Event-by-event hydrodynamics and elliptic flow from fluctuating initial state

PRC83 (2011) 034901

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Outline of this talk

1. Our event-by-event (ebye) hydrodynamics model

2. Spectra and v_2 results at RHIC

3. Conclusions

See also talks:
"Enhancement of thermal photon production in event-by-event hydrodynamics" by R. Chatterjee
"Monte-Carlo simulation for elastic energy loss of high-energy partons in a hydrodynamical background" by J. Auvinen

Monte Carlo Glauber

Nucleons are distributed into nuclei using Woods-Saxon.

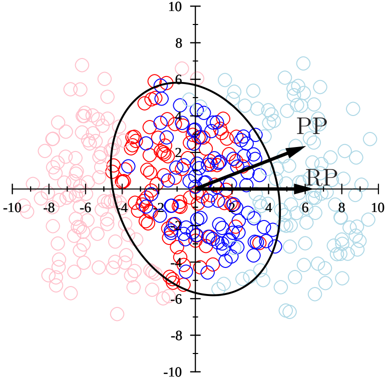
No finite nucleon size effects included.

Random impact parameter from $dN/db \sim b$.

Nucleons collide if

$$(x_i - x_j)^2 + (y_i - y_j)^2 \leq \frac{\sigma_{NN}}{\pi}.$$

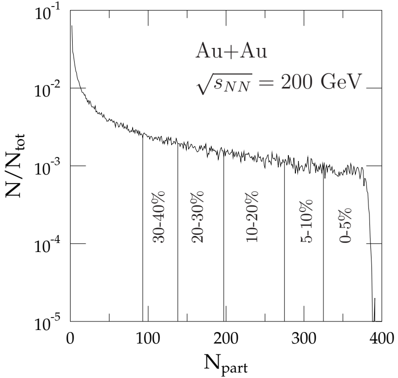
Participant plane maximises the initial eccentricity.



Centrality classes

Let's use N_{part} to define the centrality classes.

Impact parameter varies freely in each centrality class.



Centrality	N_{part} range	$\langle N_{part} \rangle$	$\langle b \rangle$ [fm]
0-5 %	325-394	352	2.25
5-10 %	276-324	299	4.07
10-20 %	197-275	234	5.72
20-30 %	138-196	166	7.40
30-40 %	93-137	114	8.76

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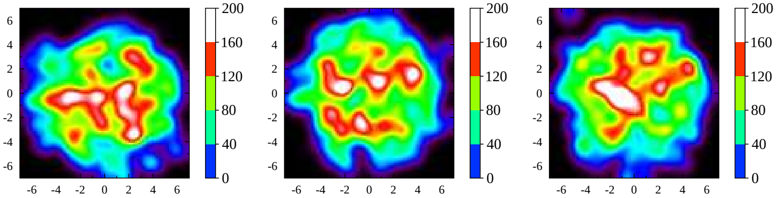
Initial profiles from MCG

In our model energy density is distributed around the centers of the wounded nucleons with 2D Gaussian

$$\epsilon(x,y) = \text{const.} \sum_{\text{wn}} \frac{1}{2\pi\sigma^2} \exp\left[-\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma^2} \right].$$

Now σ is a free parameter in our model.



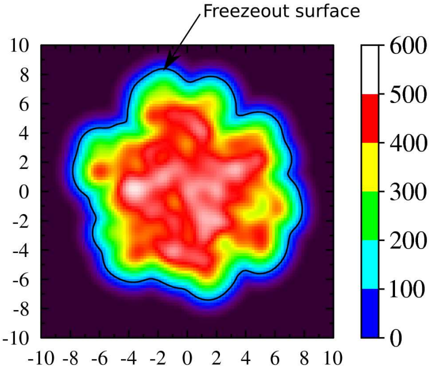
Some events with $b = 0$ fm and $\sigma = 0.4$ fm.

Our initial states are bumpy but smooth enough for hydro.

Hydrodynamical evolution

Our hydro setup for RHIC:

- 2+1 ideal hydrodynamics
- Bjorken flow in the beam direction
- No baryon number density
- Initial time $\tau_0 = 0.17$ fm and overall energy density normalization from EKRT model, Eskola et al., Nucl. Phys. B570 (2000) 379
- EoS from Laine and Schroder, PRD73 (2006) 085009
- Freeze-out temperature $T_f = 160$ MeV

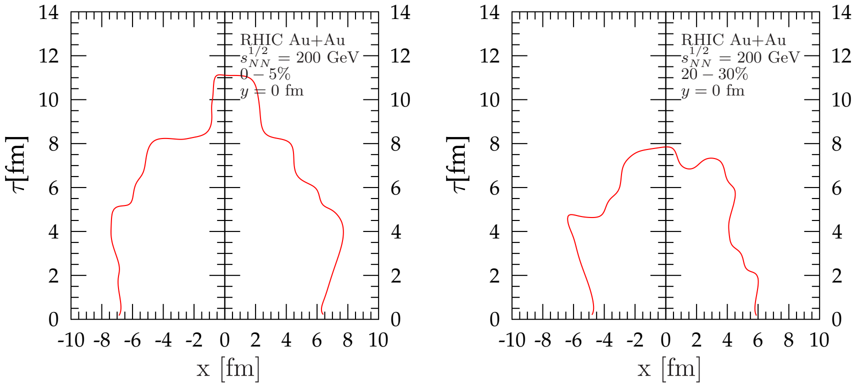


Freeze-out

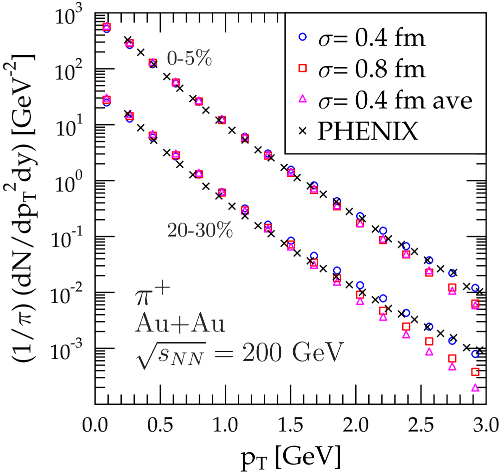
Thermal spectrum from Cooper-Frye with $T_f = 160$ MeV

$$\frac{dN}{d^2p_T dy} = \int_\sigma f(x,p)p^\mu d\sigma_\mu.$$

We sample hadrons from this and do decays with PYTHIA.



Spectra



500 hydro runs in each centrality class. 20 events from each hydro run.

Fluctuations can increase the number of the high-p_T particles since the pressure gradients are larger.

This is however quite sensitive to our free parameter σ.

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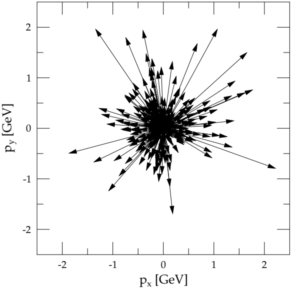
Calculating v_2 with event plane method

First we calculate the event flow vector

$$Q = \sum_i p_T^i \Big(\cos(2\phi^i), \sin(2\phi^i) \Big).$$



Event plane is determined from the event flow vector

$$\psi_{EP} = \frac{\arctan(Q_y/Q_x)}{2},$$

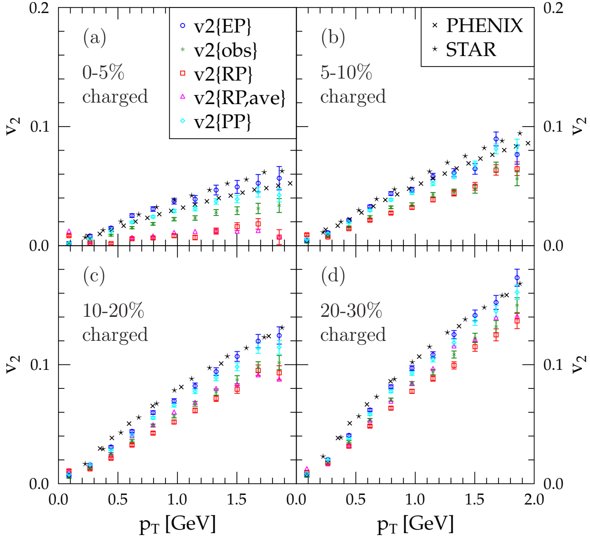
Then we can calculate elliptic flow

$$v_2 = \frac{\langle \cos(2(\phi - \psi_{EP})) \rangle}{\mathcal{R}},$$

where $\mathcal{R}$ is correction from statistical fluctuations. It is calculated with 2-subevent method.

Poskanzer and Voloshin, PRC58 (1998) 1671.

Elliptic flow



Ebye hydro reproduces the data very well at all centralities shown here.

$v_2\{PP\}$ is close to $v_2\{EP\}$.

$v_2\{RP\}$ and $v_2\{RP,ave\}$ are very similar.

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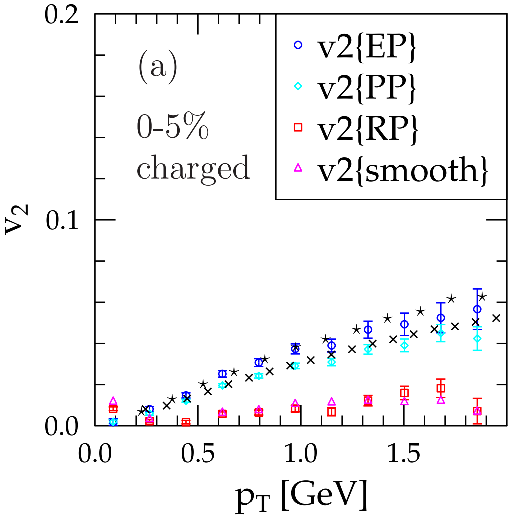
Elliptic flow



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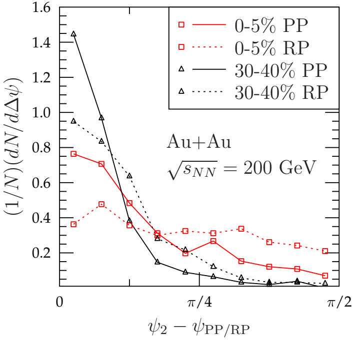
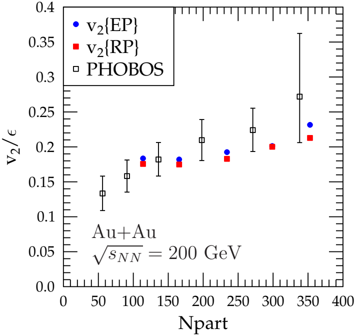
Event plane vs. participant plane





Participant plane is a quite good approximation to event plane.

Eccentricity scaling seems to work pretty well.

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Conclusions

We can simultaneously reproduce the measured p_T spectra and the elliptic flow up to $\sim$ 2 GeV.

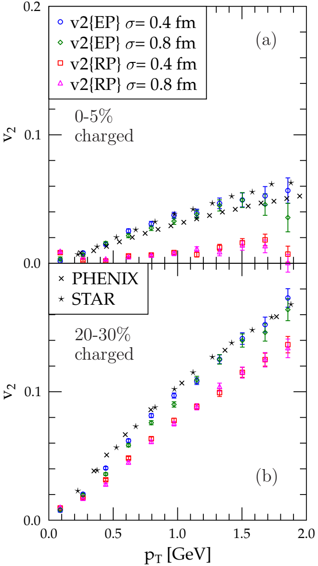
Fluctuations can increase the number of the high-p_T particles.

Fluctuations alone do not increase v_2, but the reference plane definition is very important in the v_2 analysis.

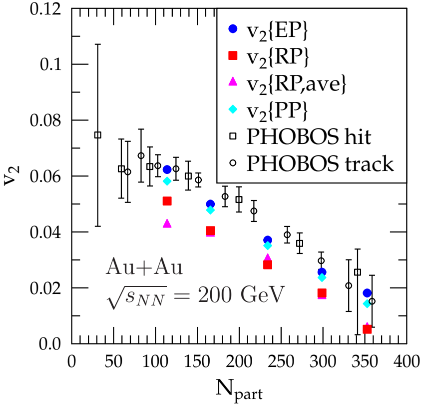
PP is a quite good approximation for the event plane.

Backup slides

Elliptic flow



<- v_2 results are insensitive to smearing radius.



Also integrated v_2 agrees with data.

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Event plane resolution

For two equal sub events

$$\mathcal{R}^{\text{sub}} = \sqrt{\langle \cos(2(\psi_2^A - \psi_2^B))}$$

For Gaussian fluctuations

$$\begin{aligned}\mathcal{R} &= \langle \cos(kn(\psi_{EP}^{\text{true}} - \psi_{EP}))\rangle \\ &= \frac{\sqrt{\pi}}{2\sqrt{2}}\chi \exp(-\chi^2/4)\left[I_{\frac{k-1}{2}}(\chi^2/4) + I_{\frac{k+1}{2}}(\chi^2/4)\right],\end{aligned}$$

where $\chi \sim \sqrt{N}$. We solve χ^{sub}. Then

$$\chi^{\text{full}} = \sqrt{2}\chi^{\text{sub}}$$

Finally using equation above we can calculate $\mathcal{R}^{\text{full}}$.

Poskanzer and Voloshin, PRC58 (1998) 1671.