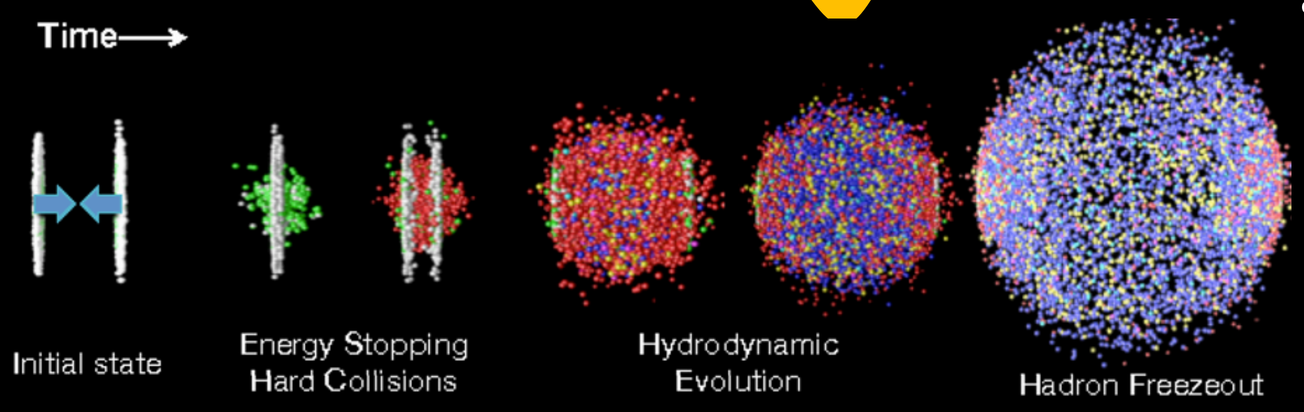
Instituto de Ciencias Nucleares UNAM

Thermodynamics properties of the system created in relativistic heavy ion collisions



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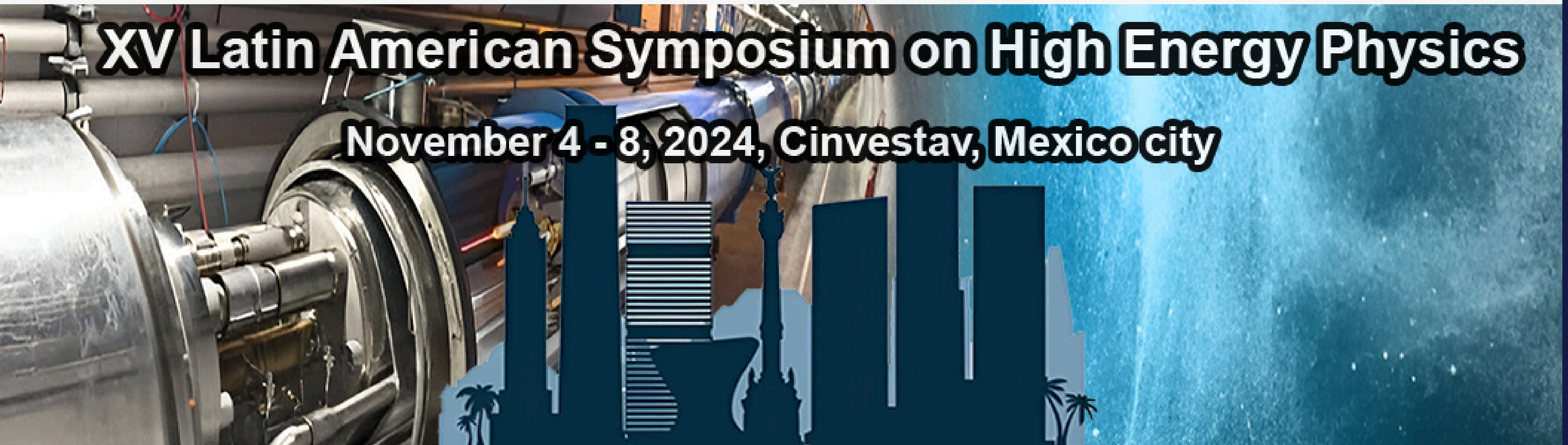

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Outline

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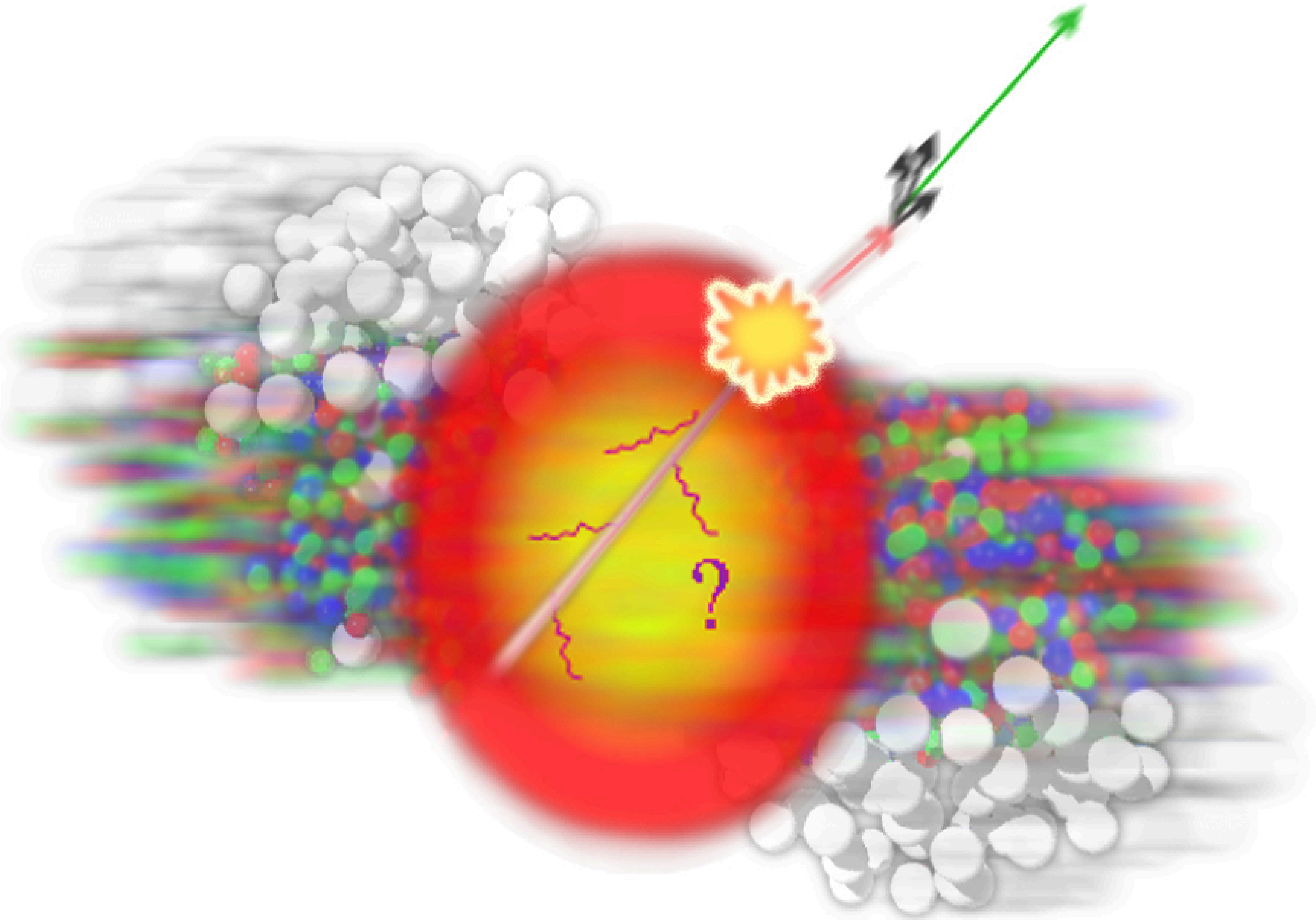
- Model
- Results
- Conclusions



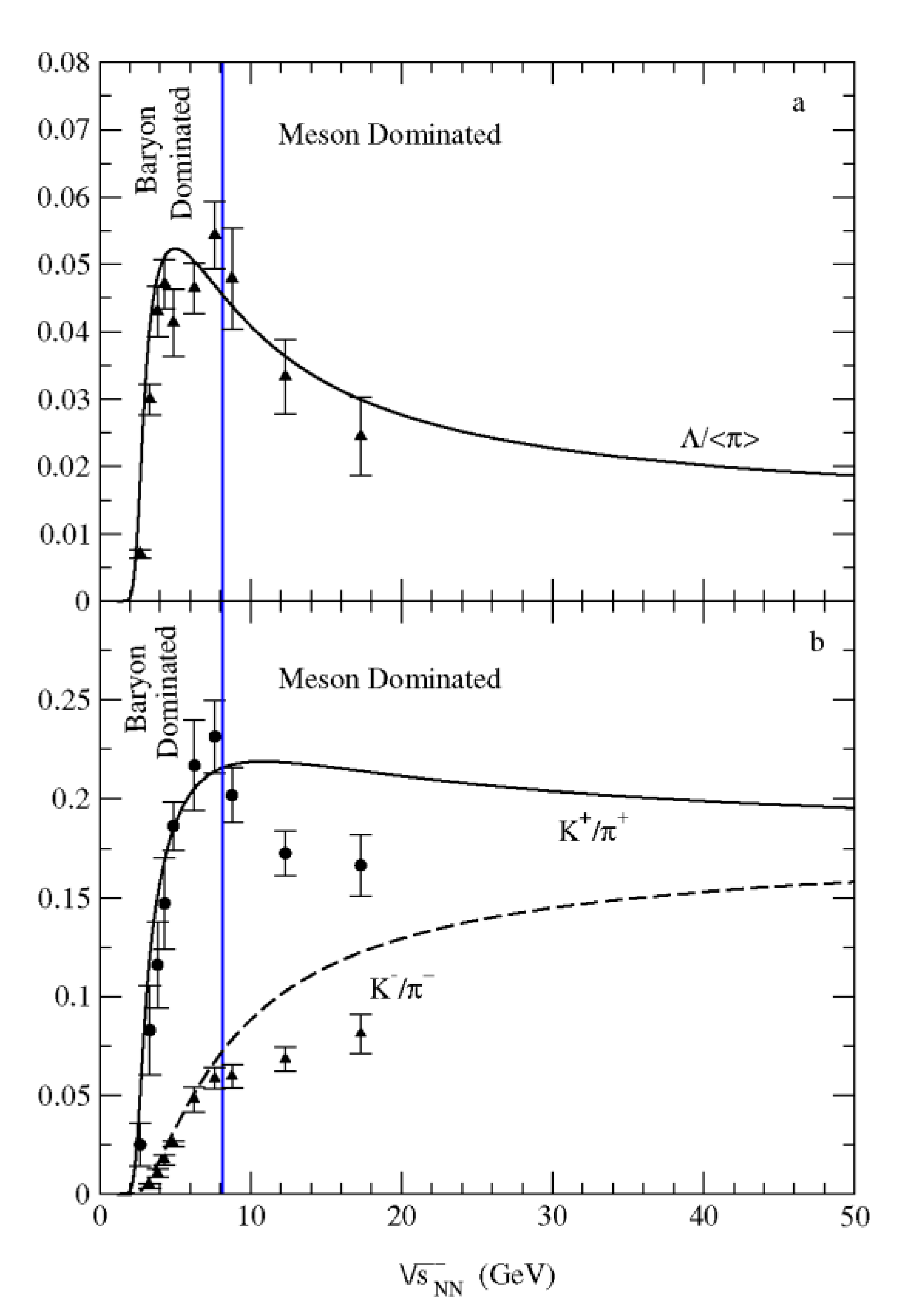
Motivation

The horn structure on the baryon to meson and meson to meson ratios

Experiments at NA49, RHIC, and recently ALICE, have reported a strongly interacting medium, known as sQGP.

To understand it, we analyze particle ratios with strangeness, as seen in the NA49 horn experiment.

This work studies strangeness production using a statistical model to describe fireball properties across centralities.



J. Cleymans, et. al, Phy. Letter. C.15.52 (2005)

Model

Thermus:
The grand-canonical ensemble

THERMUS has 3 different modes. In this work, we use the grand canonical ensemble. It is the most appropriate mode because it allows us to create a more realistic evolution of the fireball.
The software uses multiplicities as input and allows us to extract parameters and densities.

Parameters

$$T_{ch} \quad \mu_B \quad \mu_s \quad \gamma_s \quad R$$

Partition Funcion

$$\ln Z^{GC}(T, V, \mu_i) = \sum_{species\, i} \frac{g_i V}{(2\pi)^3} \int d^3p \ln(1 \pm e^{-\beta(E_i - \mu_i)})^{\pm 1}$$

g_i Degeneracy

i hadron species

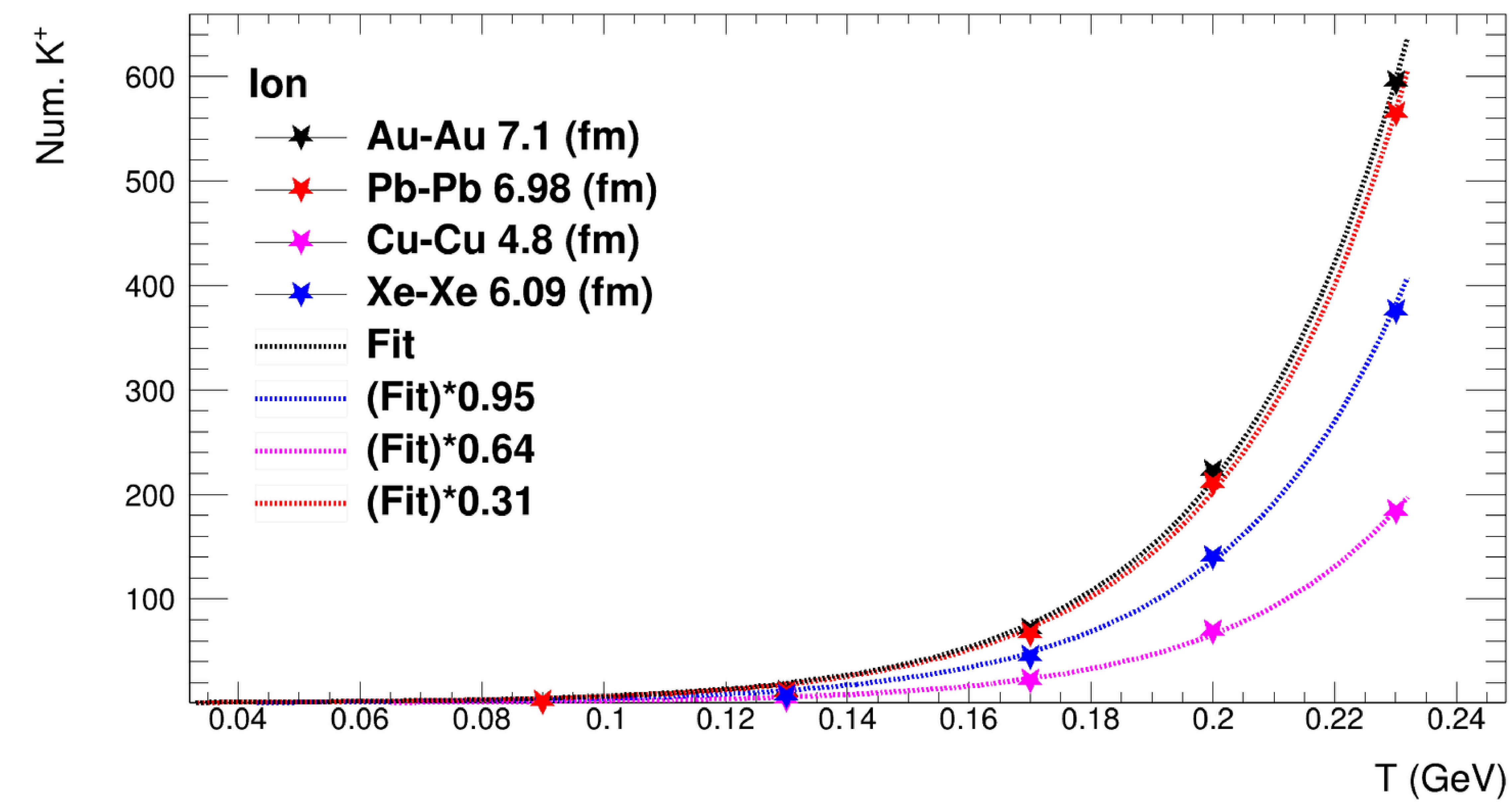
$$\beta = 1/T$$

$$E = \sqrt{p^2 + m_i^2}$$

$$\mu_i = B_i\mu_B + S_i\mu_S + Q_i\mu_Q$$

Results

Kaon Multiplicity as a function of the Temperature



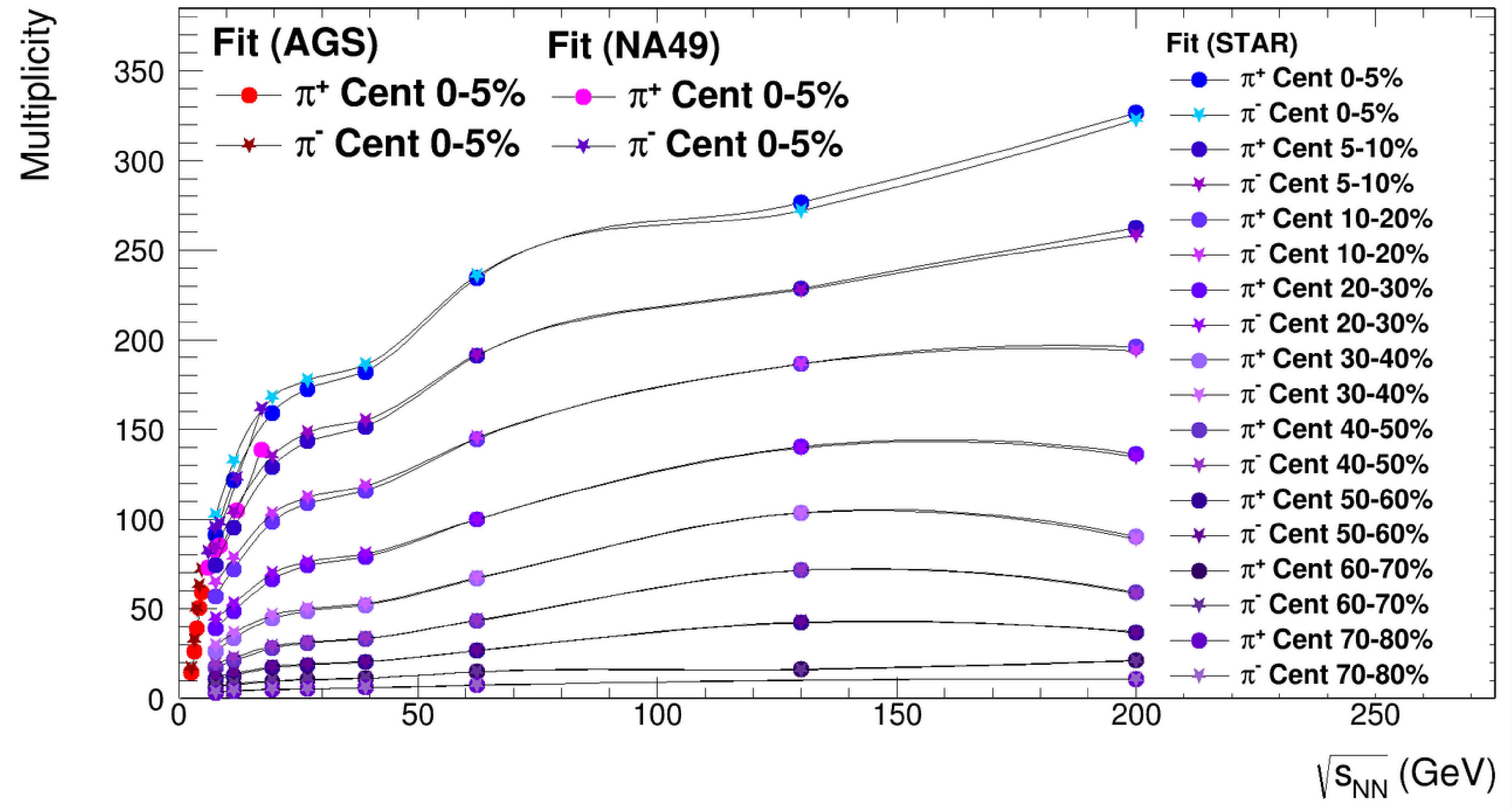
$$Fit = 0.00364(e^{4.1277+34.242\sqrt{s_{NN}}}))$$

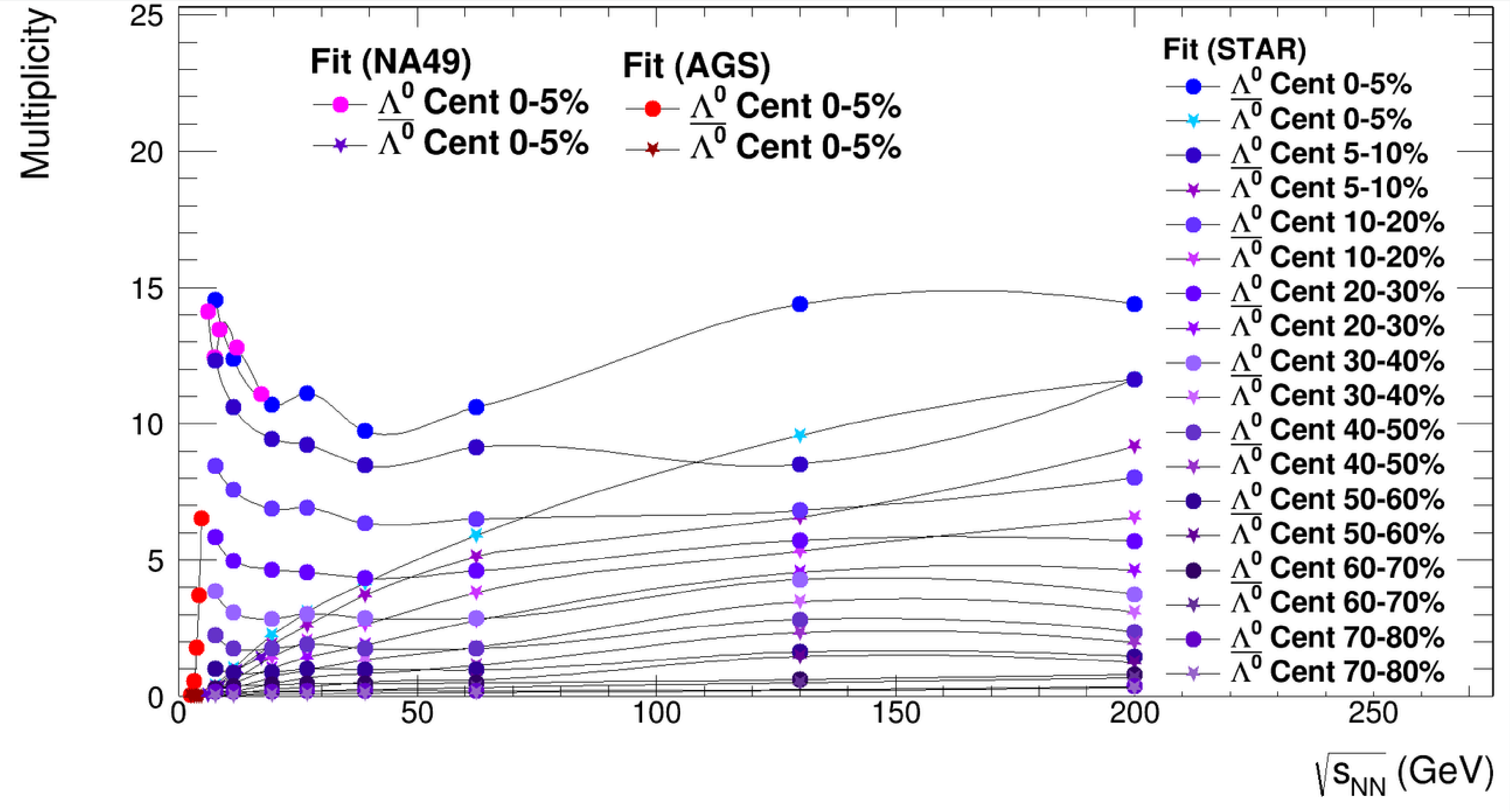
The model allows computing the multiplicity for the different radius of the system created in the collision, which means different ions colliding.

Multiplicity

Used multiplicities data from AGS(Au-Au), NA49 (Pb-Pb) and STAR (Au-Au). For particles without strangeness, particles, and antiparticles have almost equal constant growth.
For particles containing strangeness, it is shown that the particulates have a peak near 7.7 GeV, after saturation, but for antiparticles, the growth is constant.

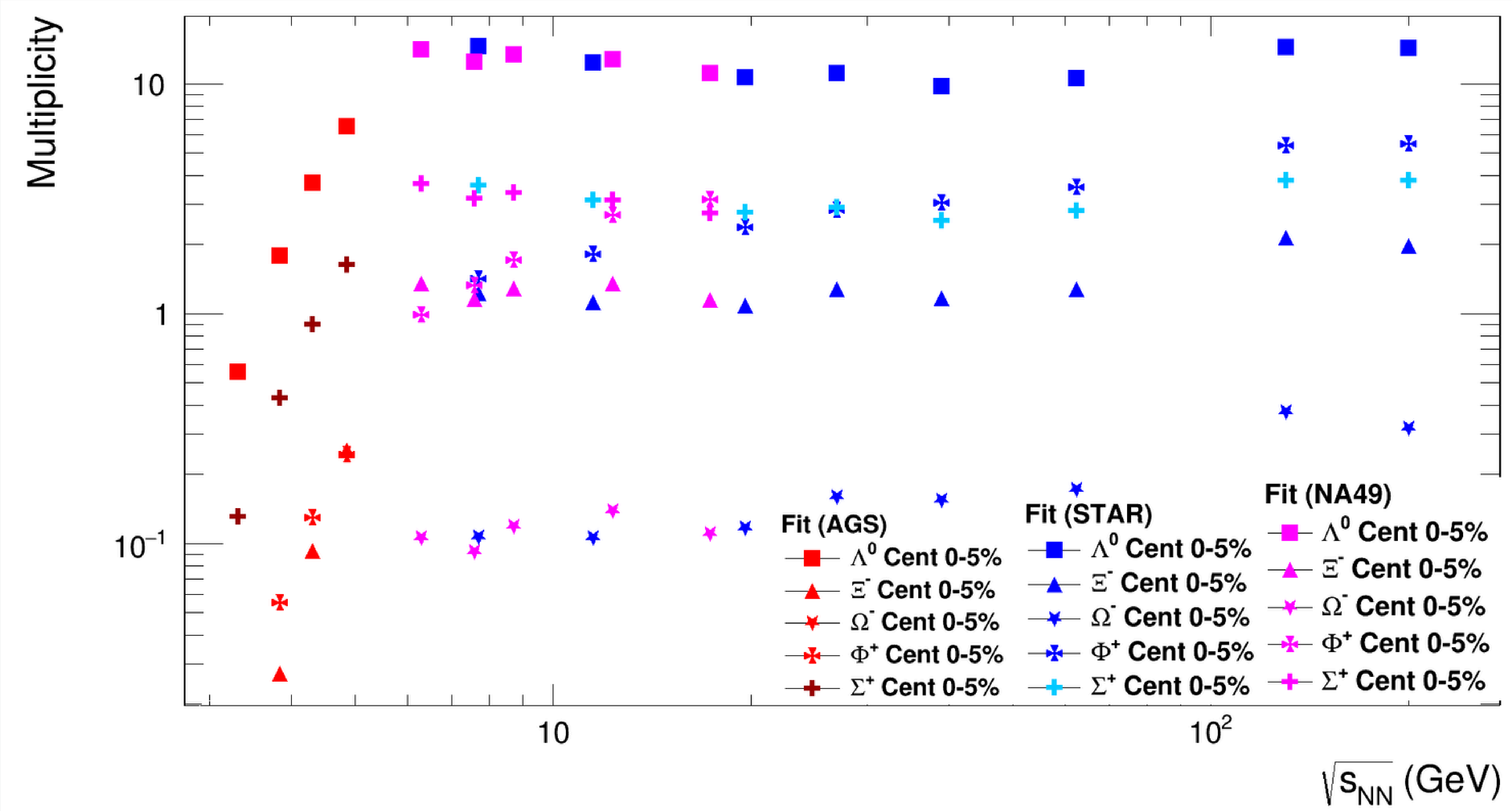
$$N_i^{GC} = T\frac{\partial \ln Z^{GC}}{\partial \mu_i}$$





Multiplicity for strangeness

- In particles with strangeness, an abrupt production ratio is observed at low energy, which then tends to saturate.
- Despite not having reported multiplicities oddly like the omegas, it is possible to find multiplicities as presented here



$\Lambda^0(uds)$ $\Phi(s\bar{s})$ $\Xi^-(dss)$

$\Sigma^+(uus)$ $\Omega^-(sss)$

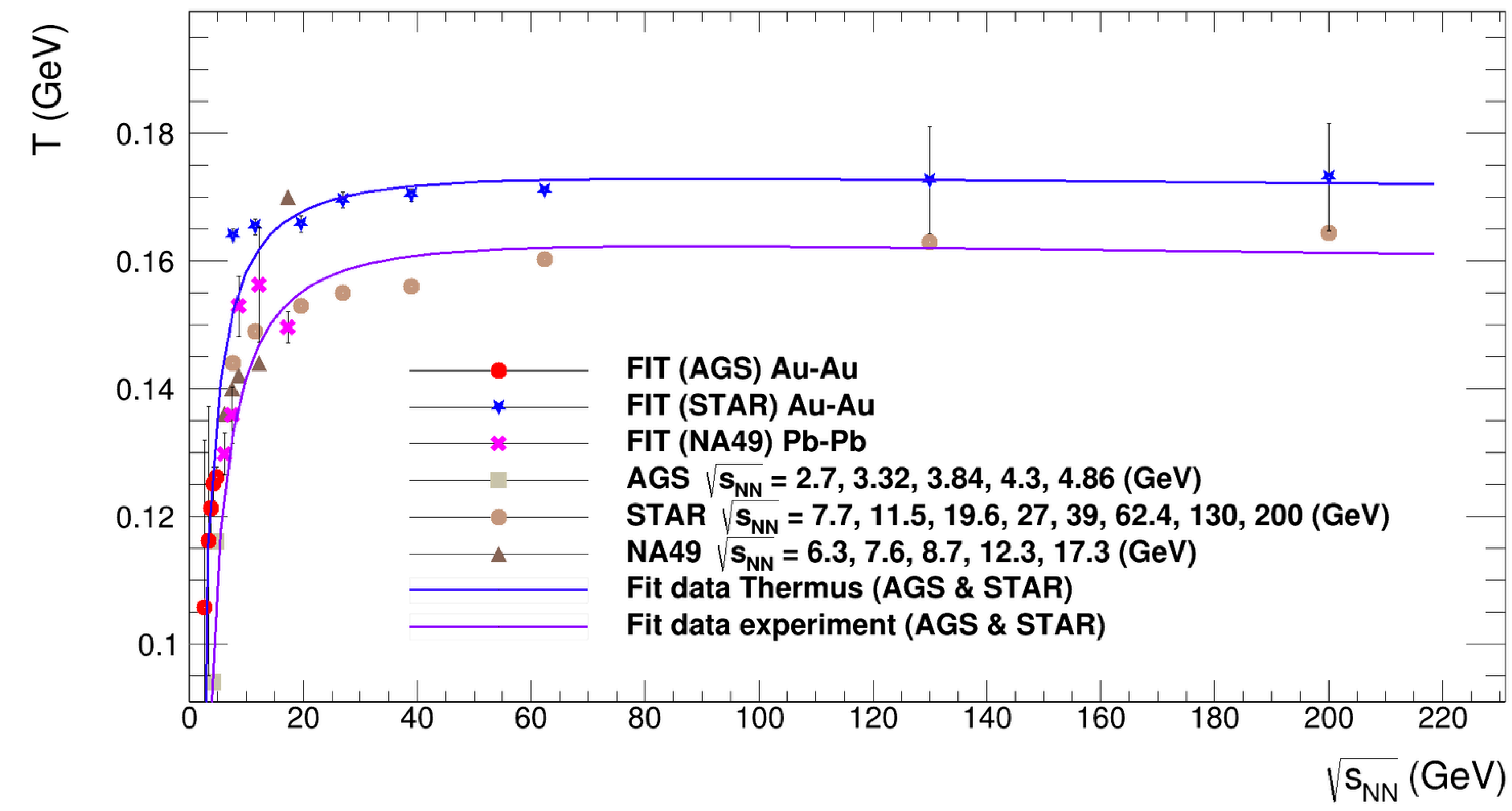
Extracting temperature from data

Various parameters can be extracted from the input data, such as the fireball's temperature.

$$T_{model} = 0.182 + \frac{(-0.322)}{(\sqrt{s_{NN}})} + (-0.00513)\ln(\sqrt{(\sqrt{s_{NN}})})$$

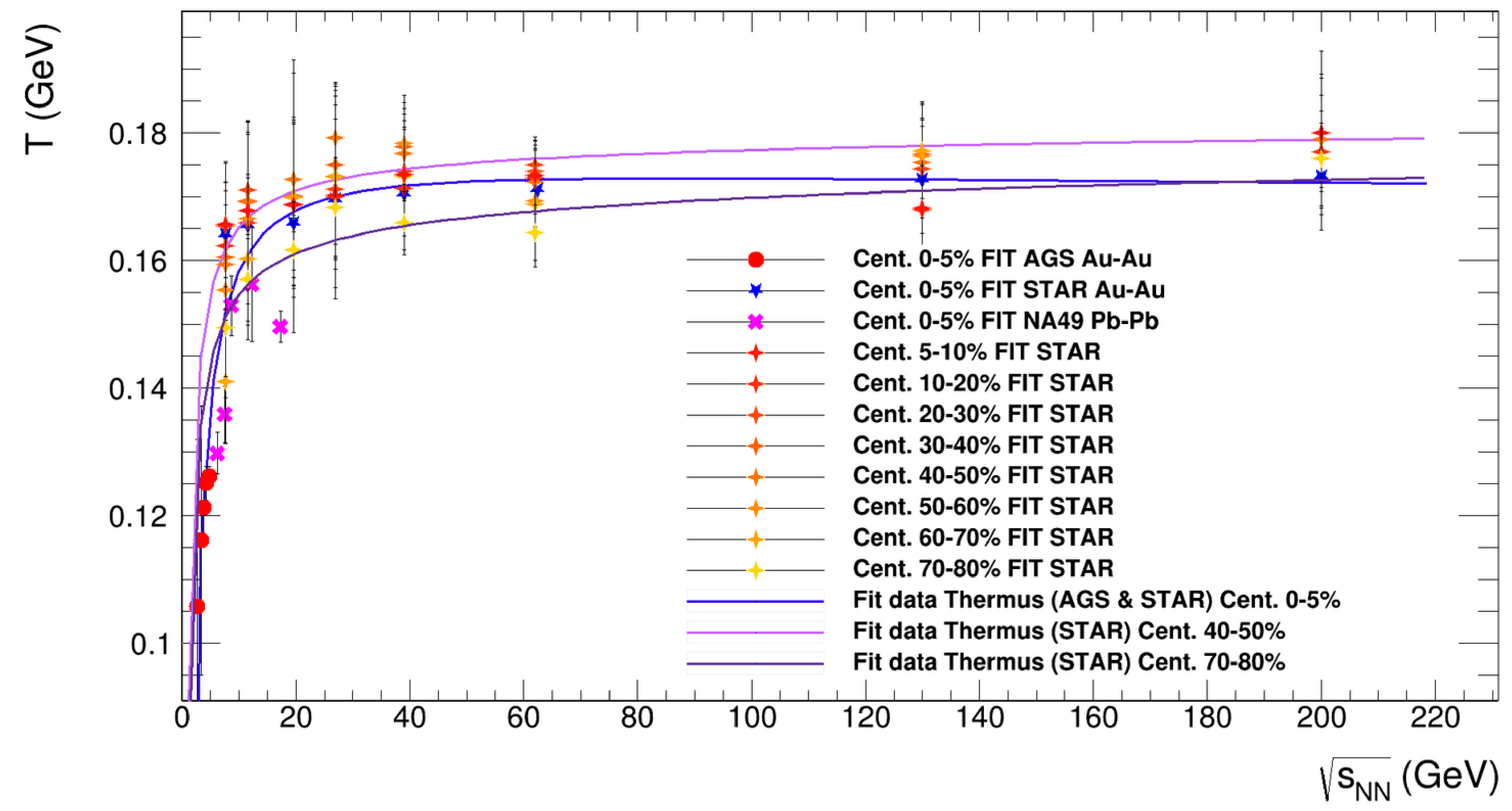
$$T_{experiment} = 0.1868 + \frac{(-0.227)}{(\sqrt{s_{NN}})} + (-0.0051)\ln(\sqrt{(\sqrt{s_{NN}})})$$

Different data from publications were modeled with THERMUS but without using strangeness potential, with a fixed gamma-s, and in the STAR fixed radius.



Temperature as a function of centralities

- The different parameters were extracted at different temperatures with STAR data, and the ratio of the most central to the most peripheral shows a more significant difference at low energy.
- Different studies have been done on temperature, but in this work, we included different centralities.



$$T = 0.182 + \frac{(-0.322)}{(\sqrt{s_{NN}})} + (-0.00513)\ln(\sqrt{(\sqrt{s_{NN}})})$$ Cent. 0-5%

$$T = 0.1706 + \frac{(-0.0921)}{(\sqrt{s_{NN}})} + 0.00329\ln(\sqrt{(\sqrt{s_{NN}})})$$ Cent. 40-50%

$$T = 0.155 + \frac{(-0.0827)}{(\sqrt{s_{NN}})} + 0.0675\ln(\sqrt{(\sqrt{s_{NN}})})$$ Cent. 70-80%

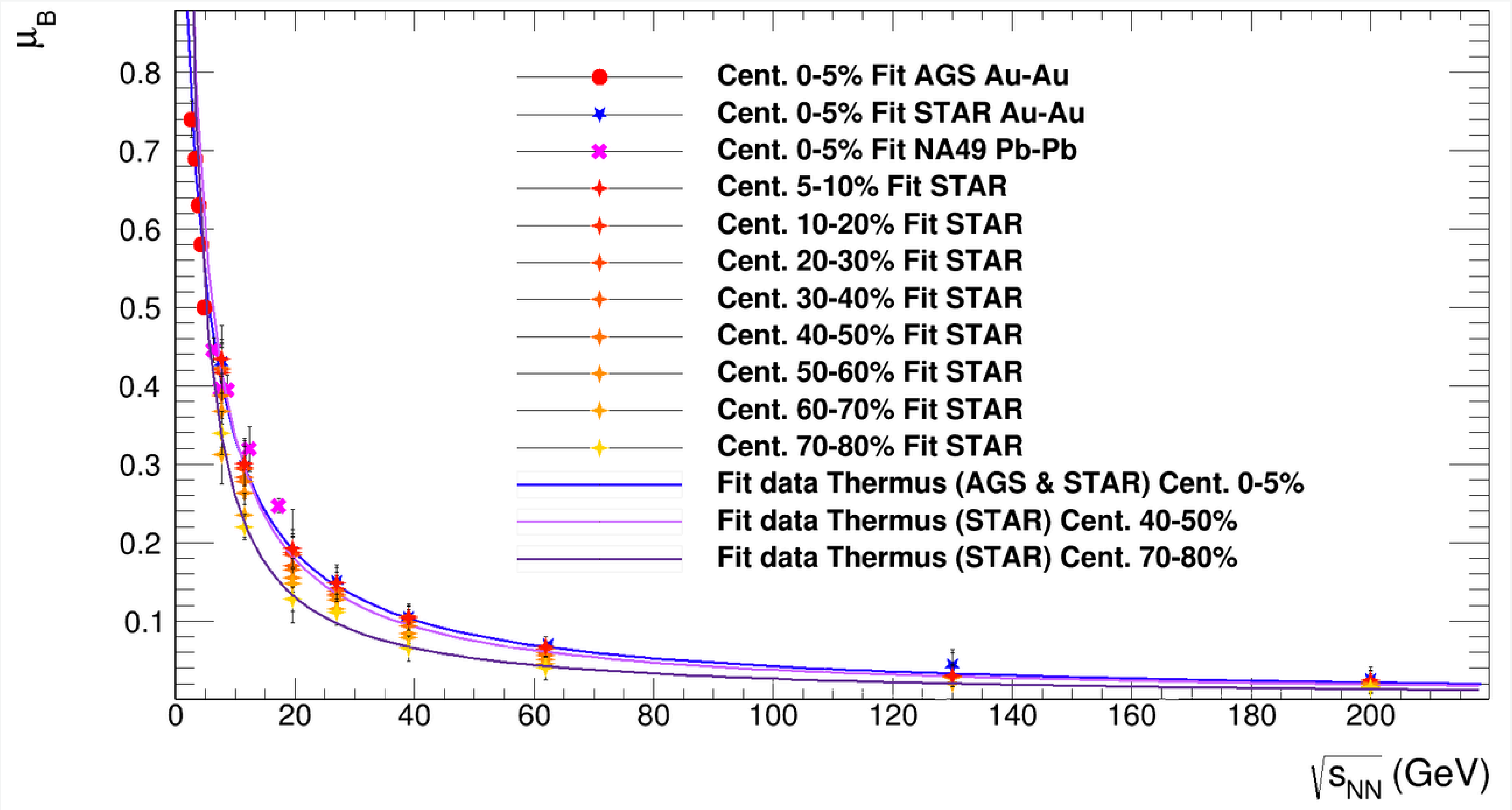
Chemical and strangeness potential

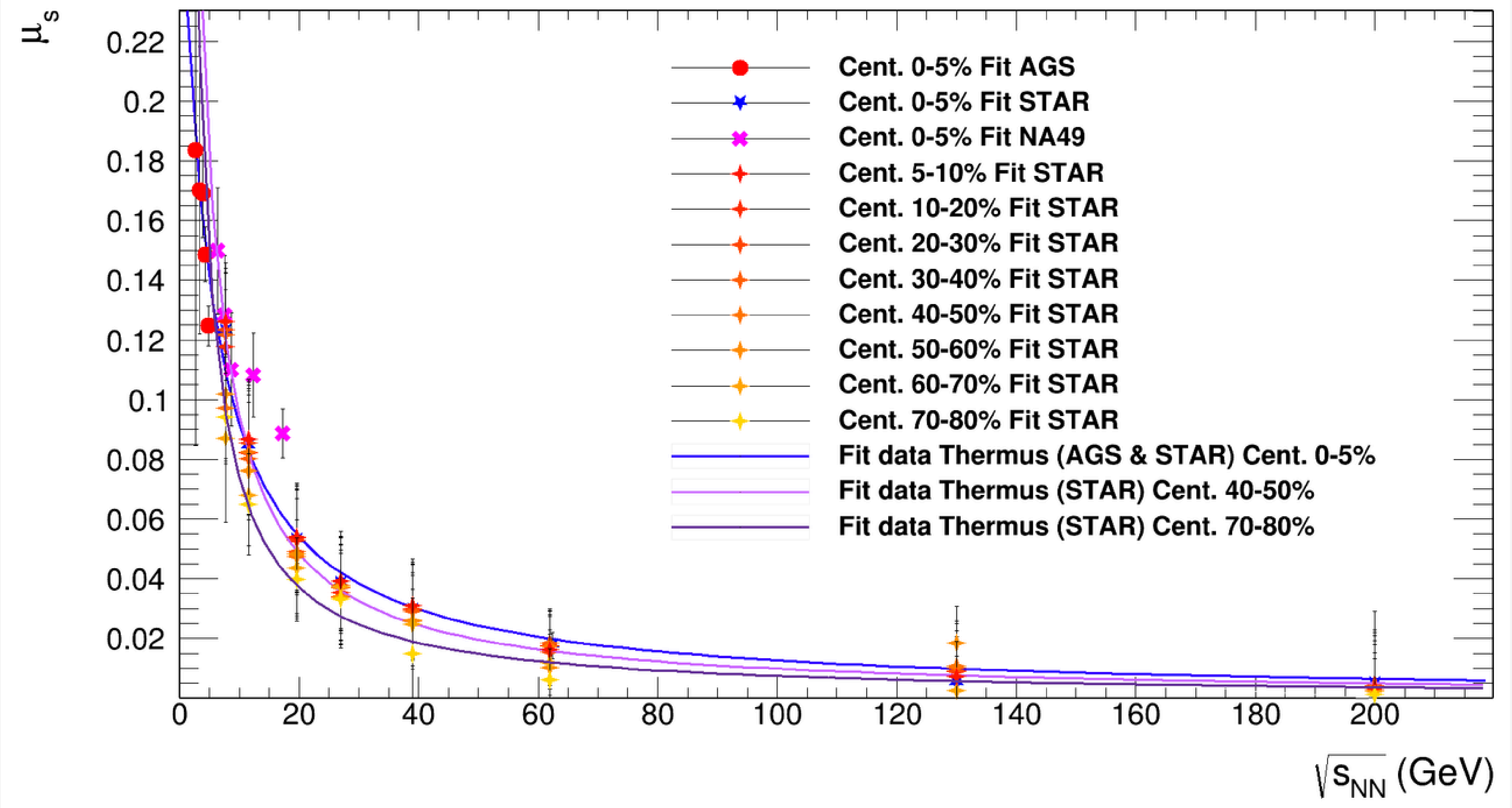
- The same behavior can be observed for potentials, with higher values at greater centrality and lower values at more peripheral collisions.
- It is possible to extrapolate the strangeness potential without having experimental data on this parameter.

$$\mu_B = \frac{1.373}{1 + 0.3148\sqrt{s_{NN}}} \qquad \mu_B = \frac{12.27}{1 + 4.65\sqrt{s_{NN}}}$$

$$\mu_s = \frac{0.295}{1 + 0.223\sqrt{s_{NN}}} \qquad \mu_s = \frac{1.97}{1 + 7.16\sqrt{s_{NN}}}$$

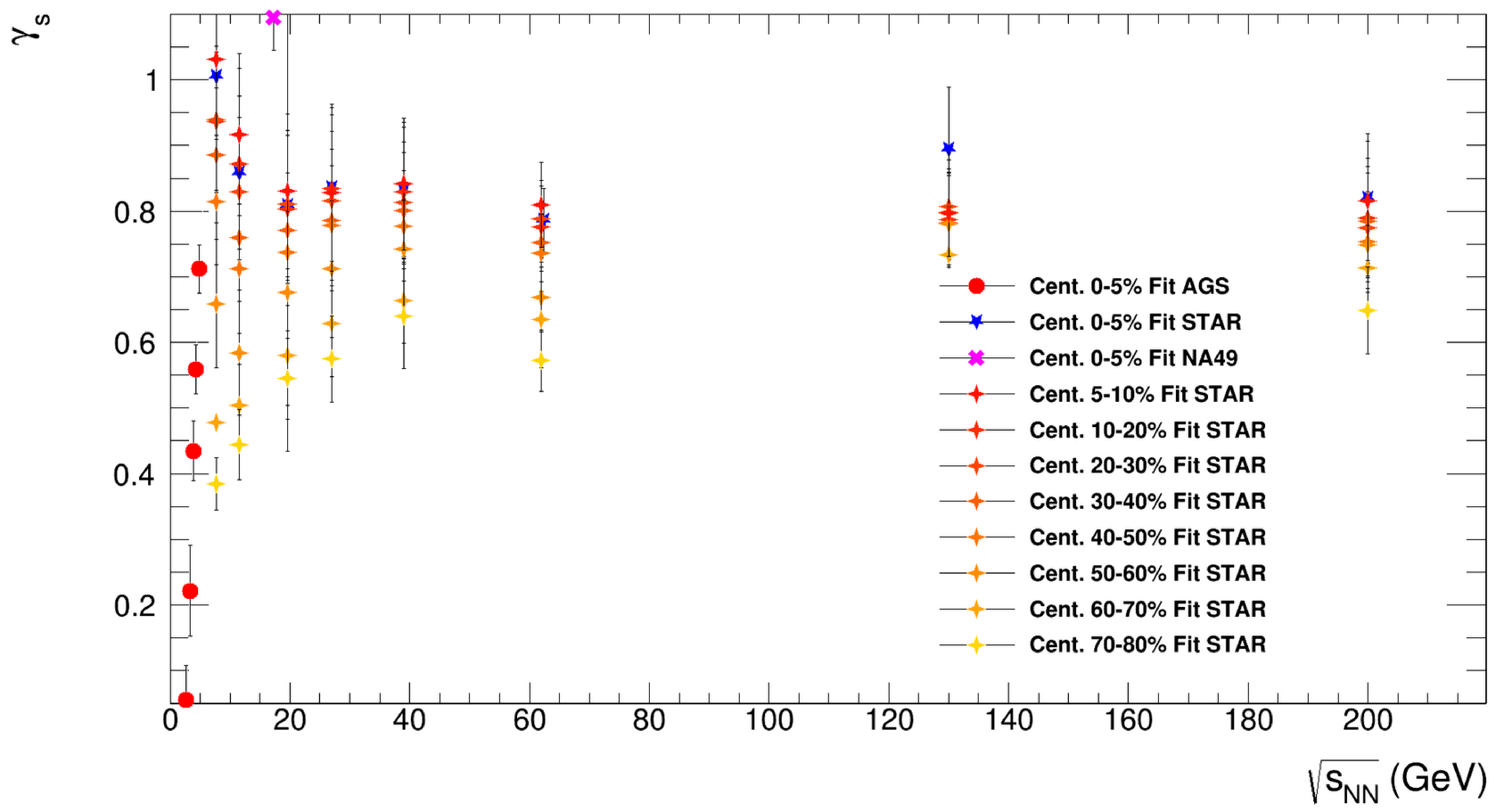
Cent. 0-5% | Cent. 80-90%





Gamma-s

- In more central collisions, a peak is found close to 7.7 GeV, but the more peripheral the results, the behavior is softer.
- Data for gamma-s were also obtained, and different centralities were used.

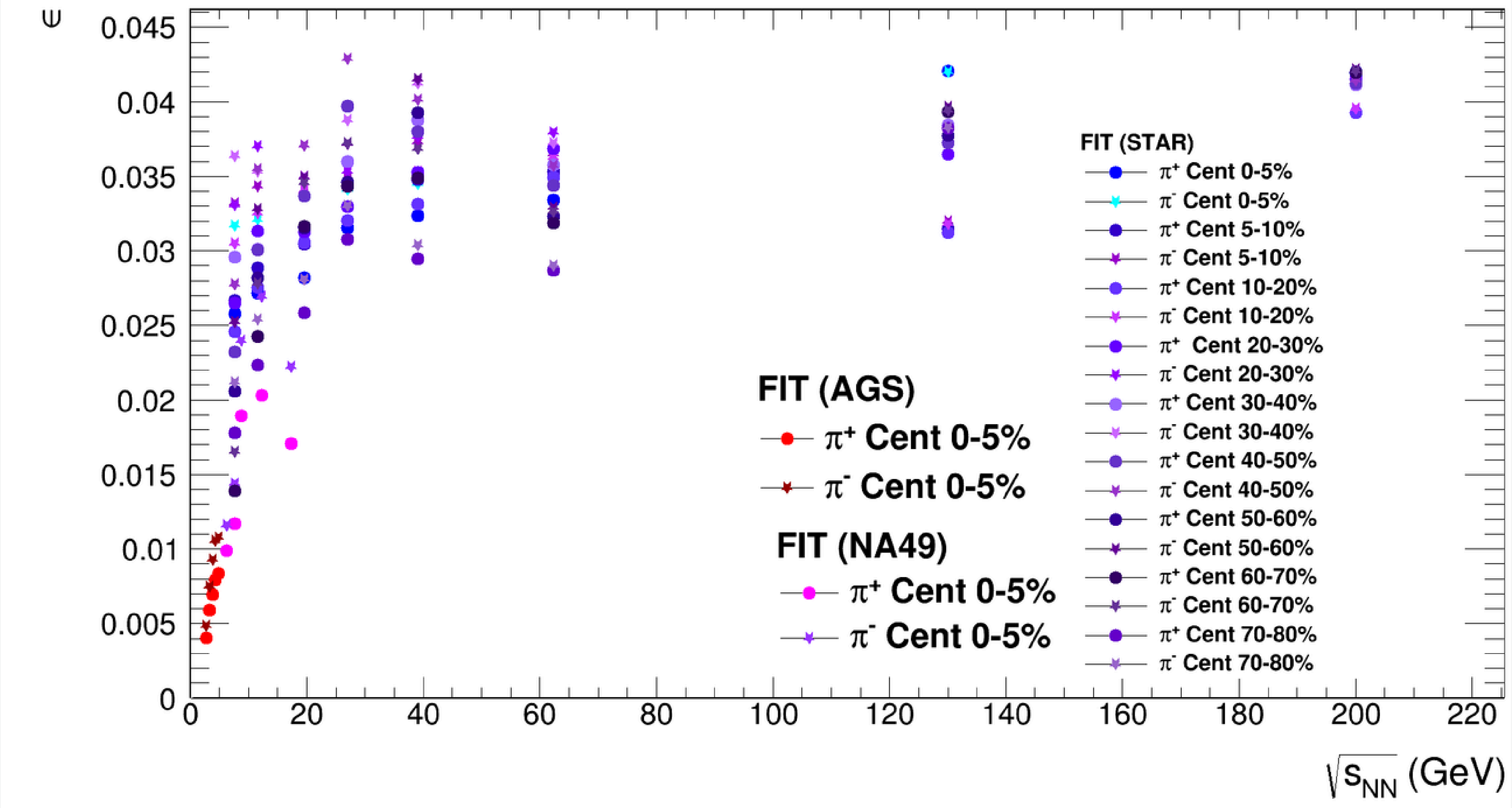


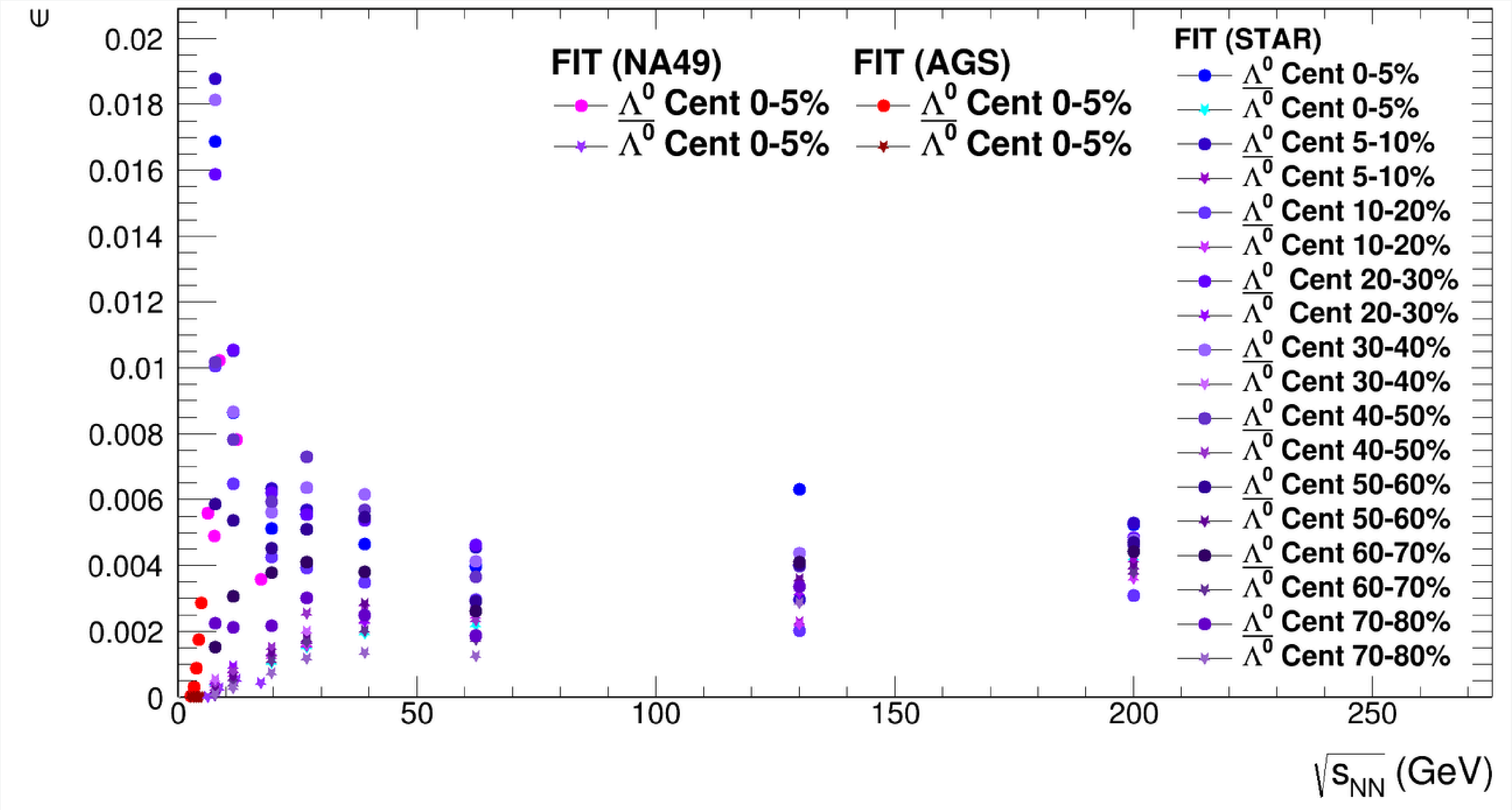
Energy density

The energy for no strangeness tends to rise and saturate it.
At low energy, a big difference between particle and anti-particle is observed.

For particles with strangeness, a peak and saturation is noted; for their anti-particles, there is constant growth until equating to the particle.

$$E^{GC} = T^2 \frac{\partial \ln Z^{GC}}{\partial T} + \sum_{species\,i} \mu_i N_i^{GC}$$





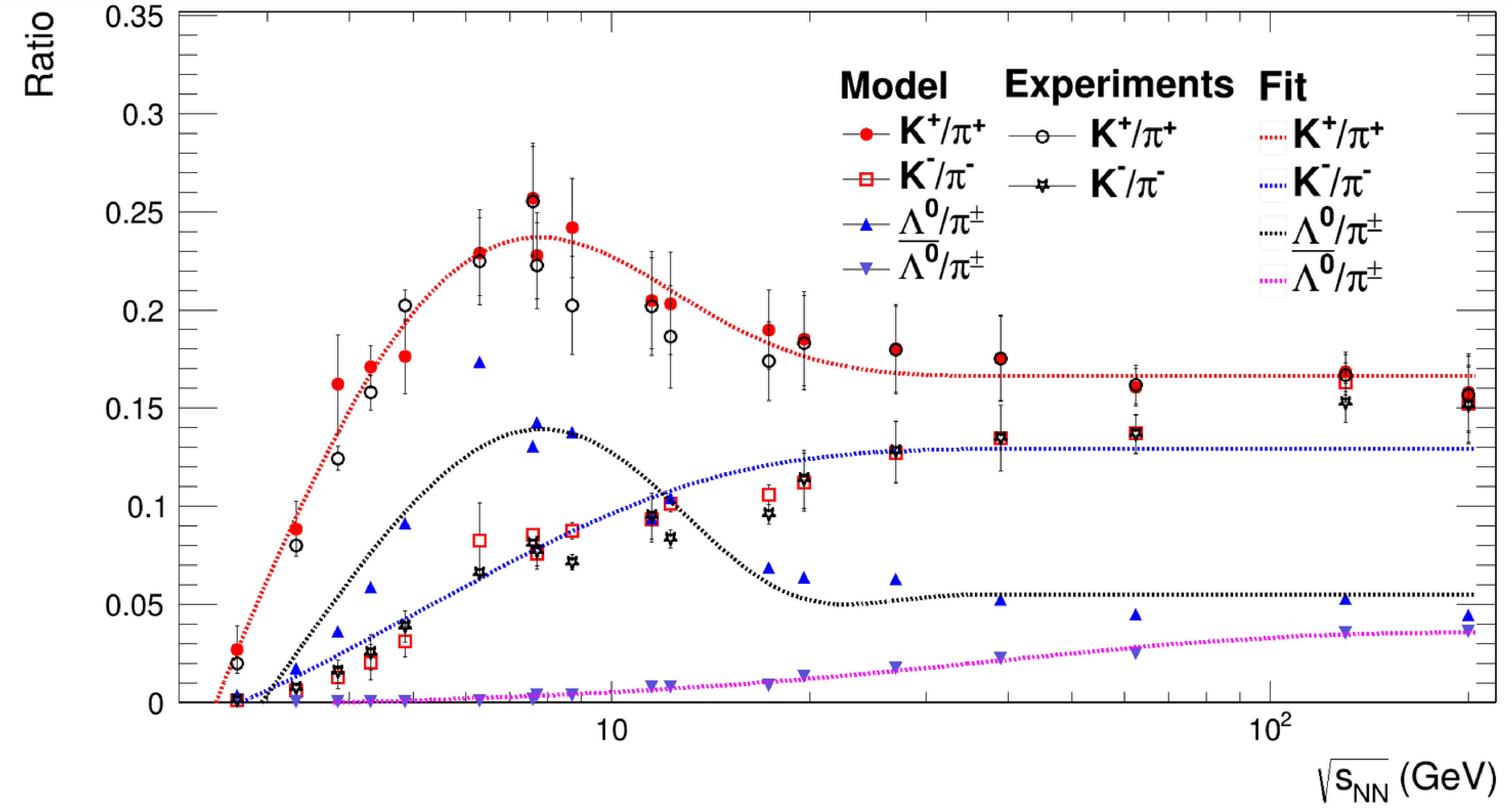
Baryon/meson meson/meson ratios

Fit

$$K^+/\pi^+ = 1.542 * e^{2.892*\sqrt{s_{NN}}} * sin(-1.24 * \sqrt{s_{NN}} + 3.19) + 1.66$$
$$K^-/\pi^- = 2.801 * e^{1.87*\sqrt{s_{NN}}} * sin(-3.76 * \sqrt{s_{NN}} + 4.022) + 1.29$$
$$\Lambda^0/\pi^+ = 0.503 * e^{-0.189*\sqrt{s_{NN}}} * sin(-0.2102 * \sqrt{s_{NN}} + 3.95) + 0.0547$$
$$\bar{\Lambda}^0/\pi^+ = 0.0846 * e^{-0.0296*\sqrt{s_{NN}}} * sin(0.00227 * \sqrt{s_{NN}} + 3.626) + 0.0358$$

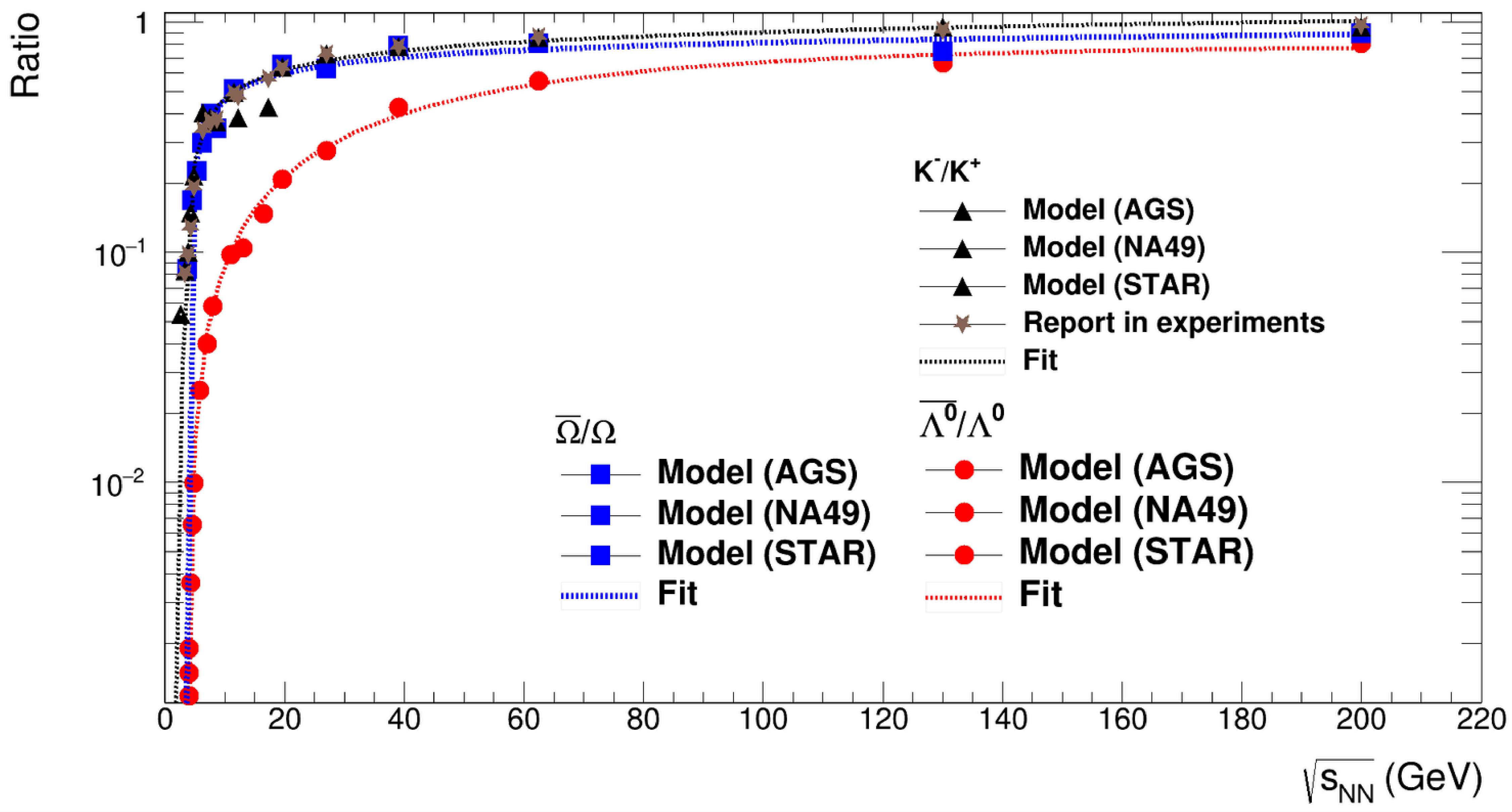
$$K^+(u\bar{s})/\pi^+(u\bar{d}) \approx \bar{s}/\bar{d}$$
$$K^-(s\bar{u})/\pi^-(\bar{u}d) \approx s/d$$
$$\Lambda^0(uds)/\pi^{\pm}(u\bar{d}) \approx ds/\bar{d}$$
$$\bar{\Lambda}^0(\bar{u}\bar{d}\bar{s})/\pi^{\pm}(u\bar{d}) \approx \bar{u}s/u$$

It is possible to find the "horn" for the K+/pi+ relation and for the lambdas containing a different maximum associated with the abundance of particles with strangeness.



Strangeness baryon/meson and meson/meson ratios

In the relations of particles with their anti-particles strangeness, it is possible to notice a growth at low energy and saturation at higher energy.
Abrupt changes in the production of particles with strangeness content are researched as a mechanism to understand what happens when sQGP is created.



$$K^-/K^+ = 0.233 + \frac{(-1.09)}{(\sqrt{s_{NN}})} + (0.296)\ln(\sqrt{(\sqrt{s_{NN}})})$$

$K^-(s\bar{u})/K^+(\bar{s}u)$

$$\bar{\Lambda}^0/\Lambda^0 = 0.395 + \frac{(-1.55)}{(\sqrt{s_{NN}})} + (0.188)\ln(\sqrt{(\sqrt{s_{NN}})})$$

$\bar{\Lambda}^0(\bar{u}\bar{d}\bar{s})/\Lambda^0(uds)$

$$\Omega^-/\Omega^+ = 1.27 + \frac{(0.0086)}{(\sqrt{s_{NN}})} + (-28596)\ln(\sqrt{(\sqrt{s_{NN}})})$$

$\Omega^-(sss)/\Omega^+(\bar{s}\bar{s}\bar{s})$

Conclusions

We use a statistical model to study the properties of the medium created in heavy ion collisions. Thermodynamic properties were studied. The main results are the following:

- Multiplicity results from experimental data were reproduced.
- Properties of multiplicity, Temperature, energy density, and entropy of particles were extracted for strangeness hadrons not published in experiments
- An extensive study was carried out on a wide range of collision energy.
- Ratios for different particles species were studied.

Susy says thanks for your attention

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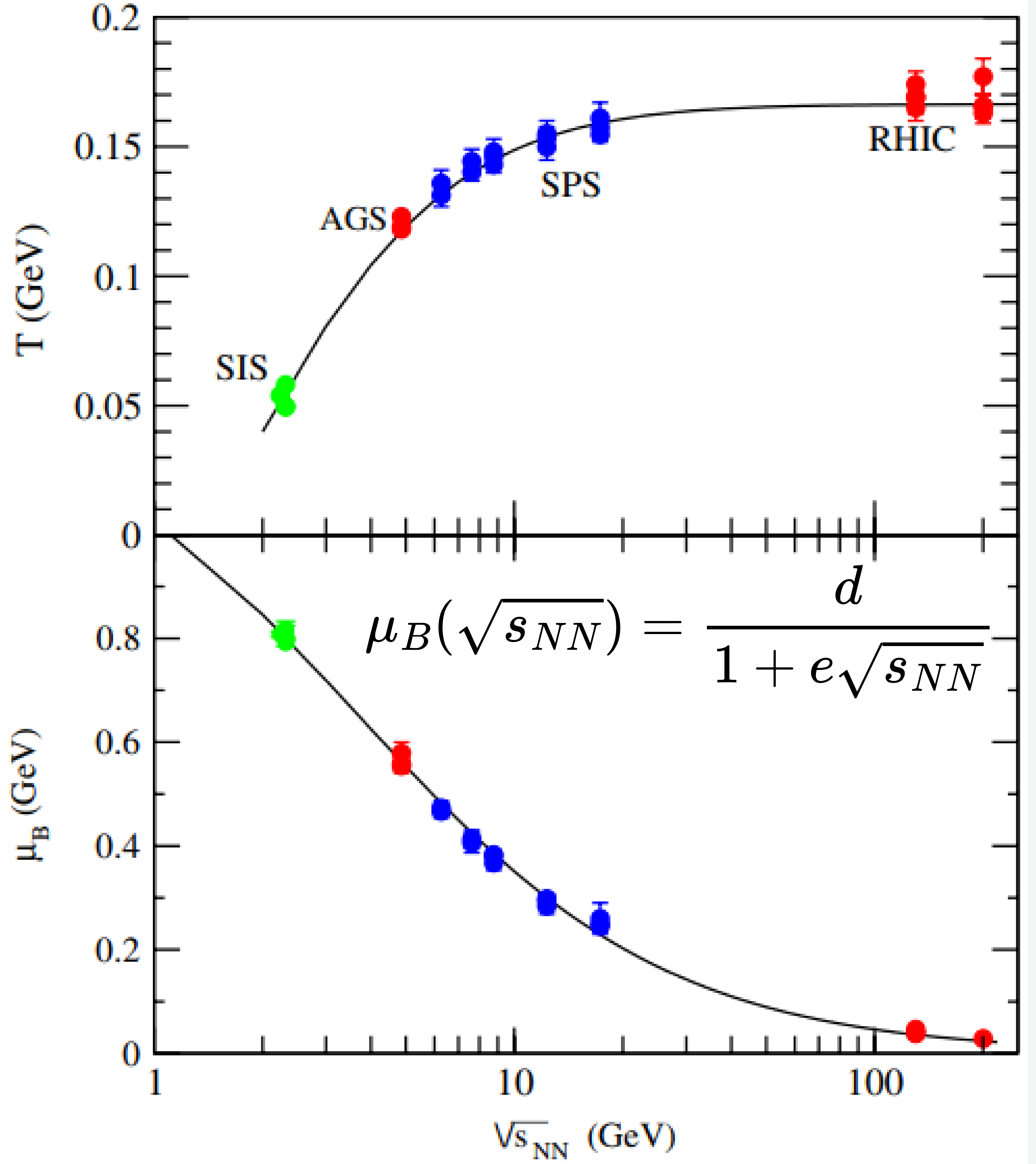
J. Cleymans, et. al, Phy. Rev. C.73.03 (2006)

Temperature and barionic potential parameterized and published as background

Values have been extracted from the thermal model and properties such as temperature and barionic potential have been parameterized



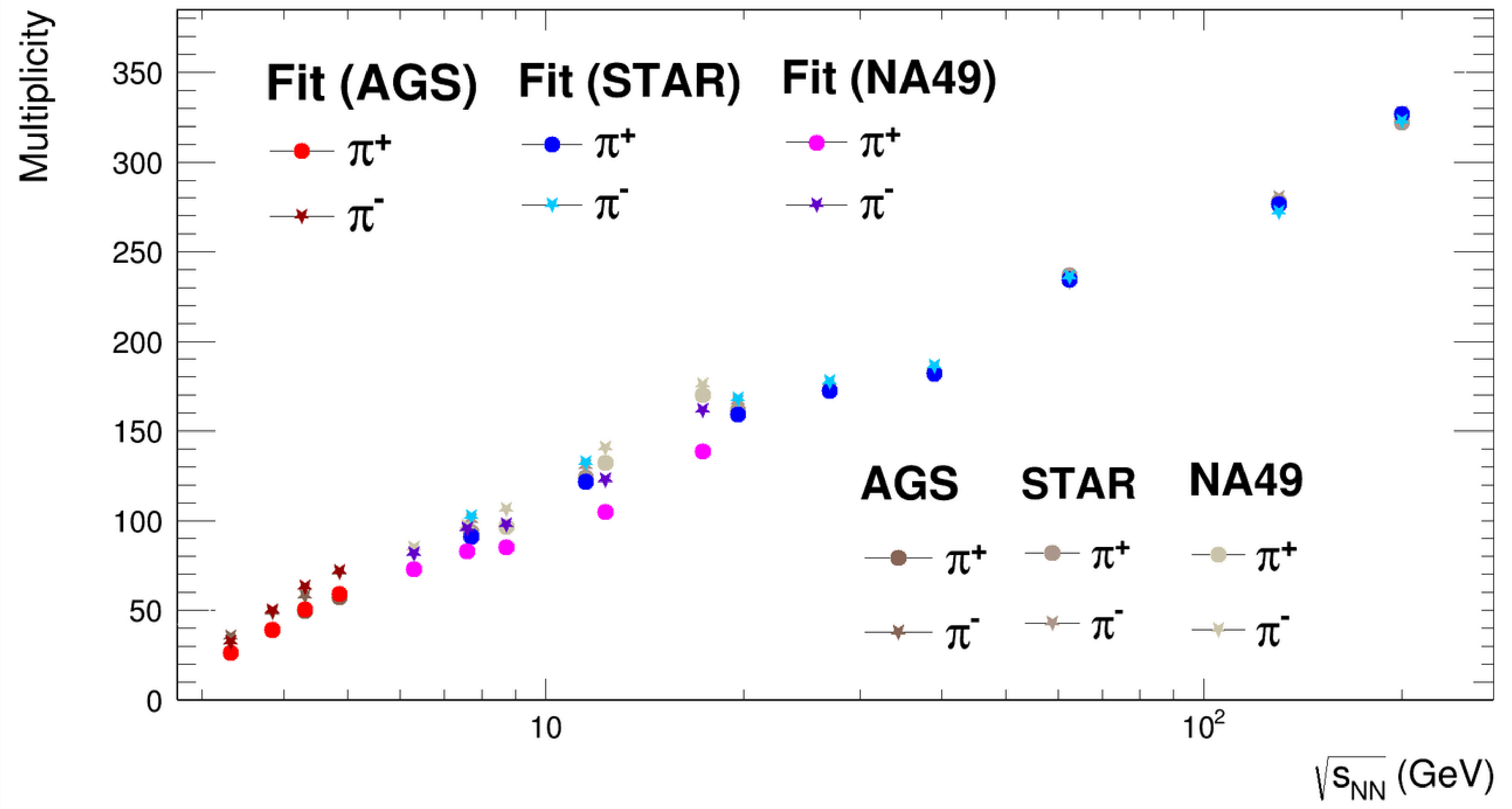
$$T(\sqrt{\mu_B}) = a - b\mu_B^2 - c\mu_B^4$$

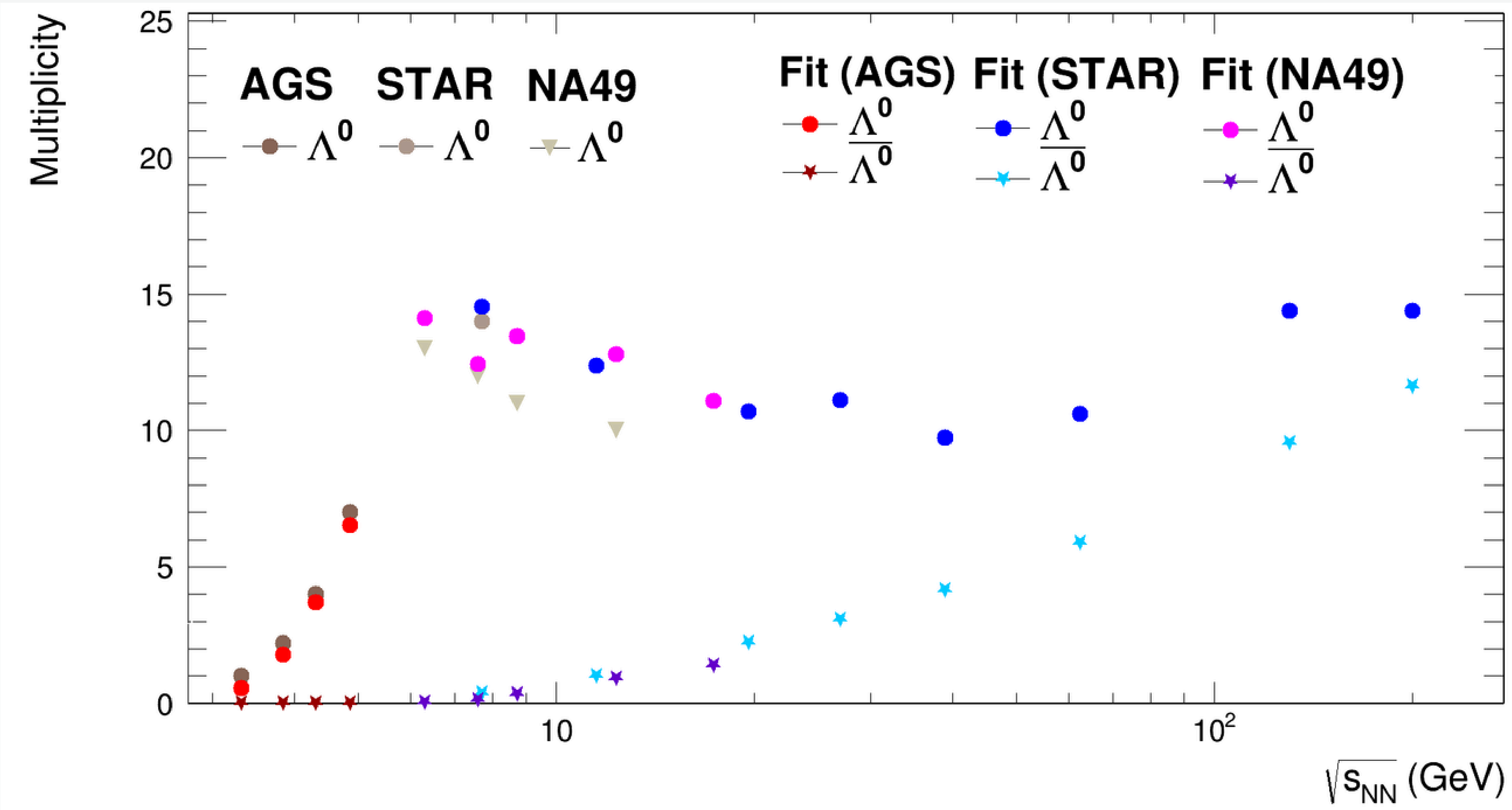
Multiplicity

Used multiplicities data from AGS(Au-Au), NA49 (Pb-Pb) and STAR (Au-Au).

The adjustment was made with data from Pions, Kaons, Protons and in some cases Lambdas.

There are two main distributions, particulas without strangeness (piones) and with strangeness (lambdas).



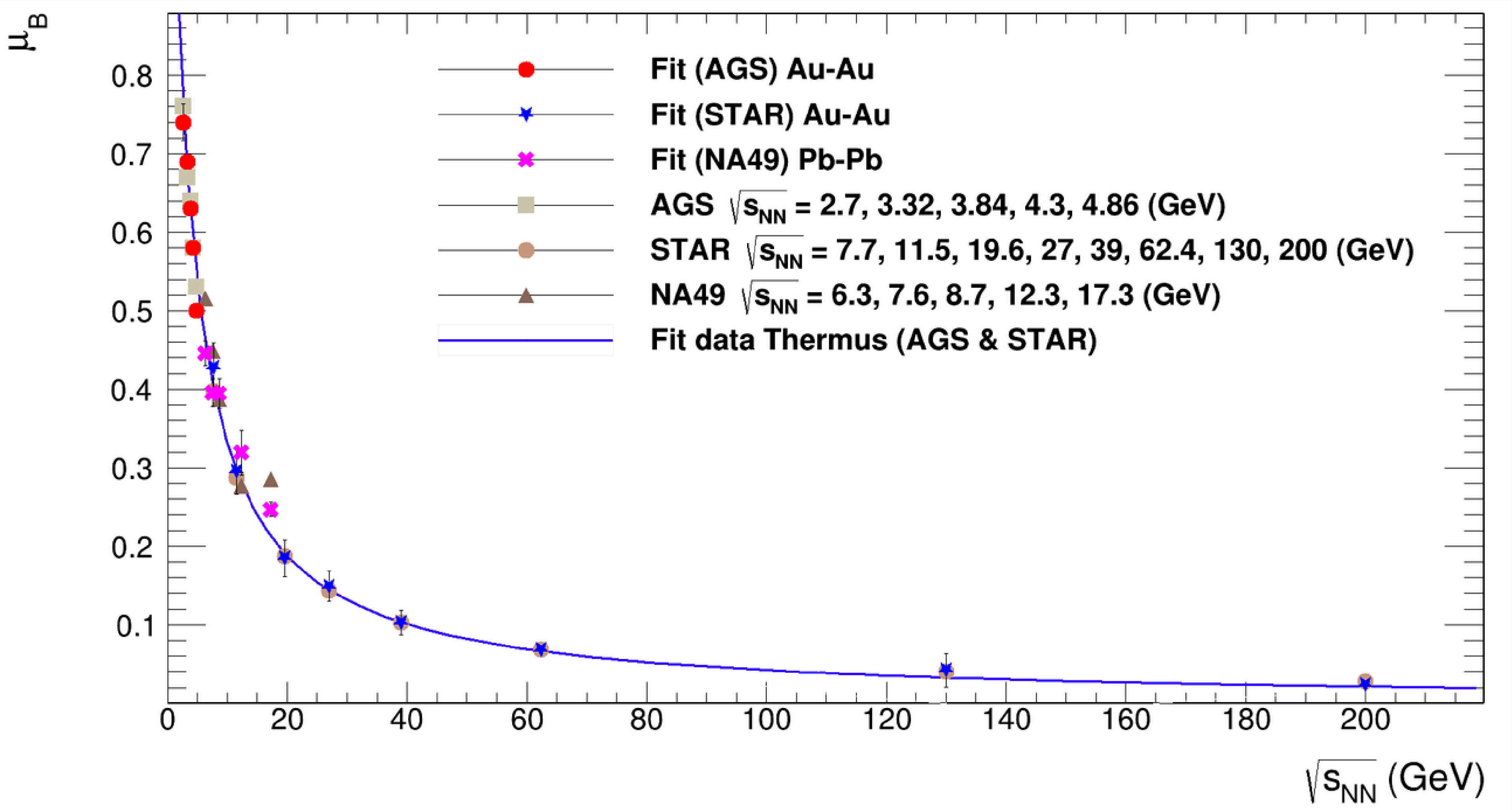


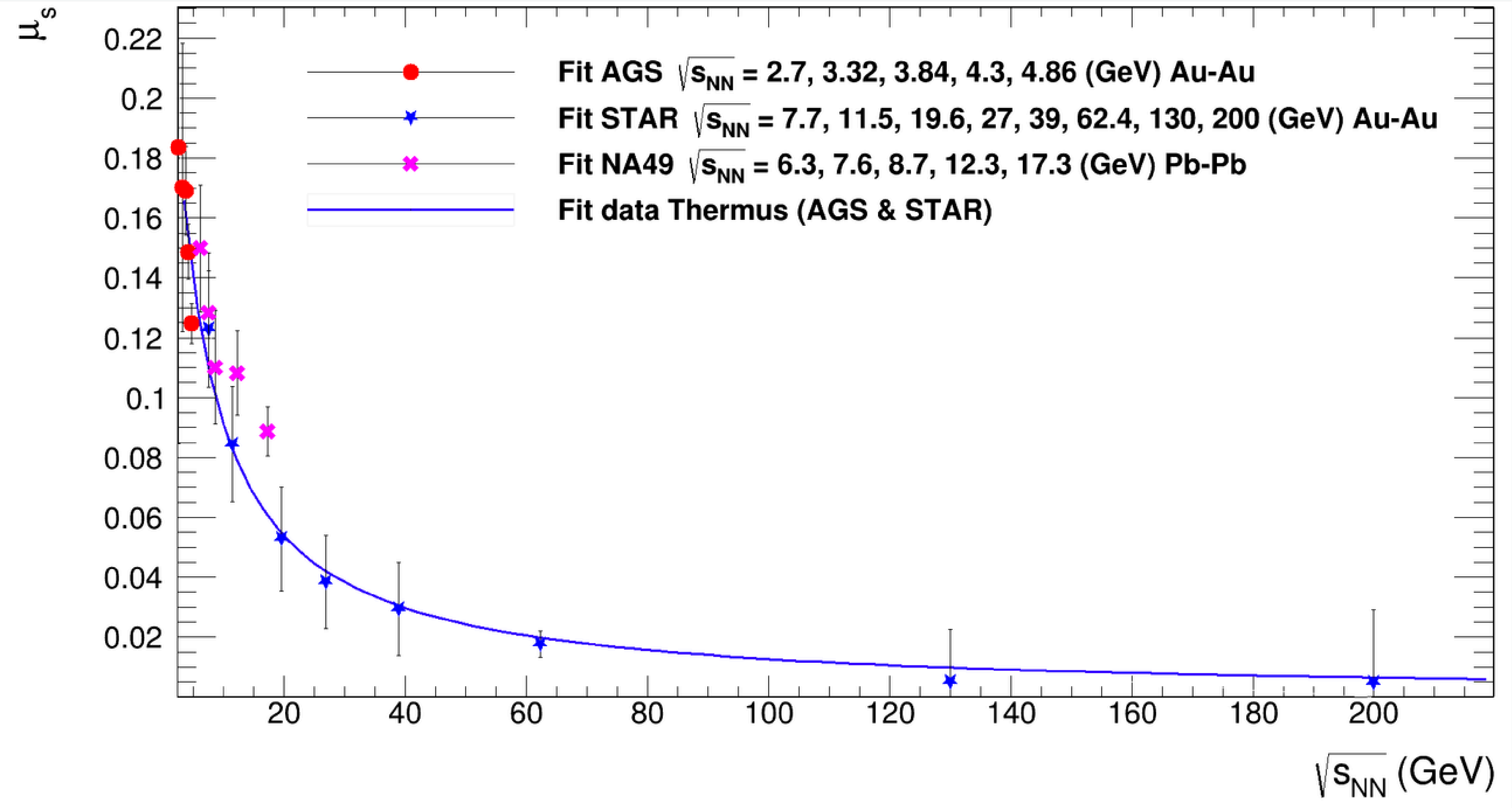
Chemical potentials (barionic and strangeness)

It is possible to describe the baryonic and strangeness chemical potentials at different energies and fit them with the same function.

$$\mu_B = \frac{1.373}{1 + 0.3148\sqrt{s_{NN}}}$$

$$\mu_s = \frac{0.295}{1 + 0.223\sqrt{s_{NN}}}$$



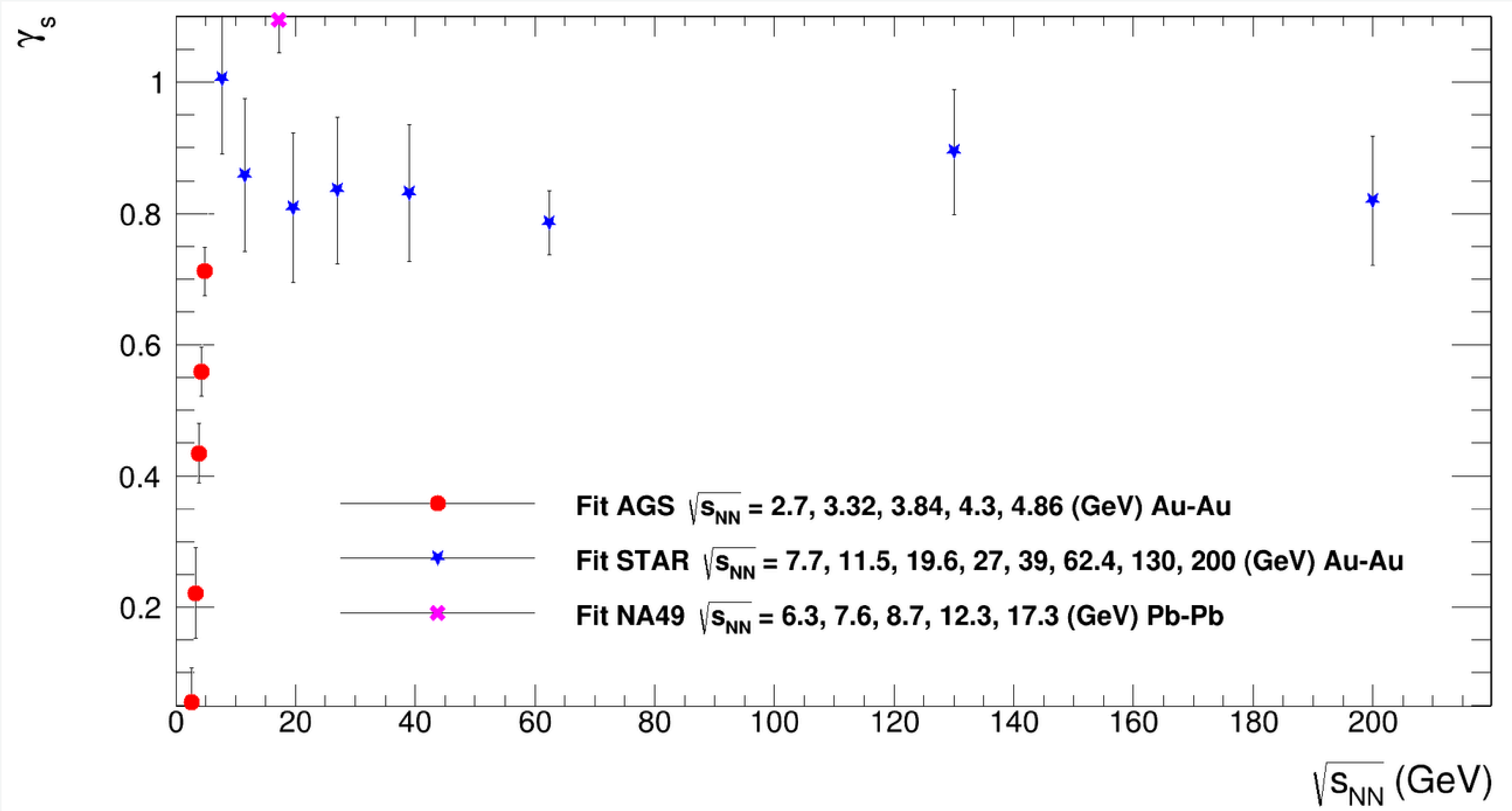


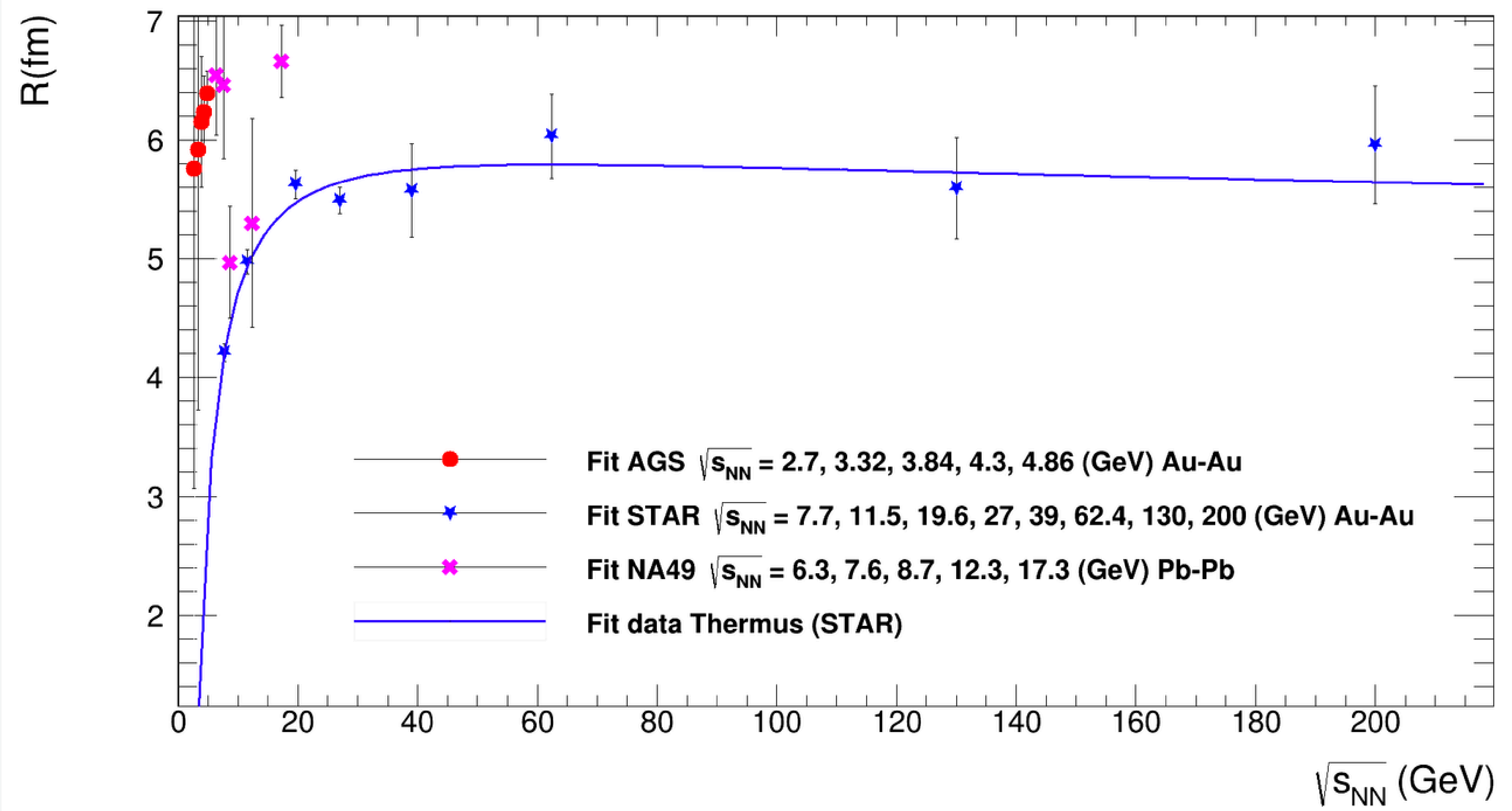
Radio and Gamma-s

The GC ensemble extracts the gamma-s factor, which is the strangeness fugacity factor, describing a rapid increase at low energy up to a peak, after which it tends to saturate.

The ratio shows a discrepancy at very low energy because the model attempts to compensate for low-energy particle production with a larger ratio.

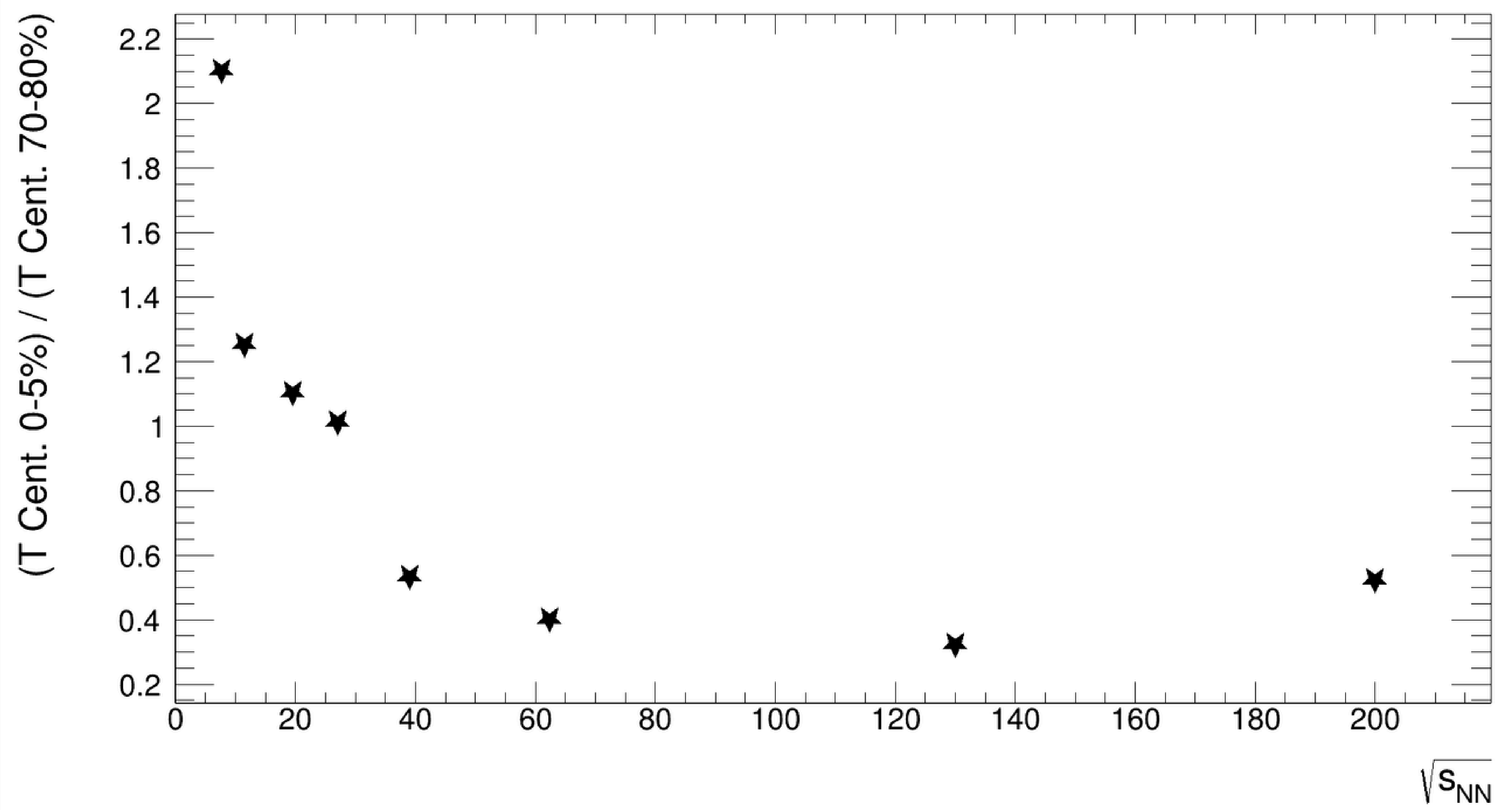
$$\gamma_s \equiv \frac{\int d^3p/2\pi^3 n_s(p,x;t)}{N_0/V}$$



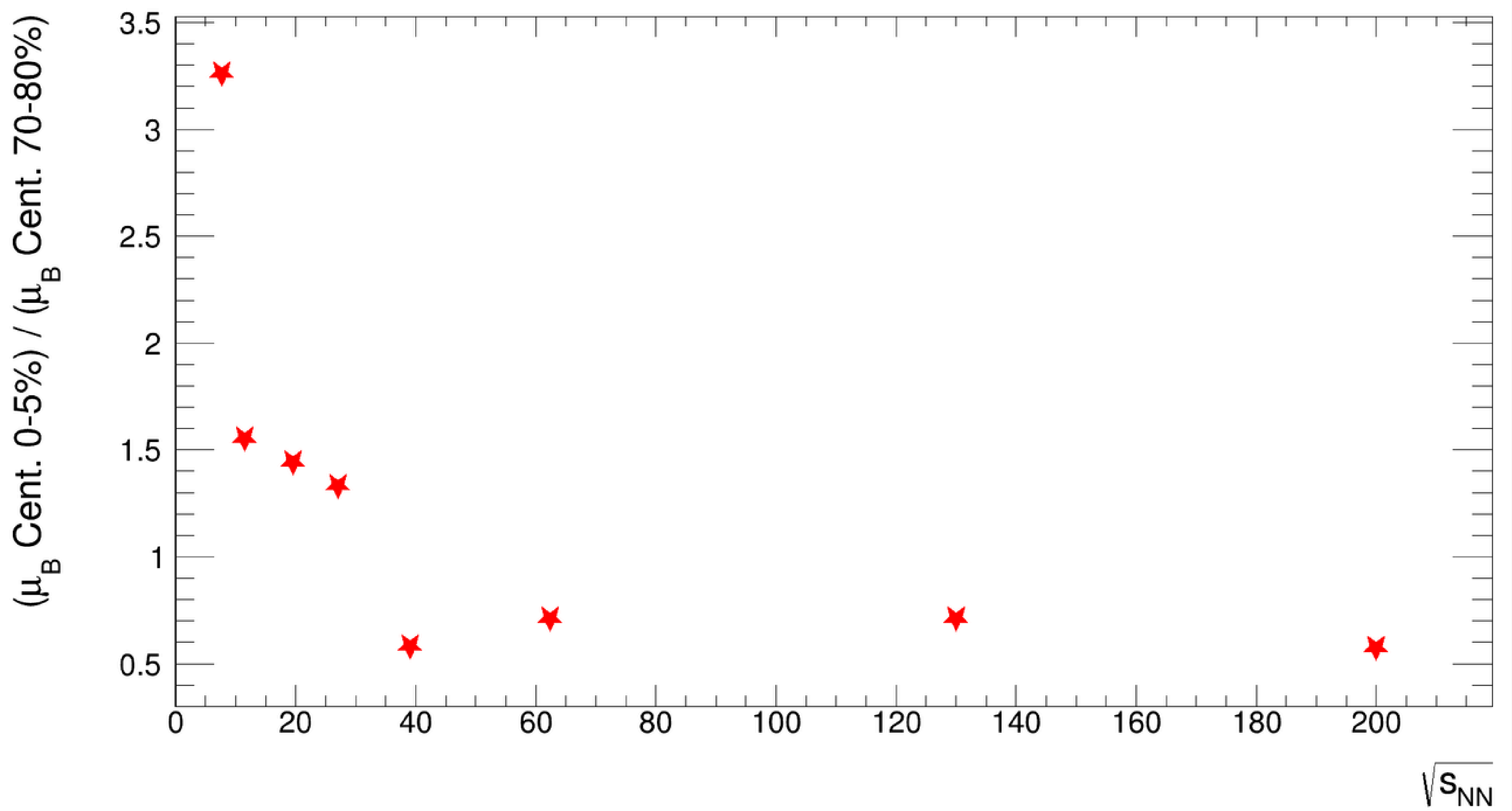


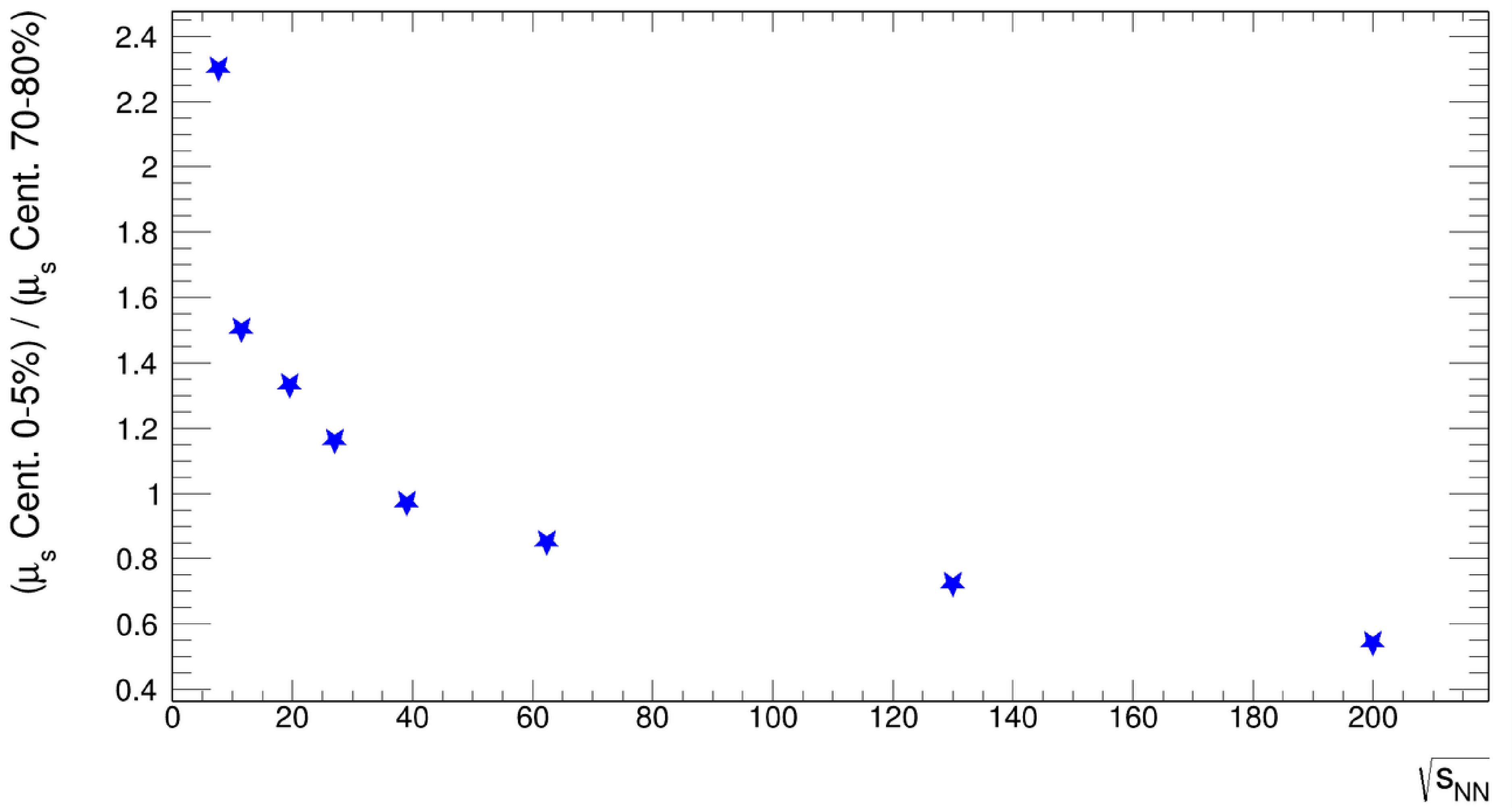
Ratio for different temperature centrality

At lower energy there are greater differences in the centrality values for temperature and potentials



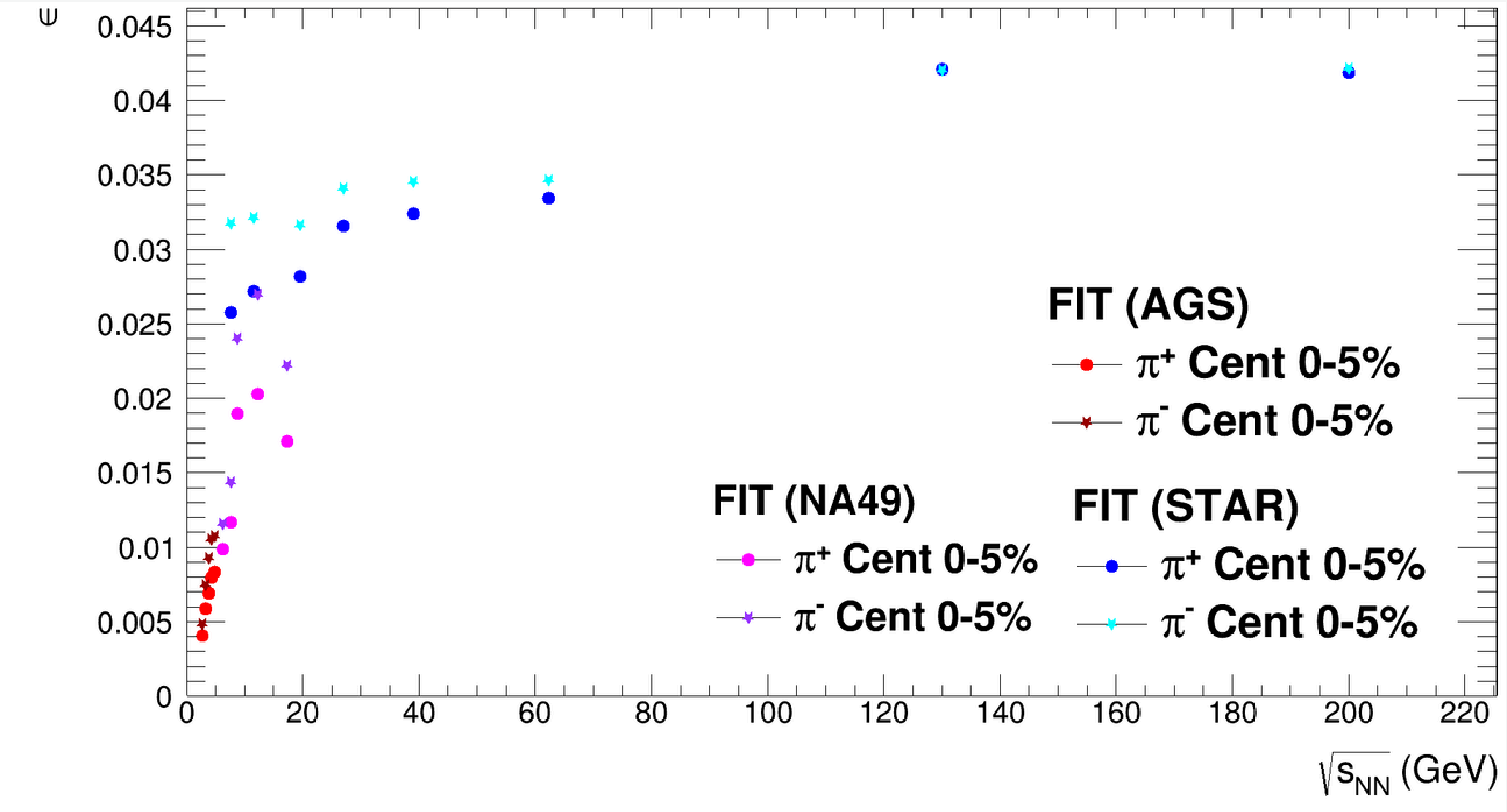
Ratio for different centrality for chemical potentials

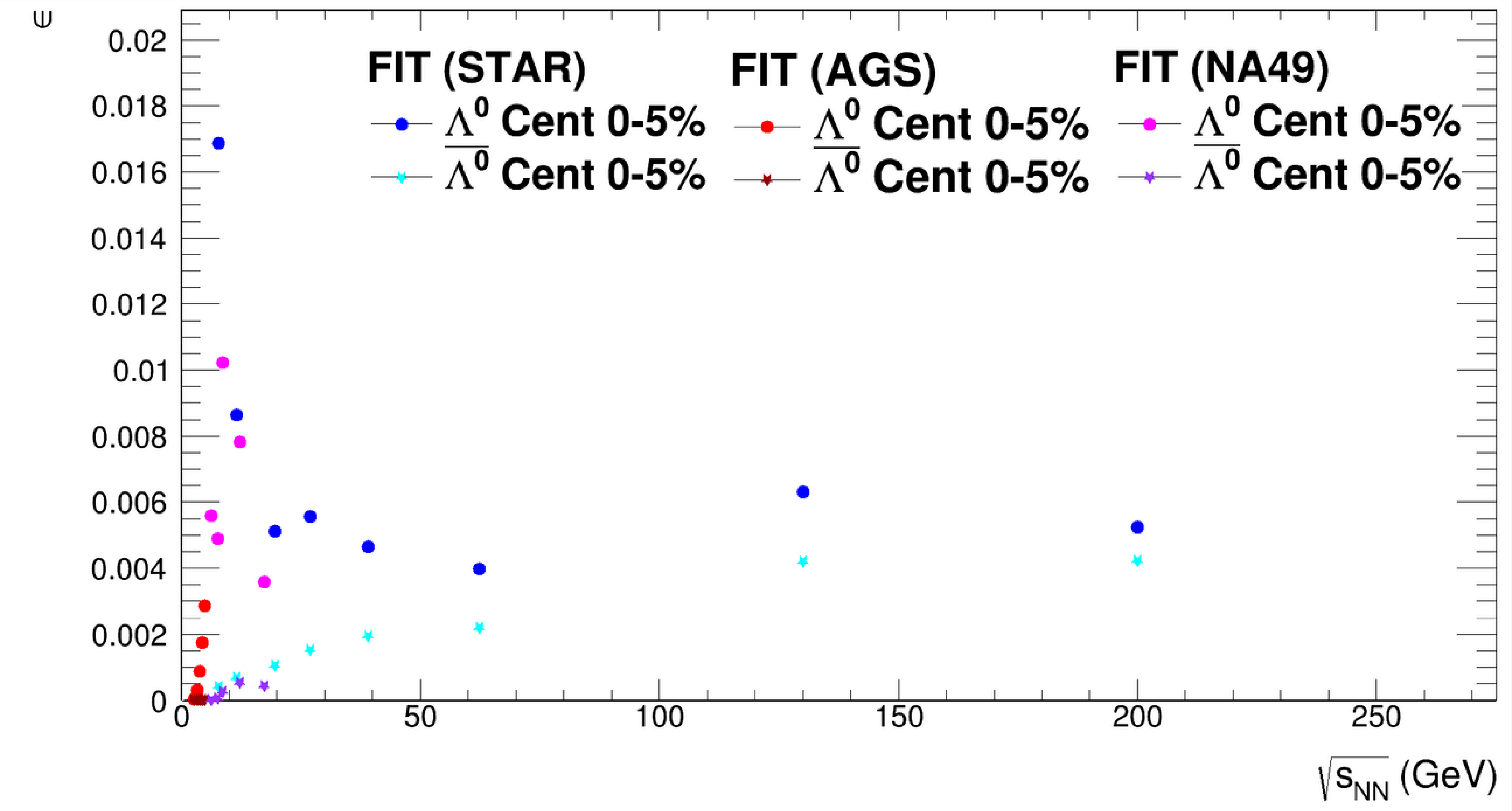




Energy density

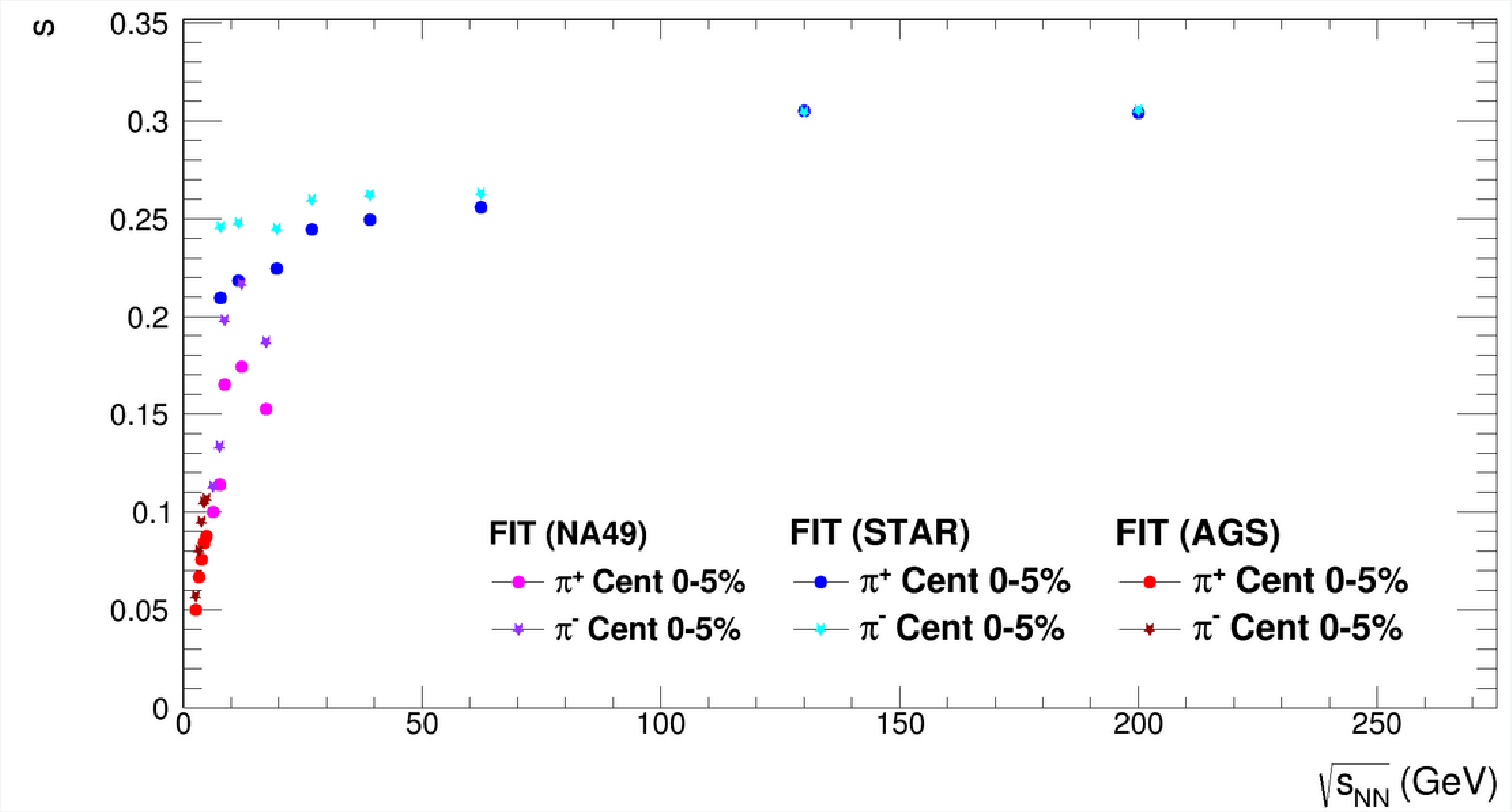
Again, there are two different distributions, one of particulas without strangeness and another of particulas with strangeness

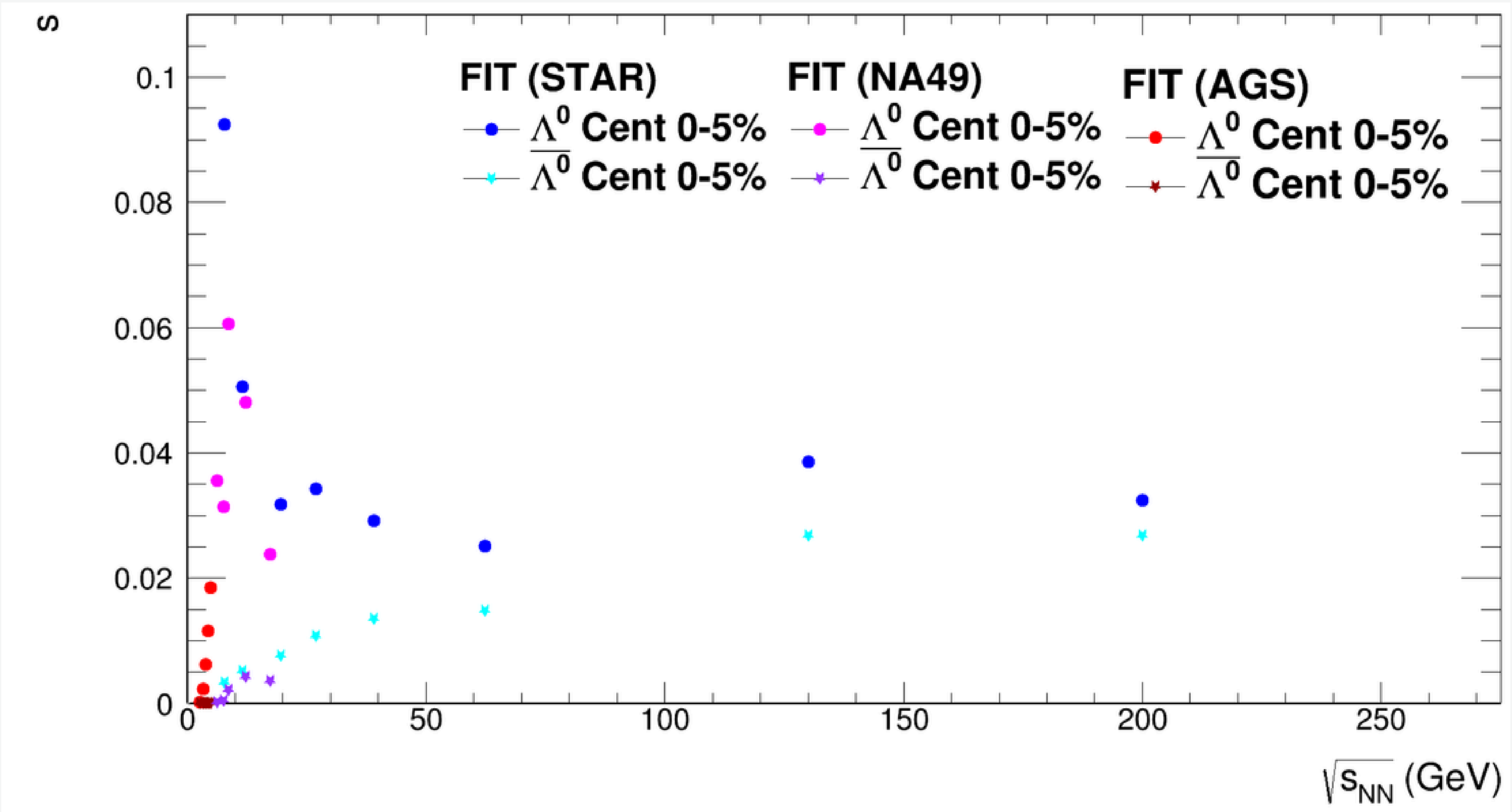




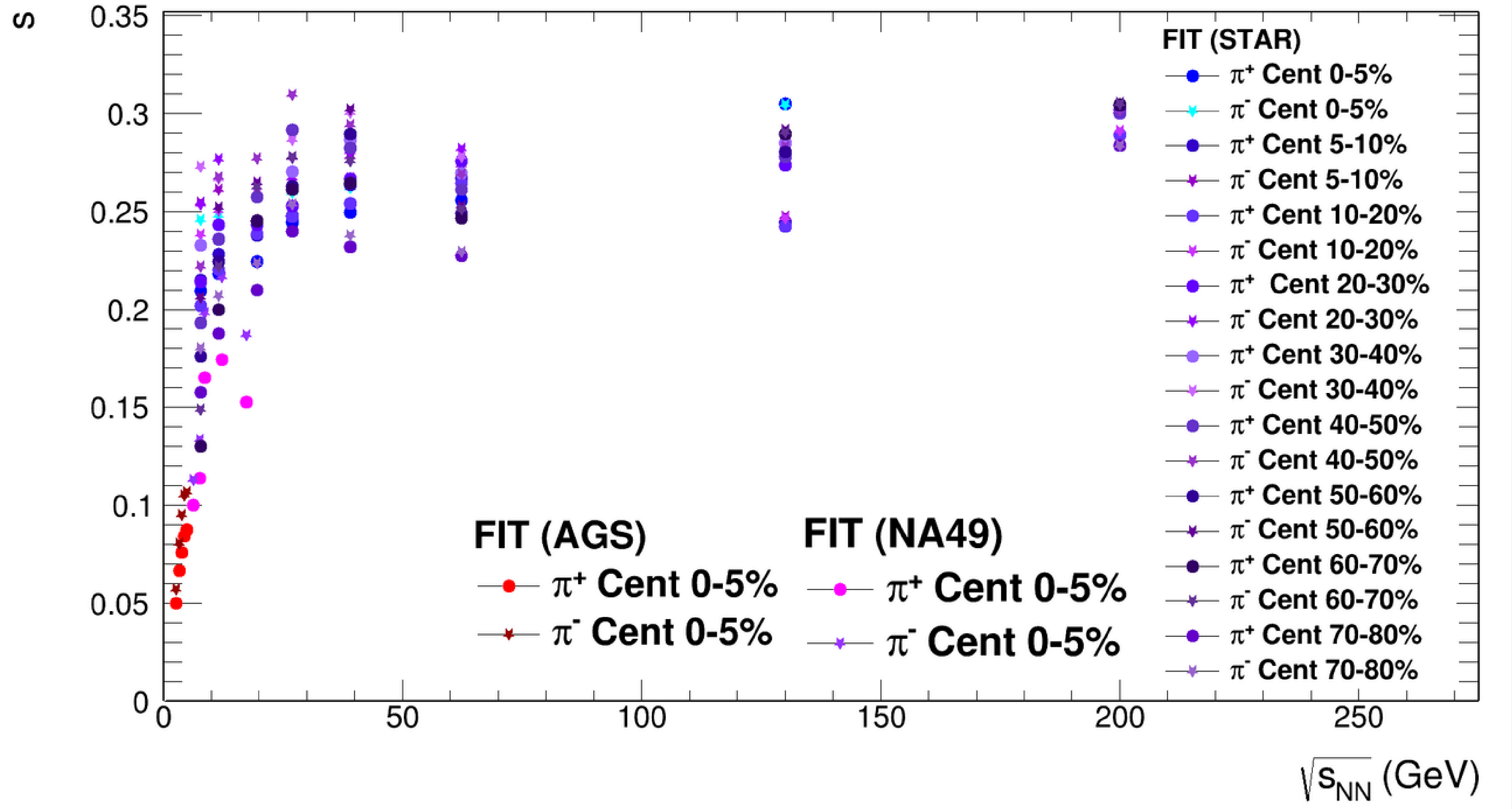
Density of entropy

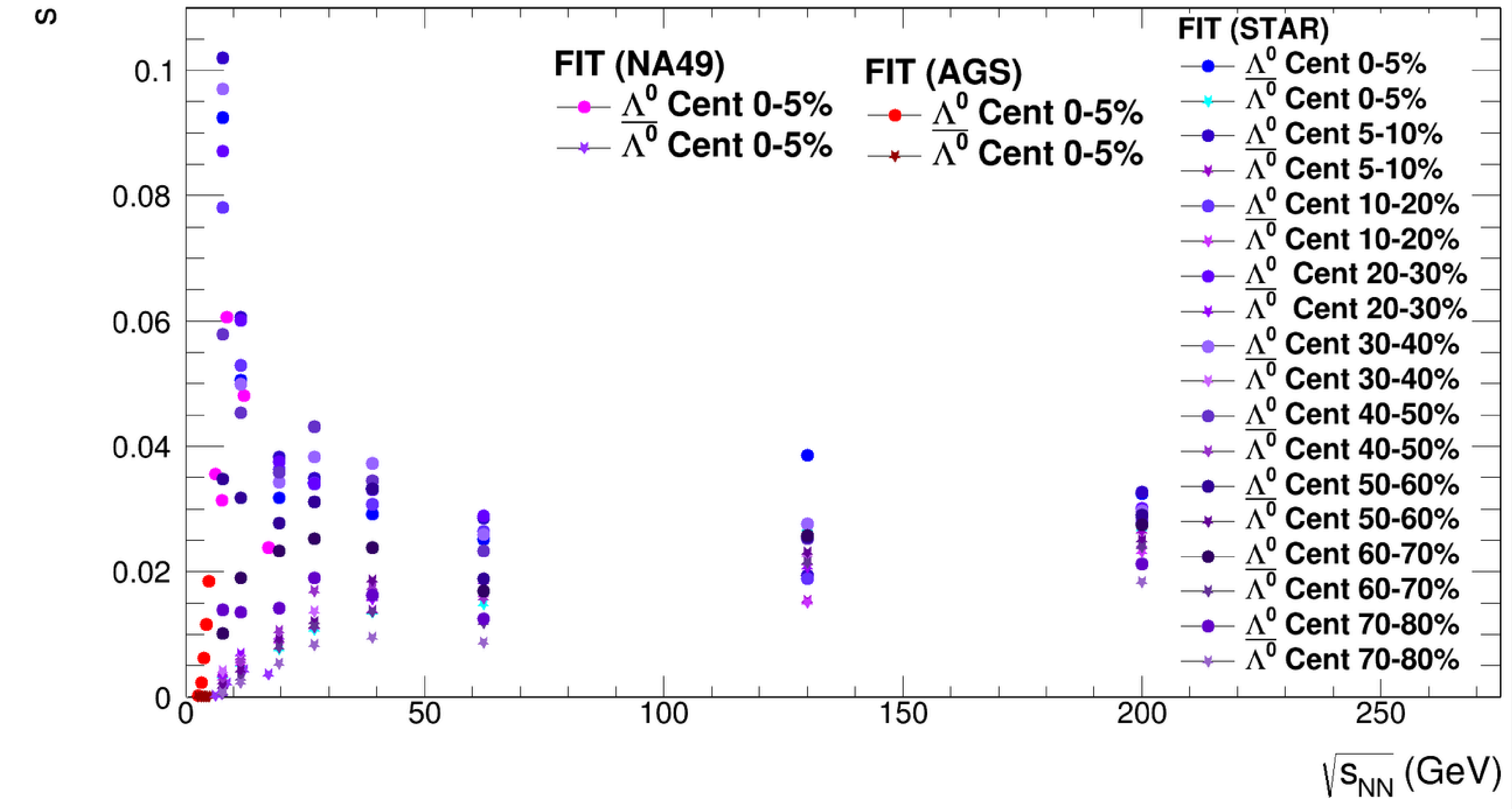
The distributions are repeated for the entropy





Entropy density

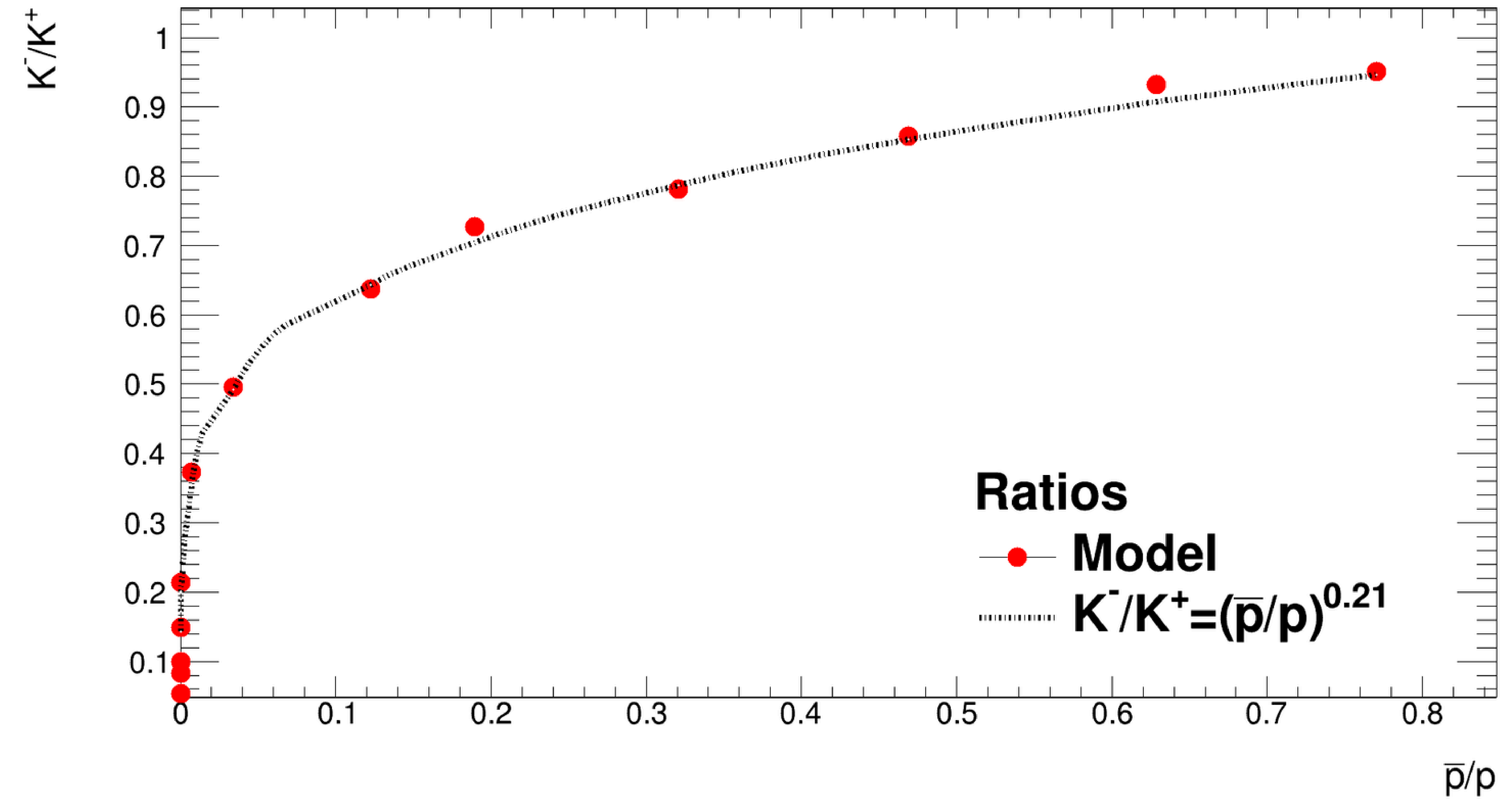




Ratio

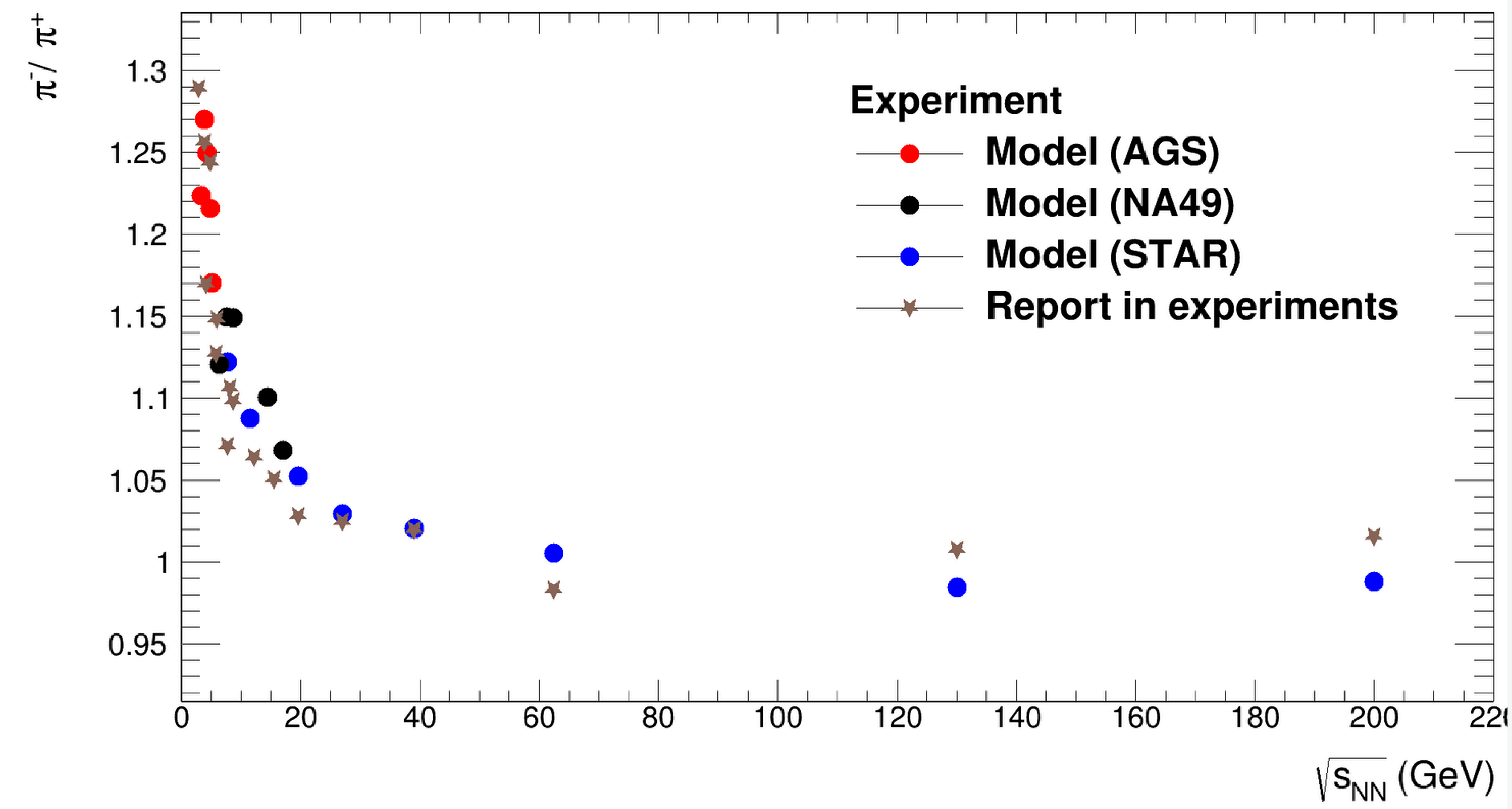
$$K^-(s\bar{u})/K^+(\bar{s}u)$$

$$\bar{p}(\bar{u}\bar{u}\bar{d})/p(uud)$$



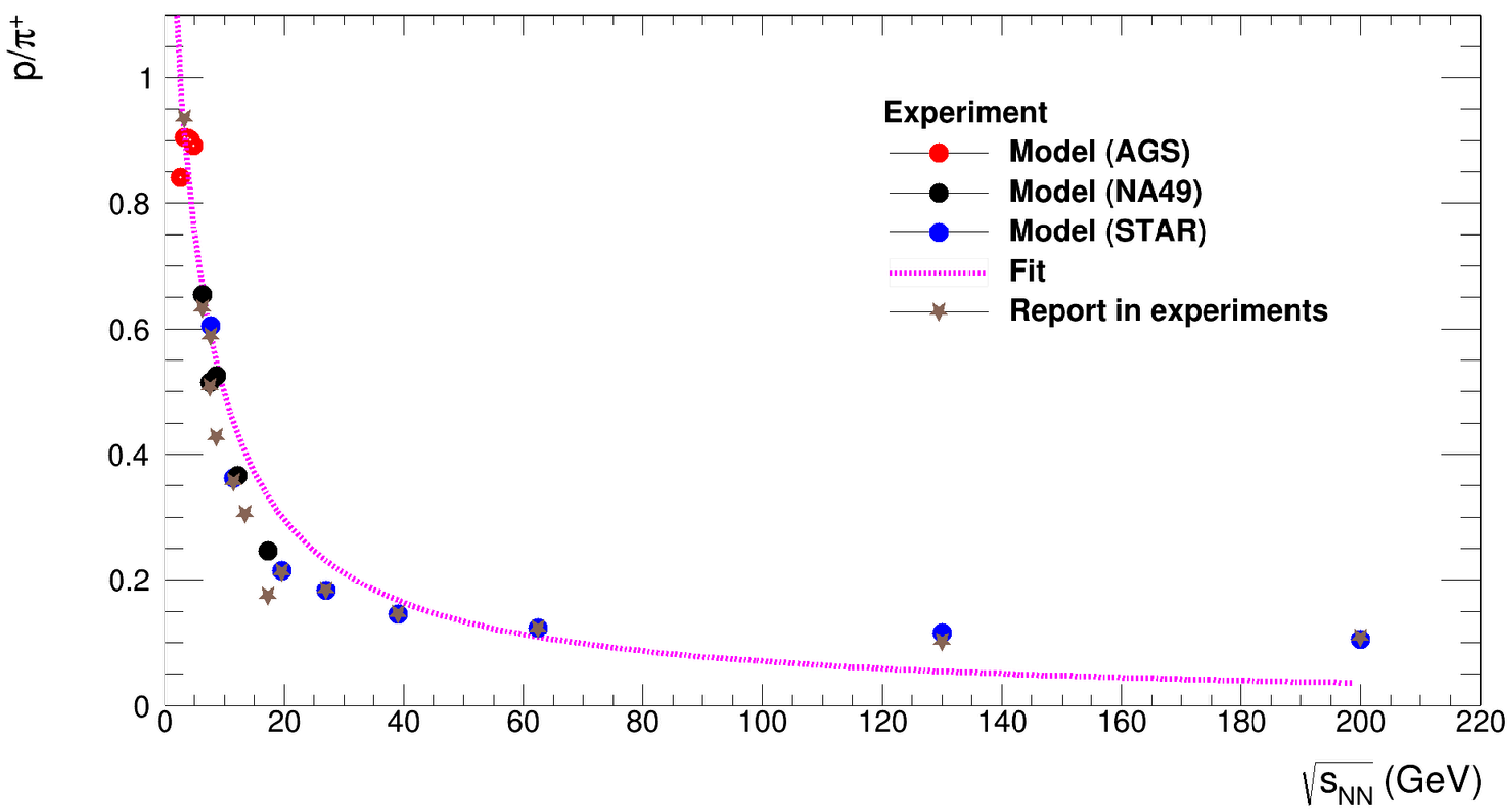
Ratio

$$\pi^-(\bar{u}d)/\pi^+(\bar{d}u)$$



Ratio

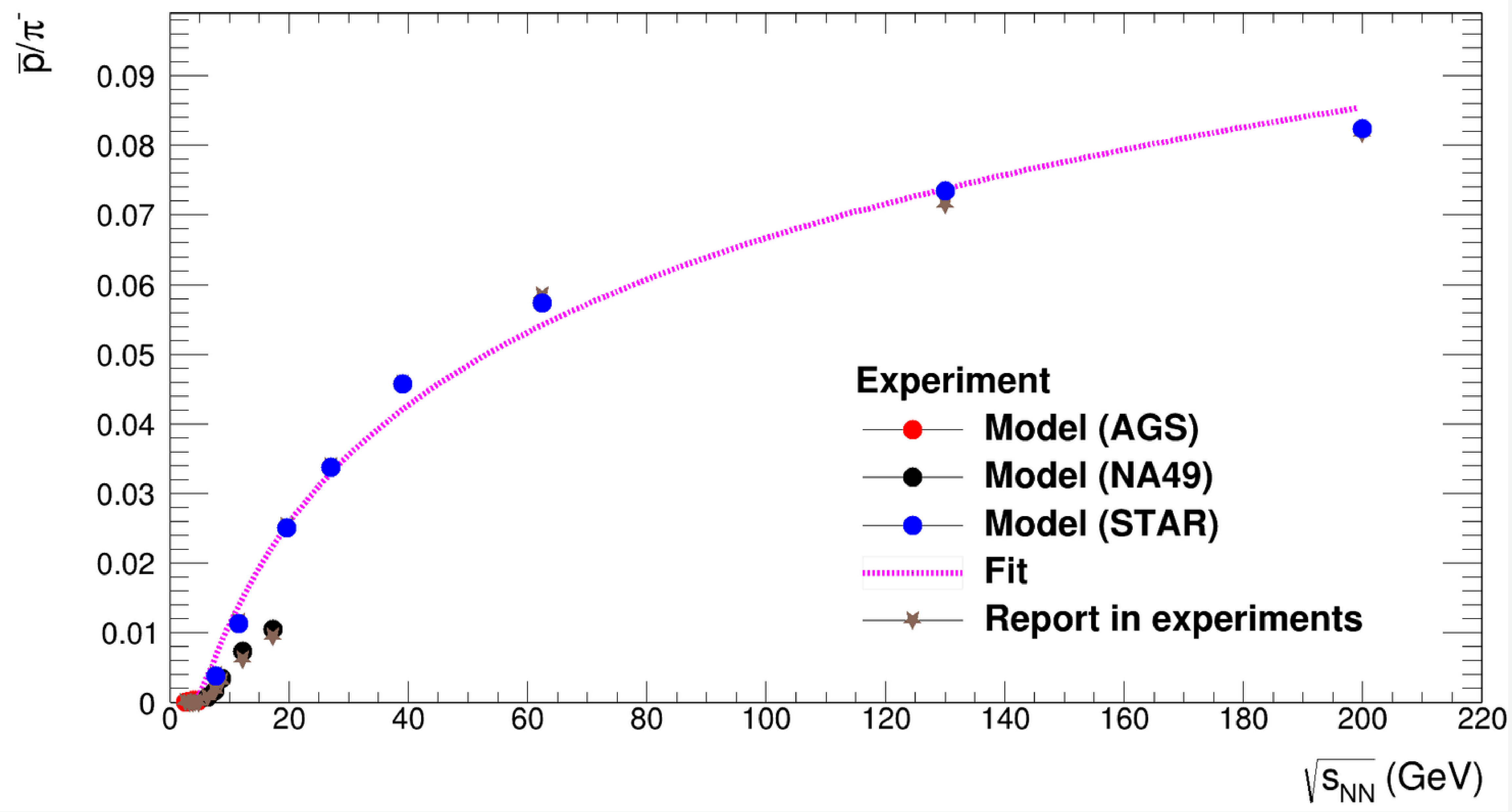
$$p(uud)/\pi^+(\bar{d}u)uud$$



$$p/\pi^+ = \frac{1.551}{1 + 0.211\sqrt{s_{NN}}}$$

Ratio

$$\bar{p}(\bar{u}d)/\pi^{-}(\bar{u}\bar{u}\bar{d})$$



$$\bar{p}/\pi^{-} = 0.86 * e^{0.0196*\sqrt{s_{NN}}} * sin(-0.000214 * \sqrt{s_{NN}} + 4.83) + 0.79$$