Strangeness Production and Color Deconfinement

Helmut Satz

Universität Bielefeld, Germany

Joint work with P. Castorina and S. Plumari

ECT* Workshop, Oct. 15 - 19, 2018
Observables of Hadronization and the QCD Phase Diagram
in the Cross-Over Domain

- **QCD phase boundary and hadronic collisions: "normal" hadrons are on this side of boundary**
- **possible tool to check boundary: effect of QGP formation on strange hadron production in high energy collisions?**

Müller, Rafelski 1982

- QCD phase boundary and hadronic collisions:
  "normal" hadrons are on this side of boundary
- possible tool to check boundary: effect of QGP formation on strange hadron production in high energy collisions?

Müller, Rafelski 1982

Relative Hadron Abundences in High Energy Collisions

Ideal gas of hadrons and resonances,
at temperature T, baryochemical potential μ.

In elementary collisions (pp, e^+e^-) up to RHIC energy and in some range of nuclear collisions up to SPS energies:
overprediction of strange hadron production.

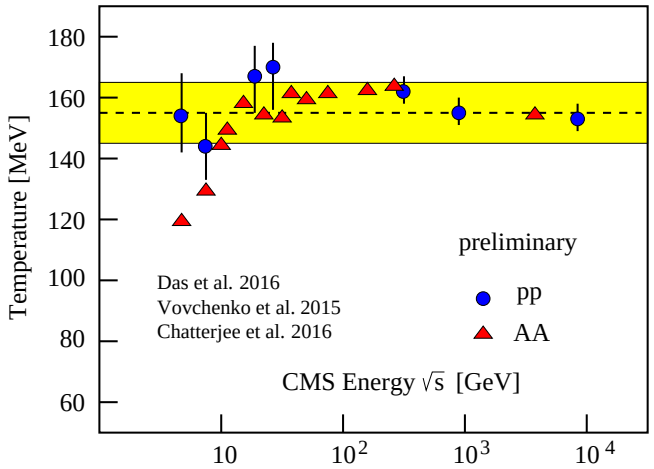
strangeness suppression factor γ_s, with γ_s^ν for hadrons with $\nu = 0, 1, 2, 3$ strange quarks

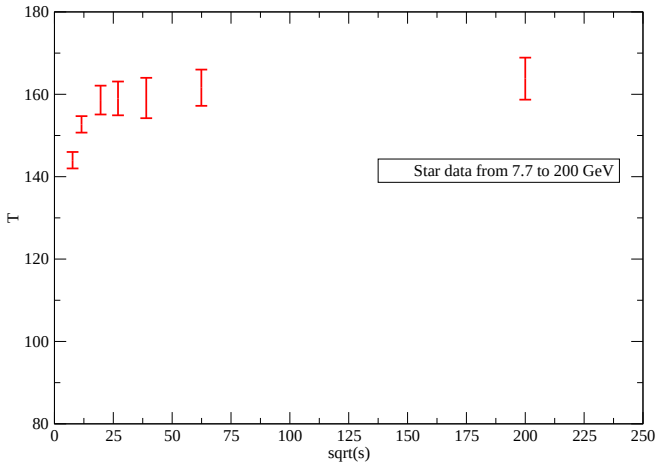
Letessier, Rafelski, Tounsi 1994

Ideal gas of hadrons and resonances, at temperature T,
baryochemical potential μ, strangeness suppression γ_s,
gives excellent agreement for abundances at all energies,
all collision configurations (e^+e^-, pp, pA, AA)

Ideal gas of hadrons and resonances, at temperature T,
baryochemical potential μ, strangeness suppression γ_s,
gives excellent agreement for abundances at all energies,
all collision configurations (e^+e^-, pp, pA, AA)

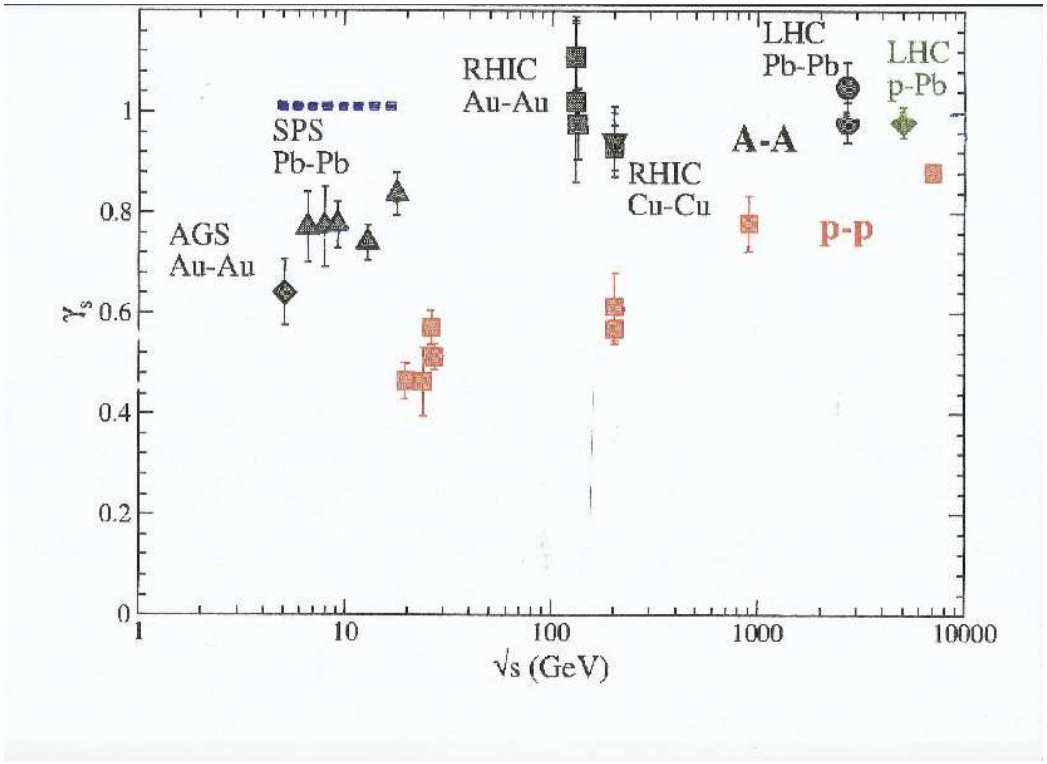
For $\sqrt{s} \geq 10$ GeV, $T \simeq 160 \pm 10$ MeV, for pp, pA and AA, independent of μ, in accord with the color deconfinement temperature $T_c = 155 \pm 10$ MeV from lattice QCD.





For AA below 10 GeV, increasing μ, decreasing T.

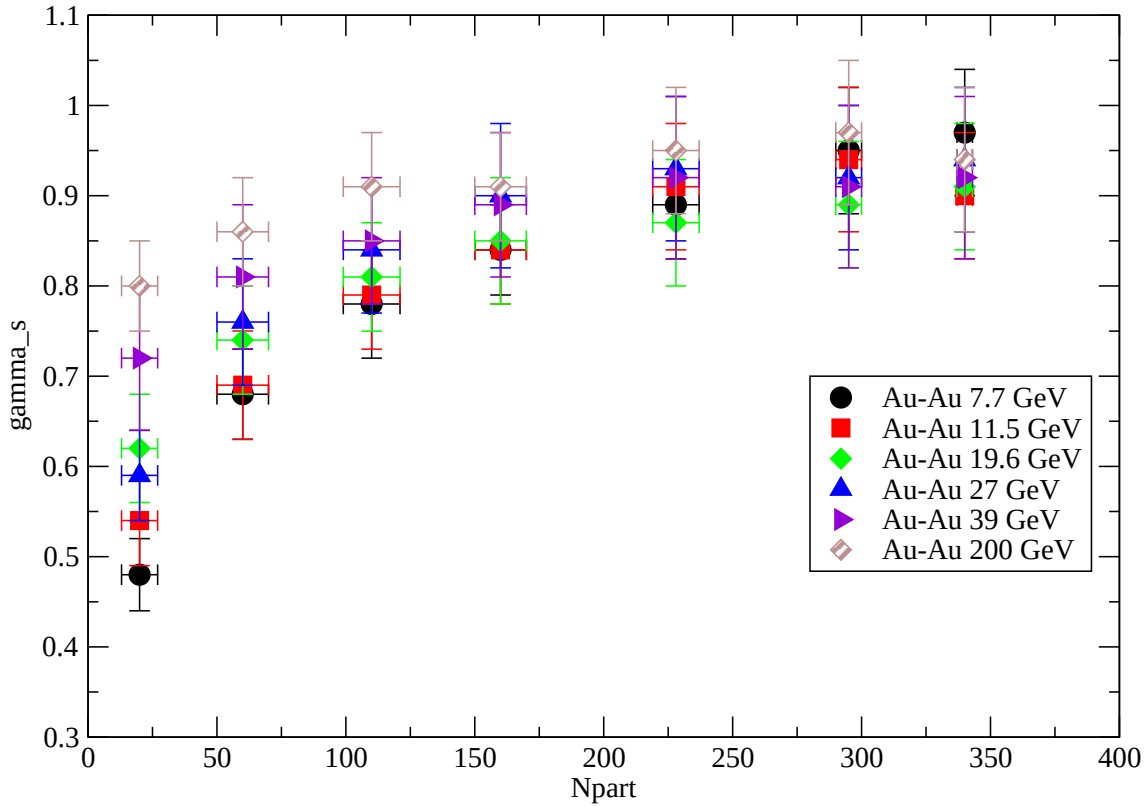
Strangeness suppression as function of $\sqrt{s}$ much stronger in pp than in AA:



- **Some discrepancy in fits at AGS/SPS energies; why?**

Possible answer: new STAR BES data, giving resonance gas analyses at $\sqrt{s} = 7.7, 11.5, 19.6, 27, 39$ and 200 GeV as function of centrality.

Consider γ_s vs. centrality at different $\sqrt{s}$



conclude: $\gamma_s \simeq 1$ for central collisions at all energies;
$\gamma_s < 1$ for peripheral collisions & lower energies

- Is there a unified description of strangeness suppression for pp, pA and AA data at all energies and centralities?

$\Rightarrow$ Consider γ_s as function of a thermal variable.

Castorina, Plumari, HS 2016/2017

- 1d hydro (Bjorken) $\Rightarrow$ initial entropy density s_0

$$s_0\,\tau_0 \simeq \frac{1.5A^x}{a_T^x}\left(\frac{dN_{ch}}{dy}\right)^x_{y=0}, \text{ with } x \sim pp, pA, AA,$$

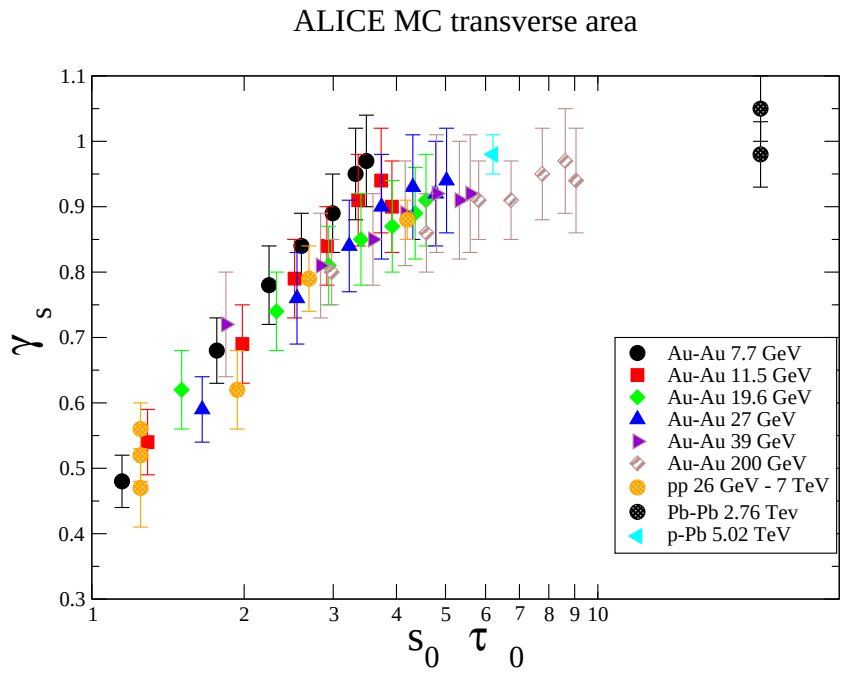
where a_T is effective tranverse area of collision.

transverse area:
simplest form $a_T = \pi R_x^2$, with
$R_{pp} = 0.8$ fm, $R_{pPb} = R_{pp}(4)^{1/3}$, $R_{AA} = 1.25A^{1/3}$

better: Glauber determination, ALICE

a_T *vs.* N_{part} for AA, a_T *vs.* $(dN/d\eta)$ for pp

Now have strangeness suppression factor $\gamma_s(s)$ and initial entropy density $s_0(s)$; eliminate s to get $\gamma_s(s_0)$:



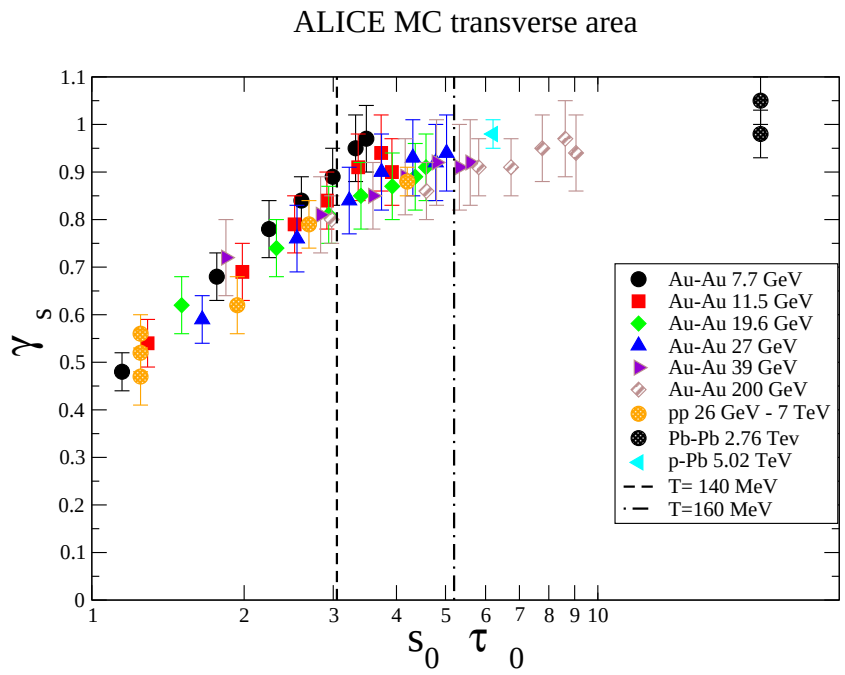
As function of the initial entropy density, the pp, pPb and AA data for γ_s all fall on the same curve:

universal strangeness suppression

NB: also $\gamma_s \to 1$ also for high energy pp. Castorina,HS 2016

finite temperature lattice QCD: Bazavov et al. 2014

$T_c = 155 \pm 5$ MeV; $s_0(T_c)\tau_0 = 4 \pm 1$ fm^{-3}.



Conclusion:

- Strangeness suppression is a universal function of initial thermal state.
- Strangeness suppression vanishes with the onset of color deconfinement. Castorina, Plumari, HS 2017

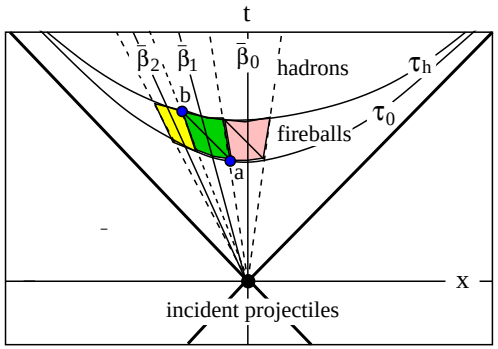
Remaining theoretical questions:

- Why is there suppression in hadronic regime?
- Why does the suppression vanish with deconfinement?

Local strangeness conservation $V_s < V \Rightarrow$ suppression of strangeness production. Hamieh, Redlich, Tounsi 2000

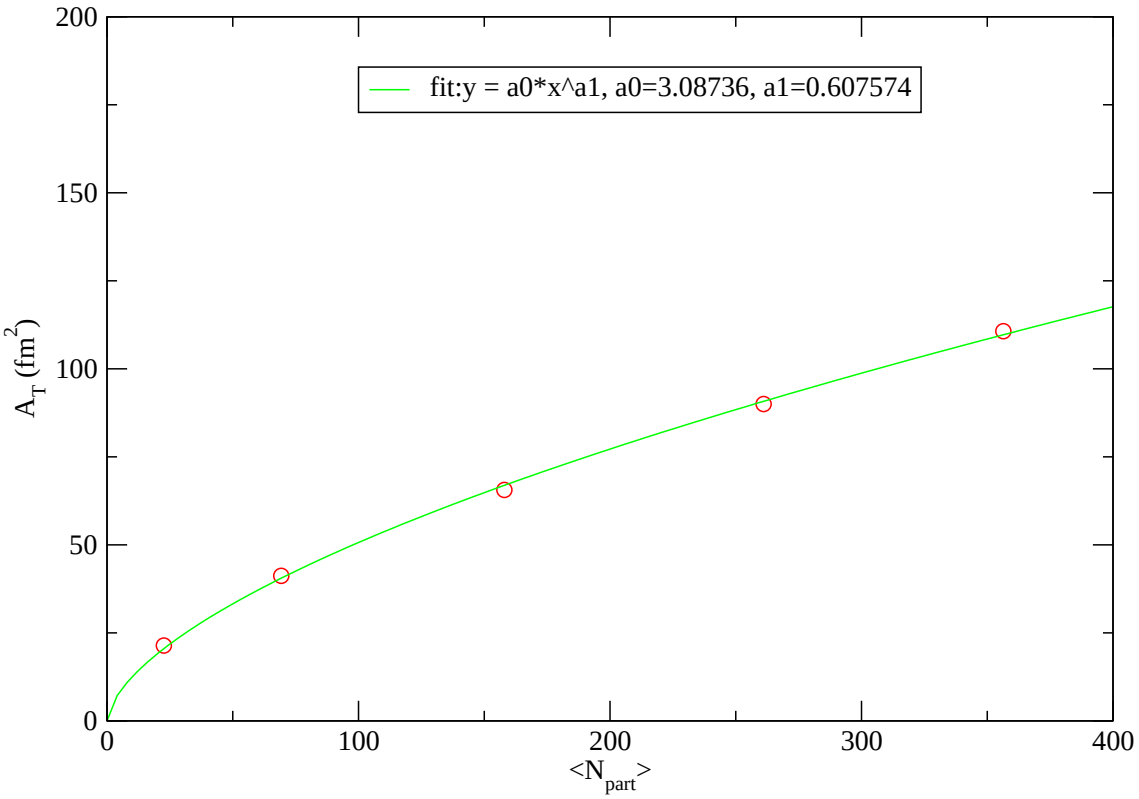
Causality structure of production evolution $\Rightarrow$ spatial restriction to strangeness conservation.

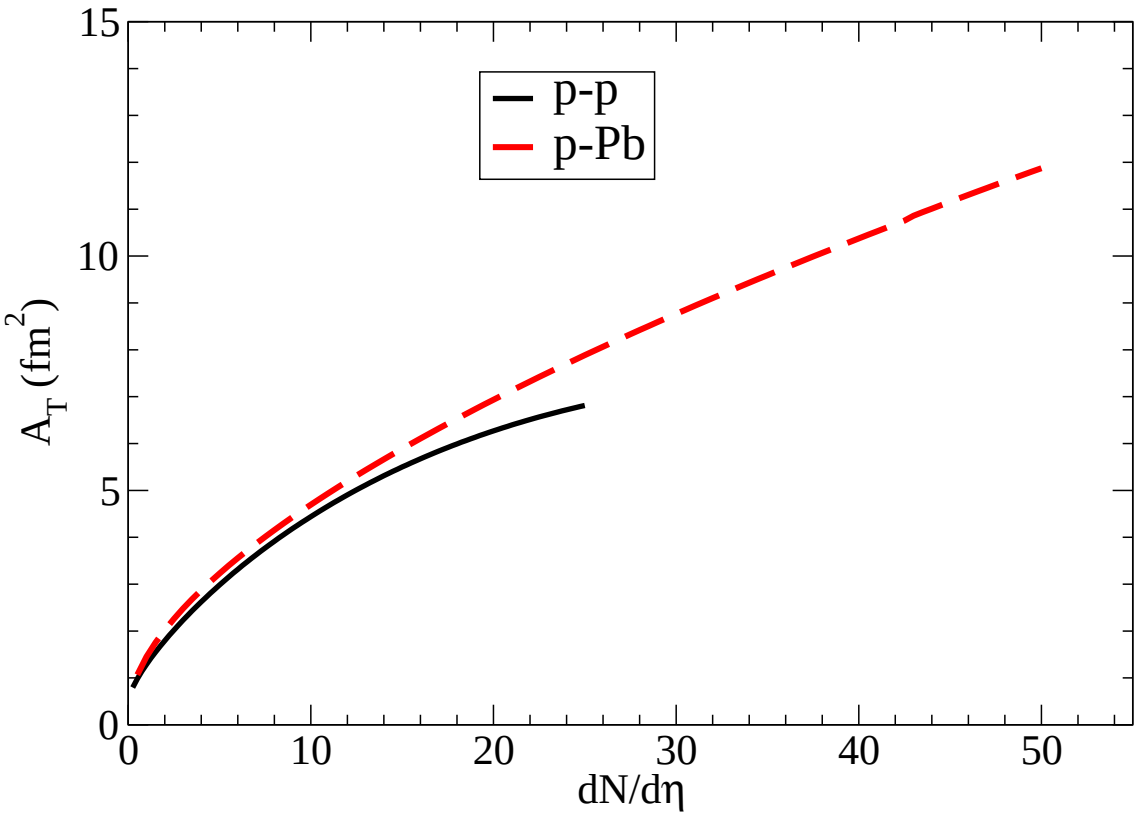
Castorina, HS 2013

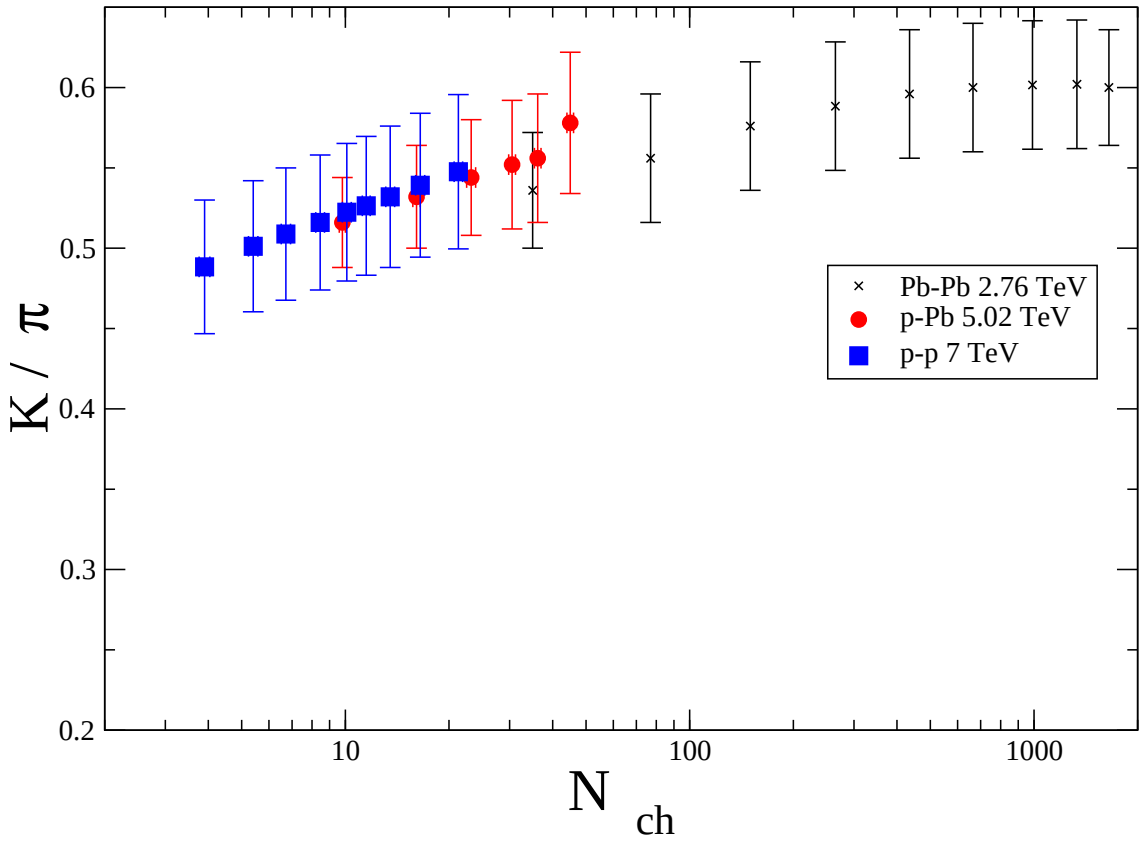


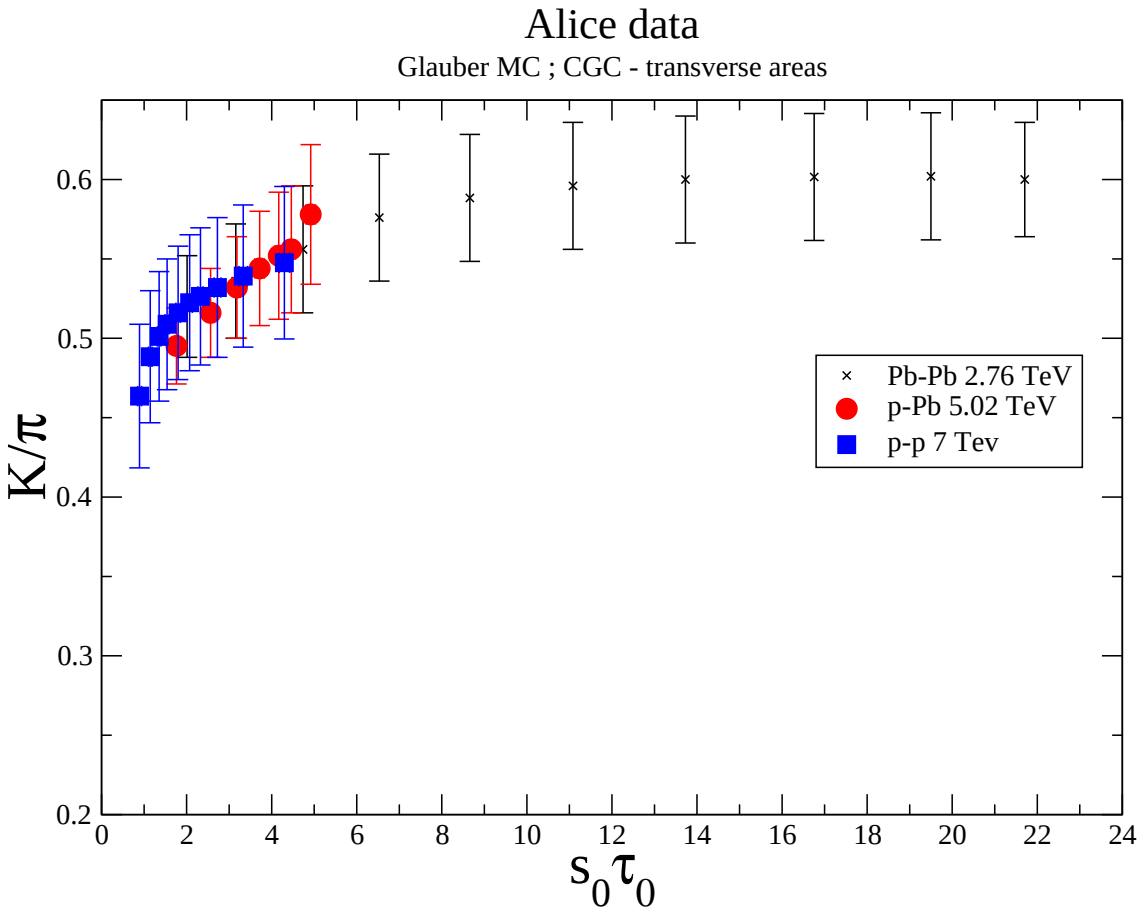
Why does causal volume become large enough at deconfinement?

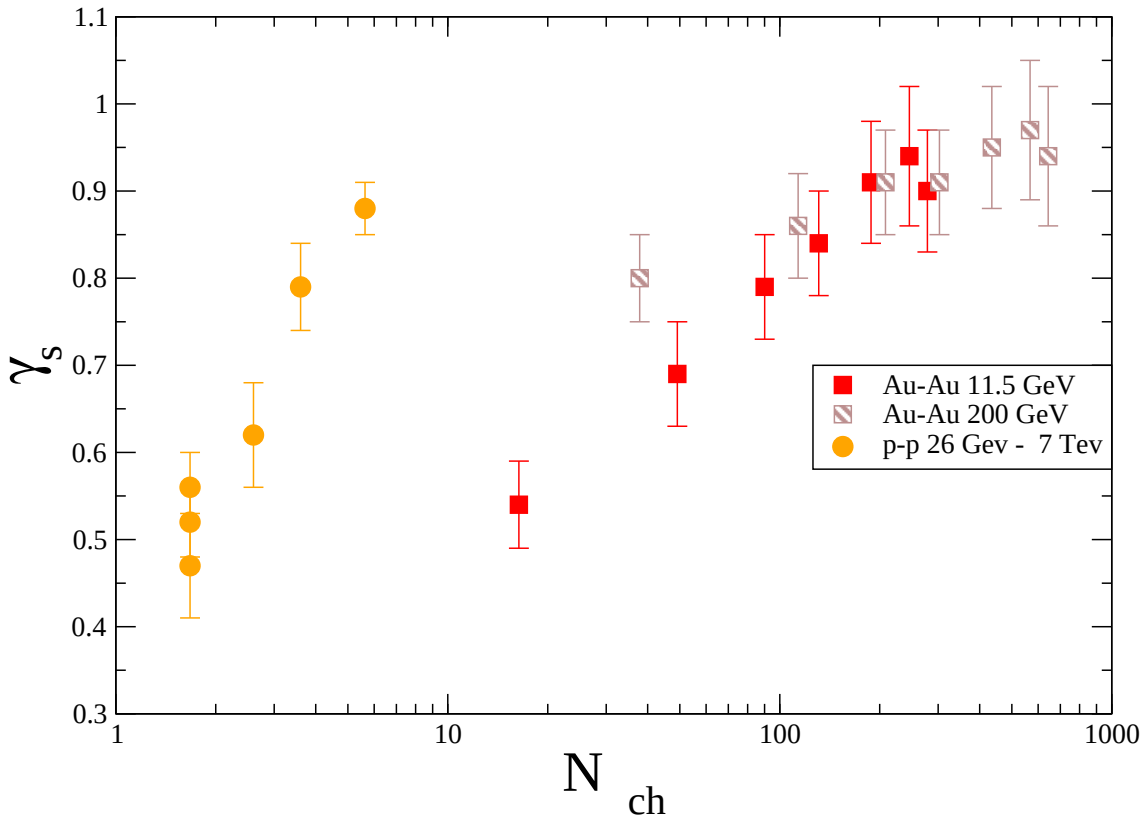
deconfinement $\sim$ transition from endogamous to exogamous quark behavior?


fit:y = a0*x^a1, a0=3.08736, a1=0.607574
200
150
100
50
0
0
100
200
300
400
A_T (fm^2)
<N_part>


p-p
p-Pb
A_T (fm^2)
dN/dη
0
5
10
15
0
10
20
30
40
50


0.6
0.5
0.4
0.3
0.2
K / π
10
100
1000
N ch
Pb-Pb 2.76 TeV
p-Pb 5.02 TeV
p-p 7 TeV


Alice data
Glauber MC ; CGC - transverse areas
K/π
$s_0\tau_0$
Pb-Pb 2.76 TeV
p-Pb 5.02 TeV
p-p 7 Tev
0.2
0.3
0.4
0.5
0.6
0
2
4
6
8
10
12
14
16
18
20
22
24


1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
γ_s
1
10
100
1000
N ch
Au-Au 11.5 GeV
Au-Au 200 GeV
p-p 26 Gev - 7 Tev