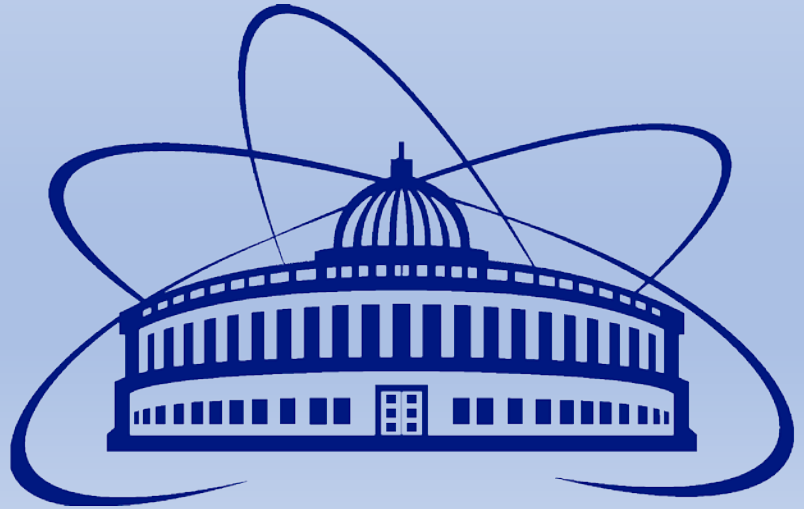
Kaon and pion meson production in the pp and AA collisions in a wide initial energy range

Gennady Lykasov, Alexander Malakhov, Andrei Zaitsev*

JINR, Dubna



*speaker

Outline

- **Self-similarity approach for *p-p* and *A-A* collisions**
- **Description of inclusive spectra of pions and kaons in *p-p* collisions in the mid-rapidity region of a wide energy range**
- **Description of inclusive spectra of pions and kaons in *BeBe* collisions in the mid-rapidity region**
- **Ratio yields K^+/π^+ and K^-/π^- at mid-rapidity as a function of $\sqrt{s}$**
- **Calculations of the yield ratios of antinuclei to nuclei**
- **Summary**

SELF-SIMILARITY APPROACH

Pioneering papers on similarity of inclusive spectra of particles produced in h-h and A-A interactions: I.Ya. Pomeranchuk (1951), E. Fermi (1953), L.D. Landau (1953), R. Hagedorn (1965).
Further development: the self-similarity parameter *Π* was introduced (A.M. Baldin, A.A. Baldin, 1998) and their analytical solution at the y=0 of produced hadrons was obtained (A.M. Baldin, A.I. Malakhov, 1998). The inclusive production of hadron 1 in the interaction of nucleus *A* with nucleus *B*:

$$A + B \rightarrow 1 + \cdots ,$$

It satisfies the conservation law of four-momentum in the following form:

$$(N_A P_A + N_B P_B - p_1)^2 = (N_A m_0 + N_B m_0 + M)^2$$

where N_A and N_B are the fractions of four momenta transmitted by the nucleus *A* and nucleus *B*; P_A, P_B, p_1 are four momenta of the nuclei *A* and *B* and particle 1, respectively; m_0 is the mass of the nucleon; *M* is the mass of the particle providing conservation of the baryon number, strangeness and other quantum numbers.

For π mesons $m_1 = m_\pi$ and $M = 0$;
For K^- mesons $m_1 = m_K$ and $M = m_K$;
For K^+ mesons $m_1 = m_K$ and $M = m_\Lambda - m_0$, m_Λ is the mass of the Λ-baryon.

$$\Pi = min\left\{\frac{1}{2}\sqrt{(u_{\mathrm{I}} \cdot N_{\mathrm{I}} + u_{\mathrm{II}} \cdot N_{\mathrm{II}})^2}\right\}$$

where u_A and u_B are the four-velocities of nuclei A and B.

FURTHER DEVELOPMENT OF S-S APPROACH

The relation of *Π* to the relativistic invariants *s* and m_t^2 was found in the paper by D.A. Artemenkov, G.Lykasov, A.I. Malakhov, Int.J.Mod.Phys. A30, 1550127 (2015); G.I. Lykasov, A.I. Malakhov, Eur.Phys. J. A54, 187 (2018). At y=0:

$$\Pi = \left\{ \frac{m_{1t}}{2m_0\delta} + \frac{M}{\sqrt{s}\delta} \right\} \left\{ 1 + \sqrt{1 + \frac{M^2 - m_1^2}{m_{1t}^2}\delta} \right\}$$

where δ=1 – s_{th}/s, m_{1t} is the transverse mass of hadron *h*, s_{th} is the threshold energy square in c.m.s.
The inclusive spectrum of particle 1 produced in the *AA* collision can be presented as the general universal function dependent on the self-similarity parameter *Π:*

$$Ed^3\sigma/dp^3 = A_A^{\alpha(N_A)} \cdot A_B^{\alpha(N_B)} \cdot F(\Pi)$$

where $\alpha(N_A) = 1/3 + N_A/3$, $\alpha(N_B) = 1/3 + N_B/3$. For symmetric colliding nuclei $N_A = N_B = N$ and *N* is directly related to *Π* at y = 0 as $N = 2m_0\Pi/\sqrt{s}$. Therefore, $\alpha(N) = 1/3 + 2m_0\Pi/\sqrt{s}$.
Function F(*Π*) at *y*=0 has the following form:

$$F(\Pi) = \left[A_q exp(-\Pi/C_q) + A_g\sqrt{m_{1t}} exp(-\Pi/C_g) \right.$$
$$\left. (1 - \sigma_{nd}/g((s/s_0)^{\Delta})) \right] \cdot g(s/s_0)^{\Delta} .$$

where $\Delta = \alpha_P(0)-1$ = 0.08-0.12, *g*= 21 *mb*.

N.A. Abdulov, H.Jung, A.V. Lipatov, G.I. Lykasjv., M.A.Malyshev, Phys.Rev. D 98, 054010 (2018)

THE IMPROVED FORM OF F(*Π*) AT NON-ZERO RAPIDITY OF PRODUCED HADRONS

By A.I.Malakhov, G.I. Lykasov, Eur.Phys. J. A56, 114 (2020) – Pion production in *p-p*:

$$F(\Pi) = \left[A_q \exp\left(-\frac{\Pi}{C_q}\right) + A_g \sqrt{p_T}\,\phi_1(s) \exp\left(-\frac{\Pi}{C_g}\right)\right]\sigma_{tot}$$

where

$$\Pi(s, m_{1T}, y) = \left\{\frac{m_{1T}}{2m_0\delta_h} + \frac{M}{\sqrt{s}\delta_h}\right\}\cosh(y)G \qquad G = \left\{1 + \sqrt{1 + \frac{M^2 - m_1^2}{(m_{1T} + 2Mm_0/\sqrt{s})^2\cosh^2(y)}\delta_h}\right\}$$

Here $\phi_1(s) = 1 - \sigma_{nd}(s)/\sigma_{tot}(s)$ $\quad s_{th}^{K^+} = (m_0 + m_K + m_\Lambda)^2$ $\quad s_{th}^{K^-} = (2m_0 + 2m_K)^2$

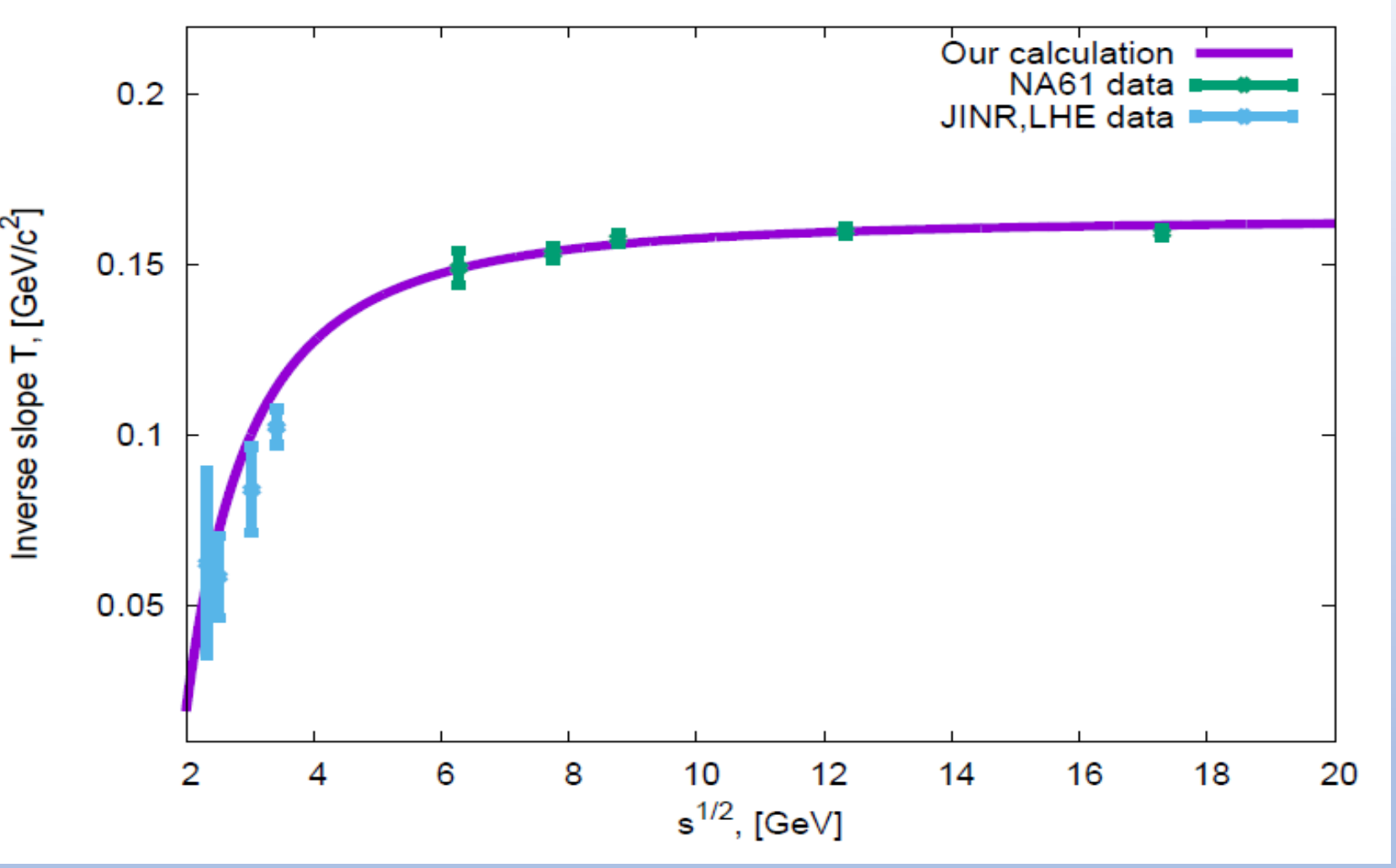
$\delta_h = \left(1 - \frac{s_{th}^h}{s}\right)$ $\quad s_{th}^{\pi} \simeq 4m_0^2$ $\quad \sigma_{nd} = (\sigma_{tot} - \sigma_{el} - \sigma_{SD})$

For K^- meson production in *p-p* the contribution of one Reggeon exchange in *p-p*, as $1/\sqrt{s}$ is considered. It leads to the modification of parameter A_q, i.e.:

$$A_q \rightarrow A_q(1+\sqrt{(s_{th}/s)}) \rightarrow A_q \exp(\sqrt{(s_{th}/s)}).$$

For π-meson production this contribution is too small, therefore A_q is not modified. The parameters A_q, A_g, C_q, C_g do not depend on the energy $\sqrt{s}$. They depend on a kind of the hadron and were found from the fit of all the data.

Inverse slope parameter



$$E(d^3\sigma/dp^3) \sim \exp(-\Pi/C_1) =$$

$$= \exp(-m_t/[C_1 m_0(1-4m_0^2/s)]$$

$$E(d^3\sigma/dp^3) \sim \exp(-m_t/T),$$
$$T = const$$

$$T = C_q m_0 (1 - 4m_0^2/s)$$

Lykasov G.I., Malakhov A.I. Eur. Phys. J. A 54, 187 (2018)

DESCRIPTION OF THE PION AND KAON p_t SPECTRA IN p-p COLLISIONS

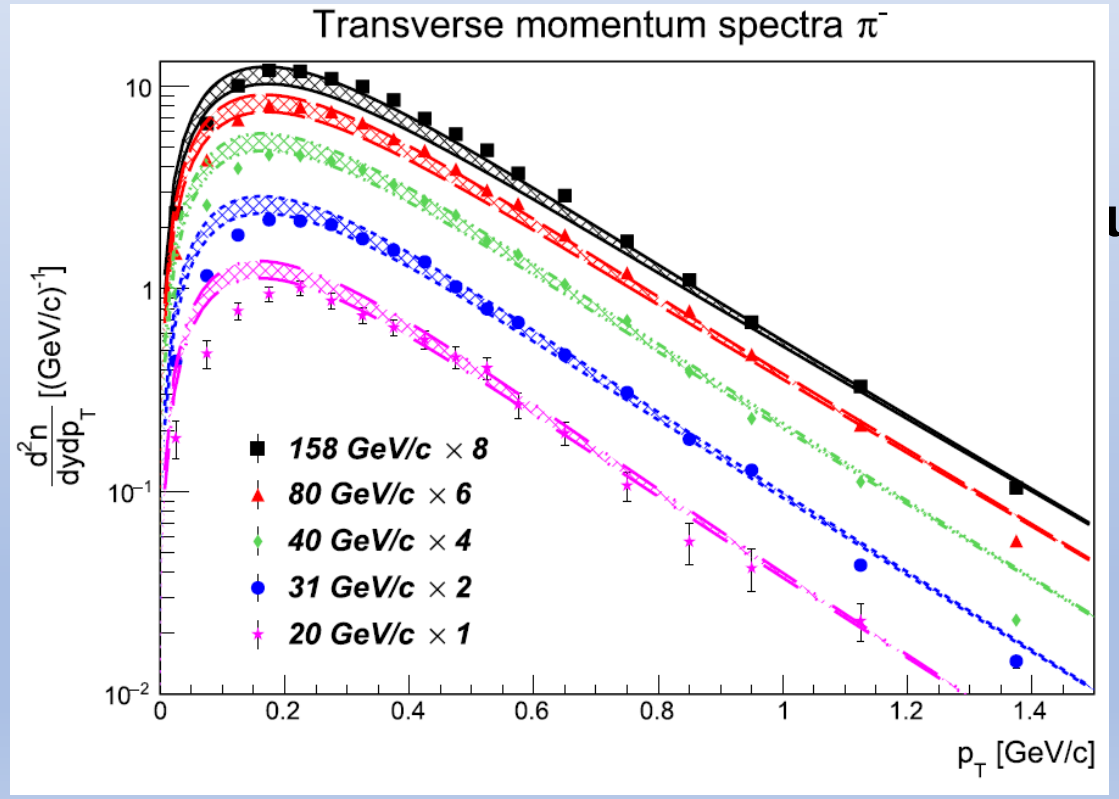
Eur. Phys. J. A (2021) 57:91
https://doi.org/10.1140/epja/s10050-021-00408-9

THE EUROPEAN PHYSICAL JOURNAL A

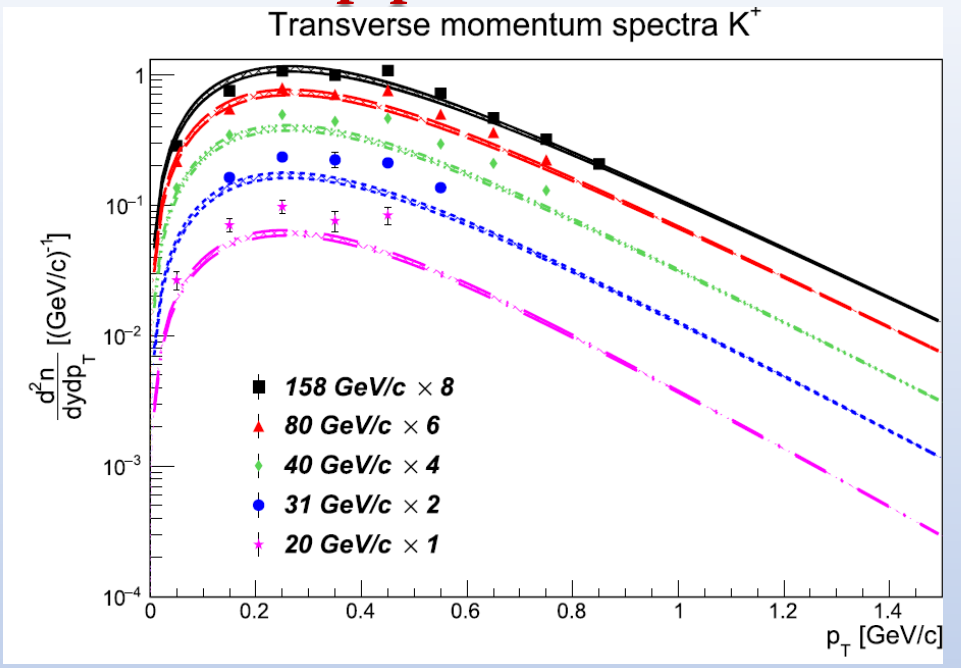
Regular Article - Theoretical Physics

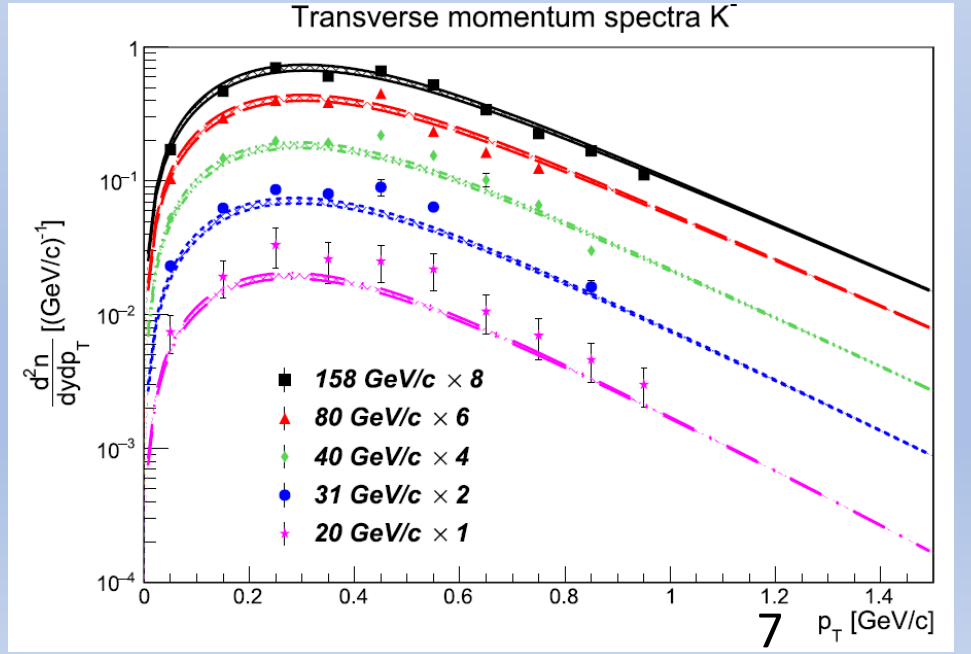
Ratio of cross-sections of kaons to pions produced in pp collisions as a function of $\sqrt{s}$

G. I. Lykasov[a], A. I. Malakhov, A. A. Zaitsev



Bands of uncertainty are due to data fitting of NA61/SHINE, STAR, PHENIX, ALICE.





Ratios of kaons to pions in *pp* collisions as functions of $\sqrt{s}$

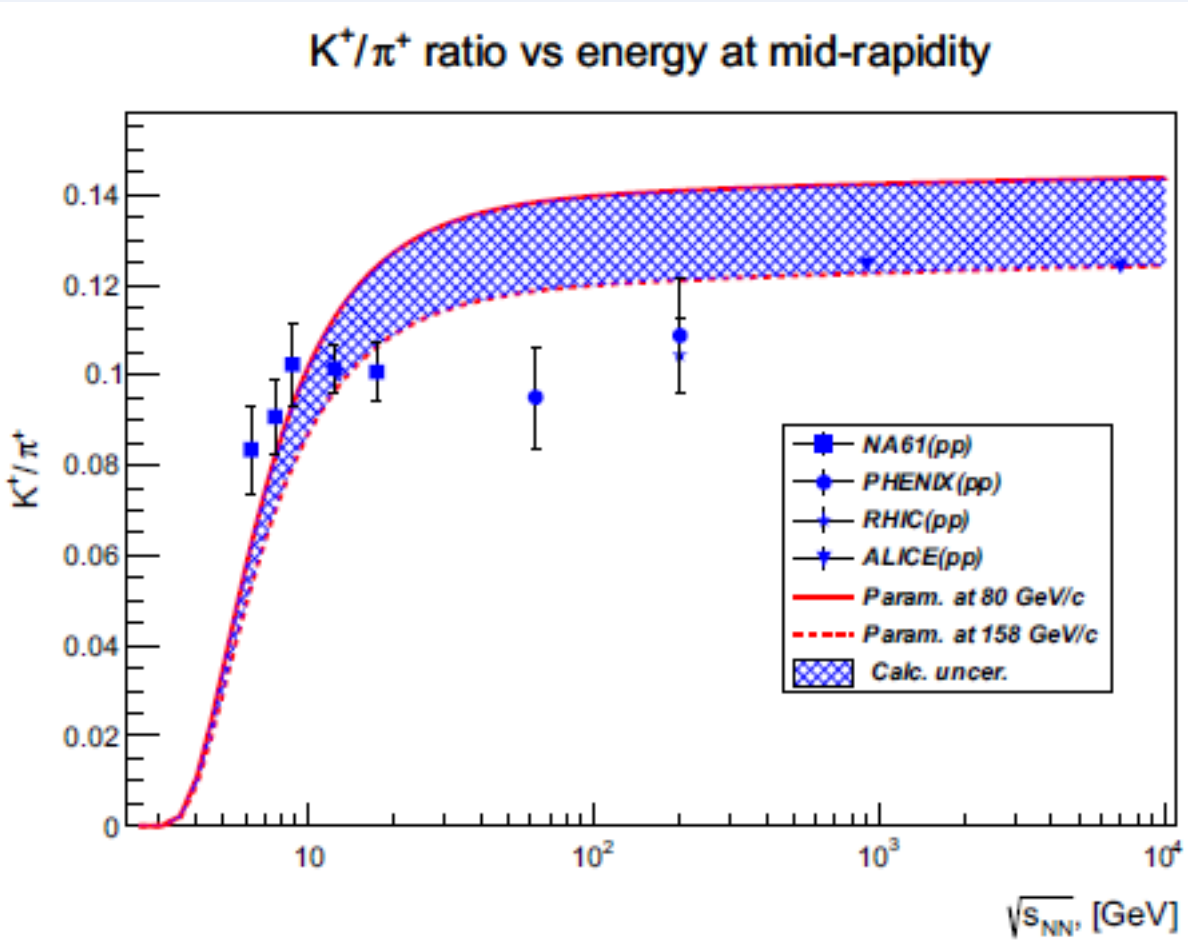


Fig. 4 The ratio between yields of K^+ and π^+ mesons produced in *pp* collisions as a function of $\sqrt{s}$

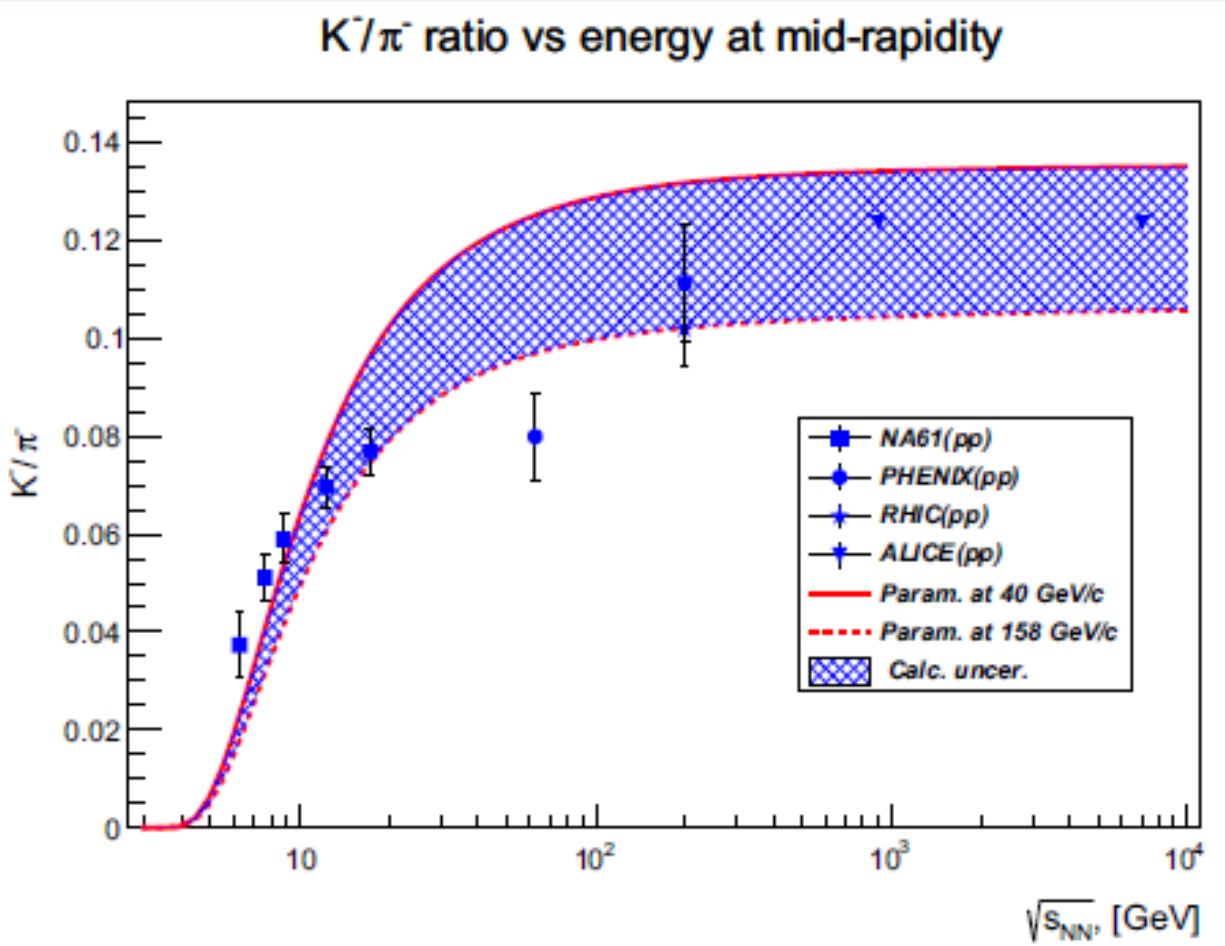
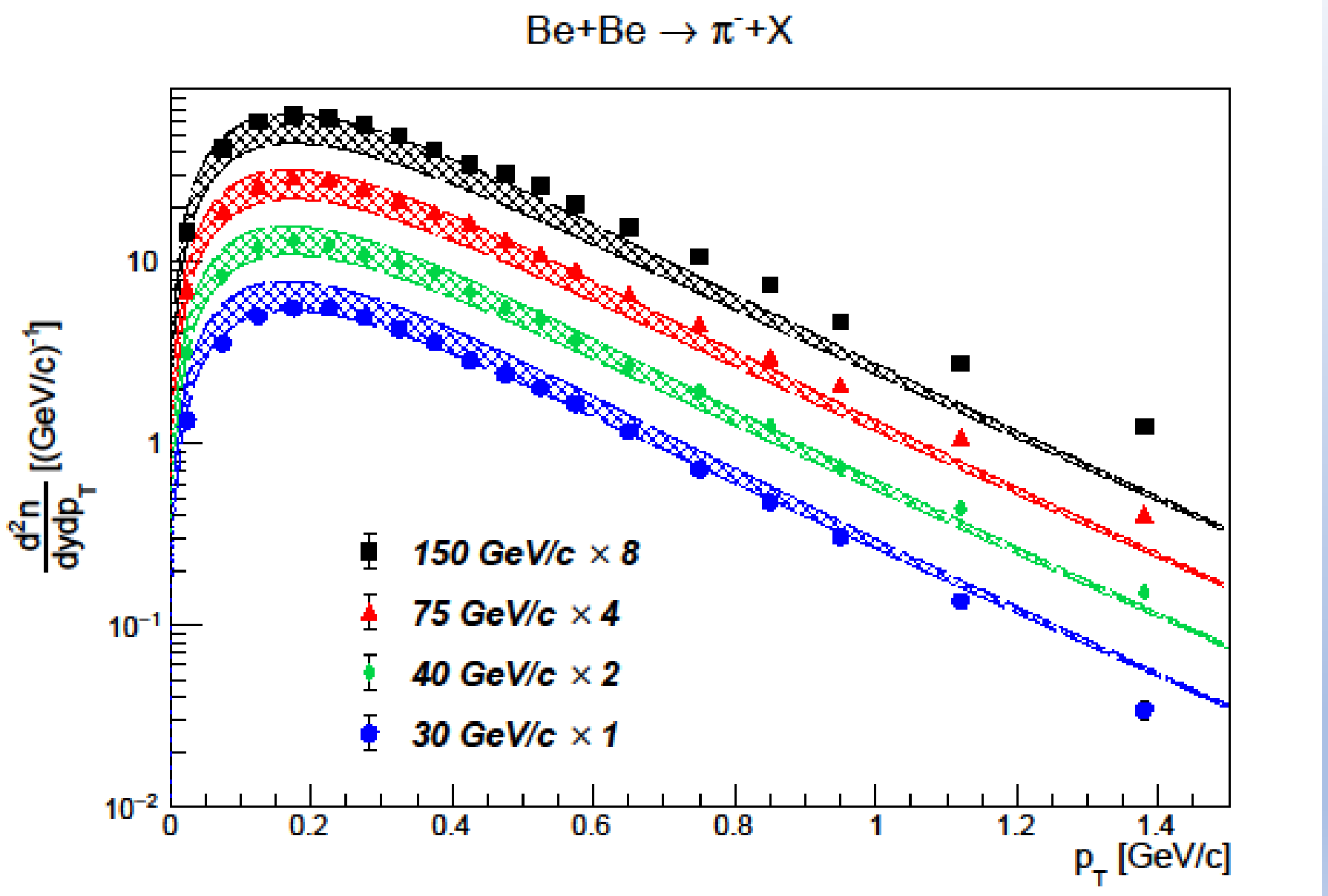


Fig. 5 The ratio between yields of K^- and π^- mesons produced in *pp* collisions as a function of $\sqrt{s}$

G. I. Lykasov, A. I. Malakhov, A. A. Zaitsev Eur. Phys. J. A (2021) 57:91

Description of π spectra in BeBe collision

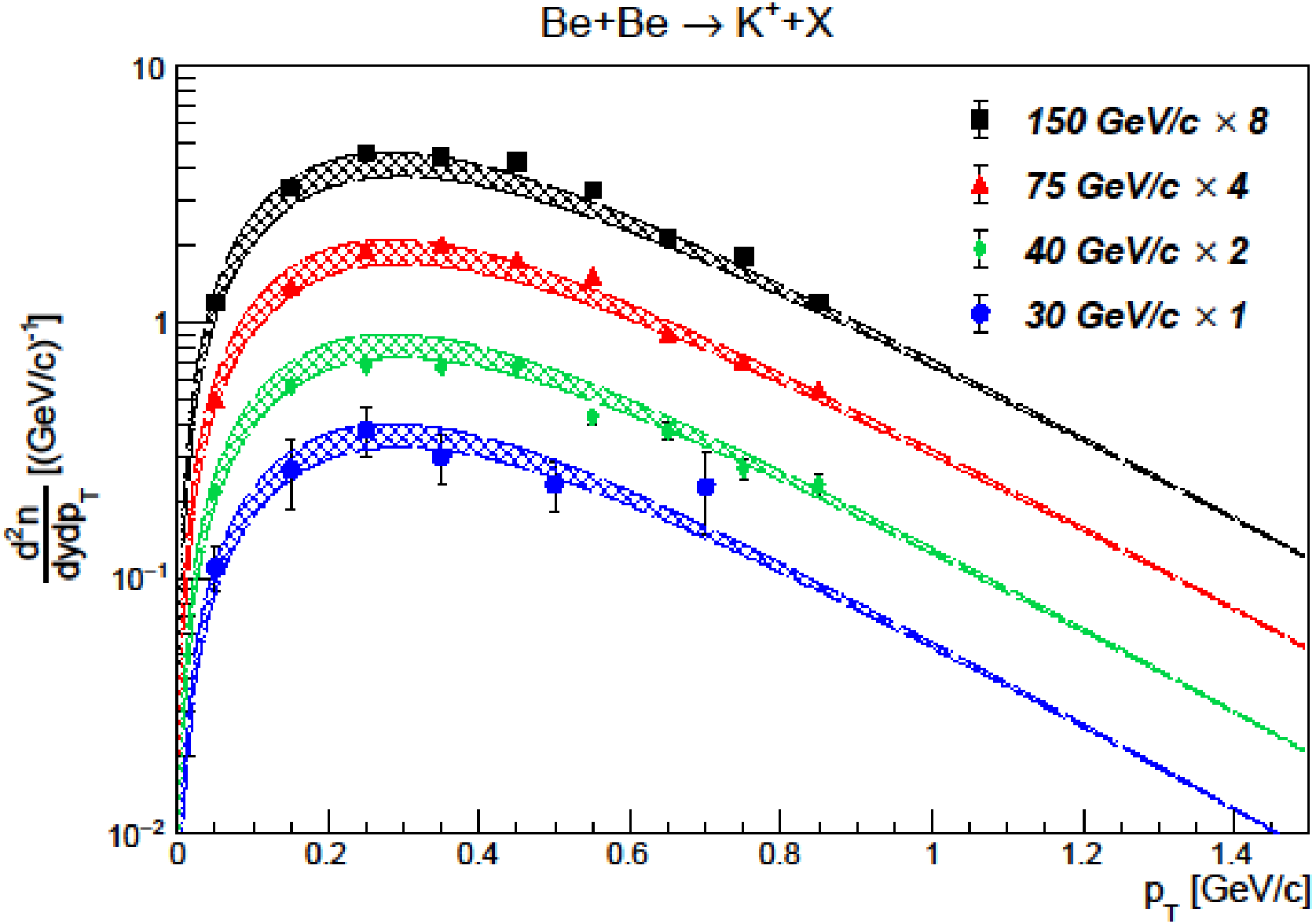


Black line is the quark contribution;

Blue line is the gluon contribution;

Red line corresponds to the sum of the quark and gluon contributions.

Description of K^+ spectra in BeBe collisions

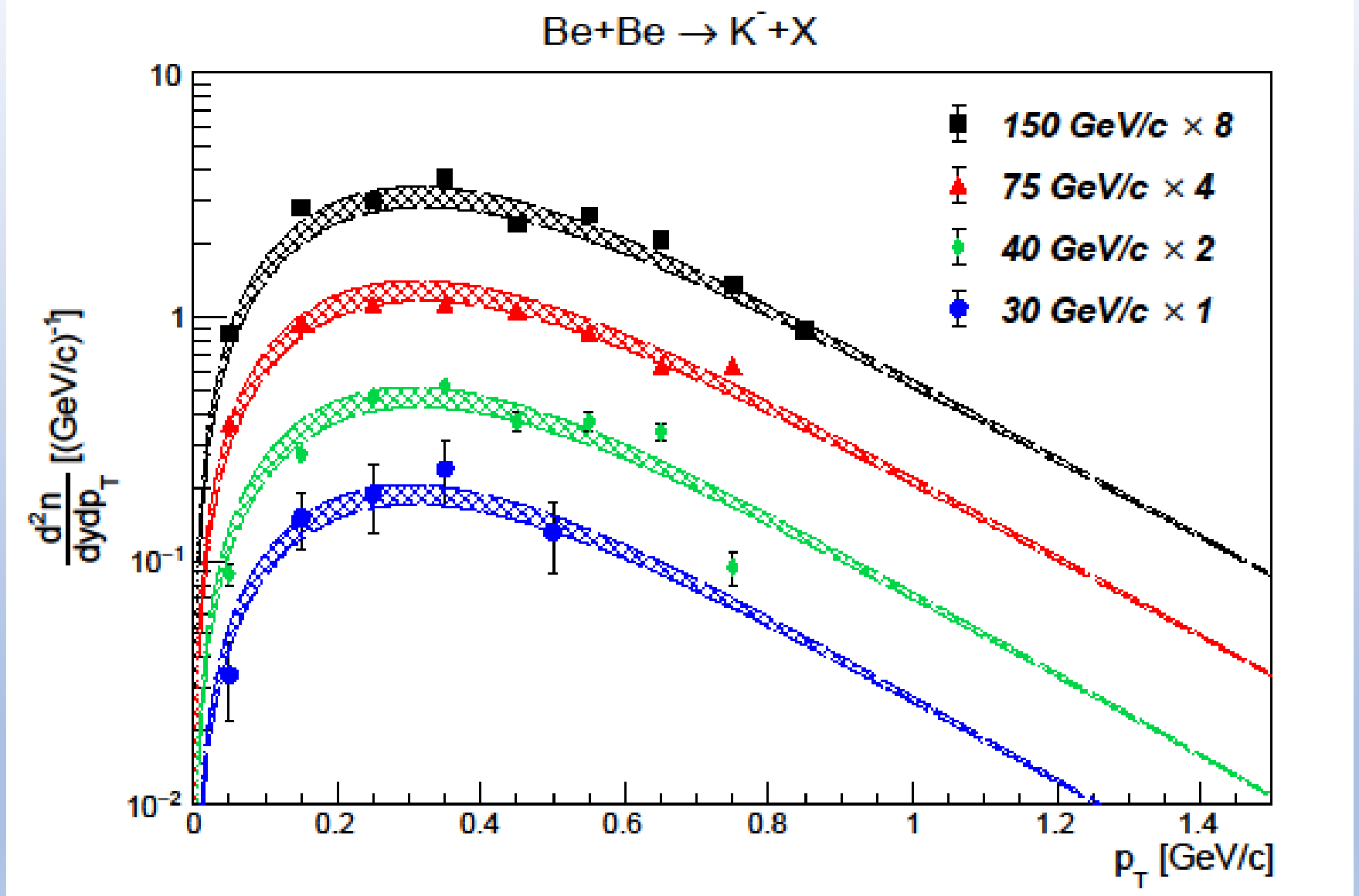


Black line is the quark contribution;

Blue line is the gluon contribution;

Red line corresponds to the sum of the quark and gluon contributions.

Description of K^- spectra in BeBe collisions

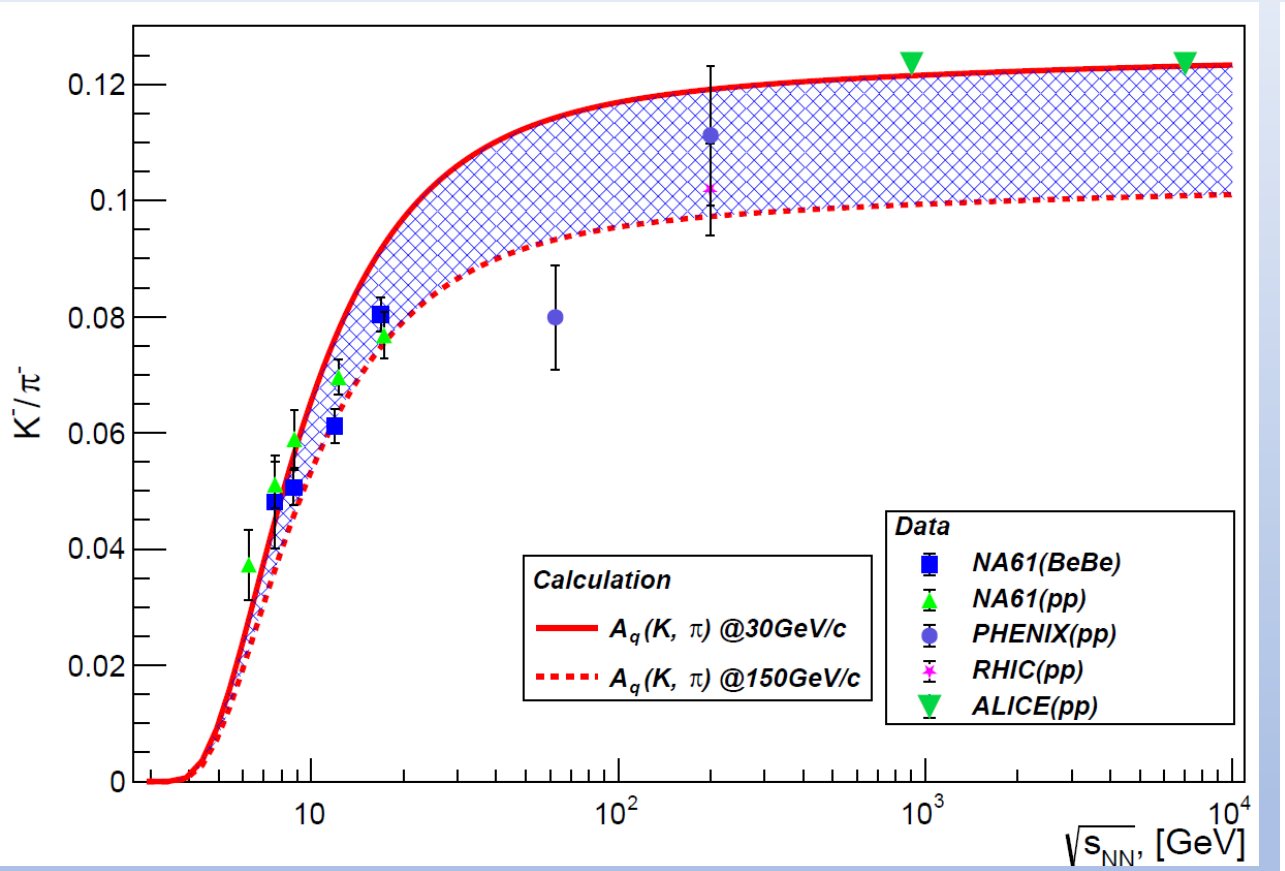


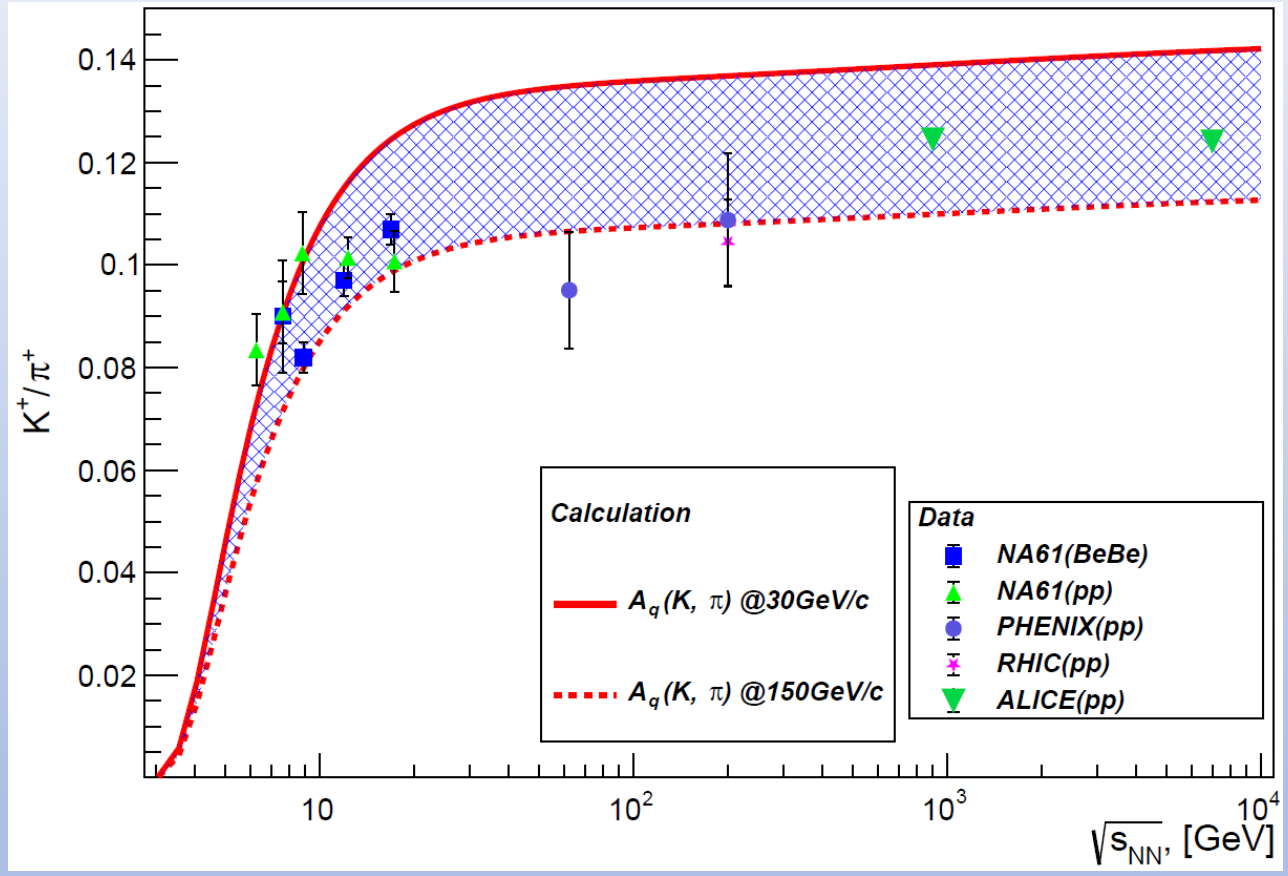
Black line is the quark contribution;

Blue line is the gluon contribution;

Red line corresponds to the sum of the quark and gluon contributions.

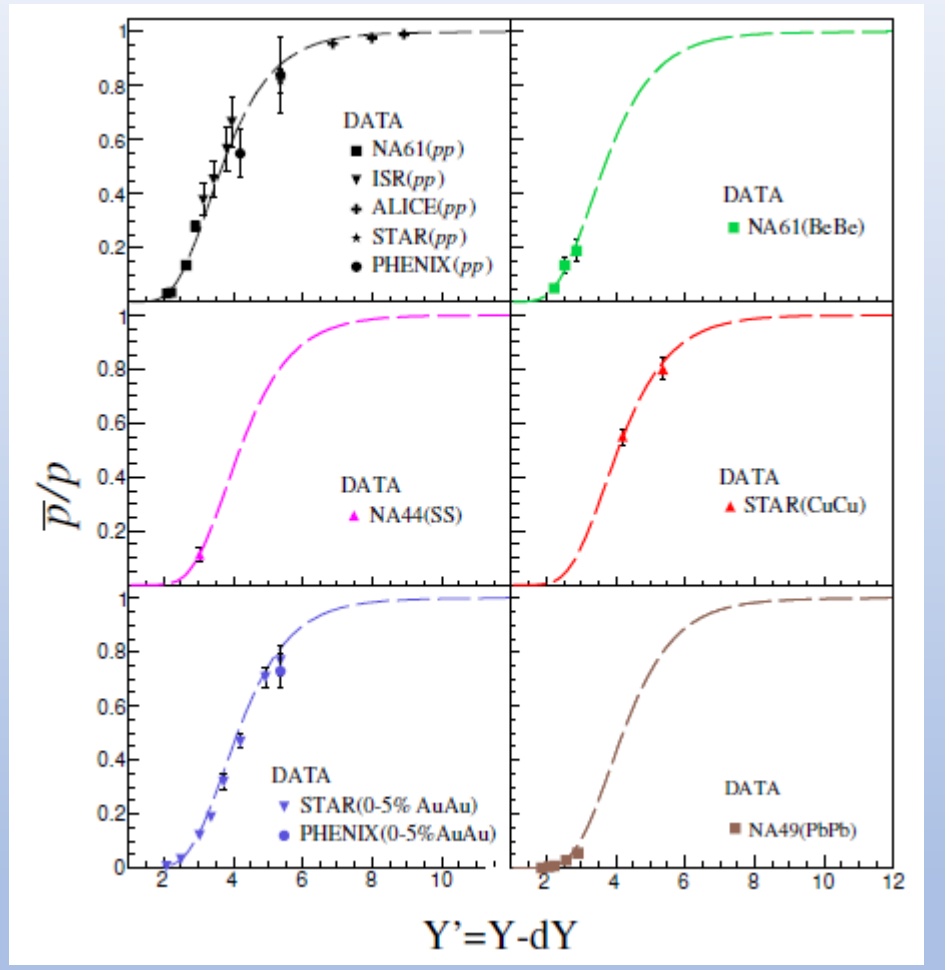
Ratios of kaons to pions as functions of $\sqrt{s}$

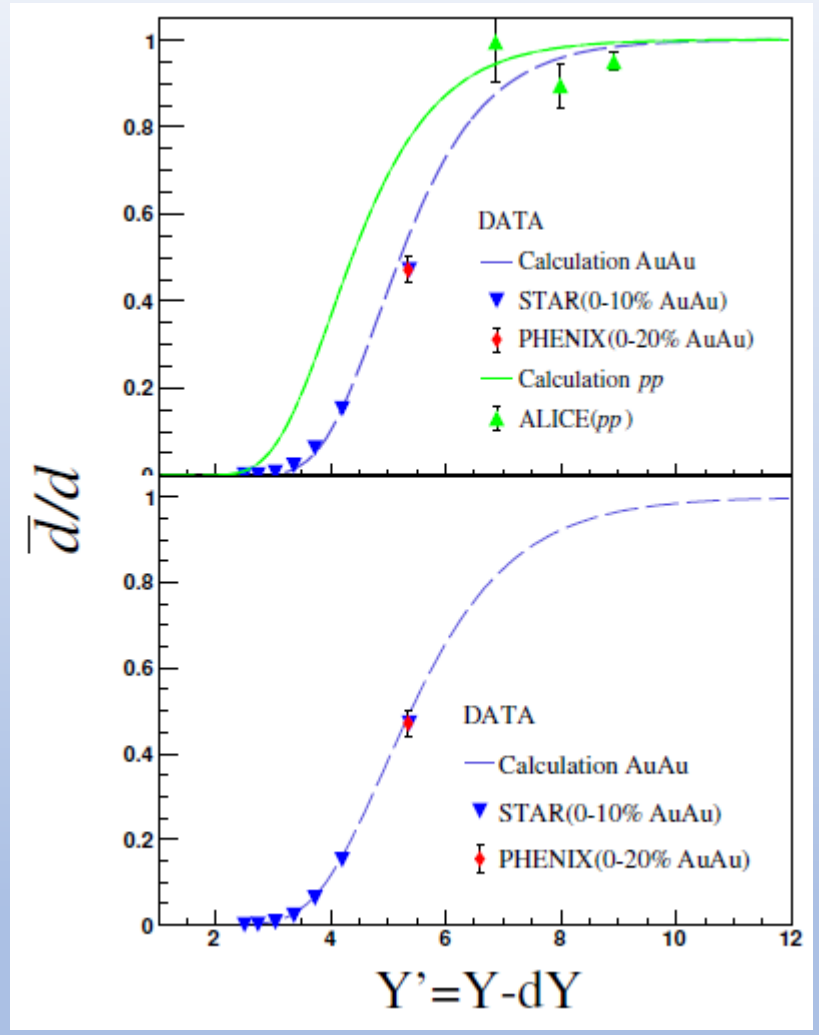


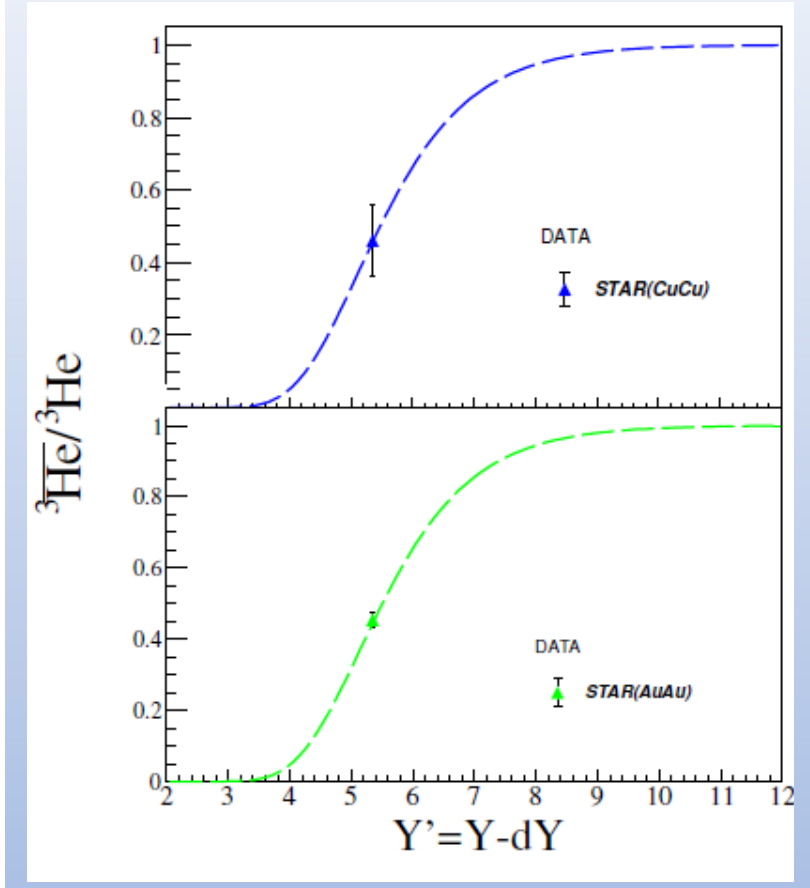


Lykasov G.I., Malakhov A.I. & Zaitsev A.A. Eur. Phys. J. A 58, 112 (2022)

Ratios of antiparticle to particle yields







arXiv:2201.04540v1 [nucl-th]

Summary

- **We have applied the self-similarity approach based on the assumption of the similarity of inclusive spectra of hadrons produced in *AA* collisions at their low transverse momenta and in the mid-rapidity region. To do this, we have modified the simple exponential form of the spectrum and presented it in two parts due to the quark and gluon contributions.**
- **Applying the offered approach to the pion and kaon production in the most 20% central *BeBe* collisions at the mid-rapidity region we have obtained a satisfactory description of p_T spectra of NA61/SHINE data.**
- **We have got rather satisfactory description of ratio yields K^+/π^+ and K^-/π^- as functions of $\sqrt{s}$. The physical reason of their energy dependence happens due to the conservation law of four-momenta and quantum numbers, and also to the Regge behavior of the cross-section.**
- **The approach allows us to describe the ratio of the total yields of anti-nuclei to the nuclei produced in *NN* collisions as a function of $\sqrt{s}$ at y=0.**
- **The future plans are to describe the inclusive spectra of pions and kaons produced in the most central of ArSc, AuAu and PbPb collisions.**

Thank you for the attention!