Viscosity and HBT

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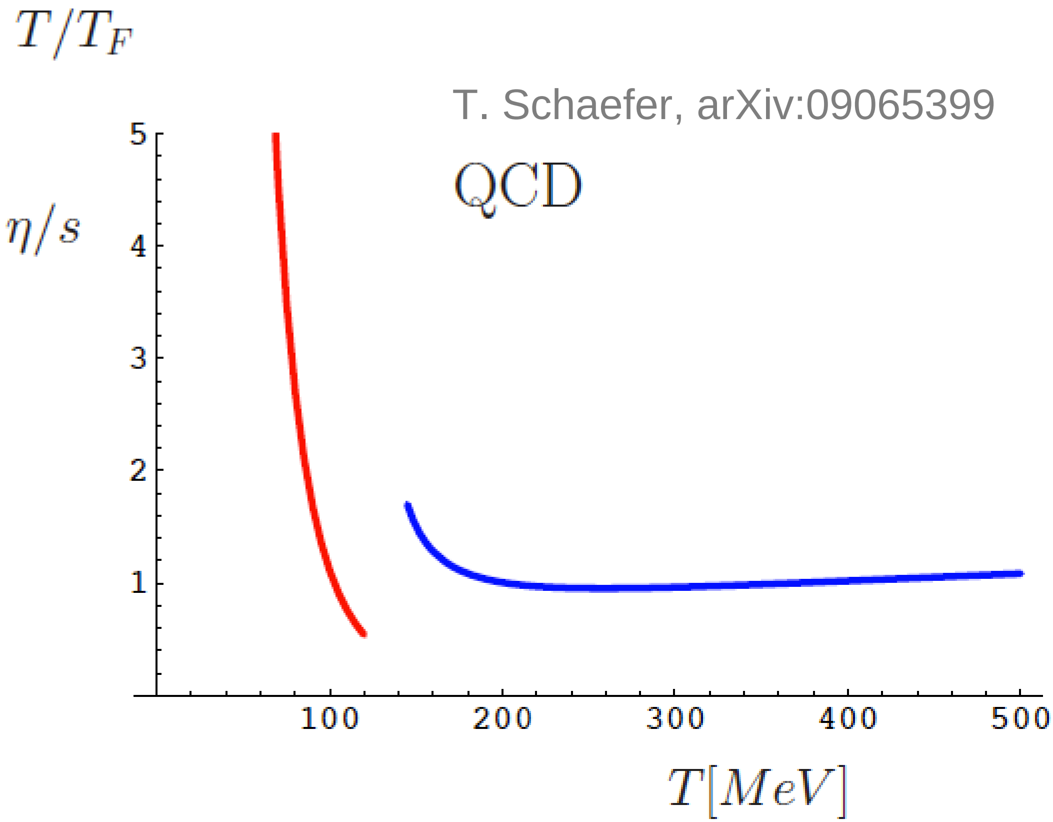
WPCF2009, CERN, 15-Oct-2009

- **attempt of CERES to extract η/s from $R_{long}(k_t)$**
- **problems with this approach**
- **other approaches?**

prerequisites: R_{out}, R_{side}, R_{long}, η/s, v_2, m_t

Viscosity in nuclear collisions – what to expect



- η/s reaches minimum near the critical point
- at the critical point it diverges
- high viscosity at low energies

Viscosity in nuclear collisions - observables

finite viscosity reduces velocity gradients

less in-plane, more out-of-plane expansion

- **reduced v_2**

less longitudinal, more transverse expansion

- **narrower dN/dy distributions**
- **harder p_t spectra**
- **reduced R_{long}**
- **reduced R_{out}**

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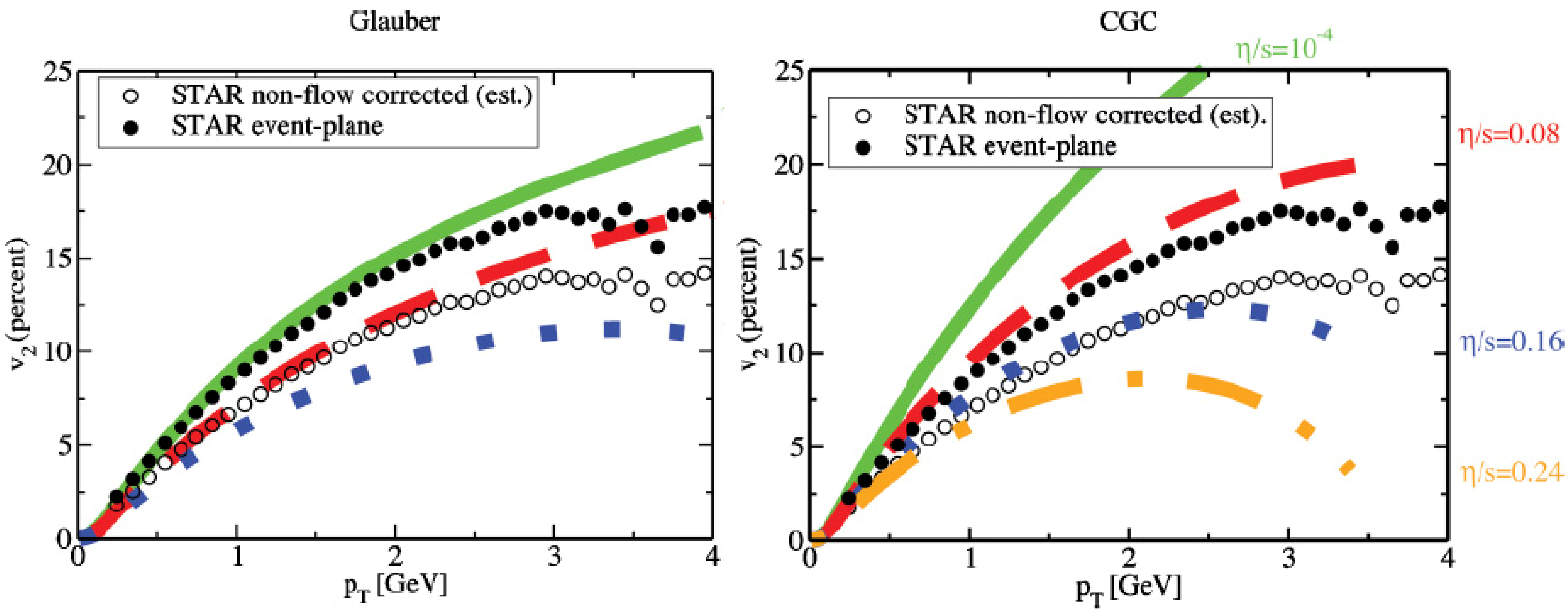
Viscosity via v_2

	η/s
PRL 99 (2007) 172301	0.03, 0.08
PRC 78 (2008) 034915	0.10 ± 0.13
PRL 98 (2007) 092301	0.1
PRC 76 (2007) 024905	0.19, 0.11
arXiv:0901.0460	0.15 ± 0.6

result close to the lower limit of η/s = 0.08

Viscosity via v_2

Luzum and Romatschke, PRC 79, 039903 (2009)



result depends on the assumed initial conditions

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R_{long} basics

Makhlin-Sinyukov

$$R_{long} = \tau_f \sqrt{\frac{T}{m_t}}$$

Herrmann-Bertsch

$$R_{long} = \tau_f \sqrt{\frac{T}{m_t} \frac{K_2(m_t/T)}{K_1(m_t/T)}}$$

τ_f ~ **inverse of the longitudinal Hubble constant**

How finite viscosity affects R_{long}

enhanced transverse expansion

reduced lifetime

reduced longitudinal length at freeze-out

smaller R_{long}

How finite viscosity affects R_{long}

enhanced transverse expansion

reduced lifetime

~~reduced longitudinal length~~ at freeze-out
larger Hubble constant

smaller R_{long}

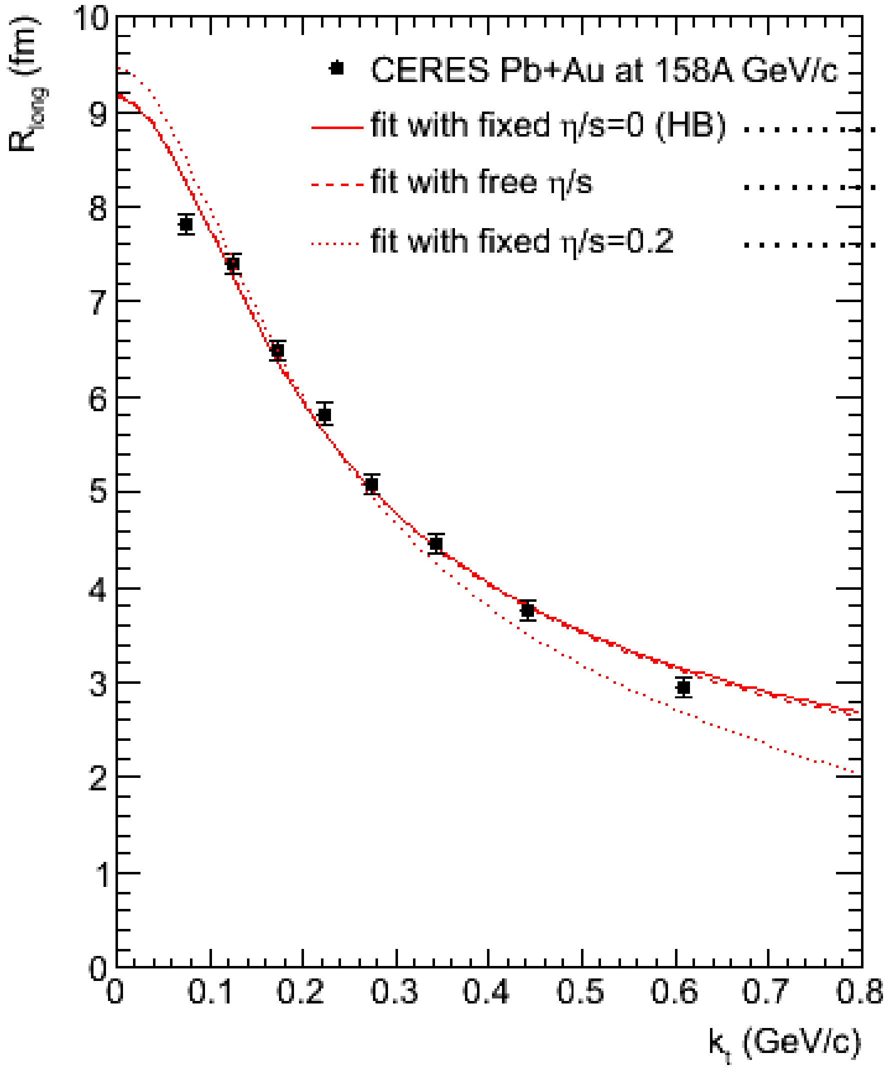
Effect of viscosity on R_{long} quantitatively

viscous correction, D. Teaney, PRC 68, 034913 (2003)

$$\frac{\delta R_L^2}{(R_L^2)^{(0)}} = -\frac{\Gamma_s}{\tau}\left[\frac{6}{4}\frac{xK_3(x)}{K_2(x)} - x^2\frac{1}{8}\left(\frac{K_3(x)}{K_2(x)} - 1\right)\right], \qquad \Gamma_s \equiv \frac{\frac{4}{3}\eta}{sT}$$

$$x \equiv \sqrt{m^2 + K_T^2}/T$$

Viscosity via R_{long} – fit to CERES data



τ_f = 6.3 fm

τ_f = 6.5 fm   η/s = 0.02

τ_f = 8.0 fm

T = 120 MeV (fixed)

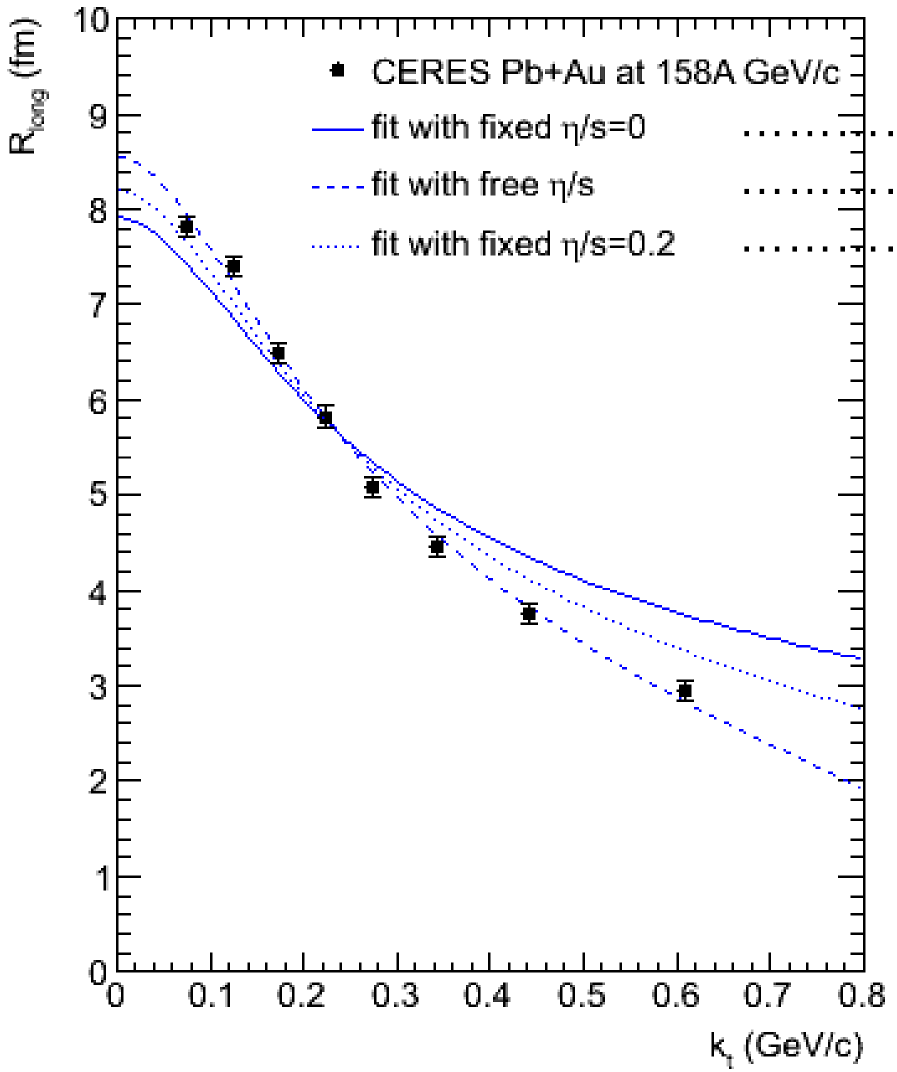
fit function:

Herrmann-Bertsch with viscous correction

$$\frac{\delta R_L^2}{(R_L^2)^{(0)}} = -\frac{\Gamma_s}{\tau}\left[\frac{6}{4}\frac{xK_3(x)}{K_2(x)} - x^2\frac{1}{8}\left(\frac{K_3(x)}{K_2(x)} - 1\right)\right]$$

result: η/s below 0.1
(recall lower bound 0.08)

Viscosity via R_{long} – fit to CERES data



.... τ_f = 8.5 fm

.... τ_f = 9.9 fm   η/s = 0.42

.... τ_f = 9.2 fm

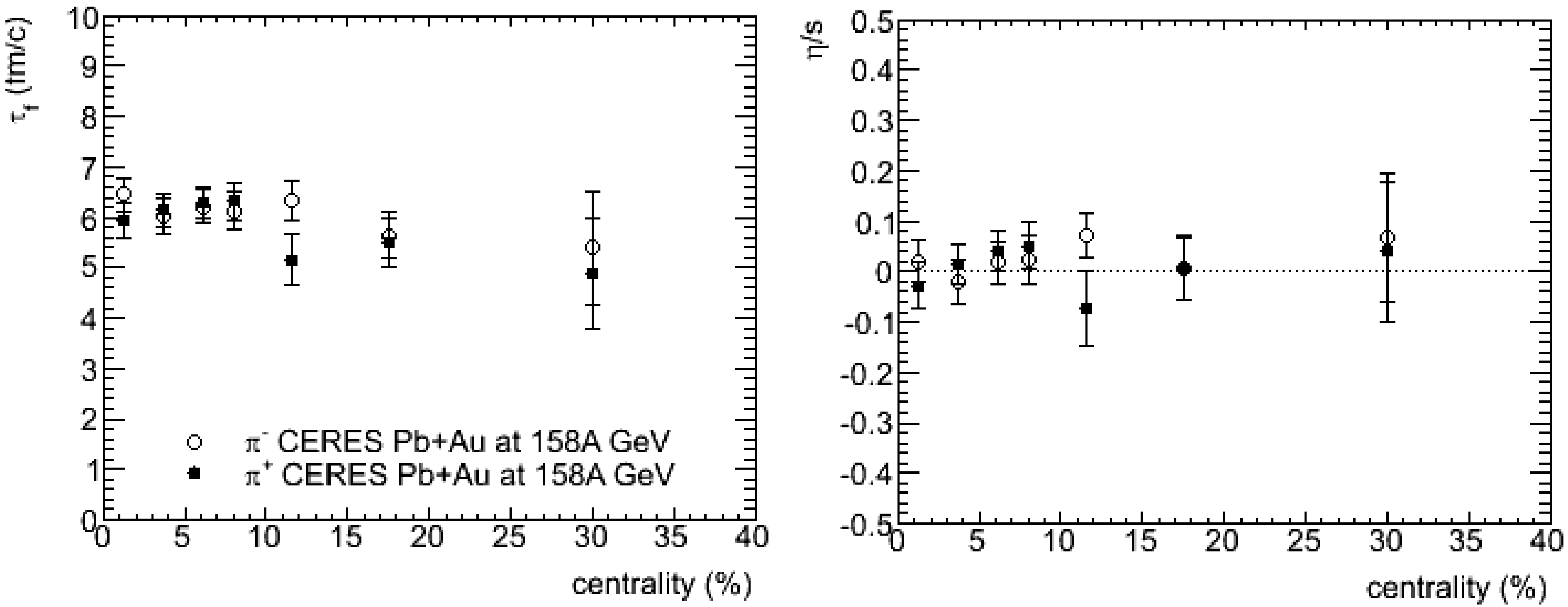
T = 120 MeV (fixed)

fit function:
Makhlin-Sinyukov with appr. visc. cor.

$$(R_L^2)^{(0)} + \delta R_L^2 = \tau_o^2 \left(\frac{T}{m_T} - \frac{19}{16} \frac{\Gamma_s}{\tau_o} \right)$$

very different result, beware!

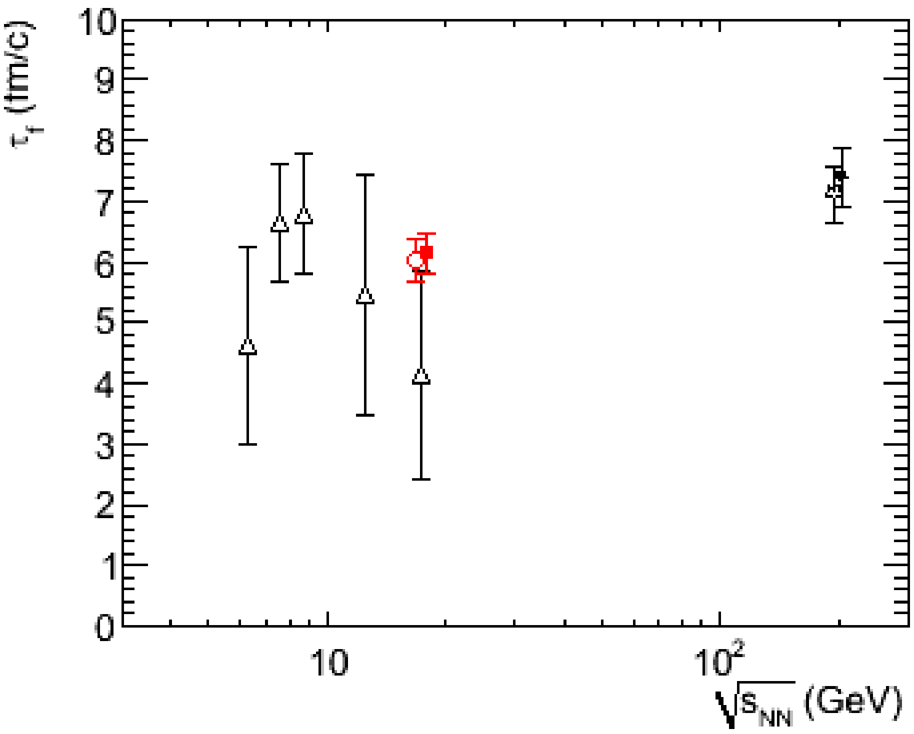
Viscosity via R_{long} – fit to CERES data

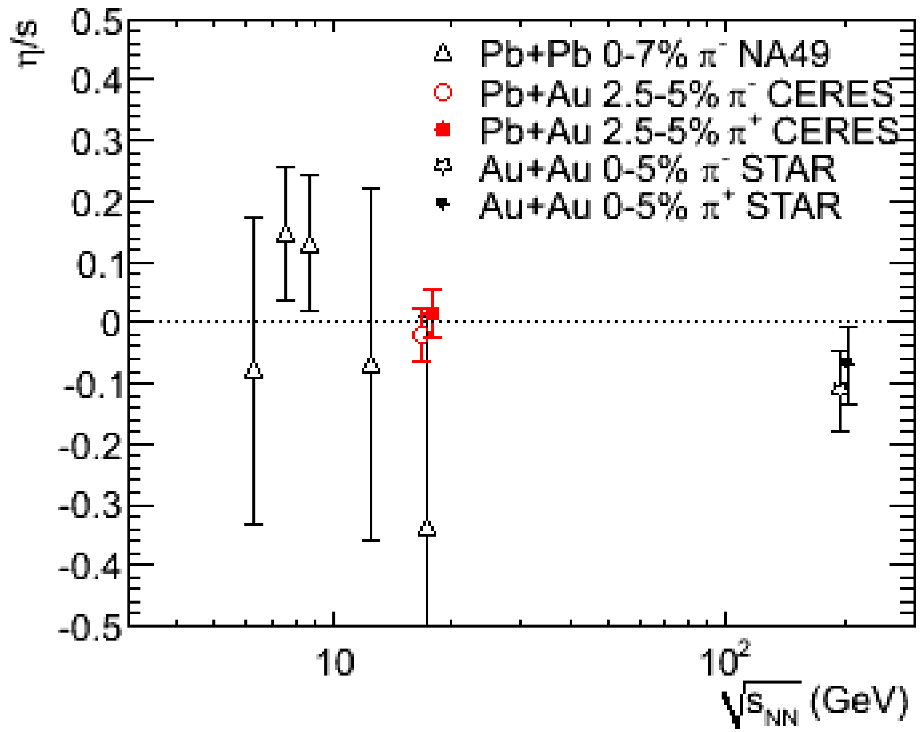


η/s is small for both charges and all centralities

Viscosity via R_{long} – fit to NA49, CERES, STAR data

CERES Collaboration, arXiv:0907.2799





η/s is small for all energies

Viscosity low at all energies? Why not!

N. Auerbach and S. Shlomo
"The η/s ratio in finite nuclei"
arXiv:0908.4441v1 [nucl-th], 31-Aug-2009

- **giant resonance width** → $\eta \approx 0.5\text{-}2.5 \times 10^{-23}$ MeV fm^{-3} s
- **fission** → $\eta \approx 0.9\text{-}1.9 \times 10^{-23}$ MeV fm^{-3} s
- **Fermi gas of nucleons in Woods-Saxon well → s**

→ η/s ~ 0.3-1.5 for large nuclei
η/s ~ 0.2-1.0 for small nuclei

However, serious problems in our analysis:

- neglected transverse expansion
- Teaney's formula accounts for the modified distribution at freeze-out but not for flow! (M. Lisa, U. Heinz)
- even the freeze-out part is not clear:

  → Bożek/Wyskiel see no effect on HBT radii when using the same method with $\eta/s=0.16$

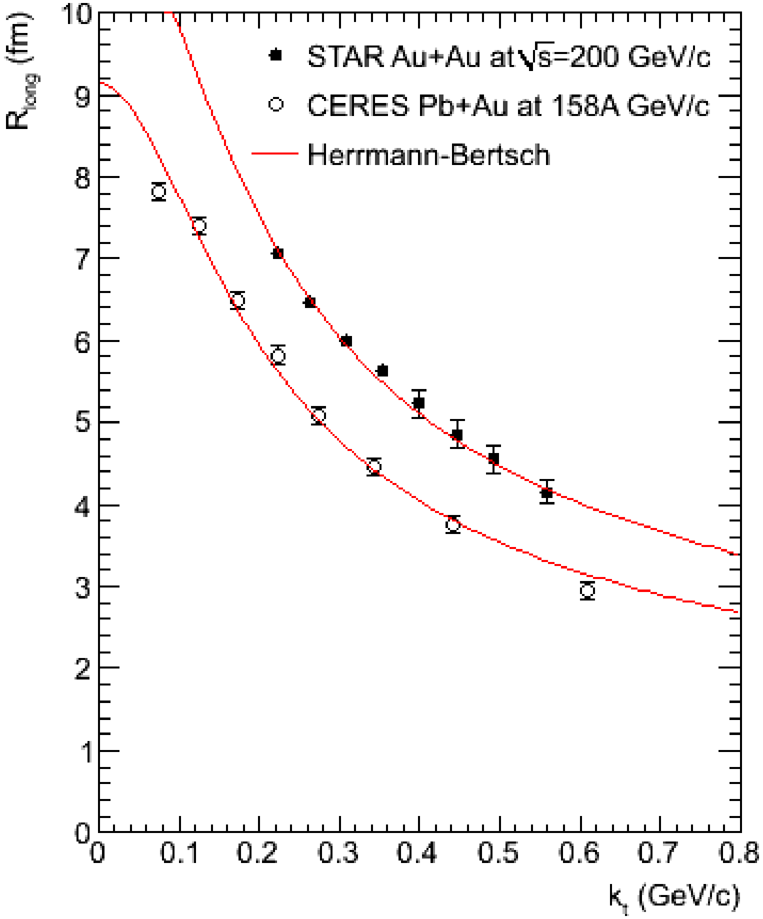
  → Song/Heinz get opposite modification of p_t spectra

- last but not least:

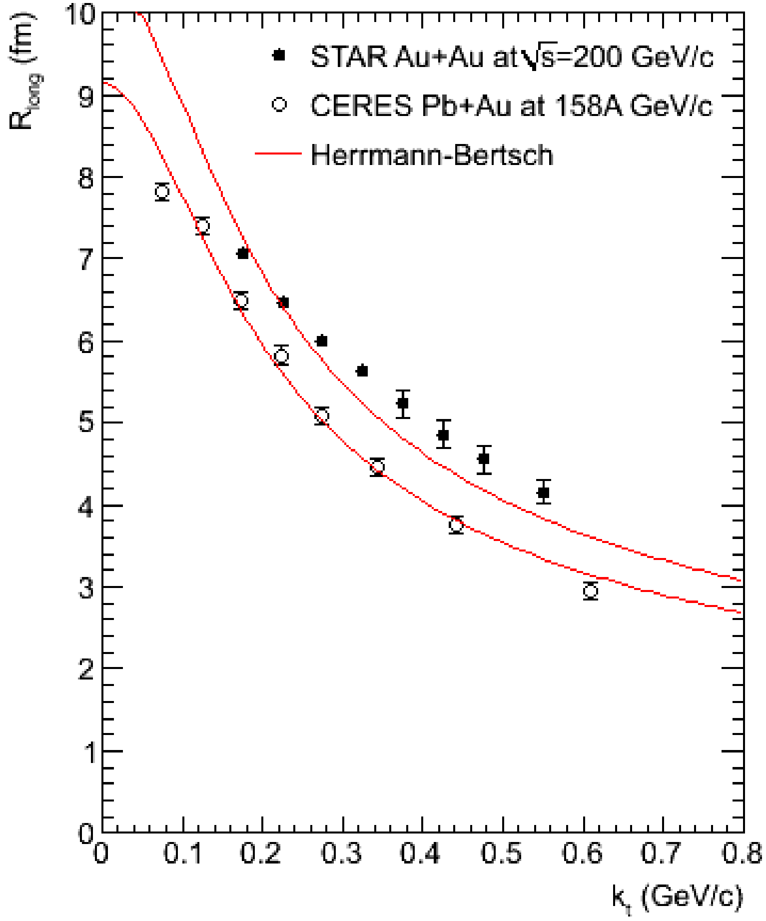
  my mistake when interpreting STAR data (m_t vs k_t)

mistake when interpreting STAR data (m_t vs k_t)

STAR points misplaced



STAR points placed correctly



$$R_{long} = \tau_f \sqrt{\frac{T}{m_t} \frac{K_2(m_t/T)}{K_1(m_t/T)}}$$

no room for viscosity, even the pure Herrmann-Bertsch curve is steeper than the data

mistake when interpreting STAR data (m_t vs k_t)

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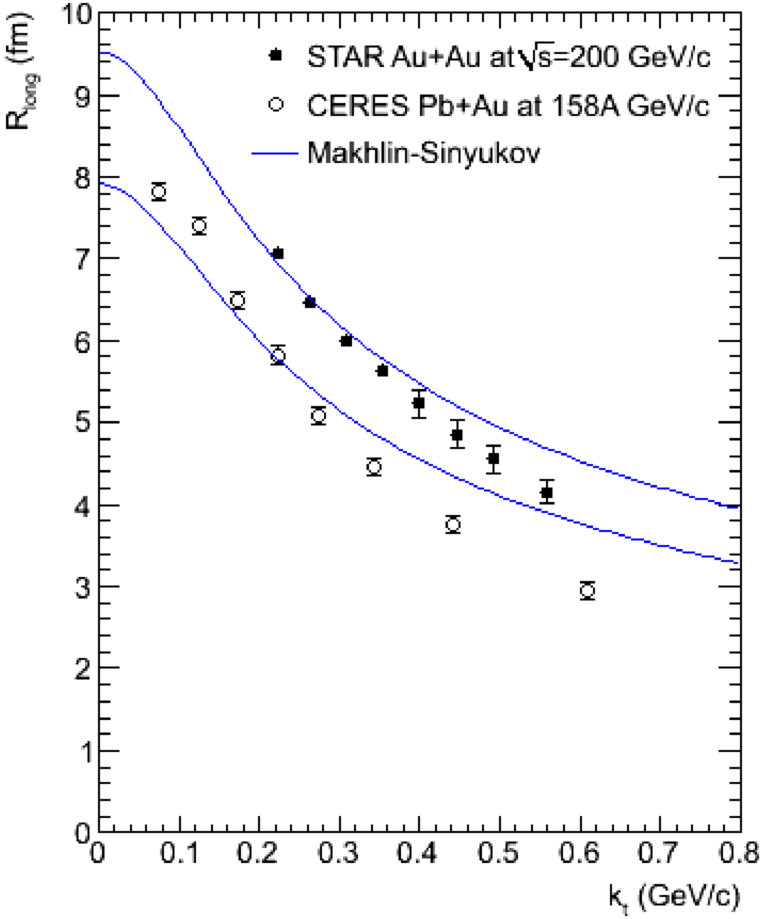

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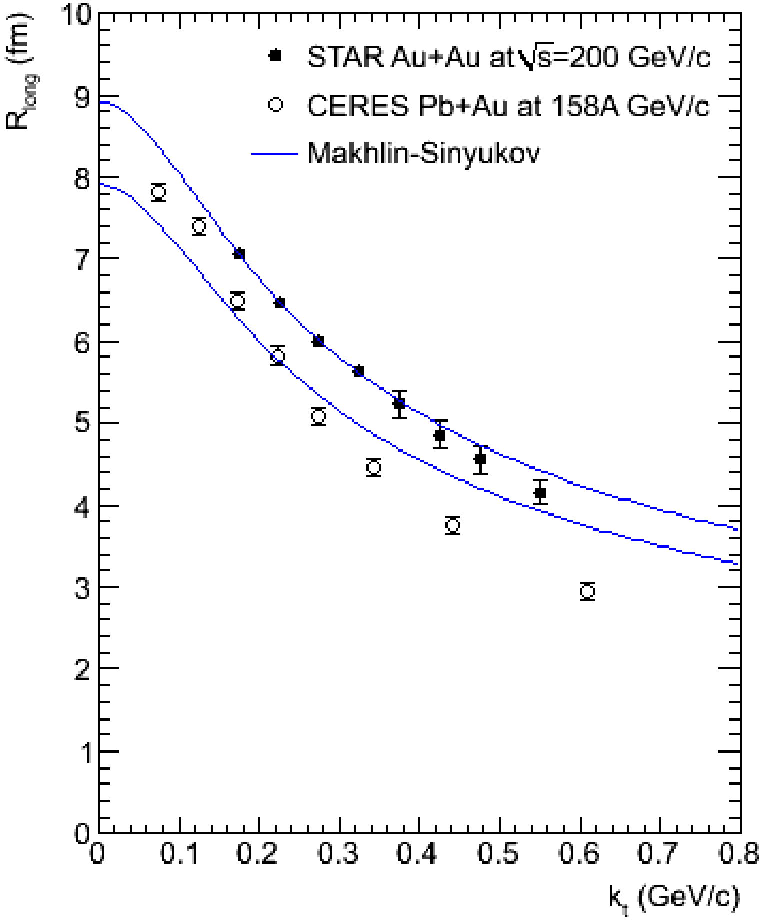
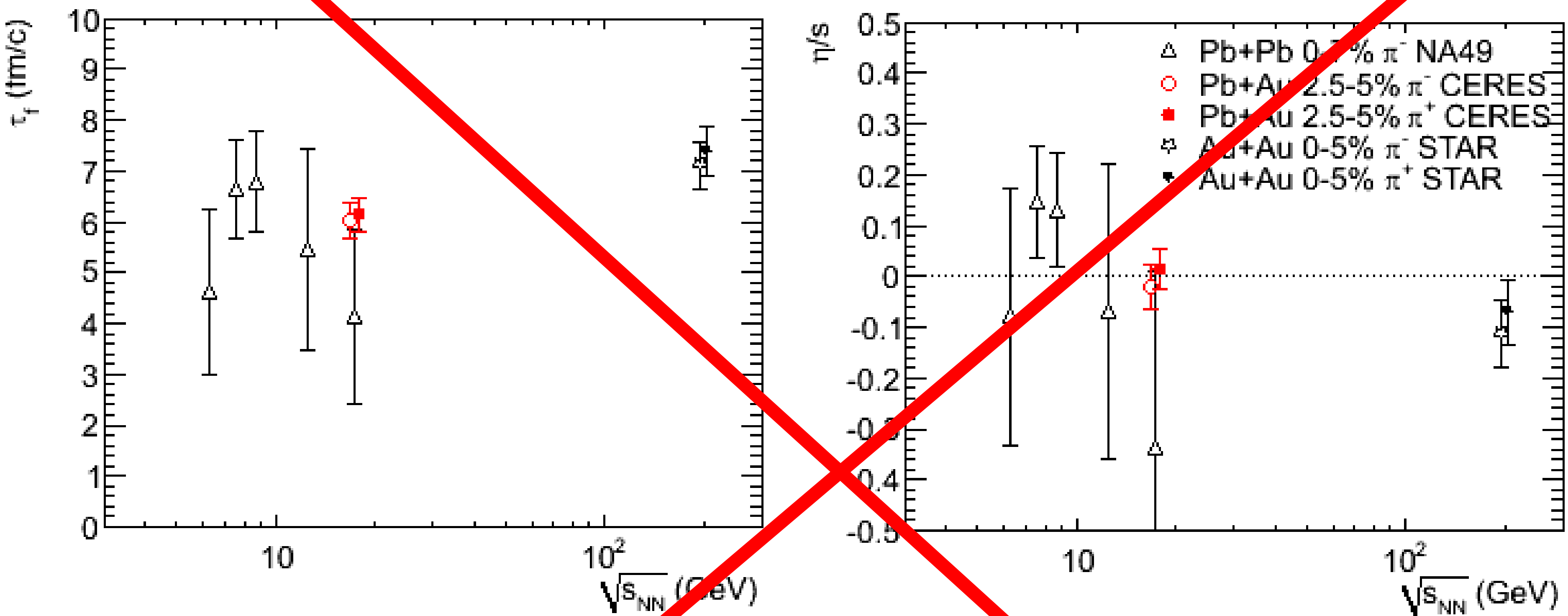


btw., Makhlin-Sinyukov fits much better…

Viscosity via R_{long} – fit to NA49, CERES, STAR data



η/s is small for all energies

Viscosity in nuclear collisions - observables

finite viscosity reduces velocity gradients

↓

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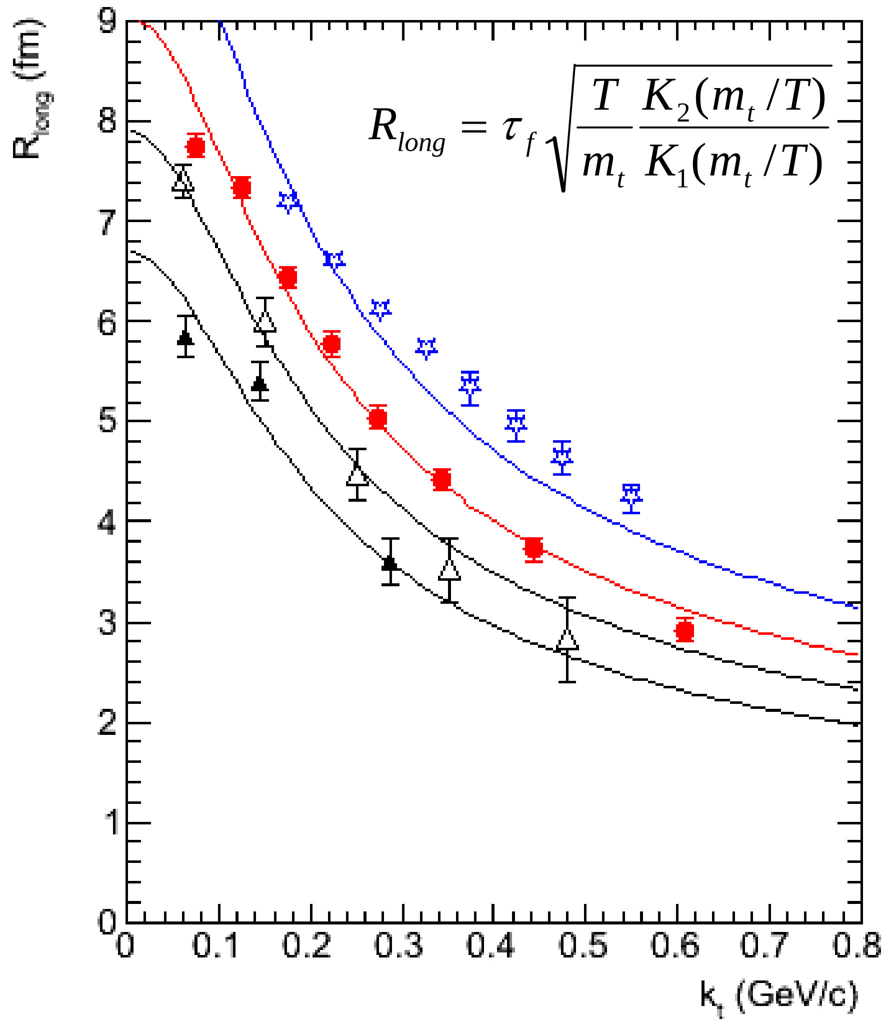
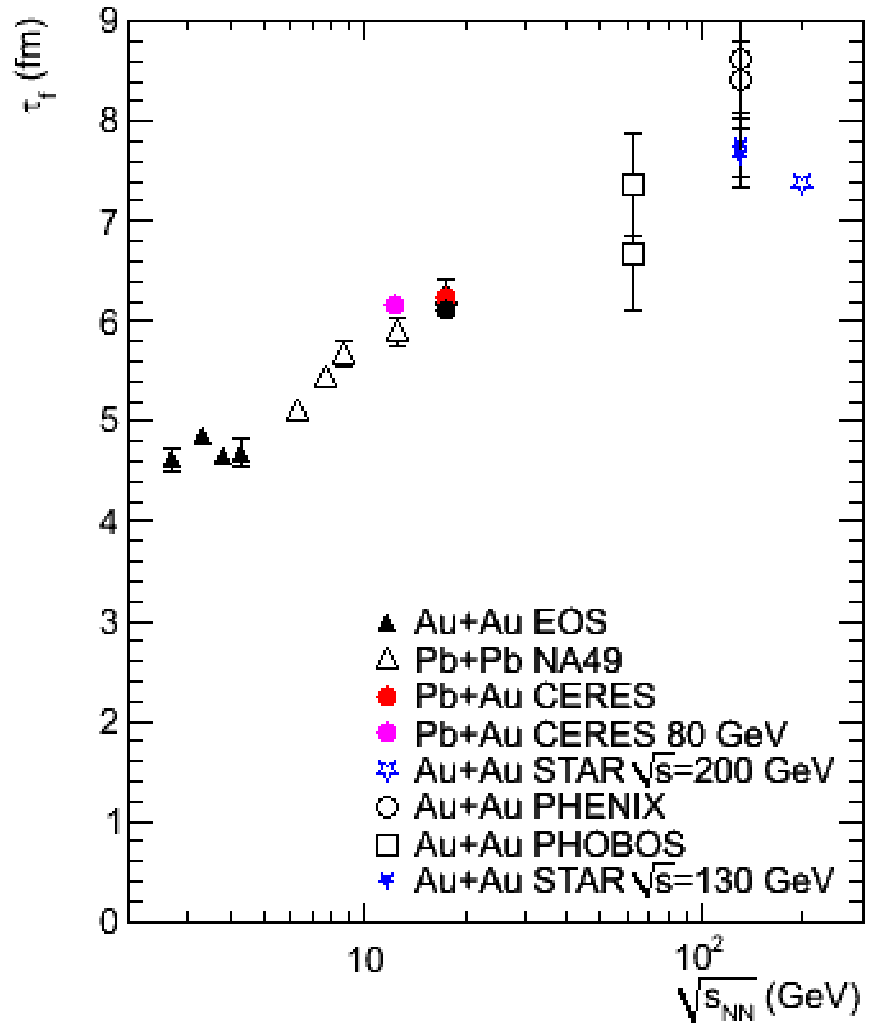
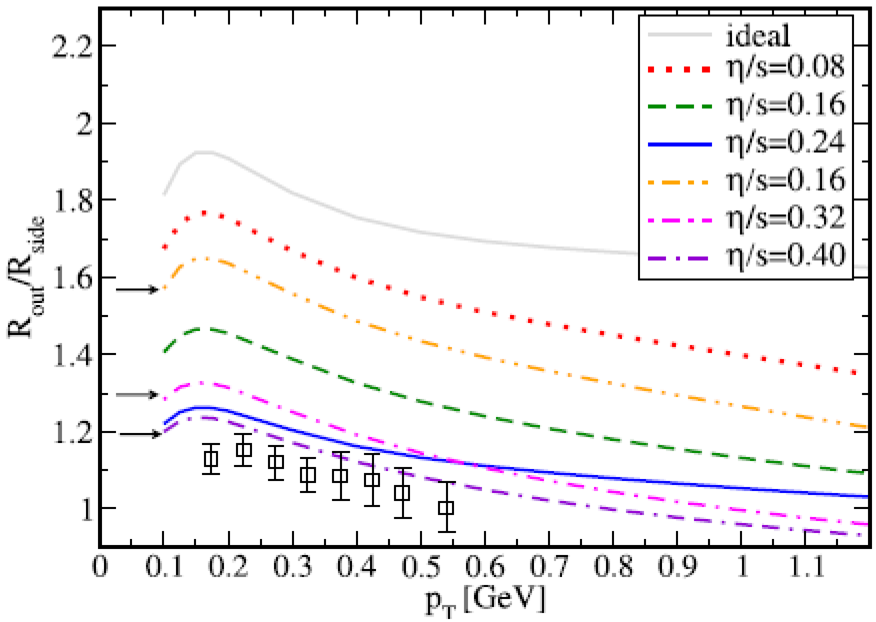
R_{long} systematics

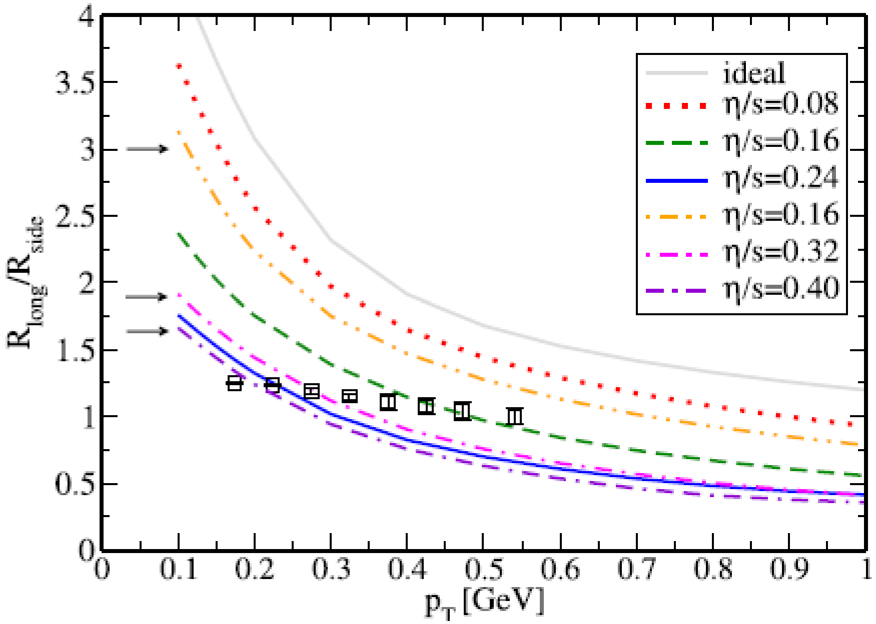




Viscosity via R_{out}/R_{side} and R_{long}/R_{side} ratios

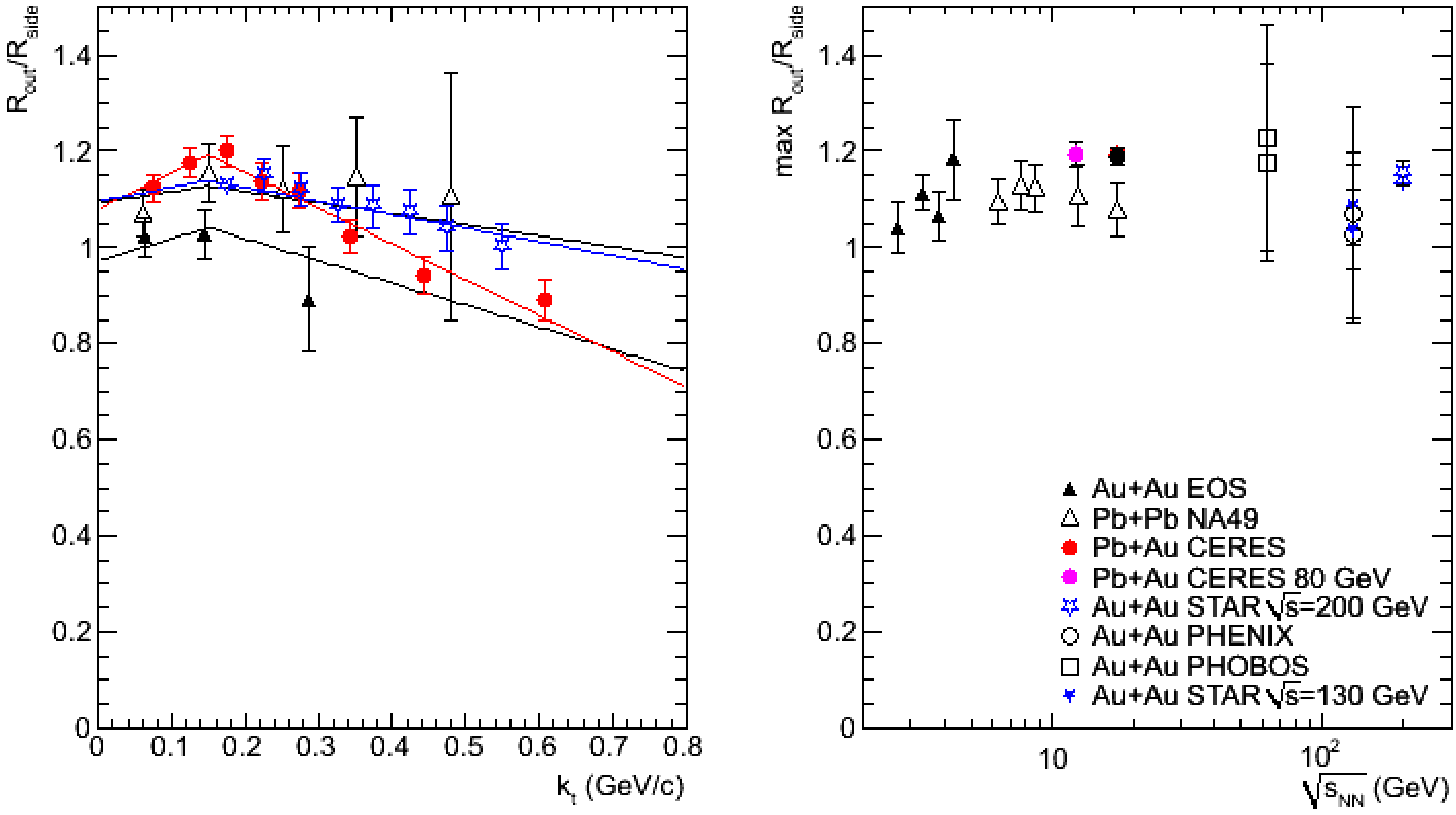
P. Romatschke, Eur. Phys. J C 52 (2007) 203





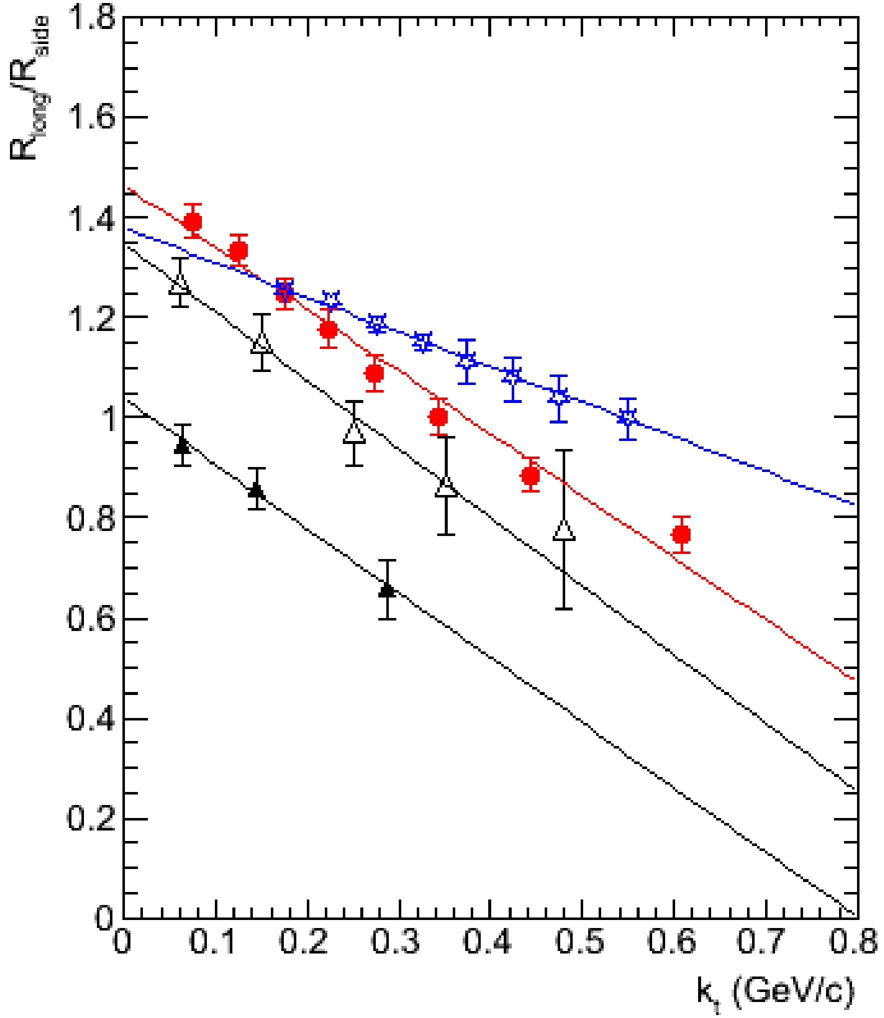
R_{out}/R_{side} and R_{long}/R_{side} ratios are sensitive to viscosity

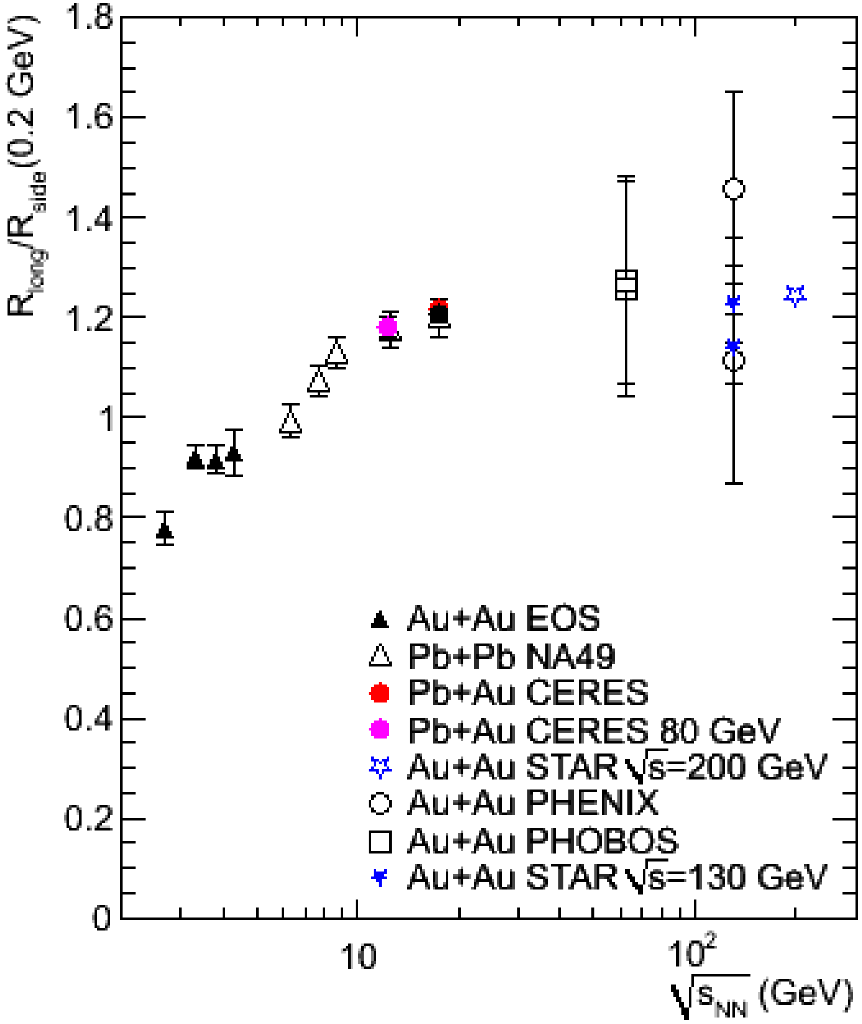
R_{out}/R_{side} systematics



R_{out}/R_{side} ratio is constant from AGS to RHIC

R_{long}/R_{side}

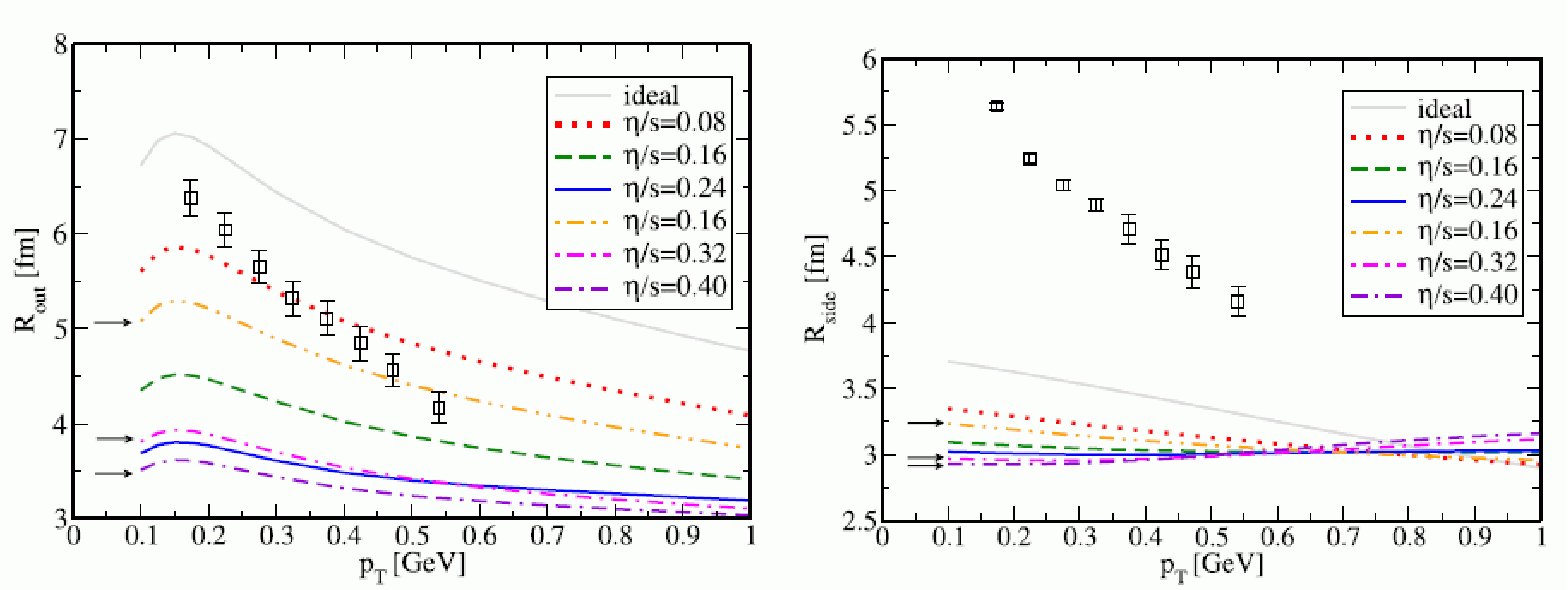




R_{long}/R_{side} ratio is constant from top SPS to RHIC

Viscosity via R_{out}/R_{side} and R_{long}/R_{side} ratios

P. Romatschke, Eur. Phys. J C 52 (2007) 203



Quantitatively:

no statement can be made given the calculation does not reproduce the HBT radii but only their ratios

Qualitatively:

no indication of RHIC viscosity being lower than at SPS

summary

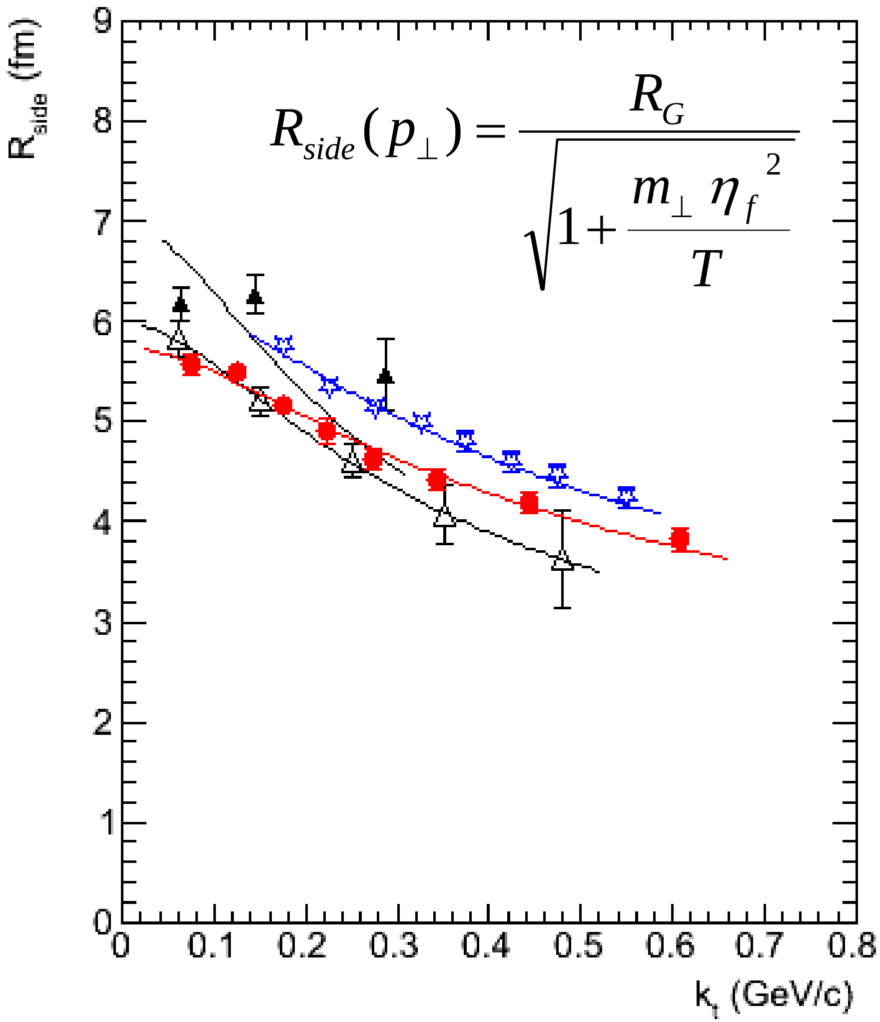
- **our quantitative method was wrong for several reasons; the preprint will be withdrawn**

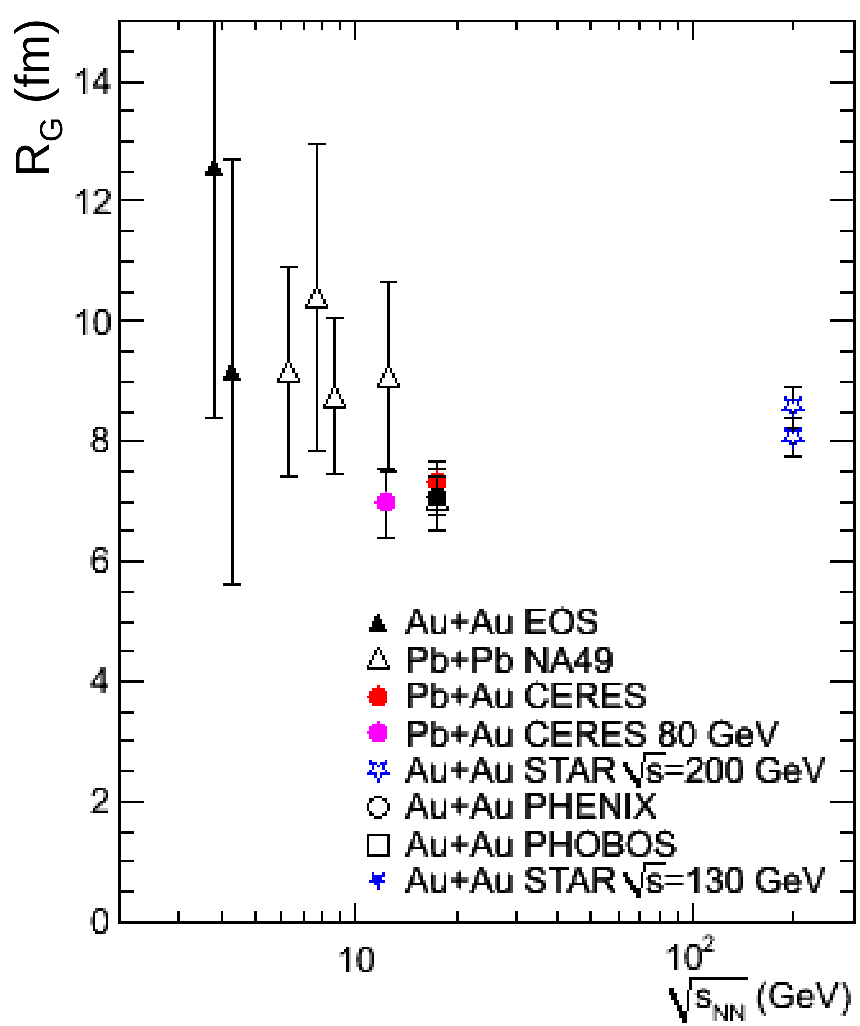
- **however, the conclusion seems to hold:**

  no indication of increasing viscosity when going from RHIC down to SPS

BACKUP

R_{side} systematics

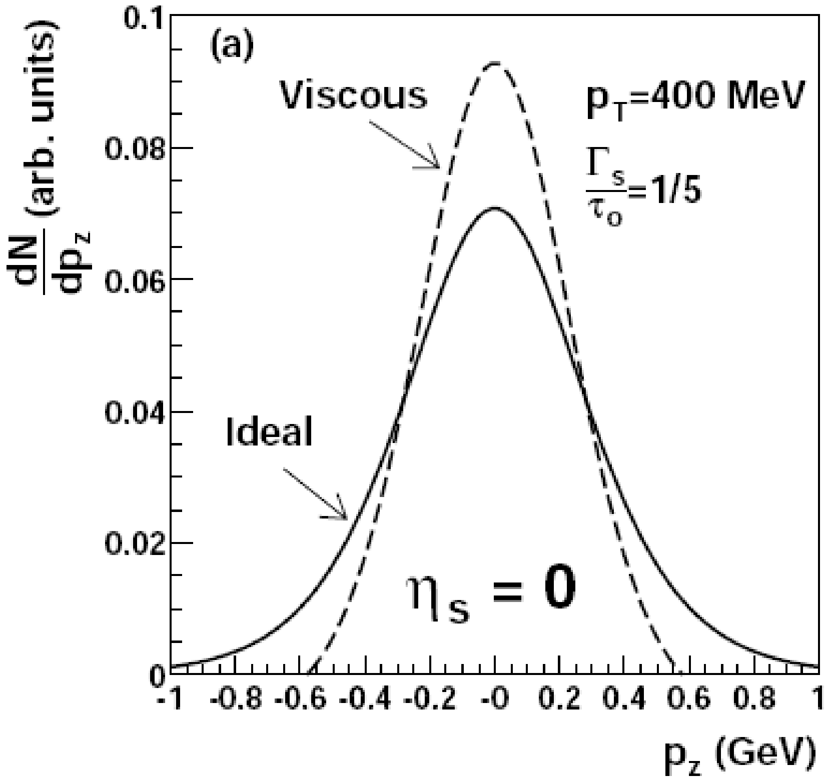


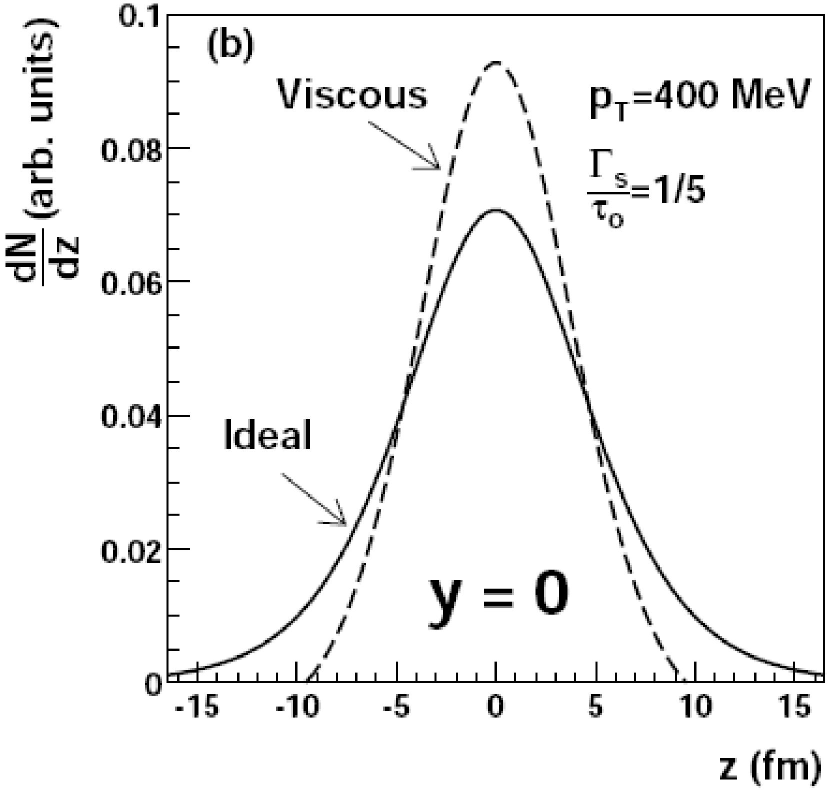


Viscosity via R_{long}

D. Teaney, Phys. Rev. C 68,034913 (2003)

"Viscous corrections to a Bjorken expansion"





Viscous gas

$$\lambda = \frac{1}{n\sigma}$$

mean free path
hydrodynamics applies when λ small

$$\eta = \frac{np\lambda}{3} = \frac{p}{3\sigma}$$

dynamical viscosity
(independent on n)
(infinite for ideal gas)
(not quite 0 for inf. σ)

$$\nu = \frac{\eta}{\rho} = \frac{<v> \lambda}{3}$$

kinematical viscosity

$$\frac{\eta}{s} = \frac{3}{4}\lambda T$$

Teaney

$$\eta \sim np\lambda$$
$$s \sim n$$

uncertainty principle provides lower bound

$$\frac{\eta}{s} \sim p\lambda \sim \frac{\text{mean free path}}{\text{de Broglie wavelength}} \geq const$$

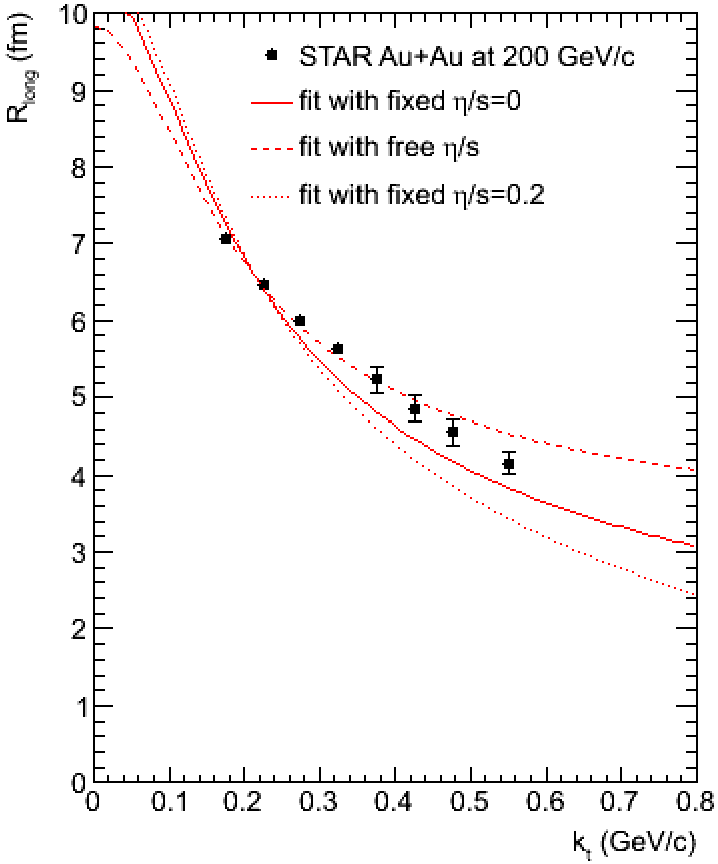
Teaney's formulas

$$(R_L^2)^{(0)} = \tau_o^2 \frac{T}{m_T} \frac{K_2(x)}{K_1(x)} \qquad x \equiv \sqrt{m^2 + K_T^2}/T$$

$$\frac{\delta R_L^2}{(R_L^2)^{(0)}} = -\frac{\Gamma_s}{\tau}\left[\frac{6}{4}\frac{xK_3(x)}{K_2(x)} - x^2\frac{1}{8}\left(\frac{K_3(x)}{K_2(x)} - 1\right)\right]$$

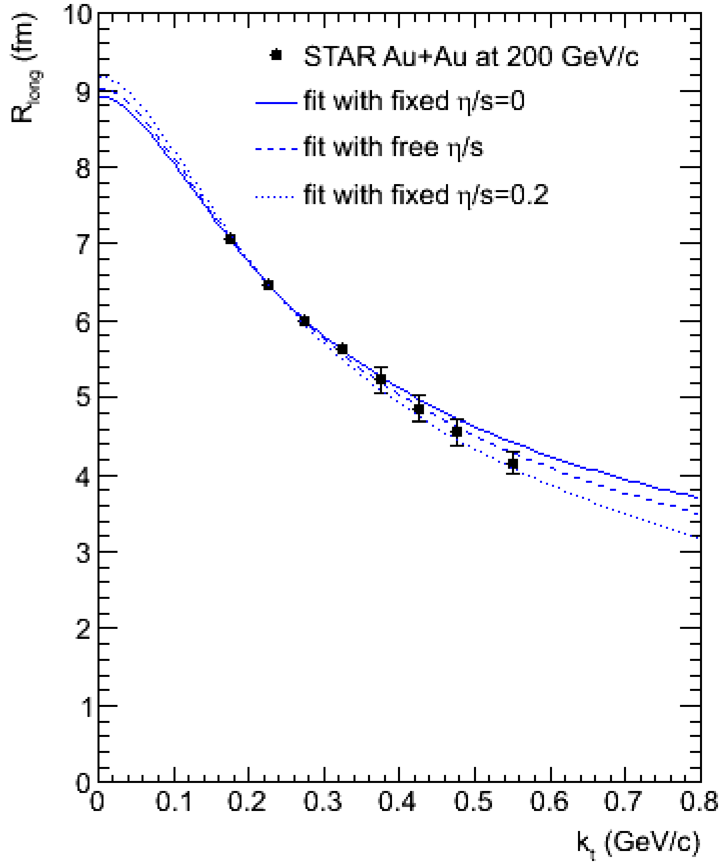
$$(R_L^2)^{(0)} = \tau_o^2 \frac{T}{m_T} \qquad (R_L^2)^{(0)} + \delta R_L^2 = \tau_o^2\left(\frac{T}{m_T} - \frac{19}{16}\frac{\Gamma_s}{\tau_o}\right) \qquad \Gamma_s \equiv \frac{\frac{4}{3}\eta}{sT}$$

Fit to STAR Rlong, full formula



fitfun	tau0 (fm)	T (GeV)	eta/s
fixed eta/s=0	7.224+-0.022	0.120+-0.000	0.000+-0.000
free eta/s	1.850+-1.721	0.120+-0.000	1.956+-1.596
fixed eta/s=0.2	8.926+-0.022	0.120+-0.000	0.200+-0.000

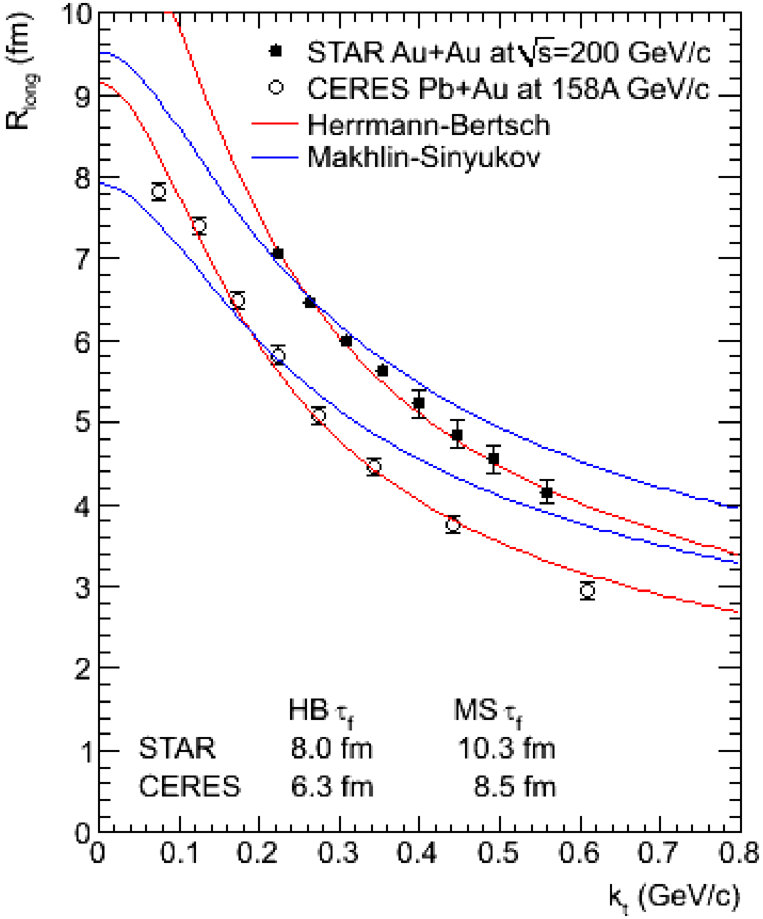
Fit to STAR Rlong, simplified formula



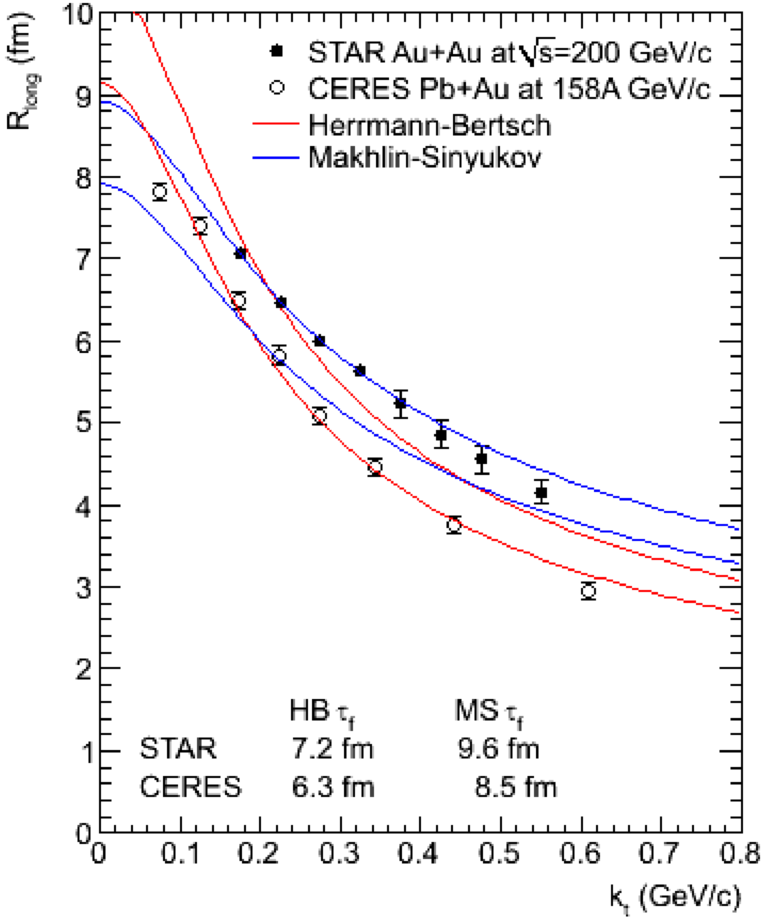
fitfun	tau0 (fm)	T (GeV)	eta/s
fixed eta/s=0	9.618+-0.030	0.120+-0.000	0.000+-0.000
free eta/s	9.861+-0.131	0.120+-0.000	0.084+-0.044
fixed eta/s=0.2	10.205+-0.030	0.120+-0.000	0.200+-0.000

mistake when interpreting STAR data (m_t vs k_t)

STAR points misplaced

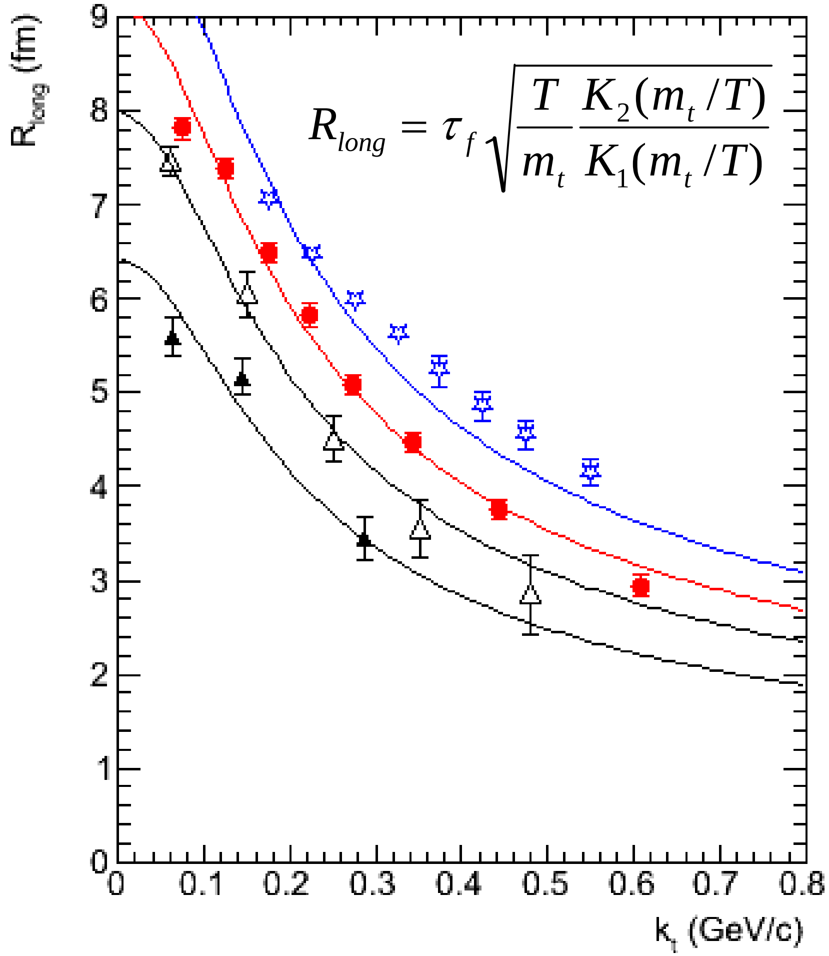


STAR points placed correctly

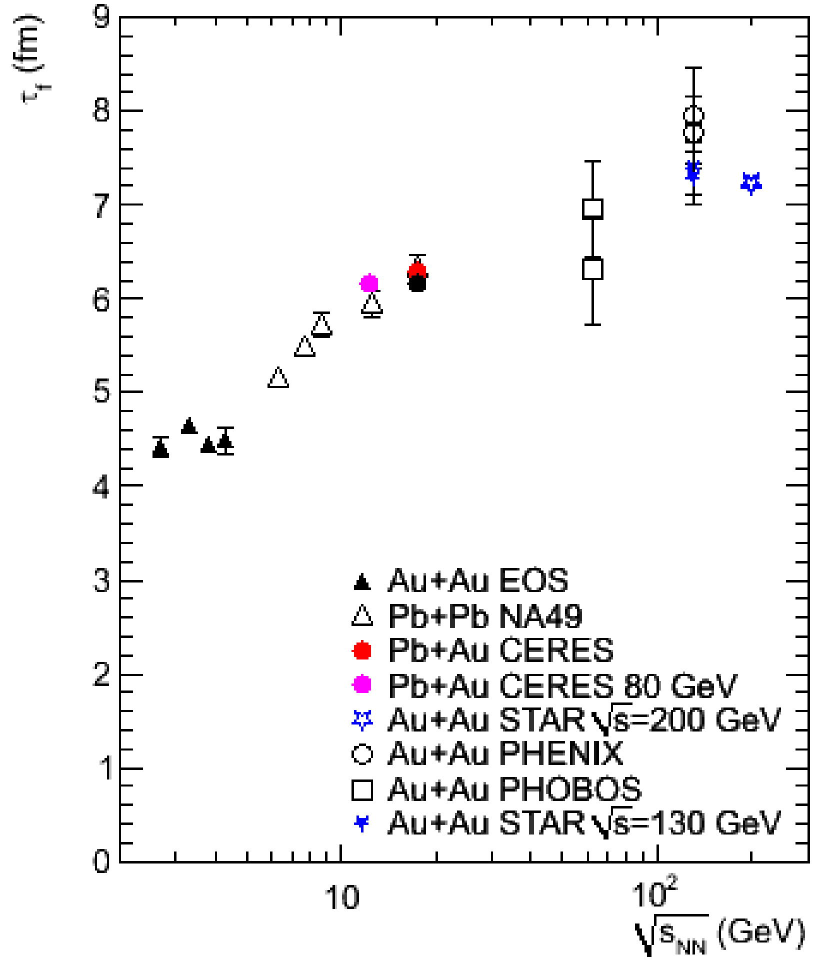


Herrmann-Bertsch vs Makhlin-Sinyukov

R_{long}

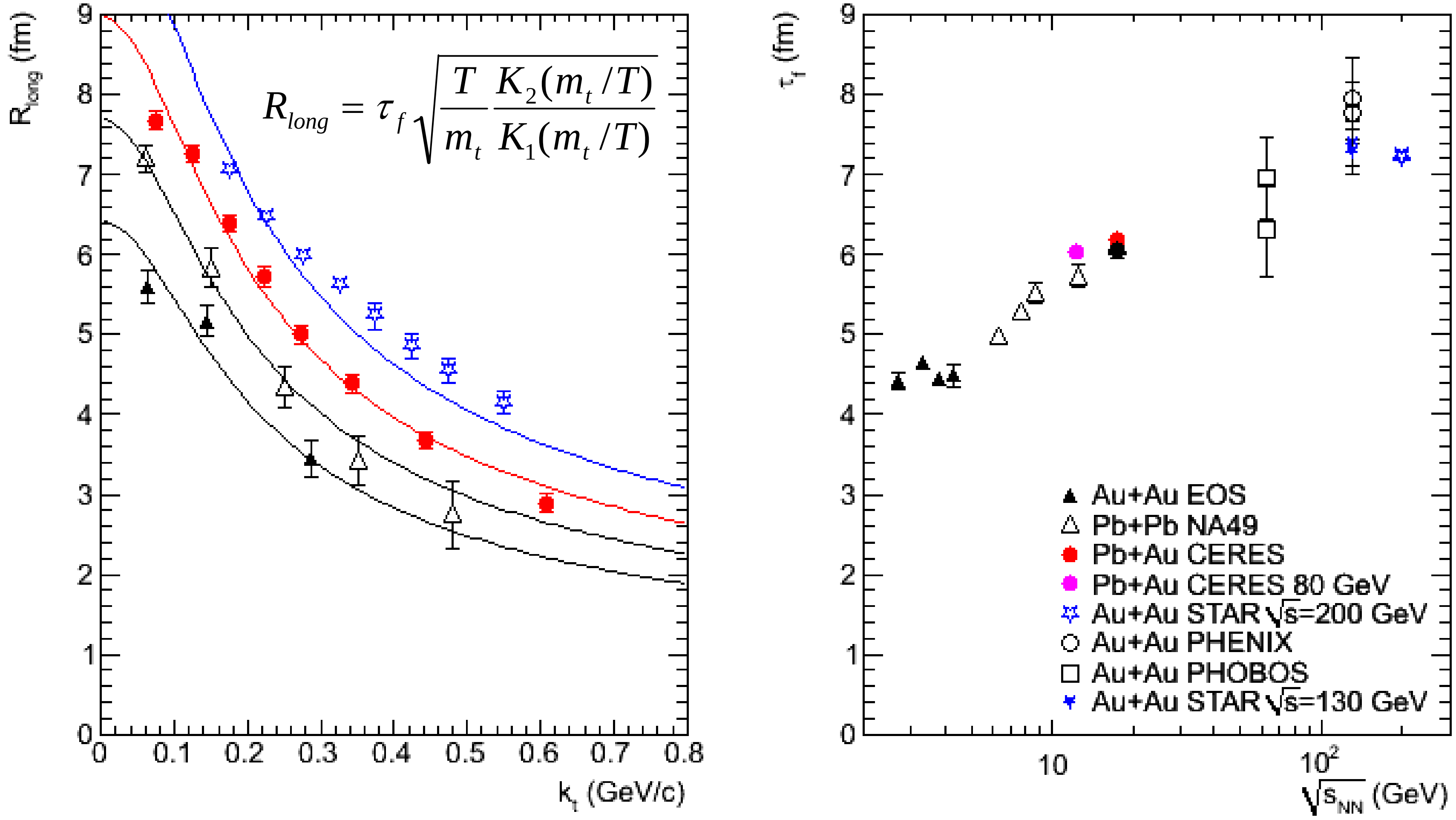


R_{long} (fm)
k_t (GeV/c)
$R_{long} = \tau_f \sqrt{\frac{T}{m_t} \frac{K_2(m_t/T)}{K_1(m_t/T)}}$

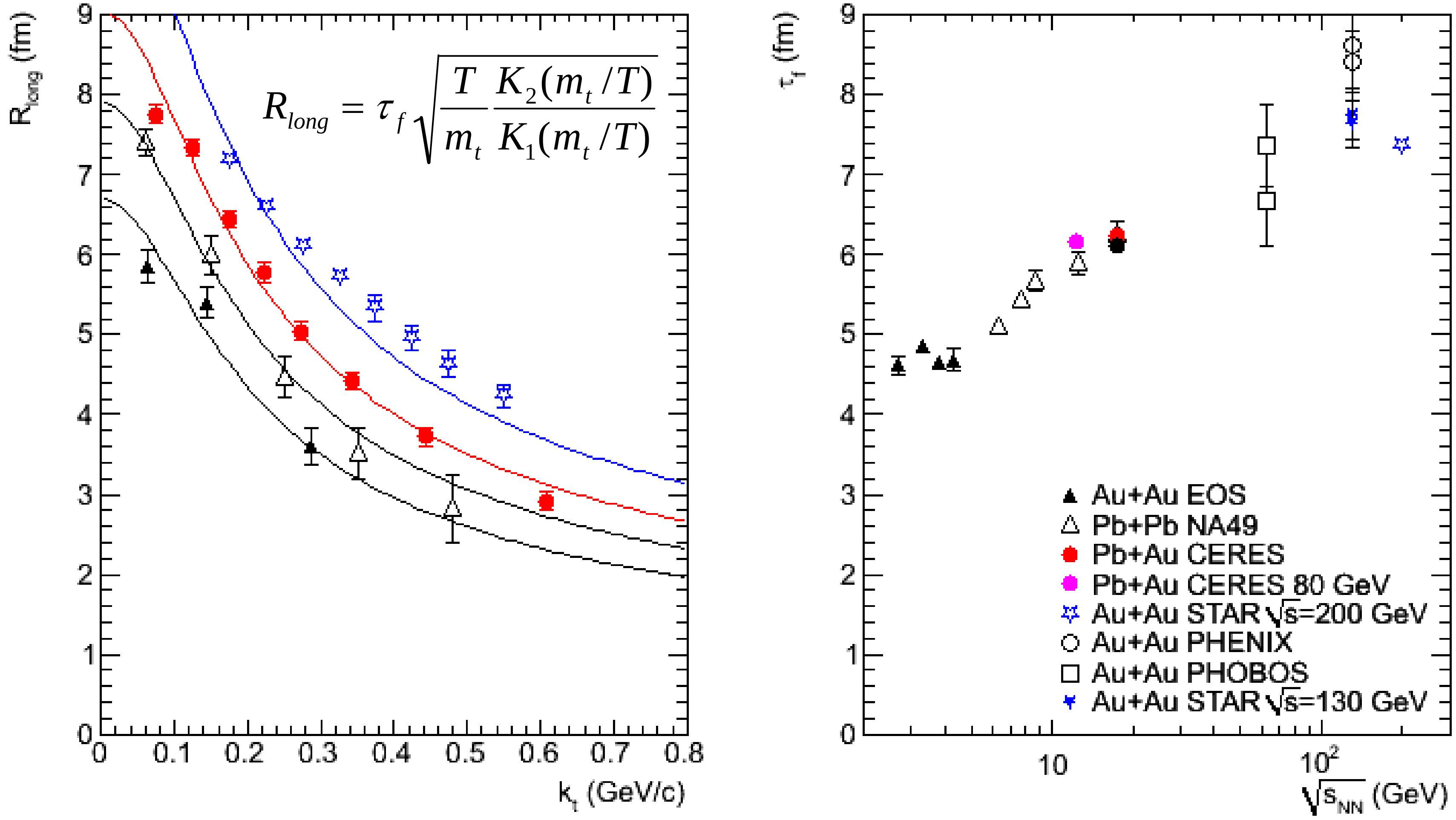


τ_f (fm)
$\sqrt{s_{NN}}$ (GeV)
Au+Au EOS
Pb+Pb NA49
Pb+Au CERES
Pb+Au CERES 80 GeV
Au+Au STAR $\sqrt{s}$=200 GeV
Au+Au PHENIX
Au+Au PHOBOS
Au+Au STAR $\sqrt{s}$=130 GeV

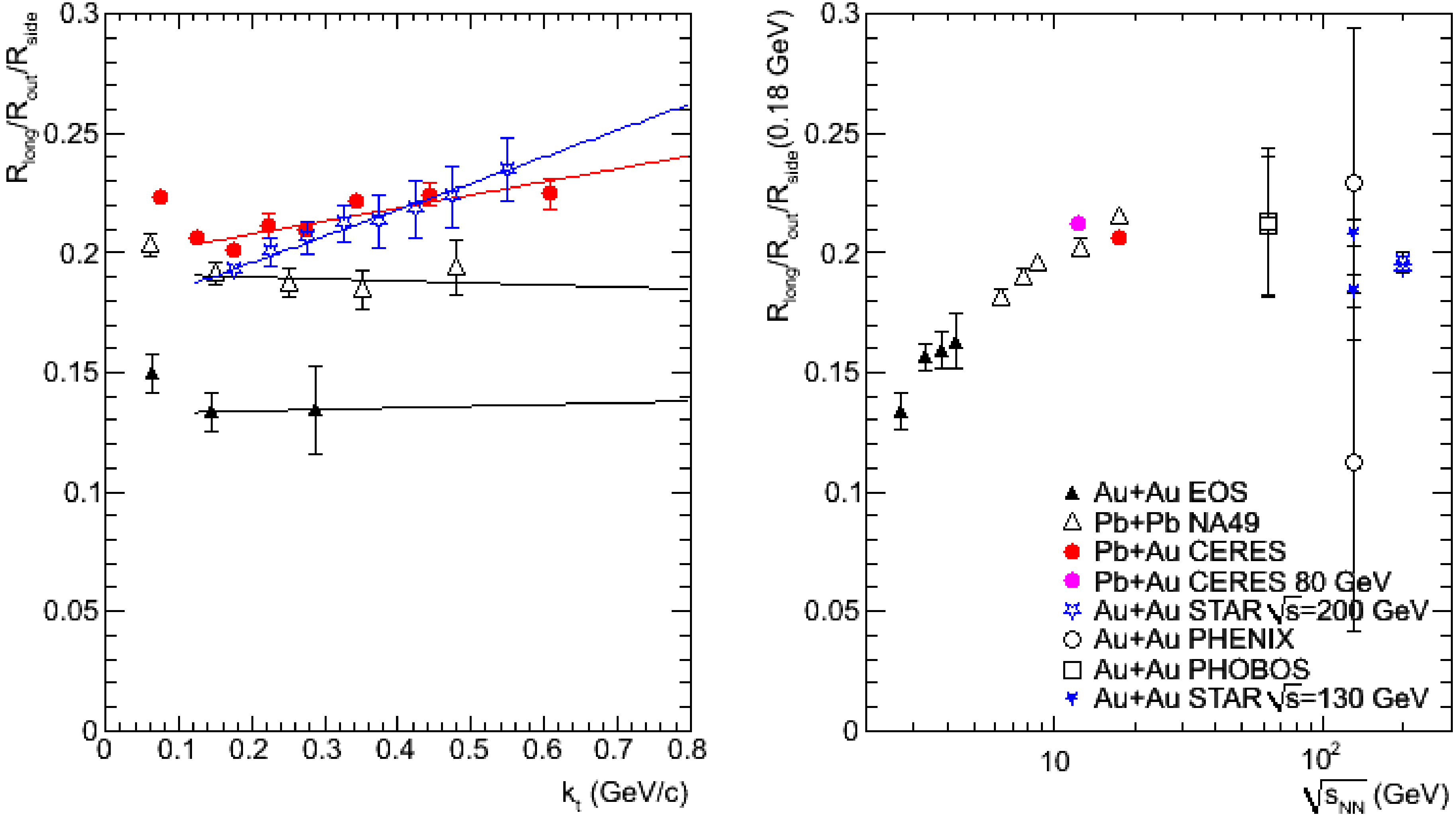
R_{long} corrected by $(A/197)^{1/3}$



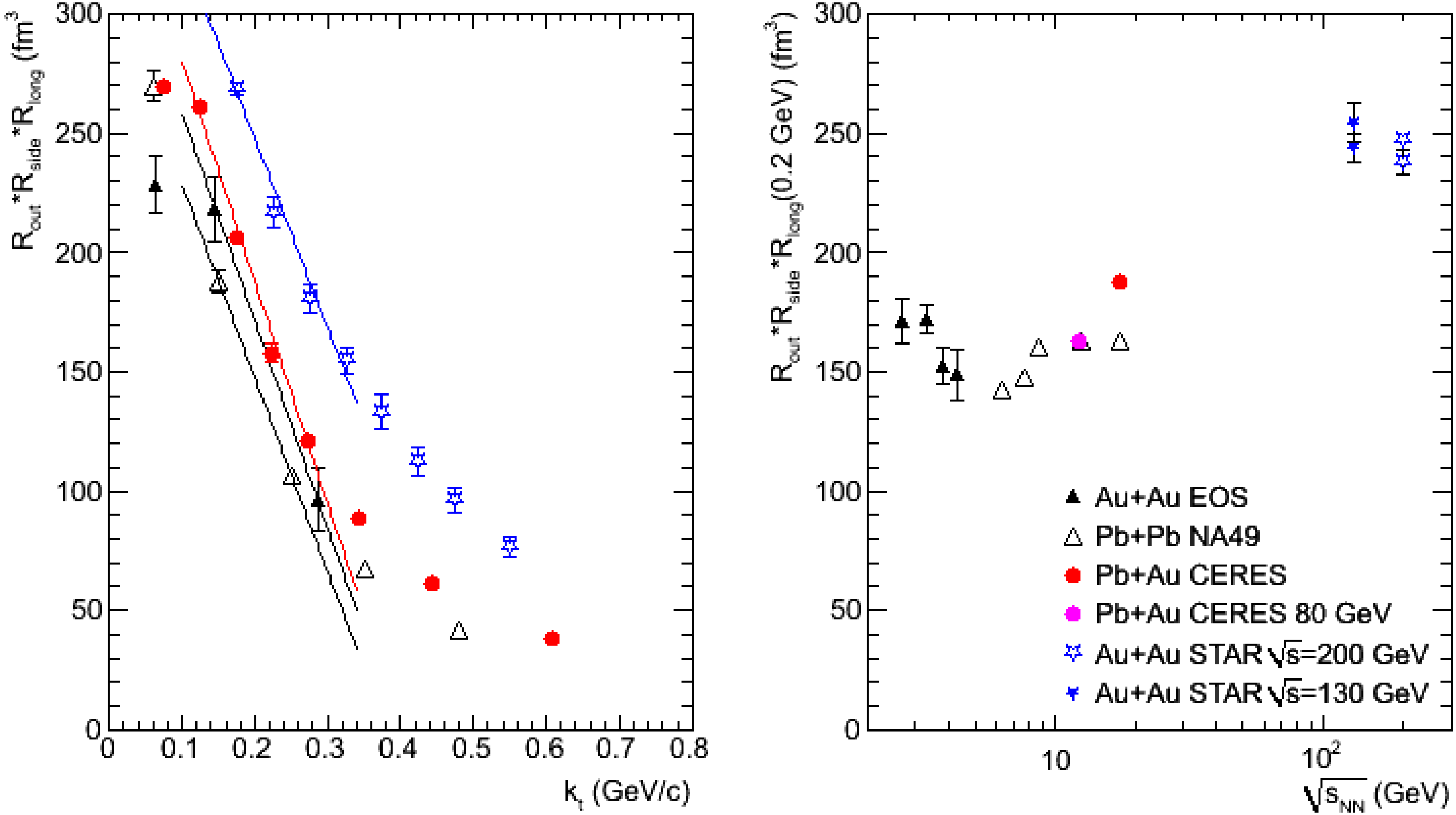
R_{long} corrected by $(A/197)^{1/3}$ and for centrality



$R_{long}/R_{out}/R_{side}$



R_{out}*R_{side}*R_{long}



$R_{side}*R_{side}*R_{long}$