Long range rapidity correlations in high energy nucleus collisions at RHIC and LHC

Heavy Ion Pub @ Ohsaka University

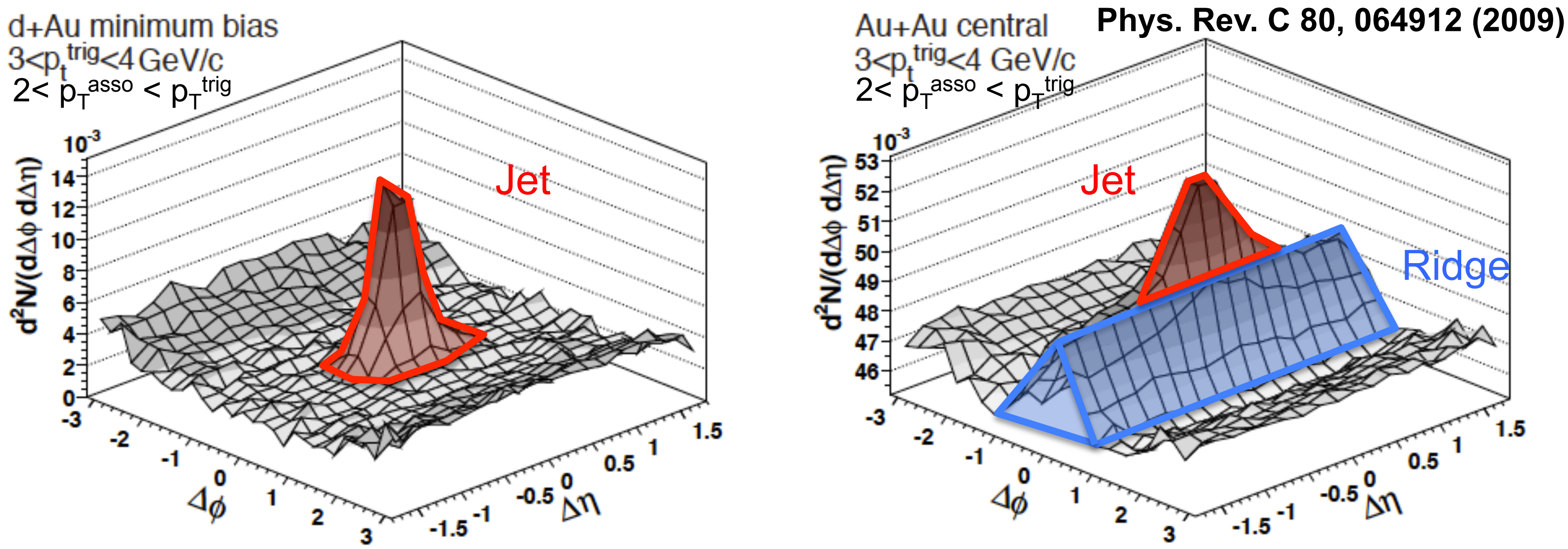
Takahito Todoroki

University of Tsukuba & Riken Nishina Center

Outline

- Overview of basic ridge property
- Ridge study via $\Delta\phi$ correlations with respect to Reaction Plane
- Triangular flow
- $\Delta\eta$ correlations with respect to trigger η
- Ridge in high multiplicity p+p events at LHC-CMS
- Summary

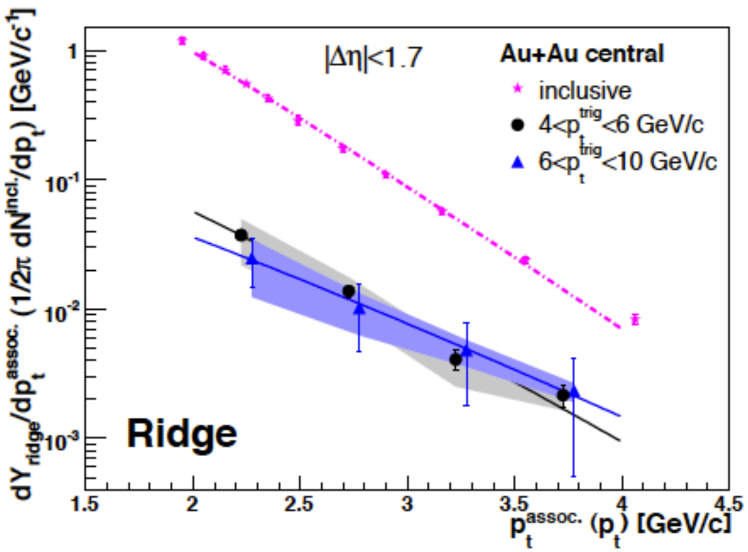
Long range rapidity correlations

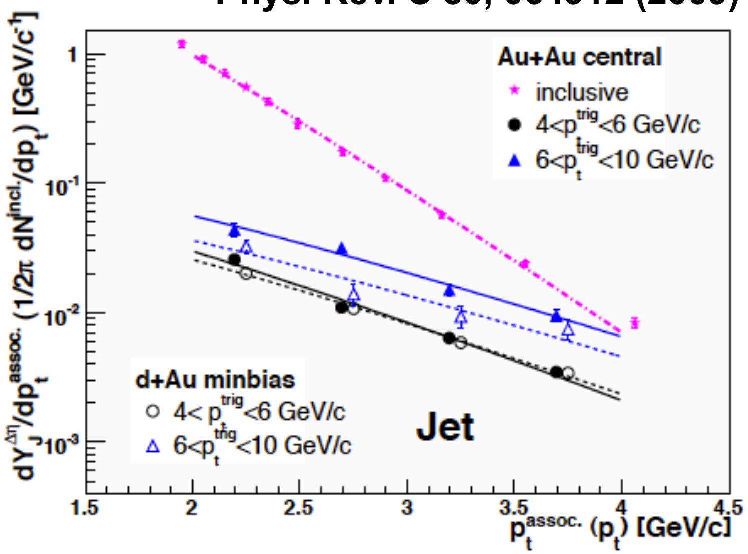


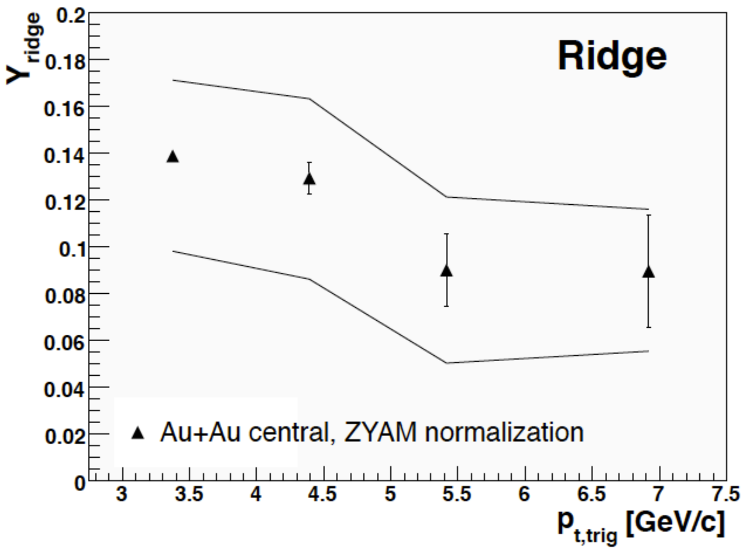
- Long range rapidity correlations up to large rapidity = "Ridge"
- Seen in Au+Au, absent in d+Au collisions
- Superposition of jet and ridge at $\Delta\phi\sim0$ & $\Delta\eta\sim0$ in Au+Au collisions

p_T spectra of Jet and Ridge yield

Phys. Rev. C 80, 064912 (2009)



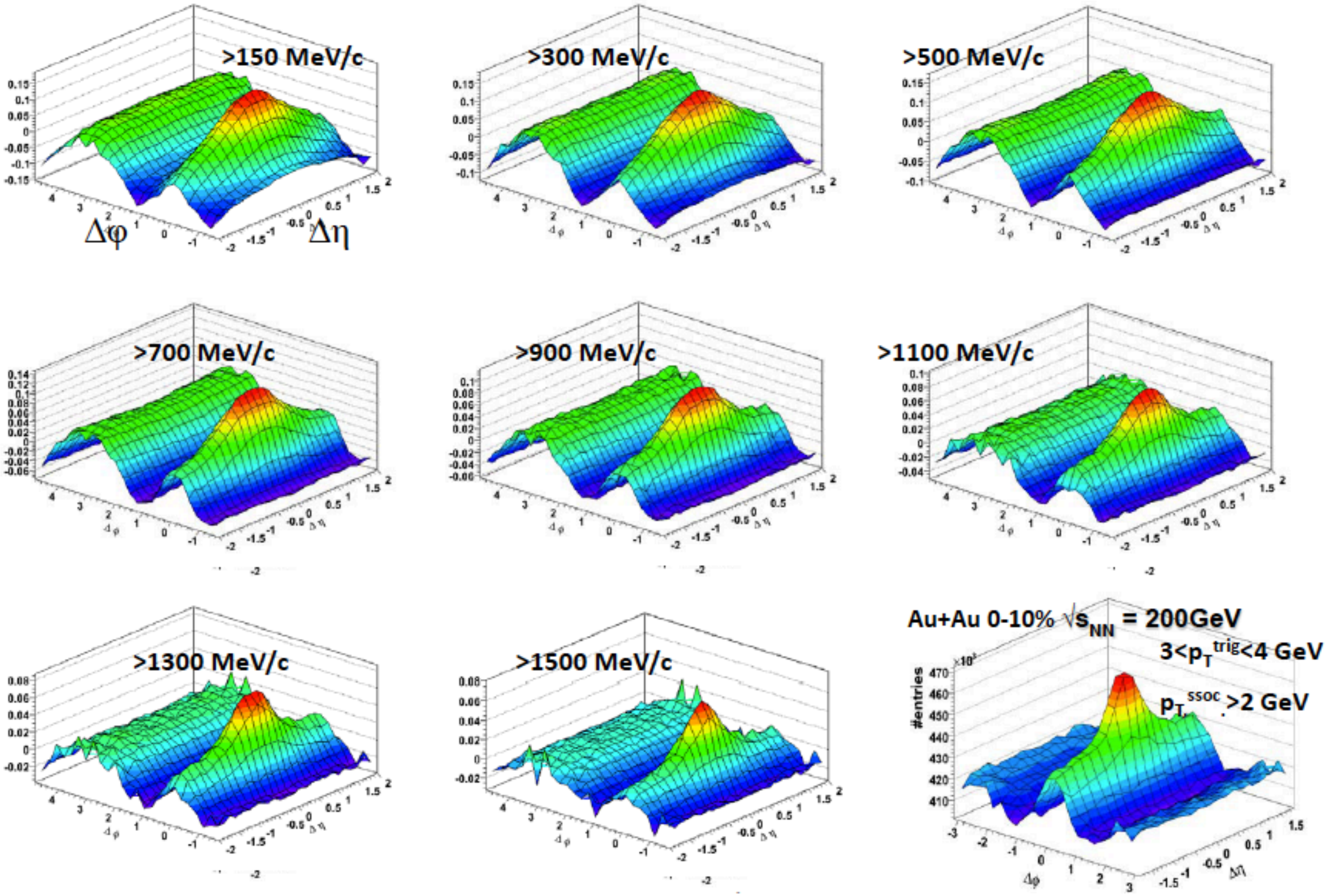




- **Jet spectrum is increasing with p_T^{trig} as jet fragmentation**
- **Ridge spectrum is softer and approximately independent of p_T^{trig}**
- **Ridge is “bulk-like”**

Ridge shape gets clearer with p_T

Cu+Cu 200 GeV 0–10%, Chanaka De Silva, April APS Meeting 2010, STAR Preliminary

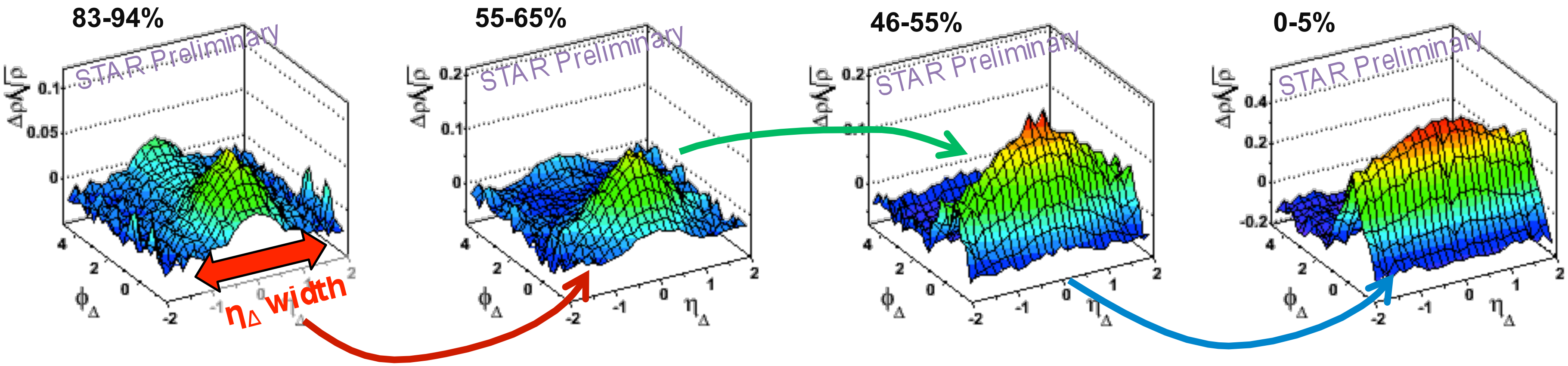


Centrality evolution of Ridge

Au+Au 200GeV data - fit (except same-side peak)

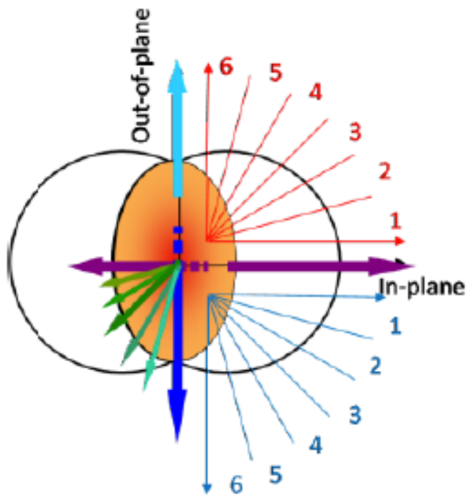
$p_T > 0.15$ GeV

M.Daughersity, QM08, J.Phys.G35:104090,2008

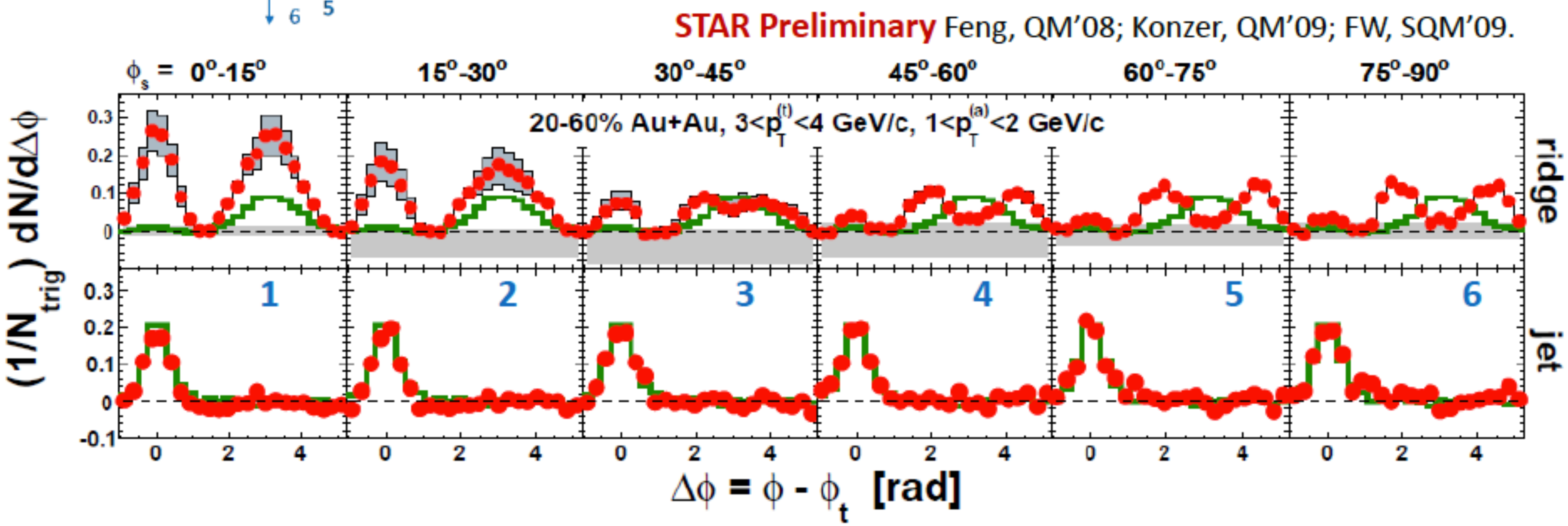


- Rapid transition from 55-65% to 46-55%
- Small change to most central after transition
- Ridge may be phenomena of underlying event

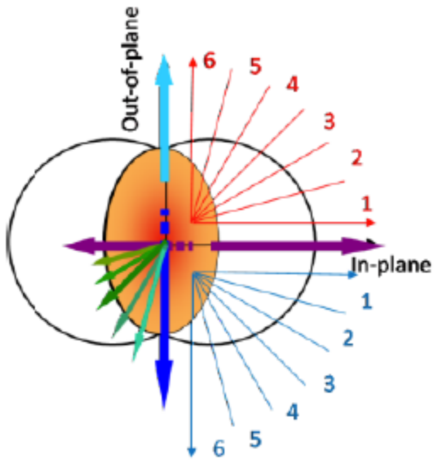
Ridge and Jet Δϕ correlations with respect to Reaction Plane

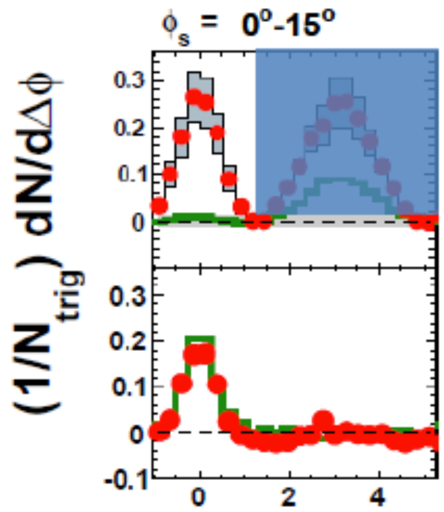


- **Jet = (|Δη|<0.7) -Accep*(|Δη|>0.7)**
- **|Δη|>0.7 = near-side ridge + away-side**
- **Flow subtraction by ZYAM**

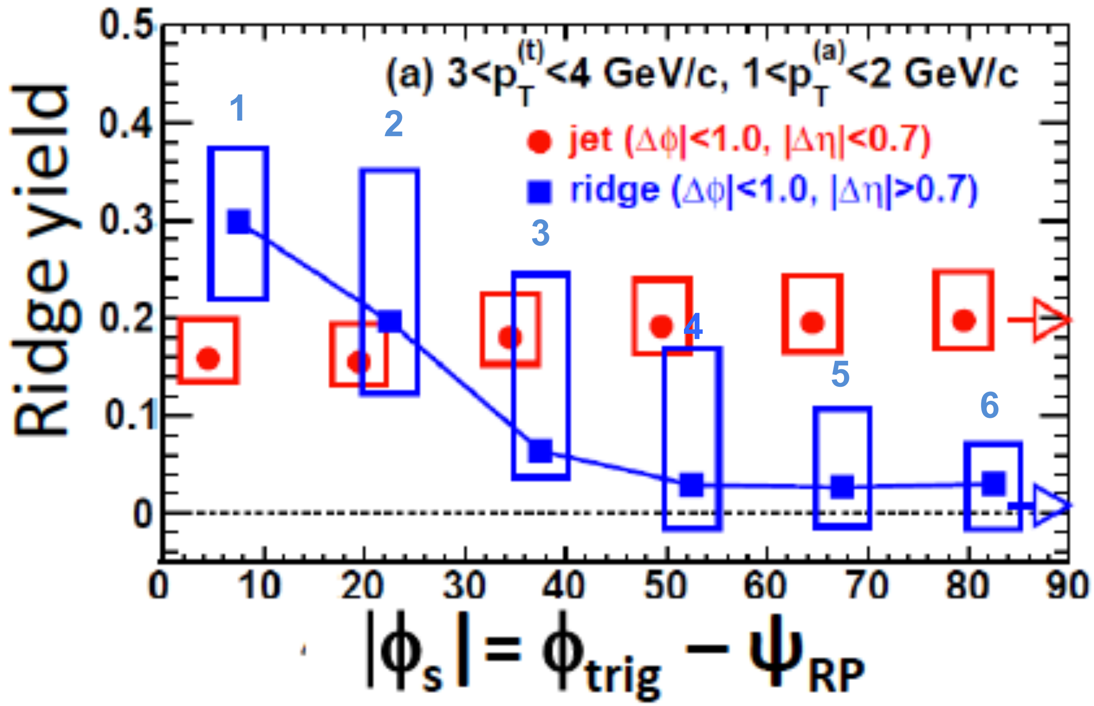


Ridge correlations have reaction plane dependence



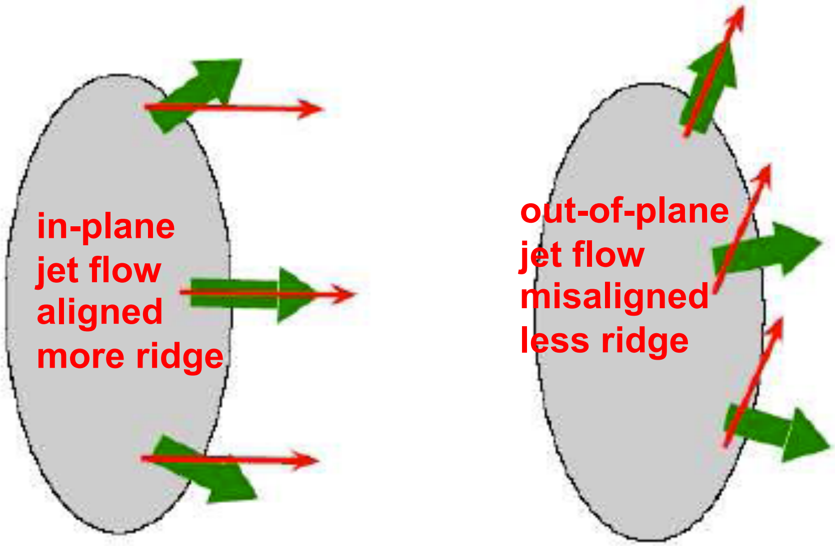


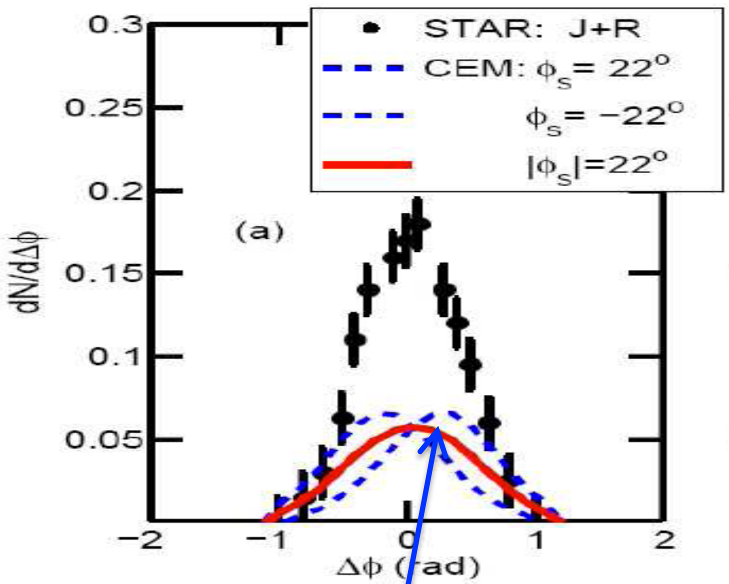
STAR Preliminary Feng, QM'08; Konzer, QM'09; FW, SQM'09.



Correlated Emission Model

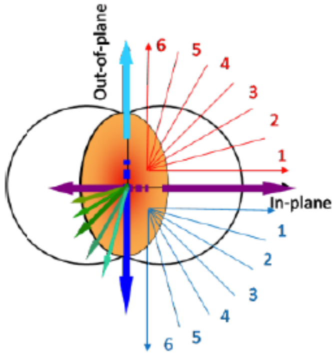
Chiu,Hwa, arXiv:0809.3018
Correlated Emission Model (CEM)



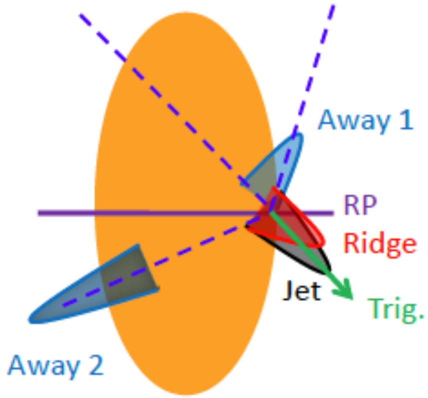


Asymmetric ridge peak predicted

Ridge and Jet Δφ correlations with respect to Reaction Plane

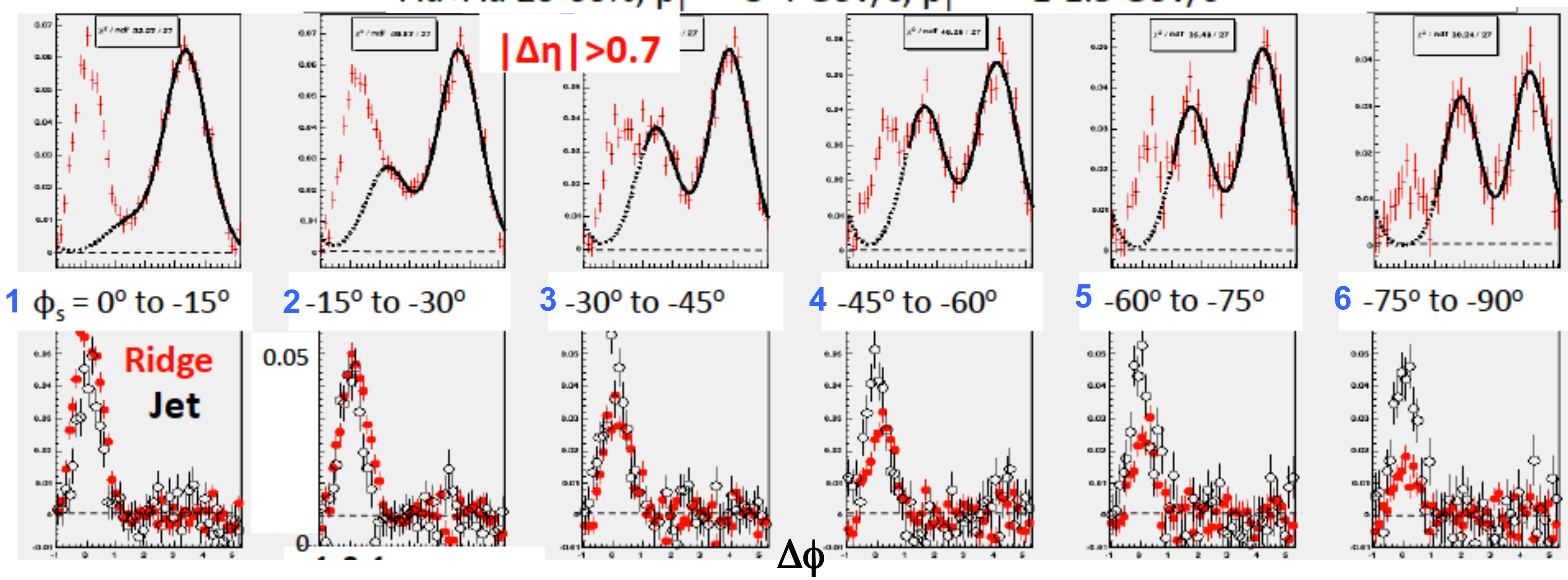


- **Jet = (|Δη|<0.7) -Accep*(|Δη|>0.7)**
- **|Δη|>0.7 = near-side ridge + away-side**
- **Flow subtraction by ZYAM**
- **2 Gaussian fit to away side and subtracted**
  - **Ridge obtained**

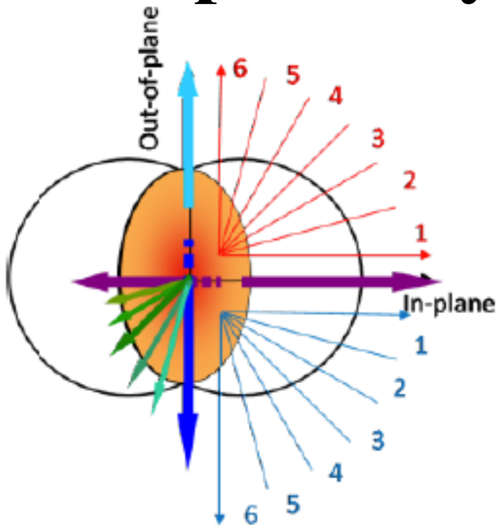


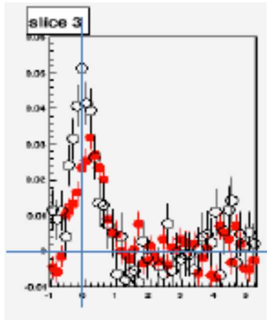
STAR Preliminary Konzer, QM'09; FW, SQM'09.

Au+Au 20-60%, p_T^{trig}=3-4 GeV/c, p_T^{assoc}=1-1.5 GeV/c

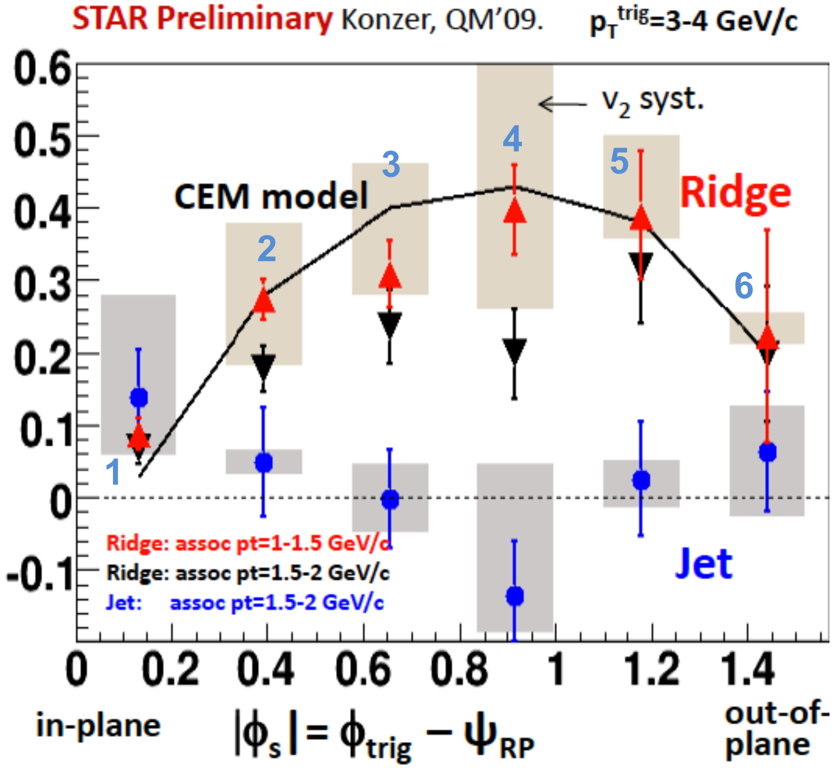


Near side peak asymmetry



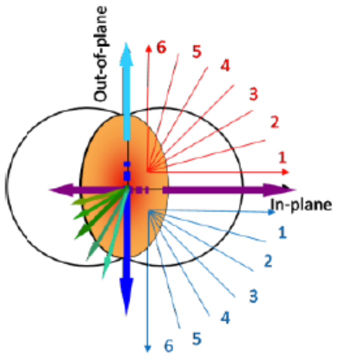


$$A = \frac{N_{0<\phi<1} - N_{-1<\phi<0}}{N_{0<\phi<1} + N_{-1<\phi<0}}$$



- Jet shape is symmetric
- Ridge is asymmetric!
  – shift to $\Delta\phi>0$ side
- Ridge may come from jet-flow alignment

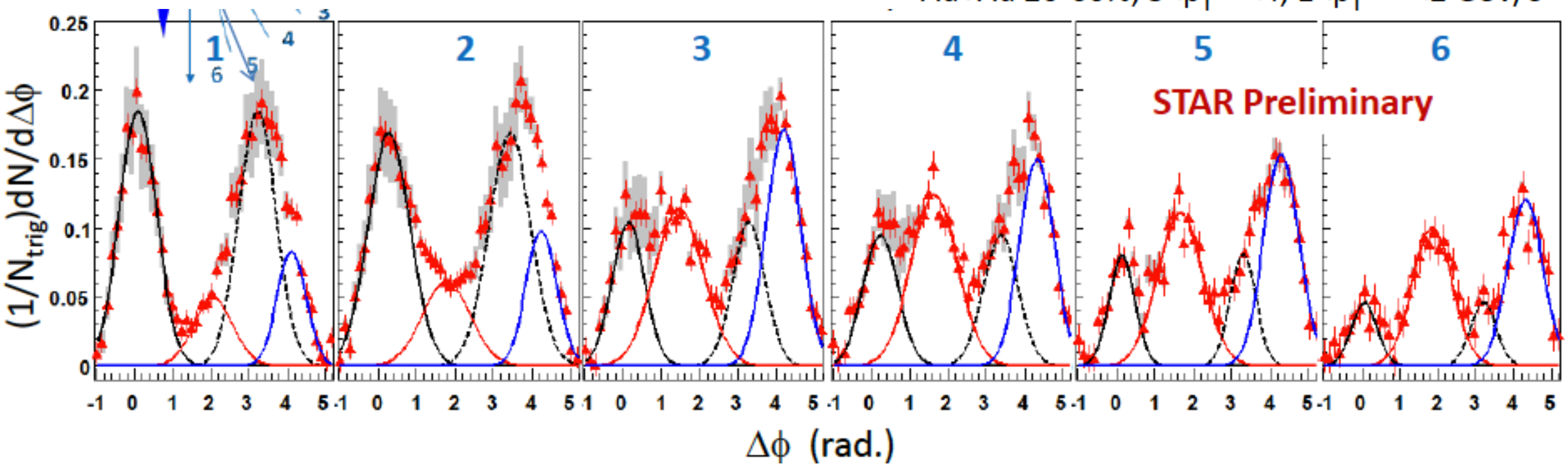
Back to Back Ridge



- Jet = ($|\Delta\eta|<0.7$) -Accep*($|\Delta\eta|>0.7$)
- $|\Delta\eta|>0.7$ = near-side ridge + away-side
- Flow subtraction by ZYAM
- Fit : Back-to-Back Ridge + away conical emissions

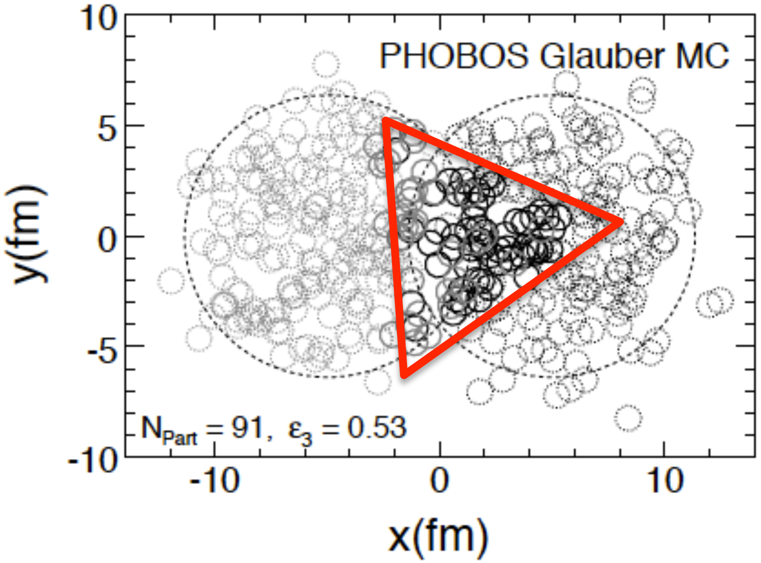
STAR Preliminary Konzer, QM'09; FW, SQM'09.

Au+Au 20-60%, $3<p_T^{trig}<4$, $1<p_T^{assoc}<2$ GeV/c



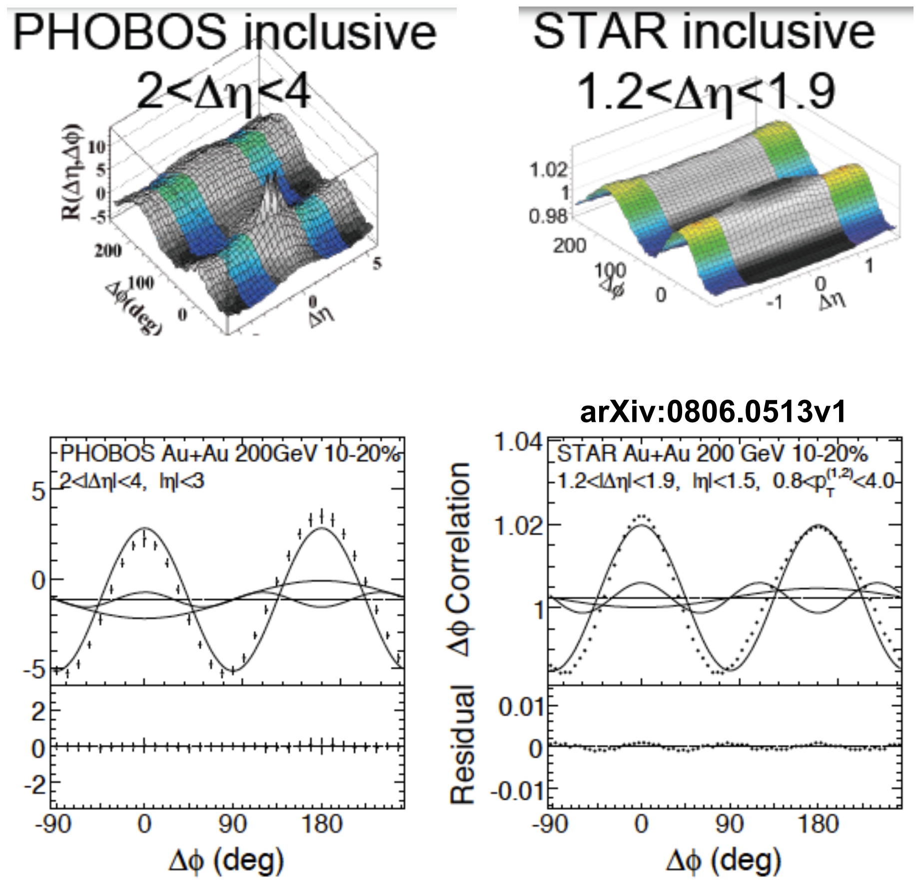
Triangular Flow

PHYSICAL REVIEW C **81**, 054905 (2010)



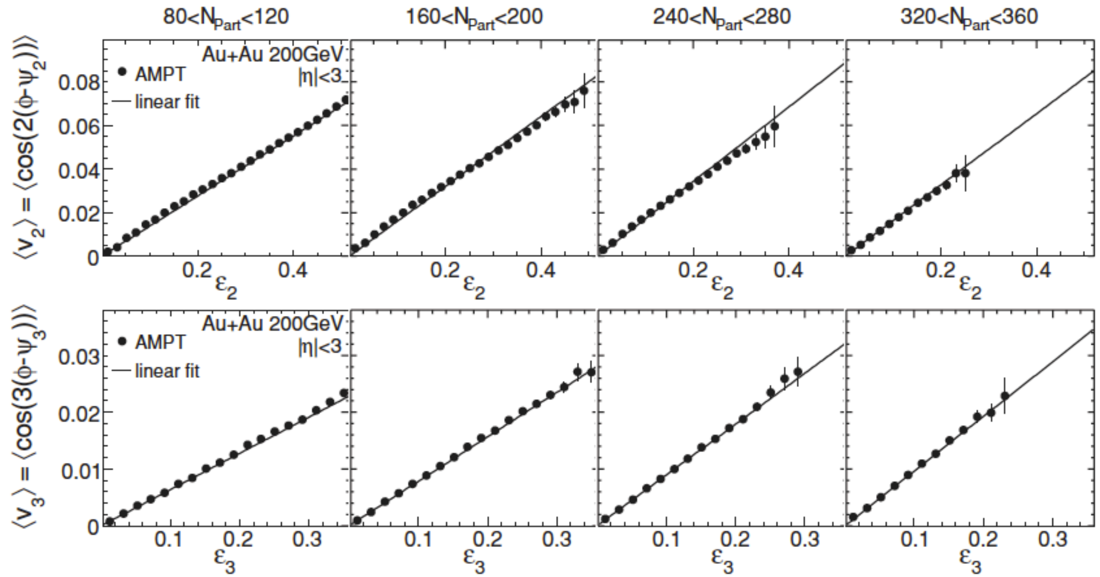
$$\varepsilon_3 \equiv \frac{\sqrt{\langle r^2 \cos(3\phi_{\mathrm{part}})\rangle^2 + \langle r^2 \sin(3\phi_{\mathrm{part}})\rangle^2}}{\langle r^2 \rangle}$$

Pictures : Alver RHIC-AGS Meeting 2010



- **Triangular flow is possible source of ridge!**

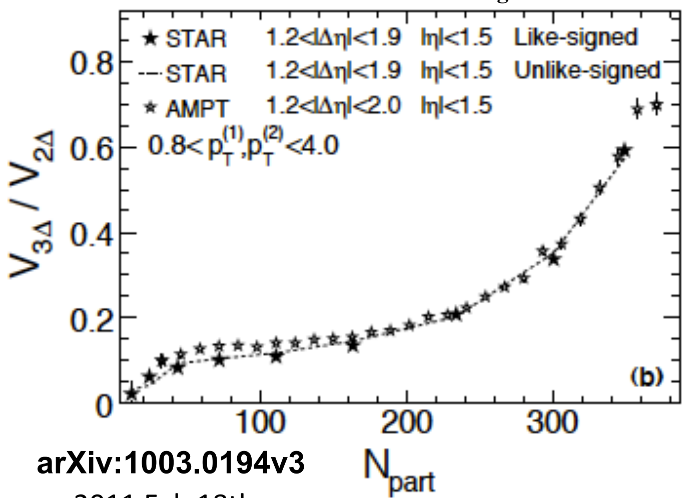
Comparison of AMPT and STAR



$$v_2 = \left\langle \cos\left(2(\phi - \psi_2)\right) \right\rangle \propto \varepsilon$$

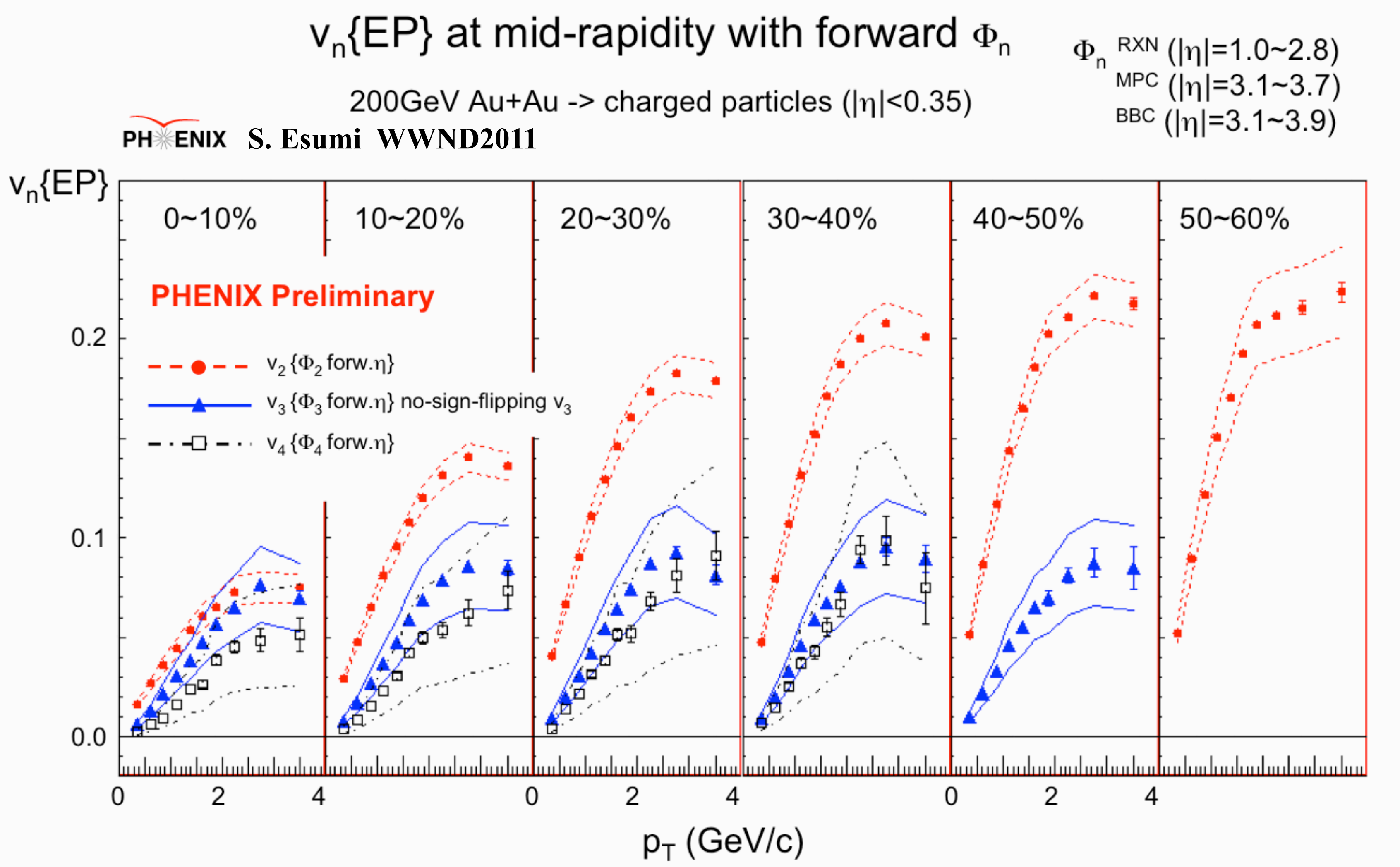
$$v_3 = \left\langle \cos\left(3(\phi - \psi_3)\right) \right\rangle \propto \varepsilon_3$$

$V_{n\Delta}$ = <cos n(ϕ_{asso} − ϕ_{trig})>~ V_n^2



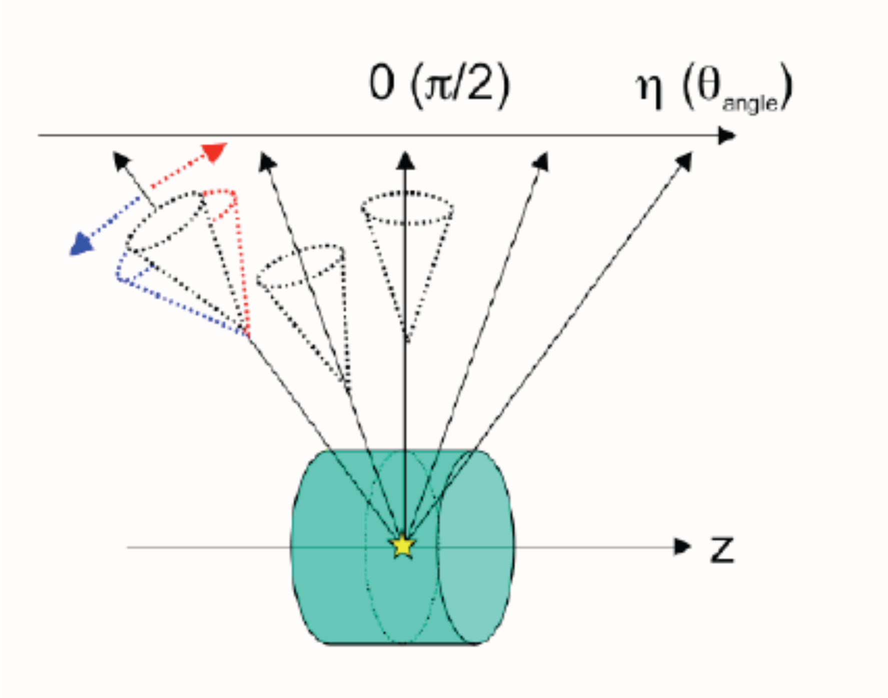
arXiv:1003.0194v3

- **v_2 & v_3 are depending on initial geometry in AMPT**
- **AMPT simulations have good consistency with data at p_T >0.8GeV**



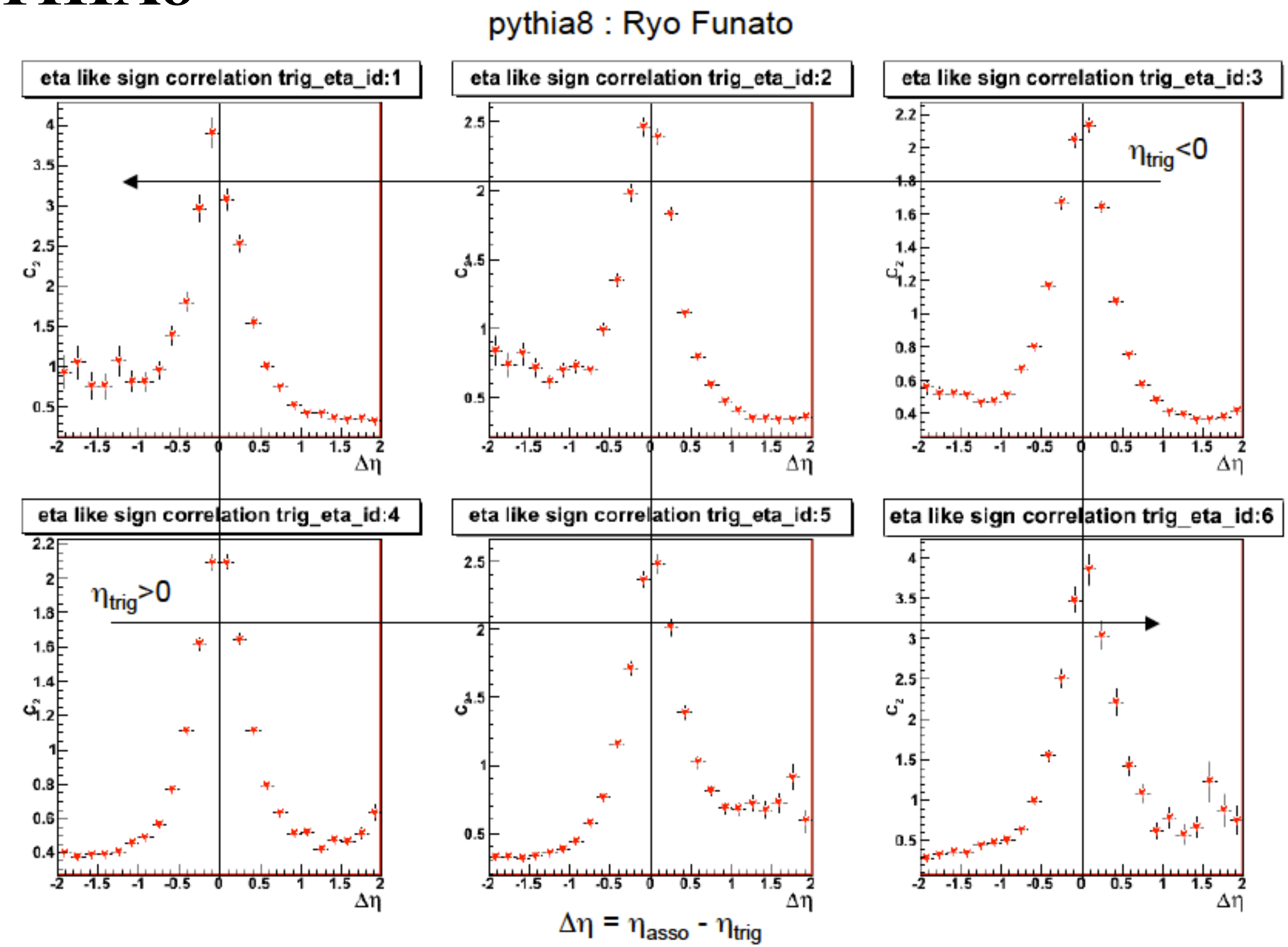
systematic errors are defined by the variations with Φ_n from different η and from different methods including central-forward 2-particle correlation. Therefore it could include some physics biases.

Δη correlations with respect to trigger η



- **Jet and Ridge property as function of trigger η**
  - **Back/Forward asymmetry of correlation shapes**
  - **Gradient of correlation functions**

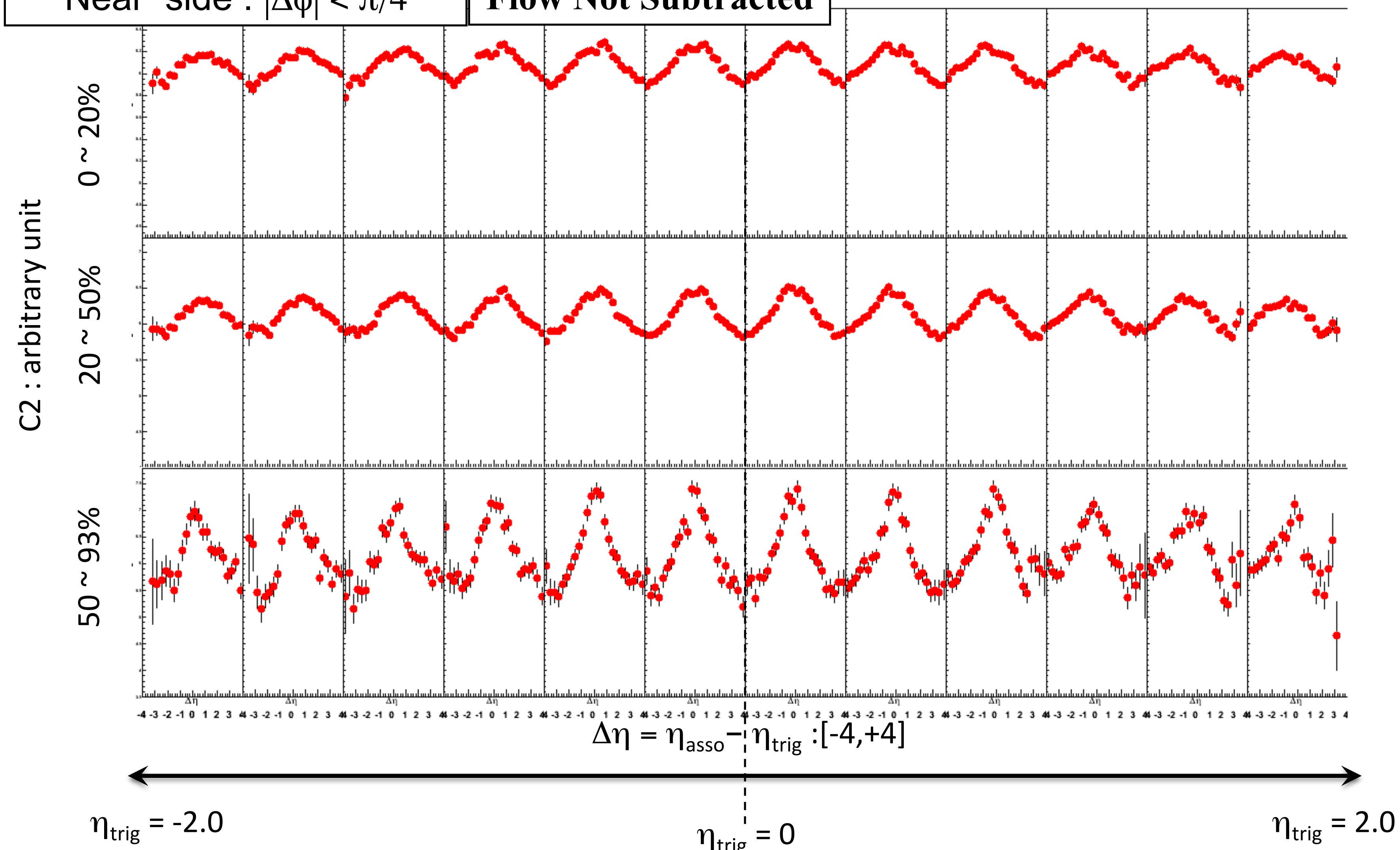
PYTHIA8


pythia8 : Ryo Funato
eta like sign correlation trig_eta_id:1
eta like sign correlation trig_eta_id:2
eta like sign correlation trig_eta_id:3
eta like sign correlation trig_eta_id:4
eta like sign correlation trig_eta_id:5
eta like sign correlation trig_eta_id:6
$\eta_{trig}<0$
$\eta_{trig}>0$
c_2
$\Delta\eta$
$\Delta\eta = \eta_{asso} - \eta_{trig}$

AMPT

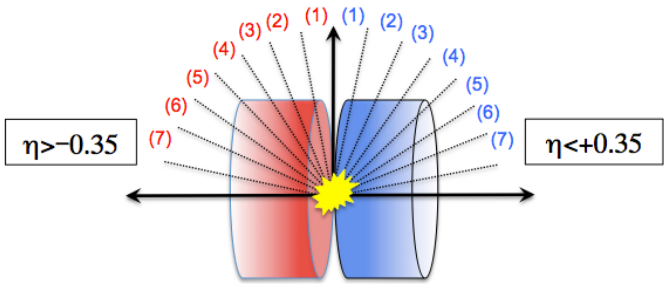
Near side : $|\Delta\phi| < \pi/4$

Flow Not Subtracted



PHENIX Data Analysis

- Trigger "sign" selection : "η<0" and "η>0"
- Precise trigger selection : [-0.35,0.35] 14bins. 0.05 step.

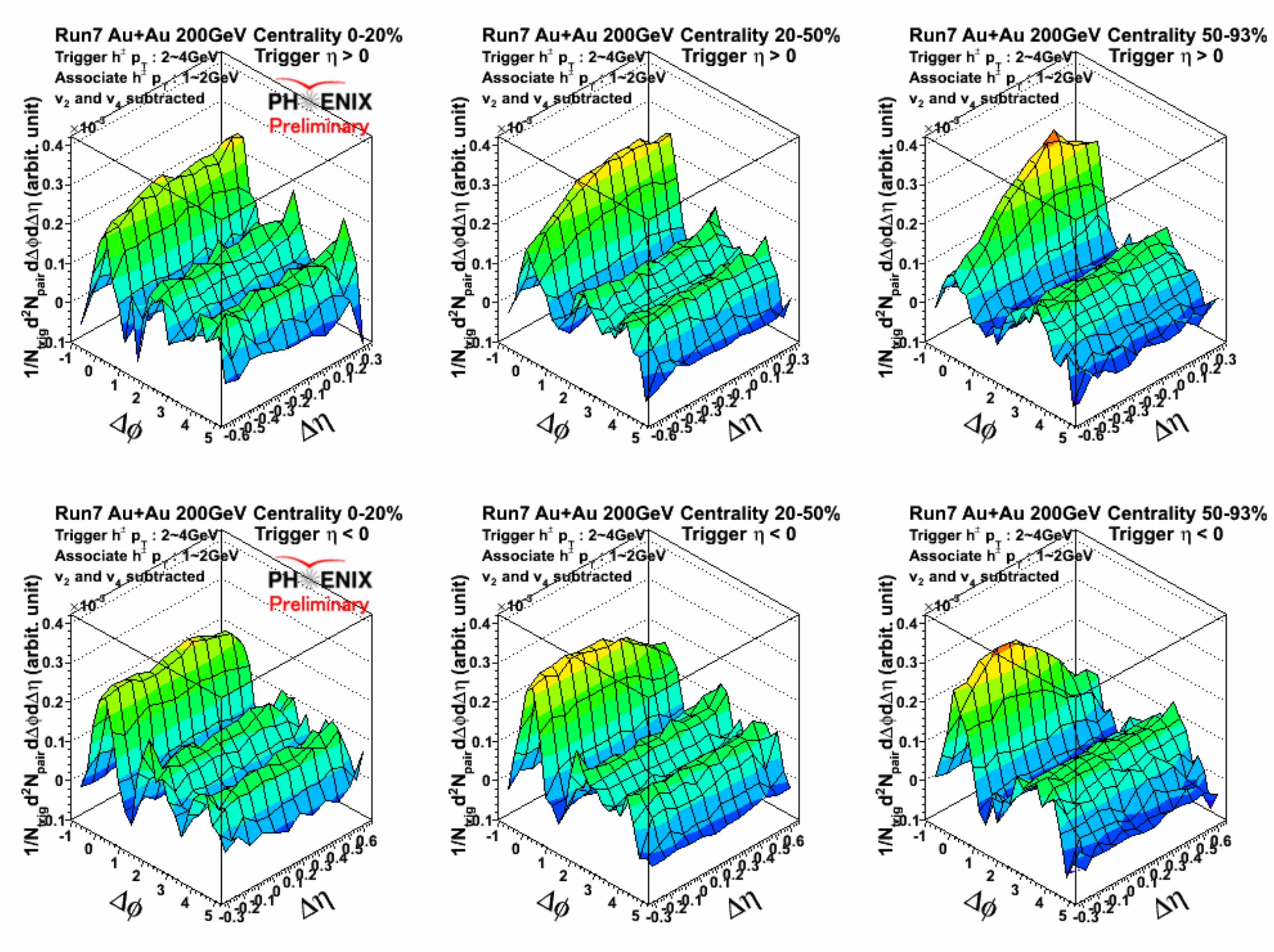


- Δη correlations : projected from Δφ − Δη correlations
  - Near side : $|\Delta\phi| < \pi/4$
  - Away side : $|\Delta\phi - \pi| < \pi/4$

$$\frac{1}{N_{trig}}\frac{dN_{pair}}{d\Delta\eta} = \int d\Delta\phi \left[\frac{1}{N_{trig}}\frac{d^2N_{pair}}{d\Delta\phi d\Delta\eta}\right]$$

- Superposition of jet and ridge due to central arm accep. $|\eta|<0.35$

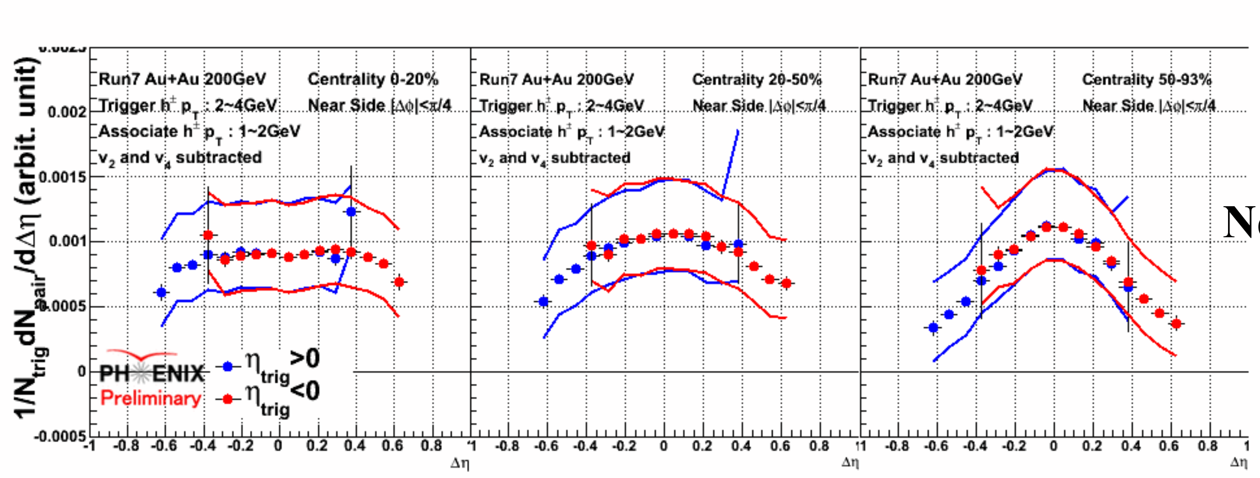
Trigger η sign selected correlations



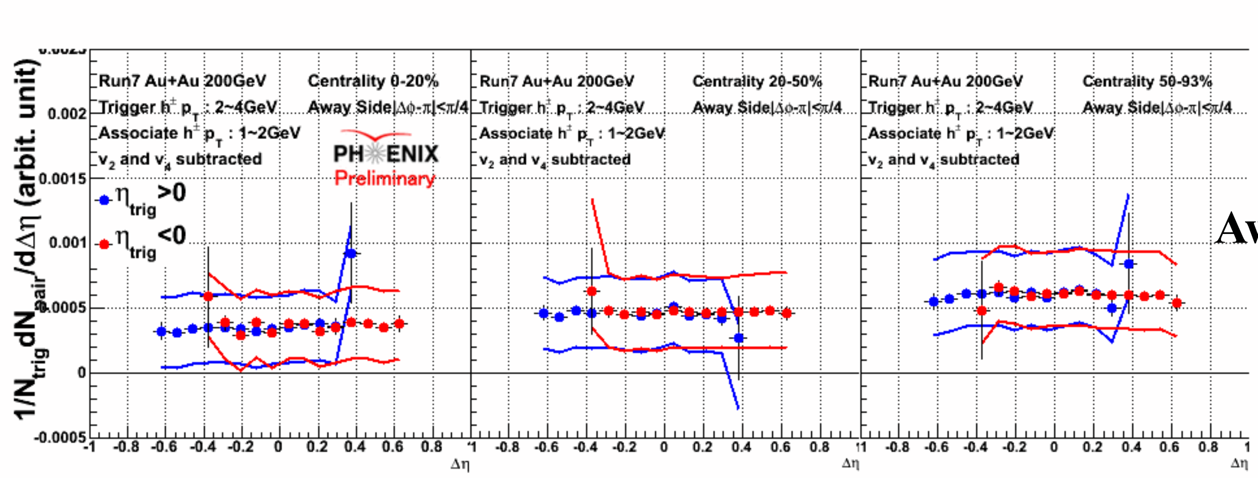
η>0

η<0

Projected Δη correlations : Trigger η sign selected



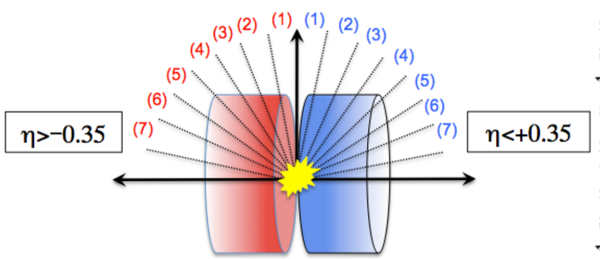
Near : $|\Delta\phi|<\pi/4$

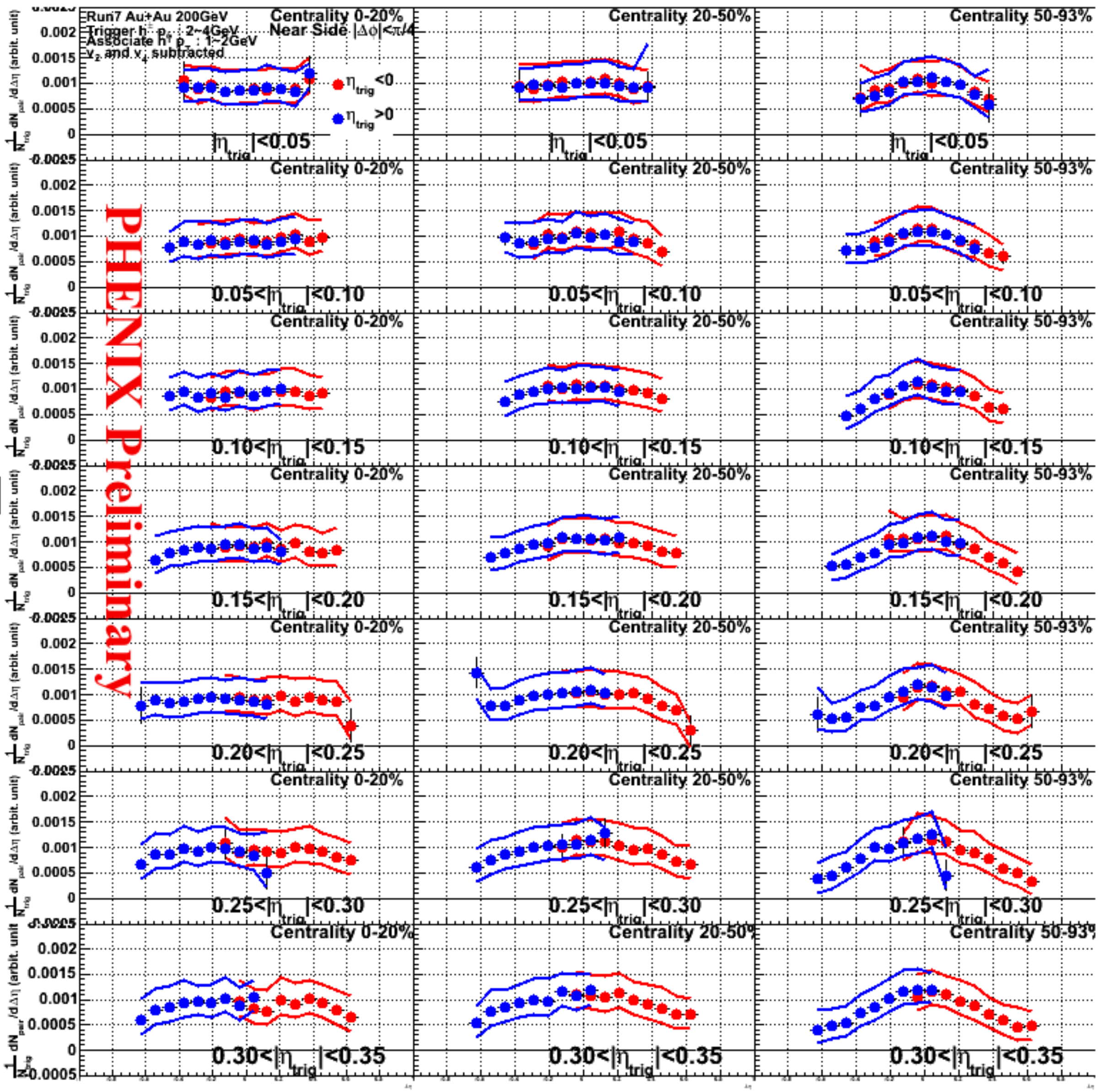


Away: $|\Delta\phi - \pi|<\pi/4$

Near side Δη correlations : precise trigger selection

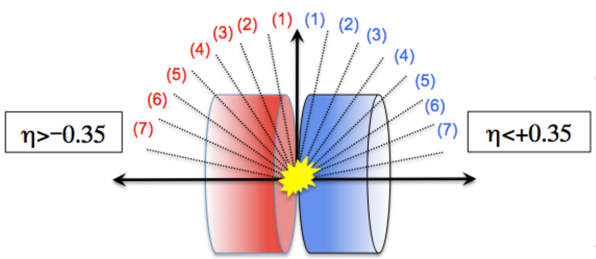
Near : $|\Delta\phi|<\pi/4$

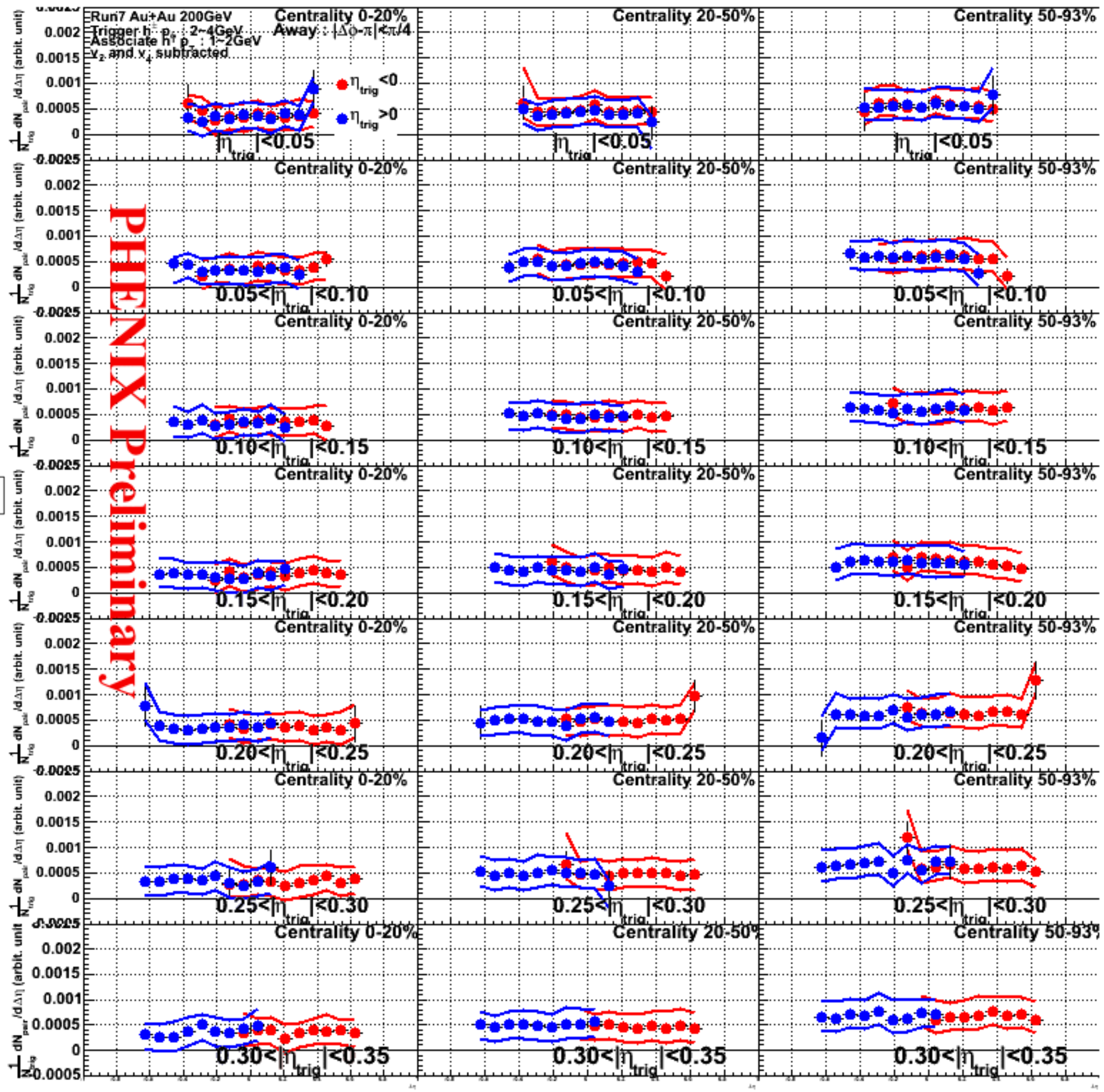




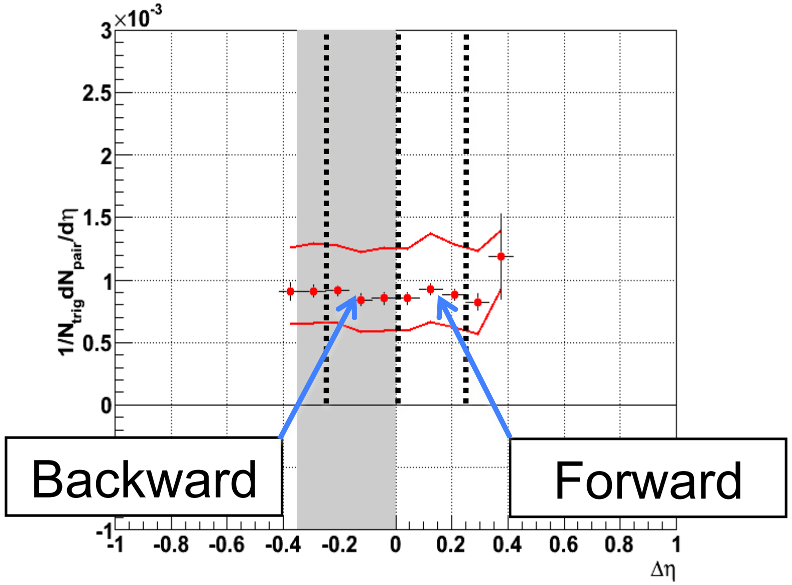
Away side Δη correlations : precise trigger selection

Away: $|\Delta\phi - \pi| < \pi/4$





Backward / Forward asymmetry

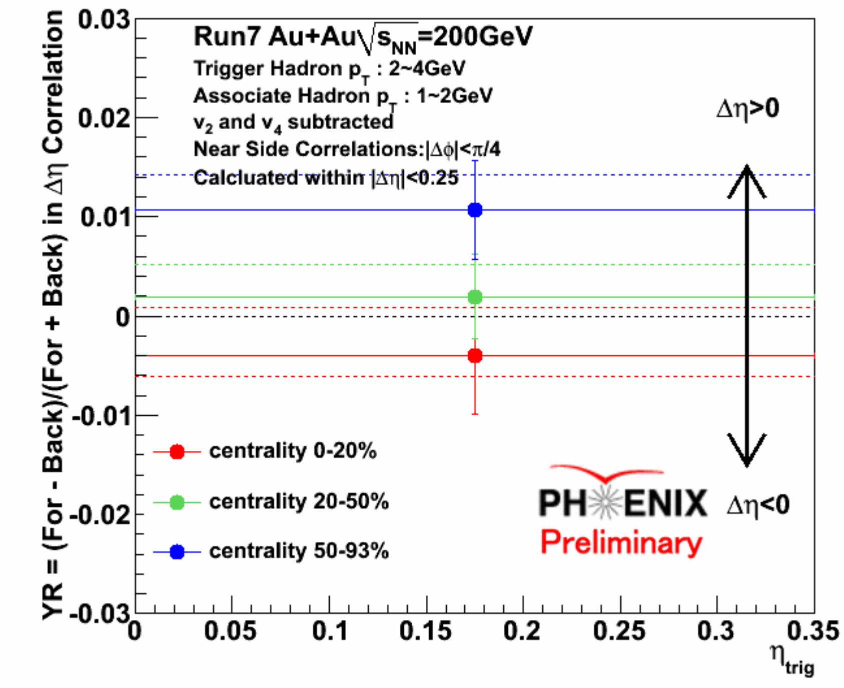


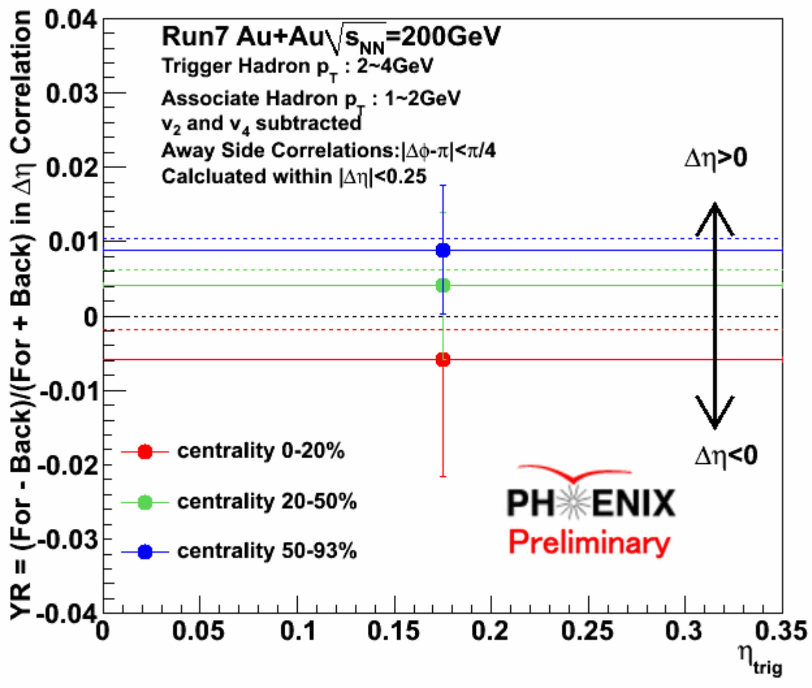
"Forward" : $\Delta\eta>0$
"Backward" : $\Delta\eta<0$

Centrality : 0~20
trigger (hadron): Pt 2~4GeV
η_{trig} [0, 0.05]
associate (hadron) : Pt 1~2GeV

- **Yield Ratio = $(Avg_{Forward} - Avg_{Backward})/(Avg_{Forward} + Avg_{Backward})$**
  - **Forward : $0 < \Delta\eta < 0.25$**
  - **Backward : $-0.25 < \Delta\eta < 0$**
- **YR=0 : symmetric shape**
- **YR>0 or <0 : shift for Forward or Backward direction**

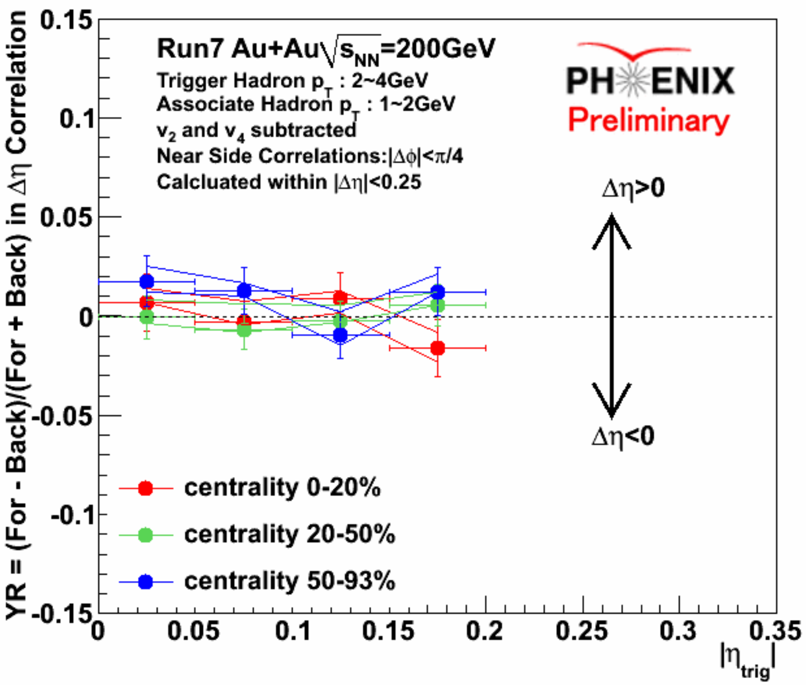
Backward / Forward asymmetry : trigger sign selection

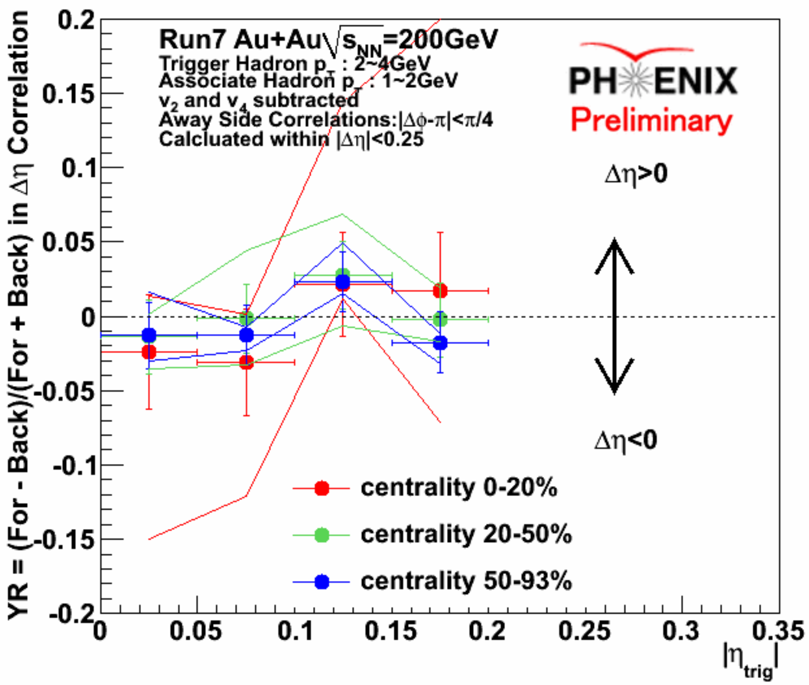




- **Degree of asymmetry**
  - **at most 2σ in peripheral at near side**
  - **at most 1σ in peripheral at away side**

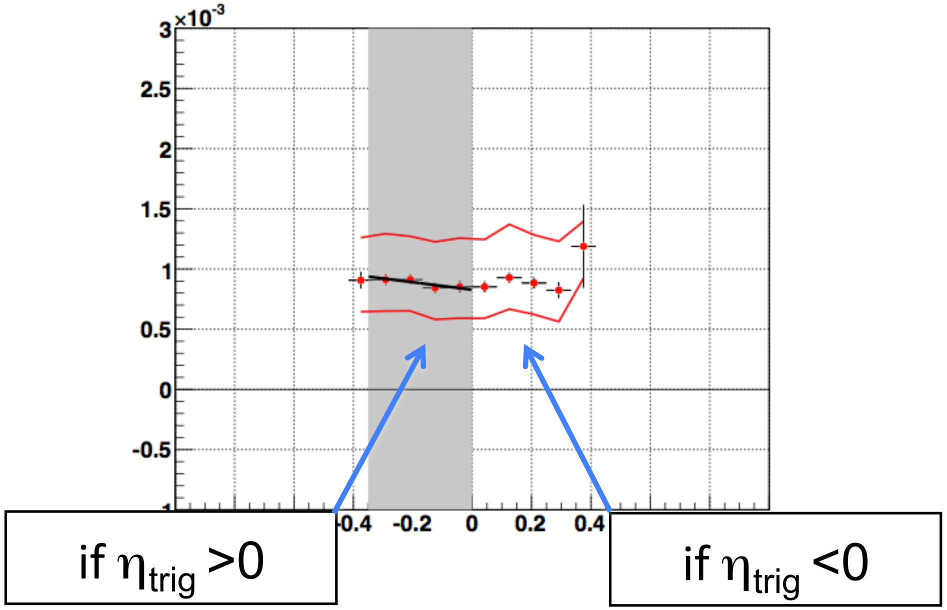
Backward / Forward asymmetry : trigger precise selection





- Large statistical & systematic error on both near and away side

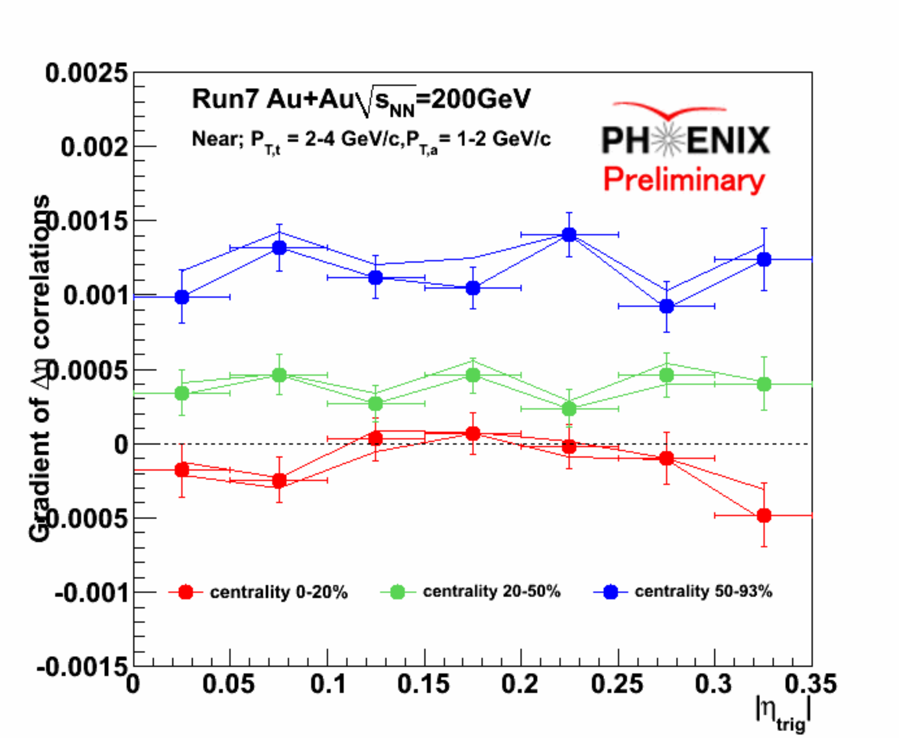
Gradient of correlations as function of trig η

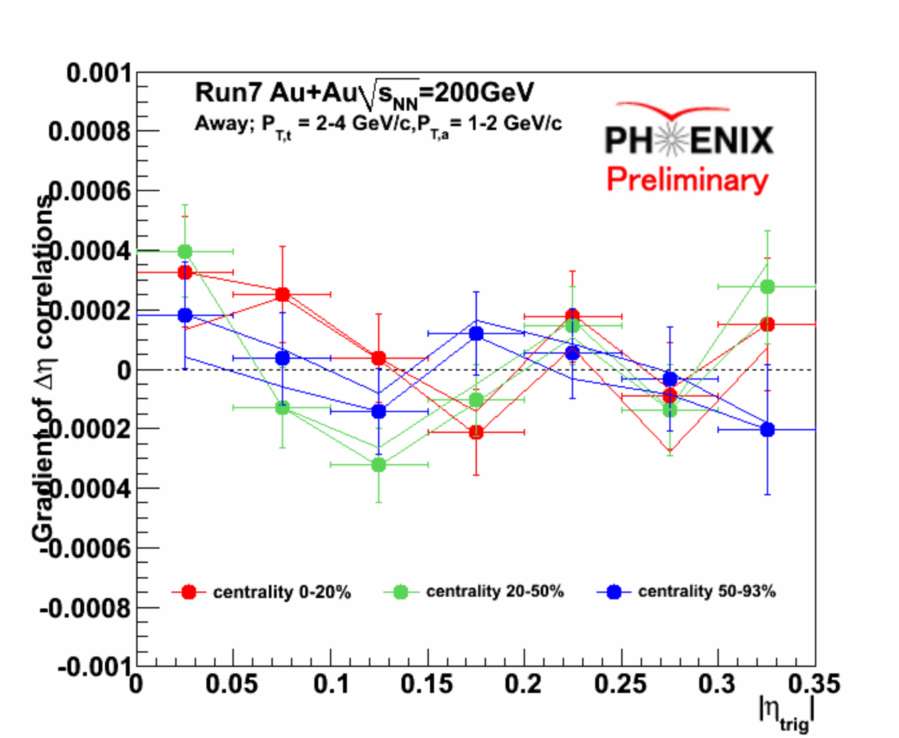


Centrality : 0~20
trigger (hadron): Pt 2~4GeV
η_{trig} [0, 0.05]
associate (hadron) : Pt 1~2GeV

- **Fitting function : [0] + [1]*x**
- **Fitting range**
  - **$\Delta\eta$: [0,0.35] if η_{trig} <0**
  - **$\Delta\eta$: [-0.35,0] if η_{trig} <0**

Gradient of correlations seems to be flat





- **Gradient of correlations seems to be flat at near side**
- **Away side also seems to be flat though still large statistical error**

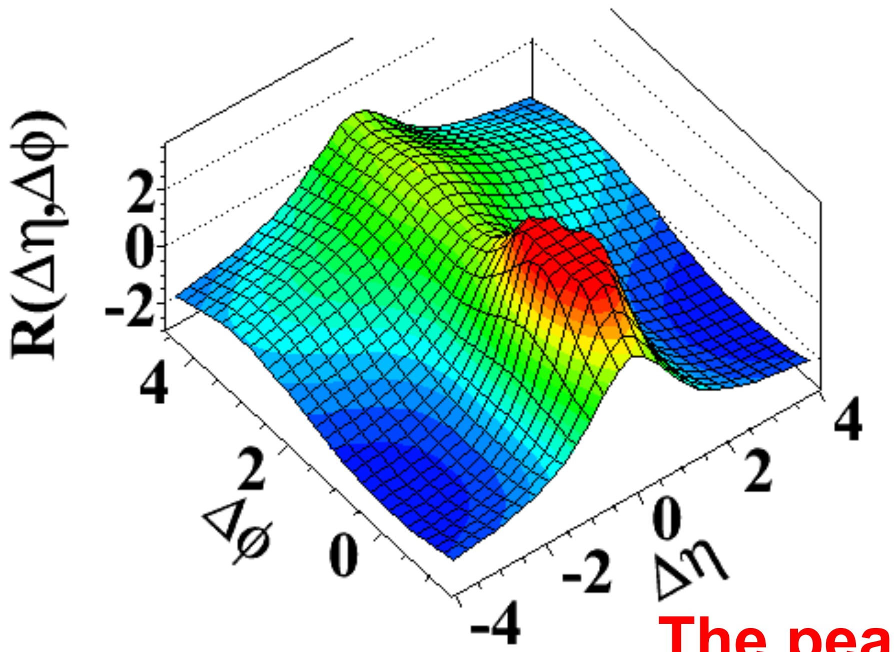
Correlations in high multiplicity p+p events at LHC-CMS

Minimum Bias
no cut on multiplicity

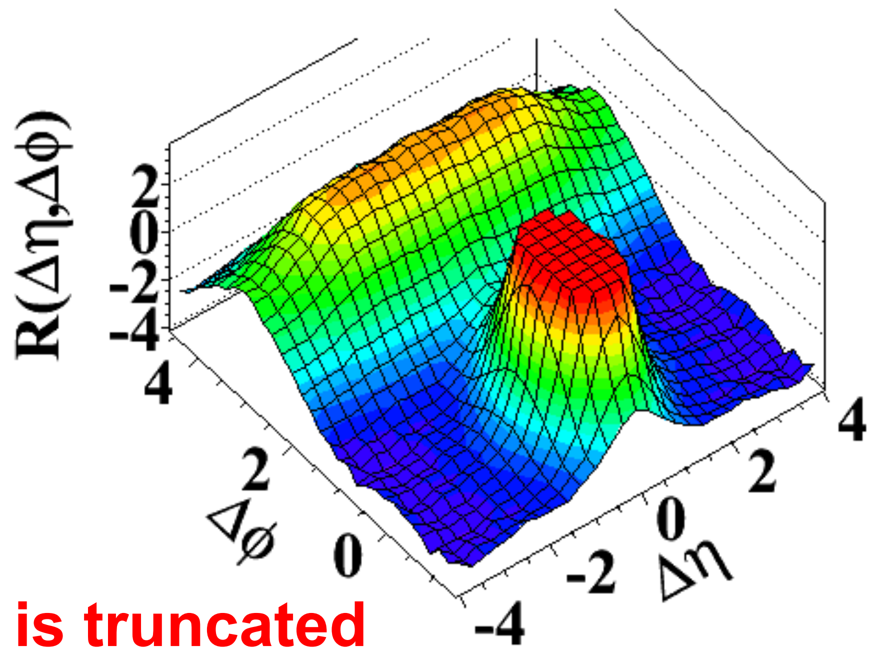
High multiplicity data set
and N > 110

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

(a) MinBias, p_T>0.1GeV/c



(c) N>110, p_T>0.1GeV/c



The peak is truncated in both distributions

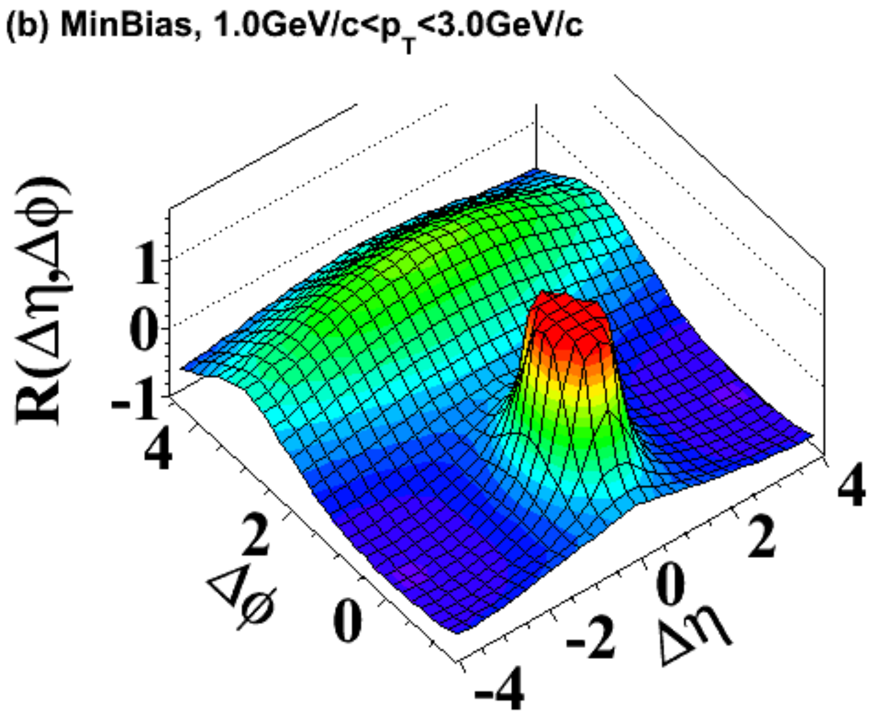
Back-to-back jet correlations enhanced in high multiplicity sample.

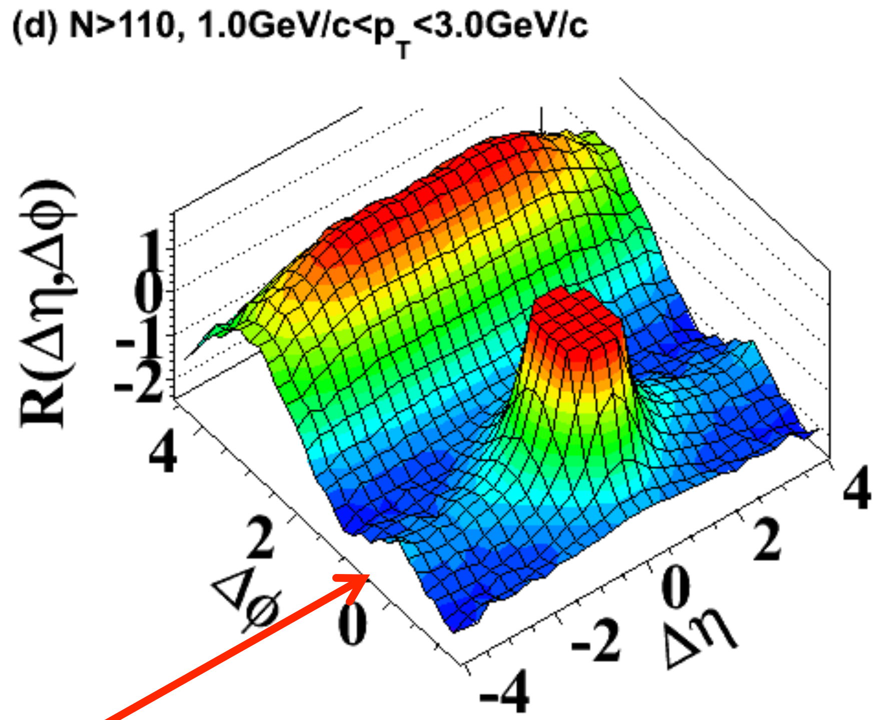
CERN Seminar September 21 2010

Minimum Bias
no cut on multiplicity

High multiplicity data set
and N>110

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

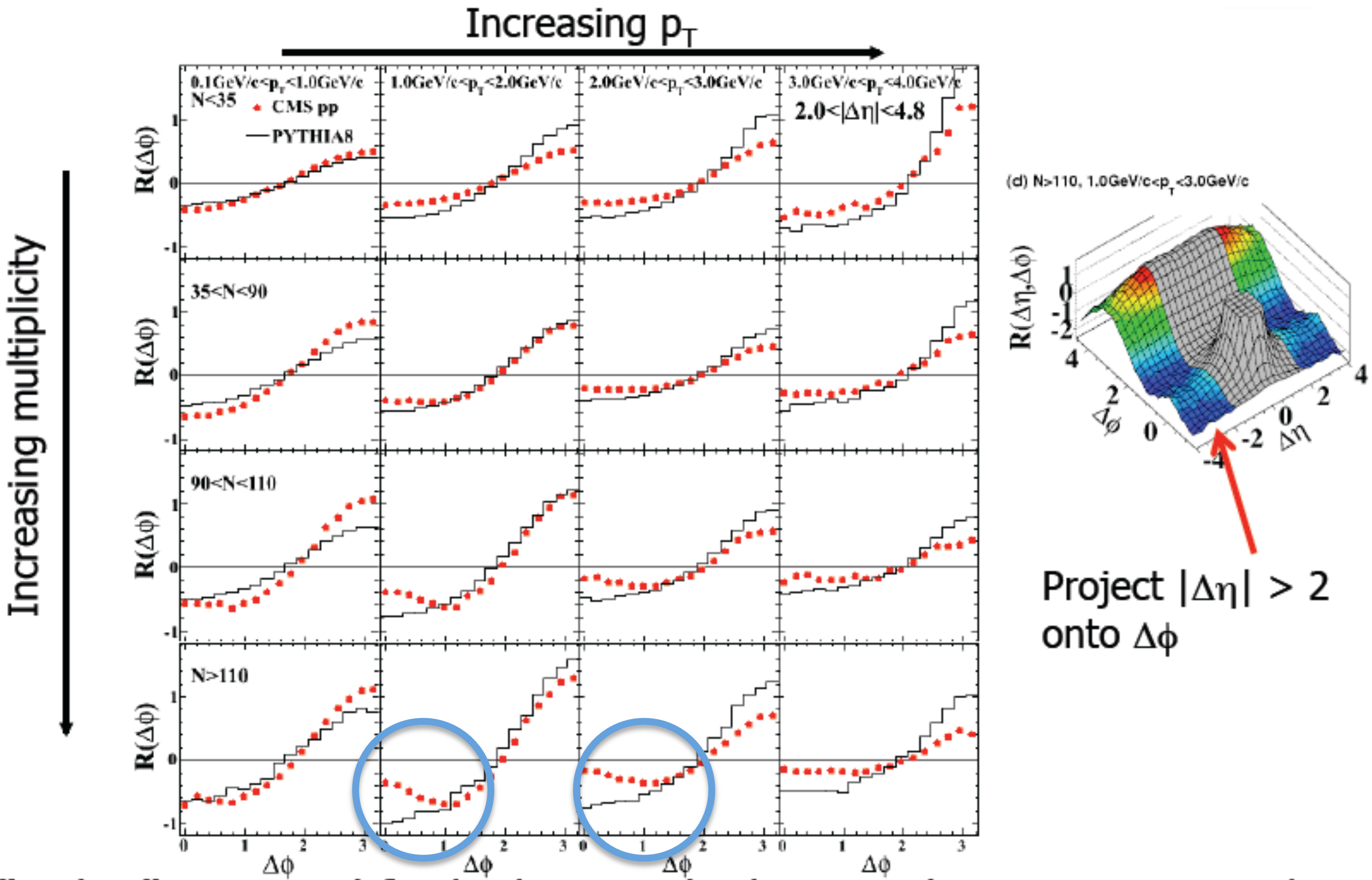




CERN Seminar September 21 2010

New "ridge-like" structure extending to large $\Delta\eta$ at $\Delta\phi \sim 0$

Data and PYTHIA8

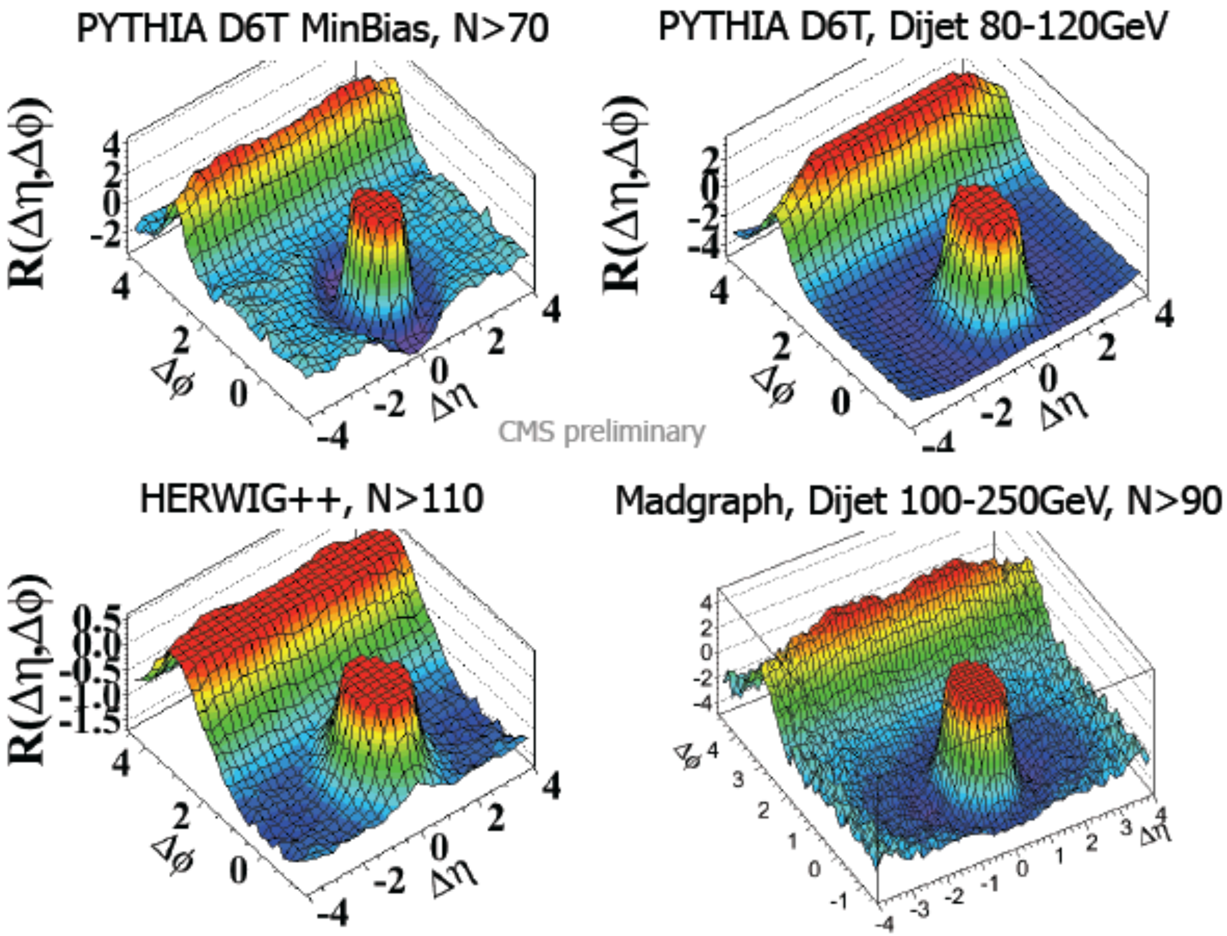


"Ridge" maximal for highest multiplicity and $1 < p_T < 3$ GeV/c

CERN Seminar September 21 2010 19

Other simulation models

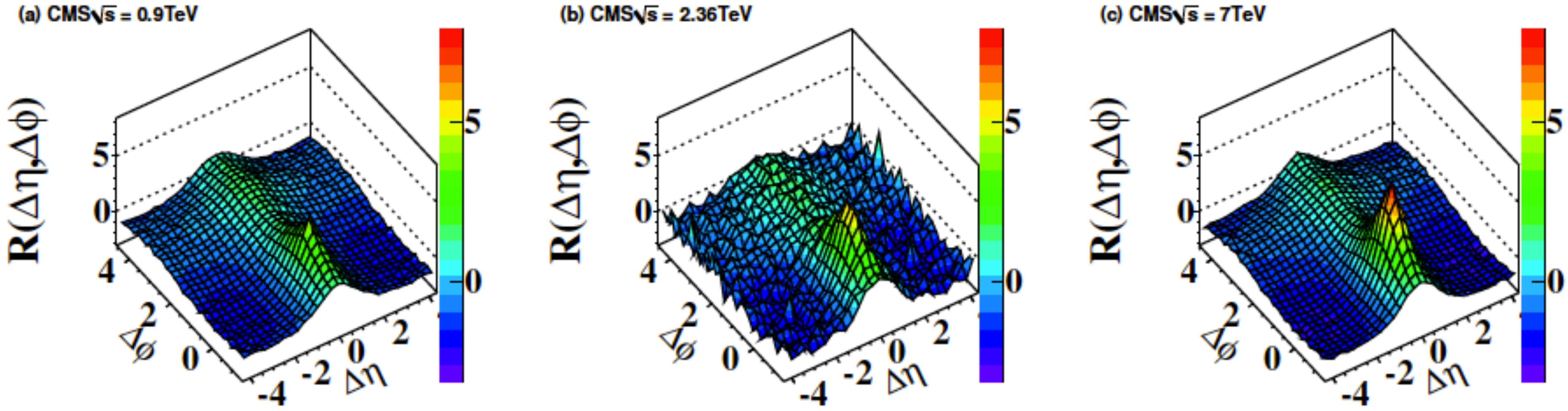
CERN Seminar September 21 2010



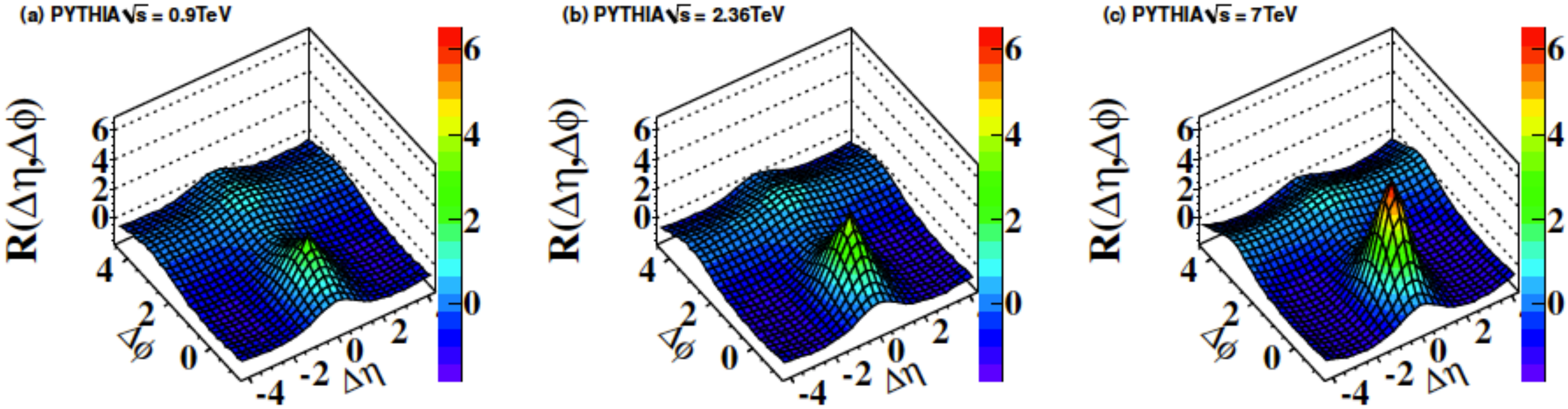
$1<p_T<3$GeV/c

No ridge effect in these models (with the tunes used)

Data and PYTHIAD6T at 0.9, 2.36 and 7 TeV



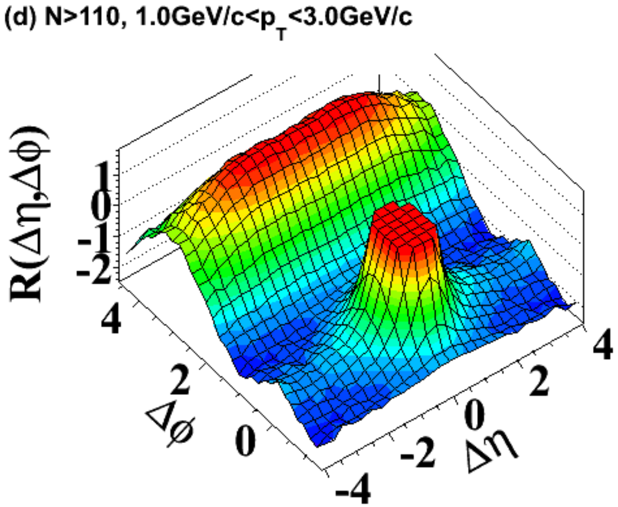
PYTHIA D6T PT inclusive

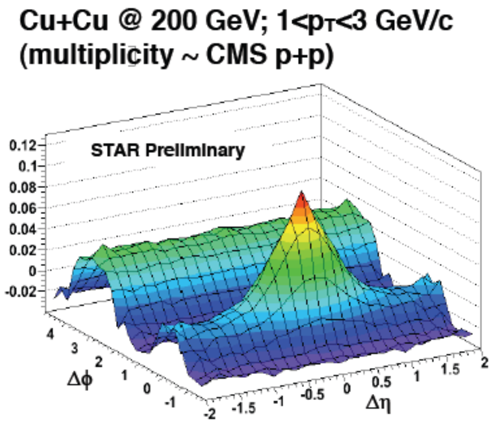


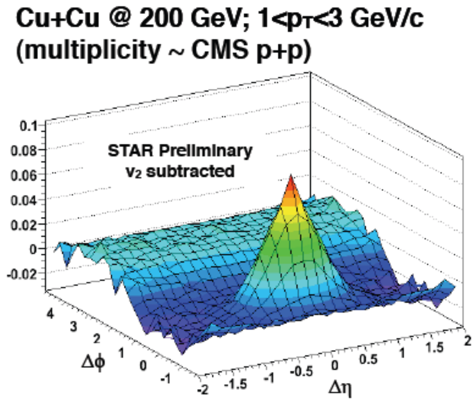
Comparison 7 TeV p+p and 200 GeV Cu+Cu correlations

High multiplicity data set N>110

Hard Probe 2010, Putschke







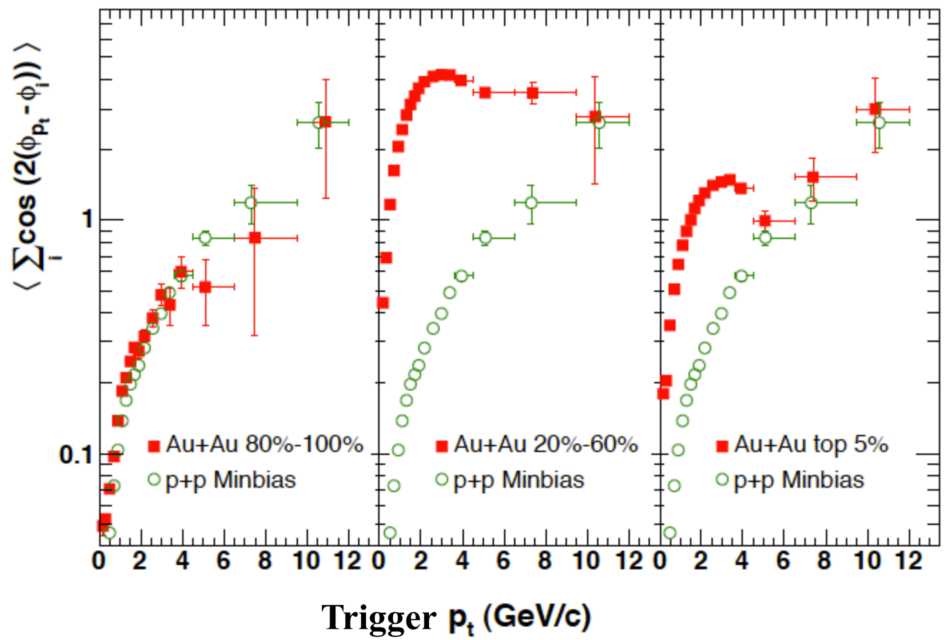
- **Correlations in Cu+Cu at similar multiplicity dominated by flow.**
- **How correlation shape changed if v_2 exists in high mult. p+p event?**
- **Need to survey azimuthal dynamics in high mult. p+p events**

Accumulative azimuthal correlations

STAR AuAu 200GeV arxiv:nucl-ex/0407007v3

$<\Sigma_i \cos 2(\phi_{trig} - \phi_i^{asso})> = \text{Mult.}^* v_2 (p_T^{trig})\, v_2^{asso} + \{\text{non-flow}\}$

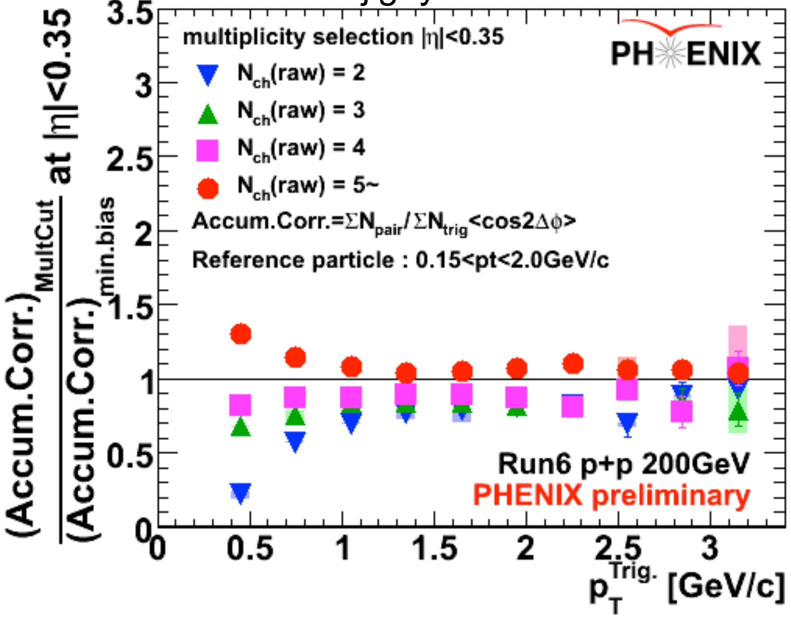
$0.15 < p_T^{asso} < 2.0\text{GeV/c at } |\eta| < 1.0$

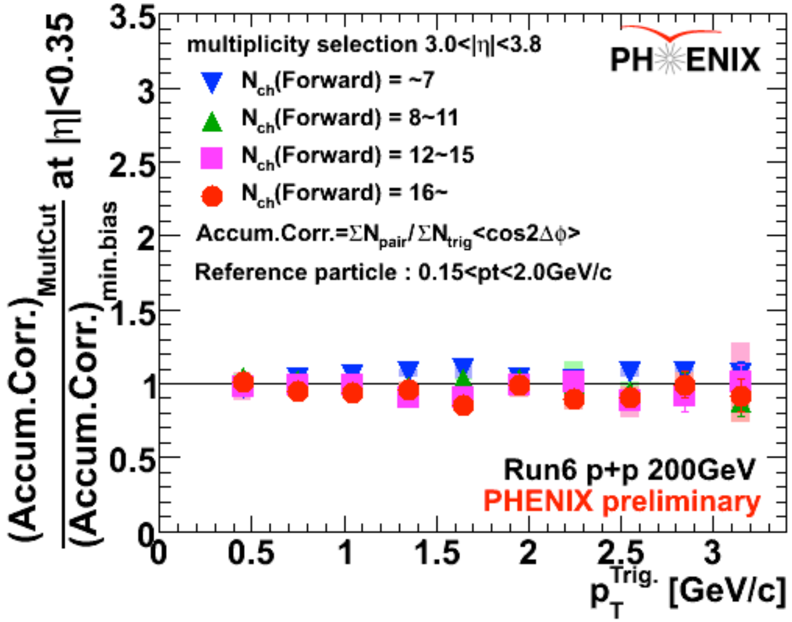


- Consistent with p+p minimum bias at peripheral
- Enhance of Au+Au correlations at mid central & central by flow-like component
- Method to search the possible modification in high multiplicity p+p events from minimum bias because ***no event plane needed***

Accumulative correlations in high multiplicity p+p events at 200 GeV

Midori Kajigaya Univ. of Tsukuba

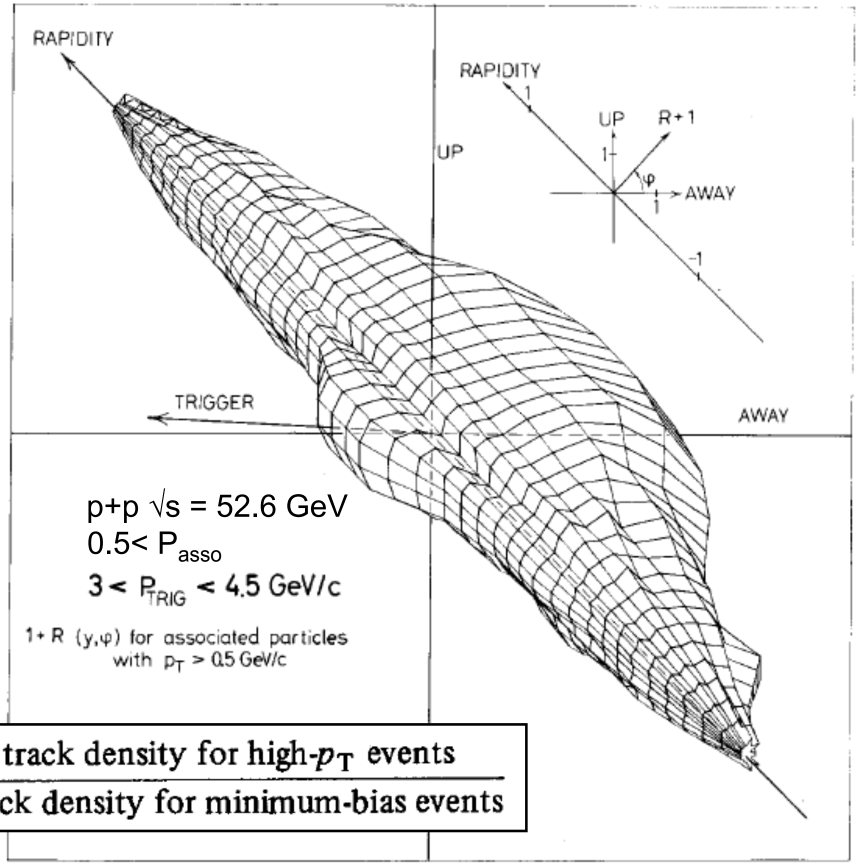




$$\boxed{\langle \Sigma_i \cos 2(\phi_{Pt} - \phi_i)\rangle = \text{Mult.}^{*} v_2\,(p_T)\, v_2^{asso} + \{\text{non-flow}\}}$$

- **Enhance in mid-rapidity high multiplicity event**
- **Azimuthal dynamics in p+p events depends on multiplicity if track number count and calculation done in same rapidity range.**

Possible ridge in p+p collisions at RHIC energy?



$$R + 1 \approx \frac{\text{mean track density for high-}p_T\text{ events}}{\text{mean track density for minimum-bias events}}$$

CERN-ISR
Nucl. Phys. B145 (1978)
305-348

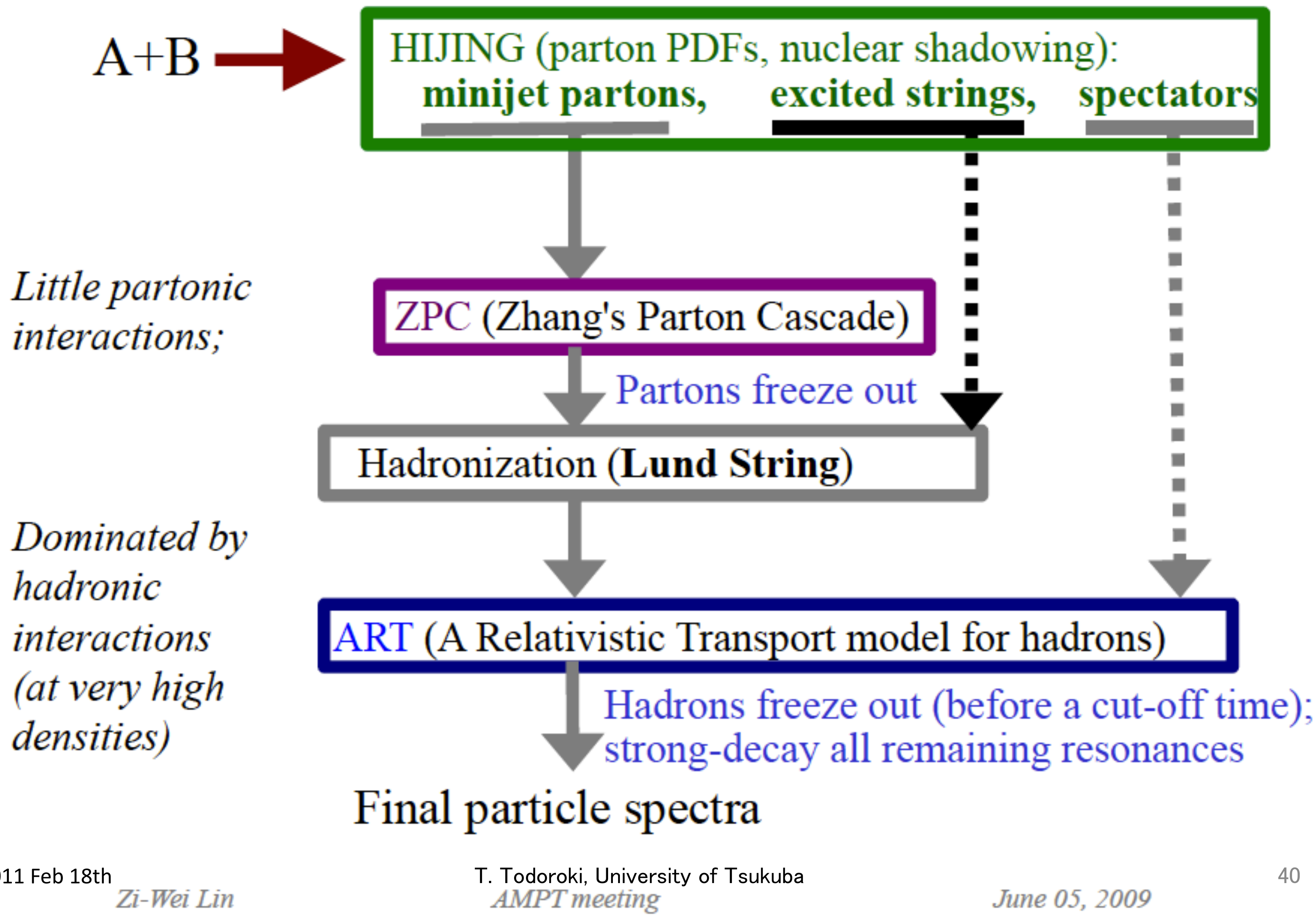
- **data to analyze : 500GeV, 200GeV and 62.4 GeV**

Summary

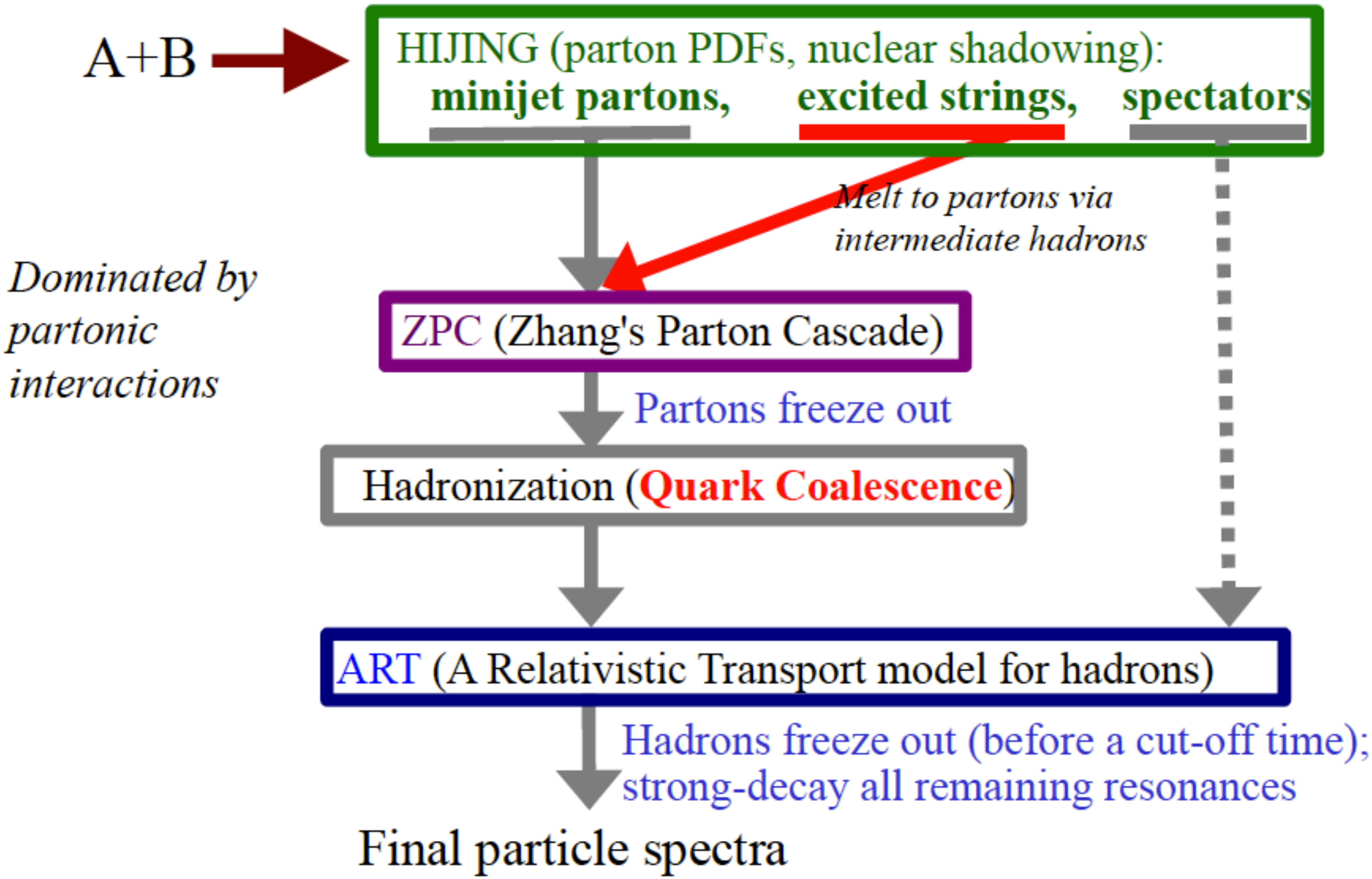
- Overview of basic ridge property
- Ridge study via $\Delta\phi$ correlations with respect to Reaction Plane
  – Ridge depends on Reaction Plane
- Triangular flow
  – Possible source of ridge
  – AMPT well describes STAR experimental data at p_T >0.8GeV
- $\Delta\eta$ correlations with respect to trigger η
  – No trigger η dependence seen in PHENIX acceptance…
- Ridge in high multiplicity p+p events at LHC-CMS

Back Up Slides

Structure of AMPT v1.xx (default model)

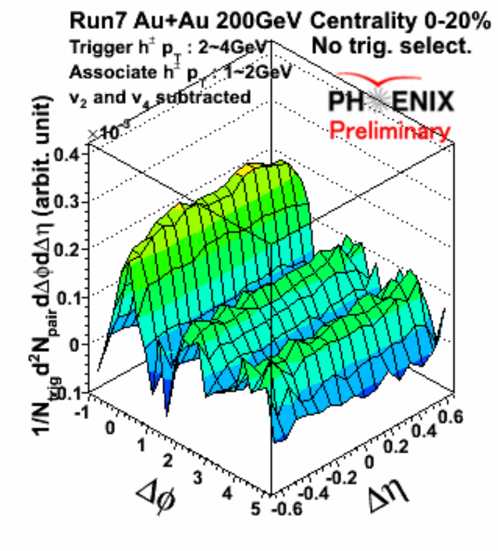


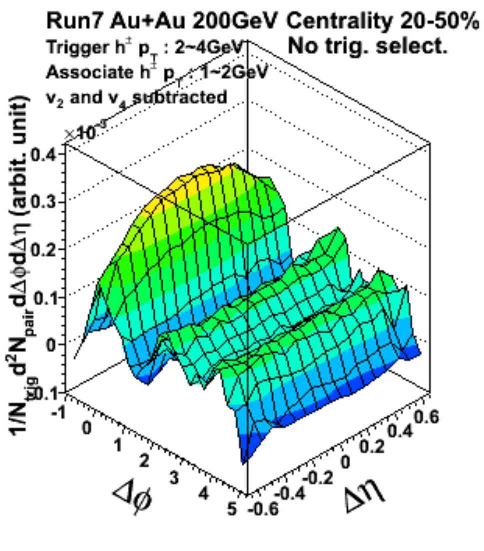
Structure of AMPT v2.xx (String Melting model)

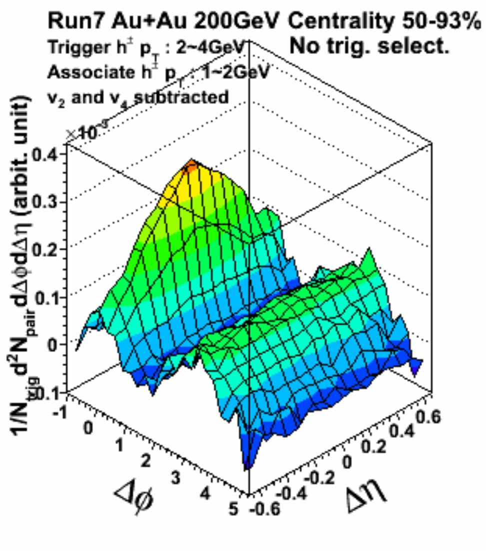


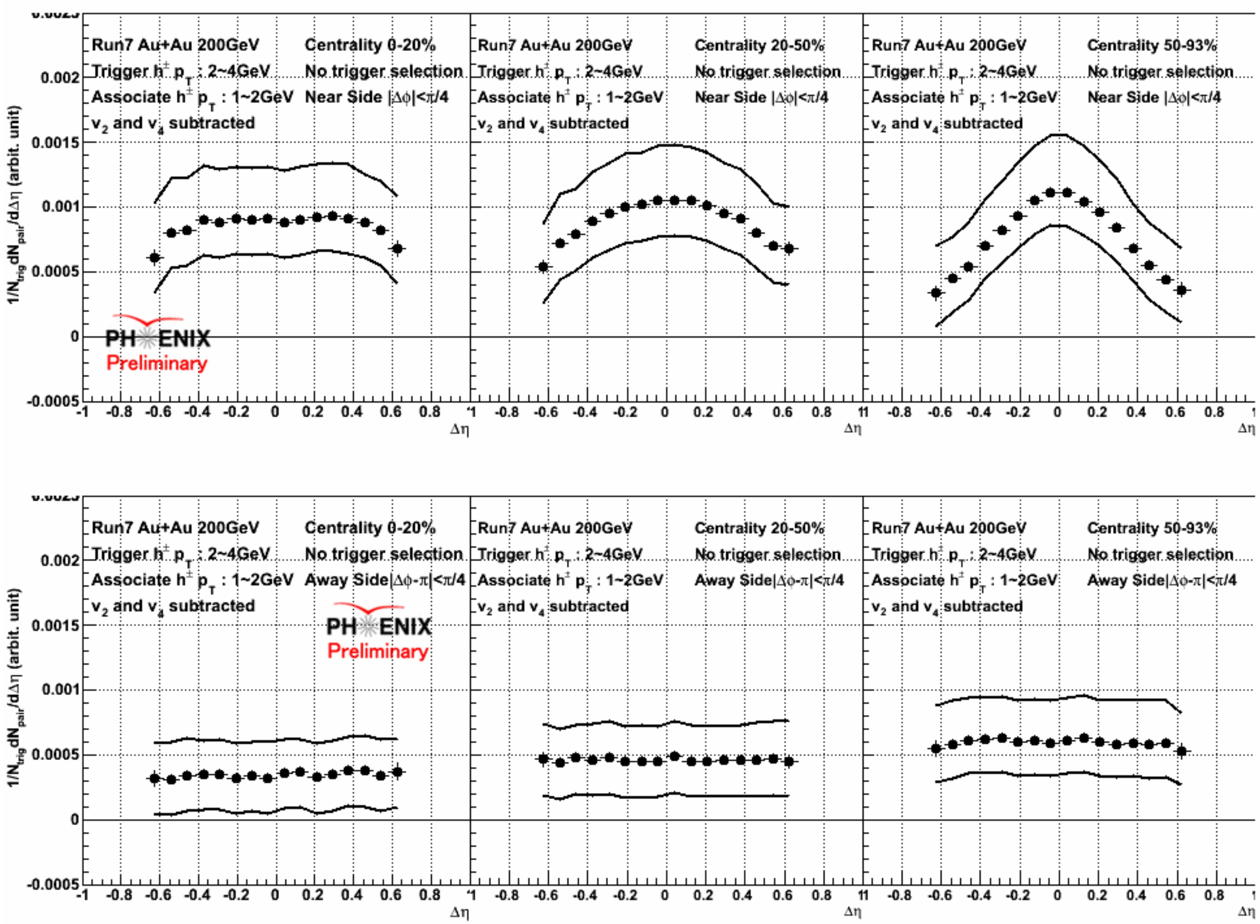
Zi-Wei Lin *AMPT meeting* *June 05, 2009*

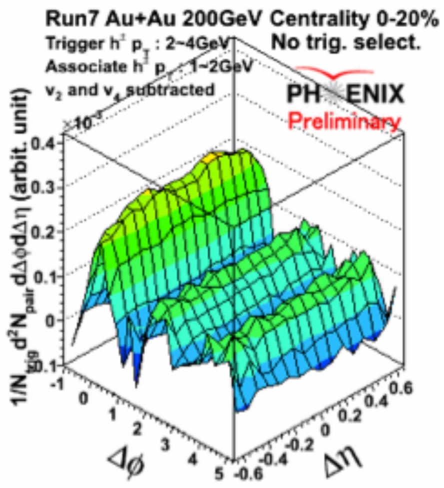
None trigger selected Δφ−Δη correlations








Run7 Au+Au 200GeV
Trigger h± pT : 2~4GeV
Associate h± pT : 1~2GeV
v2 and v4 subtracted
Centrality 0-20%
Centrality 20-50%
Centrality 50-93%
No trigger selection
Near Side |Δφ|<π/4
Away Side|Δφ-π|<π/4
PHENIX
Preliminary
1/NtrigdNpair/dΔη (arbit. unit)
Δη


Run7 Au+Au 200GeV Centrality 0-20%
Trigger h± pT : 2~4GeV
No trig. select.
Associate h± pT : 1~2GeV
v2 and v4 subtracted
PHENIX
Preliminary
1/Ntrig d²Npair dΔφdΔη (arbit. unit)
Δφ
Δη