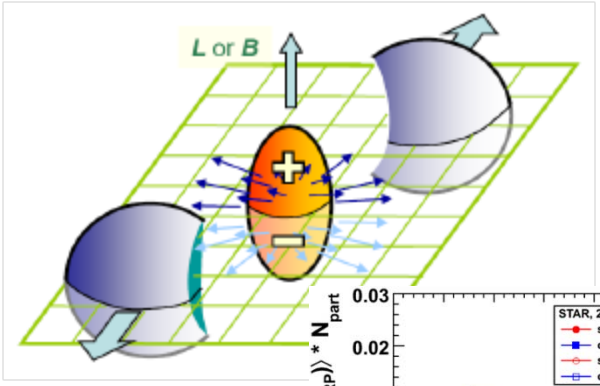
# Measurements of Charge Asymmetry Correlations in High Energy Nuclear Collisions

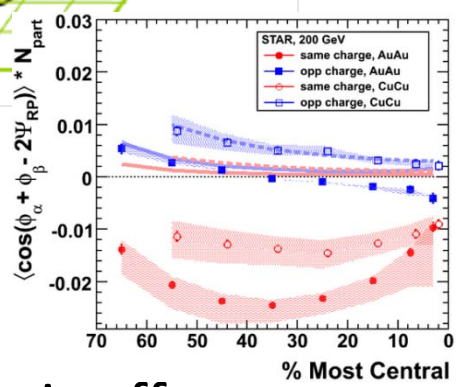
Quan Wang, Fuqiang Wang, Purdue University

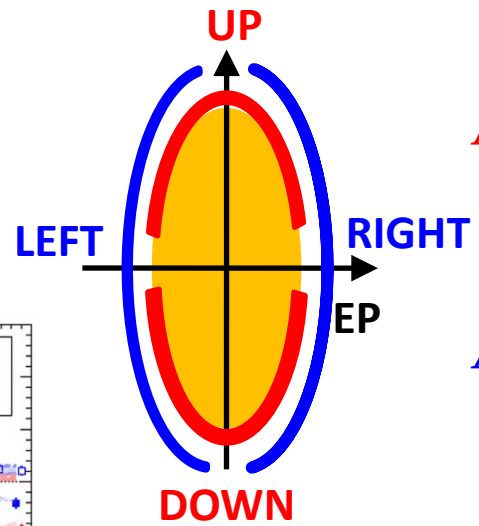
For the STAR Collaboration

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

# Motivation and Observables




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

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

Chiral magnetic effect:

- LPV + large magnetic field

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

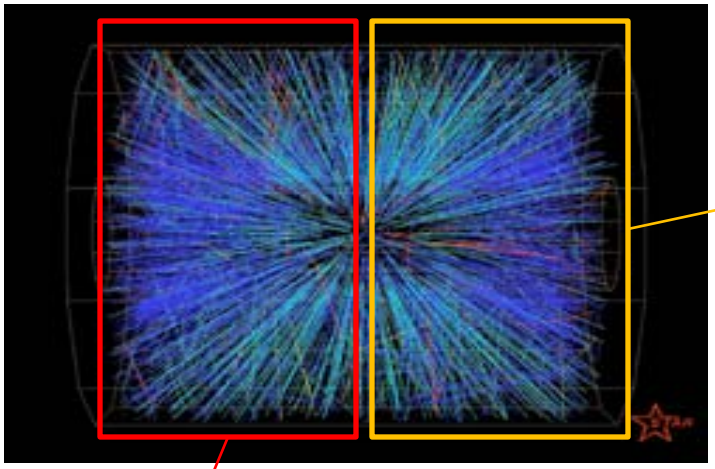
*Kharzeev et al. NPA 803 (2008) 227*

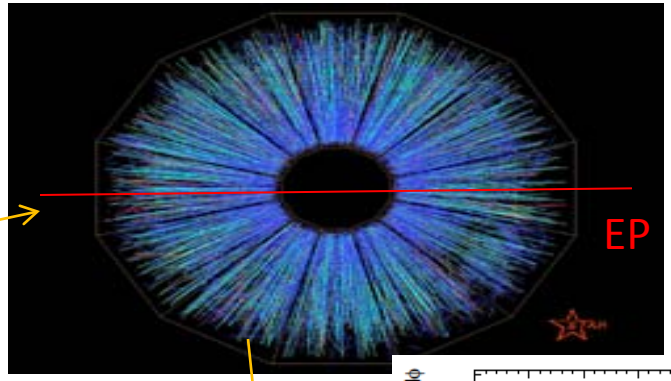
LPV effects in UD. LR is null-reference.

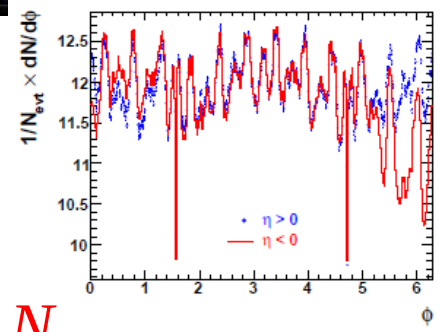
LPV expectations:

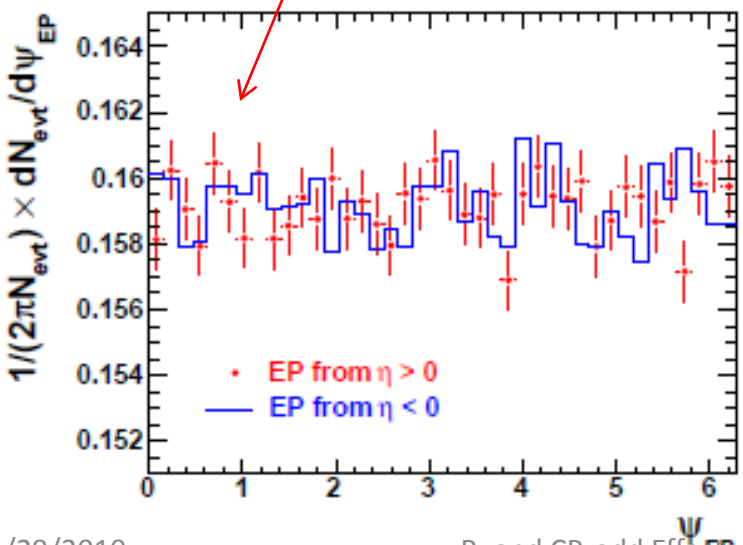
- $A_{+UD}$ and $A_{-UD}$ are anti-correlated
  → $\langle A_+A_-\rangle_{UD} < \langle A_+A_-\rangle_{LR}$
- Additional dynamical fluctuation broadens $A_{\pm UD}$ distributions
  → $\langle A_\pm^2\rangle_{UD} > \langle A_\pm^2\rangle_{LR}$

# Analysis: to avoid self-correlation





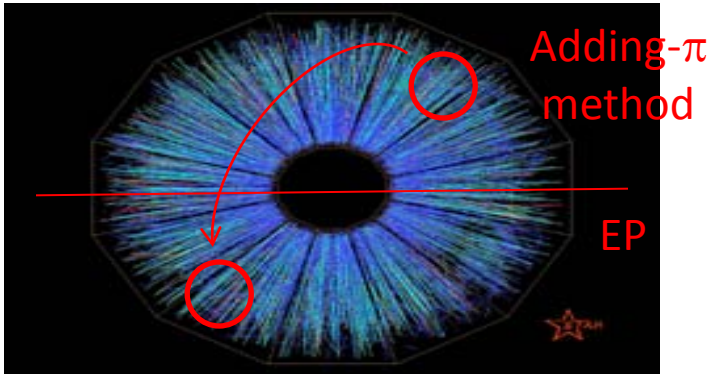




$$A_{\pm,UD} = \frac{N_{\pm,up} - N_{\pm,down}}{N_{\pm,up} + N_{\pm,down}}$$

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

# Stat. fluc. + detector effects in ‹A²›

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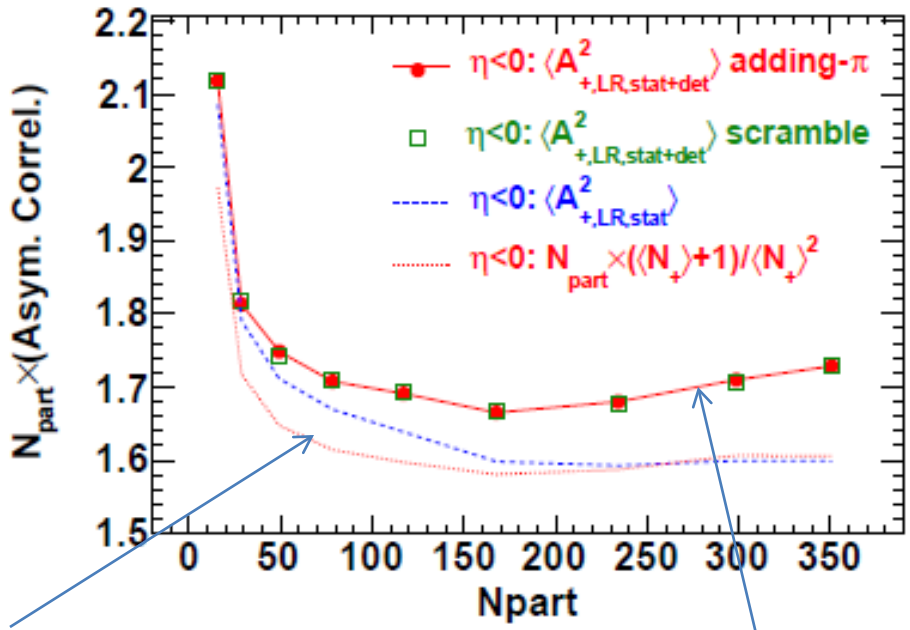


$$\frac{1}{\langle N \rangle} + \frac{1}{\langle N \rangle^2}$$

Stat. fluct. +
Detector effects

# Subtracting stat+det effects

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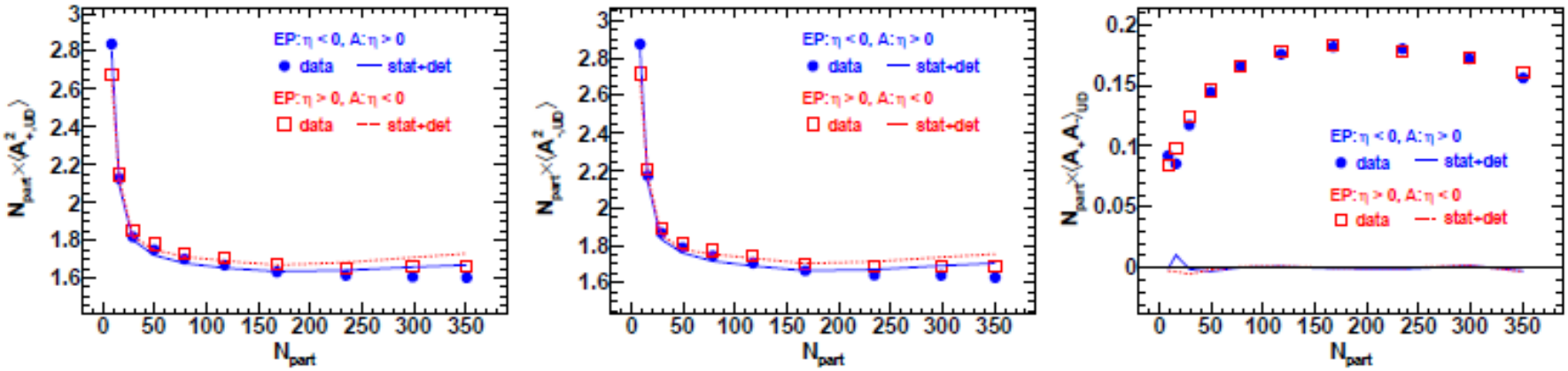
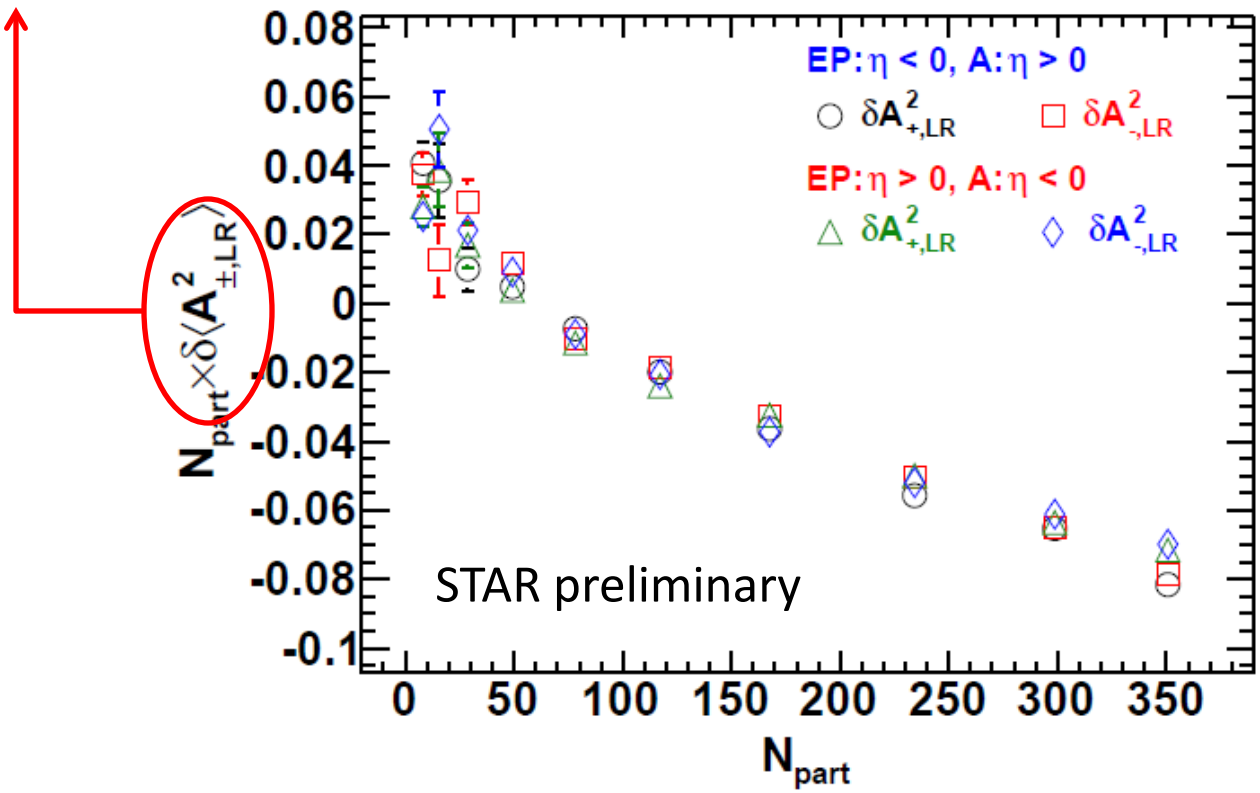



- Symbols are data (TPC left/right, positive/negative charges).
- Curves: net effect of statistical fluct. and detector non-uniformity.
- Stat+det effects are actually wider than data in $\langle A_{\pm}^2 \rangle$.
- Physical processes narrow charge asymmetry distributions → same-sign back-to-back pairs.

# 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

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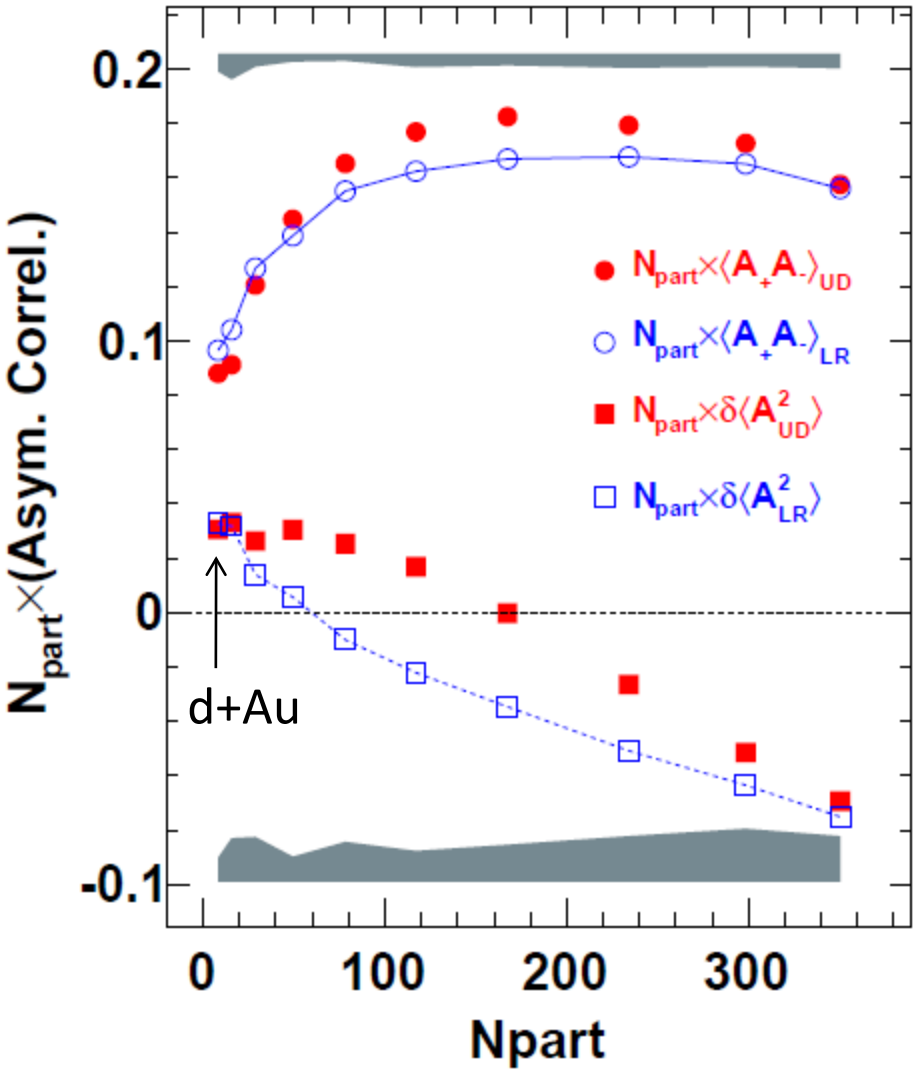
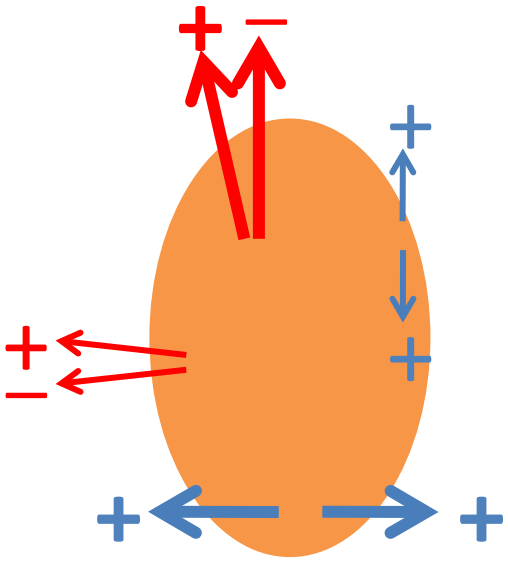
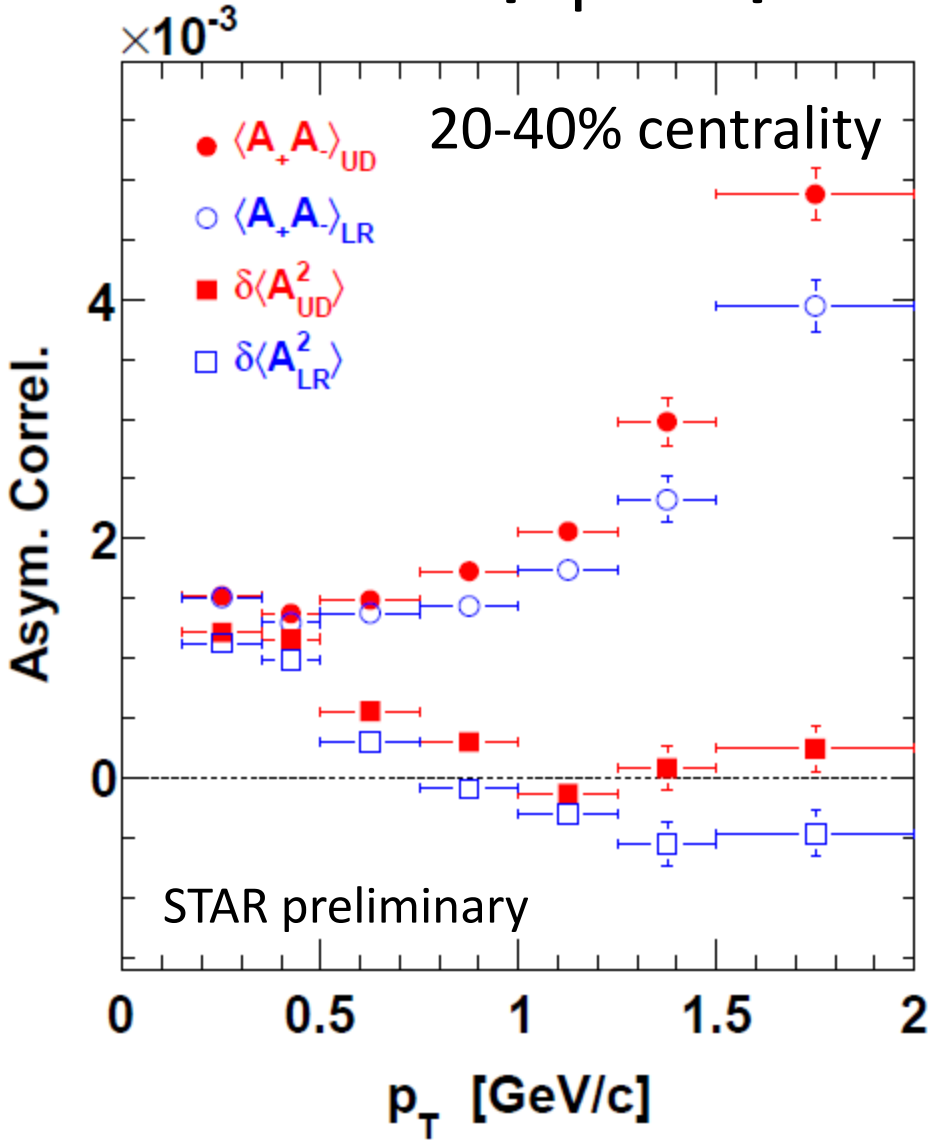



- Oppo-sign aligned; $\langle A_+A_-\rangle_{UD} > \langle A_+A_-\rangle_{LR}$
  LPV expects: $\langle A_+A_-\rangle_{UD} < \langle A_+A_-\rangle_{LR}$
  Contradicts LPV expectations.



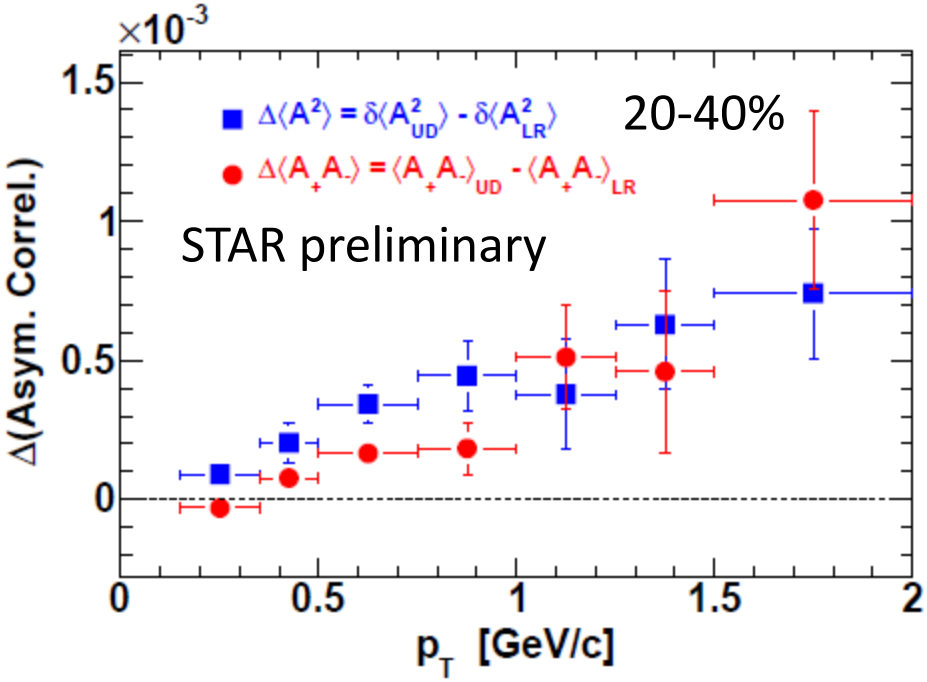

- Same-sign back-to-back in central, unexpected from *only* LPV.
  Data: $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$
  LPV expects: $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$

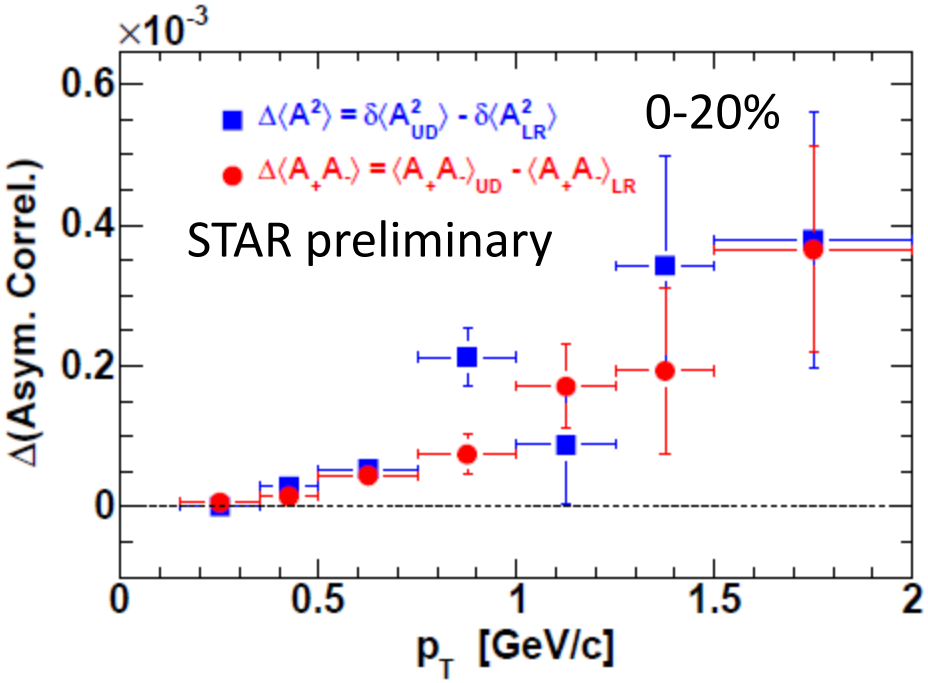
# $p_T$ dependence




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

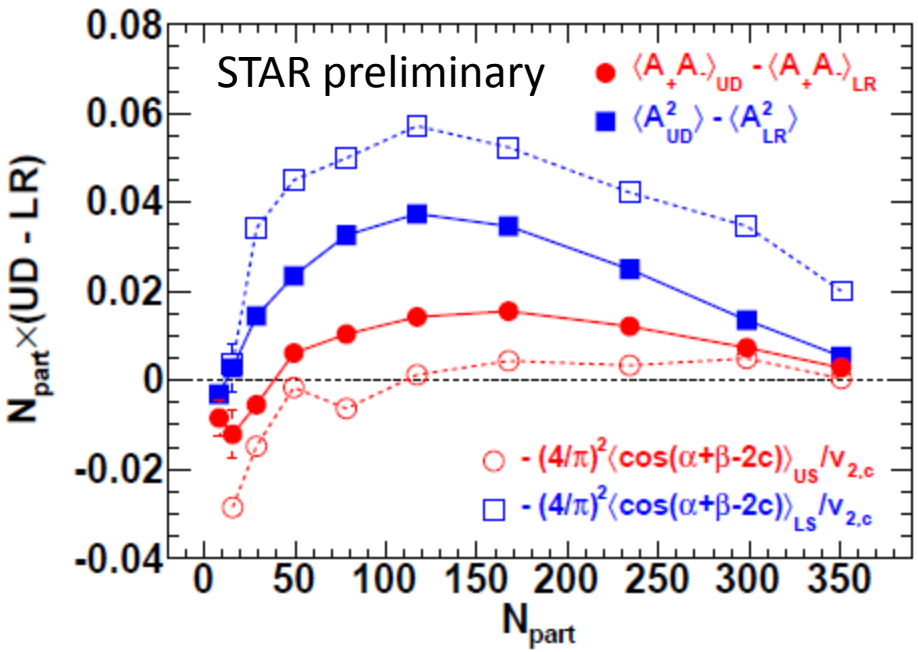
# UD-LR vs pt




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

# UD-LR compared to correlator



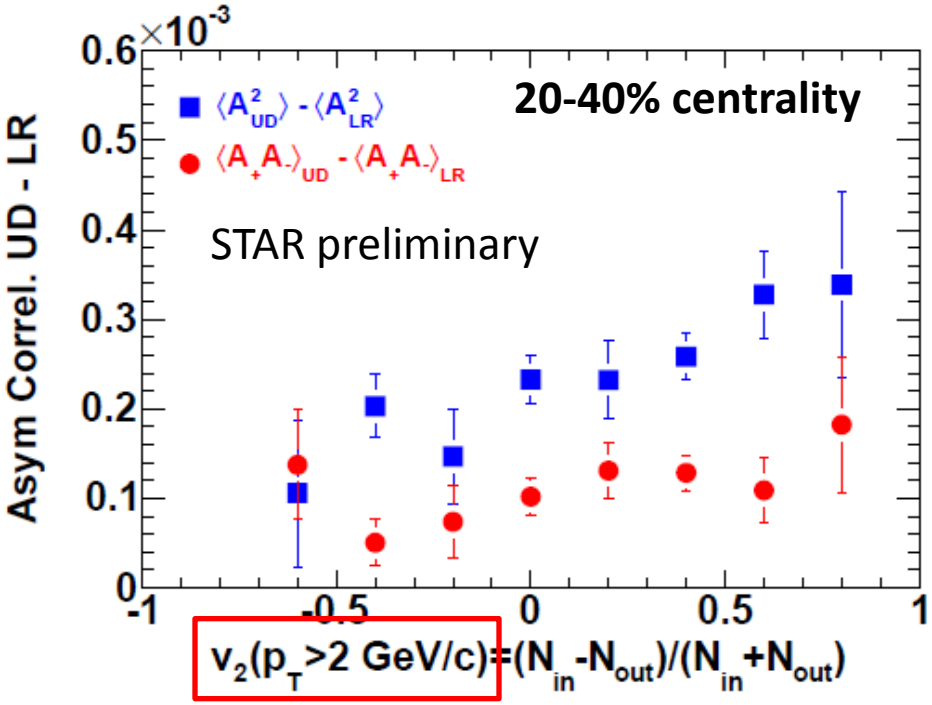

Observations:

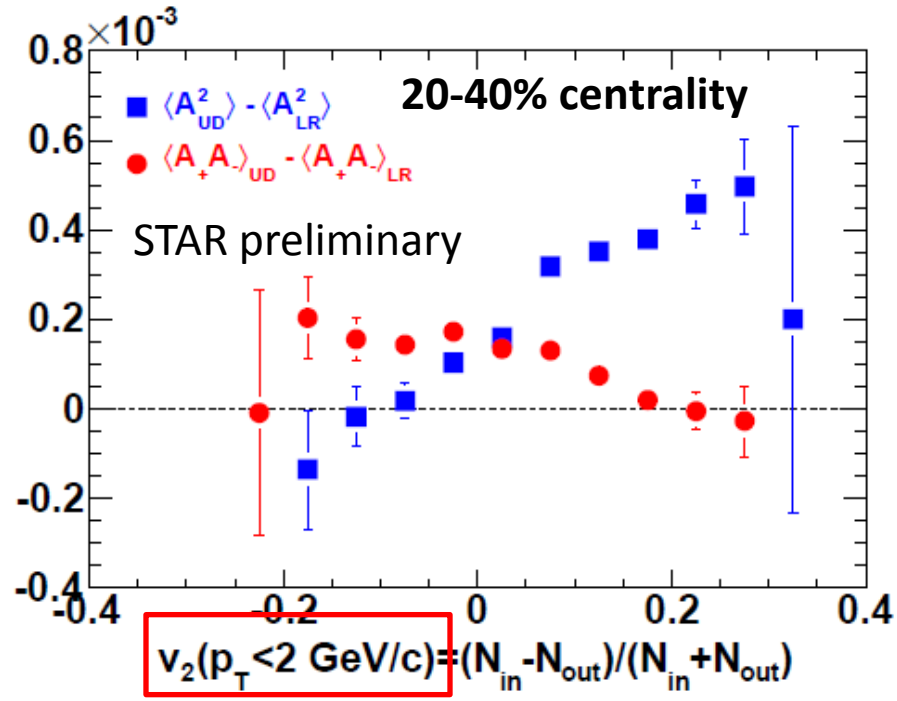
- $\langle A^2\rangle_{UD} > \langle A^2\rangle_{LR}$ consistent with LPV expectation
- $\langle A_+A_-\rangle_{UD} > \langle A_+A_-\rangle_{LR}$ inconsistent with LPV expectation
- Similar centrality dep.

- Possible causes: correlation overlaid with $v_2$ (*F. Wang, 0911.1482*)
  - Charge balance (*S. Pratt*): ~$-v_2/N*\langle\cos 2\Delta\phi_{BF}\rangle$, only in $\langle A_+A_-\rangle$.
  - Momentum conservation (*S. Pratt*): ~ $v_2/N$, in both $\langle A_+A_-\rangle$ and $\langle A^2\rangle$.
  - Path-length dependent jet-quenching, opacity. (Hannah Petersen: unlikely)

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

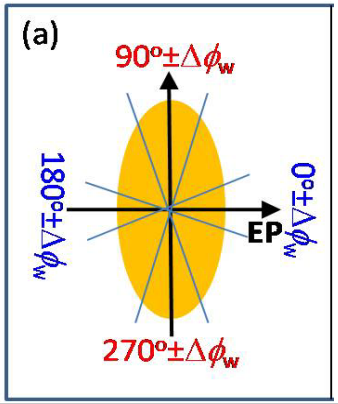



- Same trend in high-pt $v_2$.
- Stronger jet-quenching out-of-plane enhance UD asymmety for both $\langle A^2_{UD}\rangle$ and $\langle A_+A_-\rangle_{UD}$?

- $\langle A^2\rangle$, $\langle A_+A_-\rangle$ 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

# Results vs wedge size




**20-40% centrality**

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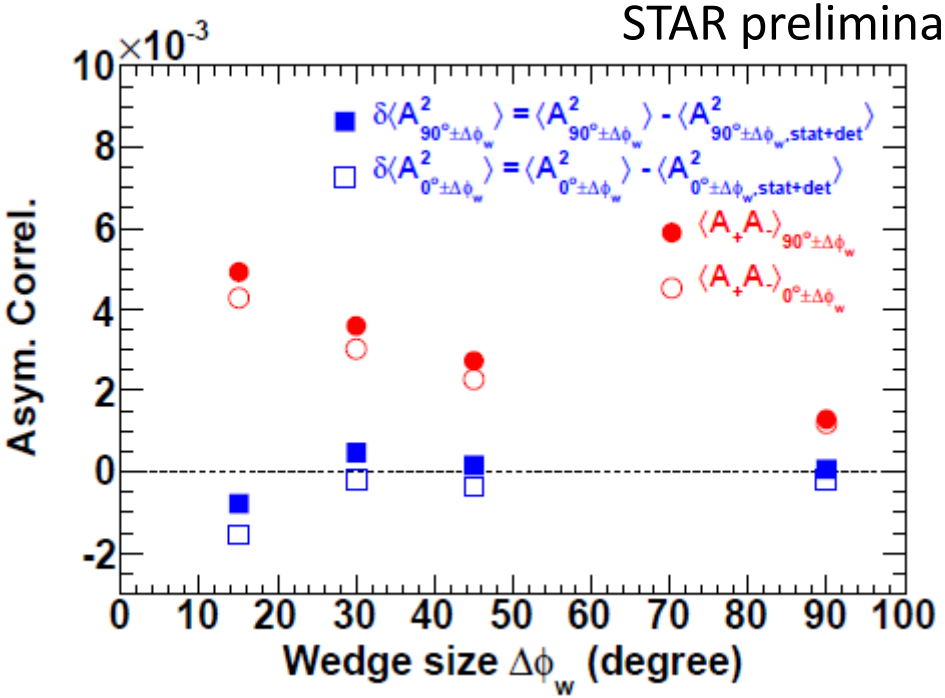
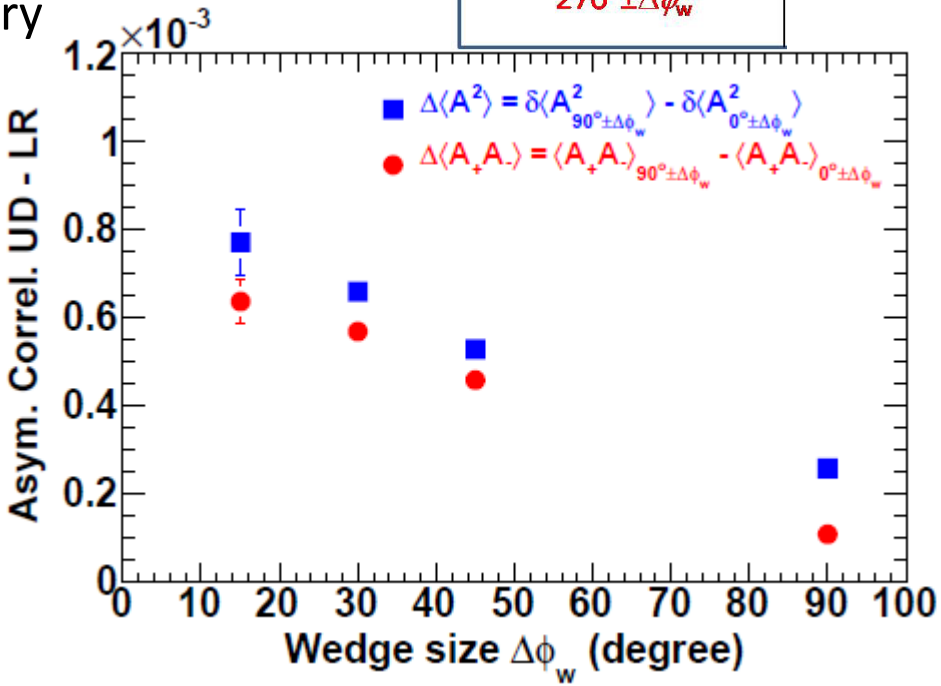
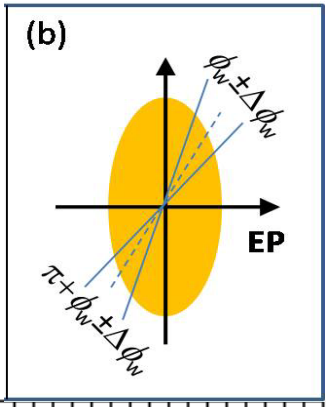



- Stronger effect with smaller wedge.
- Charge correlations seem local.
- Similar between same- and oppo-sign.
- Correlations appear charge-indep.

# Charge Asym Correl vs Azimuth




**20-40% centrality**

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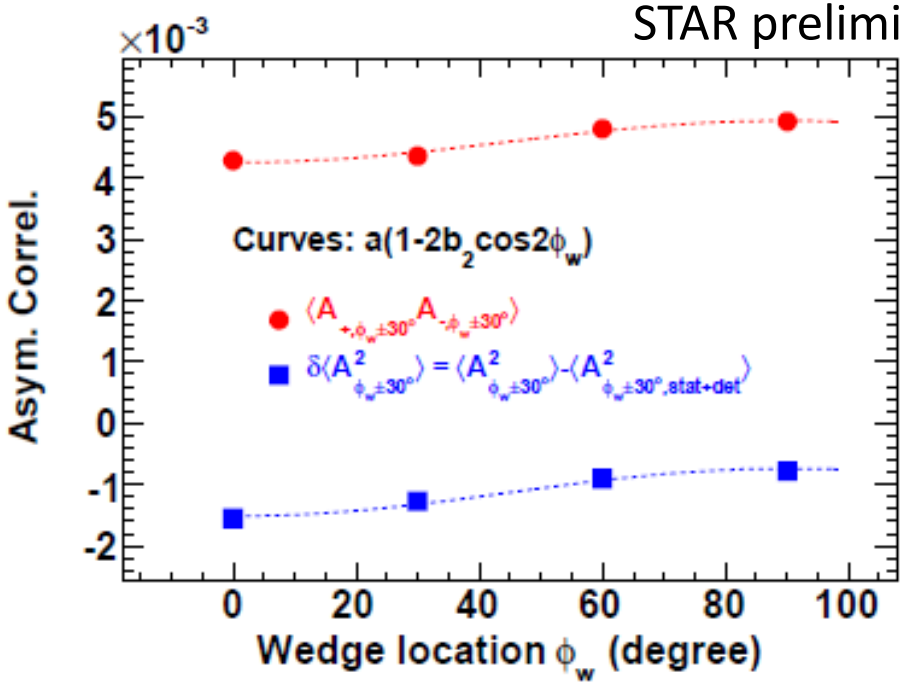


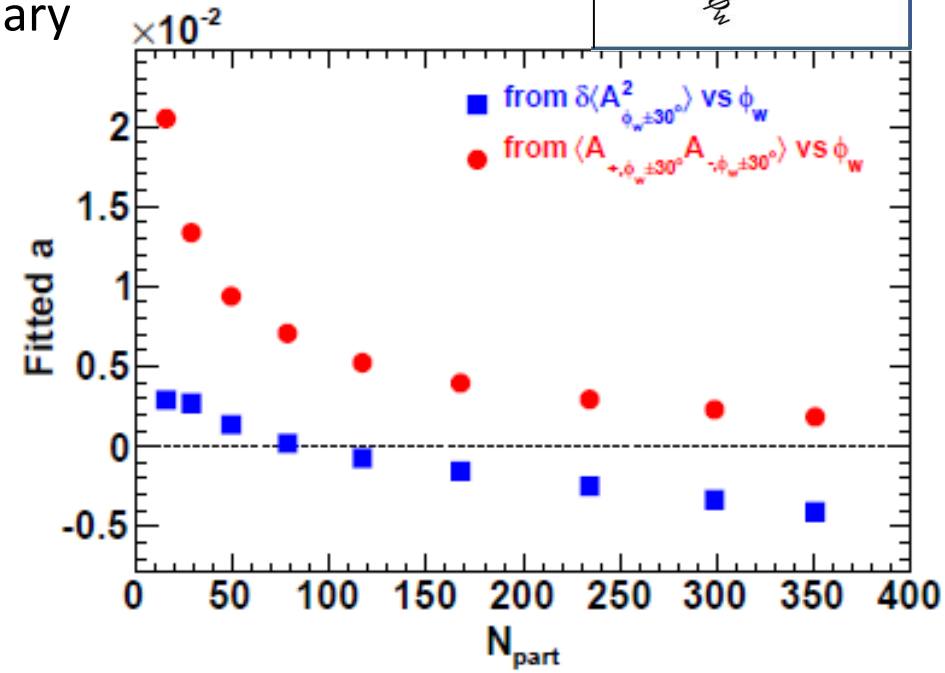


- Increases from in- to out-of-plane.
- Trends similar between same- and opposite-sign charges.

- Opposite-sign charges are aligned.
- Same-sign charges change from aligned to back-to-back.

# 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:
  - UD-LR *v.s.* E-by-E high-$p_T$ and low-$p_T$ $v_2$'s.
  - Dependence on wedge size
  - Dependence on wedge azimuth

# Backup slides

# Stat. fluc. + detector effects in ‹A²›

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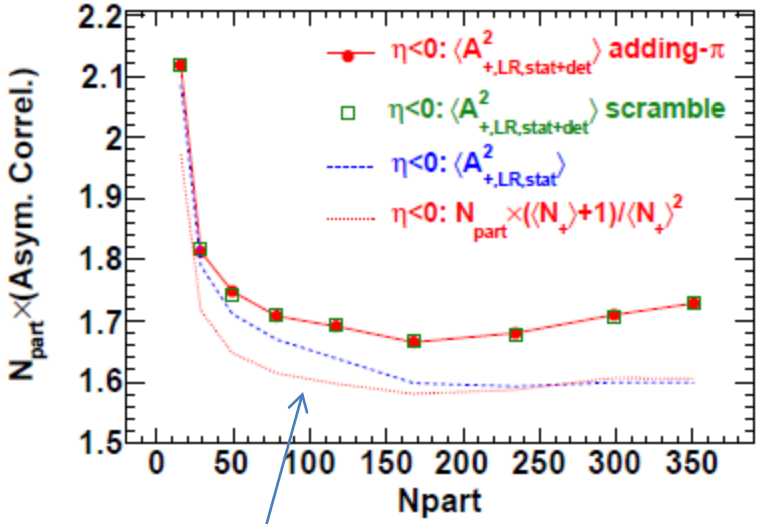
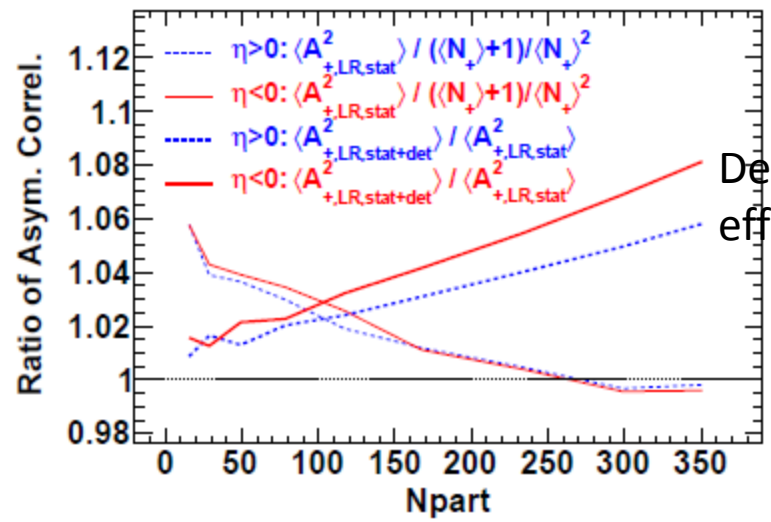
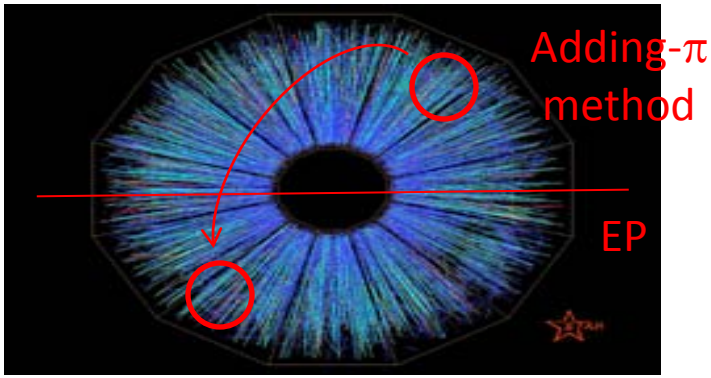



Detector effects

$$\langle A^2\rangle = \left\langle \left( \frac{N_{up}-N_{down}}{N_{up}+N_{down}} \right)^2 \right\rangle$$

$$= \frac{1}{\langle N\rangle^2} \left\langle \left( \frac{\delta N_{up}-\delta N_{down}}{1+(\delta N_{up}+\delta N_{down})/\langle N\rangle} \right)^2 \right\rangle$$

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