F. Becattini, University of Florence

Strangeness and onset of deconfinement

OUTLINE

- Strangeness enhancement in heavy ion collisions
- Statistical model and strangeness undersaturation
- Core-corona model
- Seeking the onset of the core

CPOD, Dubna, Aug 25 2010

Strangeness enhancement was proposed as a signature of deconfinement Quark Gluon Plasma

B. Muller, J. Rafelski, Phys. Rev. Lett. 48, 1066 (1982)

Chiral symmetry restoration favours (relative) strange quark production in a deconfined medium

Strange quark coalescence favours the enhancement of multiple strange hyperons

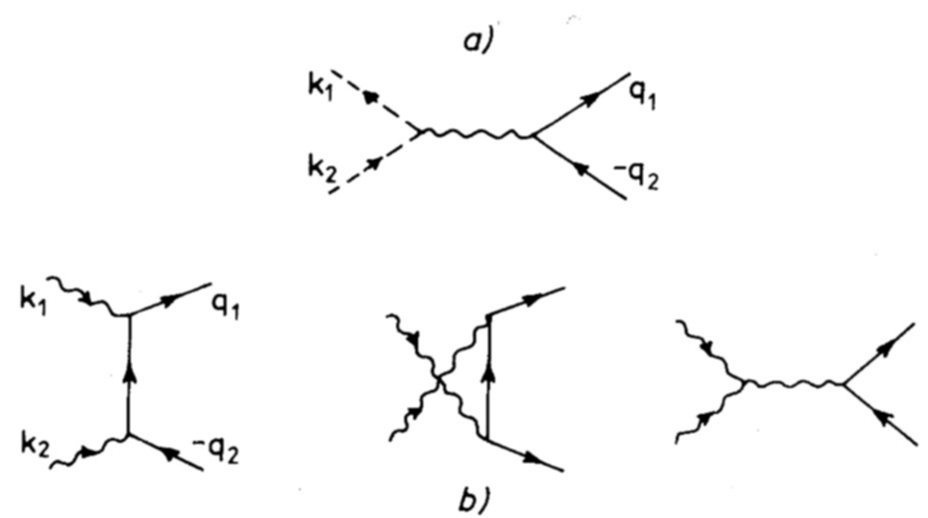
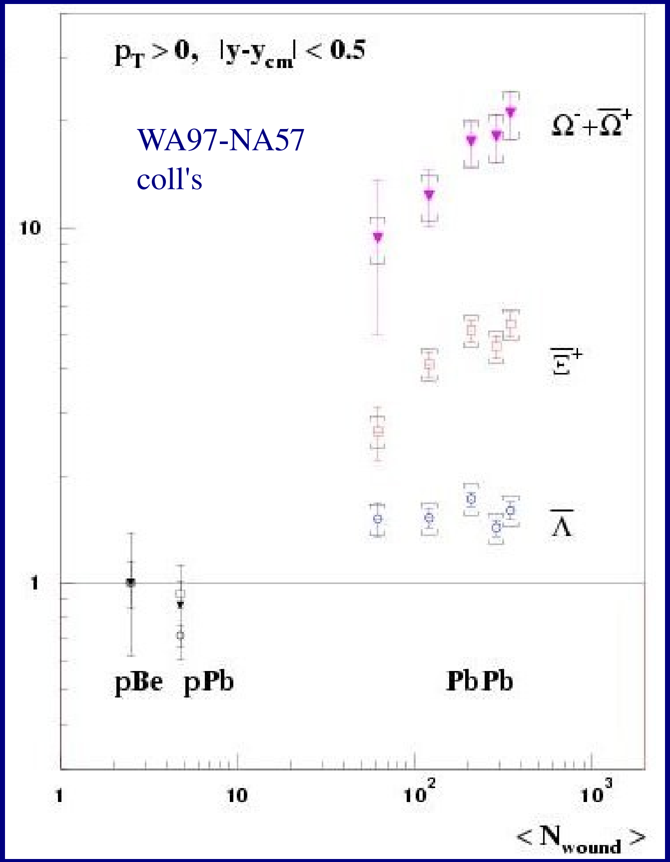
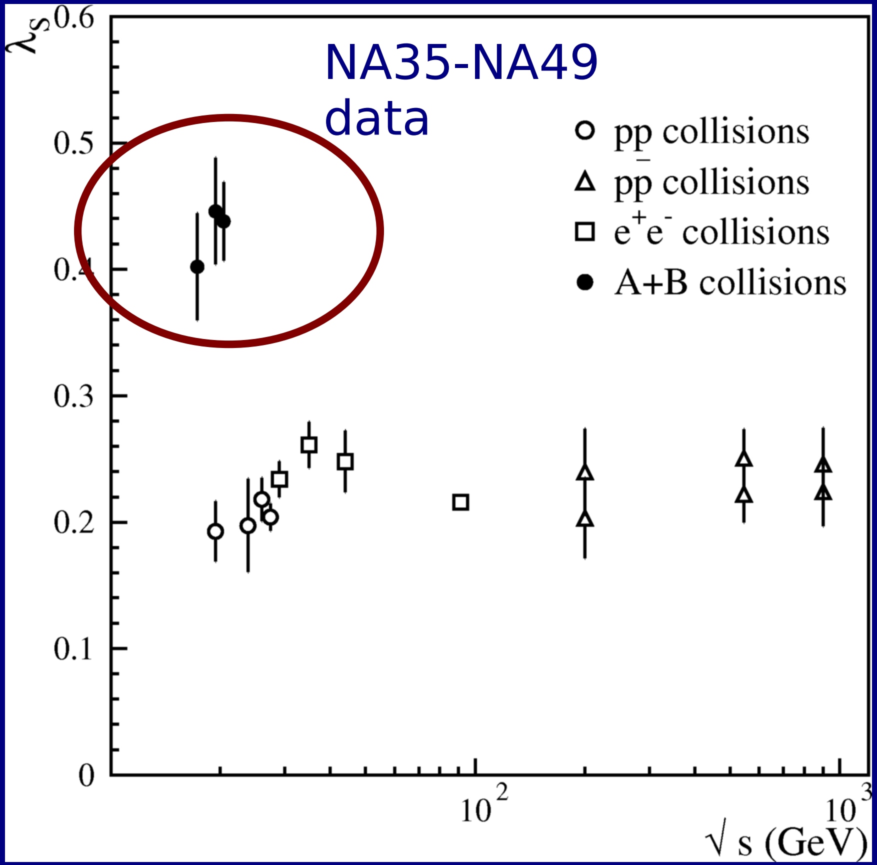


FIG. 1. Lowest-order QCD diagrams for $s\bar{s}$ production: (a) $q\bar{q}\rightarrow s\bar{s}$, (b) $gg\rightarrow s\bar{s}$.

Enhancement was found in PbPb collisions at SPS

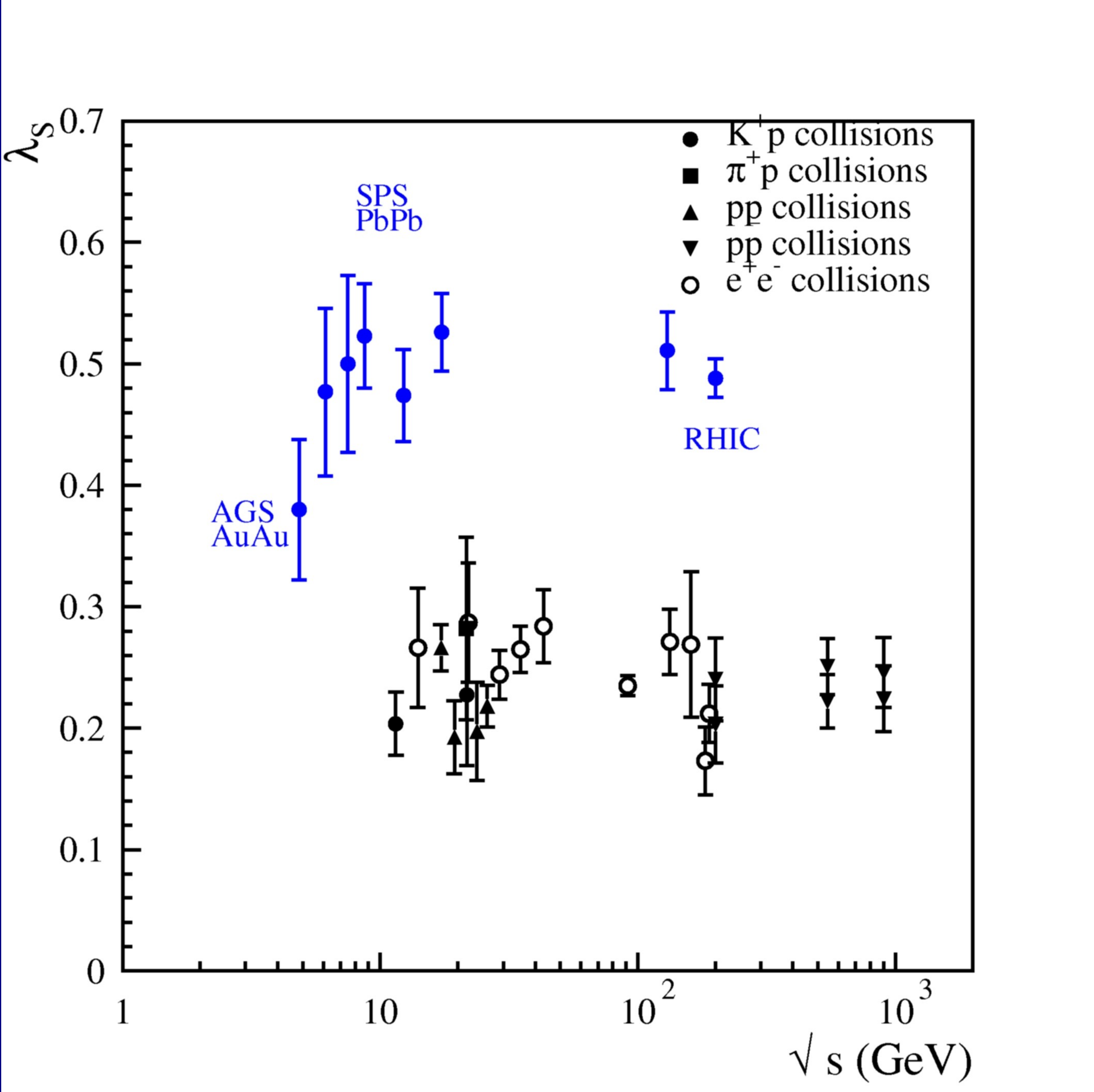


$$\lambda_S = \frac{2\langle s\bar{s}\rangle}{\langle u\bar{u}\rangle + \langle d\bar{d}\rangle}$$



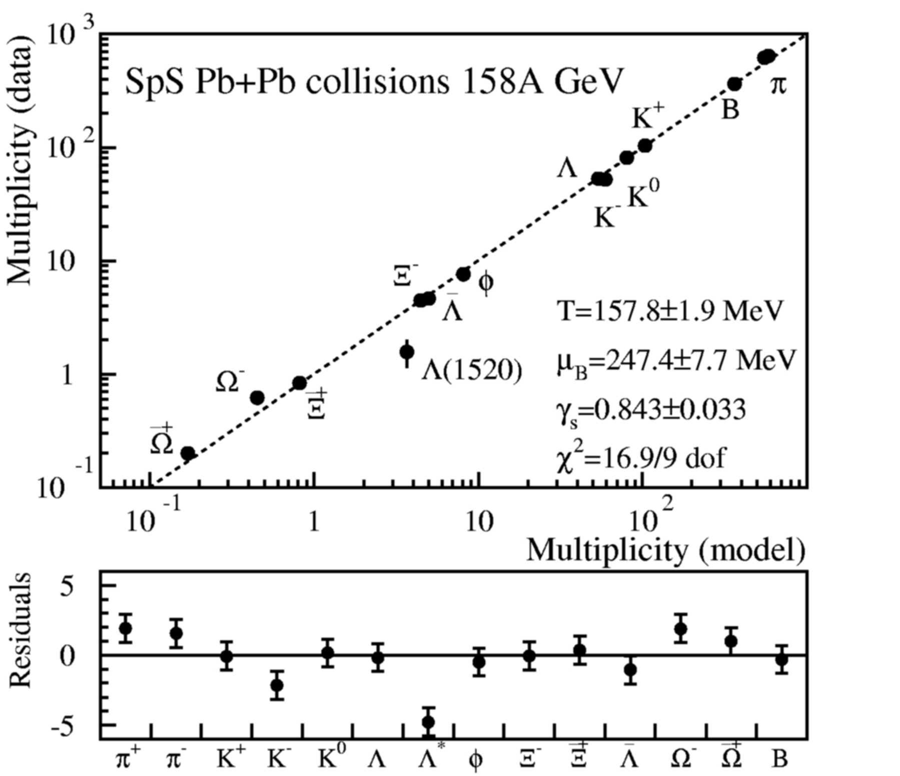
F. B., M. Gazdzicki, J. Sollfrank, Eur. Phys. J. C 5. 143 (1998)

Wroblewski ratio: current status

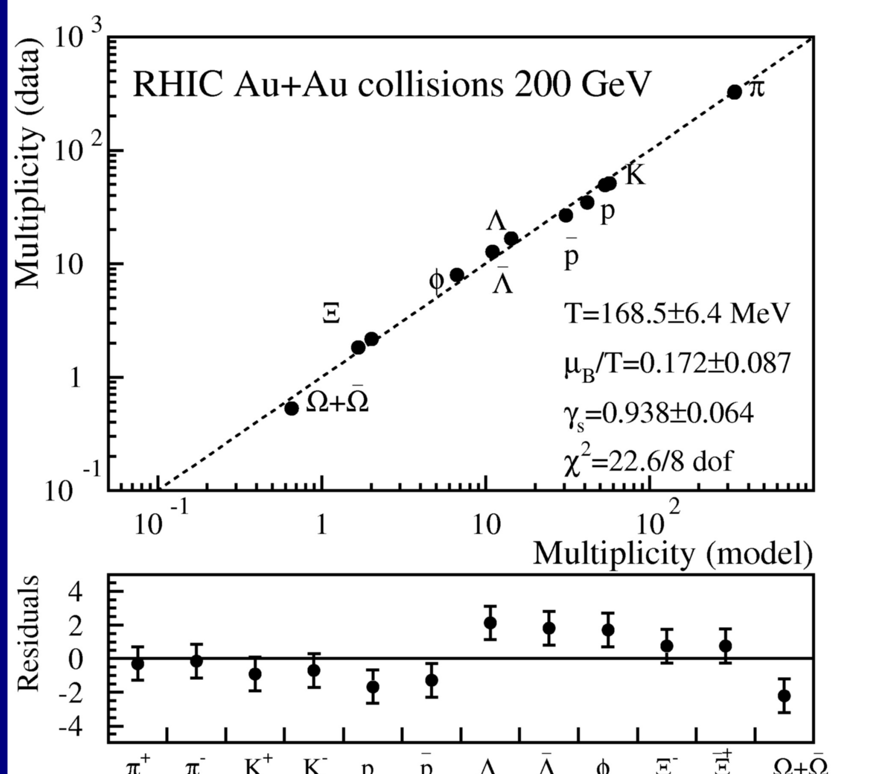


Statistical model results in heavy ion collisions

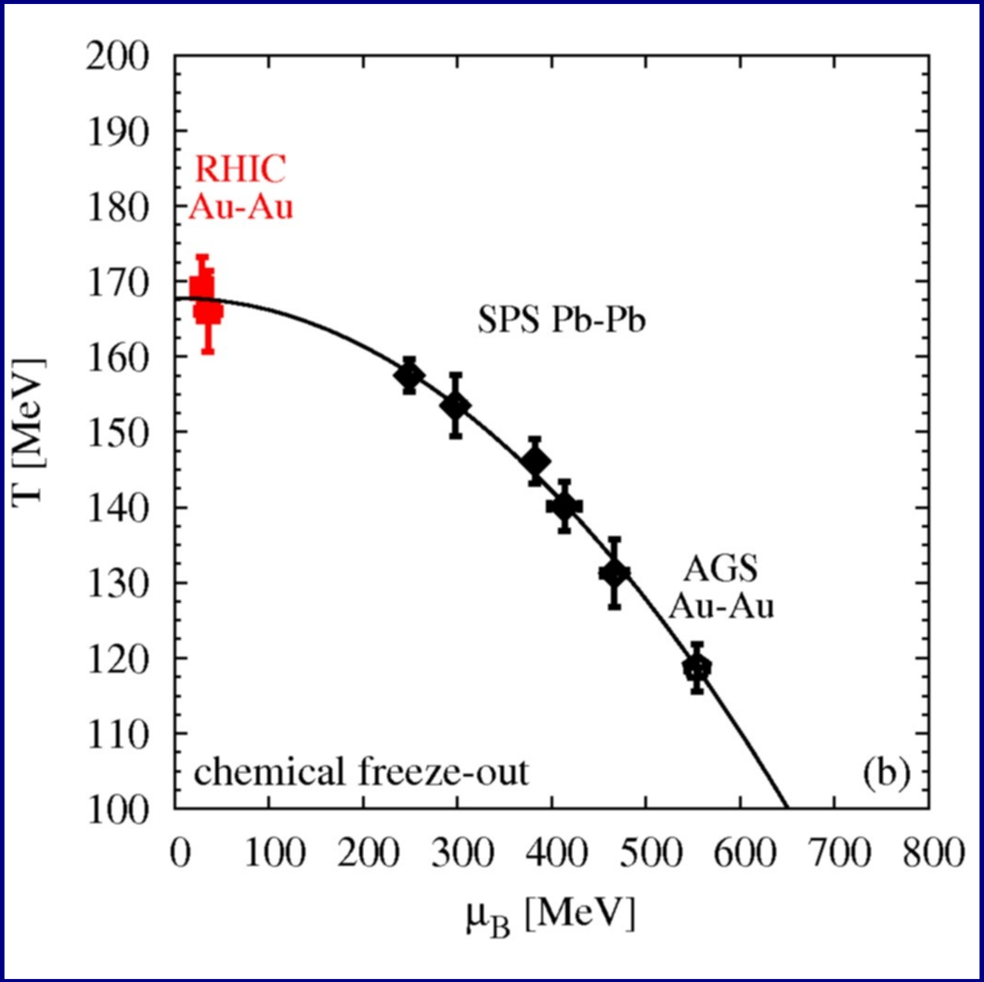
$$\langle n_j \rangle_{\text{primary}} = \frac{(2S+1)V}{(2\pi)^3} {\gamma_S}^{N_s} \int d^3p \; e^{-\sqrt{p^2+m_j^2}/T} \; e^{\boldsymbol{\mu}\cdot\mathbf{q}_j/T}$$

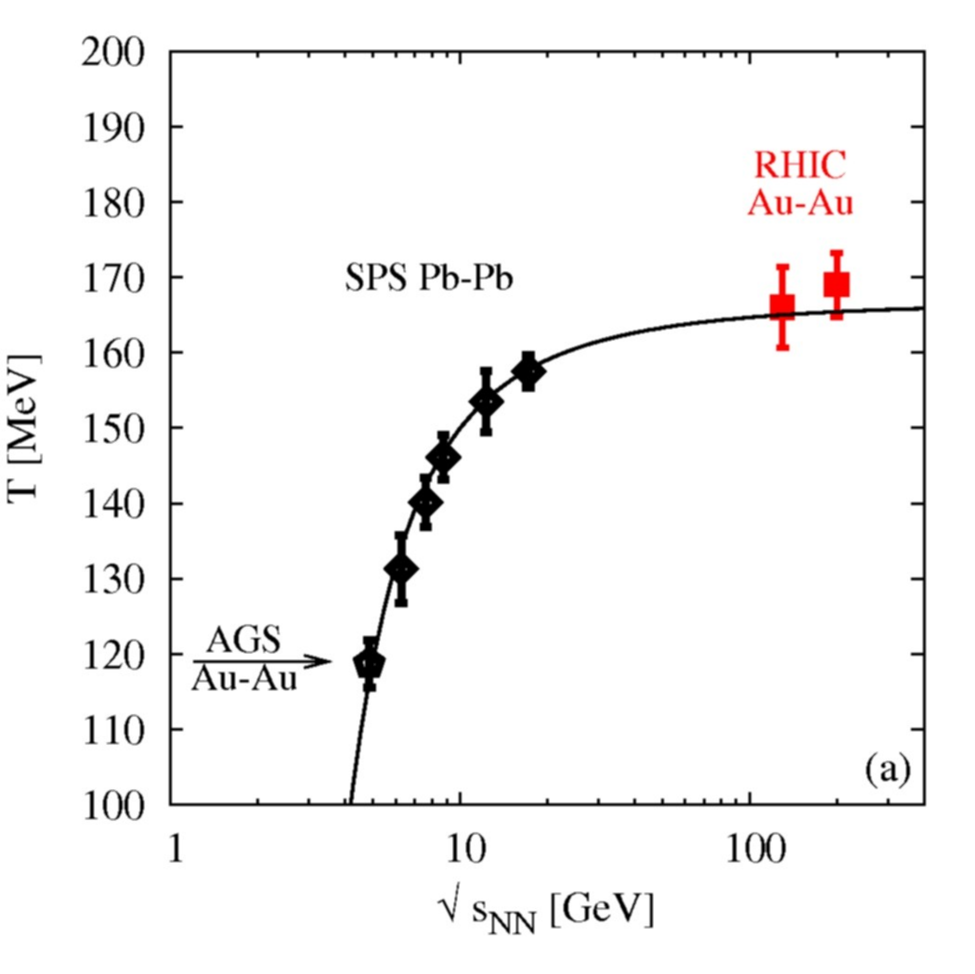


F. B., M. Gazdzicki, A. Keranen, J. Manninen, R. Stock Phys. Rev. C 69 (2004),024905



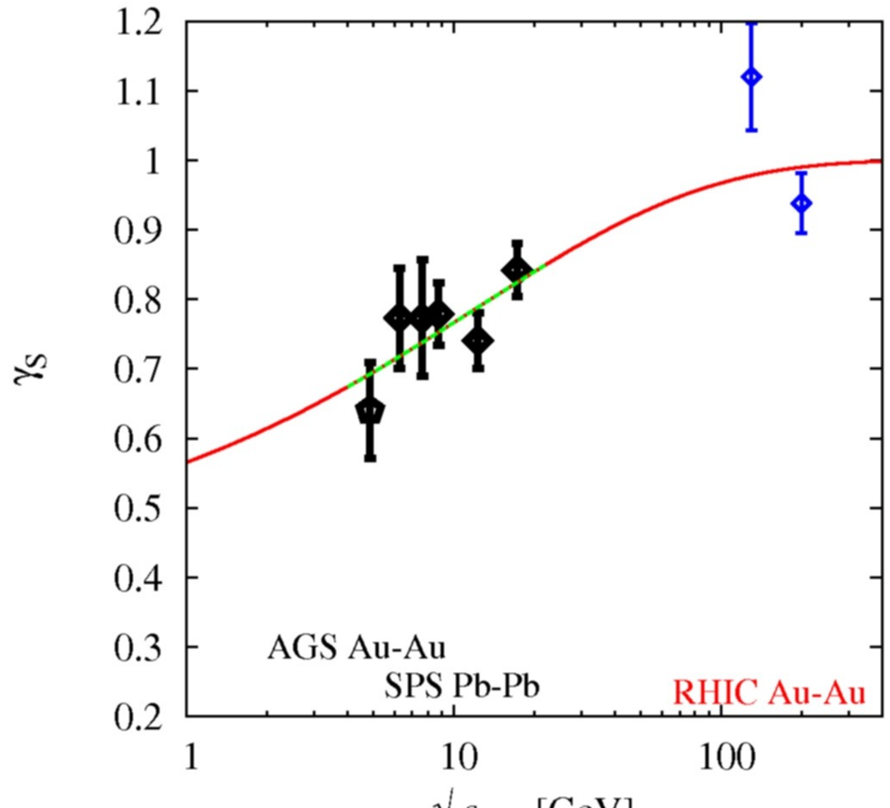
J. Manninen, F. B., Phys. Rev. C 78, 054901 (2008)



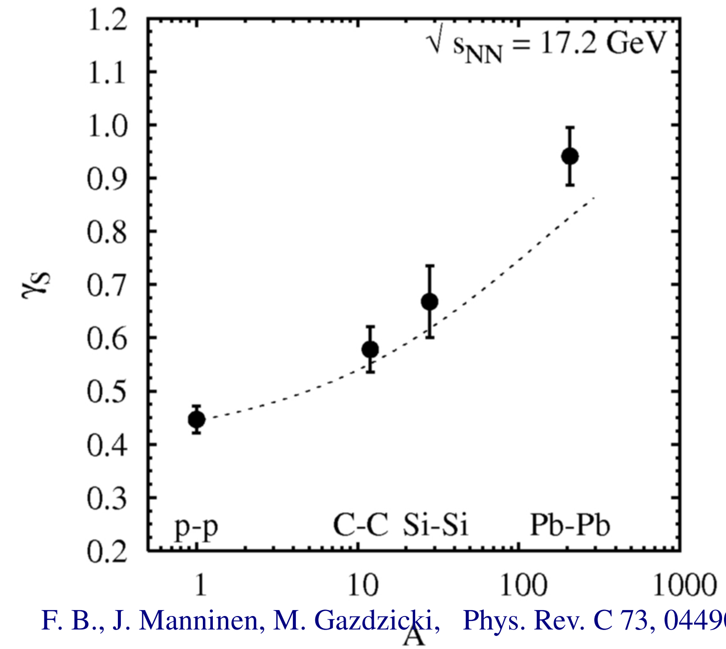


Smooth curves for T and μ_B

Statistical model: strangeness undersaturation parameter γ_s



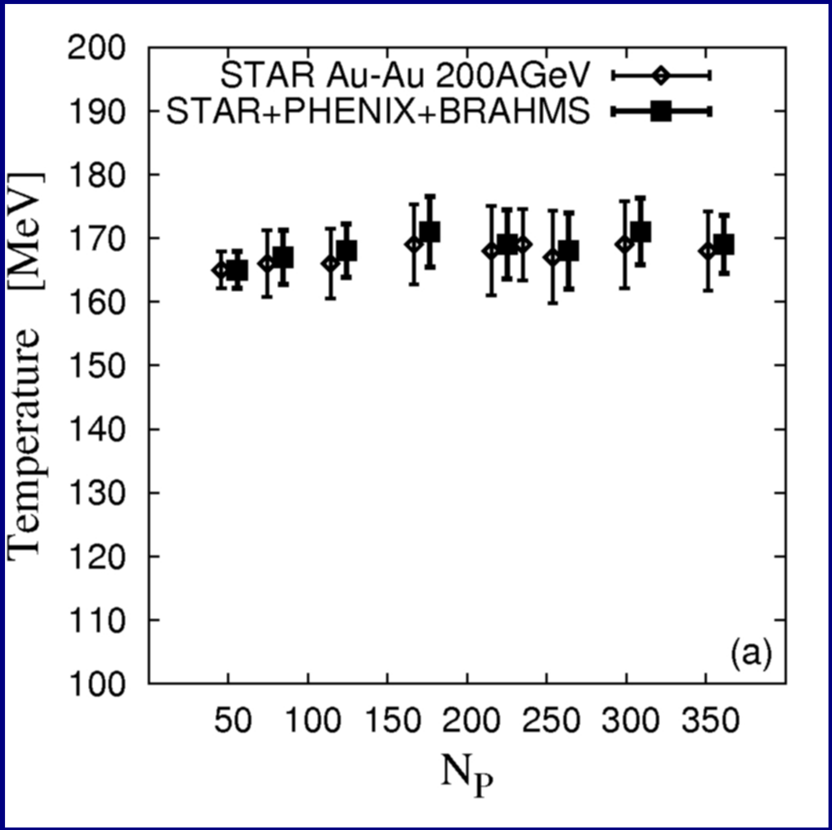
J. Manninen, F. B., Phys. Rev. C 78, 054901 (2008)

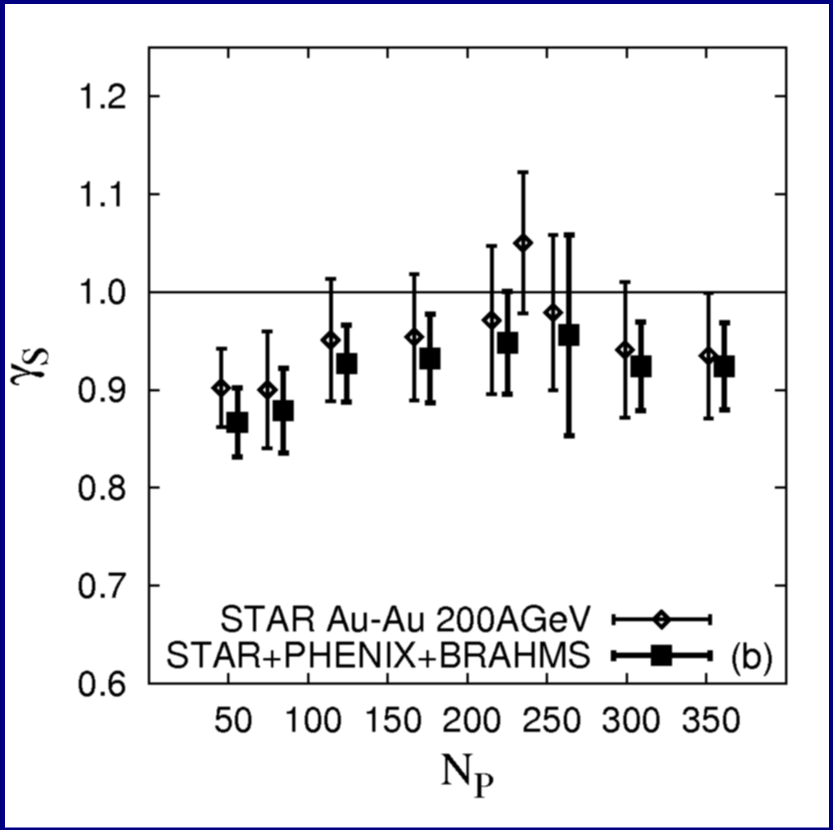


F. B., J. Manninen, M. Gazdzicki, Phys. Rev. C 73, 044905 (2006)

Strangeness undersaturation parameter γ_s at RHIC

Study of the freeze-out conditions and strangeness undersaturation parameter as a function of collision centrality

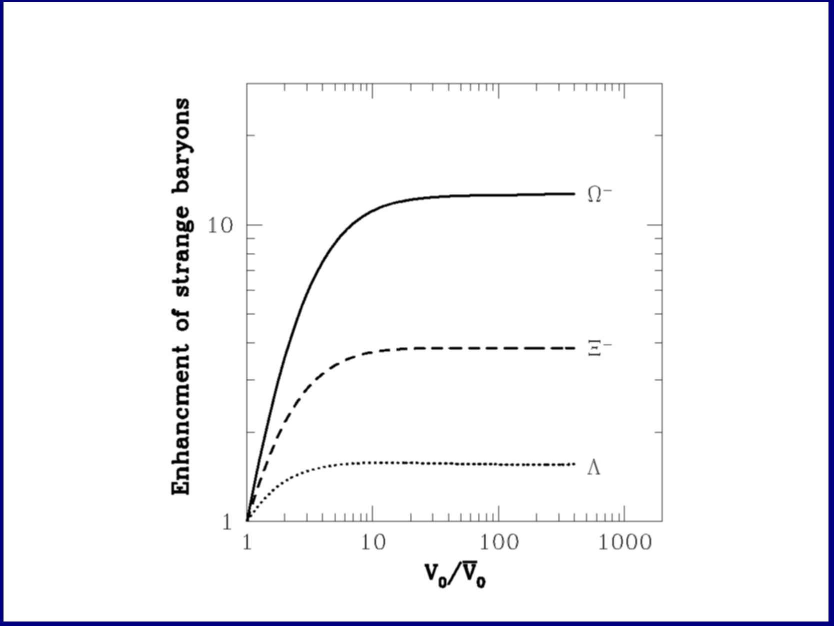




The decrease of γ_s at low centrality
is confirmed by other analyses, e.g.
J. Takahashi, STAR coll., J. Phys. G 36 (2009) 064074

γ_s = canonical suppression ?

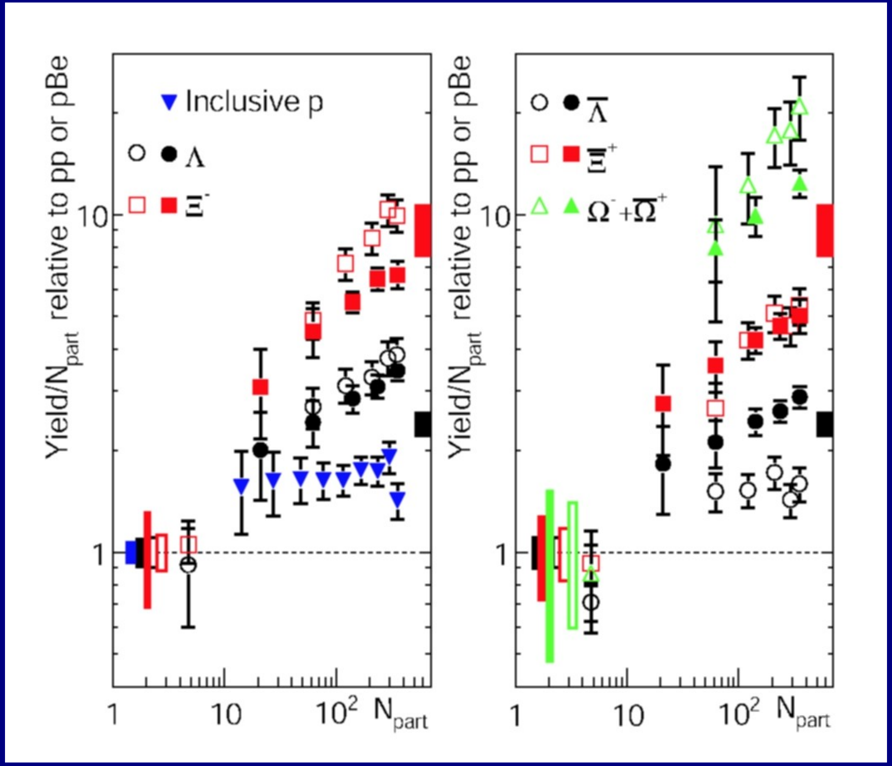
Assume exact strangeness conservation enforced in *subregions* with S=0
This entails a reduction of multiplicity of OPEN STRANGE hadrons



S. Hamieh, K. Redlich. A. Tounsi, Phys. Lett. B 486 (2000) 61

Strangeness correlation volume (SCV)
= volume within which S=0

SCV is significantly small even for the most central events and
it is proportional to *some function of* N_w

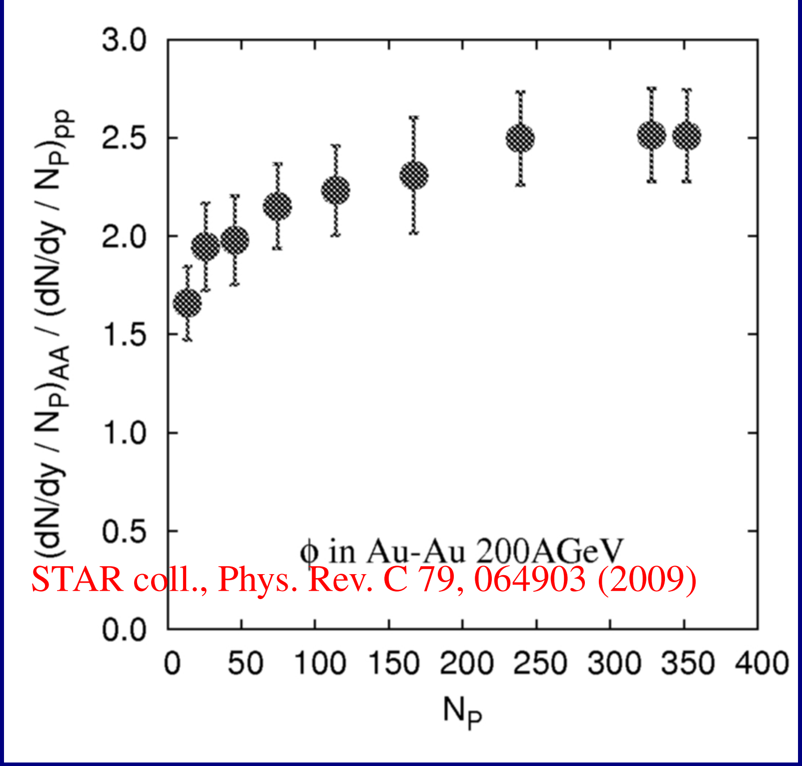


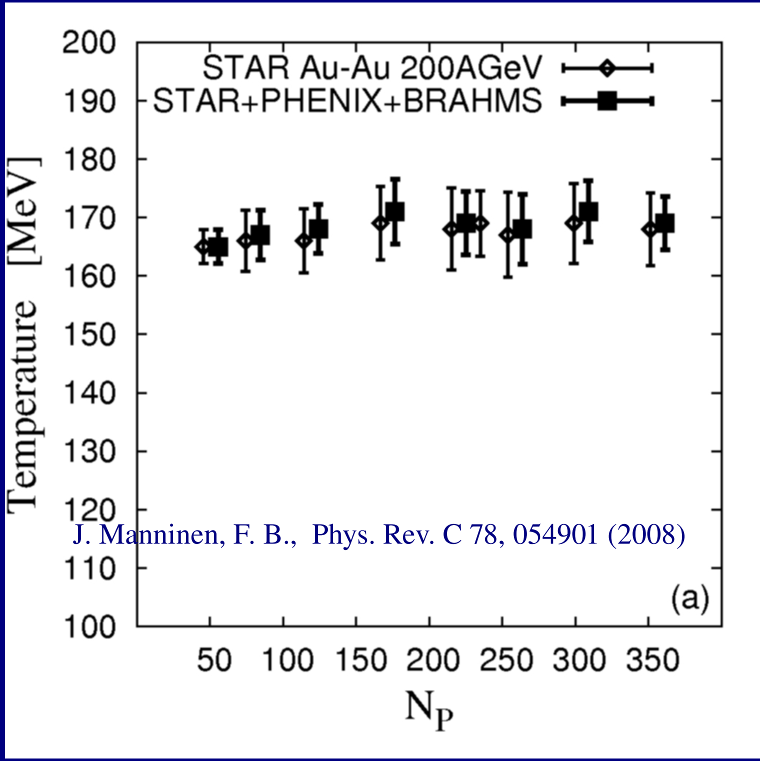
STAR coll., Phys. Rev. C 77 (2008) 044908

The ϕ meson: $\gamma_S{}^2$ suppressed, no canonical suppression

No contribution from decays of heavier states

$$\langle n_\phi \rangle = \frac{(2S_\phi + 1)V}{(2\pi)^3} \gamma_S{}^2 \int d^3p \, \mathrm{e}^{-\sqrt{p^2+m^2}/T}$$





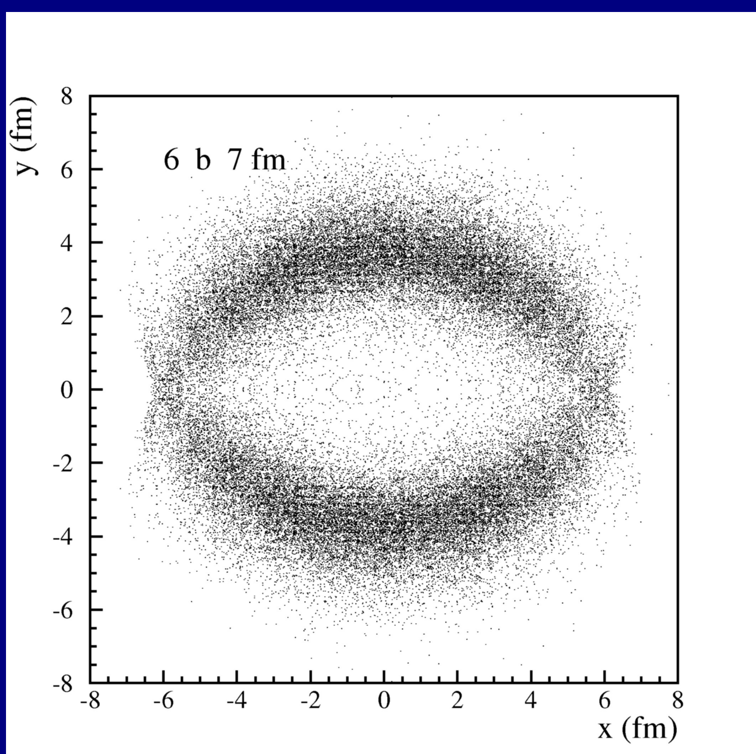
Cannot be explained by canonical suppression in any version

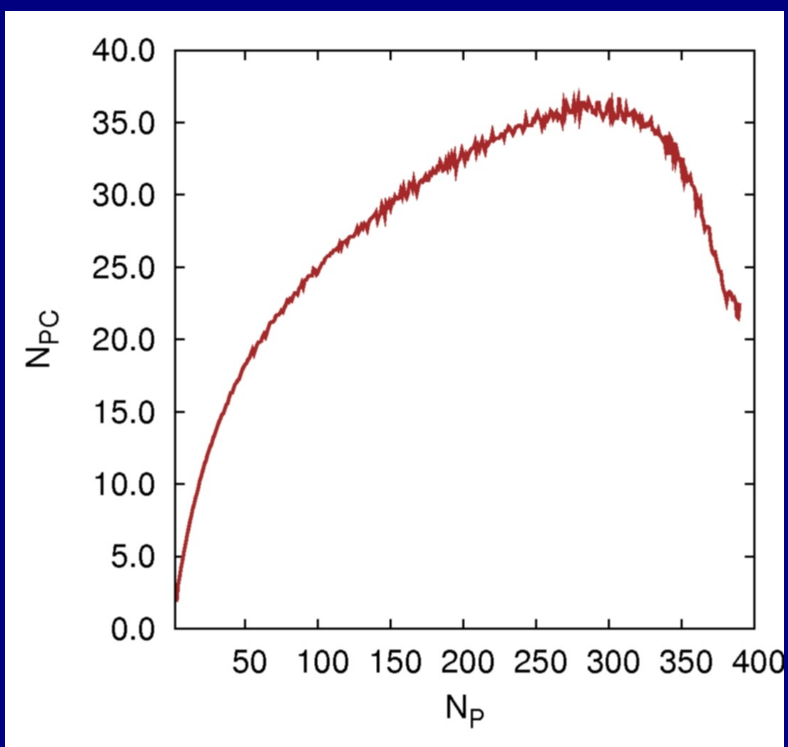
Core-corona model

F.B., M. Gazdzicki, A. Keranen, J. Manninen, R. Stock, Phys. Rev. C 69, 024905 (2004)
P. Bozek, Acta Phys. Pol. B 36 (2005) 3071; arXiv 0811.1918
C. Hohne, F. Puhlhofer, R. Stock, Phys. Lett. B 640, 96 (2006)
K. Werner, Phys. Rev. Lett. 98, 152301 (2007)
V. Pantuev, JETP lett. 85 (2007) 107

An effective definition:
Corona as the number of nucleons colliding once in a Glauber Monte-Carlo model

Introduced in: F.B., J. Manninen, J. Phys. G 35 (2008) 104013, arXiv:0805.0098 ,
talk given at Quark Matter 2008





S-undersat. S-satur. $\gamma_s=1$

$$\langle\frac{dN}{dy}\rangle = \frac{N_{PC}}{2}\langle\frac{dN}{dy}\rangle_{pp} + \langle\frac{dN}{dy}\rangle_{core}$$

$$N_{PC} = N_{1A} + N_{1B}$$

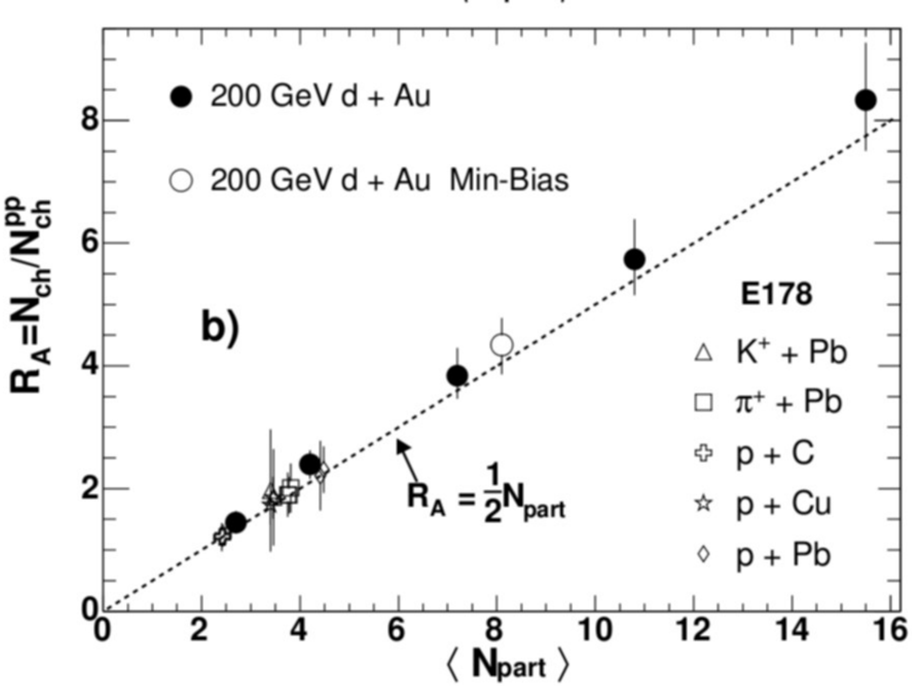
The factor ½ is motivated by relevant observations in pA and D-Au collisions

$$\langle\frac{dN}{dy}\rangle_{core} = f(V_0-\delta V_0)\rho_0\langle\frac{dn}{dy}\rangle_{core} = \frac{f\rho_0}{2n_0}(N_P-N_{PC})\langle\frac{dn}{dy}\rangle_{core}$$

$$R_A = \frac{2\langle\frac{dn}{dy}\rangle_{AA}}{N_P\langle\frac{dn}{dy}\rangle_{pp}} = \frac{2f\rho_0}{2n_0}\frac{\langle\frac{dn_i}{dy}\rangle_{core}}{\langle\frac{dn}{dy}\rangle_{pp}}\left(1-\frac{N_{PC}}{N_P}\right) + \frac{N_{PC}}{N_P}$$

$$R_A = \frac{N_{PC}}{N_P} + A\left(1-\frac{N_{PC}}{N_P}\right)$$

For the ϕ meson, A is independent of centrality!



PHOBOS Collaboration,
Phys. Rev. C72 (2005) 031901

J. Elias et al, Phys. Rev. D 22 (1980) 13.

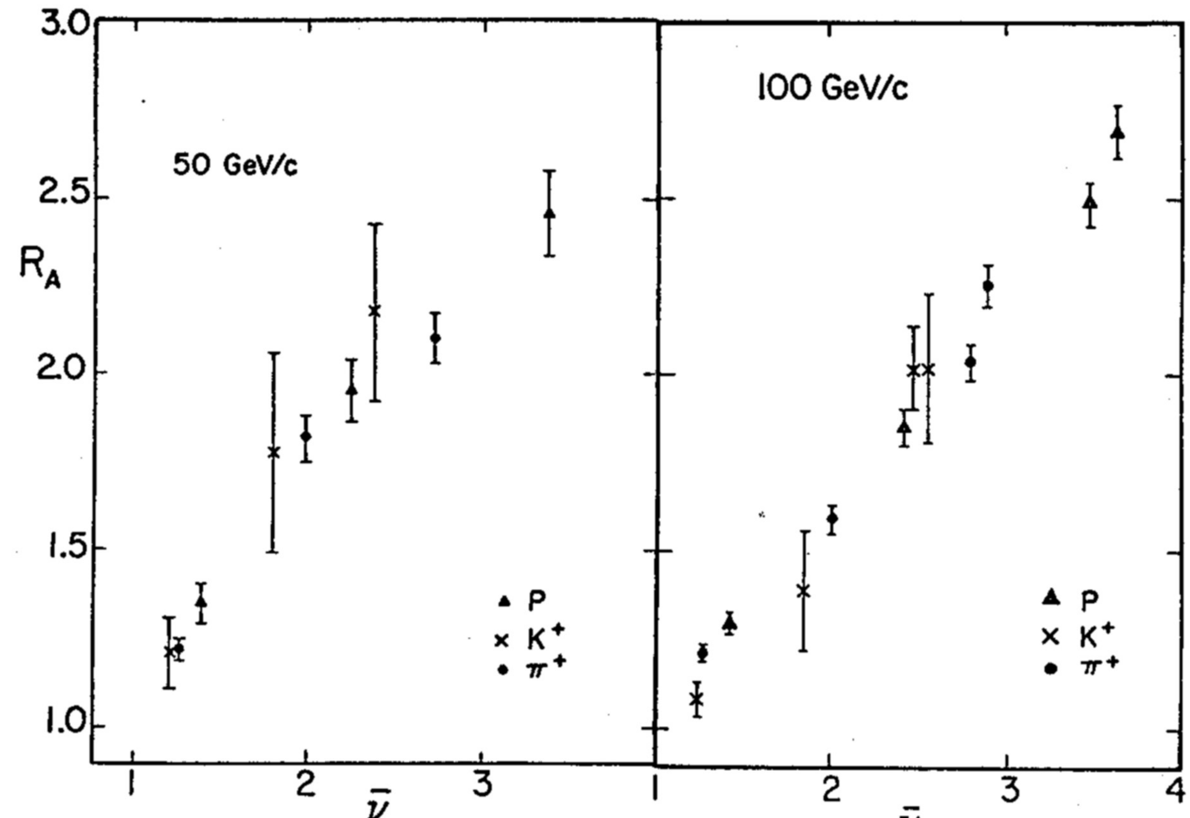
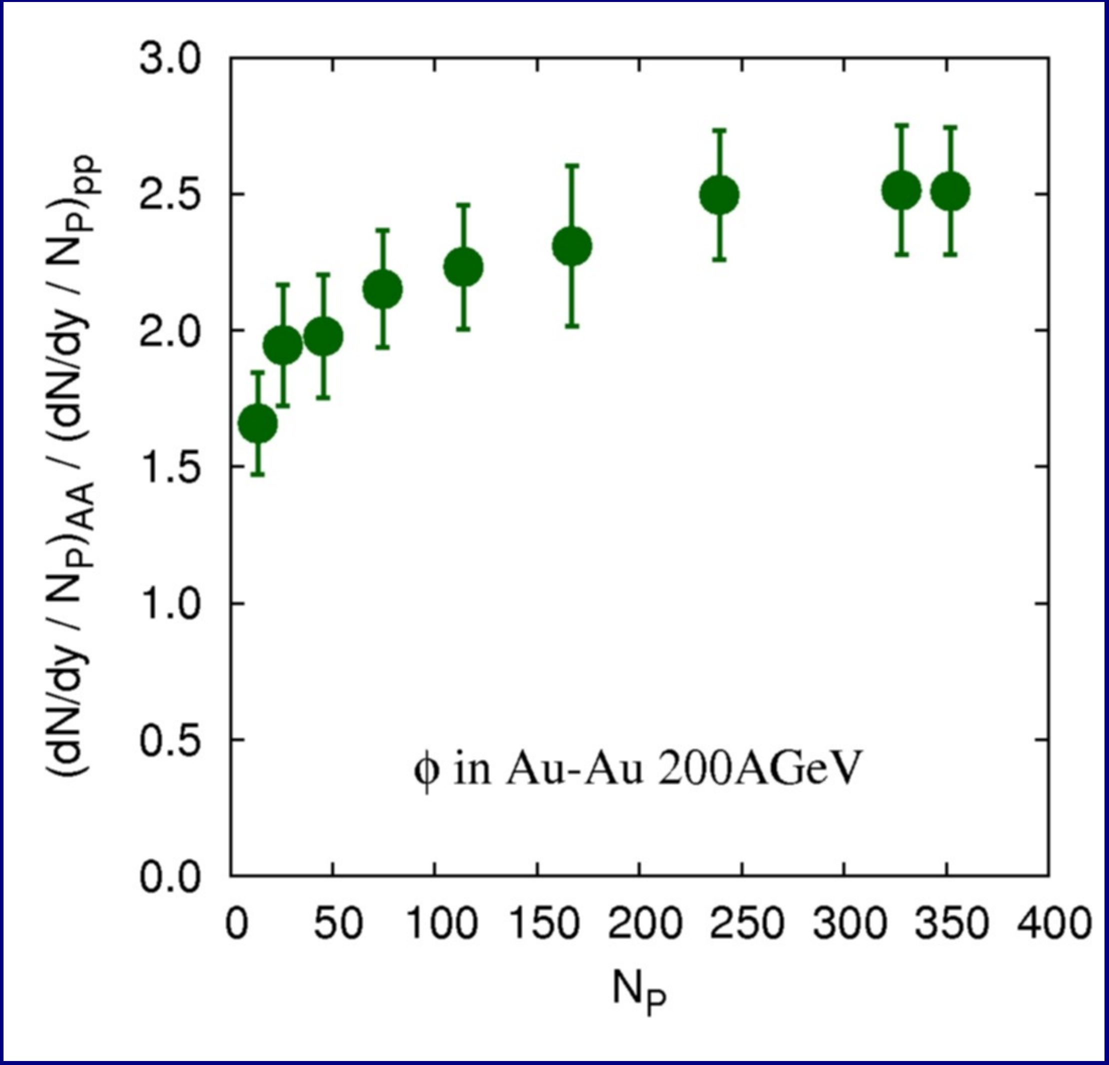


Fig. 12.

- Run a Glauber Monte-Carlo and calculate N_{PC}, N_P
- Fix A from, say, the most central bin and compare with the data of ϕ meson at RHIC



- Run a Glauber Monte-Carlo and calculate N_{PC}, N_P
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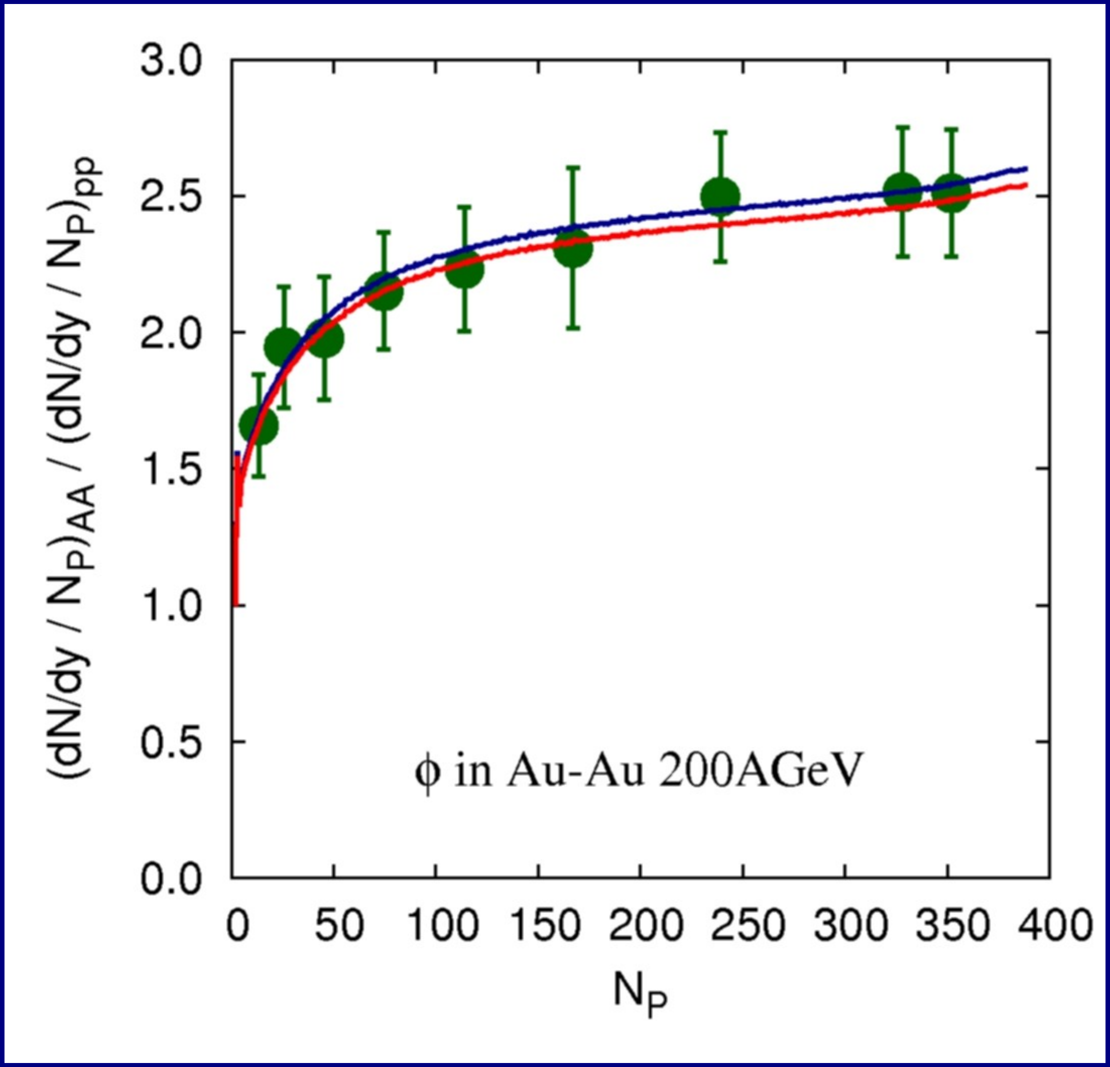
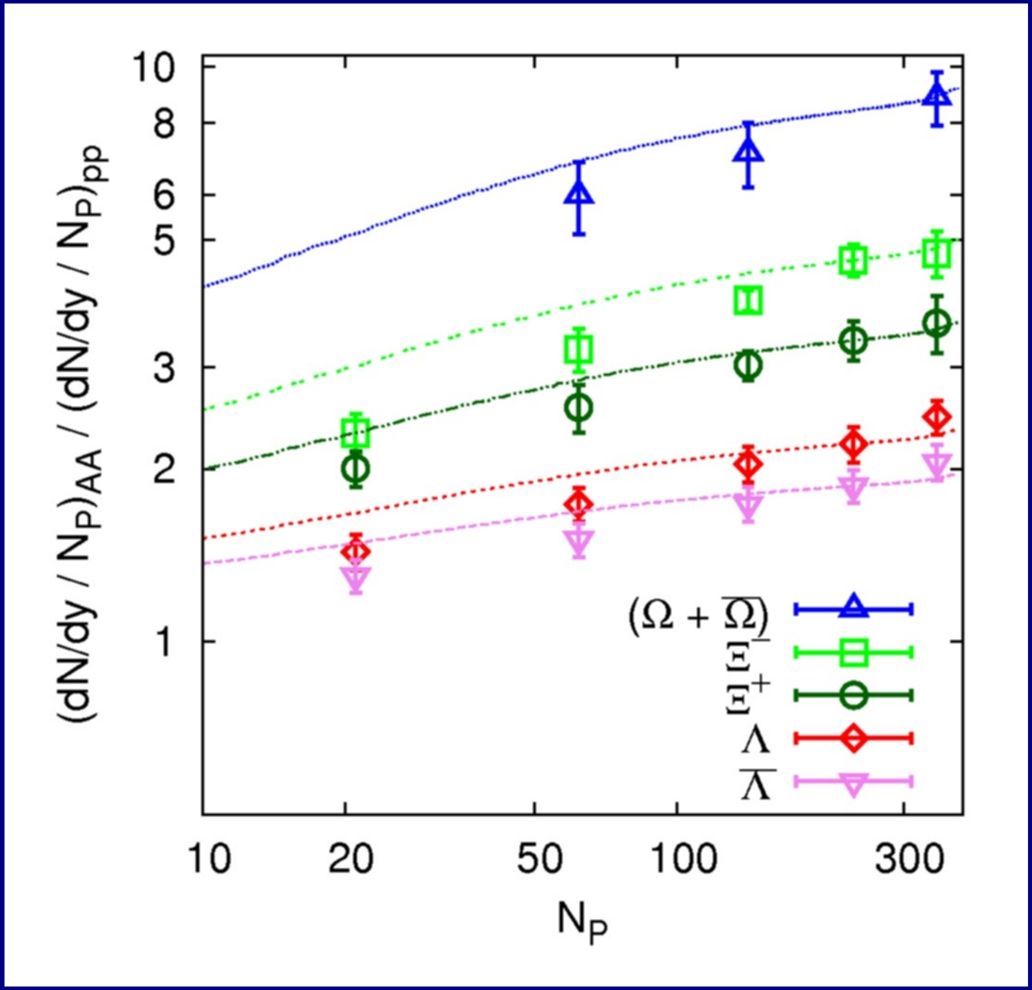
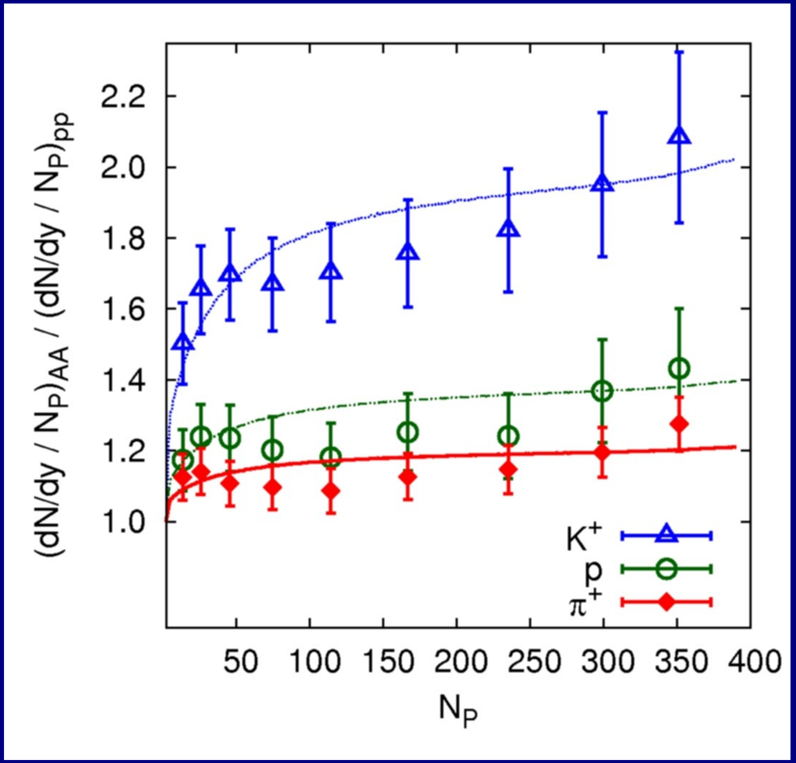


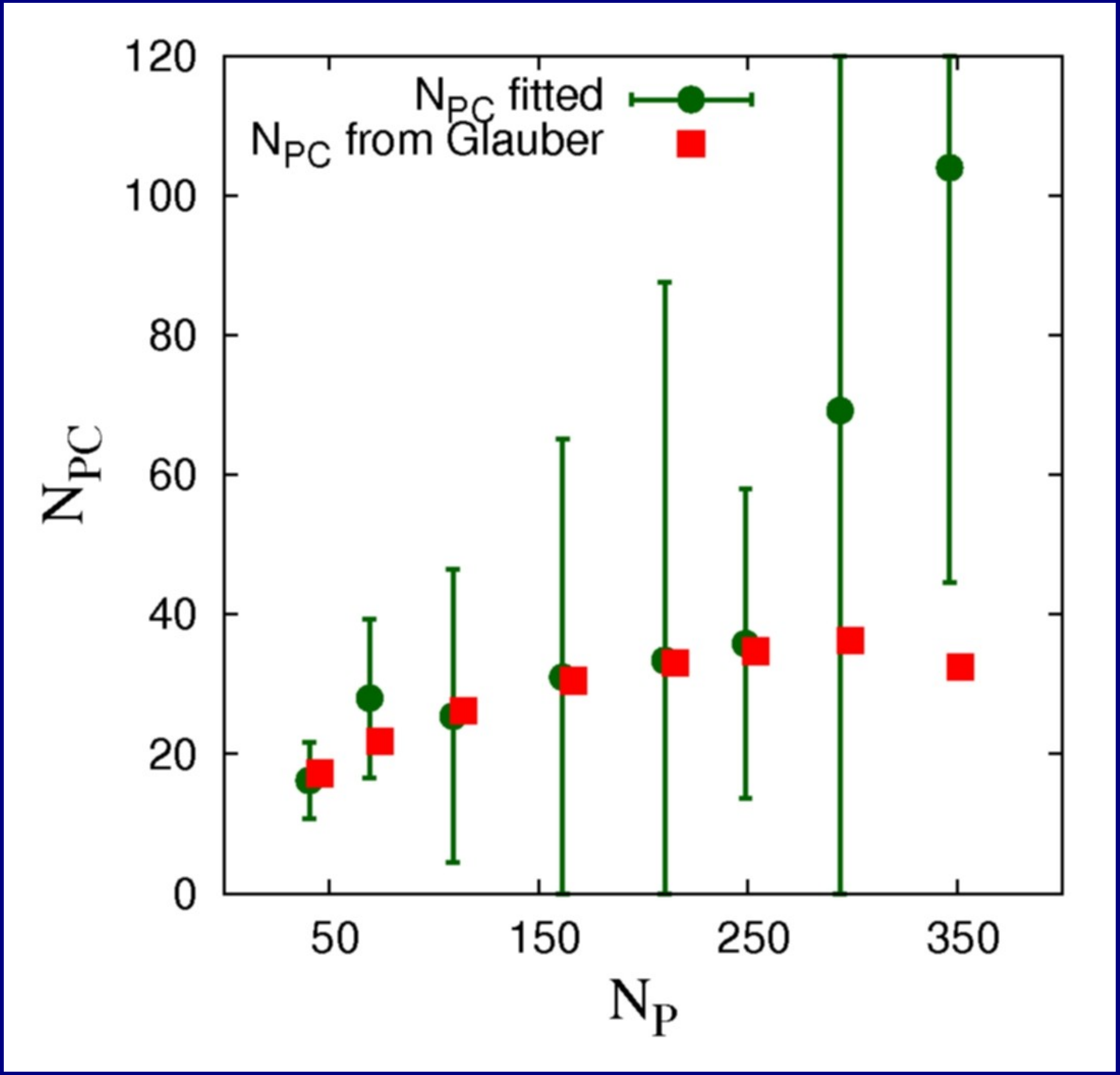
Strangeness enhancement for hyperons





Canonical suppression is a only a correction at low N_P

Replacing γ_S with N_{PC} in statistical model fits to multiplicities: very good agreement with Glauber model



F. B., J. Manninen, Phys. Lett. B 673 (2009) 19

Validity of core-corona model with Glauber-based definition confirmed by subsequent studies

J. Aichelin, K. Werner, Phys. Rev. C 79 064907 (2009) [idibem C 81 029902]

P. Bozek, arXiv: 0811.1918, Phys. Rev. C 79 054901 (2009)

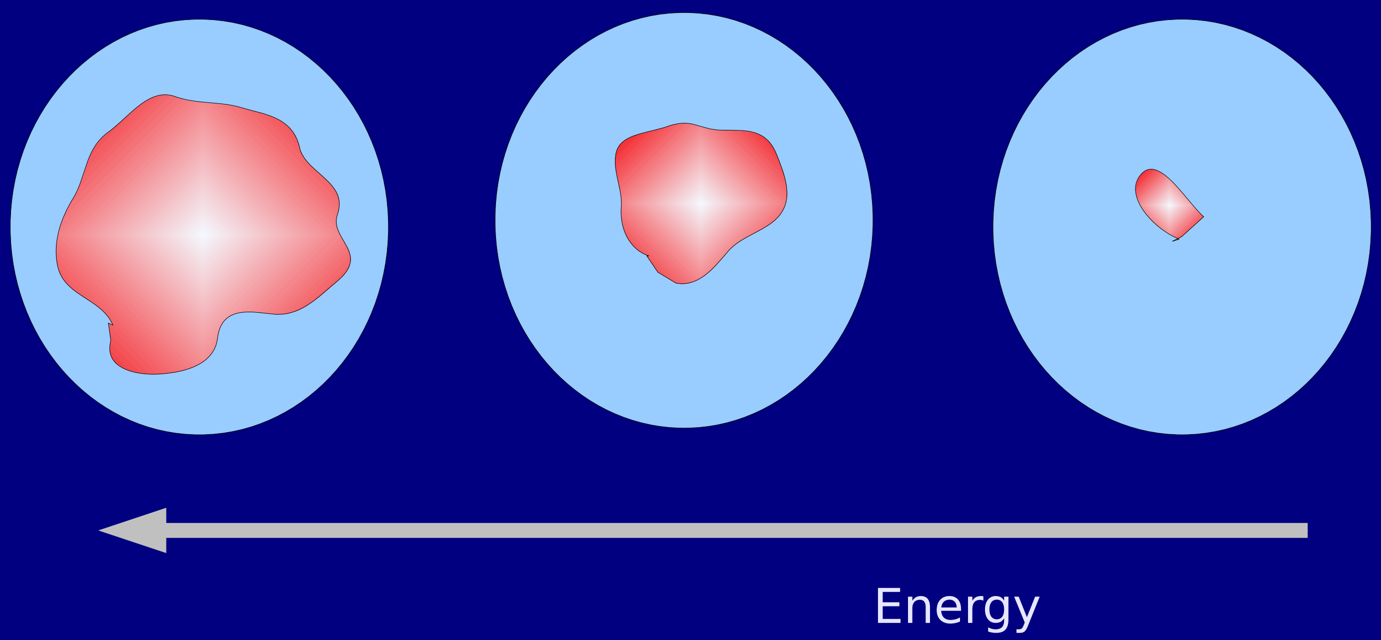
J. Aichelin, K. Werner, arXiv:1001.1545 (see talk in this conference)

C. Blume, arXiv:1007.1114, J. Phys. Conf. Ser. 230, 012003 (2010)
(see talk in this conference)

Working hypotheses

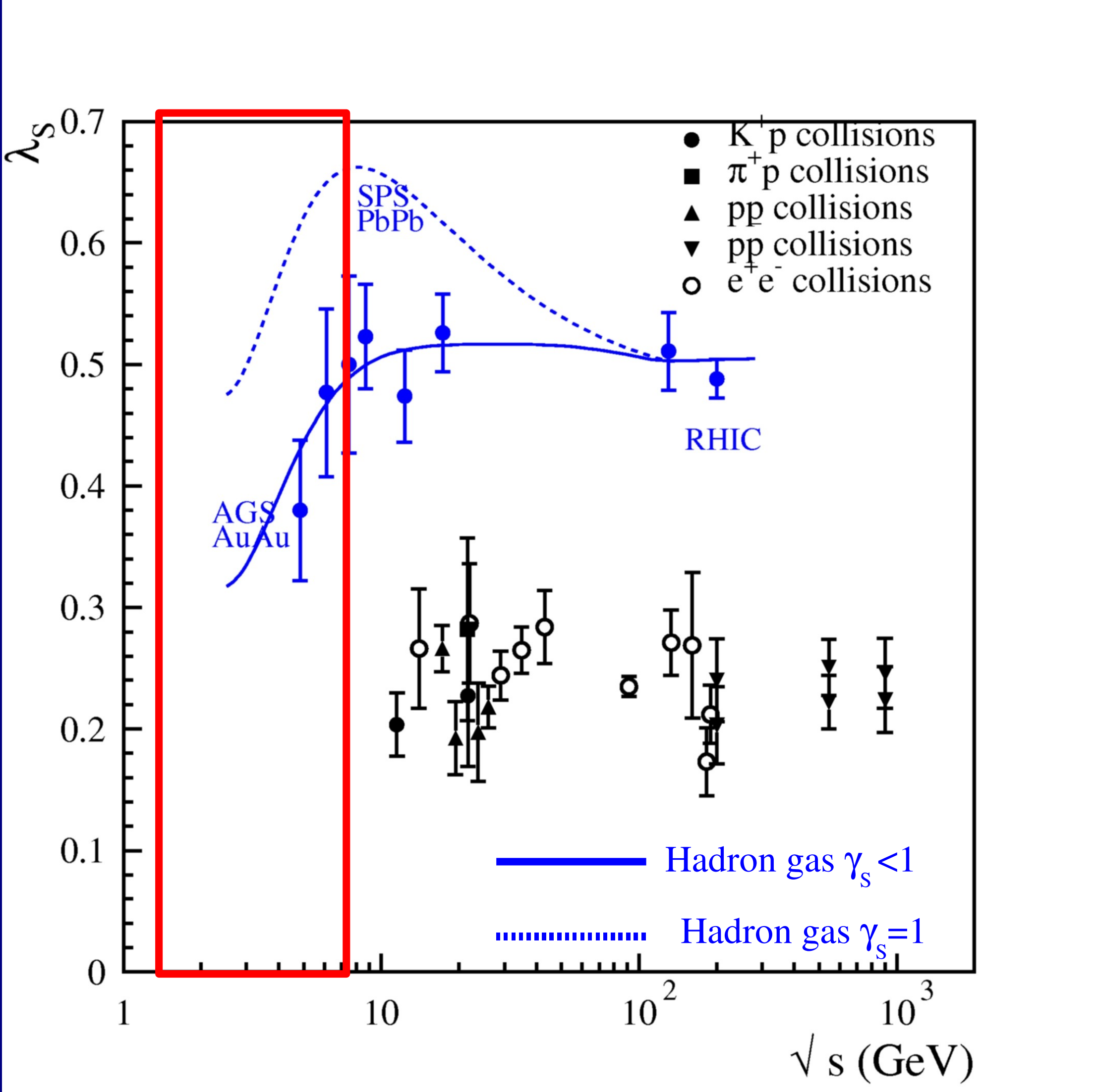
Core: *large* (=deconfinement) region successor of the plasma producing a hadron gas at full chemical equilibrium

At sufficiently low energy one expects no core, so the search of the onset of deconfinement could be possibly accomplished by finding where a SHM fits with a core at full chemical equilibrium <u>fails</u>



Where is the onset of full chemical equilibrium in the core?

Need to re-analyze carefully SPS, AGS data as a function of centrality and system size



PROBLEMS

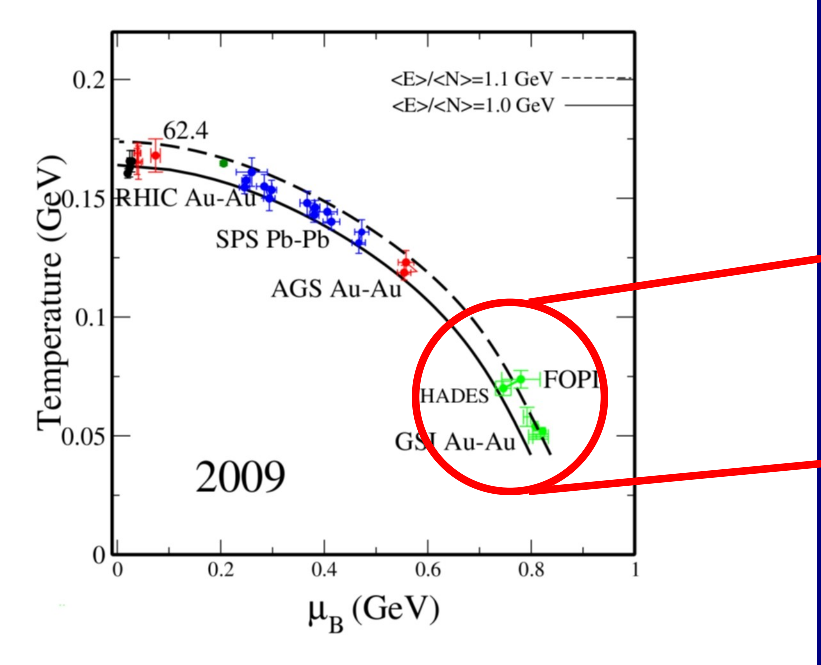
- Does the hadron-resonance gas model hold when T < 100 MeV ?

Based on the theory (Dashen-Ma-Bernstein theorem) one expects corrections due to non-resonant interactions. Difficult to assess, no study in literature.

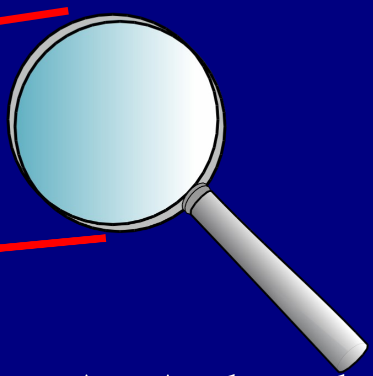
- How to subtract the “corona” ? Can the “corona” be defined the same way as at high energy?

Glauber model is not expected to work at low energy.

Common wisdom is that statistical model in its simplest hadron-resonance gas implementation works for AB collisions at low energy even without γS

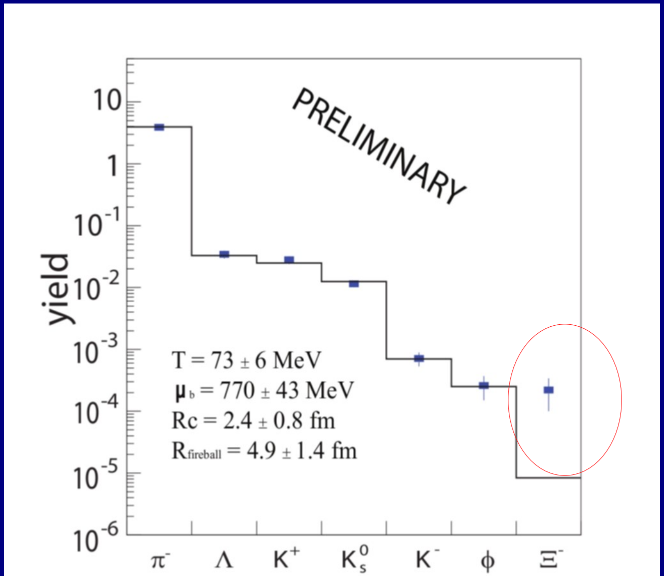


J. Cleymans, arXiv:1005.4114

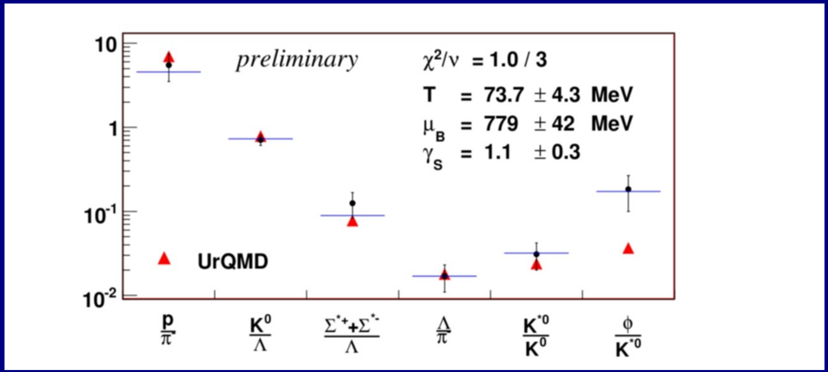


Some points are Au-Au based on very few and old measurements

However, there are two recent analyses (2009-2010) based on new data: HADES Ar-KCl T_{beam} = 1.76 A GeV and FOPI Al-Al T_{beam} =1.9 A GeV



HADES, arXiv:0911.0516



FOPI coll., Acta Phys. Pol. 41 (2010) 405

Cross-check: using the same data set, we get fairly consistent results.

However, it seems that the fit sensitivity is rather poor, at least in FOPI case. POSSIBLE REASON: the FOPI fit uses ONLY ratios, which is not suitable when the system is small, because the volume dependence is only through the canonical chemical factors and no longer as an overall normalization factor...

OUR FITS (preliminary)

By replacing ϕ/K and K/Λ with ϕ and K yields (published in FOPI coll., arXiv:1006.1905 and Acta Phys. Pol. 41 379, 2010) in FOPI fit we obtain

PARAMETER	Value	Error
T(MeV)	80.6	4.2
μ_B (MeV)	815	35
γ_S	0.47	0.13
V(fm3)	169.	90
$\chi 2$	9.5/3	

PRELIMINARY

To be confirmed...

It would be interesting to have a Ξ measurement in FOPI to compare with HADES

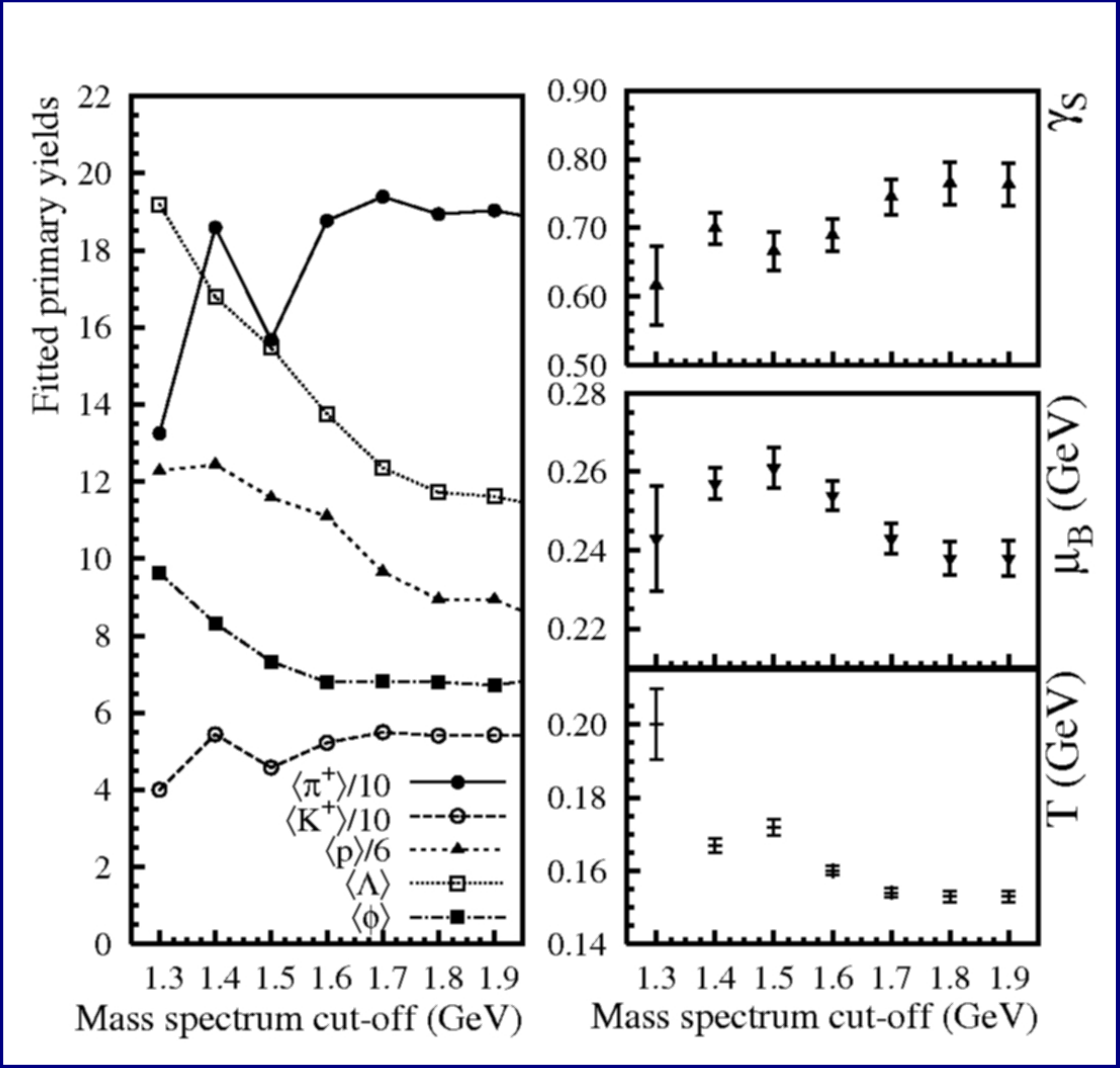
CONCLUSIONS

- At RHIC the strangeness production as a function of centrality can be explained by a geometrical core-corona superposition.

ϕ meson is the key probe.

- The core, at RHIC and top SPS energy, is consistent with a *completely equilibrated hadron gas* throughout all centralities whereas corona is best described as NN collisions where at least one of the nucleons undergoes one collision in a Glauber model
- If the core is a by-product of the deconfinement, it should disappear at some low energy. Can this be detected as a failure of statistical model ?

NEED MORE DATA, MORE ACCURATE, AND MORE DETAILED ANALYSES BETWEEN $\sqrt{s}_{NN}$ = 1 and 10 GeV



Fitted primary yields
⟨π+⟩/10
⟨K+⟩/10
⟨p⟩/6
⟨Λ⟩
⟨ϕ⟩
Mass spectrum cut-off (GeV)
γS
μB (GeV)
T (GeV)
Mass spectrum cut-off (GeV)

What is the origin of full chemical equilibrium in the core?

- Collisional equilibration

P. Braun-Munzinger, J. Stachel, C. Wetterich, Phys. Lett. B596, 61 (2004).

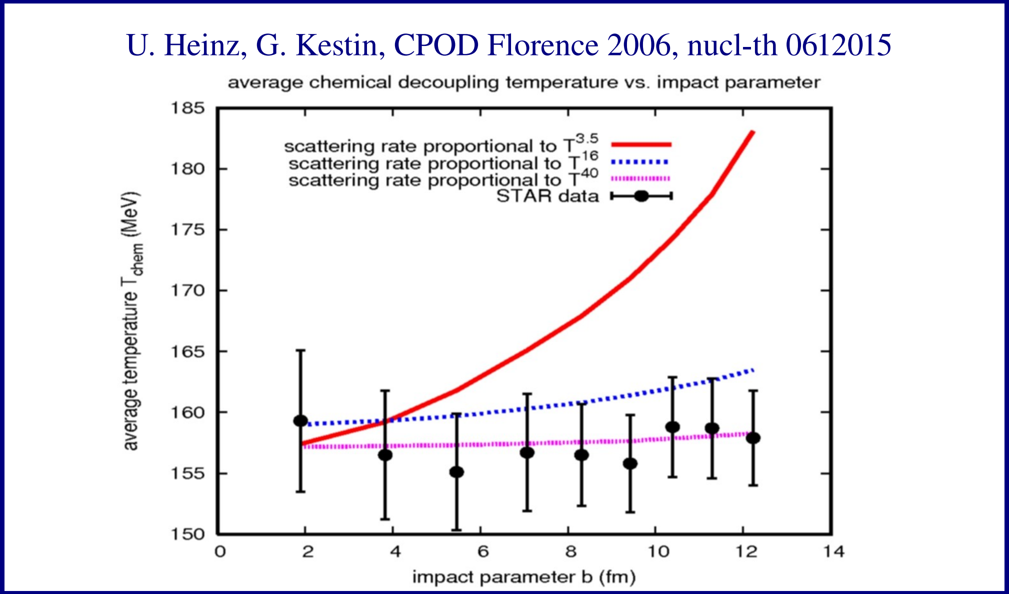
no dependence of T on centrality (U. Heinz, G. Kestin, CPOD Florence 2006, nucl-th 0612015)

multi-meson collisions cannot reproduce Ω yields (J. Kapusta, SQM03); need of introducing "Hagedorn states" which decay statistically (C. Greiner et al., arXiv:0711.0930, nucl-th/0703079)

- Direct statistical hadronization

F. B., U. Heinz, Z. Phys. C 76, 269 (1997)
R. Stock, Phys. Lett. B456, 277 (1999)
U. Heinz, Nucl. Phys. A 661, 140 (1999)

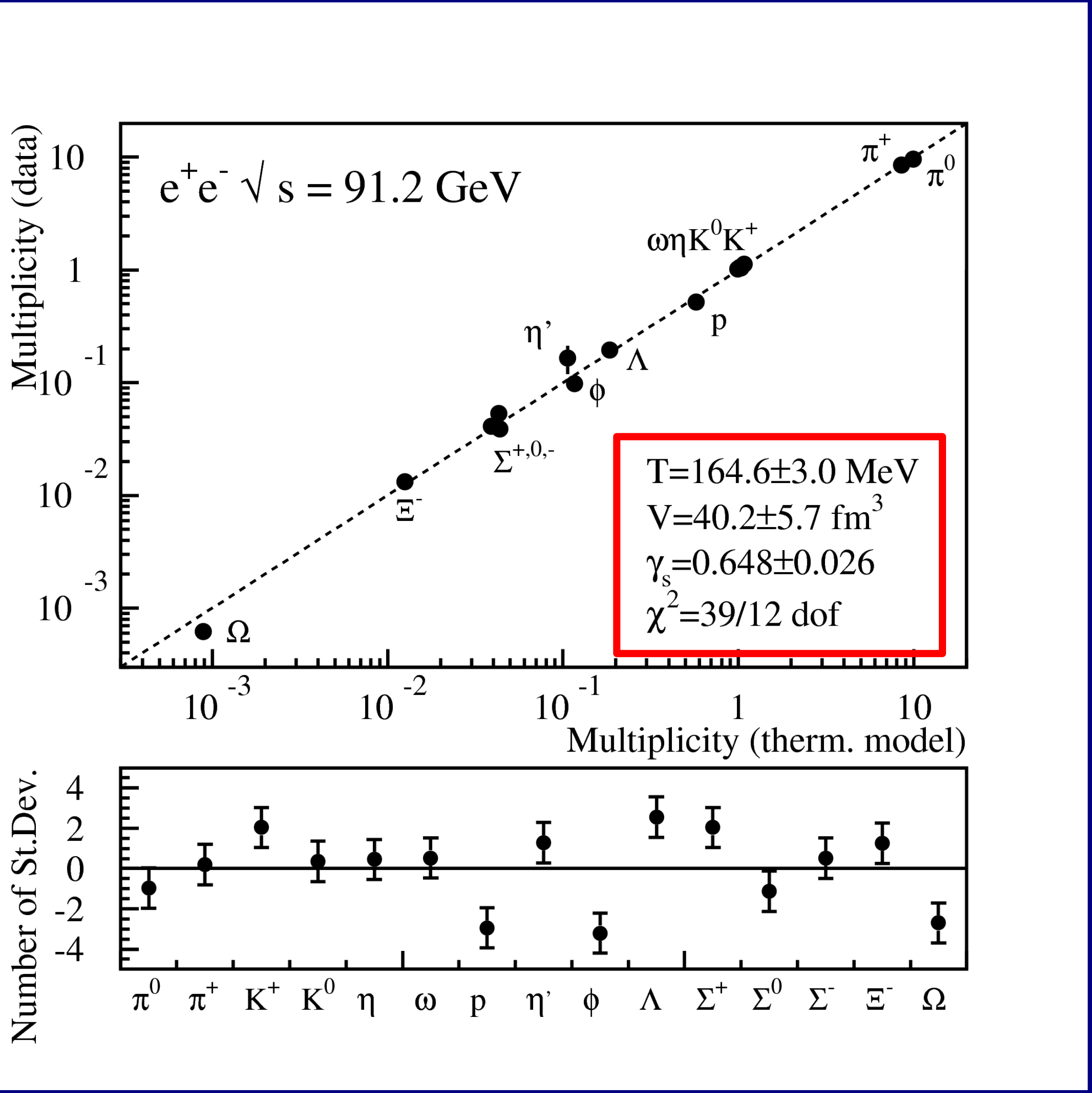
full equilibrium



U. Heinz, G. Kestin, CPOD Florence 2006, nucl-th 0612015

Are these points of view equivalent?

Statistical hadronization in elementary collisions

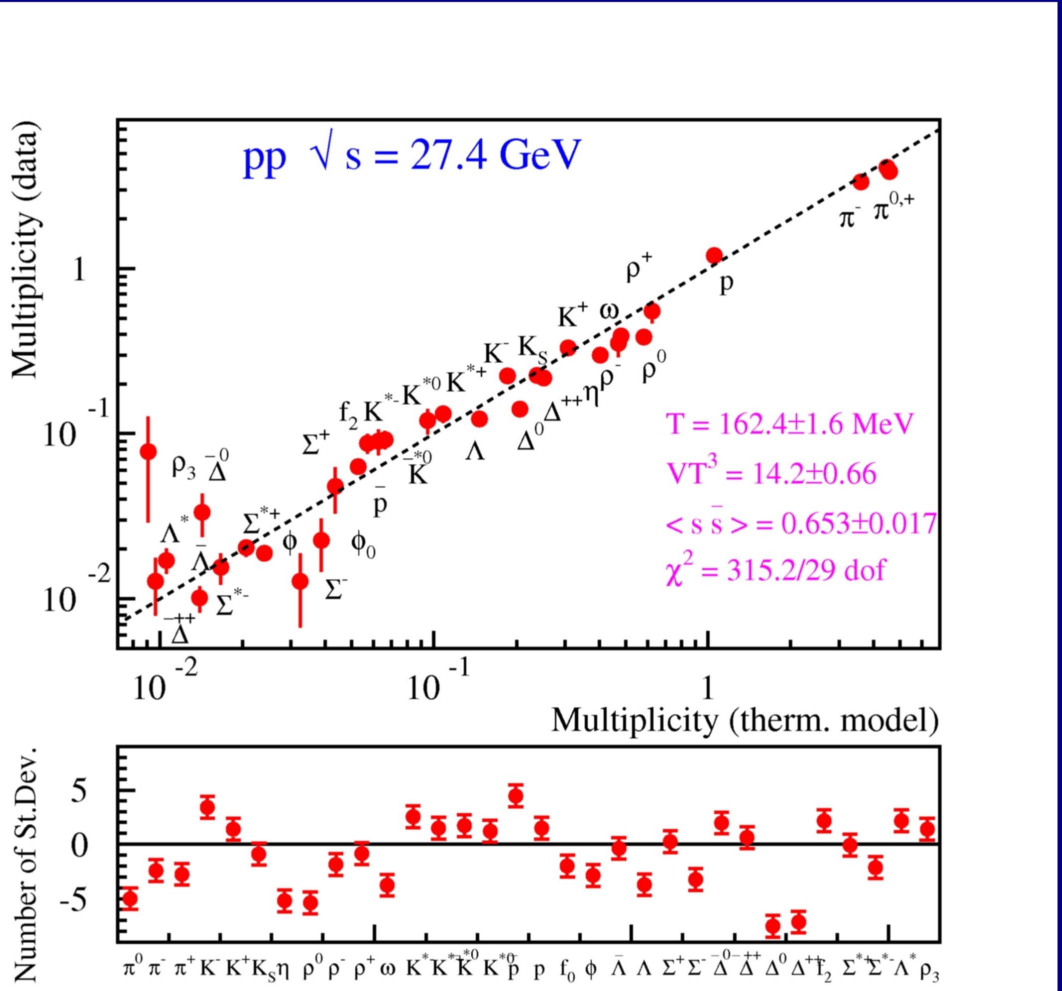


Is it all in the volume of the fireballs-clusters (deconfinement)?

F.B., G. Pettini, Phys. Rev. C 67, 015205 (2003)

Results in pp collisions

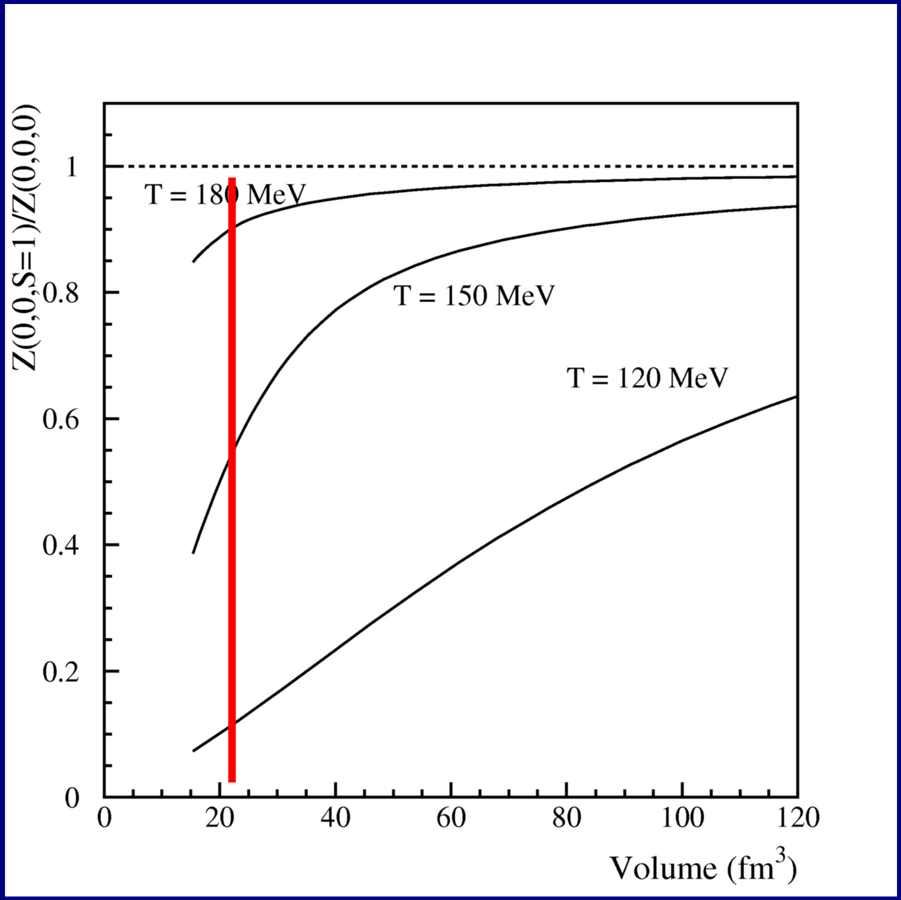
$$\langle n_j \rangle = \frac{(2S_j+1)V}{(2\pi)^3} {\gamma_S}^{N_s} \int d^3p \, \mathrm{e}^{-\sqrt{p^2+m_j^2}/T} \, \frac{Z(\mathbf{Q}-\mathbf{q}_j)}{Z(\mathbf{Q})}$$



F. B., G. Passaleva, Eur. Phys. J. C 23 (2002) 551

The role of the chemical factor Z(Q-q)/Z(Q) is crucial in determining the overall strangeness production.

In the framework of this model, the observed strangeness enhancement might be the result of the simple increase of system size.



But it seems that this is not enough, because also the phenomenological parameter γ_s increases...