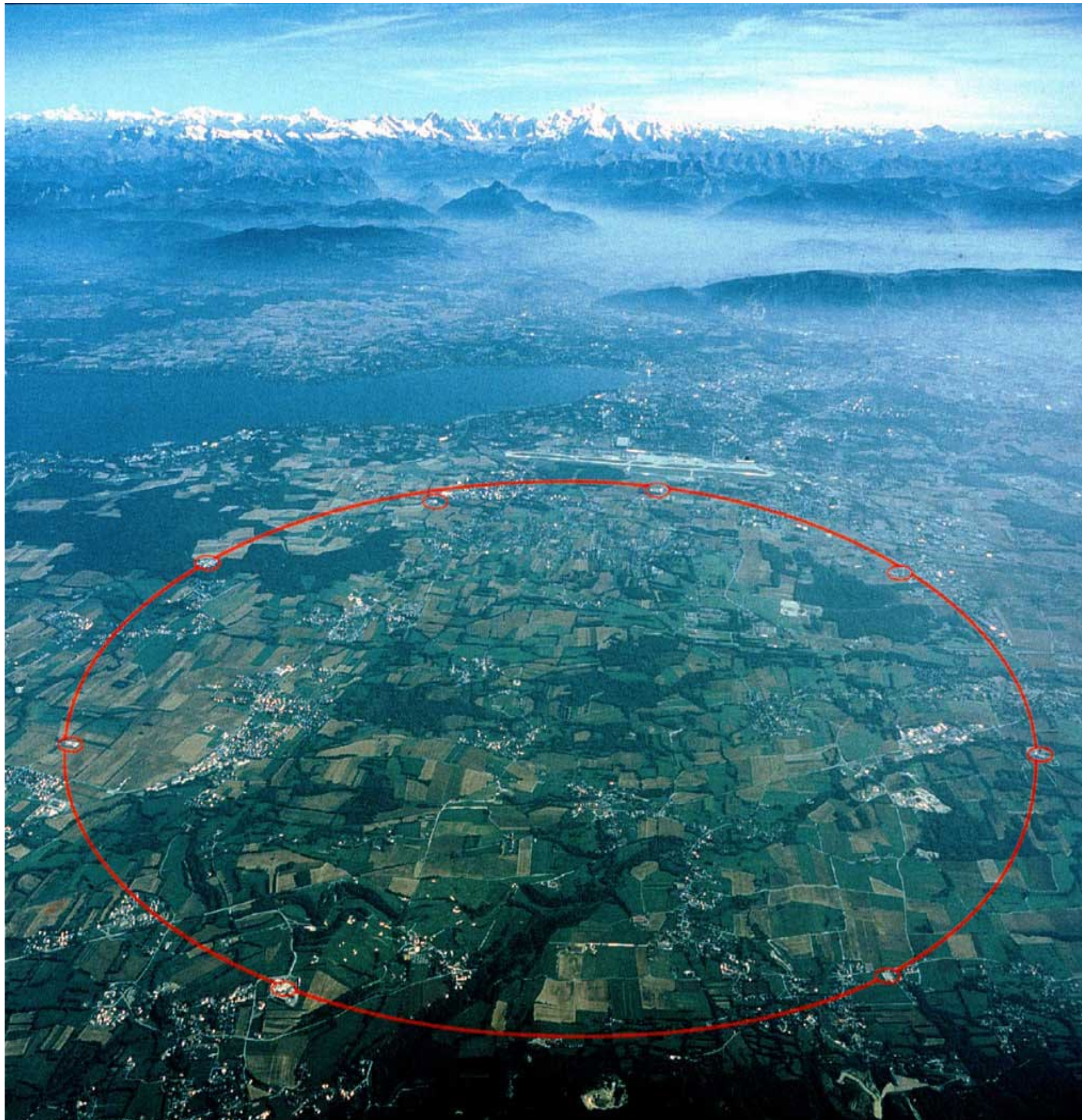
PRODUCTION OF K-MESONS AND ISO-SPIN SYMMETRY IN PP AND AA COLLISIONS



Alexey Guskov, Gennady Lykasov, Alexander Malakhov, Andrey Zaitsev

JINR, Dubna,

OUTLINE

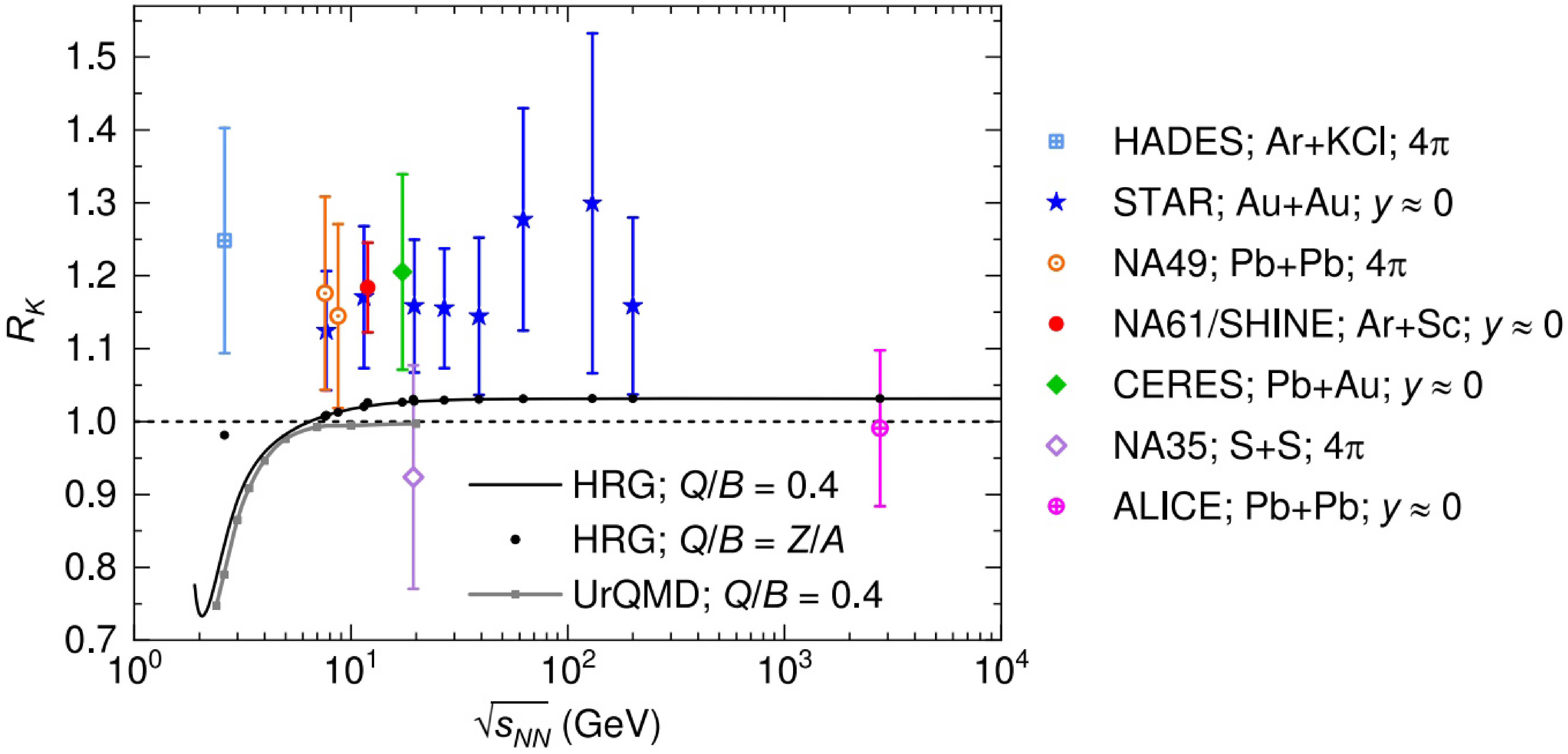
1. Quark- anti quark symmetry and K-meson production in pp and AA collisions
2. Experimental data on the ratio of charge kaons to the neutral ones
3. Similarity approach and the ratio $R_K=(K^+ + K^-)/(2K^0_S)$.
4. Calculation of R_K within Monte Carlo generator.
5. Summary.

FLAVOR SYMMETRY means that the interactions are independent of quark type (flavor), when quarks are massless.

For light quarks up and down it reduces to the Iso-spin symmetry.

The difference $m_d - m_u$ is about 2 MeV, which is much smaller than the QCD scale, Λ_{QCD}, therefore for light quarks the Iso-spin symmetry can be conserved.

For K-meson production it leads to equal numbers of charged ($K^+ + K^-$) and neutral ($K^0 + \overline{K^0}$) mesons in final state.



Here Q is the electric charge, B is the baryon number of a nuleus

Conservation low of four-momenta in A+B->h+X

$$A \ + \ B \rightarrow \ h \ + \ X:$$
$$(N_A P_A + N_B P_B - p_1)^2 = (N_A m_0 + N_B m_0 + M)^2,$$

- where $P_{A,}$ P_B and p_1 are for-momenta of A, B and produced hadron h, respectively. M is the particle mass providing the conservation of the quantum numbers.

Similarity function

$$\Pi = \min \frac{1}{2}\sqrt{(u_A N_A + u_B N_B)^2},$$ from minimisation principle $$\frac{d\Pi}{dN} = 0$$ (1)

Here u_A and u_B are four-velocities of A and B; N_A and N_B are the fractions of four-momentum transmitted by A and B.

The exact solution of Eq.(1) at the rapidity y = 0 and $N_A = N_B$ = N is the following:

$$N = \frac{\Pi}{\cosh(Y)} \equiv \frac{2m_0\Pi}{\sqrt{s}}$$

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- ## Inclusive hadron spectrum in A-B collisions

$$Ed^3\sigma_{AB}/d^3p = A_A^{\alpha(N_A)} \cdot A_B^{\alpha(N_B)} \cdot F(\Pi)$$

where $\alpha(N_A) = 1/3 + N_A/3$, $\alpha(N_B) = 1/3 + N_B/3$

For quark and gluon contributions in proton

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

where

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

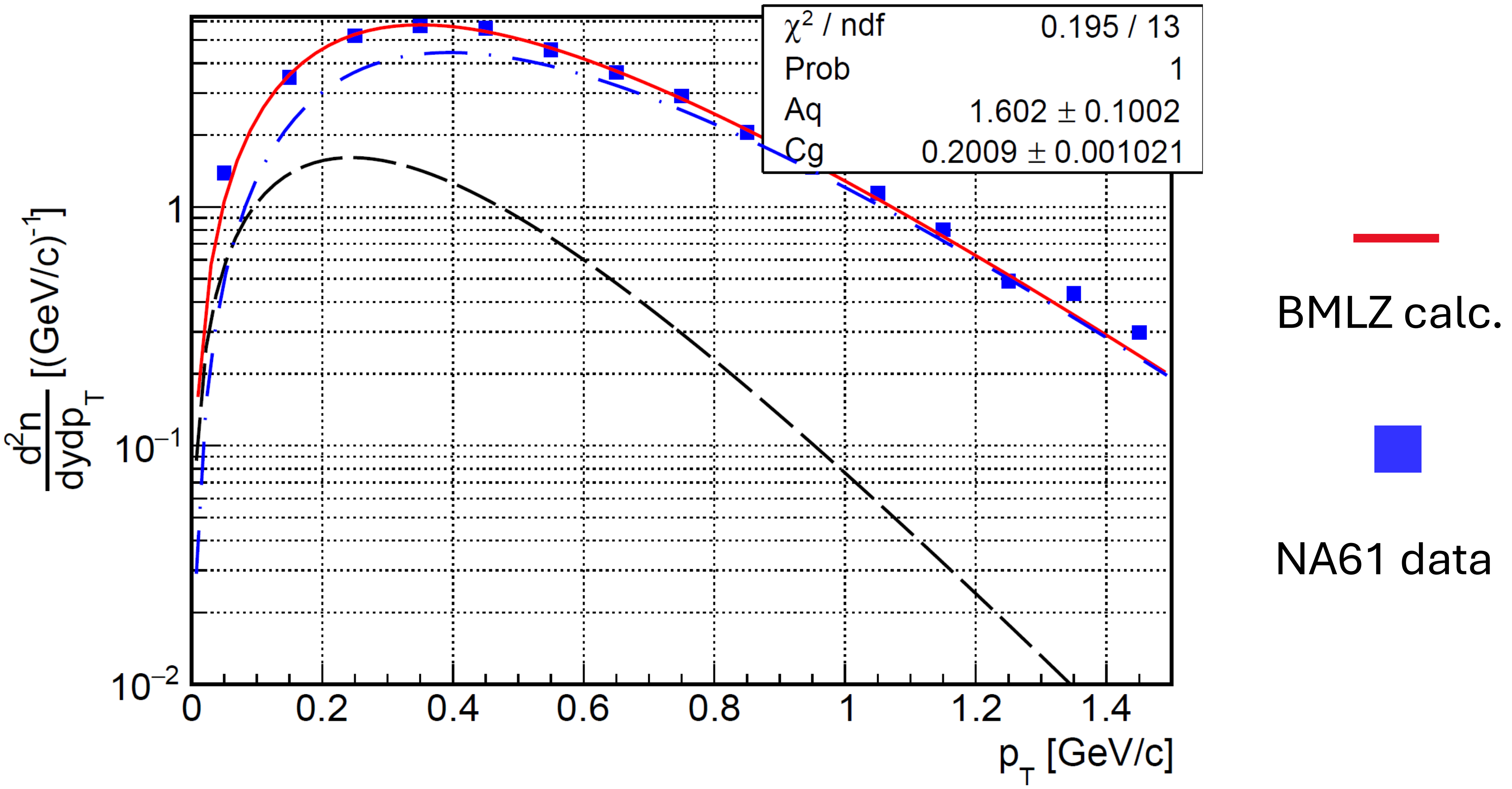
For antinuclei $M = m_1$ and for K^--mesons $M = m_1 = m_K$, m_K is the mass of the K-meson. For nuclear fragments $M = -m_1$. For K^+-mesons $m_1 = m_K$ and $M = m_\Lambda - m_0$, $\delta h = 1 - sth/s$

For π-mesons $m_1 = m_\pi$ and $M = 0$.

m_Λ is the mass of the Λ-baryon.

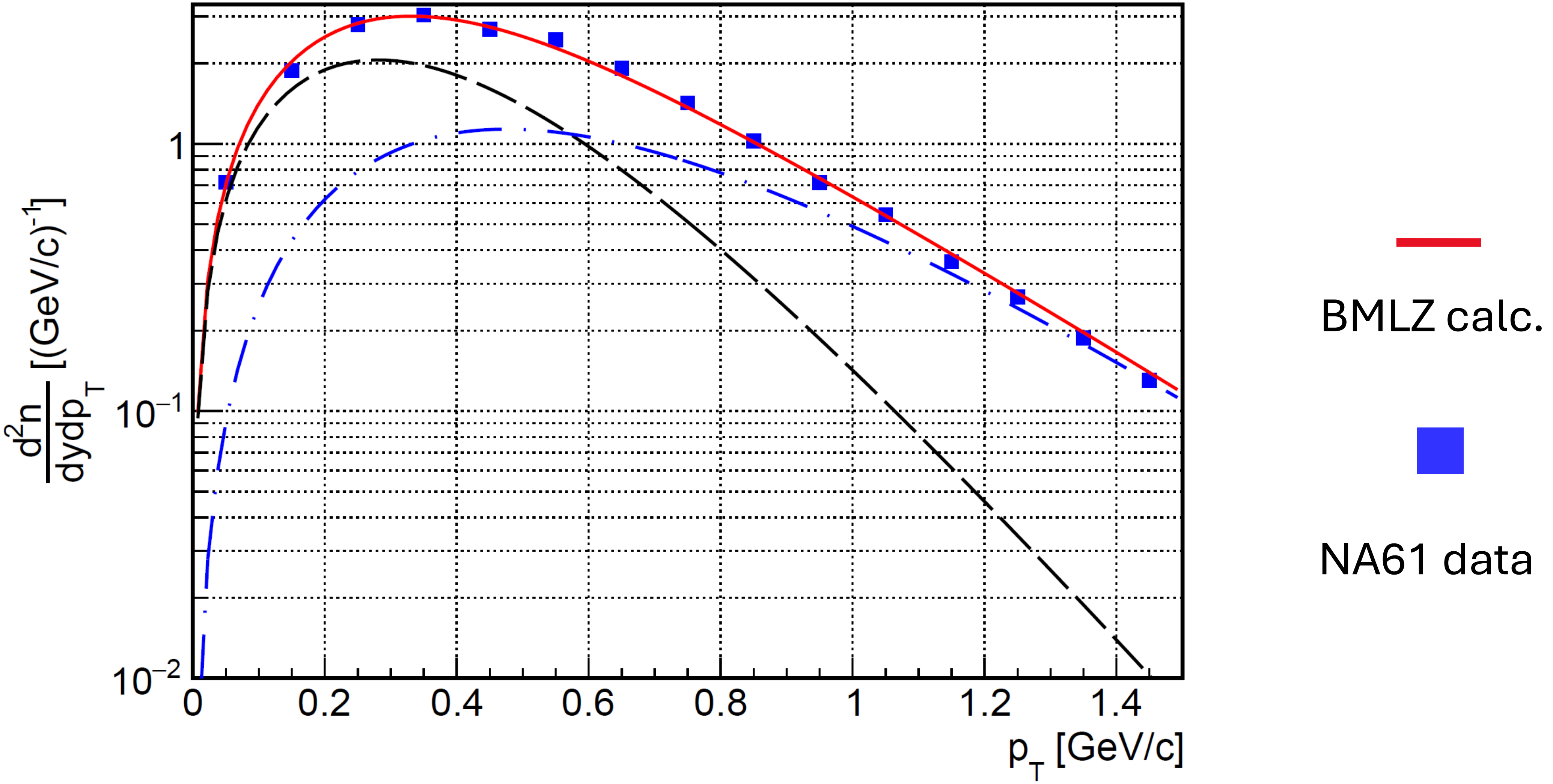
Ar+Sc → K^+ +X at 80A GeV/c

(BMLZ means Baldin, Malakhov, Lykasov, Zaitsev)



The black dashed line is the quark contribution, the blue dashed line is the gluon contribution, the red line is the sum of these contributions.

Ar+Sc → $K^- + X$ at 80A GeV/c



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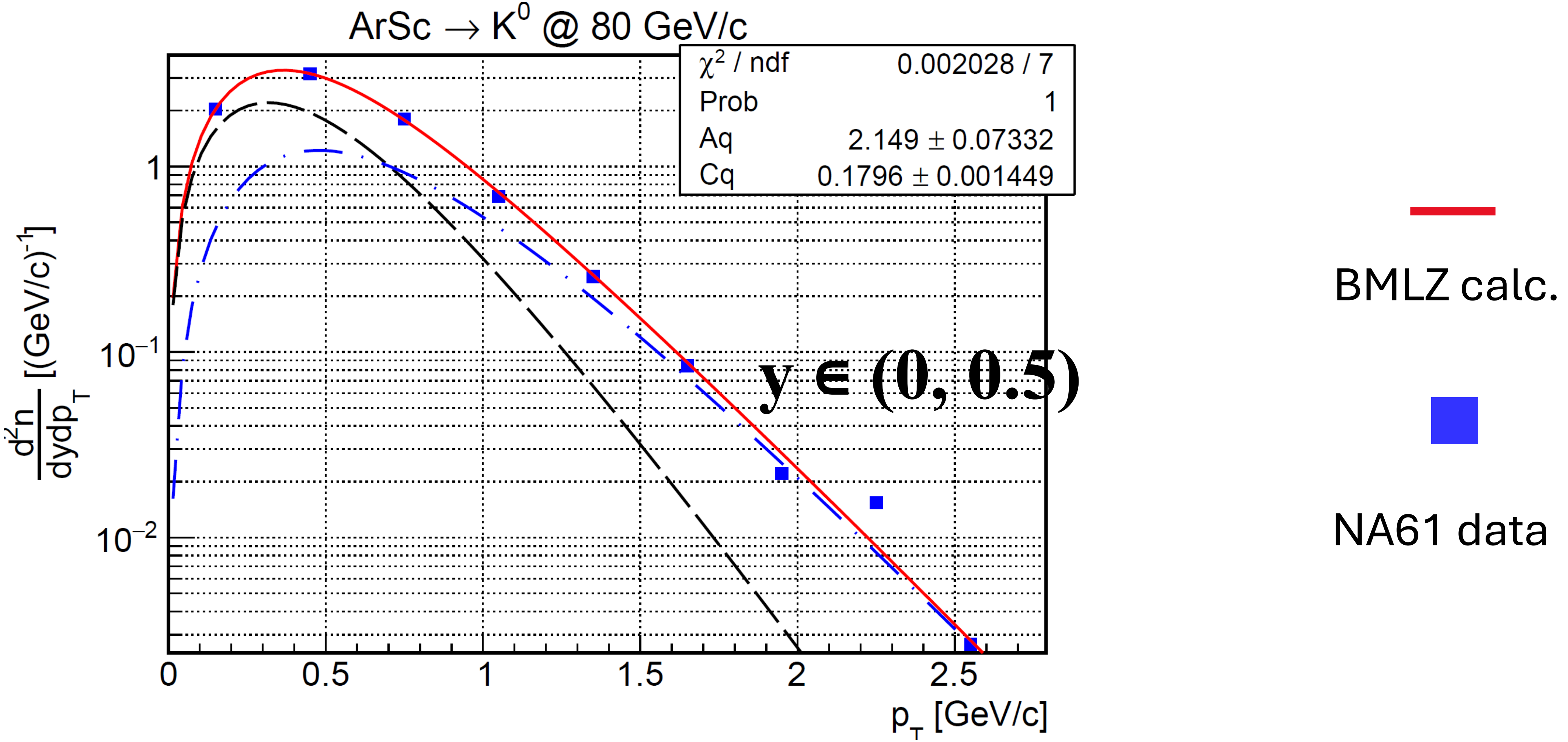
Ar+Sc → K^0+X at 80A GeV/c



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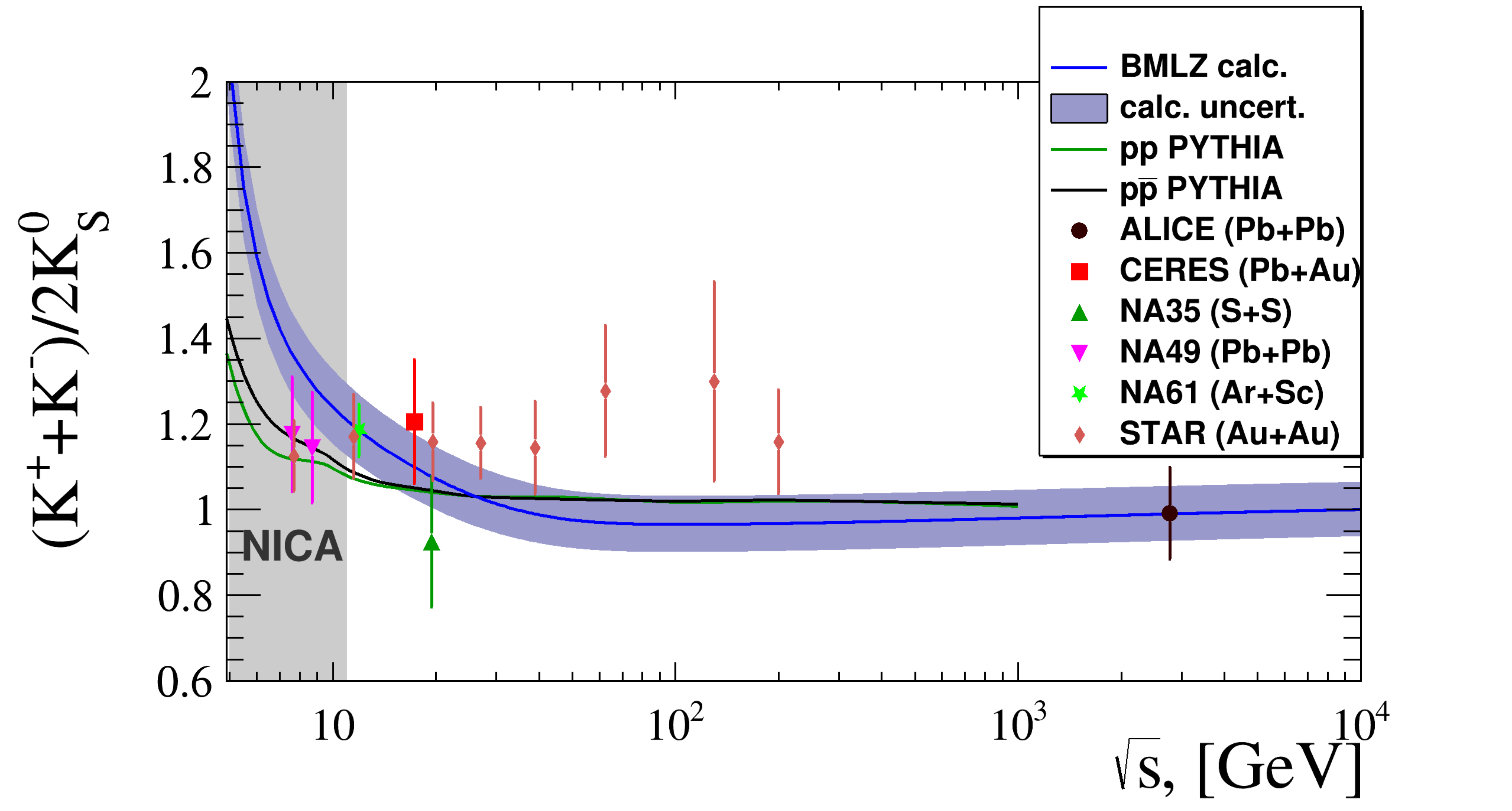


BMLZ calc.
calc. uncert.
pp PYTHIA
p$\bar{p}$ PYTHIA
ALICE (Pb+Pb)
CERES (Pb+Au)
NA35 (S+S)
NA49 (Pb+Pb)
NA61 (Ar+Sc)
STAR (Au+Au)
NICA
$(K^+ + K^-)/2K^0_S$
$\sqrt{s}$, [GeV]
0.6
0.8
1
1.2
1.4
1.6
1.8
2
10
10^2
10^3
10^4

ALTERNATIVE APPROACH ON $R_K > 1$

W. Brylinski, et al, ArxiV:2312.0717 V2 [nucl-th]

$$R_K = R_K^{(0)} + (m_d - m_u)/\Lambda_{QCD}\, R_K^{(1)} + \ldots,$$

where $R_K^{(0)} = 1$, it corresponds to the iso-spin symmetry (md =mu). $R_K^{(1)}$ is the fitting function.

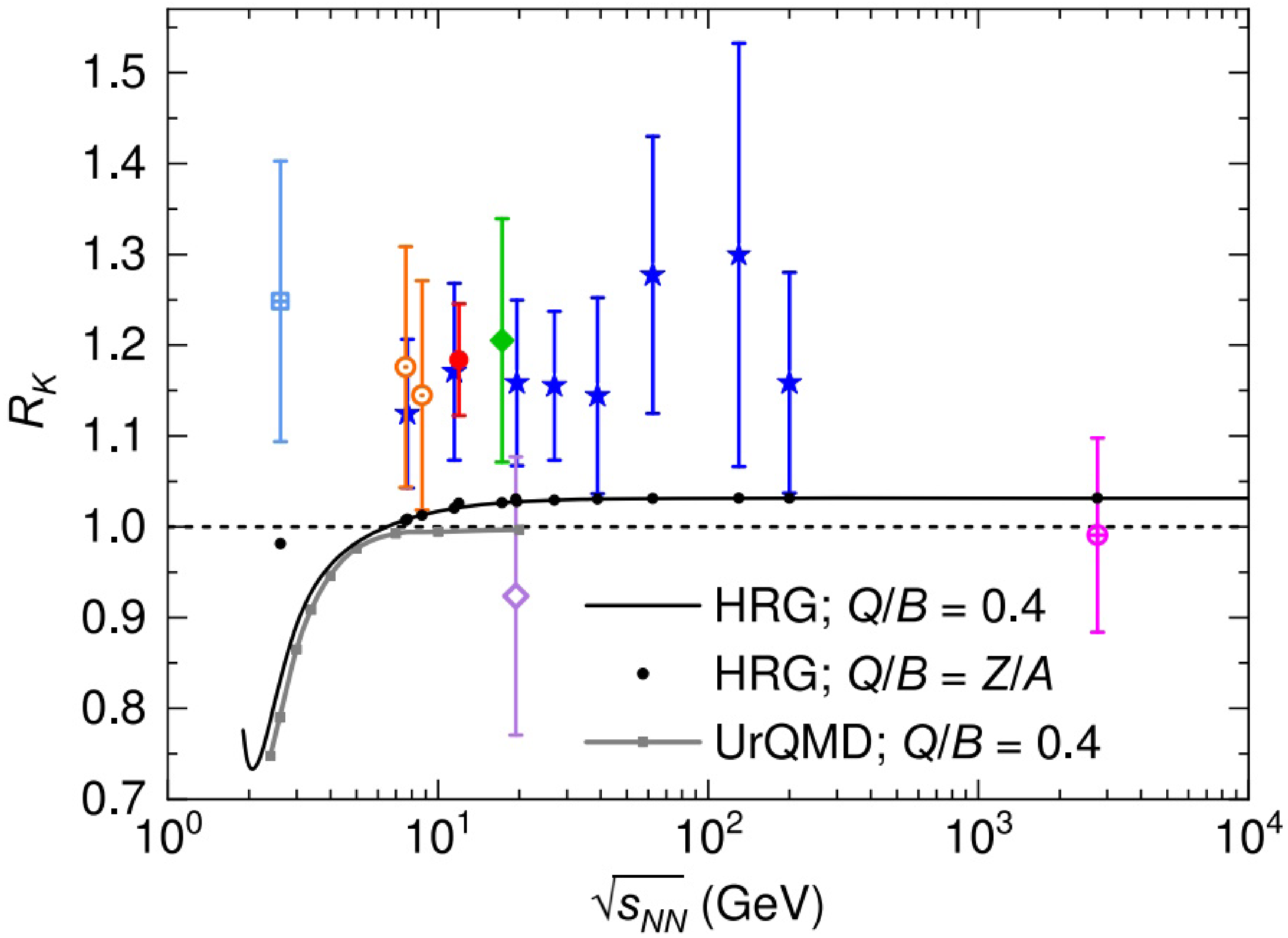
Let us note that $(m_d - m_u)/\Lambda_{QCD}$ is about 0.01; here $\Lambda_{QCD} = 250$ MeV.

1) It can not explain the world data on $R_K = 1.2\text{-}1.3$.
2)The UrQMD and HRG models also contradict to these data.

The NA61/SHINE, et al., suggest the violation of isotop-spin symmetry, according to the world experimental data on $R_K > 1$ at $s^{1/2} < 200$ GeV and asymptotically $R_K \to 1$

The NA61/SHINE Collaboration, F. Giacosa, M. Gorenstein, R. Poberezhniuk, S. Samanta, Nature Communication, 16, p.2849 (2025).

$R_K = (K^+ + K^-)/(2K^0_S)$



R_K
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
10^0
10^1
10^2
10^3
10^4
√s_NN (GeV)
HRG; Q/B = 0.4
HRG; Q/B = Z/A
UrQMD; Q/B = 0.4

SUMMARY

1 . The production of K^+ meson in pp and AA collisions appears together with Λ^0 baryon due to the strangeness conservation ($M = m_{\Lambda^0} - m_0$). K^- meson is produced together with K^+ ($M=m_K$). This is the main reason that $R_K > 1$ at low and middle energies. When $M/\sqrt{s}\,\delta h \ll 1$, $R_K = 1$.

2. In our approach and within the MC generator Pythia the energy dependence of R_K can describe the world data on R_K satisfactorily at 6 GeV$<s^{1/2}<$40 GeV and y=0. There is an excess at 40-50bGeV$<s^{1/2}<$200 GeV of STAR data at big error bars over our calculations. In this calculation we do not suggest the iso-spin symmetry violation.

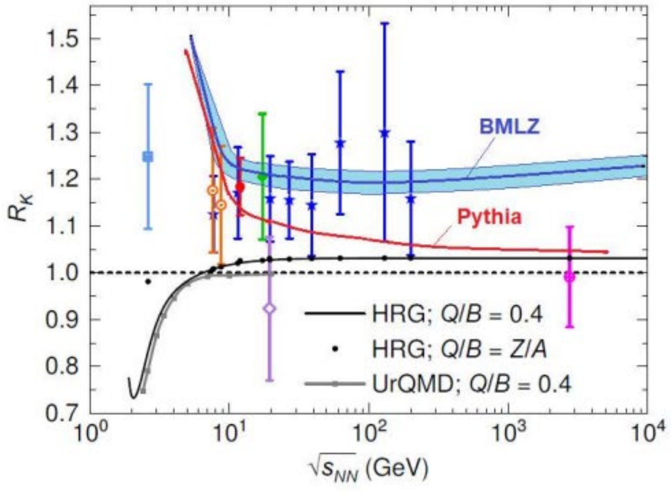
3. Asymptotically at large $s^{1/2}$ R_K goes to 1.

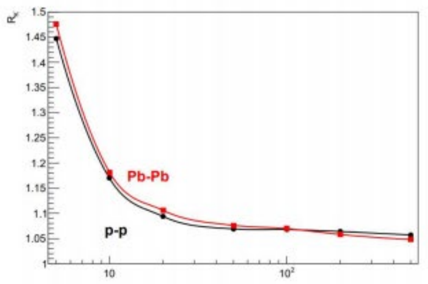
4. Therefore, it is desirable to check the isospin-symmetry violation by improving the measurement accuracy

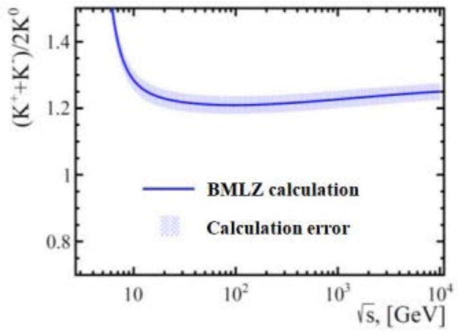
THANK YOU VERY MUCH FOR YOUR ATTENTION !

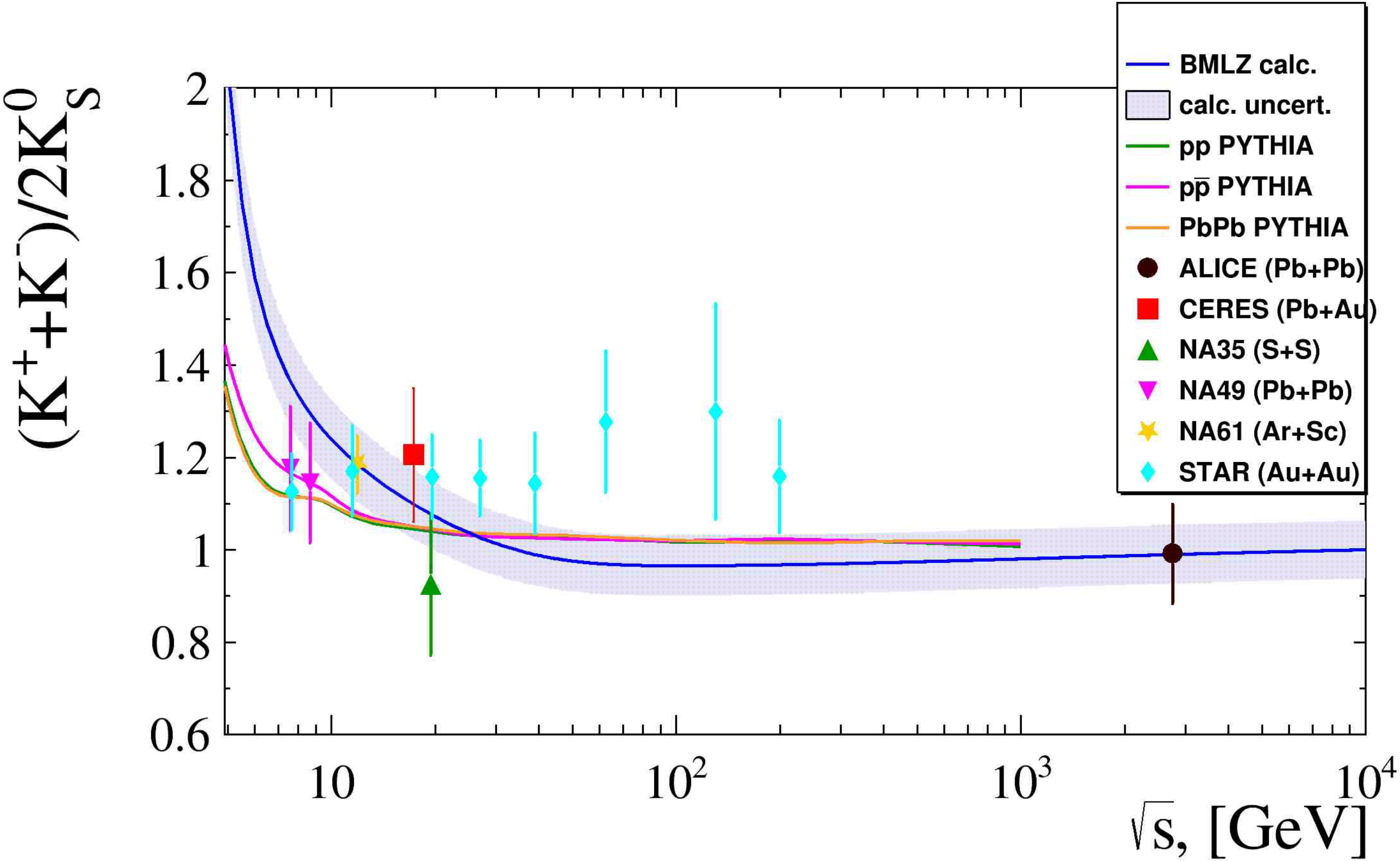
BACK UP

Ratio $R_K = (\sigma_{K+} + \sigma_{K-})/(2\sigma_{K0s})$









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STAR (Au+Au)
$(K^+ + K^-)/2K^0_S$
2
1.8
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1.2
1
0.8
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10
10^2
10^3
10^4
$\sqrt{s}$, [GeV]