

*ISMD 2011 – Hiroshima*

**Review of Soft Interactions  
*and*  
Multiparticle Correlations**

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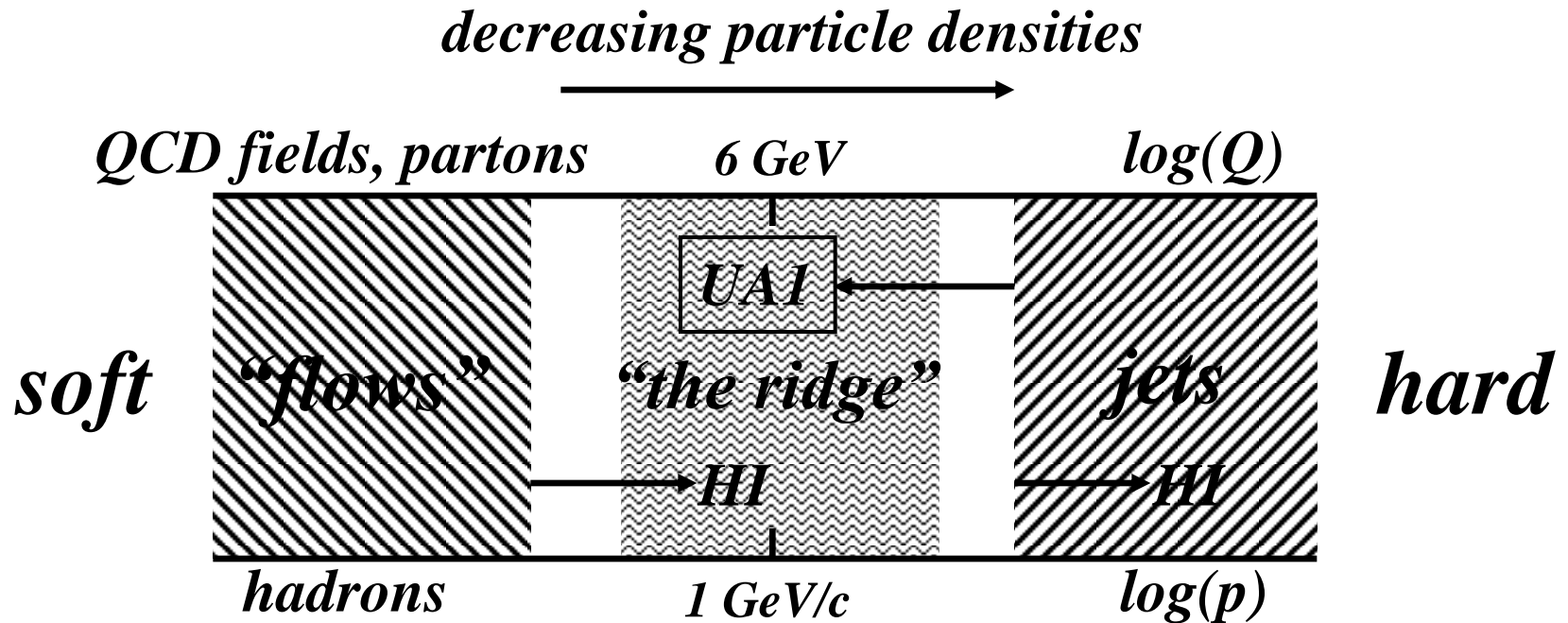
**September, 2011**

# Agenda

- *Jets and flows compete for  $p_t$  real estate*
- *Initial-state geometry (?) tries for center stage*
- *Dual description systems are interpreted oppositely nearly 100 years old!*
- *UA1 is still centrally important after 25 years*
- *Minijet systematics may play a significant role*
- *Underlying Event? – move back one space*
- *Flows? – move back two spaces*

# Jets vs Flows in Heavy Ion Collisions

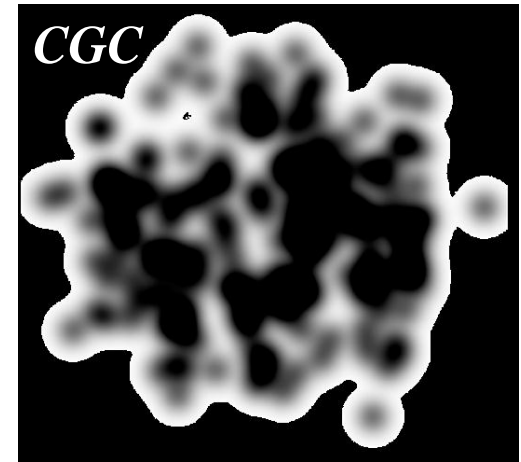
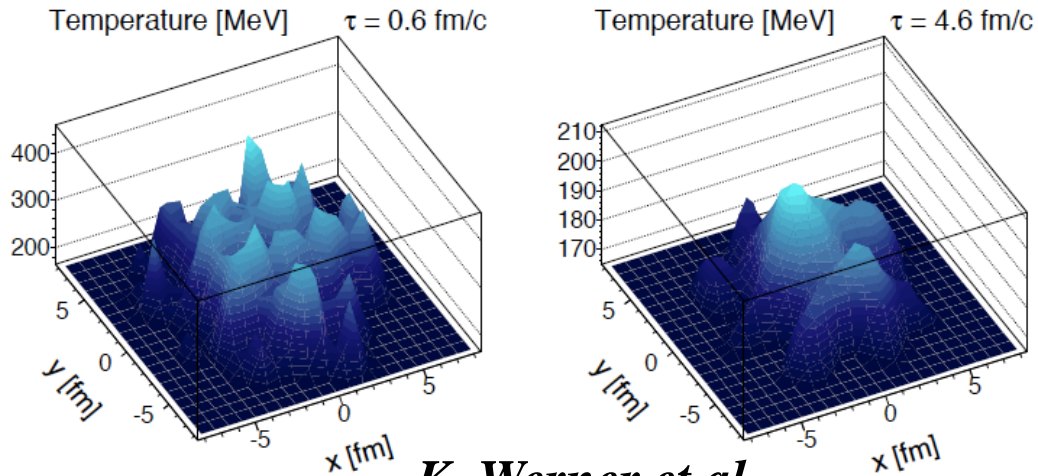
*“there’s plenty of room in the middle”*



*there has emerged a dramatic struggle  
for possession of the hadronic final state  
centered on the nature of “the ridge”*

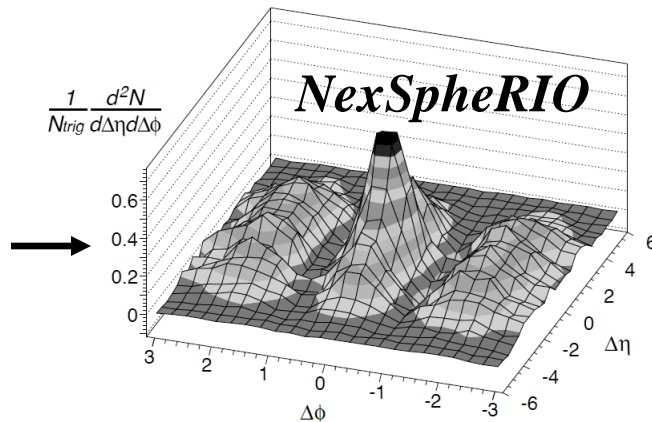
# Initial-state (IS) Geometry

*conjectured density fluctuations*



*IS conjectures expressed in Monte Carlos produce final-state (FS) structure similar in some aspects to the observed final state*

*Other aspects may be contradicted by data*



*and several others...*

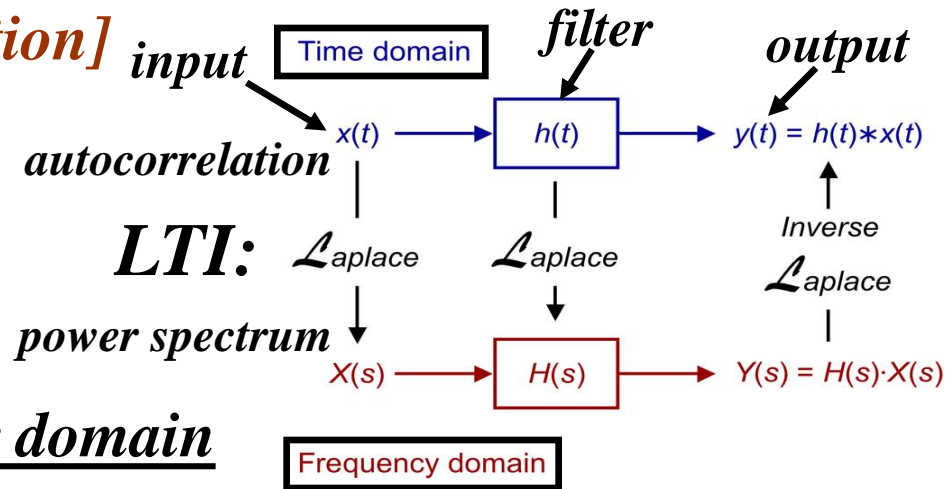
# Multipoles and Transfer Functions

*[Brownian motion, Langevin equation]*

“LTI system theory” describes both jet production and flows

jets – (momentum) space domain

geometry and flows – wave-number domain



*established QCD*

*sensitive to environment*

*observed structure*

*space domain*

*IS partons*

*fragmentation*

*FS jets*

*a new transport strategy?*

*conventional HE nuclear physics*

*input*

*output*

*wave-number domain*

*IS multipoles*

*collective expansion*

*FS multipoles*

*conjectured*

*sought*

*recent developments*

*heavy ion expectations*

# Autocorrelations and Impulse Responses

*IS partons fragment to FS jets*

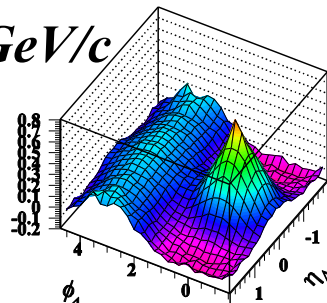
*participant partons*

*folding integral*  $\longrightarrow$

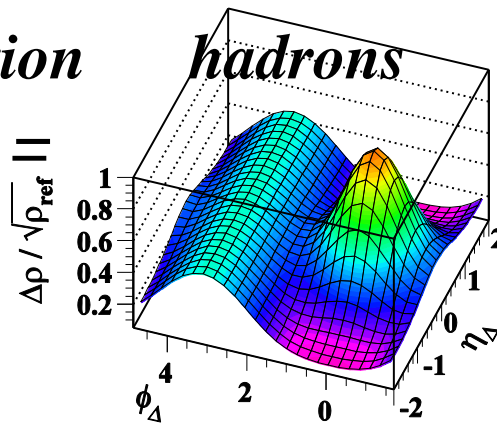
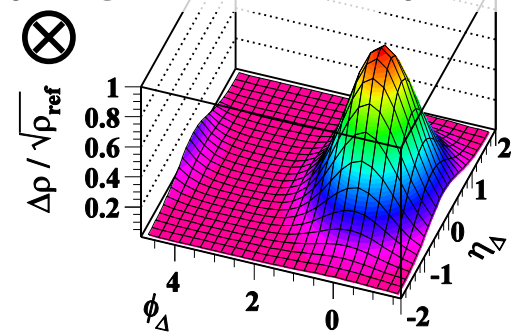
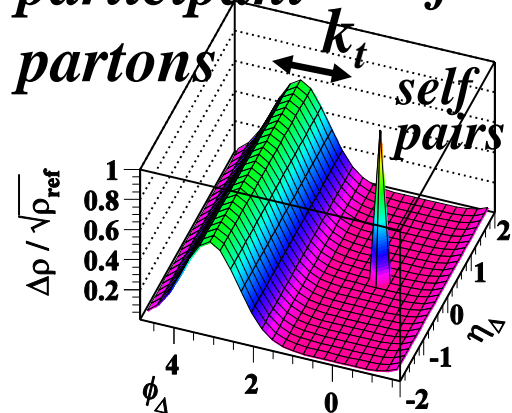
*fragmentation function*

*hadrons*

$p_t \approx 0.6 \text{ GeV}/c$



*p-p data*



*input autocorrelation*

*impulse response*

*output autocorrelation*

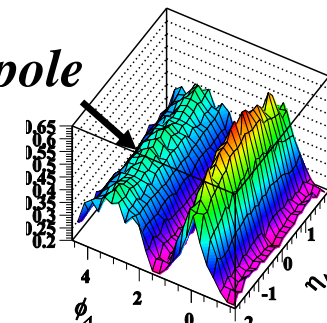
*IS geometry transitions to FS multipoles*

*participant nucleons*

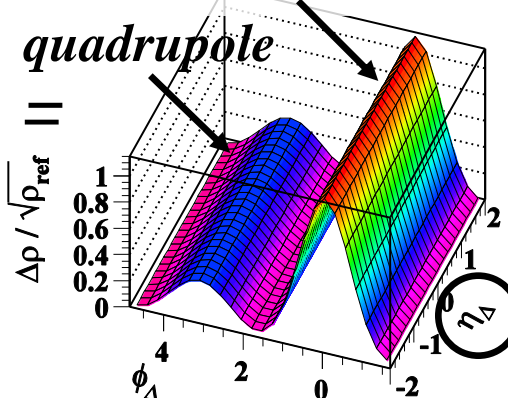
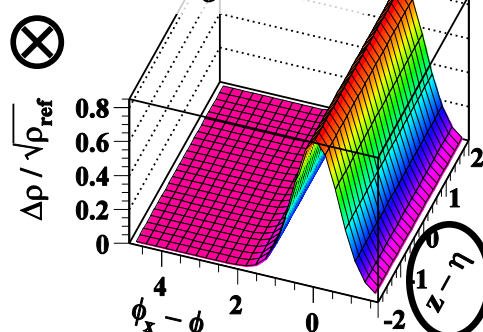
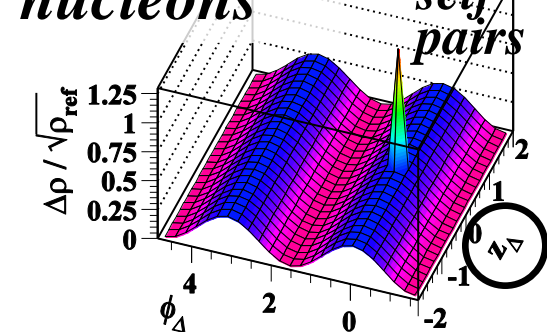
*radial flow?*

*“ridge” odd harmonics*

*dipole*



*Au-Au data 0-5%*



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# What are (mini)Jets?

*big jets:*

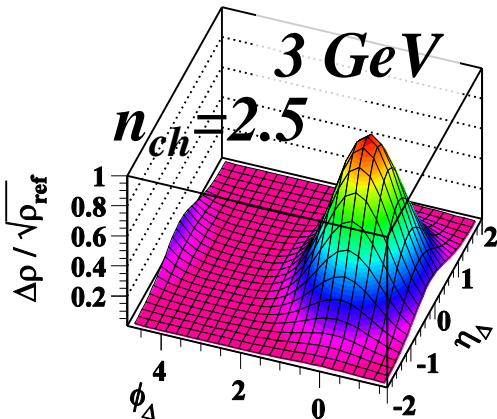
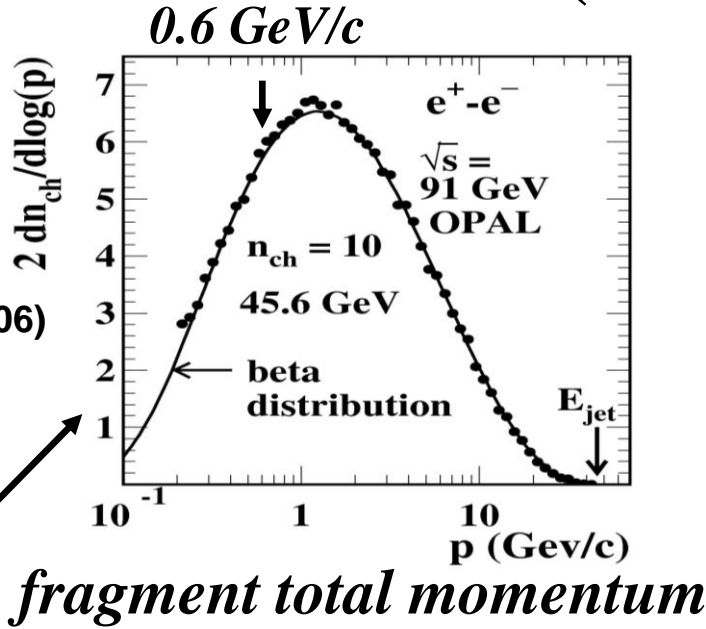
PRD 74, 034012 (2006)

*hard jets*

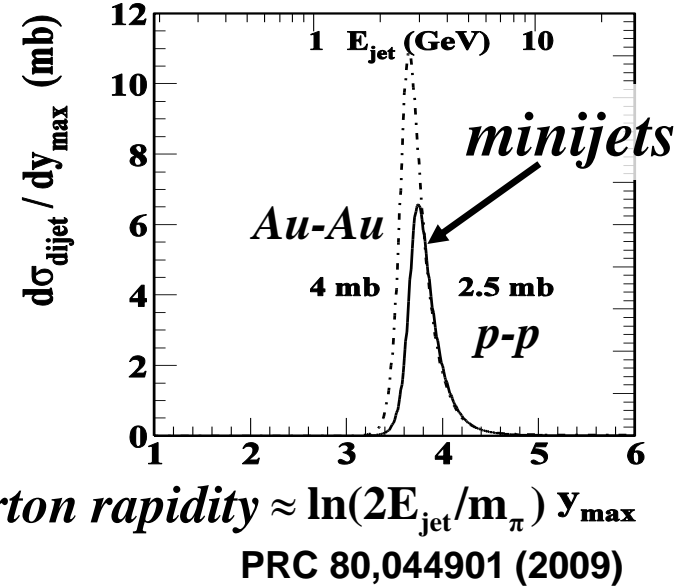
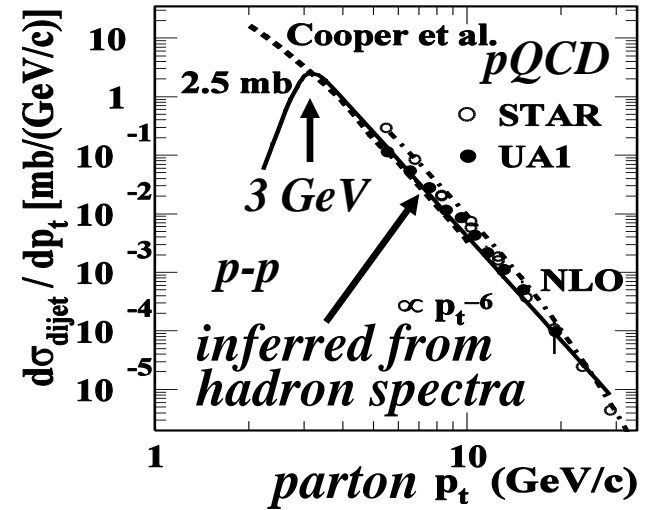
*fragmentation functions*

*small jets:*

*soft hadrons*

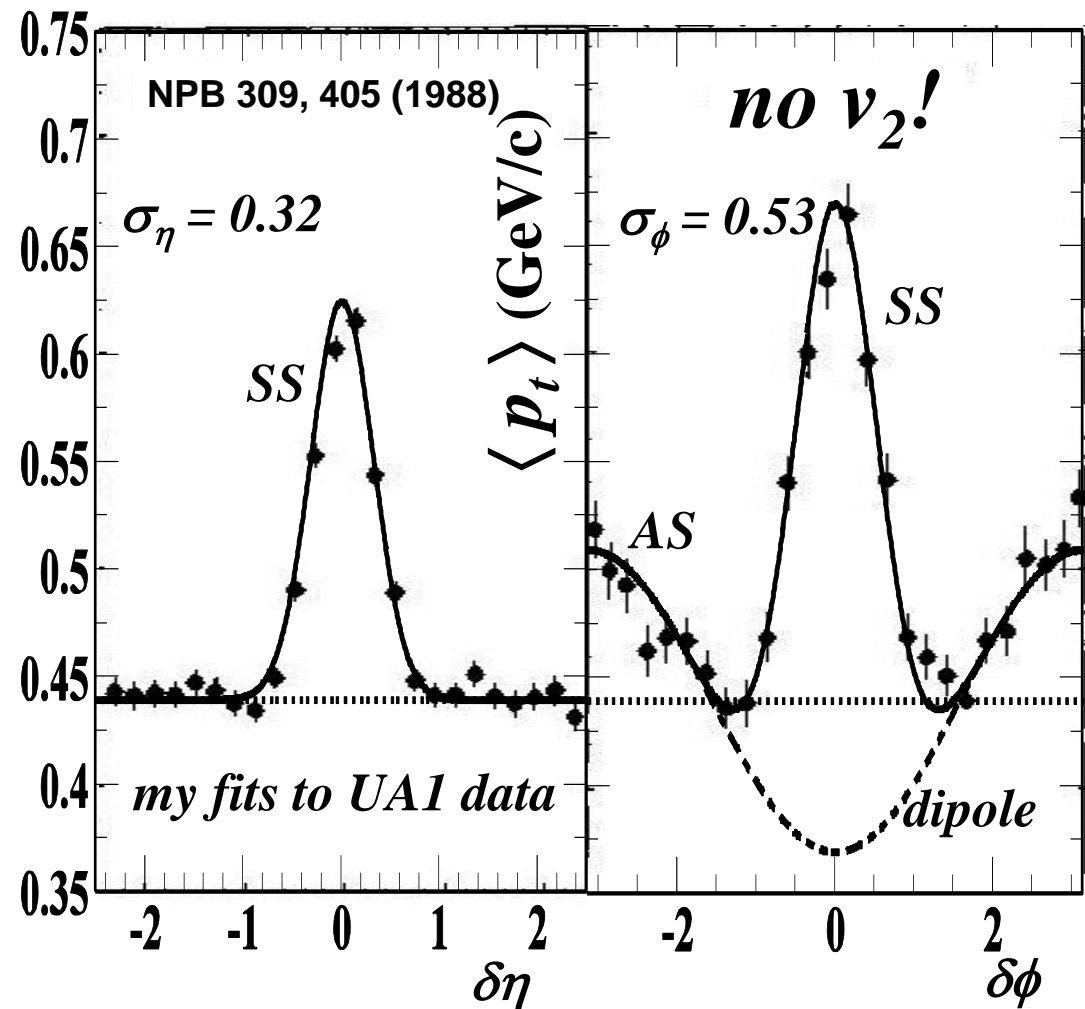


*data vs pQCD*



*minijets: 3 GeV jets consistent with UA1*

# UA1 Minijets from 900 GeV p-p



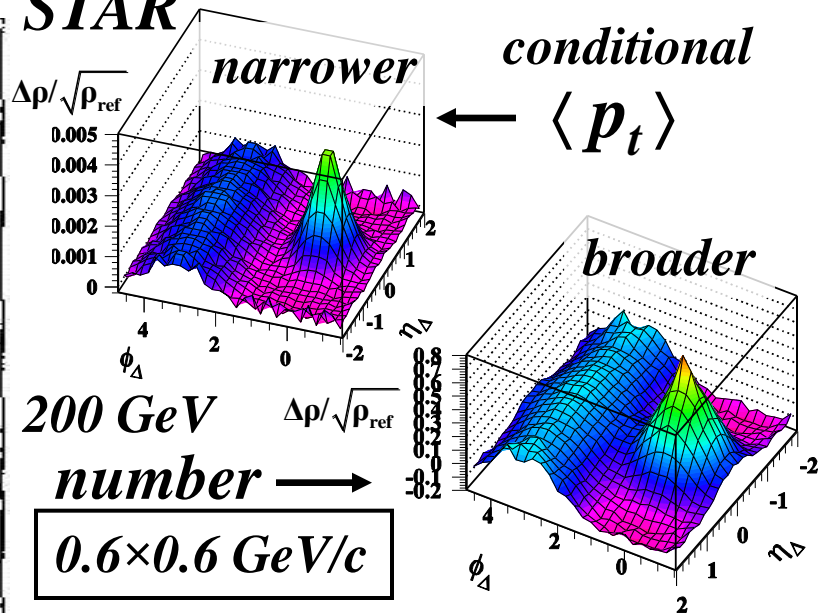
SS peak well modeled  
by 2D Gaussian

AS peak well  
modeled by dipole

particle  $\langle p_t \rangle$  relative to 3-4 GeV reconstructed-jet axis

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$0.6 \times 0.6$  GeV/c

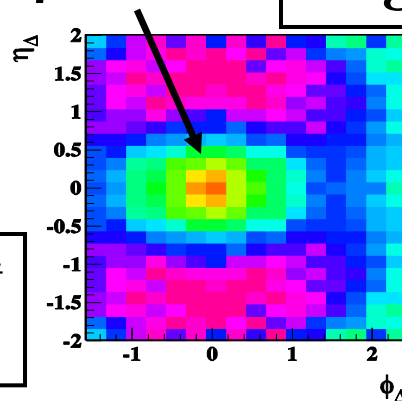
$\phi$  width 65% larger  
than the  $\eta$  width

ridge?

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200 GeV p-p

1:1 aspect  
ratio



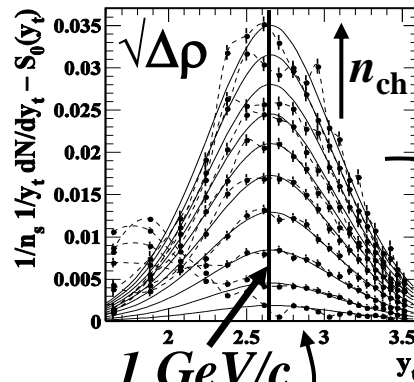
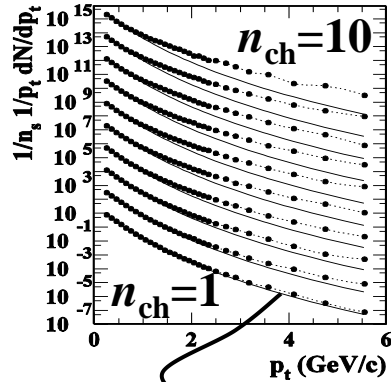


# Minijets in p-p Spectra and Correlations

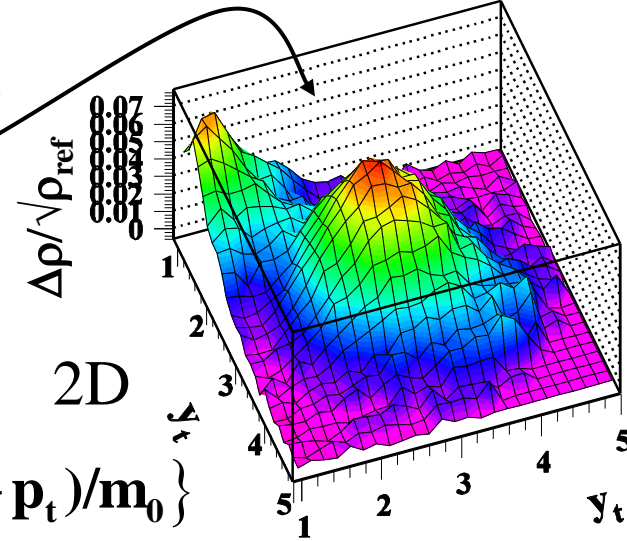
2004

*minijets from  $p_t$  spectra*

2005



*minijet fragments*



**p-p**  
**200 GeV**

subtract soft reference  
 $p_t \rightarrow y_t$

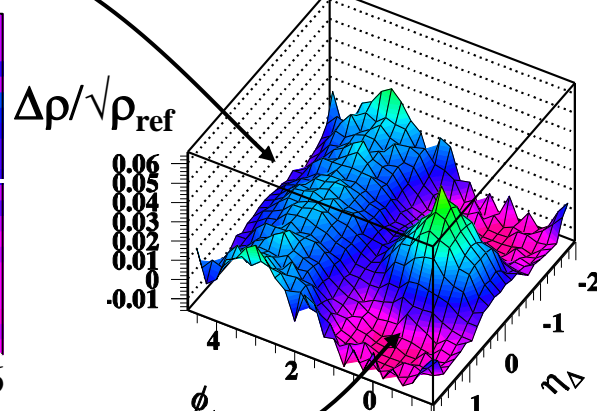
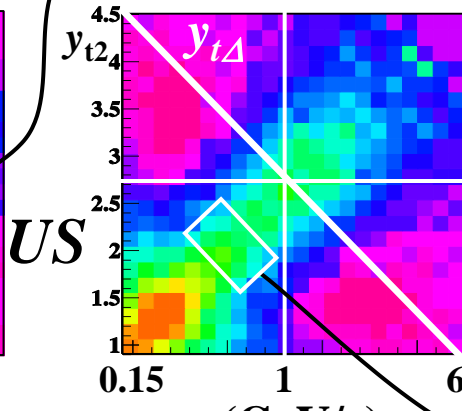
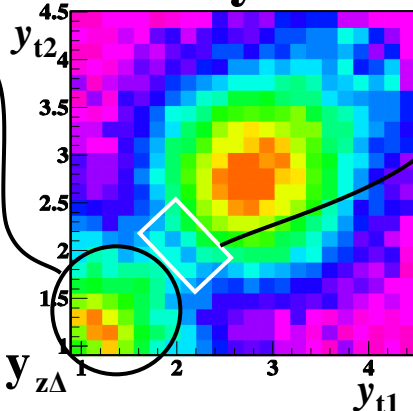
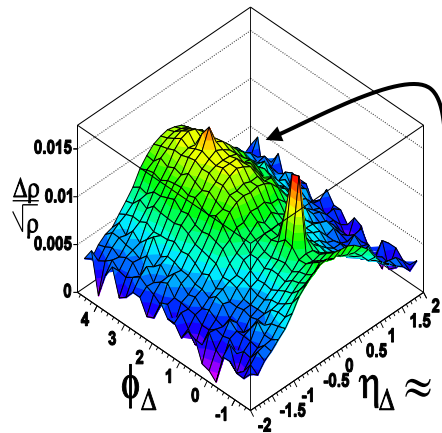
$$y_t \equiv \ln \left\{ (m_t + p_t) / m_0 \right\}$$

Phys Rev D 74, 032006 (2006)

**away side**

**same side**

hadron  $p_t \sim 0.6 \text{ GeV}/c$



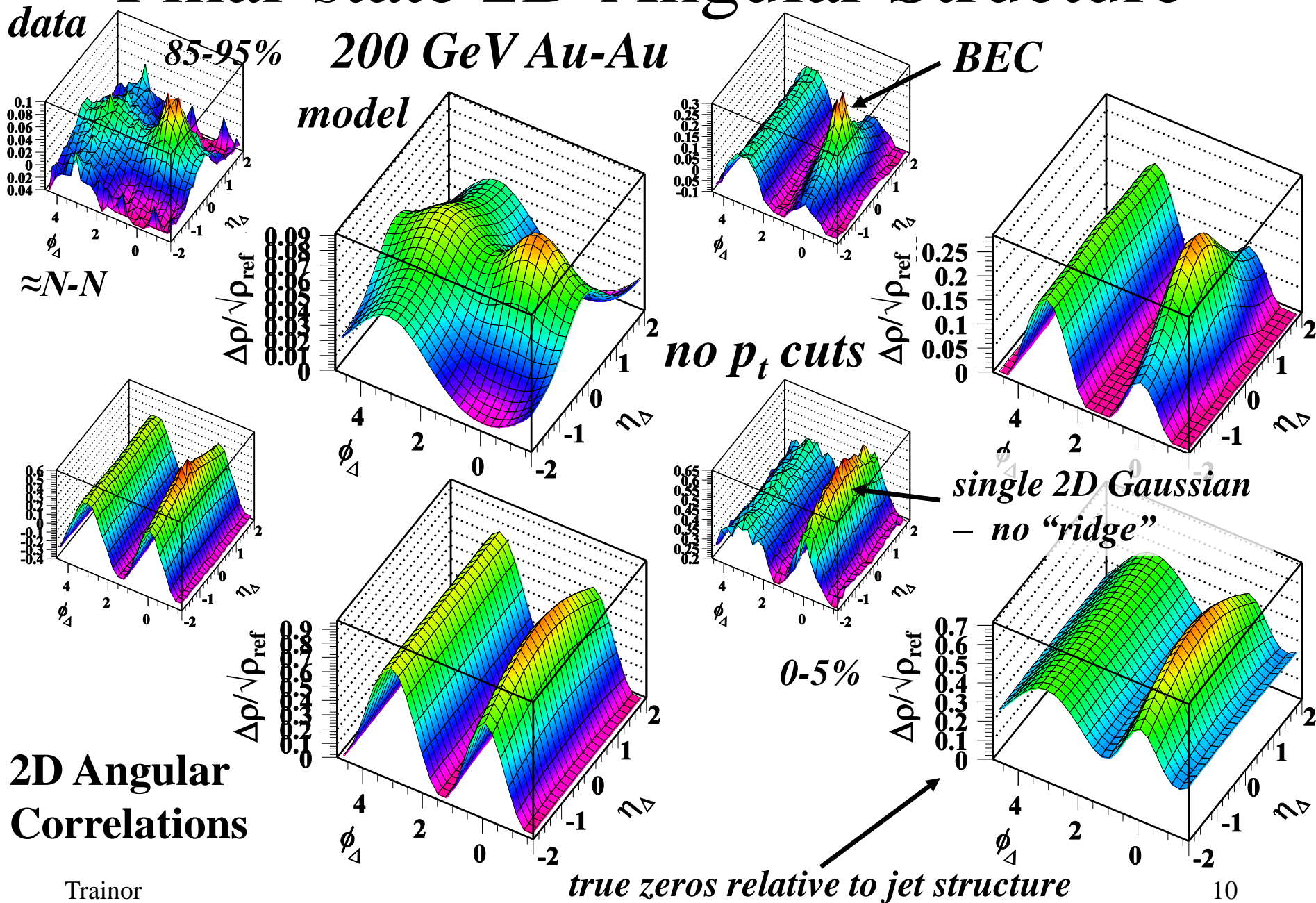
*projectile-nucleon fragments*

J Phys: Conf Ser 27, 98 (2005)

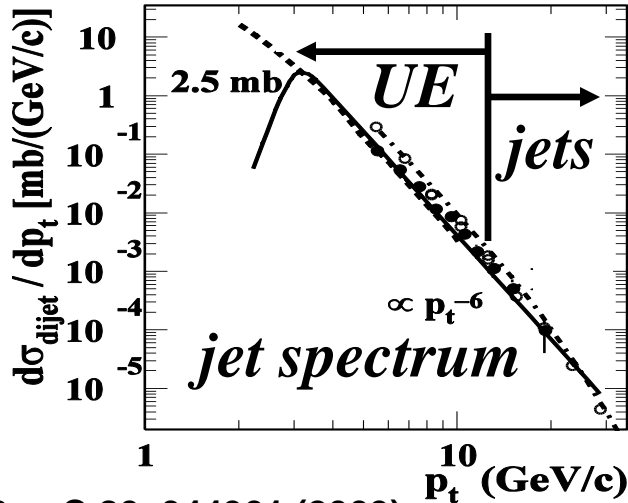
*parton fragments*

*minimum-bias: no trigger condition*

# Final-state 2D Angular Structure



# What is the Underlying Event?



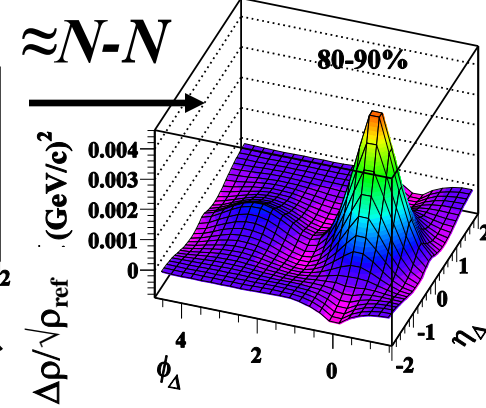
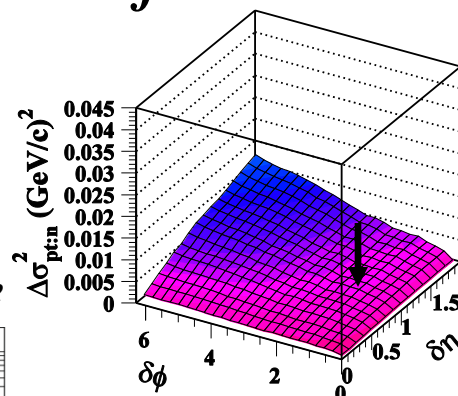
*background fluctuations in jet cone – contribution by minijets*

*fluctuation scaling inversion*

J Phys G 32, L37 (2006)

*fluctuations*

*correlations*



Phys Rev C 80, 044901 (2009)

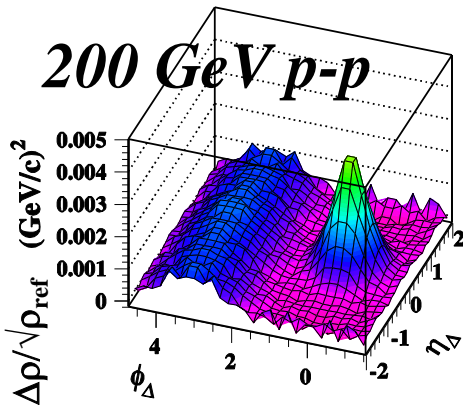
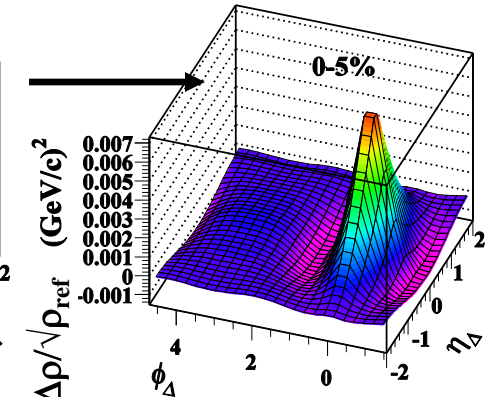
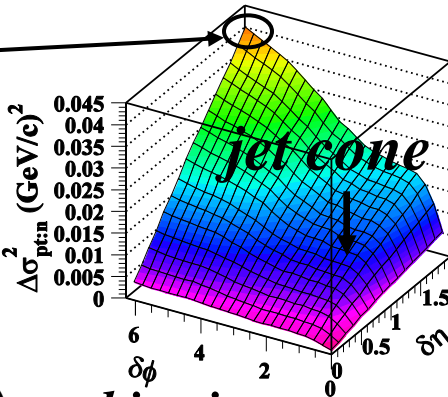
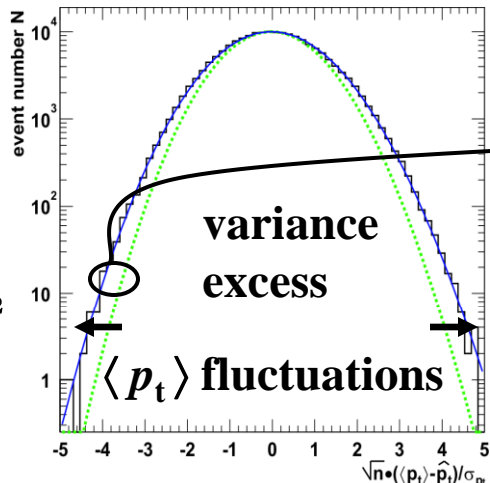
*UE is the rest of the jet spectrum*

*direct*

*full STAR acceptance*

*pair counting*

*200 GeV p-p*

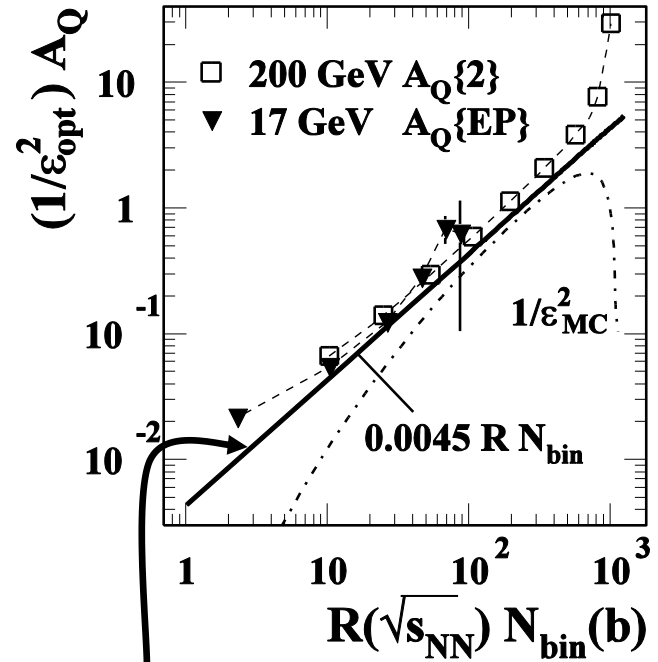
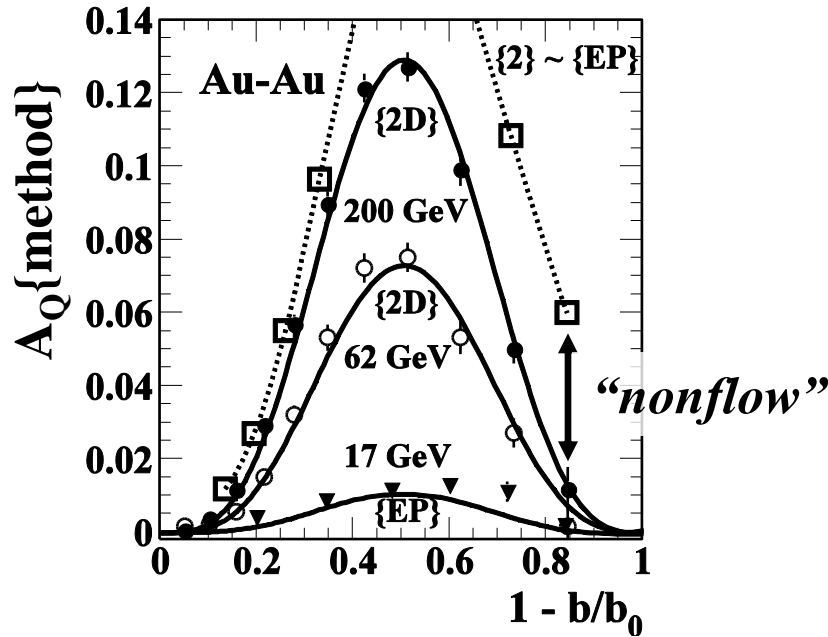


Phys Rev C 71, 64906 (2003)

*bin sizes*

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# Nonjet Azimuth Quadrupole $v_2\{2D\}$



$A_Q\{2D\}$  data from 2D model fits

*uniform over  $|\eta_\Delta| < 2$*

$$A_Q\{2D\} \equiv \rho_0(b) v_2^2\{2D\} = 0.0045 R N_{\text{bin}} \epsilon_{2,\text{opt}}^2$$

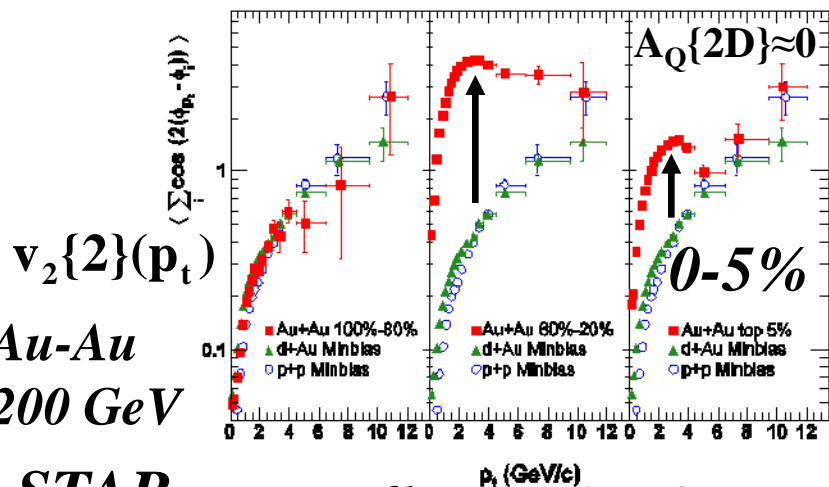
$$\rho_0(b) = dn_{\text{ch}}/2\pi d\eta$$

*is this “elliptic flow”?*

Eur Phys J C 62, 175 (2009)

*unique phenomenon independent of SS, AS jet structure*

# Flows – What Methods, What Values?



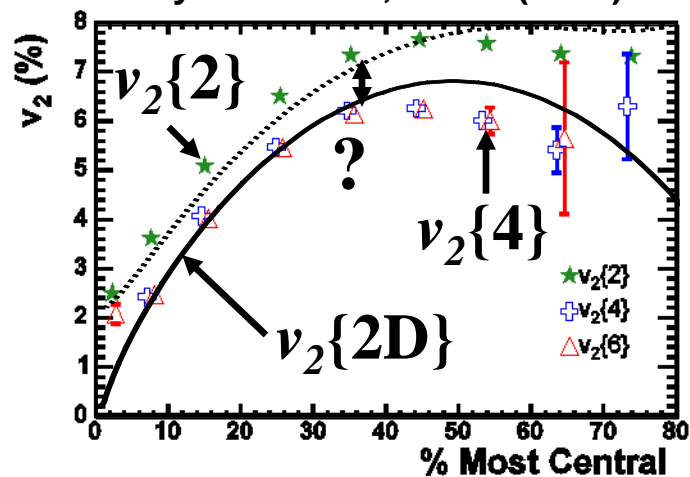
Au-Au  
200 GeV

STAR

*flow or jets?*

*assumes jets cannot change!*

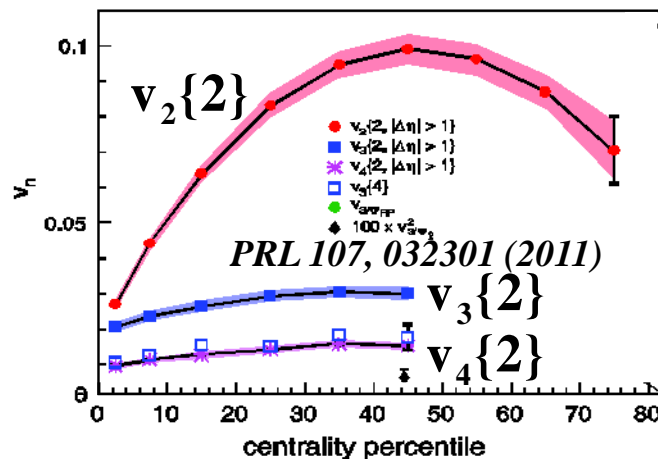
Phys Rev C 72, 14904 (2005)



*nonflow, or  $v_2$  fluctuations?*

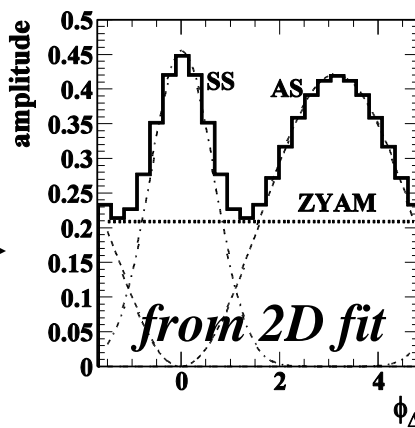
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*what interpretations?*

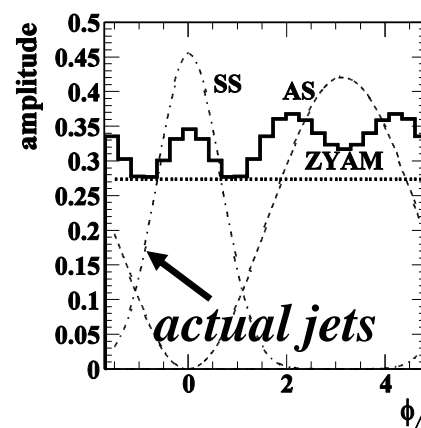


Pb-Pb  
2.76 TeV  
ALICE

*does this actually relate to jets?*



*subtract  $v_2\{2D\}$*



*subtract  $v_2\{2\}$*

*which are the jets?*

# Summary

- *Soft physics and correlations mark a critical interface*
- *Jets and their modifications are under-explored*
- *“Flow” and “nonflow” should be better defined*
- *Is any azimuth structure “harmonic flows?”*
- *“Ridge” structure may be modified (polarized) jets*
- *Alternative descriptions should be directly compared*
- *Conflict resolution may lead to important new physics*
- *Correspondence with Brownian motion (1905) is apt*