The "Soft Ridge" – Is it Initial-state Geometry or Modified Jets?

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Introduction

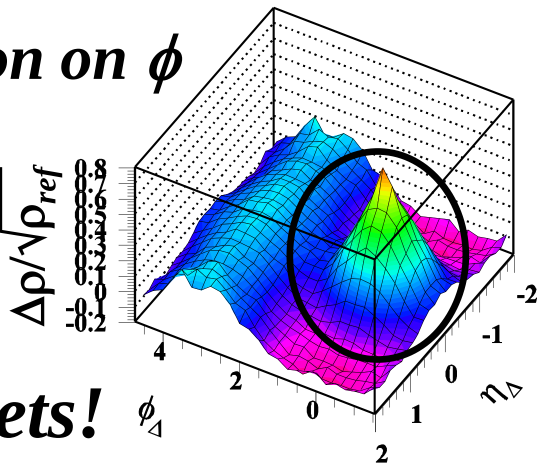
- *A same-side 2D peak dominates angular correlations*
- *In p-p collisions that peak is consistent with minijets*
- *In more-central Au-Au the peak is elongated on η*
- *Some want to interpret that "soft ridge" as flows*
- *We consider the flow conjecture in a 2D context*

What is the Same-side 2D Peak?

p-p

elongation on ϕ

2:1

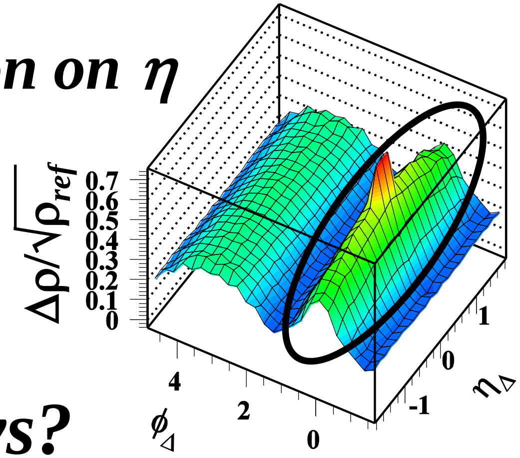


(mini) jets!

central Au-Au

elongation on η

1:3



flows?

the "Soft Ridge"

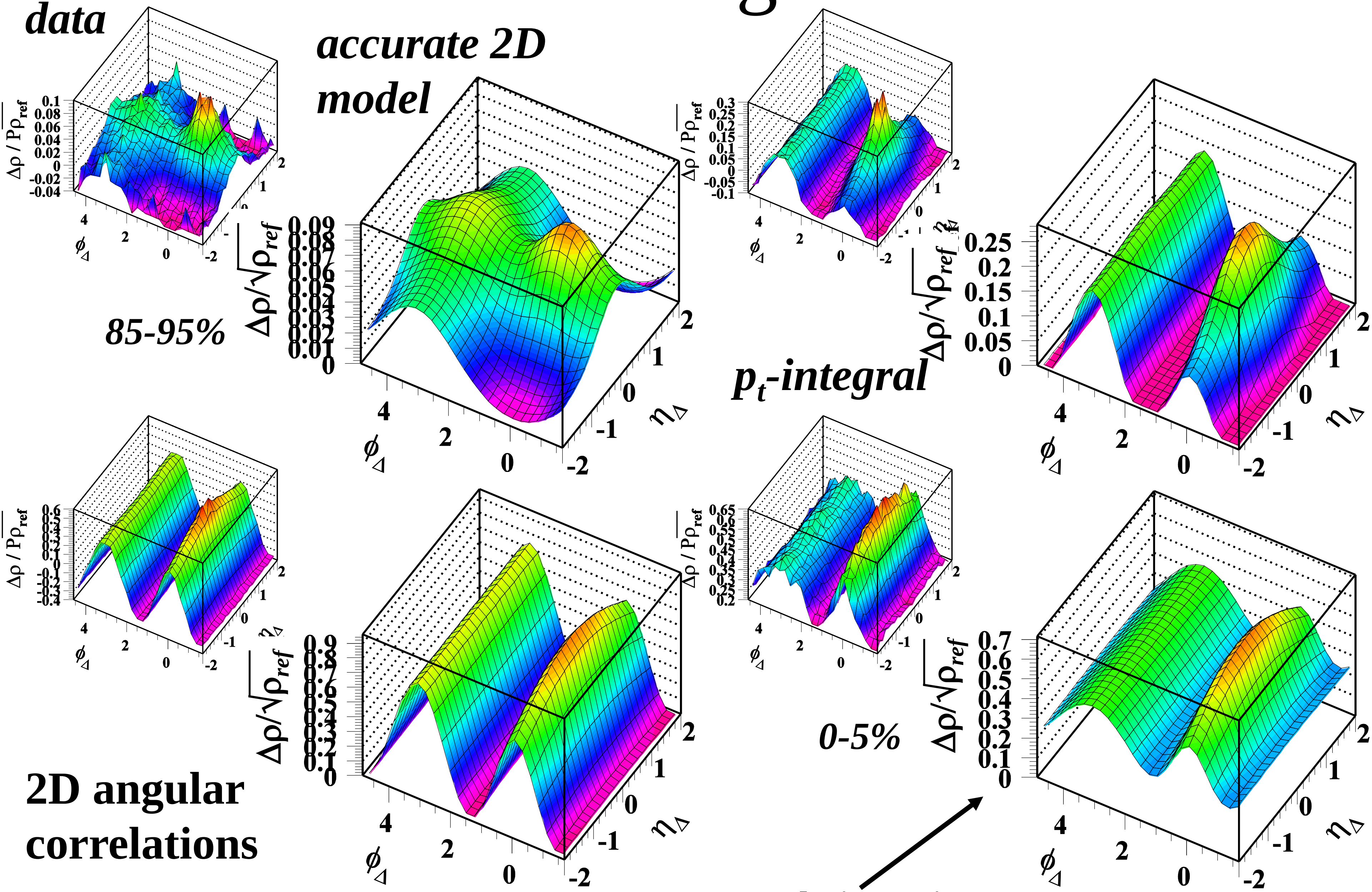
Recipe: convert jets to flows

1. ***project (part of ?) the η acceptance onto azimuth ϕ***
2. ***fit the 1D projection on ϕ with a Fourier series***
3. ***interpret each series term as a "harmonic flow"***
4. ***attribute flows to <u>conjectured</u> A-A initial-state geometry***

Final-state 2D Angular Structure

data

accurate 2D model



85-95%

p_t-integral

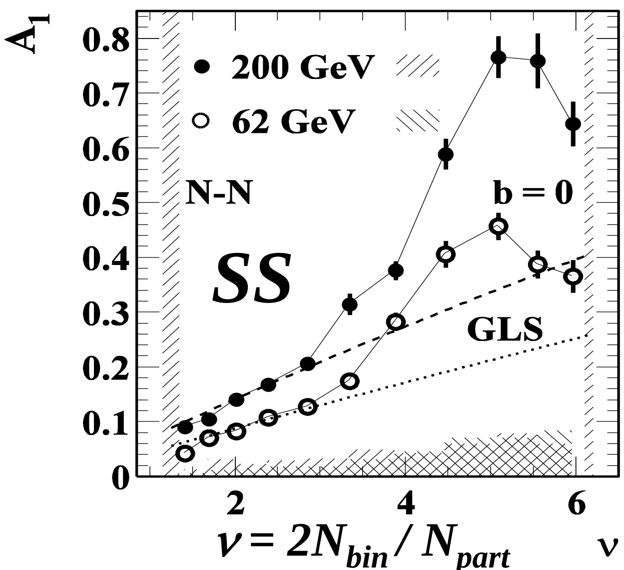
0-5%

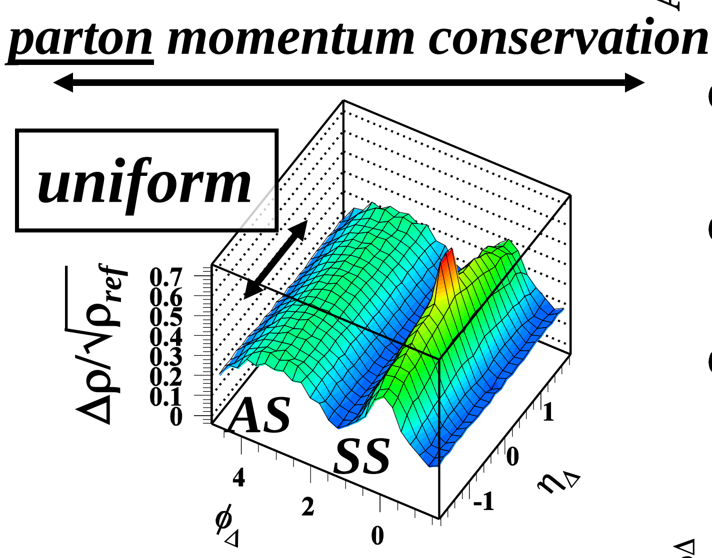
2D angular correlations

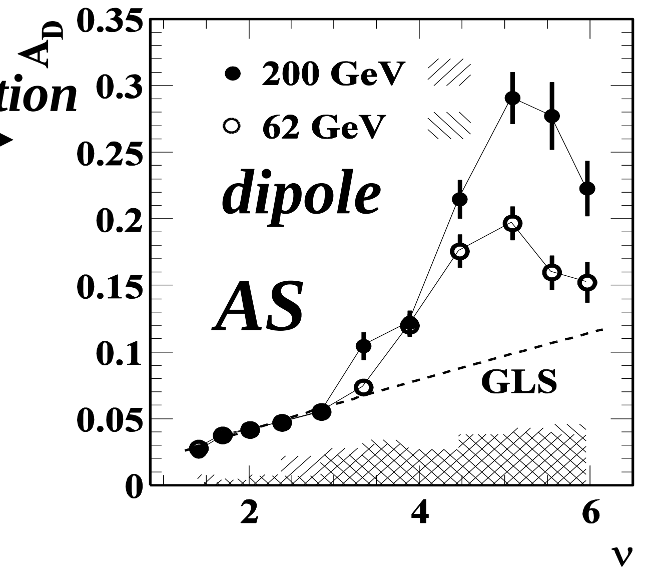
true zeros relative to jet structure

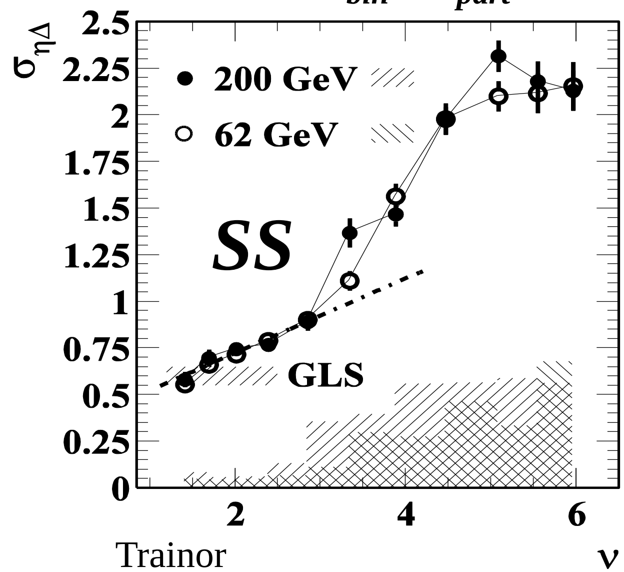
Minimum-bias Jet (minijet) Properties

2D same-side (SS) and 1D away-side (AS) peaks



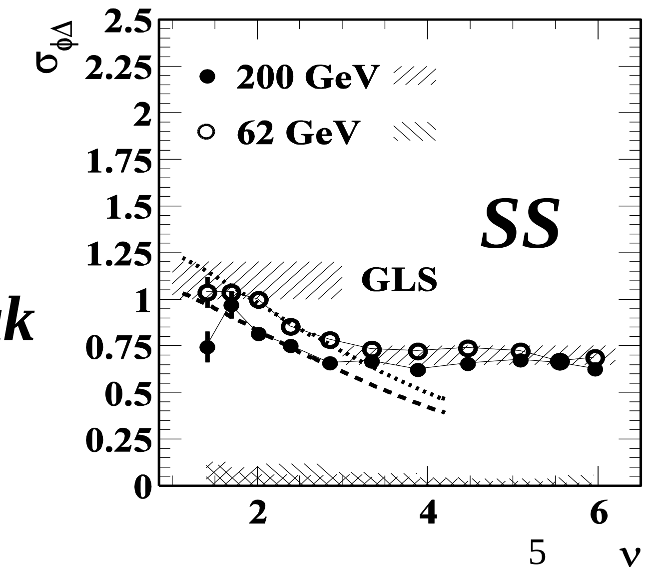




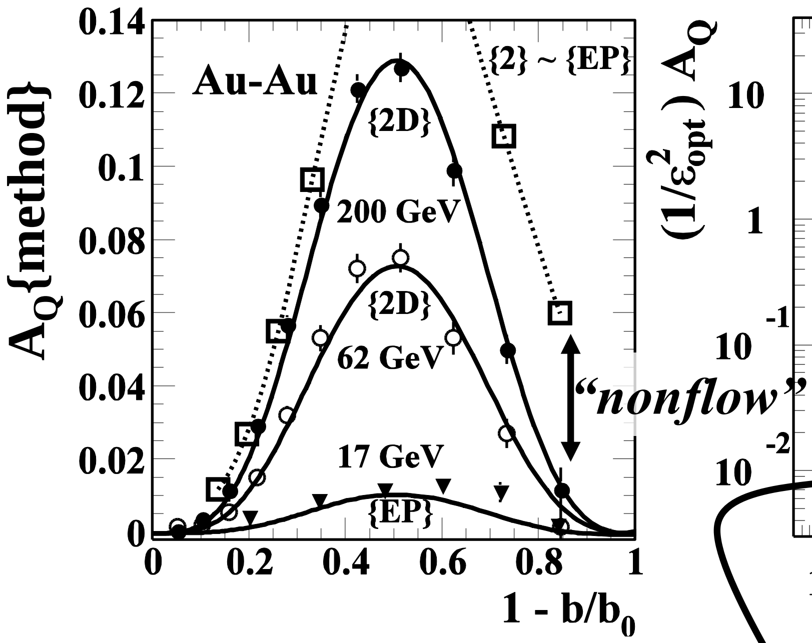


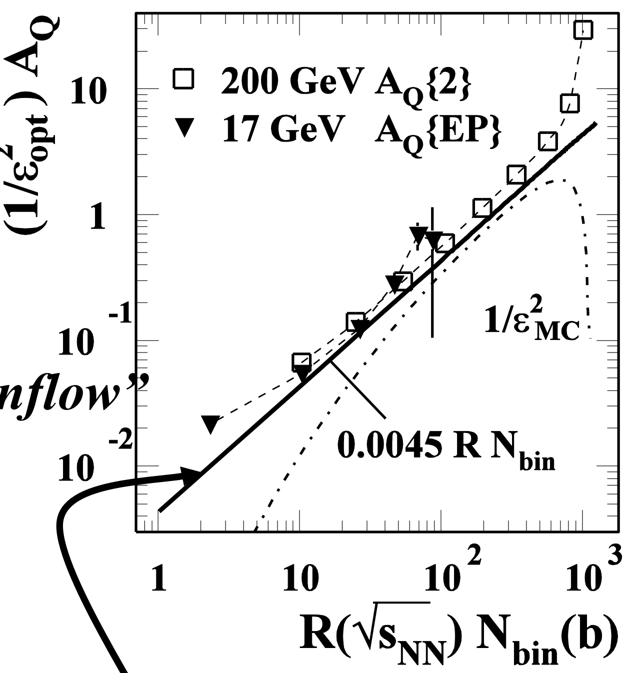
All AS structure is uniform on η_Δ

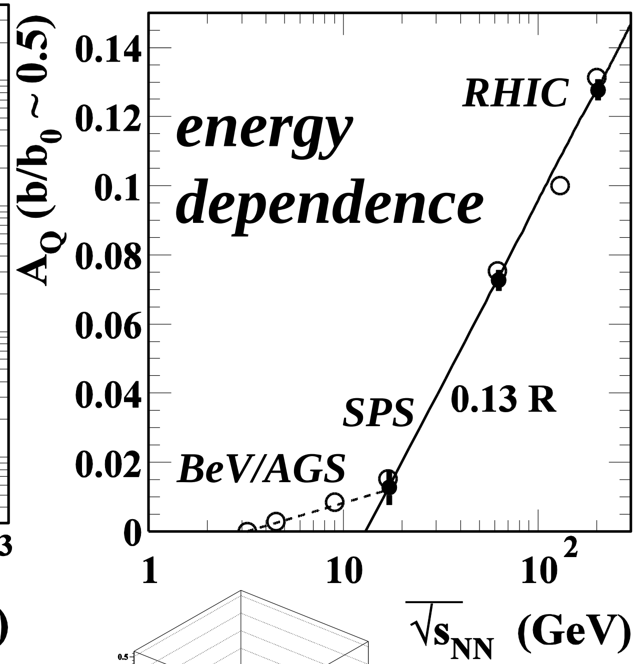
minimum-bias SS peak
≡ single 2D Gaussian
– no "ridges"



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



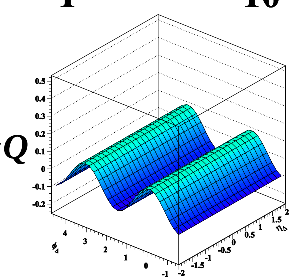




$A_Q\{2D\}$ *from 2D model fits*

universal trend

A_Q



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

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

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

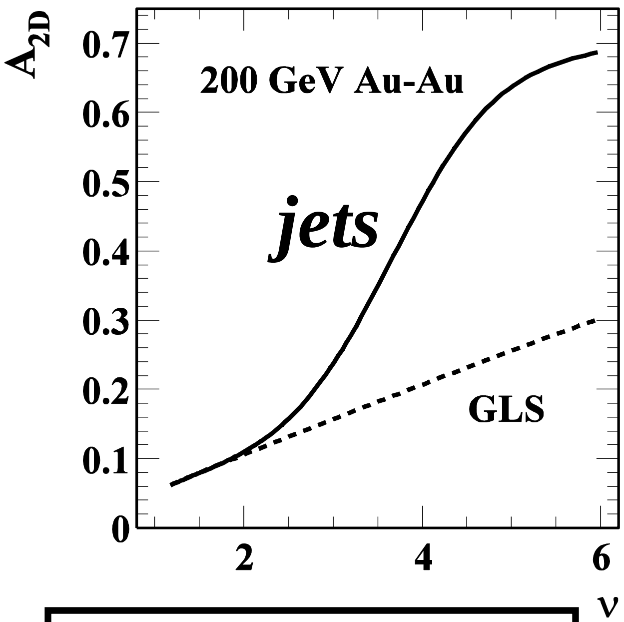
Eur Phys J C 62, 175 (2009)

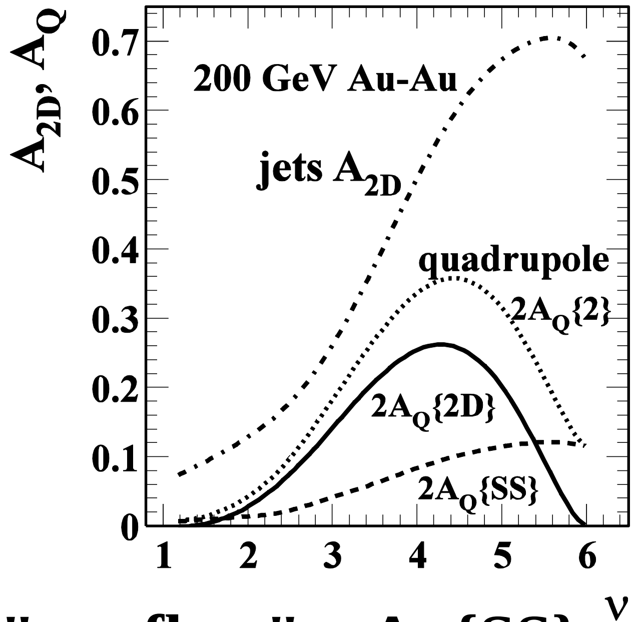
is this "elliptic flow"?

***unique phenomenon** independent of SS, AS jet structure*

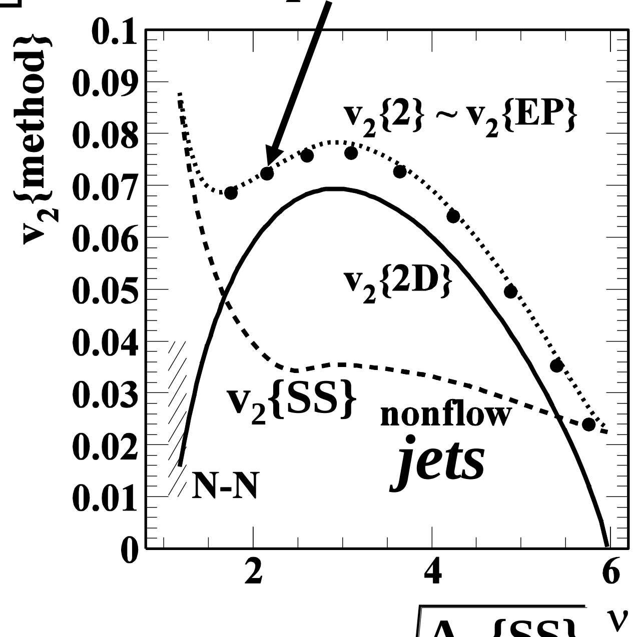
Minijets *vs* Nonjet Quadrupole

aka "flow" vs "nonflow"





STAR published data



not uniform on η_Δ

"nonflow" = $A_Q\{SS\}$

SS 2D peak quadrupole

Mod Phys Lett A 23, 569 (2008)

"nonflow" $v_2 = \sqrt{\dfrac{A_Q\{SS\}}{2\rho_0(b)}}$

<u>accurately known</u>

$$A_Q\{xx\} \equiv \rho_0(b)\, v_2^2\{xx\}$$

per-particle quadrupole amplitude

$$A_Q\{2\} = A_Q\{2D\} + A_Q\{SS\}$$

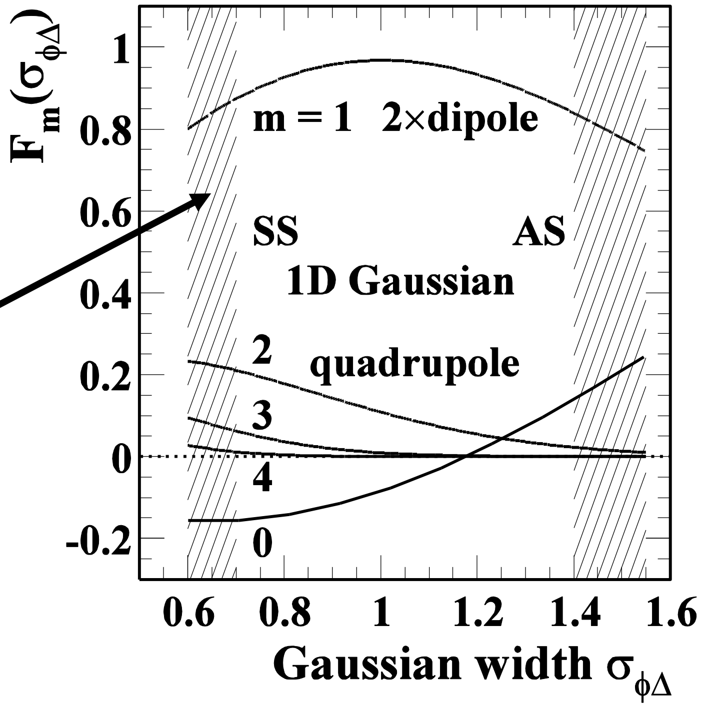
nonjet ***jet-related***

η_Δ structure (e.g., curvature) is the key issue

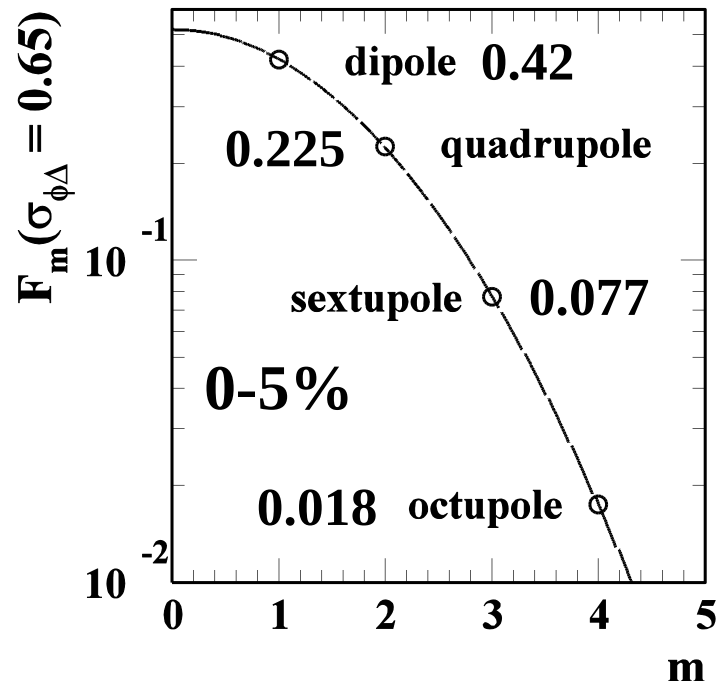
Fourier Coefficients for 1D Gaussian

$$F_m(\sigma_{\varphi_\Delta}) = \sqrt{2/\pi}\,\sigma_{\varphi_\Delta}\,\exp\left\{-m^2\,\sigma^2_{\varphi_\Delta}/2\right\}$$

0-5%



peak width dependence



Fourier coefficients for 0-5%

$\sigma_{\phi\Delta}$=0.65

PRC 81, 014905 (2010)

corresponding peak multipoles

$$2A_X\{SS\} \equiv 2\rho_0(b)\,v_m^2\{SS\} = F_m(\sigma_{\varphi_\Delta})\,A_{1D}$$

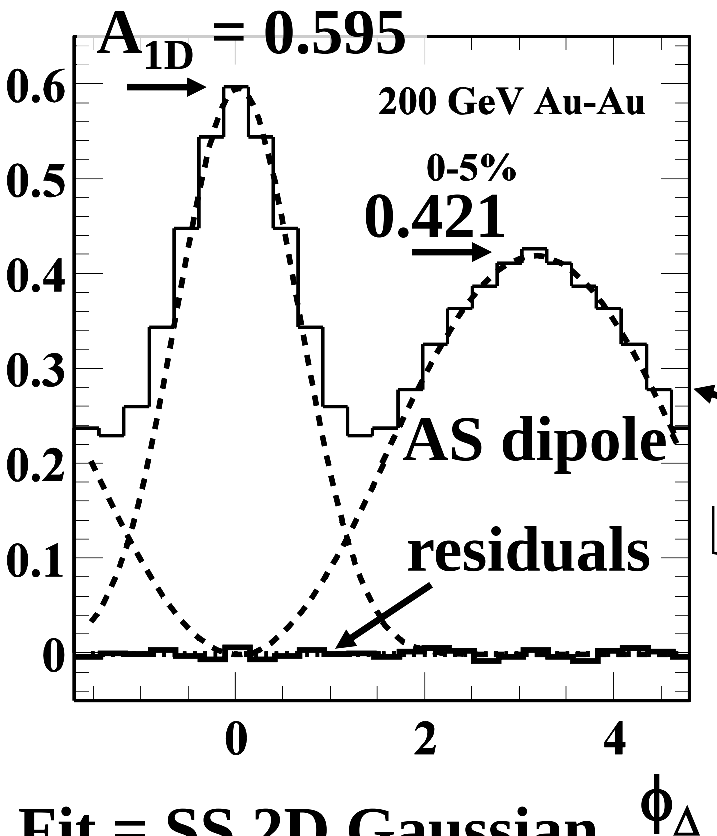
1D peak amplitude

Higher Harmonics in 0-5% Au-Au?

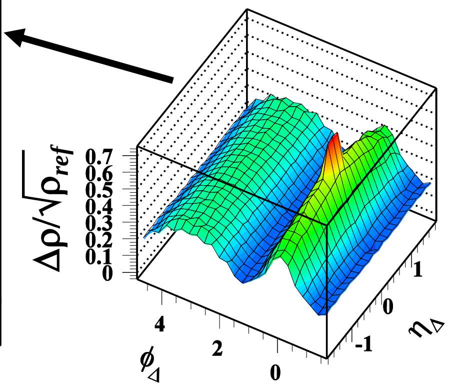
project to 1D

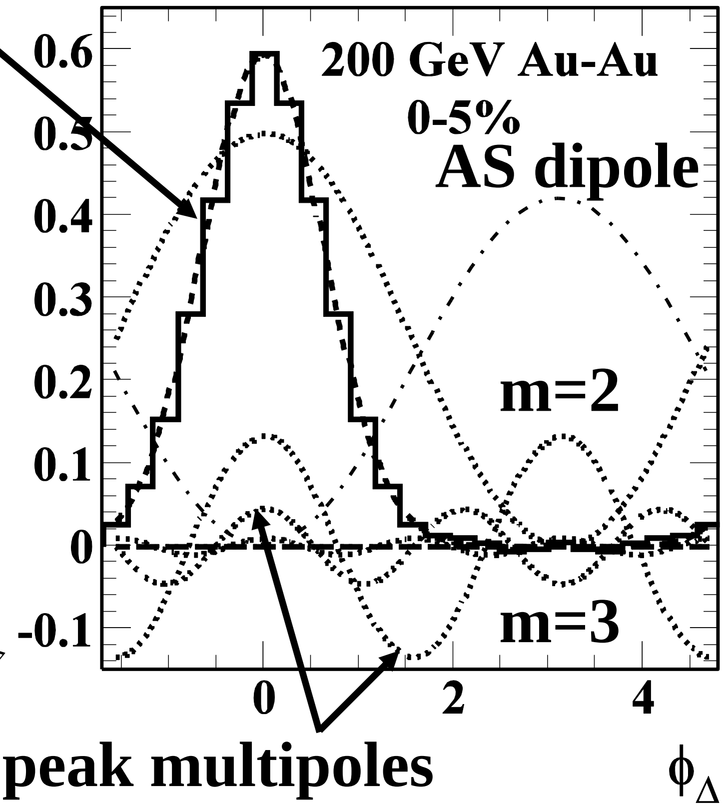
Data – AS dipole = SS 1D Gaussian

$A_Q\{2D\} \approx 0$



subtract AS dipole





Fit = SS 2D Gaussian
+AS dipole
Residuals rms < 1%

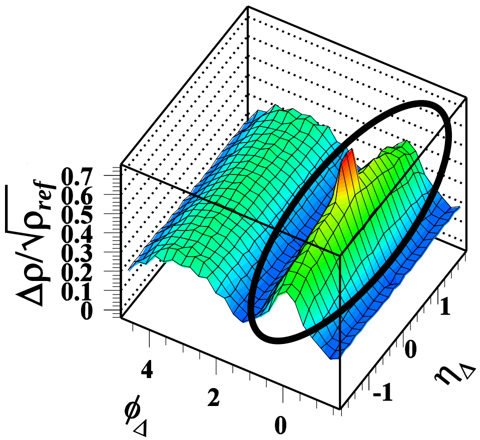
$$2\rho_0(b)v_m^2\{SS\} = F_m(\sigma_{\varphi_\Delta} = 0.65) \times A_{1D}$$

arXiv:1109.2540

$$\rho_0(0-5\%) = 107$$

$v_2\{2\} = 0.026$ $v_3\{2\} = 0.015$ $v_4\{2\} = 0.007$

Triangular Flow – I



SS 2D peak

η exclusion cuts

project 2D correlations onto φ

do a Fourier series fit:

"momentum conservation"

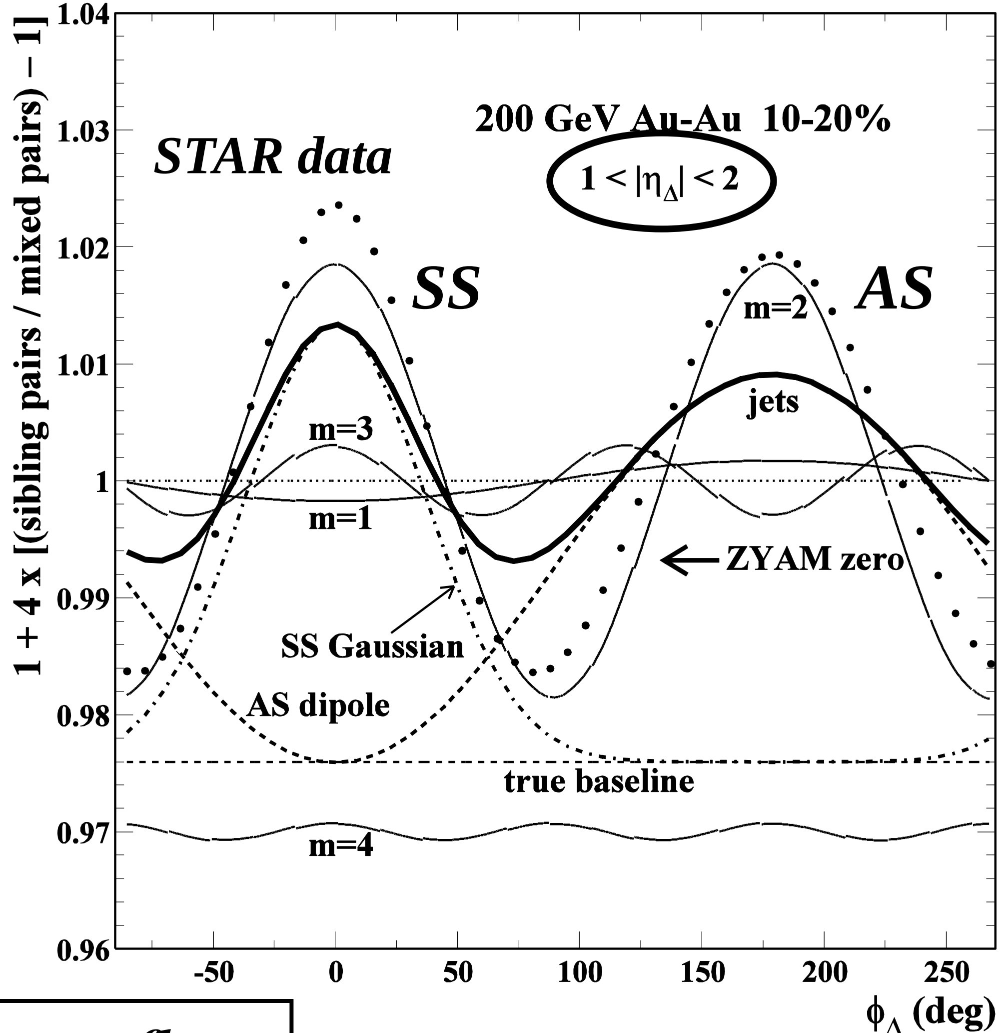
m=1 $A_D\{SS\}$ - $A_D\{AS\}$

"elliptic flow" ***nonjet***

m=2 $A_Q\{2D\}$ + $A_Q\{SS\}$

"triangular flow" **m=3 $A_S\{SS\}$**

residuals **m=4 $A_O\{SS\}$**

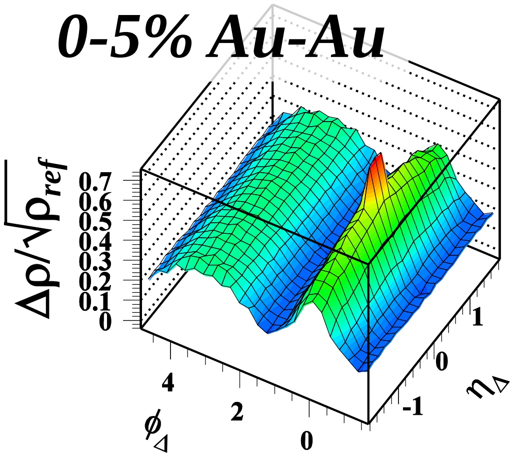


SS 2D peak "fragmented" to become flows

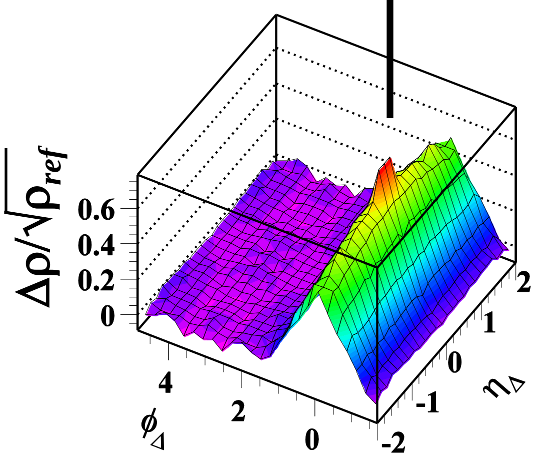
PRC 81, 054905 (2010)

"Lost in Projection"

0-5% Au-Au

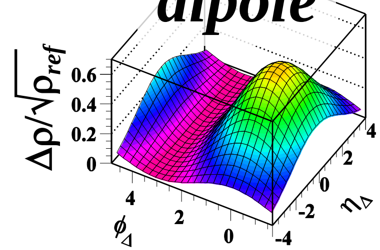


2D multipoles

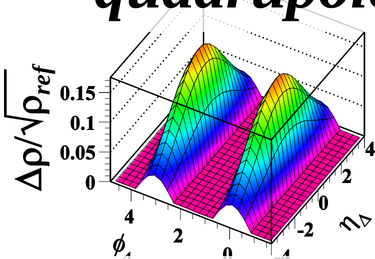


SS 2D peak

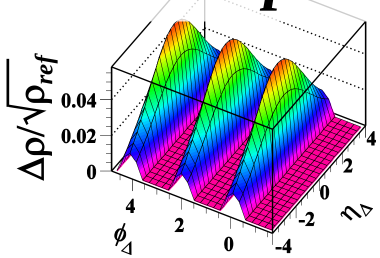
dipole



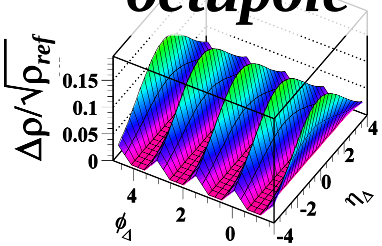
quadrupole



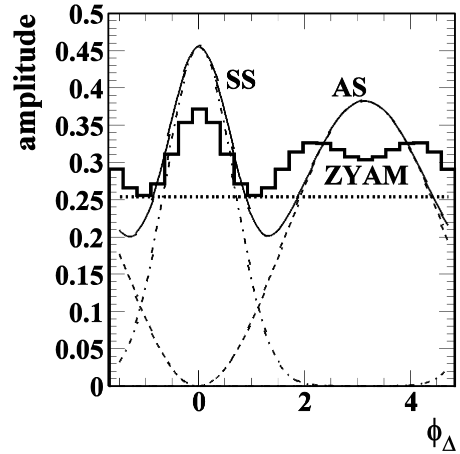
sextupole

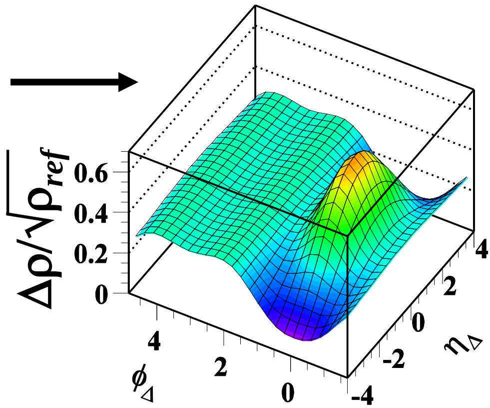


octupole



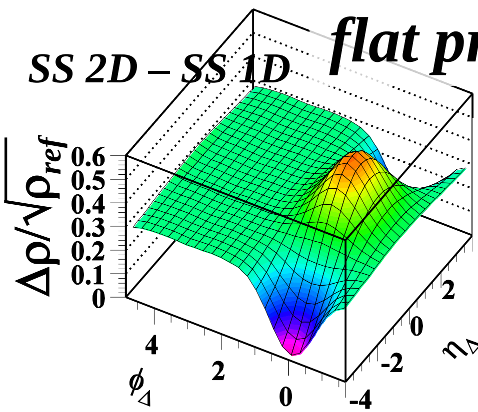
what's behind ZYAM?

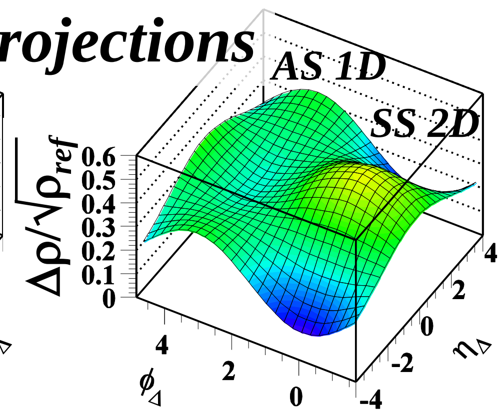




subtract ½ the SS quadrupole (1D)

flat projections

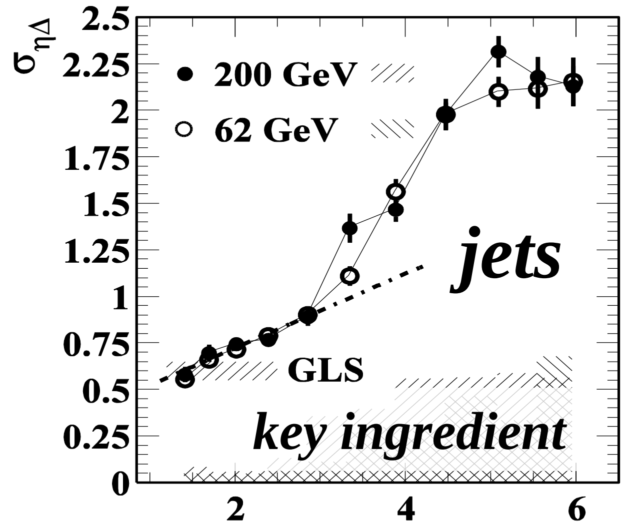




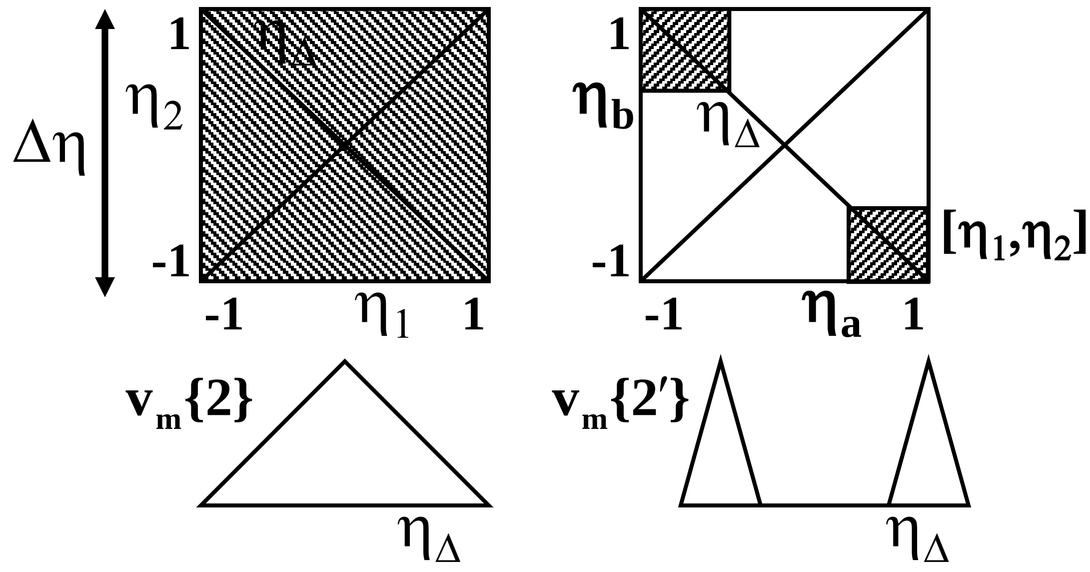
1D multipoles *2D multipoles*

subtract SS m=2,3,4

η Exclusion Cuts – Projection Factor



SS 2D peak η width



contiguous η cut *η exclusion cut*

project 2D Gaussian onto azimuth

contiguous

$$G(\sigma_\eta;\Delta\eta) = \frac{\int_0^{\Delta\eta} d\eta_\Delta \left(\Delta\eta - \eta_\Delta\right) e^{\left\{-\left(\eta_\Delta/\sigma_\eta\right)^2/2\right\}}}{\int_0^{\Delta\eta} d\eta_\Delta \left(\Delta\eta - \eta_\Delta\right)}$$

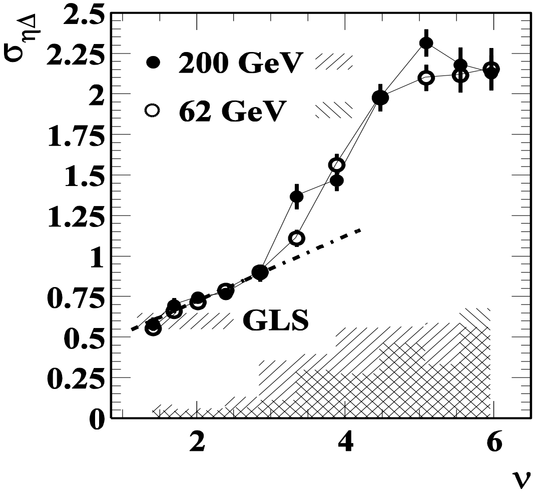
exclusion

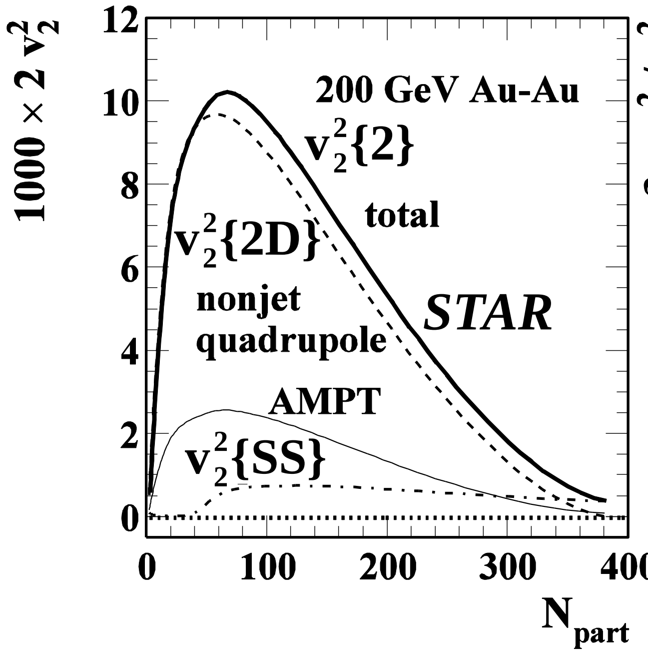
$$G(\sigma_\eta;\eta_1,\eta_2) = \frac{\int_{2\eta_1}^{\eta_1+\eta_2} d\eta_\Delta \left(\eta_\Delta - 2\eta_1\right) e^{\left\{-\left(\eta_\Delta/\sigma_\eta\right)^2/2\right\}} + \int_{\eta_1+\eta_2}^{2\eta_2} d\eta_\Delta \left(2\eta_2 - \eta_\Delta\right) e^{\left\{-\left(\eta_\Delta/\sigma_\eta\right)^2/2\right\}}}{\int_{2\eta_1}^{\eta_1+\eta_2} d\eta_\Delta \left(\eta_\Delta - 2\eta_1\right) + \int_{\eta_1+\eta_2}^{2\eta_2} d\eta_\Delta \left(2\eta_2 - \eta_\Delta\right)}$$

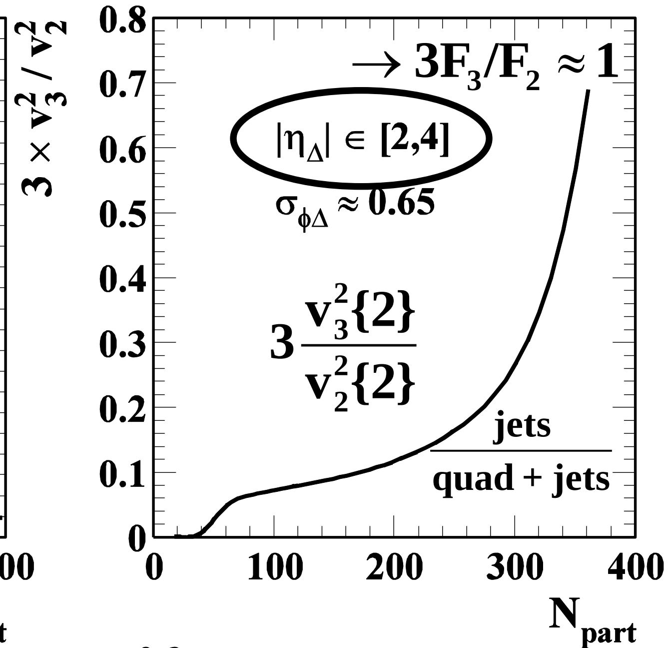
exclusion cut is supposed to remove "nonflow" – not!

Triangular Flow – II

STAR minimum-bias angular correlations







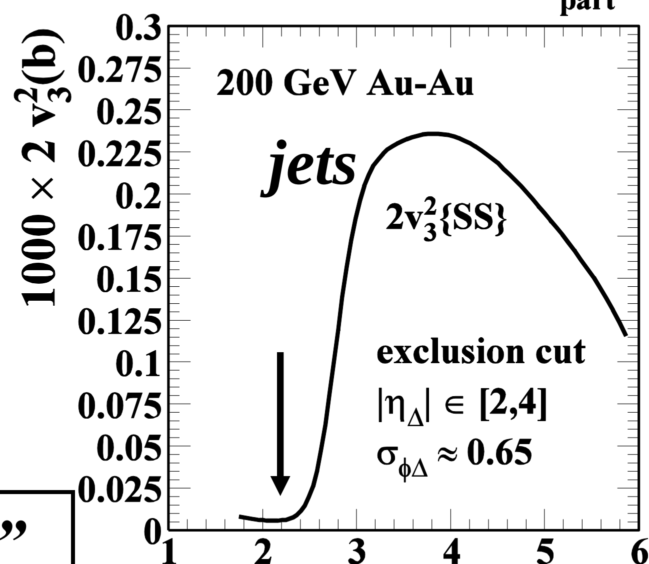
Phys Rev C 81, 054905 (2010)

"nonflow:"

$$\rho_0(b)\, 2v_m^2\{SS\} = F_m(\sigma_{\varphi_\Delta})\, G(\sigma_{\eta_\Delta})\, A_{2D} \quad \textit{(jets)}$$

$$v_2^2\{2\} = v_2^2\{2D\} + v_2^2\{SS\}$$

$$v_3^2\{2\} = v_3^2\{SS\}$$

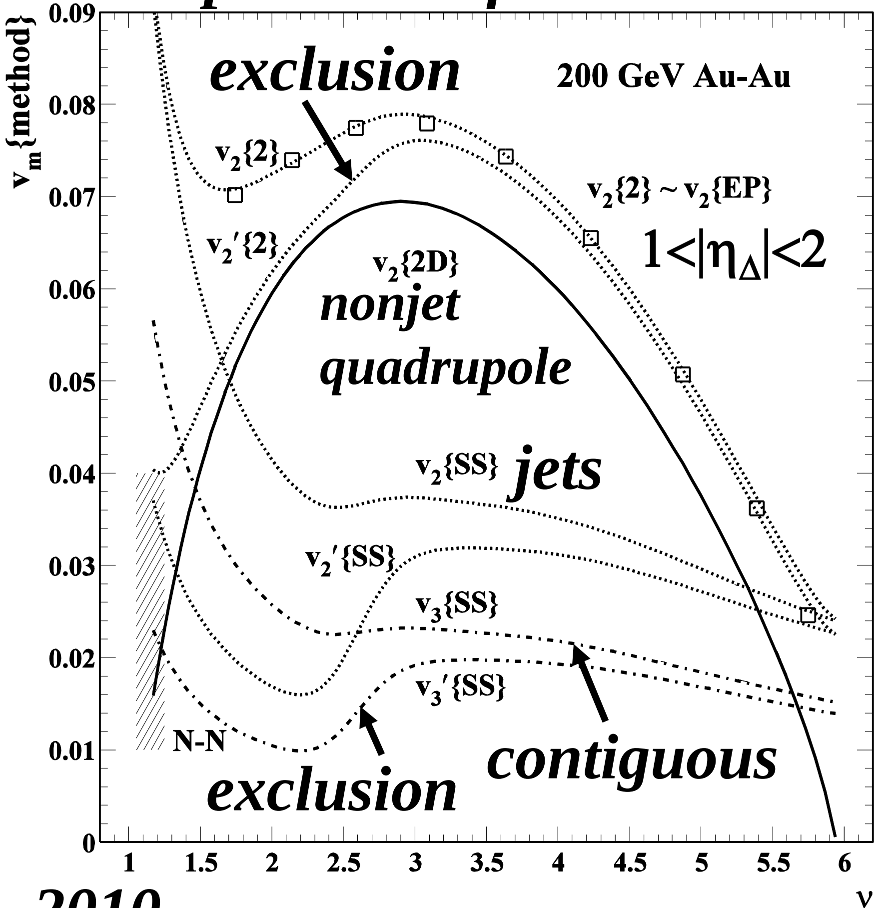


SS 2D jet peak identified with "triangular flow"

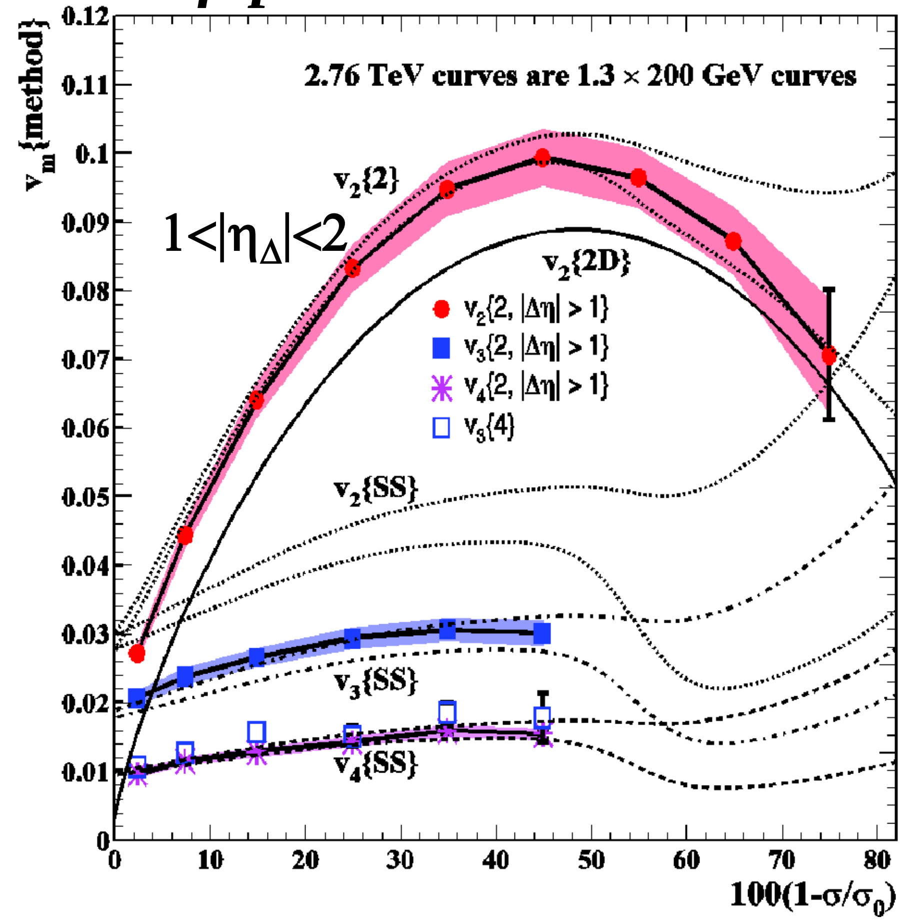
Higher Harmonic Flows at the LHC?

v_m predictions based on SS 2D peak and nonjet quadrupole

prediction for 200 GeV



left panel × 1.3 → 2.76 TeV



2010

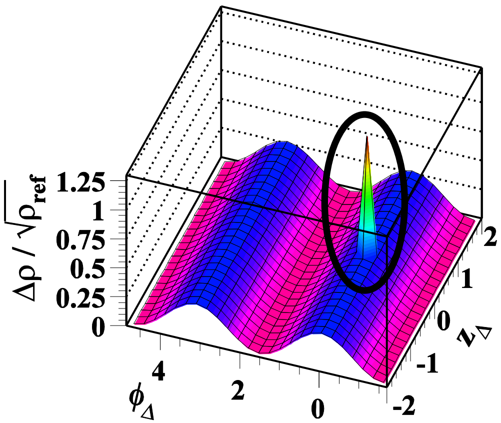
v_m\{SS\} ***at 2.76 TeV similar to 200 GeV***

v_2\{2D\} ***also similar***

Initial-state (IS) Geometry

<u>conjectured</u> azimuth structure

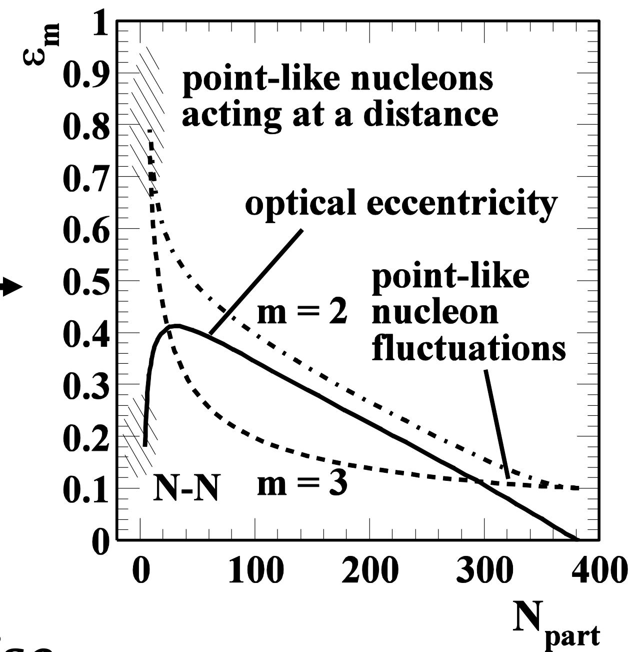
Glauber Monte Carlo



participant-nucleon autocorrelation

power spectrum

$\xrightarrow{FT}$ $$E_m^2 = N_{part}^2 \varepsilon_m^2$$ $\longrightarrow$



sampling noise

$$\varepsilon_{m,MC}^2 = \varepsilon_{m,opt}^2 + C \times 2/N_{part} \quad m = 2, 4$$

$$\varepsilon_{m,MC}^2 = C \times 2/N_{part} \quad m \neq 2, 4$$

C=0.5-2 depending on Monte Carlo details

Mod Phys Lett A 23, 569 (2008)

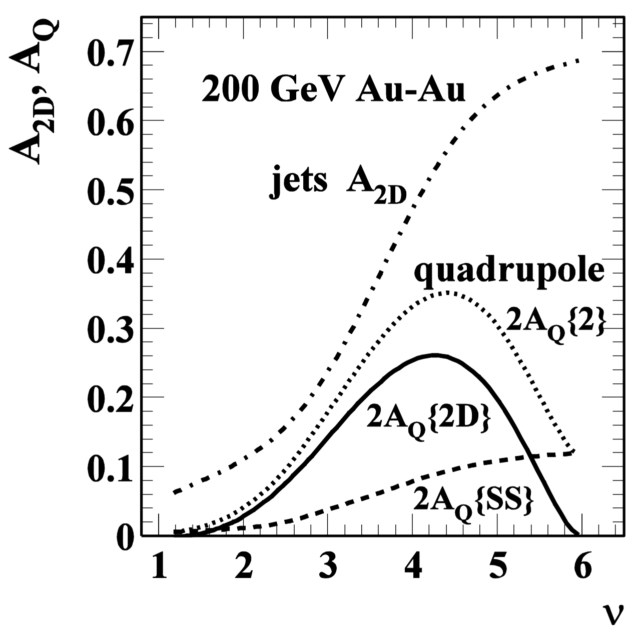
Monte Carlo sampling results in a <u>flat (noise) multipole spectrum</u>

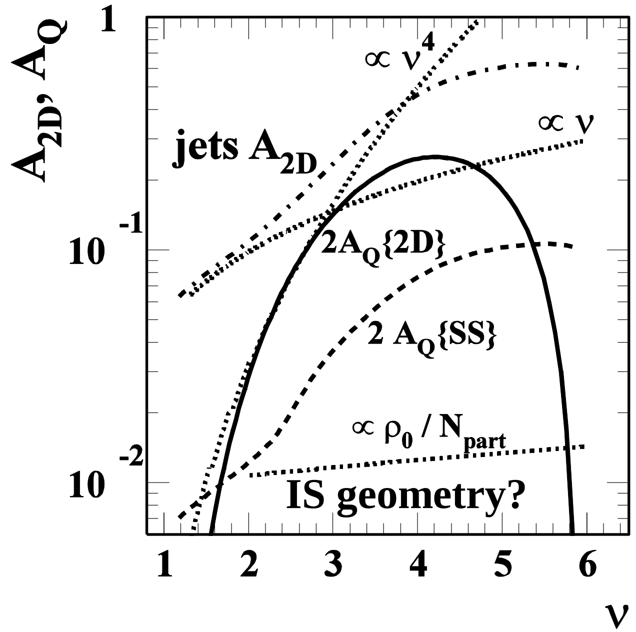
Comparing Centrality Trends

SS 2D peak (jets?) $\mathbf{A_X\{SS\} \equiv \rho_0 v_2^2\{SS\} \propto A_{2D} \propto N_{bin}/\rho_0 \approx \nu}$

nonjet quadrupole $\mathbf{A_Q\{2D\} \equiv \rho_0 v_2^2\{2D\} \propto N_{bin}\varepsilon_{opt}^2 \approx \nu^4 \varepsilon_{opt}^2}$

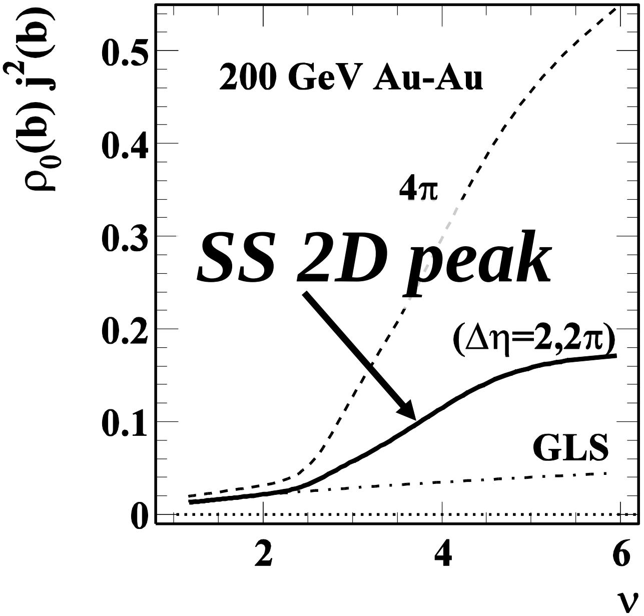
IS geometry (stochastic part) $\mathbf{\rho_0 \varepsilon_{m,MC}^2 \propto 2\rho_0/N_{part} = O(1)}$ **m odd**



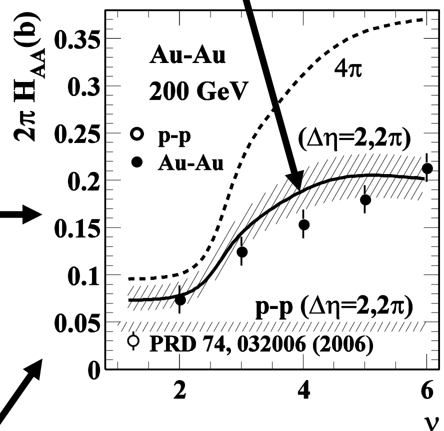


if the three elements are related through flows why are their centrality trends so different?

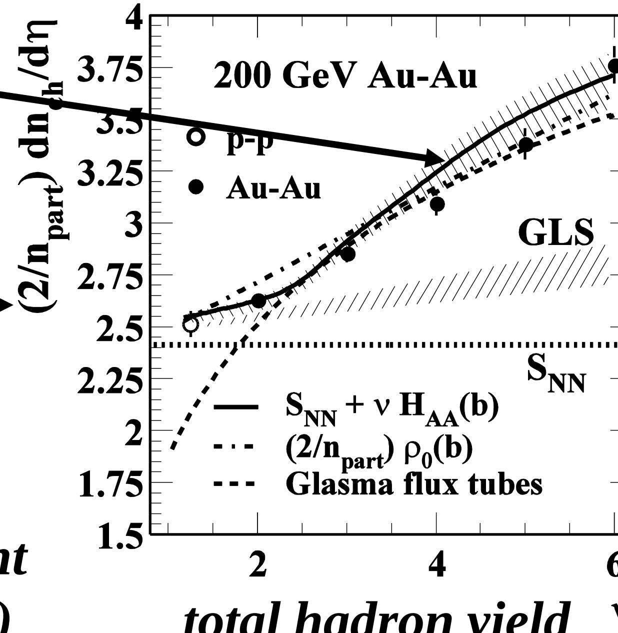
Minijets and Hadron Production



SS 2D peak (jets?)



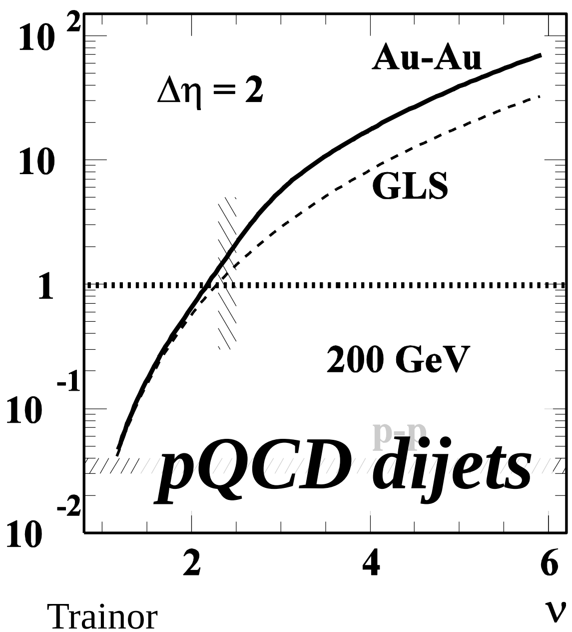
spectrum hard component (binary collision scaling)



total hadron yield

solid curve: jet correlations
points: spectrum integrals

PRC 83, 034903 (2011)



quantitative relation:
- *SS 2D peak volume*
- *pQCD cross section*
- *spectrum hard-component yields*

fragment production in Au-Au collisions

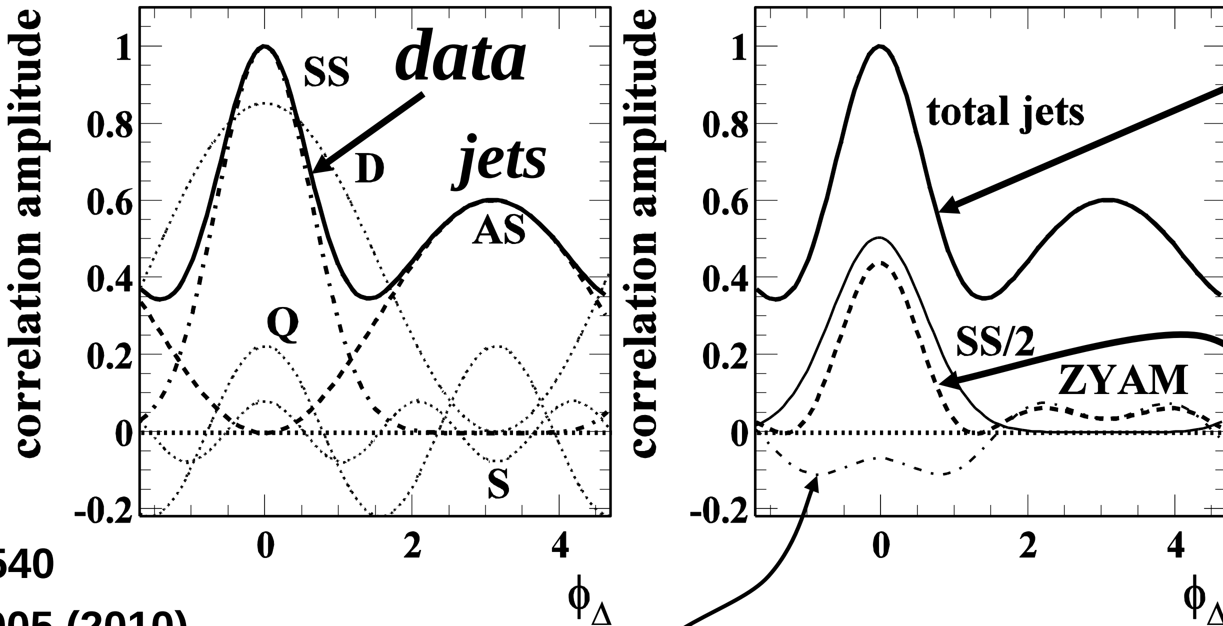
Summary

- ***2D correlations include a monolithic SS peak***
- ***v_m analysis ignores the η_Δ structure of the SS peak***
- ***The SS 2D peak biases all v_m*****{2} data – *“nonflow”***
- ***The SS 2D (jet) peak is quantitatively linked to pQCD***
- ***“Higher harmonics” are parts of the SS 2D peak***
- ***ZYAM subtraction of higher harmonics corresponds to subtraction of jets from jets***
- ***Parton fragmentation is set aside despite likely jet modification in A-A collisions***

ZYAM Subtraction

$A_Q\{2D\} \approx 0$

Au-Au
b = 0



original data

subtract
$A_Q\{SS\}$

result of ZYAM subtraction

arXiv:1109.2540

PRC 81, 014905 (2010)

data (jets): bold solid curve – SS 1D Gaussian plus AS dipole

SS 1D peak multipoles:

D – SS dipole (~ 1.2× AS dipole)

Q – SS quadrupole $2A_Q\{SS\}$

S – SS sextupole $2A_S\{SS\}$

nonjet quadrupole $\equiv 0$

ZYAM background subtraction what remains:

- ***½ the SS Gaussian***
- ***½ the SS dipole, which cancels most of the AS dipole***
- ***½ the SS sextupole***

AS structure: small net dipole plus ½ the SS sextupole