

LETTER TO THE EDITOR

**A TOPOLOGICAL PROBE OF THE SPACE-TIME STRUCTURE OF
HADRON-NUCLEUS INTERACTION USING DEUTERON TARGET**

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We present here an investigation of the space-time structure of the hadron-nucleus interaction from a detailed study on the multiplicity dependence of double scattered events in high energy proton-deuteron interactions. The rescattering probability and the even topology rescattering probe have been determined and the experimental data have been discussed in the context of conflicting theoretical estimates.

Investigation of the space-time development of hadronic high energy interactions provides information on the fundamental physics of these interactions. Unfortunately there can be no direct observation of the intermediate states of the hadronic matter, or its space time development, during the infinitesimal time of interaction. This time is determined by the nuclear dimensions as it defines the time interval for the impact products to traverse the target nucleus. The only direct data at the physicists' disposal are the initial and final observable states. Numerous theoretical models (mainly phenomenological) describe the various experimental features¹⁾, however to date, they are still partially successful in explaining the data. Most of these models impose a characteristic formation time for the final particles, i. e. they predict a prohibition on new-born particles to interact freely until a certain characteristic formation time has elapsed.

The deuteron has an unique position amongst target nuclei in being the simplest multi-nucleon system. It thus serves as an incisive tool for probing the space time structure of high energy particle interactions — and in particular the probability of new-born matter to react, as a function of time.

The fraction of events where both nucleons of the deuteron participate is called the rescattering fraction P_n . Investigation of the multiplicity dependence of P_n is of primary importance in probing the space-time evolution of hadronic matter within nuclear dimensions. These studies can test the predictions of the various theoretical models for the intermediate space-time development of hadronic matter.

Isospin symmetry can be invoked to predict hadron-neutron cross-sections. However as free neutron targets are not available in practice, the only way of probing the behaviour of neutron targets is by efficient analysis of deuteron data. The process of double scattering within the deuteron effectively reduces hadron-neutron events in deuteron targets as compared to those expected on the basis of isospin symmetry.

Initial p - n events that rescatter on the second nucleon of the deuteron are displaced to the even topology sample. This sample include also initial pp events that rescatter and of course all pp interactions, and any coherent events. The rescattered events must therefore be extracted from the even prong events. The excess of even over odd prong events in a topologically analysed sample should give a measure of the rescattered events.

Double scattered events display themselves as an enhancement of the even prong events as compared to the distributions in pure proton target pp interactions at the same energy. Thus this incorrect inclusion of double scattered events causes an excess of even prong cross-sections which should otherwise categorise pp events. The ratio $\alpha_n = \sigma_{\text{even}}^{pd} / \sigma_{pp}$ is called the even prong rescattering probe²⁾.

Similarly, odd prong events which should label p - n interactions is found to be less in deuteron targets than the number expected for pn distributions. This defect of odd prong events as compared to pn distributions give the pn events that have rescattered³⁾. In view of the above, we present in this paper the first detailed study on the multiplicity dependence of double scattered events in proton-deuteron interactions at 400 GeV. The normalised scattering probability p_n and the even topology rescattering probe α_n have been determined at this energy and compared with all other available data. A discussion in this context of conflicting theoretical estimates is also given.

We use experimental data from scanning of 35 mm Bubble Chamber films of pd interactions at 400 GeV, exposed at the 30'' chamber at Fermilab, U. S. A.⁴⁾.

Experimental details and methods of measurement have been reported earlier by S. Dado et al.⁵⁾.

Multiplicity measurements were done for $n_{ch} > 3$.

It was attempted to clarify particularly obscure events by projection to 30X magnification by a 35 mm Still projector. However, this also did not resolve the multiplicity in a large number of events. These were each allotted a range and added fractionally to particular topologies by comparing with the countable event topologies. Single leptons observed near the vertex are assumed to arise from decay of charged mesons and were included amongst charged secondaries. Spectator cut was applied at 5 mm in space and a loss of forward spectators estimated by com-

paring with backward spectator distributions. Observation of closed lepton pairs yielded a much lower number of Dalitz pairs than observed in pp interactions. This was corrected for along with the incorrect inclusion of neutron decays in primary charged prongs.

A correction for $N = 2$ topology is necessary as this cannot be unambiguously determined by observations. Following the prescription given in Ref. 5 by impulse approximation consideration, we write

$$P(pd, N = 2) = 1/2 P(pn, N = 1) + P(pp, N = 2)$$

for the probability of a 2-prong inelastic collision with

$$P(px, N = i) = \sigma(px, N = i) / \sigma(px, inel).$$

This procedure neglects rescattering and coherent interaction contributions for $N = 2$ and is justified by comparing with the formulae quoted in Refs. 6 and 7 that include these effects.

The one prong inelastic contribution is estimated as

$$P(pn, N = 1) = (0.6 \pm 0.1) \sigma(pp, N = 2)$$

and σ_{pp} is taken from Ref. 8.

A raw classification of data into even-prong and odd-prong events exhibit an almost double preference for even topologies. This necessitates the extraction of rescattered and if possible coherent events from the (uncorrected) even topology, since double scattered (and coherent) events with triple nucleon participation (2 charged and one neutral) will be displayed as even visible prong events.

The final pp - pn corrected classification was obtained in the following format

All odd-prong events with no visible spectator (an invisible spectator proton is assumed).	pn events
All odd-prong events with a short visible spectator proton (up to 5 micron table) (odd excluding spectator).	
All even-prong events with no visible spectator.	pp + double scattered + coherent

The double scattered events and coherent events were subtracted from the last row leaving the pure pp distribution therein. The final values were also corrected for deuteron final state events.

The forward spectators observed were compared with the observed backward distributions and a multiplicity dependent correction was made for spectator proton events.

The following corrections must be considered in order to arrive at the final multiplicity distributions:

(i) *Short proton visibility*: It is easier to detect very short proton (or deuteron) tracks in low multiplicity events than in high multiplicity events. For this reason, the even prong events which have a stopping track of length less than 5 mm in space were added to the next lower odd-prong category. This cut at 5 mm corresponds to a momentum cut at 120 MeV/c for protons. So the odd-prong distributions are defined here as those events in which one charged particle has a range less than 5 mm. The mean multiplicity of the resulting odd-prong distribution was 0.15 units lower than that for the uncorrected distribution. This correction is not applied to the even-plus odd-prong distribution where even invisibly short tracks are included in the count.

(ii) *Unobserved Dalitz pairs*: At 400 GeV/c the mean number of π^0 per inelastic pp interaction is 3.9. Taking the same mean for pd events at 400 GeV/c it was found that 72% of Dalitz pairs were not observed in the scanning. Assuming the same multiplicity dependence for π^0 production as found for pp interactions at 300 GeV/c the corrected mean multiplicity for both odd-prong and even-plus odd-prong distributions were reduced by 0.06 units.

(iii) *Unobserved vees*: For a sample of events, a histogram was made of the distance on the scanning table of the nearest neutral particle decay or gamma conversion (vee) from the primary vertex. From an analysis of the histogram it was found that about 60% of the vees occurring within 1.5 cm of the primary vertex were incorrectly included in the primary vertex prong count. This amounts to a loss of 180 vees in the total event sample. The resulting correction, assuming the same multiplicity dependence for Λ , K_s^0 and π^0 production as for pp interactions at 300 GeV/c, reduced the mean multiplicities by 0.02 units.

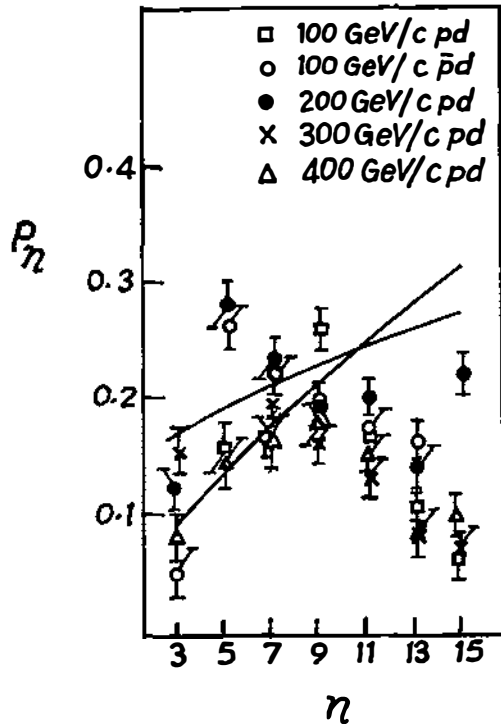
(iv) *Unobserved close secondaries*: A histogram of the distance on the scanning table from the primary vertex to the nearest secondary vertex indicated a loss of 50% of secondary interactions within 1 cm of the primary vertex. In making corrections for this loss, the observed-secondary-interaction-prong-count distribution was used. Since 80% of the observed secondary interactions have an even-prong count (51% are two-prong interactions), the result of an unobserved secondary is generally to change an odd-prong event into an apparent even-prong event, or vice versa. The resulting mean multiplicity reduction was 0.12 units for the odd-prong distribution and 0.03 units for the even-plus odd-prong distribution.

Table 1 gives the corrected topology for $n_{ch} > 3$ for pd events, (i. e. an invisible proton was added to pure odd/ pn events). A correction for inelastic 2 prong events is made to determine $\langle n \rangle_{pd}$.

We present in Fig. 1 values of normalised rescatter fraction P_n versus multiplicity n as determined by us at 400 GeV. For the sake of comparison we also present values of other experiments at all other available energies (pd , 100 GeV⁵⁾ 200 GeV⁹⁾ 300 GeV¹⁰⁾ pd , 100 GeV⁹⁾). For 300 GeV we have determined the rescatter fraction from the data of Sheng et al.¹⁰⁾. The predictions of the formation length formalism as determined in Ref. 9 and a theoretical prediction made for best fit value of the formation time for pd (100 GeV) and pd (200 GeV) data are also shown. However, the theoretical curve even then does not exhibit the wiggling

TABLE 1.

Multiplicity	Contribution from			Total
	Odd + visible spec.	Odd + visible spec.	Even	
6	122	418	722	1262 ± 43
6	138	546	816	1500 ± 47
8	112	596	890	1598 ± 47
10	110	580	842	1532 ± 48
12	84	462	682	1228 ± 39
14	66	302	482	850 ± 35
16	40	202	334	576 ± 25
18	28	104	208	340 ± 17
20	14	64	140	218 ± 13
22	10	22	84	116 ± 11
24	0	14	40	54 ± 8
26	2	10	22	34 ± 6
28	0	6	6	12 ± 4
30	0	2	0	2 ± 1
32	0	2	2	4 ± 2

Fig. 1. Plot of normalised rescattering probability P_n vs. multiplicity.

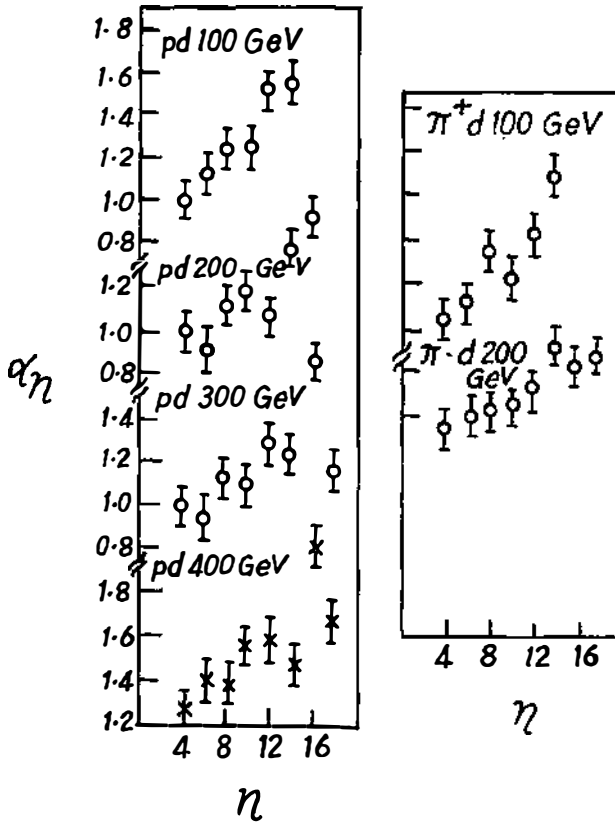


Fig. 2. Plot of rescattering probe α_n vs. multiplicity.

observable in the referred data. We note that the nature of other experimental data (including the data at 400 GeV) are similar in exhibiting a peak and then falling off. We also note an increasing trend for the peak to shift towards higher multiplicity. There is no model so far which can explain the present experimental information on the rescatter probability in the deuteron.

In Fig. 2 we present values of n determined by us at 400 GeV. σ_{pp} are taken from the values of Bromberg et al.⁸⁾ for p - p interaction at the same energy. We also present in the same figure α_n (ad extracted from the data of Sheng et al.¹⁰⁾ at 300 GeV and of Lys et al.⁶⁾ at 100 GeV. The data quoted by Baker et al.¹¹⁾ for pd , 100, 200, 300 GeV and πd 100 and 200 GeV are also shown.

Regarding this even topology probe α_n , it has been shown by Baker et al.¹¹⁾ that the BLRW model (using Reggeon field theory) predict an increase of α_n at high multiplicities. They have demonstrated that experimental data for 100, 200, 300 GeV pd and 100 GeV and 200 GeV πd are consistent with such a prediction.

It is interesting to note that α_n behaves similarly at 400 GeV. We would like to mention here the finding of Porter et al.³⁾ in this context. He reported that α_n at 15 GeV exhibits a much slower rise with n so that his results are closer to the

coherent tube model¹²⁾ rather than the Baker model¹¹⁾, which requires a more rapid rise. It is worth mentioning that at Fermilab energies, this trend seems to be reversed and experiments appear to favour the Baker model.

In conclusion, this reports the first measurements at 400 GeV of the multiplicity dependence of rescatter events and give a critical comparison of extant data at all other available energies. Although the data appear to favour the prediction of the BLRW model¹¹⁾ regarding α_n , the present experiment warrants further theoretical work in this line.

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TOPOLOŠKA PROBA PROSTORNO-VREMENSKE STRUKTURE
INTERAKCIJE HADRONA S JEZGROM UPOTREBOM DEUTERONSKE
METE

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Ovdje je prikazano istraživanje prostorno-vremenske strukture interakcije hadrona s jezgrom pomoću detaljne analize ovisnosti multipliciteta o događajima dvostrukog raspršenja pri visokoenergetskim međudjelovanjima protona i deuterona. Vjerojatnost ponovnog raspršenja i proba parne topologije pri ponovnom raspršenju su određeni, a eksperimentalni podaci diskutirani u svjetlu konfliktnih teoretskih ocjena.