A scaling law of elliptic flow in $\sqrt{S_{NN}}$ = 7.7 - 39 GeV Au+Au collisions

András Ster

MTA KFKI Wigner RCP, Budapest, Hungary

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Introduction - Motivation

The Relativistic Heavy Ion Collider (RHIC) showed significant second harmonic moments in transverse momentum distributions (known as elliptic flow).

The elliptic flow shown dependence on particle type, transverse (p_t) and logitudinal (*pseudo-rapidity*) parameters, and on the centrality and bombarding energy of the collisions.

In the soft region ($p_t < 2$ GeV/c) the measuremet are well described by hydrodynamic model.

(See the Buda-Lund hydro model descriptions, for example, in: arXiv/nucl-th/0512078v4)

Perfect fluid hydrodynamic picture

It is based on local conservation of entropy σ and four - momentum tensor $T^{\mu\nu}$:

$$\begin{aligned} \partial_\mu(\sigma u^\mu) &= 0, \\ \partial_\nu T^{\mu\nu} &= 0, \end{aligned}$$

u^μ stands fo the four-velocity of the matter and it is perfect fluid if the tensor is diagonal:

$$T^{\mu\nu} = (\epsilon + p)u^\mu u^\nu - pg^{\mu\nu}.$$

Perfect fluid hydrodynamic picture

The elliptic flow defined as the azimuthal anisotropy or the fourier-coefficient of the one particle momentum distributions $N_1(p)$:

$$v_n = \frac{\int_0^{2\pi} N_1(p)\cos(n\varphi)d\varphi}{\int_0^{2\pi} N_1(p)d\varphi},$$

Scaling law of v_2 by Buda-Lund hydro model

The result comes directly from a perfect hydro solution:

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

See:

T. Csörgő *et al.*, Phys. Rev. **C67**, 034904 (2003).
T. Csörgő, F. Grassi, Y. Hama, and T. Kodama, Phys. Lett. **B565**, 107 (2003).
M. I. Nagy, T. Csörgő, and M. Csanád, Phys. Rev. **C77**, 024908 (2008).
Y. M. Sinyukov and I. A. Karpenko, Acta Phys. Hung. **A25**, 141 (2006).
T. Csörgő and B. Lörstad, Phys. Rev. **C54**, 1390 (1996).
M. Csanád, T. Csörgő, and B. Lörstad, Nucl. Phys. **A742**, 80 (2004).

Scaling law of v_2 by Buda-Lund hydro model

For the determination of *w* the Buda-Lund model gives the following formula:

$$w = \frac{E_K}{T_*}\varepsilon \qquad E_K = \frac{p_t^2}{2\overline{m}_t},$$

$$\frac{1}{T_*} = \frac{1}{2}\left(\frac{1}{T_x} + \frac{1}{T_y}\right), \qquad T_x = T_0 + \overline{m}_t \dot{X}^2 \frac{T_0}{T_0 + \overline{m}_t a^2},$$

$$\varepsilon = \frac{T_x - T_y}{T_x + T_y}. \qquad T_y = T_0 + \overline{m}_t \dot{Y}^2 \frac{T_0}{T_0 + \overline{m}_t a^2}.$$

v_2 data

All STAR v_2 data from publication: *arXiv:1206.5528v1 [nucl-ex]*

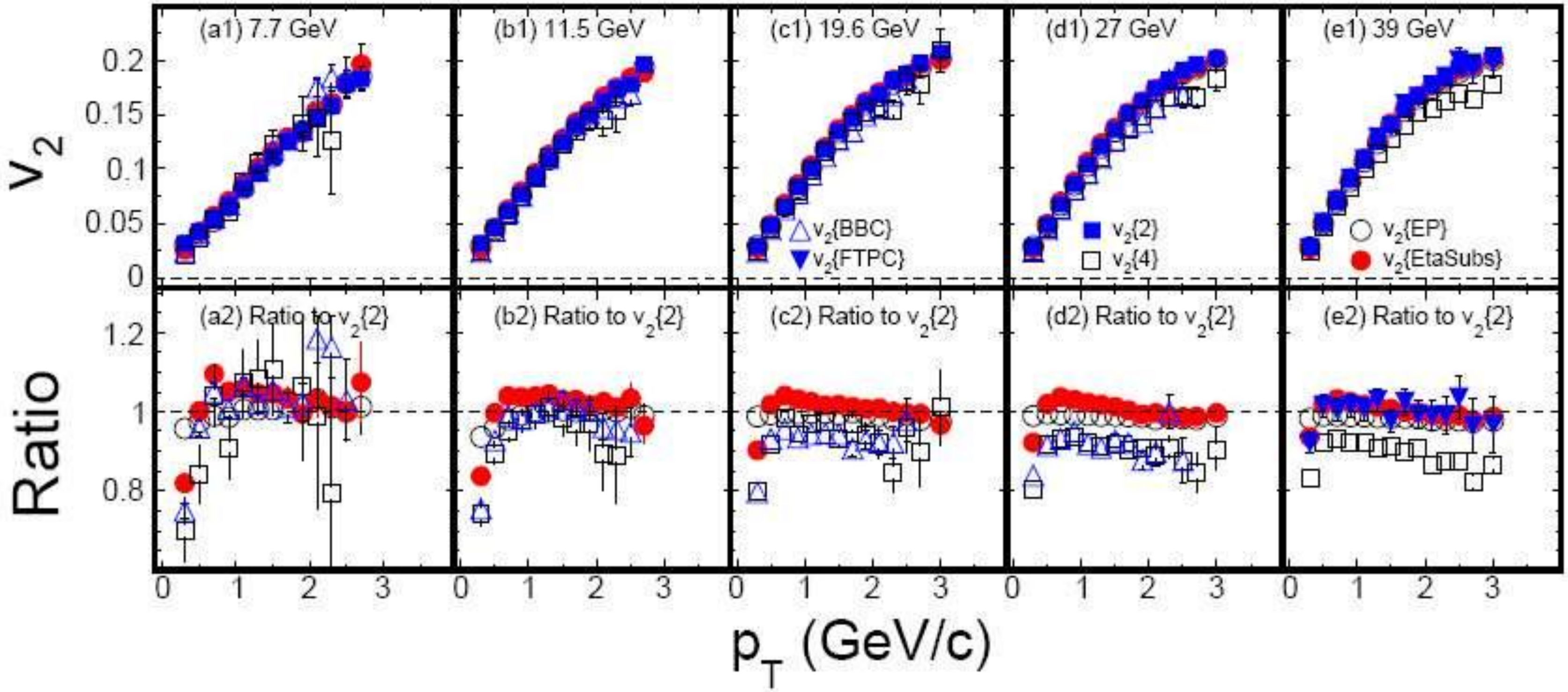
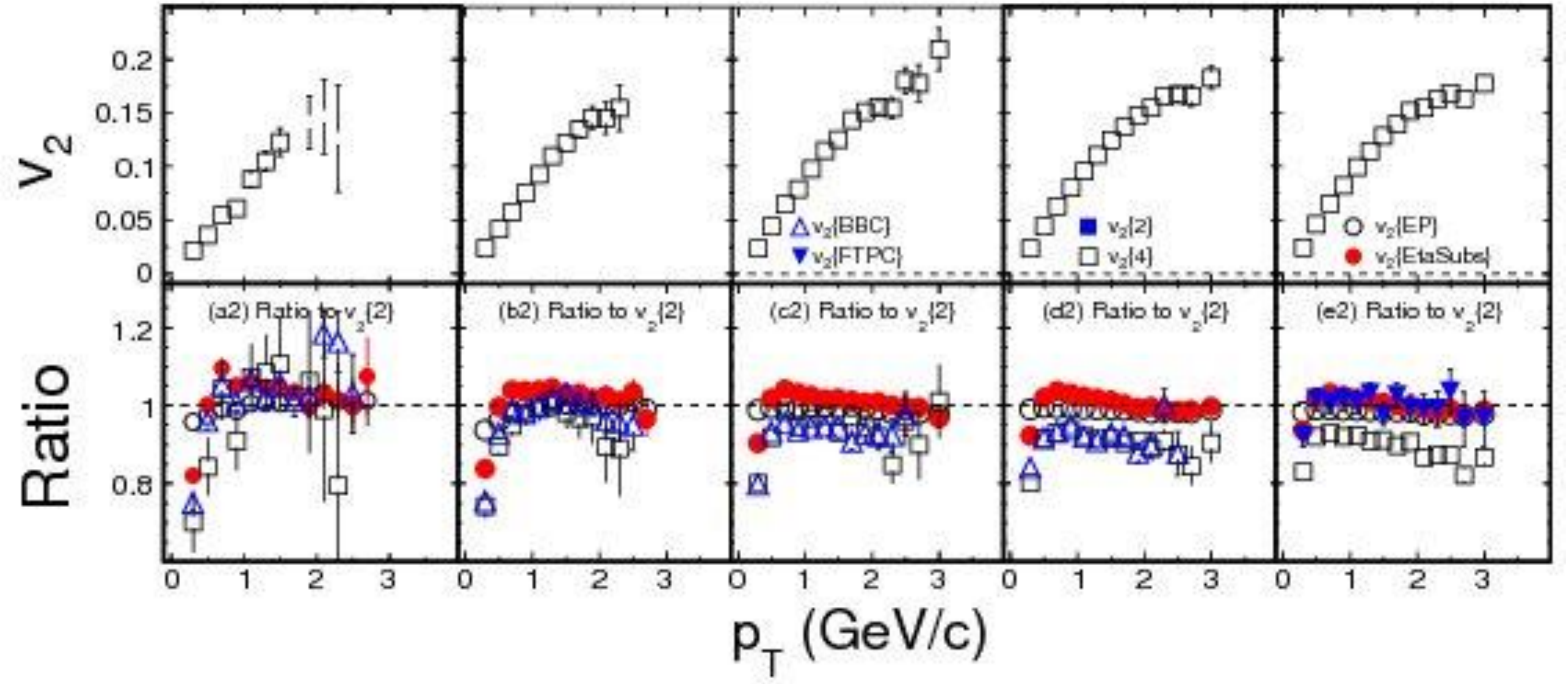


FIG. 5: (Color online) The v_2 as a function of p_T for 20 – 30% central Au + Au collisions at midrapidity for $\sqrt{s_{NN}}$ = 7.7 GeV (a1), 11.5 GeV (b1), 19.6 GeV (c1) , 27 GeV (d1) and 39 GeV (e1). The top panels show v_2 vs. p_T using various methods as labeled in the figure and discussed in the text. The bottom panels show the ratio of v_2 measured using the various methods with respect to $v_2\{2\}$.

v_2 data

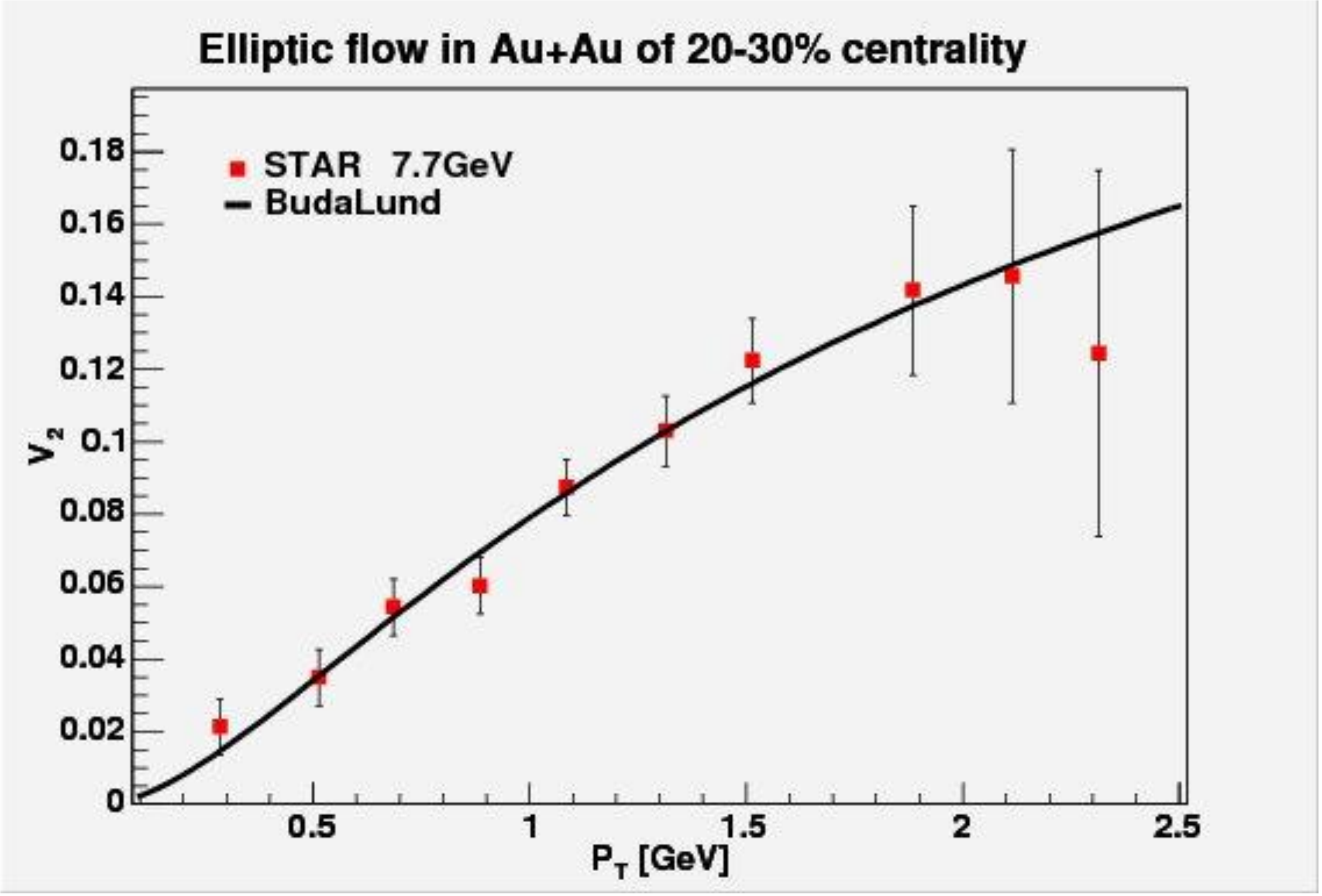
The selected $v_2\{4\}$ data for fits:



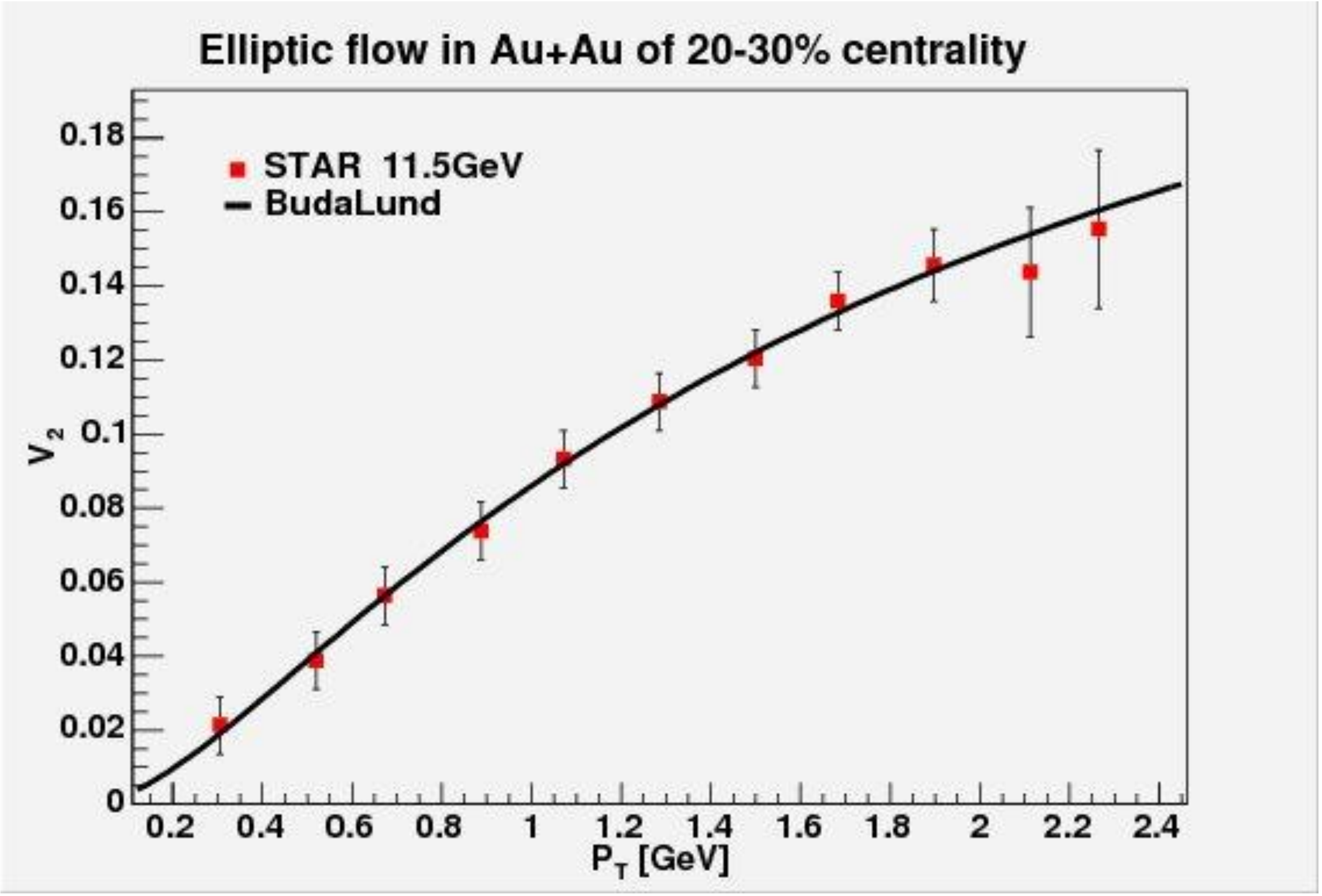
Selection based also on study of $v_2\{4\}$ in our pub: *Eur. Phys. J. A (2011) 47: 58*

Fit results

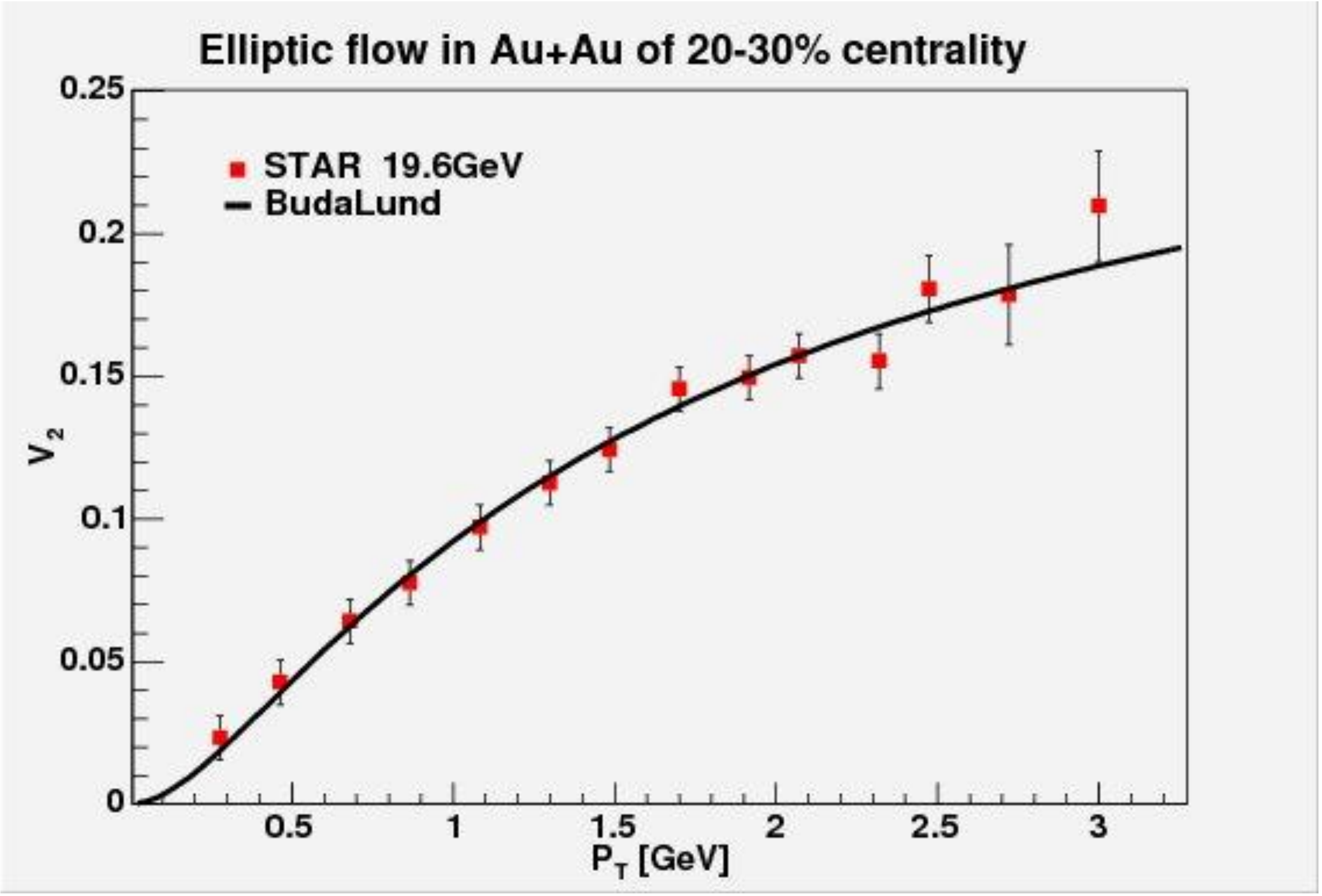
With the assumptions: m=139MeV, T_0=139MeV, a^2=0.0



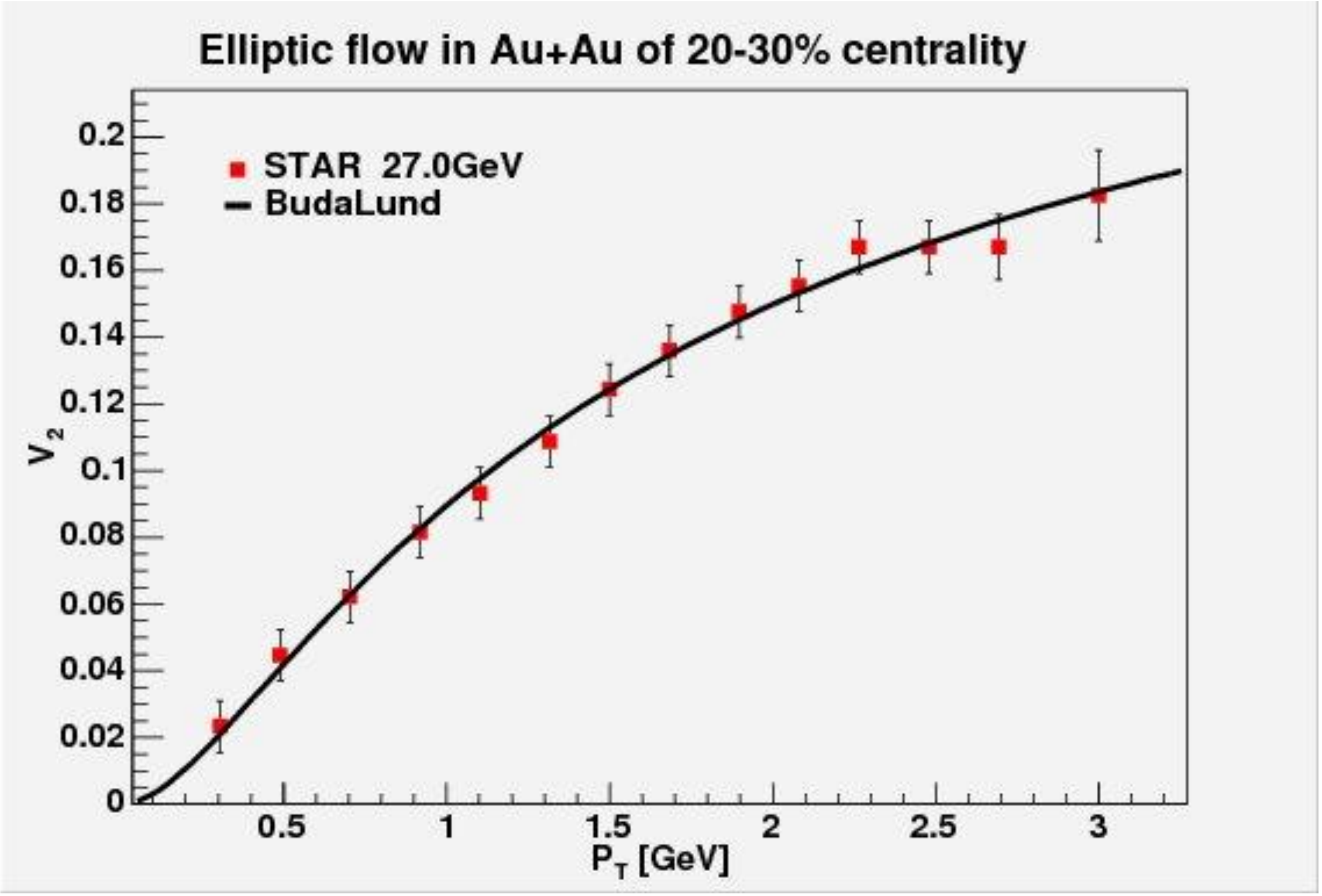
Fit results


Elliptic flow in Au+Au of 20-30% centrality
STAR 11.5GeV
BudaLund
v_2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
P_T [GeV]

Fit results

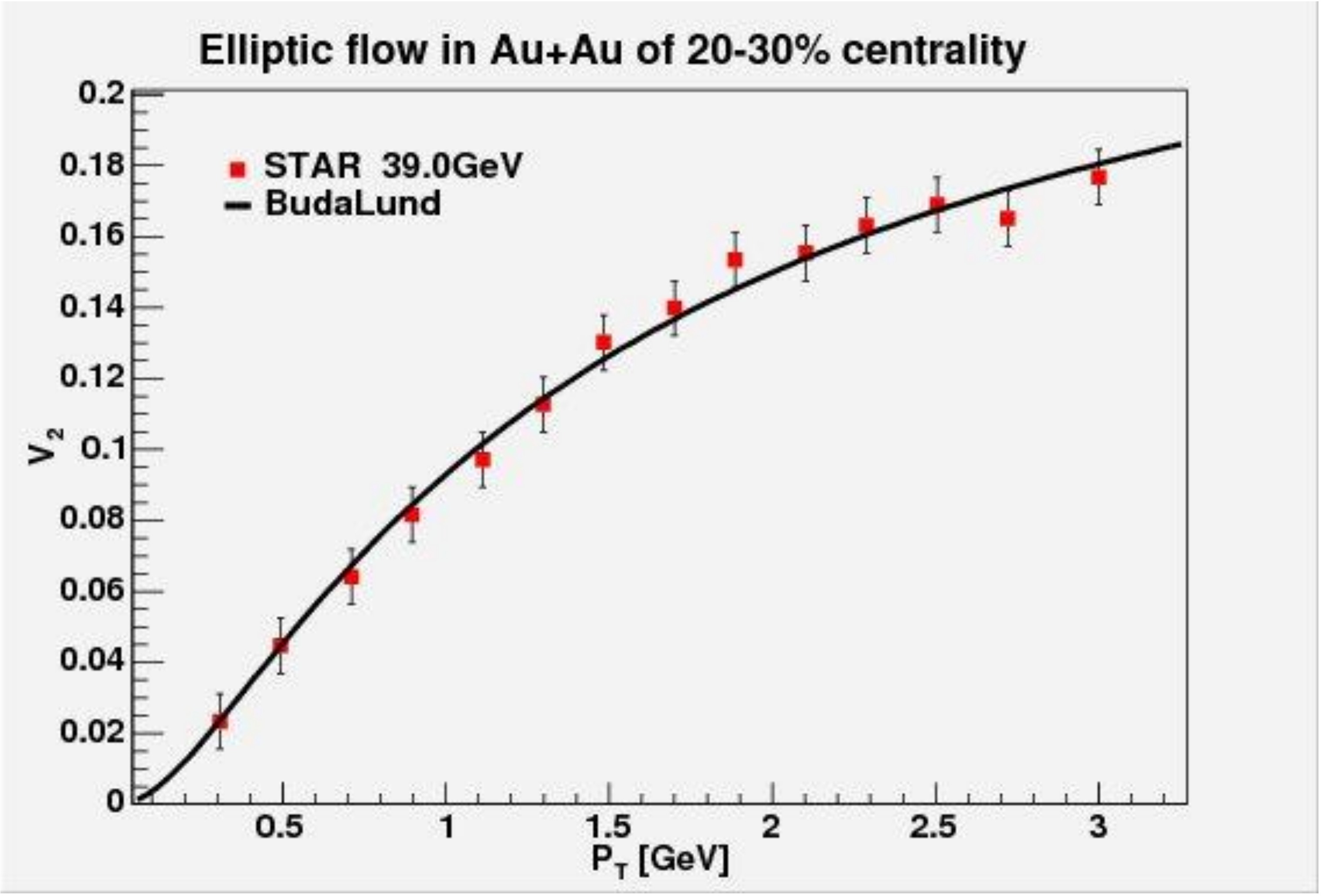

Elliptic flow in Au+Au of 20-30% centrality
STAR 19.6GeV
BudaLund
v_2
0.25
0.2
0.15
0.1
0.05
0
0.5
1
1.5
2
2.5
3
P_T [GeV]

Fit results

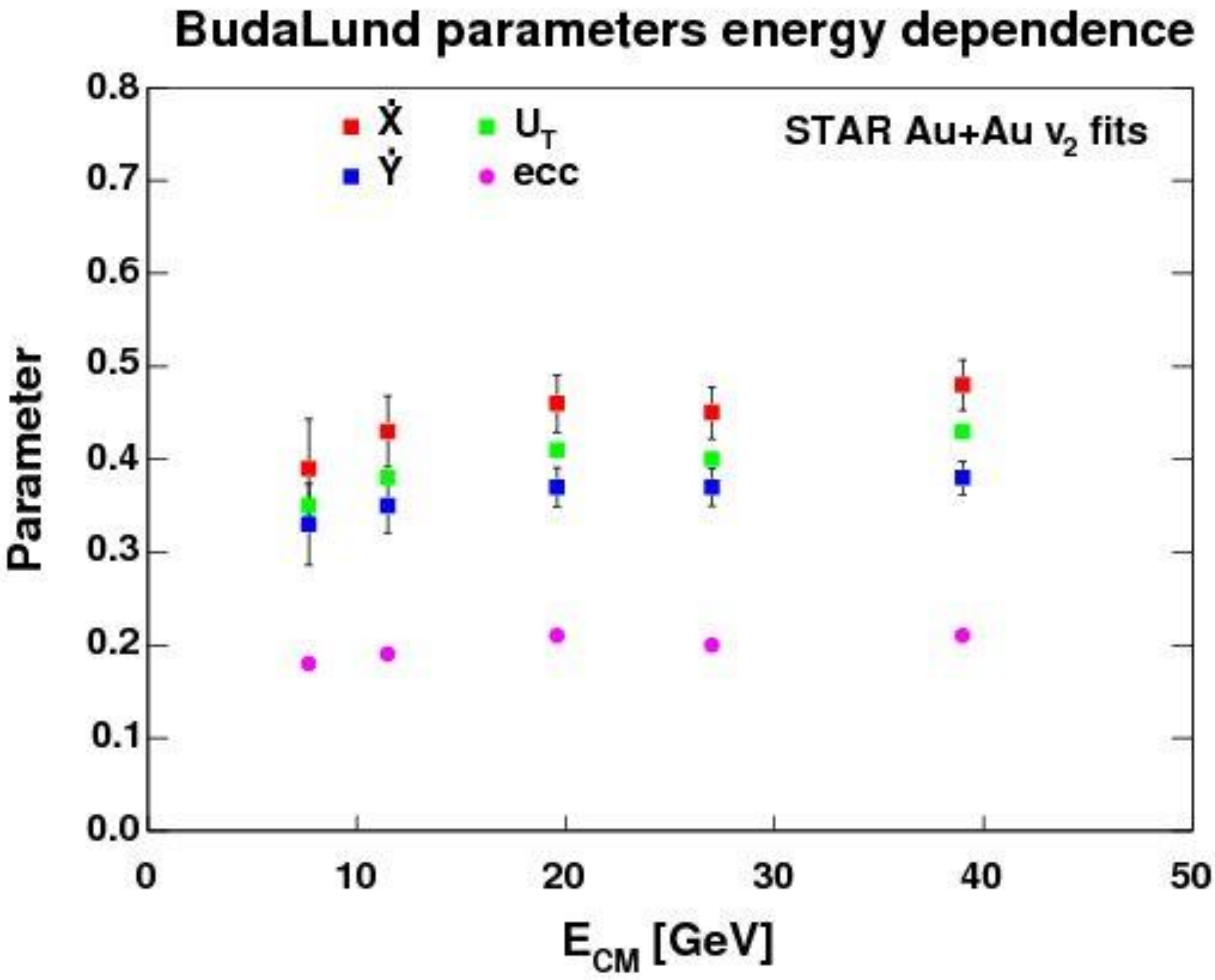


Elliptic flow in Au+Au of 20-30% centrality
STAR 27.0GeV
BudaLund
v_2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.5
1
1.5
2
2.5
3
P_T [GeV]

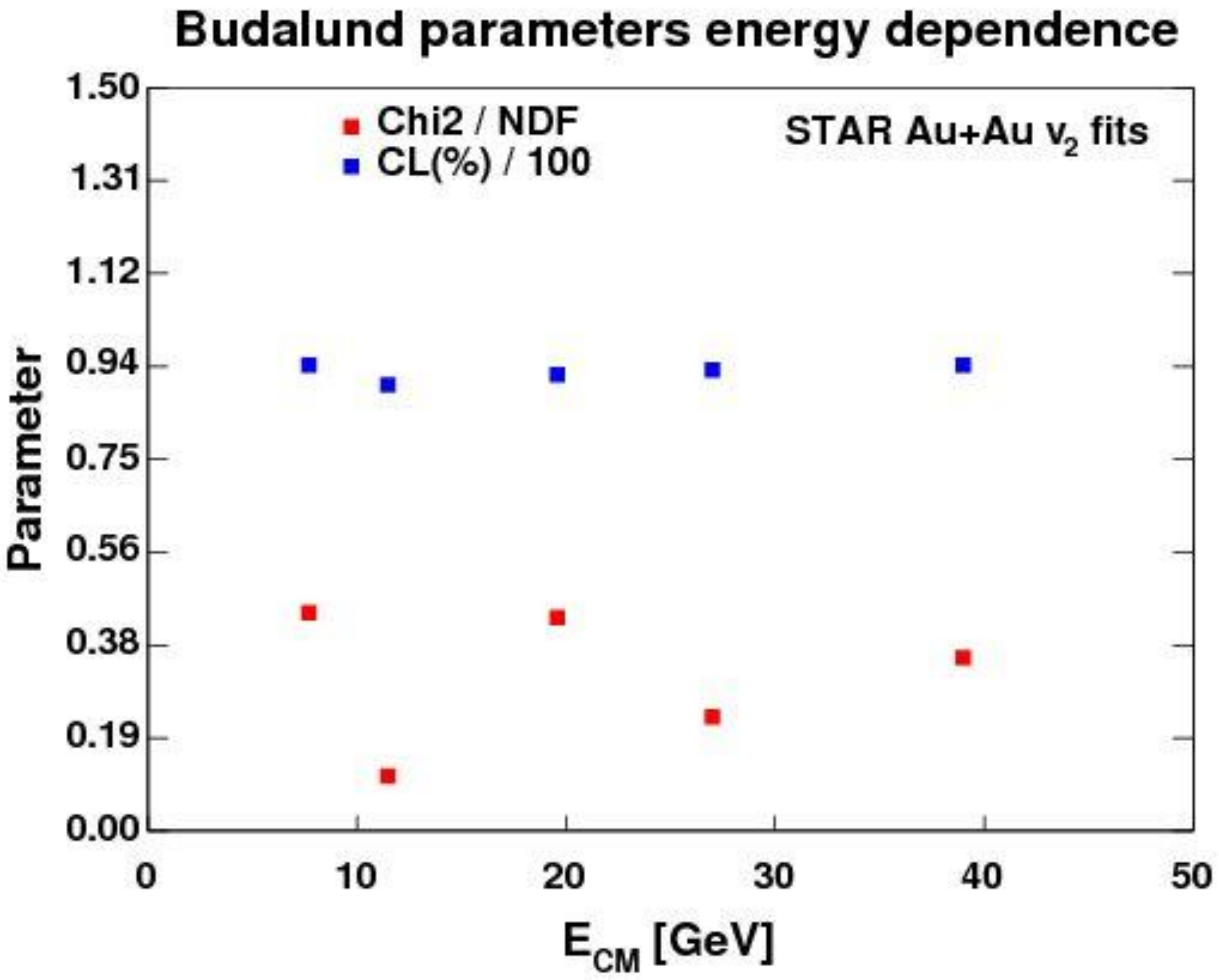
Fit results


Elliptic flow in Au+Au of 20-30% centrality
STAR 39.0GeV
BudaLund
v_2
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.5
1
1.5
2
2.5
3
P_T [GeV]

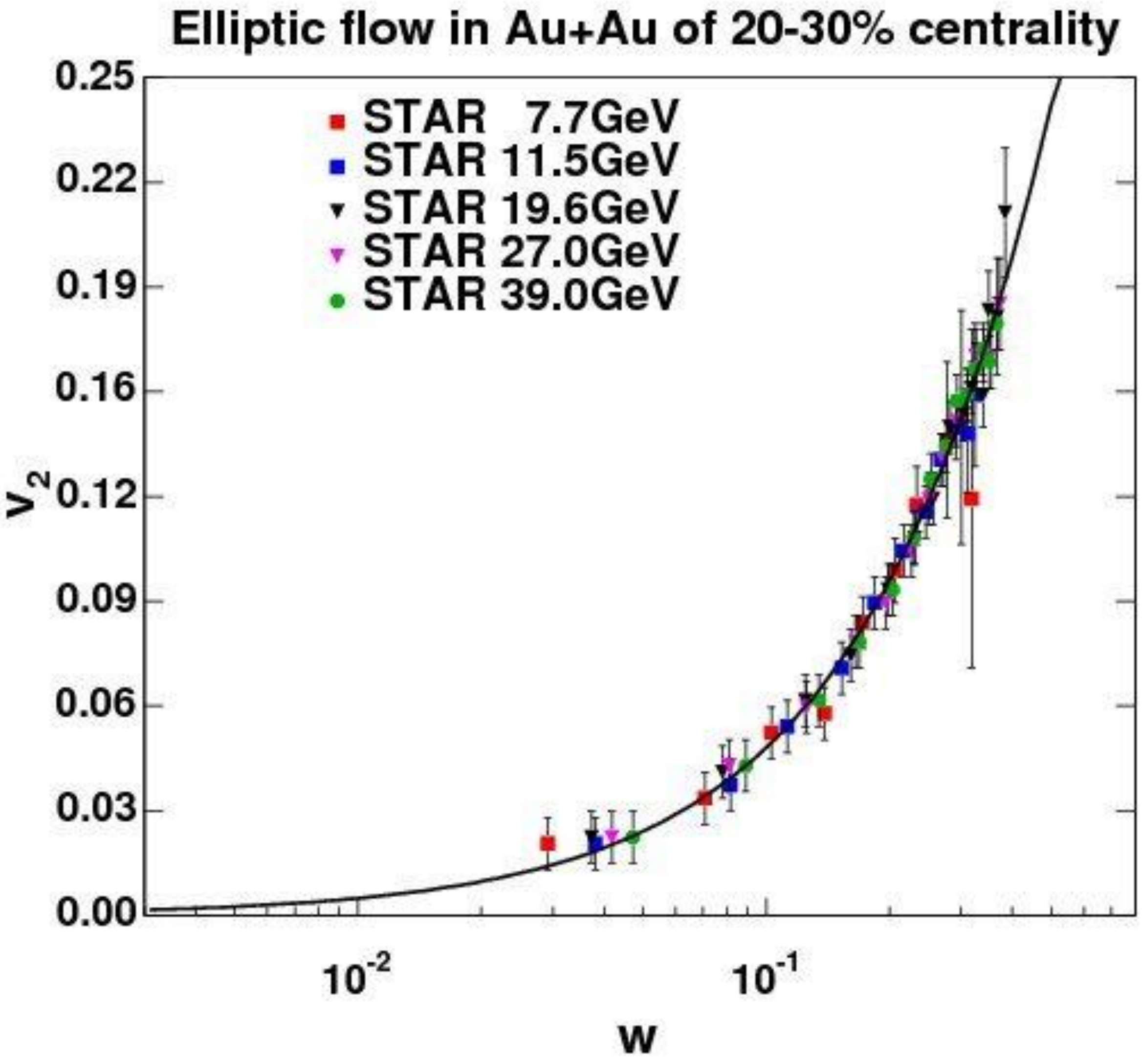
Fit results


BudaLund parameters energy dependence
$\dot{X}$
$\dot{Y}$
U_T
ecc
STAR Au+Au v_2 fits
Parameter
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0
10
20
30
40
50
E_{CM} [GeV]

Fit results

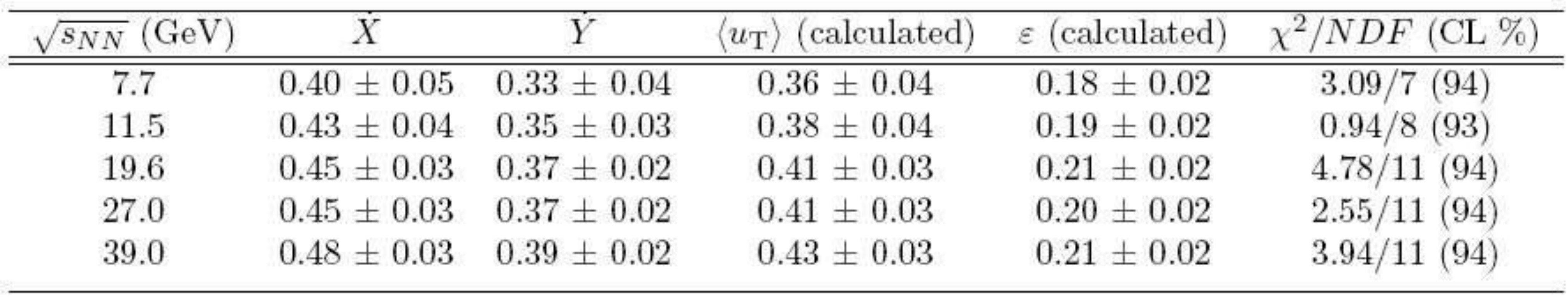

Budalund parameters energy dependence
■ Chi2 / NDF
■ CL(%) / 100
STAR Au+Au v_2 fits
Parameter
1.50
1.31
1.12
0.94
0.75
0.56
0.38
0.19
0.00
0
10
20
30
40
50
E_{CM} [GeV]

Fit results


Elliptic flow in Au+Au of 20-30% centrality
■ STAR 7.7GeV
■ STAR 11.5GeV
▼ STAR 19.6GeV
▼ STAR 27.0GeV
● STAR 39.0GeV
v_2
0.25
0.22
0.19
0.16
0.12
0.09
0.06
0.03
0.00
10^{-2}
10^{-1}
w

Fit results

Summary table of the excitation function of the Hubble expansion rates in plane and out-of-plane, as well as, average radial flows, eccentricities and fit quality parameters:



$\sqrt{s_{NN}}$ (GeV)	$\dot{X}$	$\dot{Y}$	$\langle u_{\mathrm{T}} \rangle$ (calculated)	ε (calculated)	χ^2/NDF (CL %)
7.7	0.40 ± 0.05	0.33 ± 0.04	0.36 ± 0.04	0.18 ± 0.02	3.09/7 (94)
11.5	0.43 ± 0.04	0.35 ± 0.03	0.38 ± 0.04	0.19 ± 0.02	0.94/8 (93)
19.6	0.45 ± 0.03	0.37 ± 0.02	0.41 ± 0.03	0.21 ± 0.02	4.78/11 (94)
27.0	0.45 ± 0.03	0.37 ± 0.02	0.41 ± 0.03	0.20 ± 0.02	2.55/11 (94)
39.0	0.48 ± 0.03	0.39 ± 0.02	0.43 ± 0.03	0.21 ± 0.02	3.94/11 (94)

Summary

The Buda-Lund hydrodinamic model succesfully described STAR Au+Au v_2 data with exact perfect fluid solutions.

We found that the elleptic flows consistent with a scaling law $v_2 = I_1(w)/I_0(w)$ predicted by the model.

Our results show that the radial flow increases gradually but slightly in the studied collision energy range 7.7 - 39 GeV.