Azimuthal asymmetries from jet quenched in fluctuating backgrounds

Hot Quarks 2012

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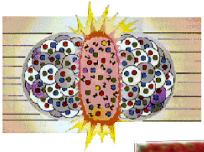
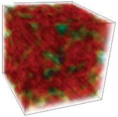
October 14-21, 2012

Outline

Motivation



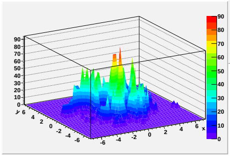


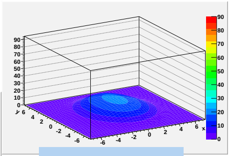
A wish list for a theorist:

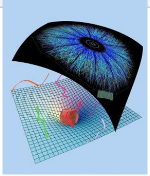
- I would like to “touch” and “see” the initial conditions.
- I would like to “feel” the hot medium.

In quantitative terms:

- Can we observe the initial energy deposition and geometry fluctuations?
- Can we distinguish between energy loss models?



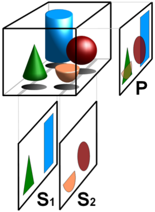


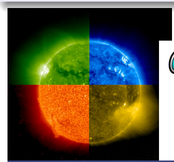


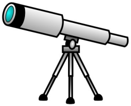
Introduction

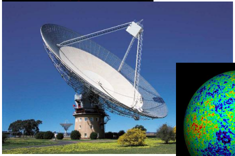
Tomography:

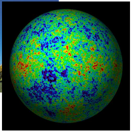
- Tomography means slice imaging.
- Today this term is applied to many methods used to reconstruct the internal structure of an object from external measurements.





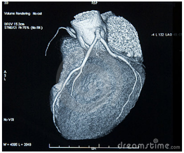






Two types of tomography:

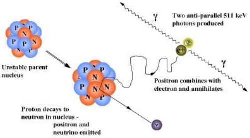
- Probe emitted by the object.
- Probe that has been emitted by an external source.



Introduction

A medical analog: PET Scan

- Inject (short-lived) positron emitting isotope (tracer).
- Positron annihilates with electron giving pair of back to back 0.511 MeVgammas.
- Detect both gammas using fast (5 ns) coincidences



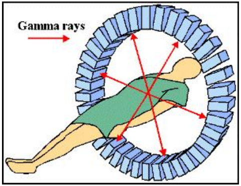
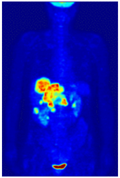


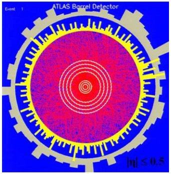
Image Reconstruction

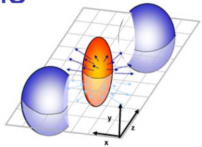
- We want to reconstruct the distribution of the tracer in the slice being imaged.
- The measurements made are converted into samples of the Radon transform of the unknown distribution.
- Use inverse Radon transform.

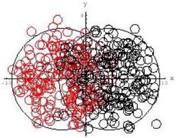


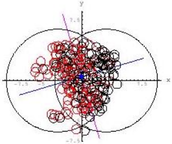
$$p(\xi,\phi) = \int f(x,y)\delta(x\cos\phi + \sin\phi - \xi)dxdy$$

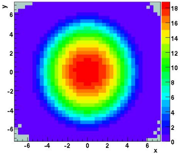
Initial State Fluctuations





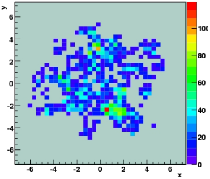






Origin

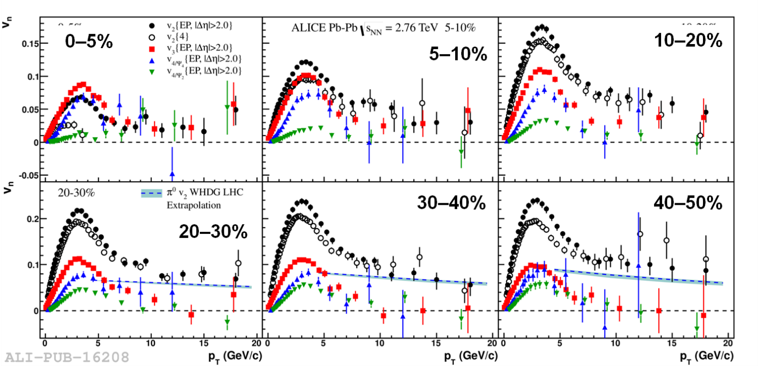
- Fluctuations in the initial energy density.
- Fluctuations in the position of the hard process are also important.



$$\frac{dN}{P_T dP_T d\Phi} = \frac{dN}{2\pi P_T dP_T}\left[1 + 2\sum_{n>0} v_n(P_T)\cos(n\Phi + \delta_n)\right]$$

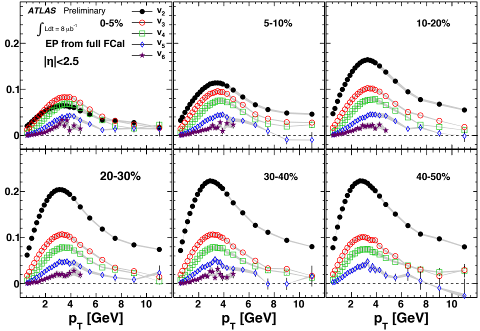
How do fluctuating backgrounds affect the v_n?

Experimental Program is Already Underway



Experimental Program is Already Underway

Higher order moments vs. p_T and centrality



Similar p_T dependence for all flow coefficients.
Weak centrality dependence observed for v_3-v_6
For the 5% most central events $\mathbf{v_2 < v_3}$

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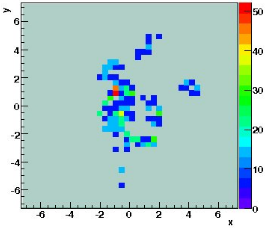
Energy Loss Models and Simulation



LPM-inspired

- $\frac{dE}{dx} = c_{\mathrm{sLPM}} \cdot \rho(\tau) \cdot (\tau - \tau_0)$
- $c_{\mathrm{sLPM}} = 0.085\ \mathrm{GeV}$

ASW-BDMPS

- $P(\Delta E; R, \omega_c) = p_0 \delta(\Delta E) + p(\Delta E; R, w_c)$
- We compute the integrals $h_1(\mathbf{r}, \psi)$ and $h_2(\mathbf{r}, \psi)$:

$$h_n \equiv \int_0^\infty (\tau - \tau_0)^n \, \hat{q}(\tau) \, d\tau \quad n = 0, 1$$

  with $\hat{q} = c_{\mathrm{ASW}} \cdot \rho(\tau)$, $\omega_c = h_1$ and $R = 2h_1^2/h_0$.
- $c_{\mathrm{ASW}} = 2.8\ \mathrm{GeV}$

Fits done to $R_{AA}^{\pi_0}$ data at RHIC

Initial Geometry and Eccentricity

Engineered events

- We need a generalization of the concept of eccentricity:

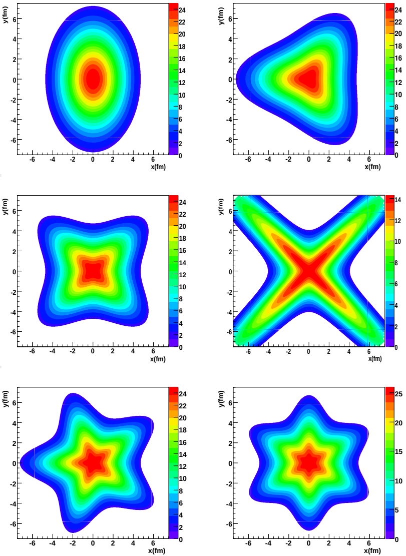
$$\epsilon_i = \frac{\sqrt{\langle r^i \cos(i\phi)\rangle^2 + \langle r^i \sin(i\phi)\rangle^2}}{\langle r^i \rangle}$$

- We also need a generalization of the flow coefficient v_2:

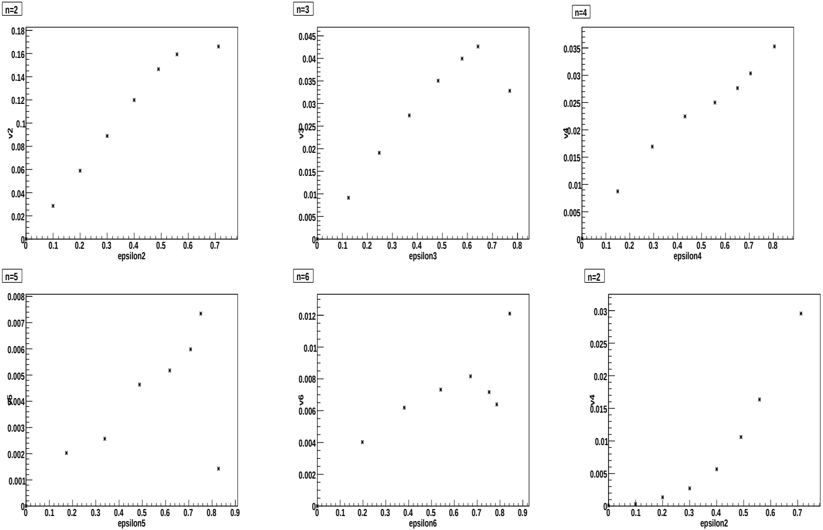
$$v_j = \langle \cos(j(\phi - \delta_j))\rangle$$

where

$$\delta_j = \frac{1}{j} \arctan \frac{\langle p_T \sin(j\phi)\rangle}{\langle p_T \cos(j\phi)\rangle}$$



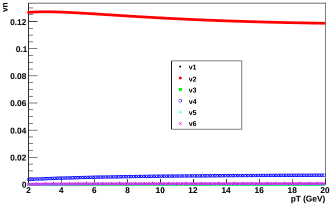
Correlations Between Eccentricity and Asymmetry

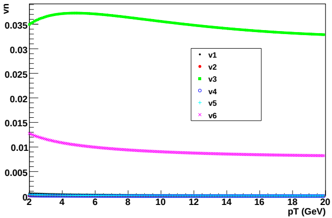


Correlations Between Eccentricity and Asymmetry

- v_i is a monotonous function of ϵ_i
- $v_j = 0$ for ϵ_i if $i \neq j$ except when j is a multiple integer of i .
- Multiple coefficients are expression of the symmetry of the underlying geometry.
- v_j decrease in magnitude with j.

$$\frac{1}{m}\int_0^{2\pi} \cos(i\phi)\, d\phi = \int_0^{2\pi} \cos(im\alpha) d\alpha$$

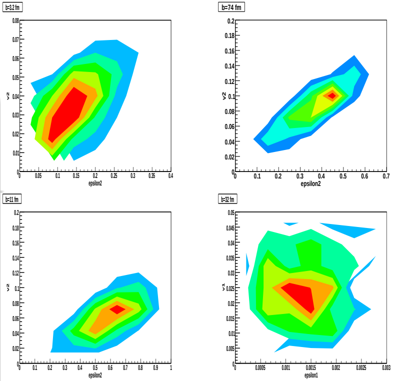




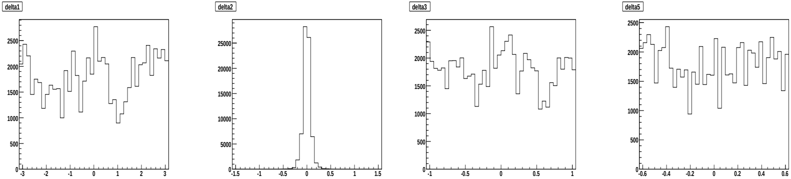
Distributions in Realistic Fluctuating Backgrounds

Again we performed a scan in v_i vs ϵ_j using realistic geometries.
We obtained:

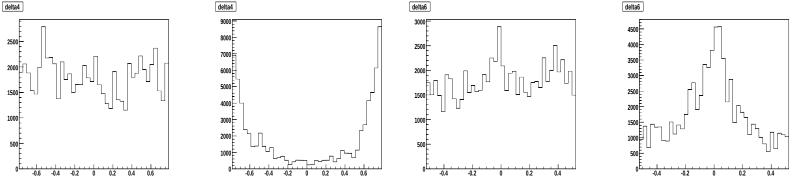
- No correlation between v_i and ϵ_i except for $i = j = 2$ in the $n = 2$ geometry.
- For this geometry v_2 is proportional to e_2
- There is centrality dependence, which sharpens and defines the value of the eccentricity.
- v_1 with a value of a few percent in the most central collisions, without correlations with ϵ_1



Distributions of Event Plane Phases For Realistic Events I

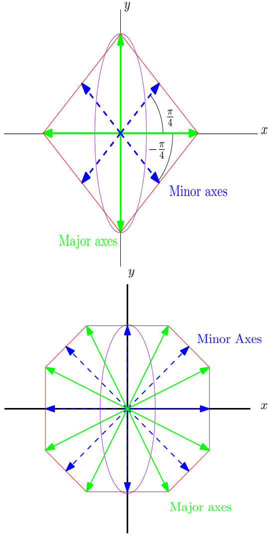


δ_i for $i = 1, 3, 5$ have no correlation with δ_2



δ_i for $i = 4, 6$ are correlated with δ_2 and this correlation is centrality dependent.

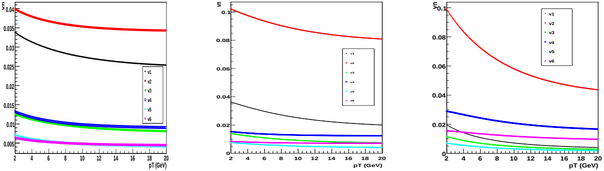
Distributions of Event Plane Phases For Realistic Events II



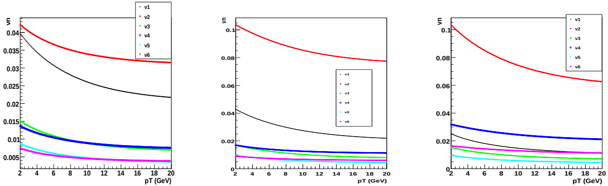
We are observing *some* multiple moments

- Origin is the $n = 2$ geometry
- Explanation is in the "best square" and "best hexagon"
- Perhaps a way to distinguish between v_4 coming from ϵ_2 and from ϵ_4

Transverse Momentum Dependence of Azimuthal Asymmetry Coefficients



sLPM for RHIC



ASW for RHIC

Conclusions

- The presence of v_n with n odd confirms the existence of initial geometries different from $n = 2$.
- v_n do not allow to distinguish between different models of energy loss.
- For the case $n = 2$, correlations between v_2 and ϵ_2 persist even when averaged over many events.
- Phases provide with a way to distinguish between same coefficients coming from different initial geometries.
- v_1 is surprisingly large and maybe a way to look into fluctuations in the position of hard events and initial energy deposition.