Eur Phys J C **33**, s01, s515–s517 (2004)
Digital Object Identifier (DOI) 10.1140/epjcd/s2004-03-1678-x

EPJ C direct
electronic only

Baryon number transfer and baryon pair production in soft hadronic interactions at the CERN SPS

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Received: 29 October 2003 / Accepted: 9 January 2004 /
Published Online: 17 February 2004 –

Abstract. Results on proton and neutron production in $p+p$ interactions at 158 GeV beam energy are presented. The distribution of net baryon density, in particular concerning the feed-over between target and projectile hemispheres, is determined from $\pi^{\pm}+p$ and $p+p$ interactions, invoking the non-baryonic nature of pion projectile. For $p+p$ collisions, net baryon density is studied in association with a final state proton. It is demonstrated that net baryon production is described by a factorizing two-component mechanism. The maximum range of baryon number transfer is limited to about 4.5 units of rapidity. Using a comparison of anti-proton production in $p+p$ and $n+p$ interactions it is shown that baryon pair production depends on the valence structure of the incoming hadrons and is characterized by strong charge-asymmetric contributions of the type $\bar{p}n$ and $p\bar{n}$ in addition to the symmetric terms $\bar{p}p$ and $\bar{n}n$.

PACS. 13.85.Ni Baryon production in hadronic interactions

1 Introduction

The concept of hadronic factorisation was introduced a long time ago (see e.g. [1]) and became an important aspect of describing elastic and diffractive hadronic processes. The independence of the forward and backward hemispheres in $p+p$ interactions was demonstrated up to a high accuracy at the ISR [2] in the fragmentation region. The present work aims to extend this picture to the complete kinematic region for baryons, using the experimental possibilities of the CERN Experiment NA49.

2 Proton production

The p_T integrated proton density has been measured in $p+p$ interactions at 158 GeV beam energy. Figure 1 shows the density distribution as a function of x_F (Feynman-x) in inelastic events. The distribution is to first order flat with a shallow maximum at about $x_F = 0.4$, and with a diffractive peak starting above $x_F = 0.9$. The maximum at $x_F = 0$ corresponds to the pair-produced protons: it has a similar shape to that of the antiprotons, also shown in Fig. 1.

The errors on the values are representing the statistical and systematic errors, with an overall normalisation error of 4% to be added. The presented distribution is consistent with bubble chamber measurements [3]. Experiments at Fermilab [4] and at the SPS [5] show mutual inconsistencies up to about 20%.

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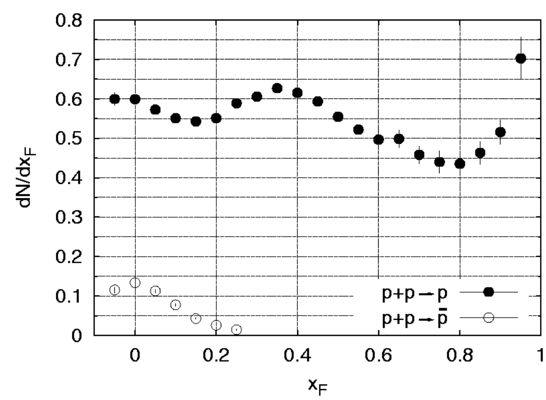

Fig. 1. Proton and antiproton, p_T integrated density in $p+p$ interactions

3 Neutron production

New results on neutron production are presented in Fig. 2. The p_T-integrated x_F distribution in $p+p$ interactions slightly decreases towards higher x_F and has no visible diffractive peak.

Comparison to earlier measurements at similar energies (from ISR [6] and FNAL [7]) reveals an inconsistency up to a factor of two between those results, and none of them are confirmed by the NA49 measurement. The situation calls for independent consistency checks, based on conservation laws and known symmetries.

Isospin symmetry suggests, that comparing reactions

$$p+p \to n \quad \text{and} \quad n+p \to p$$

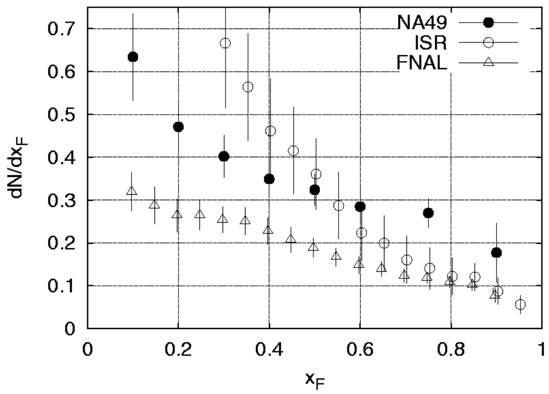

Fig. 2. Neutron integrated, compared to other data

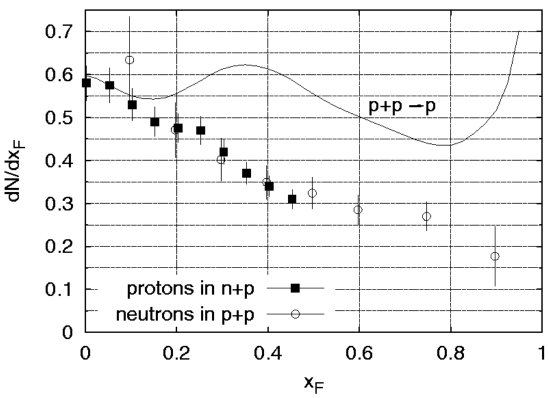

Fig. 3. Protons from $n+p$ compared to neutrons from $p+p$

Table 1. Test of baryon number conservation

Particle type	yield
proton	0.582 ± 0.03
neutron	0.370 ± 0.045
Λ^0+$\Sigma^{\pm}$	0.089 ± 0.010
-$\overline{B}$	-0.050 ± 0.007
Sum:	$\mathbf{0.991 \pm 0.06}$

the cross sections have to be equal if the symmetry holds for the forward hemisphere (in both cases, the target is the proton). Figure 3 demonstrates the fulfillment of this expectation.

Given the measurement of p, $\bar{p}$, n as well as Λ, $\bar{\Lambda}$ [8] in the same experiment, a meaningful test of the sum rule of baryon number conservation may be performed using NA49 data. The necessary assumptions on $\bar{n}$ and Σ production are straightforward and introduce only small contributions to the systematic error. Table 1 shows the total yield of baryons in the forward hemisphere obtained for inelastic $p+p$ interactions.

The two independent consistency tests discussed above give confidence that the results, both on protons and neutrons, are reliable. Note that the baryon yield sum can not be fulfilled by either the ISR or the FNAL neutron measurements presented in Fig. 2.

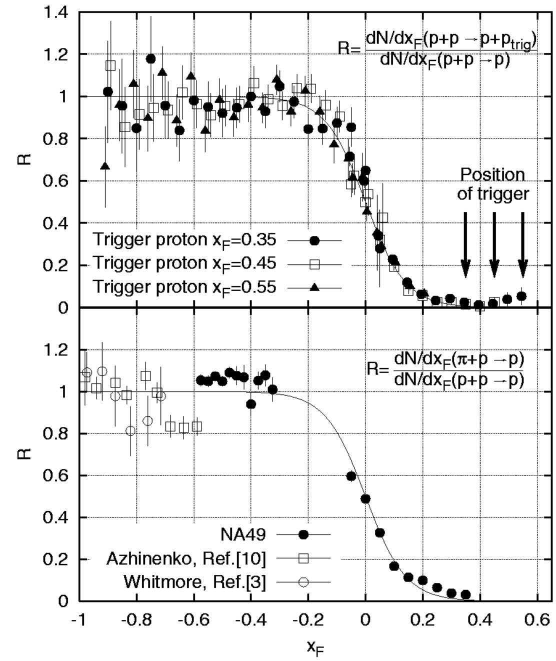

Fig. 4. Net proton density ($p-\bar{p}$) ratio with pion and proton beam (*lower part*) and ratio of correlated and inclusive net proton density in $p+p$ collisions (*upper part*)

4 Factorising two component picture

In the previous section, the consistency argument between $n+p \to p$ and $p+p \to n$ relied on the assumption that isospin symmetry holds for the two hemispheres separately, which suggests that the two hemispheres are to first order independent. This factorisation of the hemispheres introduces a picture of hadronic interactions where the net baryon distribution is built up from two components: one connected to the target and the other to the projectile [9].

The arguments of this section concern the non-pair-produced protons. Assuming that $\bar{p}$ measures the pair production, $p-\bar{p}$ measures the non-pair-produced contribution. This assumption is correct only to first order, and a quantitative estimate on its applicability will be discussed in Sect. 5.

The principle of the measurement of the target component in $p+p$ interactions is that one can choose a projectile with zero baryon number: average of π^+ and π^- beam. If the factorisation holds, the net proton density in $\pi+p$ describes the target component of the net proton density in $p+p$ collisions. The ratio of the net proton density in $\pi+p$ and $p+p$ interactions is shown in the lower part of Fig. 4.

The following conclusions can be drawn from the measurement:

– The experimentally measured ratio is 1/2 at $x_F = 0$, as it must be by symmetry, if the $\pi+p$ interaction measures the target component of the net proton density in $p+p$. The ratio approaches 1 in the backward region.

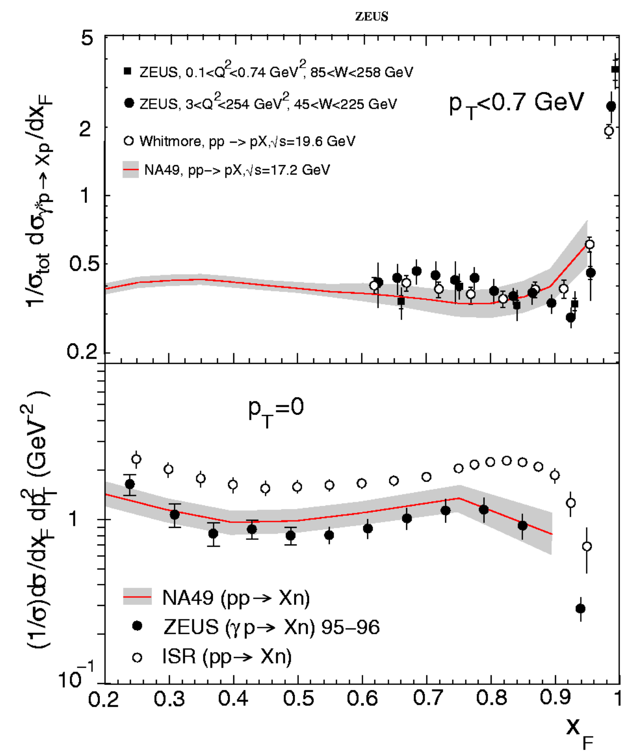

Fig. 5. Protons and neutrons at HERA, compared to $p+p$

– The ratio approaches zero at $x_F \approx 0.2$, corresponding to 4.5 units of rapidity distance from the target.

The baryon number of the projectile component in $p+p$ interactions can also be fixed by a requirement of an identified forward proton in the event. If the factorisation holds, the target component should be independent of the position of this "trigger" proton, and the distribution has to be the same as the one measured with the pion beam. This is demonstrated in the upper part of Fig. 4.

Further test of the factorising two component picture is the comparison of the reactions

$$p+\gamma^* \to p \quad \text{and} \quad p+p \to p$$

or

$$p+\gamma^* \to n \quad \text{and} \quad p+p \to n$$

as the $p+\gamma^*$ interactions are available from the HERA collider. As shown in Fig. 5 using results from ZEUS [11], the respective densities are indeed equal. In case of neutrons, based on the ISR results [13], an indication of non-factorisation was reported [12]. Under the assumption that the p_T distribution of protons and neutrons is the same in $p+p$ interactions (which is closely correct at $x_F = 0.5..0.7$), the cross section at $p_T = 0$ can be evaluated for the NA49 results. The resulting cross sections are conformal with the ISR results but by a factor of two lower. They confirm the factorization also for neutrons.

5 Baryon pair production

The assumption that the non-pair-produced protons are measured by the $p-\bar{p}$ is only a first-order approximation: due to isospin effects, there is a difference between pair produced protons and antiprotons [9]. Associate production of baryon-antibaryon pairs of type $\bar{p}n$ and $\bar{n}p$ form an isospin-triplet with the symmetric pairs, as shown in Table 2.

Table 2. Asymmetric pair production

I_3	-1	-1/2	0	1/2	1
Beam	π^-	n		p	π^+
Produced pair	$\bar{p}n$		$p\bar{p}$ $n\bar{n}$		$p\bar{n}$

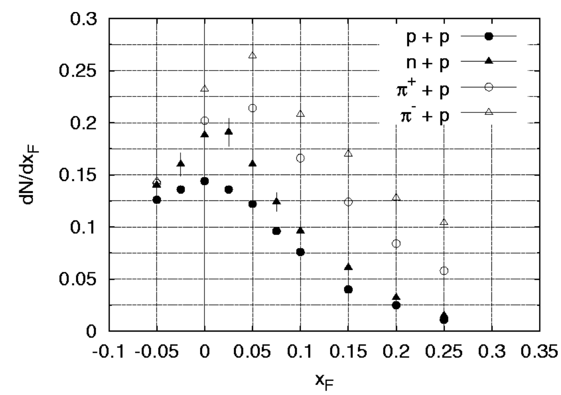

Fig. 6. Antiproton production in $h+p$

The $I_3 = -1$ states are favoured against $I_3 = +1$ states with a projectile of $I_3 = -1/2$, therefore one expects that there are more antiprotons in $n+p$ than in $p+p$, as demonstrated in Fig. 6. This also proves that there are more pair produced protons in $p+p$ than antiprotons, so $p-\bar{p}$ overestimates the net proton yield.

Similarly, there is an asymmetry between antiprotons produced by π^+ and π^-. Furthermore, one observes that the antiproton yield is higher and extends further into the projectile region with pion beam than with the nucleon beam.

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