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Neutron skin effects on pions production: UrQMD calculations for Pb+Pb, p+Pb and $\overline{p}$+Pb peripheral collisions at relativistic energies

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Topic of neutron skin is very interesting issue related to the asymmetry term in the nuclear equation of state. The last one is a basis for nuclear physics and e.g. neutron stars. One of the observables connected with the topic is ratio of number of positive and negative pions $R = N(\pi^+)/N(\pi^-)$ that can change as a function of Feymann variable x_F. In this short note we present our study of neutron skin issue by using UrQMD model for ultra relativistic reactions ^{208}Pb+^{208}Pb, p+^{208}P and $\overline{p}$+^{208}Pb.

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The Nuclear equation of state (EoS) can be written in a form: $\varepsilon(\rho,\alpha) = \varepsilon_{SNM}(\rho) + \alpha^2 S(\rho)$, where the first term represents the symmetry part of the nuclear matter binding energy per nucleon while the second term takes into account asymmetry in the number of protons and neutrons $\alpha \equiv \dfrac{\rho_n - \rho_p}{\rho_n + \rho_p}$ expressed as the respective densities ρ_p, ρ_n. It is clear that $\varepsilon_{SNM}(\rho) = \varepsilon(\rho, \alpha = 0)$, while $S(\rho)$ so called the symmetry energy term is expressed as a series expansion around saturation density ρ_0 with $S(\rho_0) = (31.6 \pm 2.7)$ MeV [1, 2].

One of the important parameters, connected with the neutron skin thickness, is the slope parameter $L = 3\rho_0(\dfrac{\partial S}{\partial \rho})_{\rho=\rho_0}$ and its value, concluded from different experiments is about $L \sim 60$ MeV [3].

To study neutron skin issue calculations were done using UrQMD model (Ultrarelativistic Quantum Molecular Dynamics) [4]. UrQMD is a Monte Carlo type code of relativistic collisions and can be run in 2 modes: CASCADE+Woods-Saxon or hard Skyrme. In the first mode only direct nucleon - nucleon collisions are considered while in the second one also mean field effects are taken into account. In both cases every particle is represented in a form of gaussian packets. We knew, but we also checked that it is sufficient to follow the time of nucleus - nucleus collision up to 60 fm/c [5].

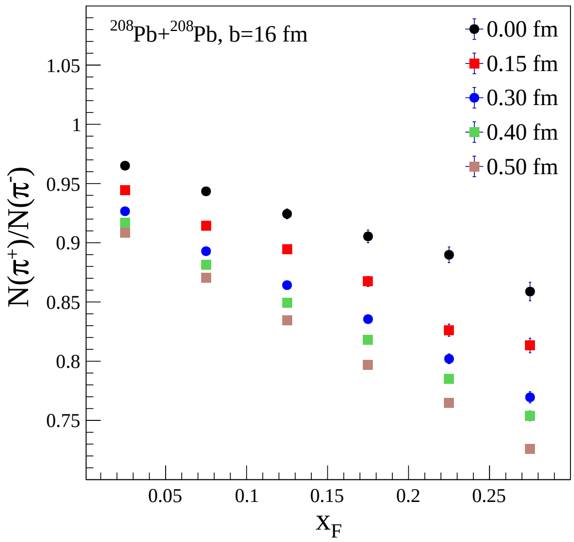

Figure 1: UrQMD results of pions ratio $R = N(\pi^+)/N(\pi^-)$ versus the Feynman variable x_F for peripheral collisions (impact parameter b given in the figure) in reaction Pb+Pb at $p_{Lab} = 150$ AGeV/c. Neutron skin thicknesses are shown in the legend. The vertical bars are statistical errors, shown when larger than symbols.

Few situations of collisions were considered. The first one it was ^{208}Pb+^{208}Pb collision, at $p = 150$ AGeV/c. We were interested in ratio of pions R vs the Feynmann variable $x_F = 2p_{LAB}/\sqrt{s}$. In that case we wanted to extend calculations done by A. Morawiec [6]. As the radius of ^{208}Pb is about 7.1 fm and taking into account diffuseness of the Pb nucleus surface we considered peripheral reaction at $b = 16$ fm. Results of our simulations are

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presented on Fig. 1. As one can see the pion ratio R depends linearly on the x_F and the thicker the neutron skin the ratio R is smaller, production of π^- is more dominant. Next we

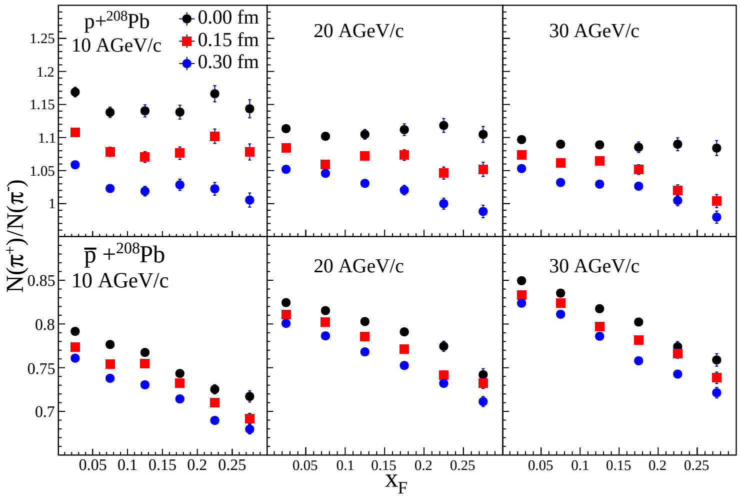

Figure 2: UrQMD results of pions ratio $R = N(\pi^+)/N(\pi^-)$ versus the Feynman variable x_F for collisions p+Pb (upper row) and $\overline{p}$+Pb (lower row) at three different protons momenta p_{Lab} indicated in the figure. In the legend thicknesses of neutron skin are given. Calculations were done for $b = 6-8$ fm.

looked at the p+^{208}Pb and finally $\overline{p}$+^{208}Pb collisions at different momenta ($p_{Lab} = 10, 20, 30$ AGeV), Fig. 2. Following observations can be drawn from the presented results. In case of p collisions the ratio R is always greater than 1 and decreases with increasing thickness of neutron skin next this ratio decreases with increasing momenta (p_{Lab}) of protons. On the other hand for $\overline{p}$ collisions (lower part of the Fig. 2) in all cases ratio R is always smaller than 1 and it is decreasing (probably linear) function for all skin thicknesses and all momenta, besides ratio slightly increases with increasing momenta. All calculations were done with CASCADE mode + Woods-Saxon option in the UrQMD model.

Summarizing, in the note we presented preliminary study of neutron skin for Pb nucleus by using pions π^+/π^- production ratio R. Ratio R could be a physical observable to study neutron skin thiknesses. Our calculations done for p+Pb, $\overline{p}$+Pb seem to confirm that conclusion. Here we used neutron skin in a version of skin type. Further simulation study should be done by using halo type skin to get the answer if the variable R is able to distinguish those two types of neutron skin. Another point is to look further for other physical observables that are sensitive to the neutron skin thickness e.g. net charge production in the midrapidity region of colliding nuclei. We are also planing to confront our results with experimental data of NA61/SHINE collaboration [7].

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