Prediction of J/ψ, φ, D production in the NICA energy range.
Self-similarity approach

Baldina E. G., Baldin A.A.

Joint Institute for Nuclear Research, Joliot-Curie 6, Dubna, Russia

e.baldina@mail.ru

The SPD (Spin Physics Detector) experiment is one of the two installations constructed at the interaction points of NICA (Nuclotron-based Ion Collider fAcility) that is under construction at the Joint Institute for Nuclear Research, Dubna. This experiment is aimed at testing the basics of QCD via the study of polarization and spin-related phenomena in collisions of relativistic ions at the center-of-mass energy up to 27 GeV and luminosity up to 10^{32} cm^{-2} s^{-1}.

The SPD will operate as a universal facility for comprehensive study of unpolarized and polarized gluon content of the nucleon at large Bjorken-x, using different complementary probes, including charmonia.

The SPD setup is a universal 4pi spectrometer with advanced tracking and particle identification capabilities based on modern technologies. It is expected that the SPD setup will provide physics runs after 2025.

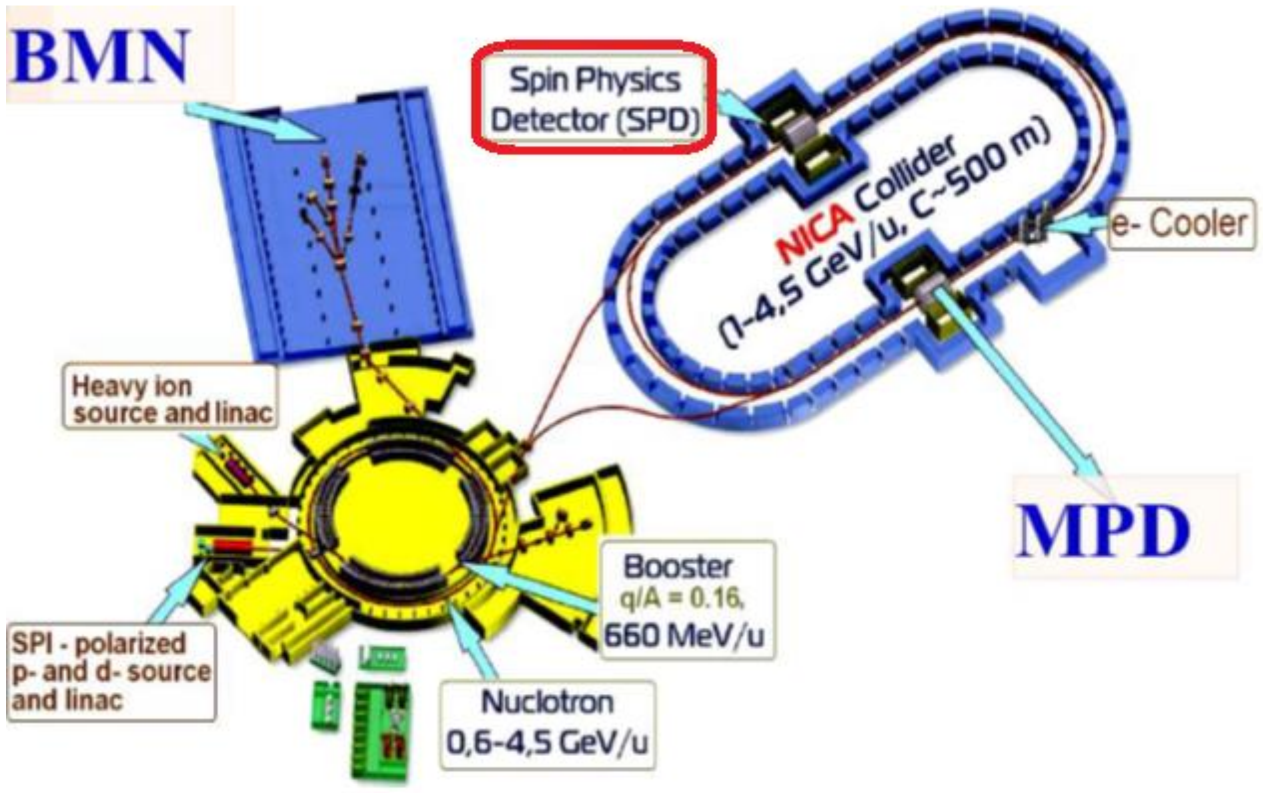

Fig. 1. NICA complex at JINR.

The J/ψ (and charmonium in general) production in hadron collisions is of great interest for several reasons. The description of the process is a challenge and an important test for our understanding of the QCD. Particles containing strange and charm quarks are important probes of the excited medium created in heavy ion collisions. There are no experimental data available on open and hidden charm in heavy ion collisions at low and intermediate energies. High statistics of inclusive J/ψ events anticipated at SPD would provide measurement of transverse spin asymmetries. Also, J/ψ production, being sensitive to the gluon content of the colliding hadrons, would allow the study of gluon parton distribution functions. Thus, the SPD experiment is a powerful tool for verification of theoretical models and gaining deeper insight into the structure of matter.

The SPD experiment is designed to ensure high precision measurements of total and differential cross sections and polarization with good particle identification.

That is why it is extremely important to have reliable predictions for experimentally measured cross sections prior to planning experimental data acquisition routines.

Self-similarity is a special symmetry of solutions, when a change in scales of independent variables is compensated by a self-similarity transformation of other dynamical variables.

The presented functional self-similarity approach provides the construction of a solution quantitatively describing angular, energy and A-dependences of inclusive production cross sections for hadrons in relativistic nuclear collisions.

This self-similarity solution [2, 3] has proved to describe well the wide set of experimental data, including cumulative, subthreshold particle production [4-6]. It was applied for prediction of ϕ [7] and D [8] meson production in heavy ion collisions. Here, we apply it to estimation of charm production at the future NICA collider, with the focus on production of the heaviest considered particle, J/ψ, in the conditions of the SPD experiment at NICA accelerator complex with heavy and light nuclei. The results will be used for simulation of SPD detection system operation and optimization as a part of preparation for the physics run at the facility.

The form of the self-similarity solution is as follows:

$$E\frac{d^3\sigma}{dp^3}=C_1A_1^{\frac{1}{3}(1+X_1)}A_2^{\frac{1}{3}(1+X_2)}\exp\left(-\Pi/C_2\right), \tag{1}$$

where Π is the similarity parameter, $\Pi=\frac{1}{2}\left(X_1^{\ 2}+X_2^{\ 2}+2X_1X_2\gamma_{12}\right)^{\frac{1}{2}}$, the fractions of four-momenta of interacting nuclei X_1 and X_2 are found by minimization of Π, and C_1, C_2 are constants found to fit experimental data.

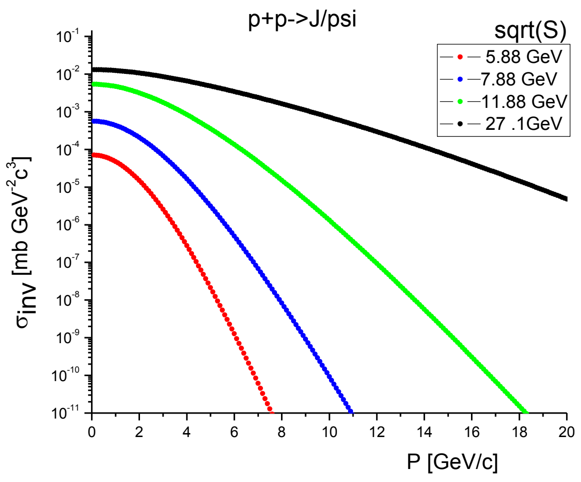

Fig. 2a. Invariant cross section of J/ψ production in p-p collisions ($S^{1/2}$ from ~6 to~27GeV).

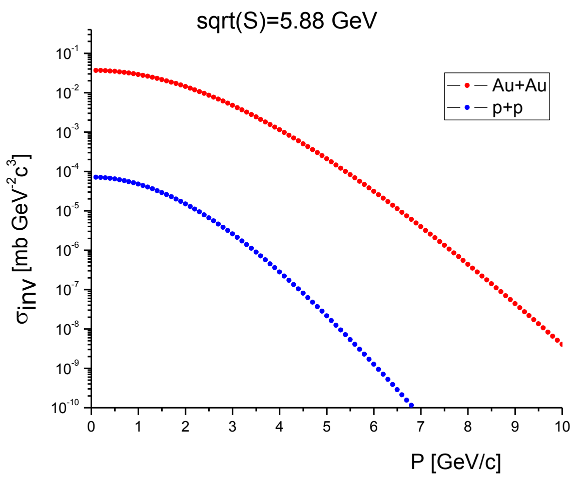

Fig. 2b. Invariant cross section of J/ψ production in p-p and Au-Au collisions ($S^{1/2}$ ~ 6 GeV).

Here, we illustrate the kinematic range in which the particle production cross sections will be the largest or the most conveniently measurable. The particle yield changes by orders of magnitude with varying angle, which is extremely important from the experimental point of view. It should also be noted that the cross section maximum shifts toward the central region with increasing angle of emitted particle.

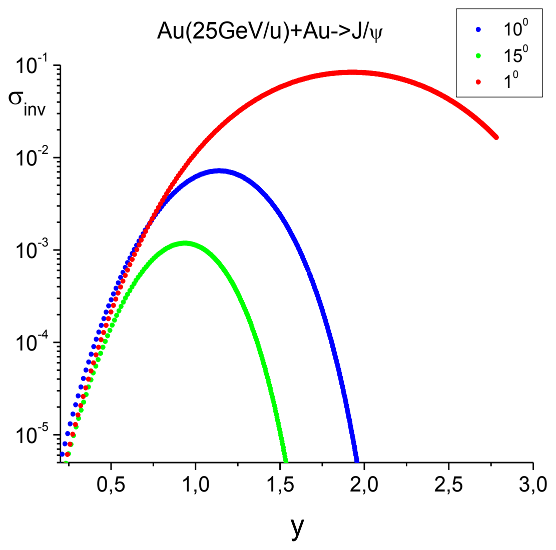

Fig. 3a. Invariant cross section of J/ψ production at different angles in Au(25 GeV/n)+ Au collisions as a function of rapidity y.

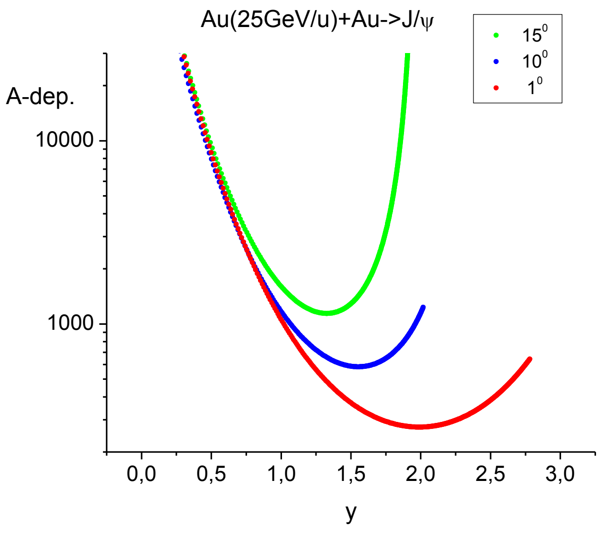

Fig. 3b. A-dependence of J/ψ production at different angles in Au(25 GeV/n)+ Au collisions as a function of rapidity y.

The maximum cross section corresponds to the minimum A-dependence, which means the least manifestation of collective phenomena. This is especially important for experiments in which the ratios of particle yields are studied. Therefore, the acceptance of a particular experimental setup is crucial in data analysis of such experiments.

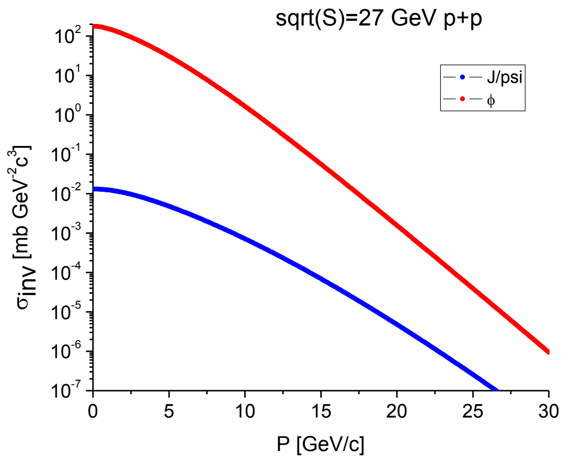

Fig. 4a. Invariant cross sections of J/ψ and φ production in 12.6 GeV p-p collisions ($S^{1/2}$ = 27 GeV)

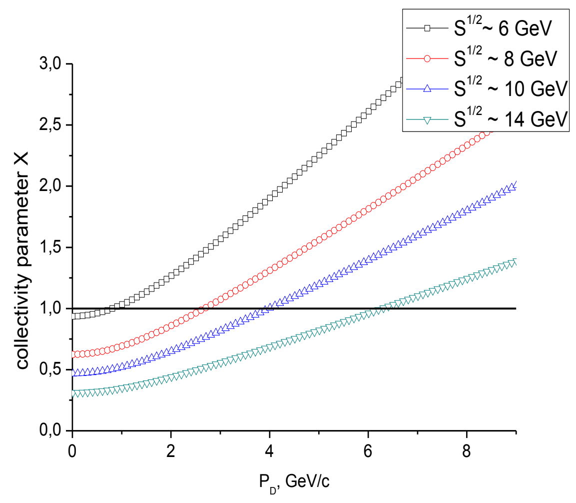

Fig. 4b. D meson production at 90º in Au-Au collisions

The "collectivity" effect is illustrated in Fig. 4b. In this figure, the fraction of four-momentum (or number of nucleons) participating in the reaction (X) is plotted as a function of D meson momentum. Horizontal line X=1 shows the boundary of single-nucleon interactions for both colliding nuclei (below X=1 the particle can be produced in a single-nucleon interaction, while above X=1 more than one nucleon from each colliding nucleus is required).

It can be seen that while for Au-Au collisions at ~6 GeV/c collective (with respect to both colliding nuclei) phenomena occur for rather high D meson momenta (6 GeV/c and higher), moderate collider energies (~2 GeV/c Au) require multinucleon interaction of both nuclei to produce D mesons at less than 1 GeV/c.

It should be pointed out that the multi-nucleon processes of D, φ, and J/ψ production are experimentally measurable in a wide range of collision energies covered by the NICA collider.

The above functional self-similarity solution quantitatively describes angular, energy and A-dependences of inclusive production cross sections of all hadrons with transverse momentum up to 1GeV/c. Higher transverse momenta require an additional mechanism to account for momentum dependence in the invariant cross section.

The analysis of inclusive spectra for the data selected in different ways shows that multiplicity in relativistic nuclear collisions has its origin basically in independent nucleon-nucleon interactions. Interaction of very heavy nuclei (Au, Pb, etc.) may "entangle" the experimental picture of the reaction and complicate theoretical interpretation. Collective effects can be observed already for light and intermediate nuclei, although with lower multiplicity and combinatorial background.

Collective phenomena become extinct with increasing collision energy. Therefore, the energy range from hundreds MeV to tens of GeV is optimal for experimental observation of collective effects in nuclear collisions. Of interest is the study of the whole energy range available at the NICA collider, toward the lowest possible energies in order to gain better understanding of QCD physics.

REFERENCES

1. http://spd.jinr.ru/
2. A. A. Baldin, Phys. Part. Nucl. 56(3), 385 (1993)
3. A. M. Baldin and A. A. Baldin, Phys. Part. Nucl. 29(3), 577 (1998)
4. A. A. Baldin, E.G. Baldina, in Selected Papers of the Seminar (2000-2005) Symmerties and Integrable Systems, Ed. A. N. Sissakian, 1, 41 (JINR, Dubna, 2006)
5. A. A. Baldin et al., JINR Rapid Comm. 3(92), 20 (1992)
6. A.A. Baldin, E.G. Baldina, E.N. Kladnitskaya, and O.V. Rogachevsky, Phys. Part. Nucl. Lett. 121, 7 (2004)
7. E. G. Baldina and A. A. Baldin, EPJ Web of Conferences "Baldin ISHEPP XXIIII" 138, 05001 (2017)
8. E. G. Baldina and A. A. Baldin, EPJ Web of Conferences " Baldin ISHEPP XXIV" 204, 07003 (2019)