Wide acceptance measurement of $K^-/K^+$ ratio from Ni+Ni collisions at 1.91A GeV

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The FOPI Collaboration at GSI SIS-18 synchrotron measured the charged kaons from central and semi-central collisions of Ni+Ni at the beam energy of 1.91A GeV. We present the distribution of $K^-/K^+$ ratio on the plane of energy vs polar angle in the nucleon-nucleon centre-of-mass frame, with and without the subtraction of the contribution of $\phi(1020)$ meson decays to the K$^-$ yield. The acceptance of the current experiment is substantially wider compared to the previous measurement of the kaons in the same central energy collisions. The $K^-/K^+$ ratio is expected to be sensitive to the in-medium modifications of basic kaon properties like mass. Recent results obtained by the HADES Collaboration at 1.23A and 1.76A GeV indicate, that no mass-shift effect is needed to explain the difference between energy slopes of charged kaon spectra within uncertainties. The $K^-/K^+$ ratios obtained in this experiment, even after correction for the contribution due to the $\phi(1020)$ meson decays, decrease with increasing kinetic energy, as generally predicted in models assuming mass modifications.

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I. INTRODUCTION

The modifications of basic properties of kaons (like mass or decay constant) inside hot and dense nuclear medium have been a subject of intensive study and debate throughout last 30 years [1, 2]. It is predicted that in such conditions the system should tend toward the partial restoration of the chiral symmetry. Deviations from the vacuum kaon masses (0.494 GeV [10]) have been parameterized in terms of the density dependences of either kaon-nucleus potentials $U_{KN}$ [3, 4] or the spectral functions $\Gamma_{\pi K}$ [5, 6, 7]. If nuclei are collided at beam energies around the thresholds for the production of the respective K mesons in the nucleon-nucleon (NN) collision (about 1.6 GeV for K$^+$ and 2.5 GeV for K$^-$), the kaons are produced mostly singly, and therefore can serve as probes of dynamics in the nuclear medium. These collisions have

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been intensively studied in particular at the SIS-18 accelerator, delivering heavy-ion beams up to the energy of 2A GeV.

It is predicted that while kaons (K$^+$ and K$^0$) are “good” quasiparticles with narrow width, the antikaons (K$^-$ and K$^0$) exhibit non-trivial structure of self-energy [3, 4, 8]. In particular, the most probable K$^-$ production channel around the threshold is $\pi Y \rightarrow K^-N$, where Y denotes the hyperon ($\Lambda$ or $\Sigma$). This channel is predicted to have an intermediate step in medium involving $\Lambda^*(1405)$ or $\Sigma^*(1385)$, where the production of the latter particle in these conditions was experimentally confirmed [11].

Various theoretical models predict some attraction of antikaons towards centers of nuclear density and repulsion of kaons. Therefore, as the K$^-$ leaving the centers of density are predicted to slow down, the K$^+$ should accelerate. Thus, the ratio of K$^-$/K$^+$ as function of kinetic energy is expected to become steeper. Also, the attraction toward centers of density should cause K$^-$ to exhibit the flow pattern similar to that of protons, whereas for K$^+$ the effect is predicted to be opposite.

However, in course of the propagation of kaons in the heavy-ion collision zone, the effects of modifications of basic kaon properties compete with other phenomena like absorption (affecting mainly K$^-$ via K$^-N \rightarrow \pi Y$) or rescattering at surrounding nucleons. In addition, the K$^-$ spectra are fed by the dominant $\phi(1020)$ meson decay channel, $\phi \rightarrow K^+K^-$ (BR = 48.9% [10]), as the threshold for $\phi$ production is very close to that for the K$^+$K$^-$ pair.

The search for the in-medium effects in the flow pattern was investigated recently [12]. A comparison of the rapidity dependence of $v_1$ coefficient of charged kaons emitted from Ni+Ni collisions at 1.9A GeV to the predictions of the IQMD and HSD transport models [13, 14] pointed to rather small values of $U_{K^+N}$, between 0 and 20 MeV. For K$^-$ the IQMD prediction with $U_{K^-N} = -45$ MeV reproduced the $v_1$ pattern, whereas the HSD calculations employing the G-Matrix formalism corresponding to $U_{K^-N} = -50$ MeV overestimated the experimental values. Concerning the comparison of the transverse momentum dependence of $v_1$ for K$^+$, the transport model predictions again pointed to values between 0 and 20 MeV, although none of these models reproduced the trend of data points in full.

Studies of the in-medium effects via the experimentally measured K$^-$/K$^+$ ratio were presented in [15-17]. Whereas these analyses demonstrated sensitivity of this observable to the in-medium effects, they were hampered either by low statistics, lack of (or insufficient) inclusion of the $\phi(1020)$ meson decay feeding, or very narrow acceptance. A comparison of four data points of the energy dependence of K$^-$/K$^+$ ratio from Al+Al collisions at 1.9A GeV to the HSD transport model calculations with $U_{K^+N} = 40$ MeV and $U_{K^-N} = -50$ MeV [17] initially appeared to reproduce the data successfully. However, they did not account for the feeding from $\phi$ mesons. The available samples of $\phi$ in its dominant decay channel, $\phi \rightarrow K^+K^-$ (BR = 48.9% [10]), were quite scarce (100-170 events [17, 20]). Despite this, the contribution of their decays to the K$^-$ spectra was found to significantly reduce the slope of energy spectrum [17, 19, 21-22], and therefore compete with the effect of attractive KN potential.

On the other hand, one can put forward the hypothesis, that the difference between the slopes of energy distributions of K$^-$ and K$^+$ mesons can be fully explained by feeding of $\phi$ meson decays to the K$^-$ meson distribution. This approach was considered by the HADES Collaboration for Ar+KCl at 1.76A GeV [21] and for Au+Au at 1.23A GeV [22], and was found to be consistent with experimental data within errors.

The distributions of the kaon polar angle, the second phase space dimension, were found to often deviate from isotropy [17, 23]. For most of investigated systems the $a_2$ anisotropy coefficient for K$^+$ and K$^-$ were found to be equal within 3 standard deviations. However, globally the values of $a_2$ for K$^+$ appear to be somewhat larger than that for K$^-$. Thus, in the phase space distribution of K$^-$/K$^+$ ratio, the anisotropy effects for K$^+$ and K$^-$ may not cancel out. Additionally, the analysis of the polar distribution within the IQMD transport model showed, that the degree of anisotropy should be sensitive to both the potential and rescattering effects [9]. Thus, a measurement of this ratio not only as a function of energy, but also of polar angle could deliver a more precise probe of these phenomena. It should be also supplemented by the measurement of the contribution of $\phi(1020)$ mesons to K$^-$ spectrum obtained for the same reaction.

The FOPI collaboration has addressed this goal, in particular benefitting from the MMRPC detector, the Time-of-Flight device characterized by high granularity and excellent timing properties [24]. In this paper we present the kinematic distributions and production ratio of charged kaons emitted from central and semi-central Ni+Ni collisions at the beam kinetic energy of 1.91A GeV (the same experiment as for the K$^+$ flow study [12] and $\phi$ meson analysis in [19]). The advantages of this data sample with respect to earlier analyses of K$^+$/K$^-$ ratio are the considerably wider acceptance, and the additional experimental information on the $\phi$ meson production.

II. EXPERIMENT

A detailed description of the FOPI spectrometer was given in [25], and the experiment was reported in [12, 19]. Here we highlight only the features most relevant to the present analysis.

The innermost detector of the FOPI apparatus was the Central Drift Chamber (CDC) covering the polar angles ($27^\circ < \theta_{lab} < 113^\circ$) [29]. It was encircled by two time-of-flight (ToF) devices, the Plastic Scintillation Bar-
III. PHASE SPACE DISTRIBUTIONS

A. Raw kaon spectra

The particle identification methods used in our experiment were described in Refs. [12, 13]. Here only the key points are highlighted. For each event the tracks of particles traversing the CDC are reconstructed from the activated wires (“hits”). A reconstruction of the vertex position allows to reject reactions occurring outside the target. In the next step, the “good track candidates” are selected by requiring the minimum multiplicity of hits in a track, and maximum distance between the track and the vertex. Fitting the helix curve to the series of hits marked by a particle in a solenoidal magnetic field allows to obtain the momentum vector $\vec{p}$. The amplitude of signals from activated wires is used to measure the specific energy loss. Correlating these two observables allows to identify many of charged emission products, and extract the CDC-based mass parameter, $m_{\text{CDC}}$. This procedure is, however, insufficient for most of investigated $K^\pm$ mesons. An additional information is obtained from either of the two installed ToF devices: PSB and MMRPC. A combination of time of flight and path length allows to obtain the velocity $v$ of particle emitted from the target. A histogram of identified tracks on the $p - v$ plane is shown in Fig. 1 of Ref. [13]. Substituting $p$ and $v$ into the relativistic dependency $p = m\gamma v$, where $\gamma$ is the Lorentz factor, allows to extract the particle’s mass parameter $m_{\text{ToF}}$. The distributions of $m_{\text{ToF}}$, shown for the same data in Fig. 1c,d of Ref. [12], clearly exhibit a peak around the nominal mass of charged kaon.

To minimize the edge effects, the range of accepted polar angles was trimmed down to $30^\circ < \vartheta_{\text{lab}} < 53^\circ$. In addition, to account for the limits of detection of low-$p_T$ particles by the CDC-ToF pair of detectors, and some slight inconsistency in reproduction of the detection capability within the GEANT [20] environment in this region, the $K^+$ ($K^-$) candidates were required to have the transverse momentum $p_T$ of at least 0.18 (0.14) GeV/c.

The raw spectrum of measured kaons, shown in Fig. 1, was obtained with about 232300 measured $K^+$ and 5660 $K^-$ mesons. A common multiplicative factor of 60 was applied to the $K^-$ data points, in order to both profiles be presentable on one plot.

B. Efficiency determination

The efficiency correction for charged kaons on the $E_{\text{kin}}^\text{NN} - \cos \vartheta_{\text{NN}}$ plane was obtained in two stages: via the GEANT-based simulations, and an additional procedure aimed to extract and apply the internal efficiency of ToF detectors.

In the first stage kaons were sampled from the homogeneous distribution on this plane. They were subsequently added to the events of Ni+Ni collisions generated within the IQMD transport code [13], which aims to reproduce the realistic background of particles emitted from the heavy-ion collisions. Within the GEANT environment particles were transported to the detection modules of the virtual FOPI setup. After the detector responses were simulated, the events were processed by the same tracking and matching routines, as for the true experimental data. The resulting efficiency maps are shown in Fig. 2. An elongated drop of efficiency toward lower kinetic energy and $\cos \vartheta_{\text{NN}}$ is due to the decays of kaons.

FIG. 1: (Color online) Raw kinetic energy spectra of charged kaons emitted from central and semi-central collisions of Ni+Ni at the beam energy of 1.91A GeV within six bins of $\cos \vartheta_{\text{NN}}$. Red triangles correspond to $K^+$, and blue inverted triangles to $K^-$. The yield of $K^-$ was multiplied by 60.

FIG. 2: (Color online) Raw $E_{\text{kin}}^\text{NN} - \cos \vartheta_{\text{NN}}$ efficiency maps for $K^+$ (left) and $K^-$ (right) kaons. The distributions were obtained with the IQMD model [13].
in Fig. 4. The overall value of this ratio was found to be
emitted from heavy-ion collisions at similar energies [23].

- applied to K

netic energy spectra appear to be clearly softer than these
propriate factors.

By weighting the experimental kaon signal with the ap-

curves mark the geometric boundaries for the MMRPC and
Plastic Barrel detectors. See text for details.

FIG. 2: (Color online) GEANT-based part of efficiency map
on the $E_{\text{kin}}^{\text{NN}} - \cos \vartheta_{\text{NN}}$ plane for detection of charged kaons
from Ni+Ni collisions at 1.91A GeV within FOPI. Dotted
lines denote the intrinsic efficiency of the

FIG. 3: (Color online) Kinetic energy spectra of charged kaons
emitted from central and semi-central collisions of Ni+Ni at
the beam energy of 1.91A GeV for subsequent bins of $\cos \vartheta_{\text{NN}}$. Red
triangles correspond to K$^+$, and blue inverted triangles to K$^-$. The yield of K$^-$ was multiplied by 60. Grey boxes
 denote systematic errors. The best fits of Eq. 2 to the data
are shown in dashed lines.

IV. RESULTS

The distributions of charged kaons on the $E_{\text{kin}}^{\text{NN}} - \cos \vartheta_{\text{NN}}$ plane are shown in Fig. 3 (note the factor 60
applied to K$^-$ as mentioned in Sect. IV B of
Ref. [19], whereas the maps are shown in the lower panels
of Fig. 3 therein. This efficiency component was included
by the dedicated procedure, described in Sect. IV B of

By varying these conditions, slightly different values of
kaon yields and K$^-$/K$^+$ ratio were obtained. The final
results were determined by averaging these values. This
approach also allowed to select the confidence level (CL)
at which the systematic errors were estimated. In this
analysis we chose CL = 68.3% (1 $\sigma$).

Previously two kinetic energy distributions of K$^-$/K$^+$

ratio were measured at 1.9A GeV within narrow $\cos \vartheta_{\text{NN}}$
ranges. The distribution for the previous experiment of
Ni+Ni with slightly different FOPI setup and ToF detectors
was measured within $-0.97 < \cos \vartheta_{\text{NN}} < -0.87$ [10],
and is shown for a rough comparison in panel (a) of
Fig. 4. Also the data from Al+Al collisions, obtained
within $-0.87 < \cos \vartheta_{\text{NN}} < -0.72$ [17], were placed in
panel (b). We find our data consistent with the previ-
ously obtained results, but covering much broader accep-
tance. The full data on the phase space distributions of
charged kaons, and the K$^-$/K$^+$ ratio is listed in Table A.1
in Appendix A. It should be noted that the averaging of the
K$^-$/K$^+$ ratios (as was done here) may produce values
slightly different than by dividing averaged production
probabilities.

\begin{equation}
P(K^-) \quad \frac{P(K^+)}{P(K^-)} = (2.78 \pm 0.07 \pm 0.11) \times 10^{-2} \tag{1} \end{equation}

in agreement with the result obtained by the KaoS col-

Lab at which the systematic errors were estimated. In this
analysis we chose CL = 68.3% (1 $\sigma$).

The leading contributions to the systematic errors were
found to be:

- sensitivity to the selection of minimum number of
  CDC hits forming a “good track”,
- choice of the background function (linear or expo-
  nential) under the kaon peak in the mass spectrum,
- minimum cutoff value of the $m_{\text{CDC}}$ parameter in
  case of tracks matched with the Plastic Barrel hits,
- binning of the ToF mass parameter spectrum.

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parameterized by the effective temperature $T_{\text{eff}}$, multiplied by the angular anisotropy term, where $a_2$ is the polar anisotropy coefficient. $N$ is the yield of emitted kaons per triggered collision, and $C$ is the normalization constant, defined so that the integral of Eq. (2) yields $N$. As the energy and polar angle are not correlated in this formula, the fit to the data shown in Fig. 3 allows also to extract $N$ directly, with the uncertainty $\Delta N$ free from correlation terms. The results of this procedure, shown in Table V.1, confirm that the inverse slope of the energy spectrum of $K^-$ is smaller than that of $K^+$. Despite the fact that the parameterization of the distribution by Eq. (2) is not the same as that of Eq. 3 in Ref. [19], applied to the same $K^-$ data, the slope obtained here is in agreement with the profile of slopes shown in Fig. 6 of that paper. It also agrees within $2\sigma$ with the slope obtained by the KaoS Collaboration for the inclusive reactions [23]. Concerning the $a_2$ coefficient, they appear to be somewhat smaller than the values for inclusive Ni+Ni collisions, obtained by KaoS (c.f. Table II of Ref. [23]), however the minimum bias triggers were not defined identically. It also has to be noted that the $\chi^2$/NDF value for our fit to the $K^+$ distribution is considerably high. Turning to the yields obtained with Eq. (2) the result for $K^-$ agrees well with that presented in [19] and obtained with the different model. The novelty is the yield for $K^+$, obtained for the first time for this colliding system and centrality. Due to similarity of $\langle A_{\text{part}}/b \rangle$ to the data from Al+Al collisions at the same beam energy (46.5 $\pm$ 2.0 for Ni+Ni vs 42.5 for Al+Al [17, 20]), these datasets can be juxtaposed. Despite somewhat different acceptances and spectator sizes, all the parameters obtained in our procedure are in good agreement with these shown in Tab. 2 of Ref. [17], if the systematic errors are included.

**V. DISCUSSION**

**A. Phase space analysis of charged kaons**

The efficiency-corrected phase space distribution of $K^\pm$ mesons, reported in Sect. IV was fitted with the following ansatz,

$$\frac{d^2N}{dE_{\text{kin}}^\text{kin} \, d\cos \theta_{\text{NN}}} = \frac{N}{C} \cdot p_{\text{NN}} \cdot E_{\text{NN}} \cdot \exp \left(-\frac{E_{\text{NN}}}{T_{\text{eff}}}\right) \cdot \left(1 + a_2 \cos^2 \theta_{\text{NN}}\right)$$

which consists of the Boltzmann-like kinetic term parameterized by the effective temperature $T_{\text{eff}}$, multiplied by the angular anisotropy term, where $a_2$ is the polar anisotropy coefficient. $N$ is the yield of emitted kaons per triggered collision, and $C$ is the normalization constant, defined so that the integral of Eq. (2) yields $N$. As the energy and polar angle are not correlated in this formula, the fit to the data shown in Fig. 3 allows also to extract $N$ directly, with the uncertainty $\Delta N$ free from correlation terms. The results of this procedure, shown in Table V.1, confirm that the inverse slope of the energy spectrum of $K^-$ is smaller than that of $K^+$. Despite the fact that the parameterization of the distribution by Eq. (2) is not the same as that of Eq. 3 in Ref. [19], applied to the same $K^-$ data, the slope obtained here is in agreement with the profile of slopes shown in Fig. 6 of that paper. It also agrees within $2\sigma$ with the slope obtained by the KaoS Collaboration for the inclusive reactions [23]. Concerning the $a_2$ coefficient, they appear to be somewhat smaller than the values for inclusive Ni+Ni collisions, obtained by KaoS (c.f. Table II of Ref. [23]), however the minimum bias triggers were not defined identically. It also has to be noted that the $\chi^2$/NDF value for our fit to the $K^+$ distribution is considerably high. Turning to the yields obtained with Eq. (2) the result for $K^-$ agrees well with that presented in [19] and obtained with the different model. The novelty is the yield for $K^+$, obtained for the first time for this colliding system and centrality. Due to similarity of $\langle A_{\text{part}}/b \rangle$ to the data from Al+Al collisions at the same beam energy (46.5 $\pm$ 2.0 for Ni+Ni vs 42.5 for Al+Al [17, 20]), these datasets can be juxtaposed. Despite somewhat different acceptances and spectator sizes, all the parameters obtained in our procedure are in good agreement with these shown in Tab. 2 of Ref. [17], if the systematic errors are included.

**B. Subtraction of the $\phi$ meson contribution from $K^-$ spectra**

For the analysed experiment $\phi$ mesons were found to be produced with the yield comparable to that of $K^-$: $P(\phi)/P(K^-) = 0.44 \pm 0.07^{+0.10}_{-0.13}$ [19]. Assuming that the
vacuum value of $\text{BR}(\phi \rightarrow K^+K^-) = 48.9\%$ \[^{10}\] remains the same in the heavy-ion collisions, it means that about 22% of negative kaons originate from the decays of $\phi$. The kinematic properties of those $K^-$ mesons are different than for $K^+$’s emitted directly from the collision zone. Also, various transport models aiming at extraction of kaon in-medium effects may or may not reproduce the $\phi$ meson contribution well. Therefore, it might be of interest to obtain the ratio of charged kaon yields unaffected by the contribution from $\phi$ mesons. This procedure was performed as in Sect. 6.2 of Ref. \[^{17}\]. In brief, the $\phi$ mesons were sampled within PLUTO package \[^{28}\] from the isotropic thermal distribution characterized by temperature of $106 \pm 18^{+18}_{-14}$ MeV, as reported in \[^{19}\]. They were decaying into the $K^+K^-$ pairs, from where the phase space distribution of negative kaons was reconstructed. It was subsequently subtracted from the experimental spectrum, shown in Fig. 5 with values of BR and $P(\phi)/P(K^-)$ as described earlier. The resulting distribution of ratio of yields of charged kaons without the $\phi$ meson contribution is presented in the right panel of Fig. 5. In order to check whether the obtained distribution exhibits some drop with kinetic energy, it was fitted with the linear function of this quantity. The slope of this function was found to be $-0.109 \pm 0.013 \pm 0.019$, which allows to conclude, that the described distribution on average drops with kinetic energy.

VI. SUMMARY

We have presented the phase space distributions of $K^+$ and $K^-$ mesons, as well as of the $K^-/K^+$ ratio from the central and semi-central collisions of Ni+Ni at the beam energy of 1.91A GeV, measured within wide acceptance by the FOPI apparatus. An overall value of this ratio was found to be $(2.78 \pm 0.07 \pm 0.11) \times 10^{-2}$. The data are tabularized for convenient comparisons with the predictions of transport models, hoping for a more precise extraction of parameters quantifying the in-medium modifications of properties of charged kaons.

Benefitting from the $\phi$ meson data measured in the same experiment, we also present the distribution of $K^-/K^+$ ratio obtained after subtraction of the contribution of $\phi \rightarrow K^+K^-$ decays to the negative kaons. It was found to decrease with kinetic energy.

In addition, the analysis of phase space distributions of charged mesons provided the multiplicities, inverse slopes and the polar anisotropy coefficients. The inverse slope for $K^-$ was found to be clearly lower than that for $K^+$. With exception of the $a_2$ coefficient for $K^-$ mesons, the presented results are in line with the previously published data.

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Appendix A: Experimental data points

| Particle | $N$ (mul. per triggered event) | $T_{\text{eff}}$ [MeV] | $a_2$ | $\chi^2$/NDF |
|----------|--------------------------------|------------------------|-------|--------------|
| $K^+$    | $(3.598 \pm 0.012 \pm 0.043) \times 10^{-2}$ | $110.9 \pm 0.6 \pm 0.4$ | $0.430 \pm 0.016 \pm 0.013$ | $36.2$ |
| $K^-$    | $(9.1 \pm 0.2 \pm 0.2) \times 10^{-4}$ | $71.3 \pm 2.6 \pm 9.0$ | $0.16 \pm 0.08 \pm 0.11$ | $2.5$ |

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TABLE A.1: Measured values of phase space distribution of charged kaons, and $P(K^-) / P(K^+)$ ratio as function of kinetic energy and $\cos \vartheta_{NN}$ in the NN frame. Kaons were emitted from Ni+Ni collisions at the beam kinetic energy of 1.91A GeV. The first uncertainty is statistical, whereas the second one is systematic. See text for details.

| $E_{NN}^{kin}$ [GeV] | $P(K^+) \times 10^4$ | $P(K^-) \times 10^6$ | $P(K^-) / P(K^+) \times 10^2$ | $P(K_{direct}) / P(K^+) \times 10^2$ |
|----------------------|----------------------|----------------------|-----------------------|------------------------|
| $-0.95 < \vartheta_{NN} < -0.8$ |
| 0.07 | 9.71 ± 1.60 ± 1.01 | 8.76 ± 0.85 ± 0.62 | 6.17 ± 0.79 ± 0.45 | 1.85 ± 0.04 ± 0.03 9.42 ± 0.54 ± 0.40 | 2.67 ± 0.30 ± 0.22 2.02 ± 0.31 ± 0.23 2.22 ± 0.04 ± 0.03 4.63 ± 0.51 ± 0.19 | 2.08 ± 0.23 ± 0.10 1.70 ± 0.24 ± 0.10 2.17 ± 0.04 ± 0.04 3.69 ± 0.57 ± 0.42 | 1.70 ± 0.27 ± 0.20 1.42 ± 0.27 ± 0.20 2.04 ± 0.04 ± 0.02 3.64 ± 0.76 ± 0.63 | 1.79 ± 0.37 ± 0.31 1.58 ± 0.33 ± 0.31 2.00 ± 0.04 ± 0.01 3.36 ± 0.68 ± 0.66 | 1.68 ± 0.34 ± 0.32 1.53 ± 0.34 ± 0.32 |
| $-0.80 < \vartheta_{NN} < -0.65$ |
| 0.07 | 11.84 ± 0.90 ± 0.44 | 9.48 ± 0.65 ± 0.20 | 8.78 ± 0.60 ± 0.14 | 2.04 ± 0.03 ± 0.03 4.66 ± 0.90 ± 1.65 | 2.62 ± 0.03 ± 0.05 8.78 ± 0.60 ± 0.14 | 3.35 ± 0.23 ± 0.08 2.73 ± 0.24 ± 0.08 1.98 ± 0.03 ± 0.03 4.83 ± 1.00 ± 2.28 | 1.78 ± 0.04 ± 0.03 3.18 ± 0.95 ± 1.83 1.59 ± 0.04 ± 0.04 |
| $-0.65 < \vartheta_{NN} < -0.50$ |
| 0.07 | 13.20 ± 0.91 ± 0.34 | 9.42 ± 0.62 ± 0.13 | 8.01 ± 0.57 ± 0.21 | 2.21 ± 0.03 ± 0.04 6.97 ± 0.59 ± 0.27 | 3.15 ± 0.27 ± 0.14 2.60 ± 0.28 ± 0.14 2.79 ± 0.04 ± 0.06 13.20 ± 0.91 ± 0.34 | 4.74 ± 0.33 ± 0.15 3.71 ± 0.34 ± 0.14 2.66 ± 0.03 ± 0.05 9.42 ± 0.62 ± 0.13 | 3.54 ± 0.24 ± 0.06 2.70 ± 0.24 ± 0.05 2.51 ± 0.03 ± 0.04 8.01 ± 0.57 ± 0.21 | 3.19 ± 0.23 ± 0.06 2.52 ± 0.23 ± 0.07 2.21 ± 0.03 ± 0.04 6.97 ± 0.59 ± 0.27 | 3.15 ± 0.27 ± 0.14 2.60 ± 0.28 ± 0.14 |
| $-0.50 < \vartheta_{NN} < -0.35$ |
| 0.07 | 10.09 ± 0.81 ± 0.50 | 7.09 ± 0.58 ± 0.23 | 5.56 ± 0.52 ± 0.27 | 1.80 ± 0.03 ± 0.02 3.88 ± 0.49 ± 0.33 | 2.16 ± 0.27 ± 0.18 1.68 ± 0.29 ± 0.19 1.56 ± 0.02 ± 0.02 1.33 ± 0.03 ± 0.02 | 1.56 ± 0.02 ± 0.02 | 1.33 ± 0.03 ± 0.02 |
| $-0.35 < \vartheta_{NN} < -0.20$ |
| 0.07 | 10.09 ± 0.81 ± 0.50 | 7.09 ± 0.58 ± 0.23 | 5.56 ± 0.52 ± 0.27 | 1.80 ± 0.03 ± 0.02 3.88 ± 0.49 ± 0.33 | 2.16 ± 0.27 ± 0.18 1.68 ± 0.29 ± 0.19 1.56 ± 0.02 ± 0.02 1.33 ± 0.03 ± 0.02 | 1.56 ± 0.02 ± 0.02 | 1.33 ± 0.03 ± 0.02 |
| $-0.20 < \vartheta_{NN} < -0.05$ |
| 0.07 | 9.96 ± 1.56 ± 0.61 | 6.10 ± 0.68 ± 0.40 | 4.14 ± 0.58 ± 0.46 | 1.93 ± 0.03 ± 0.02 3.69 ± 0.55 ± 0.41 | 1.92 ± 0.29 ± 0.21 1.46 ± 0.29 ± 0.22 1.50 ± 0.03 ± 0.01 2.55 ± 0.70 ± 0.86 | 1.70 ± 0.47 ± 0.57 1.30 ± 0.48 ± 0.57 1.40 ± 0.02 ± 0.01 | 1.40 ± 0.02 ± 0.01 |
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