Viscosity and HBT

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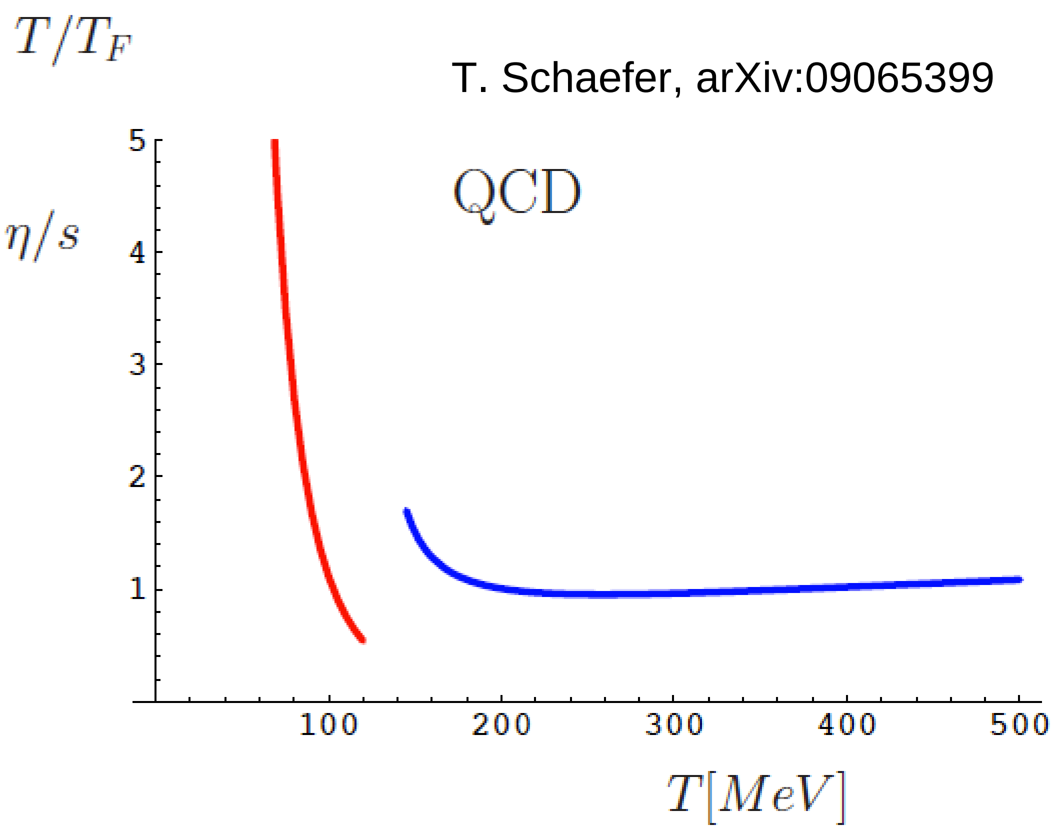
Hirschegg 2010

Strongly Interacting Matter under Extreme Conditions

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

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}***

Viscosity in nuclear collisions - observables

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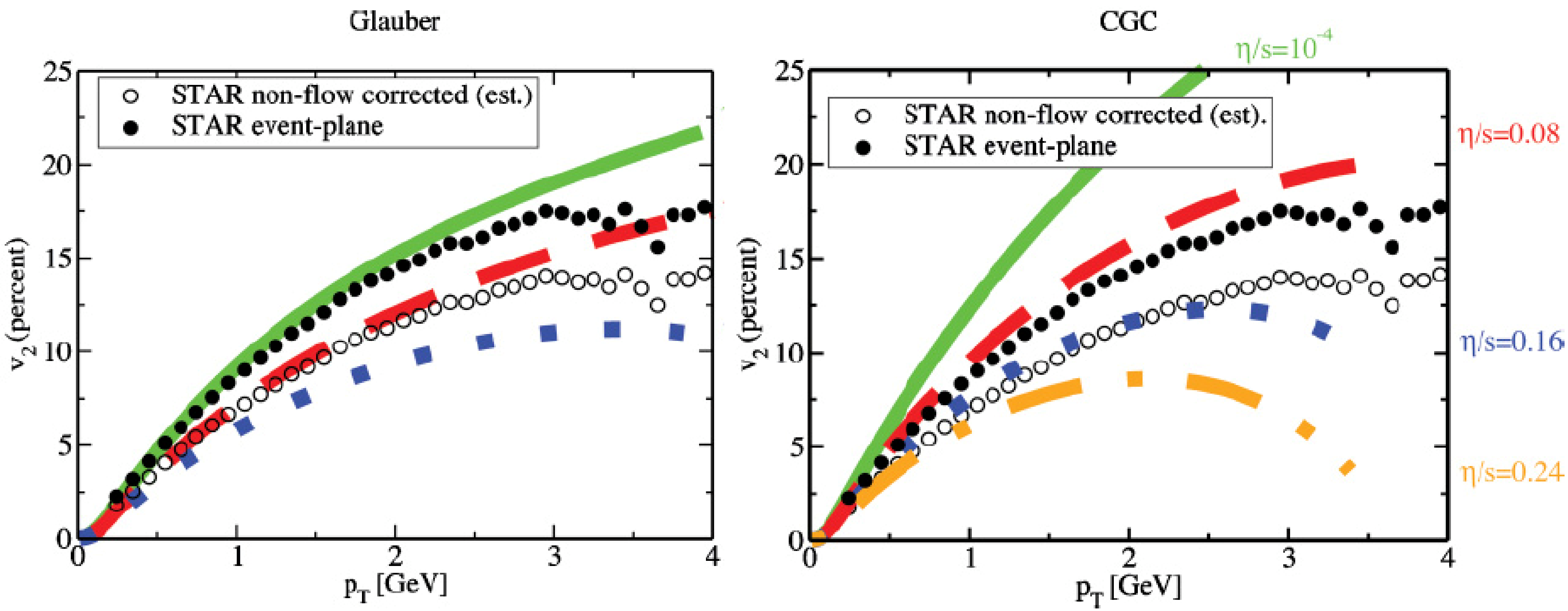
Viscosity via v_2

	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

Viscosity in nuclear collisions - observables

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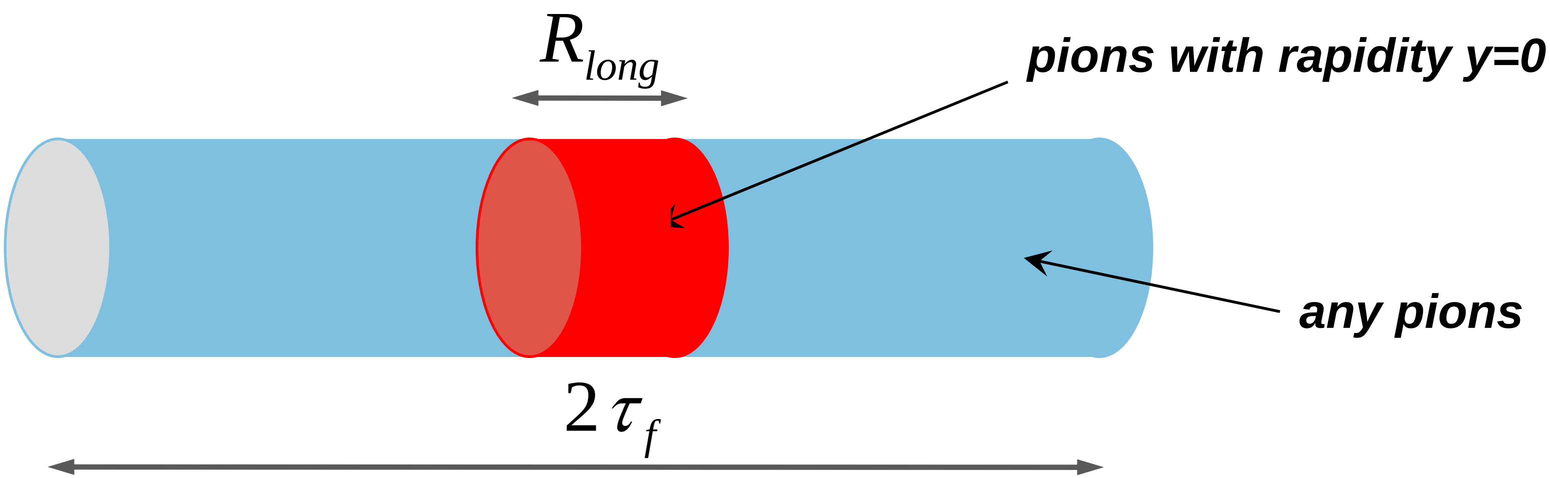
- ***reduced R_{out}***

out-side-long aka Bertsch-Pratt coordinates

G.F. Bertsch, Nucl. Phys. A498, 173c (1989)
S. Pratt, Phys. Rev. D33, 1314 (1986).

- ***R_i (px,py,pz)*** ***size of the region emitting pions with mom. (px,py,pz)***
- ***R_{long}*** ***…parallel to beam***
- ***R_{side}*** ***…perp. to beam and to pair momentum***
- ***R_{out}*** ***…parallel to pair transverse momentum***

R_{long} basics



Makhlin-Sinyukov

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

Herrmann-Bertsch

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

$\tau_f \sim$ ***inverse of the longitudinal Hubble constant***

How finite viscosity affects R_{long}

enhanced transverse expansion

reduced lifetime

reduced longitudinal size at freeze-out

smaller R_{long}

How finite viscosity affects R_{long}

enhanced transverse expansion

reduced lifetime

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

smaller R_{long}

Effect of viscosity on R_{long} quantitatively

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

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

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

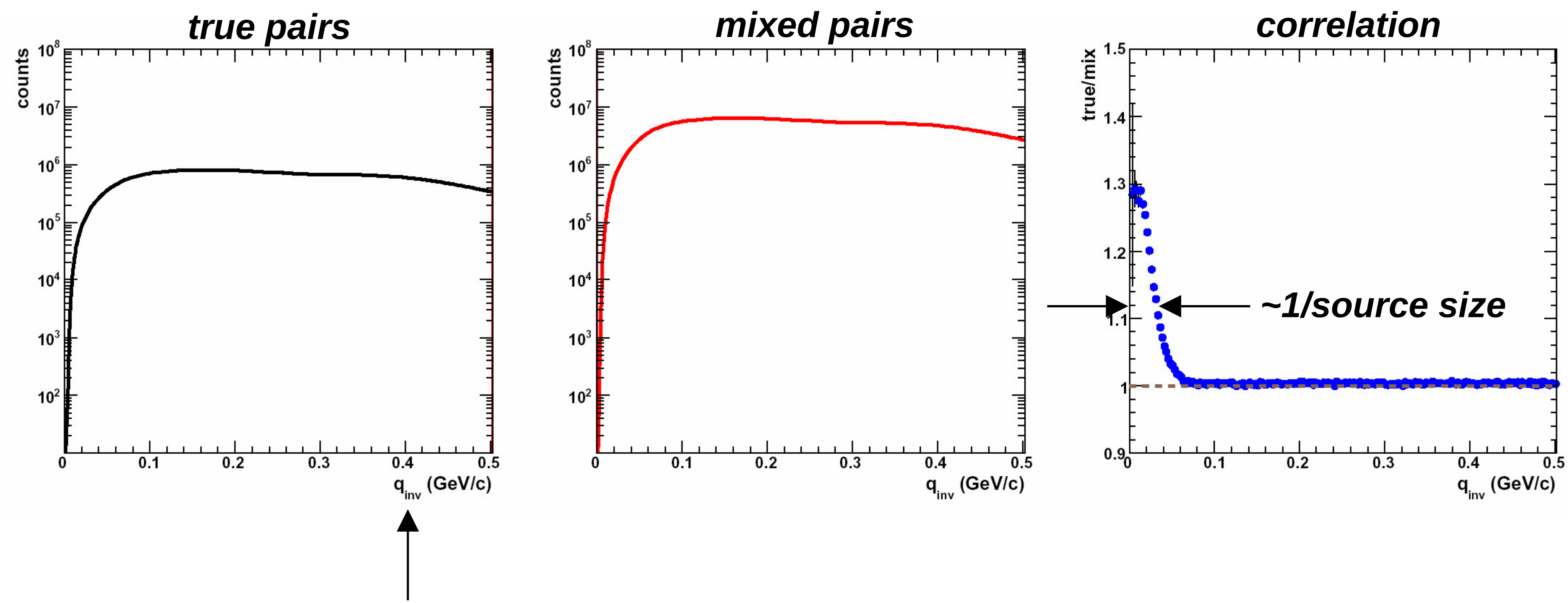
the simplest HBT analysis

D. Antonczyk, thesis intro

- loop over events
- make pi-pi- pairs
- fill a p2-p1 histogram

- mix events
- make pi-pi- pairs
- fill a p2-p1 histogram

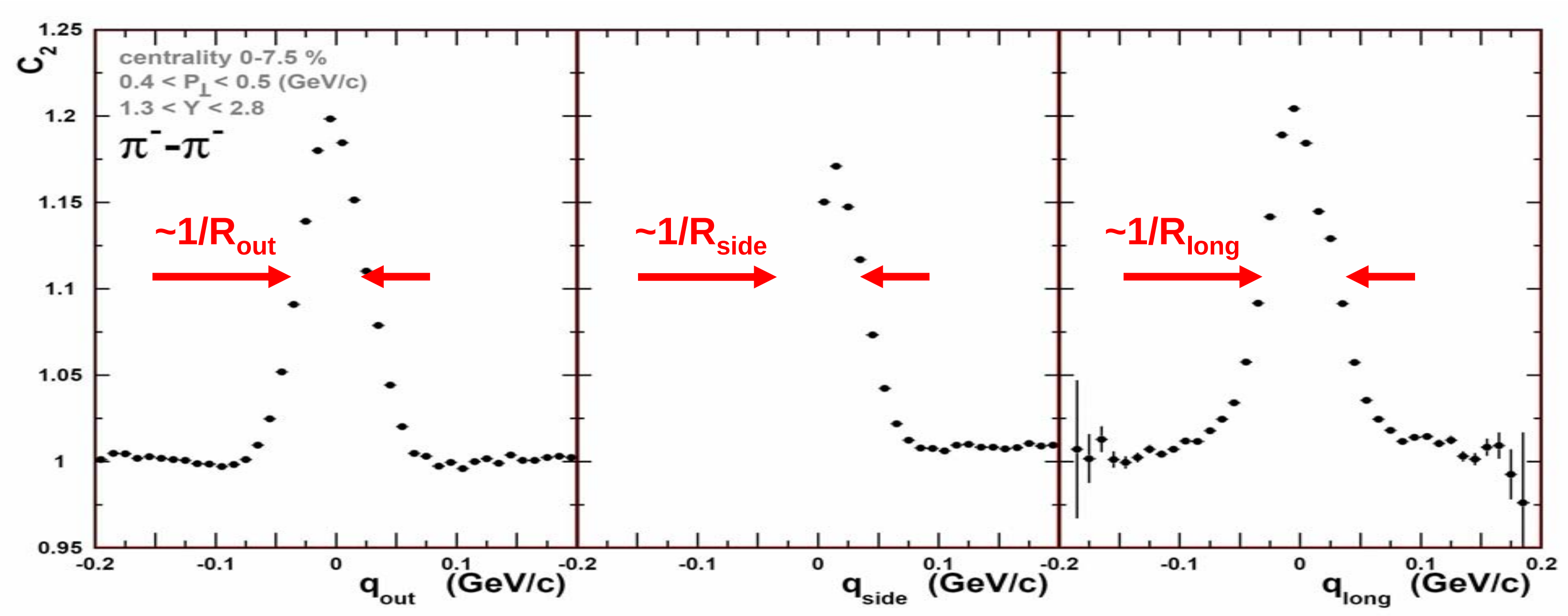
- divide tru/mix



p2-p1 in the pair c.m.

two-pion correlation function

Pb+Au at 158 AGeV ***D. Antonczyk***



fit with $$C_2(q) = 1 + \lambda \exp\left\{ \sum_{i,j} R_{i,j}^2 q_i q_j \right\}$$ *with i,j = out, side, long*

correct for Coulomb and finite momentum resolution

CERES Collaboration

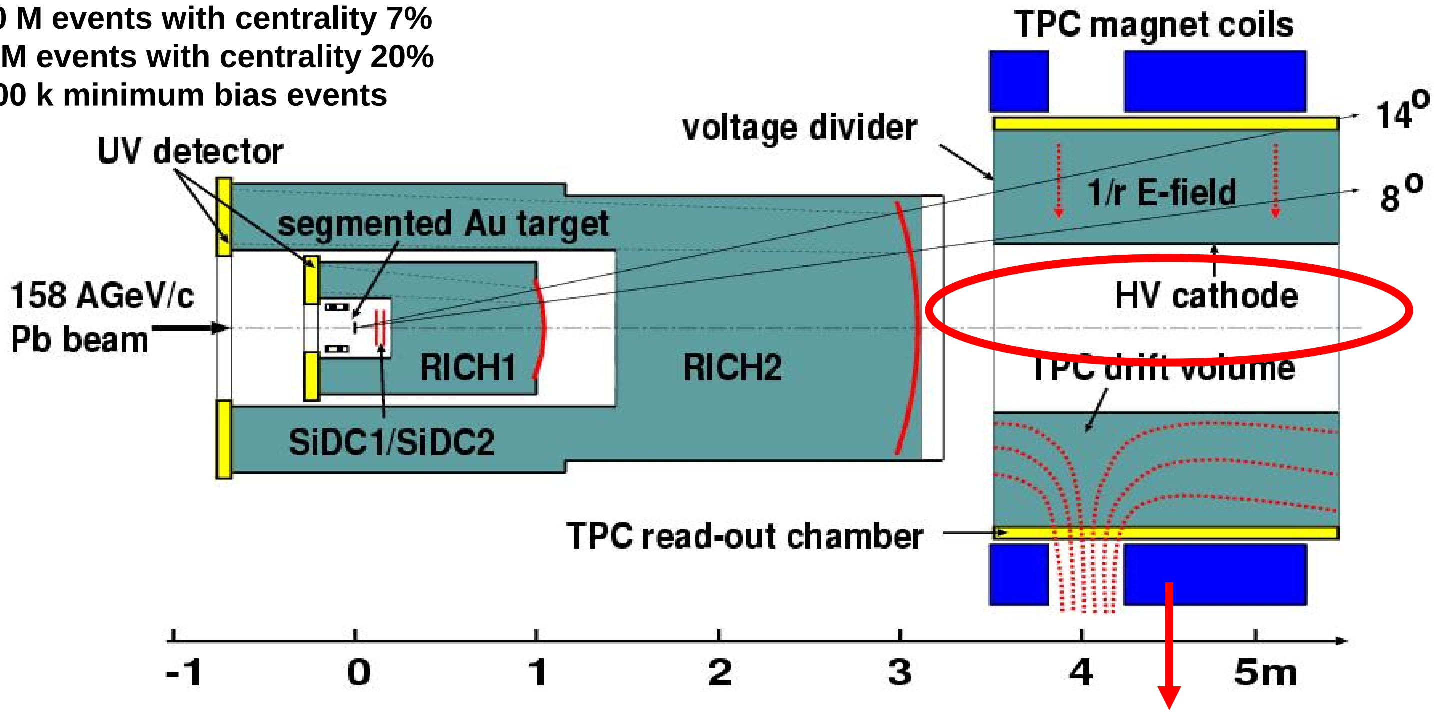
D. Adamova, G. Agakichiev, D. Antonczyk, A. Andronic, H. Appelshäuser, V. Belaga, J. Bielcikova, P. Braun-Munzinger, O. Busch, A. Cherlin, S. Damjanovic, T. Dietel, L. Dietrich, A. Drees, S. Esumi, K. Filimonov, K. Fomenko, Z. Fraenkel, C. Garabatos, P. Glässel, G. Hering, J. Holeczek, M. Kalisky V. Kushpil, B. Lenkeit, W. Ludolphs, A. Maas, A. Marin, J. Milosevic, A. Milov, D. Miskowiec, R. Ortega, Yu. Panebrattsev, O. Petchenova, V. Petracek, A. Pfeiffer, M. Ploskon, S. Radomski, J. Rak, I. Ravinovich, P. Rehak, W. Schmitz, J. Schukraft, H. Sako, S. Shimansky, S. Sedykh, J. Stachel, M. Sumbera, H. Tilsner, I. Tserruya, G. Tsiledakis, T. Wienold, B. Windelband, J.P. Wessels, J.P. Wurm, W. Xie, S. Yurevich, V. Yurevich

CERES run history

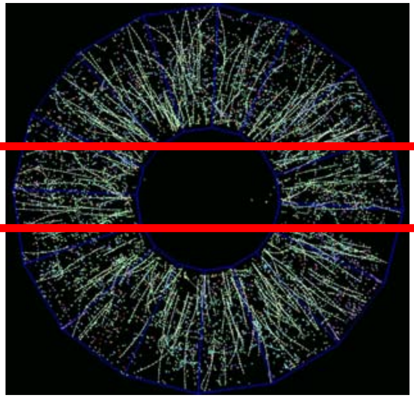
1990	installation	
1991	completed	
1992	200 GeV S+Au	4M central 445 open pairs
1993	450 GeV p+Be 450 GeV p+Au	10M pairs 3M pairs
1995	160 GeV Pb+Au	10M central
1996	160 GeV Pb+Au	50M central 2700 open pairs
1997	upgrade	
1998	upgrade	
1999	40 GeV Pb+Au	10M central 185 open pairs
2000	80 GeV Pb+Au 160 GeV Pb+Au	1M central 30M central

setup with TPC: 1999 and 2000

run 2000: 30 M events with centrality 7%
2 M events with centrality 20%
500 k minimum bias events



radial drift TPC: momentum and energy loss

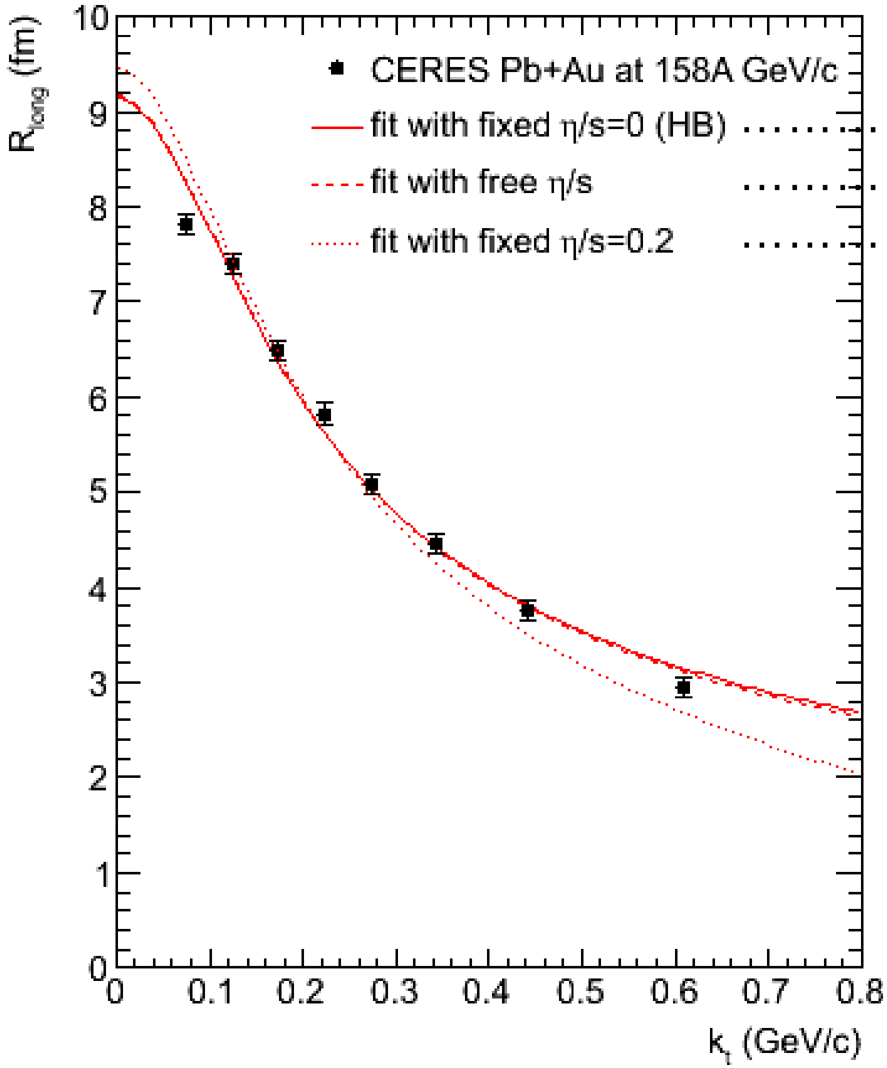


$\Delta p/p = 2\% \oplus 1\% * p/GeV$

$\Delta m/m$ = 3.8 % for ϕ

$\Delta(dE/dx)/(dE/dx)$ = 10%

Viscosity via R_{long} – fit to CERES π−π− data



τ_f = 6.3 fm

τ_f = 6.5 fm   η/s = 0.02

τ_f = 8.0 fm

T = 120 MeV (fixed)

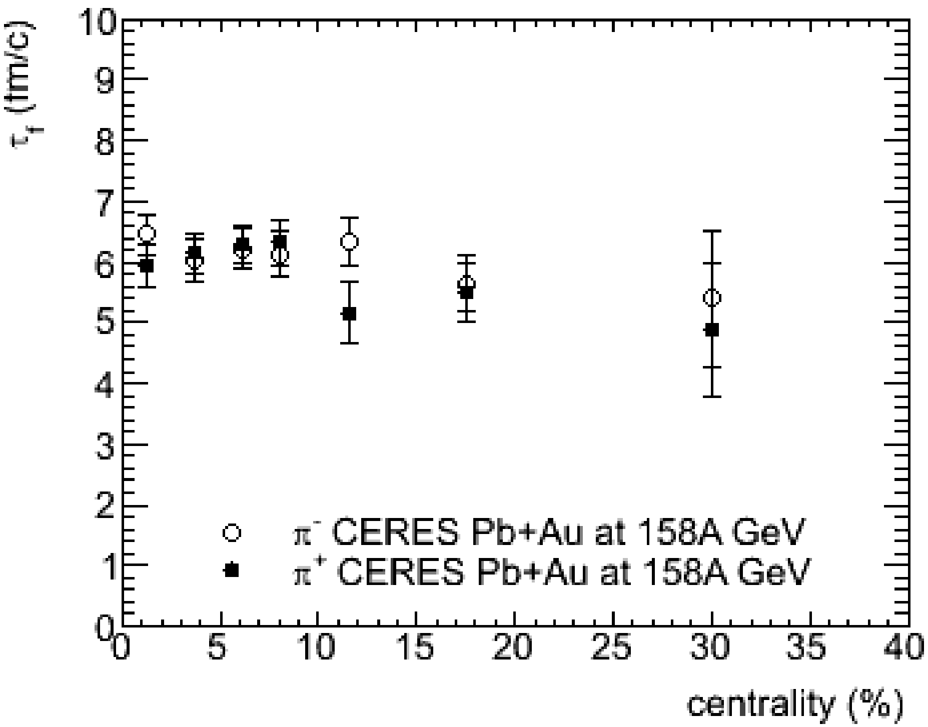
fit function:

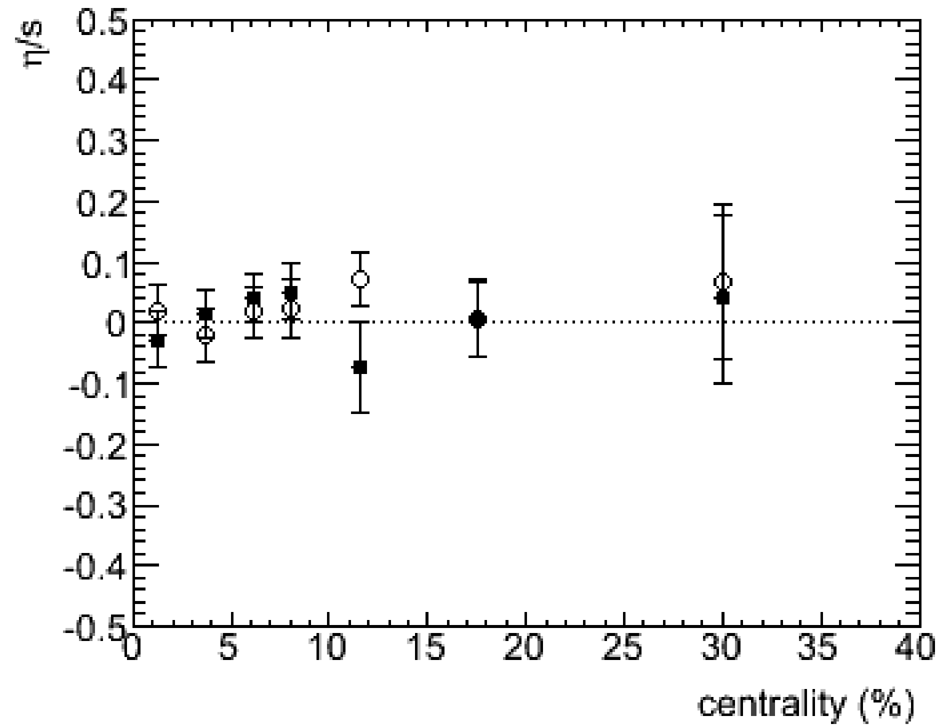
Herrmann-Bertsch with viscous correction

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

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

Viscosity via R_{long} – fit to CERES data

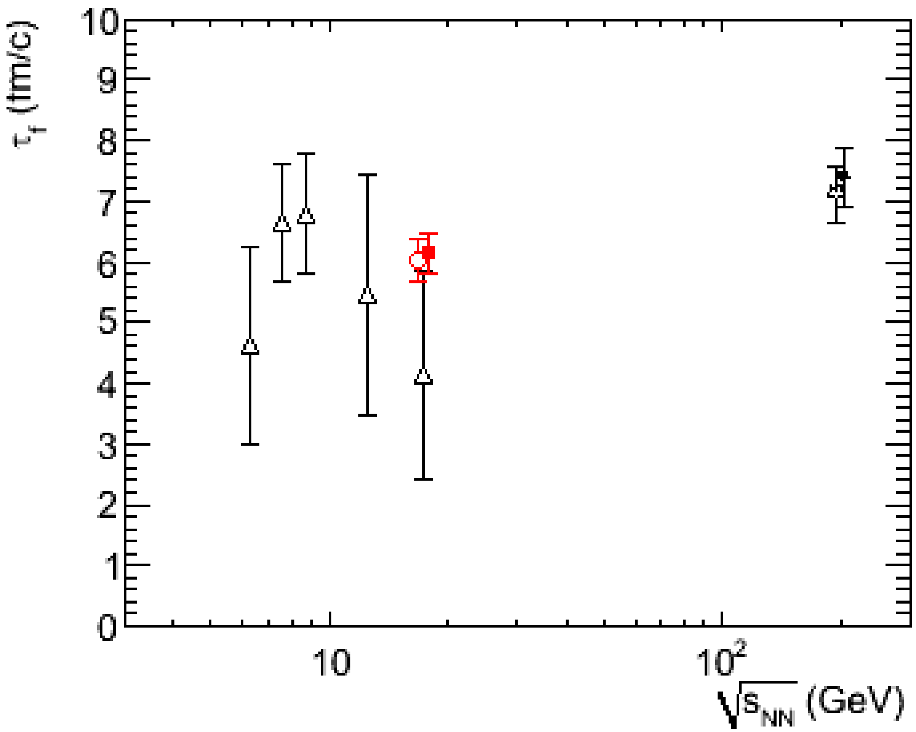


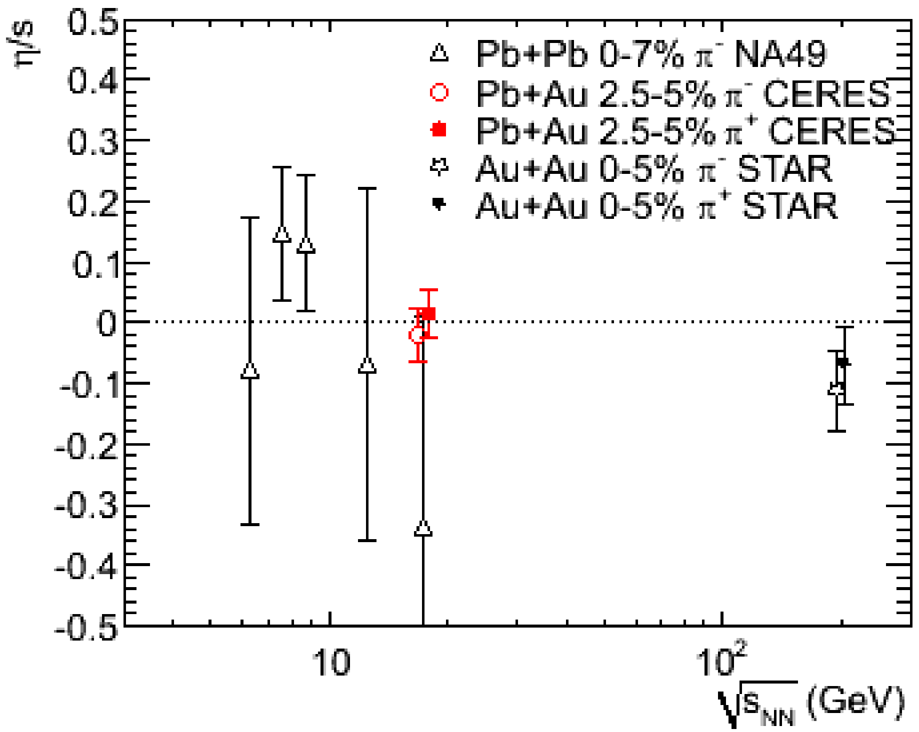


η/s is small for both charges and all centralities

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
Phys. Rev. Lett. 103, 172501 (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 η/s=0.16

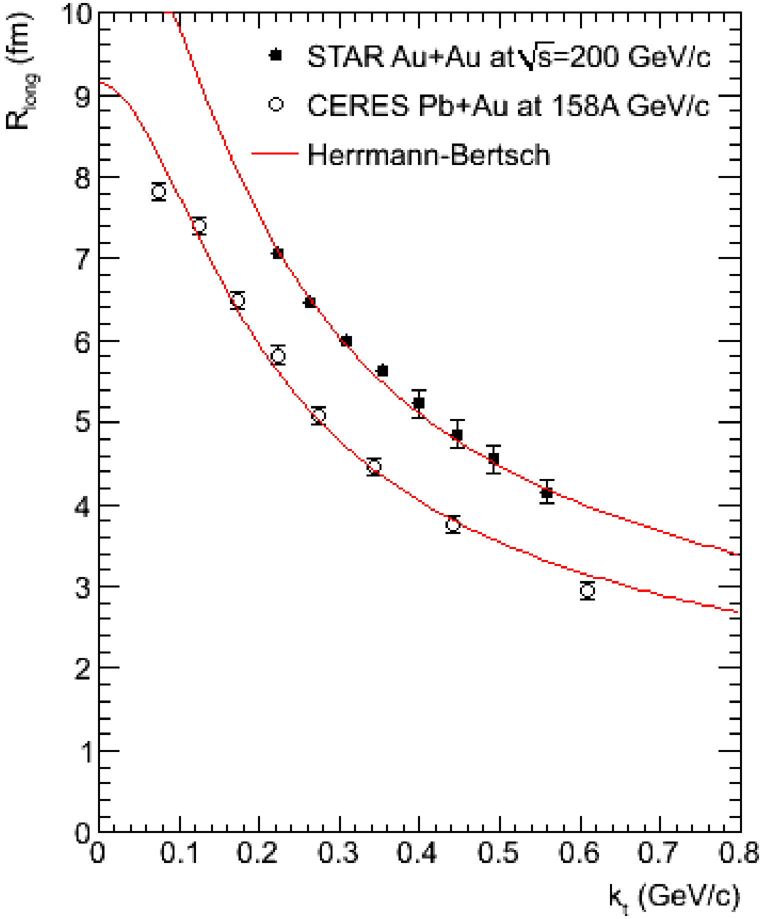
  → Song/Heinz get opposite modification of p_t spectra

- ***last but not least:***

  my mistake when interpreting STAR data (m_t vs k_t)

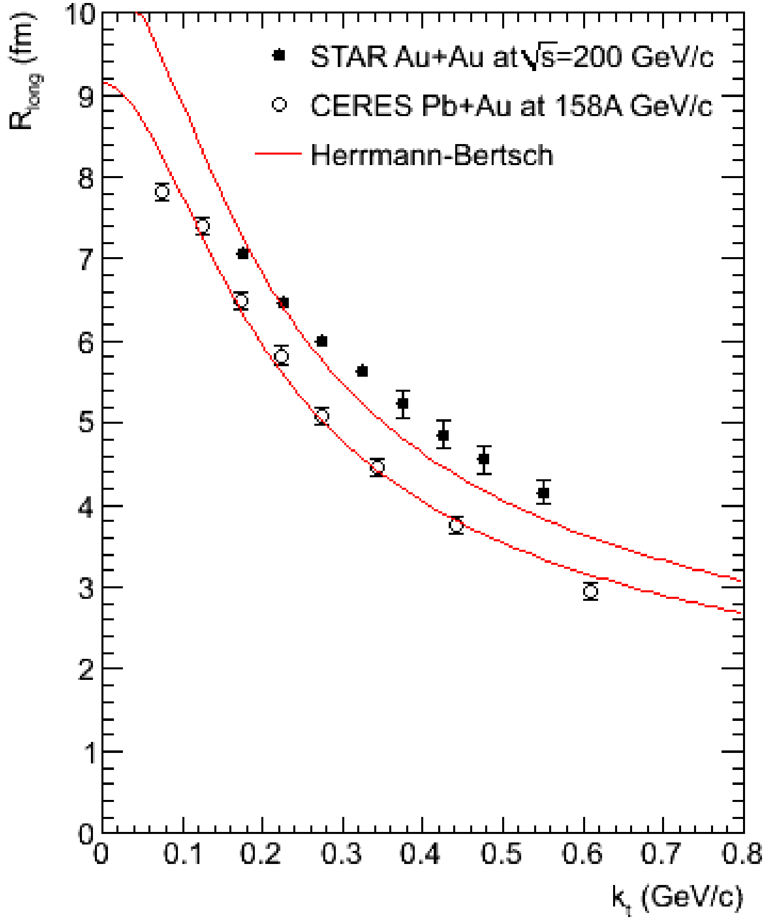
mistake when interpreting STAR data (m_t vs k_t)

STAR points misplaced



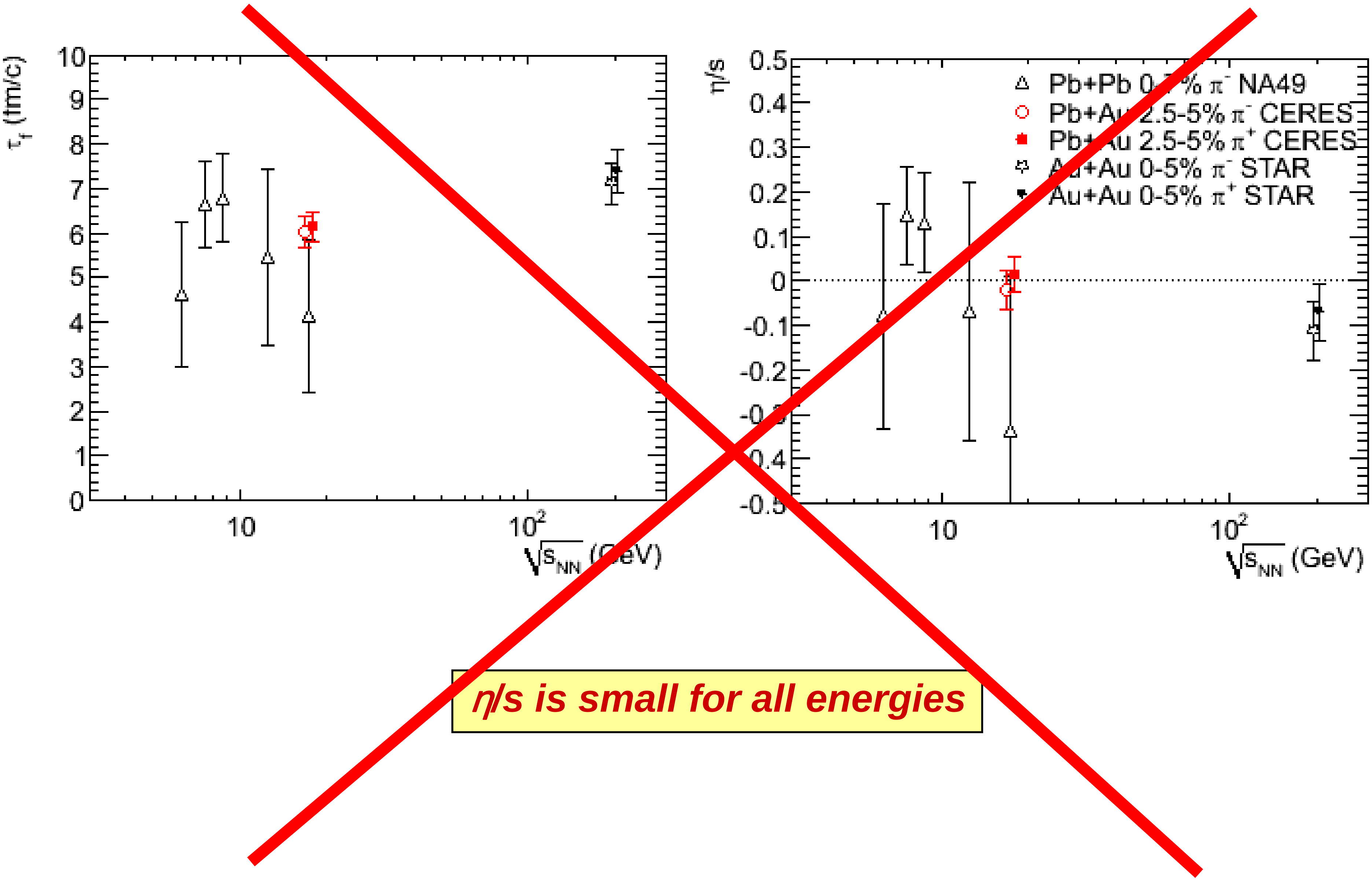
$$R_{long} = \tau_f \sqrt{\frac{T}{m_t} \frac{K_2(m_t/T)}{K_1(m_t/T)}}$$

STAR points placed correctly



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

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



η/s is small for all energies

This is not the way to get η/s quantitatively.

Can HBT radii provide some info on η/s at least qualitatively?

Viscosity in nuclear collisions - observables

finite viscosity reduces velocity gradients

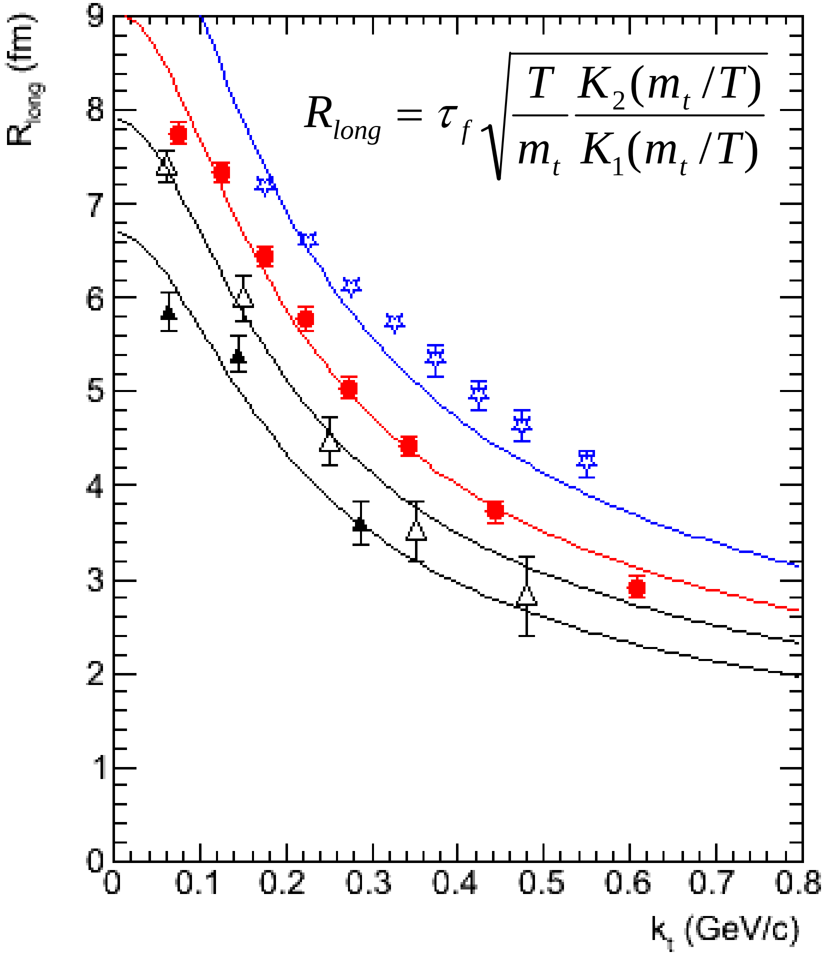
less in-plane, more out-of-plane expansion

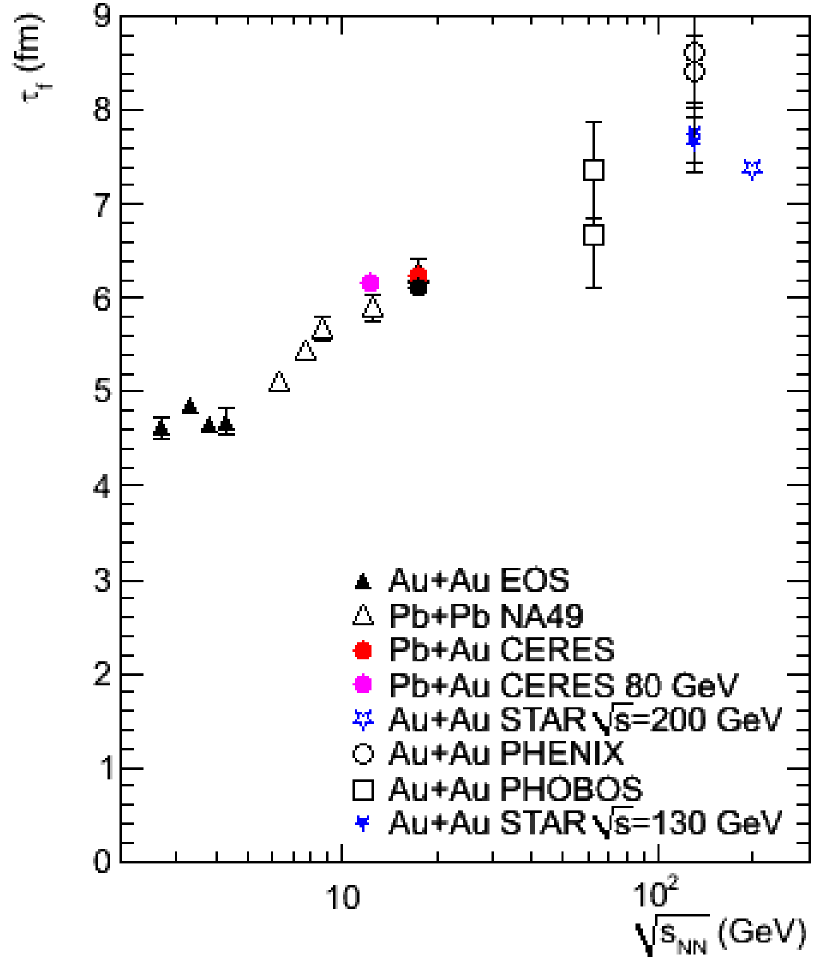
- *reduced v_2*

less longitudinal, more transverse expansion

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

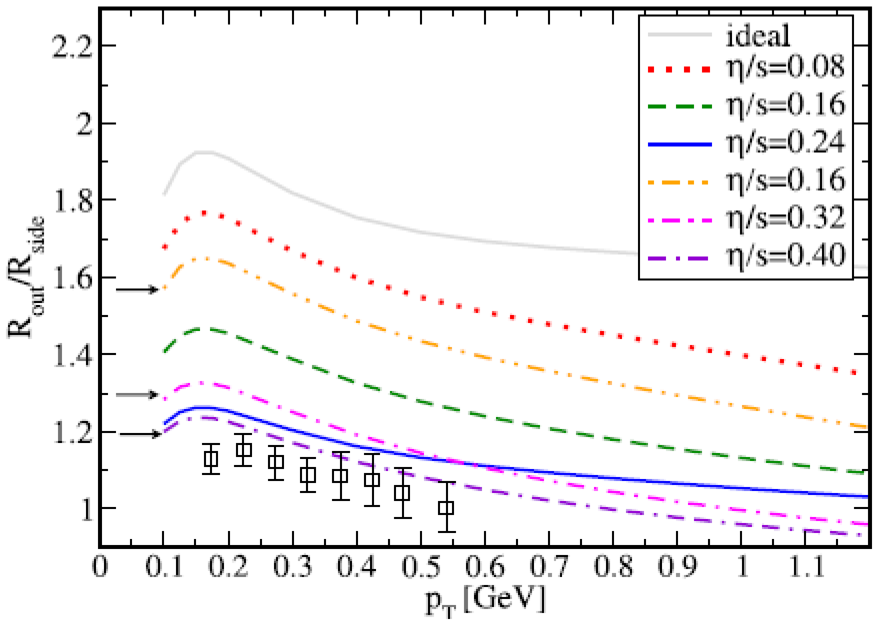
R_{long} corrected by $(A/197)^{1/3}$ and for centrality

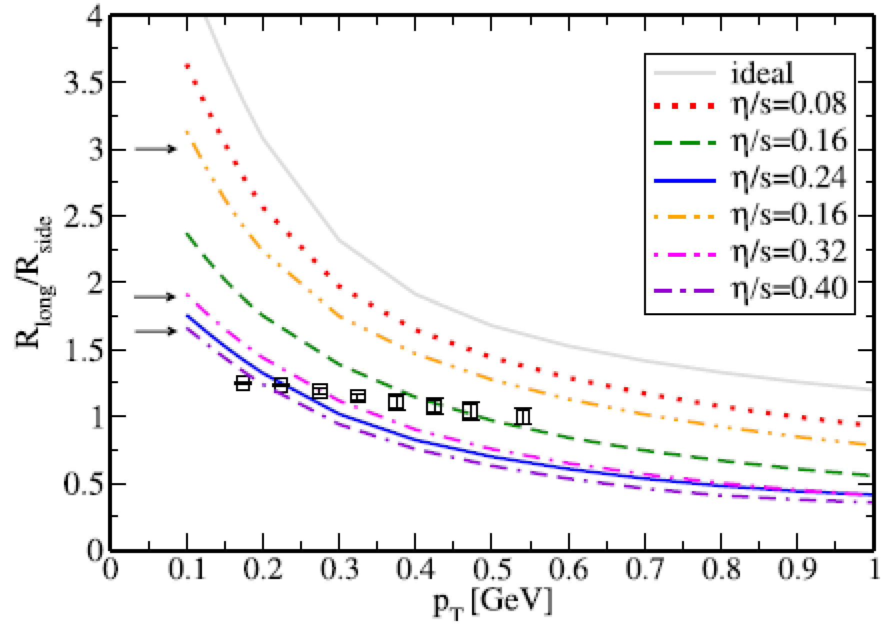




Viscosity via R_{out}/R_{side} and R_{long}/R_{side} ratios

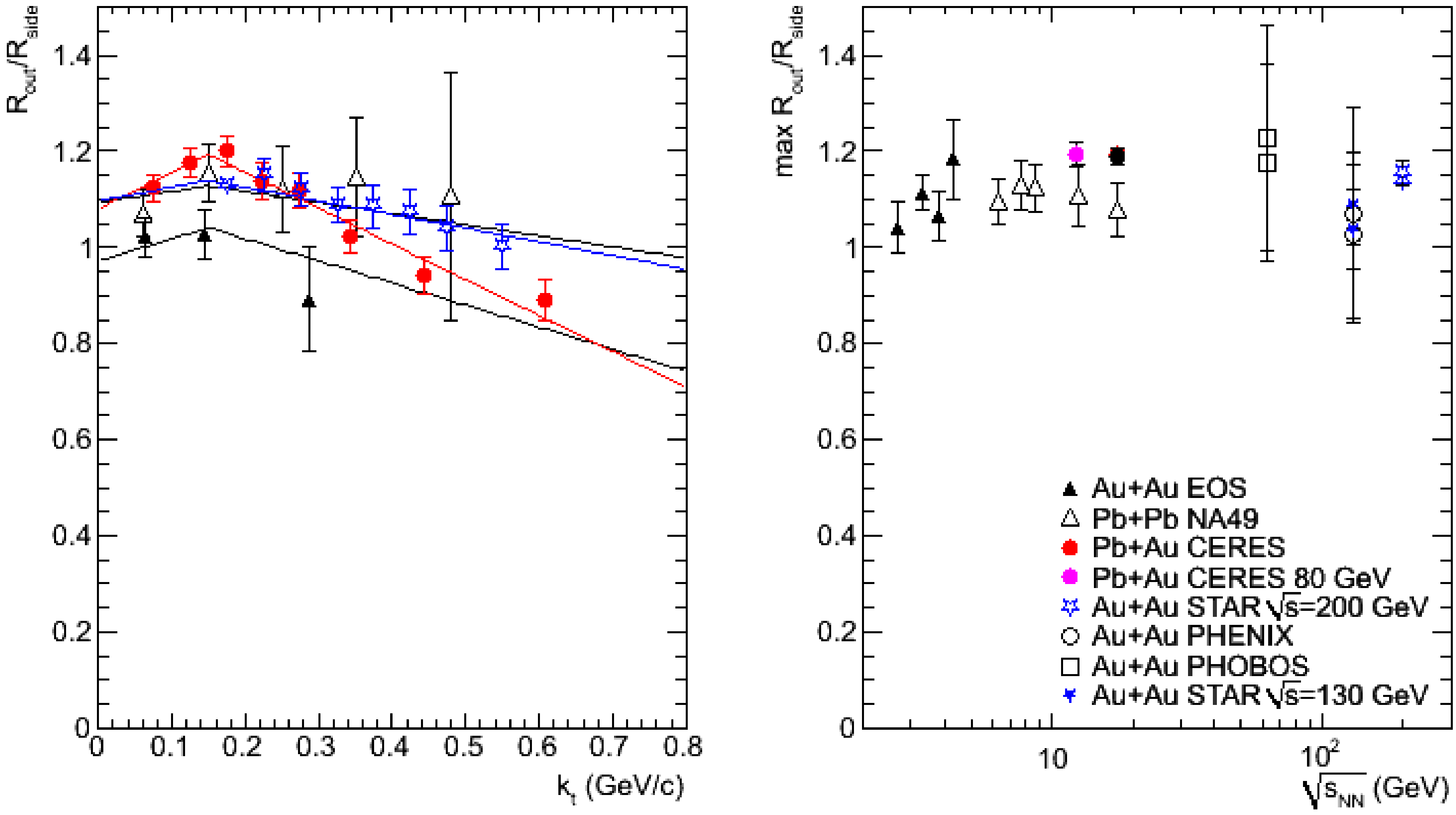
P. Romatschke, Eur. Phys. J C 52 (2007) 203





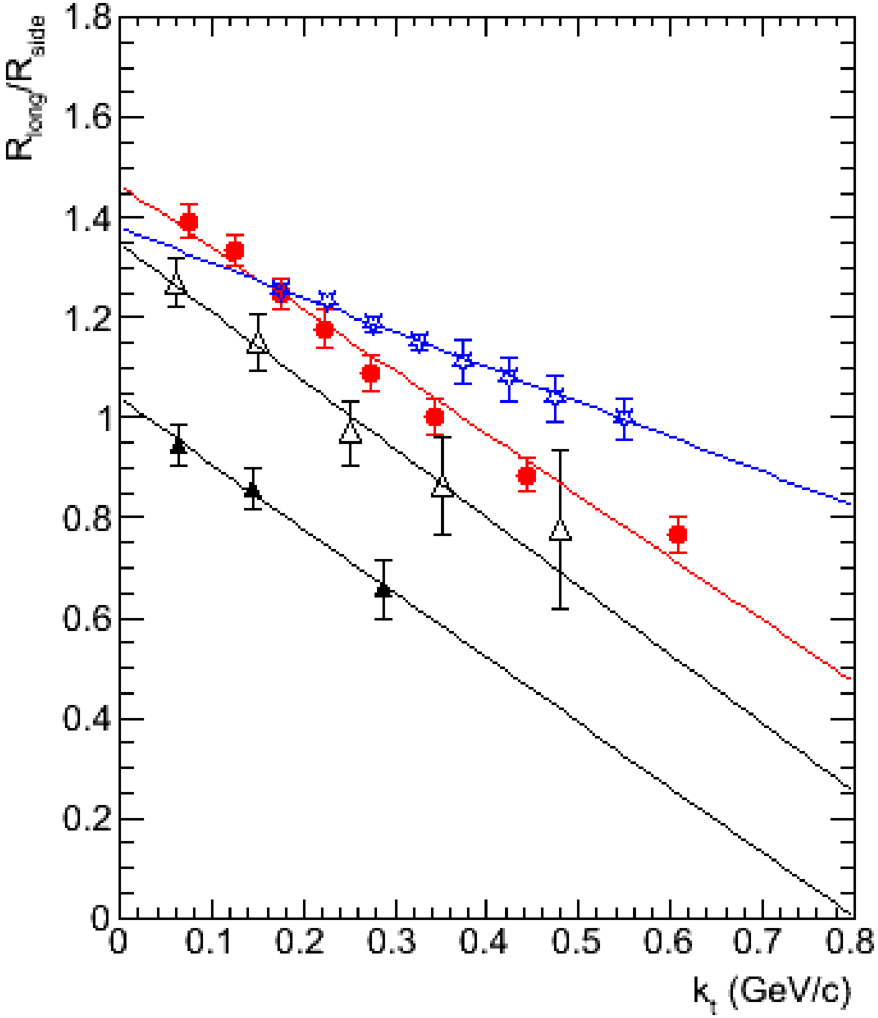
R_{out}/R_{side} and R_{long}/R_{side} ratios are sensitive to viscosity

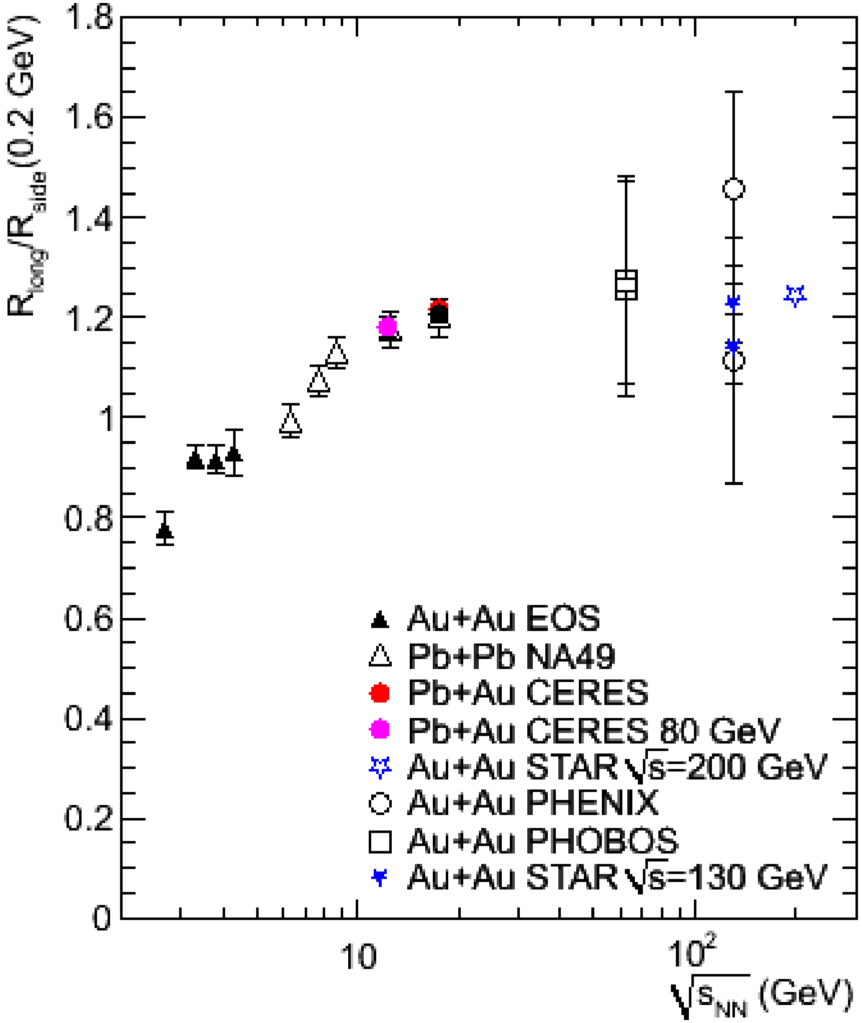
R_{out}/R_{side} systematics



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

R_{long}/R_{side}

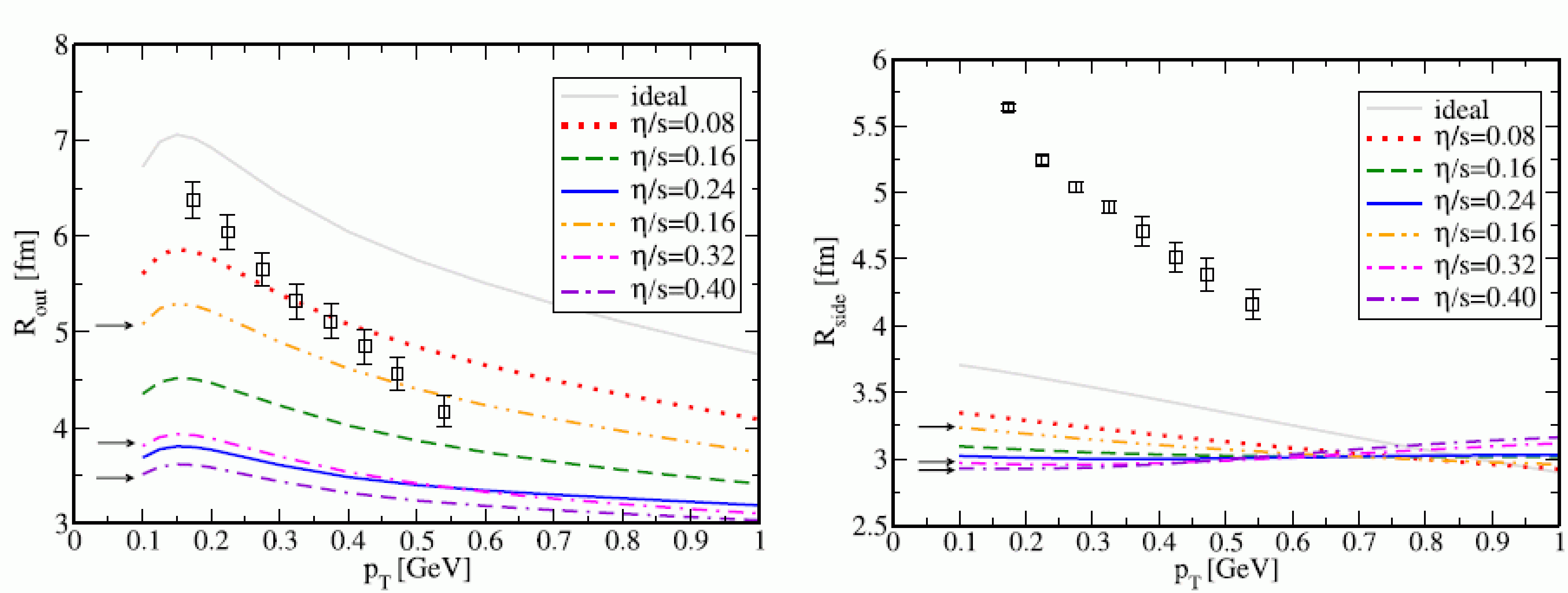




R_{long}/R_{side} ratio is constant from top SPS to RHIC

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

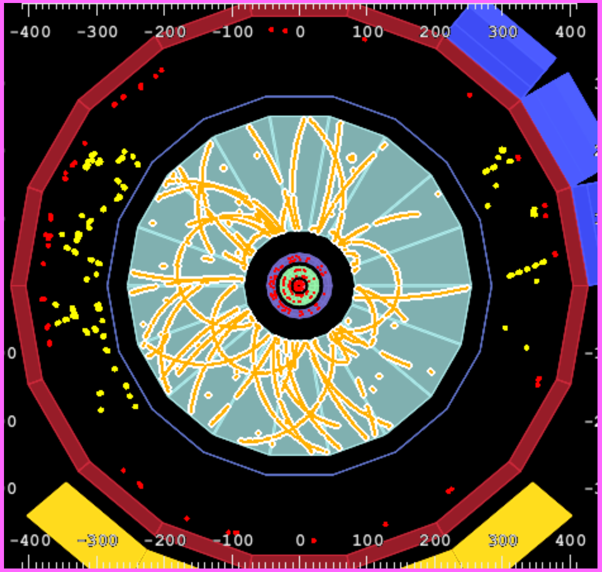
Qualitatively:

no indication of RHIC viscosity being lower than at SPS

summary

- one cannot extract viscosity from a simple fit to $R_{long}(kt)$
- however, the conclusion seems to hold:
  no indication of increasing viscosity
  when going from RHIC down to SPS

two-pion correlations in pp at sqrt(s) = 900 GeV from ALICE



ALICE femtoscopy analysis

- ***ALICE femtoscopy group chaired by Adam Kisiel***

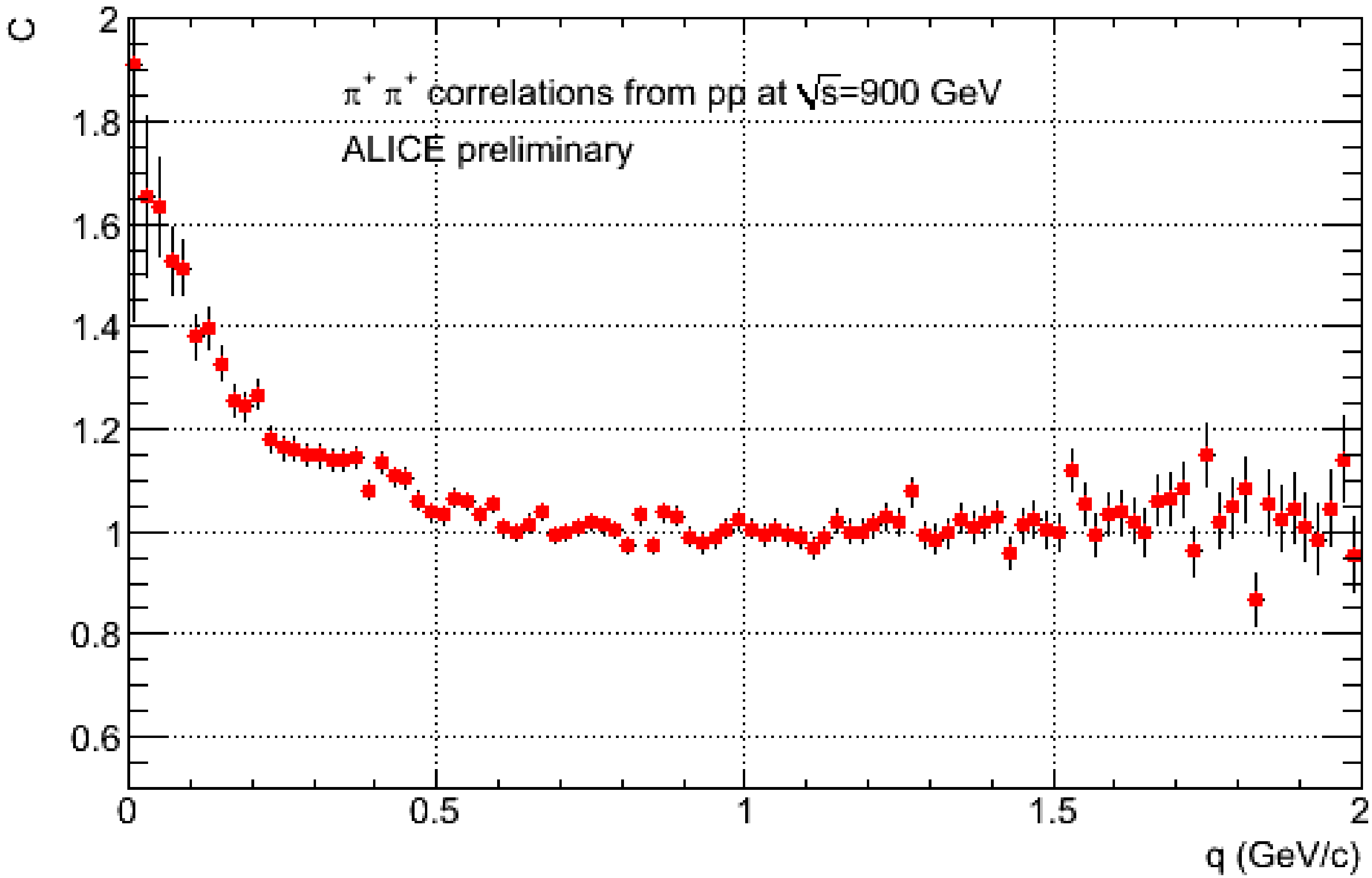
two analysis packages:

- ***AliFemto (EOS → STAR → ALICE)***
- ***UNICOR (E877 → CERES → ALICE)***

} ***good agreement***

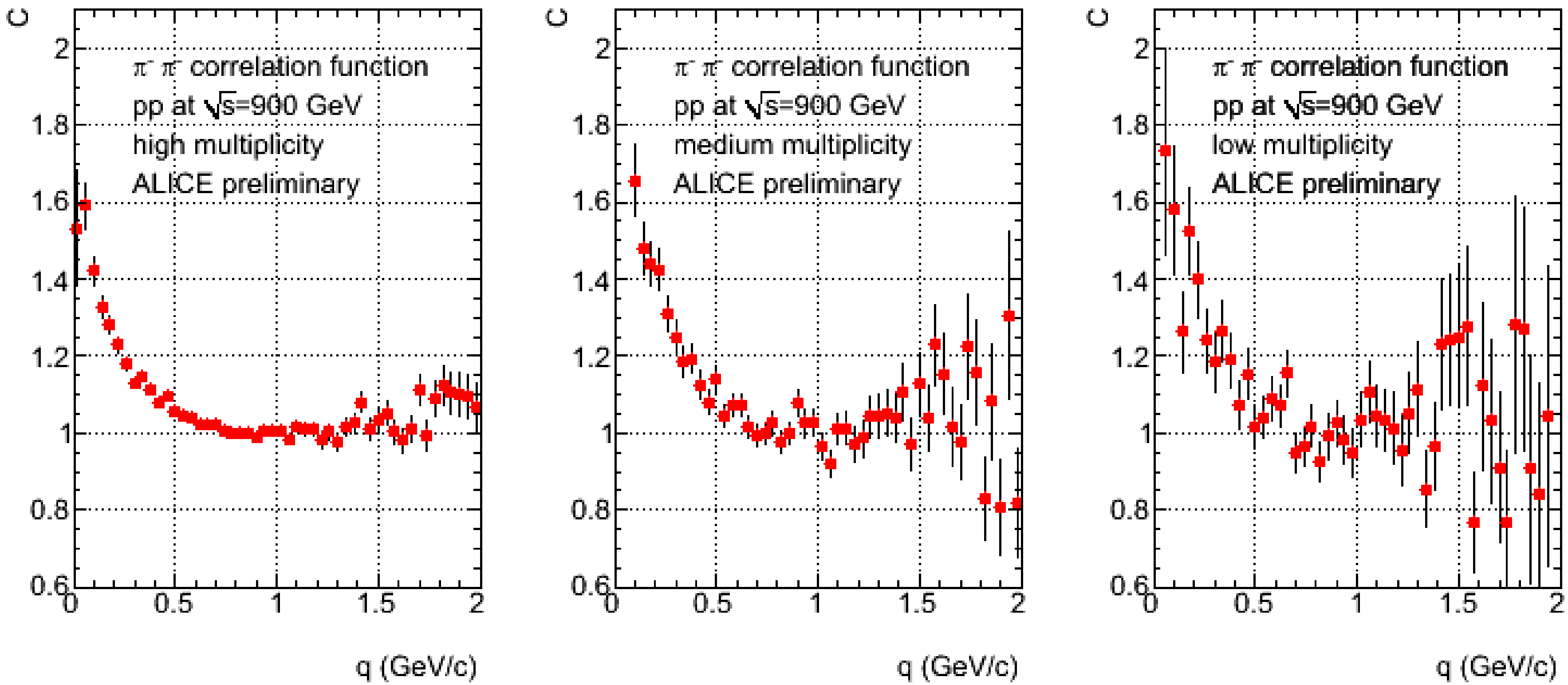
- ***the following correlation functions were obtained using UNICOR***

two-pion correlation function measured by ALICE



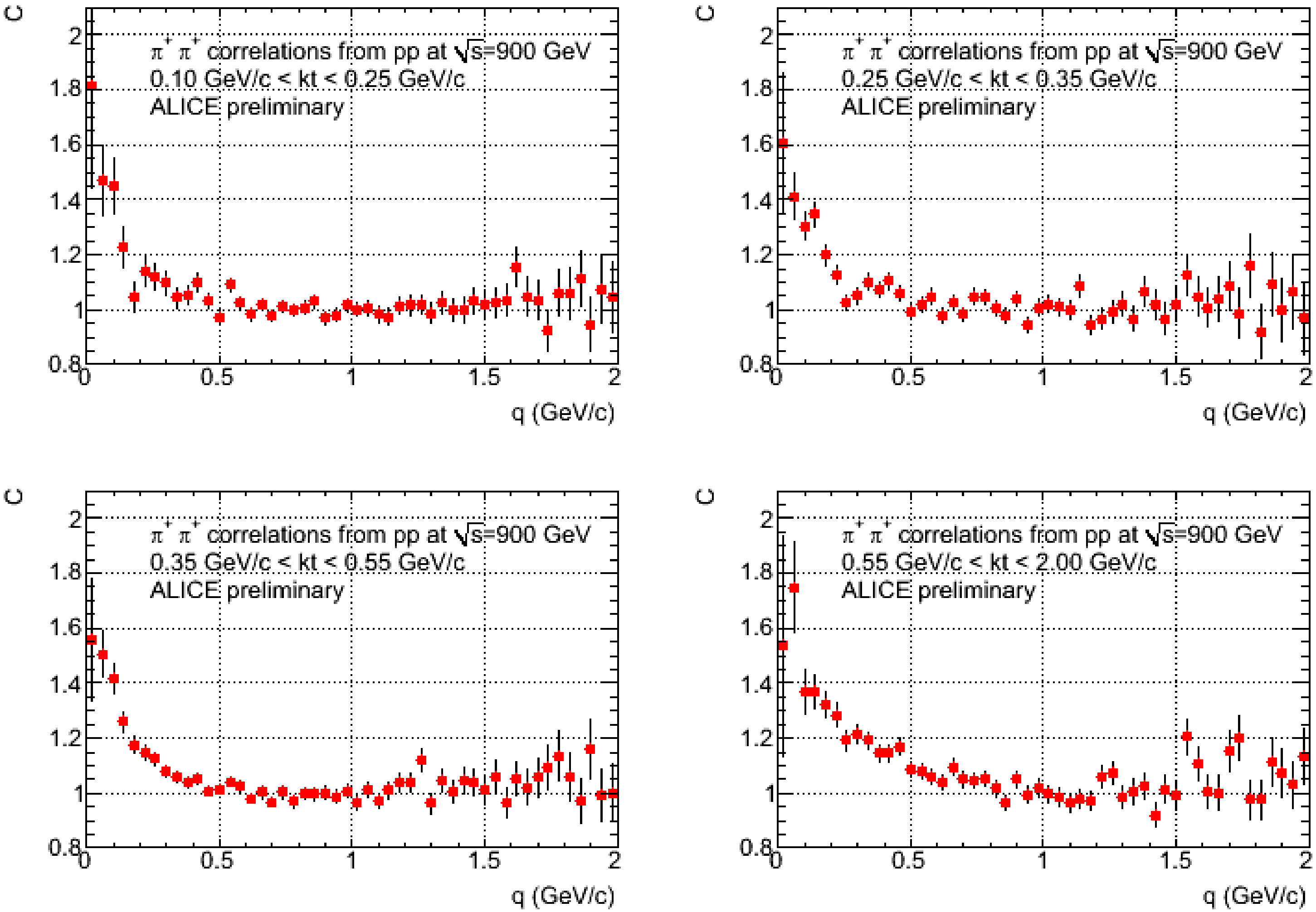
runs taken between 6th and 12th of December
results presented on December 15th

multiplicity dependence of two-pion correlations



→ *weak dependence on multiplicity*

transverse momentum dependence of two-pion orrelations

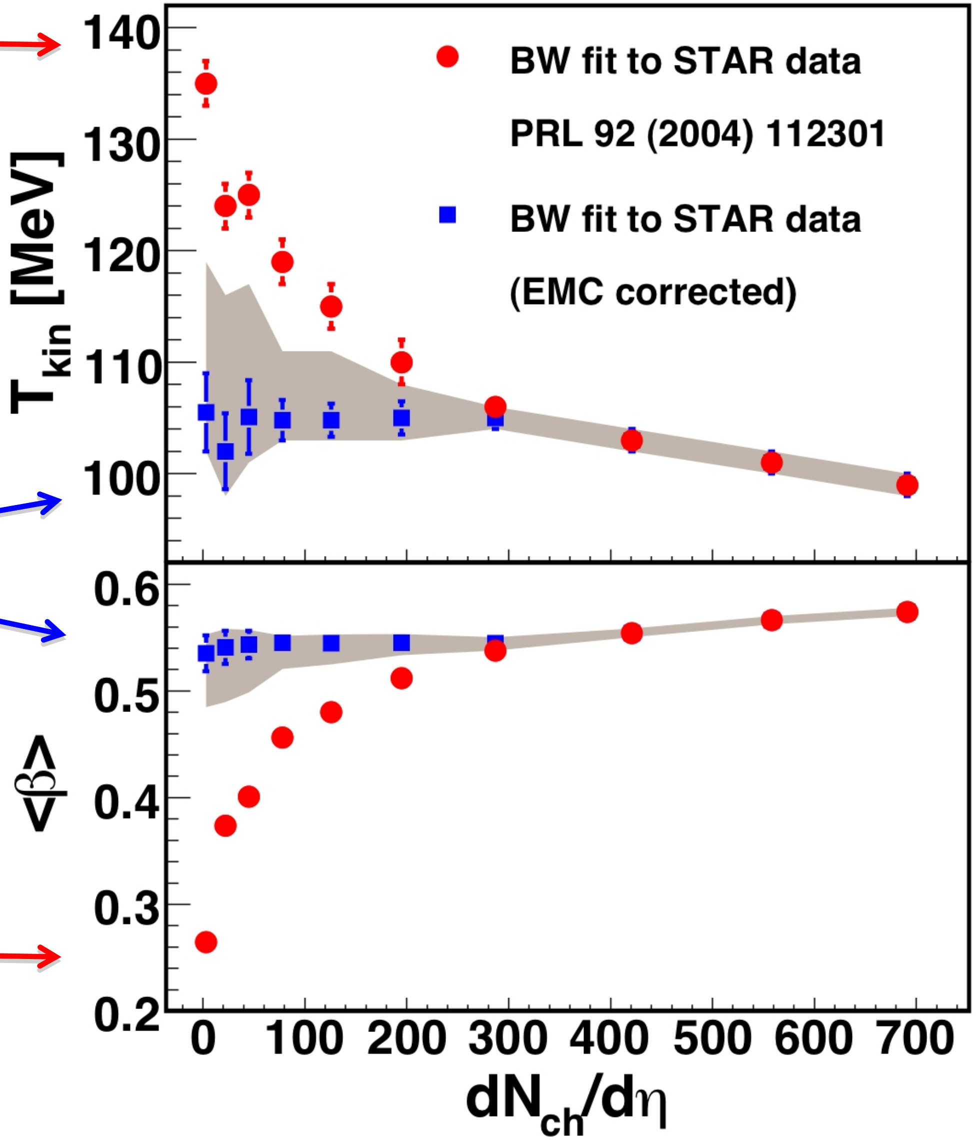


→ visible dependence on p_t – flow in pp?

"raw" (ignoring EMCICs)

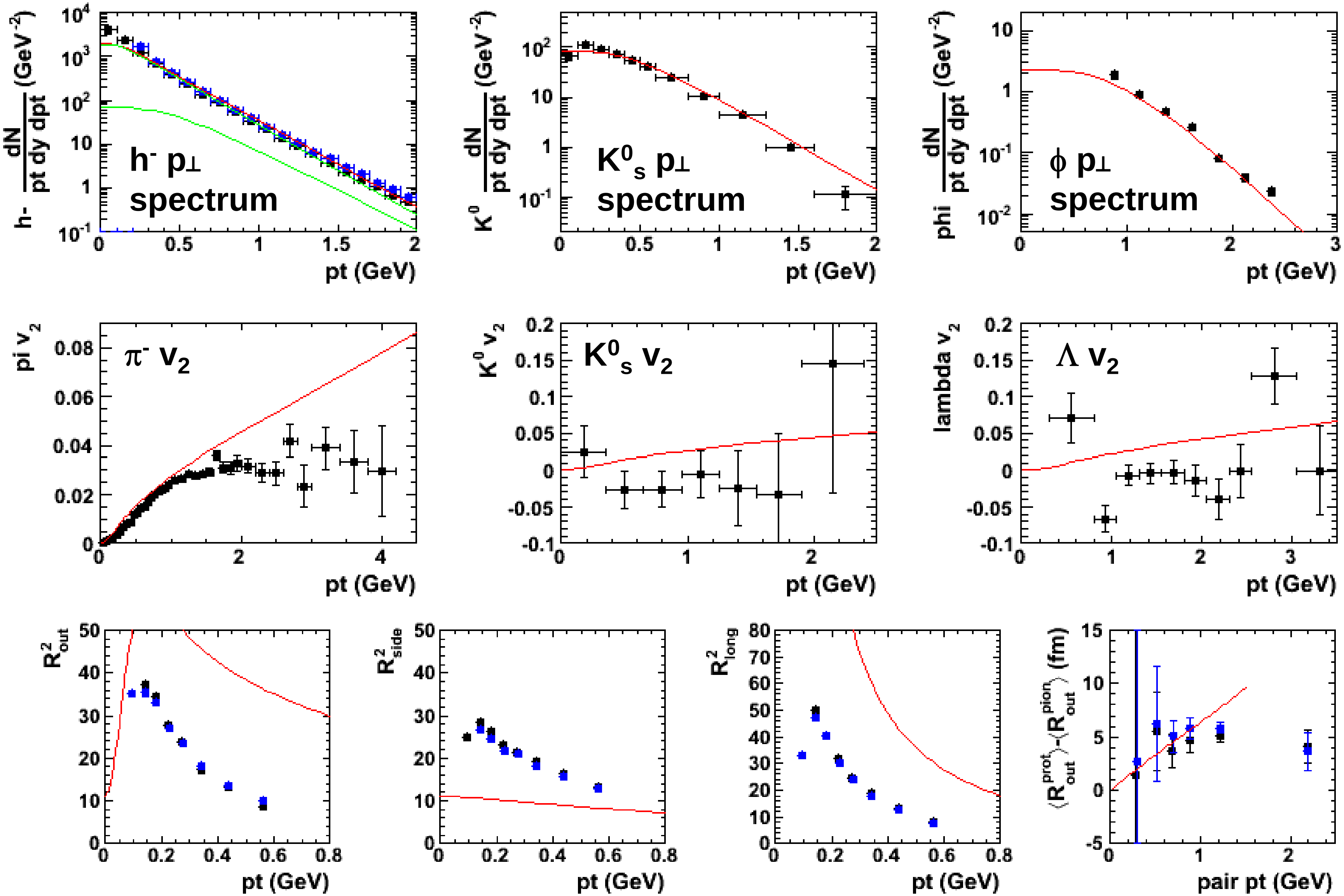
EMCICs **free adjusted**
to spectra & fit to spectra

"raw" (ignoring EMCICs)



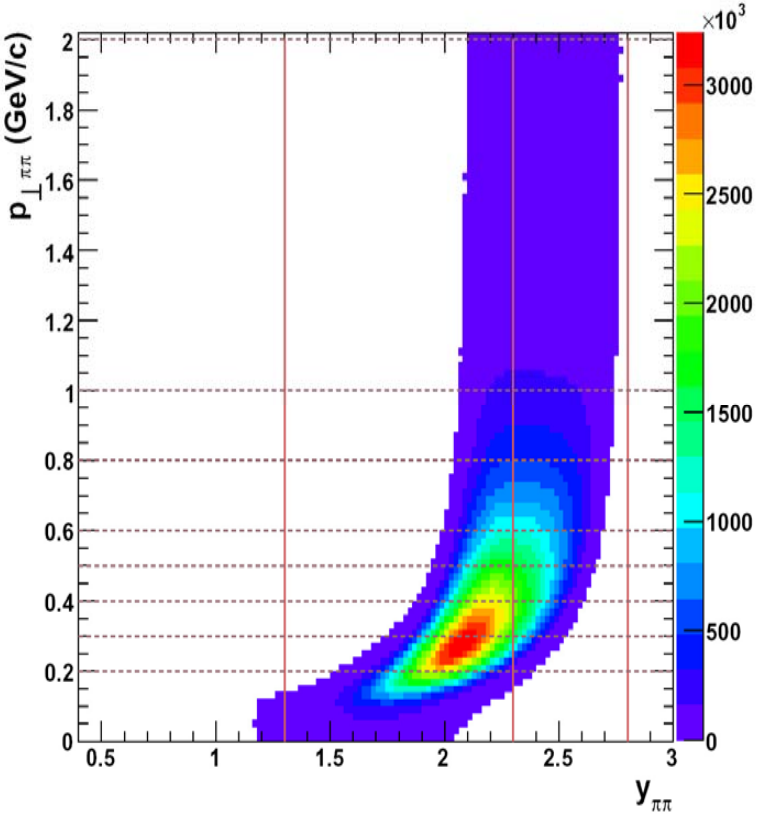
BACKUP

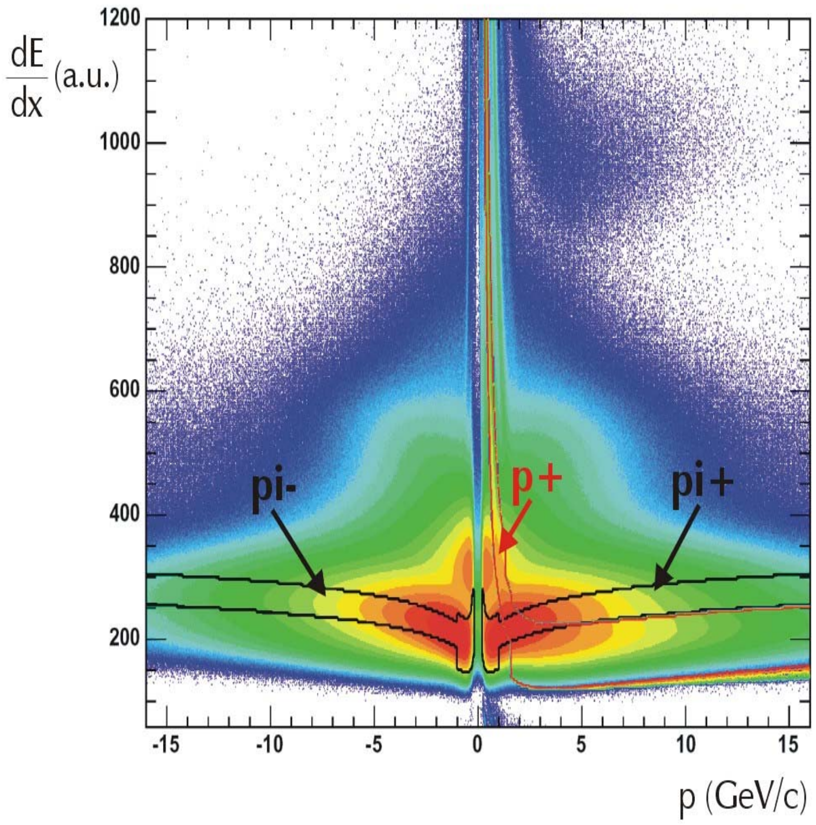
CERES (points) and hydro T=120 MeV (lines)



CERES acceptance and particle id

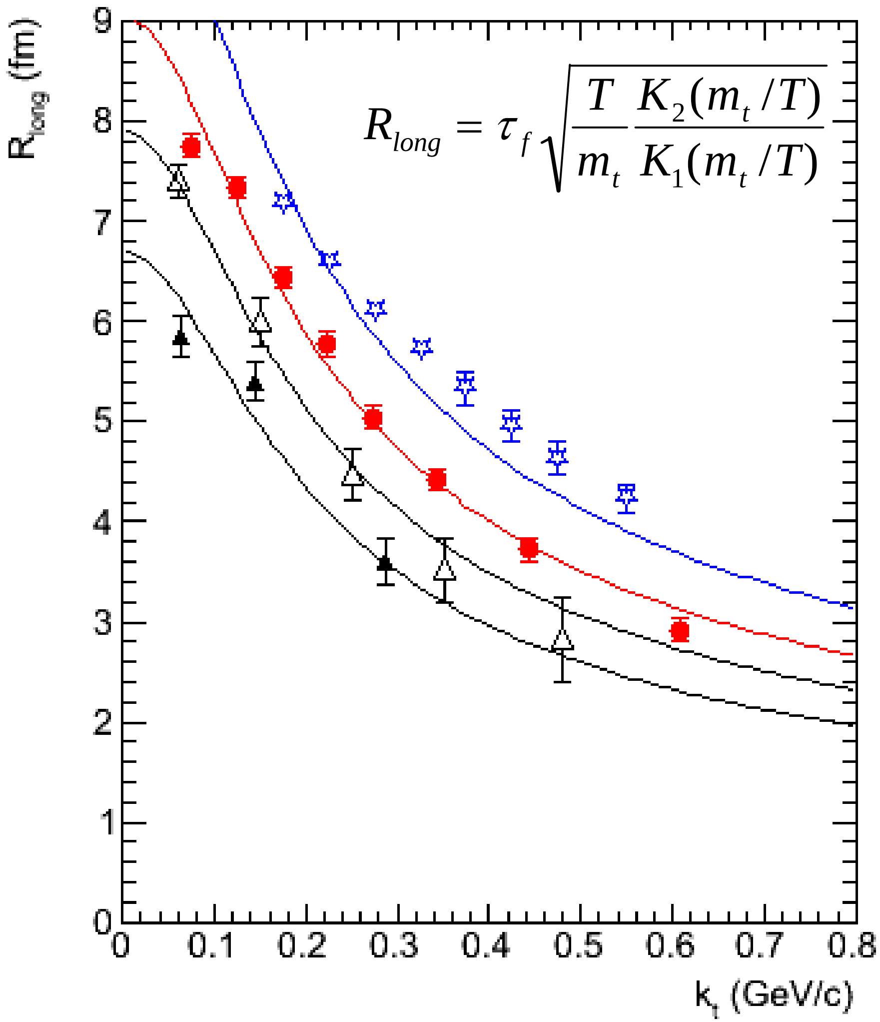
Pb+Au at 158 AGeV

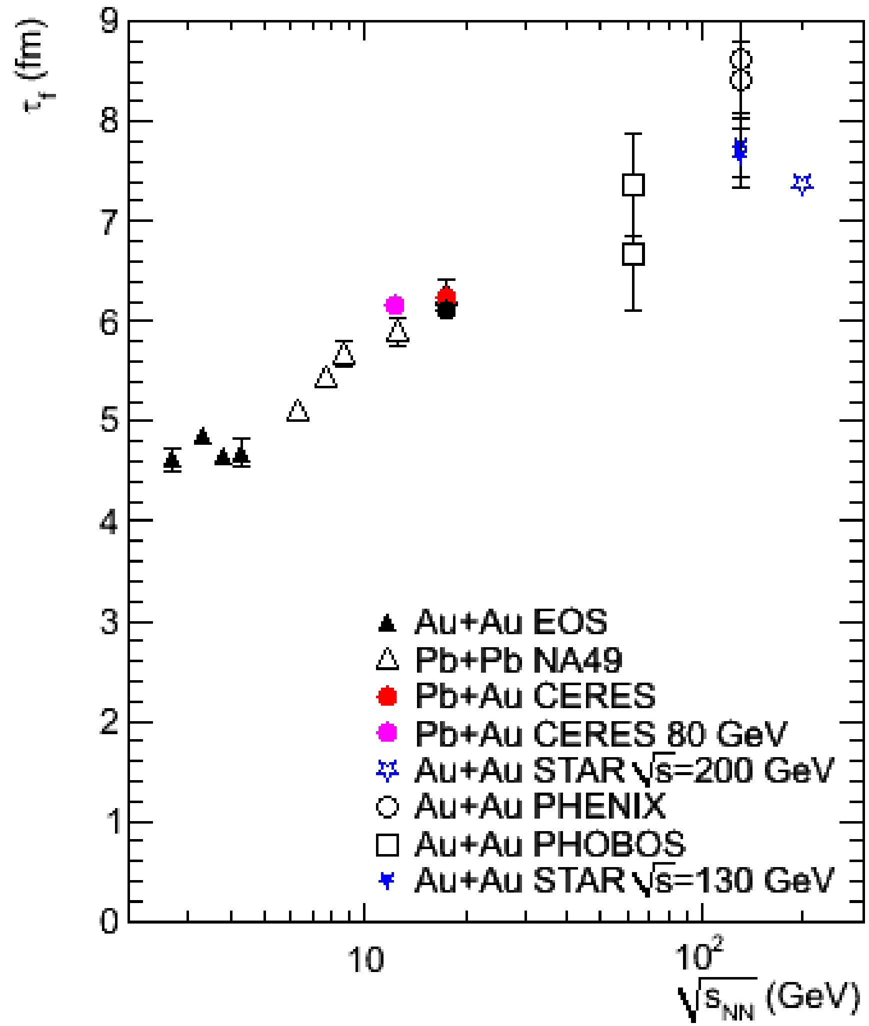




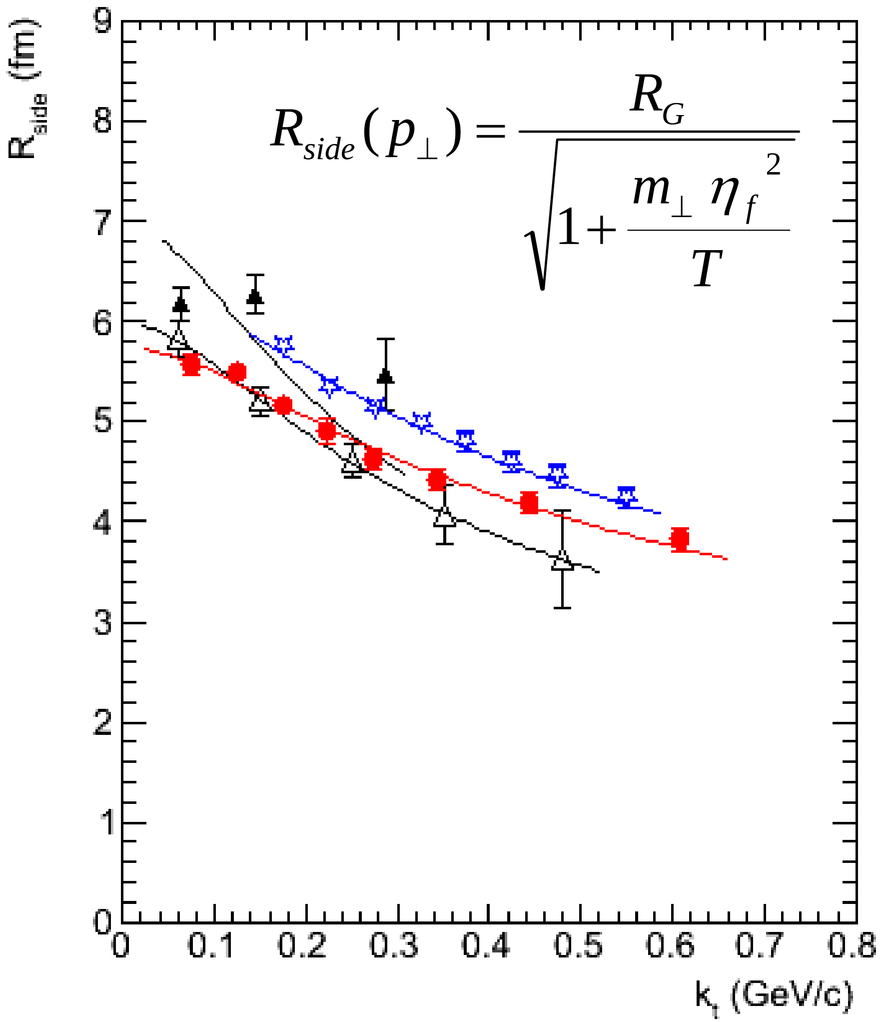
midrapidity: y=2.91

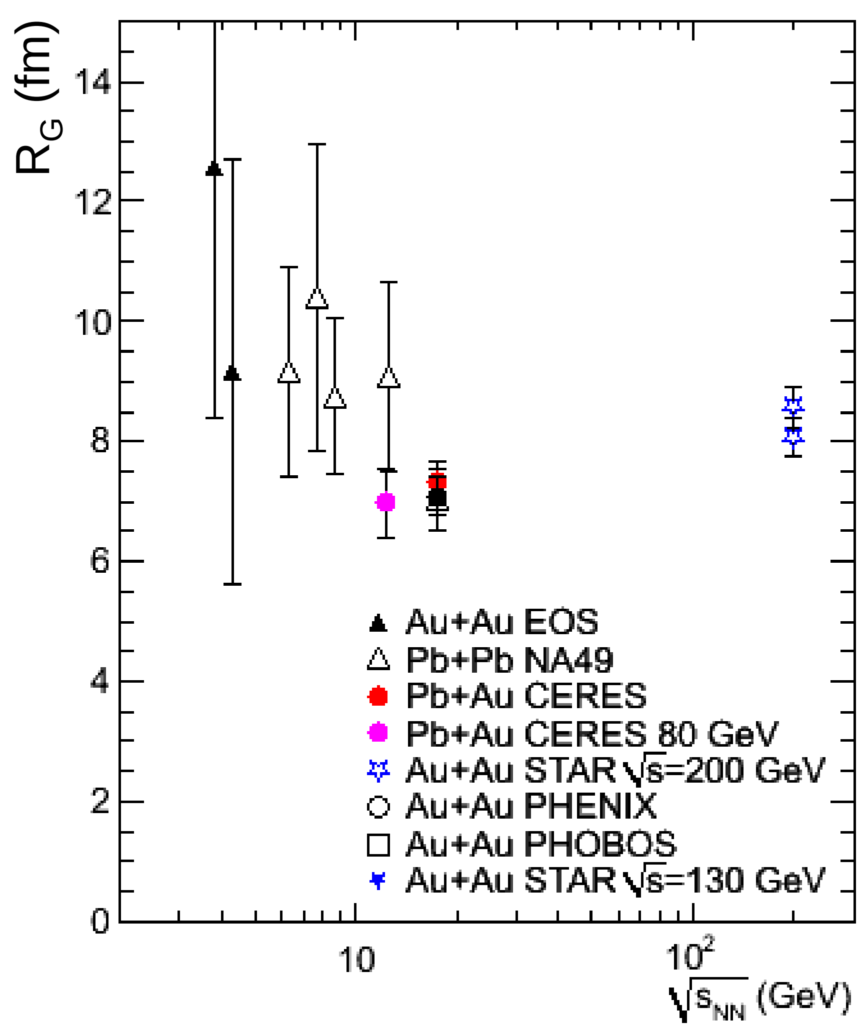
R_{long} systematics



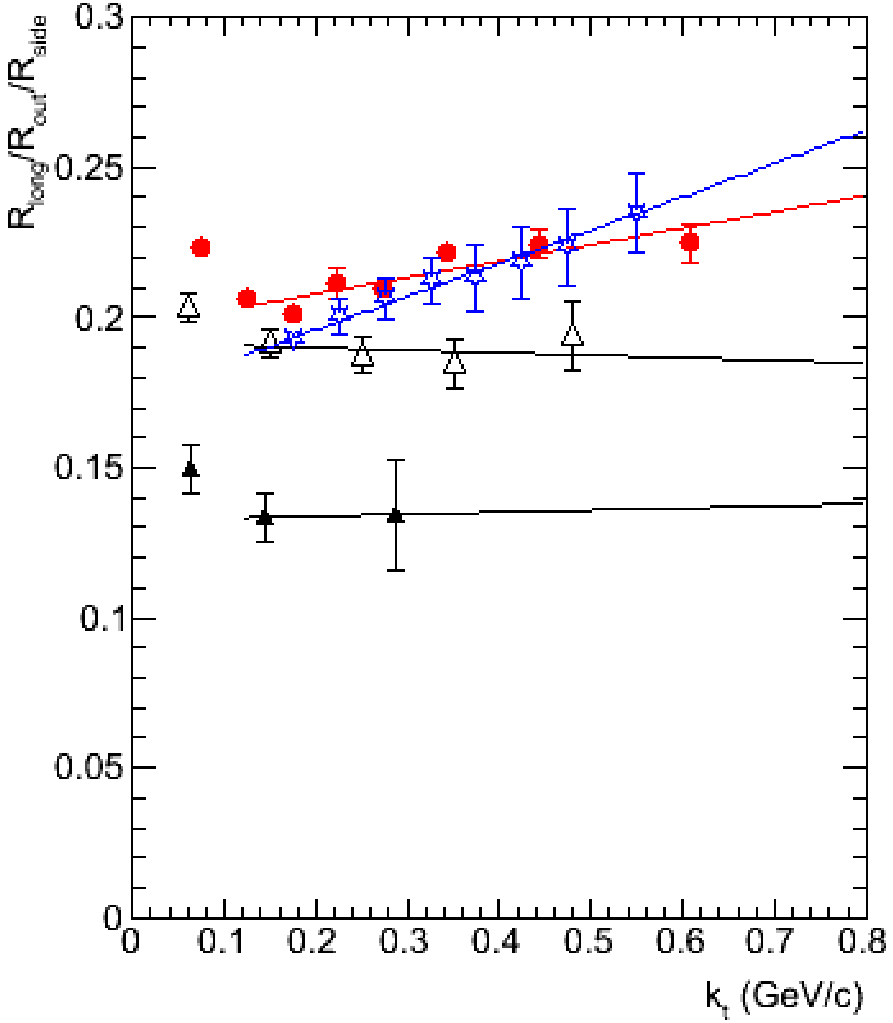


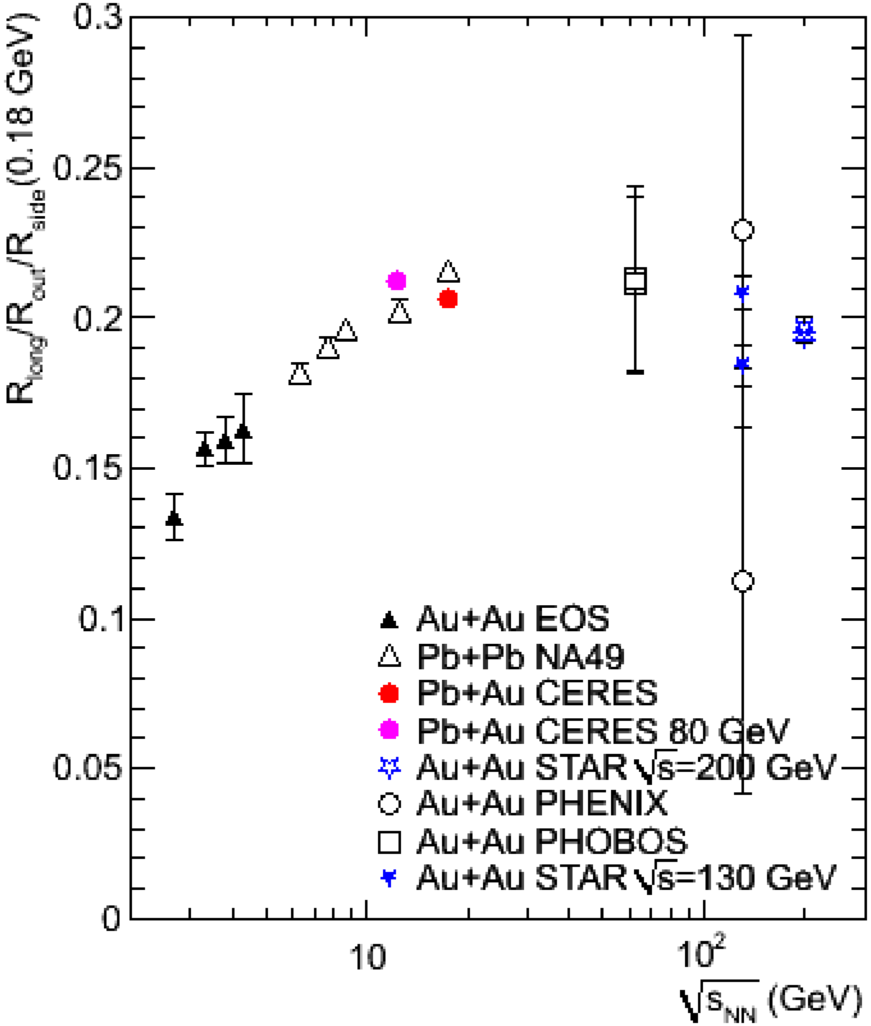
R_{side} systematics



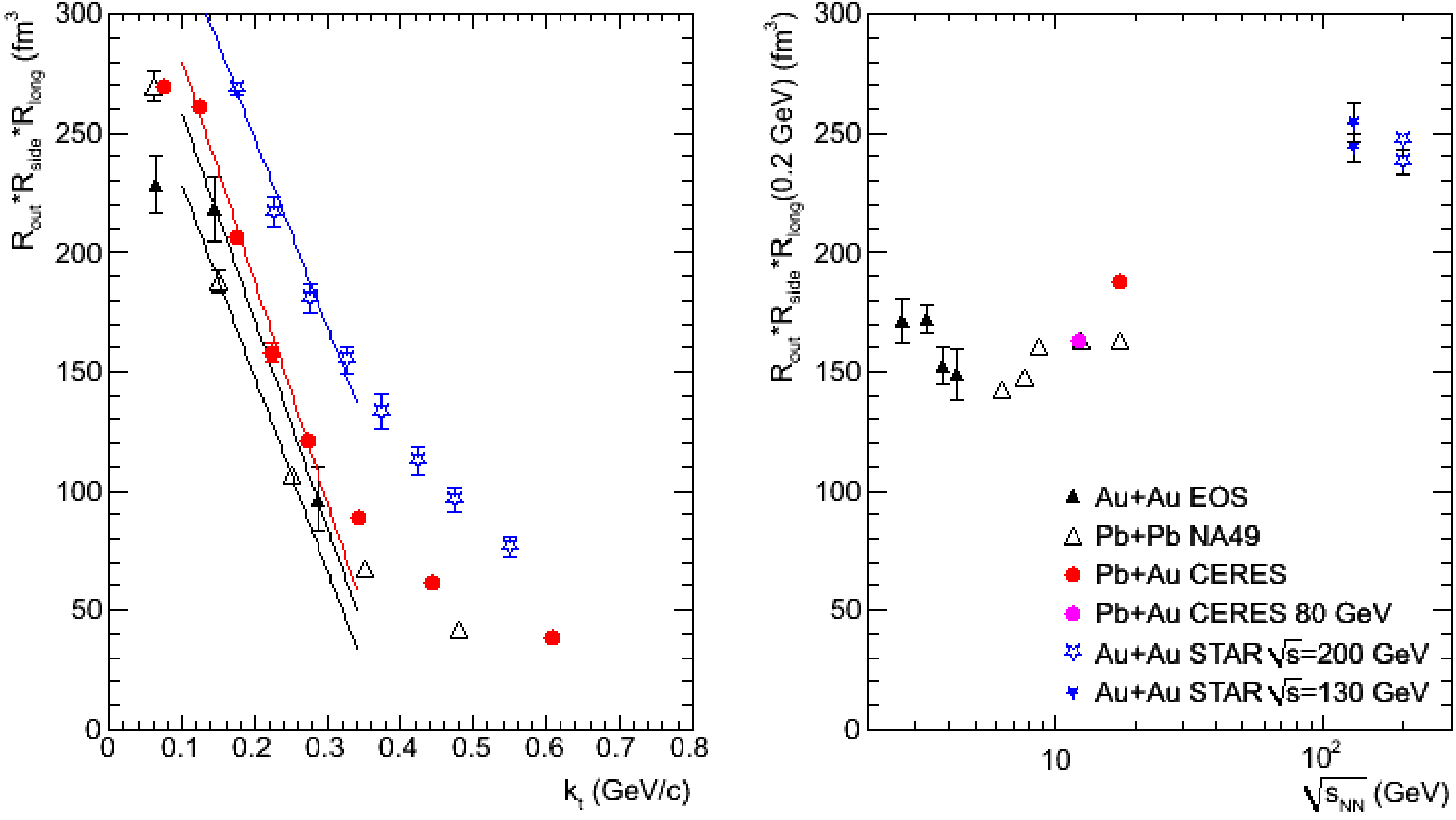


$R_{long}/R_{out}/R_{side}$

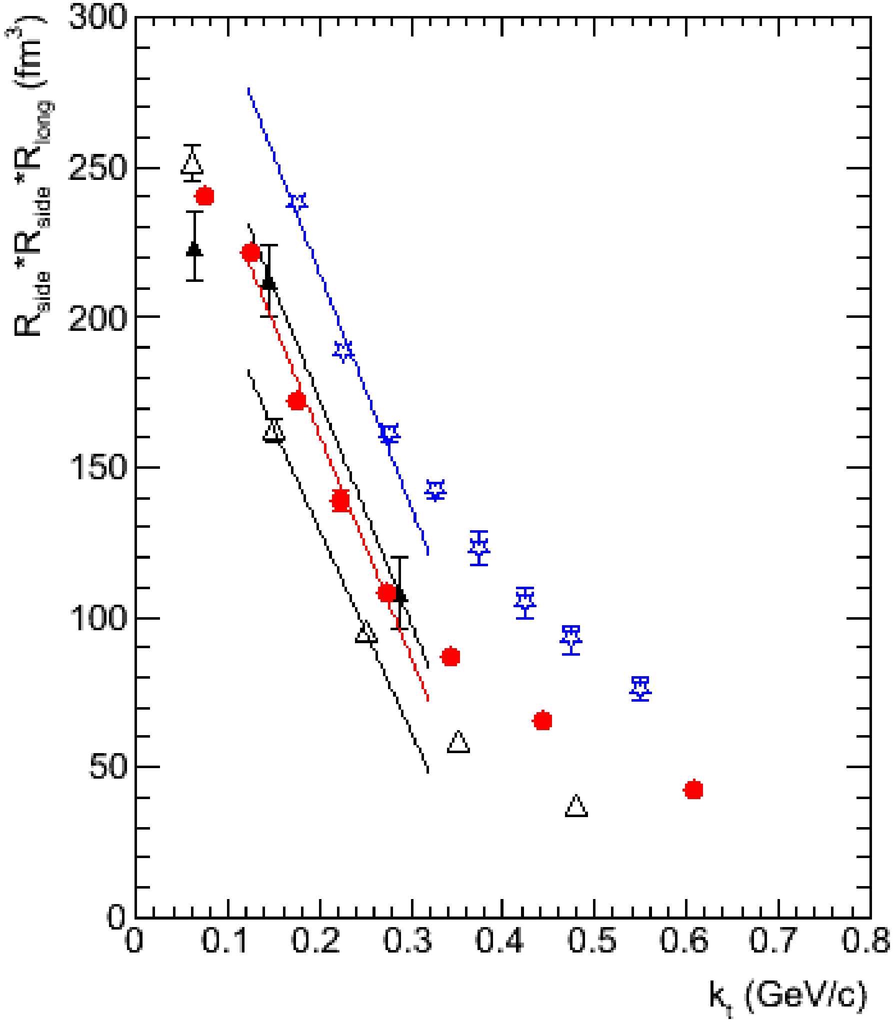


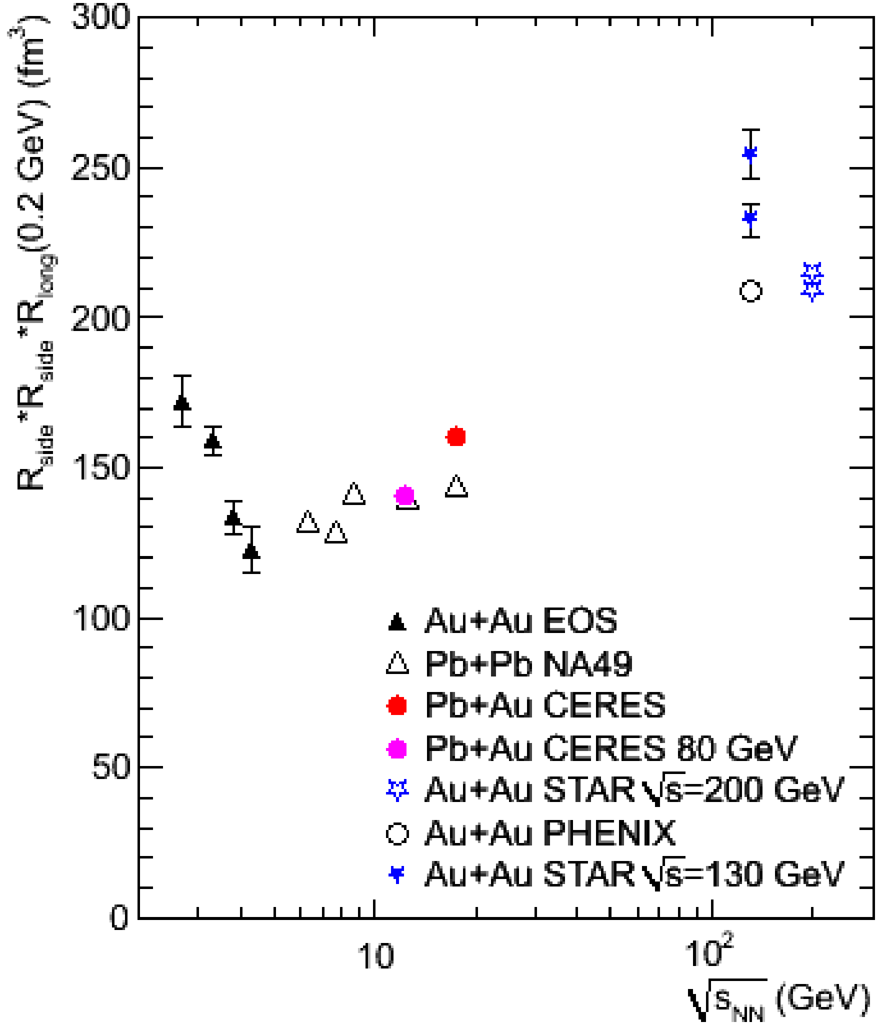


$R_{out}*R_{side}*R_{long}$



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

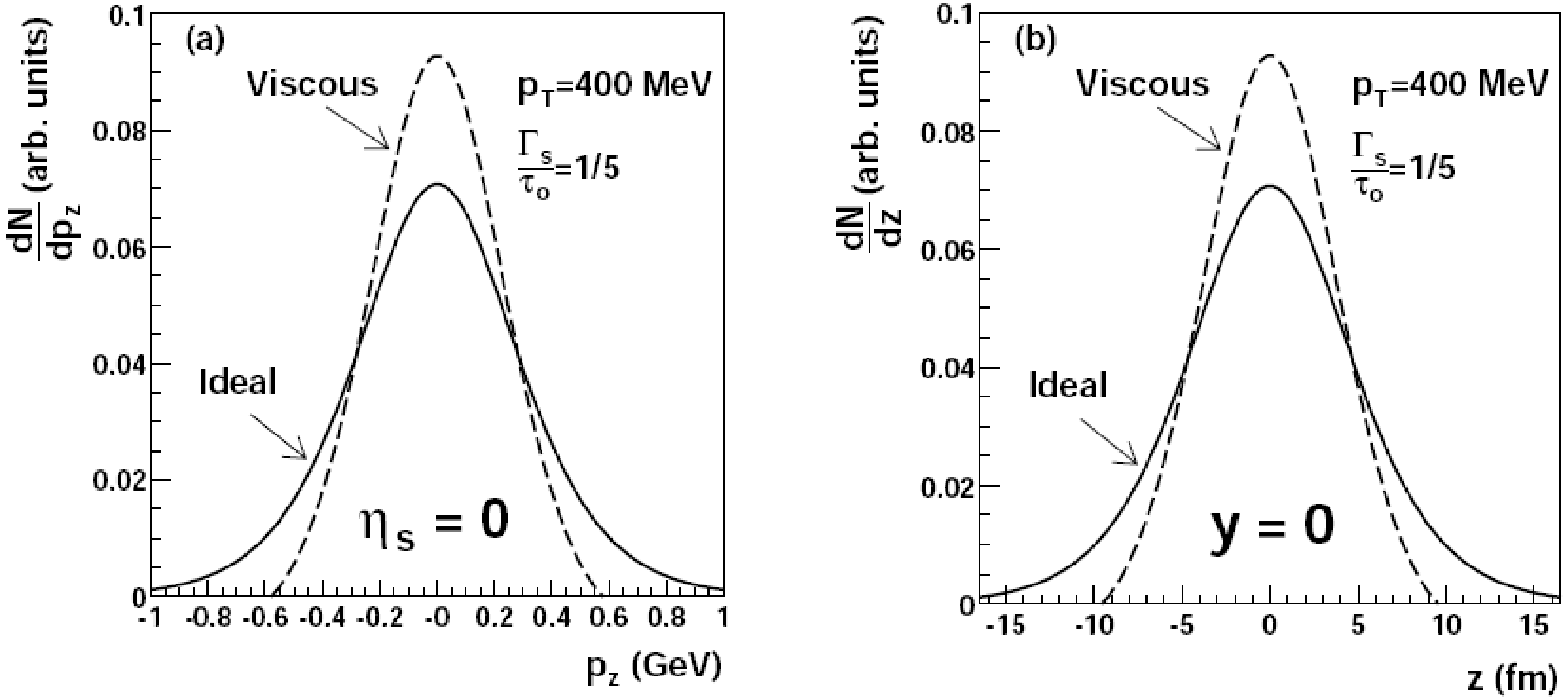




Viscosity via R_{long}

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

"Viscous corrections to a Bjorken expansion"



Teaney's formulas

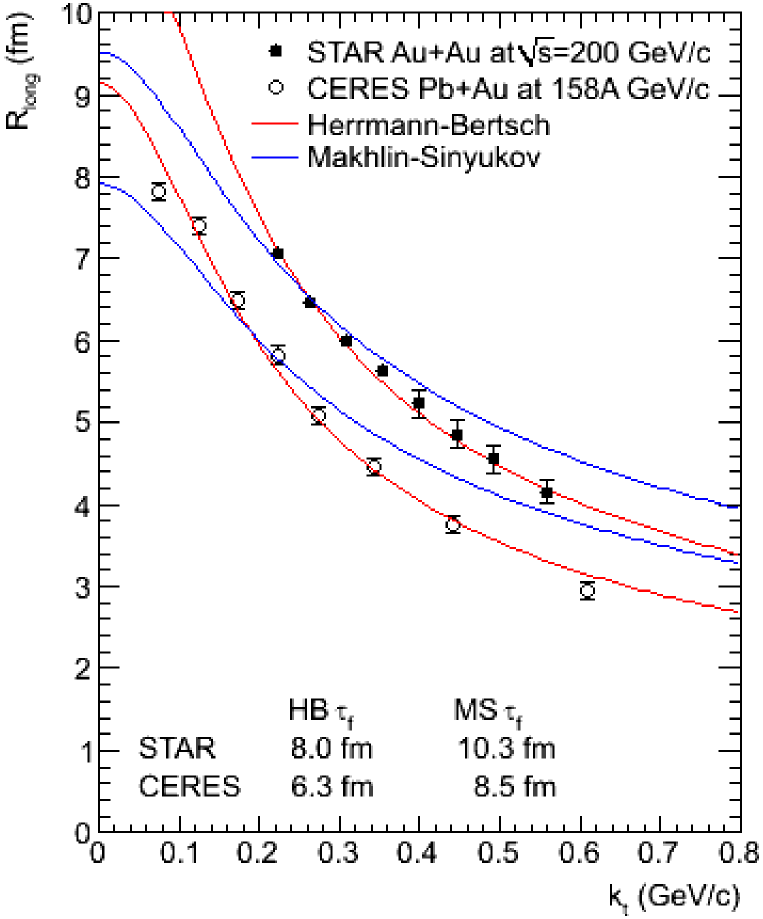
$$(R_L^2)^{(0)} = \tau_o^2 \frac{T}{m_T} \frac{K_2(x)}{K_1(x)} \qquad x \equiv \sqrt{m^2 + K_T^2} / T$$

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

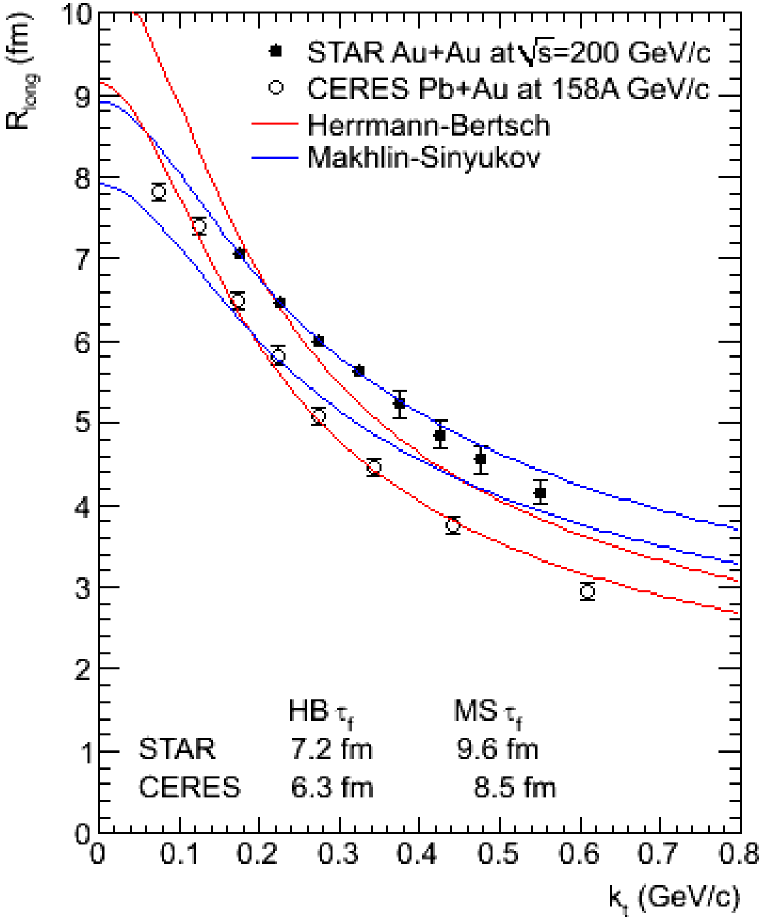
$$(R_L^2)^{(0)} = \tau_o^2 \frac{T}{m_T} \qquad (R_L^2)^{(0)} + \delta R_L^2 = \tau_o^2 \left(\frac{T}{m_T} - \frac{19}{16} \frac{\Gamma_s}{\tau_o} \right) \qquad \Gamma_s \equiv \frac{\frac{4}{3}\eta}{sT}$$

mistake when interpreting STAR data (m_t vs k_t)

STAR points misplaced

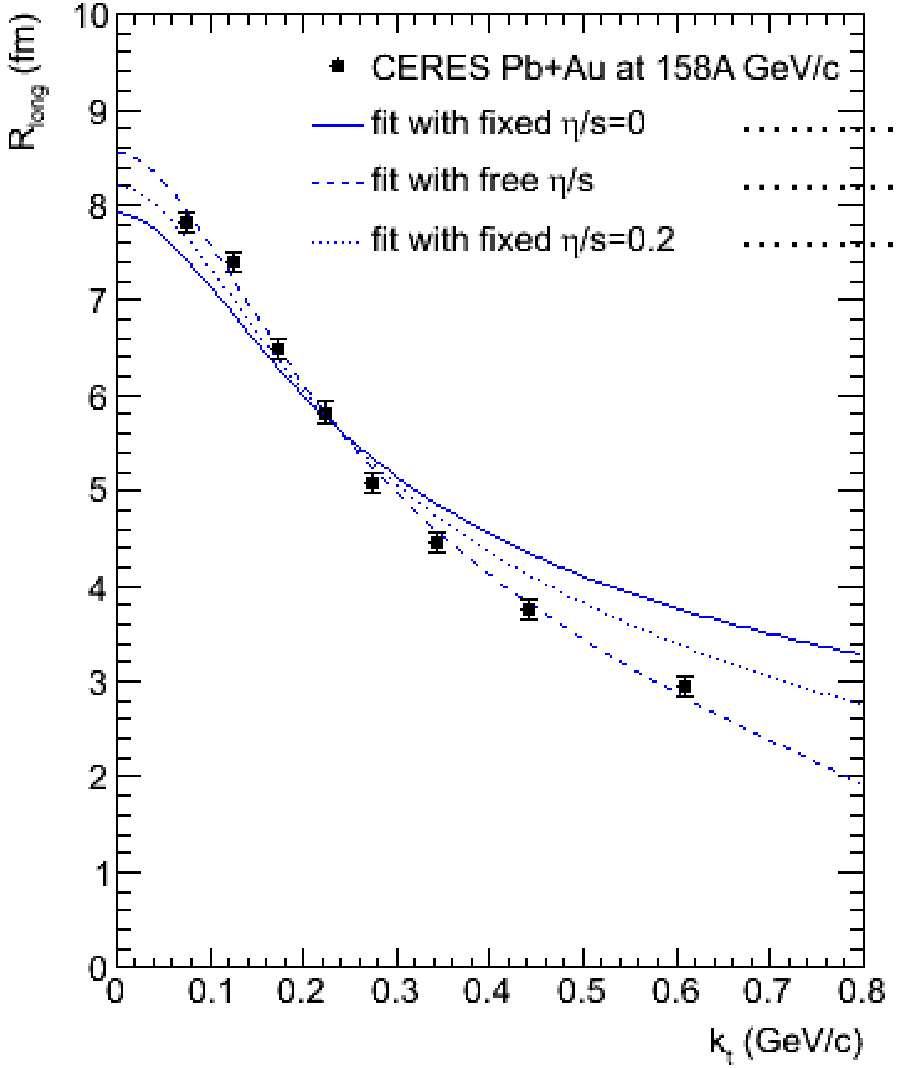


STAR points placed correctly



Herrmann-Bertsch vs Makhlin-Sinyukov

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!