Pion production in PbPb collisions at the SPS

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New data on charged pion production in PbPb interactions are measured by the NA49 experiment and compared to NN interactions. Different phenomena are isolated. It is argued that salient features of pion production in nuclear interactions can be understood as a result of NN dynamics and of other non–exotic phenomena.

1. Introduction

This paper presents a detailed comparison of charged pion spectra in nucleon–nucleon (NN) and PbPb interactions, measured by the NA49 detector at $\sqrt{s} = 17.2$ GeV/A. Connections between pion production in nuclear collisions and the dynamics of elementary interactions are investigated including the role of isospin, final state Coulomb interactions, spectator excitations, and multiple collisions of participating nucleons.

Most of the discussion concerns a peripheral PbPb sample, selected by measured event multiplicity between 150 and 300 charged tracks, corresponding to a mean number of participants $68 \pm 6$ and a mean number of collisions per participant $<\nu> = 2.7 \pm 0.1$. [1]

2. Measured pion spectra

Fig. 1 a), b) shows transverse momentum distributions of charged pions produced in peripheral PbPb collisions, and in isospin–corrected1 elementary NN interactions.

While at higher $p_T$ values, the shape of $p_T$ spectra in PbPb interactions is very similar to that in NN collisions, at lower transverse momenta a complex pattern of differences is visible. These are most pronounced at $x_F \approx 0.15$, low $p_T$.

In this kinematic region, pions have low relative momentum with respect to the spectator system. This suggests that the effect is caused by a final state Coulomb interactions between pions and spectators.

3. Ratios

To distinguish the observed behavior from a trivial manifestation of isospin symmetry, the double–ratios $(\pi^+/\pi^-)^{PbPb}/(\pi^+/\pi^-)^{NN}$ are shown in Fig. 2 a).

1$\pi^\pm$ yields from a proton fragmentation correspond to $\pi^\mp$ yields in a neutron fragmentation. Thus we can form a comparable spectra from pp collisions, taking into account $p/n = 39/61$ ratio in the peripheral PbPb sample. For detailed discussion about the isospin effects see [2,3]
In order to investigate and quantify the Coulomb interaction hypothesis stated above, a Monte Carlo model calculation was performed, tracking the pions in the electric field of the spectator system[4]. The model results explain the main features of the data well, as shown on the Fig. 2 b).

Centrality dependence of \((\pi^+/\pi^-)_{PbPb}\) at \(x_F = 0.15\), is shown in Fig. 3, together with NA52 measurements[5] at \(y = 5.7\) \((x_F = 0.134)\). With increasing centrality the spectators turn into participants, the charge of the spectator system decreases, and the effect diminishes.

4. Average pion yields

Apart from the final state Coulomb interaction, other phenomena can be isolated in PbPb interactions. These will be studied by means of average pion yields \(<\pi> = (\pi^++\pi^-)/2\) in a PbPb collision relative to a NN collision: \(R(x_F,p_T) = <\pi>_{PbPb} / <\pi>_{NN}\) \((x_F,p_T)\), shown in Fig. 4 a), b).

Three distinct \(p_T\) regions may be isolated from these plots: in the region \(p_T < 300\) MeV/c a strong variation of the relative yield for different \(x_F\) is observed, with a maximum at \(x_F \approx 0.15\); for \(300 < p_T < 600\) MeV/c the relative yield is rather stable with \(p_T\) and slowly increases with \(x_F\); for \(p_T > 600\) MeV/c the ratio smoothly increases by 30% at \(p_T = 900\) MeV/c relative to \(p_T = 500\) MeV/c, for all the \(x_F\).
Figure 2. a) Isospin corrected $\pi^+/\pi^-$ ratio in peripheral $\text{PbPb}$ for various $x_F$. b) The ratio calculated by MC[4]. The plots for $x_F = 0.15, 0.20, 0.25$, omitted due to space limits, can be found at [7], page 5. Lines are to guide the eye.

Weighting $R$ with the pion density in the mid-$p_T$ region, an average ratio of $<R> = 33.5$ is obtained, which is consistent with the number of participants. To take out the increase observed in the mid-$p_T$ region, the normalized yield ratio $R'(p_T) = R(p_T) / <R>|_{\text{mid-}p_T}$ for fixed values of $x_F$ will be considered.

The shape of the excess of pion density in the low-$p_T$ region is similar to the one of pions produced from a low-mass resonance decay in the spectator system - both peak at $x_F \approx 0.15$ and $p_T \approx 100$ MeV/c. To attribute the observed effect to spectator excitation would also explain the observed decrease of the relative excess with centrality, see [7], page 8.

The relative yield ratio in mid-$p_T$ region at $x_F = 0$, where most of the pions are produced, normalized to the number of participating pairs increases with centrality (not shown, see [7], page 9). The increase has already been attributed to multiple participant collisions and more precisely, to a connection between baryon stopping and charged pion production[6].

In the higher-$p_T$ region (Fig. 5 a)) the $p_T$ dependence of $R'$ in the peripheral $\text{PbPb}$ sample shows smooth and to first order $x_F$-independent increase. A similar behavior is seen in $p\text{Pb}$ interactions at comparable $<\nu>$ - Fig. 5 b), suggesting similar origin of the effect.

Centrality dependence of $R'$ for $0.5 < p_T < 2$ GeV/c at $x_F = 0.15$ shows an increase with both $p_T$ and $<\nu>$, see [7], page 10. Such behavior may be understood as a consequence of increasing number of multiple collisions undergone by the participating nucleons. This problem has been studied by NA49, again showing similarities between $\text{PbPb}$ and $p\text{Pb}$

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*Details of the effect are discussed in a separate publication[1]*
Figure 3. Centrality dependence of $\pi^+ / \pi^-$ in PbPb collision at $x_F = 0.15$ and various $p_T$ measured by NA49, complemented with NA52 measurements near $0^\circ$ production angle at close $x_F$. Lines are to guide the eye.

5. Conclusions

Centrality selected PbPb interactions represent an unique laboratory to study how the dynamics of elementary soft hadronic interactions enters the nuclear domain. Detailed scrutiny of pion production in nuclear interactions has allowed a study of different phenomena. Most salient features of pion production in PbPb can be understood by means of isospin symmetry, final state Coulomb interaction, low–mass resonance excitation of spectators, and multiple collisions of participating nucleons.

Comprehensive studies of these effects will be published soon by the NA49 Collaboration.

REFERENCES

1. NA49 Collaboration, to be published
4. A. Rybicki and D. Varga, to be published
Figure 4. a), b) Ratio $R$ of average pion yields in a peripheral PbPb over NN interaction as a function of $p_T$ for various $x_F$. Lines are to guide the eye.

Figure 5. a) Relative yield ratio $R'$ in peripheral PbPb collisions as a function of $p_T$ in the region $0.3 < p_T < 0.9$ GeV/c for various $x_F$; the dotted lines indicate a ±5% error band. b) Ratio $R_{pPb} = \langle \pi^{Pb} \rangle / \langle \pi^{pp} \rangle$ for pPb interactions with a similar number of projectile collisions ($\langle \nu \rangle \approx 2.5$). Lines are to guide the eye.