Kaon properties in cold or dense nuclear matter

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For the HADES Collaboration

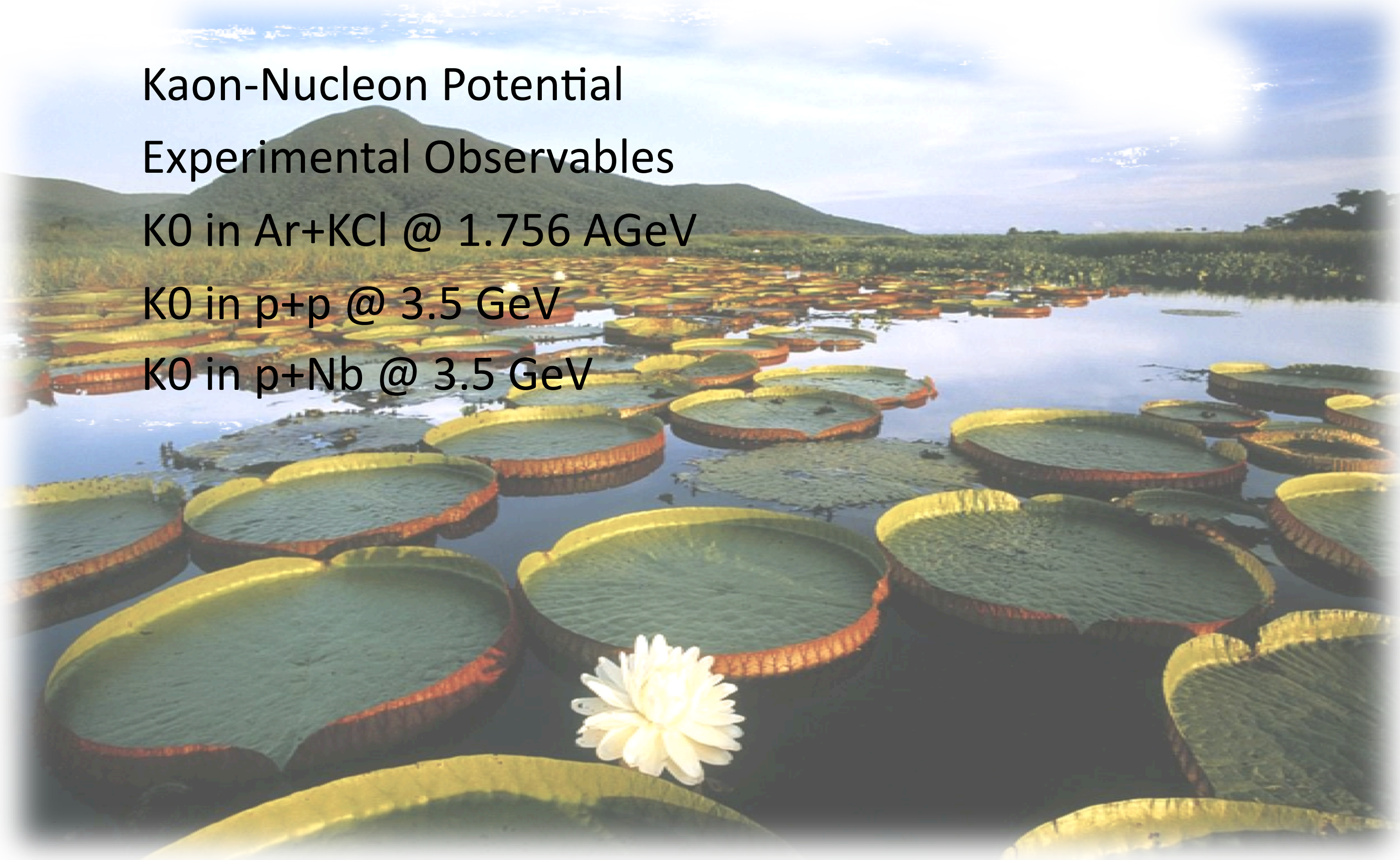
Kaon-Nucleon Potential

Experimental Observables

K0 in Ar+KCl @ 1.756 AGeV

K0 in p+p @ 3.5 GeV

K0 in p+Nb @ 3.5 GeV



Neutron Stars

Presence of strangeness in the interior of Neutron stars?

Densities= 7-10 ρ0, Radius= 10-13 km

Strangeness in the Form of antiKaons or Hyperon could appear -> EOS would become softer

The potential depth ($\bar{K}$-Nucleon, Hyeron-Nucleon) influences the stiffness of the EOS

EOS: Dependency between Pressure and density:

Imposing P(R)=0 (the internal pressure must be compensated by gravity) ->M(R) can be determined

M vs R lines for neutron stars as a function of different EOS.

Ingredients to such Models: ; S. Weissenborn, D. Chatterjee, J. Schaffner-Bielich arXiv:1111.6049v3

B/A= Binding Energy per Baryon Number

ρ_0= saturation density

asym= asymmetry coefficient (32.5 MeV)

K= Kompressibility of nuclear matter

M*= Effective Nucleon mass

K-Nucleon, Hyperon-Nucleon Potential

The Connection of the KN Potential to Neutron Stars

Kaon condensation in neutron stars? -> extract the K^- - Nucleus potential to test hypotheses.

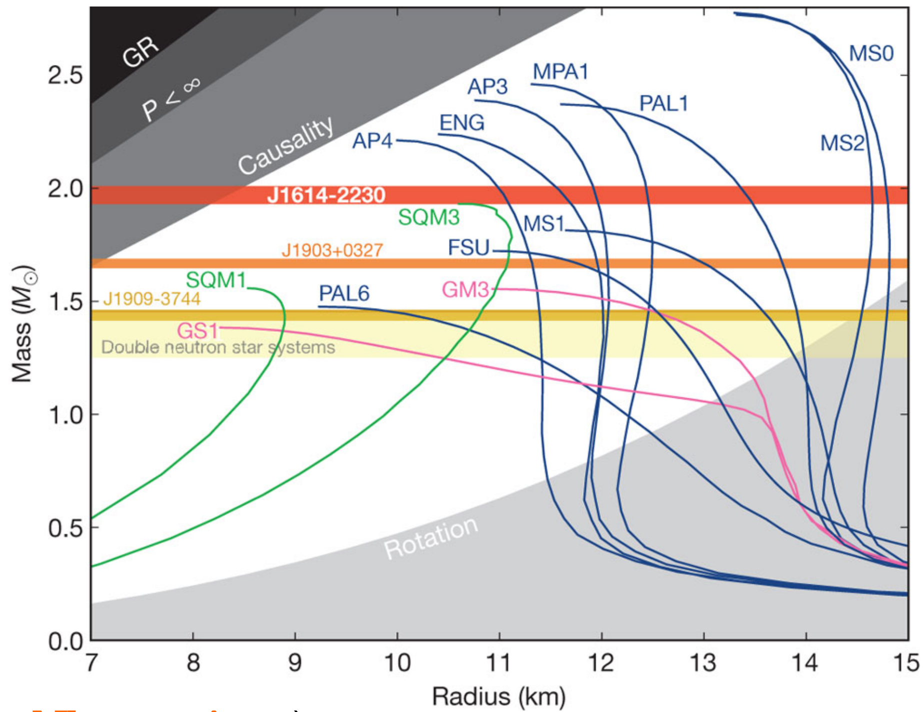
Meanwhile: Neutron stars are TOO HEAVY to contemplate kaon condensate but maybe Hyperons still stand a chance?

P.B. Demorest et al., Nature 467, 1081 (2010)

Blue: Nucleons

Pink: Nucleons + exotic matter

Green: strange quark matter



Λ-Nucleus

Σ-Nucleus

Σ-Nucleus

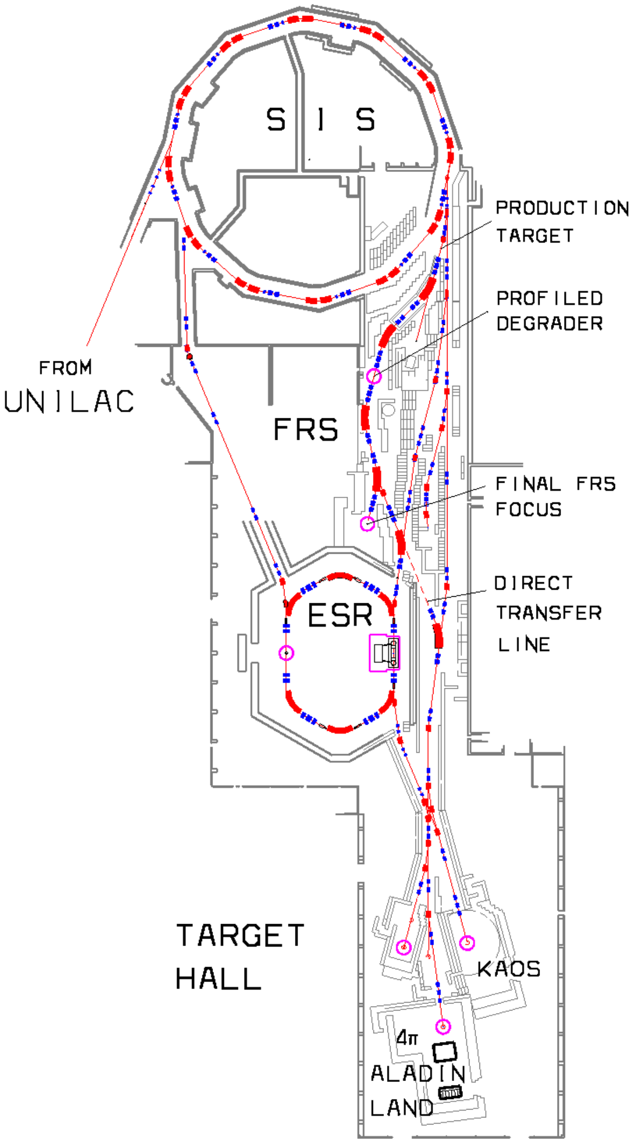
?? At different densities?

We can start with ρ_0 for K^0s, K^+, Λ (**p+p, p+Nb reactions**)

Then move to 2-3 ρ_0 for **K^0s,** K+, Λ and Ξ (Au+Au, Ag+Ag)

Heavy Ion Collisions at SIS18

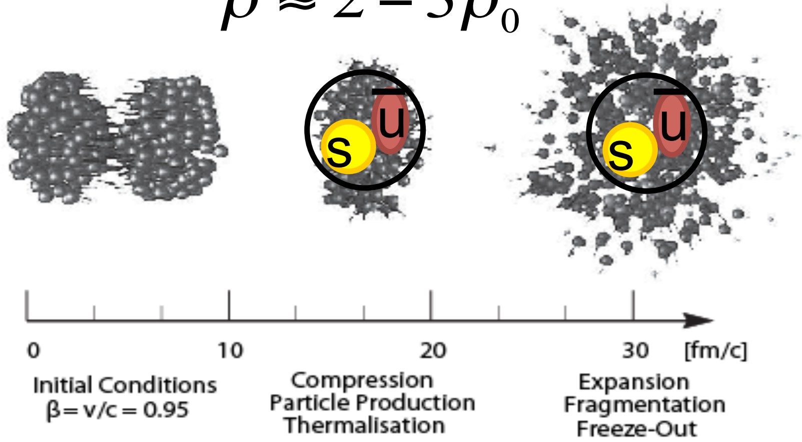
Helmholtz Zentrum: Gesellschaft für **S**chwer**I**onen forschung

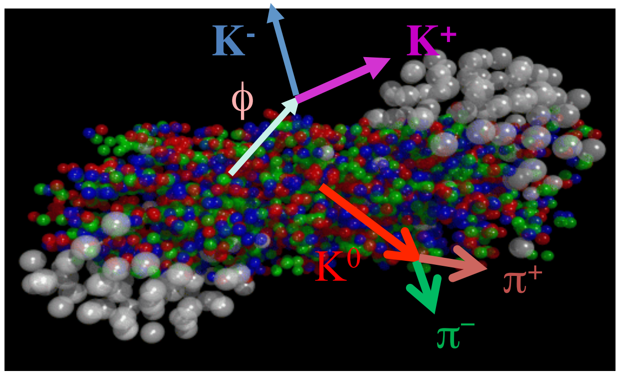


p Beam up to 3.5 GeV

C-U 2AGeV

$$\rho \approx 2 - 3\rho_0$$





Au+Au: rmax ~3ρ0

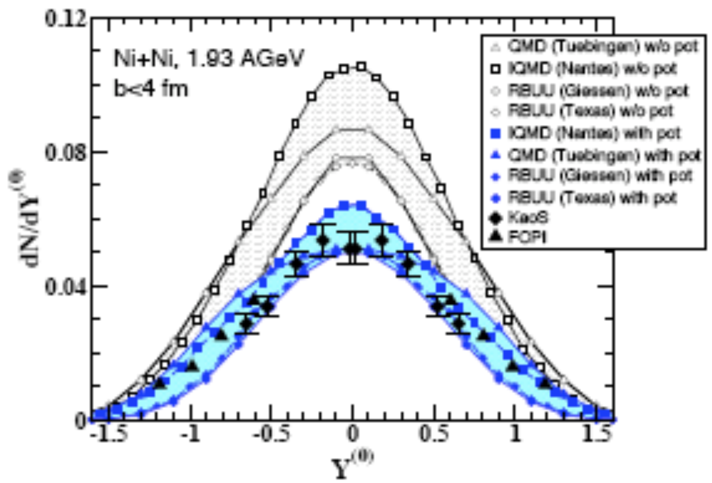
T~90 MeV

High density

Moderate temperature

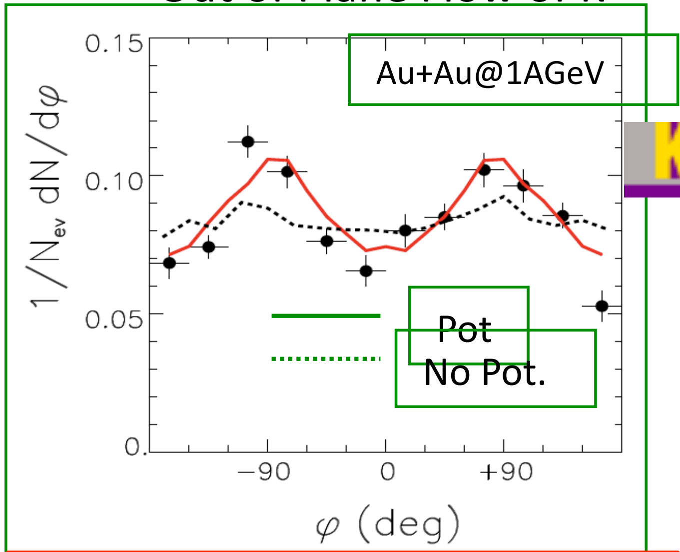
How to extract the KN potential from the data

Rapidity Distribution



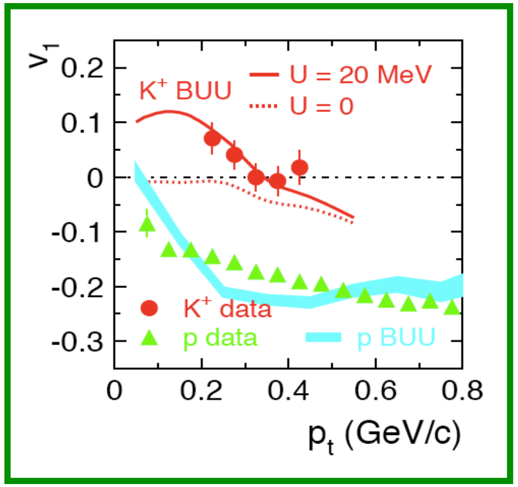
D. Best. et. al (FOPI) Nucl. Phys. A 625 (1997) 307
M- Menzel et al. (KAOS) Phys. Lett. B 495 (2000) 26.

Out of Plane Flow of K$^+$



Y. Shin et al. Phys. Rev Lett. 81 (1998) 1576-1579.
RBUU:G.Q.Li et al. Phys. Lett. B 381 (1996) 17.

Sideward Flow of K$^+$

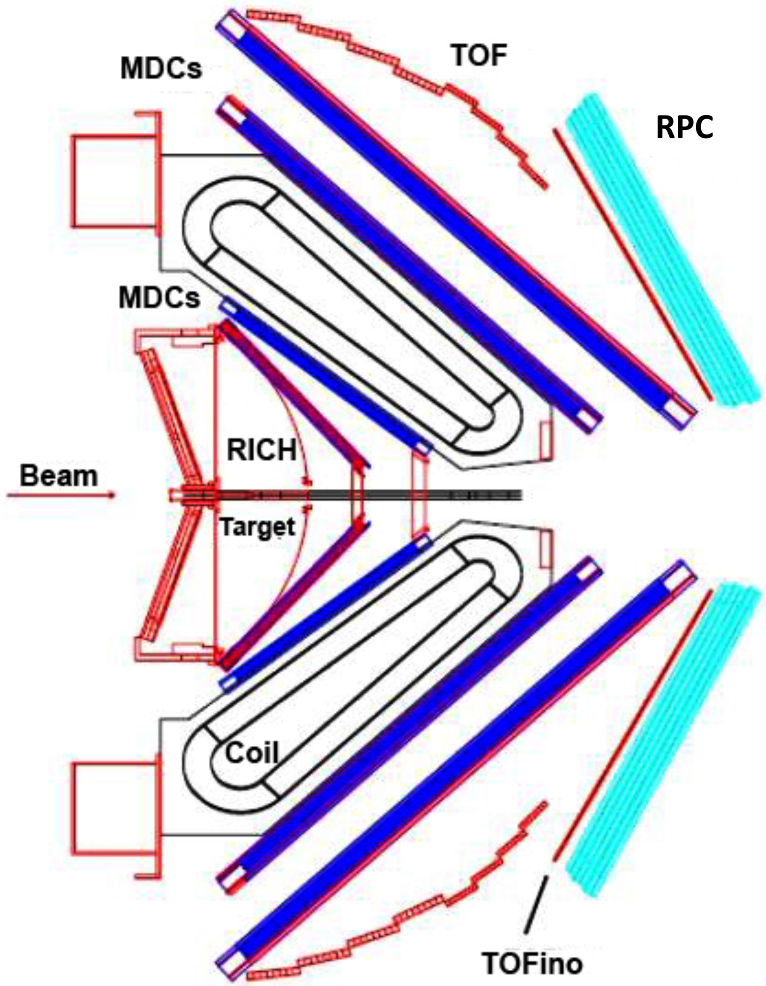


P.Crochet et al. Phys. Lett. B 486 (2000) 6.
RBBU: E. Bratkovskaya et al. Nucl. Phys. A622 (1997) 593.

New results for K+ and K- Sideward Flow are expected soon from the FOPI Collaboration

+ Study of the low Pt spectra

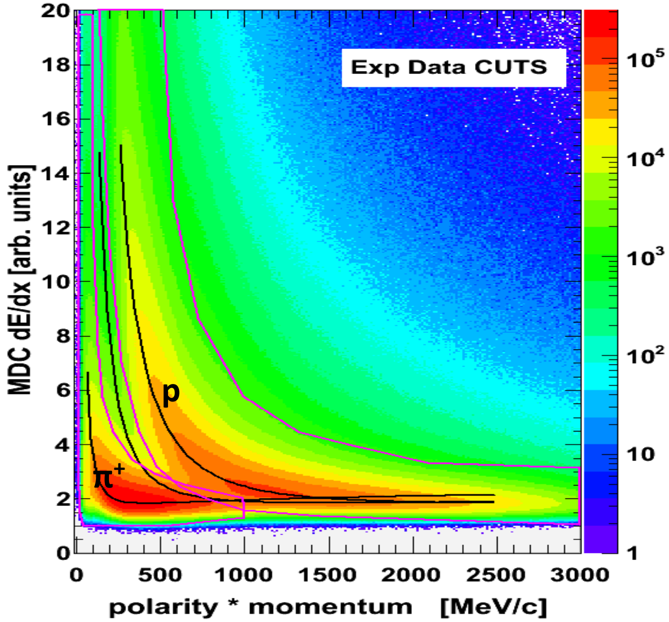
The HADES Spectrometer

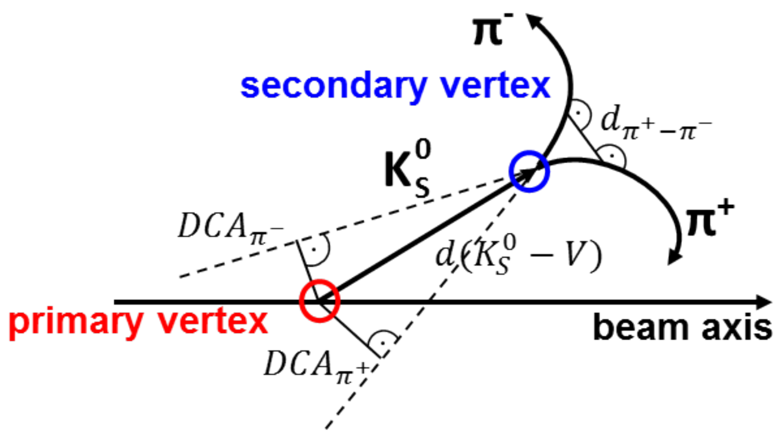


High **A**cceptance **D**i-**E**lectron **S**pectrometer:

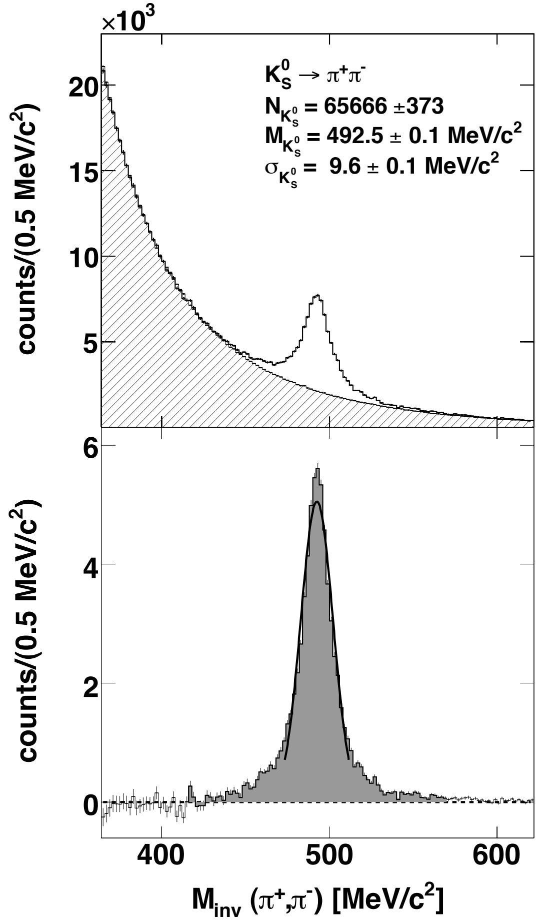
- High acceptance for dilepton pairs
- Momentum resolution ≈ 1-5 %
- Particle identification via dE/dx
- $6.9*10^8$ events in Ar+KCl @ 1.756 AGeV
- $1.2 \cdot 10^9$ events in p+p @ 3.5 GeV
- $4.2 \cdot 10^9$ events in p+Nb @ 3.5 GeV

Particle Identification





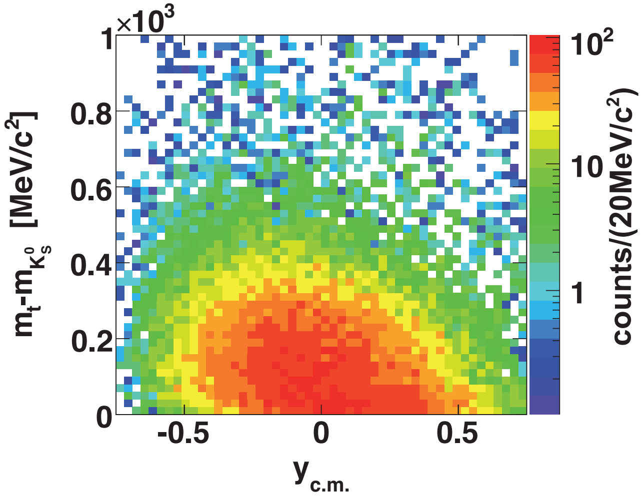
HADES: Ar+KCl @ 1.756AGeV

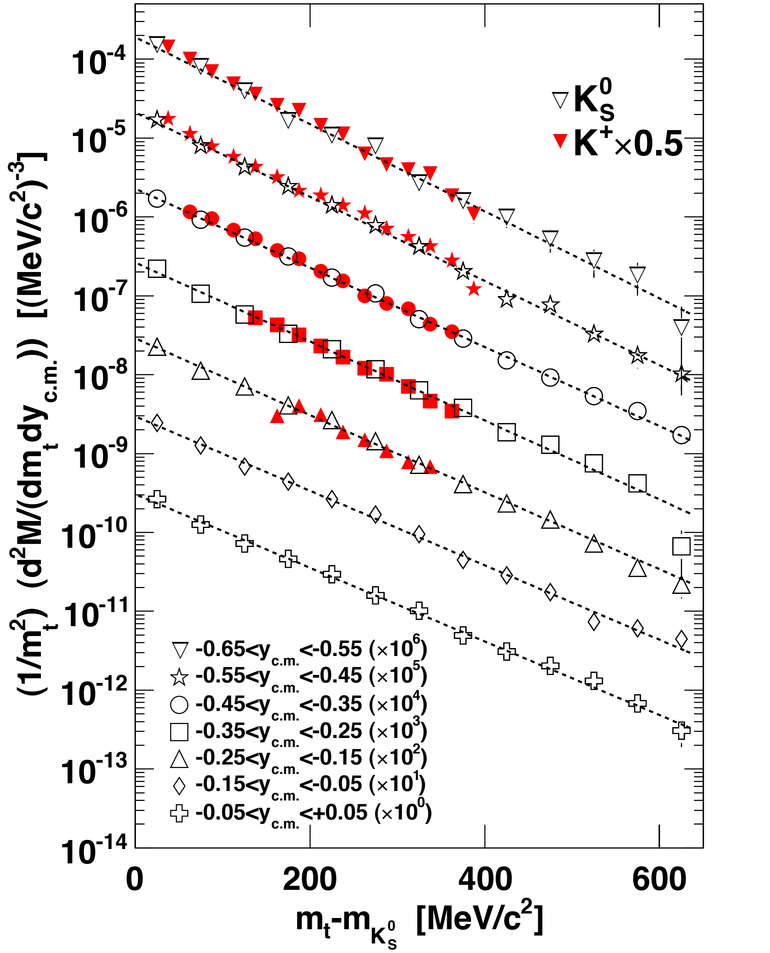


K0S in Ar+KCl @ 1.756AGeV

HADES: Ar+KCl @ 1.756AGeV

Phase Space Coverage

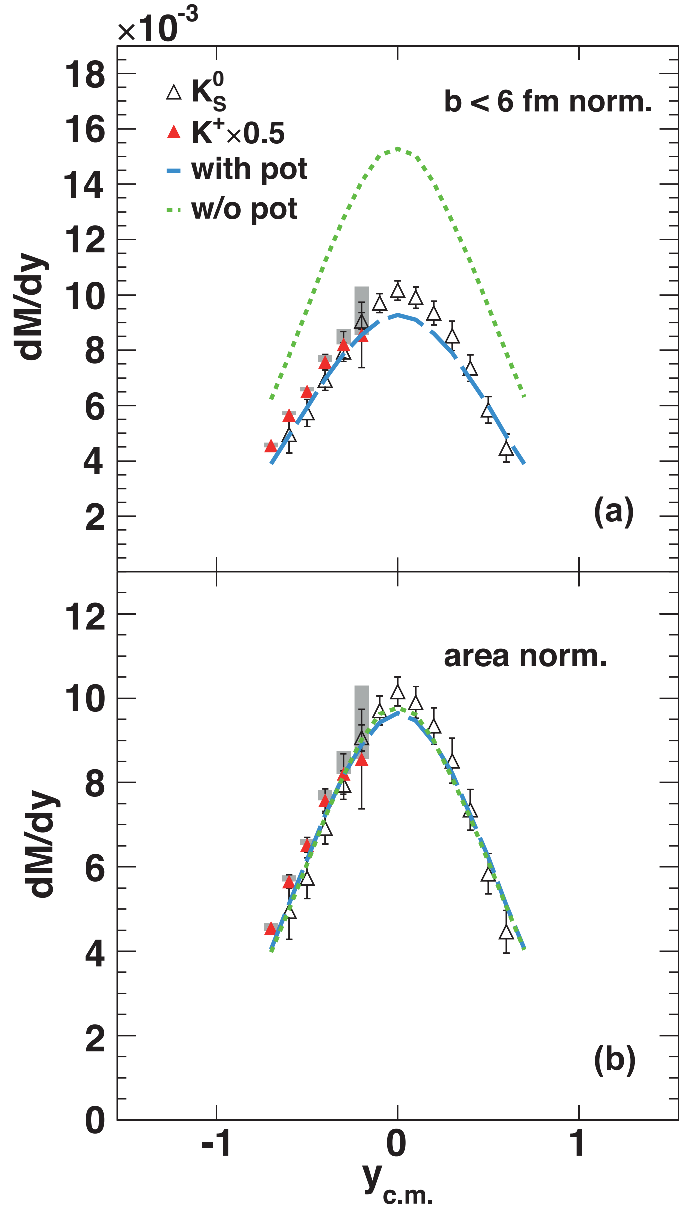




Reduced m_T spectra show consistency between K^+ and K^0_S

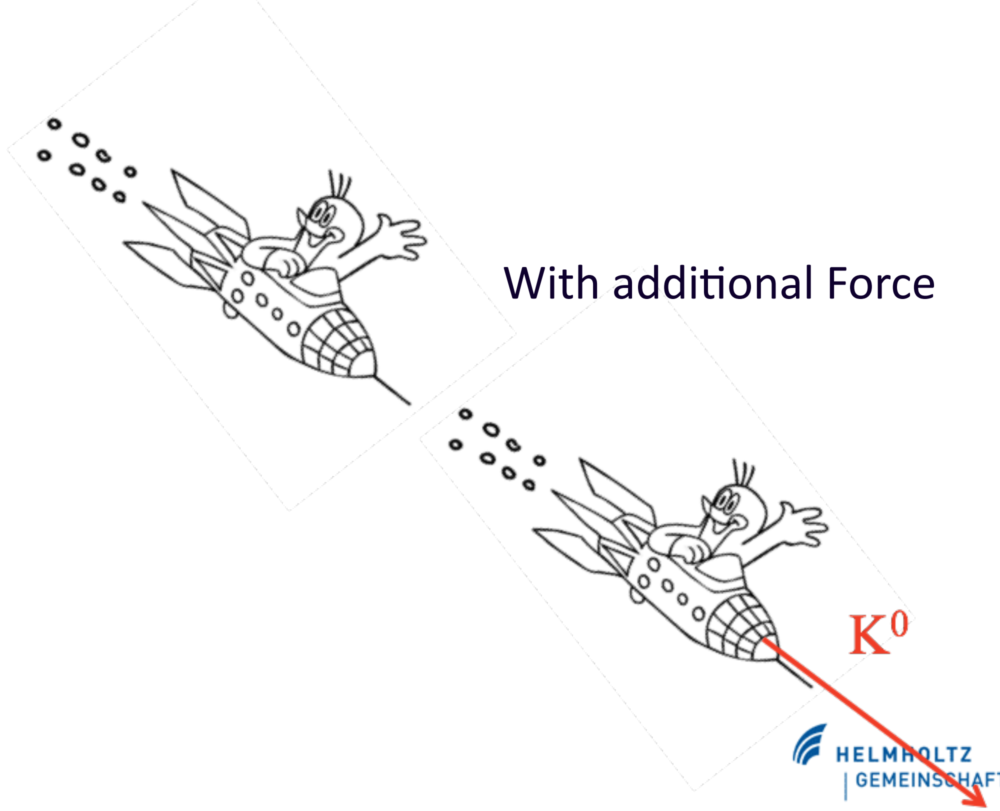
Rapidity Distribution

HADES: Ar+KCl @ 1.756AGeV



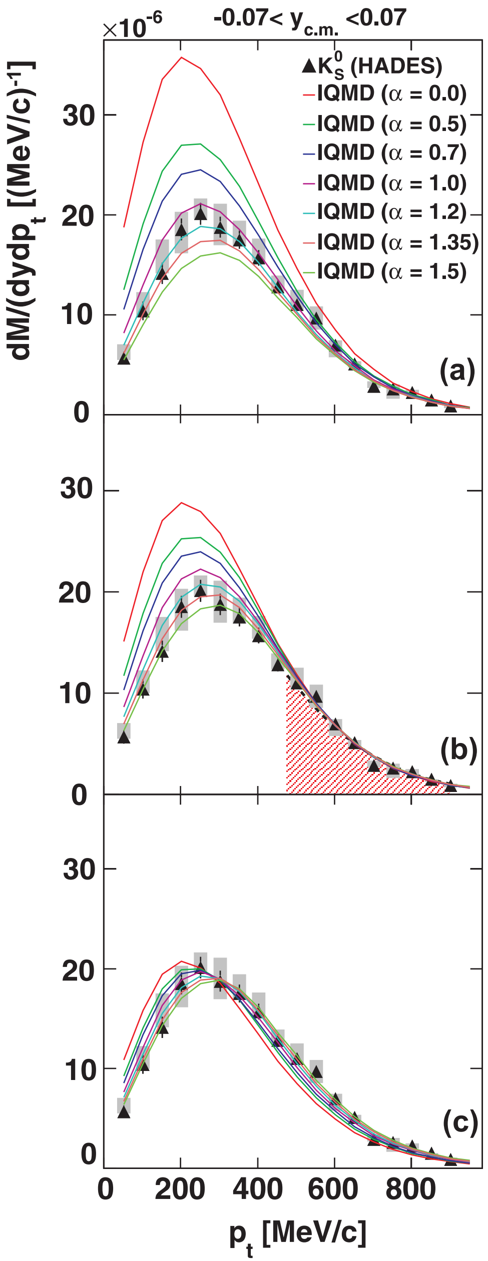
No sensitivity to the shape of the distribution!
The potential influences the absolute yield but this could vary because of scattering cross-section

Without additional Force



K^0 Potential

HADES: Ar+KCl @ 1.756AGeV



Comparison of the experimental data with the IQMD Model for different values of the potential and different normalization procedures

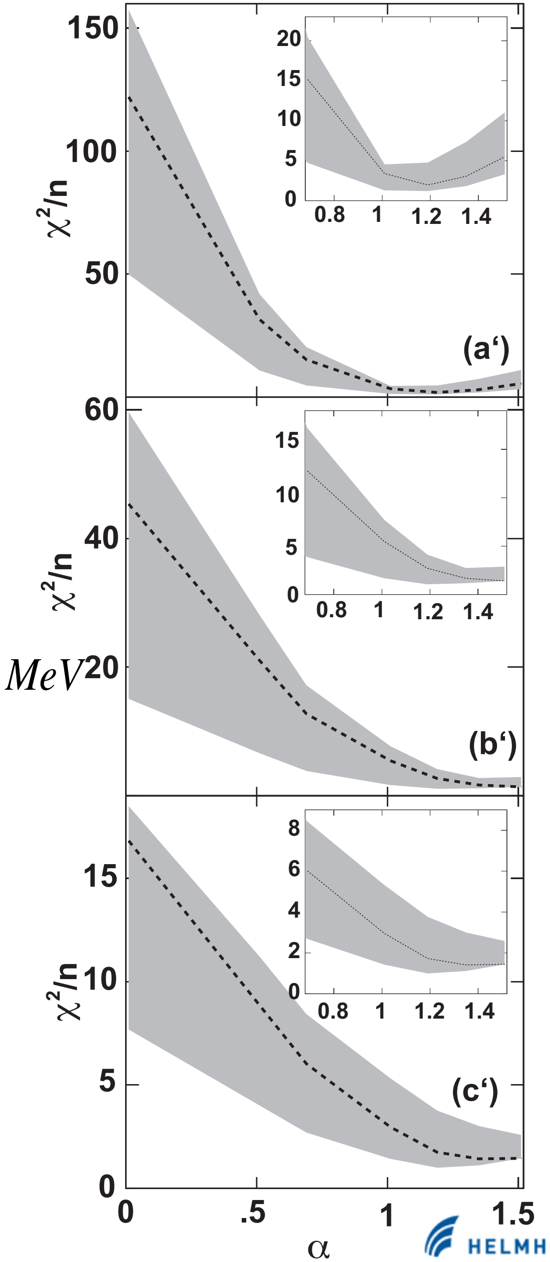
Linear Ansatz

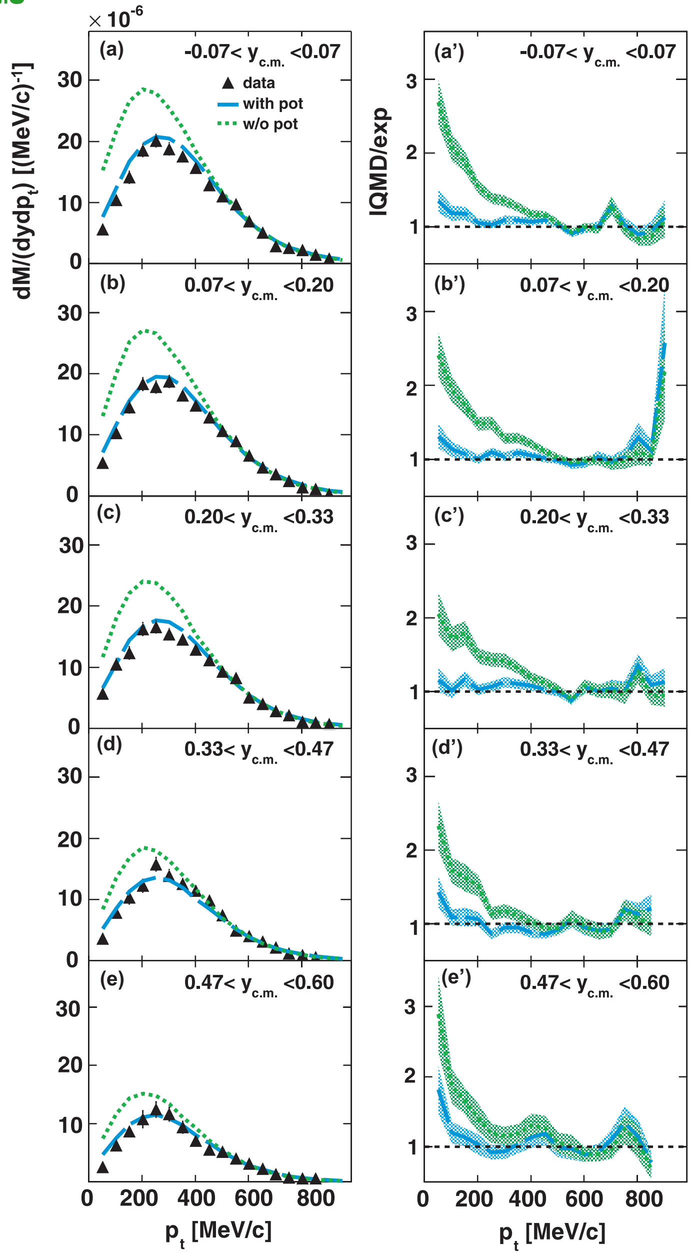
$$U(\alpha) = U_0 + U'\alpha, \quad U_0 \approx 0.8\,MeV, \quad U' \approx 38\,MeV$$

α= Parameter

α = 1.2 -> U= 46 MeV

α = 1.10 -> U = 38.8 MeV





Pt Distributions

HADES: Ar+KCl @ 1.756AGeV

IQMD Model compared to the experimental data

Normalization:

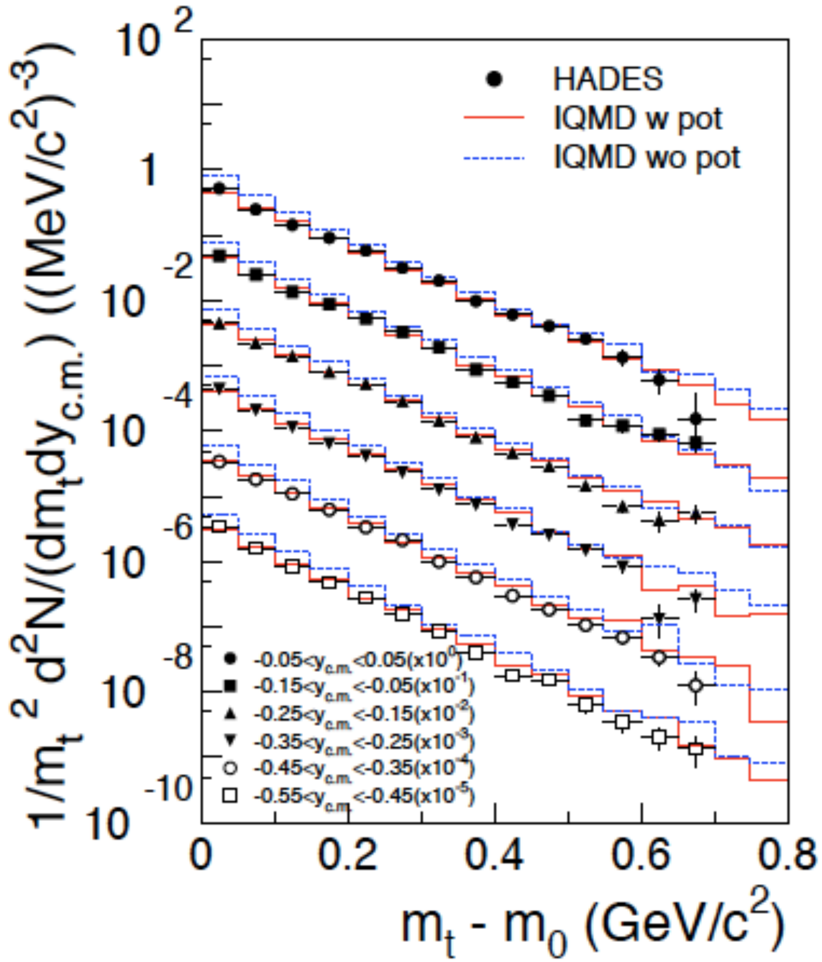
b < 6 fm -> corresponds to the experimental trigger

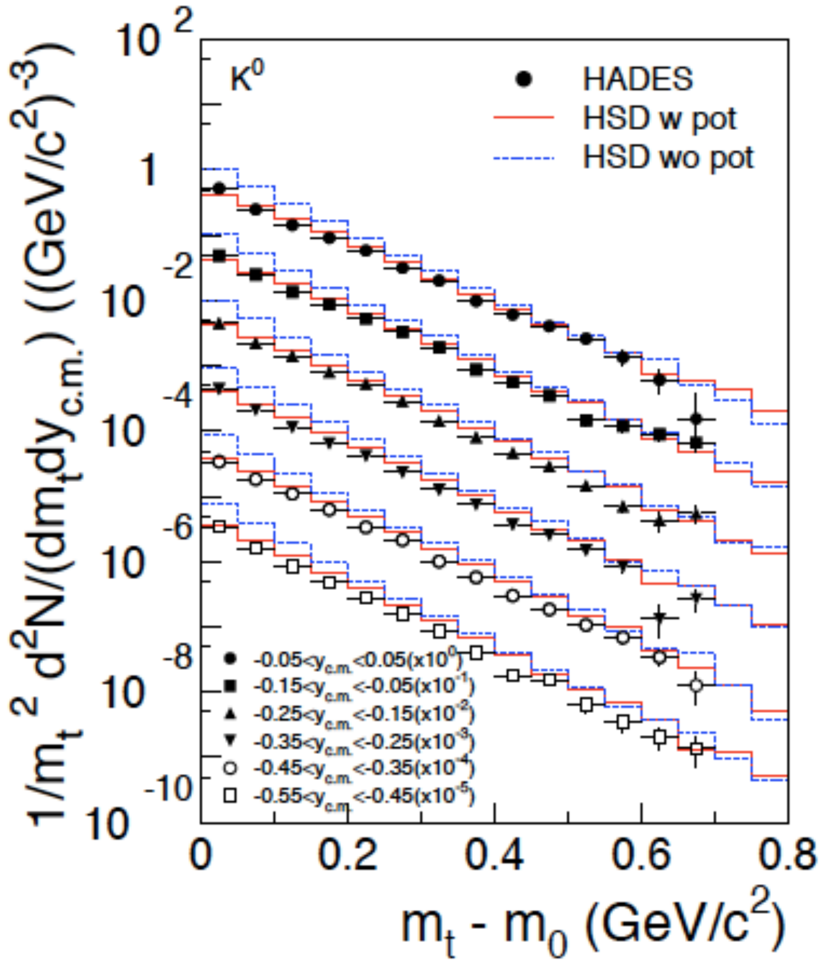
Pion spectra reproduced within 15%

HADES, IQMD and HSD

HADES: Ar+KCl @ 1.756AGeV

Hartnack, Oeschler, Leifels, Bratkovskaya, Aichelin Phys. Rep. 510, 4-5, 119 (2012)





HADES, IQMD and HSD

HADES: Ar+KCl @ 1.756AGeV

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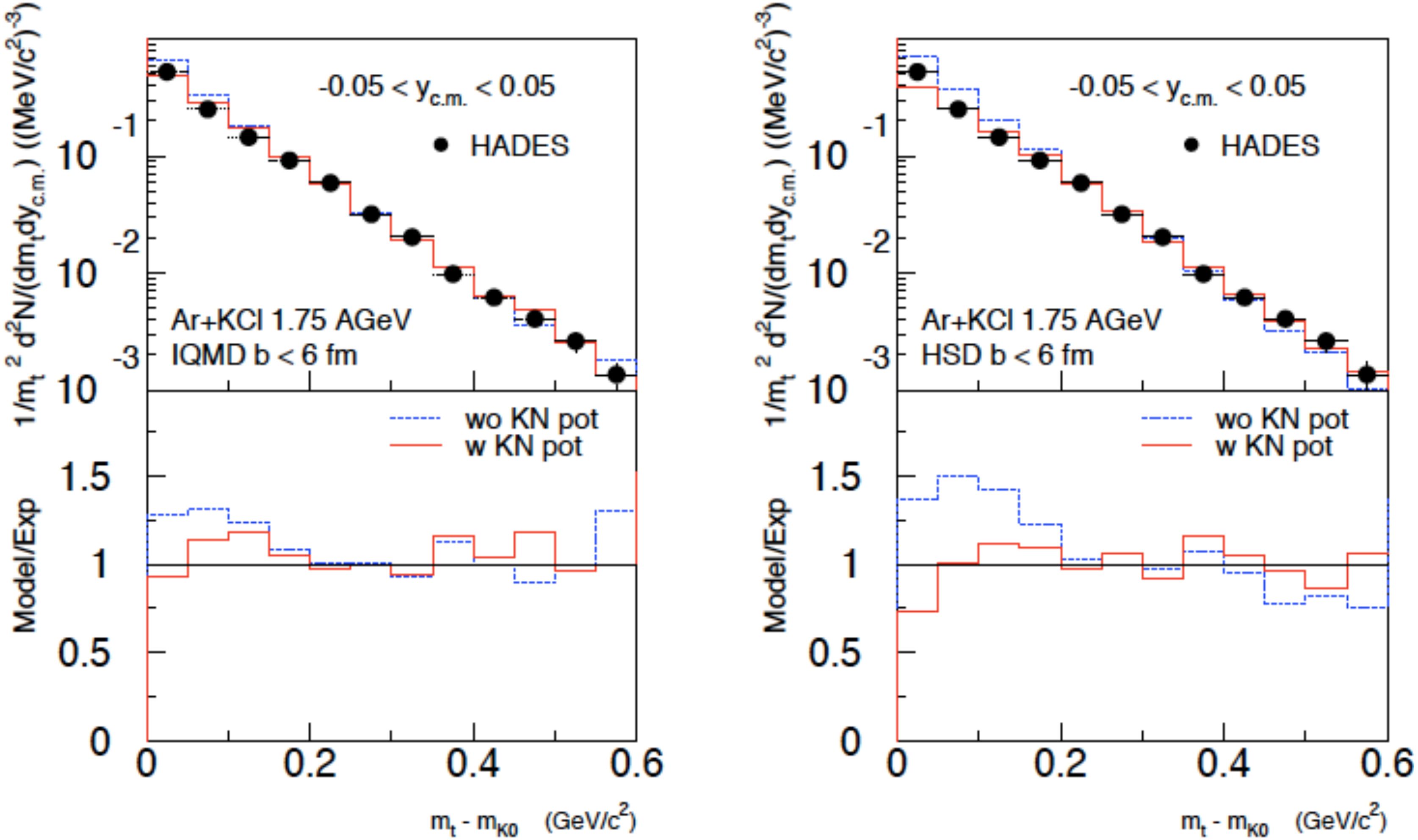


K0s Summary

	Ar+KCl - HADES	π^-+A - FOPI	p+A - ANKE
KN potential [MeV]	42.4 ± 3.7	20 ± 5	20 ± 3

Where do the differences come from?
Less sensitivity for low Ptin FOPI and ANKE?
Different theories?

Study the p+p and p+Nb reactions in HADES to verify the strength of the KN potential

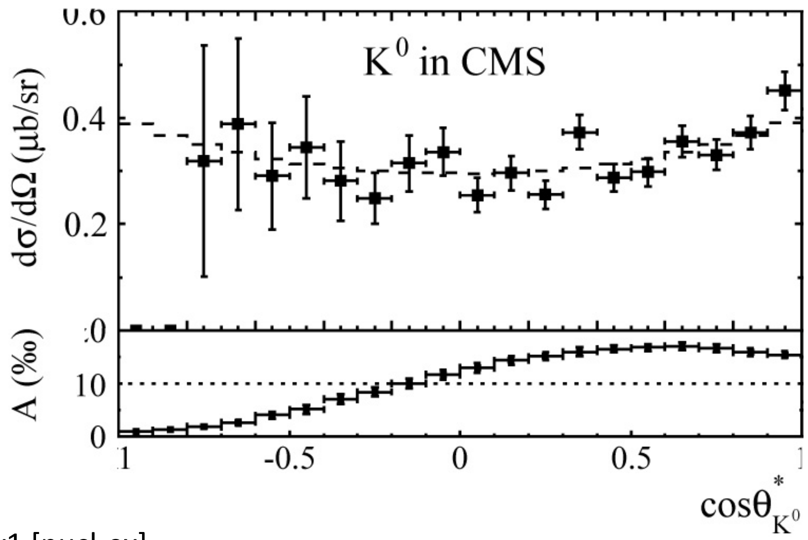
Acceptance & Efficiency Correction

- Monte Carlo simulation of 13 K^0 production channels for p+p @ 3.5 GeV (91% of σ_{tot})
- Angular distribution used for $\Sigma^+ p K^0$ channel
  $\rightarrow$ measured angular distribution from COSY-TOF studies of the same reaction at E_{kin} = 2.26 GeV
- p+Nb: UrQMD simulations

Largest contributions:

Reaction	σ [μb]
$p + p \rightarrow \Sigma^+ + p + K^0$	21.29
$p + p \rightarrow \Lambda + p + \pi^+ + K^0$	18.40
$p + p \rightarrow \Sigma^0 + p + \pi^+ + K^0$	12.38

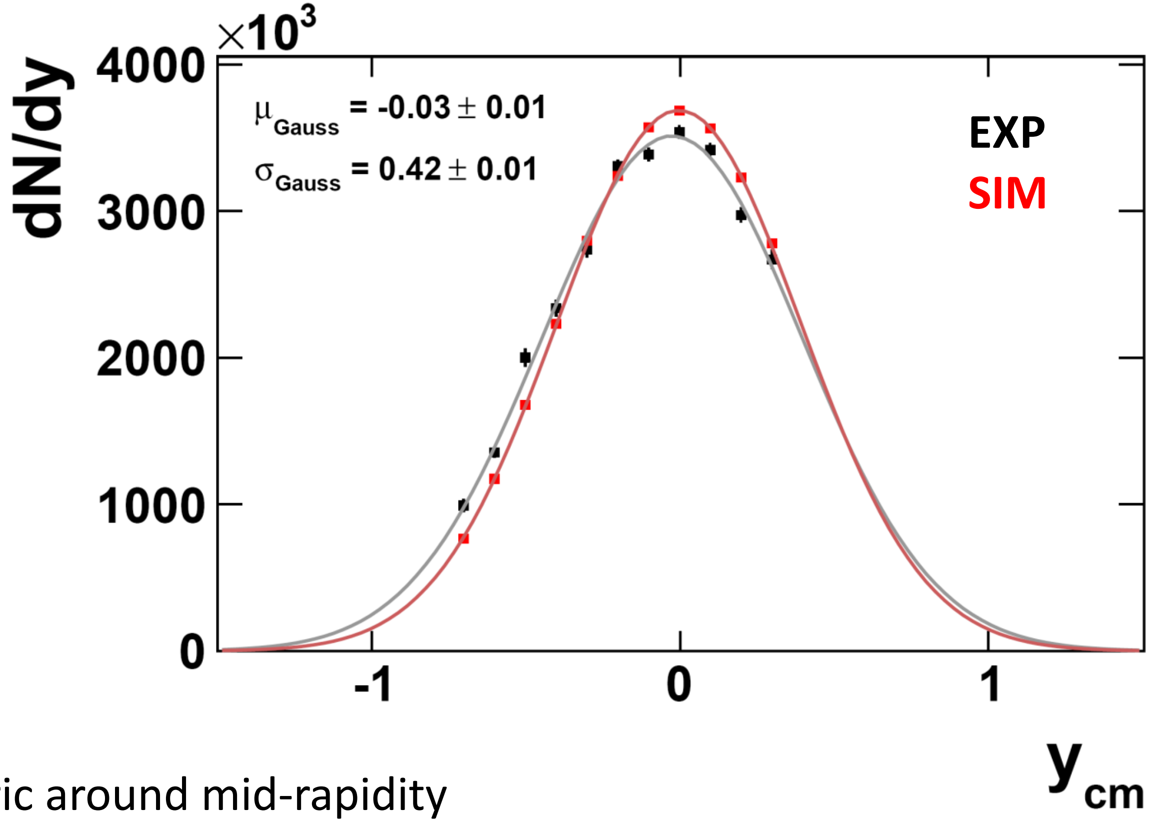
+ other minor channels



Abdel-Bary et al., arXiv:1202.4108v1 [nucl-ex]

dN/dy in p+p

HADES: p+p @ 3.5 GeV



→ symmetric around mid-rapidity

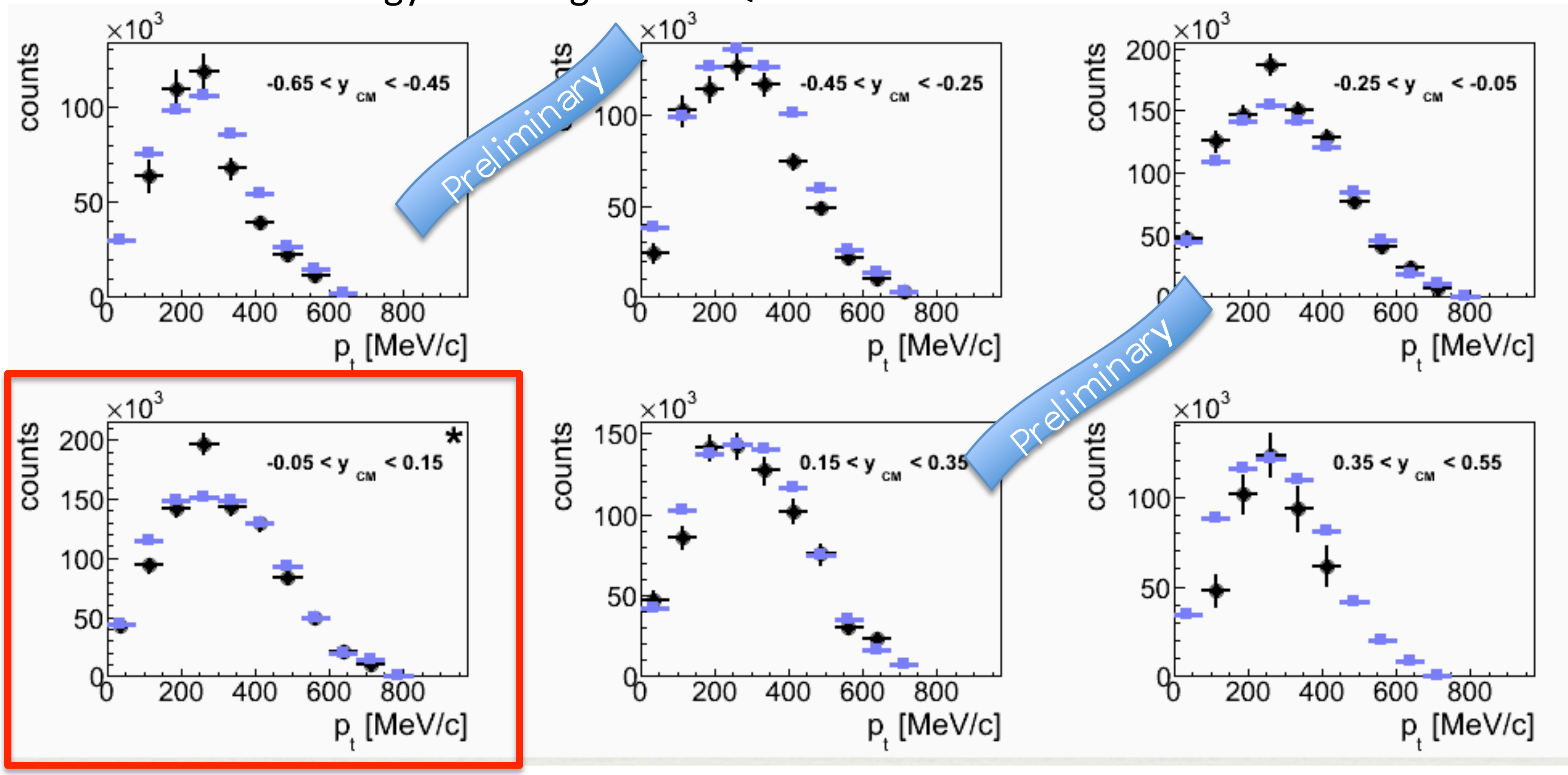
→ experimental data favors more anisotropy

$$\sigma_{tot}^{K_S^0} = 41.209 \pm 0.509(stat)\mu b \rightarrow \sigma_{tot}^{K^0} = 2 \cdot \sigma_{tot}^{K_S^0} = 82.418 \pm 1.018(stat)\mu b$$

p+p@3.5GeV: Exp vs GiBUU

3.5 GeV kinetic energy is too high for UrQMD and HSD!!

HADES: p+p @ 3.5 GeV



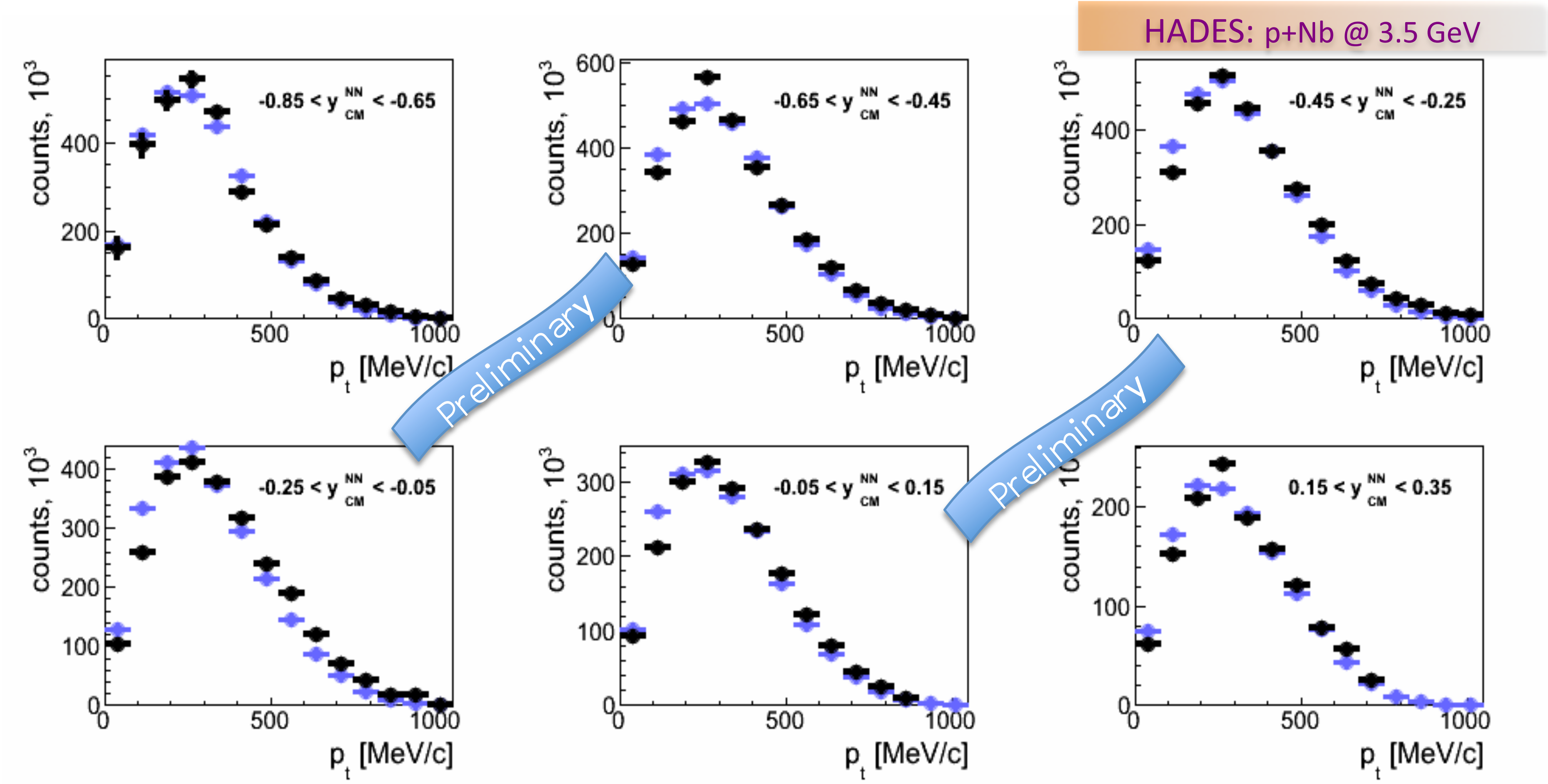
$p+p \rightarrow \Sigma^{+} + p + K^{0} \quad \sigma = 21.29\ \mu b$

$p+p \rightarrow \Lambda + p + \pi^{+} + K^{0} \quad \sigma = 18.40\ \mu b$

$p+p \rightarrow \Sigma^{0} + p + \pi^{+} + K^{0} \quad \sigma = 12.38\ \mu b$

Normalized to the mid-rapidity bin

p+Nb@3.5Gev:Exp vs GiBUU



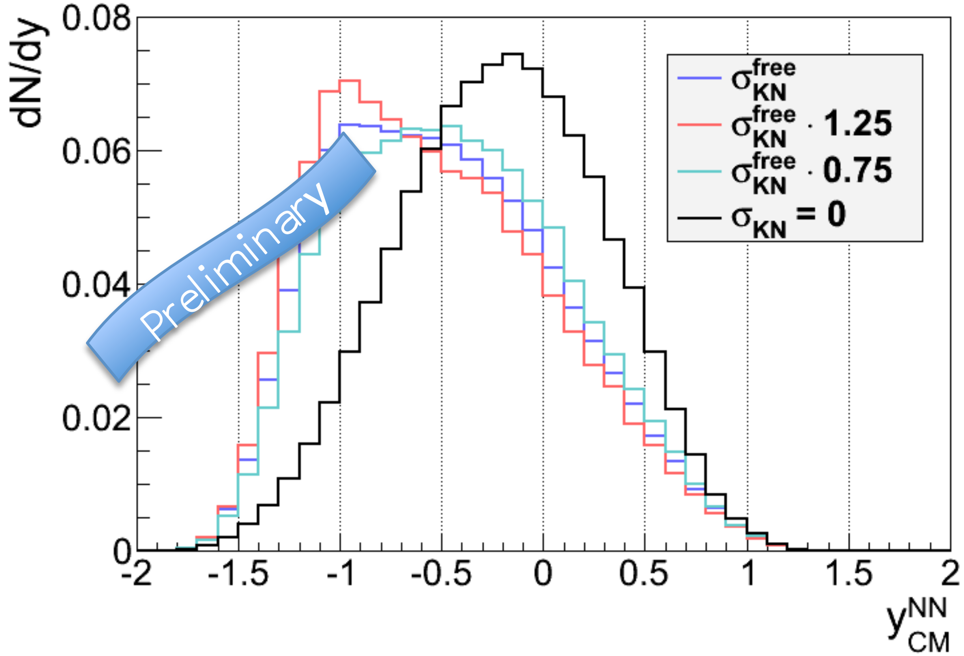
Sytematic overestimation of the low p_T region-> Effect of the repulsive potential

Issue of the K0-Nucleon scattering cross-section: Does this influence the p_T distribution

p+Nb: Rapidity Distribution

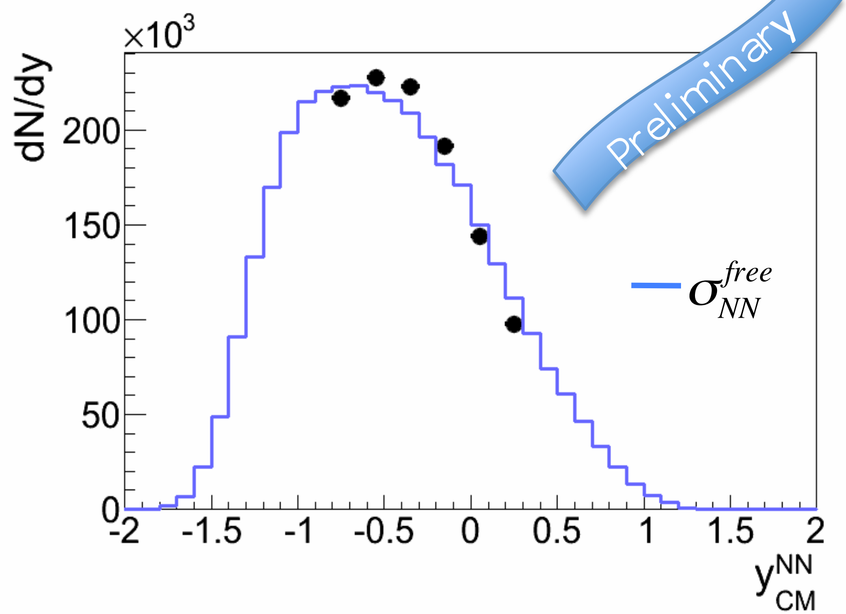
HADES: p+Nb @ 3.5 GeV

GiBUU with different KN cross sections



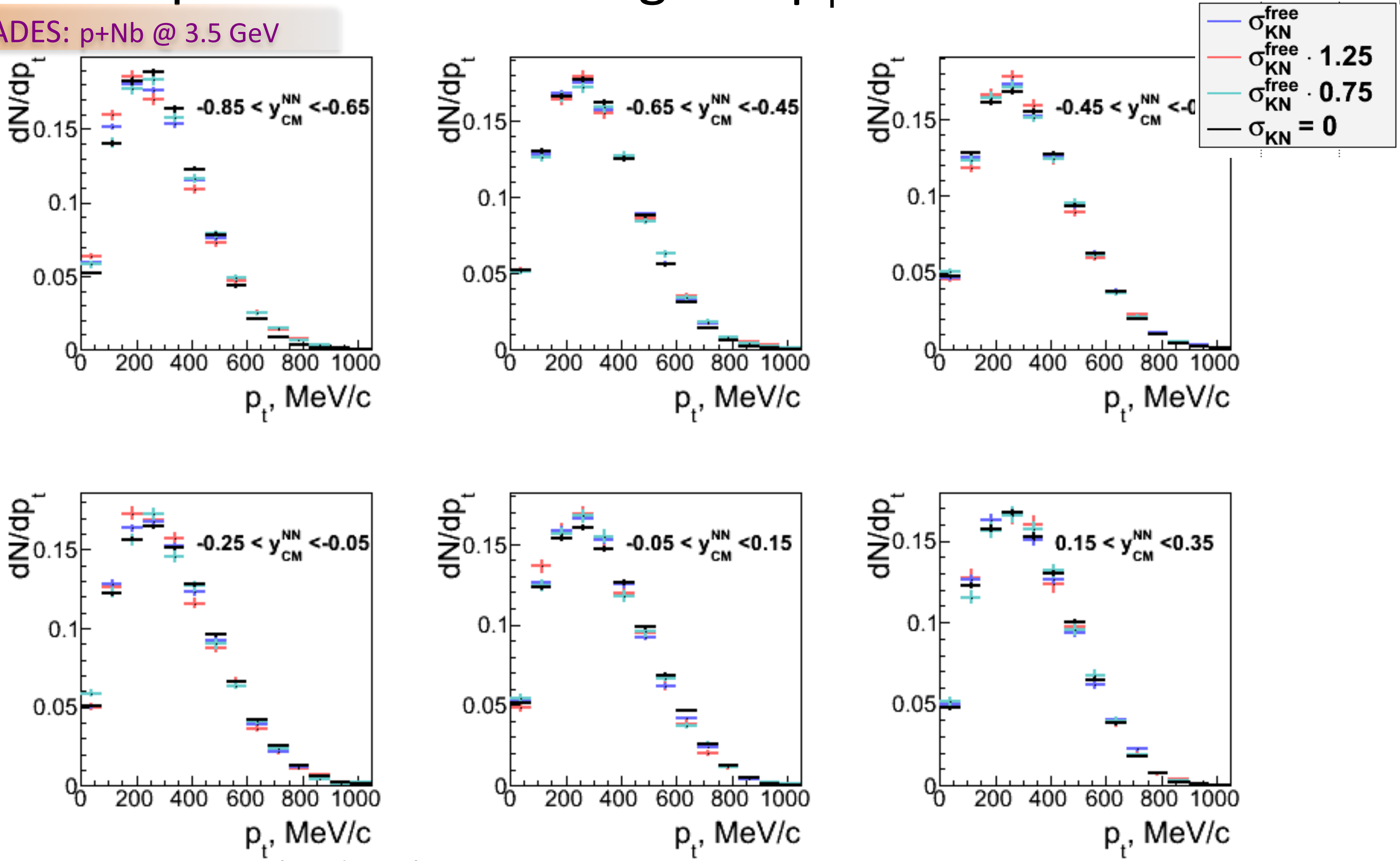
- Strong backward shift due to the KN scattering
- Which is the influence of the potential?

Experimental Data and GiBUU



p+Nb: KN scattering and p_T Distributions

HADES: p+Nb @ 3.5 GeV



Spectra normalized to the same area

No dependency of the pT spectra upon the KN scattering

-> p_T is a good observable to quantify the effect of the repulsive potential

Summary and Outlook

- Ar+KCl : IQMD model used to describe the data
  - a) Pions reproduced within 15%
  - b) **K^0_S** P_T distributions are compatible with **U~40 MeV**

- p+p: Pluto Cocktail used to calculate corrections
  GiBUU model used to describe the data
  - a) p+p well reproduced: Reference

- p+Nb: GiBUU comparison
  - a) No Potential effects are yet included in the GiBUU code
  - b) **K^0_S** Rapidity density distribution depends upon the KN scattering cross-section and probably from the KN potential
  - c) **K^0_S** PT distributions are not sensitive to the KN scattering cross-section!

To do: Implement the KN potential in the GiBUU code

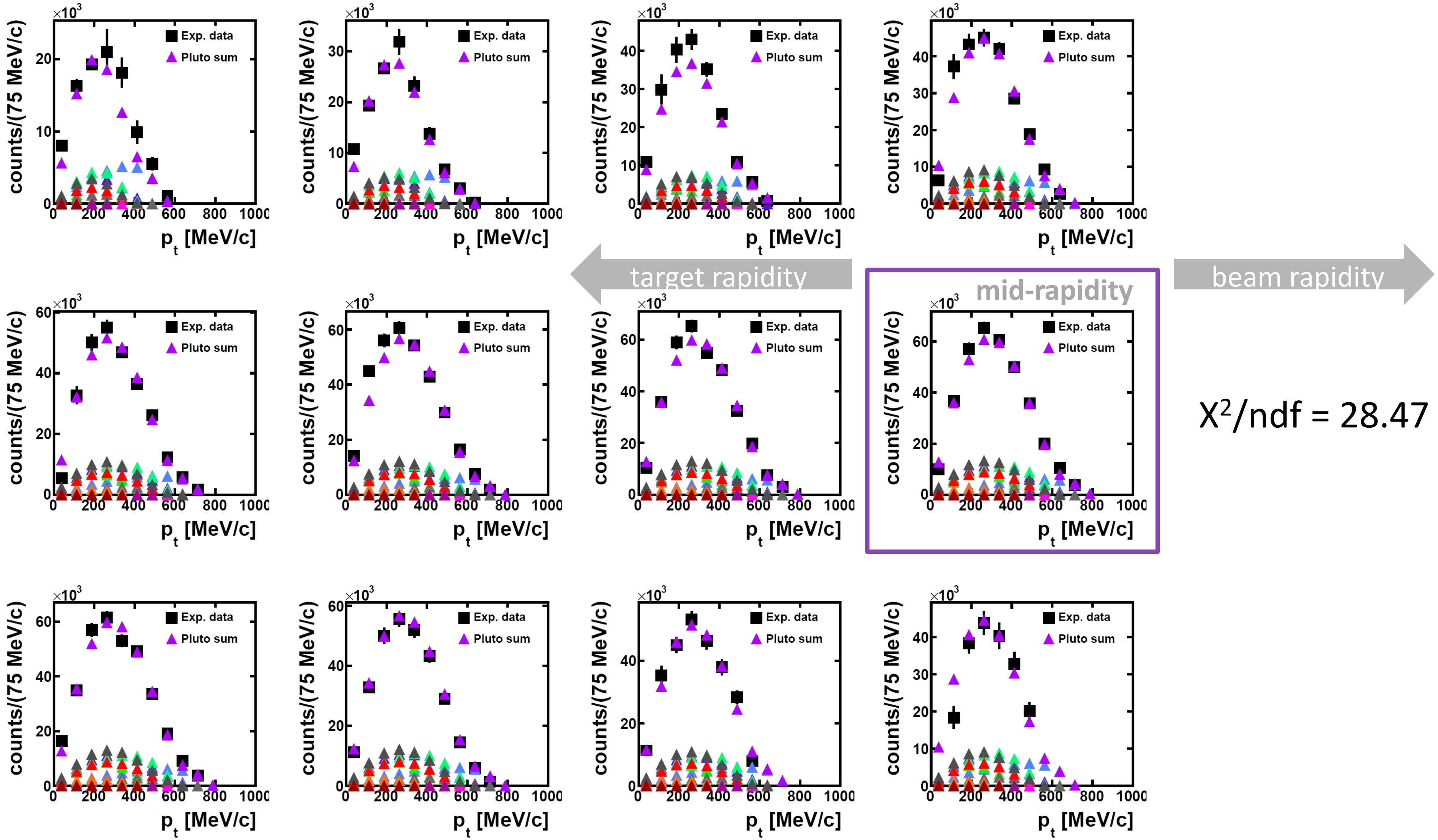
Simultaneous Fit of All Channels to 12 exp. p_t-y Distributions

Start parameter for minimization:
Scaling factors ($\sigma_{ch} \cdot f_{norm}(y_{cm})$) used for PLUTO-Exp comparision

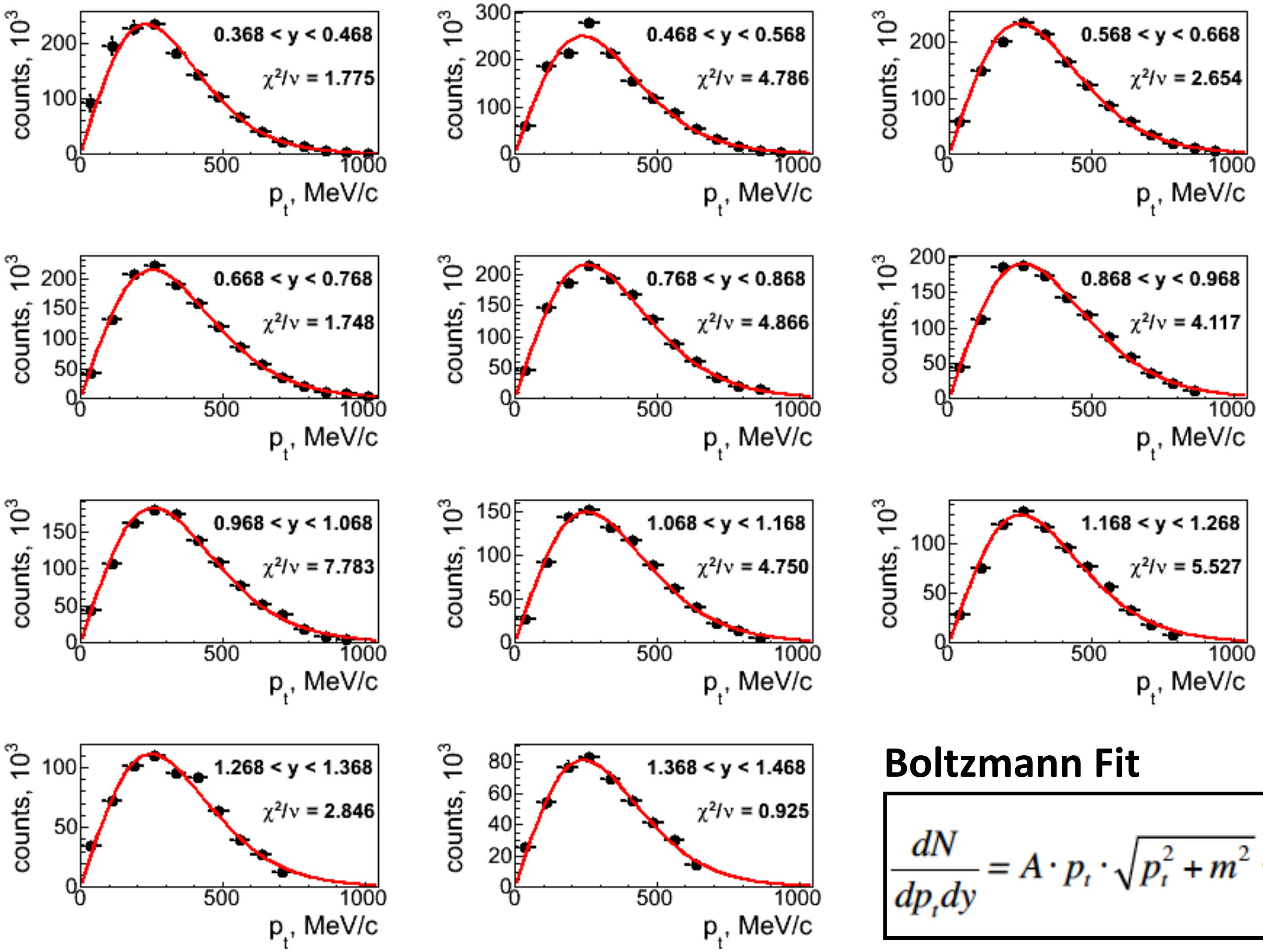
Constraints: $p+p \rightarrow \Lambda + p + \pi^+ + K^0 \leq p+p \rightarrow \Sigma^+ + p + K^0$

$$p+p \rightarrow \Lambda + p + \pi^+ + K^0 \geq \left\{ \begin{array}{l} p+p \rightarrow \Sigma^0 + p + \pi^+ + K^0 \\ p+p \rightarrow \Lambda + \Delta^{++} + K^0 \\ p+p \rightarrow p + n + K^+ + K^0 \\ p+p \rightarrow \Sigma(1385)^+ + p + K^0 \\ p+p \rightarrow \Lambda + n + \pi^+ + \pi^+ + K^0 \\ p+p \rightarrow \Sigma^+ + n + \pi^+ + K^0 \\ p+p \rightarrow \Lambda + p + \pi^+ + \pi^0 + K^0 \\ p+p \rightarrow \Sigma^+ + p + \pi^0 + K^0 \\ p+p \rightarrow \Sigma^- + p + \pi^+ + \pi^+ + K^0 \\ p+p \rightarrow \Sigma^+ + p + \pi^+ + \pi^- + K^0 \\ p+p \rightarrow p + p + \pi^+ + K^- + K^0 \end{array} \right.$$

K_S^0 differential p_t-y Distribution vs. PLUTO after Minimization



Boltzmann Fits



Boltzmann Fit

$$\frac{dN}{dp_t dy} = A \cdot p_t \cdot \sqrt{p_t^2 + m^2} \cdot \exp\left(- \frac{\sqrt{p_t^2 + m^2}}{T_B} \right)$$