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ELASTIC p-^{4}He SCATTERING NEAR 1 GeV

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ABSTRACT

New 1.029 GeV p-^{4}He data from an Argonne-UCLA-Minnesota collaboration are in excellent agreement with existing multiple diffraction theory predictions. The theoretical calculation includes spin and isospin dependence of the Δ intermediate state process that fills the first diffraction minimum. The recently normalized Saclay data and the older Brookhaven data disagree with our calculation and the new data.

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The theory of multiple diffraction scattering developed initially by Glauber[1] and extended[2] and modified[3] by others, makes an unambiguous prediction for hadron-nucleus multiple scattering _if_ one knows in advance the nucleon-nucleon scattering amplitudes and the nuclear wave functions. In this Letter we compare the prediction of multiple diffraction theory including leading eikonal corrections[2] to four sets of p-^{4}He elastic scattering data near 1 GeV (Figure 1) and show that the very recent Argonne-UCLA-Minnesota data[4] at 1.029 GeV are in excellent agreement with the theory.

Three experiments[4,5,6] to date have measured 1 GeV proton-Helium elastic differential scattering including the small angle range. In addition, larger angle helium-proton scattering has been measured[7] at Saclay very near the same cm momentum. The 1967 Brookhaven results[5] at 1.0 GeV showed a diffraction minimum at $t=0.24(\mathrm{GeV/c})^2$ which was given a natural theoretical explanation[8] in Glauber's multiple diffraction theory using a simple Gaussian density for ^{4}He, and simple Gaussian approximations for nucleon-nucleon scattering amplitudes. However, the 1973 Saclay data[6] at 1.05 GeV (referred to as Saclay-A) differed substantially in its t-dependence, particularly in the region of the first diffraction minimum and beyond. The Saclay-A data were reported with an arbitrary normalization and hence, it was not clear whether the disagreement with Brookhaven data was at small- or large-t. However, the filling of the first diffraction minimum was not unanticipated. A paper by M. Ikeda[9] showed that production of Δ intermediate states could fill in the minimum. In this process, the fast nucleon becomes a Δ in one collision and returns to a nucleon state in a later collision thereby re-entering the elastic channel. The Ikeda result was not compelling[10] because it ignored the strong spin and isospin dependence of Δ production amplitude which suppresses the effect in nuclear eleastic scattering. However, the Saclay-A data obtained later were in quite good agreement with the Ikeda prediction.

While theoretical explanations[11] of the Saclay-A data were advanced (which did not include the Δ intermediate states), normalized versions of the data also began to appear[12,13] which cast considerable doubt on both the original data and theoretical fits to it. In 1976, the final normalized data, herein referred to as Saclay-B, were communicated in tabular form[14]. The Saclay-B data are quite similar to the earlier Brookhaven data except in the region of the first minimum[12], however, they are at variance with the calculations mentioned above.

This puzzling situation is not rectified by a number of improvements in the theoretical calculations. A high energy expansion method[2] for nuclear multiple scattering was developed which showed that the leading non eikonal corrections to Glauber's multiple diffraction theory in a k^{-1} expansion were indeed small (typically less than 15%) and that their inclusion should in principle lead to accuracy to about 5% in the $\theta_{cm}=0$ to 60^o range. Comparison of the multiple scattering approaches[1,2,3] with exact results[15] verifies these estimates. Using the Glauber theory plus leading corrections formalism, we have performed second generation p-^{4}He elastic scattering calculations based on existing phase shifts[16] for the pp amplitudes and very simple assumptions for the p-n amplitudes. Our calculations include a kinematic transformation of single scattering amplitudes similar to that developed in reference 3 and shown to be partly responsible for filling of the second diffraction dip (at $t \simeq 1.0 (GeV/c)^2$). The full spin and isospin dependence of the NN amplitudes has been included but we find that only the scalar (A) and spin-flip (C) amplitudes play a significant role. Coulomb effects are included as are the effects of center-of-mass correlations. The nuclear wave functions used are based on sums of Gaussian terms which provide an accurate fit to the measured ^{4}He form factor while maintaining positivity of the coordinate space density. The nucleon-nucleon amplitudes for single scattering are based directly on the pp phase shift amplitude[16] and on a fit to the pn differential cross section measurements[17]. Double, triple, etc. scattering terms of the multiple scattering expansion are based on Gaussian approximations to the NN amplitudes valid at the small t range relevant for multiple scattering. We assume that the pn spin flip amplitude is 0.7 times the pp spin flip amplitude (consistent with observed pn polarizations) and we also assume that the ratio of the real and imaginary parts of the pn scalar amplitude is −.5.

Finally, the amplitude for Δ intermediate states between scatterings has been evaluated in a spin and isospin dependent model which results in a factor 1/4 suppression compared to the $pp \rightarrow N\Delta$ cross section which involves averaging over initial spins and summing over final spins and isospins. Because earlier scalar estimates[9,18] of Δ effects in p-^{4}He scattering contained an incorrect factor 1/2 and a spin counting factor $2^{-1/2}$ from detail balance considerations, the net suppression of the Δ effects relative to the earlier scalar estimate is just $2^{-1/2}$. Based on a strength corresponding to $\sigma(pp \rightarrow N\Delta) = 20$ mb, the spin-isospin dependent Δ intermediate state processes are now found to have essentially the same crucial role in filling the first diffraction minimum as in the earlier estimates. Details of our results will be given in another paper.

All of these refinements lead to a theoretical <u>prediction</u> in substantial disagreement with the Saclay-B data <u>and</u> the Brookhaven data but in quite good agreement with the Saclay-A results. This situation was initially reported[18] in the fall of 1975 and has not changed significantly as refinements have been made to the theoretical calculations to eliminate sources of uncertainty. Our theoretical prediction was reported by G. J. Igo[19] in 1976 based on slightly different nucleon-nucleon spin dependent amplitudes and a scalar estimate of Δ intermediate state effects.

A very recent experiment[4] at Argonne National Laboratory by an Argonne-UCLA-Minnesota collaboration has provided a new experimental differential cross section. The new data provide an excellent fit to the theoretical prediction, which is essentially the same as reported in reference 19. Figure 1 summarizes the correspondence of our prediction (solid lines) with each of the four data sets. The effect of not including the Δ intermediate states is shown by the dashed line and one sees that this process is responsible for filling the first diffraction minimum.

The new Argonne-UCLA-Minnesota measurements are quoted to 15% accuracy. The agreement with the multiple diffraction theory prediction is within 10% with the exception of some points at very small t. A very clear theoretical preference for the new Argonne-UCLA-Minnesota data is evident from this work. The disagreement of our calculation and the Saclay-B data is 50% in normalization, the shapes being nearly identical.

In conclusion we mention two additional sets of calculations whose details will be published elsewhere:

1. The effect of short range correlations has been found to be quite small, neither improving the explanation of the recent data, nor aiding the understanding of previous results.

2. The analysis of the Δ intermediate state and our assumptions regarding the nucleon-nucleon amplitudes are further tested in calculating the p-^{4}He polarization, where qualitative agreement with the preliminary data

has been obtained. Minor refinements of the phase of the NN amplitudes to obtain quantitative agreement are in progress. We note that simple choices of NN phases do not yield even qualitative agreement with the polarization data without the inclusion of the Δ contribution.

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Figure Caption

Figure 1 Comparison of a single theoretical 1 GeV p-^{4}He elastic differential cross section prediction (solid lines) with four sets of experimental data; Argonne-UCLA-Minesota (ref. 4), Salclay-B (ref. 14), Saclay-A (ref. 6), Brookhaven (ref. 5). The dashed line shows the result when Δ intermediate states are absent.

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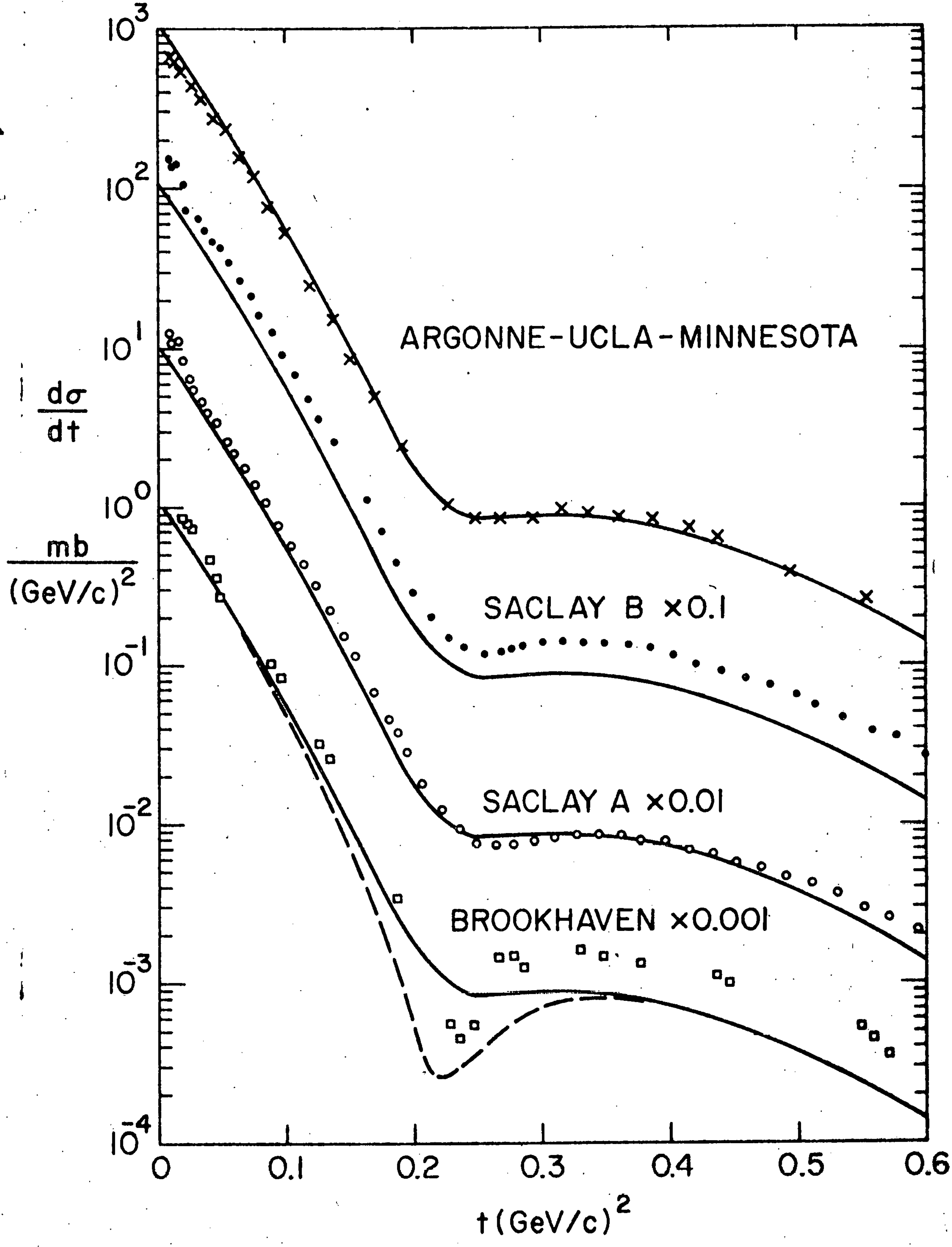

ARGONNE-UCLA-MINNESOTA
SACLAY B ×0.1
SACLAY A ×0.01
BROOKHAVEN ×0.001
dσ/dt
mb/(GeV/c)²
t (GeV/c)²
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
10⁻⁴
0
0.1
0.2
0.3
0.4
0.5
0.6