Influence of the in-medium Kaons Potential on Kaons Production in Heavy Ion Collisions

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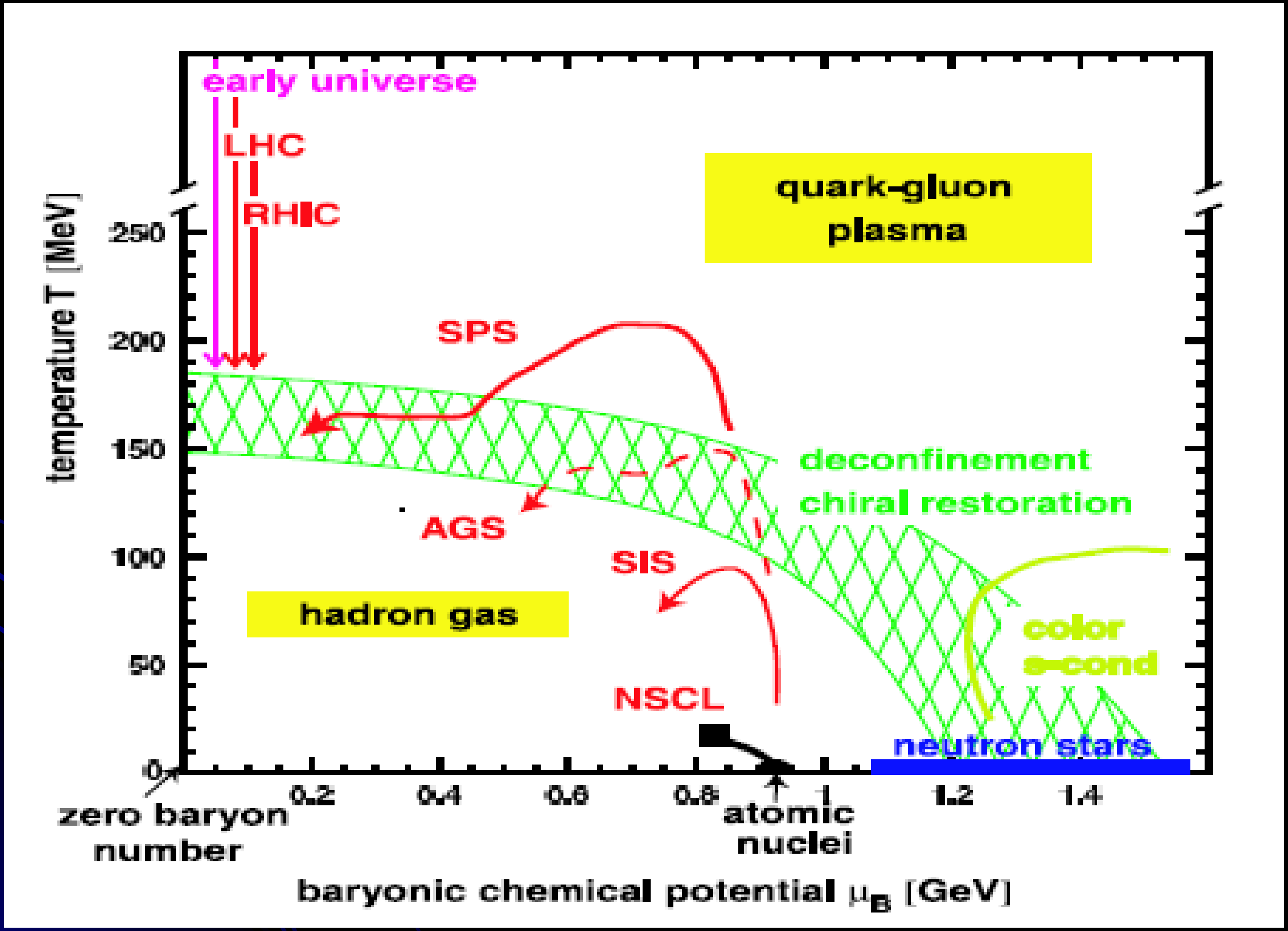
Outline

- The Kaon properties in dense matter
- Probing in-medium kaon potential and EOS
- Results and Discussion
- Summary

How much energy is needed to compress hadronic matter?



Good probes for dense matter

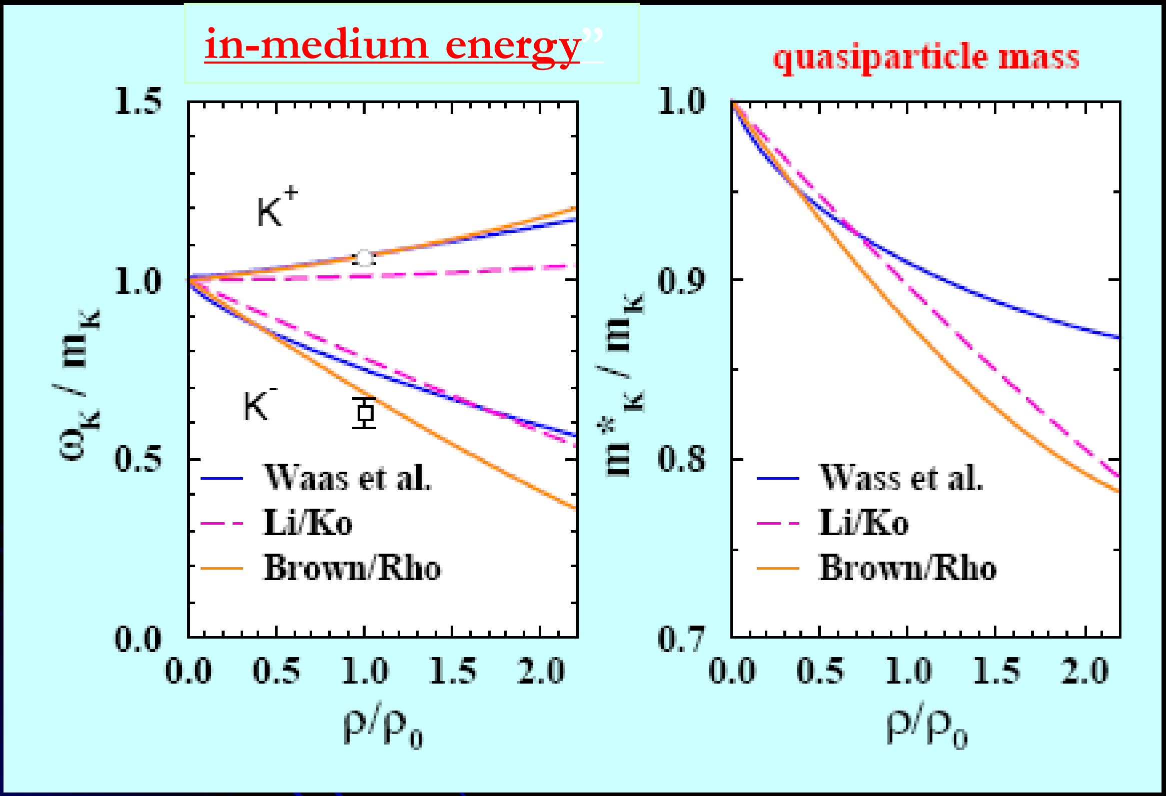
Kaons:

$$K^+(u\bar{s}): \quad NN \to N\Lambda K^+ \qquad E_{thr} = 1.58 \;\; GeV$$

$$\pi N \to \Lambda K^+$$

$$K^-(\bar{u}s): \quad NN \to NNK^+K^- \qquad E_{thr} = 2.5 \;\; GeV$$

• Do kaons change their properties in dense matter?



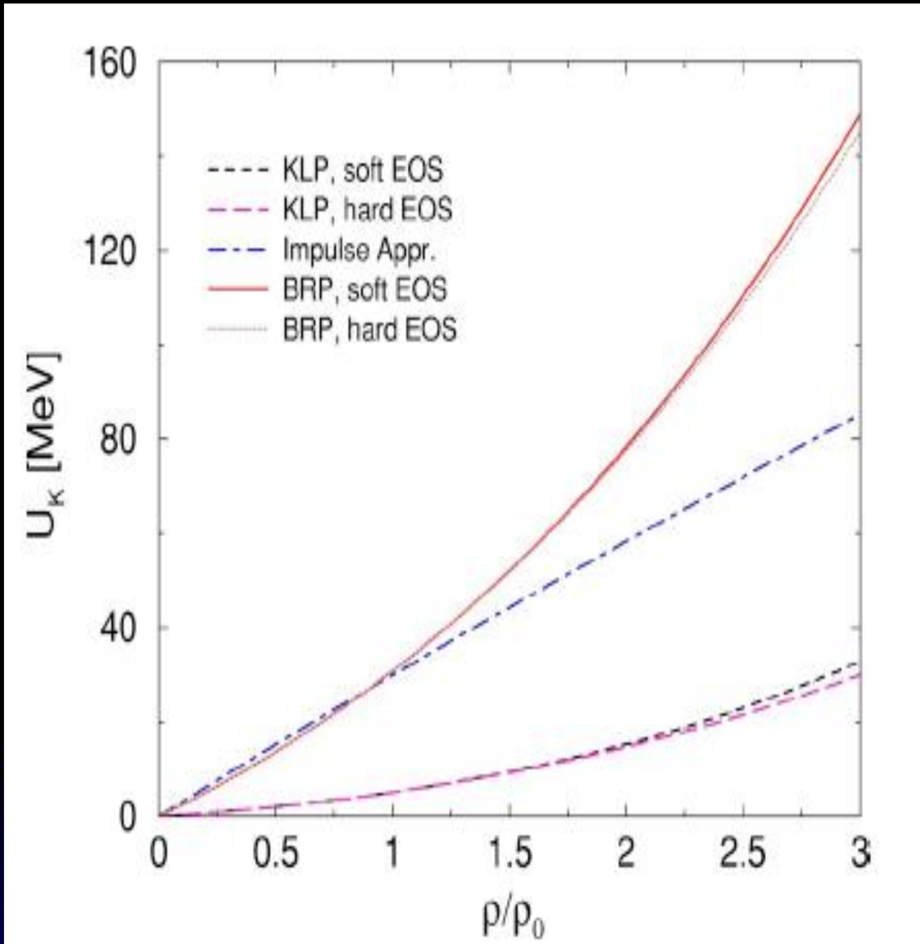
$$\left[\left(\partial_\mu \pm iV_\mu\right)^2 + m_K^{*2}\right]\phi_{K^\pm} = 0$$

$$m_K^* = \sqrt{m_K^2 - \frac{\sum_{KN}}{f_\pi^2}\rho_s + V_\nu V^\mu}$$

$$\left[k^{*2} - m_K^{*2}\right]\phi_{K^\pm} = 0$$

Dispersion relation :

$$\omega = \sqrt{k^{*2} + m_K^{*2}} \pm V_0$$



$$U(\rho,\mathbf{k}) = \omega(\rho,\mathbf{k}) - \omega_0(\mathbf{k})$$

$$= \sqrt{\mathbf{k}^2 + m_K^2 - \frac{\Sigma_{KN}}{f_\pi^{*2}}\rho_s + V_0^2} \pm V_0$$

$$-\sqrt{\mathbf{k}^2 + m_K^2}$$

BR potential $U_K(\rho_0) \approx 30 \quad MeV$

$$\Sigma_{KN} = 450 \quad MeV$$

$$f_\pi^{*2} = 0.6 f_\pi^2 \quad ; \quad f_\pi^{*2} = f_\pi^2$$

KL potential $U_K(\rho_0) \approx 5 \quad MeV$

$$\Sigma_{KN} = 350 \quad MeV$$

$$f_\pi^{*2} = f_\pi^2$$

Density dependence of the in-medium kaon potential at zero momentum. IA: the impulse approximation

[NPA 567 (1994) 937],

Skyrme forces in the QMD model

Skyrme forces are easy to handle, cover the range of uncertainty concerning the EOS for isospin symmetric nuclear matter and therefore widely used in transport calculations for heavy ion collisions.

The QMD N-particle Hamiltonian is given by

$$H = \sum_i \sqrt{k_i^2 + m_i^2} + \frac{1}{2} \sum_{\substack{i,j \\ (j \neq i)}} \left(V_{ij}^{Sk} + V_{ij}^{Yuk} + V_{ij}^{Coul} \right) \quad (1)$$

$$V_{ij}^{Sk} = t_1 \delta^3(\mathbf{q} - \mathbf{q}') + t_2 \delta^3(\mathbf{q} - \mathbf{q}') \rho^{\gamma-1}(\mathbf{q}) + t_3 \ln^2\left(\varepsilon |\mathbf{k} - \mathbf{k}'|^2 + 1\right) \delta^3(\mathbf{q} - \mathbf{q}')$$

$$V^{Yuk} = t_4 \frac{e^{-|\mathbf{q}-\mathbf{q}'|/\mu}}{-|\mathbf{q}-\mathbf{q}'|/\mu}$$

$$V^{coul} = \left(\frac{Z}{A}\right)^2 \frac{e^2}{|\mathbf{q} - \mathbf{q}'|}$$

The individual nucleons are described by Gaussian wave packets with fixed width $2L^{1/2}$. This leads to a One-particle Wigner density

$$f_i(\mathbf{q},\mathbf{k},t) = \frac{1}{\pi^3} e^{-(\mathbf{q}-\mathbf{q}_i(t))^2 2/\mathbf{L}} e^{-(\mathbf{k}-\mathbf{k}_i(t))^2 \mathbf{L}/2} \quad (2)$$

$$\begin{aligned} V_{ij}^{Sk} &= \int d^3q d^3q' d^3k d^3k' f_i(\mathbf{q},\mathbf{k},t) V^{Sk}(\mathbf{q},\mathbf{k};\mathbf{q},\mathbf{k}') f_j(\mathbf{q}',\mathbf{k}',t) \\ &= \alpha\left(\frac{\rho_{ij}}{\rho_0}\right) + \beta\left(\frac{\rho_{ij}}{\rho_0}\right)^{\gamma} + \delta \ln^2\left(\varepsilon\left|k_i - k_j\right|^2 + 1\right)\left(\frac{\rho_{ij}}{\rho_0}\right) \end{aligned} \quad (3)$$

$$\left(\rho_0 = 0.16\, fm^{-3}, E_B = -16 MeV\right)$$

Where ρ_{ij} is an interaction density

$$\rho_{ij} = \frac{1}{(4\pi L)^{3/2}} e^{-(q_i - q_j)^2/4L}$$

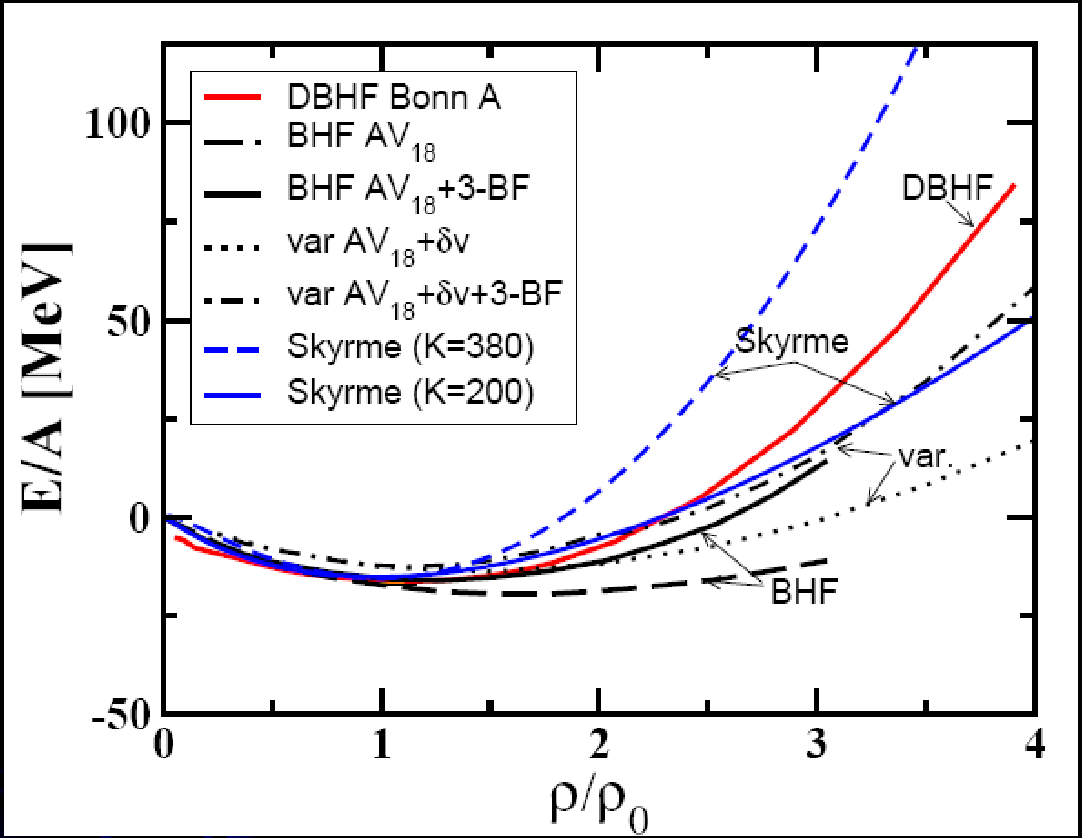
The parameters $\alpha, \beta, \gamma, \delta, \varepsilon$ in Eq. (3) are fitted to the saturation point $\left(\rho_0 = 0.16\, fm^{-3}, E_B = -16 MeV\right)$ and the momentum dependence of the real part of the nucleon-nucleon optical potential.

With this Hamiltonian Eq. (1) the EOS of isospin saturated nuclear matter , i.e. the binding energy per Particle, is of the simple form

$$E_{bind} = \frac{E}{A} = \frac{3k_F^2}{10M} + \frac{\alpha}{2}\left(\frac{\rho}{\rho_0}\right) + \frac{\beta}{1+\gamma}\left(\frac{\rho}{\rho_0}\right)^{\gamma} + \frac{\delta}{2}\ln^2\left(\varepsilon\left(\frac{\rho}{\rho_0}\right)^2 + 1\right)\frac{\rho}{\rho_0} \qquad (4)$$

Parameters of the momentum dependent potentials

K (MeV)	α (MeV)	β (MeV)	γ	δ (MeV)	ε	EOS
200	−390	320	1.14	1.57	21.54	SM
380	−130	59	2.09	1.57	21.54	HM

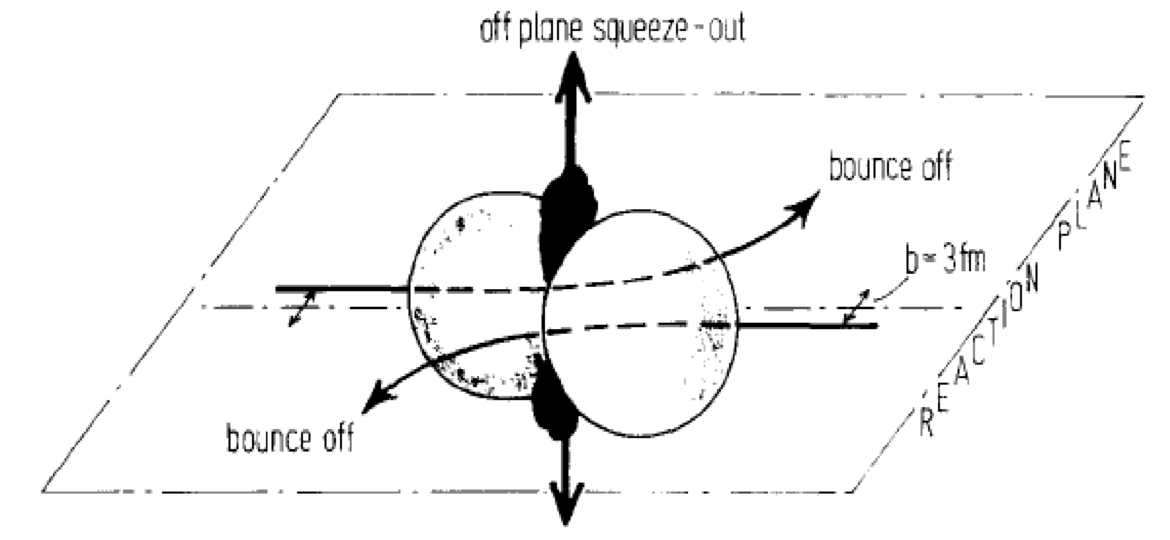


We can see that below $3\rho_0$, the DBHF EOS with K=200MeV is close to the soft Skyrme EOS, But becomes significantly stiffer at higher density.

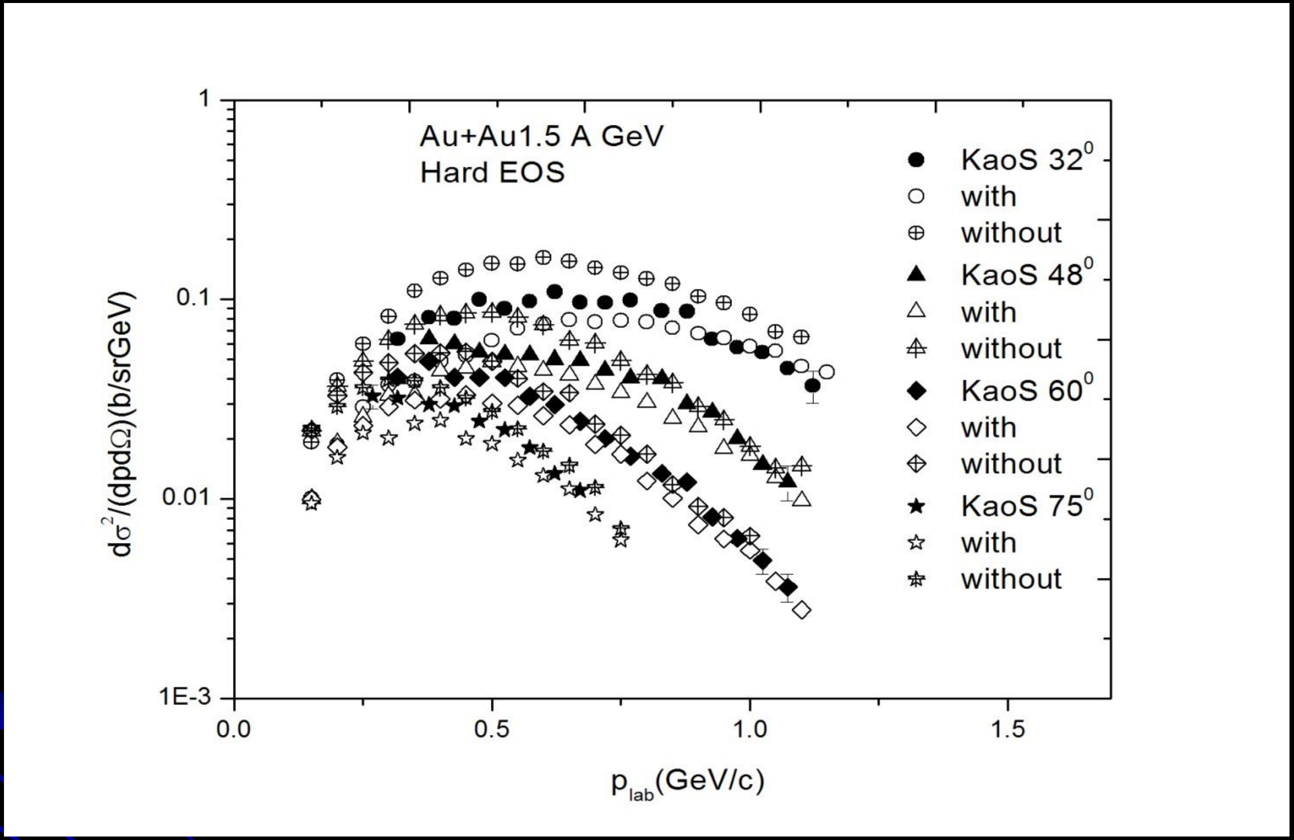
The nuclear EOS from soft and hard Skyrme forces are compared to the Predictions from microscopic ab inito calculations, i.e. relativistic DBHF[Nucl. Phys. A648 (1999)105], non- relativistic BHF [Nucl. Phys. A706 (2002)418] and variantional [Phys. Rev. C58 (1998)1804] calculations.

How can we measure the eos?

The nuclear EOS is studied by particle (Δ, N*, π, K, Λ, Σ, η, ρ,…) production in heavy ion collisions ---- pion and kaon production in HIC



The Influence of K⁺N by (BR)



The cross sections of K^+ at difference polar angle distributions, Data are from KaoS [Phys.Rev,C75,024906(2007)].

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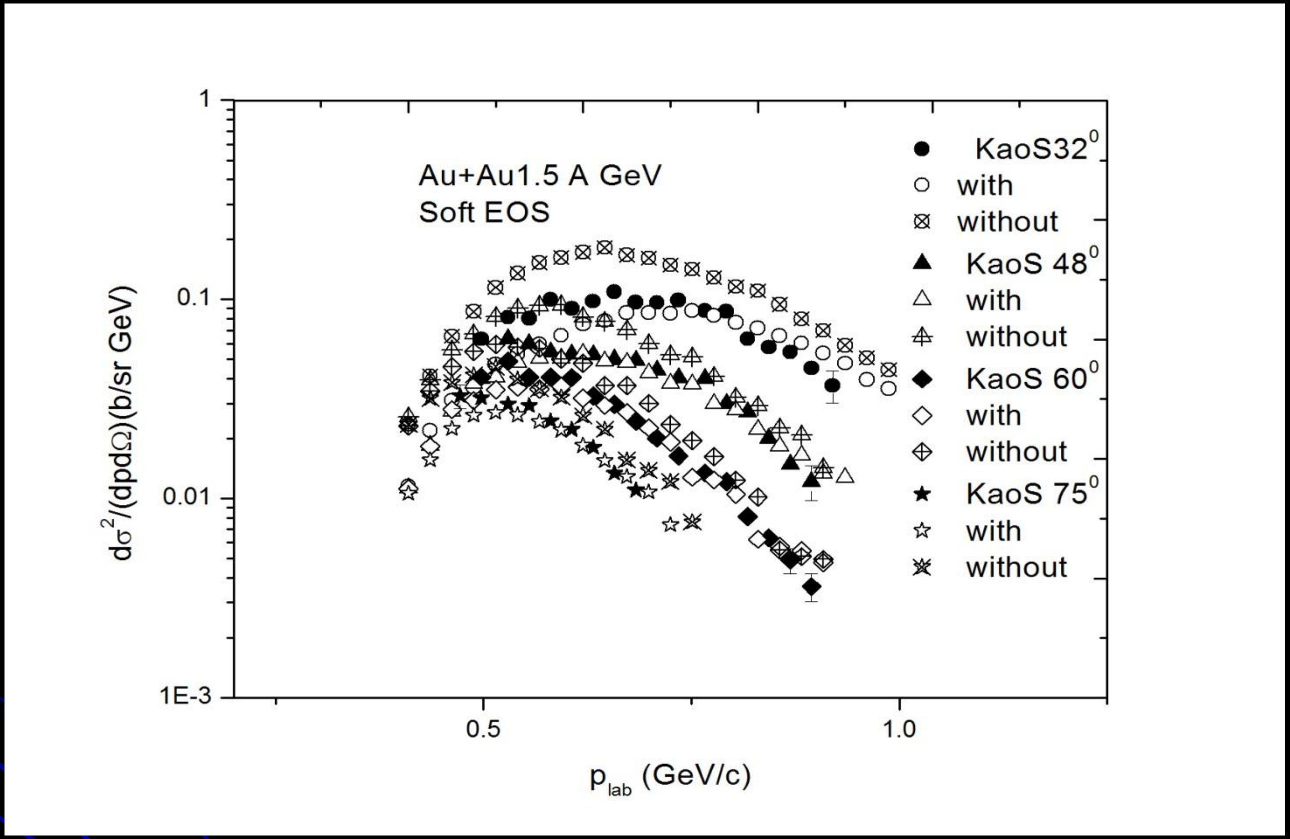

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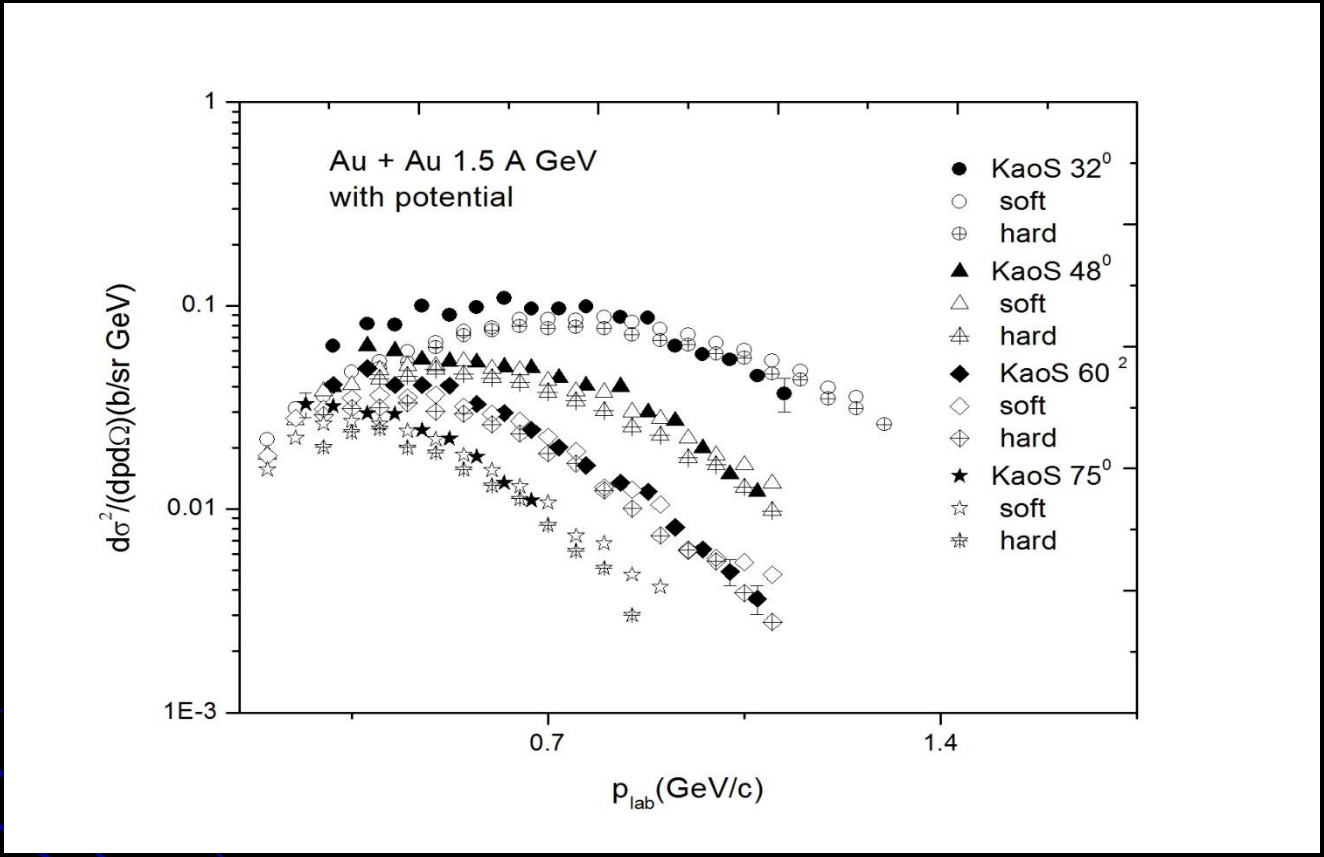

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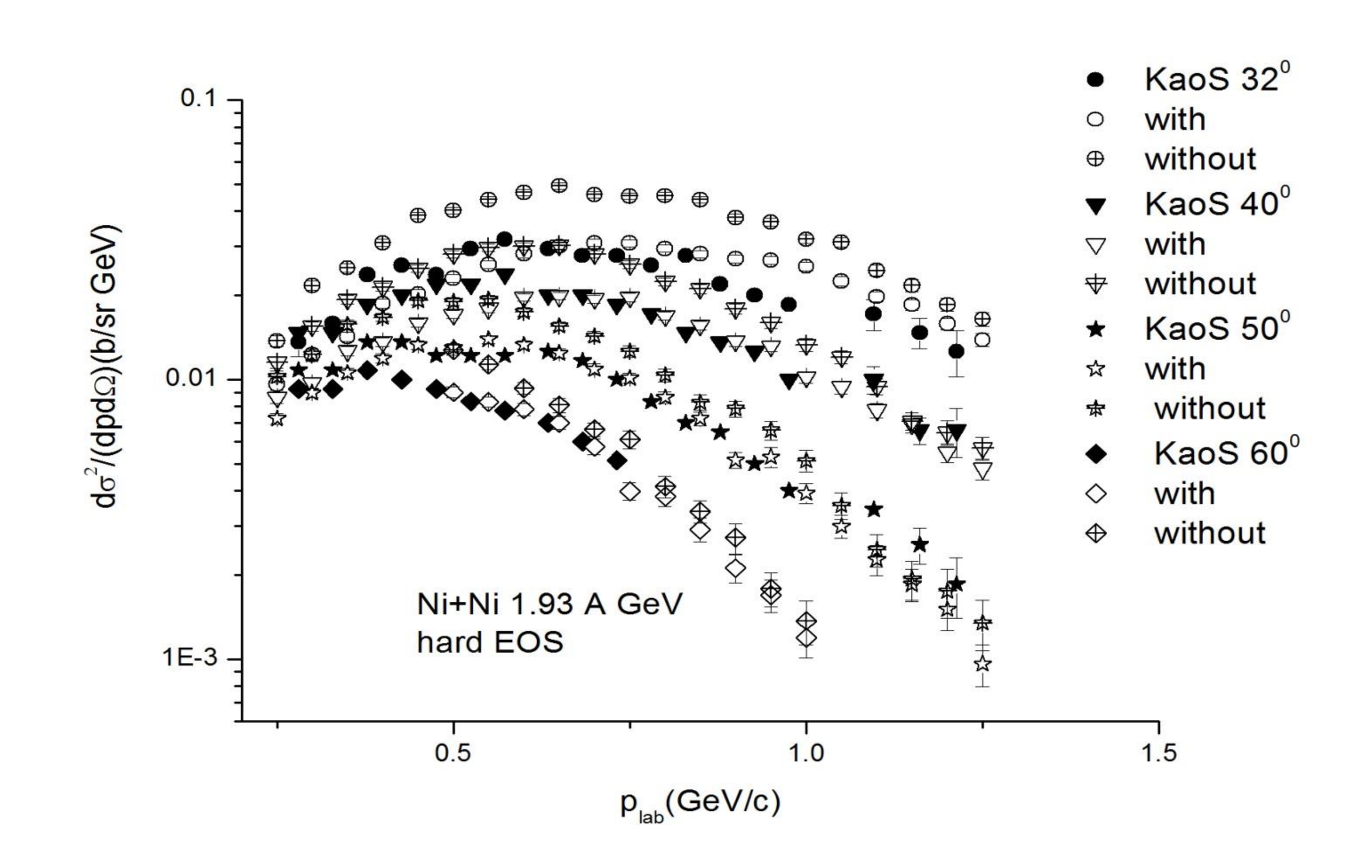

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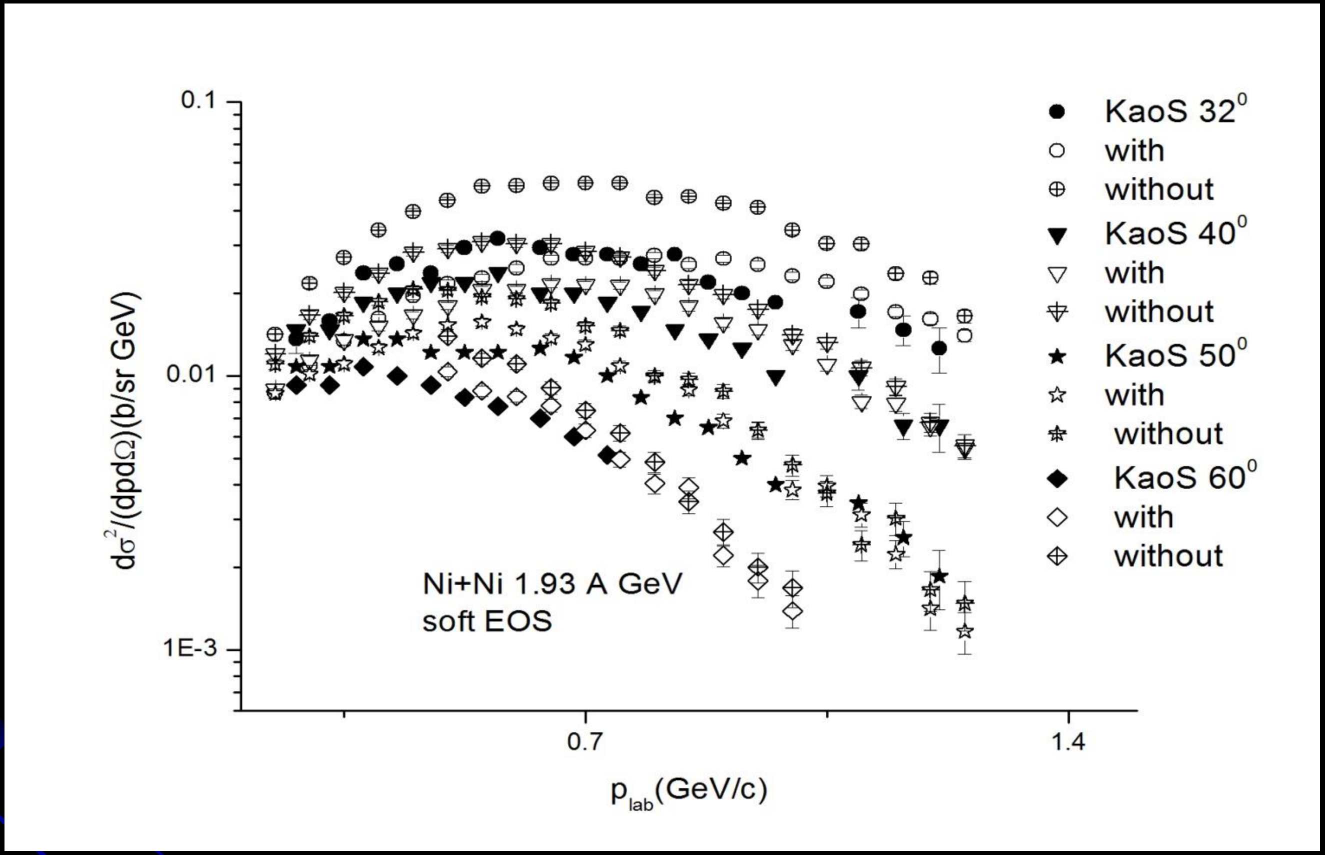

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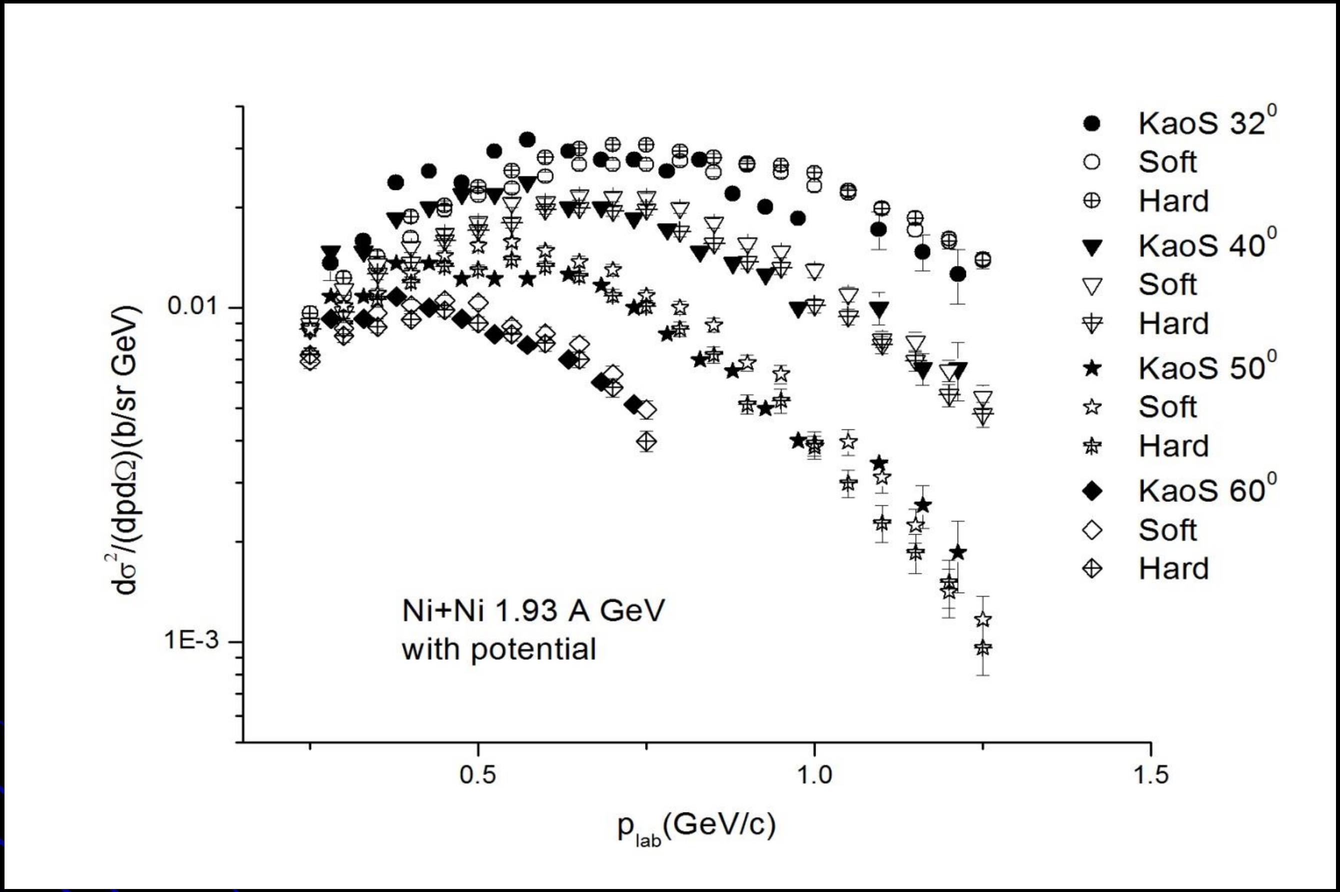

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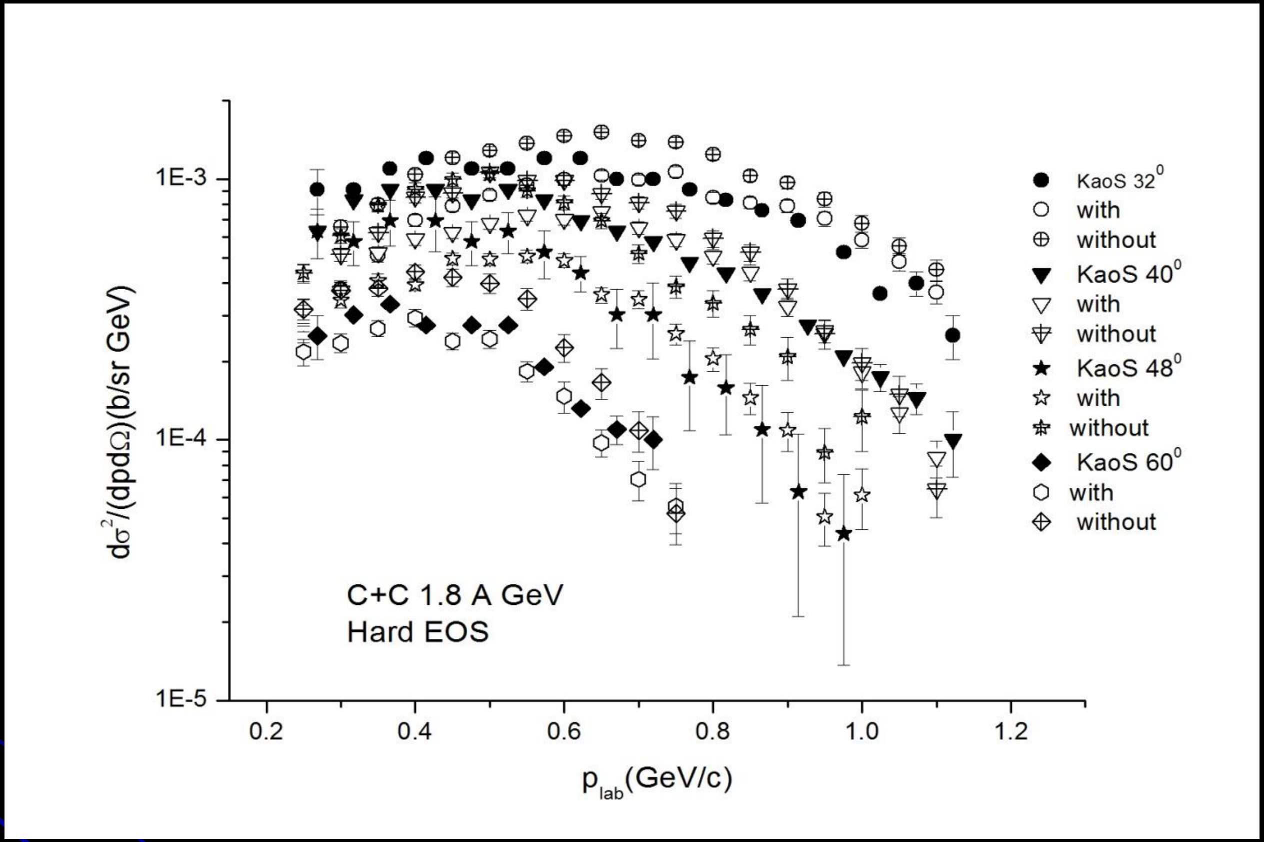

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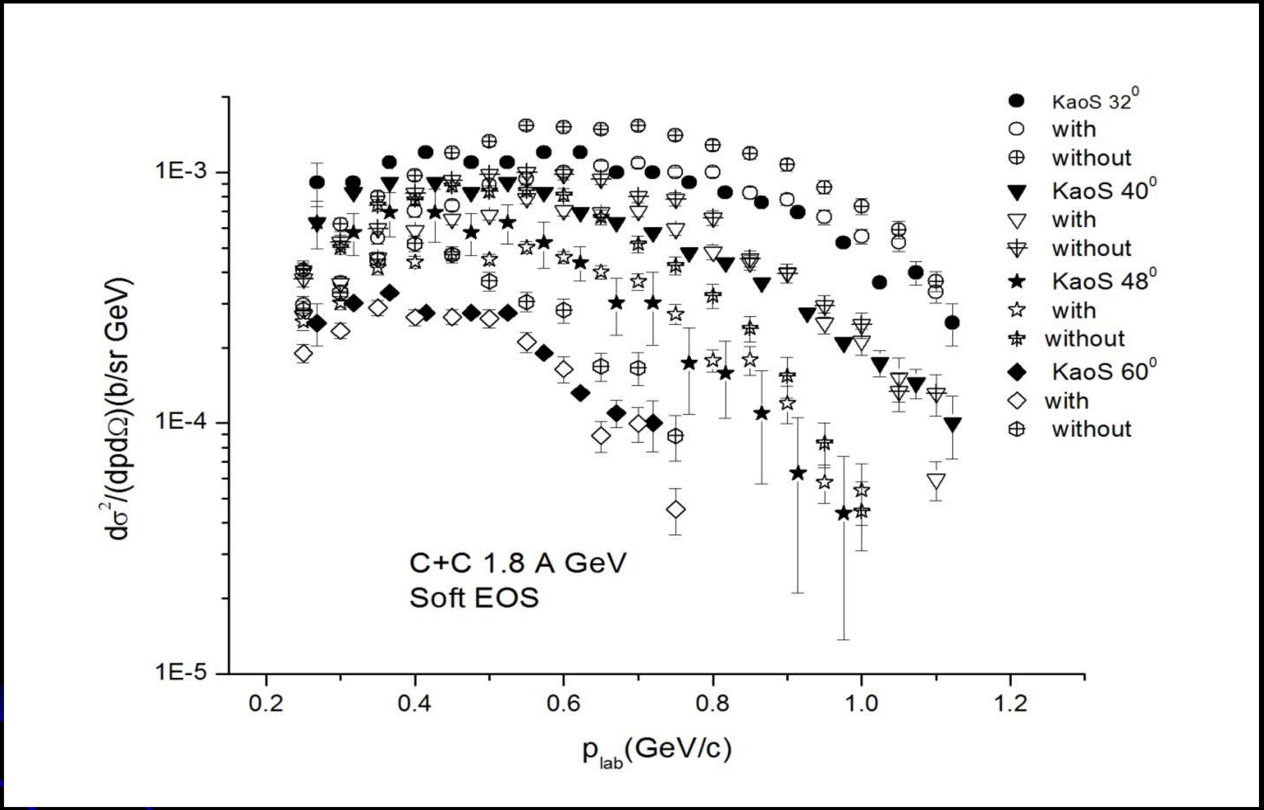

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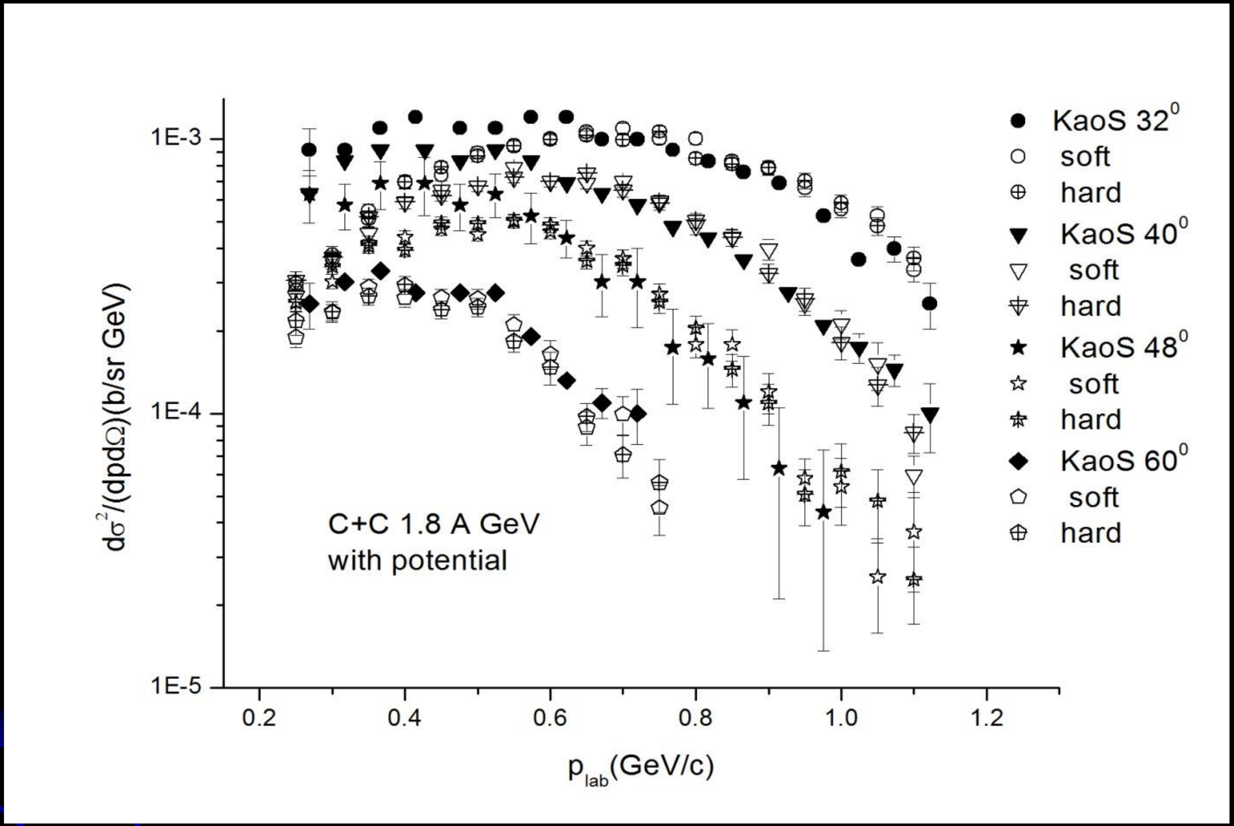

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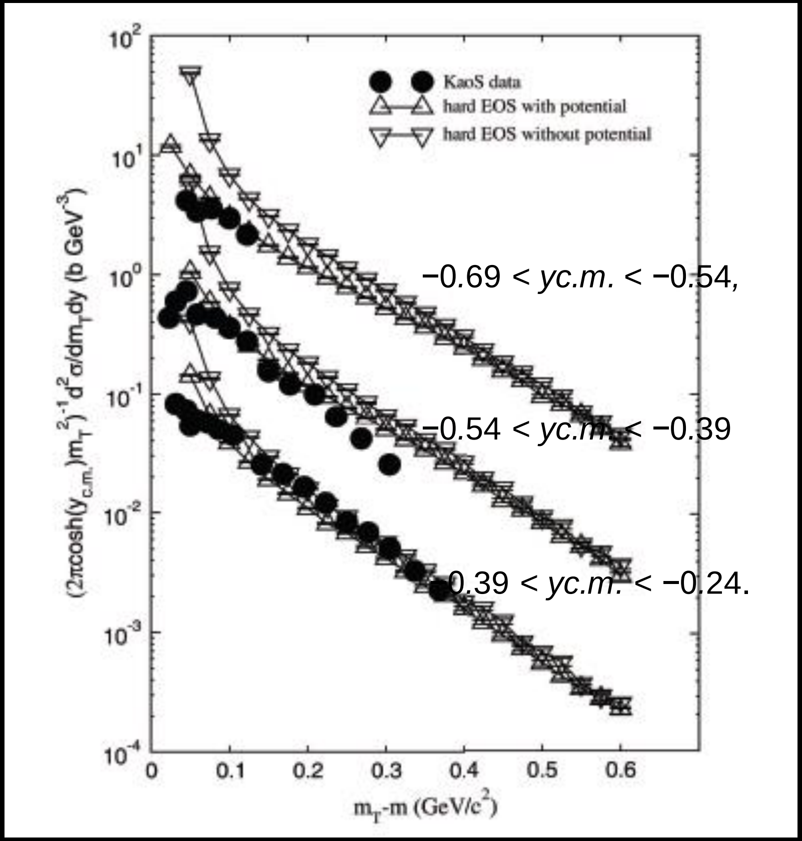

The transverse mass spectra K^+ of Ni + Ni 1.93 A GeV, Data are from KaoS [Senger, P., et al.: Nucl. Instr. Meth. Phys. Res. A. **327**, 393 (1993)].

The scaling factors 10^2, 10^1 and 10^0 are applied to the spectra from *top* to *bottom*

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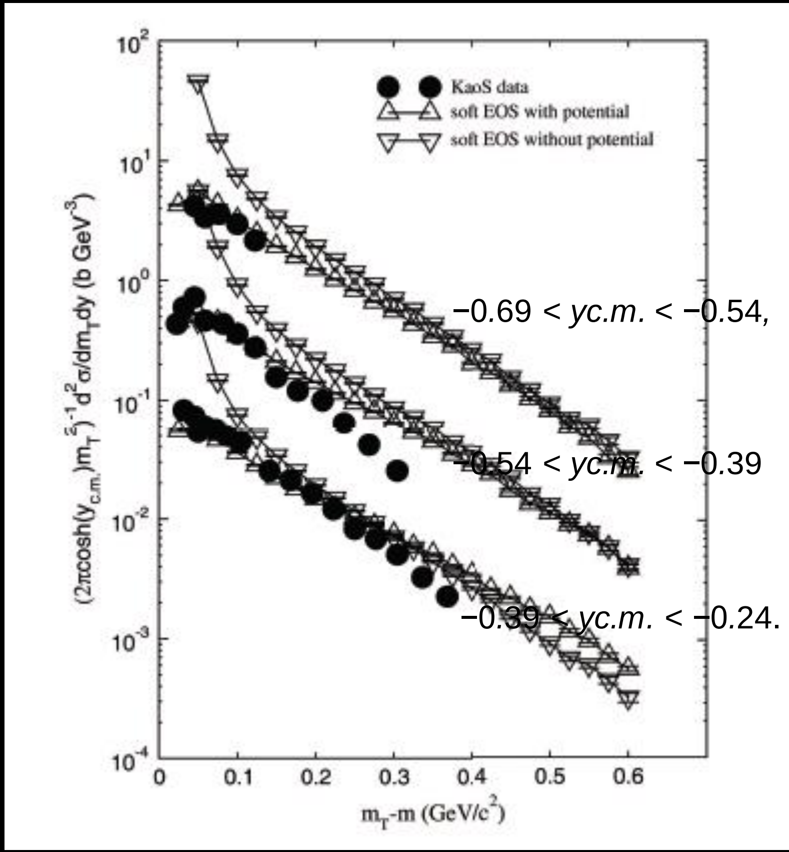

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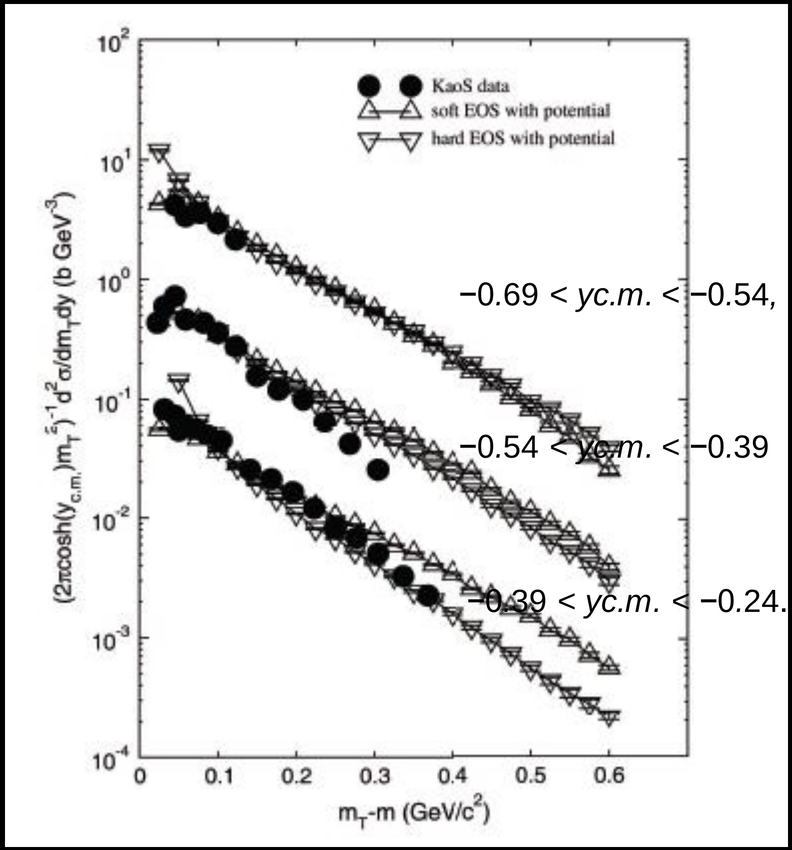

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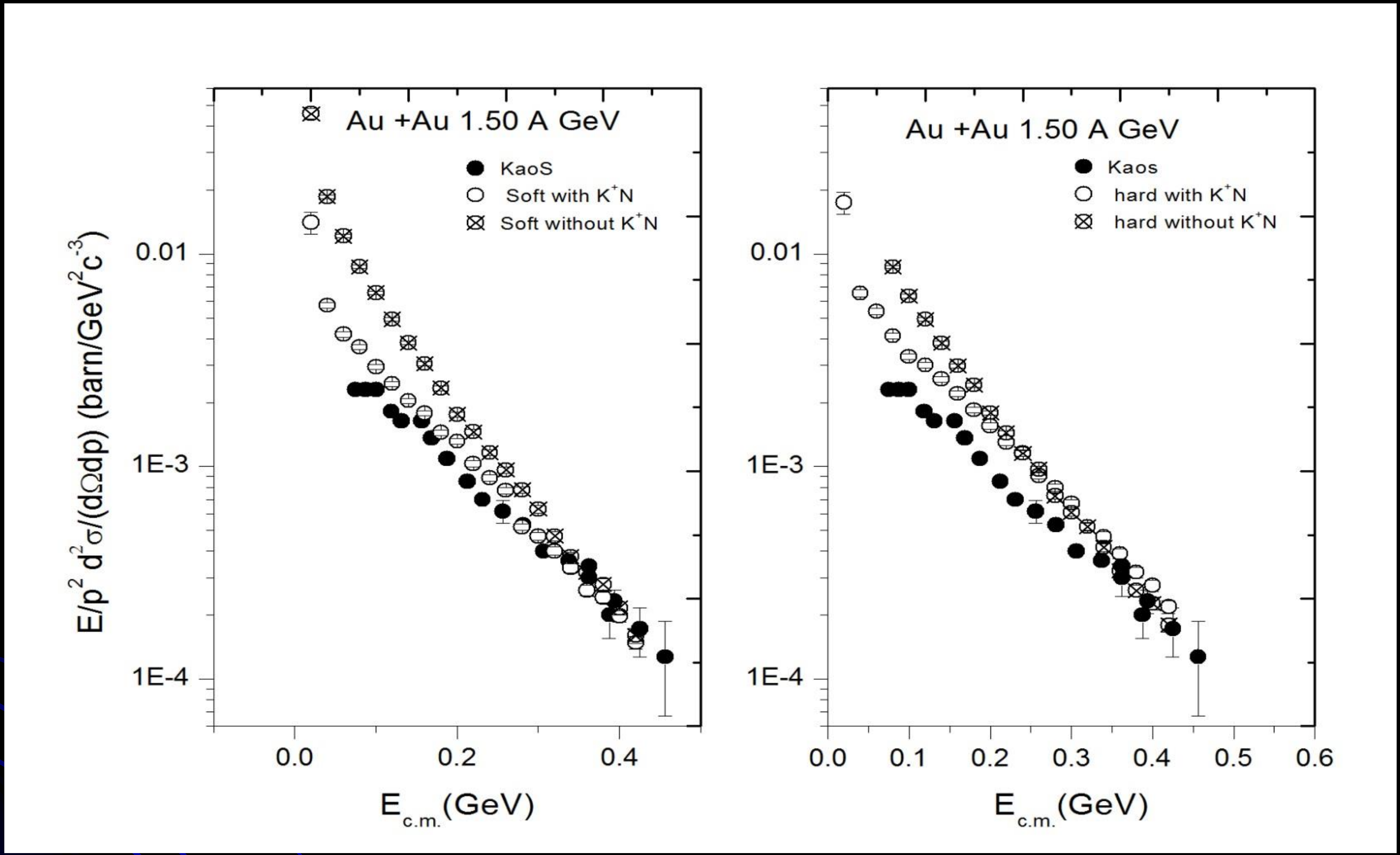
The influence of K⁺N by (BR) & EOS



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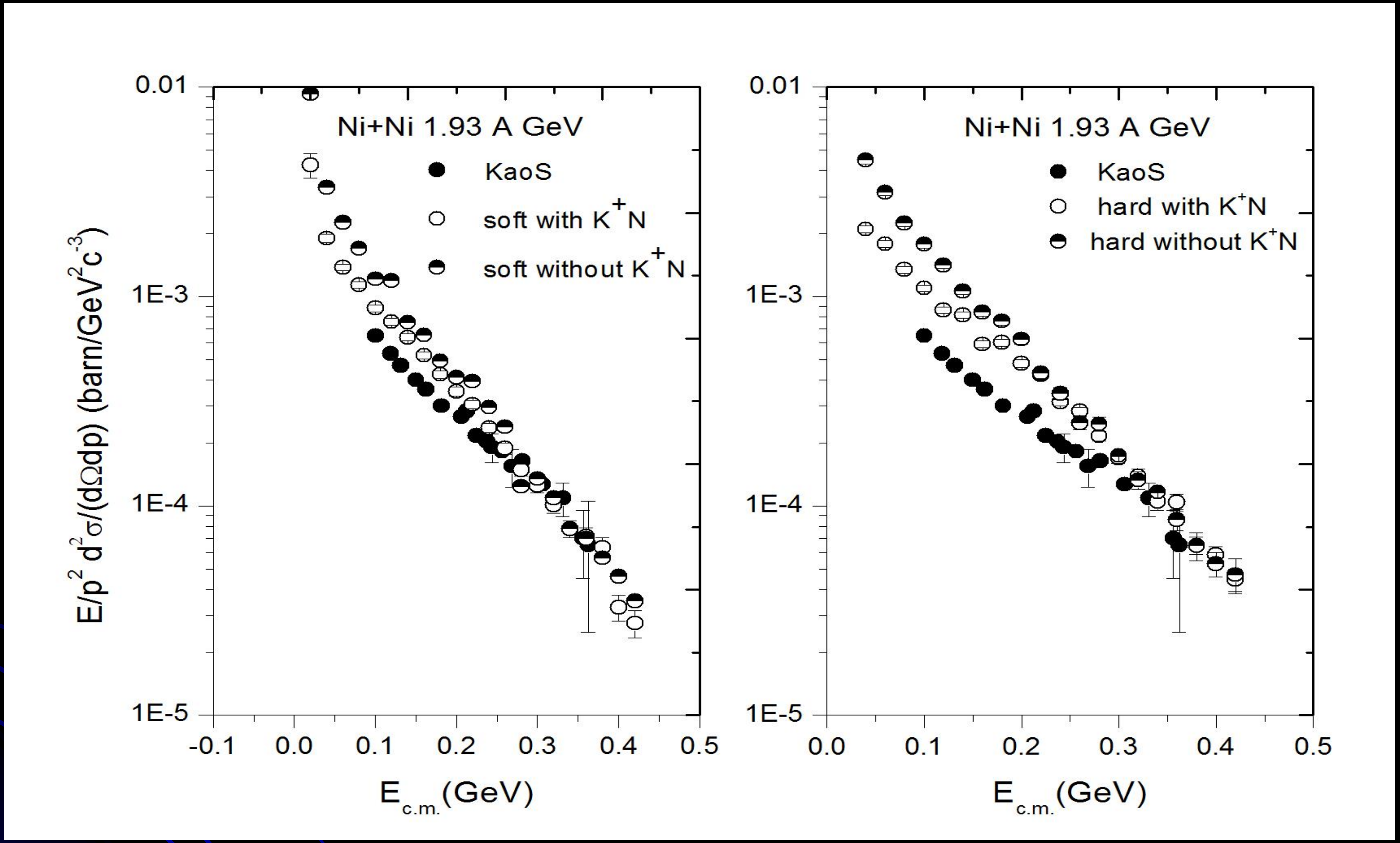

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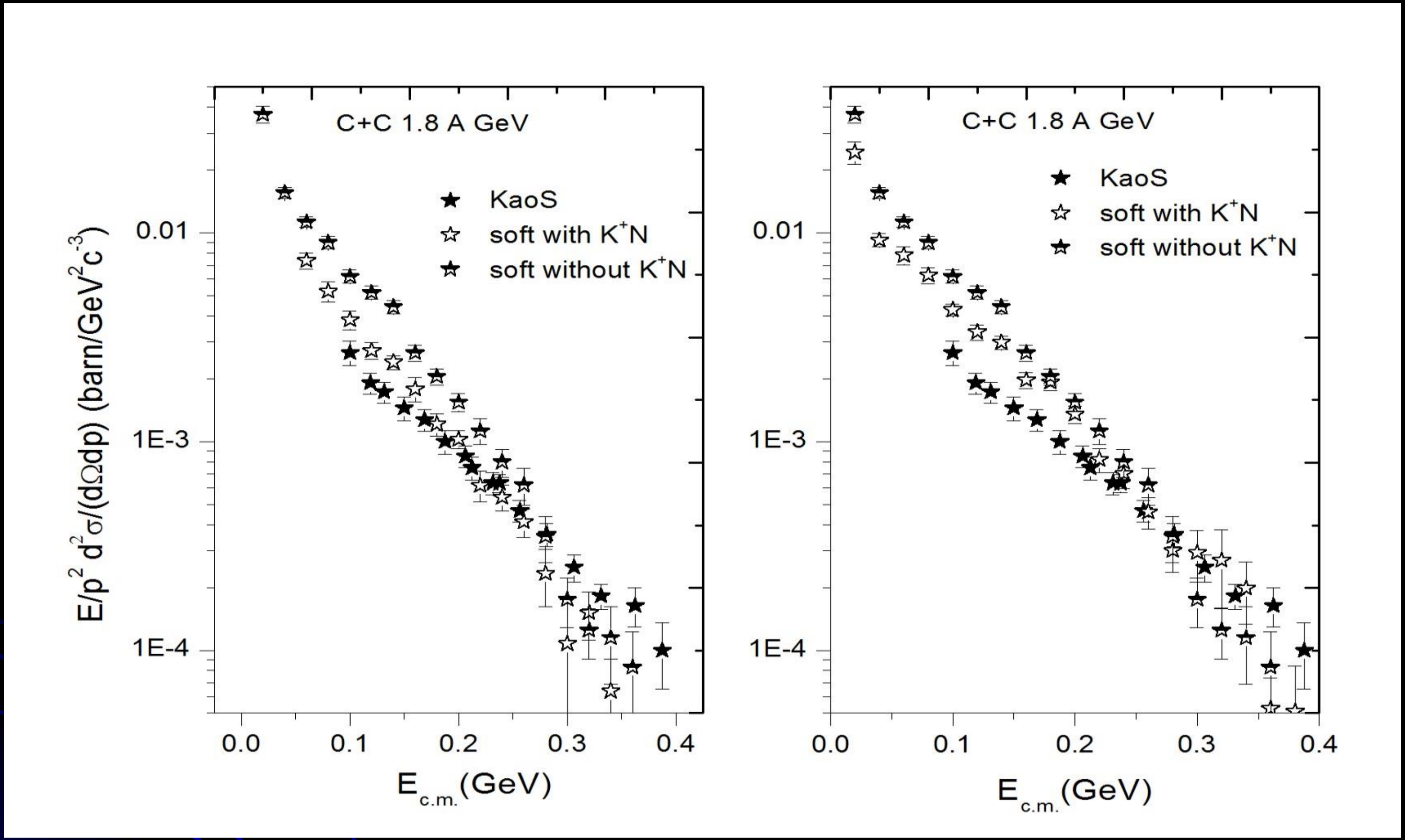

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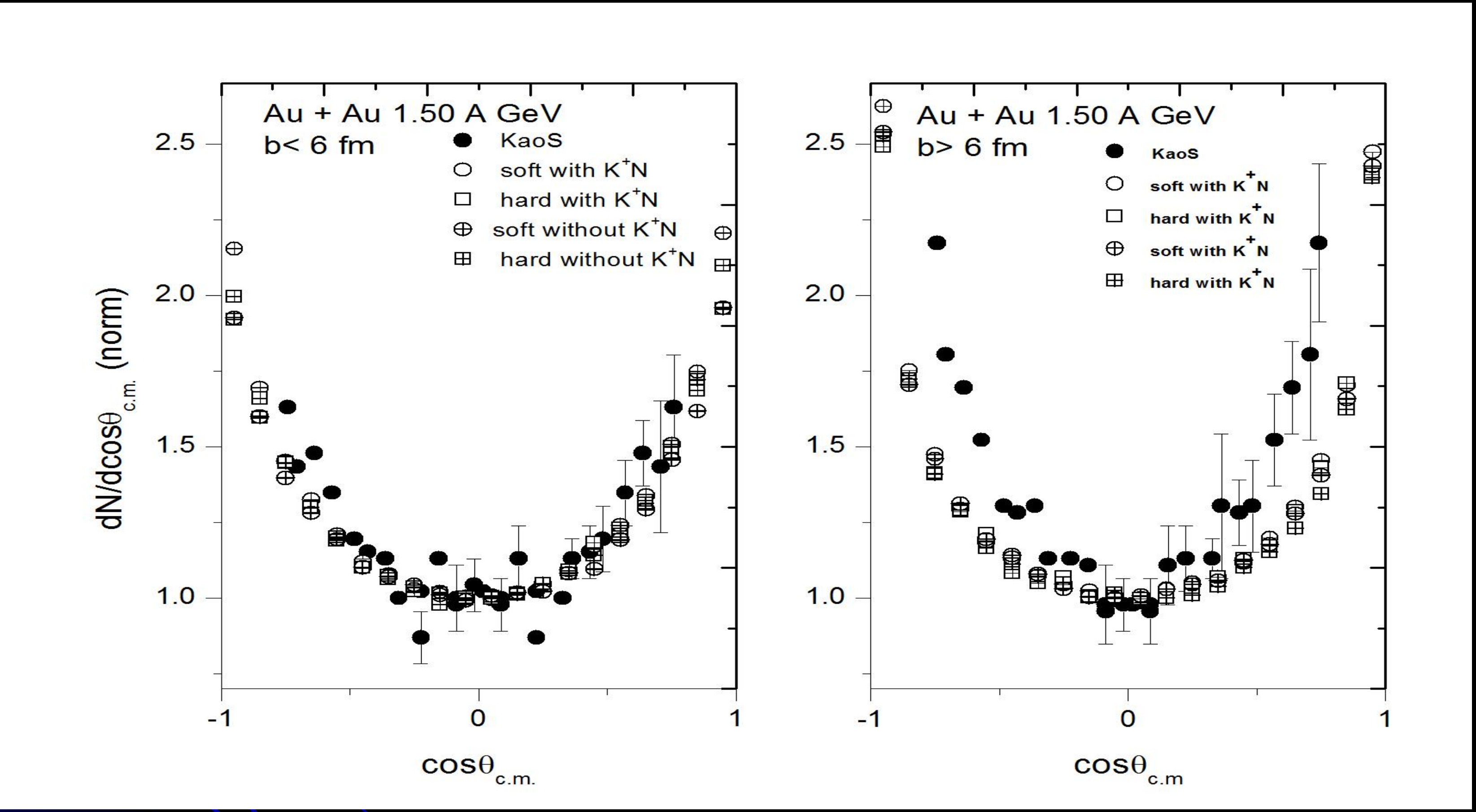
The polar angle distribution of K^+



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The distributions are normalized to 1 for cos $\theta_{c.m.}$ = 0

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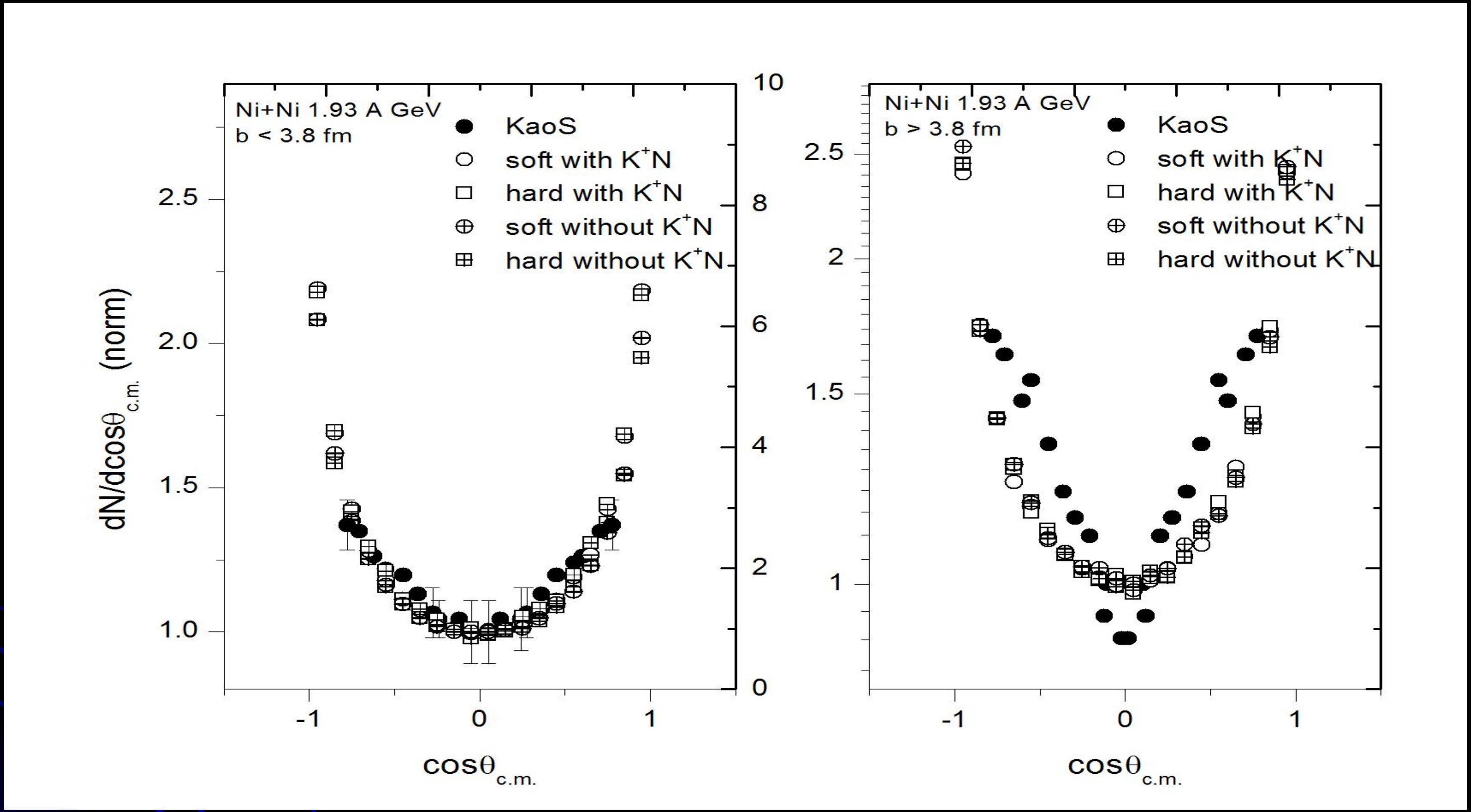
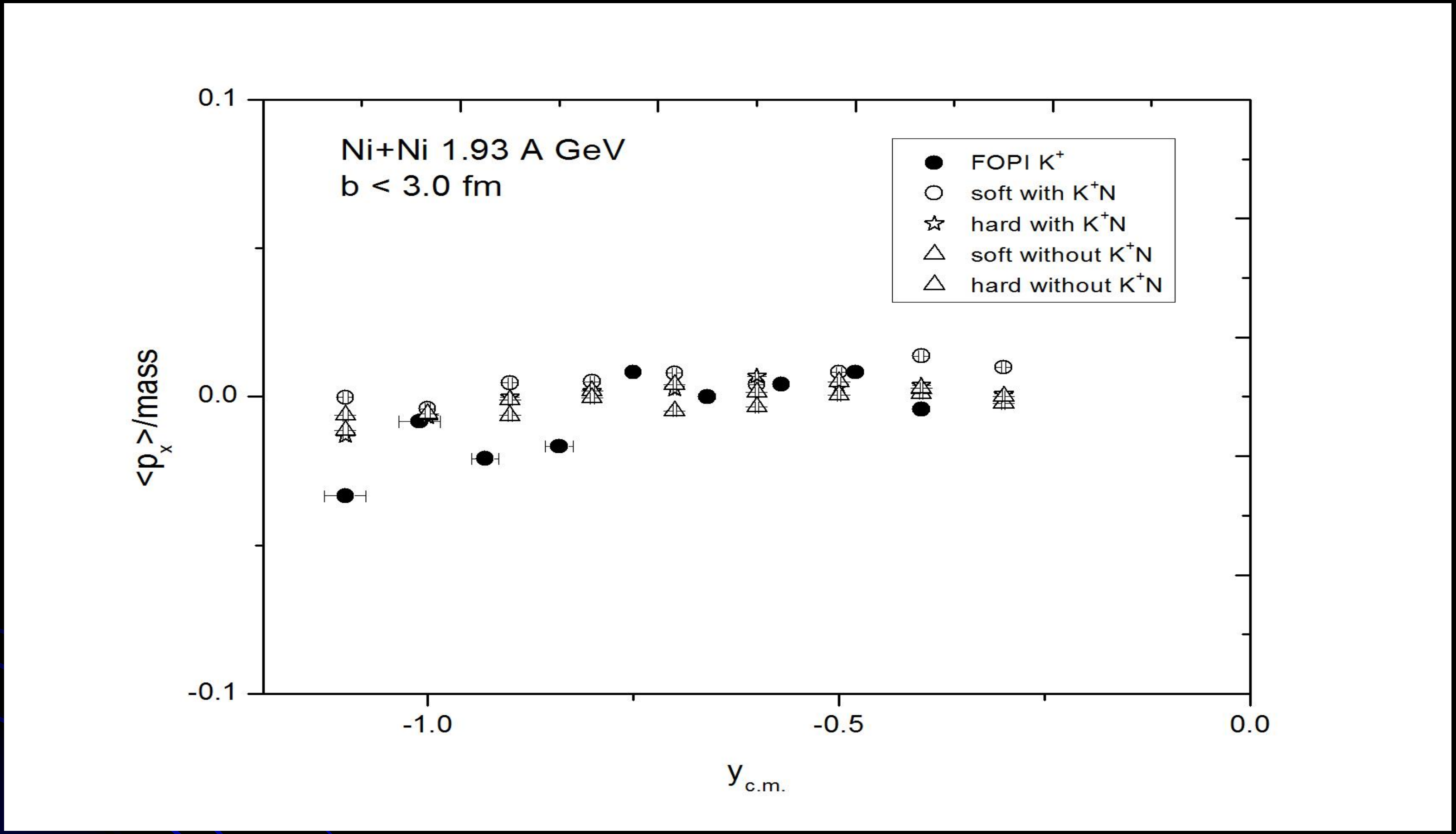


The influence of K^+N by (BR), Data are from KaoS [A. Forster, et al., Phys ReV, C75, 024906 (2007)].

The distributions are normalized to 1 for cos $\theta_{c.m.}$ = 0

The directed transverse momentum of K^+



The influence of K^+N by (BR), Data are from KaoS **[J. Ritman, private communication]**

Summary

- Most transport simulations reproduce corresponding data only when in-medium potentials are included
- The BR parametrization of kaon mean field pvovides the best overall description of the K^+ observables at SIS energies.
- Calculated results with a in-medium K^+N potential can reasonably describe the features of KaoS and Fopi data.This indicates that production cross section, transverse mass spectra are sensitive probes to extract information on in-medium properties of K^+ and prefer soft equation of state.

Summary

❖ **However K^+ the polar distribution and the directed transverse momentum are not sensitive observes in kaon nucleus potential and equation of state.**

❖Details concerning the interplay between density and momentum dependence have still to be settled and require future efforts. More experimental measurements with improved errors, theoretical innovations, and detailed analyses are needed.

It is also needed to study the EOS at the FAIR/GSI energies between 20 -30 A GeV ($\frac{\rho_{max}}{\rho_0} \sim 8$)


IMΦ
Thank you
for your attention !