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MEASUREMENT OF THE POLARIZATION PARAMETER FOR THE REACTION $\pi^- p \rightarrow \pi^0 n$ BETWEEN 1.03 AND 1.79 GeV/c[*]

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ABSTRACT

The polarization parameter for the reaction $\pi^- p \rightarrow \pi^0 n$ has been measured at five incident beam momenta between 1.03 and 1.79 GeV/c. The results are compared with predictions of recent phase shift analyses.

We report here the results of an experiment at the Berkeley Bevatron in which we measured the polarization parameter, $P(\theta)$, for the reaction $\pi^- p \rightarrow \pi^0 n$ ($\pi^0 \rightarrow \gamma\gamma$) at the five incident beam momenta 1030, 1245, 1440, 1590, and 1790 MeV/c. Charge exchange polarization measurements have been made previously at higher energies,[1] primarily to test high energy interaction mechanisms, but except for one very rough measurement by Hill et al.,[2] at 310 MeV, this marks the first time that measurements of $P(\theta)$ have been made in a region where phase shift analyses are available (<2 GeV/c). These measurements of $P(\theta)$, together with recent results on the differential cross section for the charge exchange reaction,[3] should provide a strong constraint on the solutions to the various phase-shift analyses. Preliminary results from this experiment have been reported elsewhere.[4]

The experimental layout is shown schematically in Fig. 1 (and detailed in Ref. 5). The π^- beam with a typical momentum bite of ±1.5% was focussed onto a polarized proton target (primarily propylene glycol), with length along the beam direction of 7.5 cm and a cross-sectional area 2.5 cm square. The polarization of the target averaged between 50-55% (at 1°K). The target polarization was reversed every 2-3 hours to reduce possible systematic errors. The free protons constituted only about 14% of the protons in the target, the rest being protons bound in the carbon and oxygen nuclei of the propylene glycol and in the heavier nuclei of the cavity. Hence, a large background was expected from quasi-elastic charge exchange scattering from these bound protons as well as from inelastic scattering. To measure this background, we also collected data from a "dummy" target at each momentum. This dummy (essentially graphite) contained no free protons but otherwise simulated the target as closely as possible. An important feature that reduced the background considerably was the detection of both the neutron and the γ rays from the π^0 decay in order to identify the charge exchange reaction.

Neutrons produced in the final state were detected in twenty 20-cm thick scintillation counters. These neutron counters, each subtending a lab angle of ∿2.5°, at a distance of ∿5 m from the target, typically spanned the angular range $-0.78 < \cos\theta_{cm} < 0.87$ in the center of mass system; further, they provided neutron time-of-flight measurements accurate to ±0.6 nsec. The photons from the π^0 decay were detected in two lead-plate optical spark chambers. Gamma rays originating at the center of the target were restricted by the magnet aperture to scattering angles <21° above and below the median plane. The chamber plates were made thin (∿0.14 radiation lengths) to ensure a low-energy γ-ray detection threshold of about 10 MeV.[3,6] The downstream chamber (1.52 m square) was 9 radiation lengths thick, and the side chamber (1.22 m square) was 8 radiation lengths thick.

Surrounding the target was a system of scintillation counters that allowed identification of those π^-p interactions having neutral final states. Those veto counters not in the incident beam were also used to veto events that had γ rays emitted in directions other than toward the spark chambers. These counters had scintillator and gamma-converter (1-2 radiation lengths of either Pb, W, or Pt) in a sandwich construction.

An event was recorded whenever the following criteria were satisfied: (1) a charged pion went into the target and no veto counter had a pulse, and (2) a neutral particle went into one of the neutron counters and was detected there. Those events which satisfied our conditions for candidates for $\pi^-p \rightarrow \pi^0 n$ (a neutron count within a wide timing window, and two showers in the spark chambers as determined by a scan of the film) were then measured and digitized using the SASS[7] measuring system at LBL.

With the program SQUAW,[8] least-squares kinematic fits were made to the hypotheses $\pi^- p \to \pi^0 n$ and $\pi^- C \to \pi^0 nB$, using the measured directions of the two γ rays and the time-of-flight and direction of the neutron. Here C represented ^{12}C, and the mass of the recoil boron (B) was chosen to be one proton mass less than that of C.[9] B was assumed to have zero measured momentum, but with a large uncertainty in each component of ±300 MeV/c. Elastic charge exchange events from free protons as well as quasi-elastic charge exchange scattering from "stationary" protons bound in the target nucleus should correspond to near zero momentum for spectator B, whereas scattering from moving protons should impart a finite momentum transfer to B.

We used the following method to determine the background contribution. Those events which satisfied the hypothesis $\pi^- C \to \pi^0 nB$ but fit the hypothesis $\pi^- p \to \pi^0 n$ with a confidence level < 0.1% were called "failing-$n\pi^0$" events, i.e., they were predominately non-hydrogen events. Similar failing events from the dummy target, normalized to those from the polarized target, have a fitted momentum (p_B) distribution for B which agrees very well in shape with the distribution of failing events from the polarized target, as shown in Fig. 2(a). (The normalization ratio is consistent with the ratio of beam fluxes incident on the dummy and polarized targets.) The normalization ratio was then applied to all the $\pi^0 nB$ events from the dummy data to give the total background distribution, indicated in Fig. 2(b) along with the total events (for both signs of target polarization) from the polarized target. For each counter, the polarization parameter was evaluated for a series of cuts in p_B, and was relatively independent of the value of p_B used. The value of the polarization parameter quoted is the one having minimum error (typically for $p_B < 120$ MeV/c). A complete description of the data analysis procedures, including the use of an independent method[10] for the calculation of $P(\theta)$, is given in Ref. 5.

The results are tabulated in Table I and are also compared in Fig. 3 with recent phase shift predictions[11,12] and with isospin bounds calculated from the Saclay (1973) phase shifts.[12] Qualitatively, the Saclay (1973) phase shift predictions reproduce reasonably well the general features of the data at all momenta, except for the backward region at 1030 MeV/c. This is also true of the CERN (1972) predictions[11] except at 1790 MeV/c where the disagreement is quite severe. This disagreement is also manifest in the comparison of the charge exchange differential cross-section measurements of Ref. 3 with the predictions given in Ref. 11 for momenta $\gtrsim 1790$ MeV/c

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Footnotes and References

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9. This method is also valid for the other heavy nuclei in the target (e.g., ^{16}O); the significant fact is that the mass difference $m_C - m_B$ equals the proton mass.

10. This method used the entire event sample (i.e., regardless of γ-ray multiplicities) and completely ignored information on the γ rays. $P(\theta)$ was evaluated from the neutron time-of-flight distribution for each counter. The neutron time-of-flight distributions for the dummy target were used to determine the background. The results from both analyses were in excellent agreement.

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Table I. Polarization parameter $P(\theta)$ in $\pi^- p \rightarrow \pi^0 n$ scattering.[a]

1030 MeV/c			1245 MeV/c			1440 MeV/c			1590 MeV/c			1790 MeV/c		
$\cos\theta_{cm}$	$P(\theta)$	$\pm \Delta P(\theta)$	$\cos\theta_{cm}$	$P(\theta)$	$\pm \Delta P(\theta)$	$\cos\theta_{cm}$	$P(\theta)$	$\pm \Delta P(\theta)$	$\cos\theta_{cm}$	$P(\theta)$	$\pm \Delta P(\theta)$	$\cos\theta_{cm}$	$P(\theta)$	$\pm \Delta P(\theta)$
0.755	0.24	0.10	0.770	-0.57	0.16	0.783	-0.09	0.19	0.792	-0.10	0.10	0.803	0.08	0.17
0.705	0.46	0.15	0.723	0.02	0.18	0.738	-0.24	0.08	0.749	-0.24	0.11	0.761	-0.27	0.14
0.655	0.94	0.23	0.676	-0.36	0.13	0.693	-0.24	0.13	0.705	-0.36	0.13	0.719	-0.28	0.16
0.604	0.61	0.15	0.627	0.17	0.11	0.645	-0.27	0.12	0.659	-0.63	0.18	0.675	-0.38	0.17
0.535	0.20	0.13	0.561	-0.02	0.12	0.582	-0.72	0.19	0.598	-0.82	0.18	0.616	-0.44	0.38
0.464	-0.44	0.12	0.492	-0.18	0.10	0.516	-0.30	0.10	0.533	-1.16	0.29	0.554	-0.26	0.27
0.347	-0.56	0.09	0.379	-0.27	0.12	0.406	-0.52	0.10	0.425	-0.56	0.18	0.449	-0.38	0.17
0.256	-0.82	0.11	0.290	-0.58	0.13	0.319	-0.78	0.15	0.340	-0.77	0.11	0.366	-0.79	0.27
0.168	-0.77	0.09	0.203	-0.47	0.12	0.234	-0.97	0.15	0.256	-0.87	0.15	0.283	-0.52	0.11
-0.014	-0.82	0.15	0.022	-0.88	0.47	0.054	-0.57	0.19	0.077	-0.37	0.10	0.107	-0.61	0.16
-0.099	-0.67	0.18	-0.063	0.41	0.47	-0.031	-0.17	0.14	-0.008	-0.33	0.13	0.022	-0.23	0.10
-0.164	-1.48	0.65	-0.128	0.26	0.27	-0.097	0.20	0.14	-0.074	-0.02	0.10	-0.044	-0.15	0.10
-0.235	-0.26	0.21	-0.200	0.92	0.84	-0.170	0.48	0.14	-0.146	0.24	0.12	-0.117	0.39	0.12
-0.365	-0.14	0.12	-0.332	-0.51	0.21	-0.304	0.65	0.15	-0.283	0.88	0.15	-0.255	0.65	0.21
-0.450	-0.22	0.08	-0.420	-0.93	0.17	-0.394	0.31	0.11	-0.374	0.64	0.12	-0.348	1.06	0.29
-0.572	-0.24	0.07	-0.547	-1.16	0.17	-0.524	-0.19	0.12	-0.507	0.21	0.10	-0.485	0.40	0.13
-0.660	-0.11	0.07	-0.639	-1.11	0.18	-0.620	-0.53	0.19	-0.605	-0.51	0.22	-0.586	-0.33	0.22
-0.741	-0.11	0.08	-0.724	-0.75	0.19	-0.708	-0.65	0.23	-0.697	-0.33	0.12	-0.681	-0.43	0.13
-0.815	-0.15	0.17	-0.802	-0.42	0.30	-0.791	-0.10	0.19	-0.781	-0.19	0.12	-0.770	-0.38	0.18
-0.882	0.26	0.09				-0.866	0.92	0.28	-0.860	0.20	0.32			

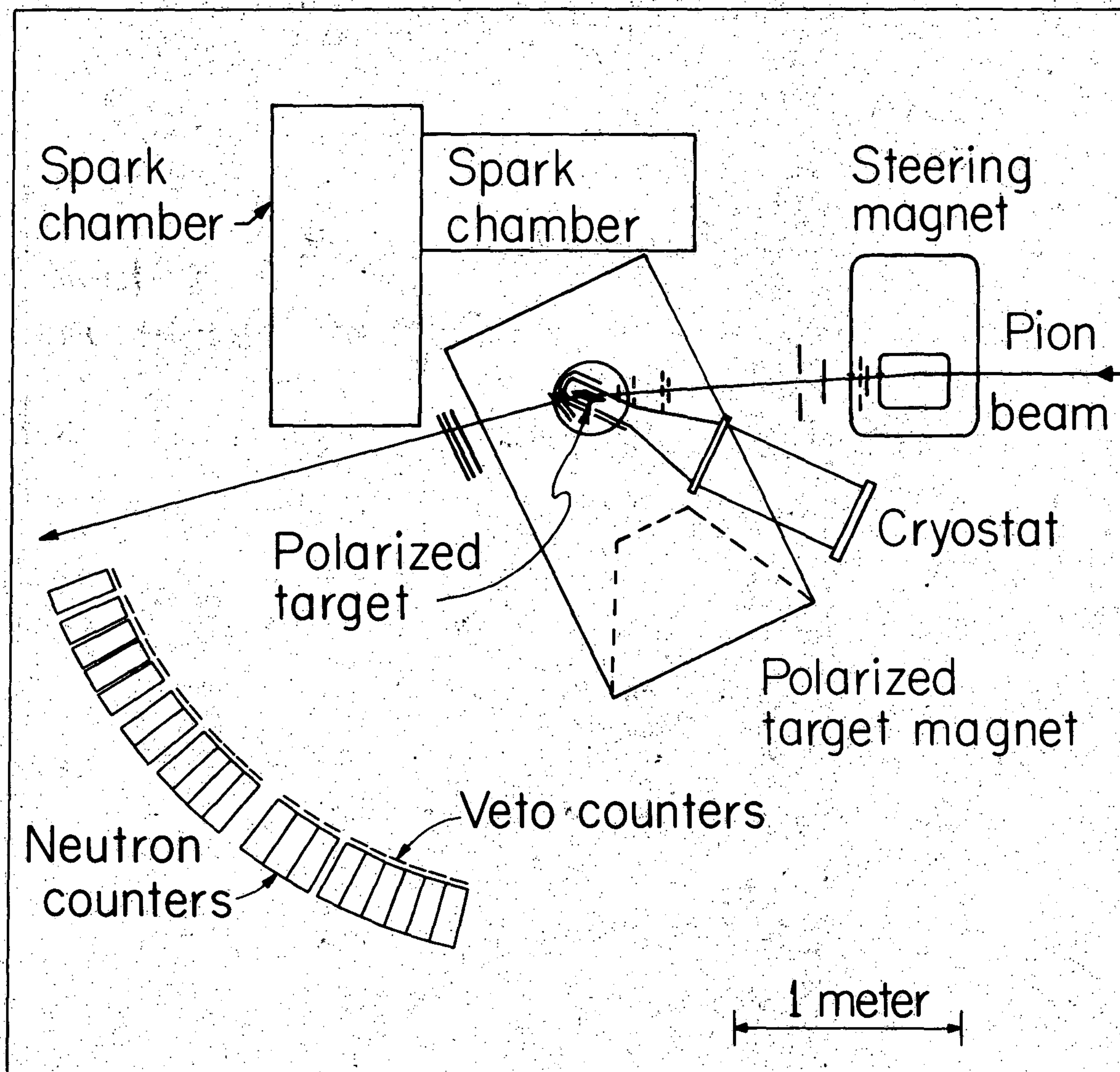
[a] The error $\Delta P(\theta)$ is statistical only; the estimated systematic errors are ±0.06 for each momentum except 1245 MeV/c, for which the error is ± 0.09.

Figure Captions

1. Experimental layout (the distances of the neutron counters from the target are not to scale). Scintillation counters are indicated (but not labelled) along the beam line.

2. Fitted momentum distributions for recoil B in the reaction $\pi^- C \rightarrow \pi^0 nB$ for both the polarized target events and (normalized) dummy events summed over all neutron counters at 1590 MeV/c. (a) The "failing-$n\pi^0$" events fit $\pi^- p \rightarrow \pi^0 n$ with confidence level <0.1%. (b) The total events from the polarized target (for both signs of target polarization) are compared with the background events.

3. The $\pi^- p \rightarrow \pi^0 n$ polarization parameter results. The smooth curves are the predictions of Almehed and Lovelace[11] (CERN (1971)) and Ayed et al.,[12] (SACLAY (1972,1973)), evaluated at the indicated momenta close to our beam momenta. Isospin bounds given in Ref. 12 (using the 1973 smoothed phase shifts) are indicated with slashed lines.



XBL 743-491

Fig. 1.

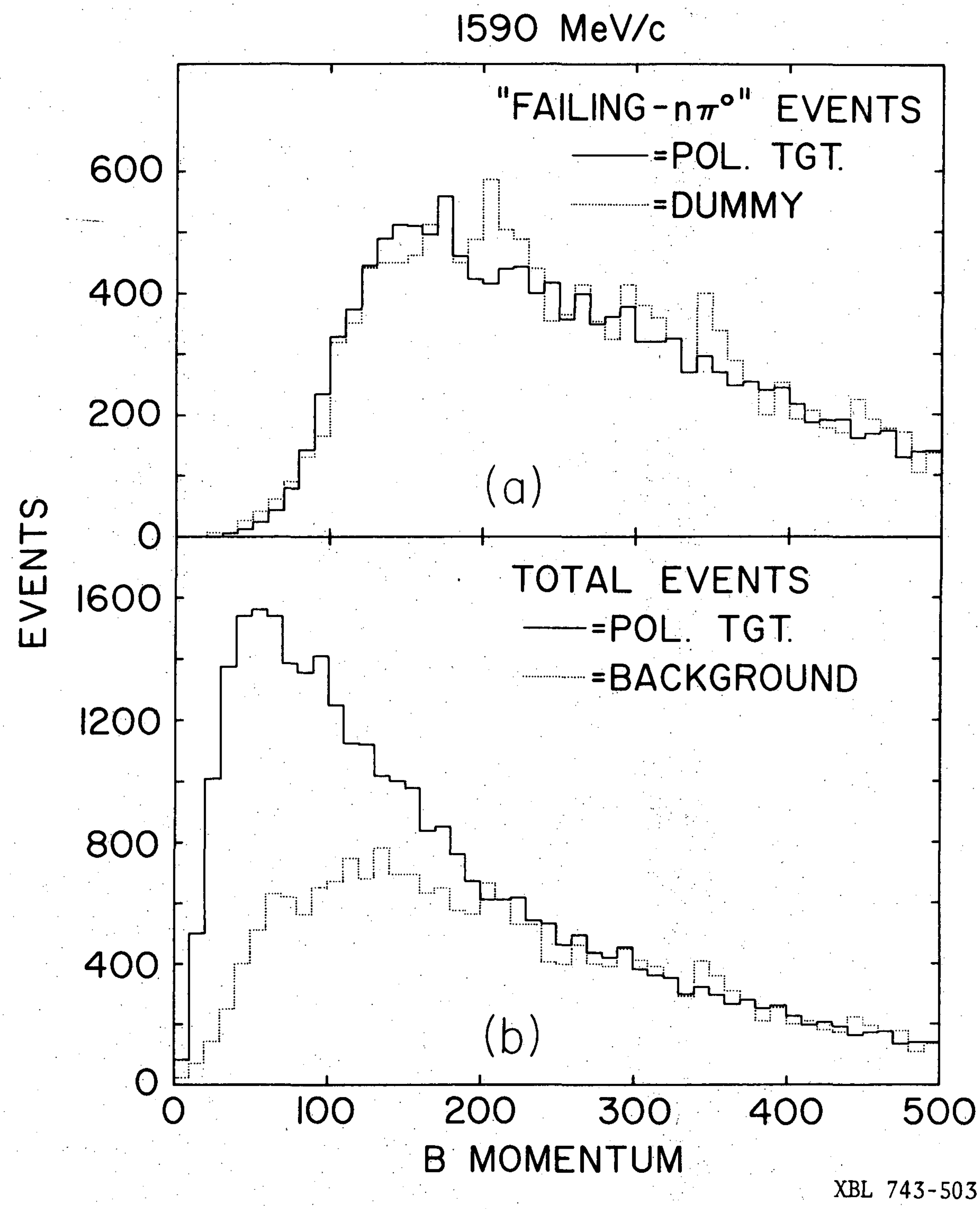
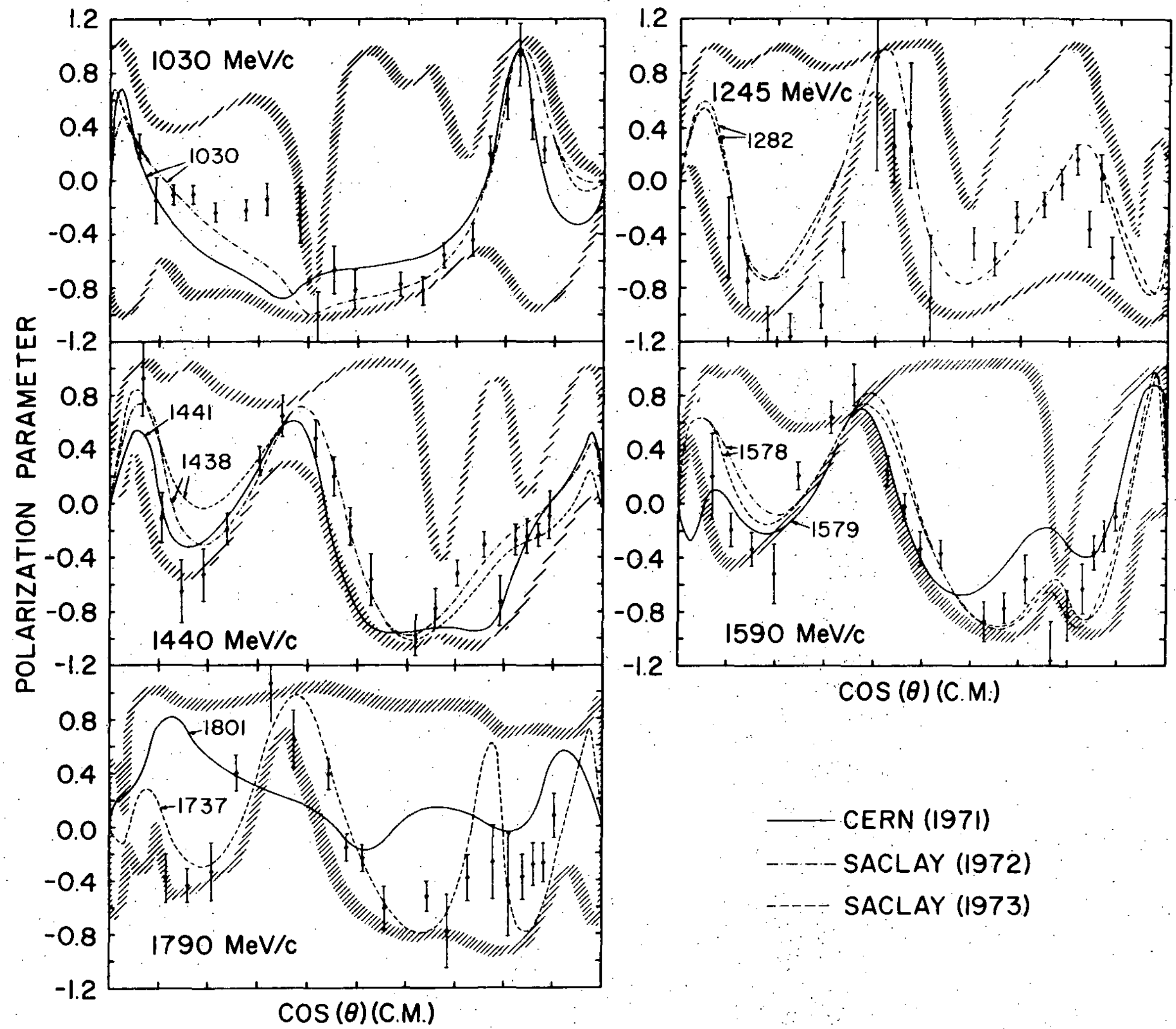

1590 MeV/c
"FAILING-nπ°" EVENTS
=POL. TGT.
=DUMMY
(a)
EVENTS
TOTAL EVENTS
=POL. TGT.
=BACKGROUND
(b)
0
200
400
600
1600
1200
800
0
100
200
300
400
500
B MOMENTUM
XBL 743-503

Fig. 2.



XBL 743-507

Fig. 3.

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