CLASSIFICATION OF $\bar{p}+p$ INDUCED REACTIONS

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Annihilation cross sections of antiproton-proton into hadronic channels are studied and related experimental data are compiled. These channels constitute a high source of background to the annihilation reactions $\bar{p}+p \to \ell^+ + \ell^-, \bar{p}+p \to \ell^+ + \ell^- + \pi^0$, used for the measurement of proton form factors in Time-like region. Pion multiplicity in final state is also analysed, since the 2 neutral or charged pion production is expected to be an important issue in the detection of the leptons pair.

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1. INTRODUCTION

The PANDA experiment will be one of the key experiments at the Facility for Antiproton and Ion Research (FAIR) which is currently being built on the area of the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt. One of the aims of this experiment is to access the electromagnetic structure of the proton by the annihilation reaction $\bar{p}+p$ into leptons.

The reactions involving hadrons in final state are orders of magnitude larger than the reaction of interest and constitute the source of physical background. They are also interesting by themselves as they contain information on QCD subprocesses.

We illustrate the total cross sections of the known reactions induced by $\bar{p}+p$, involving hadrons in final state, for which experimental data (even partial) exist and are at [mb] level. We give the parametrization for the total, elastic and inelastic cross sections and we study the pions multiplicity in the final state.

This analysis may be used for evaluating counting rates and as a base for selection methods, at trigger level, too, of the reaction of interest $(\bar{p}+p \to \ell^+ + \ell^-,\ \ \bar{p}+p \to \ell^+ + \ell^- + \pi^0)$ which cross section is of the order of [nb].

2. TOTAL AND ELASTIC CROSS SECTION

The world data for the total and elastic cross sections for the $\bar{p}+p$ induced reactions are illustrated in Fig. 1 as function of the laboratory antiproton momentum $p_{\bar{p}}$ expressed in [GeV/c]. The references of the experimental measurements can be found in [1]. The lines are the results from a new parametrization which describes the global structure of $p\bar{p}$ total cross sections and includes a low energy extension of the Regge theory based on three-body forces in relativistic quantum theory [2].

From the Fig. 1 we see that $\sigma^{el}_{\bar{p}p}/\sigma^{tot}_{\bar{p}p} \simeq 1/3$, in agreement with the quasi-eikonal approach of the reggeon field theory [3].

This fit which reproduces the experimental data, allows us to calculate the contribution for the inelastic channels. The difference between the total and elastic cross section parametrizations (green line) represents the contribution of inelastic events. It is of the order of 40 mb for $p_{\bar{p}}$ >10 GeV/c.

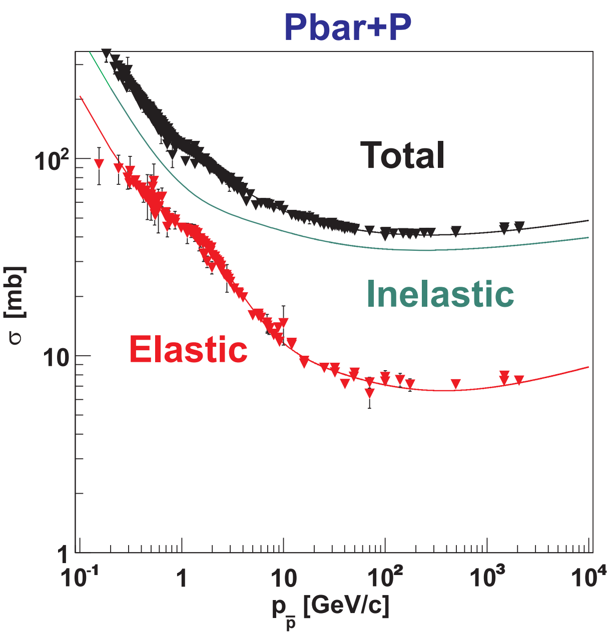

Fig. 1. *Total (black) and elastic (red) cross section for the $\bar{p}+p$ reaction, as function of the antiproton beam momentum. The contribution of inelastic events is also shown (green line)*

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3. INDIVIDUAL CONTRIBUTION OF (SOME) INELASTIC CHANNELS

The reactions of interest for form factor measurements in the Time-like region involve two leptons in final state and no hadrons ($\bar{p} + p \to \ell^+ + \ell^-$), or two leptons and a pion if one wants to investigate the near threshold and the unphysical kinematical regions ($\bar{p} + p \to \ell^+ + \ell^- + \pi^0$). Experimental data on cross sections and angular distributions concerning 230 final channels involving hadrons have been classified [1]. Based on this compilation, various cross sections are shown for selected processes in the [0.01... 10 mb] range, in Figs. 2 and 3.

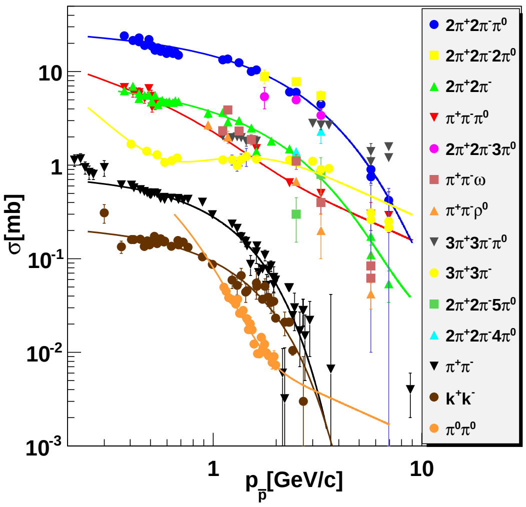

Fig. 2. *Cross sections for different inelastic channels in the $\bar{p} + p$ reaction as a function of $p_{\bar{p}}$*

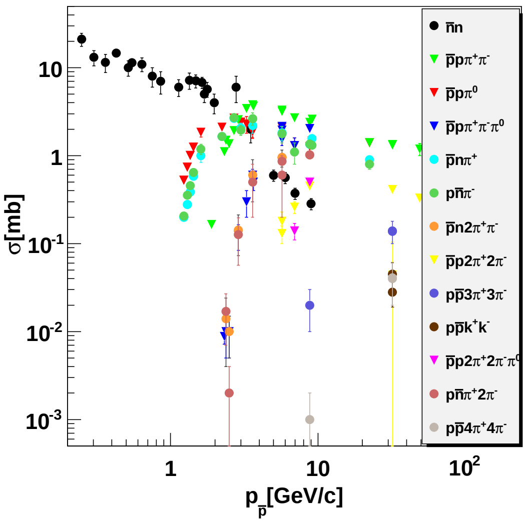

Fig. 3. *Cross sections for different inelastic channels (pions with nucleons) in the $\bar{p} + p$ reaction as a function of $p_{\bar{p}}$*

Let us focus our interest to the production of pions alone and pions accompanied by nucleons. Fig. 2 shows that the most probable reaction involving pions, corresponds to more than three pions in the final state. We parametrize the cross section for the reactions given in Fig. 2 as:

$$\sigma = a e^{-b p_{\bar{p}}} + \frac{c}{p_{\bar{p}}}, \tag{1}$$

where $p_{\bar{p}}$ and σ are expressed in [GeV/c] and [mb] respectively. The coefficients a, b and c of the parametrization (1) are given in the Table 1 for some reactions.

Table 1. *Coefficients for the parametrization, Eq. (1), of selected inelastic channel cross sections*

Final state	a [mb]	b [GeV/c]$^{-1}$	c [mb GeV/c]
$\pi^0\pi^0$	3.88	4.04	0.012
$\pi^+\pi^-\pi^0$	6.1	1.99	1.41
$2\pi^+2\pi^-$	7.05	0.727	0.24
$3\pi^+3\pi^-$	-10.58	1.949	2.654
$2\pi^+2\pi^-\pi^0$	26.14	0.599	0.26

Table 2. *Threshold kinetic, total energies and momentum for $\bar{p} + p$ annihilation into the final states illustrated in Fig. 3*

Final state	T_{thr}[GeV]	$E_{\bar{p}}$[GeV]	$p_{\bar{p}}$[GeV/c]
$\bar{n}n$	0.005	0.943447	0.0986851
$\bar{p}p\pi^+\pi^-$	0.599	1.53808	1.21874
$\bar{p}p\pi^0$	0.279	1.21793	0.776536
$\bar{p}p\pi^+\pi^-\pi^0$	0.919	1.85789	1.60356
$\bar{p}p2\pi^+2\pi^-$	1.283	2.22092	2.013
$\bar{p}p3\pi^+3\pi^-$	2.049	2.98682	2.83562
$\bar{p}p2\pi^+2\pi^-\pi^0$	1.643	2.5809	2.40431
$\bar{p}p4\pi^+4\pi^-$	2.897	3.83576	3.71923

In Fig. 3 we illustrate the cross sections for the production of proton-antiprotons (neutrons) with a different number of charged and neutral pions (the other reactions with a larger number of pions are less probable). We see that the cross sections increase from threshold with the incident energy until a certain value of $p_{\bar{p}}$, except the charge exchange reaction ($\bar{p} + p \to \bar{n} + n$) which has a sizeable cross section for $p_{\bar{p}} < 3$ GeV.

Over the corresponding threshold, the production of any number of pions accompanied by a proton-antiproton pair is more (less) probable for a large (small) incident energy, than when they are produced alone. Consequently, the most probable reactions are the (4,5) pions production, or the charge exchange reaction, but when the incident momentum increases it is necessary to evaluate, either the production of a larger number of pions (6,7, see following paragraph), or of a lower number (2,3) but accompanied by a proton-antiproton pair.

The difference between the behavior of the cross sections can be explained at small incident energy region by the effect of threshold. The threshold is defined by the condition that the emitted particles are at rest, which corresponds to zero three-momentum. We have calculated the threshold kinetic energy $T_{\rm thr}$ from the equality of the invariant s in center of mass and laboratory system $s_{\rm lab} = s_{\rm cm}$ with $s_{\rm lab} = (p_{\bar p} + p_p)^2 = (2M)^2 + 2MT$ and $s_{\rm cm} = (\sum m_f)^2$, where $\sum m_f$ is the sum of the masses of the final particles:

$$T_{\rm thr} = \frac{(\sum m_f)^2 - 4M^2}{2M}. \quad (2)$$

The pion final states can be obtained by the proton-antiproton annihilation at rest, but their production with nucleon requires a certain threshold, which is different from zero (Table 2). In the considered kinematical region, we see that the most important reactions are those which have smaller threshold energy.

4. PROBABILITY OF n PION PRODUCTION

Two (or three) pion production is the reaction that constitutes the background which is most difficult to eliminate for the reaction of interest : $\bar p + p \to \ell^+ + \ell^-$ ($\bar p + p \to \ell^+ + \ell^- + \pi^0$) [4]. However, the production of a larger number of pions is more probable, which might be a problem at the trigger level. A detailed description and relative references can be found in Ref. [5].

In the statistical bootstrap model [5], the average pion multiplicity from $\bar p + p$ annihilation depends linearly on $\sqrt{s}$. The dependence on $p_{\bar p}$ [GeV/c] can be parametrized as

$$\langle n_\pi \rangle = 2.6 + 1.3 \left(1.76 + 1.88\sqrt{0.88 + p_{\bar p}^2}\right)^{0.5}. \quad (3)$$

A similar parametrization which applies to the range $s^{1/2} \le 30$ GeV can be found in [5]:

$$\langle n_\pi \rangle = 2.65 + 1.78 \log \left(1.76 + 1.88\sqrt{0.88 + p_{\bar p}^2}\right). \quad (4)$$

These two parametrization reproduce the experimental data where we can see that the average pion multiplicity for e^+e^- and $\bar p p$ at the same CM energy is essentially the same, for energies above the threshold.

The emission probability as a function of the pion multiplicity can be parametrized as:

$$P(n_\pi) = \frac{1}{\sqrt{2\pi}D} \exp \frac{-(n_\pi - \langle n_\pi \rangle)^2}{2D^2},$$
$$\frac{D^2}{\langle n_\pi \rangle} = 0.174 \left(1.76 + 1.88\sqrt{0.88 + p_{\bar p}^2}\right)^{0.2}. \quad (5)$$

where $\langle n_\pi \rangle$ is the pion multiplicity and $P(n_\pi)$ is the probability for the n-pions emission, obtained from Eq. (3), which is consistent with the existing experimental values. The standard deviation D^2 increases with $\langle n_\pi \rangle$ and with $p_{\bar p}$. From numerical application of the previous equations, it is seen that the contribution of six and seven pions (any charge state) in the final state is larger than the five pion contribution for $p_{\bar p} > 5$ GeV/c. At lower momenta, five pion emission has the largest contribution.

5. CONCLUSIONS

We have reported the world data and recalled a recent physical parametrization for the total and elastic $p + \bar p$ cross section. The elastic contribution amounts to 1/3 of the total contribution.

We have classified the cross section data corresponding to a number of interesting reactions with cross section in the [mb] region, and illustrated as a function of the incident momentum $p_{\bar p}$. These reactions are more probable by orders of magnitude than the ones which provide access to the electromagnetic form factors of the proton.

We have shown that the pion multiplicity in the final state of the $\bar p + p$ annihilation depends on the incident energy. The annihilation at rest is dominated by five pion emission. When the energy increases the probability for a larger number of pions increases.

We have given useful parametrizations for selected distributions using simple analytical formulas.

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КЛАССИФИКАЦИЯ РЕАКЦИЙ, ИНДУЦИРОВАННЫХ $\bar{p}+p$ - ВЗАИМОДЕЙСТВИЕМ

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Изучены сечения аннигиляции протонов с антипротонами в адронные каналы и выполнена компиляция соответствующих экспериментальных данных. Эти каналы представляют источник большого фона для реакций аннигиляции, $\bar{p}+p \to \ell^+ + \ell^-$, $\bar{p}+p \to \ell^+ + \ell^- + \pi^0$, которые используются для измерения протонных формфакторов во времениподобной области. Проанализирована также множественность пионов в конечном состоянии, так как ожидается, что образование двух нейтральных или заряженных пионов будет серьезной проблемой при детектировании лептонной пары.

КЛАСИФІКАЦІЯ РЕАКЦІЙ, ЯКІ ІНДУКОВАНІ $\bar{p}+p$ - ВЗАЄМОДІЄЮ

А. Дбейсі, Егле Томасі-Густафсон

Вивчено перерізи анігіляції протонів та антипротонів у адронні канали і виконано компіляцію відповідних експериментальних даних. Ці канали являють собою джерело великого фону для реакцій анігіляції, $\bar{p}+p \to \ell^+ + \ell^-$, $\bar{p}+p \to \ell^+ + \ell^- + \pi^0$, які використовуються для вимірювання протонних формфакторів у часоподібній області. Проаналізовано також множинність піонів у кінцевому стані, тому що очікується, що утворення двох нейтральних або зарядженних піонів буде серйозною проблемою при детектуванні лептонної пари.