PHENIX Measurement of J/ψ Elliptic Flow in 200 GeV Au+Au Collisions at Forward Rapidity

Luis Bichon III

Vanderbilt University

Department of Physics and Astronomy

QGP, heavy quarks, and J/ψ

QGP & Heavy Quarks

- The QGP produced exhibits a nearly perfect fluid behavior.
- This behavior manifests itself in strong correlations between the produced particles.
- This behavior is seen for both light and heavy-flavor particles, but the detailed interactions of the heavy quarks in the medium are still under investigation.
- Because of their large mass they *may* not be thermalized and flow with the medium.

Particle Masses

Name	Symbol/Content	Charge	Mass (GeV)
Charm	c	2/3	1.27 ± 0.02
Beauty	b	-1/3	4.18 ± 0.03
J/ψ	$c\bar{c}$	0	$3.096 \pm 6 \times 10^{-6}$
$\psi(2S)$	$c\bar{c}$	0	$3.686 \pm 4 \times 10^{-5}$

J/ψ Meson & Flow

- Production in p+p collisions vs. A+A collisions; Open heavy flavor vs. Quarkonia physics.
- Sources of J/ψ flow (path length dependence, thermalization/recombination, primordial J/ψ).
- At RHIC energies it is inconclusive if J/ψ exhibit flow.

Dataset & J/ψ identification

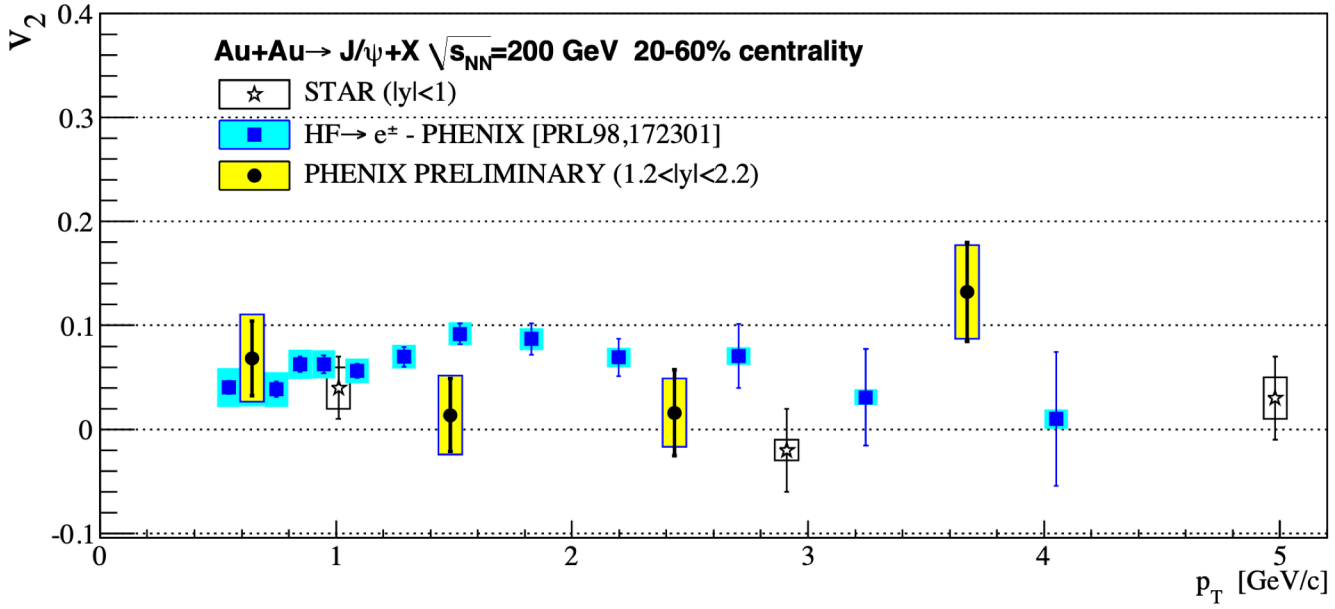
- PHENIX has unique coverage at forward rapidity with muon identification
- The addition of FVTX in 2012 further improves the J/psi reconstruction and event plane determination
- Large Au+Au data sets collected by PHENIX in 2014 and 2016 will allow for statistically improved measurement of J/psi elliptic flow

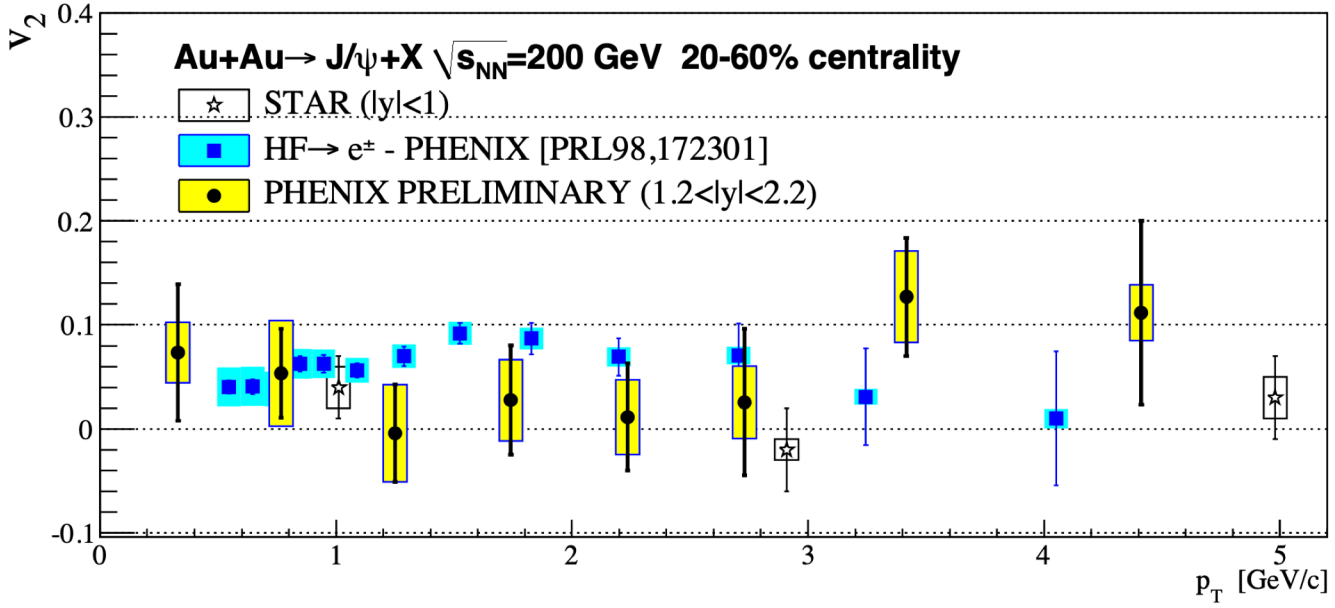
Run 16 200 GeV Au+Au (MinBias)	
# of events	15 B
Integrated Luminosity	7 nb^{-1}

Run 14 200 GeV Au+Au (MinBias)	
# of events	19 B
Integrated Luminosity	7.5 nb^{-1}

Run 10 200 GeV Au+Au (MinBias)	
# of events	5.7 B
Integrated Luminosity	1.5 nb^{-1}

Current J/ψ flow results (RHIC)





STAR (Published):

- v2 for Run 10 Au+Au collisions at 200 GeV
- Mid-rapidity at centrality 20-60%
- Electron decay channel

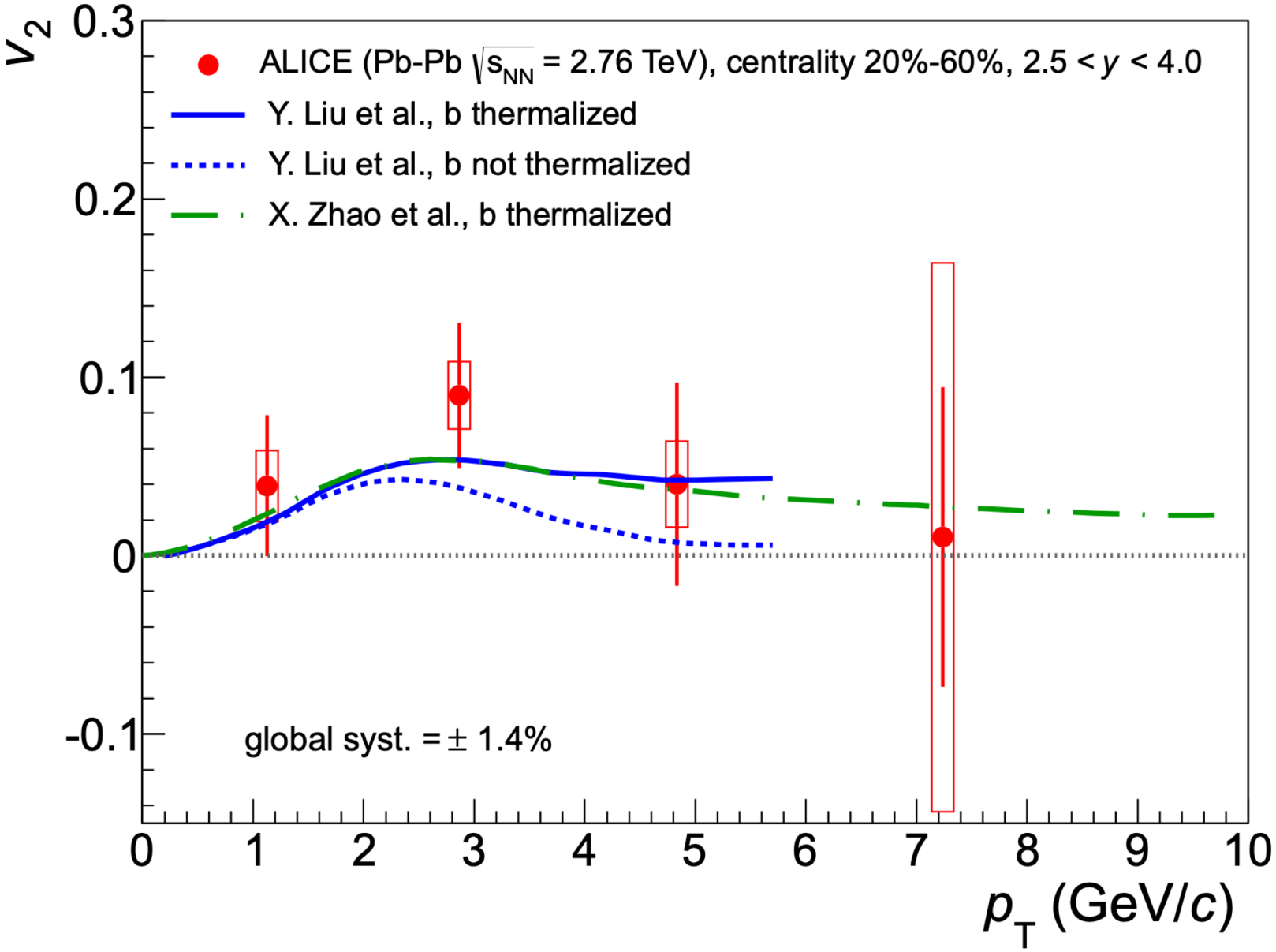
Heavy-Flavor decays:

- v2 for Run 4 Au+Au collisions at 200 GeV
- Mid-rapidity at centrality 20-60%
- Electron decay channel

PHENIX Preliminary:

- v2 for Run 10 Au+Au collisions at 200 GeV
- Forward rapidity at centrality 20-60%
- Dimuon decay channel

J/ψ flow at LHC energies



ALICE (Published):

- Inclusive J/ψ v2 for Pb+Pb collisions at 2.76 TeV
- Non-zero J/psi flow was measured both in Pb+Pb collisions as well as in p+Pb collisions.
- Transport model calculations:
  - Include J/ψ regeneration (30%)
  - Thermalized charm quarks
  - Primordial J/ψ path length dependence

Combinatorial background subtraction

Like-sign Technique

- Uses geometric mean of positive and negative like-sign pairs to obtain a subtracted signal:

$$S = N^{+-} - 2\sqrt{N^{++}N^{--}}$$

- Where N^{+-} is the number of dimuon pairs, N^{++} & N^{--} are the number of like-sign pairs in each mass bin.

Event-Mixing Technique

- Obtain the uncorrelated background by using unlike-sign pairs from 2 different events.

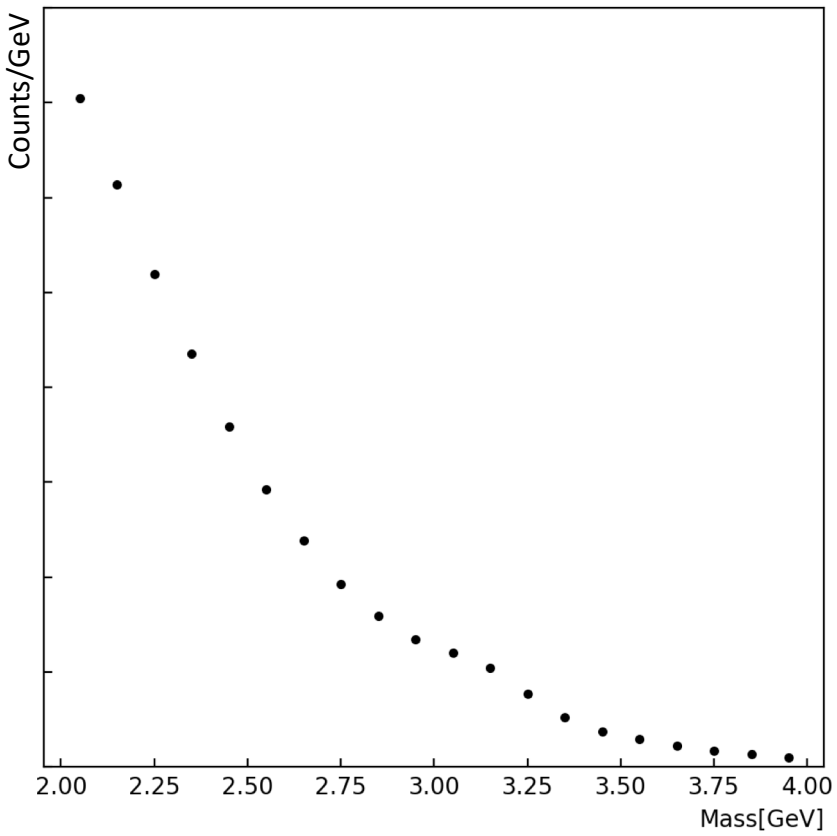
$$S = FG^{+-} - (N \cdot BG^{+-})$$

- Where FG+- is the foreground signal, N is the normalization factor, and BG+- is the background signal obtained through event-mixing.

- Increased statistical precision when compared to the previous method.

Muon pair mass distribution

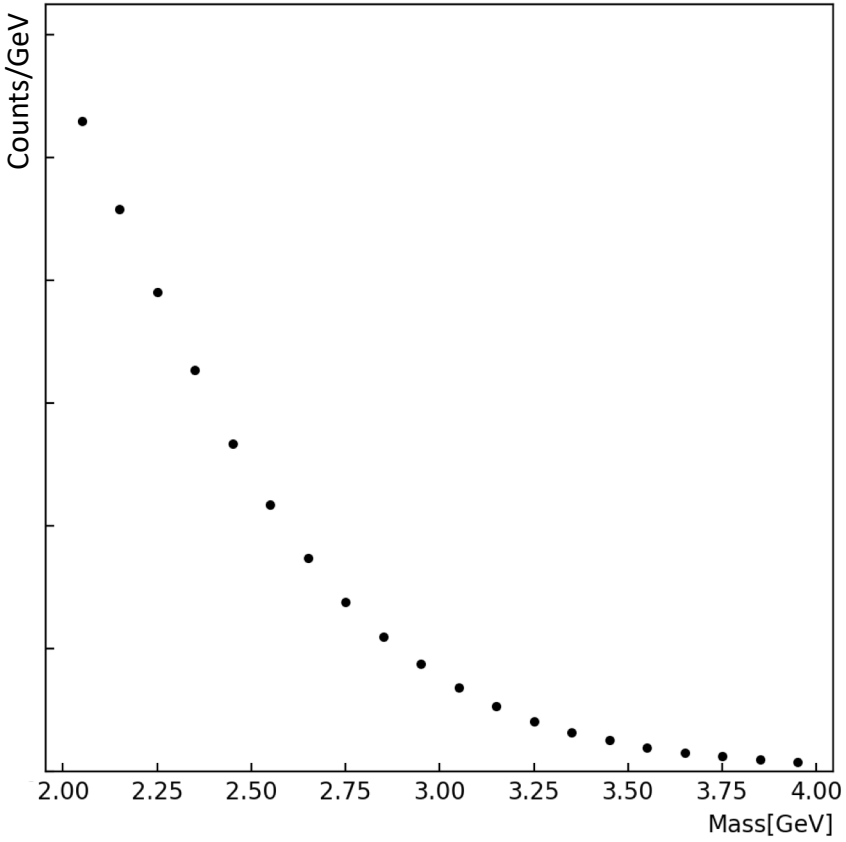
$\mu^+\mu^-$ Mass Distribution



N^{+-}

- Same Event
- Centrality: 0-100%
- Rapidity: [-2.2,-1.2]

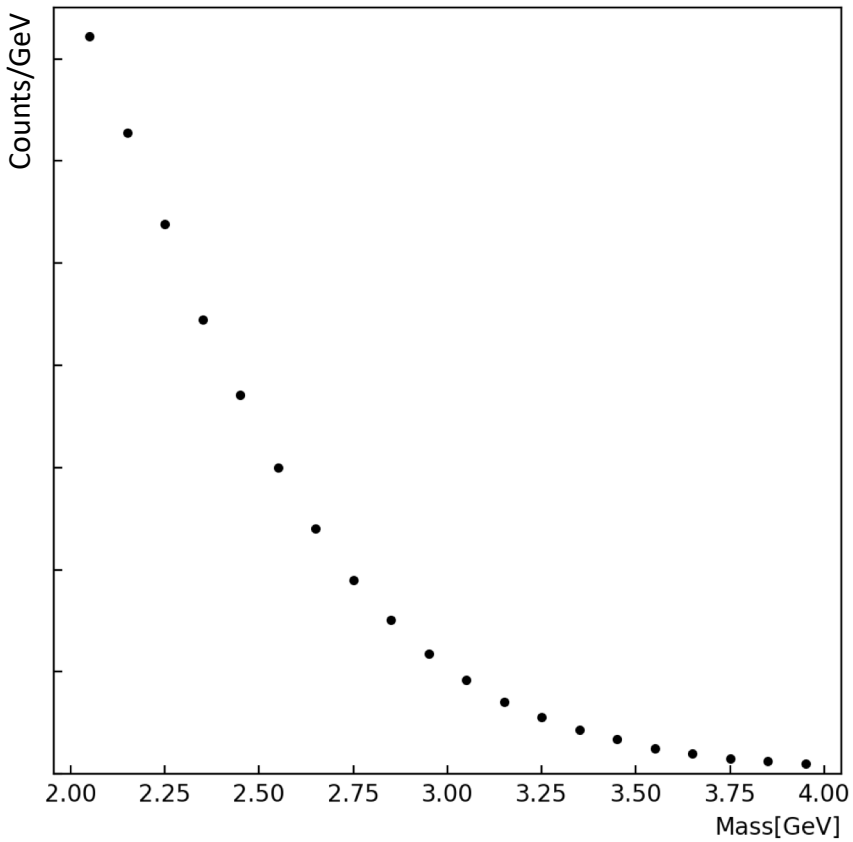
$\mu^+\mu^+$ Mass Distribution



N^{++}

- Same Event
- Centrality: 0-100%
- Rapidity: [-2.2,-1.2]

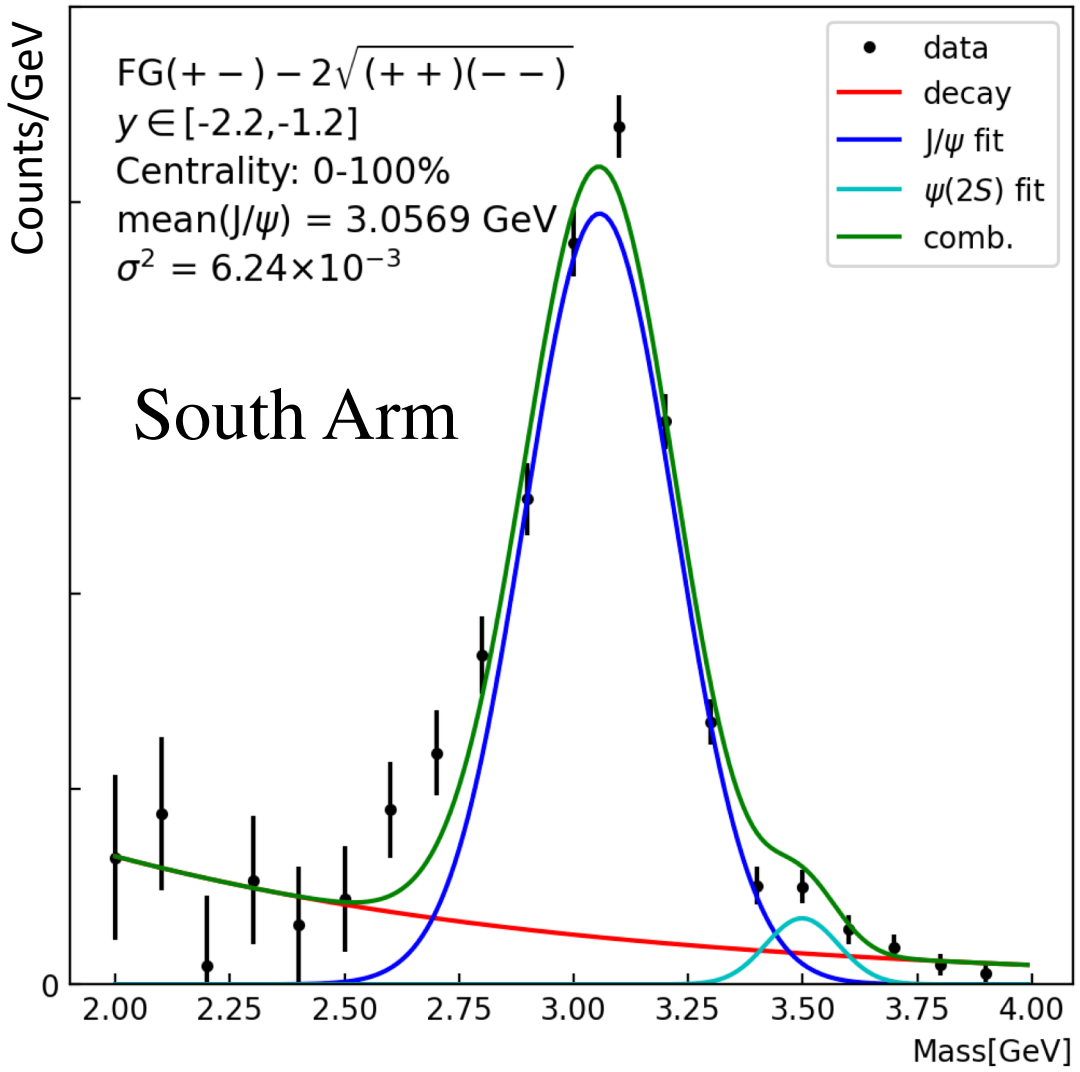
$\mu^-\mu^-$ Mass Distribution

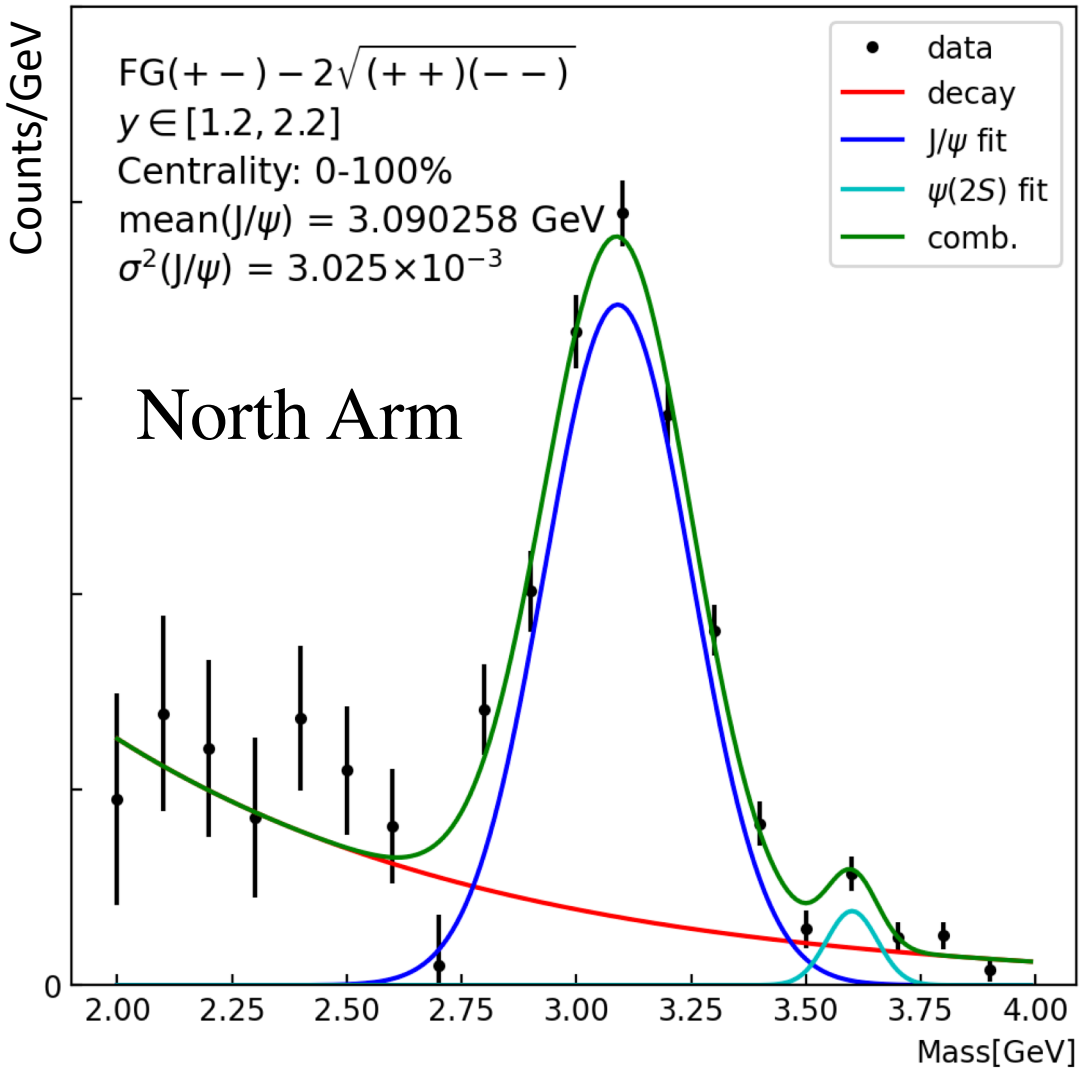


N^{--}

- Same Event
- Centrality: 0-100%
- Rapidity: [-2.2,-1.2]

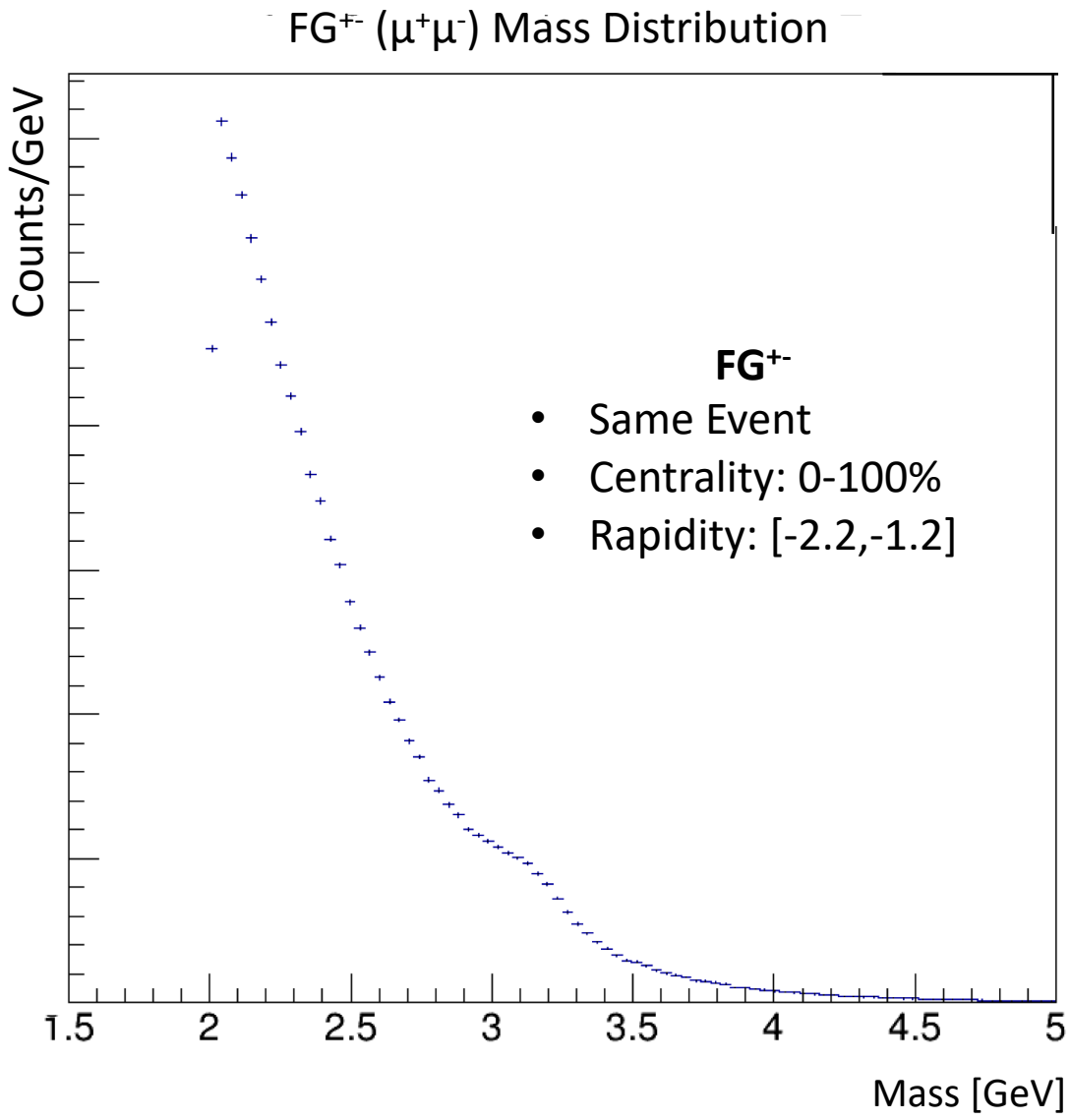
Like-sign subtracted dimuon mass distribution

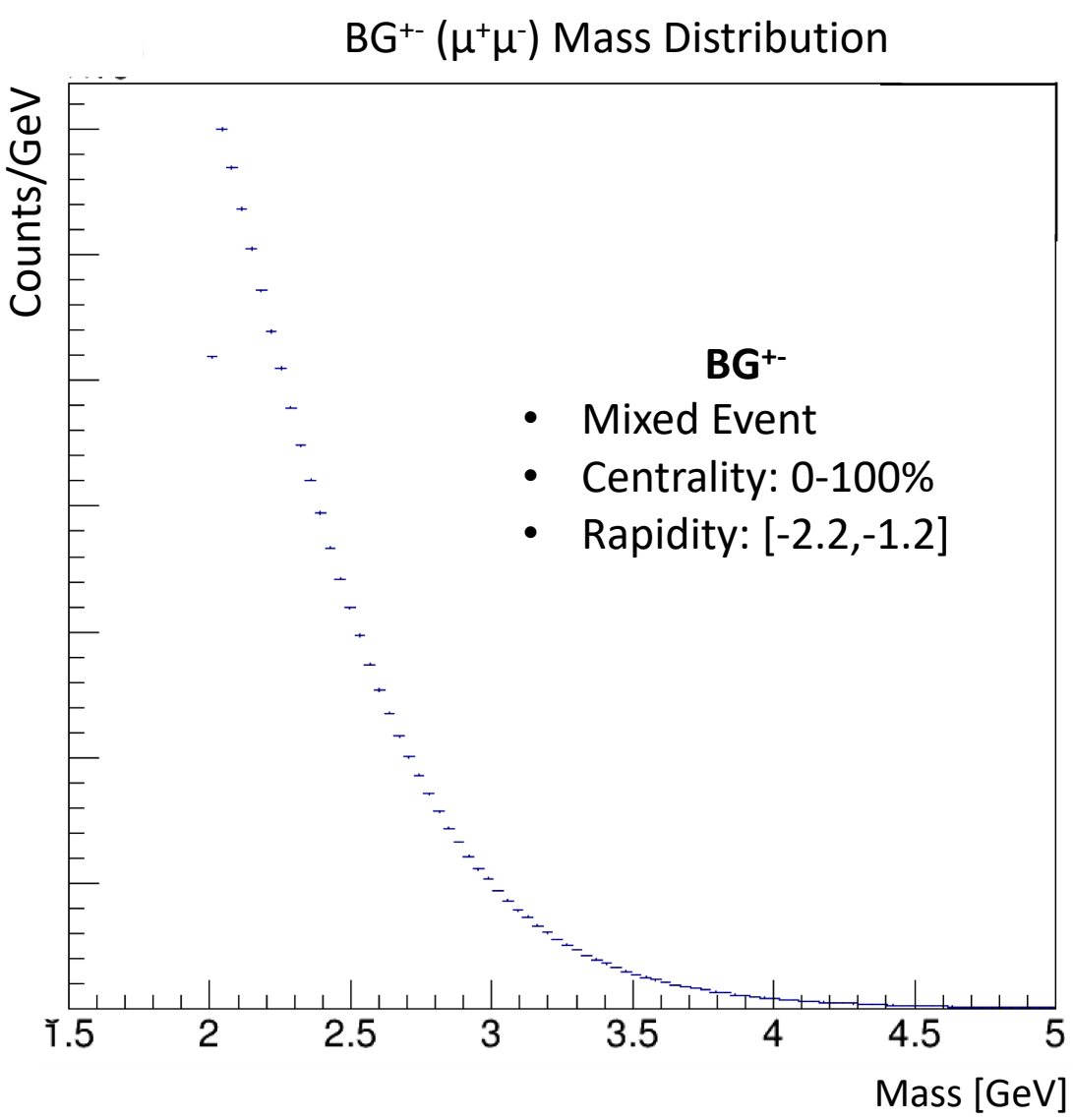




$$S = N^{+-} - 2\sqrt{N^{++}N^{--}}$$

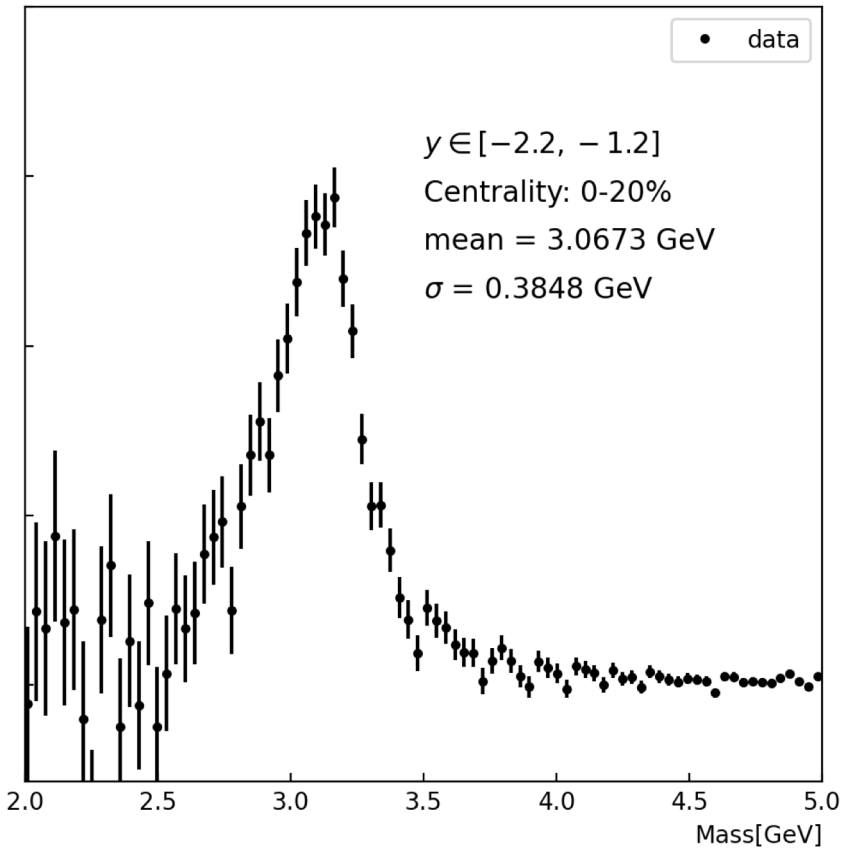
Same & mixed event dimuon mass distribution



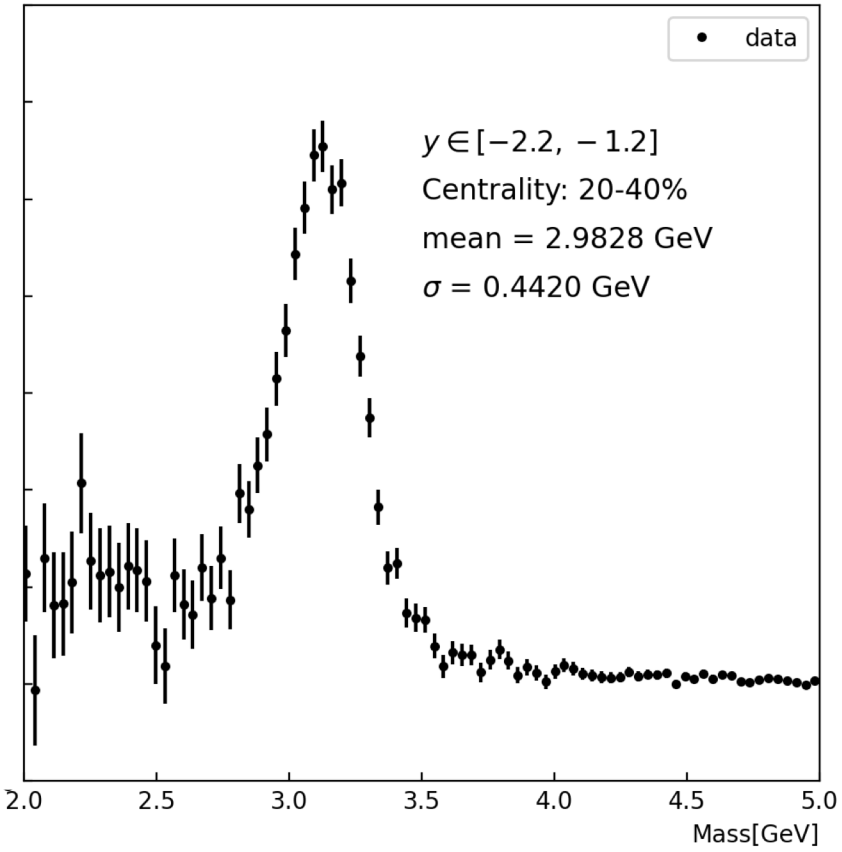


Mixed-event subtraction dimuon mass distribution

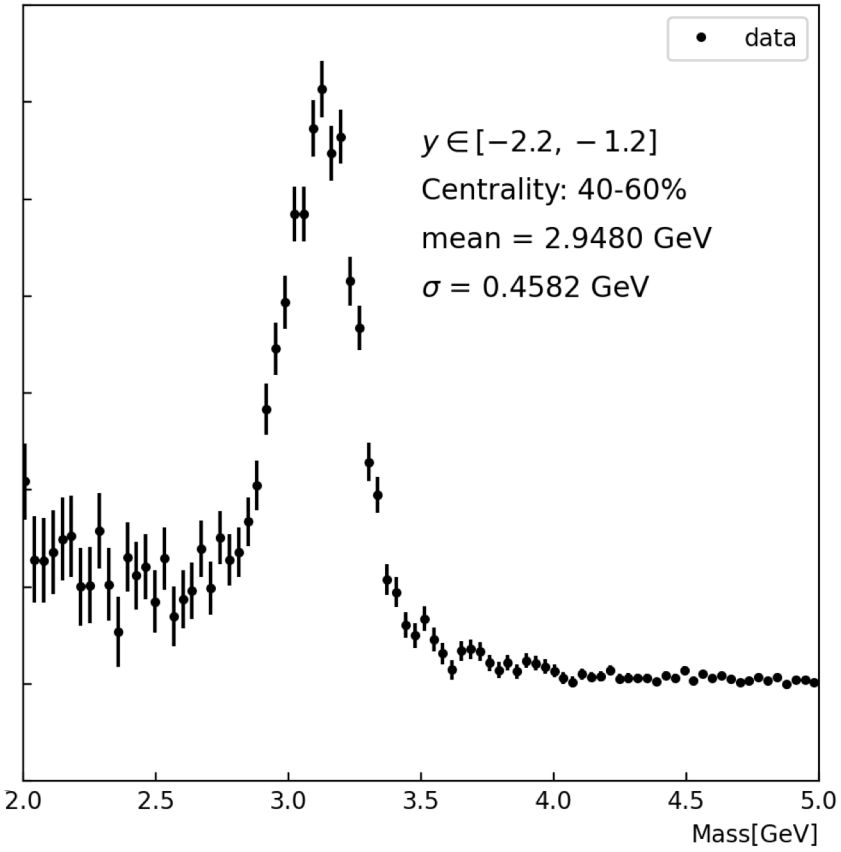
South Arm – Centrality: 0-20%



South Arm – Centrality: 20-40%

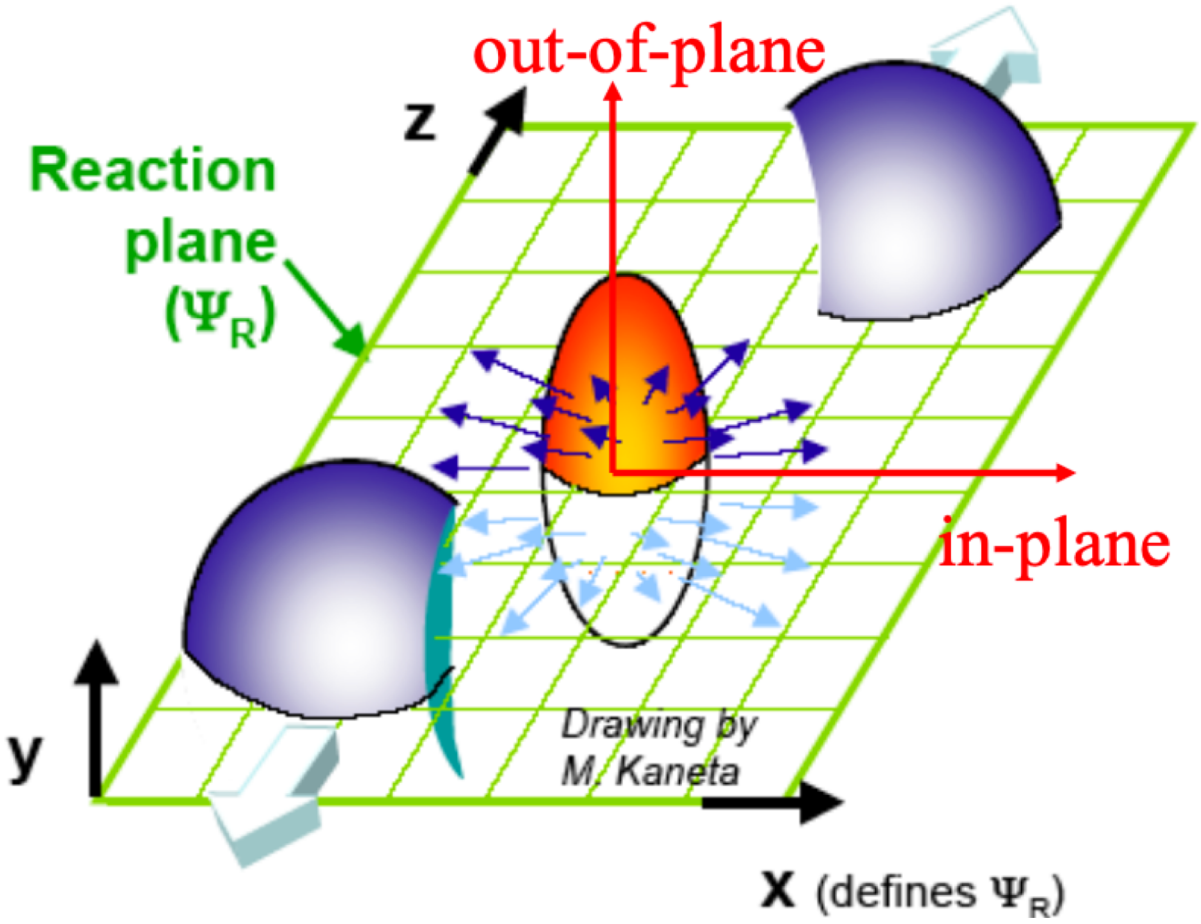


South Arm – Centrality: 40-60%



$$S = FG^{+-} - (N \cdot BG^{+-})$$

Event plane method



Fourier expansion of the invariant triple particle distribution:

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}(1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_r)))$$

Event flow vectors:

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

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

Event plane angle:

$$\Psi_n = \left(\tan^{-1}\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right)/n$$

Observed Flow:

$$v_n^{\text{obs}}(p_T, y) = \langle \cos[n(\phi_i - \Psi_n)] \rangle$$

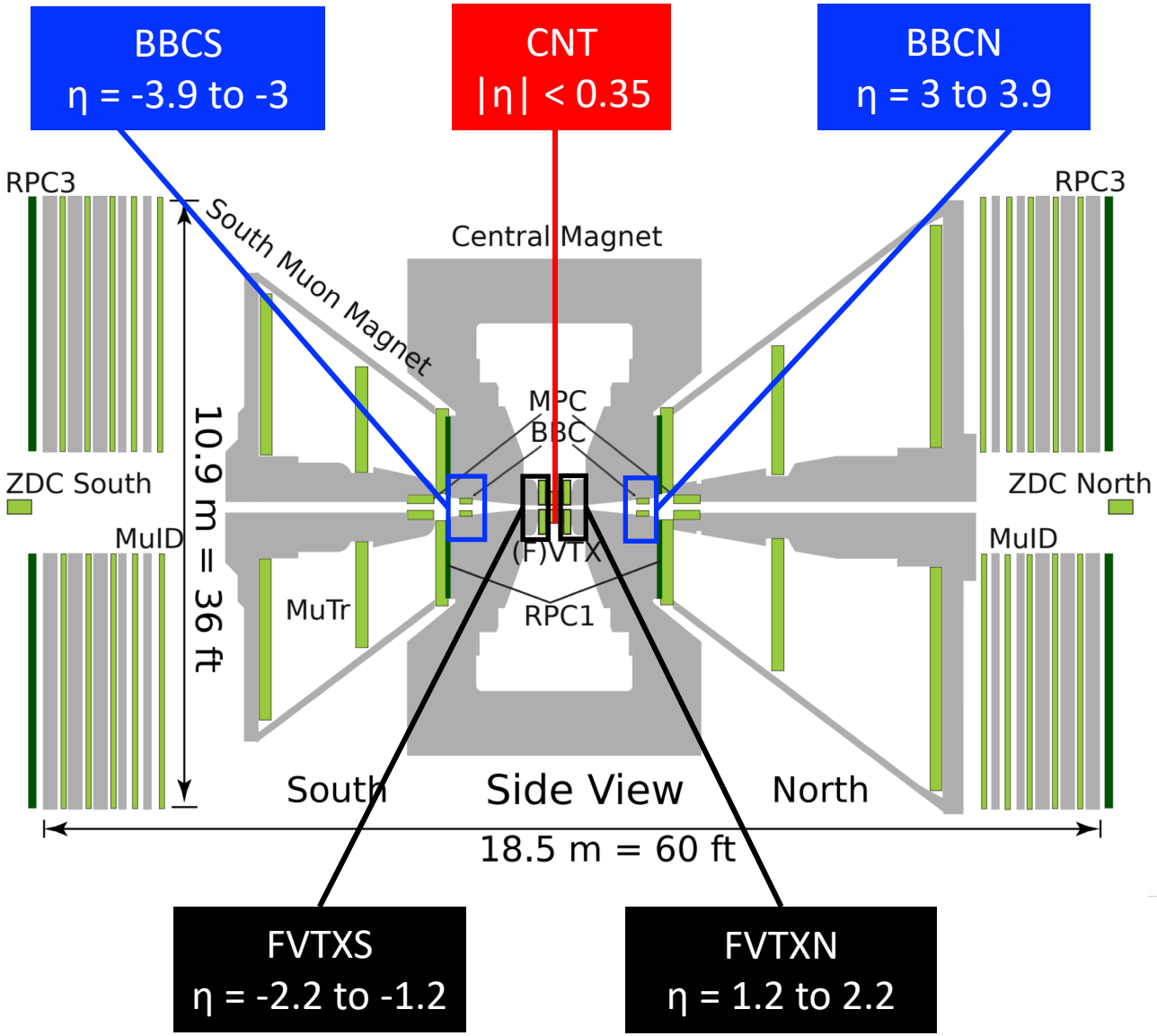
Event Plane Resolution:

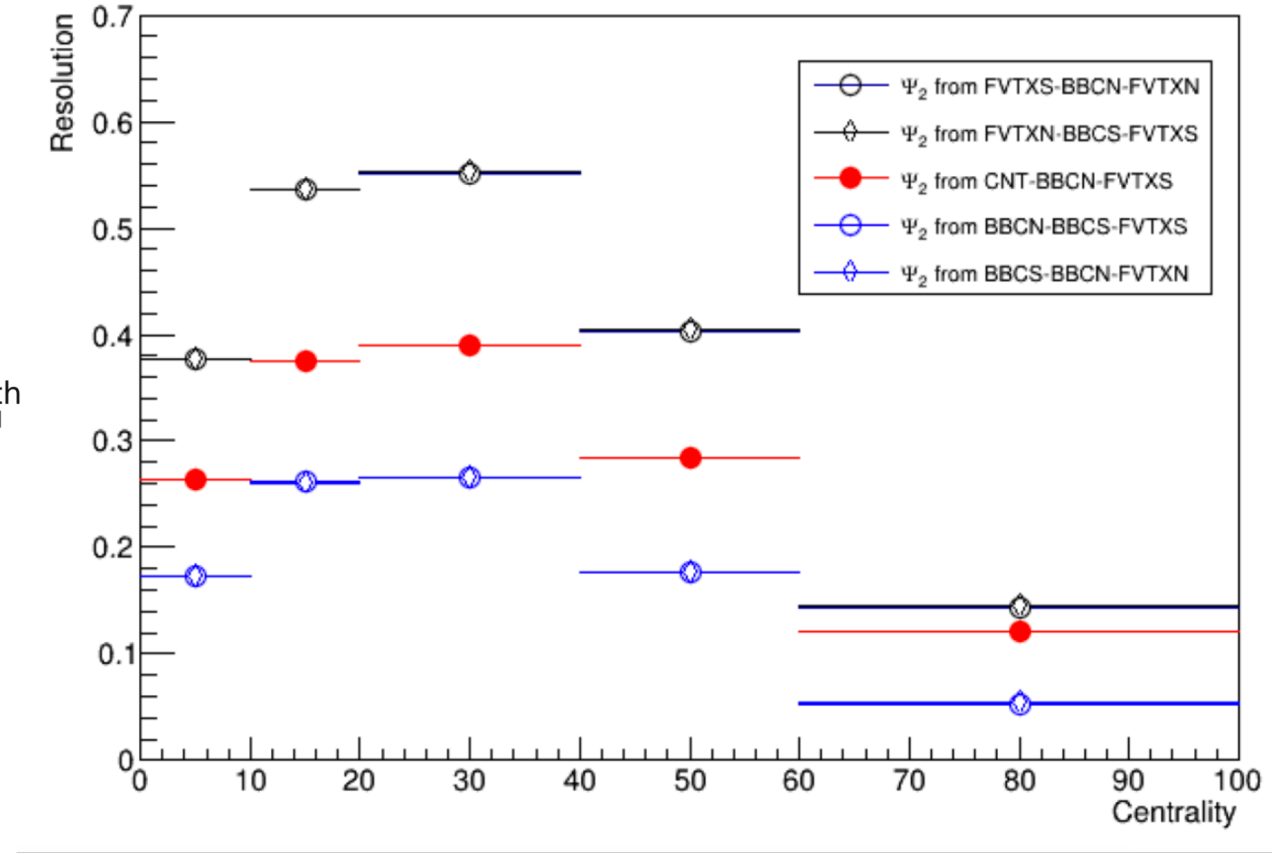
$$\mathcal{R}_n = \sqrt{\frac{\langle \cos(2(\Psi_a - \Psi_b))\rangle \langle \cos(2(\Psi_a - \Psi_c))\rangle}{\langle \cos(2(\Psi_b - \Psi_c))\rangle}}$$

True Flow:

$$v_n = \frac{v_n^{\text{obs}}}{\mathcal{R}_n}$$

Event plane resolution





Summary & moving forward

Summary:

- Using the PHENIX Run 14 Au+Au 200 GeV dataset dimuon invariant mass distributions are created and used in like-sign and mixed-event subtraction procedures.
- Signals centered at around the J/ψ mass are clear, as well as ψ(2S) signal.
- A much better dataset and the addition of the FVTX detector to PHENIX will lead to a measurement of v_2 with significantly lower uncertainty.

Moving Forward:

- We will measure v_2 for J/ψ and if we observe significant flow this could imply charm quark thermalization in QGP and J/psi formation by recombination
- Investigation of the ratio of yields between J/ψ and ψ(2S), as well as the flow of open heavy flavor particles will provide a more complete understanding of the heavy flavor dynamics at RHIC.