PHOBOS collaboration

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A method for measuring Elliptic Flow Fluctuations in 200 GeV Au+Au collisions at RHIC

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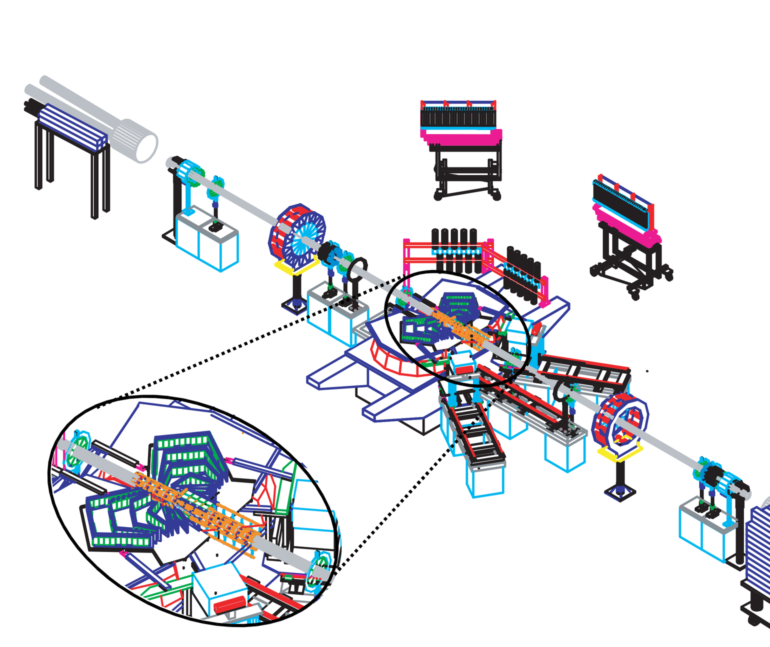
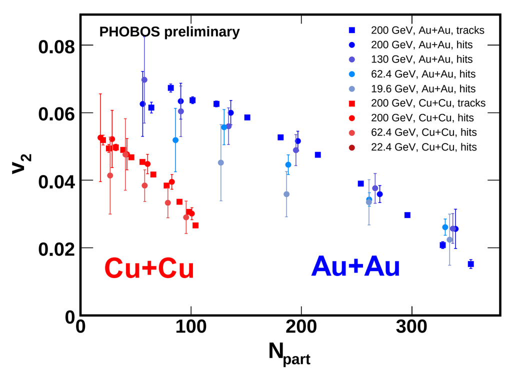
PHOBOS detector



Motivation



Au+Au, 200,130,62.4+19.6 GeV: PRL 94 122303 (2005)
Cu+Cu, 200+62.4 GeV: nucl-ex/0610037 (sub.to PRL)
Cu+Cu, 22.4 GeV: prel. QM06

Elliptic Flow in Cu+Cu collisions is observed to be significantly large.

Note: v_2 is quite large even for the most central collisions where the collision region is on average azimuthally symmetric relative to the impact parameter.

The azimuthal anisotropy of the initial collision region is quantified by the eccentricity

Standard Eccentricity (ε_{std}) is calculated in a Glauber MC with respect to the impact parameter.

Assumes no fluctuation in initial shape geometry for given b.

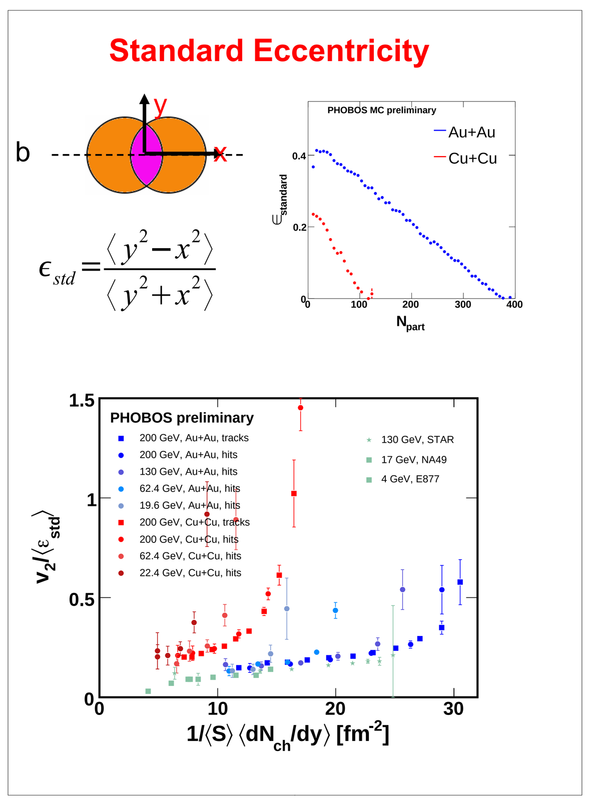
Participant Eccentricity (ε_{part}) is calculated with respect to the minor axis of the ellipse defined by the collision zone.

Takes event-by-event fluctuations in the Glauber MC into account.

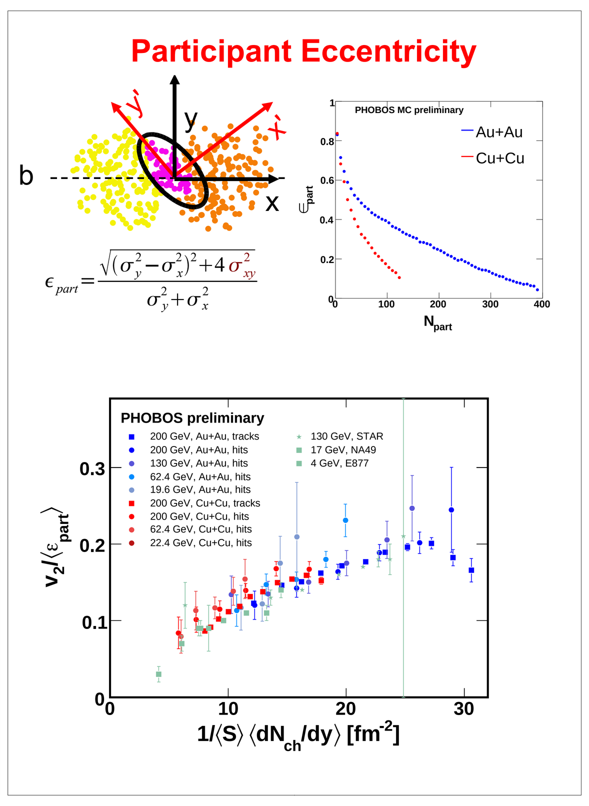
Ideal hydrodynamics predicts scaling between v_2 and ε.

v_2 in Cu+Cu and Au+Au scale with ε_{part}.

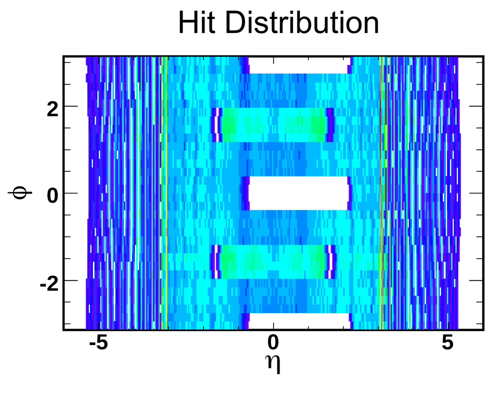
If ε_{part} is the correct description of initial state geometry and if hydrodynamics work event by event, we should observe v_2 fluctuations



$$\varepsilon_{std}=\frac{\langle y^2-x^2\rangle}{\langle y^2+x^2\rangle}$$



$$\varepsilon_{part}=\frac{\sqrt{(\sigma_y^2-\sigma_x^2)^2+4\sigma_{xy}^2}}{\sigma_y^2+\sigma_x^2}$$



The figure on the left shows the distribution of hits on the PHOBOS multiplicity array.

The array has a wide pseudorapidity coverage:

-5.4 < η < 5.4

The detector has holes and granularity differences at midrapidity.

A new event-by-event flow measurement technique has been developed

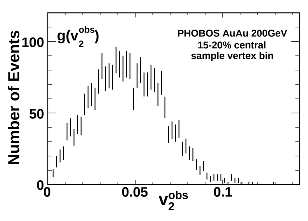
to use all the available information in the detector and

to allow an efficient correction for the acceptance effects.

Measuring elliptic flow fluctuations

nucl:ex/0608025

In this analysis v_2 is measured event-by-event: $g(v_2^{obs})$

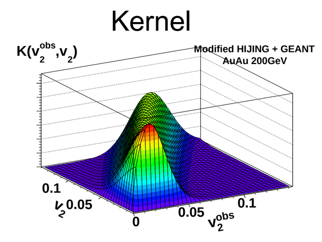


The response of the event-by-event measurement, $K(v_2^{obs},v_2)$, is calculated using detailed MC simulations, taking into account:

Finite-number fluctuations

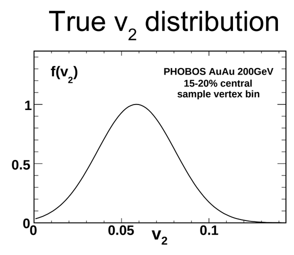
Detector effects

Dependence of the resolution on multiplicity



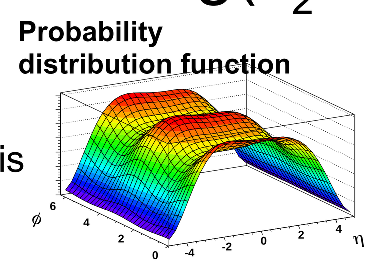
The true v_2 distribution in data, $f(v_2)$, is calculated by finding a solution to:

$$g(v_2^{obs})=\int_0^\infty K(v_2^{obs},v_2)f(v_2)dv_2$$



Event-by-event measurement $g(v_2^{obs})$

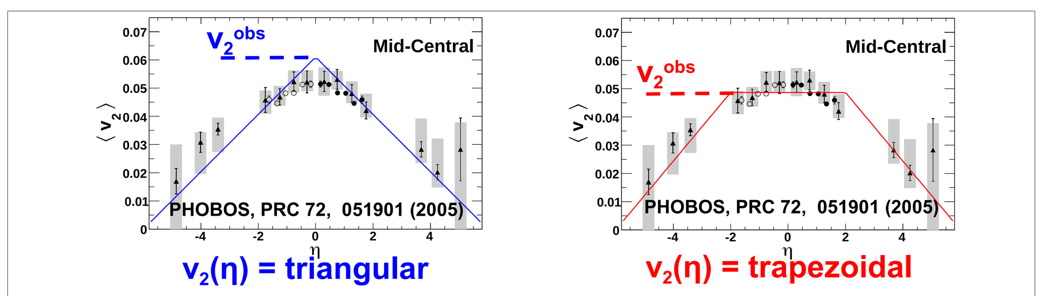
The probability to observe a hit at a certain angle (η, φ) for a given value of elliptic flow magnitude v_2^{obs} and reaction plane angle φ_0 is described by the probability distribution function (PDF):



$$P(\eta,\phi;\ v_2^{obs},\phi_0)=\frac{1}{s(v_2^{obs},\phi_0,\eta)}[1+2v_2(\eta)\cos(2\phi-2\phi_0)]$$

where the normalization parameter, s, is included to make sure the PDF, folded by the acceptance, is normalized to the same value for different values of v_2^{obs} and φ_0.

$$s(v_2^{obs},\phi_0;\eta)=\int A(\eta,\phi)[1+2v_2(\eta)\cos(2\phi-2\phi_0)]$$



The known η dependence of v_2 is used as input to the PDF

The likelihood of v_2^{obs} and φ_0 is defined as:

$$L(v_2^{obs},\phi_0)=\prod_{i=1}^{n}P(\eta_i,\phi_i;\ v_2^{obs},\phi_0)$$

Event-by-event, v_2^{obs} and φ_0 are selected as the most likely values to generate the observed hit distribution.

$$g(v_2^{obs})=\int_0^\infty K(v_2^{obs},v_2)f(v_2)dv_2$$

Determining the kernel $K(v_2^{obs},v_2)$

The resolution of the measurement depends on the number of hits observed in the event.

Define n=observed number of hits

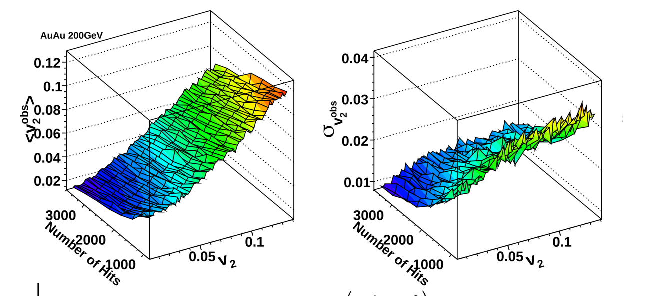
Therefore the kernel is $K(v_2^{obs},v_2,n)$

The kernel is determined by "measuring" v_2^{obs} in bins of true v_2 and n in MC simulations.

HIJING, modified to include flow, is used to generate MC events. Particle azimuthal angles are redistributed with a probability distribution function defined by desired $v_2(\eta)$.

GEANT is used to simulate the detector response.

Plots on the right show $\langle v_2^{obs}\rangle$ and $\sigma(v_2^{obs})$ as a function of v_2 and n.

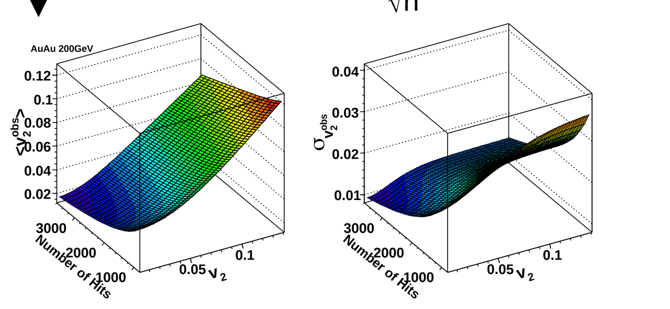


fit

$$K(v_2^{obs},v_2,n)=\frac{v_2^{obs}}{\sigma^2}e^{-\left(\frac{v_2^{obs2}+v_2^2}{2\sigma^2}\right)}I_0\left(\frac{-v_2^{obs}v_2}{\sigma^2}\right);$$

$$v_2\to(An+B)v_2,\ \sigma=\frac{C}{\sqrt{n}}+D$$

J.-Y.Ollitrault, PRD (1992) 46, 226

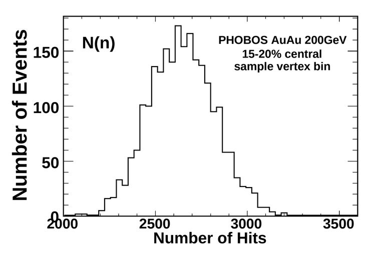


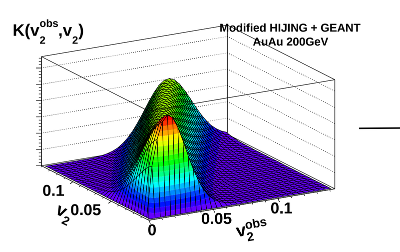
Fitting $K(v_2^{obs},v_2,n)$ with smooth functions reduces bin-to-bin fluctuations.

Theoretical distribution of $K(v_2^{obs},v_2,n)$ modified for experimental effects is used as fit function

Assuming that the true v_2 distribution for a set of events in a given centrality class is independent of n, it is possible to integrate out the multiplicity dependence:

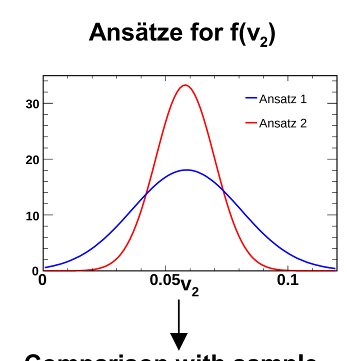
$$K(v_2^{obs},v_2)=\int K(v_2^{obs},v_2,n)N(n)dn$$





Extracting dynamical fluctuations $f(v_2)$

In this measurement the quantities of interest are $\langle v_2\rangle$ and $\sigma(v_2)$

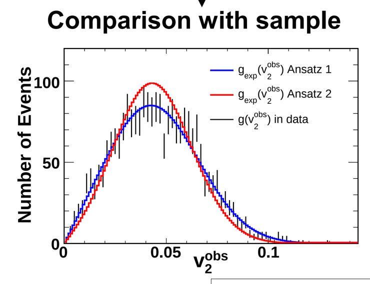


A gaussian Ansatz is used to model the true v_2 distribution in data.

$$f(v_2)=\exp\left[\frac{-(v_2-\langle v_2\rangle)^2}{2\sigma_{v_2}^2}\right]$$

Figures on the left show two Ansätze and their corresponding expected v_2^{obs} distributions.

A likelihood fit is applied to find the matching Ansatz to the data.

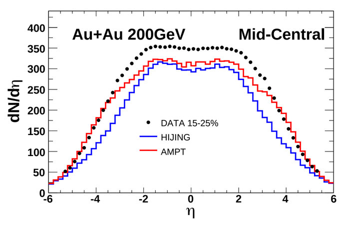


AMPT

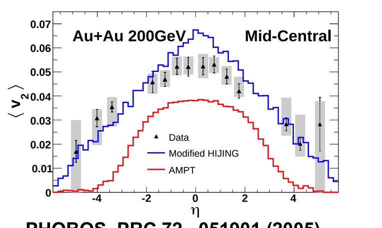
Robustness of the kernel can be tested using events from a different MC generator, e.g. AMPT as "data" and reconstructing event-by-event flow fluctuations using kernel from HIJING.

$v_2(\eta)$ and dN/dη were measured for AMPT and modified HIJING at the MC particle level.

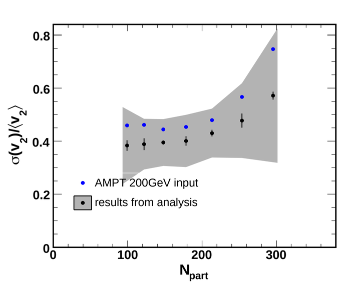
AMPT is significantly different from HIJING.



PRL 91 052303 (2003)



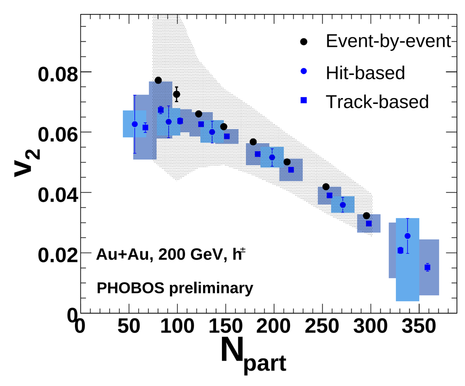
PHOBOS, PRC 72, 051901 (2005)



The complete analysis chain was applied to AMPT

For all centralities, the event-by-event fluctuations at the particle level are within the systematic errors of our measurement.

Results



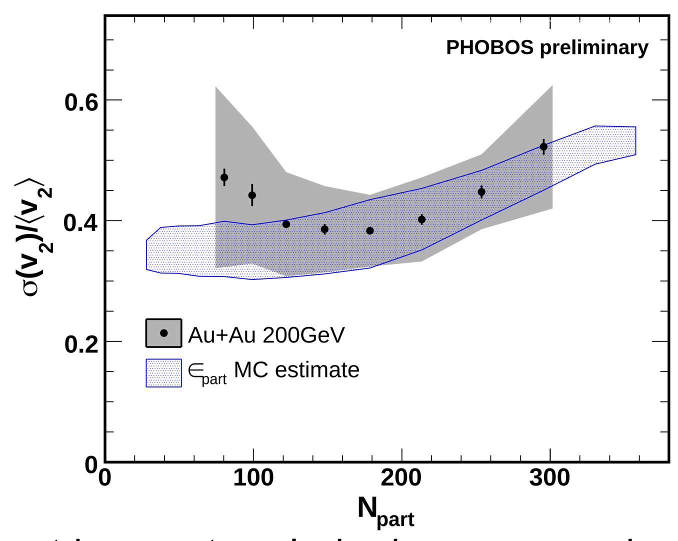
The analysis is run in bins of centrality and collision vertex.

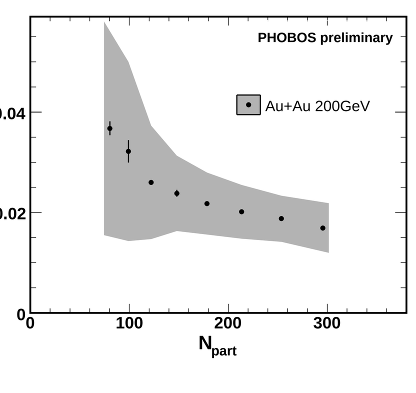
Results from different vertex bins are averaged within each bin of centrality.

Two MC samples with triangular and trapezoidal $v_2(\eta)$ are used.

The midrapidity values from two results are calculated as:

$$v_2=0.5(11/12\,v_{2,tri}+v_{2,trap})$$





Midrapidity $\langle v_2\rangle$ results from this event-by-event analysis show very good agreement with results from other event averaged PHOBOS analyses.

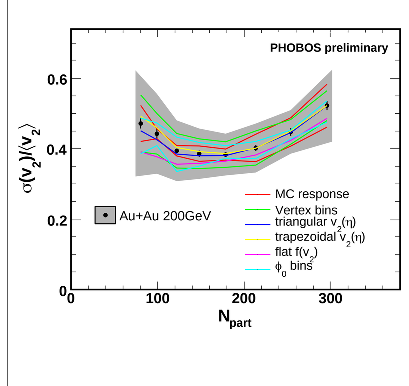
Taking the ratio $\sigma(v_2)/\langle v_2\rangle$ allows cancellation of various systematic errors.

These results are shown in the upper right plot in comparison with participant eccentricity predictions.

Results strongly support the existence of fluctuations in the initial state geometry and the event-by-event realization of the relationship $v_2\propto\varepsilon$.

See Talk by Constantin Loizides (Saturday, 4:20, Parallel 2.4)

Systematic Studies



Systematic errors include

Variations in $v_2(\eta)$

Variations in $f(v_2)$ flat / gaussian

Vertex binning dependence

φ_0 binning dependence

MC response to known input

MC samples with the same multiplicity distribution, i.e. N(n), and $\langle v_2\rangle$ as data, with varying $\sigma(v_2)$, are used in bins of centrality for systematic studies.

The analysis is run on these samples.

The difference between the input and output relative fluctuations in the vicinity of the results in data are added to the systematic errors.