Measurements of higher-order flow harmonics and two particle correlations in relativistic heavy ion collisions at RHIC-PHENIX

(RHIC-PHENIX実験における相対論的重イオン衝突における高次方位角異方性及び二粒子相関の測定)

2012/12/21 TACセミナー

数理物質科学研究科
轟木　貴人

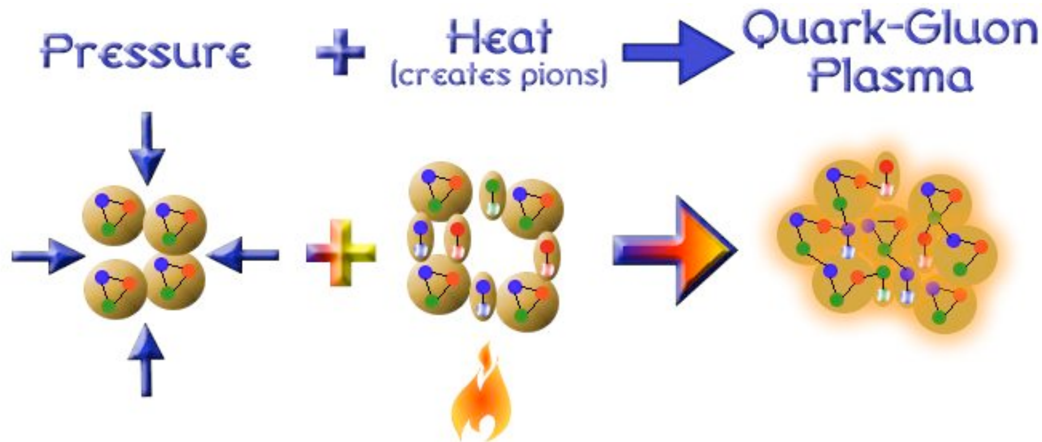
Outline

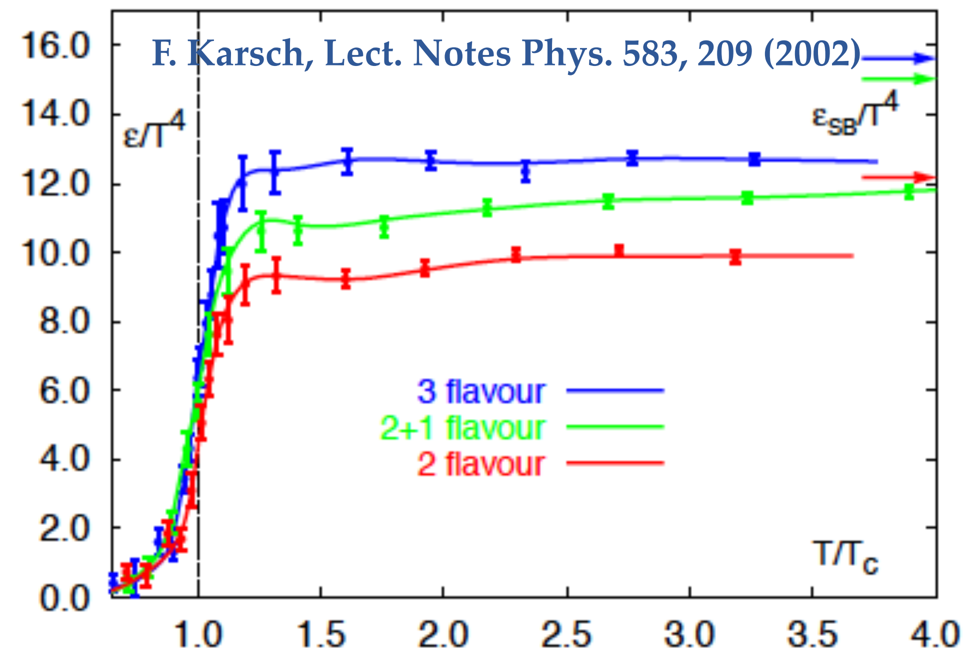
- **Introduction**
  - QGP
  - Higher-Order Flow Harmonics
  - Jet Quenching
  - Two Particle Correlations
- **Experiment**
  - RHIC
  - PHENIX
- **Analysis**
  - Event Plane (EP)
  - Two Particle Correlations
  - EP Dependent Correlations
  - Unfolding of EP Resolution
- **Results & Discussions**
  - v_n subtracted correlations
    - Fourier Decomposition
  - EP Dependent Correlations
    - Yield as a function of trigger angle
    - Gravity Position as a function of trigger angle

Introduction

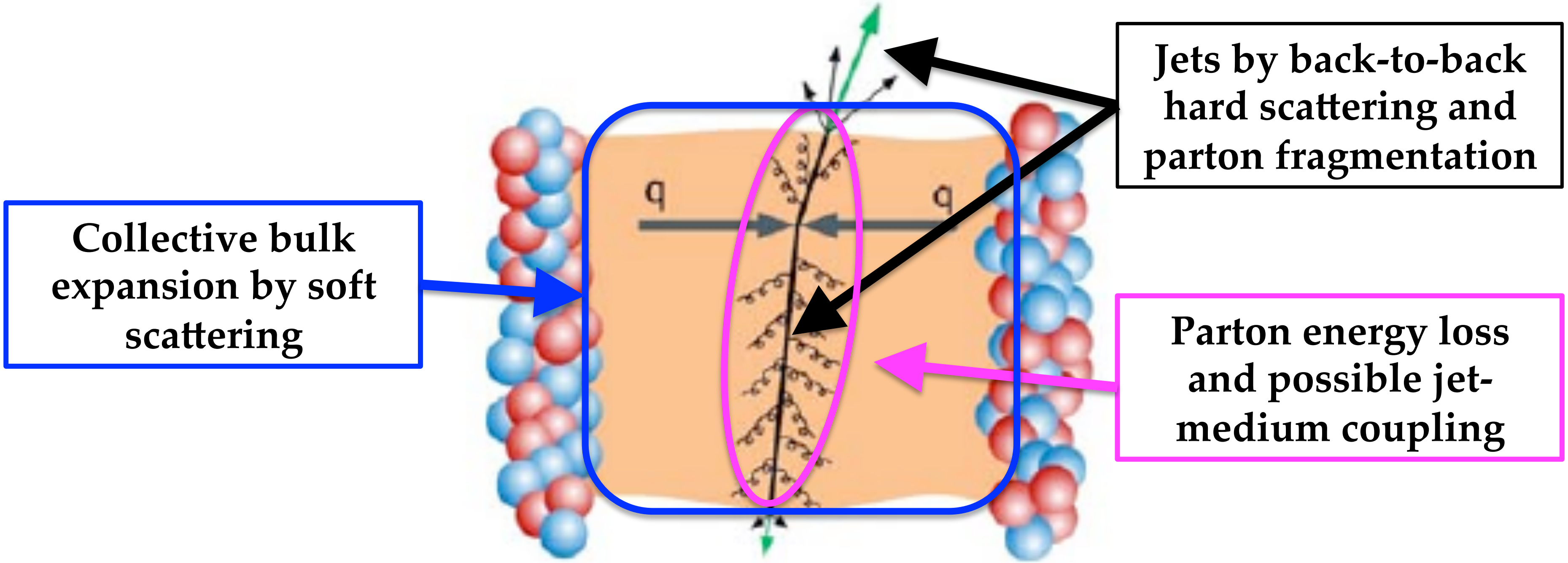
Quark Gluon Plasma(QGP)

- A state of matter where Quarks & Gluons are de-confined from hadrons at high energy-density(ε)/ temperature(T)
- Predicted transition ε & T by Lattice-QCD
  - T ~ 170 [MeV]
  - ε ~1.0 GeV/fm^3
- Relativistic Heavy Ion Collision at RHIC
  - ε~ 5-15 GeV/fm^3





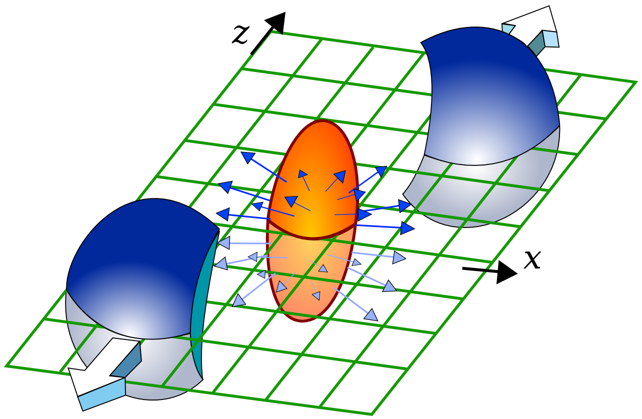
Collective & Penetrating Probes



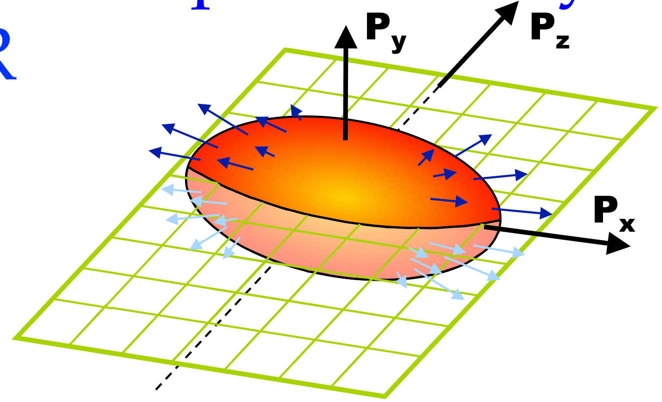
- Collective probes
  - Flow Harmonics, HBT …
- Penetrating probes
  - Nuclear Modification Factor(R_{AA}), two particle correlations at high p_T …

Higher-Order Flow Harmonics

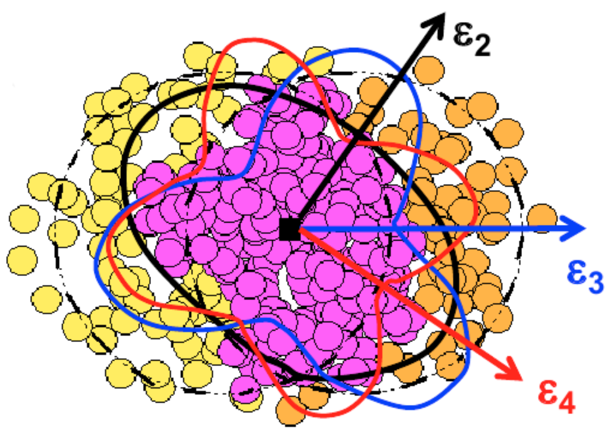
Smooth Geometry



- Pressure Gradient due to smaller mean free path than system size $\lambda << R$



Fluctuating Geometry



- Expansion w.r.t. each Ψ_n

$$E\frac{d^3N}{dp^3} = \frac{d^2N}{2\pi dp_T d\eta}\begin{cases} 1 + \sum 2v_n' \cos n(\phi - \Psi_2) \\ 1 + \sum 2v_n \cos n(\phi - \Psi_n) \end{cases}$$

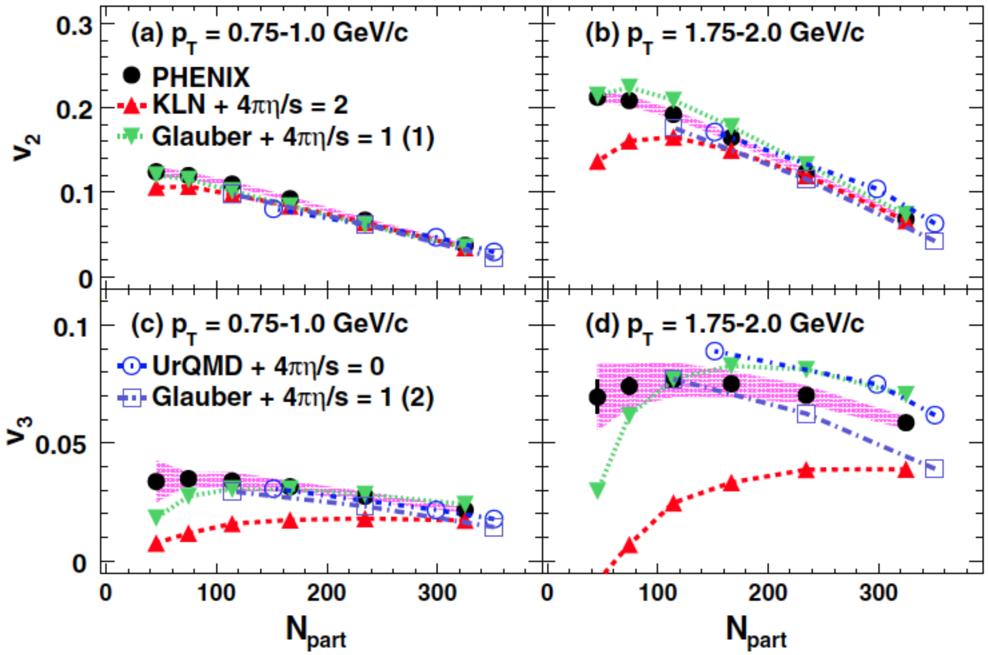
$$v_n =< cos n(\phi - \Psi_n) >$$

ϕ : azimuthal angle of emitted particles

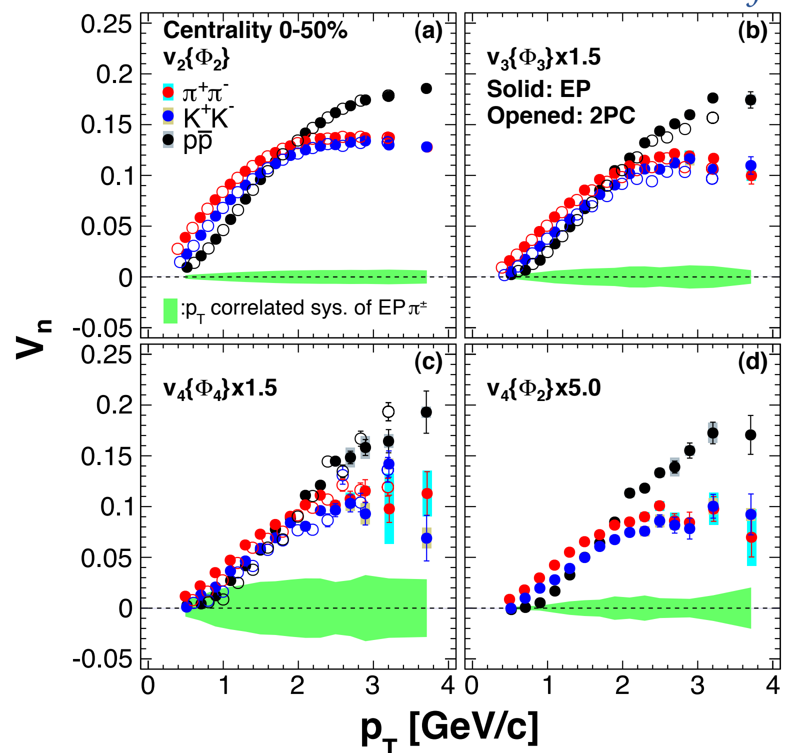
Ψ : azimuthal angle of event plane

Sensitivity to Bulk Property

PRL107.052301



PHENIX Preliminary

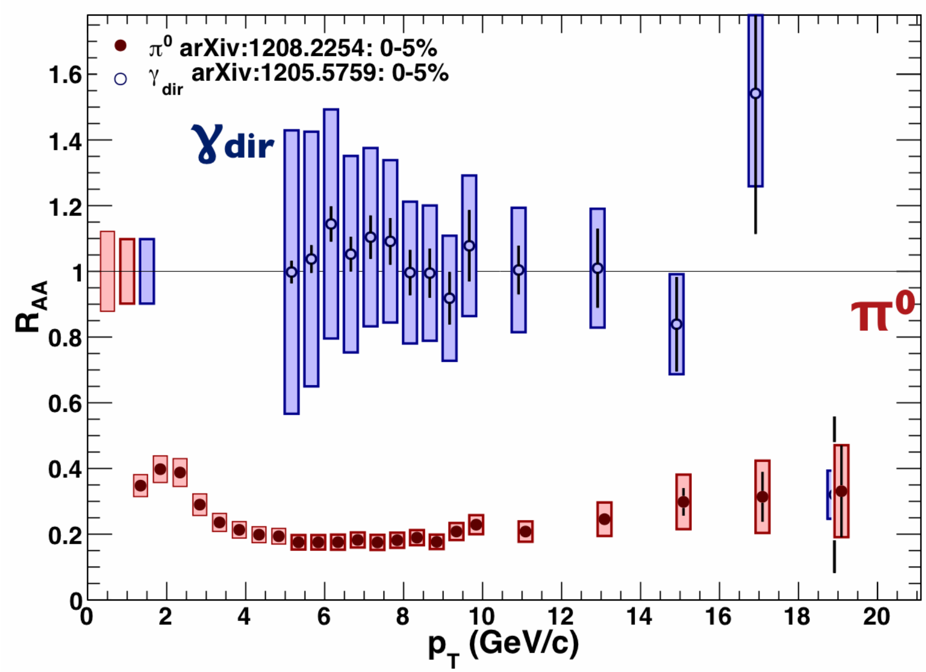


- v_n break the degeneracy among models & give more constraints than v_2
- PID v_n shows mass ordering at low p_T and coalescence like behavior at intermediate p_T

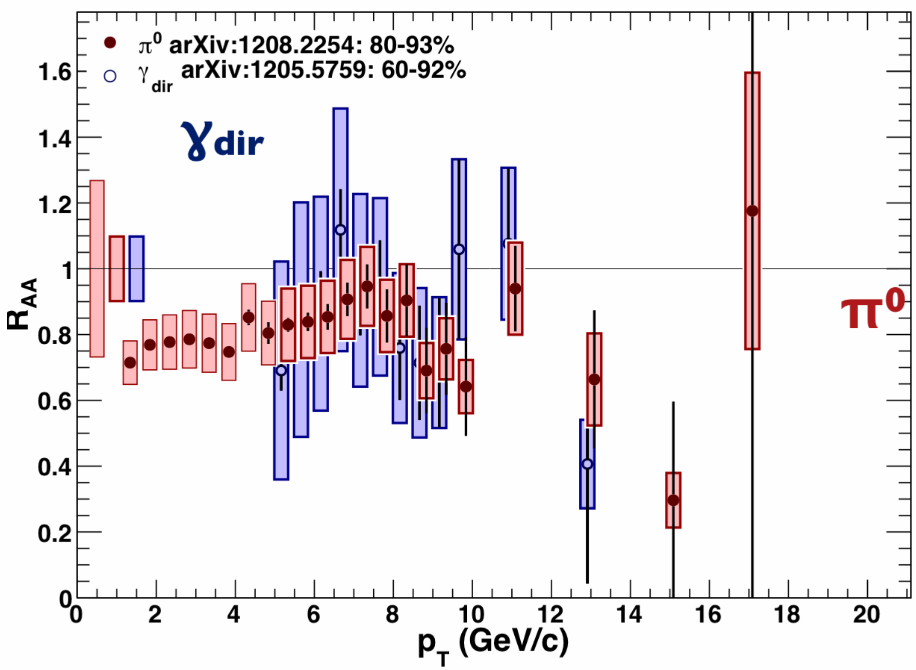
Suppression of Invariant Yield

arXiv: 1208.2254
arXiv: 1205.5759

central Au+Au



peripheral Au+Au

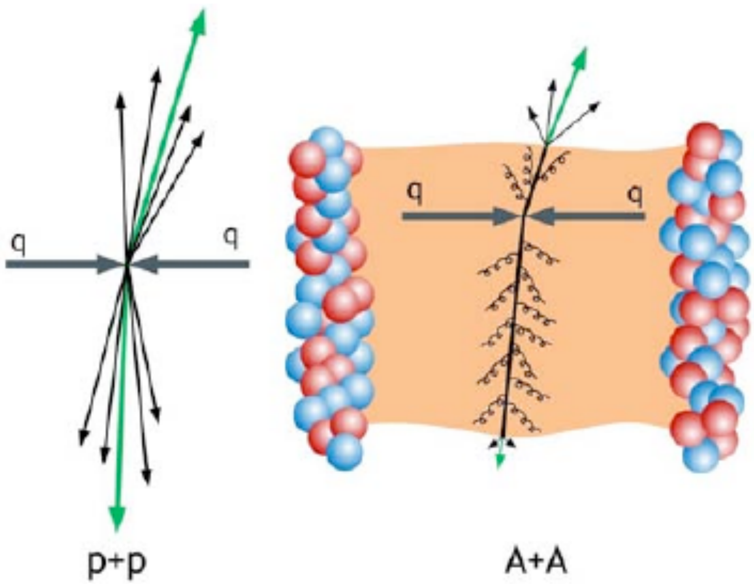


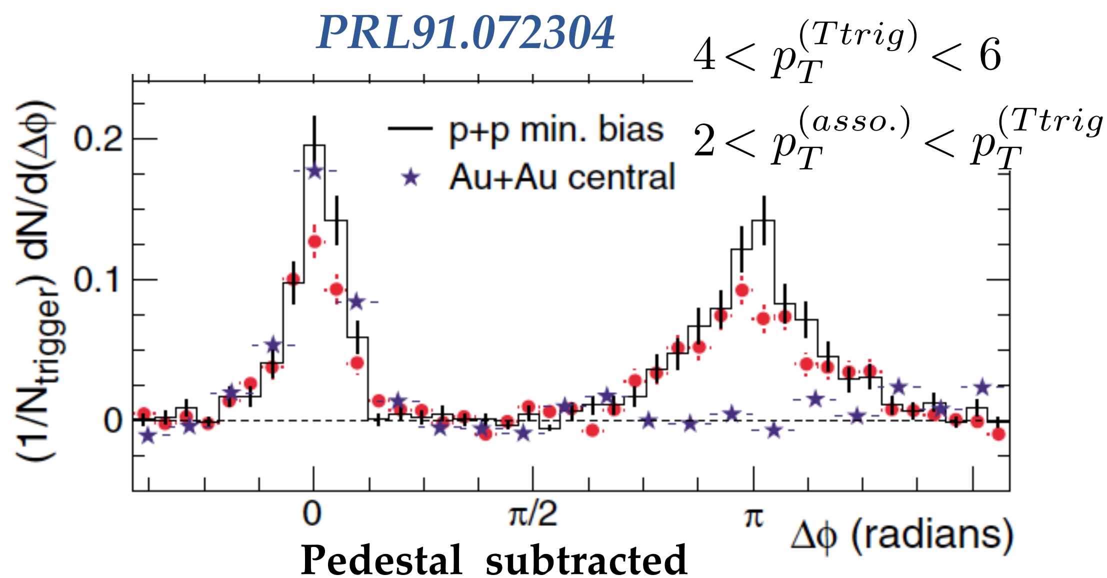
- Hadron suppression in Au+Au
- Stronger in central than peripheral collisions
  - Jet Quenching by Medium at high p_T

$$R_{AA} = \frac{d^2N/dp_T d\eta}{T_{AB} d^2\sigma^{pp}/dp_T d\eta}$$

$$T_{AB} = < N_{col} > /\sigma^{pp}_{inel}$$

Two Particle Correlations





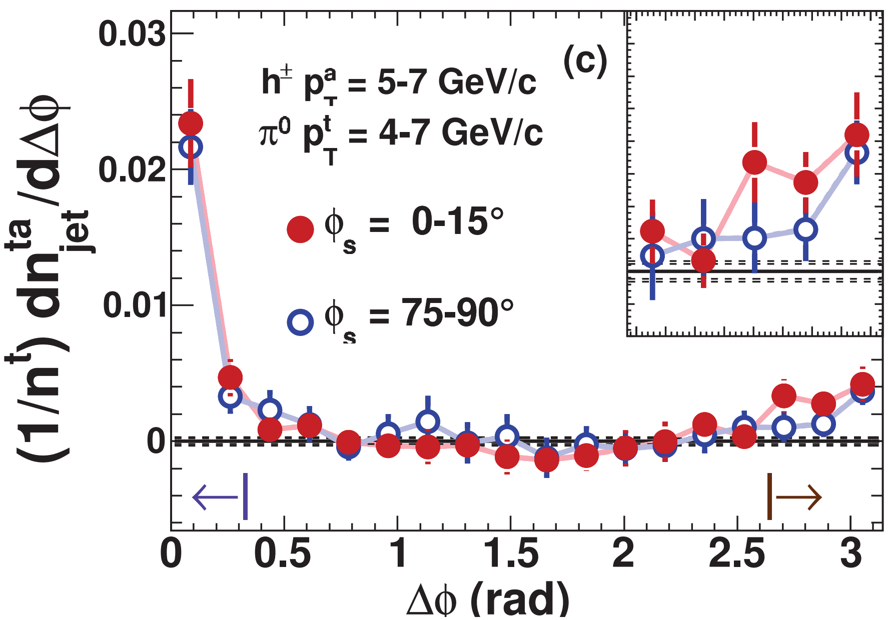
- Can deal with azimuthal differential information
- **Suppression of high p_T correlation yield compared to p+p**
  - Dominated by away side suppression

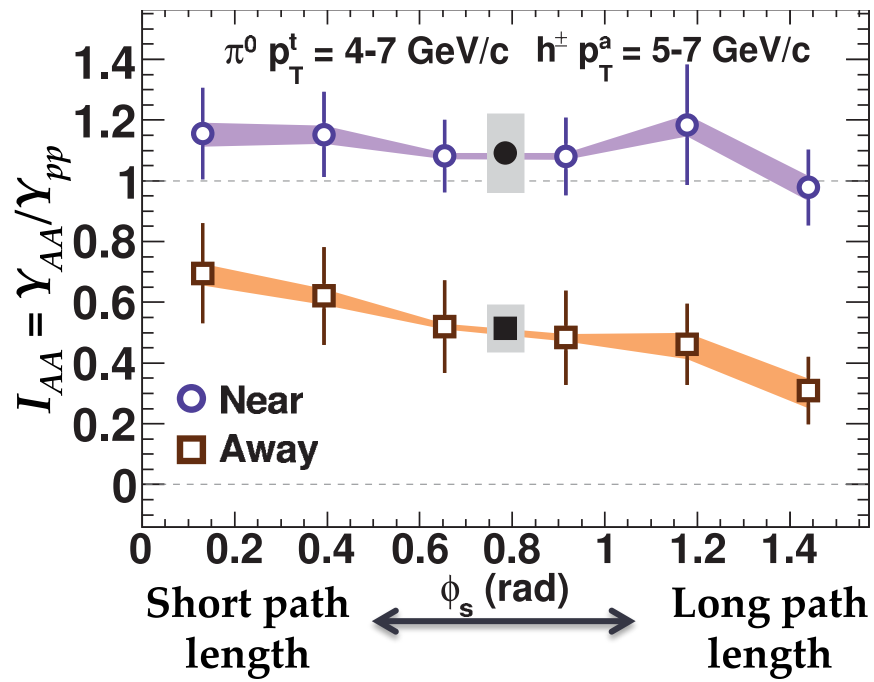
Path Length Dependence

Au+Au 200GeV 20-60%

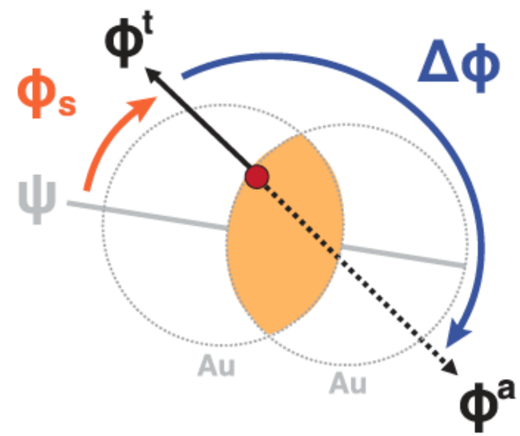
v_2 & $v_4\{\Psi_2\}$ subt.

PRC.84.024904

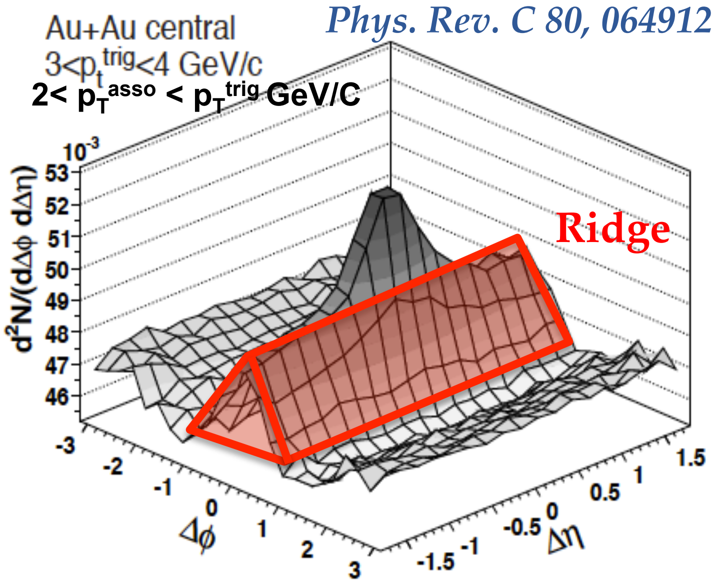


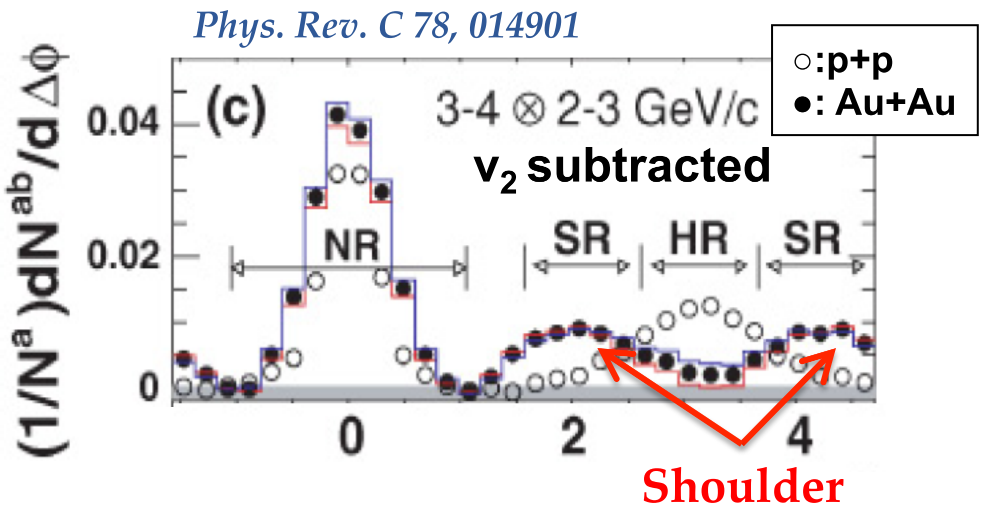


- Controlling path length of partons
- Monotonic suppression of away side yield in high p_T correlations



Characteristic Structures





- **Ridge & Shoulder at low ~ intermediate p_T correlations**
- **Different physics in QGP from high p_T correlations?**
  - Contributions of v_2 and $v_4(\Psi_2)$ are subtracted
  - Contributions from v_n $\sim b_0 2 v_n^{trig} v_n^{asso} \cos n\Delta\phi$
- **Need to consider v_n effects to obtain real correlation shape**

Motivations

Discuss the behavior of low-intermediate p_T partons in QGP medium by measuring two particle correlations with the subtraction of contributions from v_n in \sqrt{s_{NN}} Au+Au 200GeV collisions

- Definitive correlation shape after v_n subtractions
- Trigger angle (Path length) dependence of correlations w.r.t. 2, 3
- Testing sensitivity to each harmonic event plane

My Activity

* Categories of Activity

*Oral (intern.) *Oral (Domestic) *Experimental *Analysis *Service work

M1,2 : 2008~2009

DNP-JPS Joint Meeting

PHENIX Run9 PHENIX Run10

D1 (RIKEN JRA) : 2010

Heavy Ion Pub

preliminary request
Au+Au ridge analysis

D2 (RIKEN JRA) : 2011

JPS Fall

WPCF2011

PHENIX Run12

preliminary request
Au+Au vn-correlation

preliminary request
Au+Au PID vn

D3 (RIKEN JRA) : 2012 ~ Present

JPS Spring

HIC・HIP

Hard Probes2012

Quark Matter2012

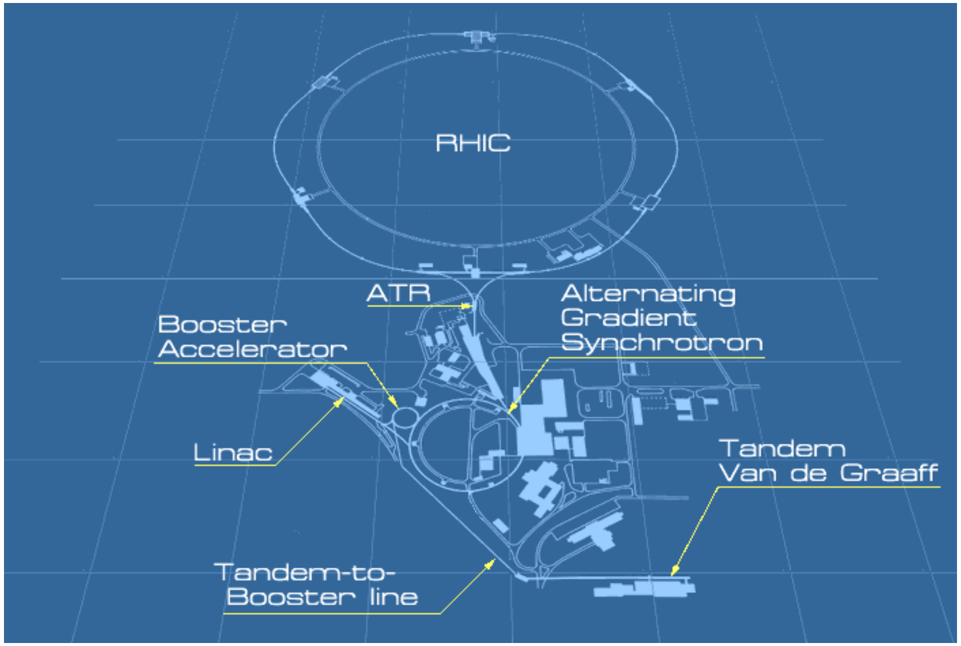
Nagoya-Mini Workhop2012

preliminary request
Au+Au correlations w.r.t. EP

vn EP calibration

Experiment

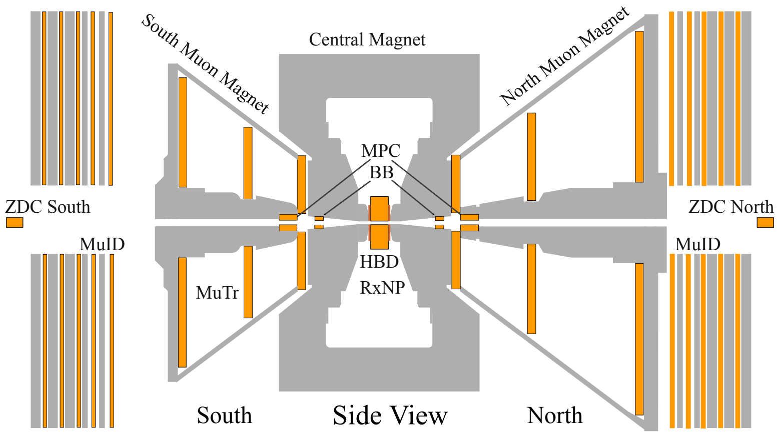
RHIC

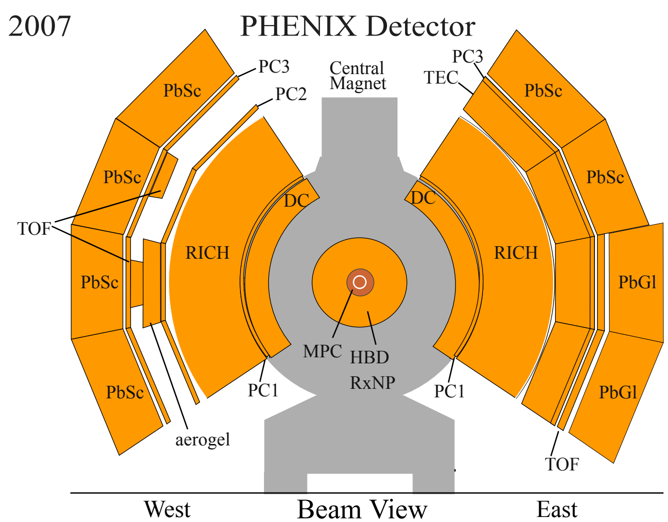


	Year	Species	$\sqrt{s}$ [GeV]	$\int Ldt$	N_{tot} (sampled)	Data Size
Run1	2000	Au - Au	130	1 μb^{-1}	10 M	3 TB
Run2	2001/02	Au - Au	200	24 μb^{-1}	170 M	10 TB
		Au - Au	19		< 1 M	
		p - p	200	0.15 pb^{-1}	3.7 B	20 TB
Run3	2002/03	d - Au	200	2.74 nb^{-1}	5.5 B	46 TB
		p - p	200	0.35 pb^{-1}	6.6 B	35 TB
Run4	2003/04	Au - Au	200	241 μb^{-1}	1.5 B	270 TB
		Au - Au	62.4	9 μb^{-1}	58 M	10 TB
Run5	2005	Cu - Cu	200	3 nb^{-1}	8.6 B	173 TB
		Cu - Cu	62.4	0.19 nb^{-1}	0.4 B	48 TB
		Cu - Cu	22.4	2.7 μb^{-1}	9 M	1 TB
		p - p	200	3.8 pb^{-1}	85 B	262 TB
Run-6	2006	p - p	200	10.7 pb^{-1}	233 B	310 TB
		p - p	62.4	0.1 pb^{-1}	28 B	25 TB
Run-7	2007	Au - Au	200	813 μb^{-1}	5.1 B	650 TB
Run-8	2007/08	d - Au	200	80 nb^{-1}	160 B	437 TB
		p - p	200	5.2 pb^{-1}	115 B	118 TB
		Au - Au	9.2		few k	

- Accelerators
  - Tandem van de Graaff
  - Linear Accelerator
  - Booster Synchrotron
  - Alternating Gradient Synchrotron
  - Relativistic Heavy Ion Collider
- Experiments
  - **PHENIX**
  - STAR
  - PHOBOS
  - BRAHMS

PHENIX Experiment



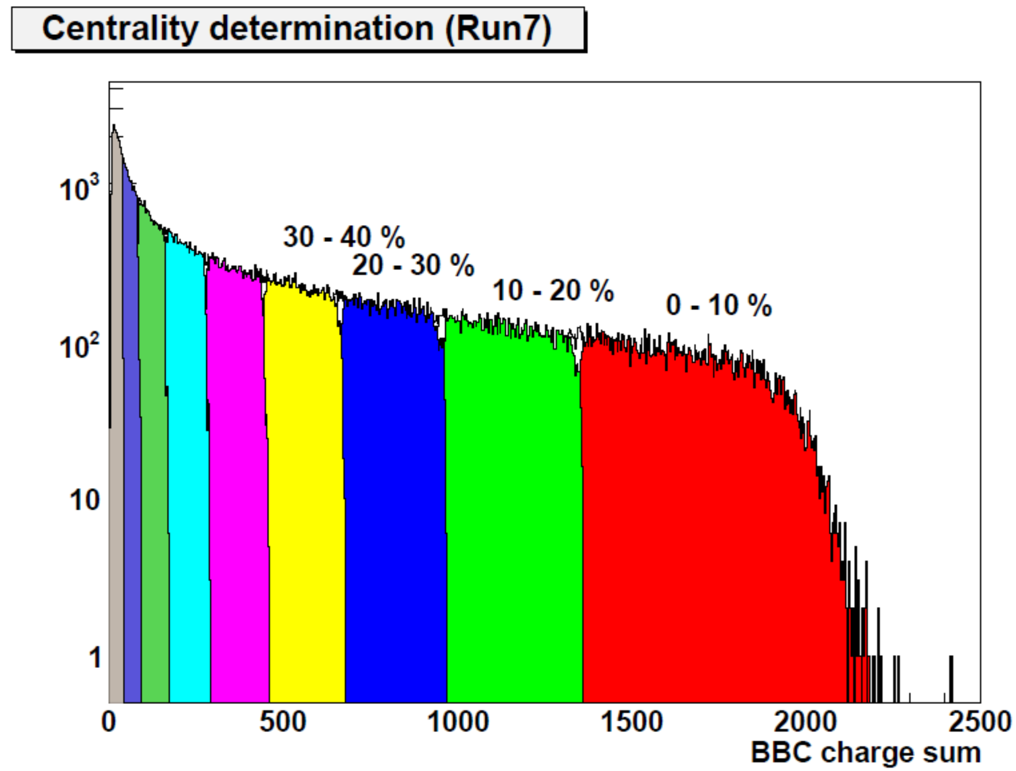


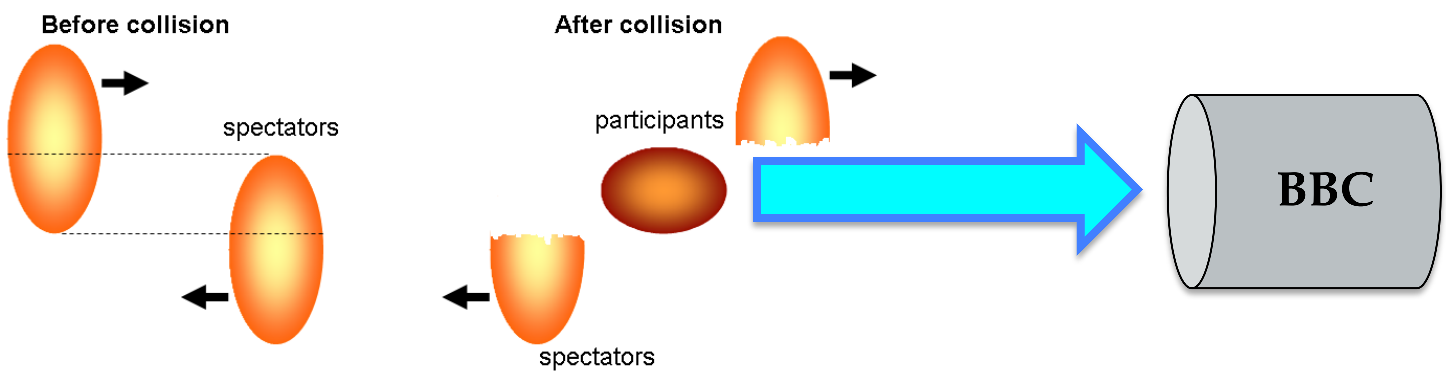
- Global Detectors(Trigger[1], centrality[2], vertex position[3], event plane[4])
  - Beam Beam Counter(BBC)[1,2,3,4] |h|=3~4
  - Zero Degree Counter(ZDC)[1] |h|>5
  - Reaction Plane Detector(RXN)[4] |h|=1-2.8
- Tracking[5] & Momentum[6] at central arm |h|<0.35
  - Drift Chamber (DC)[5,6]
  - Pad Chamber (PC)[5]
  - ElectroMagnetic Calorimeter(EMC)[5]

Analysis

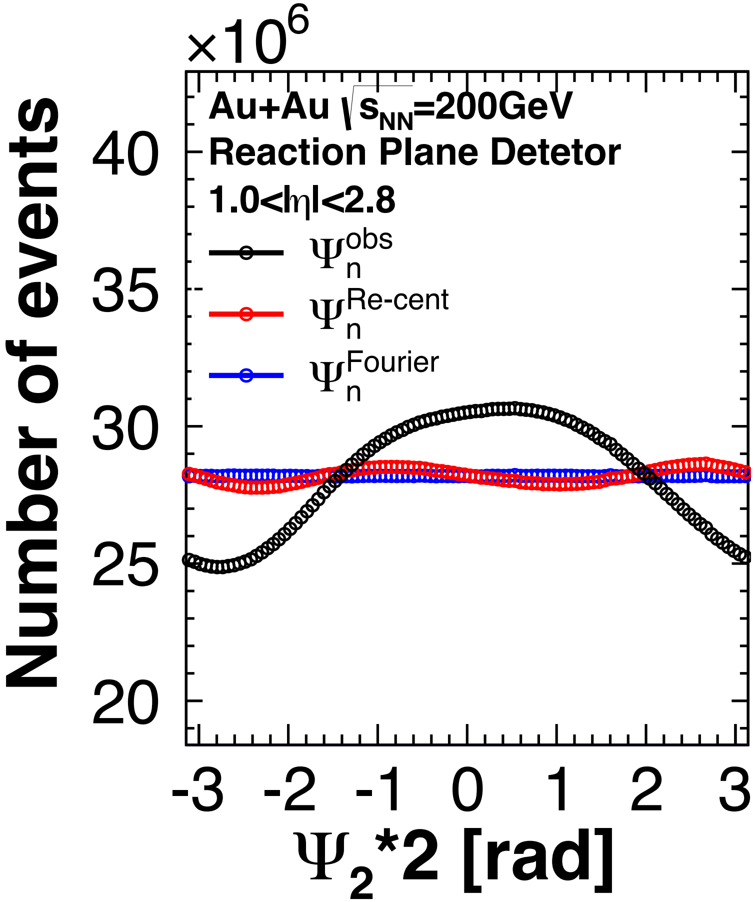
Centrality Calibration

- The centrality is determined using the BBC charge sum.
- Defined in percentile scale to have each bin contains same number of events.





Event Plane (EP) Calibration



Raw distribution

$$\Psi_n = \frac{1}{n}\tan^{-1}\left(\frac{Q_y}{Q_x}\right)$$

$$Q_x = \frac{\sum_i w_i \cos(n\phi_i)}{\sum_i w_i}, Q_y = \frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i}$$

Re-centering

$$\Psi_n^{Rec} = \frac{1}{n}\tan^{-1}\left(\frac{Q_y^{Rec}}{Q_x^{Rec}}\right)$$

$$Q_x^{Rec} = \frac{Q_x - \langle Q_x\rangle}{\sigma_x}, Q_y^{Rec} = \frac{Q_y - \langle Q_y\rangle}{\sigma_y}$$

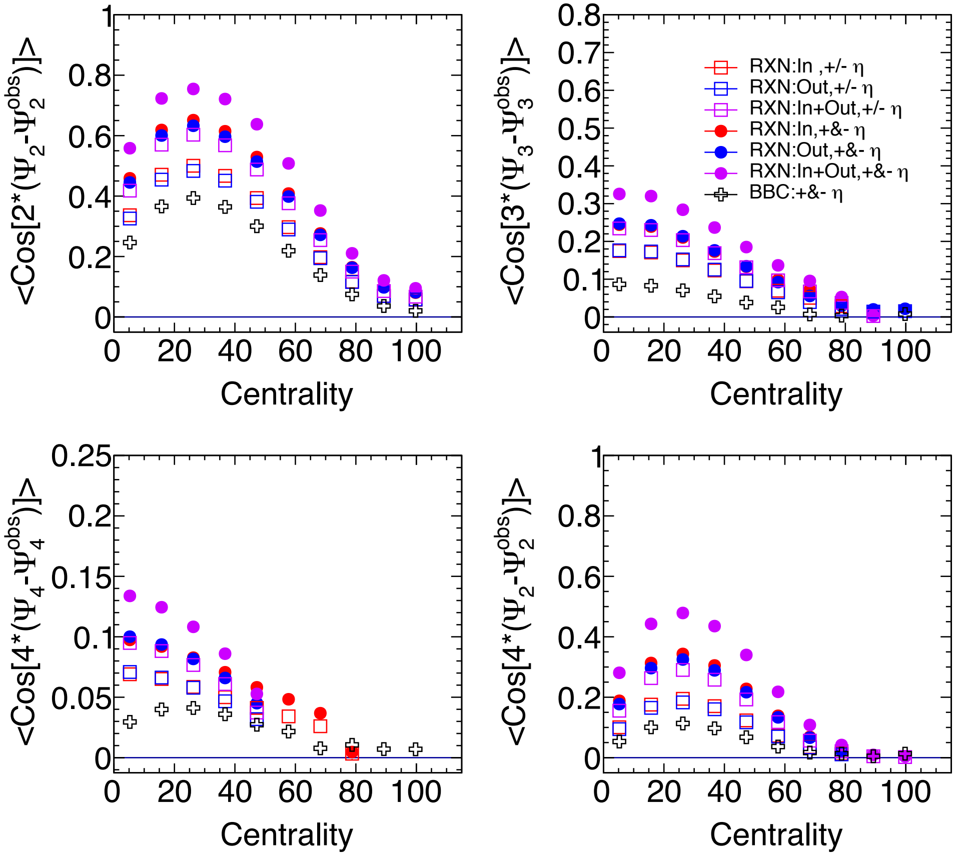
Fourier correction

$$n\Psi_n^{Fourier} = n\Psi_n^{Rec} + n\Delta\Psi_n$$

$$n\Delta\Psi_n = \sum_k \left\{A_k \cos\left(kn\Psi_n^{Rec}\right) + B_k \sin\left(kn\Psi_n^{Rec}\right)\right\}$$

$$A_k = -\frac{2}{k}\left\langle\cos\left(kn\Psi_n^{Rec}\right)\right\rangle, B_k = \frac{2}{k}\left\langle\sin\left(kn\Psi_n^{Rec}\right)\right\rangle$$

EP Resolution & Flow



EP Resolution

$$\sigma_n^{EP} = \left\langle \cos kn(\Psi_n^{EP\pm\eta} - \Psi_n) \right\rangle$$ *Phys. Rev. C 58, 1671*

$$= \sqrt{\left\langle \cos kn(\Psi_n^{EP(+\eta)} - \Psi_n^{EP(-\eta)}) \right\rangle}$$

$$= \frac{\pi}{8}\chi_n^2 \left[I_{(k-1)/2}\left(\frac{\chi_n^2}{4}\right) + I_{(k+1)/2}\left(\frac{\chi_n^2}{4}\right) \right]^2$$

- **Flow measurements & correction**

$$v_n = \frac{v_n^{obs}}{\sigma_n^{EP}} = \frac{\left\langle \cos n(\phi - \Psi_n^{EP}) \right\rangle}{\left\langle \cos n(\Psi_n^{EP} - \Psi_n) \right\rangle}$$

Two Particle Correlations

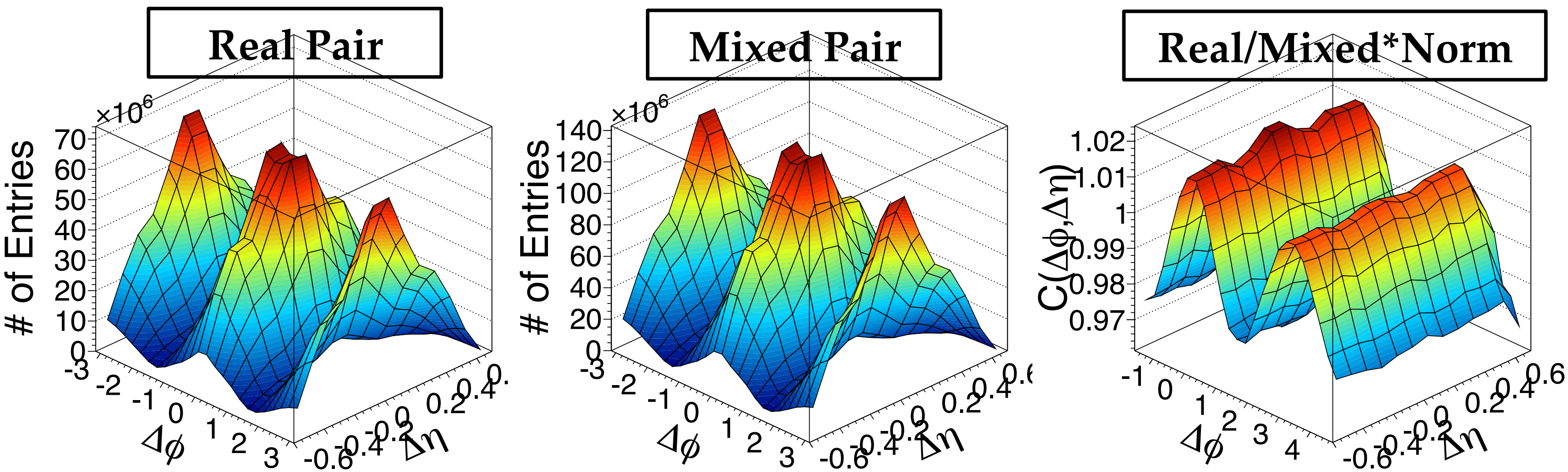
- Correlation function
  - Ratio of two-particle probability distribution over single one
  - Ratio of real pair(w/ physics corre.) over mixed pair(wo/ physics corre.)

$$C(\Delta\phi, \Delta\eta) \equiv \frac{P(\phi^t, \phi^a, \eta^t \eta^a)}{P(\phi^t, \eta^t) P(\phi^a, \eta^a)}$$

$$= \frac{N_{mixed}}{N_{real}} \cdot \frac{d^2 N_{real}/d\Delta\phi d\Delta\eta}{d^2 N_{mixed}/d\Delta\phi d\eta}$$

$$\Delta\phi = \phi^a - \phi^t,$$

$$\Delta\eta = \eta^a - \eta^t$$

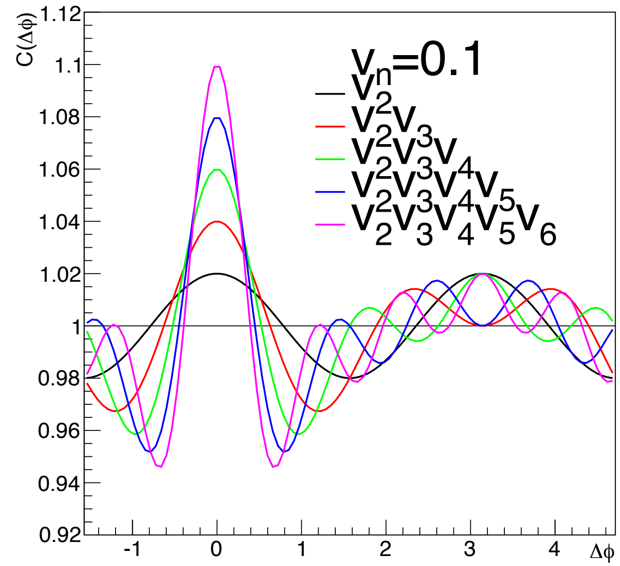


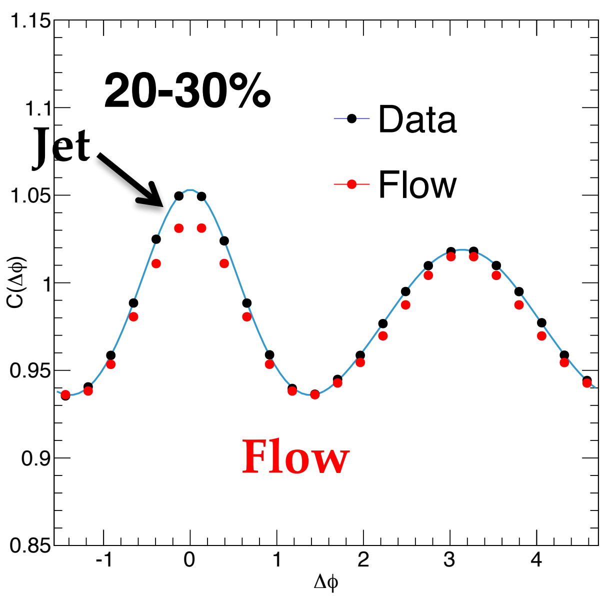
Flow Contributions

- **Pure flow correlations**

$$F(\Delta\phi) = 1 + \sum 2V_{\Delta n} \cos(n\Delta\phi)$$
$$= 1 + \sum 2v_n^t v_n^a \cos(n\Delta\phi)$$

$$V_{\Delta n} = \langle \cos n\Delta\phi \rangle$$
$$= \langle \cos n(\phi^t - \Psi_n) \rangle \langle \cos n(\phi^a - \Psi_n) \rangle$$
$$= v_n^t v_n^a$$





- **Flow subtractions**
  - Zero Yield at Minimum Assumption

$$j(\Delta\phi) = C(\Delta\phi) - b_0 \left[1 + \sum_{n=1} 2v_n^t v_n^a \cos(n\Delta\phi) \right]$$

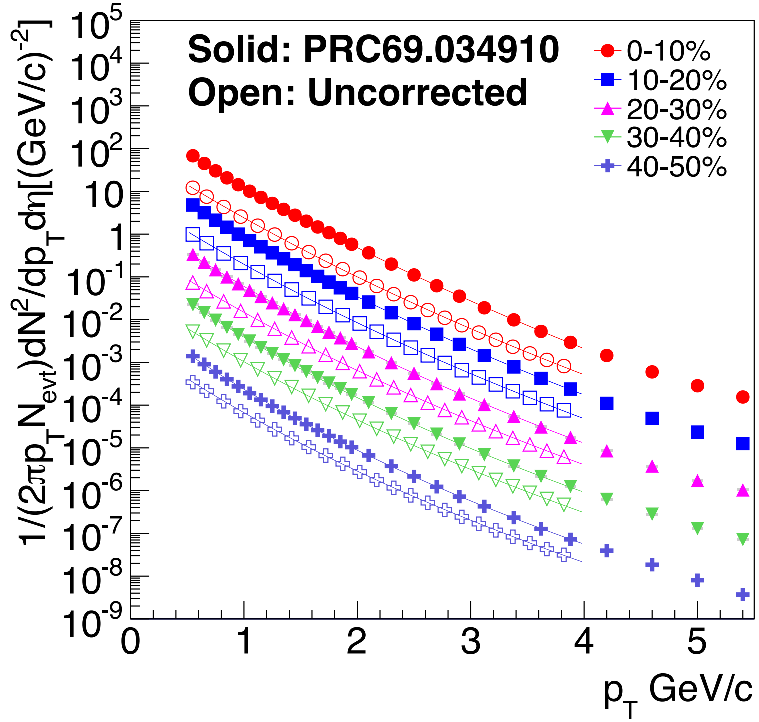
Pair Yield per a Trigger

- **Pair Yield per a trigger**

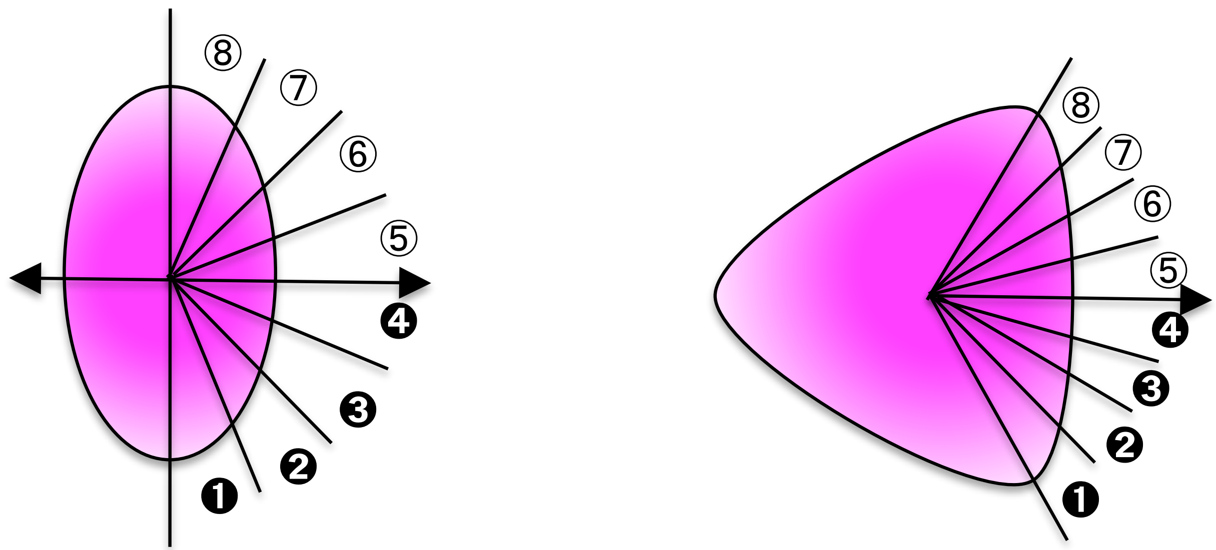
$$\frac{1}{N^t}\frac{dN^{ta}}{d\Delta\phi} = \frac{1}{2\pi\varepsilon}\frac{N^{ta}}{N^t}j(\Delta\phi)$$

  - Scaled to single particle cross section at associate p_T

$$\varepsilon = \frac{\sigma^{uncor}}{\sigma^{cor}}$$

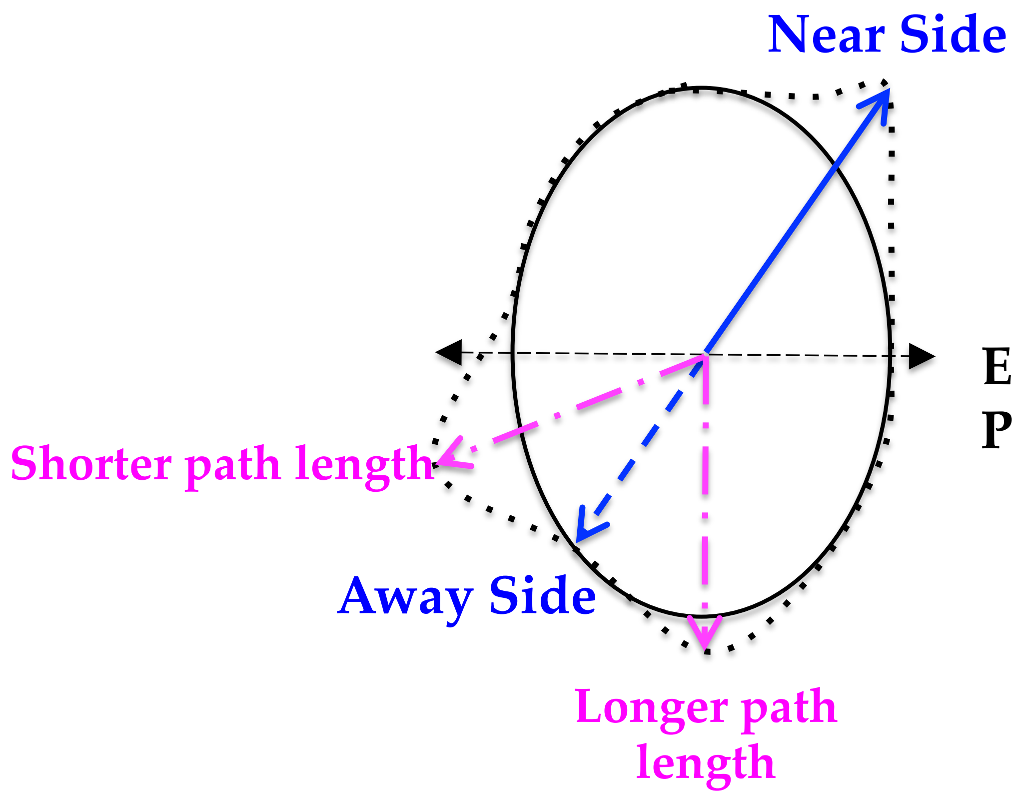


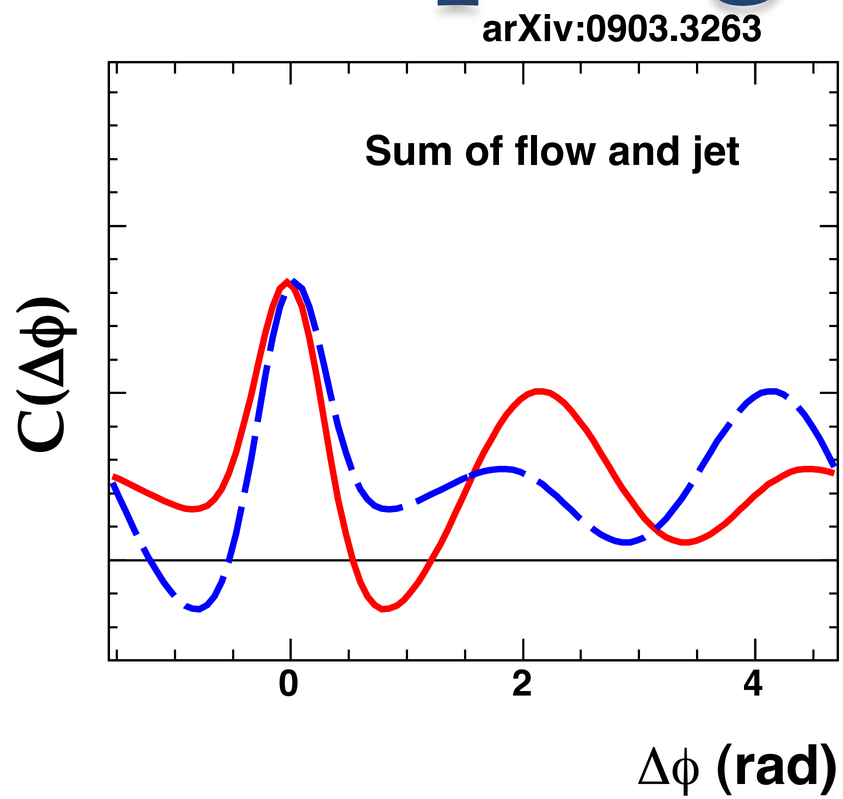
EP Dependent Correlations



- Selecting trigger particle w.r.t. Ψ_2 & Ψ_3
- **Controlling path length parton propagates**
- **Testing sensitivity to each harmonic plane**
  - correlation shape, yields in near/away etc.

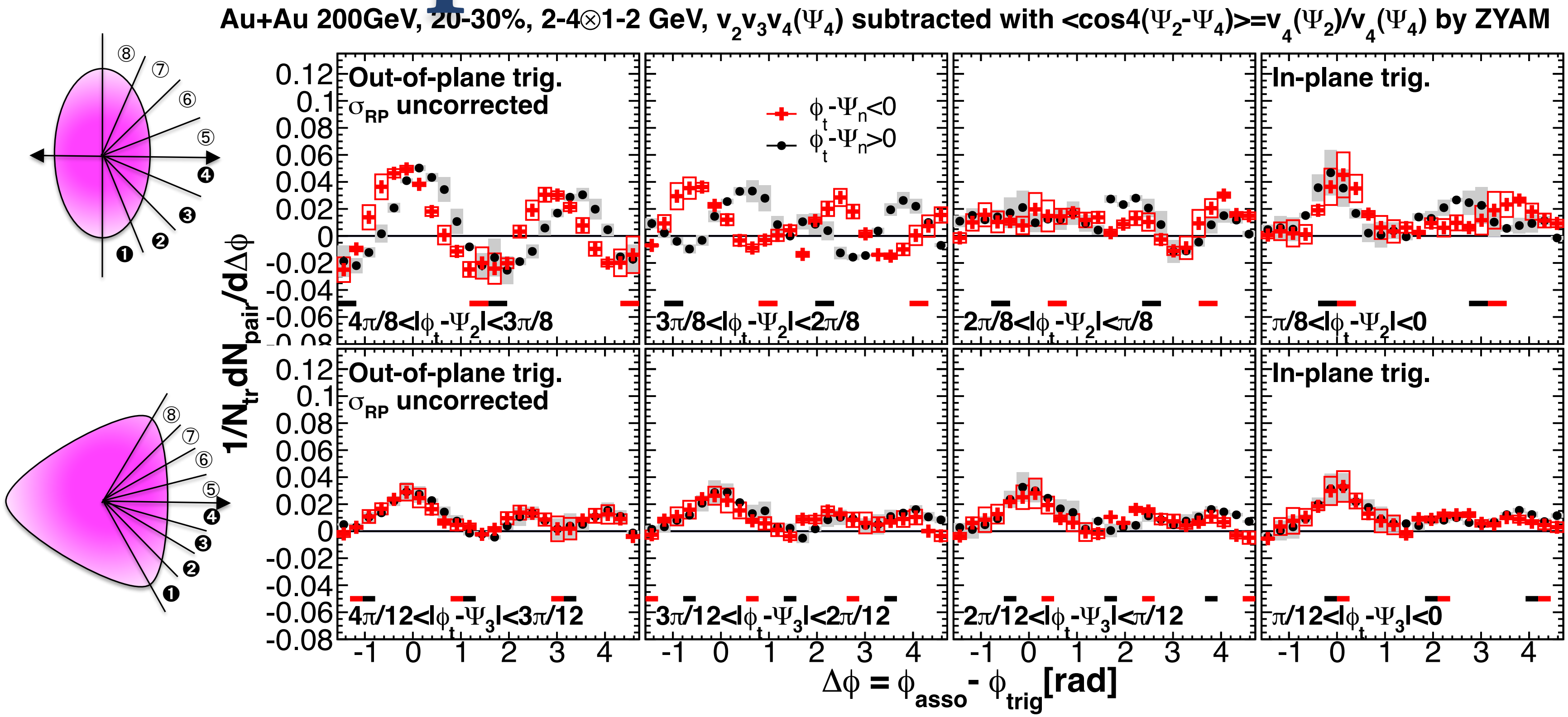
Parton - Medium Coupling





- Left/Right trigger selection relative to event plane results in non-uniform path length at away-side
- Modification expected in away-side as Left/Right asymmetry

EP Dependent Correlations



- Left/Right Asymmetry observed in Ψ_2 & Ψ_3
  - Consistent within systematics in Ψ_3
- Have sensitivity to event plane, but smeared by limited event plane resolution

Unfolding of EP Resolution

Ψ_2 dependent case

Based on PRC84.024904

$$\lambda + Y^{cor}(\phi_s, \Delta\phi) = \frac{\lambda + b_0\left[1 + 2v_2^Y/\sigma\cos 2(\phi_s+\Delta\phi) + 2v_4^Y/\sigma_{42}\cos 4(\phi_s+\Delta\phi)\right]}{\lambda + b_0\left[1 + 2v_2^Y\cos 2(\phi_s+\Delta\phi) + 2v_4^Y\cos 4(\phi_s+\Delta\phi)\right]}(\lambda + Y(\phi_s, \Delta\phi))$$

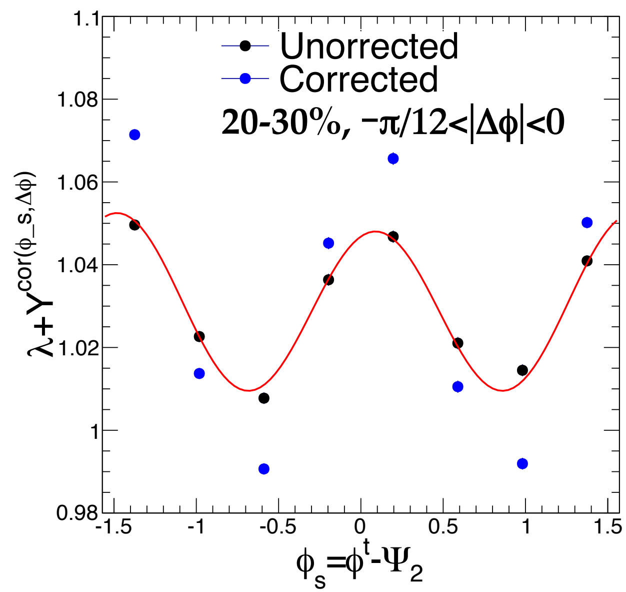
Fitting

Ψ_3 dependent case

$$\lambda + Y^{cor}(\phi_s, \Delta\phi) = \frac{\lambda + b_0\left[1 + 2v_3^Y/\sigma_3\cos 3(\phi_s+\Delta\phi)\right]}{\lambda + b_0\left[1 + 2v_3^Y\cos 3(\phi_s+\Delta\phi)\right]}(\lambda + Y(\phi_s, \Delta\phi))$$

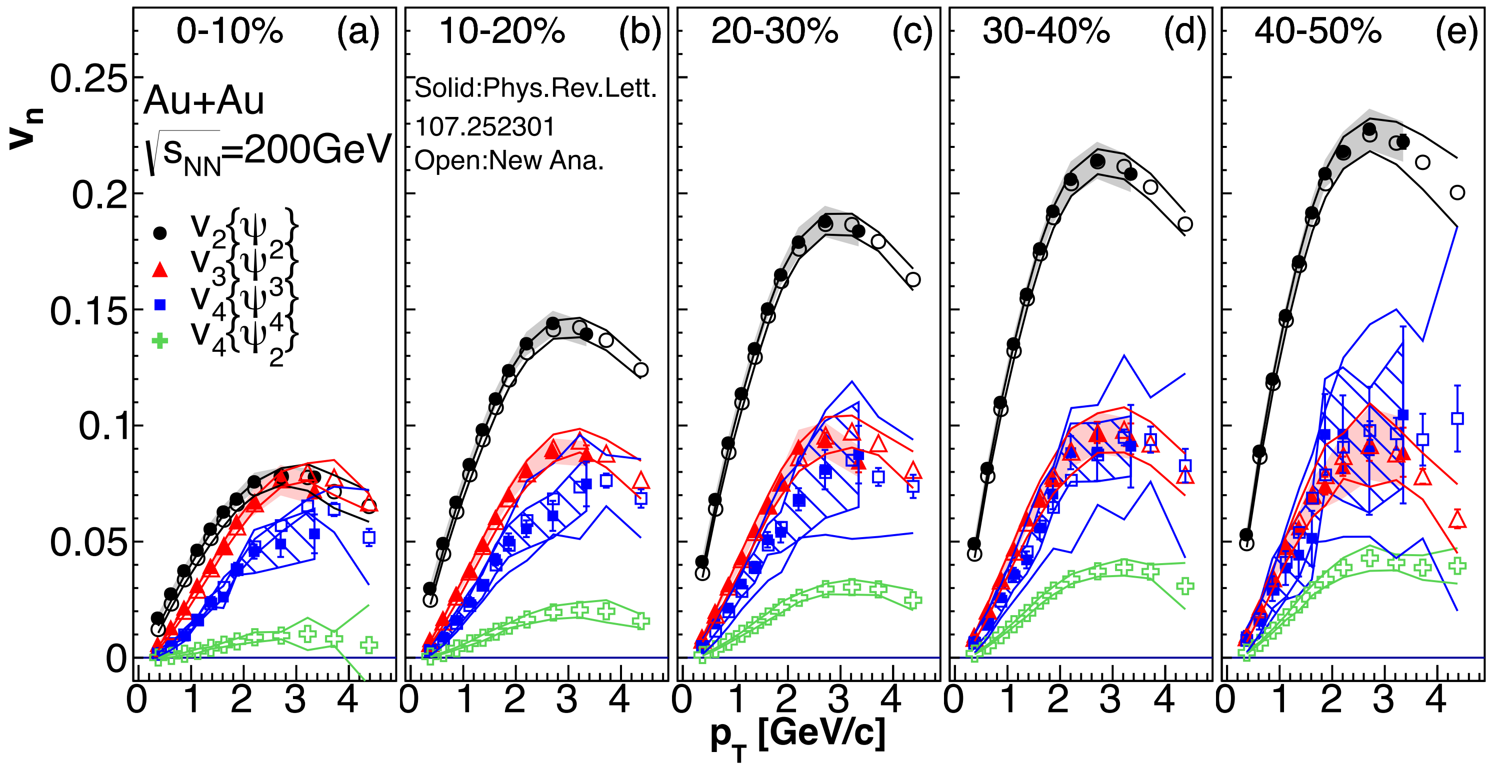
Fitting

- **Unfolding using Fourier Series**
  - Assuming effect by jet depends on trigger angle relative to EP and parameterized by Fourier series
  - Correction by EP resolution
  - Add offset λ=1.0 to avoid possible division by zero



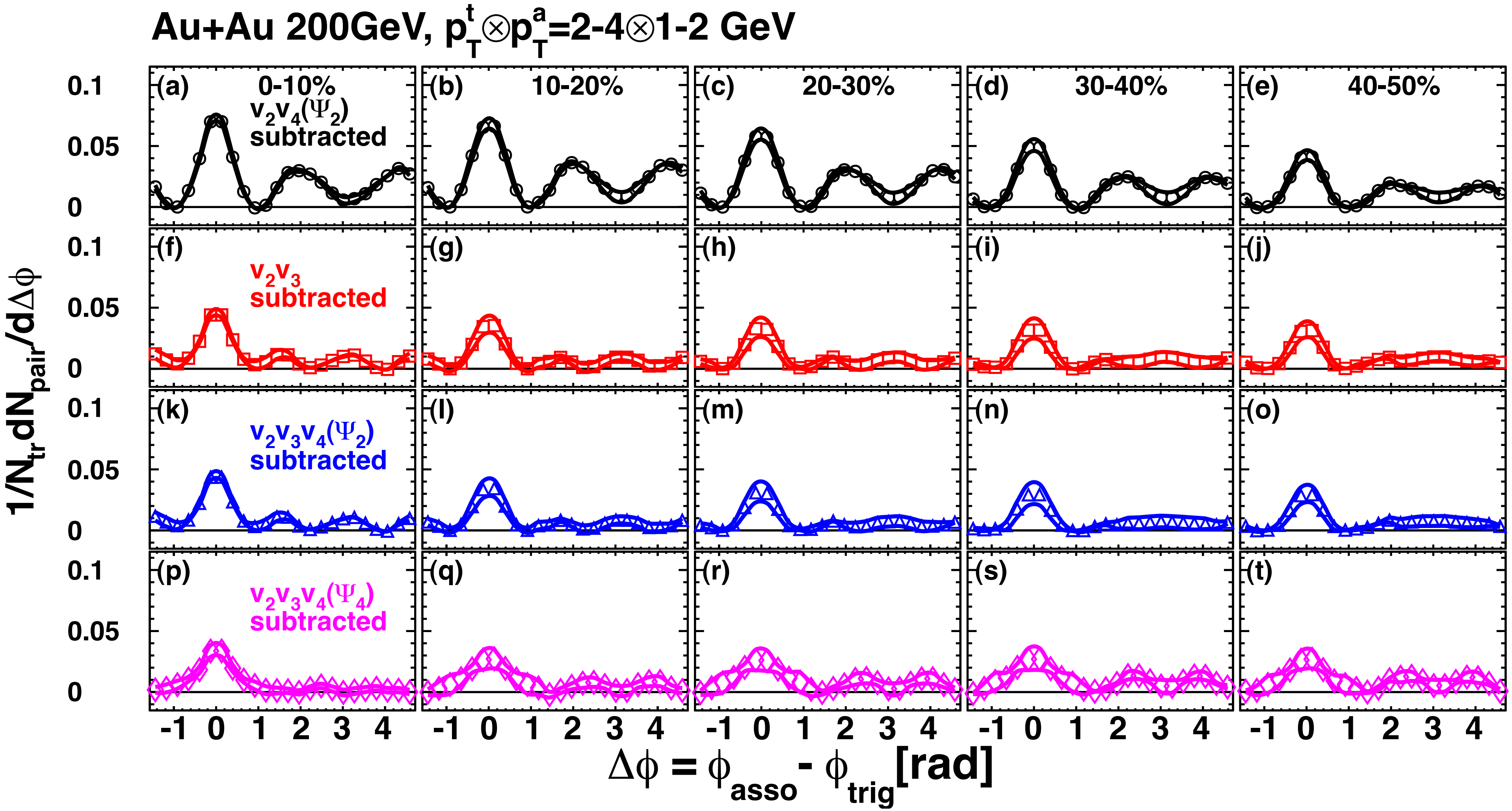
Results & Discussion

v_n as function of p_T

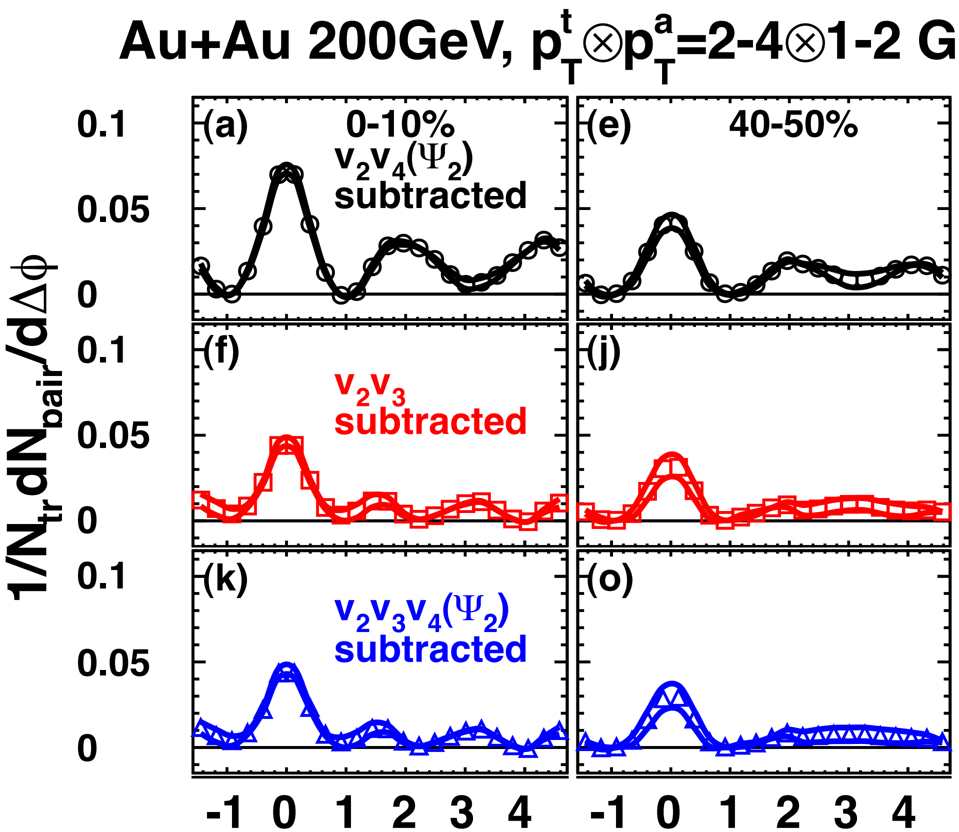


- v_2 & v_3 extended up to p_T=5GeV/c
- v_4 has larger systematics due to RXN-BBC difference

v_n subtracted to correlations

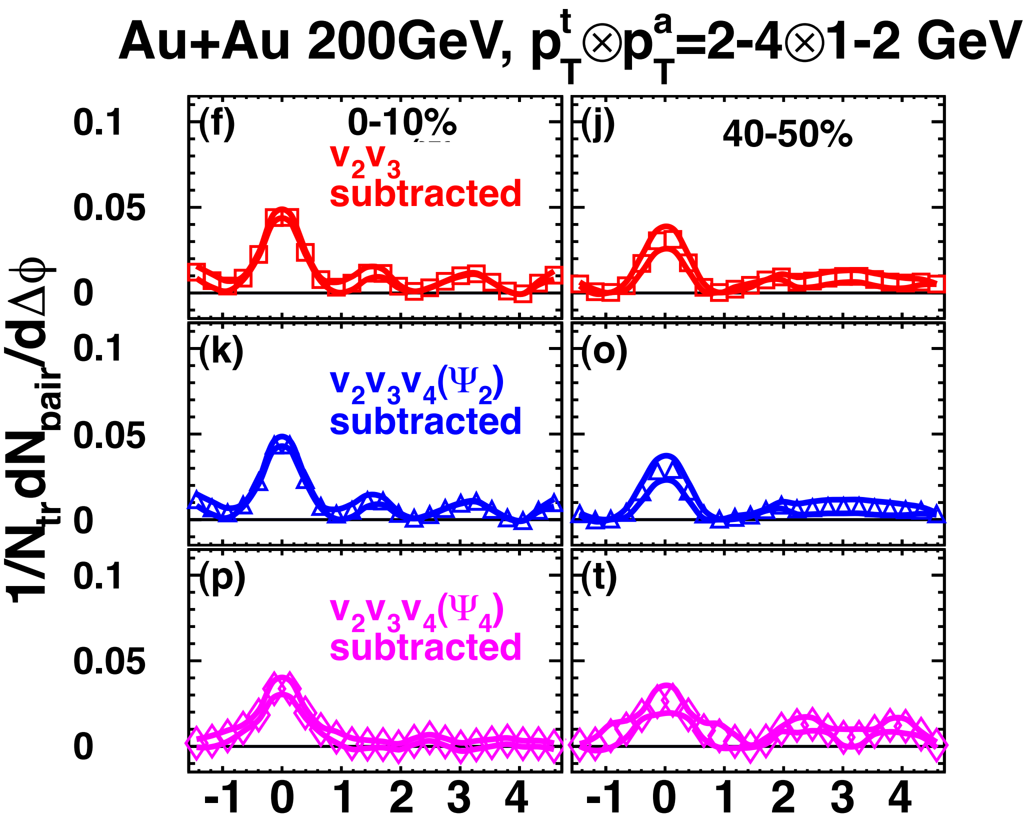


Impact of v_3 to correlations



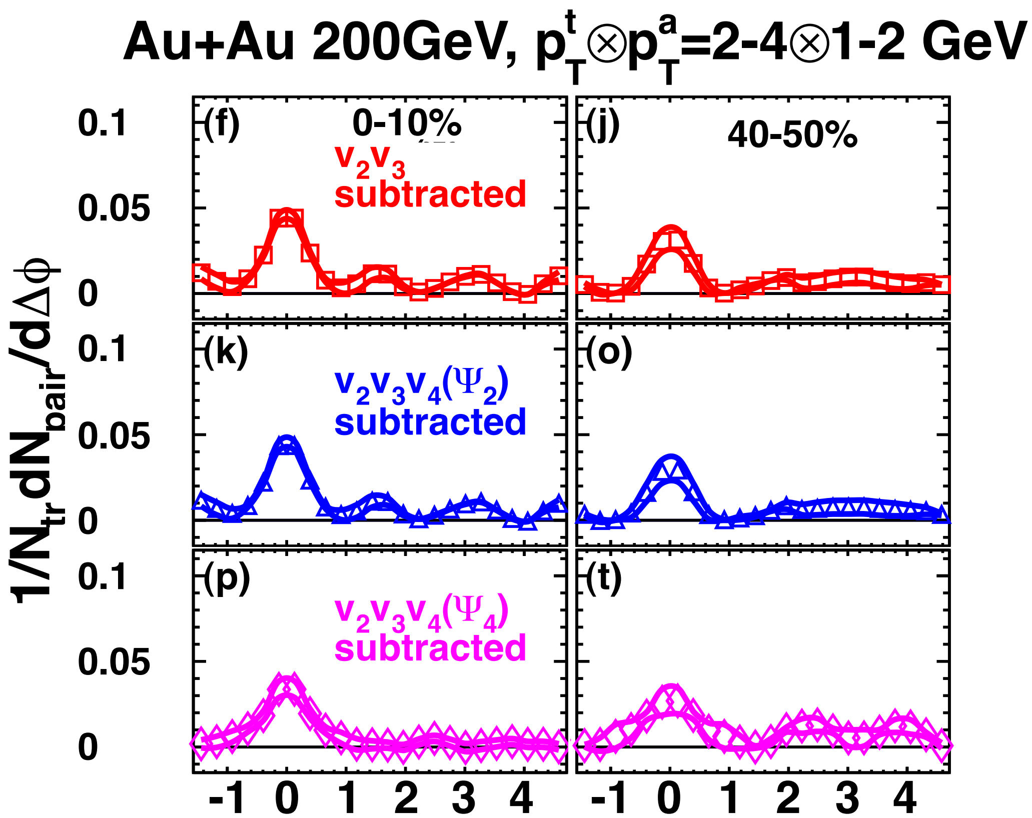
- v_3 subtraction largely reduce the away side double hump structure
- 0-10% a little remaining
- 40-50 almost vanished

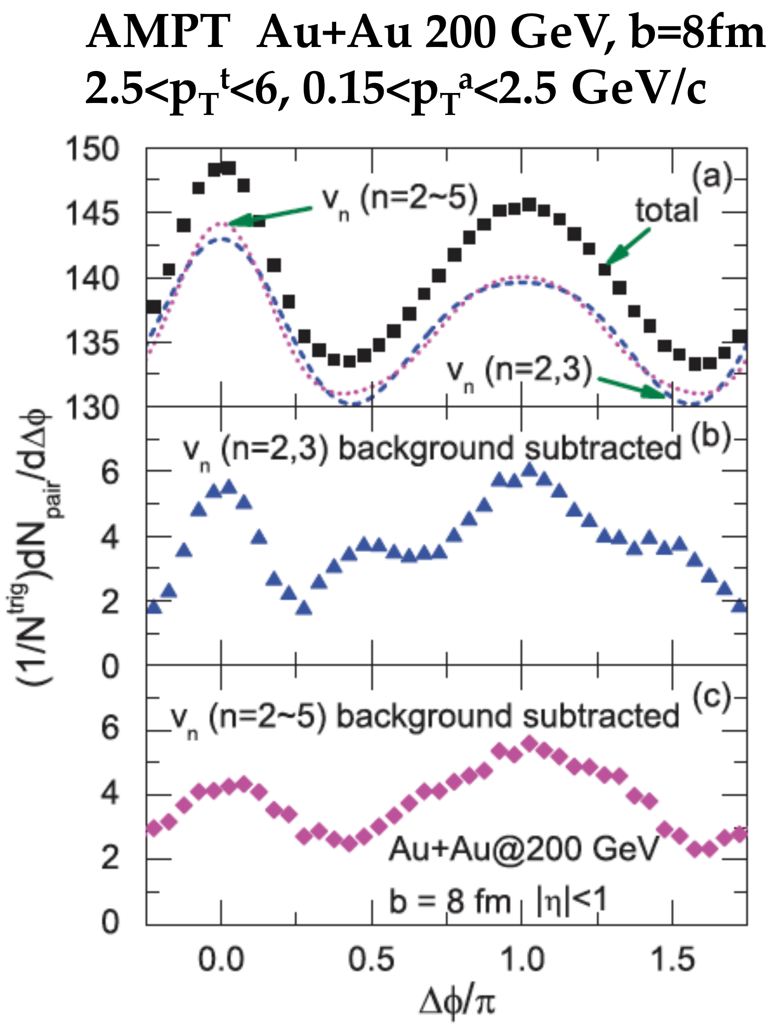
Impact of v_4 to correlations



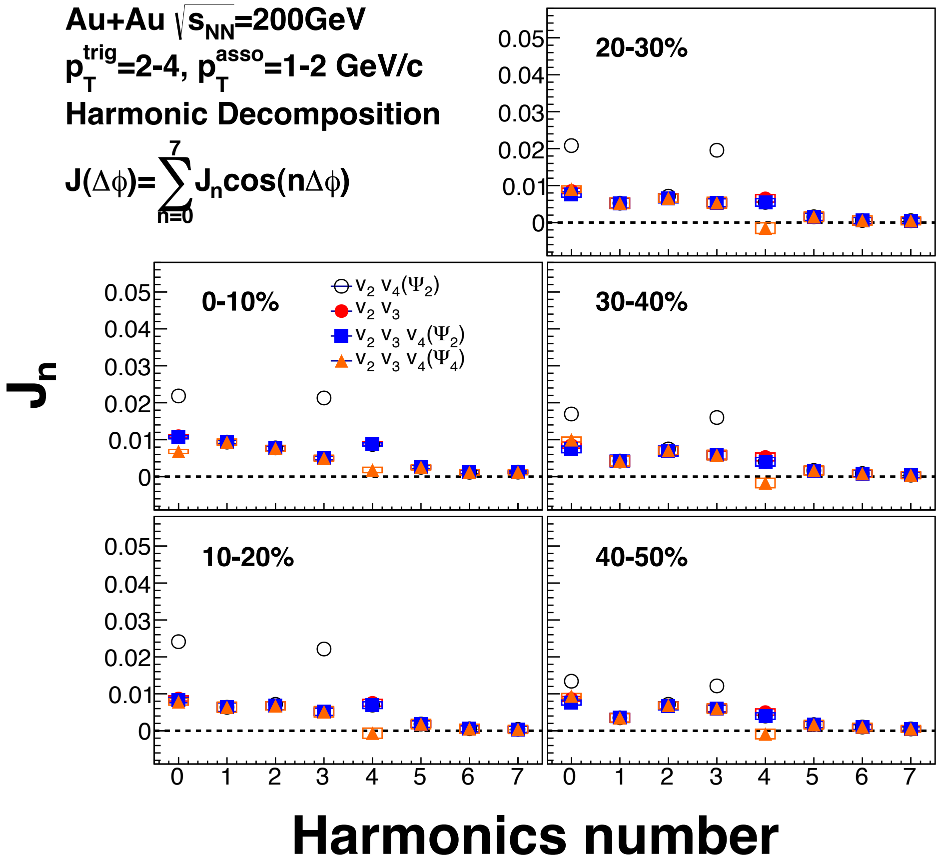
- But treatment of v_4 on away side shape
- $v_4(\Psi_2)$ doesn't change
- Again $v_4(\Psi_4)$ disturbs away side in 40-50%

Comparison with AMPT



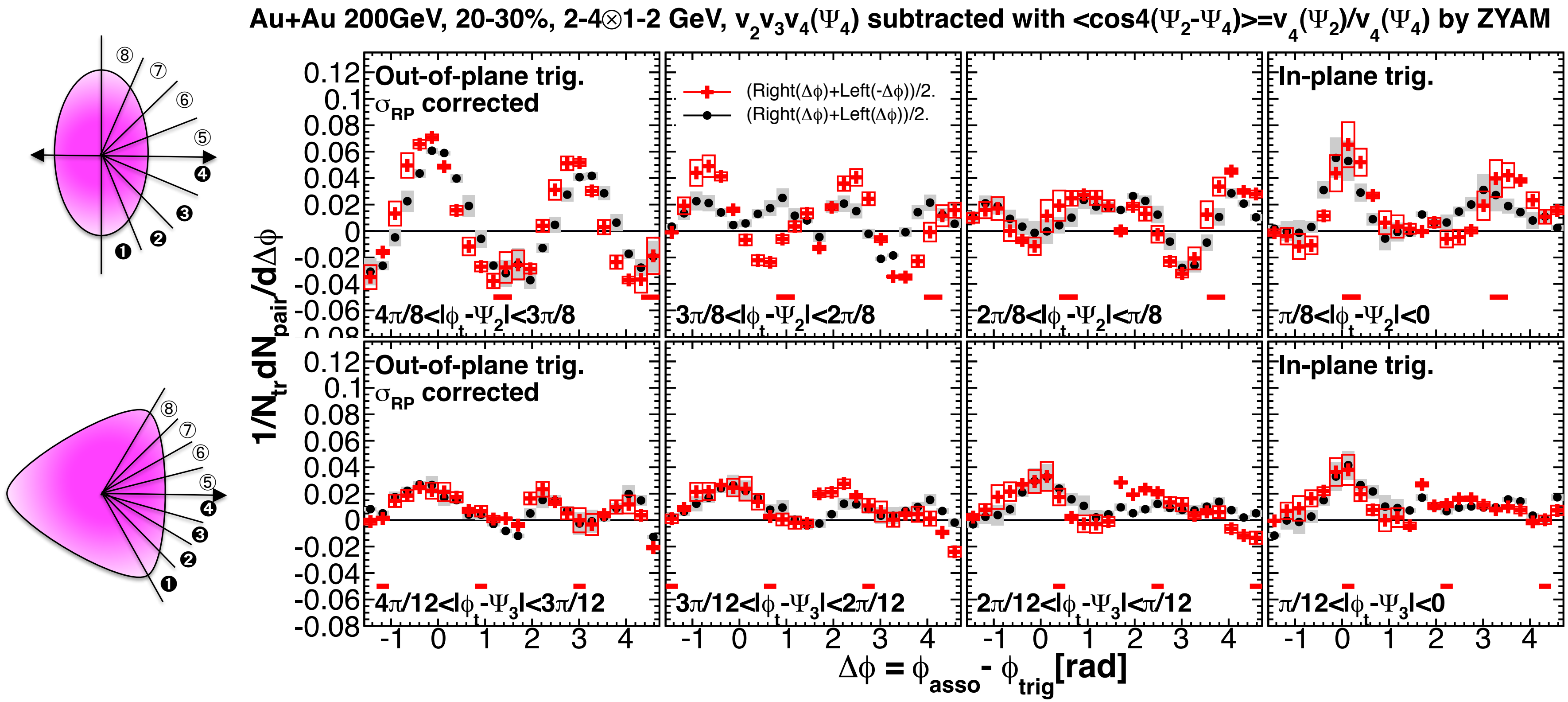


Fourier Decomposition



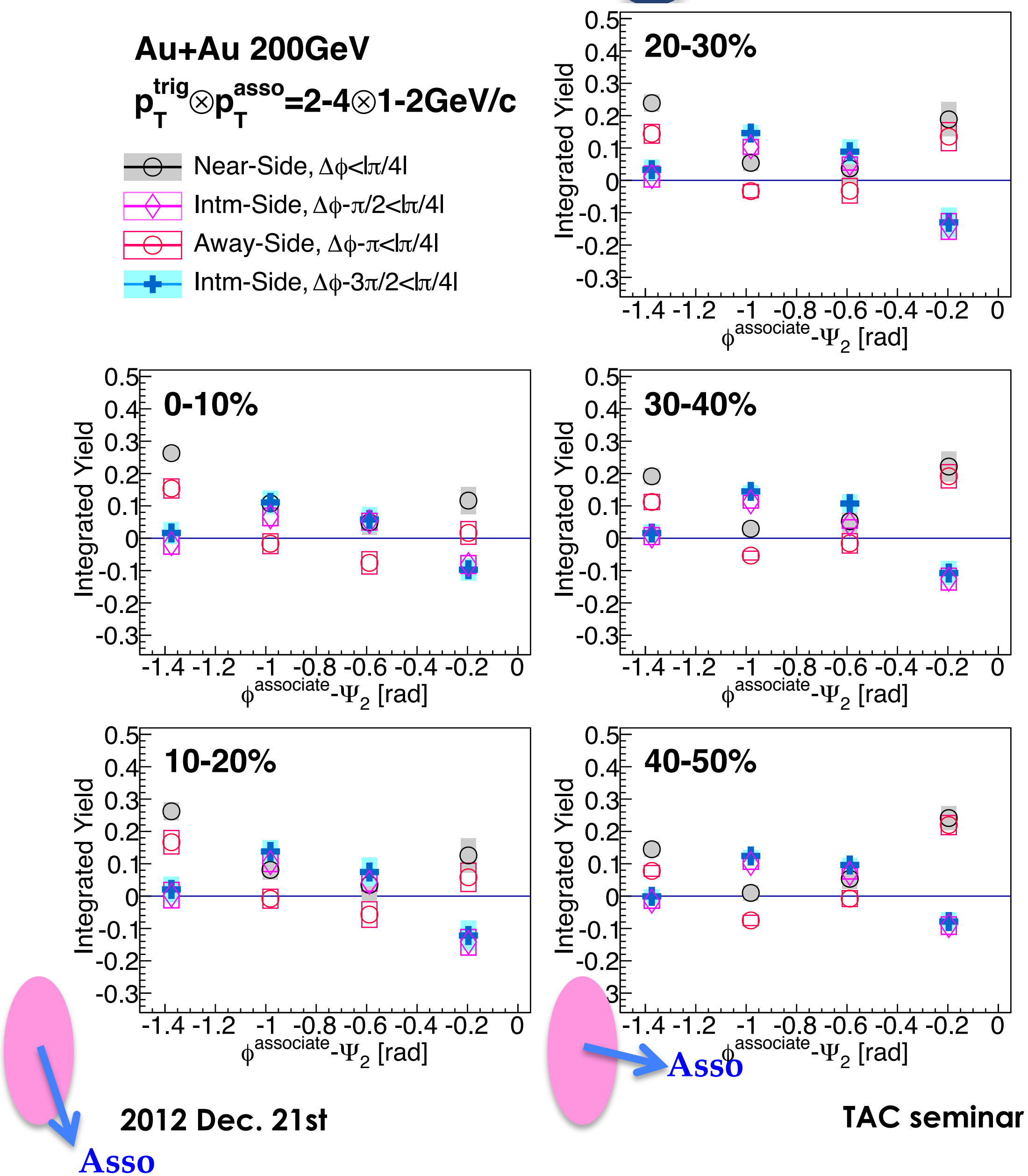
- Fourier decomposition of v_n subtracted correlations
  - 3rd harmonics survives
  - Balance between 3rd & 4th determines the away side

EP Dependent Correlations

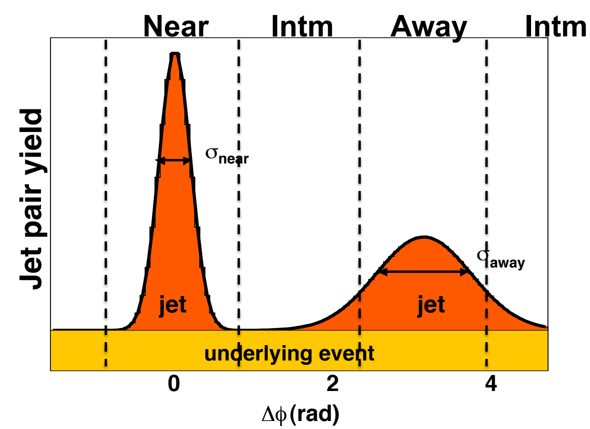


- None-trivial shape at intermediate plane of Ψ_2
  - Comparable yield in in-plane & out-of-plane of Ψ_2
- None clear Ψ_3 dependence

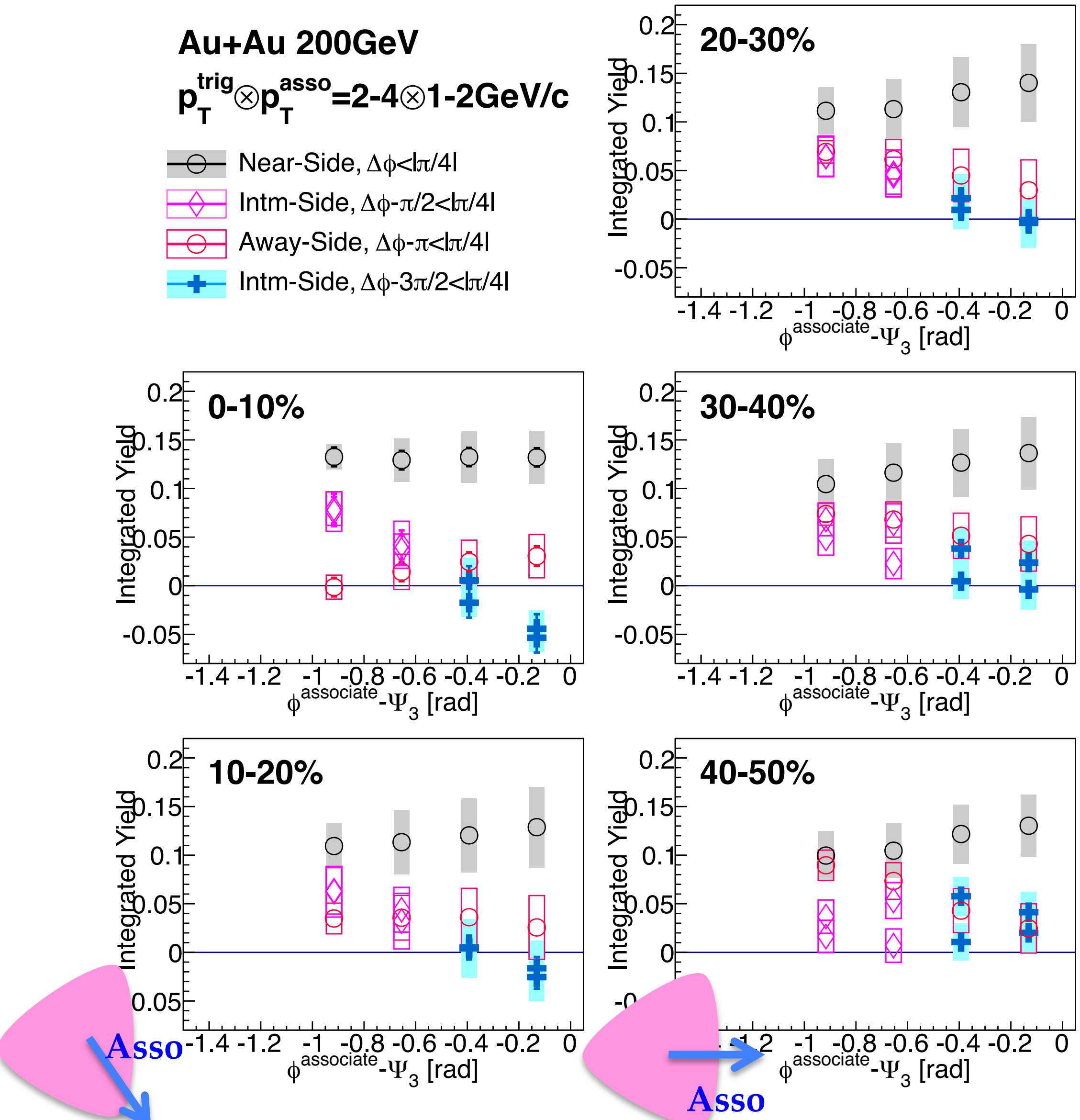
Path Length Dependence



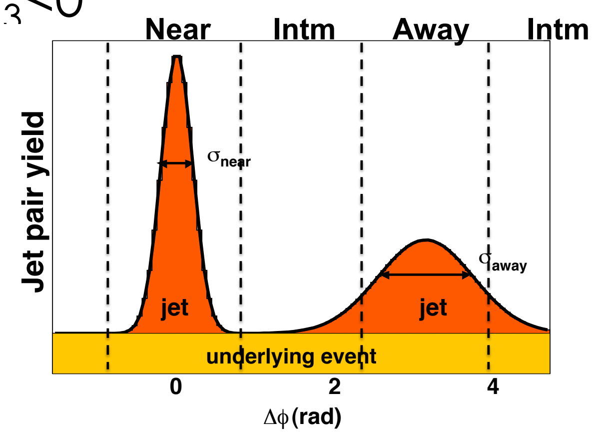
- Near/Away: 0-30%
  - $v^Y_2 < 0$, $v^Y_4 > 0$
- Near/Away:40-50%
  - $v^Y_2 > 0$, $v^Y_4 > 0$
- Intm : 0-50%
  - $v^Y_2 < 0$, $v^Y_4 < 0$



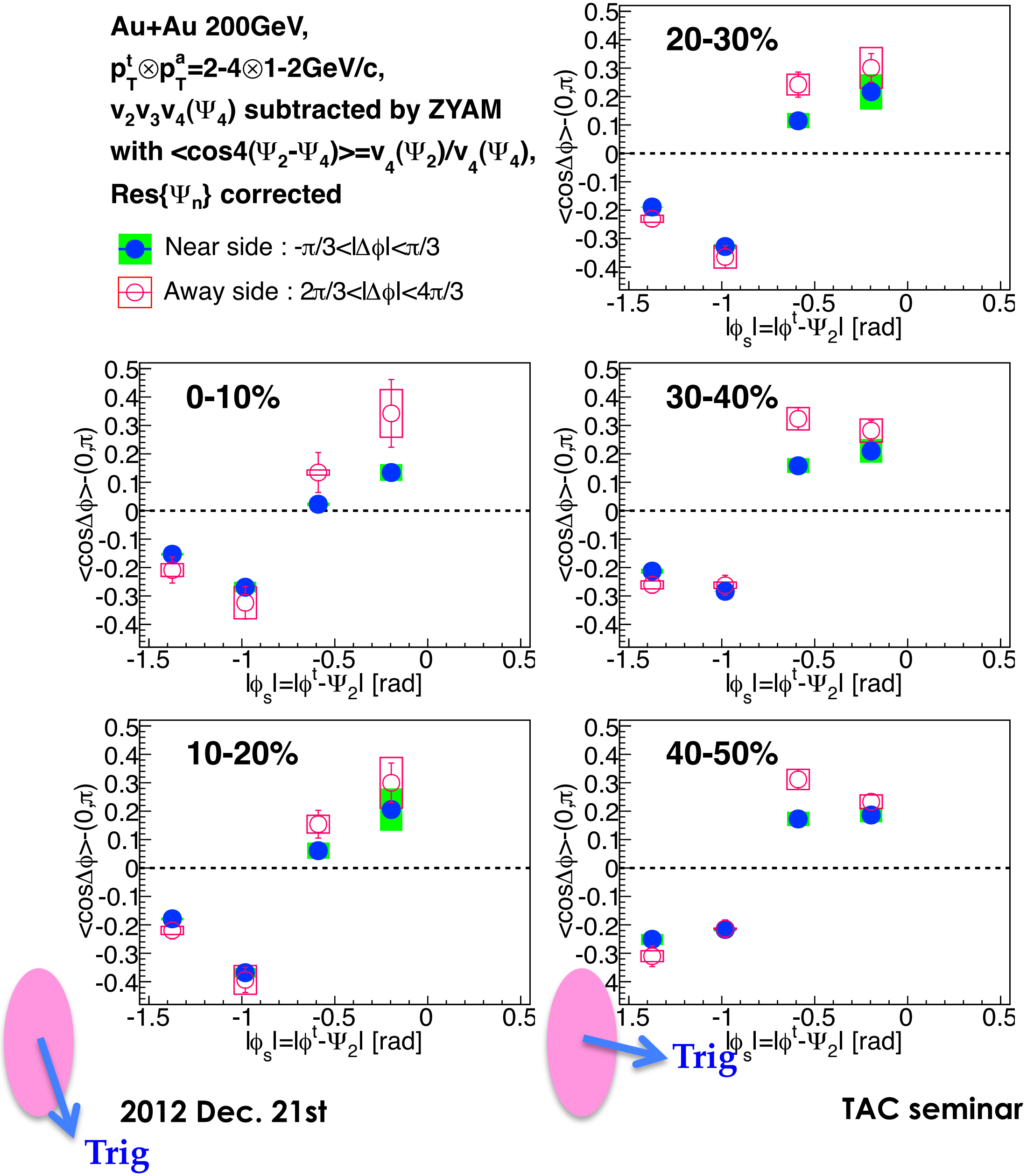
Path Length Dependence



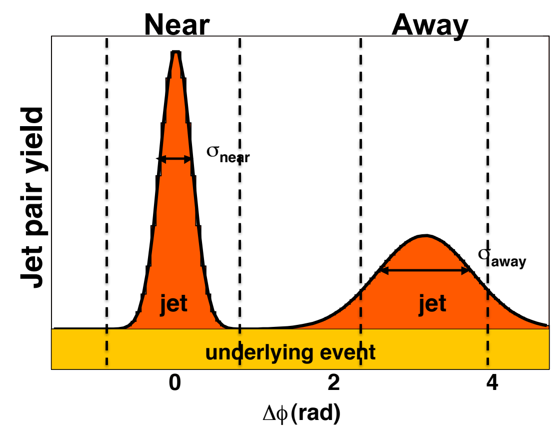
- Near: 0-50%
  - 0<= v_3
- Away: 0-10%
  - v_3<0
- Away: 10-50%
  - v_3 >0
- Intm : 0-50%
  - v_3<0



Gravity Position



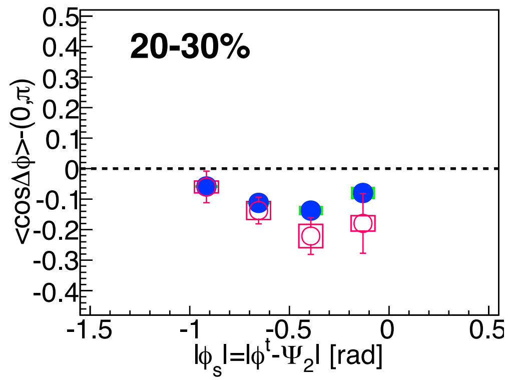
- In/Out-of plane correlations move to In/ Out-of plane direction in all centrality
- Inconsistent with path length dependence at in high p_T correlations

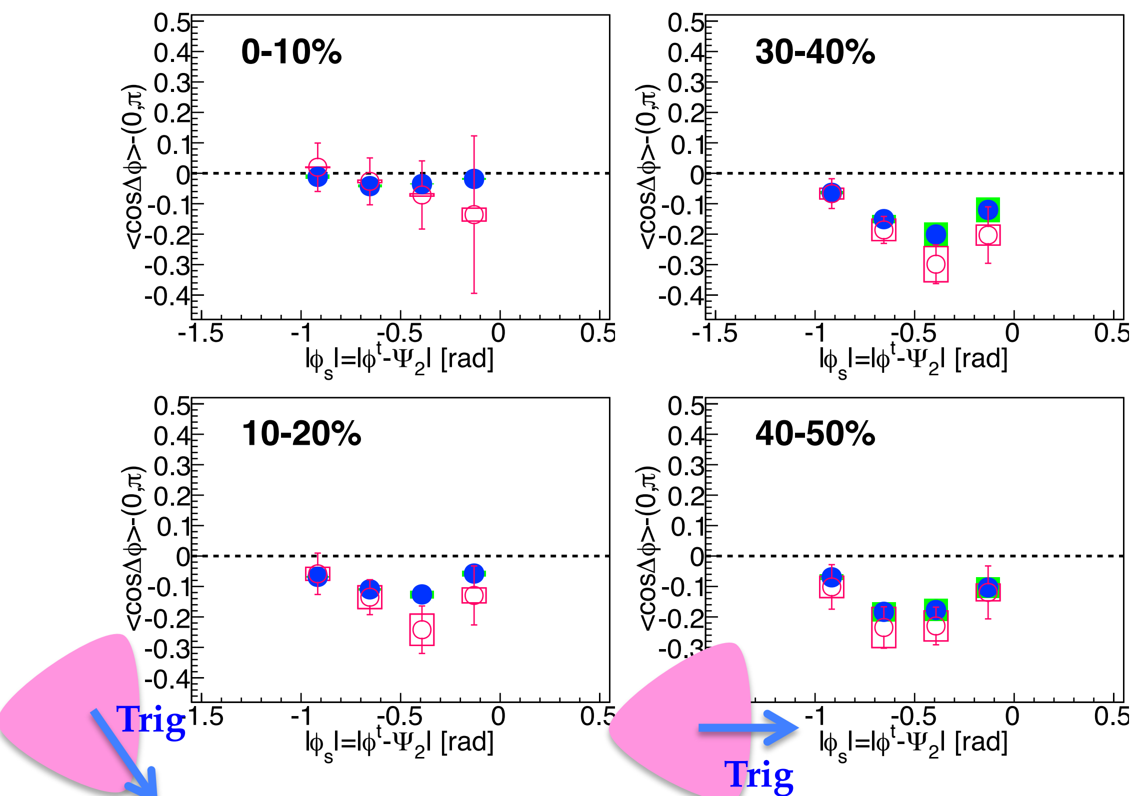


Gravity Position

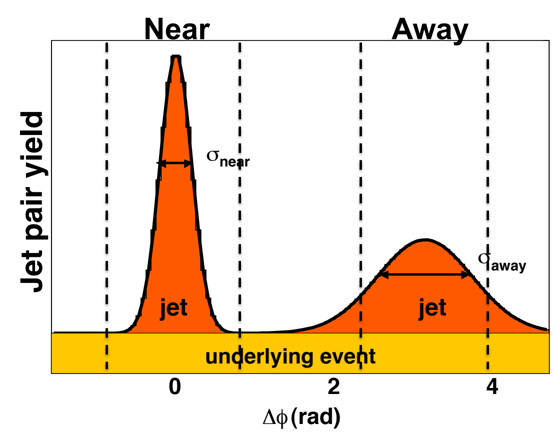
Au+Au 200GeV,
$p_T^t \otimes p_T^a$=2-4⊗1-2GeV/c,
$v_2 v_3 v_4(\Psi_4)$ subtracted by ZYAM
with $\langle\cos4(\Psi_2-\Psi_4)\rangle = v_4(\Psi_2)/v_4(\Psi_4)$,
Res{Ψ_n} corrected

Near side : $-\pi/3<|\Delta\phi|<\pi/3$
Away side : $2\pi/3<|\Delta\phi|<4\pi/3$





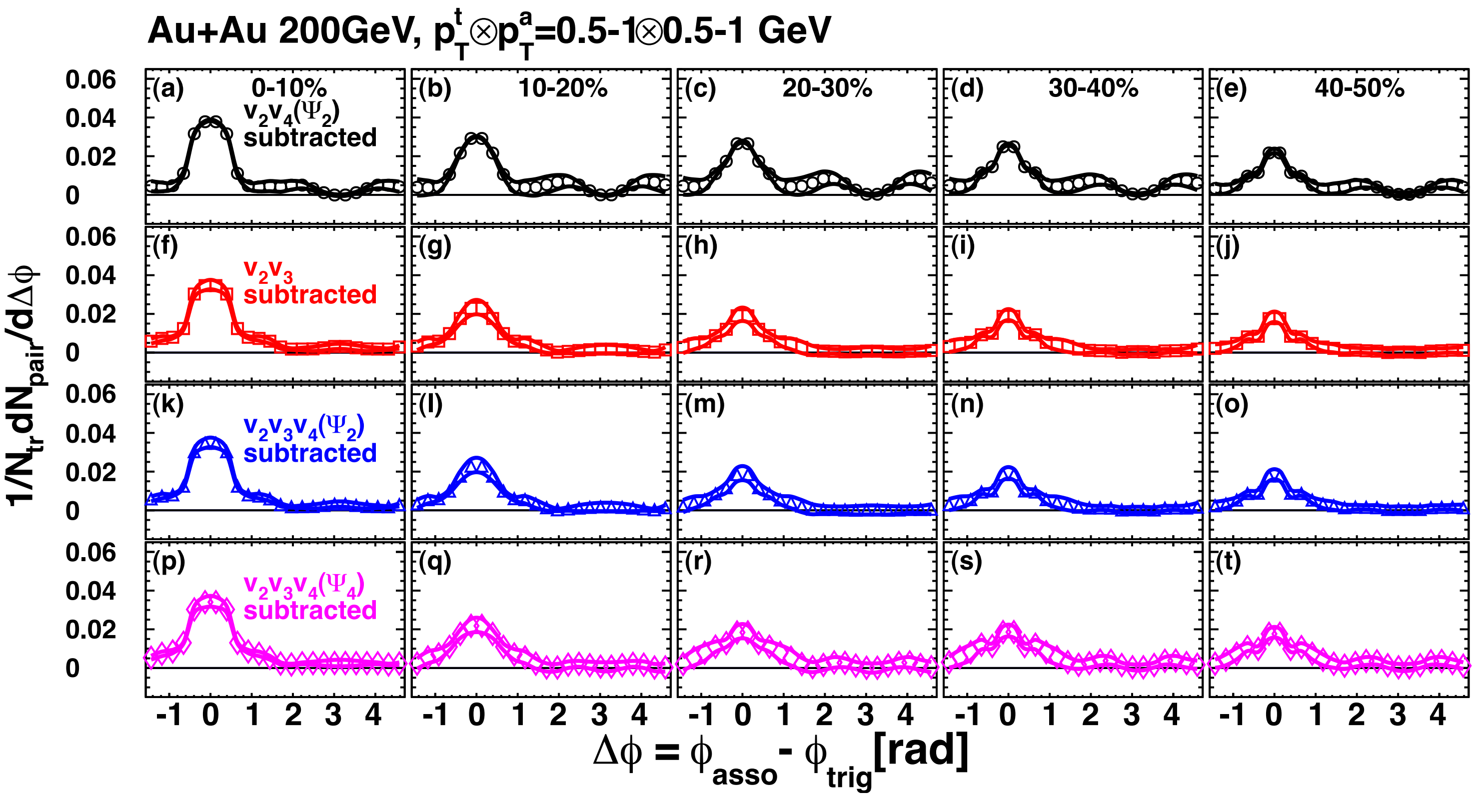
- Every triggered correlations move to positive azimuth direction in all centrality except 0-10%
- Inconsistent with path length dependence in high p_T correlations



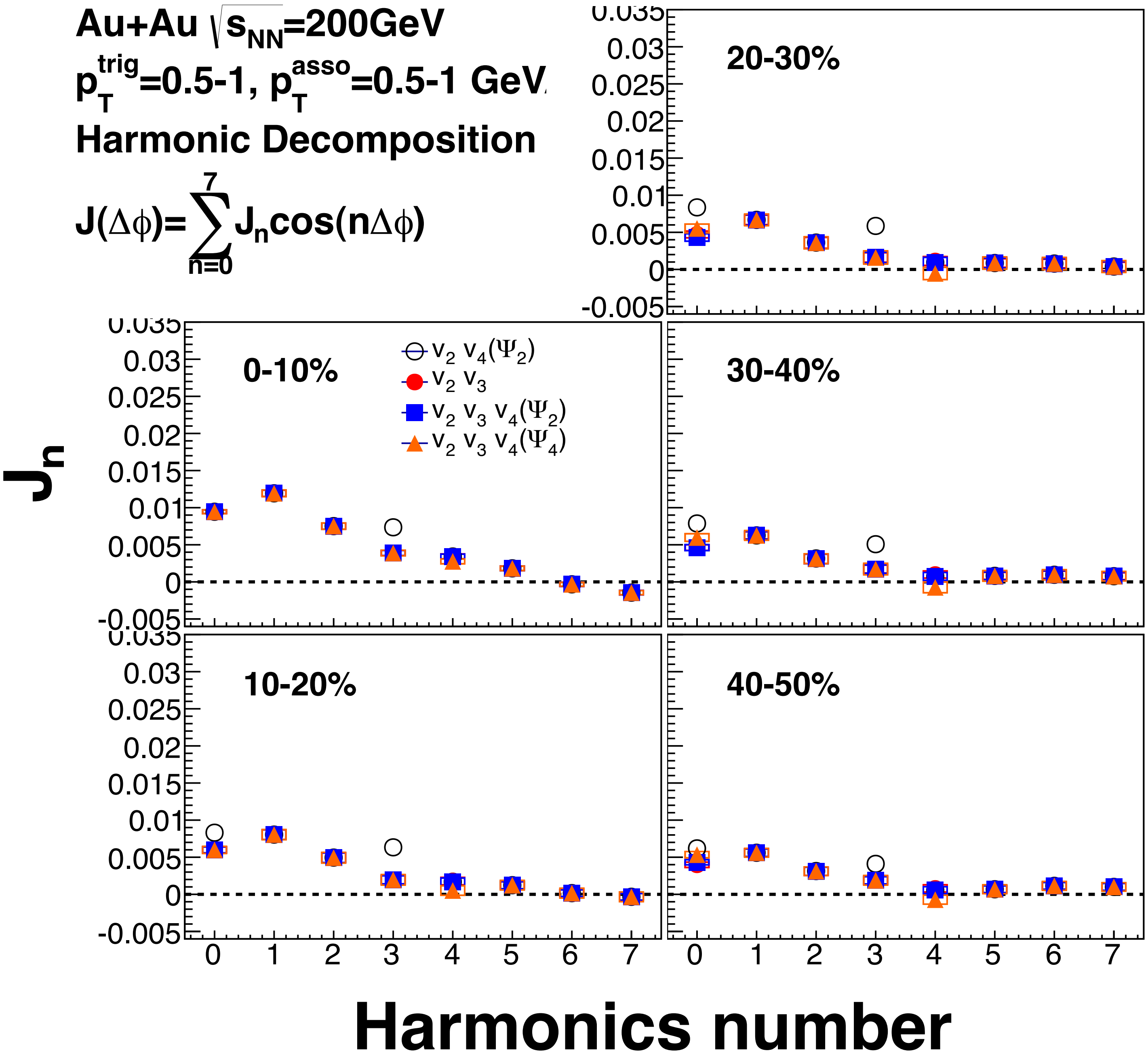
Conclusion & Outlook

- Treatment of v_4 is crucial for away side structure of intermediate p_T
  - Double hump (3^{rd} harmonics) survives in correlations at centrality 40-50%
- Simple path length dependence of parton energy loss is not validated in intermediate p_T correlations
  - Yields/Gravity position of correlations with trigger selection w.r.t. EP don't necessarily move to shorter path length side
  - Need to consider other model such as re-distribution of deposited energy to bulk etc.
- Different dependence on Ψ_2 & Ψ_3
  - Effects from almond shape vs fluctuation?
- Running Simulation Package
  - AMPT, q-PYTHIA, HYJING etc.

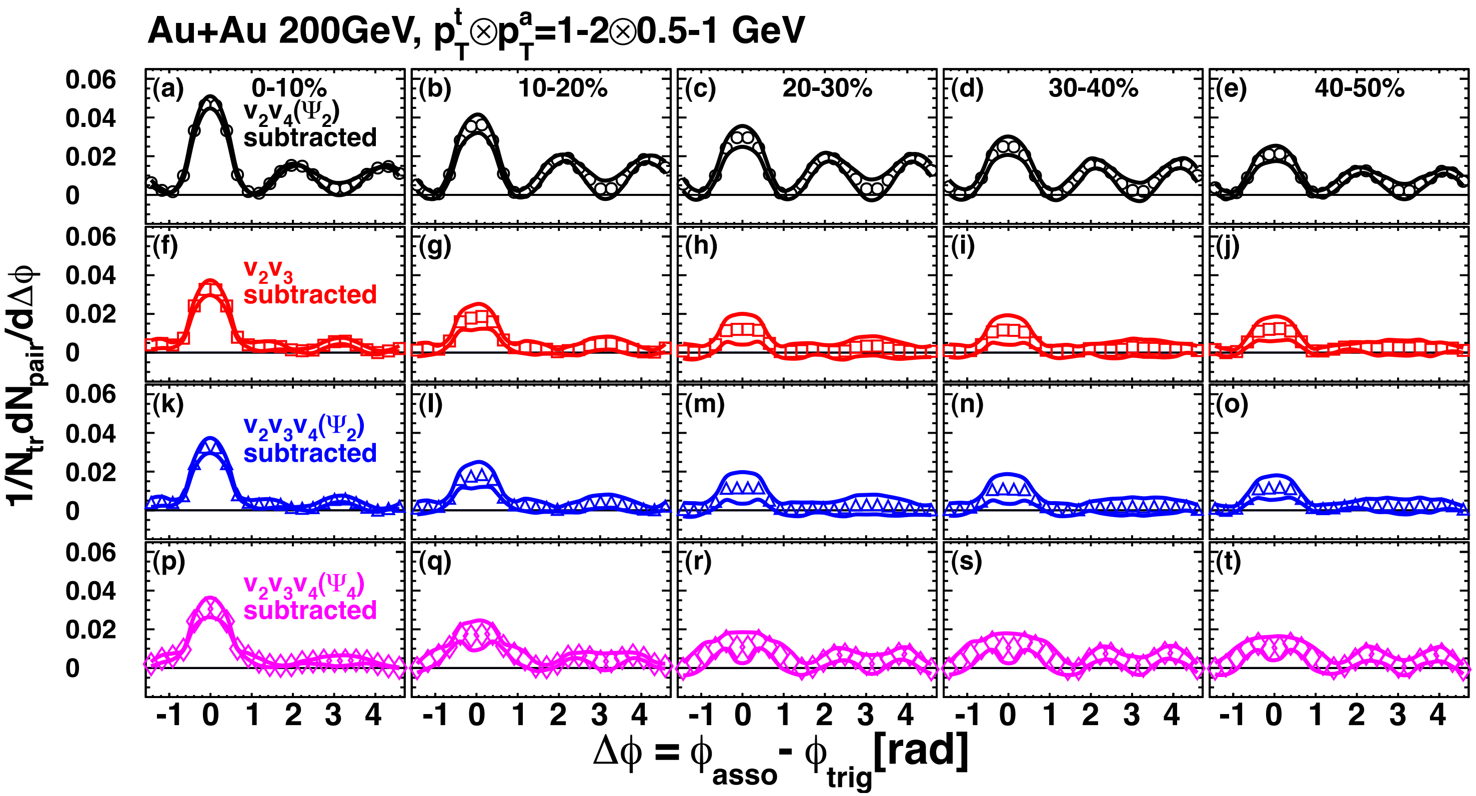
Backup Slides

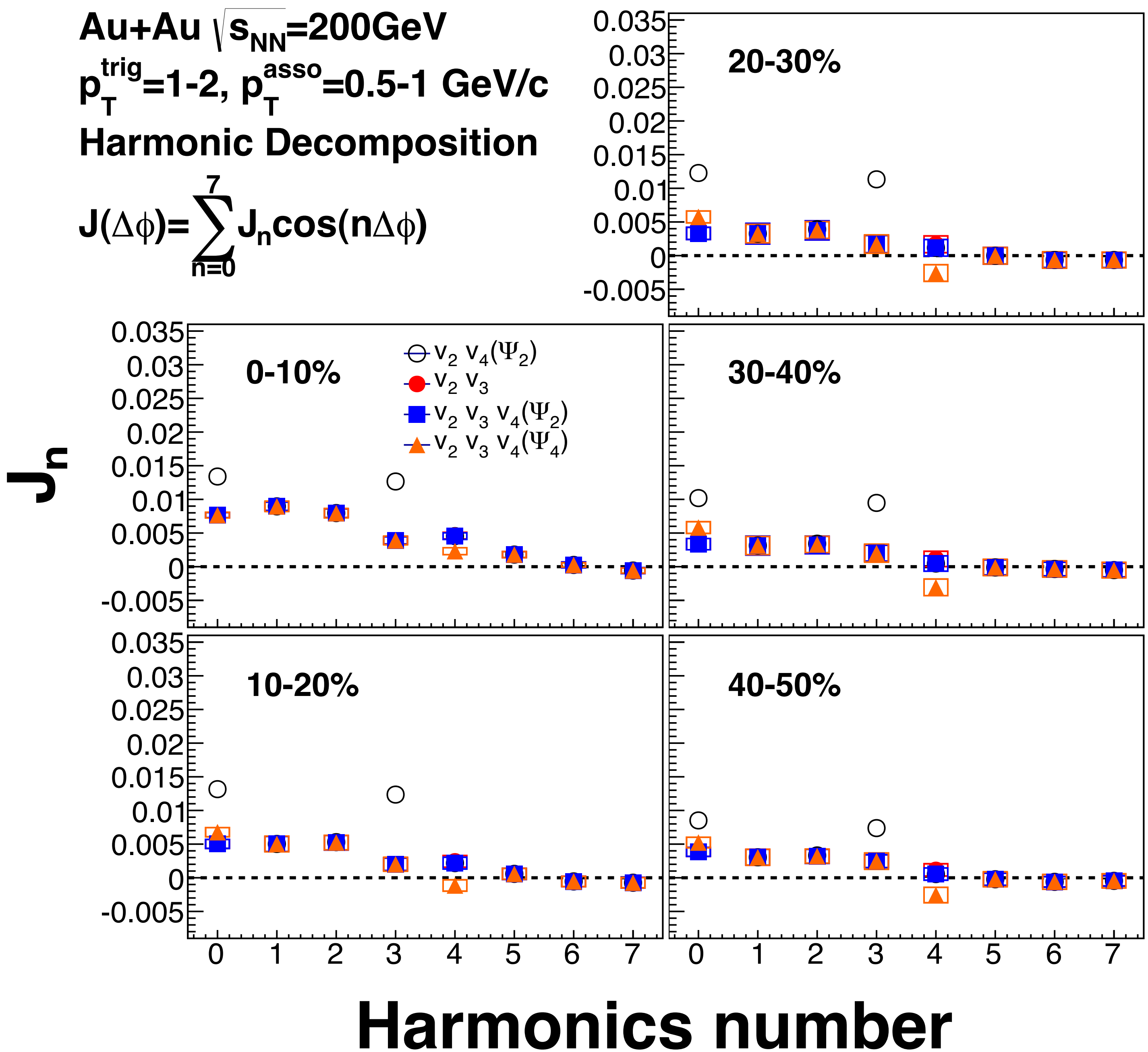


Au+Au 200GeV, $p_T^t \otimes p_T^a$=0.5-1⊗0.5-1 GeV
(a) 0-10%
$v_2v_4(\Psi_2)$ subtracted
(b) 10-20%
(c) 20-30%
(d) 30-40%
(e) 40-50%
(f) v_2v_3 subtracted
(g)
(h)
(i)
(j)
(k) $v_2v_3v_4(\Psi_2)$ subtracted
(l)
(m)
(n)
(o)
(p) $v_2v_3v_4(\Psi_4)$ subtracted
(q)
(r)
(s)
(t)
$1/N_{tr}dN_{pair}/d\Delta\phi$
$\Delta\phi = \phi_{asso} - \phi_{trig}$[rad]

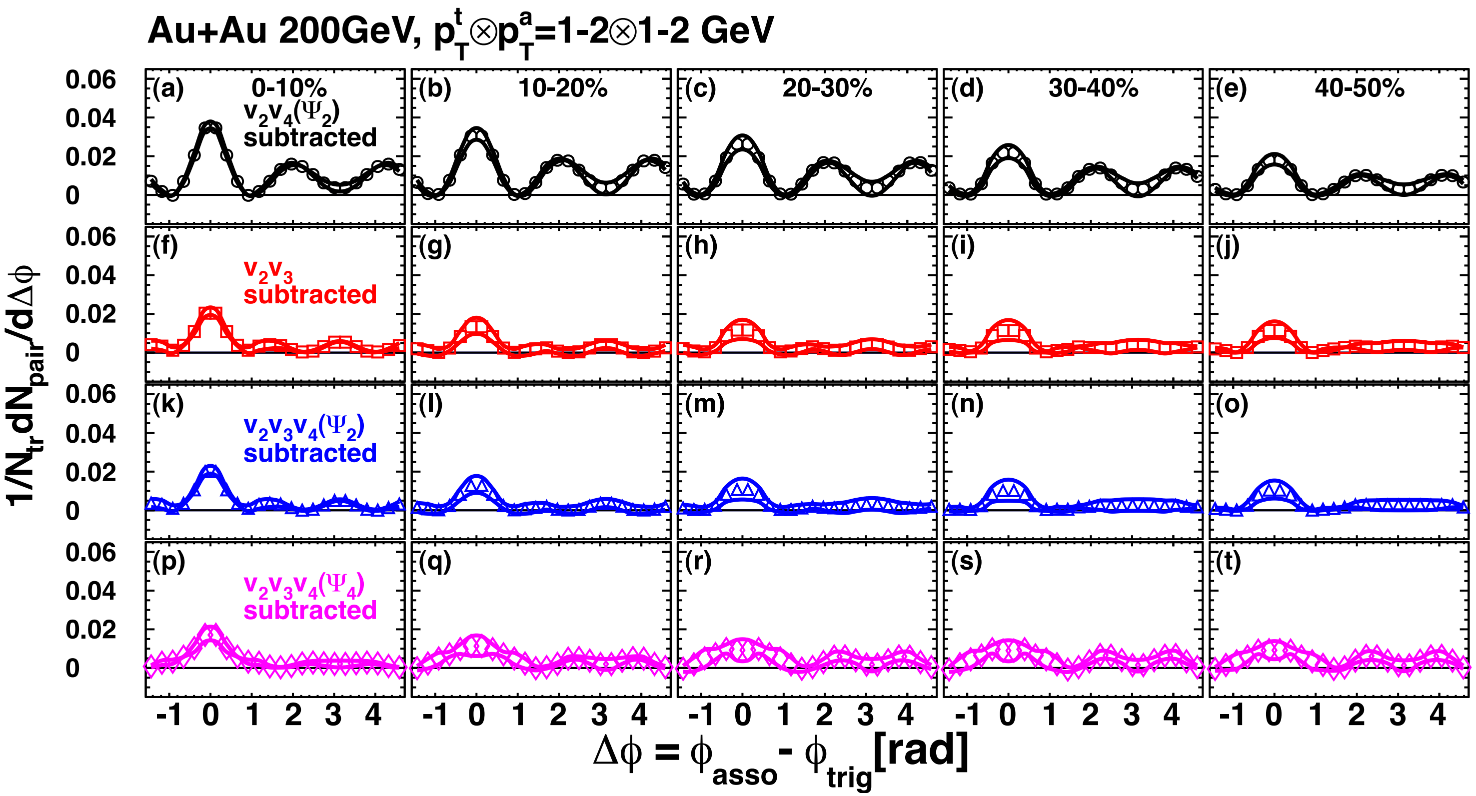


Au+Au $\sqrt{s_{NN}}$=200GeV
p_T^{trig}=0.5-1, p_T^{asso}=0.5-1 GeV
Harmonic Decomposition
$J(\Delta\phi)=\sum_{n=0}^{7} J_n \cos(n\Delta\phi)$
J_n
20-30%
0-10%
30-40%
10-20%
40-50%
$v_2\ v_4(\Psi_2)$
$v_2\ v_3$
$v_2\ v_3\ v_4(\Psi_2)$
$v_2\ v_3\ v_4(\Psi_4)$
Harmonics number

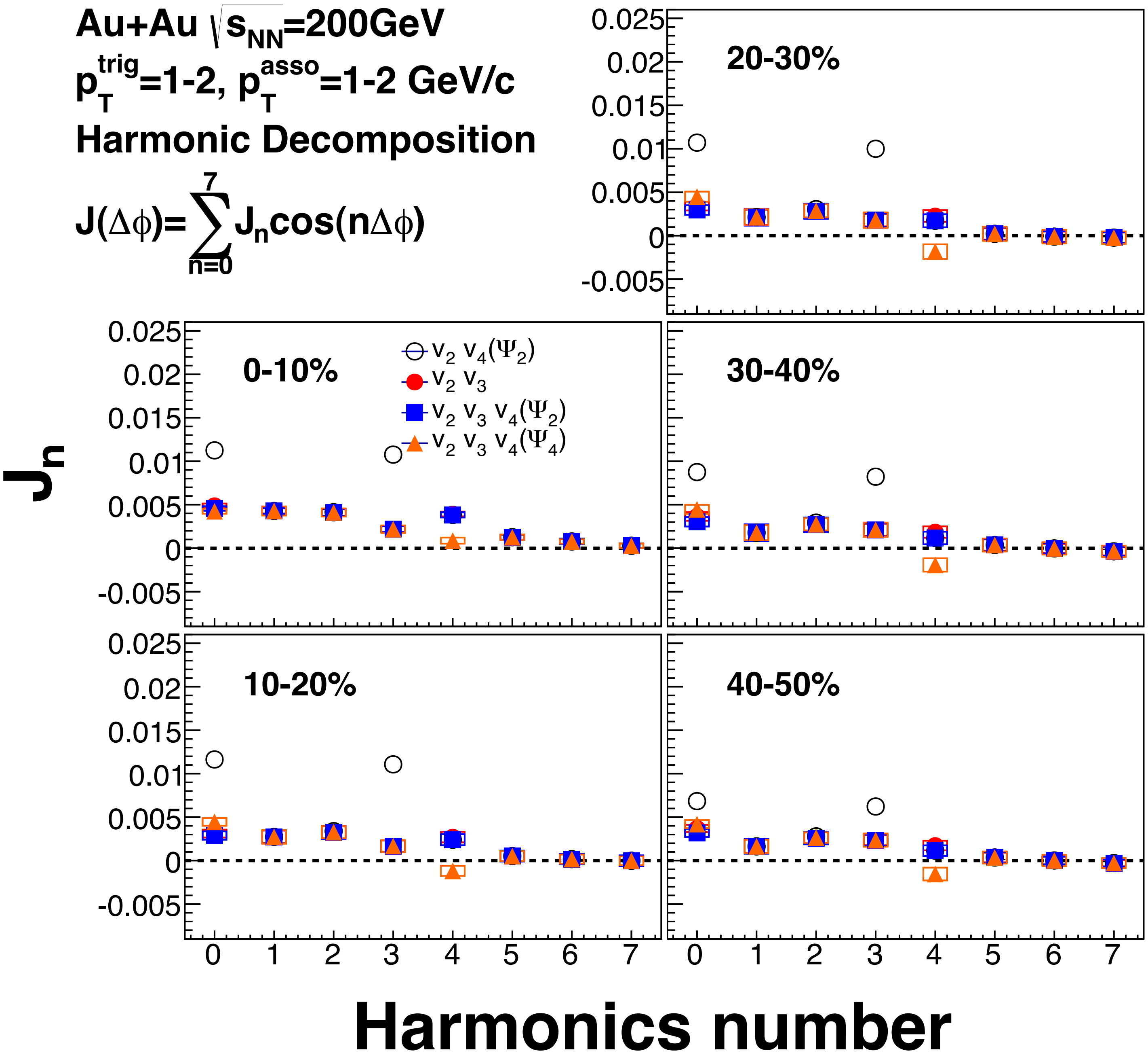

Au+Au 200GeV, $p_T^t \otimes p_T^a$=1-2⊗0.5-1 GeV
(a) 0-10%
$v_2v_4(\Psi_2)$ subtracted
(b) 10-20%
(c) 20-30%
(d) 30-40%
(e) 40-50%
(f) v_2v_3 subtracted
(g)
(h)
(i)
(j)
(k) $v_2v_3v_4(\Psi_2)$ subtracted
(l)
(m)
(n)
(o)
(p) $v_2v_3v_4(\Psi_4)$ subtracted
(q)
(r)
(s)
(t)
$1/N_{tr} dN_{pair}/d\Delta\phi$
0 0.02 0.04 0.06
-1 0 1 2 3 4
$\Delta\phi = \phi_{asso} - \phi_{trig}$[rad]



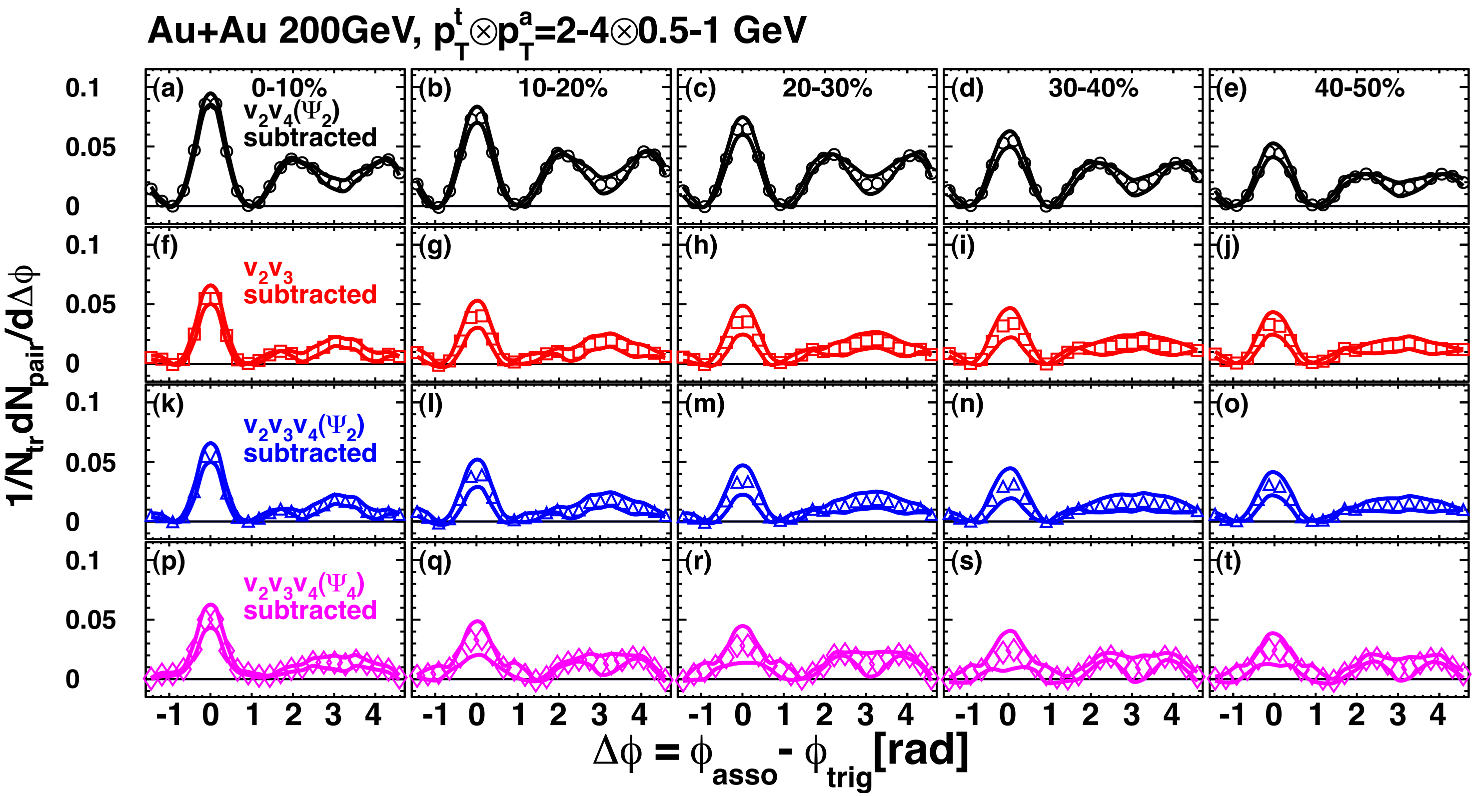
Au+Au $\sqrt{s_{NN}}$=200GeV
p_T^{trig}=1-2, p_T^{asso}=0.5-1 GeV/c
Harmonic Decomposition
$J(\Delta\phi)=\sum_{n=0}^{7} J_n\cos(n\Delta\phi)$
J_n
20-30%
0-10%
30-40%
10-20%
40-50%
$v_2\ v_4(\Psi_2)$
$v_2\ v_3$
$v_2\ v_3\ v_4(\Psi_2)$
$v_2\ v_3\ v_4(\Psi_4)$
Harmonics number



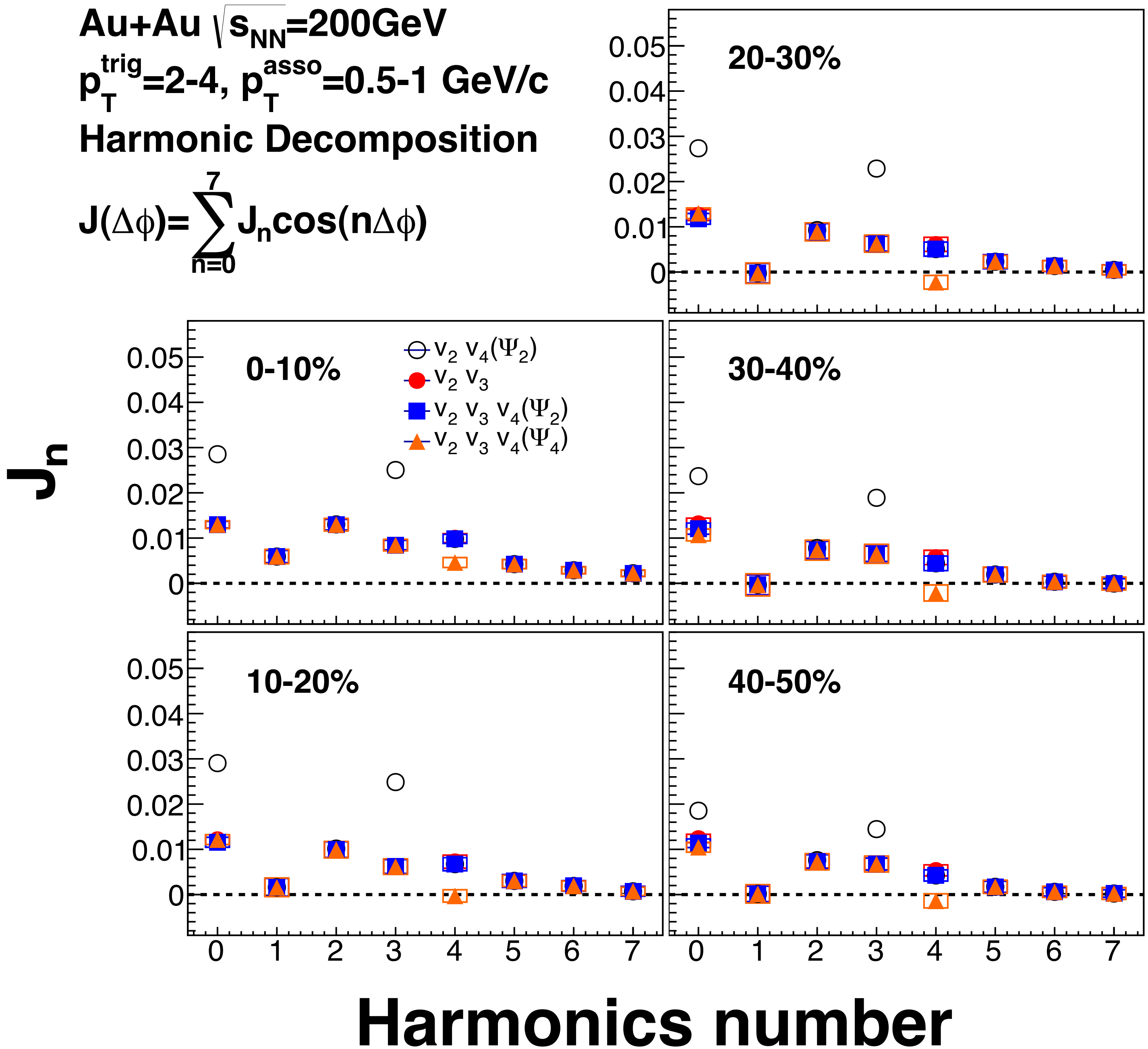
Au+Au 200GeV, $p_T^t \otimes p_T^a$=1-2⊗1-2 GeV
(a) 0-10%
$v_2v_4(\Psi_2)$ subtracted
(b) 10-20%
(c) 20-30%
(d) 30-40%
(e) 40-50%
(f)
v_2v_3 subtracted
(g)
(h)
(i)
(j)
(k)
$v_2v_3v_4(\Psi_2)$ subtracted
(l)
(m)
(n)
(o)
(p)
$v_2v_3v_4(\Psi_4)$ subtracted
(q)
(r)
(s)
(t)
$1/N_{tr}dN_{pair}/d\Delta\phi$
$\Delta\phi = \phi_{asso} - \phi_{trig}$[rad]

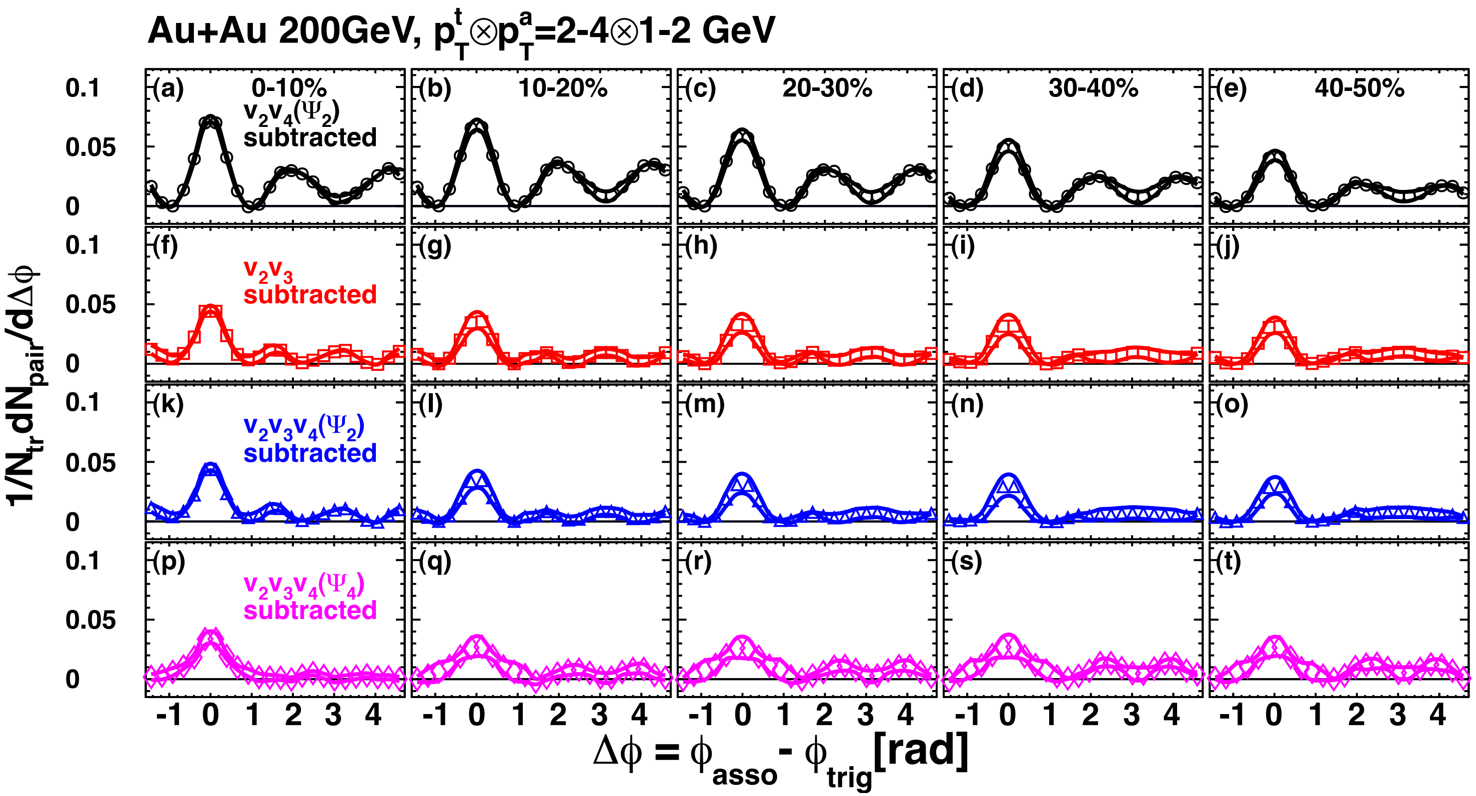


Au+Au $\sqrt{s_{NN}}$=200GeV
p_T^{trig}=1-2, p_T^{asso}=1-2 GeV/c
Harmonic Decomposition
$J(\Delta\phi)=\sum_{n=0}^{7} J_n \cos(n\Delta\phi)$
0-10%
10-20%
20-30%
30-40%
40-50%
$v_2\ v_4(\Psi_2)$
$v_2\ v_3$
$v_2\ v_3\ v_4(\Psi_2)$
$v_2\ v_3\ v_4(\Psi_4)$
J_n
Harmonics number

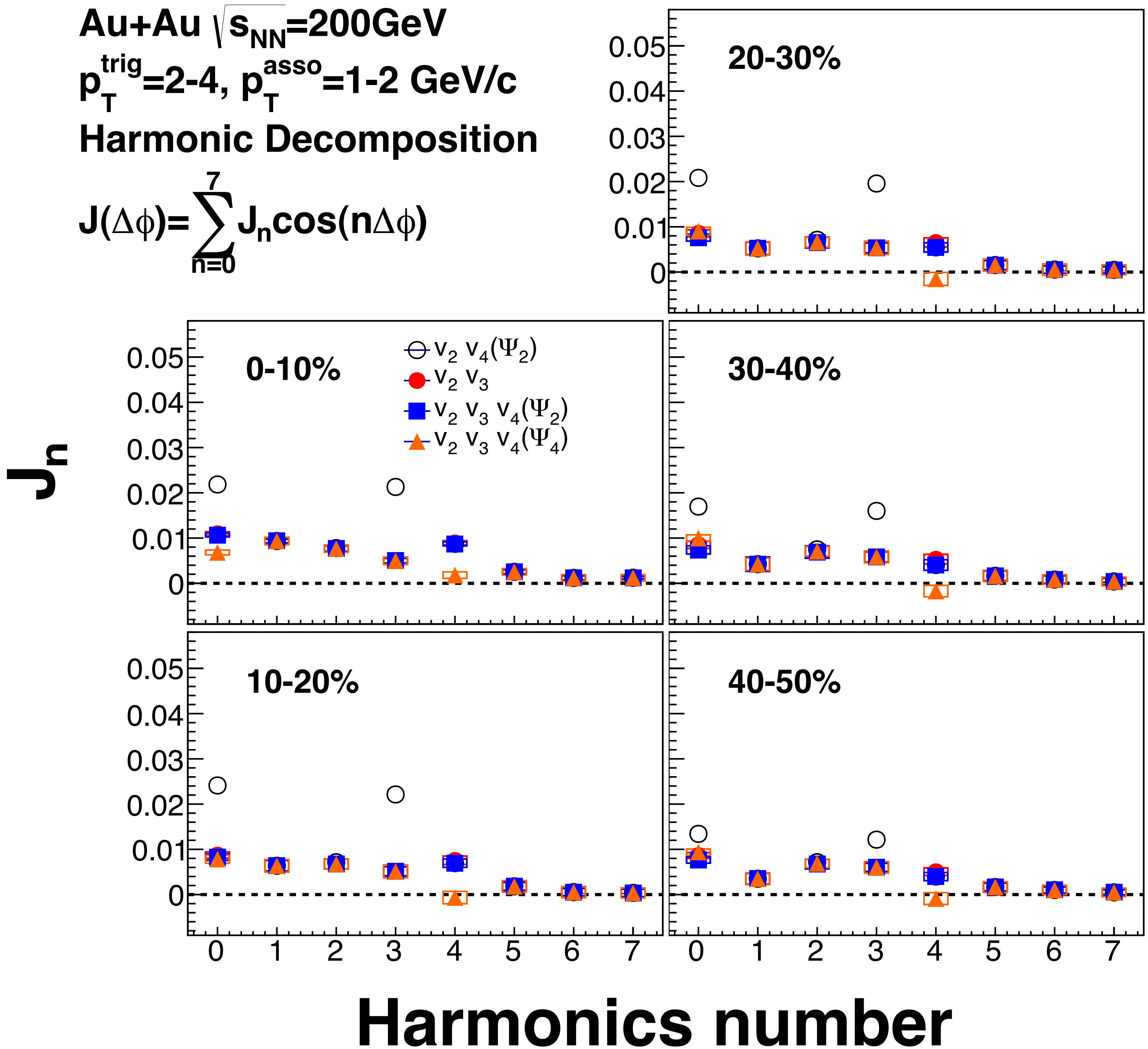


Au+Au 200GeV, $p_T^t \otimes p_T^a$=2-4⊗0.5-1 GeV
(a) 0-10%
$v_2v_4(\Psi_2)$ subtracted
(b) 10-20%
(c) 20-30%
(d) 30-40%
(e) 40-50%
(f) v_2v_3 subtracted
(g)
(h)
(i)
(j)
(k) $v_2v_3v_4(\Psi_2)$ subtracted
(l)
(m)
(n)
(o)
(p) $v_2v_3v_4(\Psi_4)$ subtracted
(q)
(r)
(s)
(t)
0.1
0.05
0
-1 0 1 2 3 4
$1/N_{tr}dN_{pair}/d\Delta\phi$
$\Delta\phi = \phi_{asso} - \phi_{trig}$[rad]

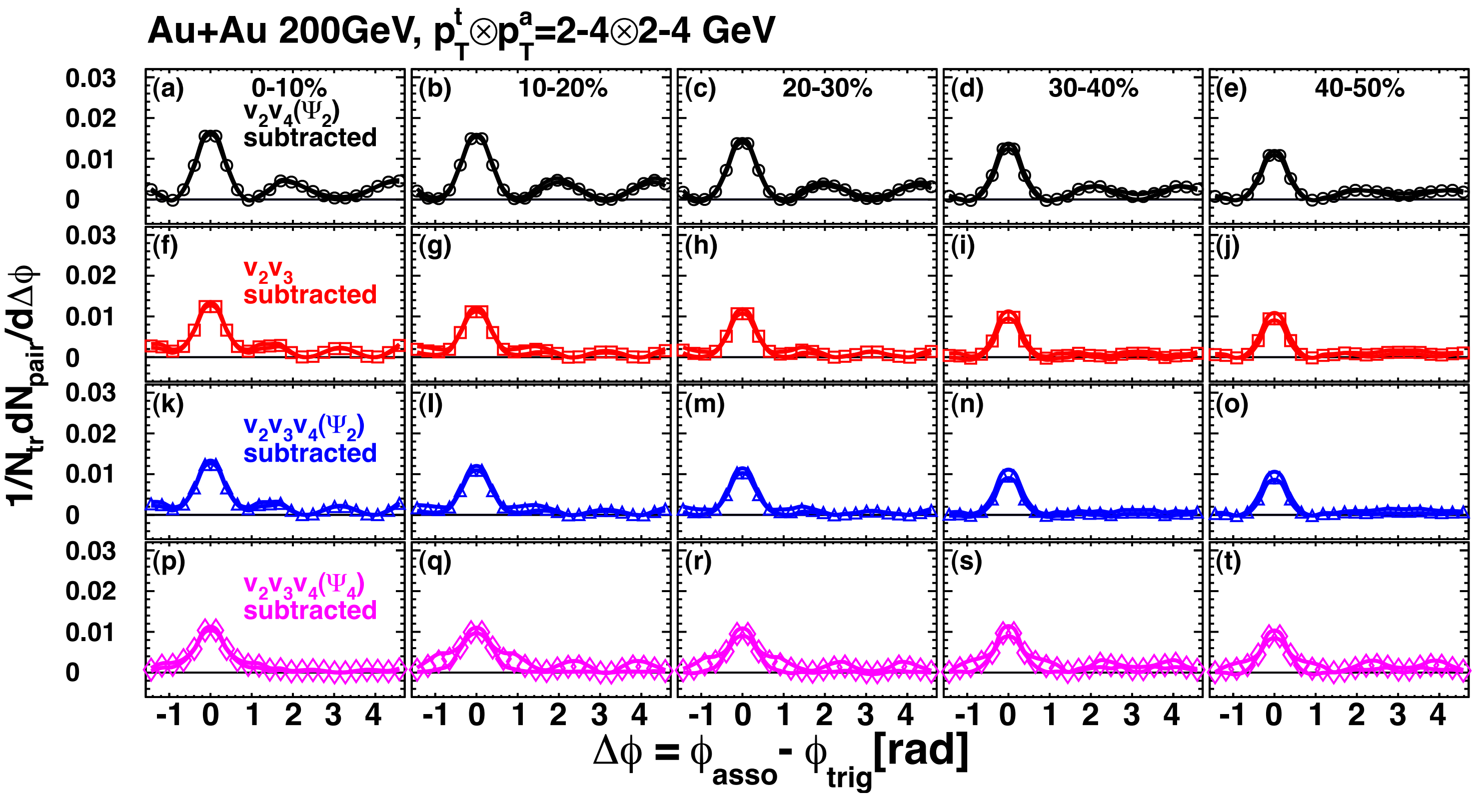

Au+Au $\sqrt{s_{NN}}$=200GeV
p_T^{trig}=2-4, p_T^{asso}=0.5-1 GeV/c
Harmonic Decomposition
$J(\Delta\phi)=\sum_{n=0}^{7} J_n \cos(n\Delta\phi)$
J_n
0-10%
10-20%
20-30%
30-40%
40-50%
$v_2\ v_4(\Psi_2)$
$v_2\ v_3$
$v_2\ v_3\ v_4(\Psi_2)$
$v_2\ v_3\ v_4(\Psi_4)$
0.05
0.04
0.03
0.02
0.01
0
0 1 2 3 4 5 6 7
Harmonics number



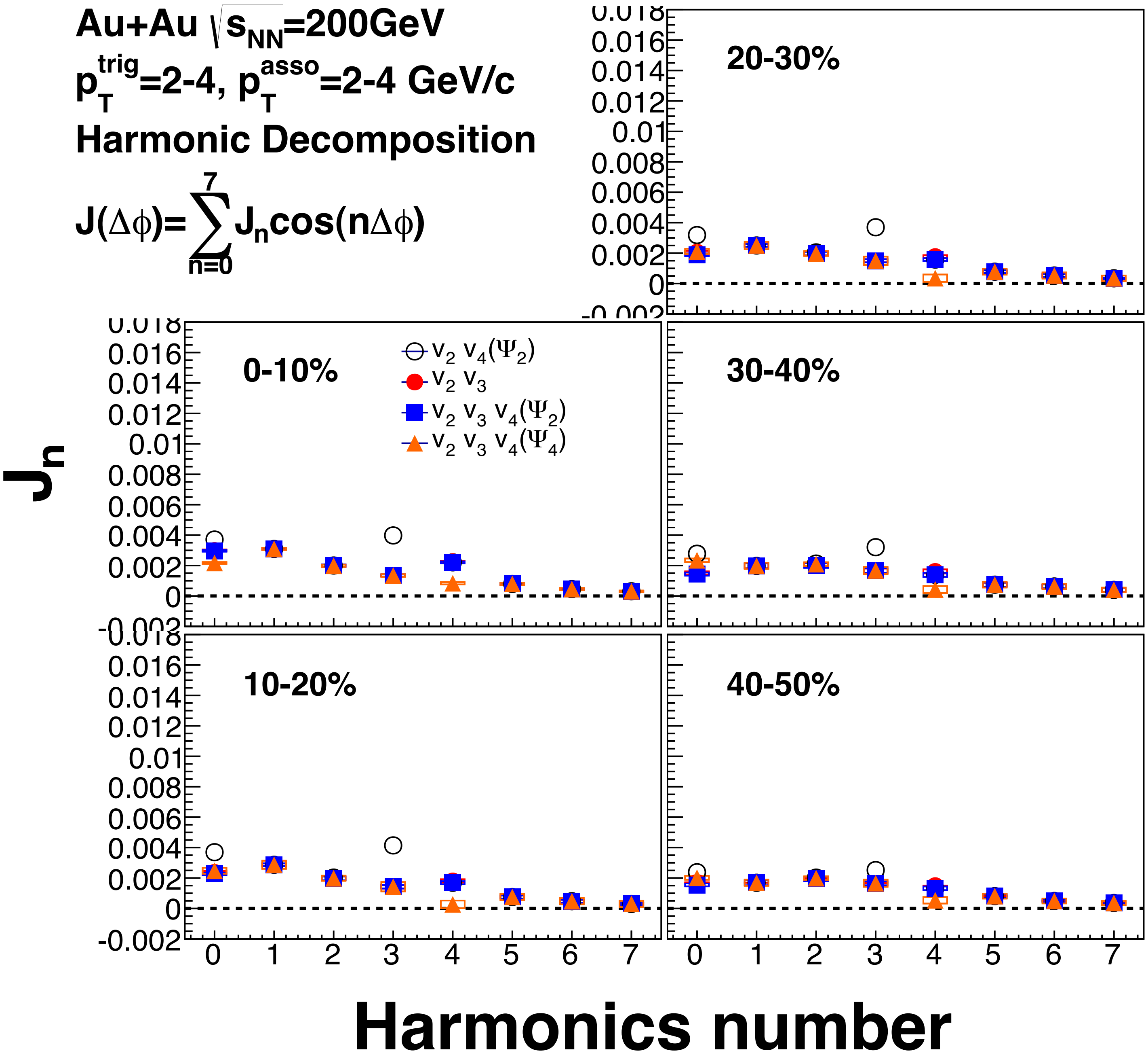
Au+Au 200GeV, $p_T^t \otimes p_T^a$=2-4⊗1-2 GeV
(a) 0-10%
$v_2v_4(\Psi_2)$ subtracted
(b) 10-20%
(c) 20-30%
(d) 30-40%
(e) 40-50%
(f)
v_2v_3 subtracted
(g)
(h)
(i)
(j)
(k)
$v_2v_3v_4(\Psi_2)$ subtracted
(l)
(m)
(n)
(o)
(p)
$v_2v_3v_4(\Psi_4)$ subtracted
(q)
(r)
(s)
(t)
$1/N_{tr}dN_{pair}/d\Delta\phi$
$\Delta\phi = \phi_{asso} - \phi_{trig}$[rad]



Au+Au $\sqrt{s_{NN}}$=200GeV
p_T^{trig}=2-4, p_T^{asso}=1-2 GeV/c
Harmonic Decomposition
$J(\Delta\phi)=\sum_{n=0}^{7} J_n \cos(n\Delta\phi)$
J_n
0-10%
10-20%
20-30%
30-40%
40-50%
$v_2\ v_4(\Psi_2)$
$v_2\ v_3$
$v_2\ v_3\ v_4(\Psi_2)$
$v_2\ v_3\ v_4(\Psi_4)$
0.05
0.04
0.03
0.02
0.01
0
0 1 2 3 4 5 6 7
Harmonics number

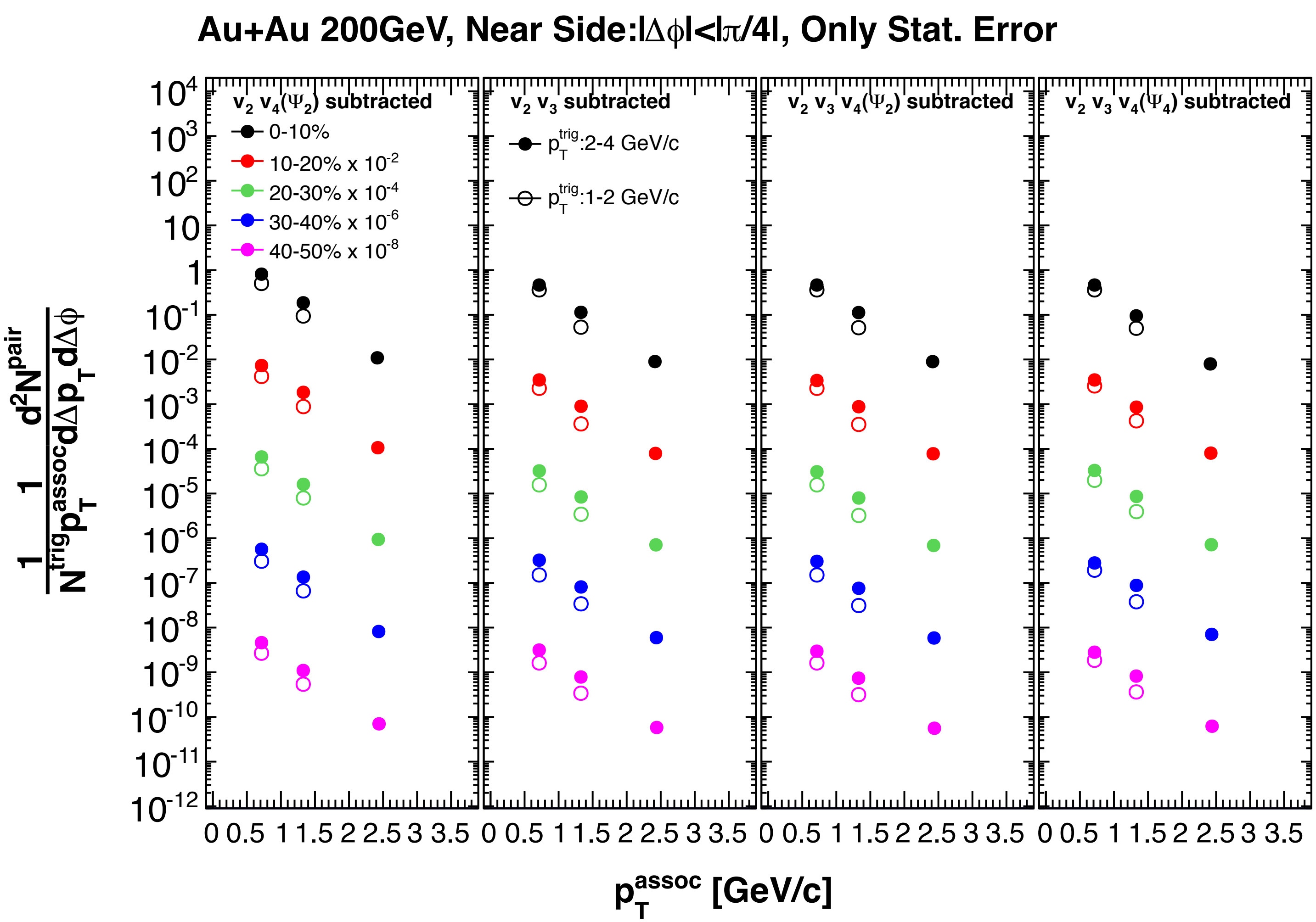


Au+Au 200GeV, $p_T^t \otimes p_T^a$=2-4⊗2-4 GeV
(a) 0-10%
$v_2v_4(\Psi_2)$ subtracted
(b) 10-20%
(c) 20-30%
(d) 30-40%
(e) 40-50%
(f) v_2v_3 subtracted
(g)
(h)
(i)
(j)
(k) $v_2v_3v_4(\Psi_2)$ subtracted
(l)
(m)
(n)
(o)
(p) $v_2v_3v_4(\Psi_4)$ subtracted
(q)
(r)
(s)
(t)
$1/N_{tr}dN_{pair}/d\Delta\phi$
$\Delta\phi = \phi_{asso} - \phi_{trig}$[rad]

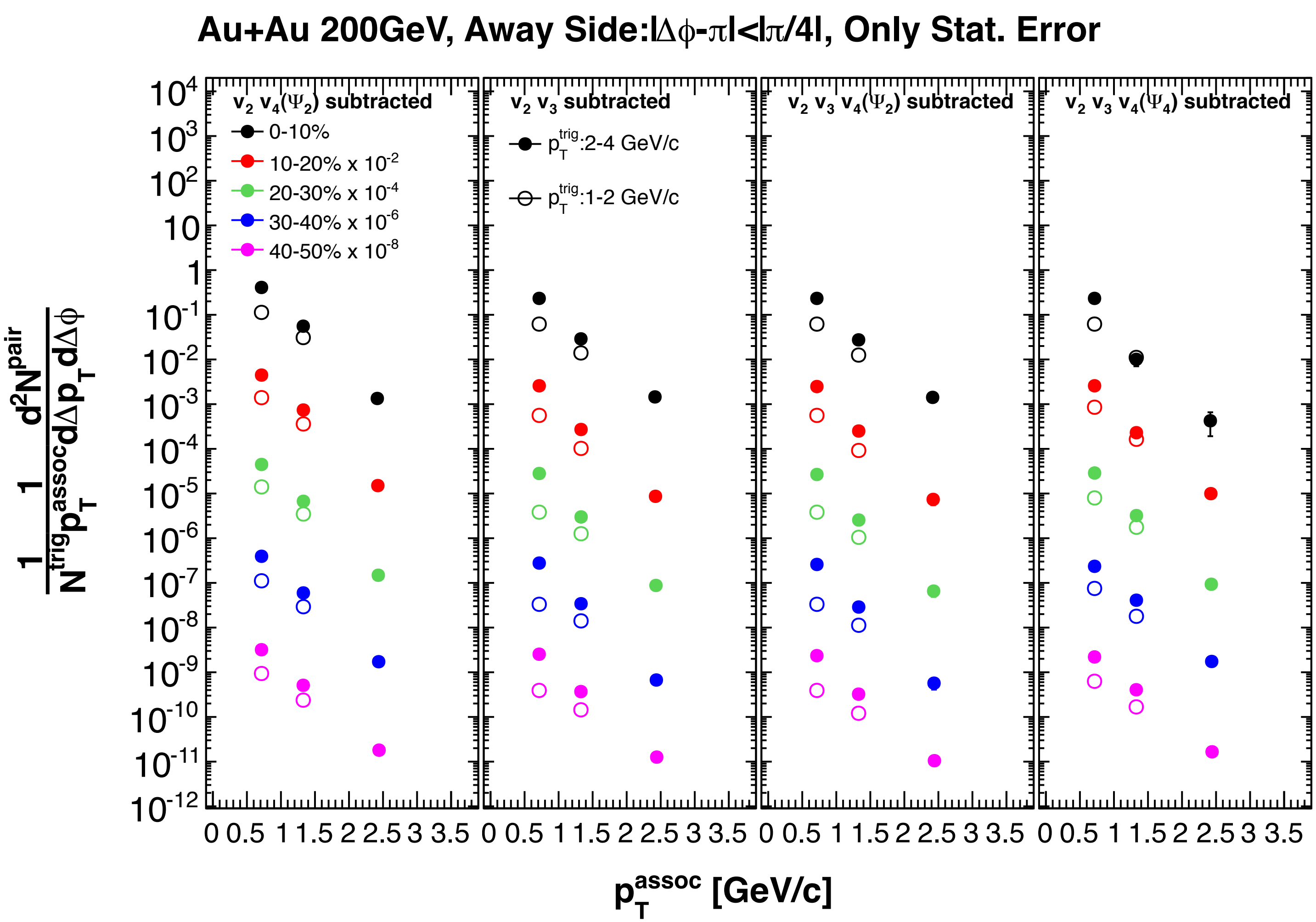


Au+Au $\sqrt{s_{NN}}$=200GeV
p_T^{trig}=2-4, p_T^{asso}=2-4 GeV/c
Harmonic Decomposition
$J(\Delta\phi)=\sum_{n=0}^{7} J_n \cos(n\Delta\phi)$
J_n
20-30%
0-10%
30-40%
10-20%
40-50%
$v_2\ v_4(\Psi_2)$
$v_2\ v_3$
$v_2\ v_3\ v_4(\Psi_2)$
$v_2\ v_3\ v_4(\Psi_4)$
Harmonics number

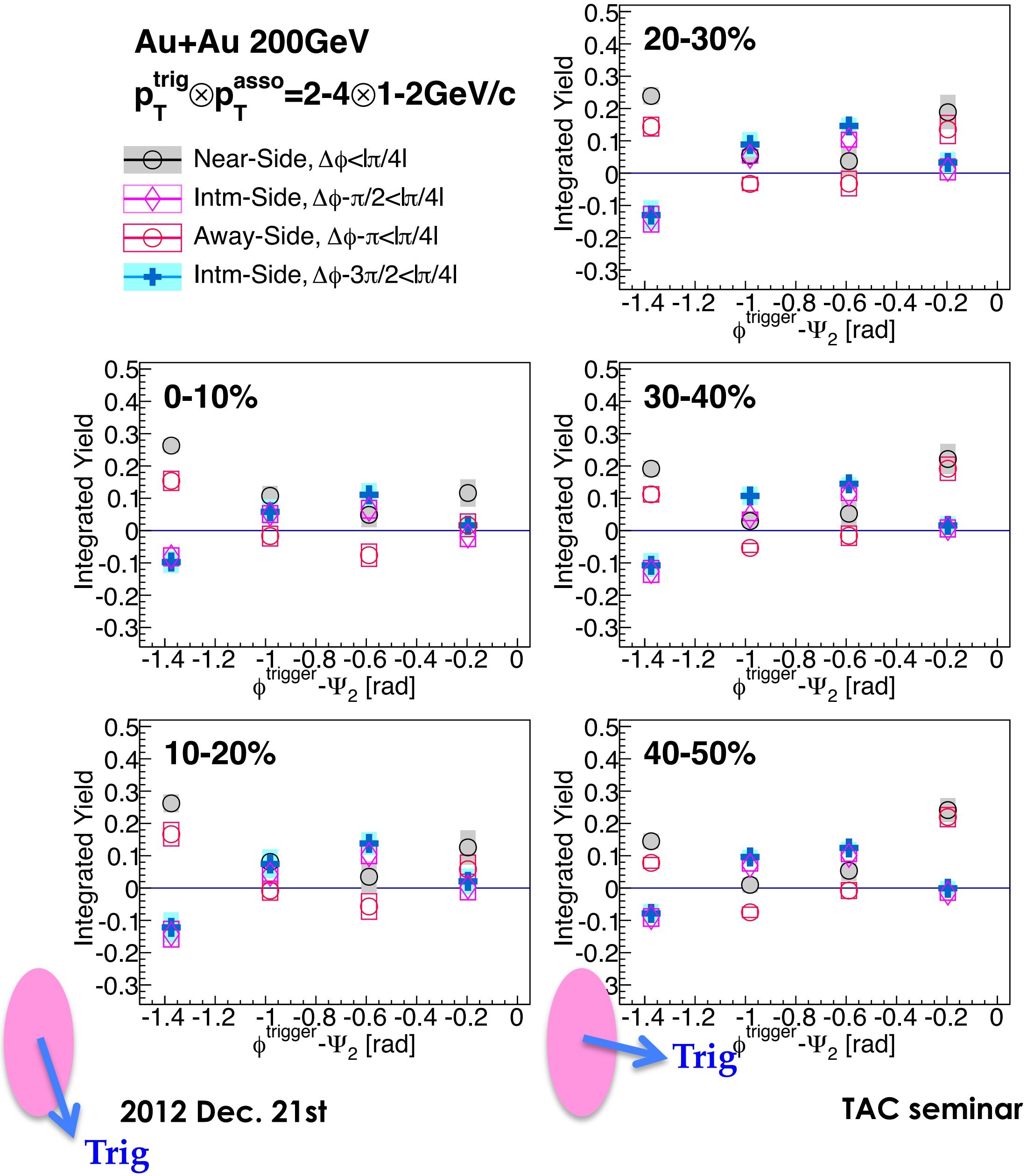
Spectra of Correlation Yield



Spectra of Correlation Yield



Path Length Dependence



Path Length Dependence