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Charged pion emission in Ag+Ag collisions with a center-of-mass energy of $\sqrt{s_{NN}}$=2.55 GeV

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This contribution covers the emission of charged pions, measured by the HADES (High-Acceptance-Di-Electron-Spectrometer) detector in March 2019, for the collision system Ag+Ag with a center-of-mass energy of $\sqrt{s_{NN}}$=2.55 GeV. After a brief motivation, the experimental set-up of HADES is summarized and the basic analysis steps concerning the identification of charged pions, acceptance and efficiency correction and extrapolation into uncovered phase space regions are explained. Within this context, the obtained transverse mass spectra are presented. The last part covers azimuthal emission anisotropies relative to the event plane of the collisions. The employed method for extracting the flow harmonics of charged pions is described and the harmonics v_1 and v_2 are inspected as a function of transverse momentum and rapidity.

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1. Introduction and Motivation

HADES (High-Acceptance-Di-Electron-Spectrometer), located at GSI, Darmstadt, investigates the reaction products of relativistic heavy-ion collisions. The goal is to probe strongly interacting QCD matter that exhibits extreme densities as assumed to be found in merging neutron stars [1]. Charged pions are mesons which are produced with the highest abundances. Due to the high statistics available combined with the geometrical acceptance, charged pions enable the investigation of the Coulomb effect, which can be used to estimate the baryon density at the point of kinematic freeze-out. Another observable of interest which is sensitive to the Equation of State of nuclear matter, is anisotropic flow. It occurs in semi-central collisions where the shape of the reaction zone is not symmetric with respect to the event plane, which is defined by the impact vector and the beam axis.

2. Experimental Setup and Analysis Basics

In March 2019, the SIS18 Synchrotron at GSI accelerated silver ions up to kinetic energies of 1.58A GeV. The ions were headed onto a fixed target, and the emitted particles from the reaction zone were measured by the HADES detector. By the fixed-target set-up, the geometrical coverage corresponds to almost the complete azimuthal angle. HADES is composed of several sub-detectors, each of them segmented into 6 identical sectors. The track detection principle is based on magnet-spectrometry. Before an incident particle enters the magnetic field, two track points are measured by inner MDCs (Mini-Wire-Drift chambers). After the track deflection, caused by a super-conducting magnet, two other hit points are acquired by outer MDCs. The track within the magnetic field is later interpolated using the 4-order Runge-Kutta method. Based on the deflection, the momentum of the particle can be derived. Combining it with the time-of-flight measurement provided by the detectors START, RPC and TOF one has all the information required to derive the particle's mass to charge ratio. The detectors RPC (Resistive-Plate-Chamber detector) and TOF (Time-of-Flight detector) cover different polar angle regions. As an additional PID (Particle Identification) observable and to separate light nuclei with the same mass to charge ratio, the specific energy loss is measured by the detectors MDC and TOF whose measurement principle is based on gas ionization. Furthermore, there are the detectors ECAL (Electromagnetic-Calorimeter) and RICH (Ring-Imaging-Cherrenkov-Detector), which are relevant to reconstructing Dileptons [2]. Concerning the analysis of emission anisotropies (collective flow) relative to the event plane, the Forward Wall detector, positioned in the beam line behind the detector set-up, is of special interest. Its objective is to measure the spatial emission pattern of the projectile spectators. This information is later used to derive the event plane angle of the reaction zone.

3. Analysis of Charged Pions

The identification of charged pion is based on the correlation between velocity β and momentum p. The spectrum region which is populated by charged pions is quantified in momentum slices. Finally, based on the extracted parameters, a 2σ wide selection window is generated. In the case of the positively charged pions additionally, the correlation of the specific energy loss dE/dx and the momentum p is considered in order to suppress the contamination from protons. The energy loss distributions in momentum slices are quantified by an asymmetric Gaussian with two different sigmas. The kinematic distribution is inspected in the longitudinal direction of the reaction by the variable rapidity y. The transverse component is covered by the transverse mass $m_t = \sqrt{m_0^2 + p_t^2}$. Where $m_0 = 139.57\ MeV/c^2$ represents the particle's nominal mass and p_t corresponds to the transverse momentum. The phase space is analyzed differentially. The bin size of 25 MeV/c and of 0.1 in the rapidity axis are chosen in such a way that the statistics is sufficiently high for most of the phase space bins. The acceptance and reconstruction efficiency of the detector is limited. The correction factors as a function of the phase space bins are determined by making use of Monte-Carlo simulations. Initially, pure Ag+Ag collisions are generated by the transport model UrQMD 3.4. [3] and the output is propagated through a GEANT simulation [4], which emulates the detector response behaviour. The GEANT results are analyzed based on the same analysis methods as applied on the raw data. Later on, the phase space spectra of UrQMD and GEANT are divided in order to obtain correction matrices. Moreover, based on the simulation also an estimation of the purity of the selected pion sample is conducted. For charged pions analysis, phase space bins exhibiting an efficiency of less than 15 % and a purity below 85 % are neglected. Analyzing the variations between the 6 sectors of HADES led to the decision to exclude 2 sectors in the case of the negatively charged pions.

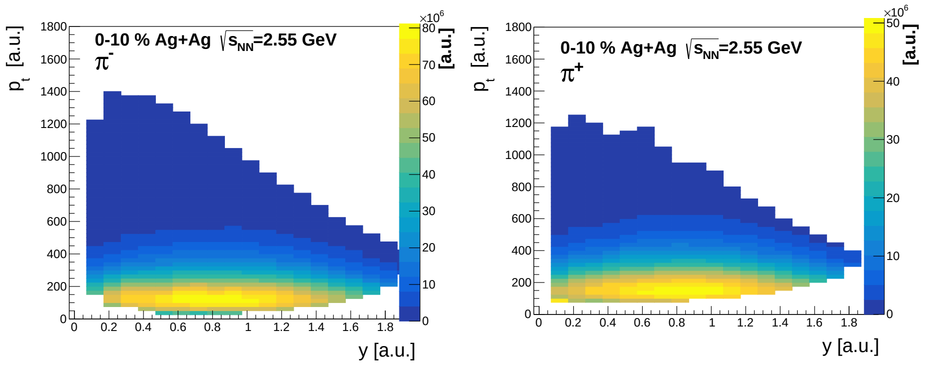

Figure 1: Acceptance and efficiency corrected phase space spectra of charged pion for the 0-10 % most central collisions, described by the variables p_t and y.

In figure 2, the acceptance and efficiency corrected differential transverse mass spectra $\frac{1}{m_t^2}\frac{dN}{dm_t dy}$ in the rapidity range of $-0.75 < y_{cm} < 0.85$ with a slice width of 0.1 are presented. The detector coverage of the phase space regions in the low and high transverse mass region is zero. In order to obtain the pion yield with respect to the full transverse scope, the spectra are modelled by Double-Boltzmann functions. A two-slope fit is necessary as charged pions in the low transverse mass region are mainly produced via Delta resonances, whereas the ones towards higher m_t originate via multiple high-energy-resonances [5], leading to different energy transfers. Integration over the transverse variable, using the fitted Double-Boltzmann function for extrapolation, leads to the rapidity distribution dN/dy. In order to obtain the full 4π yields, scaled dN/dy distributions from transport models are utilized for the extrapolation into the unmeasured rapidity scope. By implementing a theoretical description of the Coulomb Effect into the Boltzmann functions also an extraction of the Coulomb potential is feasible as conducted in [5].

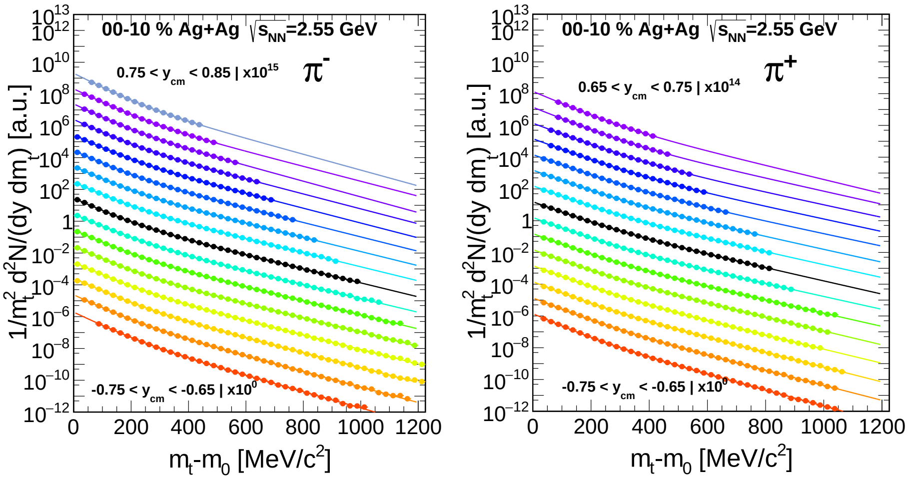

Figure 2: Reconstructed differential transverse mass spectra with fitted Double-Boltzmann function for the 0-10 % most central collisions.

4. Anisotropic Flow Analyis

In order to examine azimuthal anisotropies with respect to the event plane, a Fourier decomposition of the angular distributions is performed:

$$\frac{dN}{d(\phi - \Psi)} \sim (1 + 2\sum_{0}^{\infty} v_n cos(n(\phi - \Psi_{EP}))) \tag{1}$$

where v_n corresponds to the harmonic of order n, quantifying the anisotropies. ϕ represents the azimuthal emission angle of the charged pions out of the reaction. Because of the orthogonality, v_n can be extracted by calculating:

$$v_n =< cos(n(\phi - \Psi_{EP}) > \tag{2}$$

The angle of the event plane Ψ_{EP} is reconstructed based on the balance points of the projectile spectator hits measured with the forward wall. In order to account for the limited resolution of the event plane, the sub-event method is employed, which is then used to determine the correction factors by following the procedure applied in [7].
Furthermore, the detector's tracking efficiency depends on multiplicity, which causes directed flow to deviate from being zero at mid-rapidity. To correct for this, the track density is considered as a function of the polar angle and the emission angle relative to the event plane. As conducted in [6], a linear relation between efficiency factors and track density is assumed and the slope parameter is adjusted in such way to get directed flow close to zero at mid-rapidity. The flow harmonics of the charged pions has been extracted differentially as a function of transverse momentum p_t, rapidity y_{cm} and collision centrality with a binning of Δp_t = 100 MeV/c, Δy_{cm} = 0.1 and 10 % per centrality class.

For directed flow a rather point-symmetric behaviour with respect to mid-rapidity, as expected from the collision symmetry, is observed, see figure 3. Elliptic flow is found to be negative overall measured phase space regions, suggesting out-of plane emission for charged pions.

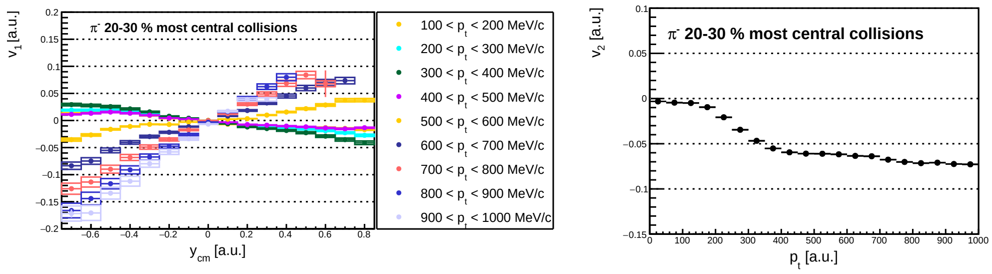

Figure 3: Left: Directed flow as a function of rapidity for different momentum slices. Right: Elliptic flow as a function of transverse momentum p_t, rapidity integrated.

5. Outlook

Due to the high statistics acquired by HADES we are also able to investigate triangular flow differentially as a function of rapidity and transverse momentum. Furthermore, the Coulomb Potential has been extracted from the transverse spectra. The investigations, e.g. in regard to the scaling as function of the number of participants and systematic uncertainties are ongoing. Moreover, HADES measured charged pions at lower beam energy of $1.23A\ AeV$. The details regarding the analysis is covered by the contribution of J. Orlinski in this proceedings book [8].

References

[1] Adamczewski-Musch et al. [HADES Collaboration], Nature Phys. 15 10 (2019)

[2] G. Agakishiev et al. [HADES Collaboration], Eur. Phys. J. A 41 (2009) 243-277

[3] Bleicher et al., Journal of Physics G: Nuclear and Particle Physics Vol. 25 9

[4] Agostinelli, S. and others, Nucl. Instrum. Meth. A 506 (2003) 250–303

[5] Adamczewski-Musch et al. [HADES Collaboration], Nuclear Experiment (nucl-ex), FOS: Physical sciences, FOS: Physical science (2022)

[6] Adamczewski-Musch et al. [HADES Collaboration], "Proton, deuteron and triton flow measurements in Au+Au collisions at $\sqrt{s_{NN}} = 2.4GeV$" (2023), Eur.Phys.J.A 59 (2023) 4, 80

[7] Jean-Yves Ollitrault, Reconstructing azimuthal distributions in nucleus–nucleus collisions (1997)

[8] Jan Orlinski (HADES Collaboration), Charged pion emission at $\sqrt{s_{NN}} = 2.4GeV$, Fairness 2022