Correlations, Fluctuations and the Observability of QCD Critical Phenomena at SPS and RHIC

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Outline

- Critical phenomena and HI collisions
- Probe-medium interactions in HI collisions
- Medium structure at decoupling
- Event structure at RHIC – a summary
- Collision-energy dependence: SPS $\leftrightarrow$ RHIC
- Measure definitions

Critical Phenomena and HI Collisions

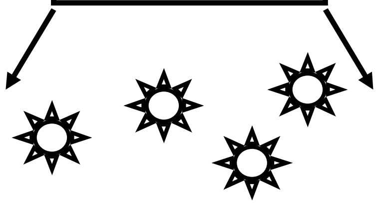
collision system: A,B,$\sqrt{s}$, b

$T_0,\mu_B,\mu_S,\beta(\eta,\phi,b)$ bulk properties

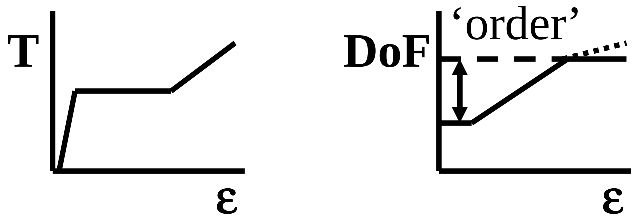
(parton) probe → local medium state → probe modifications

momentum correlations

critical phenomena: unusual *correlation states* of the medium



caloric curve



correlation measurement 'by other means'

fragment distributions (NMF)

charge, flavor, baryon-number correlations

inclusive hadron spectra, yields

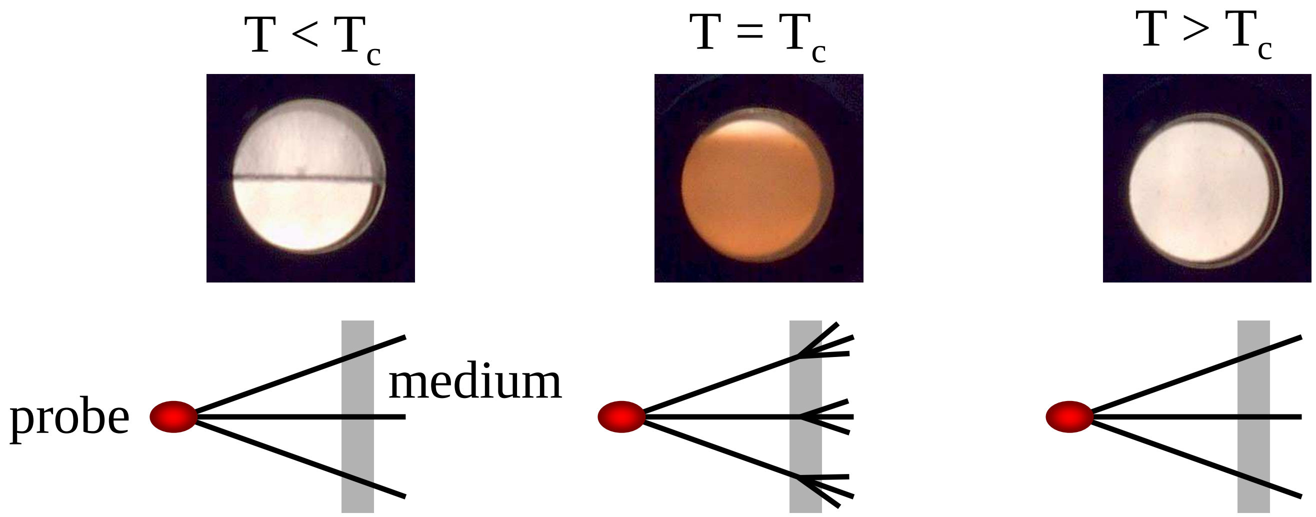
parametric variation of global variables: 'singularities'

parton probes may reveal structure, but *also* disturb the medium state

Observing Critical Phenomena

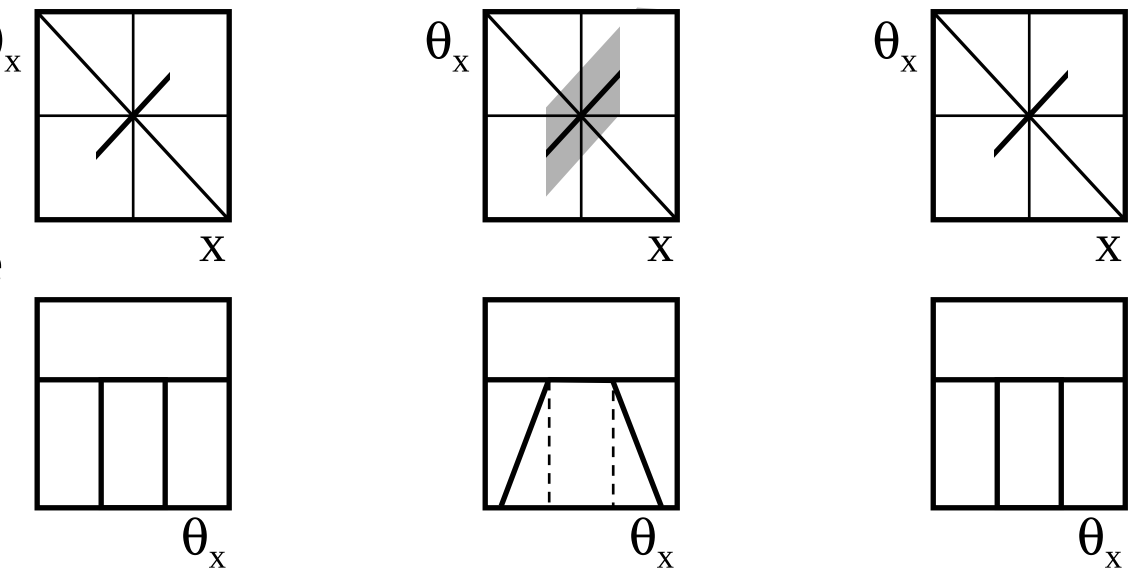
critical opalescence:
sodium hexafluoride

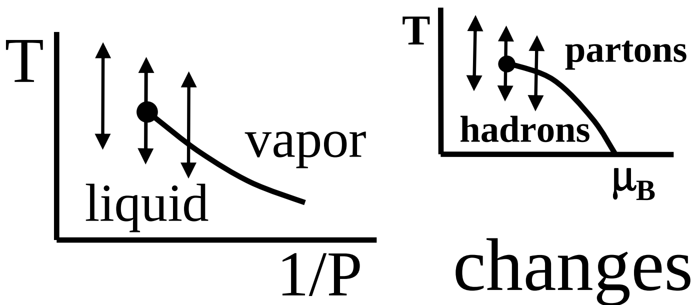
liquid-gas
critical point



At critical point:

- density acquires fractal structure (compare to NMF distributions)
- probe (light) scatters off structure





changes in probe-medium correlation structure

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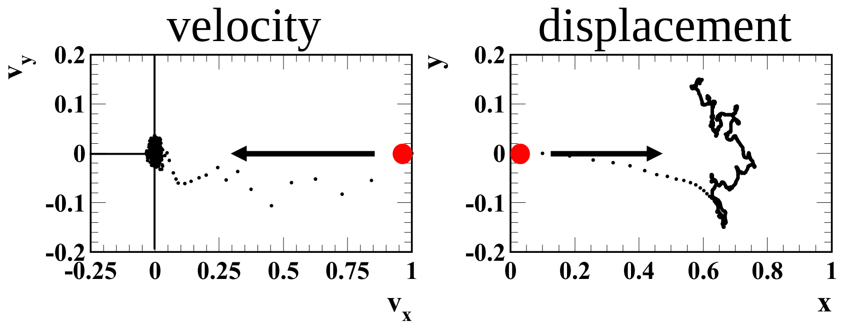
Thermalization

dissipation of probe motion in 2D

Langevin equation:

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

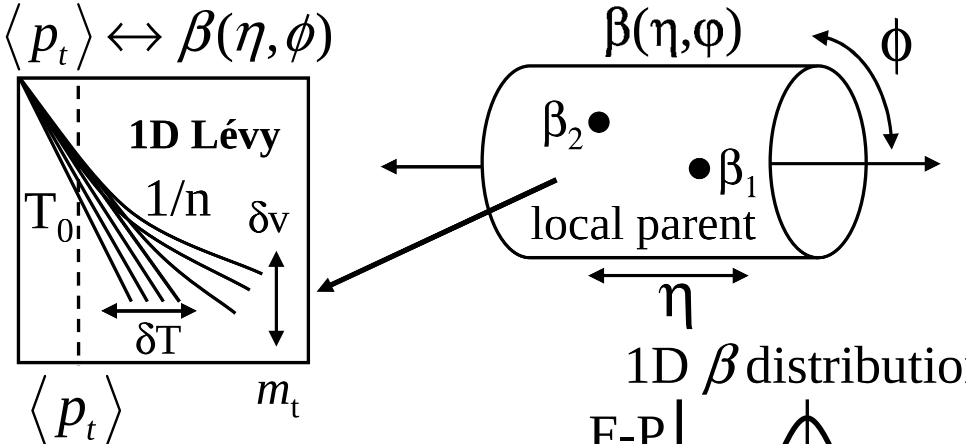
probe particle in dissipative medium



Brownian motion

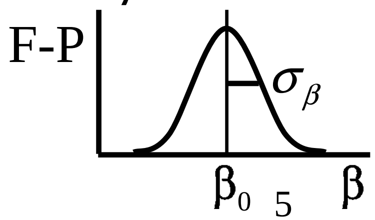
- point mass *vs* minimum-bias parton distribution
- $\beta(\eta,\phi)$: velocity/temperature structure of color medium

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



Lévy distribution: $A/(1+\beta_0\, m_t/n)^n$

1D β distribution



$$\delta\beta/\beta_0 \Rightarrow \delta T/T_0,\ \delta v/v_0 \longleftrightarrow 1/n \equiv \sigma_\beta^2/\beta_0^2$$

Minijet Dissipation

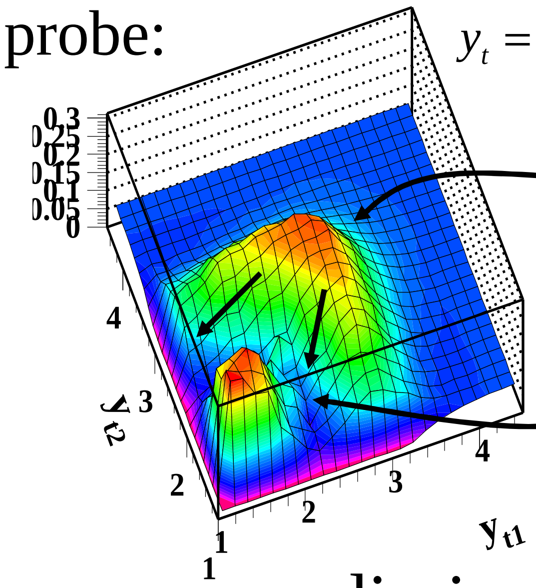
R_{AA} by other means

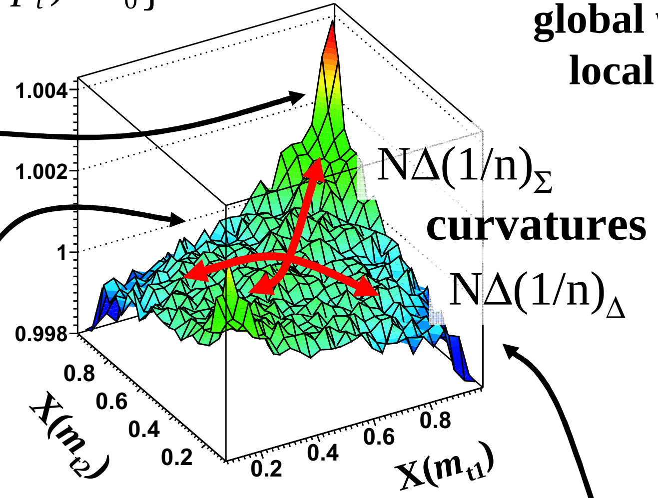
p-p minijets probe:

$y_t = \ln\{(m_t + p_t)/m_0\}$

Au-Au

global *vs* local





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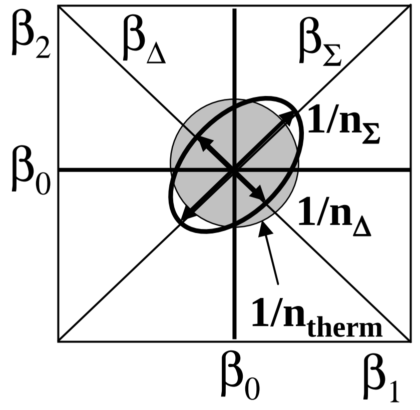
dissipation: transport on y_t

2D β distribution



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

$\langle p_t \rangle$ fluctuations:

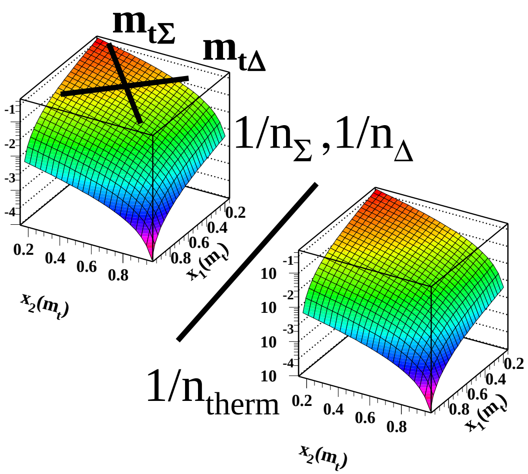
$\Delta\sigma^2_{p_t:n} \propto N(1/n)_\Sigma - N(1/n)_\Delta$

2D Lévy: sibling/mixed pair ratio

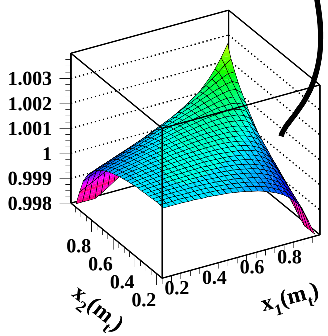
1D: $A/(1+\beta_0\, m_t/n)^n$

2D:

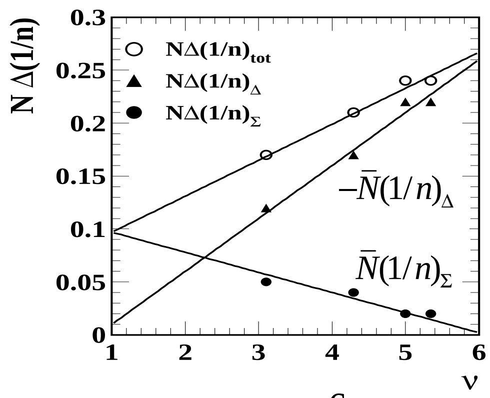
$$\frac{\left[1+\frac{\beta_0 m_\Sigma}{2n}\right]^{2n}\left[1-\frac{\beta_0 m_\Delta}{2n+\beta_0 m_\Sigma}\right]^{n}}{\left[1+\frac{\beta_0 m_\Sigma}{2n_\Sigma}\right]^{2n_\Sigma}\left[1-\frac{\beta_0 m_\Delta}{2n_\Sigma+\beta_0 m_\Sigma}\right]^{n_\Delta}} =$$



Lévy saddle



saddle curvatures



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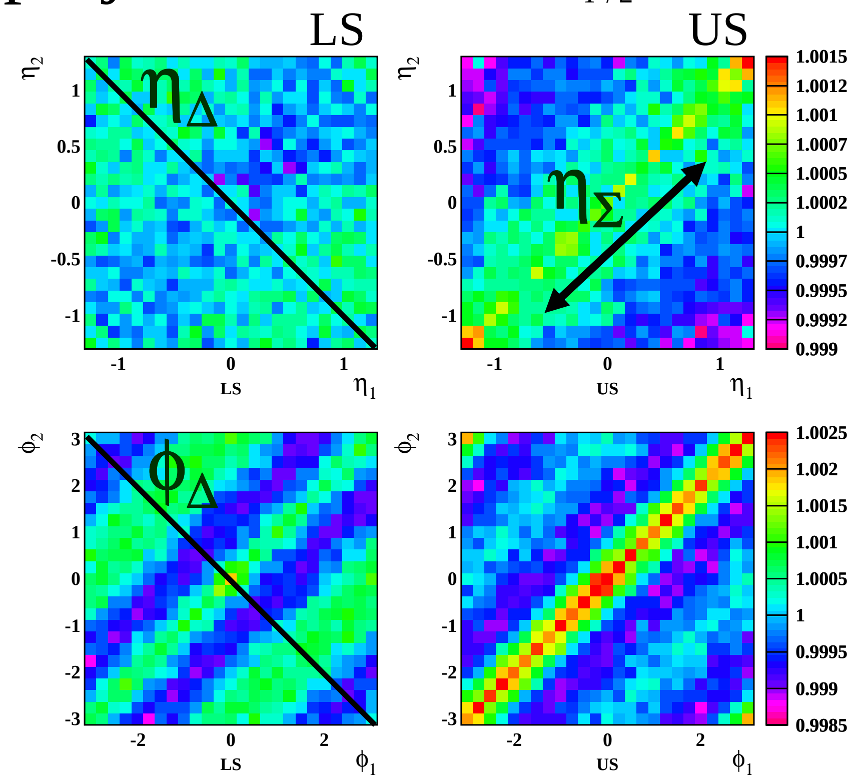
Joint Autocorrelations on $\eta \otimes \phi$

lossless projection

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

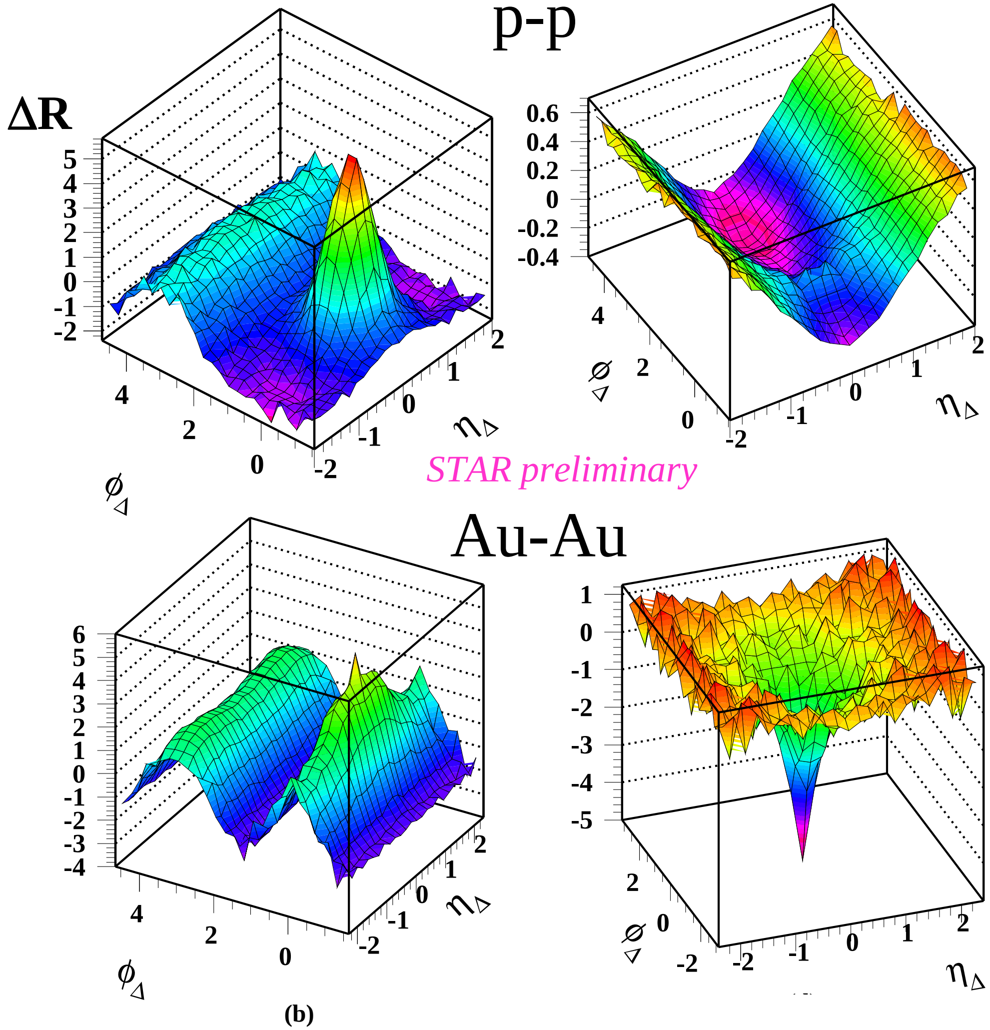


isoscalar

CI = LS + US

isovector

CD = LS – US



correlations on (x_1, x_2)

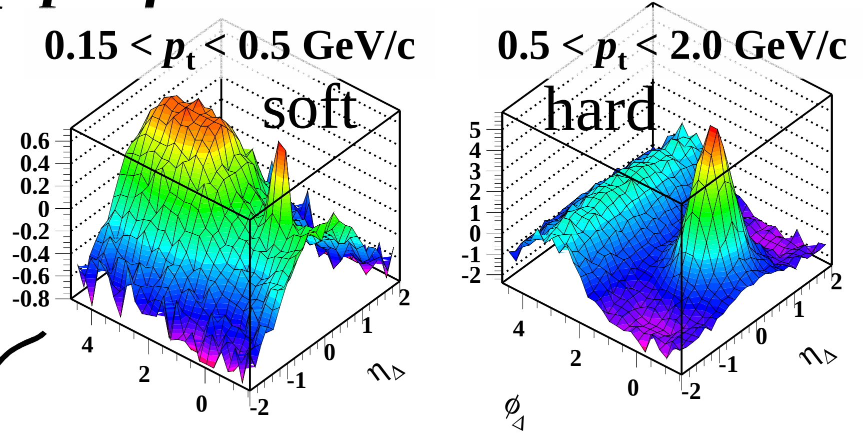
invariant on x_Σ ('stationary')

all structure retained on x_Δ

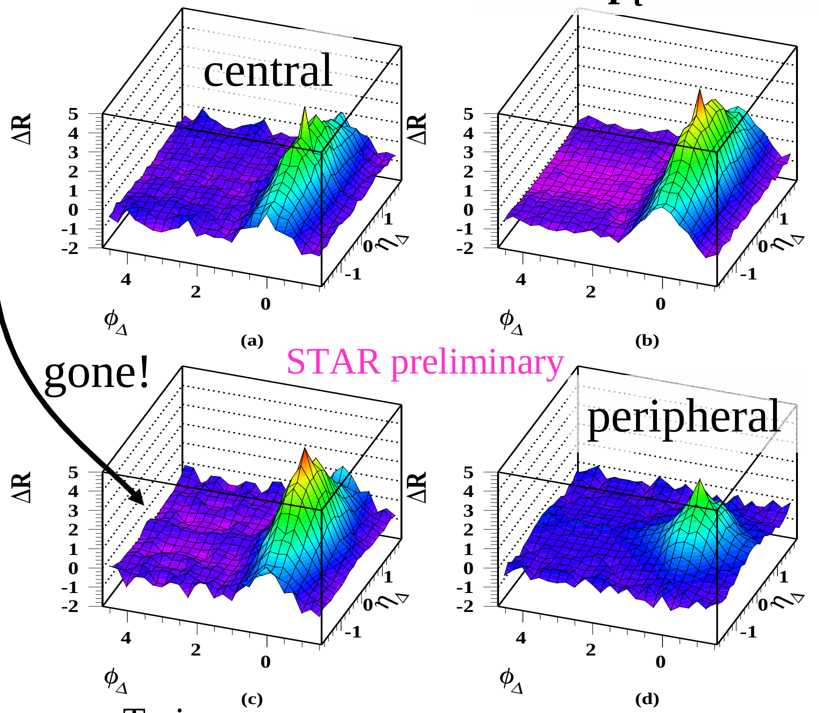
→ *autocorrelations* on x_Δ

Number Correlations on $\eta\otimes\phi$

p-p reference



Au-Au collisions **0.15 < p_t < 2.0 GeV/c**



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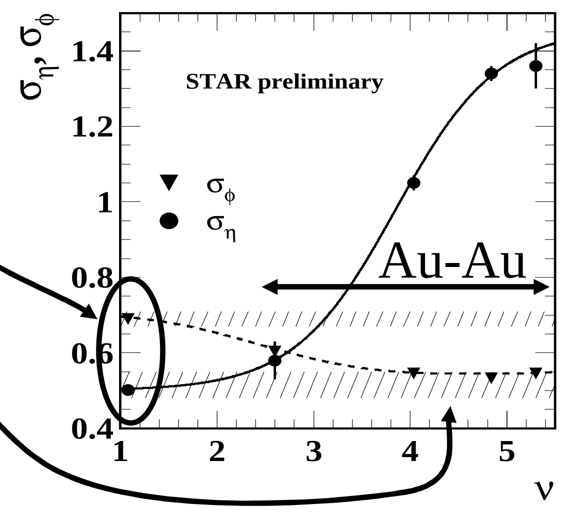
isoscalar angular correlations:
in-medium probe modifications

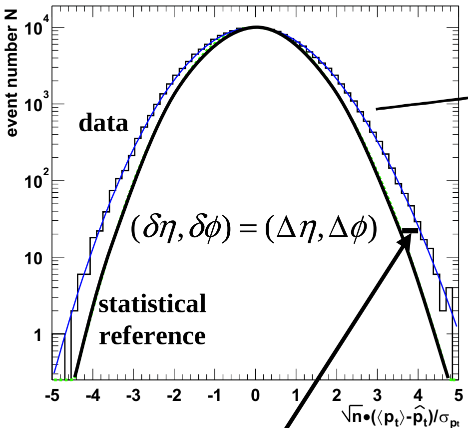
- elongation on η_Δ
- narrowing on ϕ_Δ

soft partons probe
color medium properties

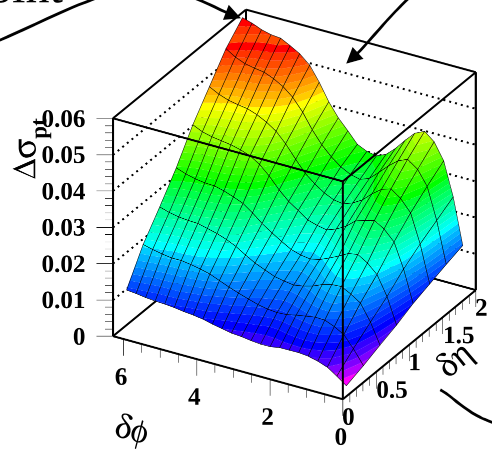
minijet peak widths



Fluctuations and Correlations

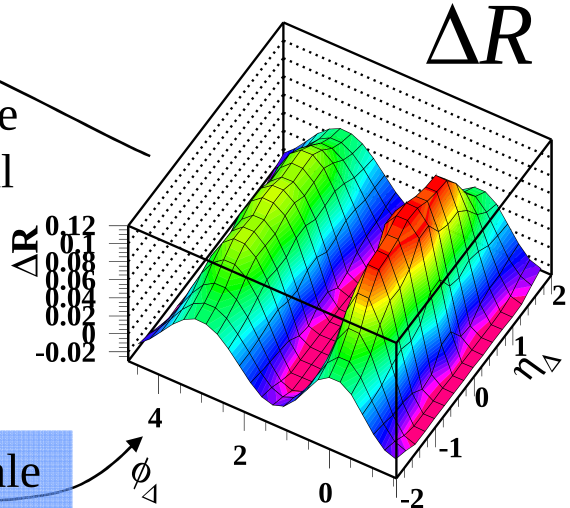


single point



2D scale integral

2D scale inversion



$\langle p_t \rangle$ fluctuation excess

fluctuation scale dependence

joint autocorrelation

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

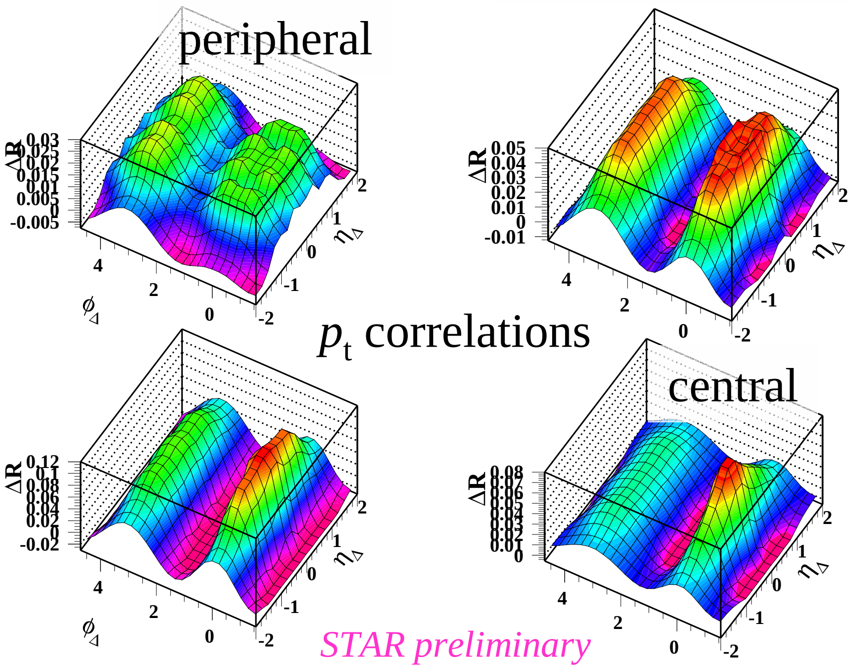
$$\Delta R \propto \overline{(p_t - n\hat{p}_t)_i \cdot (p_t - n\hat{p}_t)_j / \sqrt{n_i n_j}}$$

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

fluctuations ⇔ integral equation ⇔ correlations

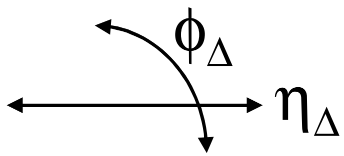
$\langle p_t \rangle$ Fluctuations $\rightarrow$ p_t Correlations

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

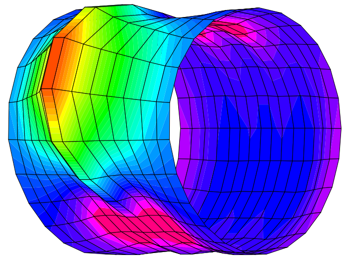


minijet dissipation &
velocity/temperature structure:

- elongation on η_Δ
- necking on ϕ_Δ

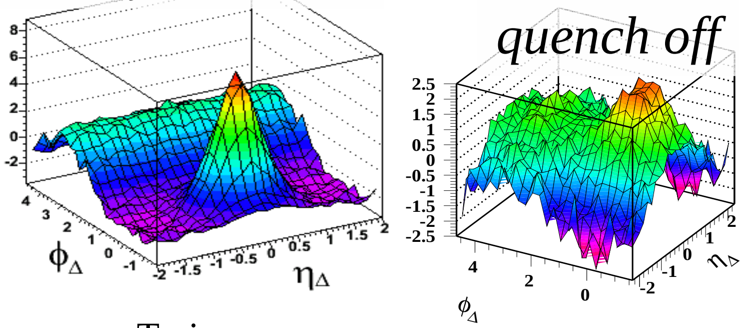


soft partons as
extended objects?



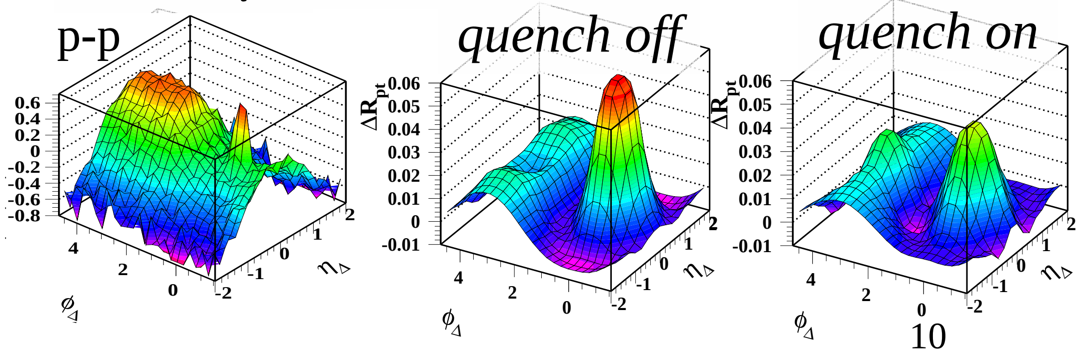
p-p minijets angular correlations

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



Hijing central Au-Au p_t correlations

$p_t \in$ 0.15-2 GeV/c



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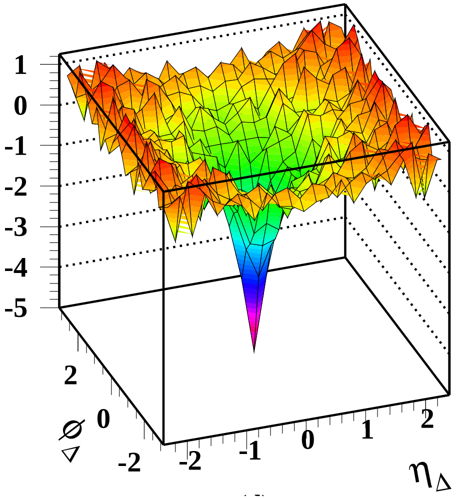
Hadronization

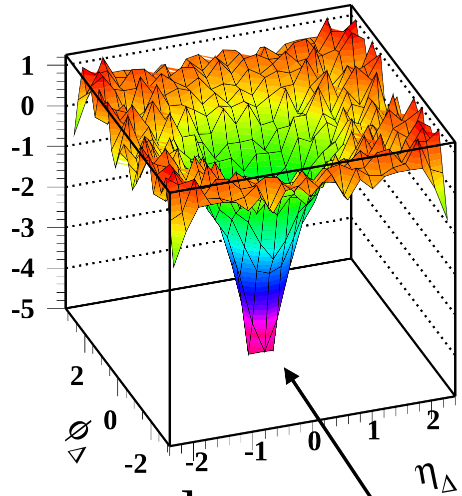
Au-Au 130 GeV

isovector angular correlations:
medium structure at decoupling

isospin antiferromagnet



mid-peripheral

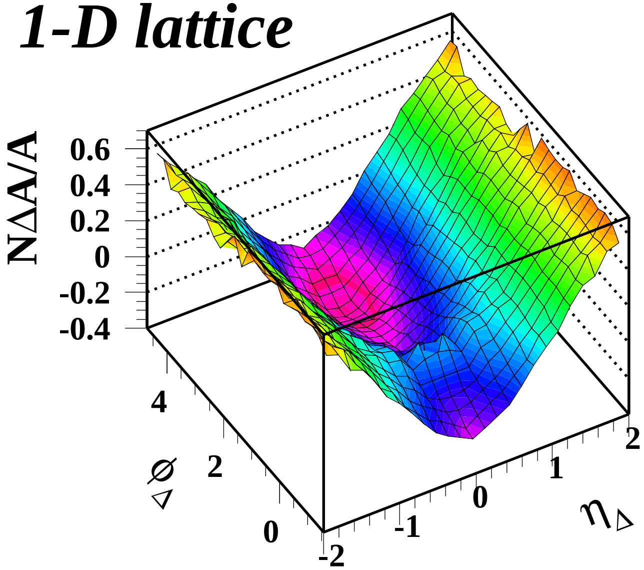


central

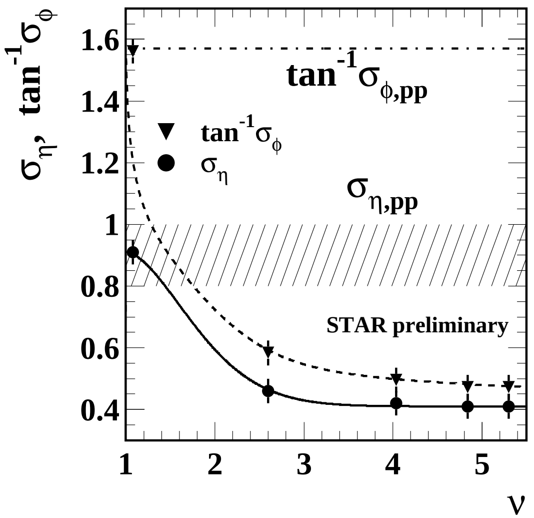
peak → -7.7

200 GeV Pythia ~ data

1-D lattice



true correlation lengths



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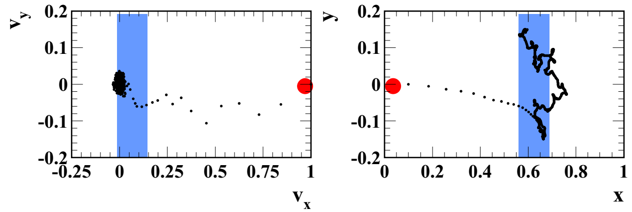
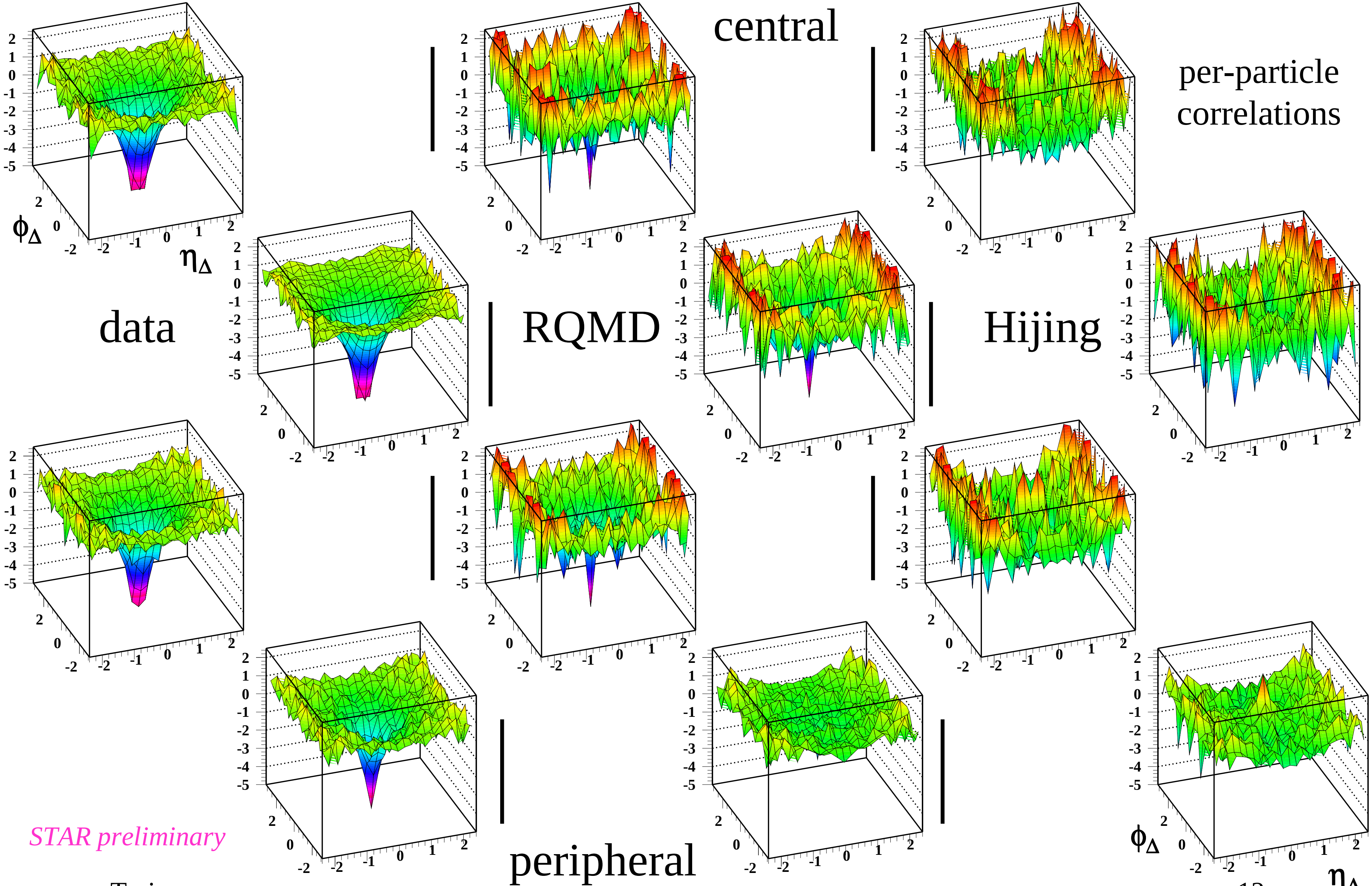
2-D lattice



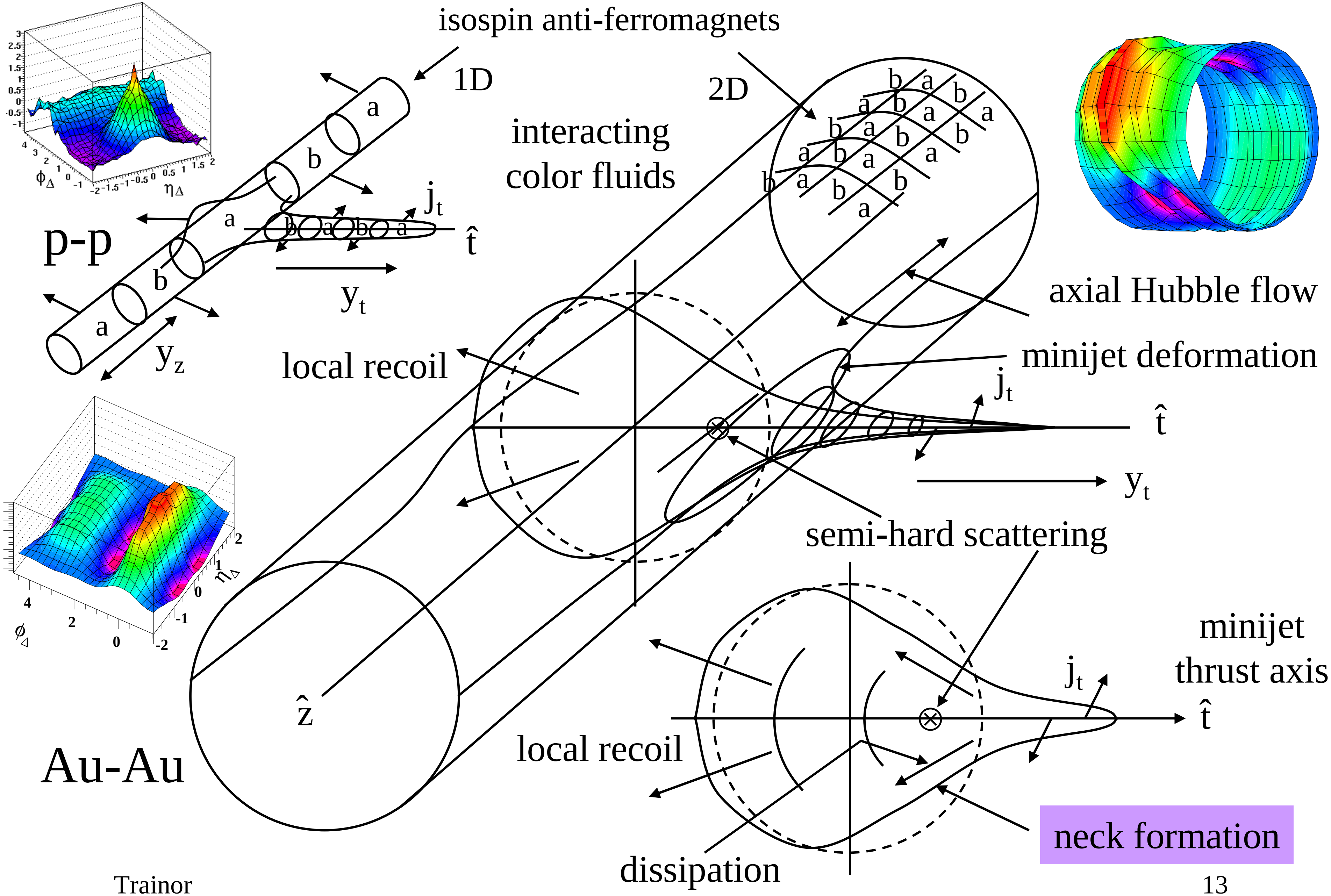
changing geometry
of hadronization

compare to NMF

Comparing Data with Models



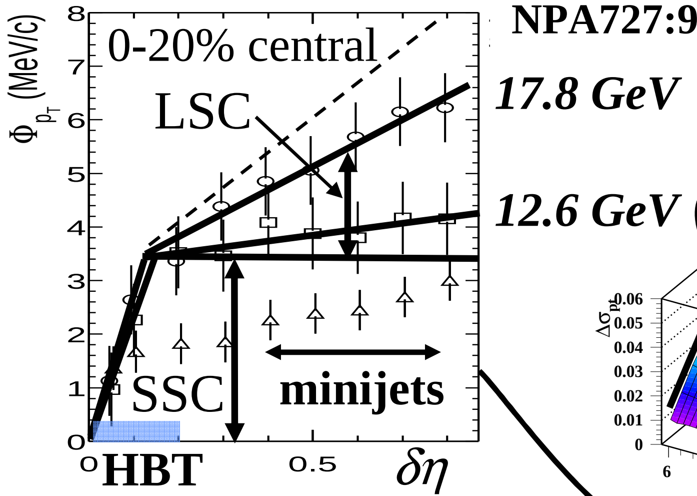
RHIC Au-Au Collision Model



SPS $\leftrightarrow$ RHIC

$$\Delta\sigma^2_{p_t:n}(m,n) = 4\hat{p}^2 \sum_{k=1}^{m} \varepsilon_\eta \sum_{l=1}^{n} \varepsilon_\phi K_{kl}^{mn} \Delta R_{kl}$$

CERES
NPA727:97, 2003



$\Phi_{p_t} \approx \Delta\sigma_{p_t:n} \quad \delta\phi \to 2\pi$

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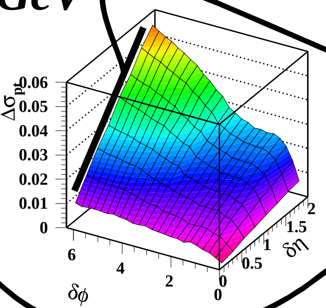
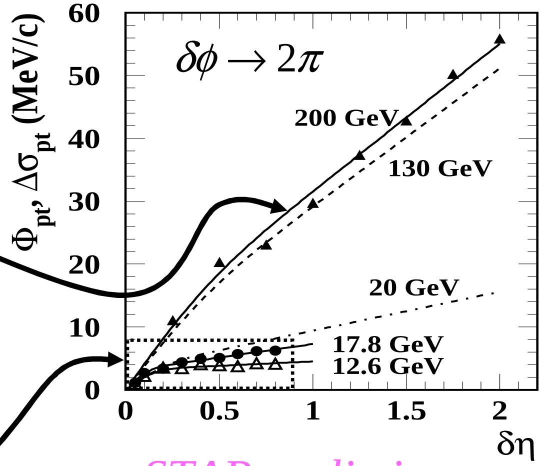


$\langle p_t \rangle$ fluctuations



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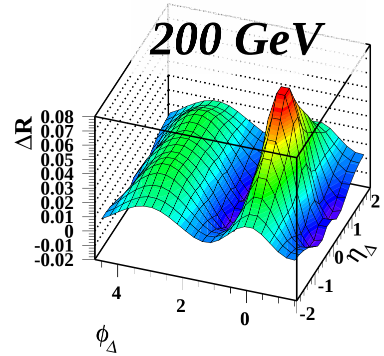

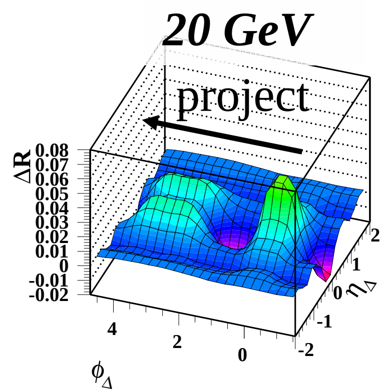

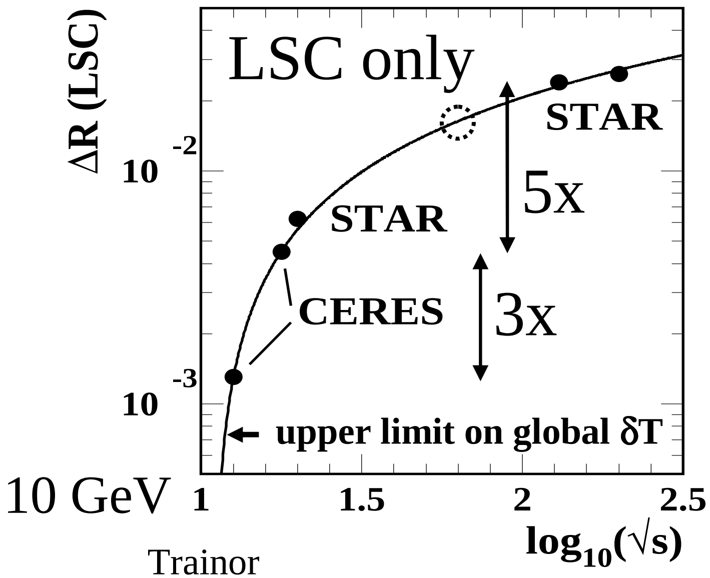

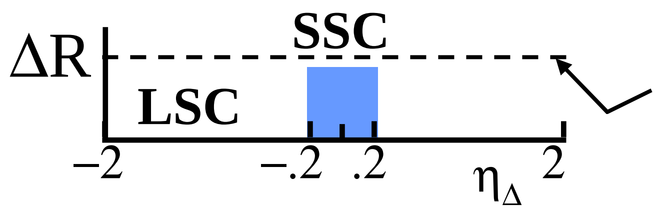

global δT: ruled out at low $\sqrt{s_{NN}}$

- SSC – *soft* physics (and minijets)
- LSC – minijets (and *global* δT)

dramatic increase in LSC with increasing $\sqrt{s_{NN}}$

Conclusions

- Critical phenomena $\Leftrightarrow$ large-scale correlations
- Medium structure studied directly and *via* probes
- RHIC collisions are highly structured: probe-medium interactions and 2D charge ordering
- Strong energy dependence of isoscalar structure
- Probe-medium interactions may reveal QCD critical point at some intermediate collision energy