First measurement of the J/ψ elliptic flow parameter v_2 in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV by the PHENIX experiment

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Quark Matter 2008 - Jaipur

Understanding J/ψ results

Previous J/ψ results

- Less suppression than what is expected from low energy extrapolation
- More suppression at forward than at mid-rapidity

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PRL 98(2007) 232301

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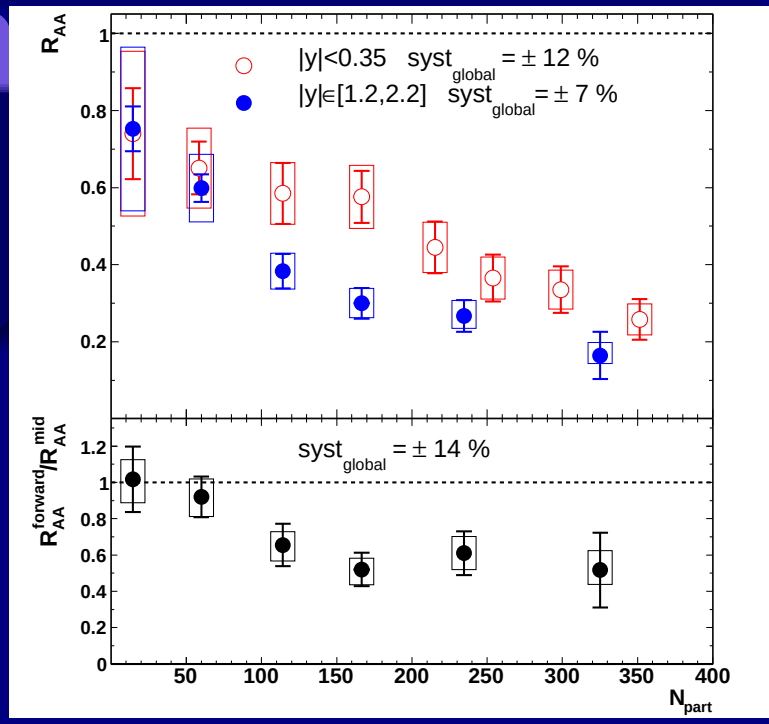

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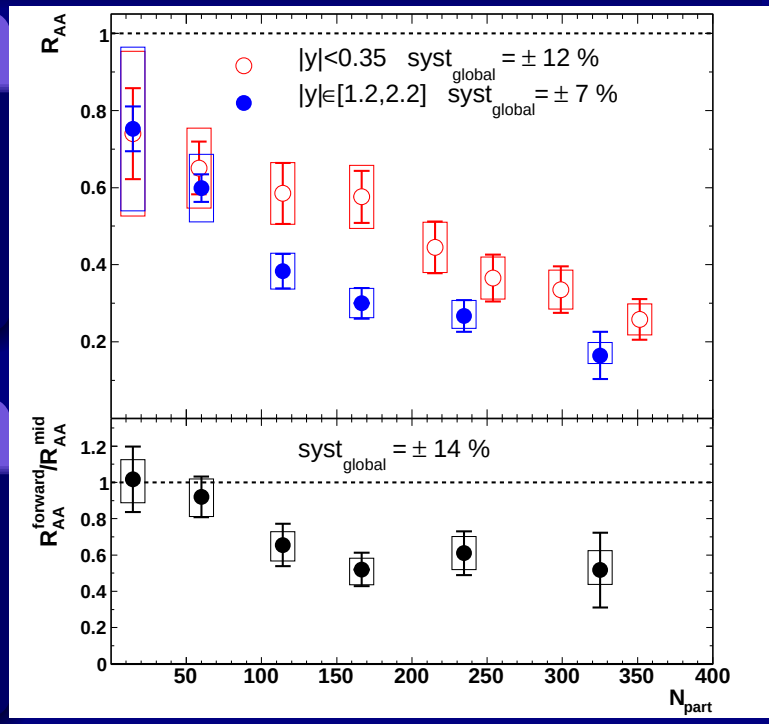
- Quarkonia regeneration via coalescence of charmed quarks ?
- Cold nuclear matter effects ? (M. Wysocki's talk)



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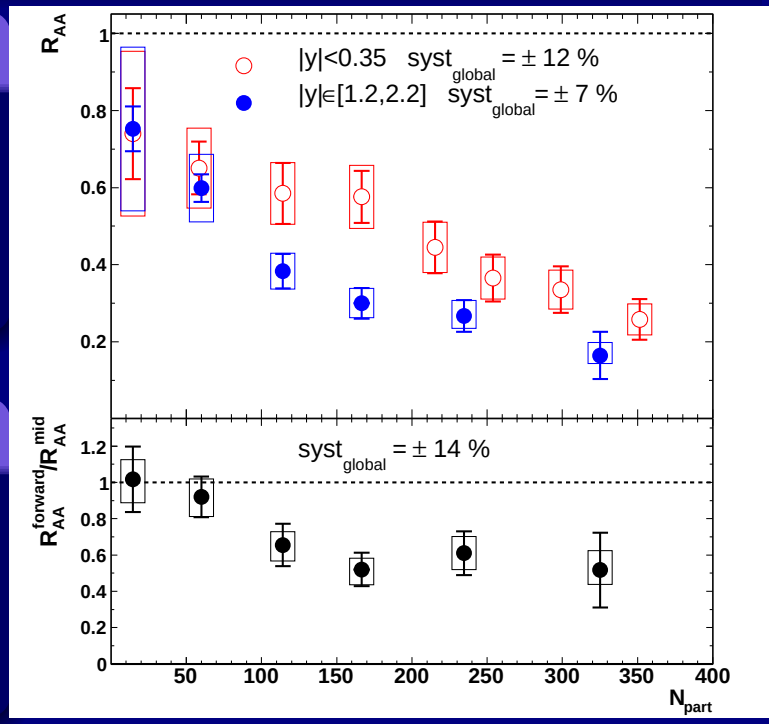

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Inputs which would provide a better understanding

- Improve d+Au statistics to further constrain cold nuclear matter effects (Run-8)
- Better handle of the total charm cross-section (Silicon Vertex upgrades)
- Measuring the feed-down contributions from ψ' and χ_c (S. Oda's talk, M. Donadelli's poster)
- Measuring the J/ψ elliptic flow

Why measure the J/ψ elliptic flow ?

Differentiate between J/ψ production mechanisms

- Produced from $c\bar{c}$ pairs created through hard processes early in the collision ?
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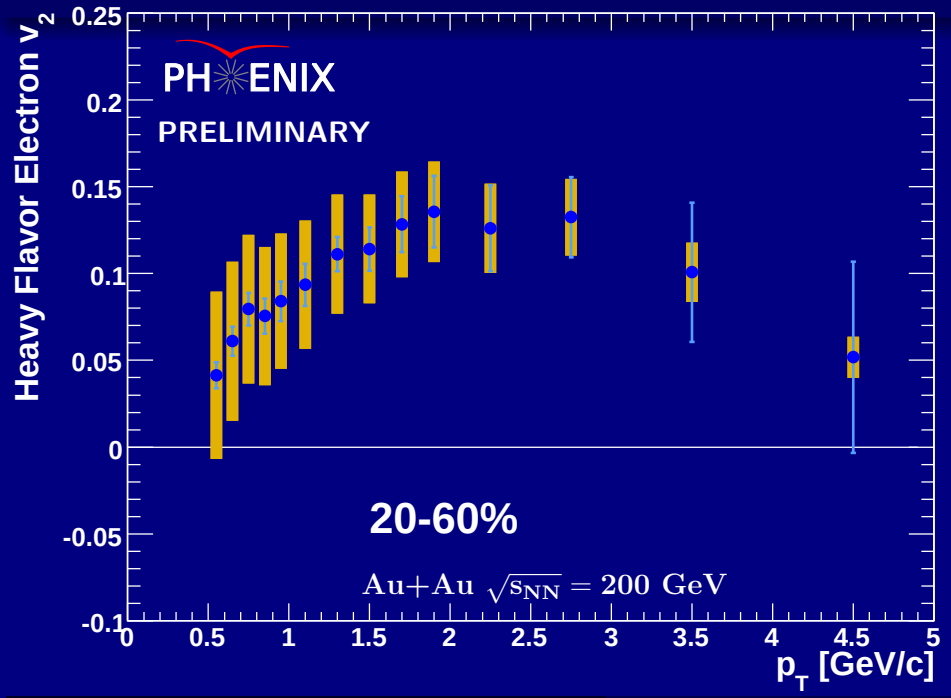

(see A. Dion poster)
(see D. Hornback and Y. Morino's talks)

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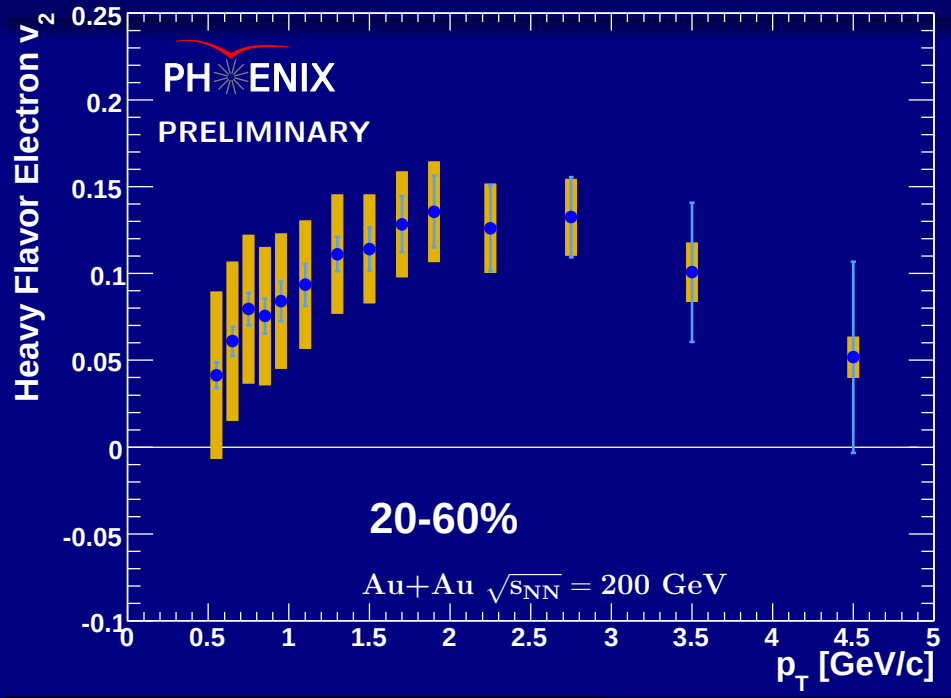

Measuring J/ψ flow will help discriminating between the 2 mechanisms

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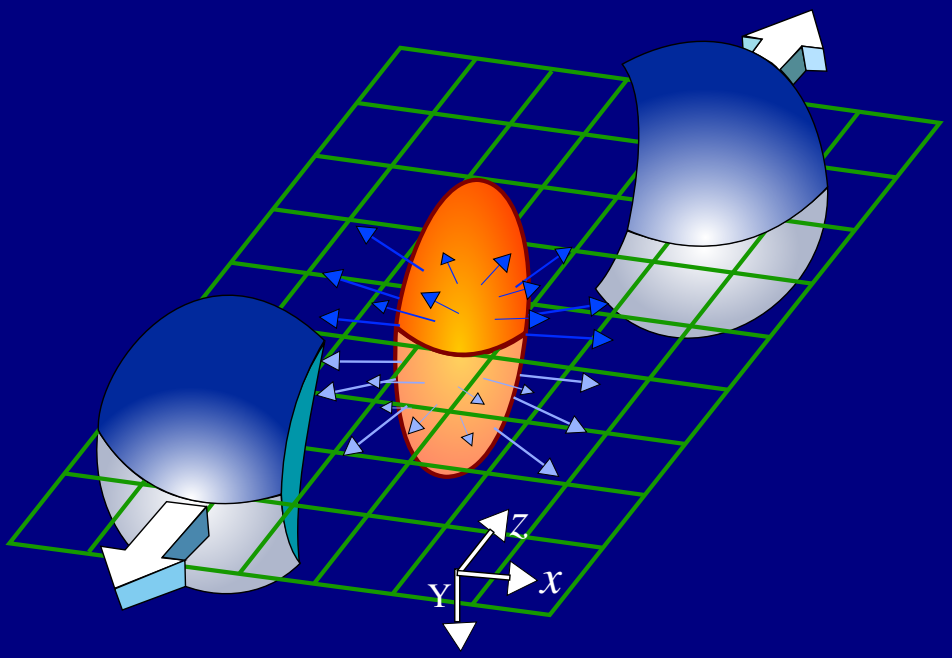
Understating the matter

- Quantify the collective behavior of the J/ψ meson and its precursors
- Constrain the space-time evolution of heavy-particles in the matter

What is elliptic flow ?

Elliptic flow

- Spatial anisotropy in the colliding matter
- If matter quickly becomes a thermalized system this leads to different pressure gradients
- Produced particles can have anisotropic distribution in the azimuthal plane

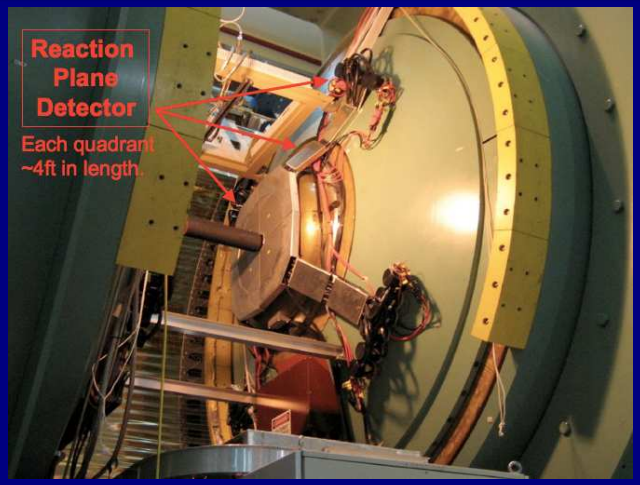


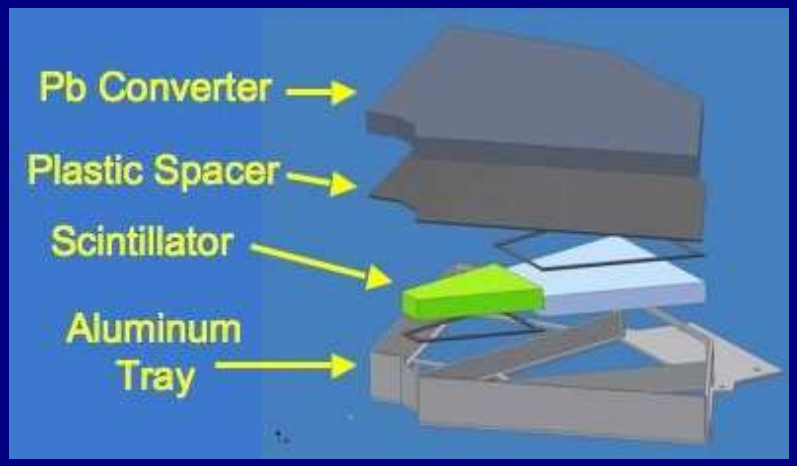
v_2

- Elliptic flow is characterized by the second Fourier coefficient of the azimuthal distribution of particles with respect to the reaction plane:

$$\frac{dN}{d(\phi-\psi)} = A[1 + 2.\mathbf{v_2}.cos2(\phi - \psi)]$$

The Reaction Plane Detector (RxnP)





How it enters the v_2 measurement

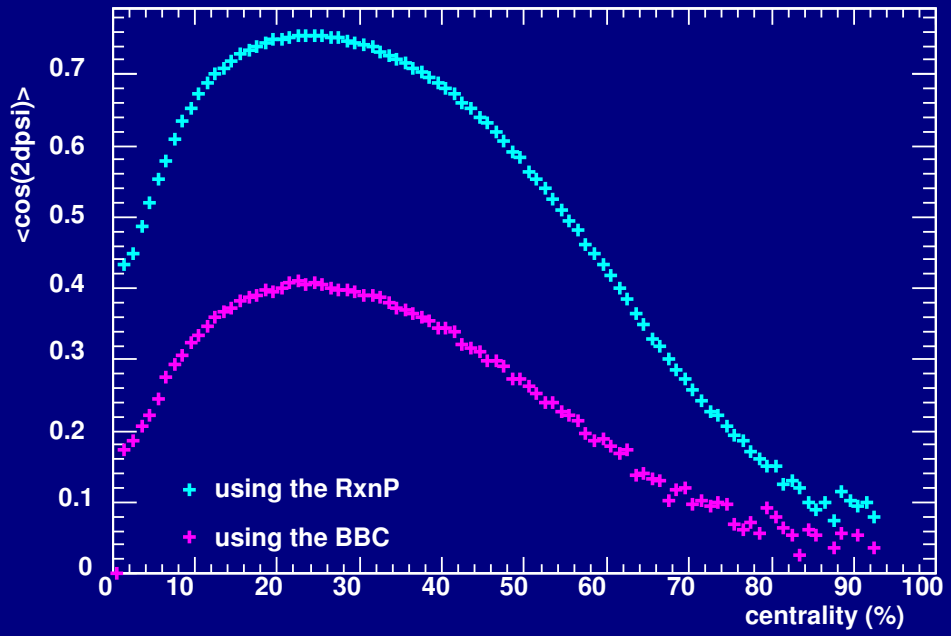
$$\psi_{meas} = \psi_{true} + \delta\psi$$

$$v_2^{true} = v_2^{meas} / \langle cos2(\psi_{meas} - \psi_{true}) \rangle = v_2^{meas} / \sigma_{RxnP}$$

Resolution of the reaction plane

- Measured using MPC, BBC, RxnP
- $\langle cos2(\psi_{meas} - \psi_{true}) \rangle$ is $\sim 1.8\times$ larger than with the BBC only

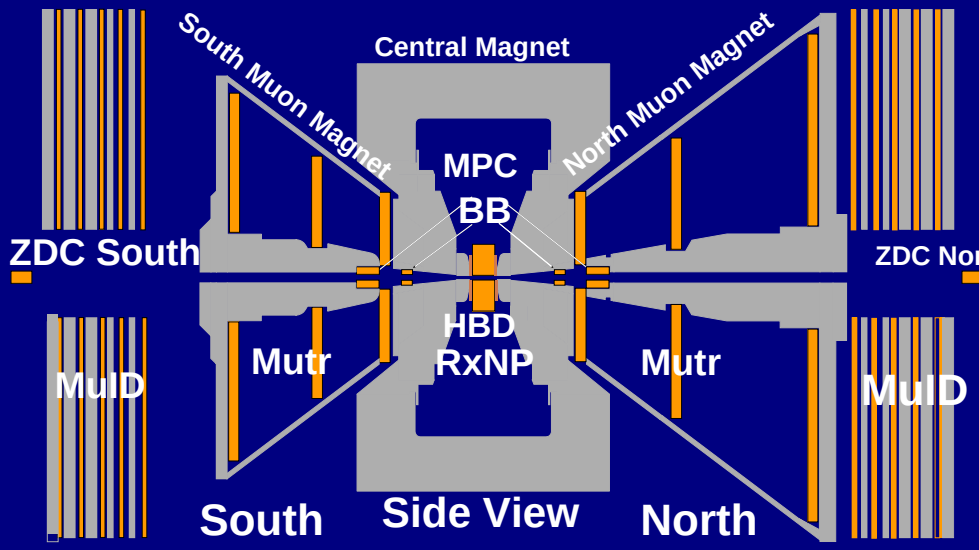
Reaction plane resolution



In the muon arms, ongoing analysis

$J/\psi \rightarrow \mu^+\mu^-$ $|y| \in [1.2, 2.2]$

- Muon identification: matching between track momentum and penetration depth in Iarroci tubes (MuID) + absorbers
- Selection with front absorber
- Momentum measured with cathode strip chambers (Mutr)



Specifics: a difficult measurement ?

- Number of J/ψ measured: 3 per million events
- J/ψ resolution: between 150 and 200 MeV
- Signal over background ratio : 1/6 in centrality bin [20,60%]
- Run-7 number of MB events: $\sim 1.8\ 10^9$ (42%)

Measuring v_2 with the muon arms

Bias when using the RxnP detector

- RxnP and Mutr acceptances overlap
- The 2 muons and the possible accompanying fragmentation products might bias the reaction plane measurement

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Test of 3 configurations (used as cross-checks)

1. "Opposite RxnP", RxnP located in the muon arm opposite to the J/ψ:
   + minimized bias
   − σ_{RxnP} worse than when using North+South RxnP
2. "Both RxnP", both North and South RxnP detectors:
   + reaction plane angle determination more accurate
   + better σ_{RxnP}
   − might be biased
3. "Same RxnP", RxnP detector located in the same muon arm as the J/ψ:
   − same resolution as with the "opposite" RxnP
   − maximum bias

Measuring v_2 with the muon arms

Using the "subtraction method"

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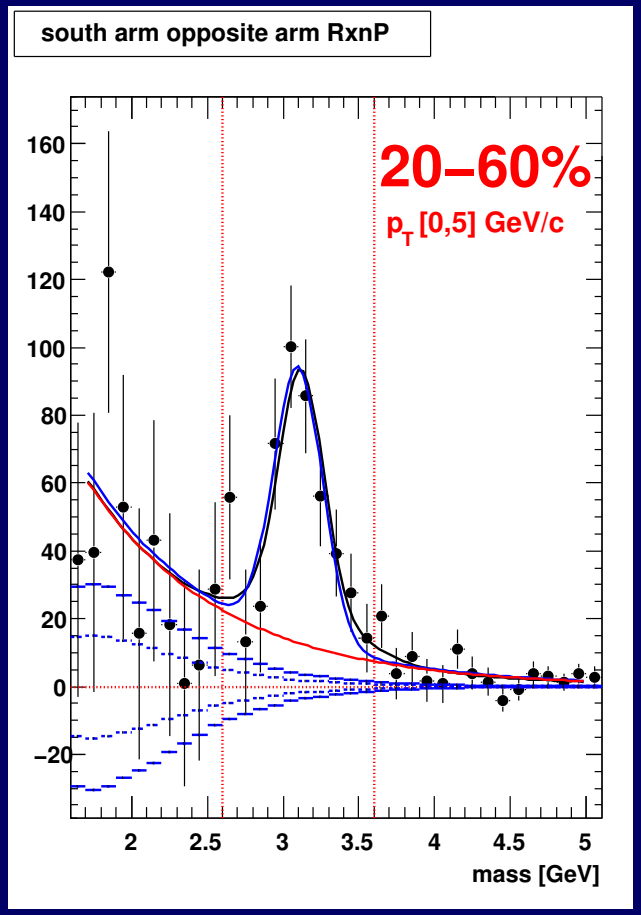
- Extract the J/ψ counts in bins of (ϕ-ψ, p_T, centrality) using mixed event background subtraction



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- Extract the J/ψ counts in bins of (ϕ-ψ, p_T, centrality) using mixed event background subtraction
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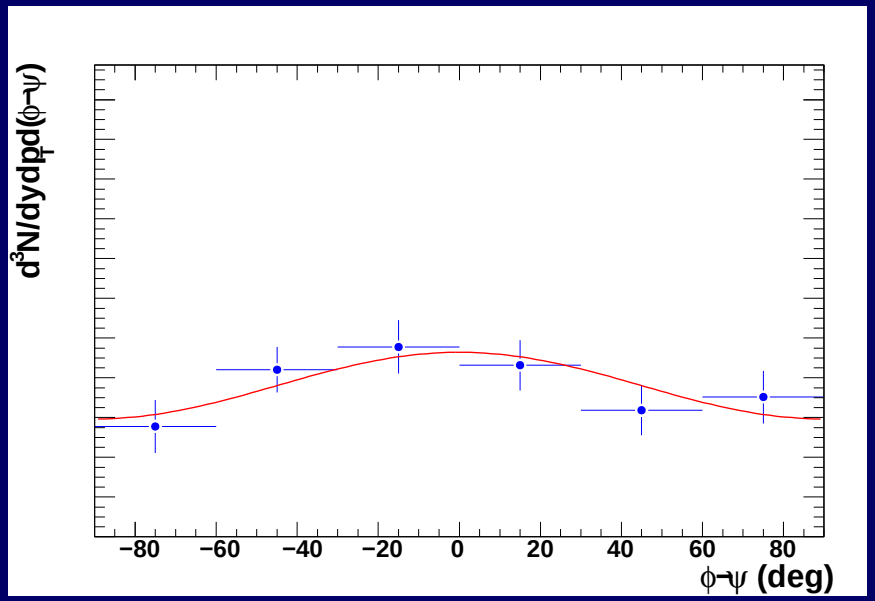

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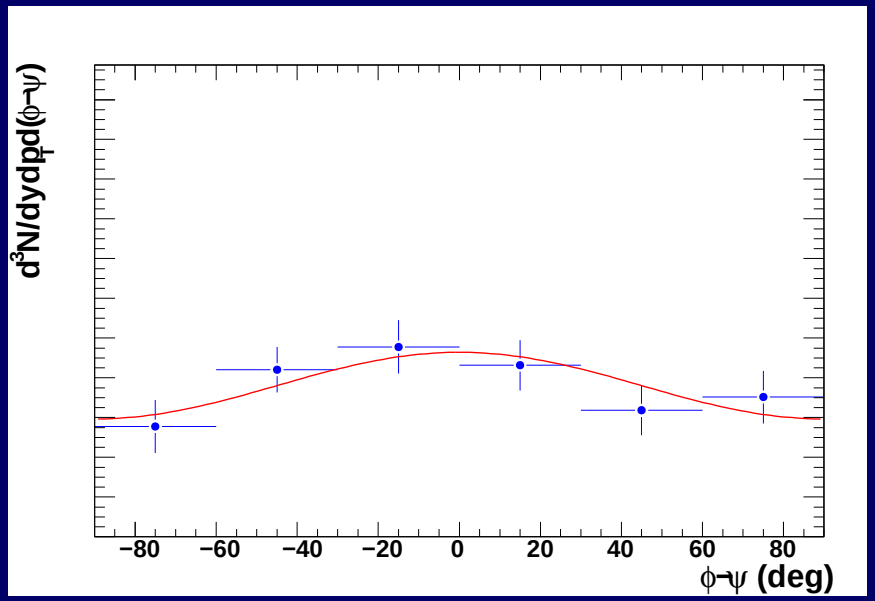

- Divide by the appropriate averaged reaction plane resolution to get v_2 as a function of p_T

Measuring v_2 with the muon arms

Status J/ψ Run-7 forward analysis

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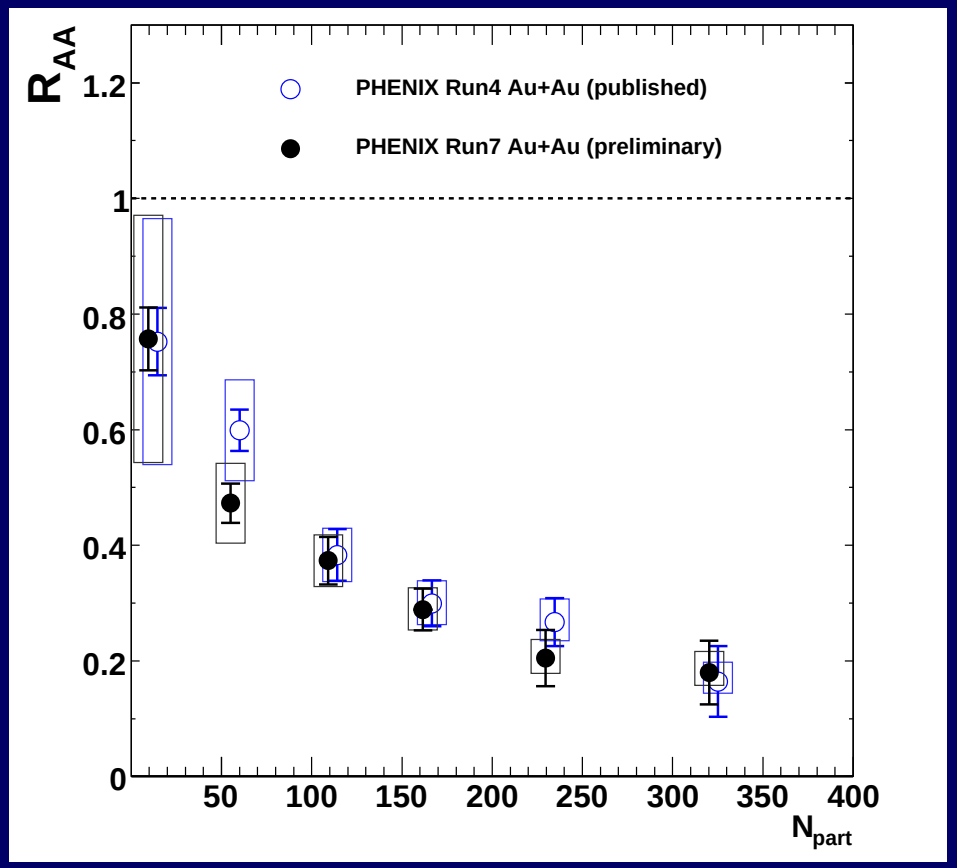
- R_{AA} has been measured and is compatible with published results



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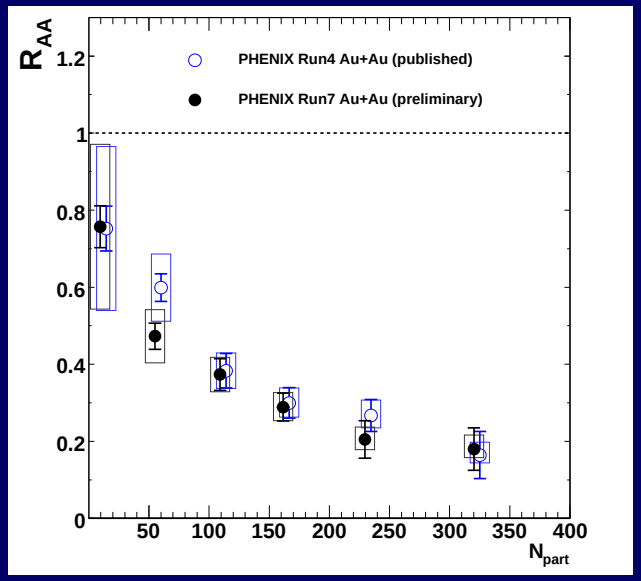


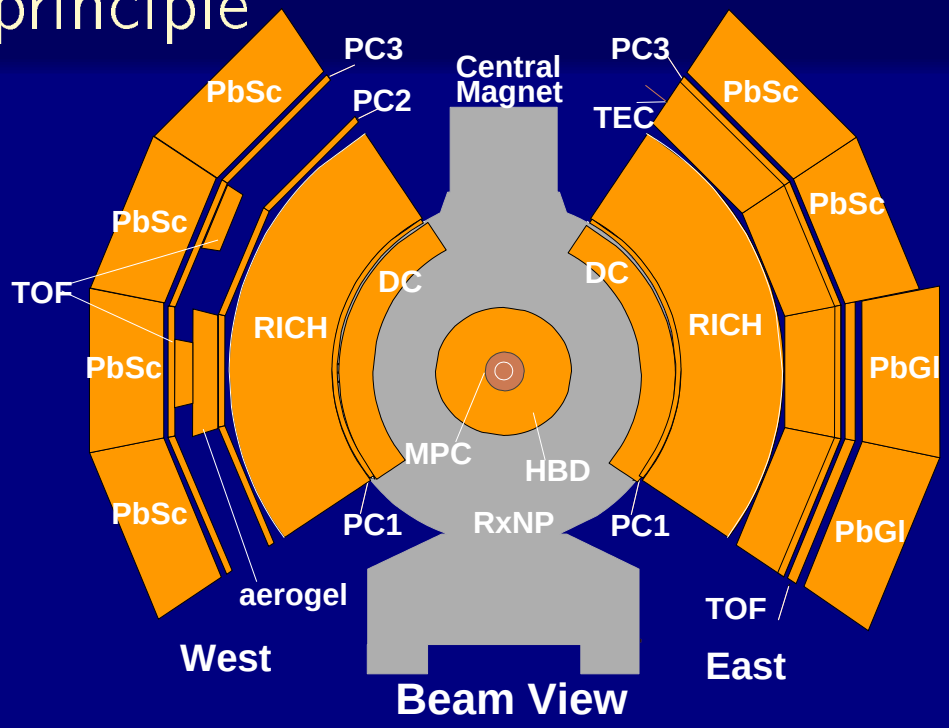
Status v_2 forward analysis

Ongoing studies $\Rightarrow$ Stay tuned!

In the central arm: a proof of principle

$J/\psi \rightarrow e^+e^-$ $|y| < 0.35$

- Momentum measurement and tracking with Drift and Pad Chambers
- Electron identification with RICH and EMCal



Specifics: a difficult measurement ?

- Less J/ψ than in the muon arms because of a smaller acceptance: 1 per million events
- Better J/ψ resolution than in the muon arms: 80 MeV
- Better signal over background ratio: 1/2.7 [20,60%]
- Run-7 equivalent number of minbias events 1.8 10^9 (42%)

Measuring v_2 at mid-rapidity

see C. L. Silva's poster

Using the "background fit method"

v_2 is additive: $v_2^S N^S = v_2^{FG} N^{FG} - v_2^{BG} N^{BG}$

$$\Rightarrow v_2^S = v_2^{FG}(M_{jpsi}) \frac{N^{FG}(M_{jpsi})}{N^S(M_{jpsi})} - v_2^{BG}(M_{jpsi}) \frac{N^{BG}(M_{jpsi})}{N^S(M_{jpsi})}$$

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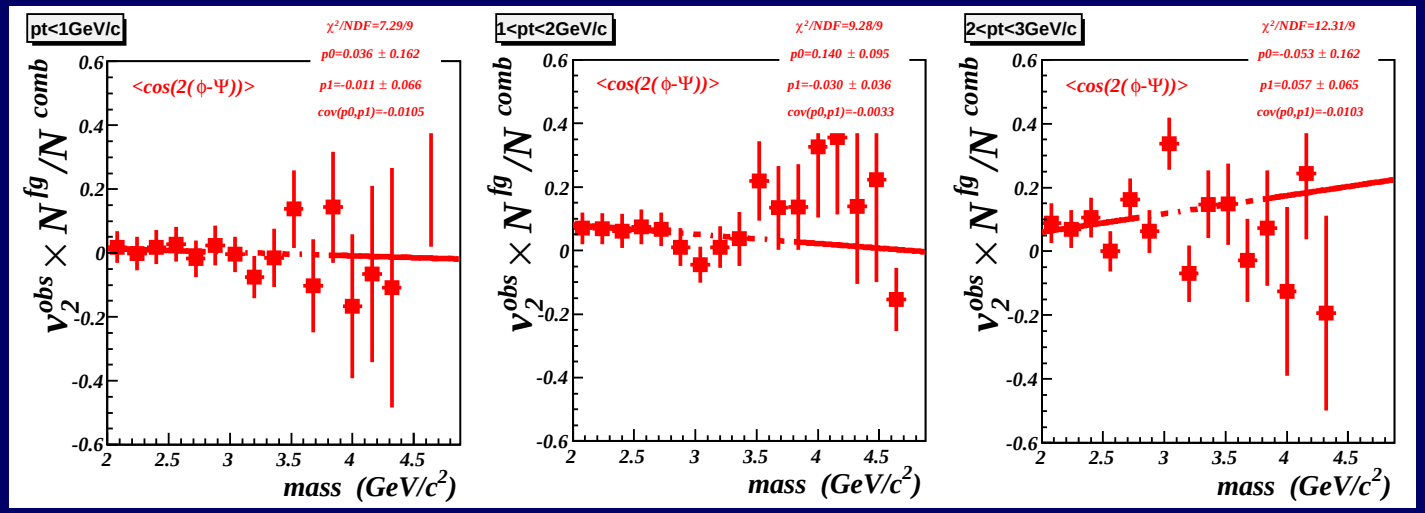

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5. $N^{signal} = N^{FG} - (N^{combinatorial} + N^{remaining})$ with $N^{remaining}$ the remaining contribution of the background fitted with an exponential

Results

Checks that showed consistancy

- Results of different methods of extracting v_2
- Varying electron identification cuts
- Changing J/ψ and background mass fit range

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- Global systematics to account for the technique used to determine the reaction plane angle and resolution: 3% (written)

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  - varying the background v_2 shape:
  with a constant, linear and quadratic polynomial
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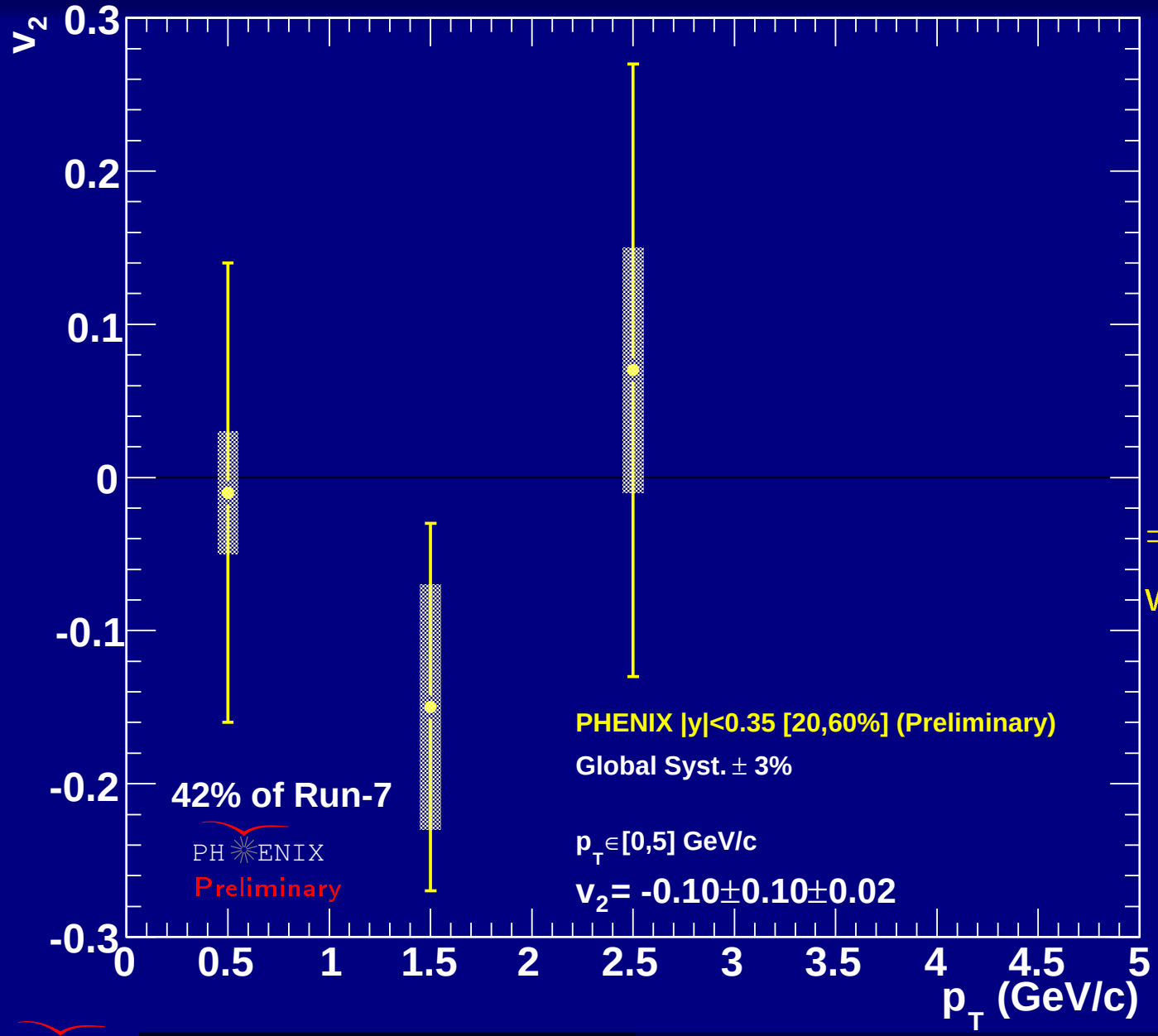
Distinguishing between models ?



PHENIX $|y| < 0.35$
42% of Run-7

$\Rightarrow$ Consistent with 0 within errors

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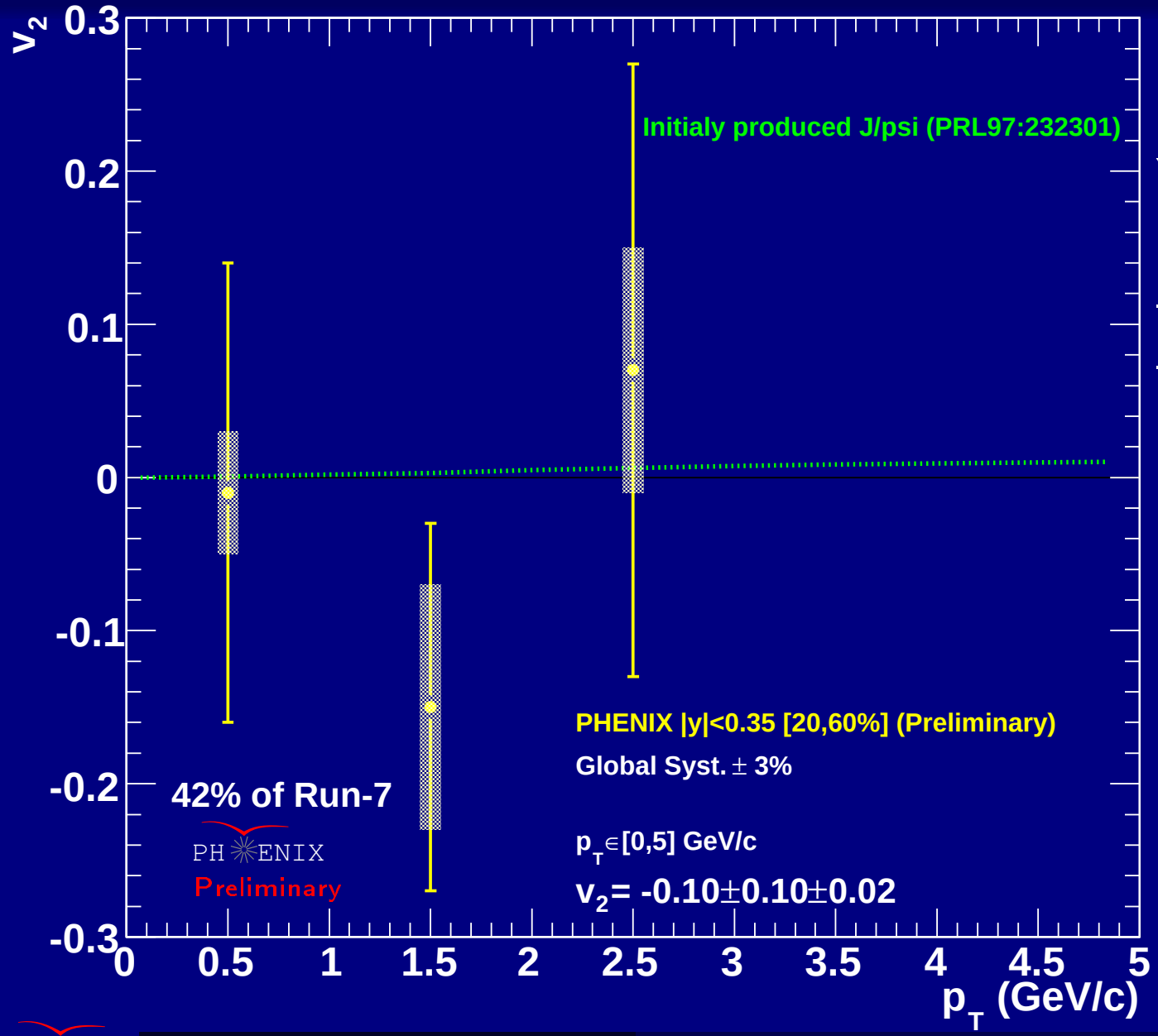
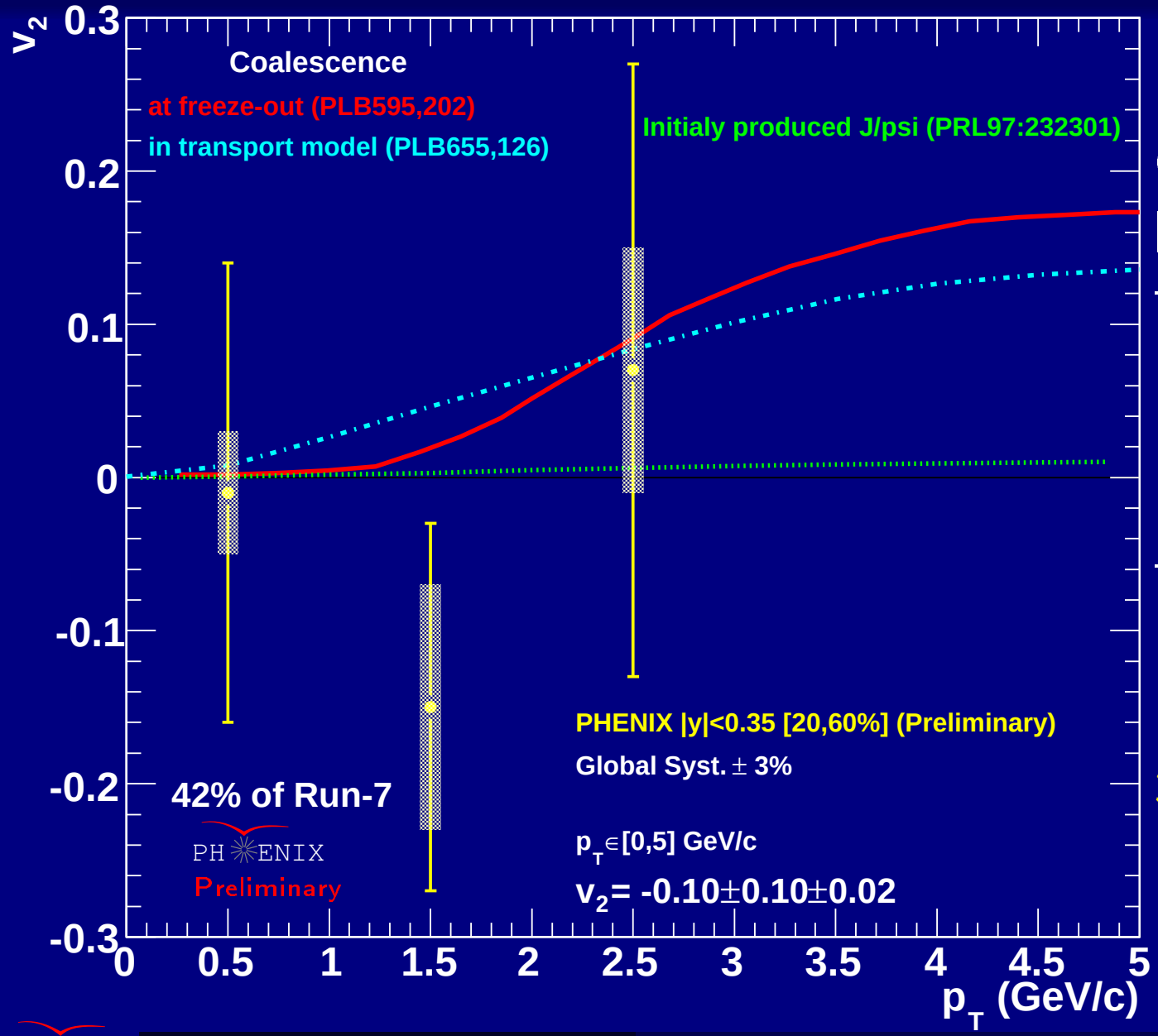


Yan, Zhuang, Xu [PRL97:232301]

- initially produced J/ψ
- slight leakage

v_2 slightly positive with increasing p_T but small

Distinguishing between models ?



Full regeneration

Greco, Ko, Rapp [PLB595,202]
- at freeze-out

Ravagli, Rapp[PLB665,126]
- in transport model

$v_2 > 10\%$ for $p_T > 3\,GeV/c$

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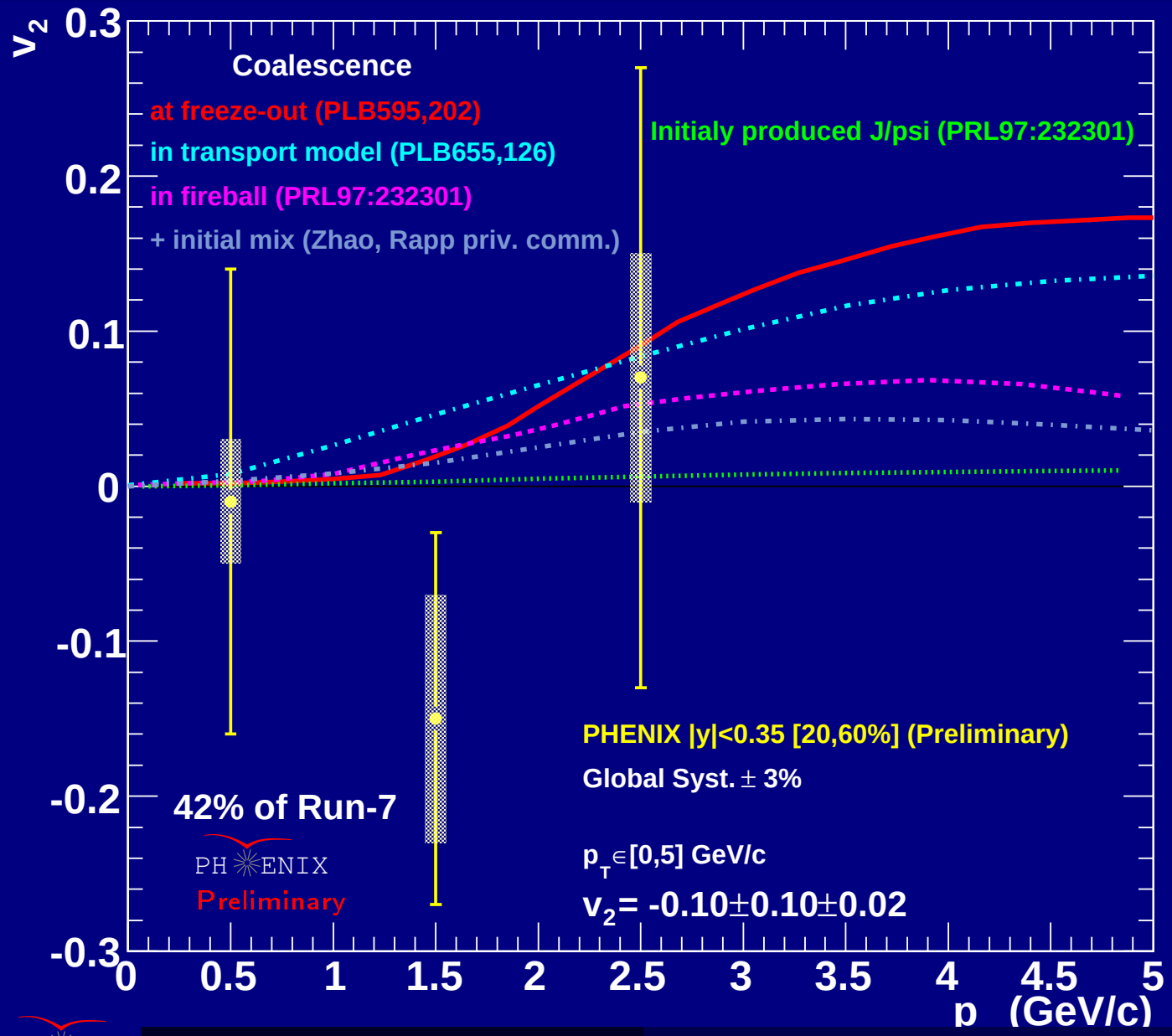


Mixing of coalescence models with initial production

Yan, Zhuang, Xu [PRL97:232301]

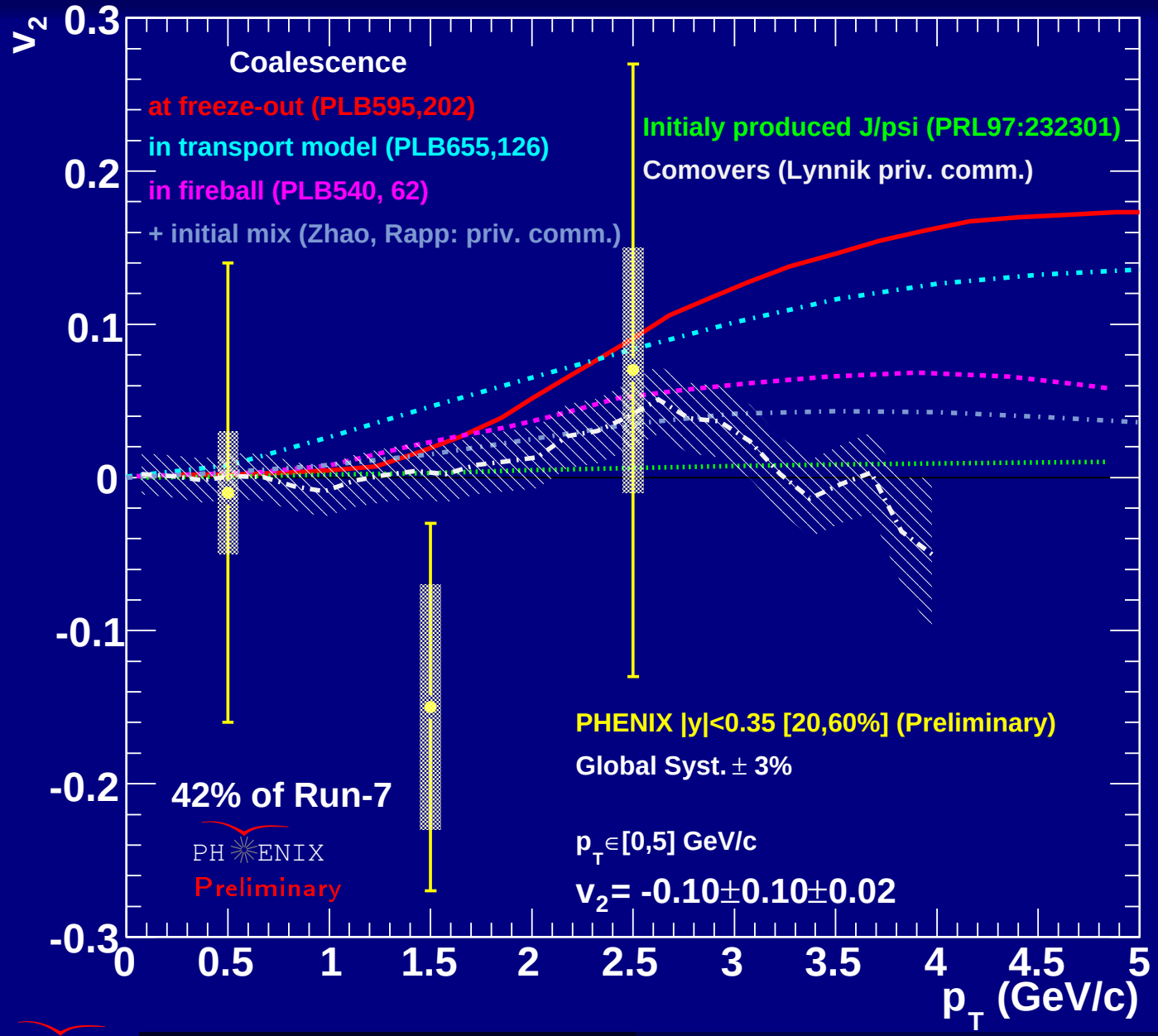
- continuous regeneration
- initially produced J/ψ

Zhao, Rapp [private comm.]

- coalescence
- primordial direct production

v_2 positive with en

Distinguishing between models ?



Linnyk, Bratkovskaya, Cassing [arXiv:0801.4282]

- comovers

v_2 encreasing up to 5% at 2.5 GeV/c then decreasing to reach -5% at 4 GeV/c but compatible with 0 within errors.

First measurement of J/ψ v_2 in PHENIX

Summary

- Ongoing analysis at forward rapidity
- The current statistical precision on the v_2 measurement for mid-rapidity results do not distinguish between models
- Proof of principle

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- Statistics $\times 2$
- More studies on the systematic errors for final results at mid-rapidity
- Forward rapidity measurements expected soon

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My personal request to theorists: predictions at forward rapidity ?

Backup slides

Calculating the reaction plane resolution

Measurement methods see Ollitrault [nucl-ex.971103] and Voloshin & Poskanzer [nucl-ex/0905001]
If we wish to measure v_2 with respect to the reaction plane we calculate:

$$\begin{aligned} v_2^{meas} &= \langle \cos 2(\phi - \psi_{meas}) \rangle \\ &= \langle \cos 2(\phi - \psi_{true} - \delta\psi) \rangle \\ &= \langle \cos 2(\phi - \psi_{true}) \cos 2(\delta\psi) - \sin 2(\phi - \psi_{true}) \sin 2(\delta\psi) \rangle \\ &= \langle \cos 2(\phi - \psi_{true}) \rangle \langle \cos 2(\psi_{meas} - \psi_{true}) \rangle \\ &= v_2^{true} \langle \cos 2(\psi_{meas} - \psi_{true}) \rangle \end{aligned}$$

Resolution (Ollitrault, arXiv:nucl-ex/9711003)

$$\langle \cos 2(\psi_a - \psi_b) \rangle = \langle \cos 2(\psi_a - \psi_{true}) \rangle \langle \cos 2(\psi_b - \psi_{true}) \rangle$$

where ψ is measured separately by detectors a and b.
For any 3 detectors one can write:

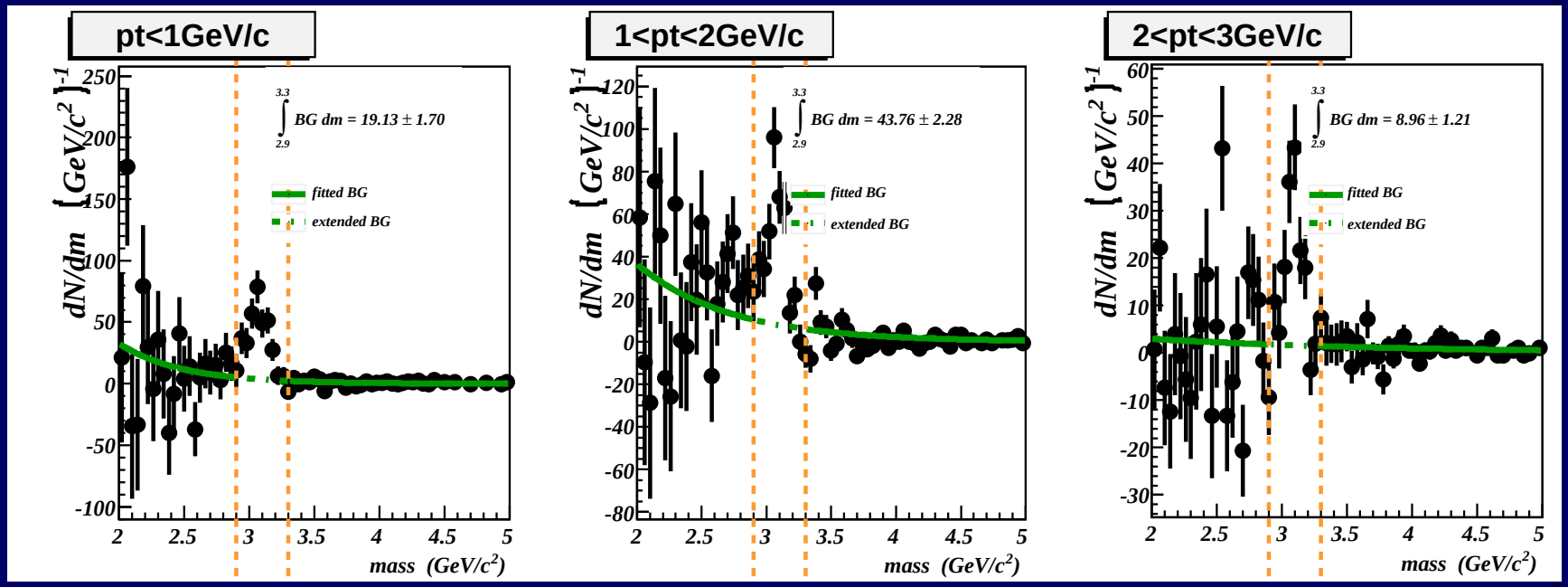
$$\sigma_a = \langle \cos 2(\psi_a - \psi_{true}) \rangle = \sqrt{\frac{\langle \cos 2(\psi_a - \psi_b) \rangle \langle \cos 2(\psi_a - \psi_c) \rangle}{\langle \cos 2(\psi_b - \psi_c) \rangle}}$$

$\Rightarrow$Measurement of σ_{RxnP} for the RxnP North and South detectors, both separately and combined, using the BBC North/South and MPC North/South as detectors b and c.

Background fit method

Remaining background

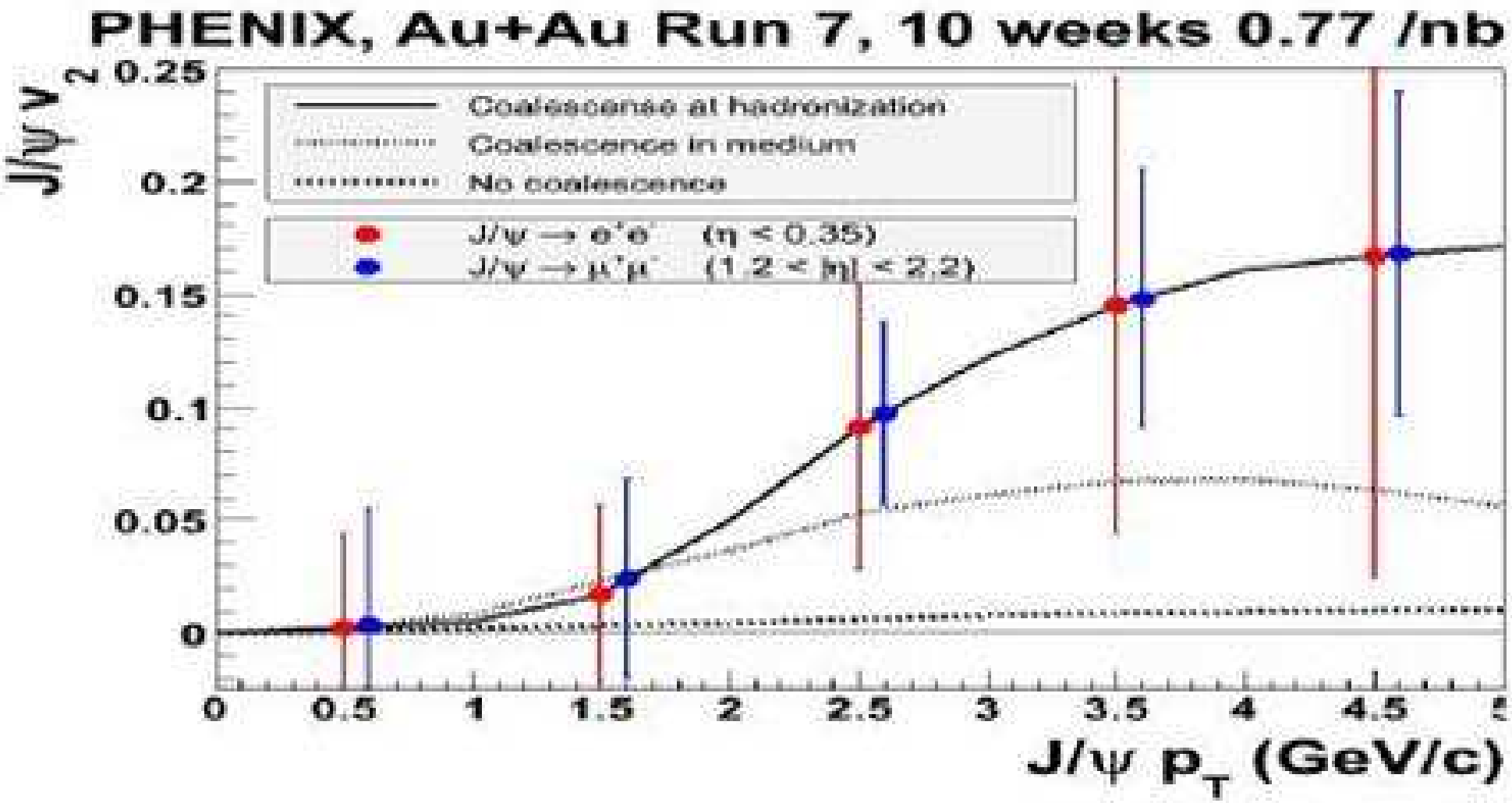
- 10% of the total direct counting in the J/ψ region
- We account for this remaining contribution for each p_T bin by integrating the exponential shape of the remaining signal after mixed event subtraction



Checks at mid-rapidity: 5 methods

Methods tried to get v_2 that gave consitent results

- ϕ-ψ bin by bin subtraction with mixed event
- ϕ-ψ bin by bin subtraction with like-sign pairs
- side bands subtraction
- invariant mass fit
- background fit

see C. L. Silva's poster

Projection before Run7