Search for an enhanced production of low energy pions in $C(p, \pi^+)X$, $Cu(p, \pi^+)X$, and $Cu(p, \pi^0)X$ reactions for $300 \text{ MeV} \leq T_p \leq 400 \text{ MeV}$

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Abstract. The observation of an enhancement in the production of low energy pions in the $Cu(p, \pi^+)X$ reaction is confirmed. The width of the bump is about 5 MeV around 350 MeV. A similar enhancement appears at 330 MeV for $C(p, \pi^+)X$ but the width has not been measured. An attempt to observe this behaviour in $Cu(p, \pi^0)X$ is described. From the data one cannot conclude about the existence of a structure around 350 MeV proton energy. The lack of resolution in the $\pi^0$ spectrometer may have washed out the small effect expected from $\pi^+$ measurements.

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Introduction

Anomalous pion production in $p + Cu$ reaction was first reported by Krasnov et al. [1]. The data showed an enhanced pion production rate at $T_p = 350$ MeV. The energy resolution of the incident beam was 6 MeV and the energy steps 25 and 50 MeV. In fitting the pion invariant cross section with an exponential shape as:

$$E d^3\sigma/d^3p = a \exp(-E/E_0)$$

the slope parameter $E_0$ was found to increase monotonically as a function of the proton energy, except at 350 MeV where it is smaller than at the preceding value of 325 MeV. The experimental values of the cross section might depend on the proton flux measurements but the $E_0$ value cannot. This unexpected anomaly was explained as a possible connection with the excitation of a dibaryonic state [1].

In order to confirm and to understand the underlying phenomena of this enhancement, another experiment [2] using the proton beam facility of the Laboratoire National Saturne (Saclay) was carried out, with a different experimental set-up. Whereas Krasnov et al. [1] used time of flight and $\Delta E - E$ technique to identify pions of kinetic energy from 30 to 155 MeV, the Saturne experiment used a range spectrometer [2]. The $\pi^+ \rightarrow \nu + \mu^+$ decay of the stopped positive pion was used to avoid a possible proton contamination. The energy variation of $R$, the ratio of lower energy part to higher energy part of the pion yields, has been reported [2, 3]. This ratio has the advantage to be independent of the beam monitoring, the solid angle determination and the detector efficiencies. This second experiment confirmed the anomaly observed for $T_p = 350$ MeV and helped to establish that it was due to an enhancement of low energy pions [4]. Both experiments were carried out for one target (Cu) and for one pion emission angle ($\theta = 90^\circ$).

An attempt to observe this structure in measurements with a magnetic spectrometer did not confirm the anomaly [5]. Three results were there presented: the ratio of $\pi^+$ production around 40 MeV to $\pi^+$ production around 100 MeV, the ratio of $\pi^+$ production around 40 MeV to proton production around 200 MeV and the ratio of $\pi^-$ production around 40 MeV to $\pi^-$ production around 100 MeV. No significant structure was reported. One can realize that the measurements with a magnetic spectrometer are much more difficult because they require an excellent monitoring of the experimental set-up as the two measurements at low and high energies are not simultaneous.

Another experiment [6] has not been able to positively identify excess pion production in neutron induced reactions, the observed bump being only 2.2 standard
deviations in the most favorable case. In this case the resolution of the incoming beam was poor (3 MeV) for looking at a narrow resonance. On the other hand the structure has again been observed by Akimov et al. [7] at Dubna at pion angles of 90°, 115° and 125°.

Several possible interpretations appeared in recent articles [8–11] and will be briefly reviewed in the part 3. More experimental information is required to help to distinguish the different processes, such as the width of this anomaly, its angular dependence, its dependence of the target mass, its existence with different charges of the produced pions, its excitation with different projectiles, etc. The present publication is a partial contribution in this area.

1. New measurements on $A(p, \pi^+)X$

Using the same range spectrometer as in [2], the reactions $C(p, \pi^+)X$ and $Cu(p, \pi^+)X$ have been studied with the accelerator Saturne, for several proton incident energies between 310 and 425 MeV, with an energy step of 2 MeV around 350 MeV. The target thicknesses were of the order of 20 mg/cm². The beam energy resolution was ±100 keV. The solid angle covered by the 12 plastic scintillator range spectrometer was 10 msr. A beam monitor was available for checking the counting rates, but it was not necessary when using the observable $R$ (previously defined).

The variation of the value of $R$ with proton energy was inferred from the data with C and Cu. Figure 1 shows the results obtained for these two targets. A structure at $T_p=350$ MeV with a width of about 5 MeV (FWHM) is observed for the copper target. No enhancement is observed for carbon at 350 MeV but a higher value of $R$ is found for $T_p=330$ MeV. Unfortunately, the energy step in this region was only 10 MeV and no information about the width of this structure could be extracted. The order of magnitude of this low energy pion production enhancement is about 5% for both targets.

Invariant cross sections were parametrized using the exponential function (1), as for the [1] data. The parameter $E_0$ is plotted against proton energy (Fig. 2) for both targets. This parameter, $E_0$, is found to be smaller at $T_p=350$ MeV for copper and at $T_p=330$ MeV for carbon, reflecting the results obtained for $R$.

A natural extension of this research was to check whether this low energy pion enhancement exists in the case of neutral pions, at which value of the proton energy and for which value of the outgoing pions. Some shifts may appear due to suppression of the Coulomb barrier. Moreover if the neutral pion emission is studied with an appropriate detector, a complete angular distribution can be obtained and one can investigate the angular dependence of the phenomenon. The variation of $R$ should be a reliable indicator since the detection of the entire $\pi^0$ spectrum is done in one unique measurement for each energy.