Single muon elliptic flow
for Au+Au collisions at 200GeV
in the PHENIX experiment at RHIC

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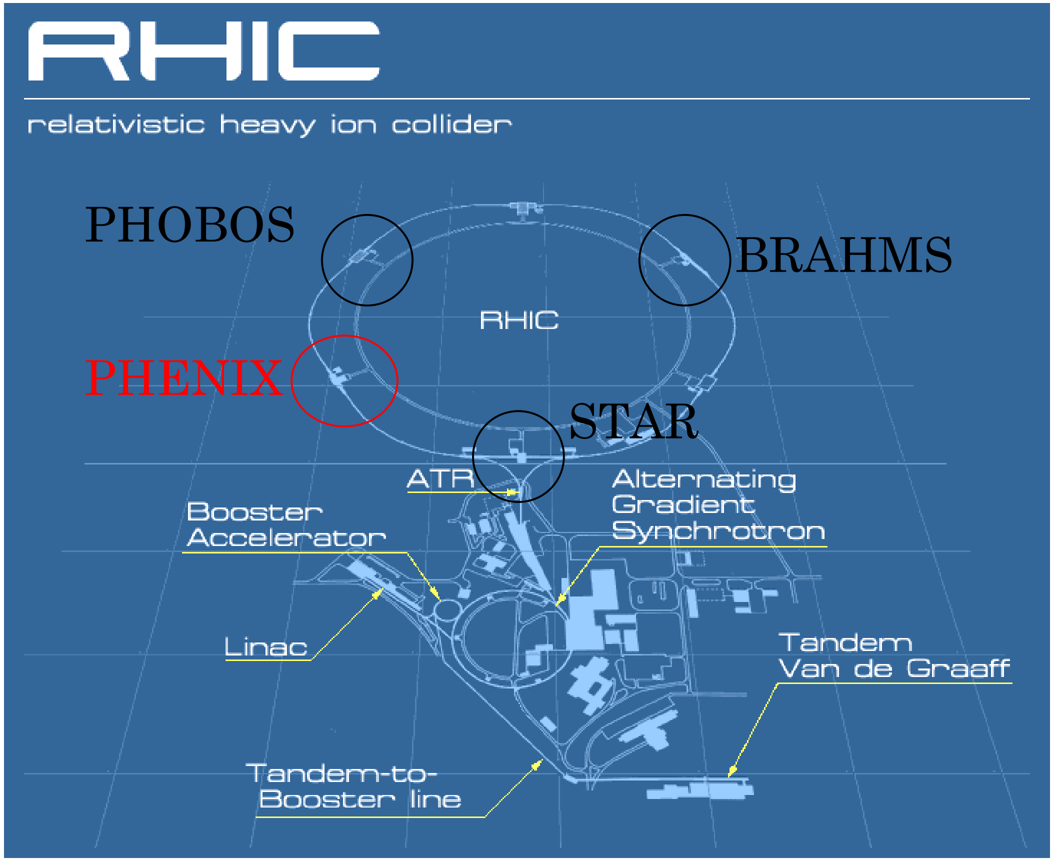
Overview

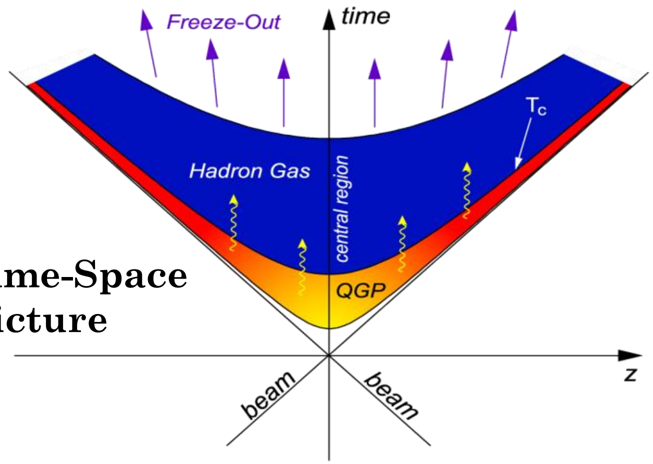
1. Heavy Ion Collision at RHIC
3. Motivation
4. Kind of Flow
5. How to measure
6. Results

Heavy Ion Collision at RHIC

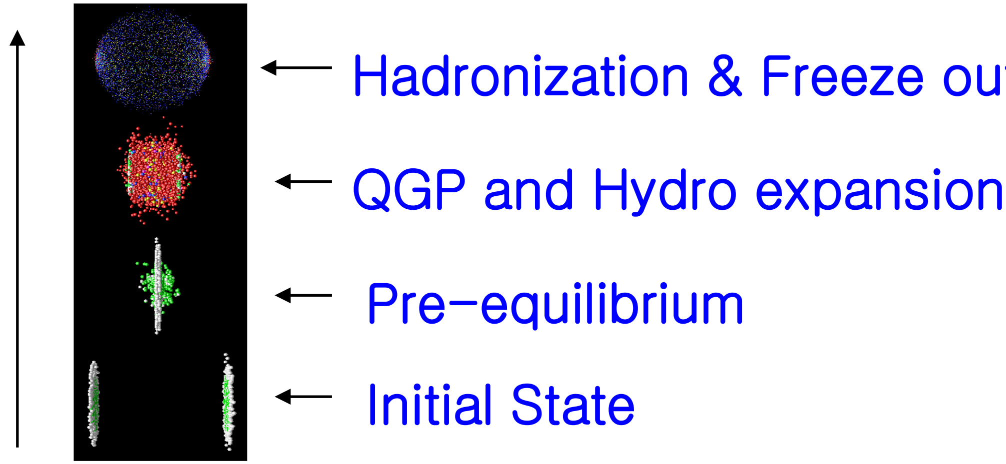


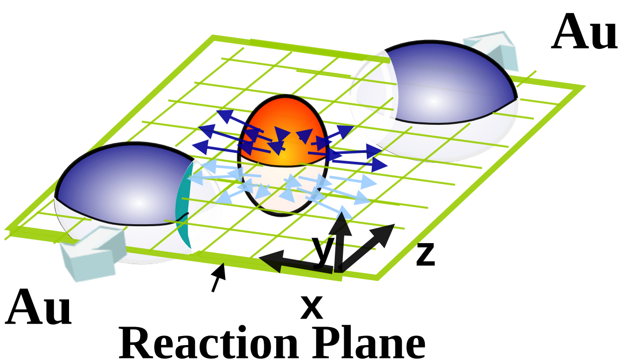
Relativistic Heavy Ion Collider,
Brookhaven National Laboratory(BNL), NewYork

Motivation

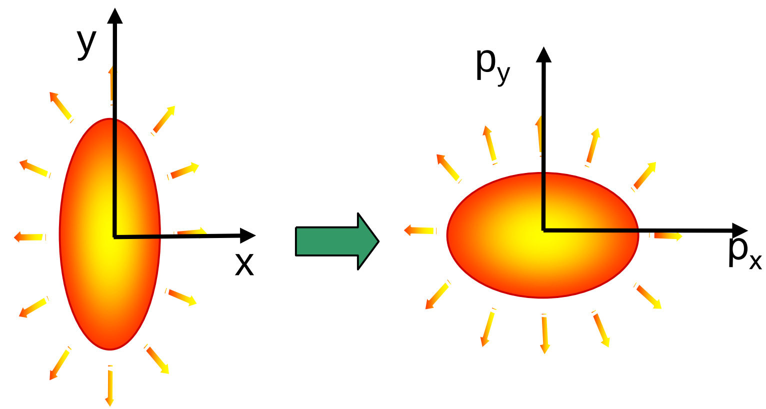


Time-Space Picture





Flow tell Equation of State (Eos)
and Degree of thermalization in the QGP

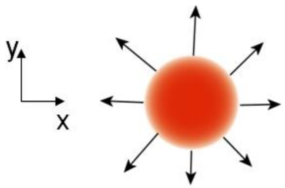


Almond shape Overlap region in Coordinate space

Momentum anisotropy

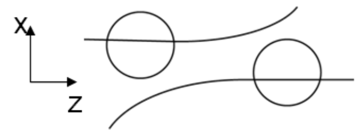
Flow components

Radial Flow (Isotropic) β_T, P_T



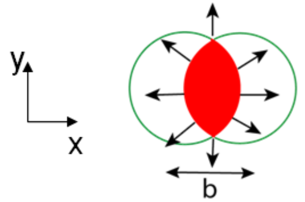
Flows

Directed Flow (v_1)

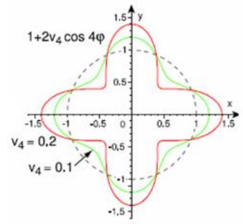


Anisotropic Flow

Elliptic Flow (v_2)



Higher Harmonics (v_4, v_6 …)



Flow Measure Methods

1) Reaction plane Method (Standard Method)
   - Need Reaction plane

$$v_n = \left\langle e^{in(\phi-\Psi_r)} \right\rangle$$
$$= \left\langle \cos n(\phi - \Psi_r) \right\rangle$$

2) Two particle correlation method
   - Do not need the reaction plane

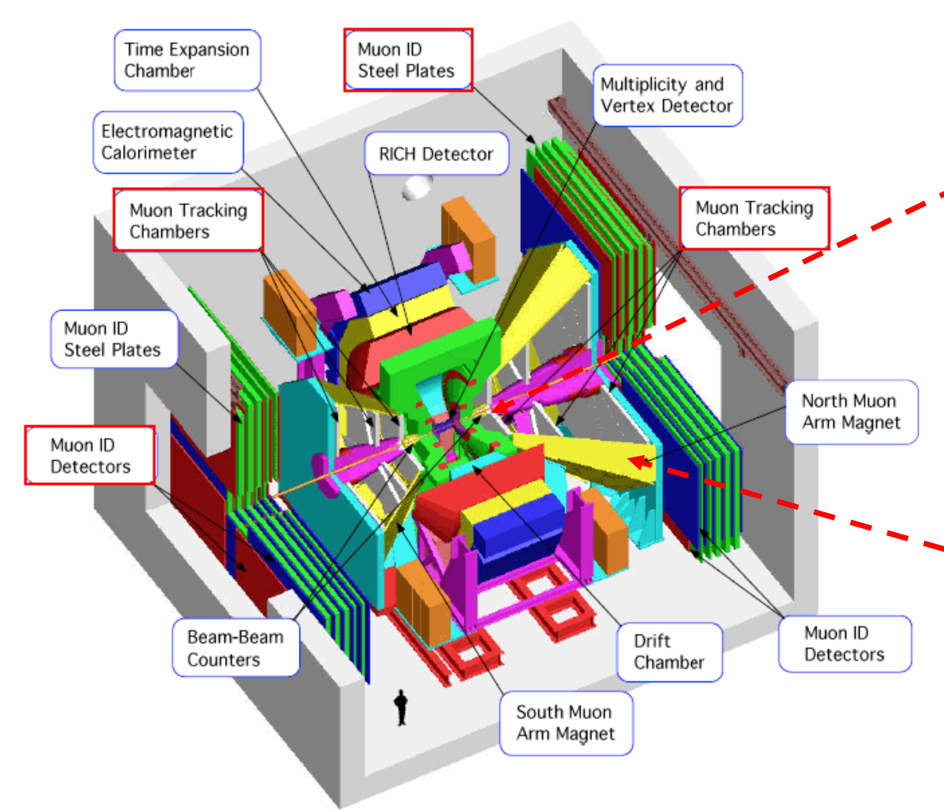
$$C(\Delta\phi) \equiv \frac{N_{pairs}(\Delta\phi)}{N_{mixed}(\Delta\phi)}$$

3) Cumulant Method
   (Multi-particle correlation method)
   - Do not need the reaction plane

$$\langle \exp[in(\phi_1 + \phi_2 - \phi_3 - \phi_4)] \rangle$$
$$= \left\langle e^{in(\phi_1-\phi_3)} \right\rangle \left\langle e^{in(\phi_2-\phi_4)} \right\rangle + \left\langle e^{in(\phi_1-\phi_4)} \right\rangle \left\langle e^{in(\phi_2-\phi_3)} \right\rangle$$
$$+ \langle\langle \exp[in(\phi_1 + \phi_2 - \phi_3 - \phi_4)] \rangle\rangle$$

4) Mixed Method
   (Cumulant Method + Reaction plane method)
   - need the reaction plane

PHENIX Detectors



PHENIX Detectors

64 Channel for both Arms

$3.1 < |\eta| < 4.0$

2π

Reaction plane

$1.2 < \eta < 2.2$

$\varphi \sim 2\pi$

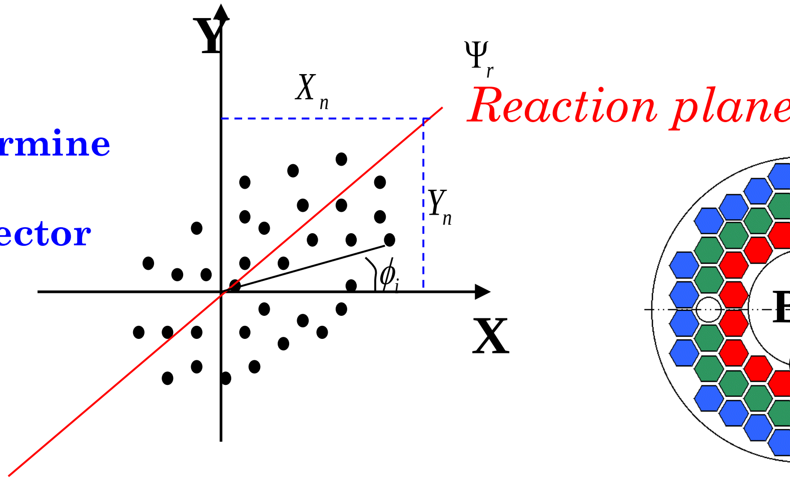
Single Muon Elliptic Flow

Muon Tracker with Muon ID
Hadron Absorber
3 Stations for each Arm
Muon Magnet

Reaction plane method

1)

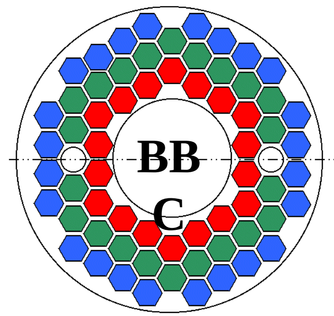
R.P determine from BBC detector

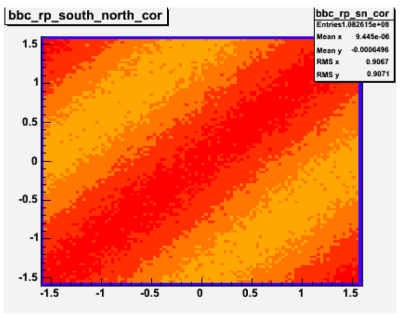


$$\Psi_n = \left(\tan^{-1}\frac{Y_n}{X_n}\right)/n$$

$$X_n = \sum_i w_i \cos(n\phi_i)$$

$$Y_n = \sum_i w_i \sin(n\phi_i)$$

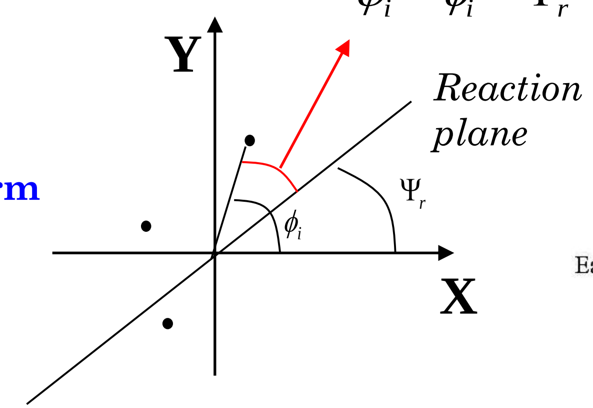




2)

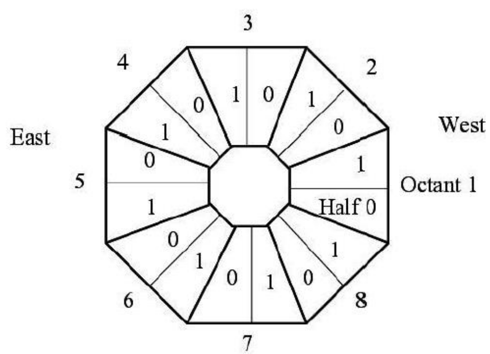
v2 from Muon Arm

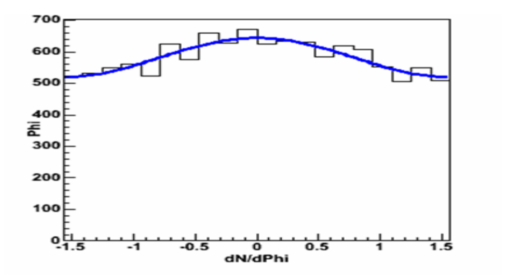
$$\varphi_i = \phi_i - \Psi_r$$



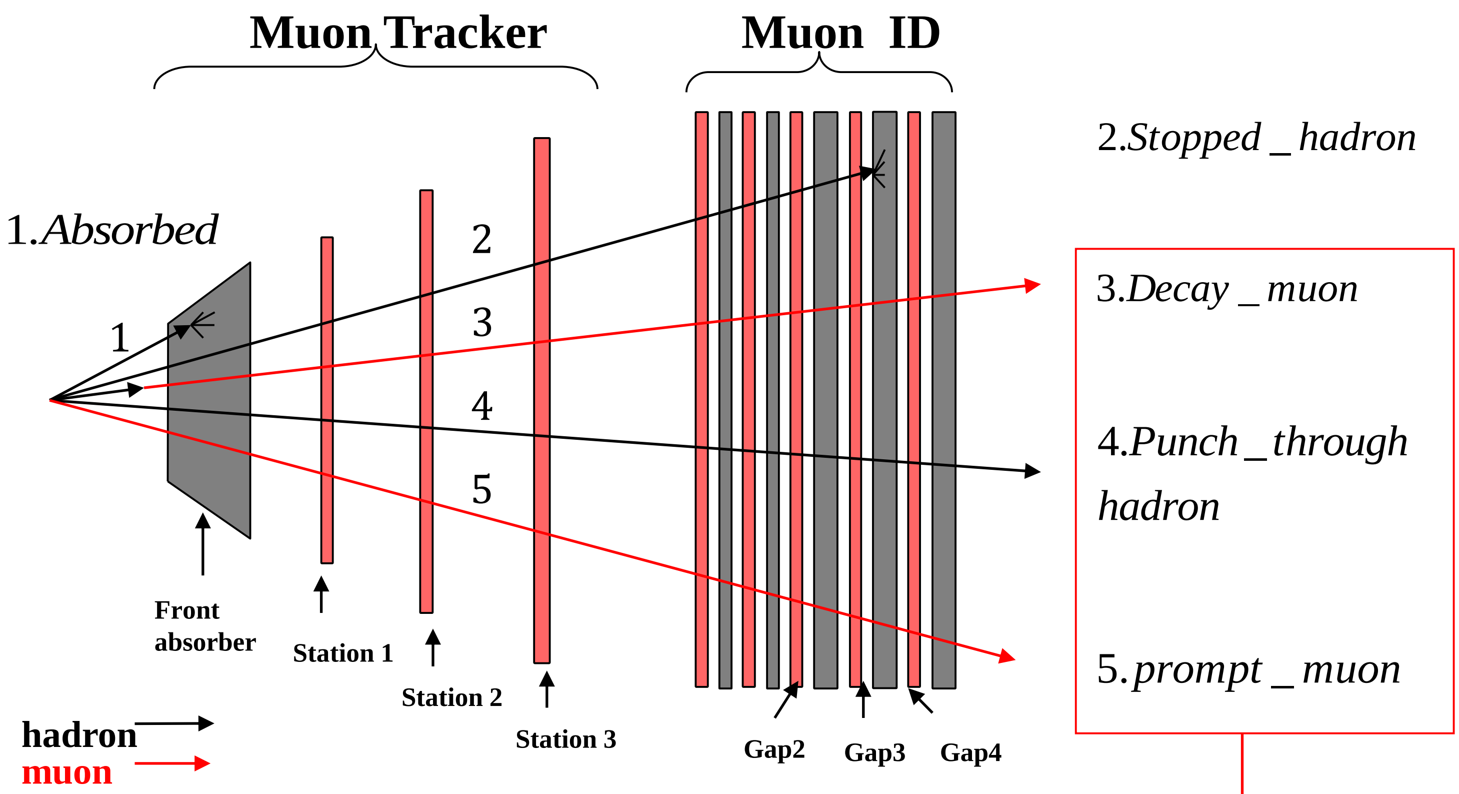
$$\frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1 + 2v_1\cos\varphi + 2v_2\cos 2\varphi + \ldots\right)$$

Elliptic Flow





What is "Inclusive single muons" ?

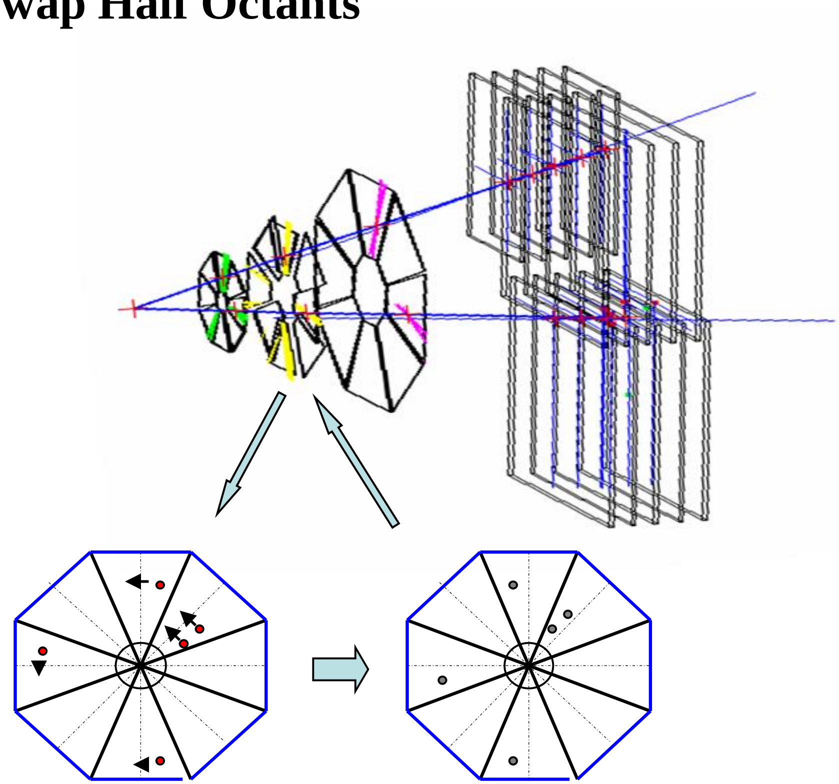


Case3, 4, 5 Sources of Inclusive single Muon tracks

Muon Tracker & Muon ID

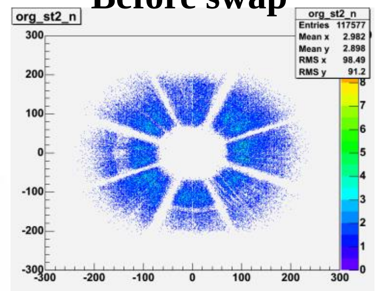
Combinatorial Background

Swap Half Octants

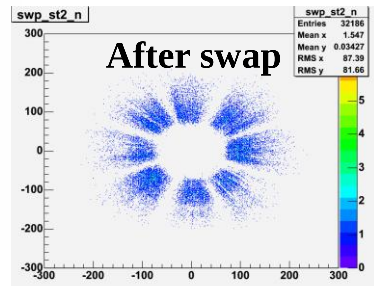


station2

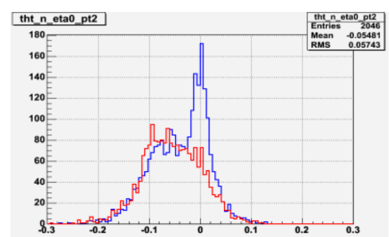
Before swap



Real and combinatorial background tracks



Almost combinatorial background tracks



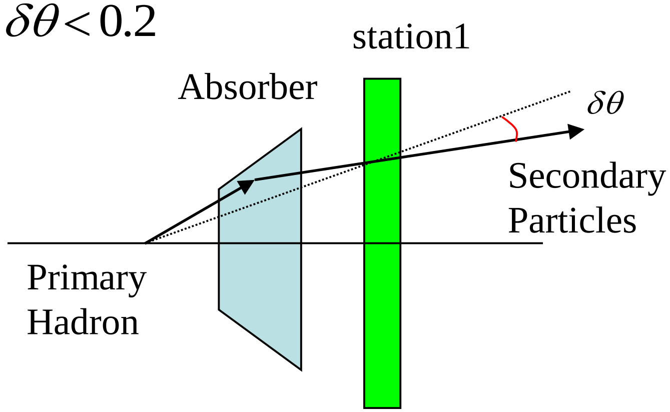
Phi angle difference Station 1 – Station3

Swap the half octant in the PHENIX Muon reconstruct code

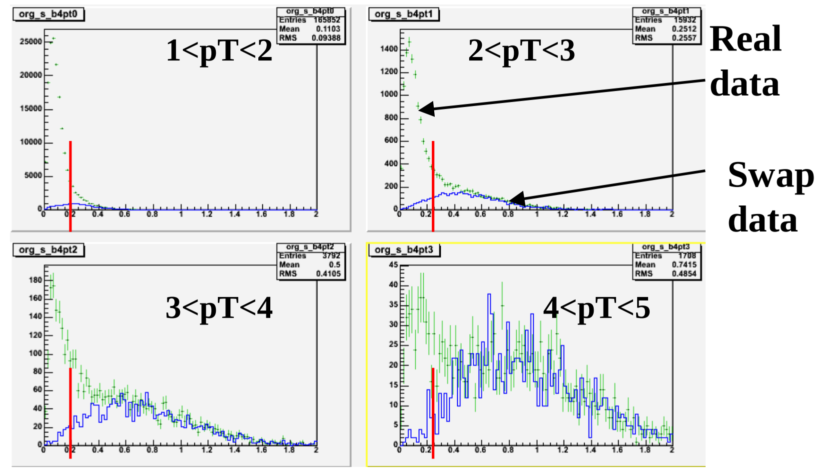
20Million events were reconstructed as swap data.

Two primary background rejection cuts

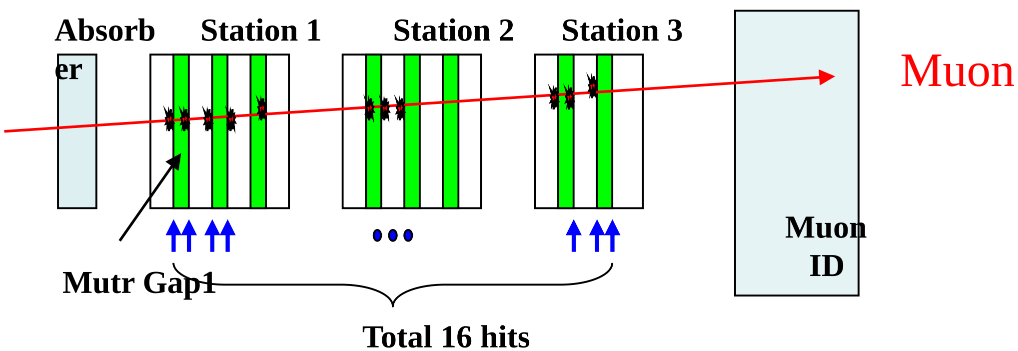
1) $P \times \delta\theta < 0.2$

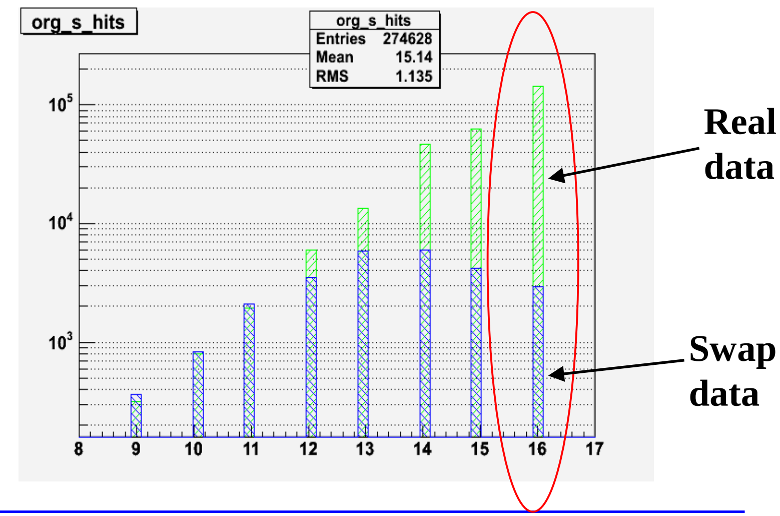


Cut off secondary particle



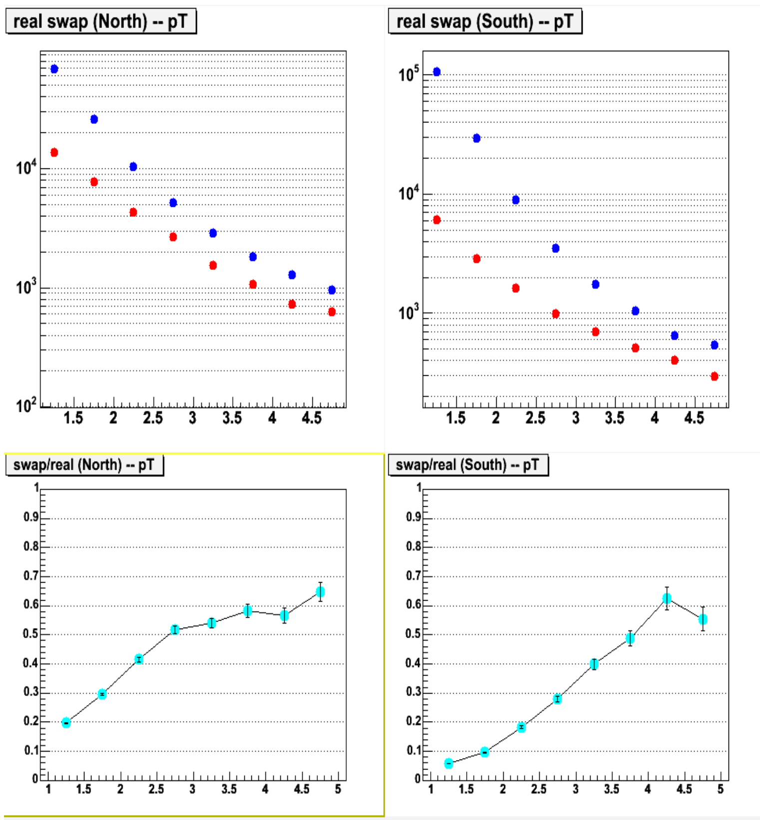
2) Mutr_nhits ==16





Swap/Real Ratios

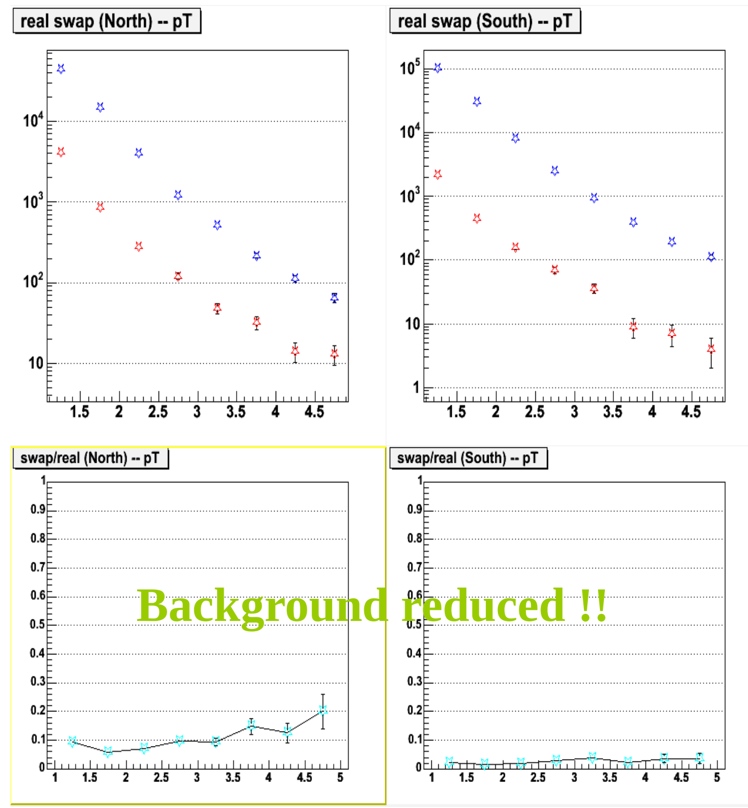
w/ old cut



Pt Dist.

Ratios

w/ new cut



Blue points -> Real data / Red points -> Swap data

We can reject the background tracks very well

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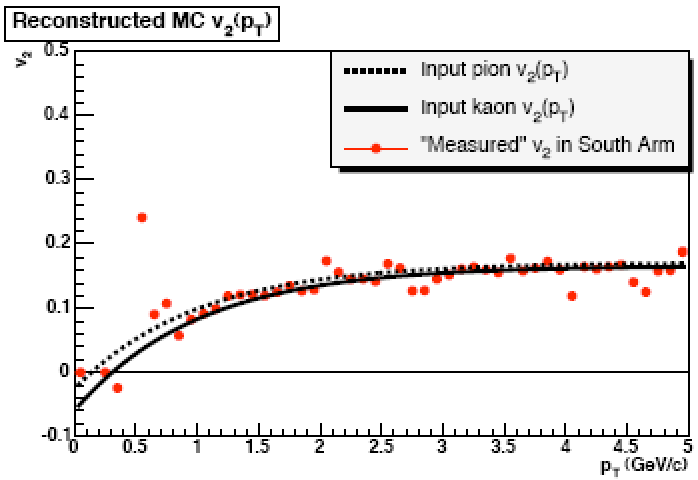
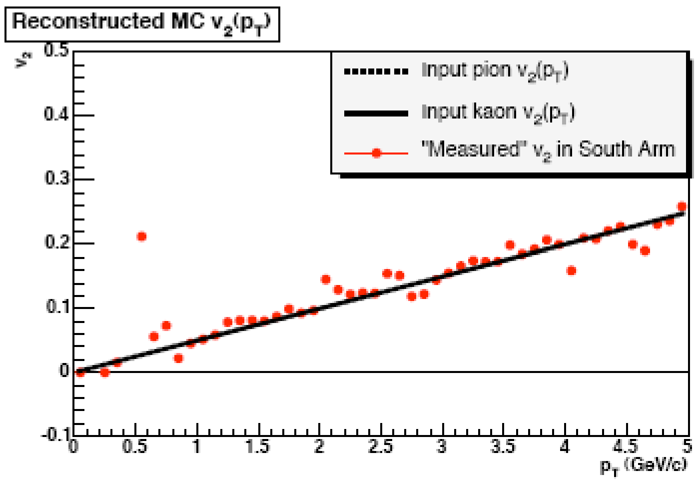
v2(pt) simulation in the Muon Tracker

10,000 pions+, 10,000 kaons+, 100MeV/c pT bin
Single track simulation



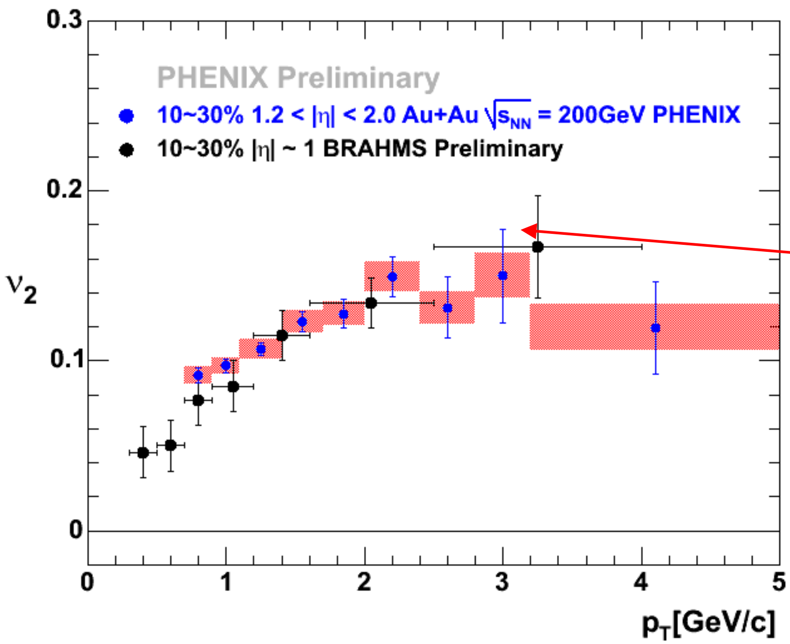


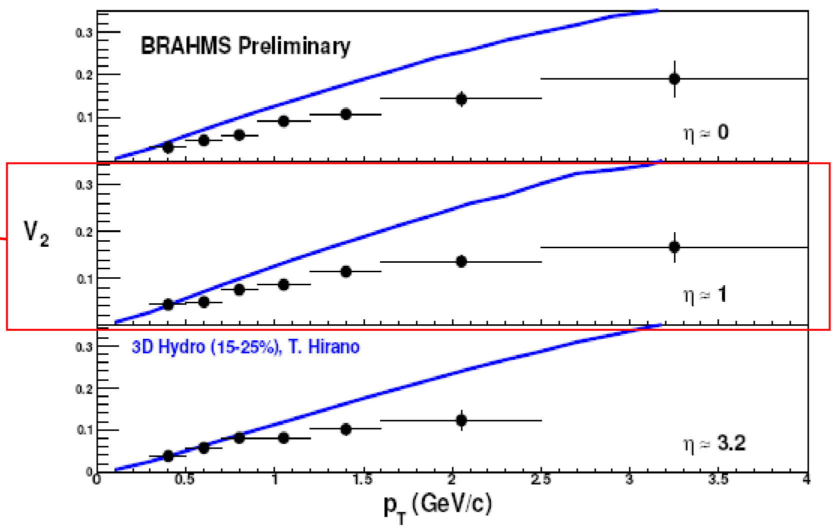
v2(pt) similar to PHENIX Central Arm measurements

v2(pt) for a linear functions

Above pT 0.7GeV/c show good agreement with reconstructed MC

Results : v2(pt) @ Centrality 10-30%

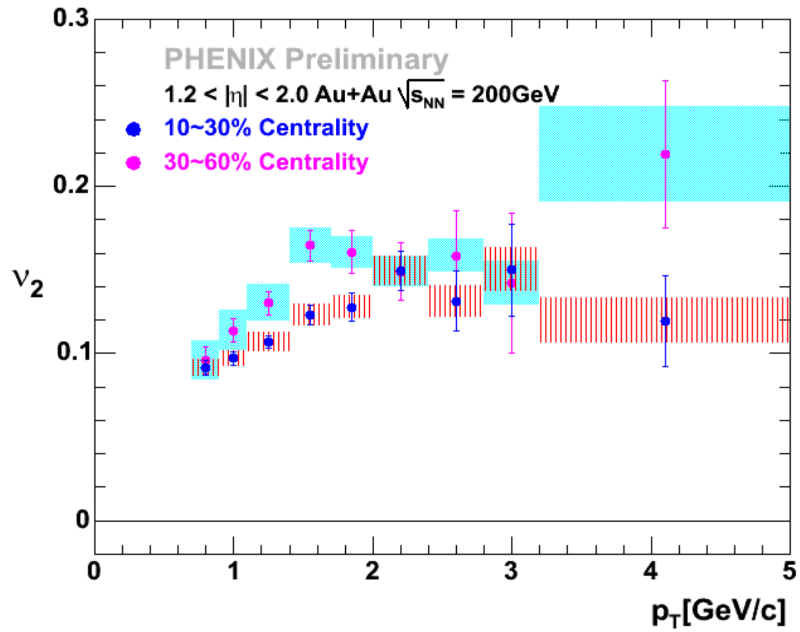




v2(pt) at centrality 10-30% (Blue points) w/ BRAHMS charged hadrons data

Pt dependent elliptic flow for charged hadrons – BRAHMS data.
For the 15% to 25%

Results : v2(pt) @ Centrality 30-60%



v2(pt) at centrality 10-30% (Pink Points)
with 30% - 60%(Blue)

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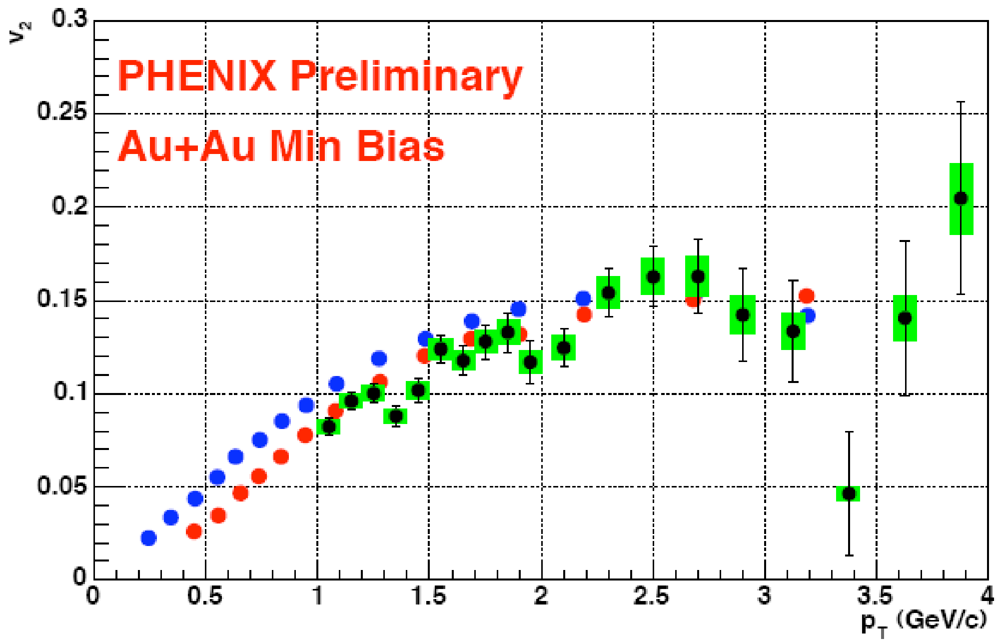
Results : Minimum Bias v2(pt)



Blue and red points are the Central Arm v2(pt) for pions and kaons
Black points are the Minimum Bias Elliptic flow at forward rapidity(Inclusive)

Summary

The Combinatorial Background track was big concern at single muon analysis in Au+Au collisions. We can now reject those tracks very well and do estimate the amount but we can lose the statistics.

The results have a good agreement with PHENIX Central Arm results and BRAHMS results.

The inclusive results showed here are just basic step to measure open charm Elliptic flow from the single muon particle in the Muon Tracker.

- We have produced all run4 Au+Au single muon data just a month ago.

Thank You

Backup

Cuts

Event Selection Cuts

-30cm < Collision Vertex < +30cm
BBC reaction plane angle > -10 (radian)
Minimum Bias Trigger($BBCN \geq 2 \& BBCS \geq 2$)

Track quality cuts

1.2 < |Eta| < 2.0
DG0<20, (North Arm <15)
DDG0<9
Muon ID Gap = 4 (LastGap)
$\chi^2 / DOF < 20$
Muon traks # hits = 16
$P(momentum) \times \delta\theta < 0.2$

Important cuts to reject fake tracks

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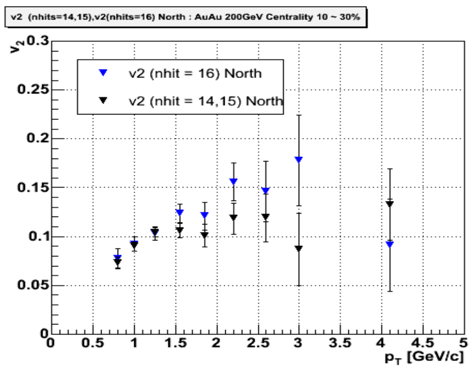
Sys. Error

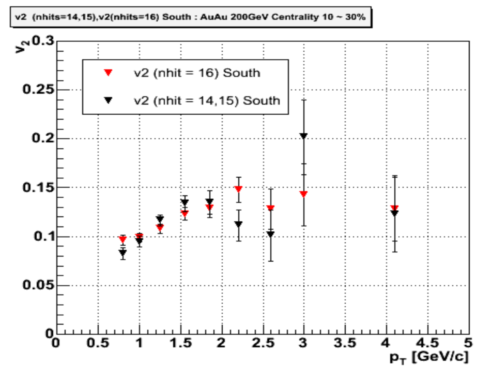
1) The source of systematic error comes mainly from the fake tracks. So by comparing v2 from the mutr_nhits(14,15) which have more b.g tracks than v2 from the mutr_nhits(16), we can estimate the systematic difference. -> next pages

2) The other source of systematic error comes from the reaction plane measurement in the BBC detectors, we estimate this effect less then 5%.

Sys. Error

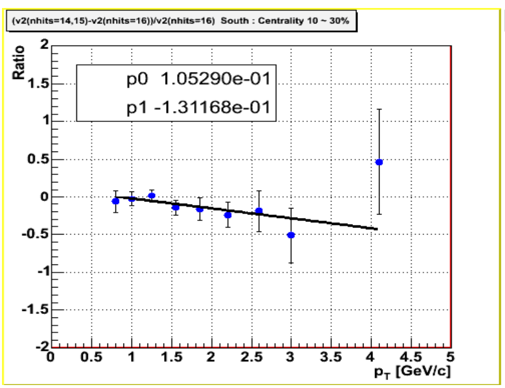
North Arm | **South Arm**

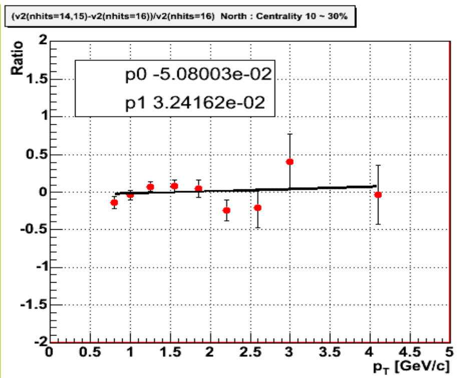




Centrality 10-30%

Differences
with mutr_nhits=14,15
and 16.



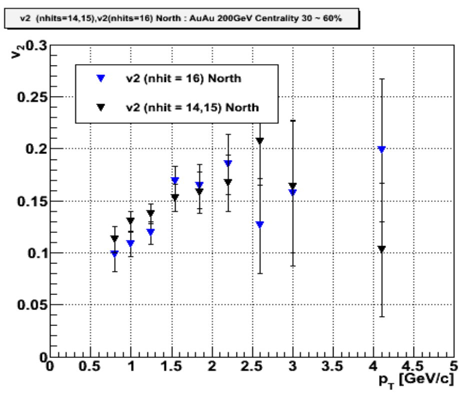


$$\frac{v_2(nhits=14{,}15)-v_2(nhits=16)}{v_2(nhits=16)}$$

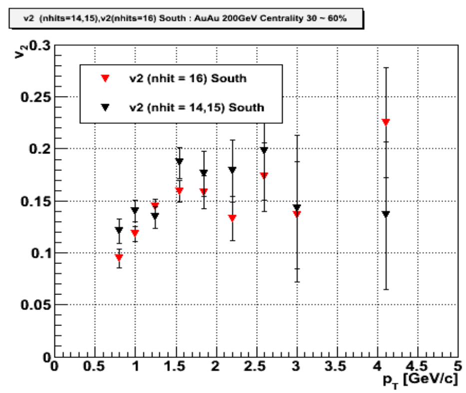
Linear fit

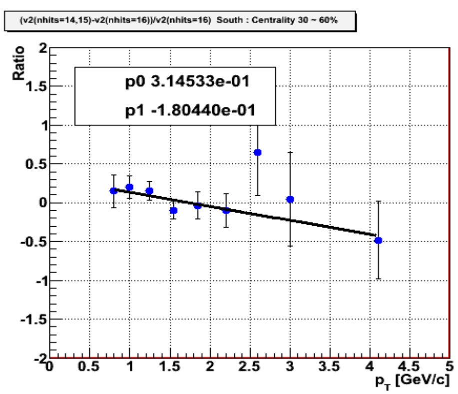
Sys. Error

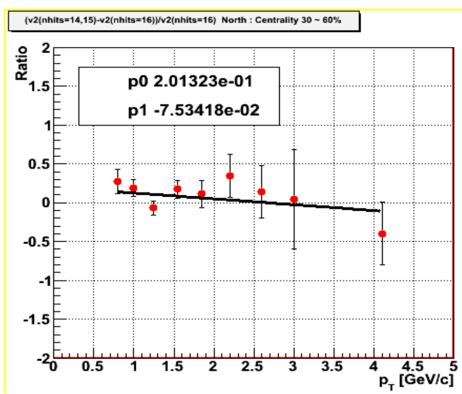
North Arm



South Arm







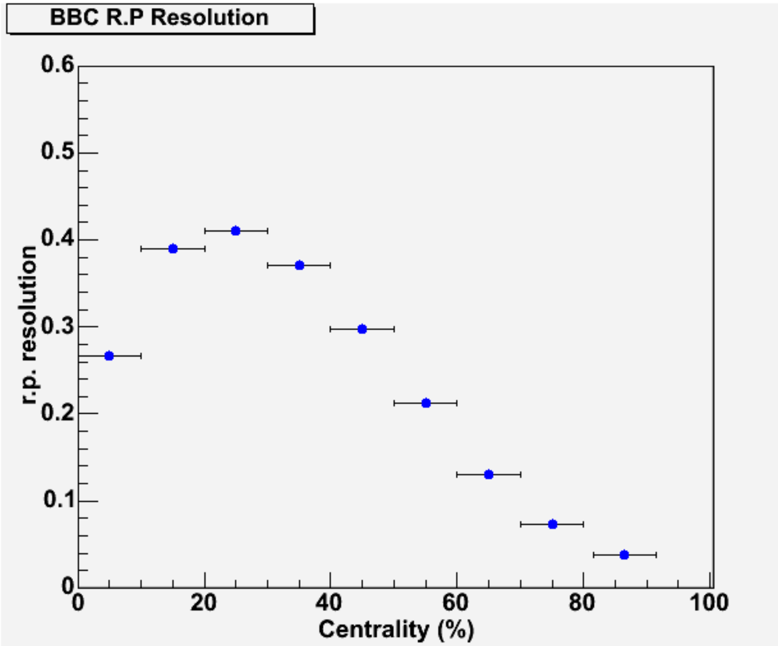
Centrality 30-60%

Differences
with mutr_nhits=14,15
and 16.

$$\frac{v_2(nhits=14,15) - v_2(nhits=16)}{v_2(nhits=16)}$$

Linear fit

Reaction Plane Resolution



Reaction Plane Resolution v.s. Centrality

centrality	Event plane resolution
0 - 5 %	0.2005 ± 0.0006
5 - 10 %	0.2952 ± 0.0004
10 - 15 %	0.3657 ± 0.0003
15 - 20 %	0.4016 ± 0.0003
20 - 30 %	0.4114 ± 0.0002
30 - 40 %	0.3780 ± 0.0002
40 - 50 %	0.3093 ± 0.0003
50 - 60 %	0.2208 ± 0.0004
60 - 70 %	0.1398 ± 0.0006
70 - 80 %	0.079 ± 0.001
80 - 93 %	0.040 ± 0.002

Au+Au
Reaction Plane Resolutions for each Centrality bins

$$\sigma_{resolution} = \sqrt{2 < \cos(2 \times (\Psi_N - \Psi_S)) >}$$

Reaction plane resolution

$$\left\langle \cos n(\Psi_n^a - \Psi_n^b) \right\rangle = \left\langle \cos n(\Psi_n^a - \Psi_r) - n(\Psi_n^b - \Psi_r) \right\rangle$$

$$= \left\langle \cos n(\Psi_n^a - \Psi_r) \right\rangle \left\langle \cos n(\Psi_n^b - \Psi)_r \right\rangle$$
$$+ \left\langle \sin n(\Psi_n^a - \Psi_r) \right\rangle \left\langle \sin n(\Psi_n^b - \Psi_r) \right\rangle$$

$$= \left\langle \cos n(\Psi_n^a - \Psi_r) \right\rangle \left\langle \cos n(\Psi_n^b - \Psi_r) \right\rangle$$

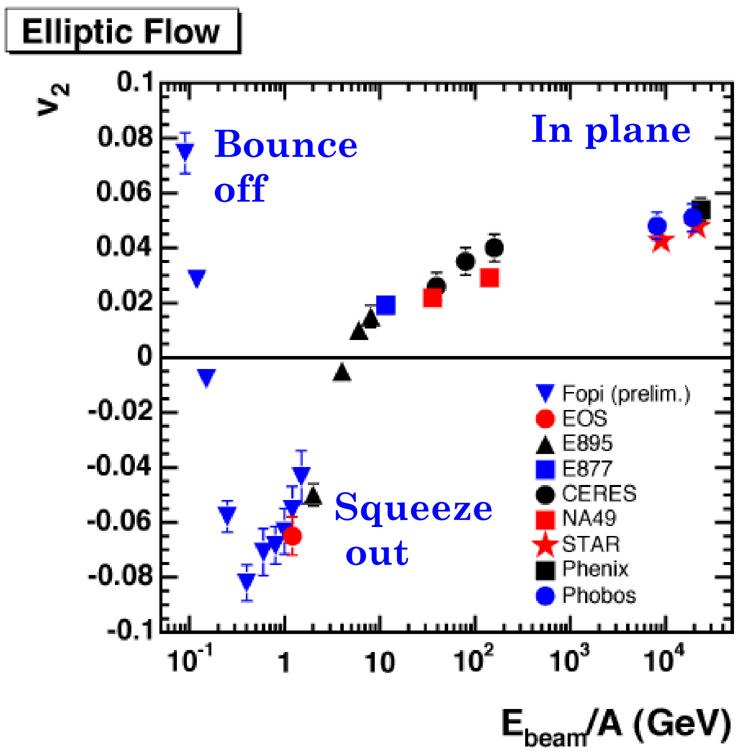
$$\approx \left\langle \cos n(\Psi_n^a - \Psi_r) \right\rangle^2$$

$$\left\langle \cos n(\Psi_n^a - \Psi_r) \right\rangle = \sqrt{\left\langle \cos[n(\Psi_n^a - \Psi_n^b)] \right\rangle}$$

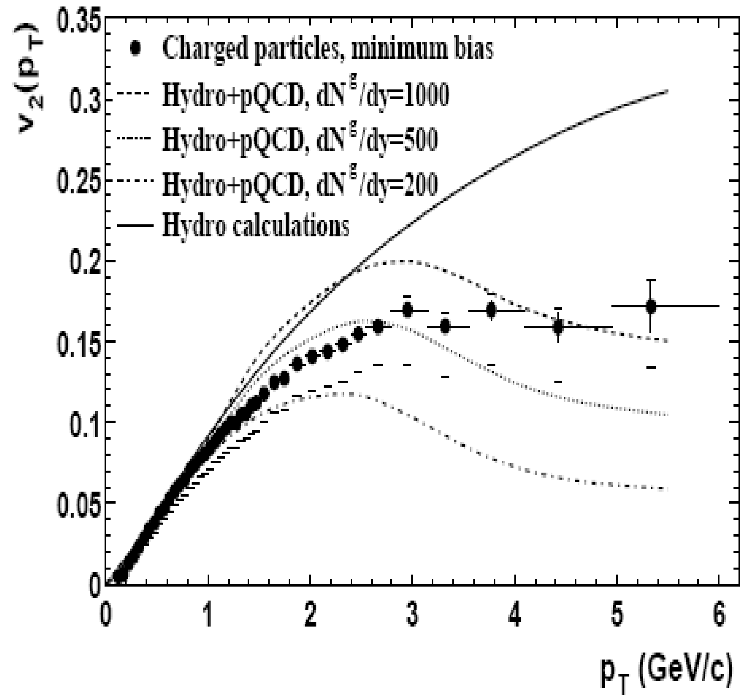
$$\left\langle \cos n(\Psi_n - \Psi_r) \right\rangle = C \times \left\langle \cos n(\Psi_n^a - \Psi_n) \right\rangle$$

$$= C \times \sqrt{\left\langle \cos n(\Psi_n^a - \Psi_n^b) \right\rangle}$$

Elliptic Flow



v2 v.s. E



v2 v.s. pT
Charged Particle
STAR