STAR Results on Charge Asymmetry Correlations

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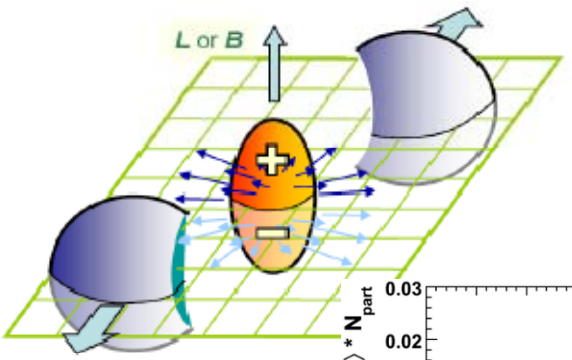
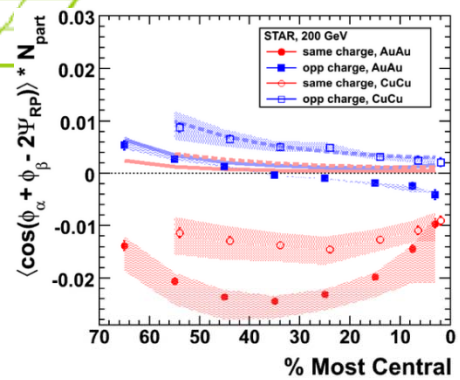
For the STAR Collaboration

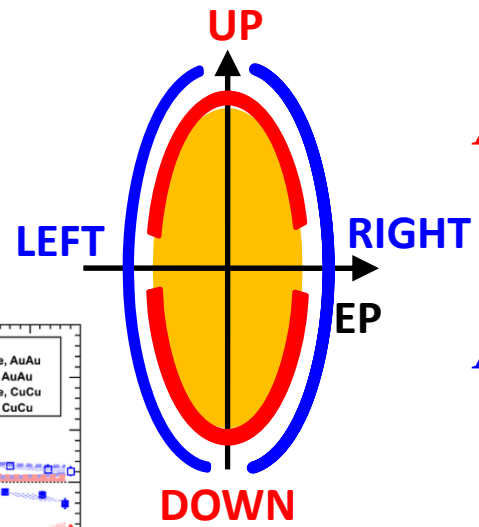
- Motivation: Local Parity Violation (LPV)
- Charge asymmetry observables
- Analysis details
- Results
- Summary

Motivation and Observables





See I. Selyuzhenkov's talk; STAR, PRL 103, 251601 (09); PRC 81, 054908 (10).



$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}}$$

$$A_{\pm,LR} = \frac{N_{\pm,left} - N_{\pm,right}}{N_{\pm,left} + N_{\pm,right}}$$

Chiral magnetic effect:

- LPV + large magnetic field

→**charge separation** along the system angular momentum.

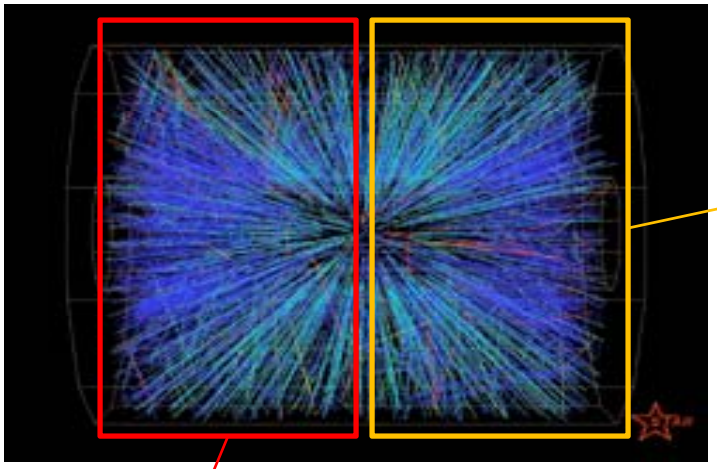
Kharzeev et al. NPA 803 (2008) 227.

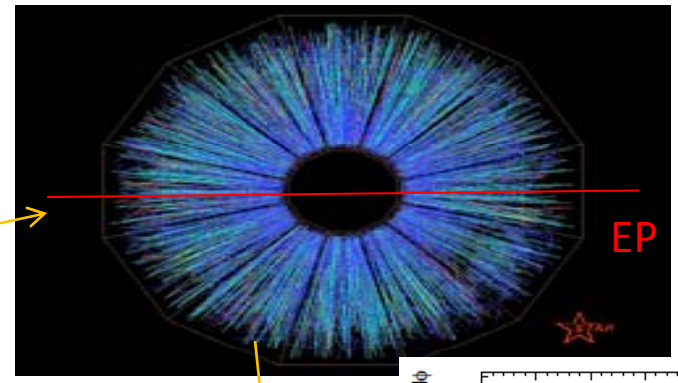
LPV effects in UD. LR is null-reference.

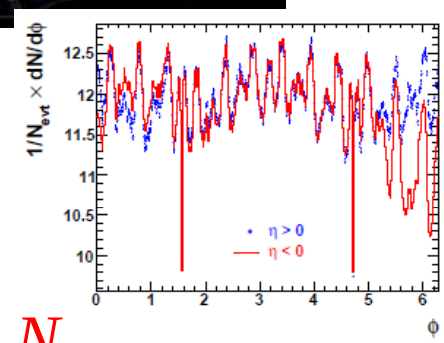
LPV expectations:

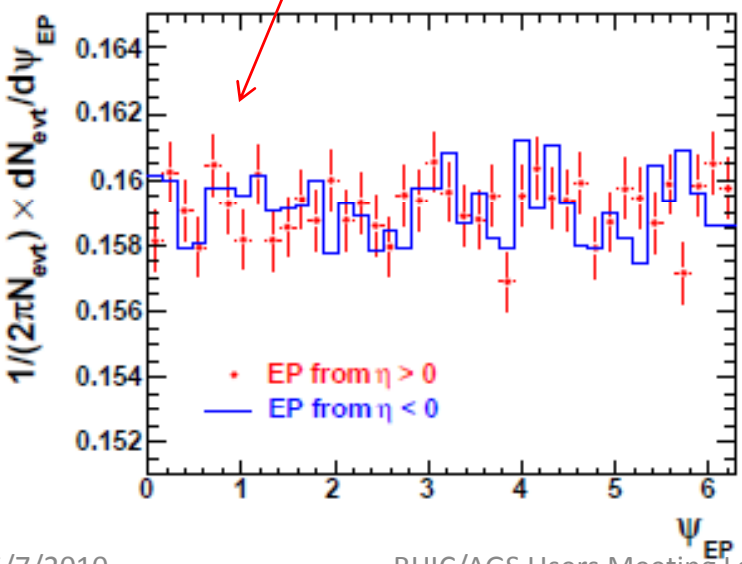
- A_{+UD} and A_{-UD} are anti-correlated
  → $\langle A_+A_-\rangle_{UD} < \langle A_+A_-\rangle_{LR}$
- Additional dynamical fluctuation broadens $A_{\pm UD}$ distributions
  → $\langle A_\pm^2\rangle_{UD} > \langle A_\pm^2\rangle_{LR}$

Analysis: to avoid self-correlation





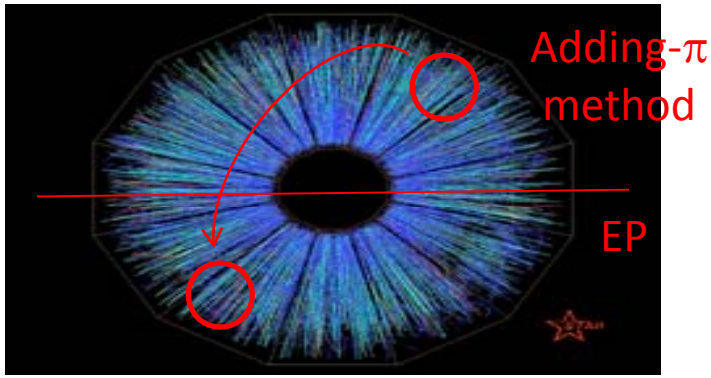


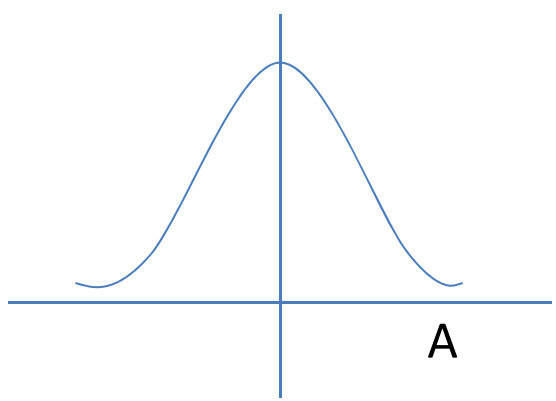


$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}}$$

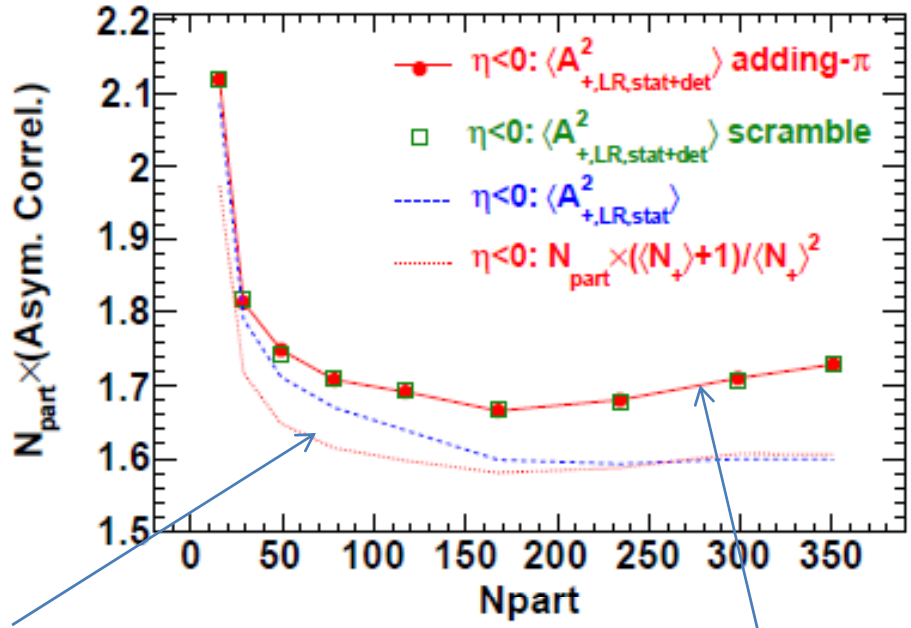
$$A_{\pm,LR} = \frac{N_{\pm,left} - N_{\pm,right}}{N_{\pm,left} + N_{\pm,right}}$$

Stat. fluc. + detector effects in ‹A²›





STAR preliminary

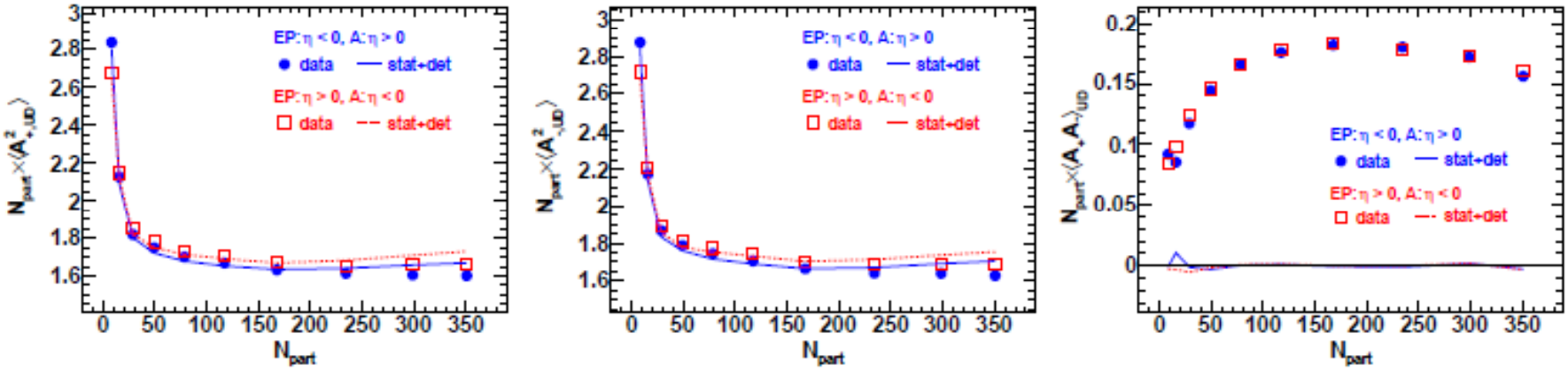


$$\frac{1}{\langle N \rangle} + \frac{1}{\langle N \rangle^2}$$

Stat. fluct. +
Detector effects

Subtracting stat+det effects

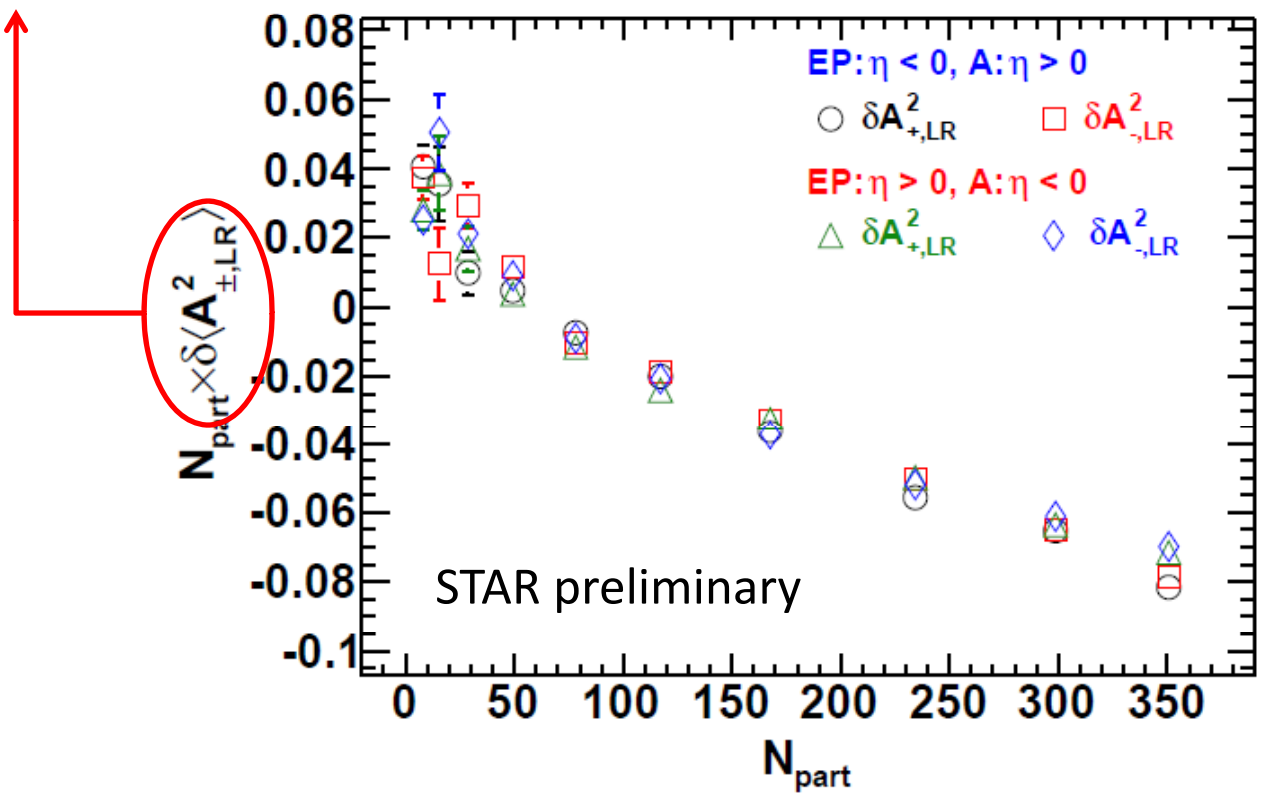
STAR preliminary



- Symbols are data (TPC left/right, positive/negative charges).
- Curves: net effect of statistical fluct. and detector non-uniformity.
- Stat+det effects are actually wider than data in $\langle A_{\pm}^2 \rangle$.
- Physical processes narrow charge asymmetry distributions → same-sign back-to-back pairs.

Consistency between TPC halves, and between + and – charge asym. correl.

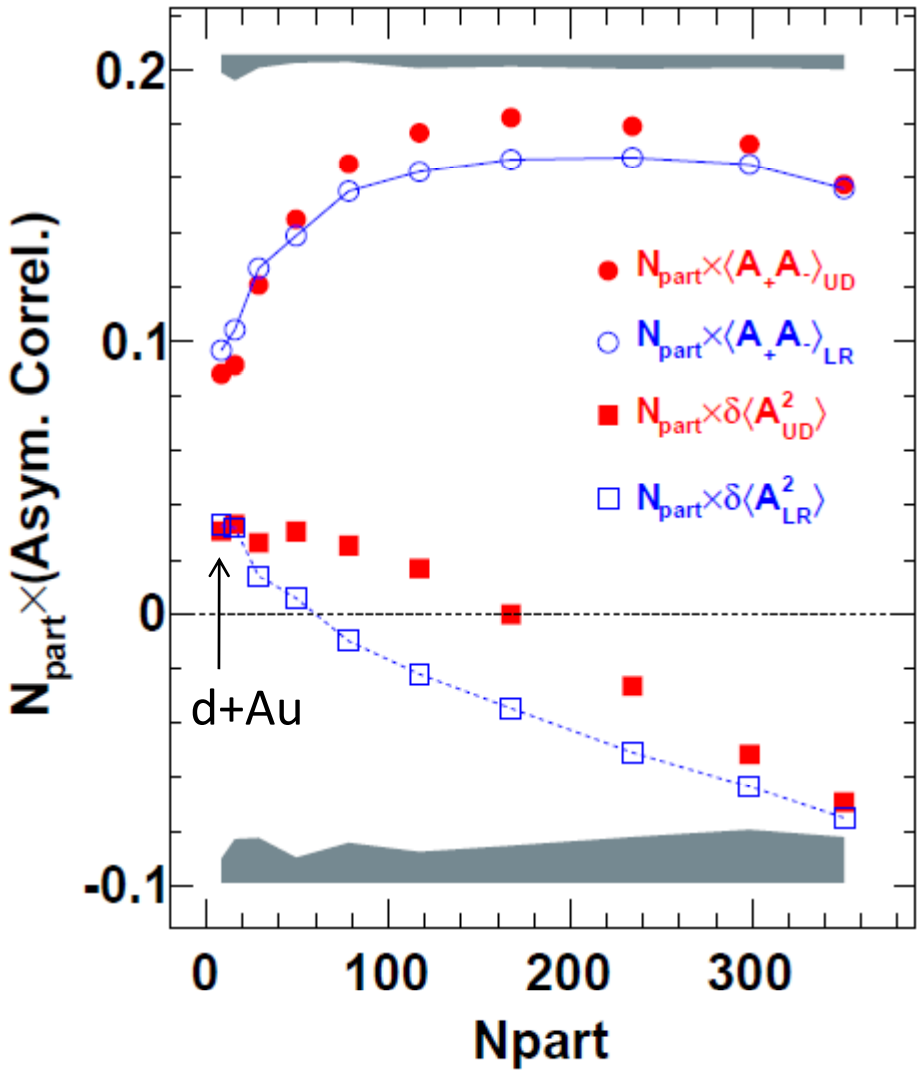
$$\delta\left\langle A^2_{\pm,LR}\right\rangle = \left\langle A^2_{\pm,LR}\right\rangle - \left\langle A^2_{\pm,LR}\right\rangle_{\text{stat+det}}$$



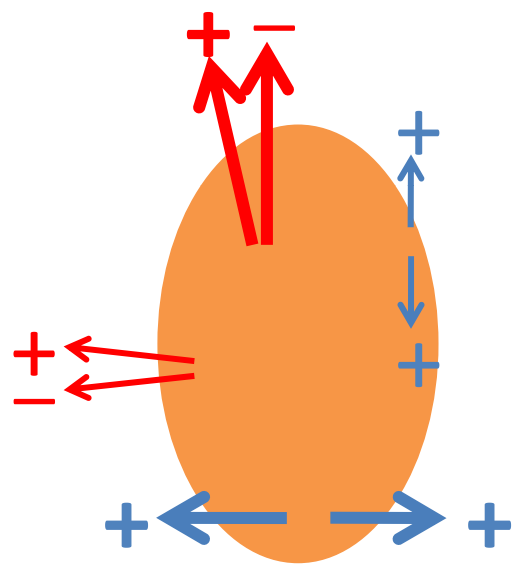
We will report: $\delta\left\langle A^2\right\rangle = \frac{1}{2}\left(\delta\left\langle A^2_+\right\rangle + \delta\left\langle A^2_-\right\rangle\right)$

Charge Asym. Correl. Results

STAR preliminary

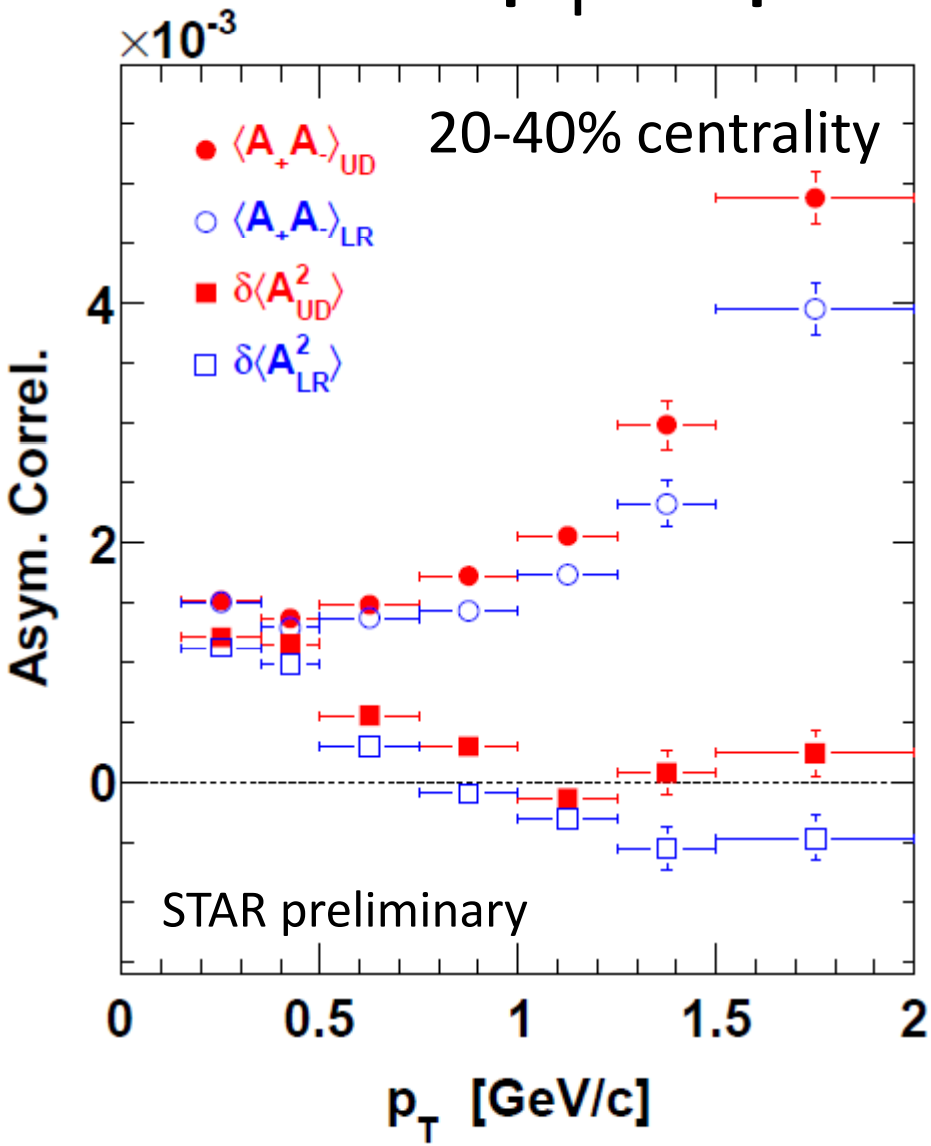


- Oppo-sign aligned; $\langle A_+A_-\rangle_{UD} > \langle A_+A_-\rangle_{LR}$
  LPV expects: $\langle A_+A_-\rangle_{UD} < \langle A_+A_-\rangle_{LR}$
  Contradicts LPV expectations.



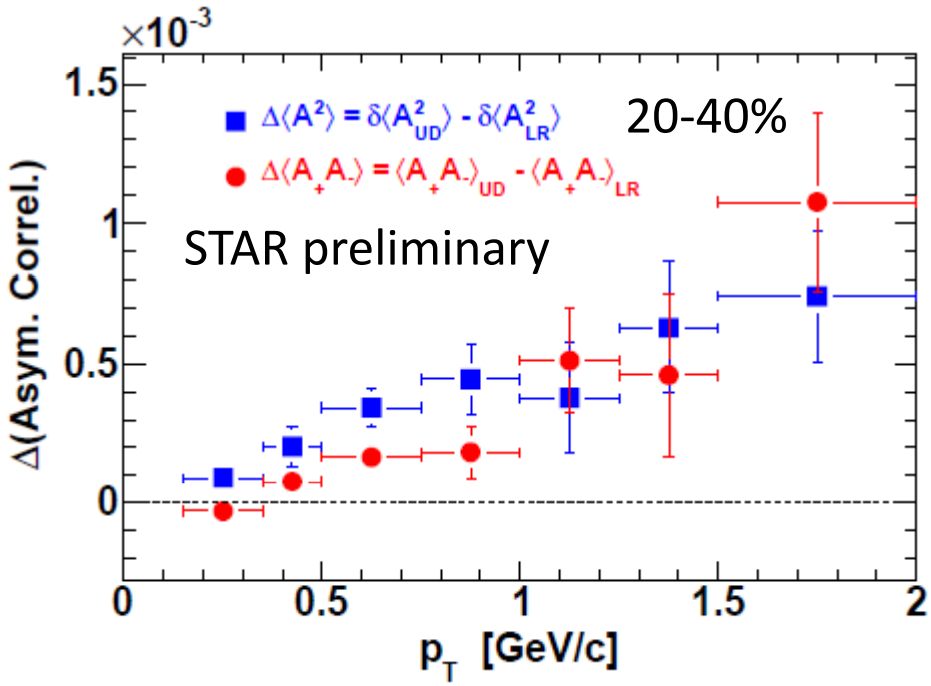
- Same-sign back-to-back in central, unexpected from *only* LPV.
  Data: $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$
  LPV expects: $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$

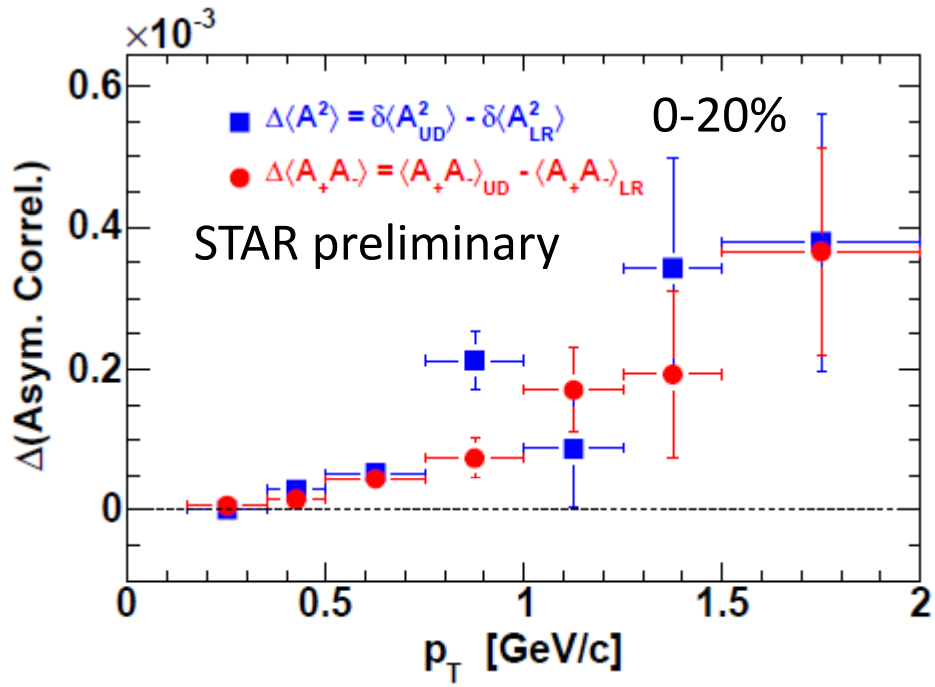
p_T dependence



- Opposite-sign charges are more aligned at high-pt.
- Same-sign charges are more preferentially back-to-back at high-pt.

UD-LR vs pt



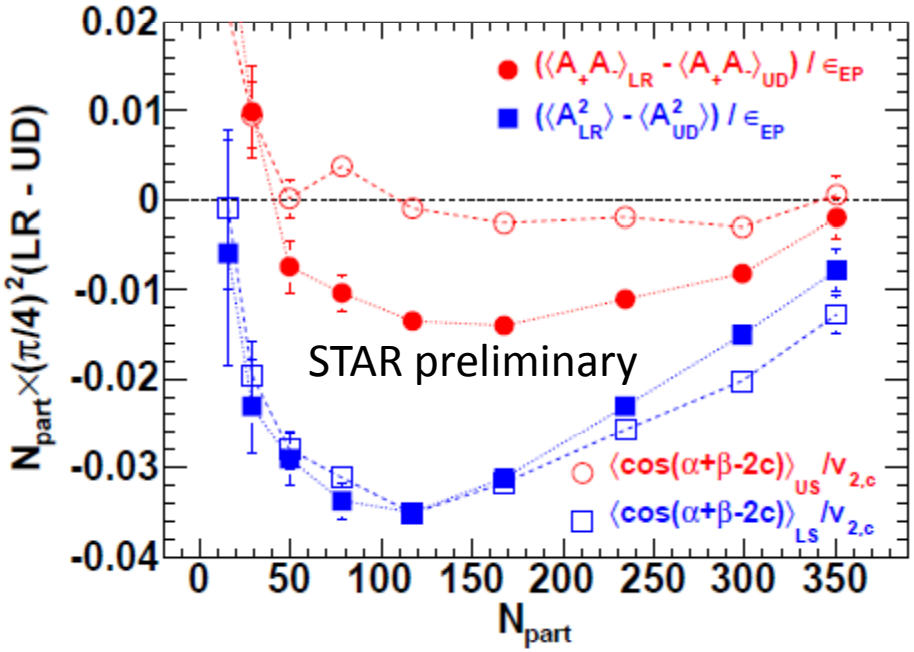


- UD-LR increases with pt, ~linearly.
- Qualitatively similar between same-sign and opposite-sign.

UD-LR compared to correlator

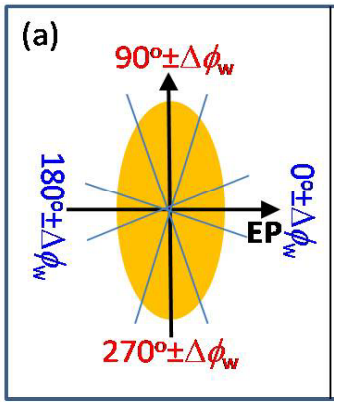
$$\langle A_\alpha A_\beta \rangle_{\rm LR} - \langle A_\alpha A_\beta \rangle_{\rm UD} = \left(\frac{4}{\pi}\right)^2 \left\langle \frac{1}{N_\alpha N_\beta} \sum_{i,j=0}^{N_\alpha,N_\beta} \sum_{n.m=0}^{\infty} \frac{\cos[(2n+1)(\phi_{\alpha,i}-\psi_{\rm EP}) + (2m+1)(\phi_{\beta,j}-\psi_{\rm EP})]}{(2n+1)(2m+1)} \right\rangle$$

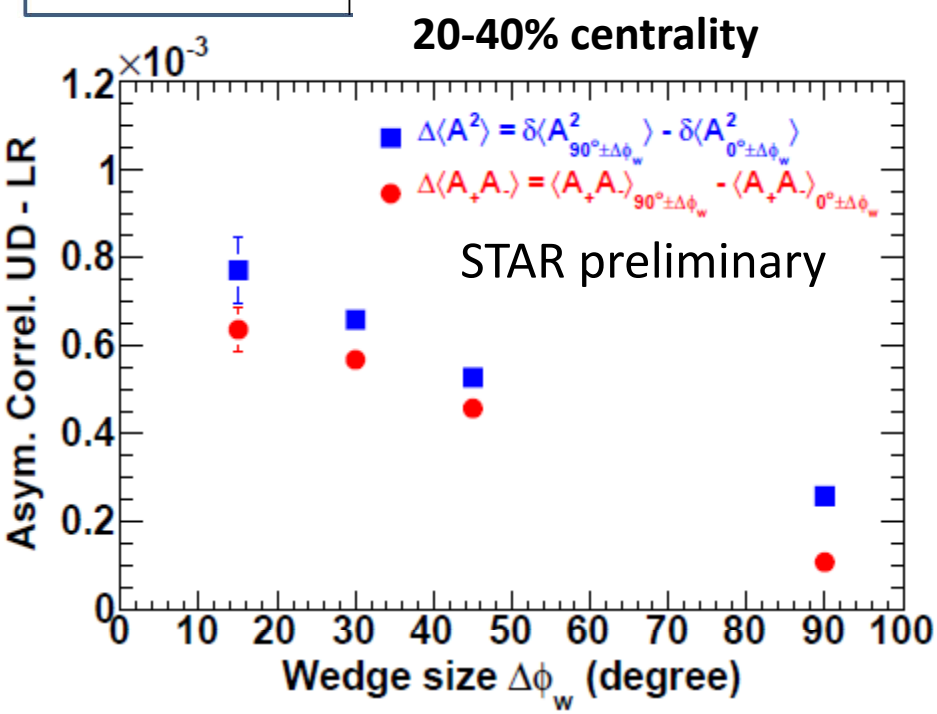
Asymmetry correlations can be expanded into harmonic terms. One term is the correlator.



- Charge asymmetry correlations have been divided by EP resolution.
- "Corrected" same-sign charge asymmetry correlation and correlator are similar: higher order terms are negligible.
- "Corrected" opposite-sign charge asymmetry correlation and correlator are different: higher order terms are important.

UD-LR vs wedge size





- Stronger effect with smaller wedge. Charge correlations seem local.
- Similar between same- and opposite-sign. Correlations appear charge-independent.

- Asym. Correl. UD-LR all positive. But opposite-sign correlator ≈ 0. Why?

$$\mathrm{LR-UD} = \frac{\text{LR diff}}{\text{LR mult.}} - \frac{\text{UD diff}}{\text{UD mult.}} \quad (\text{LR mult.} > \text{UD mult.})$$

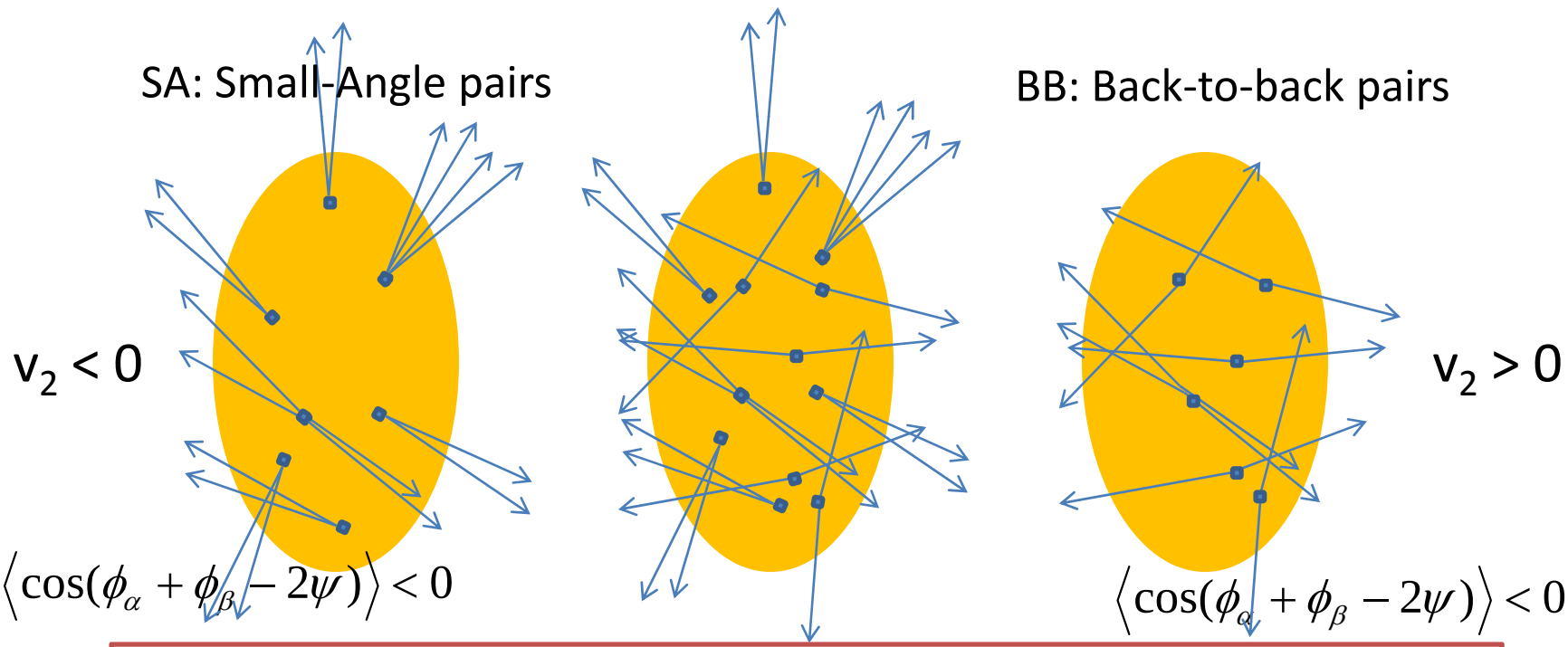
$$\text{Correlator} = \frac{\sum \cos\alpha \cos\beta}{\text{total mult.}} - \frac{\sum \sin\alpha \sin\beta}{\text{total mult.}}$$

- But they must measure the same physics…
  - Opposite-pair correlations (with v_2): LR-UD = 0, correlator > 0.
  - LPV: increases LR-UD and correlator.
  - Stronger UD opposite-pair correl.: reduces LR-UD and correlator.
  - Data: LR-UD < 0, correlator ≈ 0.

What could be the underlying physics?

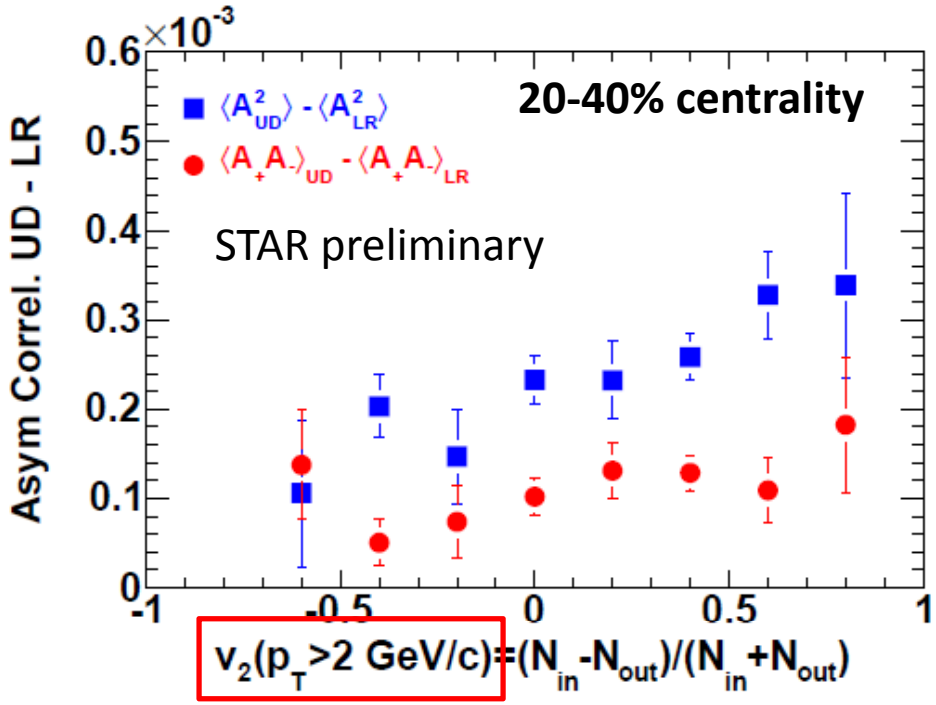
Possible causes: correlation overlaid with v_2 (*FW, 0911.1482, PRC in press*)

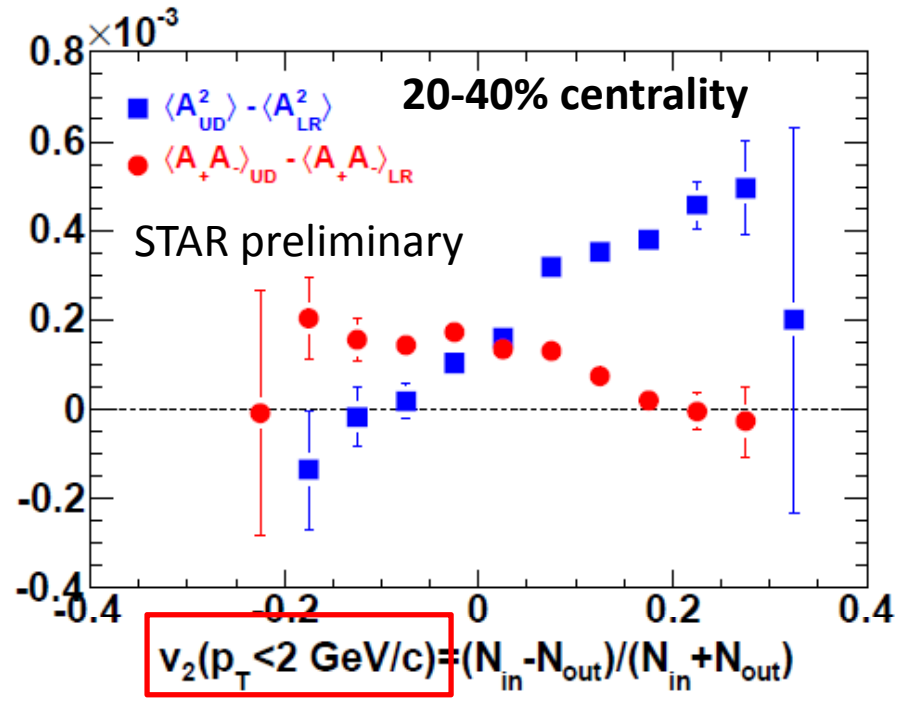
- Charge balance (*S. Pratt*): correlator ~ $-v_2/N*\langle\cos 2\Delta\phi_{BF}\rangle$, may affect $\langle A_+A_-\rangle$.
- Momentum conservation (*S. Pratt*): correlator ~ v_2/N, may affect both $\langle A_+A_-\rangle$ and $\langle A^2\rangle$.
- Path-length dependent jet-quenching, opacity.



Try to investigate those effects experimentally, by studying UD-LR vs event-by-event high-p_T v_2 (indicative of jet-quenching) and bulk v_2.

UD–LR vs Event-by-Event Anisotropy





- Same trend in high-pt v_2.
- Stronger jet-quenching out-of-plane enhance UD asymmetry for both $\langle A^2_{UD}\rangle$ and $\langle A_+A_-\rangle_{UD}$?

- $\langle A^2\rangle$, $\langle A_+A_-\rangle$ opposite trend in low-p_T v_2!
- More b-to-b same-charge pairs in-plane reducing $\langle A^2_{LR}\rangle$? → Increasing trend
- More opposite-charge pairs in-plane enhancing $\langle A_+A_-\rangle_{LR}$? → Decreasing trend

Summary

- Charge asymmetry correlations are reported.
- Opposite-sign charges are preferentially aligned.
  Same-sign charges are preferentially back-to-back in central.
- UD – LR and $\cos(\alpha+\beta-2\psi)$ are related:
  $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$ & $\cos(\alpha+\beta-2\psi)_{LS}<0$: qualitatively similar.
  $\cos(\alpha+\beta-2\psi)_{US}\approx 0$: LPV with back-to-back suppression?
  $\langle A_+A_-\rangle_{UD} > \langle A_+A_-\rangle_{LR}$: contradicts LPV expectations.
- Detailed studies of charge asymmetry correlations, hopefully providing new insights:
  - Dependence on wedge size
  - UD-LR *v.s.* E-by-E high-p_T and low-p_T v_2's