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NEW RESULTS AND PERSPECTIVES ON R_{AA} MEASUREMENTS BELOW 20 GeV CM-ENERGY AT FIXED TARGET MACHINES

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Transverse momentum spectra of $\pi^{\pm}$ at midrapidity are measured at high p_T in p+p and p+Pb collisions at 158 GeV/nucleon beam energy by the NA49 experiment. This study is complementary to our previous results on the same spectra from Pb+Pb collisions. The nuclear modification factors $R_{A+A/p+p}$, $R_{p+A/p+p}$ and $R_{A+A/p+A}$ as a function of p_T are extracted and compared to RHIC measurements, thus providing insight into the energy dependence of nuclear modification. The modification factor $R_{A+A/p+A}$ proved to be consistent with our previous results on the central to peripheral modification factor R_{CP}.

The limitation of our current p_T range is discussed and planned future upgrades are outlined. Some aspects of the FAIR-CBM experiment are also presented as a natural future continuation of the measurements at very high p_T.

1. Introduction

One of the most striking features observed at BNL-RHIC is the suppression of high p_T production in central A+A collisions relative to peripheral A+A or p+A or p+p collisions. This is generally interpreted as a sign of parton energy loss in hot and dense strongly interacting matter created at the early stage of nucleus-nucleus collisions. This interpretation implies that the suppression should decrease towards lower energies where the initial energy and parton density is expected to be much smaller.

Numerous results on the energy dependence of hadron yields and spectra indicate that the onset of deconfinement is located at lower SPS energies (see e.g. Refs. 1 and 2). Existing data on central and peripheral Pb+Pb collision at 158 GeV/nucleon from the NA49 experiment allow to measure the ratio R_{CP} up to about 3.5 GeV/c in transverse momentum (see Refs. 3 and 4). A slight suppression is seen in this range, but the interpretation of this result is hindered by the poorly known interfer-

ence with the Cronin effect[a] (see Ref. 5). Therefore, the nuclear modification factors $R_{A+A/p+p}$ and $R_{A+A/p+A}$ would give a clearer picture: the first one is expected to contain a certain amount of Cronin effect and a possible suppression, while in the second quantity the Cronin effect approximately cancels. Therefore, our experiment extracted the modification factors $R_{Pb+Pb/p+p}$, $R_{p+Pb/p+p}$ and $R_{Pb+Pb/p+Pb}$ from the existing p+p (see also Ref. 6), p+Pb and Pb+Pb data at top ion-SPS energy. The modification factor $R_{Pb+Pb/p+Pb}$ (which does not contain the Cronin effect to first order) confirms our previous observations with R_{CP}.

Our experiment, however, has only limited statistics on p+p and p+Pb collision data at top ion-SPS energy. Therefore, future data runs are planned. The proposed FAIR-CBM high luminosity experiment has also a great potential in this field, as it will be able to populate the momentum space up to the kinematic limit.

2. Data Analysis

For the data analysis strategy of p+p and p+Pb collisions, the method developed earlier for Pb+Pb collisions was adopted (see Ref. 3). This guarantees a good cancellation of the already small systematic biases. The study was performed in the rapidity interval $-0.3 \leq y \leq 0.7$ (as in Pb+Pb) .

The only limitation in our data analysis is our relatively poor statistics on p+p and p+Pb compared to Pb+Pb. This also affects our particle identification procedure. However, the area conservation property of the employed Poisson maximum-likelihood method (see Ref. 7) for the inclusive disentangling of the energy loss spectra allows to make a good quality $\frac{\mathrm{d}E}{\mathrm{d}x}$ analysis even in the low statistics range of momentum space (see Fig. 1).

For completeness, we show the currently available $\pi^{\pm}$ statistics in p+p, p+Pb and Pb+Pb (0-5%) collisions at 158 GeV/nucleon, and the lack of existing p+p reference data in the nearby energies in Fig. 2. (See also Ref. 8.)

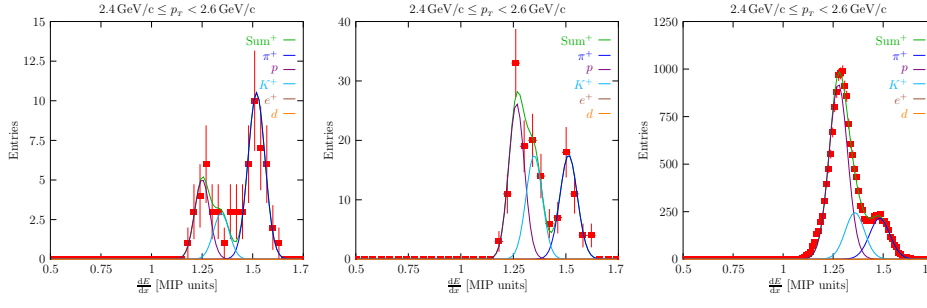

Fig. 1. Demonstration of the reliability of the inclusive particle identification by specific energy loss at high p_T, in p+p, p+Pb and Pb+Pb (0-5%) collisions, respectively.

[a]An enhancement of scaled hadron yields in p+A collisions relative to p+p collisions is called Cronin effect. The scaling is performed with the number of binary collisions.

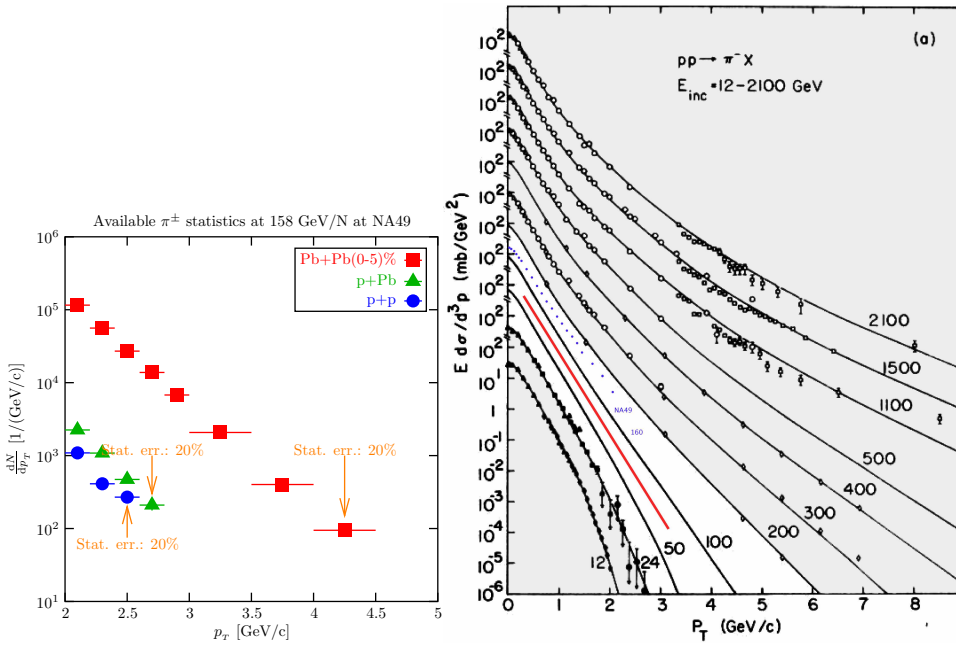

Fig. 2. Left panel: currently available p_T range for $\pi^{\pm}$ in p+p, p+Pb and Pb+Pb collisions at 158 GeV/nucleon at midrapidity in the experiment NA49. The p+p and p+Pb range is severely limited by statistics. Right panel: a compilation of all existing data for π^- production in the p+p collisions in the nearby energy range, shown together with the new NA49 data. As can be seen there are no data near 158 GeV, and the shape of the spectra changes rapidly with beam energy from convex to concave (transition shown by the solid line).

3. Physics Results

Figure 3 shows the energy dependence of the nuclear modification factors $R_{A+A/p+p}$, $R_{p+A/p+p}$ and $R_{A+A/p+A}$ from top ion-SPS to top RHIC energies (see Refs. 9 and 10). Strong increase of the modification factors $R_{A+A/p+p}$, $R_{p+A/p+p}$ is observed at top SPS energy. For $R_{A+A/p+A}$ (here the Cronin effect approximately cancels) a slight high p_T suppression is observed with binary collision scaling. When using wounded nucleon scaling, the $R_{A+A/p+A}$ shows an approximate energy-independence at low p_T. Both observations confirm our previous similar observations on R_{CP} (see Ref. 3). However, we are not able to answer the interesting question of higher p_T behavior (above about 2.5 GeV/c) with the currently existing p+p and p+Pb data.

4. Future Plans

As the current p+p and p+Pb statistics limits us to $p_T \leq 2.5$ GeV/c, one of our future plans is to record more p+p and p+Pb reference data in the NA49-future experiment which is in preparation at the CERN-SPS to increase this range up to 4 GeV/c. Due to the limitation of this upgraded experiment and the development

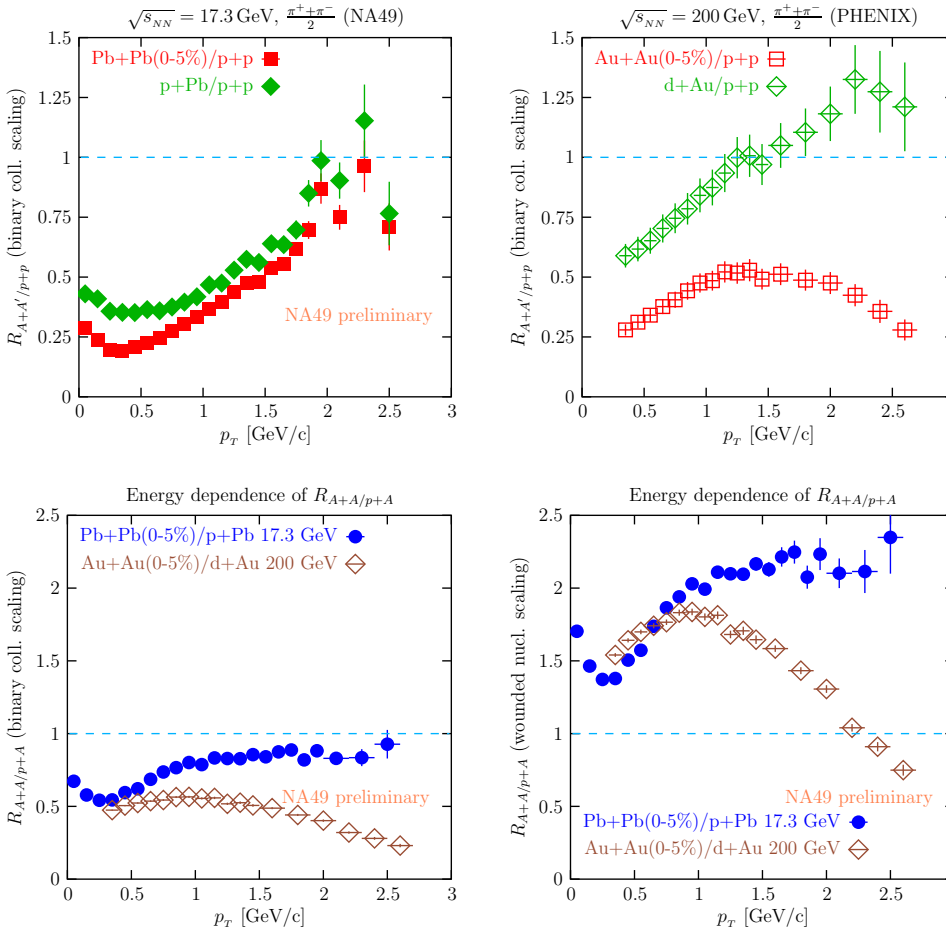

Fig. 3. Upper panels: energy dependence of the nuclear modification factor $R_{A+A'/p+p}$ for $\pi^{\pm}$ from top ion-SPS to top RHIC energies. Lower left panel: energy dependence of the nuclear modification factor $R_{A+A/p+A}$ for $\pi^{\pm}$ from top ion-SPS to top RHIC energies (binary collision scaling). Lower right panel: the same with wounded nucleon scaling.

possibilities of the detector there is no hope in the foreseeable future to reach higher luminosity than 1000 interactions per second at CERN. There is however an unique opportunity at the FAIR accelerator in GSI, Darmstadt which will be ready around 2013, where the planned CBM detector[11] will be able to tolerate an interaction rate up to 10^9 which represents an improvement by a factor of about a million relative to the available SPS setup.

Though the proton beam energy at the FAIR accelerator will be limited to 90 GeV this will not decrease the physics interest, because the main issues in p+p and p+A processes are even more exciting at high p_T at this energy, due to the fact that there is little information on either the Cronin effect or high p_T suppression in this range. As seen from Table 1, one can profit from the increased luminosity

Table 1. Rate estimates and comparisons for high p_T at low energies.

Benchmark NA49 p+p at $E_{\mathrm{Beam}} = 158\,\mathrm{GeV}$ 30 events/spill				
Events	Energy [GeV]	$> 3\,\mathrm{GeV/c}$	$> 4\,\mathrm{GeV/c}$	$> 5\,\mathrm{GeV/c}$
$2 \cdot 10^6$	158	100	1	0.01
Estimates with the assumption 10^{11} proton/sec 10^9 interaction/sec				
$1\,\mathrm{day} = 10^{14}$	158	$5 \cdot 10^9$	$5 \cdot 10^7$	$5 \cdot 10^5$
CBM Perspectives				
Suppression	$158 \rightarrow 90$	10^{-1}	10^{-2}	10^{-3}
$1\,\mathrm{day} = 10^{14}$	90	$5 \cdot 10^8$	$5 \cdot 10^5$	500
$20\,\mathrm{day} = 2 \cdot 10^{15}$	90	10^{10}	10^7	10^4
Suppression	$90 \rightarrow 45$	10^{-3}	10^{-6}	10^{-10}
$20\,\mathrm{day} = 2 \cdot 10^{15}$	45	10^7	10	0

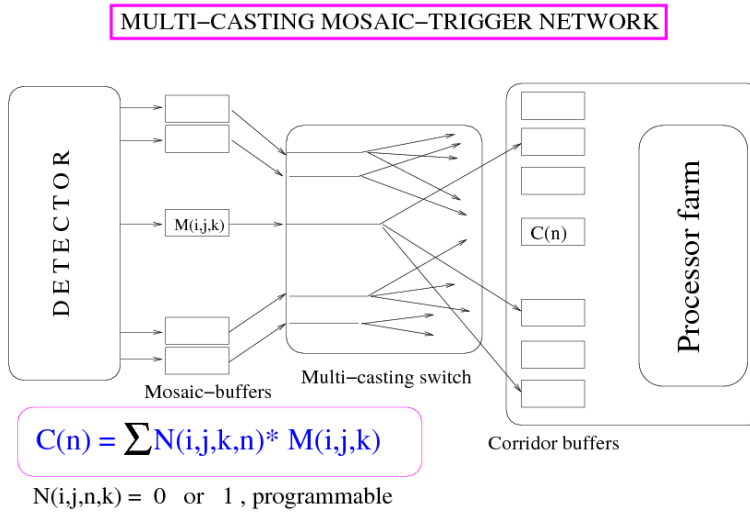

Fig. 4. High p_T filtering scheme for CBM-STS subdetector.

despite the smallness of the estimated cross-sections. Even with 45 GeV beam energy one expects significant statistics above 4 GeV/c.

Referring to the "white region" in Fig. 2 between the lines of 24 and 100 GeV beam energy, the CBM experiment will study uncharted territory where the interesting change of the p_T spectra from convex to concave is happening. According to the usual argument this phenomenon is regarded as a simple phase-space limitation effect, but one should be aware of the fact that at 90 GeV beam energy the 3.5 GeV/c transverse momentum represents only about 0.5 in x_T which is still rather far away from the kinematic boundary. There may be some deeper physical effect, because the deviation from the simple exponential spectrum already starts around 1 GeV/c. This was a big surprise at CERN-ISR in the beginning of the seventies and due to lack of systematic measurements the real cause of this effect was not elucidated since then.

Of course, this previously unimaginable luminosity which is expected at FAIR-CBM requires very special detector, data acquisition and trigger systems. The heart of the high p_T filtering system is the STS sub-detector.

The basic idea of the filtering algorithm is that one can define rather narrow corridors for the high p_T tracks because they are almost straight. Due to the relatively small number of hits in these narrow corridors one can perform extremely fast and exhaustive searches even in case of 1000-fold pileup. In order to ensure full efficiency the corresponding regions of a given silicon surface (=mosaic) can be used in a number of corridors, therefore a so-called "multi-tasking MOSAIC-trigger network" is proposed which is schematically shown in Fig. 4.

5. Concluding Remarks

First NA49 results on the nuclear modification factors $R_{A+A/p+p}$, $R_{p+A/p+p}$ and $R_{A+A/p+A}$ were presented for the particle species $\pi^{\pm}$ at 158 GeV/nucleon beam energy, based on a study on p+p, p+Pb and Pb+Pb collisions.

The current statistical limitation of our p+p and p+Pb dataset is pointed out, and future plans are discussed. The experiment FAIR-CBM is introduced as a possible continuation of this low energy p+p, p+A, A+A programme at very high p_T. Development work is in progress in the framework of the FUTURE-DAQ project as part of the EU FP6 contract nr. 506078 (HadronPhysics).

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