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University of Heidelberg

In collaboration with

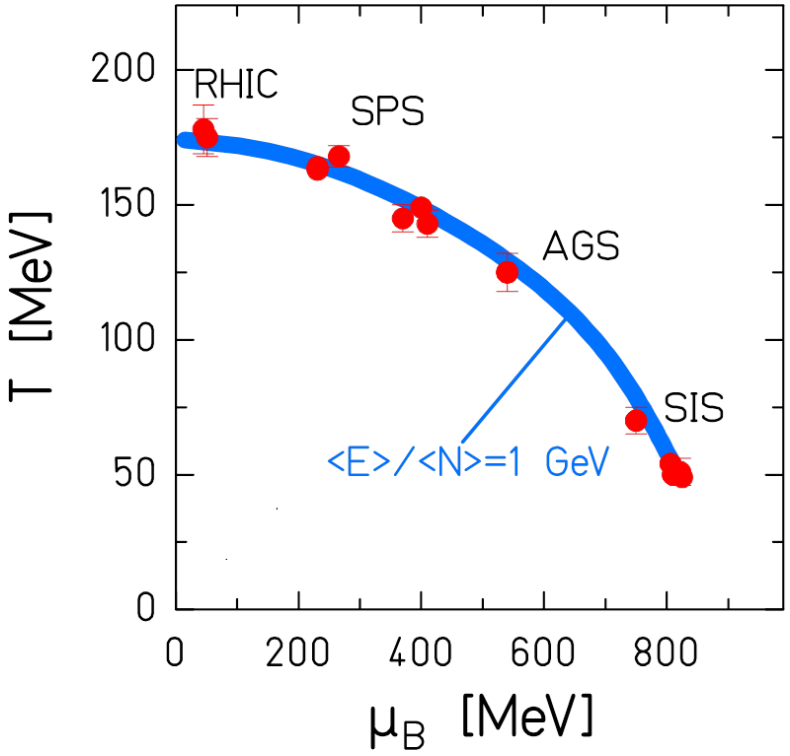
J. Cleymans, B. Hippolyte, K. Redlich, N. Sharma

SQM Berkeley, June 28th, 2016

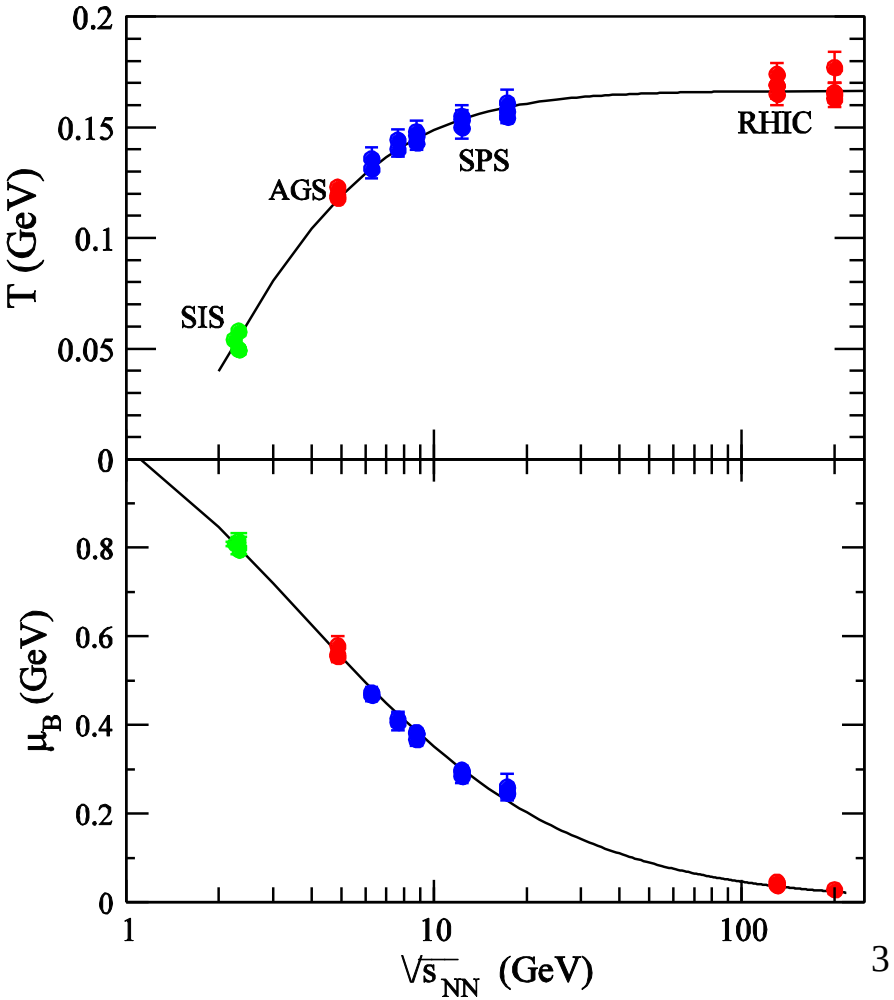
Outline

- Trigger of this talk:
- **The maximum in the K^+/π^+ ratio as a fct $\sqrt{(s)}$, 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**

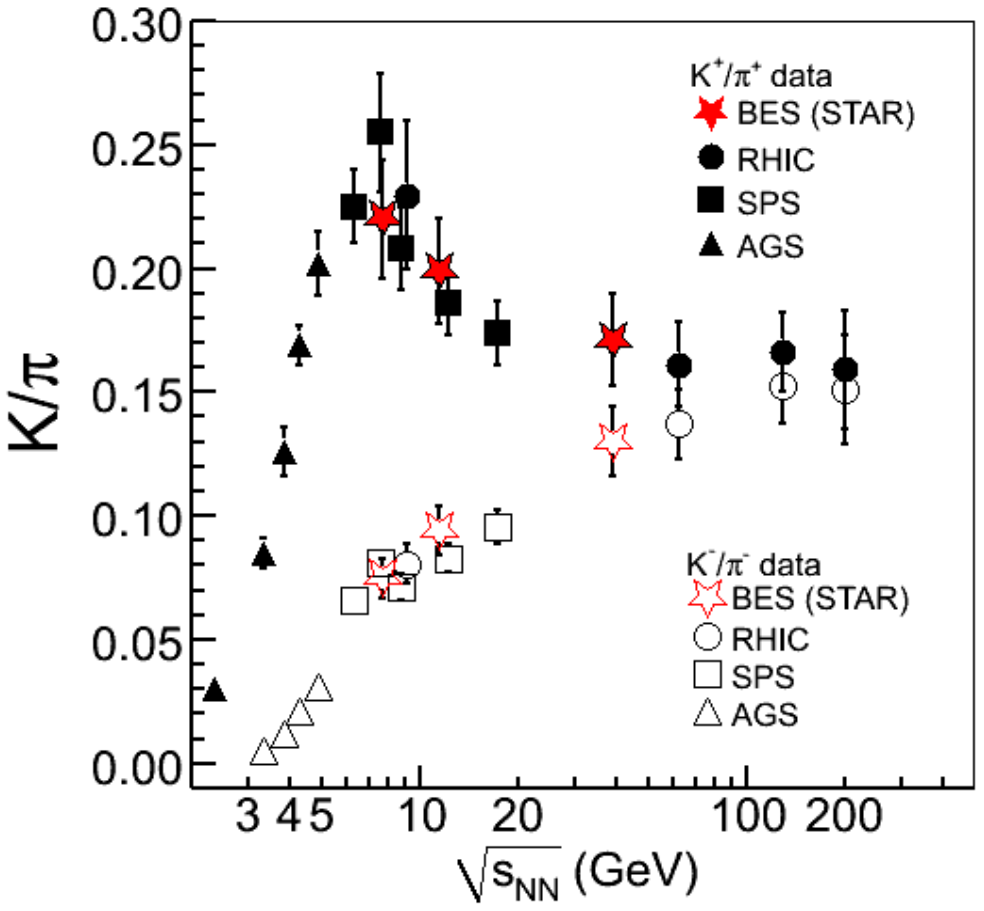


J. Cleymans, HO, K. Redlich, S. Wheaton, Phys. Rev. C 73 (2006) 034905



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

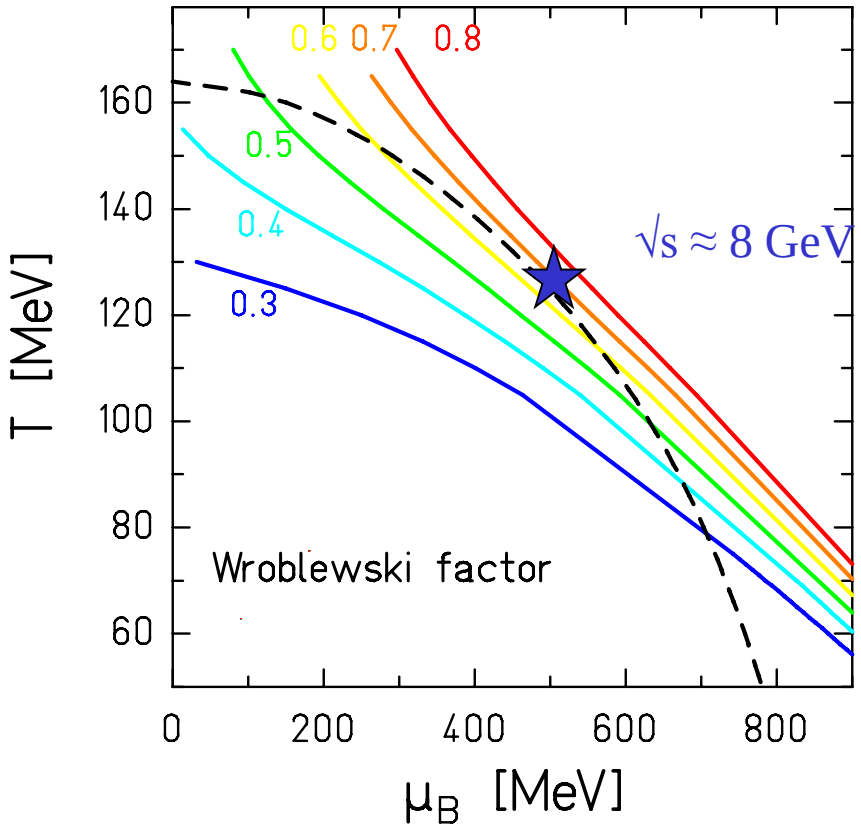
K^+/π^+ and K^-/π^-

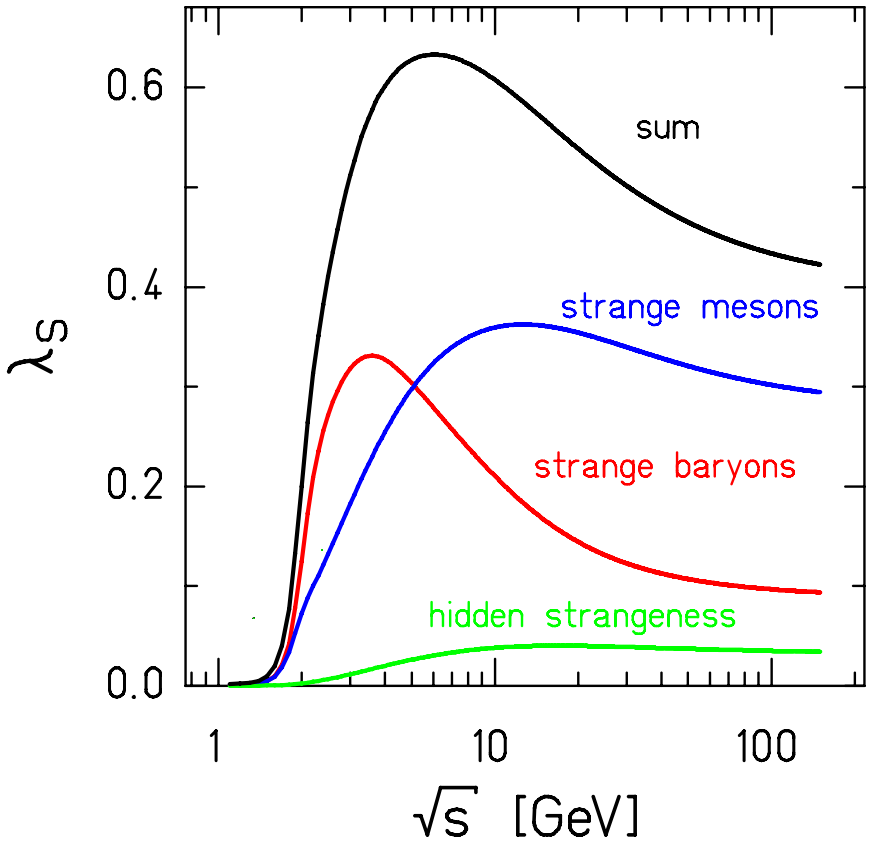


K^+ are produced together with a Λ

1. Onset of deconfined phase: M. Gazdzicki and M. I. Gorenstein, Acta Phys. Polon. B30, 2705 (1999), JHEP 0404, 050, 2004, PR C77, 024903, 2008
2. Described by thermal model: P. Braun-Munzinger, J. Cleymans, HO, K. Redlich, NPA 697(2002) 9021.

Maximum Strangeness around 30 AGeV





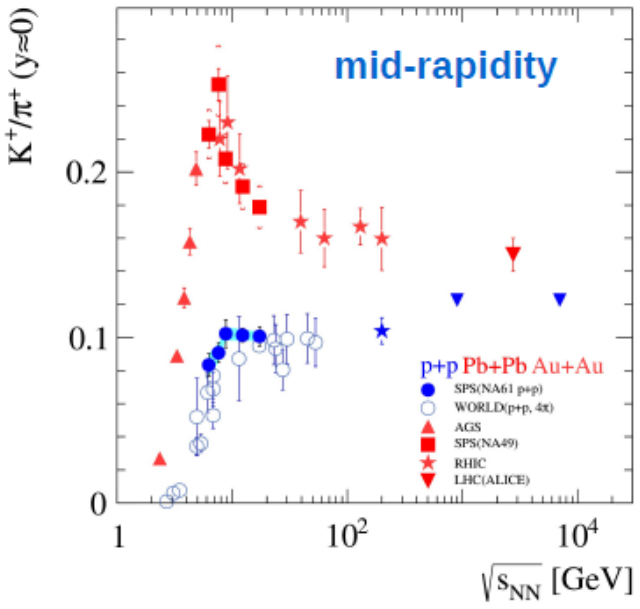
$$\lambda_s \equiv \frac{2\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle}$$

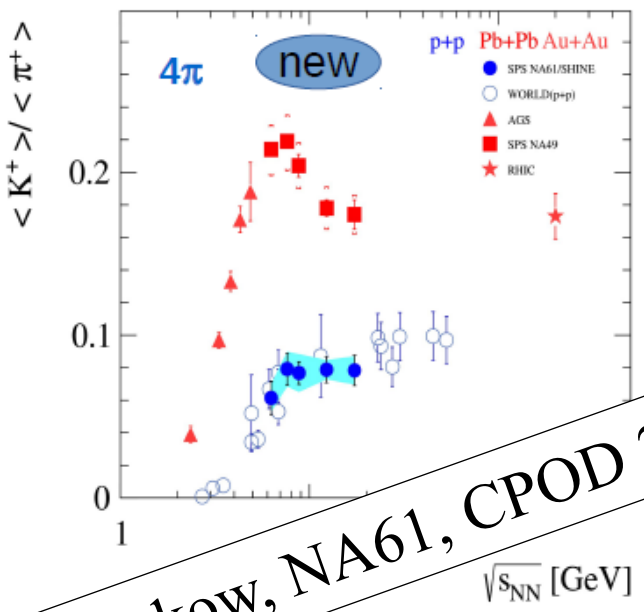
K^+ are produced together with a Λ, influence of μ_B

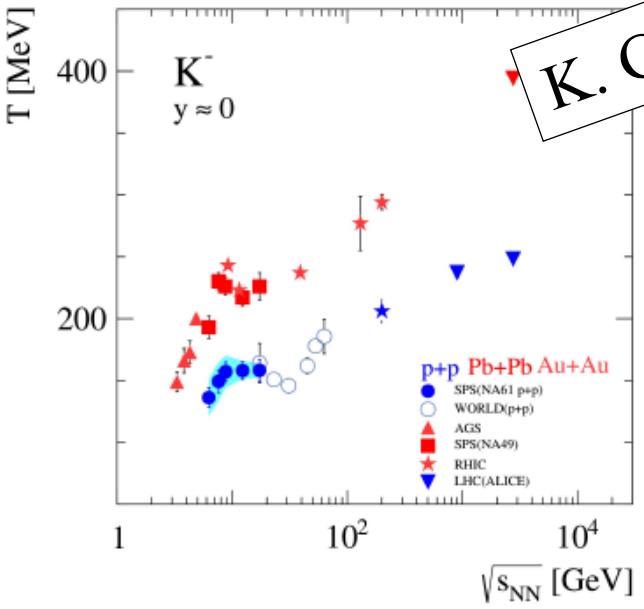
K^- together with a K^+

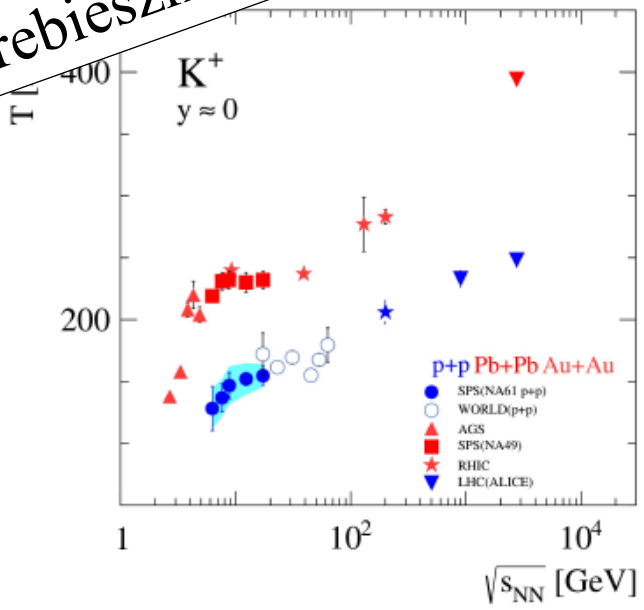
P. Braun-Munzinger, J. Cleymans, HO, K. Redlich, NPA 697(2002) 902

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









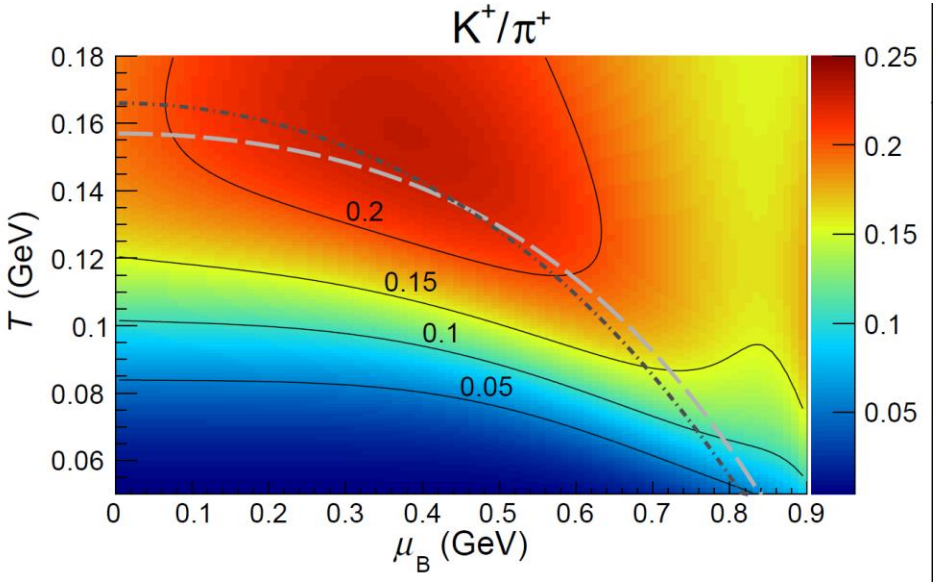
K. Grebieszkow, NA61, CPOD 2016

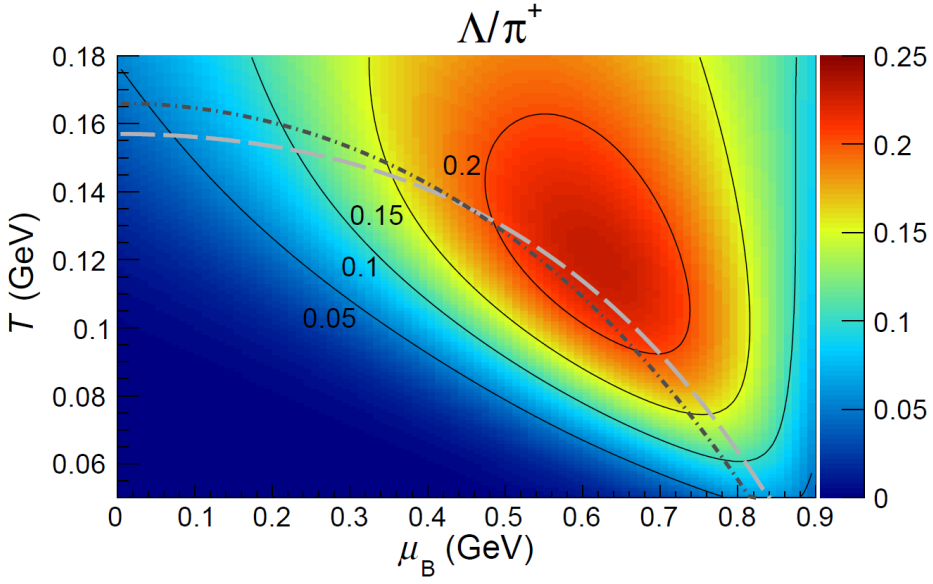
- For Pb+Pb sharp peak (**horn**) in K^+/π^+ ratio due to onset of deconfinement (OD) (APPB 30, 2705, 1999)
- For Pb+Pb ateau (**step**) in the erse slope parameter (T) of m_T spectra due to OD (constant T and p in mixed phase)
- Even **in p+p** the energy dependence of K^+/π^+ and T exhibits **rapid changes in the SPS energy range**

S. Puławski (for NA61), PoS CPOD2014, 010, 2015; and 2015 update (4π)

Maxima in a thermal model

arXiv:1603.09553





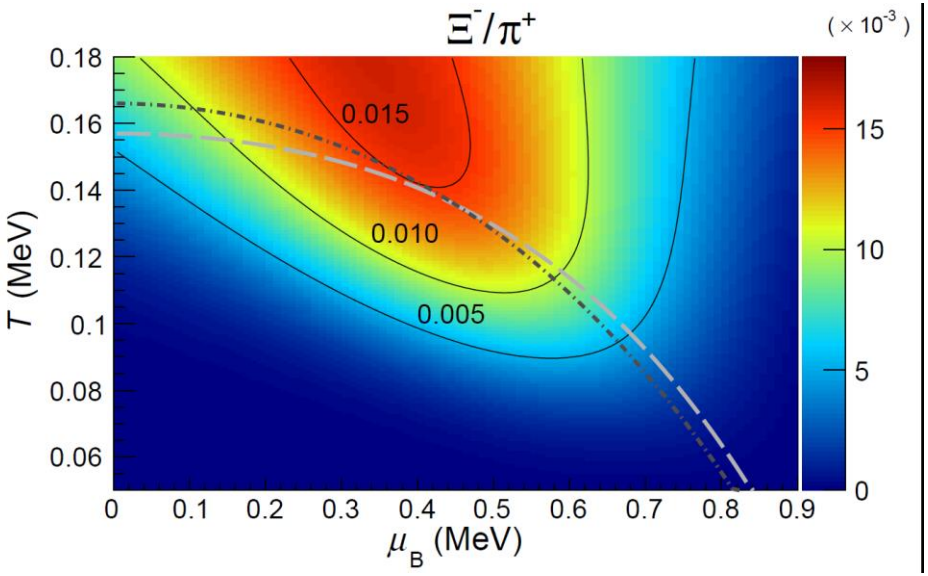
Parametrization of freeze-out line needs an update!

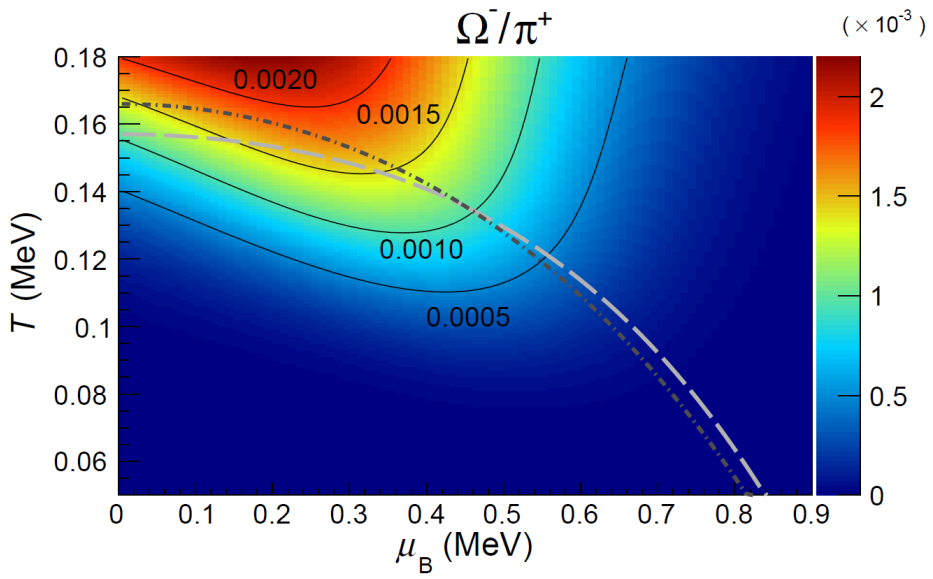
Here an old and a new one!

J. Cleymans, H. O., K. Redlich, and S. Wheaton, Phys. Rev. C73, 034905 (2006),
V. Vovchenko, V. V. Begun, and M. I. Gorenstein, 1512.08025

The maxima do NOT appear at the same √s!!!!

Again, maxima appear at different √s!!!





Canonical Approach = exact strangeness conservation

Pion density

$n(\pi) = exp(-E_\pi/T)$

Strangeness is conserved!

Kaon density

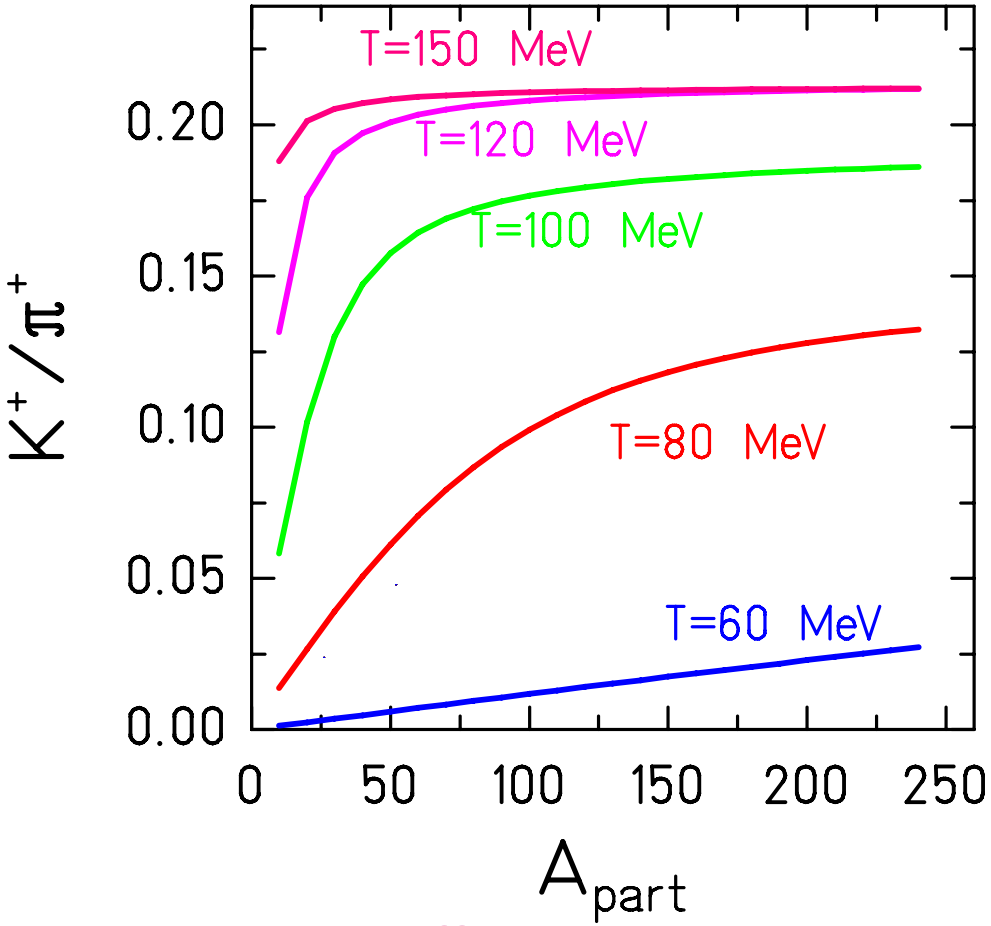
NN $\rightleftharpoons$ N Λ K^+

$n(K) = exp(-E_K/T)$

$[g\ V \int ... exp[-(E_\Lambda - \mu_B)/T]$

J. Cleymans, HO, K. Redlich,

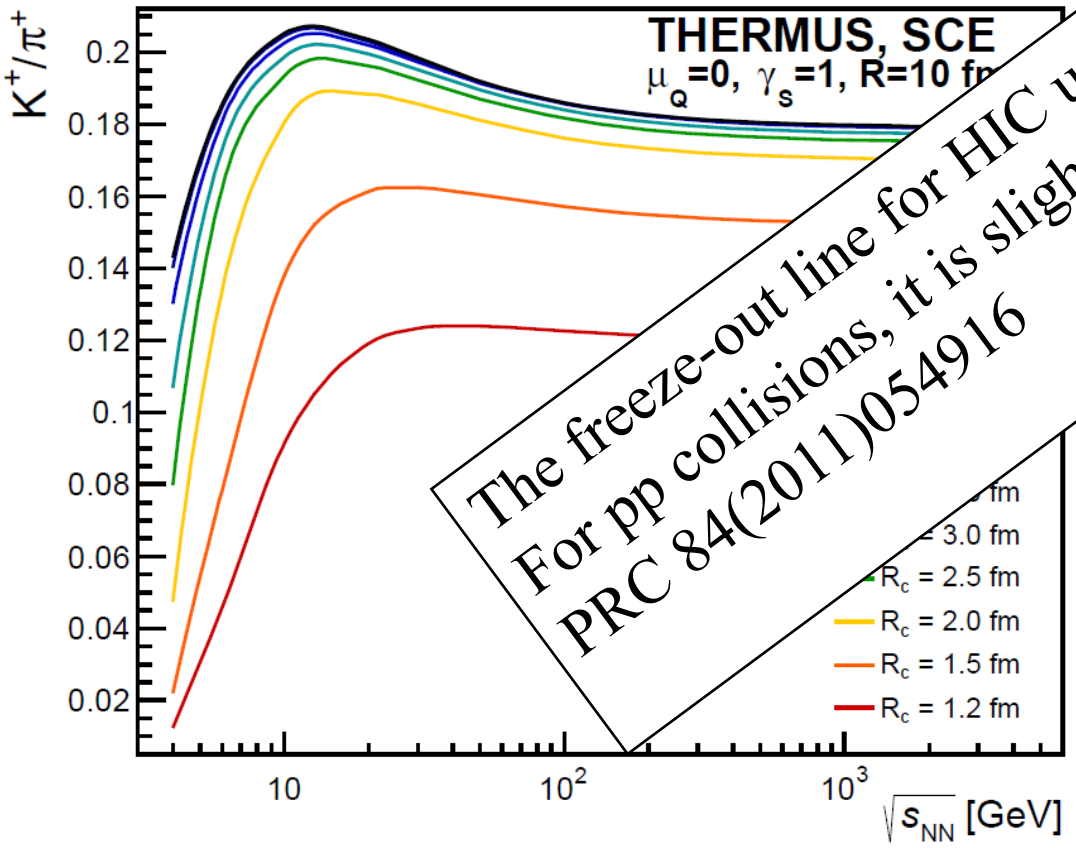
PRC 60 (1999)



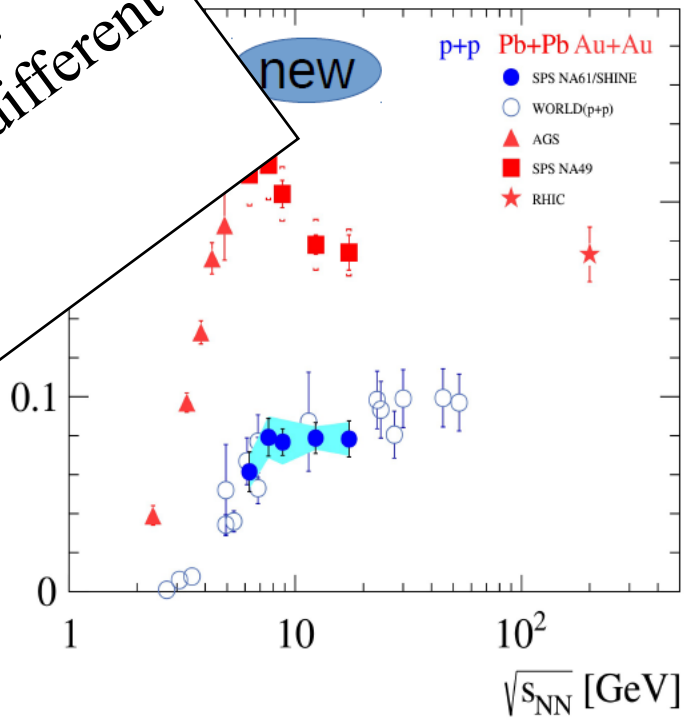
Equations in the model are different!

$$n_i^{canonical} \approx n_i^{grand-canonical} \cdot \frac{I_S(x)}{I_0(x)}$$

Calculation along the chemical freeze-out line (151[illegible]08025)

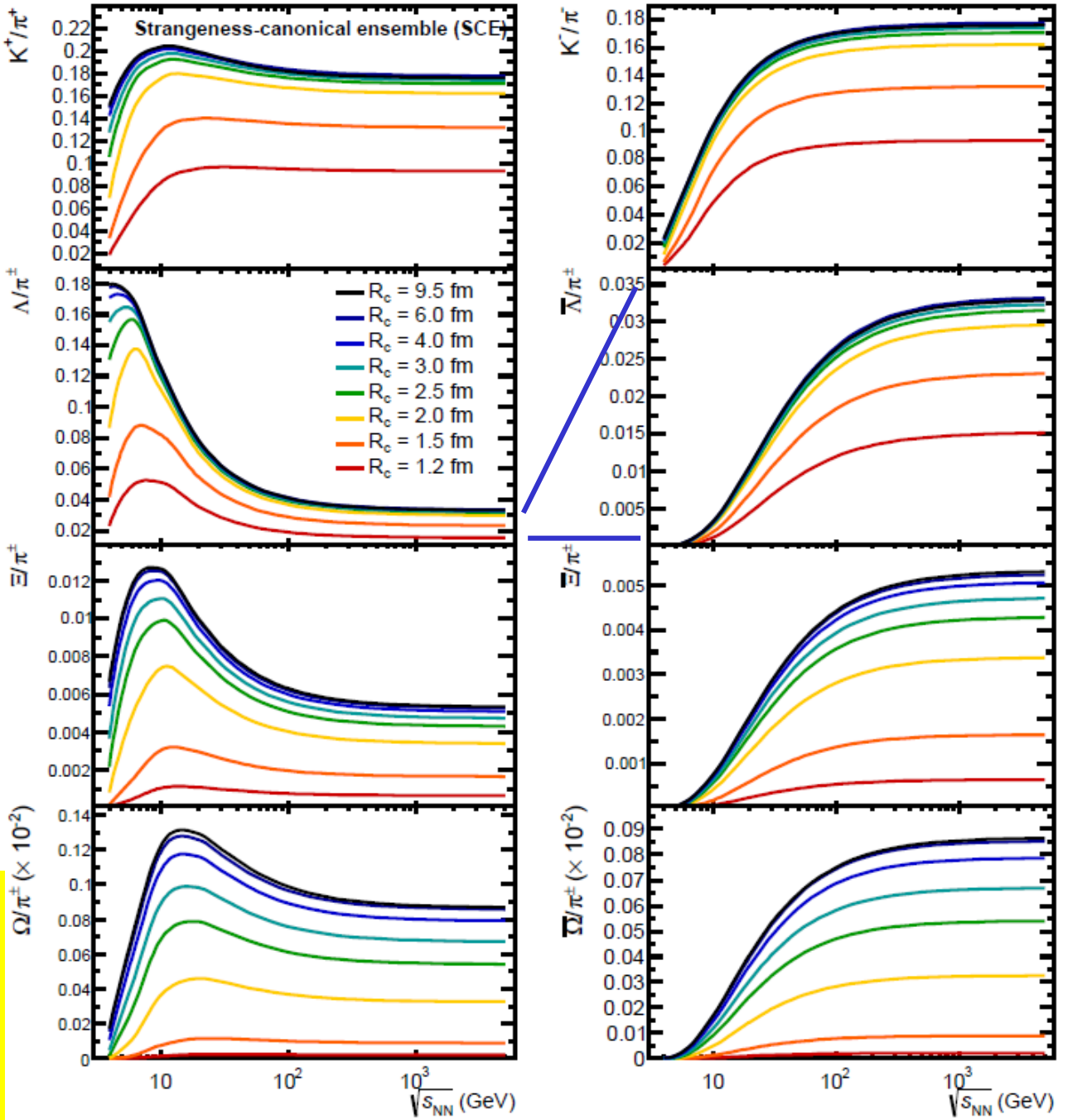


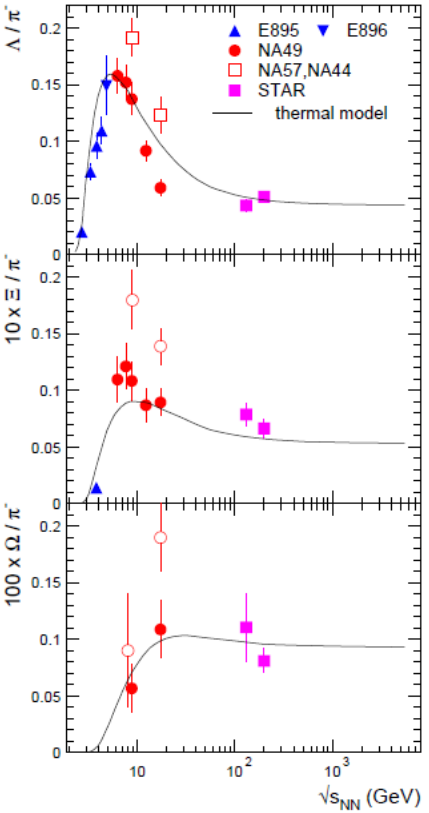
The freeze-out line for HIC used!
For pp collisions, it is slightly different
PRC 84(2011)054916



CPOD K. Grebieszkow

arXiv:1603.09553



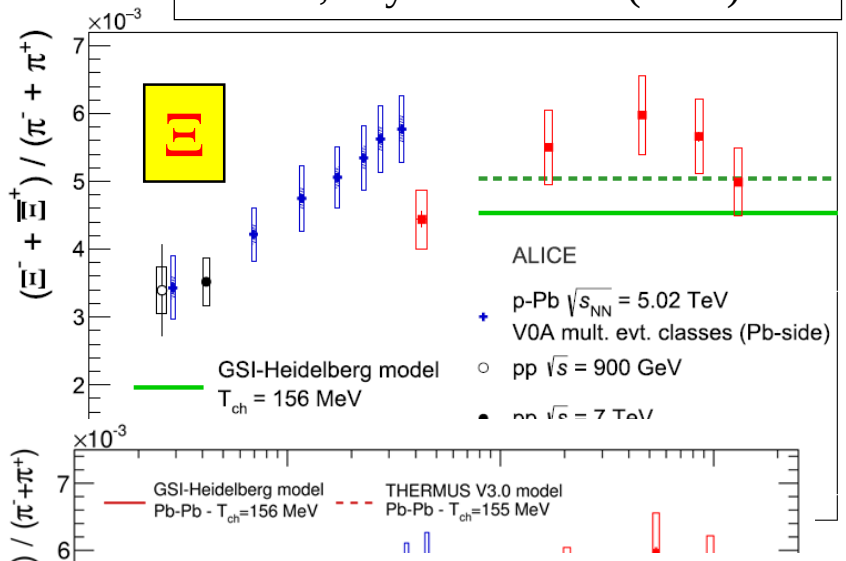


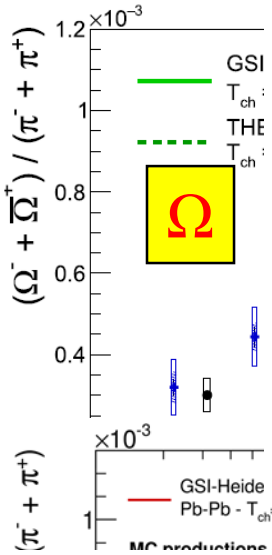
A. Andronic et al.,
Nucl.Phys. A837 (2010) 65

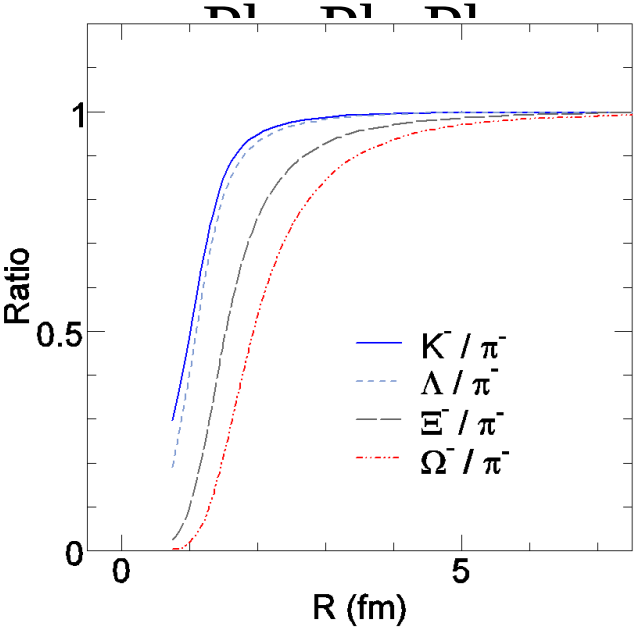
arXiv:1603.09553

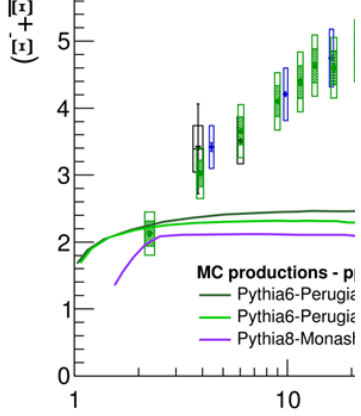
Strangeness canonical suppressior

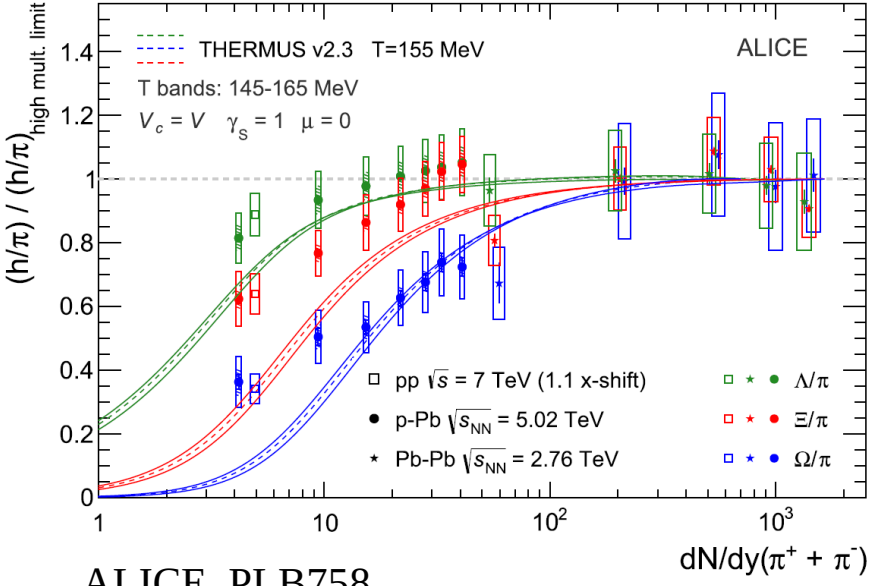
ALICE, Phys.Lett. B758 (2016) 389

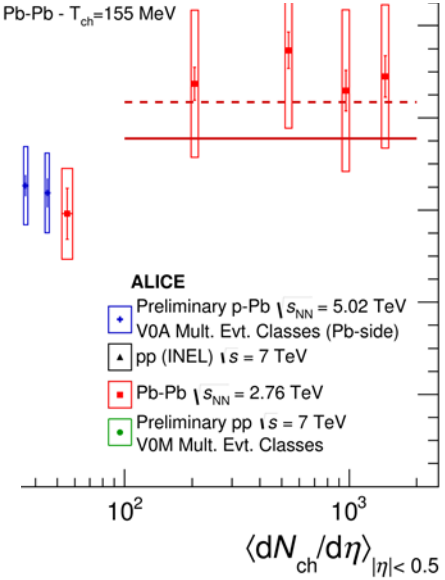












ALI-PREL-98750

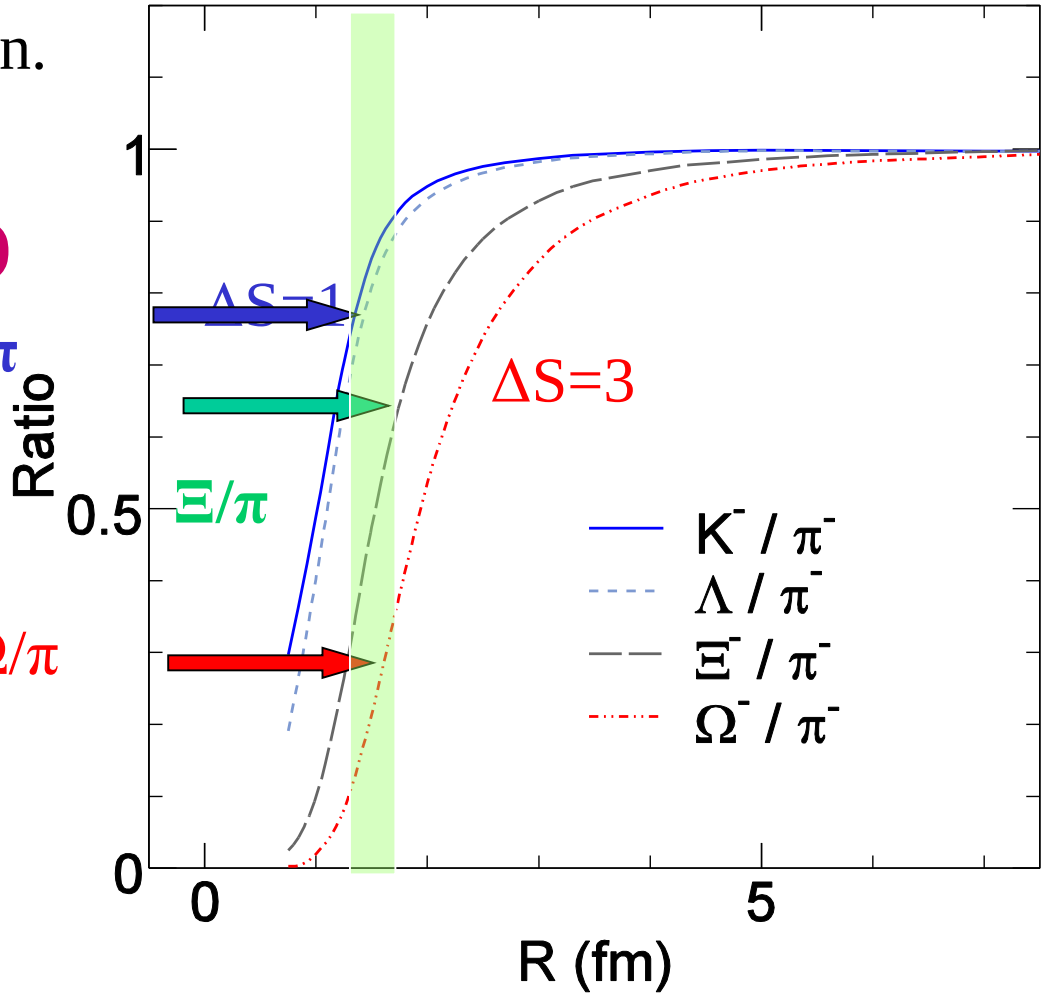
arXiv:1606.07424

ALICE, PLB758

Testing Canonical Suppression at the LHC

can./grand can.

Measured ratio(pp)/ratio(PbPb)



Example:

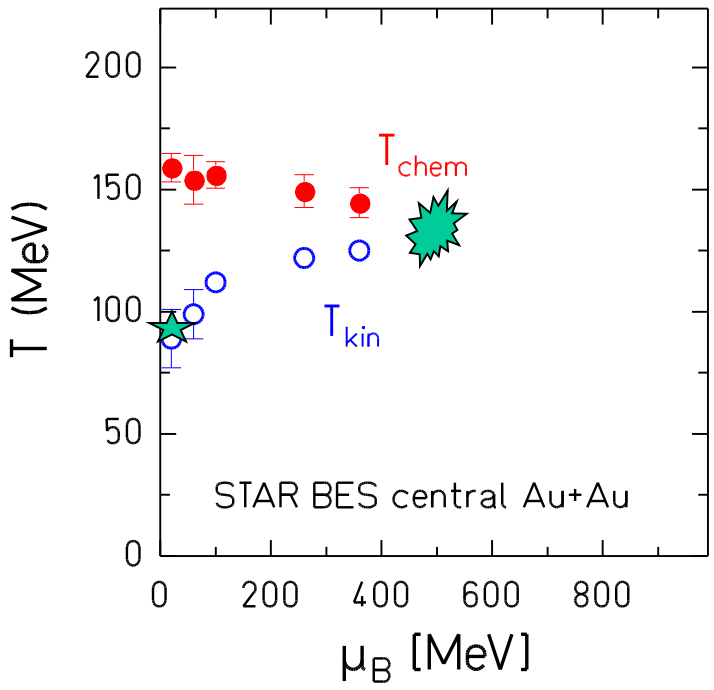
T = 170 MeV

μ_B = 1 MeV

Values for LHC

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

$T - \mu_B$ plane



At LHC and RHIC:

$T_{chem} > T_{kin}$

At SIS and AGS:

$T_{chem} = T_{kin}$

In central Pb-Pb:

$T_{chem} =$

$T_{kin} = 95 \pm 10$ MeV

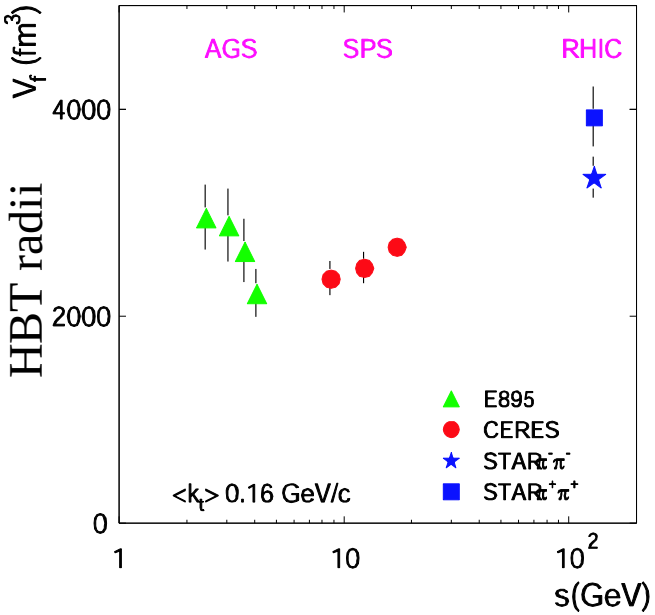
ALICE

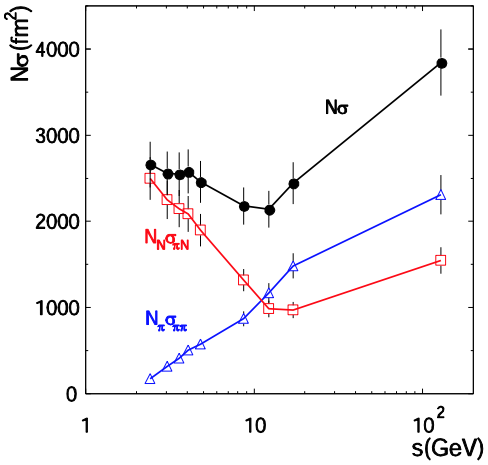
Phys. Rev. Lett. 109, 252301 (2012)

Long phase between chem. and kin. freeze out!!!
Large HBT radii!!

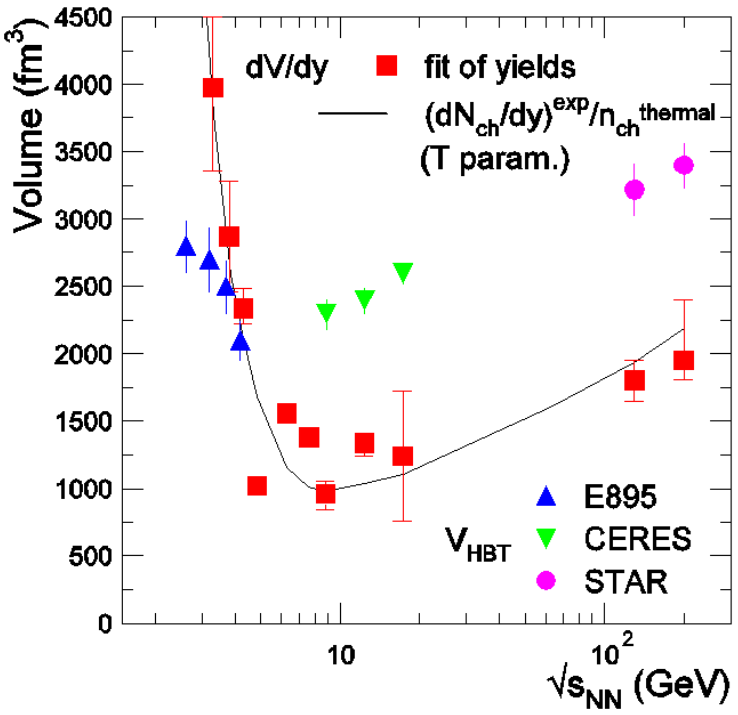
Freeze-Out Volume

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





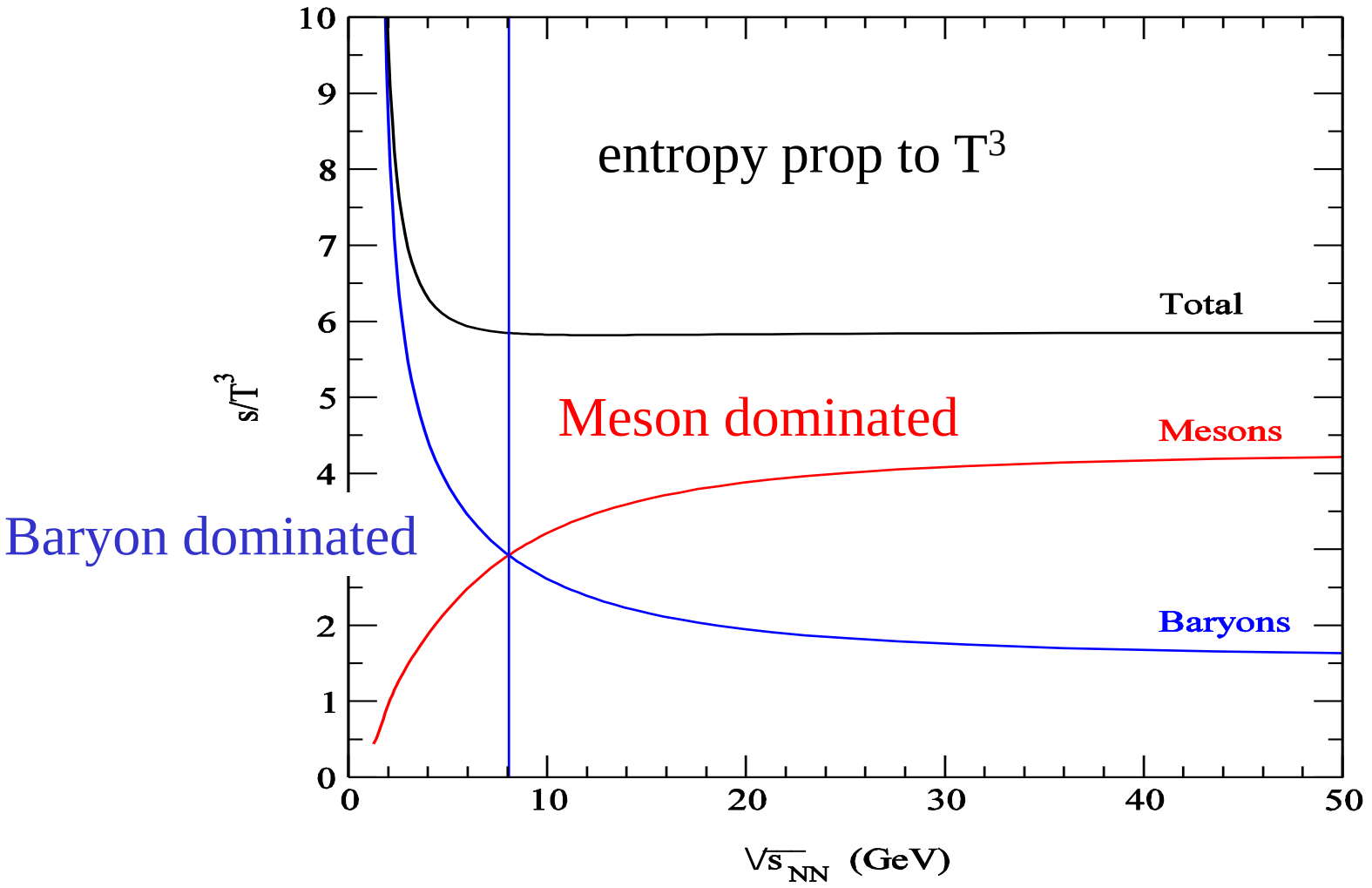
√



A. Andronic, P. Braun-Munzinger, J. Stachel, NPA772(2006) , Acta Phys. Pol. B40 (2009)

Transition from baryonic to mesonic freeze out

J. Cleymans, H.O., K. Redlich, S. Wheaton, Phys. Lett. B615 (2005)

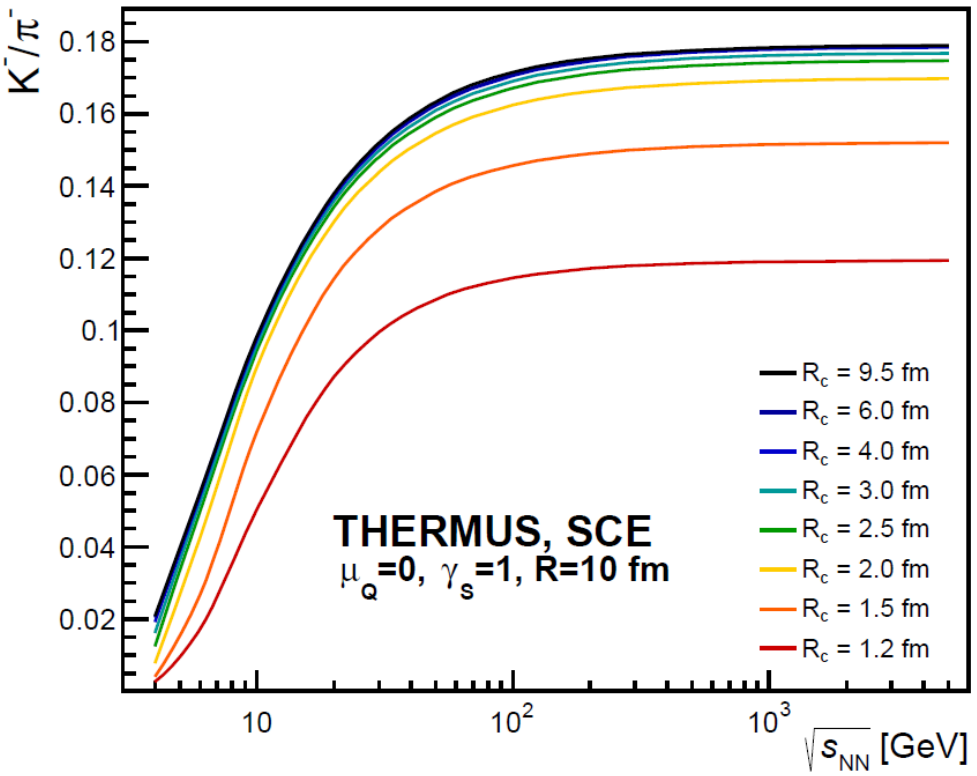


Conclusions

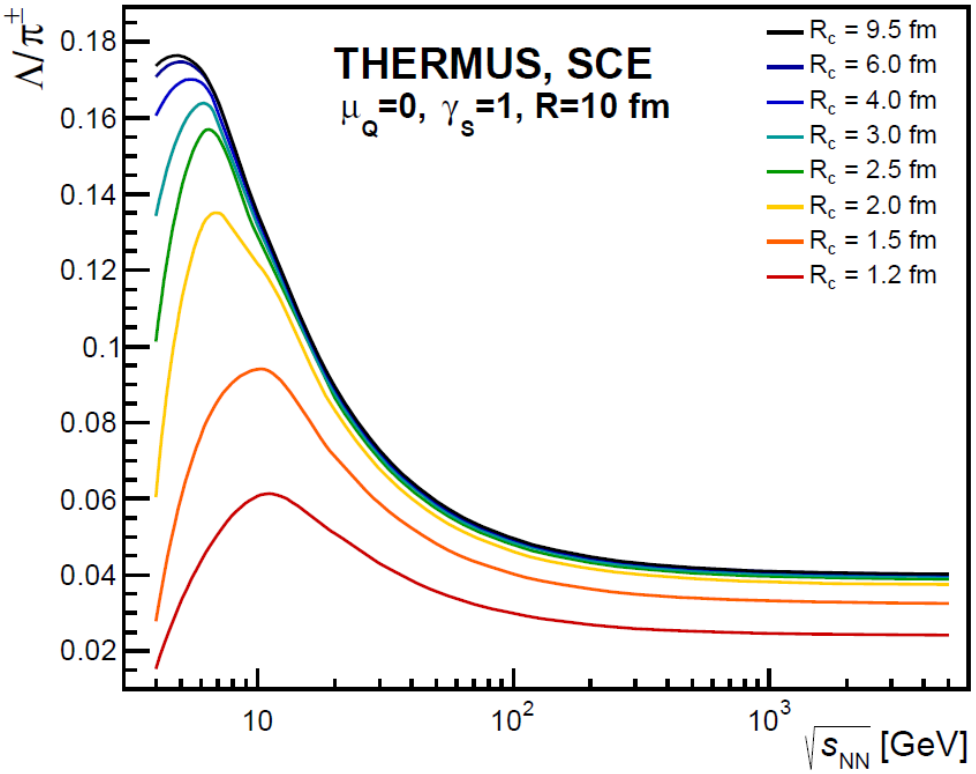
- Maximum in K^+/π^+ and smooth rise of K^-/π^- can be described by statistical model caused by saturation in T and reduction of μ_B. Associate production of K^+ together with Λ!
- Predicts: HIC: Maxima in Λ, $\sum$, and Ω over π at different $\sqrt{s}$!
- Predicts: For smaller systems: maxima gradually disappear except for Λ/π.
- At these energies: A transition from baryon to meson dominated freeze out.


Thank you!

K−/π-

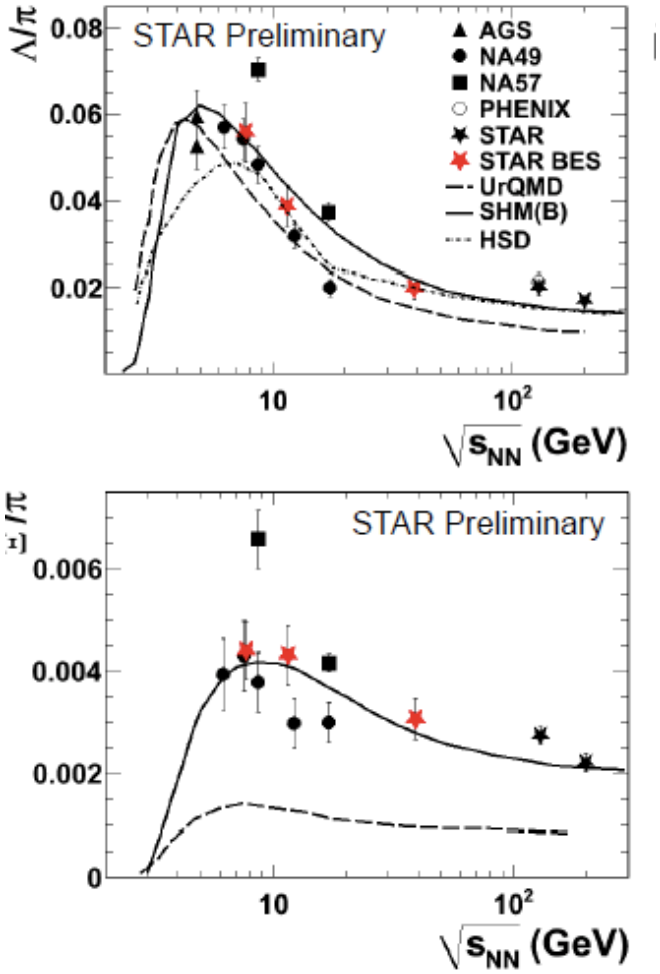

K⁻/π⁻
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
10
10²
10³
√s_NN [GeV]
THERMUS, SCE
μ_Q=0, γ_s=1, R=10 fm
R_c = 9.5 fm
R_c = 6.0 fm
R_c = 4.0 fm
R_c = 3.0 fm
R_c = 2.5 fm
R_c = 2.0 fm
R_c = 1.5 fm
R_c = 1.2 fm

Prediction: Λ/π 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 Ω/π ratio to see whether the maximum is at a higher √s!

Predictions for LHC

Prediction for heavy ions:

Grand can. (blue)

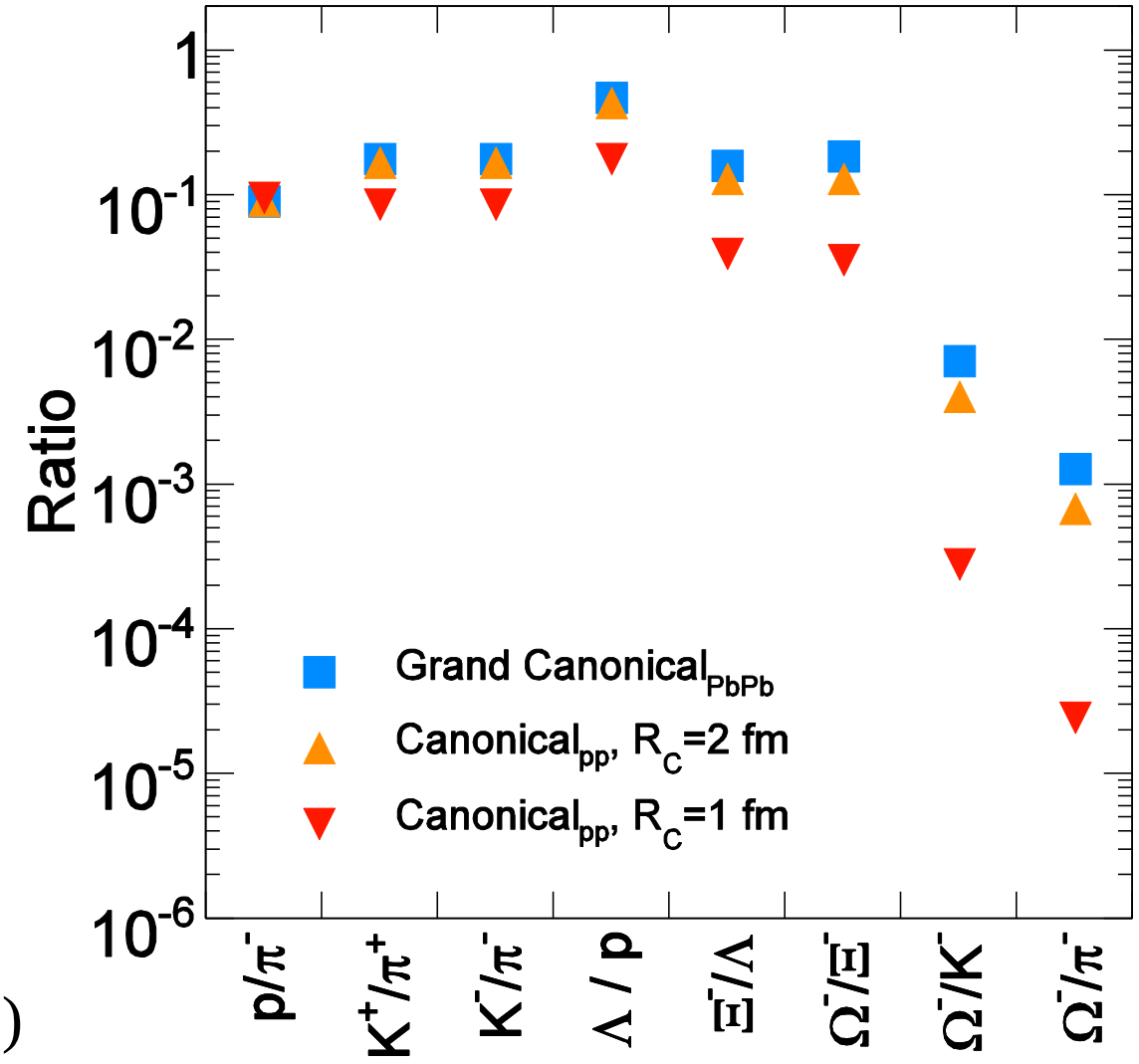
I. Kraus et al.,

PRC 74 (2007)

For pp collisions:

Canonical (yellow and red)

I. Kraus et al.,
PRC 79(2009)

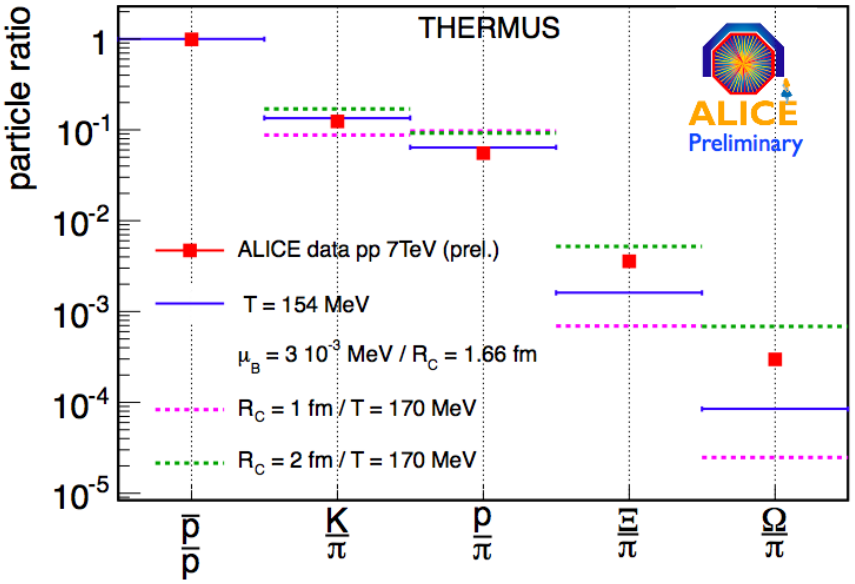


Around √s 8 -12 GeV things are happening!

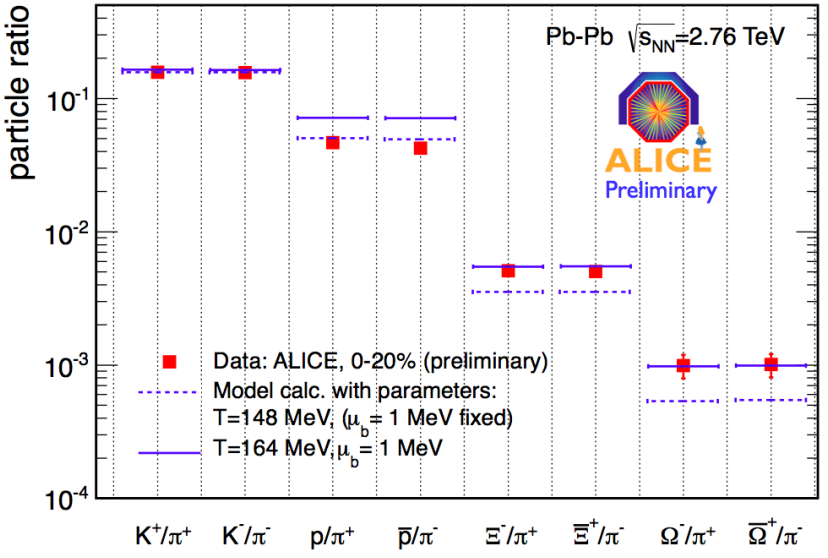
- slope of spectra is not increasing
- T_{chem} and T_{kin} separate
- Volumina have minimum

LHC Energies

pp 7 TeV



Pb-Pb 2.76 TeV



p/π the same in pp and Pb-Pb,

BUT lower than expected from stat. models

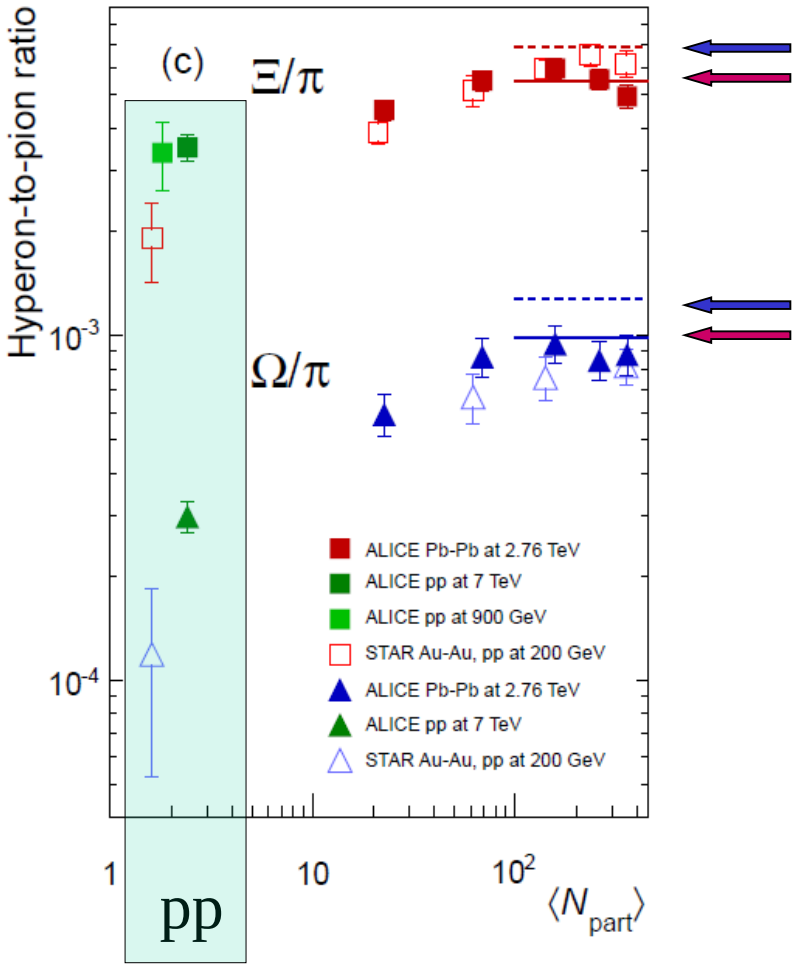
K/π in pp is lower than in Pb-Pb, expected from stat. model!

Strangeness is okay! **Fitting with γ_s -> around 1**

Centrality Depedence of Multi-strange Baryons

ALICE Coll.

PL B728 (2014) 216

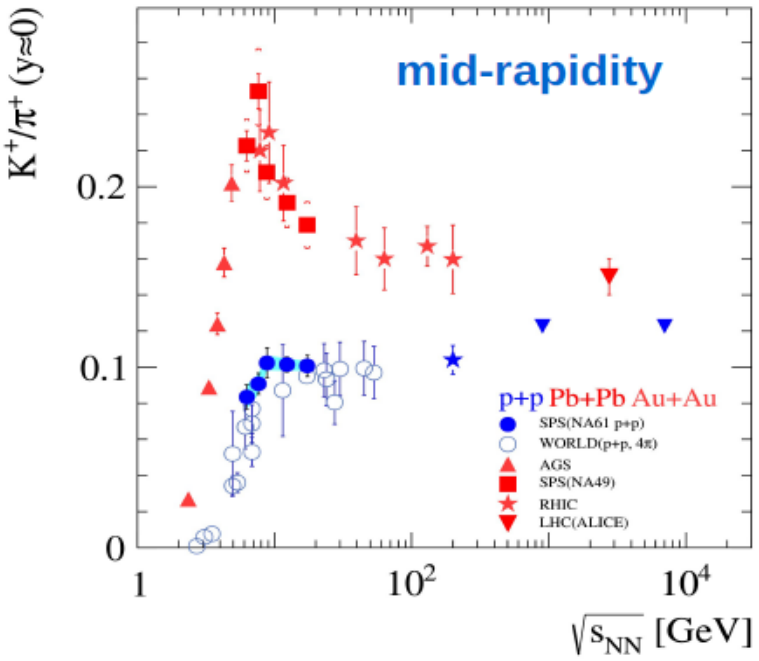


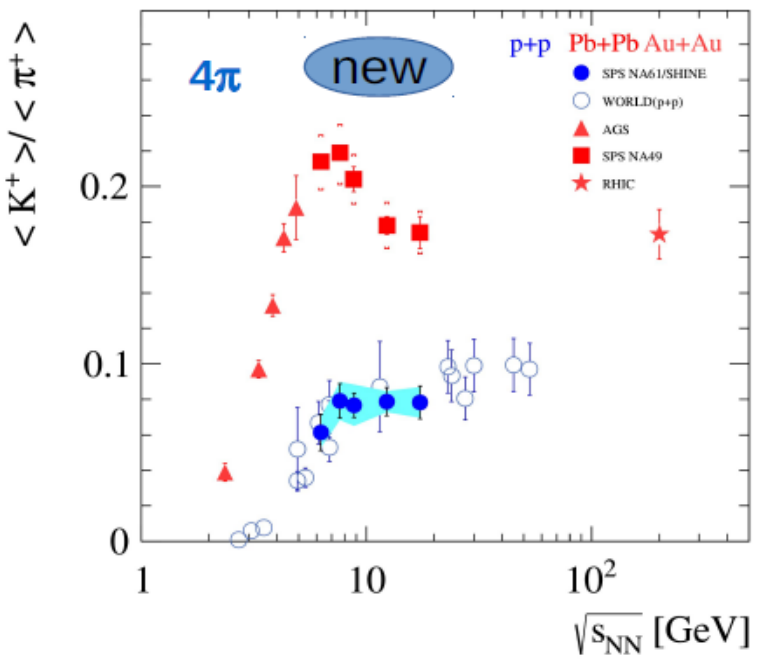
Predictions with

T = 170 MeV (J. Cleymans et al.)

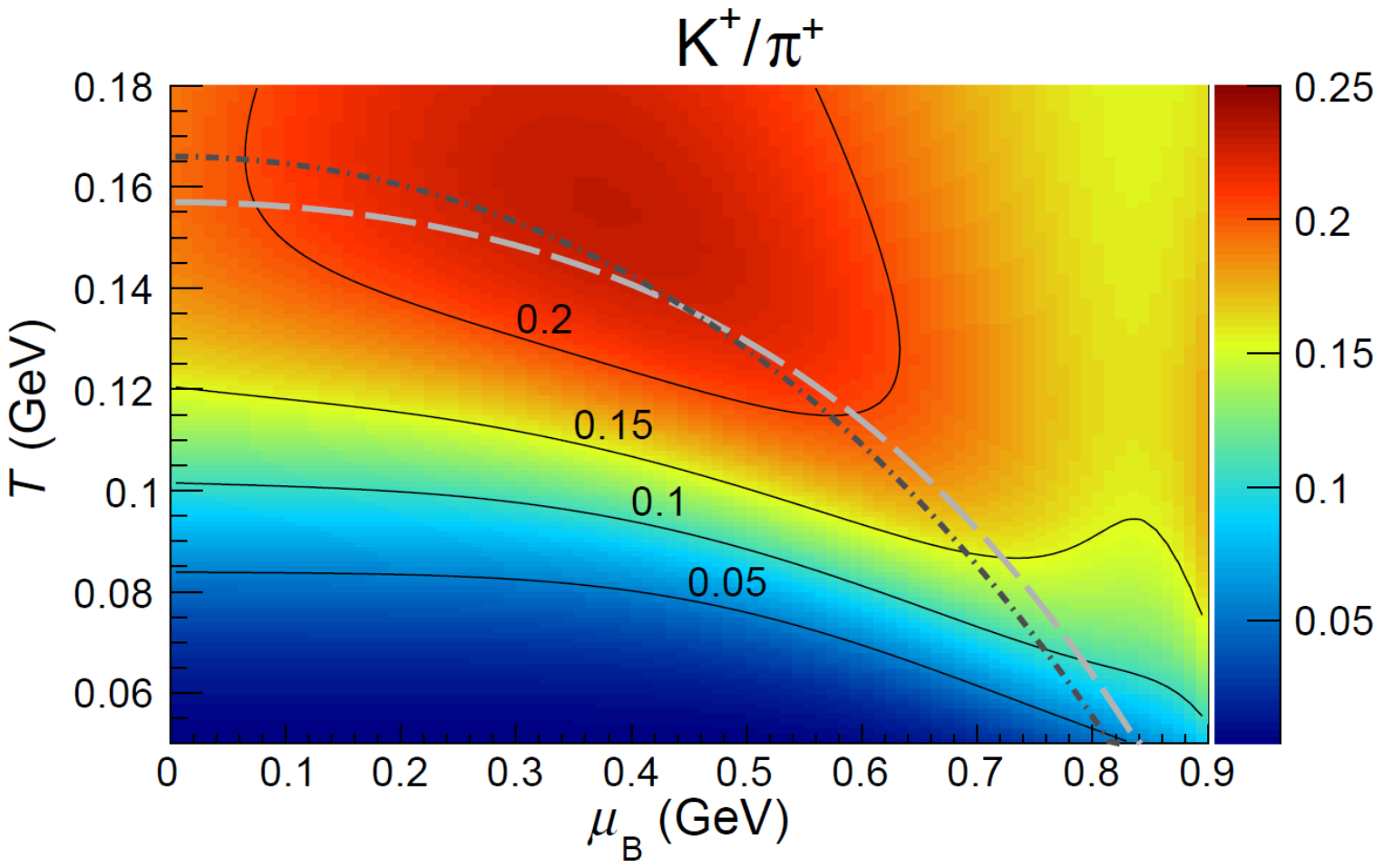
T = 164 MeV (A. Andronic et al.)

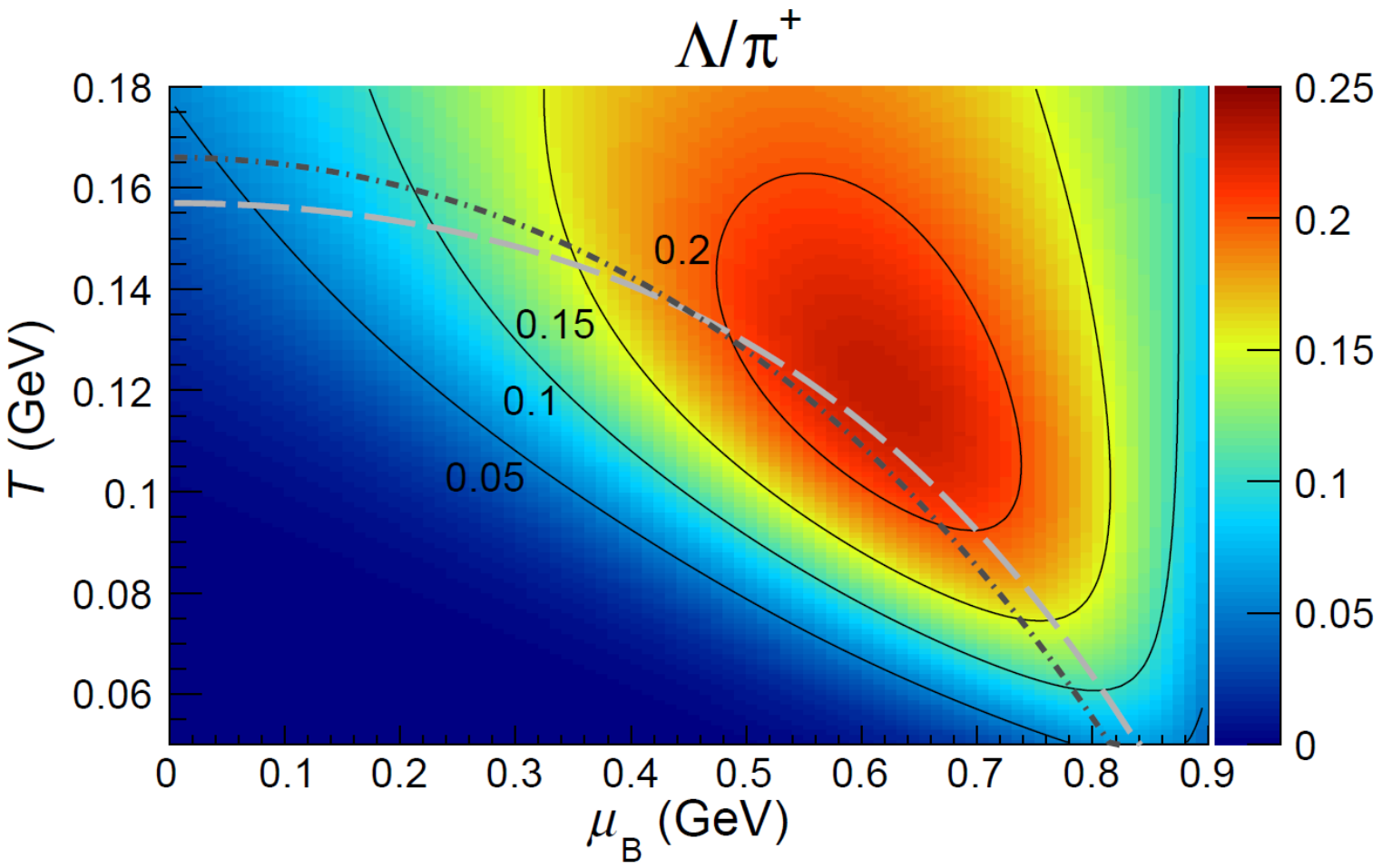
K. Grebieszkow (NA61/SHINE): Maximum in the K^+/π^+ ratio disappears in small systems

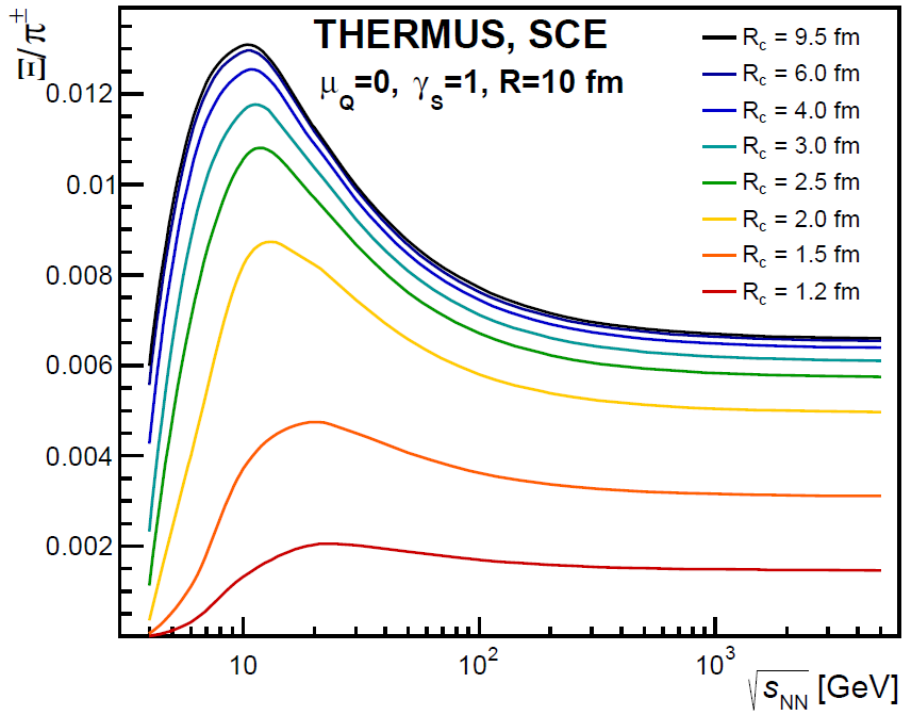


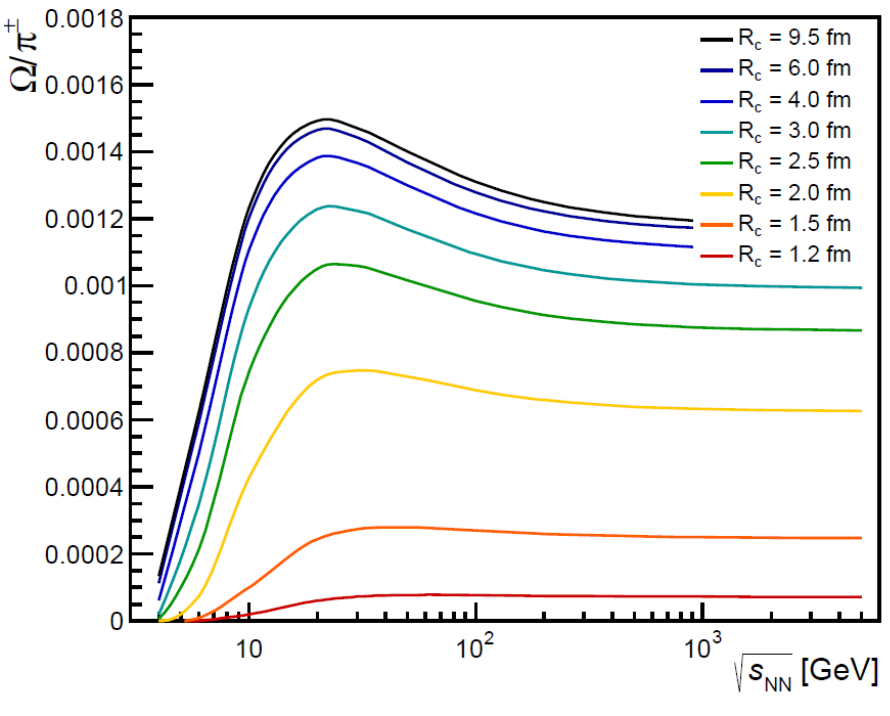


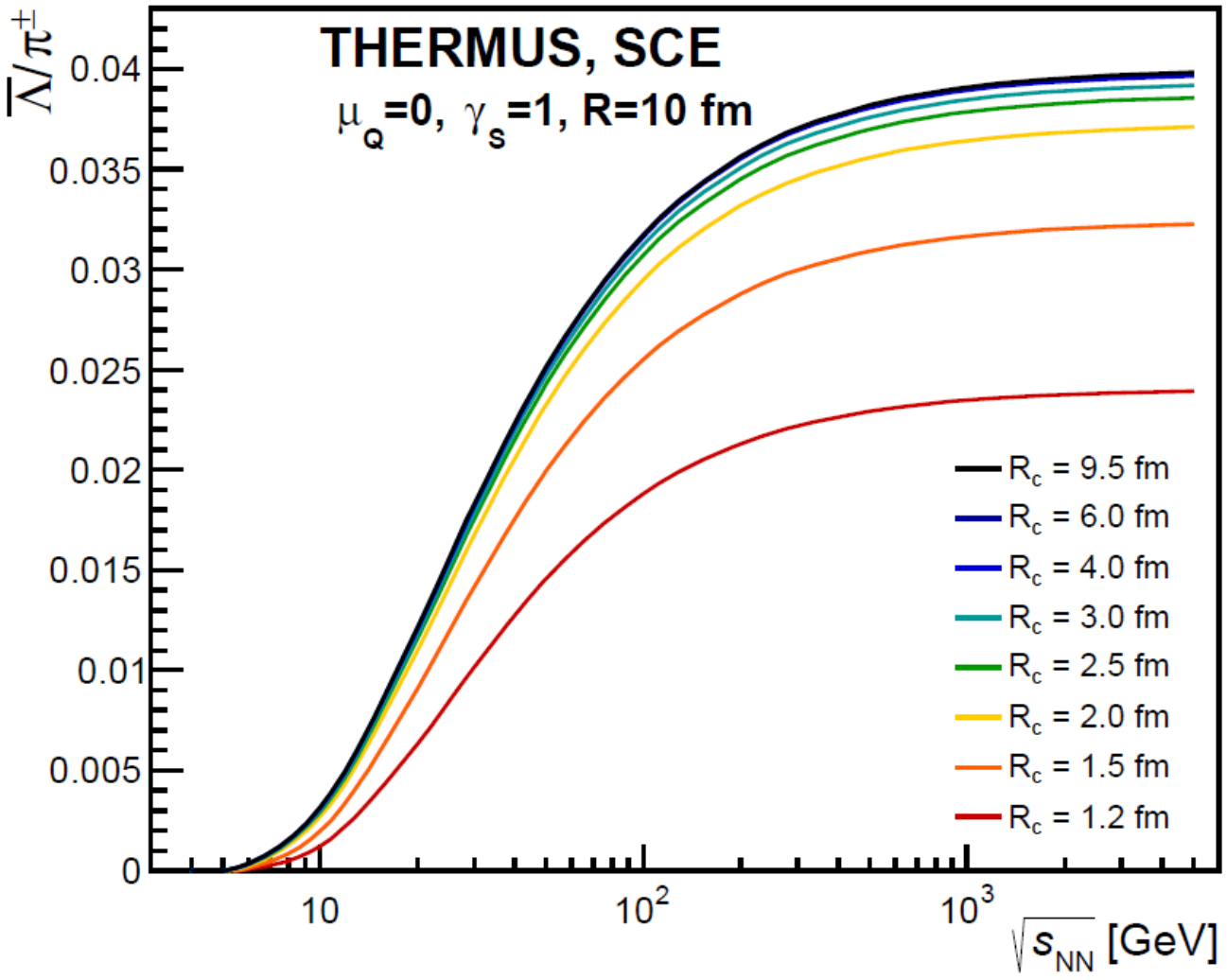
Why happens a maximum in the K+/pi ratio?




Λ/π^+
0.18
0.16
0.14
0.12
0.1
0.08
0.06
T (GeV)
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
μ_B (GeV)
0.25
0.2
0.15
0.1
0.05
0


THERMUS, SCE
μ_Q=0, γ_s=1, R=10 fm
Ξ/π^+
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
0.012
0.01
0.008
0.006
0.004
0.002
10
10^2
10^3
$\sqrt{s_{NN}}$ [GeV]


Ω/π^+
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
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
10
10^2
10^3
$\sqrt{s_{NN}}$ [GeV]


THERMUS, SCE
μ_Q=0, γ_s=1, R=10 fm
$\overline{\Lambda}/\pi^{\pm}$
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
10
10^2
10^3
$\sqrt{s_{NN}}$ [GeV]
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_{chem} -> T_{kin} (rescattering)**
- Blast wave in Pb-Pb: T around 100 MeV, high β
- **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**