Initial study of the Roy/Ajit's correlator

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Chiral Magnetic Effect (CME)

Chiral fermions in the QGP cause an electric current J_Q along the magnetic field generated in the collision

Leading to charge separation across the reaction plane

Chiral magnetic Conducativity

Electric Current

$$\vec{J}_Q = \sigma_5 \vec{B}$$

This leads to a dipole term in the azimuthal distribution of the produced charged hadrons

$$\frac{dN^{ch}}{d\phi} \propto [1 \pm 2a_1^{ch} \sin\phi + ...]$$

$$\gamma^{\alpha,\beta} = \langle \cos(\phi_\alpha + \phi_\beta - 2\Psi_{RP}) \rangle$$

$$= \langle \cos(\phi_\alpha - \Psi_{RP}) \cos(\phi_\beta - \Psi_{RP}) \rangle - \langle \sin(\phi_\alpha - \Psi_{RP}) \sin(\phi_\beta - \Psi_{RP}) \rangle$$

$$= [\langle v_{1,\alpha} v_{1,\beta} \rangle + B_{IN}] - [\langle a_\alpha a_\beta \rangle + B_{OUT}]$$

Baseline unrelated to the B field.

In-plane background

Signal of interest

Out-of-plane background

In reality, $(B_{IN} - B_{OUT}) \sim v_2 / N$

$$\gamma^{\alpha,\beta} = -\langle a_\alpha a_\beta \rangle + c \frac{v_2}{N}$$

Roy/Ajit's Correlator

Charge separation (ΔS) is measured using a multi-particle charge-sensitive in-event correlator relative to the Ψ_2 plane

$$C_p(\Delta S) = \frac{N_{\text{real}}(\Delta S)}{N_{\text{shuffled}}(\Delta S)}$$

- Event-by-event distribution
- Carries charge separation response

- Random shuffling of charges within an event
- Carries the "null" or charge averaged response

$$\Delta S = \frac{\sum_i \sin \Delta\phi_i^+}{p} - \frac{\sum_i \sin \Delta\phi_i^-}{n}$$

$$\Delta S = \langle S_p^{h+} \rangle - \langle S_n^{h-} \rangle$$

$\Psi_2 + \pi/2$ is similarly constructed and is a second multi-particle correlator where CME-driven charge asymmetry vanishes.

The next page is taken from Roy's slides.

The shape and the magnitude of the correlator determines the characterized charge separation

$$R(\Delta S) = C_p(\Delta S) / C_p^{\perp}(\Delta S)$$

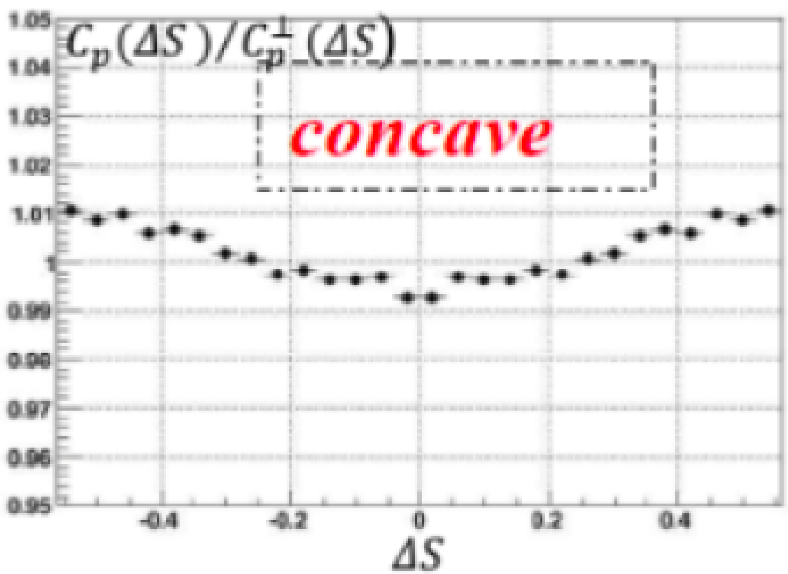
CME-driven charge separation creates a "concave" shape

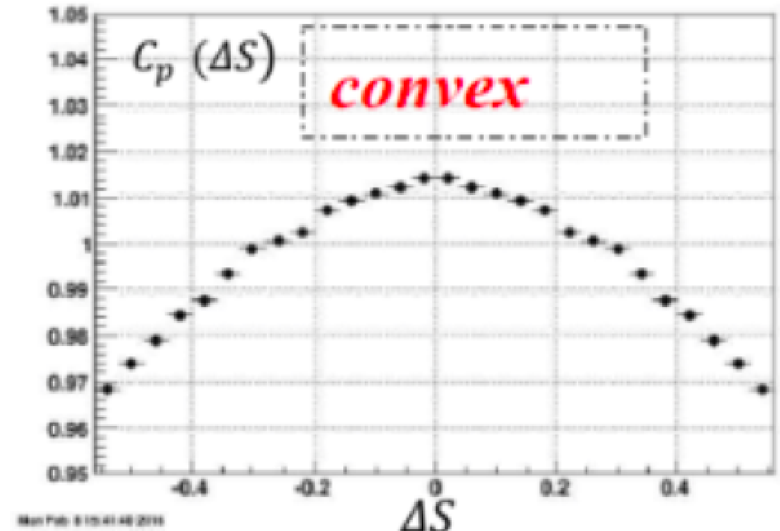
non-CME related background produces a "convex"

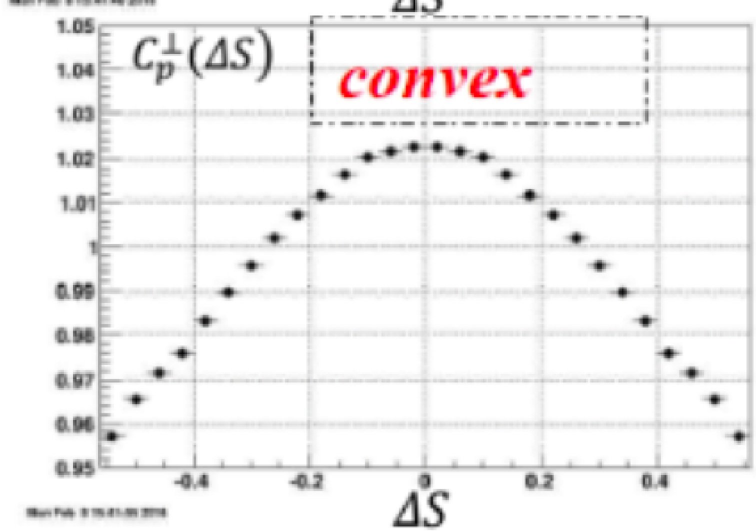
- Collective flow
- Momentum conservation
- Local charge conservation

Example:

- Flow
- Resonance decay
- Charge separation (a_1>0)







➢ **"Concave-shaped" response validates charge separation input in the presence of sizeable background**

Sergei's comparison: $\Delta\gamma$ and Roy's width

- Roy's observable is a double ratio where the concave or convex shape depends on the width of the numerator and detonator.
- Keeping positive and negative particle fixed, this is an estimate of the difference in these widths.

Quantity of interest → $\Delta\sigma^2_{RA} = \langle(\Delta S)^2\rangle - \langle(\Delta S_\perp)^2\rangle - \langle(\Delta S_{\mathrm{shuffled}})^2\rangle + \langle(\Delta S_{\perp,\mathrm{shuffled}})^2\rangle$

$$\begin{aligned}\Delta\sigma^2_{RA} = &\frac{1}{p}\langle\sin^2\Delta\phi_i^+\rangle + \frac{p-1}{p}\langle\sin\Delta\phi_i^+\sin\Delta\phi_j^+\rangle \\ &+\frac{1}{n}\langle\sin^2\Delta\phi_i^-\rangle + \frac{n-1}{n}\langle\sin\Delta\phi_i^-\sin\Delta\phi_j^-\rangle \\ &-2\langle\sin\Delta\phi_i^+\sin\Delta\phi_j^-\rangle \\ &-\frac{1}{p}\langle\cos^2\Delta\phi_i^+\rangle - \frac{p-1}{p}\langle\cos\Delta\phi_i^+\cos\Delta\phi_j^+\rangle \\ &-\frac{1}{n}\langle\cos^2\Delta\phi_i^-\rangle - 2\frac{n-1}{n}\langle\cos\Delta\phi_i^-\cos\Delta\phi_j^-\rangle \\ &+2\langle\cos\Delta\phi_i^+\cos\Delta\phi_j^-\rangle\end{aligned}$$

$$\Delta S = \frac{\sum_i \sin\Delta\phi_i^+}{p} - \frac{\sum_i \sin\Delta\phi_i^-}{n}$$

$$\Delta S_\perp = \frac{\sum_i \cos\Delta\phi_i^+}{p} - \frac{\sum_i \cos\Delta\phi_i^-}{n}$$

$$\approx -\frac{1}{n}v_2^- - \frac{1}{p}v_2^+ - \frac{n-1}{n}\gamma_{--} - \frac{p-1}{p}\gamma_{++} + 2\gamma_{+-}$$

$$-\left(\frac{1}{n}v_2^- - \frac{1}{p}v_2^+ - \frac{n-1}{n}\gamma_{--} - \frac{p-1}{p}\gamma_{++} + 2\gamma_{+-}\right)_{\text{charge average}}$$

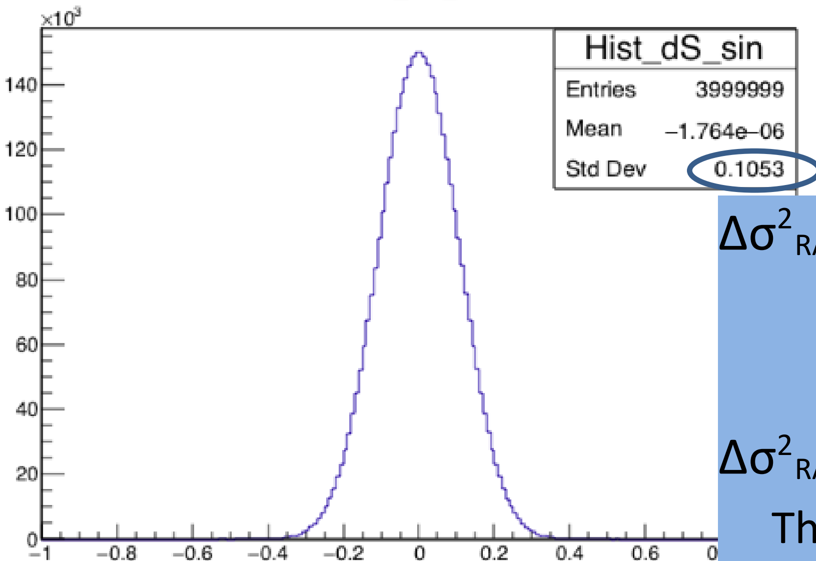
$$\approx 2(\gamma_{\text{opposite}} - \gamma_{\text{same}})$$

Equivalent!

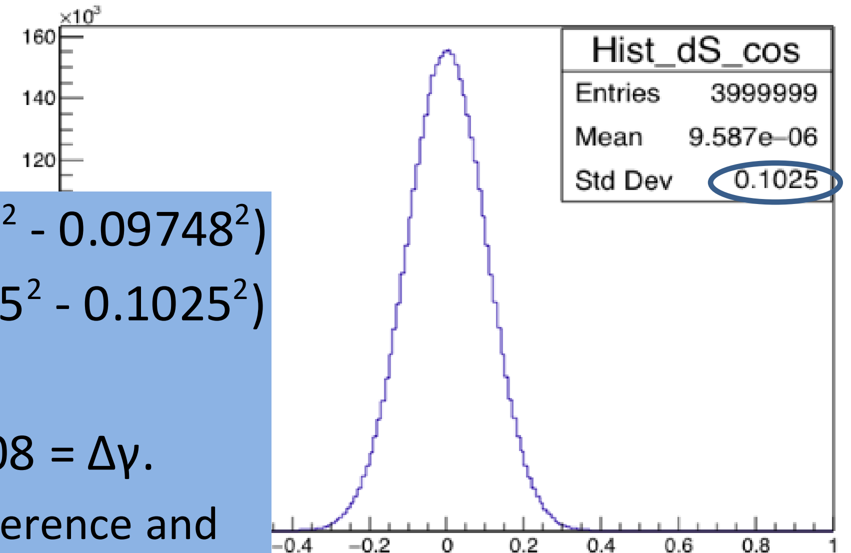
Ideal Monte Carlo simulation (no background and w.r.t the true reaction plane):

- Number of particles: 100 h^+ and 100 h^-
- $v_2 = 0.05$
- $a_1 = 0.02 \rightarrow \Delta\gamma = 0.008$

Hist_dS_sin



Hist_dS_cos

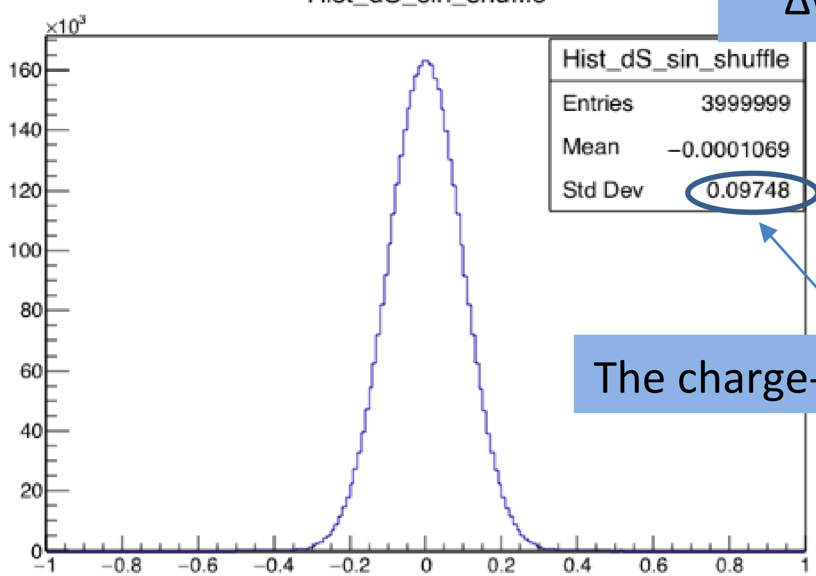


$$\Delta\sigma^2_{RA} = (0.1053^2 - 0.09748^2) - (0.1025^2 - 0.1025^2) = 0.0016$$

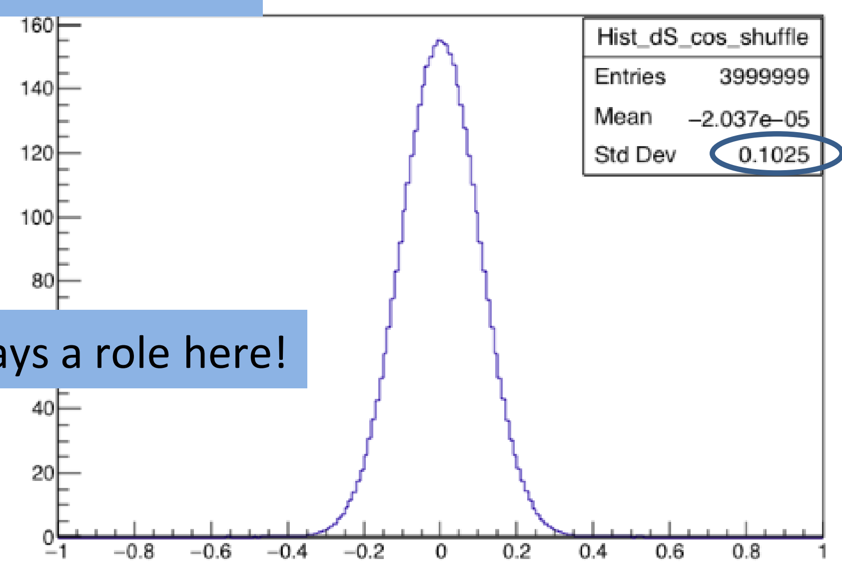
$$\Delta\sigma^2_{RA}/2 = 0.0008 = \Delta\gamma.$$

The width difference and $\Delta\gamma$ give the same result!

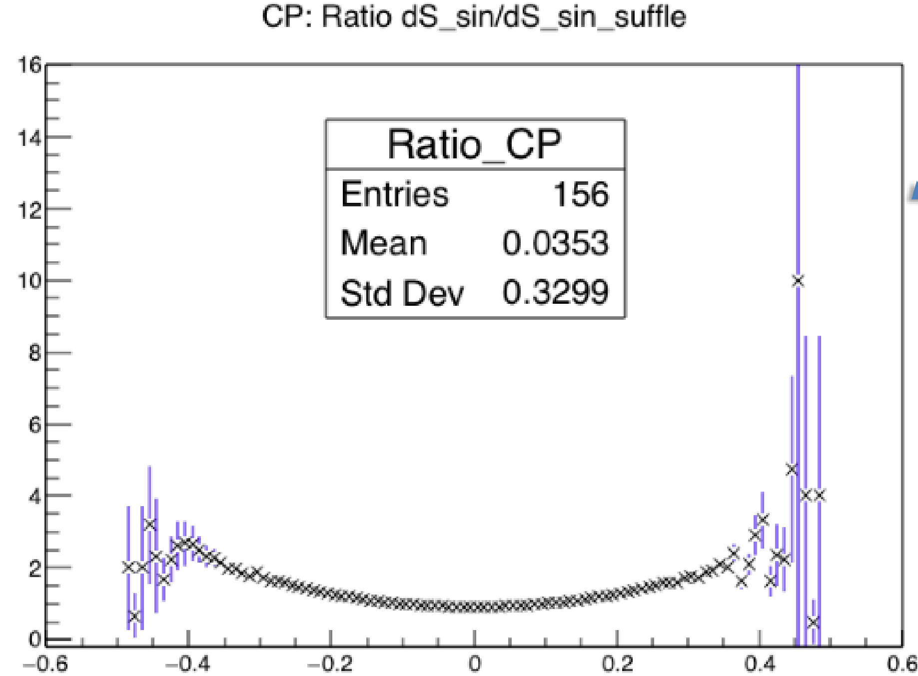
Hist_dS_sin_shuffle



Hist_dS_cos_shuffle



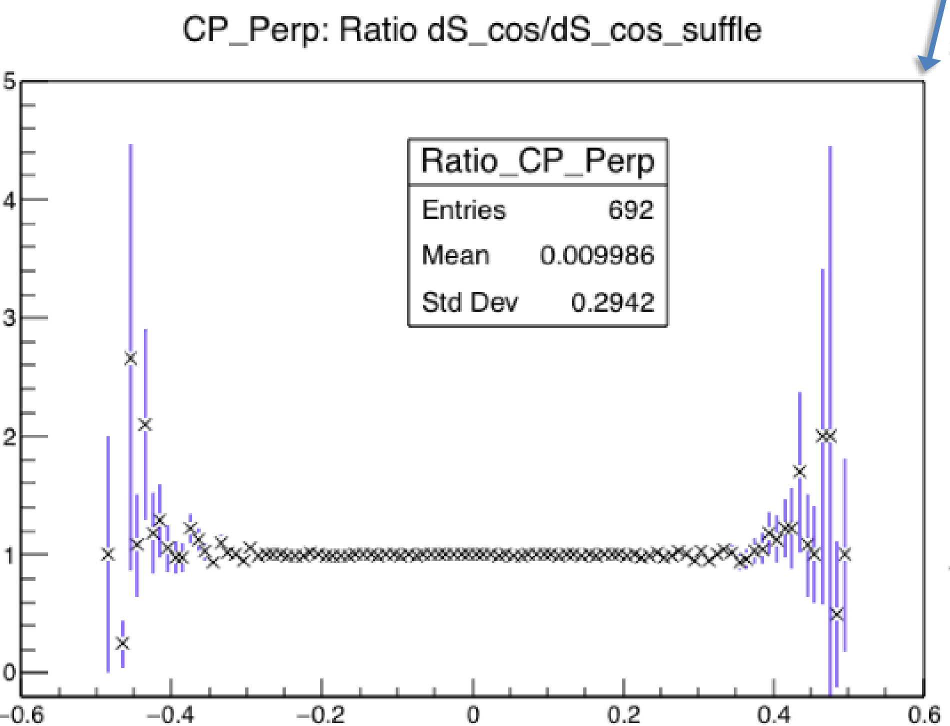
The charge-shuffling plays a role here!

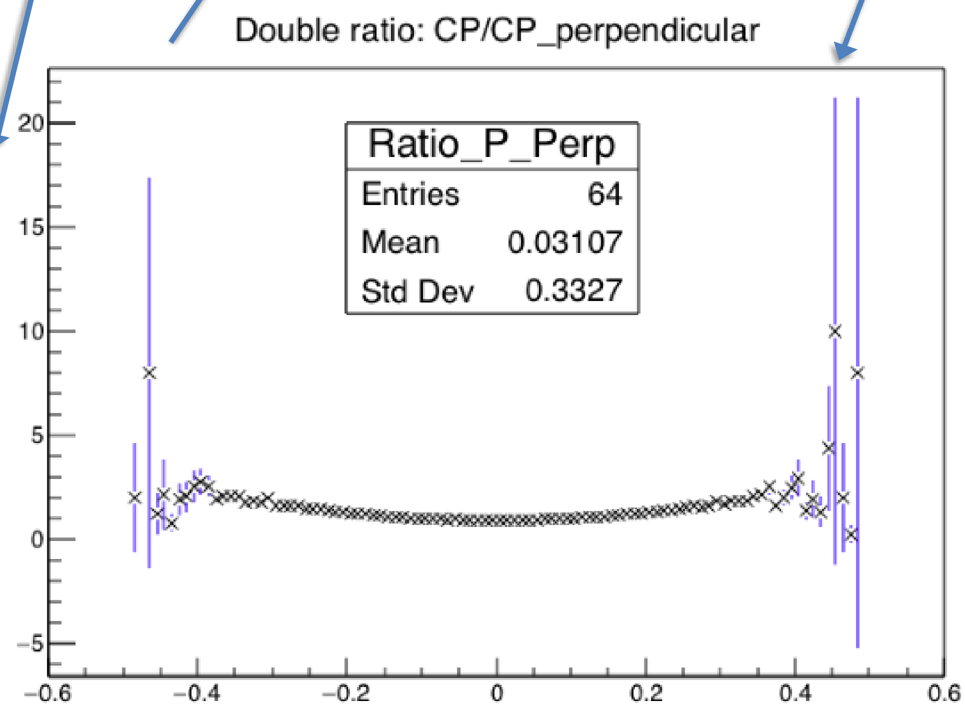


Single ratio

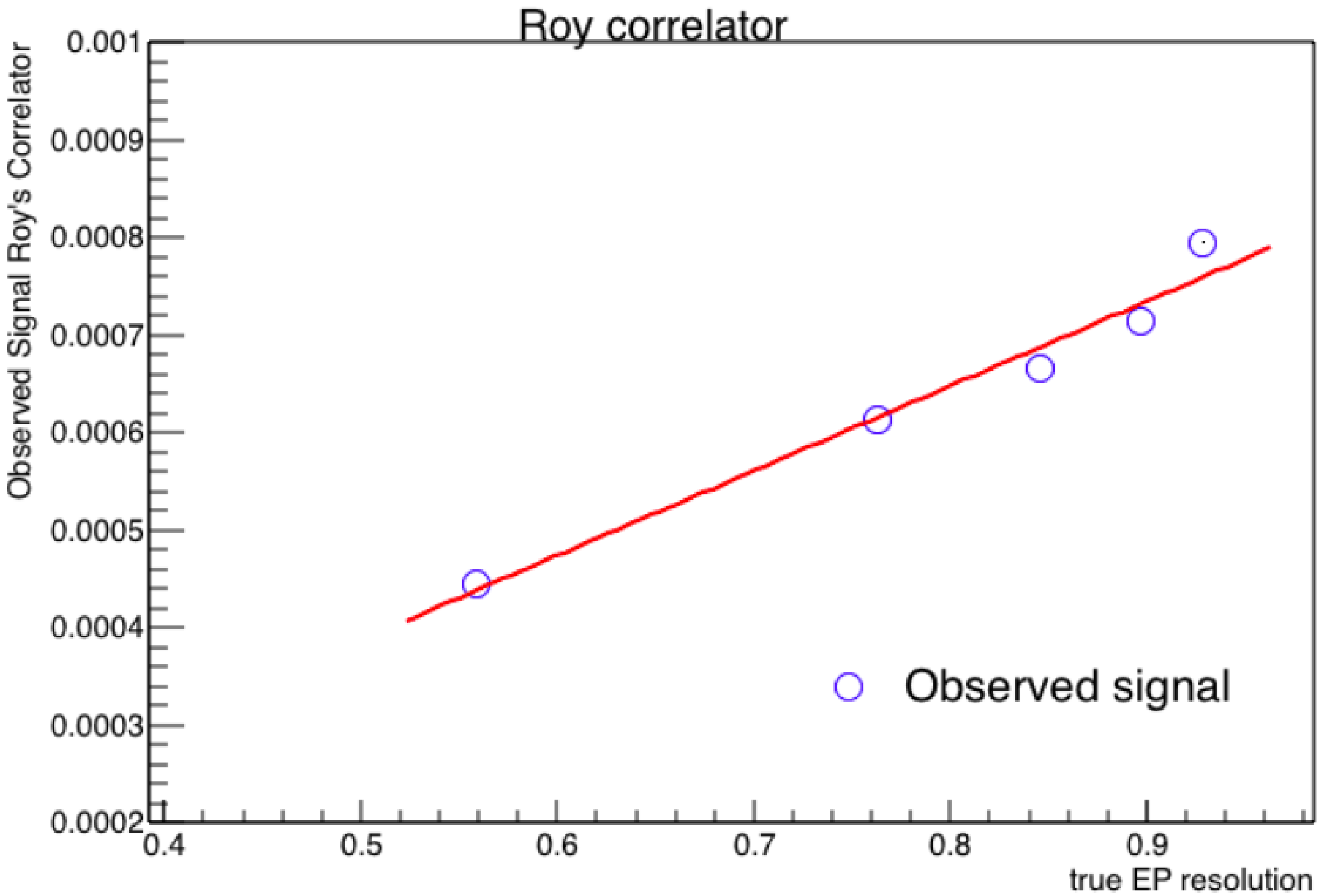
For this ideal case, the concave shape indicates a CME-driven charge separation.

Double ratio



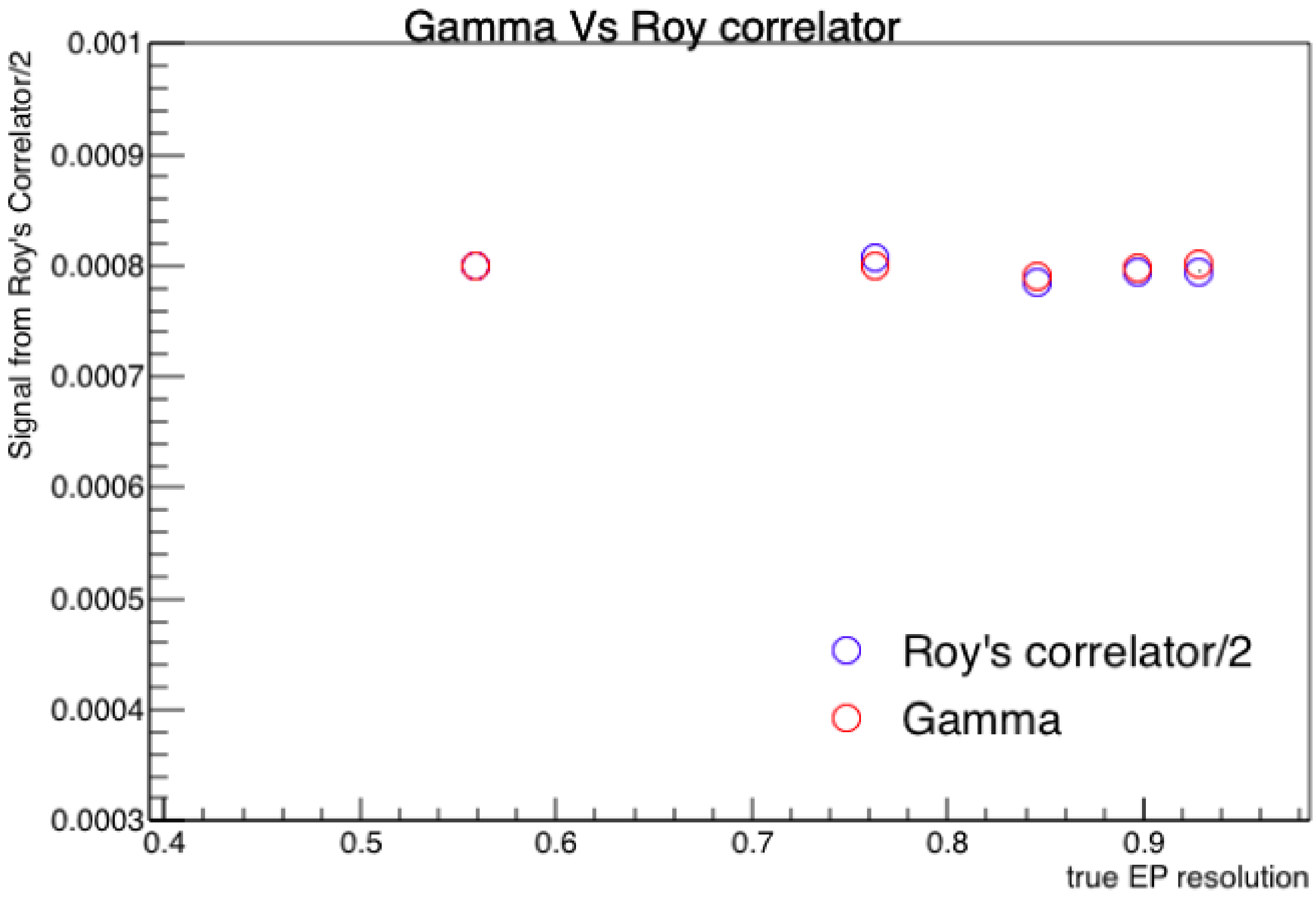


Observed width difference vs EP resolution



The EP resolution is changed by varying the v_2 of particles going into the event plane. The observed signal increases linearly with the event plane resolution.

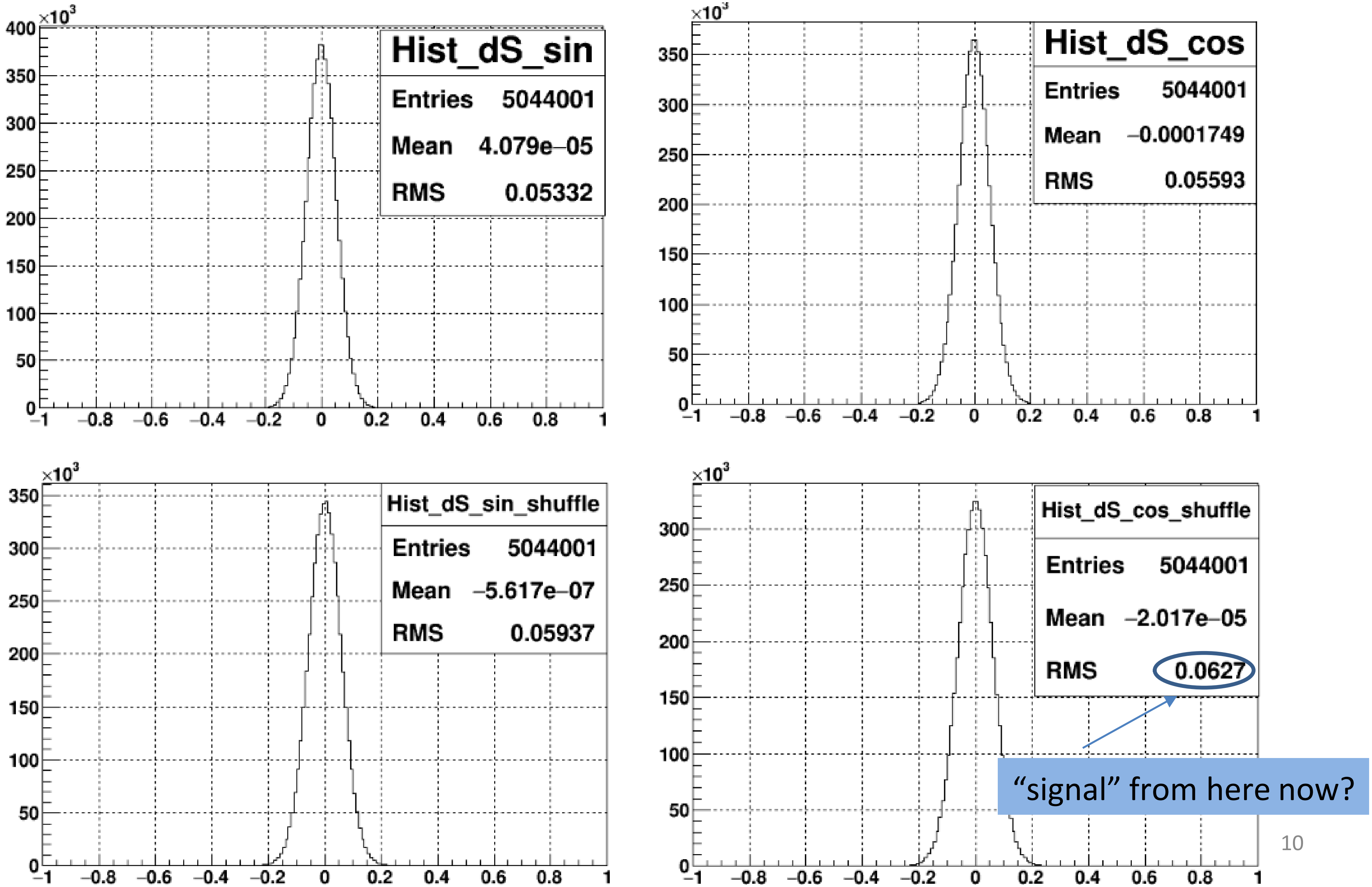
Correction for the EP resolution



After the correction for the EP resolution, both Δγ and $\Delta\sigma^2_{RA}$ restore the input value of charge separation.

AMPT from Niseem

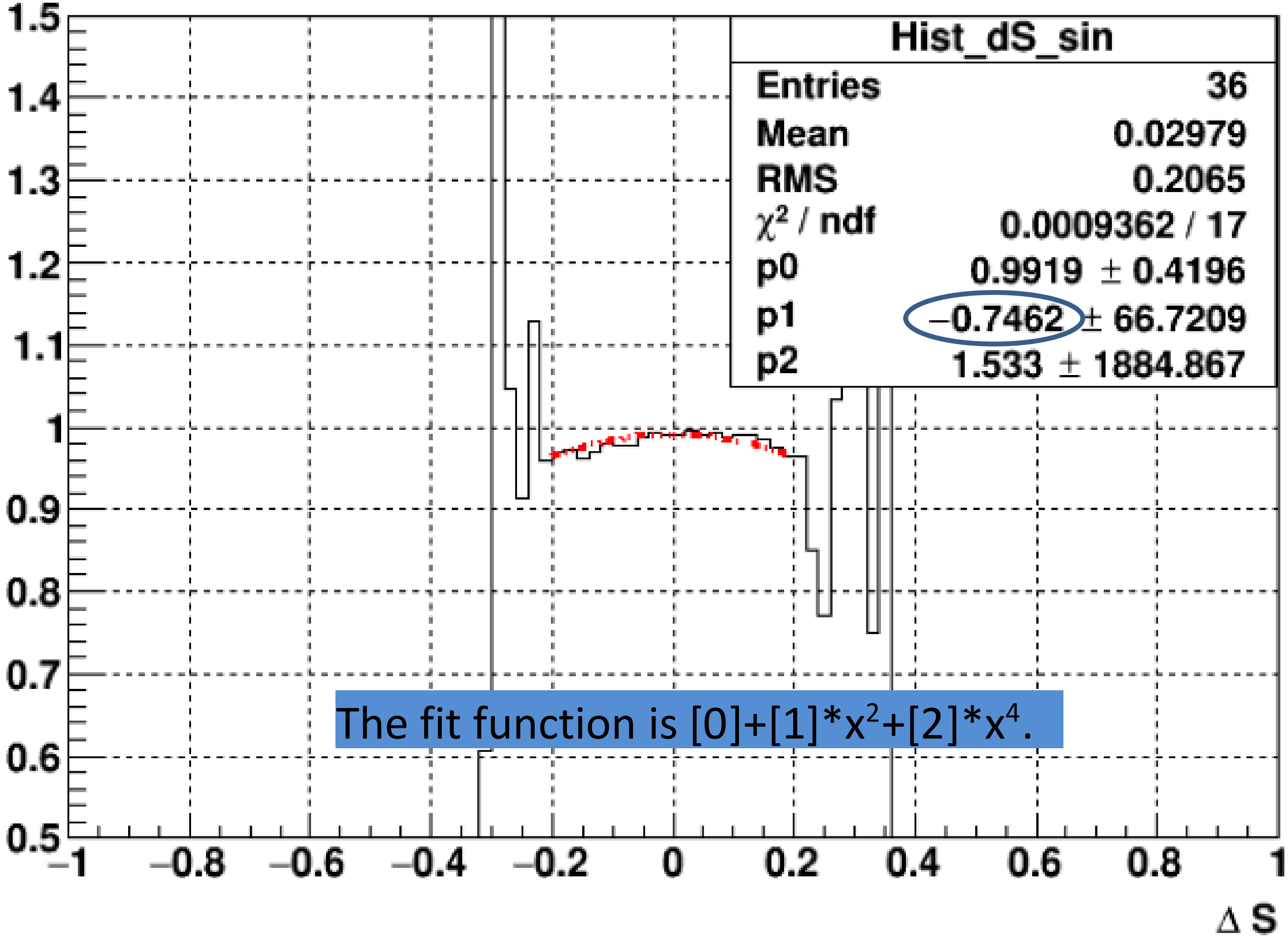
5M events for 7<b<9 fm (b is the impact parameter). w.r.t the true reaction plane.



AMPT from Niseem

$\Delta\gamma = 3.2*10^{-5}$ and $\Delta\sigma^2_{RA}/2 = 6.1*10^{-5}$.

Although both Δγ and the width difference indicate a charge separation signal, the convex shape of the double ratio says the opposite.

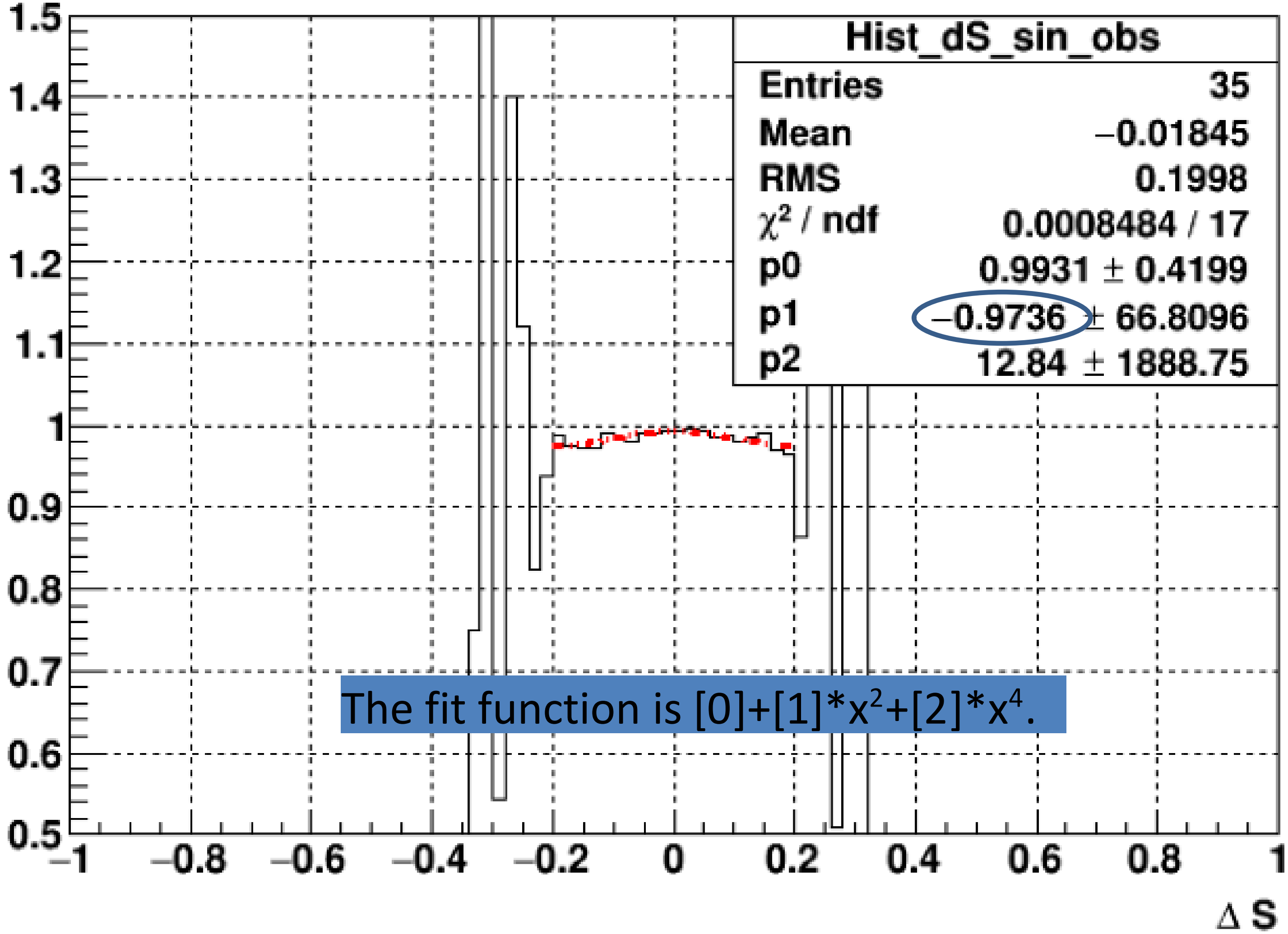


AMPT from Niseem

Now w.r.t the reconstructed event plane, and correct for EP resolution.

$\Delta\gamma = 5.8*10^{-5}$ and $\Delta\sigma^2_{RA}/2 = 6.9*10^{-5}$.

Although both $\Delta\gamma$ and the width difference indicate a charge separation signal, the convex shape of the double ratio says the opposite.

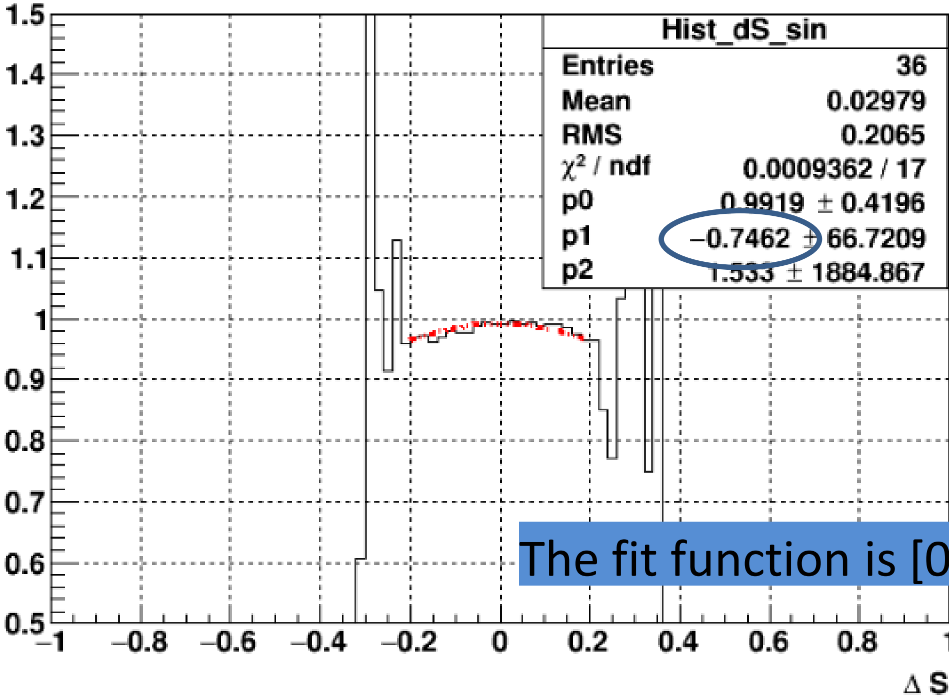


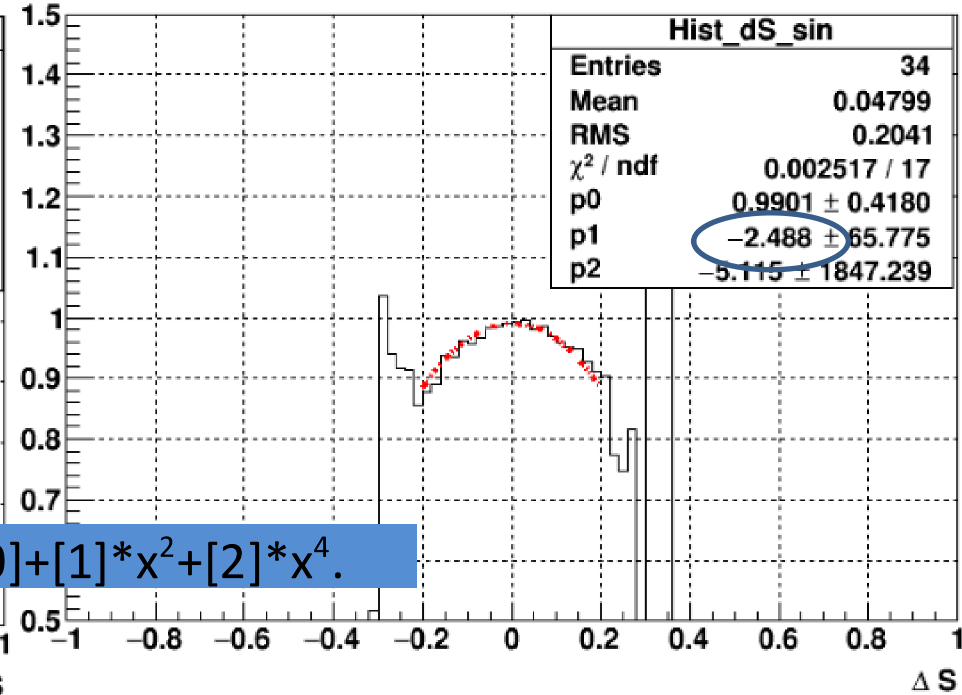
How to shuffle charges

Roy's correlator depends on the technical details of the charge-shuffling.
Case 1 gives smaller "signal", and then a flatter double ratio, though both convex.
Should we stick to case 1, which gives an apple-to-apple ratio of the original-charge over shuffled-charge?

Case 1: only shuffle the charges of particles of interest.
$\Delta\sigma^2_{RA}/2 = 6.1*10^{-5}$.

Case 2: shuffle all the particles in the event, all rapidity and p_T.
$\Delta\sigma^2_{RA}/2 = 1*10^{-4}$.





The fit function is $[0]+[1]*x^2+[2]*x^4$.

What remains to be done

- Which charge-shuffling scheme should be taken?

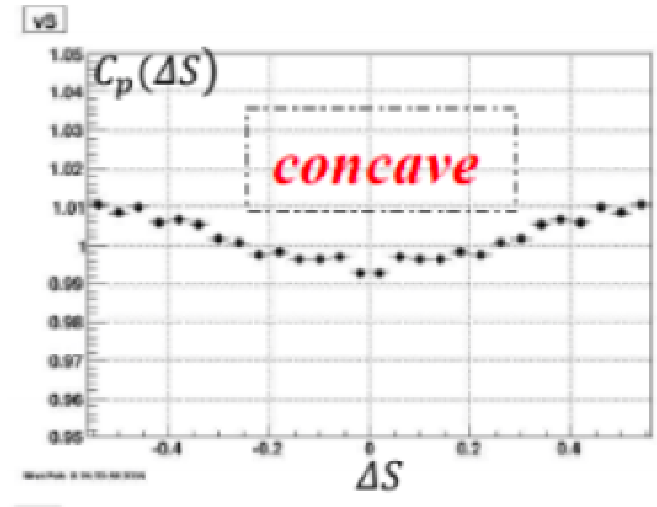
- Difference between Niseem's AMPT events and our AMPT events:
  - For the same centrality, Niseem's $\Delta\gamma$ is about half of what we have, and Niseem's $\Delta\delta$ is only a quarter of ours, though v_2 values are similar.
  - Did you turn off hadronic scattering or some other options in AMPT?

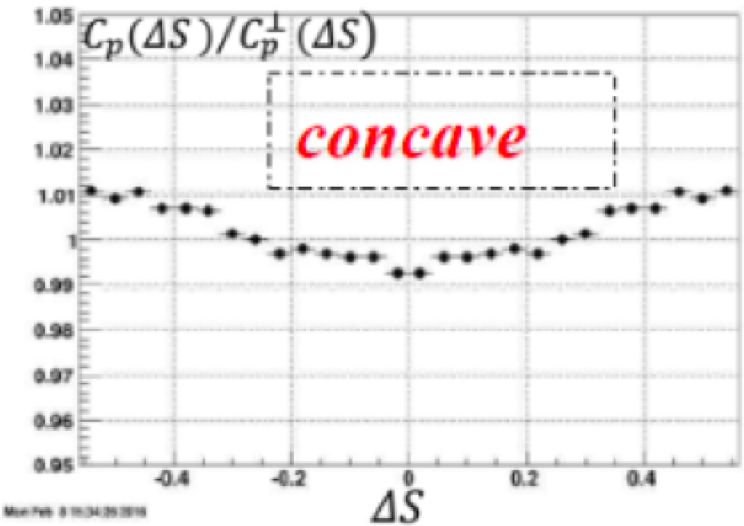
- Niseem posts the AMPT events in a rather central centrality range:
  - The fake signal itself is small.
  - Could Niseem post more peripheral AMPT events, like 50-60%?

- In real data, when we have a concave double ratio, how exactly should we extract the a_1 signal? This part is still mysterious to us.

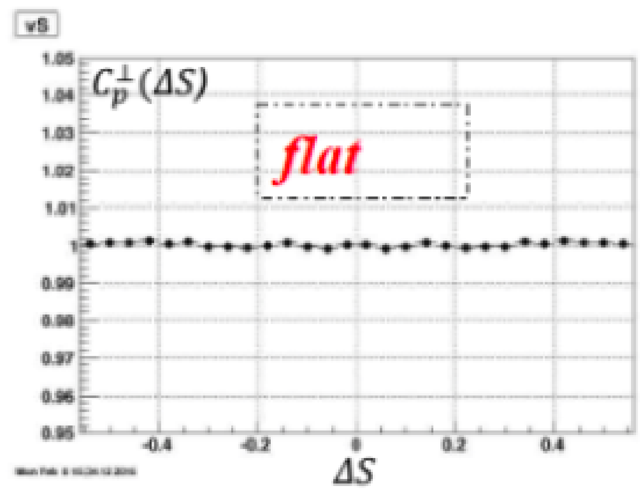
Backup slides

- Toy model
  - Flow
  - No Resonance decay
  - Charge separation (a_1>0)

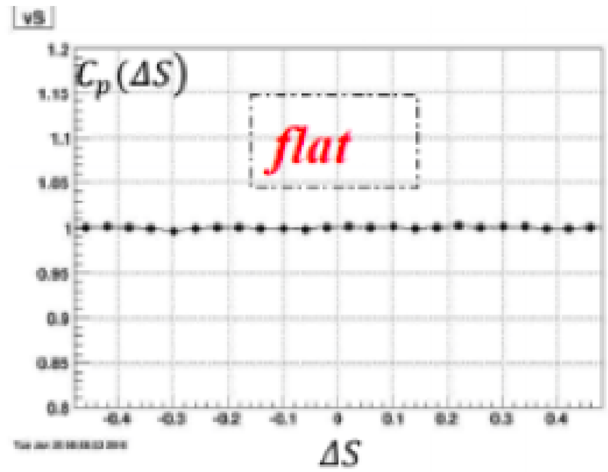


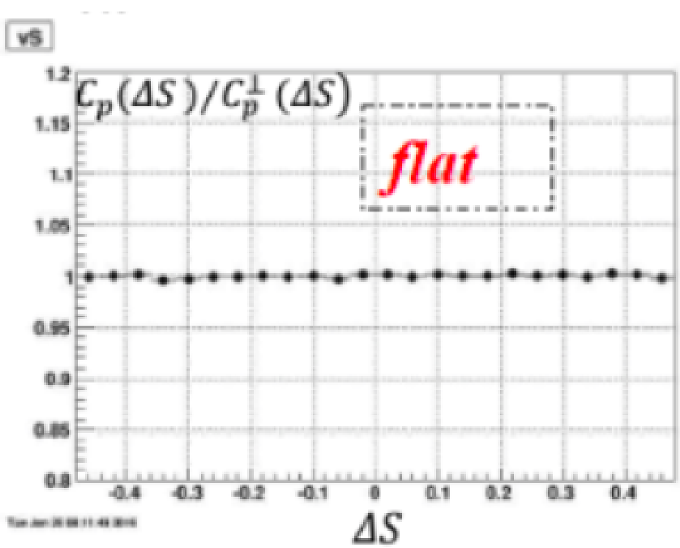


➢ "Concave-shaped" response for input charge separation validated



- Toy model
  - Flow
  - No resonance decay
  - No Charge separation (a_1=0)





➢ **Flat response for collective flow validated**