Transverse momentum spectra of hadrons in $p + p$ collisions at CERN SPS energies from the UrQMD transport model

V. Ozvenchuk and A. Rybicki

H. Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, Radzikowskiego 152, 31-342 Kraków, Poland

Abstract

The UrQMD transport model, version 3.4, is used to study the new experimental data on transverse momentum spectra of $\pi^\pm$, $K^\pm$, $p$ and $\bar{p}$ produced in inelastic $p + p$ interactions at SPS energies, recently published by the NA61/SHINE Collaboration. The comparison of model predictions to these new measurements is presented as a function of collision energy for central and forward particle rapidity intervals. In addition, the inverse slope parameters characterizing the transverse momentum distributions are extracted from the predicted spectra and compared to the corresponding values obtained from NA61/SHINE distributions, as a function of particle rapidity and collision energy. A complex pattern of deviations between the experimental data and the UrQMD model emerges. For charged pions, the fair agreement visible at top SPS energies deteriorates with the decreasing energy. For charged $K$ mesons, UrQMD significantly underpredicts positive kaon production at lower beam momenta. It also underpredicts the central rapidity proton yield at top collision energy and overpredicts antiproton production at all considered energies. We conclude that the new experimental data analyzed in this paper still constitute a challenge for the present version of the model.

Key words: Nucleon-nucleon collisions; Hadron production; Transport model.

1 Introduction

Recently the NA61/SHINE Collaboration published new, detailed experimental results [1] on inclusive spectra and mean multiplicities of $\pi^\pm$, $K^\pm$, $p$ and $\bar{p}$ produced in inelastic $p + p$ interactions at 20, 31, 40, 80 and 158 GeV/$c$ at the CERN Super...
Proton Synchrotron (SPS). These measurements were meant as a baseline in the study of the properties of the onset of deconfinement and the possibility to observe the critical point of strongly-interacting matter in nucleus-nucleus collisions. As such they were motivated by the observation of the onset of deconfinement in central \( \text{Pb} \+ \text{Pb} \) reactions at about 30 GeV/c by the NA49 Collaboration at the CERN SPS (for comparison, see also the results obtained by the RHIC beam energy scan programme and by the LHC [5]).

This new baseline significantly extends the present experimental knowledge on the energy dependence of particle production in \( p + p \) reactions at the SPS, where high quality data of comparable phase-space coverage existed only from the NA49 detector at top SPS energy [6,7,8]. The importance of these new results for the understanding on nuclear collisions has been many times advertised by the NA61/SHINE Collaboration (see e.g. results on kaon over pion multiplicity ratios presented in [9]). On the other hand, they also refine the basis of our knowledge on inclusive soft particle production in general, a subject of renewed interest in view of the recent findings made e.g. in \( p + p \) collisions at the LHC [10]. For both above reasons, it seems that an overall assessment on how these new data are being described by the presently available theoretical models of soft hadronic collisions has its own importance for the whole field of hadronic and high energy nuclear physics.

In the present paper, we perform the comparison of the recently obtained NA61/SHINE experimental data to the UrQMD transport model. We analyze the transverse momentum spectra of \( \pi^\pm, K^\pm, p \) and \( \bar{p} \) produced in inelastic \( p + p \) interactions at 20, 31, 40, 80 and 158 GeV/c and extract the inverse slope parameters as a function of the particle rapidity and collision energy. The inverse slopes are obtained from fits to the transverse momentum spectra of the different particles.

We note that earlier analyses have been performed in Refs. [11] and [12], where the authors have used the UrQMD transport model to study the precedent NA61/SHINE dataset including only spectra of negatively charged pions produced in inelastic \( p + p \) collisions at 20, 31, 40, 80 and 158 GeV/c [13], as well as NA49 data on \( \pi^\pm, K^\pm, p \) and \( \bar{p} \) spectra in \( p + p \) interactions only at top SPS energy [6,7,8]. In addition, in Ref. [12] possible improvements of the UrQMD model have been studied and we will discuss them in more detail in Sec. 4. With the existence of new data from the NA61/SHINE Collaboration which cover now the inclusive spectra of \( \pi^\pm, K^\pm, p \) and \( \bar{p} \) produced in inelastic \( p + p \) interactions at all the available SPS energies [1], we consider it necessary and important to present in this paper the first comparison of these most recent data to the UrQMD simulations. This we do for all identified particles at wide energy range from 20 to 158 GeV.

The paper is organized as follows. In Sec. 2 we provide a brief description of the UrQMD transport model. In Sec. 3 we comment on our UrQMD studies of mean particle multiplicities and rapidity distributions included in Ref. [1]. Then we present our results for the transverse momentum spectra and the inverse slope parameters of \( \pi^\pm, K^\pm, p \) and \( \bar{p} \) produced in inelastic \( p + p \) interactions at different energies,
extracted from the UrQMD simulations, and compare them to the NA61/SHINE experimental data. Finally, Sec. 4 is dedicated to the summary and conclusions.

2 The UrQMD transport model

The UrQMD (Ultra-relativistic Quantum Molecular Dynamics) transport model [14,15] is the non-equilibrium approach based on an effective solution of the relativistic Boltzmann equation

\[ p^\mu \partial_\mu f_i(x', p') = C_i, \]  

which is used to describe the time evolution of the distribution functions for particle species \( i \) and includes the full collision term on the right hand side. The underlying degrees of freedom are hadrons and strings. UrQMD includes 55 baryon and 32 meson species, ground state particle, and all resonance with masses up to 2.25 GeV. Full particle-antiparticle, isospin and flavor \( SU(3) \) symmetries are applied.

The hadrons propagate on straight lines until the covariant relative distance between two particles gets smaller than a critical distance given by the corresponding total cross section. The elementary cross sections are calculated by the detailed balance or the additive quark model or fitted and parametrized according to the available experimental data. For resonance excitations and decays the Breit-Wigner formalism is used.

The initial high energy phase of the reaction is modeled via the excitation and fragmentation of strings treated according to the LUND model [16,17,18]: for hard collisions with large momentum transfer (\( Q > 1.5 \) GeV) PYTHIA [19] is used.

In the present study, we use the most recent version of UrQMD transport model, UrQMD v3.4 [20], which has been successfully applied to describe particle yields and transverse dynamics in the energy range from \( E_{lab} = 2 \) to 160 AGeV [21].

3 Results

In this Section we present the results for the transverse momentum spectra and the inverse slope parameters of \( \pi^\pm, K^\pm, p \) and \( \bar{p} \) produced in inelastic \( p + p \) interactions at different collision energies, obtained from the UrQMD calculations. Prior to this we note that the UrQMD results for the rapidity distributions and mean multiplicities of identified particles for all energies were shown in Fig. 43 and Fig. 44 of Ref. [1], respectively. The conclusions from this first comparison to the NA61/SHINE experimental data included therein can be summarized as follows.

For pions, the model describes well the mean \( \pi^- \) and \( \pi^+ \) multiplicities (see Fig. 44
in Ref. [1] for the comparison of the mean multiplicities here and below in the text) and $dN/dy$ spectra (see Fig. 43 in Ref. [1] for the comparison of $dN/dy$ spectra here and below in the text) at high SPS energies. It gradually underestimates the mean multiplicities of both particles at lower energies. In the 20-31 GeV/c beam momentum regime, the corresponding discrepancies may reach 30% for the mean $\pi^-$ and $\pi^+$ multiplicities and a factor of two (up to 30%) for negative (positive) pion $dN/dy$ values at $y \approx 0$. We note that we always address rapidity $y$ in the collision center-of-mass system.

For kaons, the UrQMD model does not match the energy dependence of their mean multiplicity. For $K^-$ mesons, it slightly underestimates their mean multiplicities at beam momenta of 20 and 31 GeV/c, underestimates it by about 30% at 40 GeV/c, and overestimates it by up to 30% at higher beam momenta. A roughly similar behavior is apparent for $dN/dy$ distributions. For $K^+$, the model provides a rough description of mean multiplicities and $dN/dy$ spectra for the two top beam momenta,
The small cusps on the lines correspond to statistical fluctuations in our model calculation. The model overpredicts the mean multiplicities by factors from 1.5 to 2.2 for all beam momenta (no data is available below 150 GeV/c). The model matches reasonably well the experimental $d\sigma/dy(y \approx 0)$, reaching 40% of the mean multiplicity and a factor of two for $dN/dy(y \approx 0)$, respectively.

but systematically underestimates both observables at lower energies, with discrepancies reaching 40% of the mean multiplicity and a factor of two for $dN/dy(y \approx 0)$, respectively.

For protons, the model matches reasonably well the experimental $dN/dy$ spectrum for 20 GeV/c beam momentum, with the exception of the highest rapidity region. For higher beam momenta the model systematically overpredicts the data in an increasing range of rapidity. The discrepancy reaches almost a factor of two for $dN/dy(y \approx 0)$ at 158 GeV/c. For antiprotons, the model overpredicts the mean multiplicities by factors from 1.5 to 2.2 for all beam momenta (no data is available at 20 GeV/c). Consistently, it also overpredicts the $dN/dy$ distributions.

Fig. 3. The UrQMD v3.4 predictions (lines) for transverse momentum spectra of $K^-$ (left) and of $K^+$ (right) produced at $0 < y < 0.2$ in inelastic $p + p$ interactions at 31, 40, 80 and 158 GeV/c, in comparison to experimental data from the NA61/SHINE Collaboration (symbols). The small cusps on the lines correspond to statistical fluctuations in our model calculation.

Fig. 4. The UrQMD v3.4 predictions (lines) for transverse momentum spectra of $K^-$ (left) and of $K^+$ (right) produced at $1.4 < y < 1.6$ in inelastic $p + p$ interactions at 31, 40, 80 and 158 GeV/c, in comparison to experimental data from the NA61/SHINE Collaboration (symbols). The small cusps on the lines correspond to statistical fluctuations in our model calculation.
Fig. 5. The UrQMD v3.4 predictions (lines) for transverse momentum spectra of protons (left) and antiprotons (right) produced at $0 < y < 0.2$ in inelastic $p + p$ interactions at 31, 40, 80 and 158 GeV/$c$, in comparison to experimental data from the NA61/SHINE Collaboration (symbols). The small cusps on the lines correspond to statistical fluctuations in our model calculation.

Fig. 6. The UrQMD v3.4 predictions (lines) for transverse momentum spectra of protons (left) and antiprotons (right) produced at $1.4 < y < 1.6$ (for protons) and at $0.8 < y < 1$ (for antiprotons) in inelastic $p + p$ interactions at 31, 40, 80 and 158 GeV/$c$, in comparison to experimental data from the NA61/SHINE Collaboration (symbols). The small cusps on the lines correspond to statistical fluctuations in our model calculation.

3.1 Transverse momentum spectra

In Figs 1 and 2 we show the transverse momentum distributions of $\pi^-$ mesons (left) and $\pi^+$ mesons (right) produced at central ($0 < y < 0.2$) and forward rapidity ($1.4 < y < 1.6$) in inelastic $p + p$ collisions at 31, 40, 80 and 158 GeV/$c$. We note that the projectile beam rapidity is respectively 2.094, 2.223, 2.569 and 2.909 for the corresponding beam momenta [13]. Our model predictions are compared to the experimental data from the NA61/SHINE Collaboration [1] obtained at the same pion rapidity. The symbols with error bars correspond to the experimental data and the lines to our UrQMD simulations. For better visibility, the experimental and model spectra are scaled by common factors at the different beam momenta.
One observes that at central rapidity the UrQMD model describes well the transverse momentum spectra of both positive and negative pions at 158 GeV/c, but underestimates their yields at the lower beam energies and for the whole transverse momentum range where the experimental points are available. On the other hand, at forward rapidity the model gives a good description of the transverse momentum distribution of pions for $p_T < 0.8$ GeV/c, but overestimates the pion yield for $p_T > 0.8$ GeV/c at all the considered beam energies (whenever there is available experimental data). Thus a specific pattern of deviations of the two-dimensional $d^2N/dp_Tdy(y, p_T)$ distribution emerges between data and model, where the pion midrapidity density and high $p_T$ pion yield at forward rapidity go respectively below and above the experimental data with decreasing collision energy. This results, after integration over transverse momentum and rapidity, in the discrepancy between the mean pion multiplicities and $dN/dy$ distributions in the experimental data and the UrQMD model as a function of decreasing collision energy, which we discussed above.

The transverse momentum spectra of $K^-$ (left) and $K^+$ (right) mesons at central and at forward rapidity are shown in Figs 3 and 4 respectively. The model calculations overpredict the $K^-$ experimental data at top collision energy at forward rapidity and $p_T$. At low collision energies (31 and 40 GeV/c beam momentum), UrQMD predicts smaller yields of kaons than visible in the experimental data; this is generally valid for all presented values of kaon rapidity and transverse momentum and will result in the underprediction of mean $K^-$ multiplicities which we addressed above. For $K^+$ mesons a fair agreement between data and model is achieved at 80 and 158 GeV beam energy, but at lower beam momenta the UrQMD calculations visibly underestimate the $K^+$ yield as a function of both rapidity and $p_T$. This is consistent with what has been said above on the mean $K^+$ multiplicities and rapidity distributions, but emphasizes the lack of quantitative description of positive kaon production in the lower SPS energy regime by the UrQMD model. This remains important for the interpretation of the energy dependence of strangeness production, claimed to display some similarity between $p+p$ and central Pb+Pb collisions as discussed in Ref. [9].

Finally, in Figs 5 and 6 we show the transverse momentum distributions of protons (left) and antiprotons (right) produced at central and at forward rapidity in inelastic $p+p$ collisions at 31, 40, 80 and 158 GeV/c. By “forward rapidity” we mean the usual $1.4 < y < 1.6$ for protons but $0.8 < y < 1$ for antiprotons. The UrQMD calculation systematically overpredicts the central rapidity proton yield in the whole considered range of transverse momentum, an effect which is much less visible, or absent, at forward rapidity. This difference between central and forward rapidity is most evident at top SPS energies, indicating quantitative differences in transport of baryon number down to low values of rapidity in physical $p+p$ events and in the UrQMD code. Here we note that the earlier, high quality proton $dN/dy$ data at 158 GeV/c from the NA49 Collaboration [7] are in good agreement with the experimental result from NA61/SHINE as discussed in Ref. [1].

For antiprotons, in spite of the evidently larger relative uncertainties in the exper-
Fig. 7. The UrQMD v3.4 simulations (solid lines) of transverse momentum spectra of $\pi^-$ mesons produced in inelastic $p + p$ interactions at $1.4 < y < 1.6$, at 158 GeV/c beam momentum (left), and of $\pi^+$ mesons produced at $0 < y < 0.2$, at 40 GeV/c beam momentum (right). The dashed lines represent the corresponding fits, made according to Eq. (2).

Fig. 8. The UrQMD v3.4 simulations (solid lines) of transverse momentum spectra of $K^-$ mesons produced in inelastic $p + p$ interactions at $1.4 < y < 1.6$, at 158 GeV/c beam momentum (left), and of $K^+$ mesons produced at $0 < y < 0.2$, at 40 GeV/c beam momentum (right). The dashed lines represent the corresponding fits, made according to Eq. (2).

Experimental data, it is clear that the UrQMD model systematically overestimates the NA61/SHINE result. The discrepancy tends to be larger for forward rapidity and at lower collision energies, where also the shape of the transverse momentum distribution differs significantly between the data and the model.

3.2 The inverse slope parameter

In order to keep the consistency with the work performed in Ref. [1], we attempt to parametrize the results presented in Figs 1 - 6 by the exponential function [22, 23]:

$$\frac{d^2N}{dp_Tdy} = \frac{Sp_T}{T^2 + mT} \exp \left[-(m_T - m)/T\right],$$

(2)
Fig. 9. The UrQMD v3.4 simulations (solid lines) of transverse momentum spectra of protons produced in inelastic $p + p$ interactions at $1.4 < y < 1.6$, at 158 GeV/c beam momentum (left), and of antiprotons produced at $0.8 < y < 1$ at the same beam momentum (right). The dashed lines represent the corresponding fits, made according to Eq. (2).

where $m$ is the mass of the particle, $m_T = \sqrt{m^2 + p_T^2}$ is its transverse mass, $S$ and $T$ are the yield integral and the inverse slope parameter, respectively. In Figs 7 - 9 we show some examples of this parametrization fitted to the transverse momentum spectra predicted by the UrQMD for the different particles produced in inelastic $p + p$ interactions, for a selection of rapidity intervals and colliding energies. We note that our fits were performed in the whole range of transverse momentum, while the ranges of the experimental fits were defined by the available data points and the experimental results were only shown for those rapidity intervals for which there were more than six data points in the transverse momentum distribution. The solid lines represent the UrQMD predictions and the dashed lines represent the corresponding fits.

One observes that in the mesonic sector, for pions and kaons, the results of the UrQMD calculations can be reasonably well fitted by the parametrization from Eq. (2), in the whole available range of transverse momentum. For pions, some doubt is induced by the fact that the fit tends to go below the UrQMD spectrum at $p_T > 0.7$ GeV/c. We note that a similar behavior, with respect to the UrQMD predictions, can be seen for some of the experimental data at least at forward pion rapidity, see Fig. 2. Thus the agreement between two inverse slopes, one fitted to the experimental $p_T$ distribution and the other fitted to that predicted by the model will not be equivalent to the agreement between the two distributions themselves.

For kaons, Fig. 8 no significant deviations between the spectrum predicted by the model and the fitted parametrization (2) are seen. This is reminiscent of the good agreement between experimental kaon spectra and the same parametrization (2) which was demonstrated in Ref. [1]. On the other hand, one should remember the discrepancies between the experimental data and the UrQMD code shown in Figs 3 and 4.

For protons, Fig. 9 (left panel), it is not possible to fit our results for all the values
of $p_T$ simultaneously when using the parametrization (2). The presented fit attempt very significantly underpredicts the proton yield at low transverse momenta. Finally, an attempt to fit the parametrization (2) to the antiproton $p_T$ spectrum is presented in Fig. 9 (right panel). After a detailed inspection, we conclude that our statistics does not allow us to conclusively judge on the fit quality, even at top SPS energy where the produced $\bar{p}$ yield is the highest.

3.3 Inverse slope as a function of rapidity

Similarly to the work presented in Ref. [1], we apply the fit of the parametrization (2) to all the mesons studied in this paper, at all considered values of rapidity and all colliding energies. We restrict this part of our study uniquely to mesons in view of the failure of the fit for protons and its unreliability for antiprotons as discussed above. The extracted values of the inverse slope parameter $T$ are shown in Fig. 10 as a function of meson rapidity at four beam momenta, 31, 40, 80 and 158 GeV/c. The solid lines correspond to the UrQMD calculations and the symbols with the error bars represent the values of $T$ extracted in Ref. [1] from fits to experimental data.

In addition to the UrQMD results, we also show (by dashed lines) the corresponding fit results obtained from simulations by the EPOS v1.99 model [24]; these were published in Ref. [1], together with NA61/SHINE data. We mention that in the EPOS model, the interaction proceeds via excitation of strings according to the Gribov-Regge theory and then their fragmentation into hadrons.

The values of $T$ parameters fitted by the authors of Ref. [1] to EPOS simulated spectra seem to provide a fair agreement with those extracted therein from experimental data, at least for negative pions, positive pions starting from 40 GeV/c beam momentum, and negative kaons. The situation is more complicated for the values of $T$ extracted from fits to our UrQMD simulation.

For positive pions, the UrQMD-based inverse slope $T$ gives a remarkably good agreement with that extracted from experimental data, and describes well the characteristic decrease of the latter with increasing pion rapidity. Being representative of the first order characteristics of the shape of the $p_T$ distribution, the inverse slope predicted by the UrQMD matches the energy dependence seen in experimental data better than the $d^2N/dydp_T(y,p_T)$ distribution itself as shown in Figs 1 and 2 (right), and better than the $p_T$-integrated $dN/dy$ spectrum and mean $\pi^+$ multiplicity discussed above.

The situation is less favorable for negative pions, although the agreement between the values extracted from the experimental data and the UrQMD is satisfactory at top SPS energy. With decreasing beam momentum, the $\pi^-$ inverse slope at forward rapidity takes off from that extracted from experimental data, reaching deviations of about 20% in the lower energy regime where also significant discrepancies were
Fig. 10. Solid lines: the inverse slope parameter $T$, extracted from fits with the parametrization \(^{(2)}\) to the transverse momentum distributions of $\pi^\pm$ and $K^\pm$ mesons produced in inelastic $p + p$ interactions at 31, 40, 80 and 158 GeV/c, obtained from UrQMD v3.4 calculations as a function of pion and kaon rapidity. These results are compared to the values of $T$ obtained from fits to experimental data from the NA61/SHINE Collaboration (symbols) and to the EPOS model \(^{(24)}\) predictions (dashed lines). The values obtained from experimental data and from EPOS predictions are both taken from Ref. \([1]\).

visible for the mean $\pi^-$ multiplicity and the $dN/dy(y \approx 0)$ yield as mentioned above. We note that the agreement between data and model remains good for all collision energies in the central region, near $y \approx 0$.

For positively charged kaons, a similarly good agreement is present between NA61/SHINE data and UrQMD for the $T$ parameter extracted at central rapidity for all energies, while a take-off of the UrQMD prediction from experimental data at high rapidity is apparent at all beam momenta apart from $p_{lab} = 40$ GeV/c. This is somewhat in contrast with the energy dependence of the $d^2N/dydp_T(y, p_T)$ distribution, Figs \(3\) and \(4\) (right), the $dN/dy$ spectrum, and the mean $K^+$ multiplicity, where the discrepancies between data and model gradually increased with decreasing energy.

Finally, for negatively charged kaons, the values of $T$ fitted to the experimental data in Ref. \([1]\) seem to suffer from fluctuations especially in the lower beam momentum regime. This taken into account, we conclude that the overall description of the
rapidity dependence of the inverse slope as function of collision energy is reproduced by the UrQMD reasonably well. This is notwithstanding the discrepancies between experimental data and model in terms of the energy dependence of the forward rapidity $d^2N/dyd\eta(y, p_T)$ distribution, Fig. 4 (left), or the mean multiplicity of $K^-$ mesons as discussed above.

4 Summary and conclusions

In the present paper we analyzed the new data on proton, antiproton and meson production in $p+p$ collisions in the laboratory momentum range of 20 to 158 GeV/c recently published by the NA61/SHINE Collaboration [1]. These new experimental results were compared to simulations performed using the recent version 3.4 of the UrQMD transport model. Complementary to our earlier analysis of mean multiplicities and $dN/dy$ distributions published in Ref. [1], we focused on the transverse momentum spectra of $\pi^\pm$, $K^\pm$, $p$ and $\bar{p}$ produced at central and forward rapidity, starting from beam energy of 31 GeV. We also fitted these spectra with the same analytical parametrization as applied to experimental data and compared the respective inverse slopes as a function of meson rapidity and collision energy.

Taken together the information on mean multiplicities, rapidity distributions and $d^2N/dyd\eta$ spectra, an overall discrepancy between the UrQMD and the NA61/SHINE antiproton data is apparent. The model overestimates antiproton production at all collision energies where experimental data are available. For protons, a discrepancy between the experimental data and the model can be seen in the transport of baryon number down to low proton rapidity, in particular at top SPS energy. Also the $p_T$ spectra of protons simulated by the UrQMD cannot be reasonably fitted with parametrization (2), and differ from experimental data especially at higher beam momenta.

For charged pion production in $p+p$ collisions, the fair description provided by the UrQMD at higher SPS energies (80-158 GeV) considerably deteriorates with decreasing collision energy, to a different extent for the three observables mentioned above. A peculiar exception to this rule is the rapidity dependence of the fitted $\pi^+$ inverse slope, which describes the data surprisingly well down to the lowest considered beam momentum of 31 GeV/c.

For strange $K$ mesons a complicated pattern of discrepancies between data and model is apparent, the most significant being the fact that the UrQMD significantly underpredicts positive kaon production in the lower SPS energy regime.

In view of the importance of the SPS (and RHIC beam energy scan) energy regime which is claimed to host the onset of deconfinement from hadronic matter to quark-gluon plasma in heavy ion collisions [23, 25], the significance of reference $p+p$ collisions cannot be stressed enough. This is even more evident in view of the apparent
similarities in the energy dependence of kaon inverse slopes and kaon-over-pion ratios in \( p + p \) and heavy ion collisions, reported by the NA61/SHINE Collaboration [9]. In this situation, the application of transport models is particularly valuable as it gives a chance to follow in detail whether these similarities have a decisive or only a casual importance for our knowledge of conditions proper for the formation of deconfined quark-gluon plasma matter.

In the above context, however, our analysis shows that the new experimental data from NA61/SHINE constitute still a challenge for specific transport models, at least as far as the present 3.4 version of the UrQMD code is concerned. As we mentioned in Introduction the possible improvements to the UrQMD model were considered for instance in Ref. [12]. In particular, the \( \eta \)-meson decays were implemented to the model as an additional source of \( \pi \)-meson and \( K \)-meson production in inelastic \( p + p \) interactions at SPS energies. However, it was shown by the author that accounting of \( \eta \)-meson decays in the simulations leads to the increase of the spectra of pions in central regions only by a few percent and therefore it has almost a negligible effect on \( K \)-meson production. This clearly is not sufficient for a good description of the experimental data. On the other hand, it is argued that decreasing of the cross sections of binary inelastic reactions and accurate parameterizations of single diffraction cross sections would allow the UrQMD model to describe meson production in \( p + p \) collisions (see Fig. 3 in Ref. [12]). As stated in the cited reference, in order to improve baryon production the inclusion of the low mass diffraction dissociation to the UrQMD model could be performed by increasing the cross section for the process \( NN \to 
abla N^* \), including the states \( N^* \) with masses in the range \( m = 1440, \ldots, 2250 \text{ MeV/c}^2 \). To sum up, these and other improvements could be tested in view of a possible better description of the new available NA61/SHINE data on the energy dependence of \( p + p \) interactions. However, account taken that heavy ion collisions have up to now the prime interest of the model, what is to be envisaged is a complex tuning process where not only \( p + p \), but also \( A + A \) collisions would come into the game. It is therefore to be considered whether the new data on \( Be + Be \) and \( Ar + Sc \) collisions presently in progress from the NA61/SHINE Collaboration (see preliminary data in [9]) would not be necessary to obtain a robust state-of-the-art description of particle production at SPS energies.

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