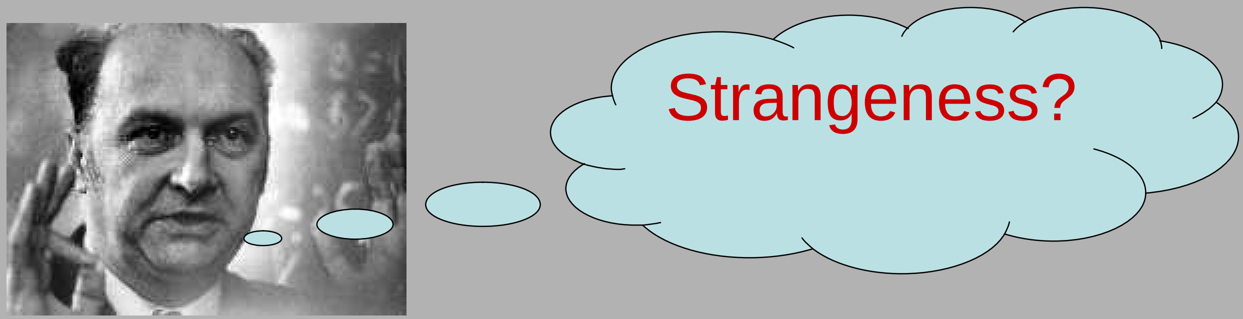


Multi-Strangeness in Heavy-ion Collisions

Evgeni E. Kolomeitsev *(University of Matej Bel, Slovakia)*

work in collaboration with B.Tomasik, D.N. Voskresensky, and I. Melo

- Why do we love strangeness?
- Minimal statistical model for strangeness
- Strangeness at AGS-SPS-RHIC
- Hidden strangeness (Φ-meson)
- Ξ puzzle at HADES
- Strangeness at LHC

September 17, 2014

Strangeness is interesting because

- It is a tag on a hadron, saying
  that it was not in colliding nuclei but is produced in the course of collision.

- Strange quarks like baryons: K,Λ,Σ,Ξ,Ω,..., anti-strange quarks like mesons K, .

  → strangeness/anti-strangeness separation in baryon-rich matter

- Strangeness is conserved in strong interaction

  → Strangeness production threshold is high,
  → sensitive to possible in-medium effect.
  QGP signal? (Rafelski-Mueller conjecture)

Strangeness is difficult because

- Strangeness production cross sections poorly known
  (new data from HADES on pp, COSY on pn, ANKA)

- Limited exp. information about elementary reactions among strange particles

- Strong couplings among various strange species. Complicated dynamics

Strange particles is nuclear medium

1. Hyperons $E_Y(p) = \sqrt{m_Y^2 + p^2} \longrightarrow \sqrt{(m + S_Y)^2 + p^2} + V_Y$

potential model

scalar and vector potentials

In relativistic mean-field models S and V originates from exchanges of scalar and vector mesons

Usually one relates vector potentials to the potential for nucleons $V_Y = \alpha_Y V_N$

where α_Y is deduced from some quark counting rule

Scalar potentials are fixed by the optical potential $U_Y = S_Y + V_Y$, acting on hyperons in an atomic nucleus

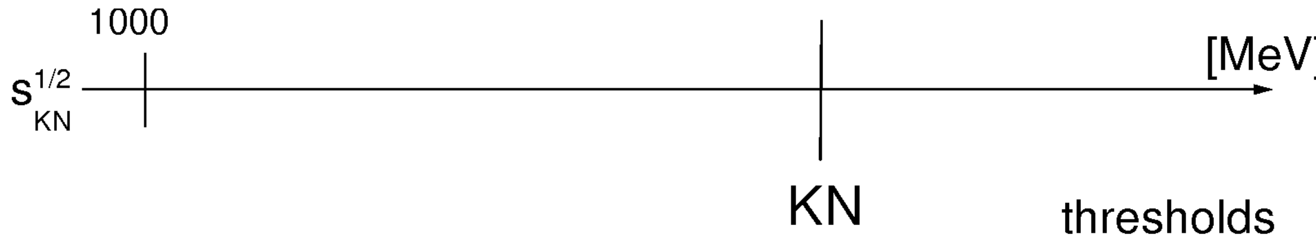
$U_\Lambda = -27\ \mathrm{MeV}$ [Hashimoto, Tamura, Prog.Part.Nucl.Phys. 57, 564 (2006)]

$U_\Sigma = +24\ \mathrm{MeV}$ [Dabrowski, Phys.Rev.C 60, 025205 (1999)]

$U_\Xi = -14\ \mathrm{MeV}$ [Khaustov et al., Phys.Rev.C 61, 054603 (2000)]

Caution: extrapolation of the attractive hyperon potentials in RMF models to higher densities may lead to problems with astrophysical constrains on the neutron star masses!!!

2. anti-strange mesons

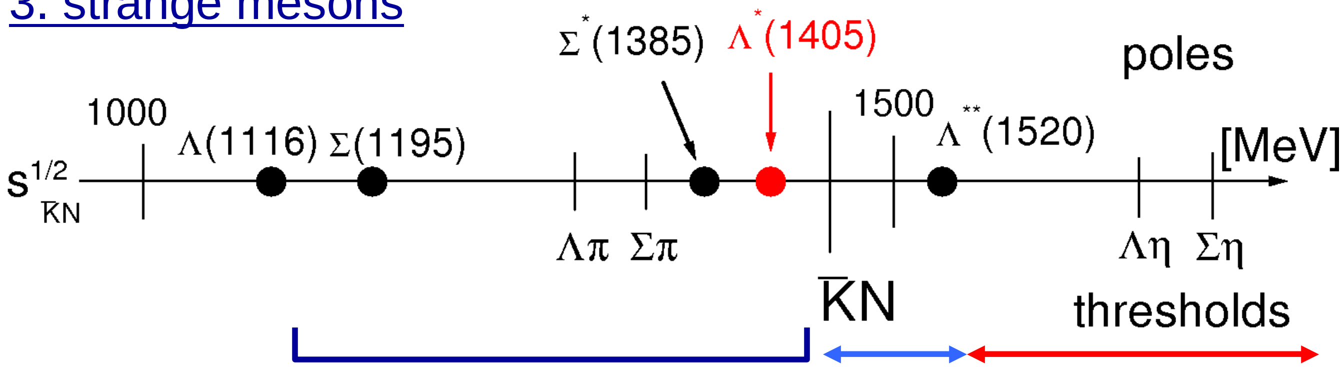


potential model

$$E(p)=\sqrt{m^2+p^2}\longrightarrow\sqrt{(m+S)^2+p^2}+V$$

scalar and vector potentials: common prejudice $S<0$; $V>0$

3. strange mesons



Exp. $\overline{K}N$ scattering

scattering amplitudes

bad data

good data

scattering model including s-,p-,d- partial waves

Coupled-channel scattering:
Weise, Kaiser,…
Oset, Ramos,…
Lutz, EEK,…

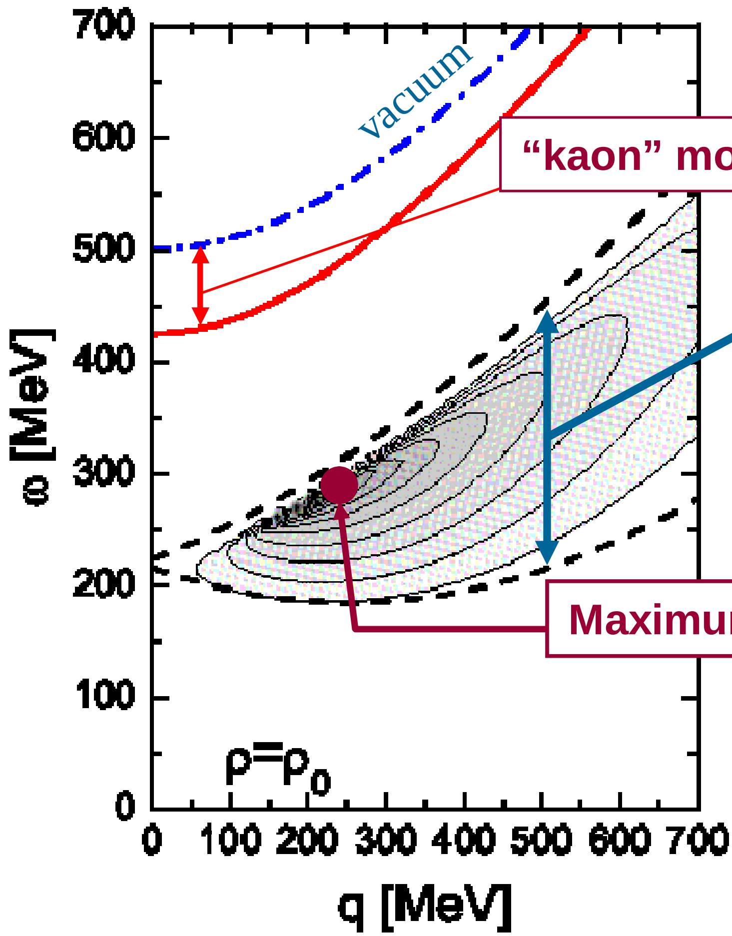
Various partial wave couple in medium

4. K⁻ in medium

schematic spectral density

EEK,Voskresensky, Kampfer NPA588(1995);
EEK, Voskresnensky, PRC60 (1999)

spectral density

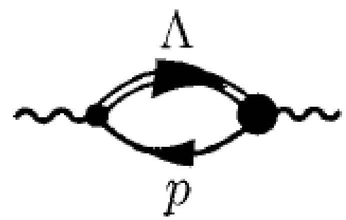


“kaon” mode with attractive potential

quasi-particle branch

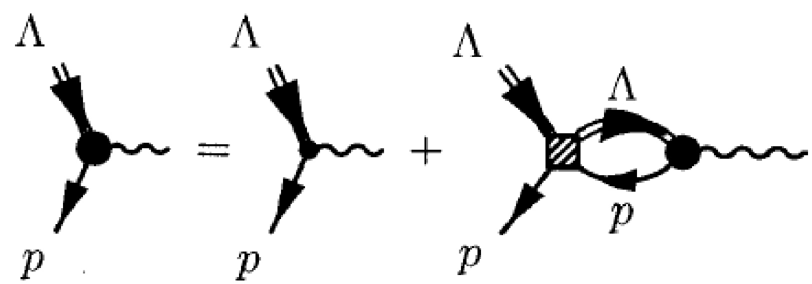
particle-hole modes

$$\omega \sim m_\Lambda - m_N$$



Maximum of the spectral function is shifted to higher energies

short-range correlations

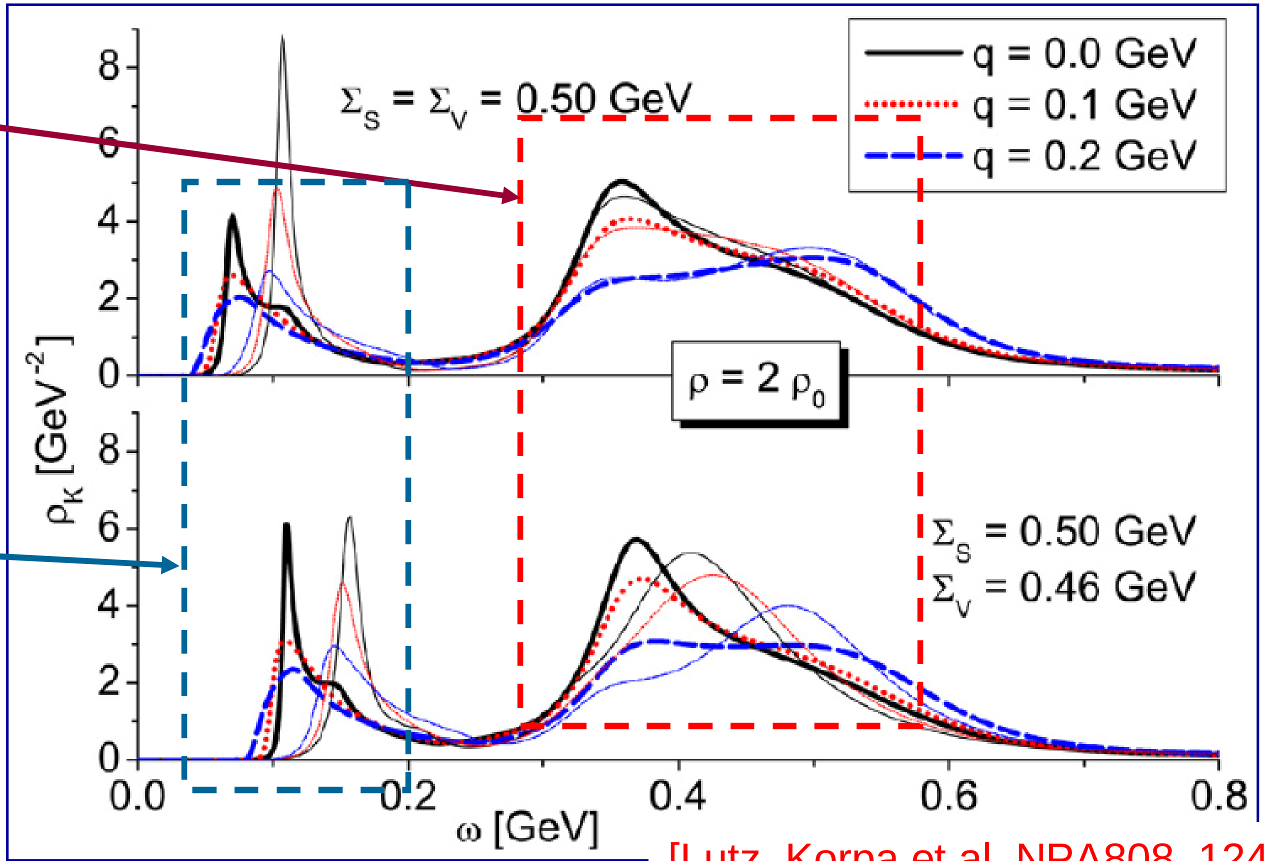


realistic spectral densities realistic K^-N interactions + self-consistent calculations

Oset, Tolos et al; Lutz, Korpa, et al

Λ(1405), Σ(1385)

Λ(1116),Σ(1190)



[Lutz, Korpa et al, NPA808, 124]

Courageous attempts to include spectral function in transport codes by Giessen, Frankfurt , and Nantes groups [Bratkovskaya, Cassing, Aichelin et al]

How to release the in-medium kaons?

fireball break up time ~$1/m_\pi$

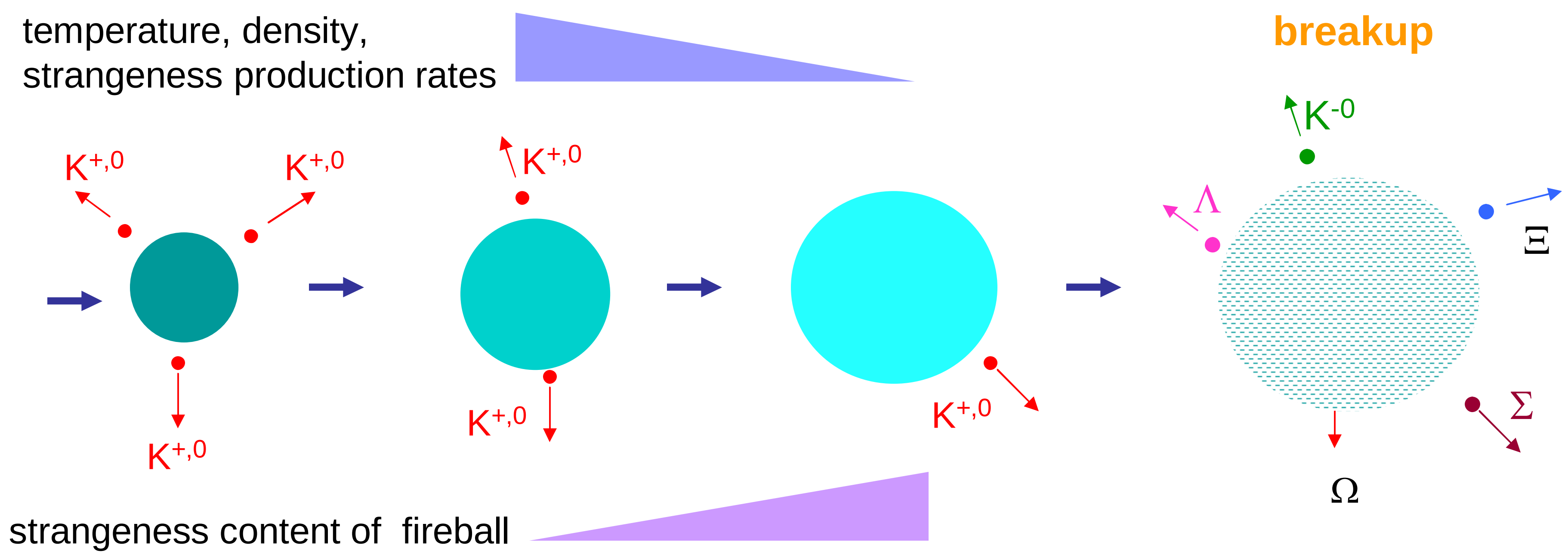
$$m_K \to m_K - 75\ \mathrm{MeV}\rho/\rho_0$$

Minimal statistical model for strange particles:

In baryon dominated matter Kaons (anti-s-inside) interacts weaker than Anti-Kaons (s inside). There is no baryon resonances with an s-quark.

Kaons leave fireball earlier and carry anti-strangeness away.

The fireball have some negative strangeness which is statistically distributed among K^-, anti-K^0, Λ, Σ, Ξ,Ω



anti-strangeness released = *strangeness accumulated inside*= **strangeness released at breakup**

Strangeness production rate at AGS-SPS

- **strangeness production** K^+ and K^0 evolution calculated from

$$\frac{d\rho_K}{d\tau} = \rho_K \left(-\frac{1}{V}\frac{dV}{d\tau} \right) + \mathcal{R}^+ - \mathcal{R}^-$$

annihilation rate

production rate

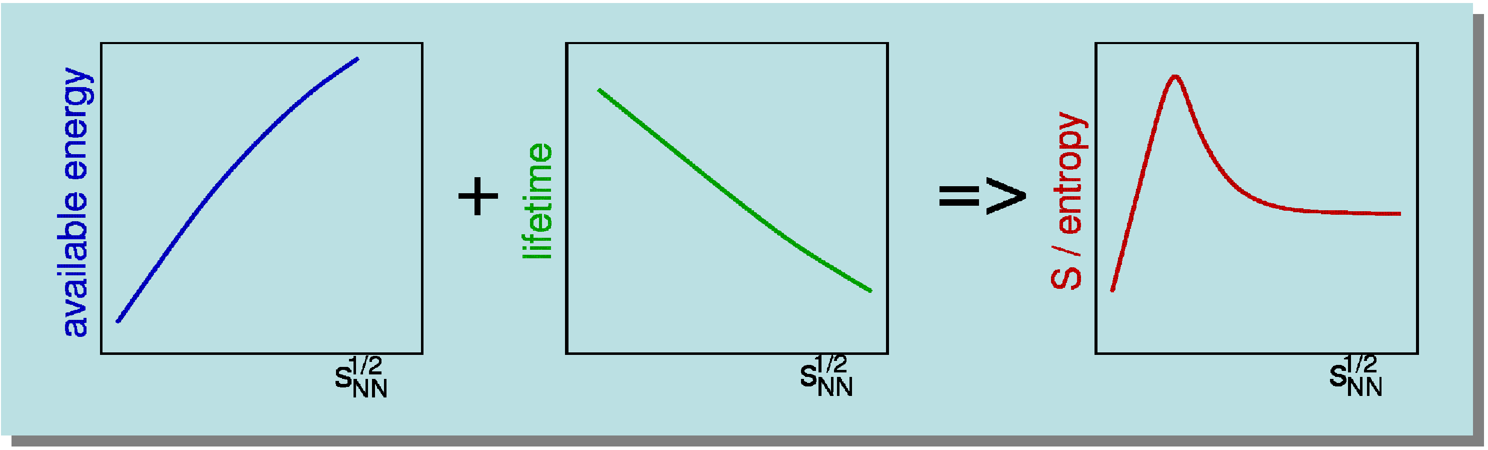
expansion rate

calculate from known cross-sections and evolved densities

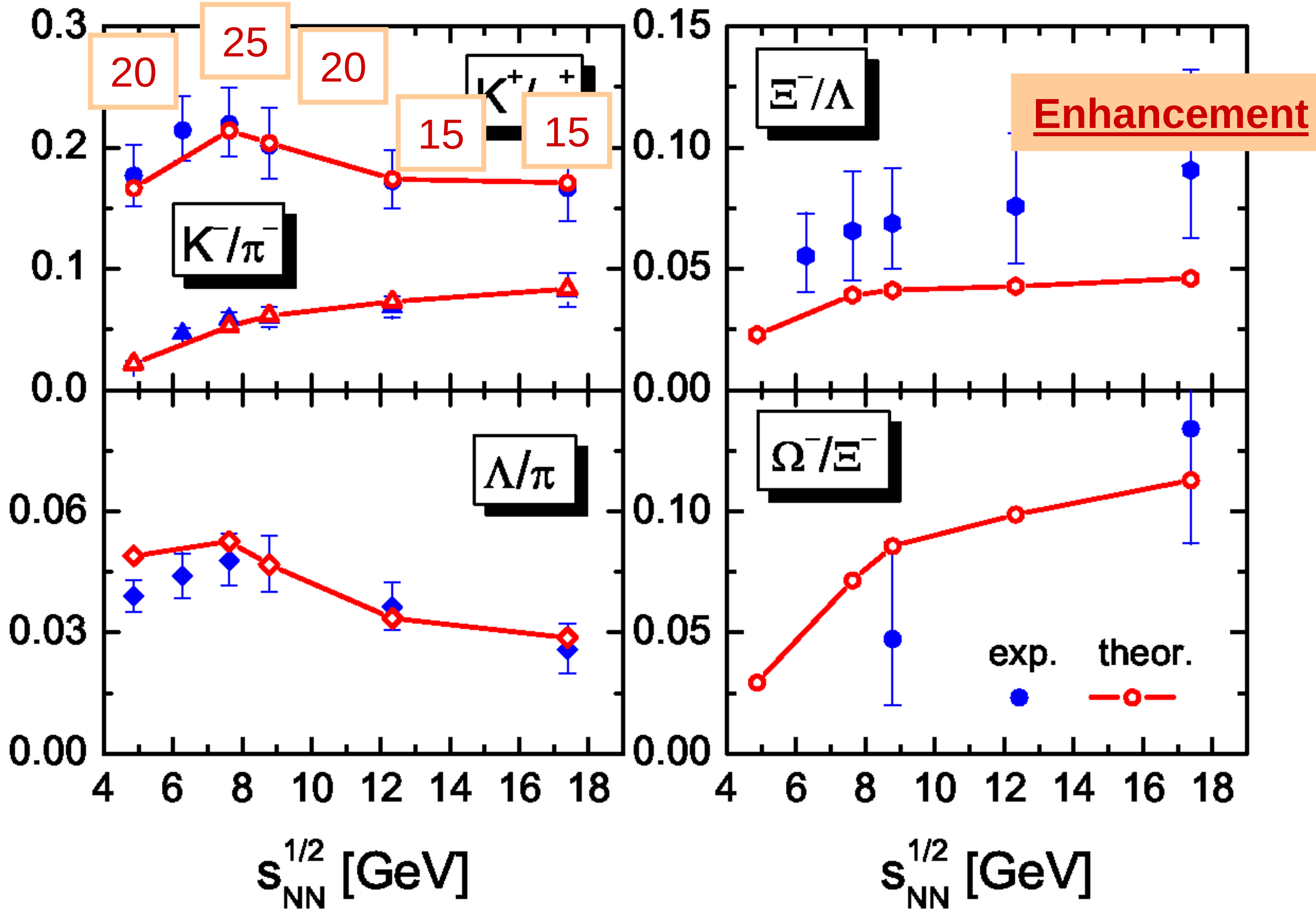
Initial strangeness: number of K^+ from pp collisions

- **fireball expansion time vs. energy** parameterized the space-time evolution

a data/experience (HBT, spectra) driven ansatz for expansion



- results



The K^+ horn can be interpreted as a **rise and fall** of the fireball lifetime

The time needed for a strangeness production is about **15-20 fm/c**.

In hydro the typical expansion time is **<10 fm/c!**.

Hidden strangeness. Φ-mesons

1985 Asher Shor [PRL 54, 1122] proposed enhancement of phi meson yield as a signal of a „colour liberation“

AGS [E917, PRC 69, 054901 (2004)]
SPS [NA49, PRC 78, 044907 (2008)]
found enhancement factor 3-4

This factor can be explained by *strangenss coalecence* [Ko, Sa,PLB 258]

$$K\bar{K} \longrightarrow \phi\rho \qquad K\Lambda \longrightarrow \phi N$$

+ phi mass drop

Surprises at low energy

FOPI: Ni +Ni @ 1.97 GeV/A [NPA 714 (2003) 89]

Large yield of phi meson wich cannot be explained in theoretically

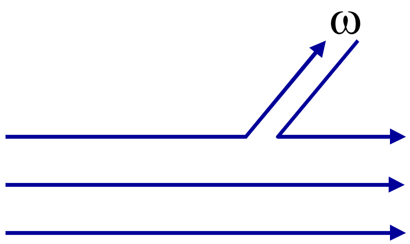
[Kämpfer, Kotte, Hartnack, Aichelin, J. Phys. G 28 (2002) 2035]

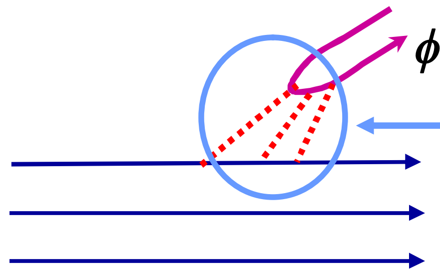
HADES: Ar+KCl @ 1.76 GeV/A [Arxive: 0902.3487] phi meson enhancement

18±7 % K^- mesons stem from phi decays! **strangeness ballance??**

Okubo-Zweig-Iizuka suppression rule

- $N \rightarrow N\,\omega$
- $N \rightarrow N\,\phi$ **suppressed**





1/N$_c$ counting

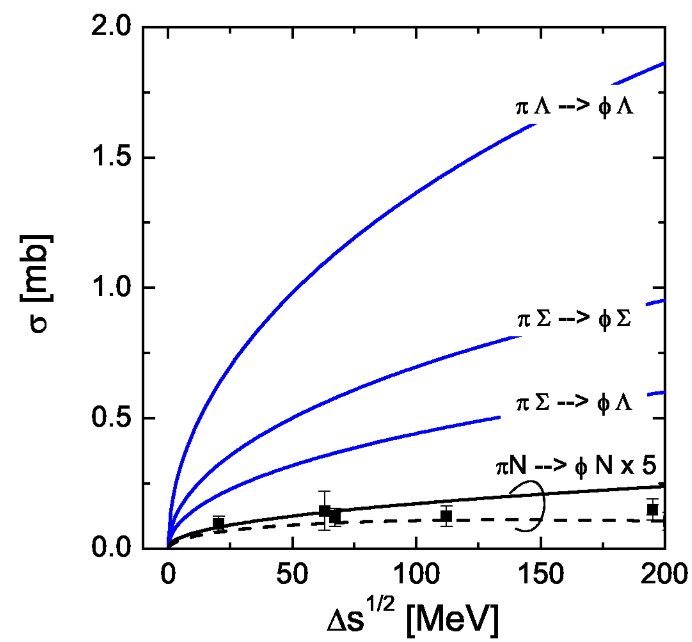
need 3 gluons to form a white hadron state

$$\frac{\sigma(\pi N \rightarrow \omega N)}{\sigma(\pi N \rightarrow \phi N)} \sim 75$$

Phi production in reactions involving strange particles is not OZI suppressed!

- **strangeness "annihilation"** $\quad K\,Y \rightarrow \phi N \quad$ strangeness hides into ϕ

- **catalytic reactions** $\quad \pi Y \rightarrow \phi Y' \qquad \overline{K}N \rightarrow \phi Y$



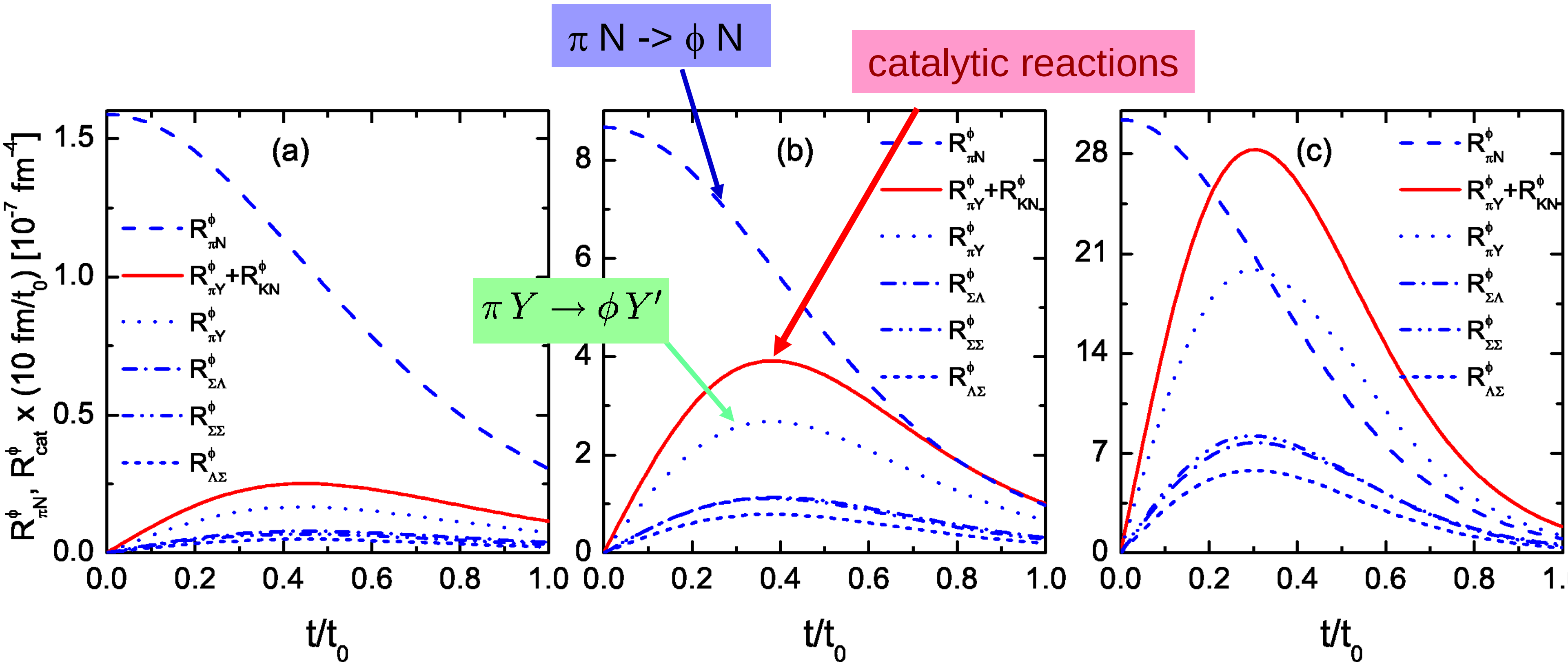
If catalytic reactions are operative then some correlations among phis and strange particles could be seen in experiment:

-- *centrality dependence*

-- *rapidity distributions*

Phi production

$$\frac{\mathrm{d}\rho_\phi}{\mathrm{d}t} - \rho_\phi(t)\,\frac{\dot\rho_B(t)}{\rho_B(t)} = R^\phi_{\pi N}(t) + \sum_{\bar Y, Y=\Lambda,\Sigma} R^\phi_{Y\bar Y}(t) + R^\phi_{\bar K N}(t) + \ldots$$



$T_m = 110$ MeV , $\rho_m = 4\ \rho_0$

$\alpha = 0.2$

$T_m = 130$ MeV , $\rho_m = 5\ \rho_0$

$\alpha = 0.3$

$T_m = 150$ MeV , $\rho_m = 6\ \rho_0$

$\alpha = 0.5$

$$T(t) = \frac{T_m}{(t^2/t_0^2+1)^\alpha} \qquad \rho_B(t) = \frac{\rho_m}{(t^2/t_0^2+1)^{3\alpha/2}}$$

Red lines scale with t_0 !!!

Catalytic reactions can be competitive if T>110 MeV and t_0>10 fm

Centrality dependence

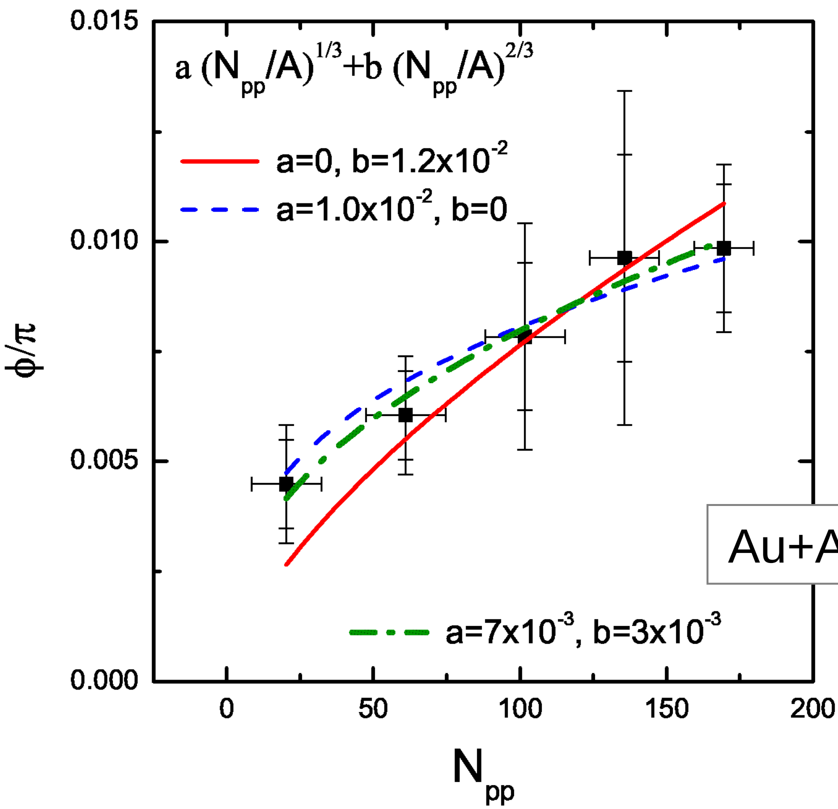
$$N_\pi \propto V \propto N_{pp}$$
$$N_{K^+} \propto V\, t_0 \propto N_{pp}^{4/3}$$

$$N_\phi \sim a_{\rm conv}\, N_{pp}^{4/3} + a_{\rm cat}\, N_{pp}^{5/3}$$

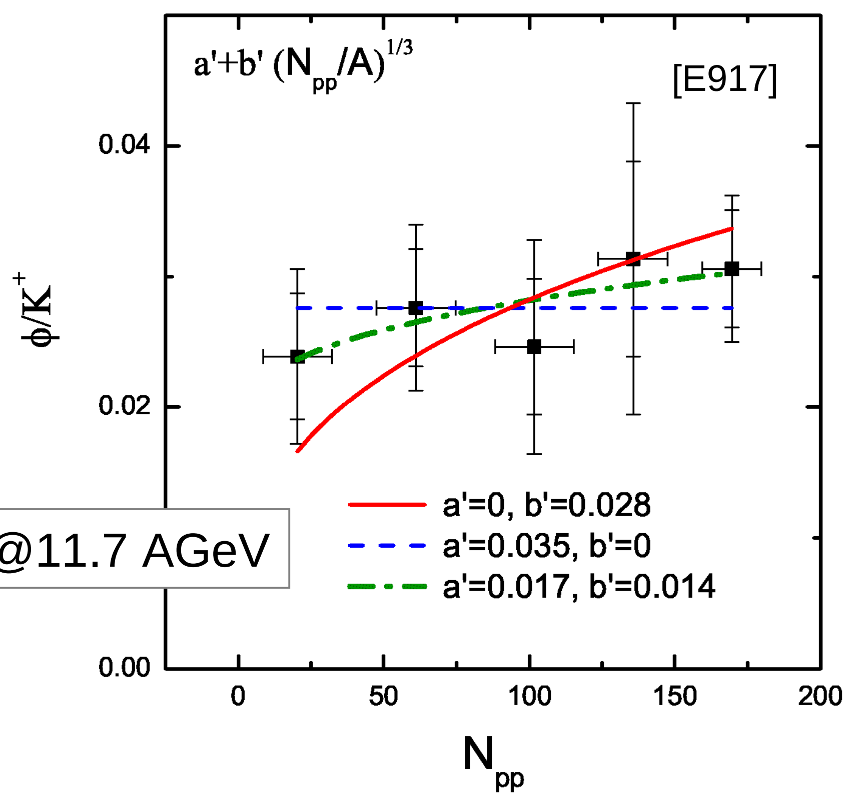
conventional *catalytic* *reactions*

$$\frac{N_\phi}{N_\pi} \sim a\left(\frac{N_{pp}}{A}\right)^{1/3} + b\left(\frac{N_{pp}}{A}\right)^{2/3}$$

$$\frac{N_\phi}{N_{K^+}} \sim a' + b'\left(\frac{N_{pp}}{A}\right)^{1/3}$$



Au+Au@11.7 AGeV



The catalytic reaction contribution can be about 30%-40% for N_{pp}=A.

Rapidity distribution

The distributions can be fitted with a sum of two Gaussian functions placed symmetrically around mid-rapidity

$$\frac{1}{\langle N\rangle}\frac{\mathrm{d}N}{\mathrm{d}y} = \frac{1}{\sqrt{8\,\pi\,\sigma^2}}\left[e^{-\frac{(y-a)^2}{2\,\sigma^2}} + e^{-\frac{(y+a)^2}{2\,\sigma^2}}\right]$$

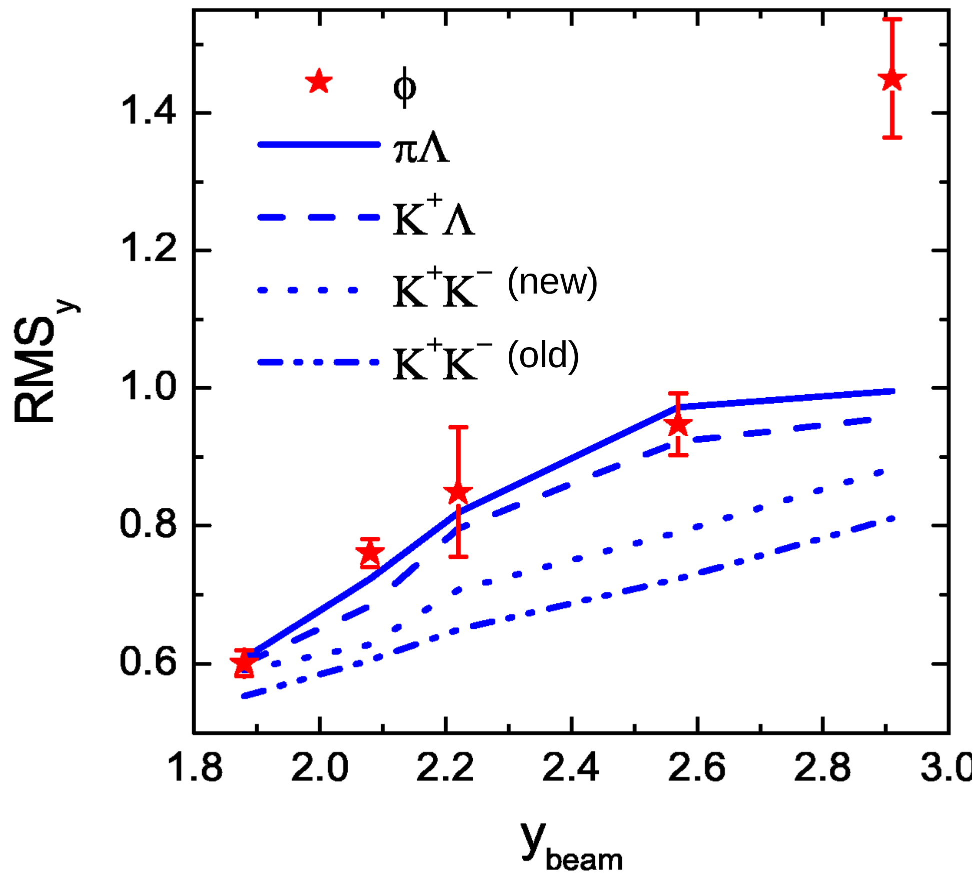
the root mean square of the distribution $\mathrm{RMS}^2 = \sigma^2 + a^2$

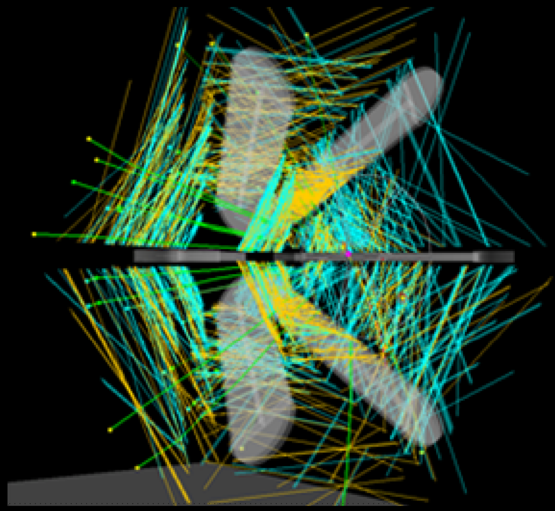
Assume: **the rapidity distributions of particles do not change after some initial stage**.

The collision **kinematics** is restricted mainly to the **exchange of transverse momenta** .

The rapidity distribution of ϕs produced in the reaction 1+2 -> ϕ +X is roughly proportional to the **product of rapidity distributions** of colliding particle species 1 and 2.

$$\mathrm{RMS}_{12}^2 = = \frac{\sigma_1^2\,\sigma_2^2}{\sigma_1^2+\sigma_2^2} + \ldots$$





Strangeness at HADES @ GSI

HADES: complete measurement of particles containing strange quarks in Ar+KCl collisions @ 1.76 AGeV

Agakishiev (HADES) PRL 103, 132301 (2009); Eur. Phys.J. A47 21 (2011)

one experimental set-up for all particles!

We study the relative distributions of strangeness among various hadron species

We are not interested in how strangeness is produced!

We know the final K^+ multiplicity!

$$R_{K^-/K^+} = \frac{N_{K^-}}{N_{K^+}} = 2.5^{+1.2}_{-0.9} \times 10^{-2} \qquad R_{\Lambda/K^+} = \frac{N_{\Lambda+\Sigma^0}}{N_{K^+}} = 1.46^{+0.49}_{-0.37}$$

$$R^{(\mathrm{Hades})}_{\Sigma/K^+} = \frac{1}{2}\frac{N_{\Sigma^+ + \Sigma^-}}{N_{K^-}} = 0.13^{+0.16}_{-0.11} \qquad R_{\Xi/\Lambda/K^+} = \frac{N_{\Xi^-}}{N_{\Lambda+\Sigma^0}\, N_{K^+}} = 0.20^{+0.16}_{-0.11}$$

if K^++K^0_s data are used for total strangeness

$$R^{(\mathrm{iso})}_{\Sigma/K^+} = \frac{1}{2}\frac{N_{\Sigma^+ + \Sigma^-}}{N_{K^+}} = 0.30^{+0.23}_{-0.17}$$

total strangeness is (1+η) K^+

This number is much bigger than the results of stat. models and transport codes

isospin asymmetry factor $\eta = \frac{A-Z}{Z}$

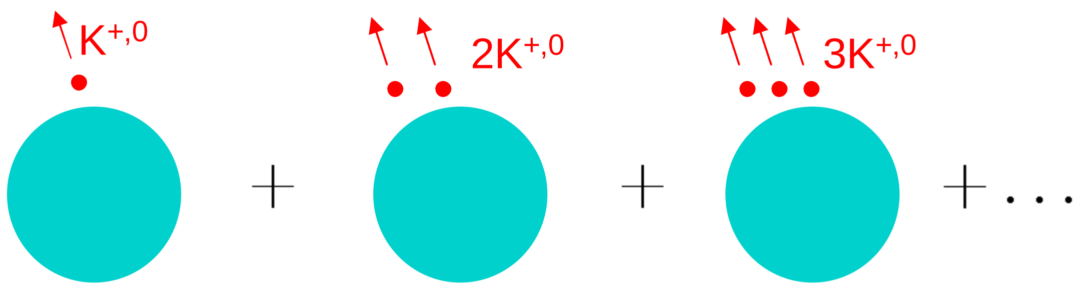
for ArK and ArCl collisions η=1.14

We know the average kaon multiplicity $\mathcal{M}_{K^+} = (2.8 \pm 0.4) \times 10^{-2}$

Of course kaons are produced not piecewise but as whole entities.

events with K$^+$ $\longrightarrow$ $N_{K+} = M_{K+} \cdot N_{tot}$ $\longleftarrow$ *total number of events*

Multi-kaon event classes:



isospin asymmetry factor

$$\eta = \frac{A-Z}{Z}$$

$$P_{s\bar{s}}^{(1)}\, N_{\rm tot} + P_{s\bar{s}}^{(2)}\, N_{\rm tot} + P_{s\bar{s}}^{(3)}\, N_{\rm tot} + \cdots = N_{\rm tot}\,(1+\eta)\,\mathcal{M}_{K^+}$$

$P_{s\bar{s}}^{(n)}$ probaility of creation of n $s\bar{s}$ pairs

at breakup

$\overline{\mathrm{K}}$,Λ,Σ — no Ξ,Ω!

$\overline{\mathrm{K}}$,Λ,Σ,Ξ — no Ω!

$\overline{\mathrm{K}}$,Λ,Σ,Ξ,Ω

$$\boxed{P_{s\bar{s}}^{(n)} = \Lambda^n e^{-\Lambda}/n!}$$

Λ -- integral probability of the pair production

$$\Lambda = \lambda\, V_{\rm fo}^{4/3}$$

$V_{\rm fo}(b)$ freeze-out volume dependent of impac parameter

$$\langle \ldots \rangle = \frac{2}{b_{\rm max}^2} \int_0^{b_{\rm max}} {\rm d}b\, b\, (\ldots)$$

-- averaging over the collision impact parameter

The value of λ is fixed by the total K^+ multiplicity observed in an inclusive collision.

We denote the multiplicity of K^+ mesons produced in each n-kaon events as:

$$M_{K^+}^{(n)} = \frac{n}{1+\eta} P_{s\bar{s}}^{(n)}$$

$$\mathcal{M}_{K^+} = \sum_n \langle M_{K^+}^{(n)} \rangle = \frac{1}{1+\eta} \sum_n n\, \langle P_{s\bar{s}}^{(n)} \rangle = \frac{\langle \Lambda \rangle}{1+\eta}$$

$$\begin{aligned}
\langle P_{s\bar{s}}^{(1)} \rangle &= (1+\eta)\, \mathcal{M}_{K^+} \left[1 - (1+\eta)\zeta^{(2)} \mathcal{M}_{K^+} + \tfrac{1}{2} \zeta^{(3)} (1+\eta)^2 \mathcal{M}_{K^+}^2 \right] \\
\langle P_{s\bar{s}}^{(2)} \rangle &= \tfrac{1}{2} (1+\eta)^2 \mathcal{M}_{K^+}^2 \left[\zeta^{(2)} - (1+\eta)\zeta^{(3)} \mathcal{M}_{K^+} \right] \\
\langle P_{s\bar{s}}^{(3)} \rangle &= (1+\eta)^3 \tfrac{1}{6} \zeta^{(3)} \mathcal{M}_{K^+}^3
\end{aligned}$$

$$\zeta^{(n)} = \frac{\left\langle V_{\rm fo}^{\frac{4}{3}n} \right\rangle}{\left\langle V_{\rm fo}^{4/3} \right\rangle^n}$$

$$\zeta^{(1)} = 1\,, \quad \zeta^{(2)} = 2.51\,, \quad \zeta^{(3)} = 8.11$$

enhancement factors!!

15% of kaons is produced pairwise **1% of kaons is produced triplewise**

The statistical probability that strangeness will be released at freeze-out in a hadron of type a with the mass m_a is

$$P_a = \mathbf{z_S}^{s_a} V_{\mathrm{fo}}\, p_a = \mathbf{z_S}^{s_a} V_{\mathrm{fo}}\, \nu_a\, e^{q_a \frac{\mu_B(t)}{T(t)}}\, f(m_a, T_{\mathrm{fo}})$$

s_a # of strange quarks in the hadron

ν_a spin-isospin degeneracy factor

q_i baryon charge of the hadron

$$f(m,T) = \frac{m^2 T}{2\pi^2} K_2\left(\frac{m}{T}\right)$$

baryon chemical potential $\mu_B(t) \simeq -T(t)\,\ln\left\{4\left[f(m_N,T) + 4\, f(m_\Delta,T)\right]/\rho_B(t)\right\}$

$\mathbf{z_S}$ is a *normalization factor* which could be related to a probability of one s-quark to find itself in a hadron a

This factor follows from the requirement that the sum of probabilities of production of different strange species and their combinations, which are allowed in the finale state, is equal to one.

This factor depends on how many strange quarks are produced.
Hence, it is different in single-, double- and triple-kaon events.

$$P_a^{(n)} = z_S^{(n)s_a}\, V_{\mathrm{fo}}\, p_a$$

single-kaon event: $n = 1$ only $\overline{\mathrm{K}}$, Λ and Σ can be in the final state

$$P_{\bar{K}}^{(1)} + P_{\Lambda}^{(1)} + P_{\Sigma}^{(1)} = 1 = z_S^{(1)}\, V_{\mathrm{fo}}\, (p_{\bar{K}} + p_{\Lambda} + p_{\Sigma})$$

multiplicity of $\bar{K}, \Lambda, \Sigma$

$$M_a^{(1)} = g_a\, P_{s\bar{s}}^{(1)}\, P_a^{(1)} = g_a\, P_{s\bar{s}}^{(1)}\, z_S^{(1)}\, V_{\mathrm{fo}}\, p_a$$

isospin factor

double-kaon event: $n = 2$ $\overline{\mathrm{K}}\overline{\mathrm{K}}$, $\overline{\mathrm{K}}\Lambda$, $\overline{\mathrm{K}}\Sigma$, $\Lambda\Lambda$, $\Lambda\Sigma$, $\Sigma\Sigma$ and Ξ can be in the final state

$$\left(P_{\bar{K}}^{(2)} + P_{\Lambda}^{(2)} + P_{\Sigma}^{(2)}\right)^2 + P_{\Xi}^{(2)} = 1$$

$$z_S^{(2)2}\, V_{\mathrm{fo}}^2\, (p_{\bar{K}} + p_{\Lambda} + p_{\Sigma})^2 + z_S^{(2)2}\, V_{\mathrm{fo}}\, p_{\Xi} = 1$$

multiplicity of $\bar{K}, \Lambda, \Sigma$

$$M_a^{(2)} = g_a\, 2\, P_{s\bar{s}}^{(2)}\, P_a^{(2)} \left(P_{\bar{K}}^{(2)} + P_{\Lambda}^{(2)} + P_{\Sigma}^{(2)}\right)$$

multiplicity of Ξ

$$M_{\Xi}^{(2)} = g_{\Xi}\, P_{s\bar{s}}^{(2)}\, P_{\Xi}^{(2)}$$

particle ratios:

We included leading and next-to-leading contributions

$$R_{K^-/K^+} = \eta \frac{\langle M_{\bar{K}}^{(1)} + M_{\bar{K}}^{(2)} \rangle}{(1+\eta)\,\mathcal{M}_{K^+}} = \frac{\eta\, p_{\bar{K}}}{p_{\bar{K}} + p_\Lambda + p_\Sigma} Y_1$$

$$R_{\Lambda/K^+} = \frac{1}{\mathcal{M}_{K^+}} \left\langle M_\Lambda^{(1)} + M_\Lambda^{(2)} + \eta \frac{M_\Sigma^{(1)} + M_\Sigma^{(2)}}{\eta^2+\eta+1} \right\rangle = (1+\eta) \frac{\left[p_\Lambda + \frac{\eta\, p_\Sigma}{\eta^2+\eta+1}\right]}{p_{\bar{K}} + p_\Lambda + p_\Sigma} Y_1$$

$$R_{\Sigma/K^+} = \frac{\eta^2+1}{2(\eta^2+\eta+1)} \frac{\langle M_\Sigma^{(1)} + M_\Sigma^{(2)} \rangle}{\mathcal{M}_{K^+}} = \frac{(\eta^2+1)(\eta+1)}{2(\eta^2+\eta+1)} \frac{p_\Sigma}{p_{\bar{K}} + p_\Lambda + p_\Sigma} Y_1$$

$$R_{\Xi/\Lambda/K^+} = \frac{\frac{\eta}{1+\eta}\langle \left(M_\Xi^{(2)} + M_\Xi^{(3)}\right) \rangle}{\langle M_\Lambda^{(1)} + M_\Lambda^{(2)} + \eta \frac{M_\Sigma^{(1)}+M_\Sigma^{(2)}}{\eta^2+\eta+1} \rangle \mathcal{M}_{K^+}} = \eta \frac{p_\Xi/(p_{\bar{K}} + p_\Lambda + p_\Sigma)}{\langle V_{\rm fo} \rangle \left(p_\Lambda + \frac{\eta p_\Sigma}{\eta^2+\eta+1}\right)} Y_2$$

in **blue** the standard results; in **red** corrections

$$Y_1 = 1 - \frac{(1+\eta)\mathcal{M}_{K^+}\, p_\Xi}{(p_{\bar{K}} + p_\Lambda + p_\Sigma)^2} \frac{\langle V_{\rm fo}^{5/3} \rangle}{\langle V_{\rm fo}^{4/3} \rangle^2}$$

small correction <5%

$$Y_2 = \frac{1}{2}\tilde{\zeta}^{(2)} = \frac{1}{2} \frac{\langle V_{\rm fo}^{5/3} \rangle}{\langle V_{\rm fo}^{4/3} \rangle^2} \langle V_{\rm fo} \rangle \simeq 0.52$$

strong suppression!

Ξ/Λ/K ratio is sensitive to the fireball freeze-out volume

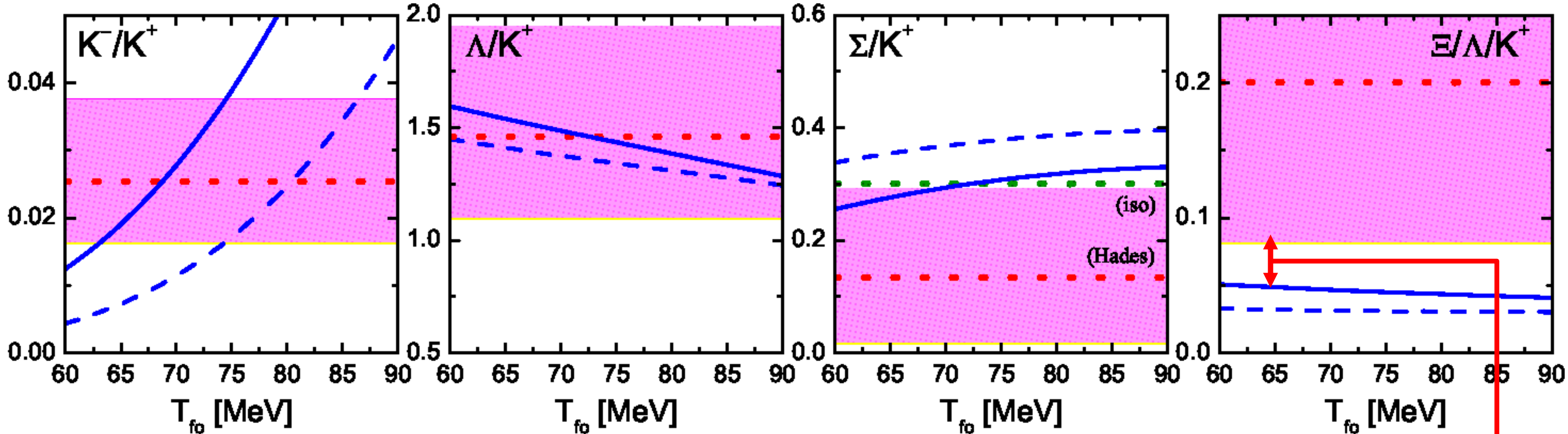
Ratios as functions of the freeze-out temperature

parameters of the model: $\rho_{B,\mathrm{fo}} = 0.6\,\rho_0$

potential models for strange particles in medium

potentials for nucleons Δs:

$$S_N \simeq S_\Delta \simeq -190\ \mathrm{MeV}\rho_B/\rho_0$$
$$V_N \simeq V_\Delta \simeq +130\ \mathrm{MeV}\rho_B/\rho_0$$



double strangeness suppression Y_2

results with in-medium potentials

results with vacuum masses

best fit for K^{-},Λ ratios: $T_{\mathrm{f.o}}$=69 MeV

Inclusion of potentials
improves the temperature match for K and Λ ratios,

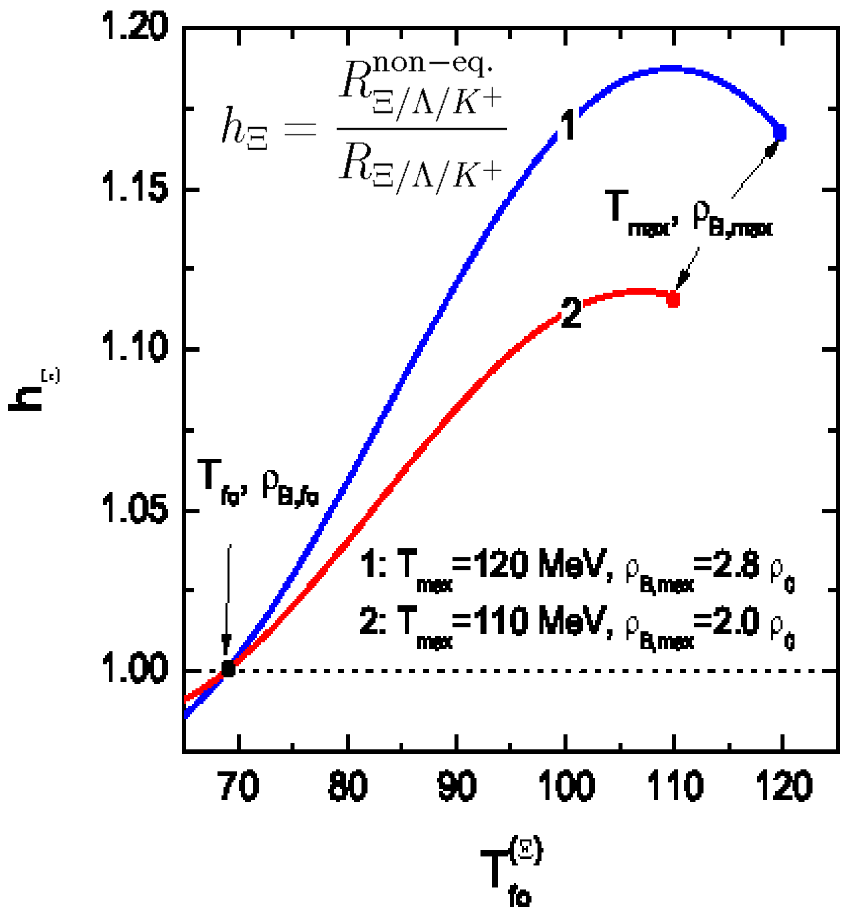
improves Σ ratio (repulsive potential),
increases Ξ ratio (not strong enough)

1. in medium potential and freeze-out density

A more attractive Ξ in-medium potential? We would need $U_{\Xi} < -120$ MeV to increase the ratio $\Xi^-/\Lambda/K^+$ up to the lowest end of the empirical error bar.

2. Earlier freeze-out

The enhancement is too small!
We need at least factor 5!



3. Direct reactions

To get any substantial increase in the number of Ξ's we have to assume that these baryons are not absorbed after being produced and their number is determined by the rate of direct production reactions, as, for example, for dileptons.

However, this raises a new question:
whether there are sufficiently strong sources of Ξ baryons and enough time t?

Where do Ξ baryons come from?

strangeness creation reactions: $\bar{K}N \rightarrow K\Xi - 380\ \mathrm{MeV}$ $\quad N_{K^-} \ll N_{\Lambda,\Sigma}$

$\pi\Sigma \rightarrow K\Xi - 480\ \mathrm{MeV}$ $\quad$ *very exothermic,*

$\pi\Lambda \rightarrow K\Xi - 560\ \mathrm{MeV}$ $\quad$ *very inefficient*

strangeness recombination reactions:

ss quarks are strongly bound in Ξ!

anti-kaon induced reactions

$\overline{K}\Lambda \rightarrow \Xi\pi + 154\ \mathrm{MeV}$ $\quad \sigma \sim 10\ \mathrm{mb}$

$\overline{K}\Sigma \rightarrow \Xi\pi + 232\ \mathrm{MeV}$ $\quad$ [Li,Ko NPA712, 110 (2002)]

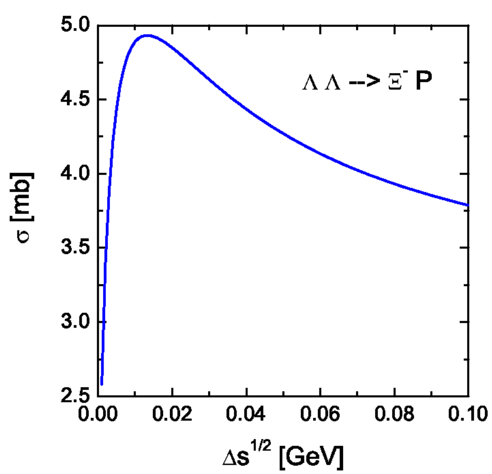
double-hyperon processes

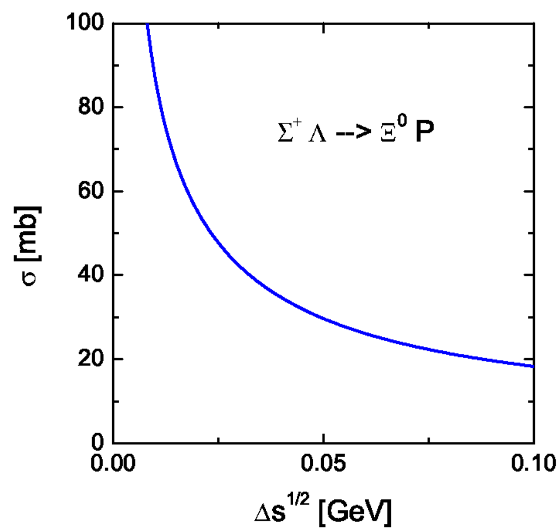
$\Lambda\,\Lambda \rightarrow \Xi N - 26\ \mathrm{MeV}$ $\quad$ can be more efficient since

$\Lambda\,\Sigma \rightarrow \Xi N + 52\ \mathrm{MeV}$ $\quad N_{K^-} \ll N_{\Lambda,\Sigma}$

$\Sigma\,\Sigma \rightarrow \Xi N + 130\ \mathrm{MeV}$ $\quad$ [Tomasik, E.K., arXiv:**1112.1437**]

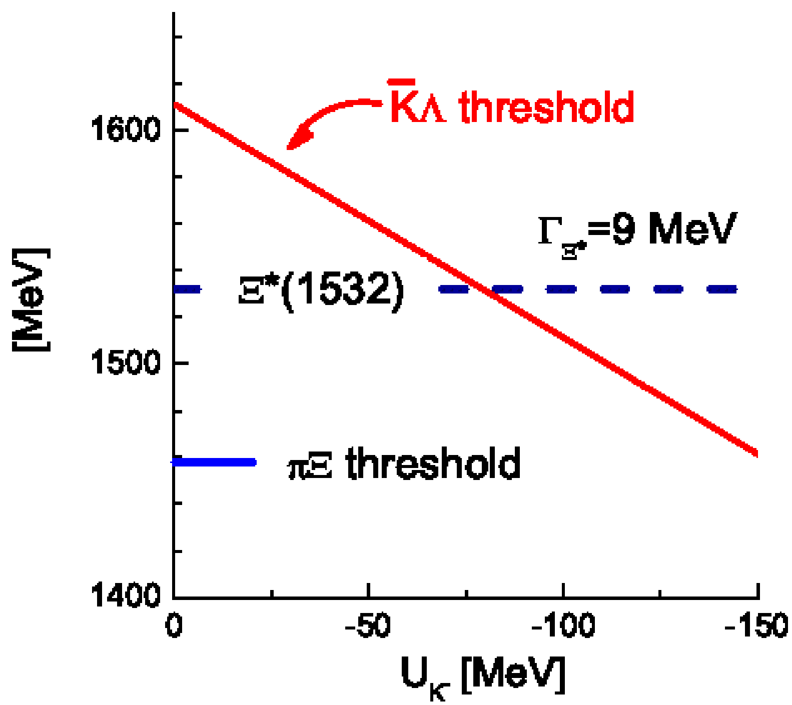
[Polinder, Haidenbauer, Meissner, PLB 653, 29 (2007)]

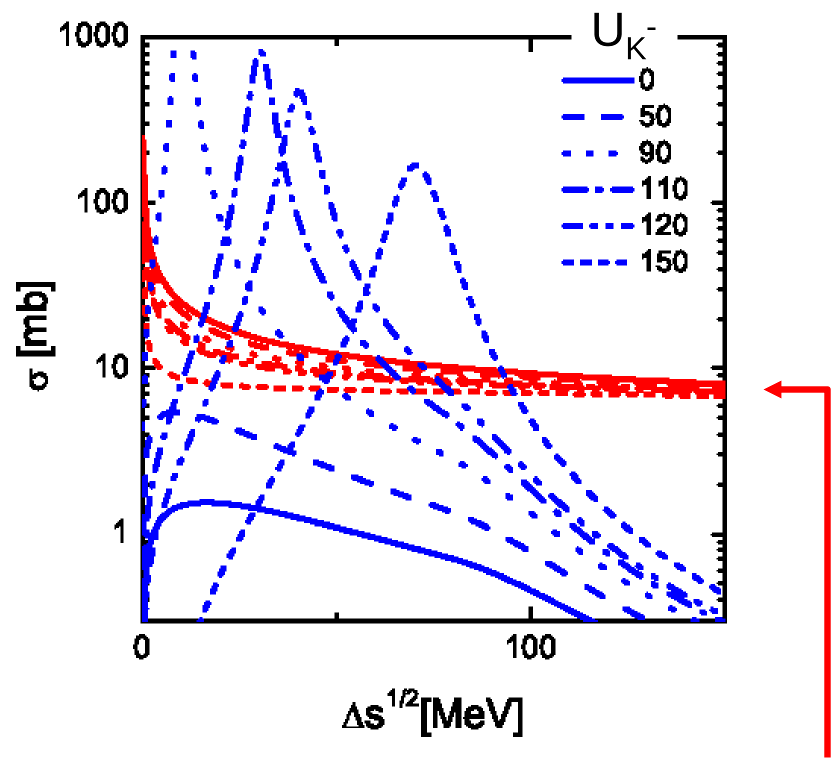




Influence of $U_{\overline{K}}$ potential on $\overline{K}\Lambda \to \Xi\pi$ reaction

Reaction threshold drops below the p-wave Ξ*(1532) resonance





Ξ* resonance contribution
for diffent values of
K- potential (in MeV)

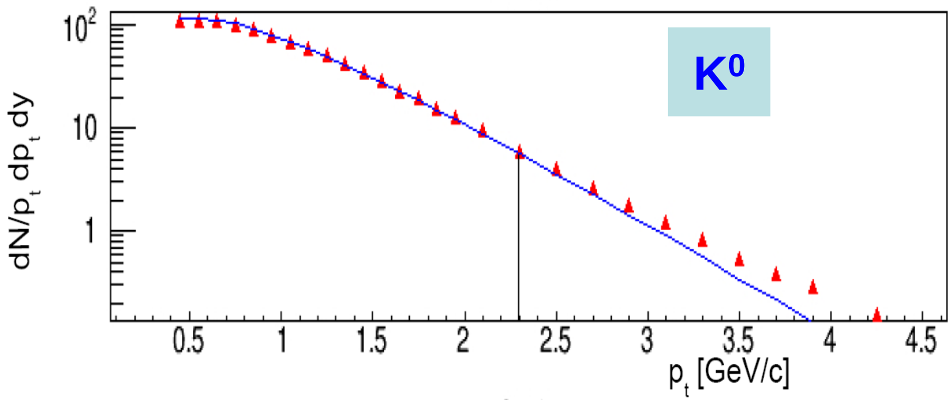
background
[Li,Ko NPA712, 110 (2002)]

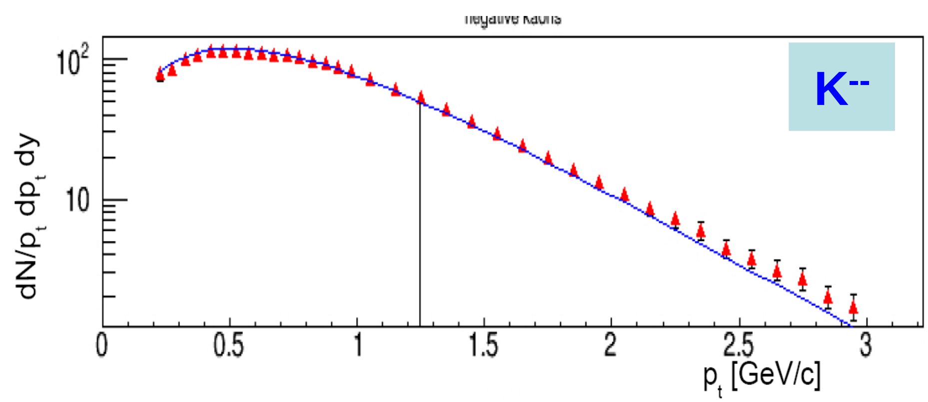
Strangeness at LHC

Freeze-out state from analysis of transverse momentum [Melo and Tomasik]

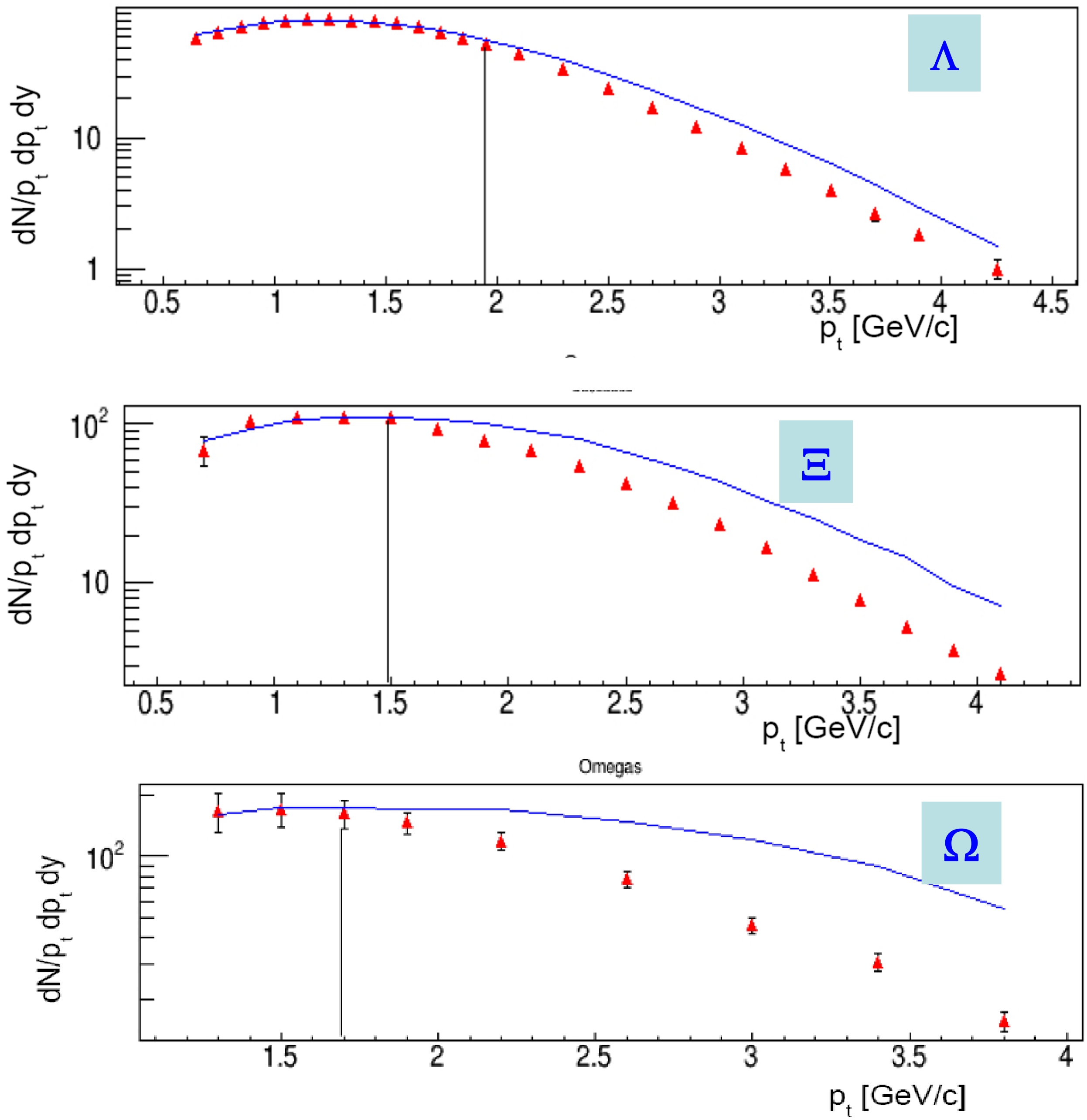
Used: *DRAGON is MC code based on Blast Wave model*
+ decays of unstable resonances, 277 hadrons included
+ possible fragmentation of fireball is included (not used here)

Pb+Pb @ 2.76 TeV





Spectra of multiply strange baryons do not agree with data, particularly at higher pt.
This might be due to earlier freeze-out.
Separate fit to these spectra yields higher temperature and weaker transverse expansion.


Λ
Ξ
Omegas
Ω
dN/p_t dp_t dy
p_t [GeV/c]
10
1
10^2
0.5
1
1.5
2
2.5
3
3.5
4
4.5

Strangeness is interesting and complicated!
We need "complete strangeness measurement not only kaons, hyperons but also multi-strange baryons and phi's!

Shopping list for NICA

just K^+ mesons – time scale for strangeness production

K^+ and K^{--} mesons – in-medium effects for K^{--}

kaons and Λ – strangeness balance

kaons mesons and Λ and Σ – check for strangeness conservation
isospin

kaons mesons and hyperons and ϕ – interesting

kaons mesons and hyperons and ϕ and Ξ – very interesting
strangeness dynamics

kaons mesons and S=1,2 hyperons and ϕ and hyperon resonances –
exciting