Title
SEARCH FOR ERICS ON FLUCTUATIONS IN n+p SCATTERING AT 3.7 and 7.1 GeV/c

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Search for Ericson Fluctuations in π^+p Scattering at 3.7 and 7.1 GeV/c*

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Abstract

Data on π^+p elastic scattering, obtained from two high-statistics bubble chamber exposures at 3.7 and 7.1 GeV/c beam momentum, have been examined for Ericson fluctuations. No evidence for such fluctuations has been found. It is shown that fixed-u features of the differential cross section will lead to non-zero values of the asymmetry parameter at fixed-t

I would like to present results from another *ex post facto* experiment on Ericson fluctuations; that is to say, although this experiment wasn't designed specifically to look for fluctuations, it appears that it might contain some information on the question, so we have done a simple analysis. The process observed is π^+p elastic scattering at the two beam momenta of 3.7 and 7.1 GeV/c. This is a bubble chamber experiment, carried out with the 82-inch hydrogen bubble chamber at SLAC. The data come from two different experimental groups at LBL: Group A has provided the data at 7.1 GeV/c, while the 3.7 GeV/c data come from the Trilling-Goldhaber group ([1]). At 7.1 GeV/c, the data come from about 700 000 pictures having a sensitivity of 43 events/μb. Some 500 000 two-pronged events have been measured, with about 139 000 fitting the four-constraint elastic hypothesis. At 3.7 GeV/c the processing of events is still underway, but we have a sample based on about 550 000 pictures, which have yielded about 50 000 elastic events.

What experimental condition permits us to make such an analysis? It is that the spread in beam momentum is significantly greater than the resolution of an individual beam track. The spread in beam momentum is between 3% and 4%, while the momentum of an individual beam track is known to 0.5% or better. This comes about because the momentum of a given track is correlated by the beam optics with the transverse position of the track in the chamber. The situation is summarized in Fig. 1, and more specifics are given in Ref. 2. Fig. 1 also shows the kinematic region covered by this experiment in terms of the conventional Mandelstam variables s and t. Keep in mind that on this plot a line of constant u lies at 45° to the t-axis. That fact will enter into our discussion of projections on t.

Fig. 2 shows the distribution of center-of-mass energy at the two momenta. For the purpose of studying fluctuations, the data are divided into three bins in c.m. energy, as indicated by the dotted lines in Fig. 2. The boundaries are chosen so that the number of events in each bin is the same. The difference in the average energy of the outermost bins is 30 MeV at 3.7 GeV/c and 60 MeV at 7.1 GeV/c.

Figs. 3a and 3b show the differential cross section $d\sigma/dt$ with the three energy bins combined at each momentum. The test for Ericson fluctuations is to make the corresponding distribution for each c.m. energy bin separately, and compute the asymmetry parameter, $A(t)$, between pairs of energy bins. $A(t)$ is defined as follows ([3]):

$$A(t) = \frac{\sigma(t,higher) - \sigma(t,lower)}{\sigma(t,higher) + \sigma(t,lower)}$$

where $\sigma(t,higher)$ and $\sigma(t,lower)$ are respectively the values of the differential cross section for the higher and lower energy bins of the pair.

Before looking at the results for $A(t)$, however, let's consider a circumstance other than Ericson fluctuations that can lead to non-zero values of $A(t)$. That circumstance is the presence of fixed-u features in the πp differential cross section. The effect of such features on $A(t)$ is illustrated schematically in Fig. 4 for two idealized cases. In the case of a fixed-u dip, an oscillation is induced in $A(t)$, as illustrated in Figs. 4b and 4c. In the case of a fixed-u slope (*i.e.* $\sigma \propto e^{bu}$), a square-wave shape is induced in $A(t)$, as illustrated in Figs. 4d and 4e. More generally, a fixed-u surface having both ingredients may be present, as illustrated in Fig. 4f.

Do we have evidence for such fixed-u features in our data? Figs. 3c and 3d show the differential cross section with respect to u for each momentum, and it may be seen that the shapes are very similar for $-u < 3$. For greater clarity, a magnified view of this region is given in Fig. 5. The backward peak and well-known dip at $-u \simeq 0.15$ are readily apparent, and there is a smooth fall-off from a secondary maximum near $-u = 0.6$ to a minimum near $-u = 3$. Since this shape persists from 3.7 to 7.1 GeV/c (an interval of 1 GeV in c.m. energy) it may be regarded as an approximately fixed-u shape. A similar shape has also been observed in CERN experiments at 5 and 10 GeV/c ([4]). The dip at $-u \simeq 0.15$ is too narrow to have an observable effect on $A(t)$ at our statistical level, but now let's look at the results for $A(t)$ to see if there is any effect from the fixed-u surface, or any indication of the presence of Ericson fluctuations, and then make a crude estimate of the expected magnitude of the effect. Fig. 3

can be used to see which t-values correspond to the fixed-u surface. The region from $-u$ = 1 to 3 maps into the neighborhood of $-t$ = 3 to 5 at 3.7 GeV/c, and $-t$ = 10 to 12 at 7.1 GeV/c. Fig. 6 shows A(t) for the outermost c.m. energy bins at each momentum. At 7.1 GeV/c, there are points about three and two standard deviations from zero at $-t$ = 11 to 12. At 3.7 GeV/c, there are points approximately two standard deviations from zero in the neighborhood of $-t$ = 5. In both cases, these non-zero points fall in the range of the fixed-u surface; otherwise, the asymmetry is consistent with zero. For completeness, Fig. 7 shows A(t) for the inner pairs of bins at each momentum, although these should be less sensitive than the outermost bins. Again, there are no significantly non-zero values of the asymmetry. Fig. 8 shows the correlation function, C(t) (defined on the figure), which uses the information from all three bins simultaneously, and should give the best indication of any real effect ([5]). Again, there are no significantly non-zero values, except possibly in the region of the fixed-u surface.

A rough quantitative estimate of the expected asymmetry for a given slope in $d\sigma/du$ can be made as shown in Fig. 9. The slope parameter, b, can be estimated by drawing lines on the data of Fig. 5 and on the CERN data of Ref. 4. The estimated values of A(t) are quite compatible with the observed asymmetries. The fixed-u features of the cross section thus provide a satisfactory explanation of the present data, and we conclude that:

- There is no evidence for Ericson fluctuations in these data . (For an estimate of the sensitivity of this experiment, see the Appendix below.)

- Experiments to study fluctuations must properly account for the gross features of πp scattering.

(continued)

Appendix

(The following remarks have been added for this written report, and were not given in the presentation to the symposium.)

Theoretical estimates of the fluctuating part of the cross section have been given by Frautschi ([5]) and Carlson ([6]). These estimates may be used to predict the value of the correlation function shown in Fig. 8. A comparison of the theoretical predictions for 90° scattering with the experimental results is given in Fig. 10. The experimental values near 90° are consistent with zero at both momenta. The theoretical estimates are said to be good to about 50% ([6]). Allowing for this, at 3.7 GeV/c Carlson's estimate is about a factor of five greater than the observed value, while Frautschi's estimate is about a factor of two greater. It thus appears that Carlson's estimate can be rejected with reasonable confidence. At 7.1 GeV/c, the theoretical values are essentially zero, and are well below the sensitivity of the data.

In the results of Schmidt, *et al.*, ([3]), shown in Fig. 11, $A(t)$ shows rather different behavior for the π^+ and π^- beams. This difference can possibly be explained by a difference in average slope or detailed shape of the fixed-u surfaces of π^+p and π^-p scattering (see Fig. 4). In the interval $-t \simeq 4$ to 7, the average slope for π^+p is roughly 40% greater than for π^-p, as may be seen in Fig. 11. Some difference in detailed shape is also apparent. This provides a qualitative alternative to the interpretation that the difference in $A(t)$ is due to a difference in the density of s-channel states in π^+p and π^-p scattering.

Footnotes and References

* Supported by the U. S. Energy Research and Development Administration.

1. The persons responsible for the data are:
M. Alston-Garnjost, A. Barbaro-Galtieri, G. R. Lynch, and F. T. Solmitz, of Group A, and G. S. Abrams, B. Y. Daugeras (visitor from Orsay), A. D. Johnson, and F. C. Winkelmann of the Trilling-Goldhaber group. For a discussion of elastic scattering *per se* based on these data, see W. Michael, *et al.*, Phys. Rev. Letters, 35, 193 (1975).

2. M. Alston-Garnjost, *et al.*, Phys. Letters 33B, 607 (1970).
S. Flatté, "Beam Averaging for the SLAC C-K Beam", Group A Memo No. 664 (1968). The same beam is used at 3.7 GeV/c, and a similar precision has been found to hold at this momentum.

3. F. H. Schmidt and Steve Frautschi, these Proceedings.
F. H. Schmidt, *et al.*, Phys. Letters 45B, 157 (1973).

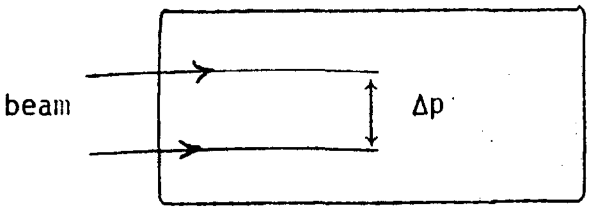
4. A. Eide, *et al.*, Nucl. Phys. B60, 173 (1973).
C. Baglin, *et al.*, Phys. Letters 47B, 85 (1973).

5. S. Frautschi, Nuovo Cimento 12A, 133 (1972).
Steve Frautschi has pointed out to us that $C_{EXP}(t)$ computed for a small energy interval will necessarily underestimate the true correlation, since $\overline{\sigma}$ over a small interval may be significantly different from the true $\overline{\sigma}$. This is illustrated schematically in Fig. 8.

6. P. J. Carlson, Phys. Letters 45B, 161 (1973).

Beam momentum spread ≈ 3% - 4%

Beam resolution ≲ 0.5%



82-inch HBC

P_{beam} (GeV/c)	FWHM (MeV/c)
3.7	110
7.1	260

$\pi^+p \rightarrow \pi^+p$ 3.7, 7.1 GeV/c

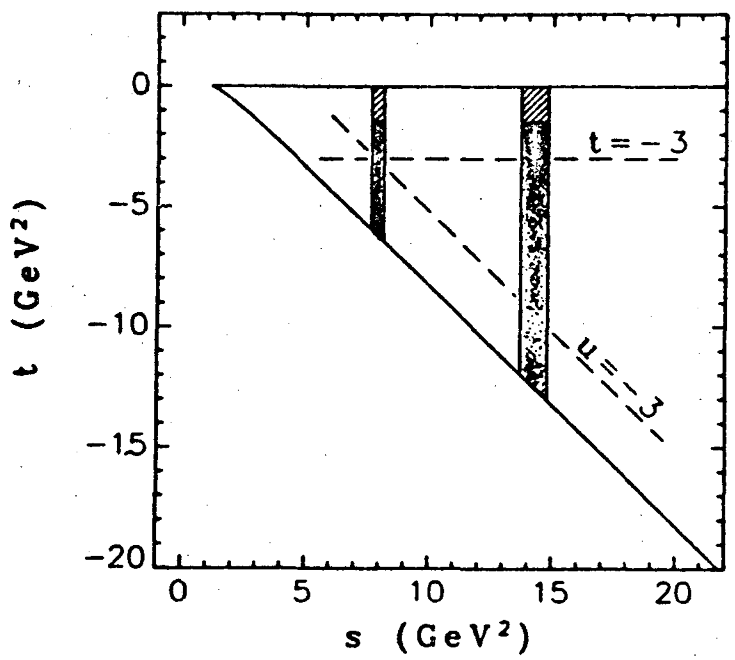


Fig. 1. A search for Ericson fluctuations is possible in this experiment because the spread in beam momentum is significantly greater than the resolution (see Ref. 2). The Mandelstam plot shows the kinematic region covered, along with a portion of the data.

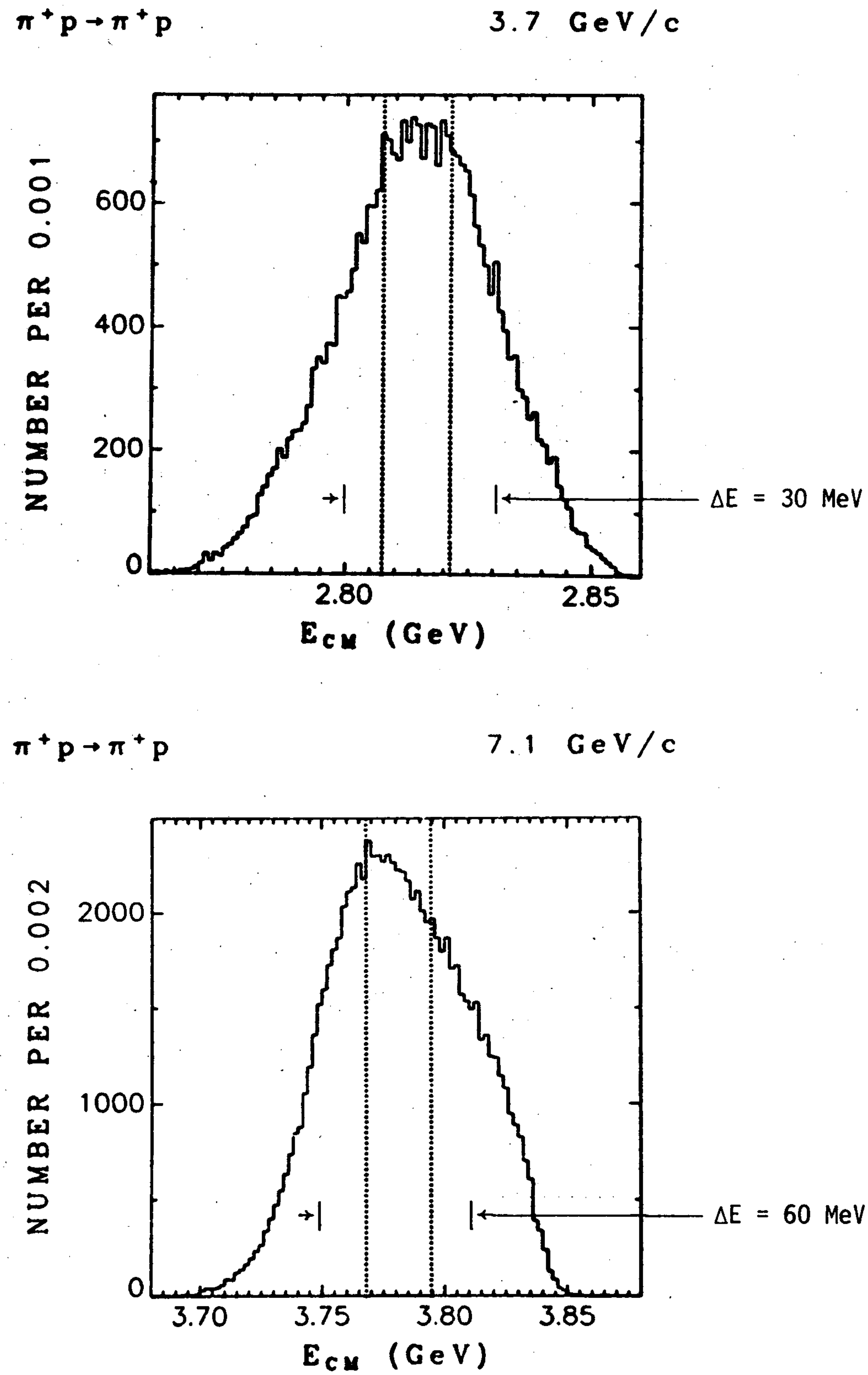


Fig. 2. Distribution of center-of-mass energy at the two momenta. Note the difference in abscissa scales. The dotted lines indicate the bins used to test for fluctuations.

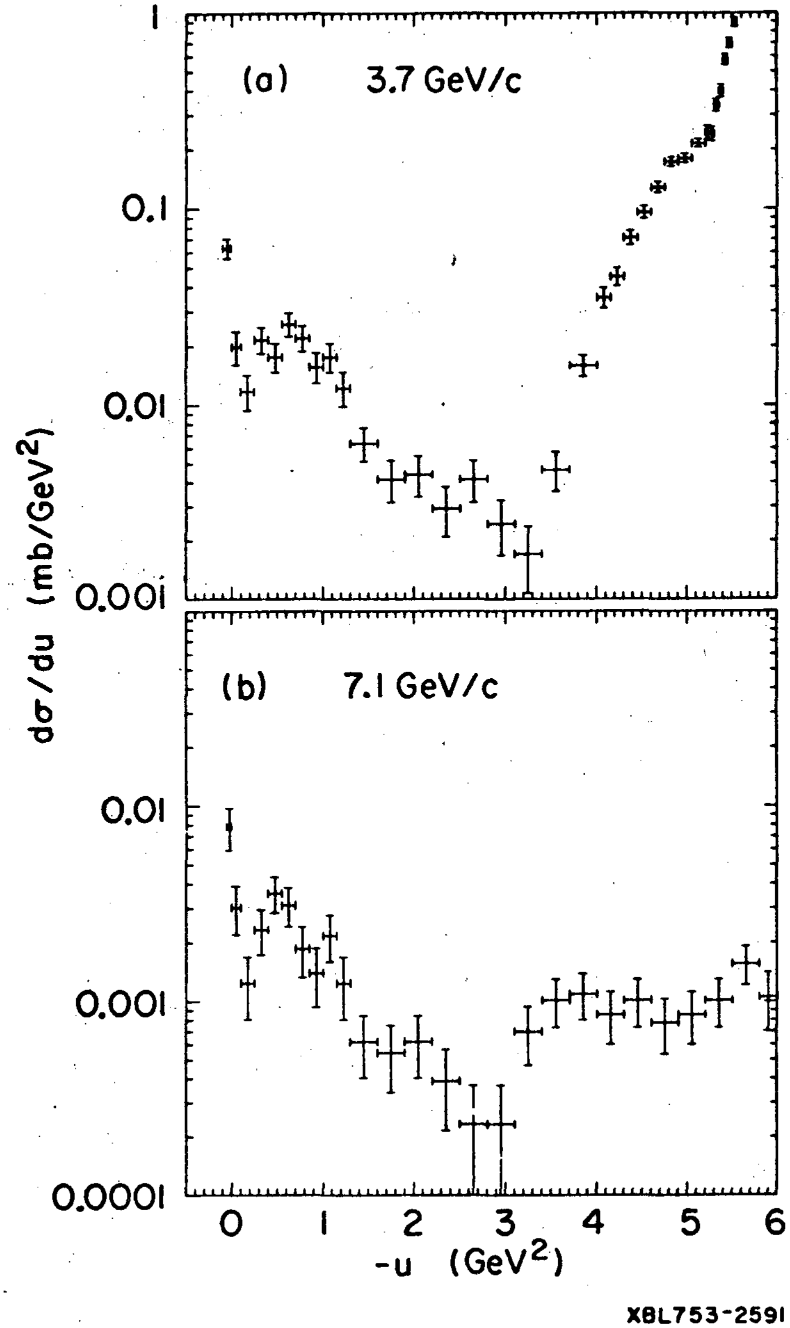
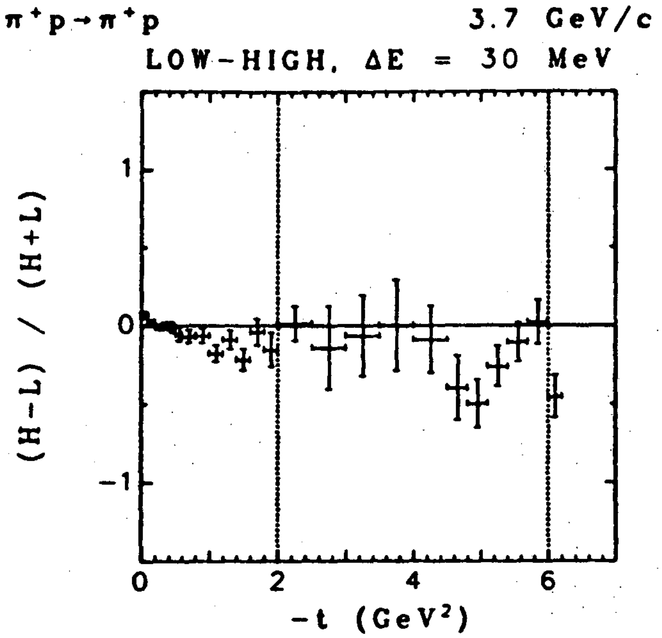


Fig. 5. Differential cross section for $-u < 6$. Note the similarity of shape for $-u < 3$.



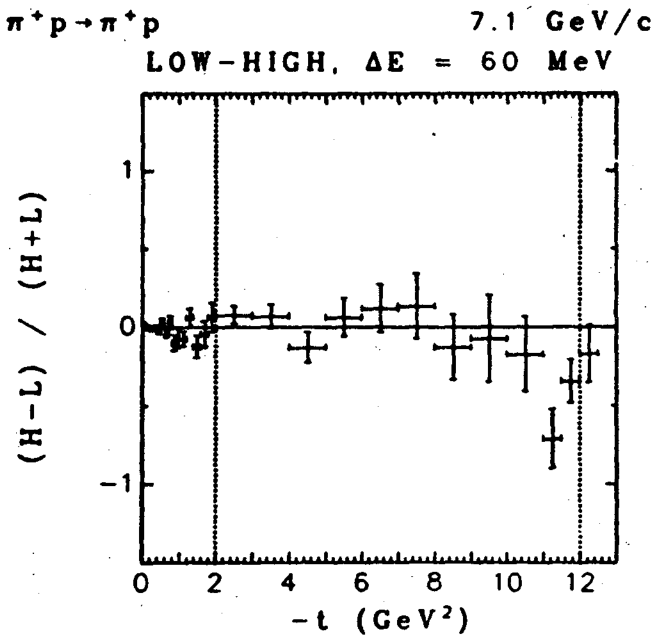


Fig. 6. Asymmetry parameter for the outer pair of bins at each momentum. The dotted lines indicate the region likely to be most sensitive to Ericson fluctuations. Values near the backward direction may show the effect of the different amount of phase space available at each energy, or the effect of the fixed-u dip at $-u \simeq 0.15$.

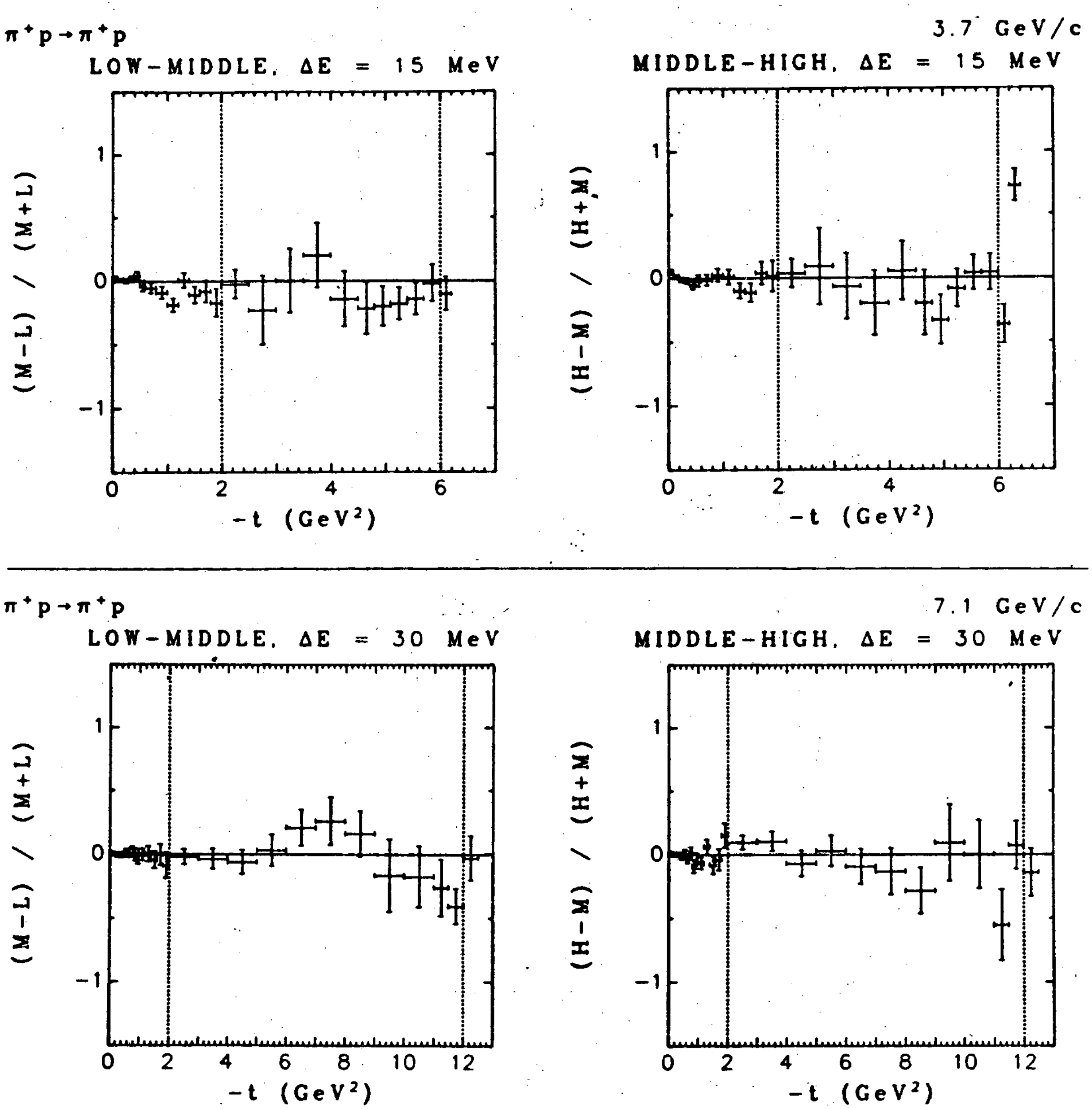
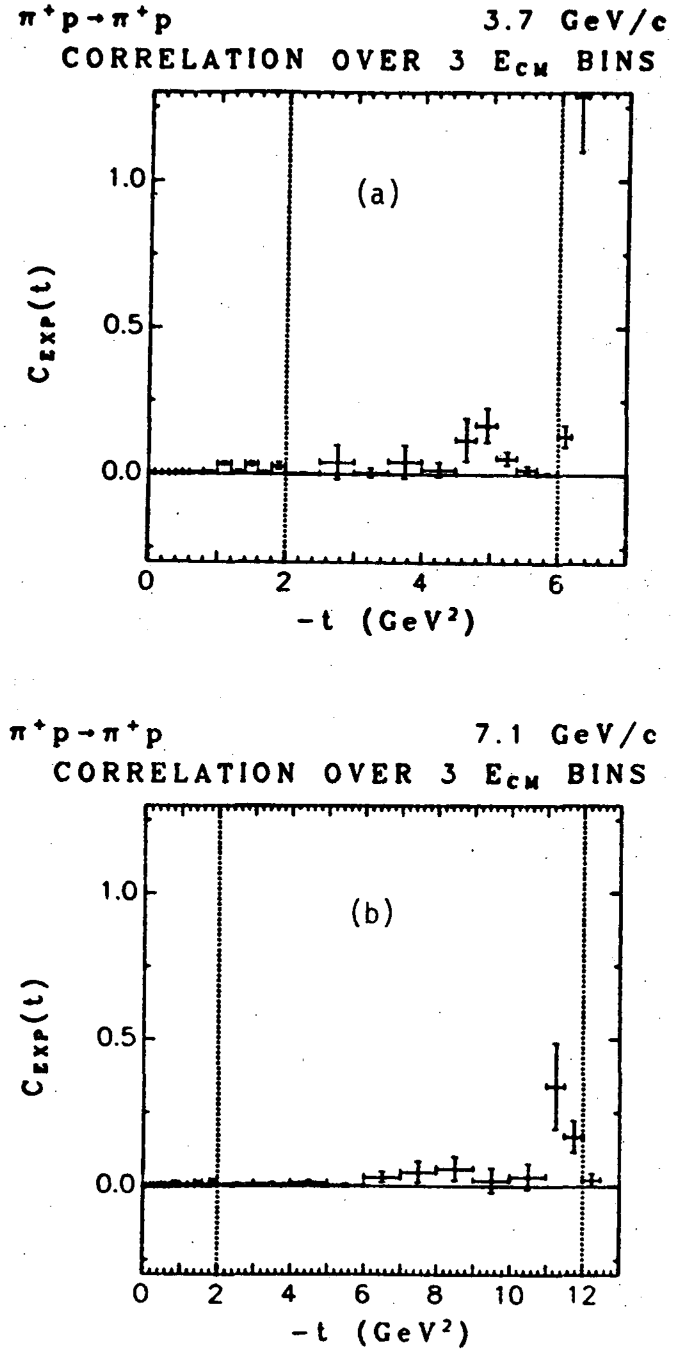


Fig. 7. Asymmetry for the inner pairs of bins at each momentum. See the caption for Fig. 6 for an explanation of the dotted lines and backward points.



$$C_{EXP}(t) = \frac{1}{N}\sum^{N}\left[\frac{\sigma(t,s_i) - \overline{\sigma}(t,s_i)}{\overline{\sigma}(t,s_i)}\right]^2$$

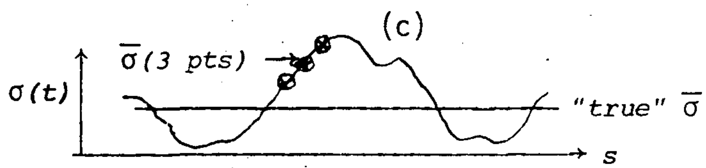


Fig. 8. Correlation function for the three bins at each momentum. See Footnote 5 for an explanation of the sketch, (c).

Definition $A(t) = \dfrac{\sigma(t,higher) - \sigma(t,lower)}{\sigma(t,higher) + \sigma(t,lower)} \simeq \dfrac{\Delta\sigma}{2\sigma}$

Assume $\sigma(u) \sim e^{bu}$

Then $A(t) \simeq b\Delta u/2$

Empirically $b \simeq 1 - 2$ (at $-u \simeq 1$. See Fig. 5 and Ref. 4)

and $\Delta u|_{fixed\ t} = -\Delta s = -2E\Delta E$ (from $s + t + u = \Sigma m^2$)

So

	P_{beam} (GeV/c)	E_{cm} (GeV)	ΔE (MeV)	Δu (GeV²)	A_b	A_{obs} (approx.)
LBL	3.7	2.8	30	-.17	-.11	-.3, -.5
CERN	5.0	3.2	20	-.13	-.09	-.2, -.5
LBL	7.1	3.8	60	-.45	-.3	-.3, -.7

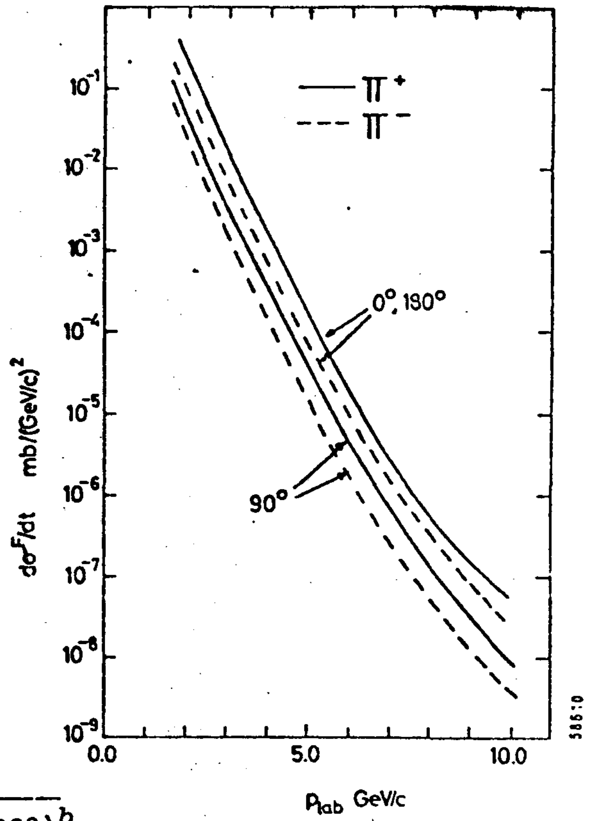
See Fig. 11 for the CERN data.
The column "A_b" is obtained by setting $b = 1.5$. If b is taken equal to 2 (as it appears to be at its steepest point) the predicted values of A are just Δu, and the agreement with the observed values is even better.
If σ is decreasing with s or b is increasing with s (shrinkage), the predicted magnitude of A will increase.

Fig. 9. Estimate of the asymmetry, $A(t)$, induced by a given slope, b, and comparison with observed asymmetries.

Theoretical correlation $C_{TH} = \frac{\sigma_F\ (2\bar{\sigma} - \sigma_F)}{2\bar{\sigma}^2}$ (Ref. 5, Eq. 12)

where σ_F = fluctuating part of cross section,
and $\bar{\sigma}$ = observed cross section at a given t-value.

Carlson's estimate of σ_F →



P_{beam} (GeV/c)	t-interval (GeV²)	C_{EXP} [a] (see Fig. 8)	$C_{TH}(90°)$ [b] (approx.)
3.7	2 - 4	.02 ± .02	.07, .2
7.1	4 - 6	.007 ± .004	< .001
	6 - 8	.04 ± .02	

[a] C_{EXP} is the average of the experimental points of Fig. 8 over the t-interval.

[b] The higher value of C_{TH} is based on Carlson's value of σ_F at 90°, taken from the graph above (6). The lower value is inferred to be Frautschi's estimate, since his $\sigma_F(0°)$ is about one-third Carlson's $\sigma_F(0°)$.

Fig. 10. Comparison of the experimental and theoretical values of the correlation function.

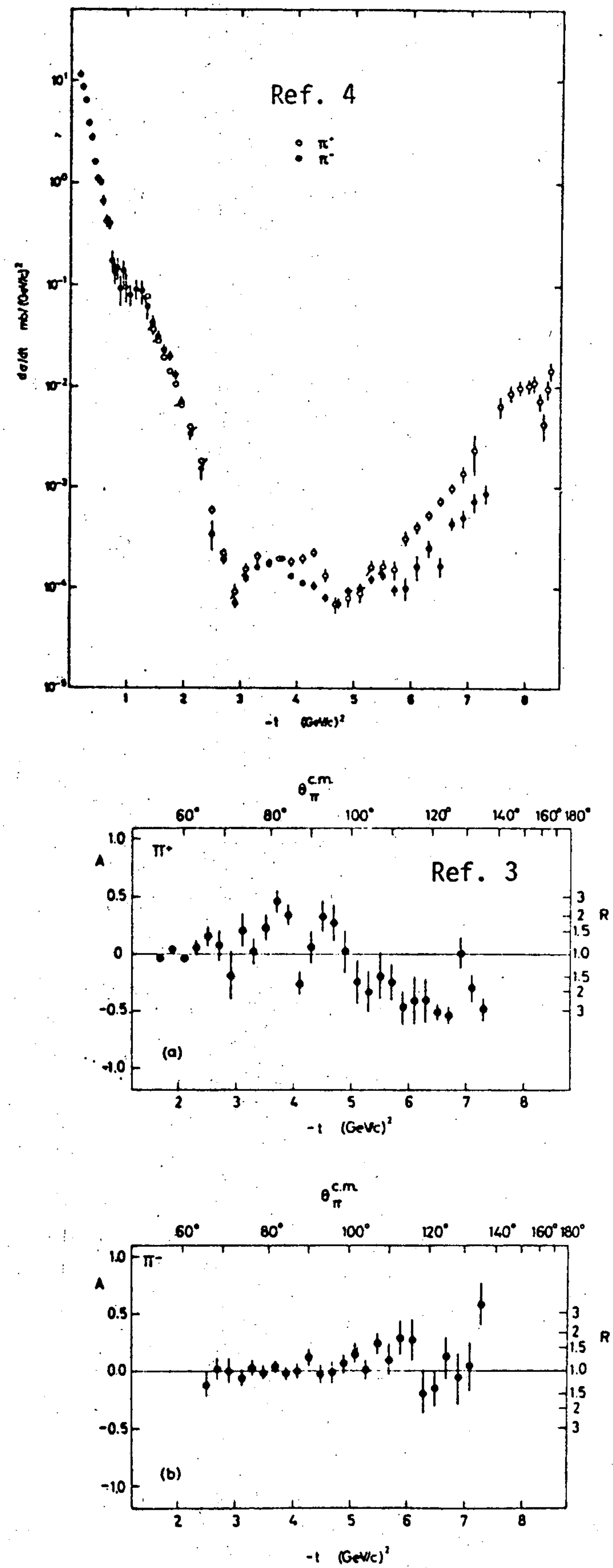


Fig. 11.

Results from the CERN experiment of Refs. 3 and 4. The difference in asymmetry between π^+ and π^- may result from a difference in average slope or detailed shape of a fixed-u surface in the range $-t \simeq 4$ to 7. See Fig. 4.

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