Early stage of RHIC collisions and its equilibration: a story told by correlations

BNL Nuclear Physics Seminar

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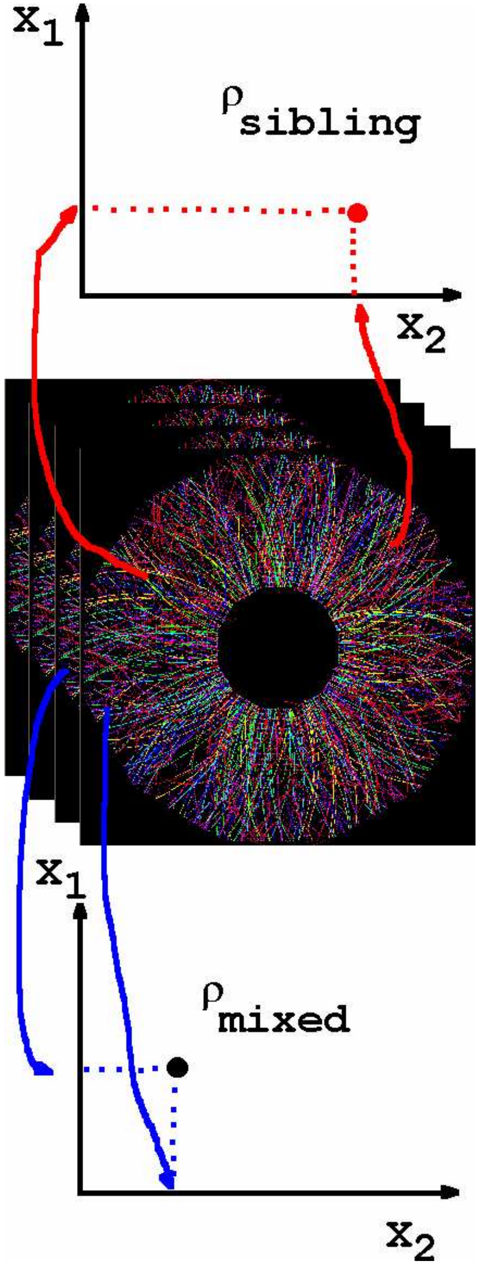

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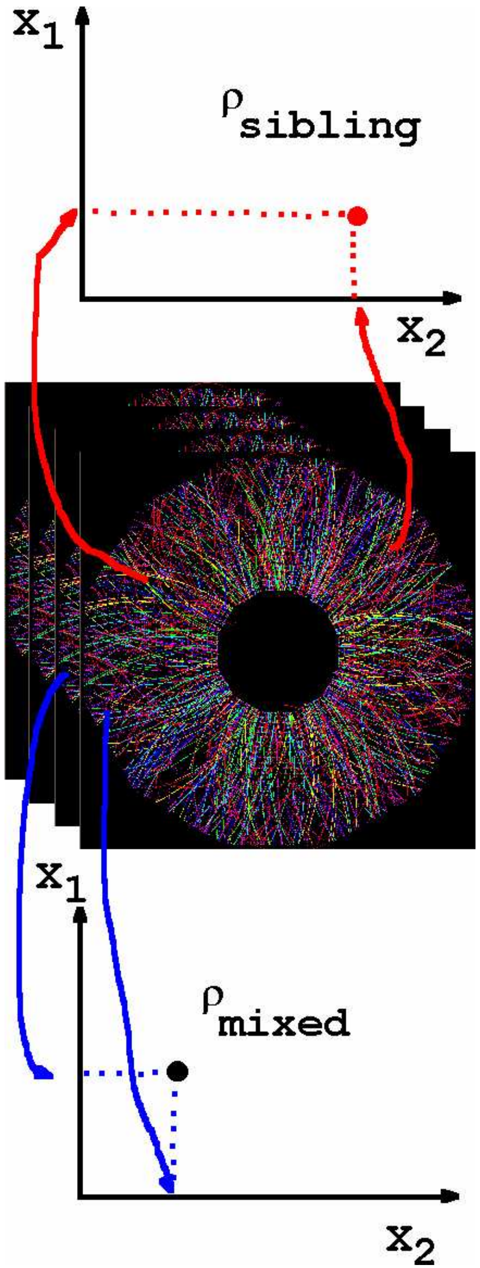
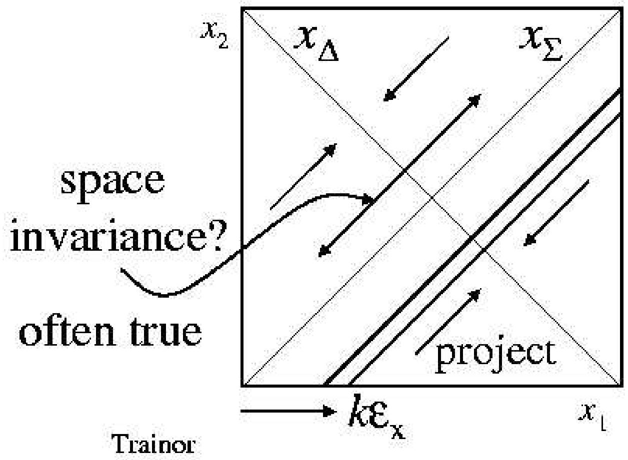


$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} \rightarrow \begin{pmatrix} x_\Sigma \equiv x_1 + x_2 \\ x_\Delta \equiv x_1 - x_2 \end{pmatrix},$$

always a lossless transformation of data.

Autocorrelation A is a projection of a two-point distribution onto difference variable(s) x_Δ, lossless for x_Σ-invariant (homogenous, stationary) problems.

$$\Delta R(x_1, x_2) = \frac{\rho_{sibling}(x_1, x_2)}{\rho_{mixed}(x_1, x_2)} - 1$$



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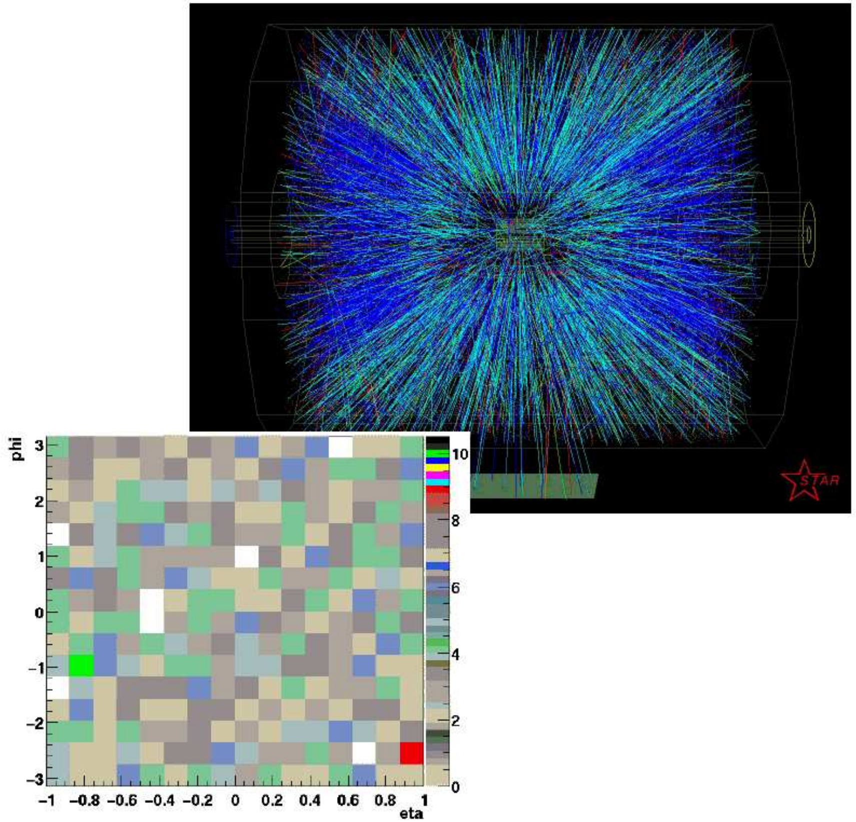

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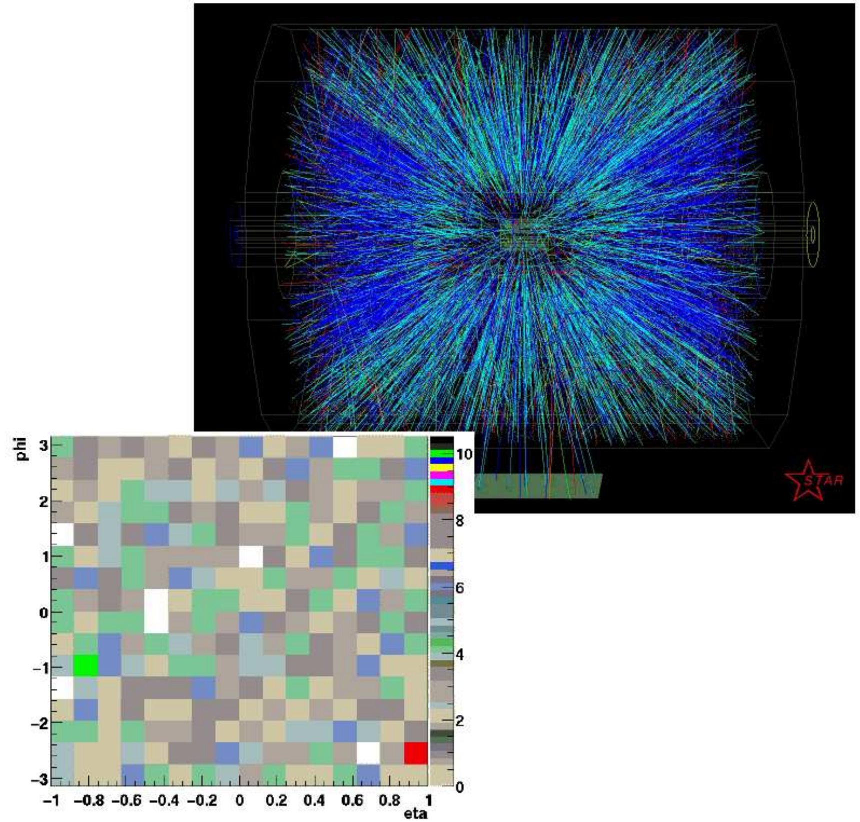

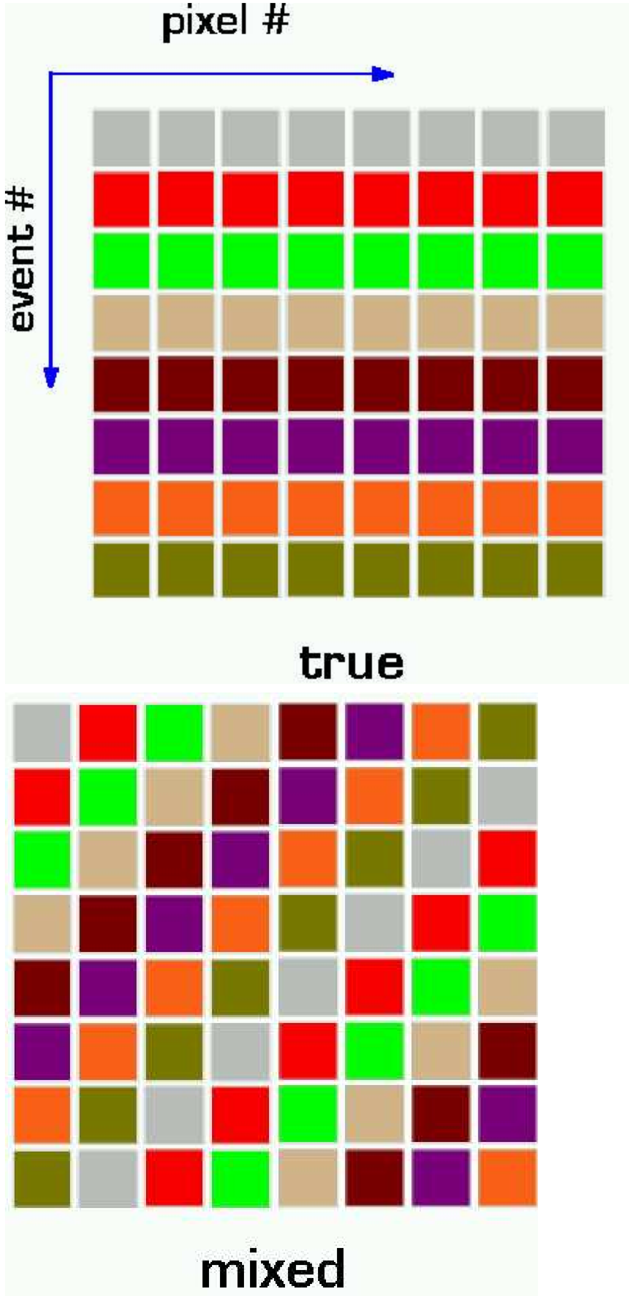

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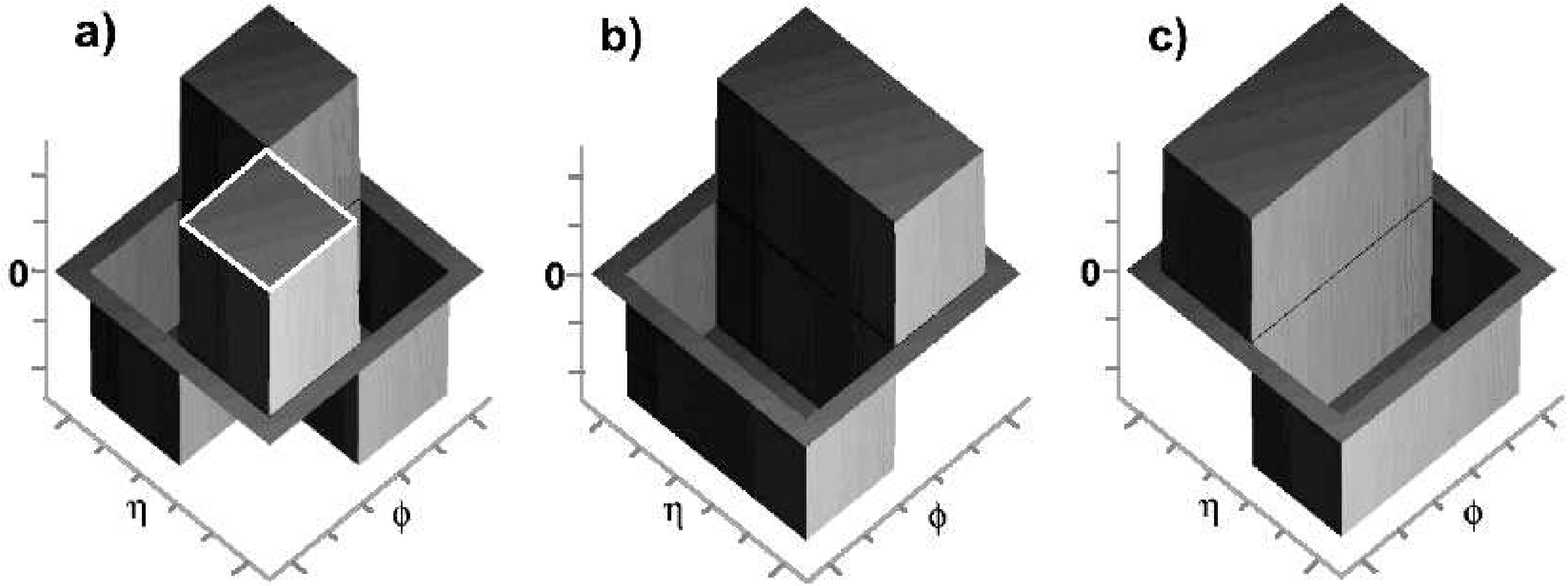

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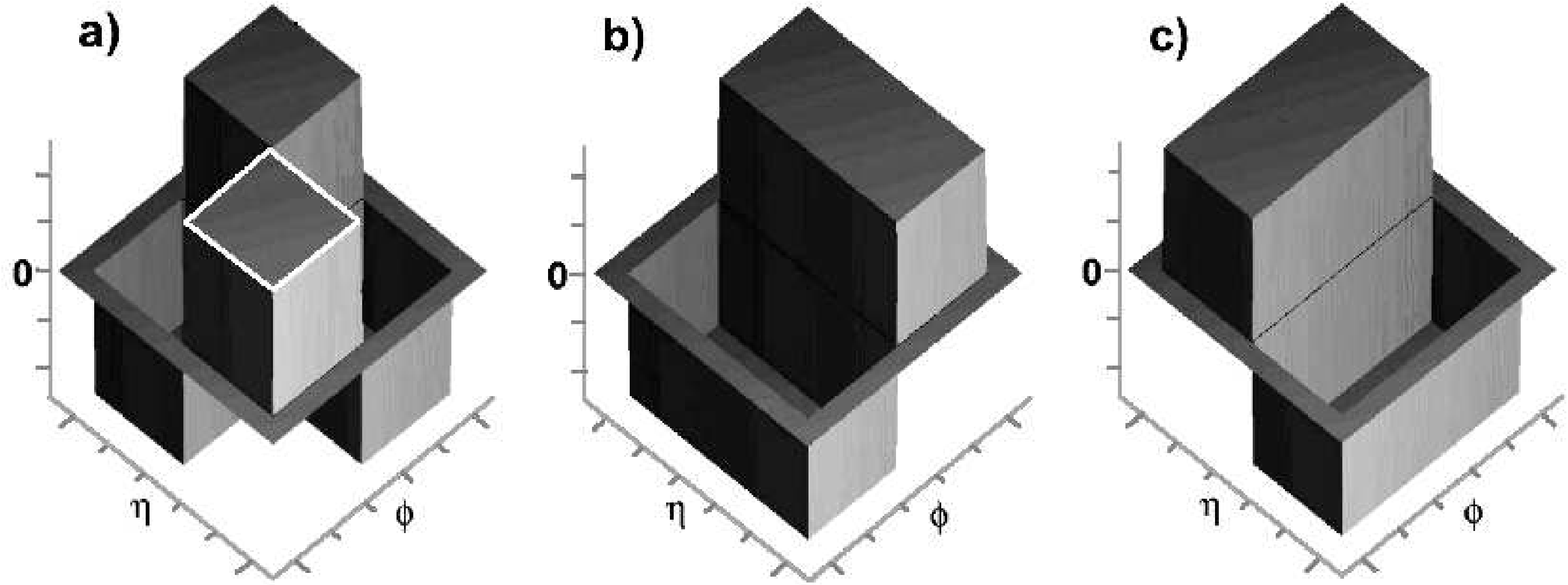

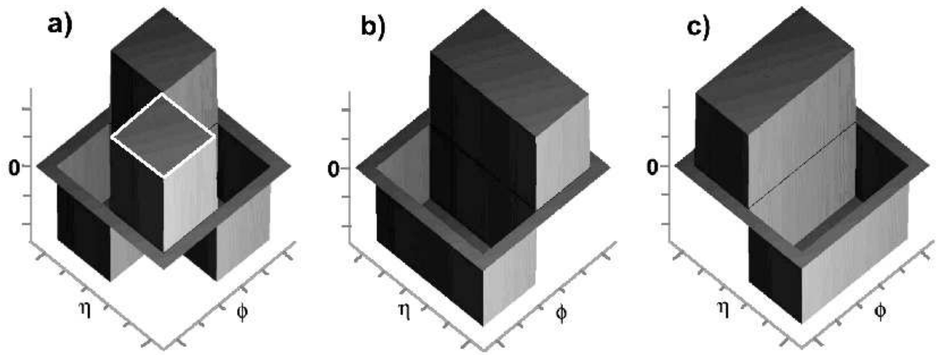

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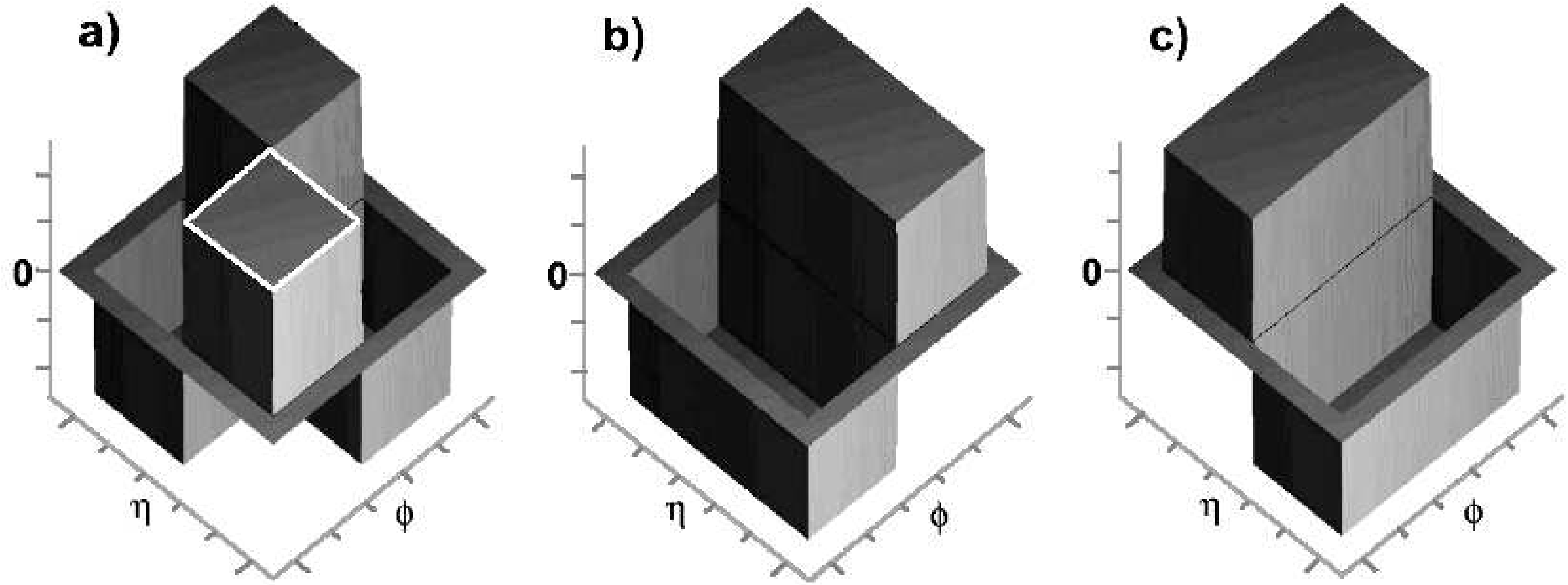

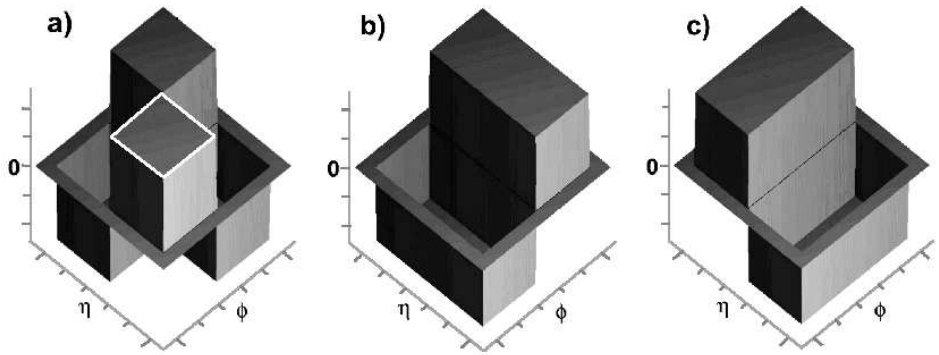

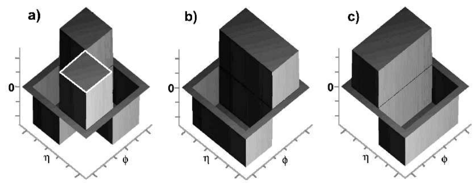

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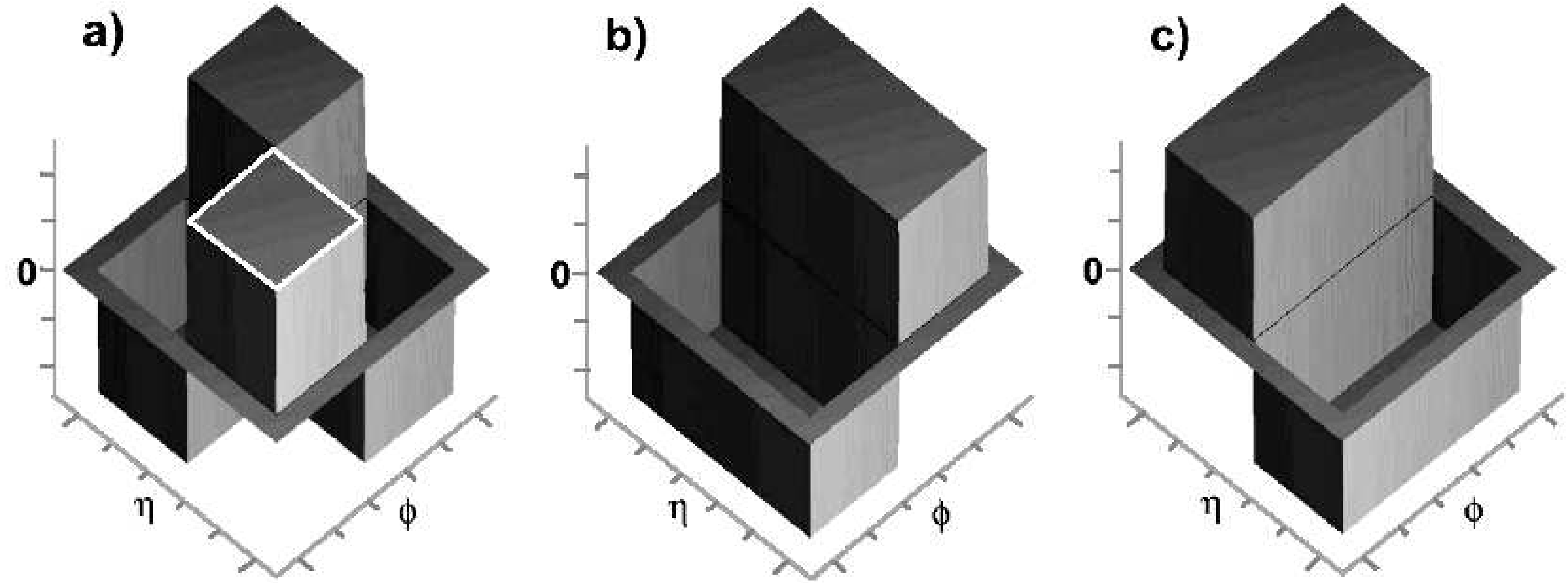

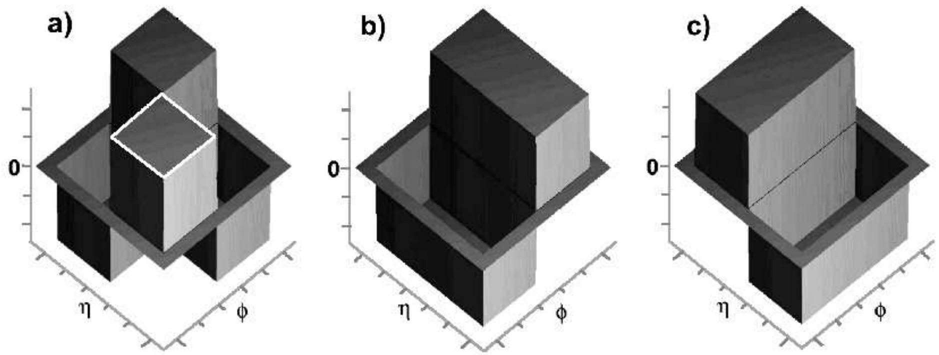

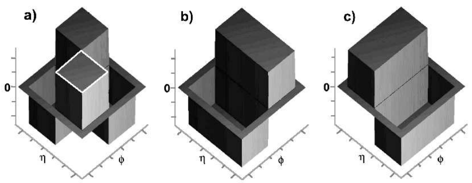

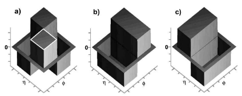

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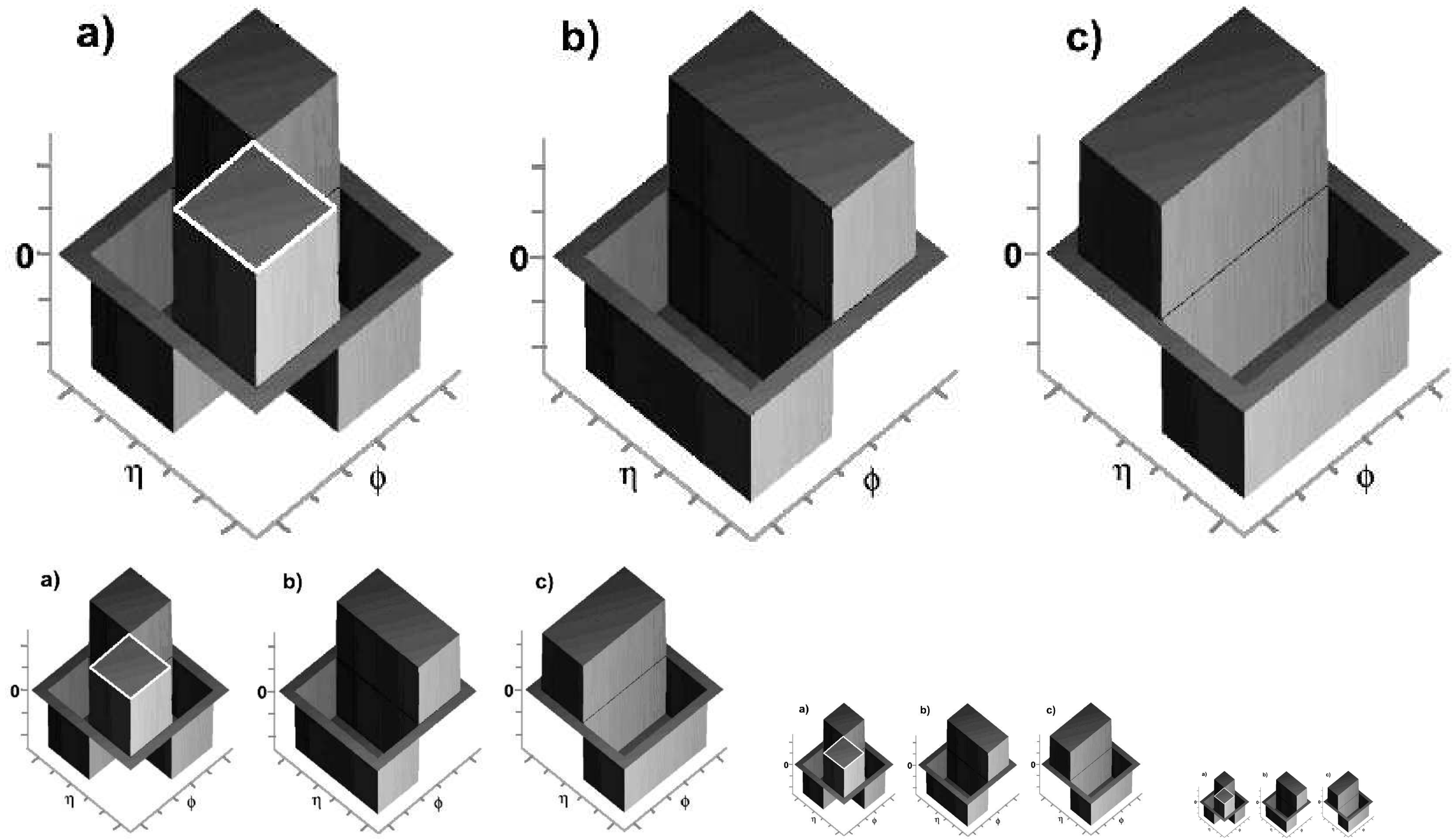

$F^{\lambda}_{m,i,j}(\phi,\eta)$–Haar wavelet **orthonormal basis** in (ϕ,η): scale fineness (m), directional modes of sensitivity (λ), track density $\rho(\eta,\phi,p_T)$, locations in 2D (i,j). **DWT is an expansion in this basis.**

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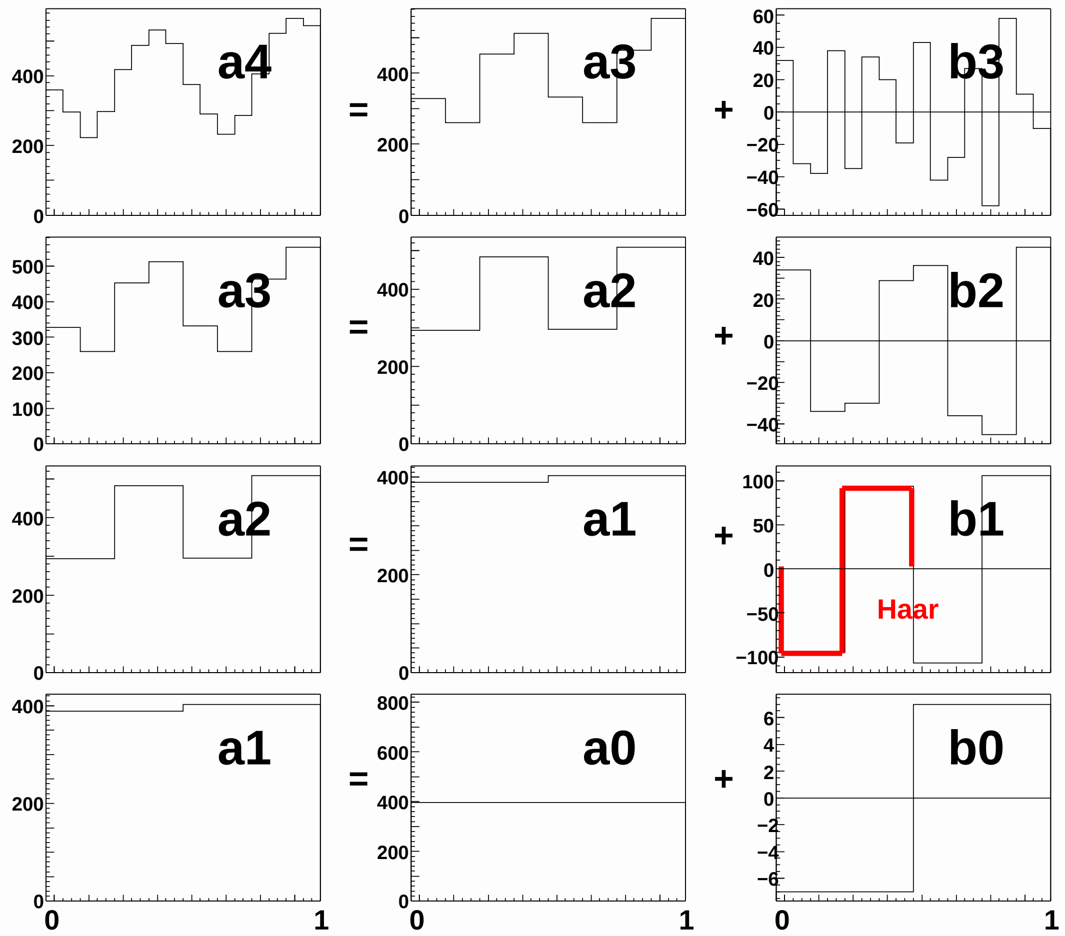
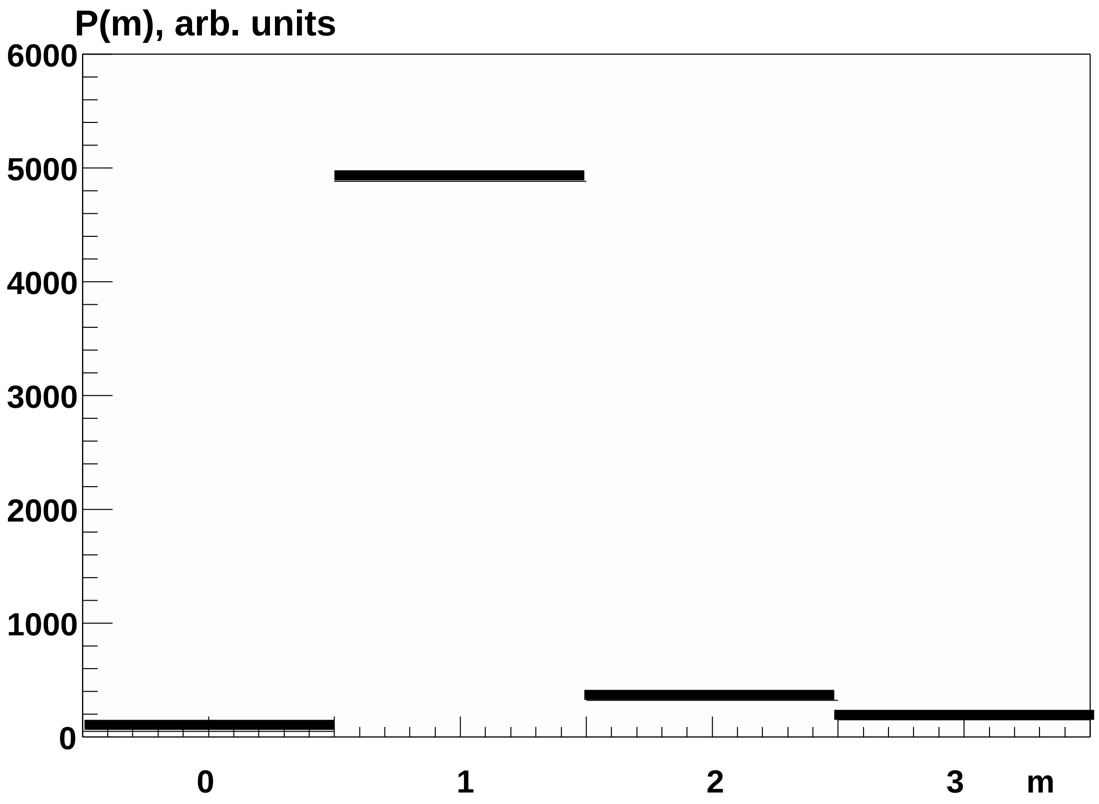


5 A flow-inspired example

Elliptic flow-inspired example: x axis – an angle in "natural units" $(2\pi = 1)$, y axis – multiplicity. The multiresolution theorem: **a4 = a0+b0+b1+b2+b3**, can have better fineness.



Power spectrum of that flow event as a function of “fineness” m. The dominant contrubution is $m = 1$ (the “v_2” harmonic, **b1**). Statistical fluctuations also contribute.

$P(m) = 2^{-m} \sum_i \langle \rho, F_{m,i} \rangle^2$.

Computational complexity $O(N)$!

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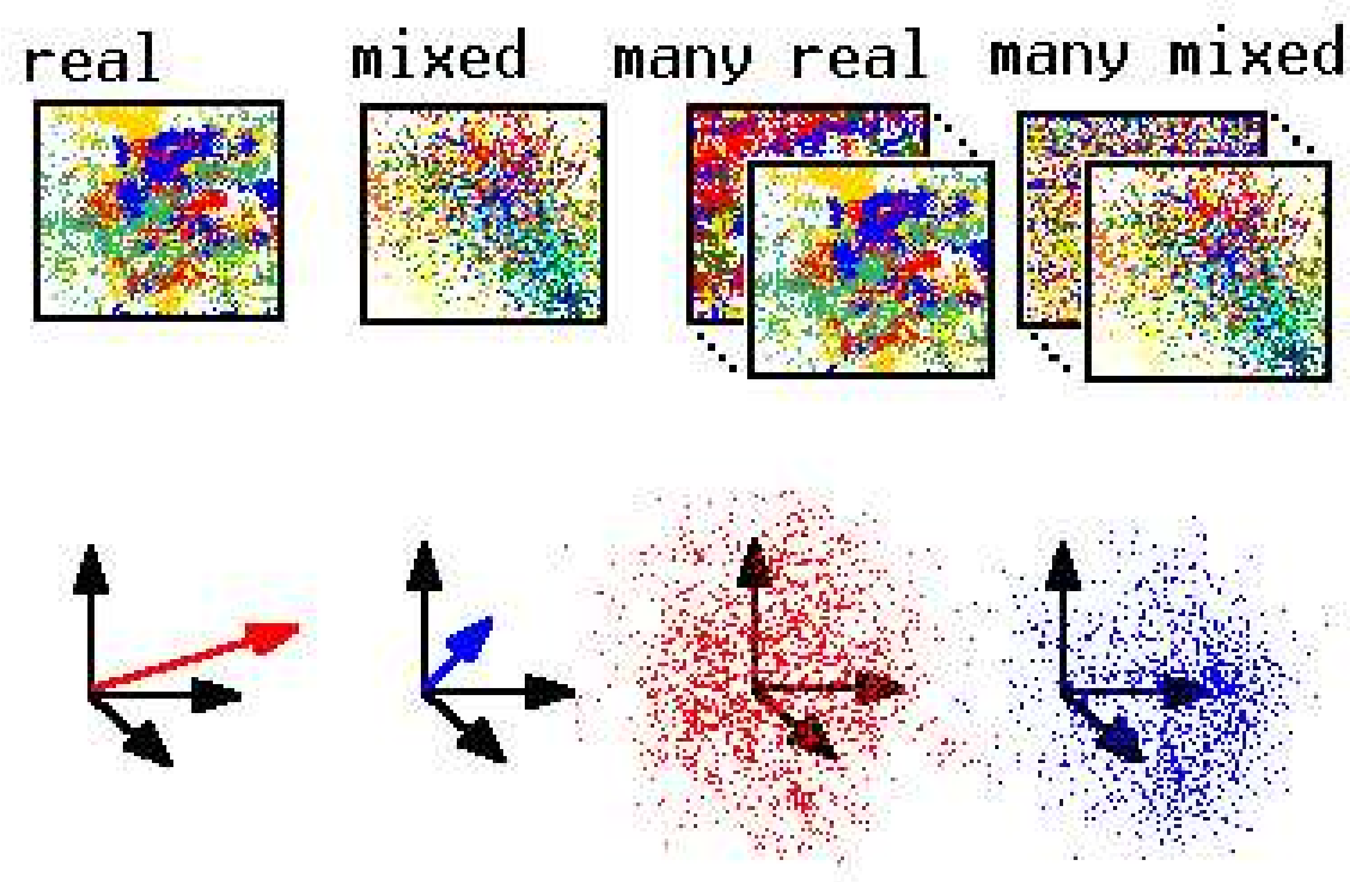

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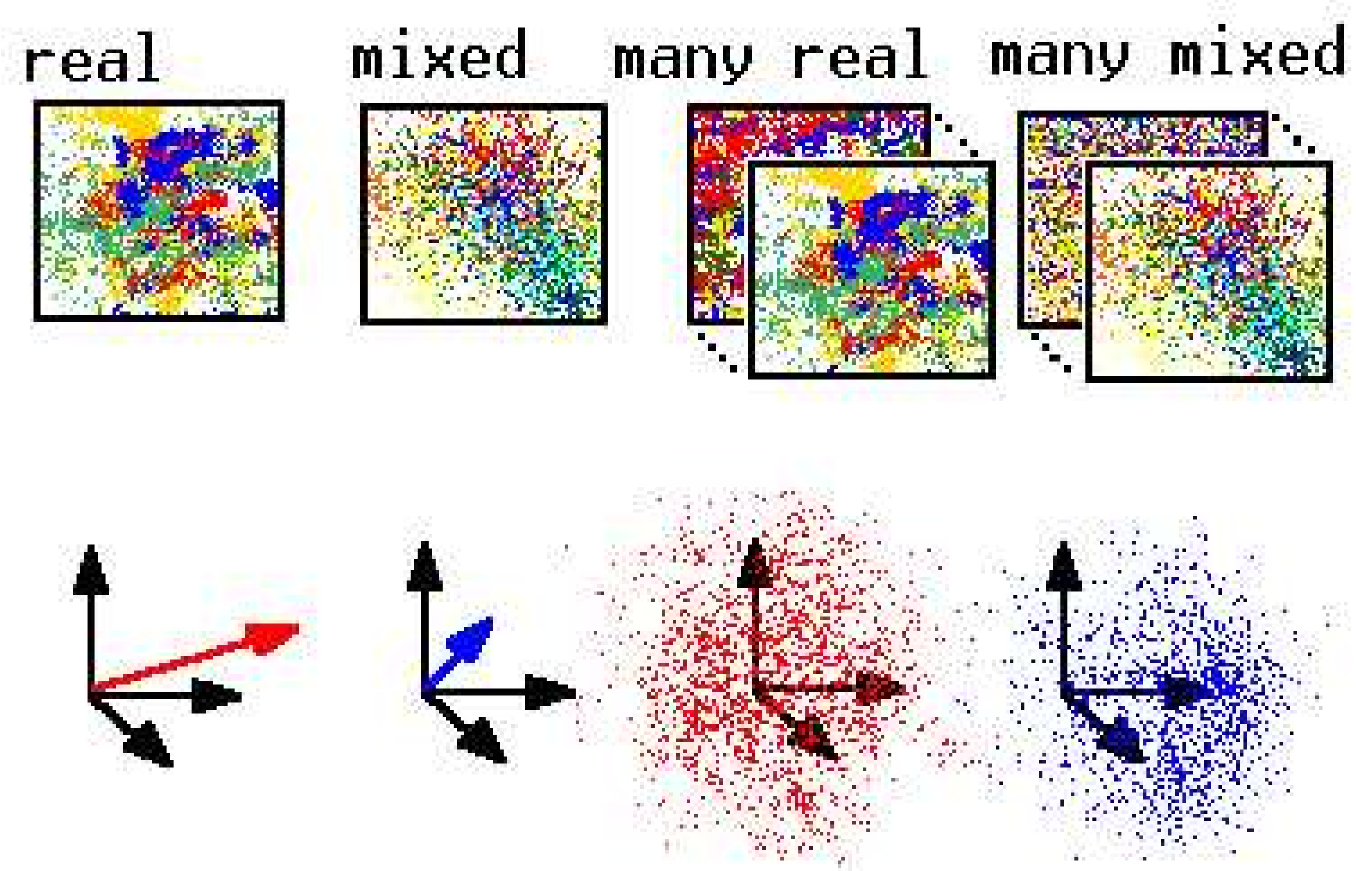

Power of local fluctuations, mode λ: $P^{\lambda}(m) = 2^{-2m} \sum_{i,j} \langle \rho, F^{\lambda}_{m,i,j} \rangle^2 \propto$ norm^2 in the DWT subspace. "Dynamic texture" $P^{\lambda}_{dyn}(m) \equiv P^{\lambda}_{true}(m) - P^{\lambda}_{mix}(m)$.

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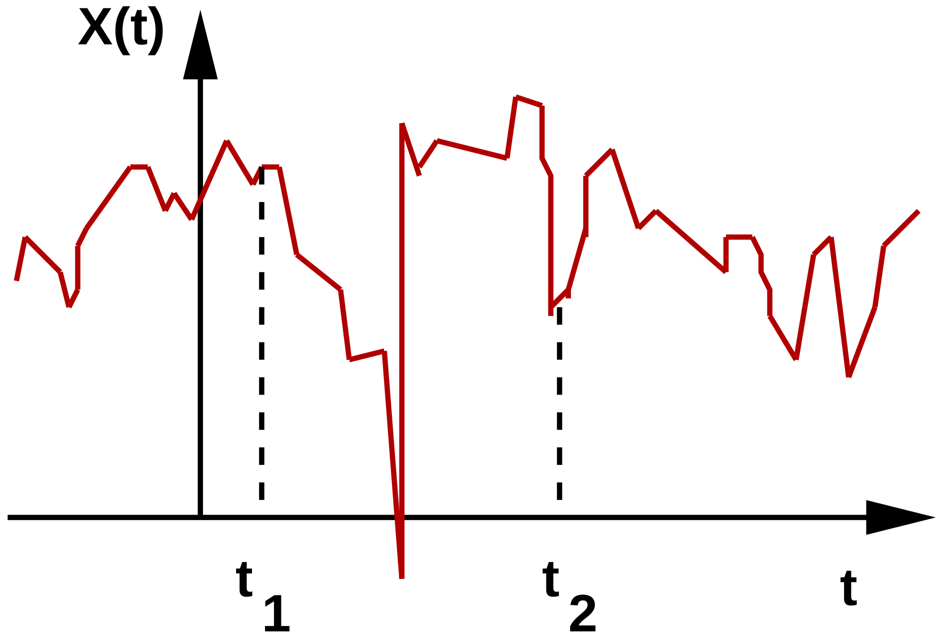

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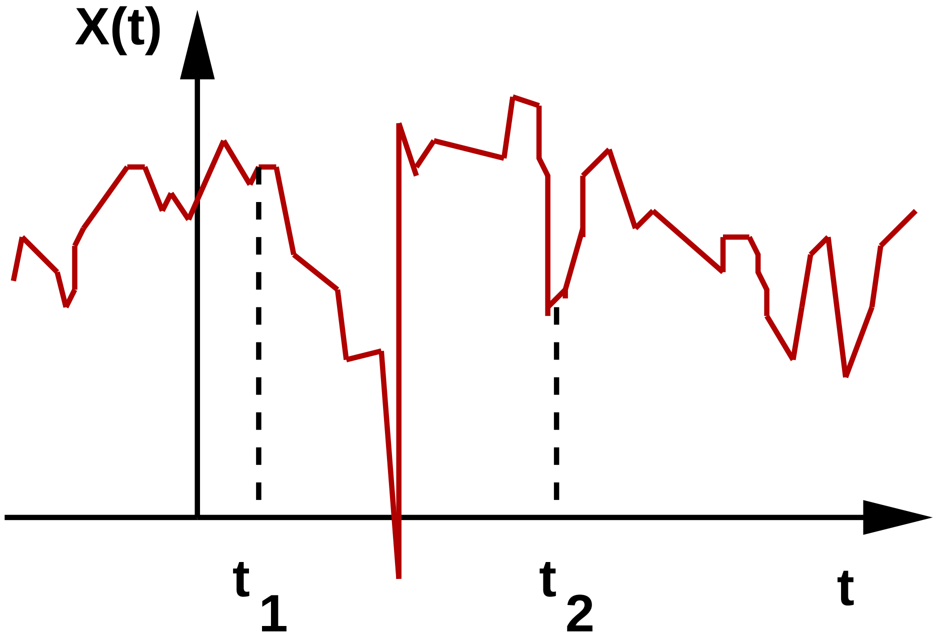

Autocorrelation

$$A(\tau) = \int_{-\infty}^{\infty} X(t) X(t+\tau)\, dt \tag{1}$$

where $\tau = t_2 - t_1$, and $X(t)$ is "homogeneous random field".

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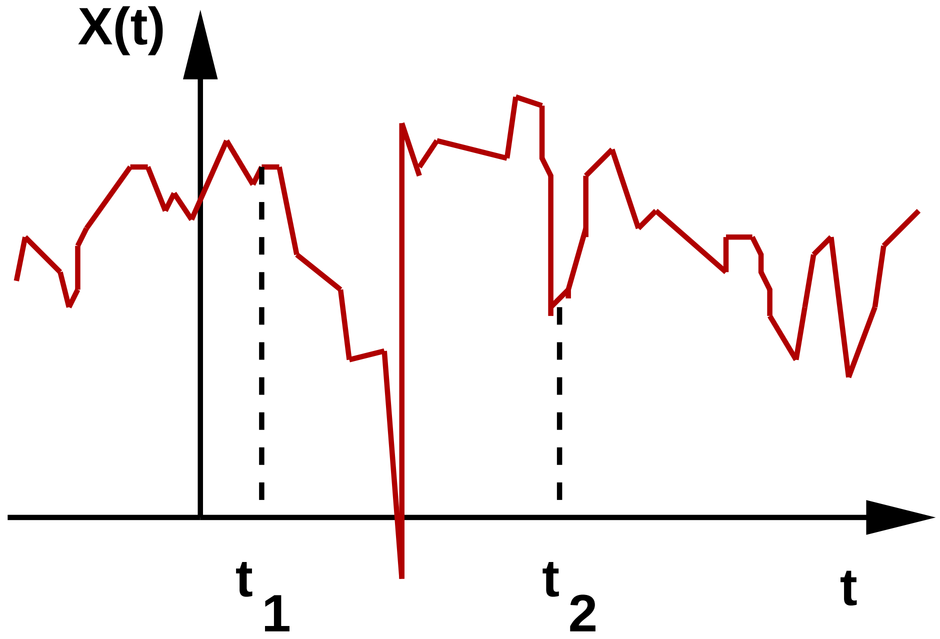

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Wiener-Khinchin theorem relates $A(\tau)$ with the local fluctuation power spectrum $P(\omega)$ via Fourier transform $\mathcal{F}$.

$$\mathcal{F}_{\omega \to \tau}(P(\omega)) = A(\tau) \tag{2}$$

$$P(\omega) = \mathcal{F}_{\tau \to \omega}(A(\tau)) \tag{3}$$

$$O(N) \to O(N^2) \tag{4}$$

Prefer $O(N)$ for initial data processing for CPU reasons.

In the **Haar discrete wavelet** basis, the integral equation 3 looks different:

$$P(m) = \overline{\int_{-\infty}^{\infty} X(\tau/2)X(-\tau/2)W(\tau,m)\,d\tau},$$

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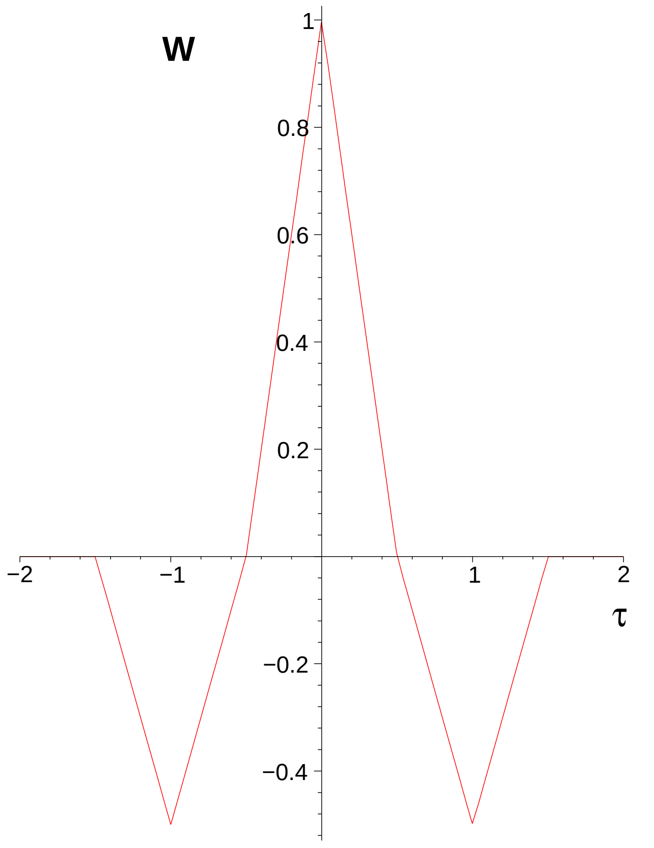

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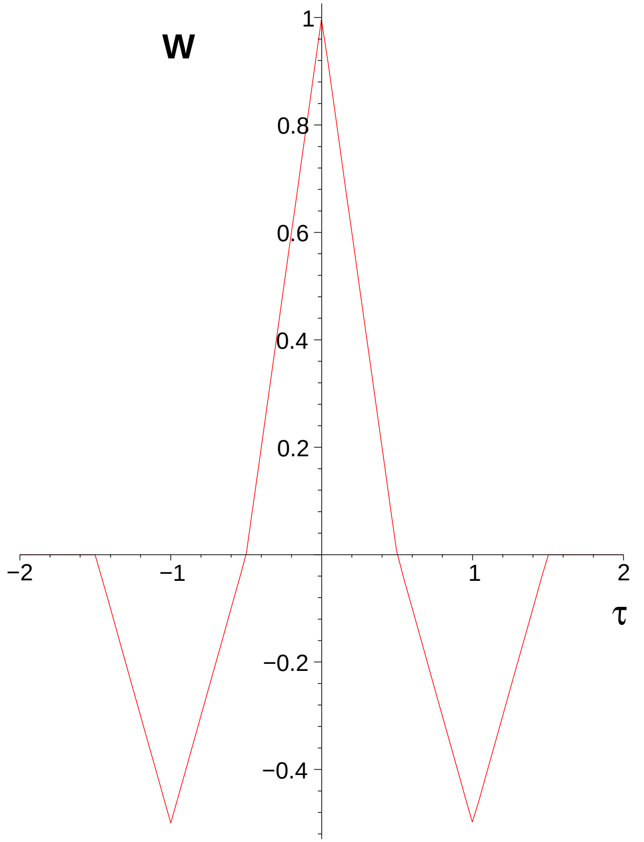

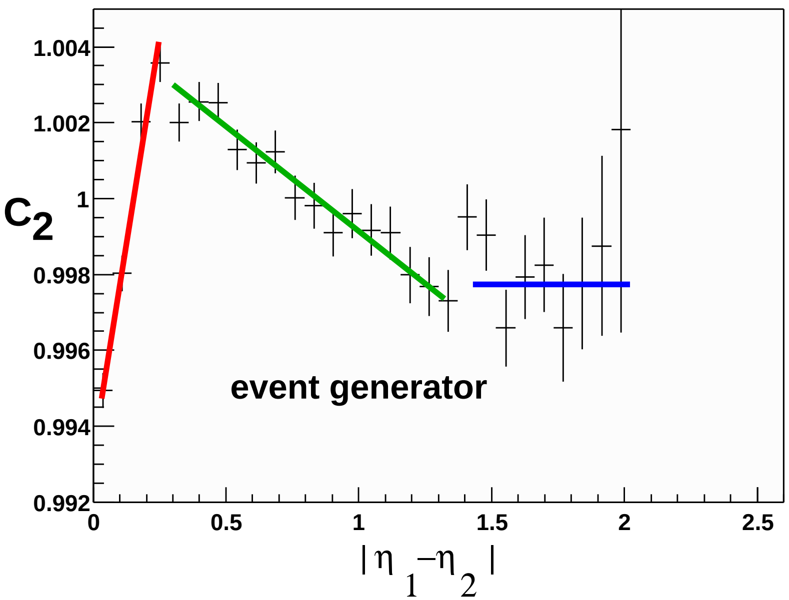

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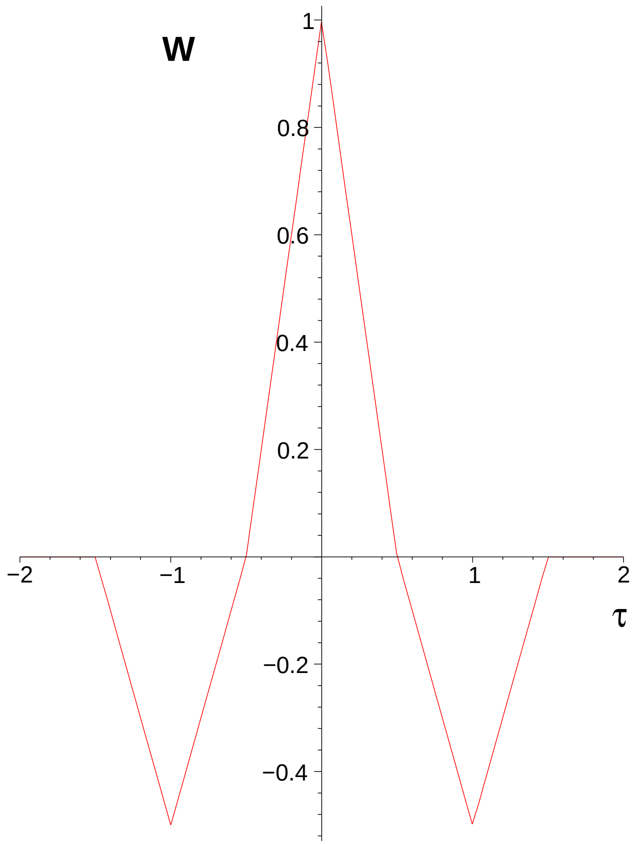

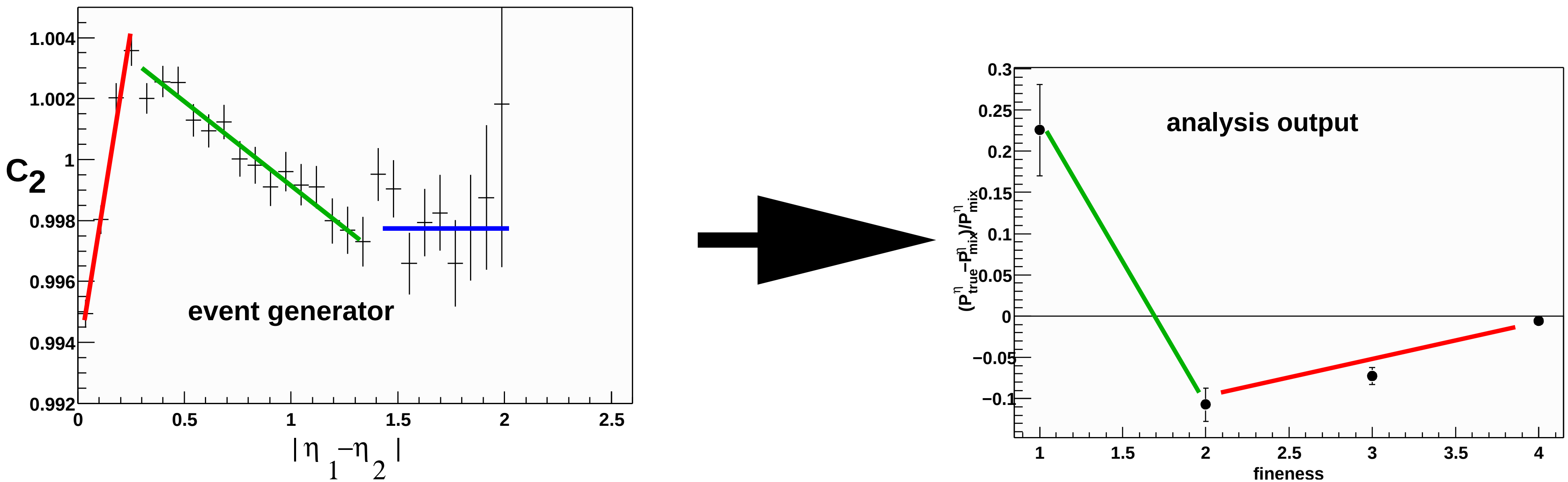

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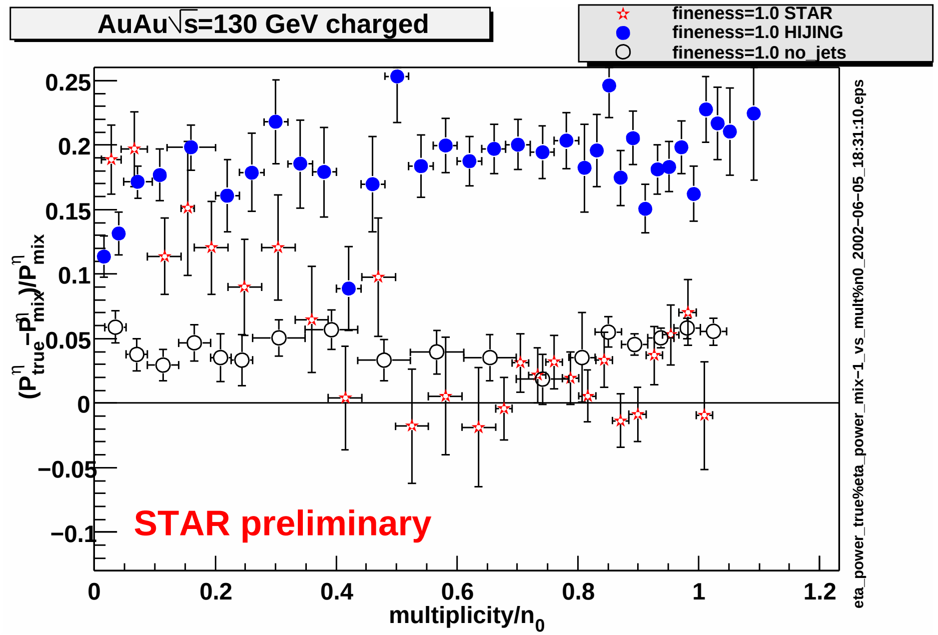
Istron Bay, Greece, June 2002, nucl-ex/0211015. STAR DWT analysis of charge-independent correlations, AuAu, $\sqrt{s_{NN}} = 130$ GeV



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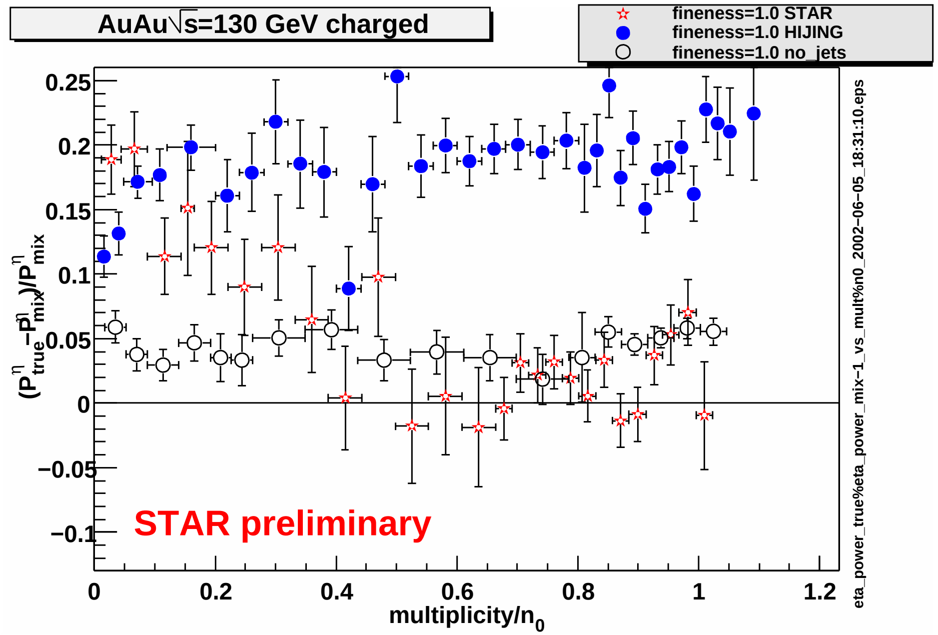

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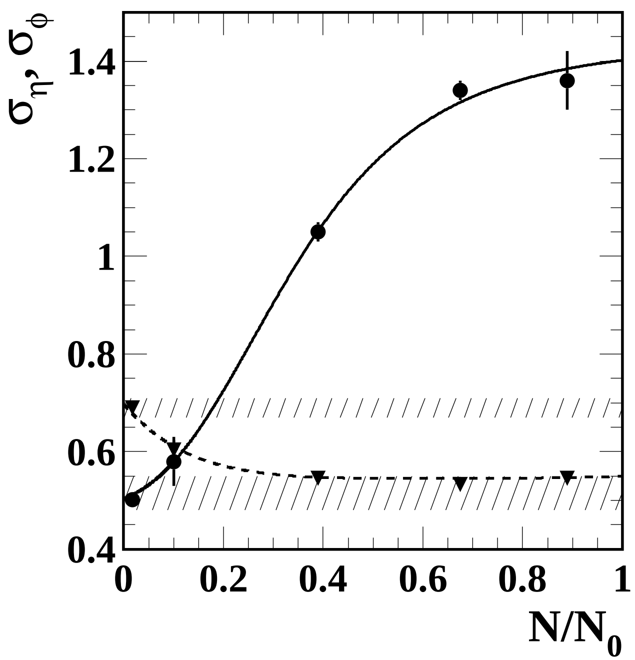
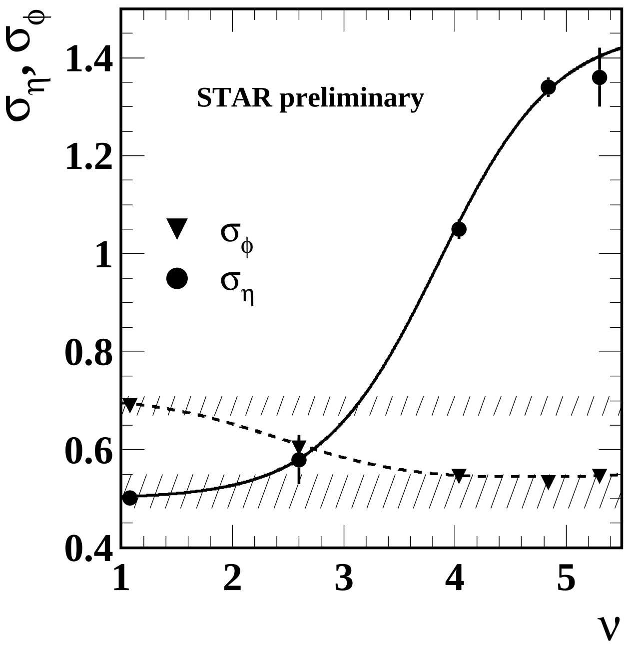
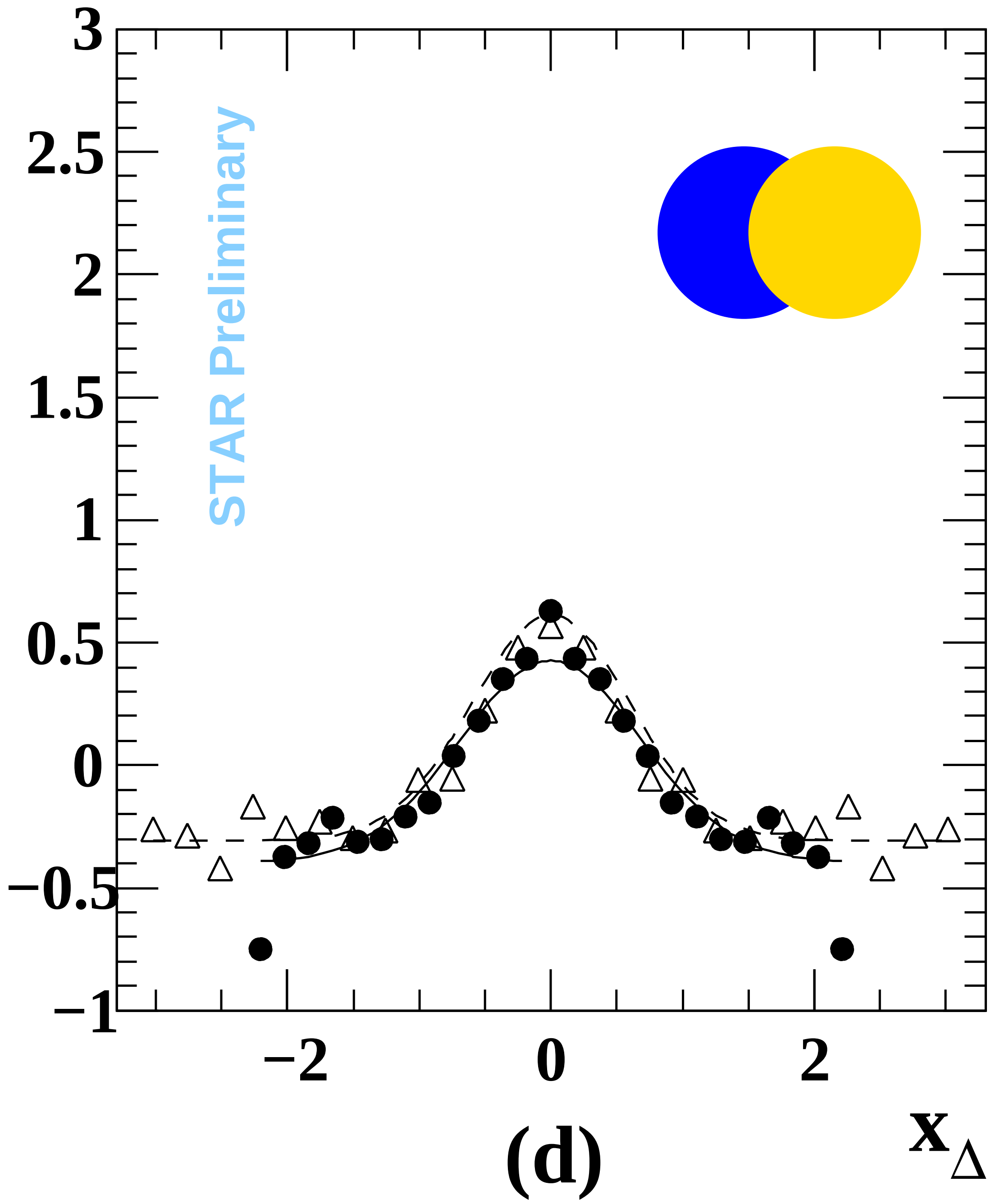
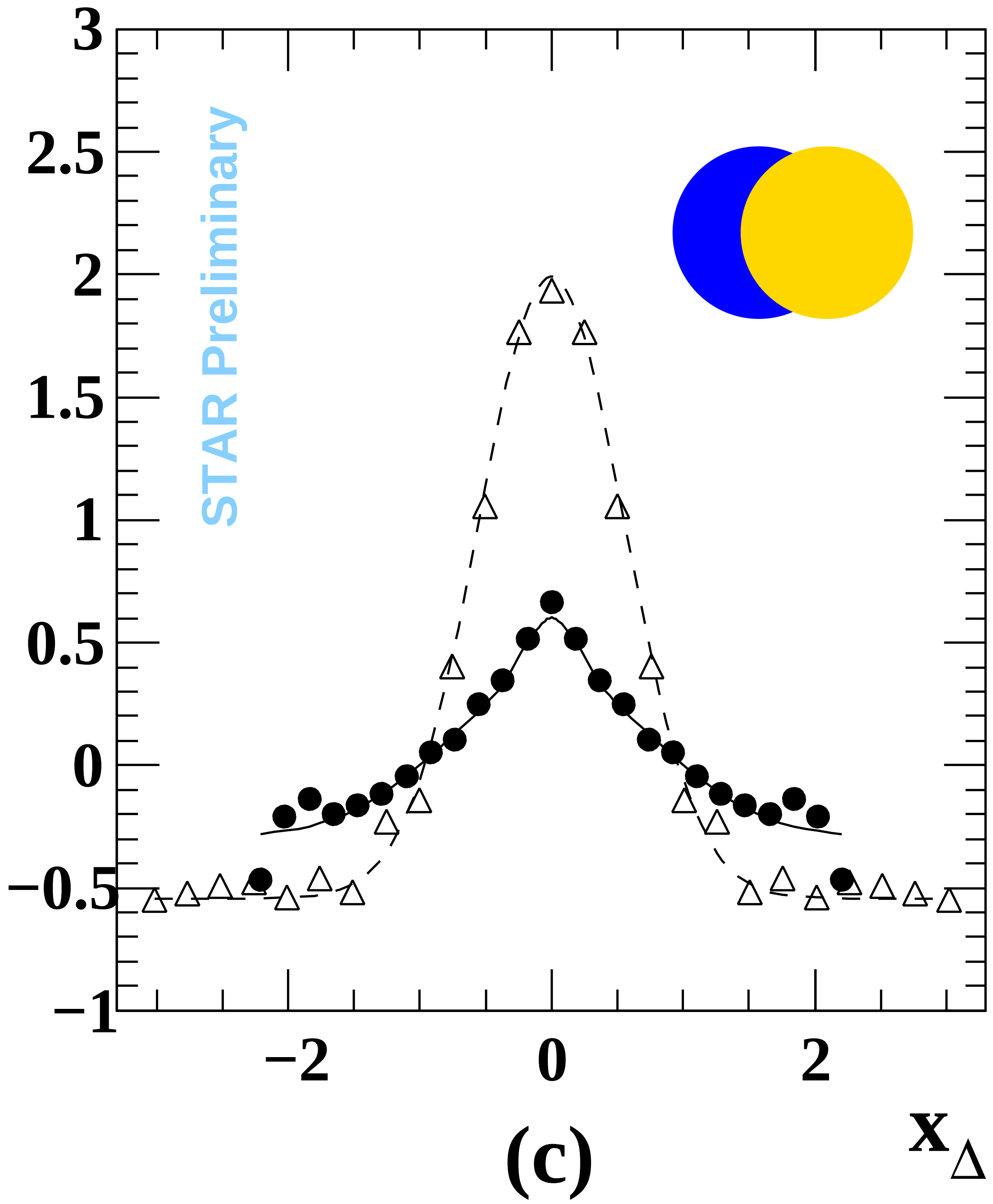




[STAR two-particle correlation analysis, to be submitted to PRL] The step-like character of the centrality dependence is elucidated using $\nu = (N_{part}/2)^{\frac{1}{3}}$



Per-particle-normalized charge-independent autocorrelations $N\Delta R$ in difference variables η_Δ (solid dots) and ϕ_Δ (open triangles).



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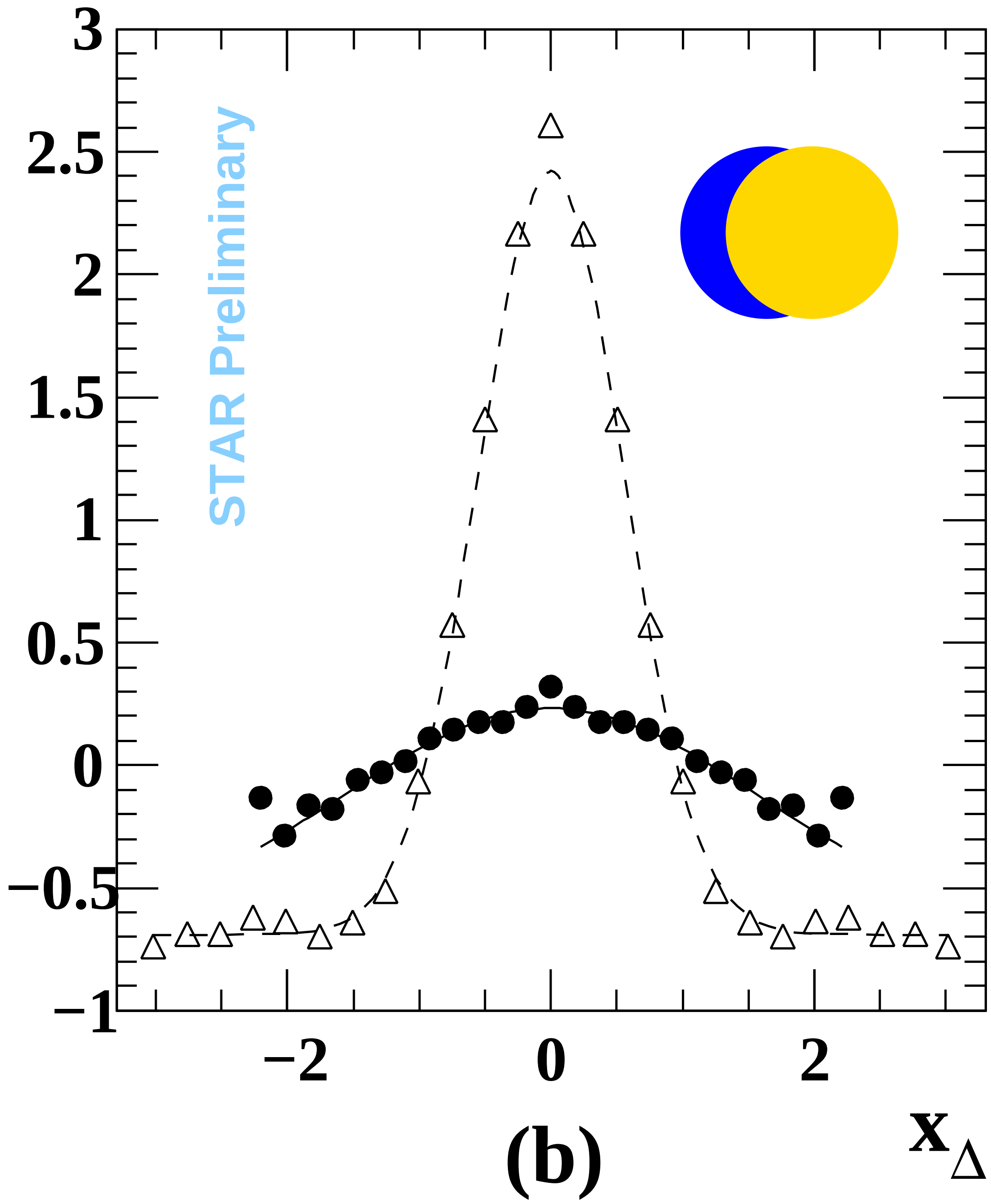

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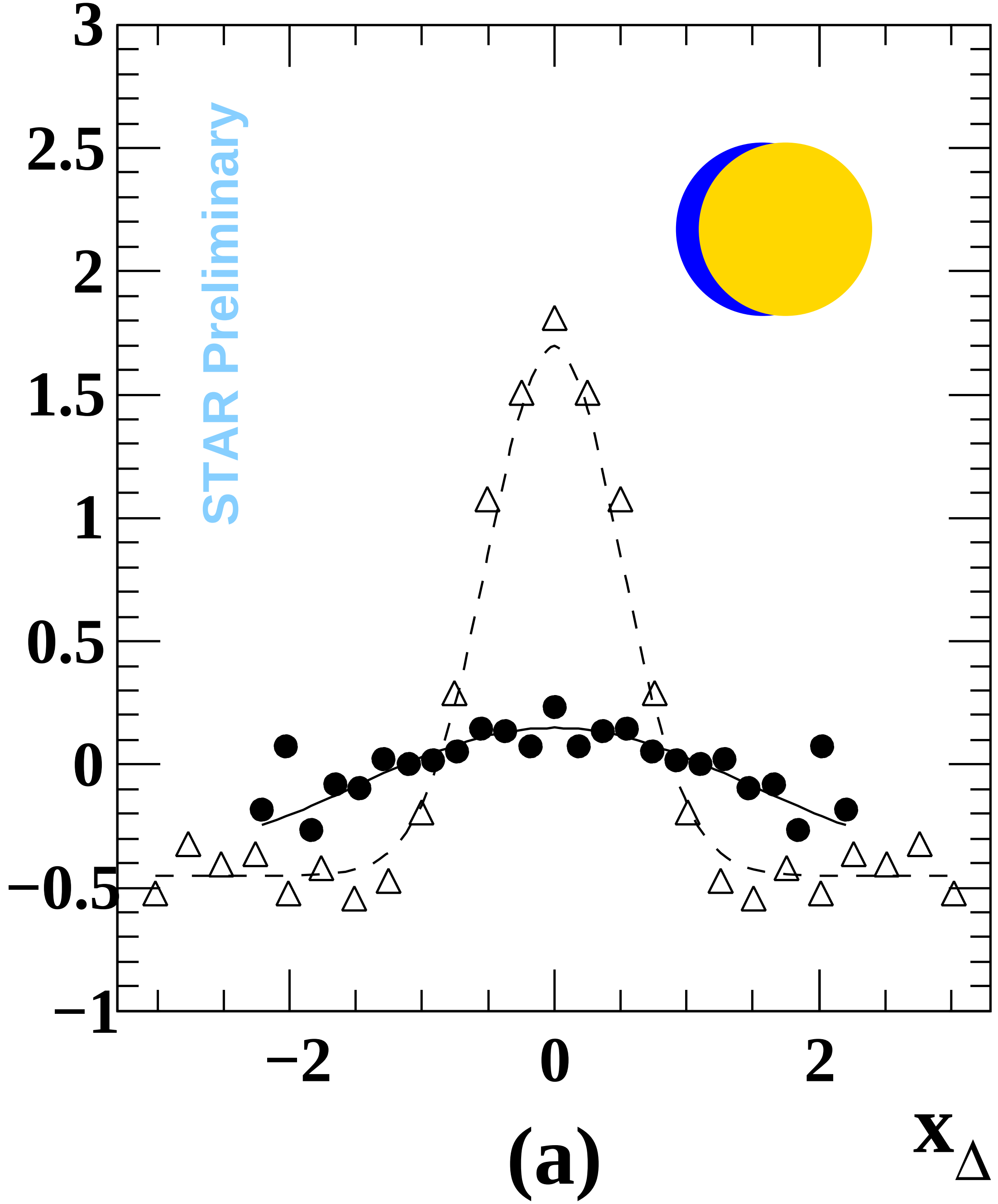

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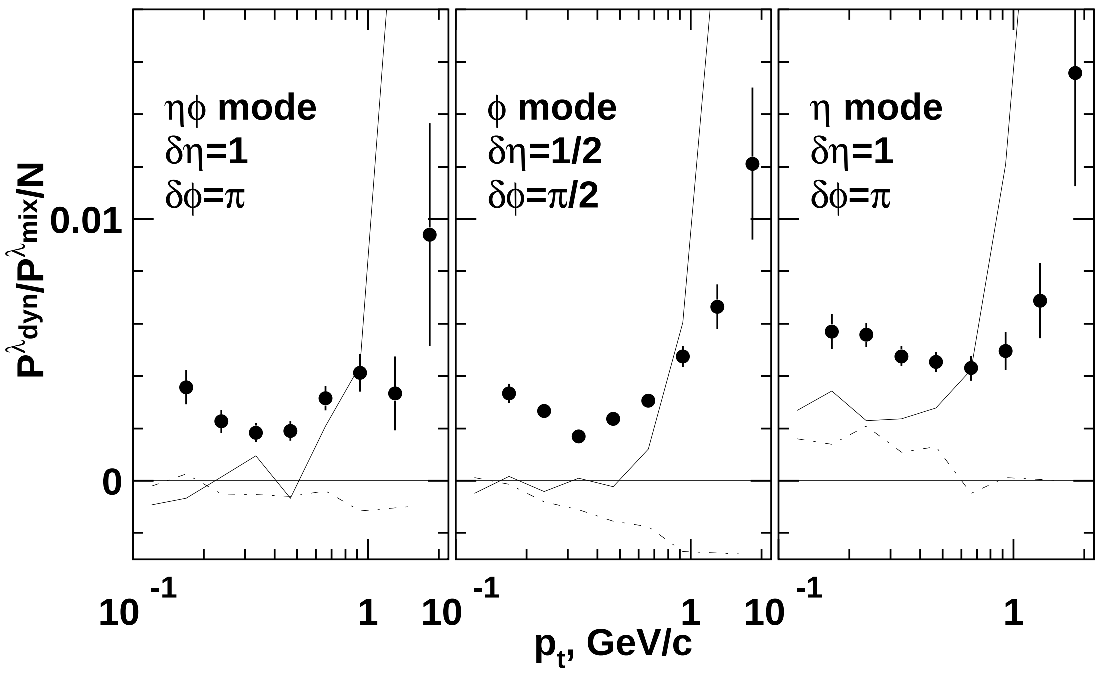
9 p_t dependence: peripheral events, $\sqrt{s_{NN}} = 200$ GeV



Peripheral events (60-84%): normalized dynamic texture for fineness scales $m = 0, 1, 0$ from left to right panels, respectively, as a function of p_t. $\bullet$ – STAR data; solid line – standard HIJING, dash-dotted line – HIJING without jets.

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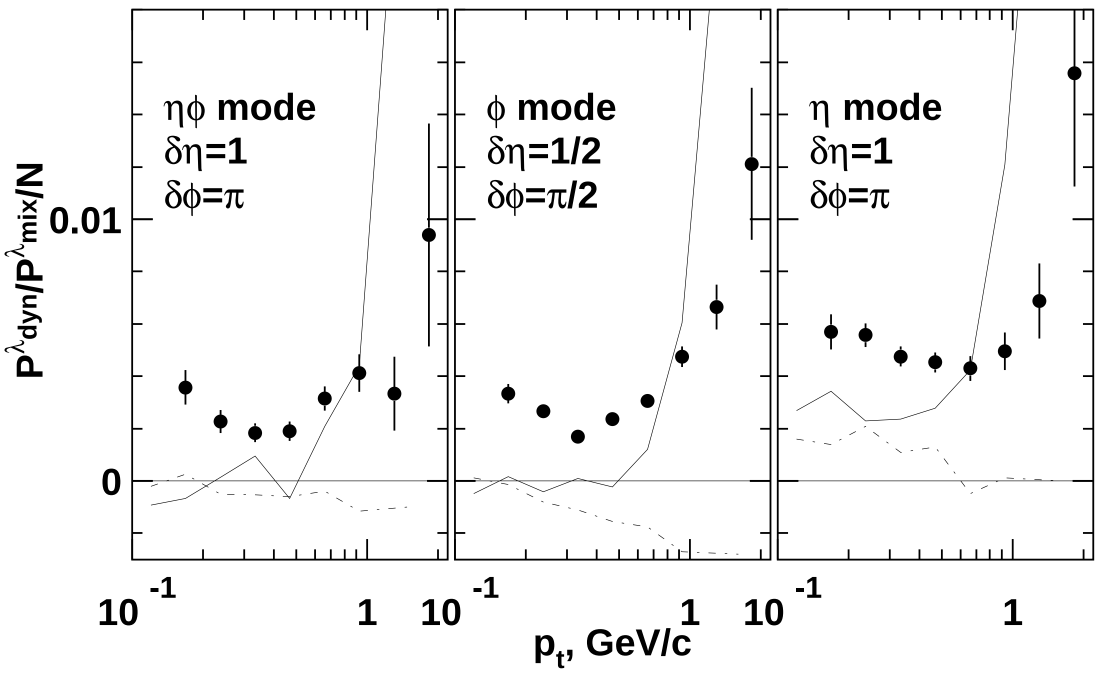

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Qualitative trends in peripheral data are as expected. What signal to expect in the central data, if correlation does not change ?

$$\left(\frac{P_{true}}{P_{mix}} - 1\right)\frac{1}{N}\bigg|_{central} = \left(\frac{P_{true}}{P_{mix}} - 1\right)\bigg|_{peripheral}\frac{1}{N_{central}} \qquad (5)$$

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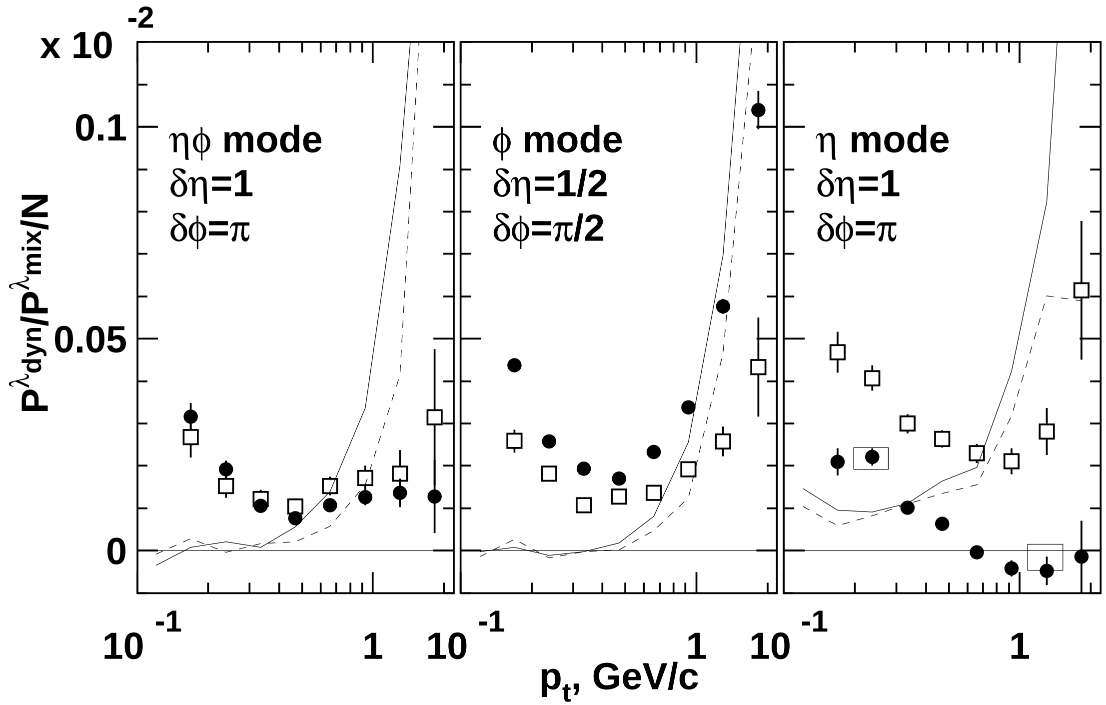

Central (top 4%) events: normalized dynamic texture for fineness scales $m = 0, 1, 0$ from left to right panels, respectively, as a function of p_t. $\bullet$ – STAR data; solid line – standard HIJING; dashed line – HIJING with jet quenching; boxes – peripheral STAR data just shown, renormalized as just described.

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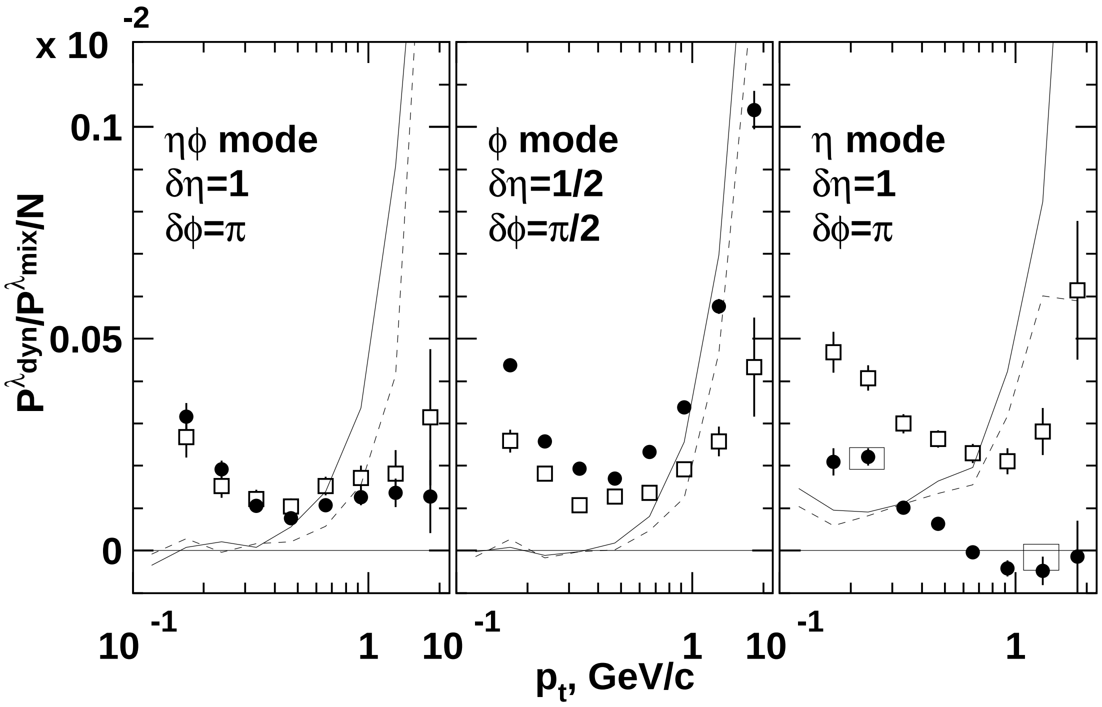

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We are observing a modification of the minijet structure predominantly in the longitudinal, η direction. Longitudinal expansion of the hot and dense medium formed early in the collision makes this direction special and is likely to be part of the modification mechanism.

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via rejection/acceptance algorithm, according to a multiparticle probability density distribution. In general, for N particles denoted $1, 2, ..., N$ the differential probability density

$$P(1, 2, ..., N) = P(1)P(2|1)P(3|1, 2)...P(N|1, 2, ..., N-1),$$

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$$C(1,2) = \frac{P(1,2)}{P(1)P(2)} = \frac{P(2|1)}{P(2)}.$$

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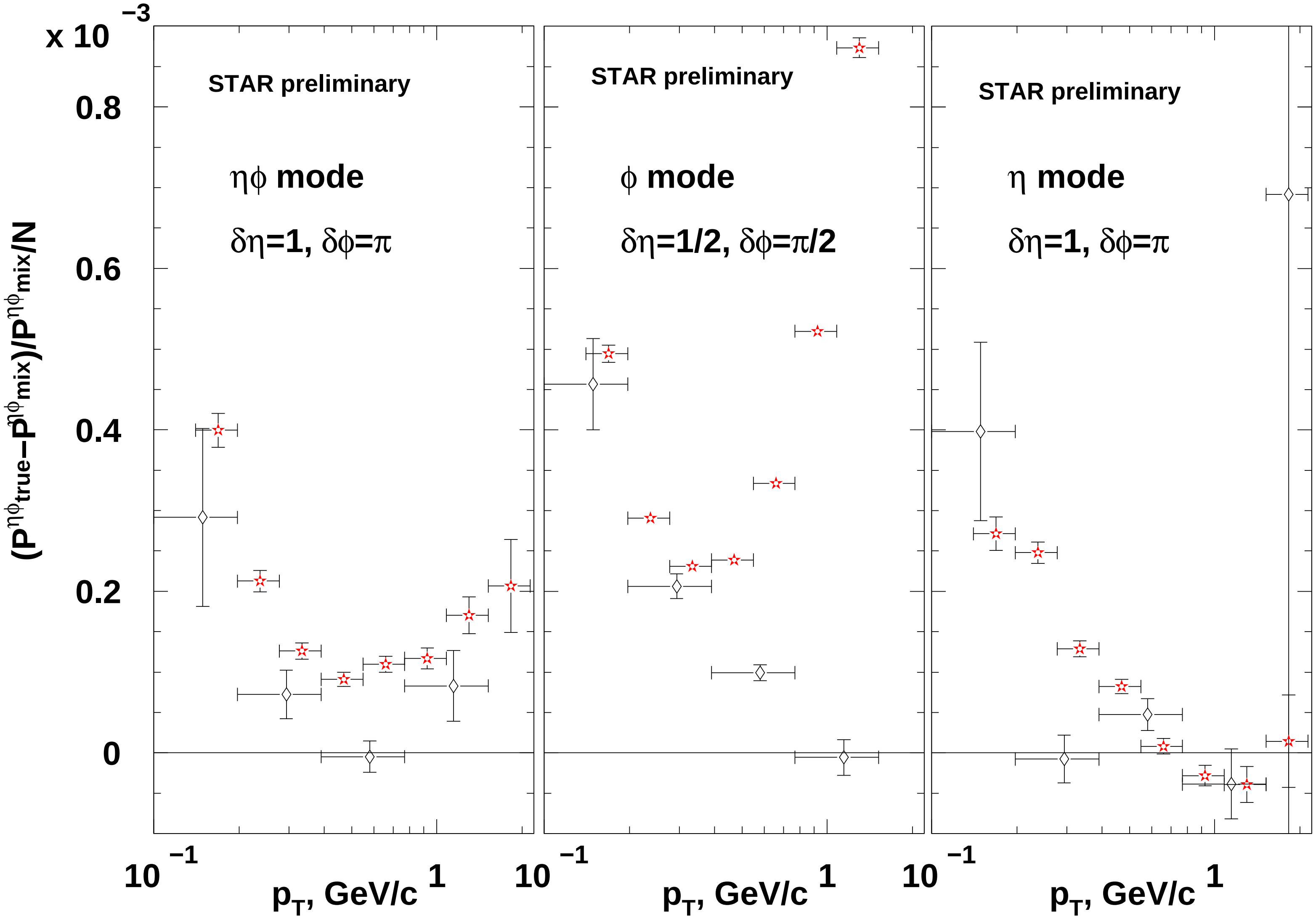
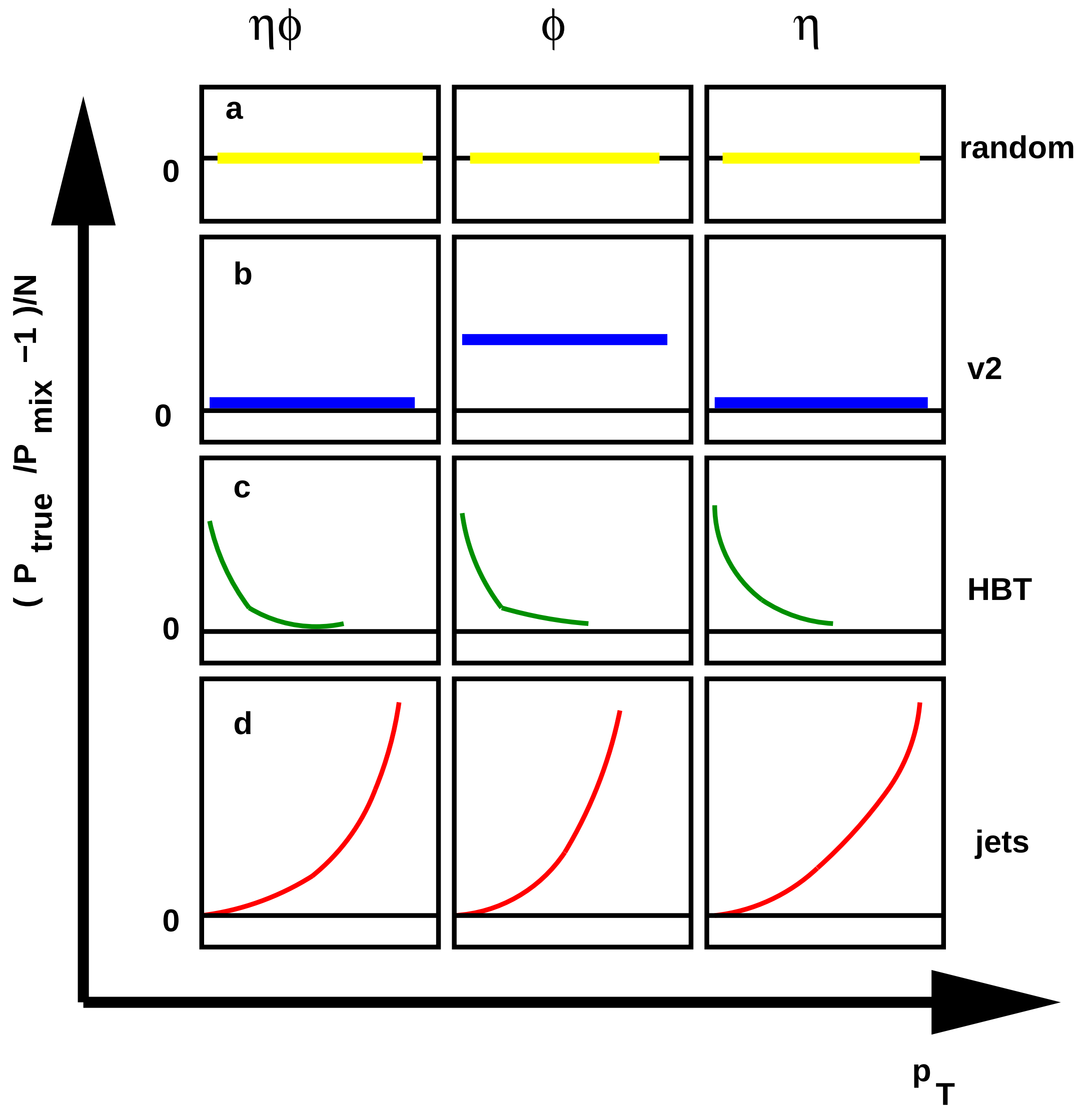
$$P(N|1, 2, ..., N - 1) \approx P(N)\Pi_{i=1}^{i=N-1}C(i, N)$$

12 Understanding low p_t



An event generator tuned to reproduce like- and unlike-sign correlations in Q_{inv}, reproduces the low p_t trends in the data. HBT, Coulomb and string fragmentation physics contribute at low p_t.



Dynamic texture response in various idealized situations (showing only one scale):

(a) events of random (uncorrelated) particles

(b) p_t-independent elliptic flow

(c) Correlations at low Q_{inv} (Bose-Einstein correlations and Coulomb effect)

(d) HIJING jets

13 Scale dependence

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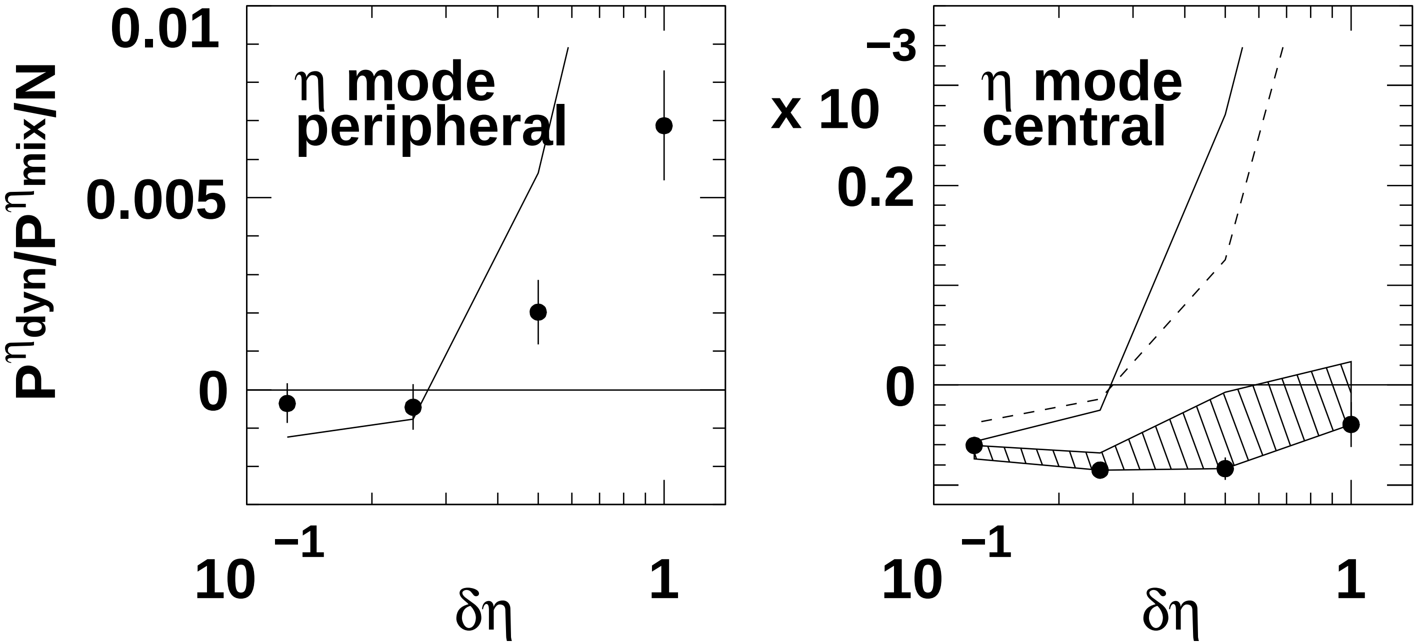

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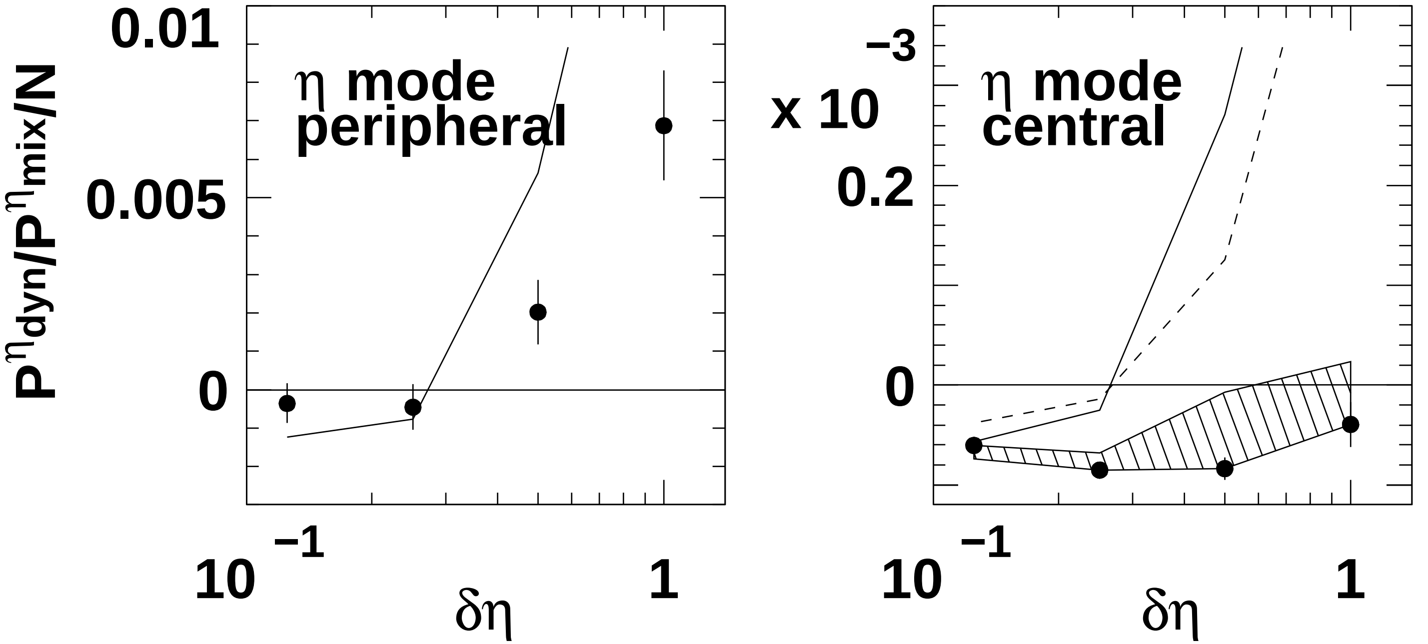

Scale dependence of the dynamic texture measure in peripheral and central events for $1.1 < p_t < 1.5$ GeV/c. •– STAR data; solid line – standard HIJING; dashed line – HIJING with jet quenching. An estimate of systematic error, mainly due to track merging, is shown as a hatched area.

14 Rapidity scale and collision history

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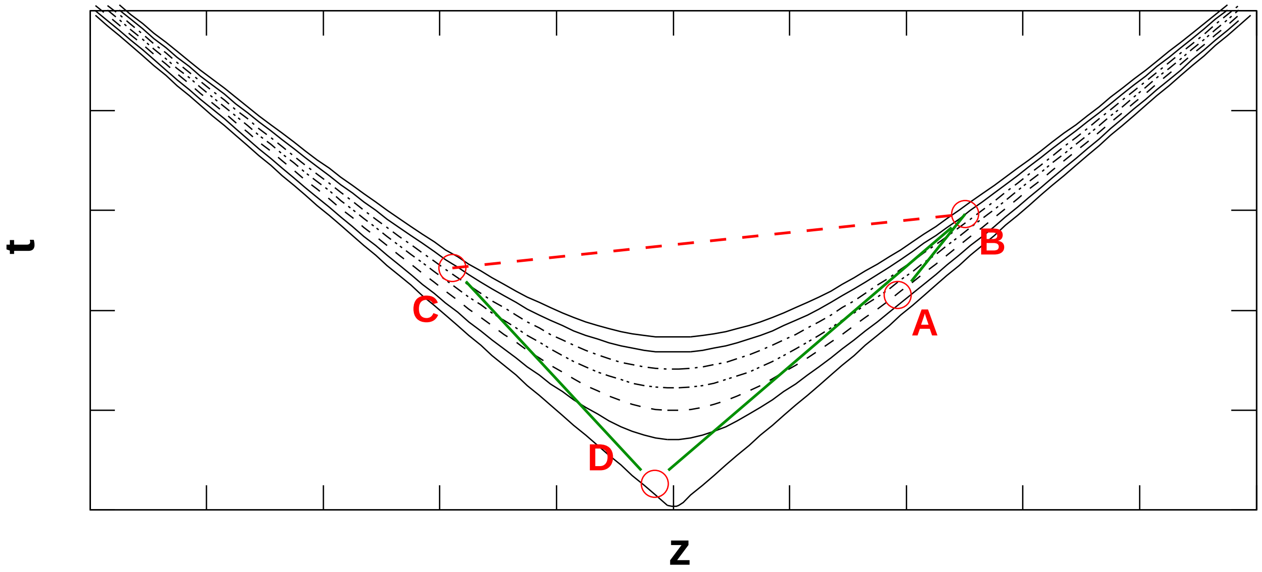

Bjorken expansion: $t = (z^2 + \tau^2)^{1/2}$, CB is space-like; DC, DA, DB, AB contacts possible.

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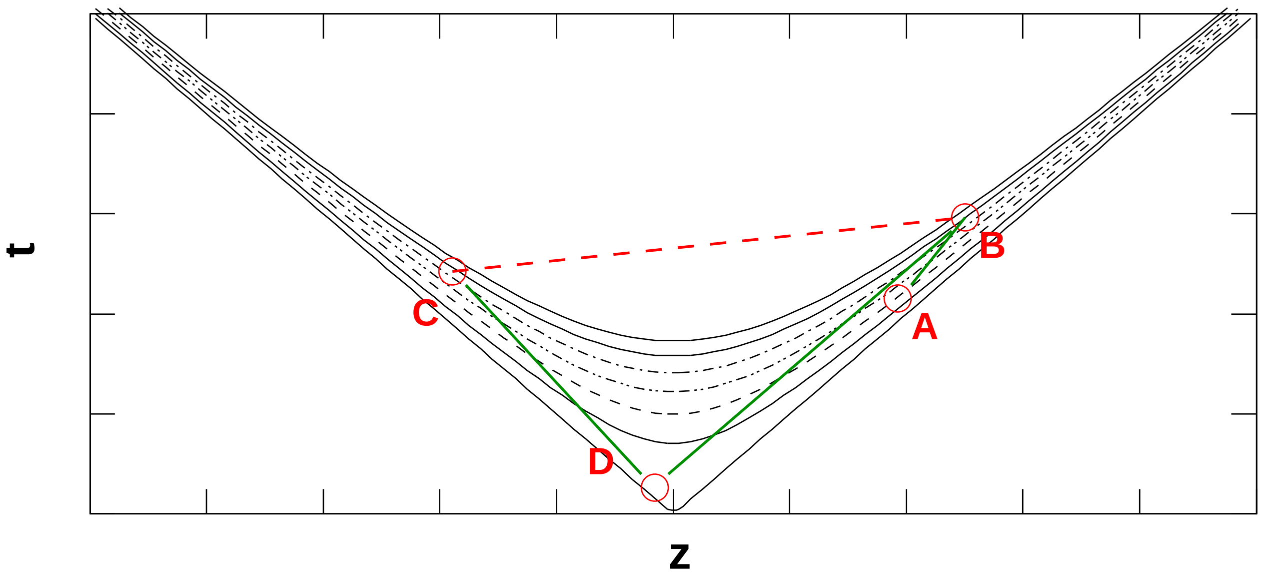

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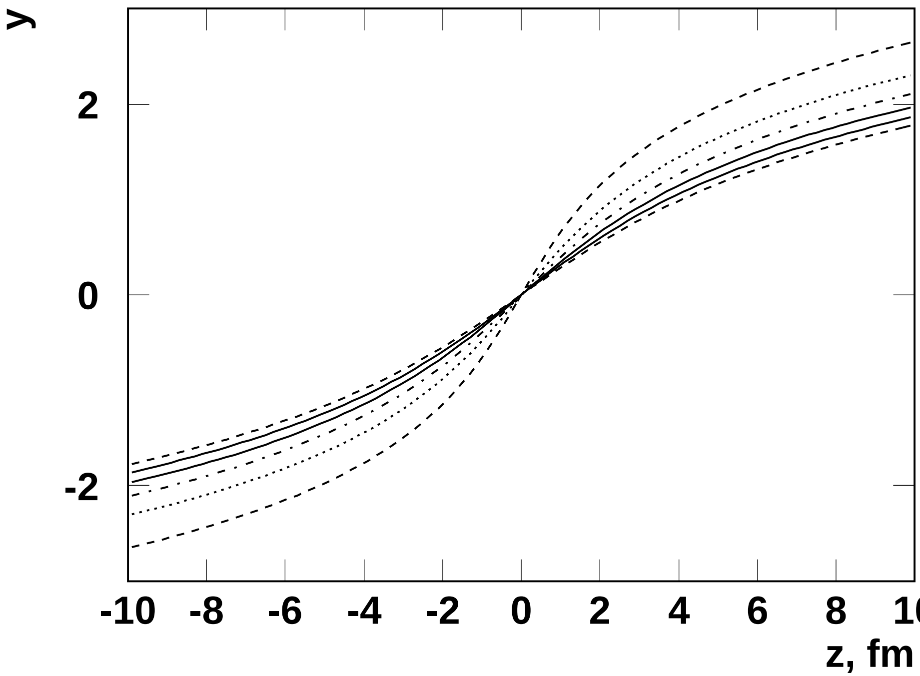

$y = \frac{1}{2} \ln \frac{t+z}{t-z}$ Rapidity and causality: large $\delta y \Longleftrightarrow$ large δz. Large δy correlations reflect early state, otherwise acausal.

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- More info: nucl-ex/0407001