Correlations, Fluctuations and Thermalization

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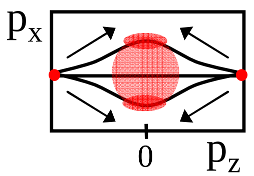
RHIC/AGS Users Meeting

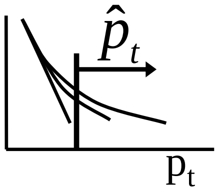
May 10, 2004

Entropy Production and Dissipation

$$S = N \ln \left\{ \frac{1}{\hbar^3} \cdot \left(\frac{\hat{z}^{d_z} \hat{r}^{d_r}}{N} \right) \cdot \hat{p}_l^{d_l} \hat{p}_t^{d_t} \right\} \begin{matrix} N = ? \\ d = ? \end{matrix}$$

Sakur-Tetrode entropy (ideal gas)





p_t, S grow with *path length* ν

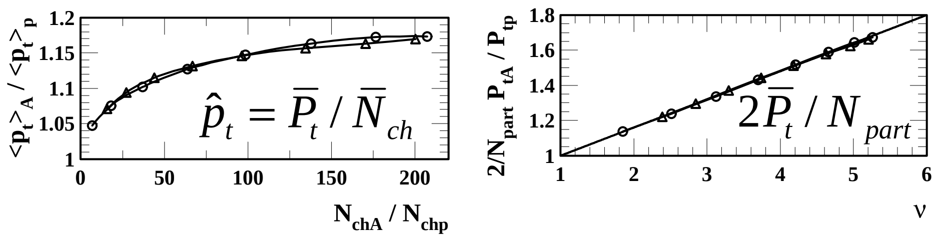
'stochastic' multiple nucleon scattering

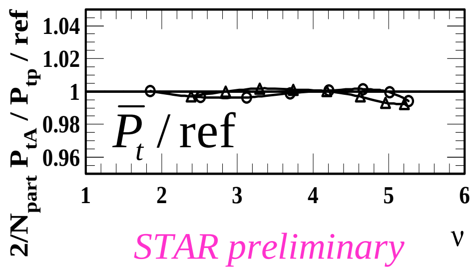
entropy production steps →

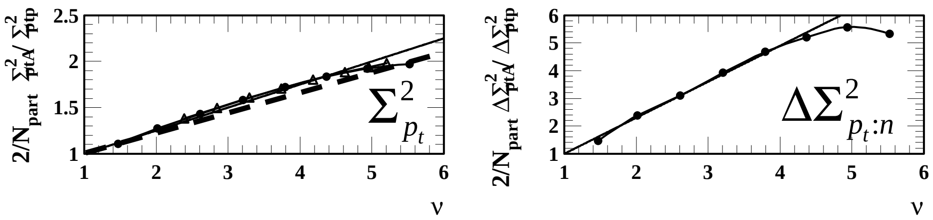
- soft p_t and multiplicity
- hard p_t probes increase ∝ ν
- *correlated* p_t structure
- dissipation of correlated structure

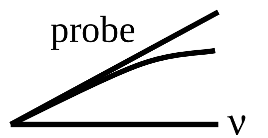
p_t growth with centrality:

probe production → dissipation









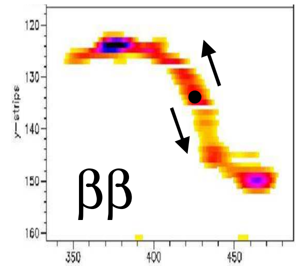
reduced correlations, fluctuations ⇔ dissipation, entropy *increase*

Langevin Equation – I

$$\dot{\vec{v}}(t) = -\frac{1}{\tau}\vec{v}(t) + \vec{a}_{stoch}(t) + \vec{a}_{mcs}(t)$$

$\vec{a}_x(t)$ gaussian random, zero mean, $\vec{a}_{mcs}(t) \perp \vec{v}(t)$

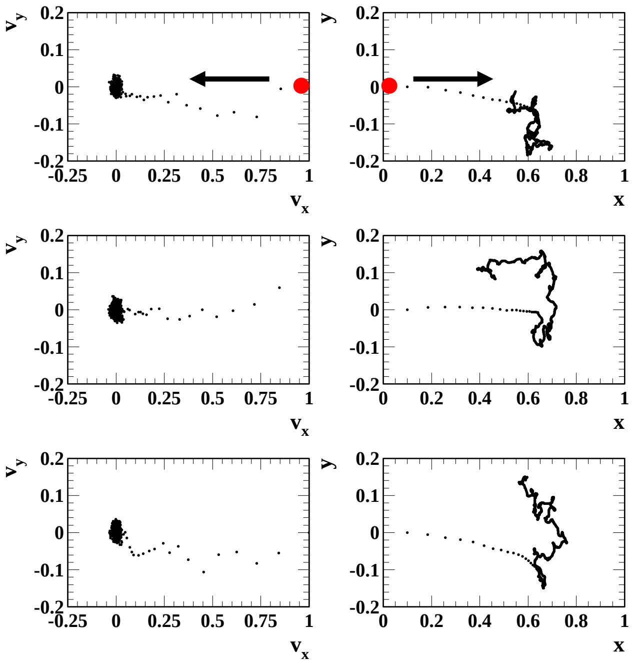
thermalization of point motion in 2D



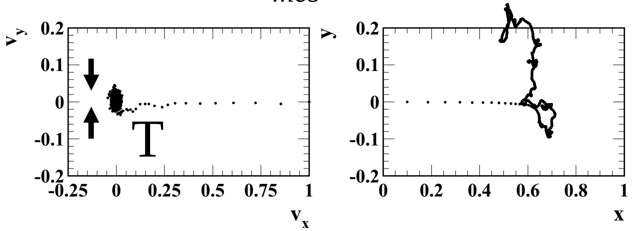
probe particle in dissipative medium

integrate Langevin

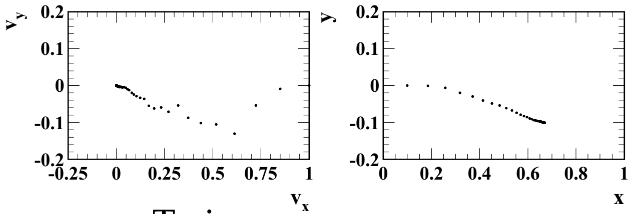
velocity displacement



$\vec{a}_{mcs} = 0$



$\vec{a}_{stoch} = 0$



Trainor

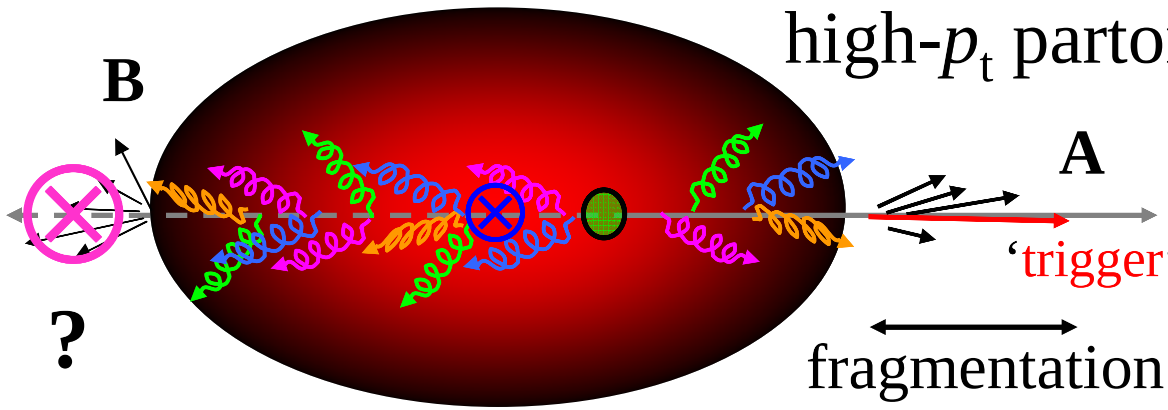
dissipation limit: thermal velocities, random walk

what happens to extended objects, internal structure?

pQCD Energy Loss

A-A collision cross section

high-p_t partons



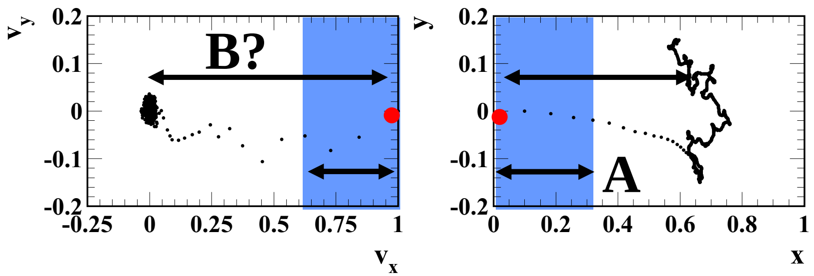
fragmentation

color energy loss

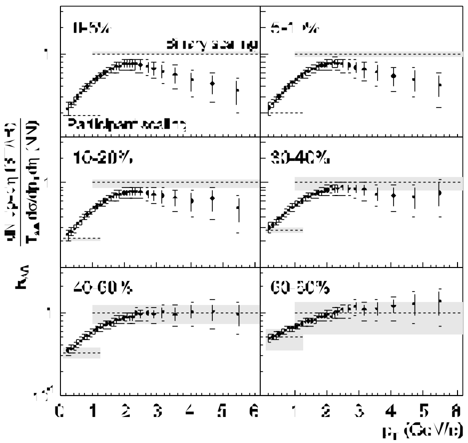
what happens to the medium?

- point interactions
- binary collisions
- gluon bremsstrahlung
- LPM effect?
- dead cone effect?

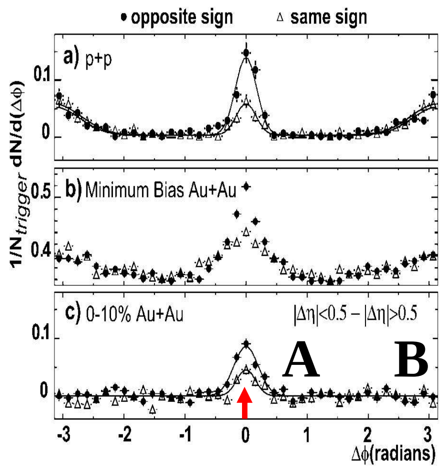
'jet quenching'



What happens to *low*-p_t partons?



inclusive p_t spectrum

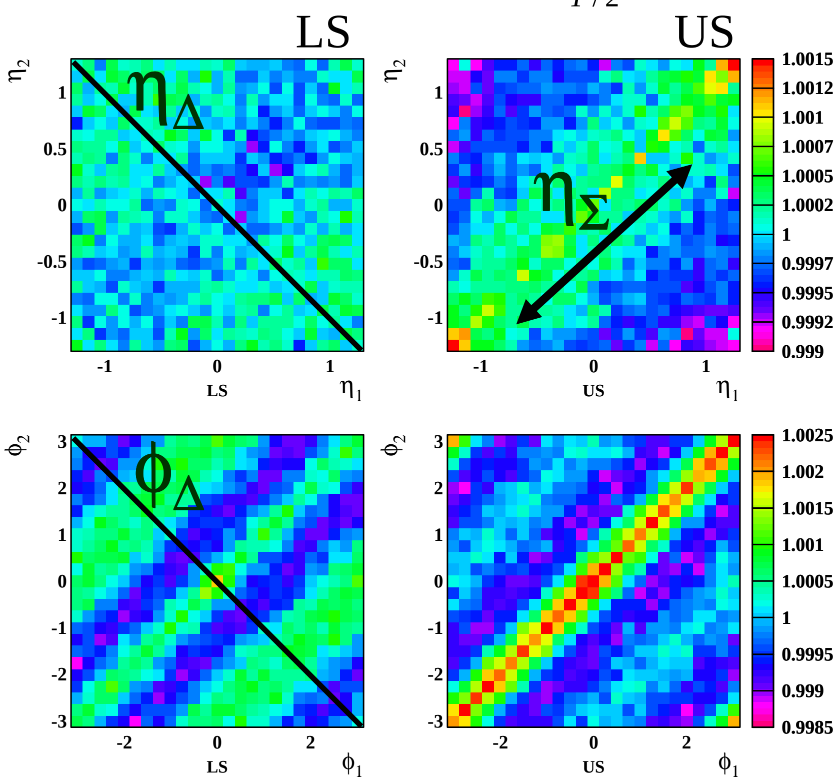


angular correlation

Joint Autocorrelations

lossless projection

$$A(\tau) = \frac{1}{T}\int_{-T/2}^{T/2} f(t)\cdot f(t+\tau)\,dt$$



correlations on (x_1, x_2)

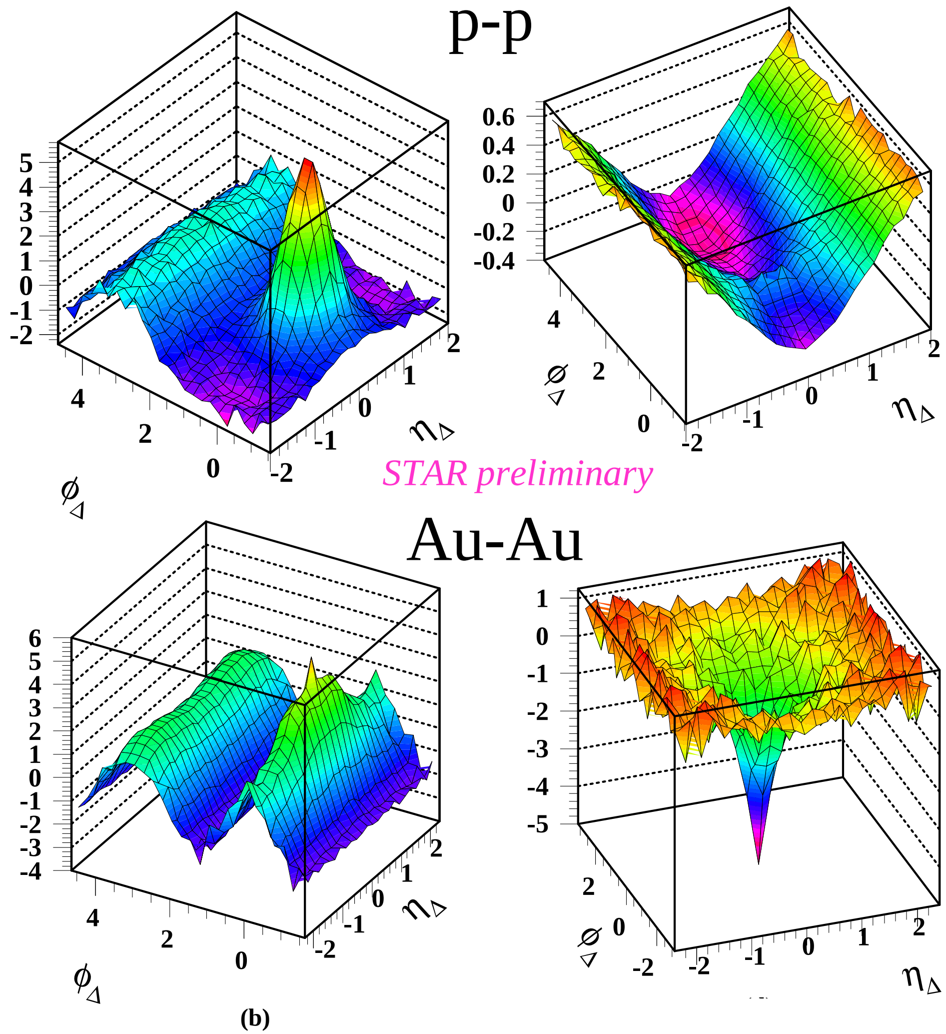
invariant on x_Σ ('stationary')

all structure retained on x_Δ

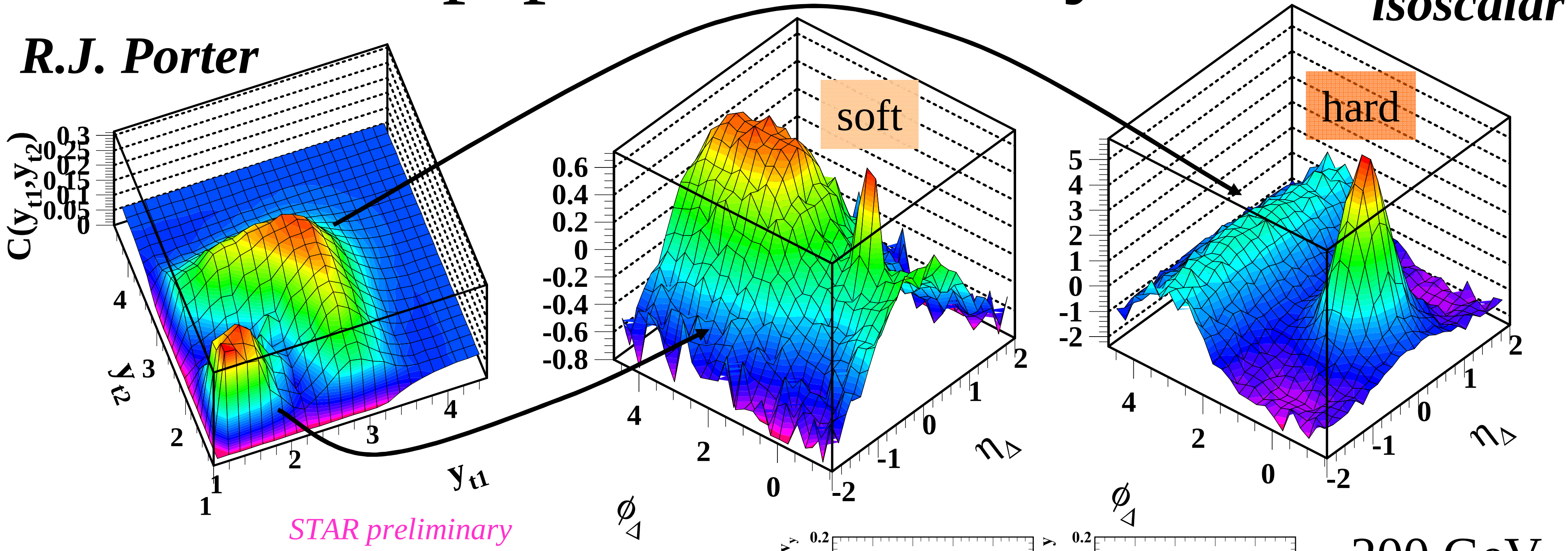
$\rightarrow$ *autocorrelations* on x_Δ

isoscalar | isovector

CI = LS + US | CD = LS – US

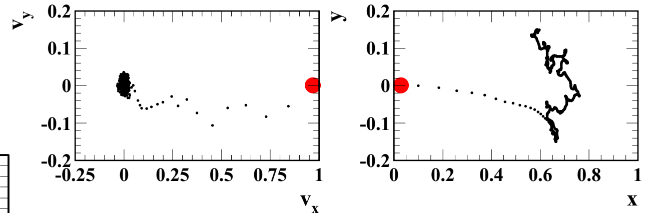


The p-p Reference System

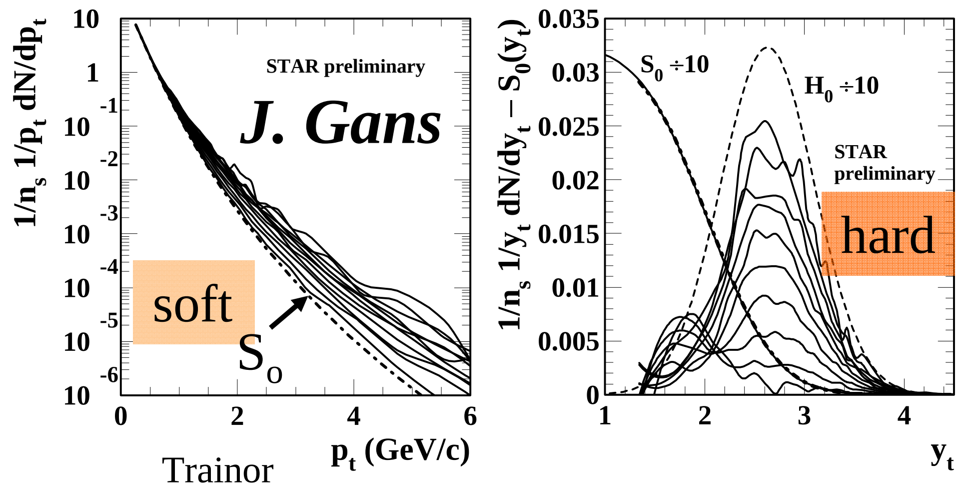


$y_t \equiv \ln\{(m_t + p_t)/m_0\}$ $\quad p_t / m_0 \equiv \gamma \beta_t$

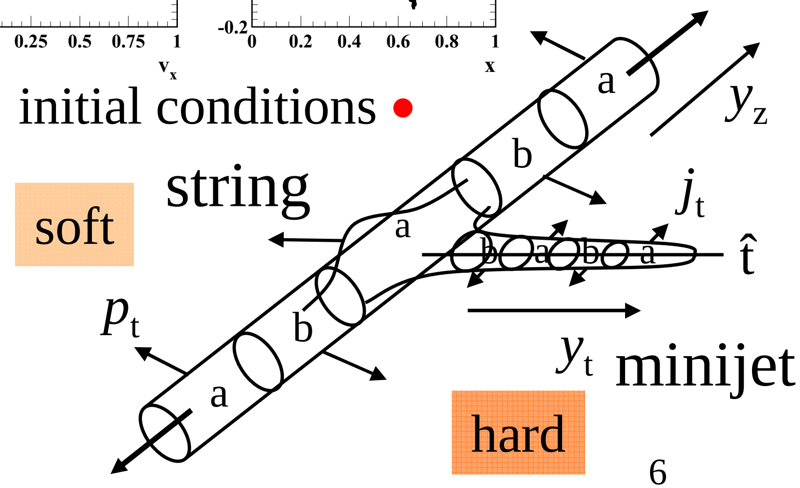
200 GeV



initial conditions •

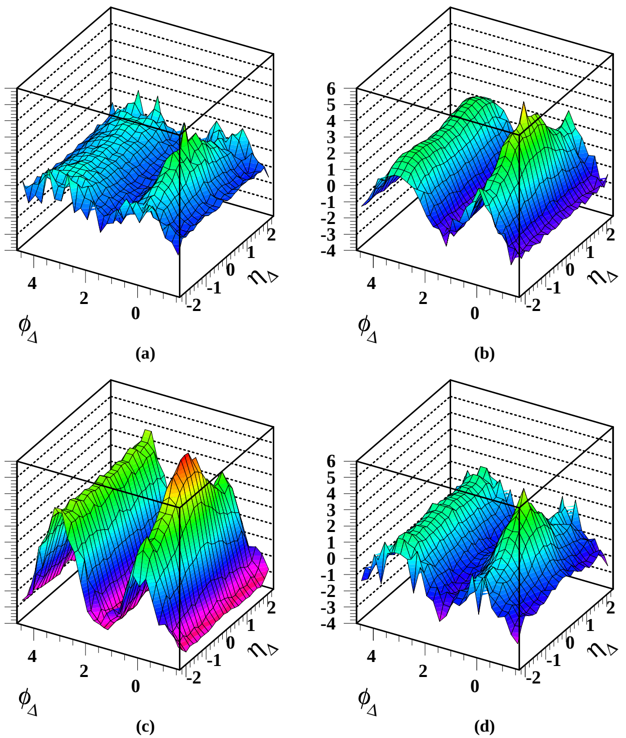


Trainor



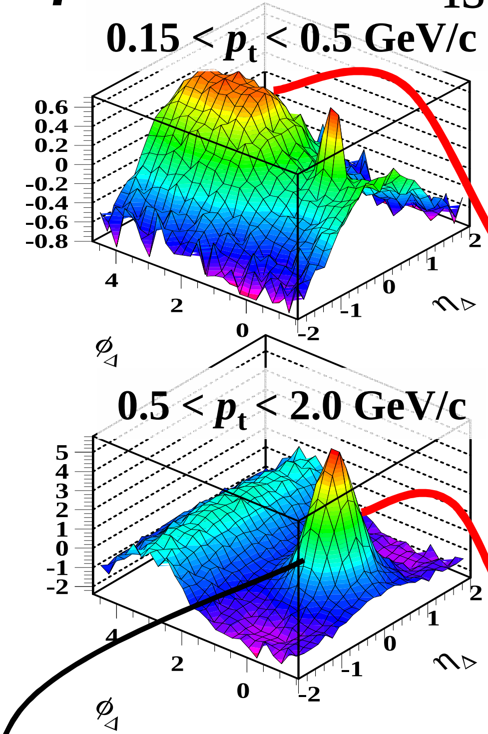
Au-Au Angular Correlations – I

A. Ishihara

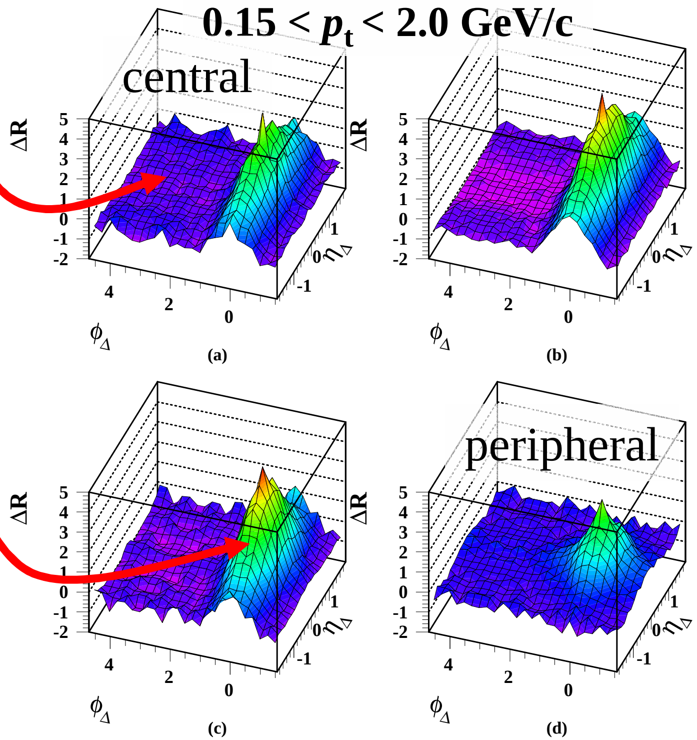


STAR preliminary

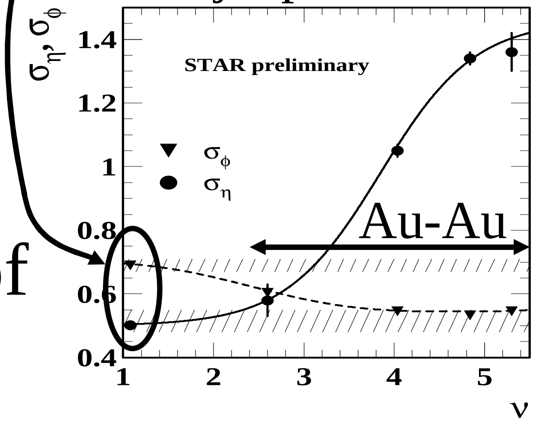
p-p reference

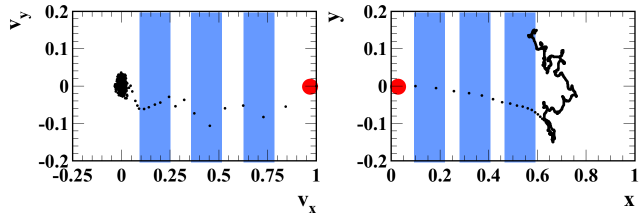


isoscalar ***angular*** correlations



minijet peak widths

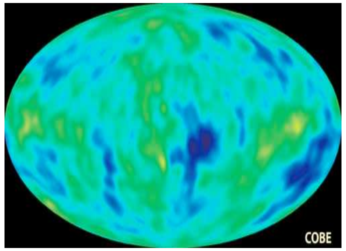




130 GeV

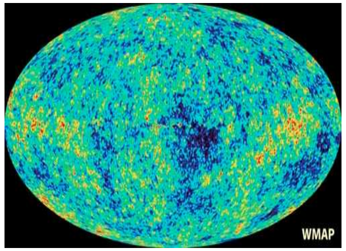
new phenomenon:
angular deformation of
parton fragmentation

COBE



Au-Au $\langle p_t \rangle$ Fluctuations

WMAP

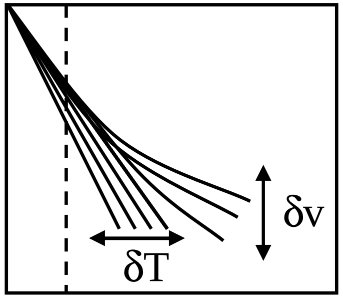


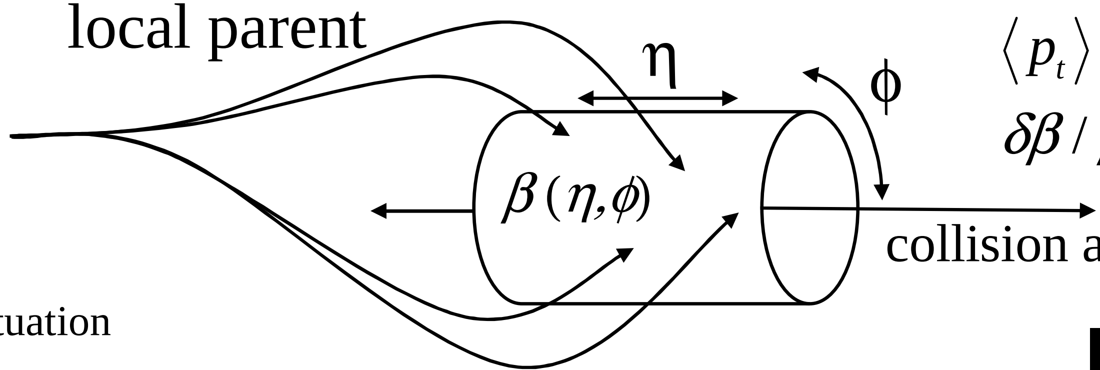
minijets in Au-Au collisions

isoscalar ***velocity*** correlations

$\langle p_t \rangle \leftrightarrow \beta(\eta,\phi)$

$\delta\beta / \beta \sim \delta T / T,\ \delta v / v$

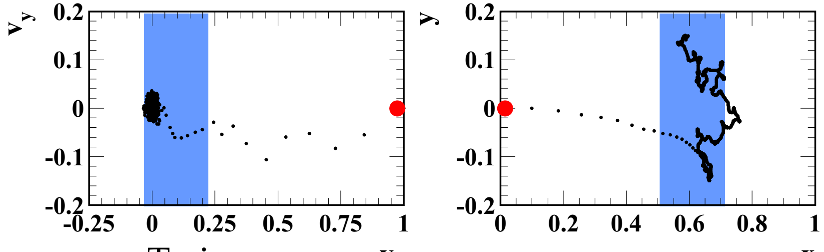


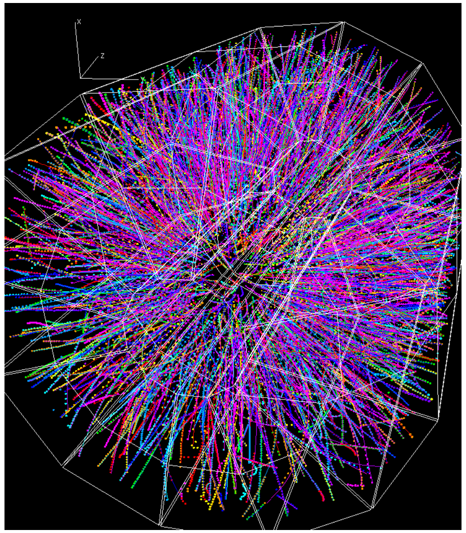


hadron p_t is drawn from *local parent*

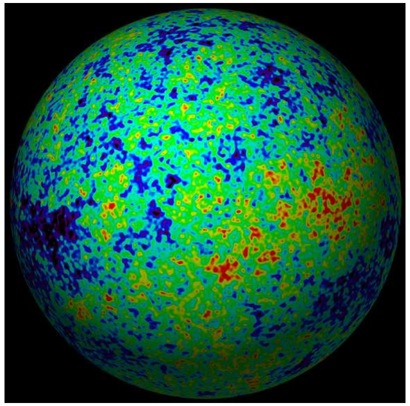
1) local temperature variation δT

2) local velocity variation δv





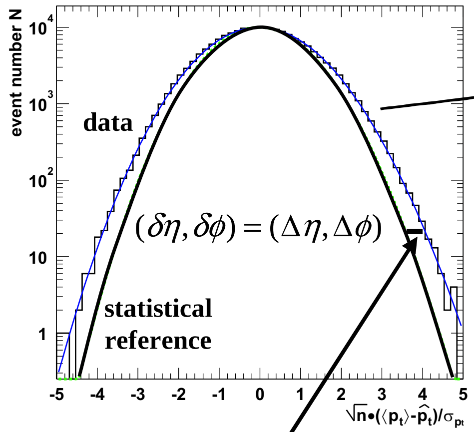
one Au-Au event



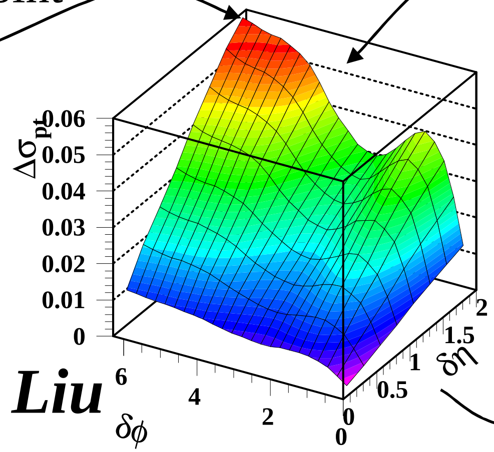
one bang

Fluctuations and Correlations

J.G. Reid

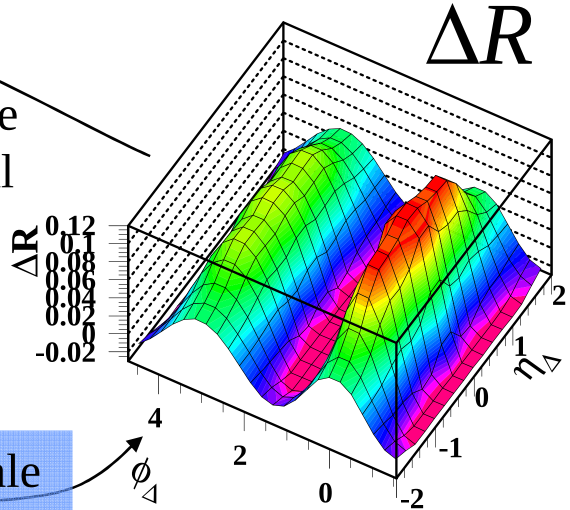


single point



2D scale integral

ΔR



Q.J. Liu

$\langle p_t \rangle$ fluctuation excess

scale dependence

2D scale inversion

D.J. Prindle

joint autocorrelation

$$\Delta\sigma^2_{p_t:n} \equiv \overline{(p_k(\delta x) - n_k(\delta x)\hat{p})^2 / n_k} - \sigma^2_{\hat{p}_t}$$

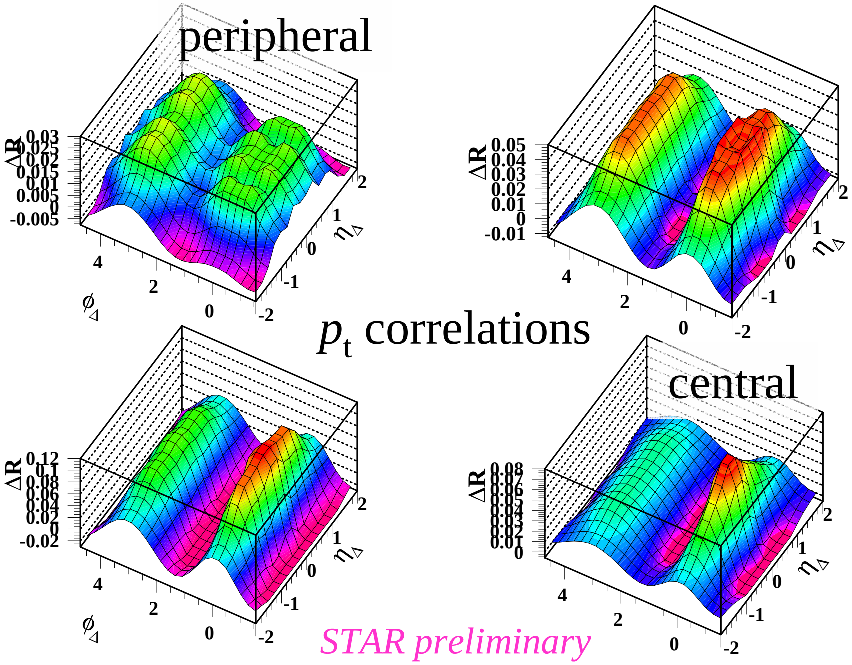
$$\Delta R \propto \overline{p_{ti} \cdot p_{tj} / \sqrt{n_i n_j}} - \overline{\sqrt{n_i n_j}}\, \hat{p}_t^2$$

$$\Delta\sigma^2_{p_t:n}(m\varepsilon_\eta, n\varepsilon_\phi) = 4\hat{p}^2 \sum_{k=1}^{m} \varepsilon_\eta \sum_{l=1}^{n} \varepsilon_\phi \left(1 - \frac{k - 1/2}{m}\right)\left(1 - \frac{l - 1/2}{n}\right)\left\{\frac{d^2\overline{n}}{d\eta_\Delta d\varphi_\Delta} \frac{\Delta A}{A}_{kl}(\varepsilon_\eta, \varepsilon_\phi)\right\}$$

fluctuations ⇔ integral equation ⇔ correlations

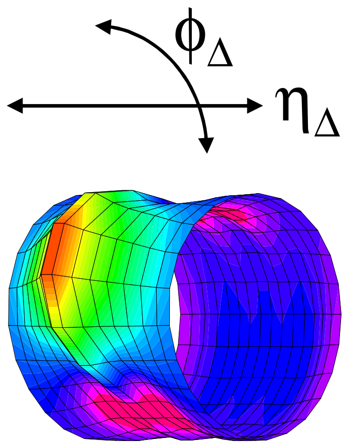
$\langle p_t \rangle$ Fluctuations $\rightarrow p_t$ Correlations

200 GeV Au-Au data $p_t \in$ 0.15-2 GeV/c



minijet dissipation & velocity/temperature structure:

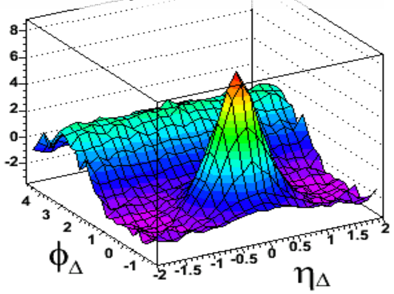
- elongation on η_Δ
- necking on ϕ_Δ



soft partons as extended objects?

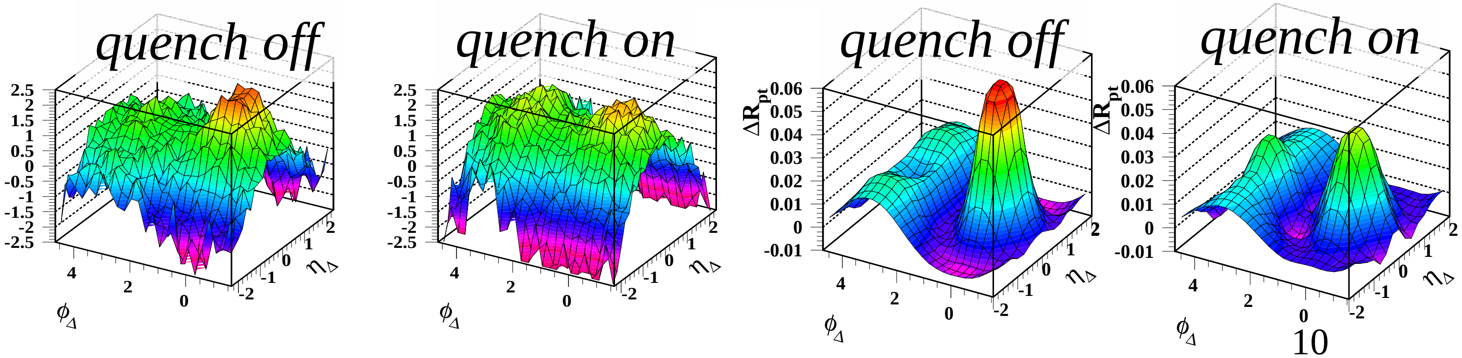
p-p minijets angular correlations

data: $p_t \in$ 1-2 GeV/c



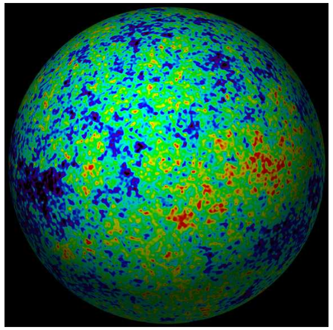
Hijing central Au-Au p_t correlations

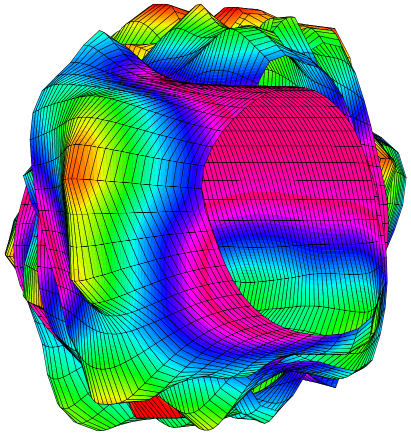
$p_t \in$ 0.15-2 GeV/c

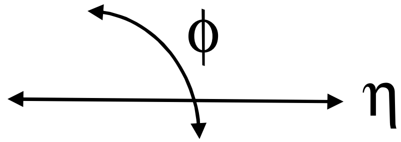


Event-wise Minijets

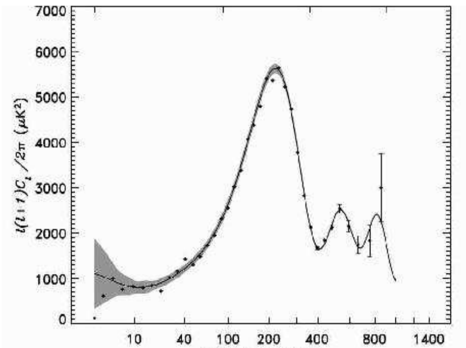
autocorrelations represent *typical* structure of many minijets within and among collisions





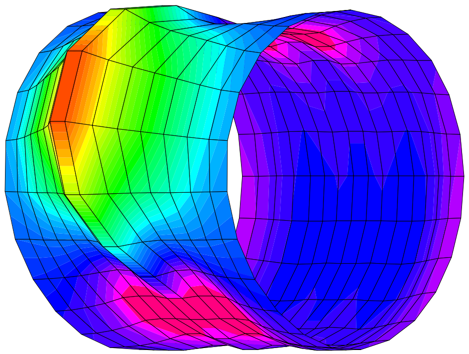


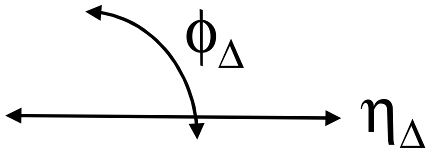
minijet structures on *primary* variables



big small

θ_Δ





minijet autocorrelation on *difference* variables

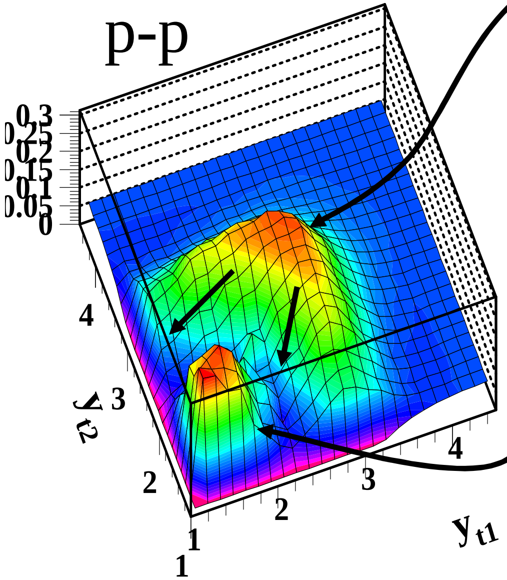
Langevin II – Minijet Dissipation

dissipation:
transport on y_t

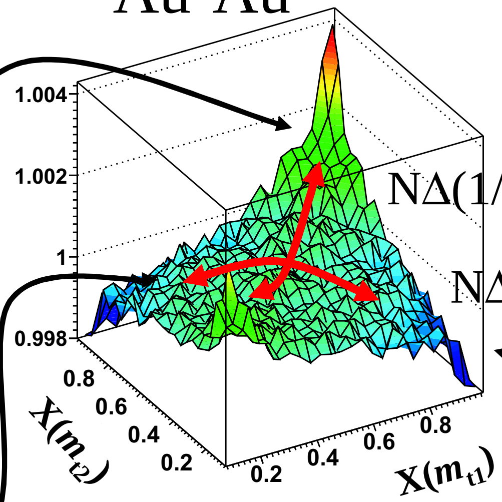
A. Ishihara

Langevin → Fokker-Planck → 2D velocity/temp distribution on $\beta(\eta,\phi)$

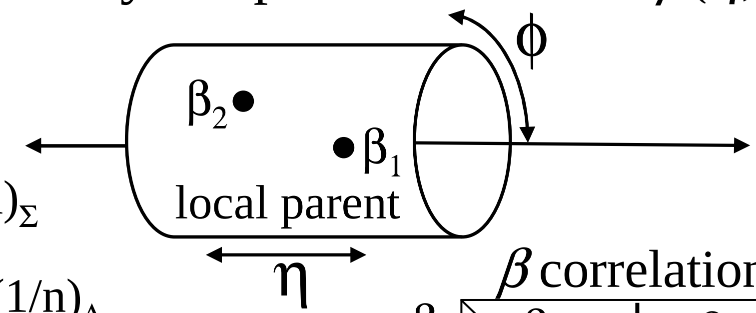
p-p



Au-Au

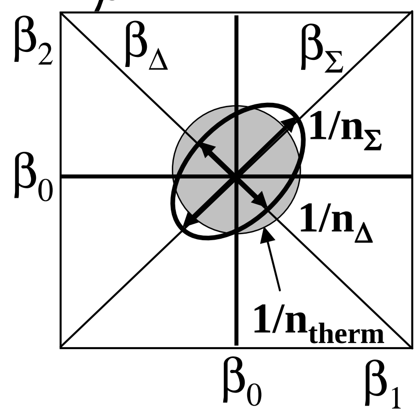


STAR preliminary



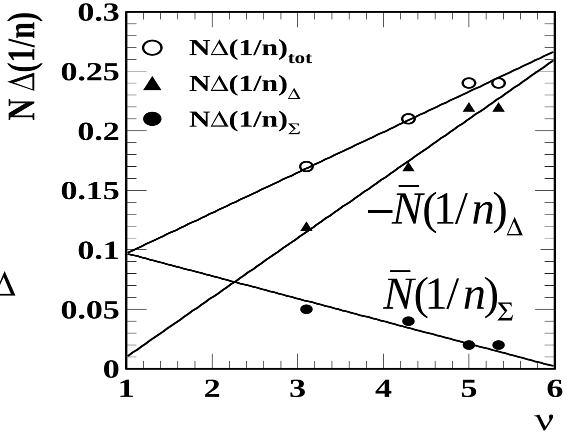
$\Delta(1/n)_x = 1/n_x - 1/n_{therm}$

β correlations



Lévy saddle

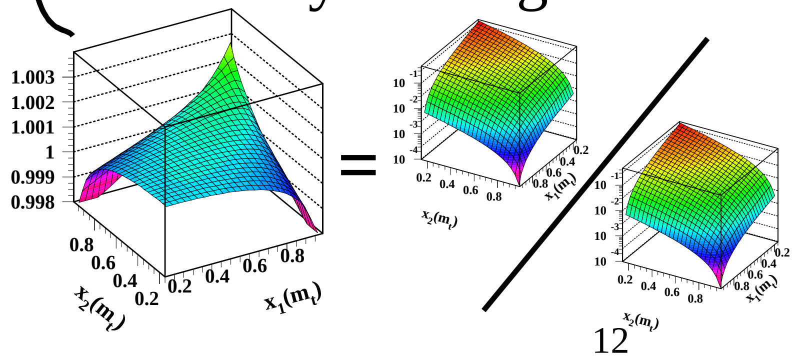
saddle curvatures



$\langle p_t \rangle$ fluctuations:

$$\Delta\sigma^2_{p_t:n} \propto \bar{N}(1/n)_\Sigma - \bar{N}(1/n)_\Delta$$

2D Lévy: sibling/mixed



Au-Au Angular Correlations – II

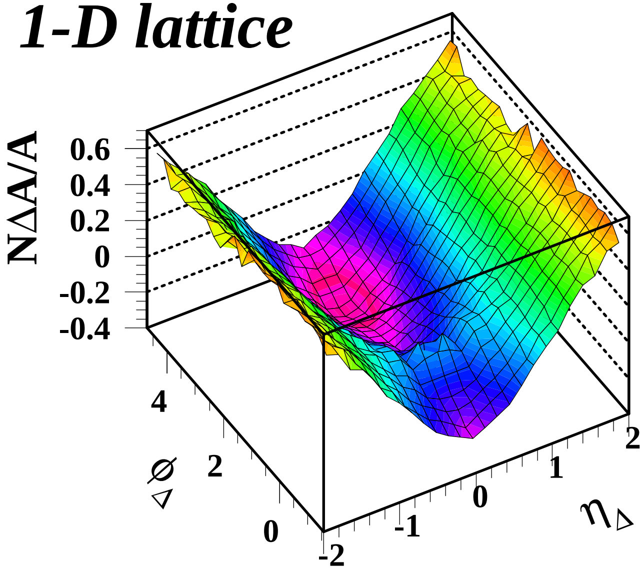
A. Ishihara

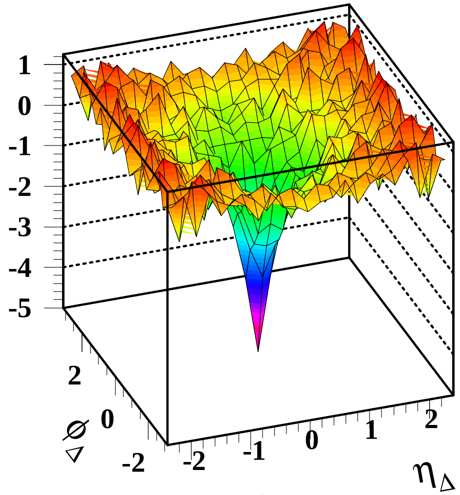
Au-Au 130 GeV

isovector number correlations

200 GeV Pythia

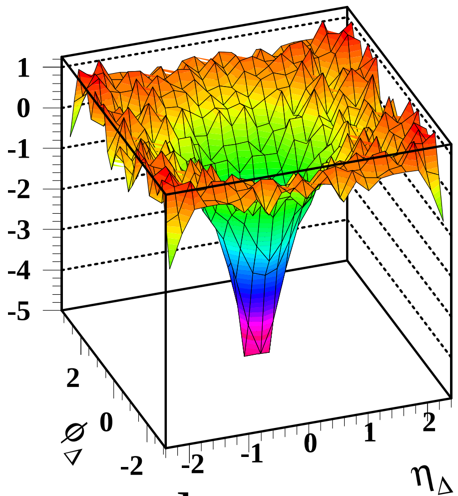
1-D lattice





mid-peripheral

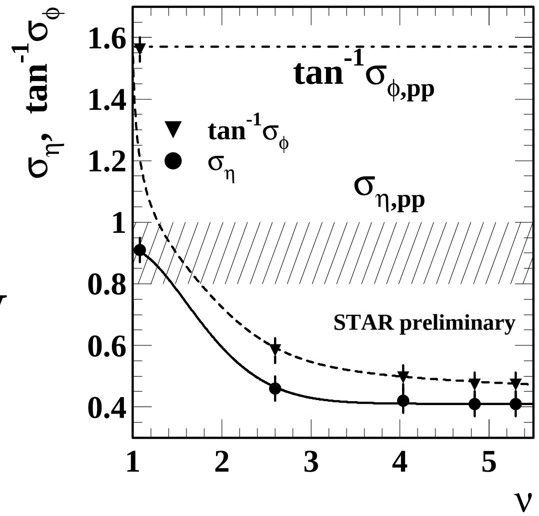
isospin antiferromagnet

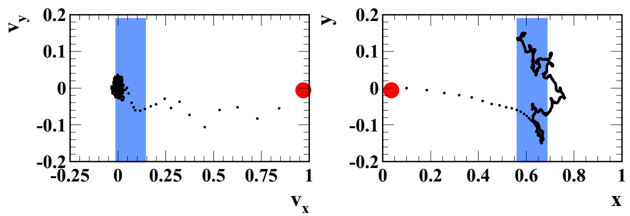


central

STAR preliminary

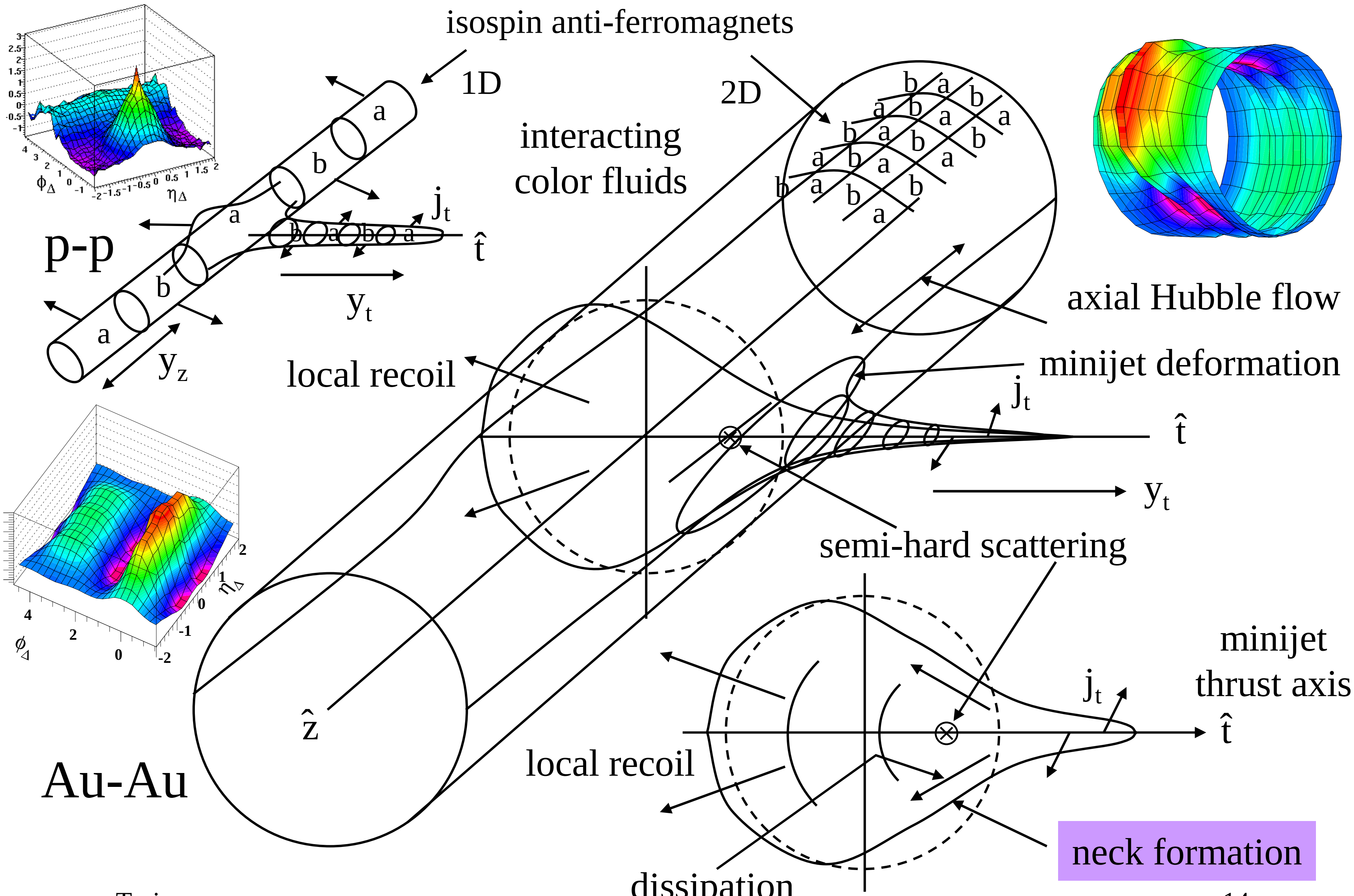
2-D lattice



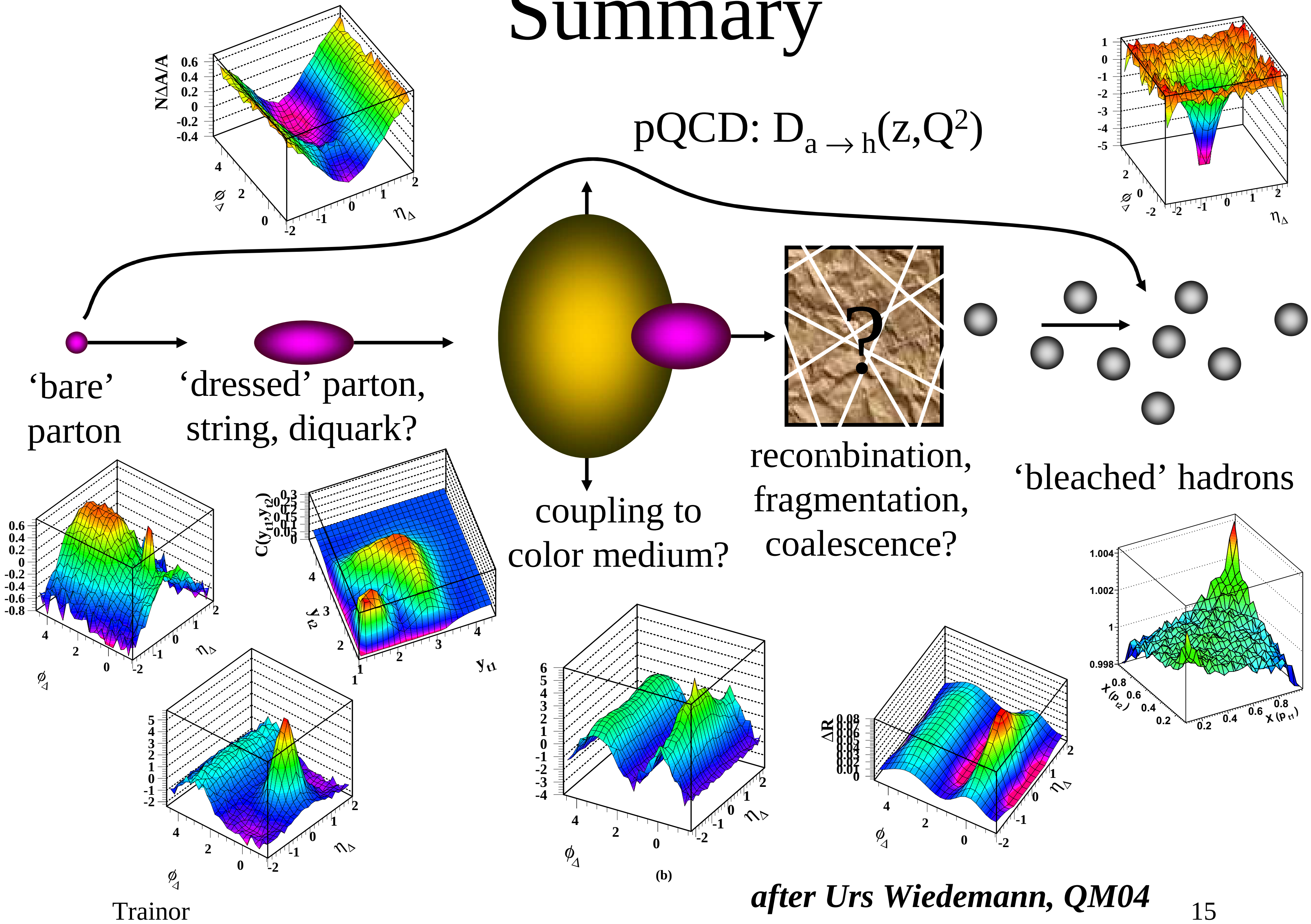


changing geometry
of hadronization

Au-Au Collision Model



Summary



after Urs Wiedemann, QM04