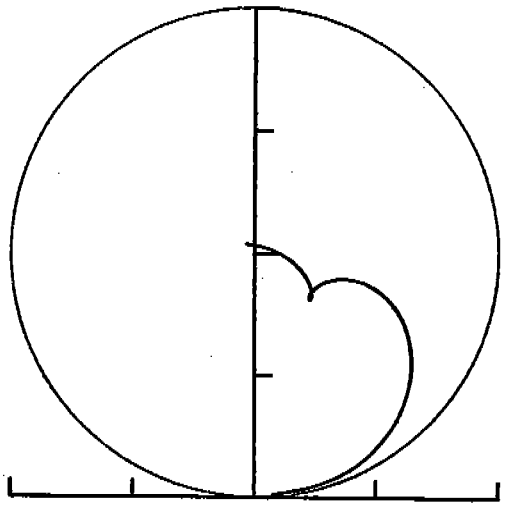
$\Sigma(1750)\frac{1}{2}^-$

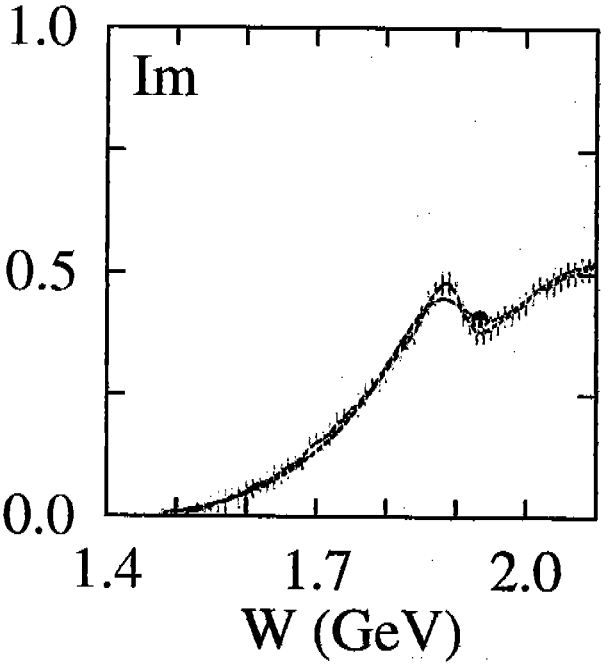
Parameter	This Work	PDG Estimate
Mass	1768(7)	1730–1800
Width	101(15)	60–160
$\Gamma(\overline{K}N)/\Gamma_{\text{total}}$	0.21(4)	0.1–0.4
$\frac{\sqrt{\Gamma(\overline{K}N)\Gamma(\pi\Sigma^*)}}{\Gamma_{\text{total}}}$	$-0.21(3)$	

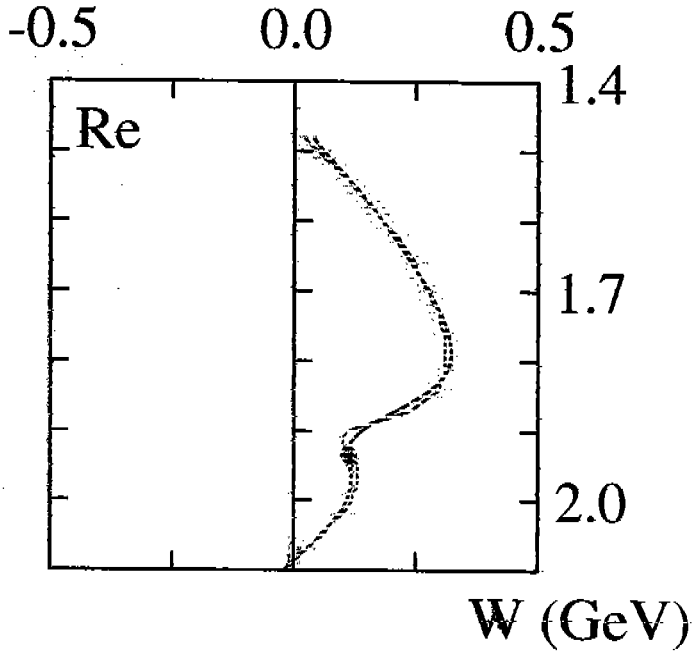
Pole Position: $M - i\frac{\Gamma}{2}$

$M = 1754$ MeV

$\Gamma = 93$ MeV

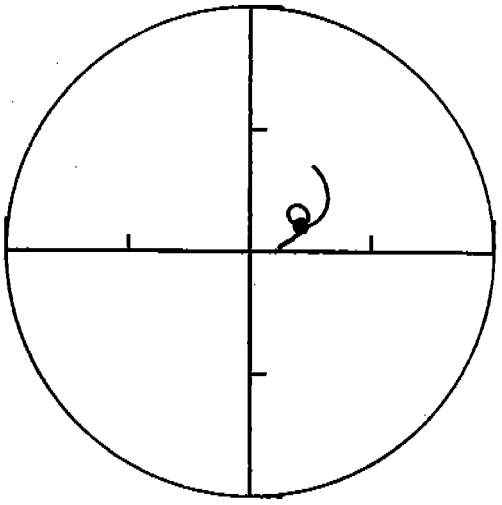


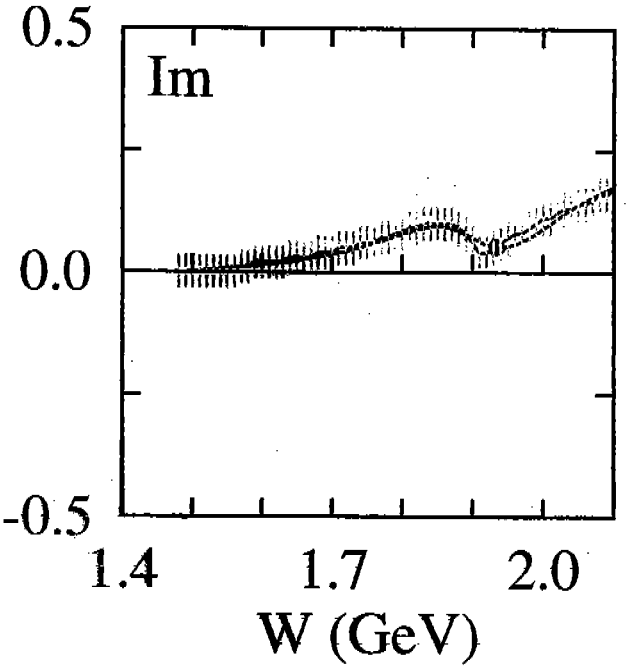


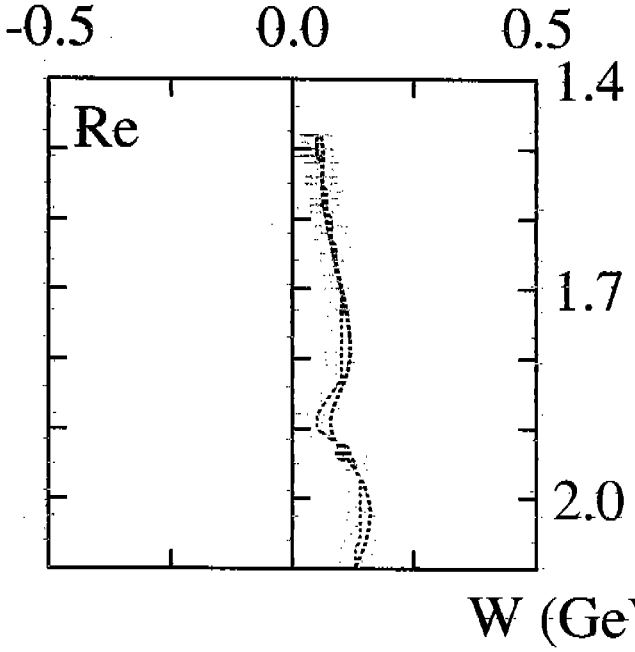


$\bar{K}N \rightarrow \bar{K}N$

P_{03}

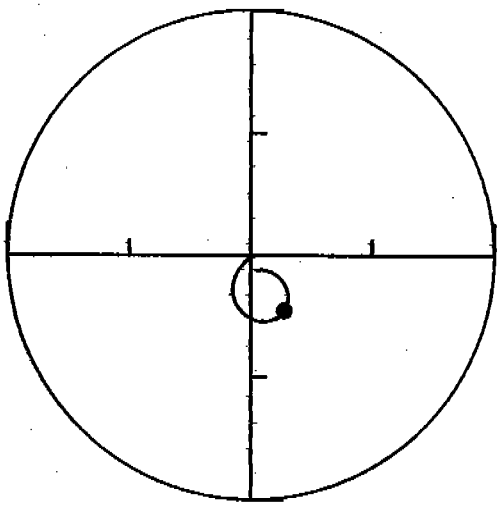


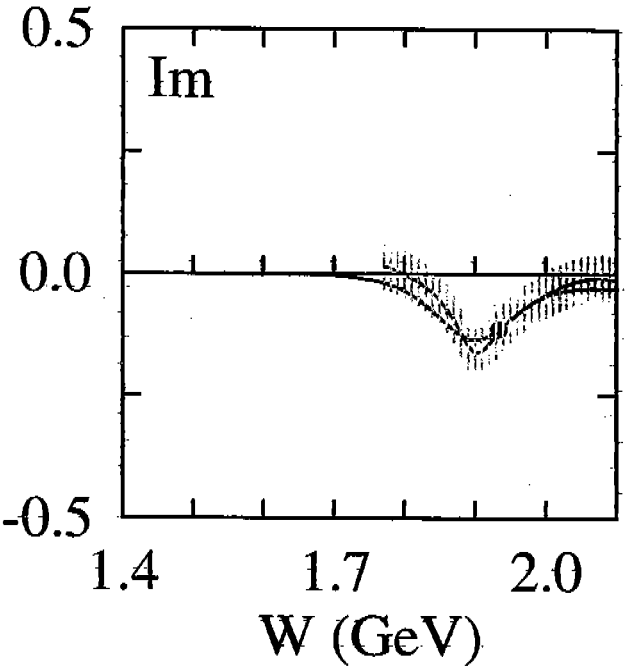


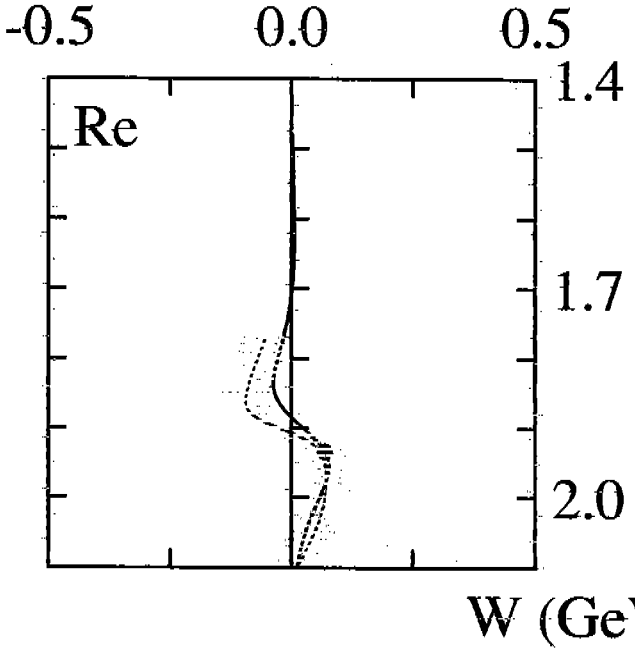


$\bar{K}N \rightarrow \pi\Sigma$

PP03

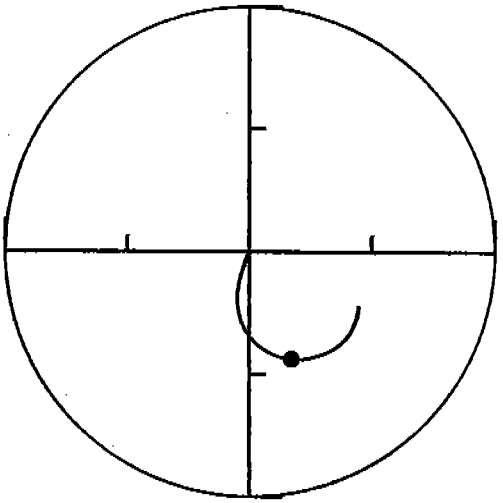


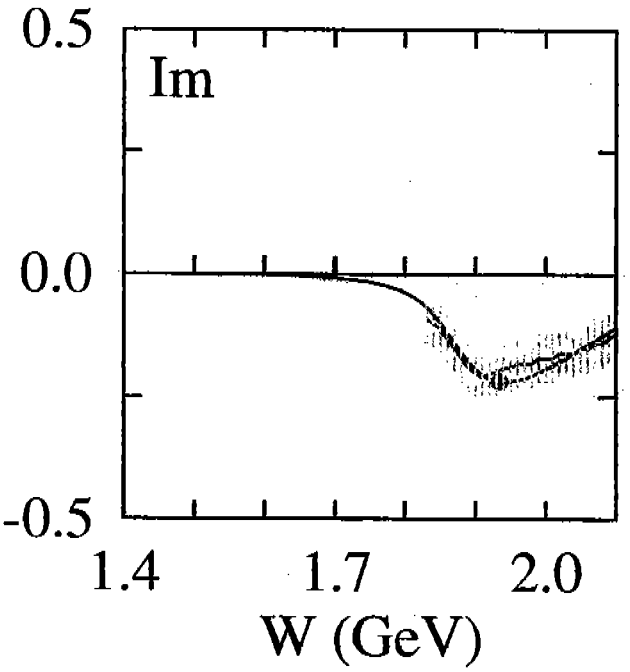


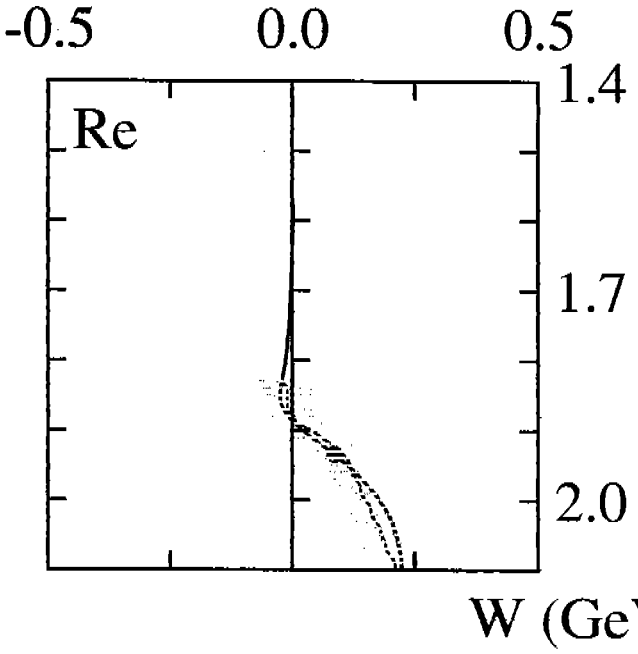


$\bar{K}N \rightarrow \pi \Sigma^*$

PF03







$\bar{K}N \rightarrow \bar{K}_1^* N$

PP03

Summary

- World's best Kaon-induced data measured (over narrow range) with Crystal Ball at BNL

- Beginning stage of first truly unitary self-consistent multichannel determination of Λ^*, Σ^* parameters

- First determination of Λ^*, Σ^* pole positions

- Plan for new multichannel PWA incorporating CB data