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Backward Elastic π^+p Scattering at 3.7 and 7.1 GeV/c*

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Abstract

The differential cross section of π^+p elastic scattering has been measured in two high-statistics bubble chamber exposures at laboratory beam momenta of 3.7 and 7.1 GeV/c. A new feature suggested by these data is a dip in $d\sigma/du$ at $-u \simeq 3$ GeV^2. This dip corresponds well to the third zero of $J_0(\sqrt{-u'})$. No dip is observed near $-t = 3$ in the 7.1 GeV/c data sample. The effective u-channel Regge trajectory computed for these two energies has a slope of 0.22 ± 0.26.

Some 189 000 events of π^+p elastic scattering have been observed in the SLAC 82-inch hydrogen bubble chamber exposed to π^+ beams of momentum 3.7 and 7.1 GeV/c. At 3.7 GeV/c, 50 000 events have been obtained from 550 000 pictures having a sensitivity of 14 events/μb, while at 7.1 GeV/c, 139 000 events have been obtained from 700 000 pictures having a sensitivity of 43 events/μb ([1]). The overall statistical level of this experiment thus approaches that typically attained using counter apparatus. Furthermore, the acceptance of the bubble chamber is essentially flat for values of the momentum transfer squared greater than about 0.07 ([2]), while background is negligible in the four-constraint fit category of elastic scattering (both relevant considerations in observing structure in the differential cross section). A further important feature of this experiment is the significant spread in beam mommentum about the two nominal values. The full-width-at-half-maximum of the beam distribution is about 110 and 260 MeV/c respectively at 3.7 and 7.1 GeV/c, while the precision with which the momentum of an individual beam track is known is about 0.5%; *i.e.*, about 18 and 35 MeV/c respectively ([3]).

The kinematics of the experiment are displayed in Fig. 1 in terms of the conventional Mandelstam variables s, t, and u, with lines of constant u sloping at 45°. It is apparent from this figure that because of the spread in s, a structure (dip) at constant u will be less well defined in a projection on t, and conversely for a structure at constant t. Fig. 2 shows the differential cross section in terms of t and u for the full range of each variable. Note that the effect of the spread in s is to cause the cross section to appear to turn over at the upper limit in each projection, and, in particular, the backward peak and dip (at $-u \simeq 0.15$) are not visible in the t-projection. This effect should be kept in mind when examining previous data, as discussed further below.

Fig. 2 shows a dip in the 3.7 GeV/c data at $-t \simeq -u \simeq 3$. In the 7.1 GeV/c data, a similar dip occurs at $-u \simeq 3$, which corresponds to $-t \simeq 10$. Furthermore, there is no significant dip near $-t = 3$. Inspection of Fig. 1 suggests that the simplest interpretation of these observations is in terms of a fixed-u feature (zero) of the amplitude [or a fixed-u' feature ([4])]. For greater clarity, the region $-u < 6$ is shown in Fig. 3. The shape of the two distributions is quite similar for $-u < 3$. The backward peak and well-known dip at $-u \simeq 0.15$ are evident at both energies. The dip at $-u \simeq 3$ is the absolute minimum of the cross section in both cases. The position of this dip is shifted downward by about 0.3 from the lower to the higher energy.

A determination of πN scattering amplitudes is, of course, not possible with a measurement of only $d\sigma(\pi^+p \to \pi^+p)/du$. However, some qualitative observations can be made; *viz.*:

(a) The observed dip at $-u \simeq -u' \simeq 3$ corresponds well to the third zero of $J_0(b\sqrt{-u'})$ with $b \simeq 1$ fm. The well-known dip at $-u' \simeq 0.2$ ($-u \simeq 0.15$) falls at the first zero of J_0. Thus the major structures in the data at both energies can be associated with zeros of J_0 (which corresponds asymptotically to the *s*-channel helicity-flip amplitude). These structures are also qualitatively in accord with the model of Chu and Hendry ([5]) in which dips are associated with the zeros of the rotation functions (*d*-functions). Furthermore, their model shows a zero not only in the helicity-flip amplitude at $-u \simeq 3$, but also in the non-flip amplitude at $-t \simeq 3$, and since these two points coincide at 3.7 GeV/c (see Fig. 1), the dip at that energy is predicted to be quite pronounced. Zeros of the helicity-flip amplitude, calculated by Buttimore and Spearman from a phase-shift analysis, have been found to correspond to the first two zeros of J_0 in an energy region in which the third zero is inaccessible ([6]). Also, over a range of lower energies, a dip at $-u \simeq 1.3$ (near the second zero of J_0) has been reported by Abe, *et al.* ([7]). The observed structures thus suggest models in which absorptive effects dominate; that is, those in which zeros of the amplitudes correspond to zeros of the Bessel functions.

(b) The conventional N_α Regge trajectory has its second wrong-signature-nonsense-zero at $-u \simeq 2.3$ ([8]), so does not correlate well with the dip at $-u \simeq 3$. However, more complex Regge models, such as that of Donnachie and Thomas ([9]) incorporating quark re-arrangement processes, appear to be capable of reproducing a broad minimum near $-u = 3$. As a further test of simple Regge ideas, an effective Regge trajectory has been computed for the two energies of this experiment using the standard dependence:

$$d\sigma/du \propto (s - t)^{2\alpha_{EFF}(u) - 2}$$

The resulting values of $\alpha_{EFF}(u)$ are shown in Fig. 4. This effective trajectory represents a mixture of isospin-1/2 and 3/2 in the u-channel, but isospin-1/2 is presumed to dominate ([10]). A straight-line fit to the points in the range $-1 < u < 0$ yields the result:

$$\alpha_{EFF}(u) = (-0.55 \pm 0.14) + (0.22 \pm 0.26)u$$

The slope obtained is consistent with zero. This slope is quite insensitive to the relative normalization of the two energies, having the same value for relative normalizations differing by ±30%. The data points obtained by Barger, *et al.* ([11]) for the isospin-1/2 trajectory are also consistent with this slope.

In examining results from past experiments at neighboring energies, it was found that experimenters either have not displayed $d\sigma/du$ beyond $-u = 3$, or have aggregated the data in bins of such width that no dip is discernible near $-u = 3$ ([12]). Furthermore, in this region of u, previous experiments appear to be inconsistent among themselves with regard to both dips and the absolute value of the cross section ([13]). However, keeping in mind the kinematic effect illustrated in Fig. 1, plots of $d\sigma/dt$ can be read approximately in terms of u, and the data of Brabson, *et al.* ([14]) at 3.5 GeV/c and those of Eide, *et al.* ([15]) at 5 GeV/c indicate a dip at the t-value corresponding to $-u \simeq 3$, so offer corroboration of the dip observed here, while the data of Rust, *et al.* ([16]) at 5 GeV/c show no significant effect in this region.

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Footnotes and References

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1. The data at 3.7 GaV/c were measured with the Flying Spot Digitizer; those at 7.1 GeV/c with the Spiral Reader. Reconstruction and kinematic fitting were done with TVGP-SQUAW. Elastic events are taken as those having a χ^2 confidence level greater that 1% for the four-constraint fit.

2. Momentum transfer is given in GeV^2 throughout this Letter.

3. The momentum is correlated by the beam optics with the transverse position of the track in the bubble chamber.

4. The variable u' is $u - u_0$, where u_0 is the u-value of the lower boundary curve in Fig. 1. The value of u_0 is about 0.09 and 0.05 respectively at 3.7 and 7.1 GeV/c.

5. S. Chu and A. W. Hendry, Phys. Rev. Letters 25, 313 (1970).

6. N. H. Buttimore and T. D. Spearman, Nucl. Phys. B84, 531 (1975). They also find that zeros of the non-flip amplitude correspond to the second and third zeros of J_1. M. G. Albrow, *et al.*, Nucl. Phys. B25, 9 (1971), have reported a fixed-u minimum of the polarization at $-u \simeq 0.65$, which is near the second zero of J_1.

7. K. Abe, *et al.*, Phys. Rev. D10, 3556 (1974).

8. The N_α trajectory is taken as $\alpha(u) = -0.4 + 0.9u$ (see Ref. 9).

9. A. Donnachie and P. R. Thomas, Nuovo Cimento 19A, 279 (1974).

10. See, for example, Ref. 11.

11. V. Barger, *et al.*, Nucl. Phys. B49, 206 (1972).

12. See, for example, Ref. 15, and C. Baglin, *et al.*, Phys. Letters 47B, 85 (1973).

13. C. Lovelace, *et al.*, "πN Two-Body Scattering Data," LBL-63, p.34 (1973). For a numerical discussion of apparent inconsistencies see: J. K. Storrow and G. A. Winbow, Nucl. Phys. B53, 62 (1973).

14. B. B. Brabson, *et al.*, Phys. Rev. Letters 25, 553 (1970).

15. A. Eide, *et al.*, Nucl. Phys. B60, 173 (1973), Fig. 13. Note that one π^+ point is nearly obscured by the π^- data plotted on the same graph. The acceptance function for that experiment is given by: F. H. Schmidt, *et al.*, Phys. Letters 45B, 157 (1973), Fig. 3, and it also has a pronounced dip at $-t \simeq 6$, so systematic errors could possibly contribute to the observed shape.

16. D. R. Rust, *et al.*, Phys. Rev. Letters 24, 1361 (1970).

Figure Captions

Fig. 1. Mandelstam plot showing the kinematic regions covered by this experiment. Note the effect of the spread in s. A portion of the data is also displayed here.

Fig. 2. Differential cross section with respect to t and u. The spread in s causes the apparent turn-over at the upper limit in either variable (see Fig. 1).

Fig. 3. $d\sigma/du$ for $-u < 6$.

Fig. 4. Chew-Frautschi plot showing the effective u-channel Regge trajectory for the two energies of this experiment. The straight line has been fitted to the points in the range $-1 < u < 0$.

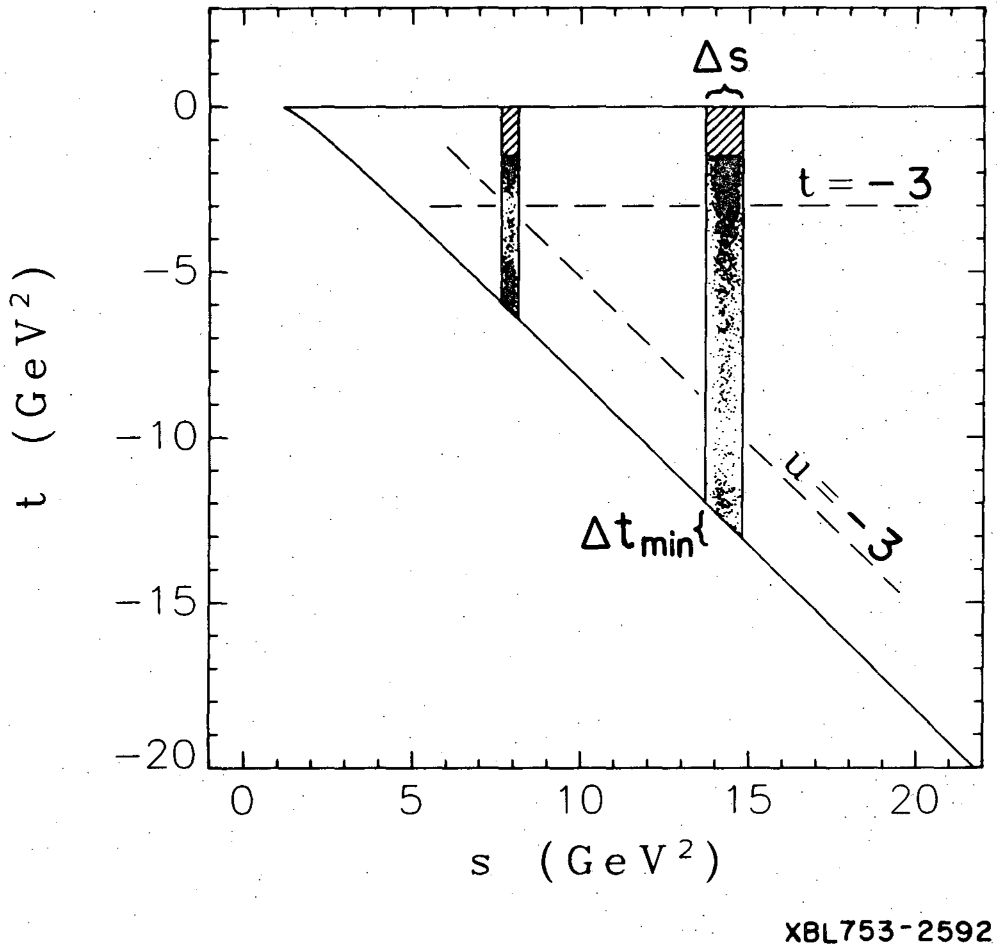

Fig. 1

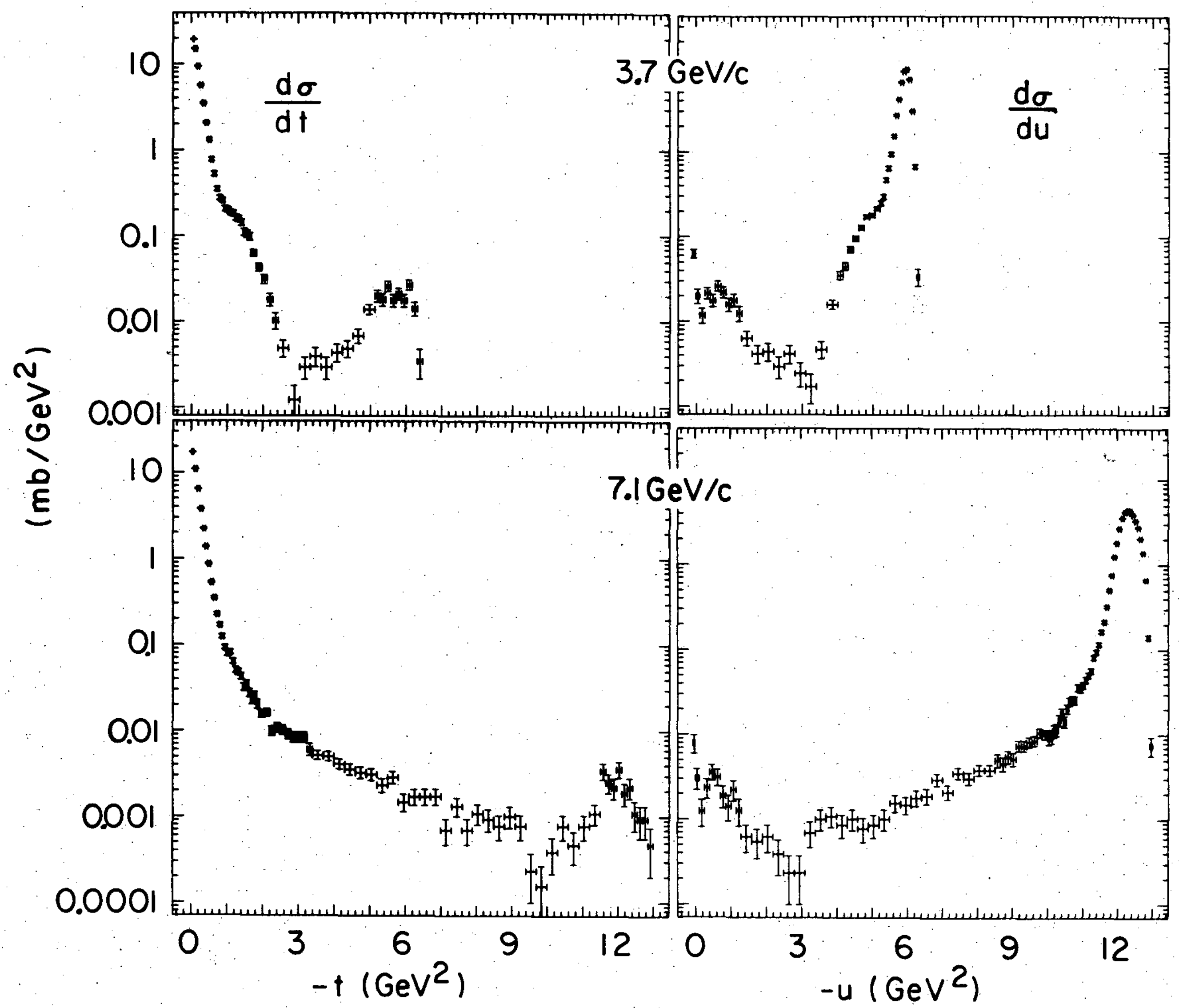

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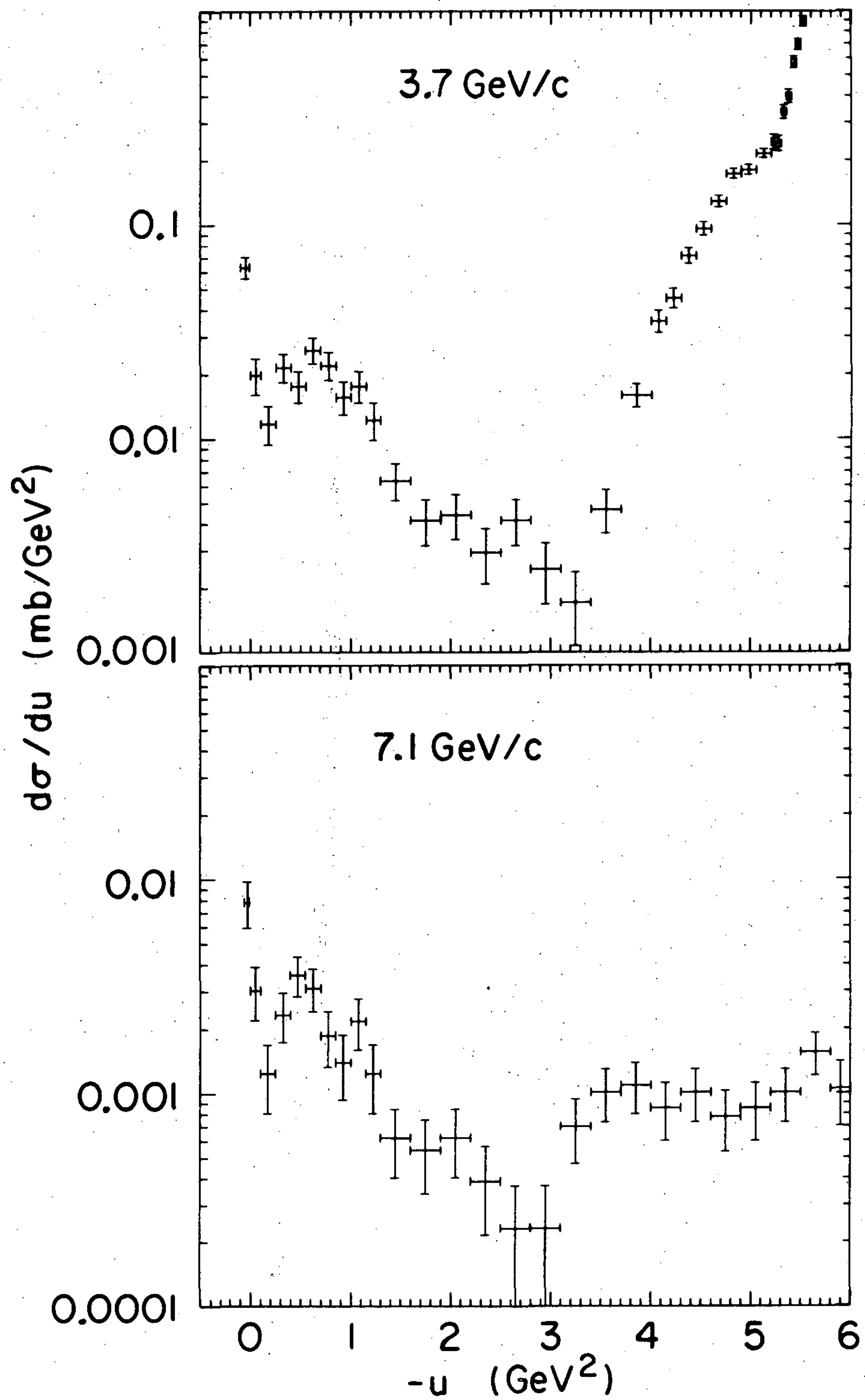
Fig. 2



XBL753-2591

Fig. 3

0 0 0 0 4 3 0 3 5 8 9

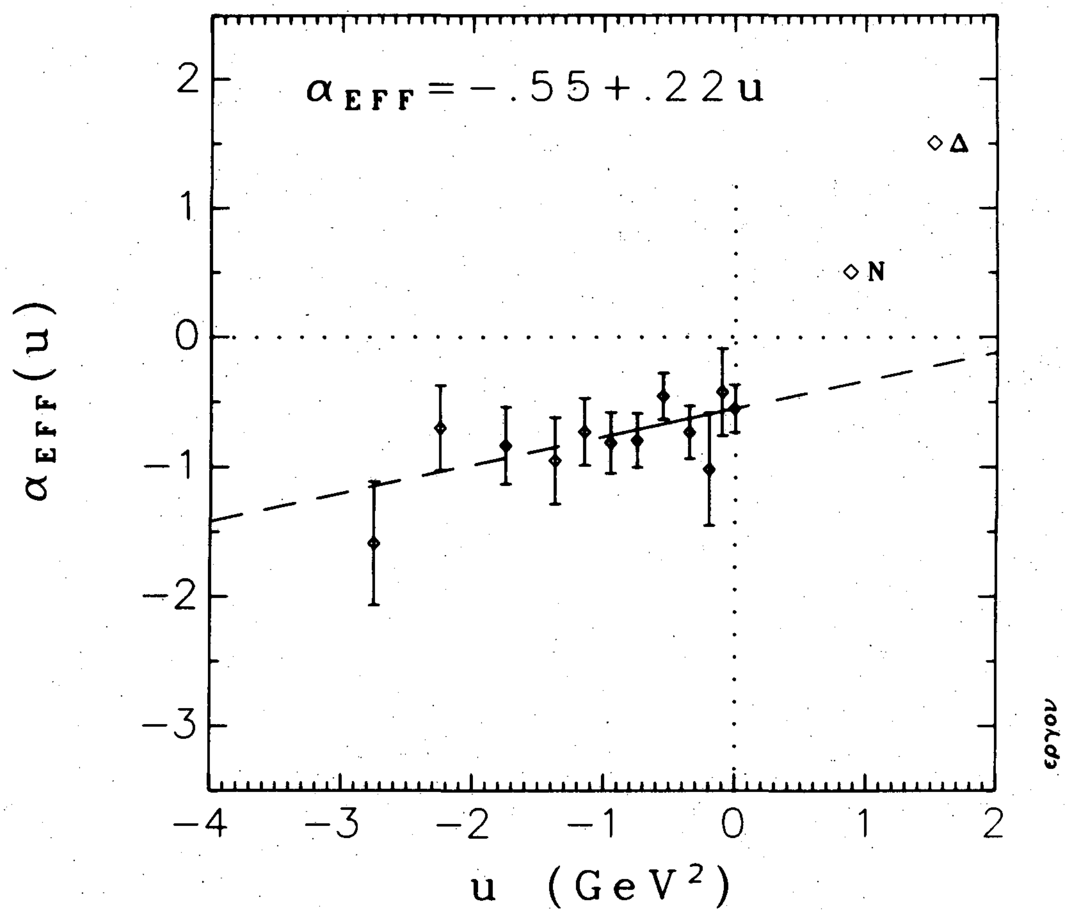


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Fig. 4