Oscillating HBT radii and the time evolution of the source

200 GeV Au+Au data analyzed with asBuda-Lund

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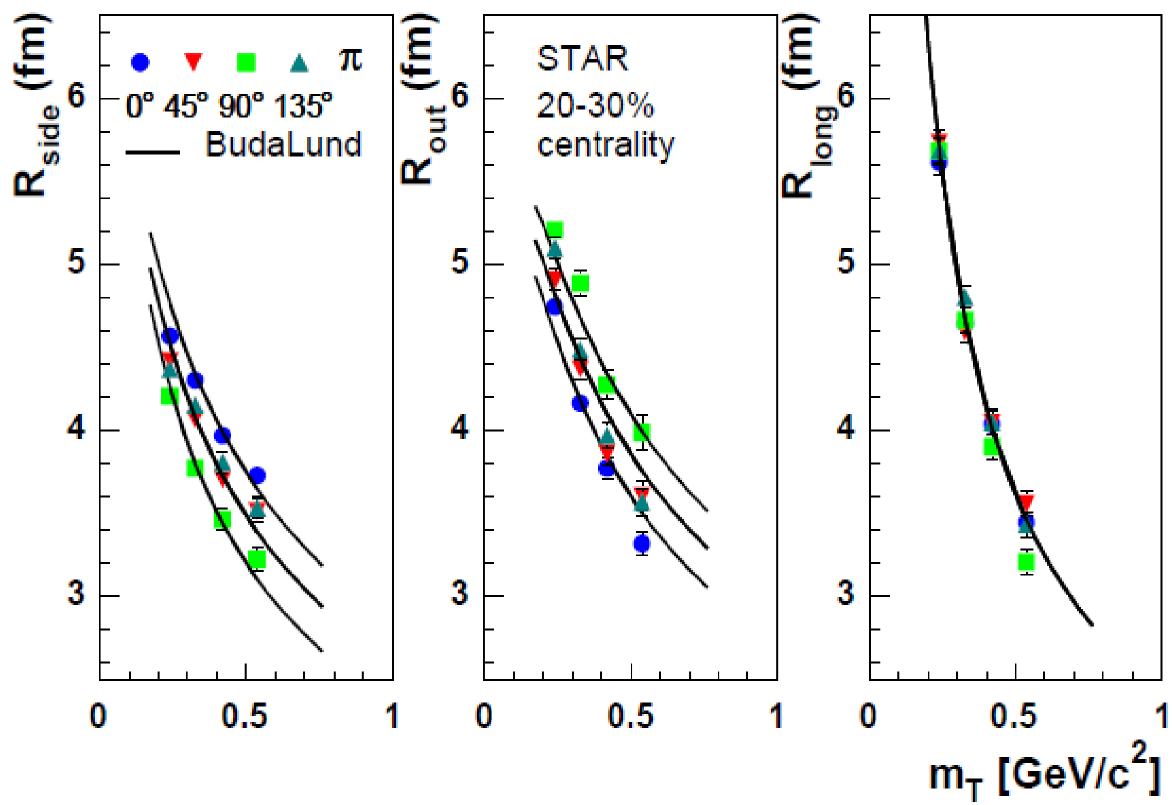


Motivation

- Exact solutions of 1+3d NR hydro with ellipsoidal symmetry

Spherical → Ellipsoidal symmetry

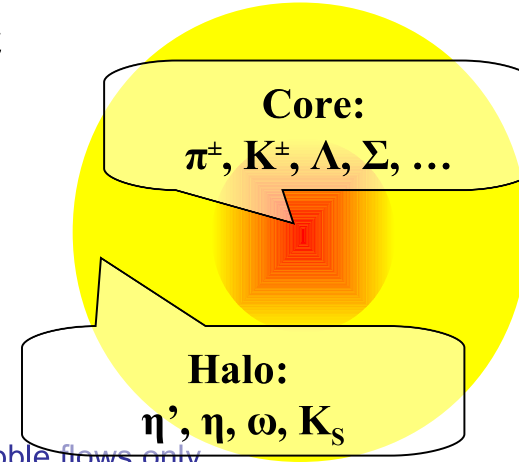
From fluid of nucleons → exact simple models for RHIC

<u>Refs</u>: J. Bondorf, S. Garpman and J. Zimányi, Nucl. Phys. A296:320-332,1978
T. Cs, S. V. Akkelin, Y. Hama, Yu. Sinyukov, Phys.Rev.C67:034904,2003
T. Cs, Acta Phys.Polon.B37:483-494,2006

Viscous solution: in preparation

Hydrodynamically evolving core + halo of resonances

<u>Ref</u>: T. Cs, B. Lörstad and J. Zimányi, Z.Phys.C71:491-497,1996



- Generalization to relativistic solutions

<u>Ref</u>: T. Cs, L.P. Csernai, Y. Hama, T. Kodama, Heavy Ion Phys.A21:73-84,2004 , but for Hubble flows only

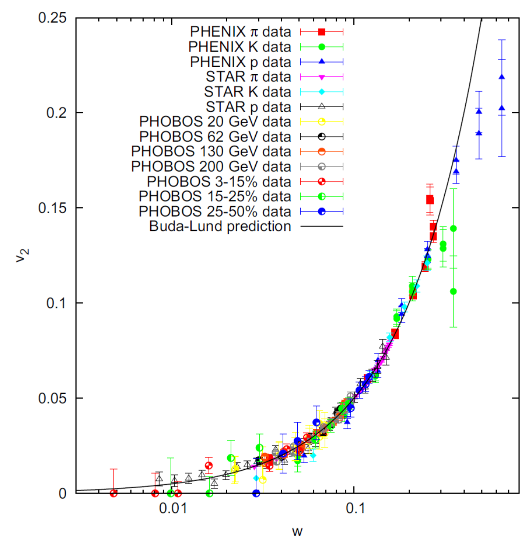
- Observation: elliptic flow scaling laws

first from non-rel 3d perfect fluid solution

$v_2(w)$: dimensionless(dimensionless)

recent result:

$$v_2 = \frac{I_1(w)}{I_0(w)}$$



holds for exact Navier-Stokes solutions, too

<u>Ref:</u> M. Csanád et al, Eur.Phys.J.A38:363-368,2008, + T. Cs. in prep.

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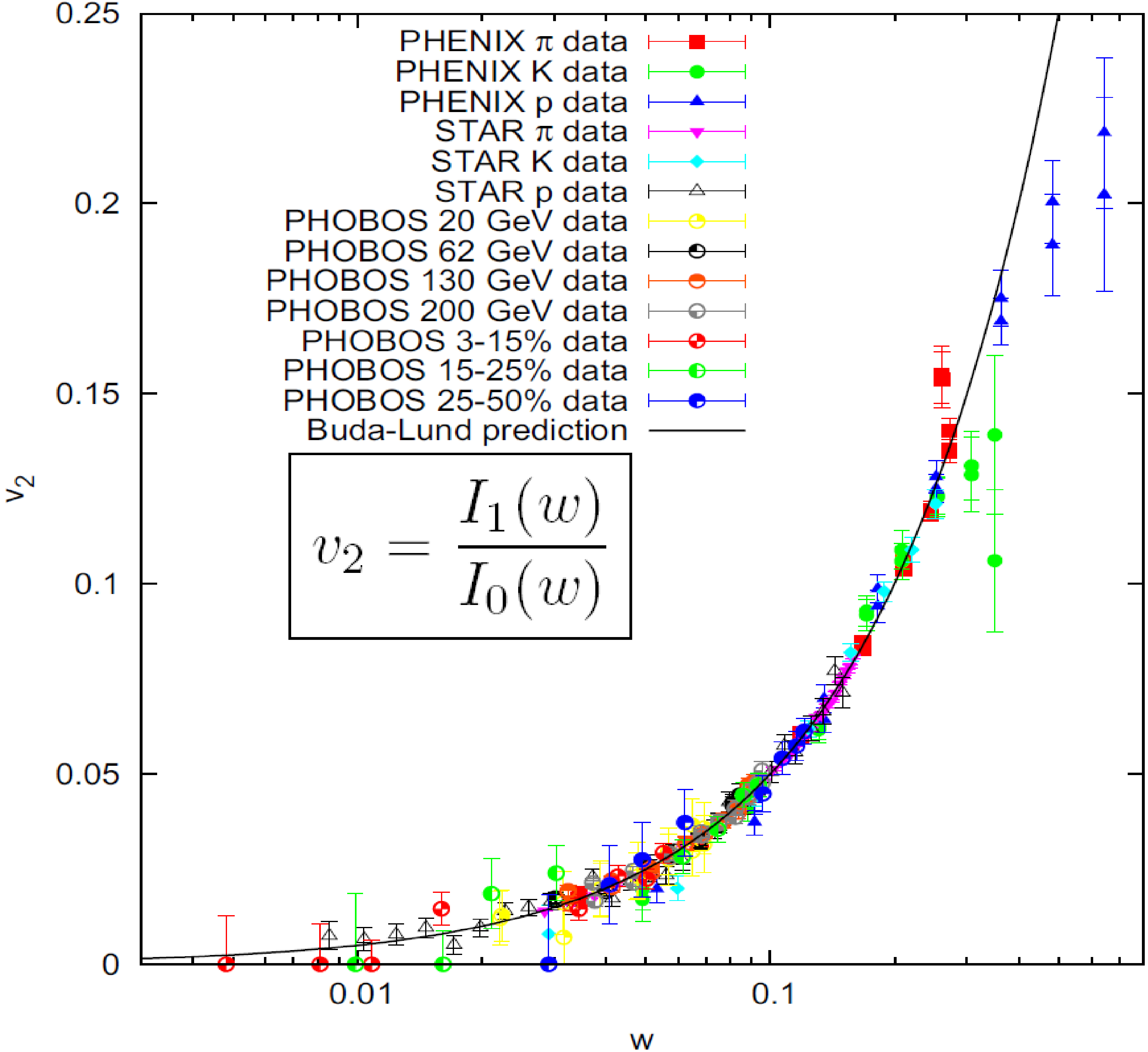
Buda-Lund: universal scaling of v_2



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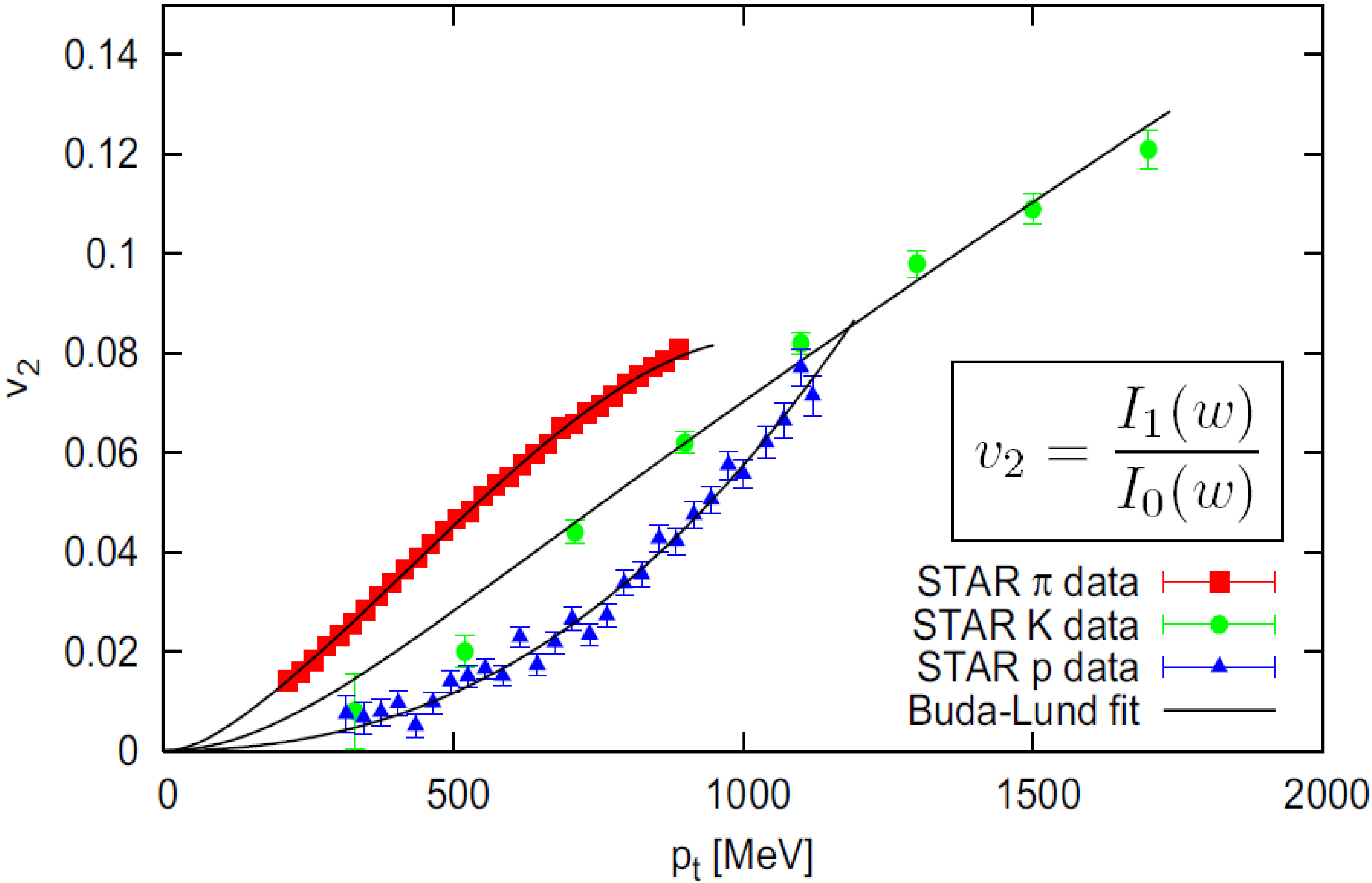

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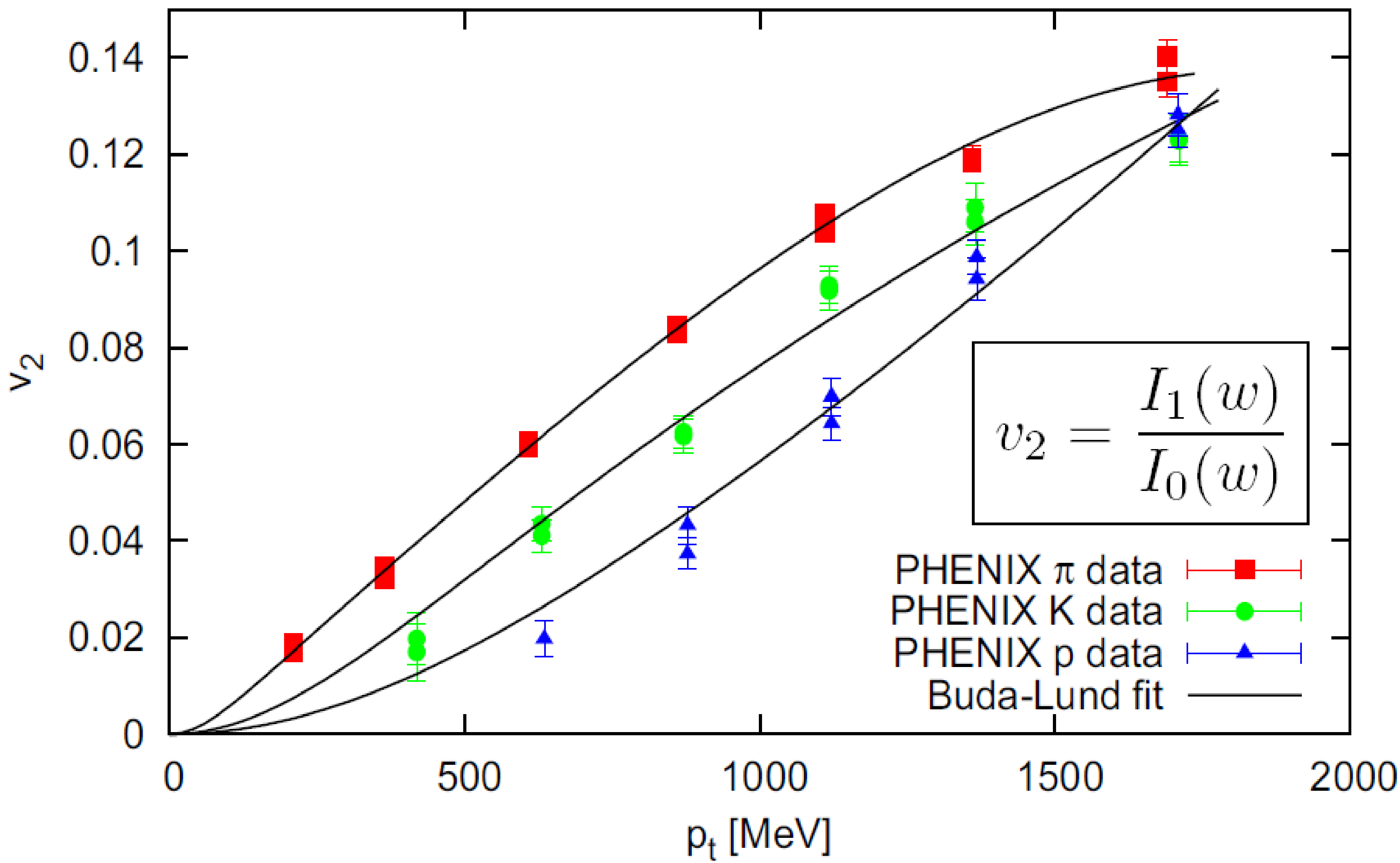

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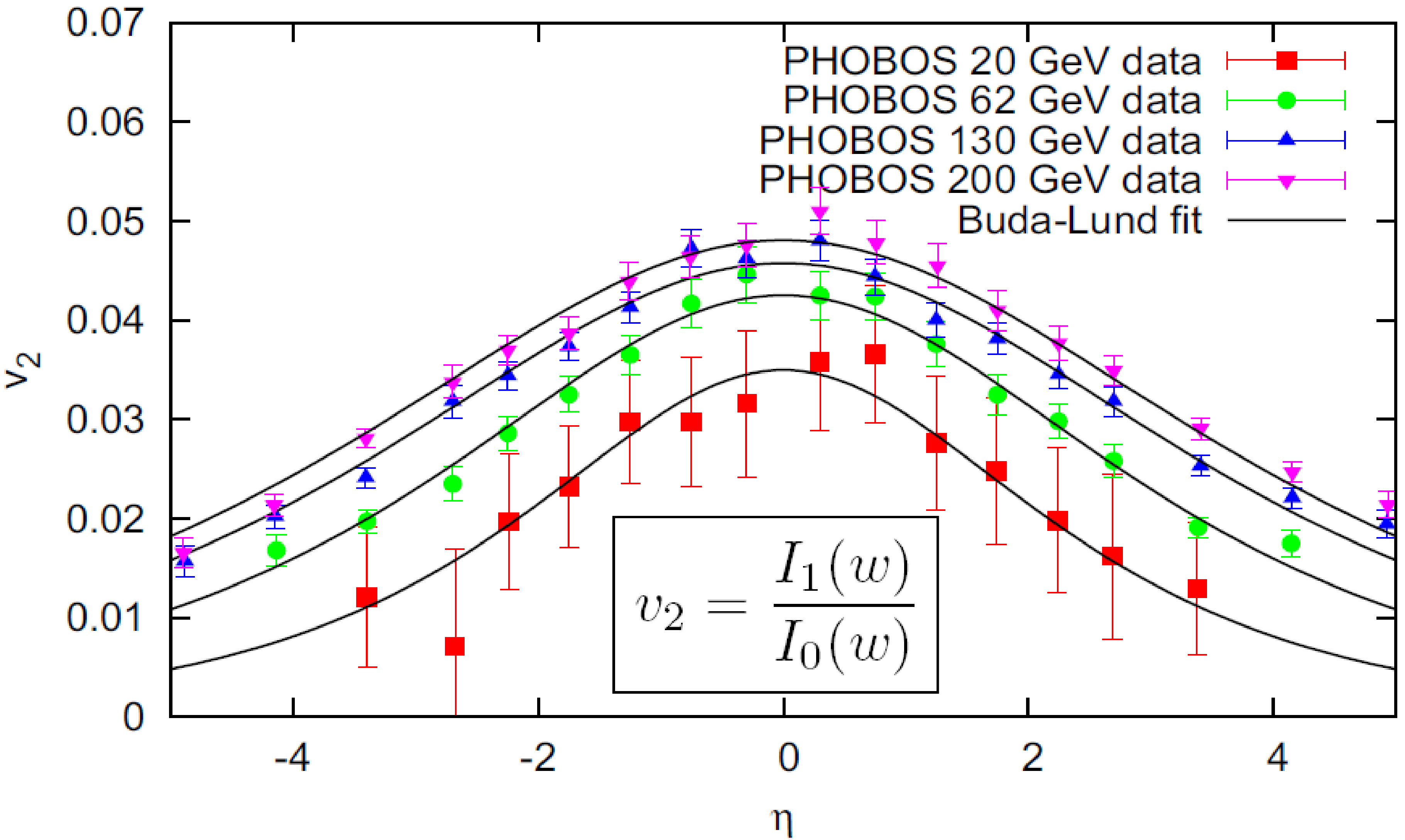

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Input from lattice: EoS of QCD Matter

Old idea: Quark Gluon Plasma

More recent: Liquid of quarks

T_c=176±3 MeV (~2 terakelvin)
(hep-ph/0511166)

at μ = 0, a cross-over

Aoki, Endrődi, Fodor, Katz, Szabó

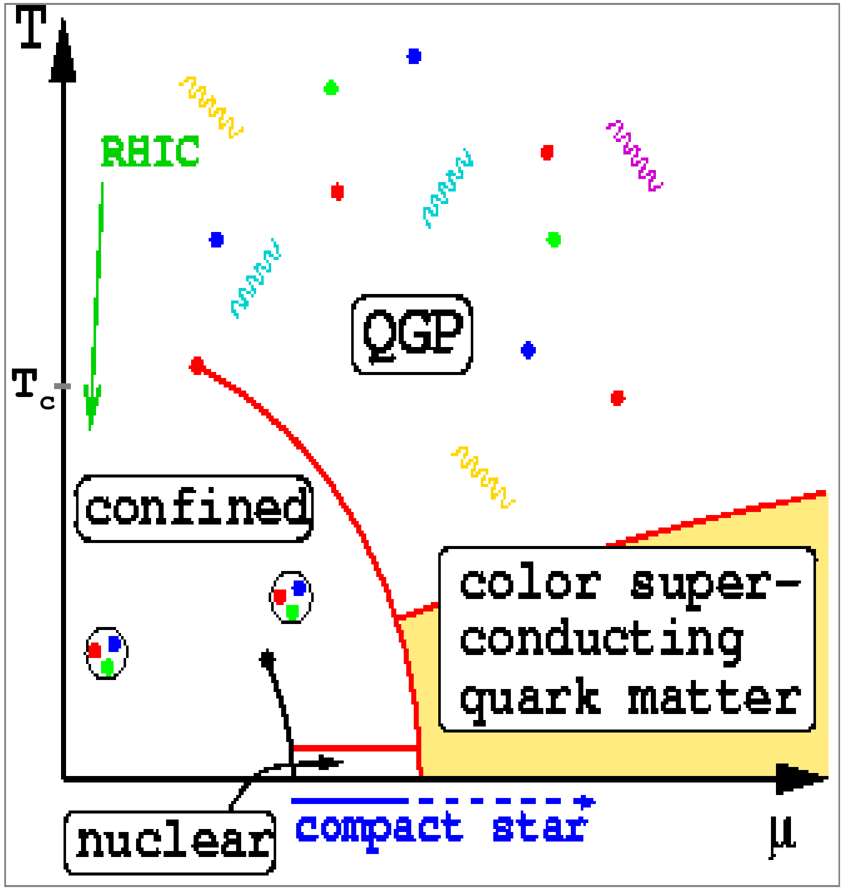
hep-lat/0611014

LQCD input for hydro: $p(\mu,T)$

LQCD for RHIC region: $p \sim p(T)$,

$$c_s^2 = \delta p/\delta e = c_s^2(T) = 1/\kappa(T)$$

It's in the family exact hydro solutions!



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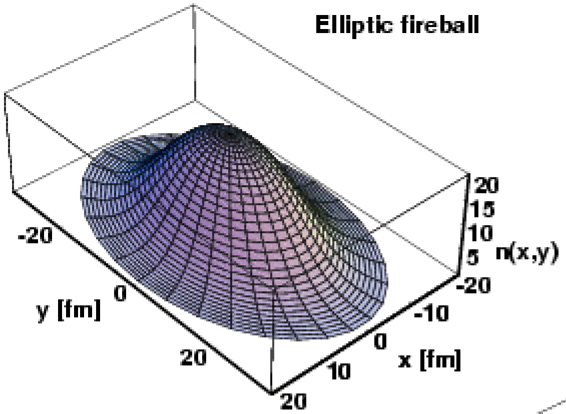
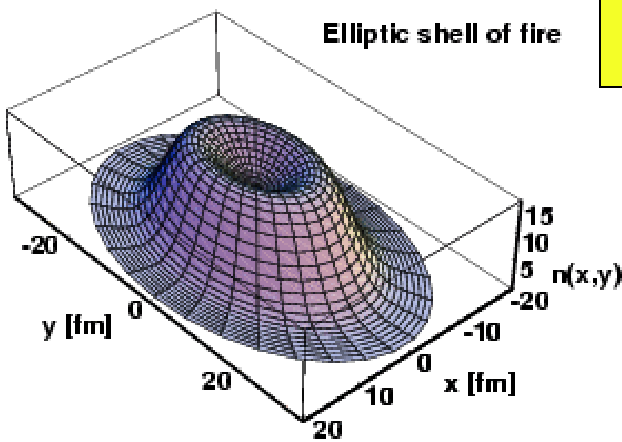
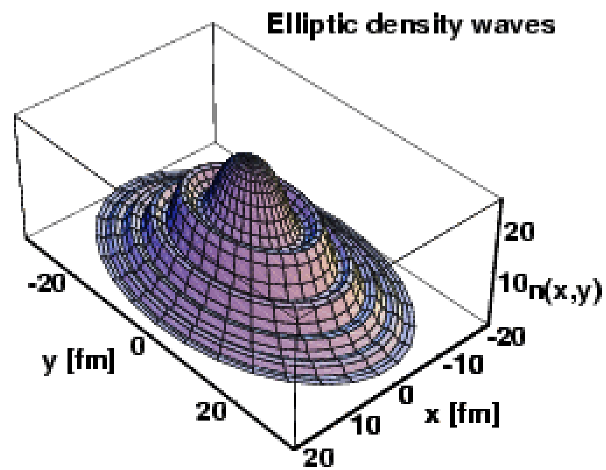
Illustrated initial T-> density profiles



Determines density profile!
Examples of density profiles
- Fireball
- Ring of fire
- Embedded shells of fire
Exact integrals of hydro
Scales expand in time





Time evolution of the scales (X,Y,Z)
follows a classic potential motion.
Scales at freeze out -> observables.
info on history <u>LOST</u>!
No go theorem - constraints
on initial conditions
(penetrating probels) indispensable.

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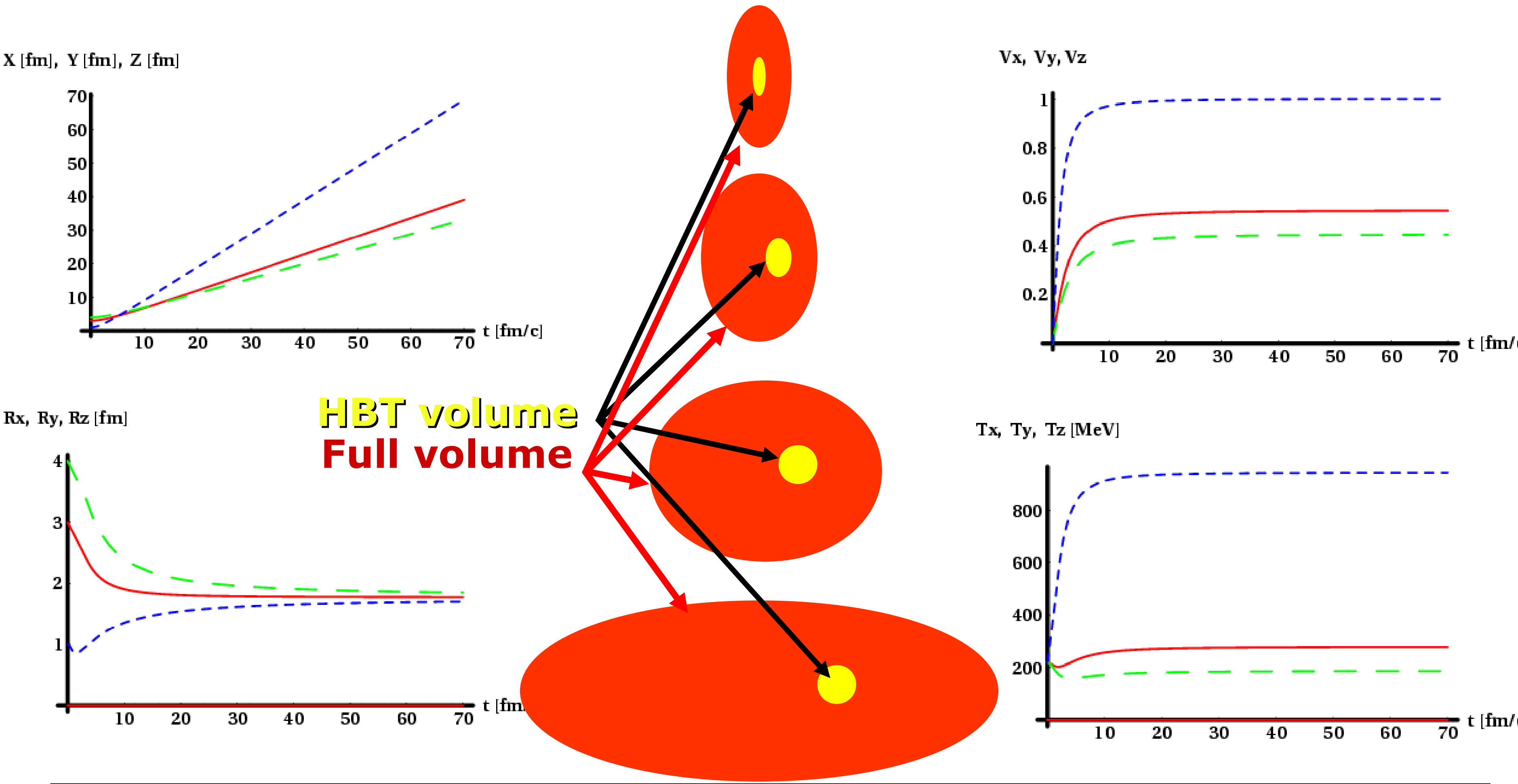
Solution of the “HBT puzzle”

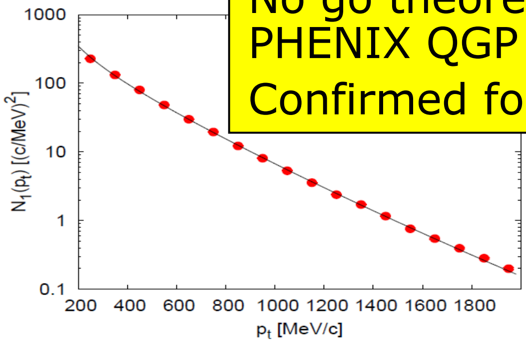


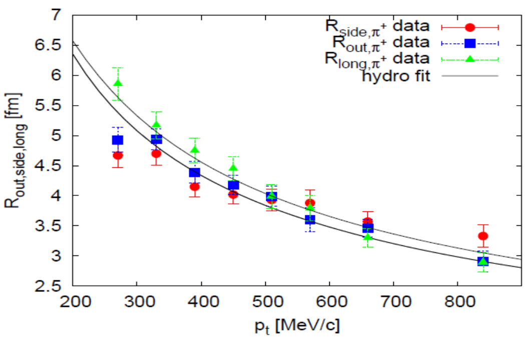
Geometrical sizes keep on increasing. Expansion velocities tend to constants.
HBT radii R_x, R_y, R_z approach a direction independent constant.
Slope parameters tend to direction dependent constants.
General property, independent of initial conditions - a beautiful exact result.

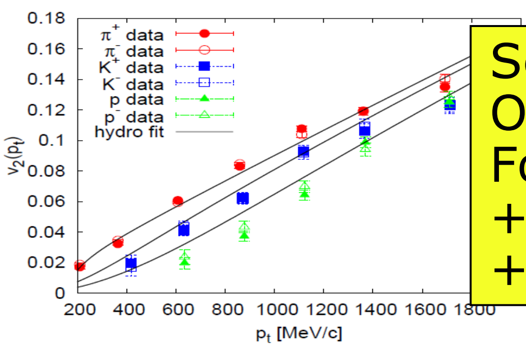
A. Ster

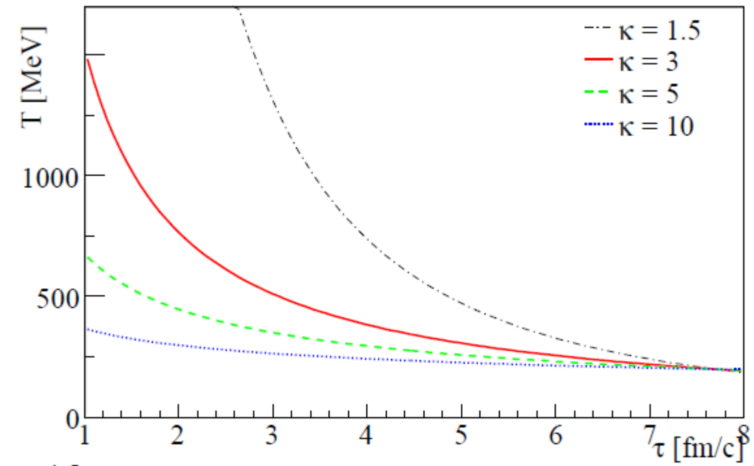
Scaling from exact hydro

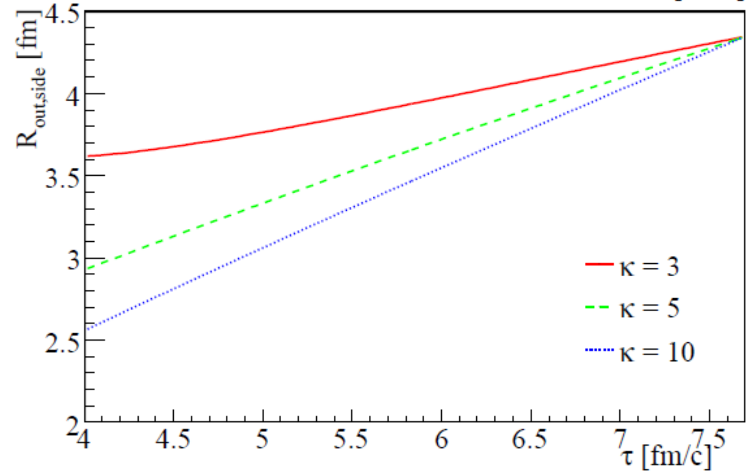
M. Csanád, M. Vargyas
Eur.Phys.J.A44:473-478,2010
Scales at freeze out -> observables.
info on history LOST!
No go theorem - illustrated, BUT
PHENIX QGP claim, $T_{init} \geq 330$ MeV
Confirmed for any reasonable $p/e \geq 0.1$

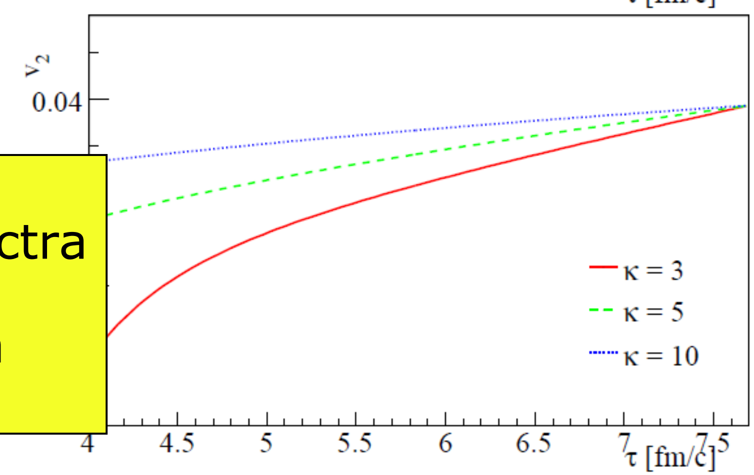












See talk of M. Csanád
On analysis of photon spectra
For more details
+ constraints on evolution
+ constraints on EoS

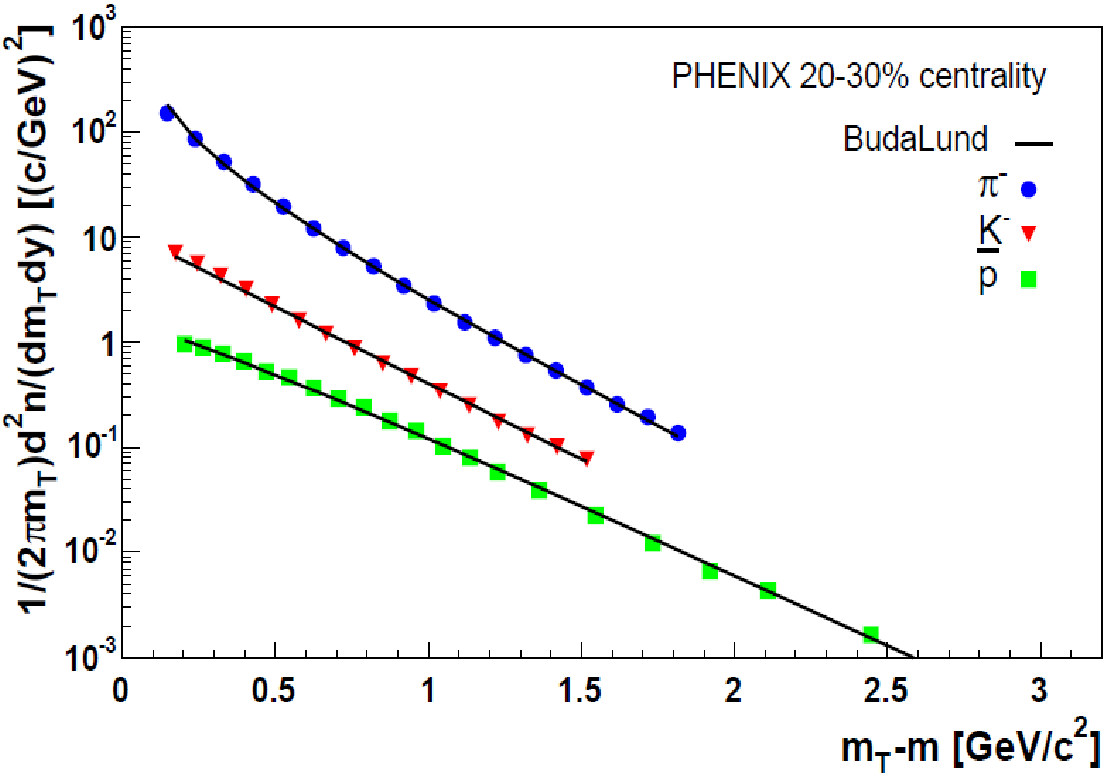
Intro/Reminder, Buda-Lund hydro model

If the finite source sizes are large compared to the thermal length-scales and if we also have $a^2 + b^2 \approx 1$, one obtains an M_t *-scaling* for the parameters of the BECF,

$$R_{side}^2 \simeq R_{out}^2 \simeq R_L^2 \simeq \tau_0^2 \frac{T_0}{M_t}, \quad \text{valid for} \quad \beta_t << \frac{1}{b}. \tag{82}$$

Axially symmetric: T. Cs, B. Lörstad, hep-ph/9509213
Ellipsoidal generalization:
M. Csanád, T.Cs., B. Lörsrad, nucl-th/0310040

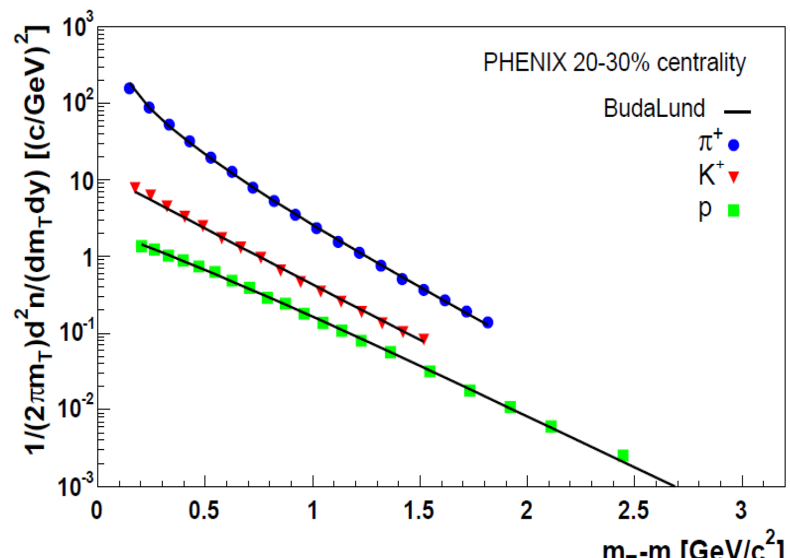
Results, asBuda-Lund fits to spectra



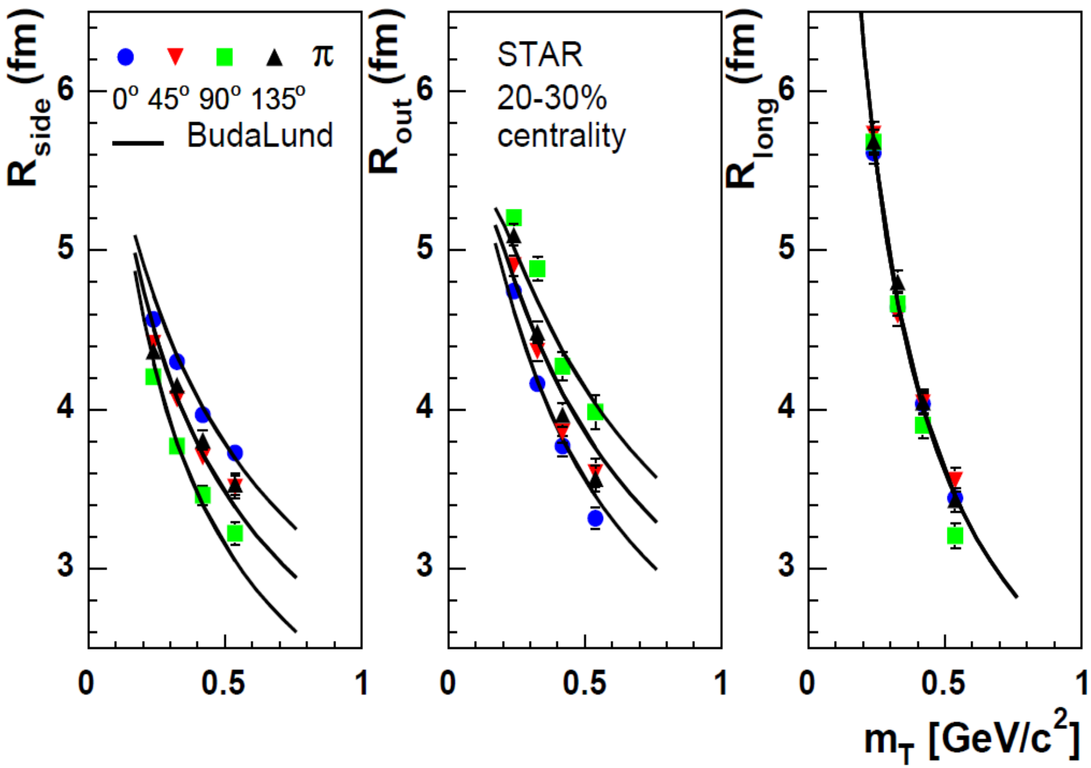
Fits 20-30 % centrality
Fits are done simulatenously
To spectra, v_2 and asHBT
Analytic formulas,
 precision < 2-4 %
Buda-Lund parameters
 Optimized by CERN Minuit

Spectra are corrected for long-lived
Resonance effects using
core-halo model.

Both positive and negative spectra
 described in stat. acceptable way



Results, asBuda-Lund fits to asHBT



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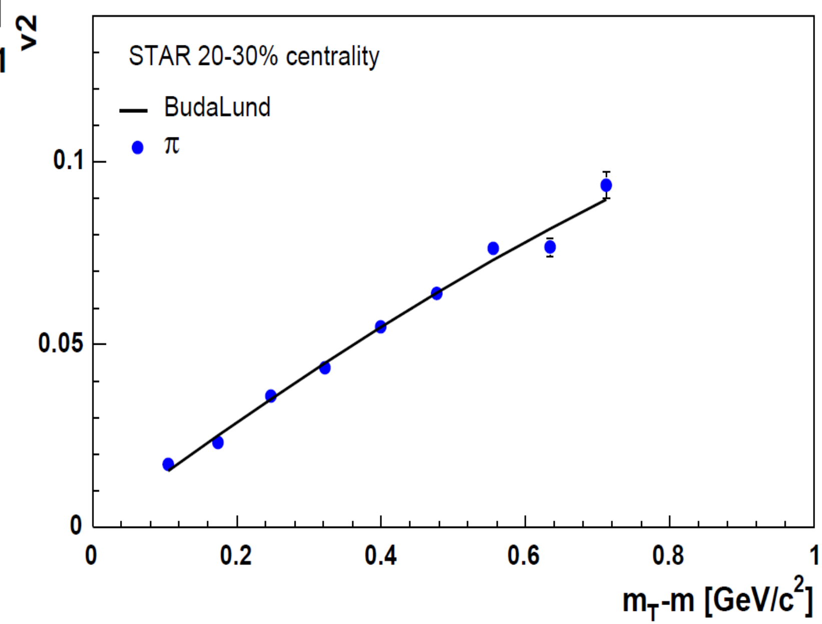
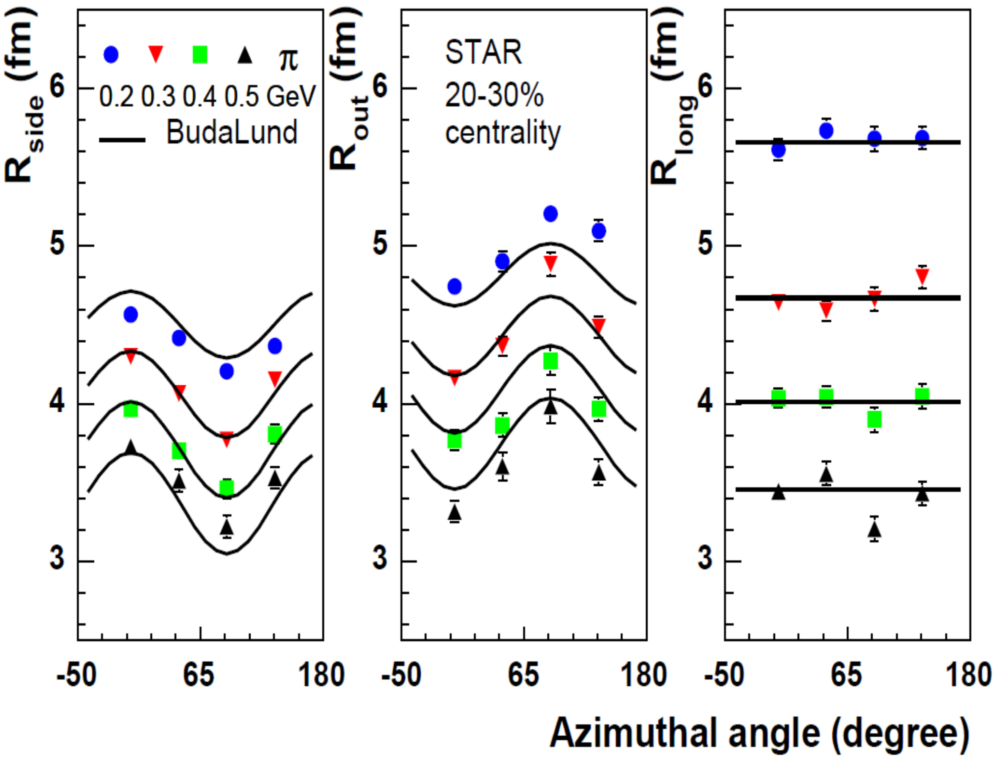
Oscillations of HBT radii are described reasonably well, as a function of transverse mass. Simultaneously with charged particle elliptic flow and spectra.



Results, asBuda-Lund fits to asHBT

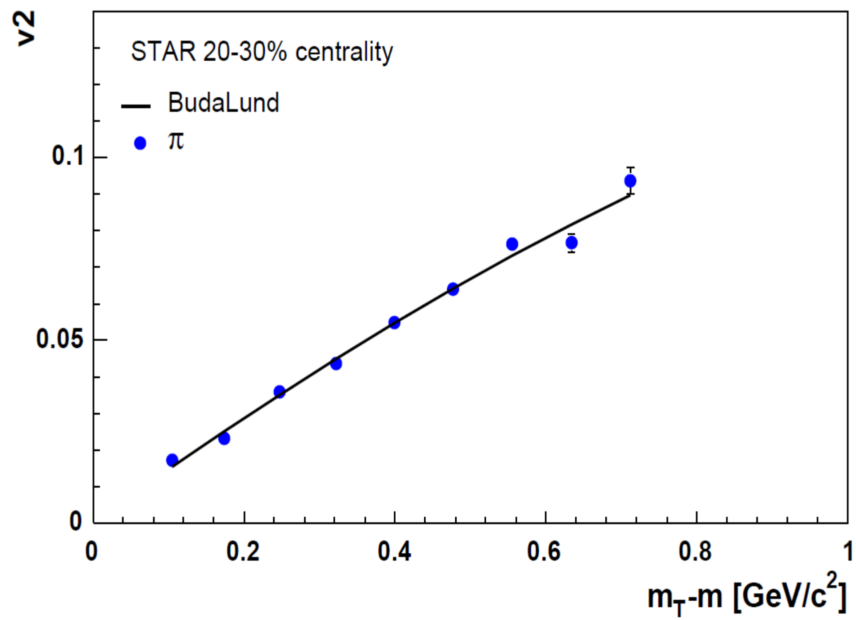


Fits 20-30 % centrality
Fits are done simulatenously
To spectra, v_2 and asHBT
Analytic formulas,
precision < 2-4 %
Buda-Lund parameters
Optimized by CERN Minuit

Oscillations of HBT radii are described reasonably well, as a function of angle small but systematics in out and side.

But chi2/NDF = 255.6 /152
CL = 0.78 % acceptable

Beyond Gaussian H(τ) distribution?



Results: from spectra, v_2, asHBT + Buda-Lund

BudaLund source parameters	RHIC 200 AGeV central (0-30%)	RHIC 200 AGeV non-central (20-30%)
T_0 [MeV]	196 ± 13	190 ± 5
T_e [MeV]	117 ± 12	118 ± 8
H_X[c/fm]	0.12 ± 0.013	0.17 ± 0.002
H_Y [c/fm]		0.12 ± 0.001
H_Z [c/fm]	0.17 ± 0.008	0.19 ± 0.003
R_X [fm]	13.5 ± 1.7	9.3 ± 0.5
R_Y [fm]		6.7 ± 0.2
$\Delta\tau$ [fm/c]	0.9 ± 1.2	2.7 ± 0.2
$\Delta\eta$	3.1 ± 0.1	2.4 ± 0.3
μ_0^{π} [MeV]	-2 ± 14	40 ± 8
μ_0^{K} [MeV]	16 ± 19	55 ± 13
μ_0^{p} [MeV]	97 ± 28	178 ± 22
χ^2/NDF	114 /208	261 /152 CL=0.7%

CL > 0.1 %
Acceptable.
Temperatures:
Similar.

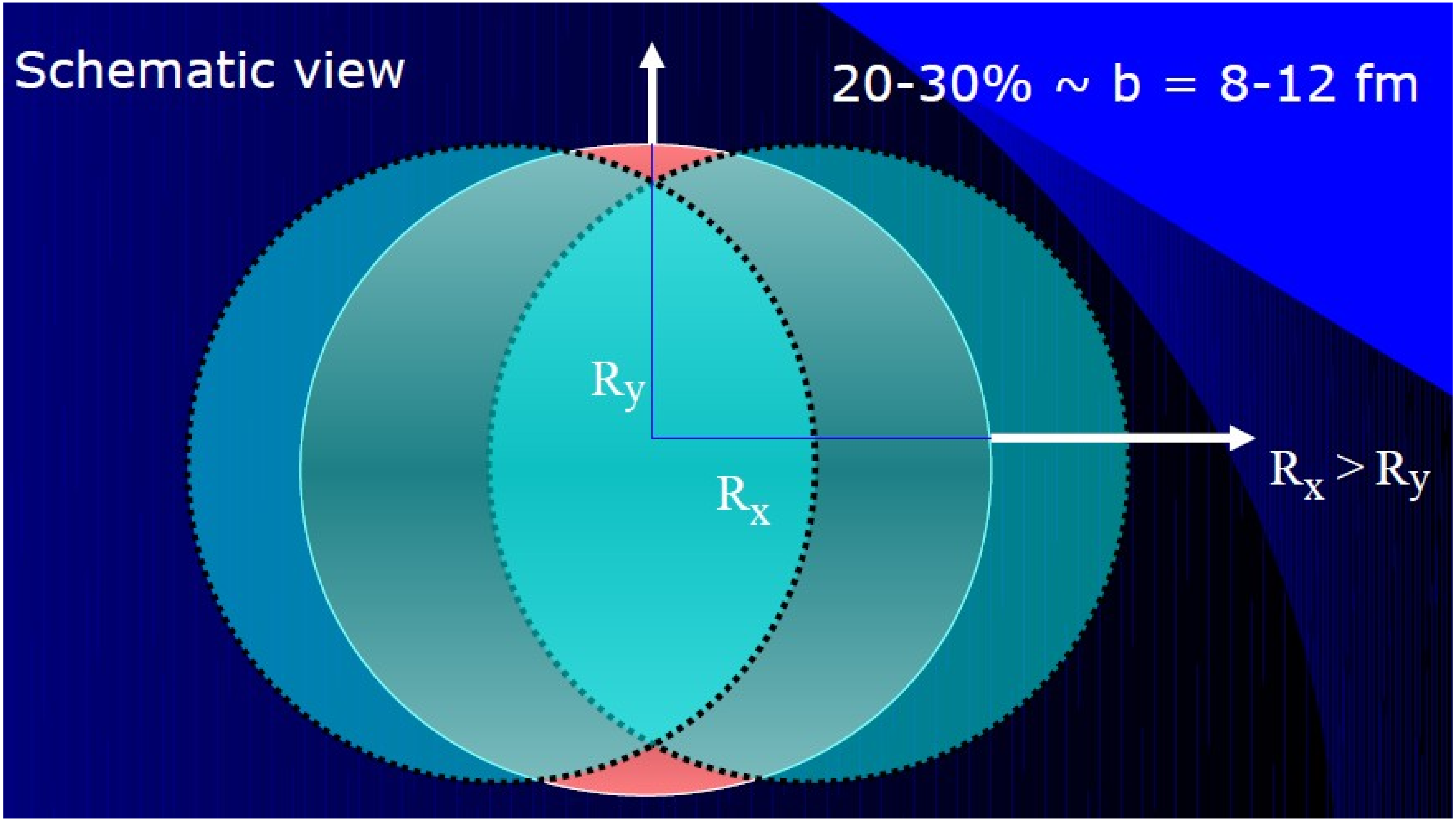
Strong expansion
in impact parameter
direction.
Homogeneity region:
out-of-plane elongated

Actual source:
in-plane elongated

a little (5 σ stat)

A. Ster

Illustration



A. Ster, talk at WPCF 2009:
First indication of in-plane extended source confirmed by the final analysis too

Summary

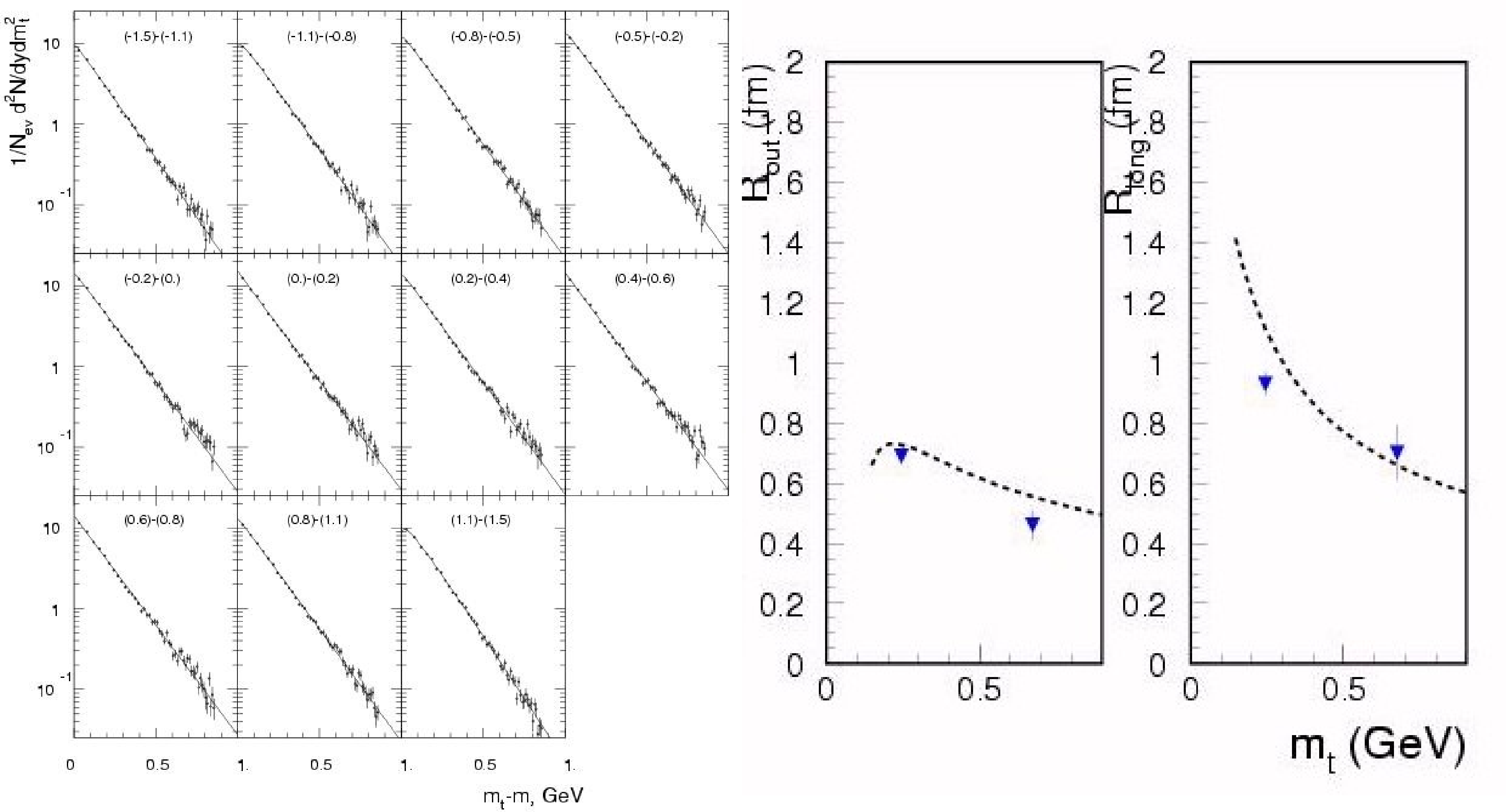
Au+Au elliptic flow data at RHIC satisfy
UNIVERSAL scaling laws
predicted in 2001, 2003 by Buda-Lund hydro model,
based on exact solutions of hydrodynamics.

Quantitative evidence for a perfect fluid in Au+Au at RHIC
- but quark number scaling suggests flow on quark level.

Buda-Lund model predicted the HBT radii successfully at RHIC,
describes azimuthal oscillations of HBT radii.

Model specific predictions:
HBT oscillation amplitudes of side, out and os are the same
V_2 is given by flow asymmetry alone

Buda-Lund hydro fits to NA22 h+p data



N. M. Agababyan et al, EHS/NA22 , PLB 422 (1998) 395
T. Csörgő, hep-ph/001233, Heavy Ion Phys. 15 (2002) 1-80

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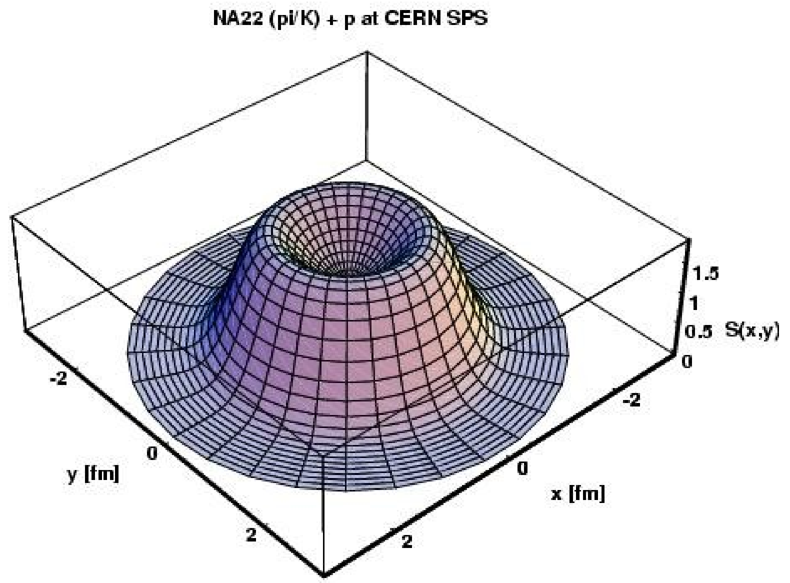

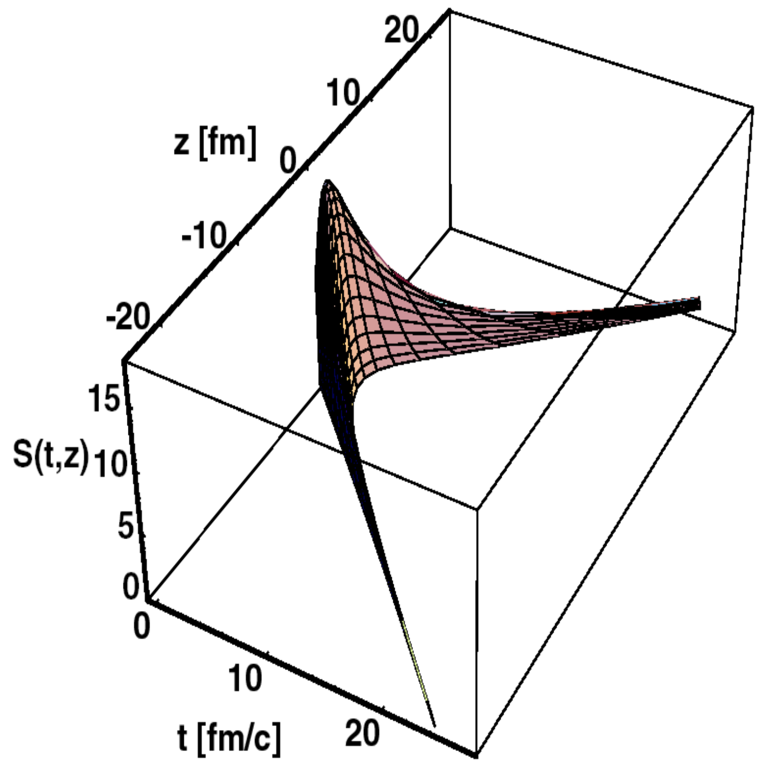

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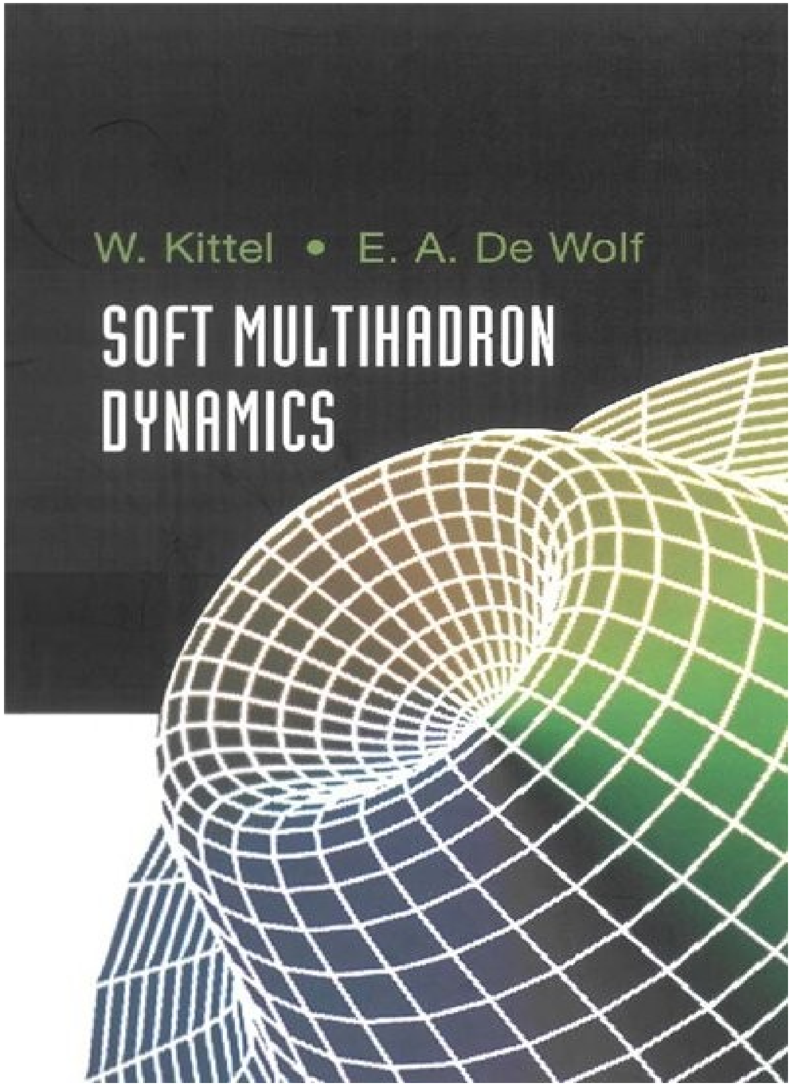

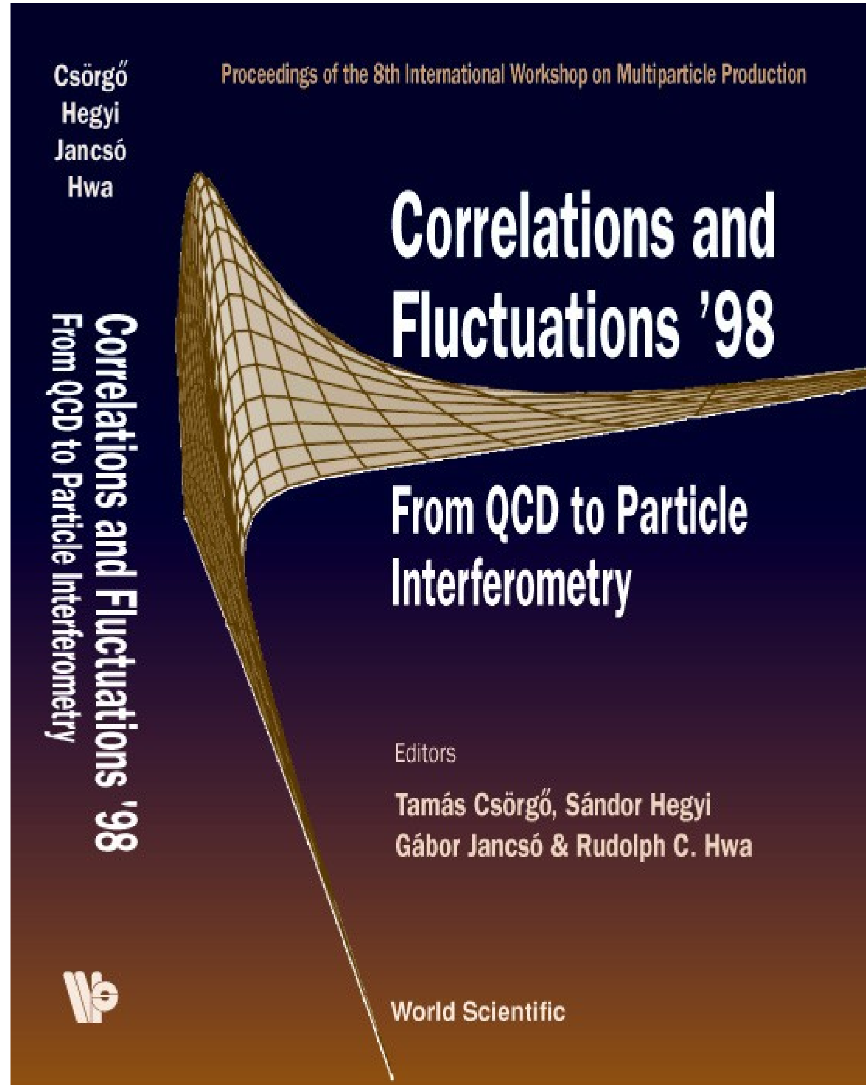

W. Kittel, E. A. De Wolf: Soft Multihadron Dynamics, World Sci. (2005)
T. Cs, S. Hegyi, G. Jancsó, R. C. Hwa, Correlations and Fluctuations'98, World Sci. (1999)

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