Thermal Model Description of Collisions of Small Systems

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Outline

• Trigger of this talk:

• The maximum in the K^+/π^+ ratio as a fct √(s), No maximum in K^-/π^-

• The continuous increase of strangeness in pp with multiplicity, in line with p-Pb and Pb-Pb

• Goal of this talk:

• Overview of thermal model with sqrt(s)

• Predictions for small systems
• Chemical decoupling conditions extracted from SIS up to LHC feature common behaviour
• Similar to Andronic et al., Nucl. Phys. A 772 (2006) 167

Maximum Strangeness around 30 AGeV

$\sqrt{s} \approx 8$ GeV

$K^+$ are produced together with a $\Lambda$, influence of $\mu_B$

$K^-$ together with a $K^+$

$\lambda_s \equiv \frac{2\langle ss\rangle}{\langle uu\rangle + \langle dd\rangle}$

Current status of **horn and step** plots – properties of the **onset of deconfinement**

- For Pb+Pb sharp peak (**horn**) in K⁺/π⁺ ratio due to onset of deconfinement (OD) (APPB 30, 2705, 1999)

- For Pb+Pb plateau (**step**) in the inverse slope parameter (T) of m_T spectra due to OD (constant T and p in mixed phase)

- Even in **p+p** the energy dependence of K⁺/π⁺ and T exhibits **rapid changes** in the SPS energy range

S. Pulawski (for NA61), PoS CPOD2014, 010, 2015; and 2015 update (4π)
Maxima in a thermal model

arXiv:1603.09553

Parametrization of freeze-out line needs an update!
Here an old and a new one!

The maxima do NOT appear at the same $\sqrt{s}!!!$
Again, maxima appear at different $\sqrt{s}$!!!
Canonical Approach \(=\) exact strangeness conservation

Pion density
\[ n(\pi) = \exp\left(-\frac{E_\pi}{T}\right) \]

Strangeness is conserved!

Kaon density
\[ n(K) = \exp\left(-\frac{E_K}{T}\right) \]

\[ [g \, V \int \ldots \exp\left[-\frac{(E_\Lambda - \mu_B)}{T}\right] \]

J. Cleymans, HO, K. Redlich,
PRC 60 (1999)

Equations in the model are different!

\[ n_i^{\text{canonical}} \approx n_i^{\text{grand-canonical}} \cdot \frac{I_S(x)}{I_0(x)} \]
Calculation along the chemical freeze-out line

The freeze-out line for HIC used!
For pp collisions, it is slightly different
PRC 84(2011)054916

arXiv:1603.09553
Strangeness canonical suppressor


\( \Xi \)

\( \Omega \)

(\( (\Xi + \Xi^0) / (\pi^+ + \pi^-) \))

GSI-Heidelberg model

\( T_{ch} = 156 \text{ MeV} \)

THERMUS V3.0 model

MC productions - \( p \)

Pythia6-Perugia

Pythia6-Monasig

ALICE

pp, \( \sqrt{s} = 900 \text{ GeV} \)

pp, \( \sqrt{s} = 7 \text{ TeV} \)

V0A mult. evt. classes (Pb-side)

Hera Tch model

MC productions - \( p \)

\( \Xi/\pi \)

\( \Omega/\pi \)

R (fm)

ALICE

Preliminary pp, \( \sqrt{s} = 7 \text{ TeV} \)

V0A Mult. Evt. Classes (Pb-side)

V0M Mult. Evt. Classes

arXiv:1606.07424
Testing Canonical Suppression at the LHC

can./grand can.

Measured
ratio(pp)/ratio(PbPb)

Example:
T = 170 MeV
μ_B = 1 MeV

Values for LHC

Prediction for LHC: I. Kraus et al., PRC 79 (2009) 014901
T − μₐB plane

At LHC and RHIC:
\[ T_{\text{chem}} > T_{\text{kin}} \]

At SIS and AGS:
\[ T_{\text{chem}} = T_{\text{kin}} \]

In central Pb-Pb:
\[ T_{\text{chem}} = \]
\[ T_{\text{kin}} = 95 \pm 10 \text{ MeV} \]

ALICE

Long phase between chem. and kin. freeze out!!
Large HBT radii!!
Freeze-Out Volume

D. Adamova et al., CERES, PRL 90 (2003)

Transition from baryonic to mesonic freeze out

Conclusions

• Maximum in $K^+/\pi^+$ and smooth rise of $K^-/\pi^-$ can be described by statistical model caused by saturation in $T$ and reduction of $\mu_B$. Associate production of $K^+$ together with $\Lambda$!
• Predicts: HIC: Maxima in $\Lambda$, $\Sigma$, and $\Omega$ over $\pi$ at different $\sqrt{s}$!
• Predicts: For smaller systems: maxima gradually disappear except for $\Lambda/\pi$.
• At these energies: A transition from baryon to meson dominated freeze out.
Thank you!
Prediction: $\Lambda/\pi$ the maximum remains!

Very old pp data indicate a rather flat behaviour, may be a weak maximum!
New results from STAR BES

Now, we need the $\Omega/\pi$ ratio to see whether the maximum is at a higher $\sqrt{s}$!
Predictions for LHC

Prediction for heavy ions:
Grand can. (blue)
I. Kraus et al., PRC 74 (2007)

For pp collisions:
Canonical (yellow and red)
I. Kraus et al., PRC 79(2009)
Around $\sqrt{s}$ 8 -12 GeV things are happening!

- slope of spectra is not increasing
- $T_{\text{chem}}$ and $T_{\text{kin}}$ separate
- Volumina have minimum
LHC Energies

**pp 7 TeV**

- $p/\pi$ the same in pp and Pb-Pb,
- BUT lower than expected from stat. models

**Pb-Pb 2.76 TeV**

- $K/\pi$ in pp is lower than in Pb-Pb, expected from stat. model!
- Strangeness is okay!

Fitting with $\gamma_s \rightarrow$ around 1
Centrality Dependence of Multi-strange Baryons

ALICE Coll.
PL B728 (2014) 216

Predictions with
$T = 170$ MeV
(J. Cleymans et al.)

$T = 164$ MeV
(A. Andronic et al.)
K. Grebieszkow (NA61/SHINE): Maximum in the $K^+ / \pi^+$ ratio disappears in small systems.
Why happens a maximum in the $K^+$/pi ratio?
$\frac{\Lambda}{\pi^+}$ vs. $\sqrt{s_{NN}}$ [GeV]

$\mu_Q = 0$, $\gamma_s = 1$, $R = 10$ fm

Legend:
- $R_c = 9.5$ fm
- $R_c = 6.0$ fm
- $R_c = 4.0$ fm
- $R_c = 3.0$ fm
- $R_c = 2.5$ fm
- $R_c = 2.0$ fm
- $R_c = 1.5$ fm
- $R_c = 1.2$ fm
• Particle ratios show a continuous evolution from pp, p-Pb to Pb-Pb. Scaling with dn/dη! (strong evidence for canonical suppression in small systems!)

• Decrease of K*/K with centrality: Fireball phase from $T_{\text{chem}} \rightarrow T_{\text{kin}}$ (re-scattering)

• Blast wave in Pb-Pb: T around 100 MeV, high $\beta$

• Nuclei: Pb-Pb: follow radial flow, d/p constant (thermal). Both in contrast to coalescence. Yet, in p-Pb rising d/p conflict with thermal interpretation