Examination of J/ψ Elliptic Flow with the PHENIX Detector in 200 GeV Au+Au Collisions at RHIC

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236th ACS National Meeting and Exposition

Philadelphia, PA

August 17-21, 2008

How about some background? …the good kind

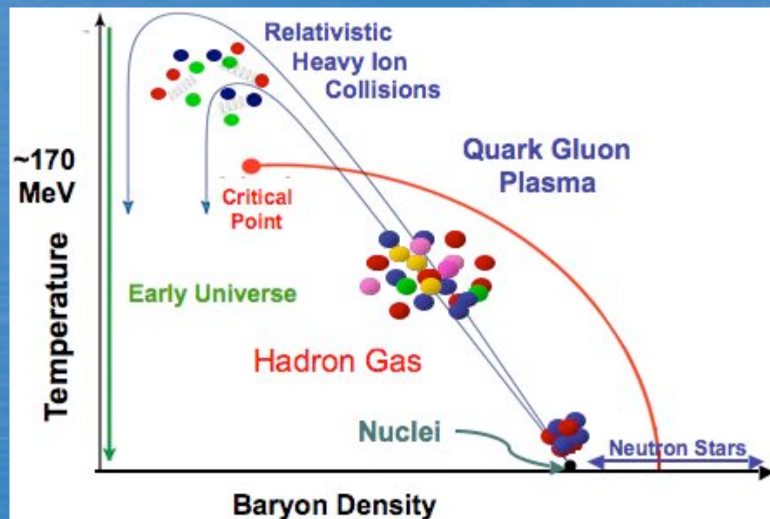
Examination of J/ψ Elliptic Flow with the PHENIX Detector in 200 GeV Au+Au Collisions at RHIC

1) Quark Gluon Plasma (QGP)
2) Au+Au collisions
3) Elliptic flow
4) Motivation
5) Relativistic Heavy Ion Collider (RHIC)
6) PHENIX detector

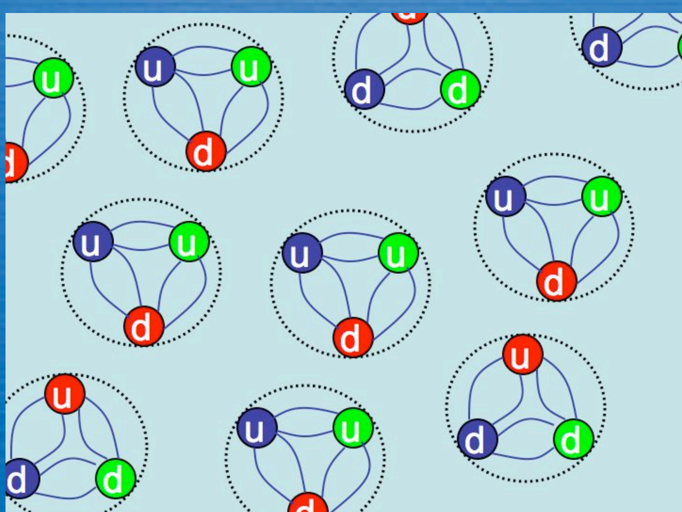
… move to "foreground" with J/ψ elliptic flow measurement

Quark Gluon Plasma (QGP)

Nuclear Phase Diagram

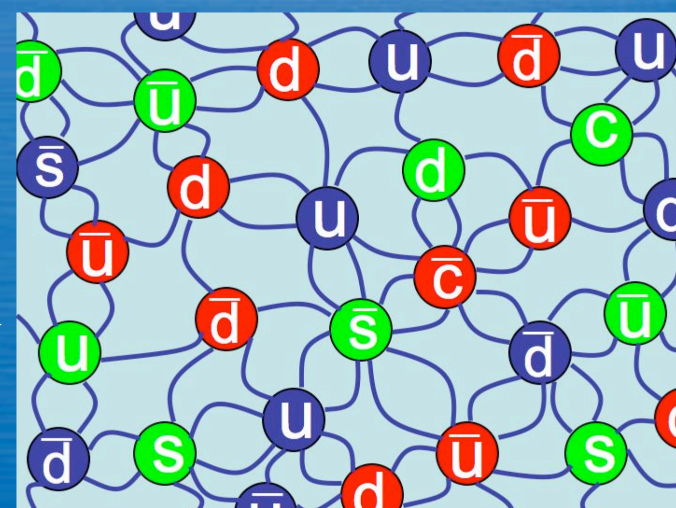


Normal nuclear matter: protons and neutrons

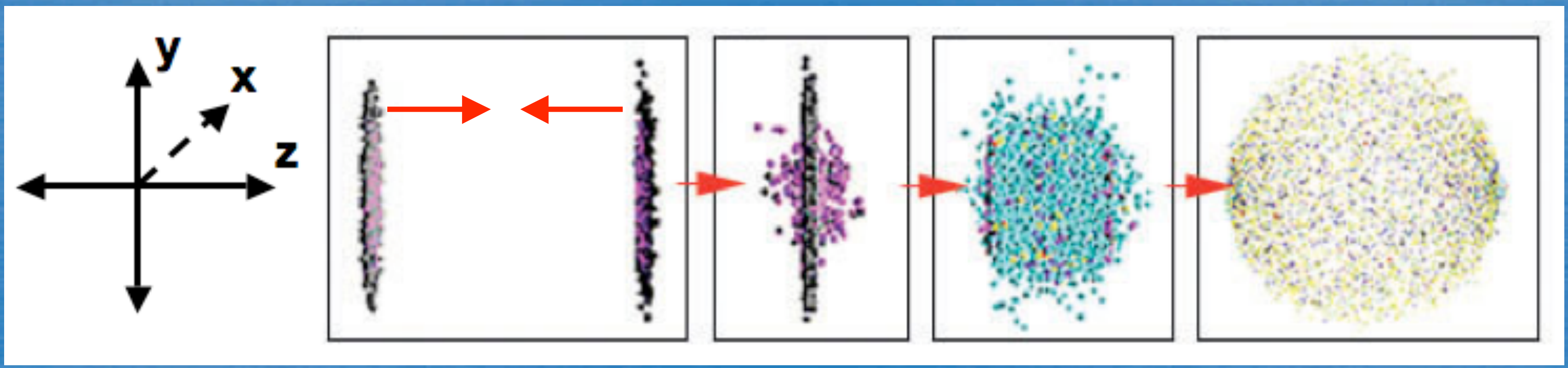


Increase temperature and/or density

QGP with deconfined quarks and gluons



Heavy Ion Collisions



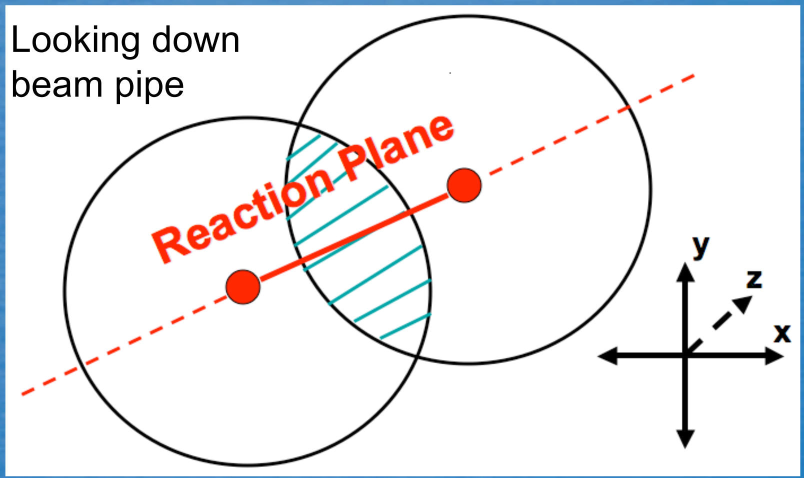
Lorentz contracted nuclei approach one another

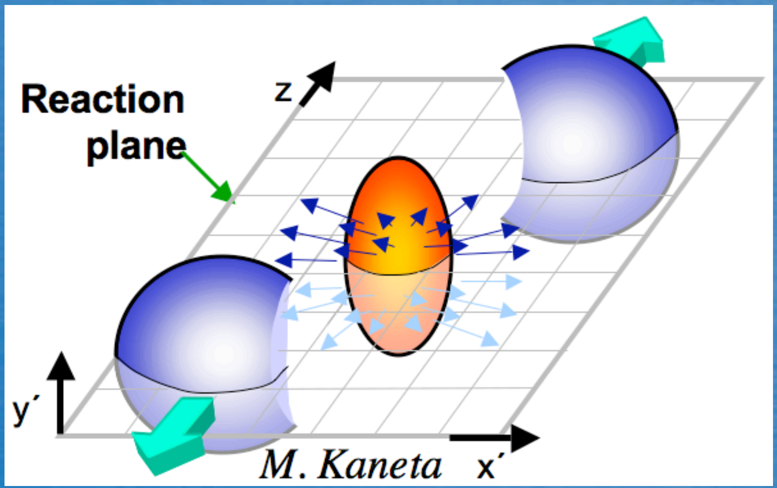
Nuclei collide and deposit energy

Particle production, high temperature QGP formed

Expansion and hadronization

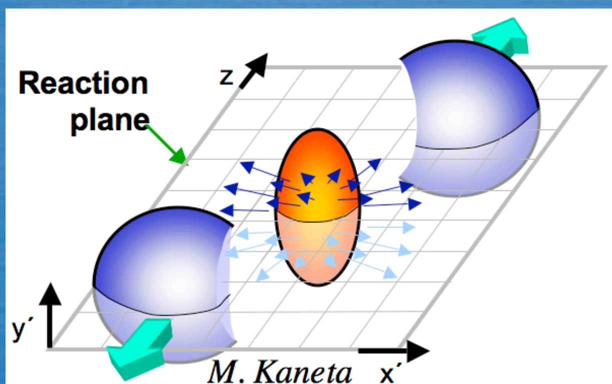
Reaction Plane and Elliptic Flow

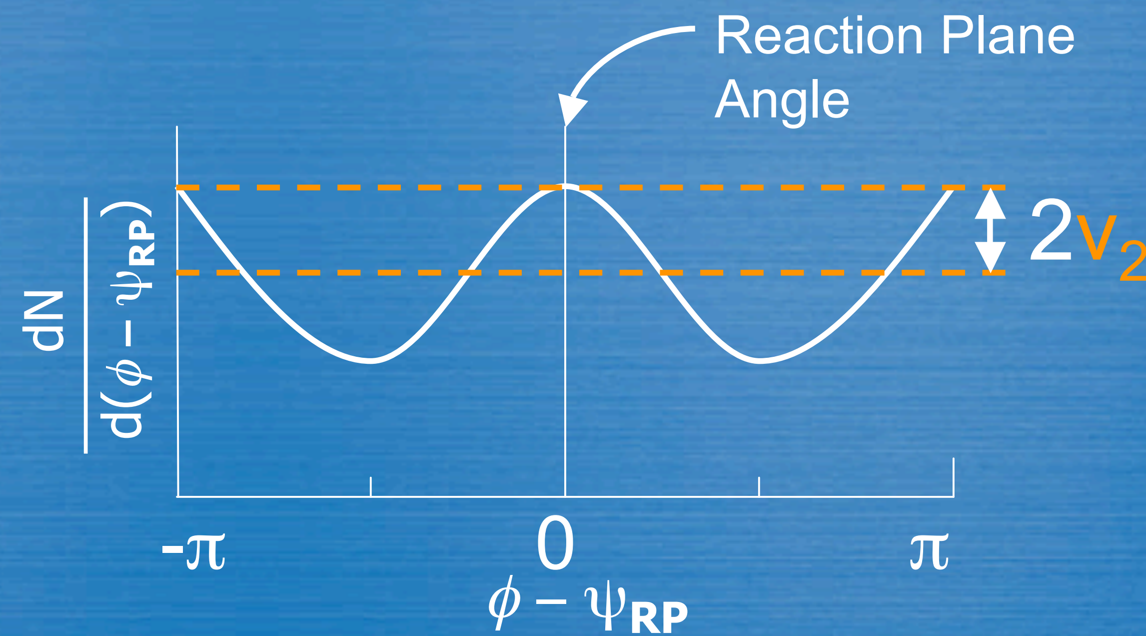




- Asymmetric distribution of produced particles in the azimuthal direction caused by a spatial anisotropy in the colliding matter
- If matter is a thermalized system this leads to different pressure gradients

Elliptic Flow Graphically





<u>Based on second Fourier component</u>

$$\frac{dN}{d(\phi-\psi_{RP})} \propto 1 + 2\,v_2 \cos(2(\phi-\psi_{RP}))$$

dN = number of particles

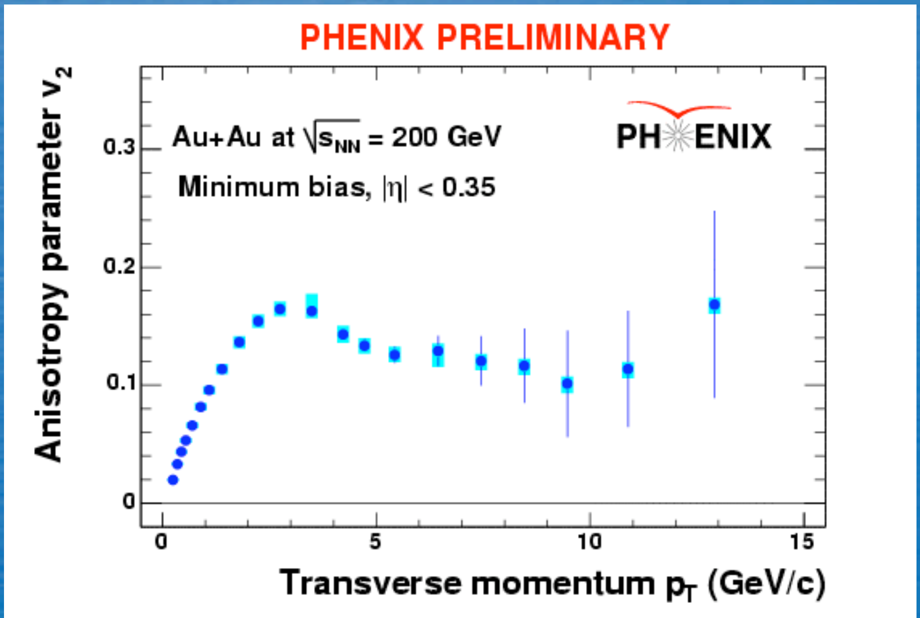
ϕ = particle angle wrt x-axis

ψ_{RP} = reaction plane angle wrt x-axis

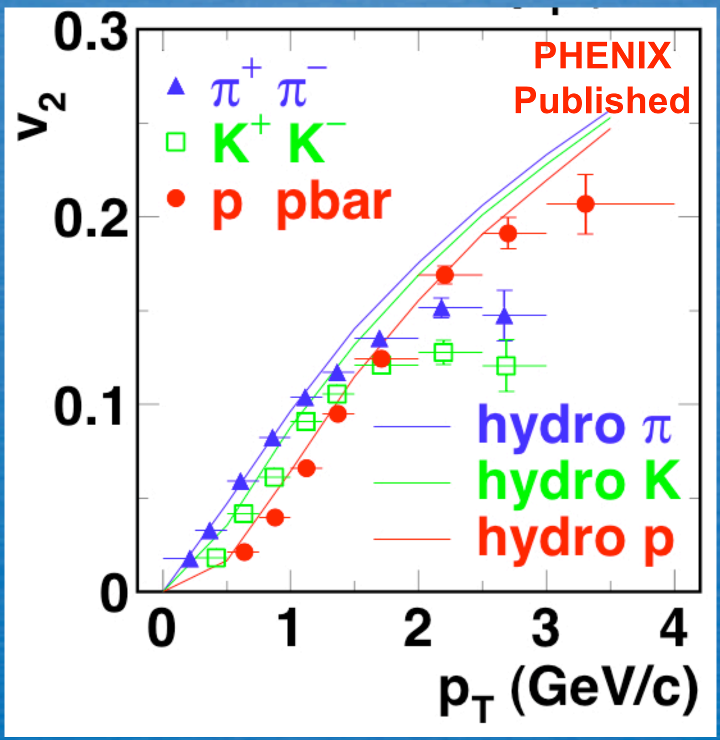
v_2 = magnitude of flow signal

Previous Elliptic Flow Measurements as a Function of Transverse Momentum (p_T)

Unidentified Hadrons



Identified Hadrons

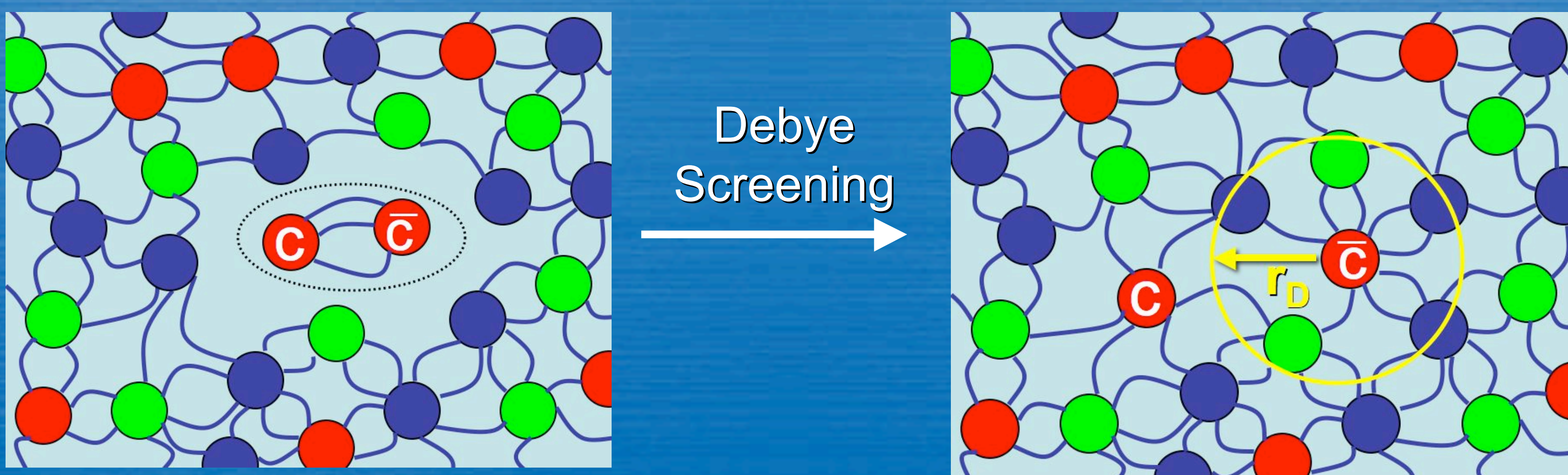


- Positive flow signal

Why measure J/ψ?

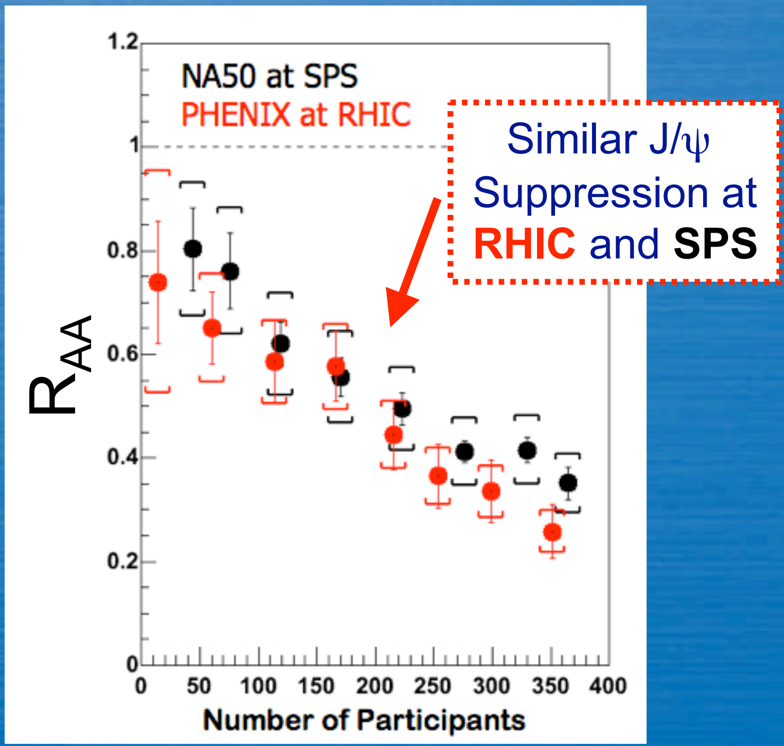
- If QGP formed and the medium becomes deconfined it was theorized that there would be a J/ψ signal suppression (less counts) - QGP Signature
- Suppression occurs through melting via Debye screening, or violently breaking up with comovers.

J/ψ will effectively melt when screening radius (r_D) becomes smaller than J/ψ radius



J/ψ Suppression

Recent measurements at high collision energies (RHIC = 200 GeV/nucleon pair) have shown no increase in signal suppression from low energies (SPS = 17 GeV/nucleon pair) where the deconfinement is not expected to be as long-lived



$$R_{AA} = \frac{N_{J/\psi}^{AA}}{N_{coll} N_{J/\psi}^{pp}}$$

$N_{J/\psi}^{AA}$ = number of J/ψ produced in Au+Au collisions

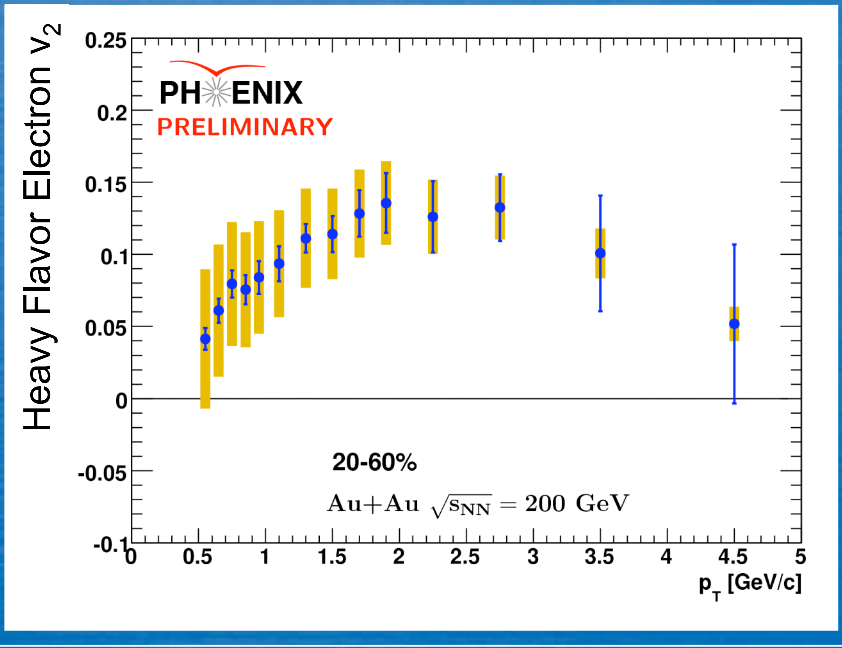
N_{coll} = number of binary collisions in Au+Au

$N_{J/\psi}^{pp}$ = number of J/ψ produced in p+p collisions

Possible Explanation

(1) J/ψ does not become screened in produced medium[1]. All of suppressed signal comes from the melting of less tightly bound higher mass states (ψ′, χ_c) of J/ψ, which are expected to contribute ~40% to J/ψ signal through feed-down[2].

(2) J/ψ does become screened, but enough uncorrelated c c-bar's are produced in the medium that a substantial number of them combine later on during hadronization to form a J/ψ[3]

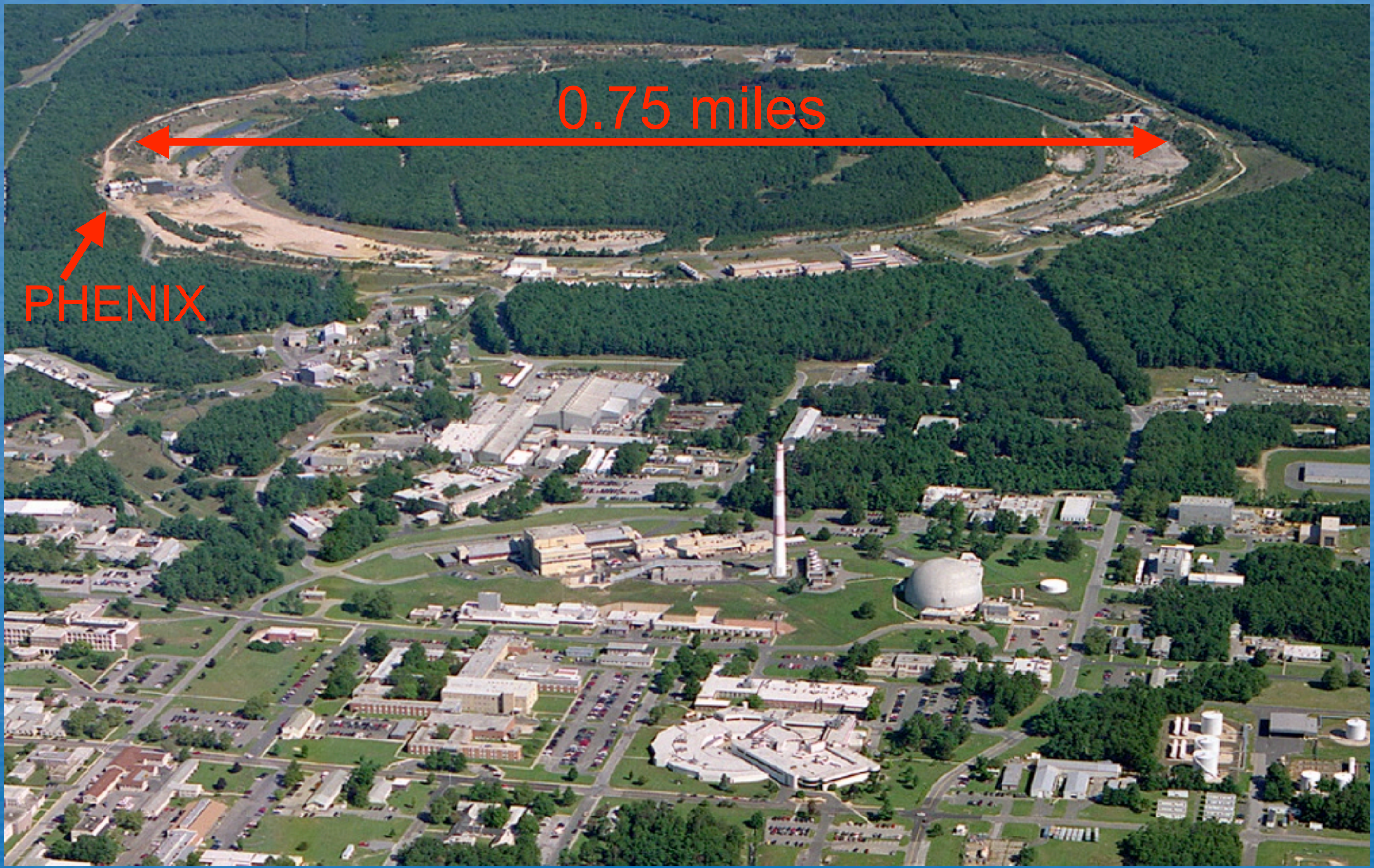


If J/ψ forms from uncorrelated c c-bar's then they should inherit the same positive flow as that of open charm decay, which has been measured by PHENIX

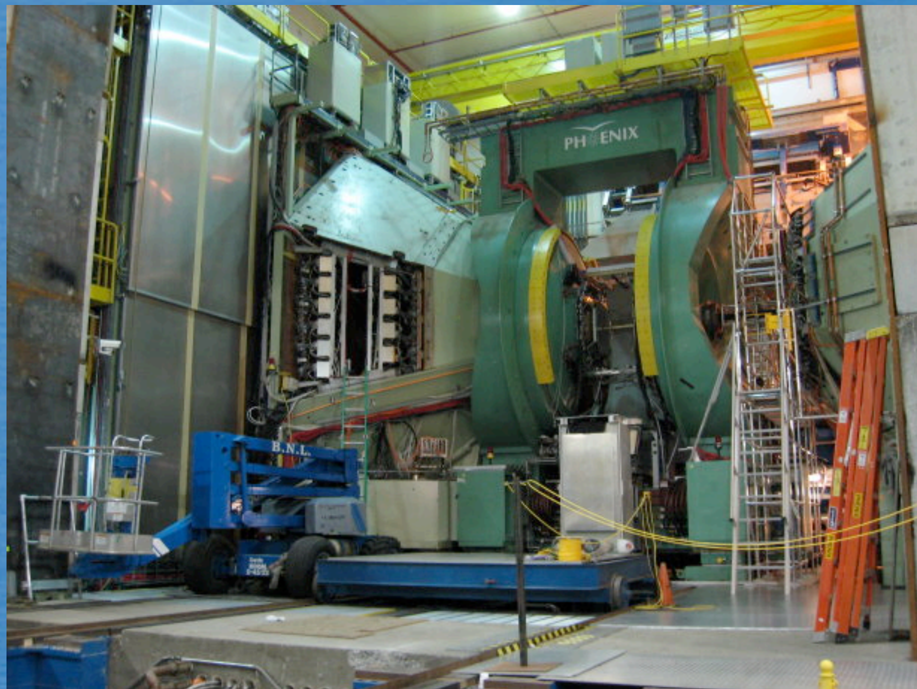
$$\bar{c}u \Rightarrow e^- + \bar{\nu}_e + K^+$$

(1) F. Karsch, et al., Phys. Lett. B637(2006) 75-80
(2) I. Abt, et al., (2006) hep-ex/0607046
(3) R.L. Thews, (2006) hep-ph/0609121

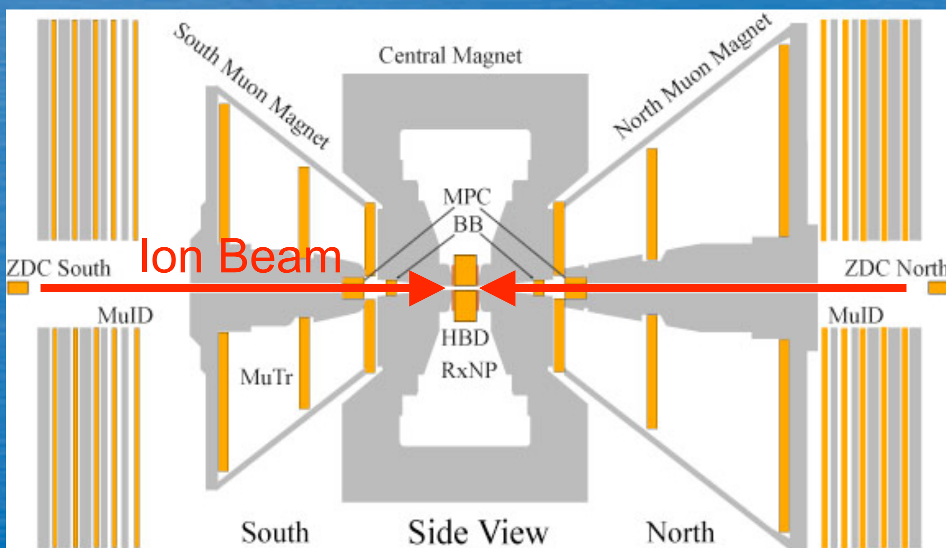
Relativistic Heavy Ion Collider (RHIC)



Brookhaven National Laboratory, Long Island NY



PHENIX Detector



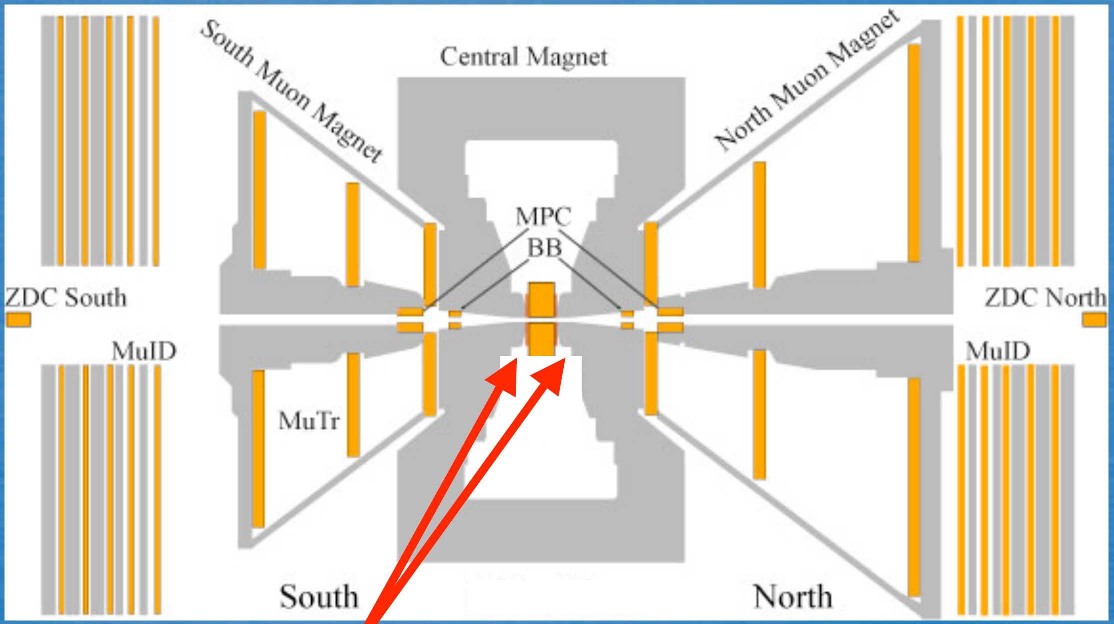
Side View of Muon Arms

$J/\psi \Rightarrow \mu^+ + \mu^-$

Measuring J/ψ Elliptic Flow

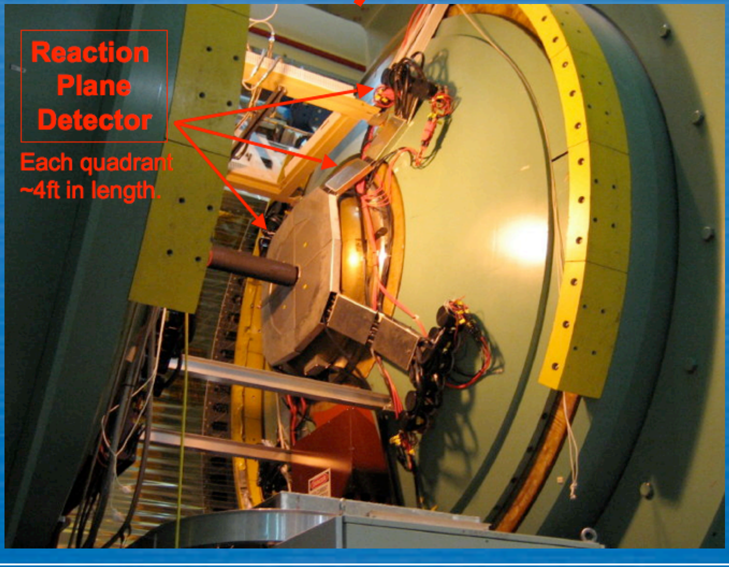
1) Determine reaction plane per event and determine reaction plane resolution for all events
2) Identify J/ψ candidates
3) Background subtraction
4) Determine flow signal and correct for uncertainty in reaction plane determination
5) Determine errors

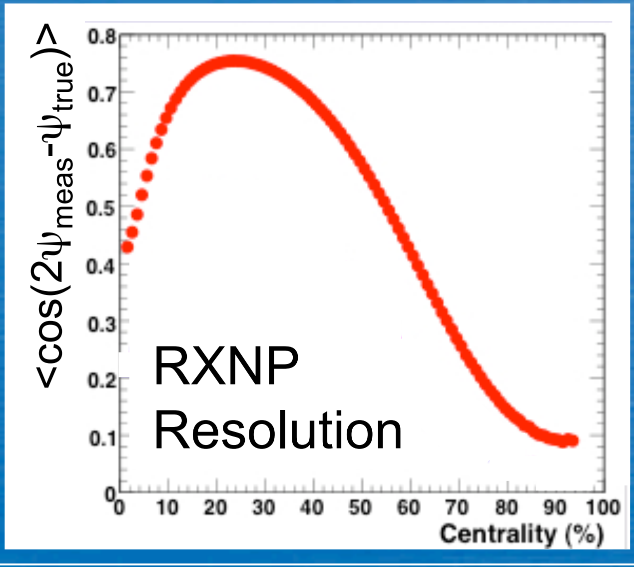
Measure reaction plane and resolution



Reaction Plane Detector (RXNP)

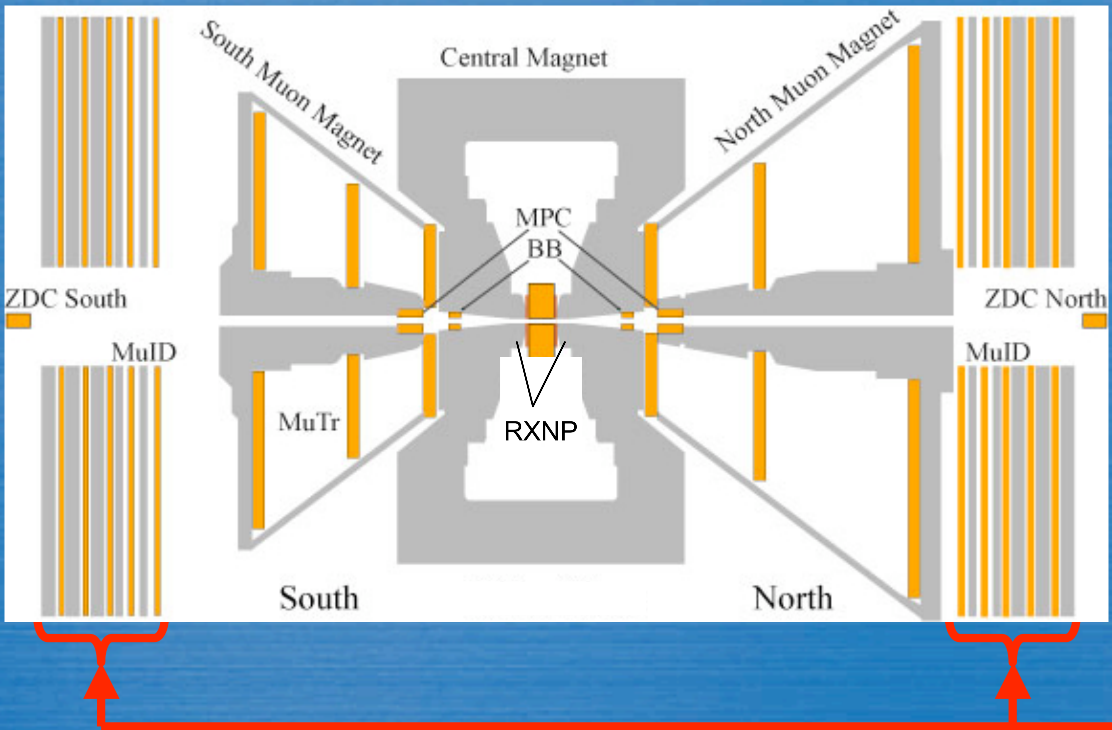
- 2 halves with each half having 24 plastic scintillators connected to PMT's
- Measures reaction plane for each collision by the asymmetric energy deposition in scintillators





Use resolution later to correct flow signal

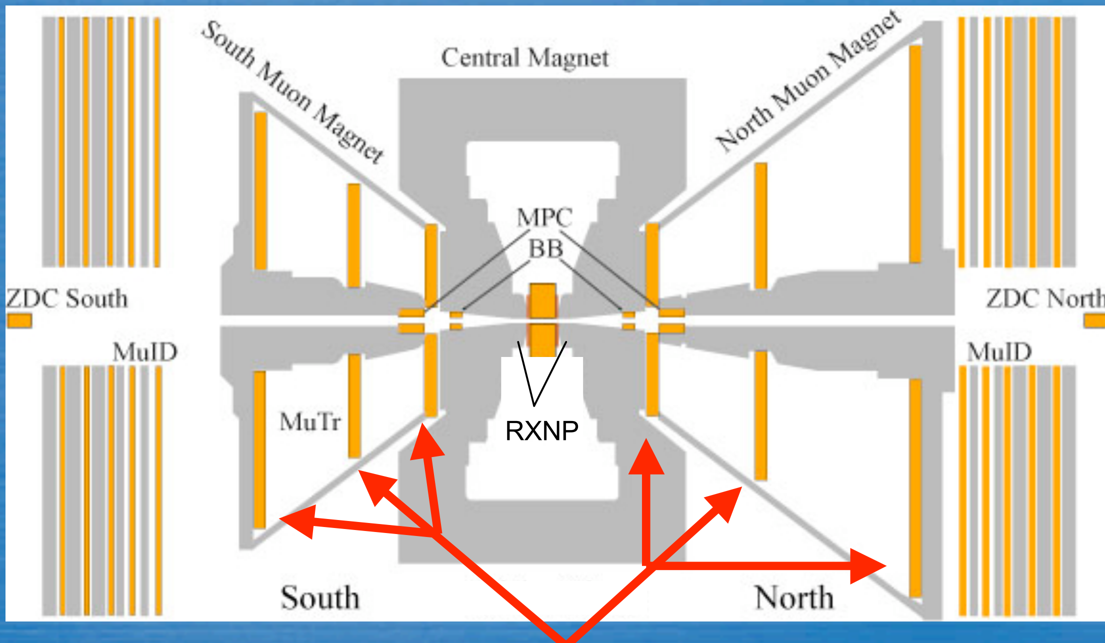
Muon Identification



Muon Identifier (MuID)

- 5 alternating layers of steel absorber and low resolution tracking chambers
- Steel filters out hadrons for muon identification

Particle Tracking



Muon Tracker (MuTr)

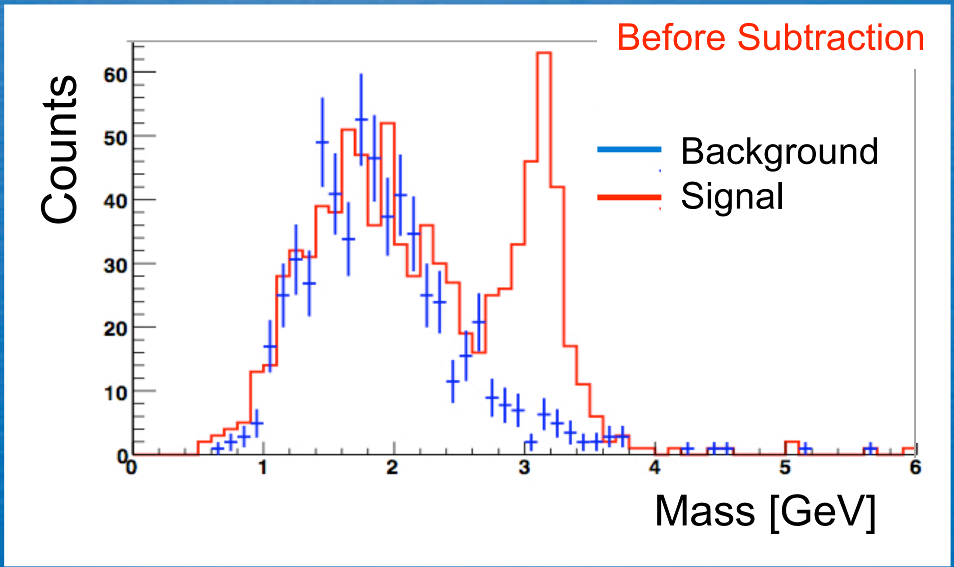
- 3 stations of precision drift chambers
- Determines particle momentum
- Track matching between MuTr and MuID

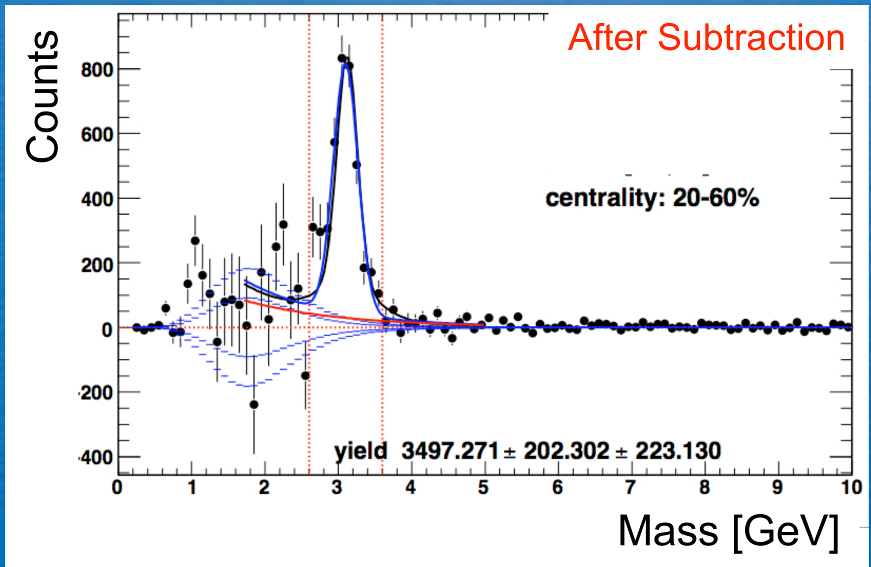
Background Subtraction

- Analyzed level 2 filtered events equivalent to ~ 3.5B min-bias
- Invariant mass histograms made of muon pairs
- Signal determined from background subtraction by :

$$Signal = Same_{+-} - Same_{like} \bullet \frac{Mixed_{+-}}{Mixed_{like}}$$

- Subtraction normalized by the different acceptance of like and unlike sign muon pairs using Mixed Events



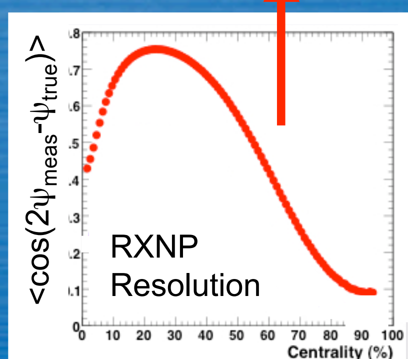


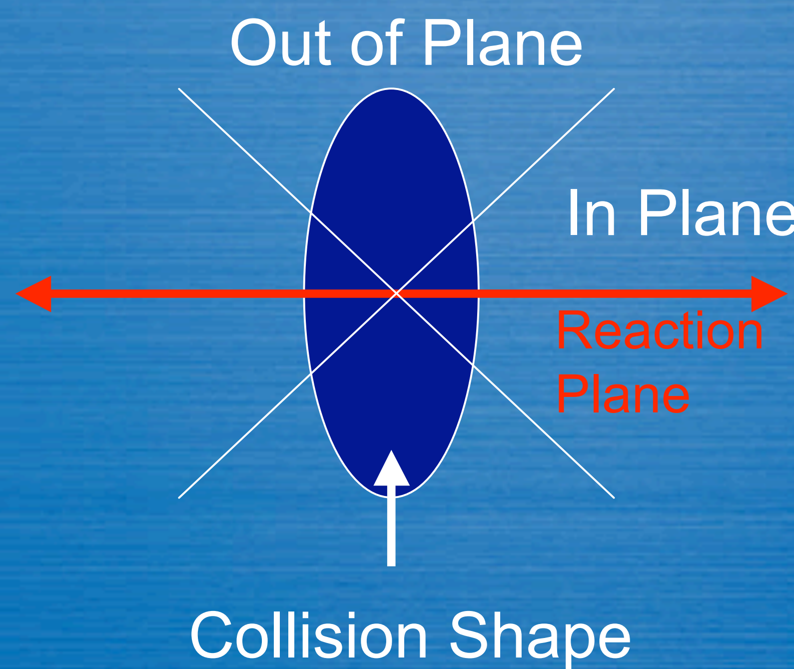
Elliptic Flow Measurement

- Find v_2 by comparing the number of J/ψ detected in-plane vs. out-of-plane

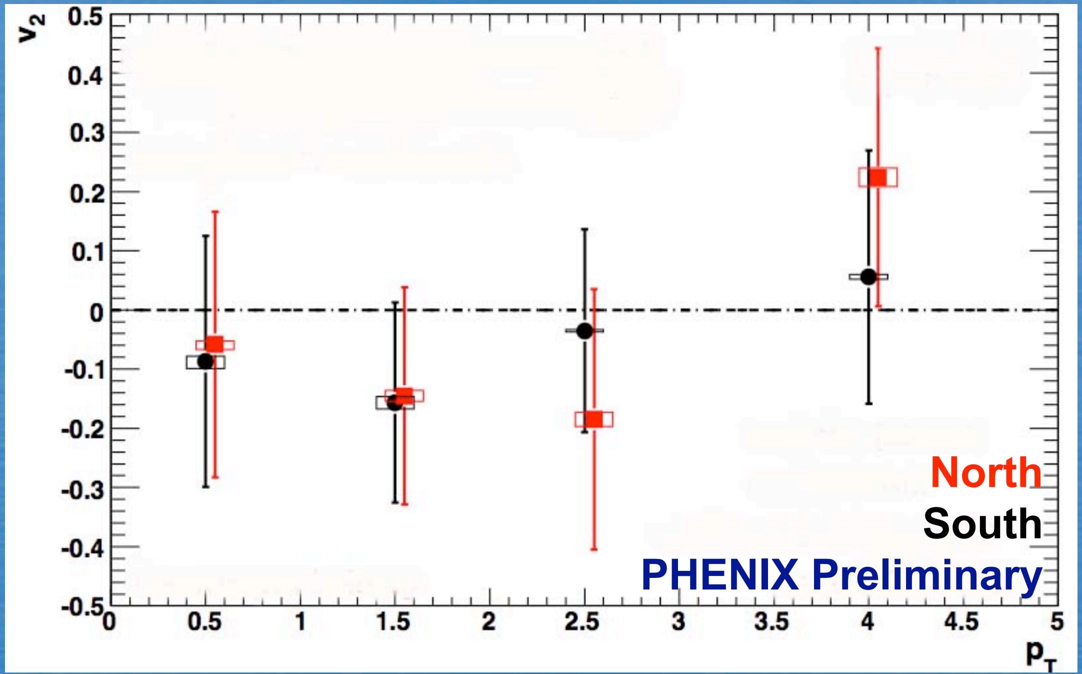
$$v_2^{meas} = \frac{\pi}{4}\frac{(N^{in} - N^{out})}{(N^{in} + N^{out})}$$

$$v_2 = \frac{v_2^{meas}}{\text{Resolution}}$$





J/ψ Elliptic Flow in Muon Arms

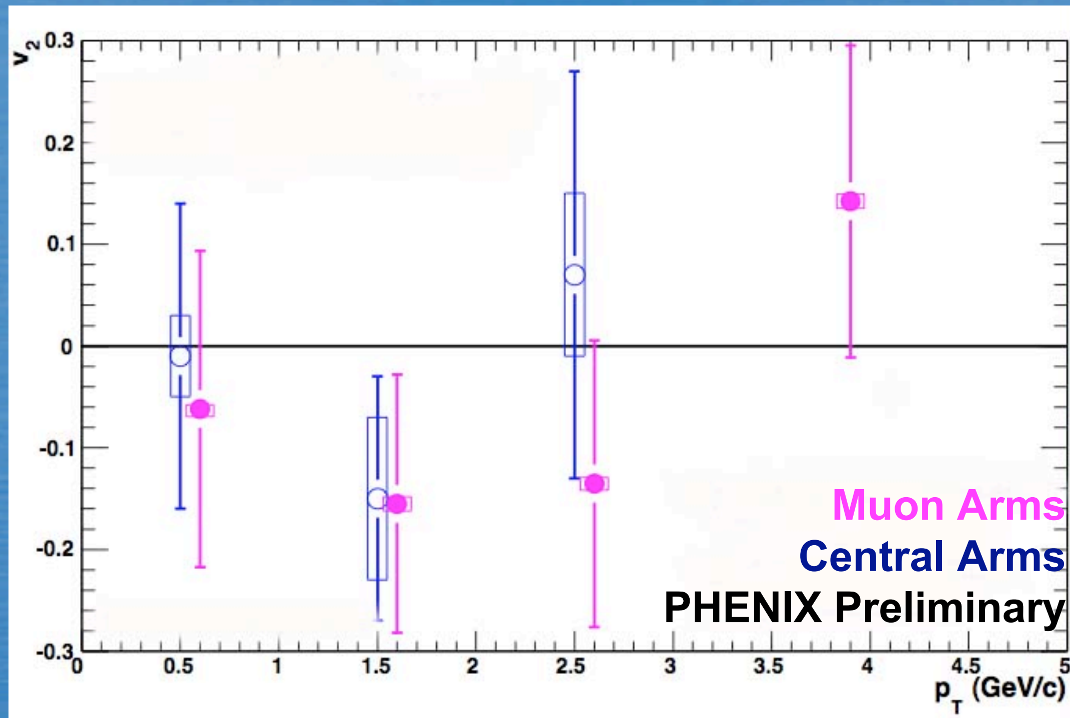


North $v_2 = -0.105 \pm 0.146 \pm^{0.005}_{0.006}$

South $v_2 = -0.066 \pm 0.144 \pm^{0.003}_{0.004}$

- Bars - statistical and systematic from signal fit
- Boxes - reaction plane resolution and J/ψ angle
- Global error for method used to determine reaction plane angle and resolution

J/ψ v_2 from PHENIX Central Arms



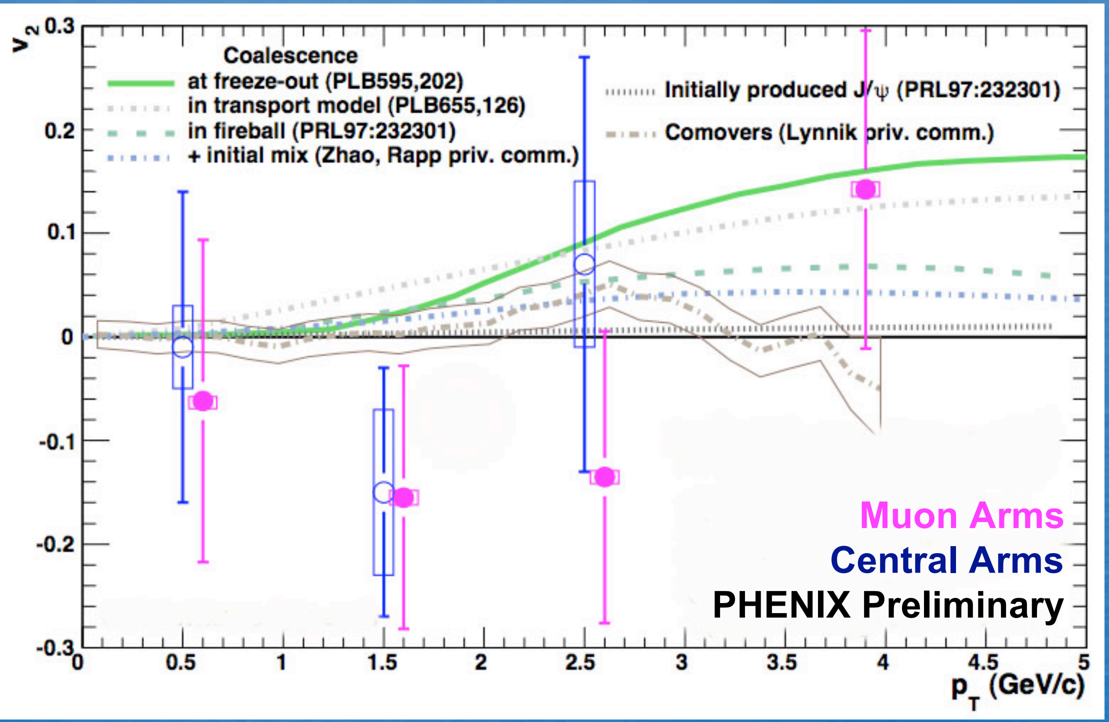
- Central Arms use dielectron decay channel J/ψ ⇒ $e^+ + e^-$

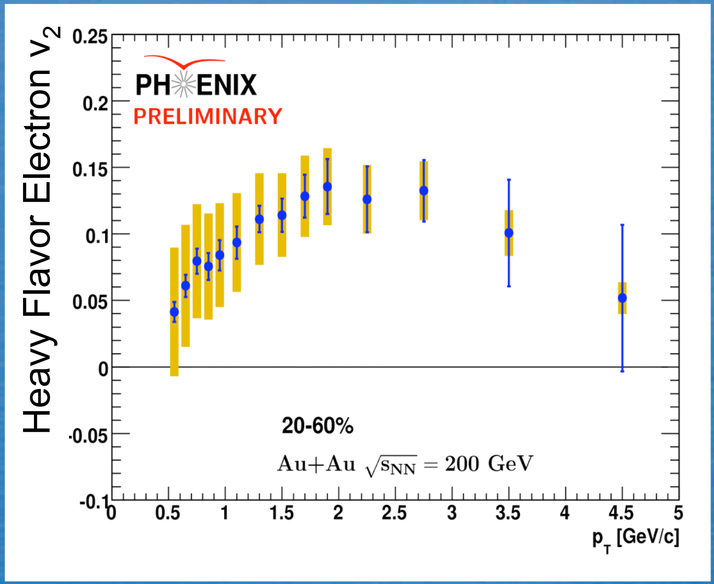
Muon $v_2 = -0.094 \pm 0.104 \pm^{0.003}_{0.004}$

Central $v_2 = -0.10 \pm 0.10 \pm 0.02$

- Keeping in mind the large error bars, both Muon and Central Arms show a possibility of zero to negative flow at low p_T contrary to previous flow measurements

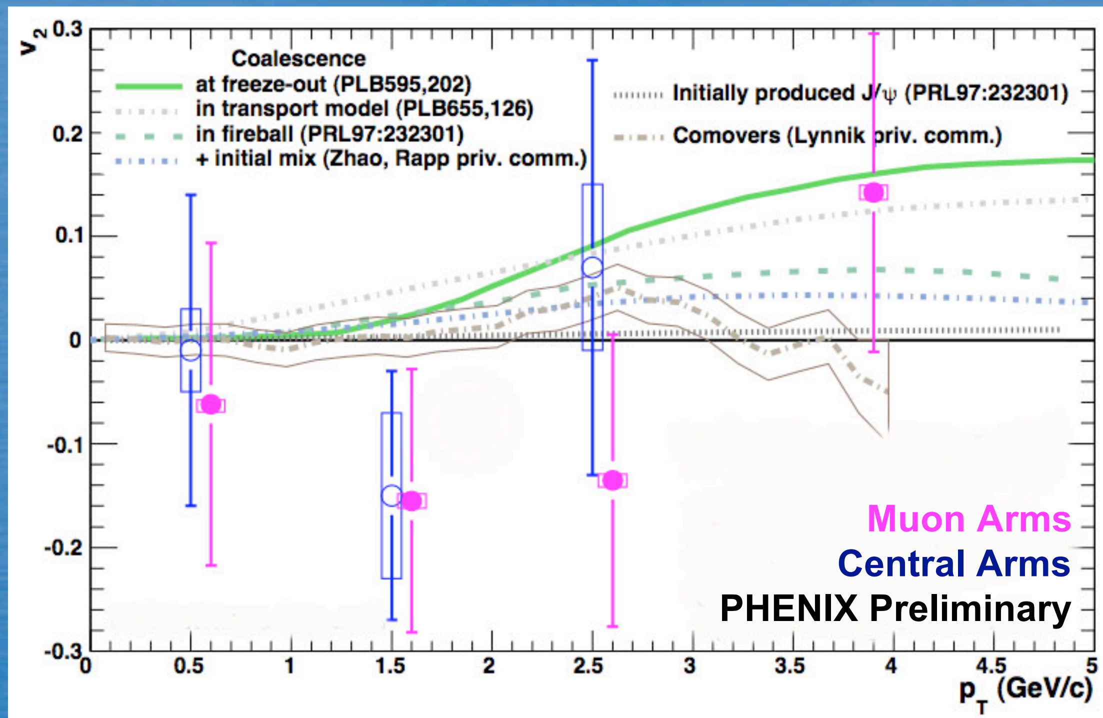
Comparison to Previous Measurements and Theory





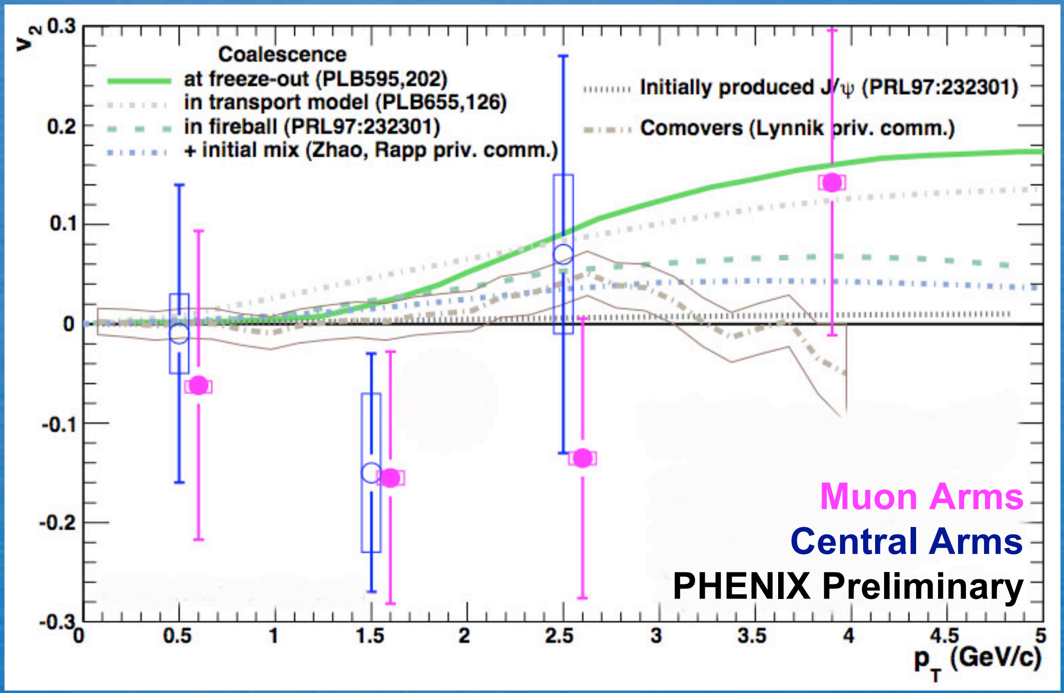
- If J/ψ formed from uncorrelated open charm then one would expect the J/ψ to inherit a positive v_2
- Models use almost no v_2 for direct J/ψ, but do incorporate an increasing v_2 with an increasing regeneration

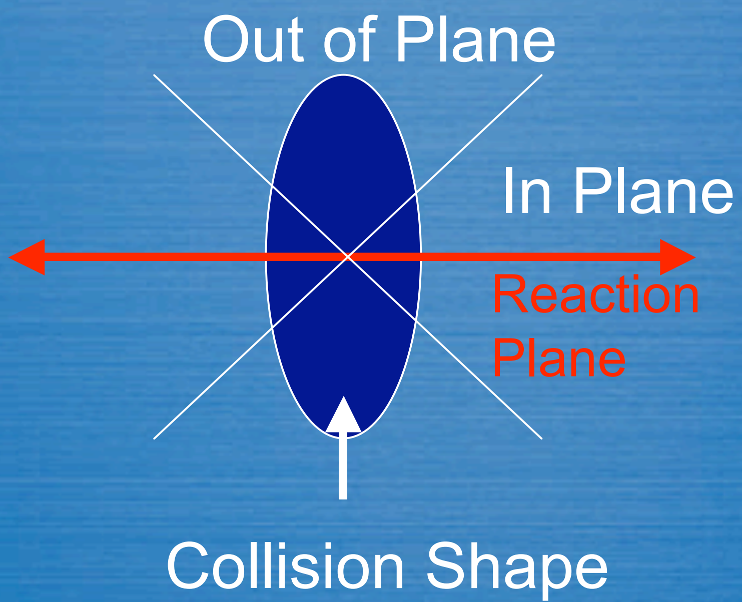
Other Interpretations



- If recombination does not occur and J/ψ doesn't become screened then perhaps it is too massive to succumb to the pressures of the medium and the v_2 will be 0

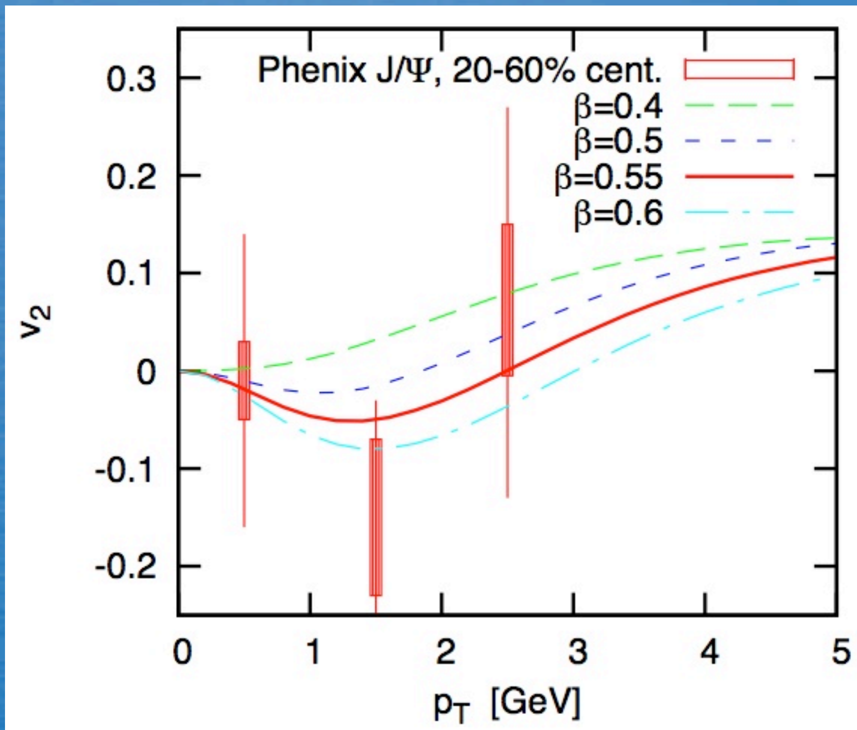
Other Interpretations

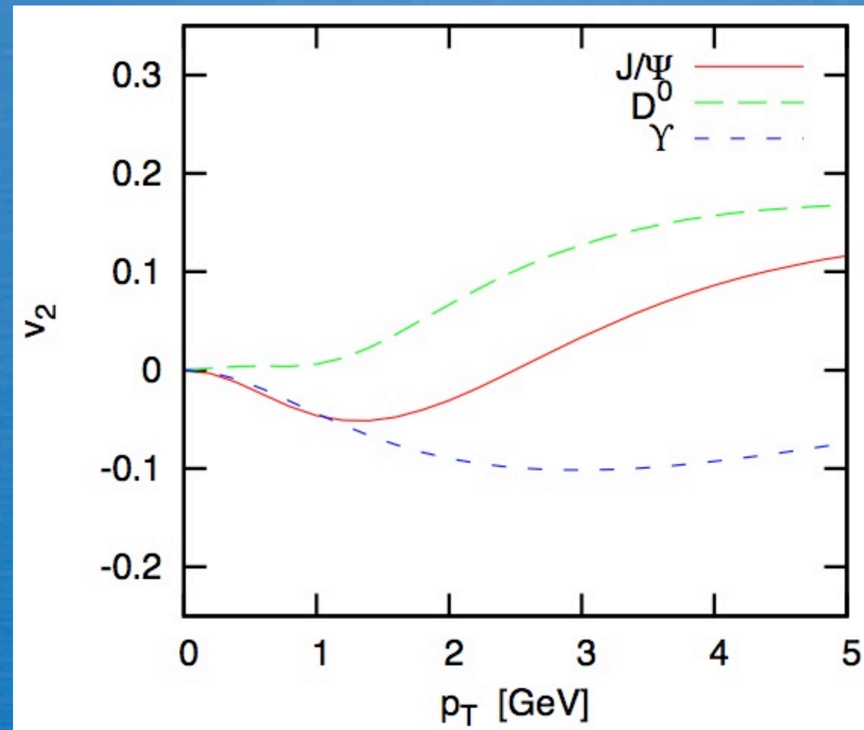




- Additional mechanism causing J/ψ to be suppressed in plane or enhancement out of plane then one could expect a negative v_2
- But what are these mechanisms?

New Theories





- Krieg and Bleicher (arXiv:0806.0736v1) have fit a recombination model to the Central Arm data by varying the transverse velocity of charm
- Also predict an even more negative v_2 for bottomonium

Conclusions

- Both Muon and Central Arms show possibility of zero or negative J/ψ flow as a function of p_T
- This contrasts previous experimental data
- However, error bars too large to draw any definitive conclusions
- Will soon repeat analysis with minimum bias data. This will improve statistics (~10%) and shrink error bars.
- However, this is not expected to significantly constrain the current conclusion
- To improve measurement, detector upgrades are in the works and additional statistics are expected in 2010

Backup

Errors

- Statistical errors are average of the 3 fits
  - Gaussian + Exponential: variable width and amplitude and centered at J/ψ mass
  - Double Guassian + Exponential : variable amplitude with fixed width centered at J/ψ mass
  - Exponential: Exponential fit outside J/ψ mass window. Count number of entries above fit
- Systematic errors
  - Signal from 3 fits
  - Vary fit window (1.5, 1.7, 2.0 GeV)
  - Change normalized background by ± 2%
  - Error is RMS of the 27 resulting values

Reaction Plane Resolution

- Used RXNP arm opposite the muon arm of interest

$$\sigma_a = \sqrt{\frac{\langle \cos 2(\psi_a - \psi_b) \rangle \langle \cos 2(\psi_a - \psi_c) \rangle}{\langle \cos 2(\psi_b - \psi_c) \rangle}}$$

σ_a = resolution of detector “a”

$\psi_{a,b,c}$ = measured rp angle of detector “a”, ”b”, “c”

- Overall resolution is weighted using J/ψ invariant yield

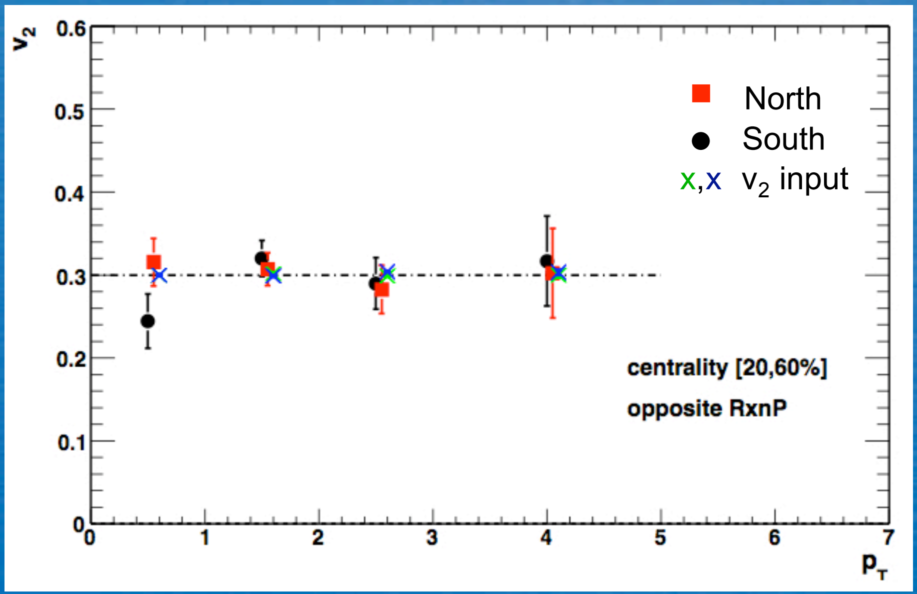
Background Subtraction

$$Signal = Same_{+-} - Same_{like} \bullet \frac{Mixed_{+-}}{Mixed_{like}}$$

- $Same_{like}$ forms a background that has the same bias that the $Same_{+-}$ has, caused by the level 2 filtering, while ensuring that none of the muon pairs can be from a J/ψ.
- $Mixed_{+-}/Mixed_{like}$ is used to correct for the fact that the number of positive and negative muons detected in the detector are different

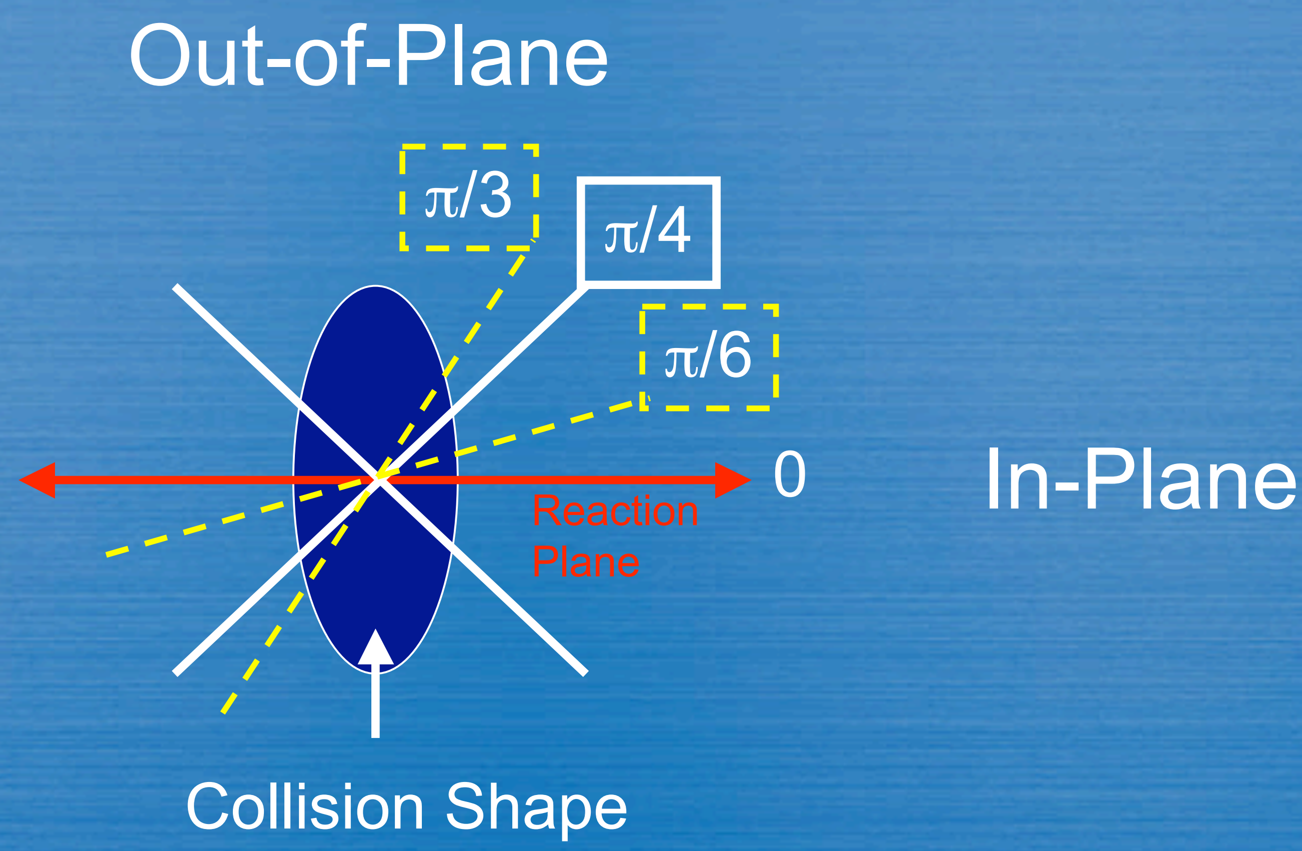
Method and Chain Verification with Simulation

- Retrieved reaction plane angle from real events
- Used PHYTHIA to generate J/ψ's with a v_2 = 0.3 wrt above reaction plane angles
- Embedded events in a GEANT simulation and used same reconstruction and analysis software as real data



- Input v_2 is retrieved

Different In-plane and Out-of-Plane Angles



- Changing angles causes the first 2 points of the north and south arms to change agreement

Averaging North and South Arm v_2

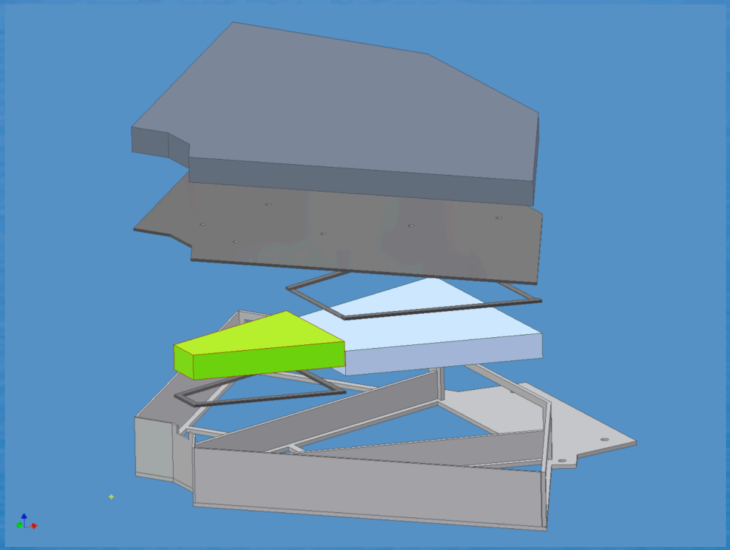
$$dN^{ave}_{J/\psi}\big/dy = \frac{\omega_s dN^{S}_{J/\psi}\big/dy + \omega_N dN^{N}_{J/\psi}\big/dy}{\omega_S + \omega_N}$$

$dN_{J/\psi}/dy$ = J/ψ invariant yield

$\omega = 1/\sigma^2_{arm}$

σ^2_{arm} = statistical and systematic errors from the signal fit

RXNP Detector



- Detector has North and South halves
- Each half divided into quadrants
- Each quadrant contains:
  - 1 Pb converter
  - 3 inner & 3 outer scintillators
  - 6 fine mesh PMT's