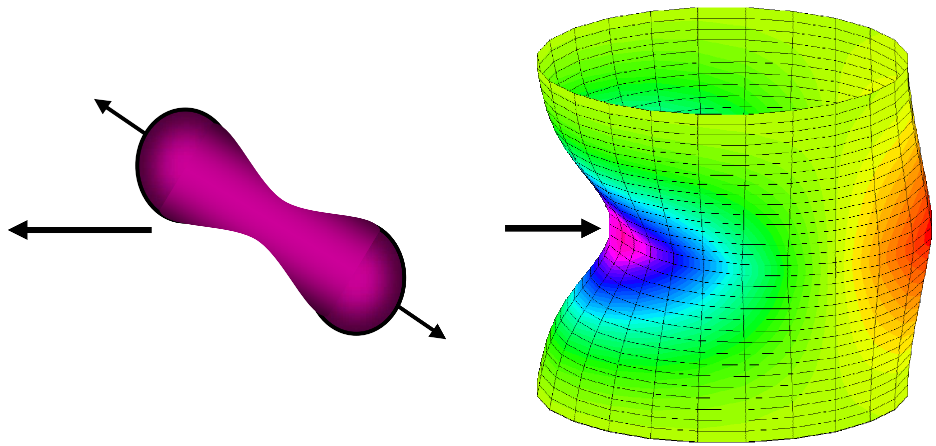


Low-Q^2 Partons in p-p and Au-Au Collisions

Tom Trainor

ISMD 2005 – *Kroměříž, CR*

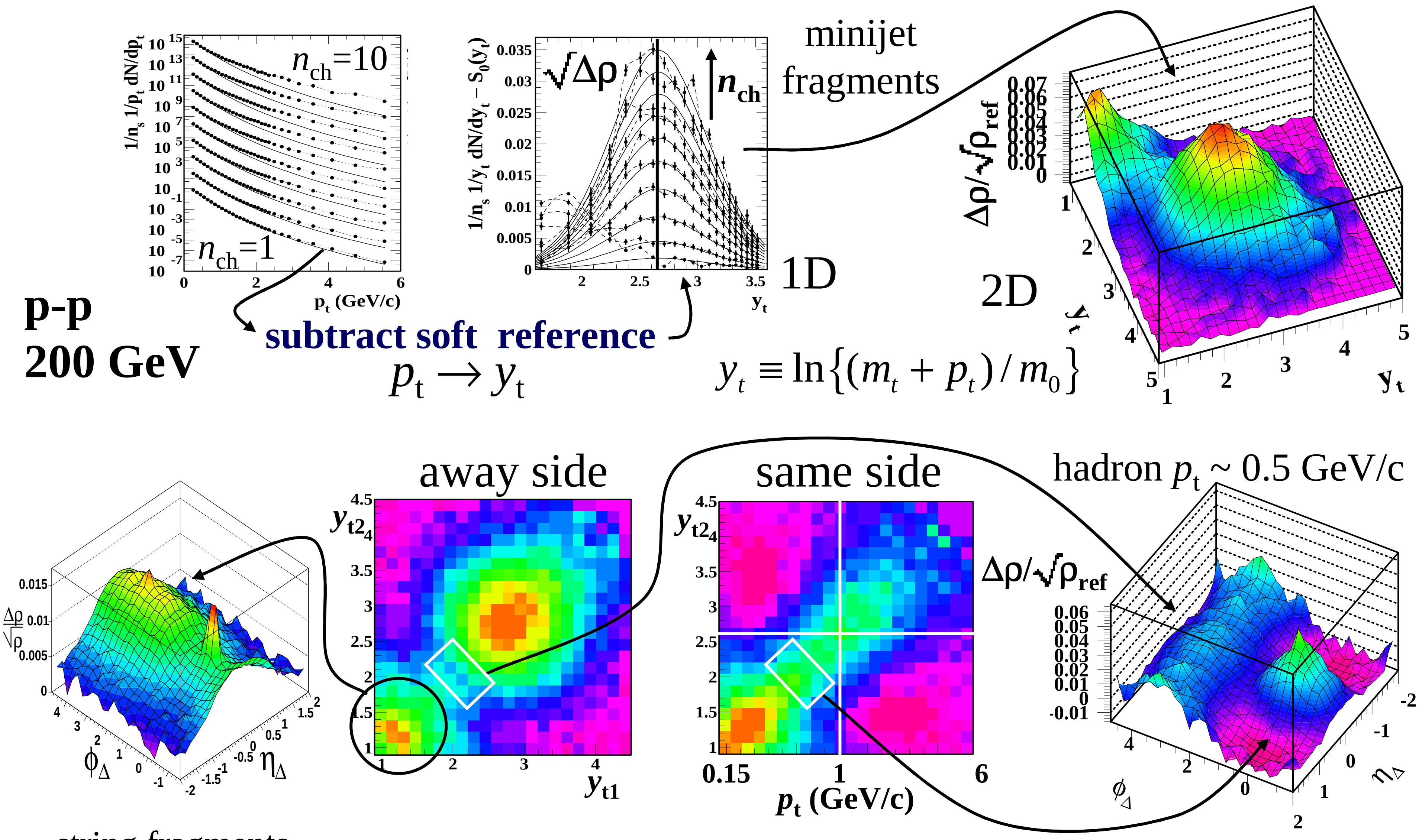
August, 2005

Agenda

- Survey of p-p correlations
- Fragment distributions on (y_t, y_t) in p-p
- Fragment distributions in Au-Au
- Angular correlations on $(\eta_\Delta, \phi_\Delta)$ in p-p
- Angular correlations in Au-Au
- p_t correlations in p-p and Au-Au

QCD from the bottom up

Low-Q^2 Partons in p-p Collisions



minimum-bias: no trigger condition

Analysis Method

(y_{t1},y_{t2}) correlations

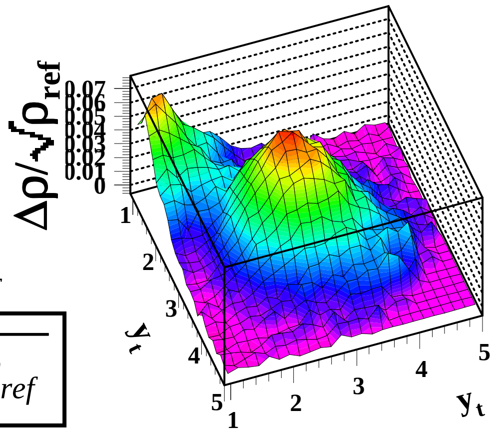
(y_t,η,ϕ)

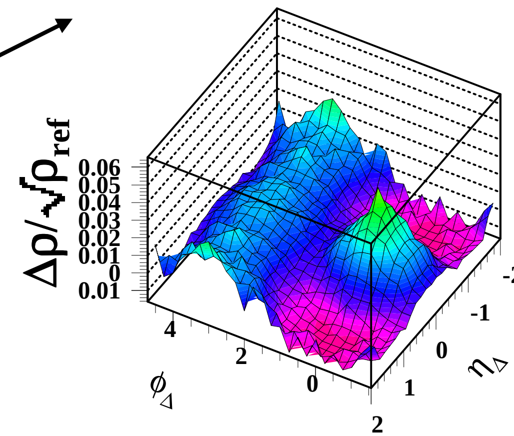
$(\eta_1,\eta_2,\phi_1,\phi_2)$ correlations

$\Delta\rho$

$\Delta\rho/\rho_{ref}$

$\Delta\rho/\sqrt{\rho_{ref}}$





$\eta_\Delta=\eta_1-\eta_2$

$\phi_\Delta=\phi_1-\phi_2$

joint autocorrelation on two difference variables

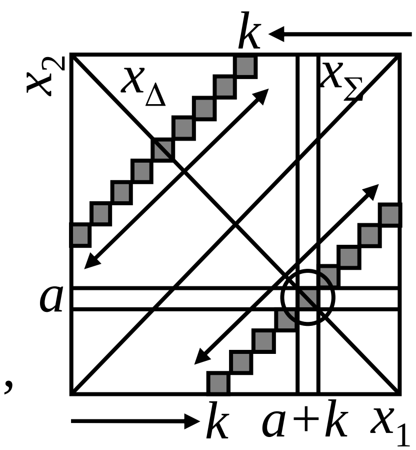
in each 2D bin:

$$\Delta\rho/\sqrt{\rho_{ref}}\,\Big|_{ab} \equiv \frac{\overline{(n-\bar{n})_a(n-\bar{n})_b}}{\varepsilon\sqrt{\bar{n}_a\bar{n}_b}}$$

ε – bin size

modified Pearson's coefficient: normalized covariance density

number of correlated pairs 'per particle'

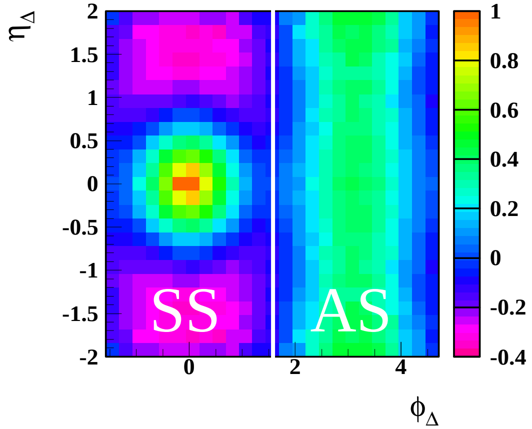


$$\frac{\Delta A_k(n)}{\sqrt{A_{k,ref}(n)}} \equiv \left\{\frac{\overline{(n-\bar{n})_a(n-\bar{n})_{a+k}}}{\sqrt{\bar{n}_a\bar{n}_{a+k}}}\right\}_{\bar{a}}$$

average over a on k^th diagonal

$$\frac{\Delta\rho(n;k\varepsilon_{x_\Delta})}{\sqrt{\rho_{ref}(n;k\varepsilon_{x_\Delta})}} \equiv \frac{\Delta A_k(n)}{\varepsilon_{x_\Delta}\sqrt{A_{k,ref}(n)}}$$

autocorrelations can be determined by pair counting or by inversion of fluctuation scale dependence

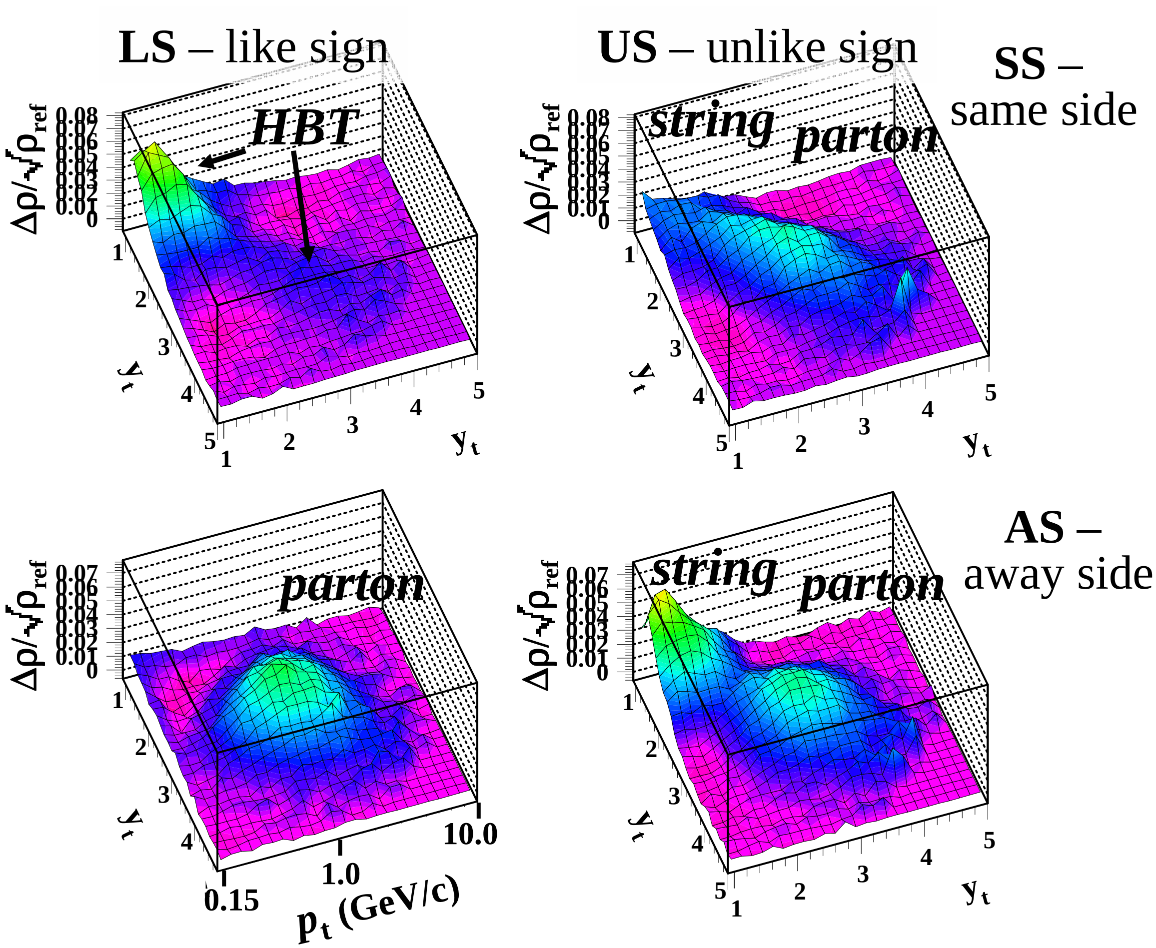


p-p Correlations on (y_{t1},y_{t2})

string and parton fragmentation:

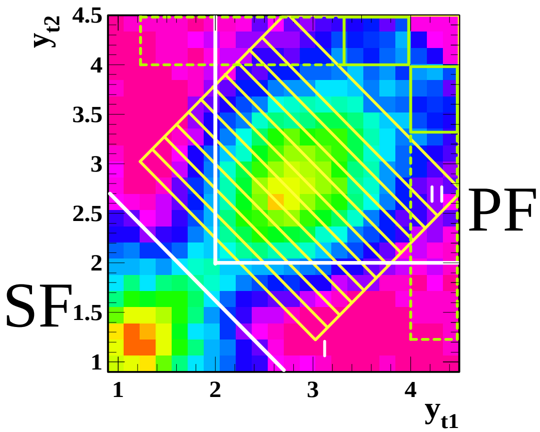
first two-particle *fragment distributions*

(except OPAL on ξ)



same-side parton fragmentation restricted to US pairs

away-side parton fragmentation is independent of charge combination

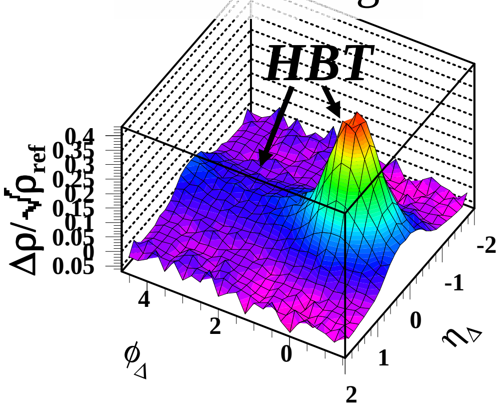


p-p Correlations on $(\eta_\Delta,\phi_\Delta)$

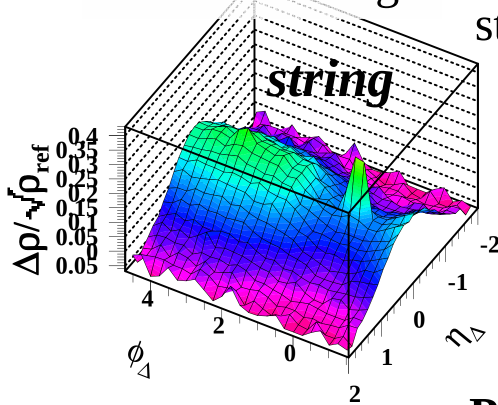
local charge and momentum conservation

joint autocorrelation on two difference variables

LS – like sign

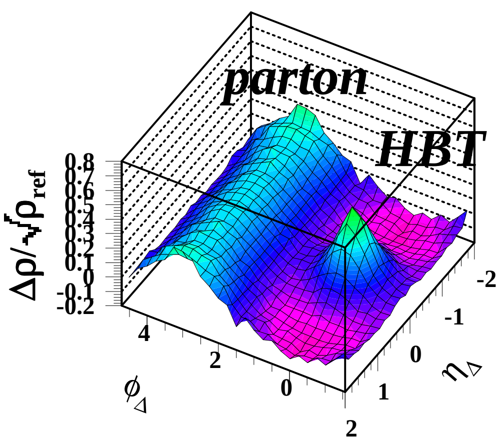


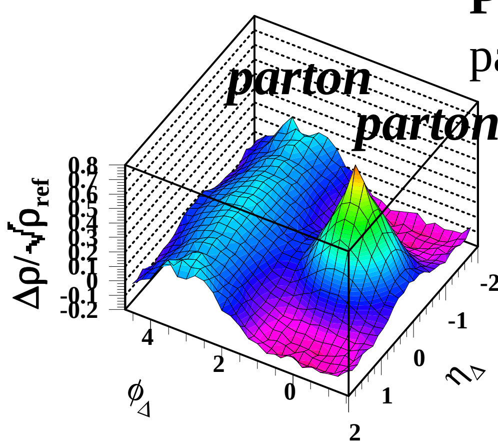
US – unlike sign



SF –
string fragments

string fragmentation reflects local measure conservation





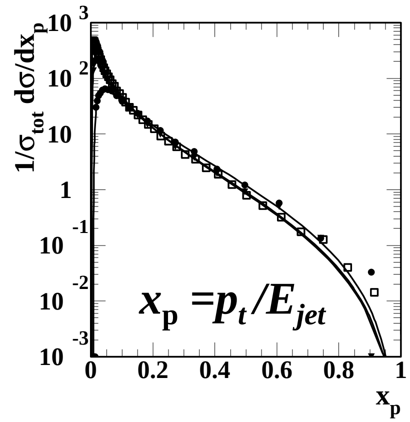
PF –
parton fragments

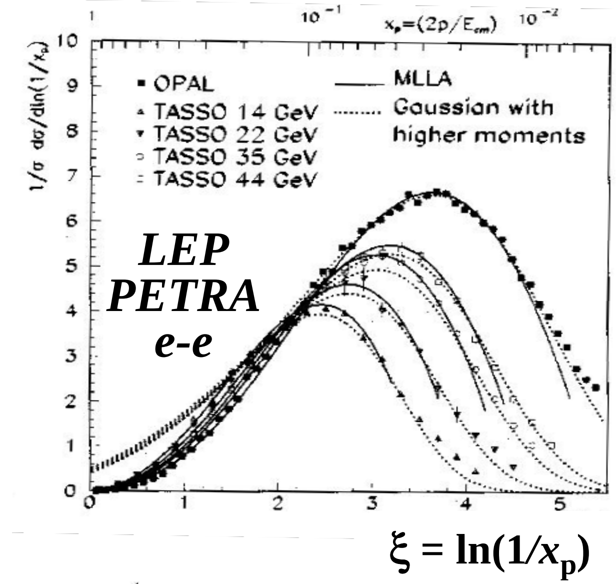
away-side parton fragmentation is independent of charge combination

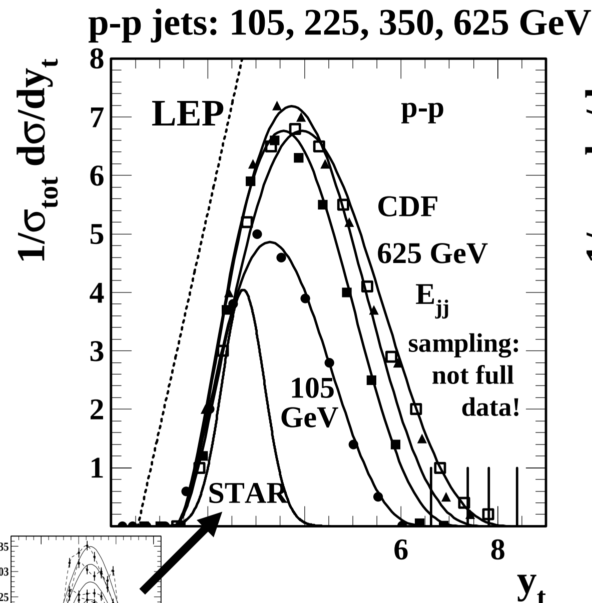
Single-particle Fragmentation – I

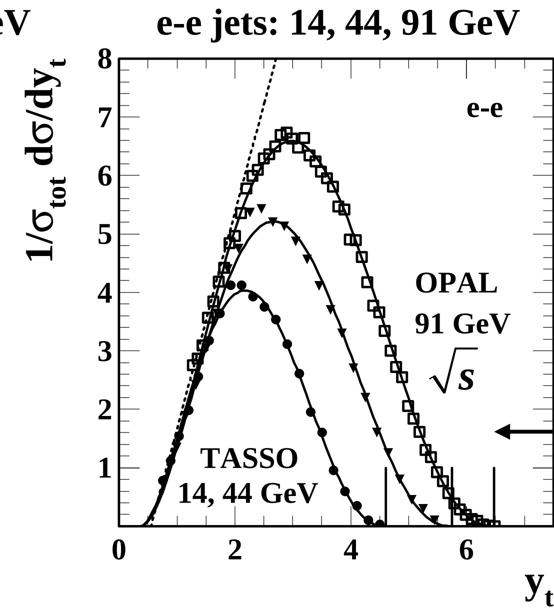
fragmentation functions on logarithmic variables

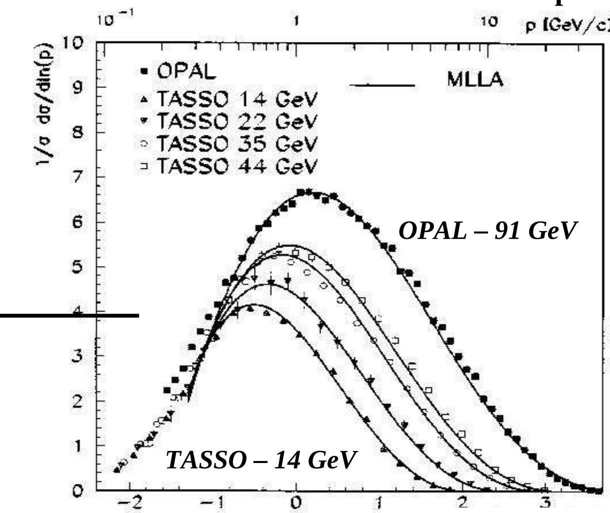
e-e fragmentation functions on transverse rapidity y_t – systematic variation described by single model function

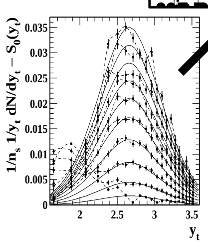












transverse rapidity y_t

$$y_t \equiv \ln\{(m_t + p_t)/m_\pi\}$$

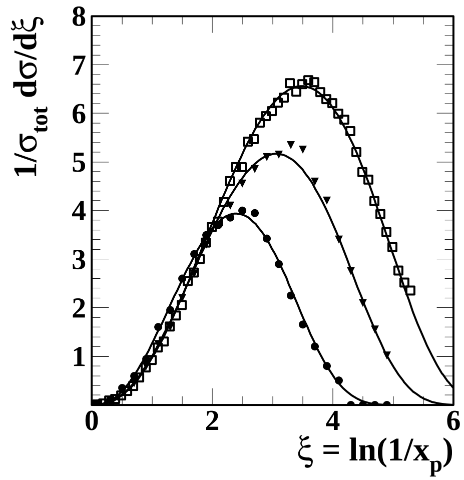
CDF PRD 68 (2003) 012003
OPAL PLB 247 (1990) 617
Biebel, Nason and Webber hep-ph/0109282 617

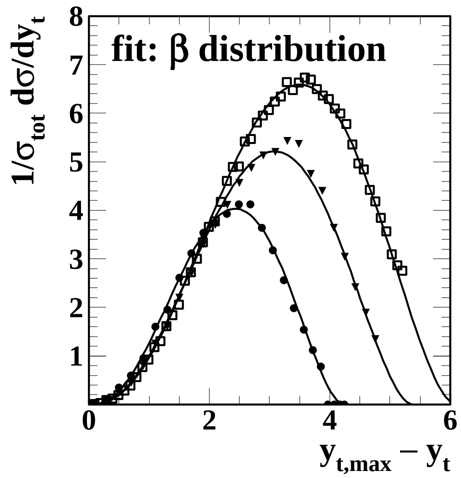
conventional $\ln(p_t)$

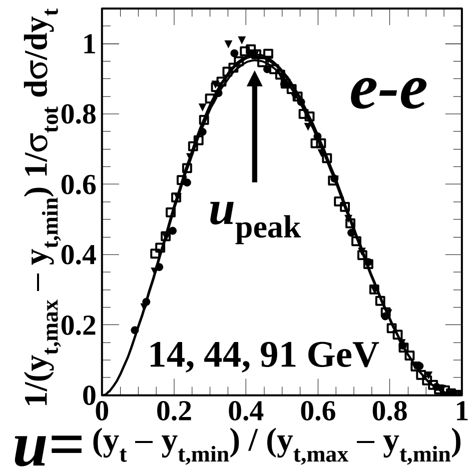
Single-particle Fragmentation – II

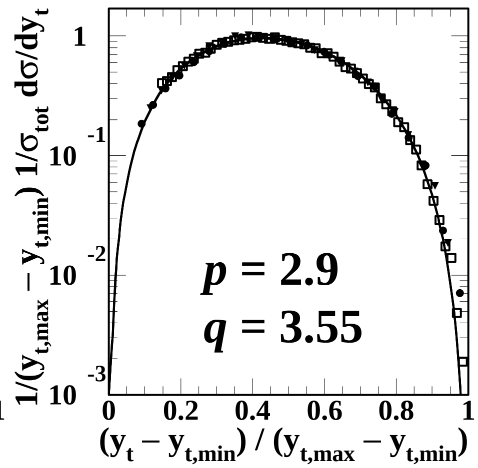
simple e-e systematics on transverse rapidity

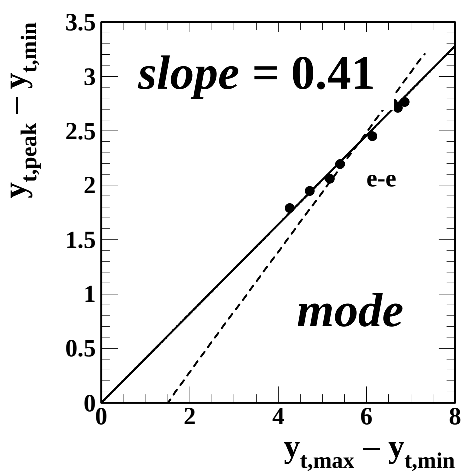
→ *two-particle fragment distribution*

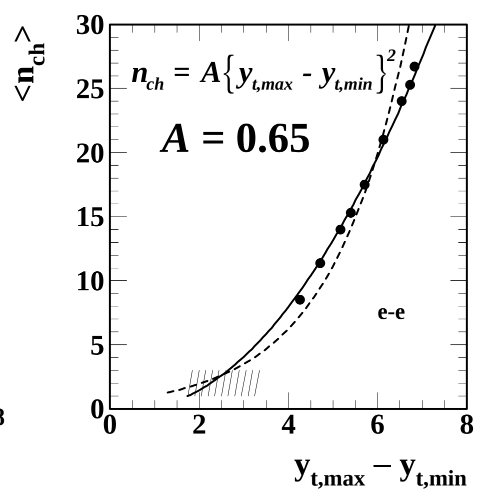












$$D_p^h(x,Q^2) \to F(y_{t,\max} \approx \ln Q^2)\, G(u \approx \ln x / \ln Q^2)$$

$\propto \{y_{t,max} - y_{t,min}\}$ ~ ***independent of*** $y_{t,\max}$

$$y_{t,\max} \equiv \ln\left\{(\sqrt{E_{jet}^2 + m_0^2} + E_{jet})/m_0\right\} \quad \text{e-e} \quad y_{t,\min} \approx 0.35$$

$$\beta(u; p,q) \equiv u^{p-1}(1-u)^{q-1} / B(p,q)$$

mode: $u_{peak} = \dfrac{p-1}{p+q-2} = 0.425$

$\langle n_{ch}\rangle$ and ξ_{peak} *values from Bethke hep-ex/9812026*

unidentified hadrons from unidentified partons

Two-particle Fragment Distributions

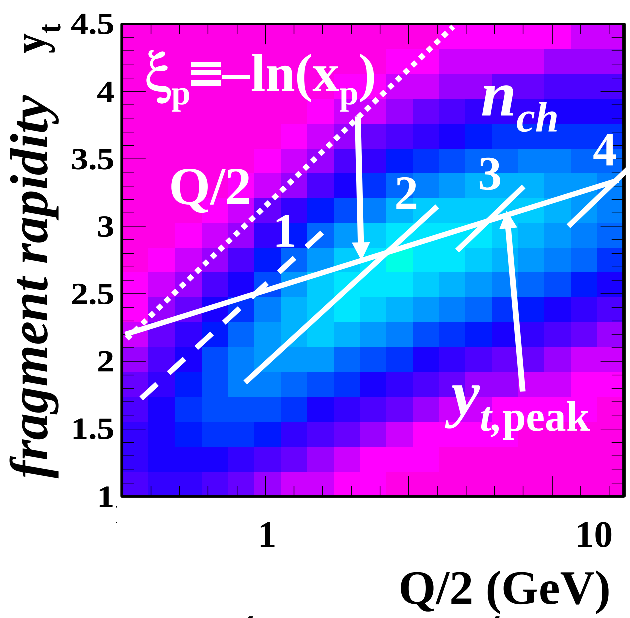
an approach derived from fragmentation functions

one can sketch a two-particle minimum-bias fragment distribution starting with a surface from which fragmentation functions are conditional slices

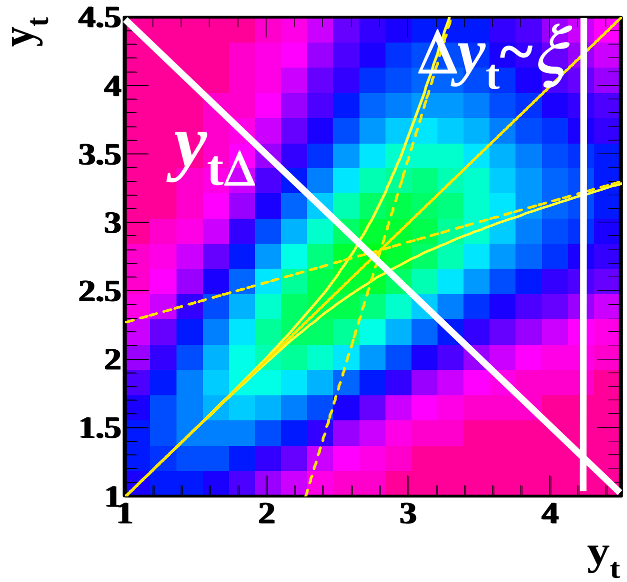
construct a surface representing frag-mentation functions vs parton momentum Q/2

symmetrize the surface to represent fragment-fragment correlations

compare to data: general features agree; string fragments appear at small y_t

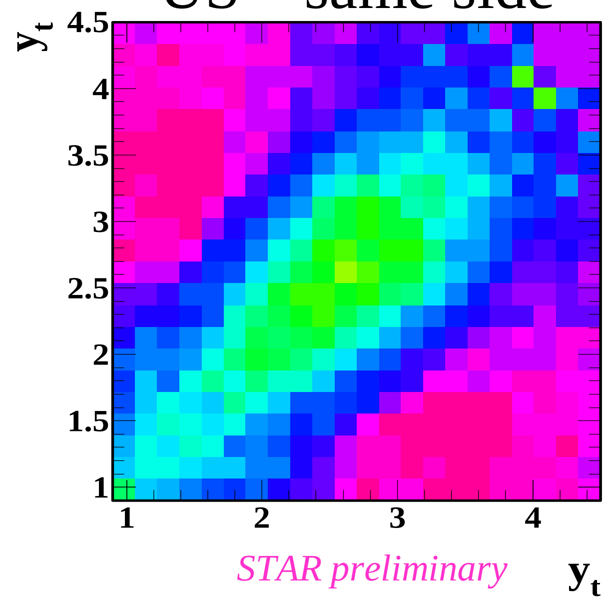


parton momentum



conditional: trigger particle

US – same side



data

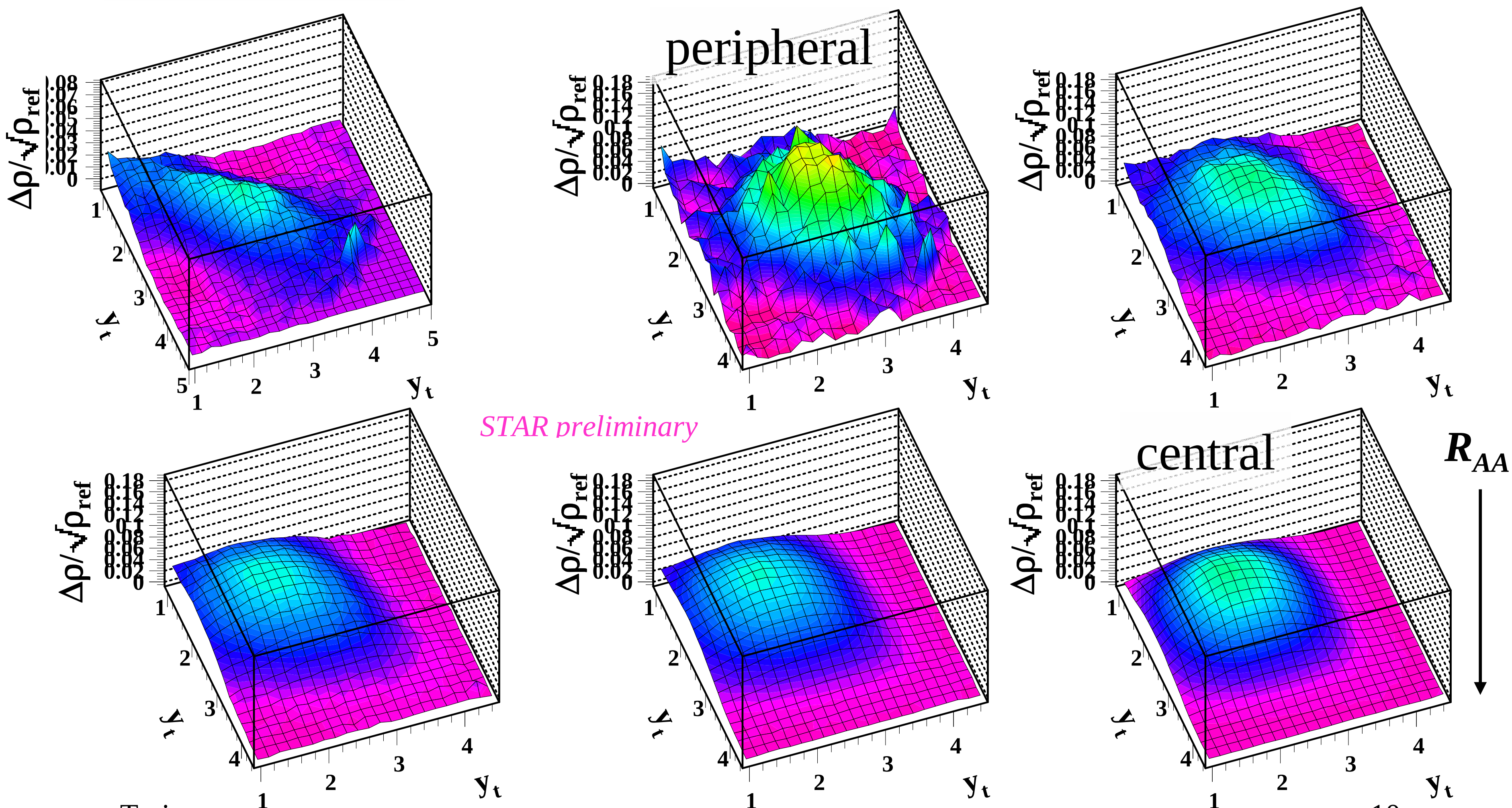
Number Correlations on $y_t \otimes y_t$

evolution of fragment distribution with Au-Au centrality

200 GeV p-p

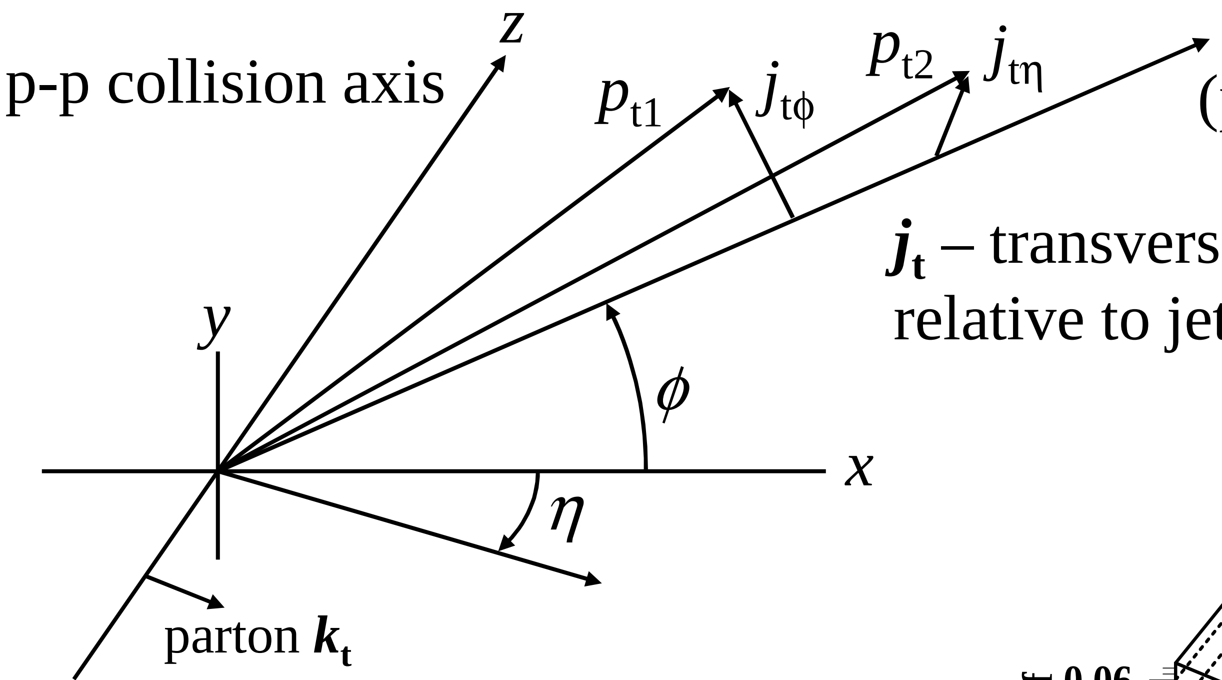
200 GeV Au-Au

same-side - US

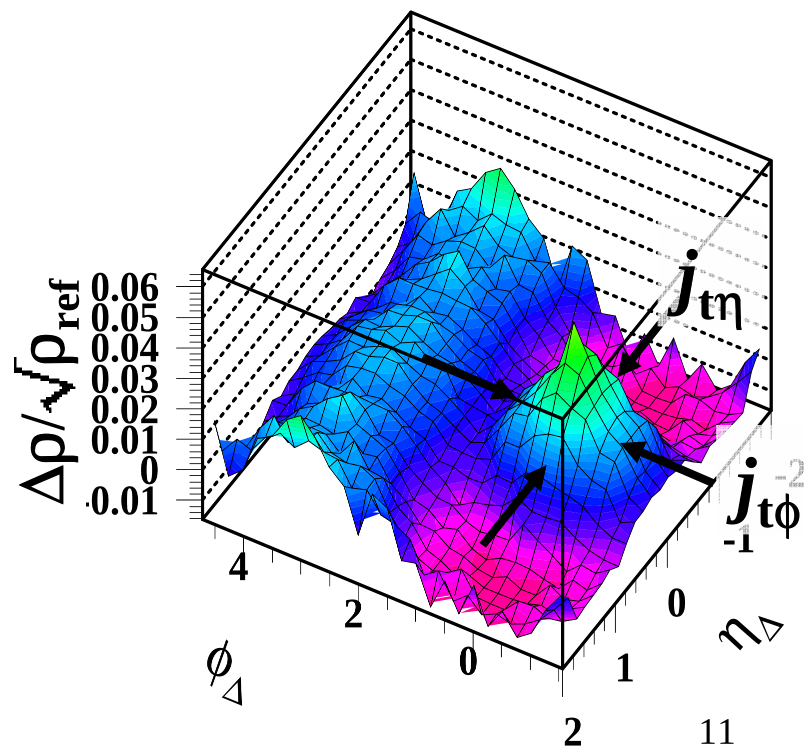


Jet Morphology Relative to Thrust

angular correlations



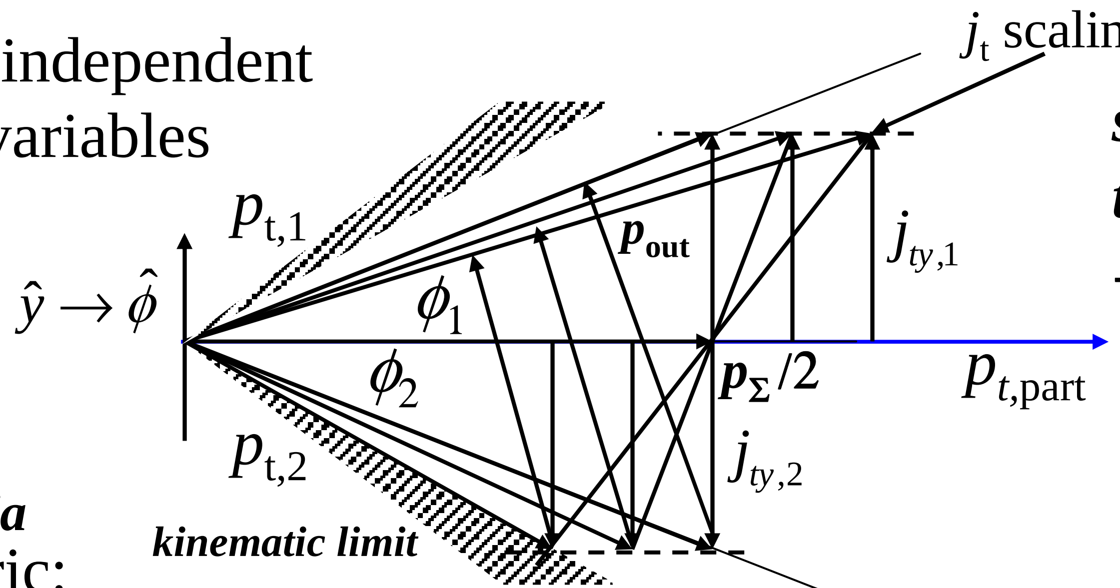
most-probable parton $Q/2$ at right is 1-2 GeV/c, *comparable* to the intrinsic parton k_t



Symmetrized Angular Kinematics

remove trigger-associated asymmetry

$p_{t1,2}$, $\phi_{1,2}$ independent random variables



***symmetrize*:**
trigger, associated
→ particles 1, 2

J. Rak, J. Jia
asymmetric:

$$\langle p_{out}^2 \rangle = \langle p_{t,assoc}^2 \rangle_{SS} \langle \sin^2 \phi_{ta} \rangle_{SS} = \langle j_{ty,assoc}^2 \rangle_{SS} + \langle x_{at}^2 \rangle \langle j_{ty,trig}^2 \rangle \left(1 - 2 \langle j_{ty,assoc}^2 \rangle_{SS} / \langle p_{t,assoc}^2 \rangle_{SS}\right)$$

T. Trainor, J. Porter
symmetric: ***remove the trigger/associated asymmetry***

$$\hat{y} \to \hat{\phi},\ \hat{j}$$

$$\sqrt{\frac{\langle p_{t,2}^2 \rangle}{\langle p_{t,1}^2 \rangle}} \langle j_{t\phi,1}^2 \rangle + \sqrt{\frac{\langle p_{t,1}^2 \rangle}{\langle p_{t,2}^2 \rangle}} \langle j_{t\phi,2}^2 \rangle = \sqrt{\langle p_{t,1}^2 \rangle \langle p_{t,2}^2 \rangle} \left\{ \langle \sin^2 \phi_{12} \rangle_{SS} + 2 \langle \sin^2 \phi_1 \rangle \langle \sin^2 \phi_2 \rangle \right\}$$

Symmetrize $\langle | j_{t\phi} | \rangle$ and $\langle | k_{t\phi} | \rangle$

no small-angle approximation, similar fragment p_t

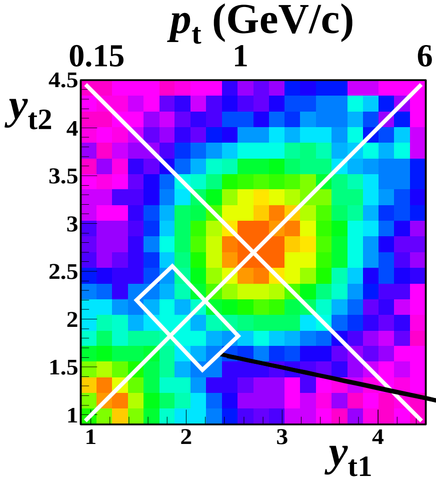
$$\overline{\left\langle j_{t\phi}^2 \right\rangle}_{12} = \frac{(m_\pi/2)^2 \exp\{y_{t\Sigma}\}}{2\cosh\{y_{t\Delta}\}} \left\{ \left\langle \sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{SS} + 2\left\langle \sin^2\left(\phi_\Delta/2\sqrt{2}\right)\right\rangle^2 \right\}$$

$$\left\langle \sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle \to \sin^2\left(\sigma_{\phi_\Delta}/\sqrt{\pi}\right)$$

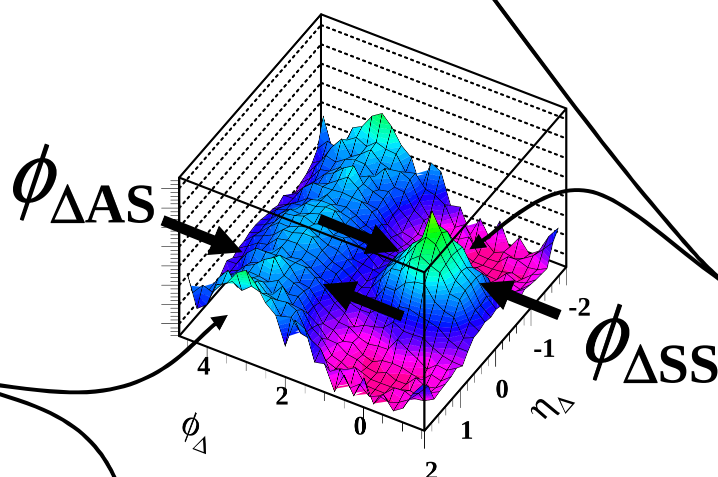
same for $\overline{\left\langle j_{t\eta}^2 \right\rangle}_{12}\left(y_{t\Sigma}, y_{t\Delta}\right)$

AS

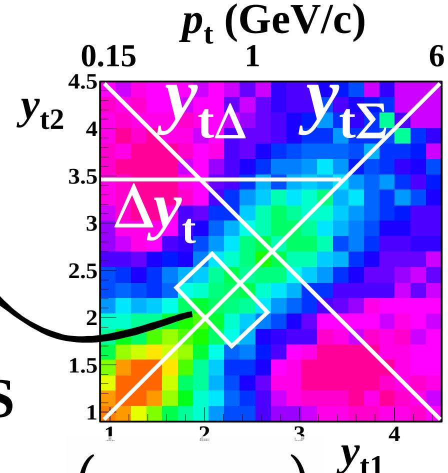
SS



autocorrelation $(\phi_\Delta = \phi_{12})$



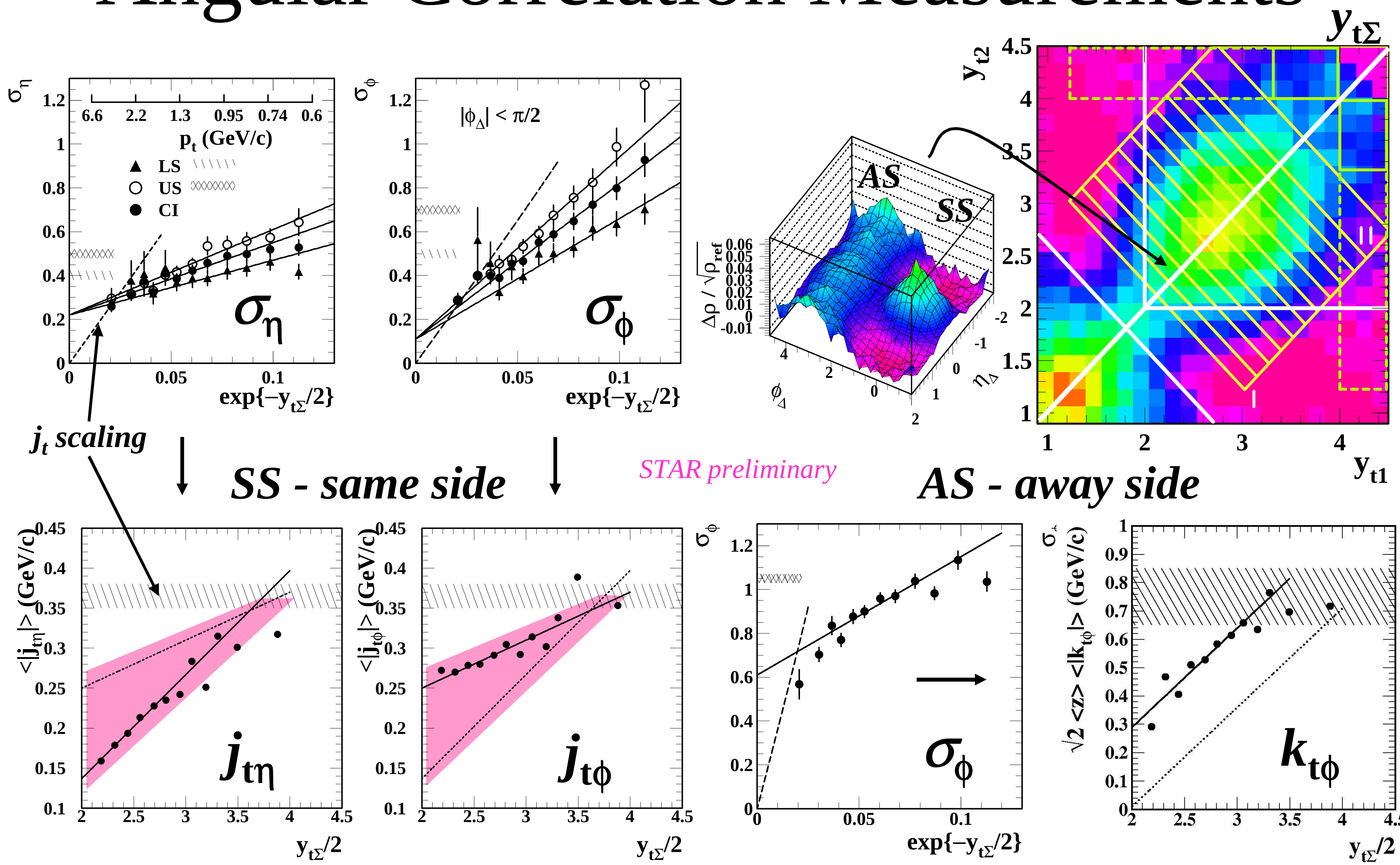
STAR preliminary



$\left(y_{t\Sigma}, y_{t\Delta}\right)$

$$\overline{\left\langle z^2 \right\rangle \left\langle k_{t\phi}^2 \right\rangle}_{12} = \frac{(m_\pi/2)^2 \exp\{y_{t\Sigma}\}}{2\cosh\{y_{t\Delta}\}} \frac{\left\{ \left\langle \sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{AS} - \left\langle \sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{SS} \right\}}{1 - 2\left\langle \sin^2\left(\phi_\Delta/\sqrt{2}\right)\right\rangle_{SS}}$$

Angular Correlation Measurements

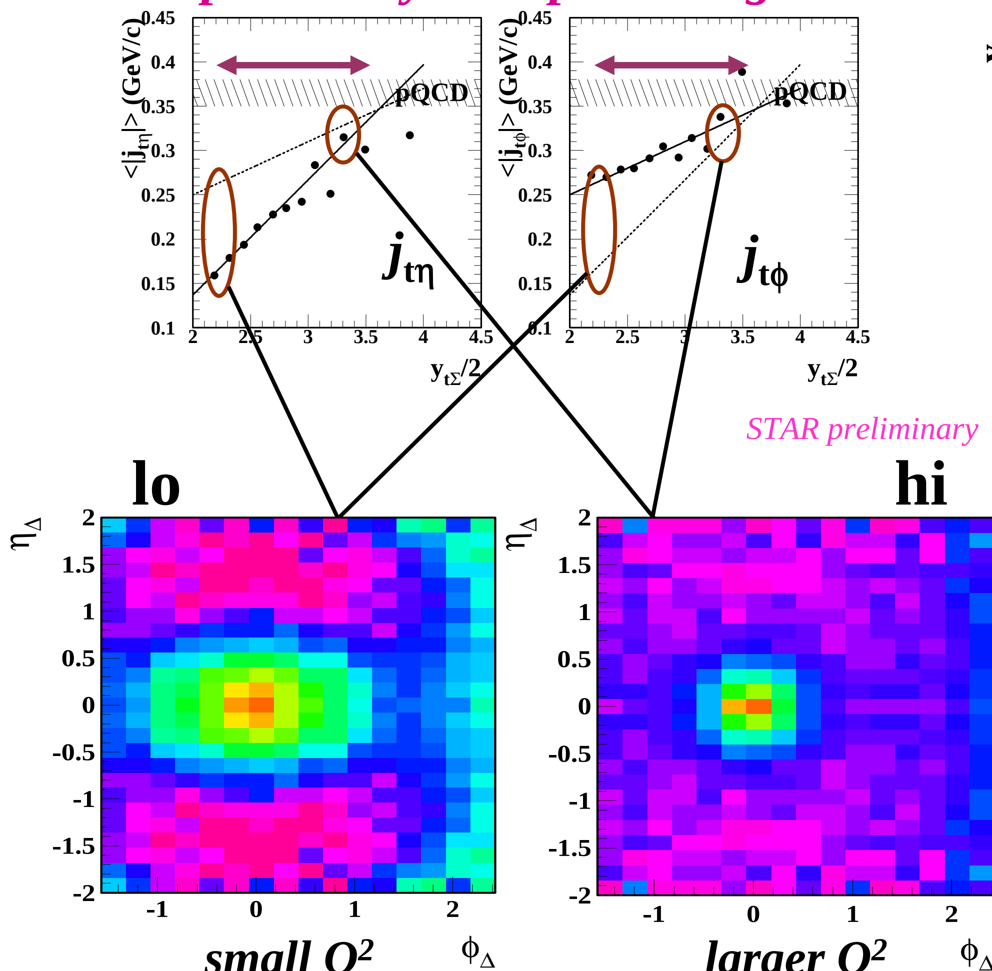


large same-side (η,φ) ***asymmetry***

Fragment Asymmetry about Thrust

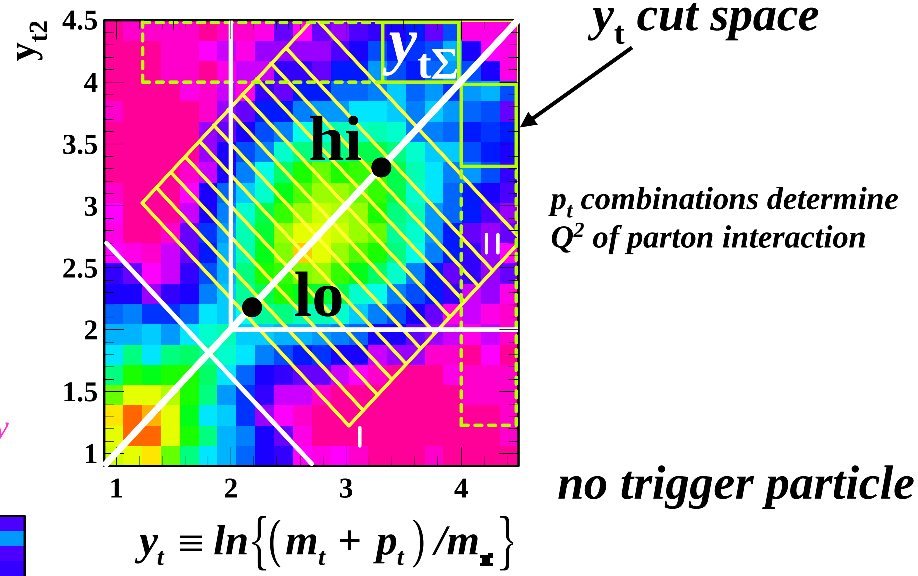
evolution with Q^2 of soft jet angular asymmetry

previously unexplored region!



1:1 aspect ratio ***200 GeV p-p***

two-particle fragmentation



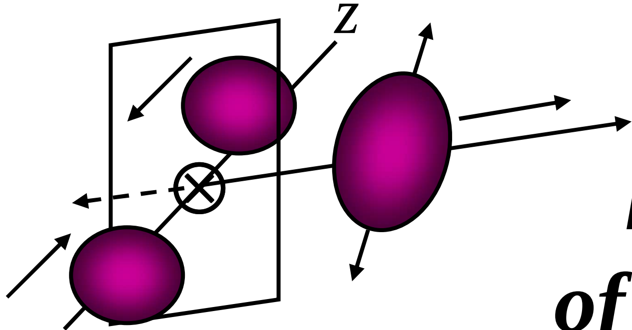
- ***Small-Q^2 partons down to 1 GeV are detectable***
- ***These softest jets are strongly elongated in the azimuth ϕ direction in p-p collisions***

softest jets ever!

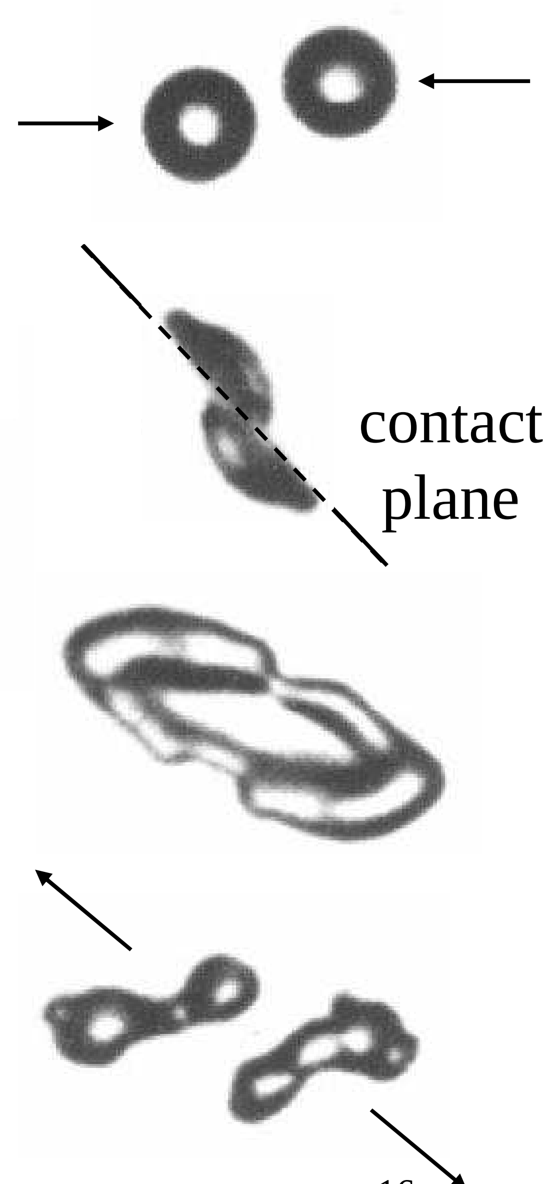
big non-perturbative effects

Interpretation

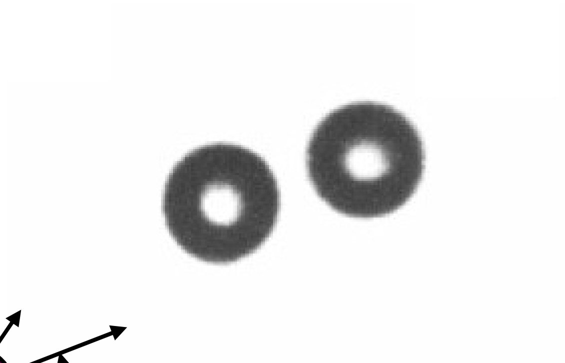
contact plane



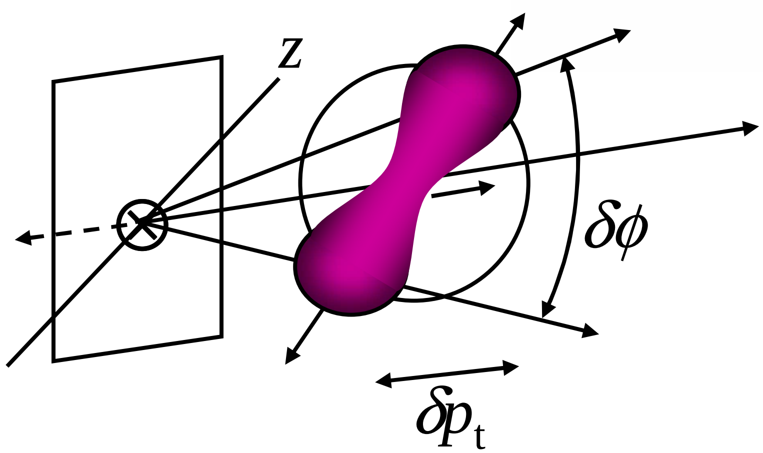
water drops
$v_{rel} = 6$ m/s



hydrodynamics
of parton collisions



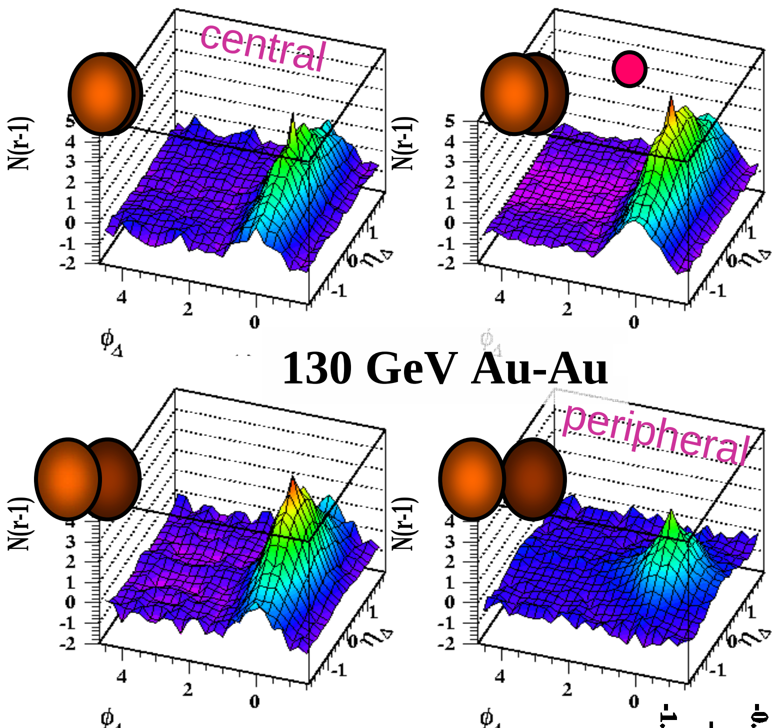
broadened in contact plane (ϕ,p_t), narrowed perpendicular to it (η)

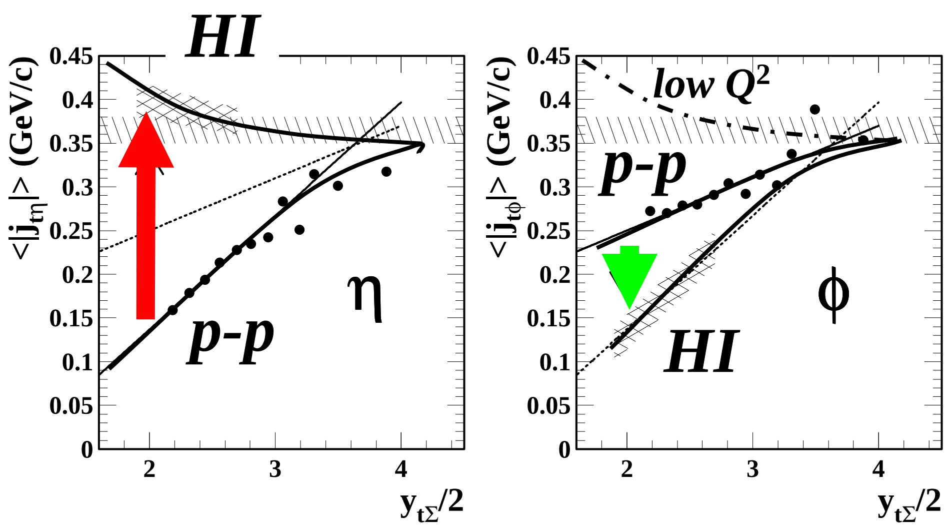


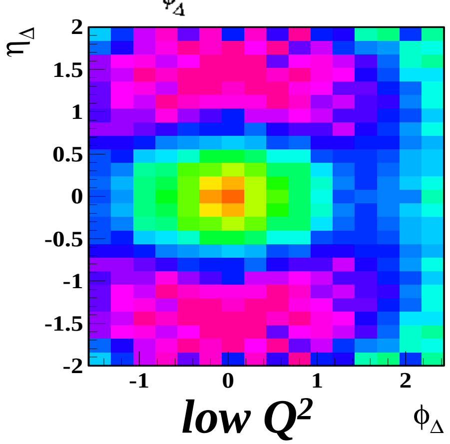
low-Q^2 fragmentation

Minijet Deformation on (η,ϕ) in Au-Au

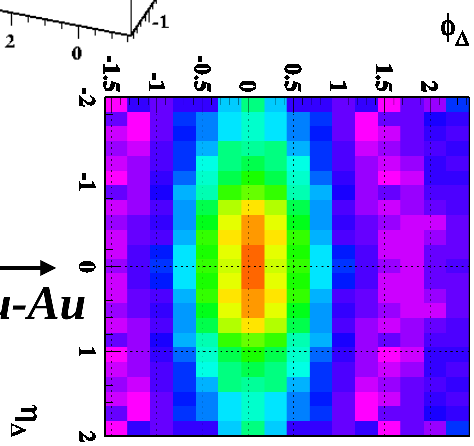
fragmentation asymmetry reverses – p-p → Au-Au



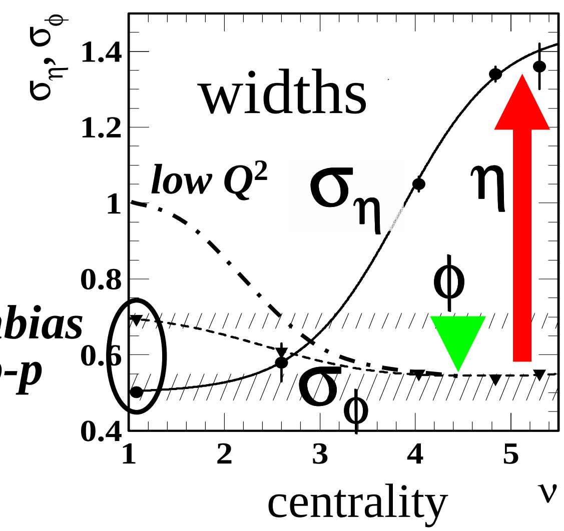




p-p → *Au-Au*



130 GeV Au-Au
mid-central



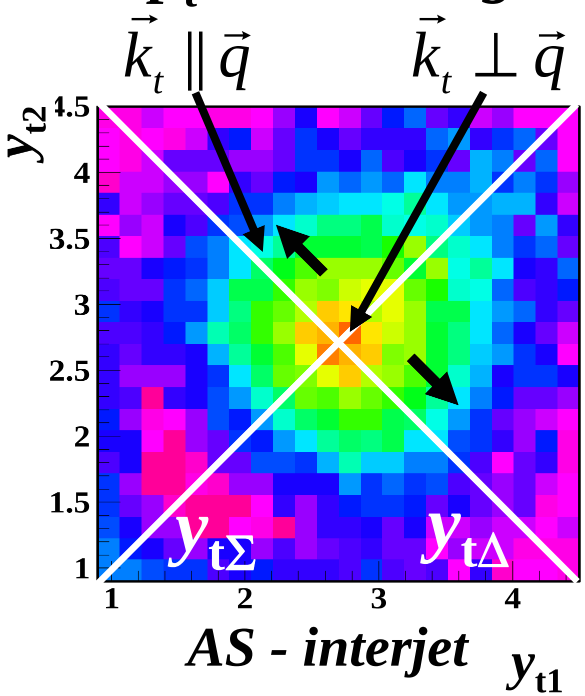
Trainor

The Other k_t Broadening

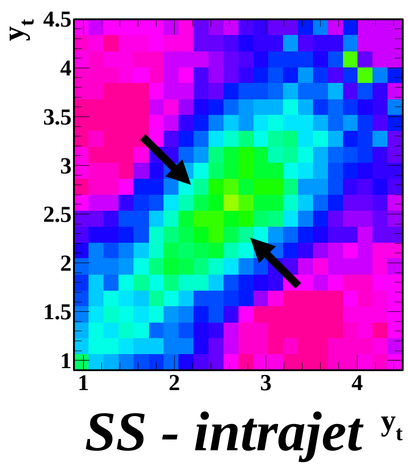
interaction between intrinsic k_t and momentum transfer q

the alignment between parton k_ts and q determines whether relative azimuth or relative p_t of fragments will broaden

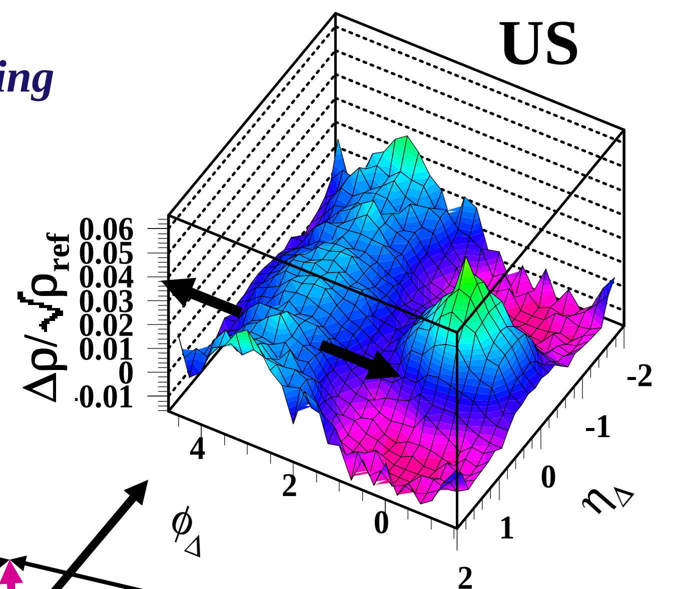
p_t broadening

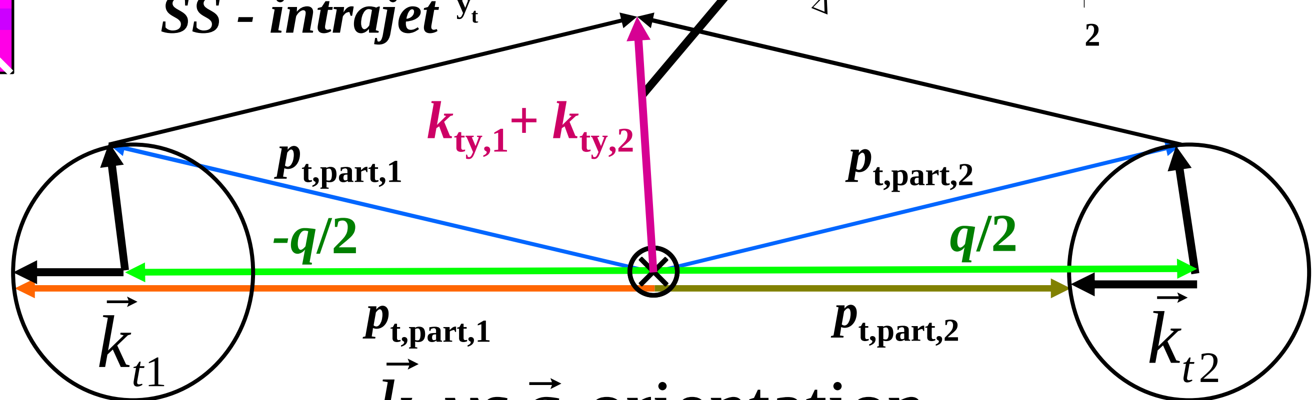


condition on (y_{t1},y_{t2}) biases away-side azimuth broadening



azimuth broadening





largest k_t effects:
small q/2, $\vec{k}_{t1} \parallel \vec{k}_{t2}$

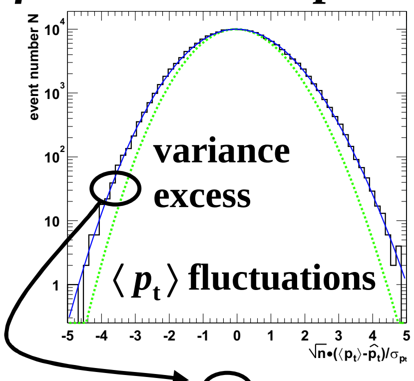
$\vec{k}_t$ *vs* $\vec{q}$ orientation

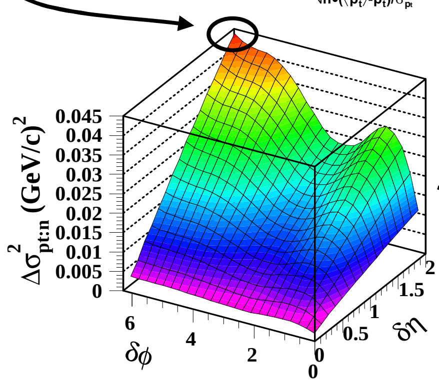
STAR preliminary

⟨ p_t ⟩ Fluctuations and p_t Correlations

partons and velocity correlations: how is p_t distributed on (η,φ)?

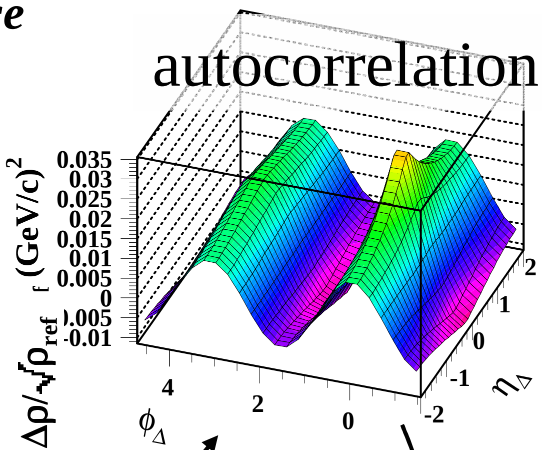
full STAR acceptance



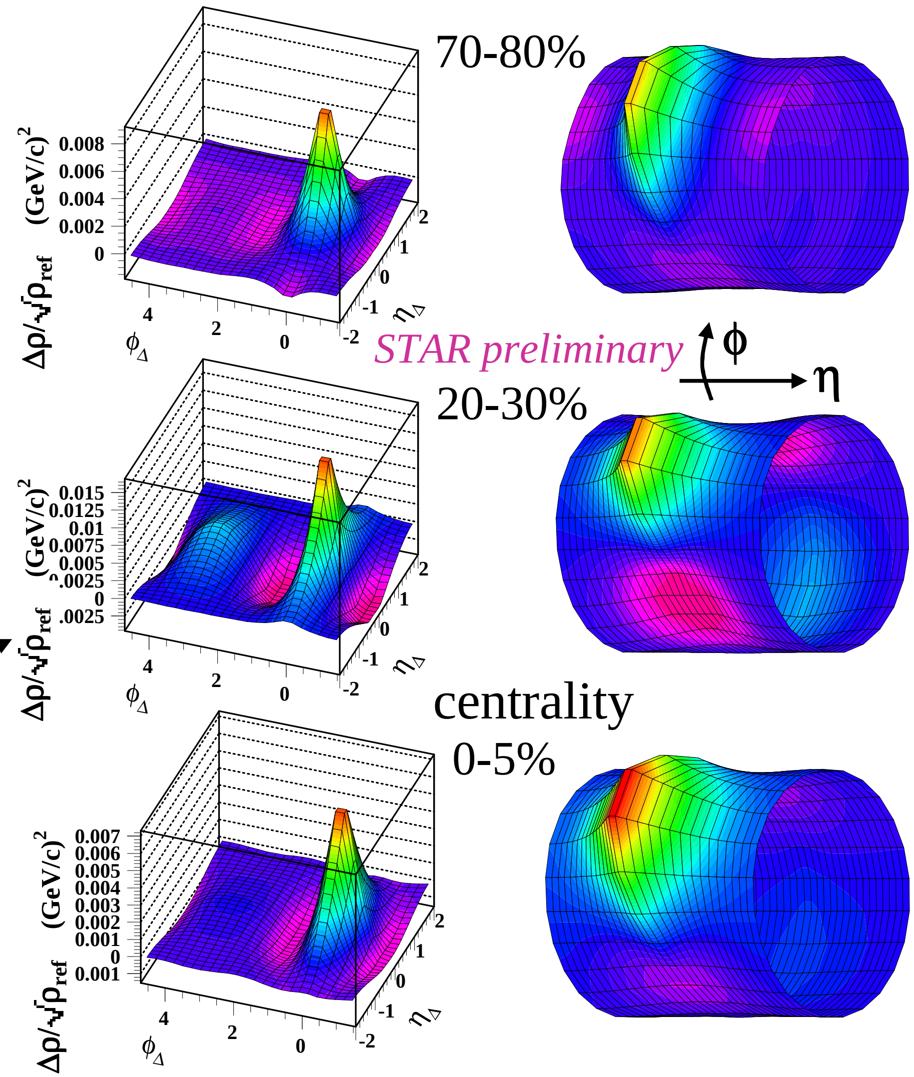


fluctuation scaling

fluctuation inversion



subtract multipoles

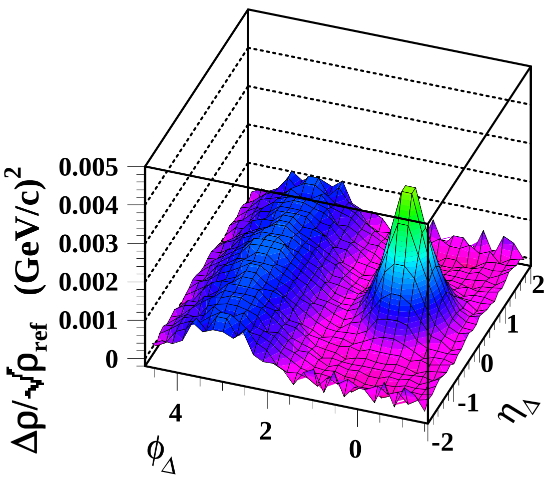


- *⟨p_t⟩ fluctuations invertible to p_t autocorrelations*

T. A. Trainor, R. J. Porter and D. J Prindle, J. Phys. G: Nucl. Part. Phys. 31 (2005) 809-824; hep-ph/0410182

Compare with p-p p_t Autocorrelations

p-p 200 GeV minbias

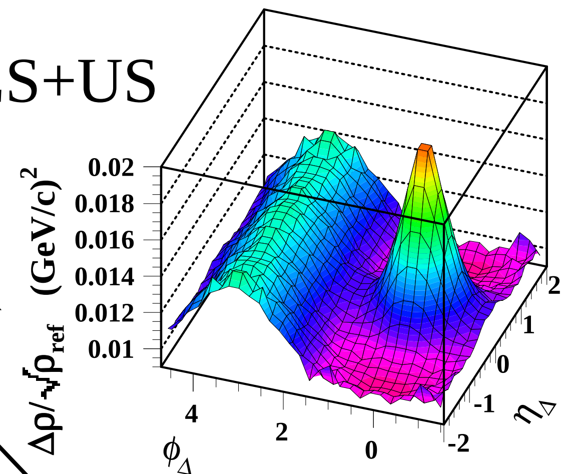


STAR preliminary

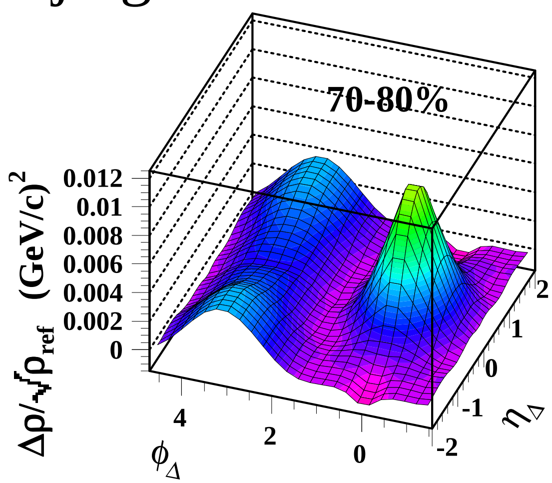
direct – from pair counting

p-p 200 GeV $n_{ch} > 9$

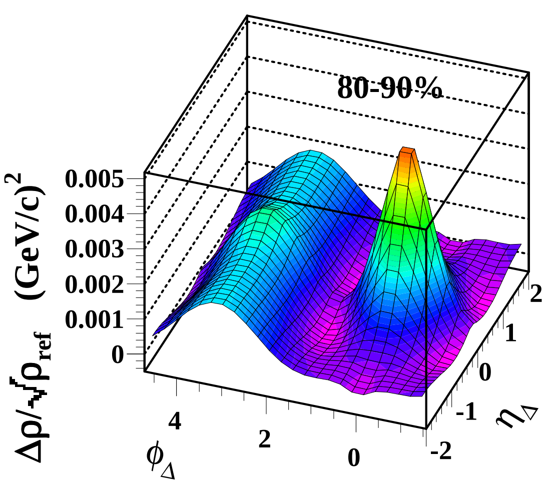
CI=LS+US



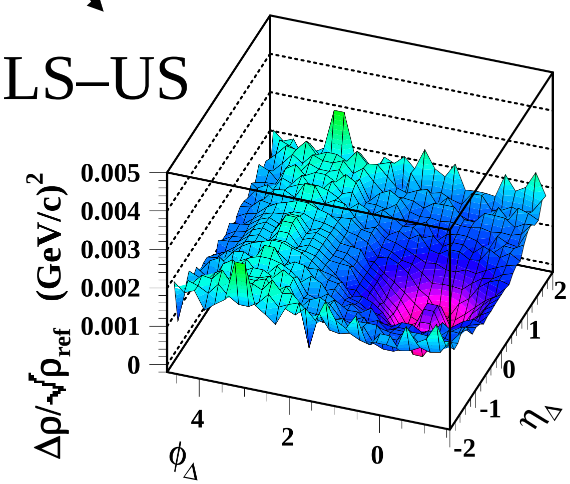
Hijing Au-Au 200 GeV



data Au-Au 200 GeV



CD=LS–US

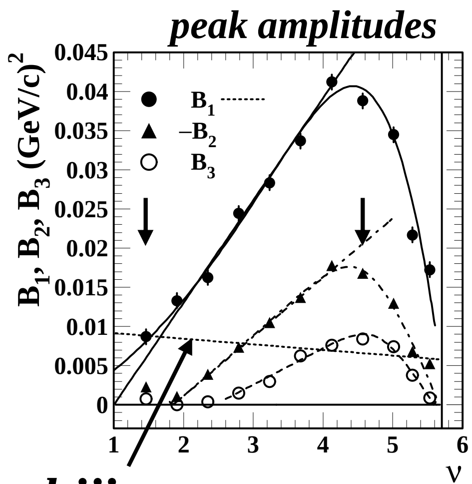


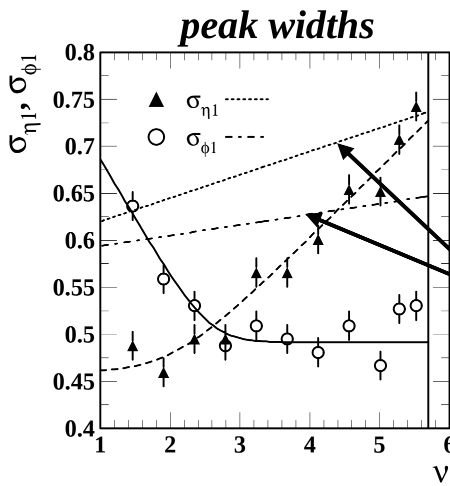
from fluctuation inversion

net-charge correlations

Model Fits

red shifts and blue shifts

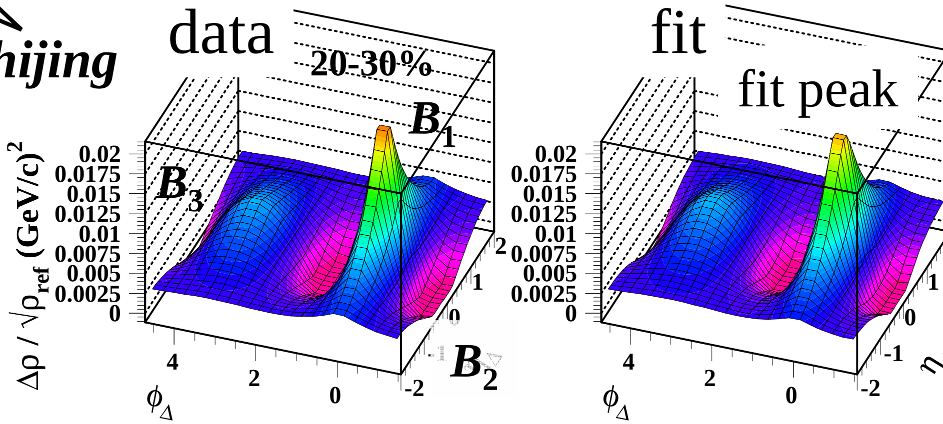


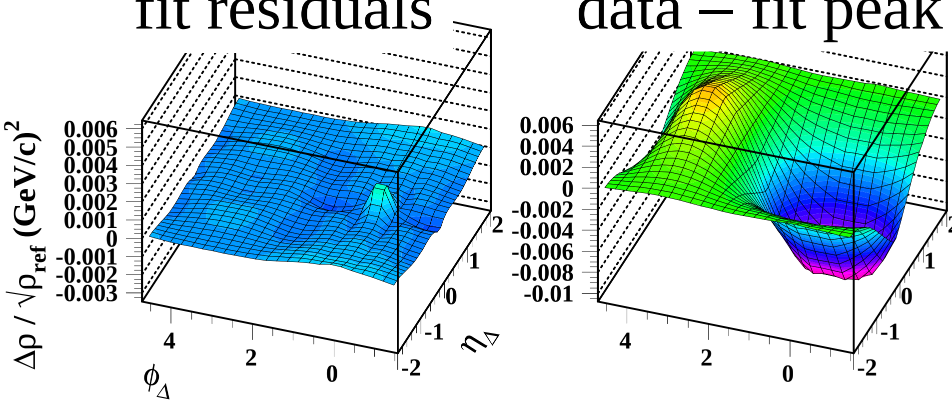


hijing

hijing

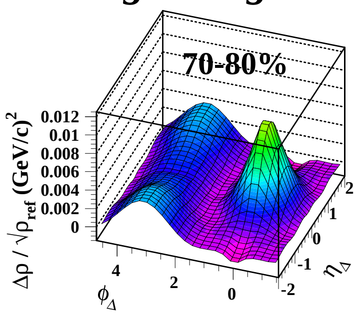
collision centrality





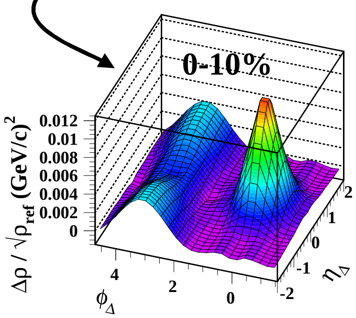
Hijing does not predict strong η broadening or negative structure

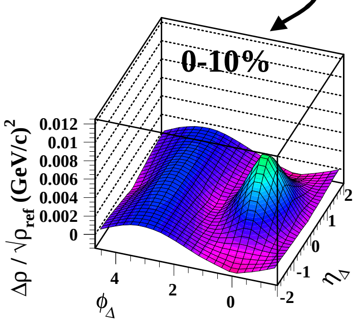
Hijing



quench off

quench on

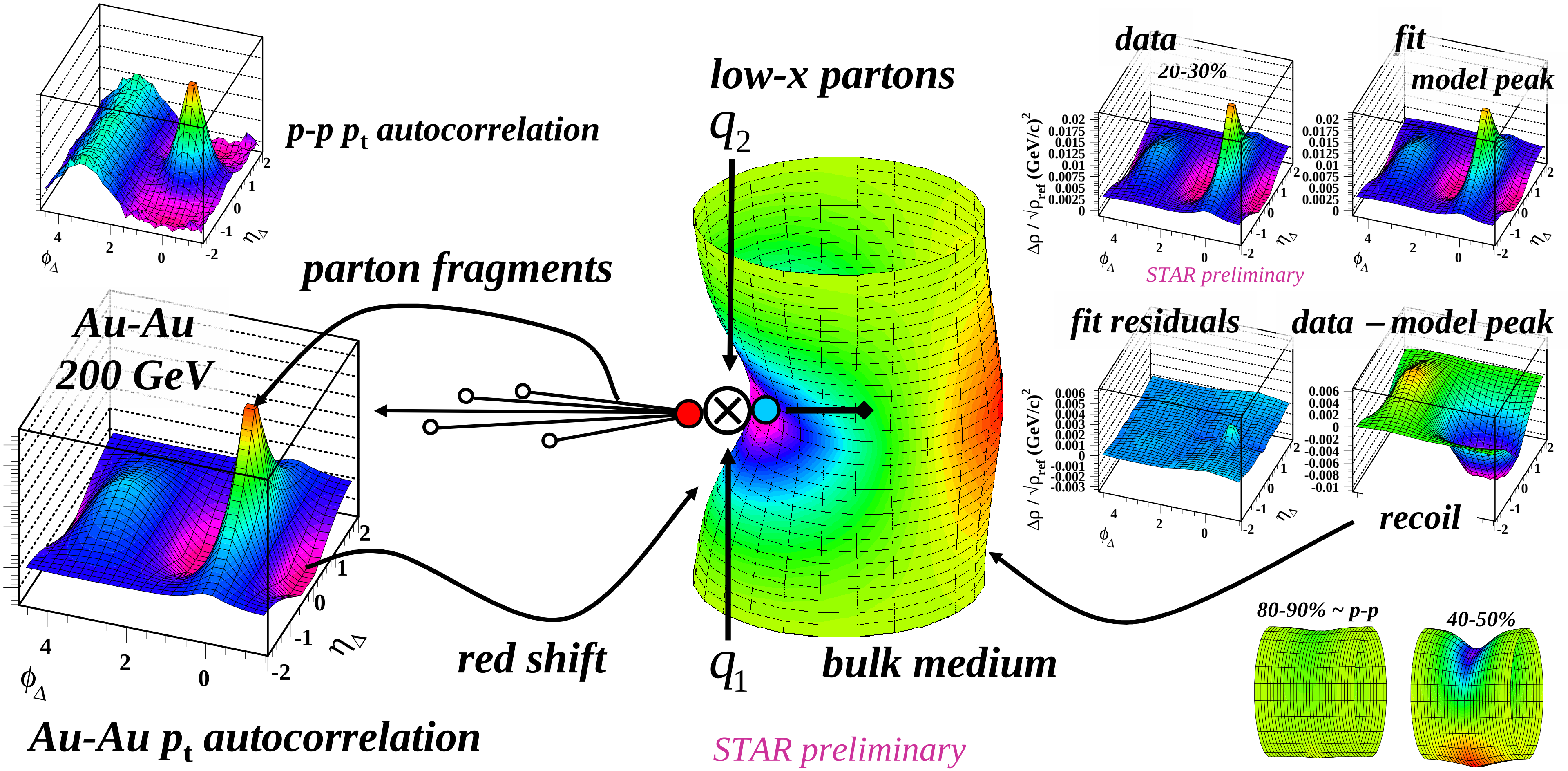


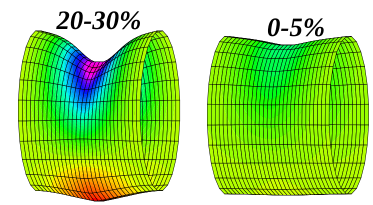


negative structure is unanticipated – what is the origin?

Recoil Response to Parton Stopping

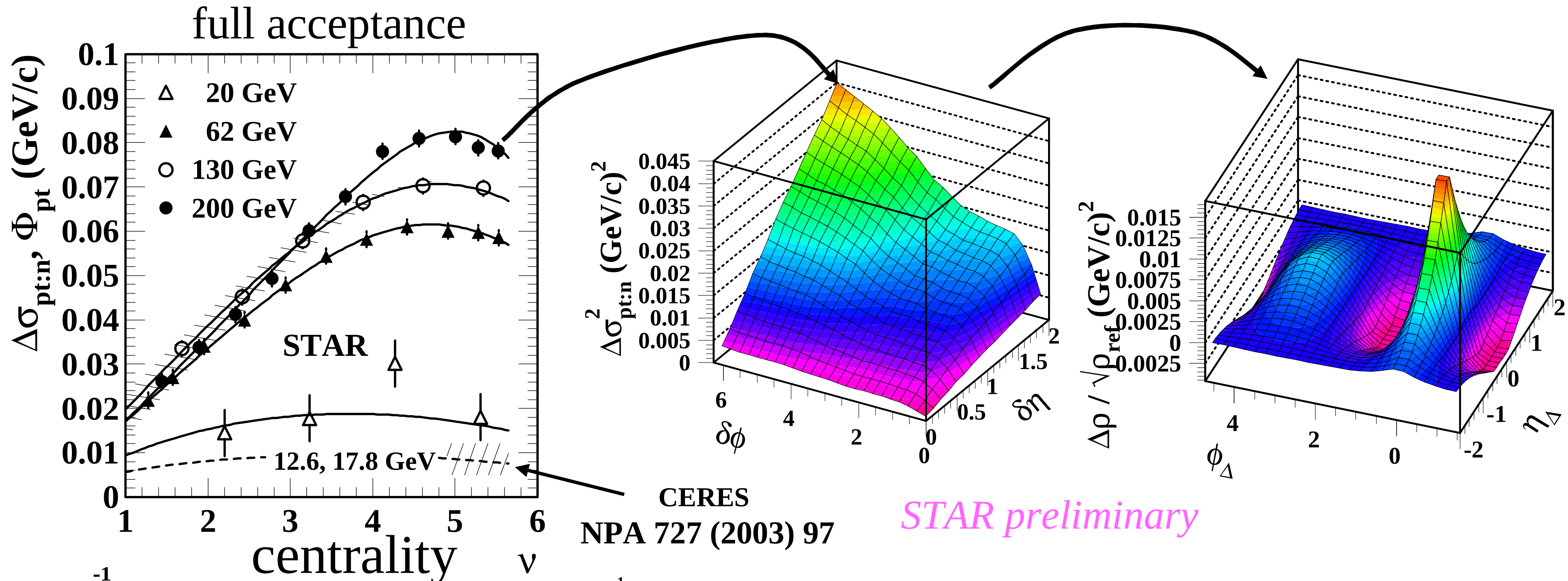
red shift: particle production may be from a recoiling source

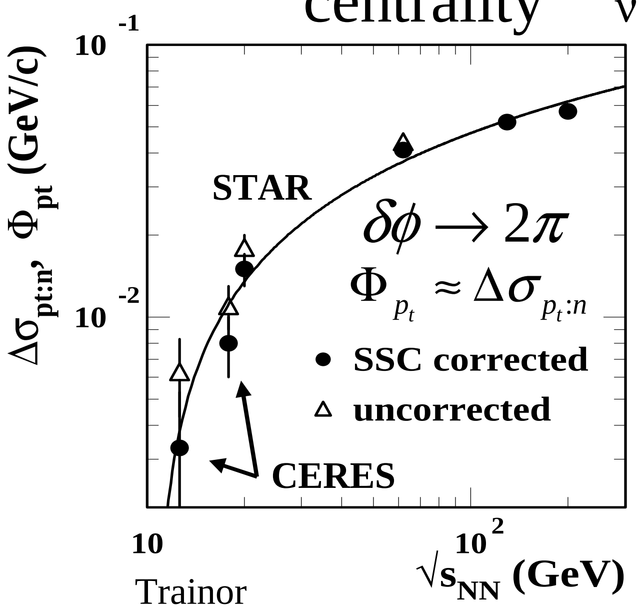


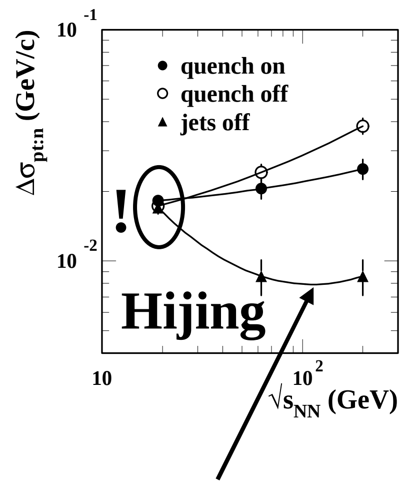


- ***Response of medium to minimum-bias parton stopping***
- ***Momentum transfer to medium***
- ***Velocity structure of medium***
- ***Medium recoil observed via <u>same-side</u> p_t correlations***

Energy Dependence: SPS ↔ RHIC





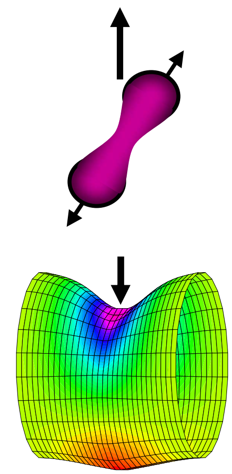


string structure in Hijing does not appear in Au-Au data

dramatic increase of $\langle p_t \rangle$ fluctuations with increasing $\sqrt{s_{NN}}$

$$\propto \ln\left\{\sqrt{s_{NN}}\,/10\ \text{GeV}\right\}$$

Summary



- Precision survey of p-p correlation structure
- Model-independent access to low-Q^2 partons
- Hydrodynamic aspects of parton scattering?
- The other k_t broadening: p_t asymmetry
- Low-Q^2 partons as Brownian probes of A-A
- Dissipation: p-p fragment distributions modified in A-A
- Non-pQCD p-p angular correlations modified in A-A
- p_t correlations: temperature/velocity structure of A-A
- Strong disagreement with pQCD Hijing Monte Carlo
- Recoil response of A-A bulk medium: viscosity $\neq 0$