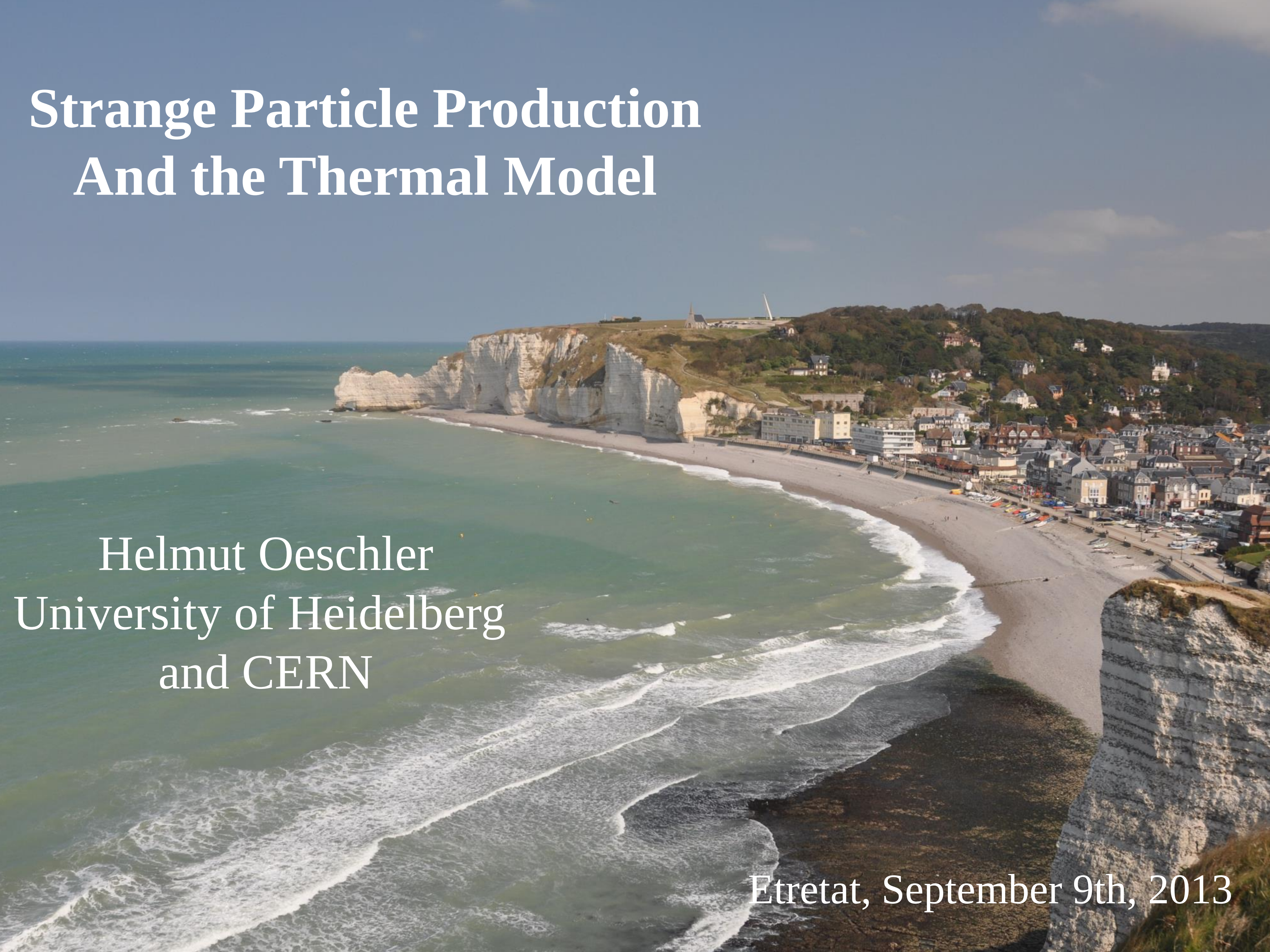


Strange Particle Production And the Thermal Model

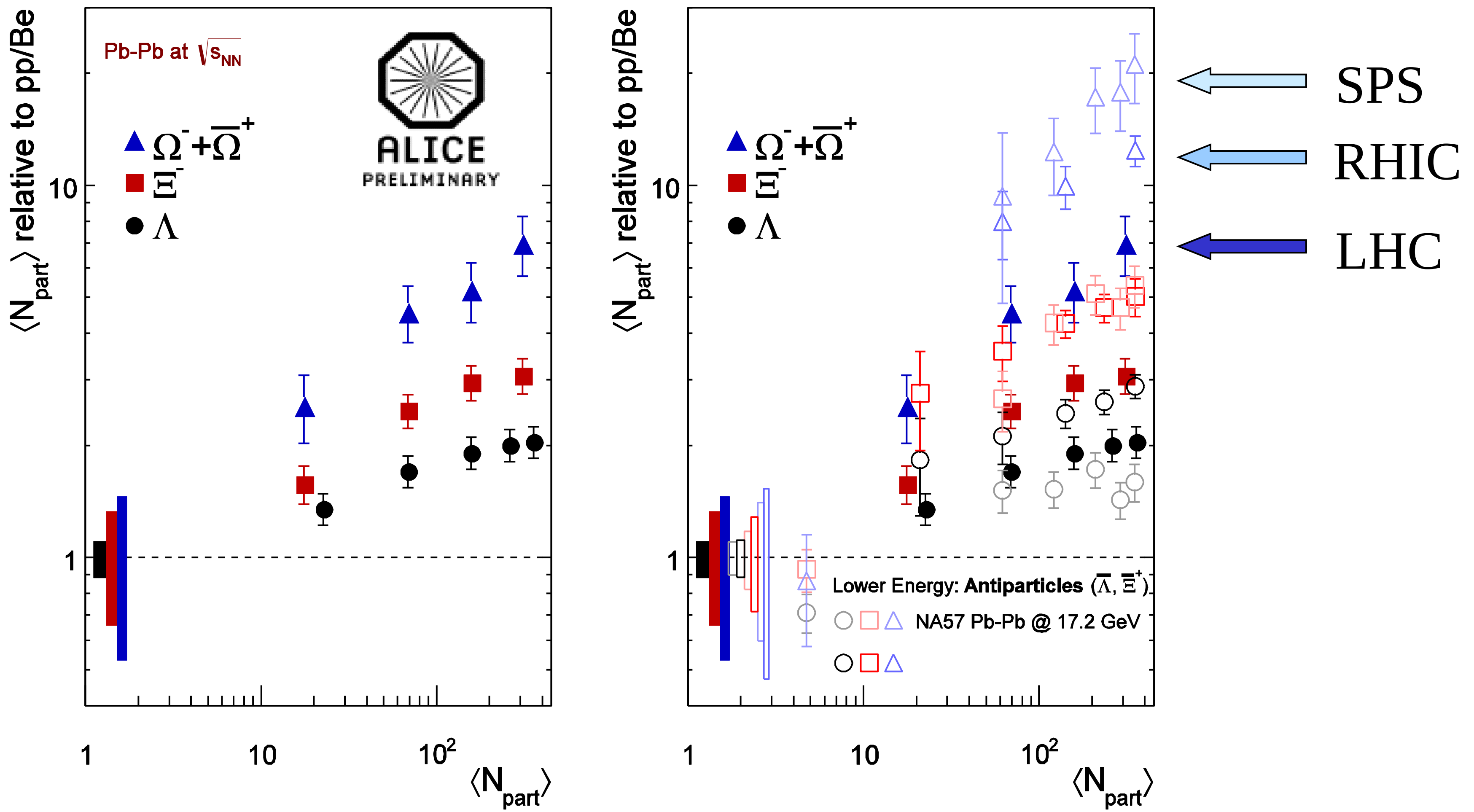
Helmut Oeschler
University of Heidelberg
and CERN

Etretat, September 9th, 2013

Outline

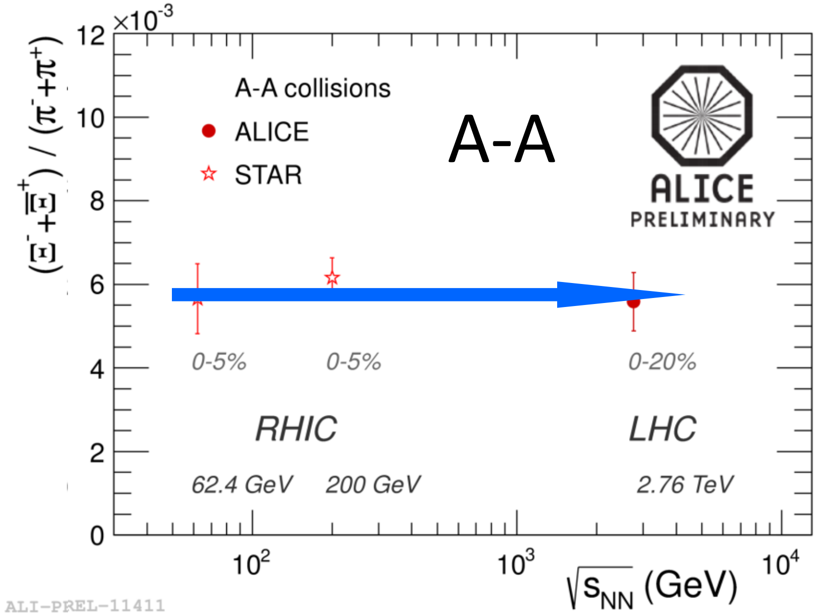
- Strangeness enhancement studied up to LHC energies
- Comparison pp and heavy-ion collisions
- Baryon-meson ratios: quark recombination or?

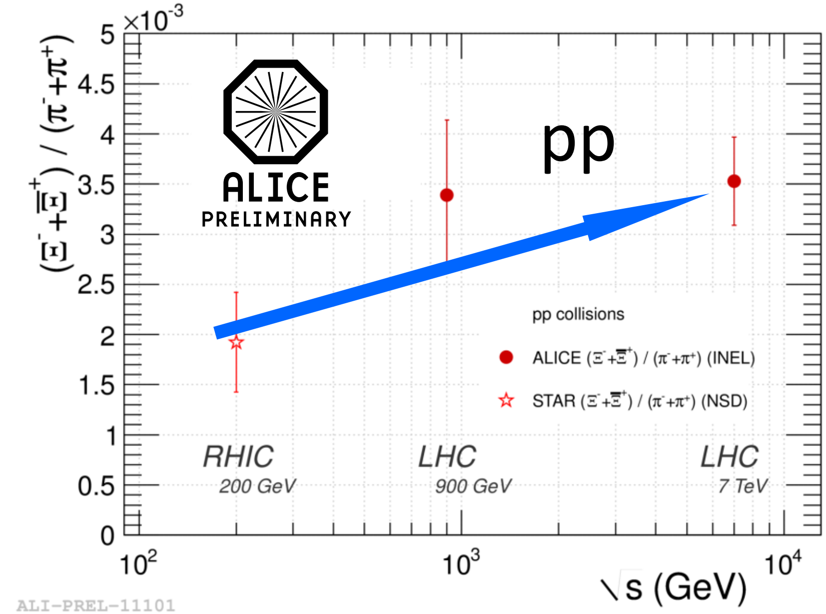
Strangeness Enhancement



What causes the decrease? An increase in pp or a decrease in Pb-Pb

Strangeness in pp and Pb-Pb





In HIC, the ratio Ξ/π remains constant, while in pp it rises!

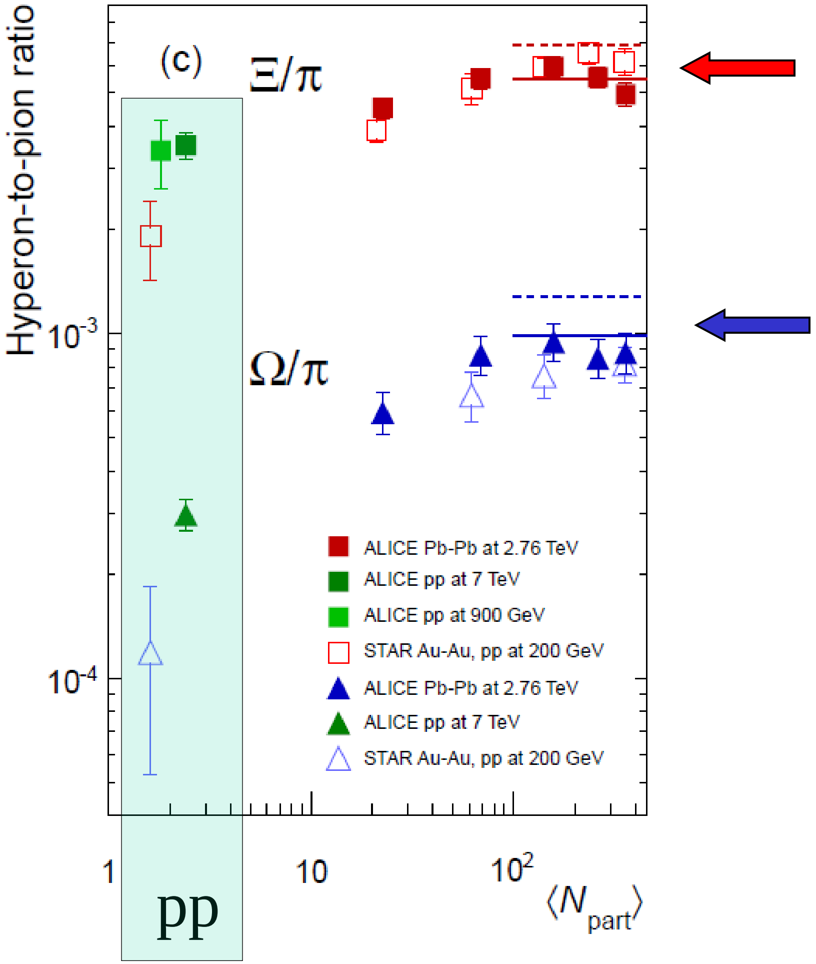
Enhancement well explained by thermal model!

No sign for QGP per se!

Multistrange in Pb-Pb

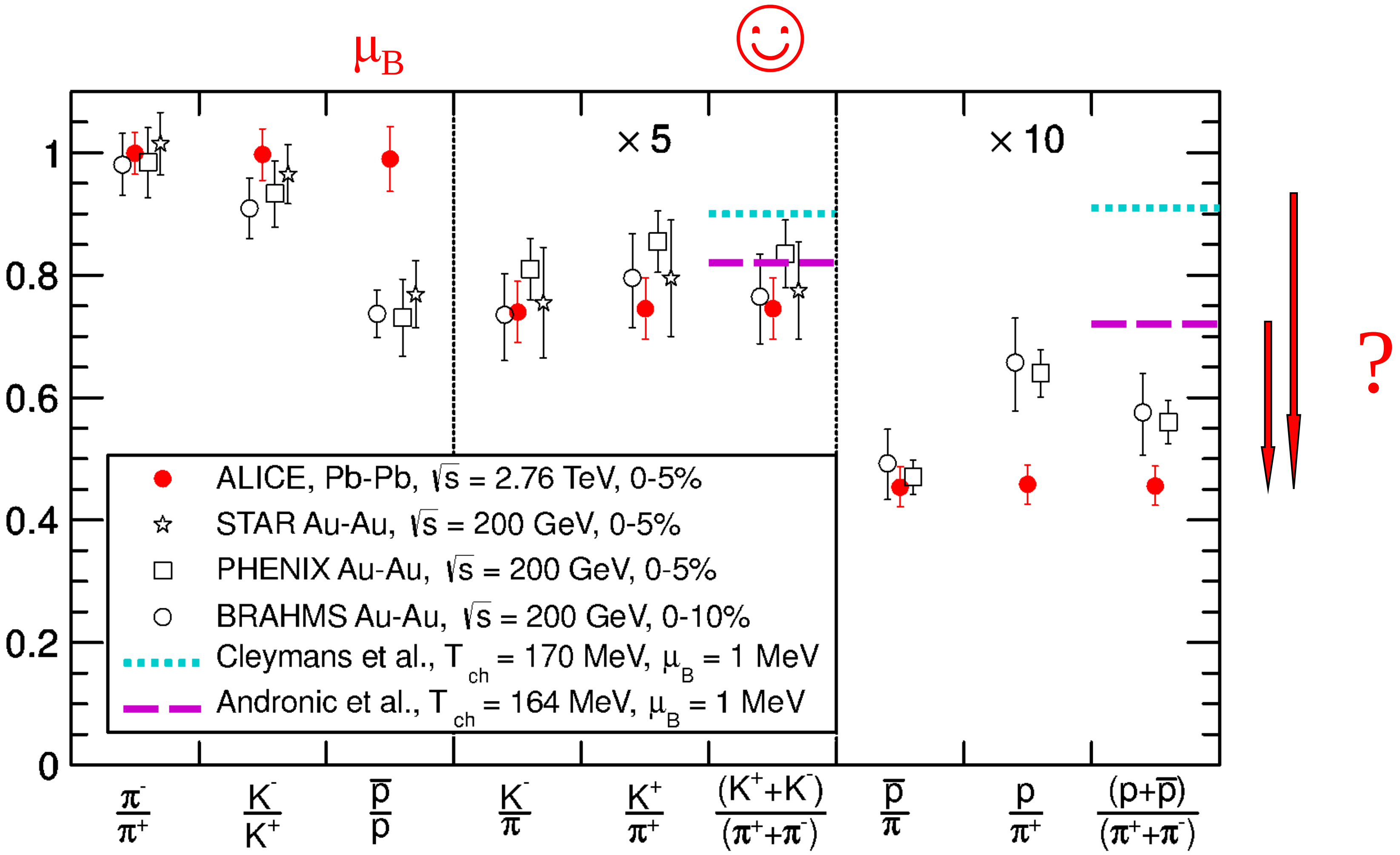
ALICE Coll.

arXiv:1307.5543



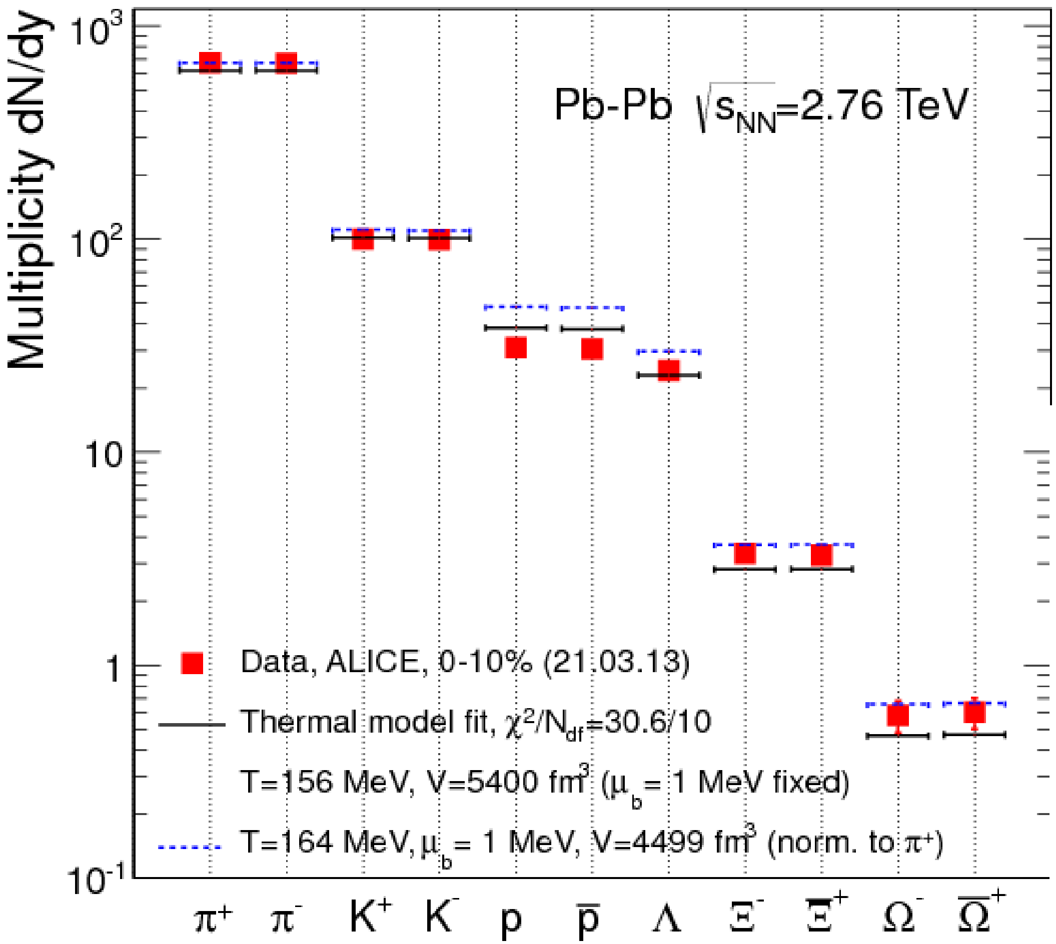
Predictions with T = 164 (A. Andronic et al.)/ 170 MeV (J. Cleymans et al.)

Particle ratios at LHC

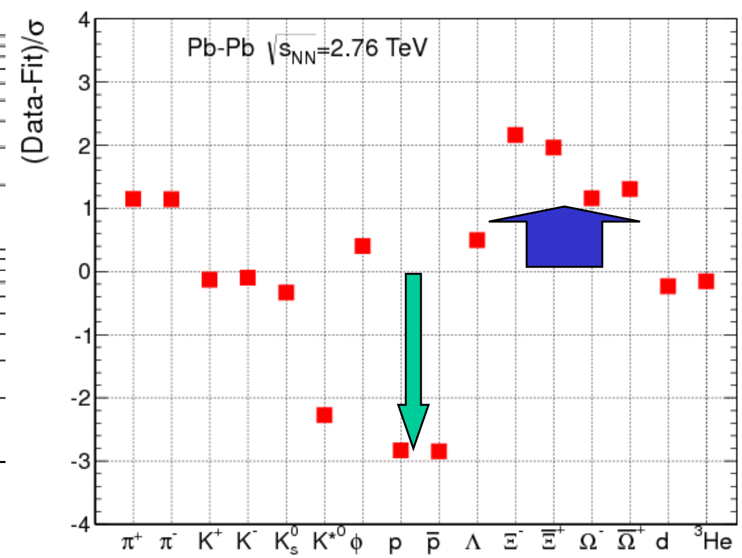


ALICE Coll., Phys. Rev. Lett. 109, 252301 (2012)

Central Pb-Pb Collisions at the LHC



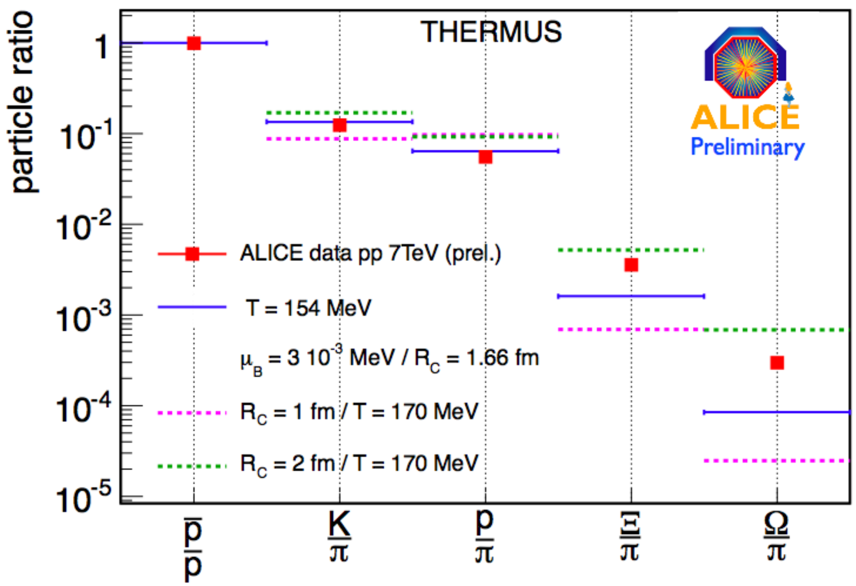
The $\chi 2$ is reasonable, yet distinct deviations!

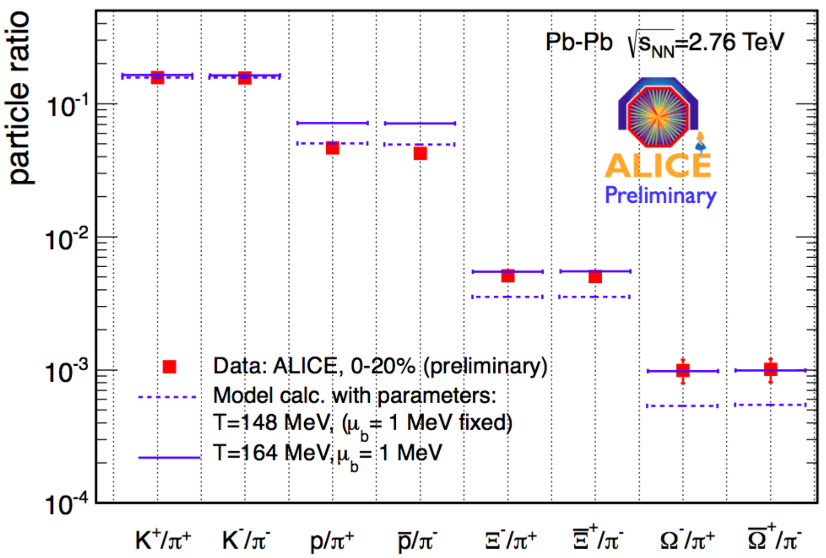


From A. Andronic, updated prel.

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!

Predictions for LHC

Prediction for heavy ions:

Grand can. (blue)

I. Kraus et al.,

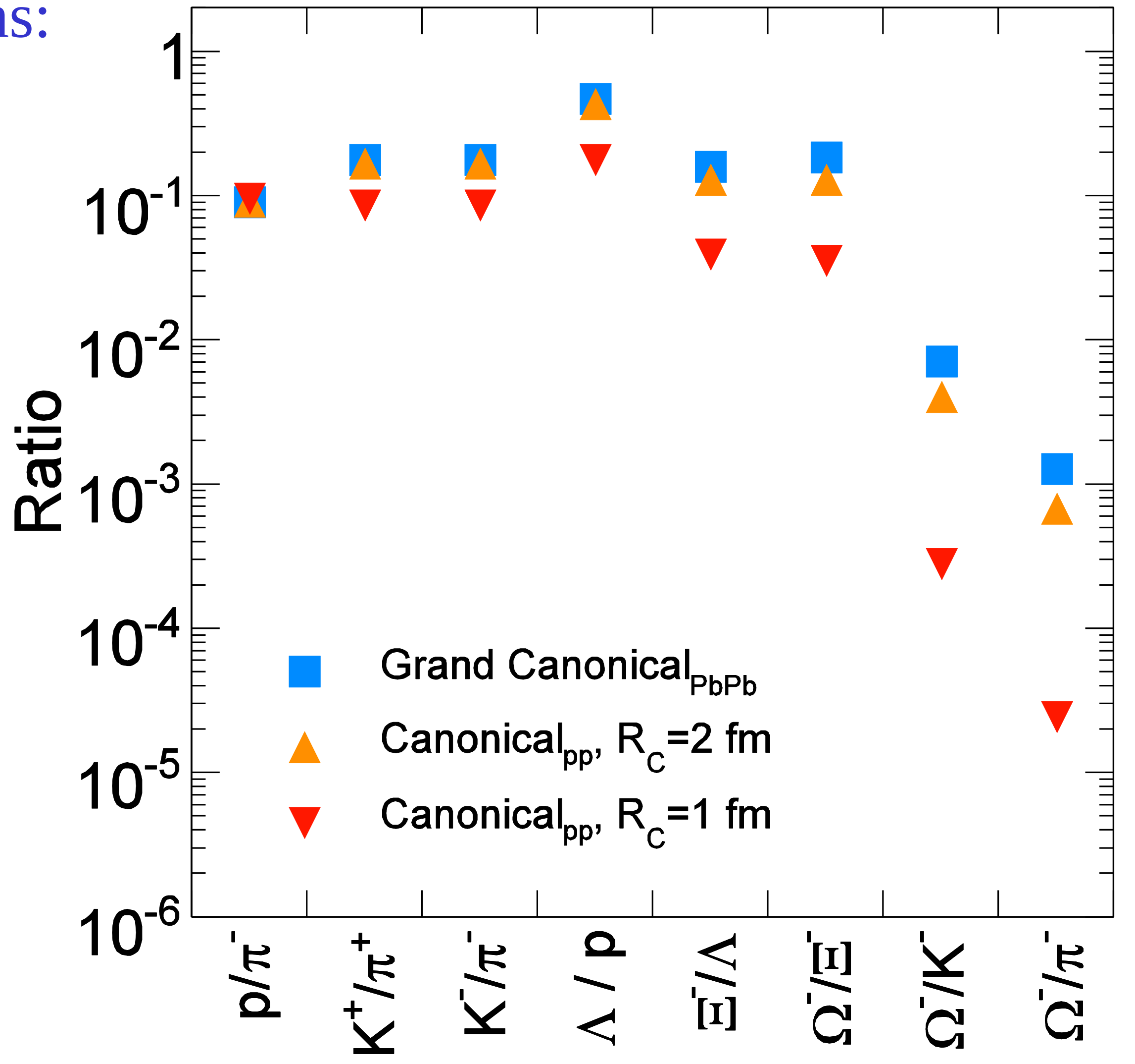
PRC 74 (2007)

For pp collisions:

Canonical (yellow and red)

I. Kraus et al.,

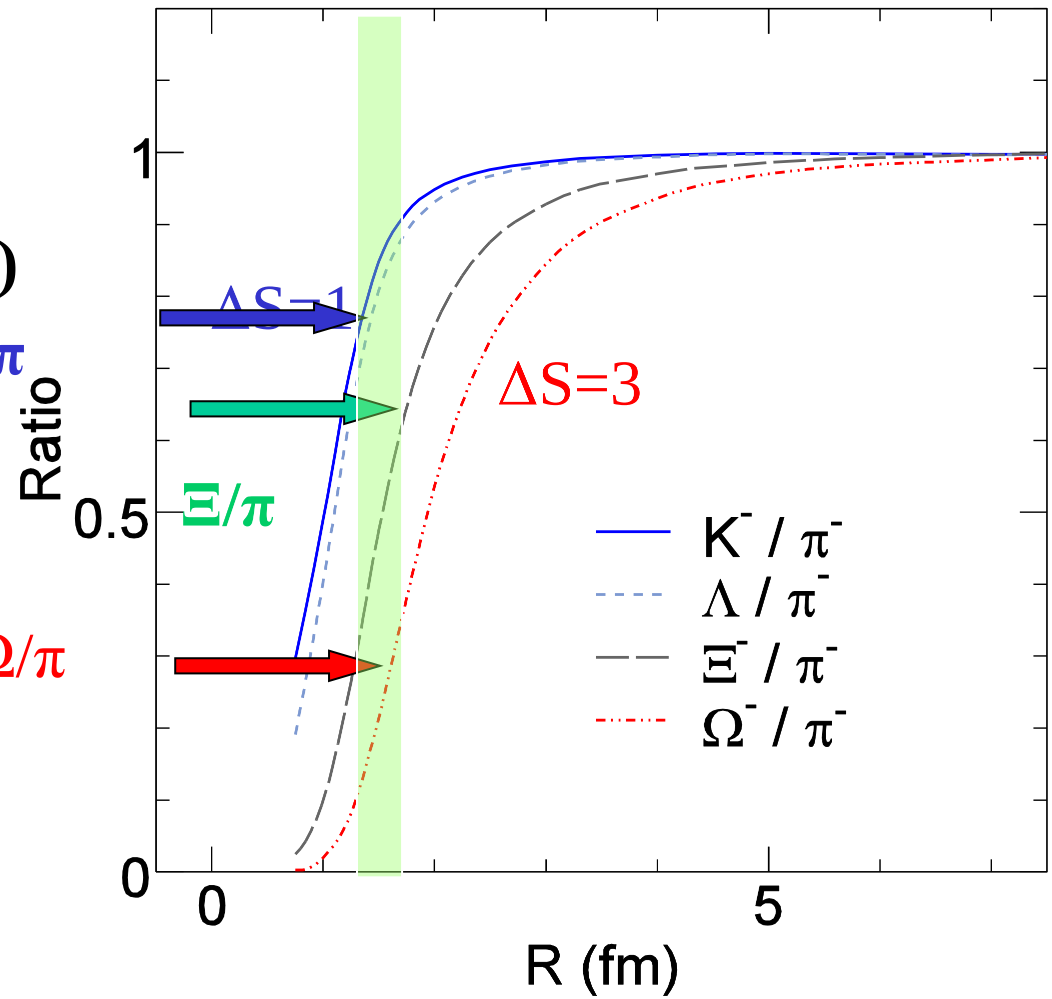
PRC 79(2009)



Testing Canonical Suppression at LHC

Calculated ratio:
can./grand can.

Measured ratio:
ratio(pp)/ratio(PbPb)



Example:

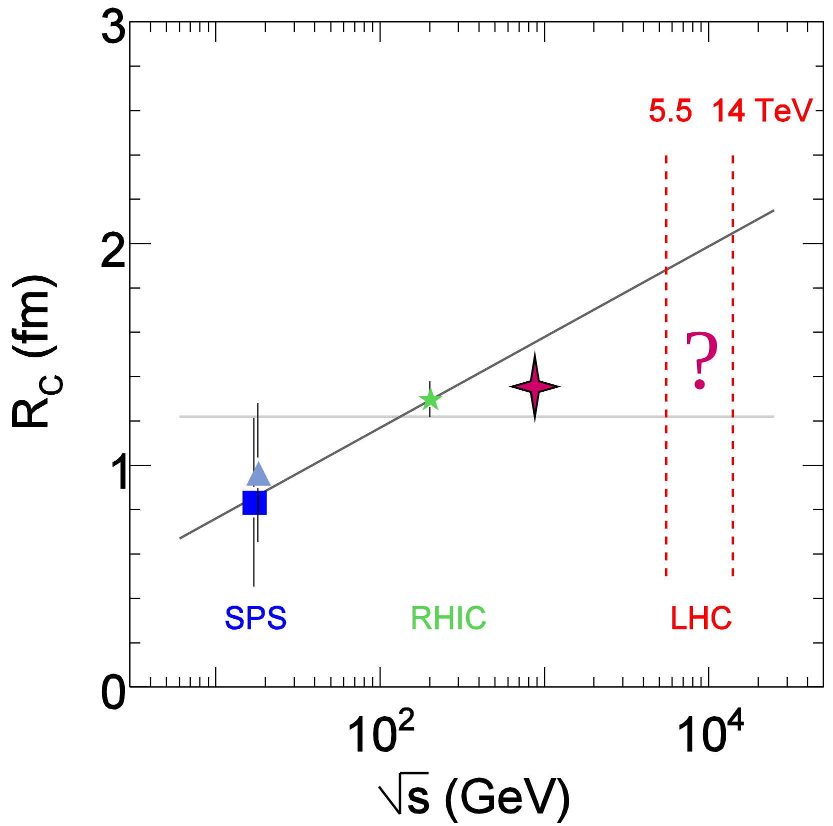
T = 170 MeV

μ_B = 1 MeV

Values for LHC

Prediction:I. Kraus et al., PR C 79 (2009) 014901

Correlation Radii at LHC



pp 900 GeV thermal fit: arXiv:1102.2745

Next: high-multiplicity events in pp 7 TeV !!!???

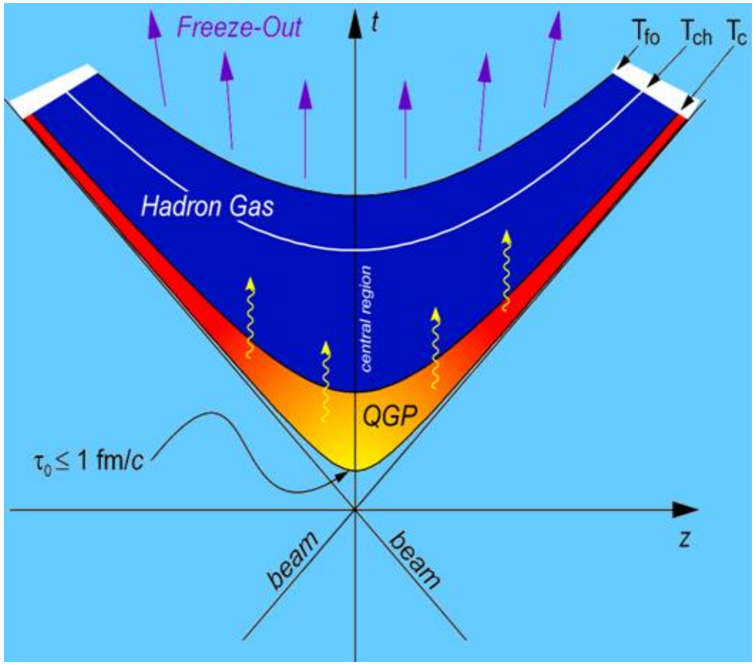
Will pp collisions approach Grand canonical limit, i.e. HIC

Resonances in heavy-ion collisions

Resonances with lifetimes of about a few fm/c

$\tau_{resonance} \sim \tau_{fireball}$

t~10 fm/c



Resonances might decay during the evolution from chemical to kinetic freeze out.

Then, the decay product might scatter. As the resonances are determined via the invariant mass, those are lost!

If their life time is longer than the one of the fire ball, this effect will be small.

Lifetime [fm/c] :	
$\Delta(1232)$	= 1.6
K(892)	= 4.0
$\Sigma(1385)$	= 5.7
$\Lambda(1520)$	= 13
$\Xi(1530)$	= 20
ϕ (1020)	= 45

$\phi(1020) \rightarrow K^+ + K^-$

$K^*(892)^0 \rightarrow \pi^\pm + K^\pm$

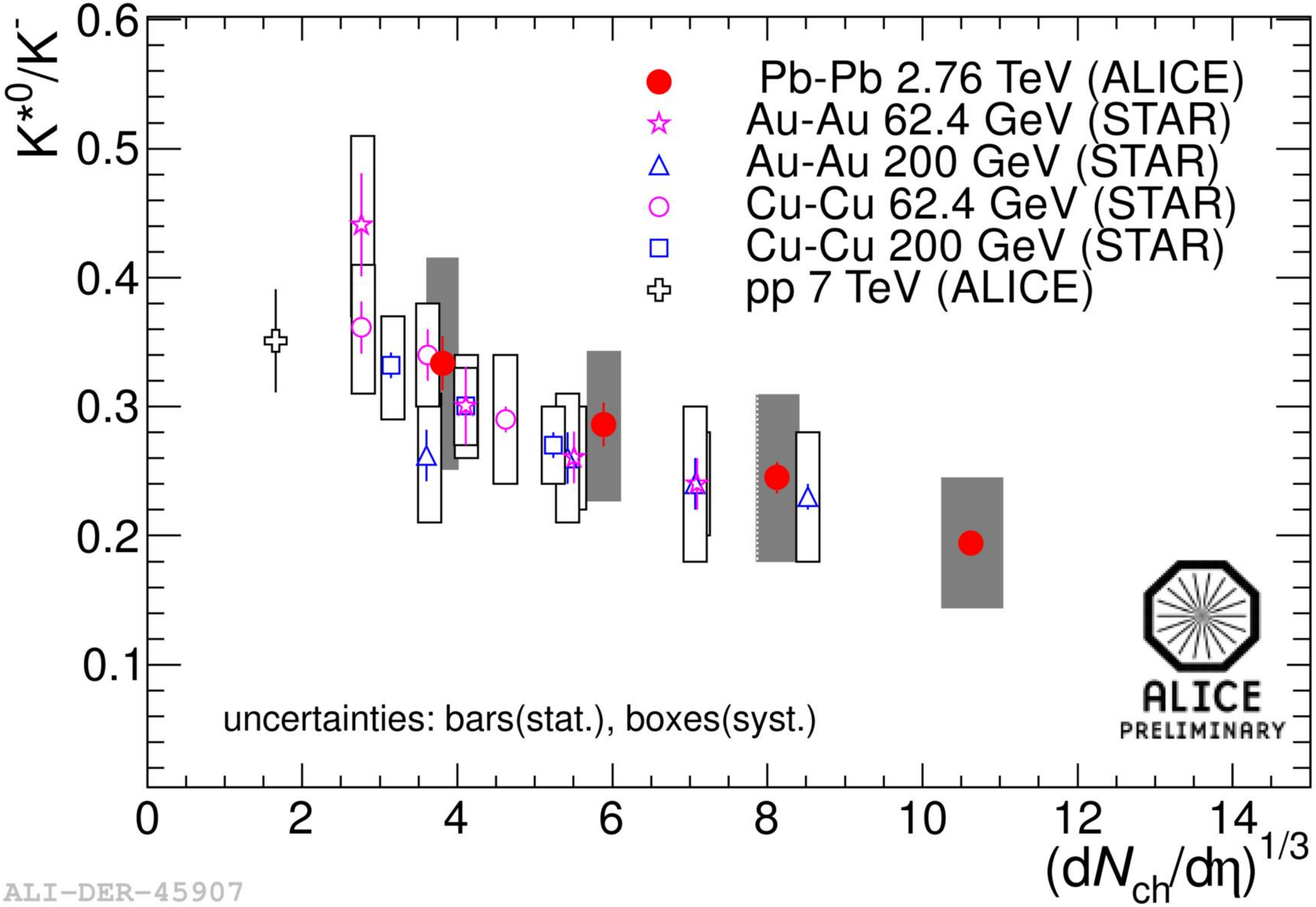
$\Delta(1232) \rightarrow \pi + p$

$\Lambda(1520) \rightarrow p + K^-$

$\Sigma(1385)^\pm \rightarrow \Lambda + \pi^\pm$

$\Xi(1530)^0 \rightarrow \Xi^- + \pi^+$

Decrease of the K*/K depends on radial extention of the fireball

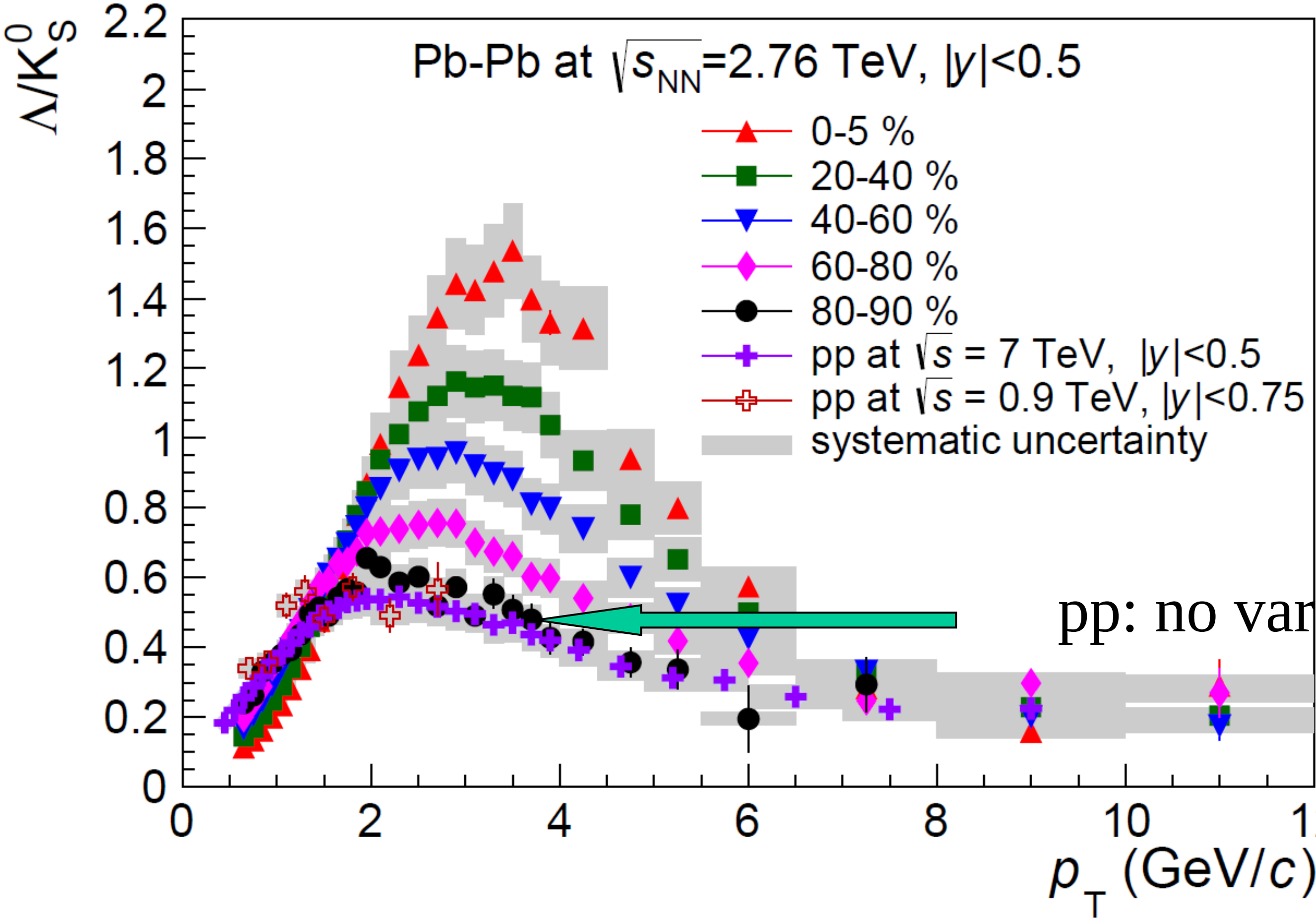


Bigger, dense

- **more rescattering**
- **stronger suppression**
- **rescattering!**
- **regeneration?**

STAR Coll. , Phys. Rev. C 84, 34909 (2010) , ALICE Coll. prel.

Baryon-meson ratio



ALICE **arXiv:1307.5530** **similar STAR: PRL 108(2012)**

Speculation: recombination of two/three quark

Comparison with results from lower energies

T is (assumed) to be the same.
μ_B is significantly different, 20 MeV – 1 MeV

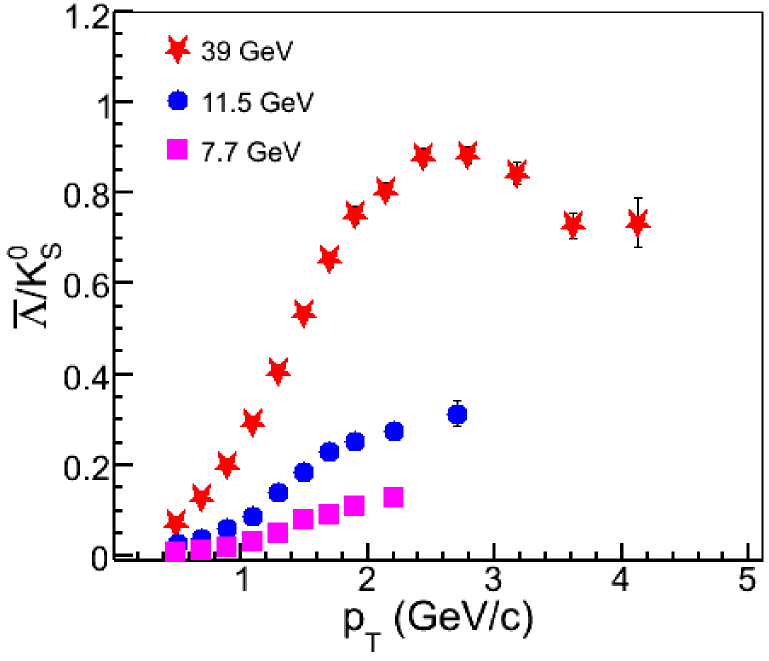
How to compare values from RHIC and LHC?

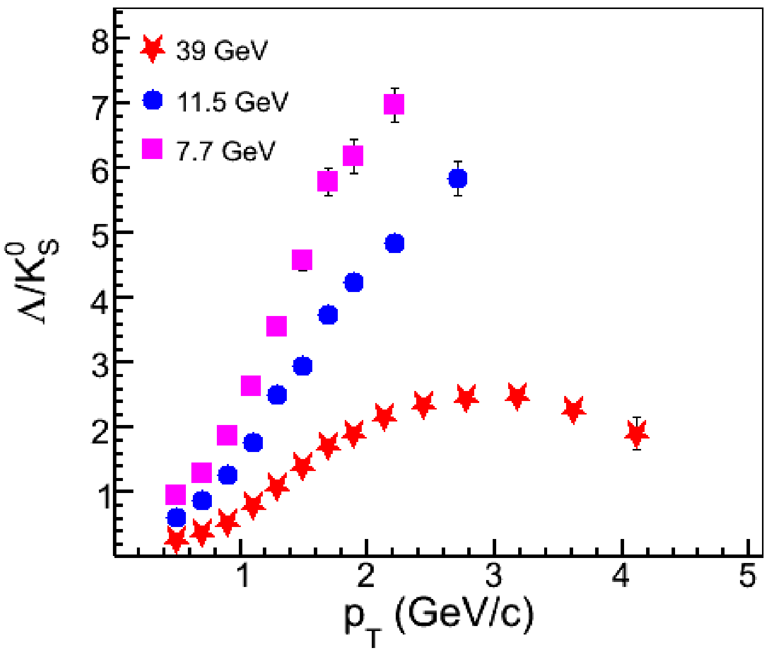
Suggested procedure correcting for the difference in μ_B:

Taking the geometrical mean of B and Bbar!

Discussed along with Λ/K0 ratios (as a fct of p_T).

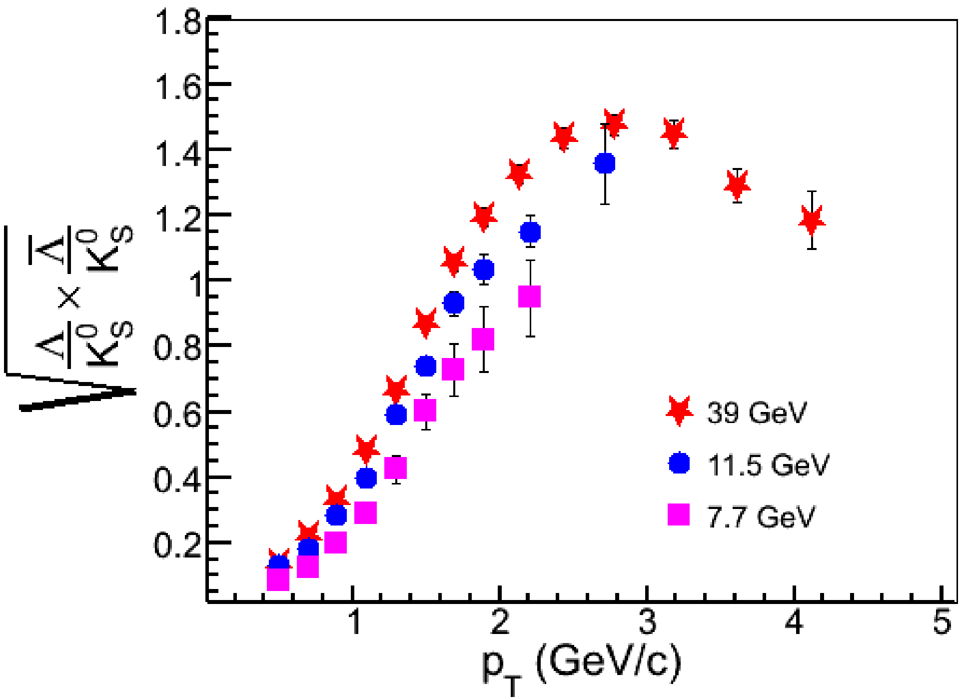
STAR Beam Energy Scan





STAR, BES CPOD March 2013

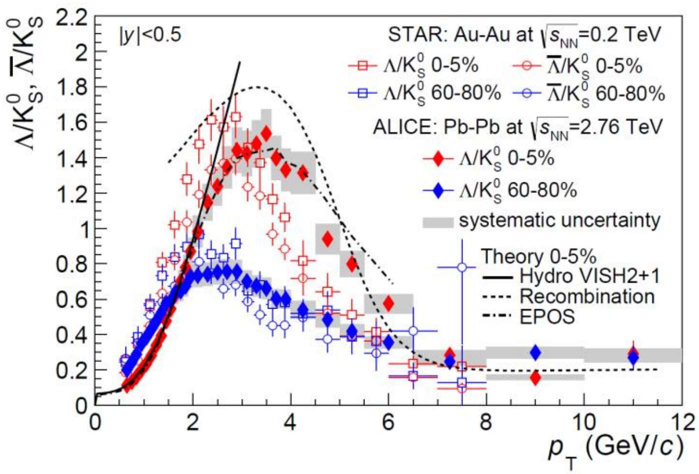
Λ without μ_B



$$\Lambda = \exp(-[E + \mu_B - \mu_S]/T)$$

$$\bar{\Lambda} = \exp(-[E - \mu_B + \mu_S]/T)$$

$$\sqrt{\Lambda \times \bar{\Lambda}} = \exp(E/T)$$



$x\,\bar{x}$ averaging via geometrical mean

arXiv:1307.5530

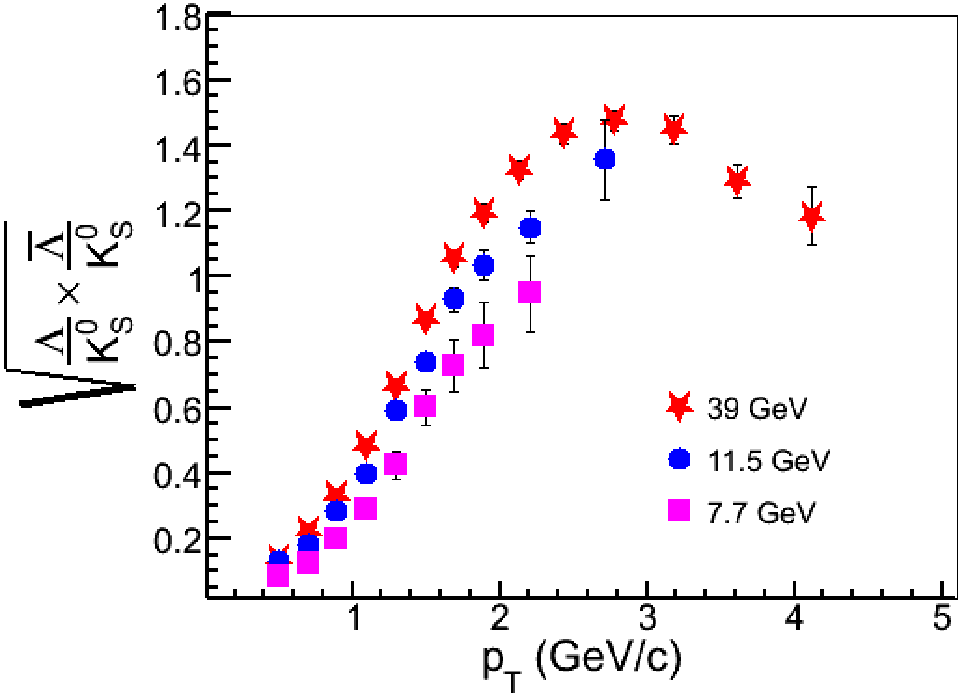
Strangeness follows thermal predictions
Enhancement decreases with increasing √s

Proton yield is lower!
K* decreases for central HIC:
rescattering!

Does the correlation radius
in pp increase with √s?

Meson-baryon ratio: more an effect from radial flow!?

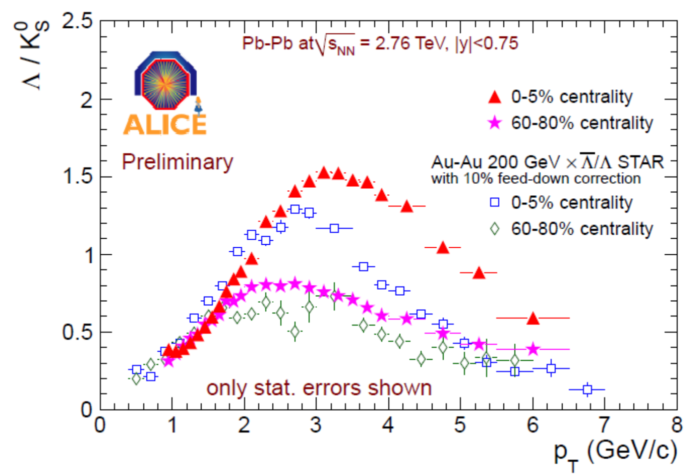
Λ without μ_B



$$\Lambda = \exp(-[E + \mu_B - \mu_S]/T)$$

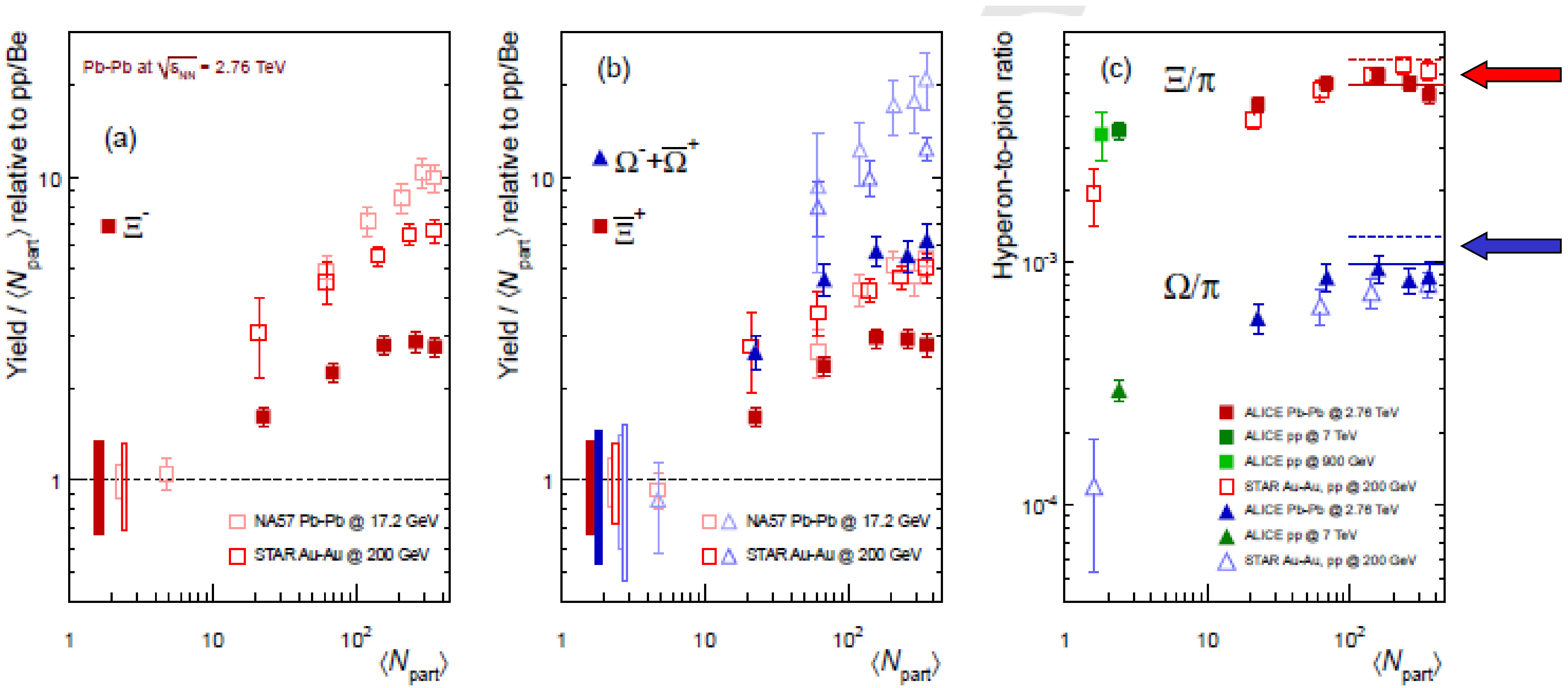
$$\bar{\Lambda} = \exp(-[E - \mu_B + \mu_S]/T)$$

$$\sqrt{\Lambda \times \bar{\Lambda}} = \exp(E/T)$$



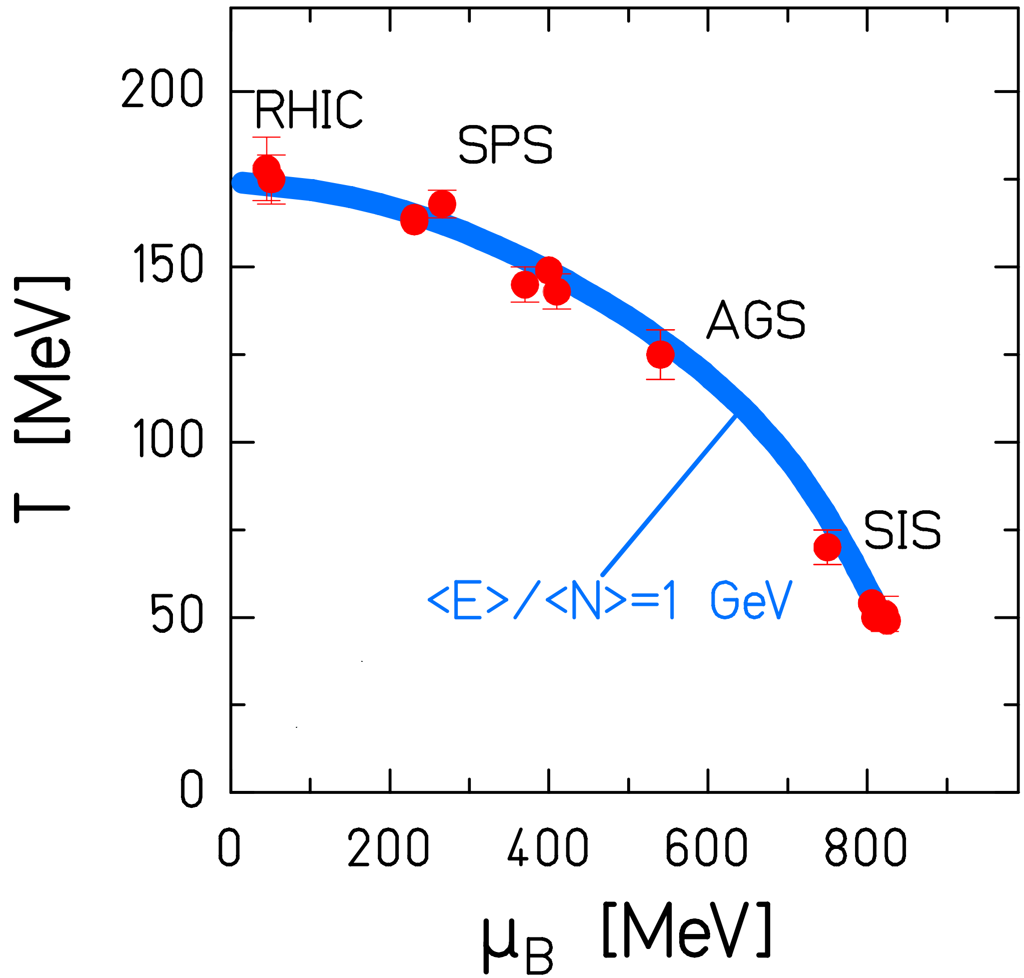
$x\,\bar{x}$ averaging via geometrical mean

Multistrange in Pb-Pb



Predictions with T = 164 (Anton et al.)/ 170 MeV (Jean et al.)

Chemical Freeze Out

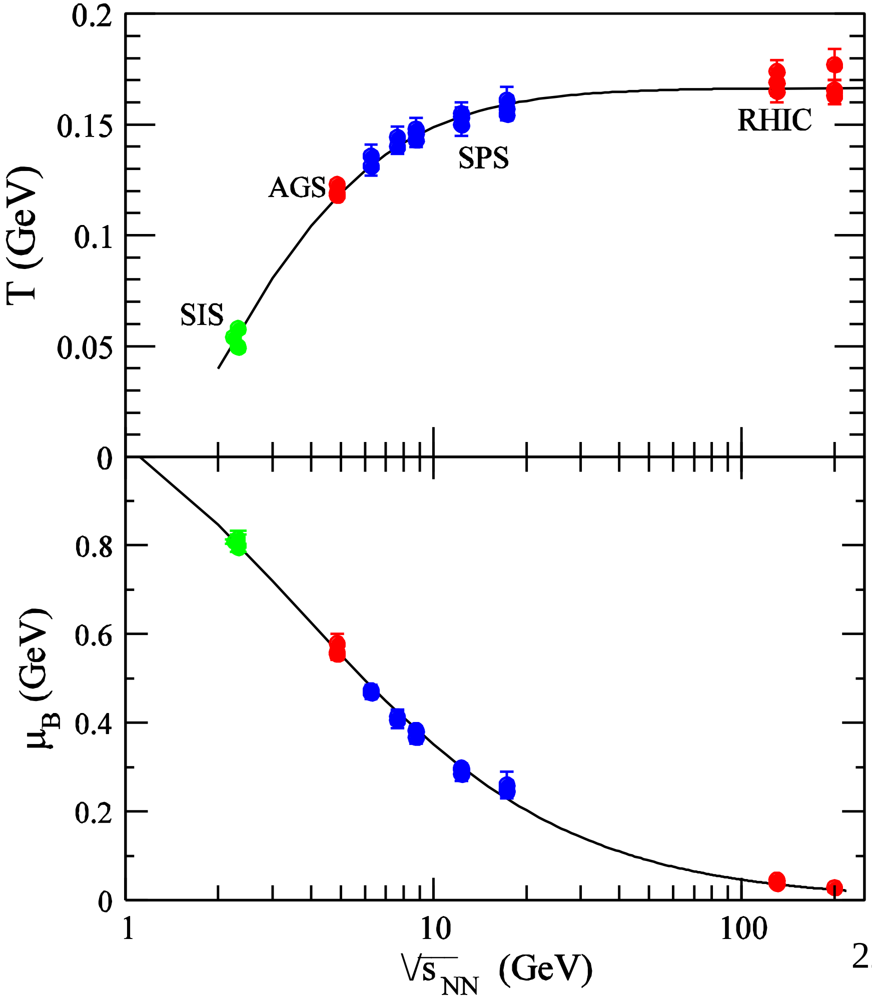


J. Cleymans and K. Redlich, PRL 81 (1998) 5284

Towards LHC energies

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

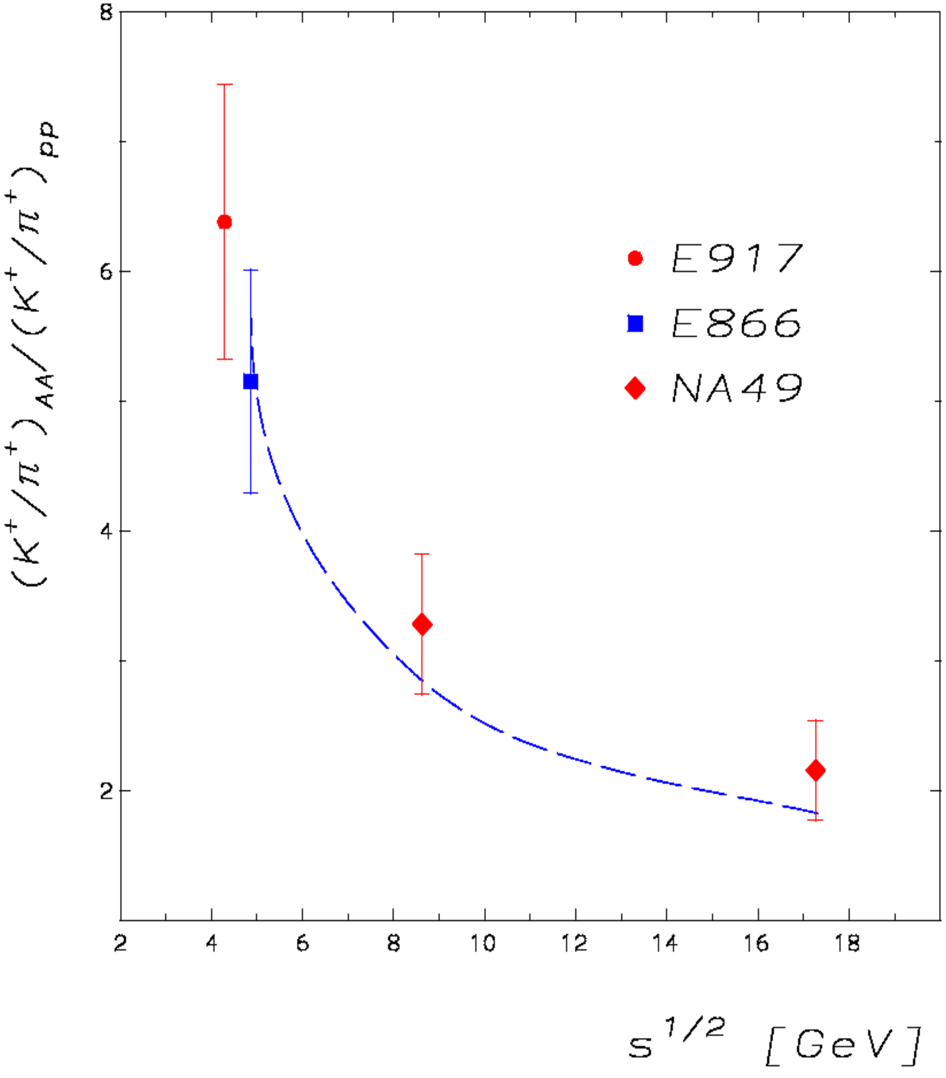
- Chemical decoupling conditions extracted from SIS up to RHIC feature common behaviour
- Similar to Andronic et al., Nucl. Phys. A 772 (2006) 167



At which energy has the highest strangeness enhancement been observed?

$$(X(S)/\pi)/N_{part}(HIC) \;\; / \;\; (X(S)/\pi)/N_{part}\,(pp)$$

Strangeness enhancement larger for lower energy



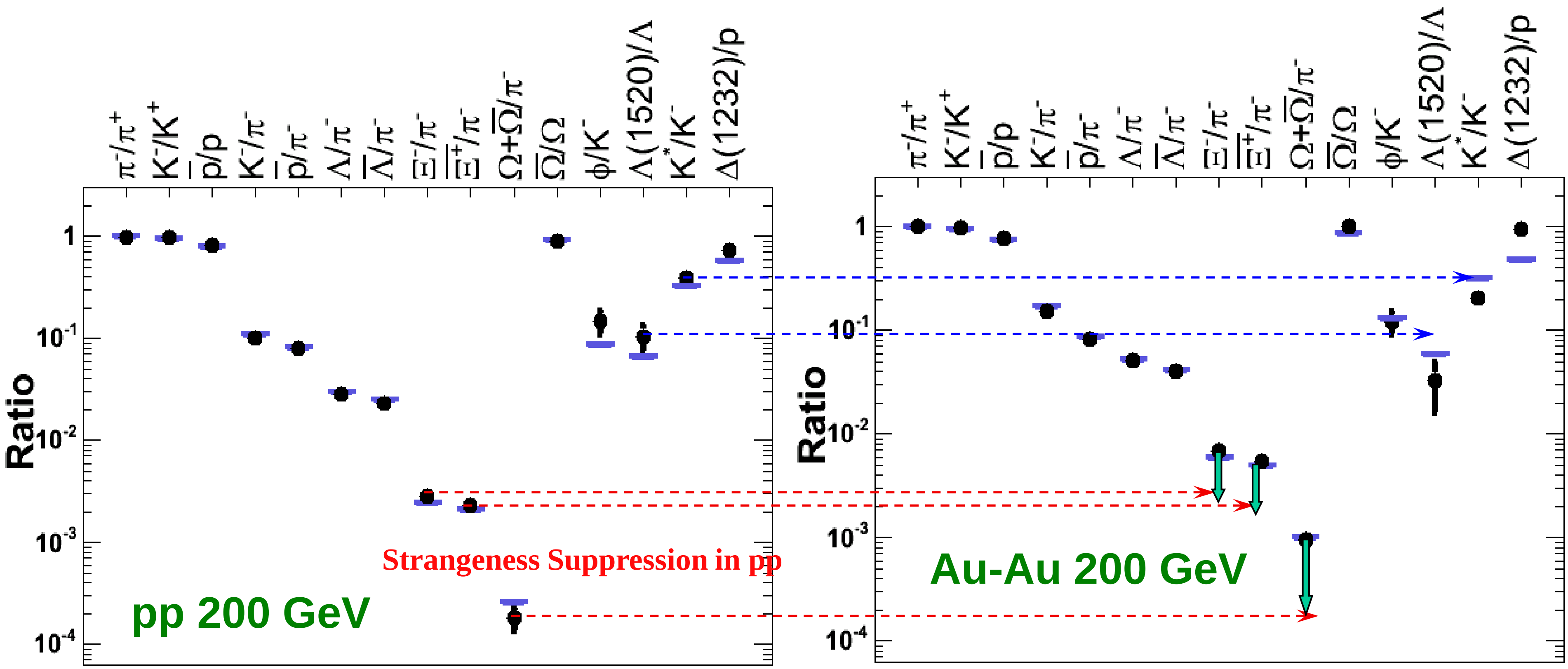
Dashed line:

Statistical model

K. Redlich

At LHC: ≈1.5

Statistical Model for pp and HIC



– In *pp* particle ratios are well described using canonical description

– In *Au+Au* only stable particle ratios are well described

Canonical Approach

Pion density

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

Strangeness is conserved!

Kaon density

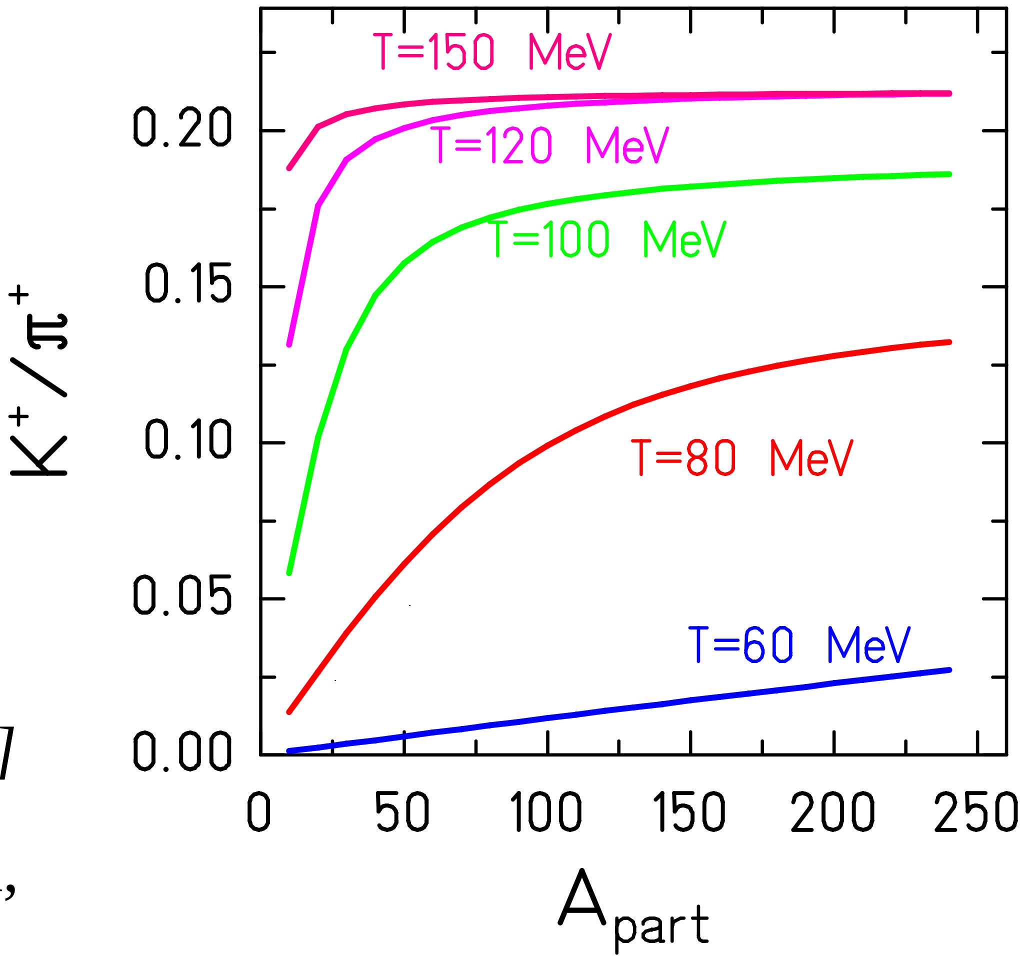
$NN \rightarrow N\,\Lambda\,K^+$

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

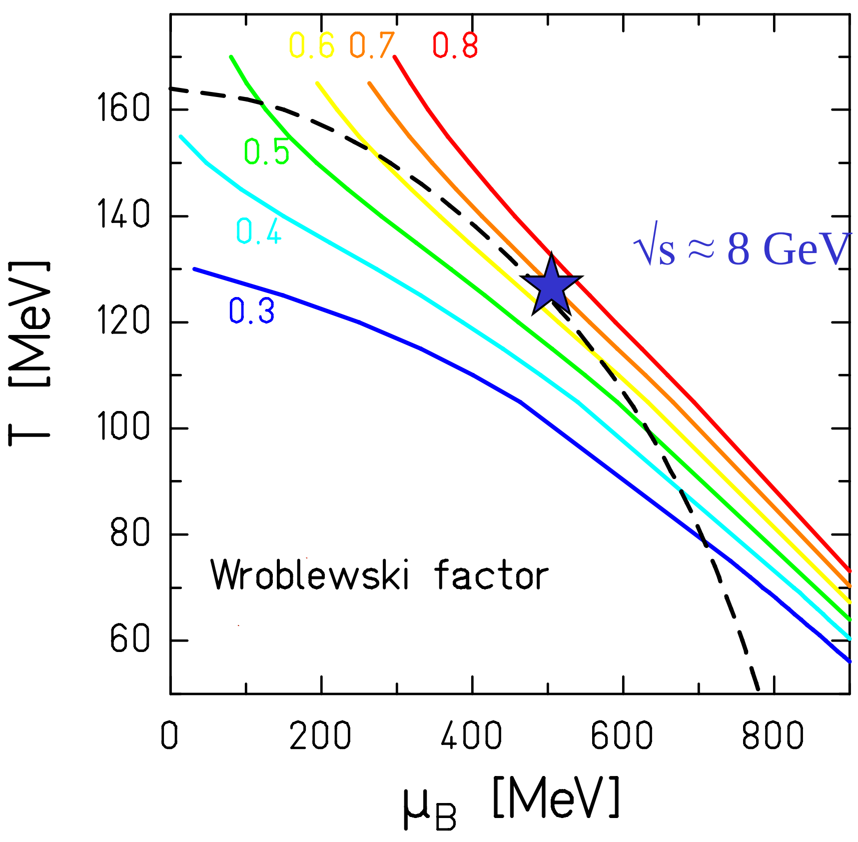
$[g\ V\ \int \ldots exp[-(E_\Lambda - \mu_B)/T]$

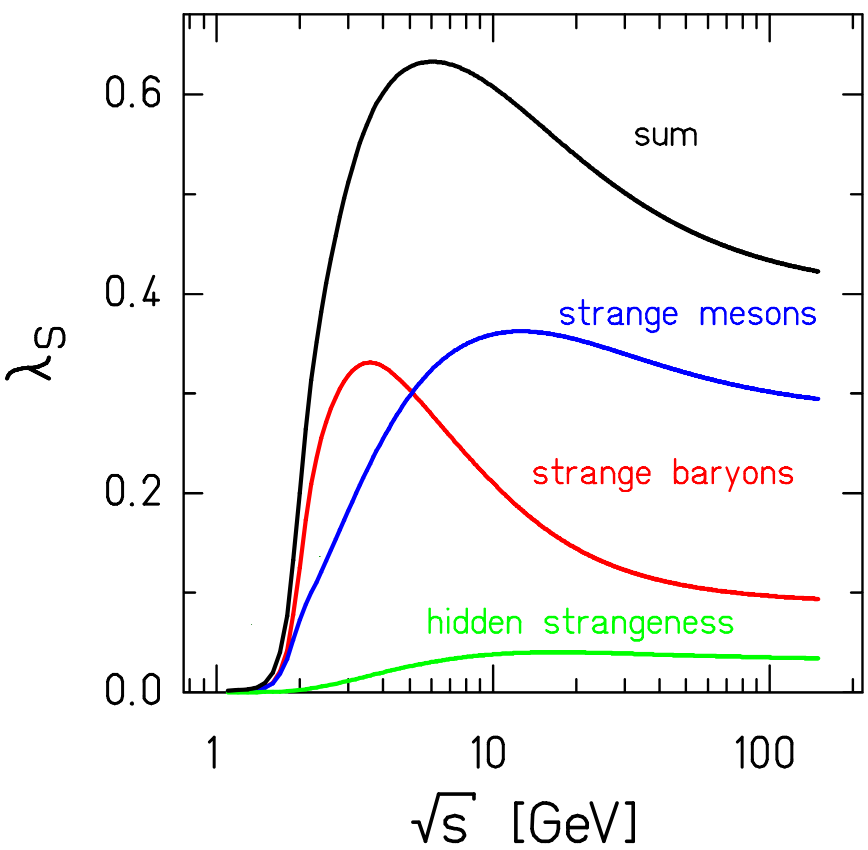
J. Cleymans, HO, K. Redlich,

PRC 60 (1999)



Maximum Strangeness around 30 AGeV





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

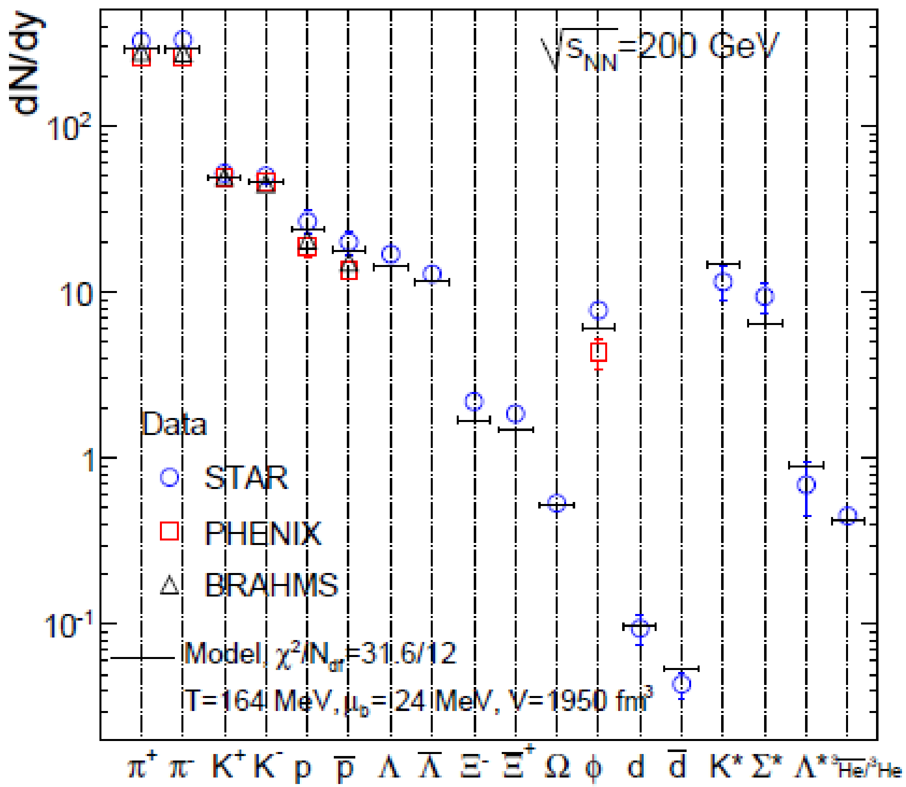
K^+ are produced together with a Λ, influence of μ_B

K^- together with a K^+

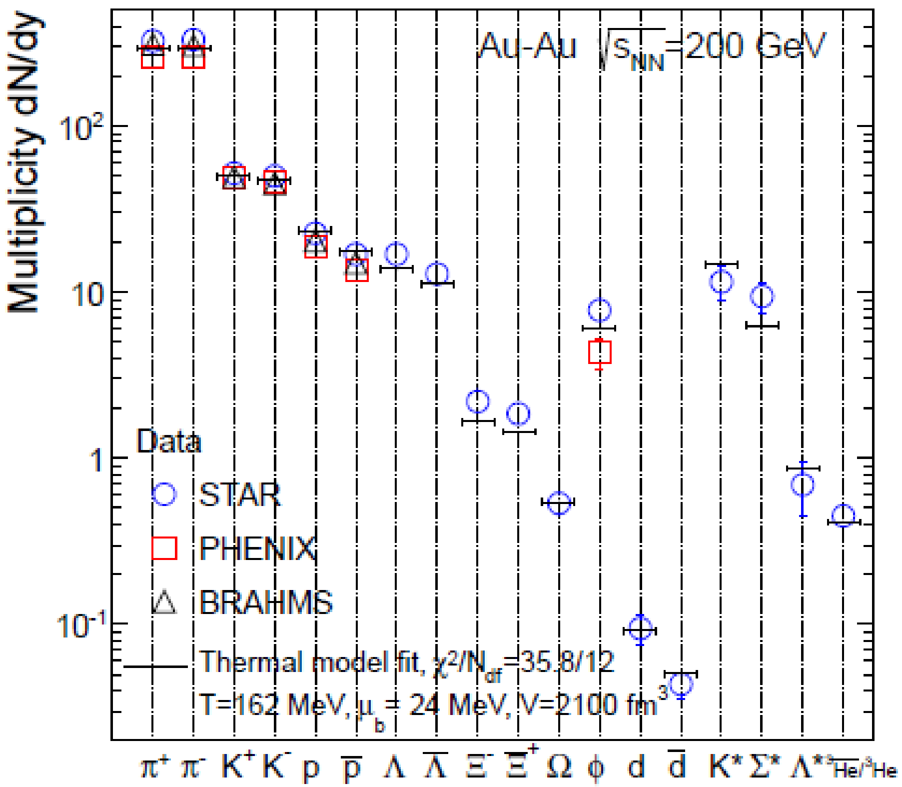
P. Braun-Munzinger, J. Cleymans, HO, K. Redlich, NPA 697(2002) 902

RHIC, $\sqrt{s_{NN}}$=200 GeV, fit of average data

2008: STAR 2/3 p from w.d. corr.;
PHENIX, BRAHMS 2/3 π w.d. corr.



2012: STAR all p from w.d. corr.;
no BRAHMS π w.d. corr.



K^*, Σ^*, Λ^* not in fit

From Anton, QM 2012