Elliptic flow of deuterons/anti-deuterons at $\sqrt{s_{NN}}$ =200 GeV Au+Au collision

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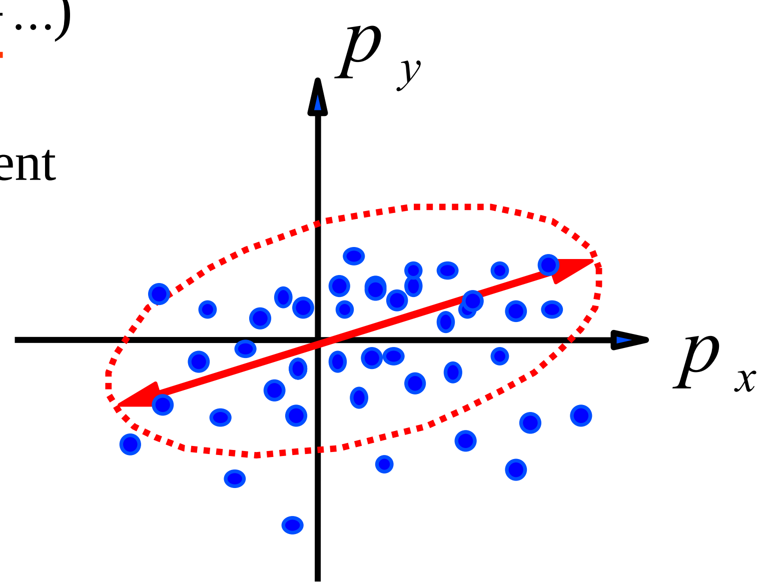
PHENIX

Azimuthal anisotropy

The azimuthal event anisotropy is considered to be very sensitive to the pressure gradient at early stage of space-time expansion. Therefore it is one of the important observables that help us to understand the early stage of unclear-nuclear collisions. The event anisotropy is evaluated with Fourier expansion of azimuthal distribution of particles

$$\frac{dN}{d\varphi} = N_0(1 + 2v_1\cos(\varphi) + \underline{2v_2\cos(2\varphi)} + \ldots)$$

where v_n is n-th order of harmonic coefficient and v_2 shows the strength of elliptic flow.

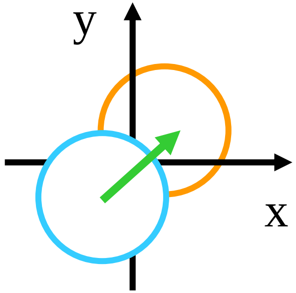


v_2 Analysis Method

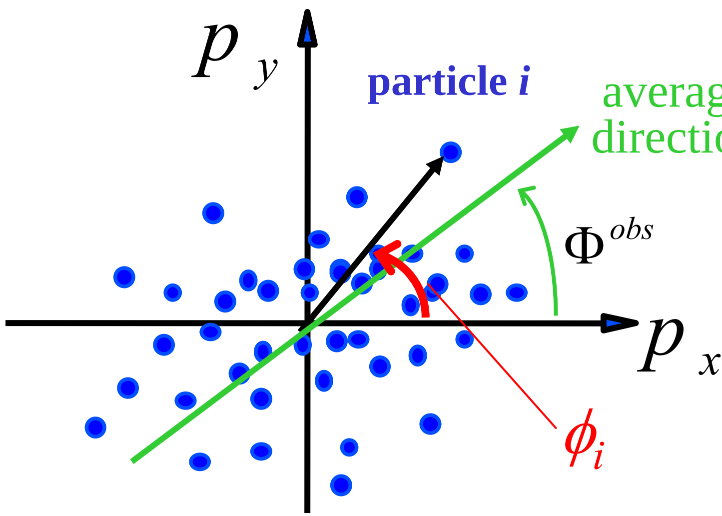
-Reaction plane method-

We determine azimuthal angle of the reaction plane which is defined as impact parameter directions (from center of a ion to center of the other ion), and compute azimuthal angle of each particle with respect to the reaction plane (plots of reaction plane are shown “Corrections of reaction plane determination”).

To define reaction plane from data, we used major axis of azimuthal distribution of charged particles in forward/backward direction



An impact paramet
direction



$$\Phi^{obs} = \left(\tan^{-1} \frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)} \right) \Big/ 2$$

The azimuthal distribution (respect to the reaction plane) is expected to have even number of order of harmonic when we take summation of positive and negative rapidity region. Assuming that 4th and larger order of harmonic is small, the distribution will be:

$$\frac{dN}{d\phi} = N_0\left(1 + 2v_2^{obs}\cos[2(\phi_i - \Phi_{obs})]\right)$$

We can obtain v_2^{obs} by fitting.

The measured second harmonic coefficient v_2^{obs} has an effect of 'smearing' from resolution of reaction plane determination. We estimate the resolution σ_{rp} by a correlation of reaction planes calculated by sub events (also see later).

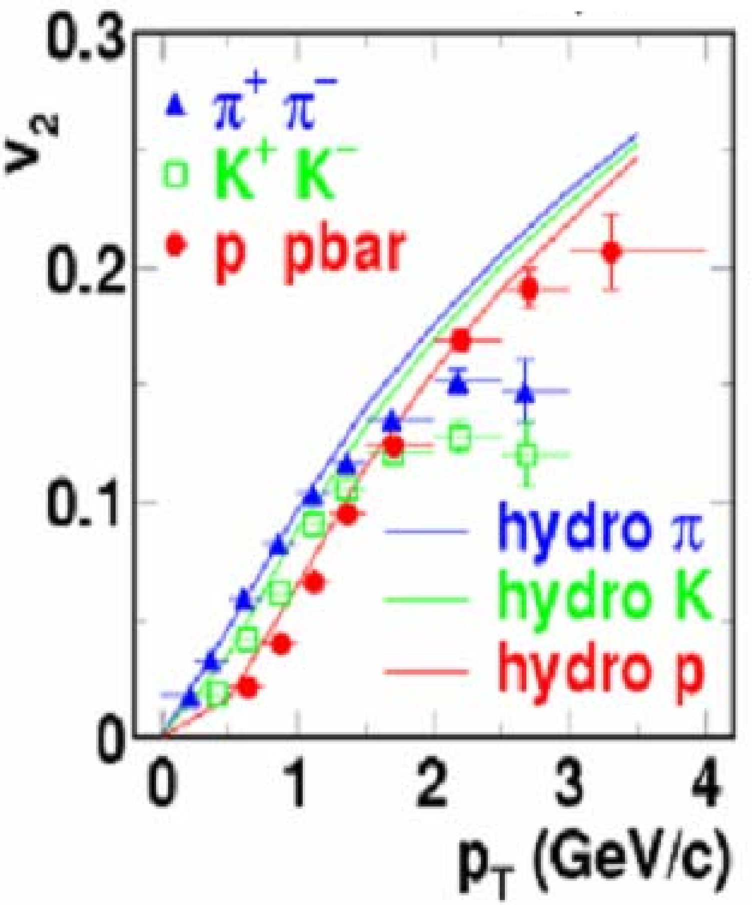
$$\sigma_{rp} = \langle\cos(2(\Psi_m - \Psi_{real}))\rangle = \{\langle\cos(2(\Psi_A - \Psi_B))\rangle\}^{1/2}$$

The v_2 is corrected by the resolution by the following equation.

$$v_2 = v_2^{obs} / \sigma_{rp}$$

Motivation

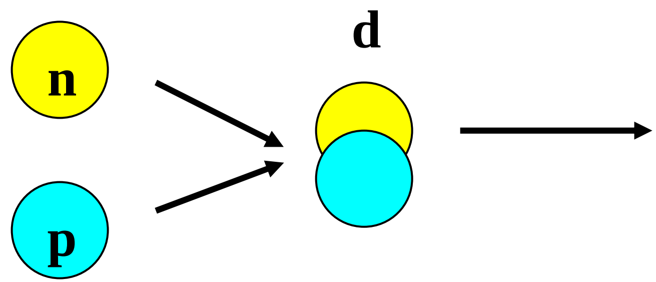
In the RHIC-PHENIX experiment the elliptic emission parameter v_2 of pion, kaon and proton have been measured with respect to the reaction plane and typical hydrodynamical behavior has been seen; at low pt region the strength of elliptic flow scales with the mass of the particles. For further study of the elliptic particle emission, it is interesting to measure v_2 of heavier particles, such as **deuterons**.



Transverse momentum dependence of v2 for identified particles, π ,K,p in Au+Au collisions at √ SNN = 200 GeV at RHIC-PHENIX (nucl-ex/0305013)

Coalescence model

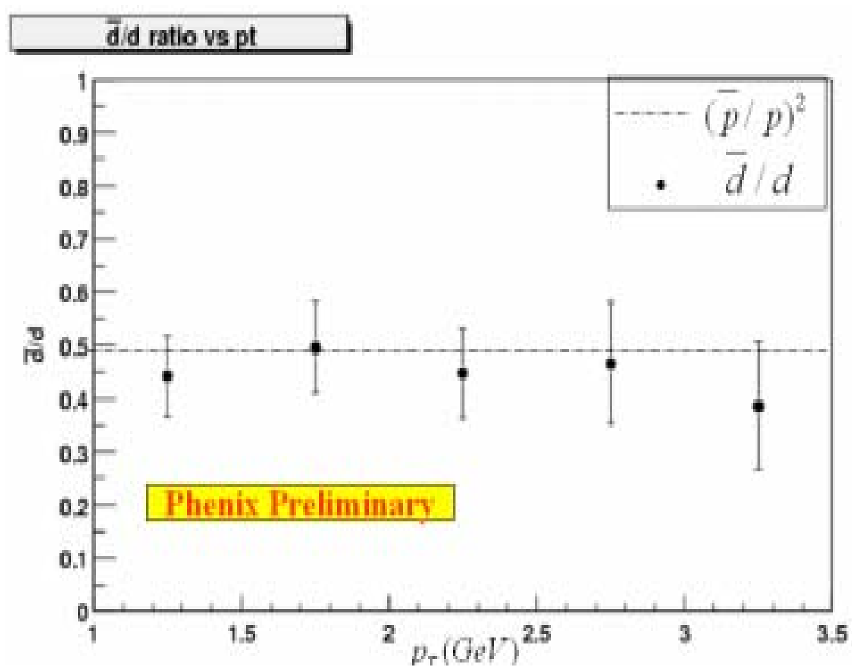
Deuterons and anti-deuterons can be produced by direct d - d-bar pair production in relativistic heavy ion collisions. But, it is likely that they are produced by final state coalescence of p(p-bar) and n(n-bar). In the coalescence model, the invariant deuteron (anti-deuteron) yields given as ;



$$E_d \frac{d^3N_d}{dp_d^3} = B_2 \left(E_p \frac{d^3N_p}{dp_p^3} \right)^2 \quad (p^d = 2p^p)$$

From the upper equation v_2 of deuteron (anti-deuteron) is estimated by

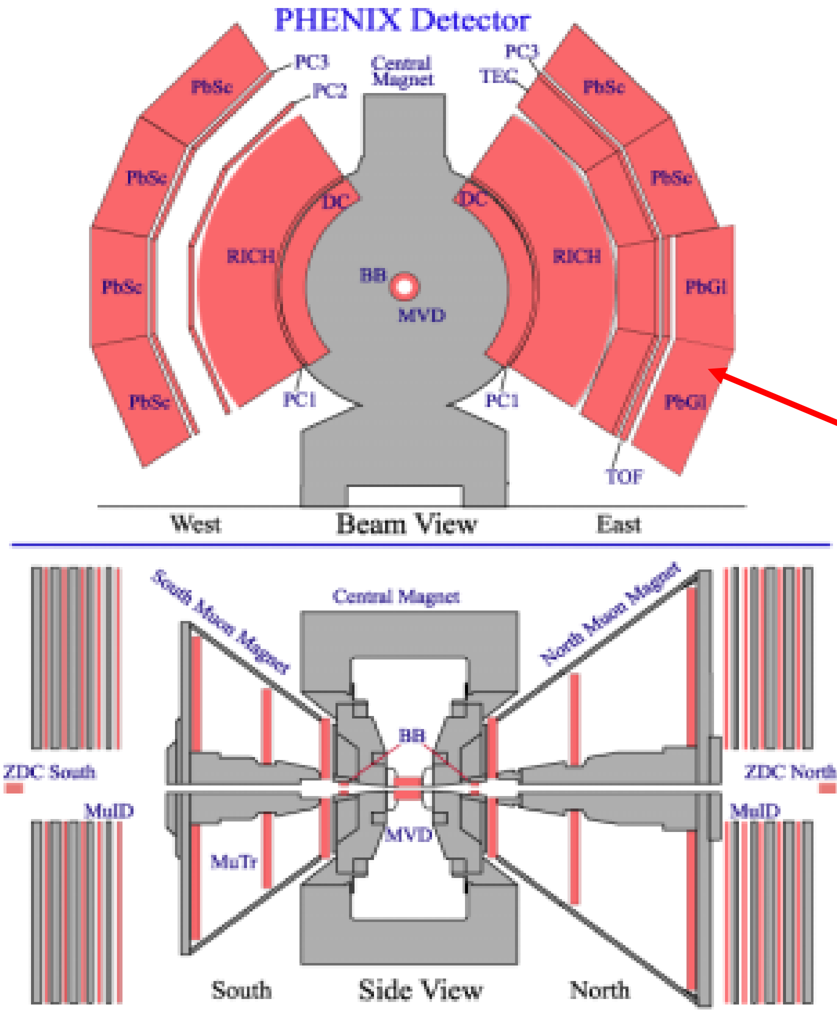
$$v_2^d(p_t) = 2v_2^p(p_t/2)$$



d-bar/d ratio vs. p_t at Au+Au collision at sqrt(S_{NN})=200GeV (quark matter 2002 Anuj K. Purwar and Rickard du Rietz)

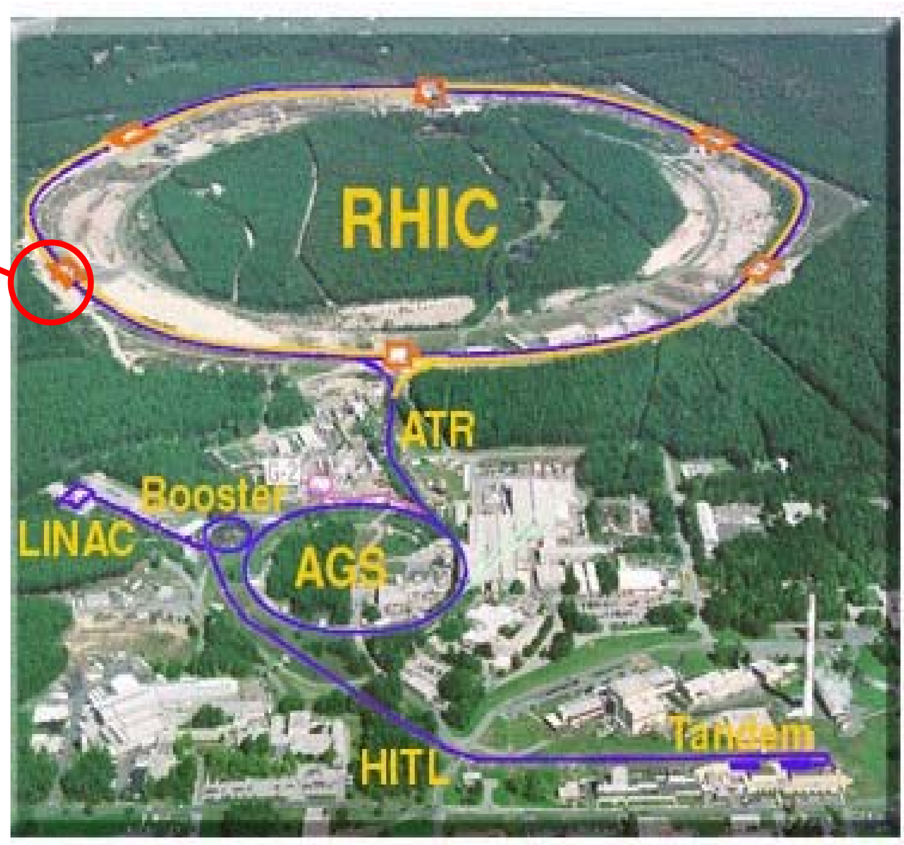
RHIC-PHENIX

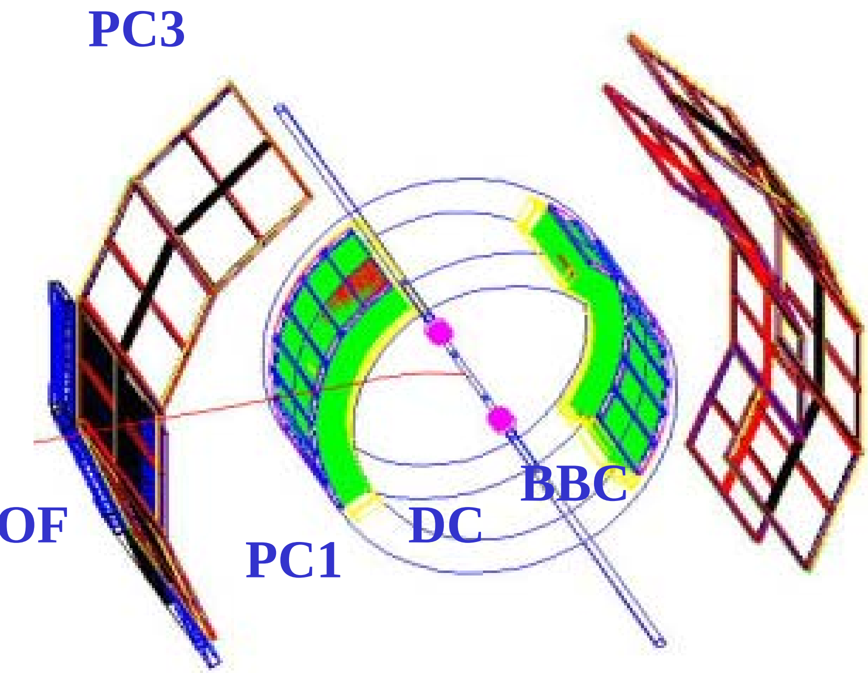
PHENIX

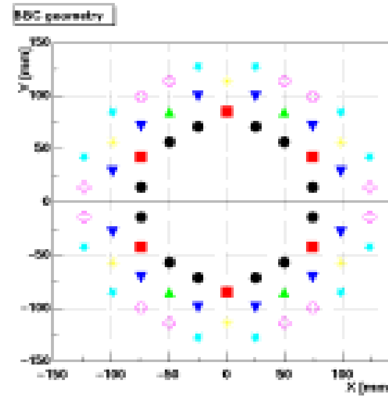


Relativistic ***H***eavy ***I***on ***C***ollider

$\sqrt{S_{NN}}$=200 GeV Au+Au collision
(run2 : 2001/02)







64 pmts in each BBC

Beam Beam Counter (BBC)
|η|=3-4

Reaction plane **--- BBC**

Tracking ⇨ **p, ϕ**

DC+PC1+PC3

PID **･･･ TOF**

$$m^2 = p^2 \{(TOF/L)^2 - 1\}$$

3 units of rapidity away

from the mid-rapidity

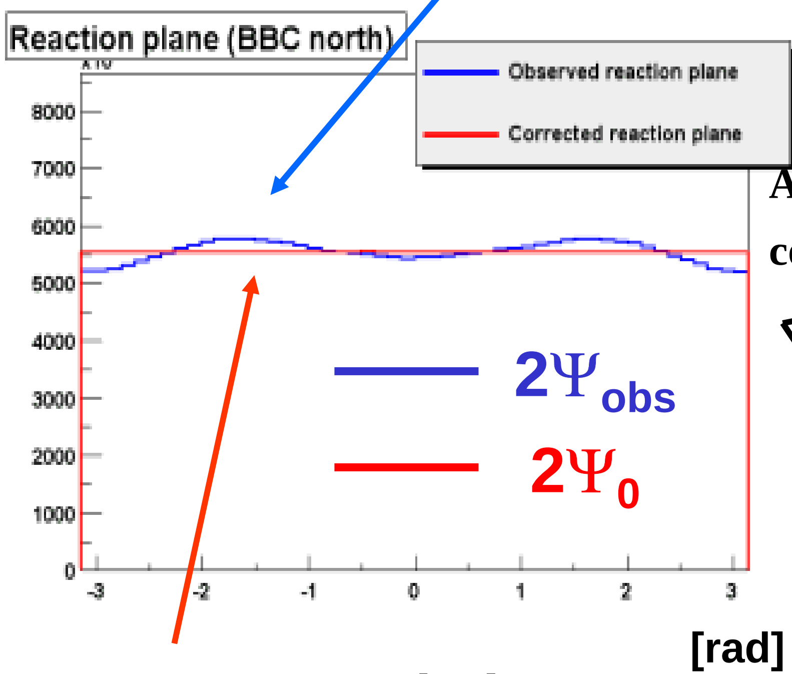
⇩

Less ***non-flow*** contribution

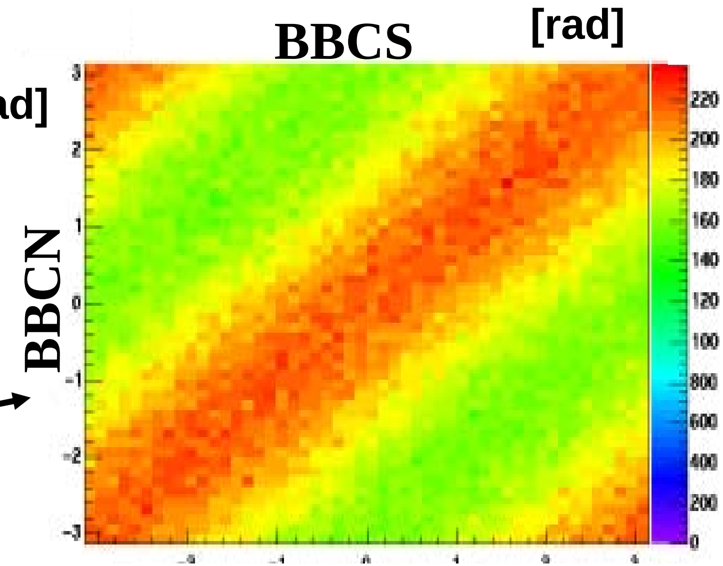
HBT、jet、resonance decay

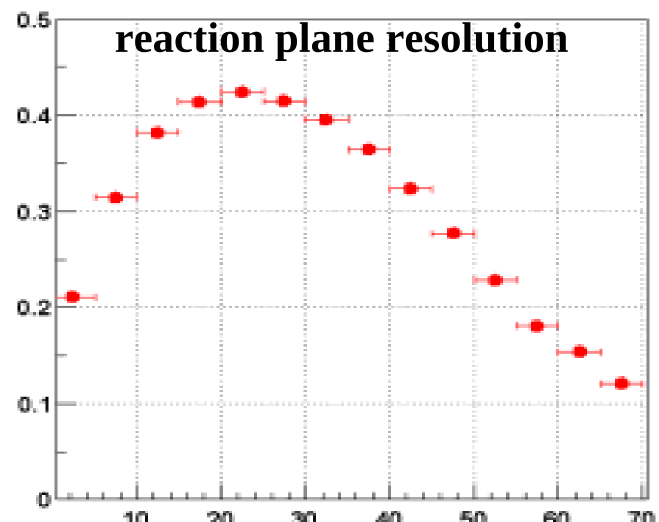
Corrections of reaction plane determination

Due to finite acceptance reaction plane



After correction





Correction method：

$$2\Psi_0 = 2\Psi_0^{obs} + \Delta\Psi_0$$

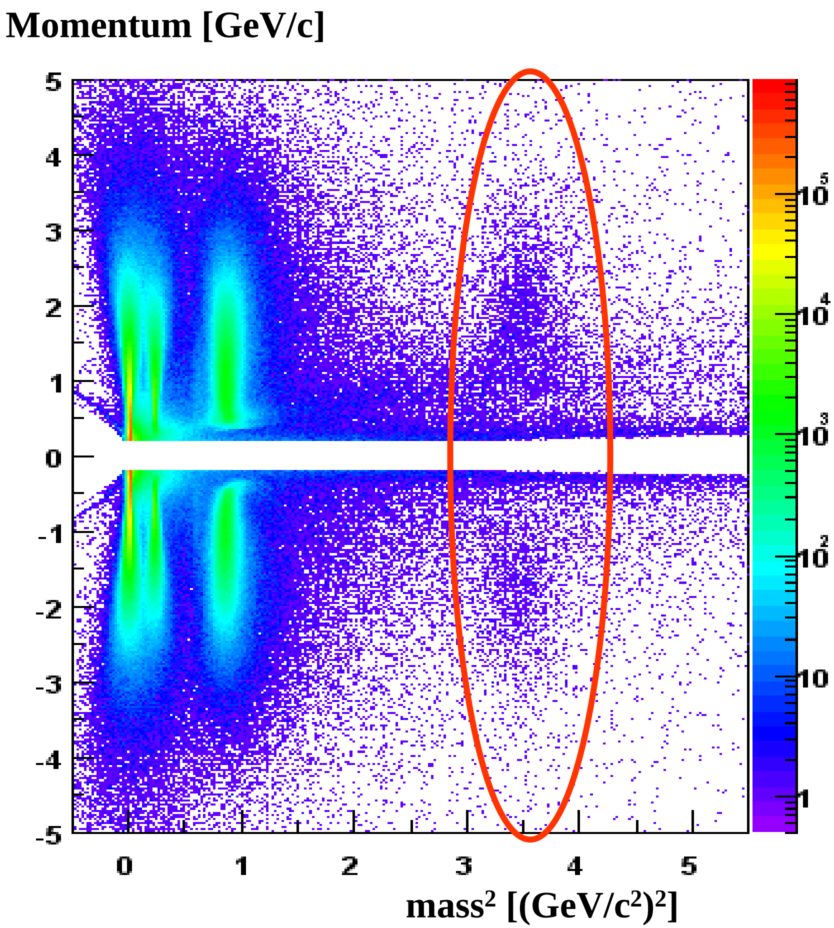
$$\Delta\Psi_0 = \Sigma(A_n \cos(2n\Psi_{obs}) + B_n \sin(2n\Psi_{obs}))$$

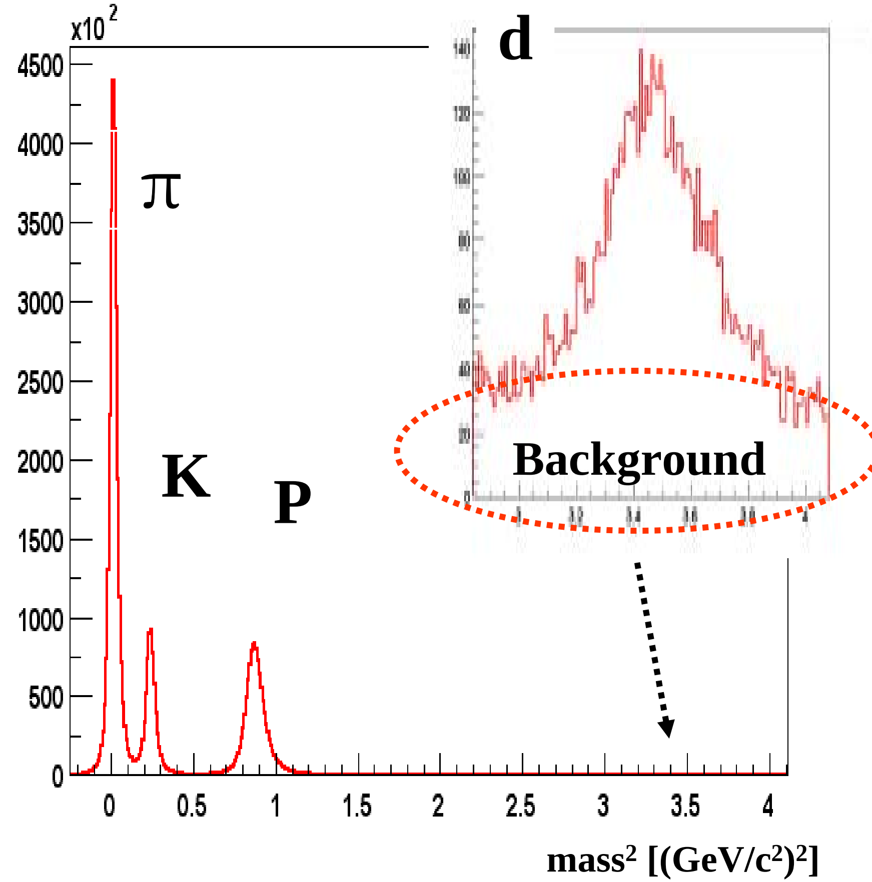
$$A_n = -2/n * \langle \sin(2n\Psi_{obs}) \rangle$$

$$B_n = 2/n * \langle \cos(2n\Psi_{obs}) \rangle$$

PID

Deuterons and anti-deuterons are identified with high resolution Time-of-Flight information (σ_{TOF} = 115 ps) .





Correction of v_2^{d+dbar}

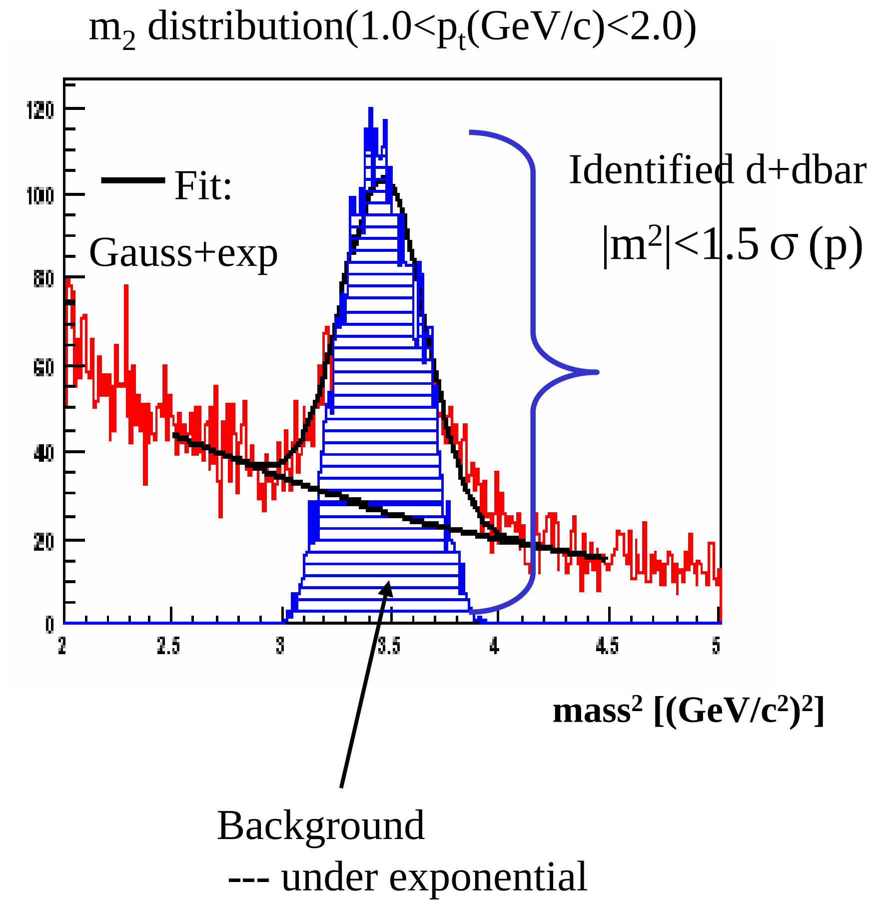
Due to the identified deuterons (anti-deuterons) include backgrounds,

v_2 of d+d-bar is corrected by subtracting backgrounds.

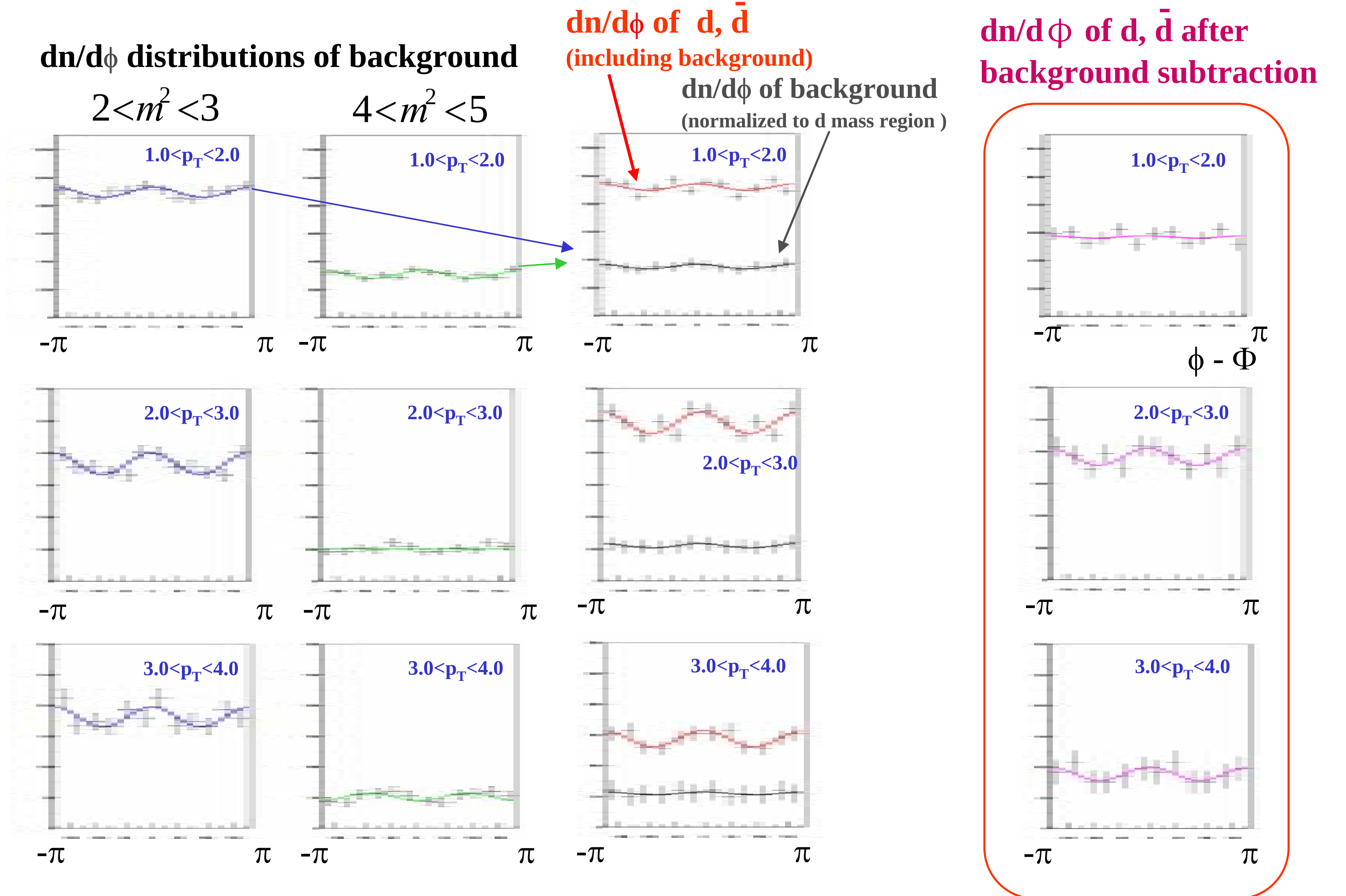
$$\frac{dN^{corr}}{d\phi} = \frac{dN^{PID}}{d\phi} - \frac{dN^{bg}}{d\phi}$$

PID --- dn/dphi of identified deuteron (anti-deuteron)
bg --- dn/dphi of background

v_2 of background is estimated from v_2 of $2.0<m^2<3.0$ & $4.0<m^2<5.0$ $[GeV/c^2)^2]$.



dN/dΦ distribution



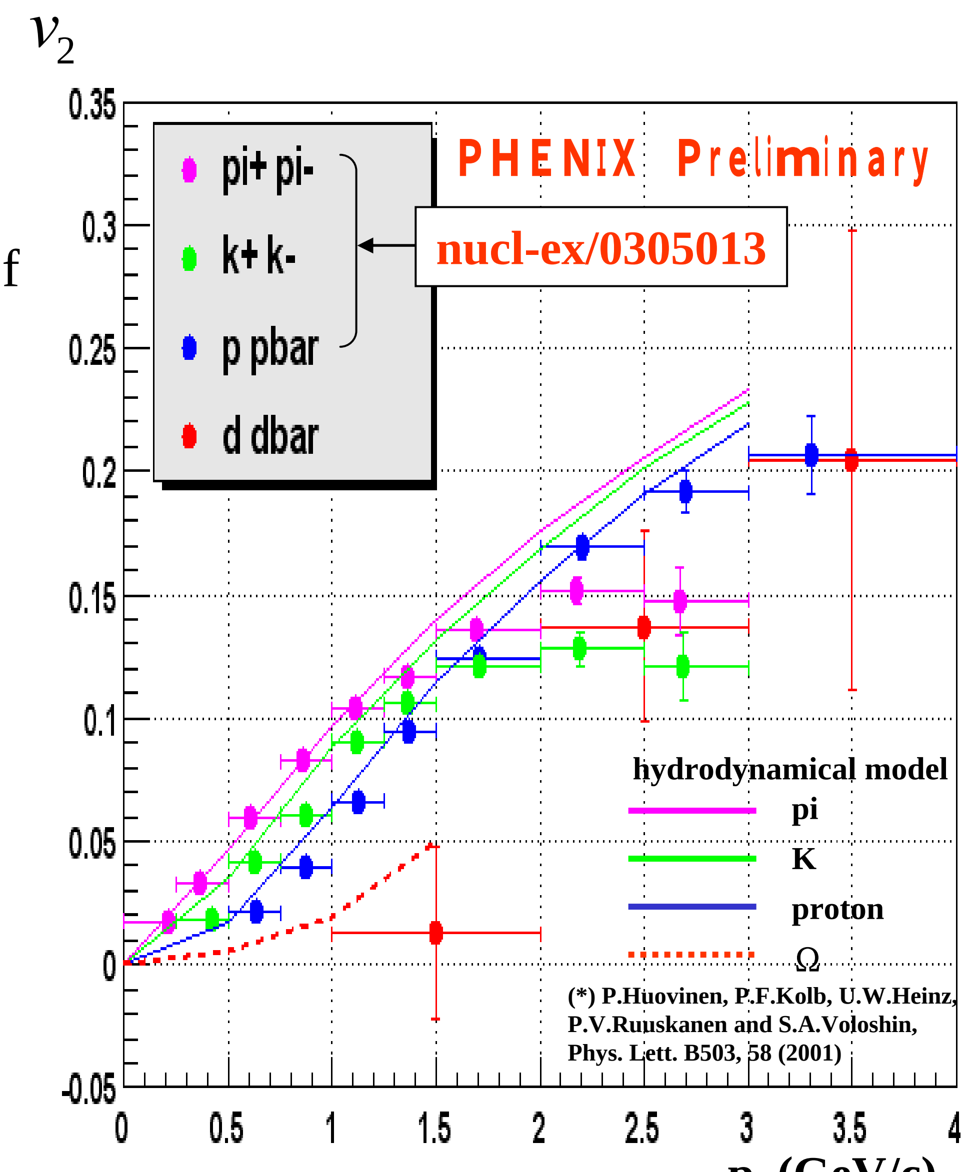
Note: Background has also cos shape. It may come from

Comparison with the v_2 of π,K,p

Transverse momentum dependence of v_2 for identified particles, pion, kaon, proton and deuteron.

At low pt (<1.5 GeV/c) clear mass dependence are measured.

$$v_2^{\pi} > v_2^{K} > v_2^{p} > v_2^{d}$$

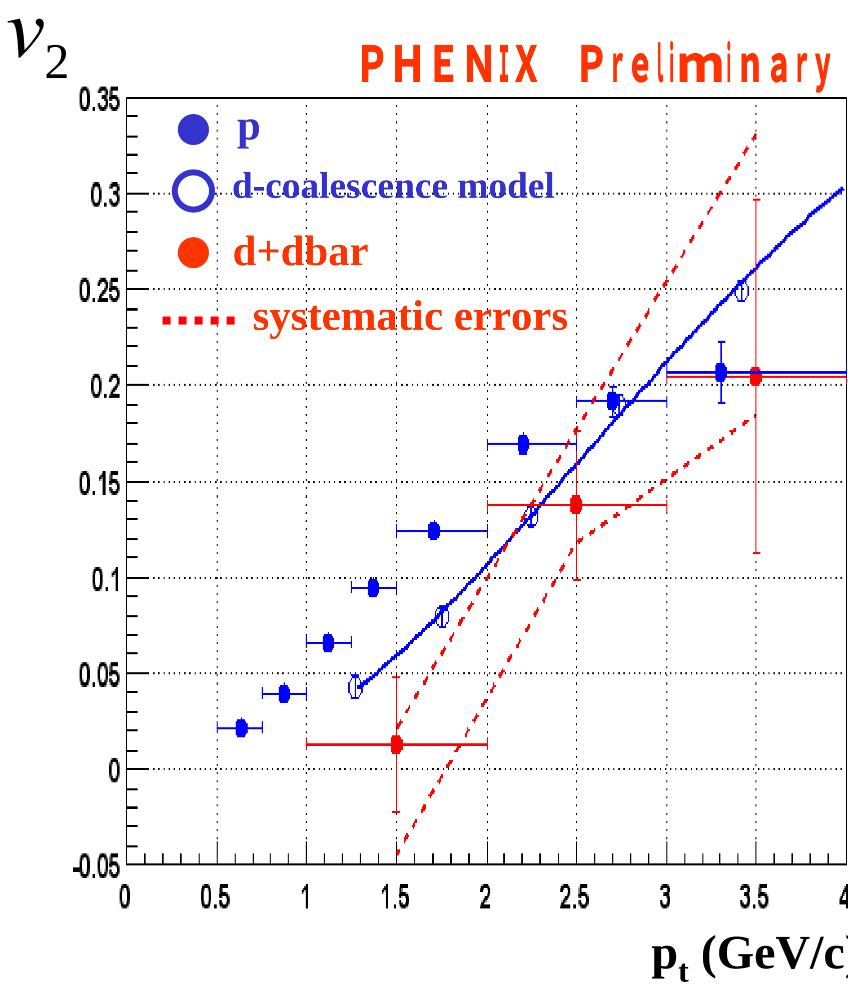


Comparison with the coalescence model

Transverse momentum dependence of v_2 of d+d-bar (red circles) compared with v_2 which is estimated from coalescence model (blue solid line).

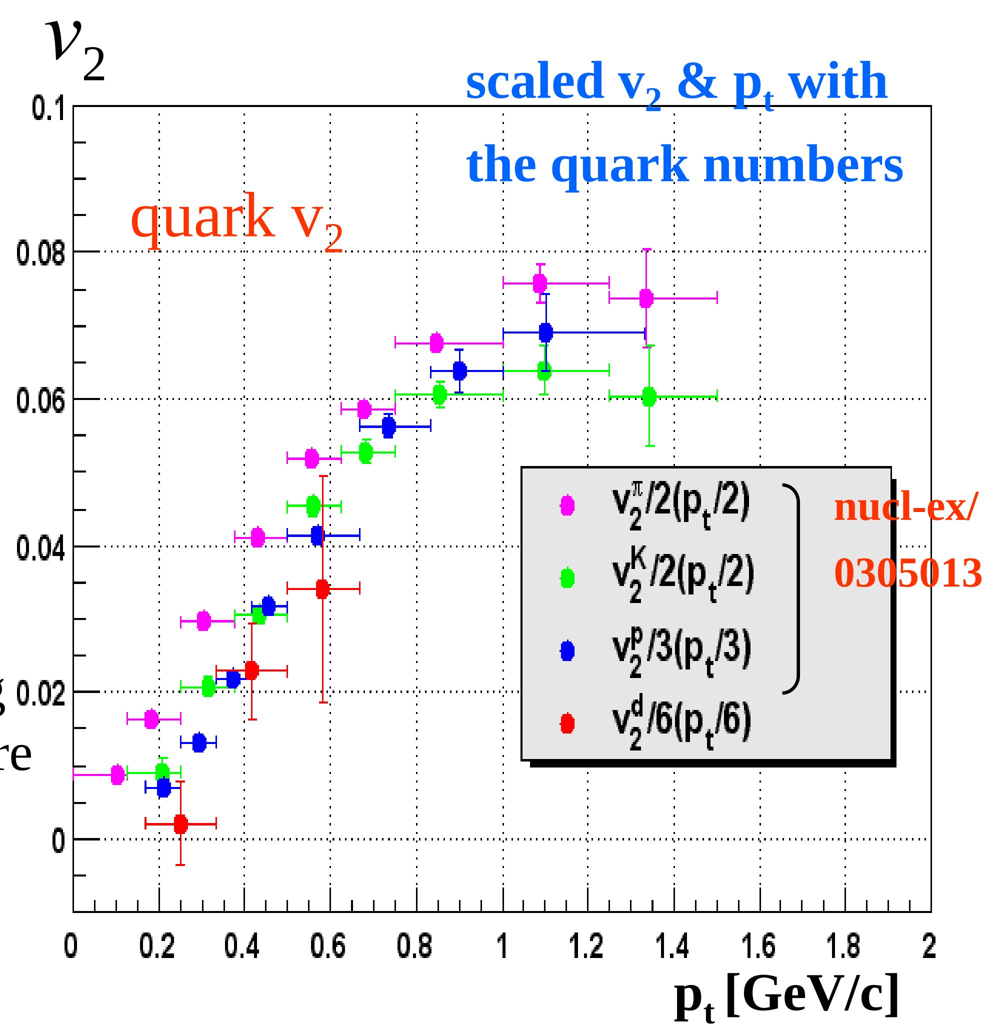
$$v_2^d(p_t) = 2v_2^p(p_t/2)$$

v_2 of d+d-bar is consistent with a coalescence model within error bars



Scaling of v_2^{d+dbar} with the number of quark

The right plots show the v_2 of identified particles, pion, kaon, proton and deuteron, which are scaled v_2 and p_t with the number of quark for each particle.
(the original idea is come from quark coalescence model :
D.Molnar and S.A.Voloshin nucl-th/030201)
Though the error bars of scaled v_2^{d+dbar} ($v_2^d/6(p_t/6)$) is large, hadron mass dependence seem like remaining after scaling. It might suggest that there is two different flow (quark flow and hadron flow) before and after phase-transition or chemical freeze-out.



Summary

- The deuteron + anti-deuteron (d+dbar) elliptic anisotropy are measured with respect to the reaction plane in 200GeV Au+Au collisions
- The v_2 of d+dbar is evaluated subtracting background
- Clear mass dependence at low momentum (<1.5 GeV/c)

  $v_2^{\pi} > v_2^{K} > v_2^{p} > v_2^{d}$
- The v_2 of d+d-bar is consistent with a coalescence model within error bars

Spare

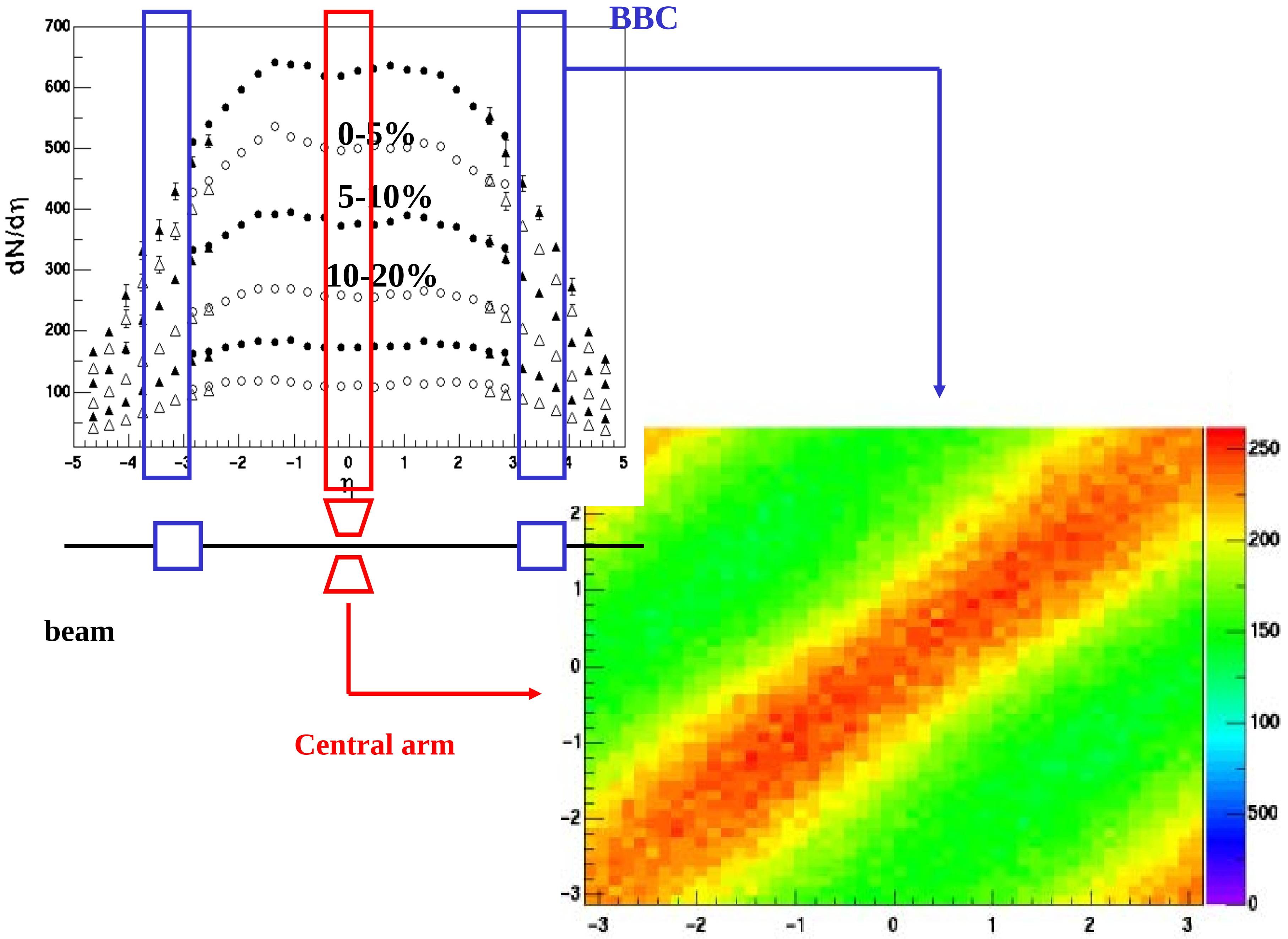
Coalescence model

$$\left(\frac{dN^d}{d\phi}\right) = \alpha\left(\frac{dN^p}{d\phi}\right)^2$$

$$(1+\sum 2v_n^d \cos(n\phi)) = \alpha(1+\sum 2v_n^p \cos(n\phi))^2$$

$$\cong \alpha(1+\sum 2(2v_n^p)\cos(n\phi))$$

$$v_2^{deuteron}(p_t) = 2v_2^{proton}(p_t/2)$$


BBC
0-5%
5-10%
10-20%
dN/dη
η
beam
Central arm

Resolution

$$\sigma = < \cos(n(\Psi_{measured} - \Psi_{true})) >$$

Can't measure

Reaction plane resolution

$$< \cos(n(\Psi_A - \Psi_B)) >$$

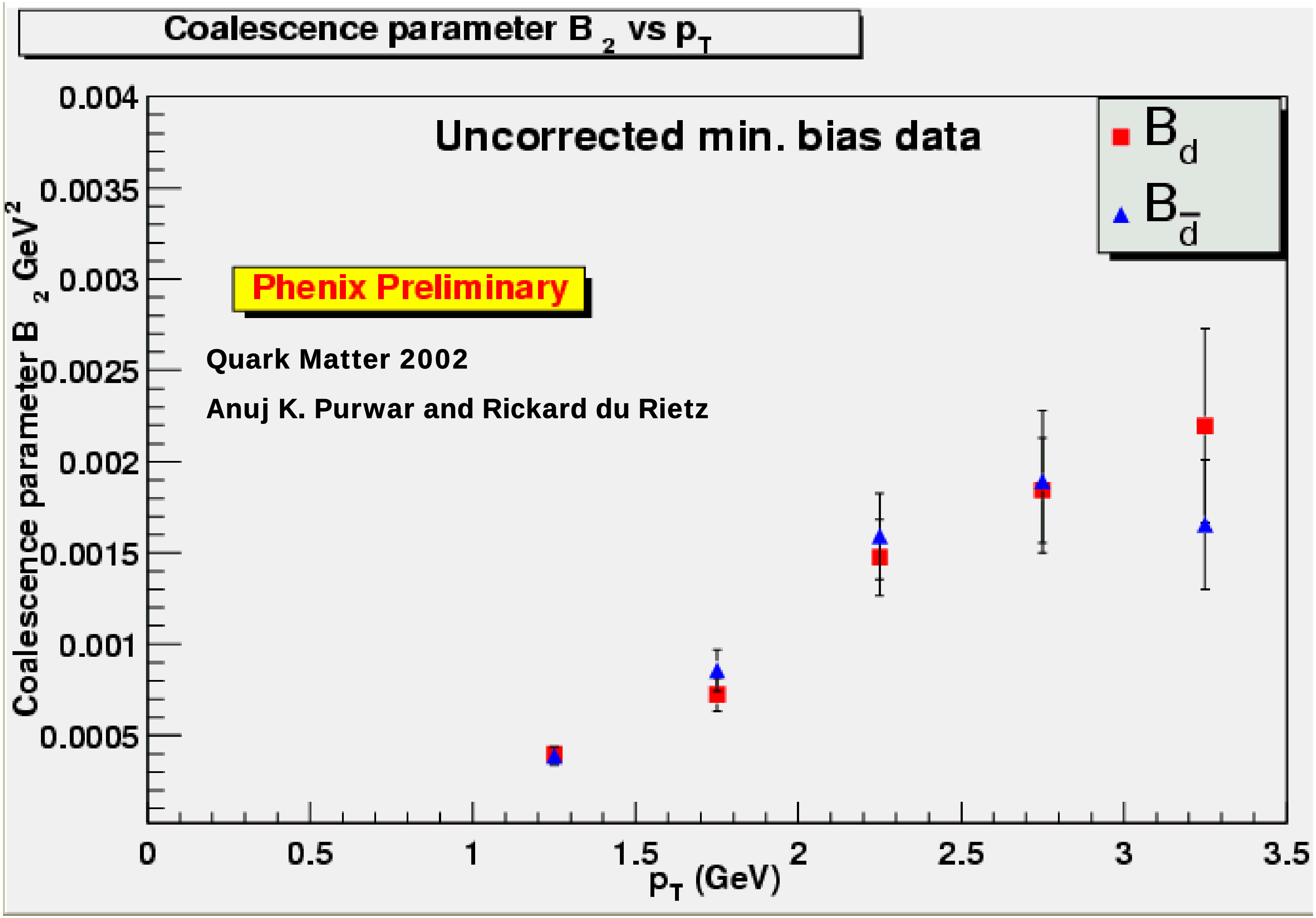
Reaction plane sub-event
(divide one event)

$$= < \cos n((\Psi_A - \Psi_{true}) - (\Psi_B - \Psi_{true})) >$$

$$\approx < \cos(n(\Psi_A - \Psi_{true})) >< \cos(n(\Psi_B - \Psi_{true})) >$$

$$\approx < \cos(n(\Psi_A - \Psi_{true})) >^2$$

B_2

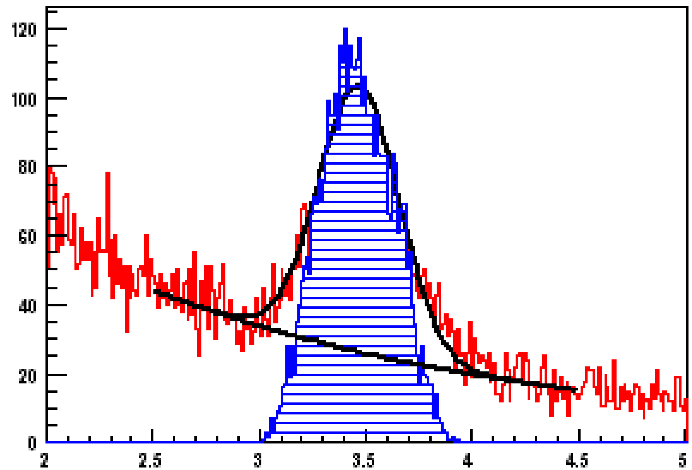


Coalescence parameter B 2 vs pT
Uncorrected min. bias data
Bd
Bd̄
Phenix Preliminary
Quark Matter 2002
Anuj K. Purwar and Rickard du Rietz
Coalescence parameter B 2 GeV2
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
0.5
1
1.5
2
2.5
3
3.5
pT (GeV)

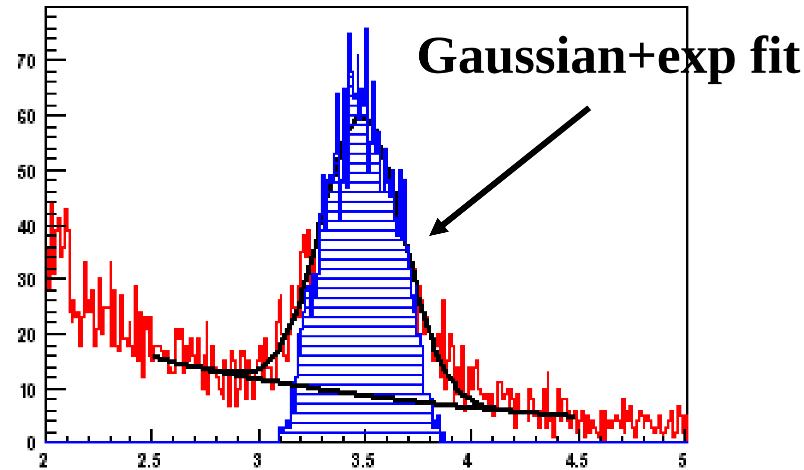
d+dbar distribution

d+dbar

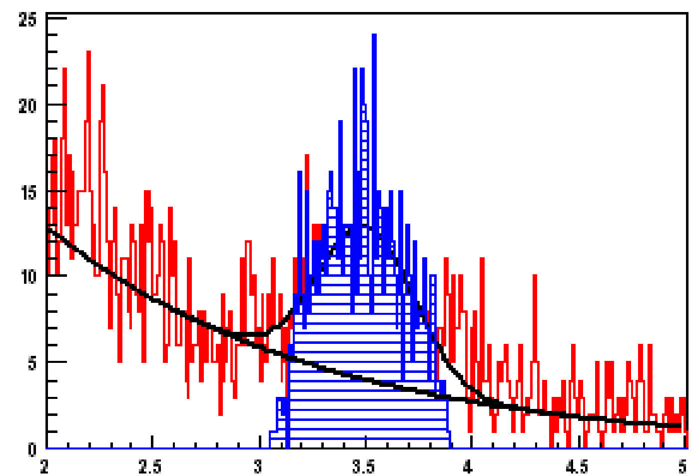
(1.0<p(GeV/c)<2.0)



(2.0<p(GeV/c)<3.0)



(3.0<p(GeV/c)<4.0)



< selection>

Quality 31 || 63

TOF-Track matching cut < 2 σ

PC3-Track matching cut < 2 σ

TOF E loss > 0.0014 β ^(-5/3)

|Mass^2|<1.5 σ (p)