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Measurement of collective flow

via Two-particle correlation method in $\sqrt{s_{NN}} = 200\text{GeV}$ ^{3}He+Au collisions at RHIC-PHENIX

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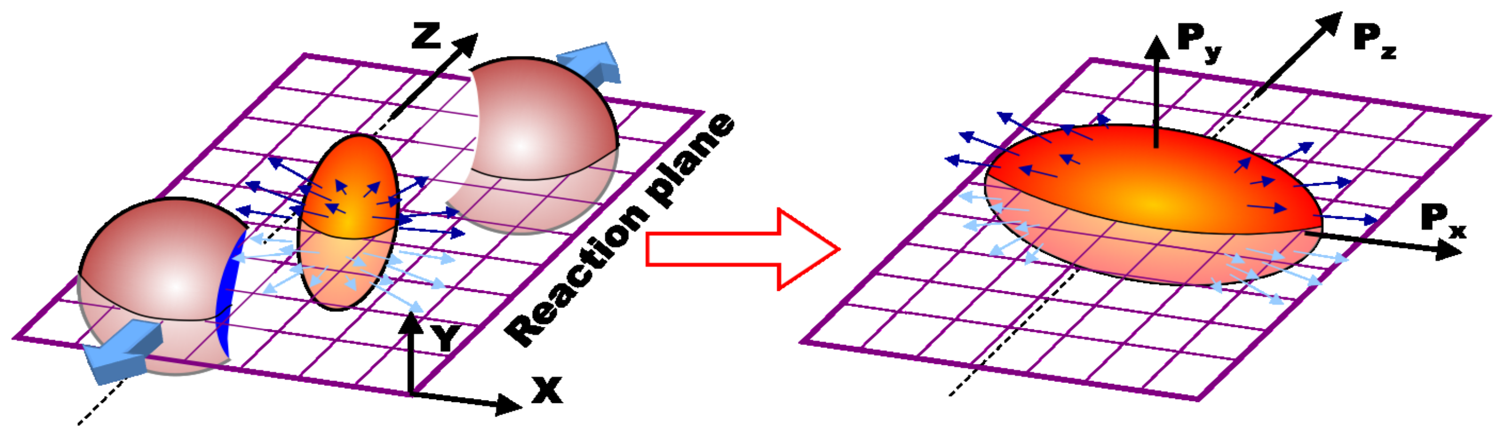
Anisotropic Flow



In heavy ion collision,
Distribution of emitted particles is anisotropic in azimuthal direction.

Anisotropic Flow

Probe sensitive to the properties of the system
Understanding QGP properties using hydrodynamics

Distribution of emitted particles can be written as Fourier formula.

$$\frac{dN}{d\phi} \propto 1 + \sum_n 2v_n cos[n(\phi - \Psi_n)] \qquad v_n = \langle cos[n(\phi - \Psi_n)]\rangle$$

Ψ_n : Azimuthal angle of Event Plane
ϕ : Azimuthal angle of emitted particles
v_n : Flow harmonics (measured parameters)

Second order flow harmonics is known as **elliptic flow(v_2)**

Flow in small collision systems

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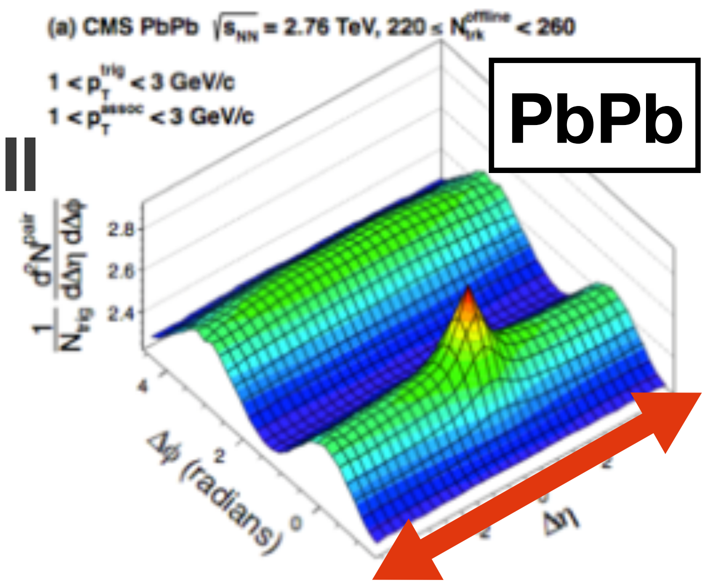
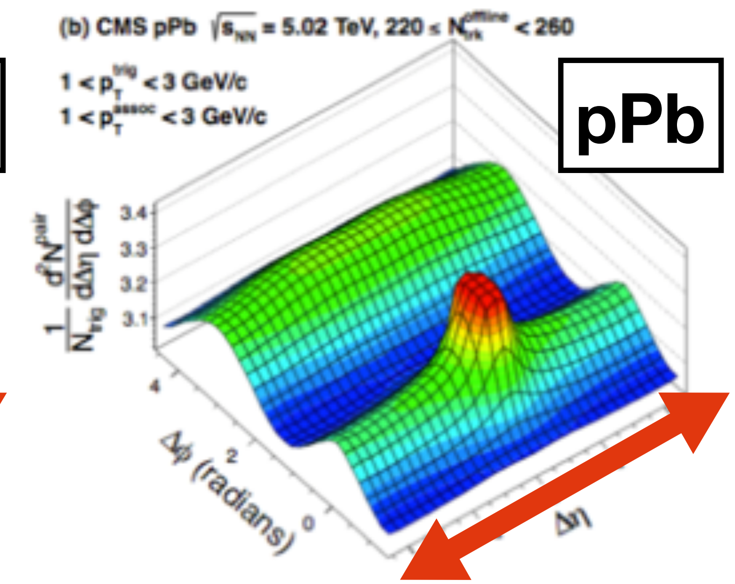
The collective flow has **not initially been expected in small collision systems.**

However

Elliptic flow and long-range angular correlation structure have been observed in small systems at RHIC and LHC.



Heavy ion collision



small system

Measured v_2 is expected to include contributions of high momentum particles and elastic scattering. ⇒ **non-flow effect**

How much do non-flow effects contribute to v2 in small systems?

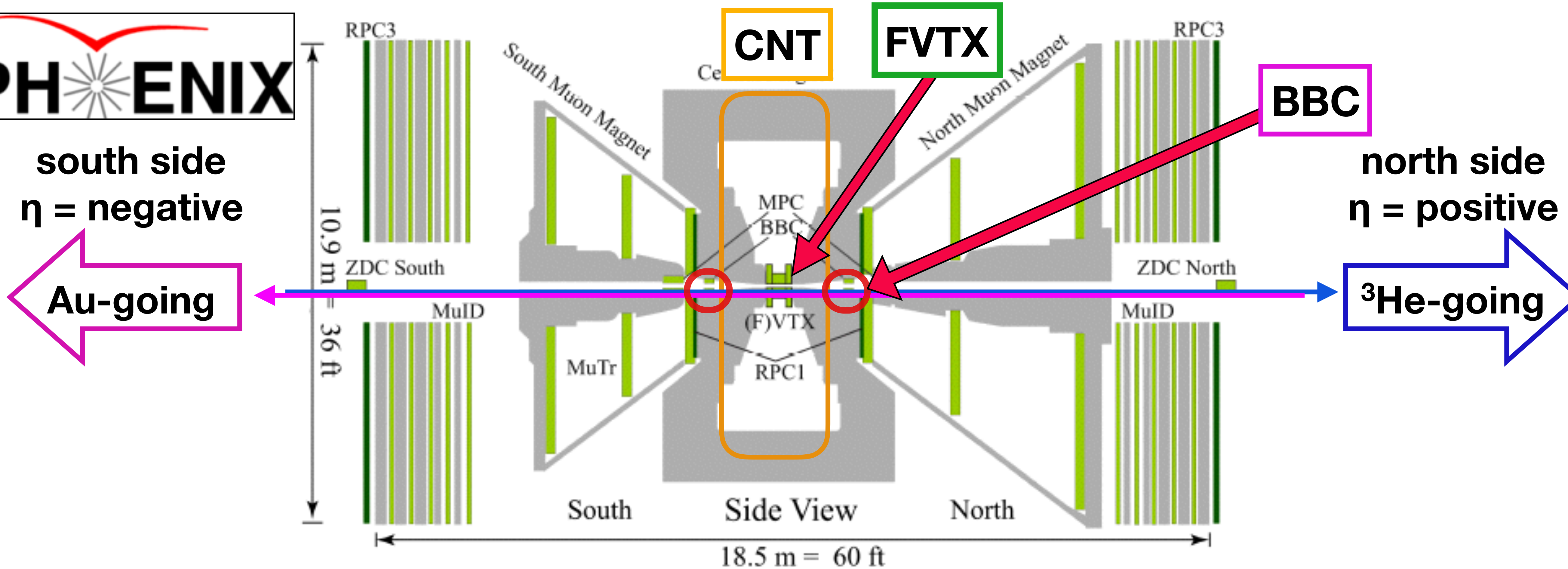
Motivation

(1) Measure v_2 by conventional method(two particle correlation method)

(2) Remove non-flow effect and measure v_2 (Future plan)

(3) Comparison between (1) and (2) (Future plan)

PHENIX(the **P**ioneering **H**igh **E**nergy **N**uclear **I**nteraction e**X**periment)



- **Central Arm Detectors(CNT)** $|\eta|<0.35$

Particle identification, 3D tracking , momentum measurement

- **Forward Silicon Vertex Tracker(FVTX)** $1.5 < |\eta| < 2.5$

  Silicon strip detecter, it can tracking by detected points.

- **Beam Beam Counter(BBC)** $3.0 < |\eta| < 3.9$

  BBC has 64 elements(PMT and quartz Cherenkov radiator) for each side.
  Measured signals are used as Centrality , collision point and Event trigger.

Two-particle correlation method and Event mixing

Correlation function is measured as the azimuthal pair distribution.
$\phi_{Trig.}$ and $\phi_{Asso.}$ are azimuthal angle of trigger and associate particle.

$$\Delta\phi = \phi_{asso} - \phi_{trig}$$

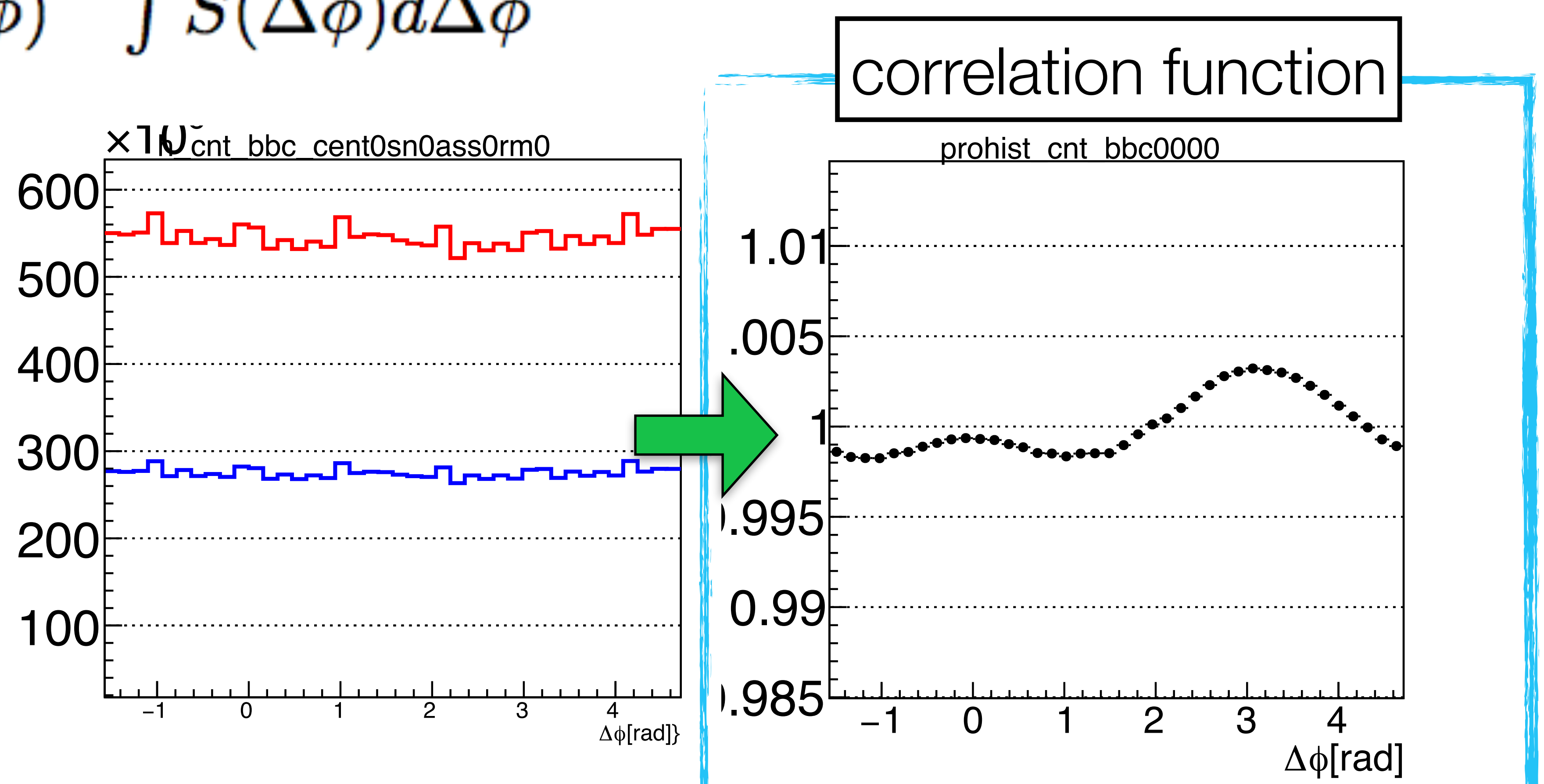
Event mixing

⇒ Event mixing is done to reduce acceptance and efficiency .

$$C(\Delta\phi) = \frac{S(\Delta\phi)}{B(\Delta\phi)} \cdot \frac{\int B(\Delta\phi)d\Delta\phi}{\int S(\Delta\phi)d\Delta\phi}$$

mix event:B
efficiency
(2 particle from other event)

real event:S
signal + efficiency
(2 particle from same event)



v_n extraction (Fourier fitting and 3-sub method)

- **Fit correlation function with 4th Fourier formula and obtain C_n**

$$F(\Delta\phi) = N_0(1 + \sum_{n=1}^{4} 2C_n \cos(\mathrm{n}\Delta\phi))$$

- **Obtained C_n can be written as below,**
  v_n^a and v_n^b are v_n for each detectors.

$$C_n = {v_n}^a * {v_n}^b$$

- **v_n parameters are extracted by 3-sub method with 3 type correlations.**

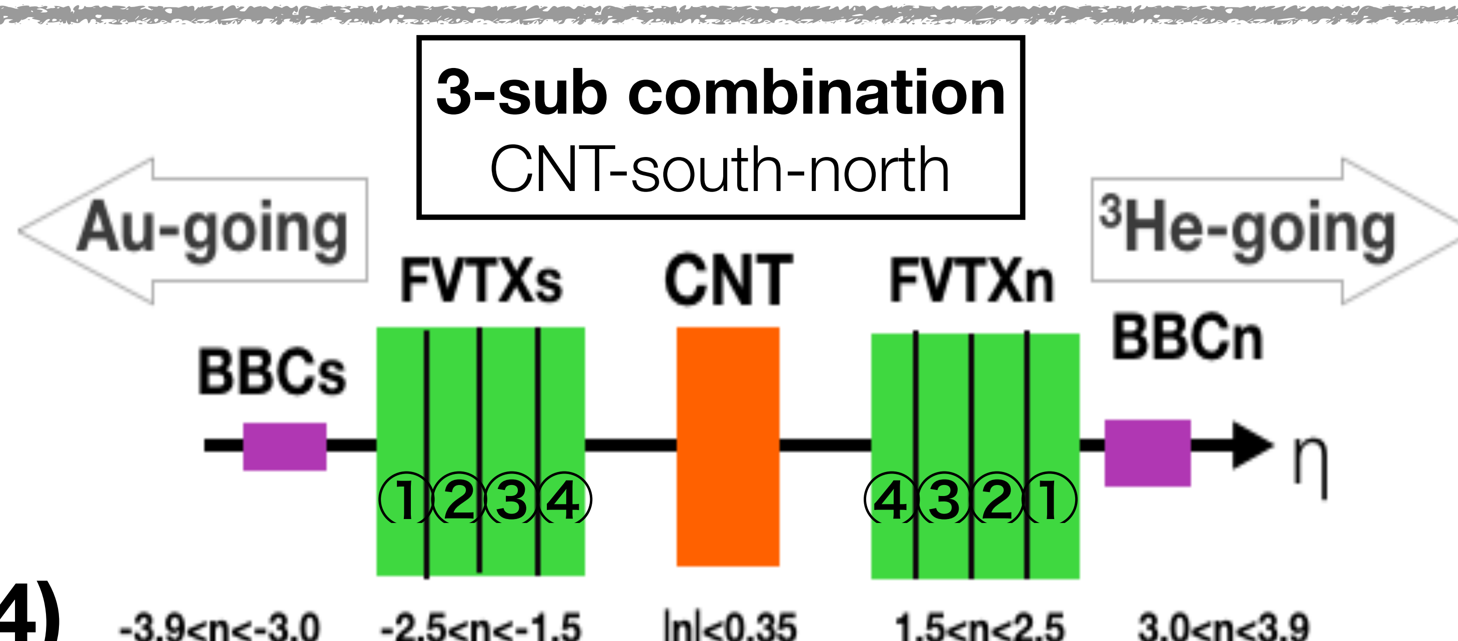
$$ {v_n}^a = \sqrt{\frac{{C_n}^{ab}{C_n}^{ac}}{{C_n}^{bc}}}$$

$${C_n}^{ab} = {v_n}^a * {v_n}^b$$
$${C_n}^{bc} = {v_n}^b * {v_n}^c$$
$${C_n}^{ac} = {v_n}^a * {v_n}^c$$

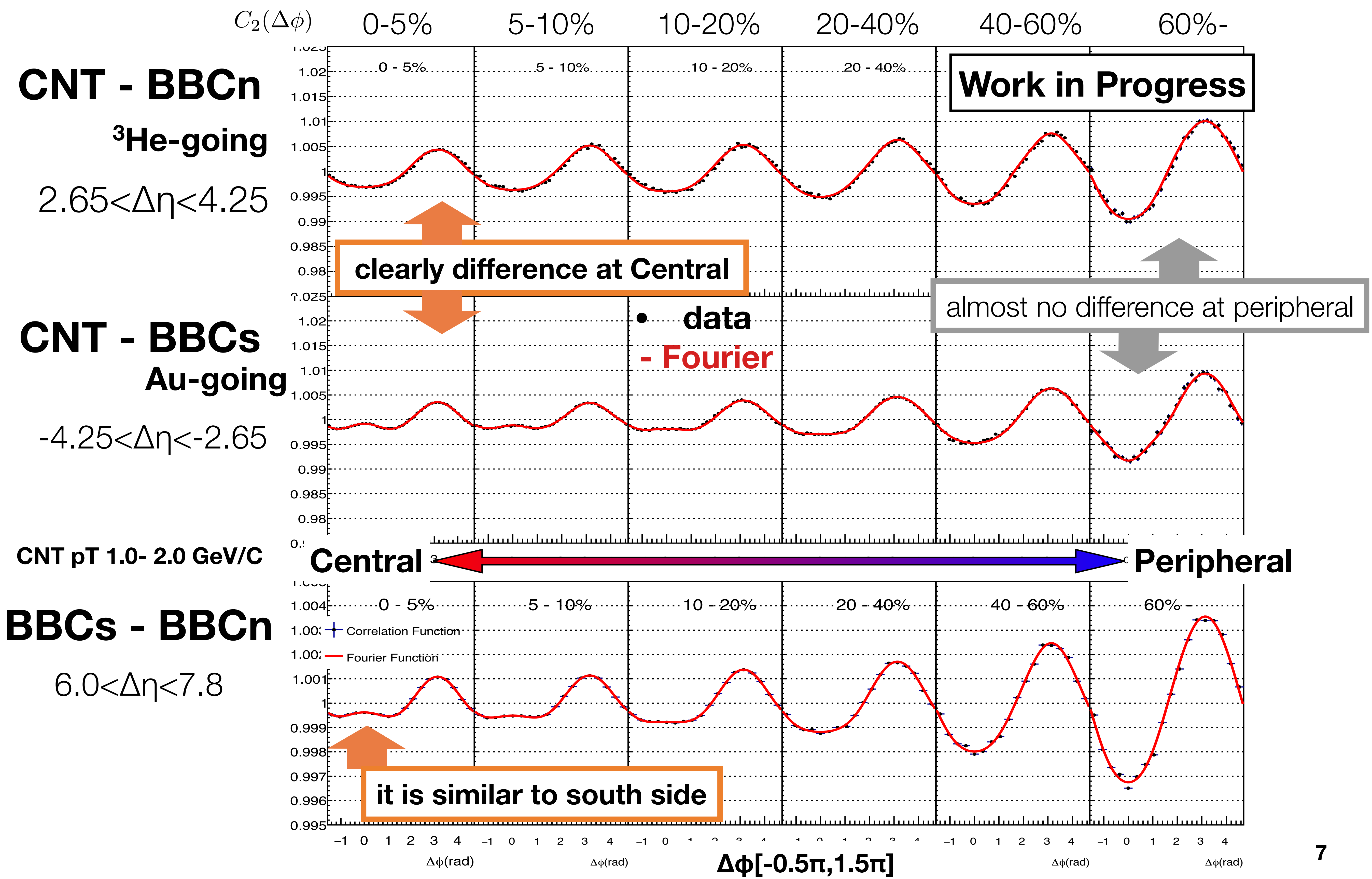
a,b,c = detectors

In this analysis,
used 3-sub combinations
have symmetric eta-gap.

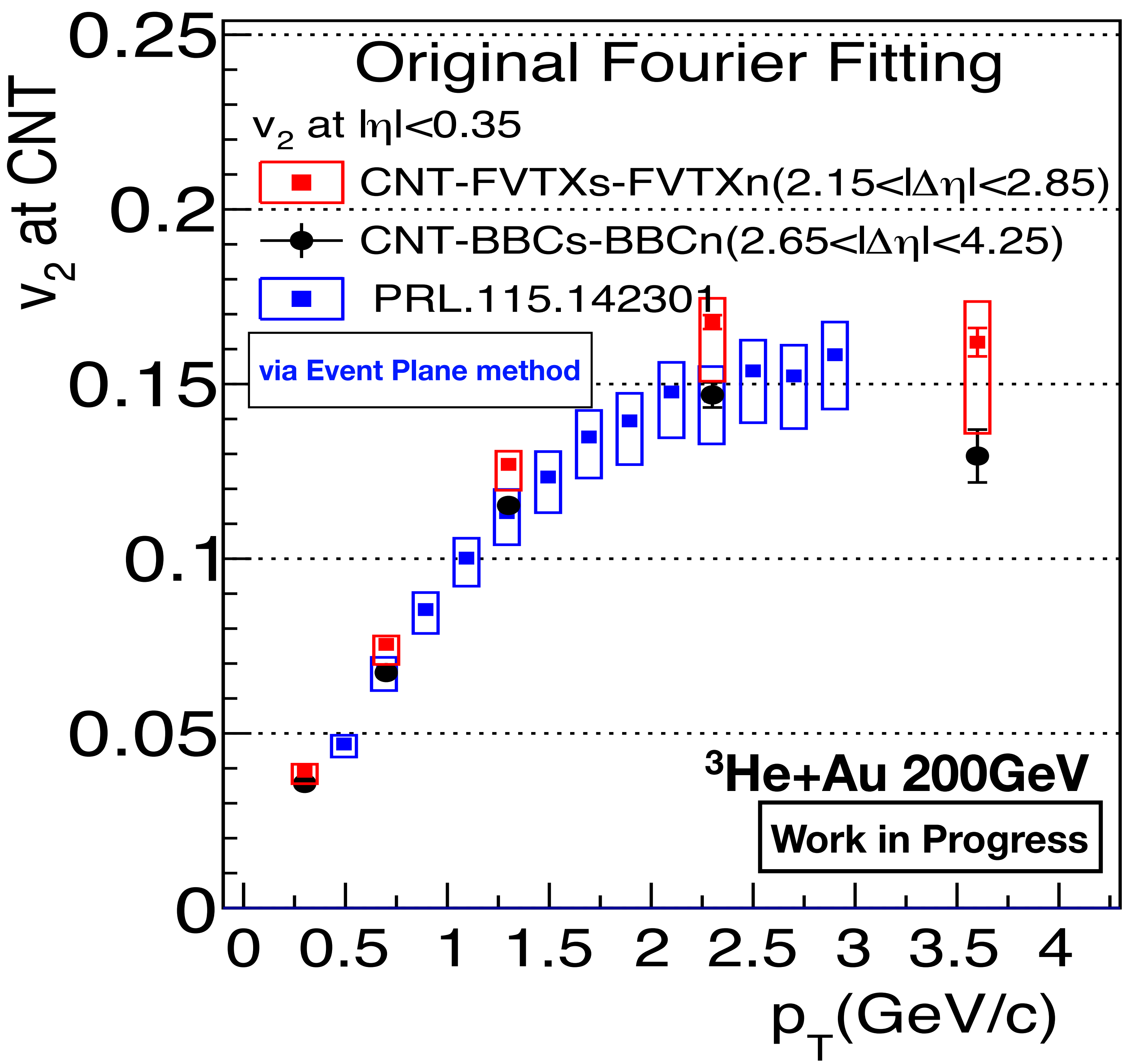
CNT-BBCs-BBCn
CNT-FVTXs(1-4)-FVTXn(1-4)



Correlation functions in CNT-BBCs-BBCn



p_T Dependence of v_2 at $|\eta|<0.35$ (Centrality:0-5%)



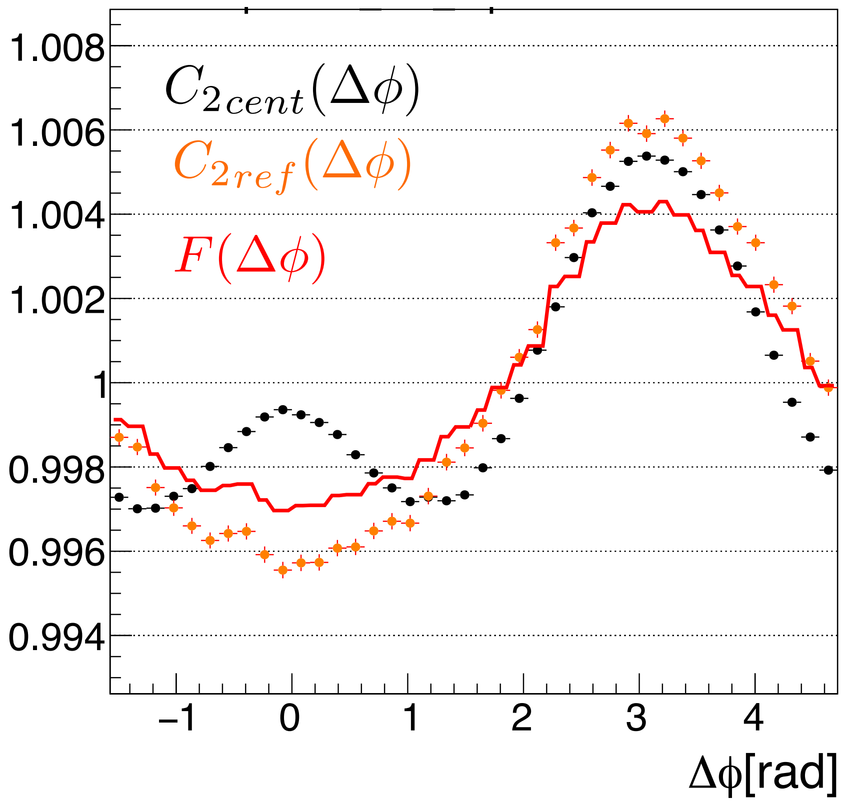
- v_2 from this work is consistent with previous publication. (blue symbols , measured by Event plane method)
- Is the Usual Fourier v_2 extraction strongly biased by different eta-gap (and pT)?

Reference fitting method

Reference fitting is done to **reduce effect of non-flow** and to **elucidate centrality dependence of v_2^{Ref}.**

Distribution of non-flow effect should have **constant parameters(ε_2, v_2...).**

Peripheral correlations are used as **reference function**.



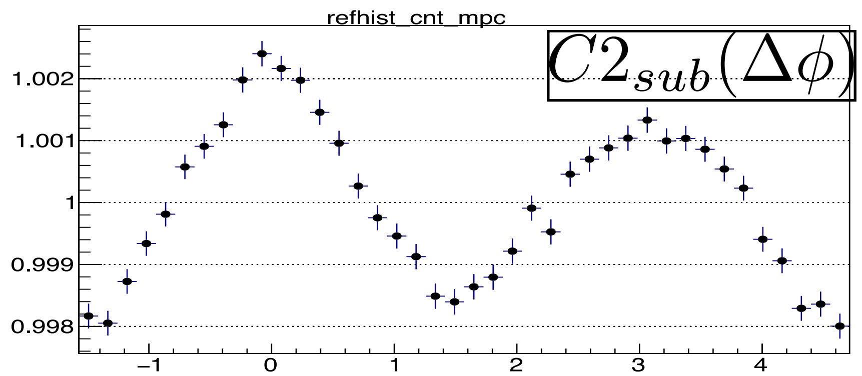
$$C_{2Cent}(\Delta\phi) = \text{ soft + non-flow}$$
$$C_{2Ref}(\Delta\phi) \simeq \text{non-flow}$$

A difference of $c_2(\Delta\phi)$ shape from reference function can be taken as evolution of $v_{2,\,ref}$.

$$F(\Delta\phi) = a * C_{2ref}(\Delta\phi) + b$$

F(Δϕ) defined by peripheral event is subtracted from central correlation function. (peripheral v2 is subtracted.)

$$C_{2sub}(\Delta\phi) = C_{2Cent} - F(\Delta\phi) + 1$$



Fit subtracted correlation function with Fourier formula and extract $v_2^{ref.}$ by 3-sub method.

$$F(\Delta\phi) = N_0(1 + \sum_{n=1}^{4} 2C_n\cos(n\Delta\phi)) \quad v_n^{Ref.} = \sqrt{\frac{C_n{}^{ab}C_n{}^{ac}}{C_n{}^{bc}}}$$

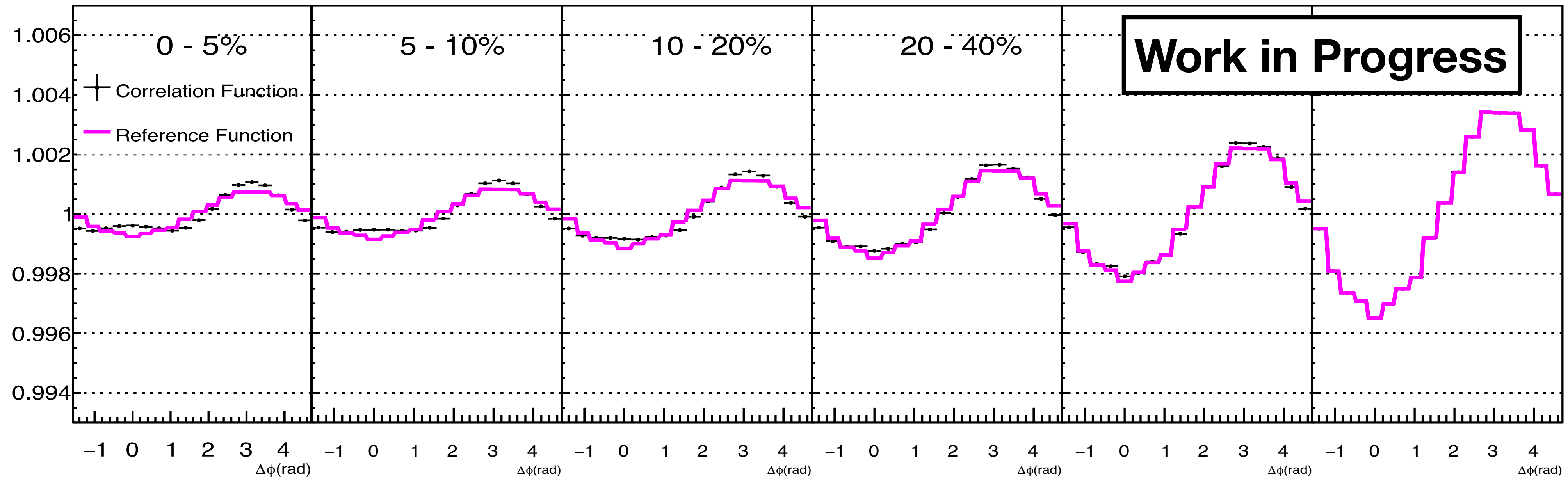
Comparison with reference function and $C_{2,sub}(\Delta\phi)$

BBCs- BBCn correlation

$F(\Delta\phi) = a * C_{2ref}(\Delta\phi) + b$ — **Reference function**

Centrality 0 - 5% 5 - 10% 10 - 20% 20 - 40% 40-60% Ref. (>60%)

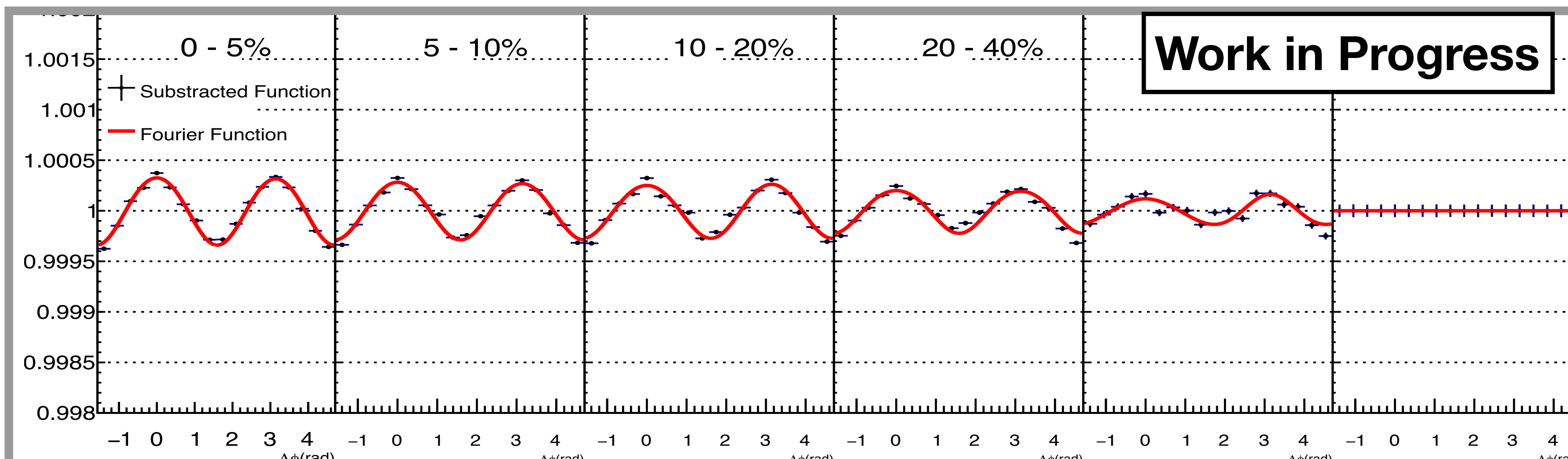
C_{2cent} and C_{2ref}



Subtraction

$$C_{2sub}(\Delta\phi) = C_{2Cent} - F(\Delta\phi) + 1$$

after subtraction



v_2^{Ref} will be extracted with using subtracted correlations

Summary and Outlook

- v_2 via two-particle correlation method is consistent with previous publication.
- **Is the Usual Fourier v_2 extraction strongly biased by different eta-gap (and pT)?**
- After Reference Fitting,
  - Subtracted correlation functions show double peak.

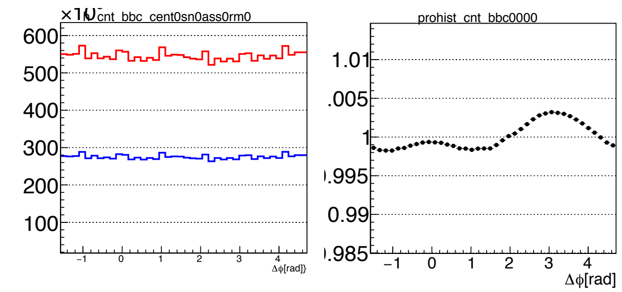
Outlook

- Extract v_2 from subtracted correlation by Reference fitting
- Compare v_2 extracted by Reference fitting with previous results

Back up

Analysis flow

- **2 particle correlation**



- **event mixing**

$$C(\Delta\phi,\Delta\eta)=\frac{\int N_{\mathrm{mix}}\Delta\phi\Delta\eta}{\int N_{\mathrm{real}}\Delta\phi\Delta\eta}\frac{N_{\mathrm{real}}(\Delta\phi,\Delta\eta)}{N_{\mathrm{mix}}(\Delta\phi,\Delta\eta)}$$

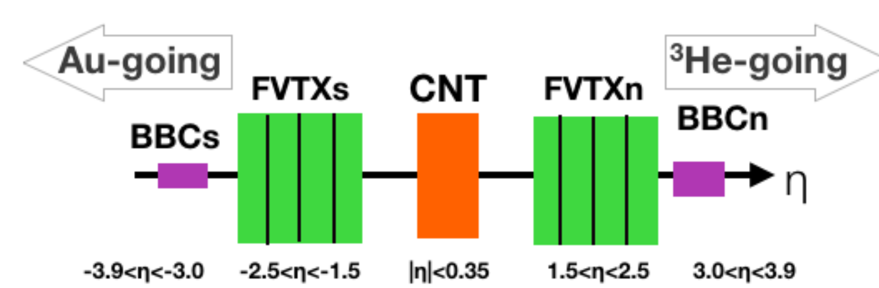
- **Fit by Fourier function.**
- **Obtain Fourier coefficients Cn**

$$F(\Delta\phi)=N_0(1+\sum_{n=1}^{4}2C_n\cos(\mathrm{n}\Delta\phi))\quad C_n={v_n}^a*{v_n}^b$$

- **Calculate v_n by 3-sub method**

$${v_n}^a=\sqrt{\frac{{C_n}^{ab}{C_n}^{ac}}{{C_n}^{bc}}}$$

3-sub combinations
CNT - south - north(symmetric eta gap)



Data Set

RHIC-PHENIX Run14 ^{3}He+Au collisions $\sqrt{S_{NN}}$ = 200GeV

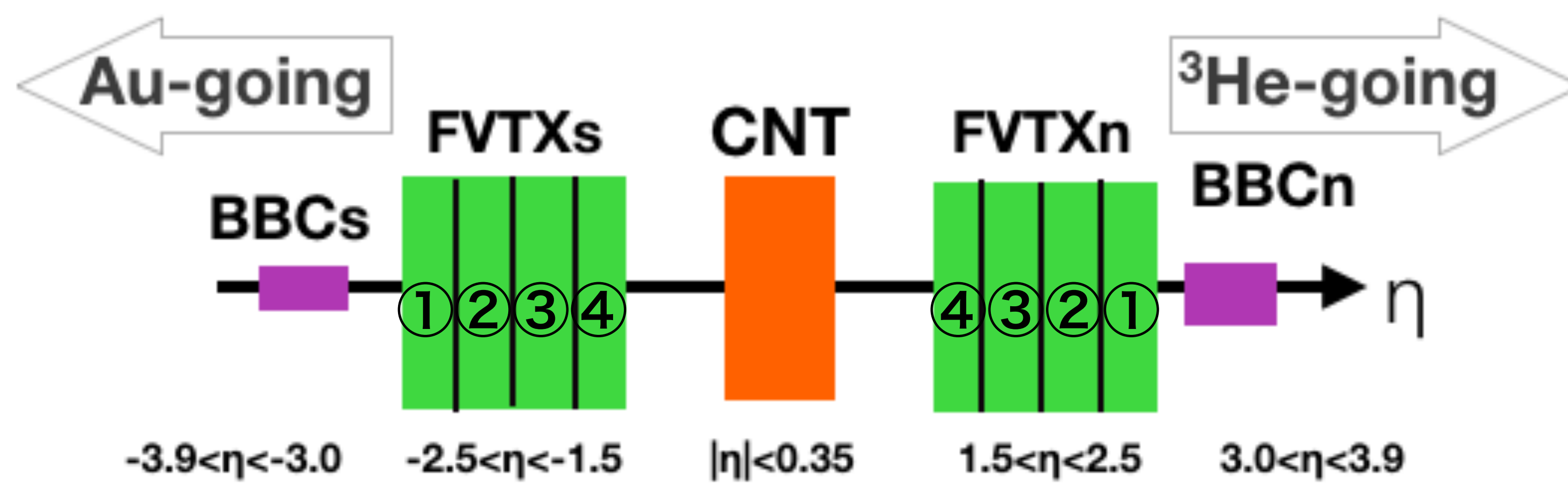
Event Cut :$BBC_Z \neq 0.0$, |BBCz| < 10 [cm] ,|BBCz - FVTXz| < 2.0cm

Centrality : BBCsouth multiplicity (MB+High-Mul.Trig)

Detectors

CNT($|\eta|<0.35$) BBC($3.0<|\eta|<3.9$)

FVTX($1.5<|\eta|<2.5$):FVTX tracks are divided to **8 region** by eta (0.25 step)



Event Mixing Class

10 classes about BBCz

6 classes about centrality

(0-5,5-10,10-20,20-40,40-60,60-%)

Track cut

- **CNT Track**

0.2 < mom<5.0 , |pc3dphi|<3σ , |pc3dz|<3σ
(tracking quality = 31 or 63) ,|zed|<70

- **BBC PMT**

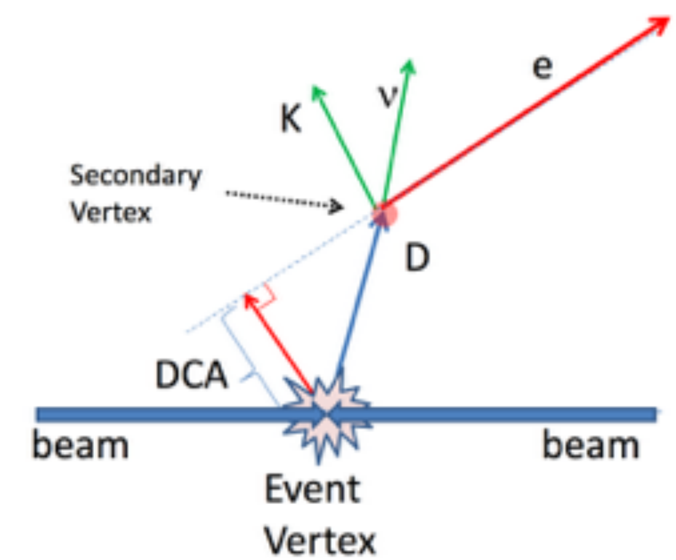
cut hit time >0, charge >0

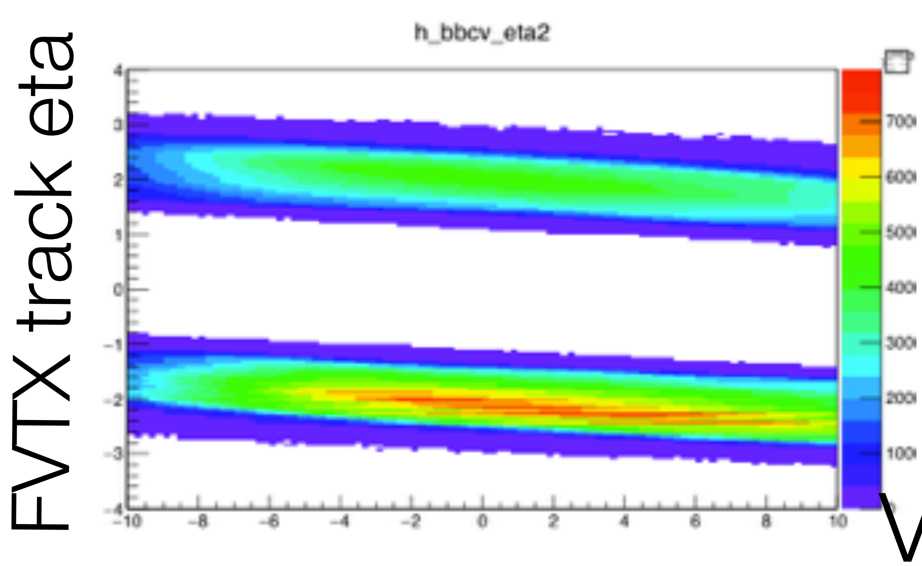
- **FVTX track**

χ2 < 5.0, nhits ≧ 3
$\sqrt{(\sigma_{DCA\_x}^2+\sigma_{DCA\_y}^2)} < 2.0$;

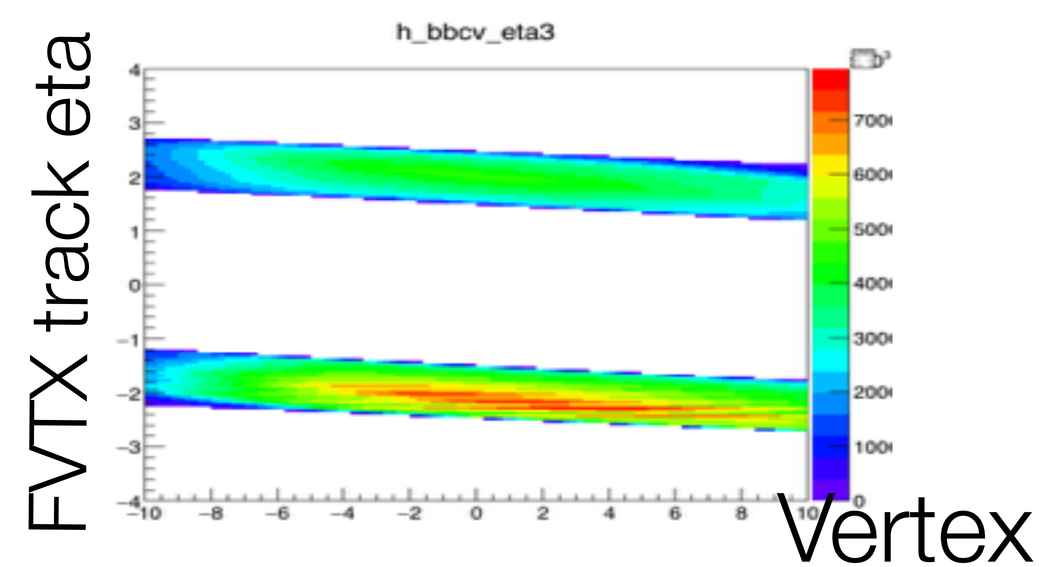
Eta acceptance cut

$$-0.025*BBC_Z - 2.45 < \eta < -0.025*BBC_Z - 1.5$$
$$-0.025*BBC_Z + 2.45 > \eta > -0.025*BBC_Z + 1.5$$





Cut



p_T Dependence of $v_2^{Fourier}$ (Cent:0-5%)