Kaon and Pion Production in Heavy-Ion Collisions around 1-2 AGeV

Andreas Förster

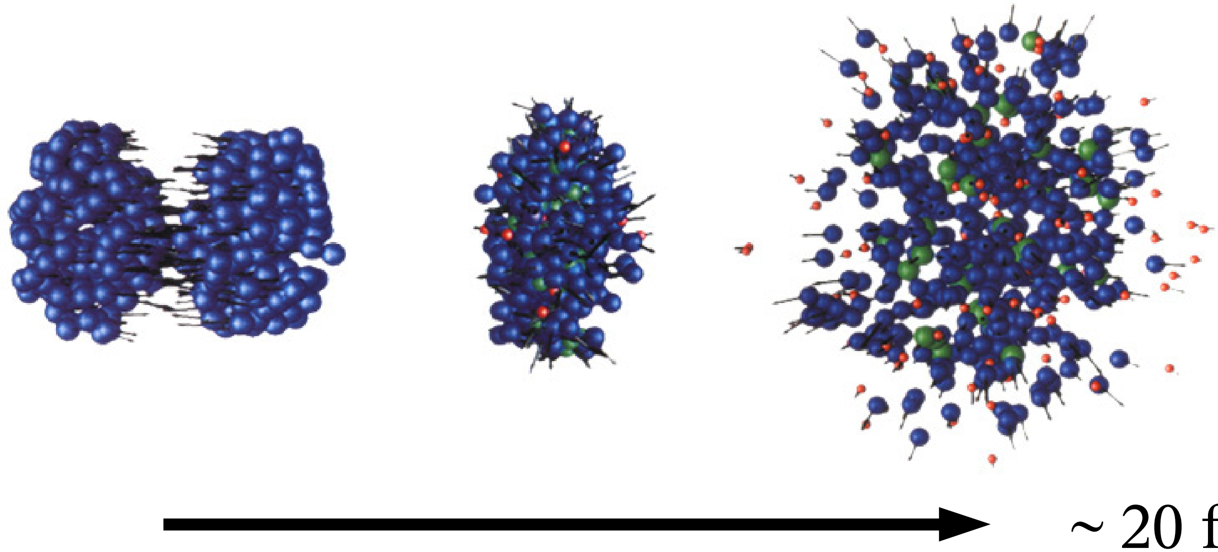
CERN-PH

(before: TU Darmstadt)

for the

KaoS Collaboration

Motivation



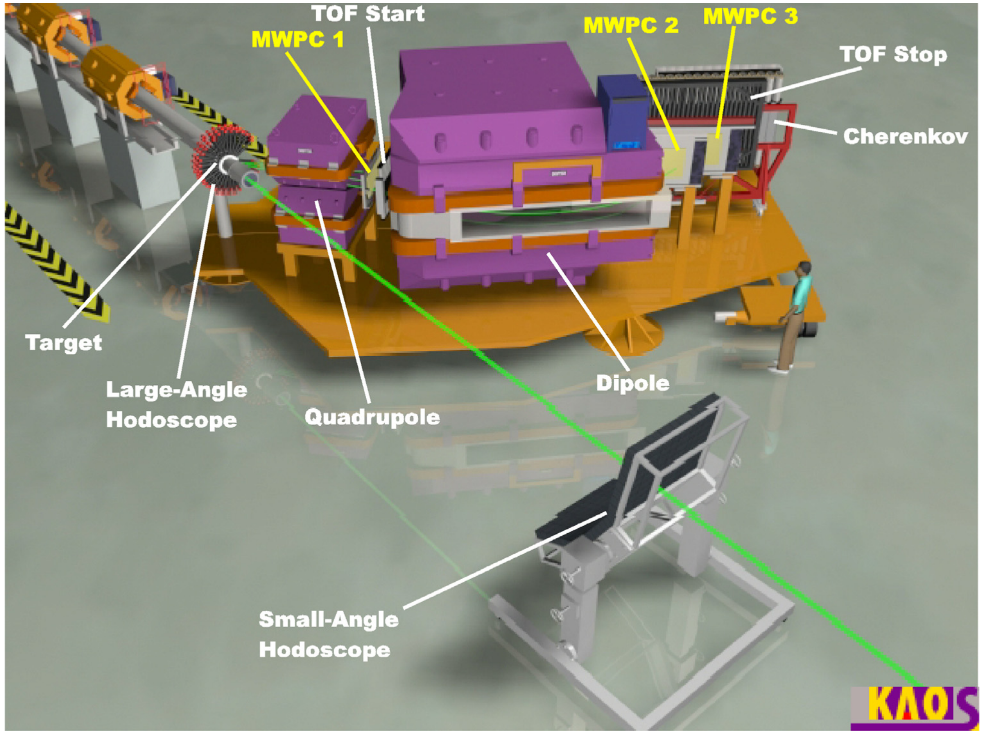
IQMD-Simulation
of an Au+Au Collision

~ 20 fm/c

Density : $\rho = 2 - 3\ \rho_0$

1) Compressibility of nuclear matter at high densities
2) In-medium modifications of K-mesons
3) Time evolution of the particle emission

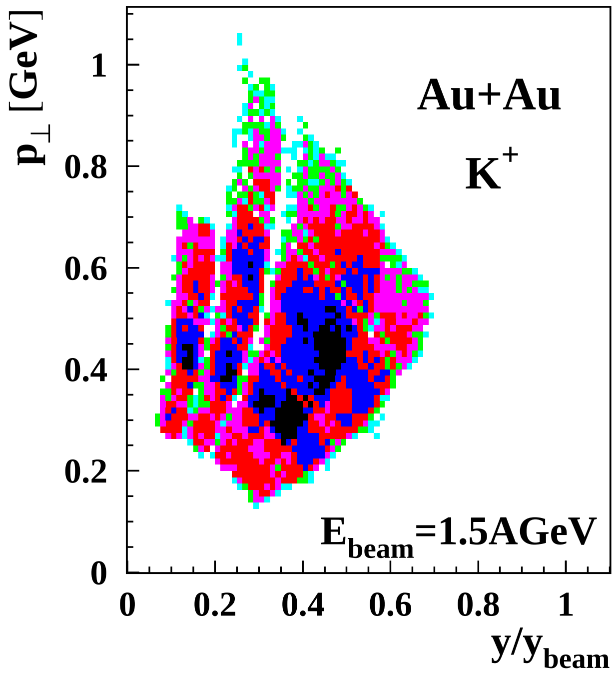
The Kaon Spectrometer



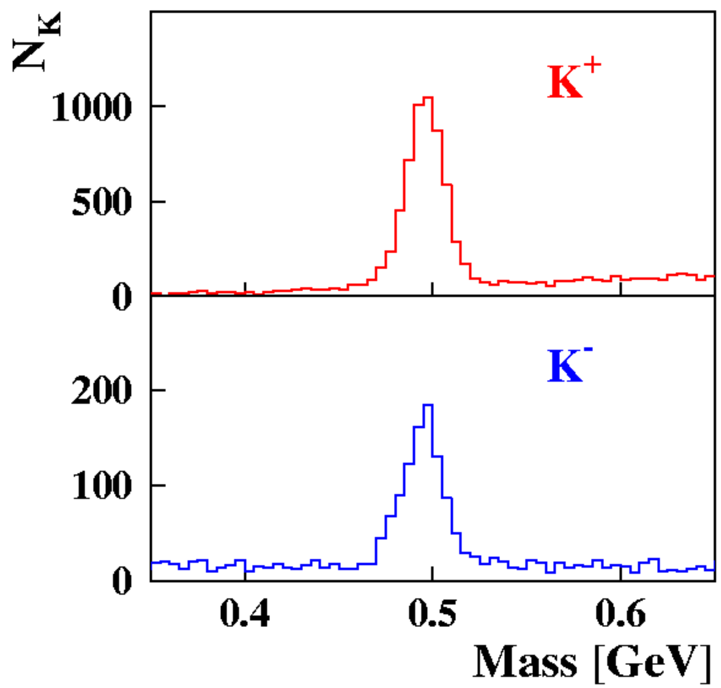
- selective kaon trigger (ToF, Cherenkov)
- background reduction (3 MWPCs, double ToF measurement)
- event characterization (2 Hodoscopes)

Detector Acceptance and Particle Identification

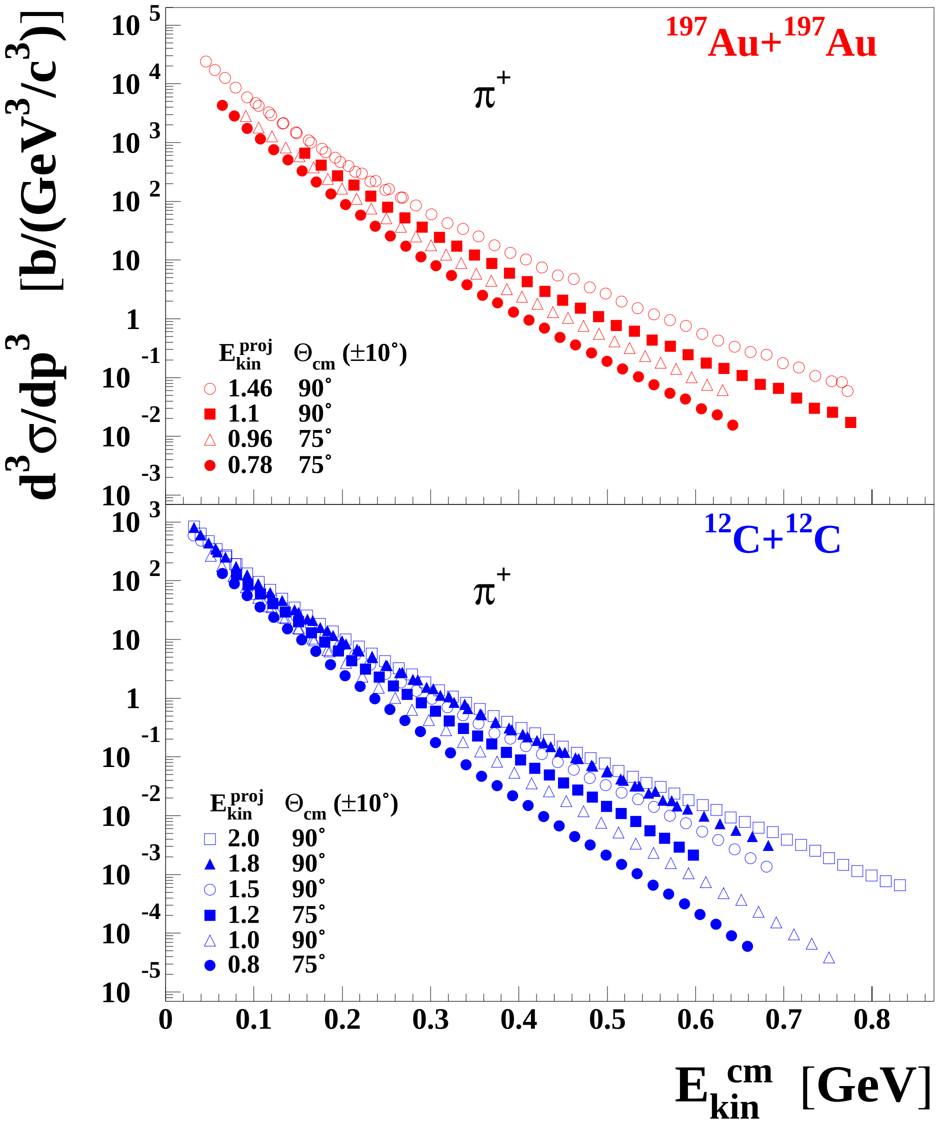
wide coverage in y and $p_\perp$



efficient background reduction

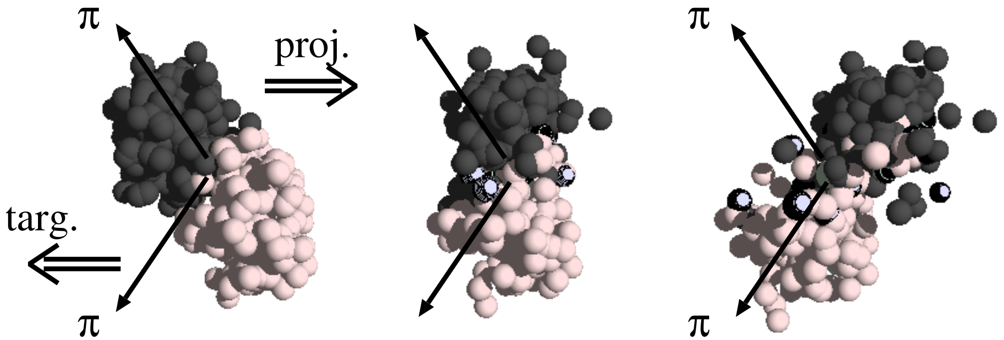


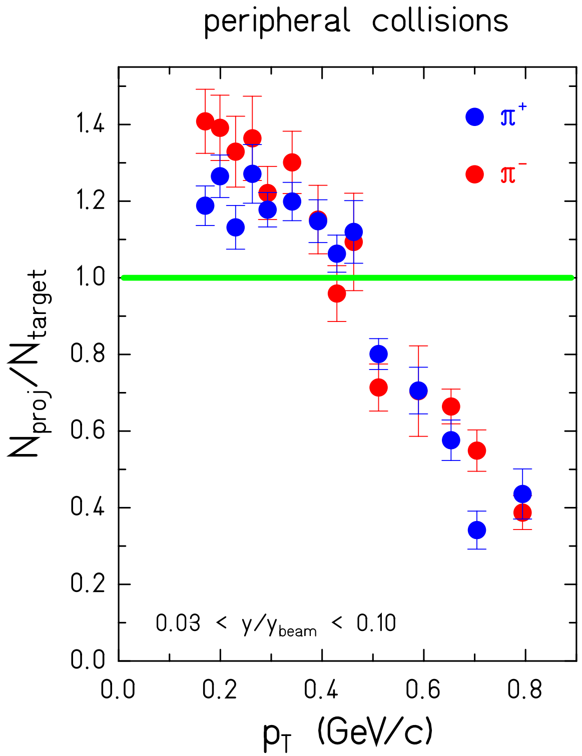
Pion Spectra



- different mass systems (Au+Au, Ni+Ni, C+C)
- different beam energies (0.8 to 2.0 AGeV)

The Pion Clock





Au+Au, 1.0AGeV,
A.Wagner et al. (KaoS), PRL 85(2000)18

high energy pions freeze out early

K^+ and K^- Production

K^+ Mesons

$NN \rightarrow N \Lambda K^+$

Production Threshold:

$E_{beam} = 1.58$ GeV

K^- Mesons

$NN \rightarrow NN K^- K^+$

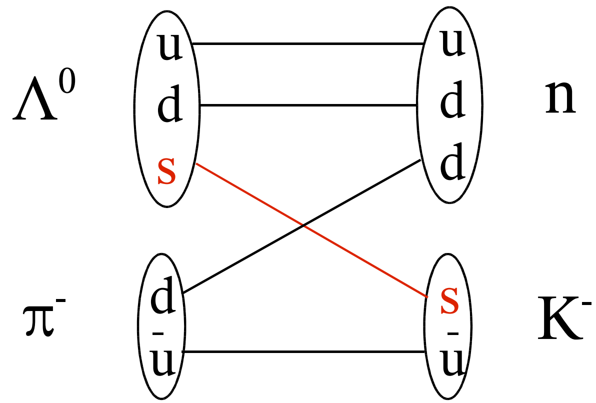
Production Threshold:

$E_{beam} = 2.50$ GeV

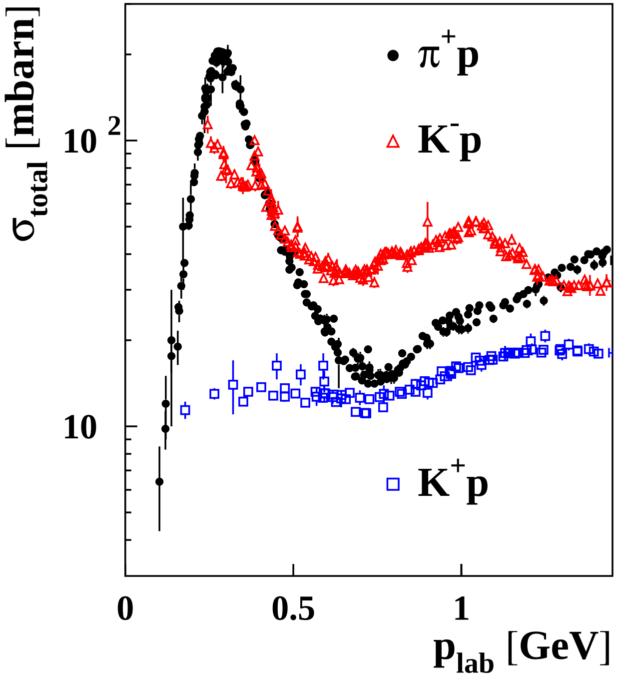
<u>additional channels in Nucleus-Nucleus-Collisions:</u>

- multi-step processes
- "storing energy" in baryonic resonances
- "strangeness exchange" for the production of K^-

$\pi Y \rightarrow K^- N \qquad Y = \Lambda, \Sigma$



K^+ and K^- Absorption



mean free path at ρ_0:

$$\lambda_{\pi^+} \approx 0.3 \text{ fm}$$
$$\lambda_{K^+} \approx 5 \text{ fm}$$
$$\lambda_{K^-} \approx 0.8 \text{ fm}$$

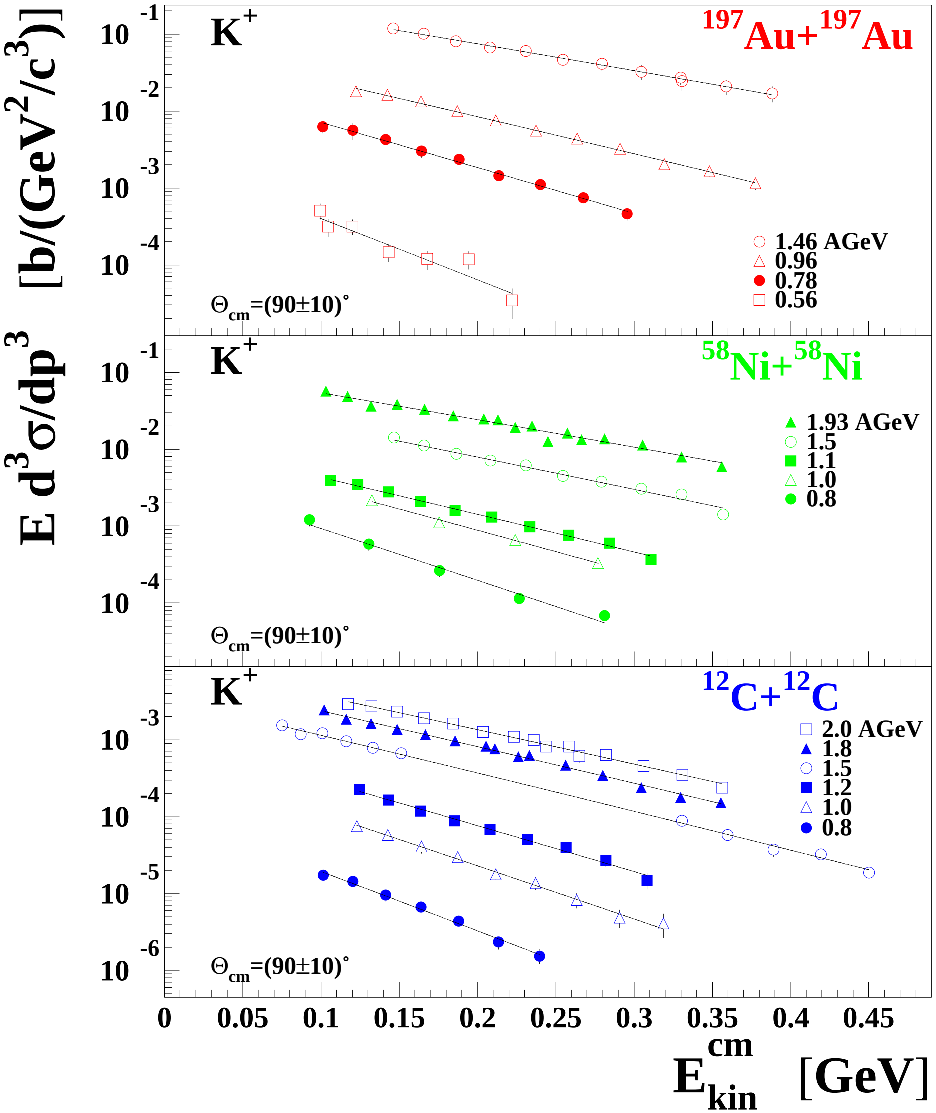
$r_{Au} \approx 7$ fm

K^- : absorption by strangeness exchange reactions:

$K^- N \rightarrow Y \pi$

K^+ : hardly any absorption (they contain an anti-s quark)

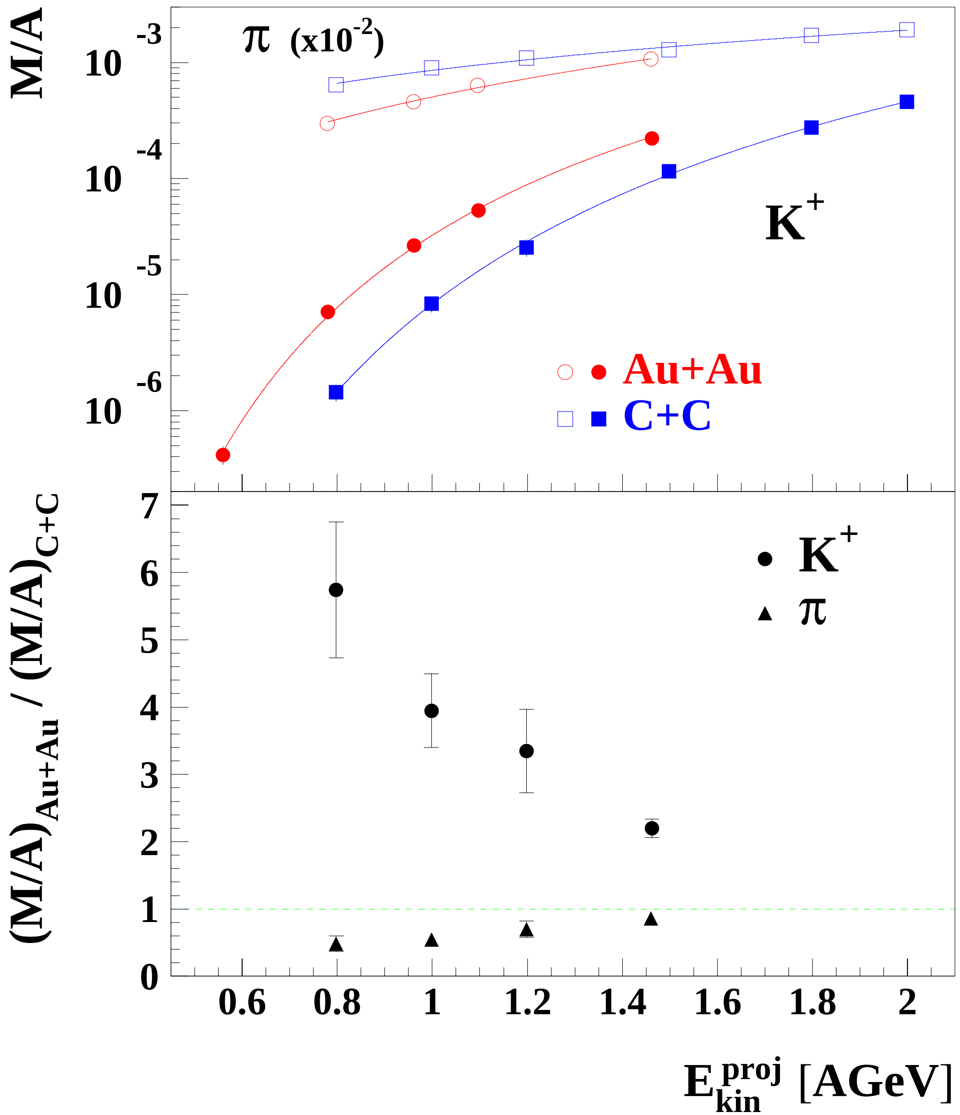
Kaon Spectra



- different mass systems (Au+Au, Ni+Ni, C+C)

- different beam energies (0.6 to 2.0 AGeV)

The Excitation Function of the K^+-Production

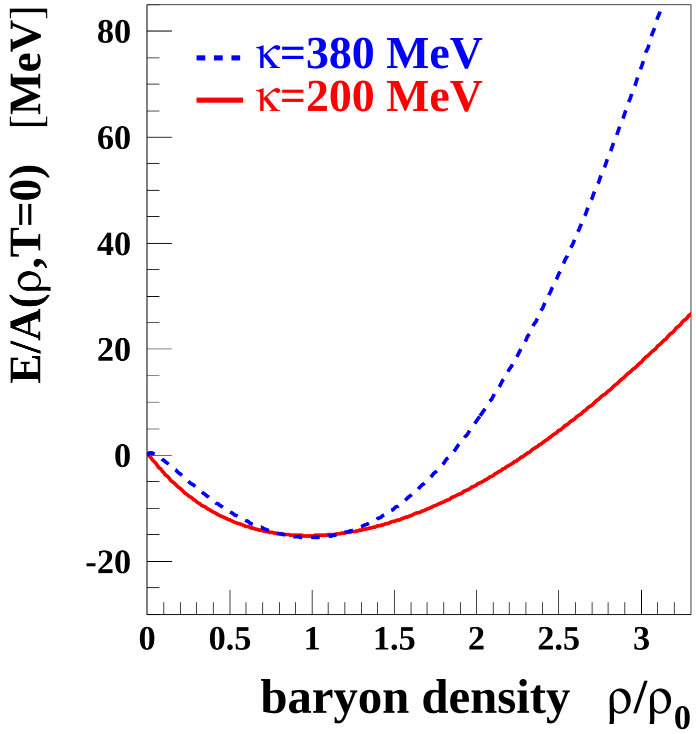


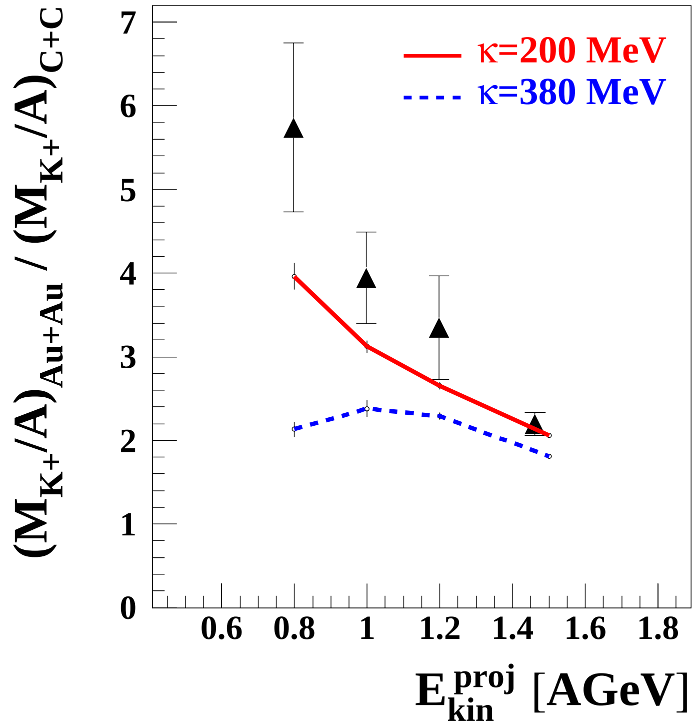
C. Sturm et al. (KaoS), Phys.Rev.Lett. 86(2001)39

Compressibility of Nuclear Matter

C. Sturm et al. (KaoS), Phys.Rev.Lett. 86(2001)39

RQMD: C.Fuchs et al., PRL 86(2001)1974



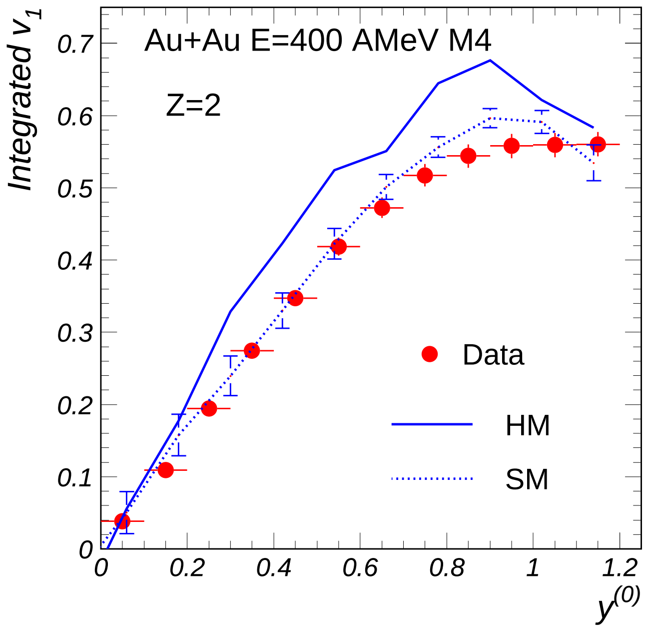


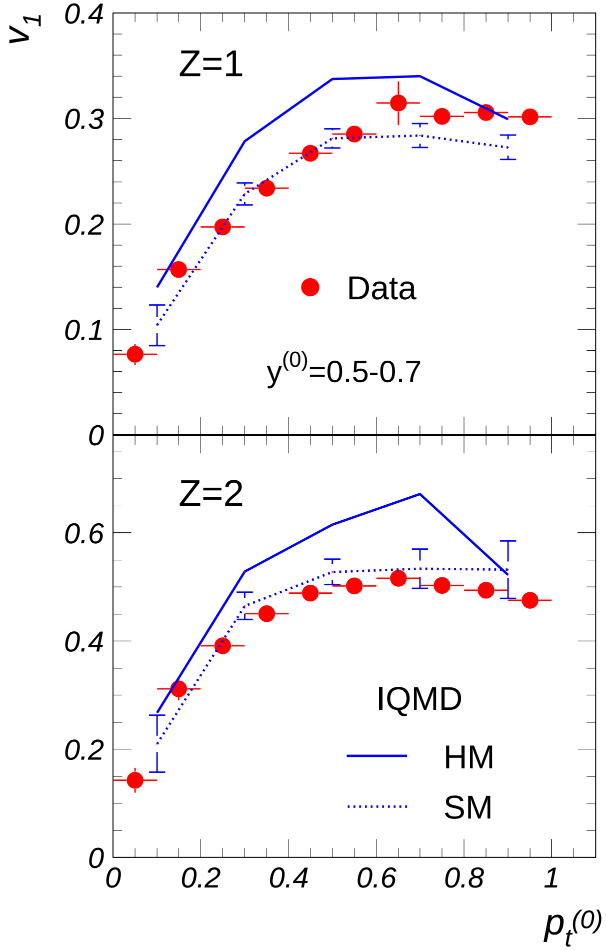
Evidence for a soft EoS

Directed flow and the EoS

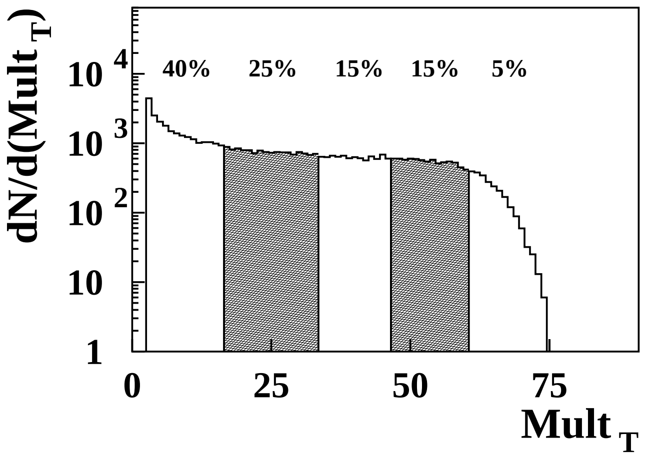
FOPI-Collaboration
A.Andronic et al.,
PRC 67 (2003) 034907

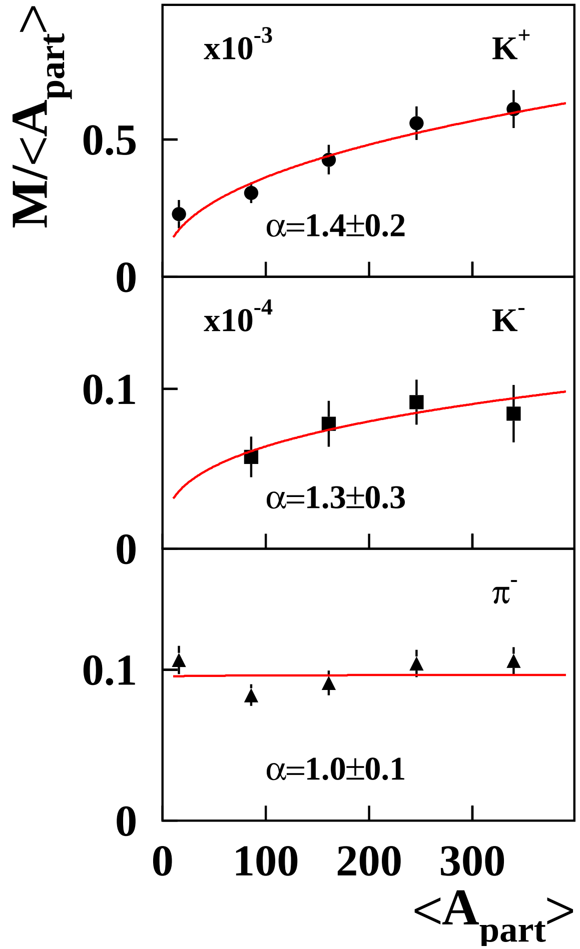
IQMD-Calculations:
κ = 380 MeV (HM)
κ = 200 MeV (SM)





Centrality Dependence Au+Au, 1.5AGeV





NN-Threshold:

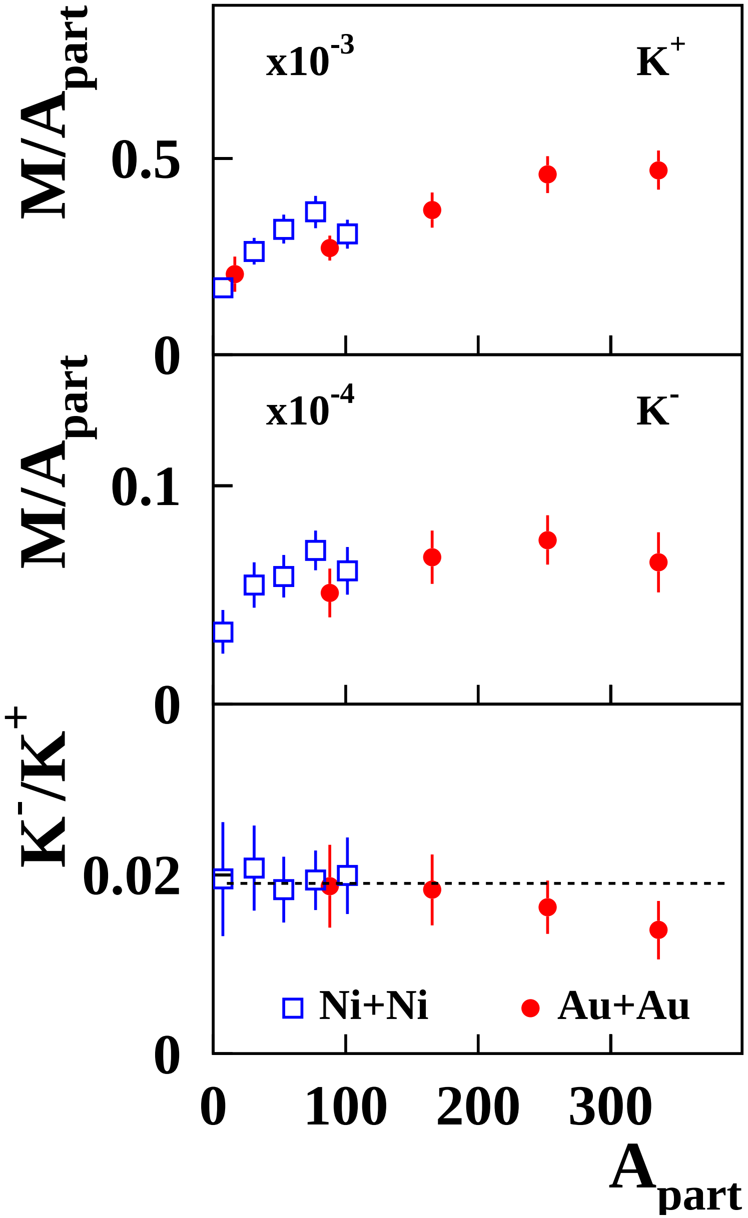
E_{beam}=1.58 GeV

E_{beam}=2.50 GeV

E_{beam}=0.29 GeV

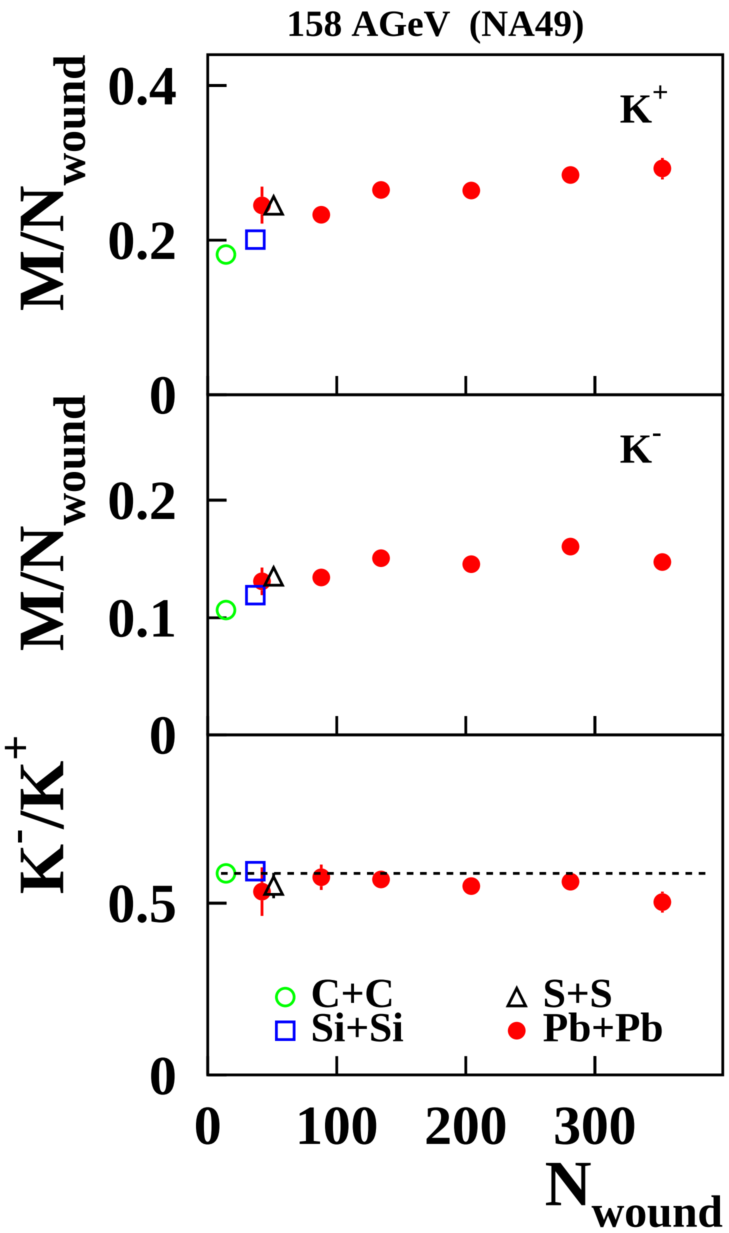
fit: $M/\langle A_{part}\rangle \sim \langle A_{part}\rangle^{(\alpha-1)}$

Centrality Dependence at 1.5AGeV (KaoS)



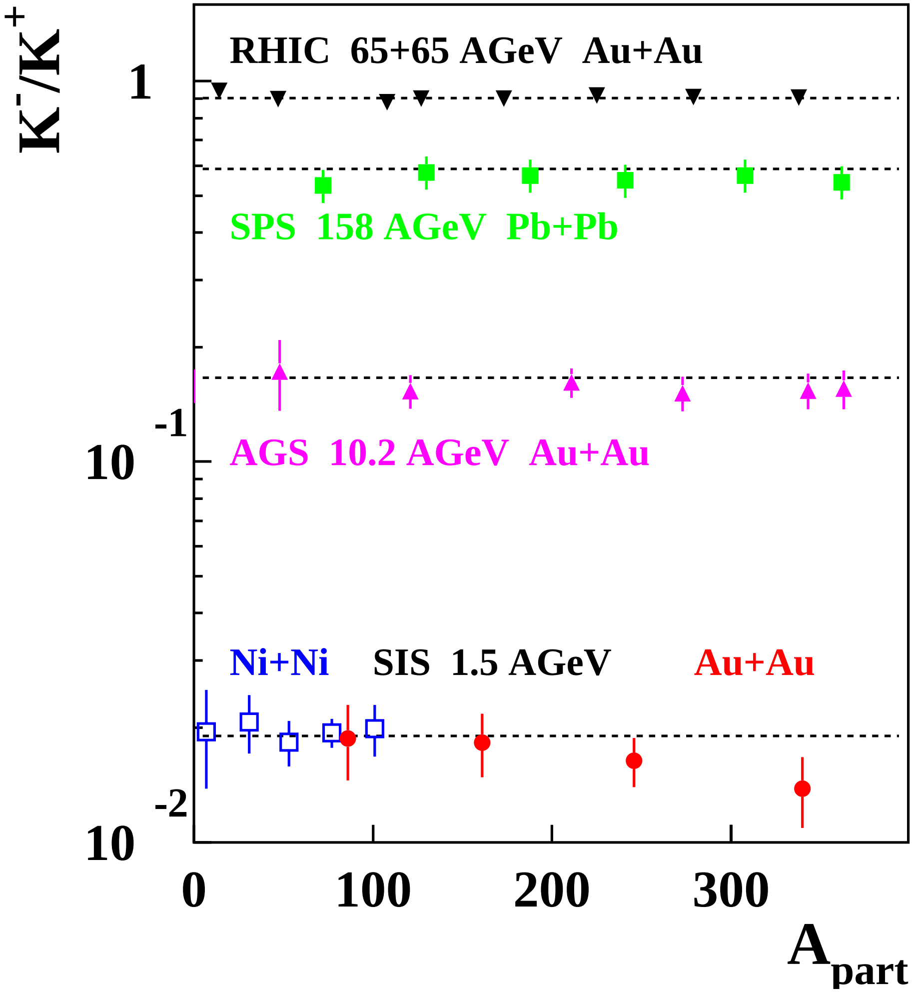
A.F., F.Uhlig et al.(KaoS), PRL 91(2003)152301

Centrality Dependence at 158AGeV (NA49)



C. Höhne, Ph.D. Thesis, Univ. Marburg

K^-/K^+ from SIS to RHIC



(J.Cleymans, A.F., H.Oeschler, K.Redlich, F.Uhlig: hep-ph/0406108)

Strangeness Exchange

K^- production at SIS energies is dominated by strangeness exchange reactions (also predicted by transport models) :

$$\pi^{(0,-)} + Y \leftrightharpoons K^- + N$$

If in equlilibrium - law of mass action applicable:

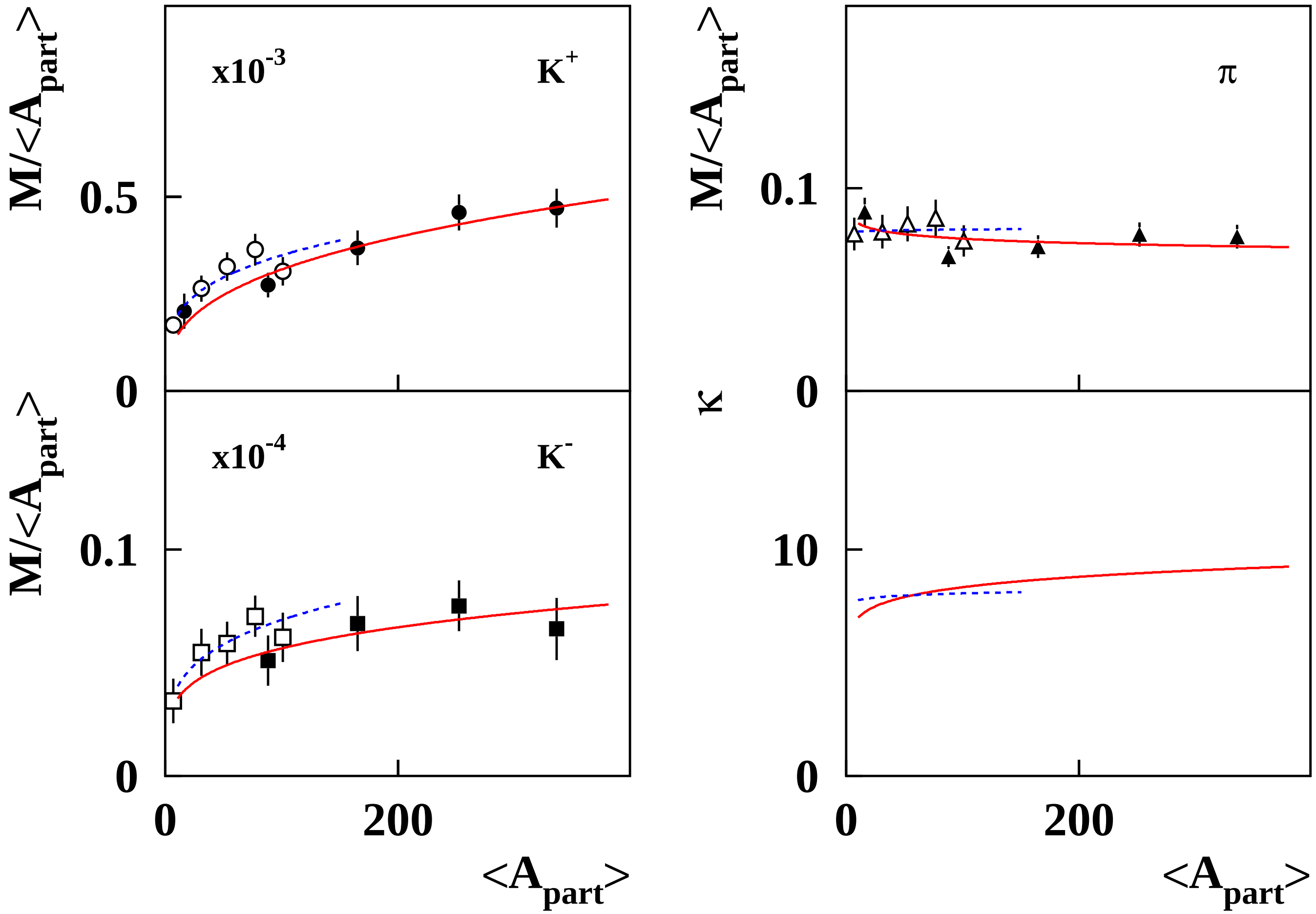
$$\frac{[\pi^{(0,-)}] \cdot [Y]}{[K^-] \cdot [N]} = \kappa$$

Y produced together with K^+, K^0: $[Y] \sim [K^+]$

$$[N] \Rightarrow A_{part}$$

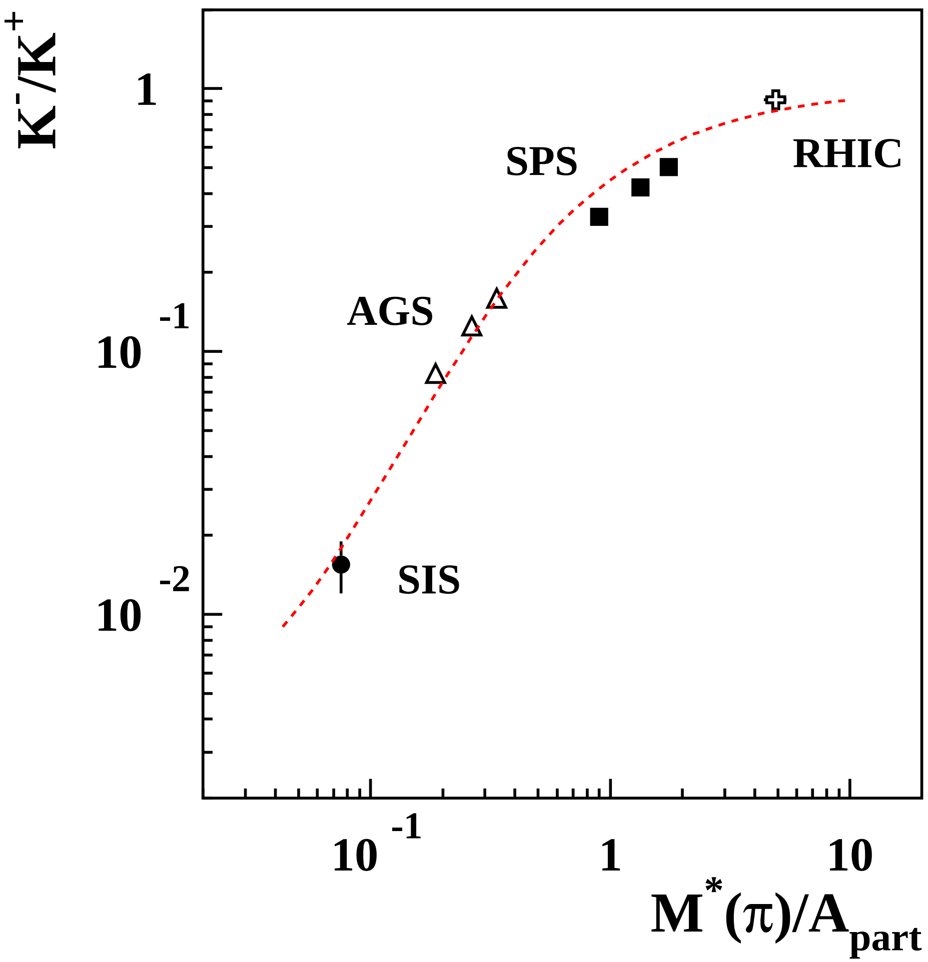
(J.Cleymans, A.F., H.Oeschler, K.Redlich, F.Uhlig: hep-ph/0406108)

Law of Mass Action



(J.Cleymans, A.F., H.Oeschler, K.Redlich, F.Uhlig: hep-ph/0406108)

K^-/K^+ from SIS to RHIC

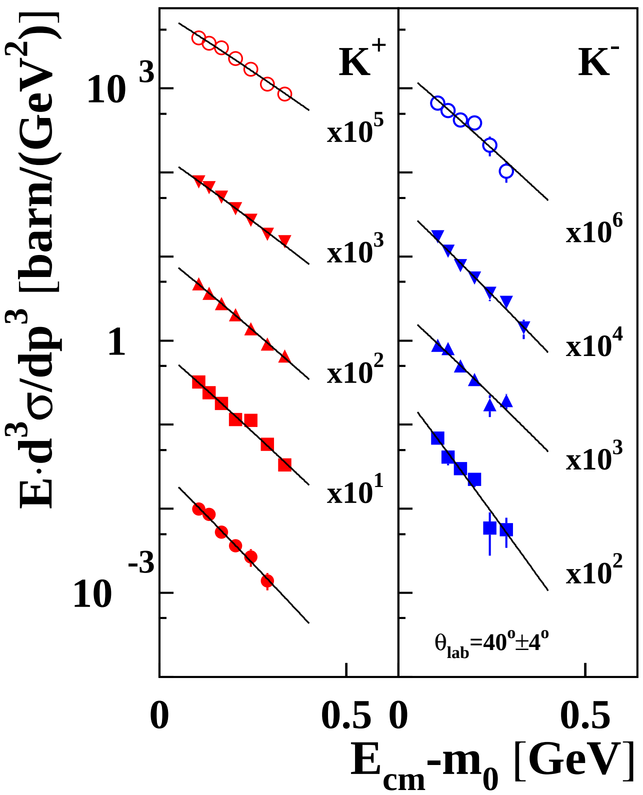


(J.Cleymans, A.F., H.Oeschler, K.Redlich, F.Uhlig: hep-ph/0406108)

Spectra as a Function of the Centrality

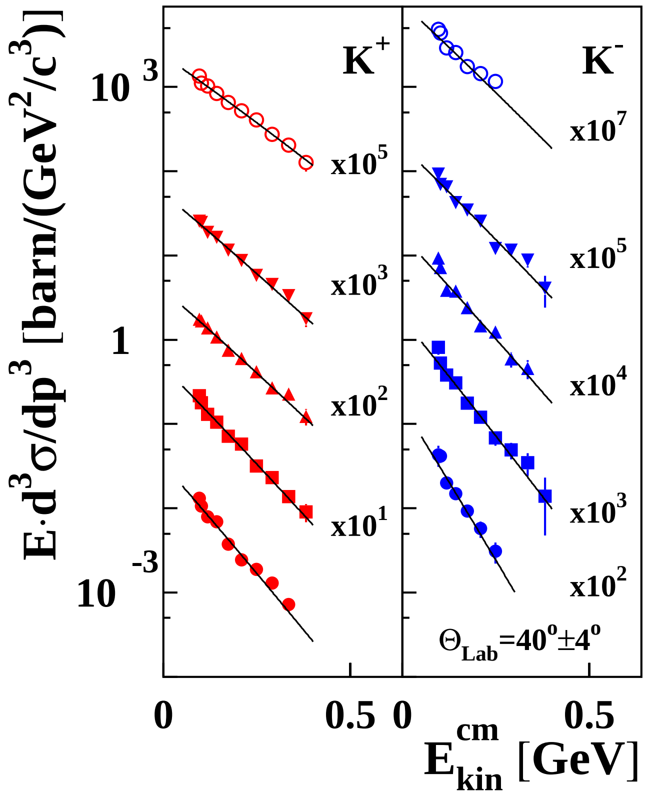
Au+Au, 1.5AGeV
A.F., F.Uhlig et al.(KaoS)
PRL 91(2003)152301

Ni+Ni, 1.93AGeV
F.Uhlig, PhD Thesis
TU Darmstadt

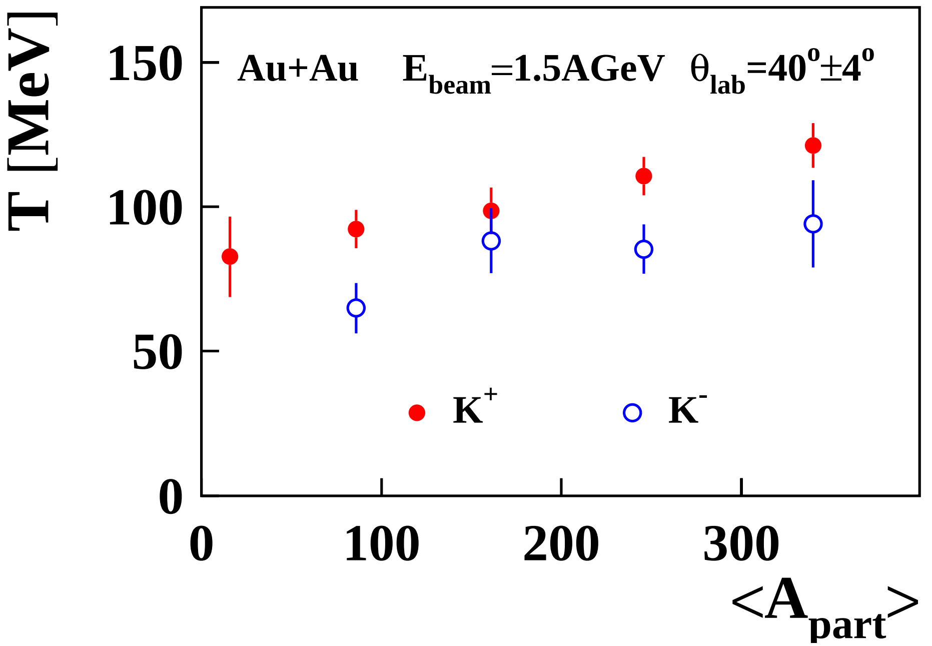


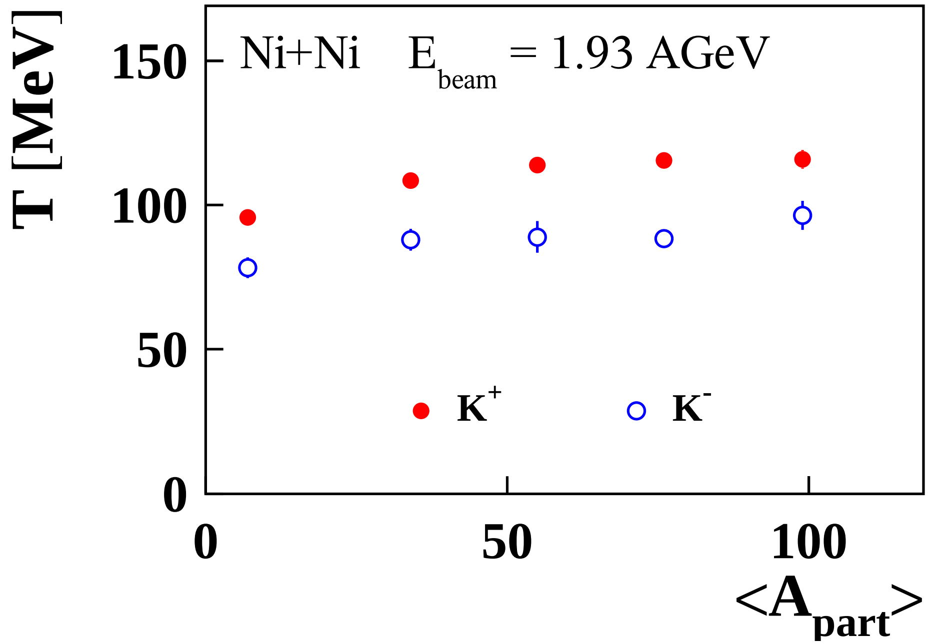
○ 5% σ_r
▼ 15% σ_r
▲ 15% σ_r
■ 25% σ_r
● 40% σ_r

central ↕ peripheral



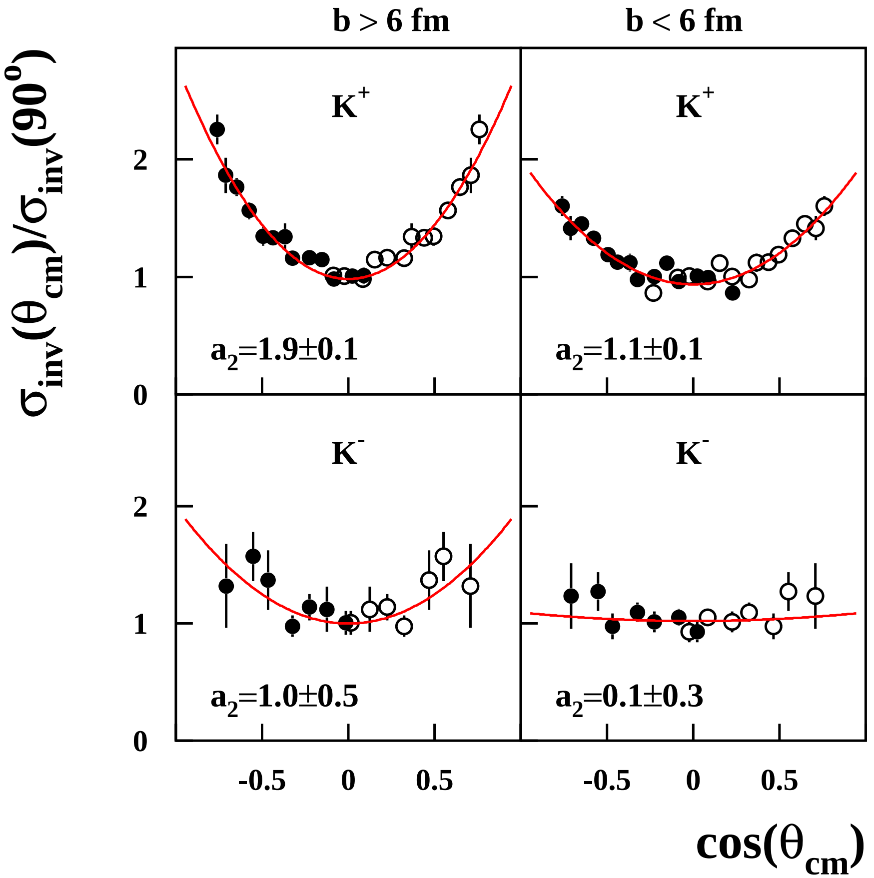
Slope Parameters as a Function of the Centrality





different slopes for K^+ and K^-

Polar Angle Distribution



Au+Au, 1.5AGeV
A.F., F.Uhlig et al.(KaoS)
PRL 91(2003)152301

fit: $\sigma_{inv}(\theta_{cm})\ /\ \sigma_{inv}(90°\ ) \sim 1 + a_2 \cdot \cos^2\theta_{cm}$

K^+ : strong forward-backward enhancement

K^- : isotropic emission for central collisions

K^+ and K^- - Emission

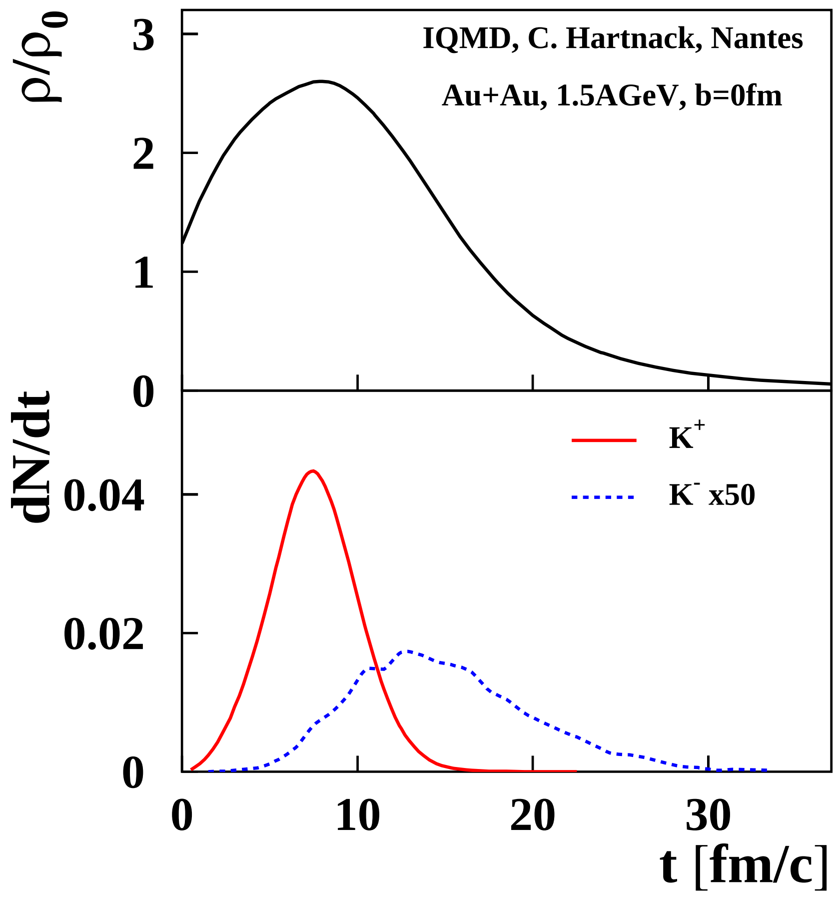
nearly constant K^-/K^+ ratio at SIS energies :

coupling of K^- to K^+ yield via hyperons

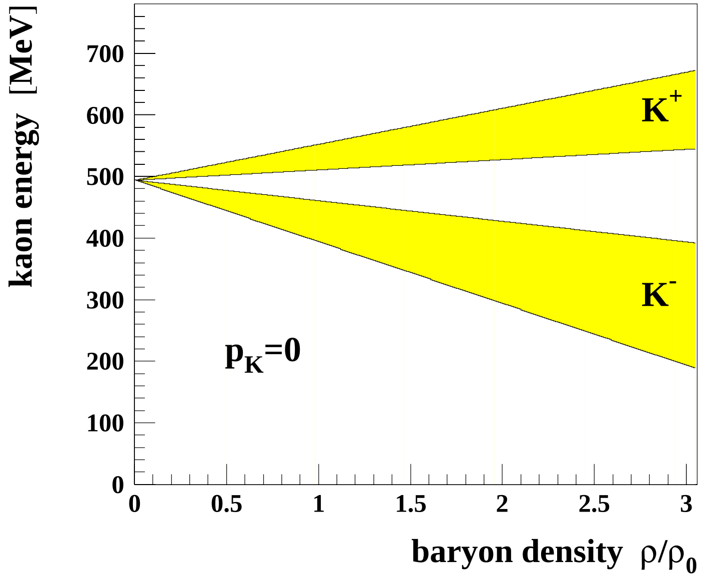
different slopes and polar angle distributions :

different freeze out conditions

- different freeze-out times
- reabsorption for K^-
- rescattering for K^+

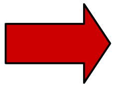


In-Medium Modifications



K^+N potential repulsive

K^-N potential attractive



intuitive expectation :

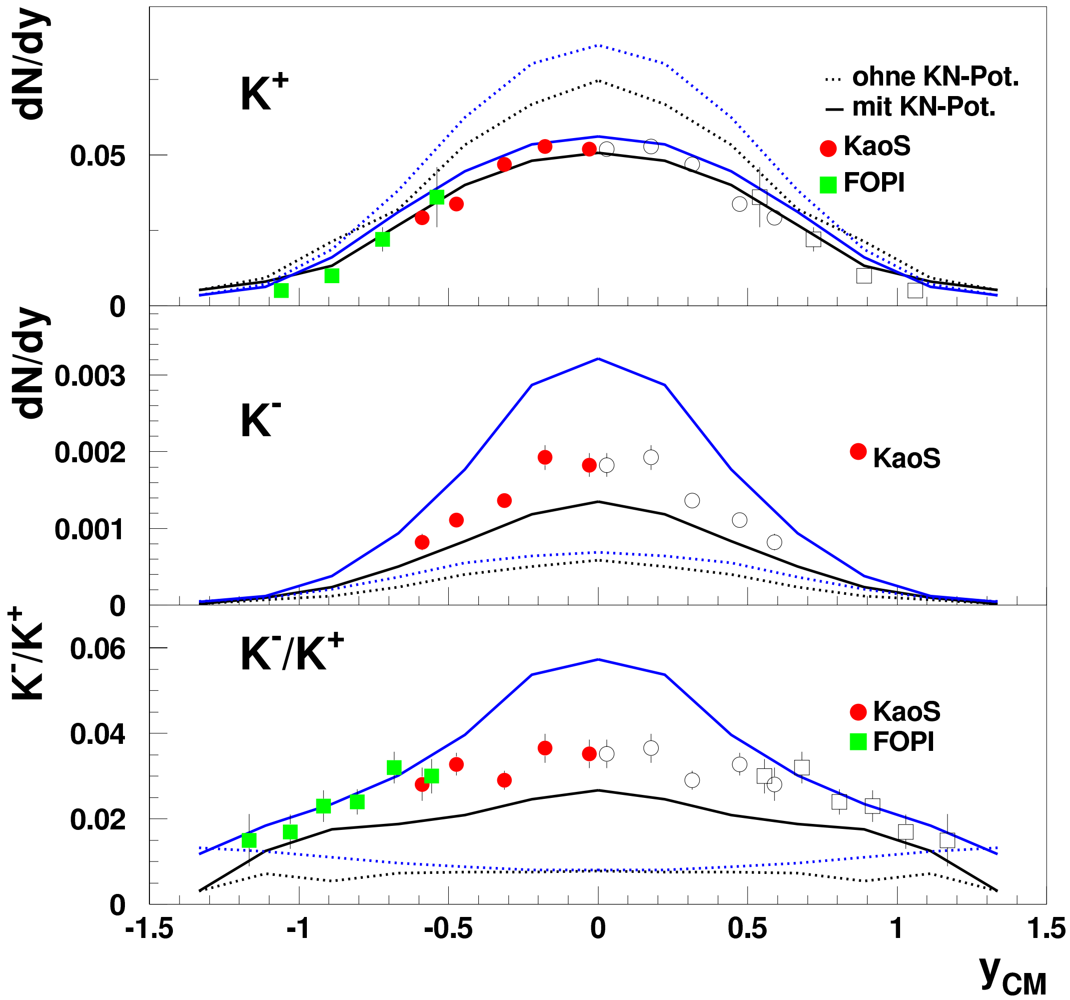
- K^+ : decrease of production yield
- K^- : increase of productions yield

dN/dy Ni+Ni 1.93AGeV

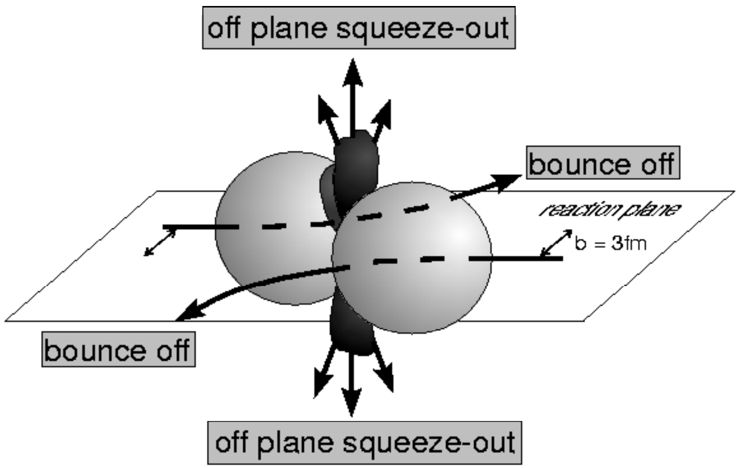
KaoS-data:
M.Menzel et al.,
PLB 495(2000)26

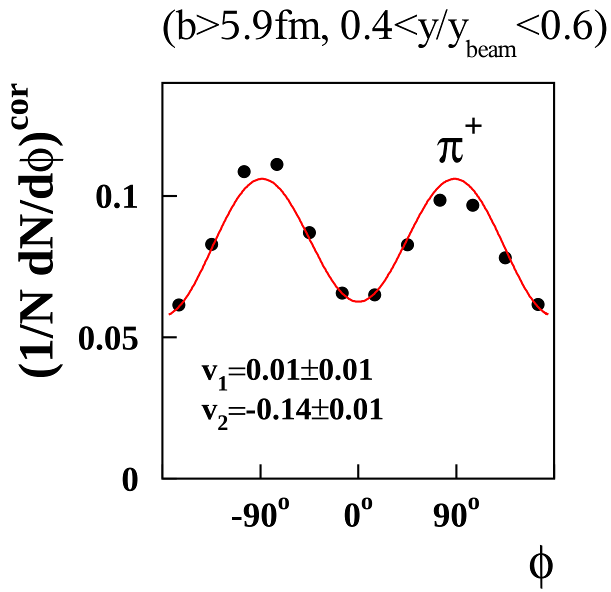
FOPI-data:
K.Wisniewski et al.
EPJ A9(2000)515

BUU-calculations:
G.Q.Li et al.
PRL79(1997)5214
W.Cassing, Giessen



Azimuthal Particle Emission





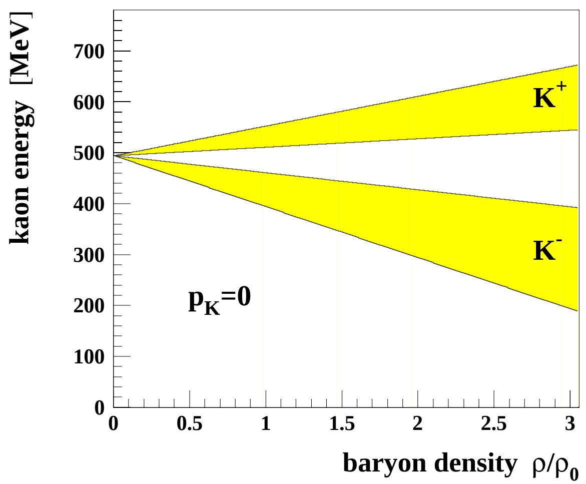
fit function: $dN/d\phi \sim 1 + 2\, v_1 \cos\phi + 2\, v_2 \cos 2\phi$ $\quad v_1 = \langle\cos\phi\rangle\ ;\ v_2 = \langle\cos 2\phi\rangle$

mean free path at ρ_0: $\lambda_{\pi+} \approx 0.3$ fm ; $\lambda_{K-} \approx 0.8$ fm ; $\lambda_{K+} \approx 5$ fm

intuitive expectation for kaons:

- K^+ : isotropic emission
- K^- : out-of-plane emission

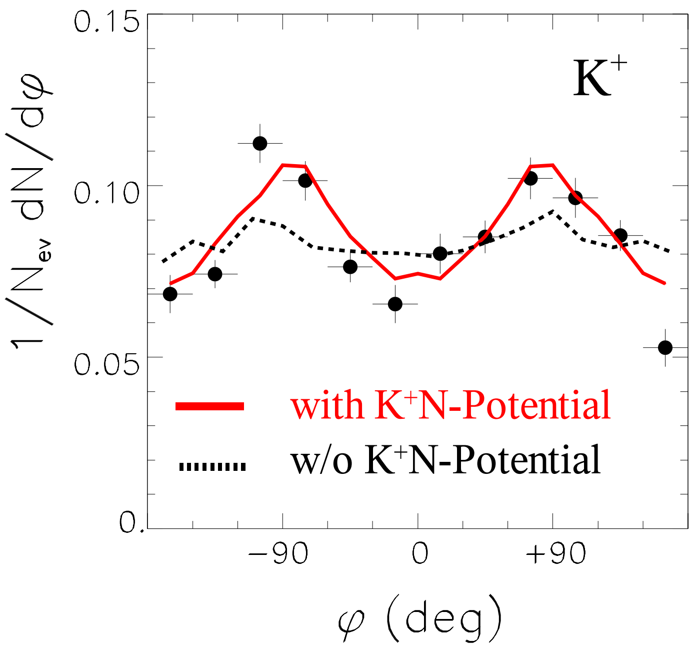
In-Medium Modifications



K^+N potential repulsive

K^-N potential attractive

RBUU: G.Q.Li et al. PLB 381 (1996) 17



K^+,Au+Au,1.0AGeV

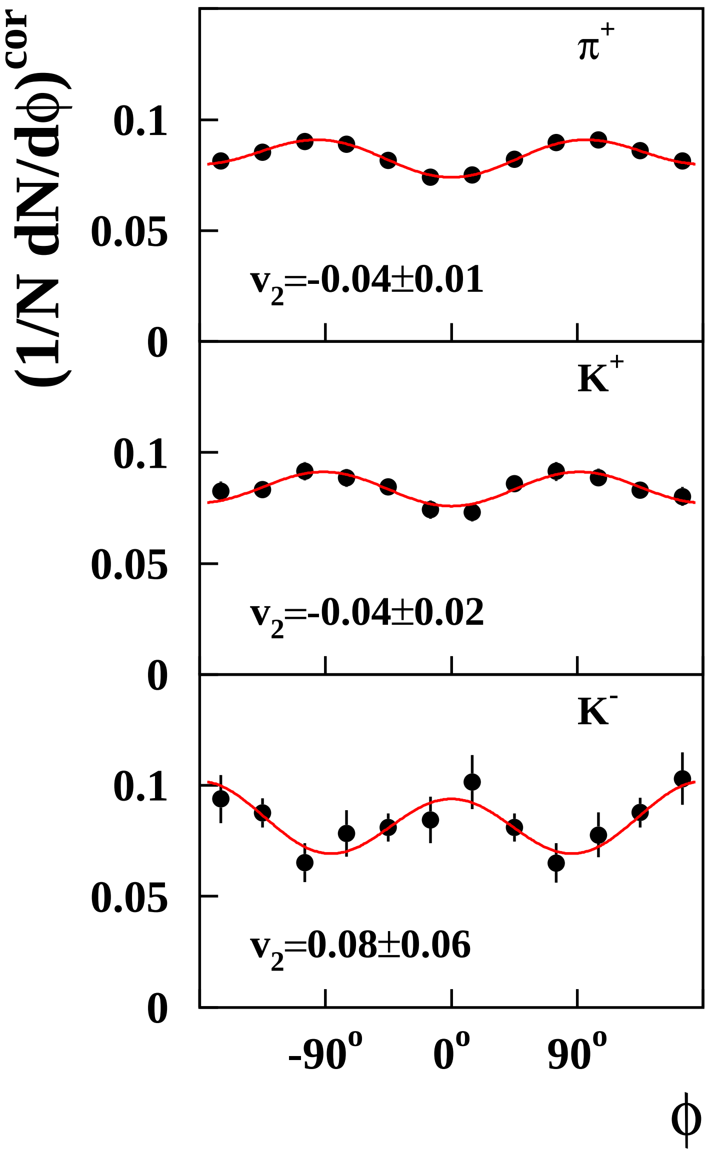
Y. Shin et al. (KaoS)
Phys.Rev.Lett. 81(1998)1576

Elliptic Flow of π^+, K^+, K^-
Ni+Ni, 1.93AGeV

$0.3 < y/y_{beam} < 0.7$

$0.2\ \text{GeV} < p_\perp < 0.8\ \text{GeV}$

F.Uhlig, A.F. et al (KaoS)
nucl-ex/0411021

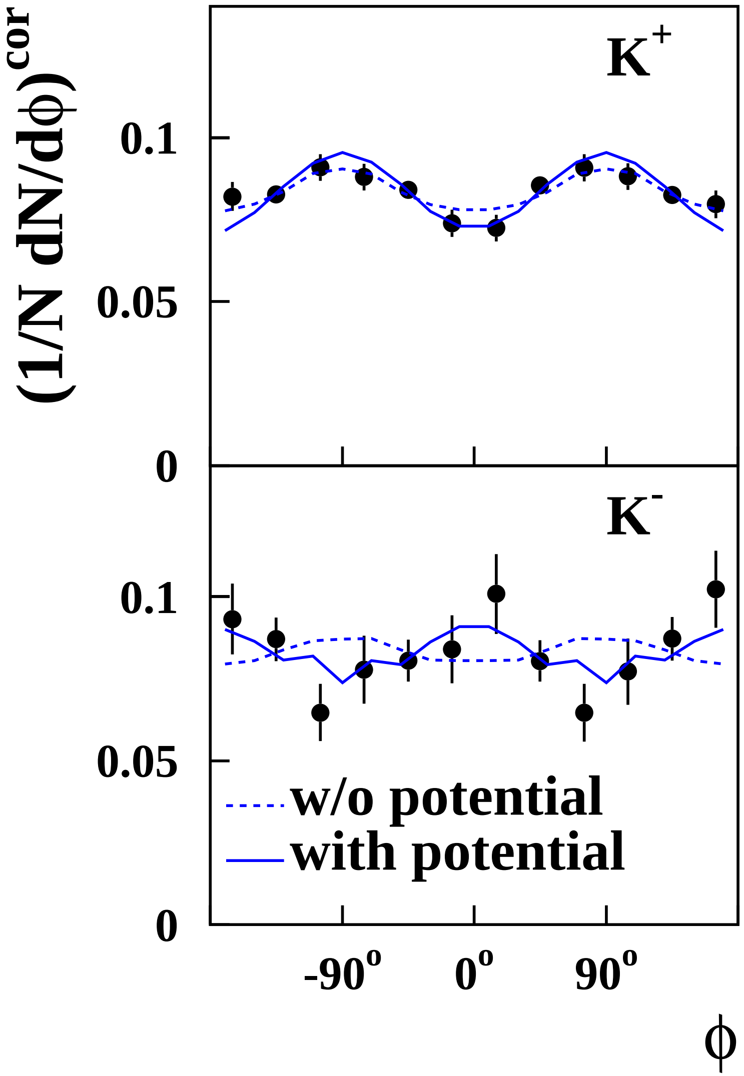


Ni+Ni, 1.93AGeV
Comparison Data ↔ IQMD

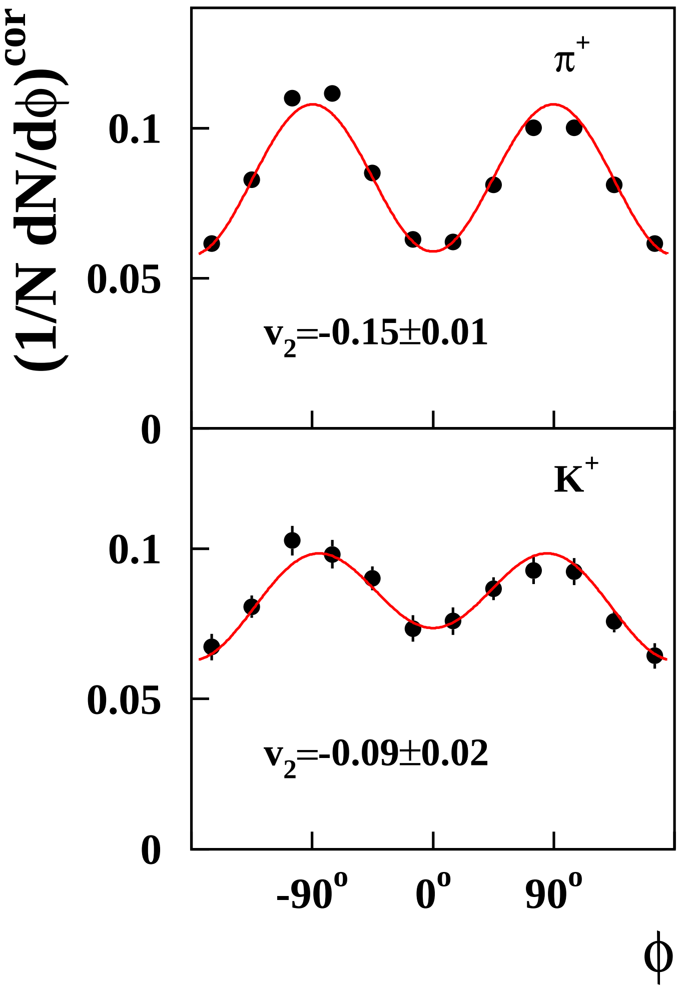
F.Uhlig, A.F. et al (KaoS)
nucl-ex/0411021

IQMD - Calculation:
C. Hartnack, Nantes

IQMD: substantial contribution to K^+ flow from rescattering



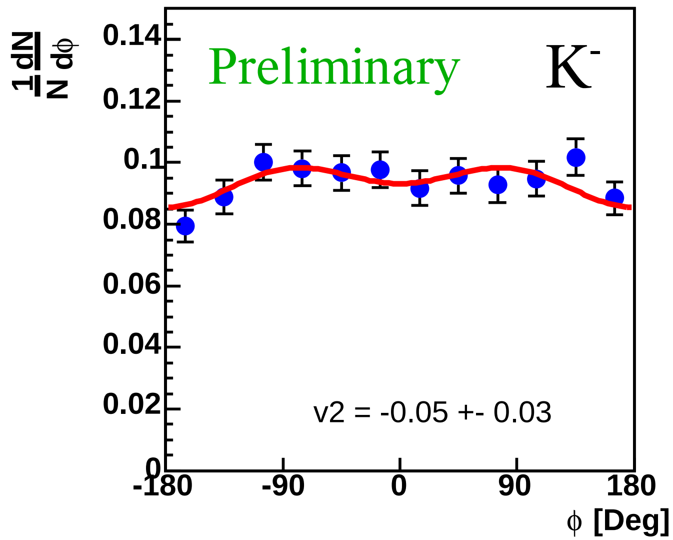
Elliptic Flow of π^+, K^+, K^-
Au+Au, 1.5AGeV



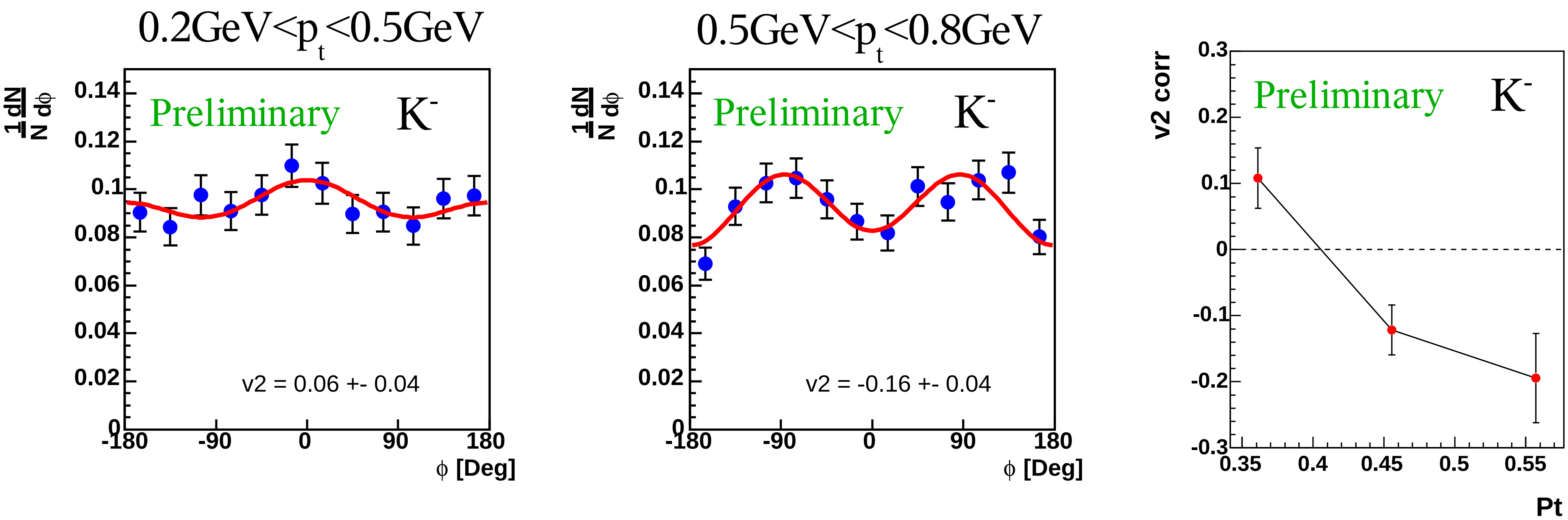
$0.3 < y/y_{beam} < 0.7$

$0.2\ \mathrm{GeV} < p_{\perp} < 0.8\ \mathrm{GeV}$

$b > 6\mathrm{fm}$

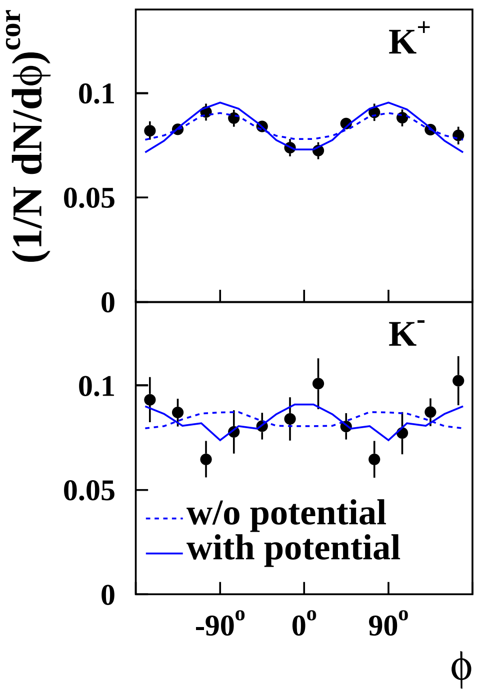


p_t-Dependence of v_2, Au+Au 1.5AGeV



- attractive K^-N potential?
- emission time ?

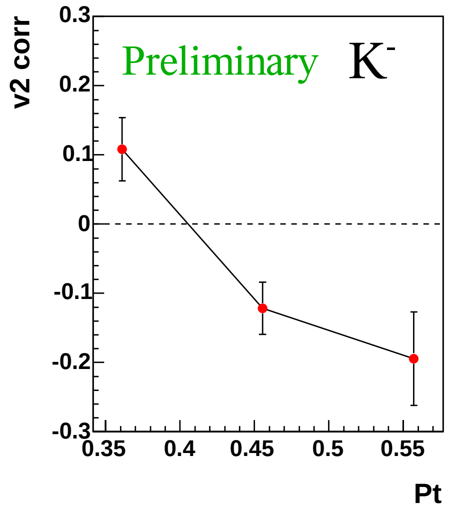
Different Effects !



K^+:

- repulsive potential?

- rescattering?



K^-:

- attractive potential?

- emission time?

To disantangle these effects, detailed studies with transport models are necessary !

Summary

- Pion Clock → high energy pions emitted early
- K^+ excitation functions in Au+Au and C+C → evidence for a soft EOS
- K^-/K^+ ratio constant → dominance of strangeness exchange
- different slopes of K^+ and K^-, different polar angle distributions
  → different freeze-out conditions
- Azimuthal distributions of K^+:
  - out-of-plane elliptic flow → repulsive K^+N-potential? rescattering?
- Azimuthal distributions of K^-:
  - Ni+Ni: elliptic in-plane flow
  - Au+Au: in-plane for small p_t, out-of-plane for high p_t

    → attractive K^-N-potential? emission time?

KaoS Collaboration

TU Darmstadt: A. Förster, H. Oeschler, S. Lang, C. Sturm,
A. Schmah, F. Uhlig

GSI Darmstadt: P. Koczoń, M. Płoskoń, E. Schwab, P. Senger

Univ. Frankfurt: Y. Shin, T. Schuck, H. Ströbele

Univ. Marburg: I. Böttcher, B. Kohlmeyer, M. Menzel, F. Pühlhofer

Univ. Kraków: M. Debowski, W. Waluś

FZ Rossendorf: E. Grosse, L. Naumann, W. Scheinast, A. Wagner