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Baryon Number Transfer in Hadron+Nucleus and Nucleus+Nucleus Collisions: a Link Between Elementary and Complex Interactions

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Abstract. The baryon number transfer is studied in elementary and complex hadronic interactions at the CERN experiment NA49 at the SPS, at 158 AGeV beam energy ($\sqrt{s} = 17.2GeV$). A two component picture is proposed, which builds up the net proton distribution from a target and a projectile component. Using pion beam, the projectile component is experimentally determined for p+p and p+A interactions. A similar stopping behaviour of the projectile component is found for p+A and A+A interactions. Based on these observations, the baryon transfer is assumed to provide a common scale of inelasticity in p+p, p+A and A+A interactions. A model-independent way is proposed to predict the pion multiplicity in A+A.

Keywords: baryon transfer, two component picture, multiplicity
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1. Introduction

The NA49 experiment at the CERN SPS is a large acceptance hadron spectrometer, based on Time Projection Chambers. [1]. The detector provides precision tracking and particle identification via the measurement of the ionization energy loss in the TPCs. The system is completed by Time of Flight detectors and calorimeters, the latter providing neutron detection above $x_F = 0.2$ in proton induced reactions. A dedicated counter is designed to control the centrality in p+A interactions, which measures the multiplicity of the recoil (grey) protons.

2. Net proton distribution in the elementary collisions

The net proton yield in a hadronic interaction is defined by $p-\bar{p}$, so antiprotons are subtracted from the protons to cancel the pairproduced component. The net proton distribution (see Fig.1) in p+p interaction is forward-backward symmetric, to first order flat with a diffractive peak. Above $x_F > 0.2$ the Feynman-scaling holds, which predicts the invariant cross-section as a function of x_F being independent of $\sqrt{s}$ at high energies. Intuitively, this symmetric distribution has two components: the forward region associated with the projectile, and the backward region with the target. In the following sections, the experimental study of this intuitive picture will be discussed.

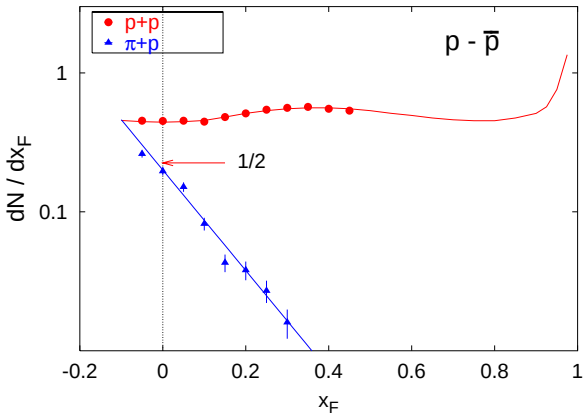

Fig. 1. Net proton distribution in p+p and π+p interactions. The prediction of the two component picture is that the π+p yield at $x_F = 0$ is half the p+p value

3. Two component picture of the elementary collisions

The basic idea of the two component picture [2] is shown on a cartoon (Fig.2): the net proton distribution in p+p is built up from two symmetric components. Assuming, that *the target component is independent of the projectile type of the interaction*, the two components can be experimentally separated. For the measurement, a baryon free projectile was used (π+p) which allows the measurement of the target component alone (see Fig.2).

As π^+ and π^- has non-zero isospin, the produced net proton on the projectile side will also be non-zero (only $p-\bar{p}+n-\bar{n}$ would vanish). To cancel this effect, the average of $\pi^+ + p$ and $\pi^- + p$ collisions were used for the measurement. The

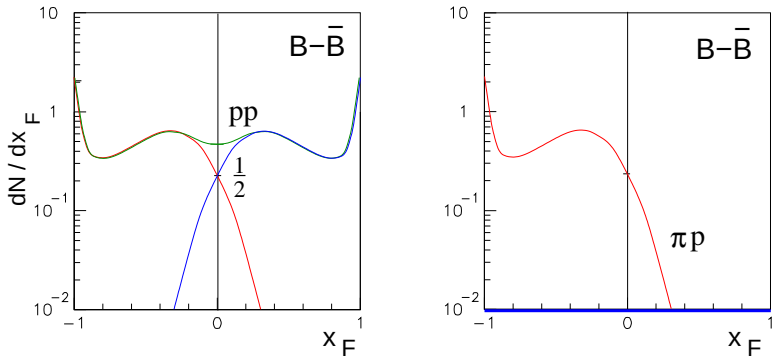

Fig. 2. In the two component picture of p+p interactions, the net proton yield is the sum of a target and a projectile component; in the middle, both components contribute with half the yield (left). The target component can be measured separately using a baryon free projectile (right)

net proton distribution in this averaged $\pi + p$ is presented in Fig.1

One simple prediction of the two component picture is that the yield of the net protons in $\pi + p$ at $x_F = 0$, so at the center of mass of the colliding system, has to be half of the value measured in $p + p$. This prediction is reasonably fulfilled. In the forward region, subtracting the $\pi + p$ measurement from the $p + p$ values, the *projectile component of the net proton spectrum in p+p* can be obtained, shown in Fig.3.

4. Net proton distribution in hadron+nucleus interactions

The net proton distribution in p+Pb at different centralities is shown in Fig 4, compared to net protons in p+p. The centrality of the p+Pb collision is measured using a dedicated detector which determines the multiplicity of the knockout protons from the nucleus. From this multiplicity, applying Glauber-model calculations and detailed detector simulation, the number of collisions (ν) is estimated. The distributions steepen up at higher centrality due to the baryon stopping phenomenon [3].

5. Two component picture of hadron+nucleus interactions

The proposed two component picture is more complicated for p+A than for p+p. The following assumption can be made: to first order, on the target side each collision of the projectile produces the target component of the net proton distribution in p+p, i.e. *the target component in pA piles up in proportion with the number*

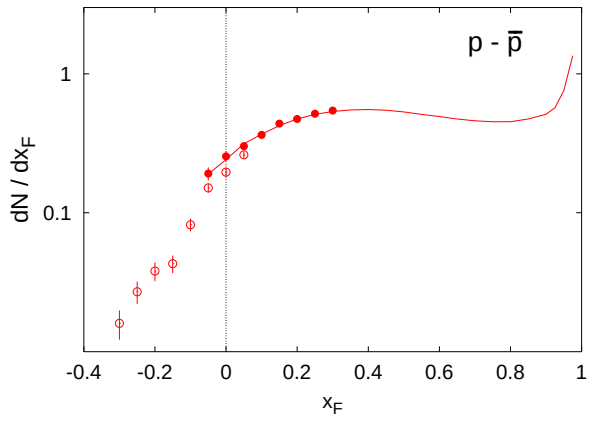

Fig. 3. The projectile component of the net proton spectrum in p+p interaction

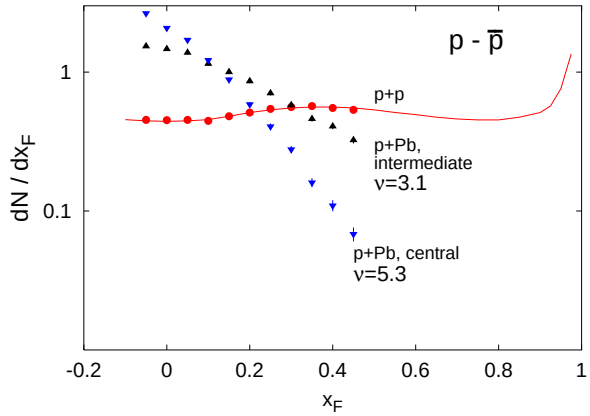

Fig. 4. Net proton distribution in p+Pb interactions at different centralities (different number of collisions)

of collisions. The projectile however, as it suffers multiple collisions, develops a *stopped projectile component.* A cartoon describing the picture is shown on Fig.5.

In order to determine the projectile component of the net proton distribution in p+A, the idea of baryon free projectile can be used again. According to the prediction of the two component picture, the target component measured by $\pi + A$

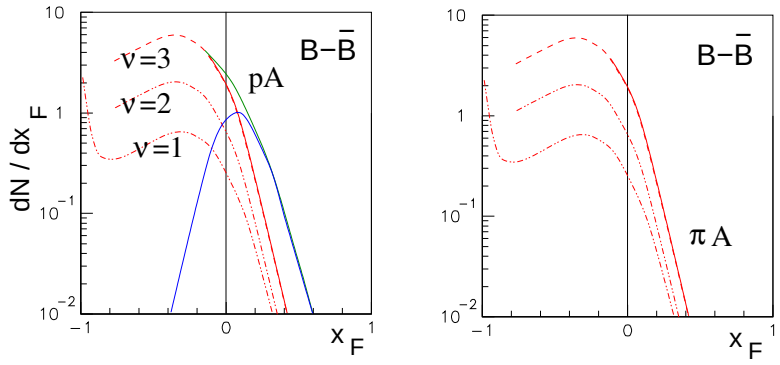

Fig. 5. In case of p+A, the target component of the net proton yield may have a similar shape as in p+p, but it is scaled up by the number of collisions (ν); the projectile component, as the projecile suffered multiple collisions, gets stopped (left). The target component can again be separately determined using pion projectile (right)

scales up from $\pi + p$ with the number of collisions; Fig.6 demonstrates this effect.

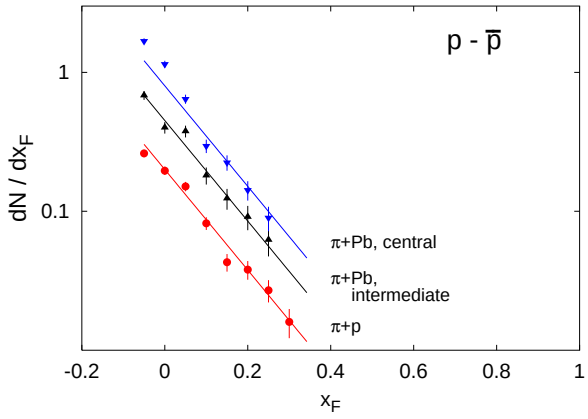

Fig. 6. Net proton distribution in π+Pb interactions at different centralities. Due to the pileup on the target side, the π+p yield is scaled up in π+Pb

Subtracting the net proton distribution measured in π+Pb from the net protons in p+Pb at the same centrality, the projectile component of the net proton distri-

bution can be determined in p+Pb (see Fig.7). A smooth progression of baryon number transfer is observed as a function of the number of collisions.

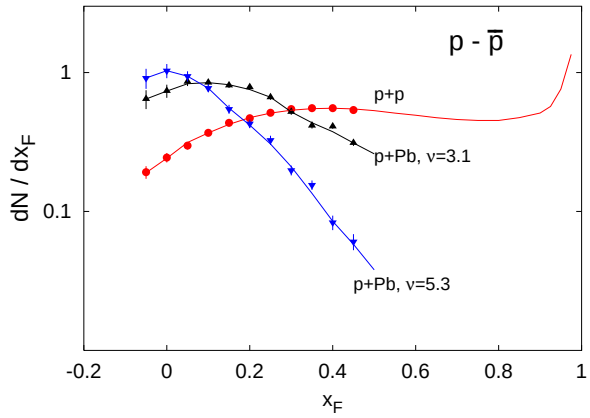

Fig. 7. Net proton projectile component in p+Pb interaction

6. Two component picture of nucleus+nucleus collisions

In case of AA, the baryon-free projectile concept is not applicable. The only constraint which provides an approximation of the projectile component of the net proton spectrum is the following: at $x_F = 0$, the value of the projectile component is half of the measured spectra, and the target component dies out fast as we move forward. In Fig.8 the measured net proton distribution and the estimated projectile component is presented.

The conclusion of the studies above is that with increasing centrality, the projectile component of the net proton distribution have a similar behaviour in p+A and A+A interactions, which is a smooth transition of baryon number transfer from the elementary to more complex interactions.

7. Reference (isospin corrected) net proton for Pb+Pb collisions

In the Pb nucleus, the n to p ratio is about 60 to 40, so the net proton distribution in a reference N+N collision has to be determined to take care of the neutron content; here N=0.4p+0.6n. Within the framework of the two component picture the isospin symmetry holds separately for the two hemispheres, so the net forward proton in n+p or n+n is equal to the net neutron in p+p. Relying on this assumption, the

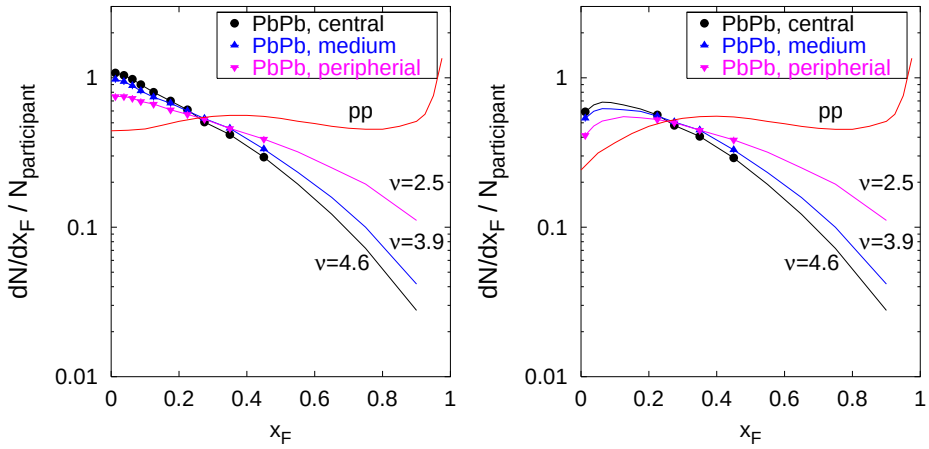

Fig. 8. Net proton distribution in Pb+Pb interaction (left); net proton projectile component in Pb+Pb (right)

net proton distribution in an isospin averaged N+N collision can be obtained; this is shown in Fig.9.

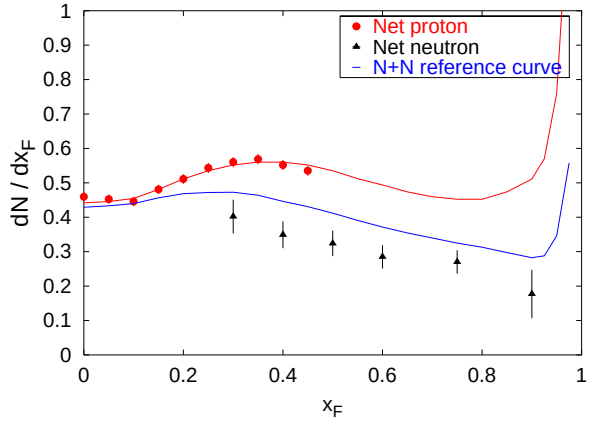

Fig. 9. Net proton distribution in the reference nucleon-nucleon collision

8. Correlation of the pion multiplicity with the final state baryon in p+p interaction

In case of the p+A and A+A collisions, the baryon number transfer is characterised by the centrality. In the elementary p+p collision the centrality can not be reliably defined, so the study must be done in the other way round: Fig.10 shows that the position of the final state baryon characterises the pion multiplicity p+p events.[4]

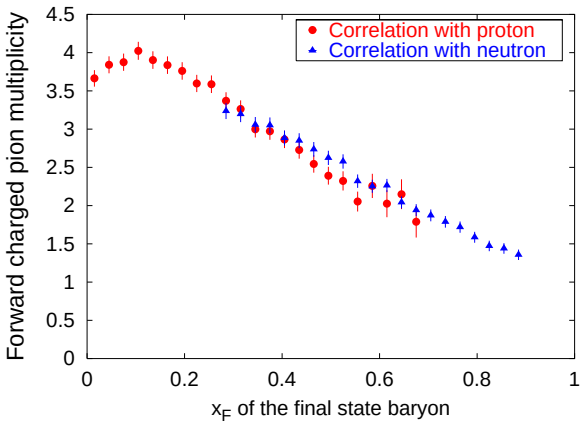

Fig. 10. Correlation of the forward charged pion multiplicity with the x_F position of the final state baryon. Strong correlation is observed; in those events where the final state baryon is close to the center, the pion multiplicity increases

The measurement confirms the intuitive expectation: in those events, where the final state baryon is fast (especially in the diffractive region), the multiplicity is low. If the final state baryon is more stopped, more pions are produced. The correlation is independent of the baryon isospin.

9. Prediction of the pion multiplicity in Pb+Pb collisions from correlation measurements in p+p

Based on the phenomenon of baryon stopping in central p+A and A+A collisions, and the strong correlation of p+p observables with the final state baryon, the following assumption can be made: *the baryon number transfer characterises the inelasticity (centrality) in p+p, p+A and A+A interactions.* This assumption provides a method to compare minimum bias p+p collisions with central A+A collisions, where the trigger bias is to be taken into account.

In a p+p collision, any quantity, e.g. the pion multiplicity measured as a function of x_F of the final state proton defines a correlation function $C(x)$. The pion

multiplicity in minimum bias p+p then can be calculated by weighing $C(x)$ with the net projectile proton distribution; this trivial statement can be expressed in the following way:

$$< \pi >_{pp} = \frac{\int C(x) P_{pp} dx}{\int P_{pp}}$$

where P_{pp} is the net projectile proton distribution in p+p as a function of x_F. In A+A, the stopped net projectile proton distribution can be viewed as protons from a superposition of p+p (or N+N) interactions, where events with more stopped final state protons have larger weight; this means that the pion multiplicity in A+A (per participating nucleon) is predicted to be

$$< \pi >_{PbPb} = \frac{\int C(x) P_{PbPb} dx}{\int P_{PbPb} dx}$$

In this case, the net proton distribution in Pb+Pb (P_{PbPb}) is to be applied. The result of this prediction is presented on Fig.11 in comparison with pion multiplicity measurements from PbPb interactions at different centralities.

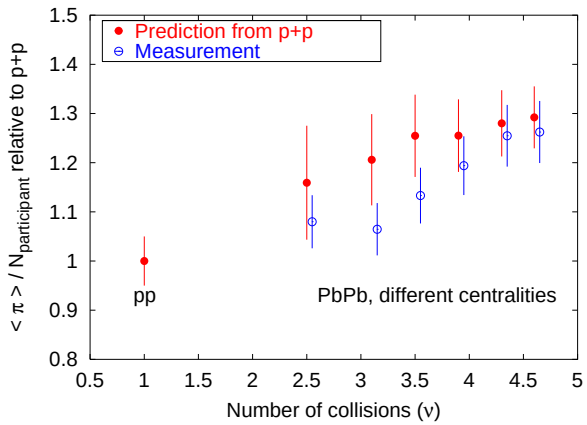

Fig. 11. Comparison of the predicted and the measured pion multiplicity in Pb+Pb collisions. The prediction, which assumes that the final state baryon characterises the inelasticity also in p+p gives a good qualitative agreement

The prediction gives a very good qualitative descriprion of the measurements. If the assumptions are correct, this means that the full increase of pion multiplicity in central Pb+Pb interaction can be explained with a superposition of elementary collisions, taking proper care of the centrality selection.

10. Conclusions

An experimental study of the two component picture of hadronic interactions at $\sqrt{s}$=17.2 GeV was discussed. In this picture, the net proton distribution is built up by a target and a projectile component; these components can be separated experimentally with a baryon free (pion) projectile. The projectile component of the net proton distribution in p+A and A+A collisions is found to behave similarly at increasing centrality, namely that the baryon number moves towards the center. Based on the assumption that the baryon transfer characterises the inelasticity of p+p, p+A and A+A collisions, a model independent procedure was developed to compare minimum bias p+p and central Pb+Pb collisions, which showed that the increase of the pion multiplicity in A+A compared to p+p interactions can be fully predicted only by taking care of the sizeable baryon stopping in A+A.

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Notes

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