Experiments With Polarized Targets

Geoffrey Fox

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Three topics were discussed:

(1) The analysis of simple meson-baryon scattering: $0^{-}1/2^{+} \rightarrow 0^{-}1/2^{+}$

(2) Polarization in $2 \rightarrow 3$ processes and, more generally, $2 \rightarrow N$ processes

(3) Polarized beams.

Item (3) is covered in great detail in a separate paper by E. L. Berger and G. C. Fox published elsewhere in this proceedings. Items (1) and (2) are written up in "Past Lessons and Future Dreams From Polarization Data in High Energy Physics", by G. C. Fox - Caltech preprint CALT-68-334 and to be published in proceedings of the 1971 Polarization Conference at Berkeley. Here we will just summarize (1) and (2) - the reader is referred to the latter paper for further details and references.

(1) Meson Baryon Scattering

In this section, we emphasized the importance of determining individual amplitudes rather than $d\sigma/dt$ - the sum of their squares. We considered a few explicit reactions, listed below, and tried to find which particular polarization, R and A measurements would best elucidate the underlying amplitudes.

$$
\begin{aligned}
&\pi N \text{ elastic and } \pi N \text{ charge exchange,}\\
&K_L^{\circ} p \rightarrow K_S^{\circ} p,\\
&\pi N \rightarrow \eta N,\\
&\pi^{+} p \rightarrow K^{+} \Sigma^{+},\\
&K^{+} p \rightarrow p K^{+},\ K^{+} n \rightarrow K^{\circ} p\ (K^{\circ} p \rightarrow K^{+} n).
\end{aligned}
\tag{1}
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πN elastic and πN charge exchange,

$$K^\circ_L p \to K^\circ_S p,$$

$$\pi N \to \eta N,$$

$$\pi^+ p \to K^+ \Sigma^+, \qquad (1)$$

$$K^+ p \to p K^+,\ K^+ n \to K^\circ p\ (K^\circ p \to K^+ n).$$

The SU_3 related reactions $K^\circ_L p \to K^\circ_S p$ and $\pi^- p \to \pi^\circ n$ are so well studied that it is possible to determine (with some assumptions) their amplitudes without the benefit of R and A measurements. Figure 1 shows the breakup of $K^\circ_L p \to K^\circ_S p$ $d\sigma/dt$ into the contributions of its constituent amplitudes. The t dependence of the amplitudes is clearly much richer than the sum of their squares -- $d\sigma/dt$. Further, no current theory can explain all these t-dependences: thus, letting N = nonflip, F = Spin flip, Regge pole theory agrees with ReF and ImF only - the absorption model with ImN and ImF only. However, both models can fit $d\sigma/dt$ ..... This demonstrates the greater insight possible if amplitudes are known.

In πN elastic scattering and πp charge exchange (CEX), a complete set of experiments exists around 5 GeV/c for $|t|$ less than $.7(\mathrm{GeV/c})^2$ and so the 7 independent observables in this system can be determined. The measurements that have been done are $d\sigma/dt$, P, and R(A) for $\pi^+ p$ and $\pi^- p$ elastic scattering and $d\sigma/dt$ and P for $\pi^- p$ CEX.

Well determined amplitudes are the imaginary part of the $I_t=0$ non-flip amplitude, which is dominated by the Pomeron, and the real part of the $I_t=1$ spin flip (F) amplitude, which corresponds to ρ exchange. Amplitudes which are badly determined by the current data are ReN(ρ) and ImF($I_t=0$). By simulating experiments with reduced errors, it is possible to determine which experiments give the most information about the badly determined amplitudes. The results of this study are that ReN(ρ) would be well determined if R and A were measured for CEX with the same errors as for the current R_{π^-} and A_{π^-} measurements. These experiments are presumably technically impossible. However, ReN(ρ) would also be well determined if R_{π^-}

and R_{π^+} were remeasured to ±.03 which is around 1/3 the current errors. Just redoing R_{π^-} alone to ±.03 or redoing P_{π^+} and P_{π^-} more accurately would not help. These results are shown in Figure 2. A similar analysis shows that measurements of R_{π^+} and R_{π^-} to ±.03 will also determine $\mathrm{ImF}(I_t=0)$ reasonably.

This type of computer experiment should be part of the planning of any experiment in this field because it is crucial to know what statistics you need to have before you learn anything new.

An important point is that at smaller t values, $|t| < .5\ (\mathrm{Gev/c})^2$, one can guess what ReN(ρ) is by looking at $K_L^o p \to K_S^o p$ (cf. Figure 1), and so these experiments are only interesting if they go to larger t, say up to $|t| = 1.0\ (\mathrm{GeV/c})^2$ or if they can determine the energy dependence of the amplitudes.

The best reactions to study are $\pi N \to K(\Sigma, \Lambda)$, $\bar{K}N \to \pi(\Sigma, \Lambda)$ because here you can do the R and A measurements "free" as the hyperon analyzes its own polarization. This gives you the K* and K** exchanges, about which we know essentially nothing. Computer experiments for this reaction show you only need to measure R and A to ±.2 to determine the hypercharge exchange amplitudes to greater accuracy than the πN amplitudes would be found by the R measurements to ±0.03, discussed earlier.

The other reactions listed in equation (1) are also interesting. For instance little is known about A_2 exchange. More data on polarization in $\pi p \to \eta N$ is needed especially near $t = -.2(\mathrm{GeV/c})^2$. Thus in this region the polarization measurement gives information on the zero structure of $\mathrm{ReN}(A_2)$ for $|t| < .2(\mathrm{GeV/c})^2$ if one makes the uncontroversial assumption that and R_{π^+} were remeasured to ±.03 which is around 1/3 the current errors. Just redoing R_{π^-} alone to ±.03 or redoing P_{π^+} and P_{π^-} more accurately would not help. These results are shown in Figure 2. A similar analysis shows that measurements of R_{π^+} and R_{π^-} to ±.03 will also determine $ImF(I_t=0)$ reasonably.

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$ImN(A_2) = 0$ at $t = -.2(GeV/c)^2$. The current data -- which has large statistical errors -- is positive. Theoretically one expects a negative value.

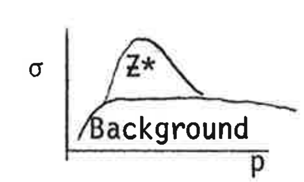
(2) Polarization in Inelastic 2 → 3 Reactions

Motivations for doing polarization experiments in inelastic processes are (a) to look for the Z*; (b) to try to understand the N*(1400) and related Deck enhancements, and (c) study of polarization in quasi two-body processes.

(a) Quest For The Holy Grail

In the K^+p total cross section there is a bump at P_{lab} around 1.2 GEv which is associated with the production of the two body states $K^o\Delta^{++}$ and K*N. This is naively attributed to a Z* resonance; if interpreted as a resonance, the Z* has a small KN but large K*N, KΔ coupling. It follows that it must be studied in the inelastic states: dσ/dt measurements in KΔ have not revealed its presence. However, this is not surprising because the amplitude consists of a real (as K^+p is exotic) $\rho + A_2$ exchange background plus a purely imaginary resonance. The effects are incoherent in dσ/dt:

So how to distinguish



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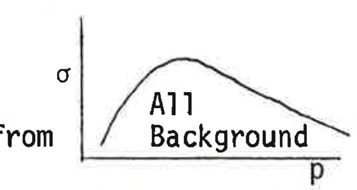

?

Clearly the distinctive resonant phase is not apparent in dσ/dt data. However, polarization picks out $Im(Z^*)\ Re(\rho + A_2)$ and is much more sensitive indicator of resonant behavior. Model calculations show that, if there is no resonance, 10% polarization is expected in $K^o\Delta^{++}$ from threshold to $P_{lab} = 1.5$ GeV/c: a resonant Z* gives 30 → 60% polarizations.

(b) Deck Distraction

Similarly, if the N*(1400) is resonant, it should show up in polarization measurements of $\pi p \to \pi N^*(1400)$ or $NN \to NN^*(1400)$. In $NN \to NN^*(1400)$, two types of polarization experiments can be done. First, if the resonance is produced at the vertex with the polarized particle, you learn about the resonance just as in ordinary low energy polarization studies. Second, if you diffractely produce a fast N*(1400) off a polarized target, you learn about the exchange mechanism. Even in this case the polarization is sensitive to the resonant nature of diffractively produced states. Figure 3 shows calculations for $KN \to Q(\to K^*\pi)N$ at 6 GeV/c. Another example of the second type of reaction would be $\pi^{\pm}p \to A_1^{\pm}p$ off a polarized target. In this reaction you learn about the secondary trajectories and it would be interesting to look for mirror symmetry.

Sections (a) and (b) are also discussed in the polarized beam paper in this proceedings.

(c) Queasy Two-Body Reactions*

In resonance production off a polarized target, one both learns about new exchanges (π, B, A_1...) not possible in meson-baryon scattering, and also sees the old exchanges (ρ, A_2..) in new clothes, e.g. double flip amplitudes**. Further an essential advantage of resonances reactions is recorded in the table following.

*Such are quasi two-body reactions when viewed by nervous physicists who worry about background and competing channels. However, the effect is, like seasickness, largely psychological and the rewards are great for those who go to the sea in ships and face their difficulties like a phenomenologist.

**Perhaps if these clothes are liken unto those of the fabled emperor of yore, the true nature of the ρ and A_2 will be apparent without the detailed phenomenological analysis now needed. Theorists will then be happy.

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Table 1: Polarized Target Observables

Generic Reaction	No. of Independent Observables	Unpolarized Observables	Polarized Target (⊥Beam) Observables
$\pi N \rightarrow \pi N$	3	1	2 < 3
$\pi N \rightarrow \pi\Delta$	7	4	10 > 7
$\pi N \rightarrow \rho N$	11	4	10
$\pi N \rightarrow \rho\Delta$	23	20	56 > 23

Whereas in $\pi N \rightarrow \pi N$, the difficult R and A measurements are necessary for a complete set of observables, one only needs a polarized target and observation of the resonance decay in quasi two-body data. Actually in $\pi N \rightarrow \rho N$ one additional experiment is necessary. However, one gets a complete set of experiments and thereby a determination of the amplitudes by observing the recoil nucleon polarization off an unpolarized target. Typical predictions are given in Figures 4 → 7 for polarized target and recoil polarization experiments. The predicted asymmetries are quite large - especially in $K^-p \rightarrow K^{*-}p$. Note that if A_1 exchange is unimportant (as predicted in all current theories), we expect the universal decay $\text{Sin}^2\theta\text{Sin}^2\phi$ for the vector meson decay from all $0^-1/2^+ \rightarrow 1^-1/2^+$ processes, in the asymmetry off a target polarized perpendicular to the production plane.

Similarly, one can predict the $\pi N \rightarrow \pi\Delta$ polarized target observables. Unfortunately the expected asymmetries are in this case rather small. It is, of course, important to check this experimentally, but it may be necessary to study, rather, the SU_3 related reactions, like $\pi N \rightarrow KY^*(1385)$.

Here one can do R and A type measurements with just a polarized target because the Y* decays to $\pi\Lambda$ and the Λ, as in $\pi N \rightarrow K\Lambda$ analyzes its own polarization. The expected asymmetries are now much larger and allow direct study of say the double flip amplitude and the origin, in terms of amplitudes, of the Stodolsky-Sakurai distribution of the Y* decay off an unpolarized target.

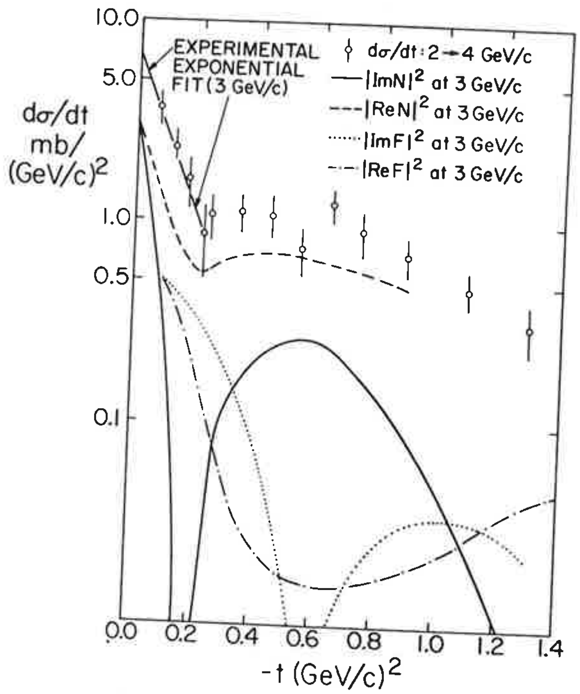

Fig. 1

Decomposition of $K_L^o p \rightarrow K_S^o p$ data at 3 GeV/c into constituent amplitudes (C. B. Chiu and G. C. Fox--unpublished)

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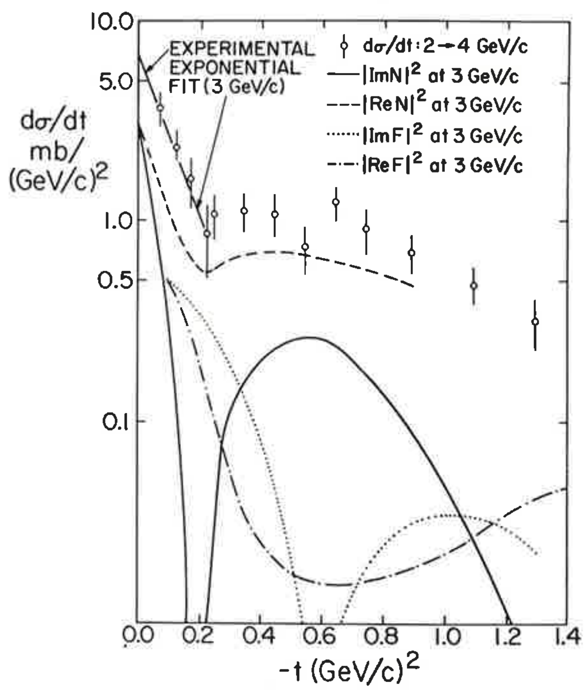

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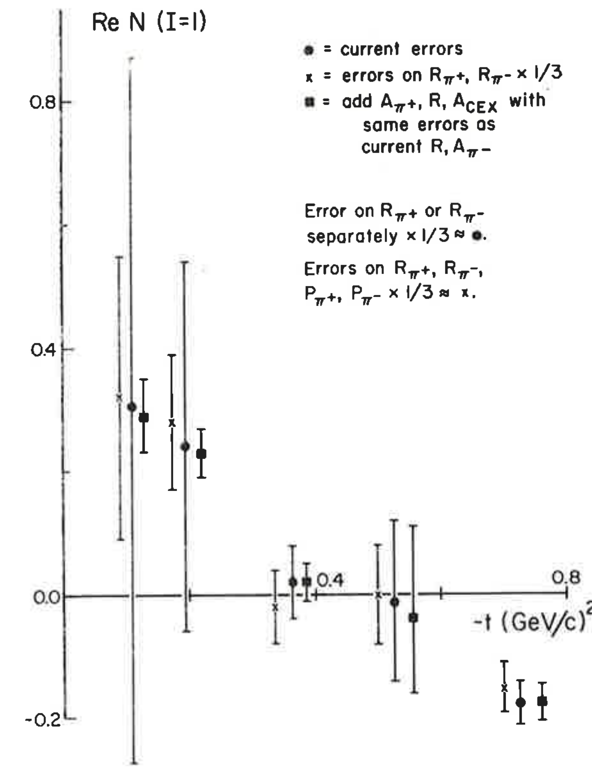


Fig. 2

Amplitude analysis of πN elastic scattering data around 5 GeV/c. We show Re N(ρ exchange)--as one of the most interesting but poorly determined amplitudes. We mark not only the results of using current data (. points) but also those from using fake data with reduced errors on some of the observables. (J. Hull and G. C. Fox--unpublished).

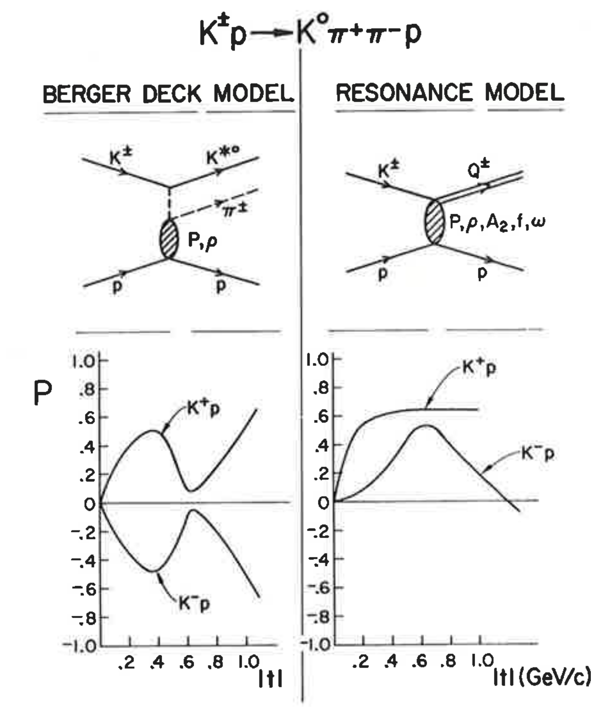


Fig. 3

The expected polarizations in $K^{\pm}p \rightarrow Q^{\pm}(\rightarrow K^{*o}\pi^{\pm})p$ at 6 GeV/c in Deck and Resonant Q models. (E. L. Berger and G. C. Fox, unpublished calculations.)

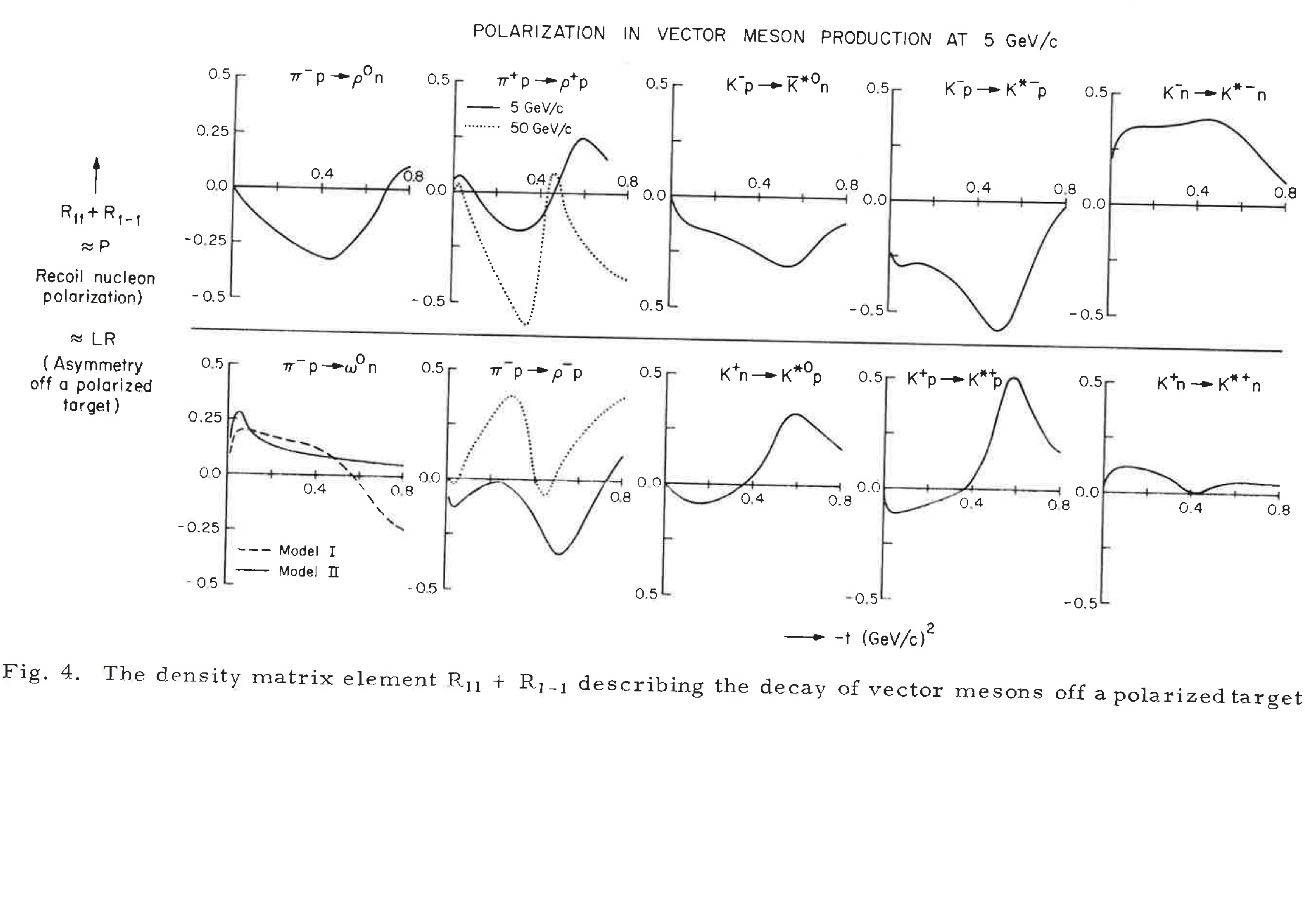
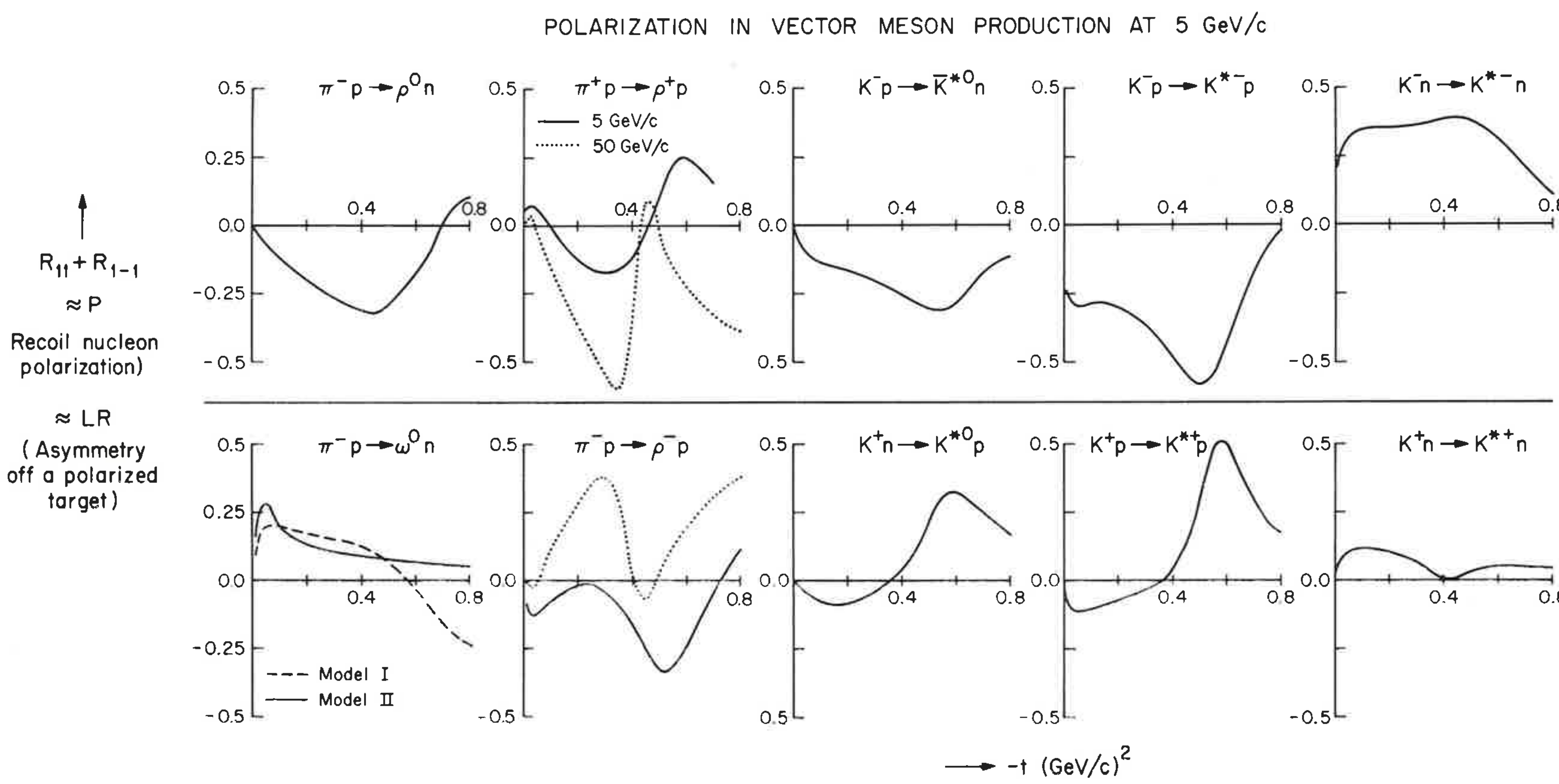


Fig. 4. The density matrix element $R_{11} + R_{1-1}$ describing the decay of vector mesons off a polarized target



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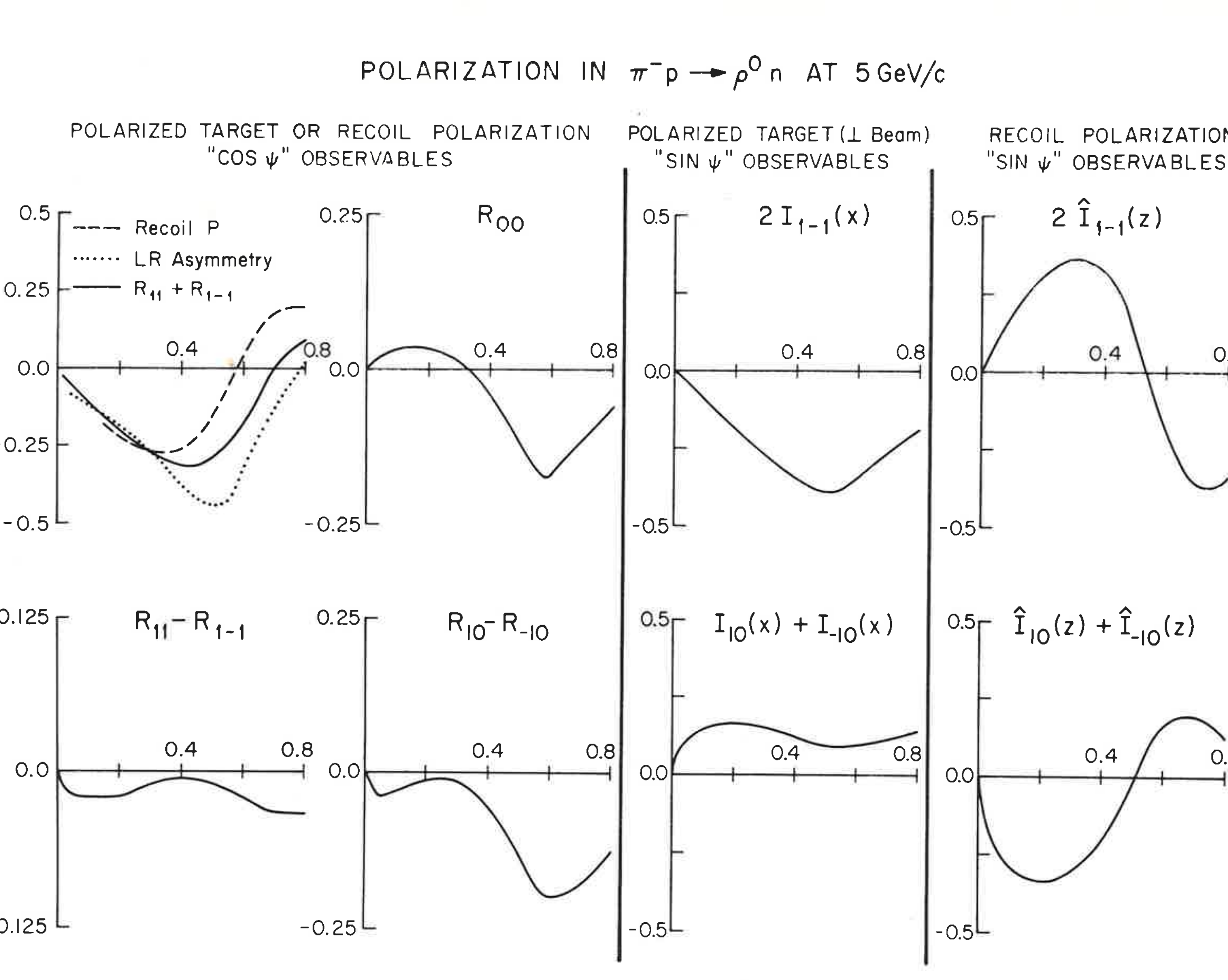


Fig. 5. Some of the density matrix elements describing the decay of $\pi^-p \to \rho^0 n$ off a polarized target. $R_{ij} = \mathrm{Re}\rho_{ij}$ refers to the (usual) configuration with polarization ⊥ to the production plane and recoil polarization and polarized target experiments give the same information. I_{ij} (polarized target) and $\hat{I}_{ij}$ (recoil polarization) are $\mathrm{Im}\rho_{ij}$ and are appropriate if the polarizations is in the production plane.

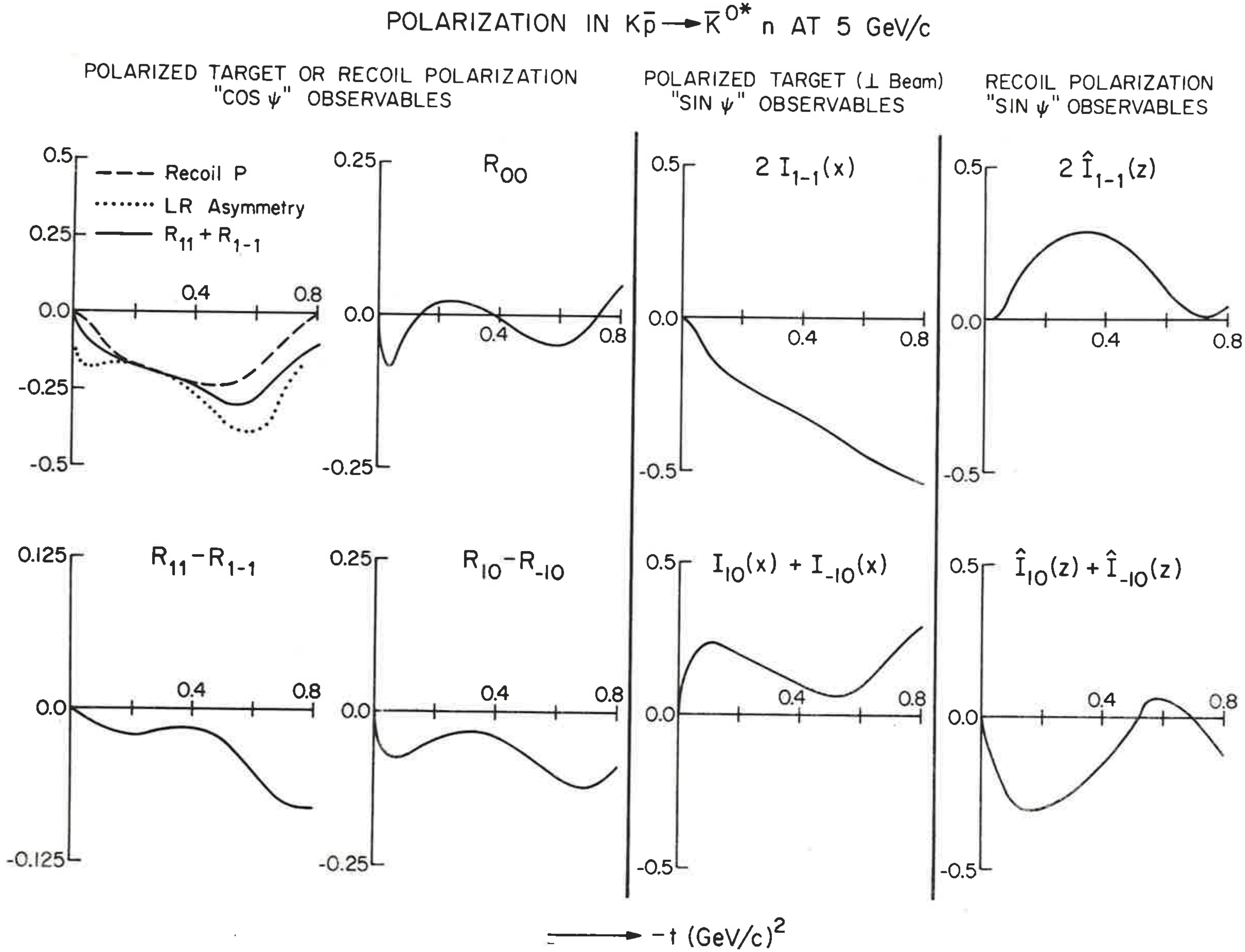
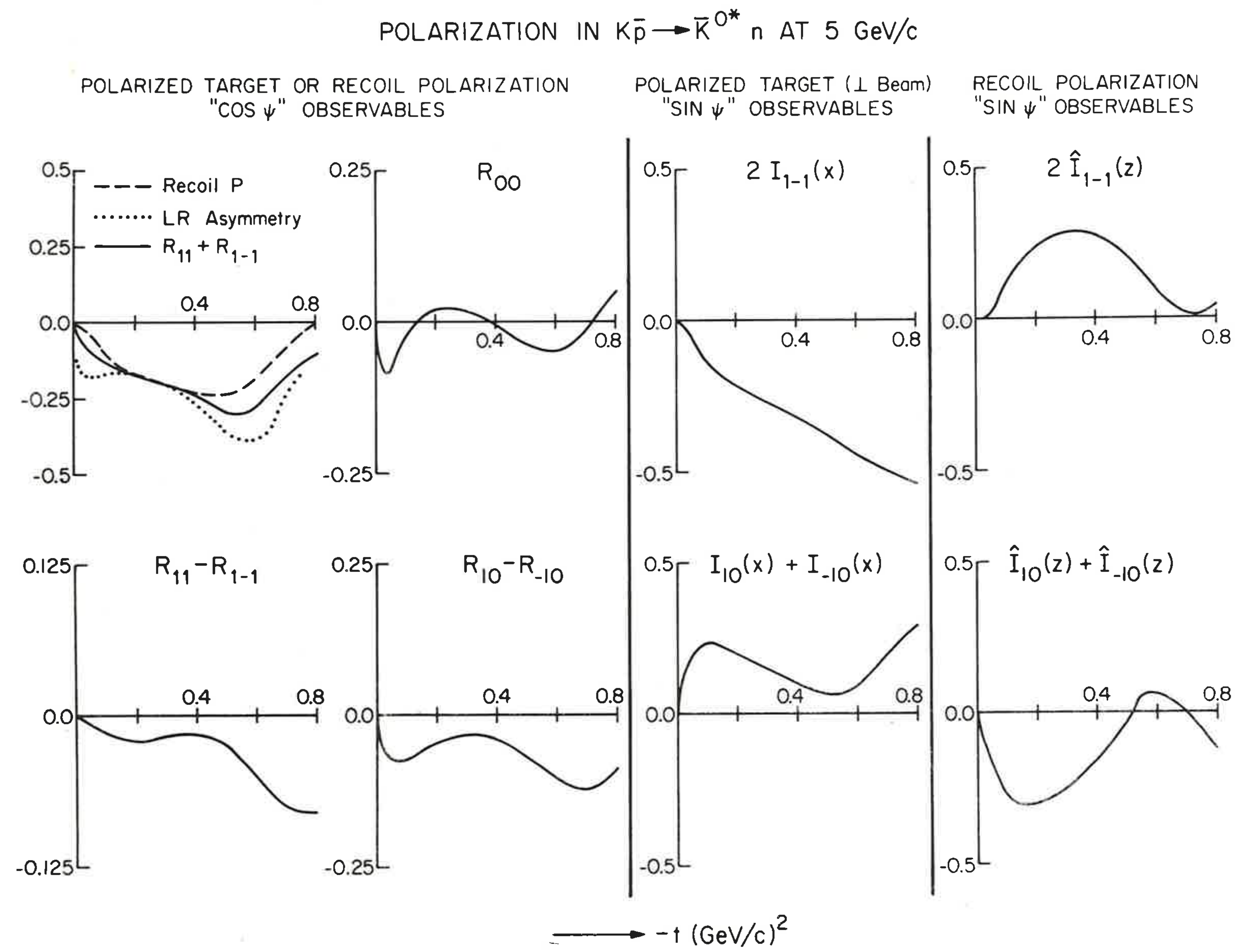


Fig. 6. The same quantities as in Fig. 5 but calculated for $K^- p \to \bar{K}^{*o} n$.



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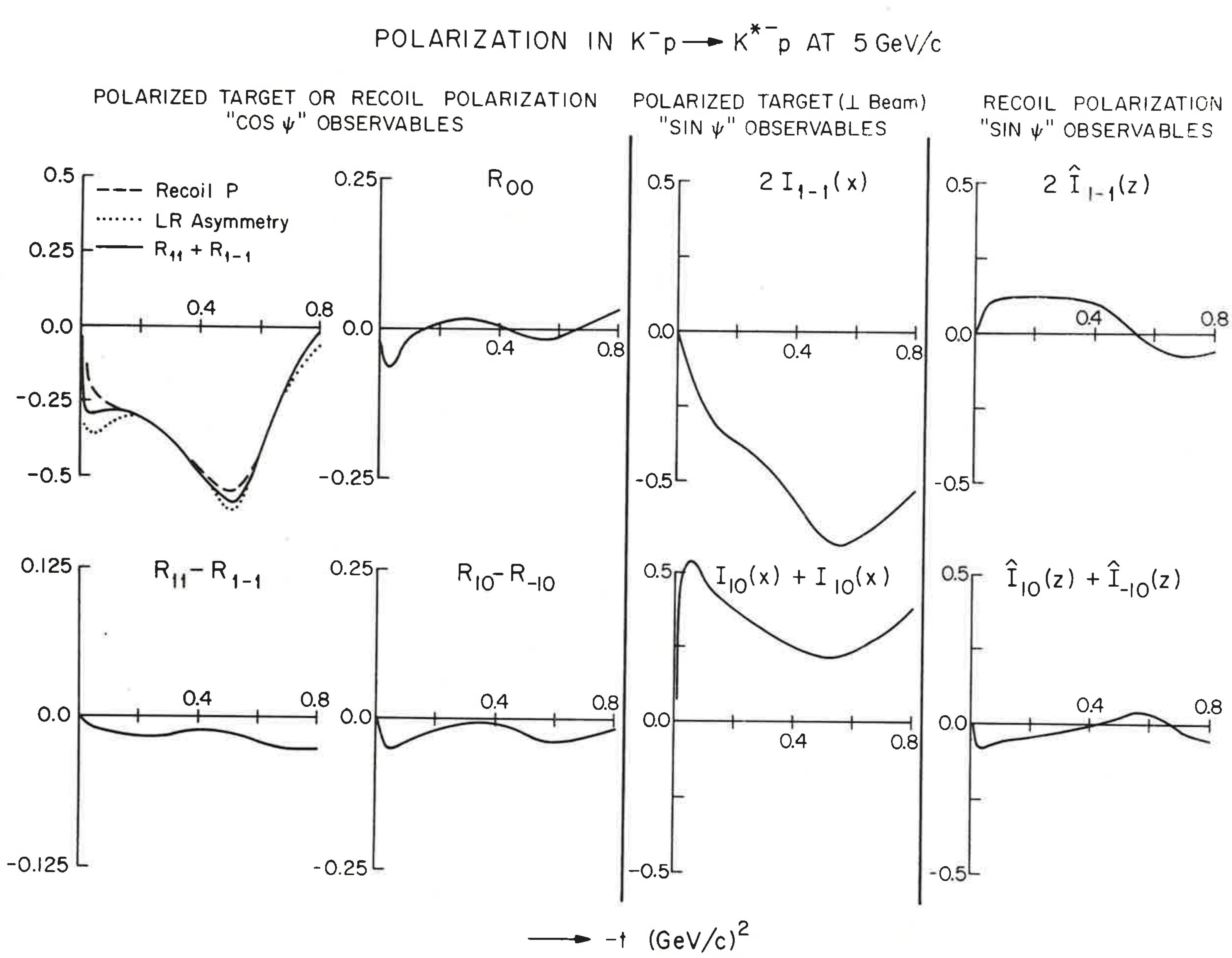

Fig. 7. The same quantities as in Fig. 5 but calculated for $K^-p \rightarrow K^{*-}p$