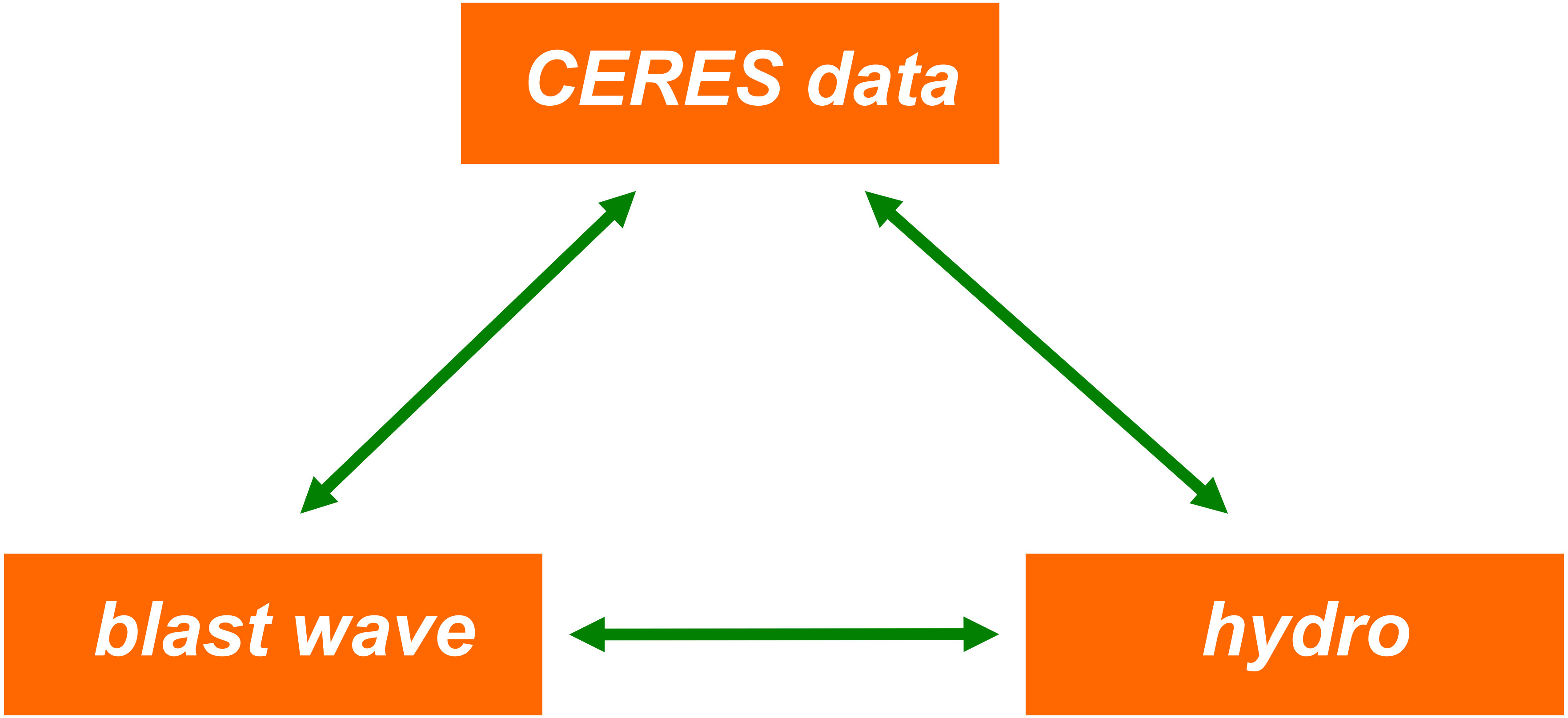
Freeze-out characterization in Pb+Au collisions at 158 AGeV

Dariusz Miśkowiec, GSI Darmstadt


CERES data
blast wave
hydro

CERES Collaboration

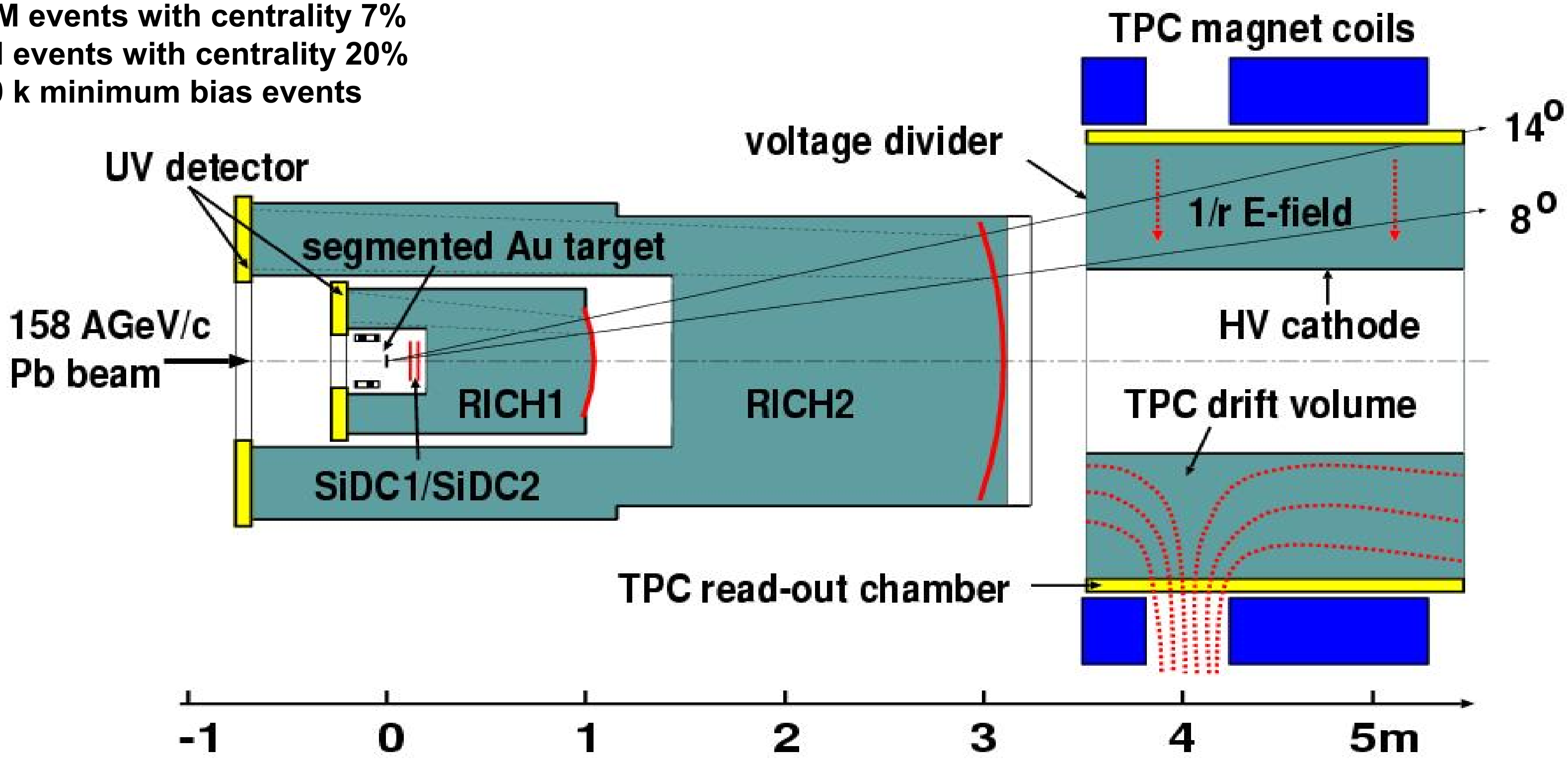
D. Adamova, G. Agakichiev, D. Antonczyk, A. Andronic, H. Appelshäuser, V. Belaga, J. Bielcikova, P. Braun-Munzinger, O. Busch, A. Cherlin, S. Damjanovic, T. Dietel, L. Dietrich, A. Drees, S. Esumi, K. Filimonov, K. Fomenko, Z. Fraenkel, C. Garabatos, P. Glässel, G. Hering, J. Holeczek, M. Kalisky V. 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	1M central
	160 GeV Pb+Au	30M central

CERES setup in 2000

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



CERES built and upgraded for leptons; but also good for...

pt spectra, elliptic flow, two-particle correlations of hadrons

blast wave model

Retière, Lisa, PRC 70(2004)044907

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\, \Omega(r,\phi_S)\, e^{\frac{-(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

with the space profile

$$\Omega(r,\phi_S) = \Omega(\tilde{r}) = \frac{1}{1+e^{(\tilde{r}-1)/a}}$$

and the normalized elliptic radius

$$\tilde{r}(r,\phi_S) = \sqrt{\frac{(r\cos(\phi_S))^2}{R_x^2} + \frac{(r\sin(\phi_S))^2}{R_y^2}}$$

and the flow four-velocity

$$u = u_\mu(x,\rho_0,\rho_2)$$

blast wave model

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\, \Omega(r,\phi_S)\, e^{-\frac{(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

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and the flow four-velocity

$$u = u_\mu(x, \rho_0, \rho_2)$$

function of four space-time coordinates

blast wave model

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\,\Omega(r,\phi_S)\, e^{\frac{-(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

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$$\Omega(r,\phi_S) = \Omega(\tilde{r}) = \frac{1}{1+e^{(\tilde{r}-1)/a}}$$

and the normalized elliptic radius

$$\tilde{r}(r,\phi_S) = \sqrt{\frac{(r\cos(\phi_S))^2}{R_x^2} + \frac{(r\sin(\phi_S))^2}{R_y^2}}$$

and the flow four-velocity

$$u = u_\mu(x,\rho_0,\rho_2)$$

function of four momentum components

blast wave model

analytic hydro-inspired 8-d emission function

$$S(x,K) = m_T \cosh(\eta - Y)\,\Omega(r,\phi_S)\, e^{\frac{-(\tau-\tau_0)^2}{2\Delta\tau^2}} \frac{1}{e^{K\cdot u/T} \pm 1}$$

with the space profile

$$\Omega(r,\phi_S) = \Omega(\tilde{r}) = \frac{1}{1+e^{(\tilde{r}-1)/a}}$$

and the normalized elliptic radius

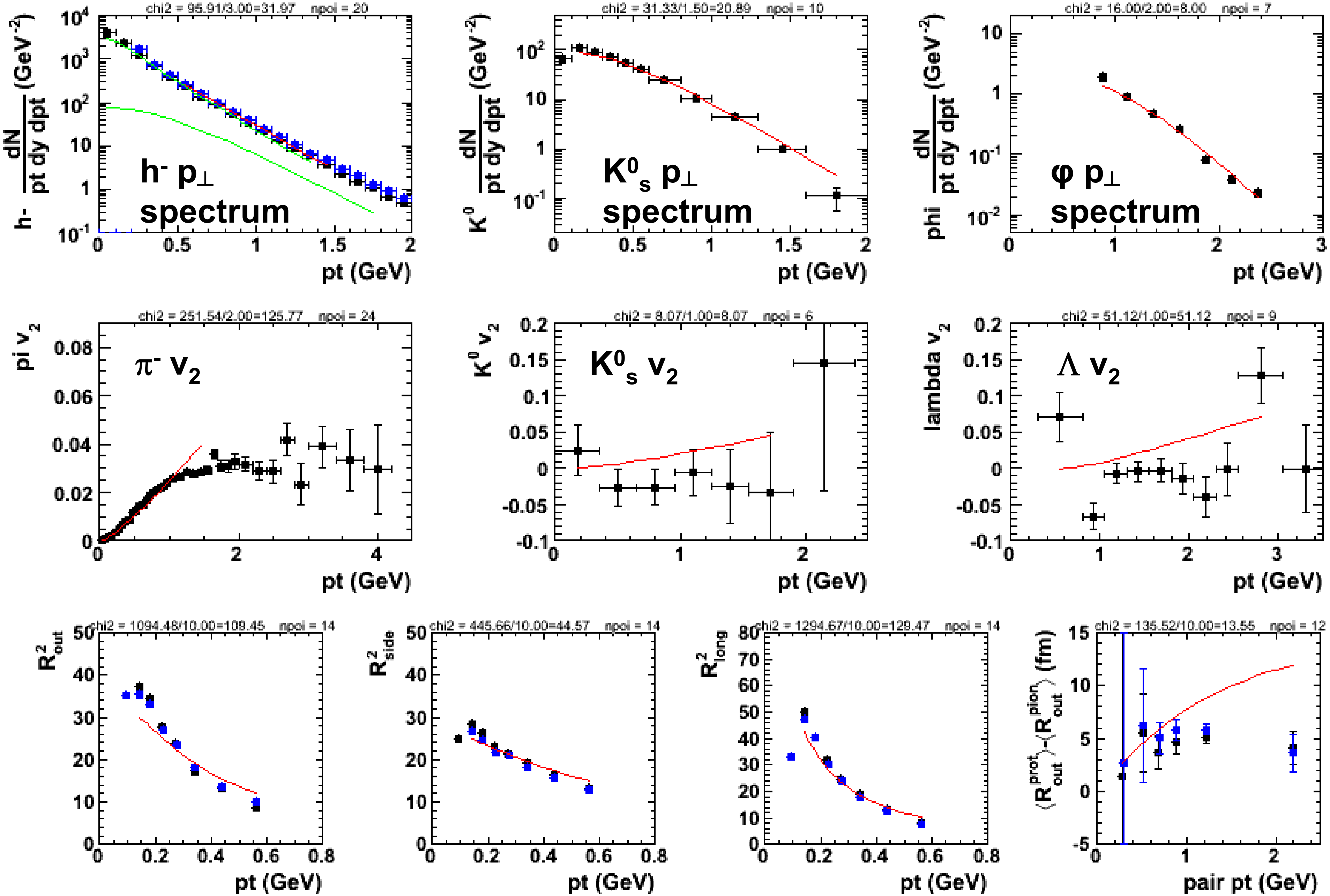
$$\tilde{r}(r,\phi_S) = \sqrt{\frac{(r\cos(\phi_S))^2}{R_x^2} + \frac{(r\sin(\phi_S))^2}{R_y^2}}$$

and the flow four-velocity

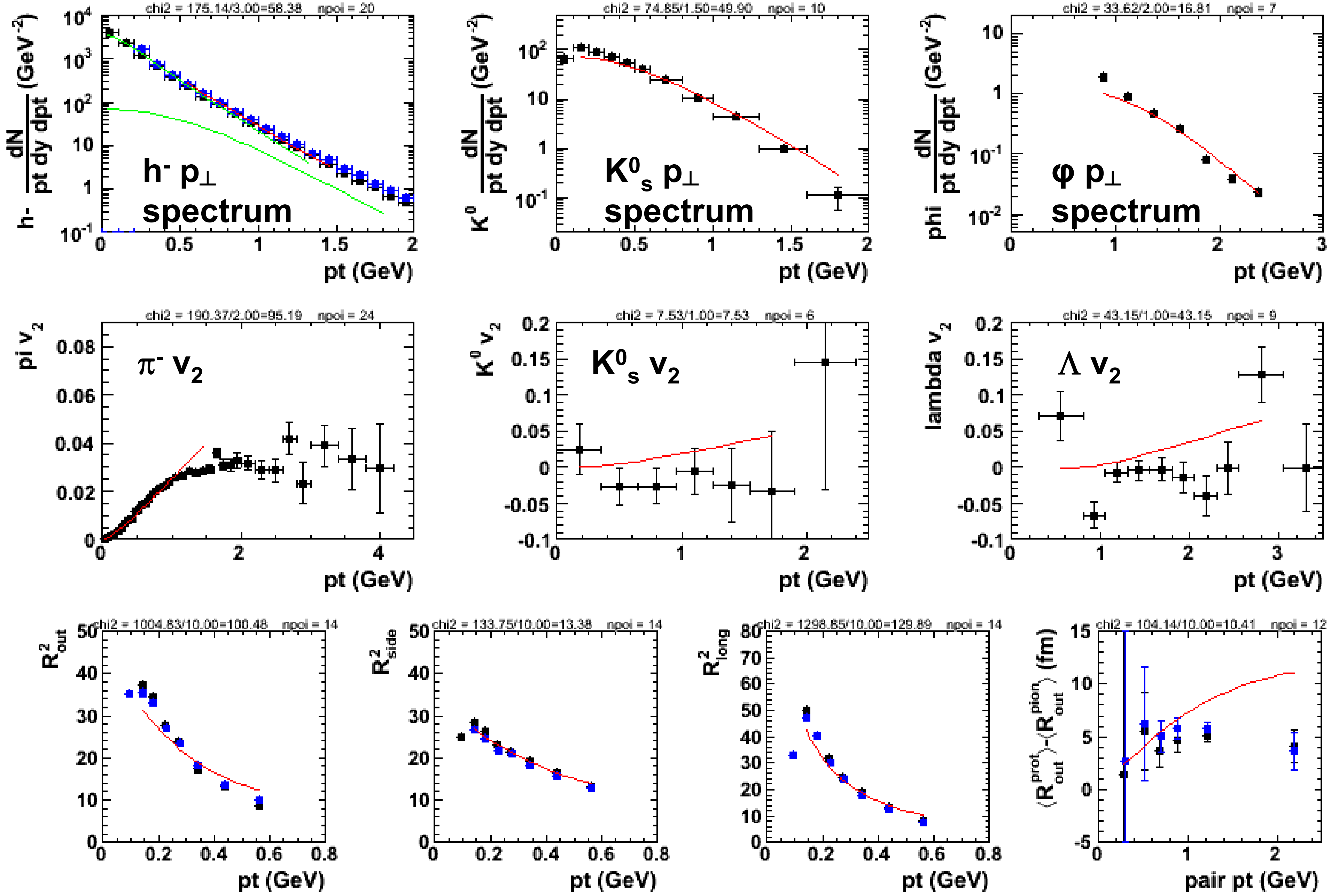
$$u = u_\mu(x, \rho_0, \rho_2)$$

with eight parameters

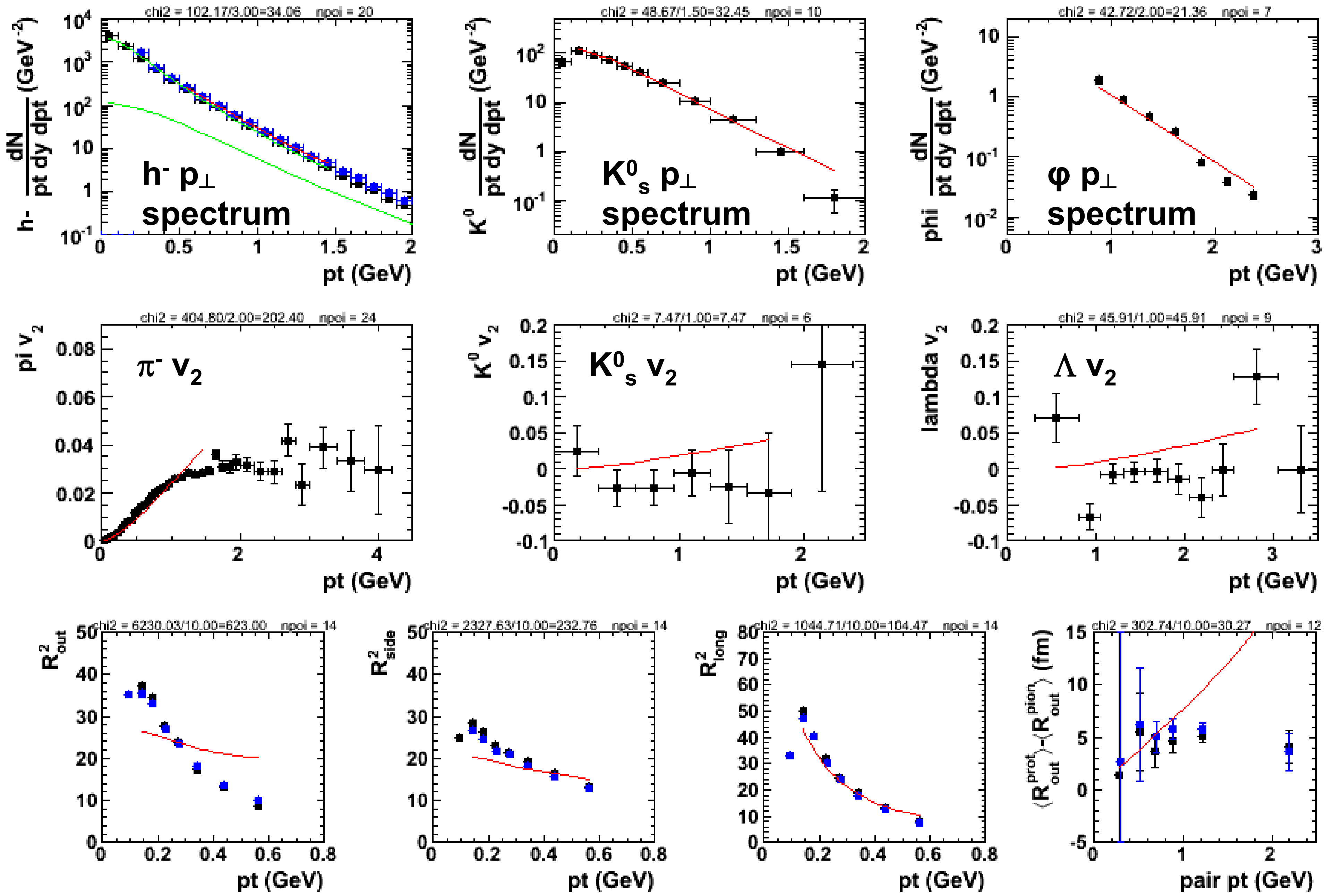
CERES (points) and blast T=100 MeV (lines)



CERES (points) and blast T=80 MeV (lines)



CERES (points) and blast T=100 MeV as=0.3 (lines)



hydro

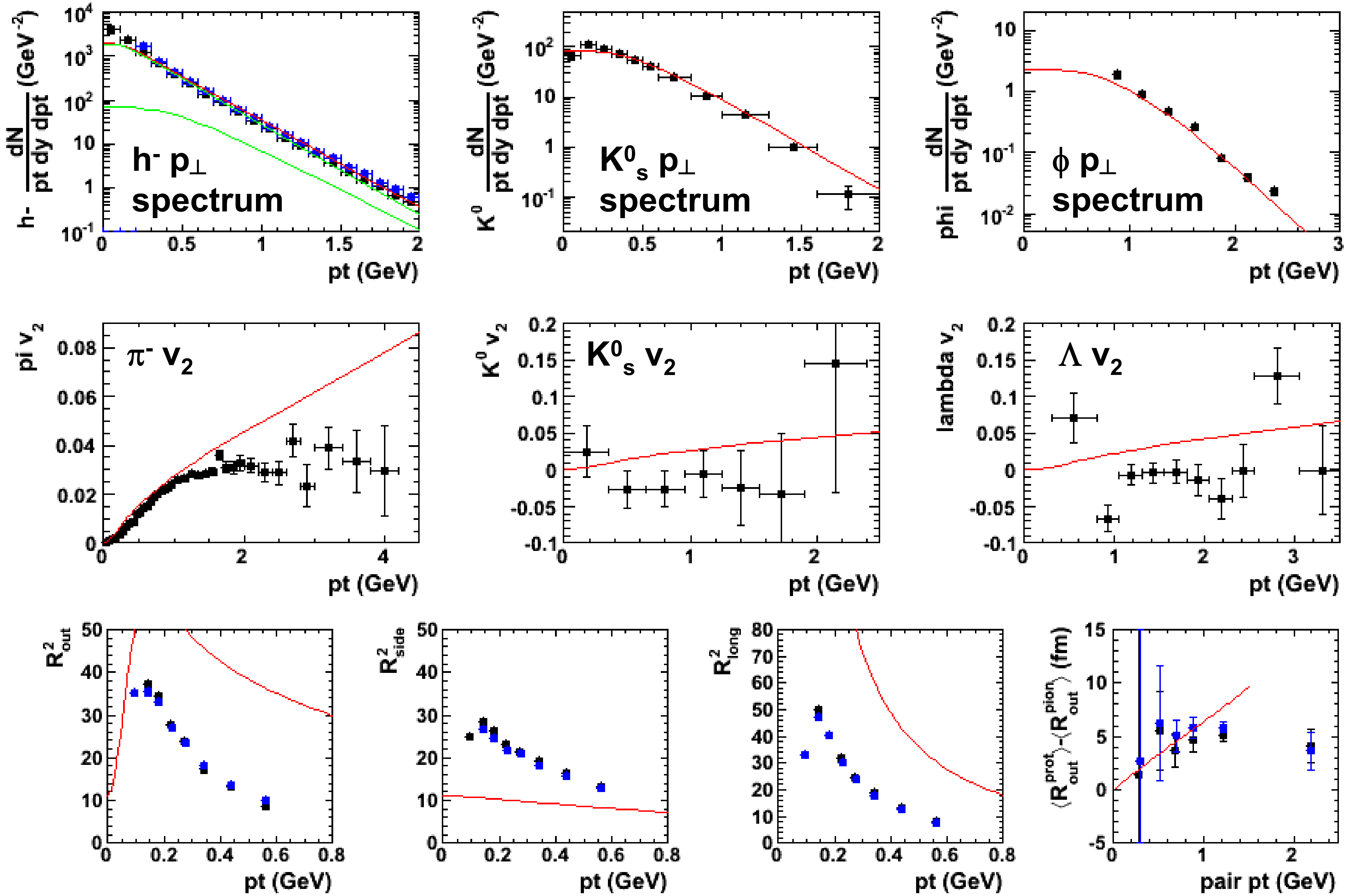
Pasi Huovinen

- ***hydrodynamical model, see e.g. nucl-th/0305064***
- ***freeze-out at a fixed energy density (similar to fixed temp)***
- ***dedicated calculation of Au+Pb at 158 A GeV, b=2.6 fm***

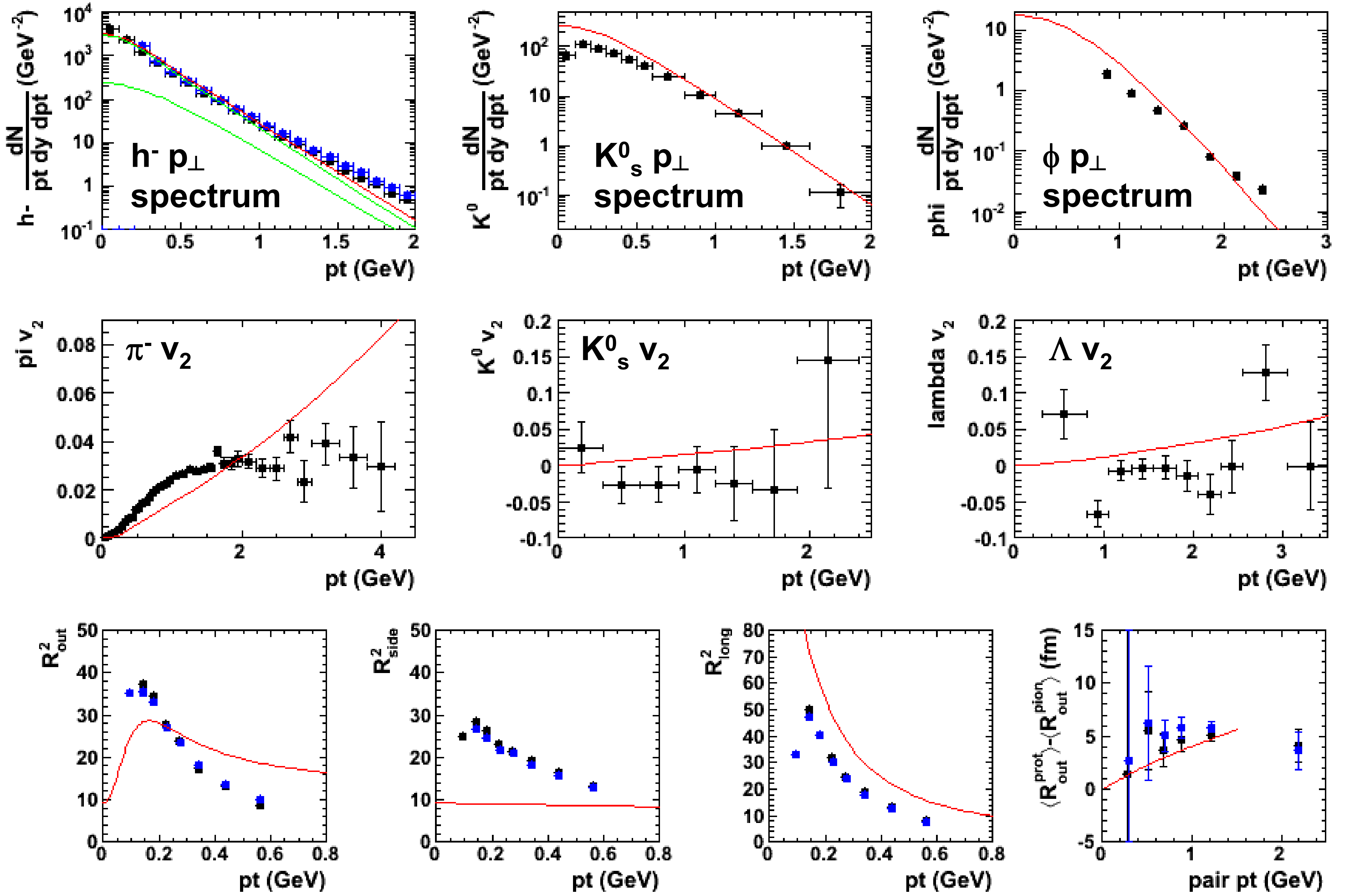
two sets of results:

- ***T=160 MeV (like at chemical freeze-out)***
- ***T=120 MeV (like at kinetic freeze-out)***

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



CERES (points) and hydro T=160 MeV (lines)



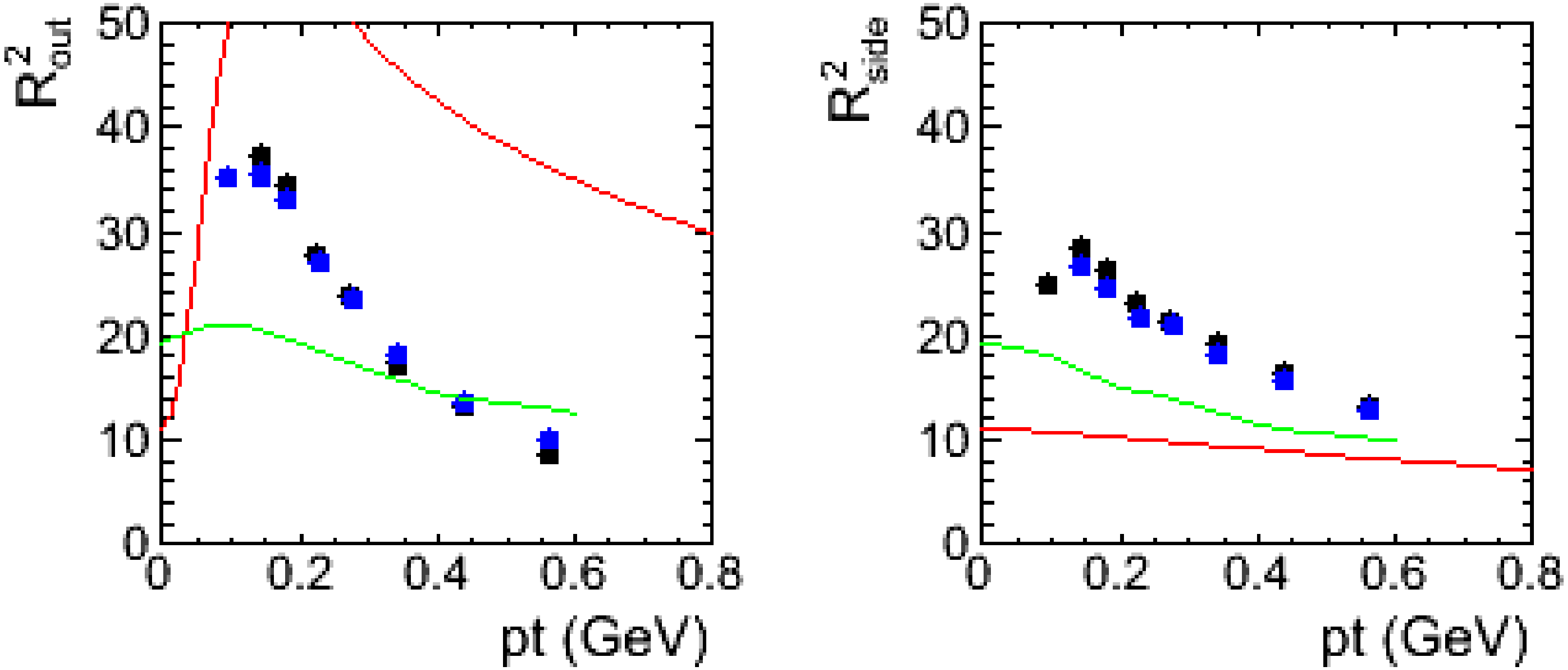
puzzle

hydro

~~RHIC~~ HBT puzzle

try another flavour of hydro

black and blue points: CERES data
red line: present day hydro (Pasi Huovinen)
green line: old days hydro (Bernd Schlei)



Ornik, Plümer, Schlei, Strottman, Weiner PRC 54(1996)1381, Pb+Pb at 160A GeV; rapidity and centrality not matched to CERES data so detailed comparison not possible; but, in any case...

Rout/Rside totally different from the present hydro

part of the puzzle?

hydro ≠ hydro

room for improvement in the present hydro?

Use blast to understand what is "wrong" in hydro:

- ***blast is "hydro inspired" and has 8 free parameters***

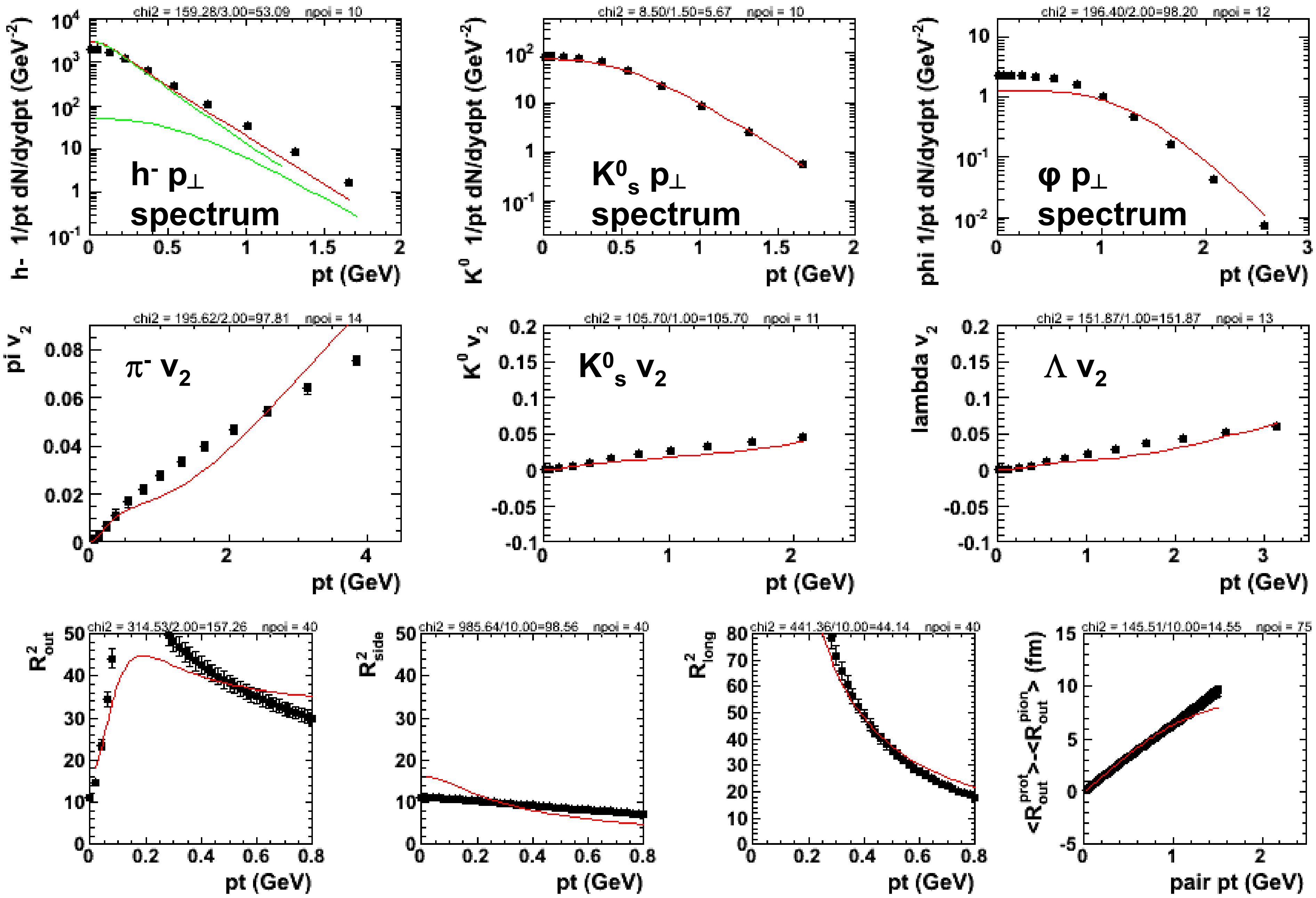
  → hydro source must be a special case of blast source

- ***fit CERES by blast and fit hydro by blast and compare the resulting parameters***

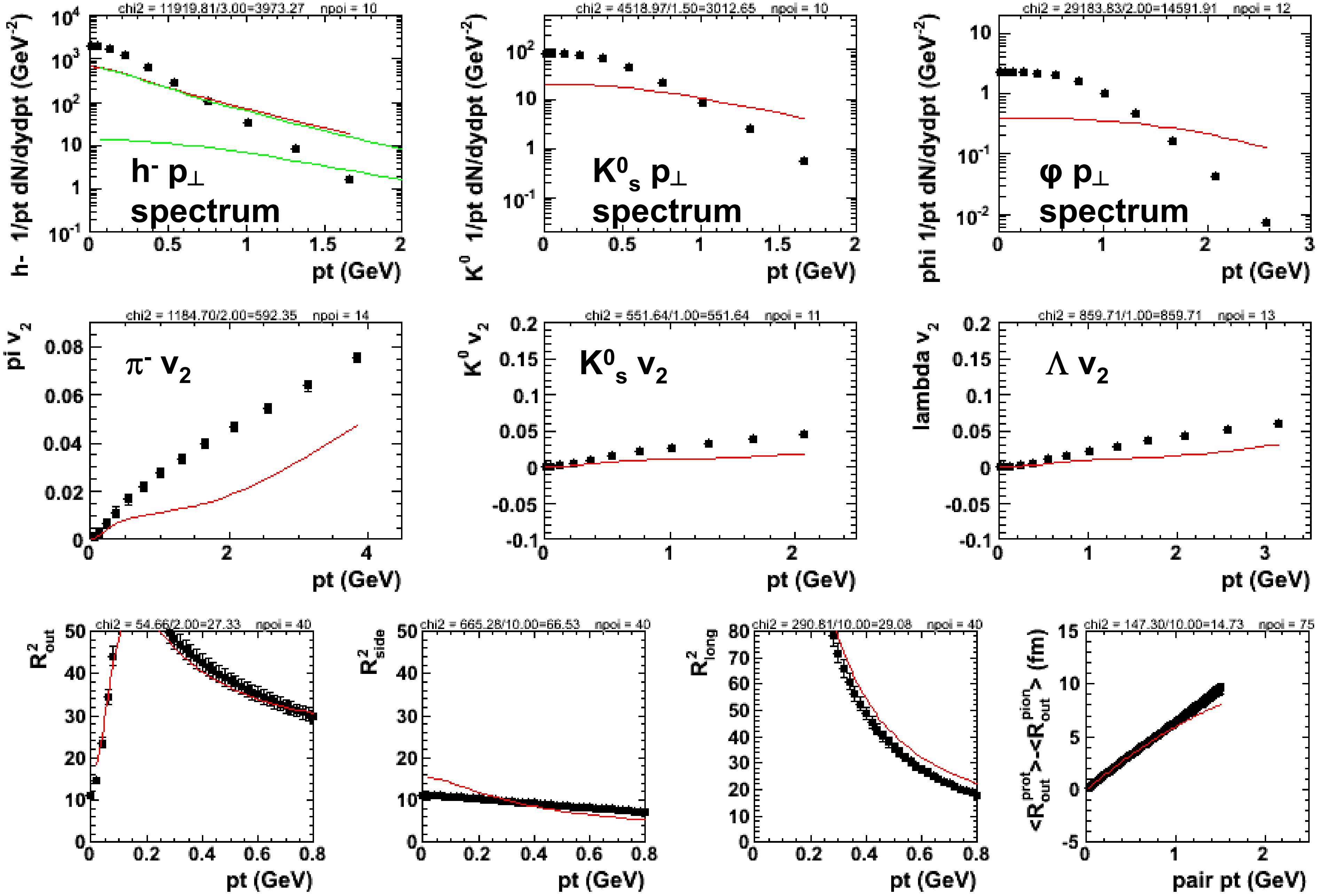
- ***identify THE parameter which is different***

  → this is what needs to be fixed in hydro

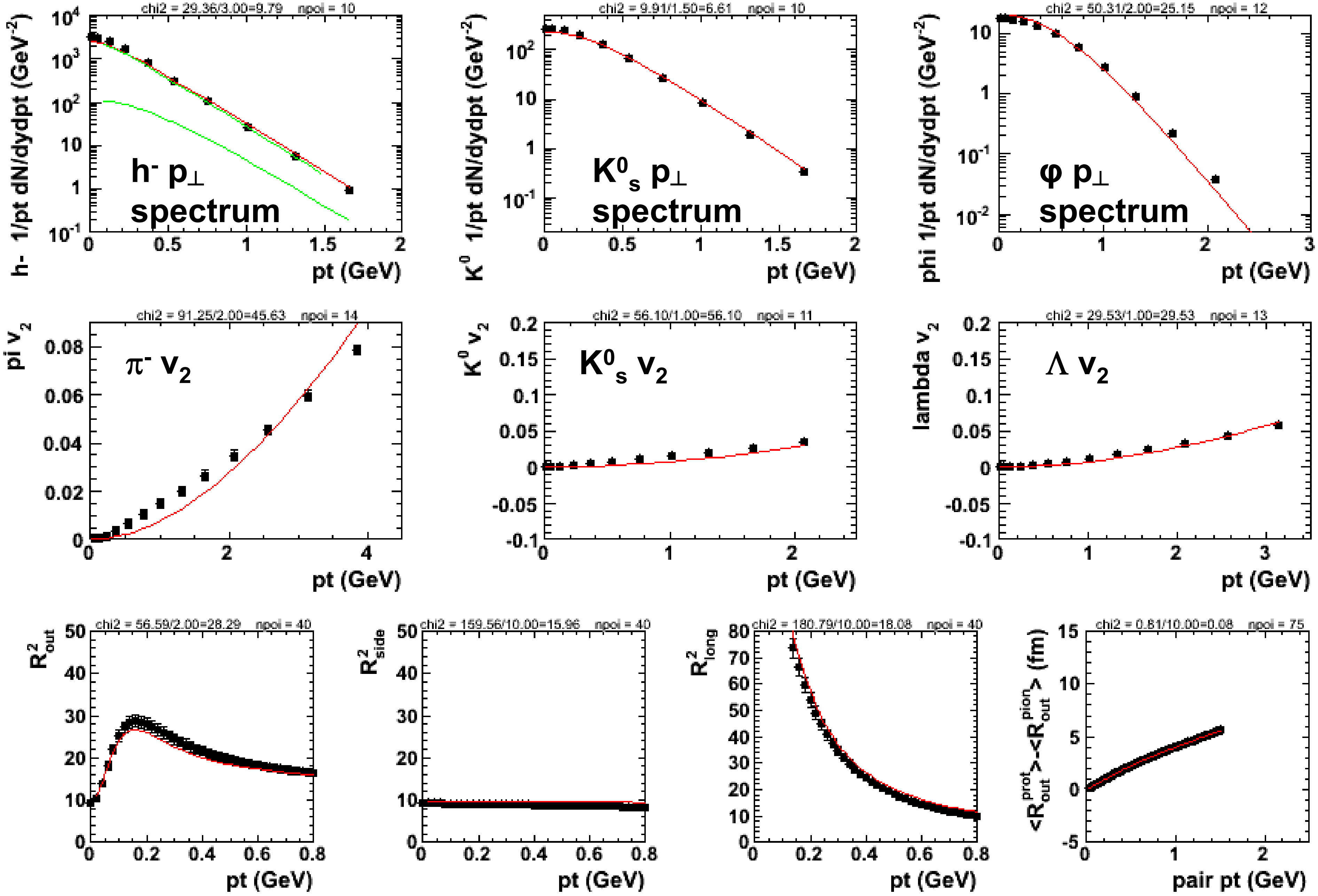
hydro 120 MeV (points) and blast (lines)



hydro 120 MeV (points) and blast, fit only HBT!



hydro 160 MeV (points) and blast (lines)



blast vs. hydro

Use blast to understand what is wrong in hydro:

- *blast is "hydro inspired" and has 8 free parameters*

  → hydro source must be a special case of blast source

- *fit CERES by blast and fit hydro by blast and compare the resulting parameters*

- *identify THE parameter which is different*

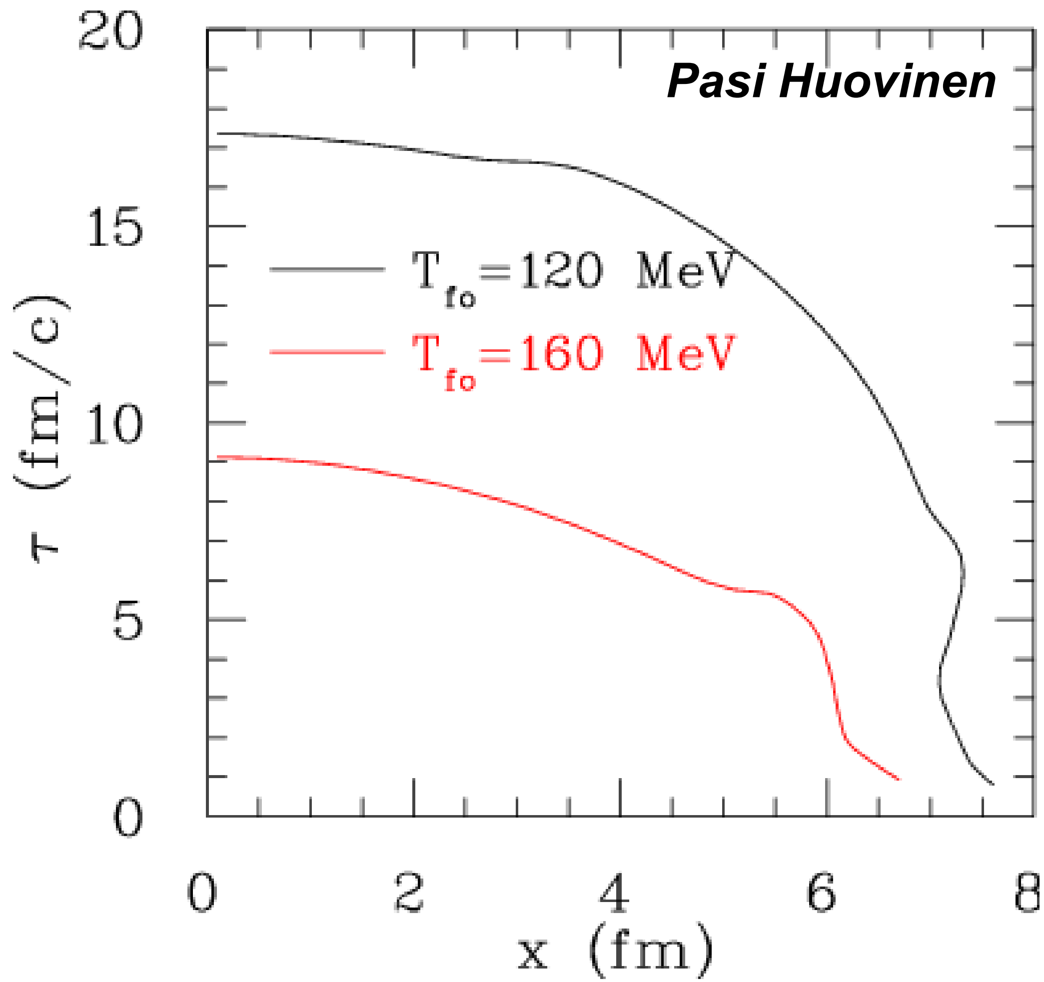
  → this is what needs to be fixed in hydro

no way to fit blast to hydro

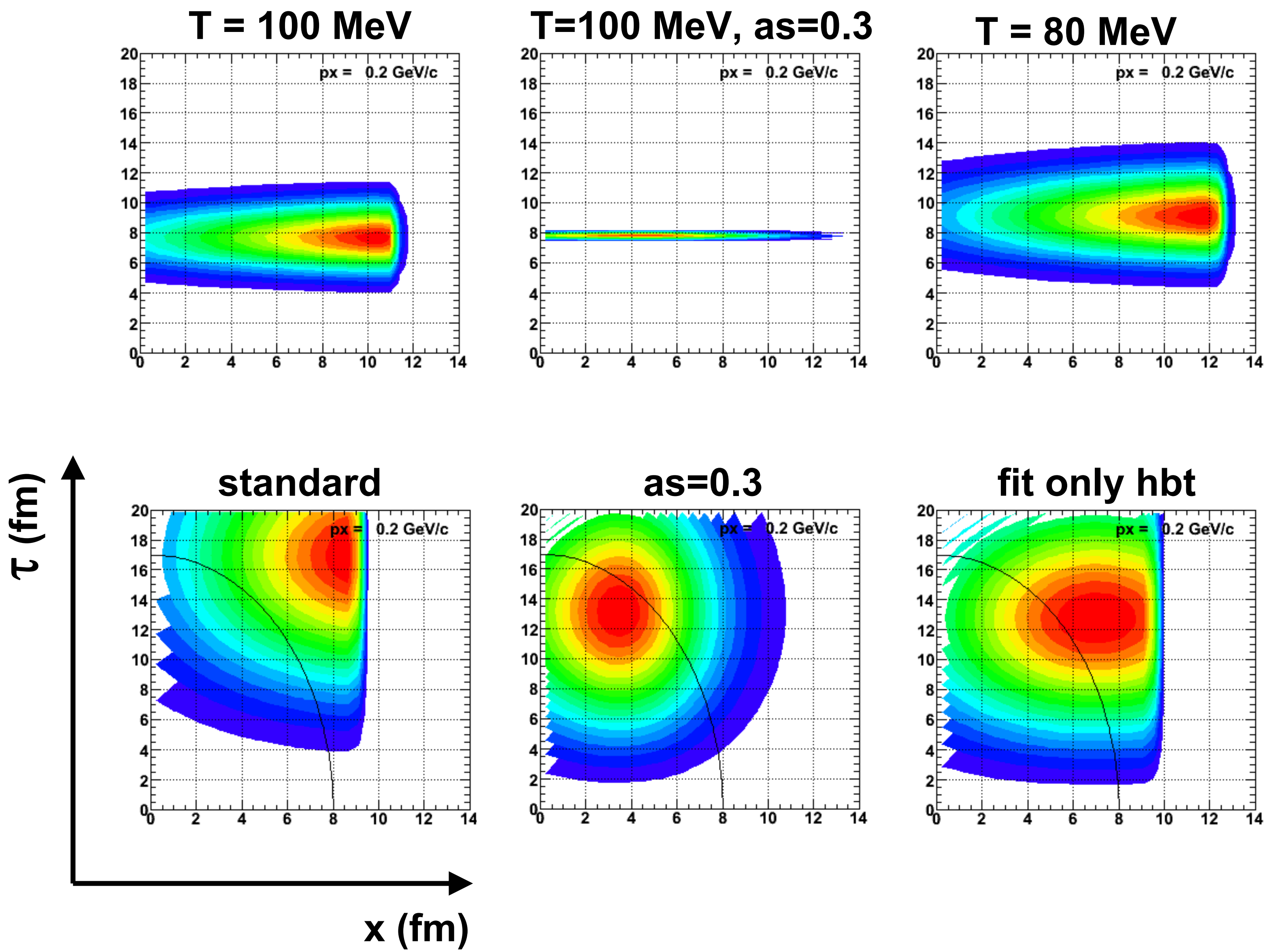
hydro freeze-out profile

Why is R_{out} so large and R_{side} so small in hydro ?

Hint by Pasi Huovinen: freeze-out profile



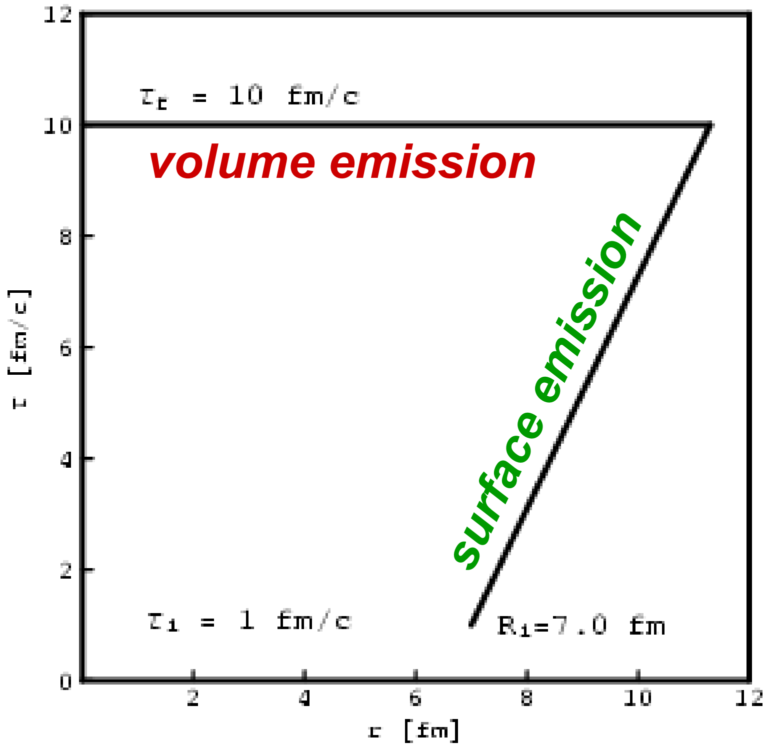
blast wave freeze-out profile



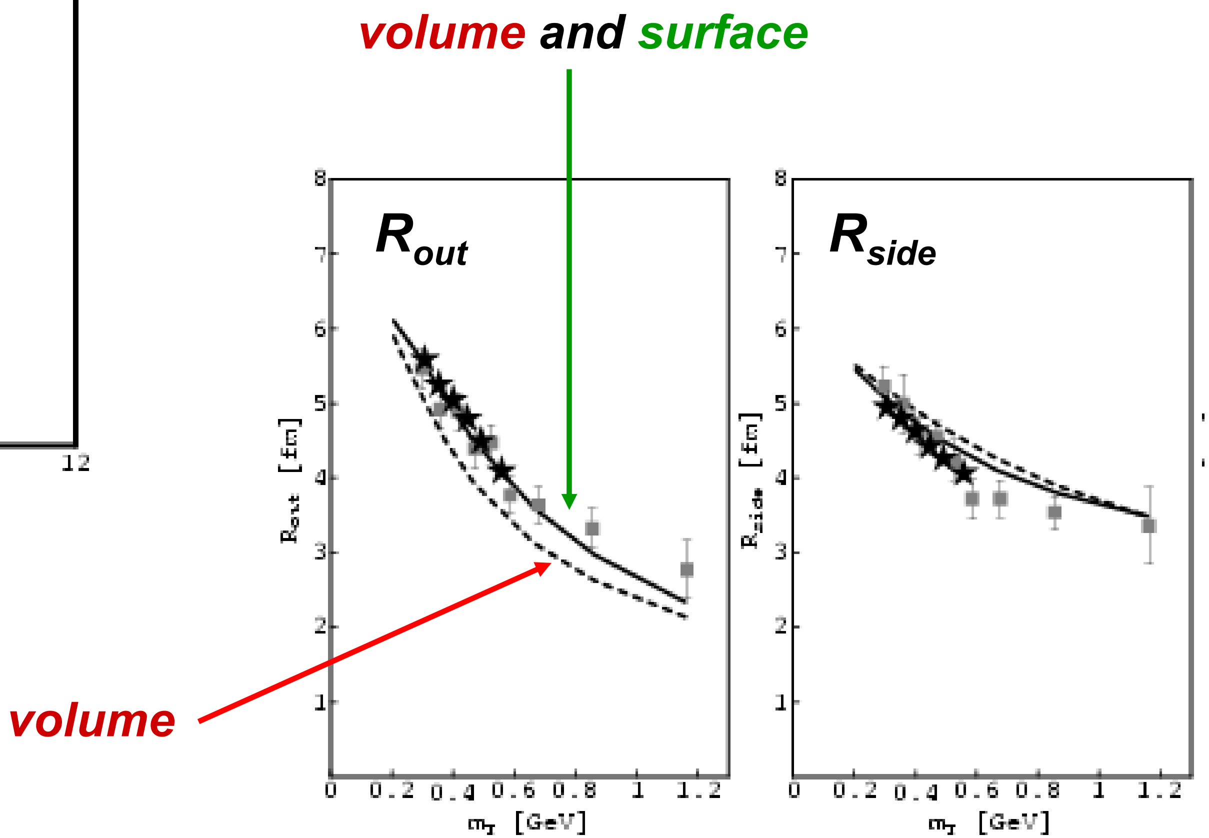
fit to CERES data

"fit" to hydro
120 MeV

Yuri Sinyukov's blast wave freeze-out profile

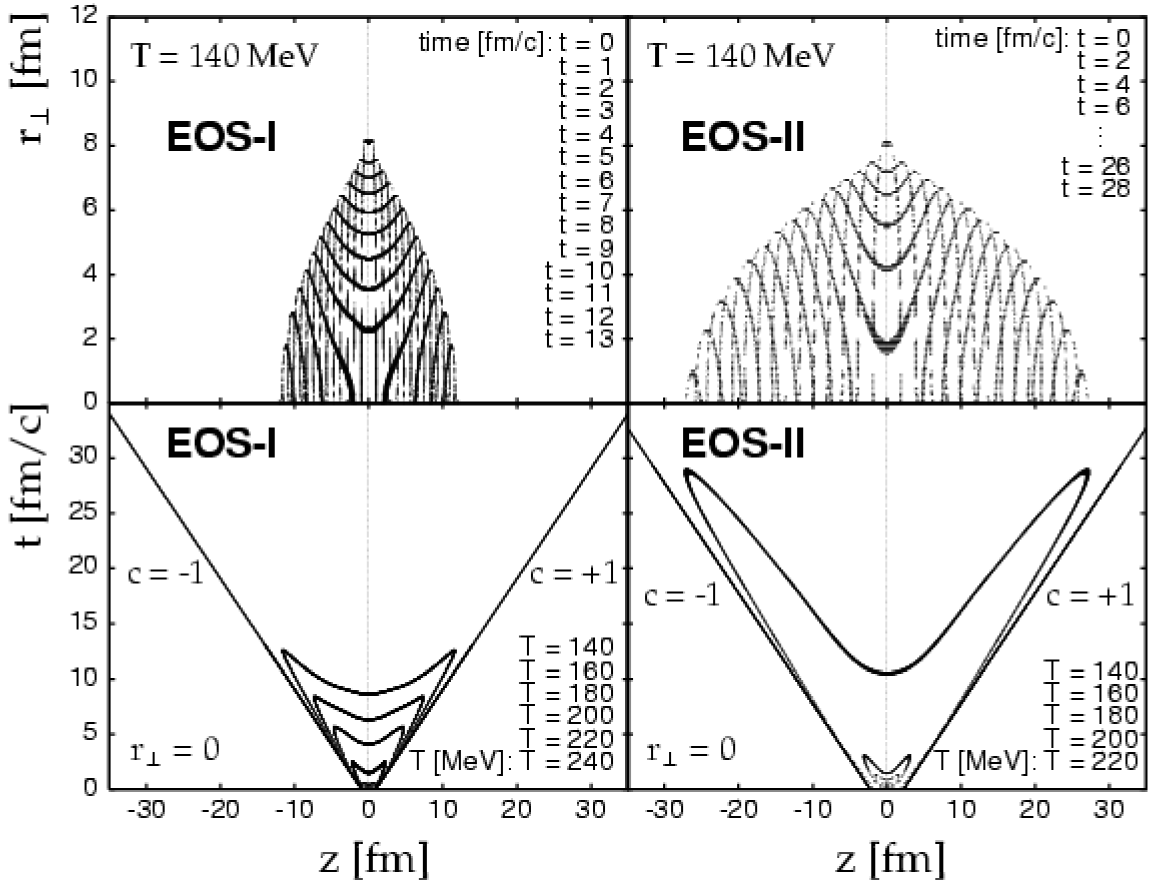


Phys.Rev. C73 (2006) 024903
pi- pi- from PHENIX and STAR

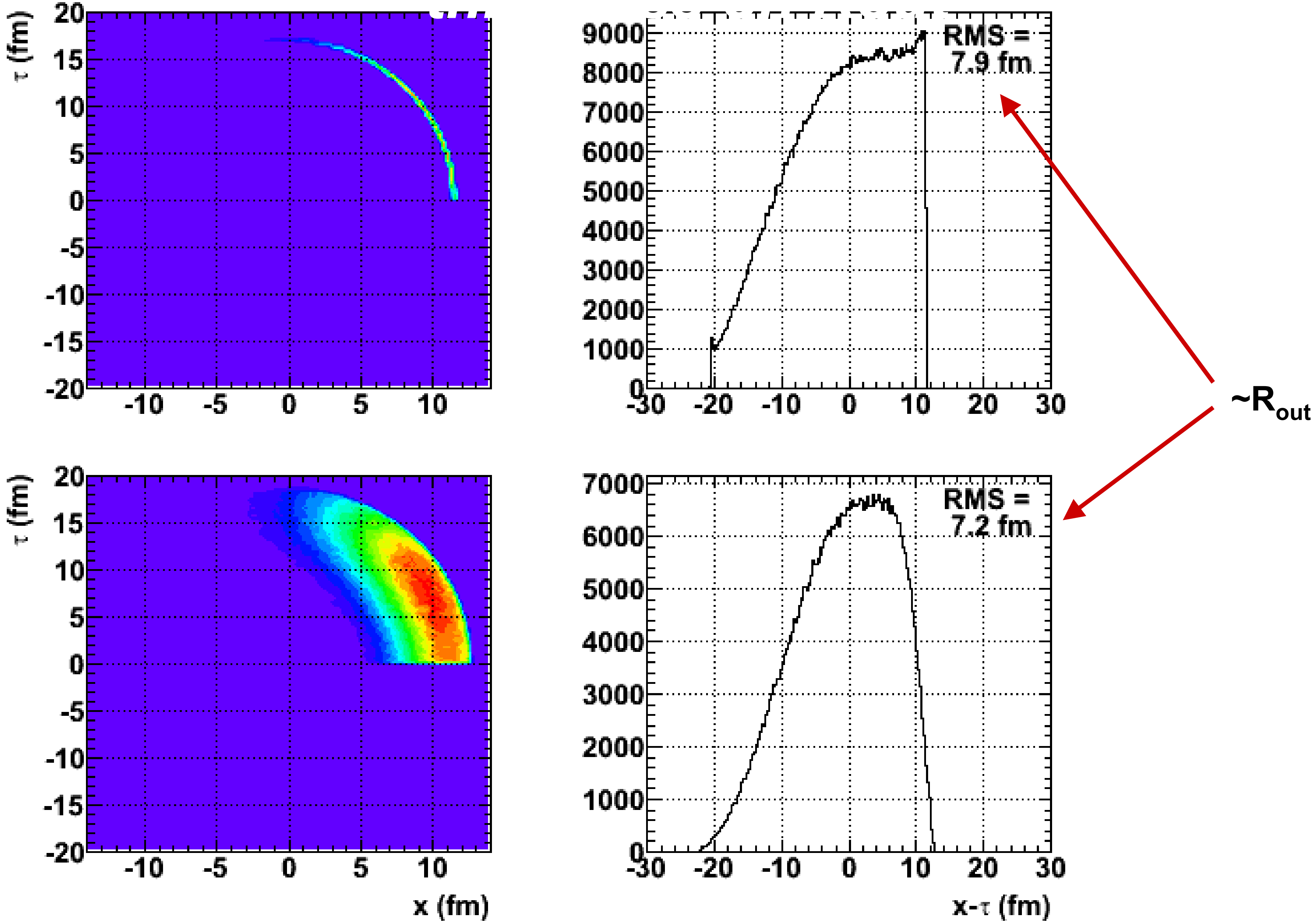


Bernd Schlei's hydro freeze-out profile

nucl-th/9706037



influence of the freeze-out surface



summary

- ***blast fits reasonably well CERES spectra, flow, and HBT***
- ***hydro fits CERES spectra and flow but not HBT radii***
- ***blast is qualitatively different from hydro (even if "inspired" by it)***
- ***troubles with hydro may be caused by:***

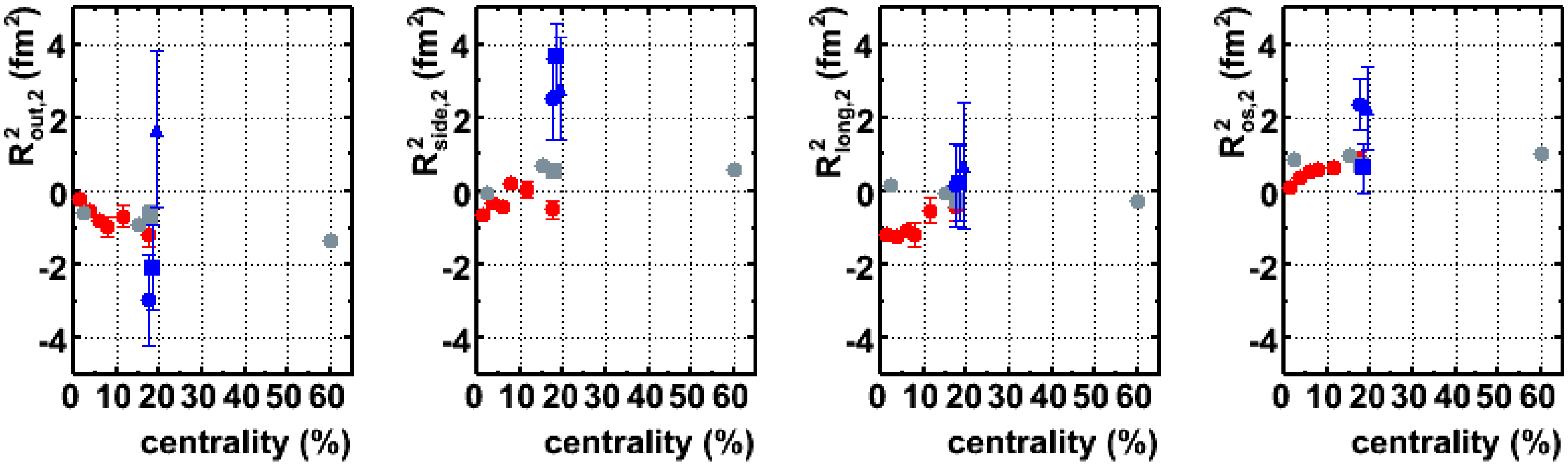
freeze-out surface moving inward? probably not...

its unrealistically small thickness? probably not...

with the two hydro versions giving so different results one should be able to nail it down!

azimuthal HBT from CERES: appetizer

Pb+Au at 158 AGeV
preliminary



suggests an out-of-plane elongation	***no effect -- inconsistent with R_{out}***	***significant -- against expectation and symmetry***	***consistent with R_{out}***

more about this subject in the talk of D. Antończyk on Friday morning

azimuthal dependence of pion HBT radii

more about this subject in the talk of D. Antończyk on Friday morning

pion-pion correlation function

correlation function
= pair distribution,
normalized to event mixing

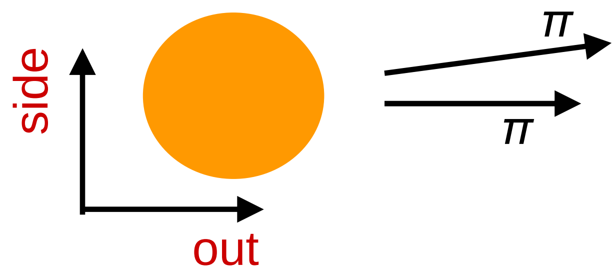
$$C_2(\mathbf{P},\mathbf{q}) = \frac{n(\mathbf{p}_1,\mathbf{p}_2)}{n(\mathbf{p}_1)\, n(\mathbf{p}_2)}$$

with mean momentum $\mathbf{P} = (\mathbf{p}_1 + \mathbf{p}_2) / 2$

and momentum difference $\mathbf{q} = \mathbf{p}_2 - \mathbf{p}_1$

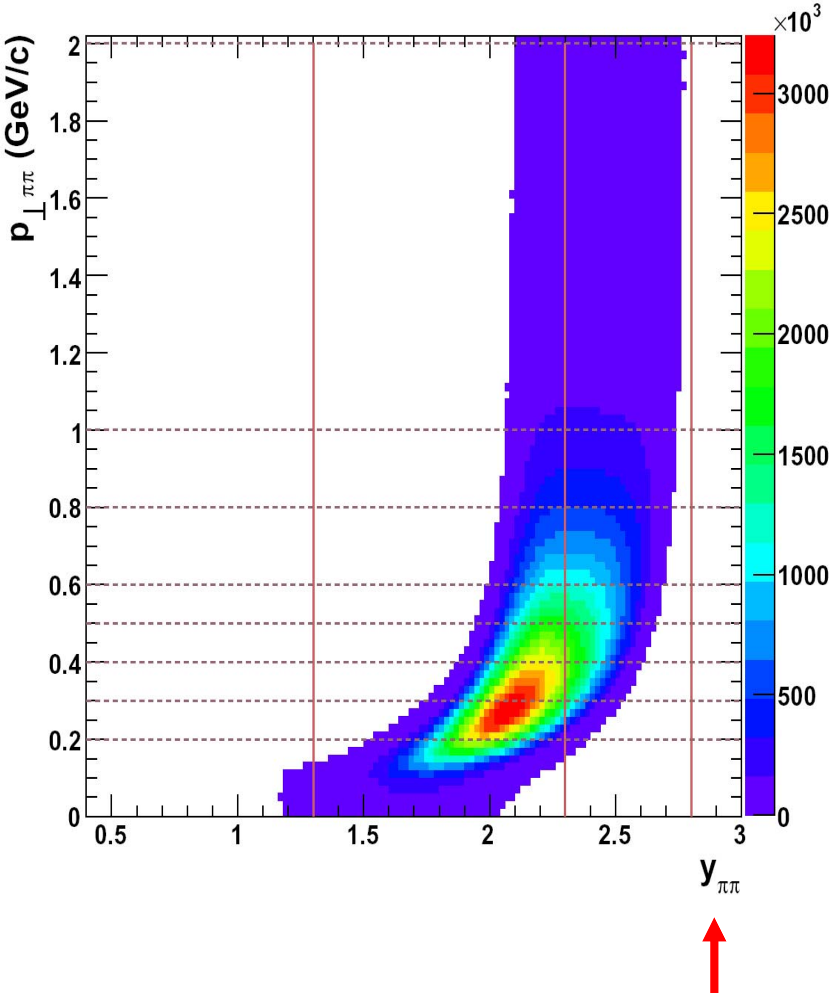
Bertsch-Pratt coordinates
LCMS frame

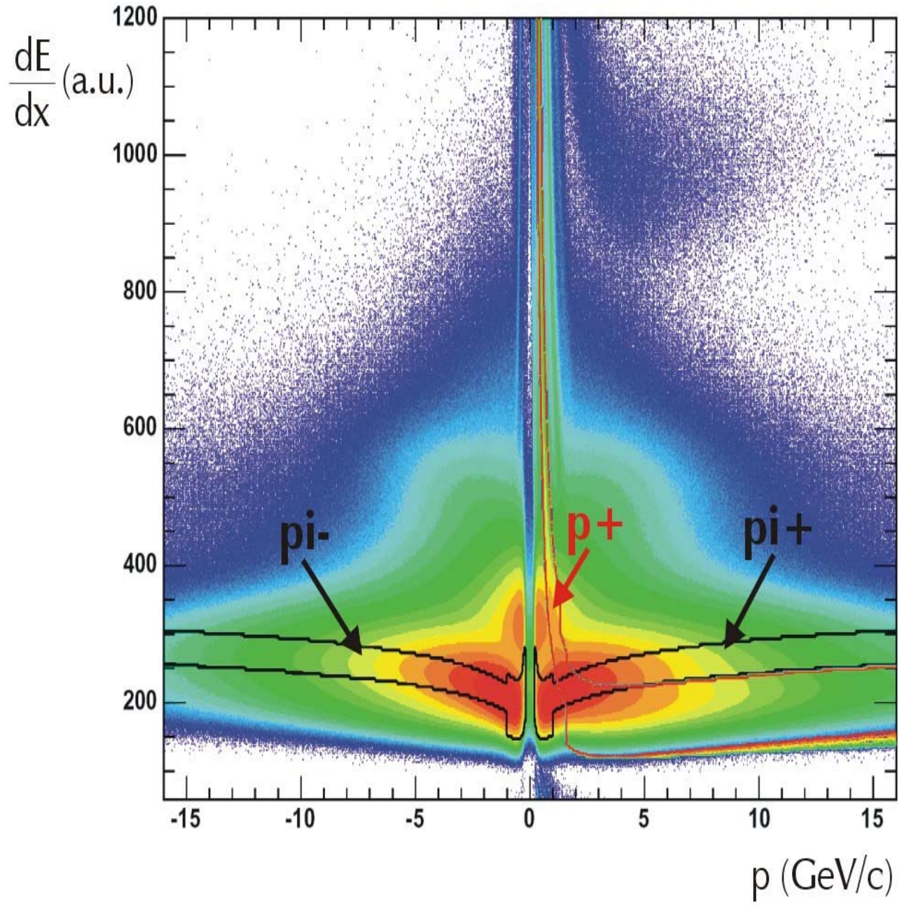
$\mathbf{q} = (q_{out}, q_{side}, q_{long})$



acceptance and particle id

Pb+Au at 158 AGeV



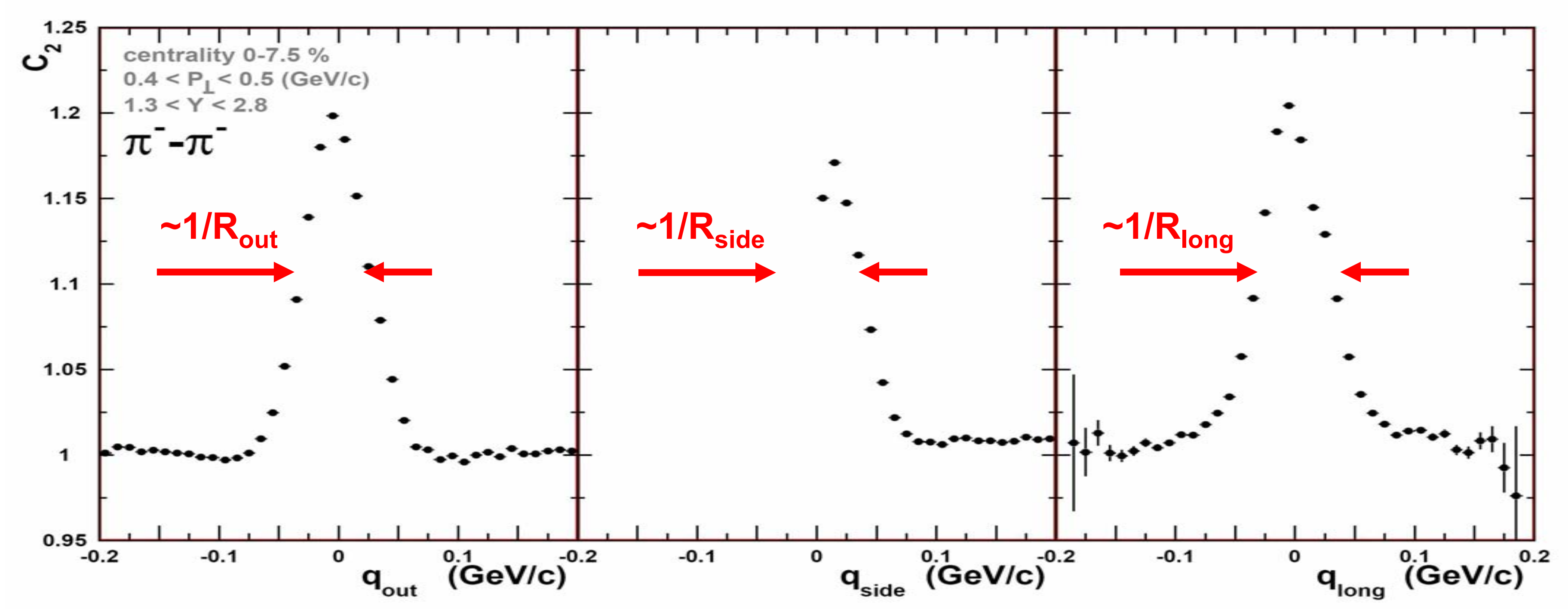


midrapidity: y=2.91

two-pion correlation function

Pb+Au at 158 AGeV

D. Antonczyk



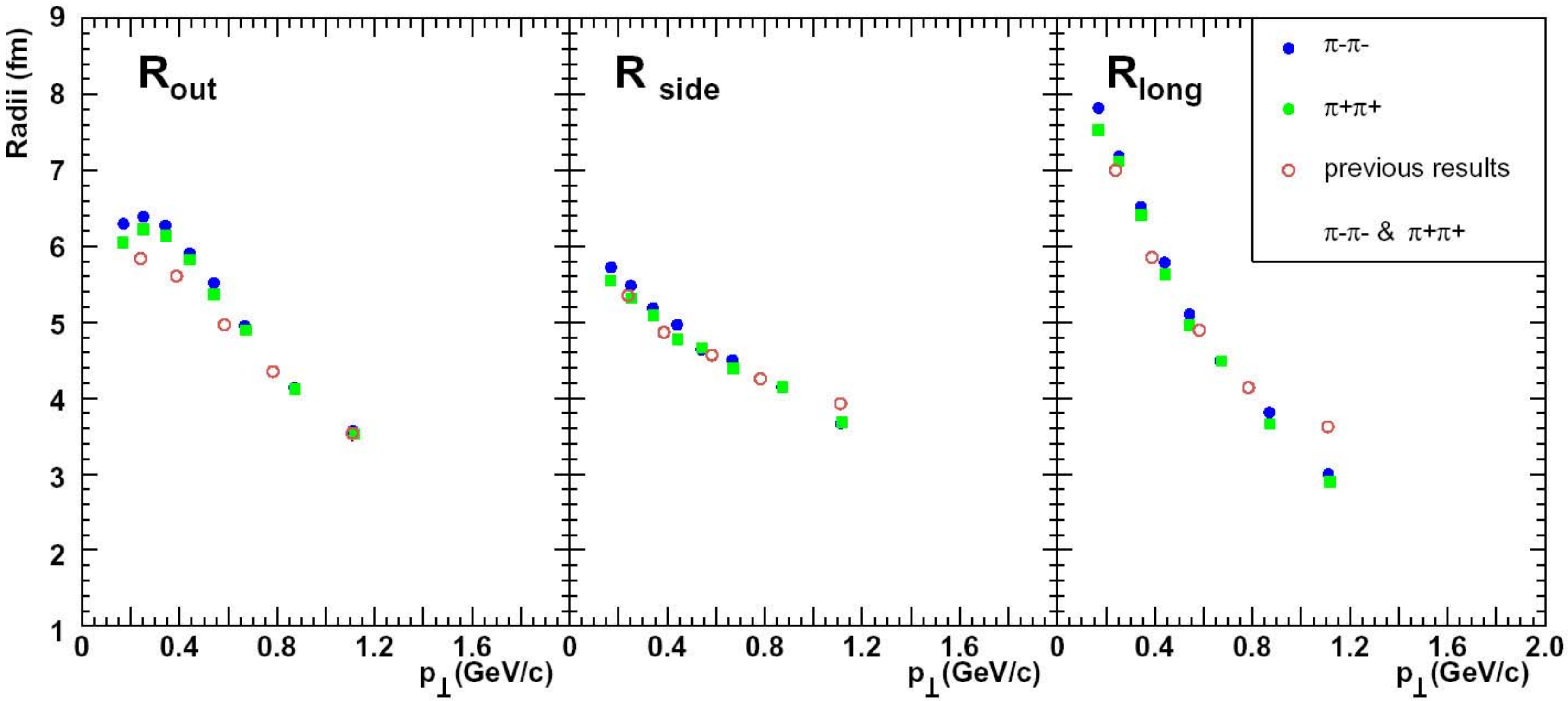
fit with $$C_2(q) = 1 + \lambda \exp\left\{ -\sum_{i,j} R_{i,j}^2 q_i q_j \right\}$$ *with i,j = out, side, long*

correct for Coulomb and finite momentum resolution

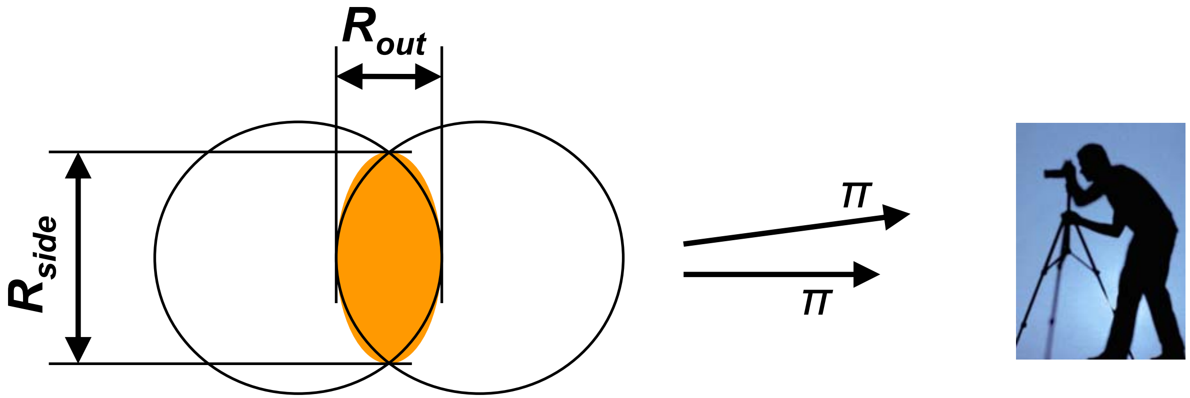
HBT radii: pt dependence

Pb+Au at 158 AGeV
centrality 5%

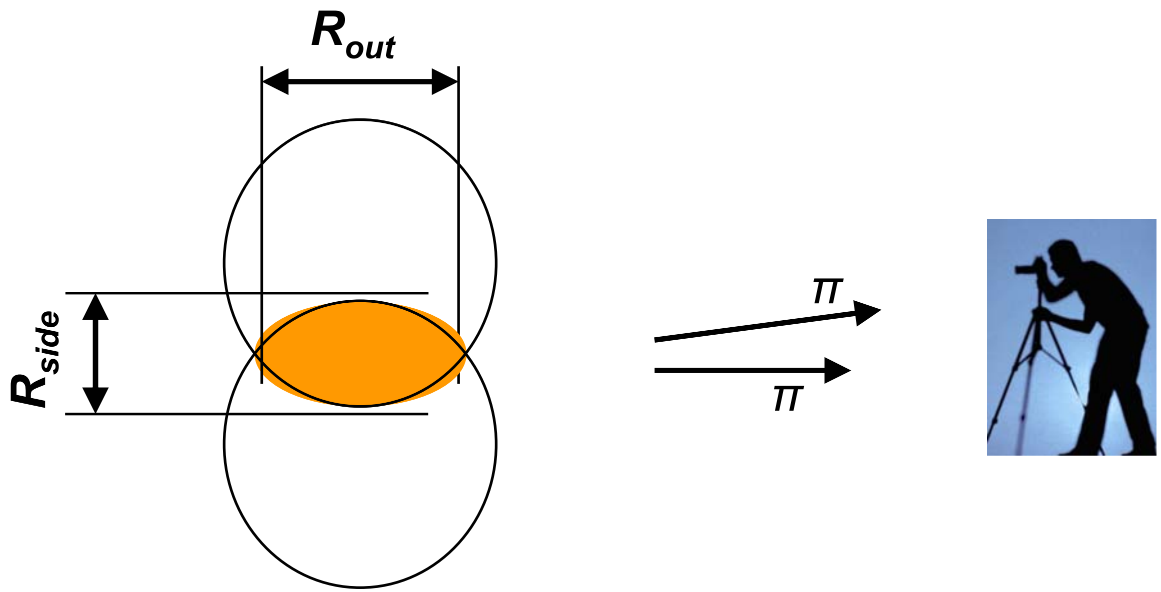
D. Antonczyk



HBT radii vs azimuthal pion angle - expectation

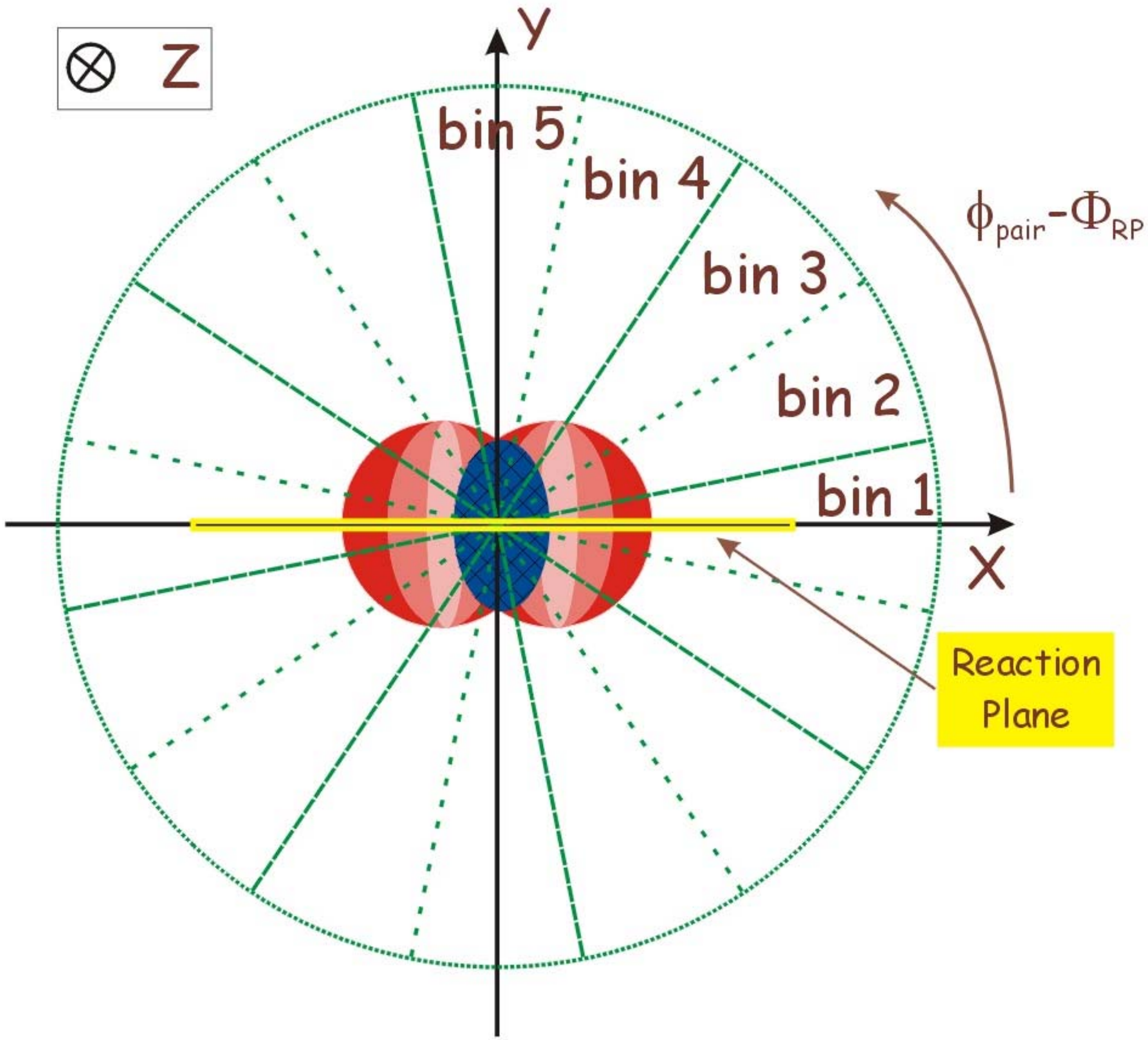


in-plane

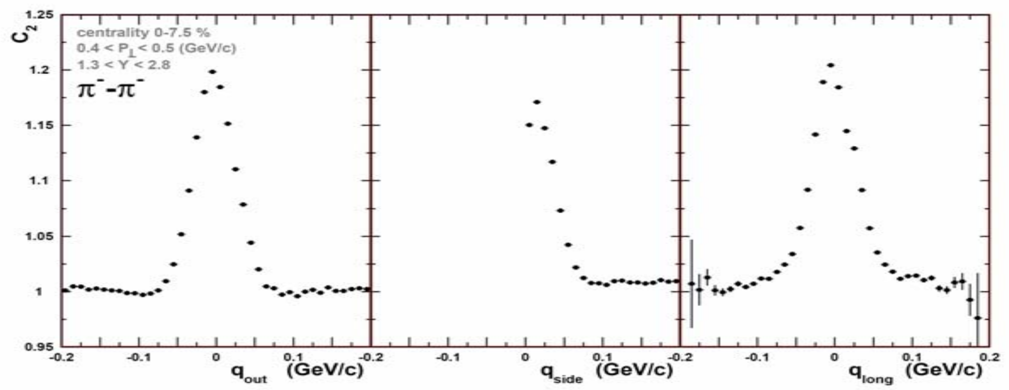


out-of-plane

HBT radii in bins of the azimuthal pair angle



pion-pion correlation function



3-dimensional fit to C_2 performed
R_{out}, R_{side}, R_{long}, R_{ol}, R_{os}, R_{sl} extracted } *separately in each Φ-bin*

$\boldsymbol{\Phi = \Phi_{\pi\pi} - \Phi_{RP}}$

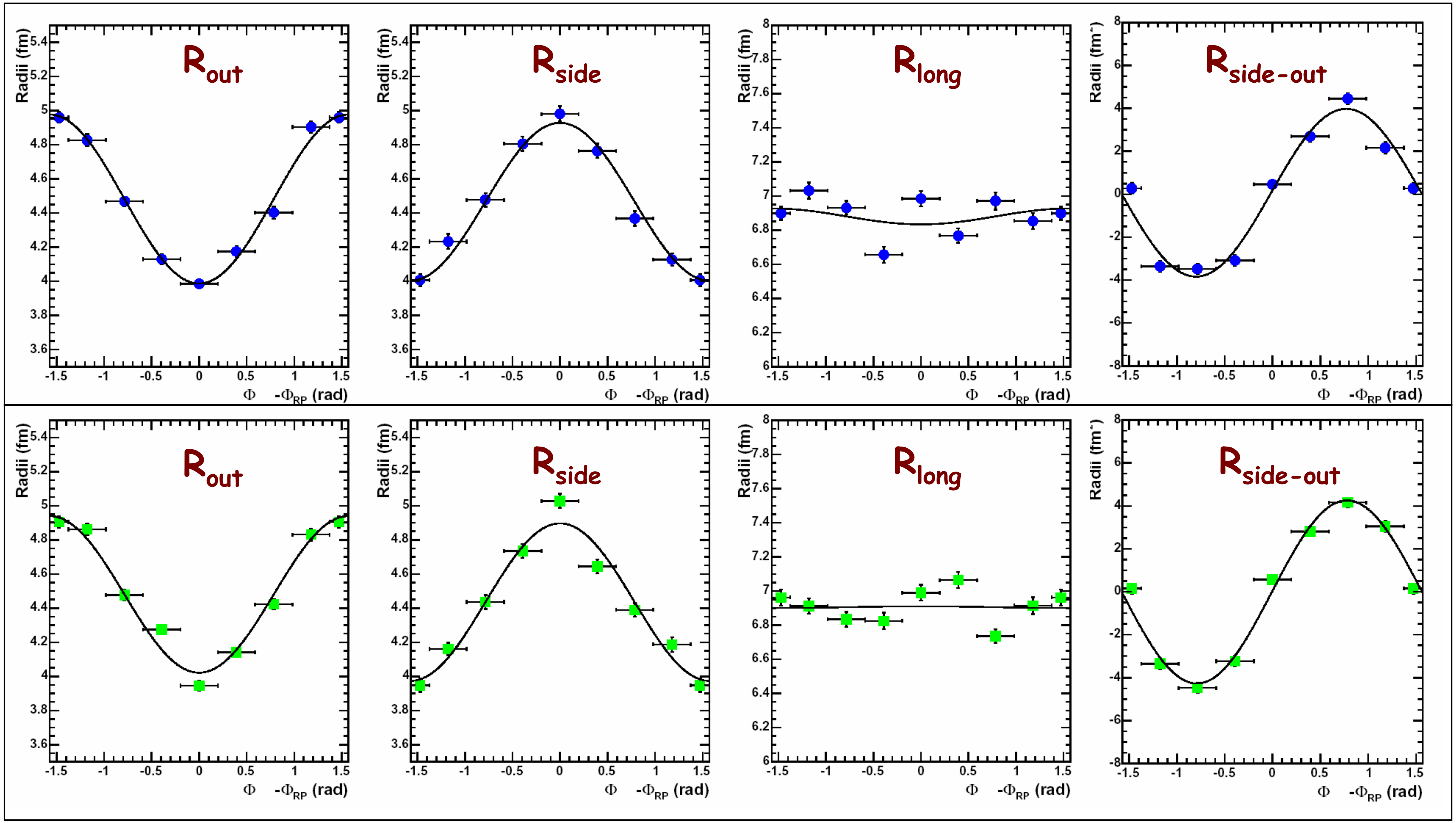
azimuthal pair angle with respect to the RP

azimuthal angle dependence of the HBT radii - simulation

D. Antonczyk

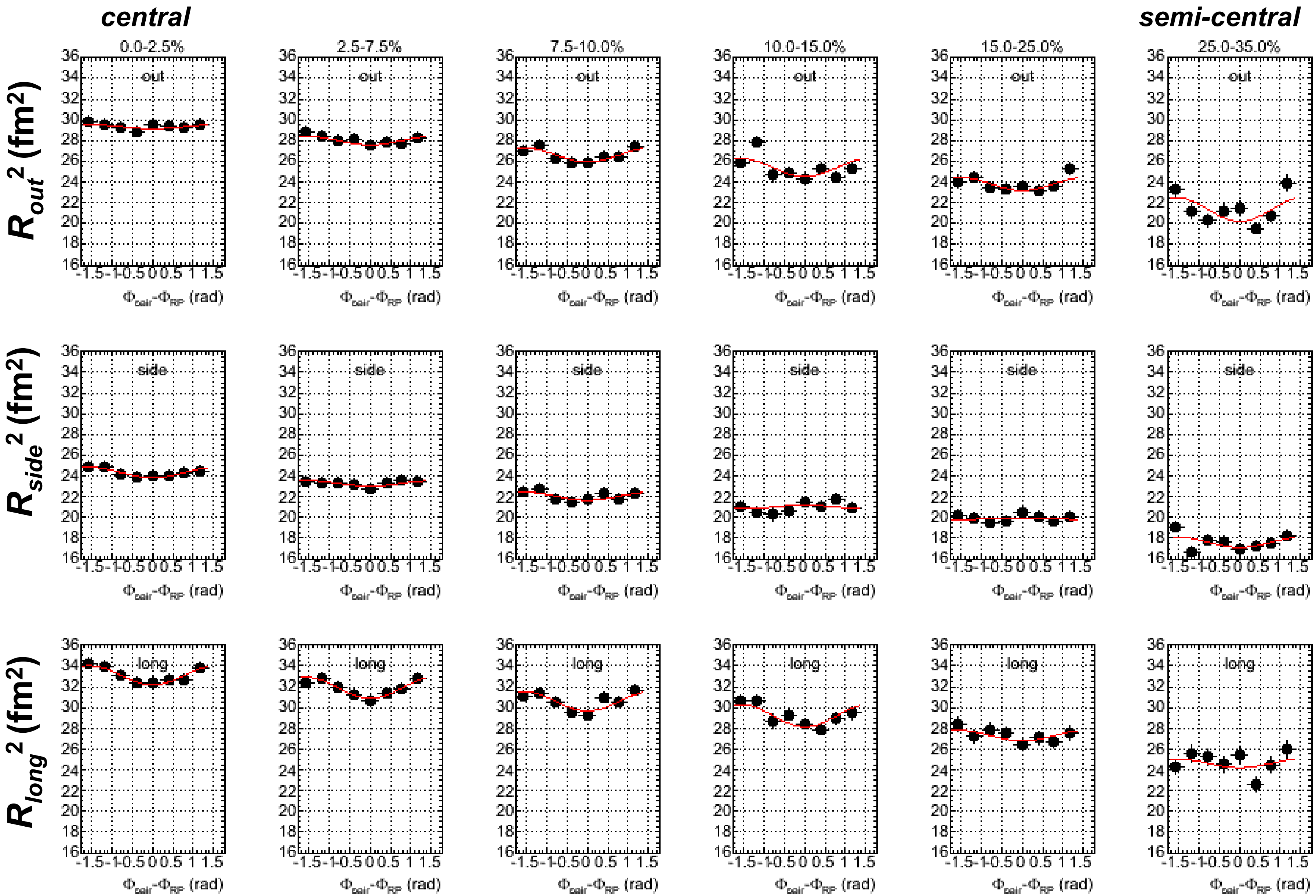
● $\pi^-\pi^-$
● $\pi^+\pi^+$

Gaussian source parameterization with R_x = 4 (fm), R_y = 5 (fm), R_z = 7 (fm)



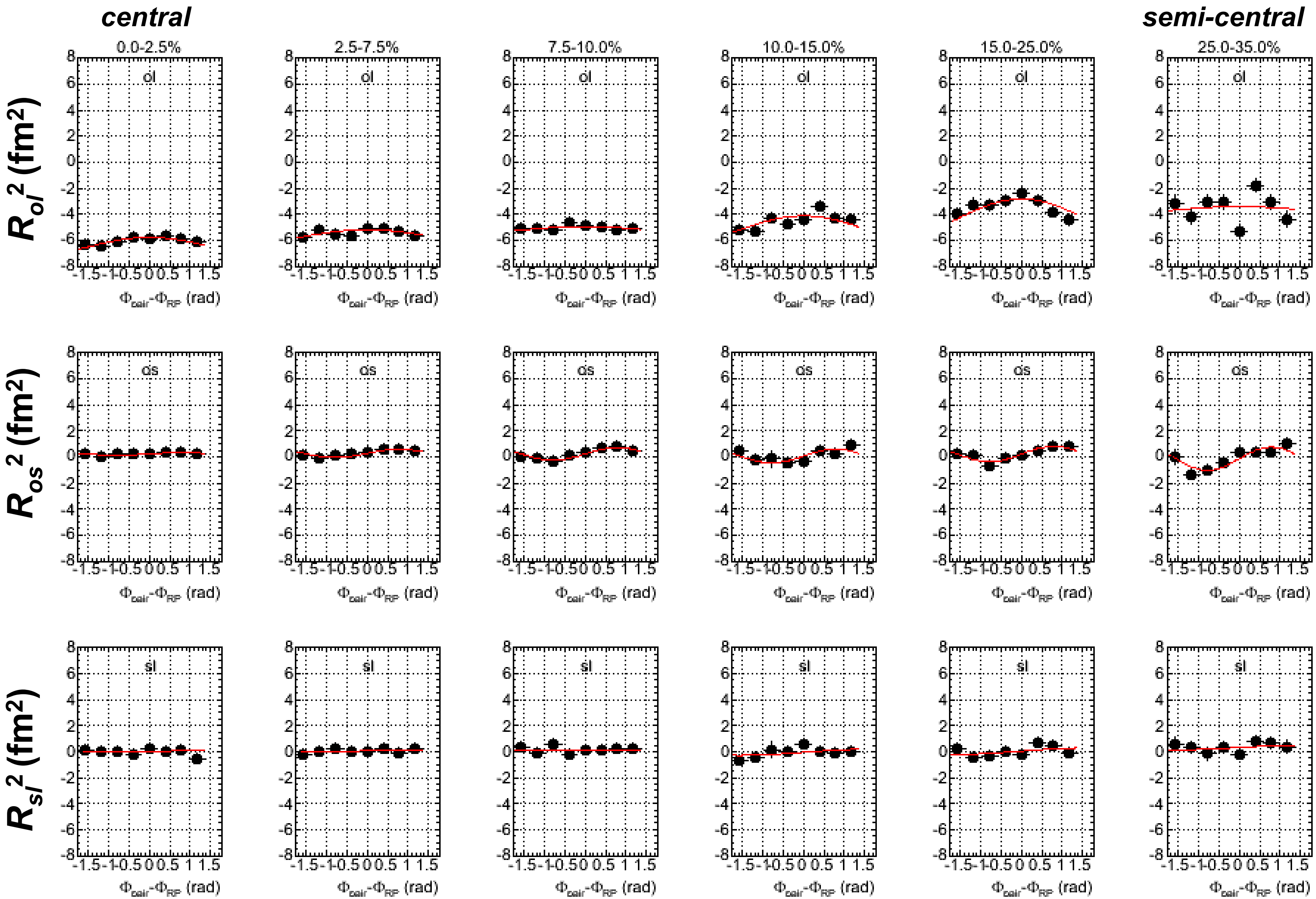
azimuthal angle dependence of HBT radii

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



azimuthal angle dependence of HBT radii

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

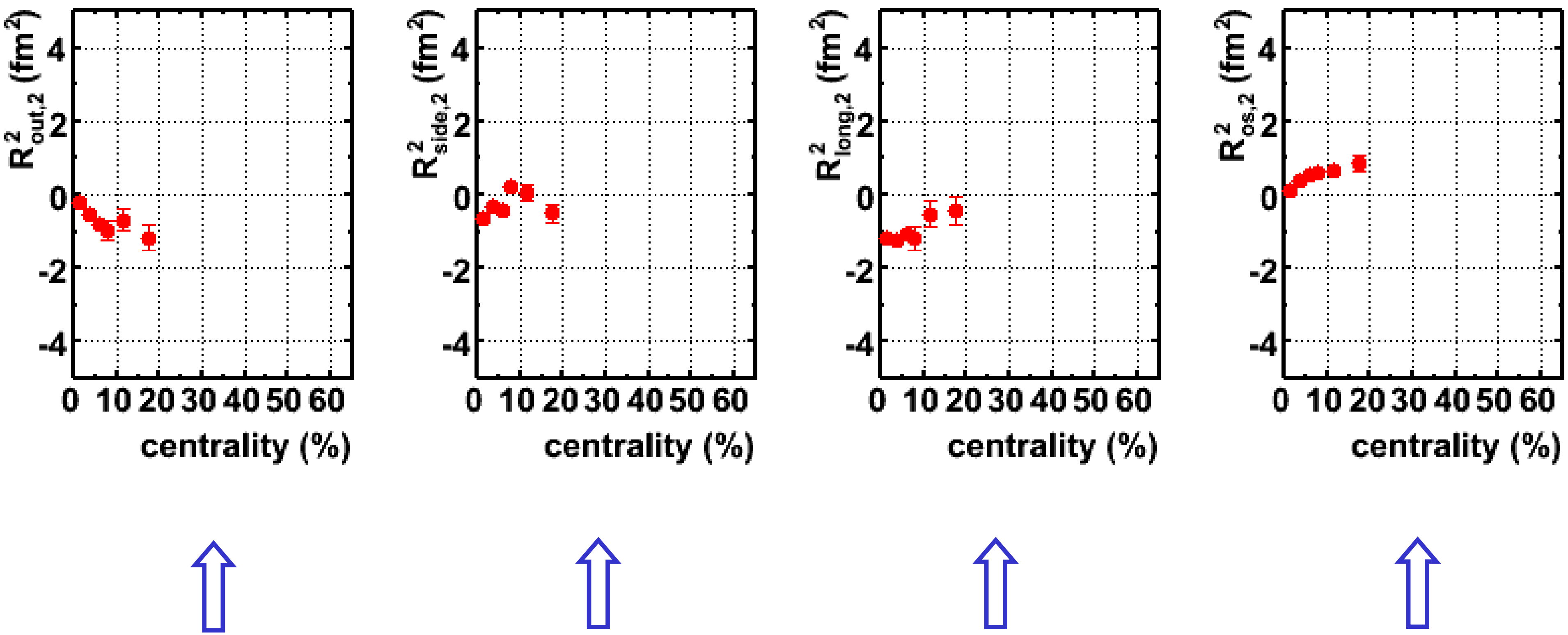


pion source size anisotropy

Pb+Au at 158 AGeV
preliminary

D. Antonczyk

parametrize the oscillation with $R_i^2 = R^2_{i,0} + 2\,R^2_{i,2}\cos[2(\Phi_{\pi\pi}-\Phi_{RP})]$ →



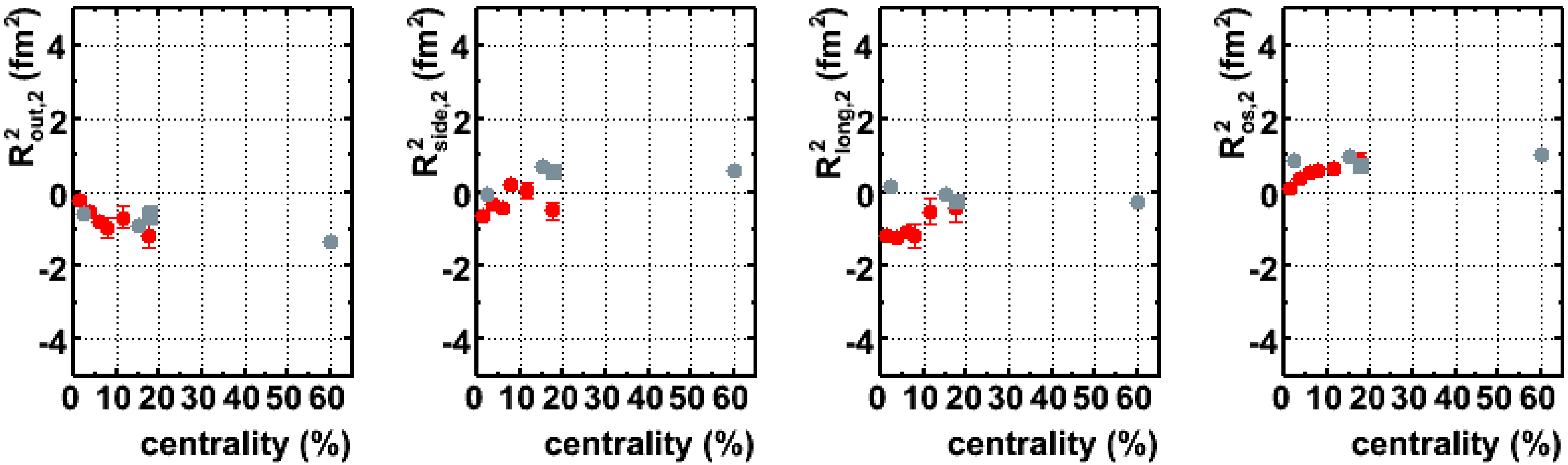
suggests an out-of-plane elongation

no effect -- inconsistent with R_{out}

significant -- against expectation and symmetry

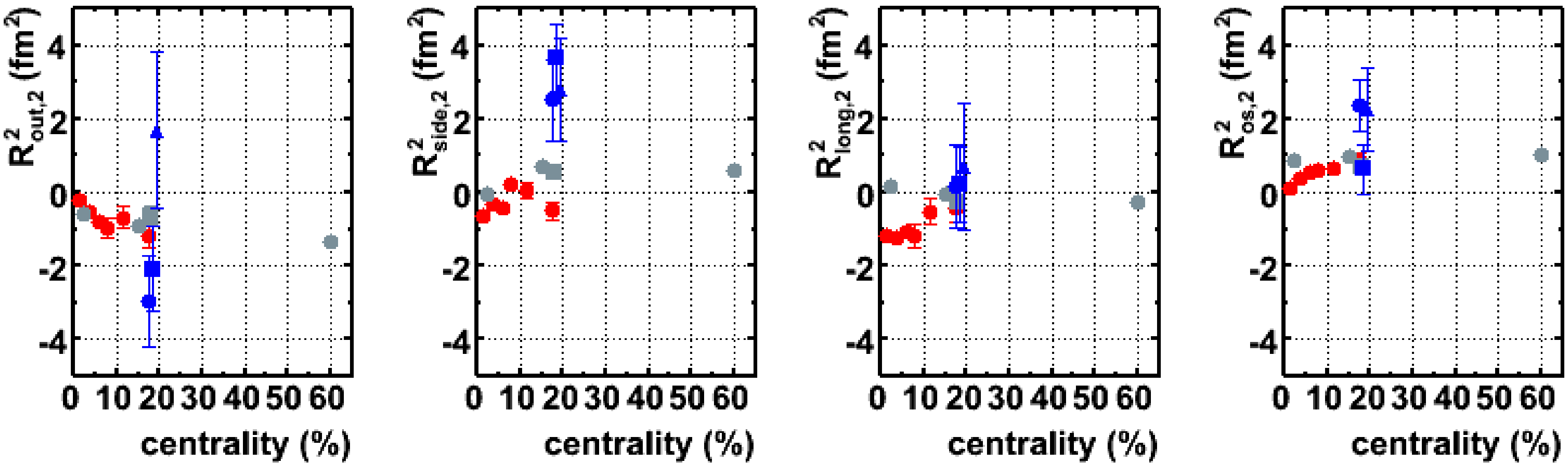
consistent with R_{out}

...compared to RHIC



● CERES	158 AGeV	<pt> = 0.47 GeV/c	D. Antonczyk, Ph.D.
■ STAR	sqrt(s) = 130 GeV	0.125<pt<0.45 GeV/c	
● STAR	sqrt(s) = 200 GeV	0.15<pt<0.6 GeV/c	PRL 93 (2004) 012301

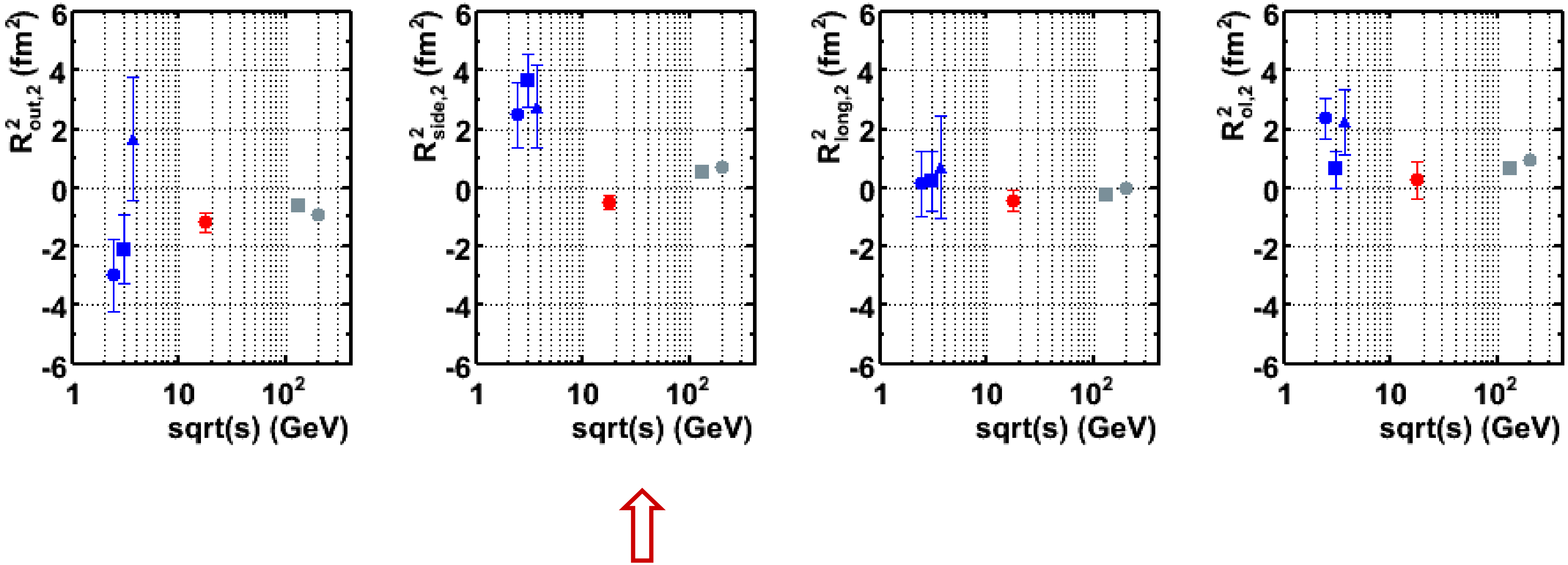
... and AGS



E895	● 2, ■ 4, ▲ 6 AGeV	<pt> = 0.11 GeV/c	Phys. Lett. B 496 (2000) 1
● CERES	158 AGeV	<pt> = 0.47 GeV/c	D. Antonczyk, Ph.D.
■ STAR	sqrt(s) = 130 GeV	0.125<pt<0.45 GeV/c	
● STAR	sqrt(s) = 200 GeV	0.15<pt<0.6 GeV/c	PRL 93 (2004) 012301

source anisotropy vs sqrt(s)

Pb+Au, Au+Au
centrality 15-20%



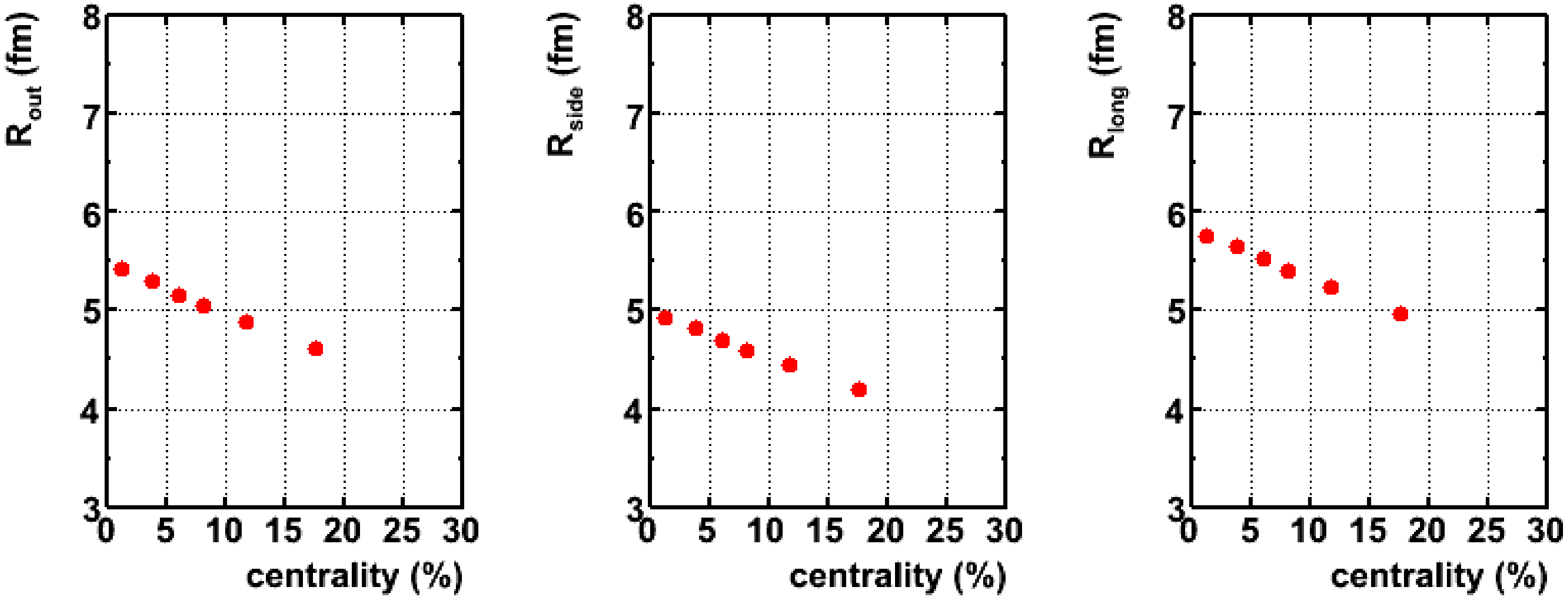
- ***non-monotonic behavior of R_{side}***
- ***R_{side} inconsistent with R_{out} → different freeze-out times in-plane and out-of-plane?***

backup slides

HBT radii: centrality dependence

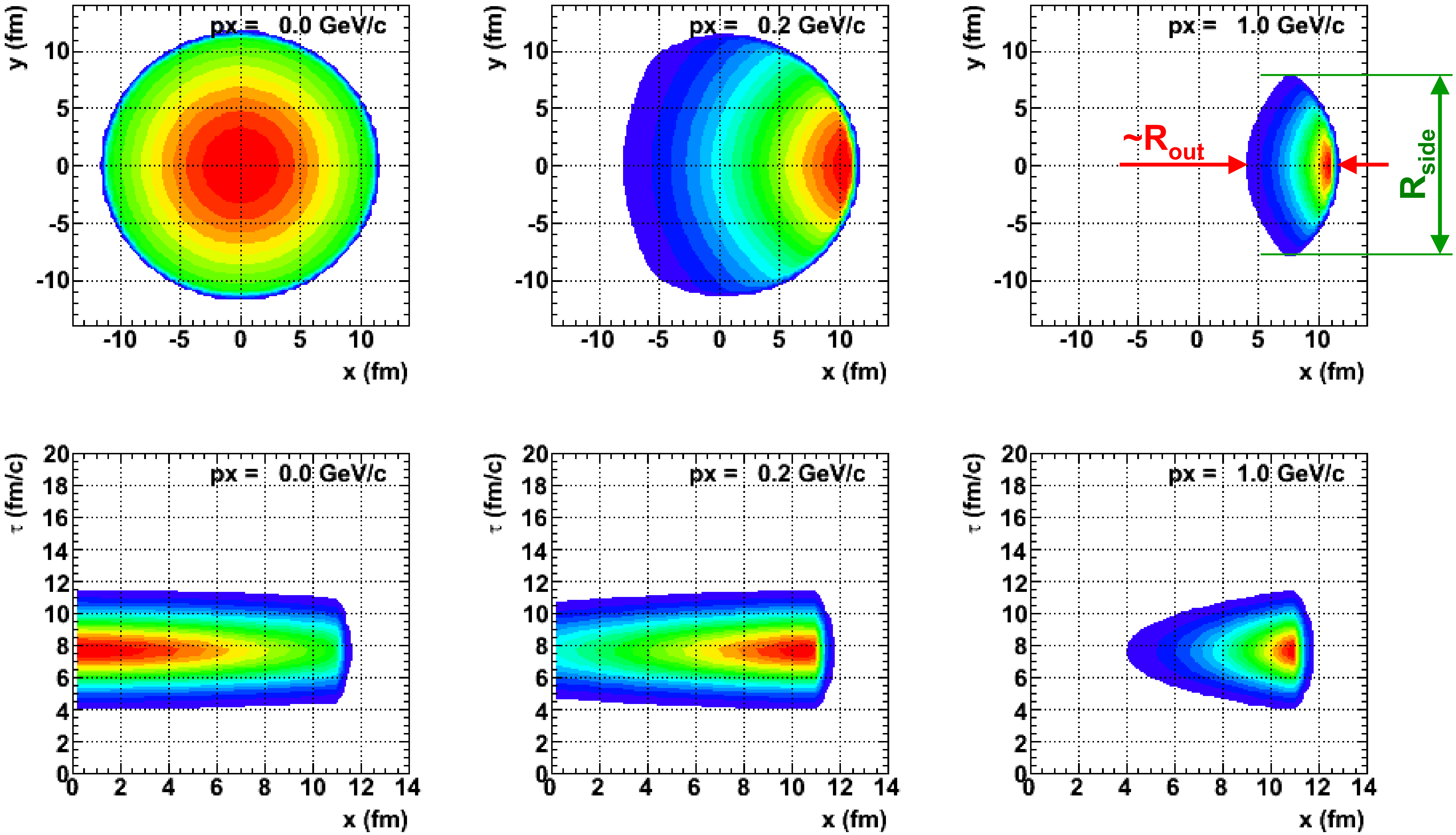
Pb+Au at 158 AGeV
$< p_t >$ = 0.47 GeV/c

D. Antonczyk

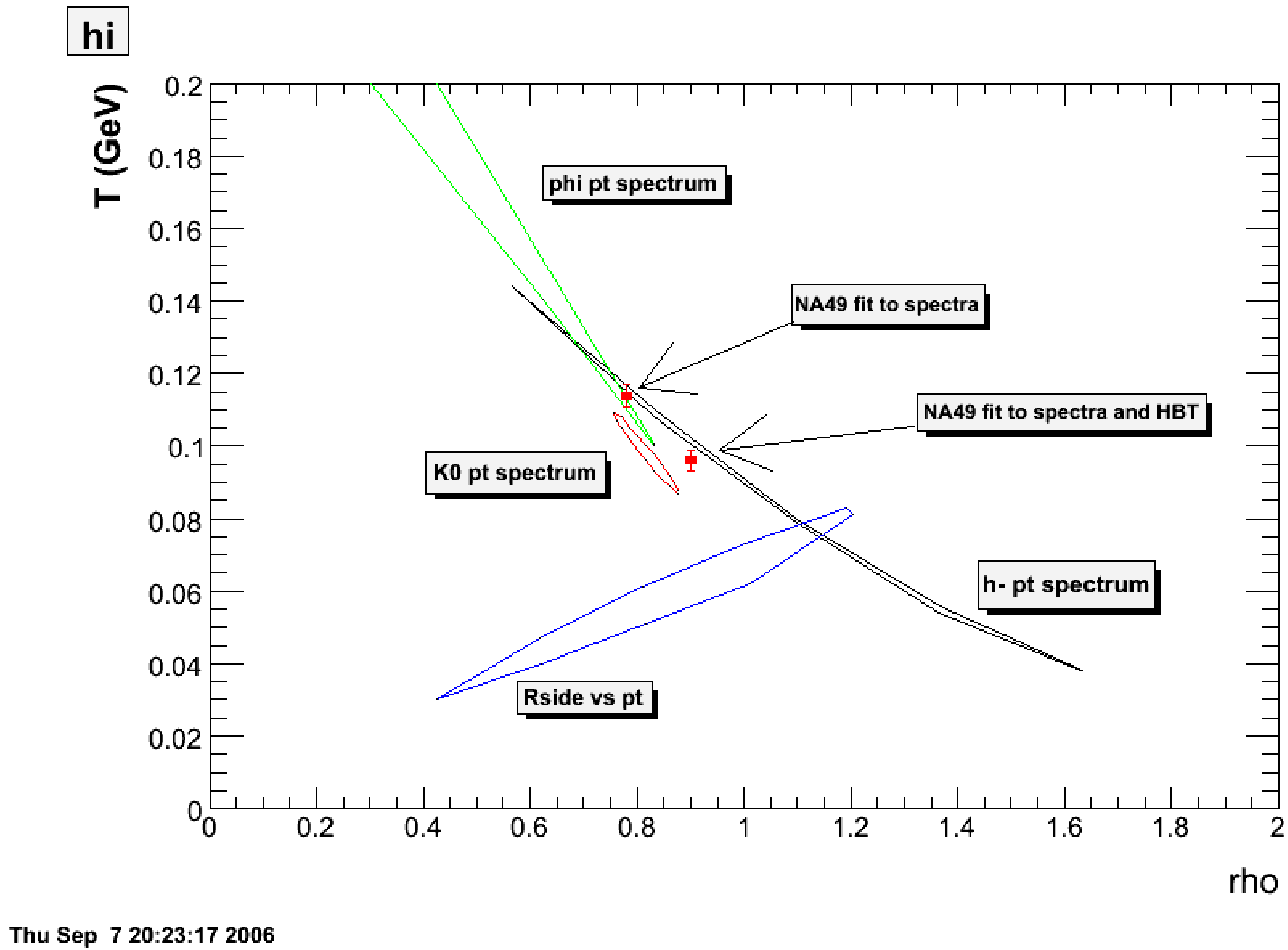


centrality is defined as σ/σ_{GEOM}
with σ_{GEOM} = 6.94 b

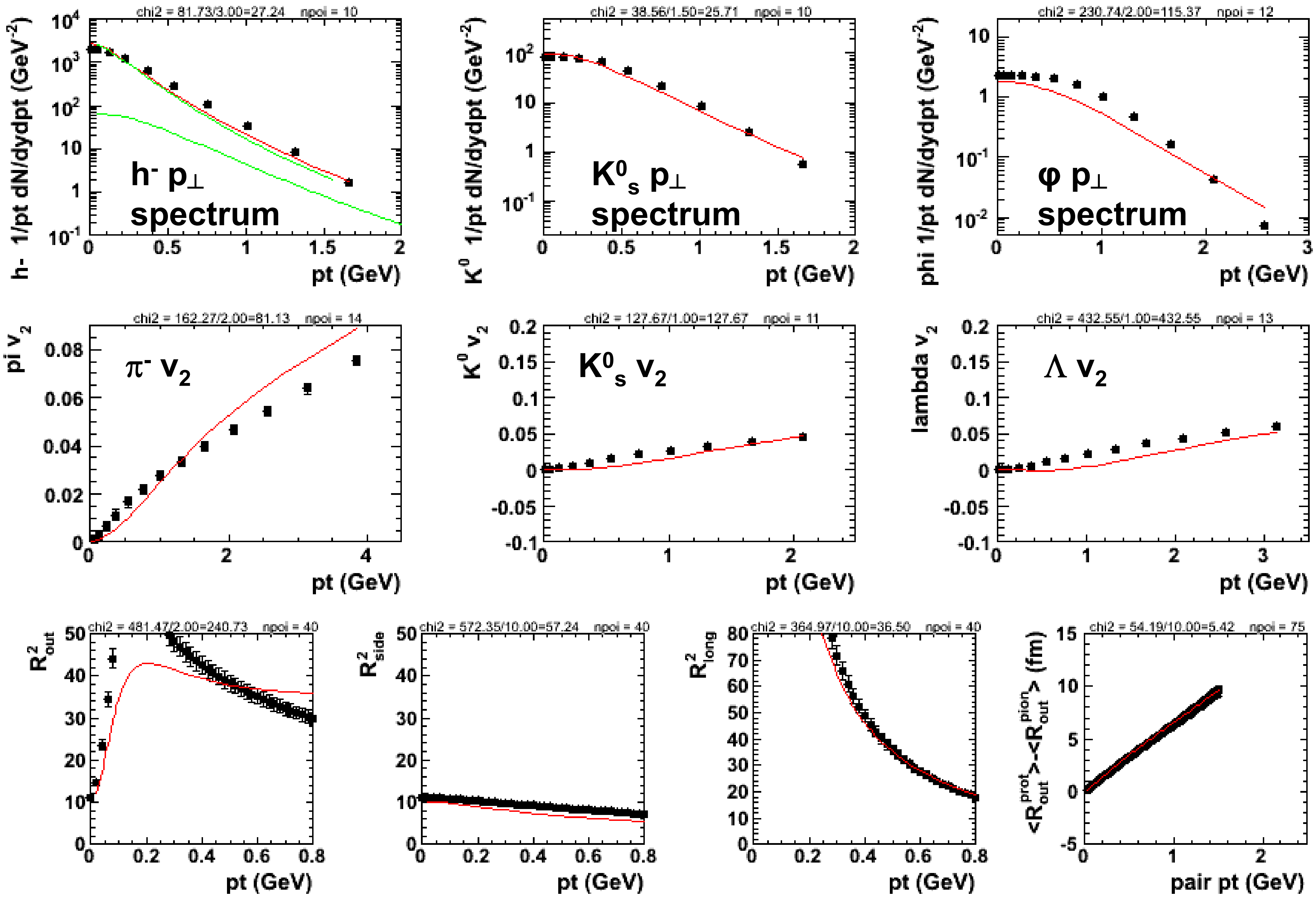
blast - source shape



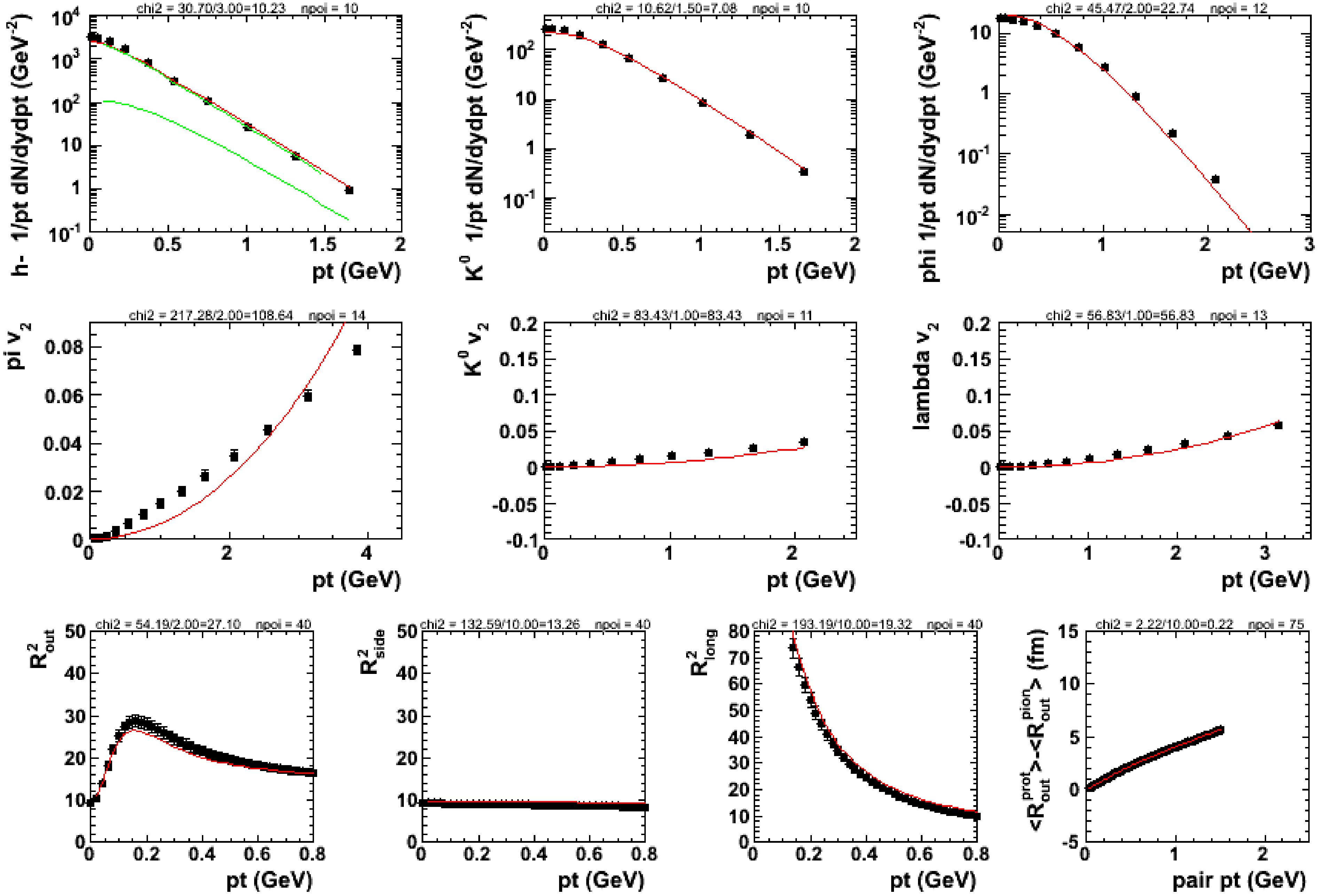
T - ρ contours


hi
T (GeV)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
rho
phi pt spectrum
NA49 fit to spectra
NA49 fit to spectra and HBT
K0 pt spectrum
h- pt spectrum
Rside vs pt
Thu Sep 7 20:23:17 2006

hydro 120 MeV (points) and blast as=0.3 (lines)



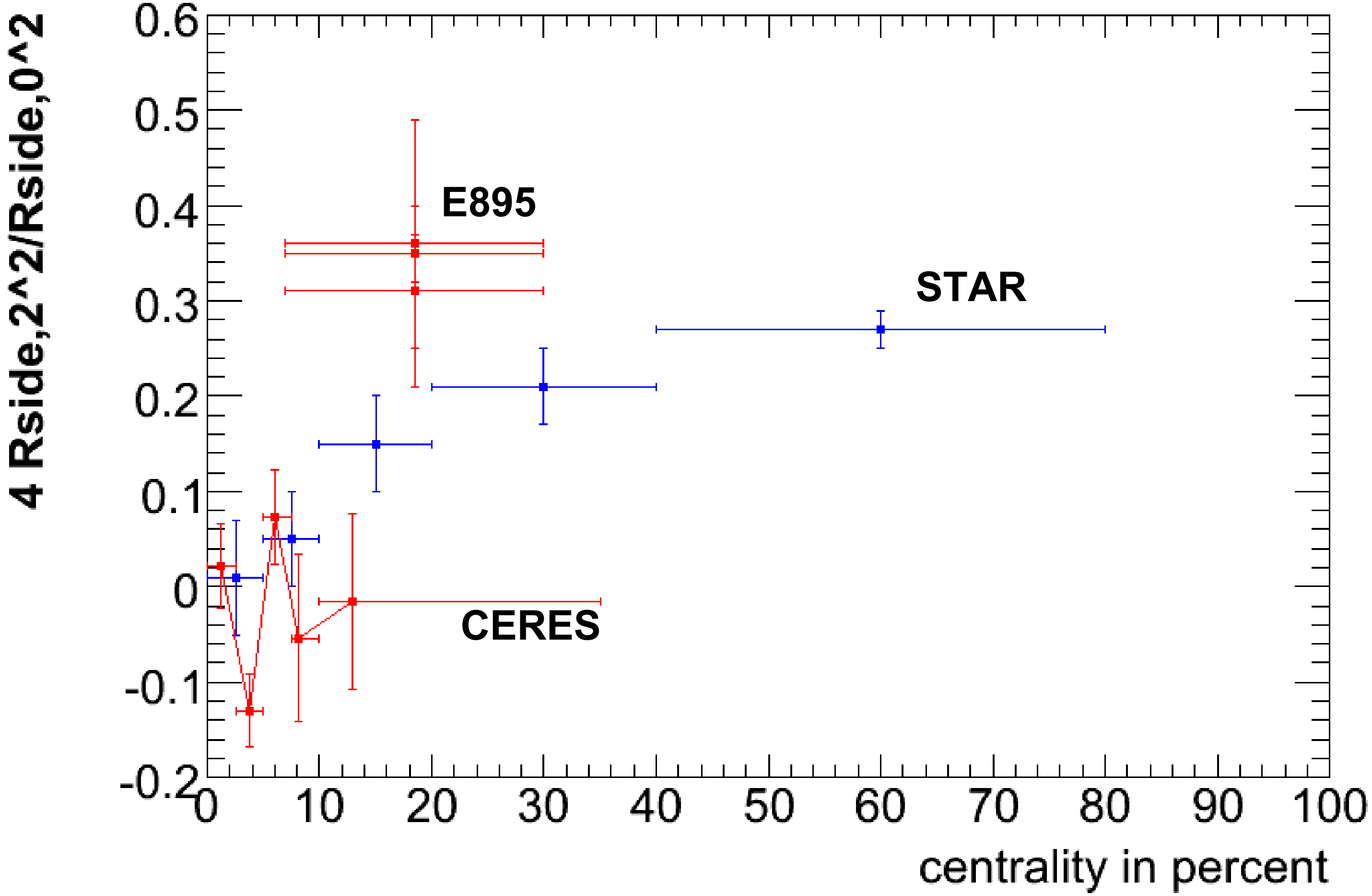
hydro 160 MeV (points) and blast as=0.3 (lines)



Source anisotropy from HBT

E895 PLB 496 (2000) 1
STAR nucl-ex/0312009

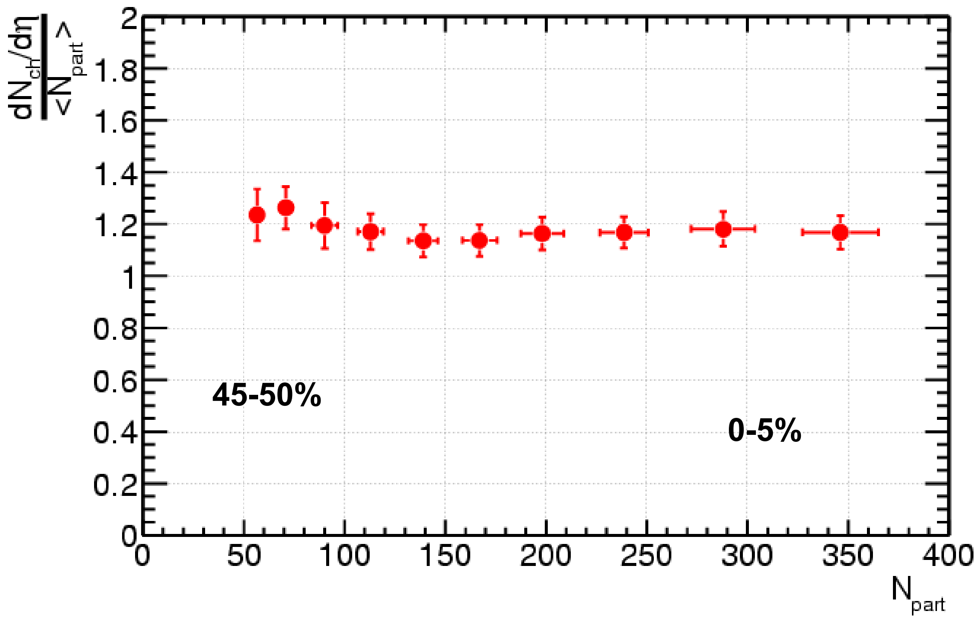
relative R_{side} asymmetry vs centrality



charged particle multiplicity

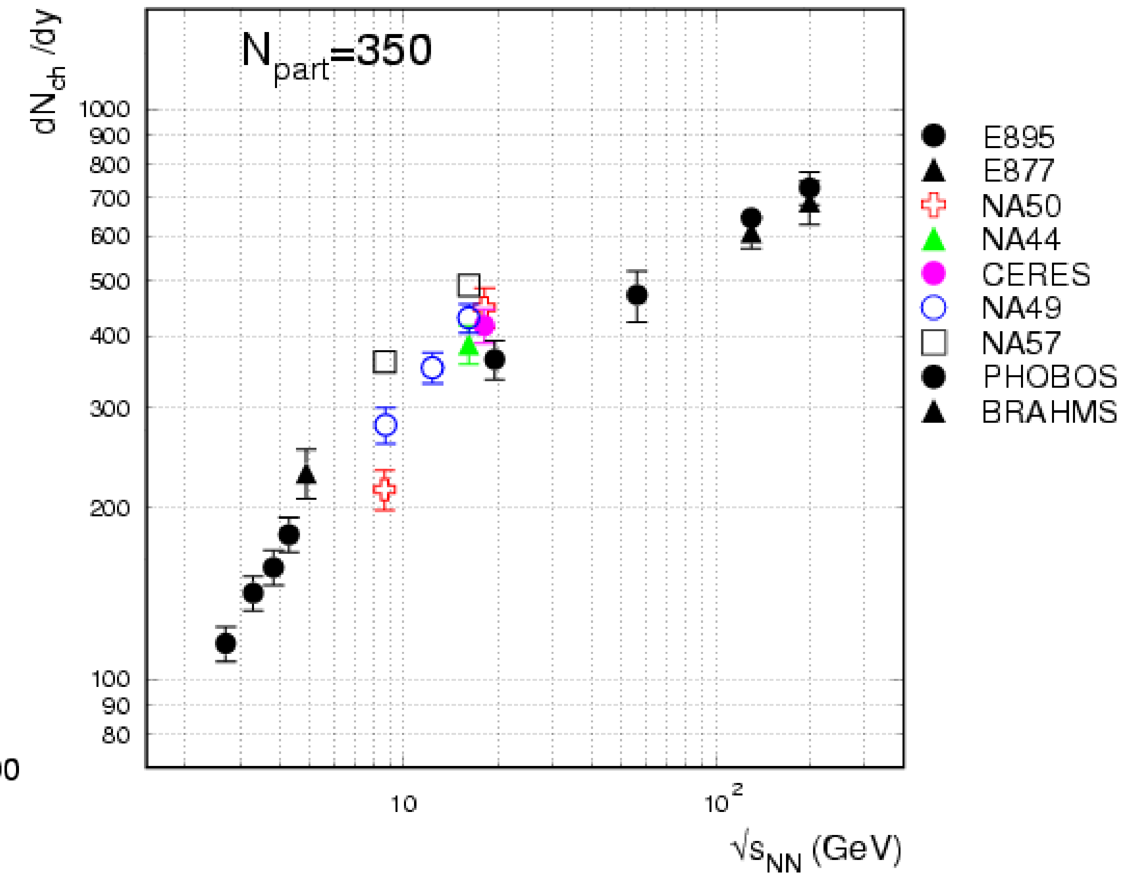
Pb+Au at 158 GeV per nucleon

charged particle multiplicity determined from hits in the two silicon detectors



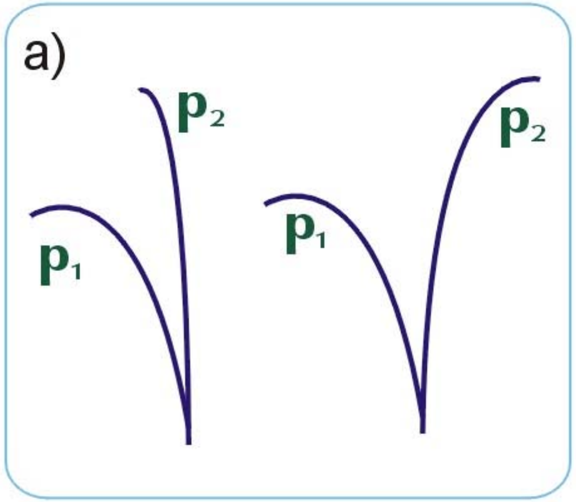
flat N_{ch} per participant

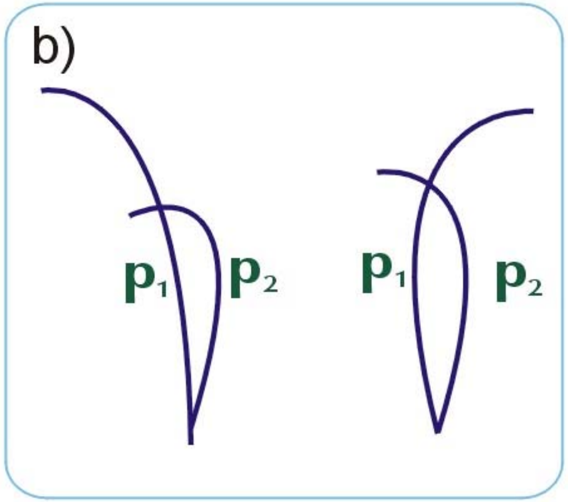
dNch/dη in central collisions of Au or Pb
compilation by A. Andronic



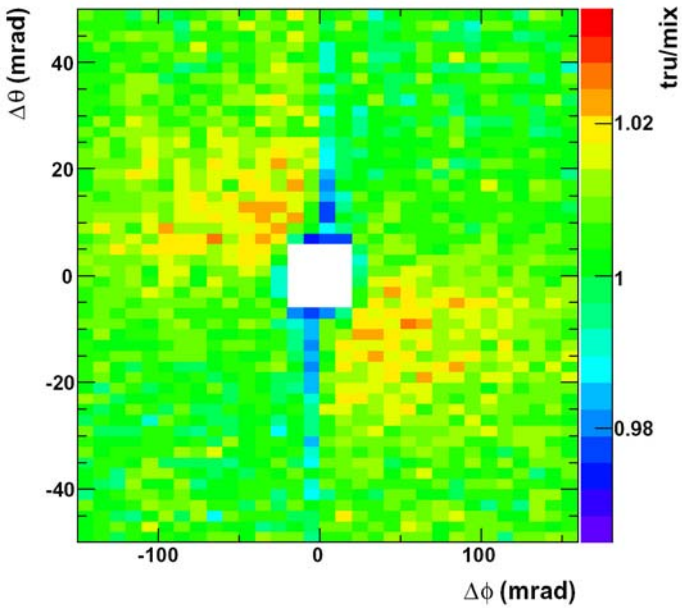
good agreement in dNch/dη between CERES, NA49, NA50, and NA44

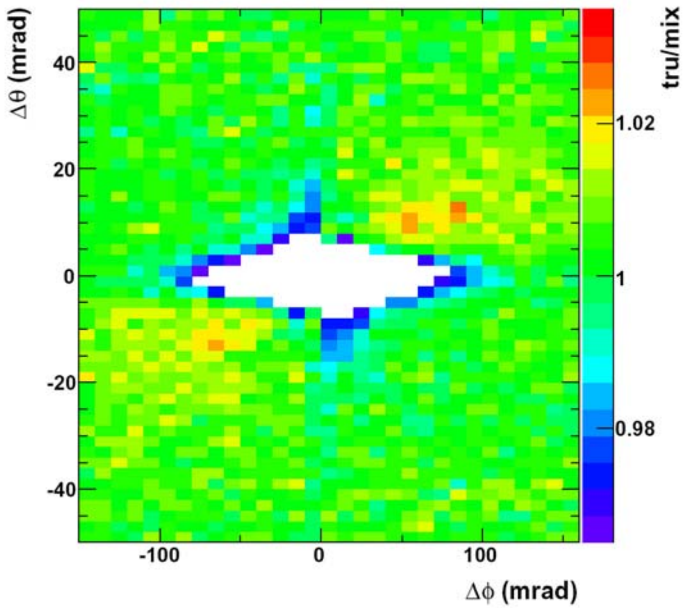
two-track cut



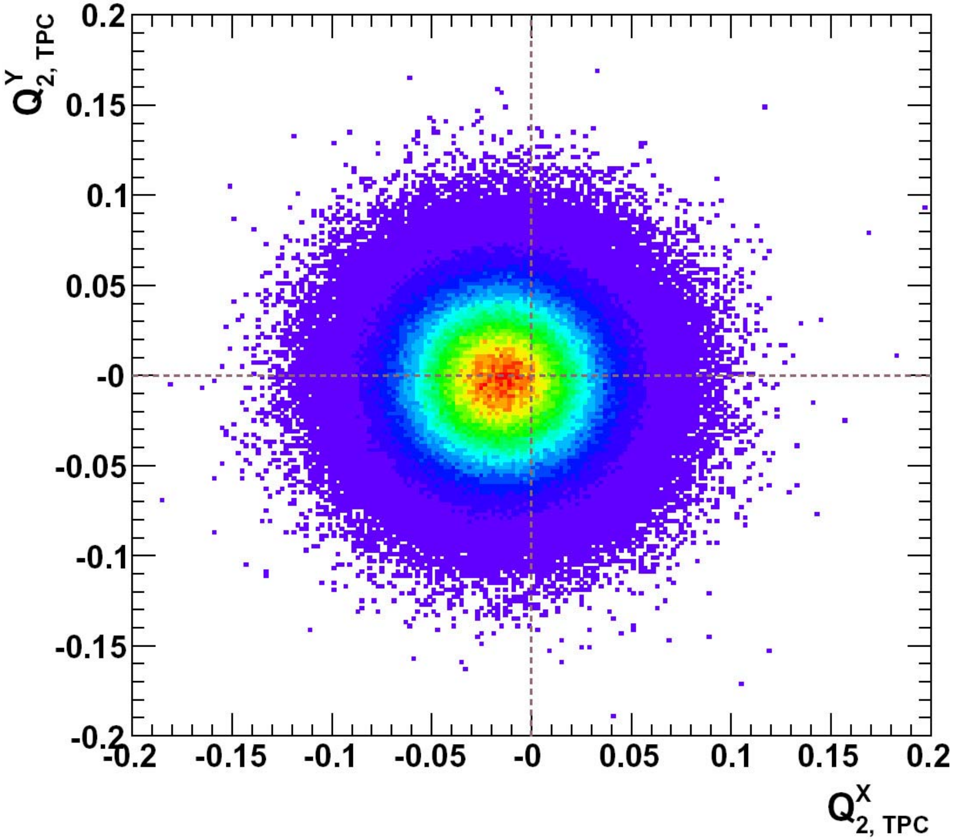


Different cuts needed for the two topologies: sailor and cowboy





determination of the reaction plane



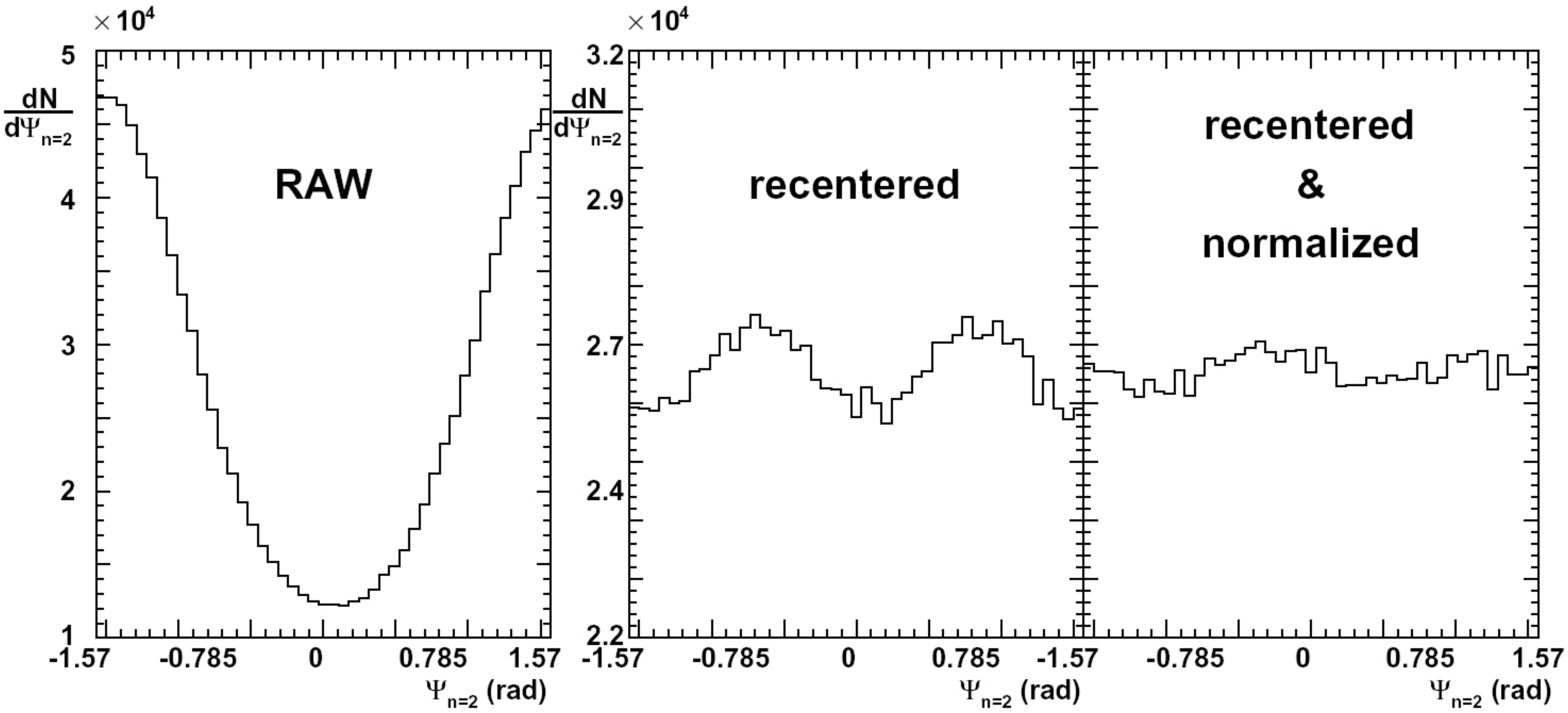
$$Q_2^X = \sum_i p_t \cdot \cos(2\varphi_i)$$

$$Q_2^Y = \sum_i p_t \cdot \sin(2\varphi_i)$$

$$\Phi_{RP} = \frac{1}{2}\arctan\left(\frac{Y_2}{X_2}\right)$$

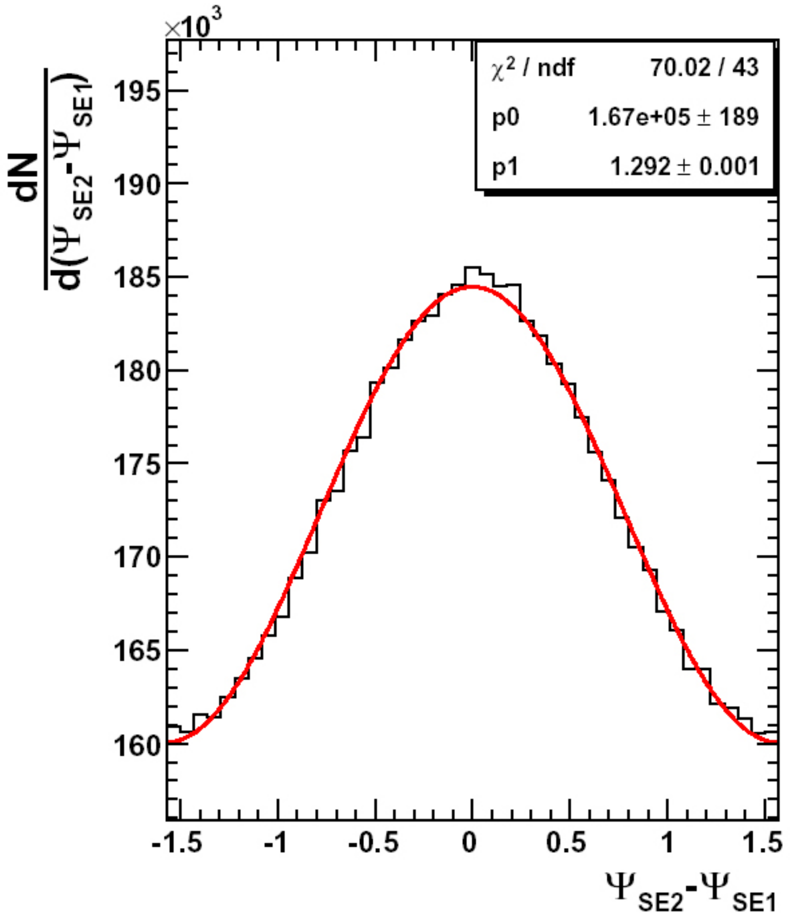
distribution of the reaction plane angle

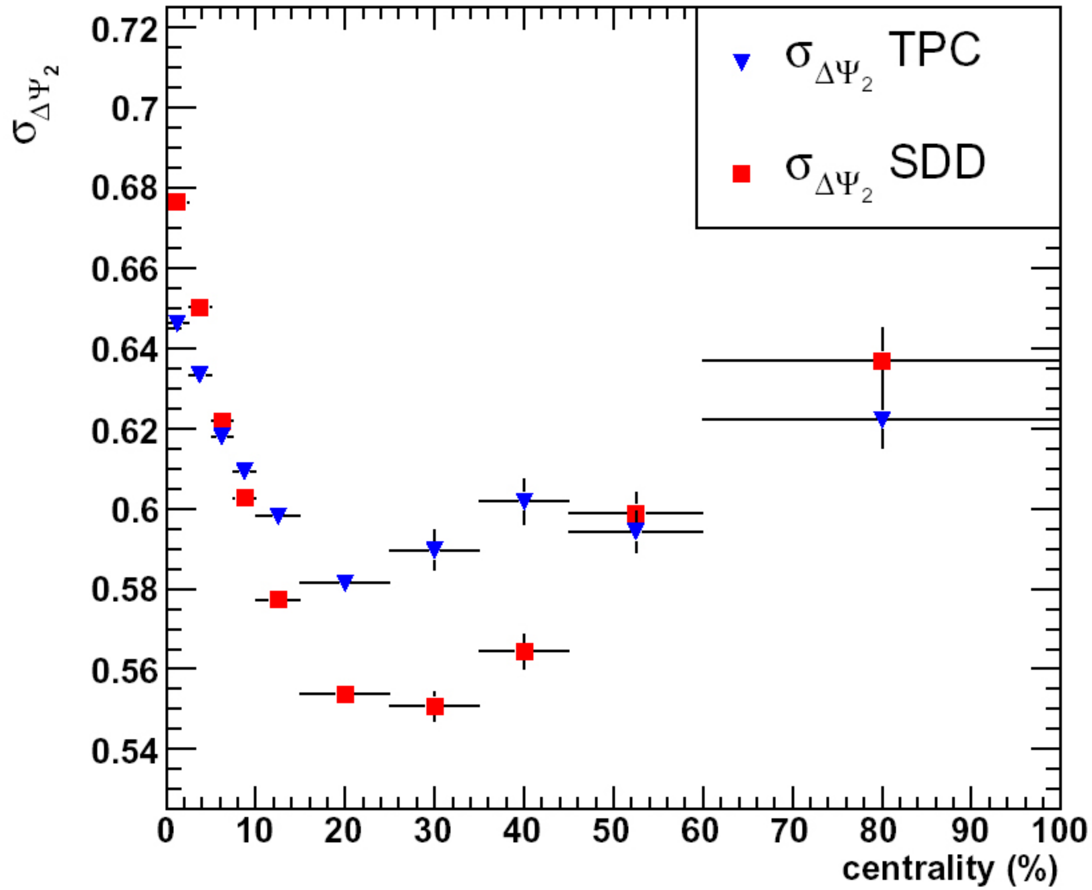
D. Antonczyk



resolution of the reaction plane

D. Antonczyk





resolution 31° - 38° (depending on centrality)