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PRELIMINARY DIFFERENTIAL CROSS SECTIONS OF THE CHARGE-EXCHANGE REACTION

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FOR THE CRYSTAL BALL COLLABORATION[1]

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The Crystal Ball Collaboration measured differential cross sections for pion-nucleon charge-exchange reaction at seven different pion momenta in the momentum region between 105 MeV/c and 180 MeV/c. When analyzed, these data will represent the highest-precision differential cross sections in this energy region. They will be essential for providing the necessary constrains on partial-wave analysis so that pion-nucleon sigma term can be extracted more reliably, and also provide a determination of the mass difference of the up and down quarks. Preliminary results for these differential cross sections are presented.

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1. Introduction and motivation

Purpose of this paper is to give a short overview on the motivation, experimental setup and preliminary results of the low energy pion charge-exchange BNL experiment E958 [1]. Detailed description of the data analysis together with the

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final results will be published later. The experiment was performed in 2002 by the Crystal Ball Collaboration as a part of the baryon spectroscopy program using Crystal Ball (CB) detector in the C6 beam line of the Alternating Gradient Synchrocyclotron (AGS) at Brookhaven National Laboratory (BNL). Differential cross sections for $\pi^- p \to \pi^0 n$ were measured and will be presented here at incident π^- momenta of 105, 113, 120, 129, 140, 153 and 177 MeV/c.

Motivation for doing the experiment is twofold: first is the evidence that the differential cross sections have not been measured yet or can be measured more precisely *and* second is that measurement may help resolve some theoretical questions. Regarding the first part, we state that experimental data for the pion single charge exchange reaction on the nucleon, $\pi^- p \to \pi^0 n$, at energies below 100 MeV are very limited. Experiments of Salomon et al. [2] and Bagheri et al. [3] used single large NaI detector to detect a single photon from the final-state π^0 decay. These measurements were performed at eight incident π^- energies between 26.4 and 121.9 MeV and covered the laboratory polar angles between 0° and 145°. The experimental uncertainties ranged from over 150% at low energies and forward angles to about 15% at energies above 40 MeV and scattering angles were larger than 60°. Excitation functions at three angles near 0° were measured at seven energies between 32 and 64 MeV by Fitzgerald et al. with the LAMPF π^0 spectrometer [4]. However, significant corrections to these data were later identified which, when applied, led to larger discrepancies between the data and phase-shift calculations [5]. With the same detector, Isenhower et al. measured cross sections at 10, 20 and 40 MeV. Experiment had the problem of implosion of the liquid hydrogen target early in the running. Final results have not been published yet and preliminary ones are reported in Ref. [6]. Frlež et al. [5] provided good absolute cross sections, but only for at energy of 27.5 MeV and in a limited angular range 0 – 55°. In 1998, Crystal Ball Collaboration measured, among other things, differential cross sections for charge exchange at many different energies the lowest two being 64 and 83.5 MeV. They overlap with two highest energies in this experiment [7]. Extensive program was performed by UCLA-ACU-GWU Collaboration to measure all observables of the πN scattering, but their charge-exchange differential cross sections were never published [8 – 11] Motivation for experiments with Crystal Ball at BNL was to complete that program. Altogether, the results from E958 experiment will more than double the number of existing experimental data points in the low energy region thus allowing the amplitudes for pion-nucleon interactions to be extracted more precisely. This is important in order to better understand the questions like the up-down quark mass difference and the effects of isospin breaking on the extraction of the Σ-term from pion-nucleon amplitudes. Evidence of violation of isospin invariance at low energy has been reported in an independent analysis [12, 13].

2. *Experimental setup*

Experimental setup will be described only briefly. A detailed description of the experimental setup used in the 1998 run can be found in the Crystal Ball

Collaboration publications [14, 15] and Ph.D. dissertations [16 − 18]. For the 2002 run, we used basically the same setup with a few small but important modifications which will be described. Beam momentum was selected by controlling the current in the dipole magnet. Electrons and muons in the beam were distinguished from pions by measuring the time-of-flight between the first scintillator on the beam path and the one closest to the target. In the 1998 run, the scintillator closest to the target was 1.6 m upstream from the target, and in the 2002 run, small scintillator (named SB), 5 cm $\times$ 5 cm, was placed 30 cm upstream from the target. This change made the beam normalization much easier because losses due to the multiple scattering from SB to the target could practically be ignored. Instead of a liquid hydrogen target in 1998, we used cylindrical 10 cm in diameter and 1 cm thick polyethylene (CH_2) target. We also took data with carbon target of the same shape for the subtraction of the background scattering of pions on carbon atoms. Downstream faces of the targets were positioned in the center of the inside cavity of the Crystal Ball detector.

Crystal Ball detector is a highly-segmented, total-energy electromagnetic calorimeter and spectrometer that covers about 93% of 4π steradians. Actually, it consists of two hemispheres that can be separated, with an entrance and exit opening for the beam. Detector is constructed of 672 optically isolated NaI(Tl) crystals that detect individual photons. The $\pi^- \mathrm{p} \to \pi^0 \mathrm{n}$ reaction was identified by measuring the energies and directions of the two photons from $\pi^0 \to \gamma\gamma$ ($BR = 98.8\%$). A veto barrel, constructed of four curved plastic scintillators that form a cylindrical shell around the beamline, was installed to reject events that had charged particles in the final state. The acceptance of the Crystal Ball for detecting π^0's was calculated using a Monte Carlo program, with a detailed description of the setup, based on GEANT [19].

3. *Preliminary results*

Preliminary results for the $\pi^- p \to \pi^0 n$ differential cross sections are presented and compared with the FA02 partial-wave analysis of the George Washington group [20] in Fig. 1. The agreement is very good for the two highest momenta of 153 and 177 MeV/c, but for other momenta our results are higher by about 5 − 15%. Error bars include only statistical uncertainties. Before the final results are published, we must gain full confidence regarding two uncertainties that may change our results: determination of the fraction of pions in the beam and precise determination of the beam momentum. The fraction of pions is determined from the fits of the time-of-flight spectra. Beam momentum in this work was obtained by calculating energy loss from the dipole magnet to the center of the target. But the actual momentum at the target center may differ from that value because of a systematic error in the magnet calibration. Precise determination of the beam momentum will eventualy be done by the comparasion of the invariant mass and the missing mass of two photons for real and simulated (Monte Carlo) events.

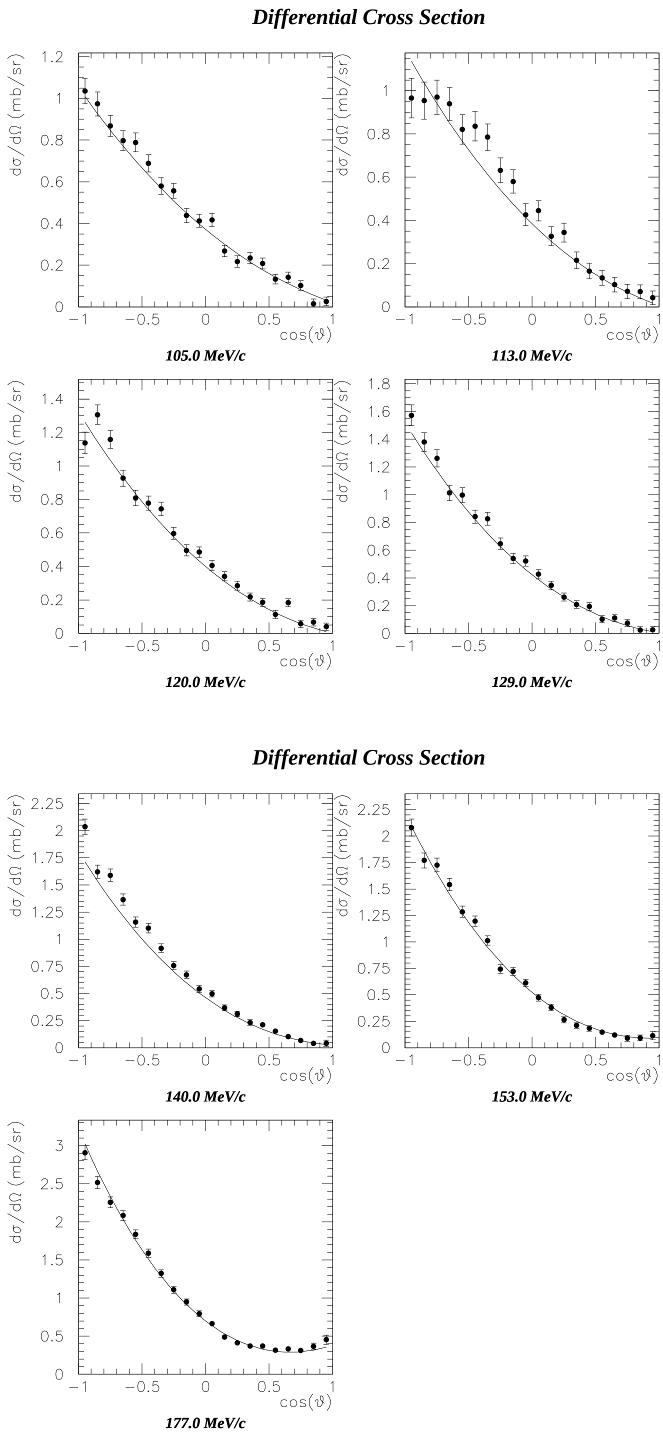

Fig. 1. Differential cross sections of reaction $\pi^- \mathrm{p} \to \pi^0 \mathrm{n}$ *for incident* π^- *momenta (kinetic energy) of 105 (35.1), 113 (40), 120 (44.5) and 129 (50.5)* MeV/c (MeV), *140 (58.1), 153 (67.5) and 177 (85.8)* MeV/c (MeV). *Differential cross sections of reaction* $\pi^- p \to \pi^0 n$ *for incident* π^- *momenta (kinetic energy) of 140 (58.1), 153 (67.5) and 177 (85.8)* MeV/c (MeV). *Black circles are the values obtained in this experiment. Error bars include only statistical uncertainties. The curve shows the results of the FA02 partial-wave analysis of the George Washington group [20] based on experiments made earlier by other groups.*

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PRETHODNI DIFERENCIJALNI UDARNI PRESJECI ZA REAKCIJU IZMJENE NABOJA

Grupa Crystal Ball načinila je mjerenja diferencijalnih udarnih presjeka izmjene naboja u reakciji pion-nukleon za sedam impulsa piona u području od 105 MeV/c do 180 MeV/c. Kad se završe analize, ti će podaci predstavljati najtočnije diferencijalne udarne presjeke u ovom području. Oni su bitni za određivanje granica u analizama parcijalnih valova kako bi se član sigma odredio pouzdanije, i također radi određivanja razlike masa kvarkova gore i dolje. Predstavljaju se prethodni ishodi mjerenja tih diferencijalnih udarnih presjeka.