Collective Flow and Correlation with Higher Harmonic Event Plane

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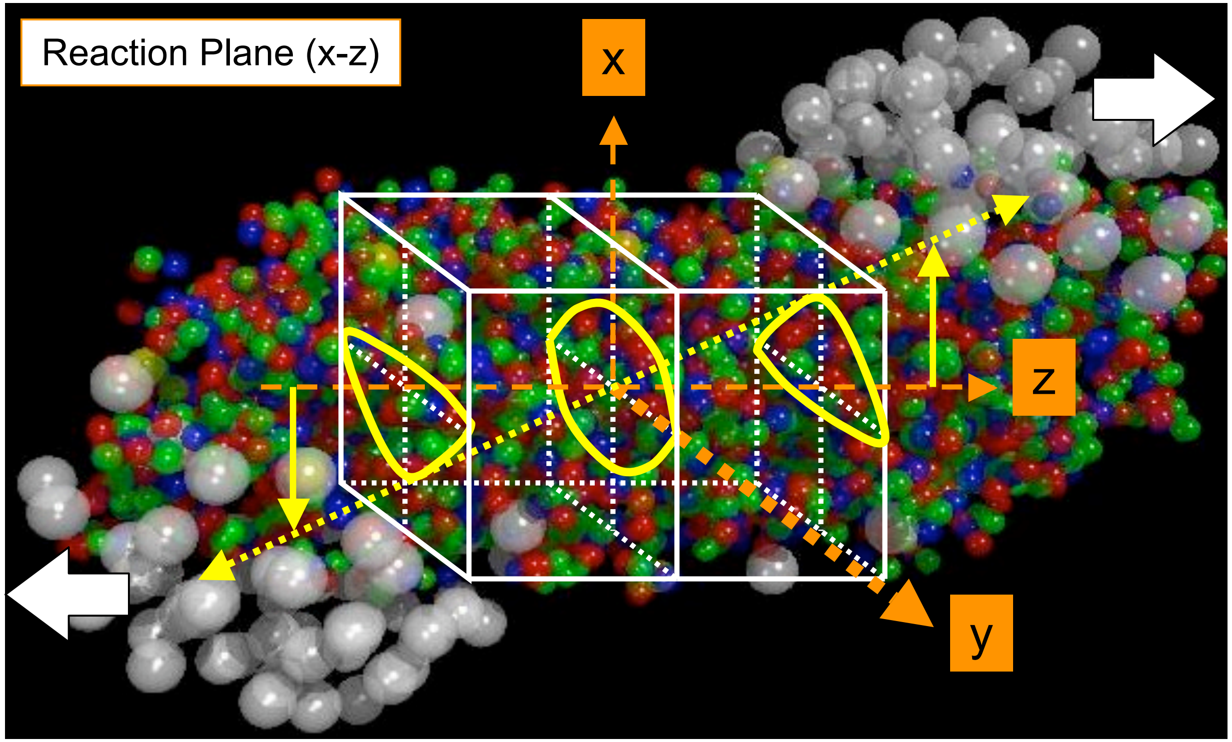
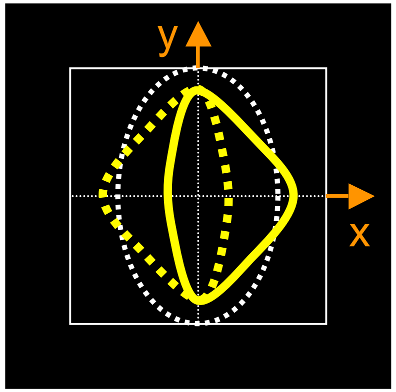
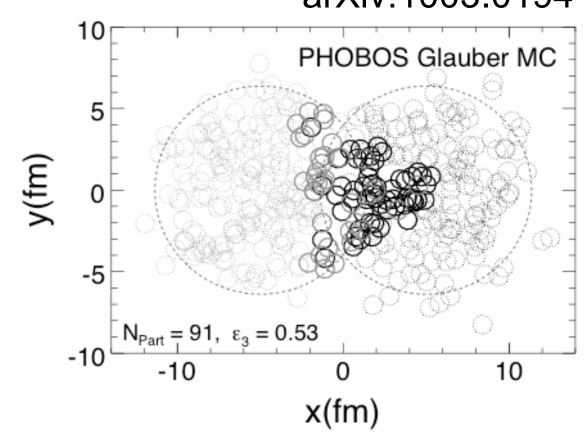
Higher Harmonics v_n and Φ_n
Multi-particle Correlation with Φ_n
AMPT model simulation test

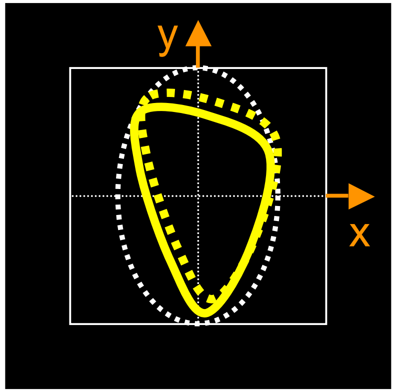
v_3 and initial fluctuation





arXiv:1003.0194

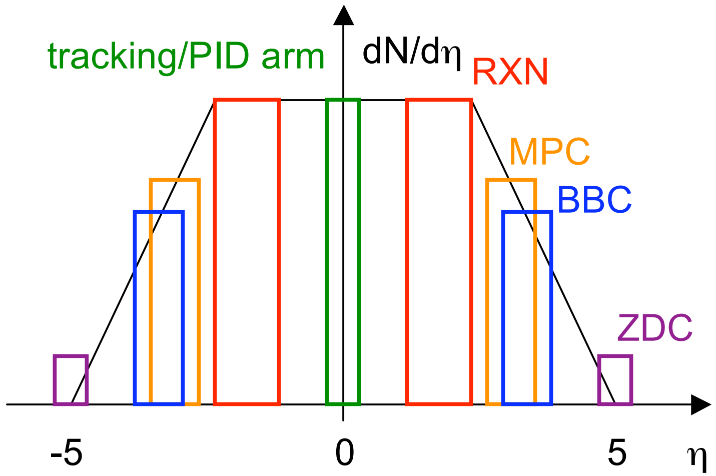


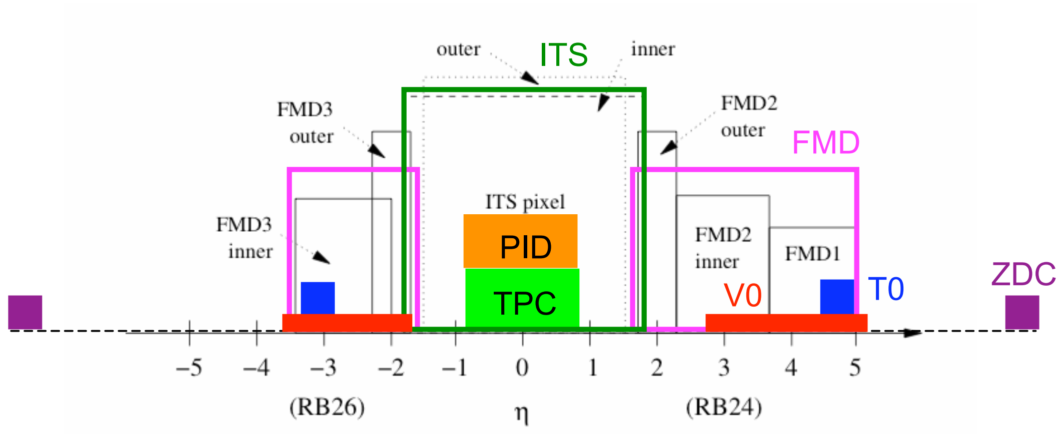


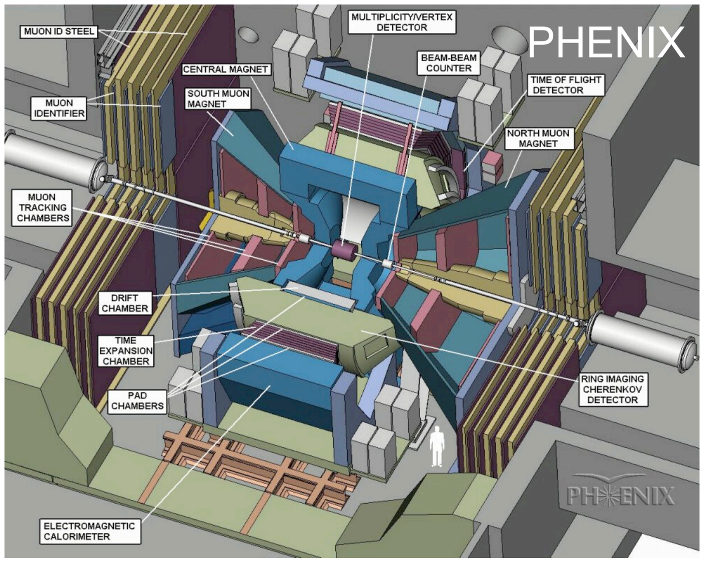
black-disk --> sign-flipping v_3

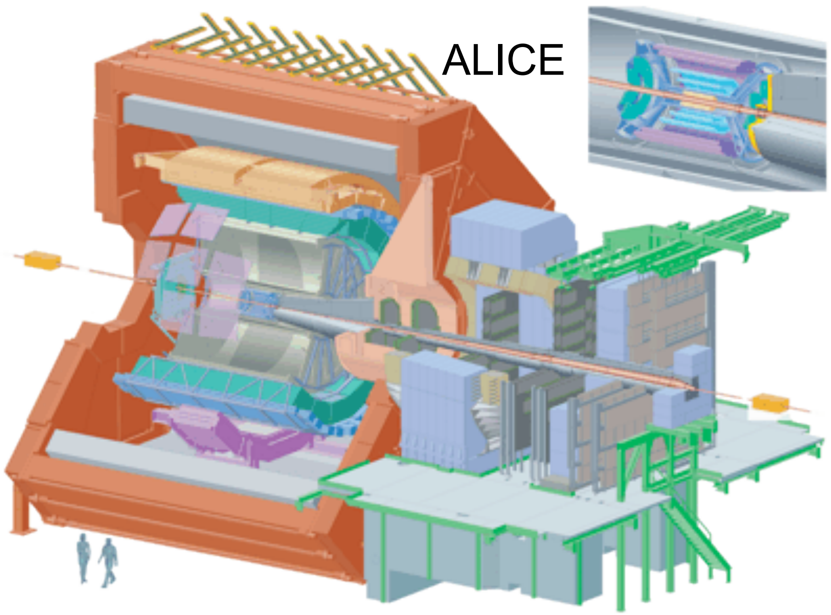
initial fluctuation --> no-sign-flipping v_3

Event Plane {Reaction Plane} determination in forward rapidity

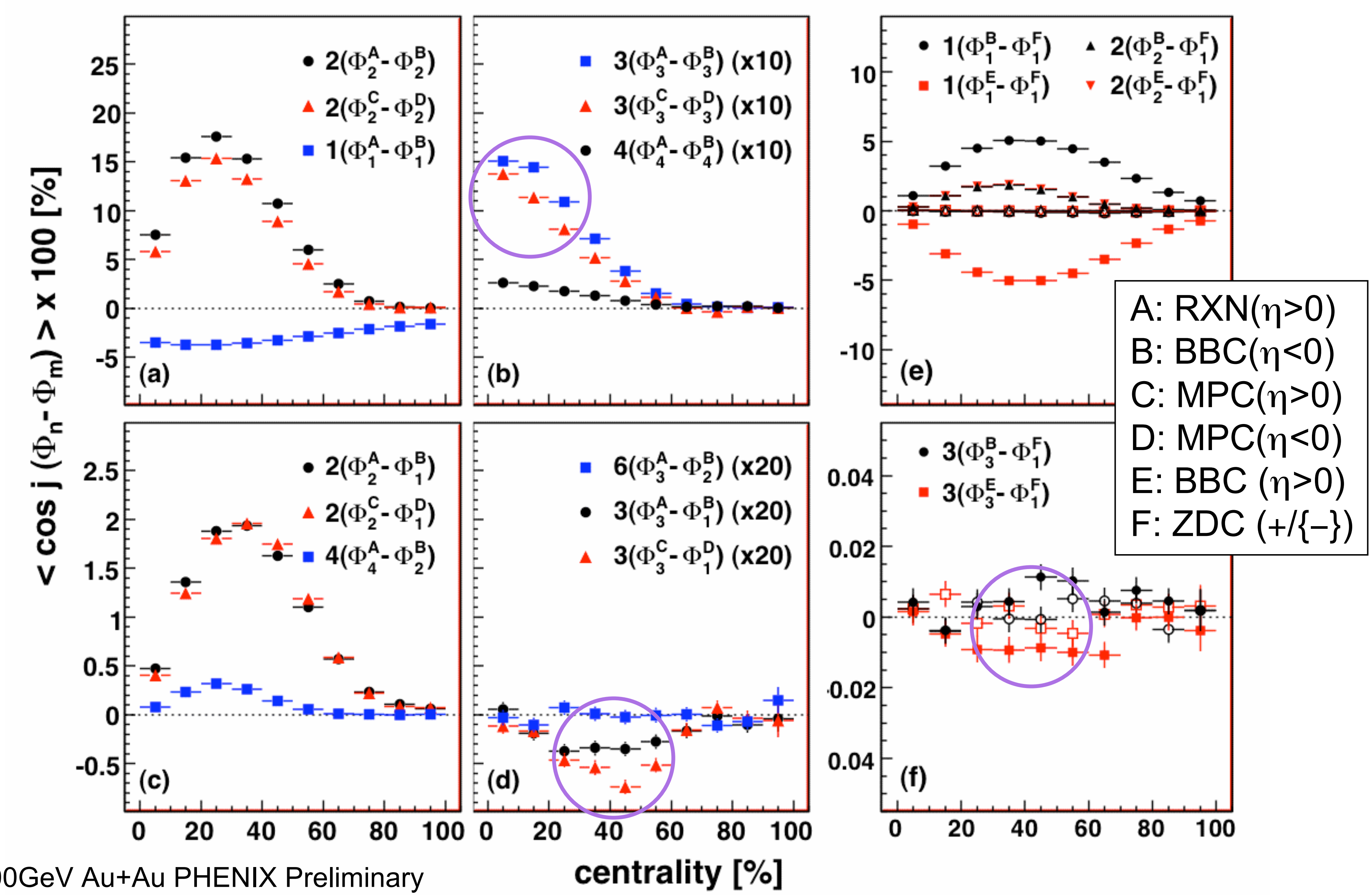






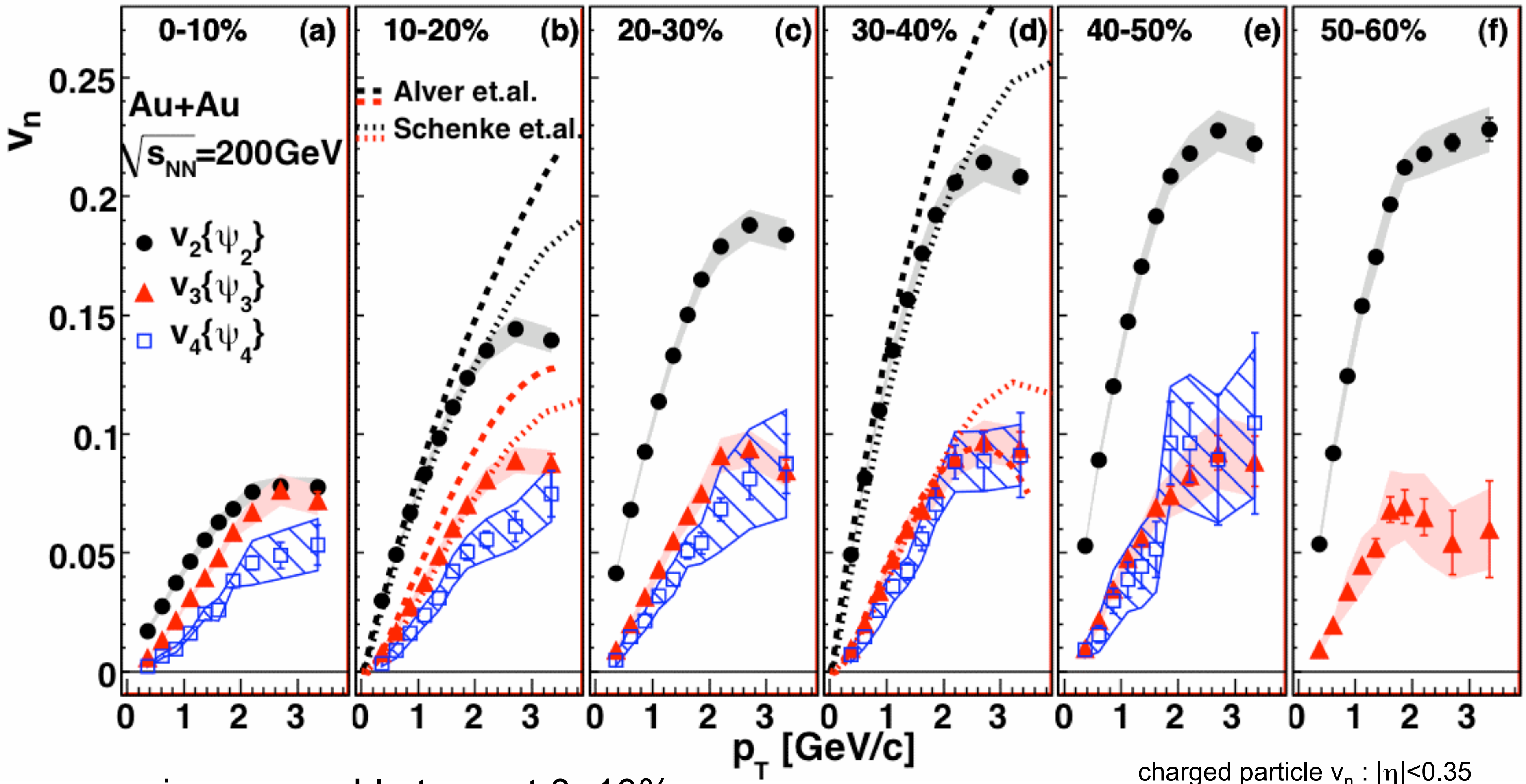


Indication of strong non-flipping and weak sign-flipping v_3



200GeV Au+Au PHENIX Preliminary

Centrality and p_T dependences of v_n at 200GeV Au+Au



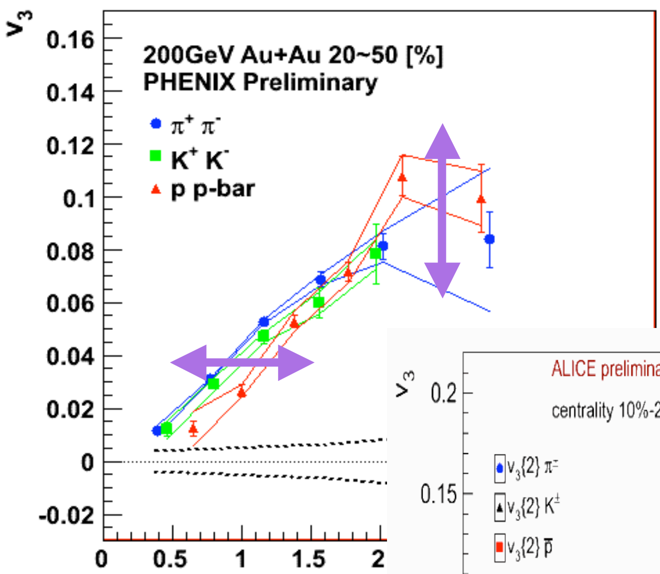
charged particle v_n : $|\eta|<0.35$
reaction plane Φ_n : $|\eta|=1.0\sim2.8$

v_3 is comparable to v_2 at 0~10%
weak centrality dependence on v_3
$v_4\{\Phi_4\} \sim 2 \times v_4\{\Phi_2\}$

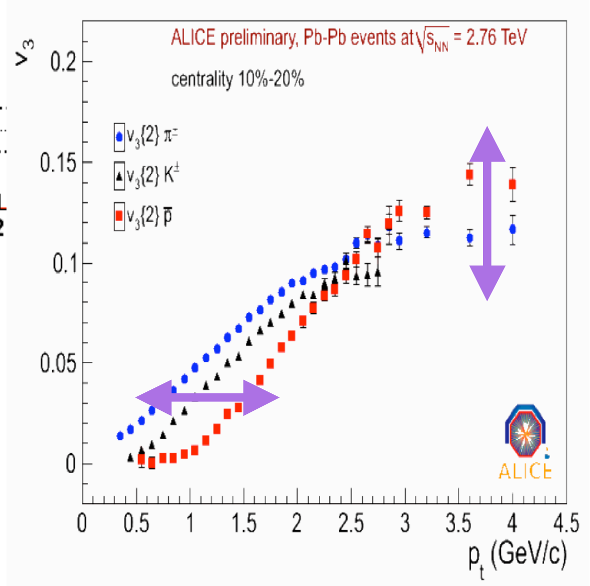
All of these are consistent
with initial fluctuation.

Particle dependence of v_3 shows the similar mass-splitting and Baryon / Meson difference like v_2.

QM11, PHENIX

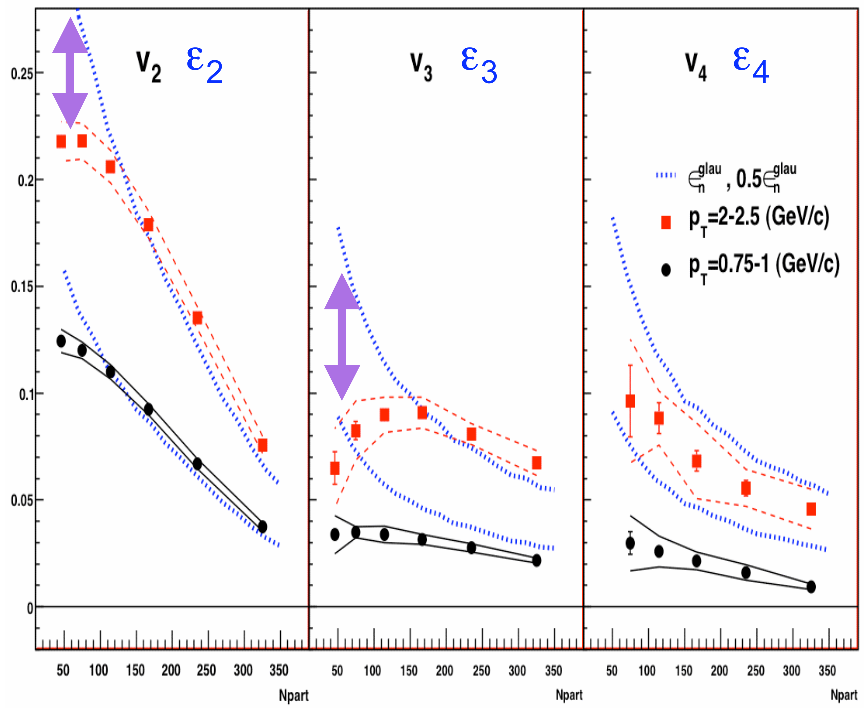


QM11, ALICE



How the initial geometrical anisotropy was transformed into the final momentum anisotropy?

arXiv:1105.3928

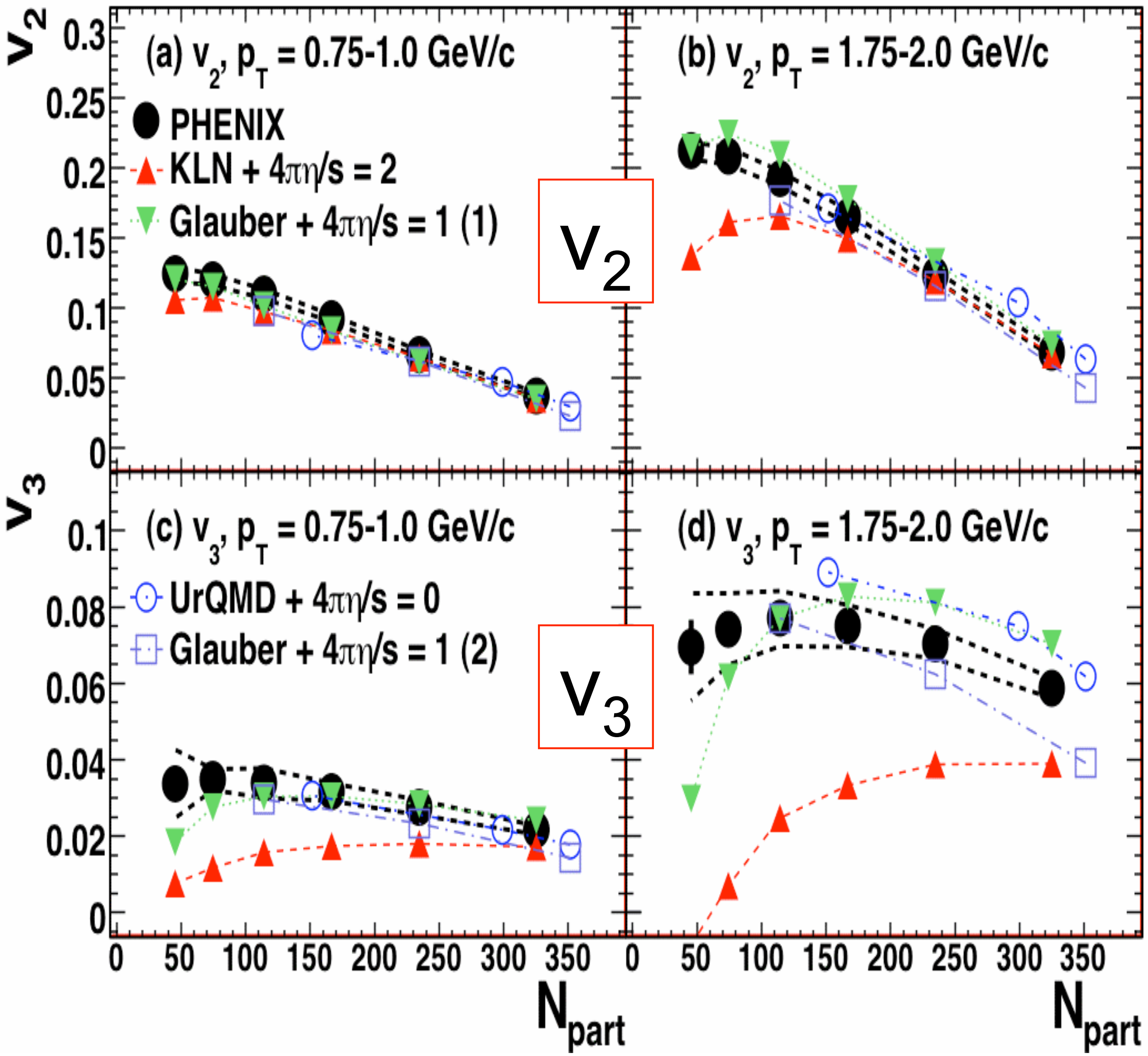


$N_{part.}$

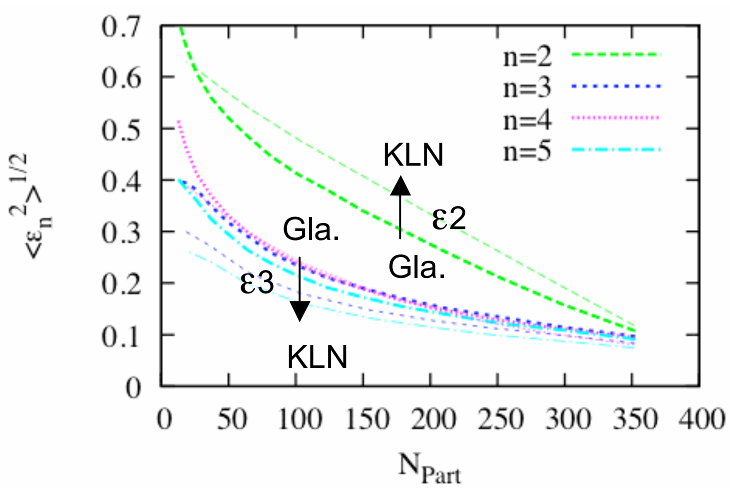
v_3 reflects the collective expansion.

v_3 breaks the degeneracy

arXiv:1105.3928



PRC82.034913



v_3 provides an additional constraining power on the hydro-model parameters.

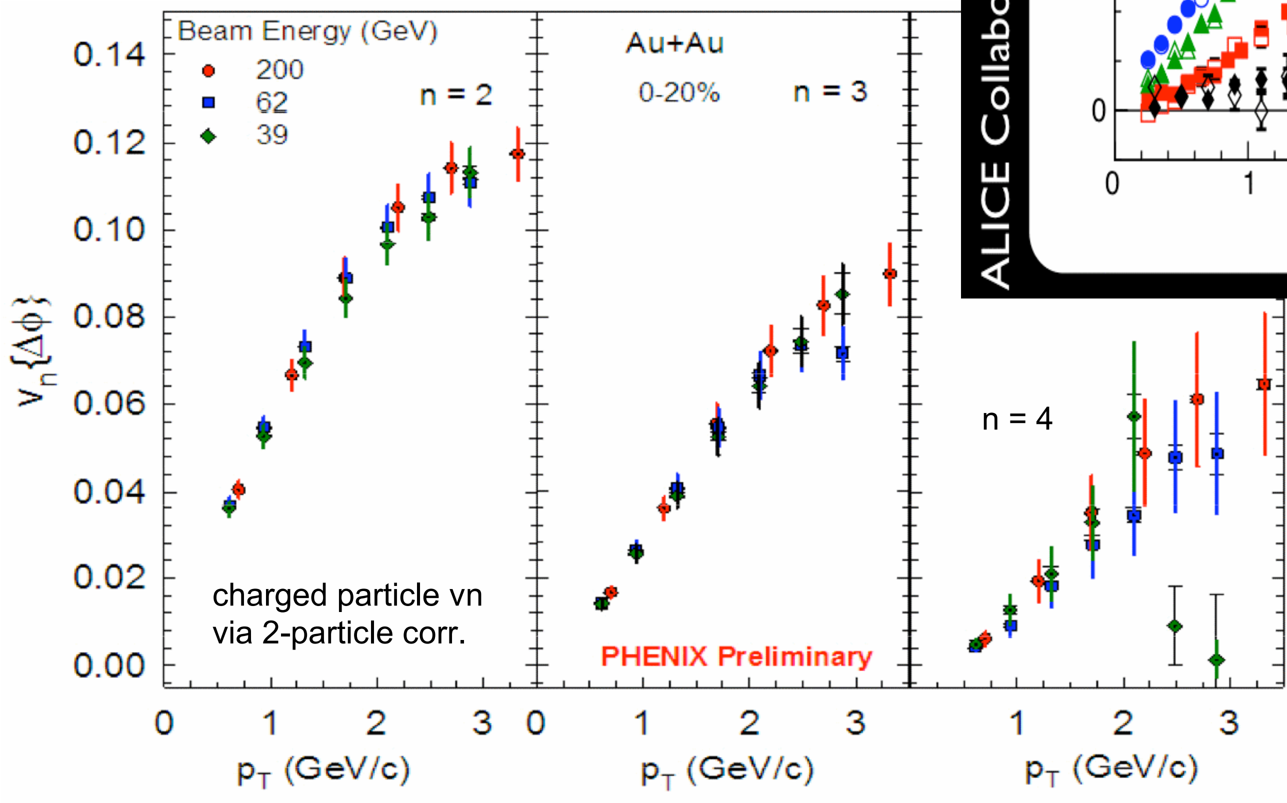
Glauber & $4\pi\eta/s=1$ works better.

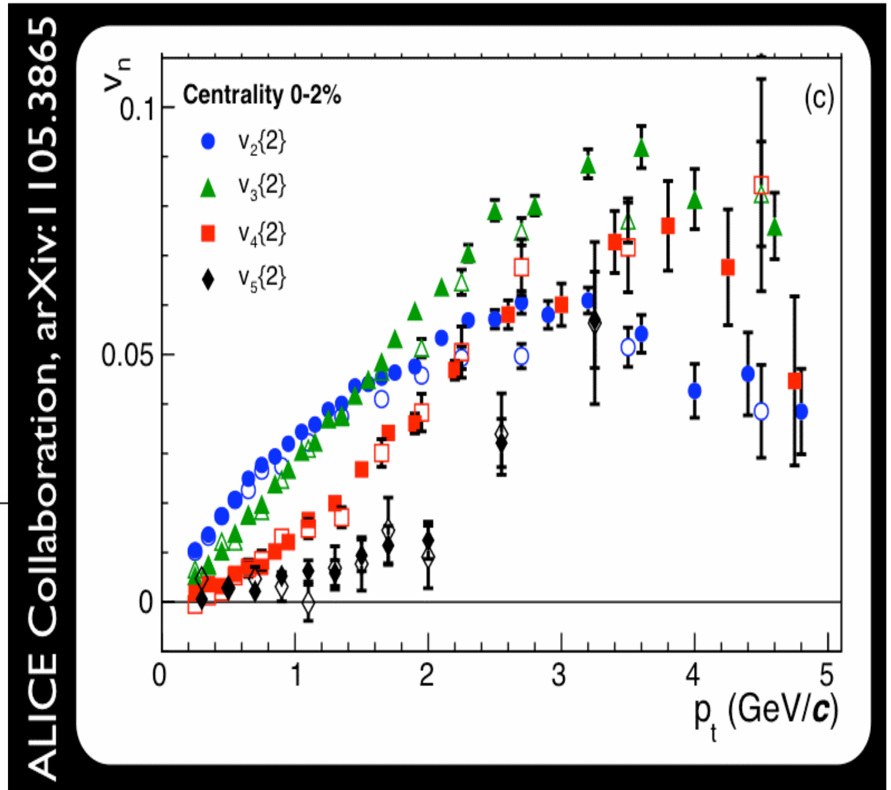
CGC-KLN & $4\pi\eta/s=2$ fails.

B. Alver et. al., Phys. Rev. C82, 034913(2010).
B. Schenke et. al., Phys. Rev. Lett. 106, 042301(2011).
H. Petersen et. al., Phys. Rev. C82, 041901(2010).

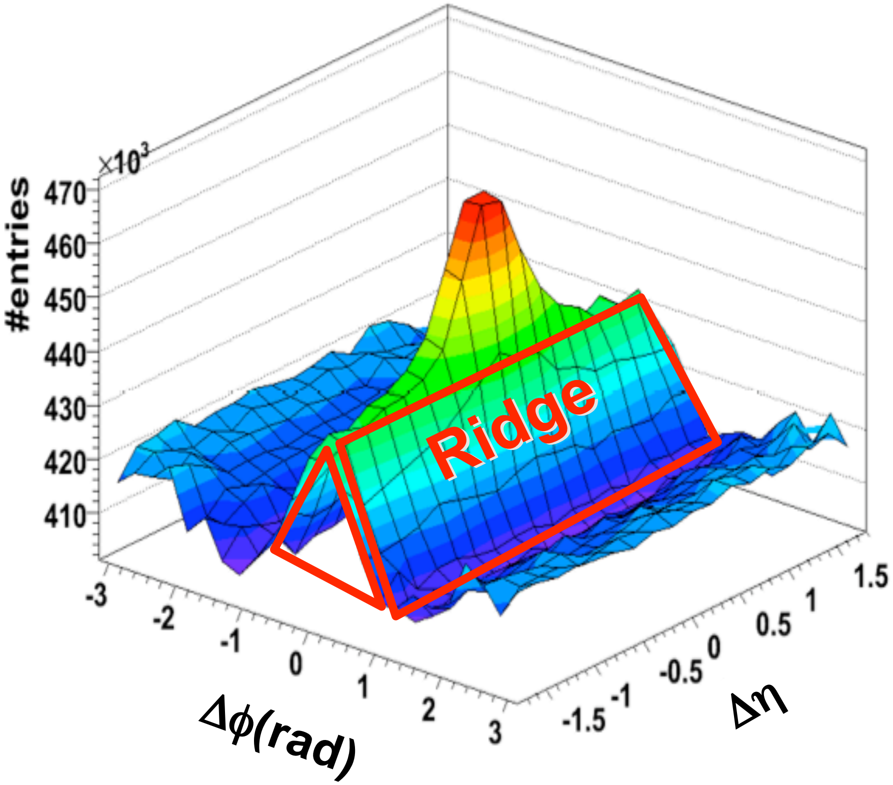
Similar v_n from 39GeV up to 2.76TeV A+A

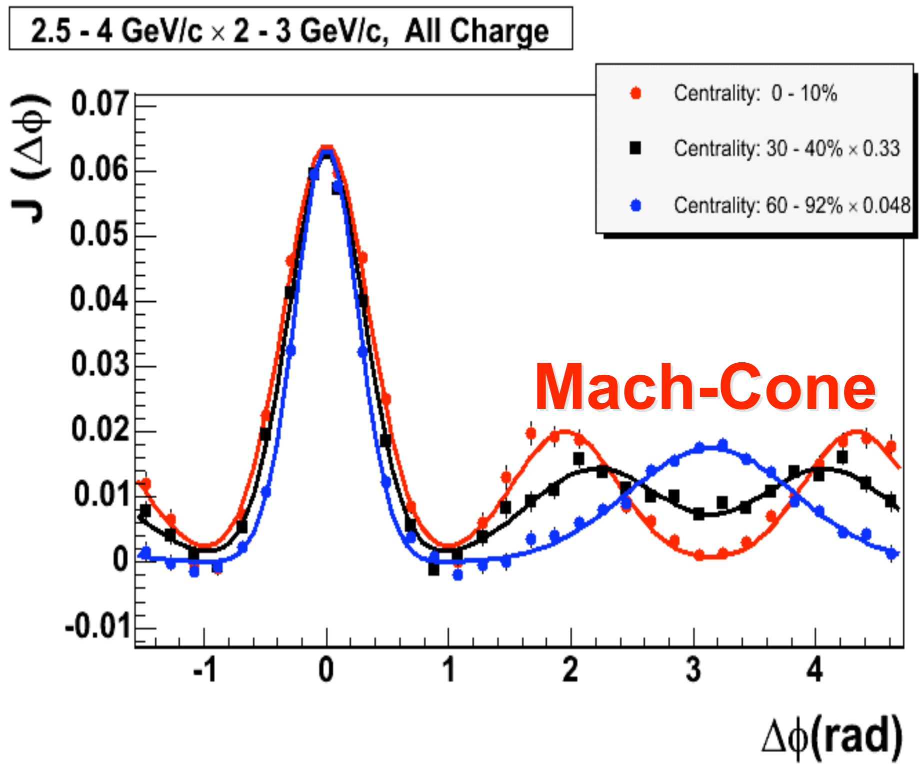
QM11, PHENIX





Does v_3 explain ridge and mach-cone?



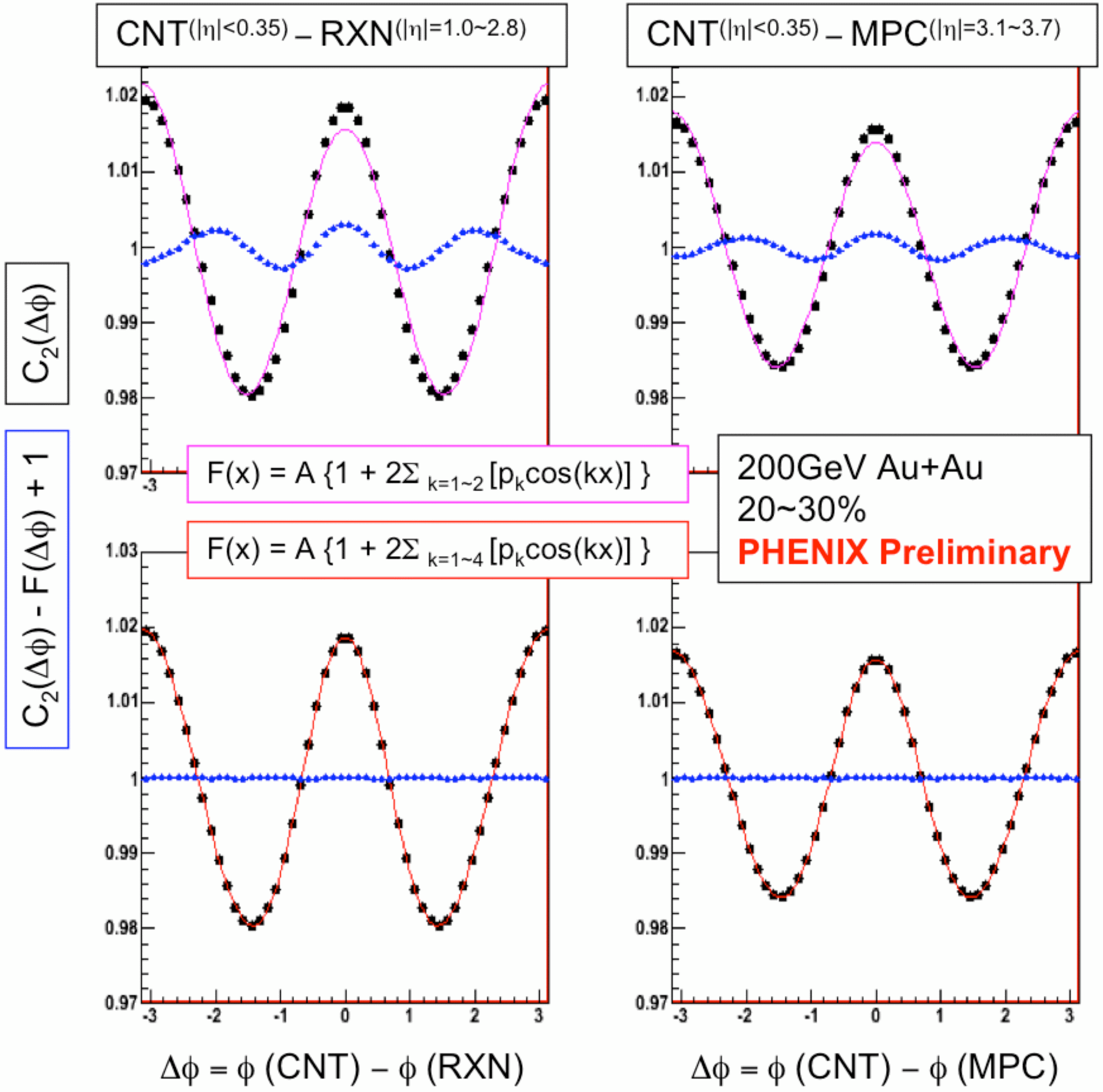


ridge : long range $\Delta\eta$ correlation at near-side

cone : double peak/shoulder at away-side (long in $\Delta\eta$)

v_3 : initial fluctuation is common over wide range of η

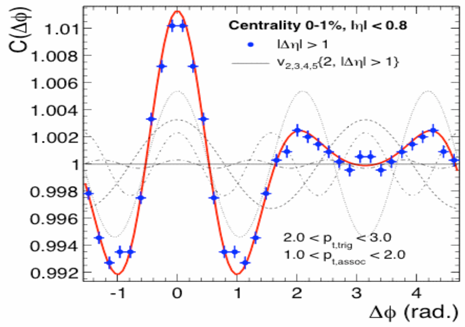
The answer is YES with |Δη| gap.



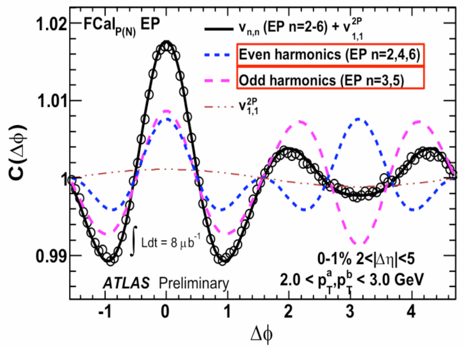
The data are unchanged, only the interpretations are being changed.

This has also been shown by various experiments.

arXiv:1105.3865

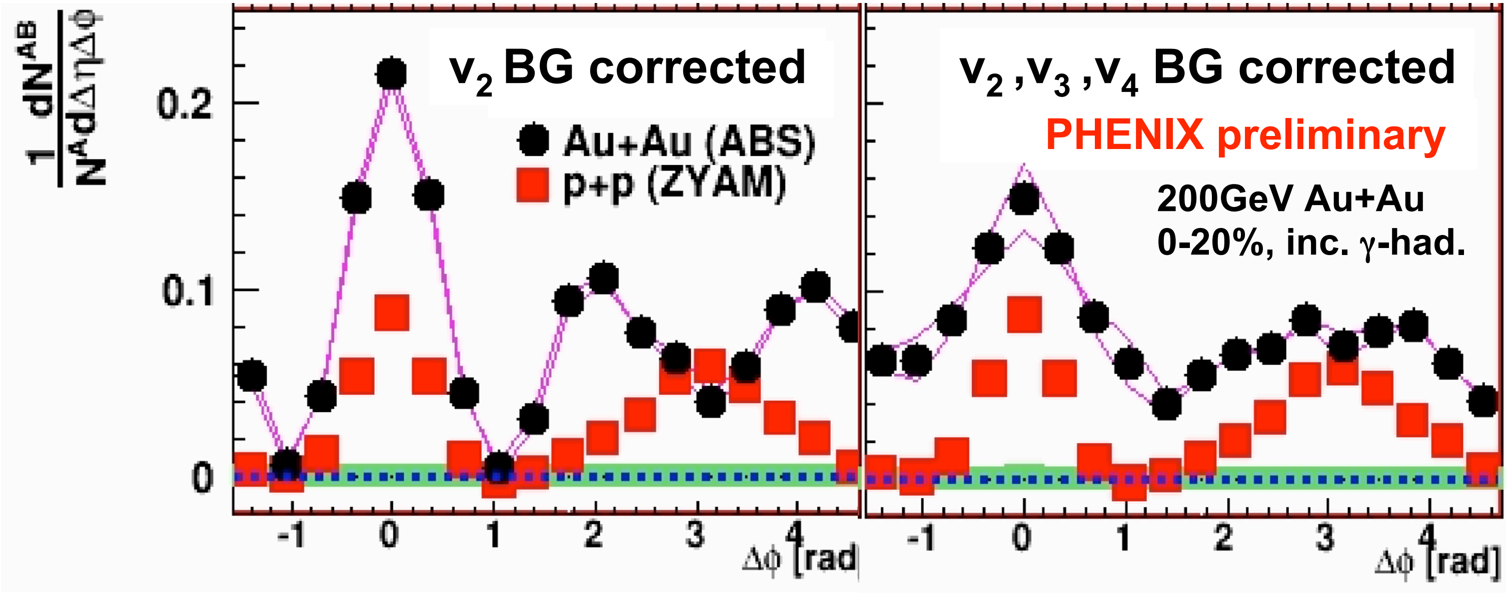


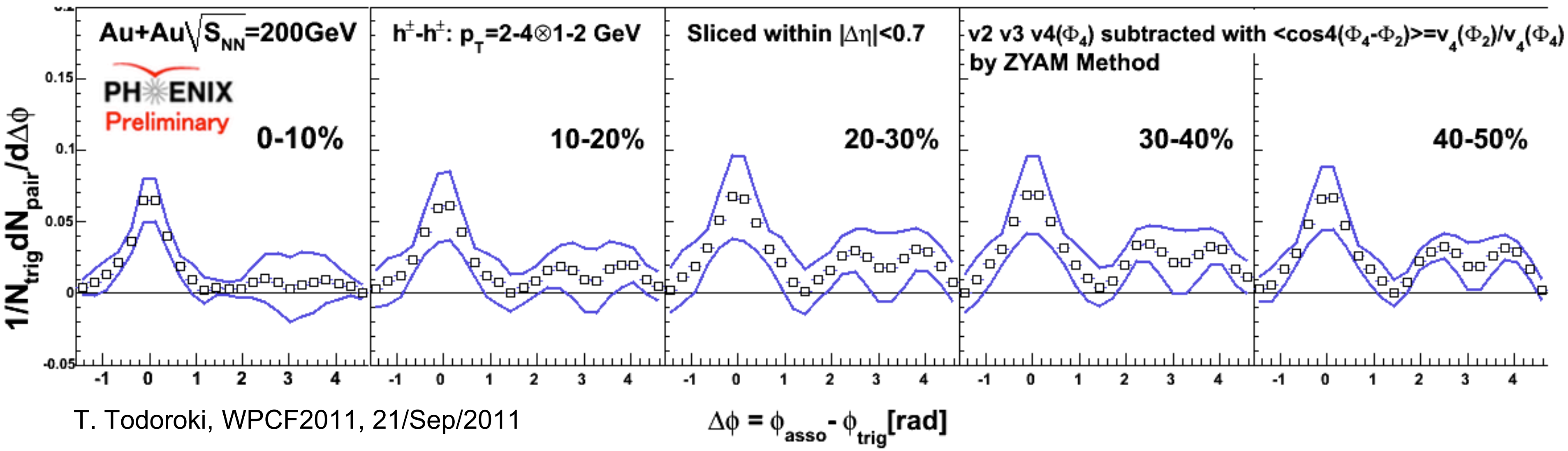
J. Jia, QM11



Not completely yet, without |Δη| gap.

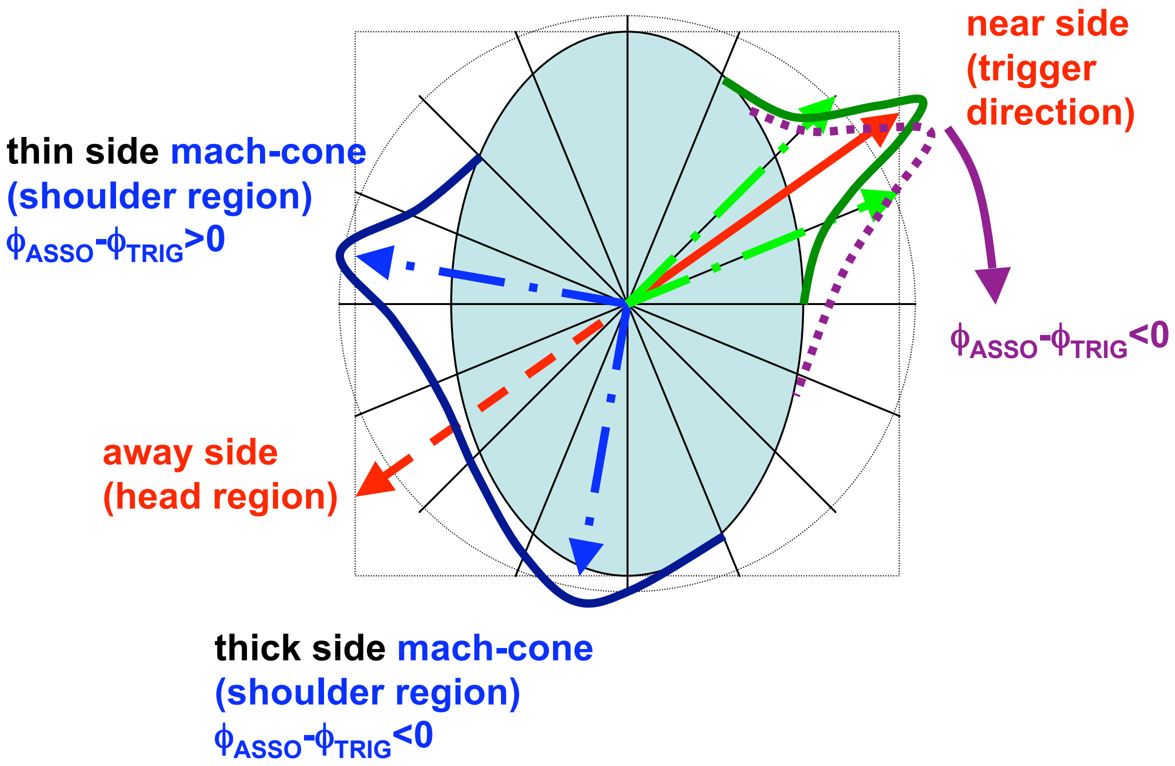
QM11, PHENIX

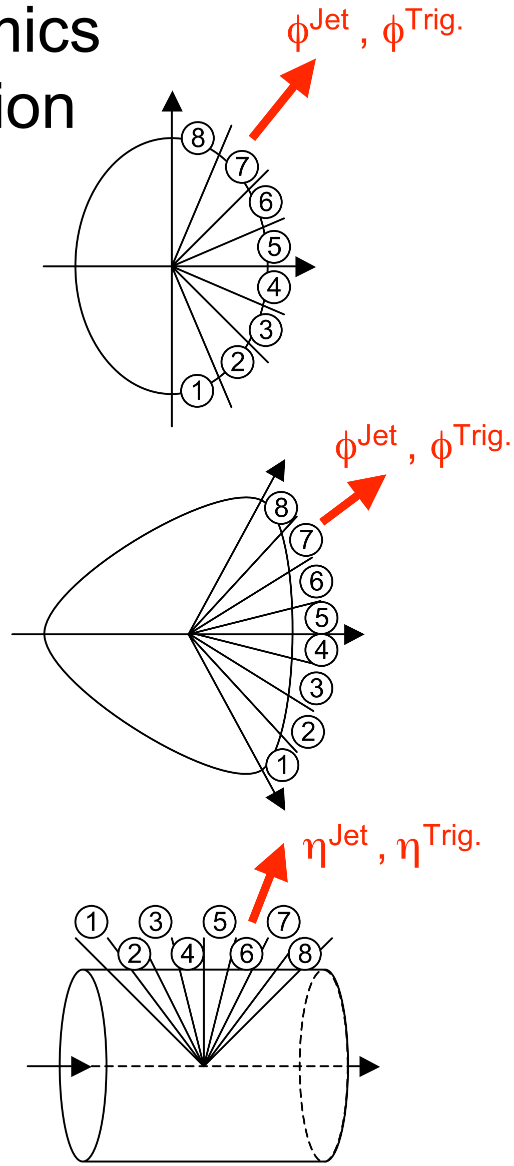




T. Todoroki, WPCF2011, 21/Sep/2011

Probe the transverse geometry and/or dynamics with trigger angle selected 2-particle correlation including the HBT correlation





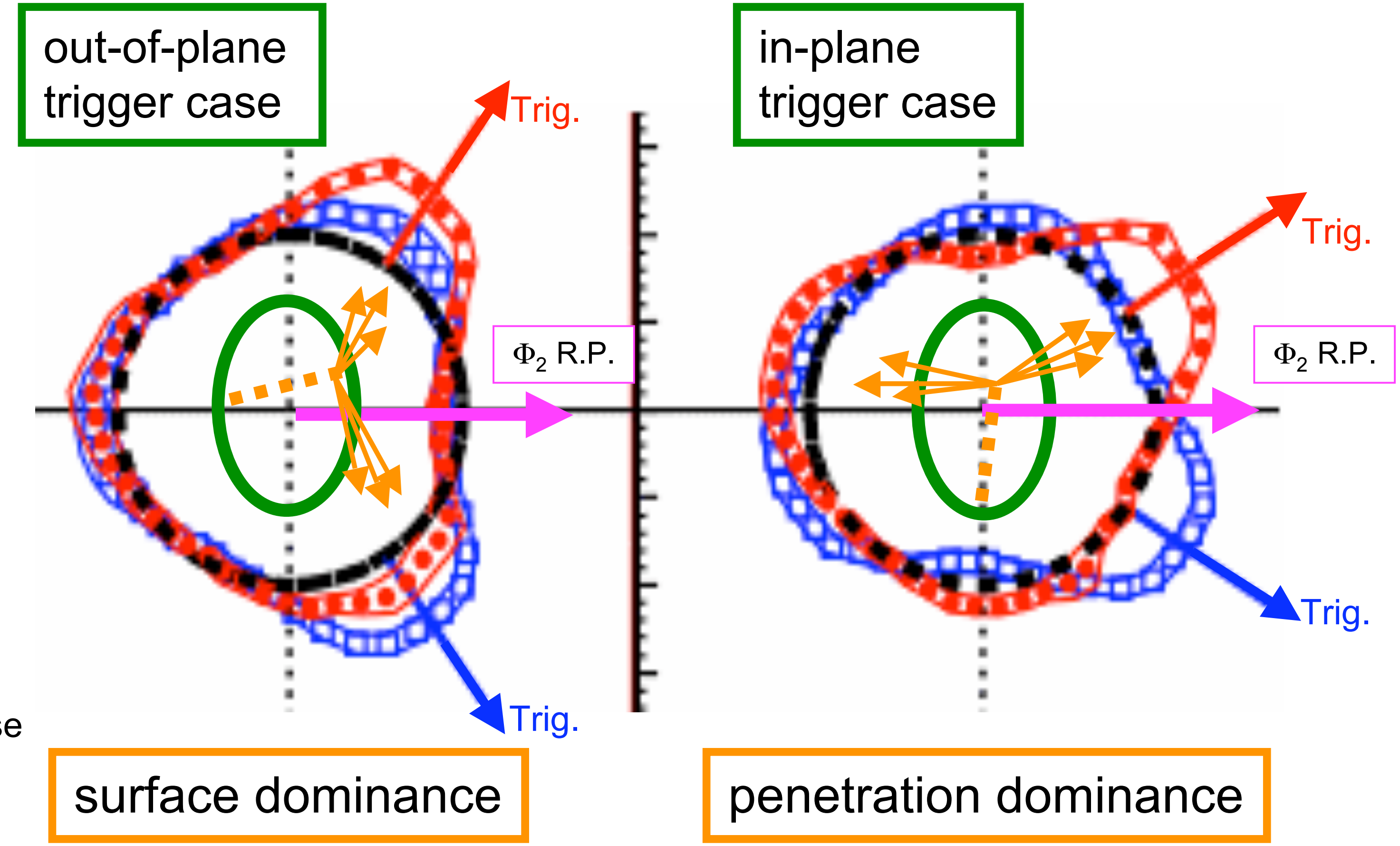
Observed left/right asymmetry remains after "the usual/normal" v_3 subtraction.

200GeV Au+Au -> h-h, 20-50%
(p_T^{Trig}=2~4, p_T^{Asso}=1~2GeV/c)
v_2,v_4\{Φ_2\} only subtraction
PHENIX preliminary

Trigger angle selection w.r.t. Φ_2 separately for left(up) / right(down)

Trigger angle selected 2-part. corr. data are plotted in polar coordinate by rotating Φ_2 R.P. angle as X-axis.

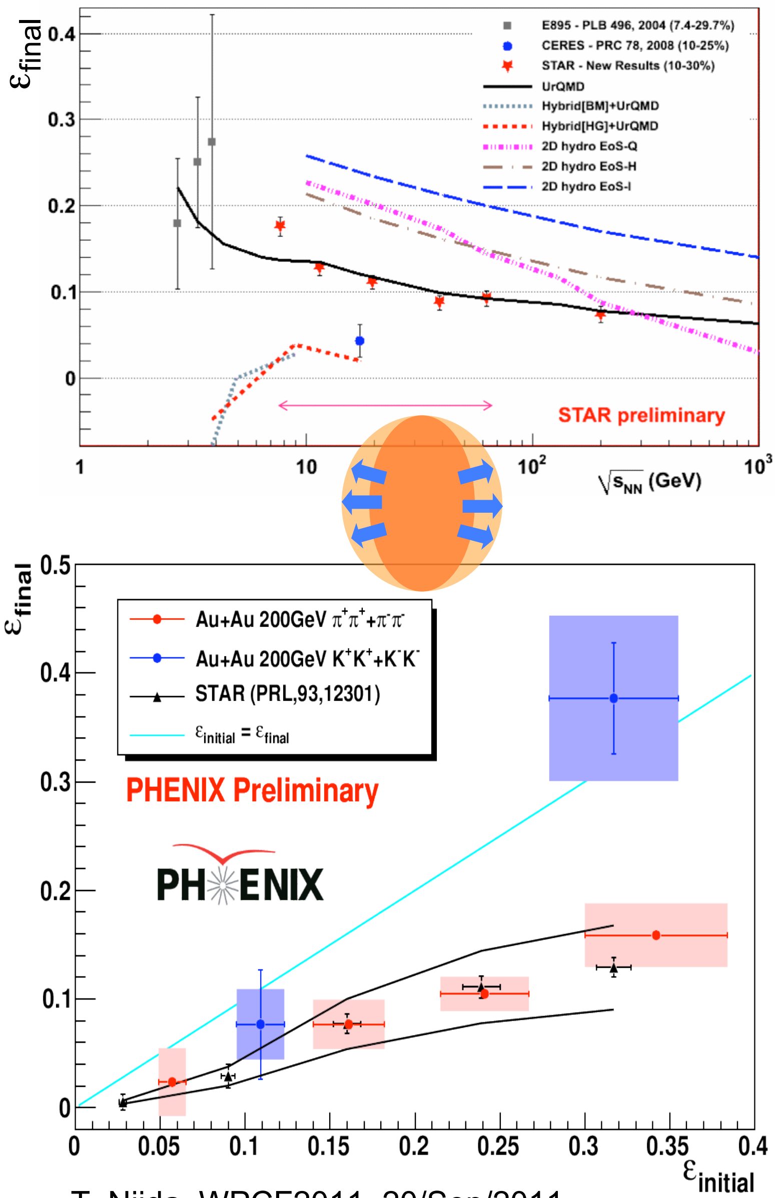
Flow subtracted yield is shown radially with base line. ■■■■■■



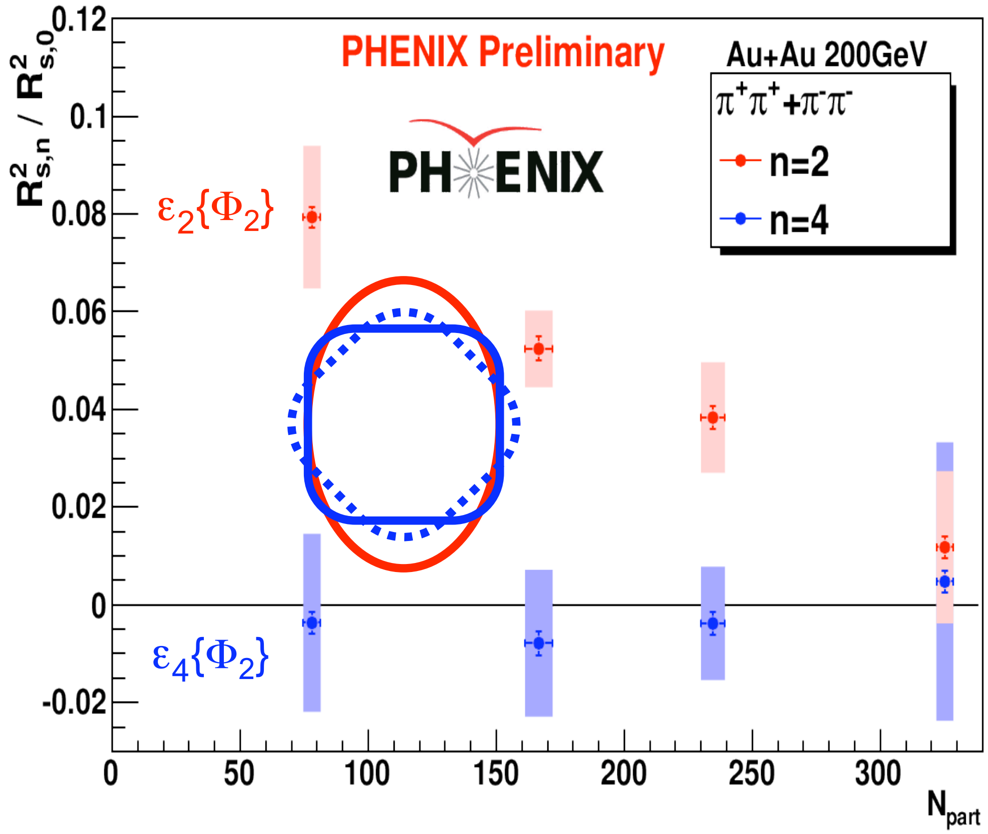
Two competing processes seen

Geometrical source anisotropy via HBT measurement at the end of freeze-out

M. Lisa, WPCF2011



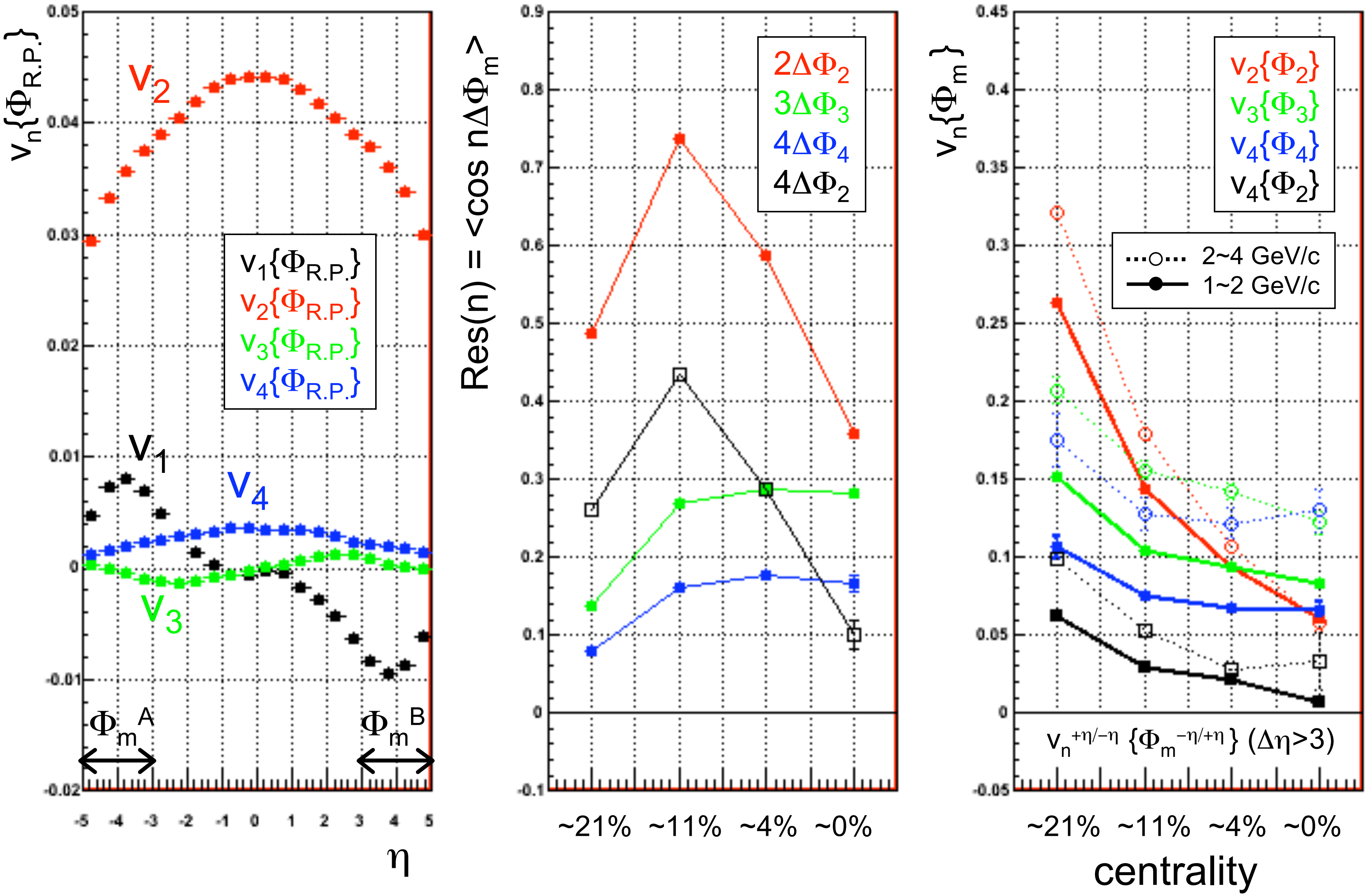
T. Niida, WPCF2011, 20/Sep/2011



The "$\varepsilon_2\{\Phi_2\}$ vs $\varepsilon_4\{\Phi_2\}$" might be different from the "$v_2\{\Phi_2\}$ vs $v_4\{\Phi_2\}$" relation, $\varepsilon_n\{\Phi_n\}$ is underway.

AMPT (string melting) simulation

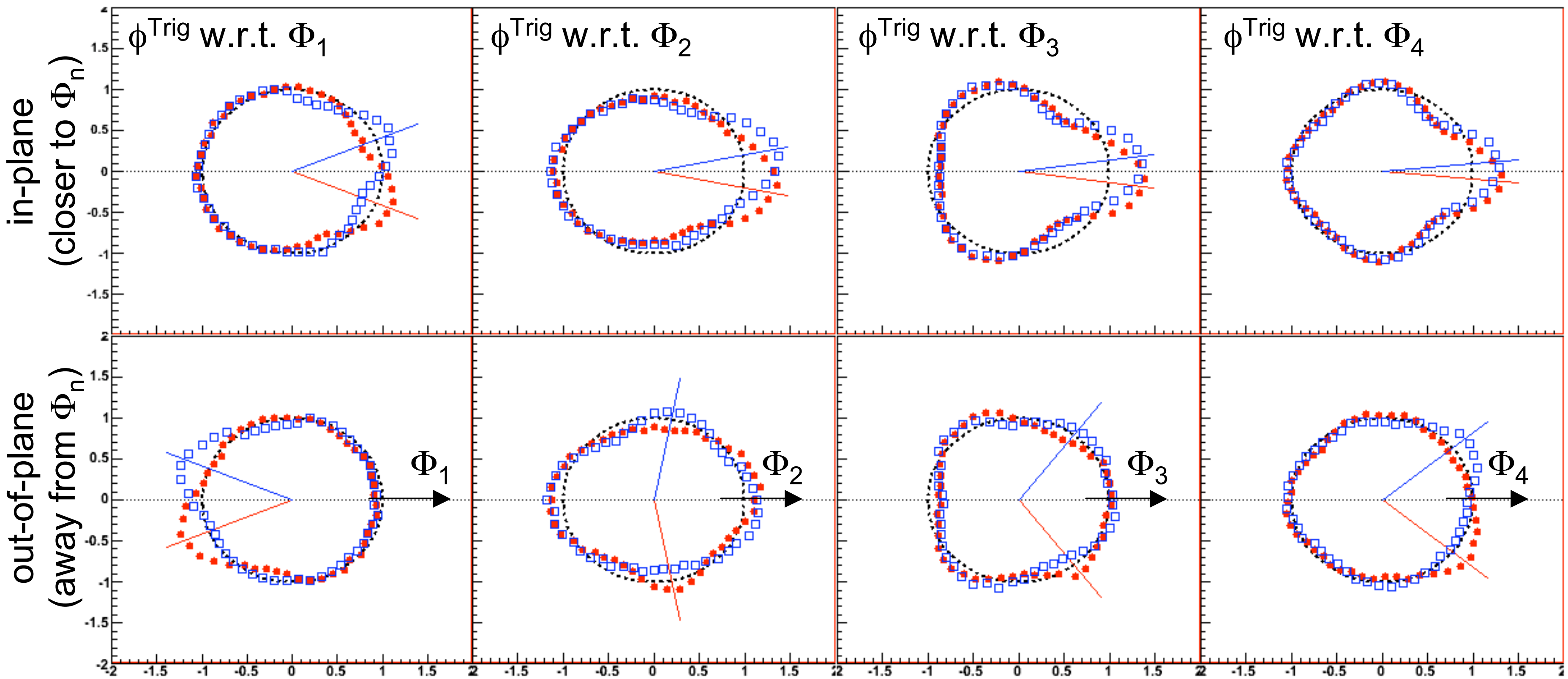
200GeV Au+Au



AMPT (string melting) simulation

200GeV Au+Au
0~4% centrality
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c

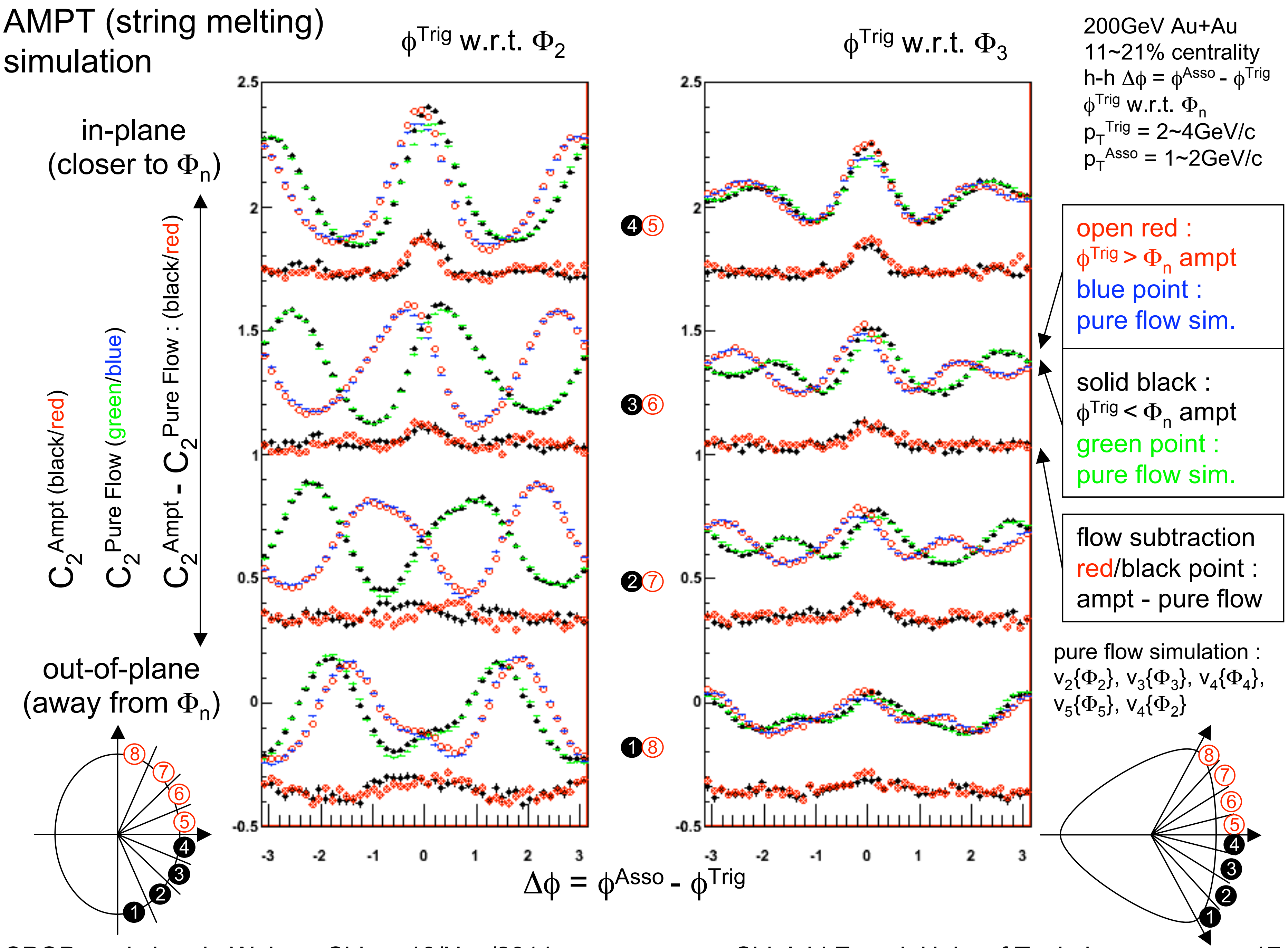
h-h $\Delta\phi = \phi^{Asso} - \phi^{Trig}$
ϕ^{Trig} w.r.t. $\Phi_n^{\{Opposite\ \eta\ from\ A/T\}}$
no flow subtraction
magnified: (C_2-1)x2+1



C_2 (= N_{real}/N_{mix}) in radius
$\Delta\phi$ (= $\phi^{Asso} - \phi^{Trig}$) in azimuth

open blue point : $\phi^{Trig} > \Phi_n$
solid red point : $\phi^{Trig} < \Phi_n$
red/blue lines : ϕ^{Trig} direction
dashed black base line : C_2=1

AMPT (string melting) simulation



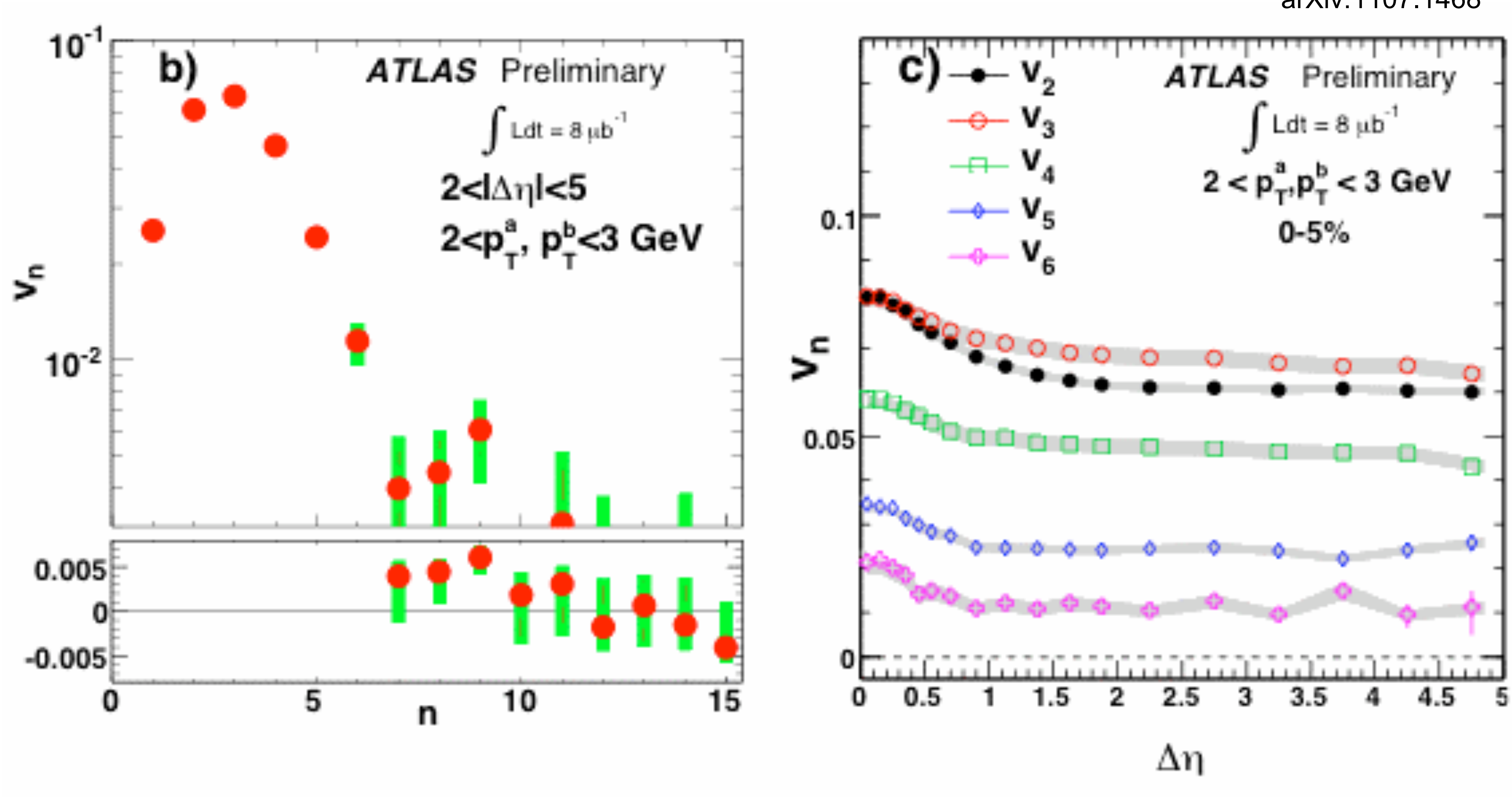
Summary

- Higher harmonic event anisotropy v_n is consistent with initial geometrical fluctuation, which seems to be followed by collective expansion.
- v_n measurement gives additional constraining power on the hydro parameters: viscosity and initial condition.
- v_n measurement provides a different way of explaining the same experimental observation on ridge and mach-corn structure, which are long in η direction.
- There must be some remaining medium response from the hard-soft interplay.

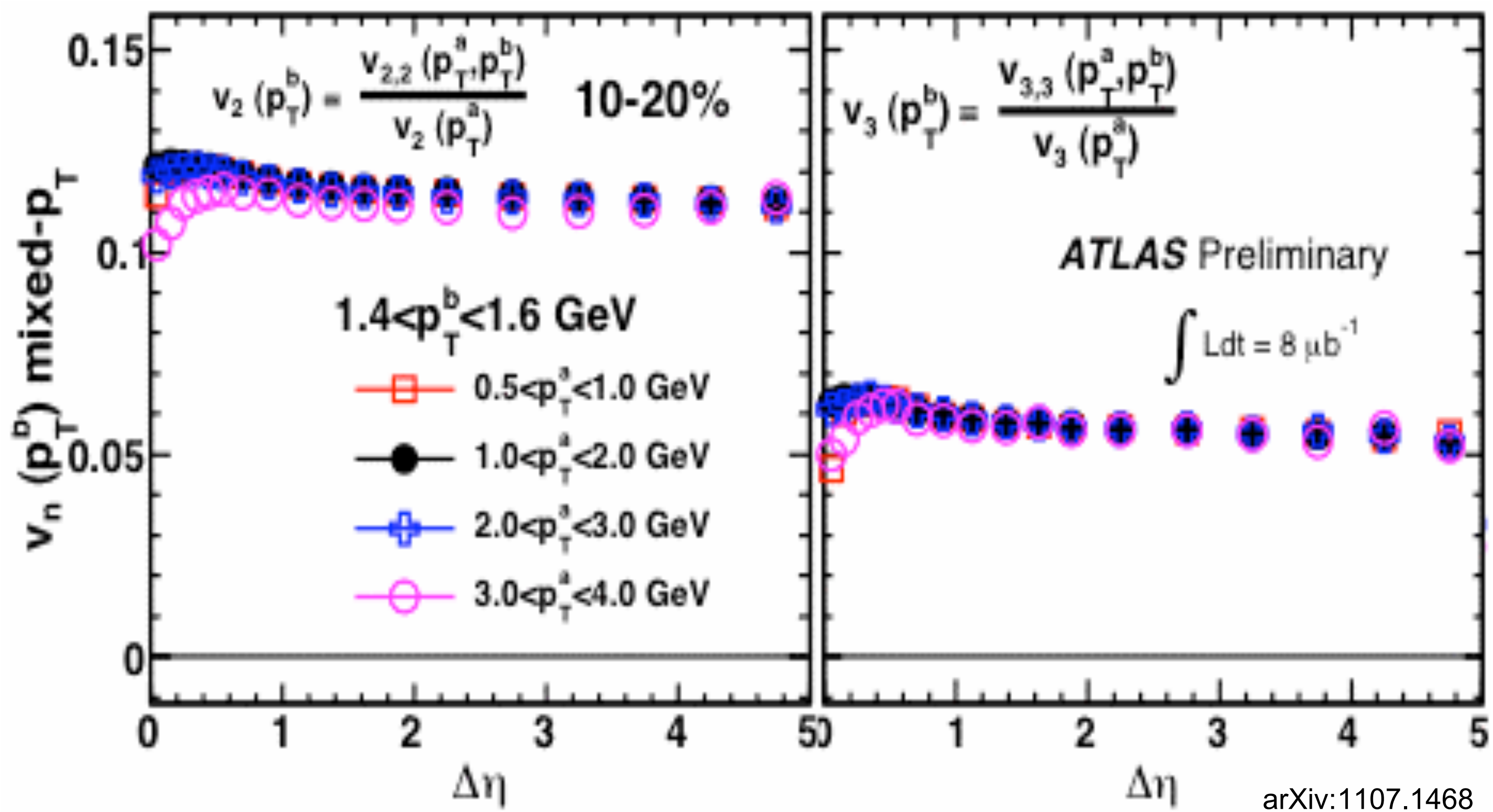
Backup slides

$|\Delta\eta|$ dependence of v_n from LHC-ATLAS

arXiv:1107.1468

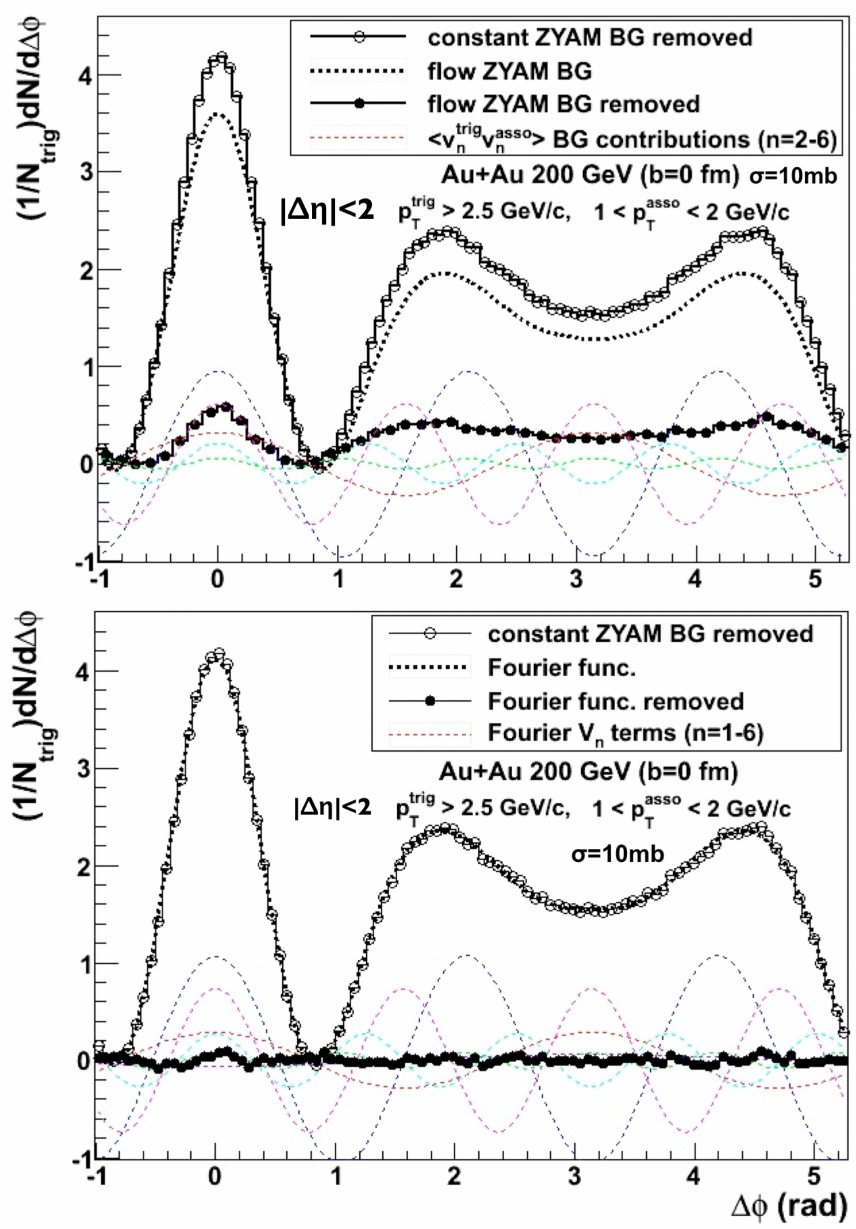


$|\Delta\eta|$ dependence of $(v_n^{trig.} \times v_n^{asso.})$ with $v_n\{C_2$ global fit$\}$, which they call v_n factorization in ATLAS

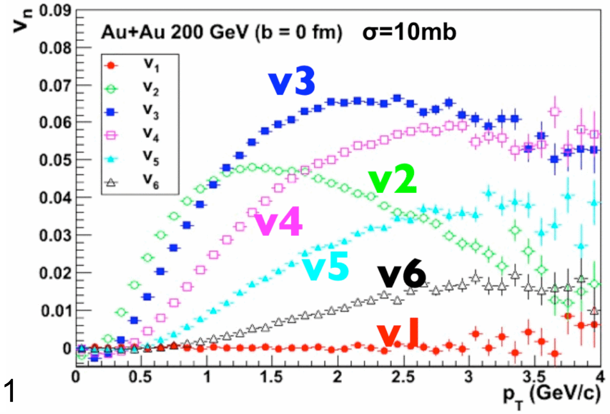


arXiv:1107.1468

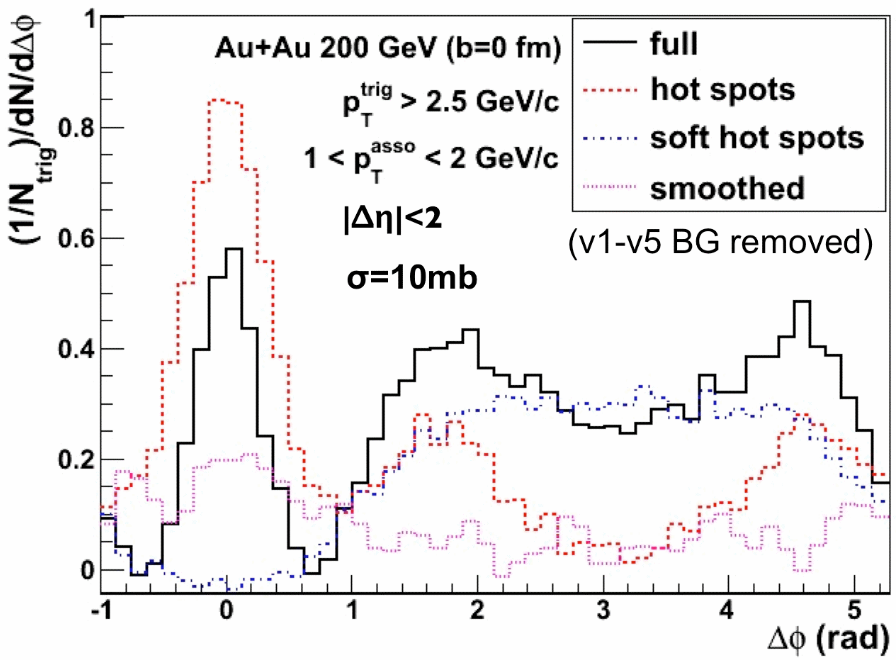
AMPT correlation test shows some remaining effects



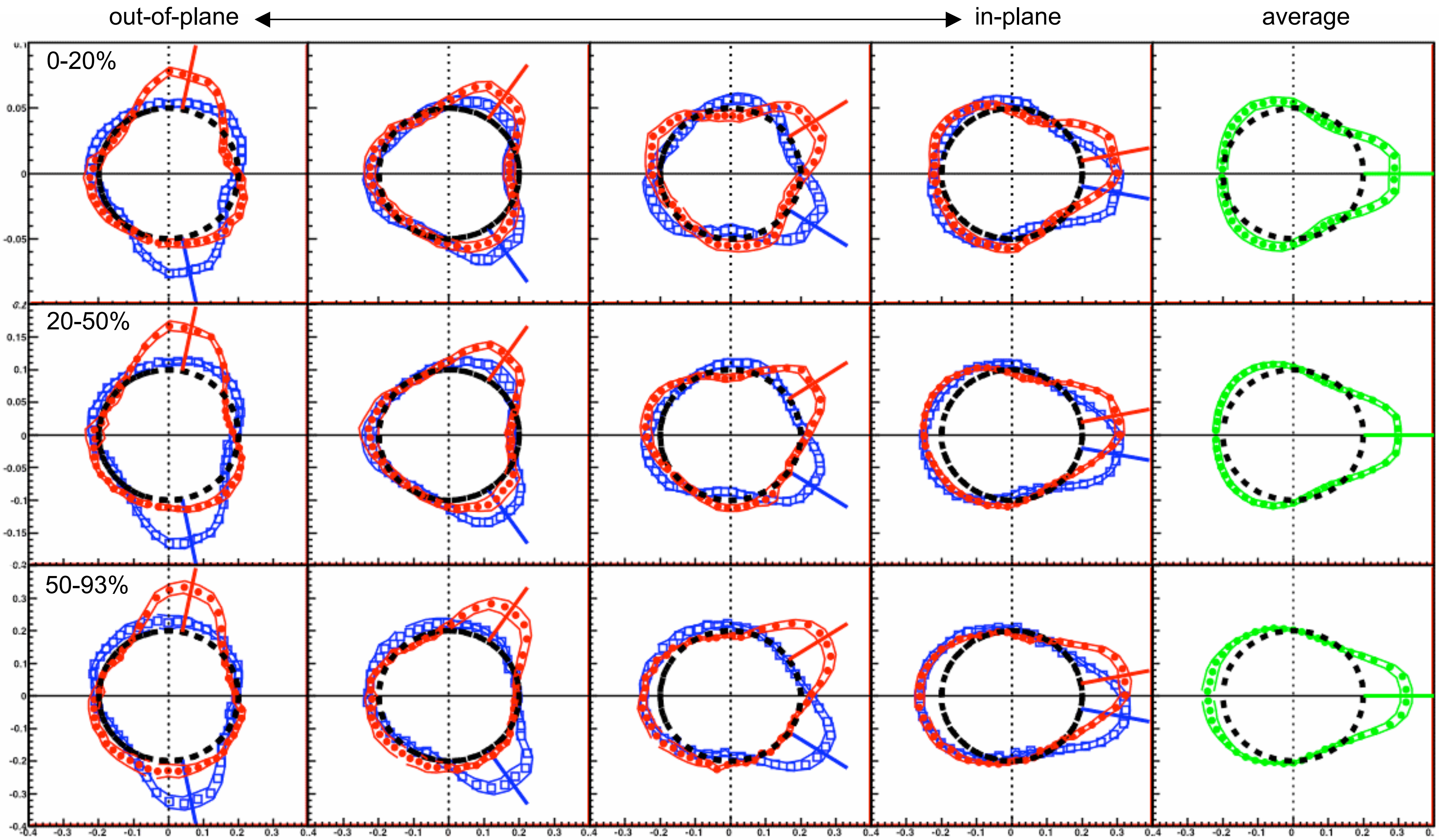
without |Δη| gap



G-L. Ma, QM11



Flow subtracted 2-particle ΔΦ correlation with trigger angle selection in 200GeV Au+Au



200GeV Au+Au -> h-h (p_T^{Trig}=2~4GeV/c, p_T^{Asso}=1~2GeV/c)
$v_2(v_4\{\Phi_2\})$-only subtraction **PHENIX preliminary**

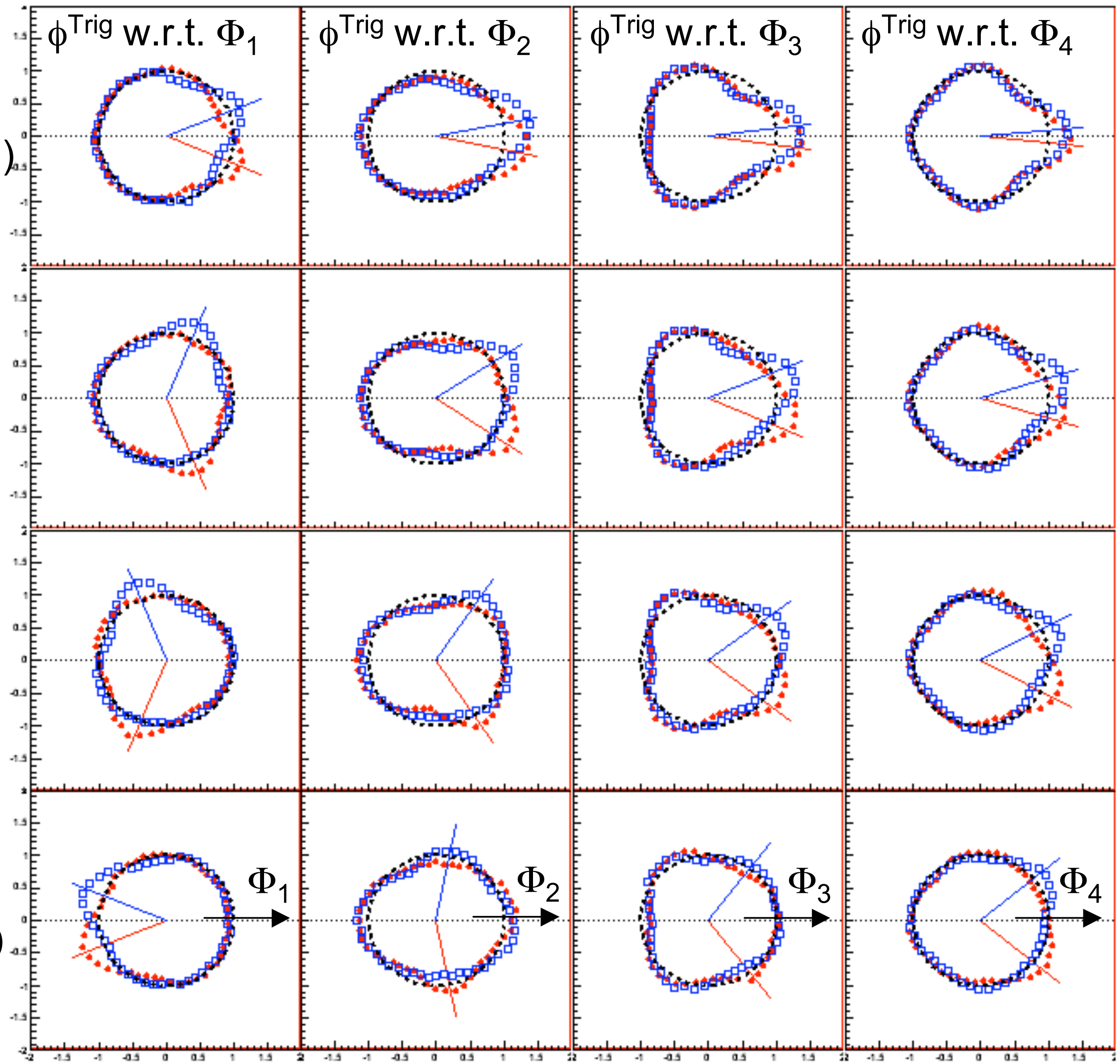
AMPT (string melting) simulation

200GeV Au+Au
0~4% centrality
h-h $\Delta\phi = \phi^{Asso} - \phi^{Trig}$
ϕ^{Trig} w.r.t. Φ_n
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c
no flow subtraction

in-plane (closer to Φ_n)

C_2 (= N_{real}/N_{mix}) in radius
$\Delta\phi$ (= $\phi^{Asso} - \phi^{Trig}$) in azimuth

out-of-plane (away from Φ_n)



open blue point : $\phi^{Trig} > \Phi_n$

solid red point : $\phi^{Trig} < \Phi_n$

red/blue lines : ϕ^{Trig} direction

dashed black base line : C_2=1

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p_T^{Trig} = 2~4GeV/c
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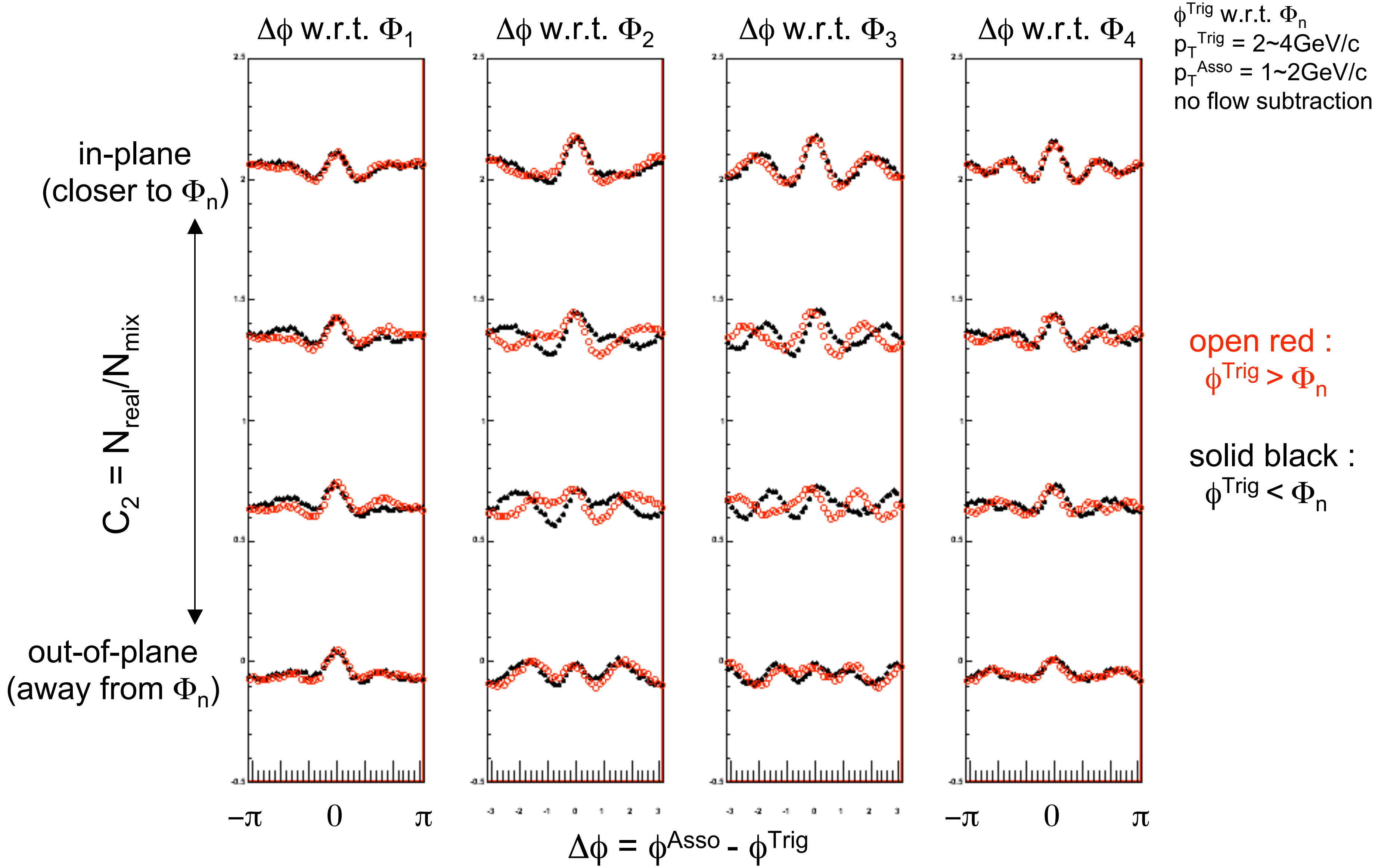

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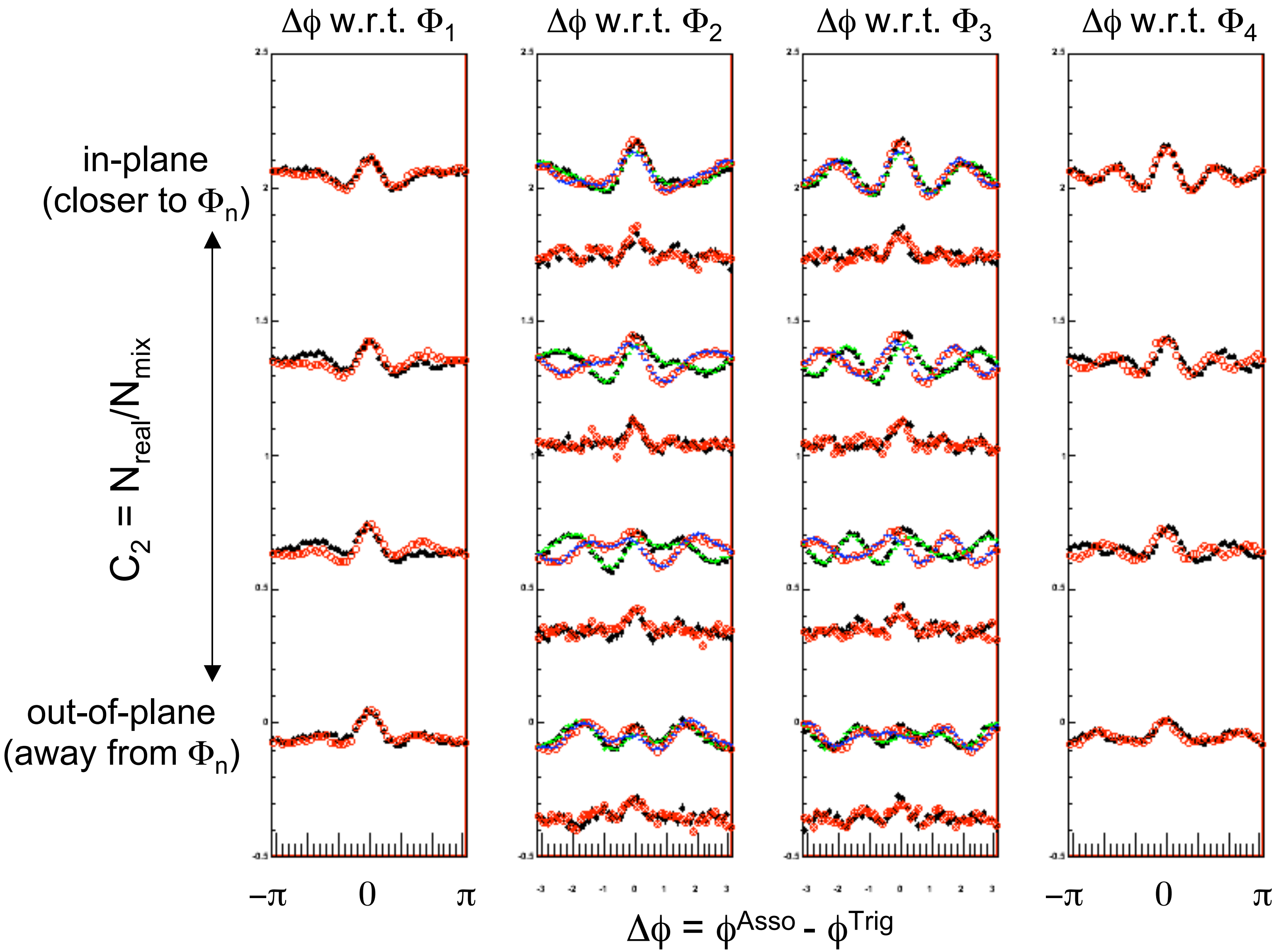
ϕ^{Trig} w.r.t. Φ_n
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c
flow subtraction
with $v_2\{\Phi_2\}$, $v_3\{\Phi_3\}$, $v_4\{\Phi_4\}$, $v_4\{\Phi_2\}$



open red : $\phi^{Trig} > \Phi_n$

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ϕ^{Trig} w.r.t. Φ_n
p_T^{Trig} = 2~4GeV/c
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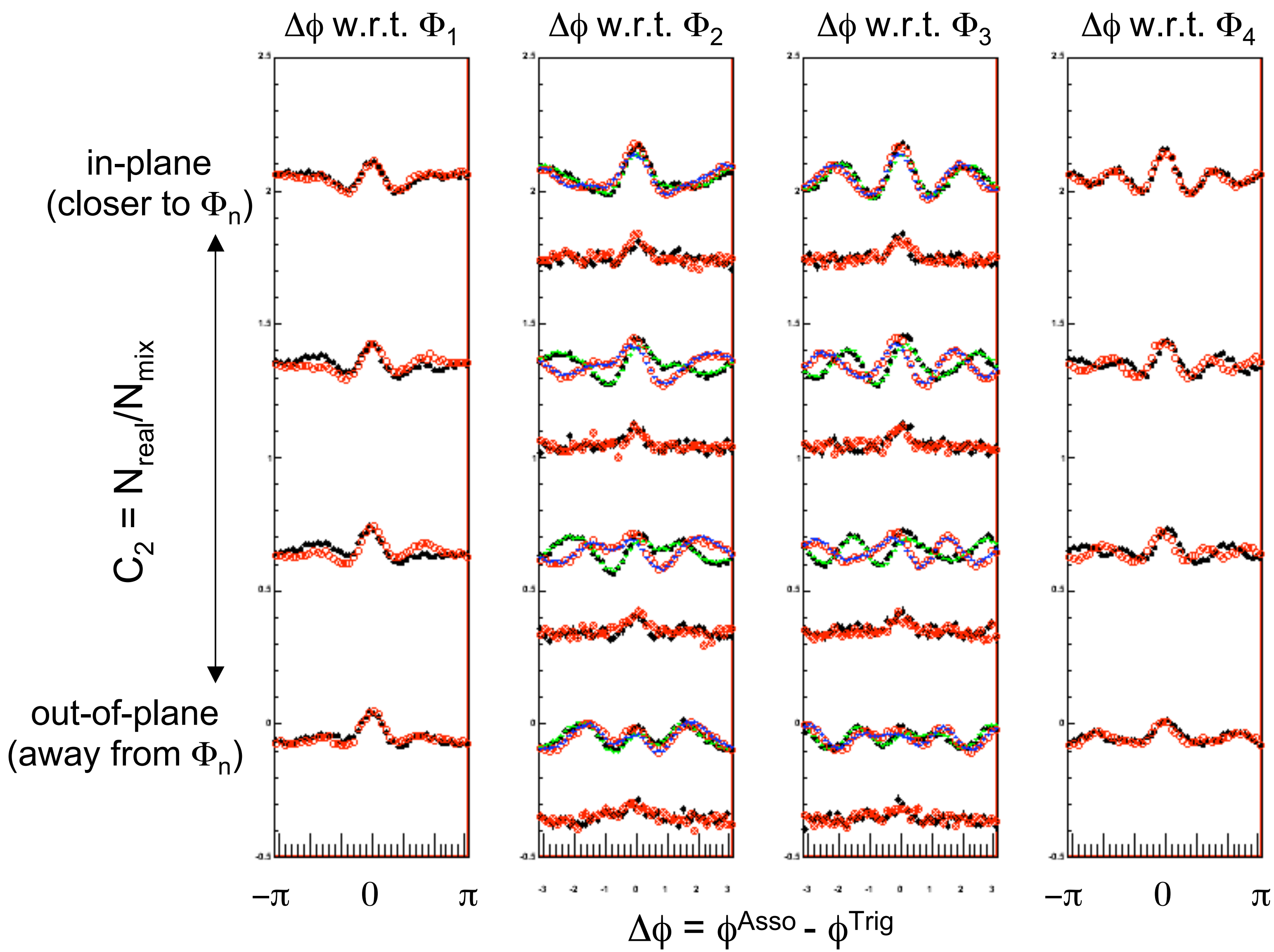
flow subtraction
with $v_2\{\Phi_2\}$, $v_3\{\Phi_3\}$, $v_4\{\Phi_4\}$, $v_4\{\Phi_2\}$ and $v_5\{\Phi_5\}$



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solid black :
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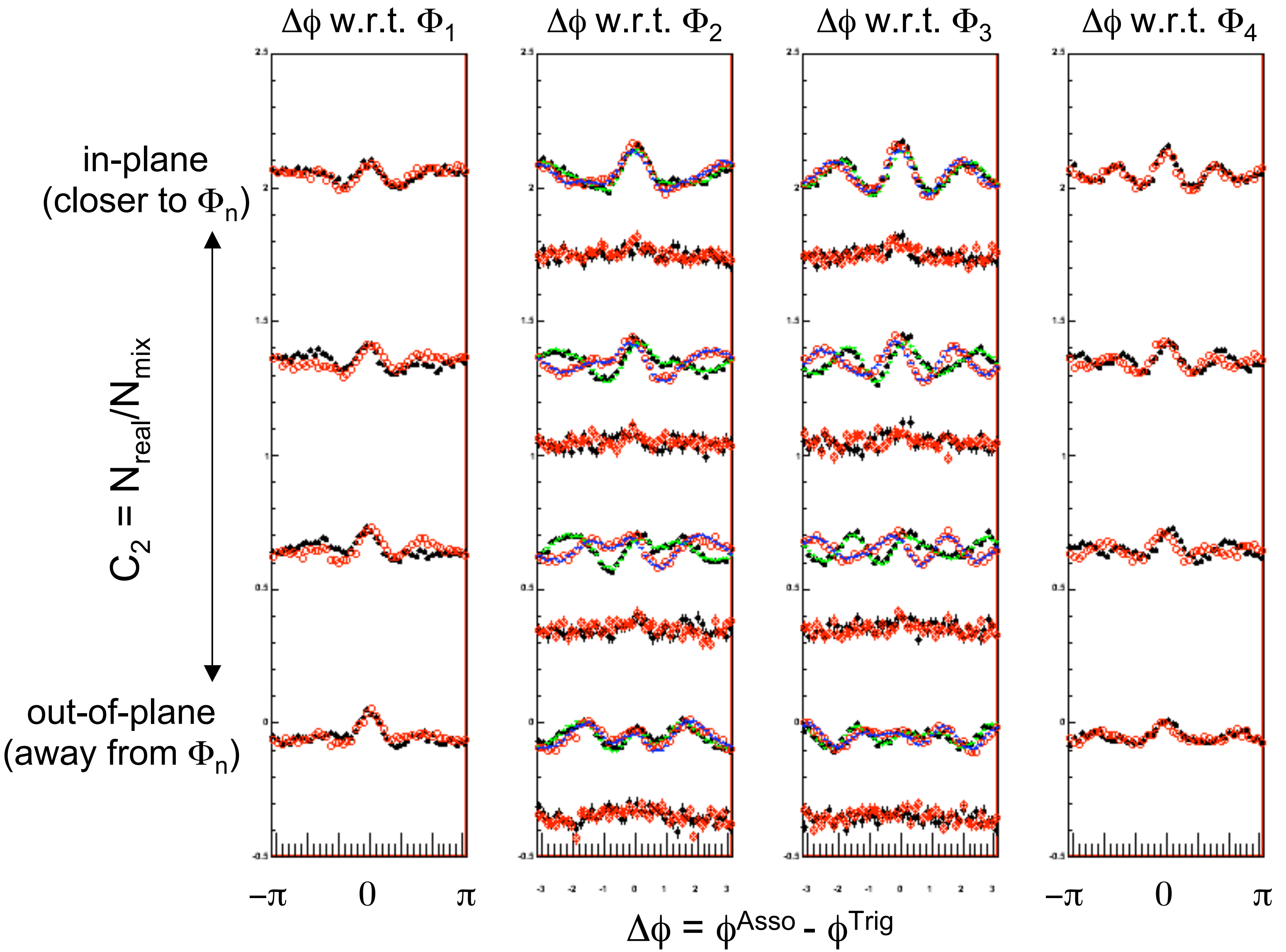
AMPT (string melting) simulation

200GeV Au+Au
0~4% centrality
h-h $\Delta\phi = \phi^{Asso} - \phi^{Trig}$
ϕ^{Trig} w.r.t. Φ_n
with $|\Delta\eta|>1$
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c
flow subtraction
with $v_2\{\Phi_2\}$, $v_3\{\Phi_3\}$, $v_4\{\Phi_4\}$, $v_4\{\Phi_2\}$ and $v_5\{\Phi_5\}$

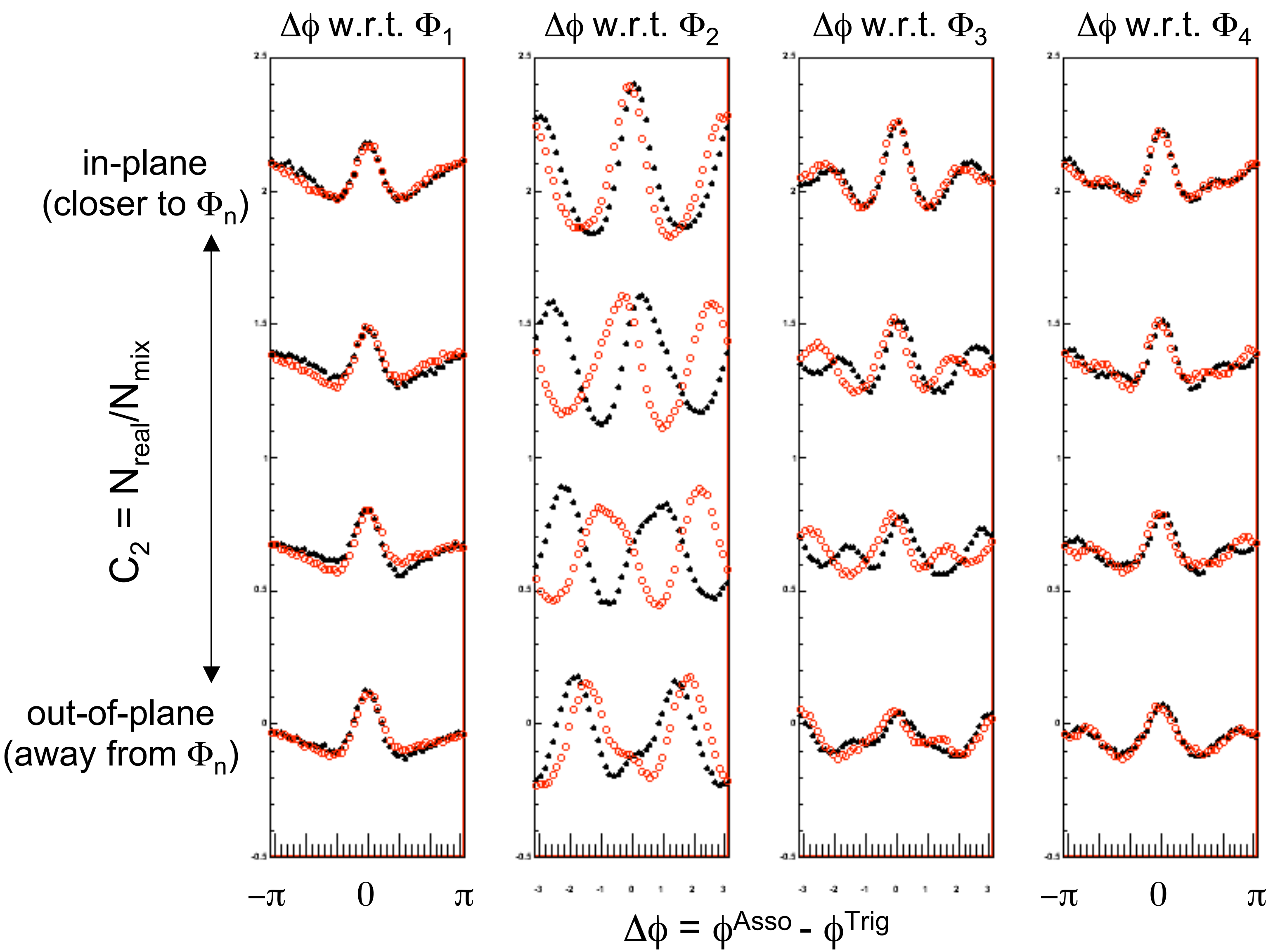


open red : $\phi^{Trig} > \Phi_n$

solid black : $\phi^{Trig} < \Phi_n$

AMPT (string melting) simulation

200GeV Au+Au
11~21% centrality
h-h $\Delta\phi = \phi^{Asso} - \phi^{Trig}$
ϕ^{Trig} w.r.t. Φ_n
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c
no flow subtraction



open red :
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AMPT (string melting) simulation

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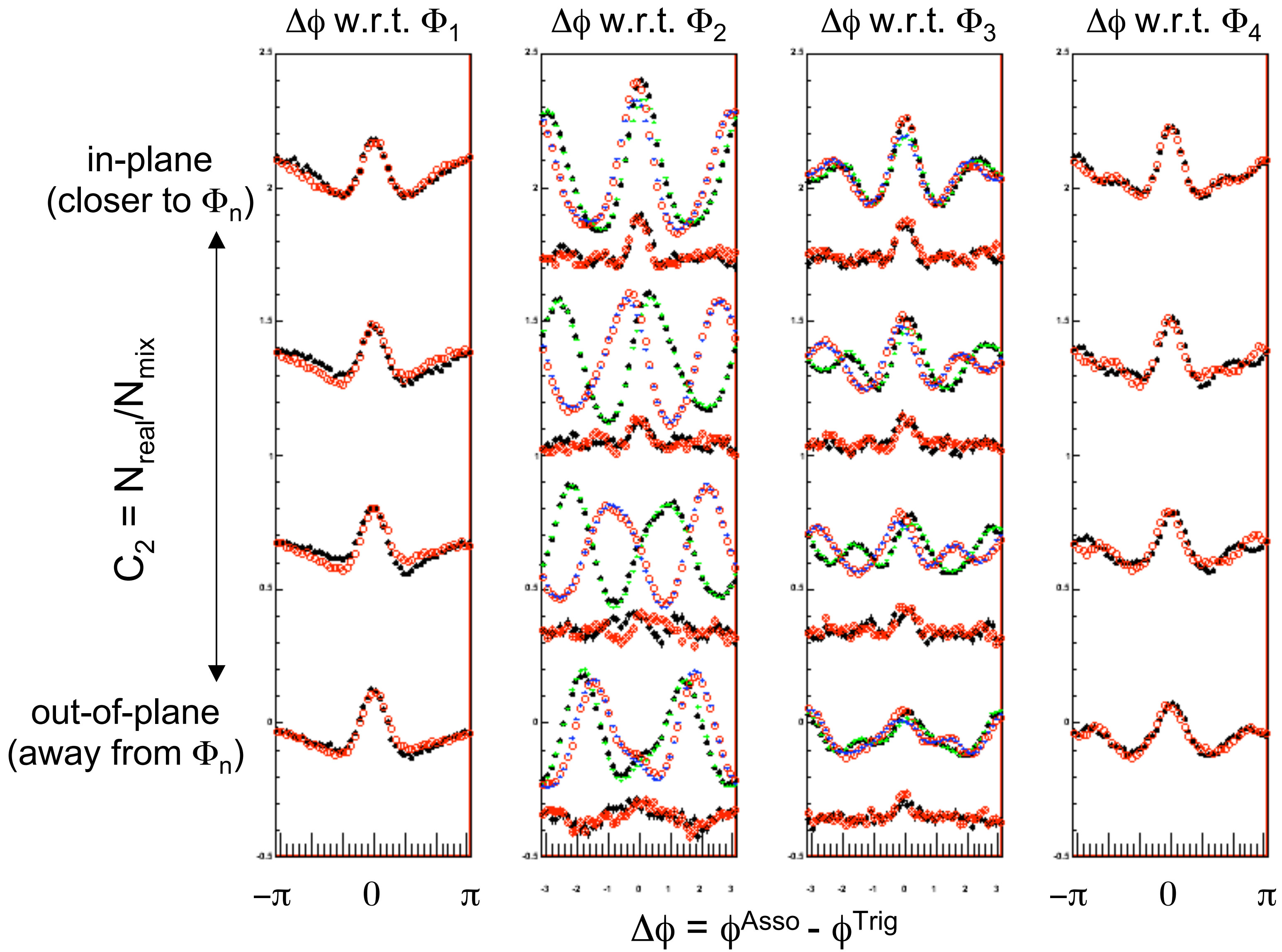
ϕ^{Trig} w.r.t. Φ_n
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c
flow subtraction
with $v_2\{\Phi_2\}$, $v_3\{\Phi_3\}$,
$v_4\{\Phi_4\}$, $v_4\{\Phi_2\}$



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p_T^{Trig} = 2~4GeV/c
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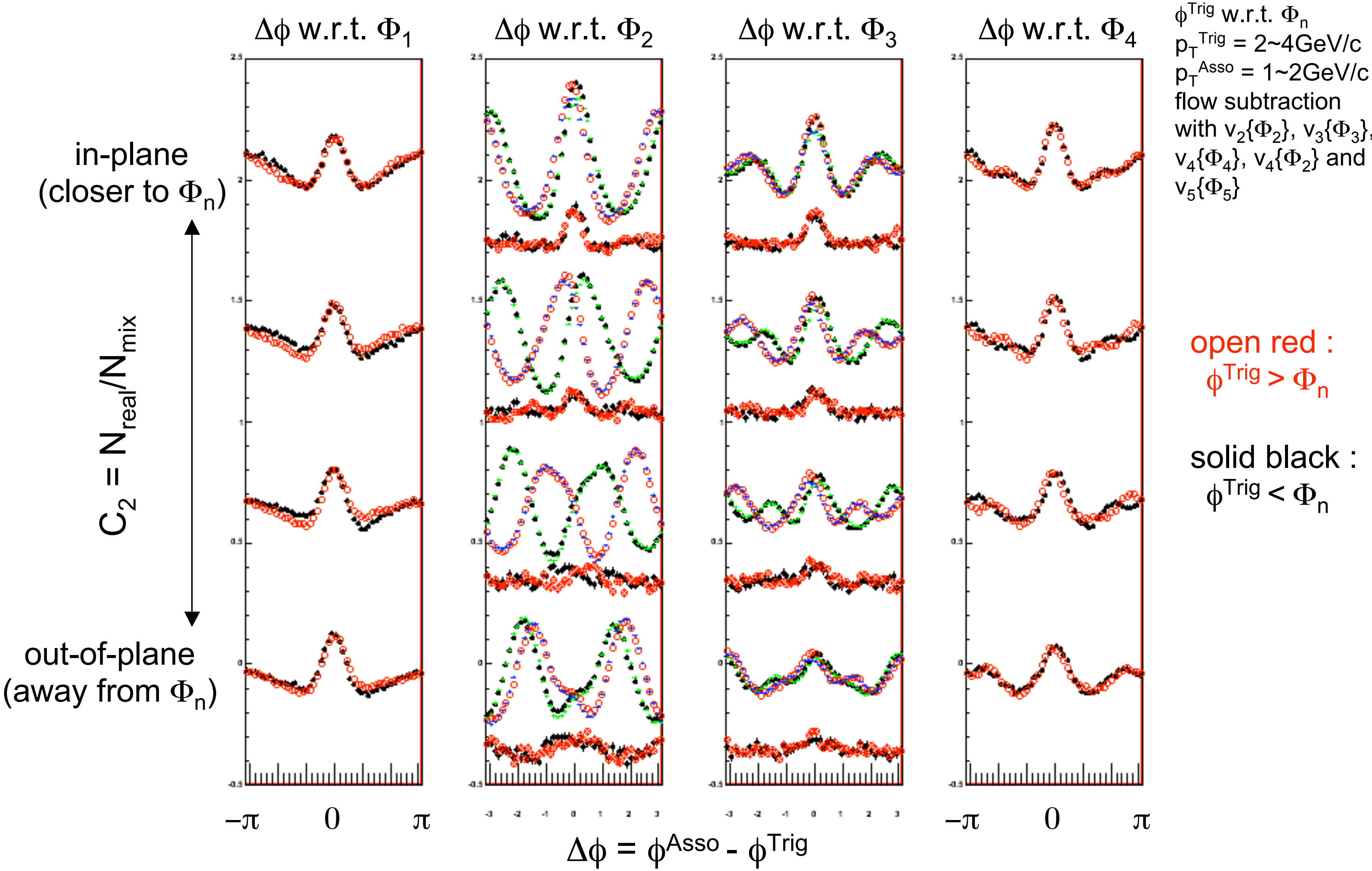
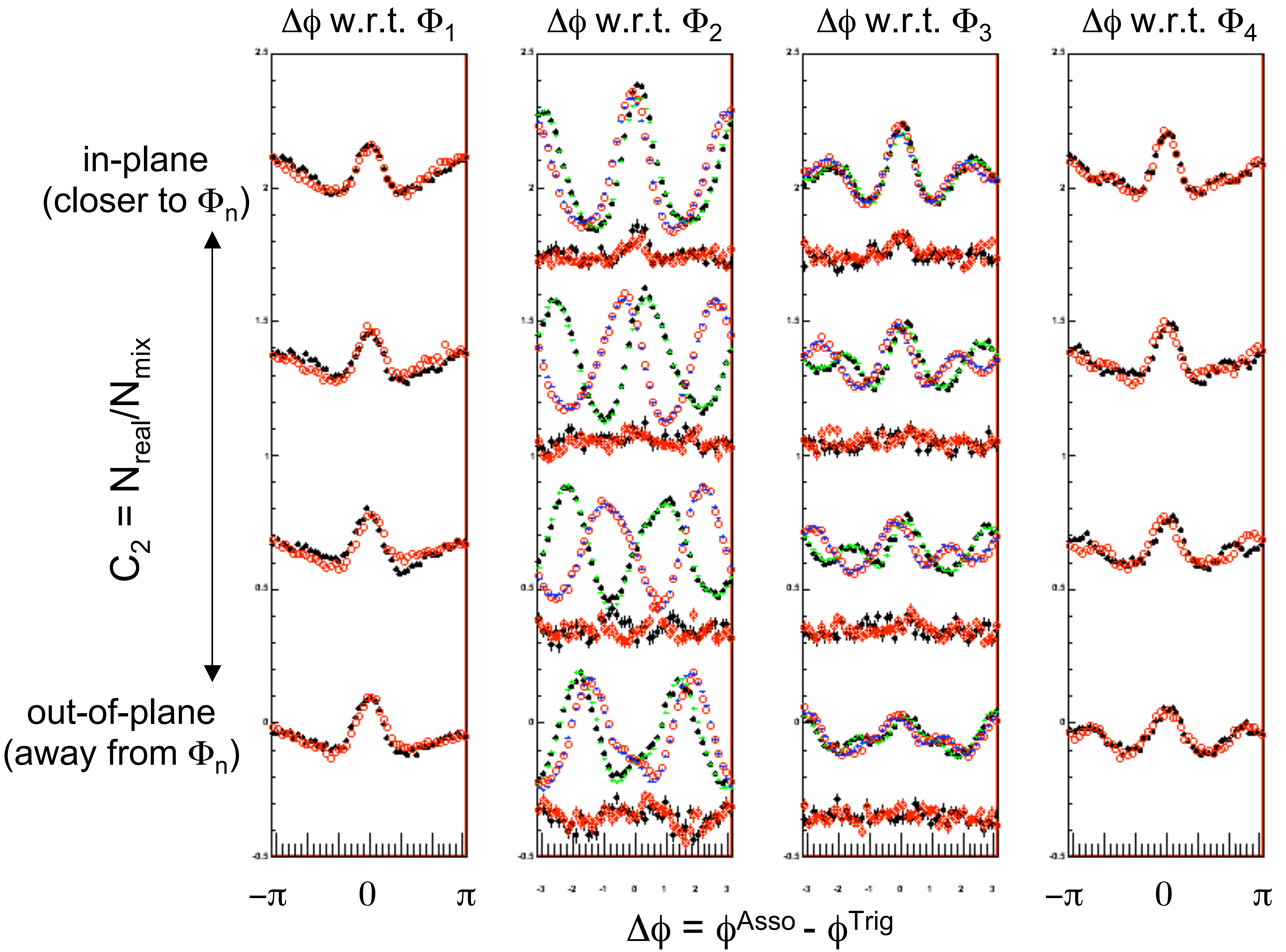
flow subtraction
with $v_2\{\Phi_2\}$, $v_3\{\Phi_3\}$, $v_4\{\Phi_4\}$, $v_4\{\Phi_2\}$ and $v_5\{\Phi_5\}$



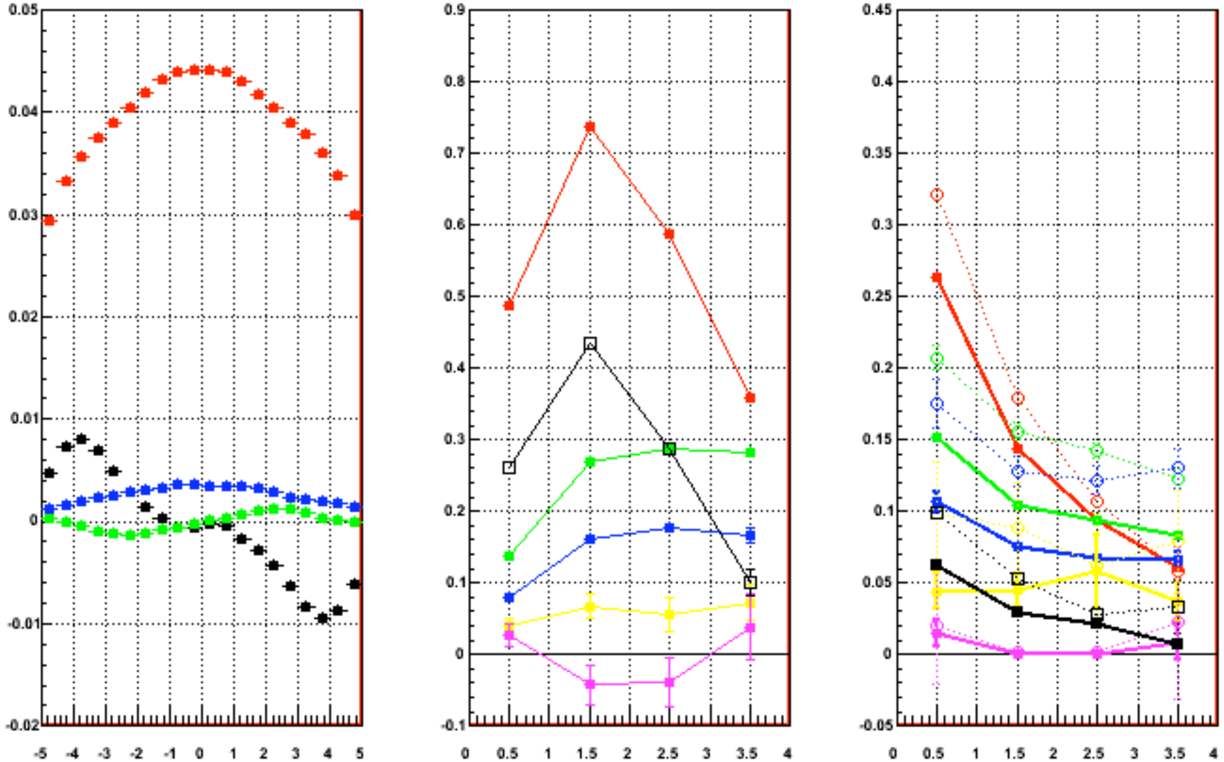
AMPT (string melting) simulation



200GeV Au+Au
11~21% centrality
h-h $\Delta\phi = \phi^{Asso} - \phi^{Trig}$
ϕ^{Trig} w.r.t. Φ_n
with $|\Delta\eta|>1$
p_T^{Trig} = 2~4GeV/c
p_T^{Asso} = 1~2GeV/c
flow subtraction
with $v_2\{\Phi_2\}$, $v_3\{\Phi_3\}$, $v_4\{\Phi_4\}$, $v_4\{\Phi_2\}$ and $v_5\{\Phi_5\}$

open red : $\phi^{Trig} > \Phi_n$

solid black : $\phi^{Trig} < \Phi_n$



0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-5 -4 -3 -2 -1 0 1 2 3 4 5
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
0 0.5 1 1.5 2 2.5 3 3.5 4
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0 0.5 1 1.5 2 2.5 3 3.5 4

Au+Au 20-60%, p_T^{trig}=3-4 GeV/c, p_T^{assoc}=1-1.5 GeV/c, large $|\Delta\eta|$>0.7

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