Constraining global initial geometry with directed flow

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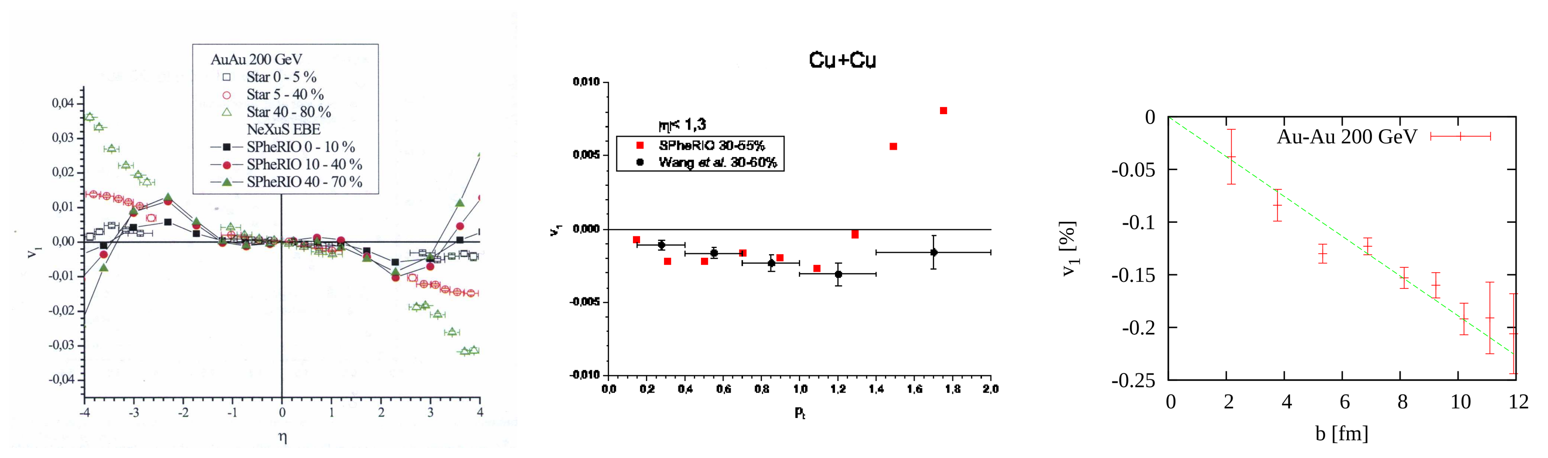
Introduction

- Data on v_n for $n > 1$ and v_1^{even} are well reproduced by event-by-event hydrodynamics $\longrightarrow$ this constrains fluctuations in the initial conditions (eg. [1-3])
- Here, data on v_1^{odd} are shown to provide constrains on the overall geometry of the initial conditions (tilt and skewness)

Data



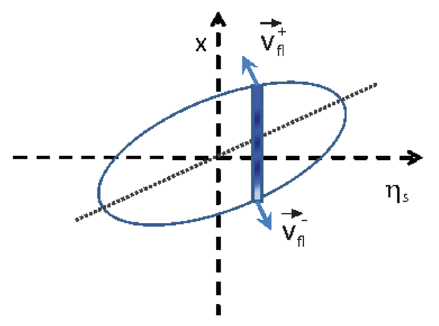
- $v_1(\eta)$ has negative slope [4,5]. Slope decreases at higher energy
- $v_1(p_t)$ has turnover [6]
- $v_1(\eta)$ does not depend on A [6,7]
- $v_1(b)$ decreases linearly, using [6]

Obs: e-by-e code NeXSPheRIO reproduces main features.

Which features in the I.C. are crucial to reproduce v_1 data?

1) η and b dependence come from tilt:

Tilted ellipsoidal shape expected for initial interaction region due to the different path lengths of nucleons from projectile and target



Assume

$$s(x, y, \eta_s, \tau_0) = s_0 \exp\left(-\frac{x^2}{2\sigma_x^2} - \frac{y^2}{2\sigma_y^2} - \frac{\eta_s^2}{2\sigma_{\eta_s}^2} + \theta \frac{x\,\eta_s}{\sigma_x \sigma_{\eta_s}}\right)$$

Parameters:

- σ_x, σ_y: from Woods-Saxon profiles
- $\sigma_{\eta_s} = 2.3$: from [8] $\sigma_Y = \sqrt{\ln \sqrt{s}/(2m_p)}$
- θ: s is peaked at $\eta_{cms} \sim$ rapidity of the 2 colliding tubes at $(x, y) \Rightarrow \theta = -\frac{\sigma_x}{\sigma_{\eta_s}} \frac{T'}{T}$

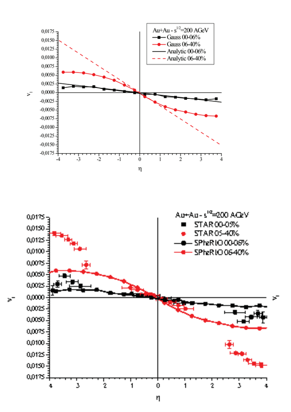
Centrality	σ_x	σ_y	θ
0-6 %	2.78	2.92	0.04
6-15 %	2.40	2.79	0.08
15-25%	2.04	2.61	0.12
25-35 %	1.76	2.44	0.16
35-45 %	1.54	2.26	0.22
45-55 %	1.36	2.09	0.30

$v_1(Y)$ can be estimated analytically for 1+1 expansion:

$$Y(\tau, \eta_s; x, y) = \eta_s - \left(c_s^2 \ln \frac{\tau}{\tau_0}\right) \frac{\partial \ln s}{\partial \eta_s}$$

$$v_1(Y) \sim \underbrace{c_s^4 \frac{1+c_s^2}{1-c_s^2}}_{eos} \underbrace{\tau_f \left\{ \ln\left(\frac{\tau_f}{\tau_0}\right) + \frac{1}{1-c_s^2}\left[\left(\frac{\tau_0}{\tau_f}\right)^{1-c_s^2} - 1\right]\right\}}_{duration} \underbrace{\left(\frac{-\theta}{\sigma_{\eta_s}^3 \sigma_x} Y\right)}_{I.C.}$$

Agreement of analytical formula with numerical solution and data

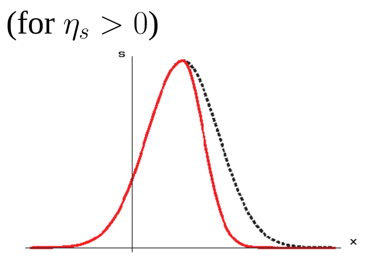


- Negative slope and Y linearity: due to $-\ Y$ term in $v_1(Y)$
- Slope decrease with $\sqrt{s}$: due to $\sigma_{\eta_s} = \sqrt{\ln \sqrt{s}/(2m_p)}$
- A dependence: contained in $\tau_f \theta/\sigma_x \sim \theta$. If θ does not depend on A, v_1 does not either.
- Increase with peripherical collision: due to $\tau_f \theta/\sigma_x \sim \theta$ and θ increase (cf. table)

2) p_t dependence comes from negative skewness:

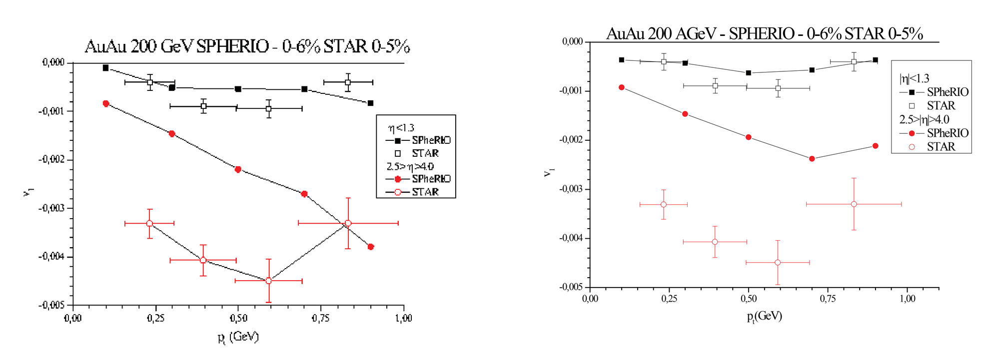
Black curve is gaussian. Red curve has negative skewness

(for $\eta_s > 0$)



Negative skewness can be added to $s(x, y, \eta_s, \tau_0)$ (for $\eta_s > 0$):
for $x < 0$, $\sigma_x \to \sigma_x$
for $x > 0$, $\sigma_x \to \sigma_x/\sqrt{1 + \lambda\theta|\eta_s|/\sigma_{\eta_s}}$

$v_1(p_t)$ decreases linearly without skewness and has turnover with skewness:

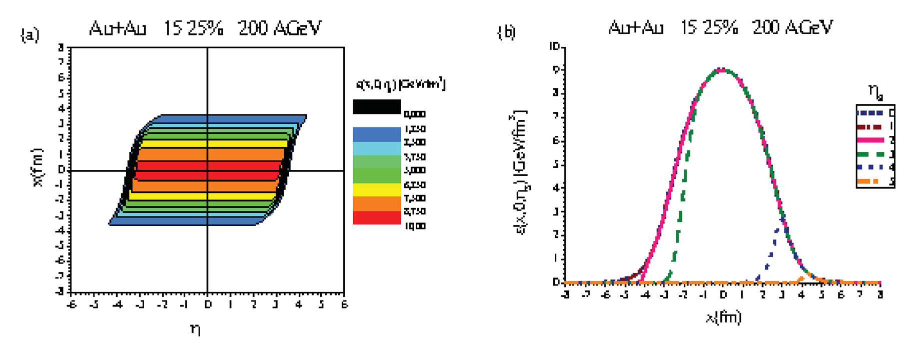


Which models for the I.C. have the right features?

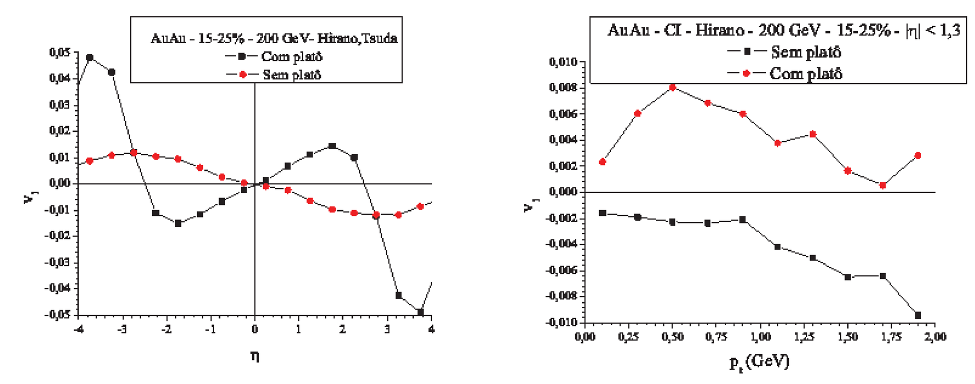
1) Hirano-Tsuda initial conditions [9]:

$E(x, y, \eta_s) = E_{max} W(x, y; b) H(\eta_s)$ with
$W(x, y; b) \propto T_+ T_-$ and $H(\eta_s) = \exp\left[-\frac{|\eta_s - \eta_{cms}| - \eta_f/2)^2}{2\sigma_\eta^2}\theta(|\eta_s - \eta_{cms}| - \eta_f/2)\right]$

These I.C. exhibit plateau+tilt and positive skewness:



As expected, $v_1(\eta)$ has no negative slope (see also [10]) and $v_1(p_t)$ has no correct turnover:

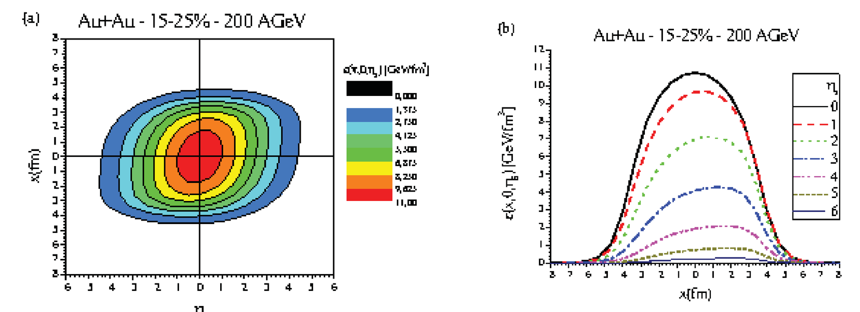


2) Adil-Gyulassy initial conditions [11]:

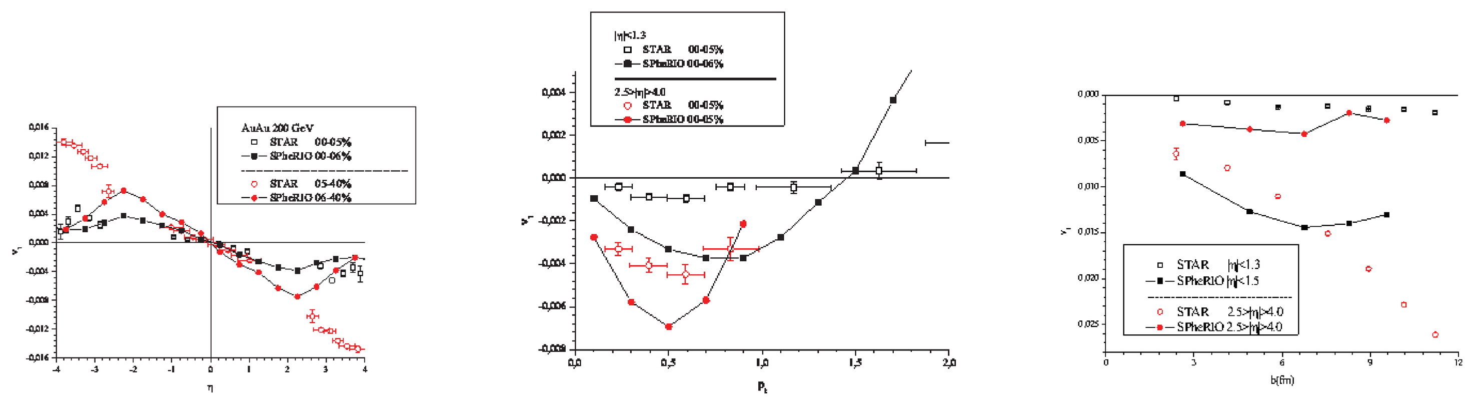
$$s(x, y, \eta_s, \tau_0) = \frac{s_0}{2Y_{max}} \exp\left(\frac{-\eta_s^2}{\sigma_{\eta_s}^2}\right) \theta(Y_{max} - |\eta|) \left[\frac{dN_{part}^+}{dx\,dy}(Y_{max} - \eta) + \frac{dN_{part}^-}{dx\,dy}(Y_{max} + \eta)\right]$$

with $\frac{dN_{part}^{\pm}}{dx\,dy} = T_{\pm}[1 - \exp(-\sigma_{in} T_{\mp})]$

These I.C. exhibit tilt and negative skewness:

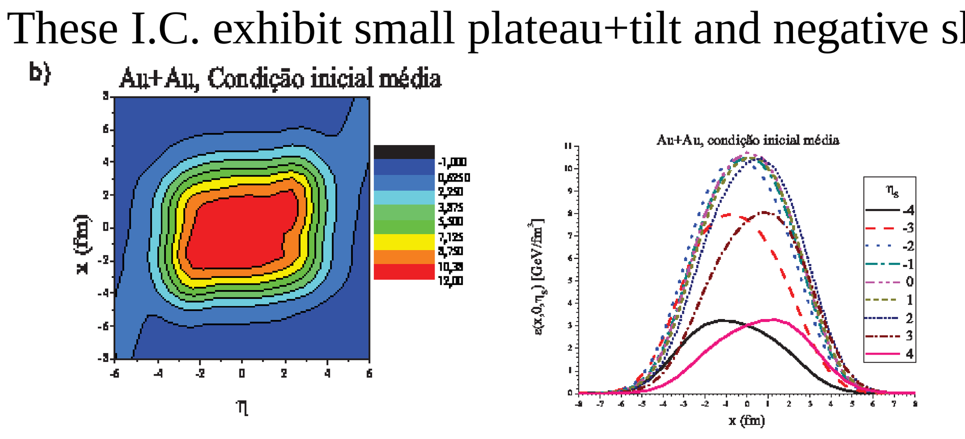


As expected, $v_1(\eta)$ has negative slope, $v_1(p_t)$ has correct turnover, however $v_1(b)$ is not right:



3) Smooth NeXus initial conditions:

These I.C. exhibit small plateau+tilt and negative skewness:



This explains why event-by-event NeXSpheRIO results in §Data have $v_1(\eta)$ with (small) negative slope and $v_1(p_t)$ with correct turnover. $v_1(b)$ is not right.

Conclusion

- I.C. with tilt (with correct b dependence) and negative skewness (for $\eta_s > 0$) allow to reproduce data
- No totally satisfactory I.C. found so far (wrong b dependence)
- Role of equation of state needs checking

References

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