Measurement of the Charge Separation Along the Magnetic Field with Signed Balance Function in 200 GeV Au + Au collisions at STAR

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(**for the STAR collaboration**)
Central China Normal University[1]
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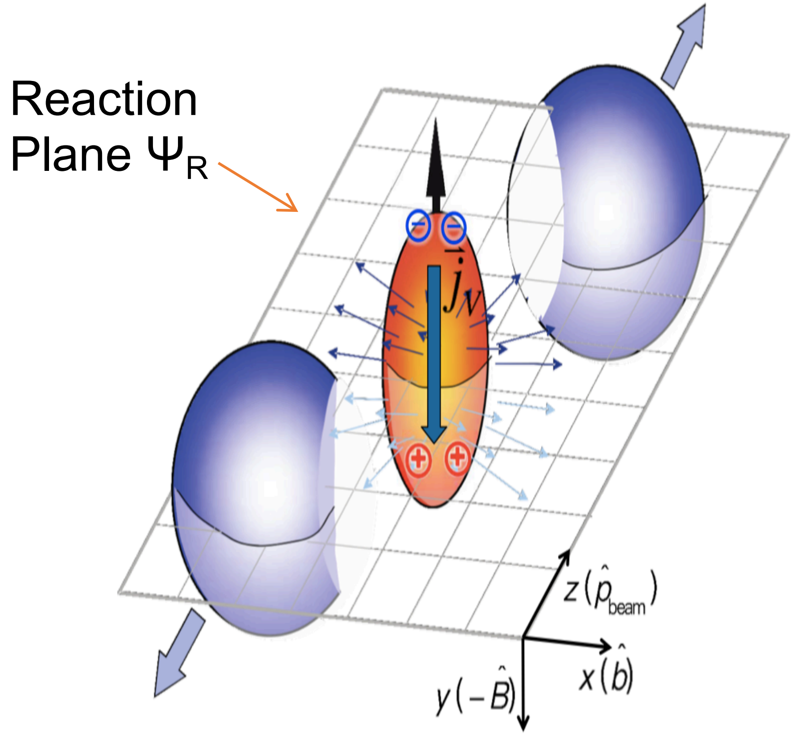
STAR

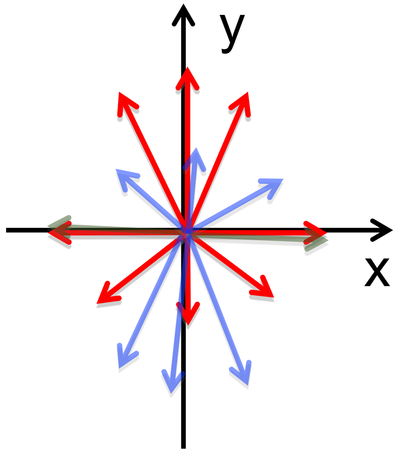
Motivation: CME-Induced Charge Separation

In non-central collisions a strong magnetic field is produced ⊥ to Ψ_R

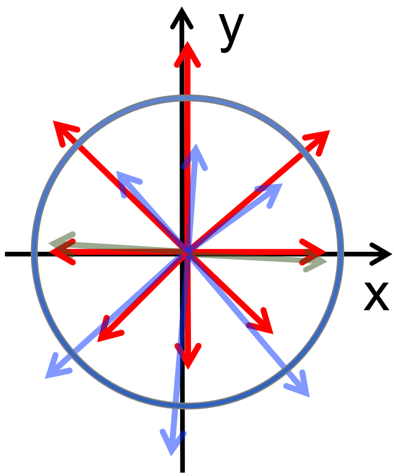


CME-induced charge separation shifts pos. and neg. particles in opposite directions (along B).

Conventional approach by angular correlation.



An event can have charge separation while being perfectly isotropic in azimuth.



To study the separation, it is tempting to focus on Δp_y directly.

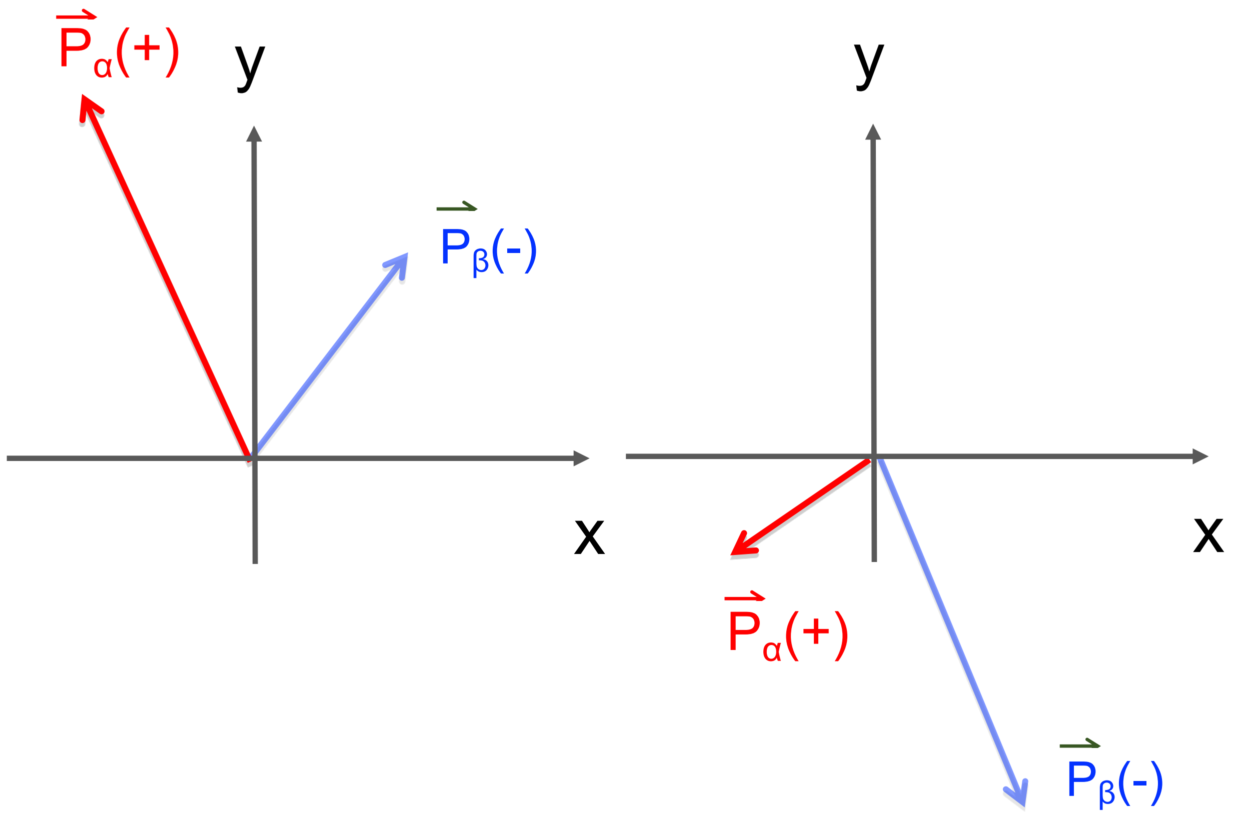
Study the Momentum Ordering : Signed Balance Function

1) Count pair's momentum ordering in p_y :

$$B_{P,y}(S_y) = \frac{N_{+-}(S_y) - N_{++}(S_y)}{N_+}$$

$$B_{N,y}(S_y) = \frac{N_{-+}(S_y) - N_{--}(S_y)}{N_-}$$

where $N_{\alpha\beta}$ denotes the number of positive -negative pairs with a sign of Sy in an event. S_y is labeled as +1 if $p^{\alpha}_y > p^{\beta}_y$, and -1 if vice versa.



Two examples of α leading β in p_y, where α, β is denoted the two particles of the pair. (S_y = +1)

A. Tang, arXiv:1903.04622

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2) Count net ordering (e.g. excess of pos. leading neg.) for each event :

$$\delta B_y(\pm 1) = B_{P,y}(\pm 1) - B_{N,y}(\pm 1)$$

$$\Delta B_y = \delta B_y(+1) - \delta B_y(-1)$$

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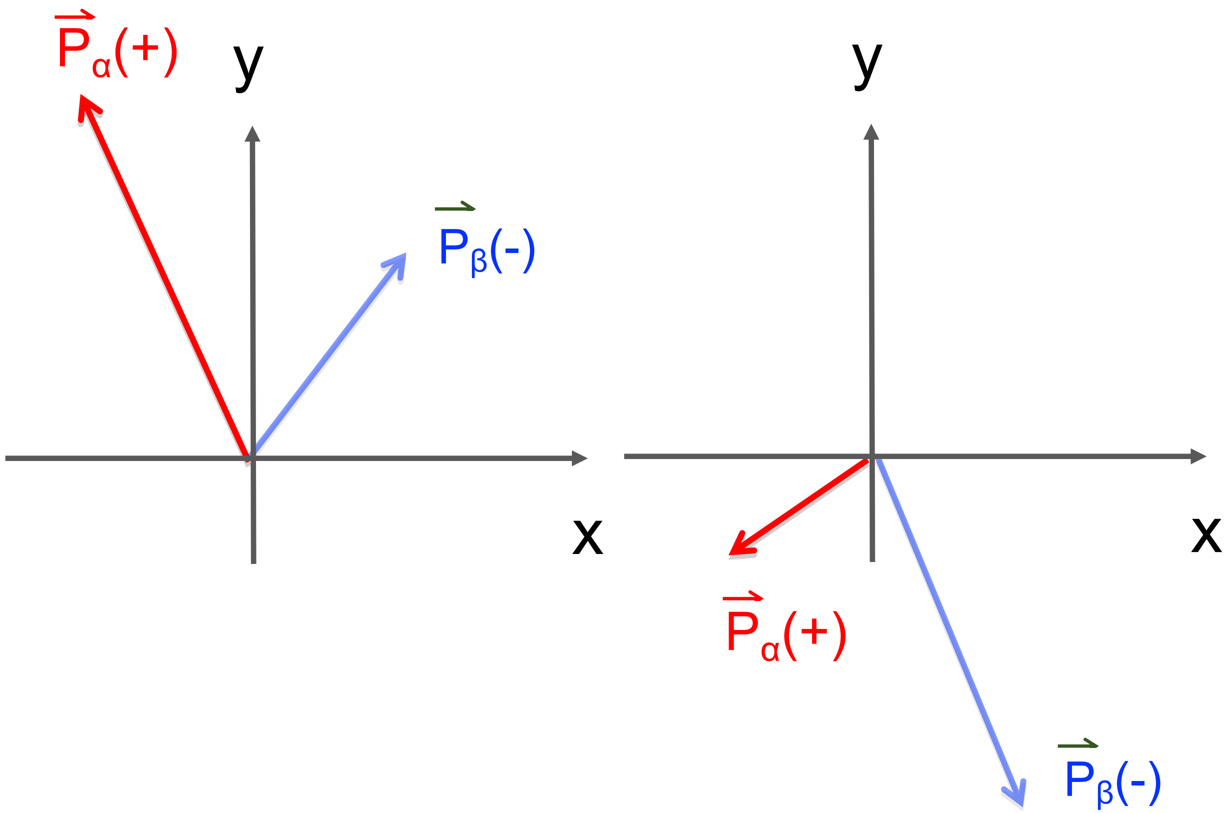

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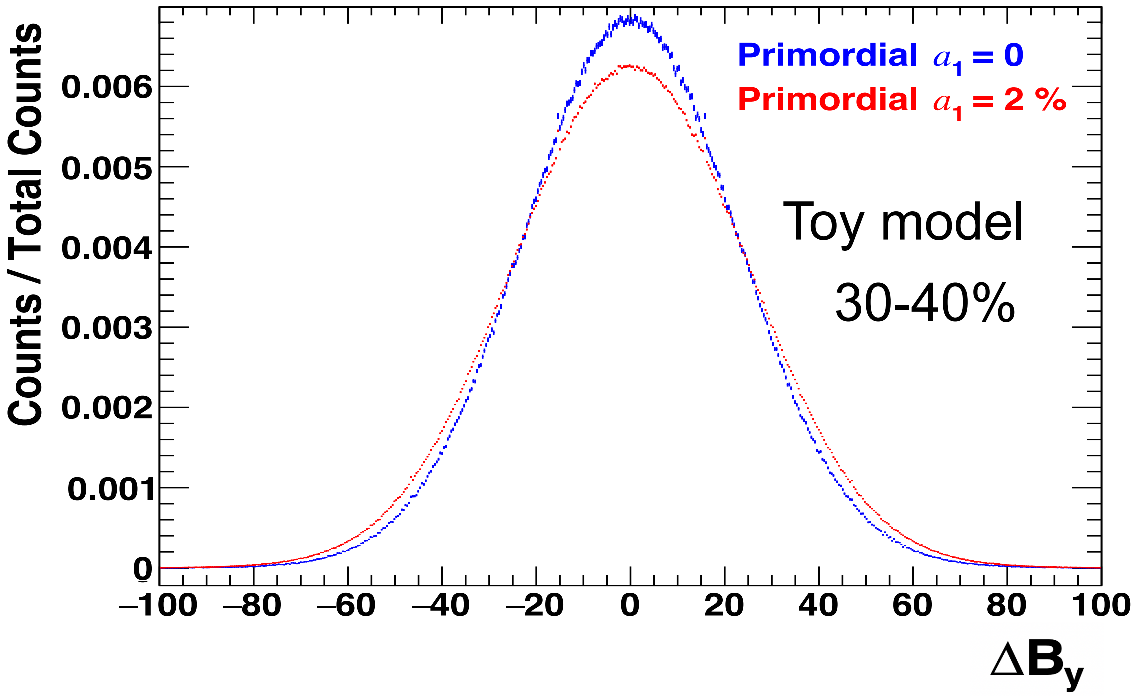
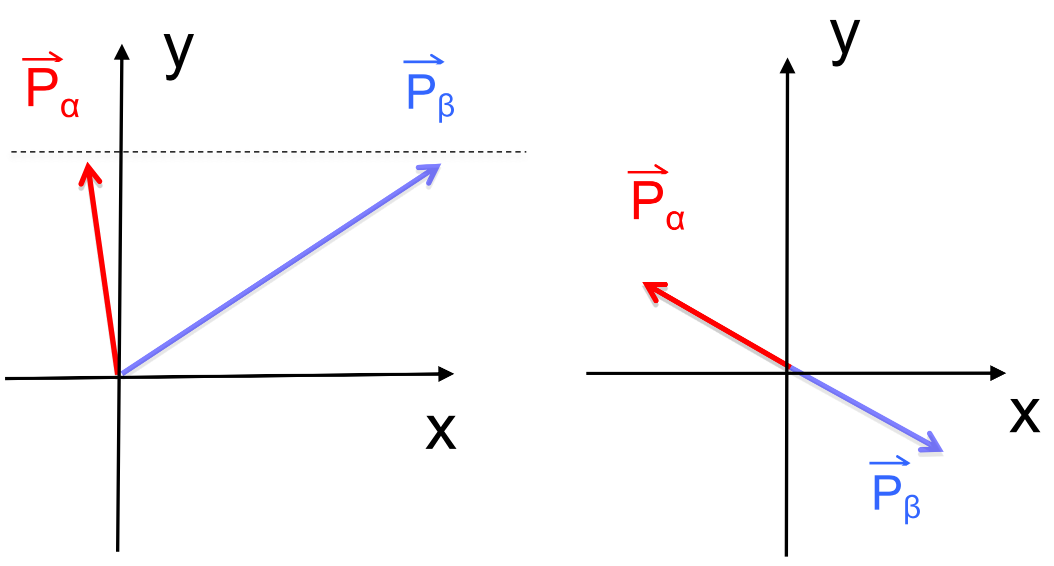
3) Look for enhanced event-by-event fluctuation of net ordering in y direction.



$$r = \frac{\sigma_{\Delta B_y}}{\sigma_{\Delta B_x}}$$ (>1 with CME)

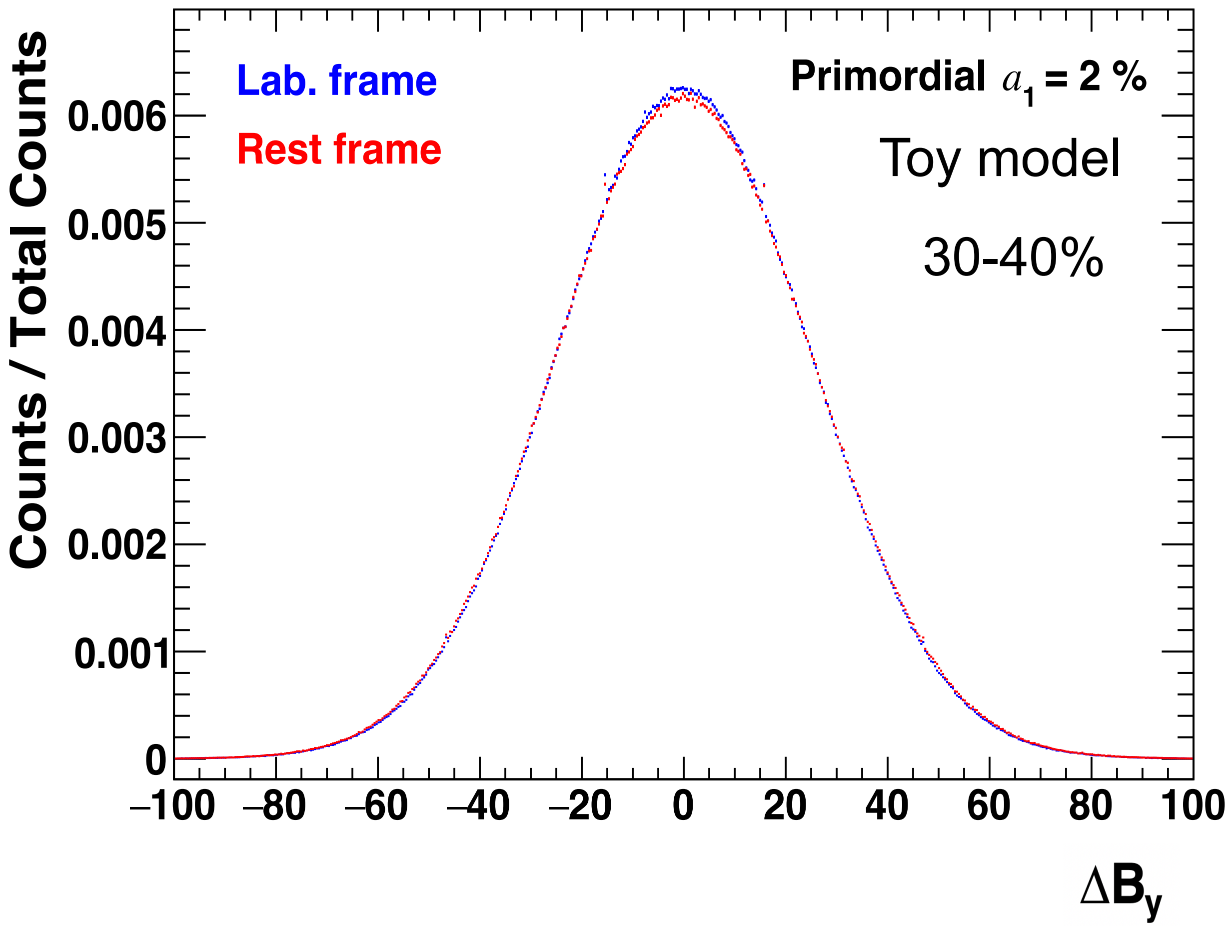
A. Tang, arXiv:1903.04622

Momentum Ordering : Best Viewed In the Rest Frame



Lab frame view
($p_y^\alpha = p_y^\beta$)

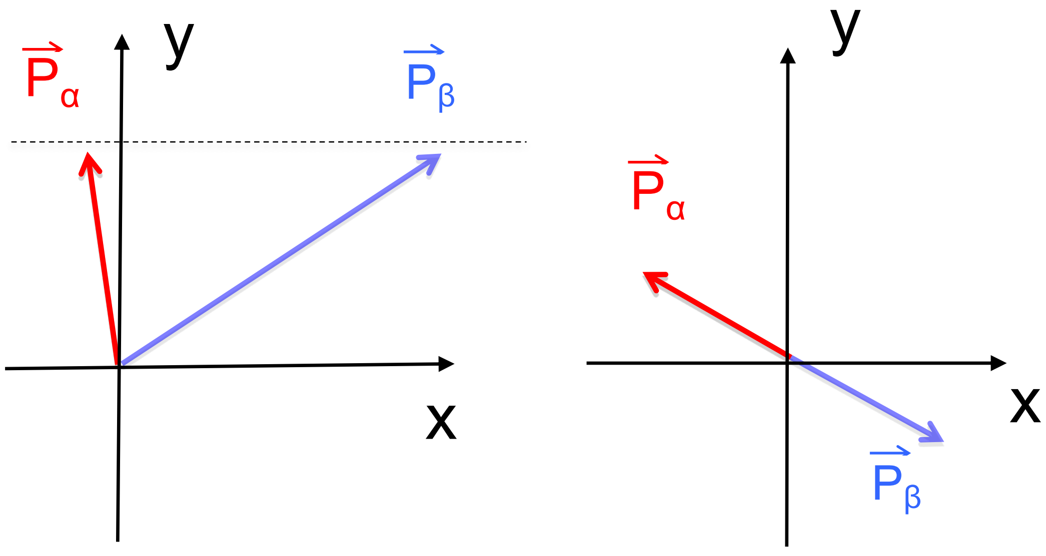
Rest frame view
($p_y^\alpha > p_y^\beta$)



Rest frame has the best sensitivity to momentum ordering.

$$R_B = \frac{r_{rest}}{r_{lab}}$$ (>1 with CME)

Momentum Ordering : Best Viewed In the Rest Frame



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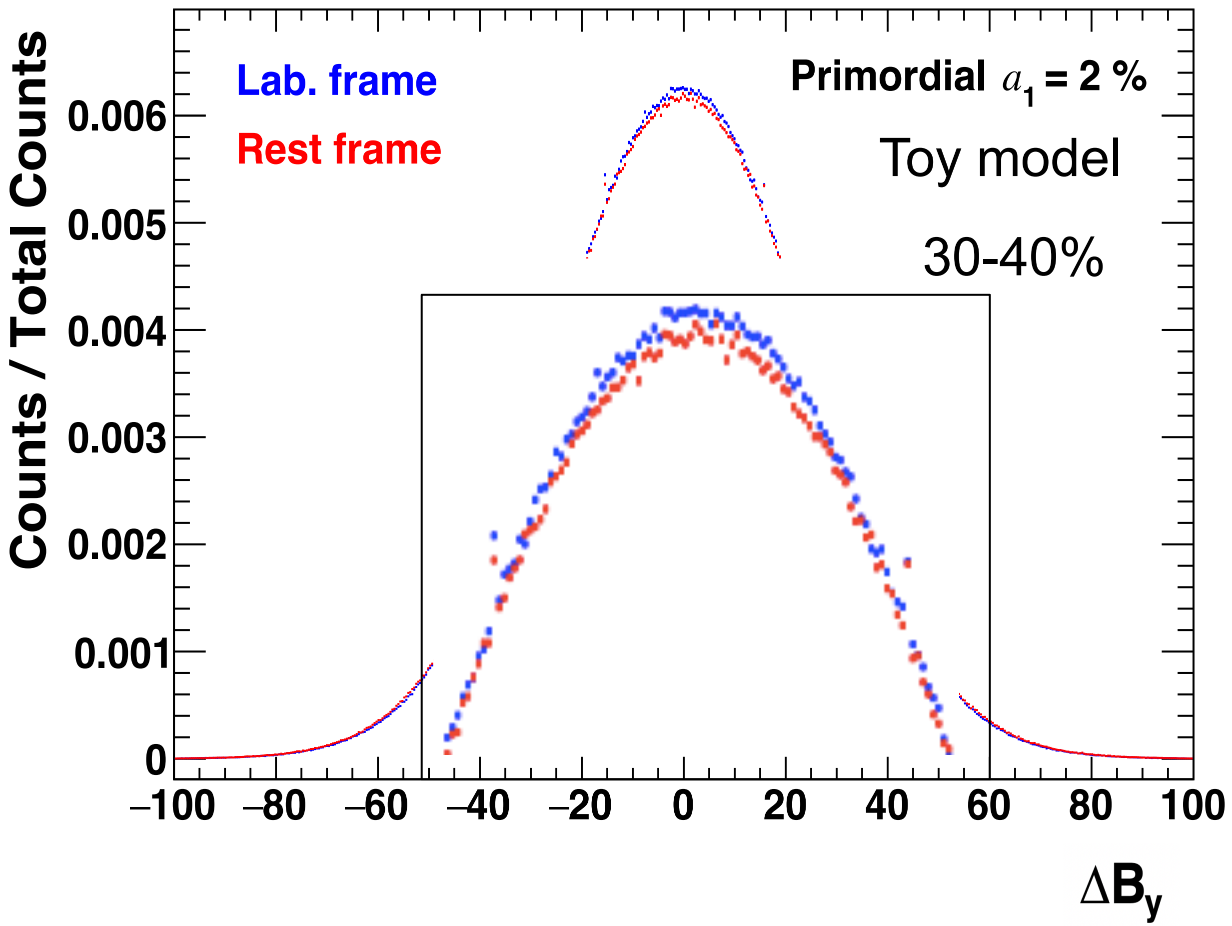

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Toy Model Simulation: Signal Only

324 primordial pions + 33 ρ (decay into $\pi^+\pi^-$)

- Matches total mult. for 30-40% AuAu 200GeV [1]
- Matches $\langle p_t \rangle$ to data.
- Matches ρ to neg. particle ratio ~ 17% [2]
- $\rho \rightarrow \pi^+ + \pi^-$ decay via PYTHIA6.

Primordial pion spectra :

$$\frac{dN_{\pi^\pm}}{dm_T^2} \propto \left(e^{m_T/T_{BE}} - 1\right)^{-1}, \text{ (Bose-Eistein distribution)}^{[1][3]}$$

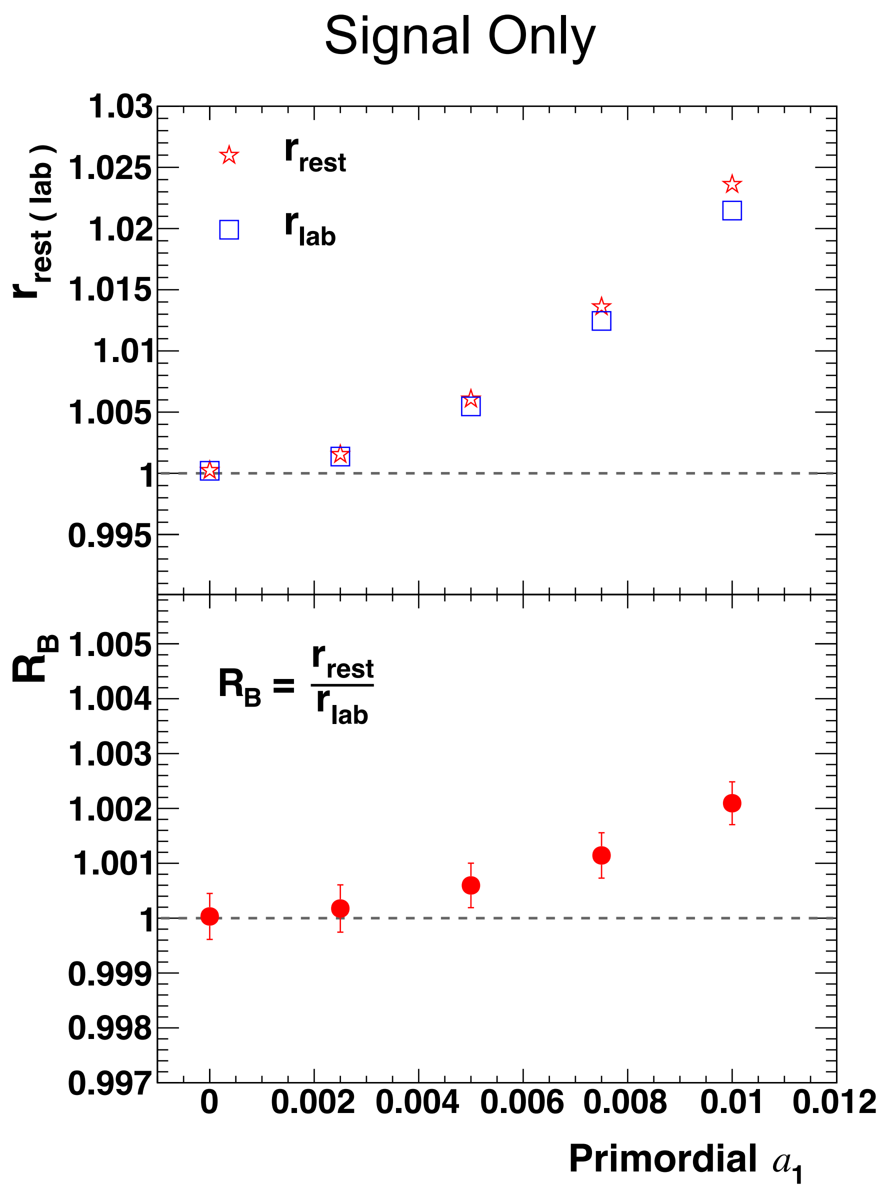
$T_{BE} = 212$ MeV (for having $\langle p_T \rangle$ of 400 MeV)[1].

ρ specta [3]:

$$\frac{dN_\rho}{dm_T^2} \propto e^{-(m_T - m_\rho)/T} / [T(m_\rho + T)].$$

$T = 317$ MeV (for having $\langle p_T \rangle$ of 830 MeV)[2].

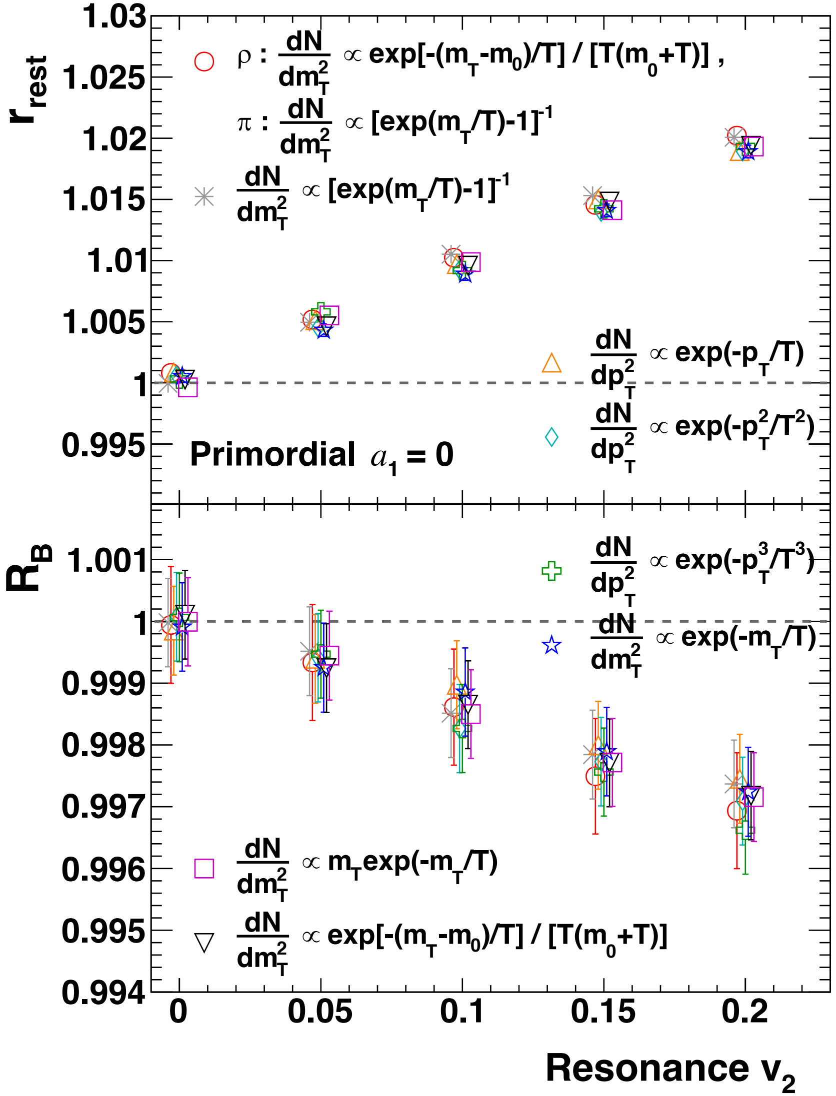
[1] STAR, PRC 79 034909 (2009)
[2] STAR, PRL 92, 092301 (2004)
[3] Wang & Zhao, PRC 95, 051901 (2017)



Study the sig. and bkg. separately, as well as their various combinations in a controlled and systematical way.

Toy Model Simulation: Resonance v_2

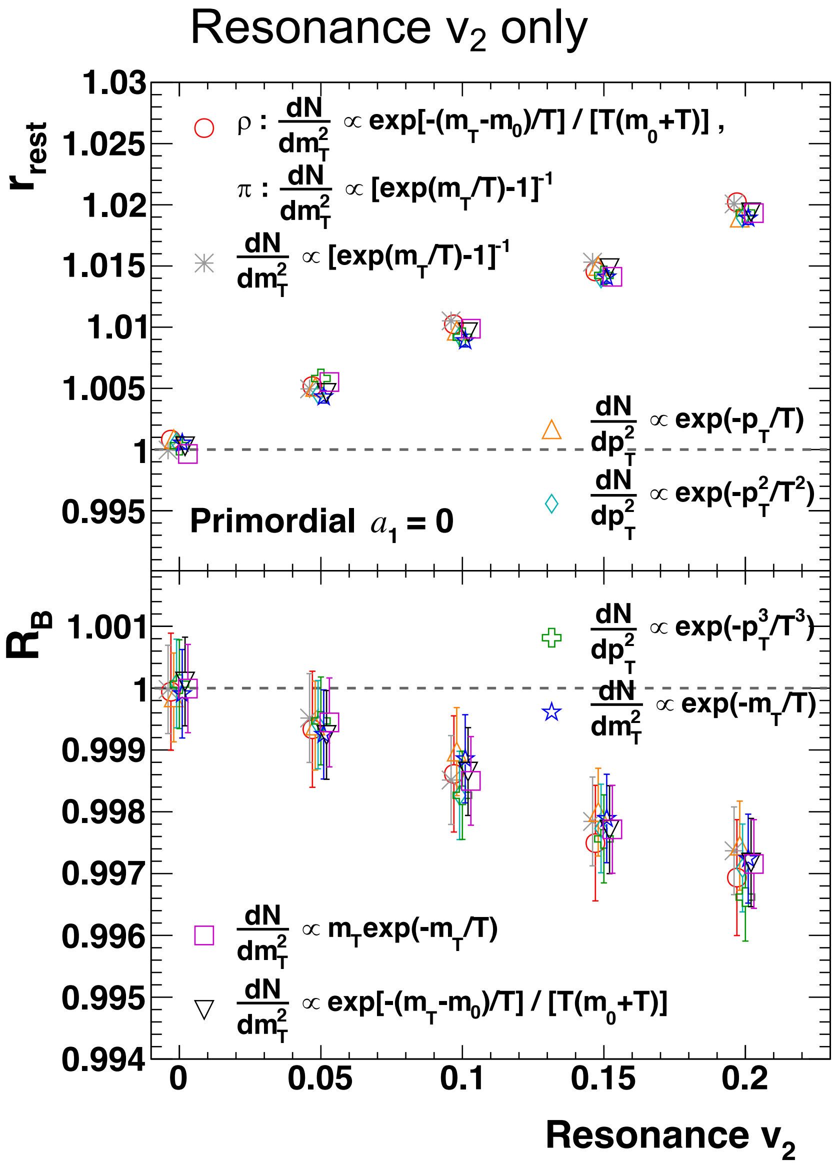
Resonance v_2 only

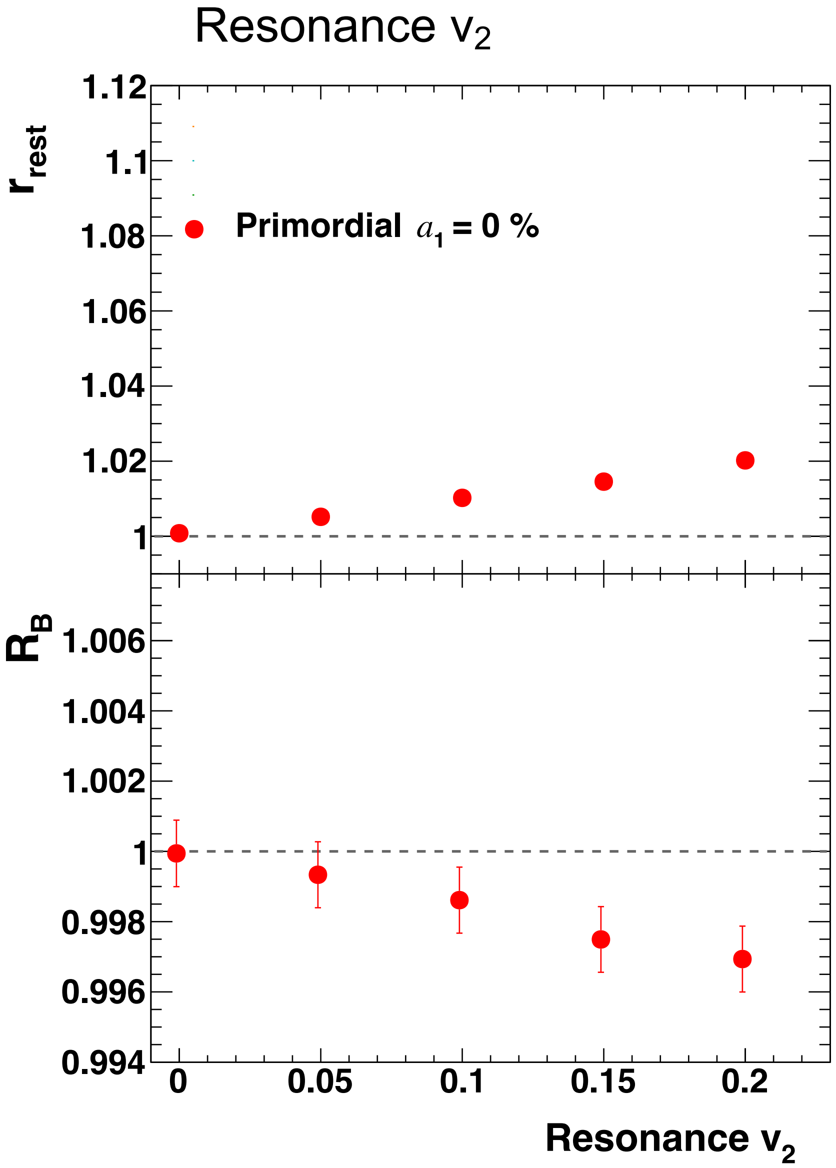


r_{rest} and R_B responds in opposite directions to the change of resonance v_2

A. Tang, arXiv:1903.04622

Toy Model Simulation: Resonance v_2





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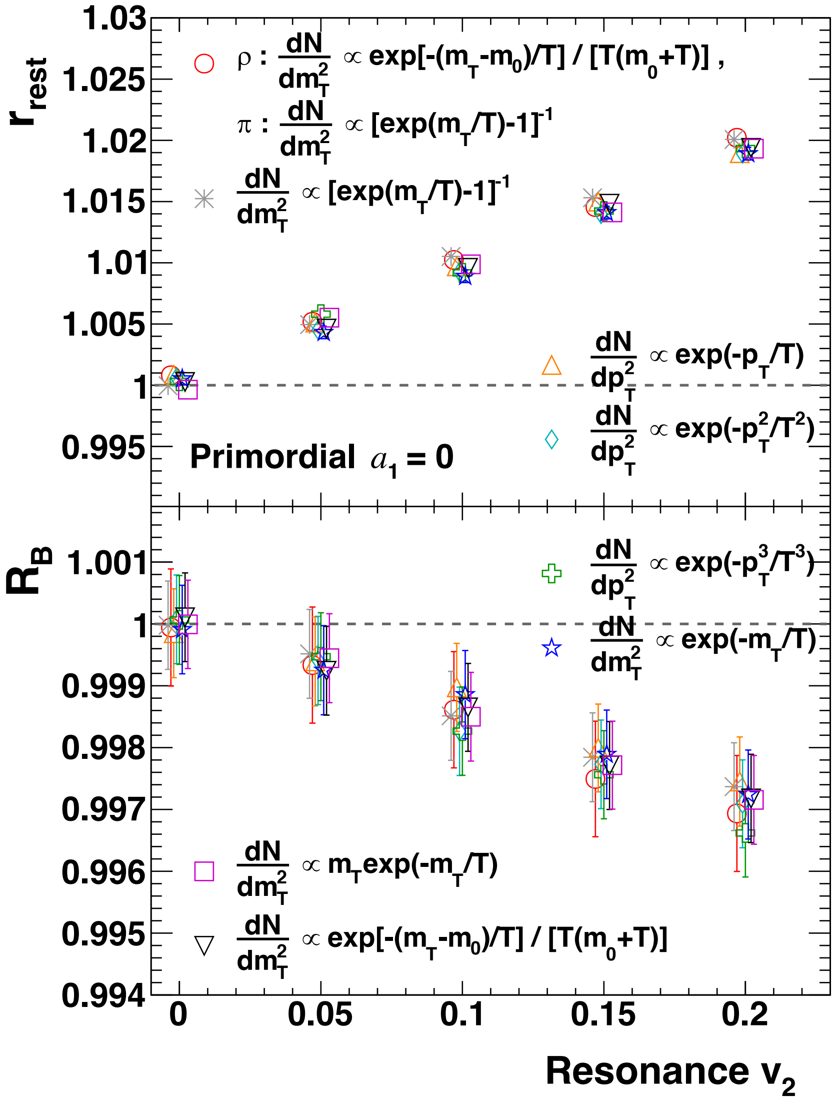
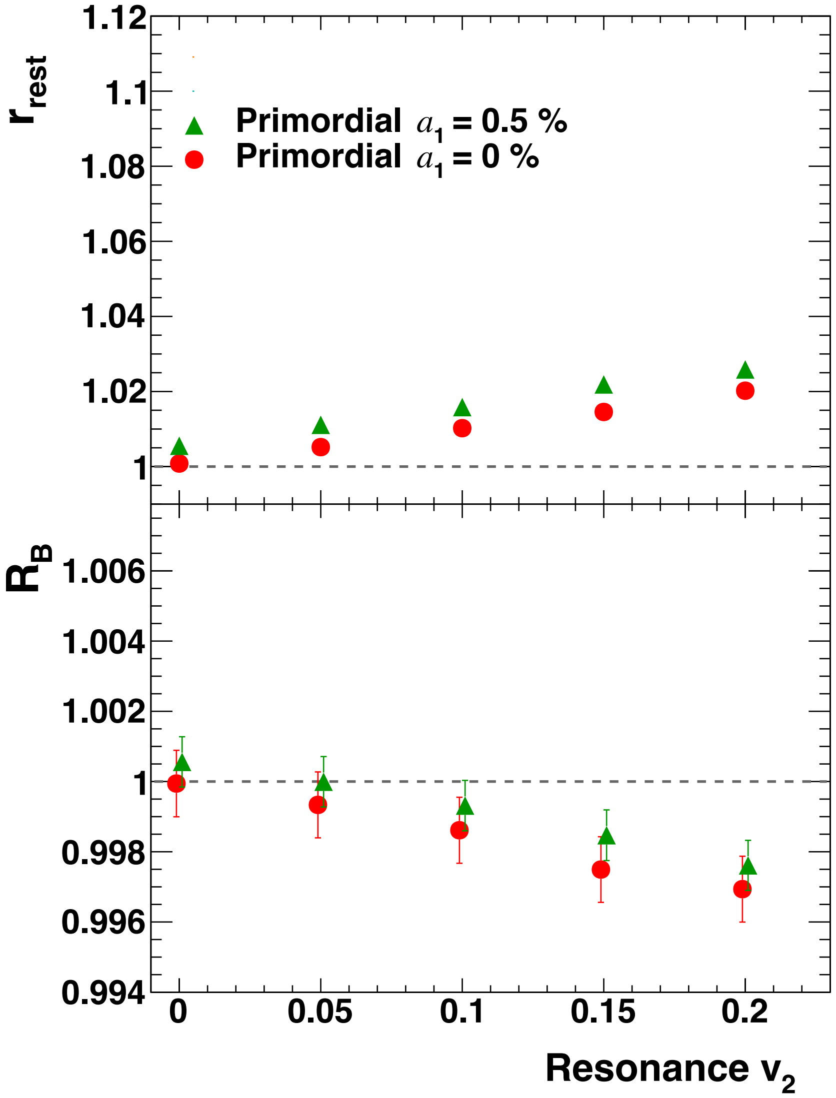
Toy Model Simulation: Resonance v_2

Resonance v_2 only



Resonance v_2 + CME signal



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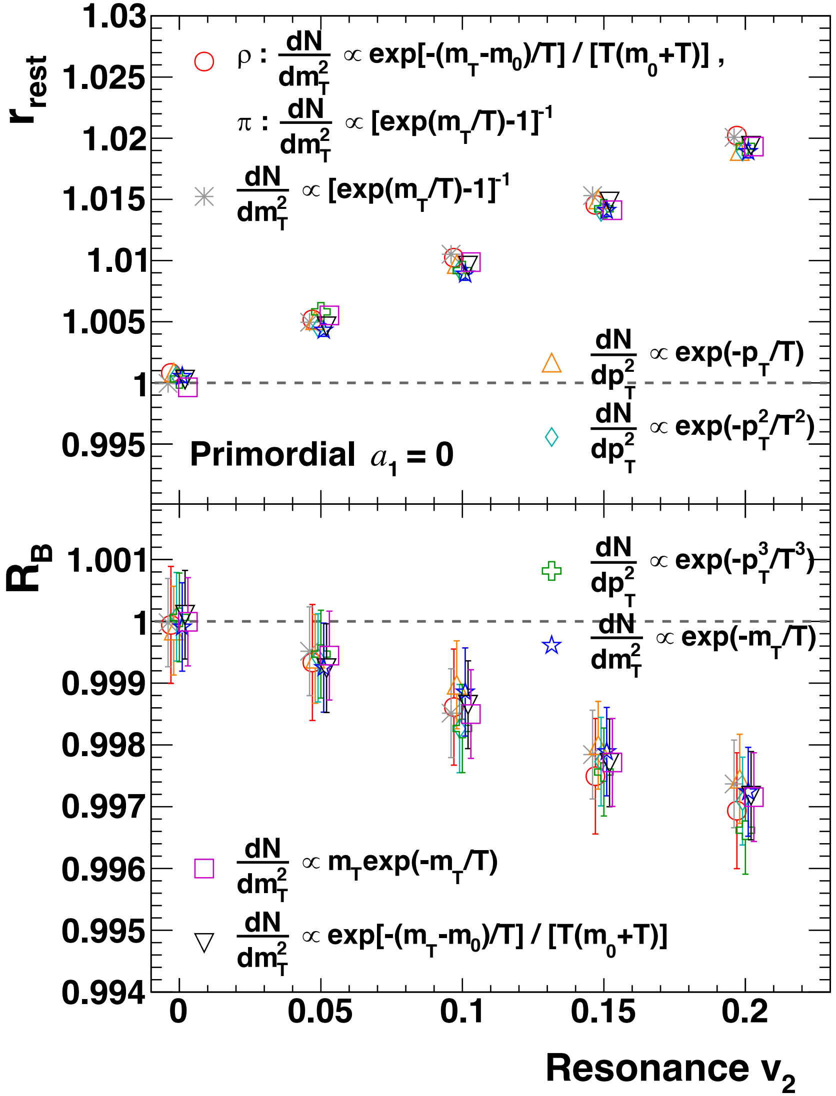

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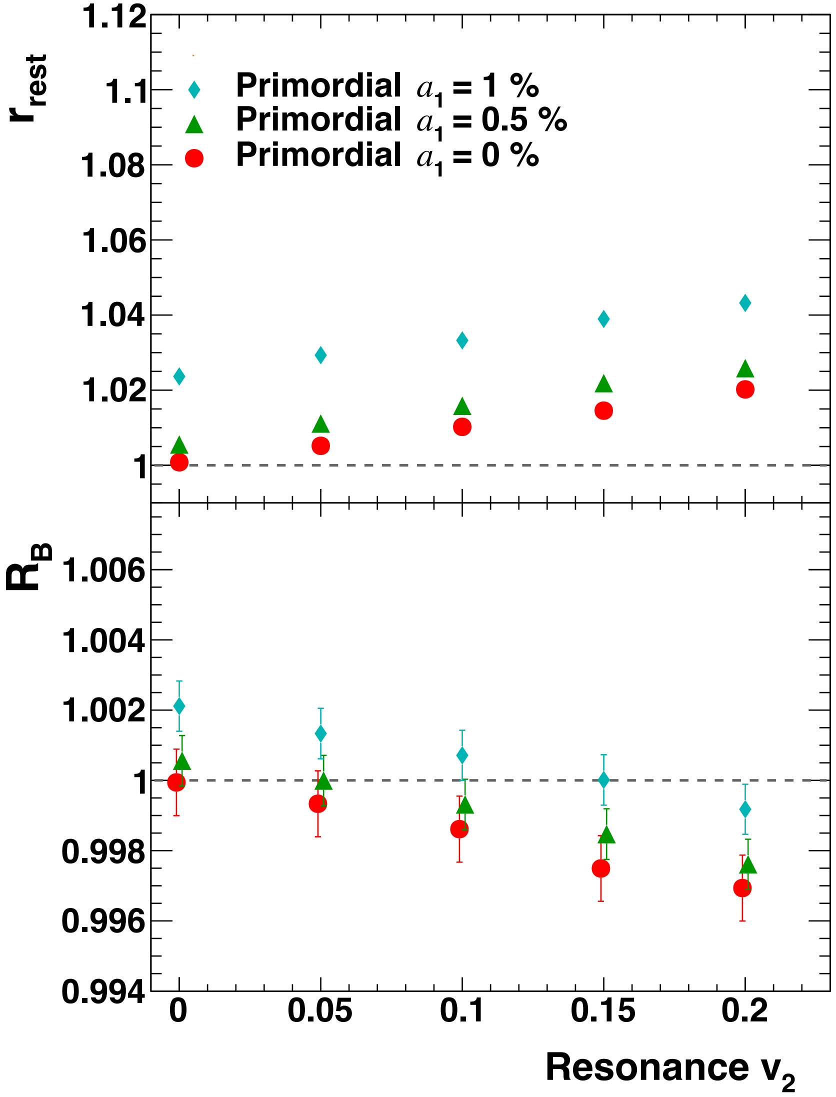

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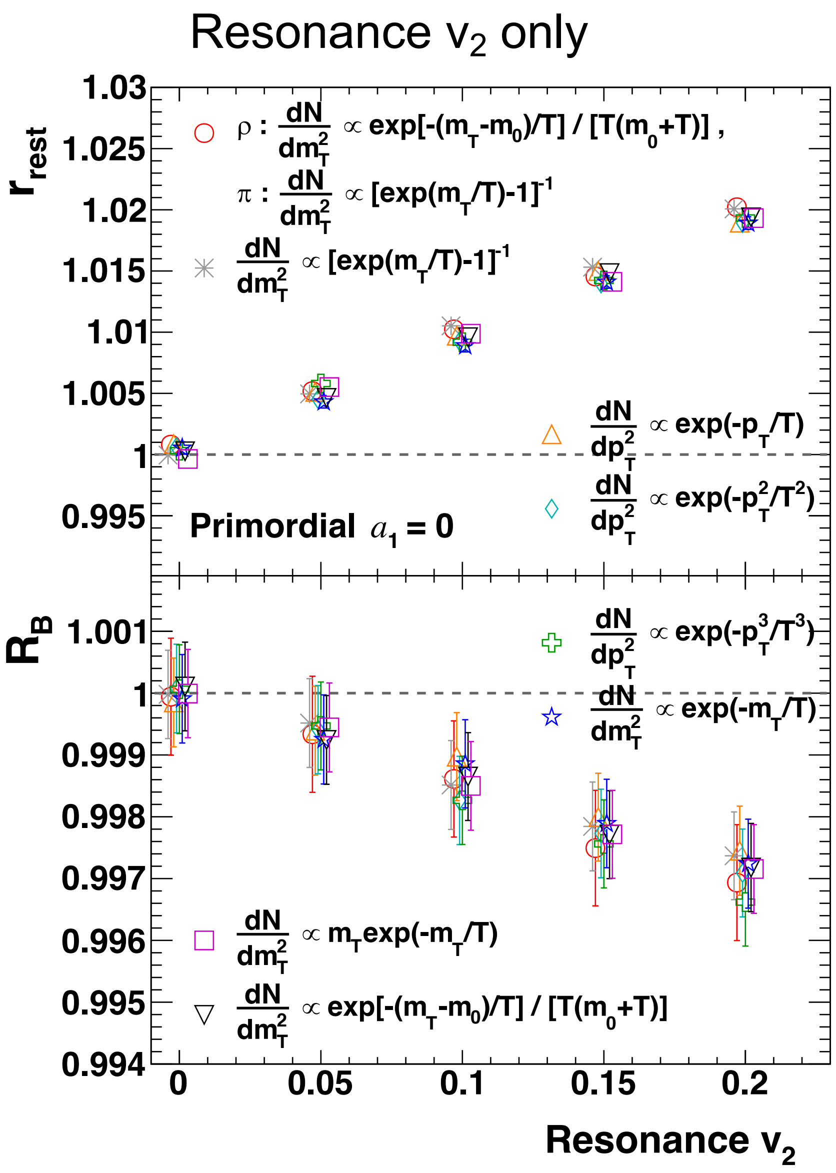
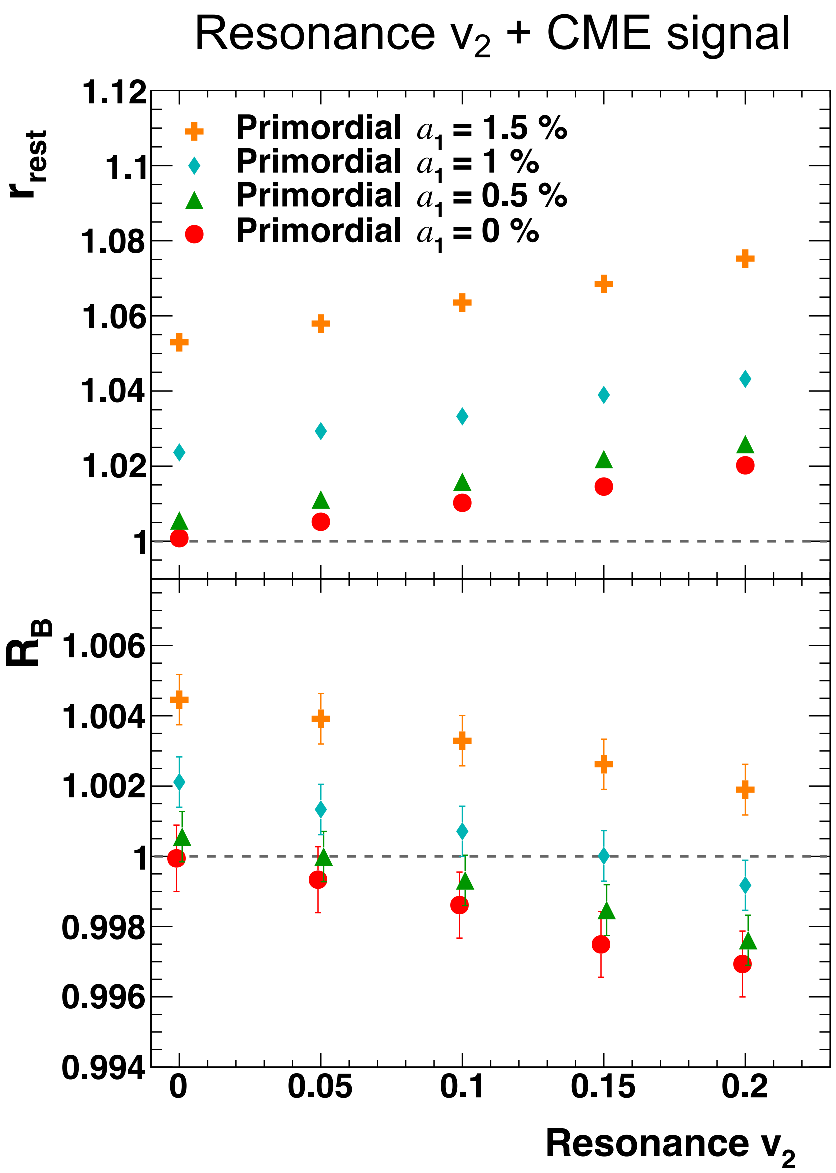


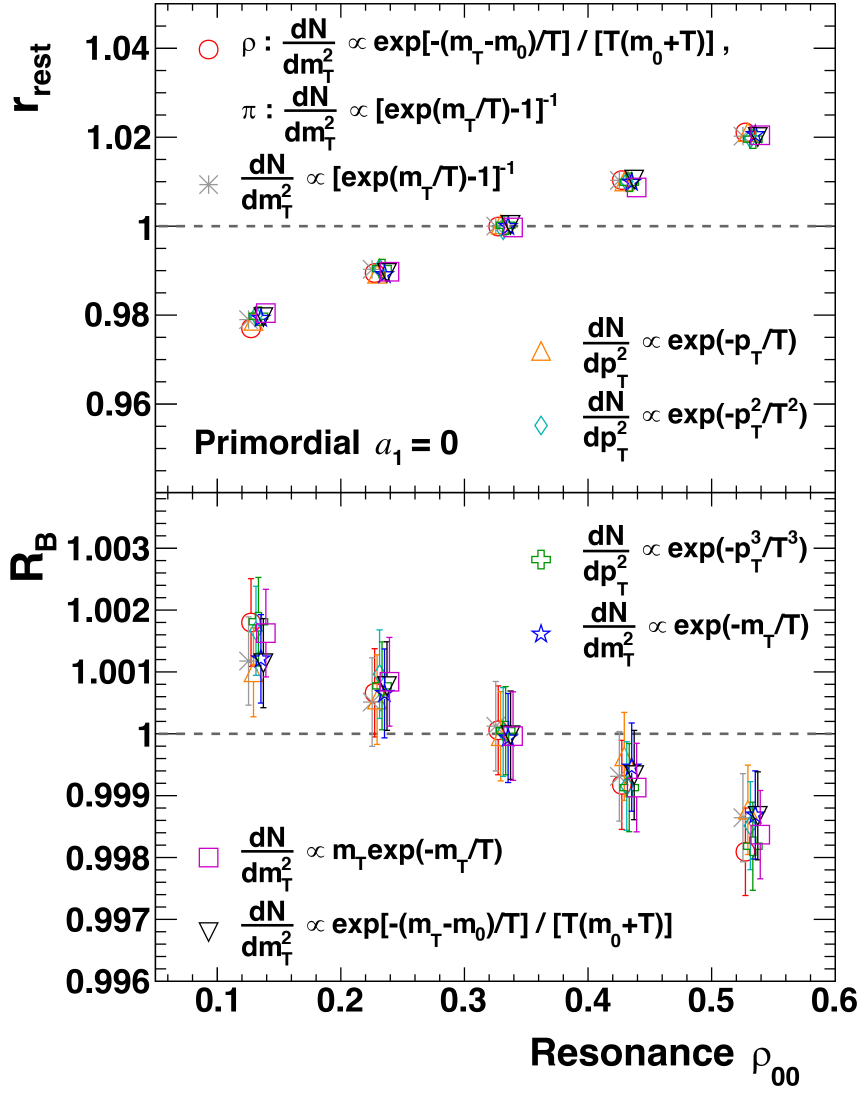


r_{rest} and R_B responds in opposite directions to the change of resonance v_2

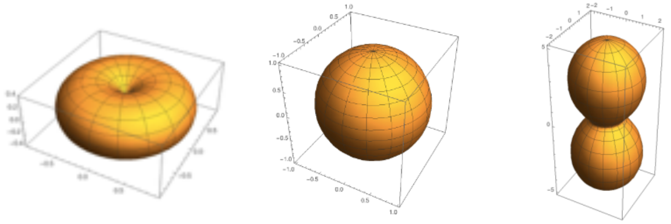
A. Tang, arXiv:1903.04622

Toy Model Simulation: Global Spin Alignment ρ_{00}

ρ_{00} only



$\rho_{00} < \frac{1}{3}$ $\rho_{00} = \frac{1}{3}$ $\rho_{00} > \frac{1}{3}$

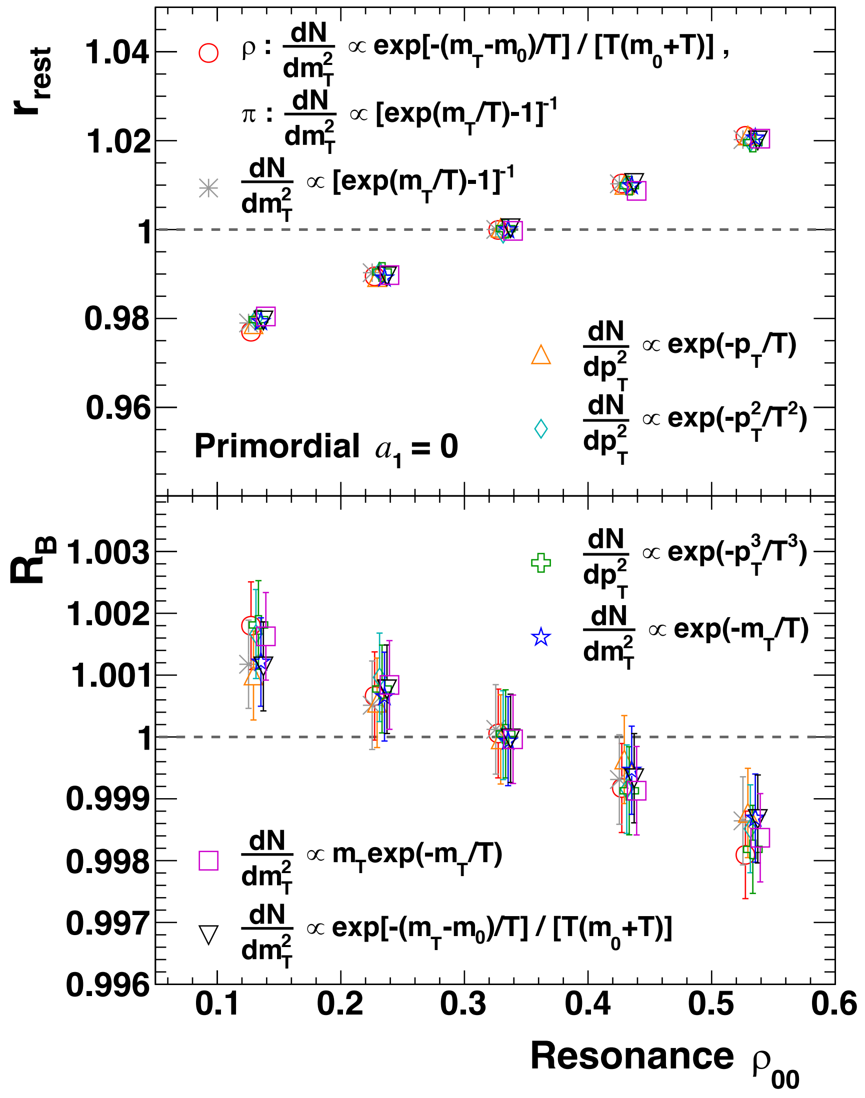


r_{rest} and R_B responds in opposite directions to ρ_{00} change.

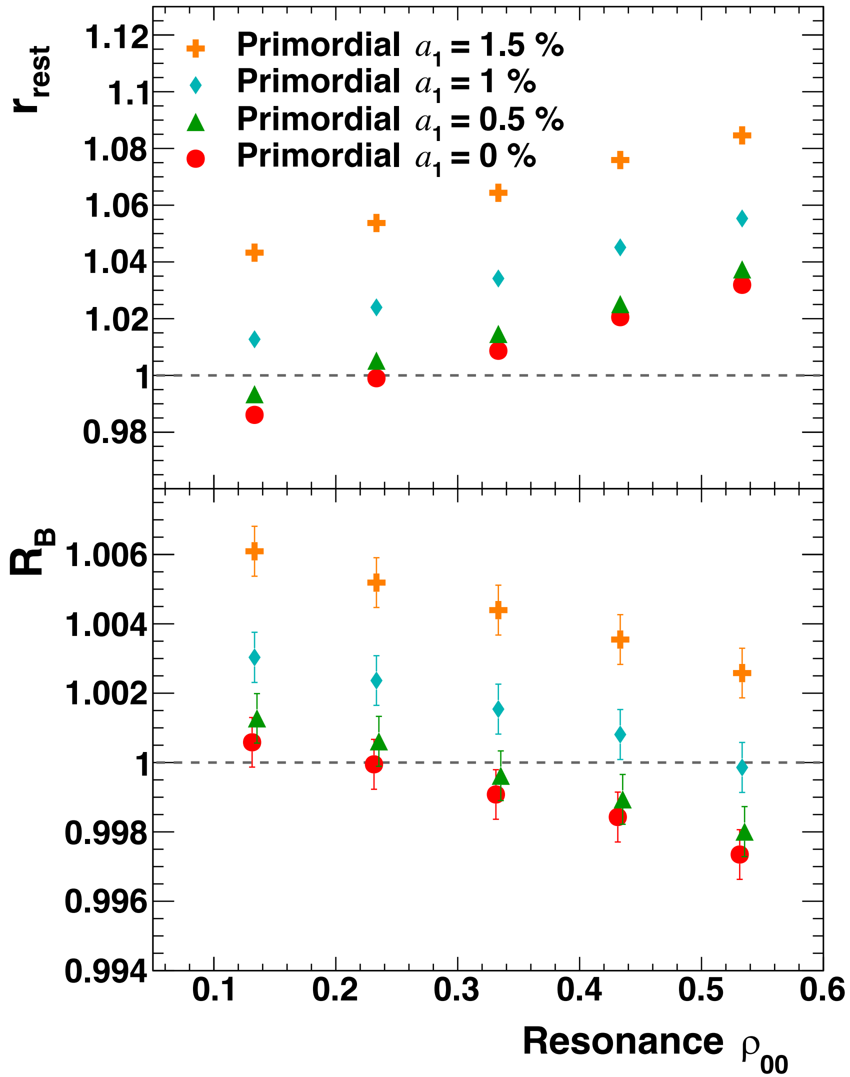
A. Tang, arXiv:1903.04622

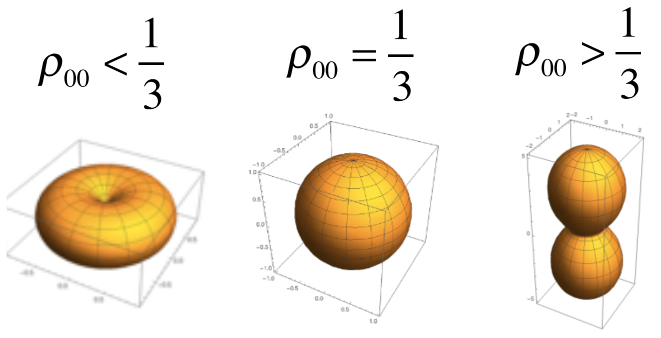
Toy Model Simulation: Global Spin Alignment ρ_{00}

ρ_{00} only



ρ_{00} + v_2 + CME





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A. Tang, arXiv:1903.04622

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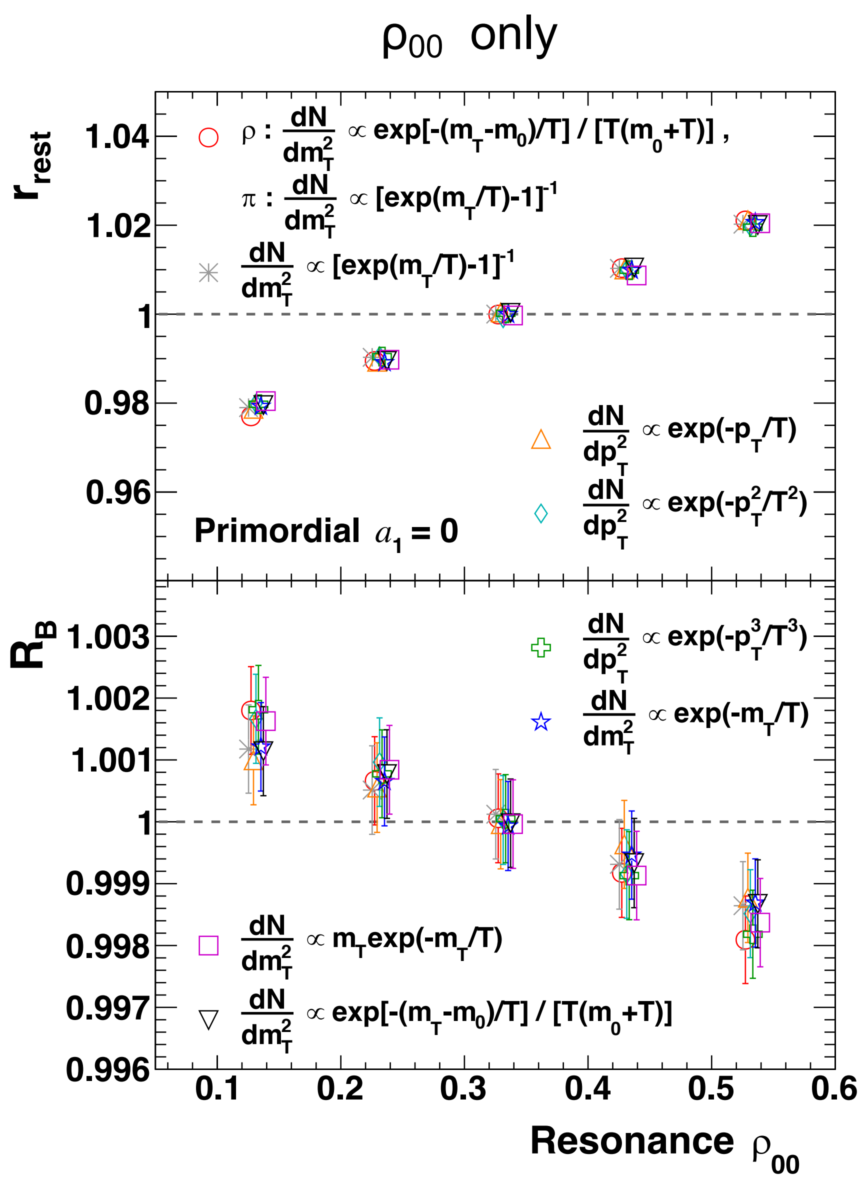
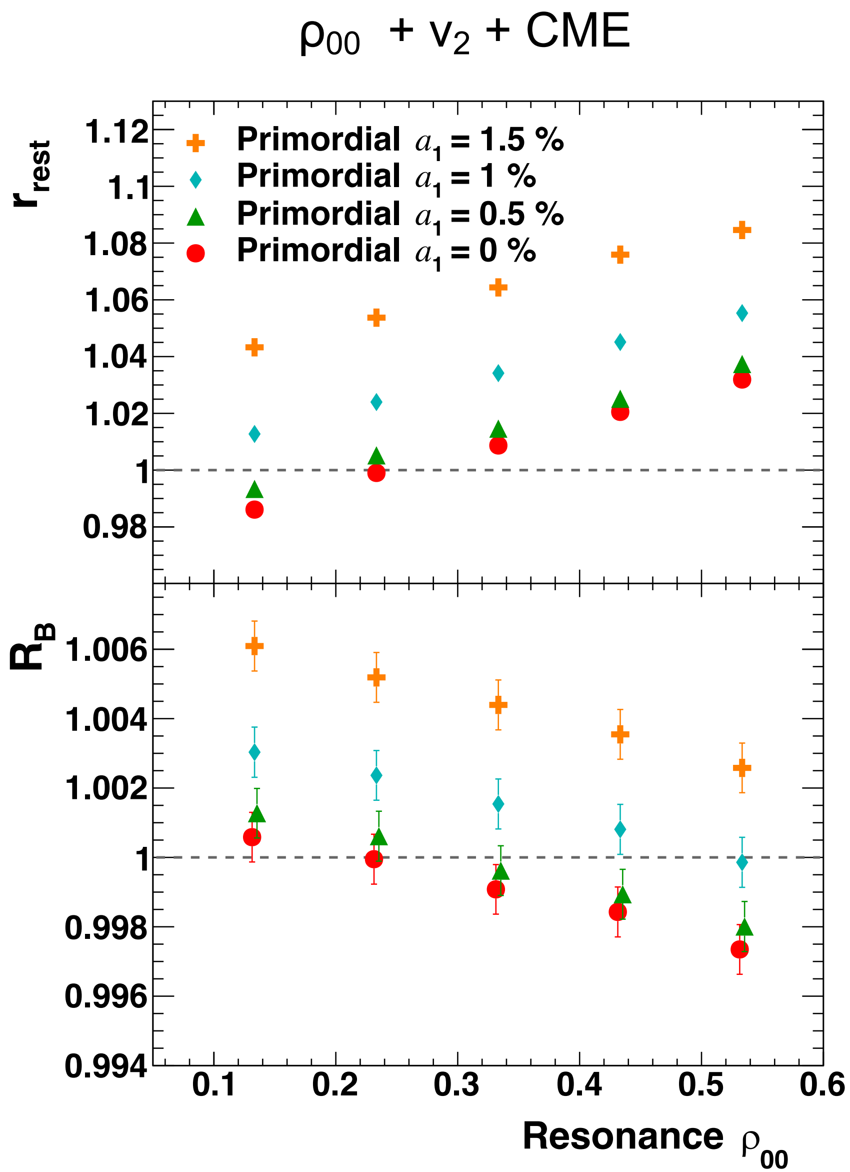
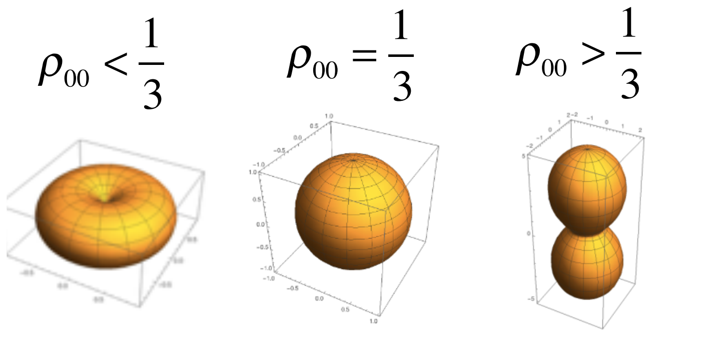




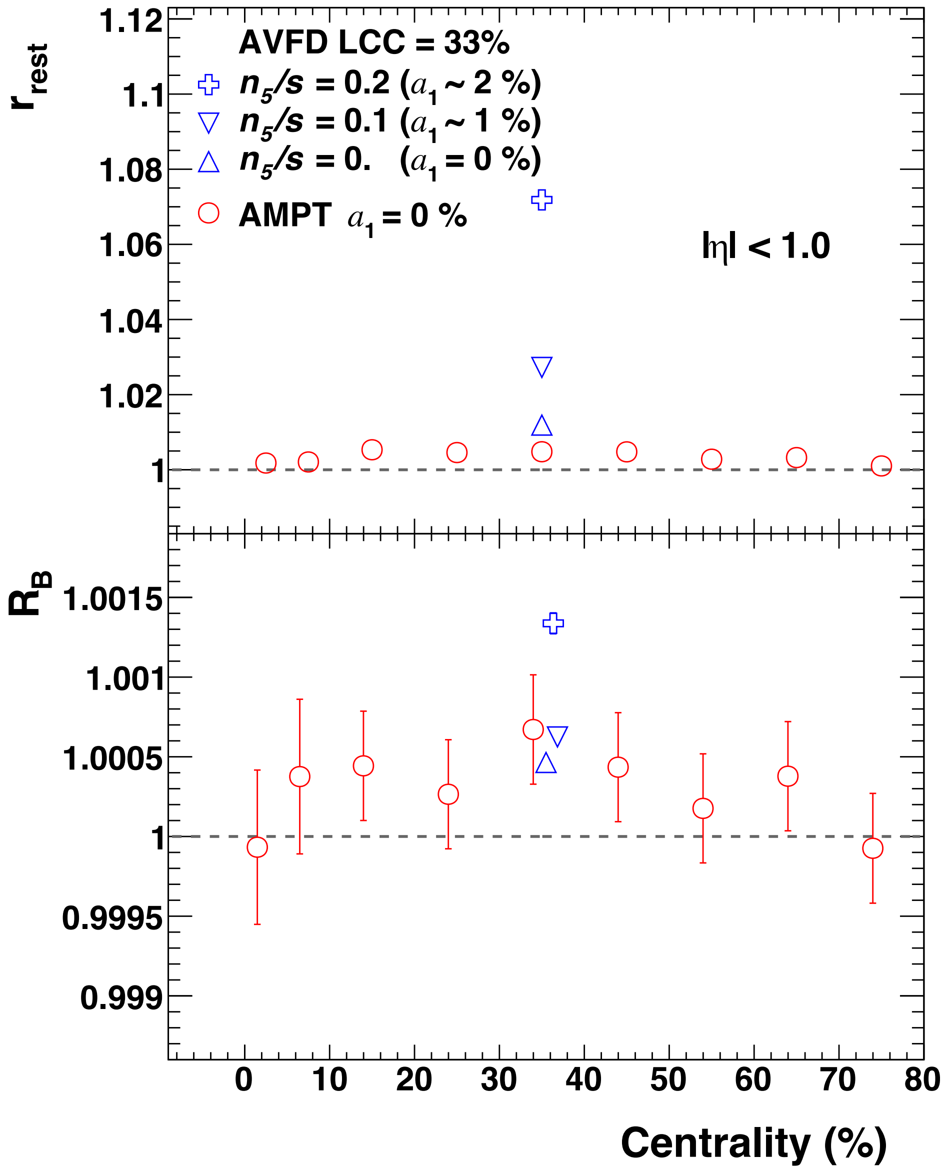


r_{rest} and R_B responds in opposite directions to ρ_{00} change.

If both r_{rest} and R_B are larger than 1, then we have a case supporting CME, barring additional background from Local Charge Conservation (**LCC**) and Transverse Momentum Conservation (**TMC**).

A. Tang, arXiv:1903.04622

LCC + TMC via Realistic Models



Two models are used:

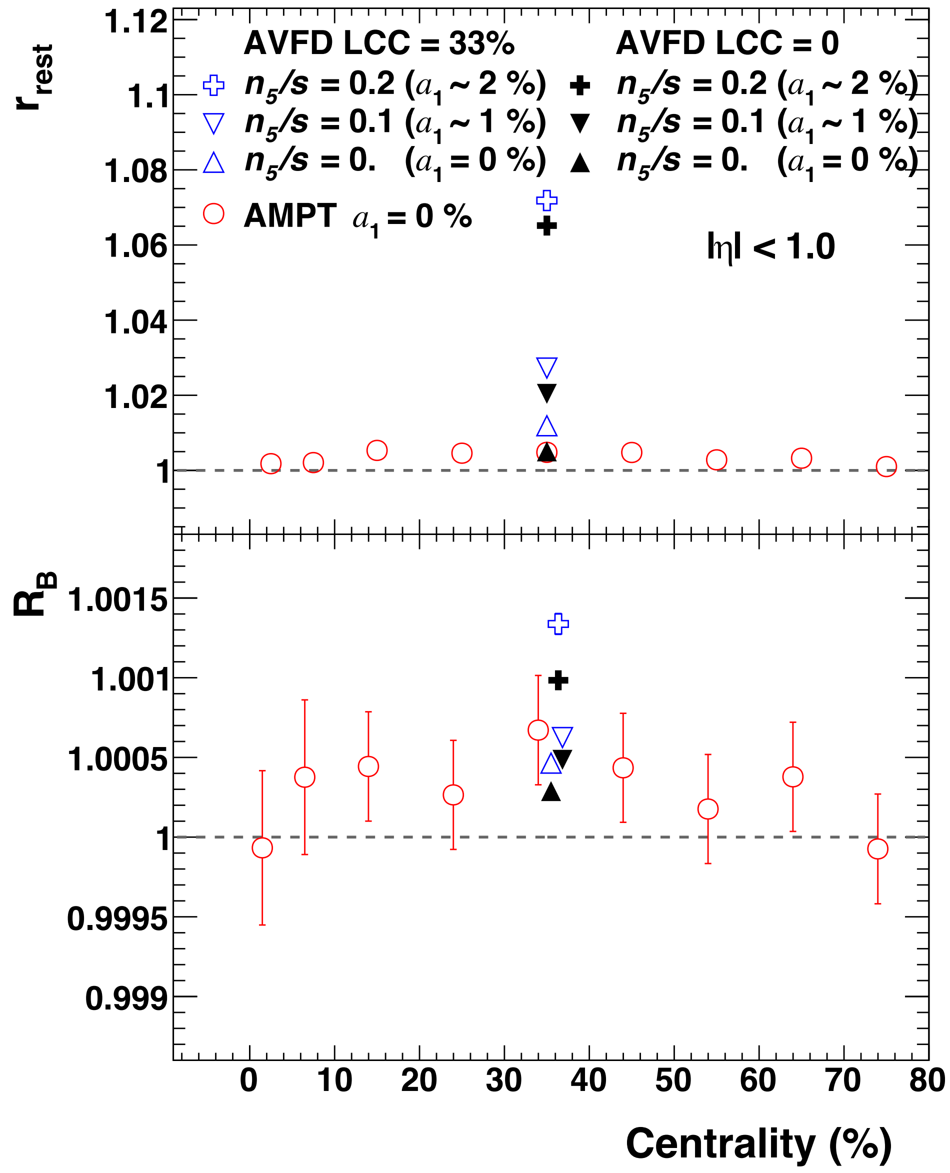
AMPT[1] version v2.25t4cu with string melting and charge conservation assured. No CME.
AVFD[2] (anomalous viscous fluid dynamics) Version beta 1.0 with CME implemented.

Clear sensitivity of r_{rest} and R_B to signal in realistic CME model.

Exhaustedly tested with toy model and realistic models with various sig+bg combinations, in a systematic and comprehensive way.

[1] Lin, Ko, Li, Zhang & Pal, Phys. Rev. C 72 064901 (2005), and private communication with Z.W.Lin and G.L. Ma
[2] Jiang, Shi, Yin & Liao, Chin. Phys. C 42 n0. 1 011001 (2018)
Shi, Jiang, Lilleskov & Liao, Annals.Phys. 394, 50 (2018)

Change LCC Only



AVFD[1] (anomalous viscous fluid dynamics)
Version beta 1.0 with CME implemented.

[1] Jiang, Shi, Yin & Liao, Chin. Phys. C 42 n0. 1 011001 (2018)
Shi, Jiang, Lilleskov & Liao, Annals.Phys. 394, 50 (2018)

LCC shifts both r_{rest} and R_B upwards.

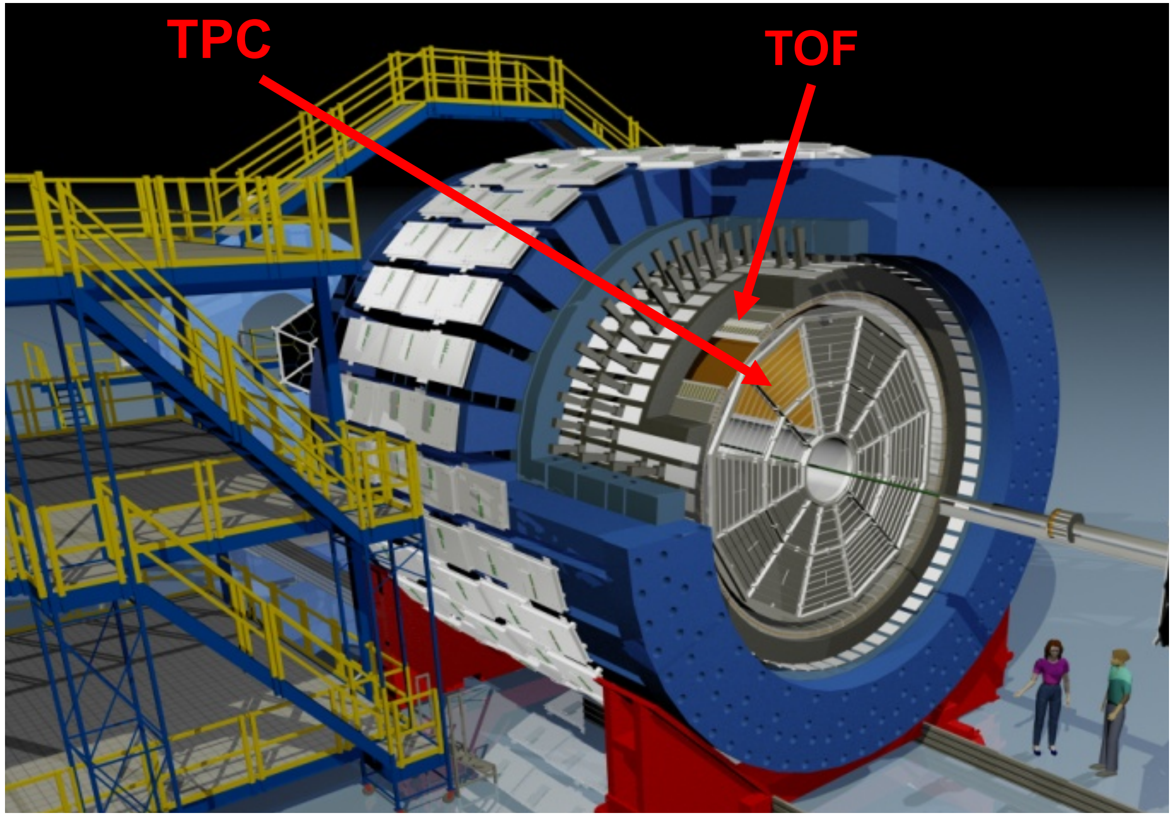
Limited response to LCC, when changing from 0% to 33%.

Data Analysis

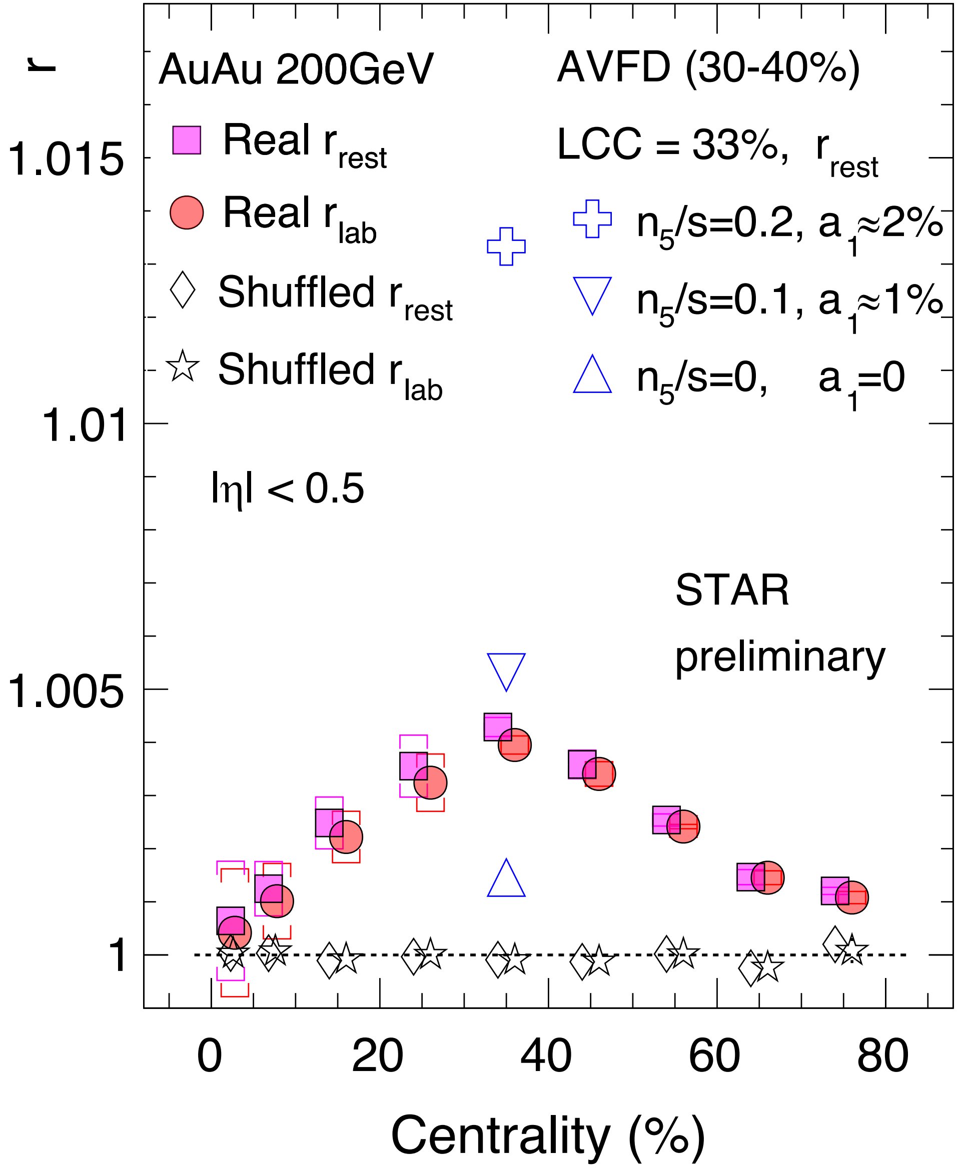
- **Data sets:**
  - ✓ Run16 Au + Au 200 GeV, about 1 billion MB events

- **Track cuts:**
  - ✓ $0.2 < p_T < 1.8$ GeV/c
  - ✓ EP reconstruction: $0.5 < |\eta| < 1.0$
  - ✓ Pions for analysis: $|\eta| < 0.5$

- **Time Projection Chamber (TPC)**
  - ✓ Charged Particle Tracking
  - ✓ Particle identification from ionization energy loss (dE/dx)
  - ✓ Pseudorapidity coverage $|\eta| < 1.0$
- **Time-of-Flight (TOF)**
  - ✓ Particle identification m^2
  - ✓ Pseudorapidity coverage $|\eta| < 0.9$



Results from Au+Au 200GeV: r

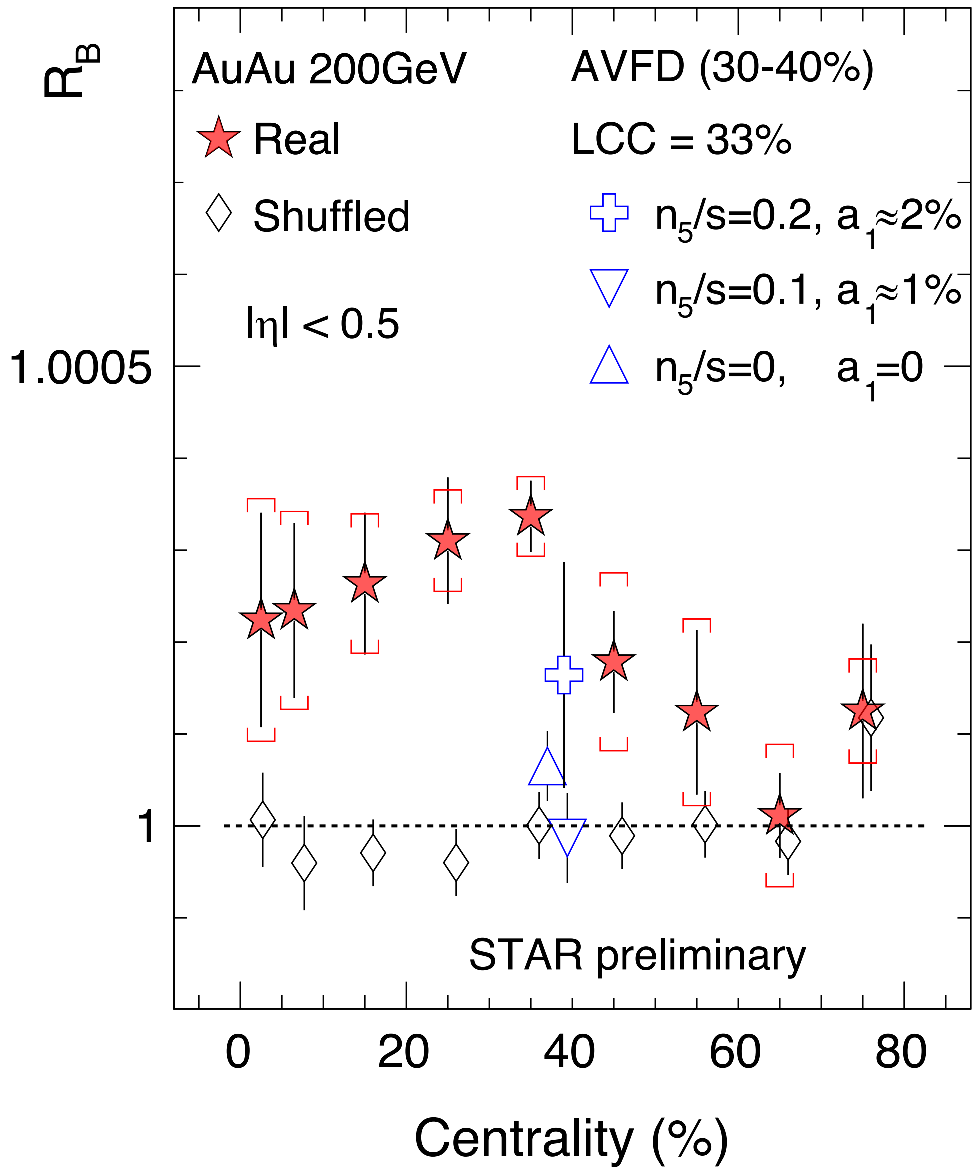


Data points are not EP resolution corrected. Instead, we smeared reaction plane in AVFD with measured EP resolution in order to compare with data

The efficiency is also applied on AVFD events for a fair comparison.

r_{lab} and r_{rest} are larger than unity in all centralities, and larger than model calculation with no CME.

Results from Au+Au 200GeV: R_B



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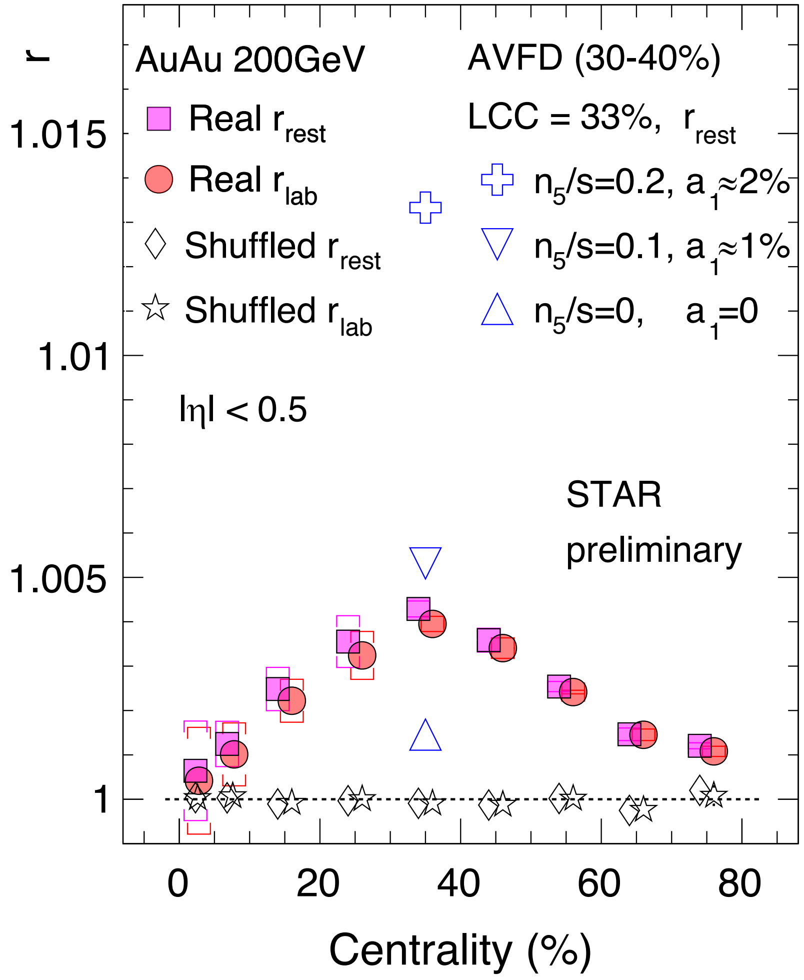
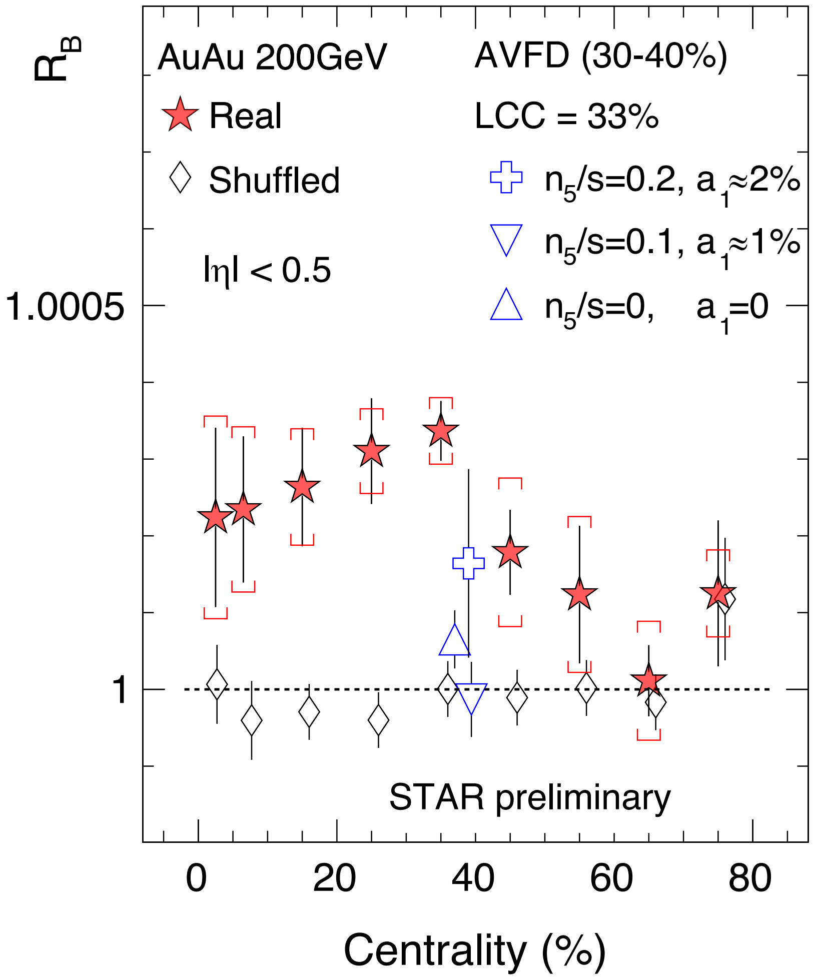
Results from Au+Au 200GeV: r and R_B





Data points are not EP resolution corrected. Instead, we smeared reaction plane in AVFD with measured EP resolution in order to compare with data

The efficiency is also applied on AVFD events for a fair comparison.

Both r_{rest} and R_B are larger than unity in all centralities, and larger than model calculation with no CME.

Summary and Outlook

- r_{rest} and R_B respond in opposite directions to signal and backgrounds arising from resonance v_2 and ρ_{00}, respectively. Their behavior have been tested systematically and exhaustedly with toy and realistic models with various sig+bkg combinations.

- A case of both r_{rest} and R_B being greater than unity would support the existence of CME.

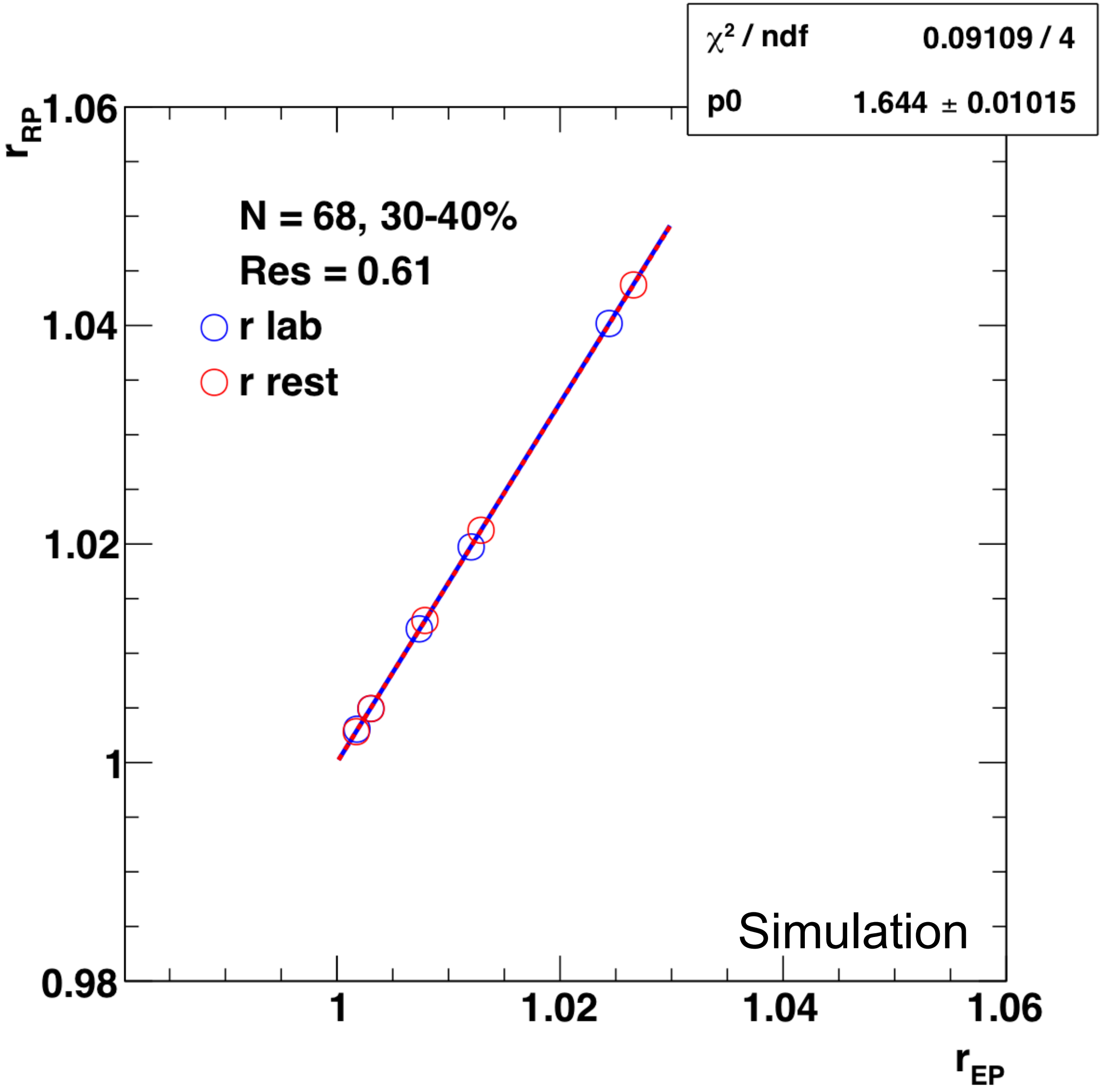
- In Au+Au collisions at 200GeV, r_{rest}, r_{lab} and R_B are larger than unity, and larger than realistic model calculations with no CME implemented. Data is difficult to be explained by backgrounds only.

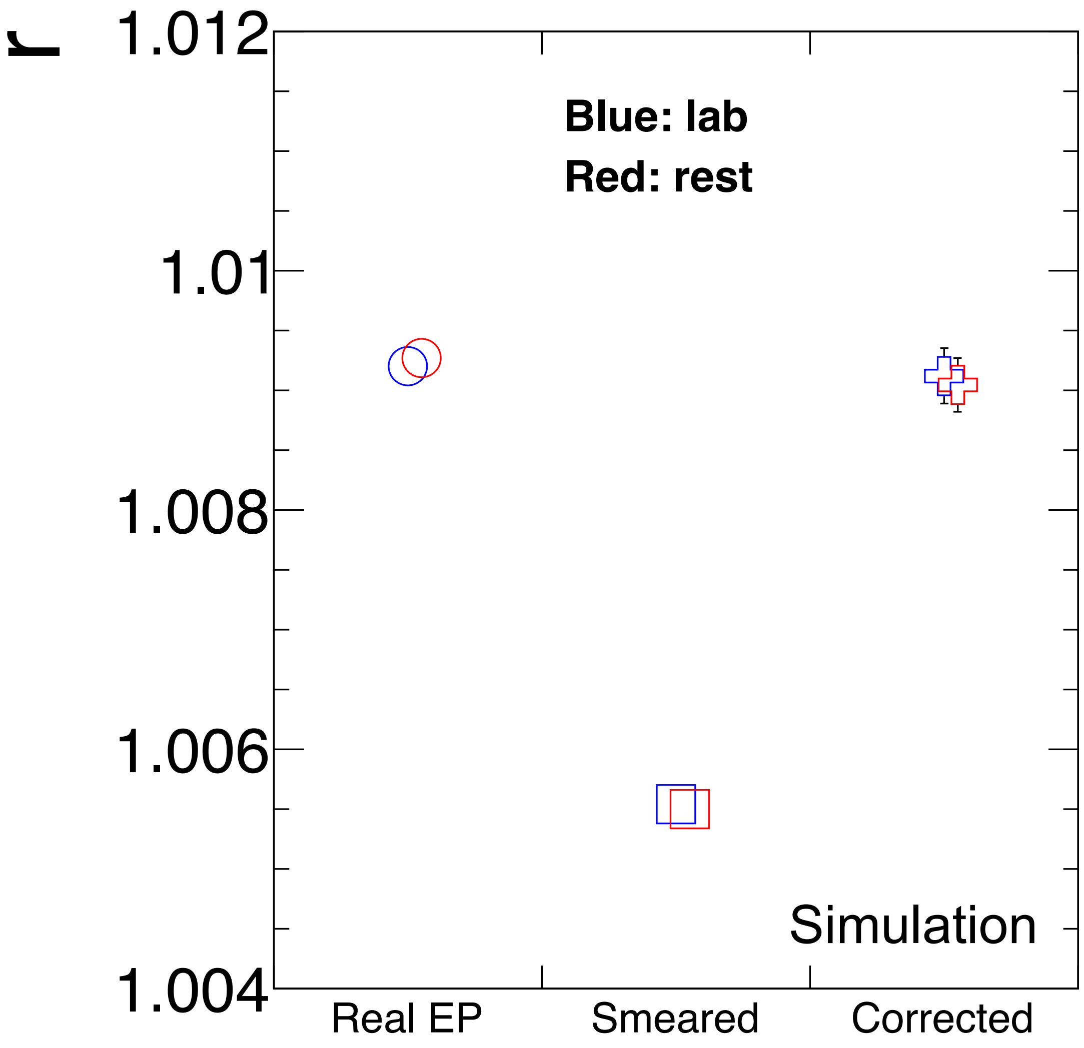
- More detail investigation on LCC is ongoing

- Stay tuned for isobar analysis.

Related Work:
- Talk: J. Zhao, Tue, 14:20 BR2
- Poster (Tue, 16:30-18:00):
  745 (CH31) N. Magdy,
  560 (CH22) J. Singh ,
  735 (CH30) S. Choudhury,
  560 (CH22) M. Sergeeva
  668 (CH26) H. Xu

BackUp: Closure test of EP smearing





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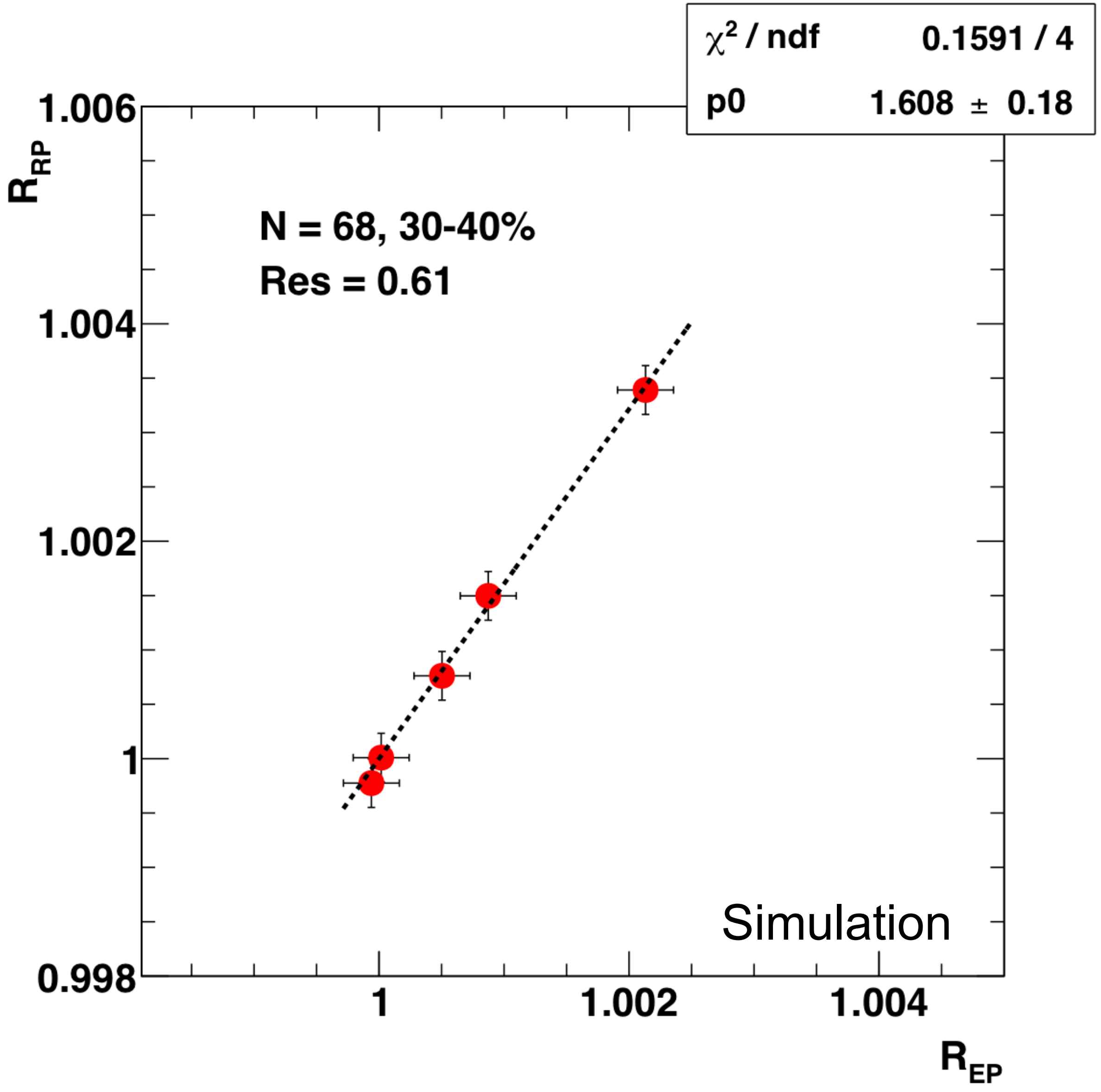
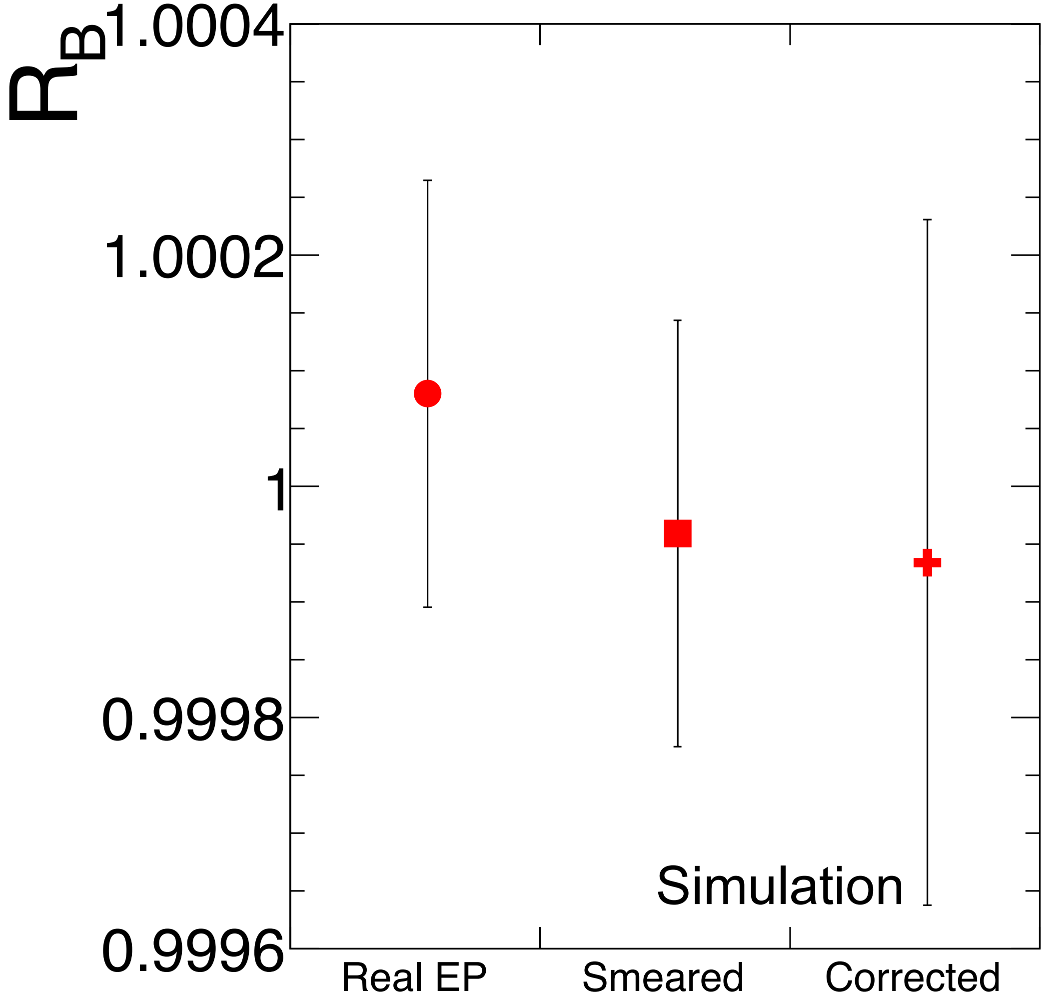
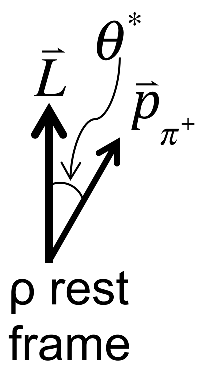
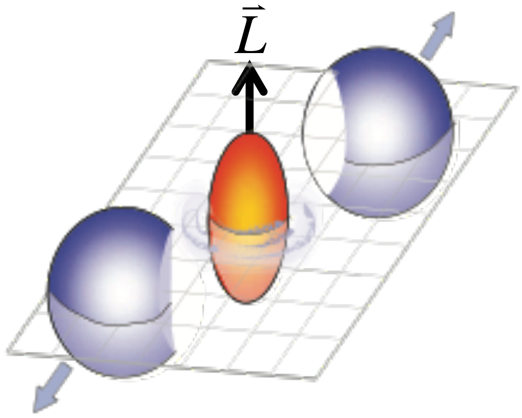




BackUp: Global Spin Alignment (ρ_{00})

The 00-component of spin density matrix (ρ_{00}) can be measured via angular distribution of decay daughter using :

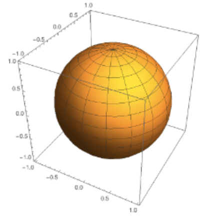




$$\frac{dN}{d(\cos\theta^*)} = N_0 \times \left[(1-\rho_{00}) + (3\rho_{00}-1)\cos^2\theta^*\right]$$

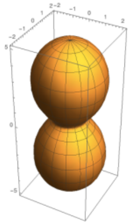
A deviation of ρ_{00} from 1/3 would indicate a non-zero spin alignment.

$\rho_{00} = \frac{1}{3}$



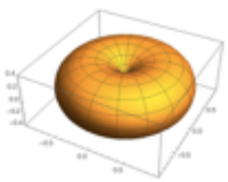
“v2” = 0

$\rho_{00} > \frac{1}{3}$



“v2” < 0

$\rho_{00} < \frac{1}{3}$

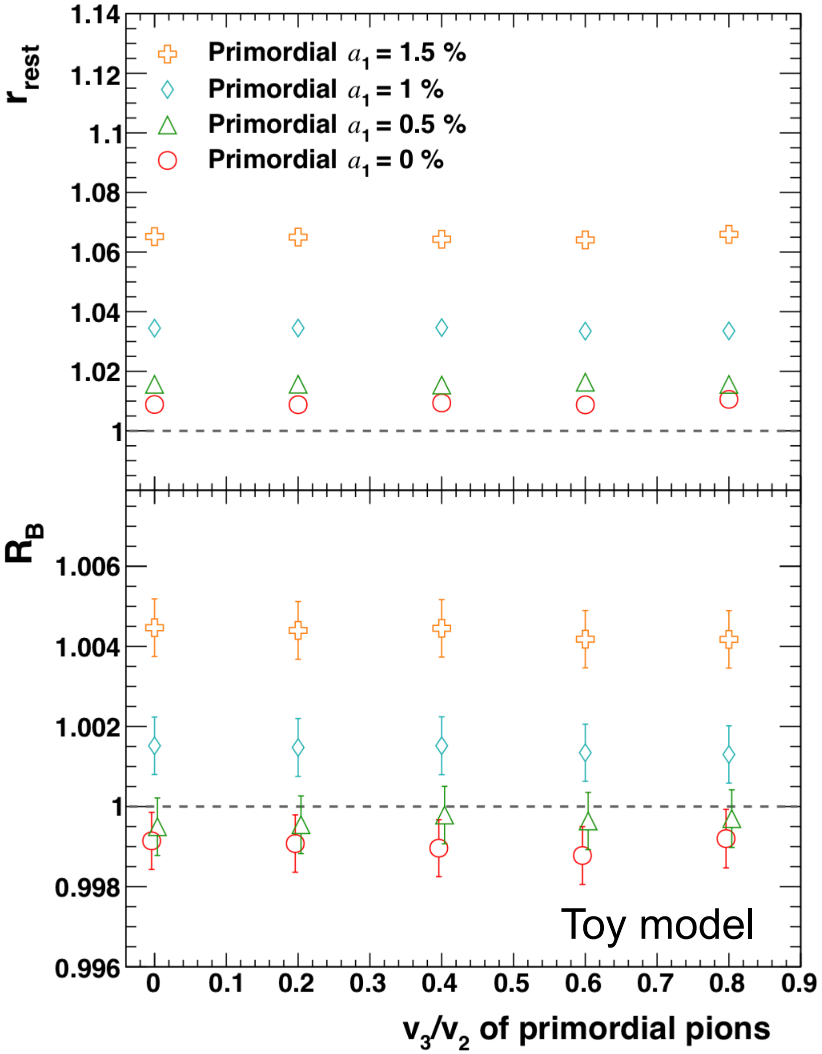


“v2” > 0

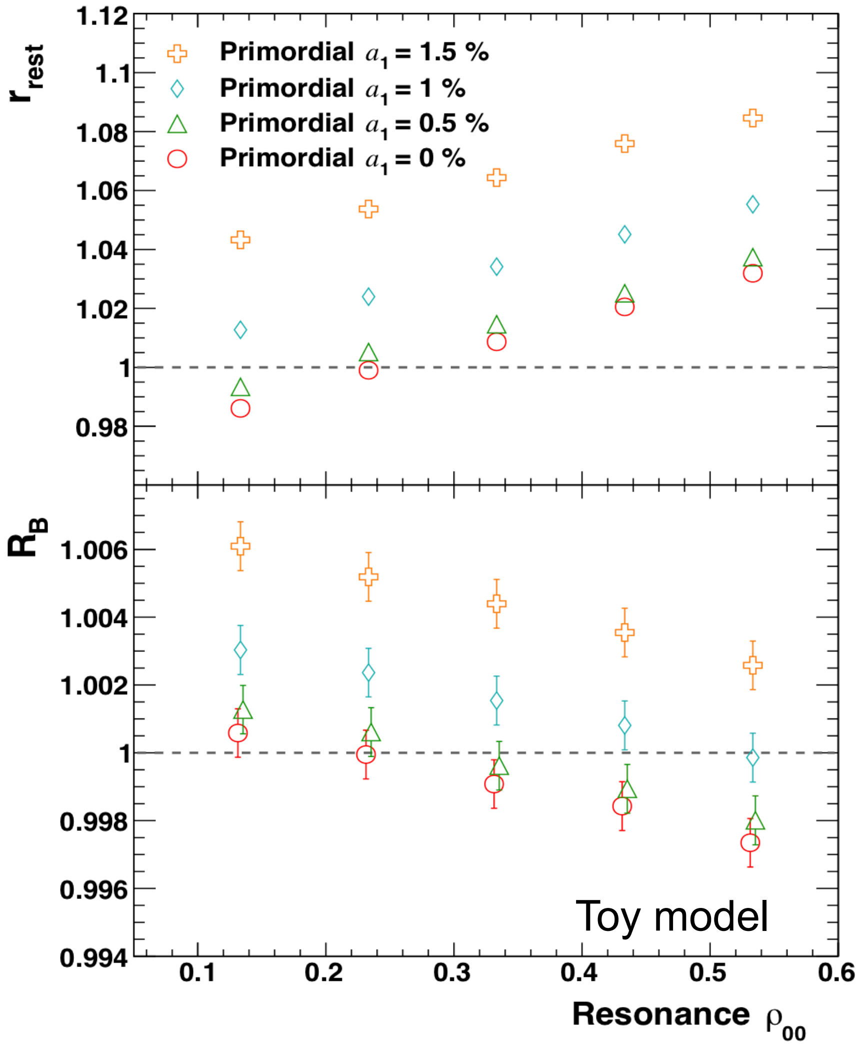
Finite spin alignment acts like “elliptic flow” in rest frame.

BackUp: p_T-dependent and resonance v_3

v_3 of resonance



Resonance ρ_{00} together with pT dependent v_2 & v_3 of primordial pions and ρ resonances



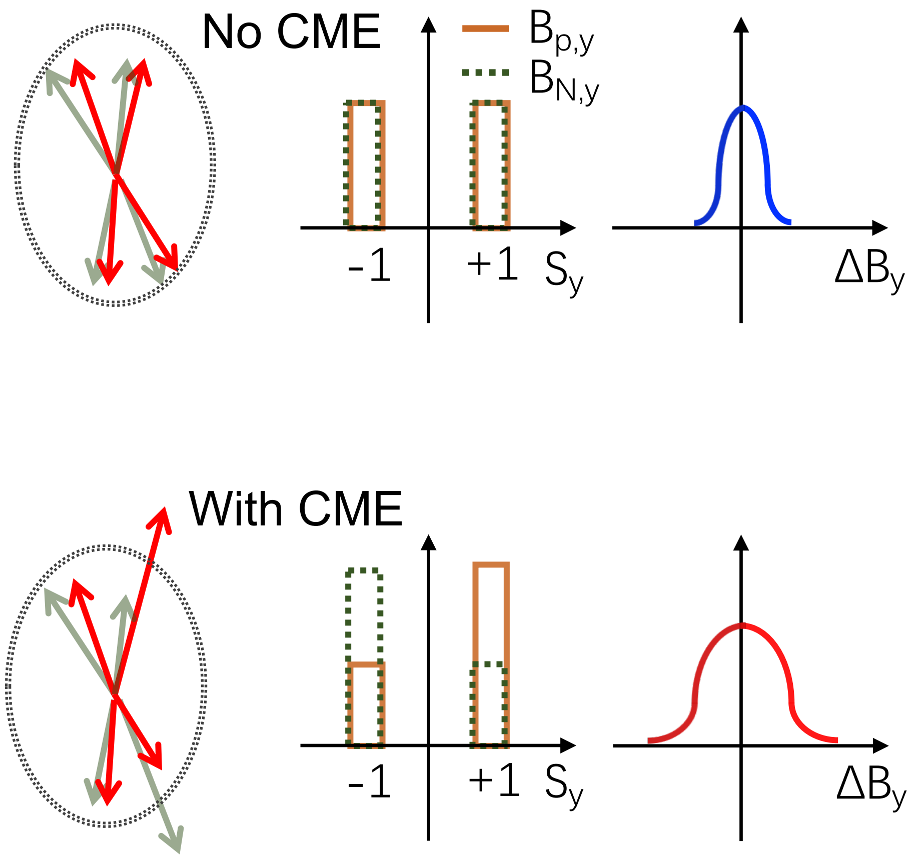
No noticeable resonance v_3 effect.

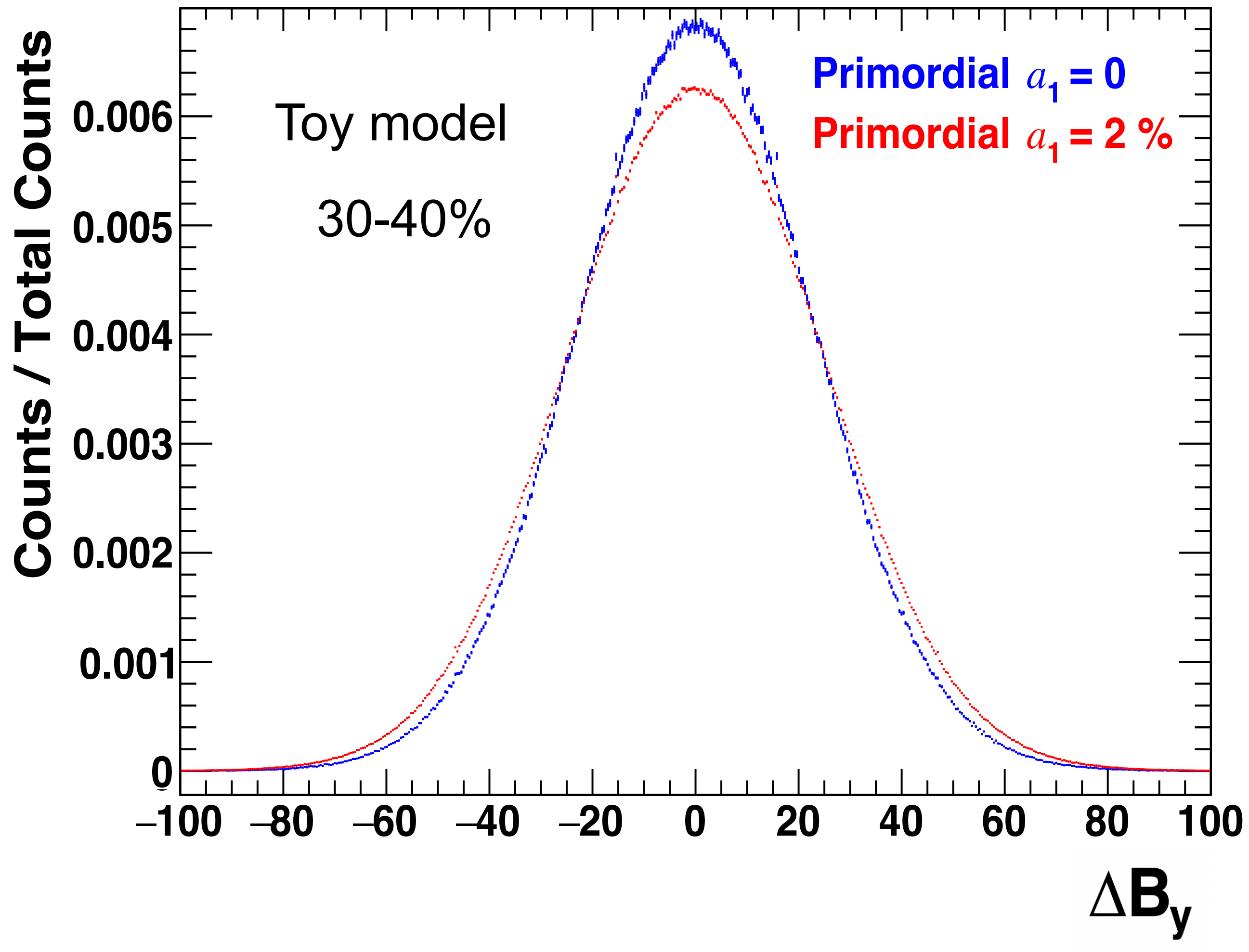
r_{rest} and R_B responds in opposite directions to ρ_{00} change.

A. Tang, arXiv:1903.04622

BackUp: Study the Momentum Odering with SBF

3) Look for enhanced event-by-event fluctuation of net-ordering ΔB_y (relative to ΔB





$$r = \frac{\sigma_{\Delta B_y}}{\sigma_{\Delta B_x}}$$ (>1 with CME)

A. Tang, arXiv:1903.04622

BackUp: ΔB_y distribution from data