Elliptic and triangular flow measurements
--- interplay between soft and hard process ---

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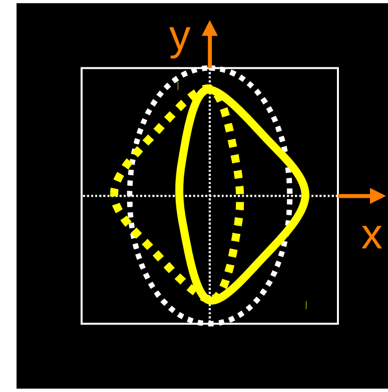
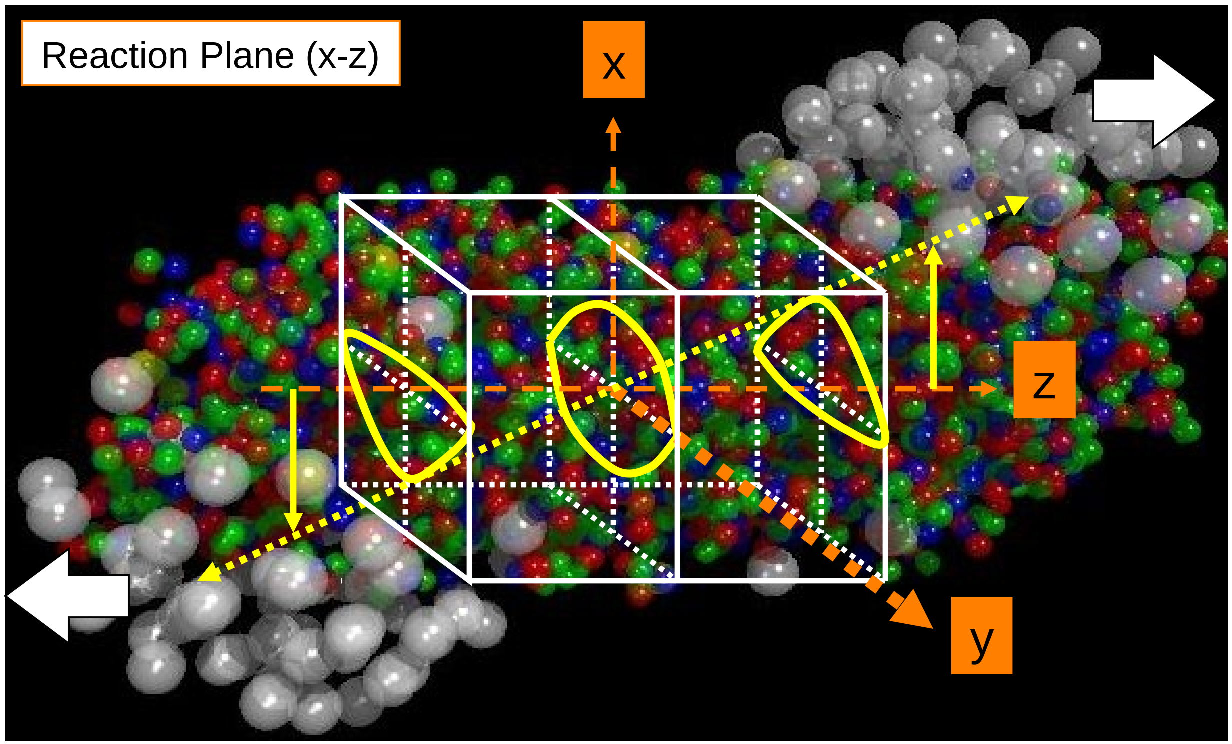
Contents

higher order event anisotropy
v_3 or ridge / mach-cone
v_n measurements with Φ_n at forward η
correlation with large rapidity gap
medium property with hard probe

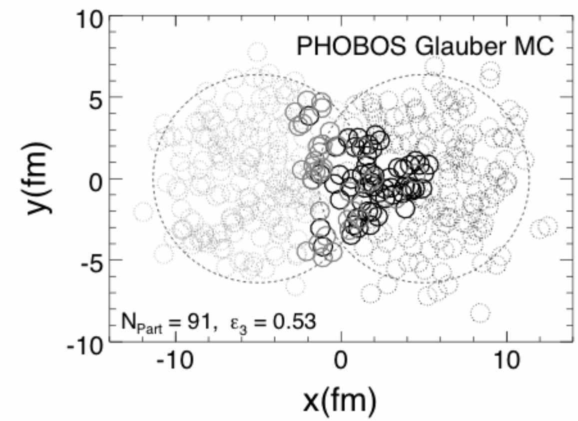
Higher order event anisotropy --- v_3 ---

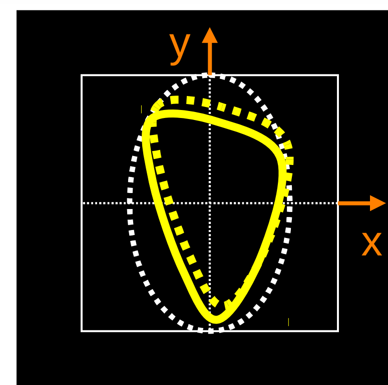
black-disk collision, sign-flipping v_3 like v_1
initial geometrical fluctuation, no-sign-flipping v_3





arXiv:1003.0194

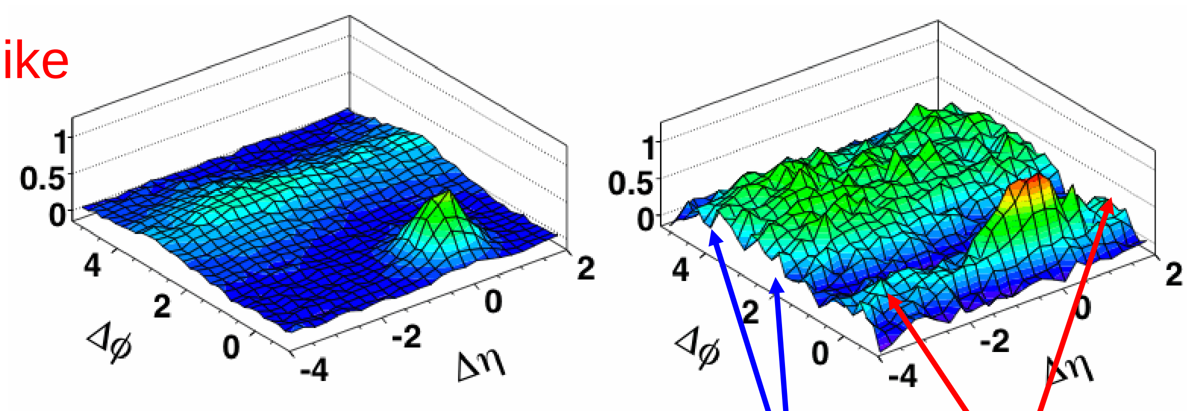




PRL104 (2010) 062301

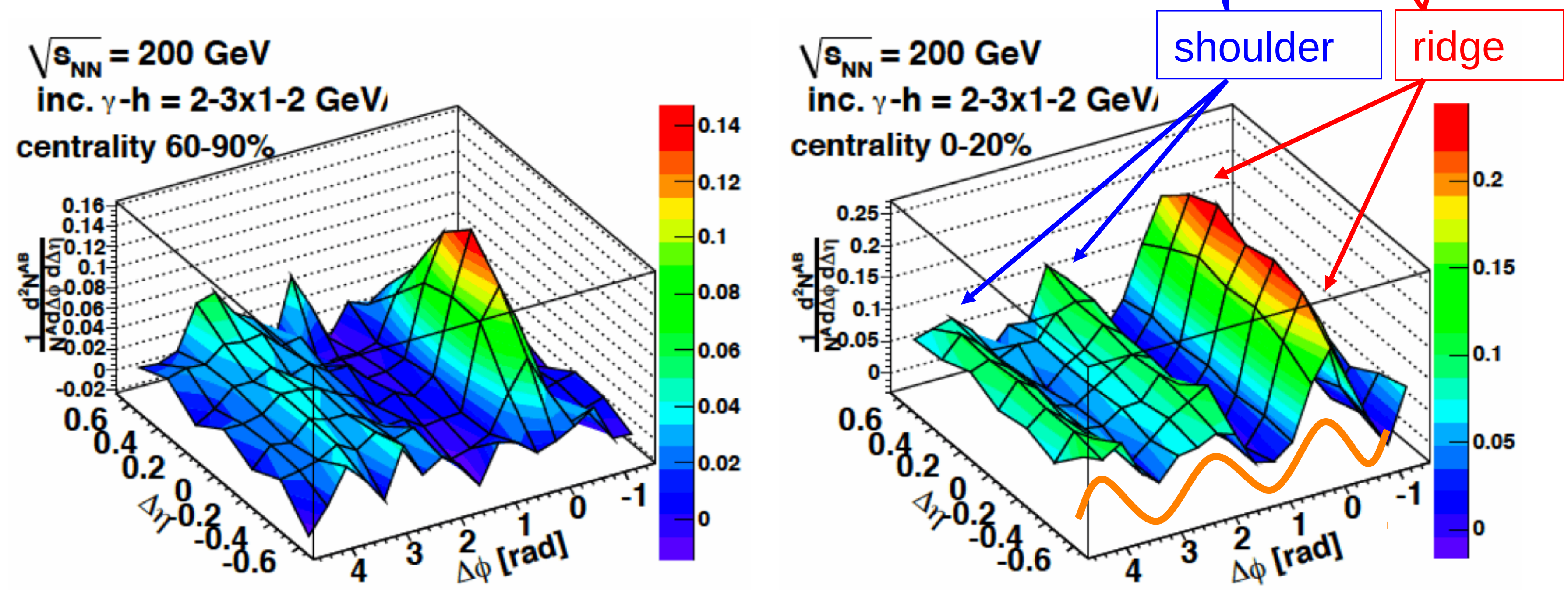
Some couplings between "mach-cone-like and ridge-like emissions" and v_3 are expected to be there!

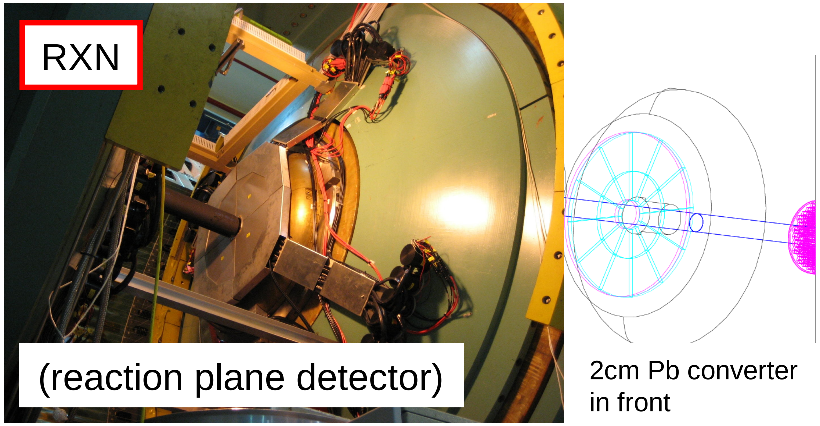
What is the origin and
what is the consequence?

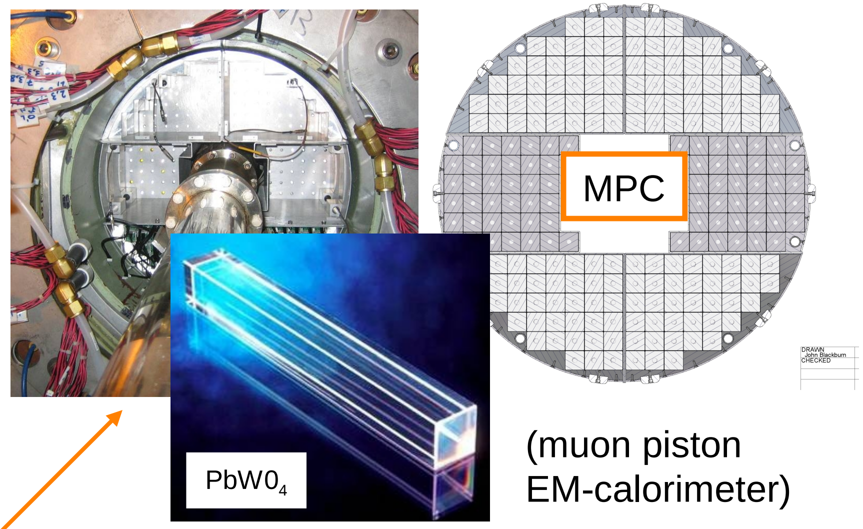


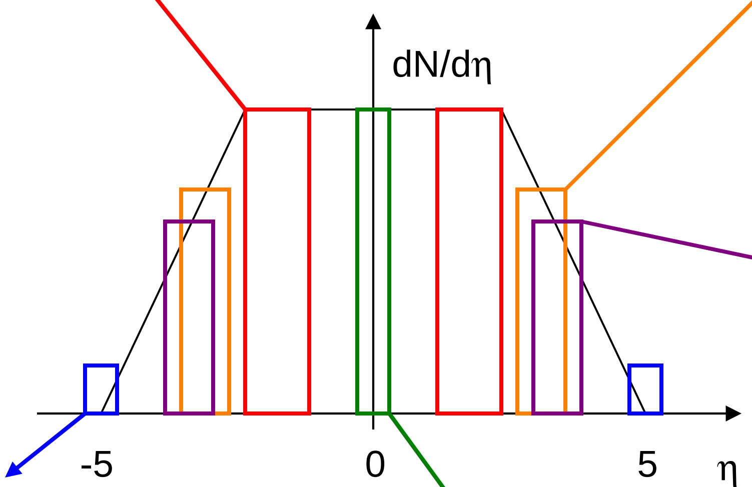
(a) p+p PYTHIA (version 6.325)

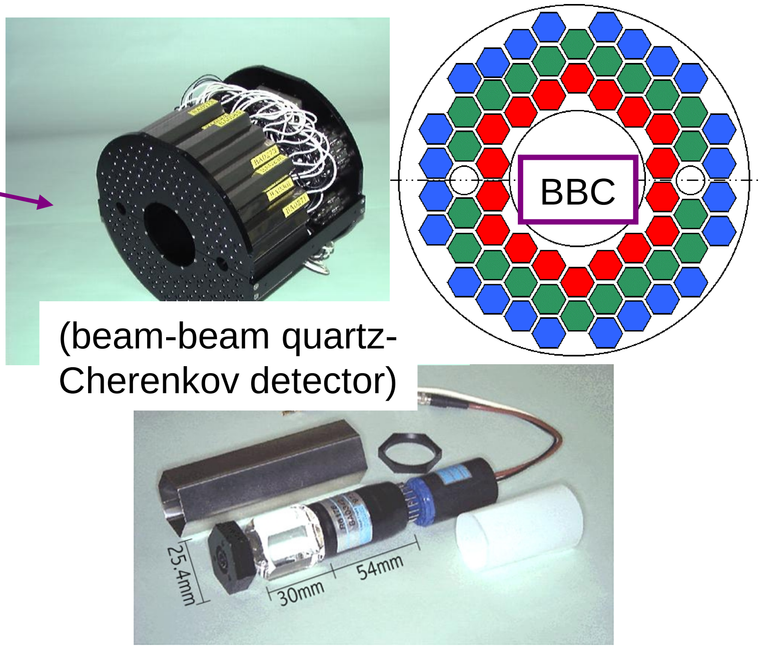
(b) Au+Au 0-30% (PHOBOS)



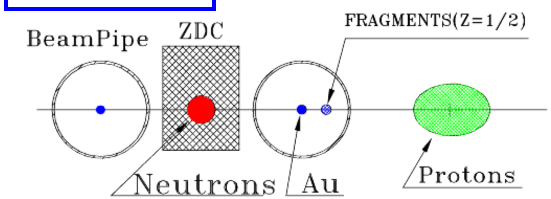

RXN
(reaction plane detector)
2cm Pb converter
in front

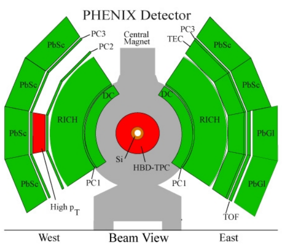

MPC
PbW0$_4$
(muon piston
EM-calorimeter)


dN/dη
-5
0
5
η

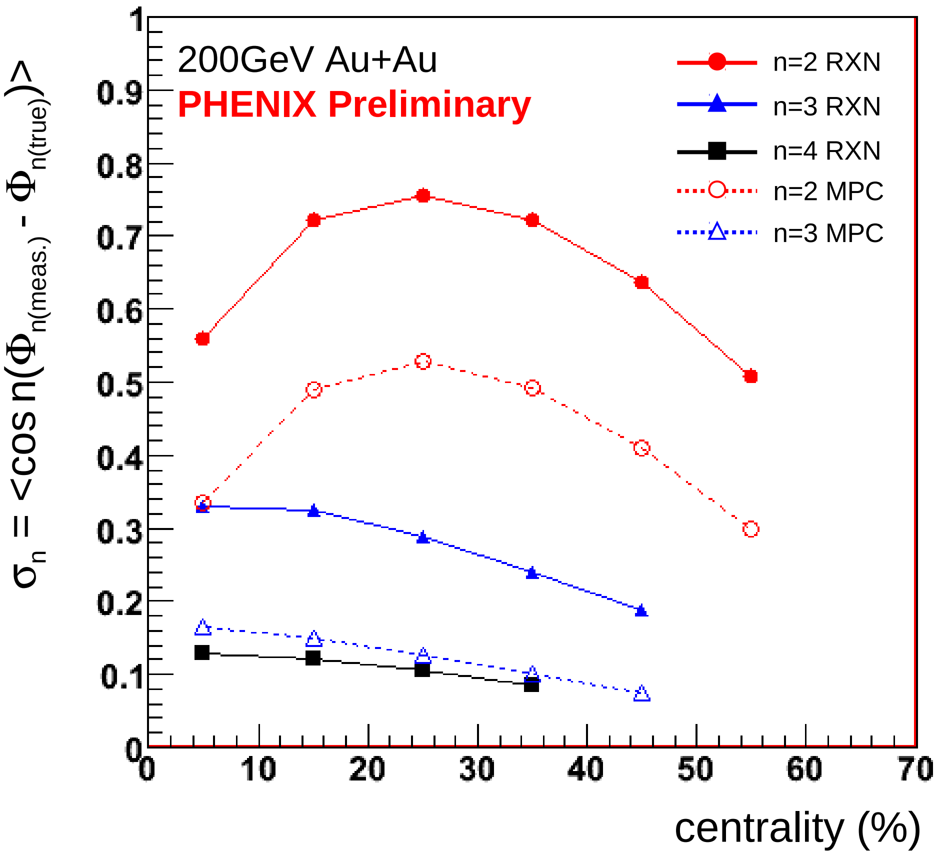

BBC
(beam-beam quartz-
Cherenkov detector)
25.4mm
30mm
54mm


ZDC/SMD
(zero degree n calorimeter
/shower max detector)


BeamPipe
ZDC
FRAGMENTS(Z=1/2)
Neutrons
Au
Protons


CNT
PHENIX Detector
Central Magnet
RICH
Beam View
West
East
(PHENIX central tracking arm)

reaction plane resolution of n^{-th} order plane

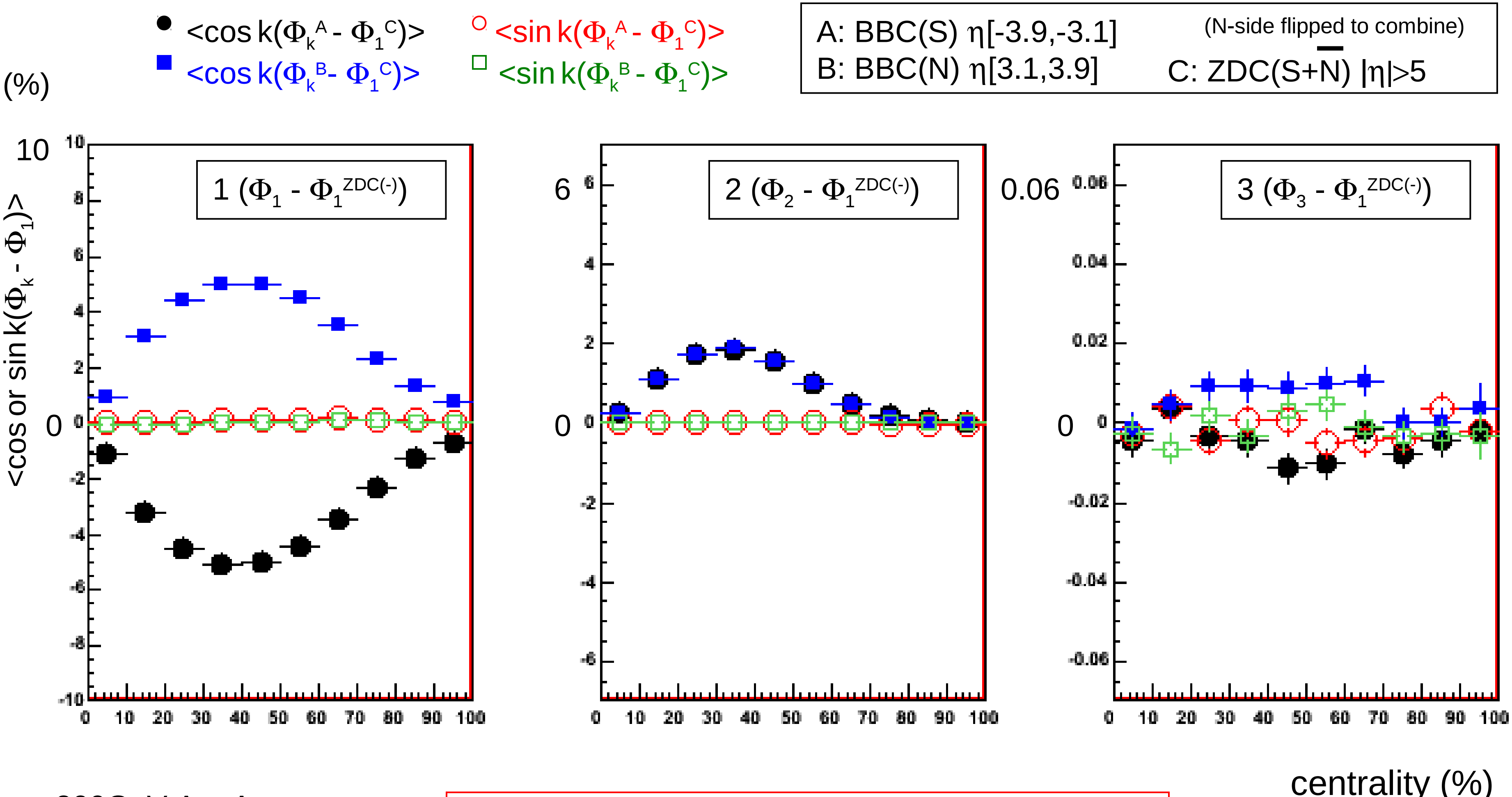


RXN $|\eta|$ = 1.0 ~ 2.8
MPC $|\eta|$ = 3.1~ 3.7

$$\tan n\Phi_n = \frac{\Sigma_i \{w_i \sin n\phi_i\}}{\Sigma_i \{w_i \cos n\phi_i\}}$$

positive correlation in Φ_3 between opposite η up to +/– 3 ~ 4
no-sign flipping in Φ_3, which is an indication initial geometrical fluctuation
Φ_n resolution estimated from Forward-Backward correlation
$\Phi_{n\{true\}}$ can be different for different order

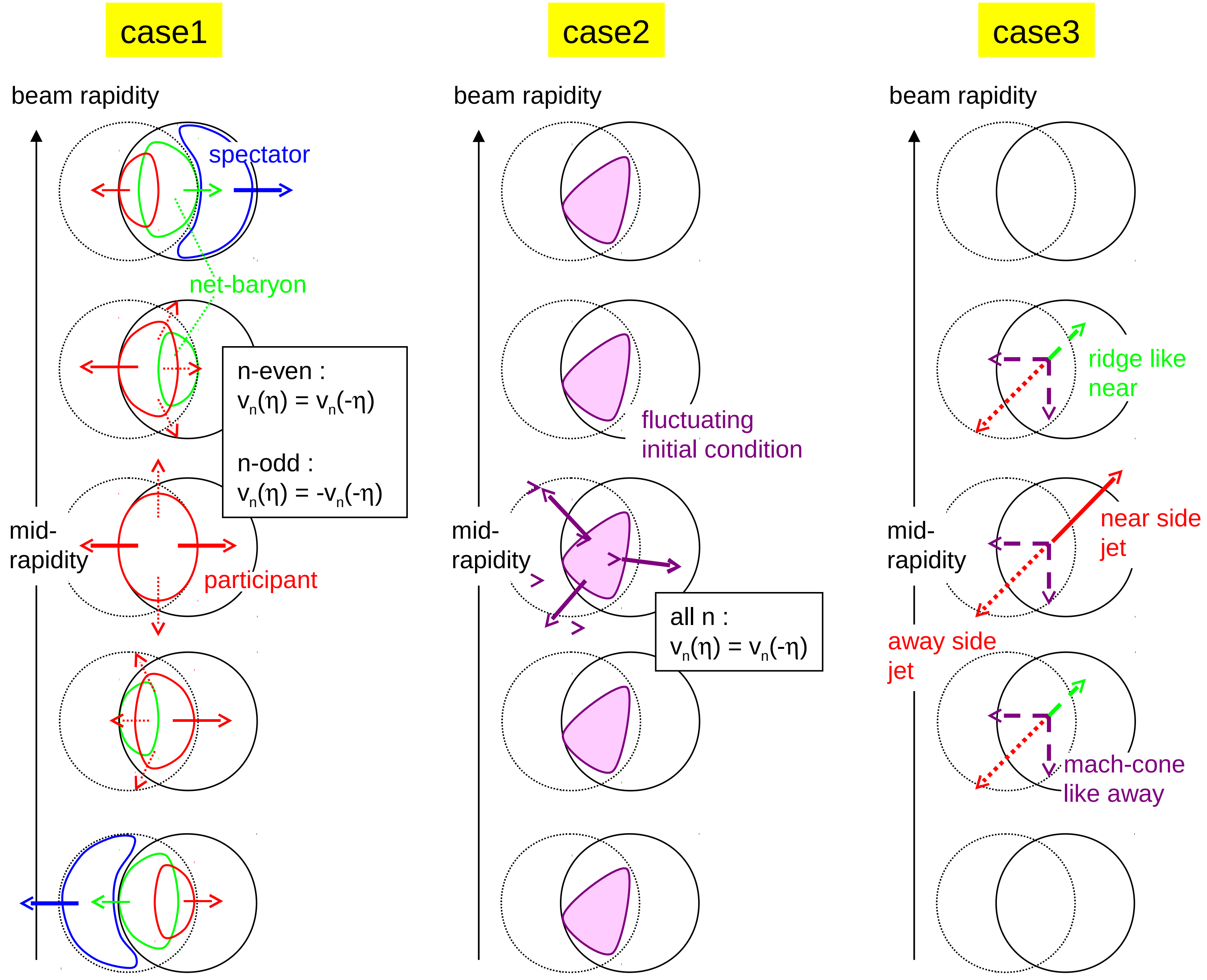
Correlation between different harmonics (w.r.t spectator Φ_1)



200GeV Au+Au

PHENIX Preliminary

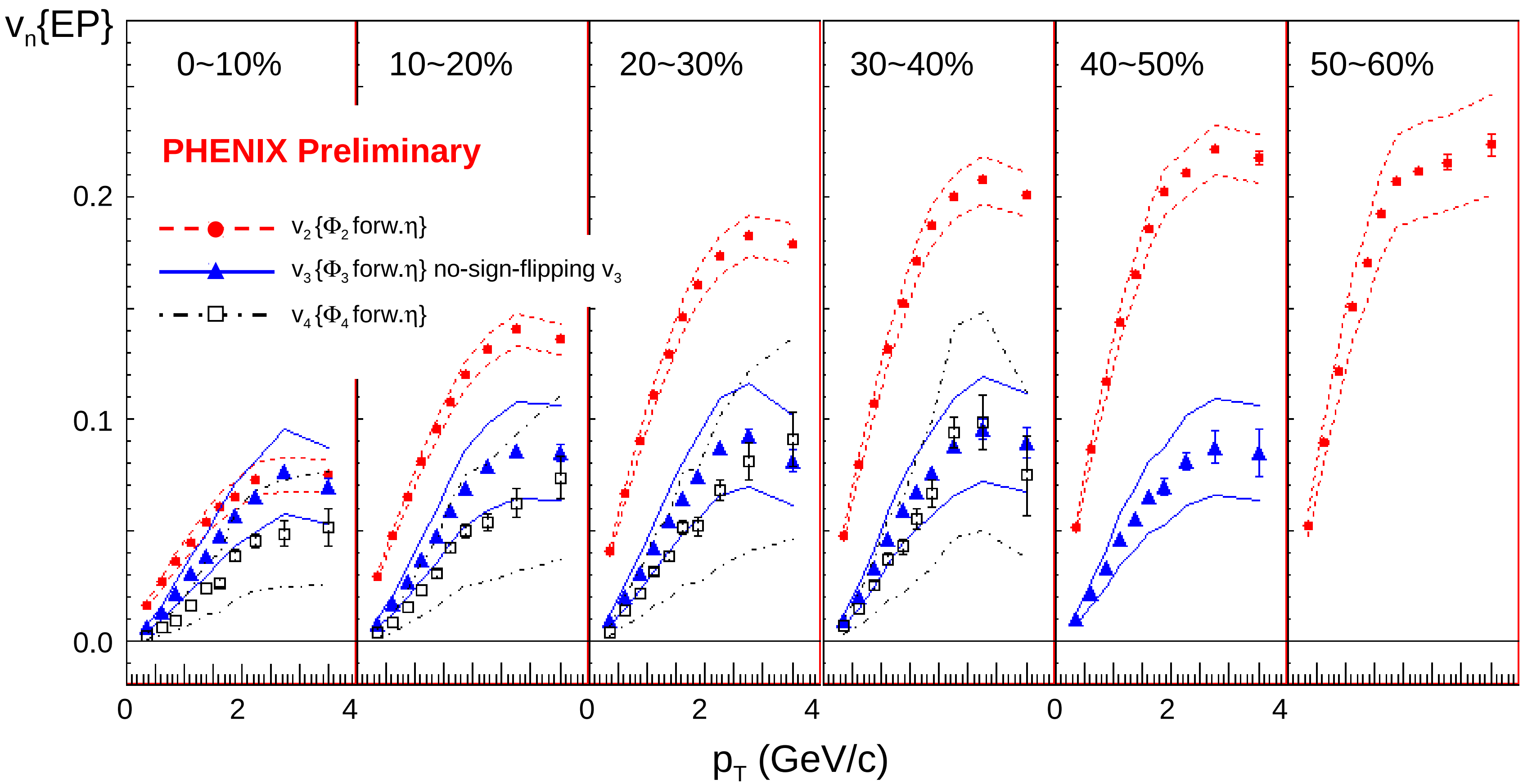
clear sign-flipping in v_1 , clear positive v_2
indication of sign-flipping in v_3 , sign(v_1) = sign(v_3)


case1
case2
case3
beam rapidity
beam rapidity
beam rapidity
spectator
net-baryon
participant
mid-
rapidity
n-even :
v_n(η) = v_n(-η)
n-odd :
v_n(η) = -v_n(-η)
mid-
rapidity
fluctuating
initial condition
all n :
v_n(η) = v_n(-η)
mid-
rapidity
ridge like
near
near side
jet
away side
jet
mach-cone
like away

v_n\{EP\} at mid-rapidity with forward Φ_n

200GeV Au+Au -> charged particles (|η|<0.35)

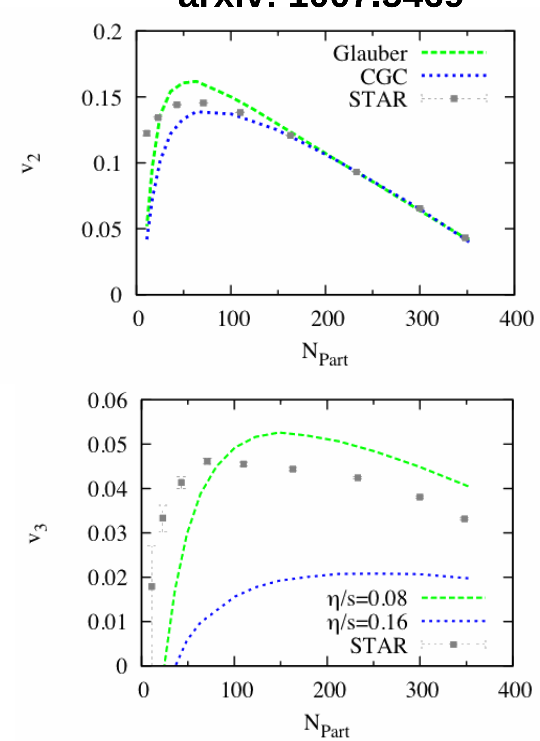
Φ_n RXN (|η|=1.0~2.8)
MPC (|η|=3.1~3.7)
BBC (|η|=3.1~3.9)

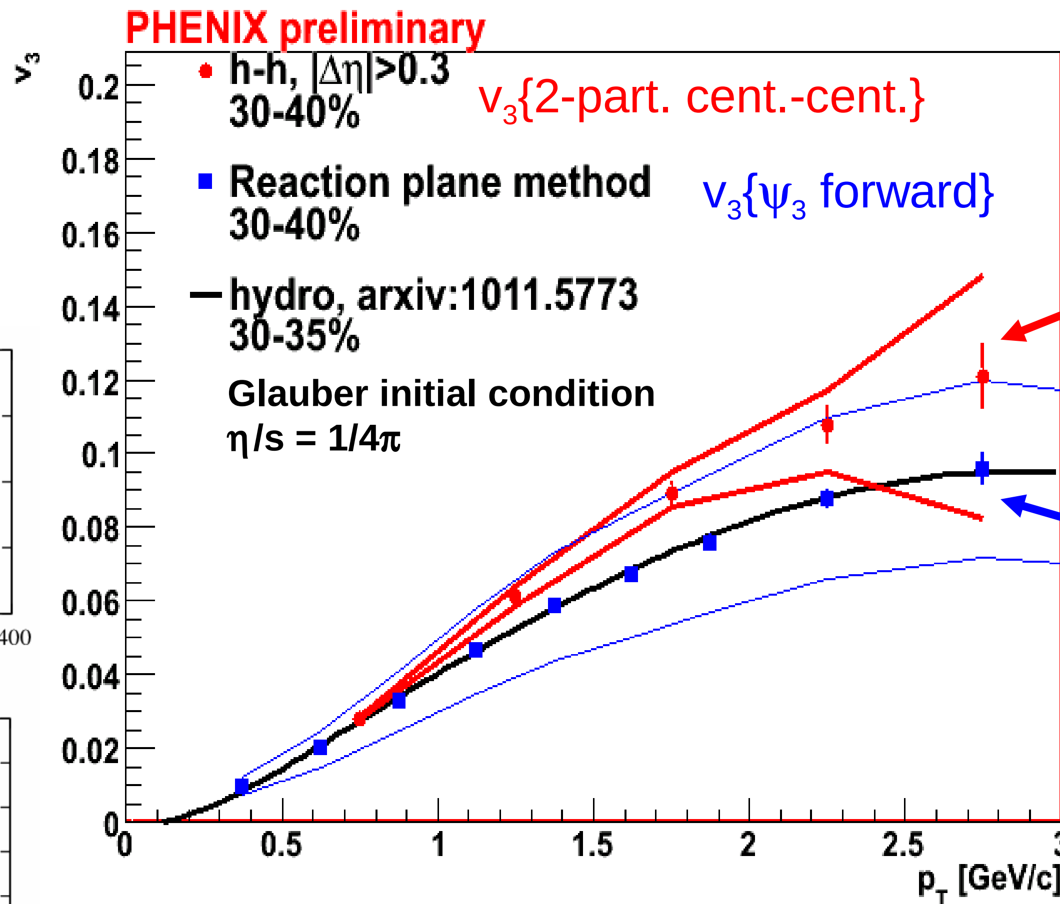


systematic errors are defined by the variations with Φ_n from different η and from different methods including central-forward 2-particle correlation. Therefore it could include some physics biases.

Comparison with Hydro calculation

arxiv: 1007.5469





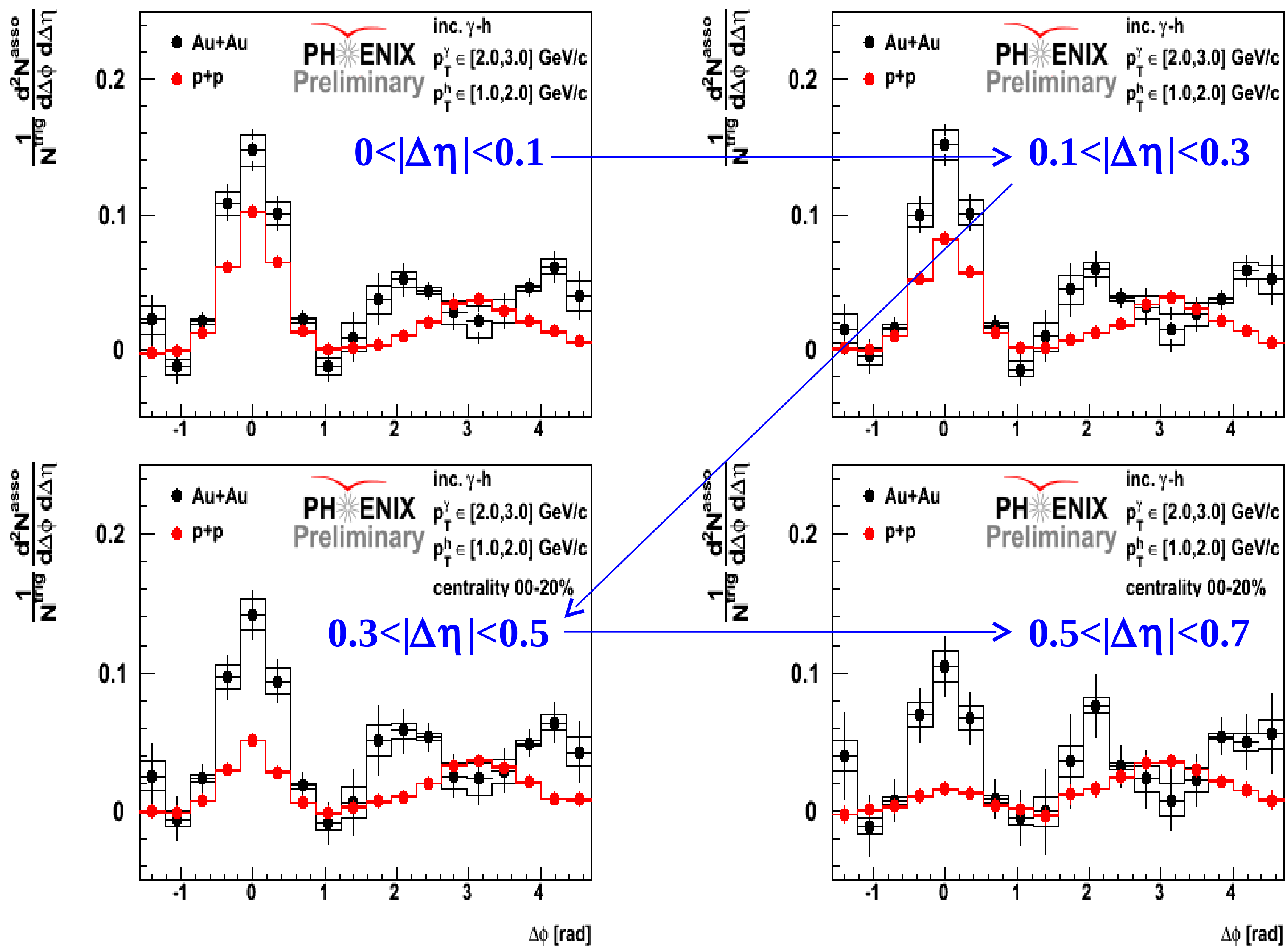
small η gap,
bulk + jet + ?

large η gap,
bulk flow only

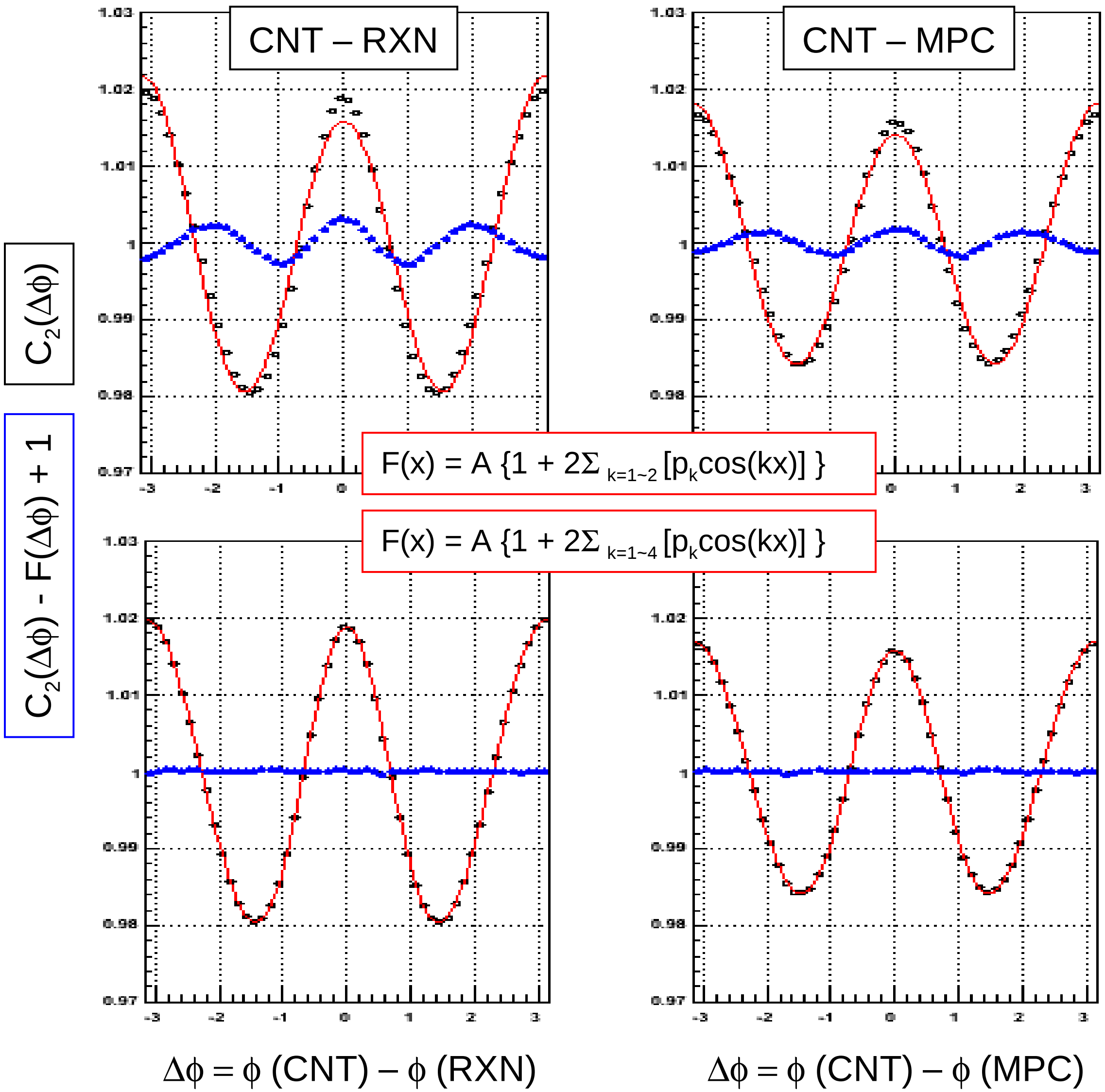
good agreement between data and theory!

central-central 2-part. correlation with Δη dependence

200GeV Au+Au
0-20%, inc. γ-had.



2-part. correlation between central and forward



200GeV Au+Au 20~30%
PHENIX Preliminary

CNT: central tracks
mid-rapidity ($|\eta|<0.35$)
charged hadrons
p_T=2~4(GeV/c)

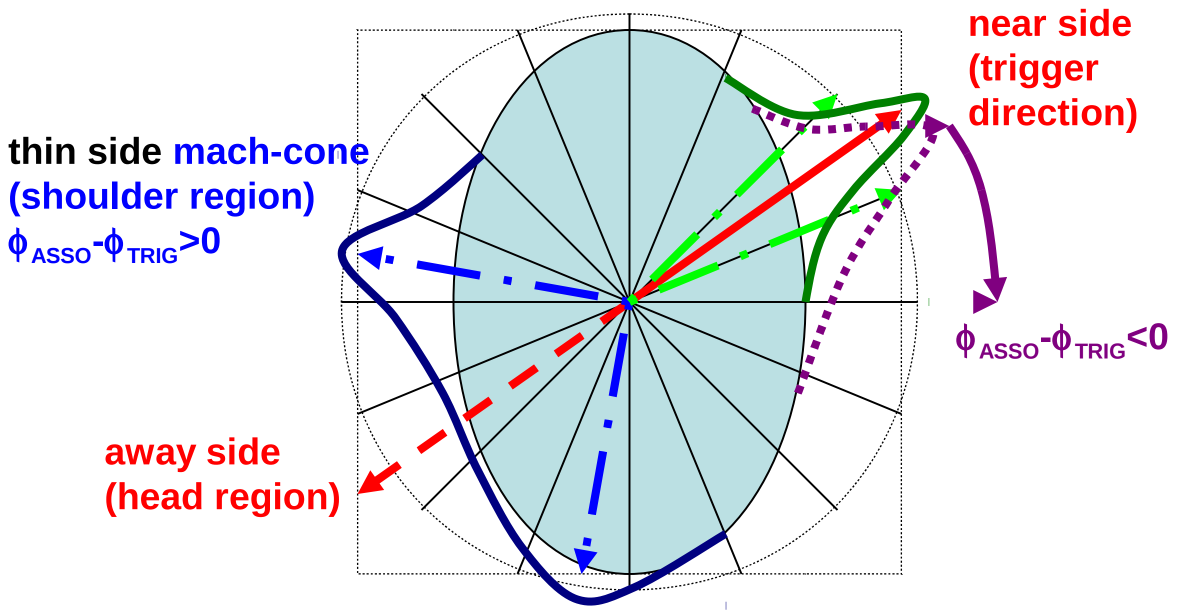
RXN: reaction plane detector
forward $|\eta|$=1.0~2.8
all cells/hits (charge weighting with Pb converter)

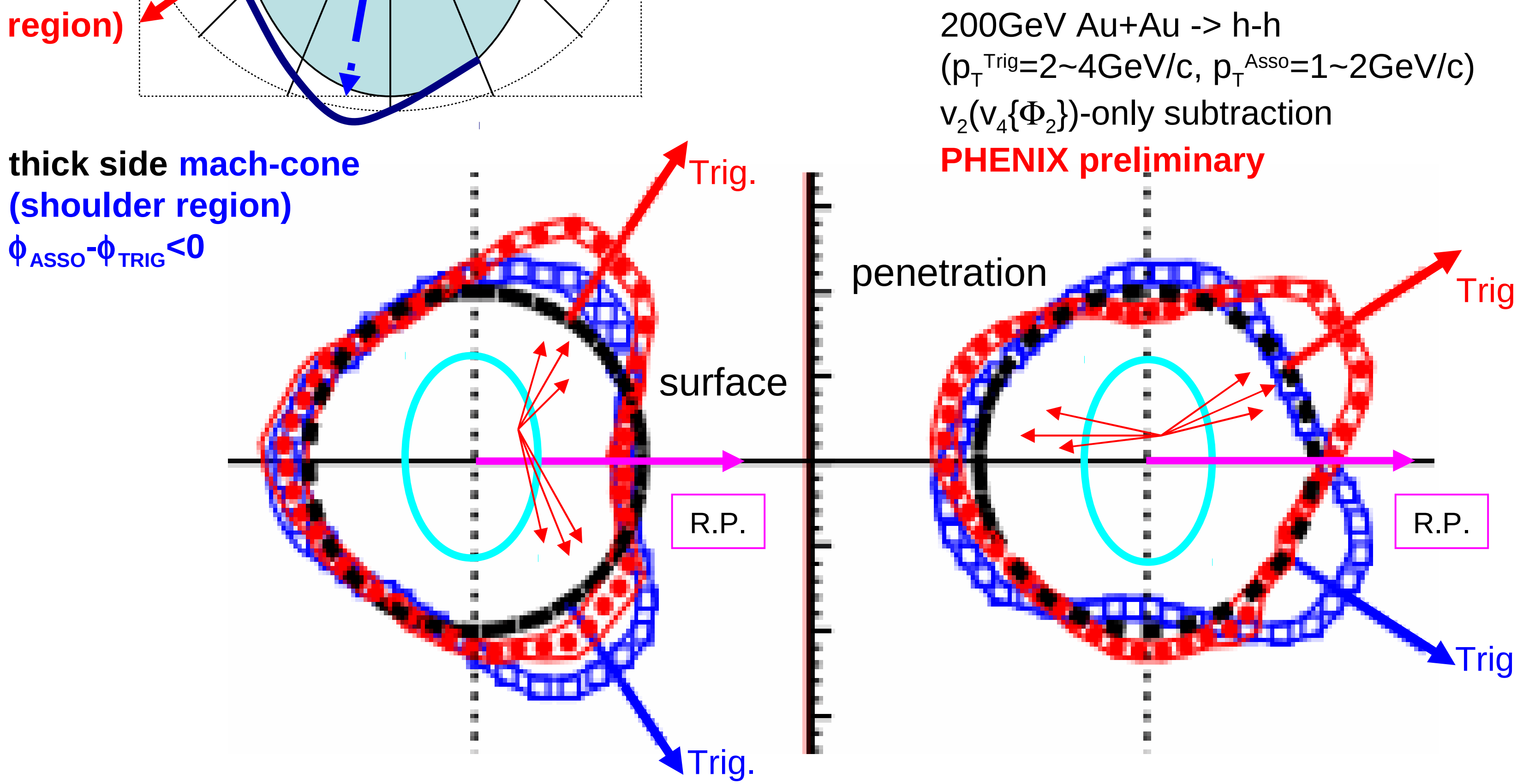
MPC: muon piston calorimeter
forward EM-cal $|\eta|$=3.1~3.7
all cells/towers (eT weighting)

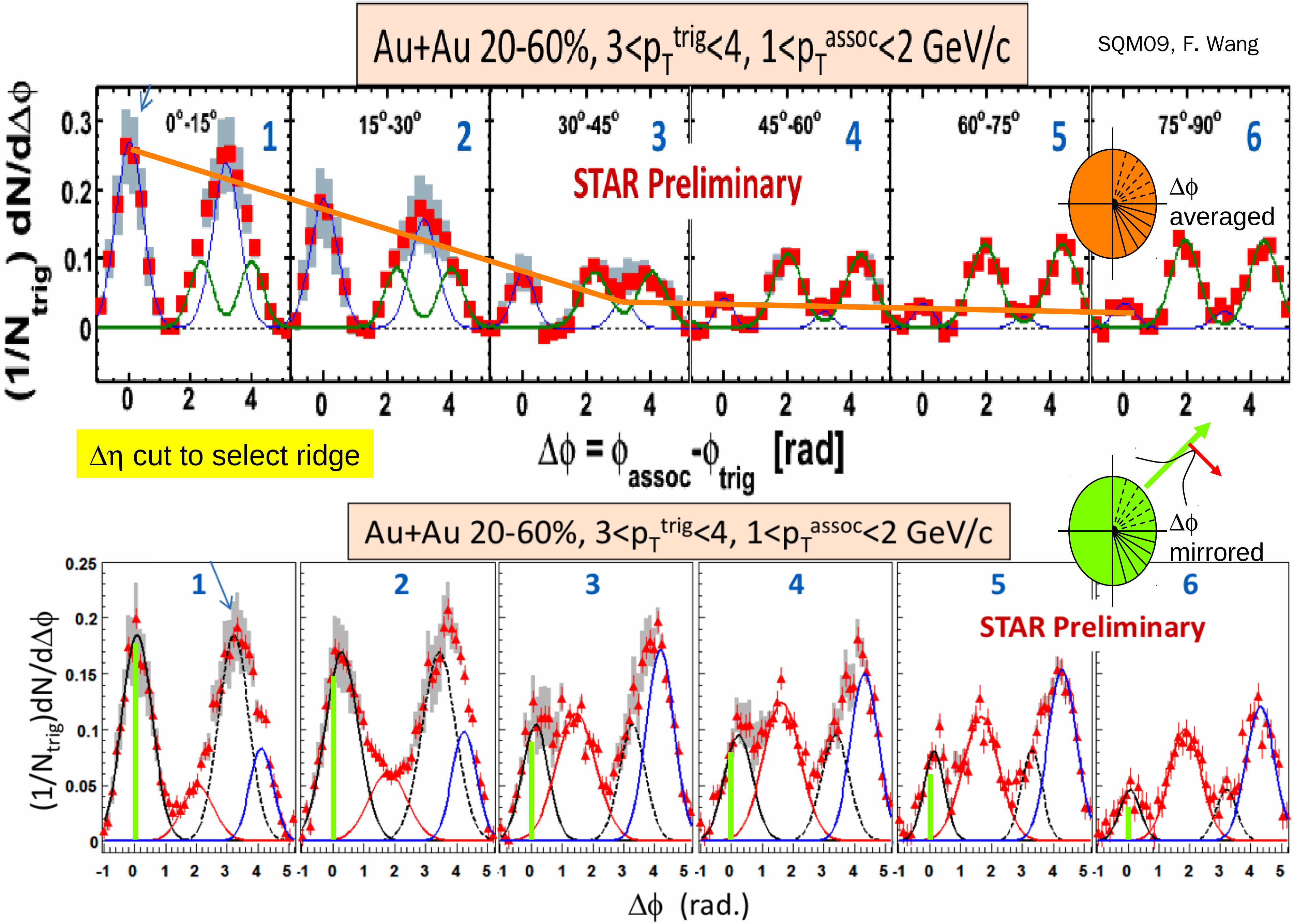
$p_n = v_n^A \times v_n^B$

clear 3rd moment in two-particle correlation with large η gap

Probe the transverse geometry and/or dynamics with triggered correlation

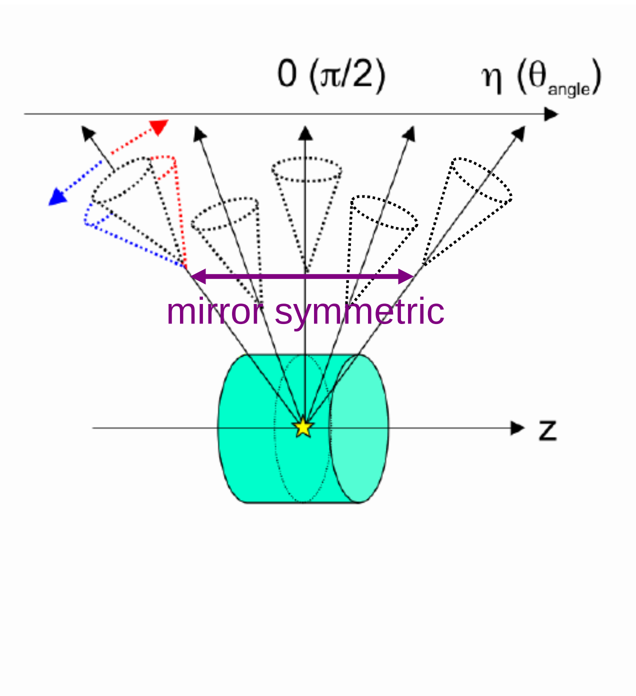


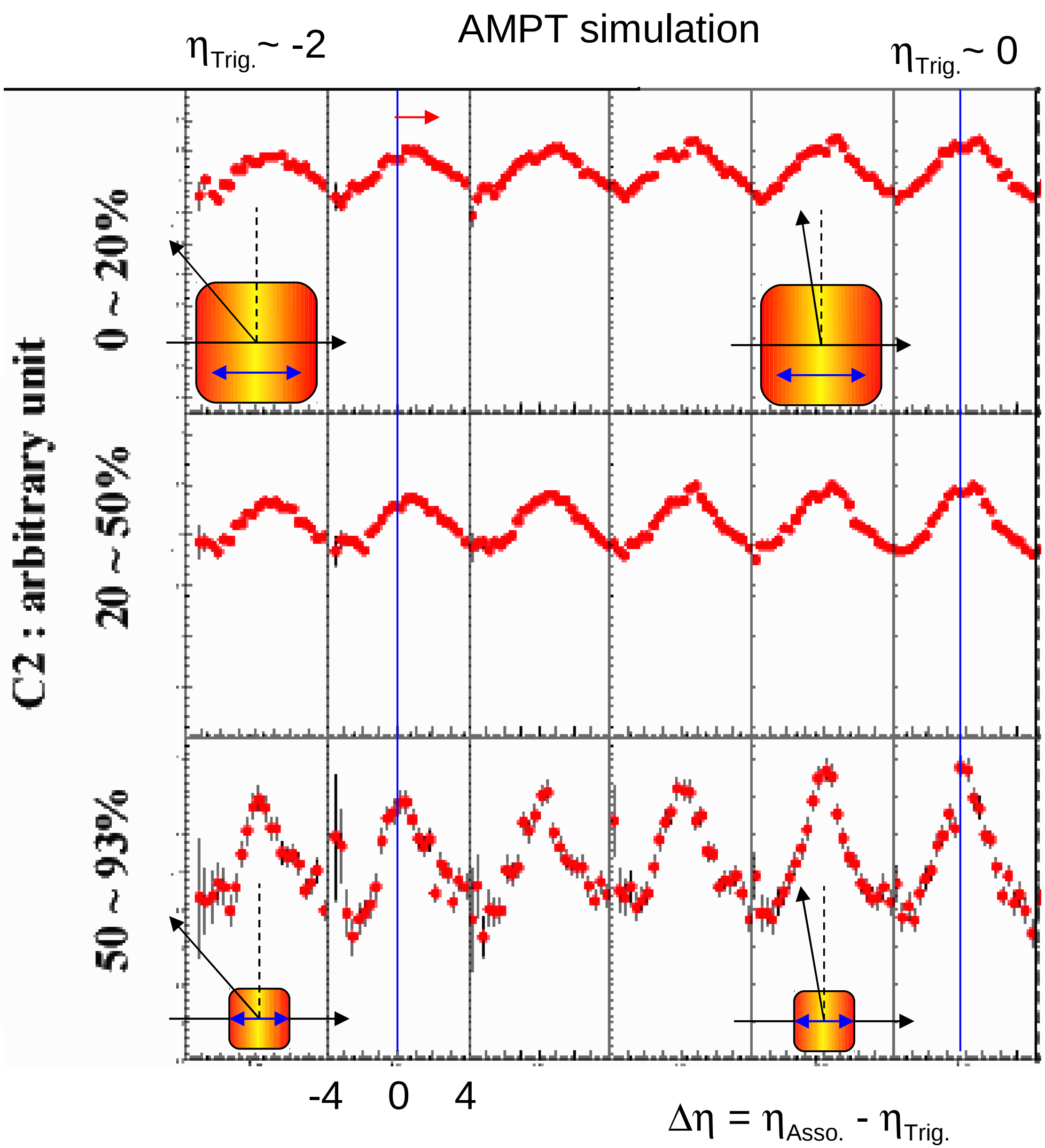


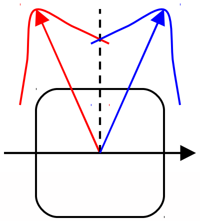


Au+Au 20-60%, 3<p_T^trig<4, 1<p_T^assoc<2 GeV/c
SQM09, F. Wang
(1/N_trig) dN/dΔϕ
0°-15°
15°-30°
30°-45°
45°-60°
60°-75°
75°-90°
1
2
3
4
5
6
STAR Preliminary
Δϕ
averaged
Δη cut to select ridge
Δϕ = ϕ_assoc - ϕ_trig [rad]
Δϕ
mirrored
Au+Au 20-60%, 3<p_T^trig<4, 1<p_T^assoc<2 GeV/c
STAR Preliminary
(1/N_trig)dN/dΔϕ
Δϕ (rad.)

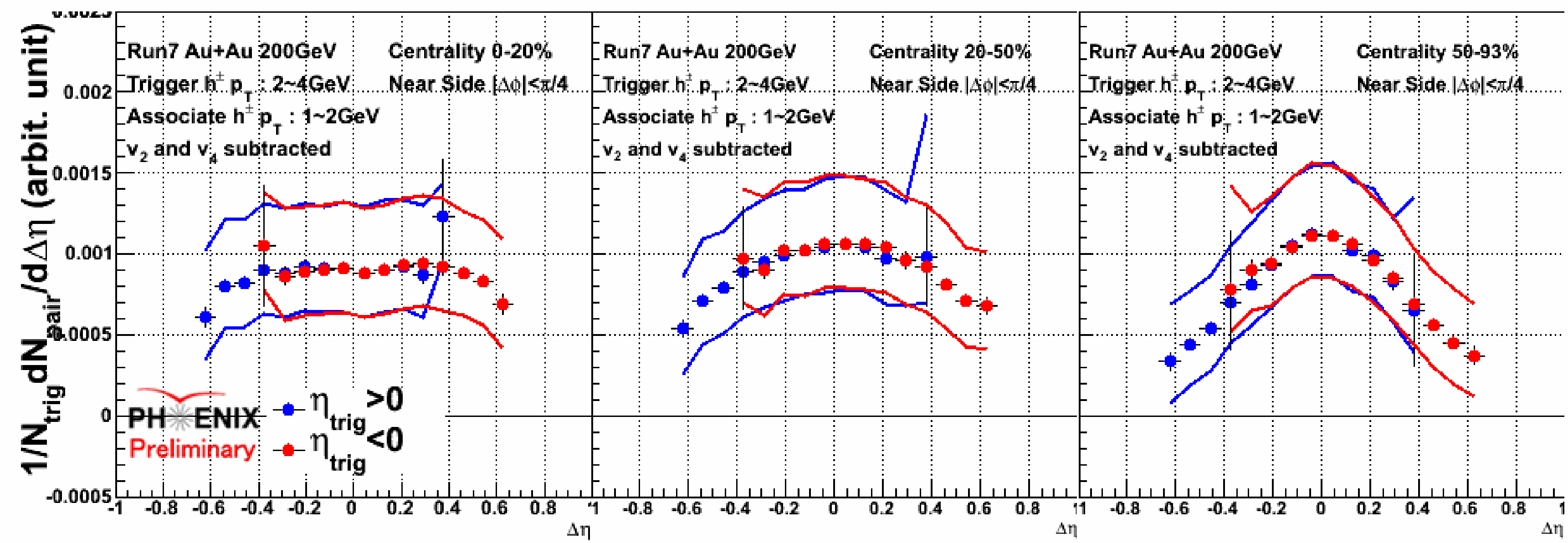
Probe the longitudinal geometry and/or dynamics with triggered correlation





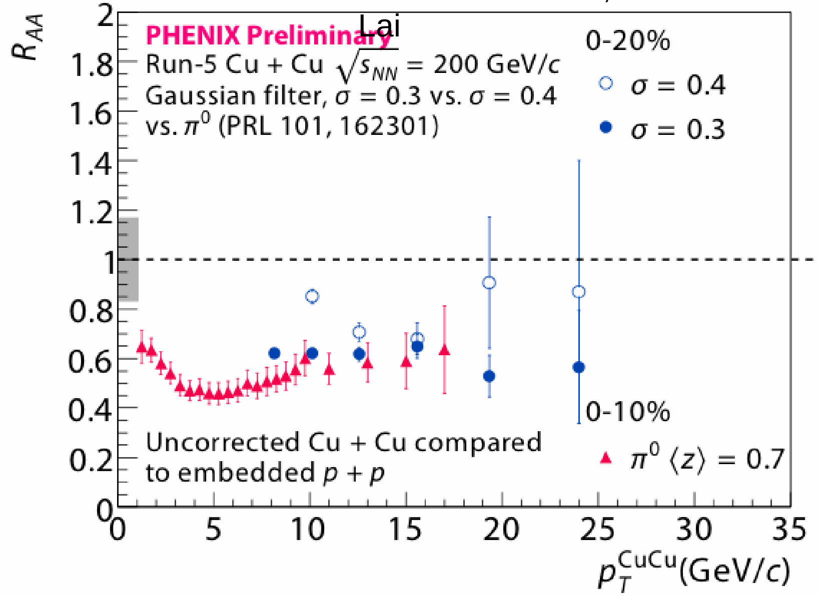


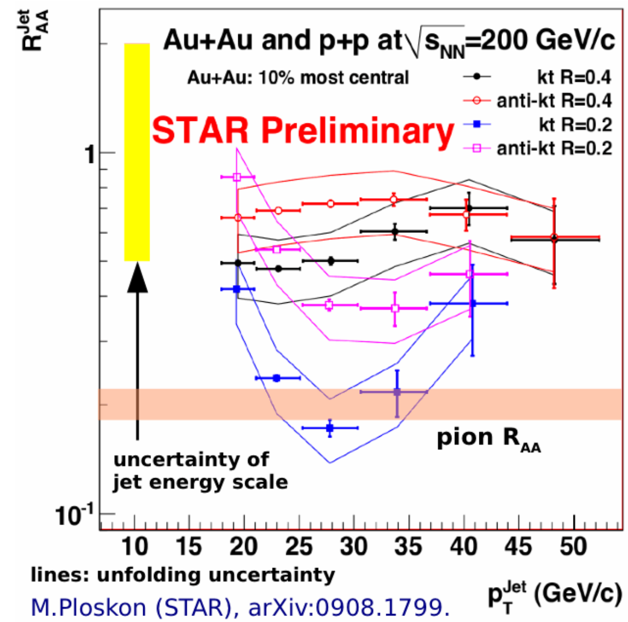
Heavy Ion Pub 18/Mar/2011, Osaka, Japan
T.Todoroki, Univ. of Tsukuba



Hard Probe 2010, Yue Shi Lai

Increasing jet cone radius and including low pT particles would recover initial parton energy.

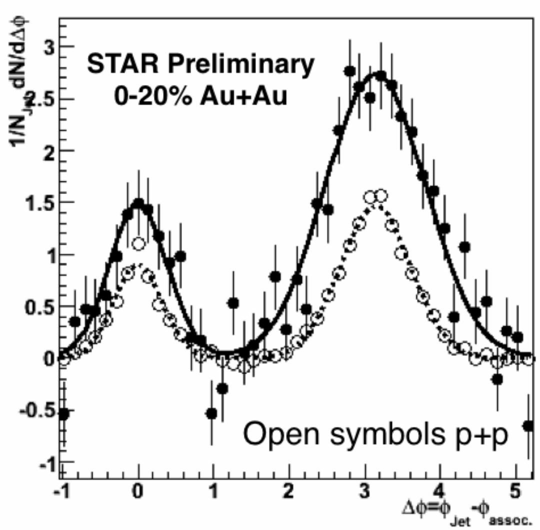




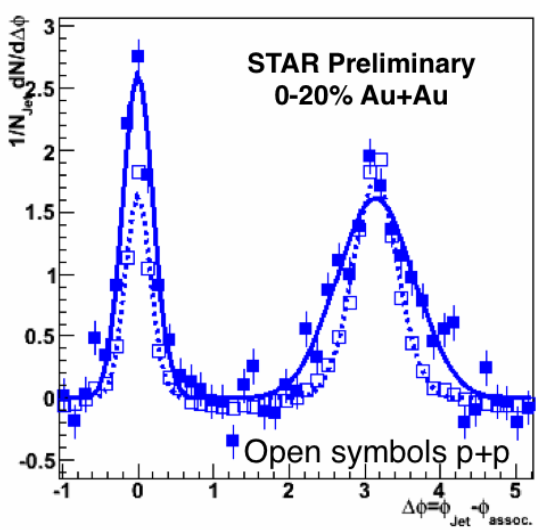
High Tower Trigger (HT) : (η x φ)=(0.05x0.05) E_T>5.4GeV

RHIC-AGS'09, J. Putschke

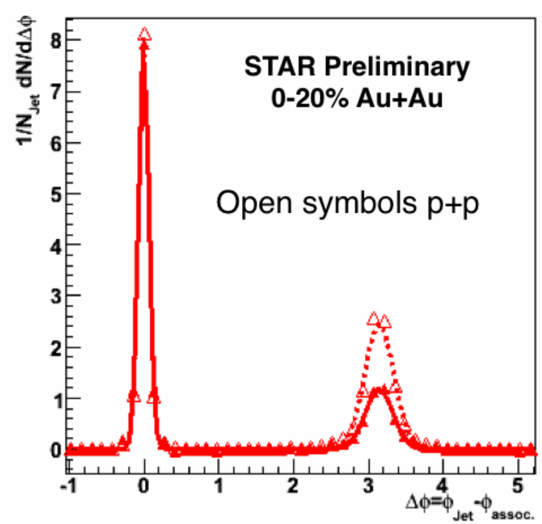
0.2<$p_{t,assoc}$<1.0 GeV



1.0<$p_{t,assoc}$<2.5 GeV

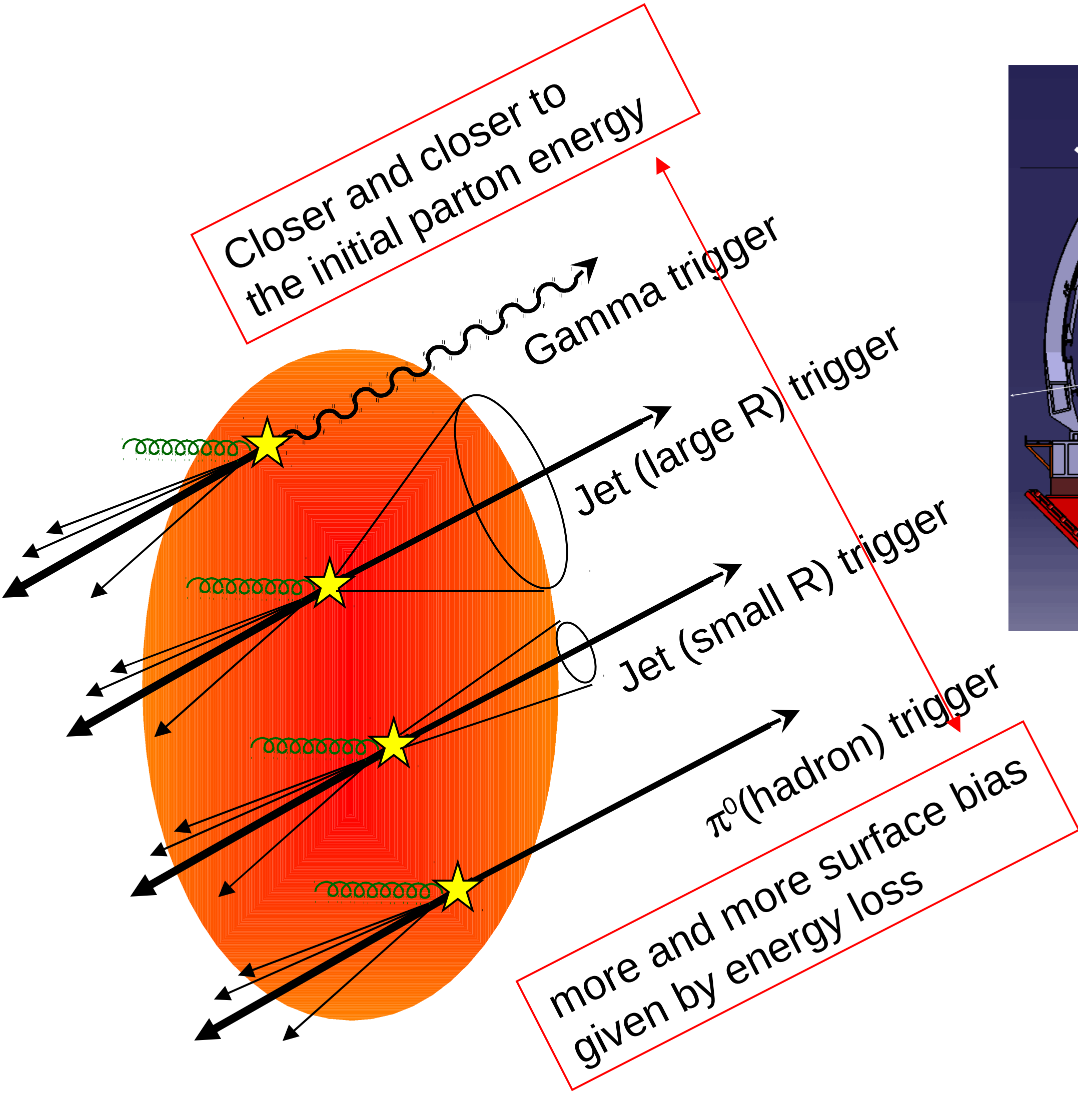


$p_{t,assoc}$>2.5 GeV

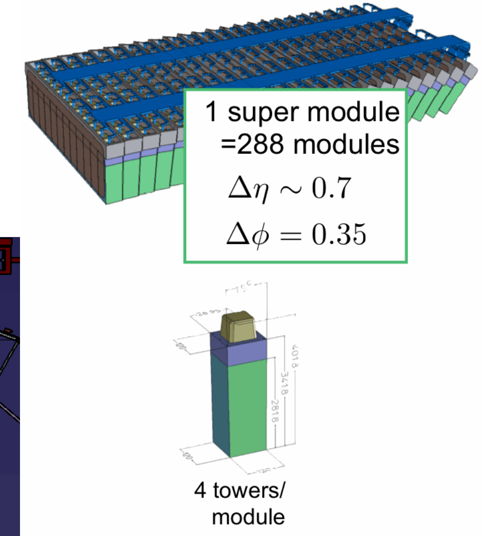


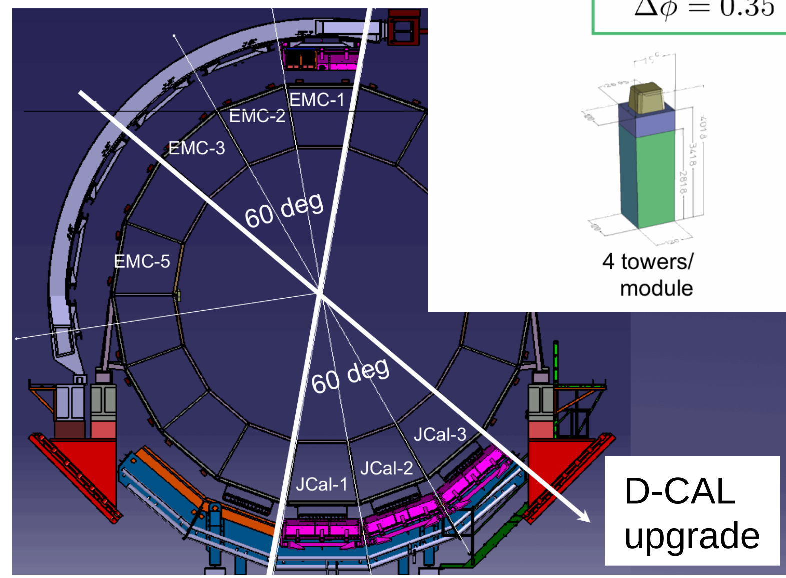
γ,Jet,π^0 - hadron correlation

--- Comparisons are the most important! ---



Back-to-back Jet Calorimeter for LHC-ALICE experiment



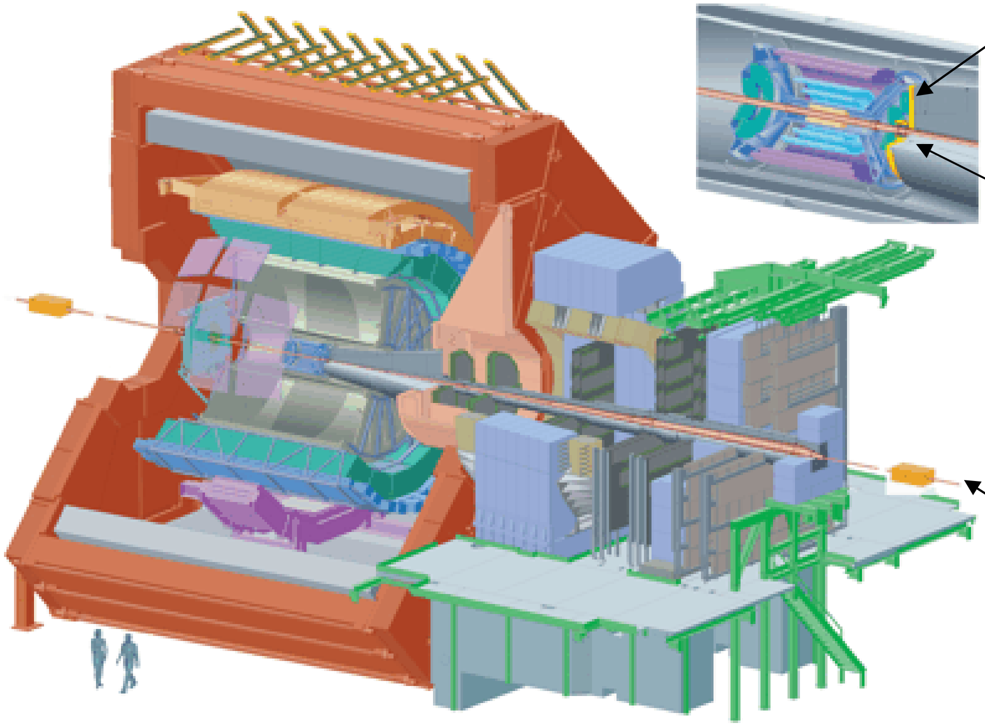


cone size dependent jet suppression can be understood by recovering of energy loss with a larger cone.

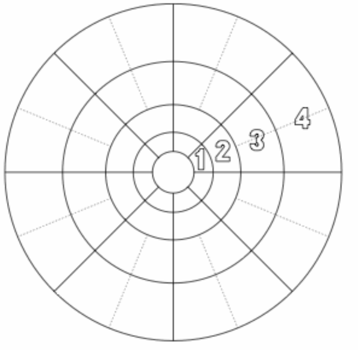
can be used to give a controlled bias in analysis and in triggering.

External Reaction Plane determination

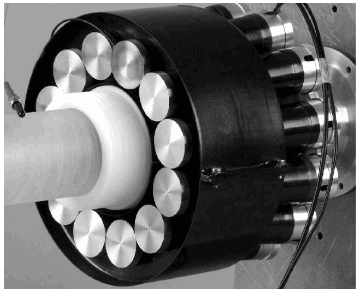
in ALICE for v_n measurement in TPC



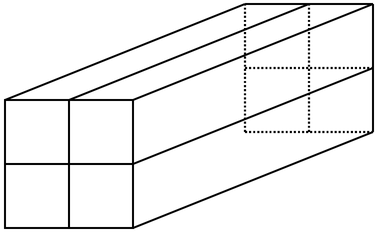
* V0 (2 arms, 4 rings/arm, 8 segments/ring)
V0C η : [-3.7 ~ -3.2 ~ -2.7 ~ -2.2 ~ -1.7]
V0A η : [2.8 ~ 3.4 ~ 3.9 ~ 4.5 ~ 5.1]



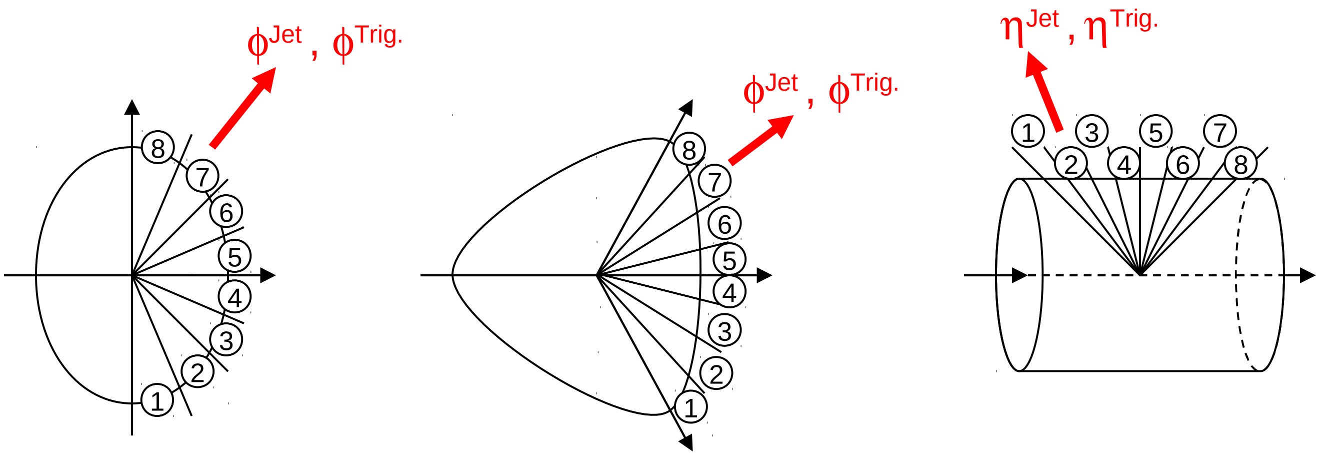
* T0 (2 arms, 1 ring/arm, 12 PMTs/ring)
T0C η : [-3.3 ~ -2.9]
T0A η : [4.5 ~ 5.0]



* ZDC (2 arms, 4 segments in x/y)

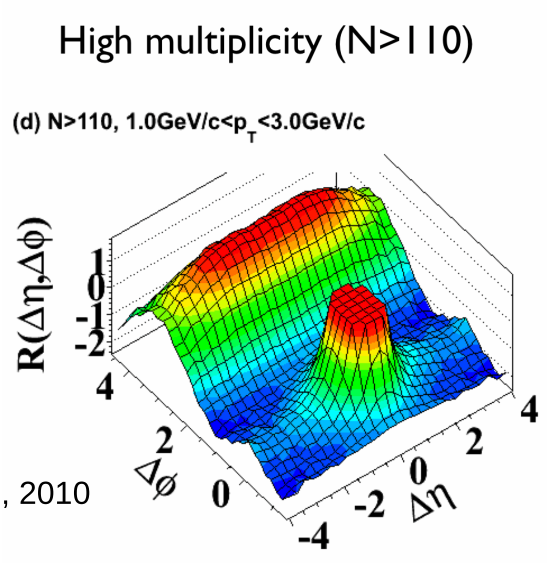


jet, di-jet and multi-particle correlation with various conditions



Summary

•Indication of weak sign-flipping (true) v3
•Strong non-sign flipping v3 observed with wide rapidity gap, which is consistent with initial geometrical fluctuation, (probably followed by collective triangular expansion)
•Strong coupling of triggered correlation with geometry/dynamics
•Jet tagging with various cone radius to be compared with direct photon or single hadron tagging



collectivity (v_2) in high mult. p+p
coupled with initial fluctuation

CMS, CERN Seminar, Sept. 21, 2010
CERN-PH-EP/2010-031
arXiv:1009.4122v1

Method of event plane determination

(1) Detector calibration / cell-by-cell calibration

(2) Q-vector, re-centering, normalization of width

$Q_{\{n\}x} = \Sigma_i \{ w_i \cos (n\, \phi_i) \}$ $Q'_{\{n\}x} = (Q_{\{n\}x} - \langle Q_{\{n\}x} \rangle) / \sigma_{Q\{n\}x}$

$Q_{\{n\}y} = \Sigma_i \{ w_i \sin (n\, \phi_i) \}$ $Q'_{\{n\}y} = (Q_{\{n\}y} - \langle Q_{\{n\}y} \rangle) / \sigma_{Q\{n\}y}$

$Q_{\{1\}x}^{ZDC} = \Sigma_i \{ w_i x_i \} / \Sigma_i \{ w_i \}$

$Q_{\{1\}y}^{ZDC} = \Sigma_i \{ w_i y_i \} / \Sigma_i \{ w_i \}$

(3) n-th harmonics reaction plane

$\Phi_{\{n\}} = \mathrm{atan2}\,(Q'_{\{n\}y} , Q'_{\{n\}x}) / n$

(4) Fourier flattening (Sergei's+Art's method paper)

$n\, \Phi'_{\{n\}} = n\, \Phi_{\{n\}} + \Sigma_i\, (2/i) \{ - \langle \sin(i\, n\, \Phi_{\{n\}}) \rangle \cos(i\, n\, \Phi_{\{n\}}) + \langle \cos(i\, n\, \Phi_{\{n\}}) \rangle \sin(i\, n\, \Phi_{\{n\}}) \}$

(5) measure v_n w.r.t. Φ_n and correct for E.P. resolution

2-particle correlation among 3-sub detectors

Forward^{Hit} (F), Backward^{Hit} (B), Central^{Track} (C)

(1) measure dϕ distribution between 2 detectors weighting by the hit amplitude

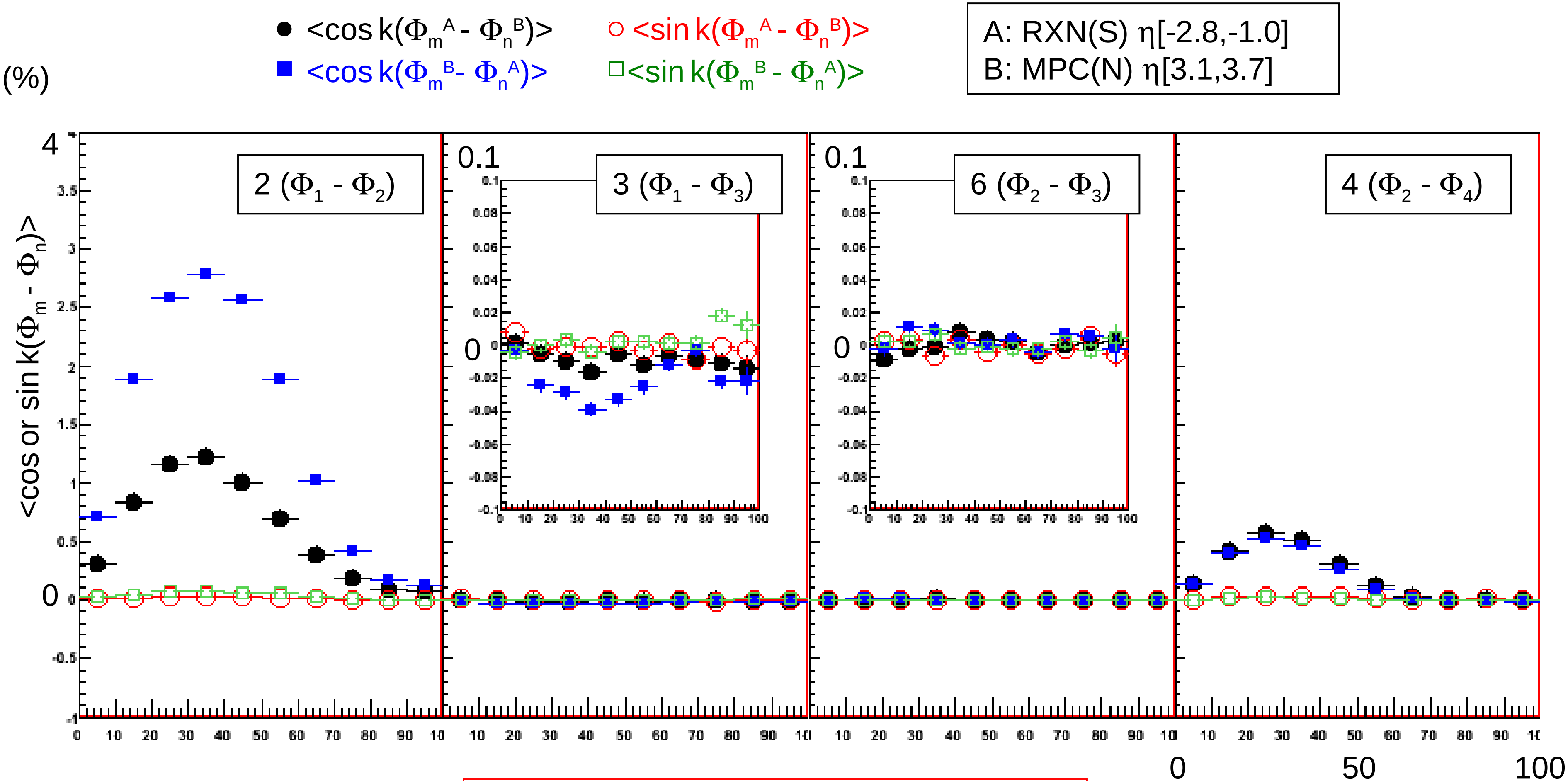
(2) normalize by the event mixing to make correlation functions for 3 combinations

(3) fit the correlation with Fourier function to extract $v_n^F v_n^B$, $v_n^F v_n^C$ and $v_n^B v_n^C$

(4) v_n^F(Hit) and v_n^B(Hit) can be determined as a function of centrality

(5) v_n^C(Track) can be determined as a function of centrality and p_T

Correlation between different harmonics (opposite η arms)



200GeV Au+Au

PHENIX Preliminary

clear positive correlation in $\Phi_1 - \Phi_2$, $\Phi_2 - \Phi_4$
very weak negative correlation in $\Phi_1 - \Phi_3$
no significant correlation in $\Phi_2 - \Phi_3$

What we have observed with Φ_n

(1) clear correlation between Φ_1 and Φ_2 as well as Φ_2 and Φ_4, where $v_{2,4}$ have also been measured with lower order harmonic planes

(2) participant (pion dominant) v_1 is opposite with respect to spectator v_1 as expected (already seen at RHIC and other energies)

(3) weak correlation between Φ_1 and Φ_3 is seen as a signature of true v_3 with sign-flipping at mid-rapidity, same sign for both v_1 and v_3

(4) no significant correlation between Φ_2 and Φ_3 is seen within current statistical accuracy

(5) clear correlations of same order $\Phi_{3,(4)}$ are seen between detectors with wide rapidity gap, which is consistent with initial geometrical participant fluctuation commonly over wide rapidity space

(6) The origin can also be jet-medium correlation, which can spread over wide rapidity space (coupled with earlier stage)