Strangeness production from SPS to LHC

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in collaboration with J. Manninen (INFN Florence)

Focus on GLOBAL strangeness production

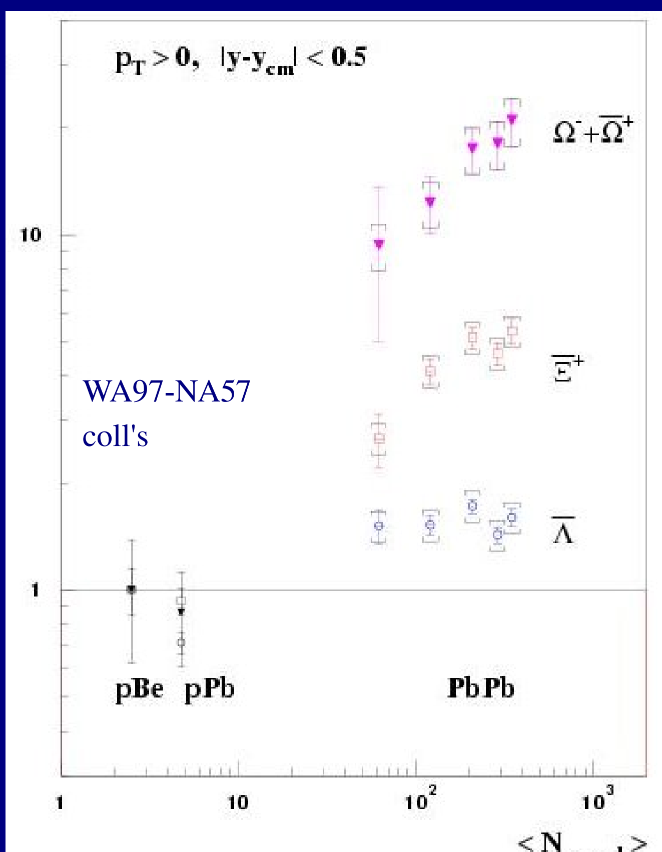
- Strangeness enhancement in heavy ion collisions
- Statistical model
- Canonical suppression ?
- Conclusions

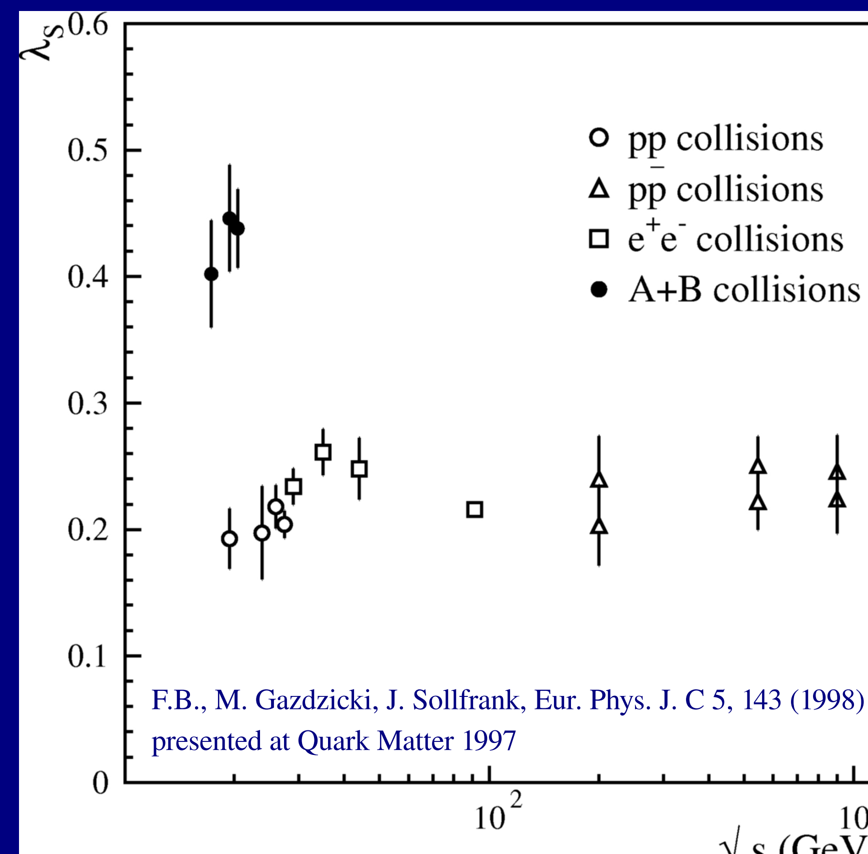
Strangeness enhancement was predicted as a signature of QGP

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

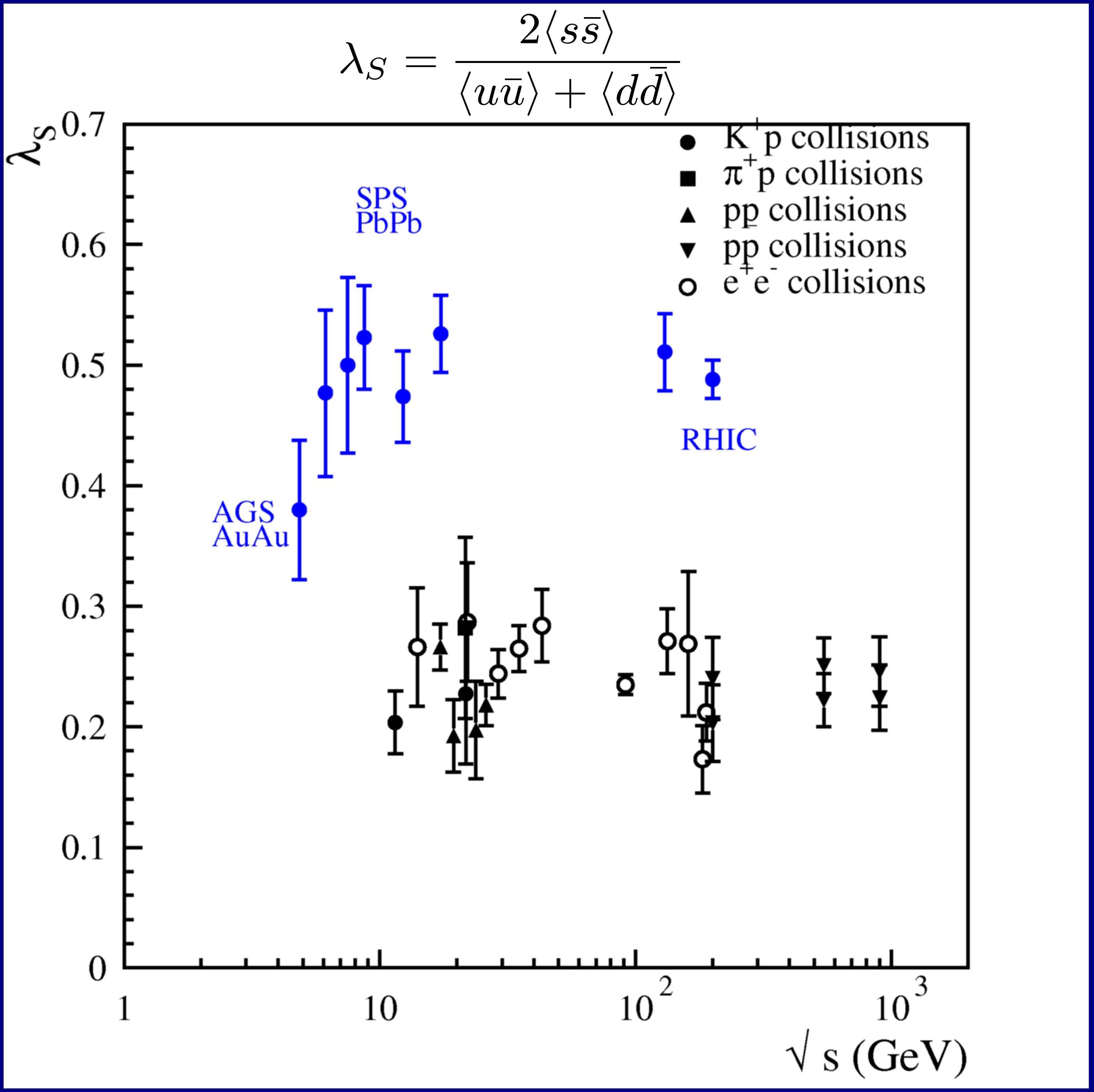
Chiral symmetry restoration favours (relative) strange quark production in a deconfined medium

Strange quark coalescence favours the enhancement of multiple strange hyperons





Wroblewski ratio: current status



For a calculation on the lattice:

R. Gavai, S. Gupta,
Eur. Phys. J. C 43, 31 (2005)
and refs. therein

What is the origin of the strangeness enhancement?

Post-hadronization collisions driving a non-equilibrated system towards equilibrium?
(transport models)

Recombination or statistical coalescence of strange quarks from the plasma?

Are strange quarks produced essentially AT the hadronization?

Do we observe a completely equilibrated hadron gas?

→ STATISTICAL MODEL FITS

answers: YES ALWAYS ; . . . ; NO NEVER

Statistical model fits

- Statistical fits and their intepretation should be VERY careful.

The fit is a way of determining the best parameters, one should not expect a PERFECT fit.

- Midrapidity yields can be safely used in these fits at RHIC energies and above, but

NOT at SPS and lower energies because the rapidity distributions are not wider enough than single fireball's

Rapidity widths of pions:

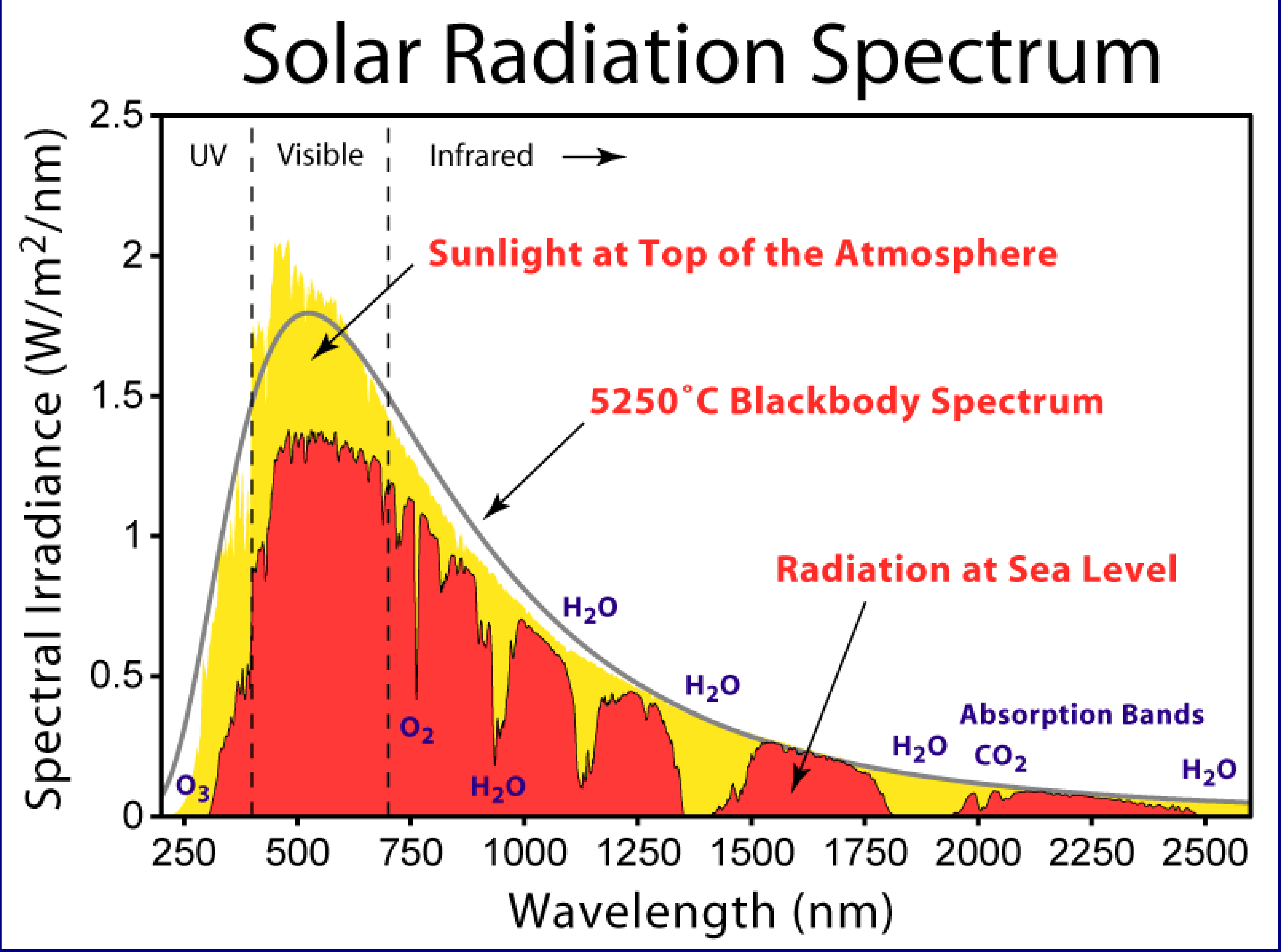
$\sigma \sim 1.3$ at top SPS $\sigma \sim 0.8$ for a fireball with T = 125 MeV

$\sigma \sim 2.1$ at RHIC 200

EXAMPLE: fit to NA49 data at top SPS

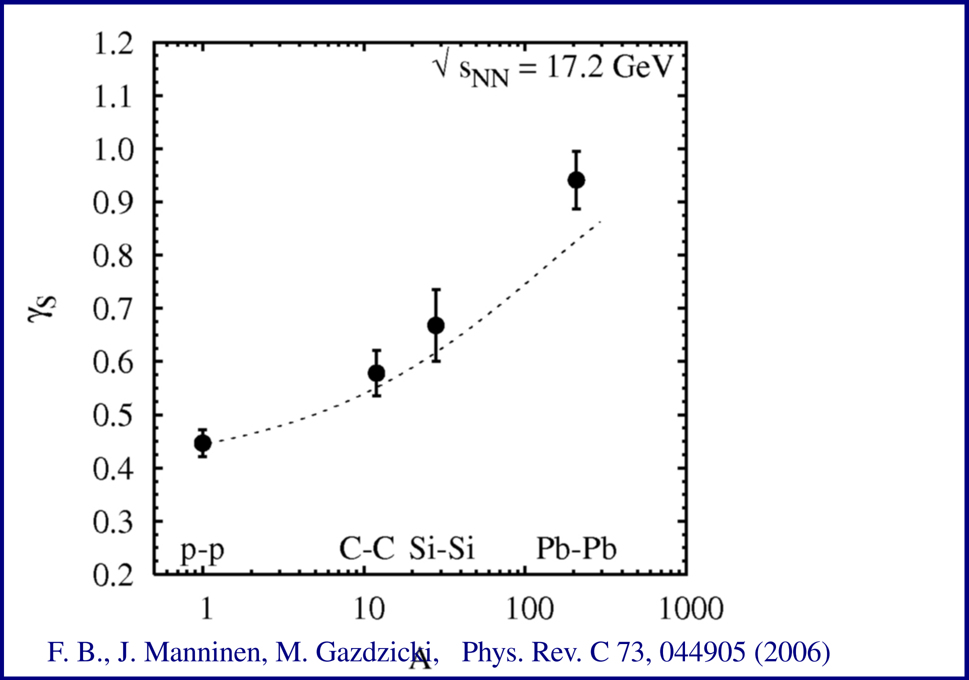
Midrap. yields $\gamma_S = 0.95 \pm 0.06$ $\chi^2 = 37.2/8$

4π yields $\gamma_S = 0.81 \pm 0.04$ $\chi^2 = 18.8/9$

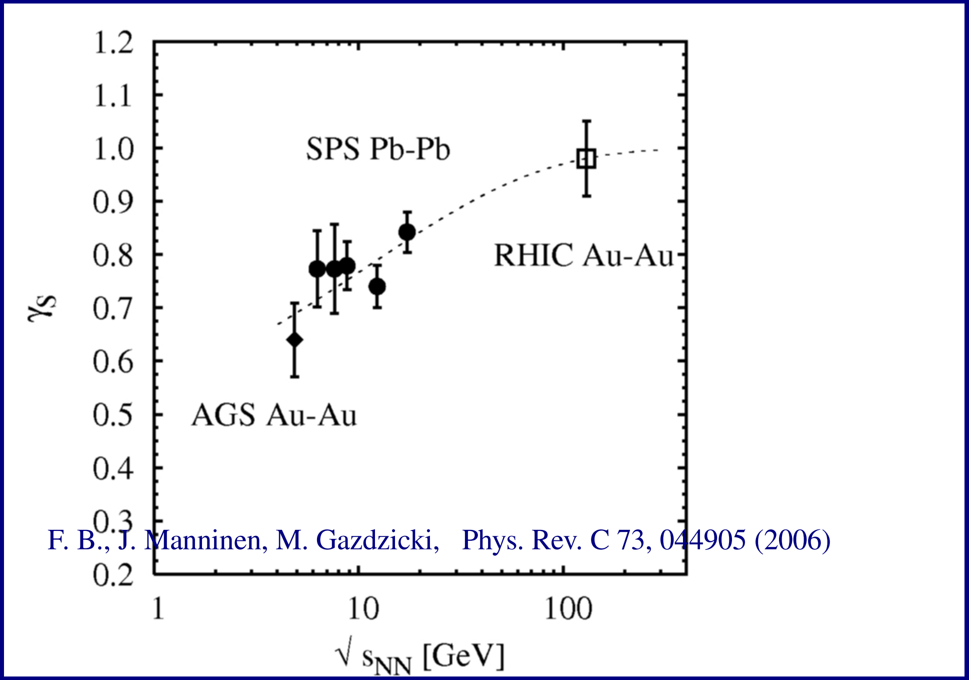


Is the “statistical model” fit perfect?

Statistical model: strangeness undersaturation parameter γ_s



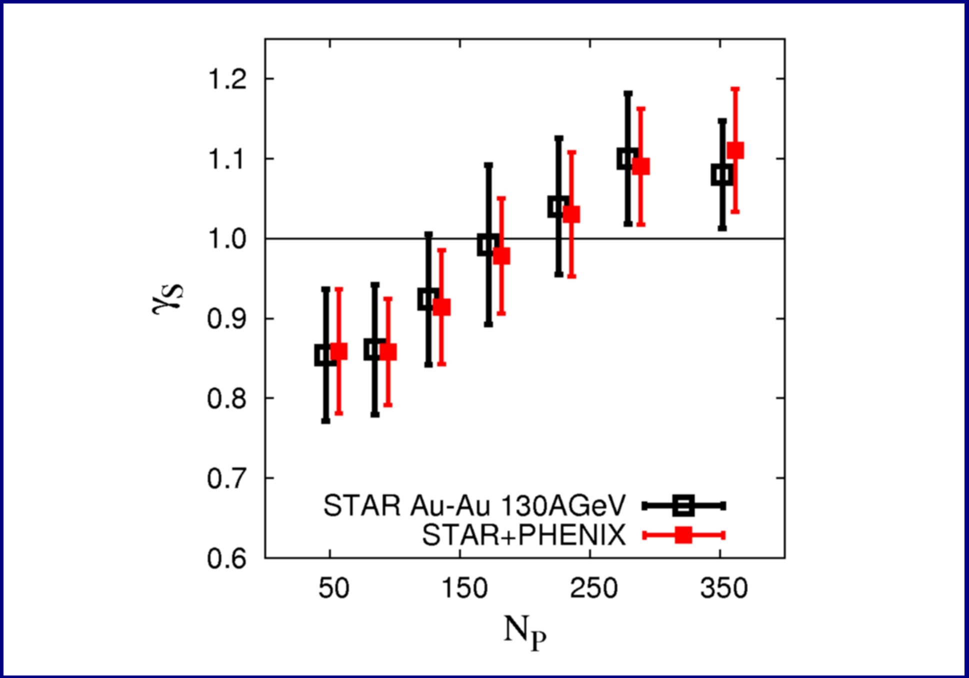
F. B., J. Manninen, M. Gazdzicki, Phys. Rev. C 73, 044905 (2006)

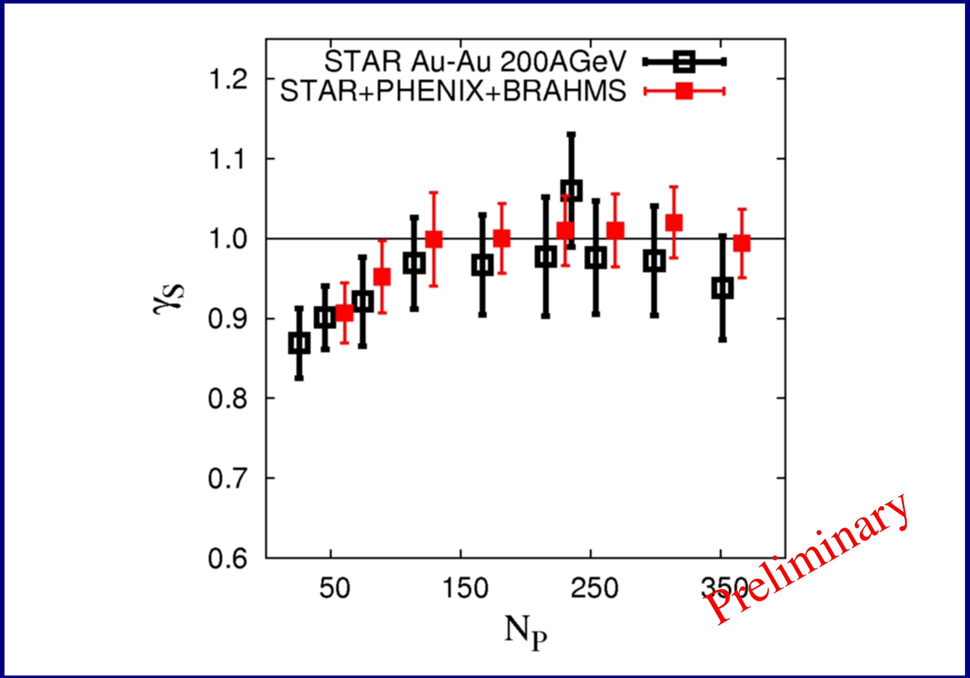


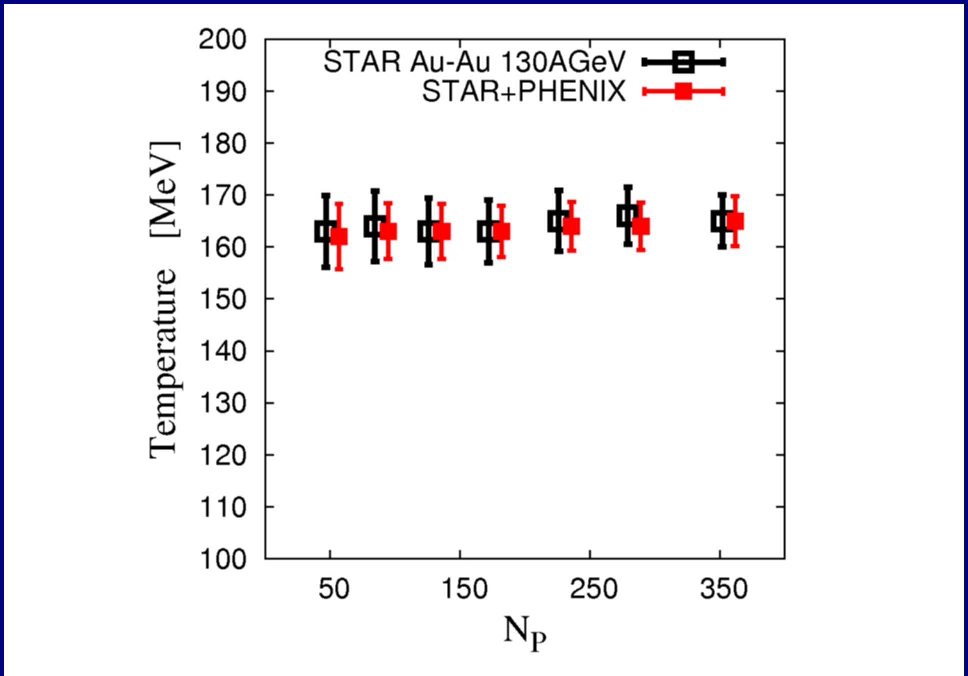
F. B., J. Manninen, M. Gazdzicki, Phys. Rev. C 73, 044905 (2006)

Strangeness undersaturation parameter γ_s at RHIC

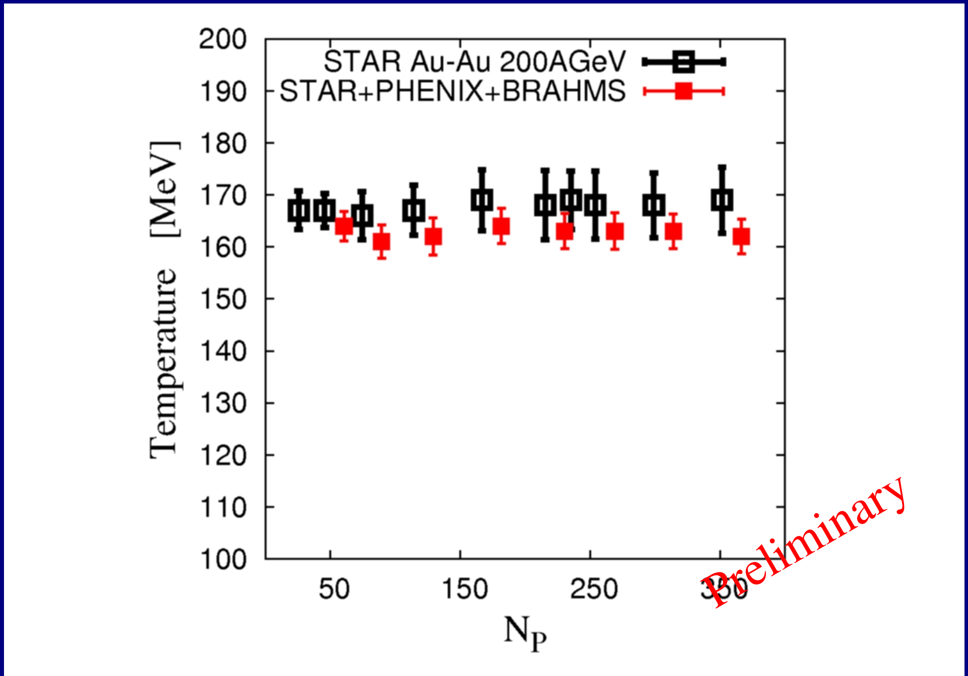
- Statistical model fits to midrapidity yields and to <u>experimentally measured ratios</u> in STAR, PHENIX, BRAHMS (see F.B. arXiv:0707.4154)
- Centrality dependence interpolated with third-degree polynomial
- Introducing different normalization constants for each experiment to take into account systematic effects in centrality determination



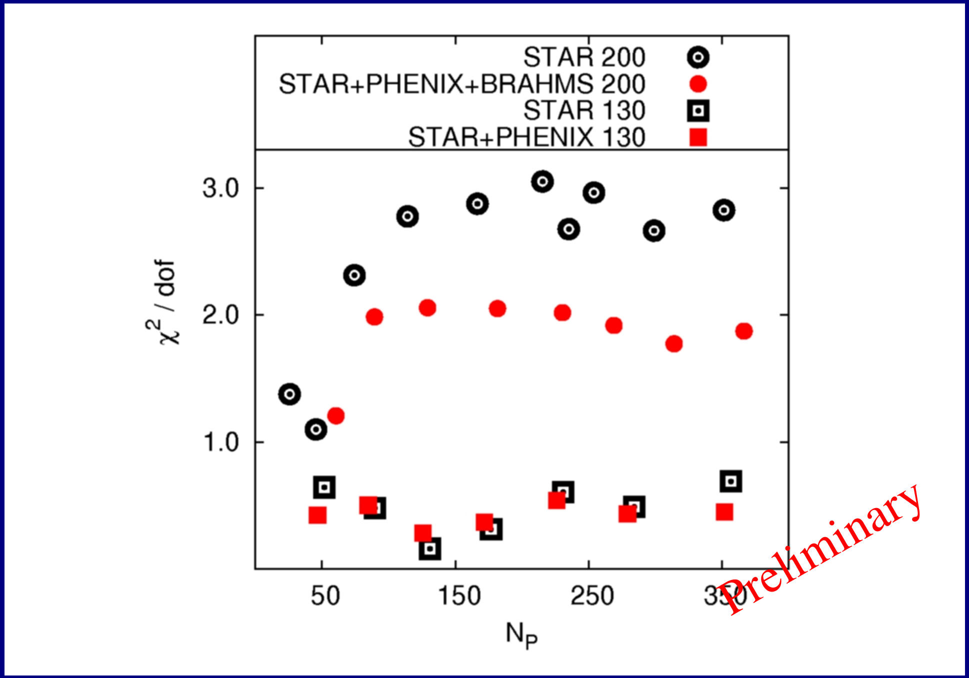




STAR Au-Au 130AGeV
STAR+PHENIX
Temperature [MeV]
200
190
180
170
160
150
140
130
120
110
100
50
150
250
350
N_P



STAR Au-Au 200AGeV
STAR+PHENIX+BRAHMS
Temperature [MeV]
200
190
180
170
160
150
140
130
120
110
100
50
150
250
350
N_P
Preliminary



STAR 200
STAR+PHENIX+BRAHMS 200
STAR 130
STAR+PHENIX 130
χ^2 / dof
3.0
2.0
1.0
50
150
250
350
N_P
Preliminary

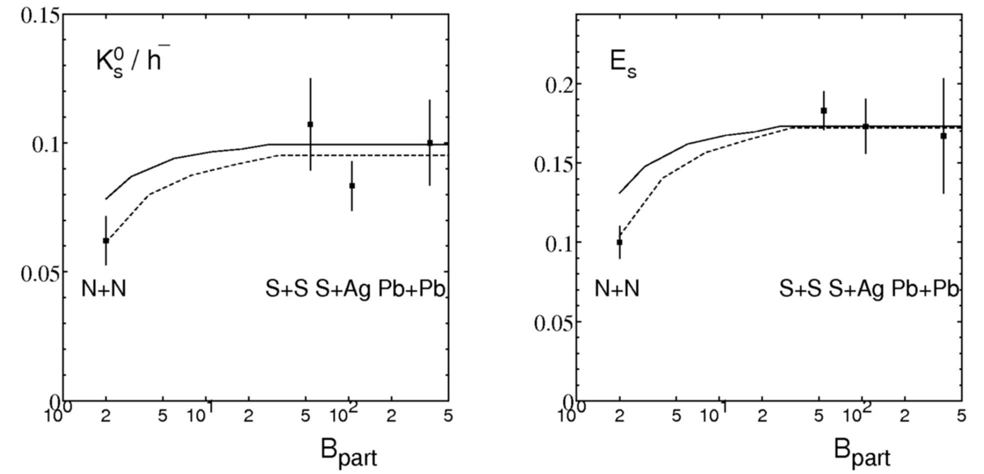
γ_s = canonical suppression ?

Finite volume effect: exact strangeness conservation enforced in a finite system with S=0 entails a reduction of multiplicity of OPEN STRANGE hadrons

As a possible explanation of strangeness undersaturation from pp to heavy ions discussed in:

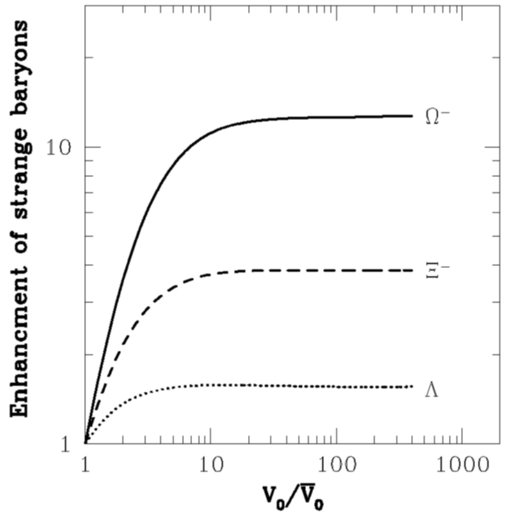
F. B., M. Gazdzicki, J. Sollfrank, Eur. Phys. J. C 5. 143 (1998)

J. Sollfrank et al., *Canonical strangeness enhancement*, Nucl. Phys. A 638, 299c (1998) and talk given by J. Sollfrank at QM97



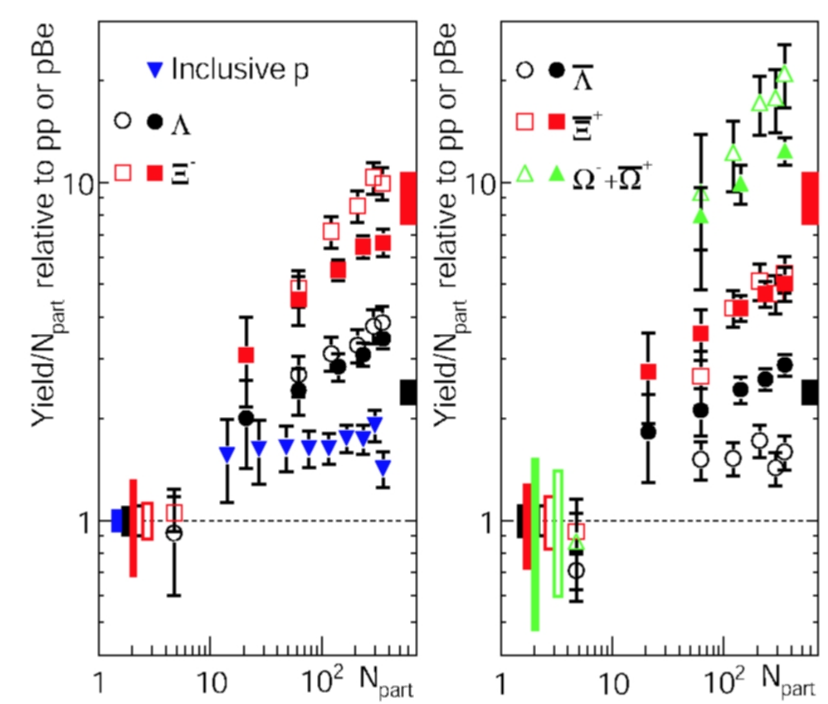
constructed. However, this suggestion suffers from a serious difficulty connected with the measured ϕ yield. The ϕ-meson is not canonically suppressed because it has zero charges. For $\gamma_s \approx 0.7$ in p+p collisions the measured ϕ abundance deviates from a thermal fit by 12σ, increasing even more the already troublesome deviation of 4σ for $\gamma_s = 0.5$ [6].

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



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



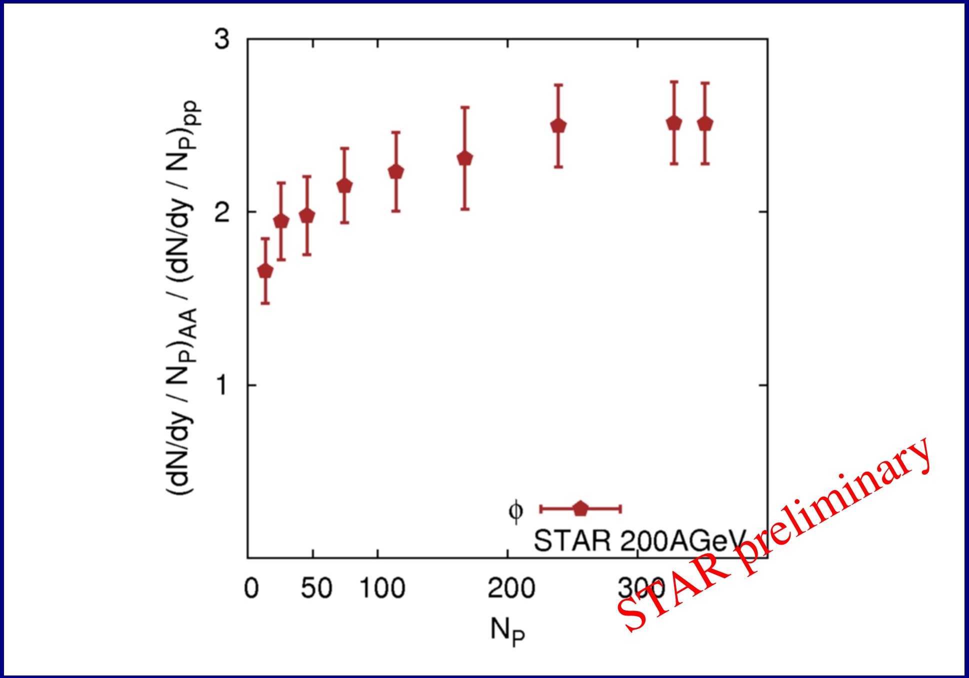
STAR coll., arXiv:0705.2511

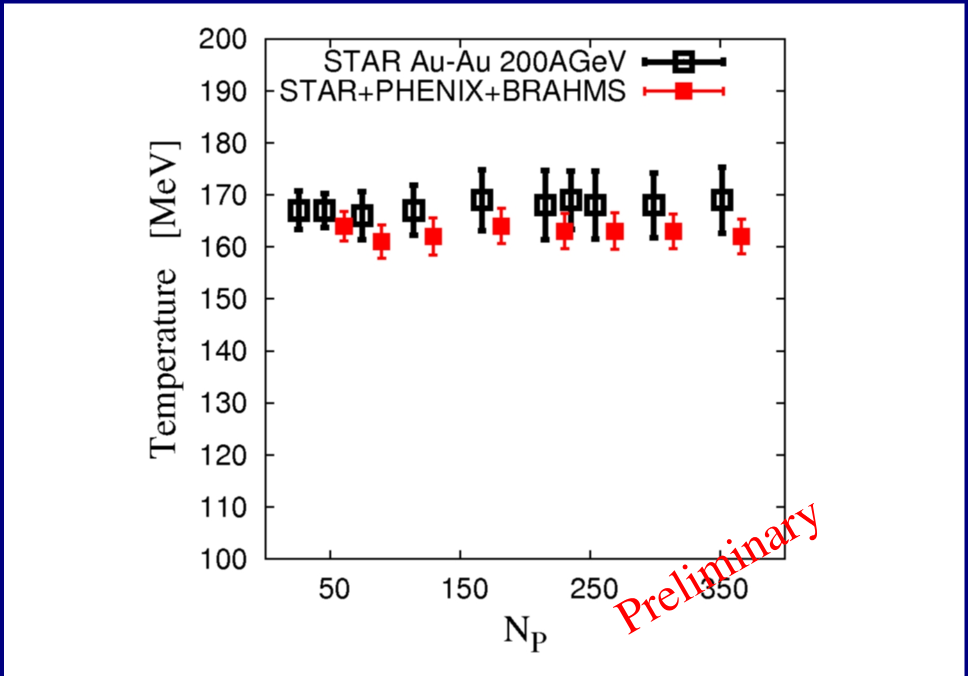
The ϕ meson: γ_s^2 suppressed, no canonical suppression

Sect. 2 which is crucial to reduce the number of free parameters. Since γ_S turns out to be < 1, it might be argued indeed that if the hadron gas fireballs were small enough and all with zero strangeness (so that the weights $w(\mathbf{Q}_1^0, \ldots, \mathbf{Q}_N^0)$ would be no longer those chosen in Sect. 2), a suitable canonical suppression [6, 8] could be generated without the need of γ_S and a hadron gas in full chemical equilibrium would be recovered. Nevertheless this mechanism would have no effect on the yield of ϕ meson which is completely neutral, thus not suppressed by quantum number conservation at hadron level and having no known feeding from heavier light–flavoured resonances. Therefore, the measurement of ϕ production in Pb+Pb collisions establishes the necessity of a significant strangeness suppression at hadronic level independently of the validity of the assumed fireball quantum

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

At SPS at 158 GeV: because of ϕ meson, statistical model fit with strangeness correlation volume is consistently worse than the one with γ_s (F.B., A. Keranen, M. Gazdzicki, J. Manninen, R. Stock, Phys. Rev. C 69, 024905)





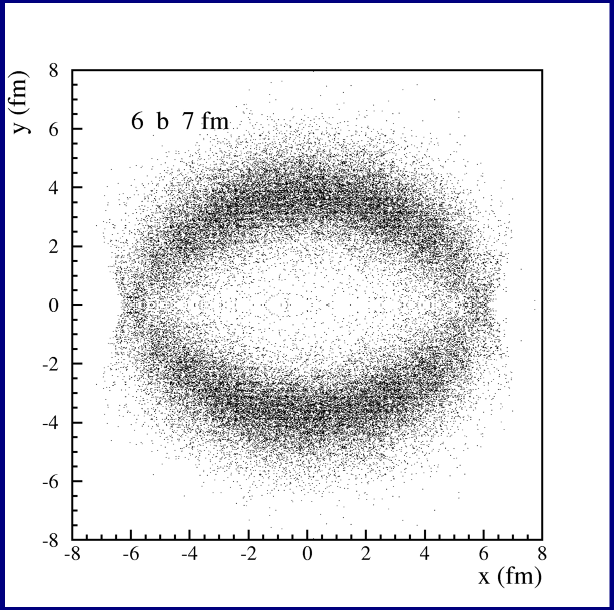
A temptative interpretation: core-corona effect

(J. Cleymans, B. Kampfer, P. Steinberg, S. Wheathon, hep-ph 0212335)

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

C. Hohne, F. Puhlhofer, R. Stock, Phys. Lett. B 640, 96 (2006)

K. Werner, *Core-corona effect in ultrarelativistic heavy ion collisions*, Phys. Rev. Lett. 98, 152301 (2007)



Distribution of nucleons colliding once

S-undersat.

S-satur. $\gamma_s=1$

$$\langle\frac{dn}{dy}\rangle = N_s\langle\frac{dn}{dy}\rangle_{pp} + f(V_0-\delta V_0)\langle\frac{d\rho}{dy}\rangle_{core}$$

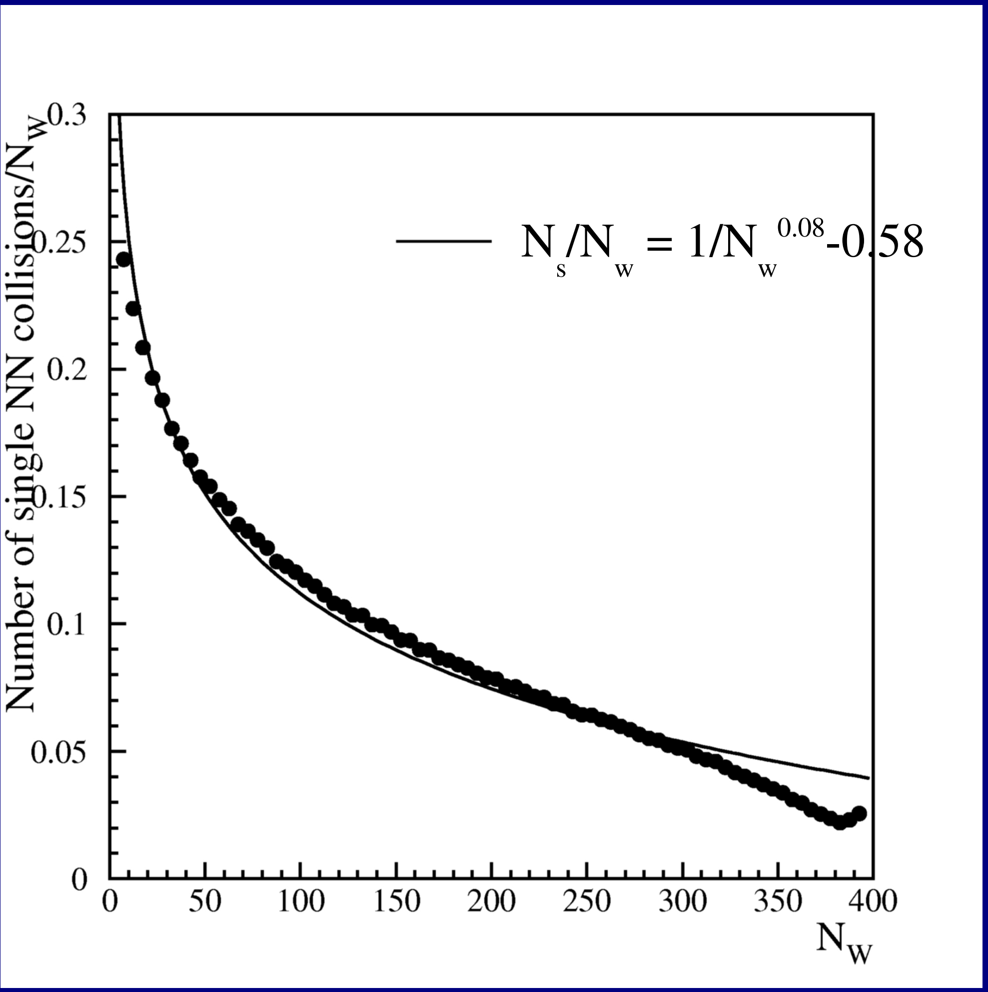
$$\delta V_0 = \frac{N_s}{\nu_s}$$

$$V_0 \sim \frac{N_W}{2n_0}$$

$$\frac{\langle\frac{dn}{dy}\rangle}{N_W\langle\frac{dn}{dy}\rangle_{pp}} \sim \frac{f}{2n_0}\frac{\langle\frac{d\rho}{dy}\rangle_{core}}{\langle\frac{dn}{dy}\rangle_{pp}} + \frac{N_s}{N_W}\left(1-\frac{f}{\nu_s}\frac{\langle\frac{d\rho}{dy}\rangle_{core}}{\langle\frac{dn}{dy}\rangle_{pp}}\right)$$

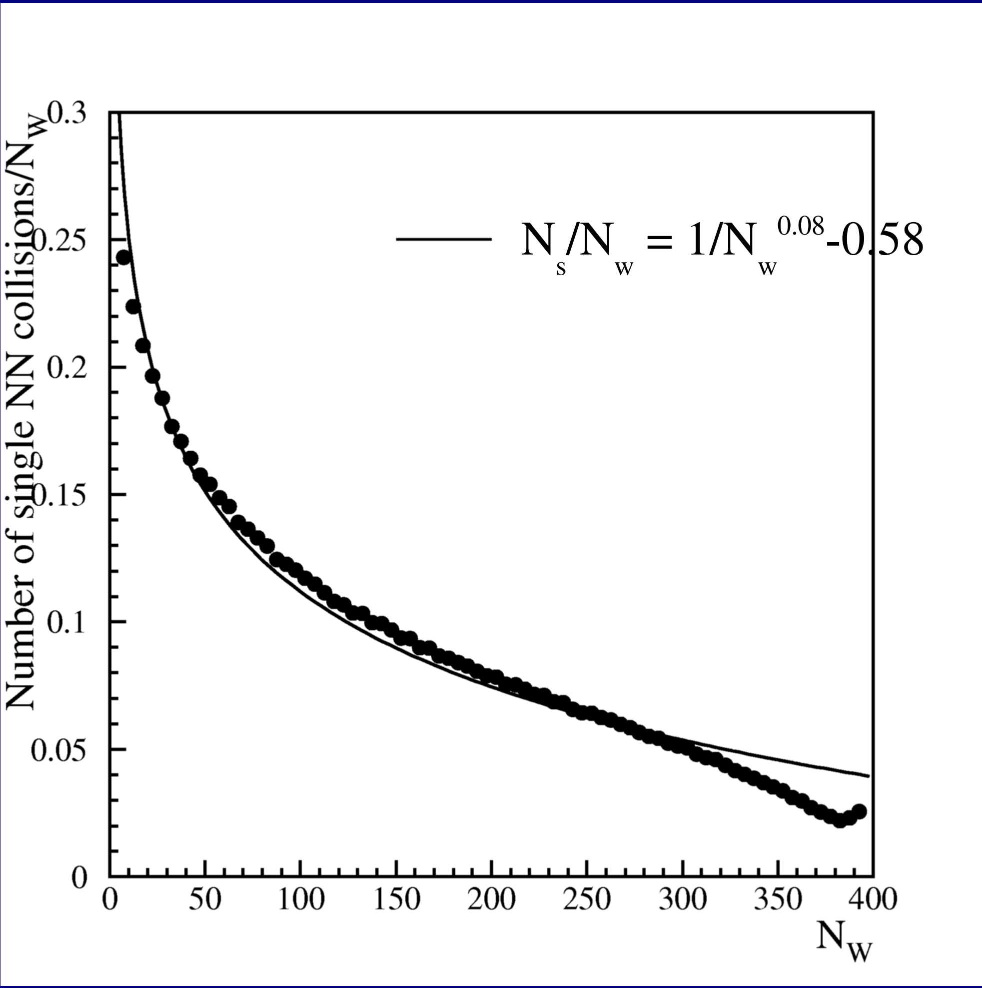
$$\frac{\langle\frac{dn}{dy}\rangle}{N_W\langle\frac{dn}{dy}\rangle_{pp}} \sim A + \frac{N_s}{N_W}(1-2A)$$

Glauber (hybrid) Monte-Carlo calculation $N_s = \min(N_{1A}, N_{1B})$



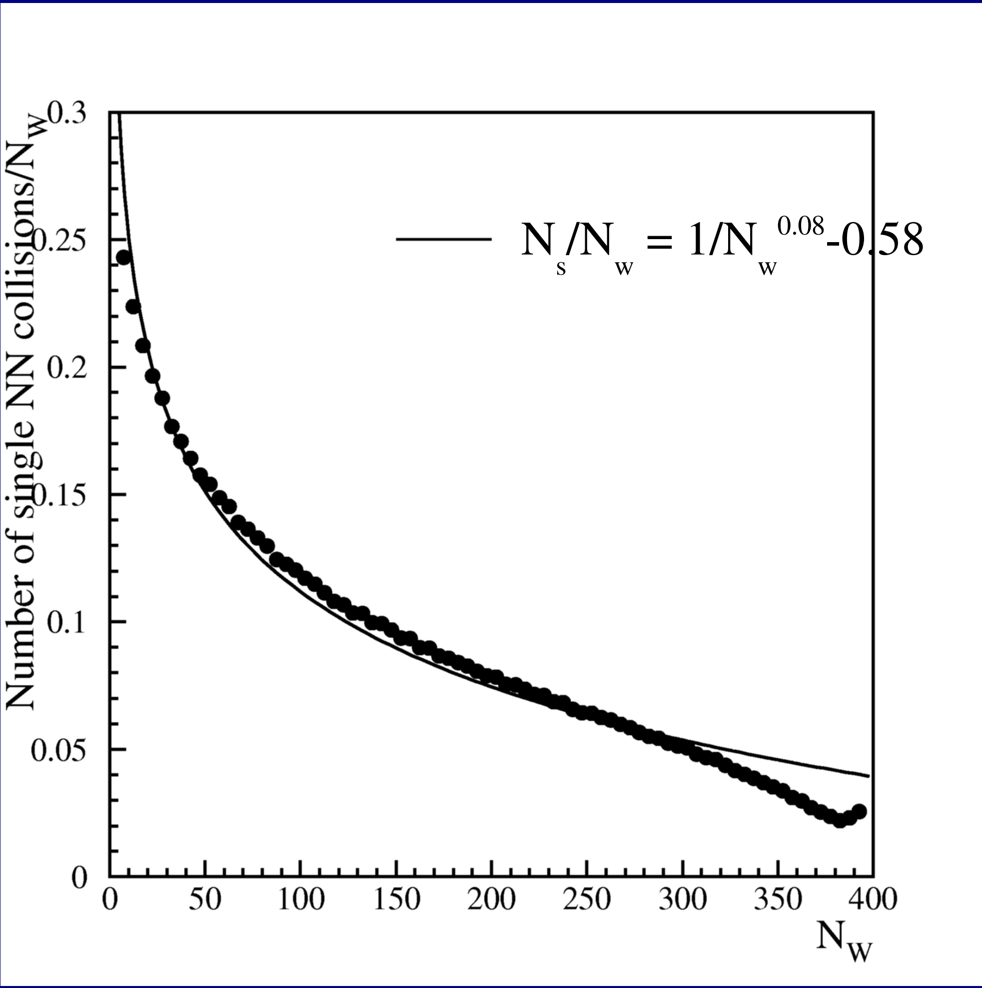
$$\frac{\langle \frac{dn}{dy} \rangle}{N_W \langle \frac{dn}{dy} \rangle_{pp}} \sim A + \frac{N_s}{N_W}(1 - 2A)$$

Glauber (hybrid) Monte-Carlo calculation $N_s = \min(N_{1A}, N_{1B})$

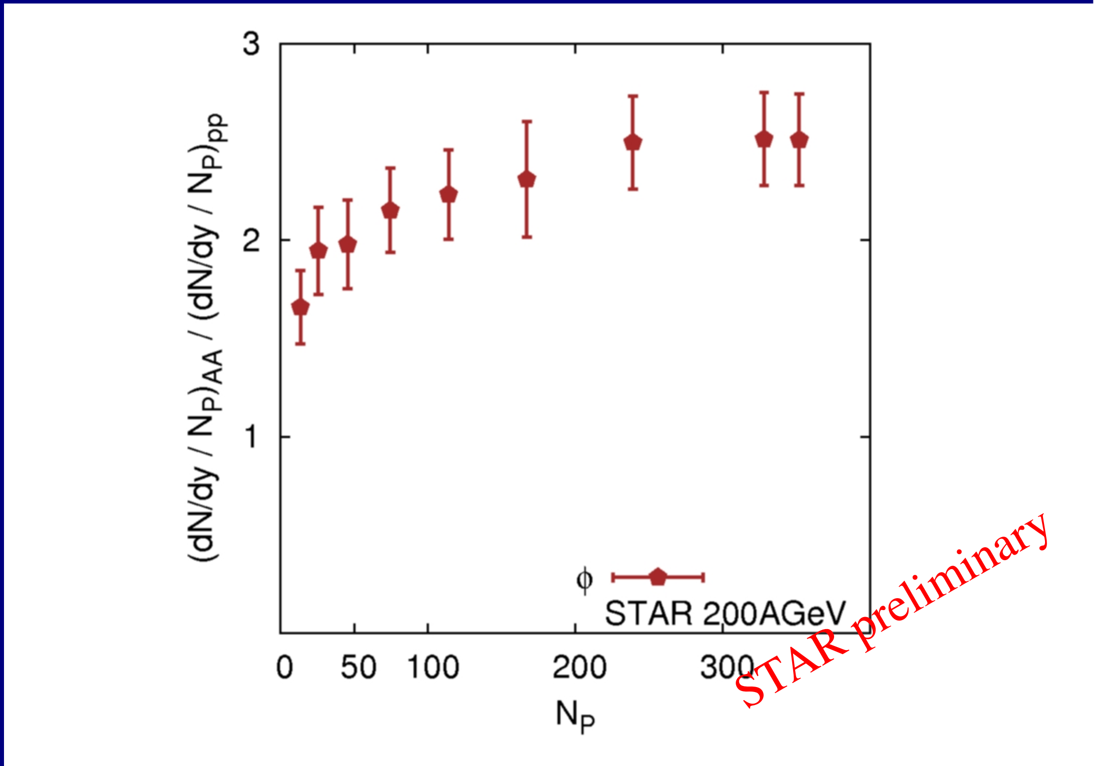


$$\frac{\langle \frac{dn}{dy} \rangle}{N_W \langle \frac{dn}{dy} \rangle_{pp}} \sim A + \left(\frac{1}{N_W^{0.08}} - 0.58 \right) (1 - 2A)$$

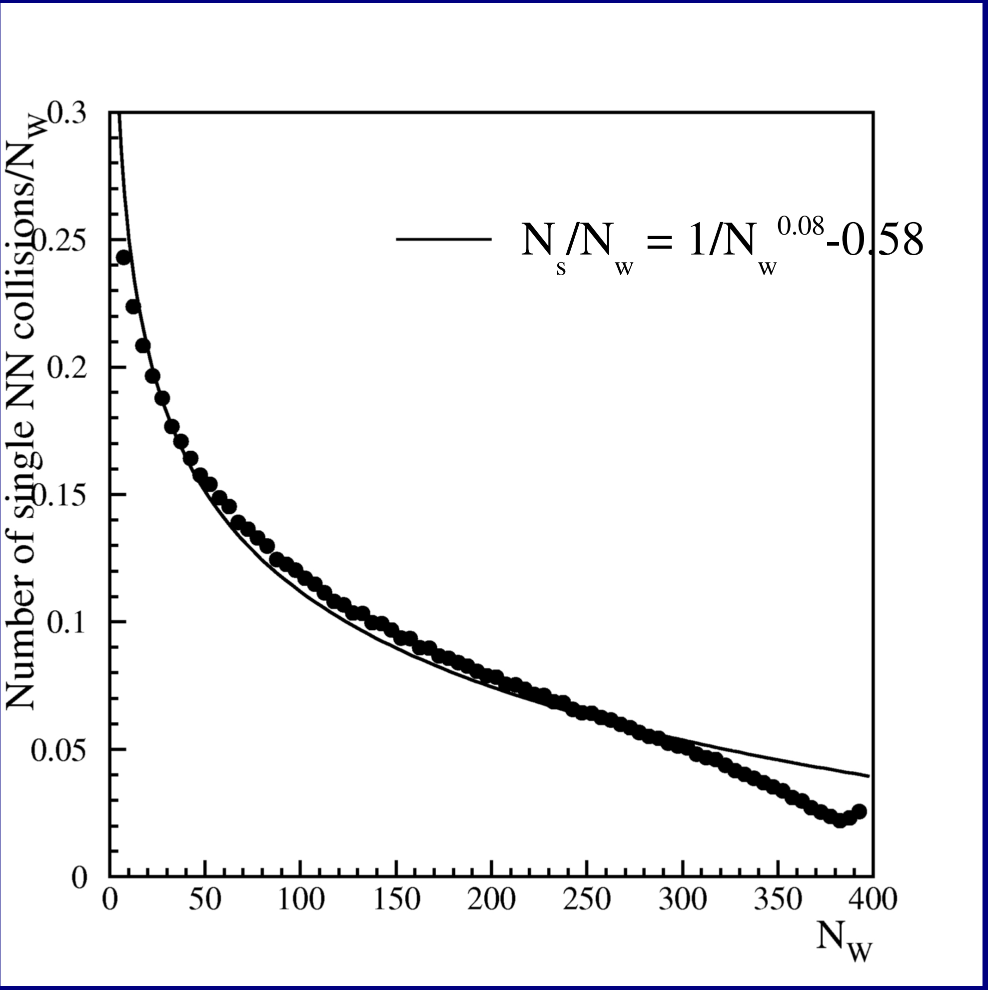
Glauber (hybrid) Monte-Carlo calculation $N_s = \min(N_{1A}, N_{1B})$



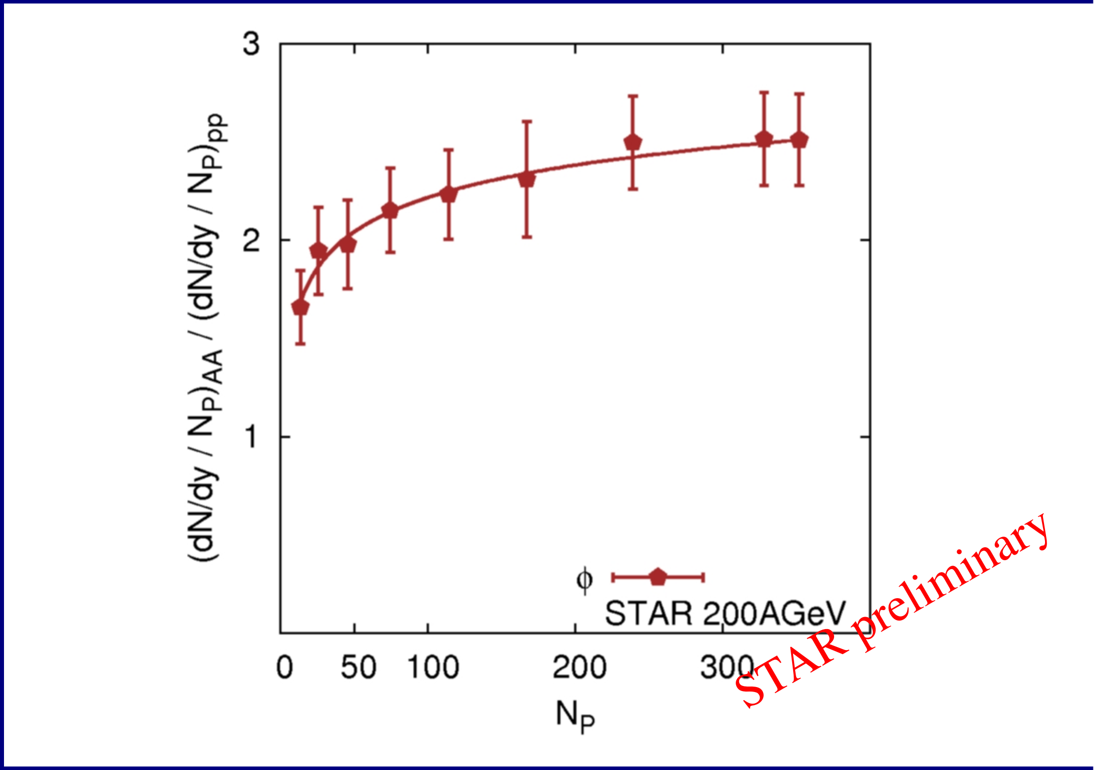
$$\frac{\langle \frac{dn}{dy} \rangle}{N_W \langle \frac{dn}{dy} \rangle_{pp}} \sim A + \left(\frac{1}{N_W^{0.08}} - 0.58 \right) (1 - 2A)$$

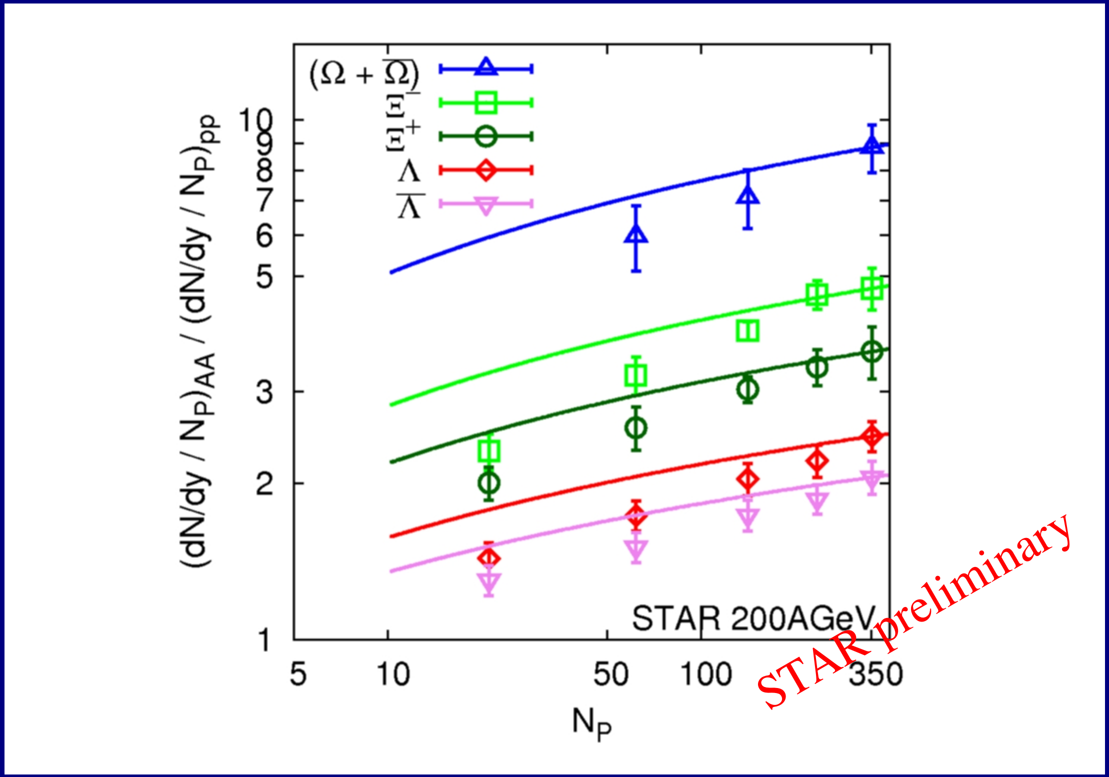


Glauber (hybrid) Monte-Carlo calculation $N_s = \min(N_{1A}, N_{1B})$



$$\frac{\langle \frac{dn}{dy} \rangle}{N_W \langle \frac{dn}{dy} \rangle_{pp}} \sim A + \left(\frac{1}{N_W^{0.08}} - 0.58 \right) (1 - 2A)$$





CONCLUSION: STAR (preliminary) data indicates that the strangeness production pattern as a function of centrality is mainly a reflection of a geometrical core-corona effect, the core being consistent with a *completely equilibrated hadron gas* throughout all centralities; canonical suppression is a correction, which becomes important for low N_w, as expected.

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

- <u>Collisional equilibration</u>

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

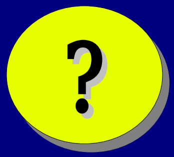
no dependence of T on centrality (U. Heinz, G. Kestin, CPOD Florence 2006, nucl-th 0612015) even multi-meson collisions cannot reproduce Ω yields (J. Kapusta, SQM03); need of introducing “Hagedorn states” which decay statistically (C. Greiner et al., arXiv:0711.0930, nucl-th/0703079)

- <u>Direct statistical hadronization</u>

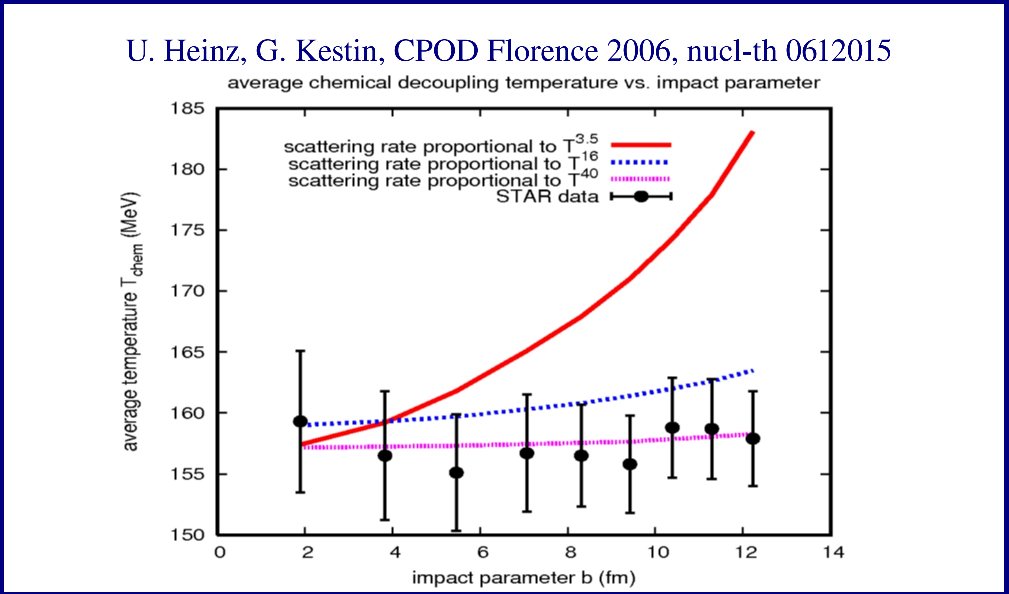
F. B., U. Heinz, Z. Phys. C 76, 269 (1997)

R. Stock, Phys. Lett. B456, 277 (1999)

U. Heinz, Nucl. Phys. A 661, 140 (1999)

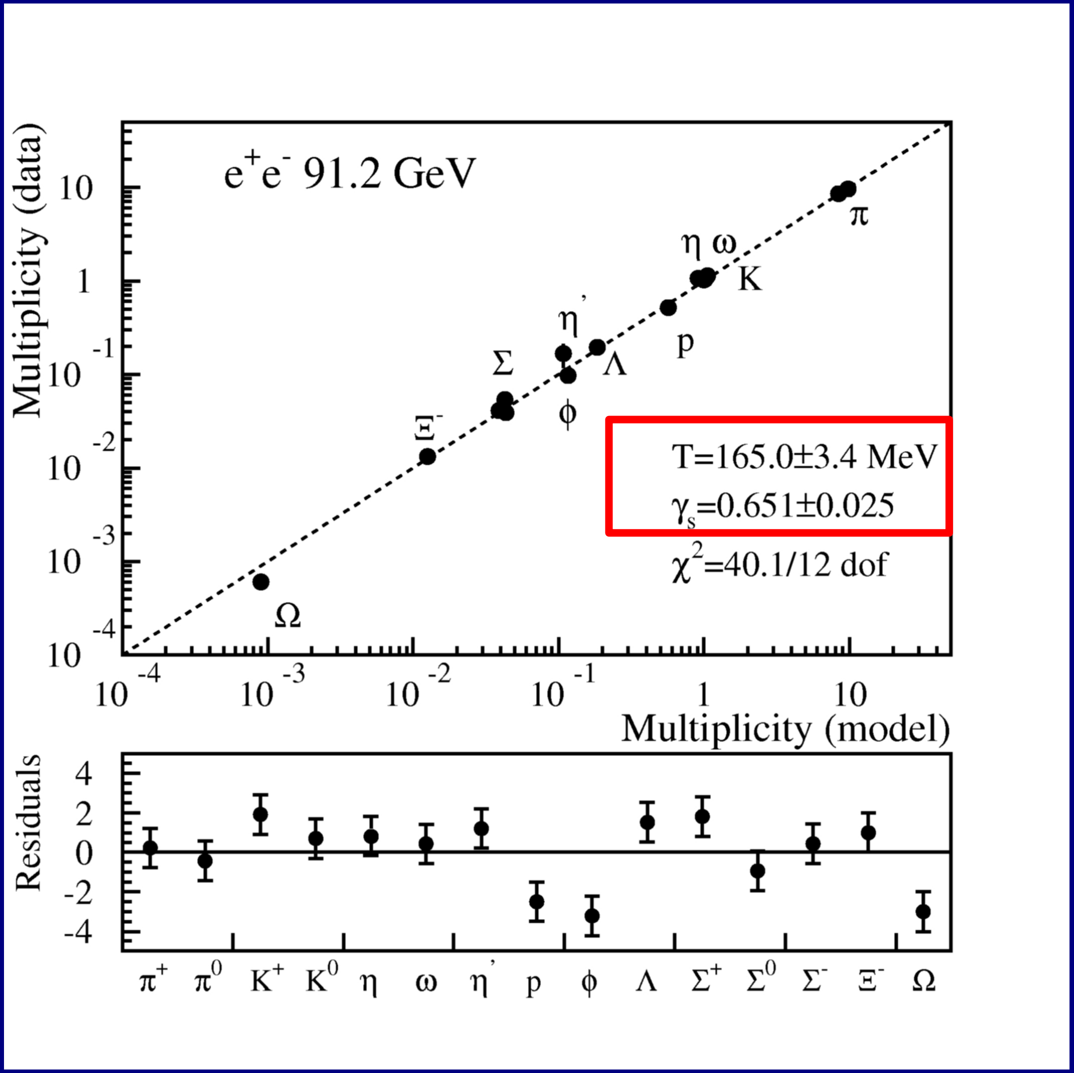


full equilibrium



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)

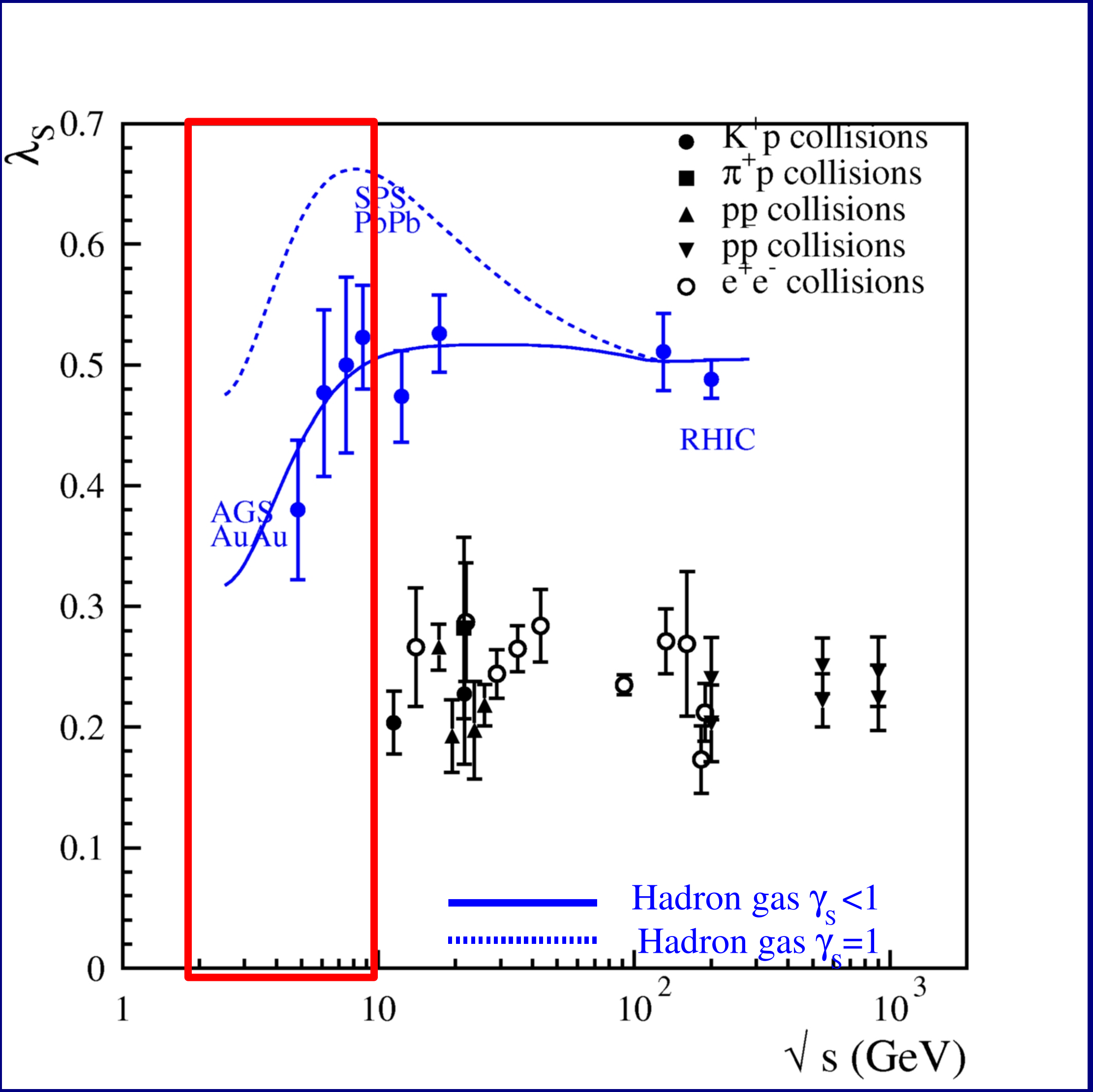
Hadronization as the emission of Hawking-Unruh radiation

P. Castorina, D. Kharzeev, H. Satz, Eur. Phys. J. C52, 187 (2007); F.B., P. Castorina, H. Satz, in preparation

What at SPS? Where is the onset of full chemical equilibrium?

Can core-corona effect account for γ_s also at SPS?

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



CONCLUSIONS

- In heavy ion collisions at RHIC energies, there is evidence for a completely equilibrated hadron gas at a temperature of 160 MeV at any centrality. This is, most likely, the phase transition-crossover temperature

- The strangeness enhancement pattern (w.r.t. NN collisions) can be accounted for by a core-corona effect with a component of single NN collisions. So-called canonical suppression within a small SCV is not the driving effect

- Needed investigations to assess whether core-corona effect can also explain the data at AGS and SPS and locate the (steep?) onset of the fully equilibrated hadron gas production

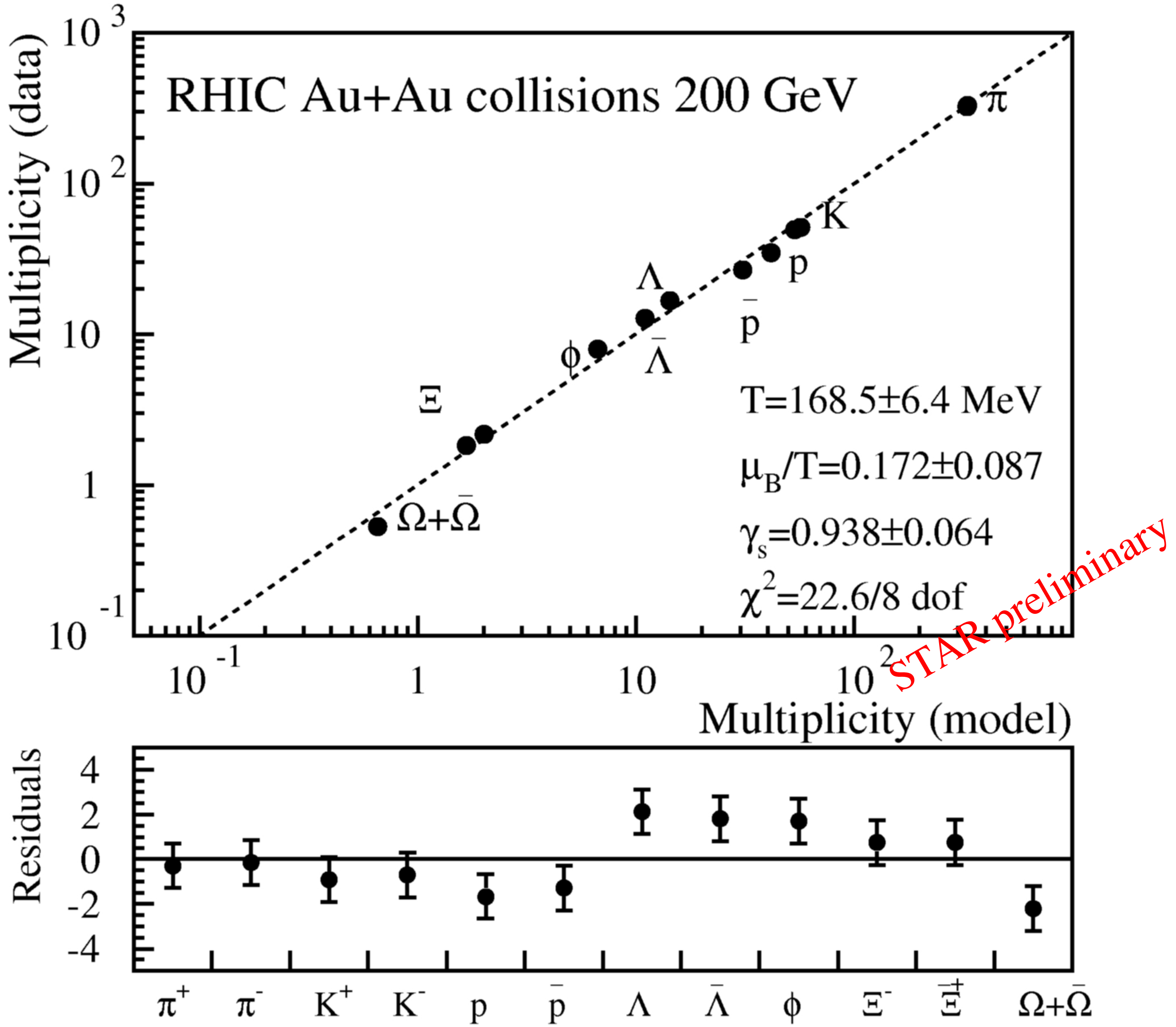
- Questions: how equilibration is achieved? What is the relation with the amazingly close temperature fitted in elementary collisions?

ACKNOWLEDGMENTS

- J. Manninen (INFN Florence)
- STAR Collaboration: H. Caines, J. H. Chen, N. Xu
- M. Gazdzicki, D. Rohrich

Parallel session on Strangeness production, this afternoon

Energy and system size dependence of phi meson production in STAR - J. H. Chen
Strangeness production in AuAu collisions at 62.4 GeV - I.C. Arsene
Multi-strange particles production in Cu+Cu collisions at 200 GeV in the STAR experiment - X. Wang
Strange baryon resonance production from quark coalescence at RHIC - G. Hamar
....



RHIC Au+Au collisions 200 GeV
Multiplicity (data)
Multiplicity (model)
T=168.5±6.4 MeV
μB/T=0.172±0.087
γs=0.938±0.064
χ2=22.6/8 dof
STAR preliminary
π
K
p
p̄
Λ
Λ̄
φ
Ξ
Ω+Ω̄
Residuals
π+ π- K+ K- p p̄ Λ Λ̄ φ Ξ- Ξ+ Ω+Ω̄

	model (m)	experiment (e)	error (σ)	error %	(m - e)/σ	(m - e)/e (%)
π^+	219.83	233.70	24.00	10.3	-0.6	-5.9
π^-	222.44	233.70	24.00	10.3	-0.5	-4.8
K^+	48.61	46.20	6.03	13.1	0.4	5.2
K^-	45.33	41.90	5.43	13.0	0.6	8.2
p	32.15	26.37	5.81	22.0	1.0	21.9
$\bar{p}$	22.24	18.72	4.12	22.0	0.9	18.8
Λ	15.96	16.48	1.94	11.8	-0.3	-3.1
$\bar{\Lambda}$	11.82	11.81	1.41	11.9	0.0	0.1
Ξ^-	1.92	2.18	0.34	15.7	-0.8	-12.2
Ξ^+	1.52	1.88	0.29	15.5	-1.2	-19.2
$\Omega + \bar{\Omega}$	0.67	0.59	0.13	21.8	0.7	14.6
ϕ	6.38	6.29	1.13	18.0	0.1	1.5

TABLE I: STAR 130

	model (m)	experiment (e)	error (σ)	error %	(m - e)/σ	(m - e)/e (%)
π^+	547.15	619.00	35.40	5.7	-2.0	-11.6
π^-	579.16	639.00	35.40	5.5	-1.7	-9.4
K^+	103.36	103.00	7.07	6.9	0.1	0.4
K^-	59.26	51.90	3.55	6.8	2.1	14.2
K_S^0	80.14	81.00	4.00	4.9	-0.2	-1.1
Λ	53.74	44.90	6.43	14.3	1.4	19.7
$\bar{\Lambda}$	4.74	3.74	0.47	12.6	2.1	26.8
Ξ^-	4.46	4.45	0.22	4.9	0.0	0.2
Ξ^+	0.78	0.83	0.04	4.8	-1.2	-5.6
Ω	0.45	0.59	0.13	21.4	-1.1	-24.0
$\bar{\Omega}$	0.16	0.26	0.07	25.8	-1.4	-37.0
ϕ	8.06	7.60	1.10	14.5	0.4	6.0
N_P	363.55	362.00	5.10	1.4	0.3	0.4

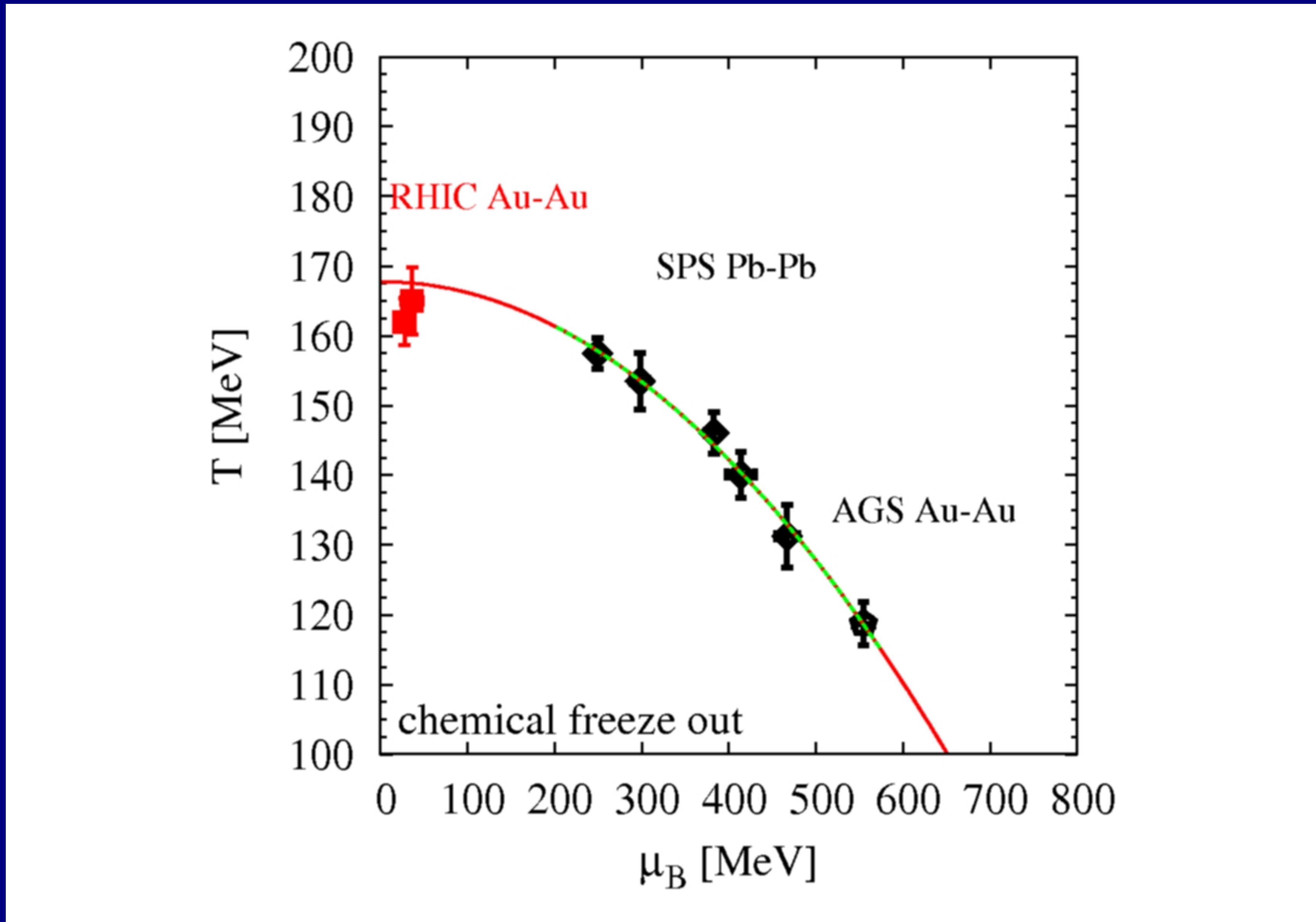
TABLE III: PbPb 160

	model (m)	experiment (e)	error (σ)	error %	(m - e)/σ	(m - e)/e (%)
π^+	327.93	322.20	19.20	6.0	0.3	1.8
π^-	329.80	327.00	19.50	6.0	0.1	0.9
K^+	56.70	51.30	5.90	11.5	0.9	10.5
K^-	53.52	49.50	5.70	11.5	0.7	8.1
p	41.55	34.70	4.10	11.8	1.7	19.7
$\bar{p}$	30.76	26.70	3.15	11.8	1.3	15.2
Λ	14.33	16.70	1.12	6.7	-2.1	-14.2
$\bar{\Lambda}$	11.03	12.70	0.92	7.2	-1.8	-13.2
Ξ^-	2.02	2.17	0.20	9.2	-0.7	-6.9
Ξ^+	1.68	1.83	0.21	11.3	-0.8	-8.4
$\Omega + \bar{\Omega}$	0.66	0.53	0.06	10.8	2.2	23.8
ϕ	6.69	7.95	0.74	9.3	-1.7	-15.9

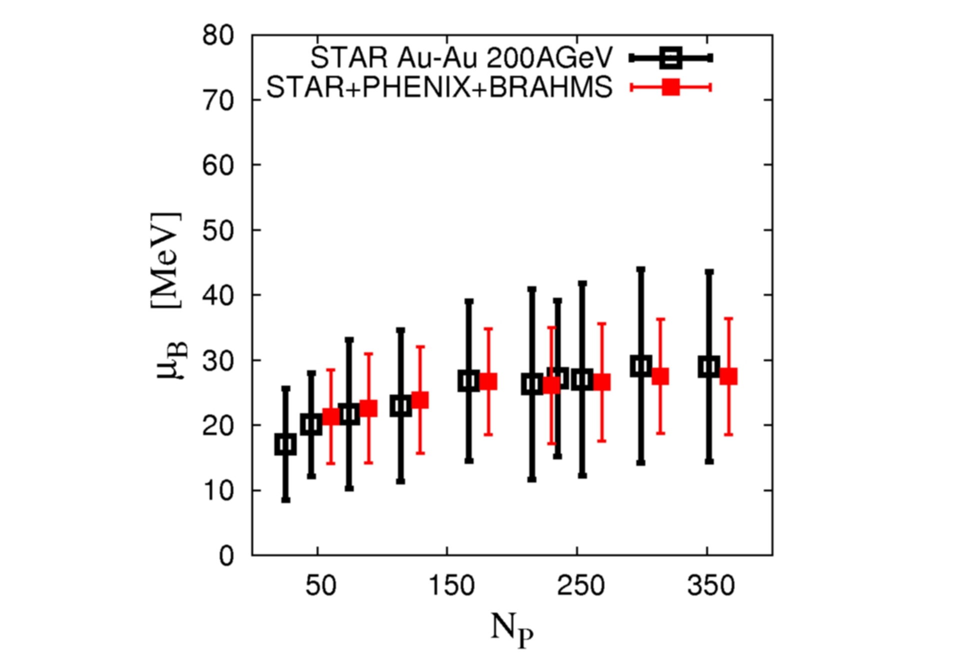
TABLE II: STAR 200

	model (m)	experiment (e)	error (σ)	error %	(m - e)/σ	(m - e)/e (%)
π^+	8.4415	8.4970	0.2585	3.0	-0.2	-0.7
π^0	9.8110	9.6067	0.4586	4.8	0.4	2.1
K^+	1.0549	1.1272	0.0377	3.3	-1.9	-6.4
K_S^0	1.0149	1.0376	0.0324	3.1	-0.7	-2.2
η	0.9102	1.0592	0.1824	17.2	-0.8	-14.1
ω	0.9958	1.0241	0.0669	6.5	-0.4	-2.8
η'	0.1082	0.1662	0.0477	28.7	-1.2	-34.9
p	0.5696	0.5187	0.0204	3.9	2.5	9.8
ϕ	0.1164	0.0977	0.0058	5.9	3.2	19.1
Λ	0.1846	0.1943	0.0064	3.3	-1.5	-5.0
Σ^+	0.0428	0.0535	0.0059	11.0	-1.8	-20.0
Σ^0	0.0435	0.0389	0.0049	12.6	0.9	11.8
Σ^-	0.0390	0.0410	0.0046	11.2	-0.4	-4.7
Ξ^-	0.0126	0.0132	0.0006	4.5	-1.0	-4.4
Ω	0.0009	0.0006	0.0001	16.1	2.3	45.1

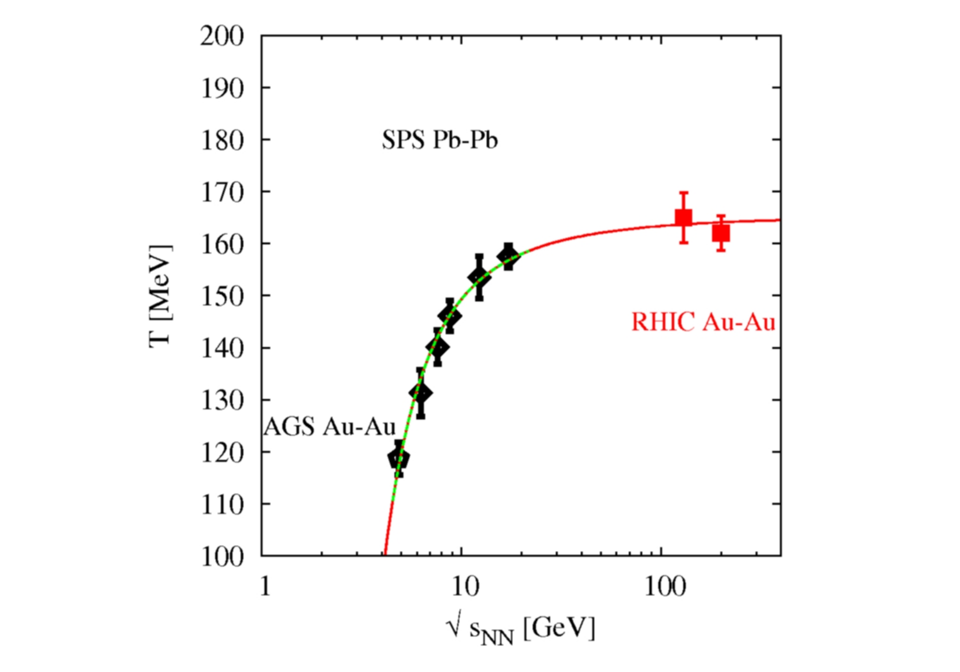
TABLE IV: e^+e^- $\sqrt{s} = 91.2$ GeV



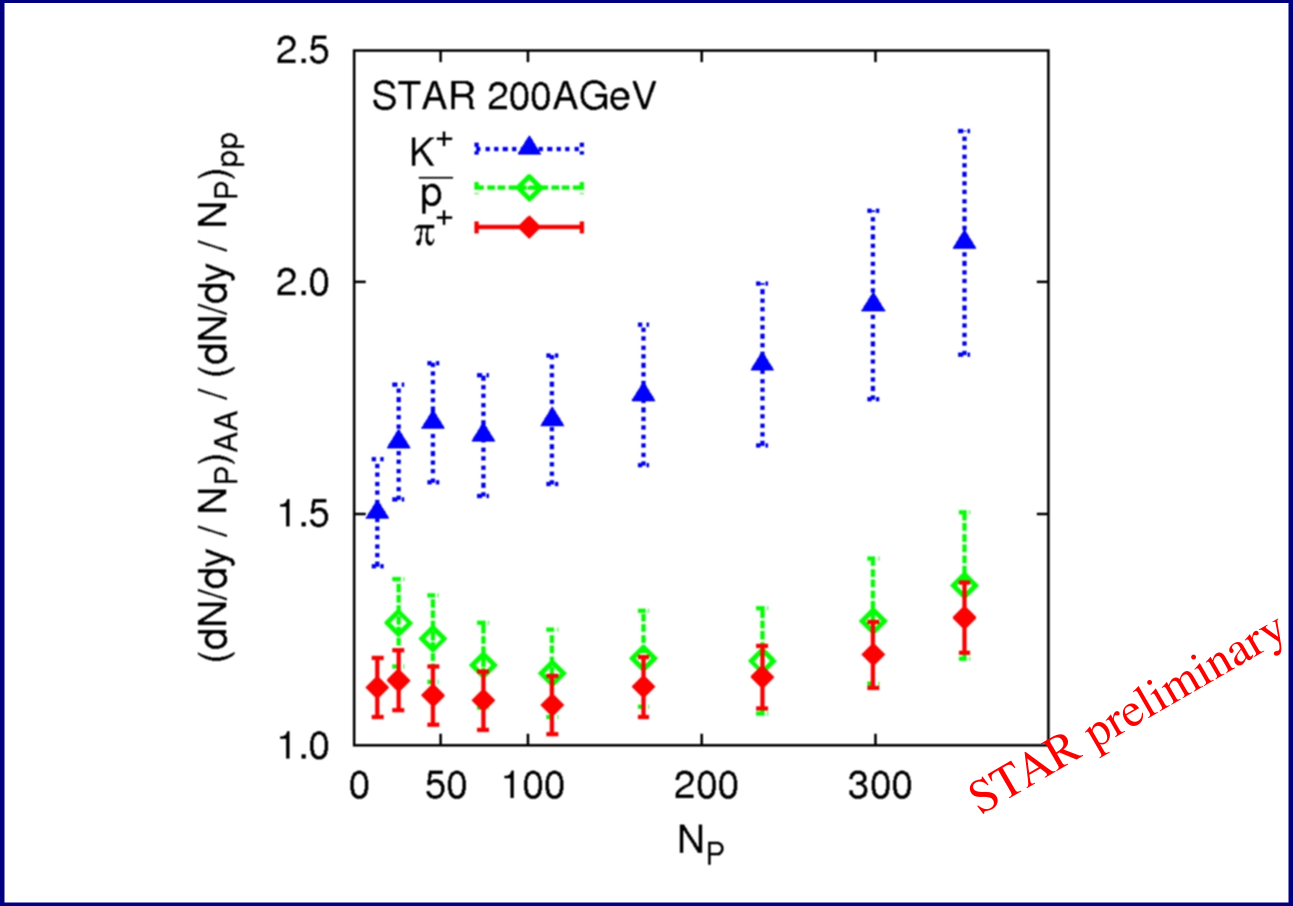
RHIC Au-Au
SPS Pb-Pb
AGS Au-Au
chemical freeze out
T [MeV]
μB [MeV]
200
190
180
170
160
150
140
130
120
110
100
0
100
200
300
400
500
600
700
800



STAR Au-Au 200AGeV
STAR+PHENIX+BRAHMS
μ_B [MeV]
N_P



SPS Pb-Pb
RHIC Au-Au
AGS Au-Au
T [MeV]
$\sqrt{s_{NN}}$ [GeV]



STAR 200AGeV
K+
p̄
π+
(dN/dy / NP)AA / (dN/dy / NP)pp
2.5
2.0
1.5
1.0
0
50
100
200
300
NP
STAR preliminary