Initial conditions for hydrodynamic simulations of collisions at RHIC-BES energies

Jakub Štěrba
CTU FNSPE

9. 12. 2021
ZIMÁNYI SCHOOL 2021

collaboration with B. Tomášik, I. Karpenko

The work was supported from the European Regional Development Fund-Project "Center of Advanced Applied Science" No. CZ.02.1.01/0.0/0.0/16_019/0000778

Introduction

- During the evolution of the QGP - collective expansion
- Azimuthal anisotropy of particle production - experimental signature of collective flow
- Fourier expansion

$$E\frac{\mathrm{d}^3N}{\mathrm{d}p^3} = \frac{1}{2\pi}\frac{\mathrm{d}^2N}{p_T\mathrm{d}p_T\mathrm{d}y}\left(1 + 2\sum_{n=1}^{\infty} v_n\cos[n(\phi - \Psi_{RP})]\right)$$

- Fourier coefficients - $v_n(p_T, y) = \langle\cos[n(\phi - \Psi_{RP})]\rangle$
- Second Fourier coefficient in Fourier series - elliptic flow - v_2
- Anisotropic flow caused by the initial asymmetries in the geometry

Glissando

- Monte Carlo Glauber simulation of the initial stages of heavy-ion collisions, including wounded nucleon model
- Generates two dimensional energy density profiles of fireball in transverse plane
- Works in simple steps:
    1. Generation of the position of nucleons in colliding nuclei according to nuclear density distribution
    2. Generation of the transverse positions of sources and relative deposited strength
- Static
- Can be used in studies of the shape of the medium - e.g. initial conditions for hydrodynamic studies

Wojciech Broniowski, Maciej Rybczynski, Piotr Bozek, Comput.Phys.Commun. 180 (2009) 69-83
M. Rybczynski, G. Stefanek, W. Broniowski and P. Bozek, Comput. Phys. Commun. 185 (2014)

vHLLE

- 3+1 dimensional relativistic hydrodynamic code
- Matter from initial state is transformed into fluid
- Evolved by solving relativistic viscous hydrodynamic equations until freeze-out
- Bulk viscosity not implemented
- Assumptions of non-zero net baryon density in the entire system and no boost-invariant longitudinal expansion
    - Which is necessary for collisions at BES energies
- hadronSampler - hadronization and rescattering - UrQMD

Iu. Karpenko, P. Huovinen, M. Bleicher, *Comput.Phys.Commun.* 185 (2014) 3016-3027

M. Bleicher, E. Zabrodin, C. Spieles, S. A. Bass, C. Ernst, S. Soff, L. Bravina, M. Belkacem, H. Weber, H. Stoecker and W. Greiner, J. Phys. G 25 (1999)

The task

- Using hybrid vHLLE package
- Elliptic flow from the simulation of RHIC BES collisions too small
- Adding initial velocity in the transverse plane to each cell of hydrodynamic grid

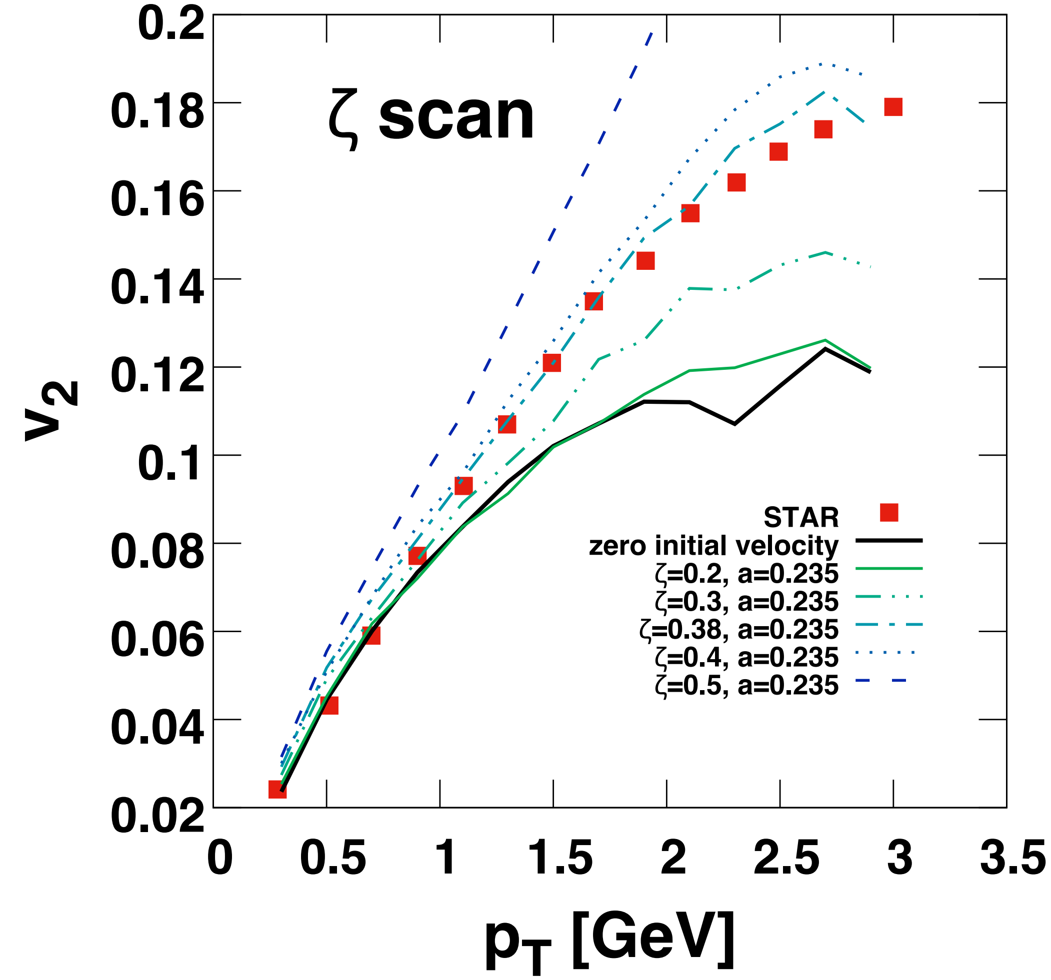
$$v(r) = \zeta\left(\frac{r}{r_{max}}\right)^2 (1 + 2a\cos(2\phi)) + v_{rand}$$

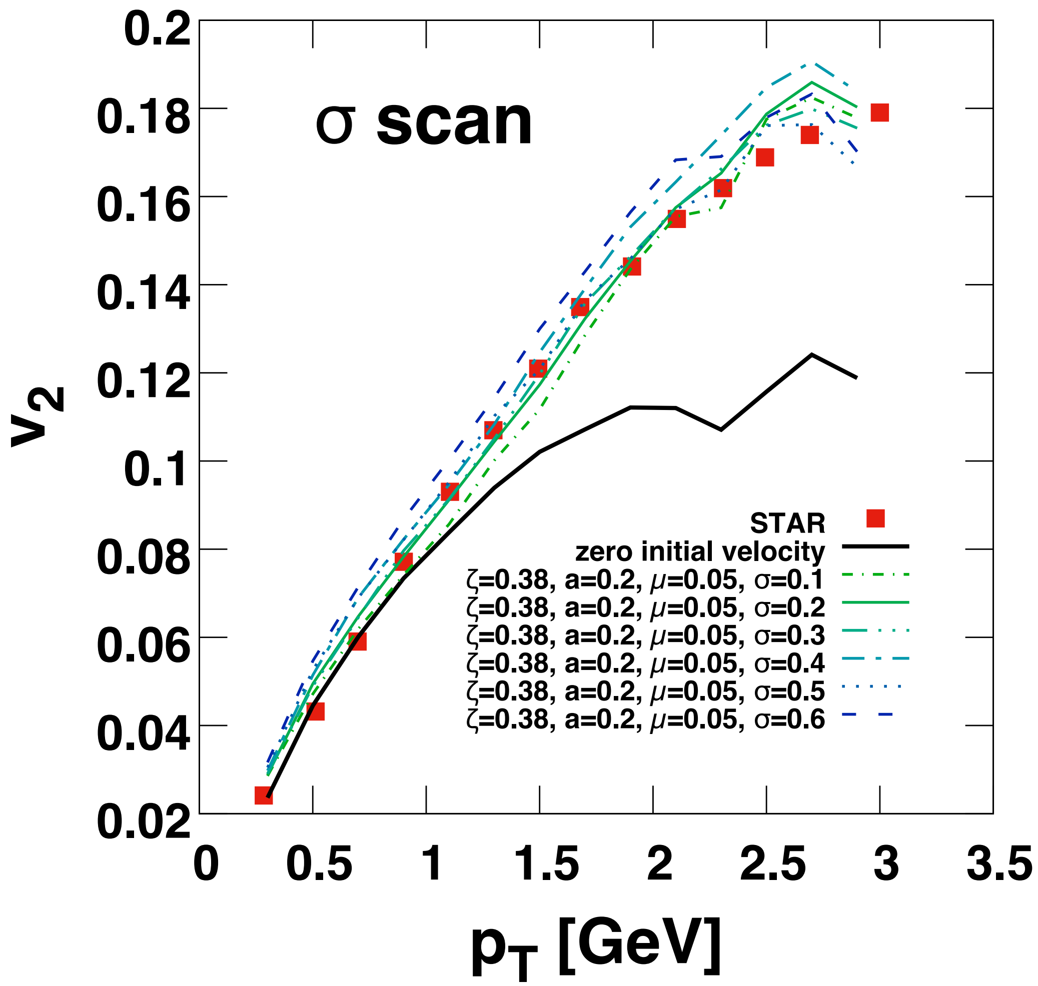
- r is radial coordinate in transverse plane, $r_{max} = 3.5$ fm, ϕ is azimuthal angle and v_{rand} is random component given by Gaussian distribution
- Condition $||v|| < 1$ is kept
- ζ and a - parameters of the model
- σ and μ - parameters of v_{rand} - σ is width of the distribution and μ its mean

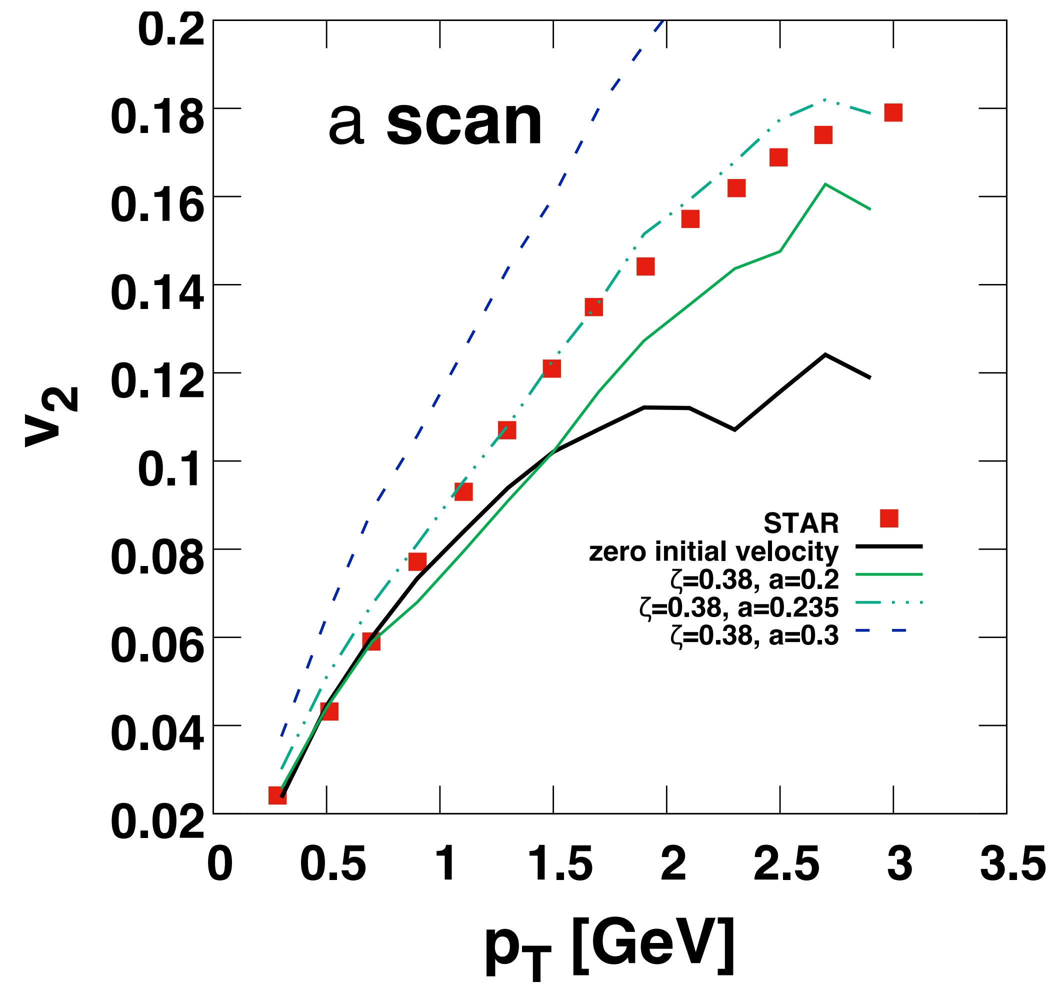
L. Adamczyk et al. [STAR Colaboration], *Phys.Rev.C* 86 (2012) 054908

Results

- Centrality 20-30%
- $\sqrt{s_{NN}} = 27$ GeV
- $v_2(p_T)$ dependence

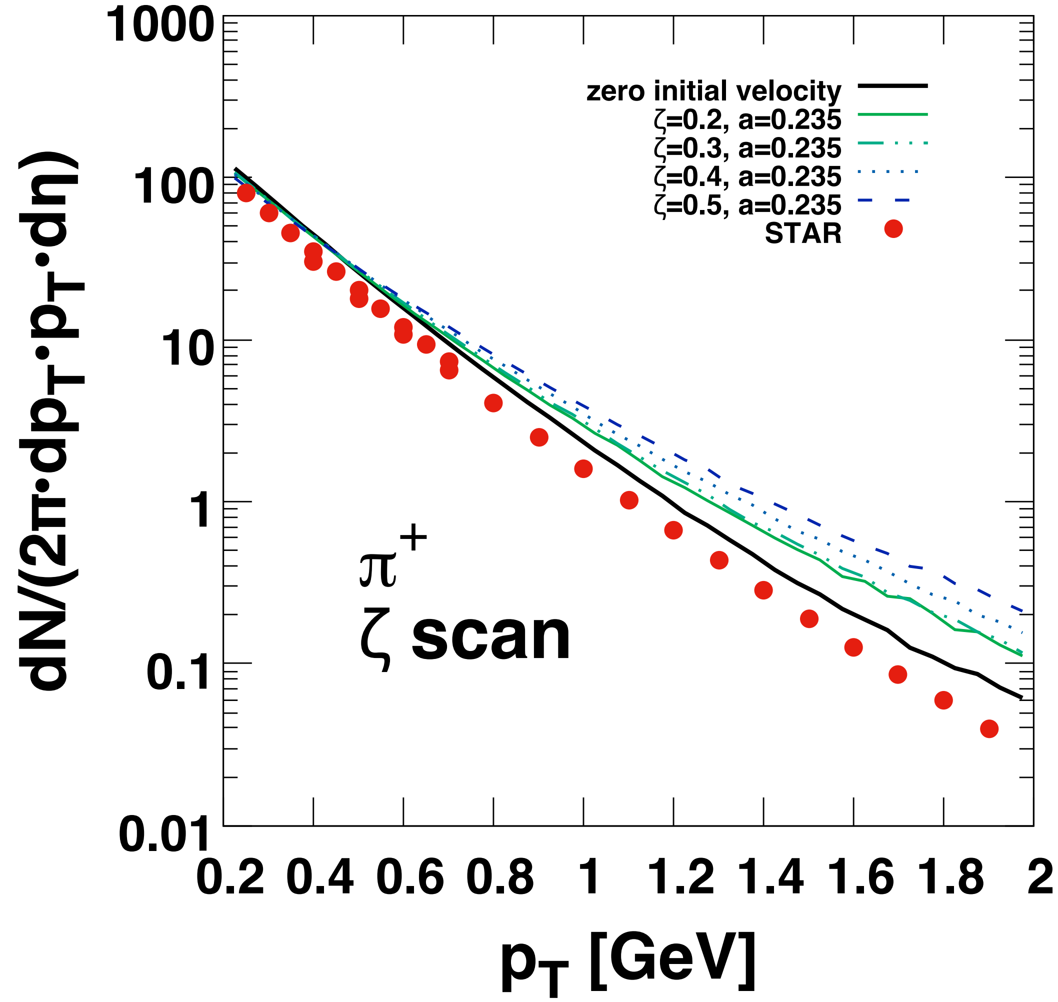


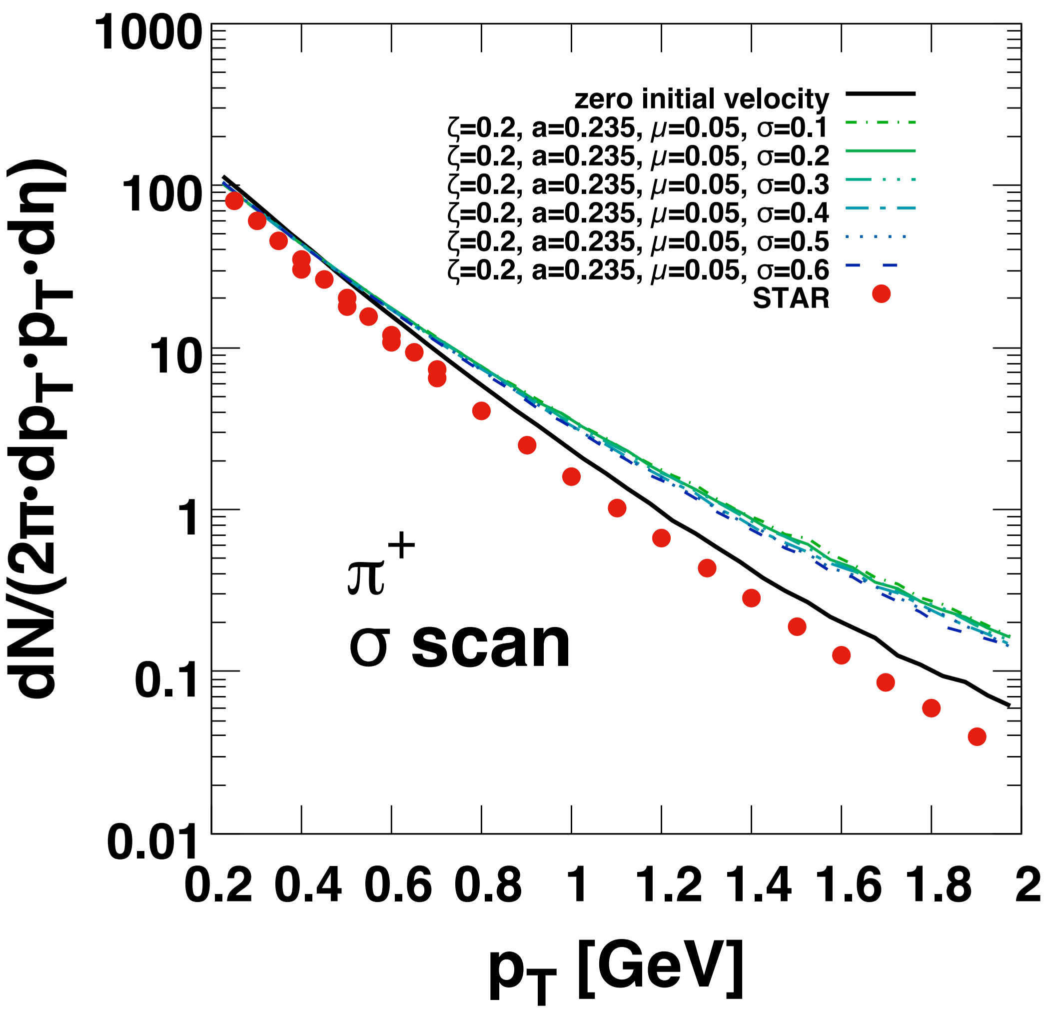


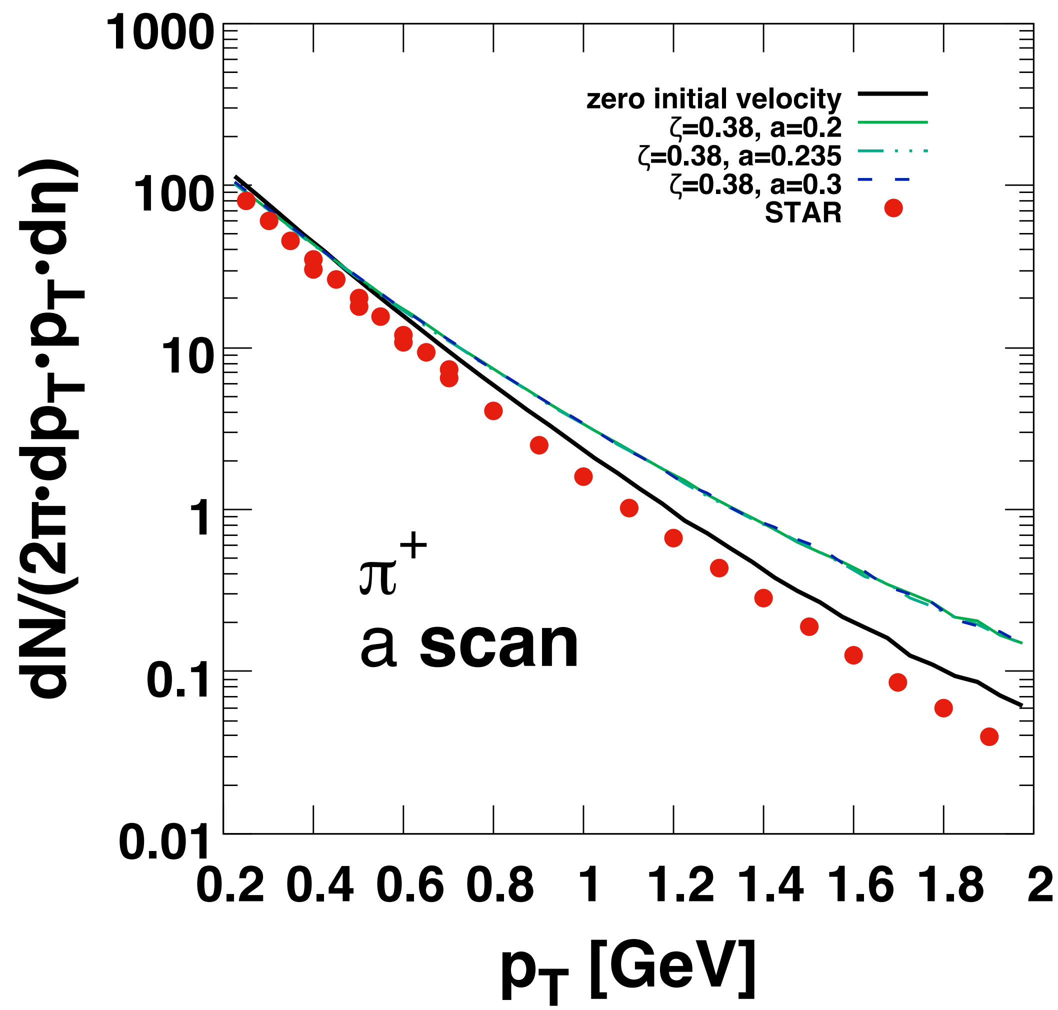


Results

- Centrality 20-30%
- $\sqrt{s_{NN}} = 27$ GeV
- Pion p_T spectrum

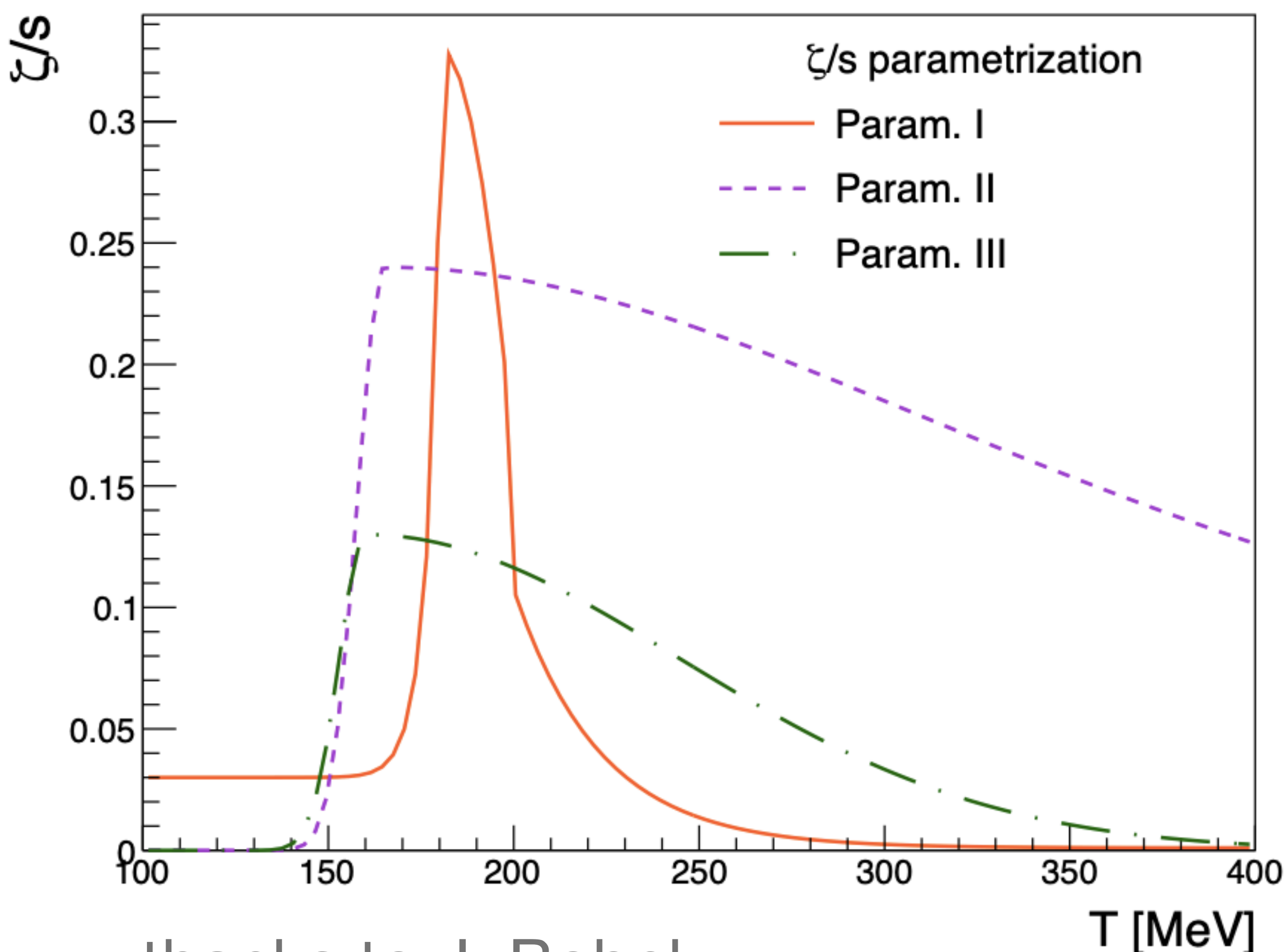






Introduction of bulk viscosity

- UrQMD -> SMASH
- $$\frac{\zeta_{bulk}}{s} = B_{norm} \cdot \exp\left[-\frac{(T - T_{peak})^2}{B^2} \right]$$
- $B_{norm} = 0.13, T_{peak} = 0.16$ GeV
- $B = 0.01$ GeV for $T < T_{peak}$
- $B = 0.12$ GeV for $T > T_{peak}$

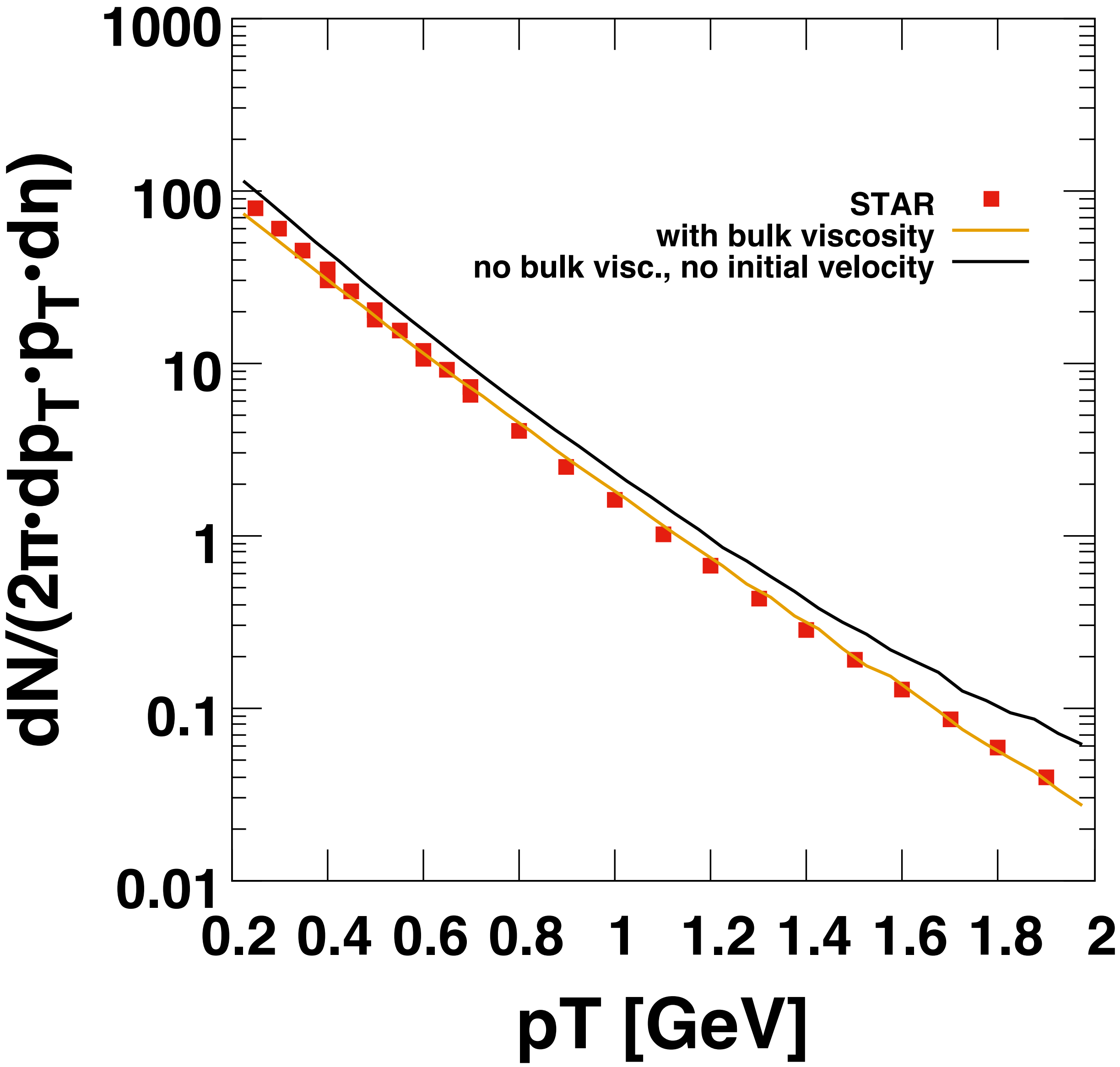


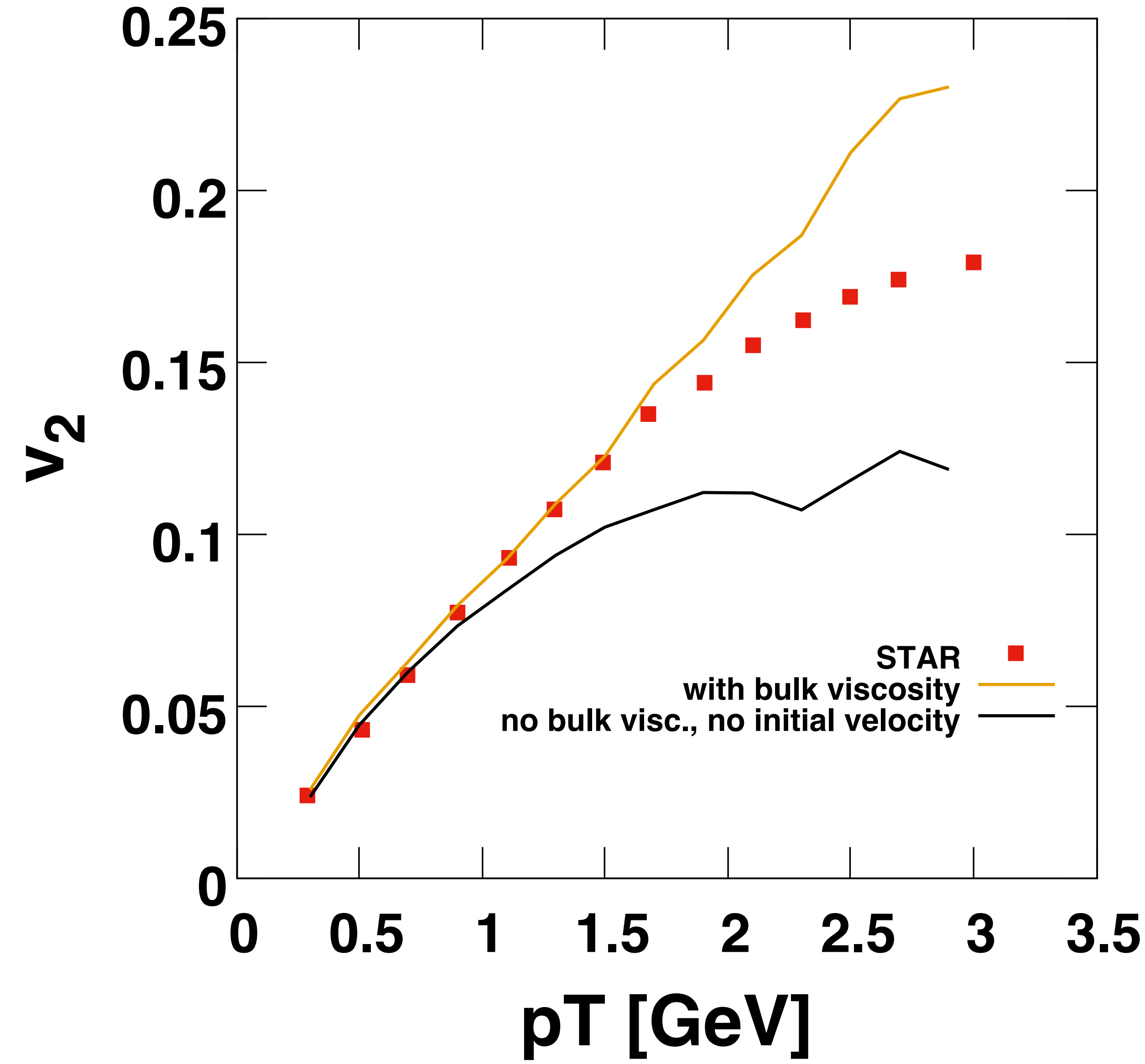
thanks to J. Bobek

- Bulk corrections also in hadronization - modification of Cooper-Frye formula - thanks to R. Vozábová

https://github.com/smash-transport/smash-hadron-sampler

Introduction of bulk viscosity





Summary

- Using hybrid vHLLE package with Glissando as i. c., the v_2 values underpredict data from RHIC BES
- Initial transverse velocity was added -> spoiling the p_T spectrum
- Solution - bulk viscosity