Minijets and their Interactions

Tom Trainor

BNL, May, 2008

Agenda

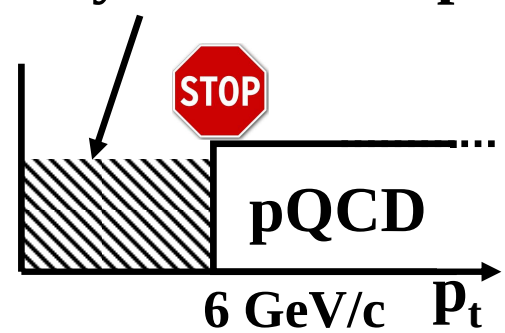
- Minijets in p-p spectra and correlations
- Minijets in A-A spectra and correlations
- Parton energy loss and QCD at small Q
- Minijets in p_t fluctuations and correlations

At what energy scale does parton scattering and fragmentation stop?

Are A-A collisions thermalized?

Does hydro dominate?

thermo/hydro or non-pQCD?

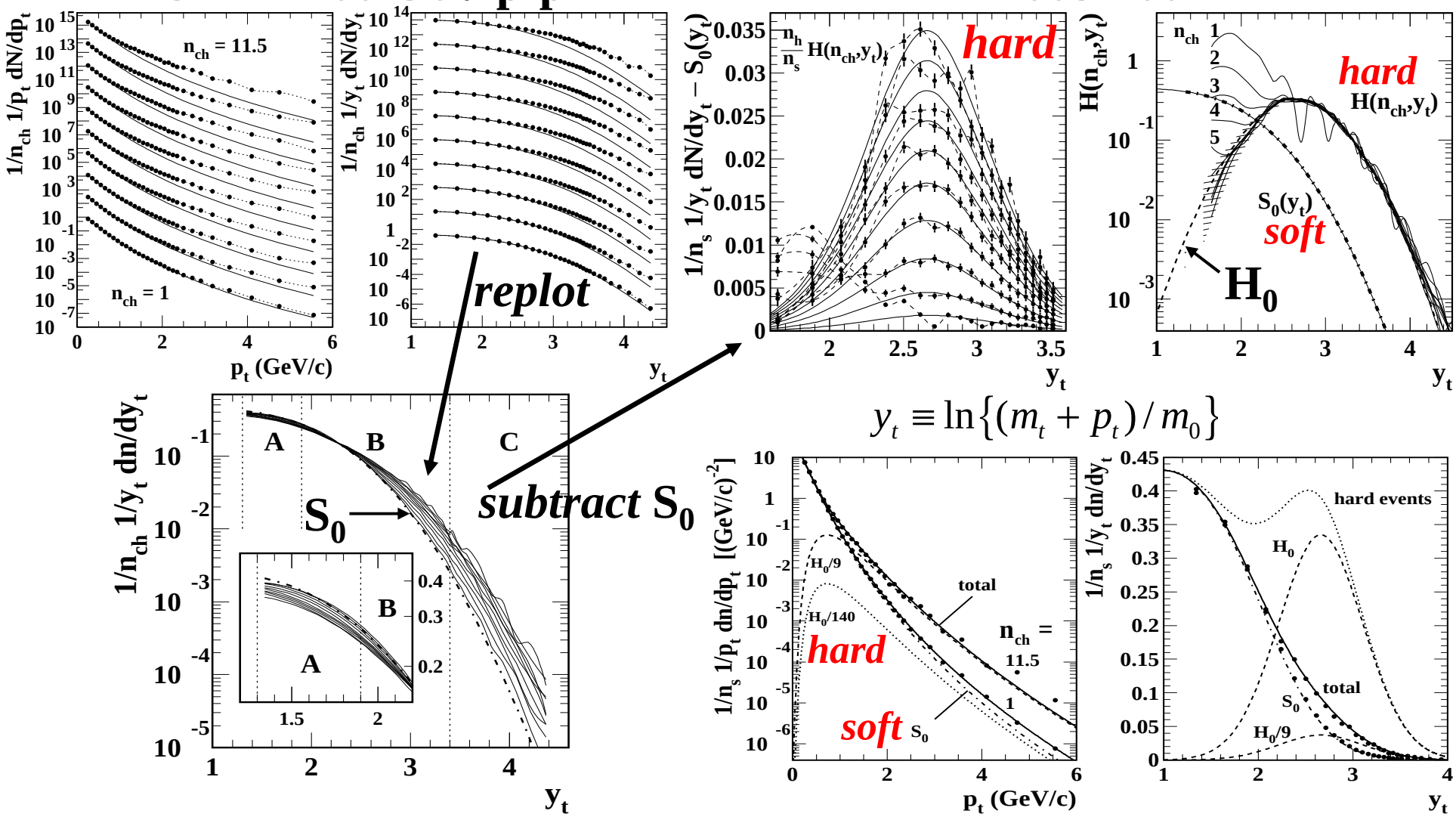


spectrum structure

restoring QCD to small-p_t hadron physics

Two-component p-p Spectra

STAR 200 GeV p-p **2003-2004**

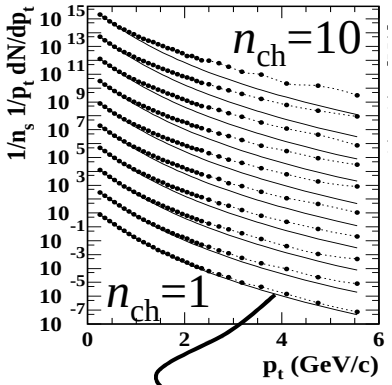


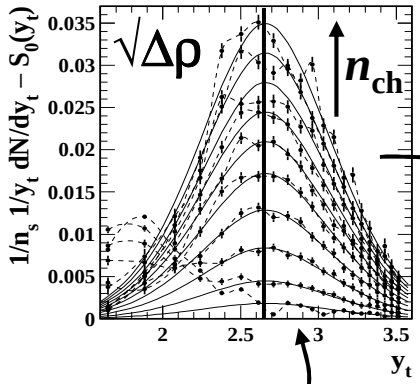
$$y_t \equiv \ln\{(m_t + p_t)/m_0\}$$

accurate separation of p-p longitudinal and transverse fragmentation

Phys Rev D 74, 032006 (2006)

Low-Q^2 Partons in p-p Collisions

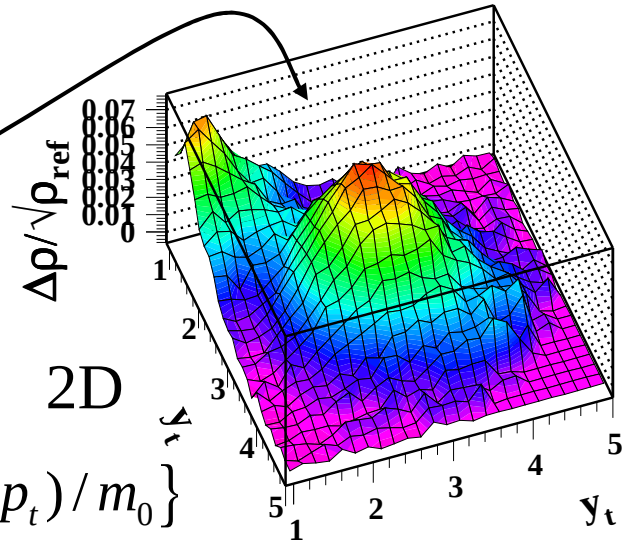




minijet fragments

1D

2D

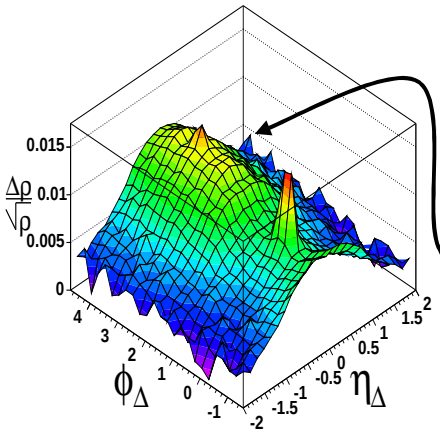


p-p
200 GeV

subtract soft reference

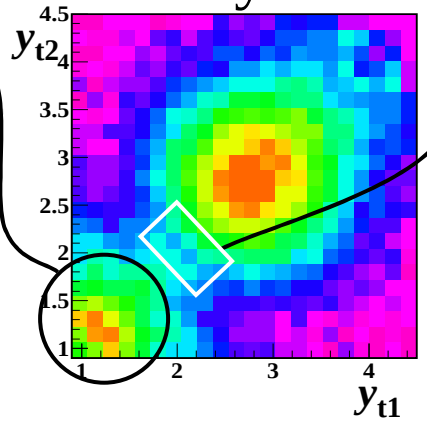
$p_t \rightarrow y_t$

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

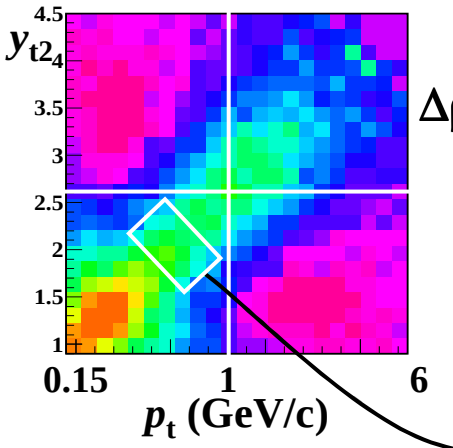


nucleon fragments

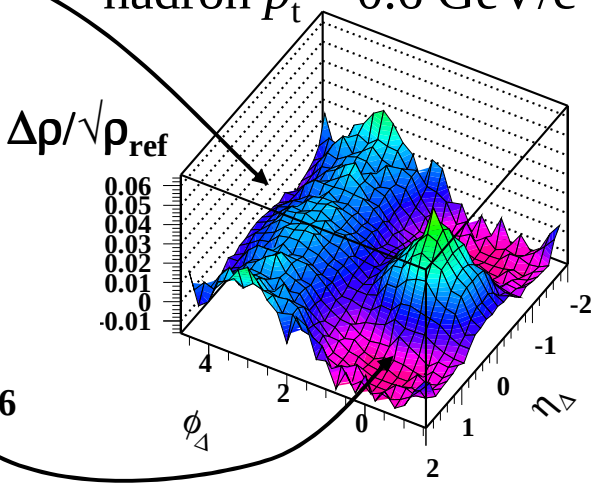
away side



same side



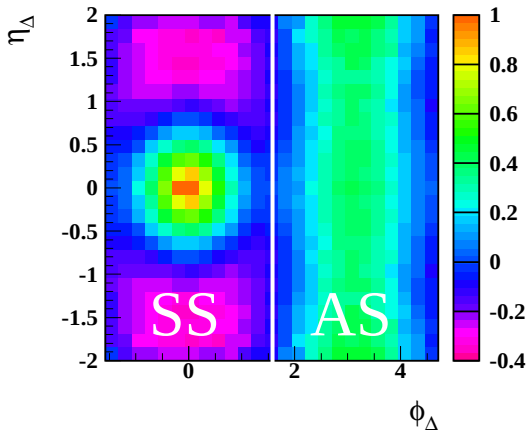
hadron p_t ~ 0.6 GeV/c



parton fragments

minimum-bias: no trigger condition

J Phys Conf Ser 27, 98 (2005); hep-ph/0506172

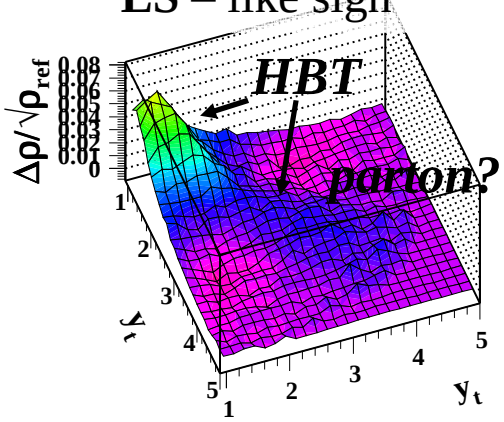


p-p Correlations on (y_{t1}, y_{t2})

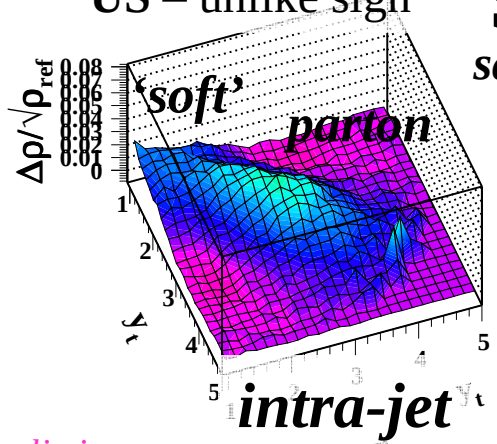
participant nucleon and parton fragmentation: first two-particle fragment distributions

(except OPAL on ξ)

LS – like sign



US – unlike sign

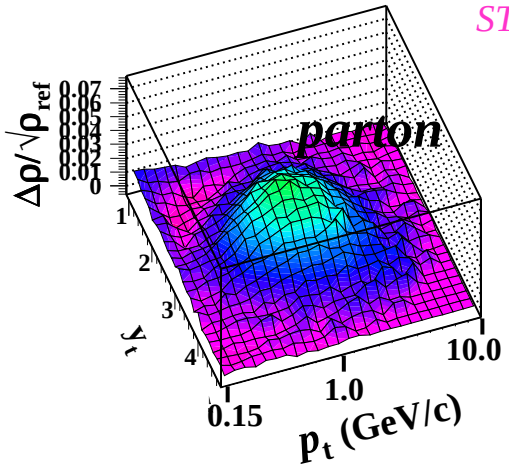


SS – ***same side***

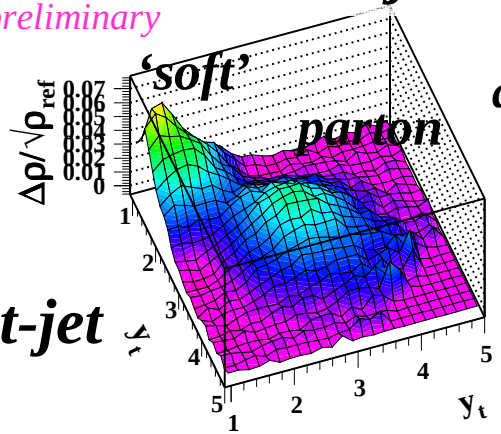
intra-jet

same-side parton fragmentation is restricted to US pairs

STAR preliminary



jet-jet

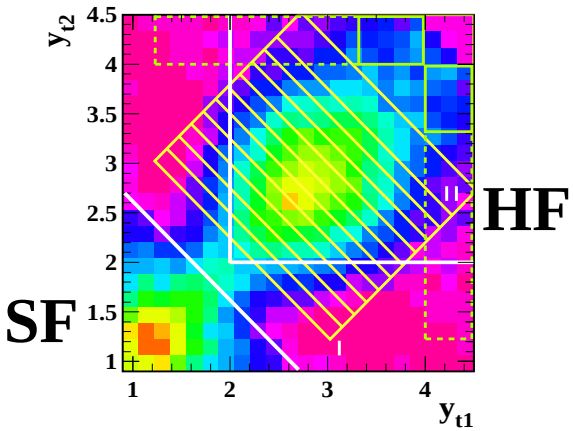


AS – ***away side***

away-side parton fragmentation is independent of charge combination

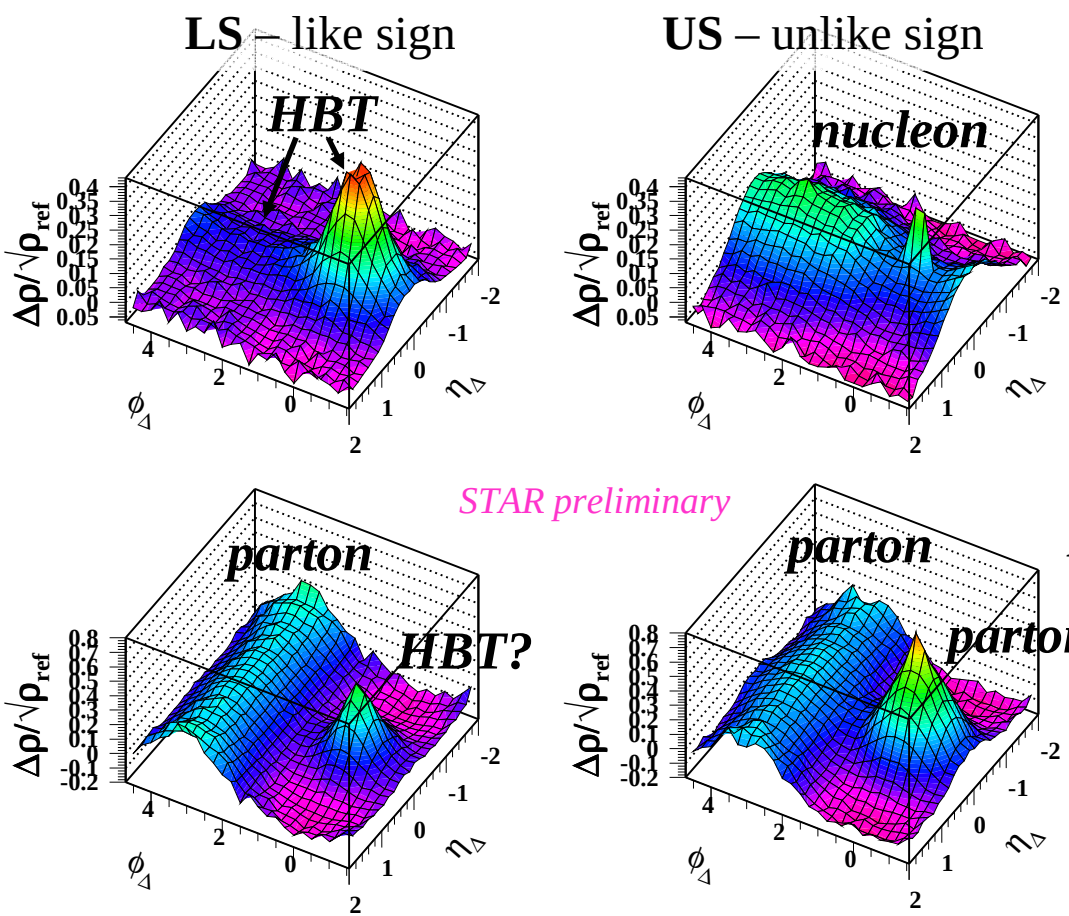
J Phys Conf Ser 27, 98 (2005); hep-ph/0506172

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



local charge and momentum conservation

2D angular autocorrelations on difference axes



SF –

nucleon fragments (PDF)

participant nucleon fragmentation reflects local measure conservation

HF –

parton fragments (FDF)

away-side parton fragmentation is ~ independent of charge combination

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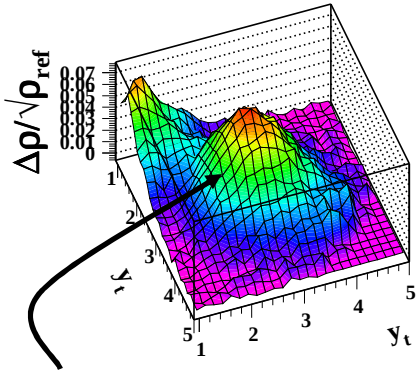
J Phys Conf Ser 27, 98 (2005); hep-ph/0506172

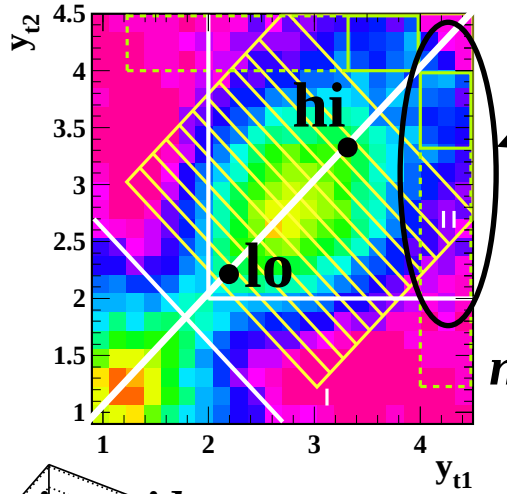
Low-Q^2 Parton Angular Correlations

p-p 200 GeV

energy scale dependence



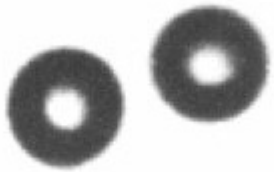
low-Q^2 partons – non-pQCD



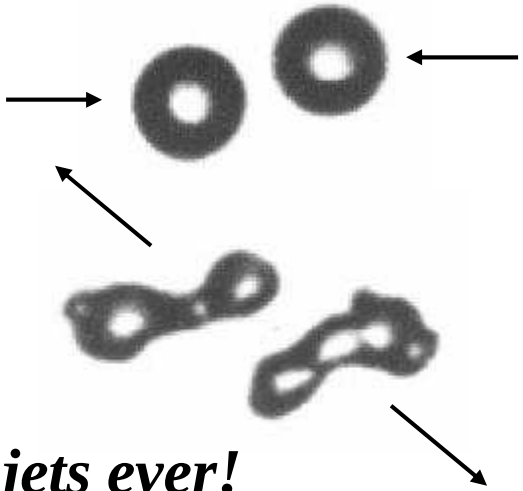
conventional high-p_t leading-particle analysis: pQCD

no trigger particle

water drops
v_{rel} = 6 m/s



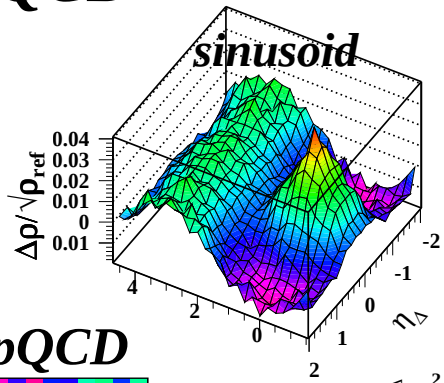
hydrodynamics of parton collisions?



softest jets ever!
big non-perturbative effects

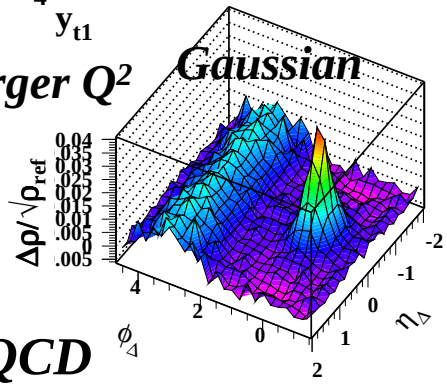
small Q^2

sinusoid

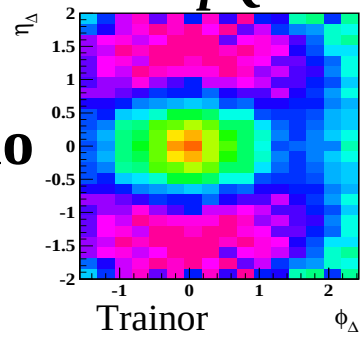


larger Q^2

Gaussian



non-pQCD

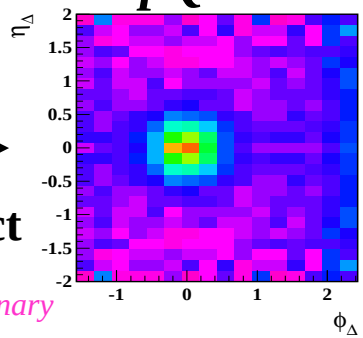


lo

Q^2 →

1:1 aspect

pQCD



hi

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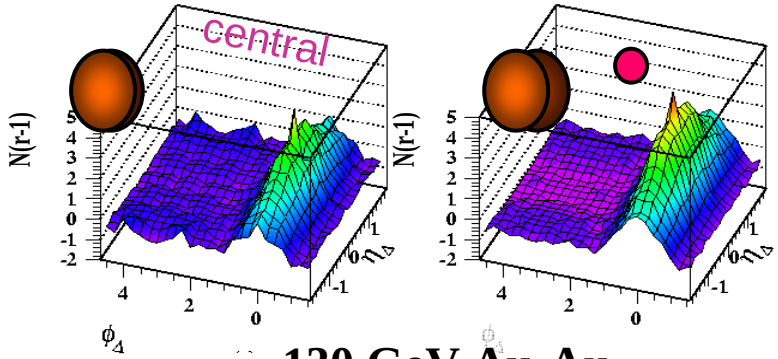
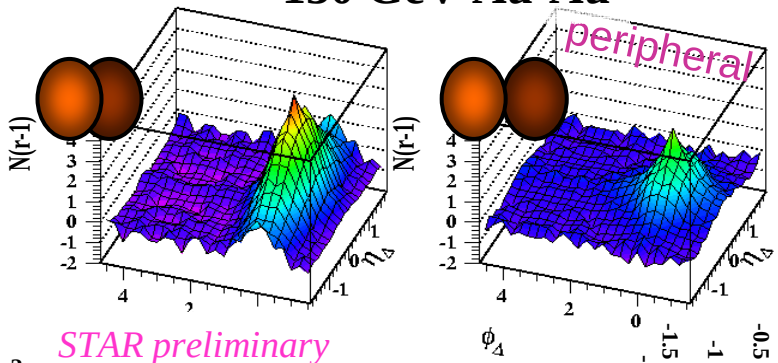
STAR preliminary

Minijet Deformation on (η,ϕ) in Au-Au

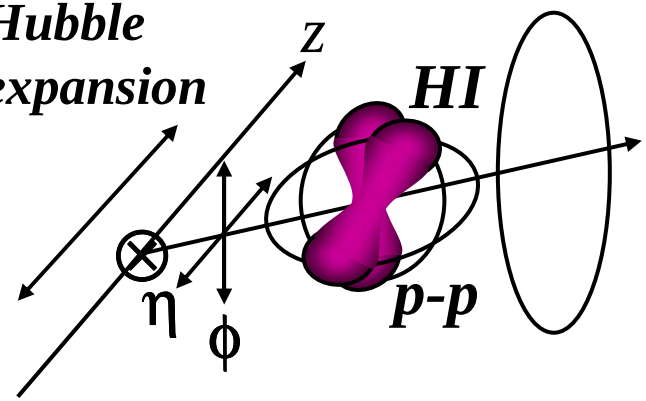
fragmentation asymmetry reverses: p-p → Au-Au



130 GeV Au-Au

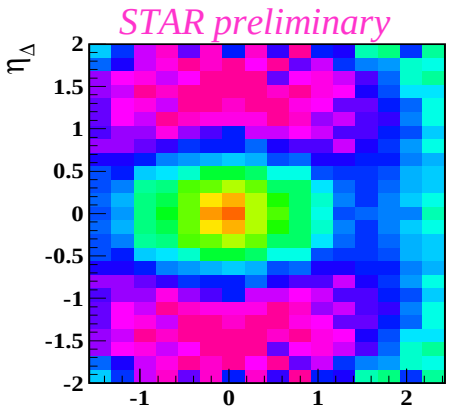


Phys Rev C 73, 064907 (2006)



dramatic evolution with centrality

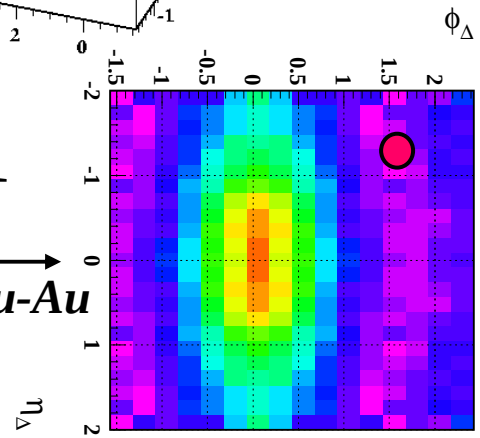
2002-2003



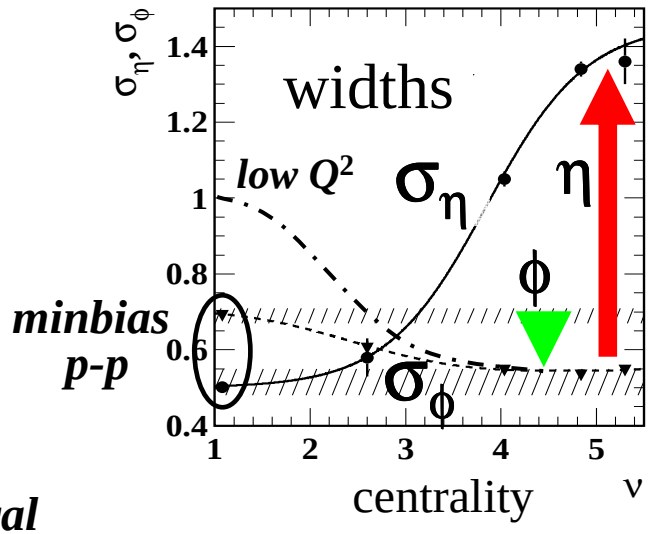
low Q^2 p-p

1:1

p-p → Au-Au

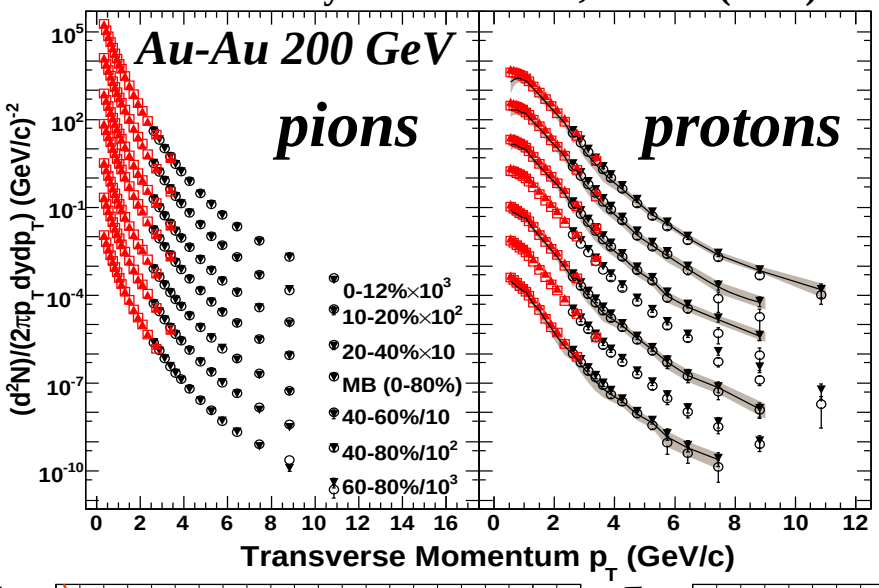


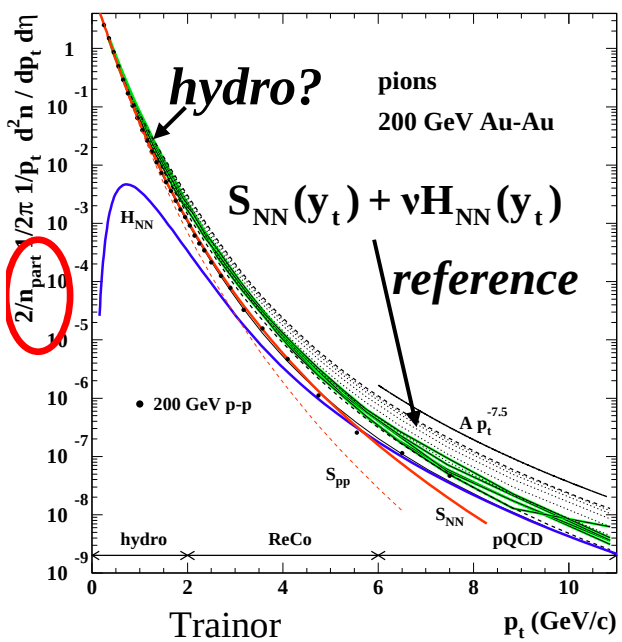
130 GeV Au-Au mid-central

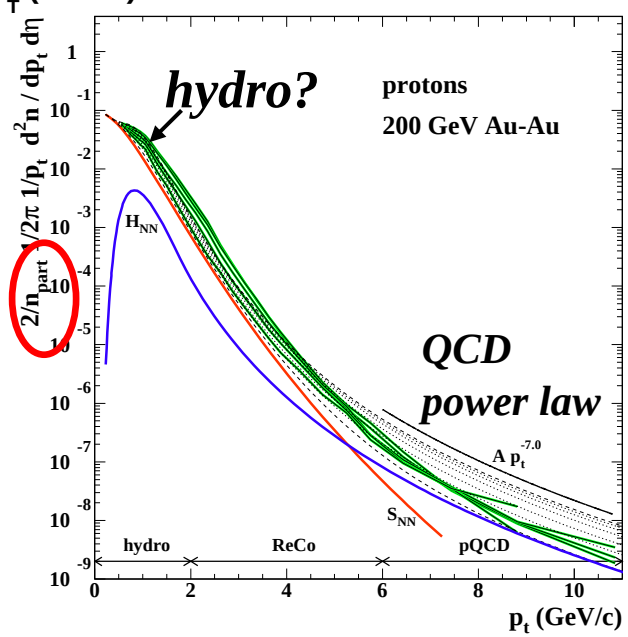


p_t Spectra – Standard Text

STAR: Phys. Rev. Lett. 97, 152301 (2006)







conventional interpretation

- ***thermalized system***
- ***state variables T, μ***
- ***blast-wave modeling***
- ***$\rightarrow$ radial flow β***

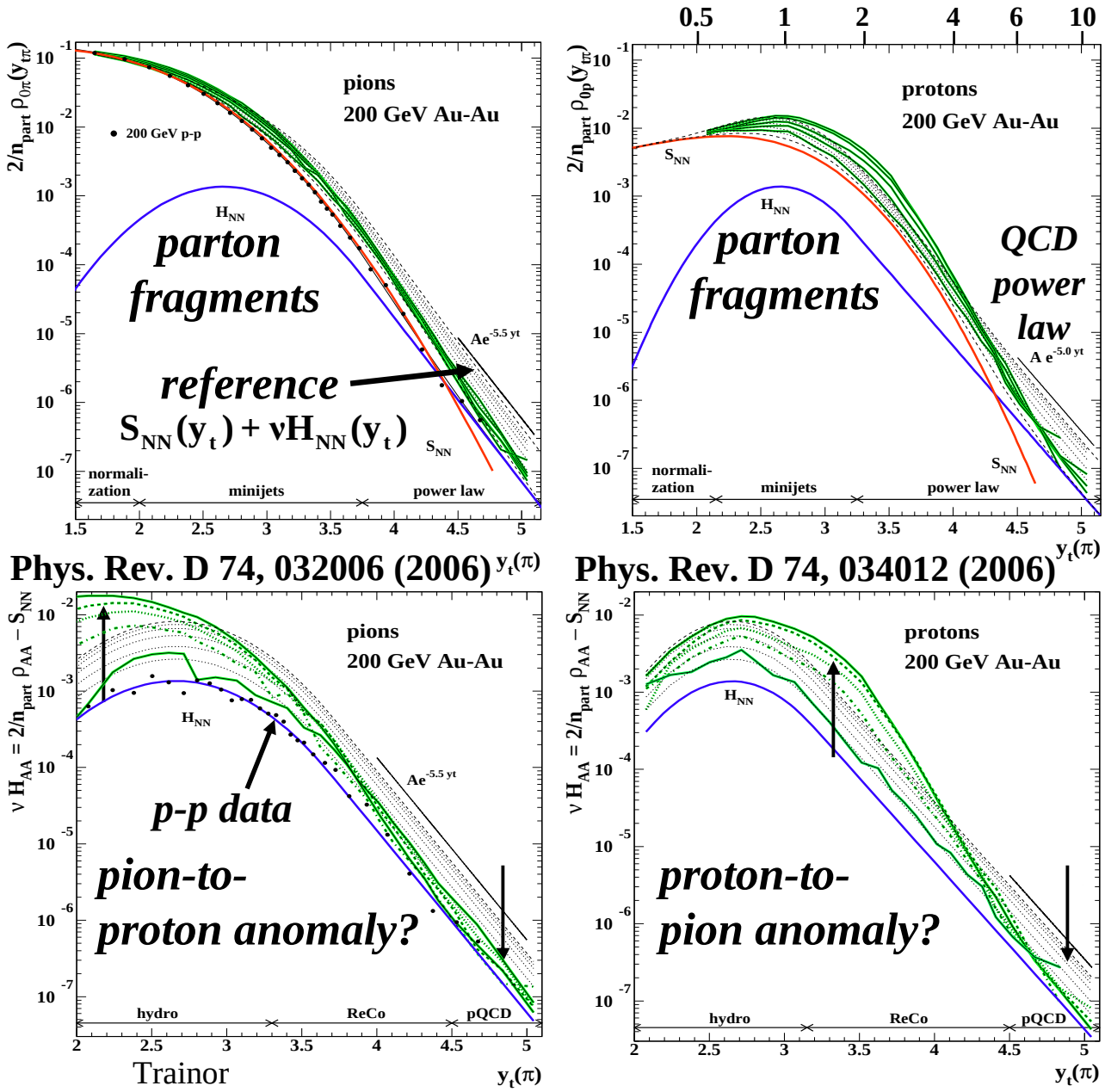
$\downarrow$

differential plot format

direct comparison with two-component model

arXiv:0710.4504

y_t Spectrum and Hard Component



Phys. Rev. D 74, 032006 (2006)

Phys. Rev. D 74, 034012 (2006)

pion rapidity

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

no apparent hydro phenomena

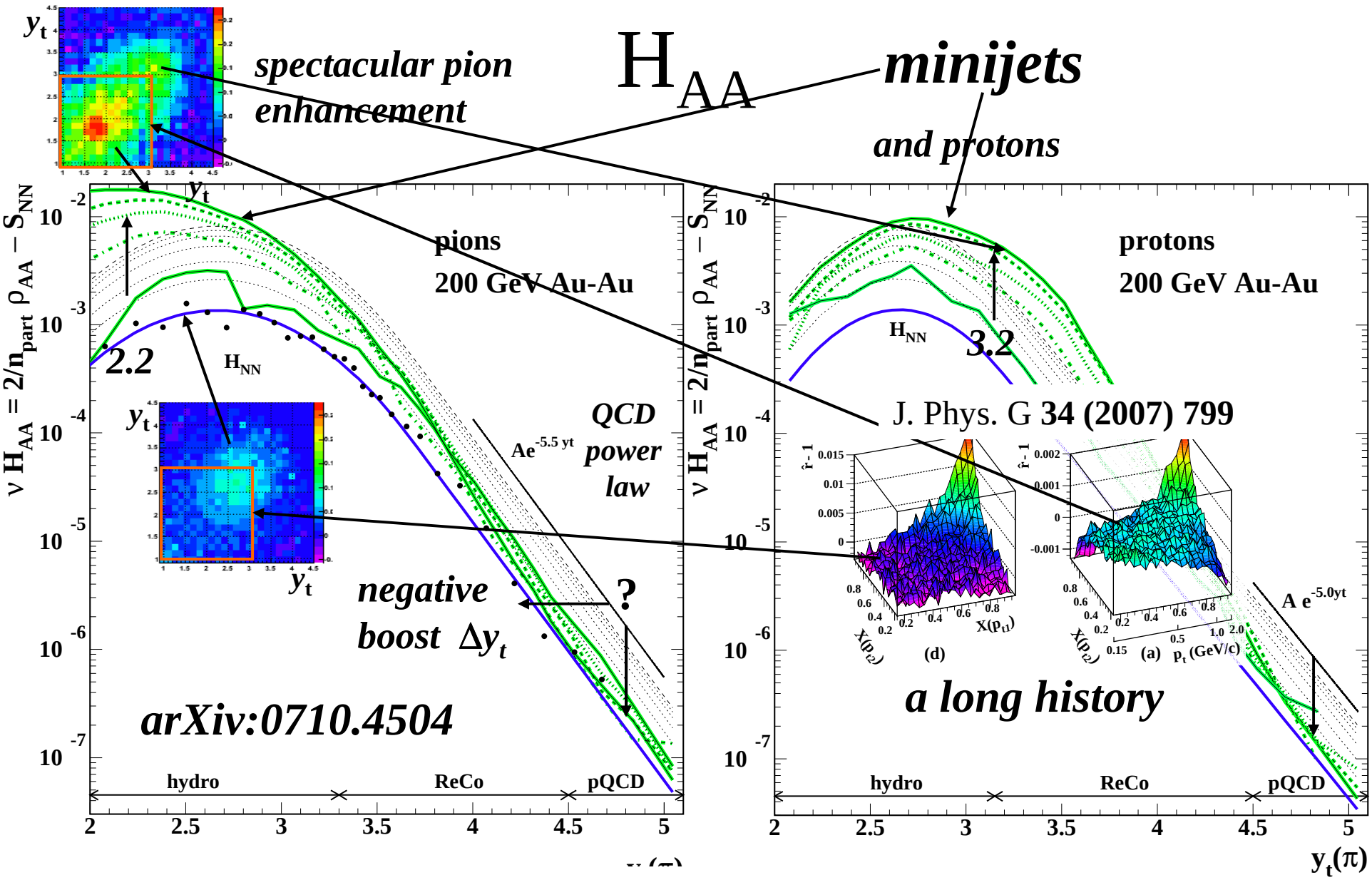
subtract soft reference

$$S_{NN}(y_t)$$

<u>all parton fragments</u>

fragments dominate centrality evolution

arXiv:0710.4504



the elephant in the living room

data hard components n_{part} *FD: fragment* distribution

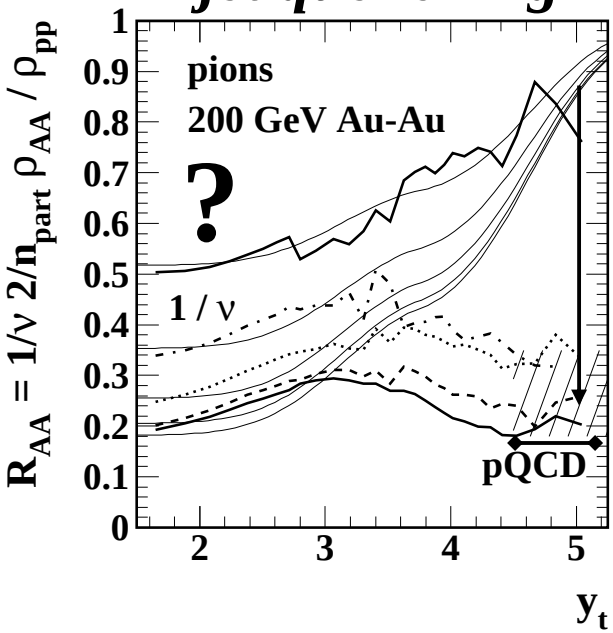
R_{AA}

$$\frac{1}{\nu}\cdot\frac{S_{NN}(y_t)+\nu H_{AA}(y_t;\nu)}{S_{pp}(y_t)+H_{pp}(y_t)}$$

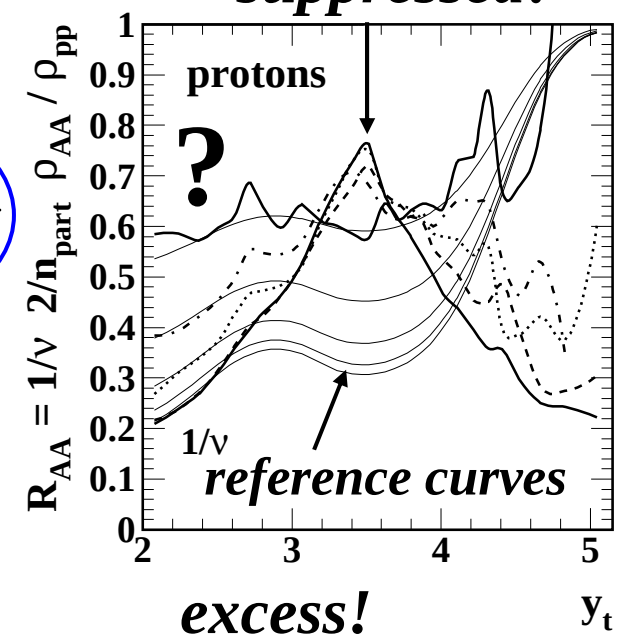
$$\nu \equiv 2n_{binary}/n_{participant}$$

mixes soft and hard components

jet quenching



suppressed?

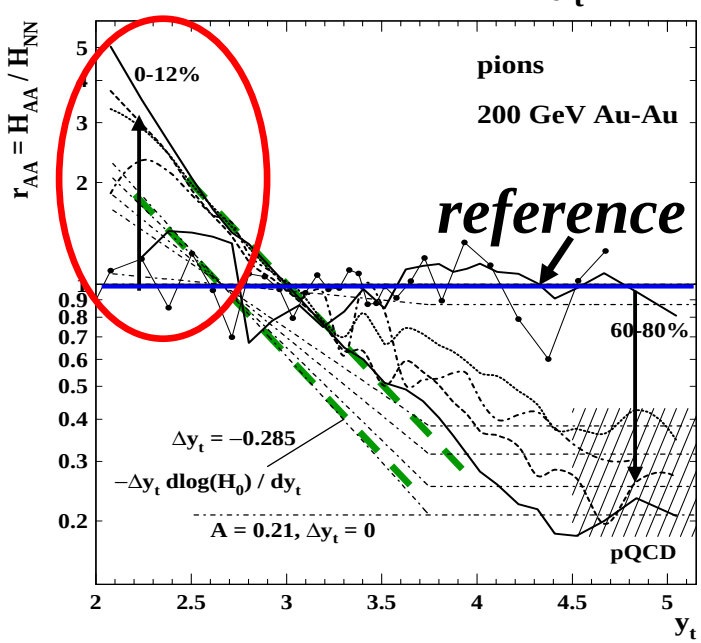


arXiv:0710.4504

r_{AA}

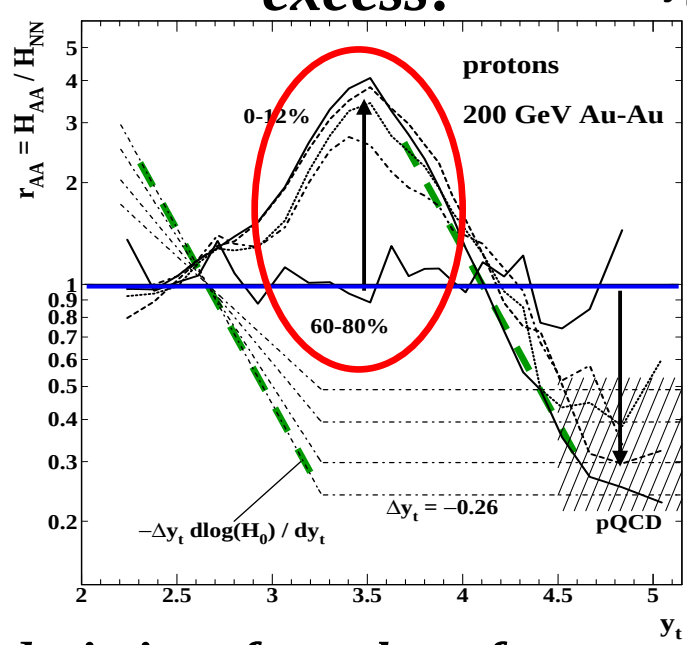
$$\frac{H_{AA}(y_t;\nu)}{H_{NN}(y_t)}$$

parton fragmentation only



hard-component ratios

excess!

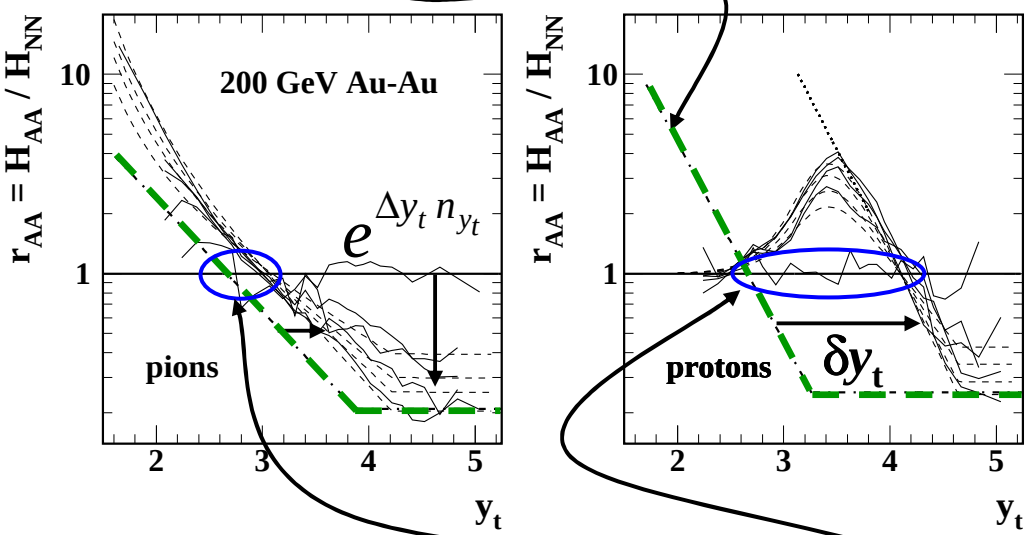


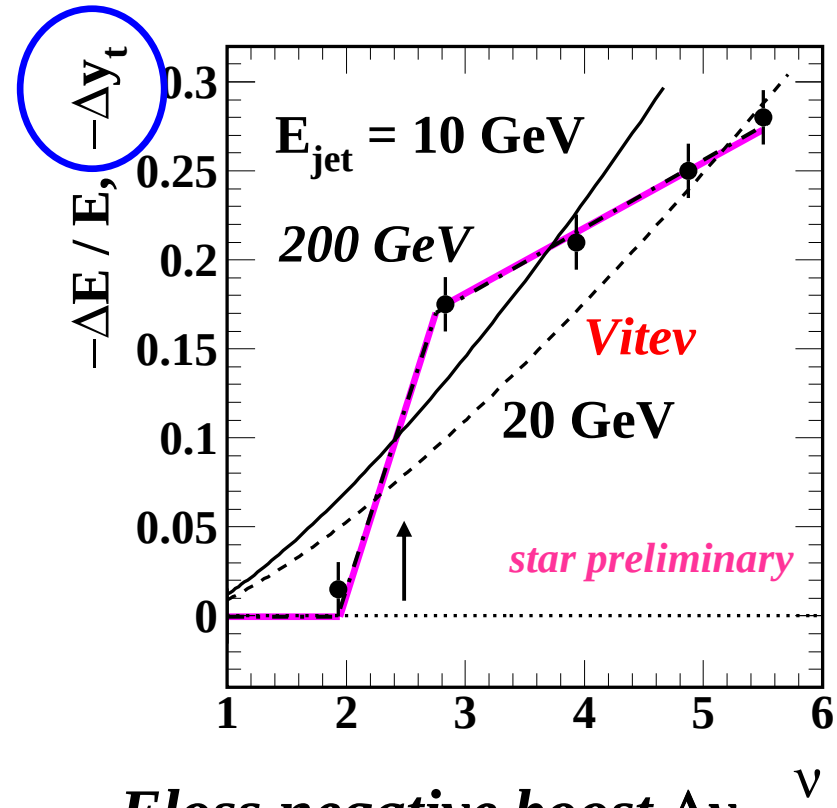
<u>all</u> deviations from the reference

Δy_t and Parton Energy Loss

naïve model

$$-\Delta y_t \; d\log[H_{NN}(y_t)]/dy_t$$





modeling r_{AA}

if 'energy loss' is a negative boost

$$H_{AA}(y_t;\nu) \approx A H_{NN}(y_t + \Delta y_t[\nu])$$

then by Taylor expansion

$$\log[r_{AA}(y_t;\nu)] \approx$$

anomalous

$$-\Delta y_t(\nu) \; d\log[H_{NN}(y_t - \delta y_t)]/dy_t$$

dashed model curves fully describe data

Eloss negative boost Δy_t

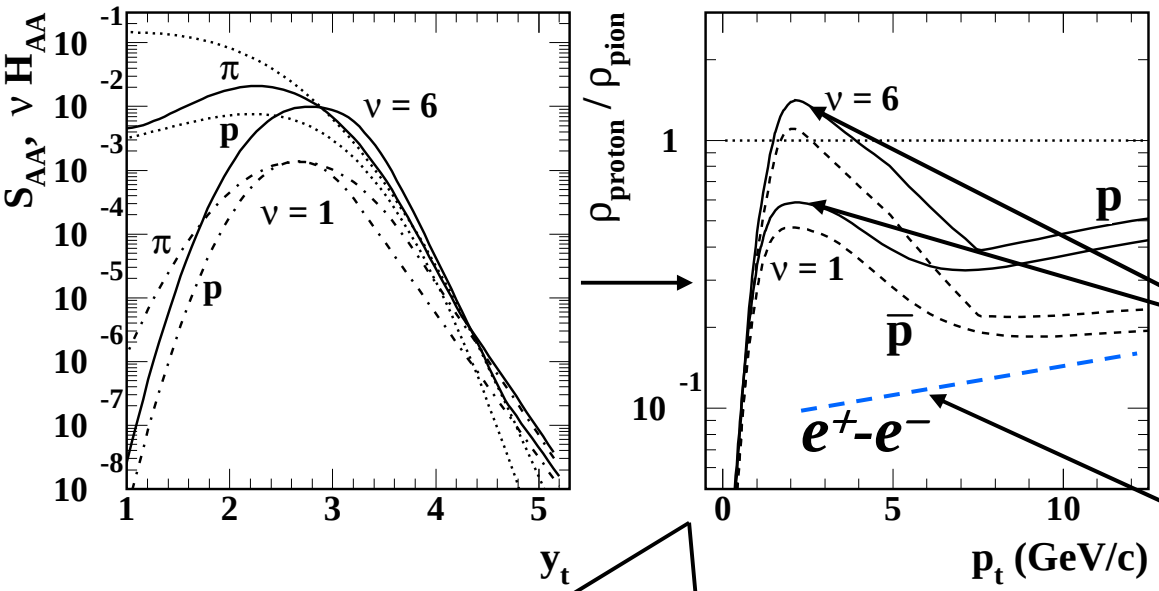
theory ΔE/E (curves) from I. Vitev

displacements may indicate color screening of partons

arXiv:0710.4504

The Proton *vs* Pion Anomaly

model summary



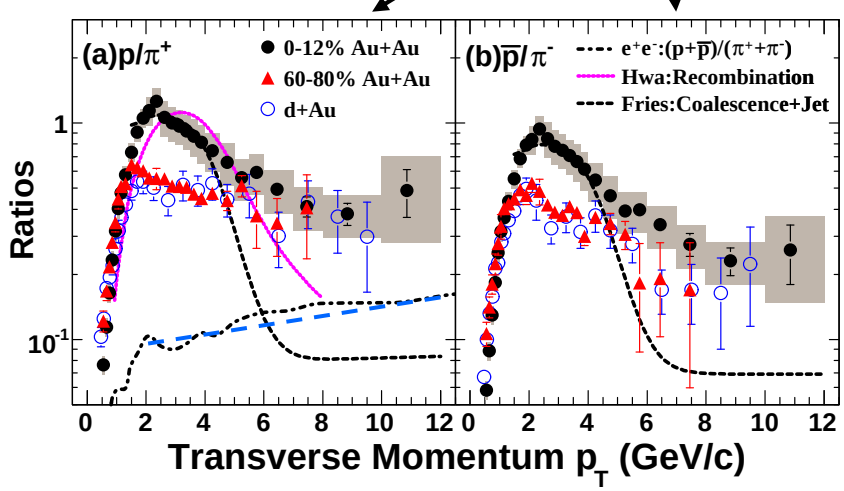
ReCo, or parton energy loss?

the Au-Au "anomaly" is only a factor 2×

arXiv:0710.4504

spectrum ratio not comparable to fragmentation* function *ratios

good agreement



Trainor **Phys. Rev. Lett. 97, 152301 (2006)**

$$\frac{\rho_{proton}}{\rho_{pion}} = \frac{S_{NNp}(y_t) + \nu H_{AAp}(y_t;\nu)}{S_{NN\pi}(y_t) + \nu H_{AA\pi}(y_t;\nu)}$$

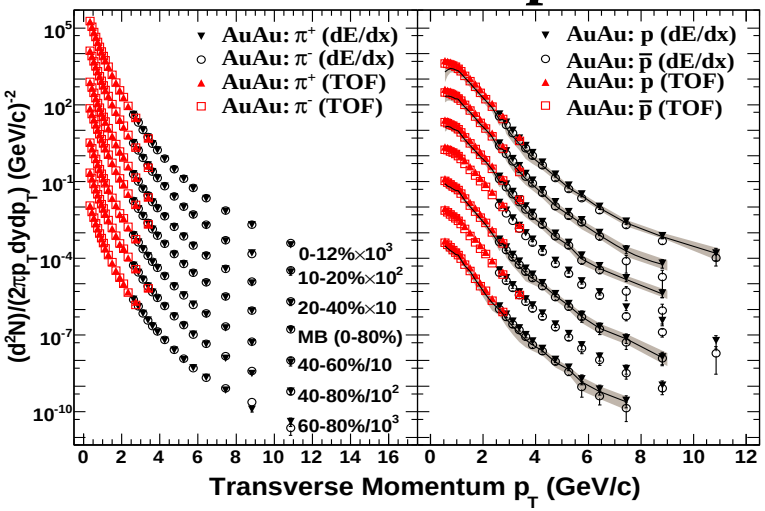
ratio mixes soft and hard components

$$H_{AAp}(y_t;\nu) / H_{AA\pi}(y_t;\nu)$$

is directly <u>interpretable</u>

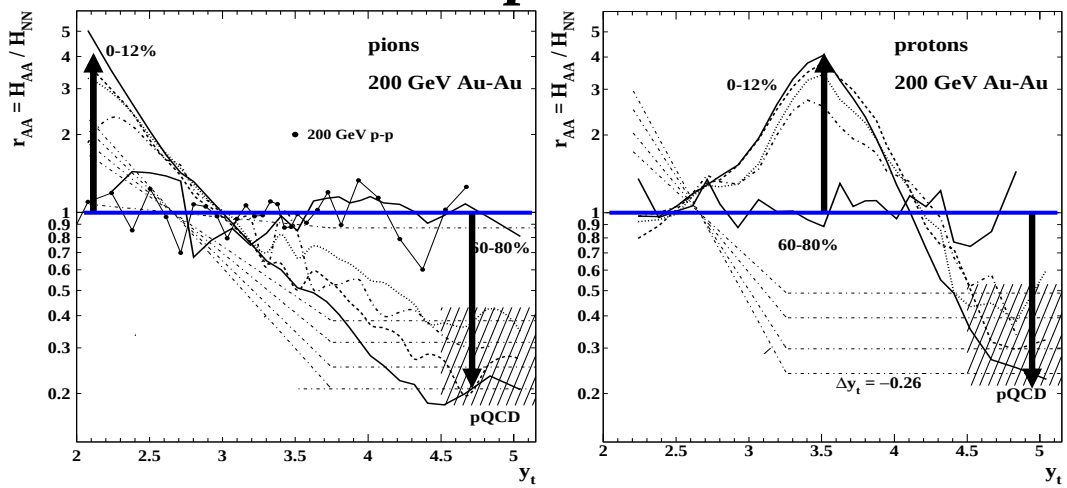
Spectrum Summary

conventional spectra



limited spectrum information

hard-component ratios



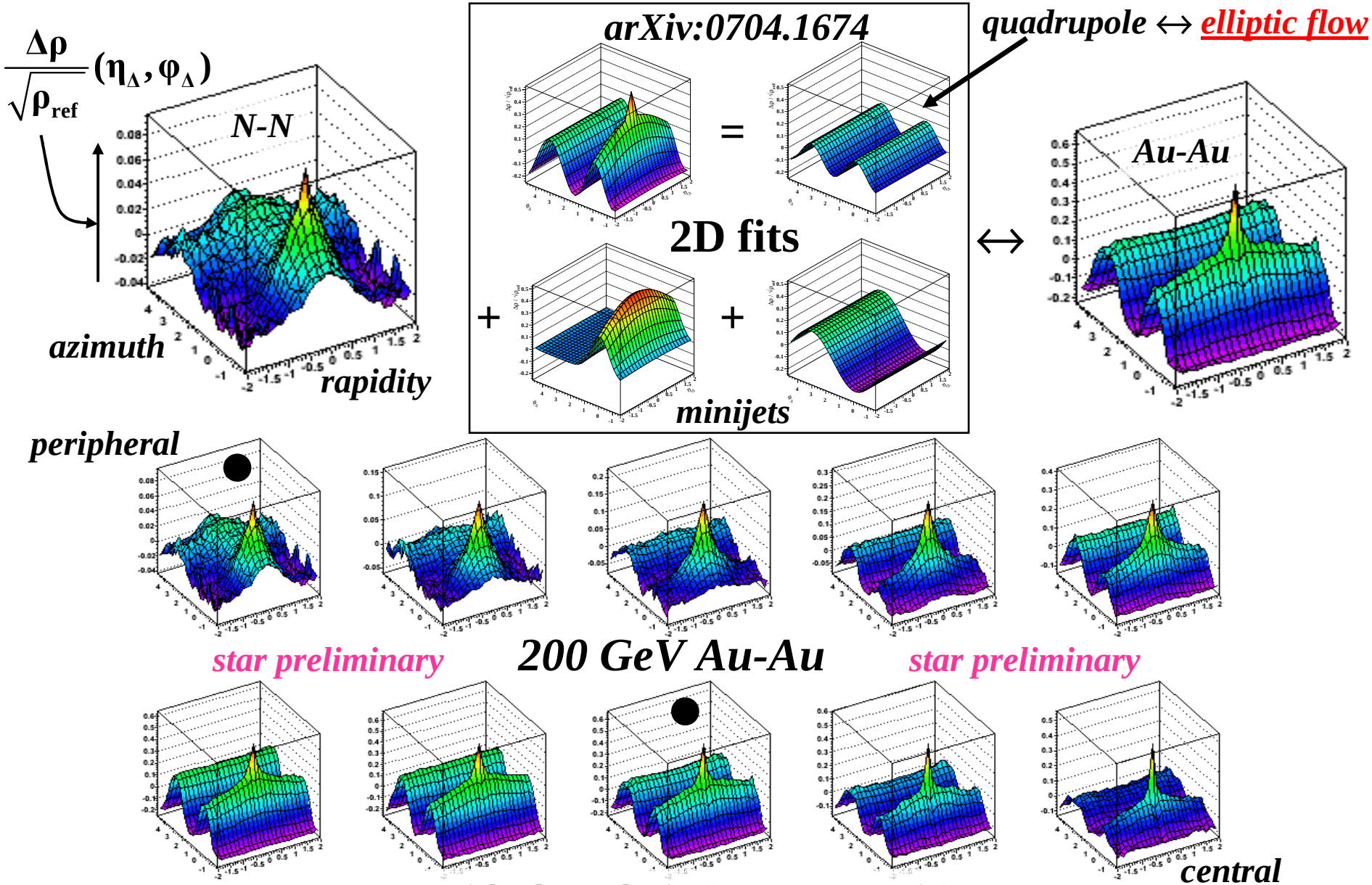
all spectrum information

pion-to-proton vs proton-to-pion

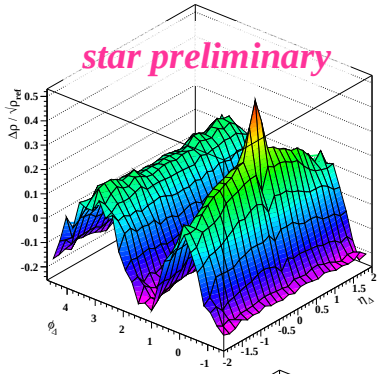
two anomalies!

- ***Spectra have two primary components***
- ***Nucleon and parton fragmentation dominate***
- ***Deviations from reference: parton energy loss***
- ***Hydrodynamics plays no evident role***

2D Angular Autocorrelations



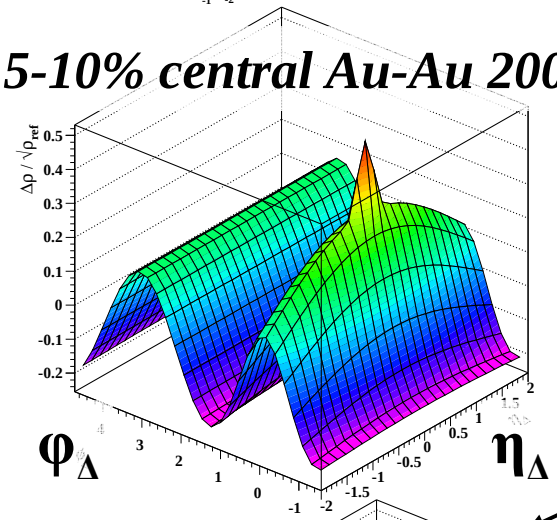
Modeling 2D Autocorrelations



$$\frac{\Delta\rho_A}{\sqrt{\rho_{ref}}}(\eta_\Delta, \phi_\Delta)$$

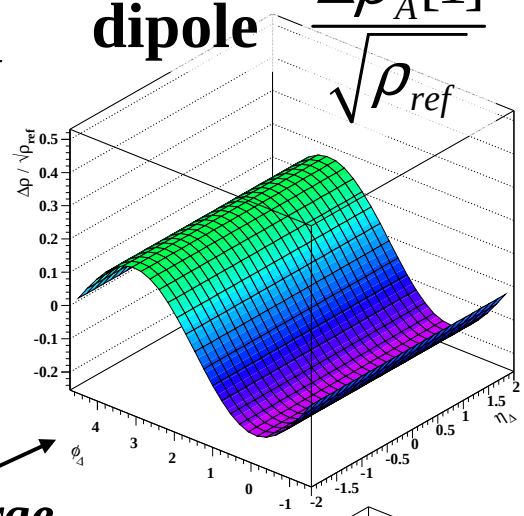
David Kettler model fits

5-10% central Au-Au 200 GeV



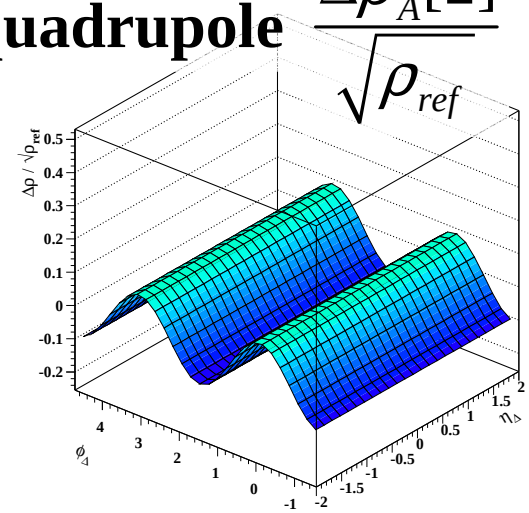
=

dipole $\frac{\Delta\rho_A[1]}{\sqrt{\rho_{ref}}}$



+

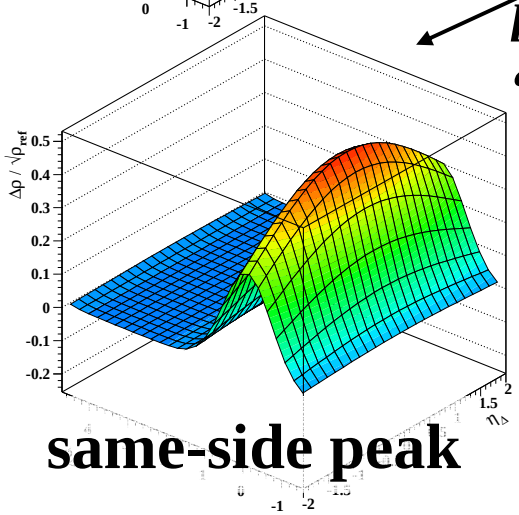
quadrupole $\frac{\Delta\rho_A[2]}{\sqrt{\rho_{ref}}}$



large "nonflow"

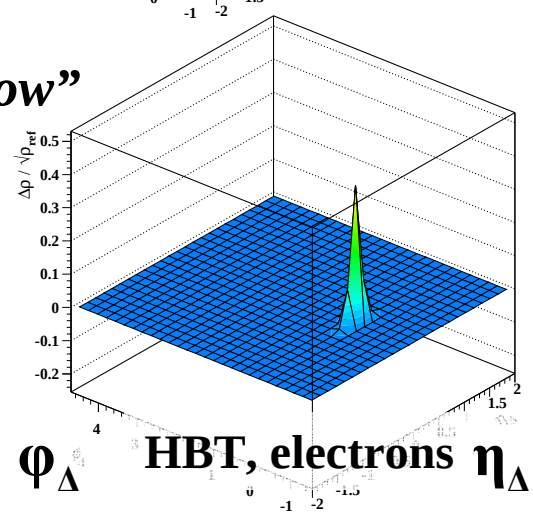
small "flow"

+



same-side peak

+



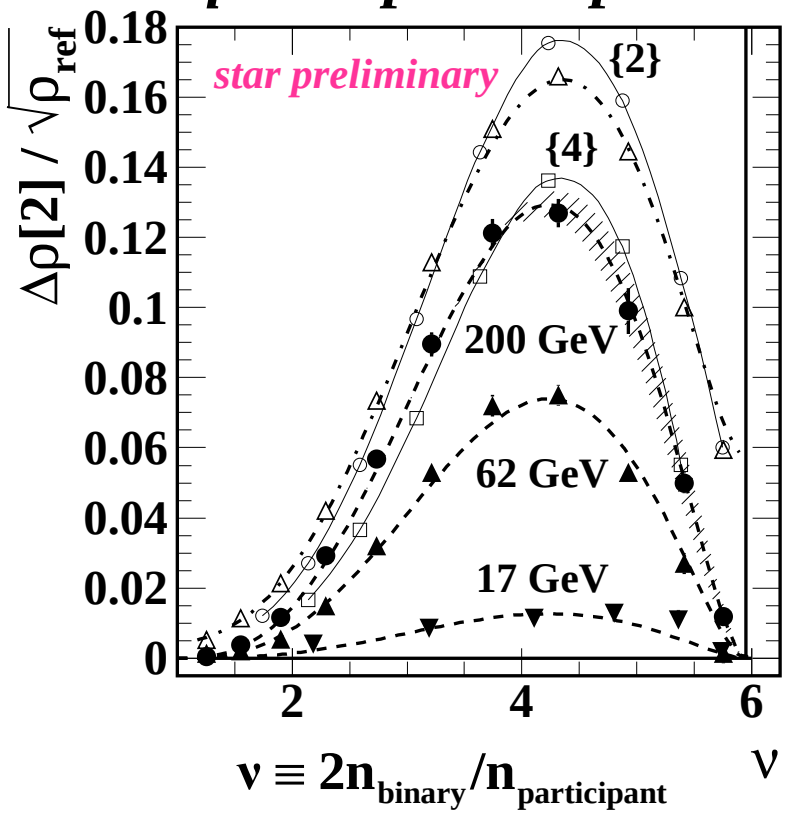
HBT, electrons

$$\Delta\rho_A \equiv \rho_A - \rho_{ref}$$

no *physical* model

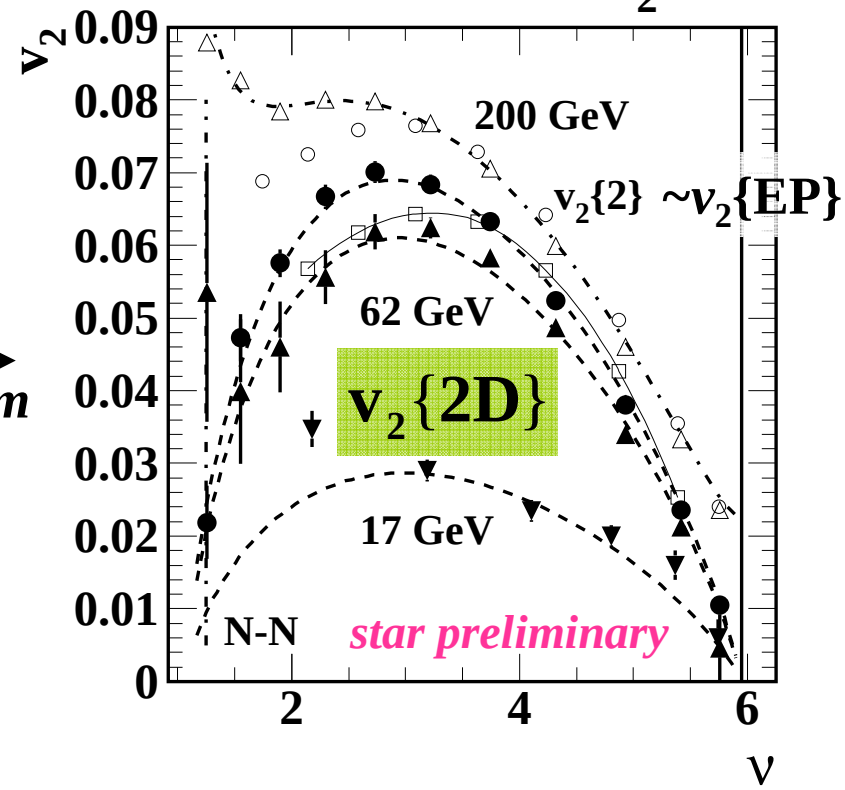
Elliptic Flow or New QCD Physics?

quadrupole amplitude



transform

conventional v_2



conventional statistic

$$\frac{\Delta\rho[2]}{\sqrt{\rho_{ref}}} = \frac{V_2^2}{2\pi\bar{n}} \equiv \frac{\bar{n}\, v_2^2\{2D\}}{2\pi}$$

hydro model

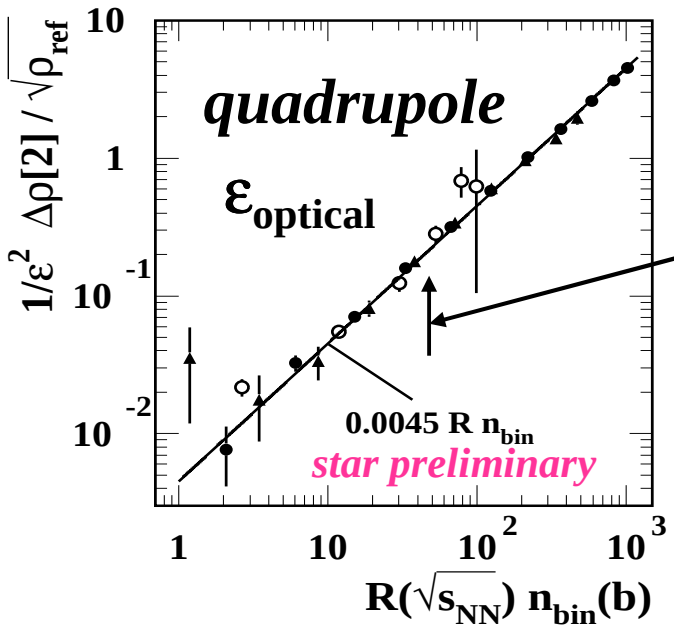
Pearson's covariance

Ollitrault/Voloshin

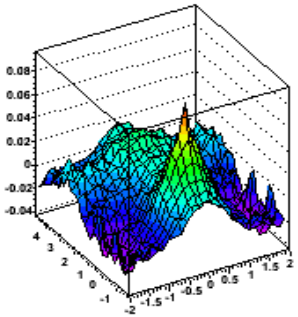
model fits

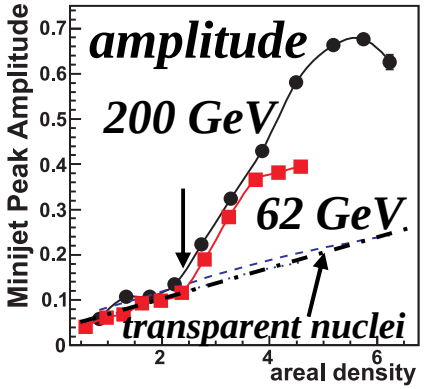
David Kettler (U. Washington – Seattle)

Does "Elliptic Flow" Relate to a Medium?

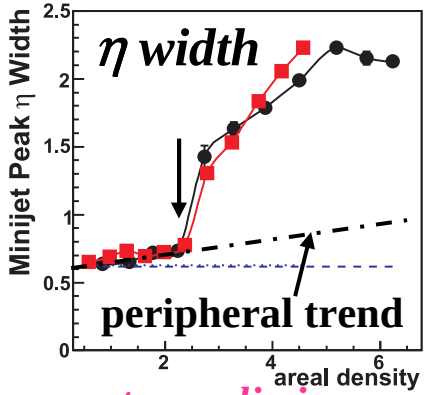


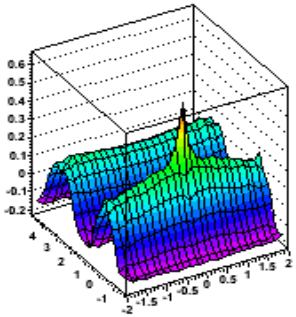
no transition
no medium?



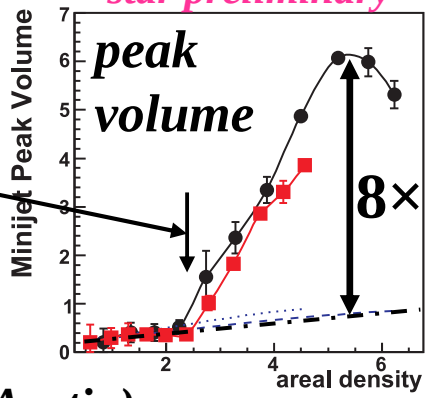


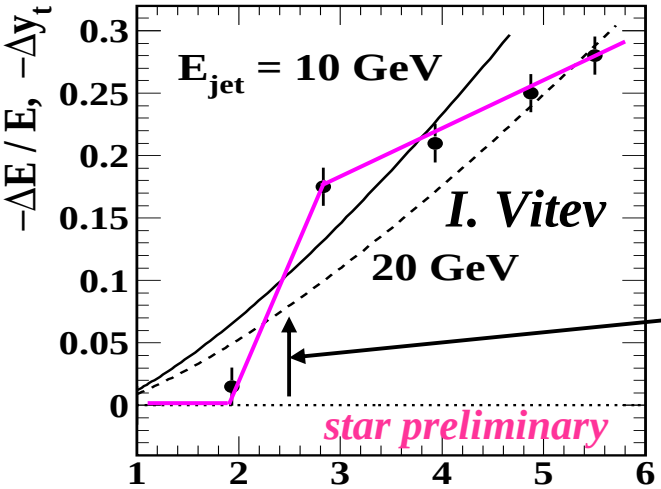
minijet same-side peak





star preliminary





medium?
sharp transitions

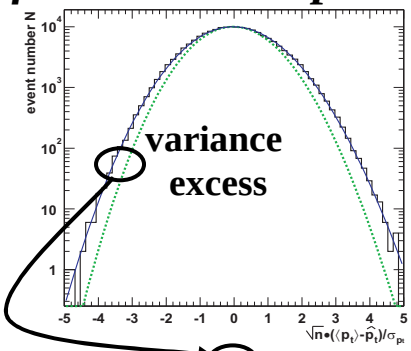
parton energy loss, spectra

M. Daugherity,
R.L. Ray, UT (Austin)

$\langle p_t \rangle$ Fluctuations and p_t Correlations

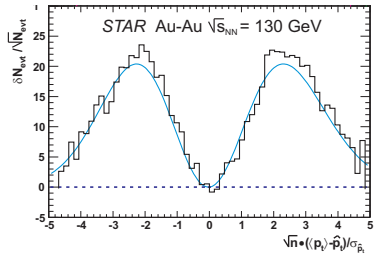
J. Phys. G 32, L37 (2006)

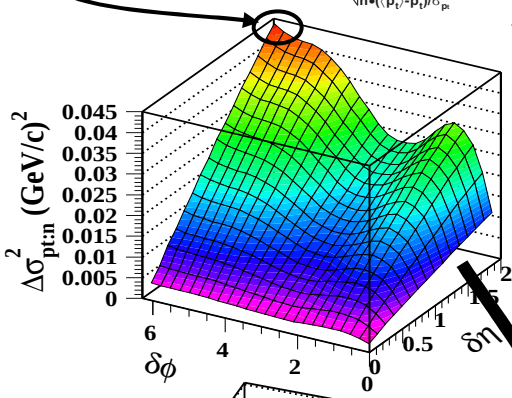
full STAR acceptance



Au-Au 200 GeV

$\langle p_t \rangle$ *fluctuations*

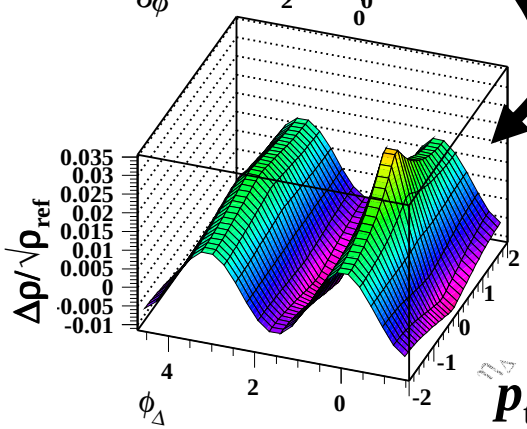




scale dependence

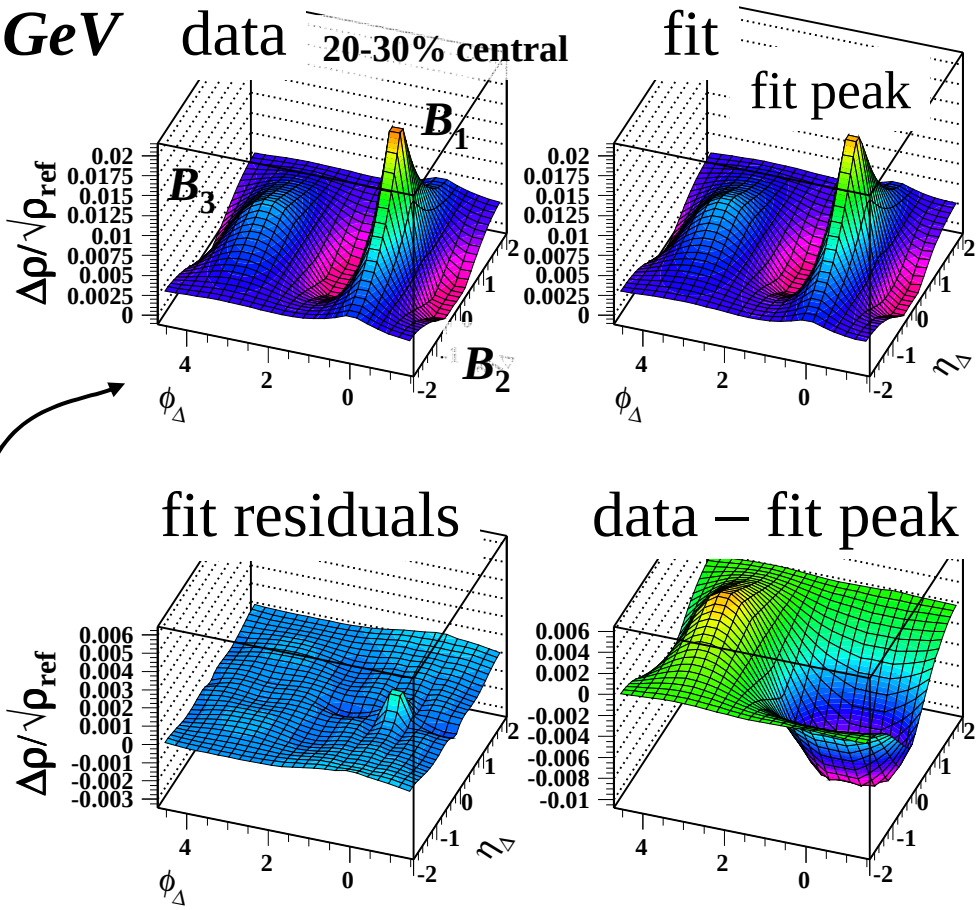
fluctuation inversion

J. Phys. G 31, 809 (2005)



p_t autocorrelation

subtract multipoles



STAR preliminary

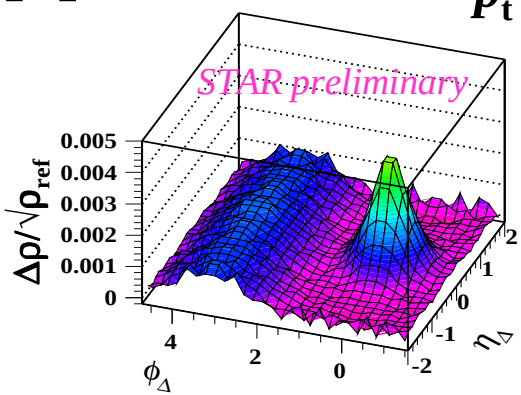
Rosetta stone for fluctuation and correlation analysis

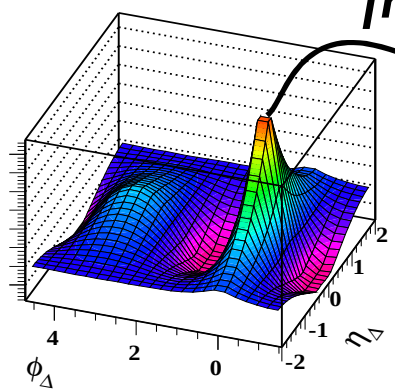
Recoil Response of the QCD Medium

red shifts and blue shifts ***Au-Au – 200 GeV***

p-p 200 GeV

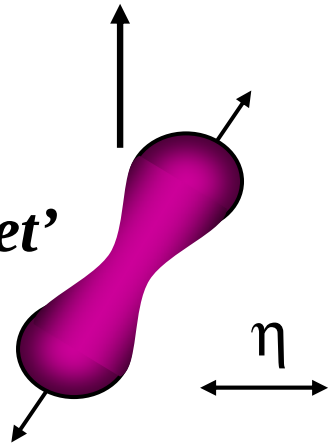
p_t autocorrelations

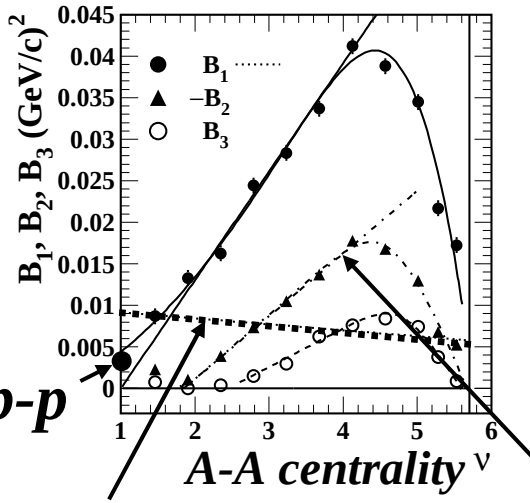




fragments

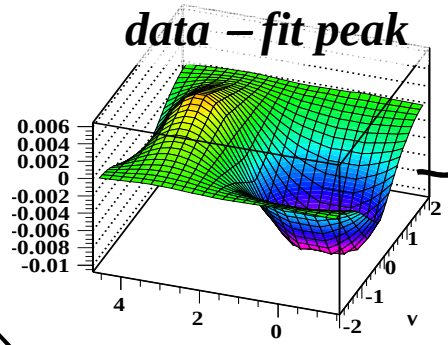
low-Q^2 'jet'



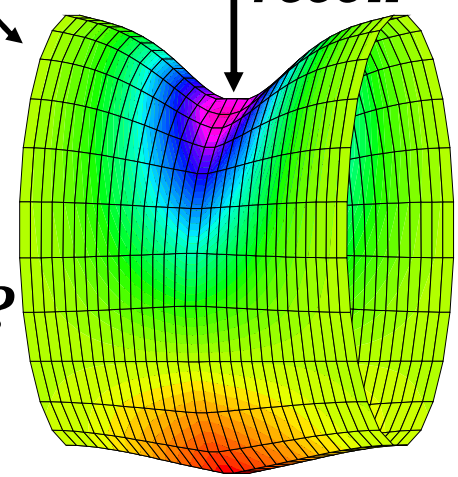


Au-Au 200 GeV

data – fit peak



recoil



colored medium?

p-p

Hubble flow

Hijing quench-on

medium response

The View from the Ridge

- **p/π *spectrum* anomaly is part of fragmentation**
- **Related π/p spectrum anomaly is *larger!***
- **Jet "ridge" is the <u>same</u> fragmentation anomaly**
- **The "ridge" is not an isolated entity**
- **What *evidence* exists for a unique "medium"**

Porky and Pogo

a couple of low-Q^2 partons converse

Minijets and their Interactions

Minijets dominate nuclear collisions

Non-pQCD plays a central role

Hydro is not relevant

New *QCD* phenomena emerge at RHIC

QCD processes at all energy scales