Utilization of Event Shape in Search of the CME

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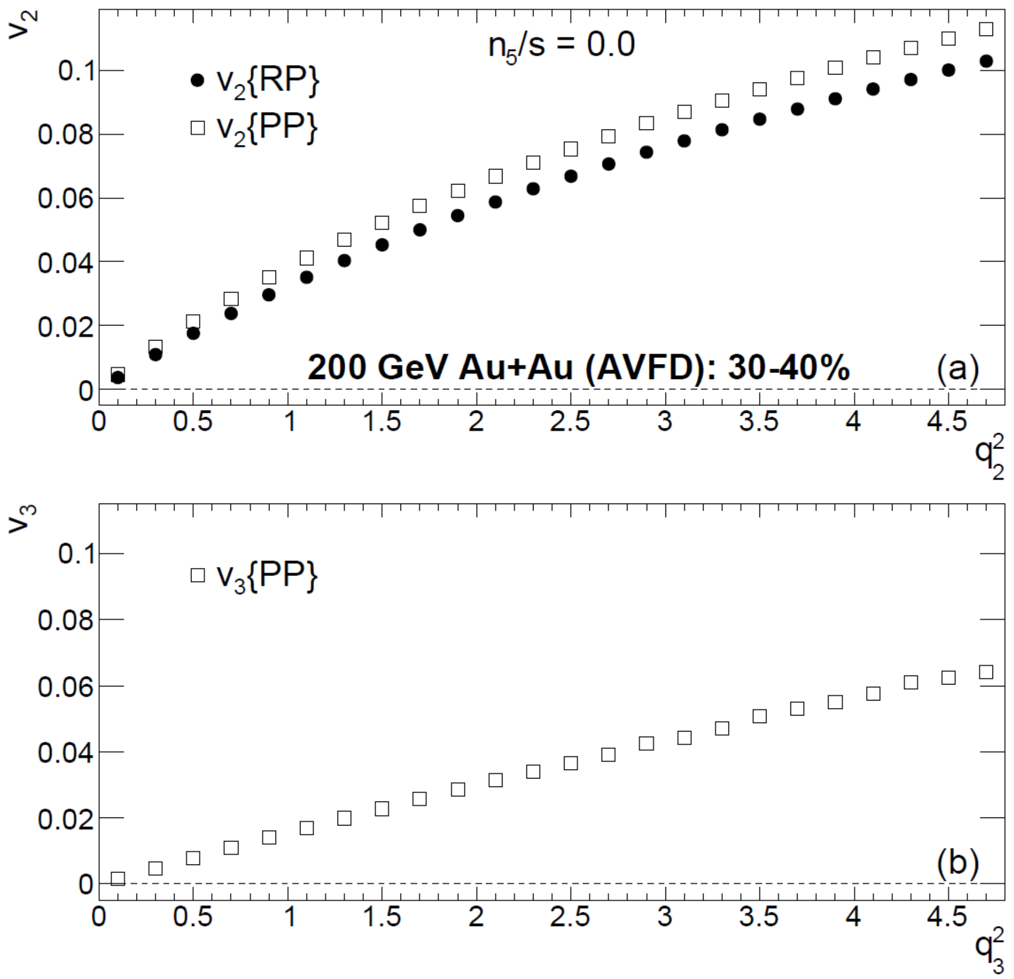
Event Handles

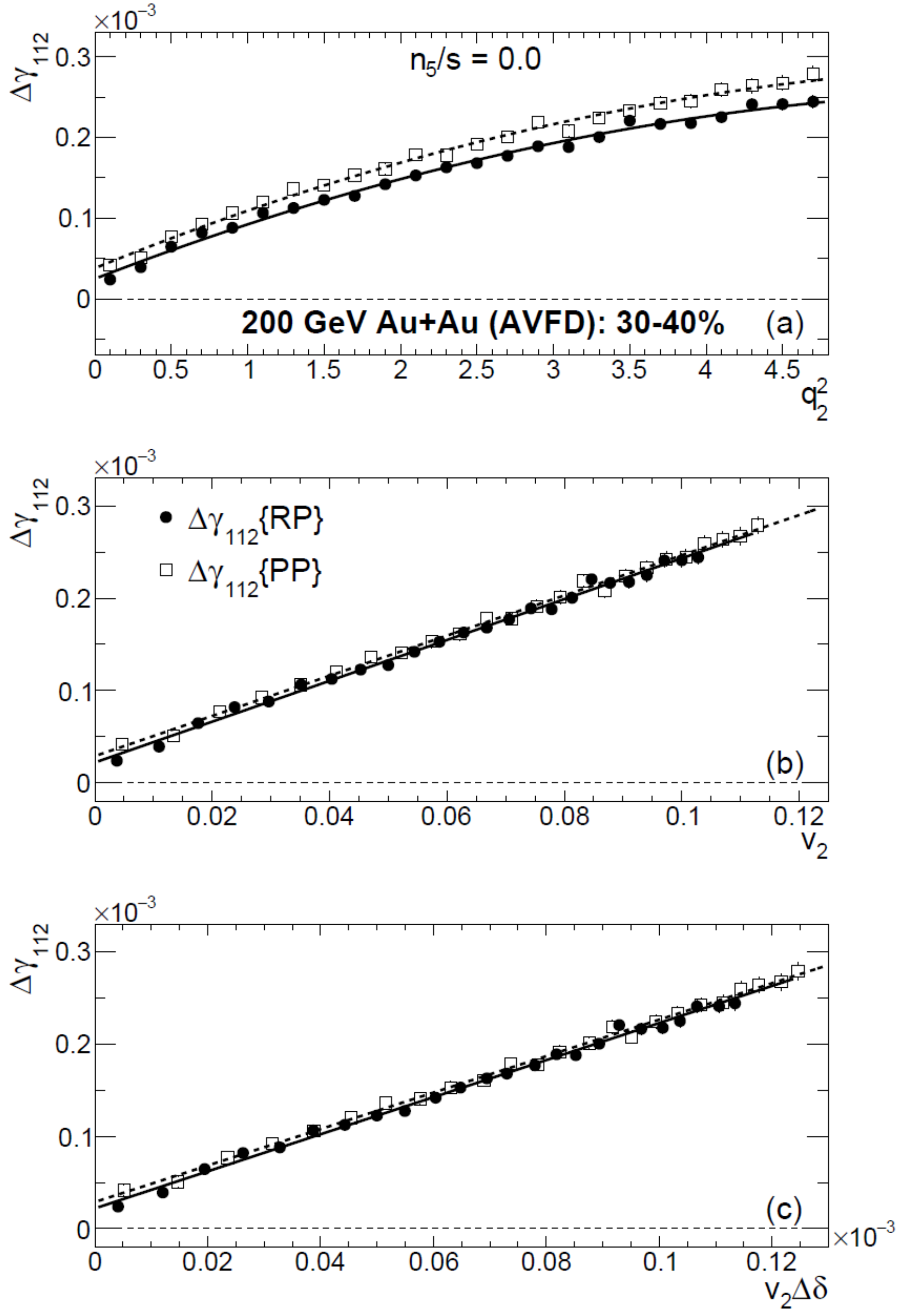
- Can project $\Delta\gamma_{112}$ measurements to zero v_2 (or zero $v_2\Delta\delta$) to eliminate residual backgrounds
  - Background stems from coupling between v_2 and δ
  - Called event-shape-engineering (ESE)
- q_2^2 is the event-handle used for projection
  - Observables are measured in q_n^2 bins (v_n presented on right)
  - When looking at $\Delta\gamma_{123}$, use 3rd-order instead
- $q_{n,x} = \frac{1}{\sqrt{N}}\sum_i^N \cos(\mathrm{n}\,\phi_i)$, $q_{n,y} = \frac{1}{\sqrt{N}}\sum_i^N \sin(\mathrm{n}\,\phi_i)$
  - $\overrightarrow{q_n} = (q_{n,x}, q_{n,y})$
- q_n obtained from POI used in observables
  - Improves reliability of the projection
  - Some residual backgrounds will remain
- Explore this method using AVFD model in Au+Au, Ru+Ru, and Zr+Zr
  - Same data used in STAR technical paper, arXiv:2105.06044



v_n approaches zero at zero q_n^2 for all n_5/s

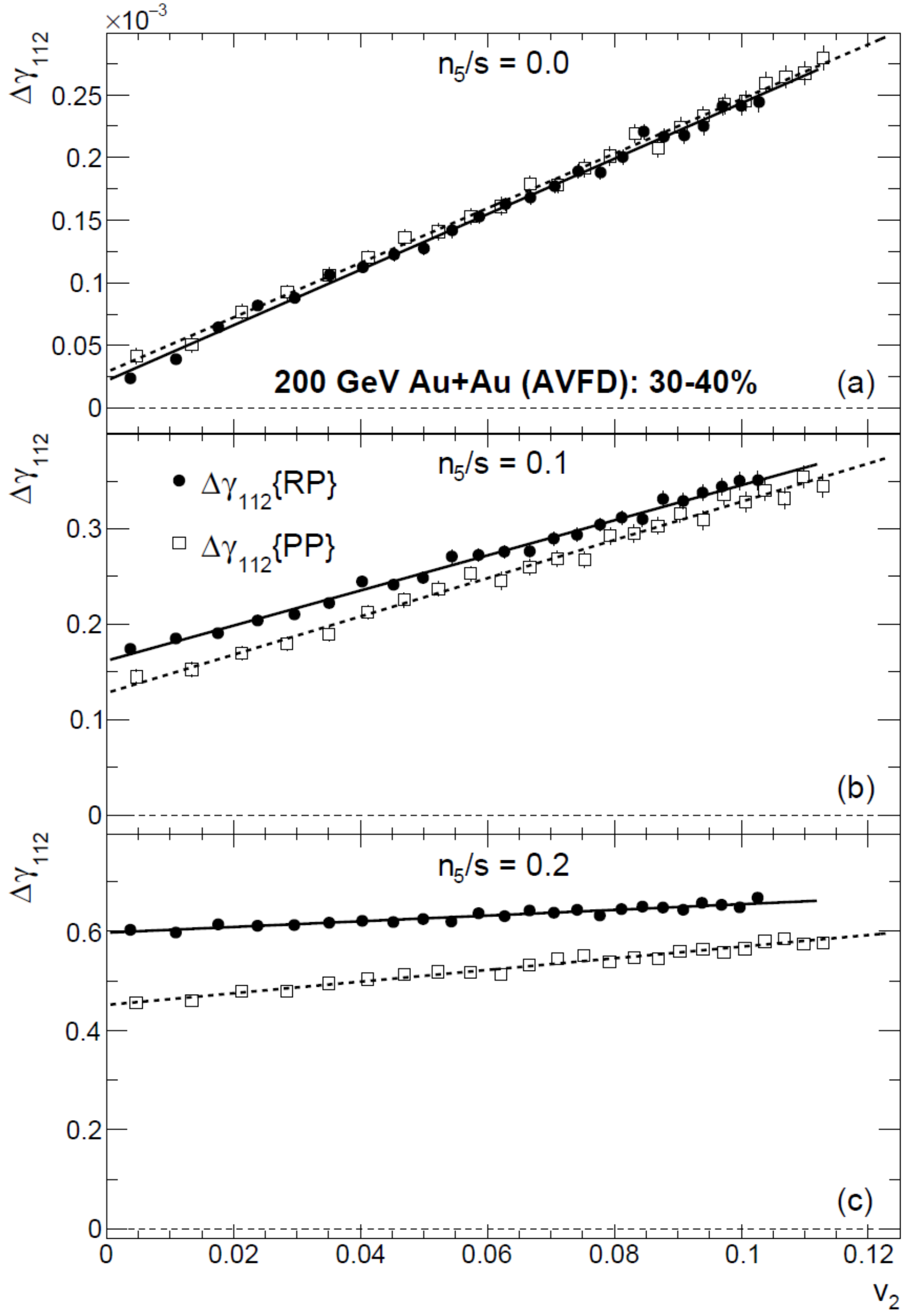
Projecting to zero-flow mode

- Use v_2, $v_2\Delta\delta$, and q_2^2 for projections
- Fit the data and use the y-intercept to obtain the zero-flow mode
- Use a first-order polynomial for v_2 and $v_2\Delta\delta$, and a second-order polynomial for q_2^2
    - Makes errors for q_2^2 larger than those of other handles
- In AVFD model, ESE approach does not completely remove the background



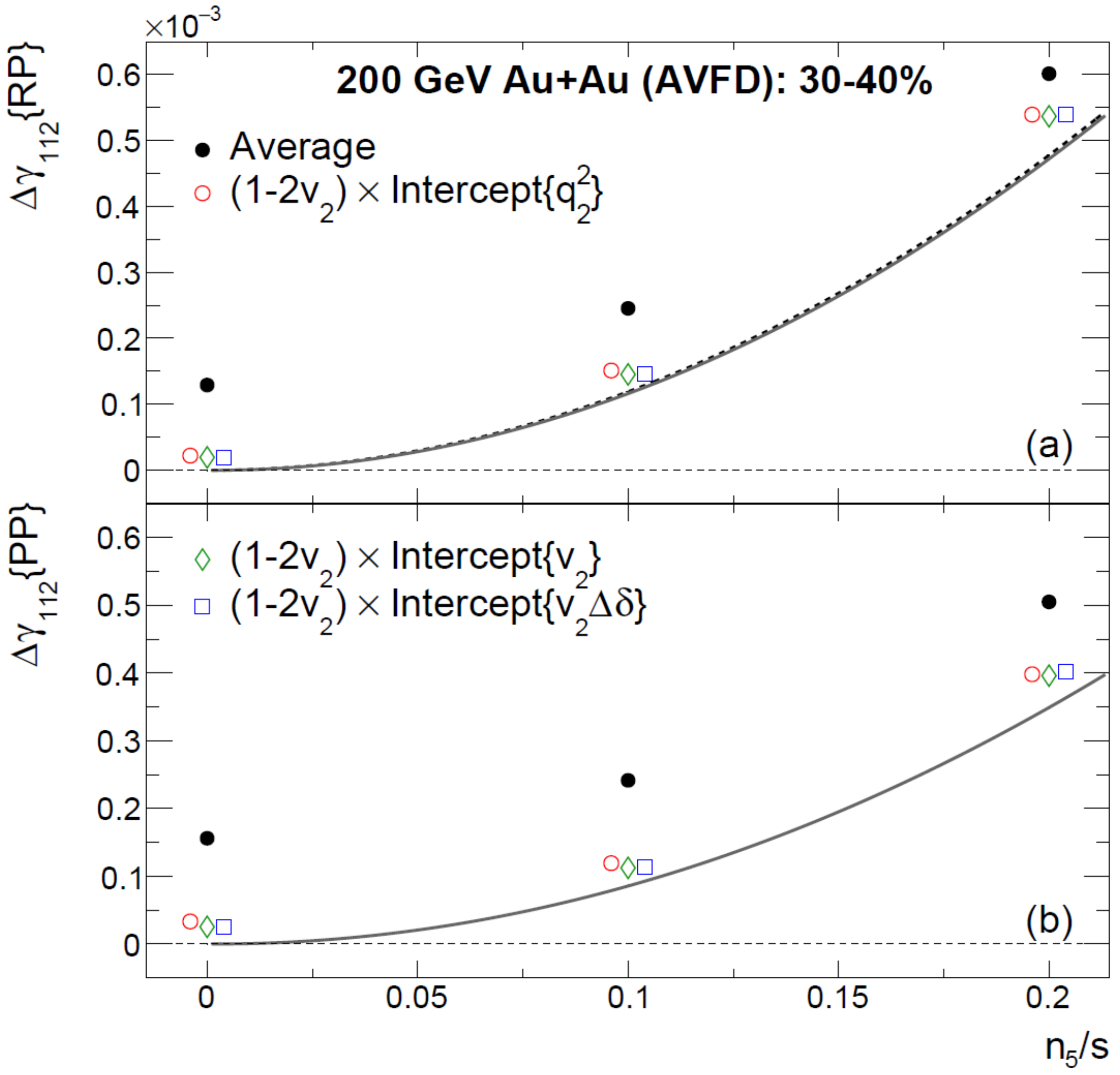
$\Delta\gamma_{112}$ with larger n_5/s

- ESE intercept increases with n_5/s, agreeing with expectations
- $\Delta\gamma_{112}\{\mathrm{RP}\}$ is consistently larger than $\Delta\gamma_{112}\{\mathrm{PP}\}$ due to its closer correlation with the magnetic field
- Currently only showing projection with v_2 for simplicity
- ESE intercepts must be corrected by factor of $(1-2v_2)$



Comparison with ensemble average

- In pure background case ($n_5/s = 0$), ESE removes large chunk of residue background
  - Suppresses background by factor of 6 relative to ensemble average
- True CME signal illustrated with curves
  - Given by $\Delta\gamma_{112}^{\text{CME}} = \Delta\gamma_{112} - \Delta\gamma_{112}|_{n5/s=0}$ (solid curves)
  - Same as $\frac{1}{2}\left(a_{1,+}^2 + a_{1,-}^2\right) - a_{1,+}a_{1,-}$ (dotted curve in top panel)
- ESE intercepts much closer to CME signal than ensemble averages are



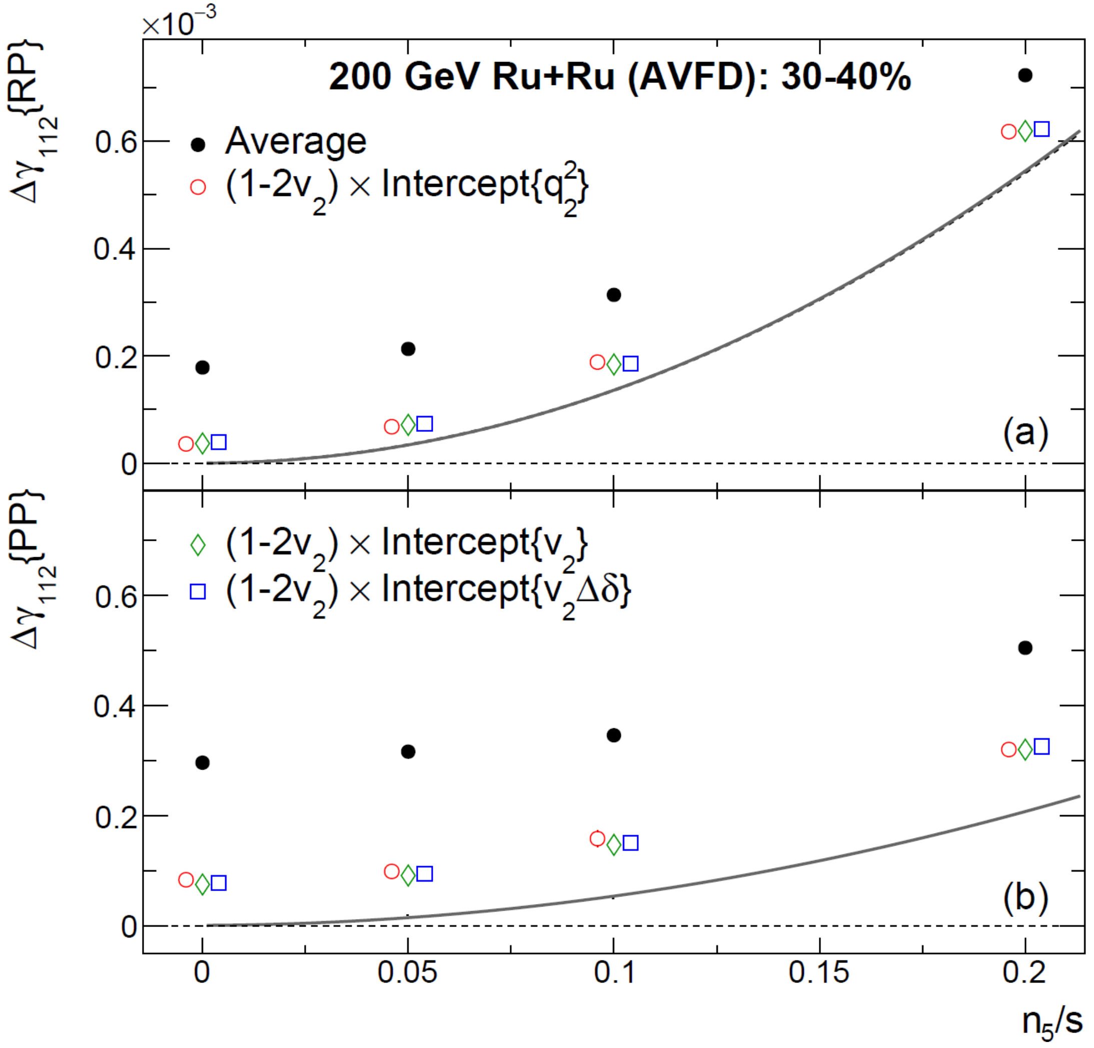
CME Fraction, f_{CME}

- Use CME fraction to better compare the ensemble average and ESE intercepts
  - $f_{\text{CME}} = \text{Signal}/\Delta\gamma_{112}$
- f_{CME} significantly larger for ESE intercepts than for ensemble averages
  - Ensemble averages have much more background than ESE intercepts
- Uncertainty for ESE intercepts are larger
  - The major downside of ESE

$n_5/s = 0.1$	Average	$\text{ESE}\{q_2^2\}$	$\text{ESE}\{v_2\}$	$\text{ESE}\{v_2\Delta\delta\}$
$f_{\text{CME}}\{\text{RP}\}$ (%)	47.4 ± 0.5	76.9 ± 1.7	80.0 ± 1.6	79.3 ± 1.5
$f_{\text{CME}}\{\text{PP}\}$ (%)	35.4 ± 0.6	71.7 ± 2.7	76.2 ± 2.6	75.1 ± 2.1
$n_5/s = 0.2$	Average	$\text{ESE}\{q_2^2\}$	$\text{ESE}\{v_2\}$	$\text{ESE}\{v_2\Delta\delta\}$
$f_{\text{CME}}\{\text{RP}\}$ (%)	78.5 ± 0.2	87.5 ± 0.5	87.9 ± 0.4	87.6 ± 0.4
$f_{\text{CME}}\{\text{PP}\}$ (%)	69.1 ± 0.3	87.7 ± 0.8	88.1 ± 0.7	86.9 ± 0.7

Isobar systems

- Similar trends in Ru+Ru and Zr+Zr
- ESE intercepts significantly reduce background
  - In pure background case, suppress background by factor of 5 relative to ensemble averages
- Results for both isobar systems are consistent with each other for all n_5/s
  - Cannot differentiate due to lack of statistics



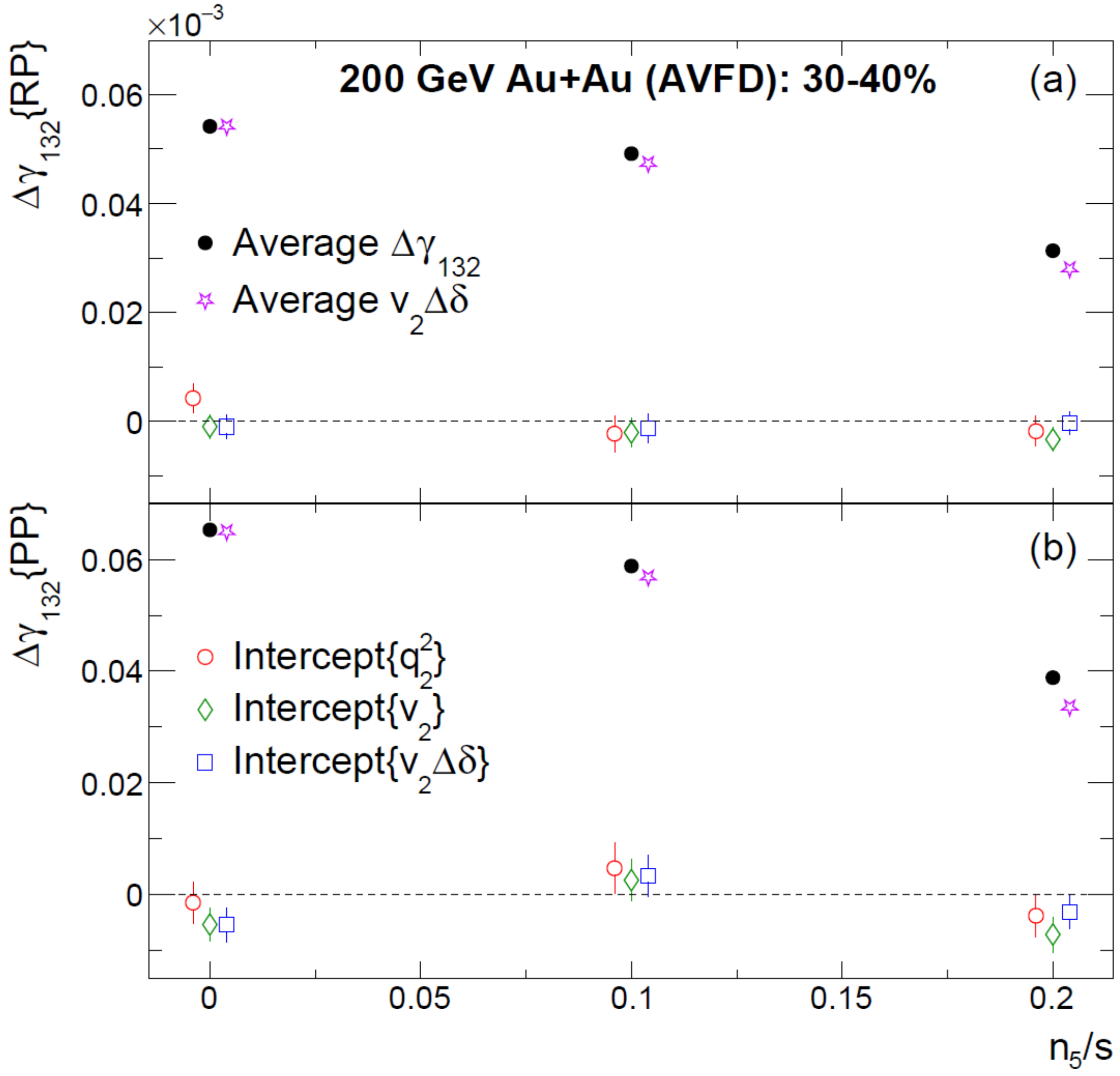
Ru+Ru f_{CME}

- $f_{\mathrm{CME}}\{\mathrm{PP}\}$ for ensemble average is much lower in isobar than Au+Au
    - Due to smaller-system induced fluctuations
- At higher n_5/s, ESE again has improved f_{CME} but worse significance
- At lower n_5/s, ESE offers better f_{CME} with similar statistical significance
    - Recent STAR data suggests f_{CME} for ensemble average is small in isobar, so ESE could be advantageous

$n_5/s = .05$	Average	$\mathrm{ESE}\{q_2^2\}$	$\mathrm{ESE}\{v_2\}$	$\mathrm{ESE}\{v_2\Delta\delta\}$
$f_{\mathrm{CME}}\{\mathrm{RP}\}$ (%)	16.3 ± 1.7	51.0 ± 6.7	48.5 ± 5.8	47.2 ± 5.5
$f_{\mathrm{CME}}\{\mathrm{PP}\}$ (%)	6.3 ± 2.1	20.2 ± 7.1	21.8 ± 7.5	21.1 ± 7.3
$n_5/s = 0.1$	Average	$\mathrm{ESE}\{q_2^2\}$	$\mathrm{ESE}\{v_2\}$	$\mathrm{ESE}\{v_2\Delta\delta\}$
$f_{\mathrm{CME}}\{\mathrm{RP}\}$ (%)	43.2 ± 1.4	71.9 ± 3.5	73.6 ± 3.1	72.7 ± 3.1
$f_{\mathrm{CME}}\{\mathrm{PP}\}$ (%)	14.4 ± 2.2	31.3 ± 5.7	33.7 ± 5.9	33.0 ± 5.7
$n_5/s = 0.2$	Average	$\mathrm{ESE}\{q_2^2\}$	$\mathrm{ESE}\{v_2\}$	$\mathrm{ESE}\{v_2\Delta\delta\}$
$f_{\mathrm{CME}}\{\mathrm{RP}\}$ (%)	75.3 ± 0.5	88.2 ± 0.9	88.0 ± 0.8	87.6 ± 0.4
$f_{\mathrm{CME}}\{\mathrm{PP}\}$ (%)	41.3 ± 1.3	65.0 ± 2.8	65.1 ± 2.5	63.9 ± 2.4

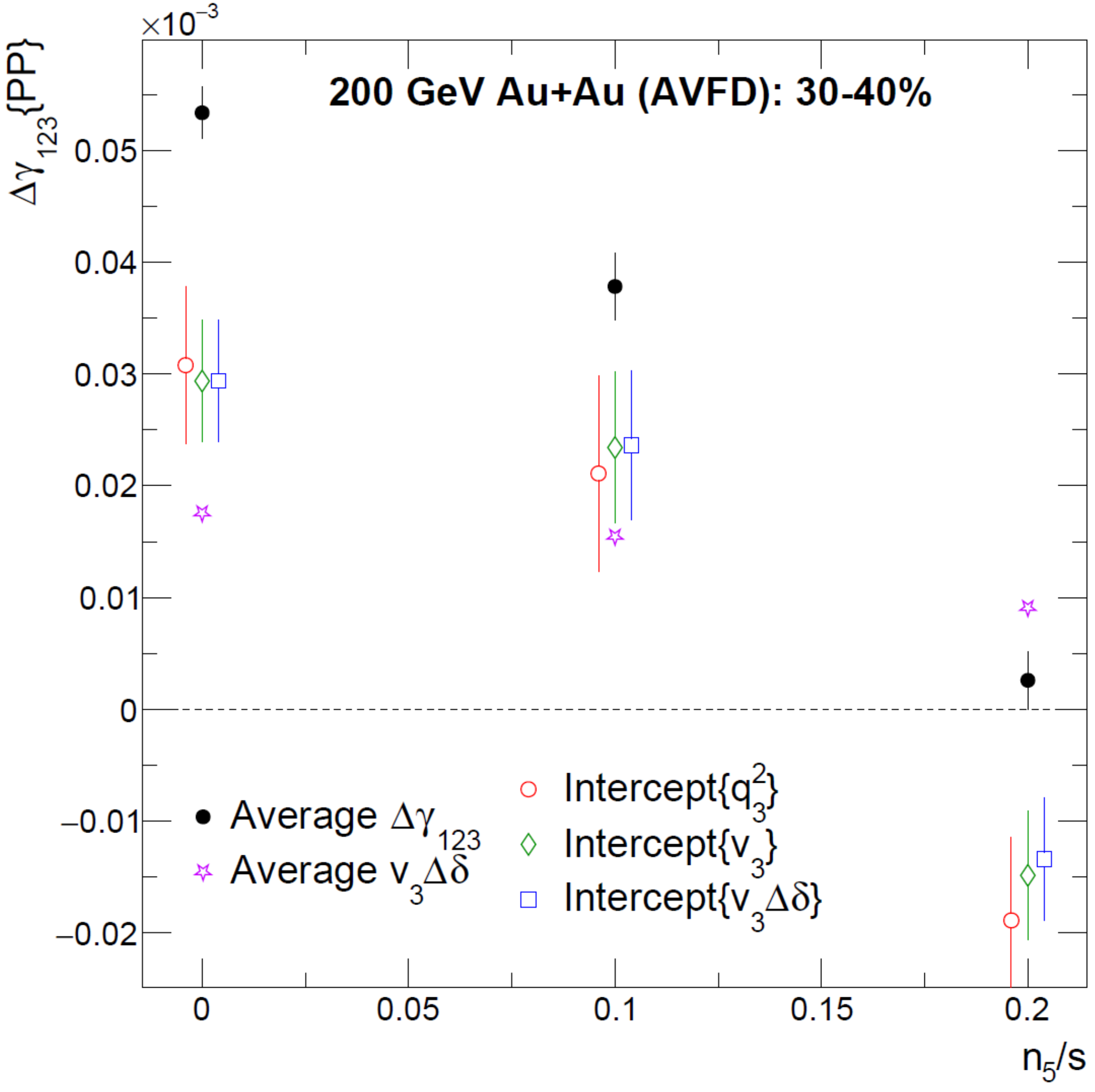
$\Delta\gamma_{132}$ in Au+Au

- $\Delta\gamma_{132} = \langle\cos(\phi_\alpha - 3\phi_\beta + 2\Psi_2)\rangle$
- $\Delta\gamma_{132}$ seems to vanish with the ESE approach
  - No residual background like $\Delta\gamma_{112}$
- Consistent with the idea that $\Delta\gamma_{132} \approx v_2\Delta\delta$
- This also explains why the ensemble average decreases with increasing n_5/s
  - v_2 constant, but $\Delta\delta$ decreases in value
- Can serve as a systematic check in real data analysis



$\Delta\gamma_{123}$ in Au+Au

- $\Delta\gamma_{123} = \langle \cos(\phi_\alpha + 2\phi_\beta - 3\Psi_3) \rangle$
- Observables w.r.t. RP give zero on average
- ESE seems to reduce the flow-related background in $\Delta\gamma_{123}$, but does not fully eliminate it like $\Delta\gamma_{132}$
- $\Delta\gamma_{123}$ does not seem to be a proper estimate for the flow-related background
- $\Delta\gamma_{123}$ likely model-dependent based on differences in AMPT and AVFD



Conclusion

- Event-shape-engineering significantly reduces the flow-related background in $\Delta\gamma_{112}$ measurements
- Compared to the standard ensemble averages, ESE reduces background in $\Delta\gamma_{112}$ by up to 6 times, but has increased uncertainty
- $\Delta\gamma_{132}$ mostly vanishes with ESE, supporting its approximate equivalence to $v_2\Delta\delta$
- $\Delta\gamma_{123}$ is not properly controlled with ESE and does not seem like a good estimate for the flow-related background

Thank you!