FLOW AT RHIC :

WHAT SHOULD WE SEE AND HOW ?

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RHIC Winter Workshop, 8.1.99

I FLOW AND THERMALIZATION

(is thermalization partial or complete?)

1. A dependence
2. Absolute magnitude of elliptic flow at RHIC
3. Flow of π, K, p.. : p_T dependence
4. Centrality dependence of elliptic flow

II METHODS FOR MEASURING THE FLOW

1. Existing methods and assumptions : a brief historical survey
2. Minijets at RHIC
3. What should be done ?

VARIATION OF FLOW

WITH THE SIZE OF THE SYSTEM

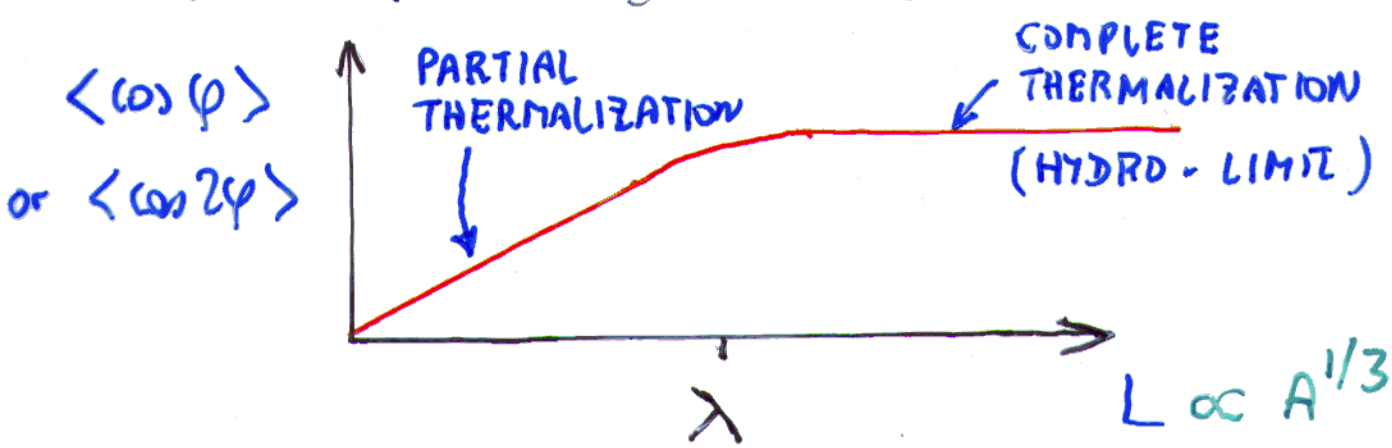
- FLOW AT HIGH ENERGIES (DIRECTED OR ELLIPTIC) RESULTS FROM COLLISIONS BETWEEN PARTICLES (NN, πN, $\pi\pi$ ...)

- LOCAL THERMAL EQUILIBRIUM (HYDRO - LIMIT) IS ACHIEVED IF

$$\lambda \ll L$$

MEAN FREE PATH $\left(= \frac{1}{\sigma n}\right)$ SIZE OF THE SYSTEM $\left(\propto A^{1/3}\right)$

- FLOW OBSERVABLES DEPEND ON L TYPICALLY LIKE (AT FIXED ENERGY)

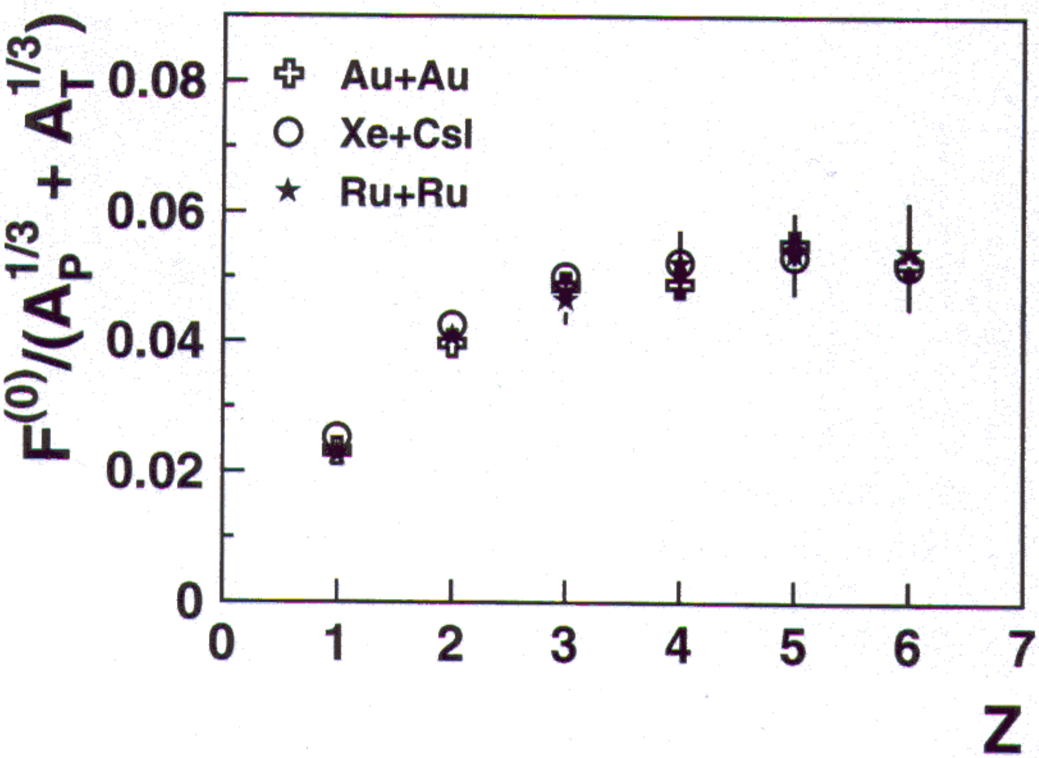


THE VARIATION OF FLOW WITH A GIVES A DIRECT INFORMATION ON THE DEGREE OF THERMALIZATION ACHIEVED IN THE SYSTEM

(SEE, HOWEVER, P. FILIP, Act. Phys. Slov 47 (1997) 53)
WHO PREDICTS A DIFFERENT BEHAVIOUR

~~Figure 4~~

A - DEPENDENCE OF DIRECTED FLOW AT $E/A \approx 400$ MeV



FROM P. RAMI et al, FOPI Collaboration, to be published - (Nov 1998)

DIRECTED FLOW SCALES LIKE $A^{1/3}$:
THERMALIZATION IS FAR FROM COMPLETE

(cf P. Danielewicz et al, PRC 38 (1988) 120)

ABSOLUTE MAGNITUDE OF IN-PLANE ELLIPTIC FLOW

THE A - DEPENDENCE OF DIRECTED AND ELLIPTIC FLOW HAS UNFORTUNATELY NOT BEEN STUDIED AT AGS AND SPS

HOWEVER, HYDRO MODELS FAIL TO PREDICT THE ABSOLUTE MAGNITUDE OF IN-PLANE ELLIPTIC FLOW OBSERVED AT SPS

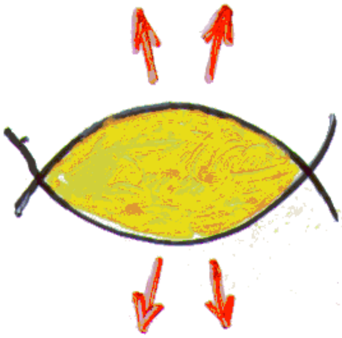
SPS : $v_2 \lessapprox 4\%$ FOR π, p

HYDRO : $v_2 \sim 20\%$

THIS SUGGESTS THAT ONLY PARTIAL THERMALIZATION IS ACHIEVED AT SPS

AT RHIC, THERMALIZATION SHOULD BE BETTER IF A LONG LIVED, STRONGLY INTERACTING PLASMA OF COLORED QUARKS AND GLUONS IS FORMED.

TIME SCALE FOR IN-PLANE ELLIPTIC FLOW



ELLIPTIC FLOW DEVELOPS FOR $t \sim \frac{R}{c_s}$ RADIUS / VELOCITY OF SOUND

THROUGH IN-PLANE ELLIPTIC FLOW, WE "SEE" THE SYSTEM AT $t \simeq 10$ fm/c, i.e. AT A LATE STAGE ($\neq J/\psi, \gamma, e^+e^- \ldots$)

(A SHORT LIVED QUARK-GLUON PLASMA WILL HAVE NO SIZEABLE EFFECT HERE)

RELEVANT DENSITY :

NOT THE "BJORKEN ESTIMATE" $\frac{1}{\pi R^2} \frac{1}{t_0} \frac{dN}{dy}$

BUT RATHER ($t_0 \to R$)

$$n \sim \frac{1}{\pi R^3} \frac{dN}{dy}$$

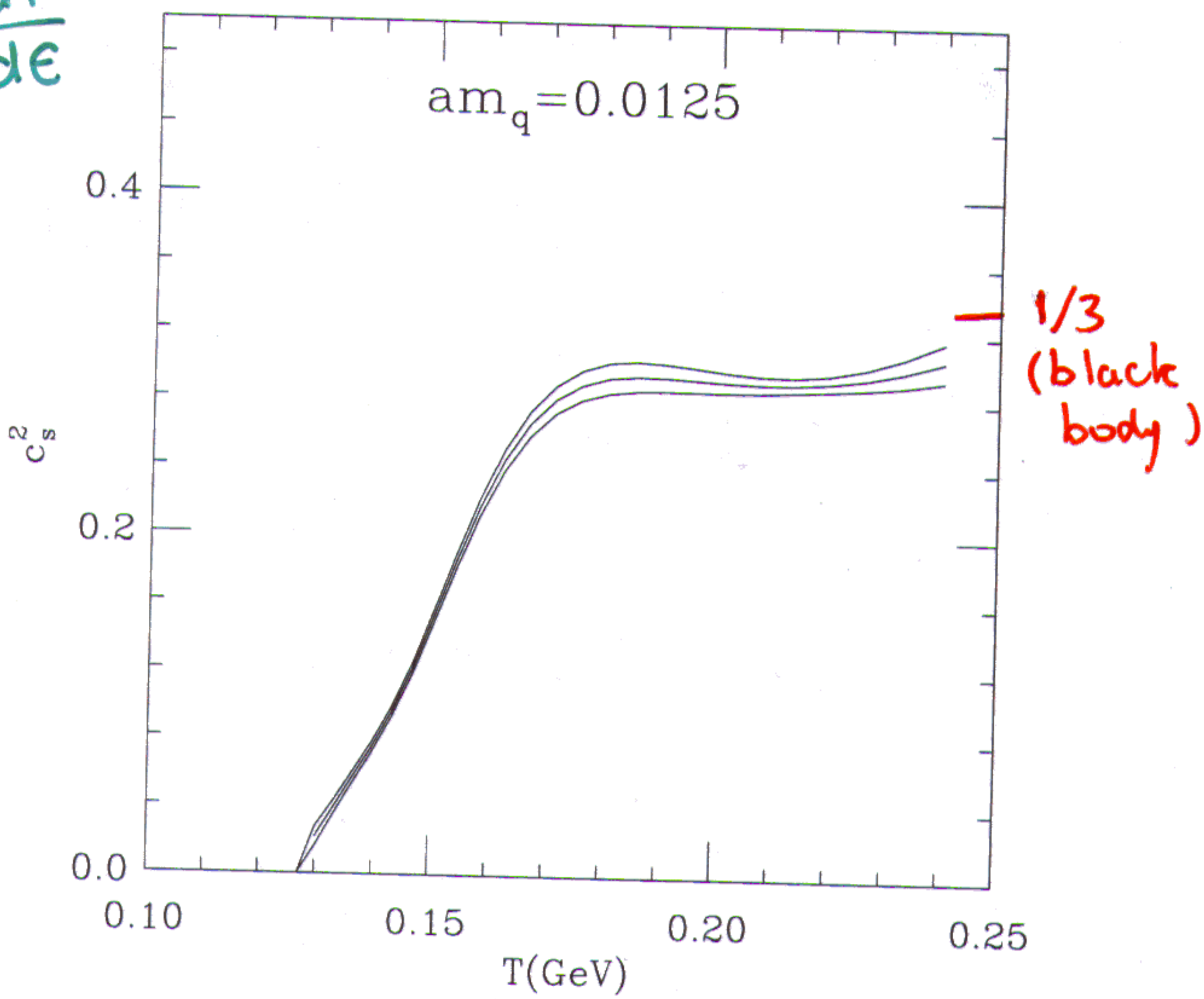
5 - 10 TIMES SMALLER

ROUGHLY INDEPENDENT OF A

(ONLY A SLIGHT INCREASE)

LATTICE CALCULATION OF THE SOUND VELOCITY

$$c_s^2 = \frac{dP}{d\epsilon}$$



FROM MILC collaboration, hep-lat/9612025

→ ABOVE T = 170 MeV, THE VELOCITY OF SOUND IS CLOSE TO THE ULTRARELATIVISTIC LIMIT $c_0^2 = 1/3$

ELLIPTIC FLOW FROM PARTIAL THERMALIZATION

H. Heiselberg and A.M Levy, nucl-th/9812034

CALCULATE IN-PLANE ELLIPTIC FLOW IF THERE IS AT MOST ONE COLLISION PER PARTICLE :

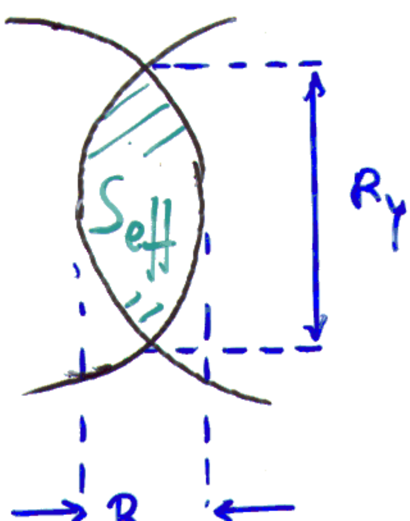
$$v_2 = \overline{v_2} \; \frac{1}{S_{eff}} \frac{dN}{dy} \; \langle \sigma v_{rel} \rangle \; \frac{v_\perp^2}{v_\perp^2 + \langle v_{\perp\,scatt}^2 \rangle}$$

ANISOTROPY OF INITIAL SPATIAL DISTRIBUTION

INTERACTION CROSS SECTION

DENSITY OF SCATTERERS PER UNIT AREA ($\propto A^{1/3}$)

p_T DEPENDENCE OF ANISOTROPY



$$\overline{v_2} = \frac{R_y^2 - R_x^2}{R_y^2 + R_x^2}$$

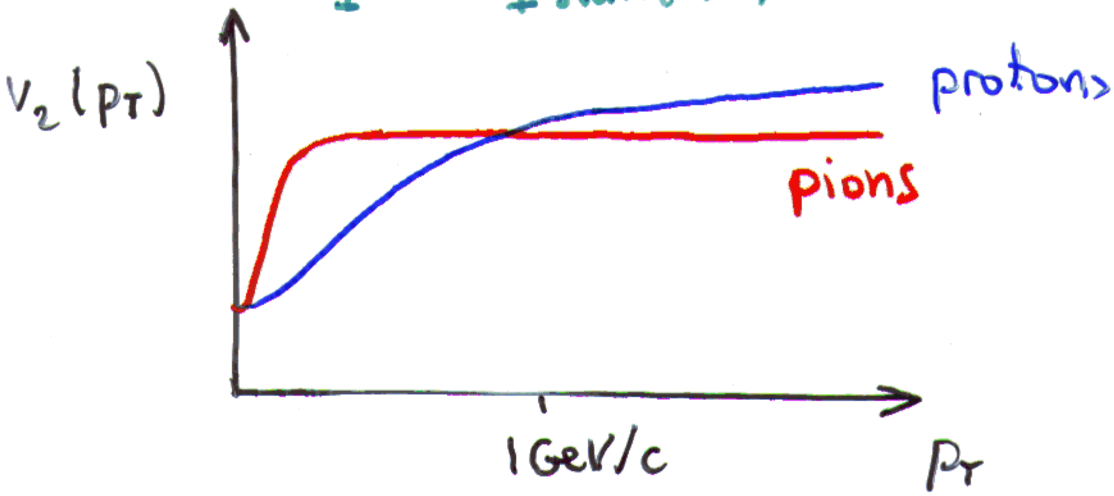
p_T DEPENDENCE OF ELLIPTIC FLOW :

PARTIAL VS COMPLETE THERMALIZATION

PARTIAL THERMALIZATION ($N_{collisions/particle} \ll 1$)

According to Heiselberg and Levy,

$$v_2(p_T) \propto \frac{v_\perp^2}{v_\perp^2 + \langle v_{\perp\,scatterer}^2 \rangle}$$



→ p_T dependence depends on particle mass

→ $v_2(p_T)$ saturates at high p_T

COMPLETE THERMALIZATION ($N_{collisions/particle} \gg 1$)

\# of emitted particles $\propto e^{-p \cdot u/T}$

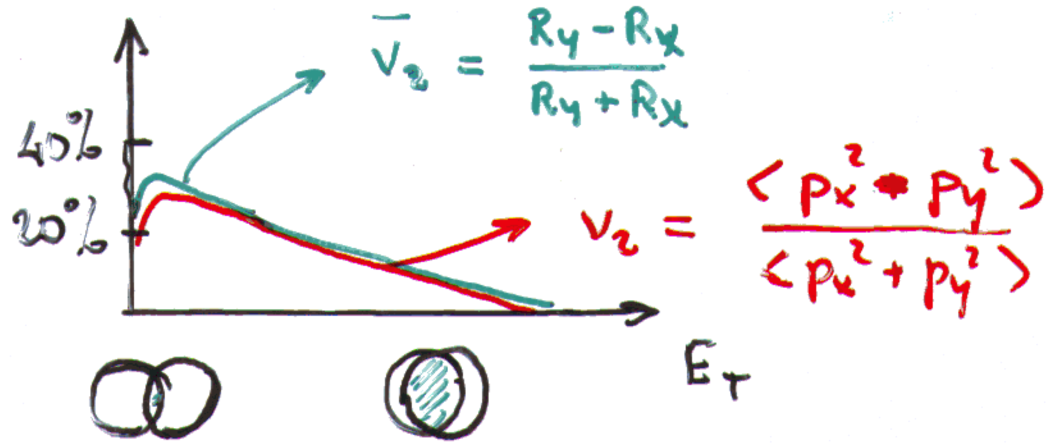
particle 4-momentum (p)   fluid 4-velocity (u)

→ $v_2(p_T)$ same for ≠ particles at given p_T
(S. Voloshin, PRC 55 (1997) 1630)

CENTRALITY DEPENDENCE OF ELLIPTIC FLOW

- THE ELLIPTIC FLOW CALCULATED IN HYDRO IS VERY CLOSE TO THE SPATIAL ANISOTROPY OF THE INITIAL DISTRIBUTION

Pb - Pb



THE MAXIMUM OCCURS FOR IMPACT PARAMETERS LARGER THAN IN ACTUAL EXPERIMENTS

- IF ONLY PARTIAL THERMALIZATION OCCURS,

$$v_2 \propto \bar{v}_2 \underbrace{\frac{1}{S_{eff}} \frac{dN}{dy}}_{\text{density of scatterers / unit area}}$$

THE MAXIMUM IS SHIFTED TOWARDS LESS PERIPHERAL COLLISIONS

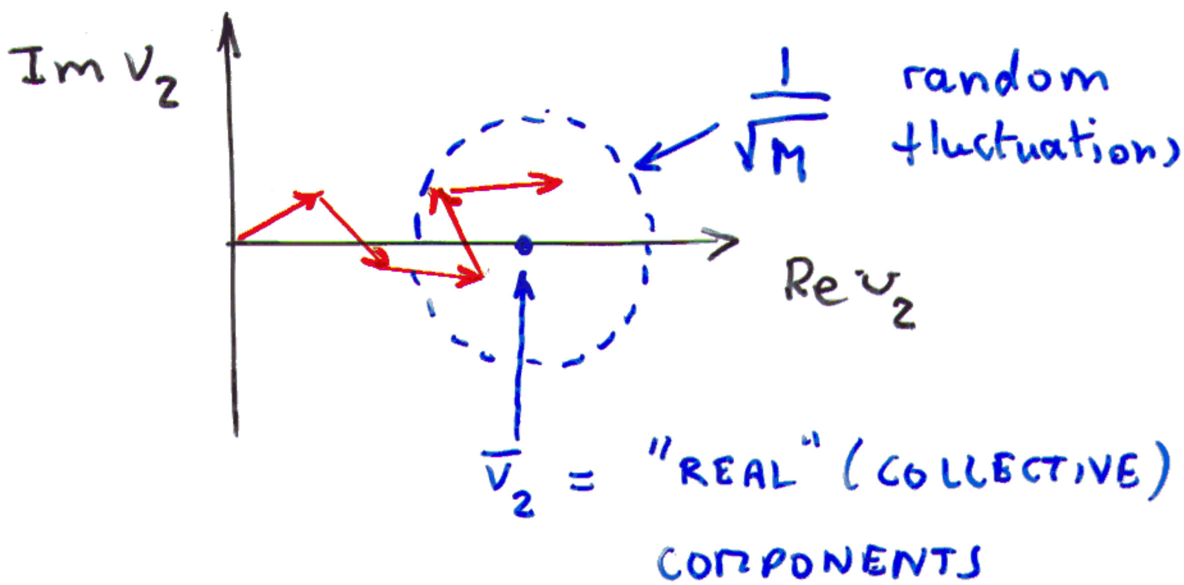
(AND THE ABSOLUTE VALUE IS MUCH SMALLER)

METHODS FOR MEASURING THE FLOW

THE GENERAL IDEA: USE A GLOBAL VARIABLE OBTAINED BY SUMMING OVER MANY PARTICLES SO THAT COLLECTIVE VELOCITIES SUM UP

RANDOM (THERMAL) VELOCITIES CANCEL IN THE SUM

$$v_2 = \frac{1}{M} \sum_{j=1}^{M} e^{2i\varphi_j}$$



THE CRUCIAL QUANTITY IS THE RATIO OF COLLECTIVE AND STATISTICAL (RANDOM) COMPONENTS

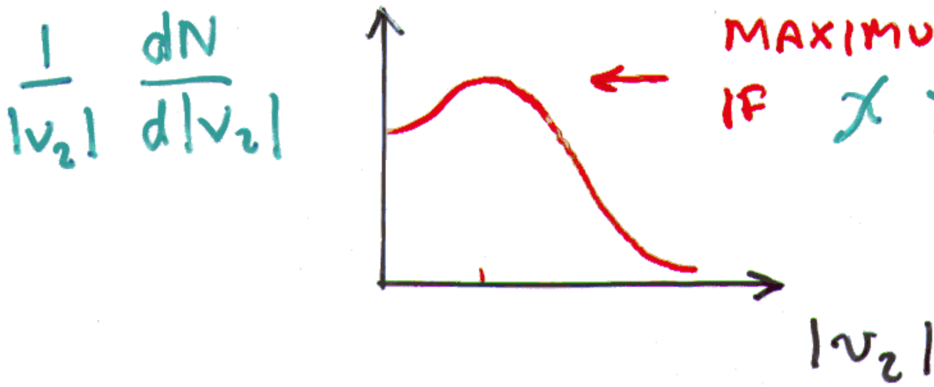
$$\chi \simeq \bar{v}_2 \sqrt{M}$$

FLOW IS OBSERVABLE UNAMBIGUOUSLY IF $\chi > 1$ (χ ranges from 0,3 to 2,4

TWO METHODS

Poskanzer, Voloshin, PRC 58 (1998) 1671

1. PLOT THE DISTRIBUTION OF $|v_2|$



MAXIMUM AT $|v_2| \neq 0$ IF $\chi > 1$

Danielewicz - Gyulassy PLB 129 (1983) 283
Ollitrault PRD 46 (1992) 229
Barrette et al, E877, PRL 73 (1994) 2532

2. SUBEVENT METHOD :

Danielewicz, Odyniec, PLB 157 (1985) 146

MEASURE V_2 IN 2 RANDOMLY CHOSEN SUBEVENTS AND STUDY THE ANGULAR CORRELATION BETWEEN SUBEVENTS

EASIER (DEPENDS ONLY ON χ, DOES NOT REQUIRE $\chi > 1$)

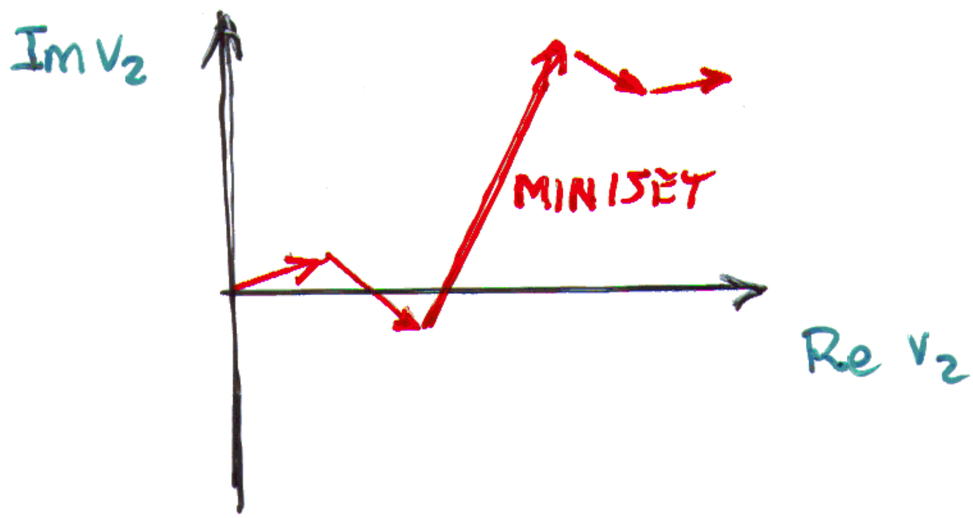
BUT ASSUMES: ONLY CORRELATIONS ARE FROM FLOW:

- UNCONTROLLABLE ASSUMPTION ?
- SEEMS TO BE OK AT LOWER ENERGIES (ONLY SIZEABLE CORRELATIONS ARE THOSE FROM MOMENTUM CONSERVATION) BUT ...

MINIJETS, EVENT-BY-EVENT FLUCTUATIONS...

- MINIJETS, DCC's ... MAY PRODUCE STRONG AZIMUTHAL CORRELATIONS AMONG THE PRODUCED PARTICLES, WHICH HAVE A DIFFERENT ORIGIN $\neq$ ELLIPTIC FLOW

- HOW DOES THIS AFFECT FLOW MEASUREMENTS?



→ INCREASE OF STATISTICAL, FINITE MULTIPLICITY FLUCTUATIONS WHICH MAY NOT SCALE LIKE $1/\sqrt{M}$

→ $\chi < v_2\sqrt{M}$ MAY BE SMALLER THAN EXPECTED (ALTHOUGH BOTH v_2 and M ARE LARGER AT RHIC THAN AT SPS)

ARE FLUCTUATIONS GAUSSIAN ?

- ASSUMPTION THAT FINITE MULTIPLICITY FLUCTUATIONS ARE GAUSSIAN ALLOWS TO PUSH METHOD 1 TOWARDS LOWER VALUES OF χ: STUDY DEVIATIONS FROM GAUSSIAN SHAPE.

- THE GAUSSIAN CHARACTER SHOULD BE TESTED FOR CENTRAL COLLISIONS (NO FLOW)

$$Q = \frac{1}{\sqrt{M}} \sum_{j=1}^{M} e^{2i\varphi_j}$$

↳ in order to scale by the fluctuations

CHECK THAT $\langle |Q|^4 \rangle = 2 \langle |Q^2| \rangle^2$

IF FLOW IS PRESENT

$$\frac{\langle |Q|^4 \rangle}{\langle |Q|^2 \rangle^2} \simeq 2 - \chi^4$$

FOR SMALL χ (DEVIATIONS FROM A GAUSSIAN ARE SMALL!)