Strangeness - Φ mesons in pA reactions

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- BUU transport model
- HADES data
- comparison with ANKE
- multistrange objects

Forschungszentrum Dresden Rossendorf

with B. Kämpfer, Gy. Wolf *, M. Hartmann #

*) KFKI #) ANKE Coll.

colliding nuclei (p) @ 1.756 (2.83) AGeV beam energy

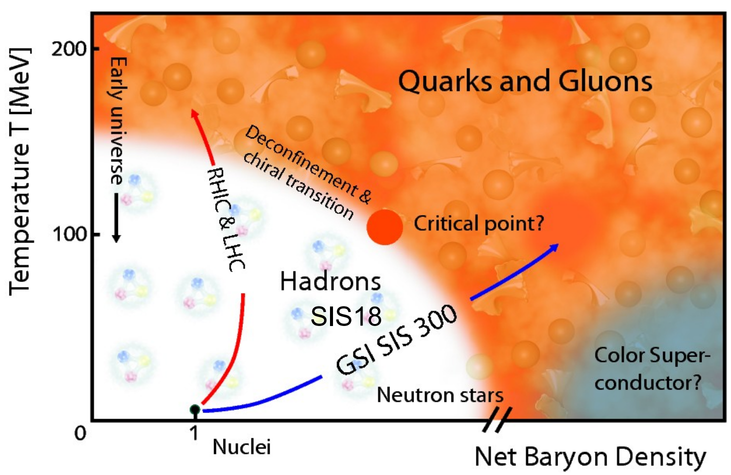
↓

dense nuclear matter, particle production & absorption

in-medium modifications of hadrons? (spectral properties, masses, widths, EoS)

↓

expansion phase with chemical and thermal freeze-out



courtesy: GSI

experiments:

HADES at SIS18/GSI	&	ANKE COSY/Jülich
Ar+KCl		p+C, Cu, Ag, Au

hadron Φ measurements

(1)

Theory: microscopic, relativistic transport model based on Boltzmann-Uehling-Uhlenbeck (BUU) kinetic theory

evolution of single-particle phase-space distribution functions $f_i(\vec{r}, \vec{p}, t)$

hadron species

quasi-particle limit:

$$\frac{\partial f_i}{\partial t} + \frac{\partial H_i}{\partial \vec{p}} \frac{\partial f_i}{\partial \vec{r}} - \frac{\partial H_i}{\partial \vec{r}} \frac{\partial f_i}{\partial \vec{p}} = \sum_j \mathcal{C}_{ij} + \sum_j \mathcal{G}_{j\to i} + \sum_j \mathcal{L}_{i\to j}$$

$$H \approx \sqrt{m_{0,i}^2 + \vec{p}^{\,2}} + U_i^{nr}$$

set of non-linear partial integro-differential equations:

$$\boxed{\begin{aligned} \frac{\partial f_i}{\partial t} + \vec{v}\,\nabla_r \cdot f_i - \nabla_r U_i^{nr} \cdot \nabla_p f_i = & -\frac{1}{(2\pi)^6} \int d^3p_2 d^3p_{2'} d\Omega \frac{d\sigma}{d\Omega} v_{12} \\ & \times \Big\{ [f_i f_2 (1 - f_{1'})(1 - f_{2'}) - f_{1'} f_{2'} (1 - f_i)(1 - f_2)] \\ & \times (2\pi)^3 \delta^3(\vec{p} + \vec{p}_2 - \vec{p}_{1'} - \vec{p}_{2'}) \Big\} + \mathcal{G}_i + \mathcal{L}_i \end{aligned}}$$

drift term

nucleon feels mean-field

Vlasov term

→ for non-interacting nucleons

collisional integral → two-body collisions

How to solve integro-differential equations?

$\rightarrow$ parallel ensemble test-particle method:

# of parallel ensembles

N = 1

$$\boxed{f_i(\vec{r},\vec{p},t) = \frac{1}{\tilde{N}} \sum_{n=1}^{\tilde{N}} \delta^{(3)}(\vec{r} - \vec{r}_i^{\,(n)}(t))\delta^{(3)}(\vec{p} - \vec{p}_i^{\,(n)}(t))}$$

$$\frac{d\vec{r}_i^{\,(n)}}{dt} = \frac{\partial H_i}{\partial \vec{p}_i^{\,(n)}} = \vec{v}_i^{\,(n)},$$

$\longrightarrow$ set of ordinary differential equations

$$\frac{d\vec{p}_i^{\,(n)}}{dt} = -\frac{\partial H_i}{\partial \vec{r}_i^{\,(n)}} = -\vec{\nabla}_r U_i(n(\vec{r}),\vec{p}),$$

better statistics $\longrightarrow$ multiple runs mean field:

$$U = A\frac{n}{n_0} + B\left(\frac{n}{n_0}\right)^{\tau} + C\frac{2}{n_0}\int \frac{d^3p'}{(2\pi)^3}\frac{f(\vec{r},\vec{p}\,')}{1+\left(\frac{\vec{p}-\vec{p}\,'}{\Lambda}\right)^2}$$

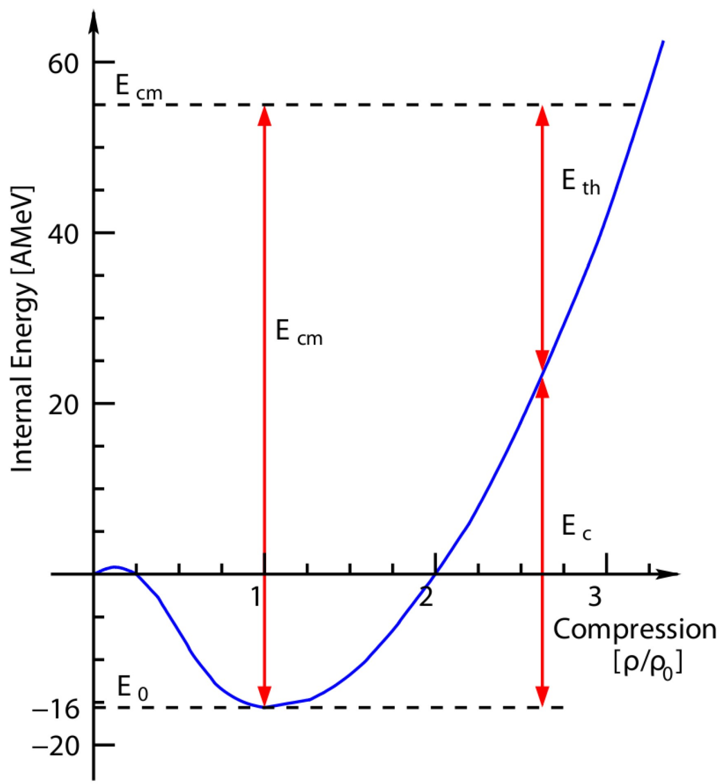
Skyrme

nucleon distribution function

soft momentum-dependent EoS

„compressional“
energy/# of nucleons
@ T=0

$$E/A(n,T=0) = \frac{1}{n}\int U^{nr}\,dn$$



with compression modulus

$$\kappa = \left(9n^2\frac{\partial^2 E/A(n,T=0)}{\partial n^2}\right)_{n=n_0}$$

$$\kappa \approx 0.215\ \mathrm{GeV}$$

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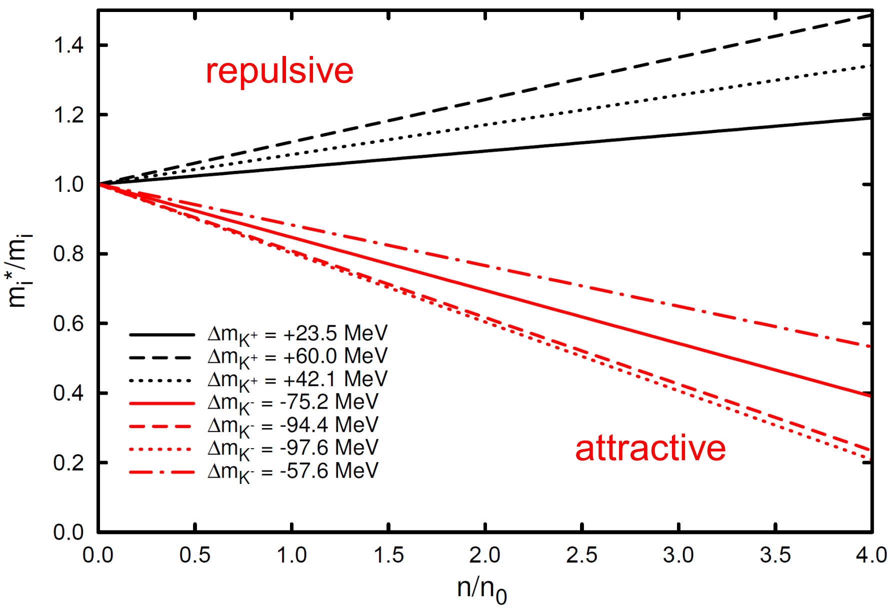
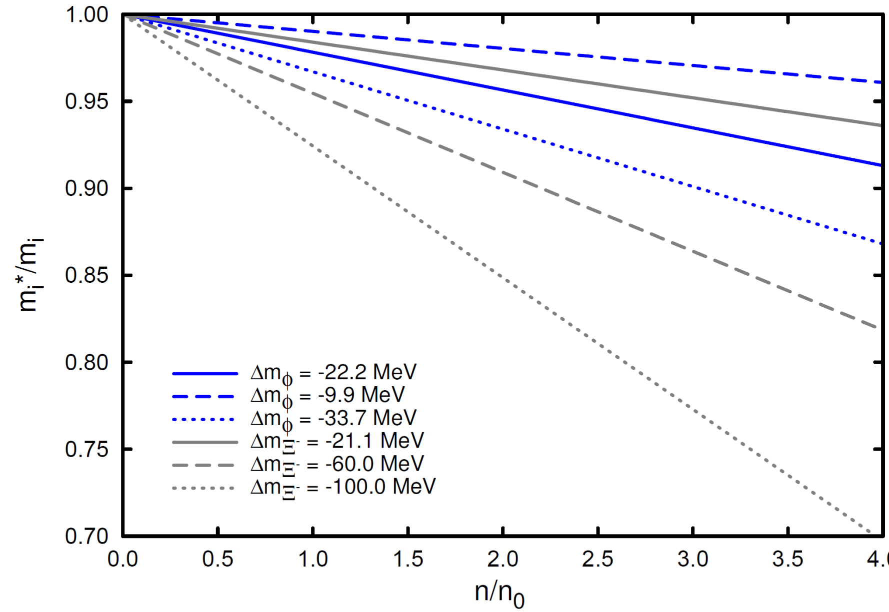
In-medium masses





Kolomeitsev, Kämpfer, Voskresensky '95
Schaffner et al. '97
Pavlenko, Kämpfer, Zschocke '03

constant mass shift @ n_0: $\longrightarrow$

$$\boxed{\Delta m_{K^\pm} = 1 + C_{K^\pm}\frac{n}{n_0}}$$

standard parameter set

$$\Delta m_{K^+} = \Delta m_{K^0} = +25.3 \text{ MeV}, \ \Delta m_{K^-} = -75.2 \text{ MeV}, \ \Delta m_\phi = -22.2 \text{ MeV}, \ \Delta m_{\Xi^-} = -21.1 \text{ MeV}$$

Strangeness

p, n

$\pi^{\pm}, \pi^0$

$K^0, K^{\pm}, \Phi, \Xi^-$

...

good probes of

reaction dynamic

$NN \to NNK^+K^-$

$NN \to N\Lambda K^+$

threshold energies $\quad E_{kin}[AGeV]$

$NN \to K^+\Lambda N$	1.58
$NN \to K^+K^-NN$	2.49
$NN \to \Phi NN$	2.59

Δ - decay $\longrightarrow$ $\pi Y \leftrightarrow K^- N$

strangeness exchange

Φ decay:

$\Phi \to K^+K^-$

$NN \to NN\Phi$

$\pi N \to \Phi N$

role of ϕ
@ SIS ?

HS, Gy. Wolf, B. Kämpfer **PRC 2010**

$\boxed{\phi/K^- = 0.28}$

HADES **PRC 2009**: 0.37 ± 0.13

HADES data Ar + KCl @ 1.756 AGeV

PRC 2009

Maxwell-Boltzmann-like distribution (fit):

$$\frac{1}{m_t^2}\frac{d^2N}{dm_t dy} = C\cdot\cosh(y)\cdot e^{-\frac{m_t - m_0}{T_B}}$$

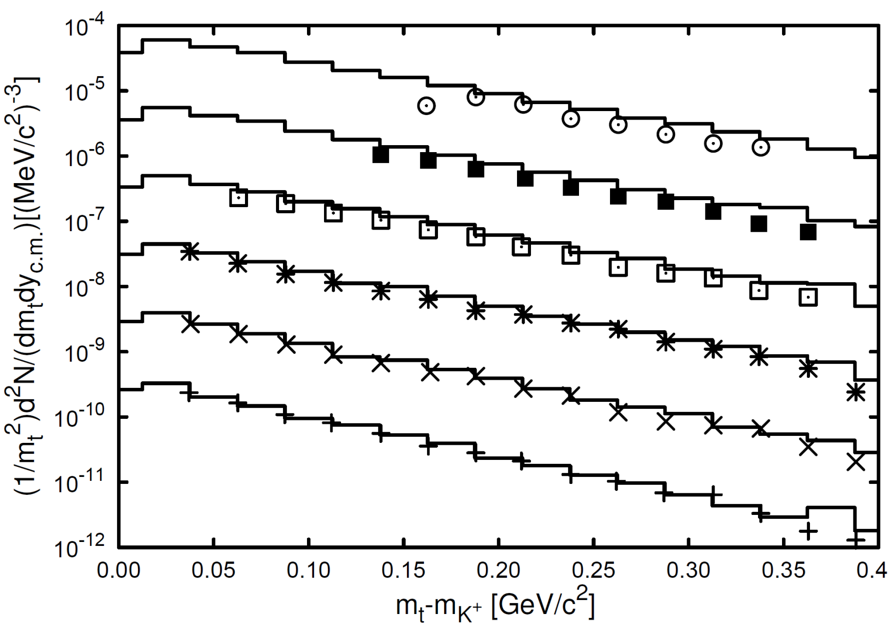
binning in rapidity

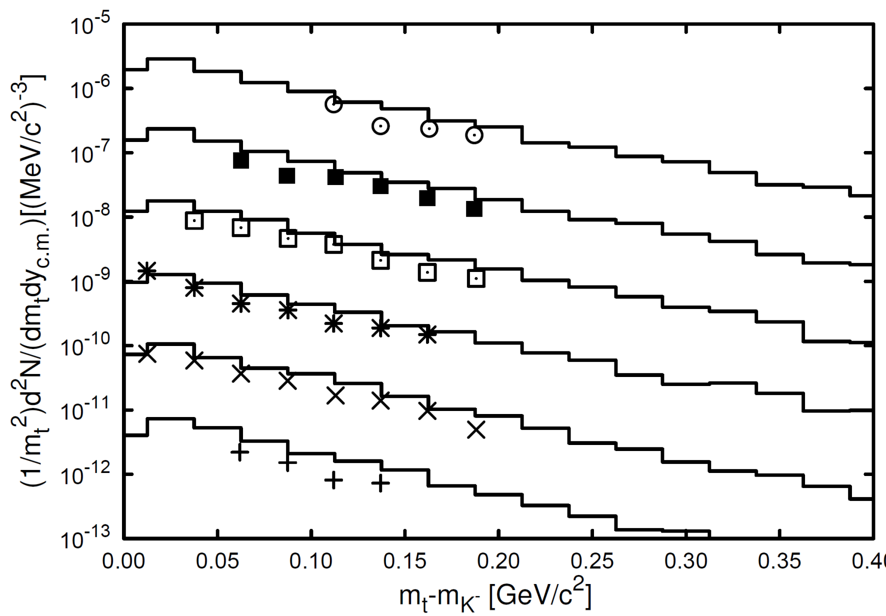
inverse slope parameter $T_B(y) = T_{eff}/\cosh(y)$

effective temp.
of kinetic freeze-out

$T_{eff}^{K^+} = 89\ \mathrm{MeV}$

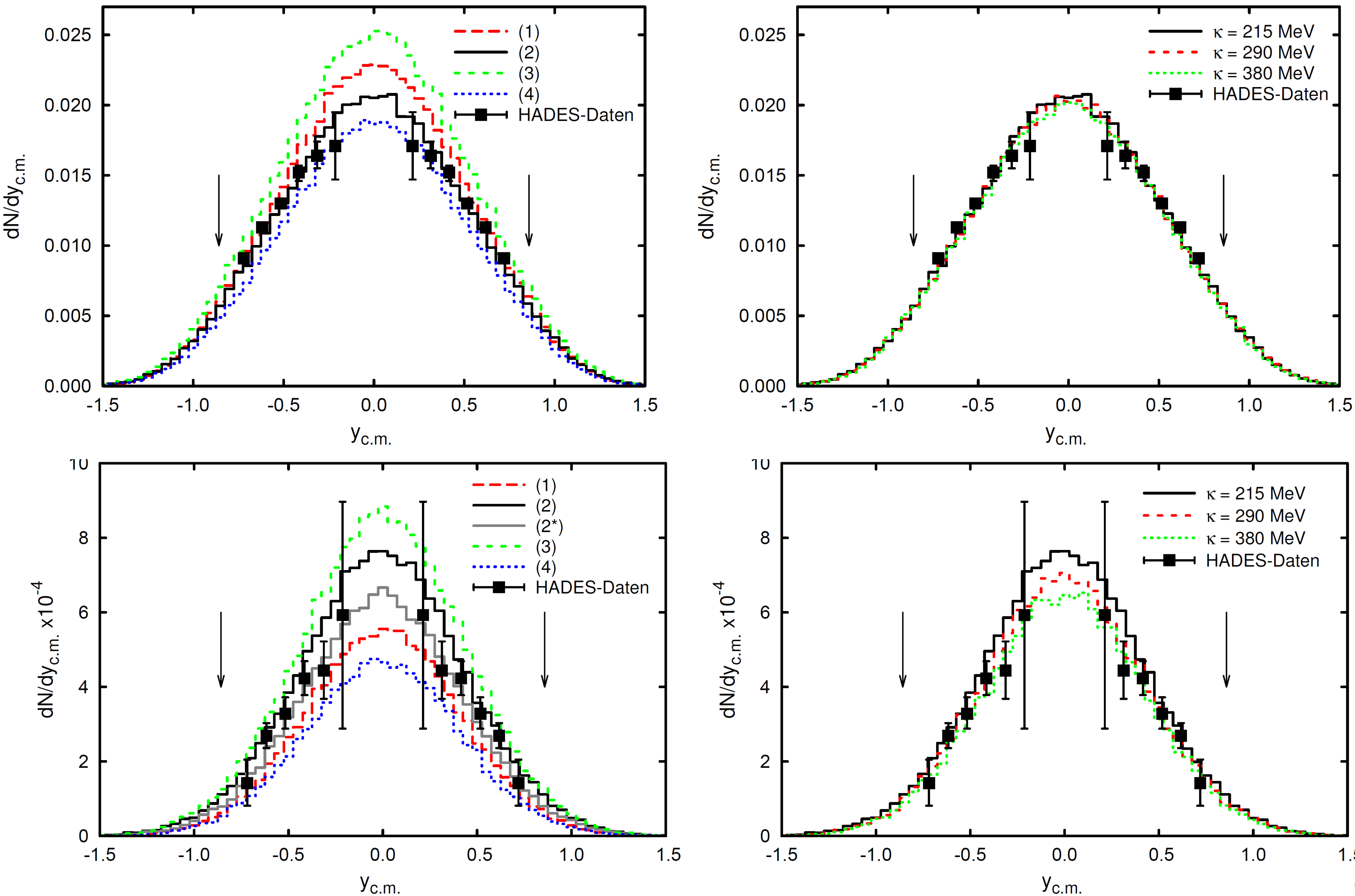
$T_{eff}^{K^-} = 69\ \mathrm{MeV}$





HS, Gy. Wolf, B. Kämpfer **PRC 2010**

rapidity: $\frac{dN}{dy} = \int_{m_t=m_0}^{\infty} \frac{d^2N}{dm_t\,dy}\,dm_t \longrightarrow dN/dy = C(y)(m_0^2 T_B(y) + 2m_0 T_B(y)^2 + 2T_B^3(y))$



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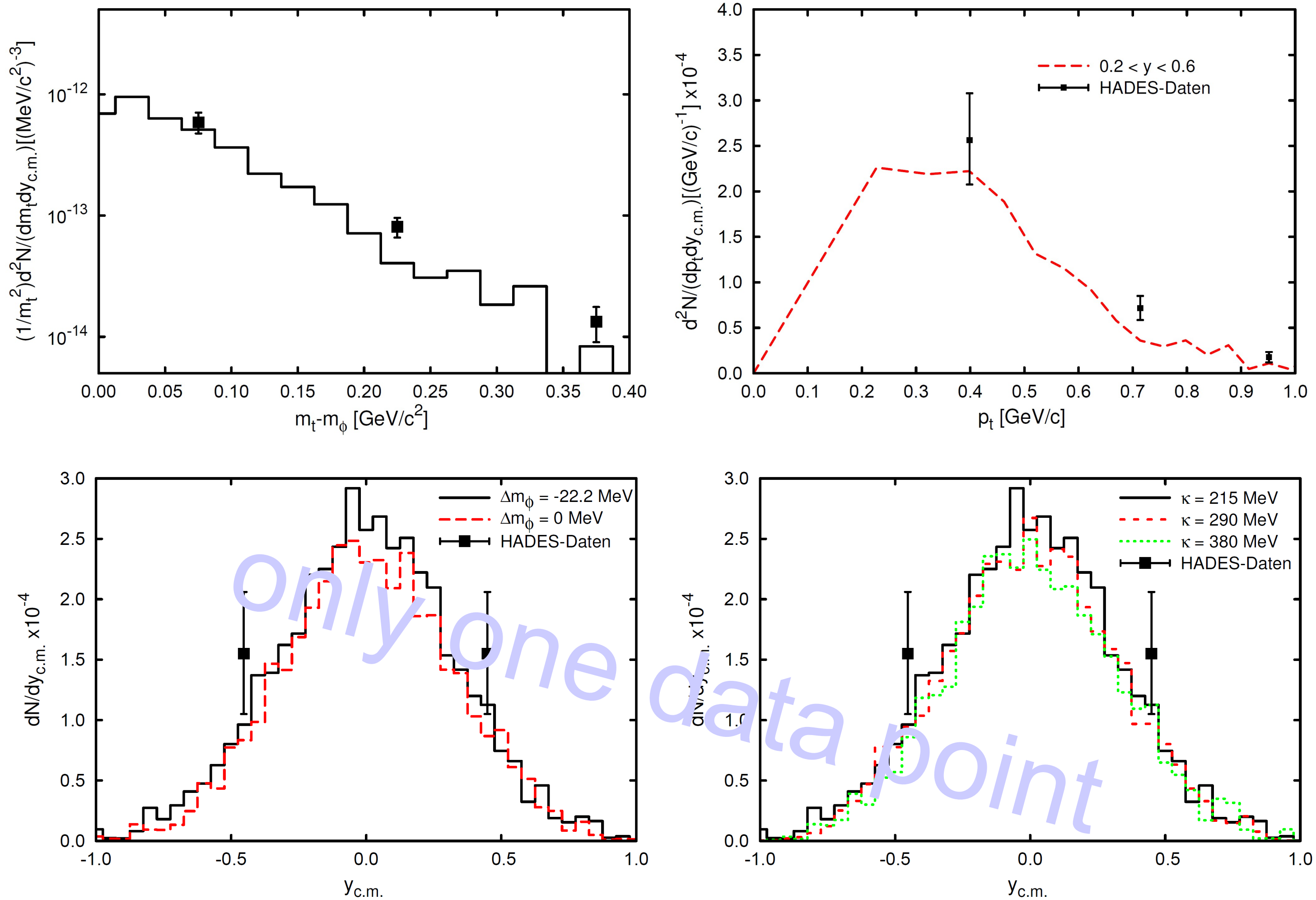
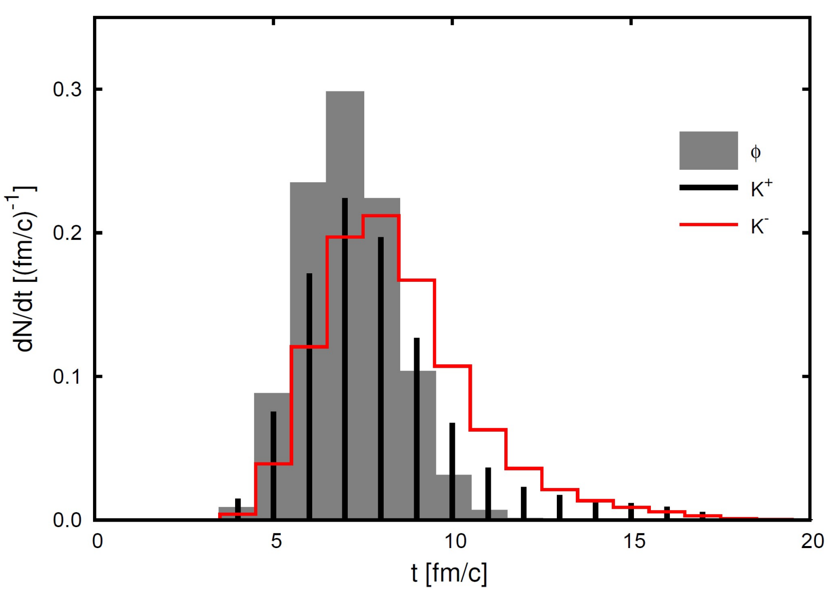
Φ mesons?

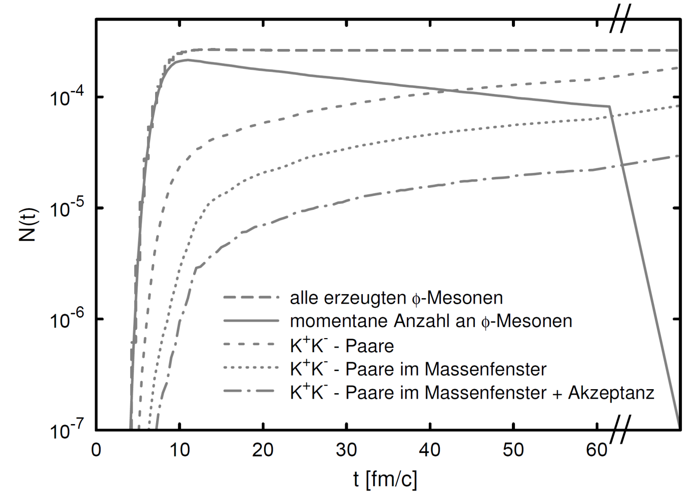


$(1/m_t^2)d^2N/(dm_t dy_{c.m.})[(MeV/c^2)^{-3}]$
m_t-m_ϕ [GeV/c^2]
$d^2N/(dp_t dy_{c.m.})[(GeV/c)^{-1}]$ x10^{-4}
0.2 < y < 0.6
HADES-Daten
p_t [GeV/c]
$dN/dy_{c.m.}$ x10^{-4}
Δm_ϕ = -22.2 MeV
Δm_ϕ = 0 MeV
HADES-Daten
$y_{c.m.}$
κ = 215 MeV
κ = 290 MeV
κ = 380 MeV
HADES-Daten
$y_{c.m.}$
only one data point

(9)

time evolution



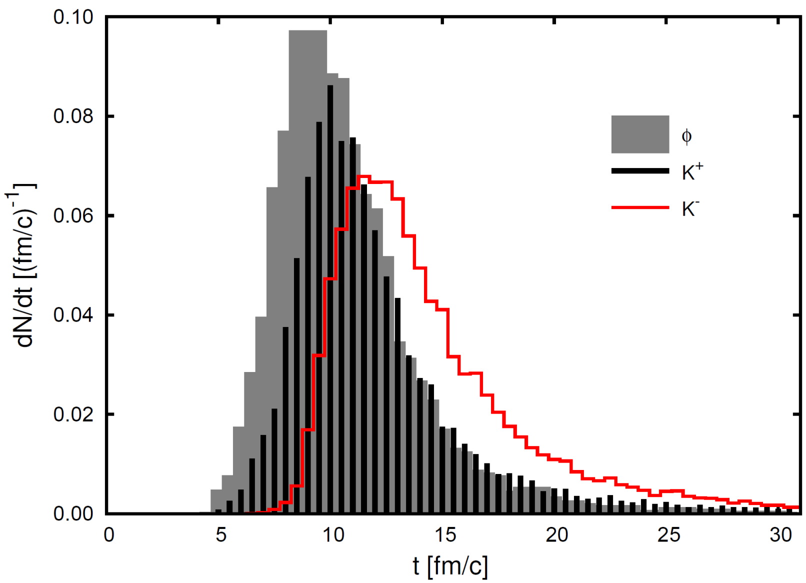


Φ decay has to be considered

production

↓

freeze-out

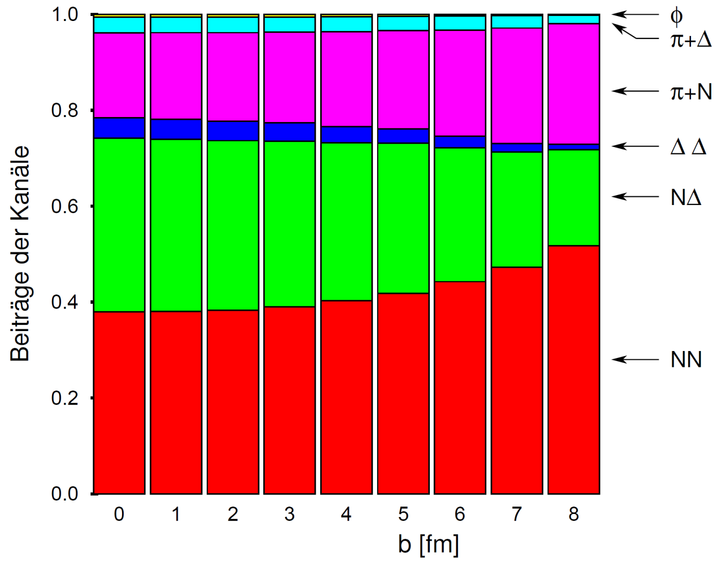


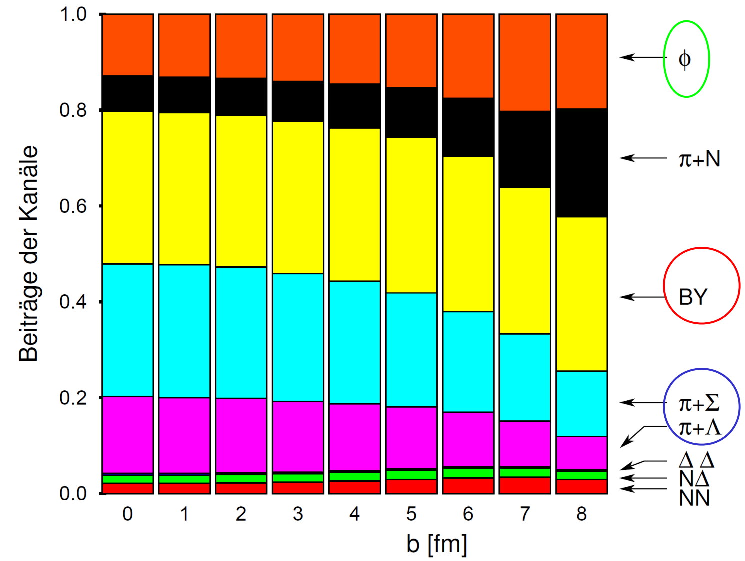
late particle production

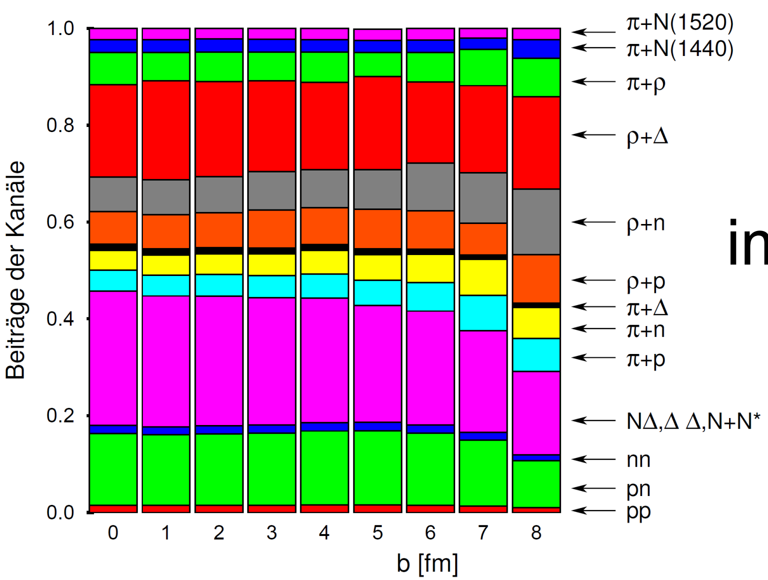
↓

sensitive to compressibility?

Centrality and individual channels







weak
impact parameter
dependence

$$\pi Y \leftrightarrow K^- N$$

$$\left.\begin{matrix} NY \\ \Delta Y \end{matrix}\right\} \to N N K^-$$

$$\phi \to K^+ K^-$$

AA | HADES

reactions

KEK

pA | **ANKE**

Polyanskiy et al.
nucl-ex/1008.0232 (2010)

absorptive ΦN interaction in p (2.83 GeV) + C, Cu, Ag and Au

Φ production:

no subthreshold prod.

no Fermi-momenta

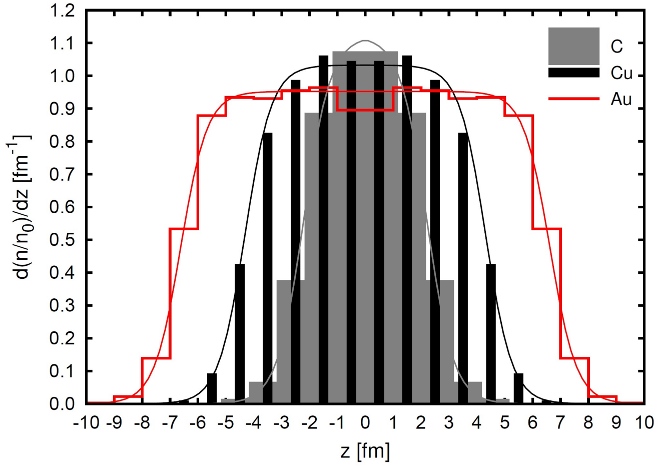
Glauber model

$$\sigma_{pA\to\phi X} = \sigma_{pN\to\phi X} \int d^2b \int_{-\sqrt{R^2-b^2}}^{\sqrt{R^2-b^2}} dz\, n(\vec{b},z)$$
$$\times \exp\left\{ -\sigma_{pN}^{\rm tot} \int_{-\sqrt{R^2-b^2}}^{z} dz'\, n(\vec{b},z') - \sigma_{\phi N}^{\rm tot} \int_{z}^{\sqrt{R^2-b^2}} dz'\, n(\vec{b},z') \right\}$$

p-attenuation

Φ-absorption

$$\boxed{T_A = \frac{\sigma_{pA\to\phi X}}{A} \frac{C}{\sigma_{pC\to\phi X}}}$$

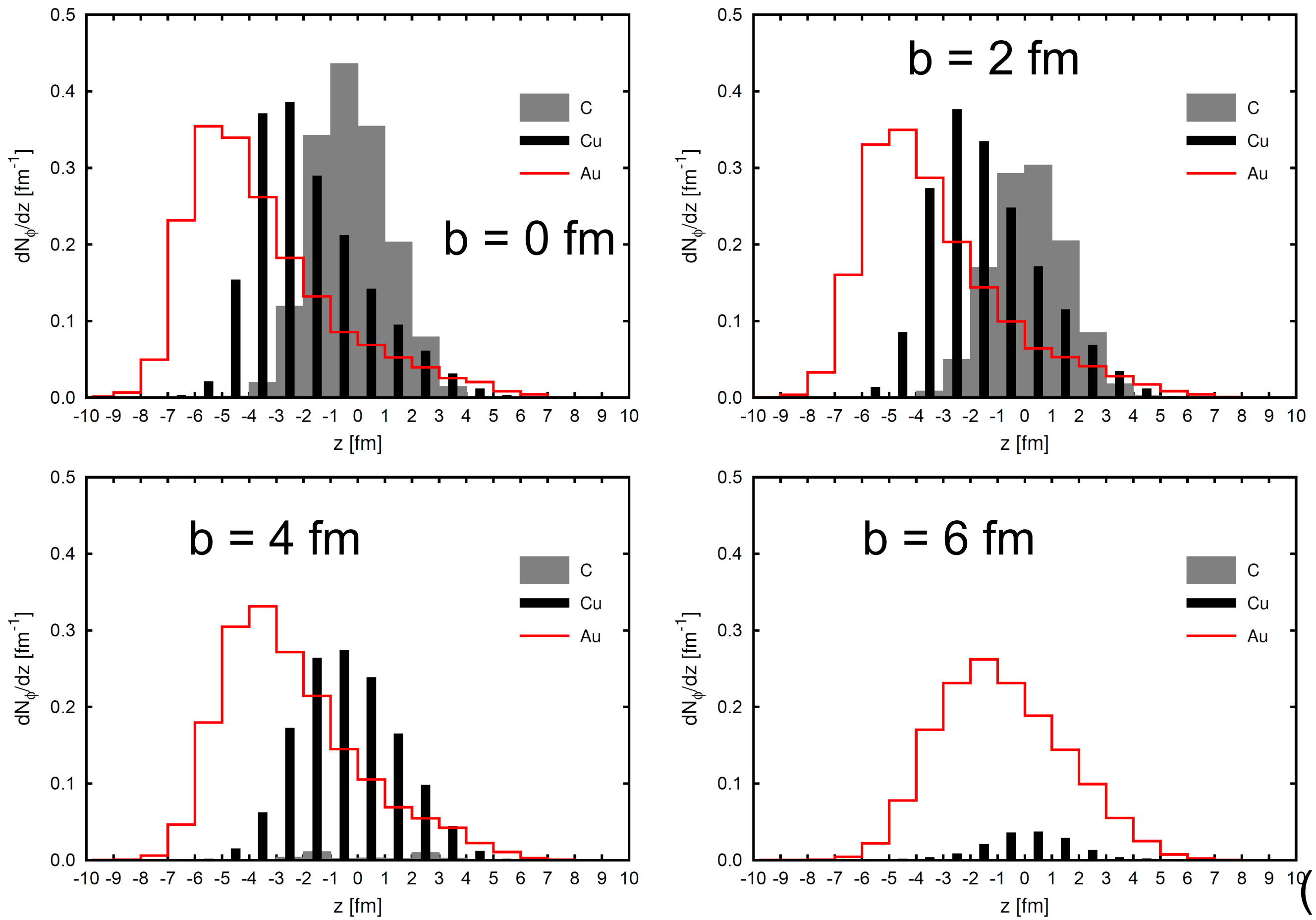


density distribution: Woods-Saxon

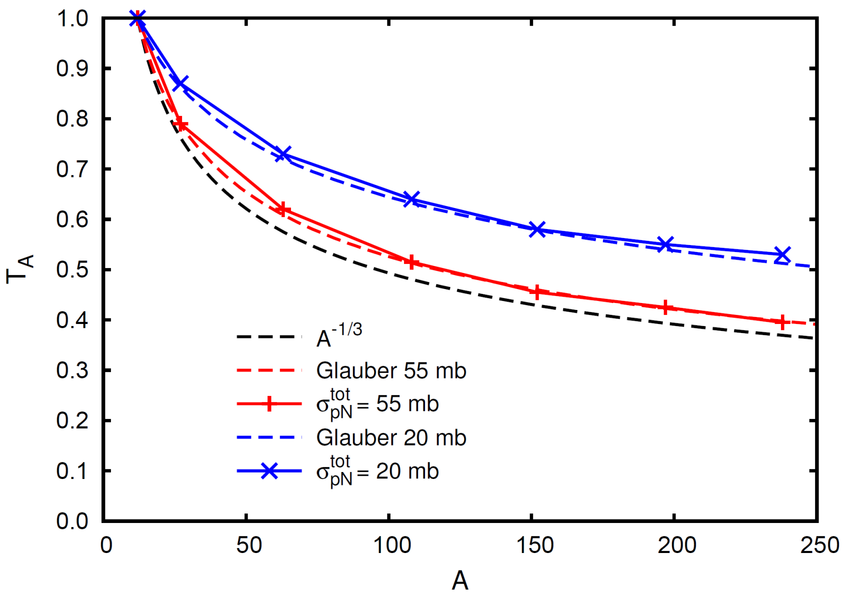
$$R = r_0 A^{1/3}$$

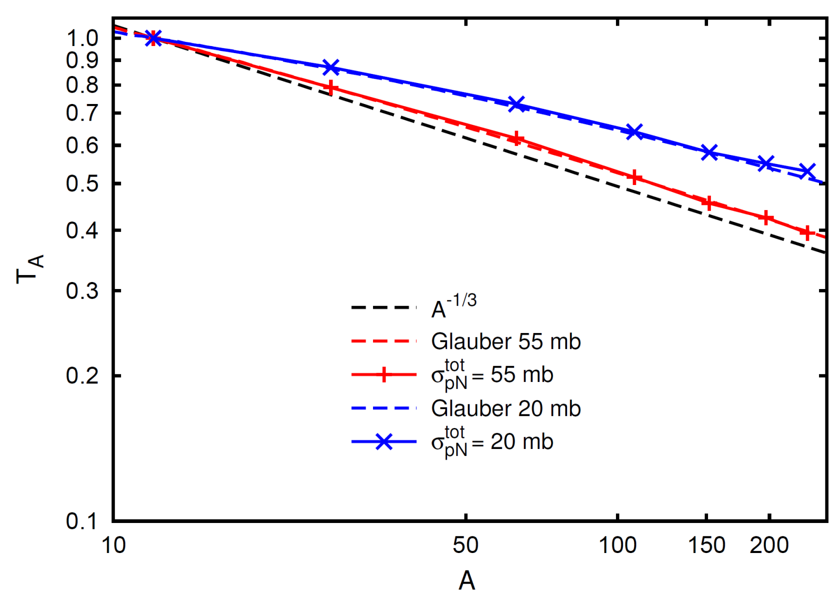
$$R(\mathrm{C,\ Cu,\ Au}) = (2.75,\ 4.77,\ 6.98)\ \mathrm{fm}.$$

Φ production in corona



check consistency with Glauber

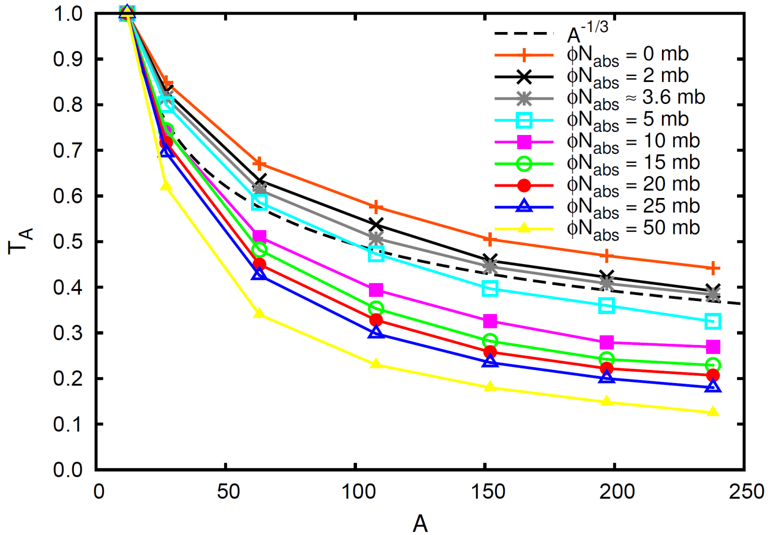


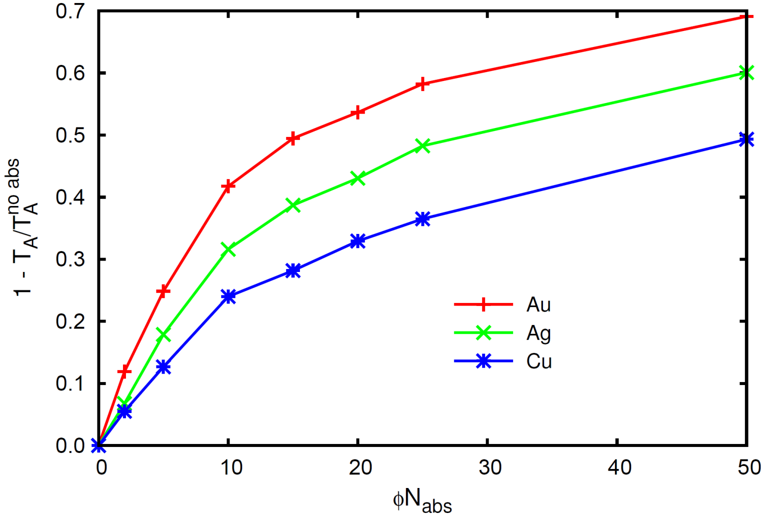


BUT 4 no's:

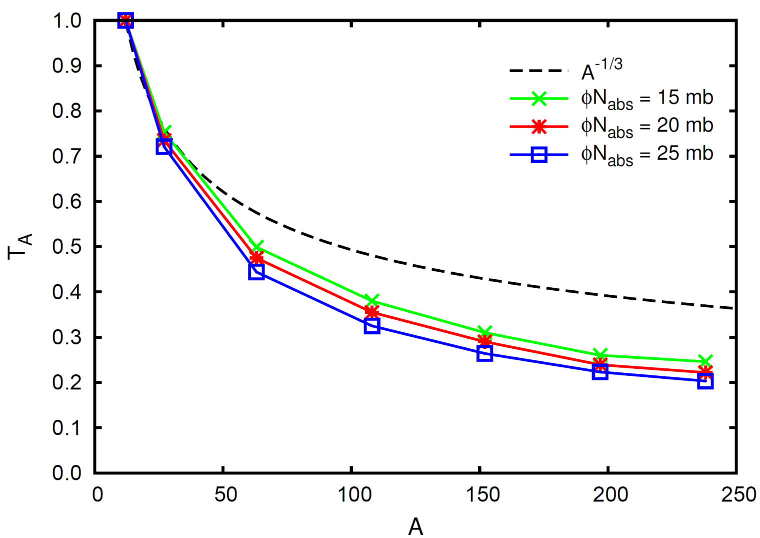
- **no isospin asymmetry**
- **no secundary channels**
- **no absorption**
- **no ANKE acceptance**

+ absorption

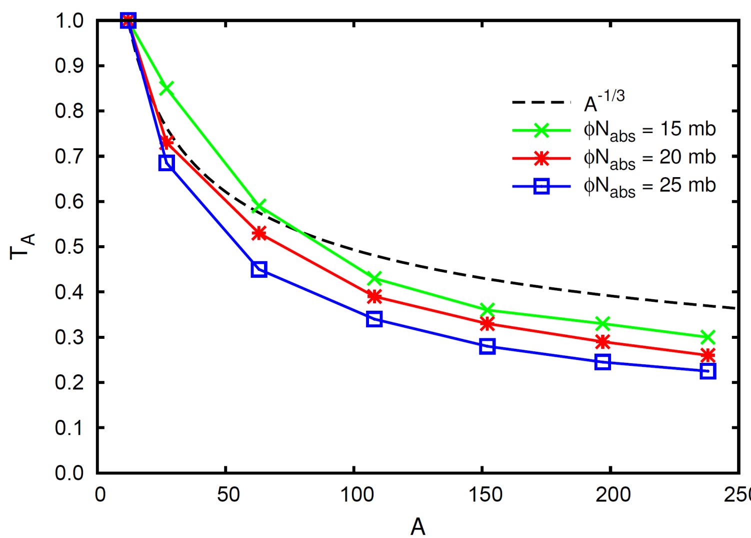




+ isospin asymmetry

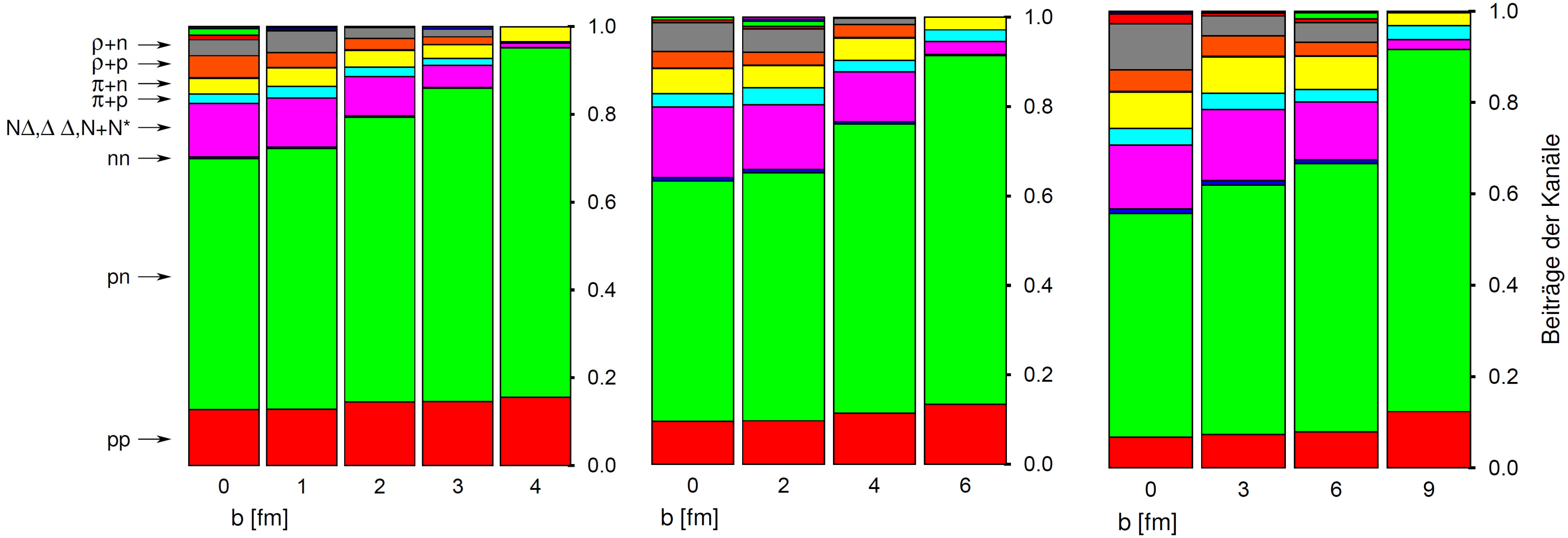


+ secundary channels



Kaptari & Kämpfer EPJ ‘05

Channels and centrality

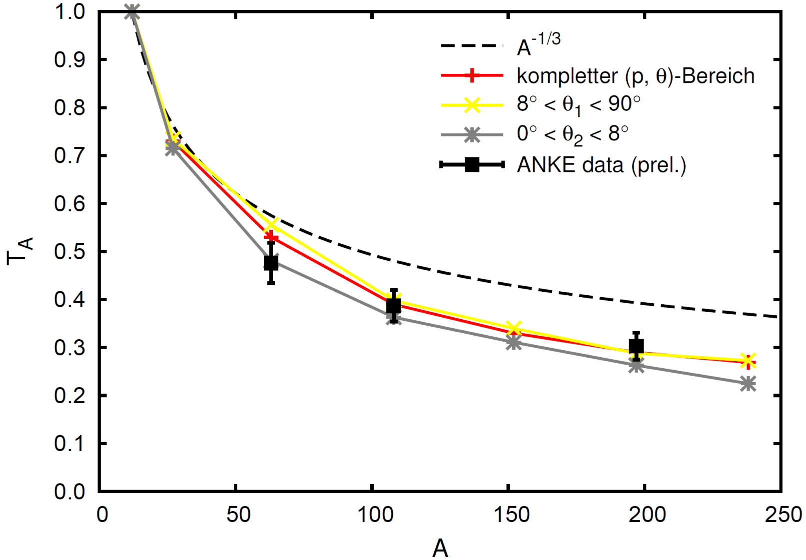


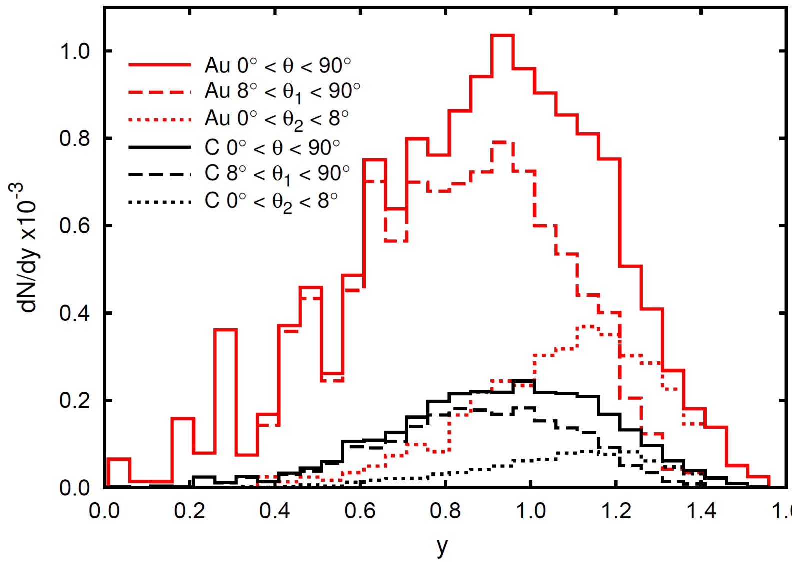
p + light → p + heavy

impact parameter dependent

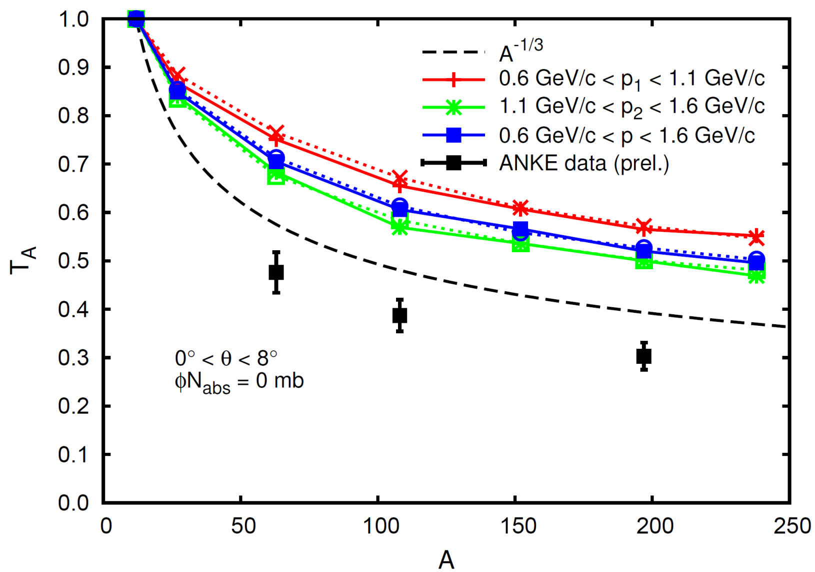
ANKE acceptance

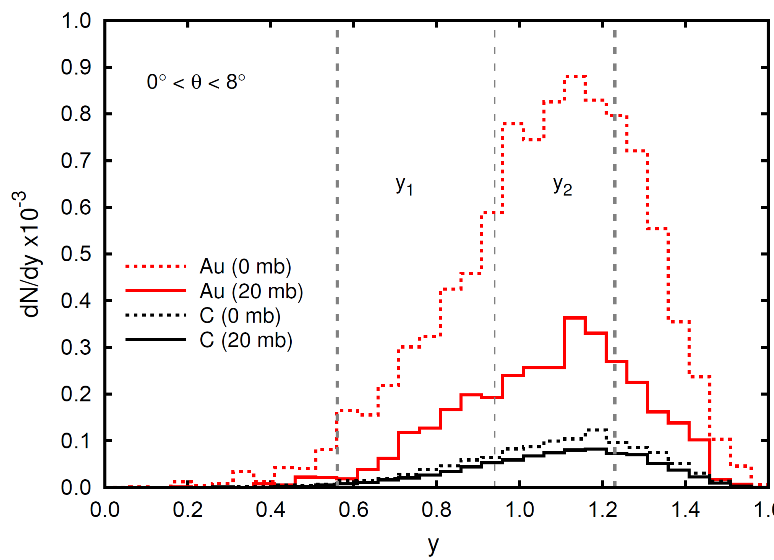
$0^\circ < \theta_\phi < 8^\circ$





+ $0.6\ \mathrm{GeV/c} < p_\phi < 1.6\ \mathrm{GeV/c}$

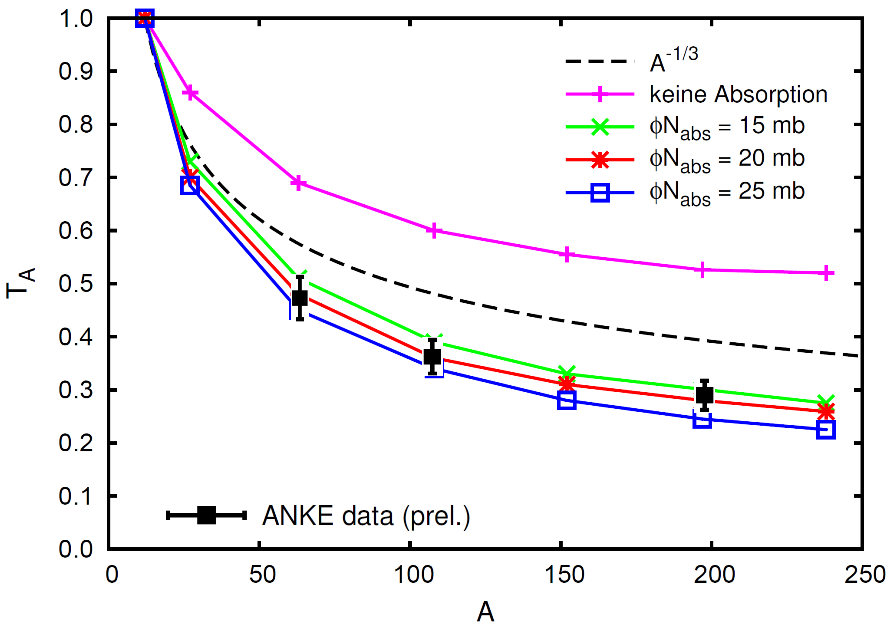


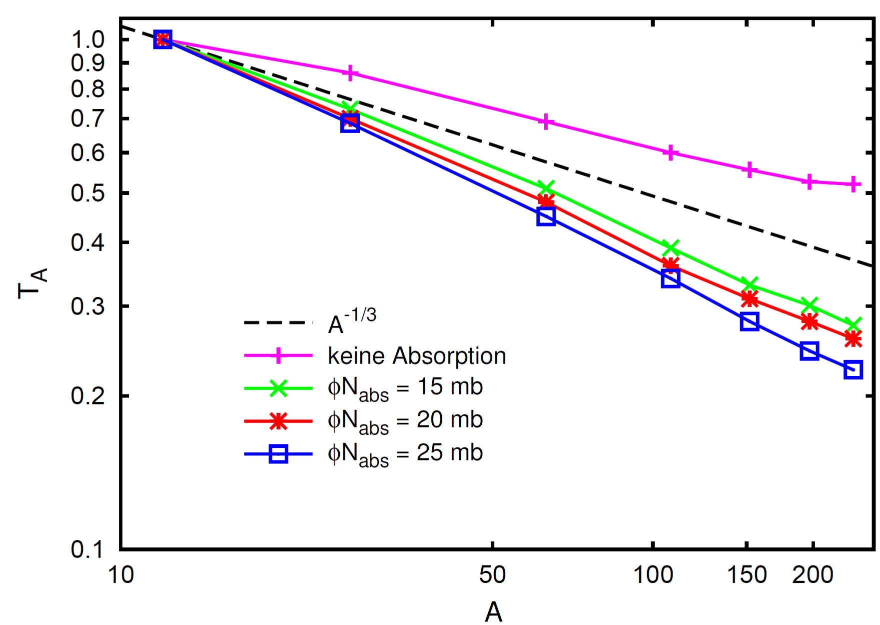


w/ abs. →

[HS, to be published]

RESULT:

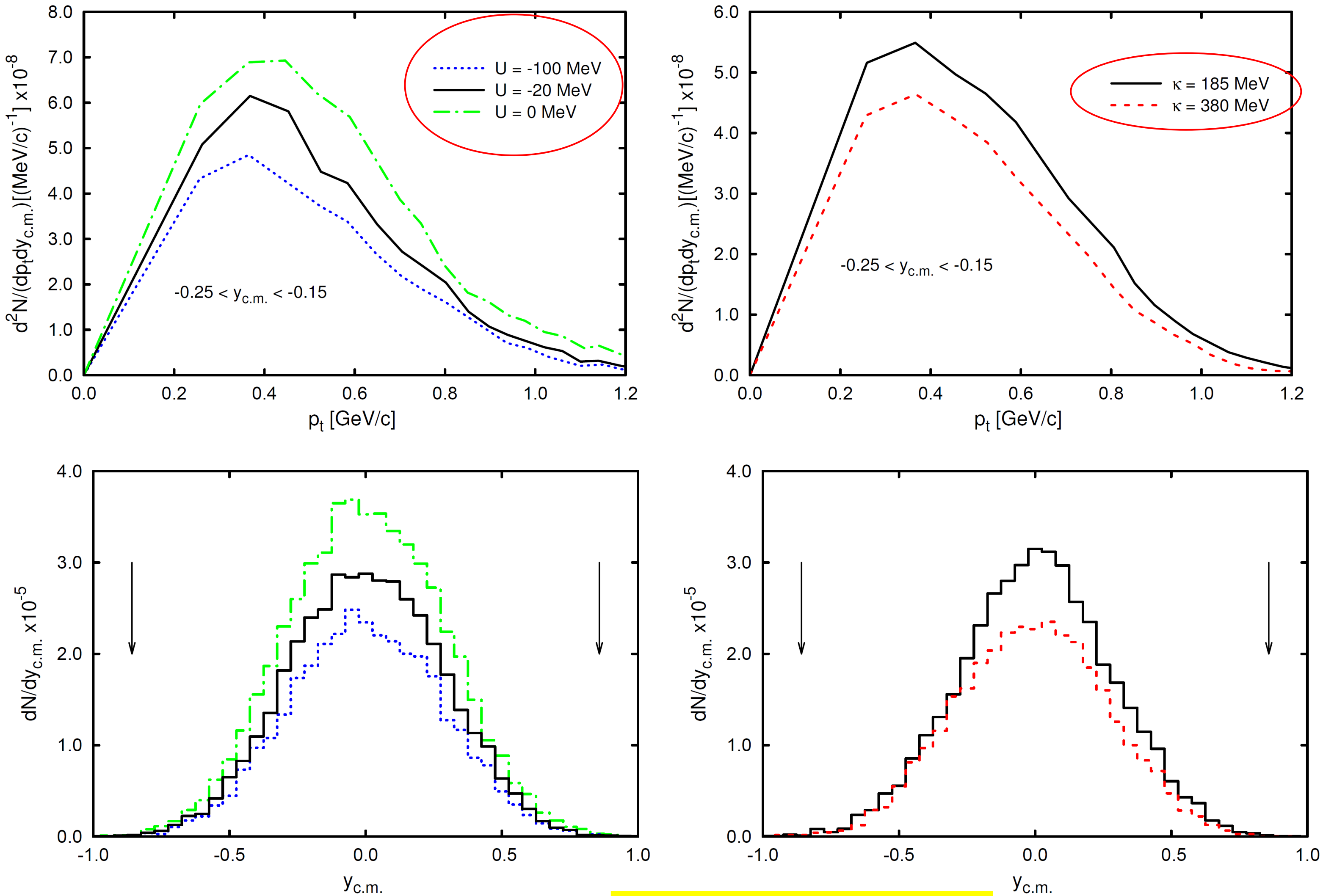




$\longrightarrow$ best with $\sigma_\phi^{\text{abs}} = 18 \pm 3 \;\text{mb}$

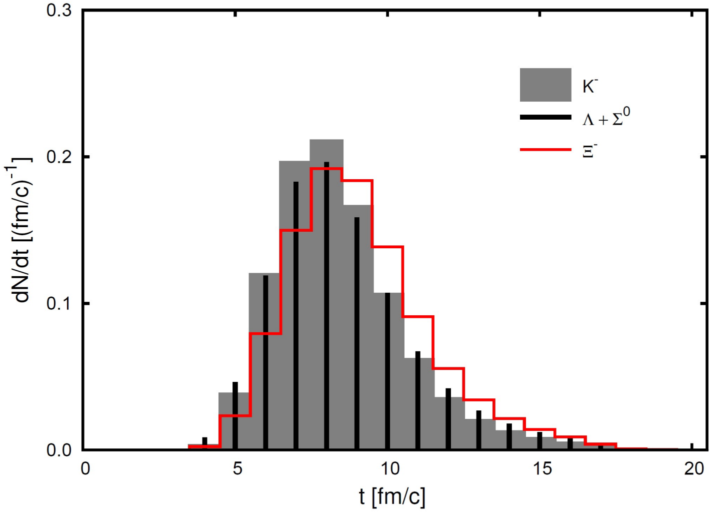
single absorption is able to describe the ANKE data set

real double-strange: Ξ^- (dss) in Ar (1.756 AGeV) + KCl

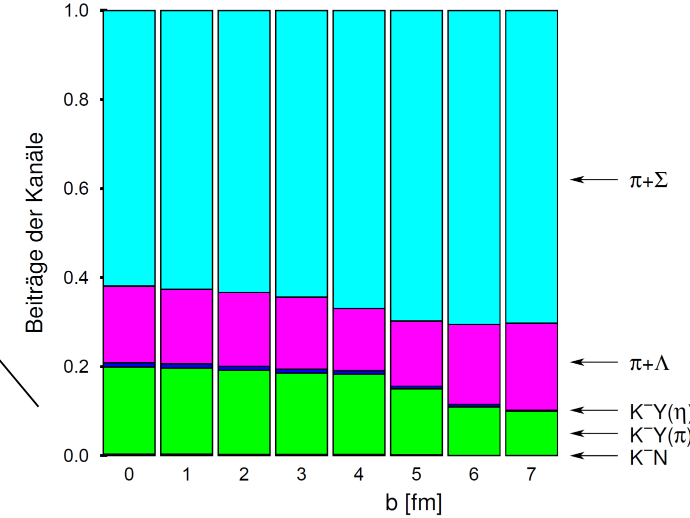


sensitive to in-medium modifications?

no reliable data!



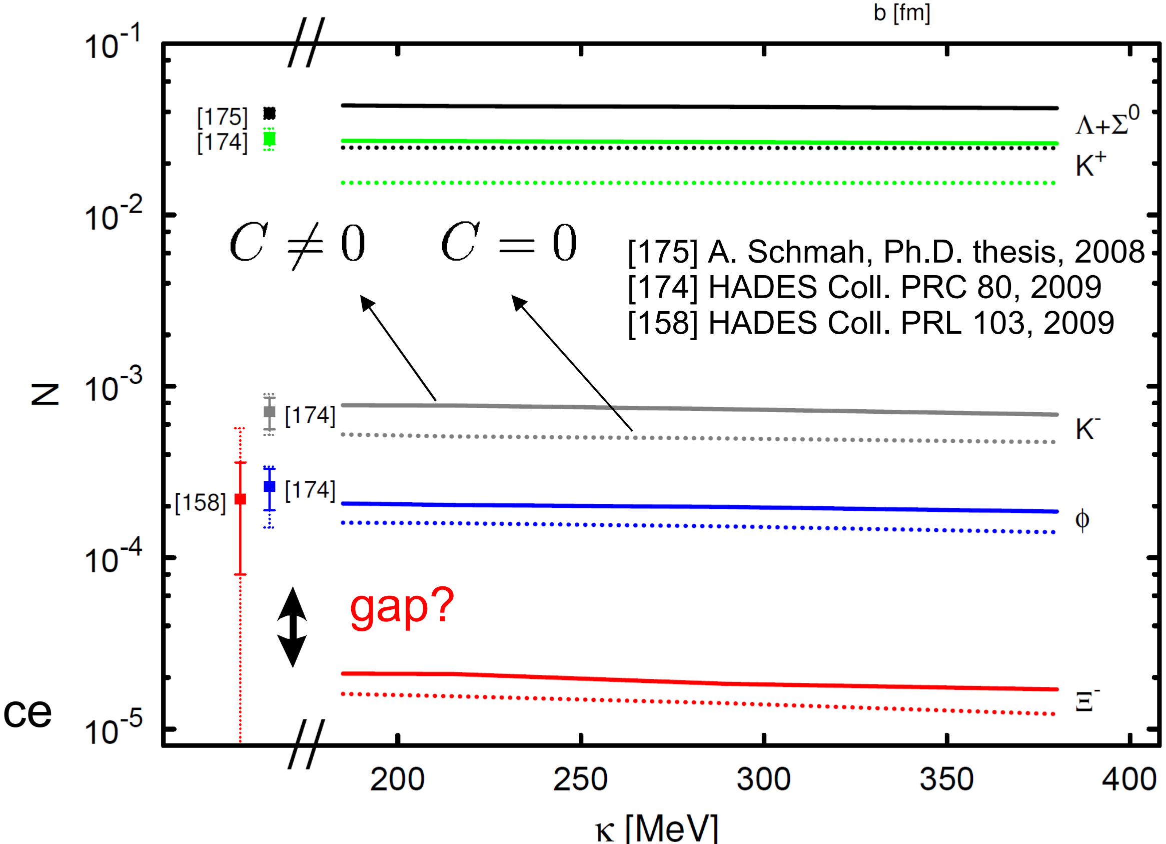
almost no
b dependence



$S = N^{-1} dN/d\kappa$ in GeV^{-1}

	$C \neq 0$	$C = 0$
$\Lambda + \Sigma^0$	-0.18	-0.03
K^+	-0.17	-0.02
K^-	-0.64	-0.54
ϕ	-0.55	-0.65
Ξ^-	-1.10	-1.39

evidence for EoS dependence



[HS, to be published]

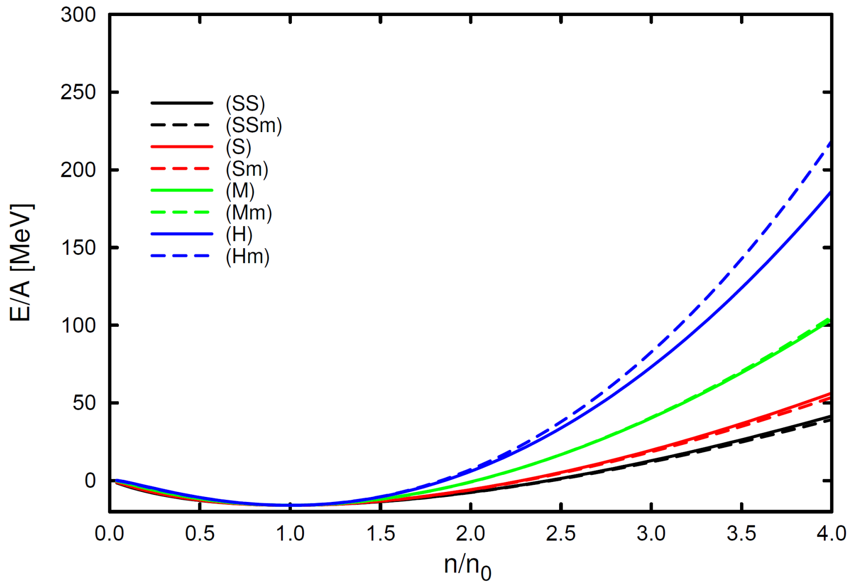
Summary

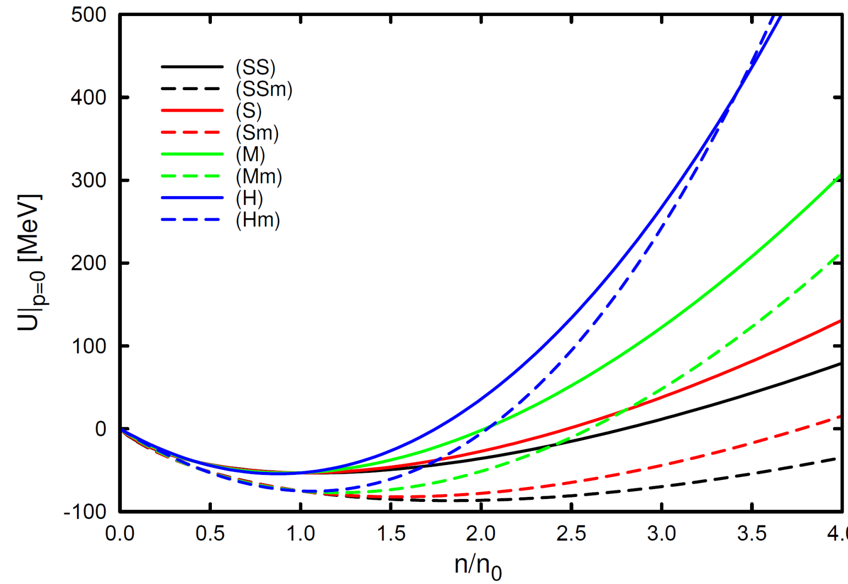
- production of K^+, K^-, Φ and Ξ^-
  (in-medium modifications & EoS)
- comparison with HADES & ANKE data
- Φ puzzle

Wishlist

- Φ decay in dileptons
- K^0_S potential?
- $K^- NN \rightarrow YN$ absorption modes
- Ξ^- and triple-strange Ω^-
- heavier systems
- ANKE: isospin dependent Φ absorption

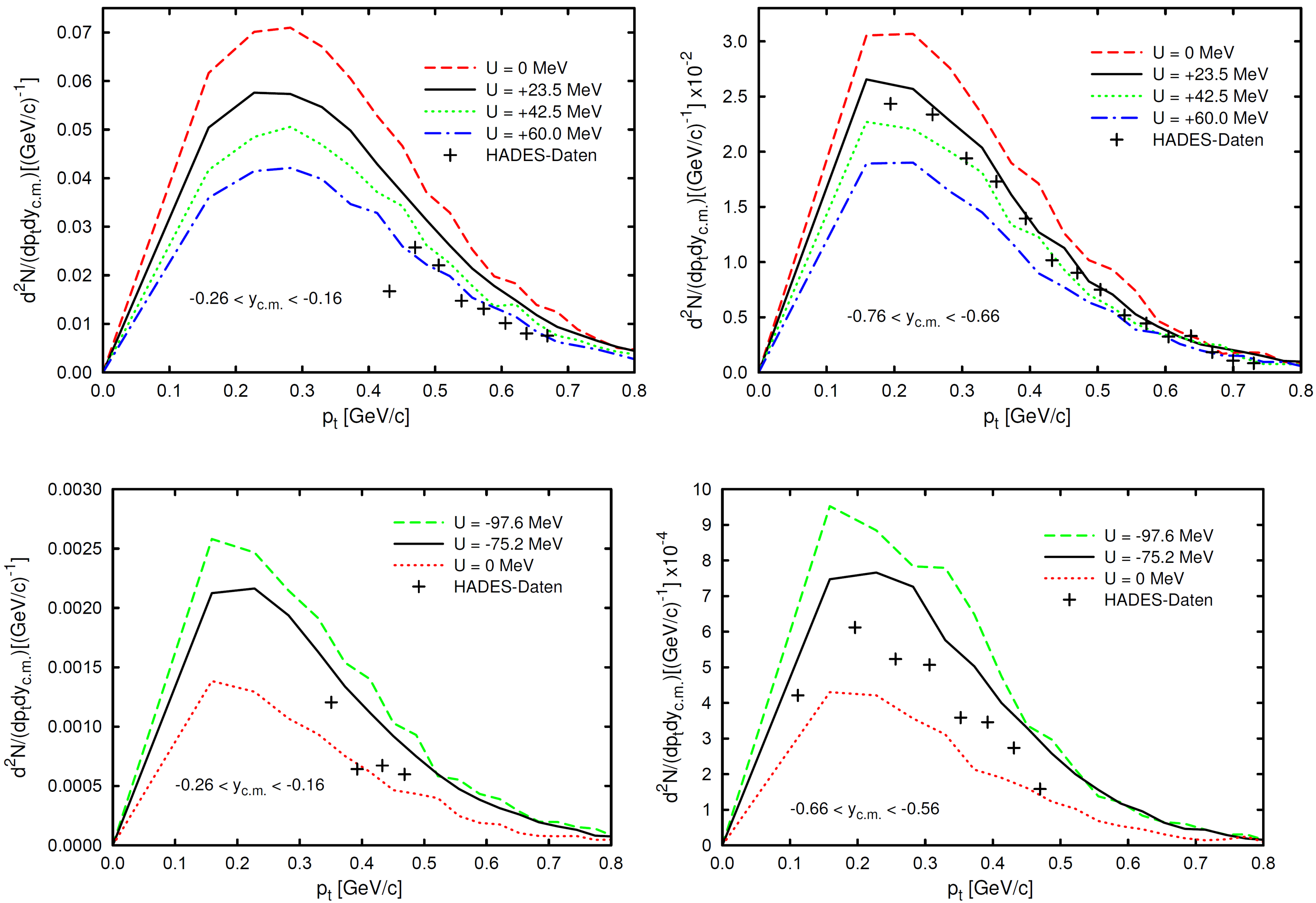
$$\delta \leq b_{\max} = \sqrt{\frac{\sigma_{ij}^{\mathrm{tot}}(\sqrt{s})}{\pi}} \qquad U_{K^-} = n\left(a + be^{-cp_{K^-}(\mathrm{GeV/c})^{-1}}\right)$$



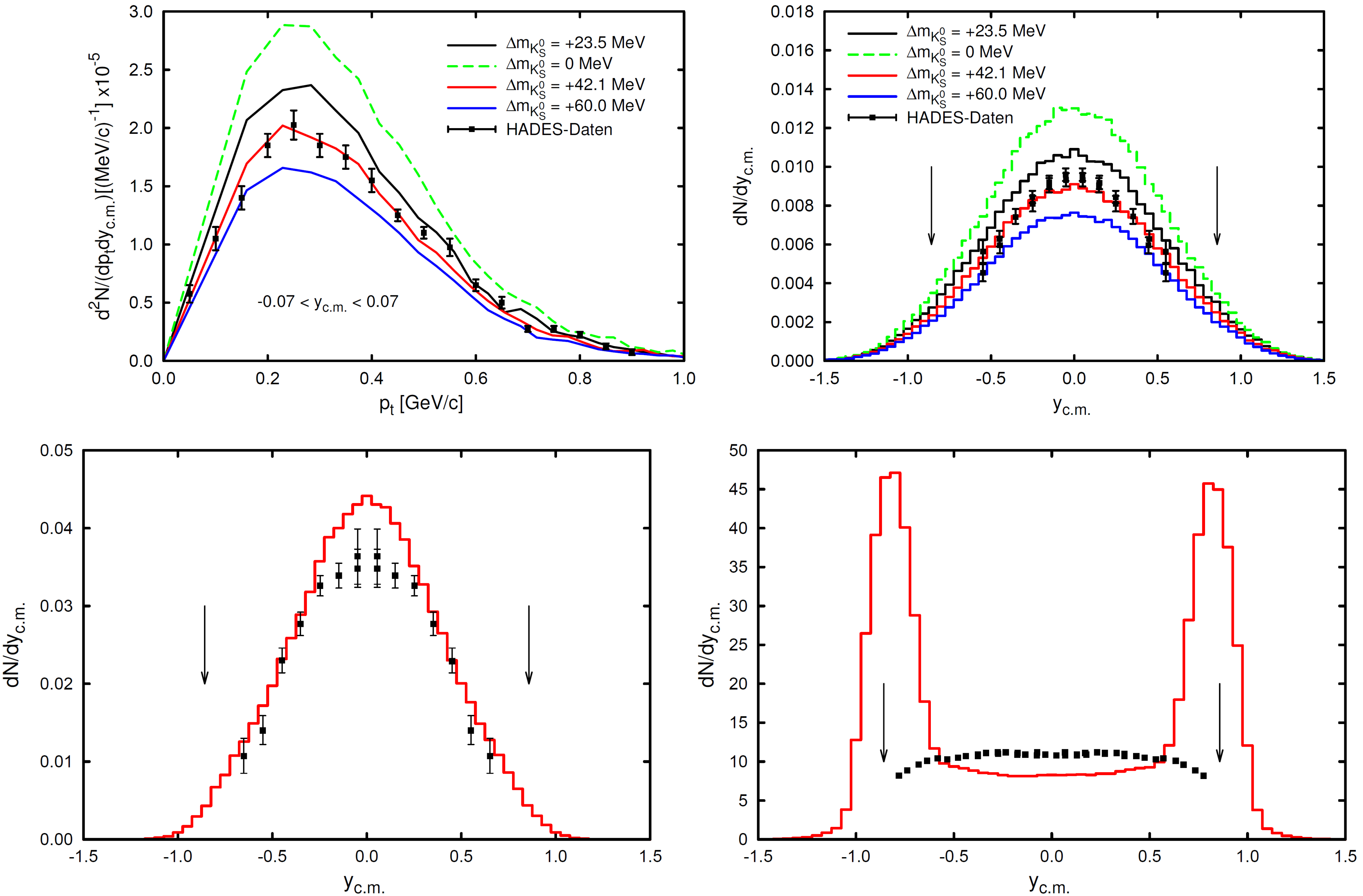


$$U(n/n_0) = A\frac{n}{n_0} + B\left(\frac{n}{n_0}\right)^{\tau} + \frac{C\Lambda^3}{\pi^2 n_0}\left[\frac{p_F^2 + \Lambda^2 - p^2}{2p\Lambda}\ln\frac{(p+p_F)^2+\Lambda^2}{(p-p_F)^2+\Lambda^2}\right.$$

$$\left. + \frac{2p_F}{\Lambda} - 2\left(\arctan\left(\frac{p+p_F}{\Lambda}\right) - \arctan\left(\frac{p-p_F}{\Lambda}\right)\right)\right].$$

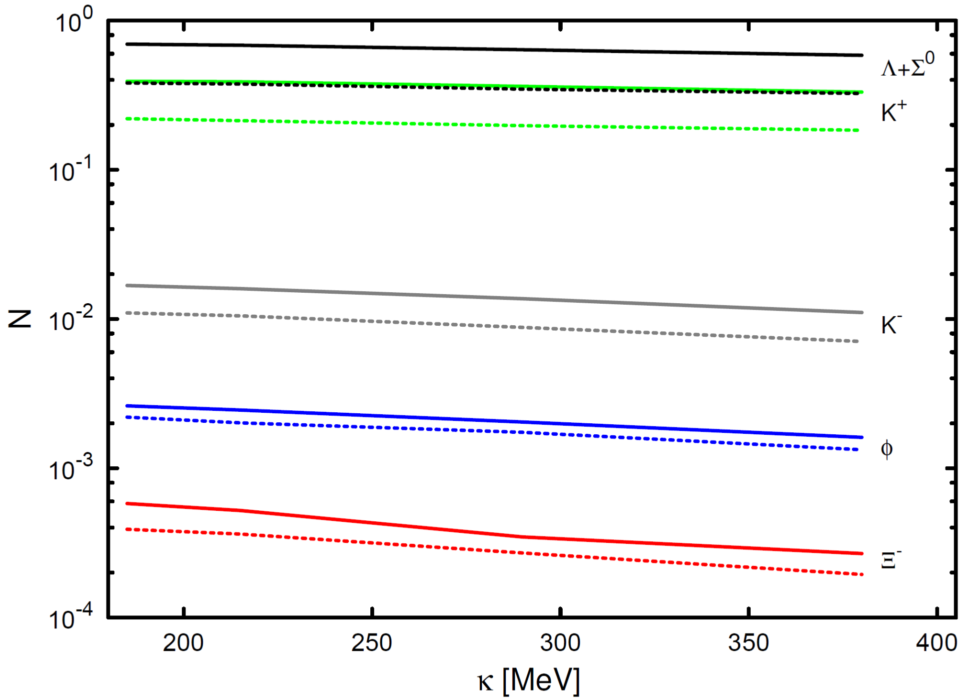


d²N/(dp_t dy_c.m.)[(GeV/c)⁻¹]
p_t [GeV/c]
U = 0 MeV
U = +23.5 MeV
U = +42.5 MeV
U = +60.0 MeV
HADES-Daten
-0.26 < y_c.m. < -0.16
d²N/(dp_t dy_c.m.)[(GeV/c)⁻¹] x10⁻²
-0.76 < y_c.m. < -0.66
U = -97.6 MeV
U = -75.2 MeV
U = 0 MeV
HADES-Daten
-0.26 < y_c.m. < -0.16
d²N/(dp_t dy_c.m.)[(GeV/c)⁻¹] x10⁻⁴
-0.66 < y_c.m. < -0.56

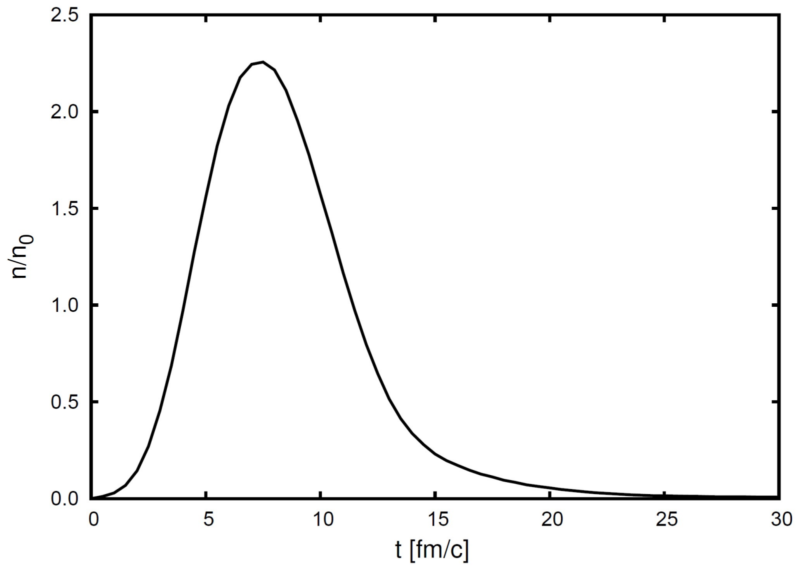


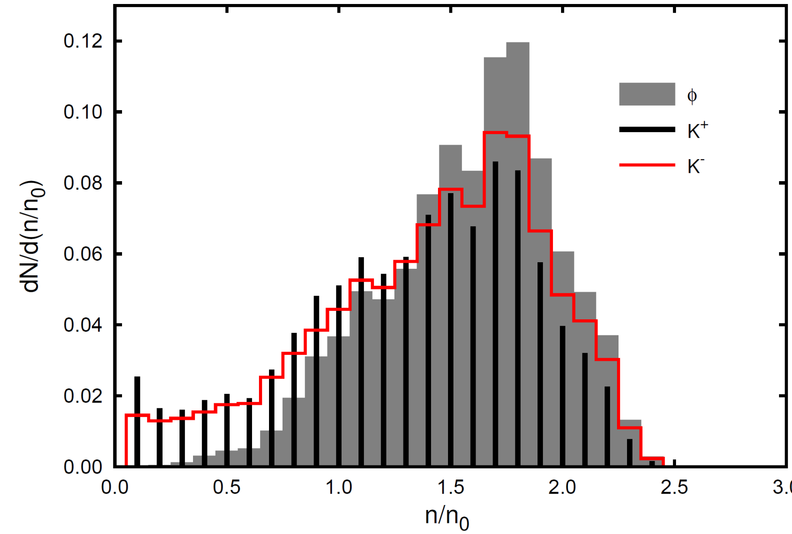
Δm_KS0 = +23.5 MeV
Δm_KS0 = 0 MeV
Δm_KS0 = +42.1 MeV
Δm_KS0 = +60.0 MeV
HADES-Daten
-0.07 < y_c.m. < 0.07
d²N/(dp_t dy_c.m.)[(MeV/c)^-1] x10^-5
p_t [GeV/c]
dN/dy_c.m.
y_c.m.

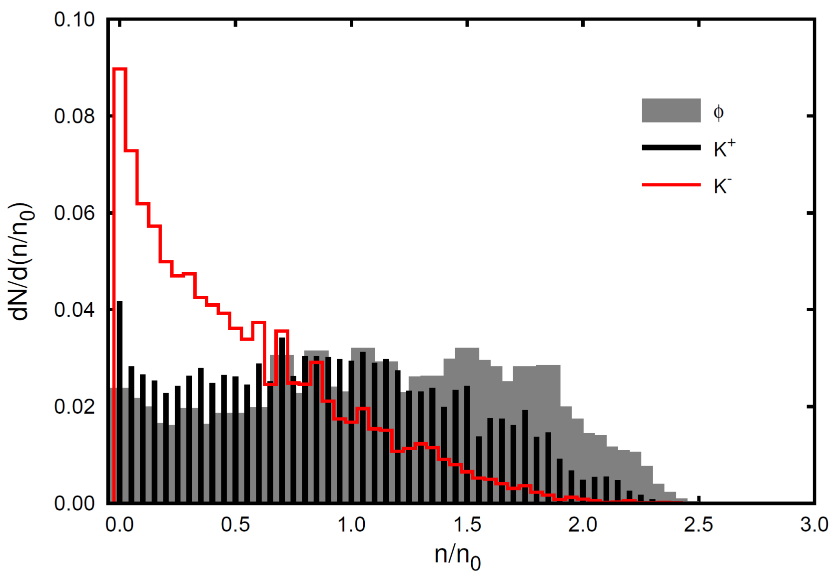
	Multiplizität
K^+	2.7×10^{-2}
K_S^0	1.4×10^{-2}
K^-	7.8×10^{-4}
ϕ	2.2×10^{-4}
Ξ^-	2.1×10^{-5}
$\Lambda + \Sigma^0$	3.9×10^{-2}
π^-	4.2×10^0
π^+	3.8×10^0

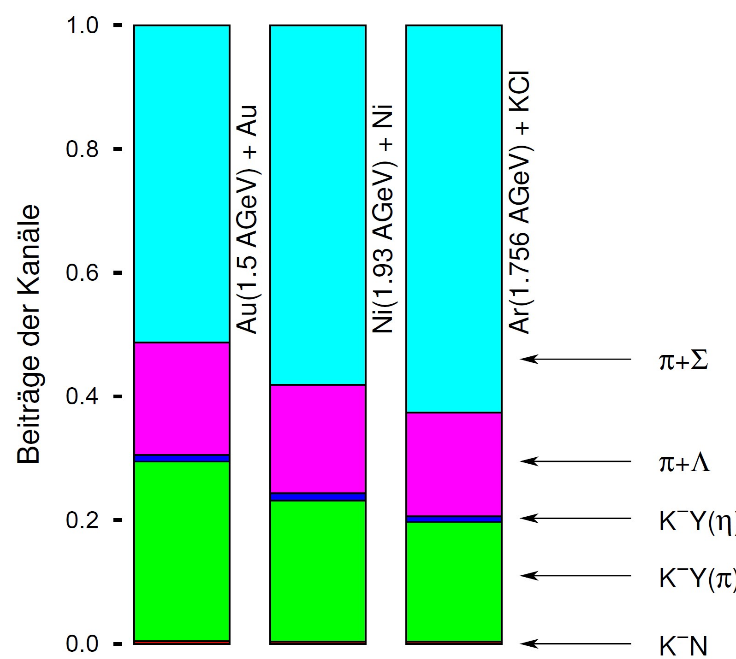


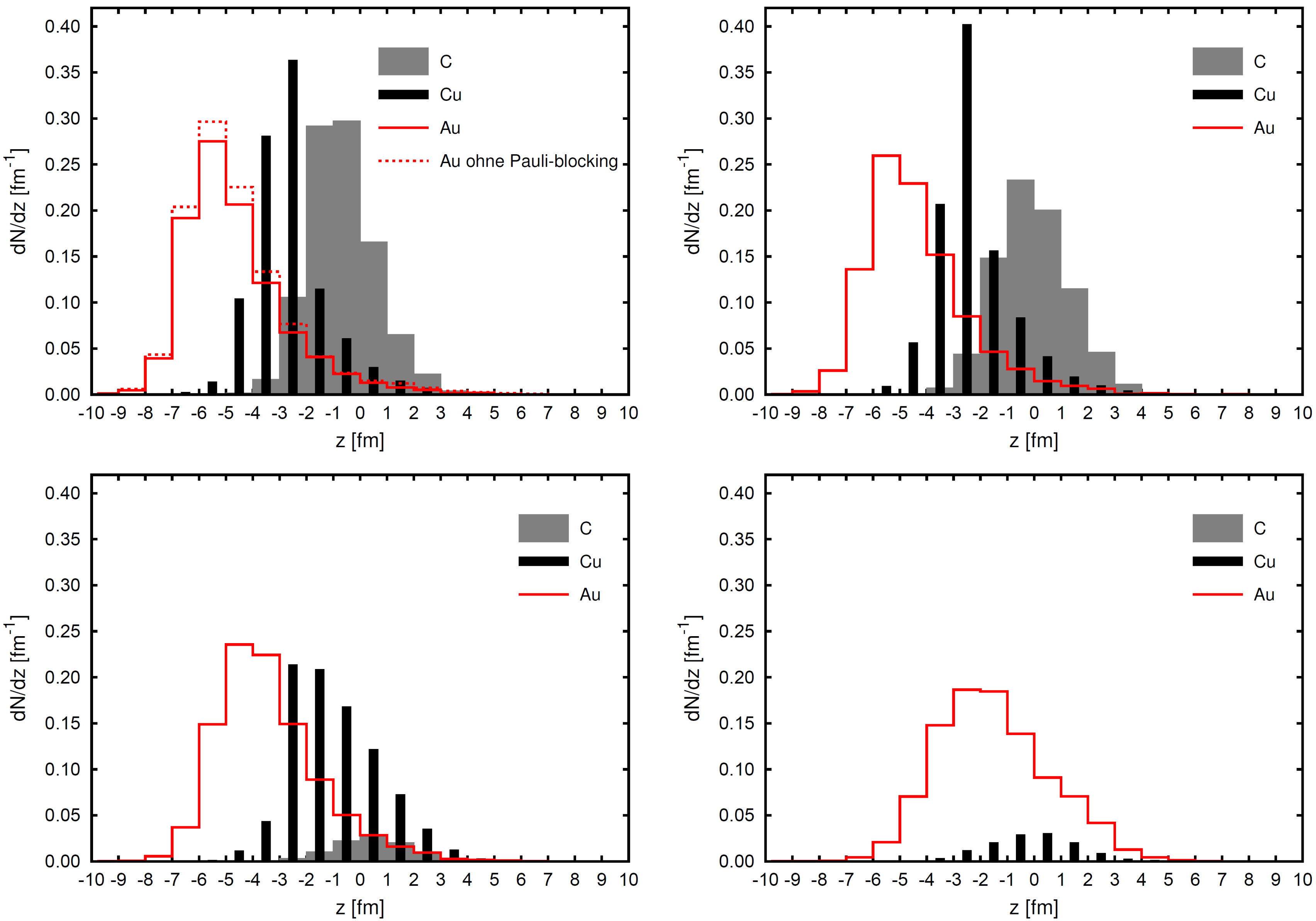
for Au (1.50 AGeV) + Au

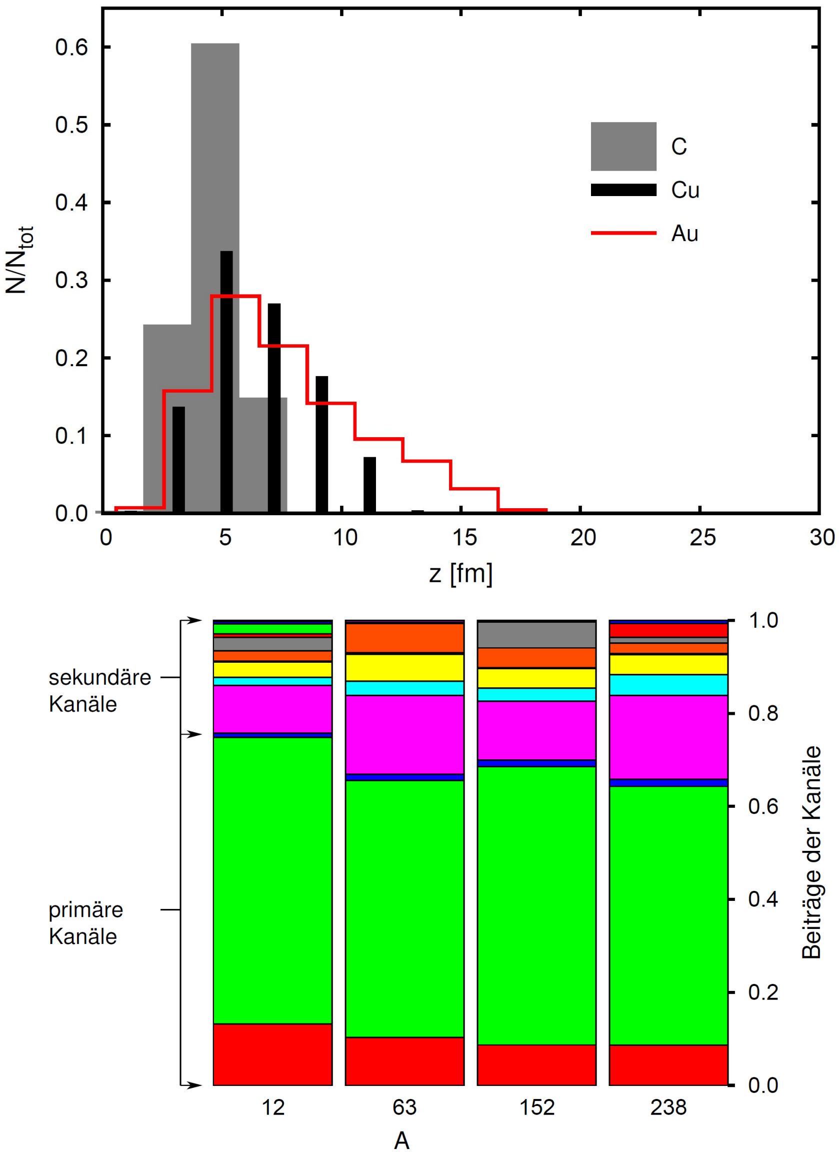

n/n0
t [fm/c]


dN/d(n/n0)
n/n0
ϕ
K+
K-

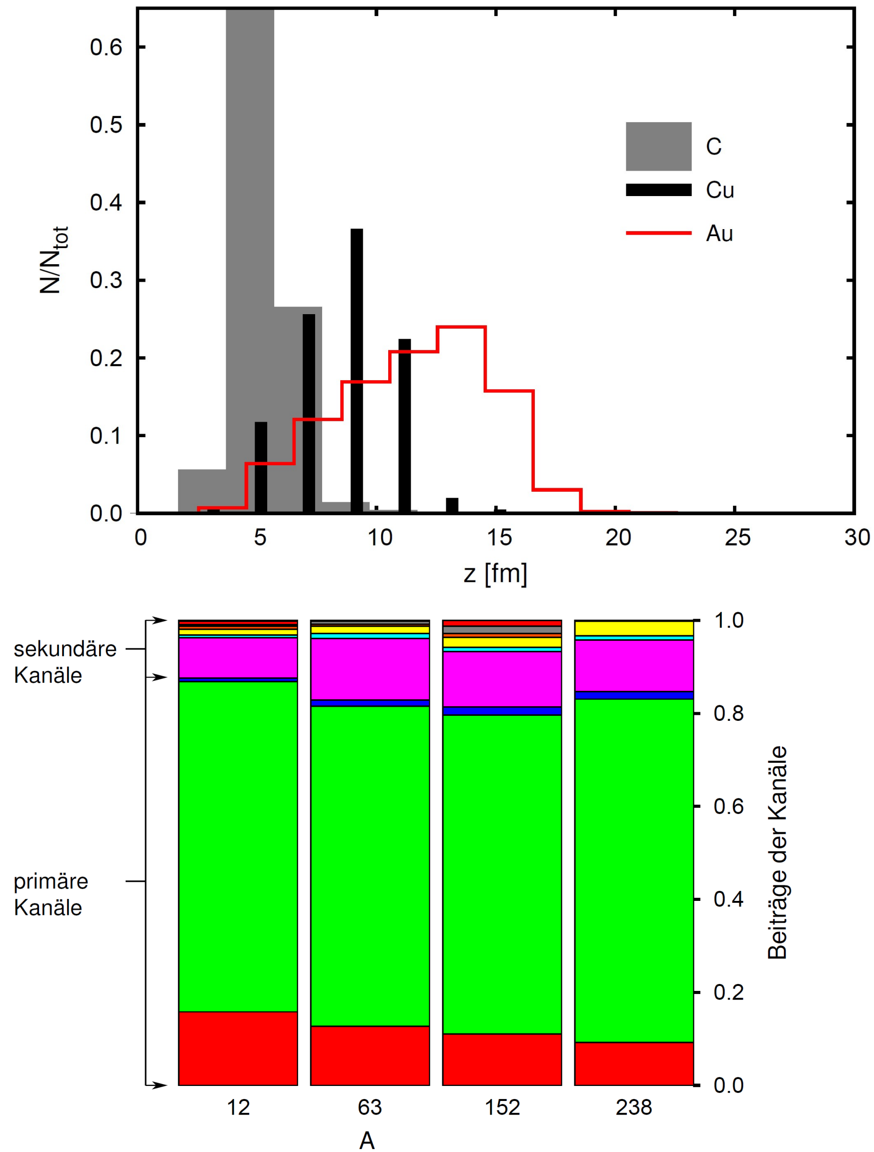

dN/d(n/n0)
n/n0
ϕ
K+
K-


Beiträge der Kanäle
Au(1.5 AGeV) + Au
Ni(1.93 AGeV) + Ni
Ar(1.756 AGeV) + KCl
π+Σ
π+Λ
K−Y(η)
K−Y(π)
K−N


C
Cu
Au
Au ohne Pauli-blocking
dN/dz [fm^{-1}]
z [fm]



slow phi‘s



fast phi‘s