Searching for the chiral magnetic effect with the sliding dumbbell method in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE

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OUTLINE

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- ☐ Analysis Method
- ☐ Results
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Physics Motivation

Electric field induced by the strong magnetic field created by energetic spectator protons, causes charge separation along the system's angular momentum direction.

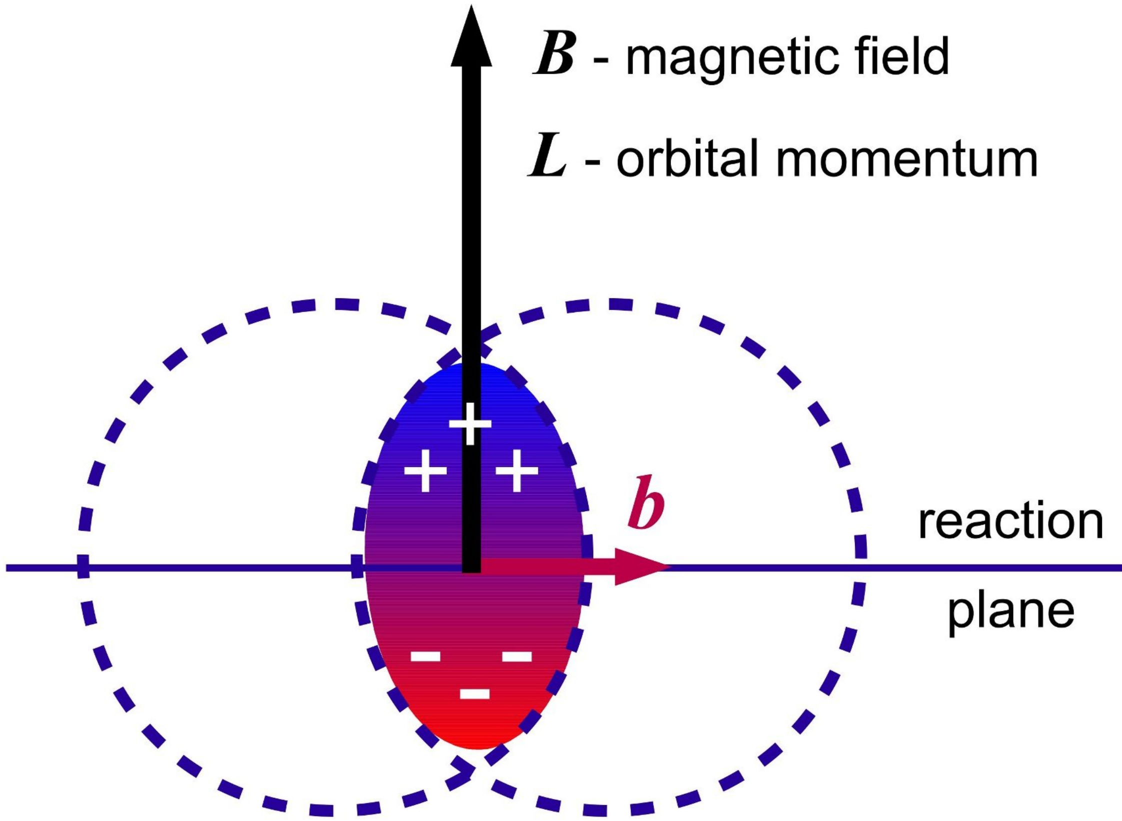
An event-by-event study of "localized" charge separation is one of the observable to investigate the Chiral Magnetic Effect (CME).

Voloshin(PRC 70,057901(2004)) described this charge separation in terms of azimuthal distribution as:

$$\frac{dN_{\pm}}{d\phi} \sim (1 + 2a_{\pm}sin(\phi - \Psi_{RP}))$$

where parameter $a_{-} = -a_{+}$ which relates to asymmetry across the plane as [D. Kharzeev, Phys. Lett. B 633:260-264, 2006]:

$$A^{+} = \frac{(N_{+}^{up} - N_{+}^{down})}{(N_{+}^{up} + N_{+}^{down})} \propto a_{+}$$



3 - particle correlator used to study CME is

$$\gamma = \langle cos(\phi_a + \phi_b - 2\Psi_{RP}) \rangle \approx (v_{1,a}v_{1,b} - a_a a_b) \; = \langle cos(\phi_a + \phi_b - 2\phi_c) \rangle / \; v_{2,c}$$

here, φ_a , φ_b , φ_c are azimuthal angles of particle a, b and c ; ψ_{RP} is reaction plane angle, $v_{1,a(b)}$ is direct flow and $v_{2,c}$ is elliptic flow of third particle "c". **For symmetric rapidity, direct flow, $v_{1,a} = v_{1,b} \sim 0$, so** $\gamma \approx |a_a . a_b|$

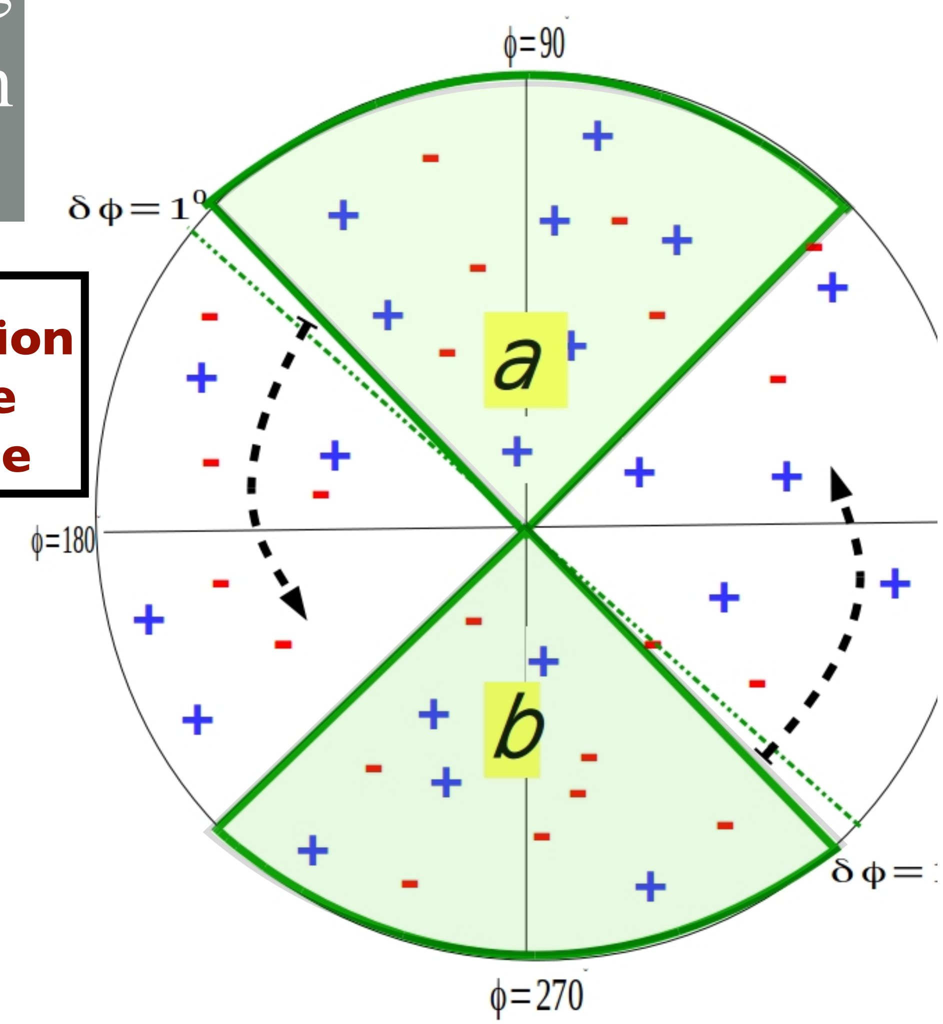
Sliding Dumbbell Method (SDM)

New technique, Sliding Dumbbell Method, is developed to search event-by-event back-to-back charge separation and to pinpoint the events which show higher back-to-back charge separation and are CME-like events.

Aim is to get CME-like enriched sample for a given collision centrality.

Azimuthal plane in each event is scanned by sliding dumbbell of $\Delta\varphi = 90^{o}$ in steps of $\delta\varphi = 1^{o}$ to obtain maximum values of $Db_{\pm}$ in each event i.e. $Db_{\pm}^{max}$

$Db_{\pm} =$ **positive charge fraction on one side of the dumbbell i.e. "a" side** $+$ **negative charge fraction on other side of the dumbbell i.e."b" side**



Particles in the shaded area represent the particles inside the dumbbell.

γ is studied for whole event as well as for the particles inside the dumbbell only just to magnify the CME-like signal.

Fractional dumbbell charge separation is defined, f_{DbCS}, as : $f_{DbCS} = Db_{\pm}^{max} - 1$

Analysis Strategy

Step 1.

$Db_{\pm}^{max}$ distributions with the asymmetry cut, $|Db_{asy}| < 0.25$ are measured to get CME like events.

$$Db_{asy} = \frac{(Pos_{ex}^{a} - Neg_{ex}^{b})}{(Pos_{ex}^{a} + Neg_{ex}^{b})}$$

$Pos_{ex}^{a} = N_{+}^{a} - N_{-}^{a}$ **Positive charged particle excess on "a" side of the dumbbell**

$Neg_{ex}^{b} = N_{-}^{b} - N_{+}^{b}$ **Negative charged particle excess on "b" side of the dumbbell**

Step 2.

$Db_{\pm}^{max}$ distributions are obtained for different collision centralities and divided into 10 percentile bins highest(lowest) corresponding to 0-10% (90-100%).

Step 3.

Calculated γ for all $Db_{\pm}^{max}$ bins for SS and OS charge pairs as a function of collision centrality.

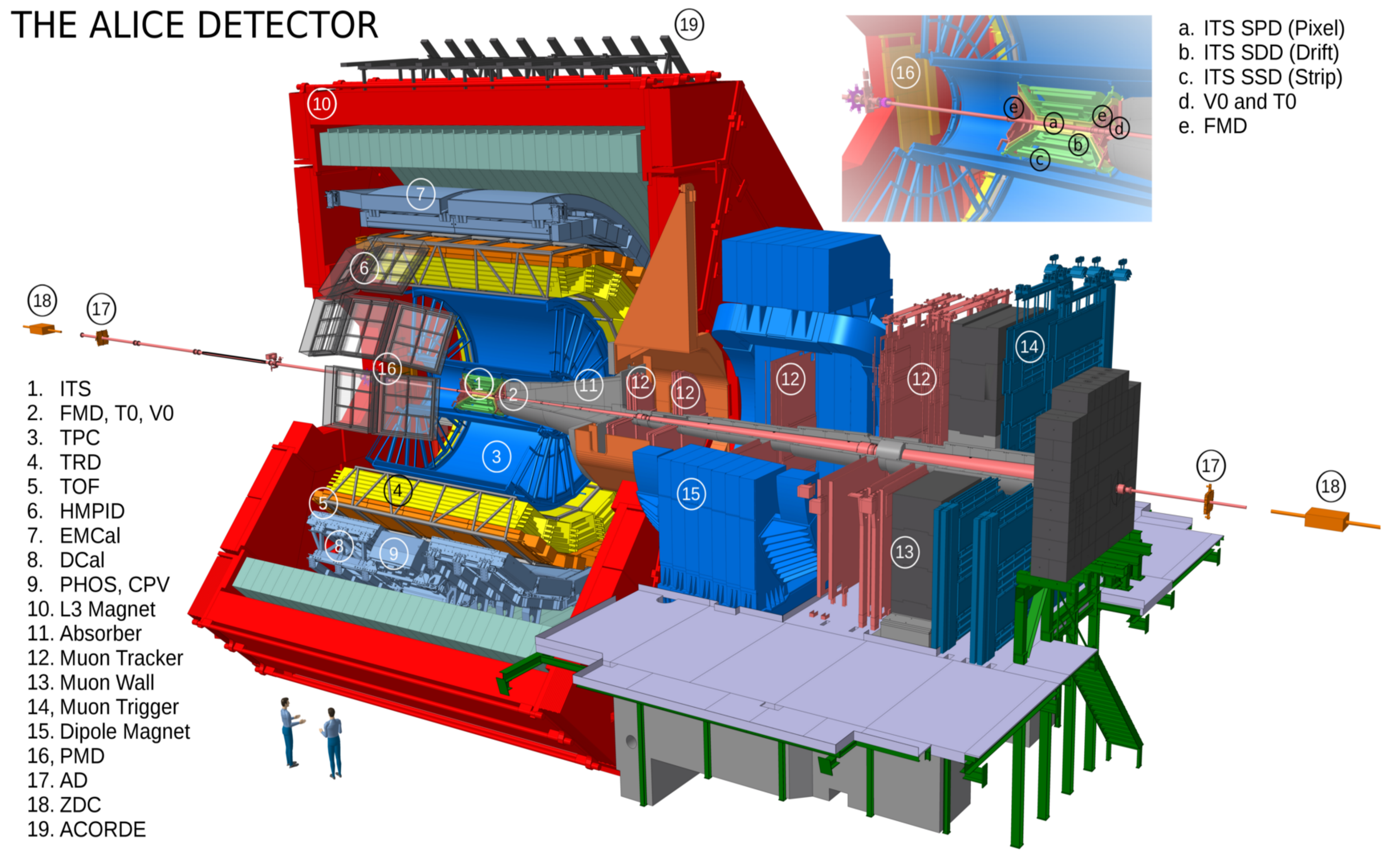
3p correlators and $v_{2,c}$ are calculated using Q-Cumulant method **Phys. Rev. C 83 044913(2011)**

Step 4.

For background estimation, charge reshuffle where charges of particles are reshuffled randomly keeping θ, ϕ same and correlated background from original event itself corresponding to charge reshuffle, are used.

Data Set

- Pb-Pb collisions @ **2.76 TeV**
- ~14M events analysed



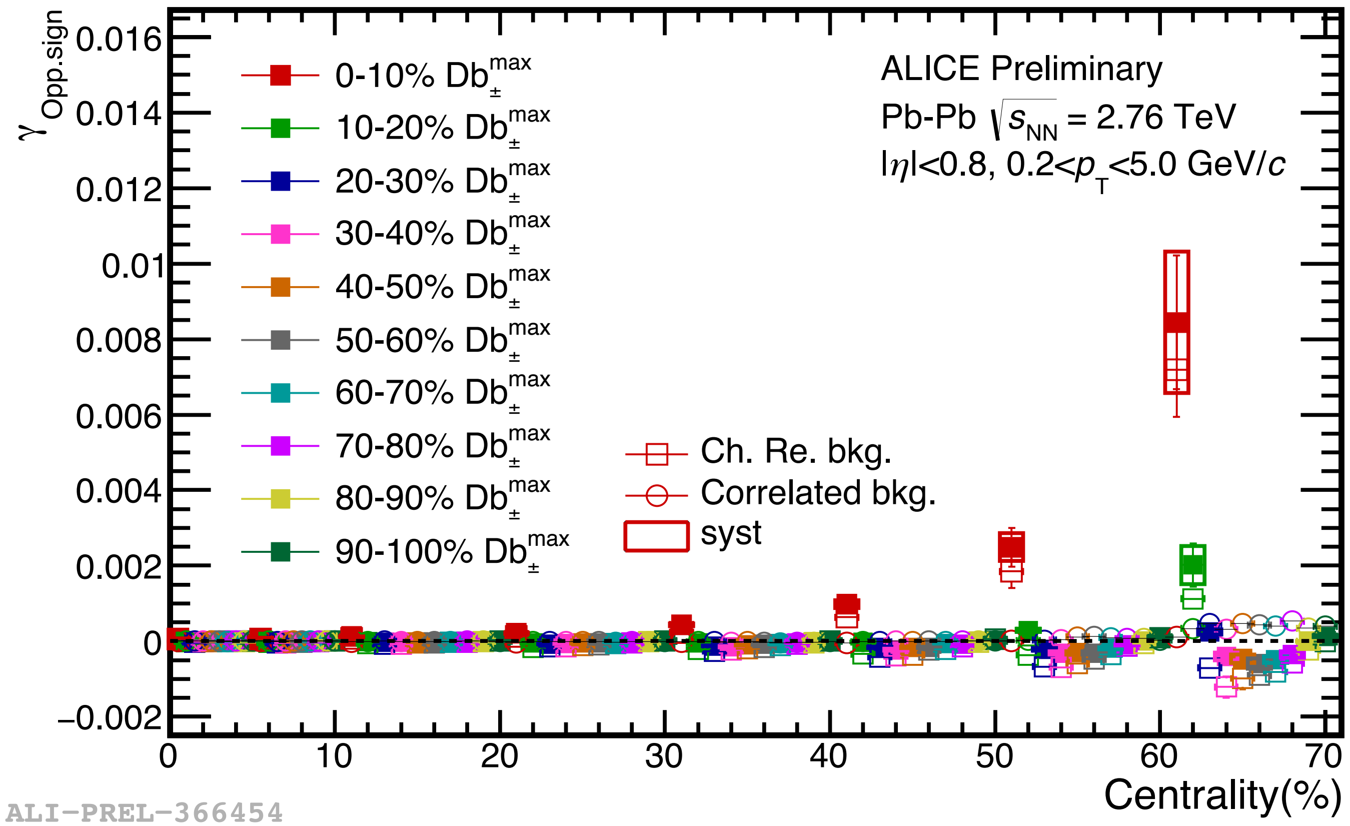
Event Selection

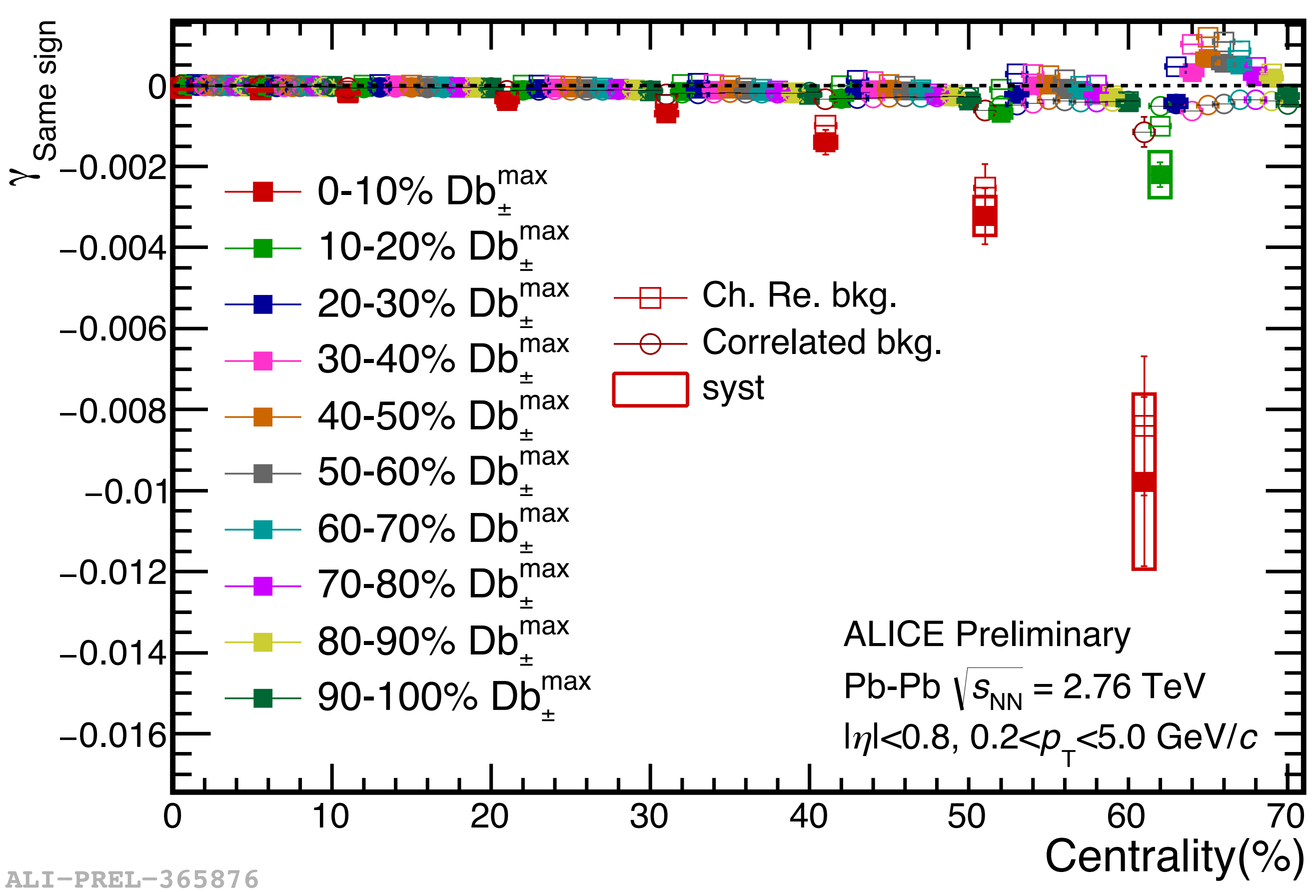
- Minimum bias events
- Centrality by signal in V0 detector

Track Selection

- Transverse momentum: 0.2-5.0 GeV/c
- $-0.8 < \eta < 0.8$

Variation of γ

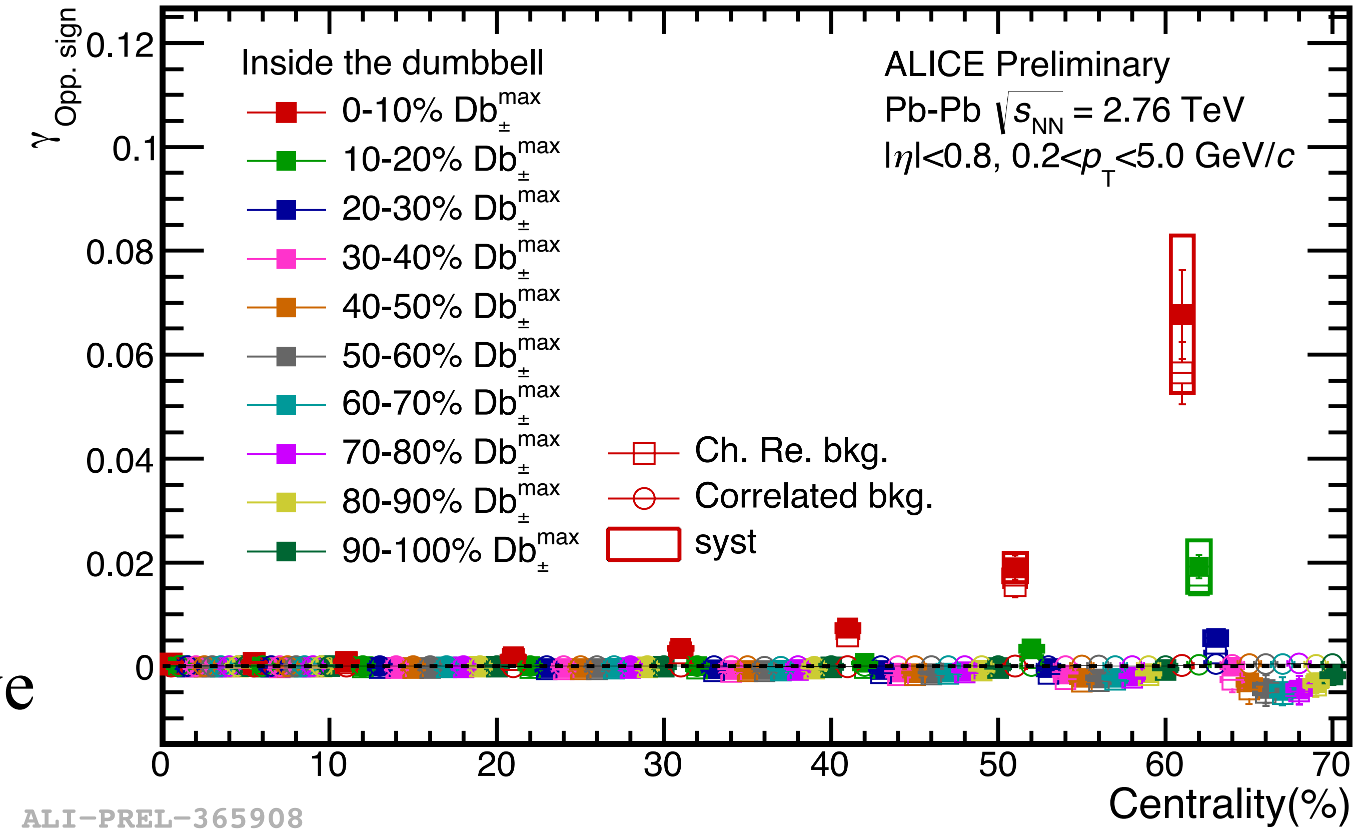


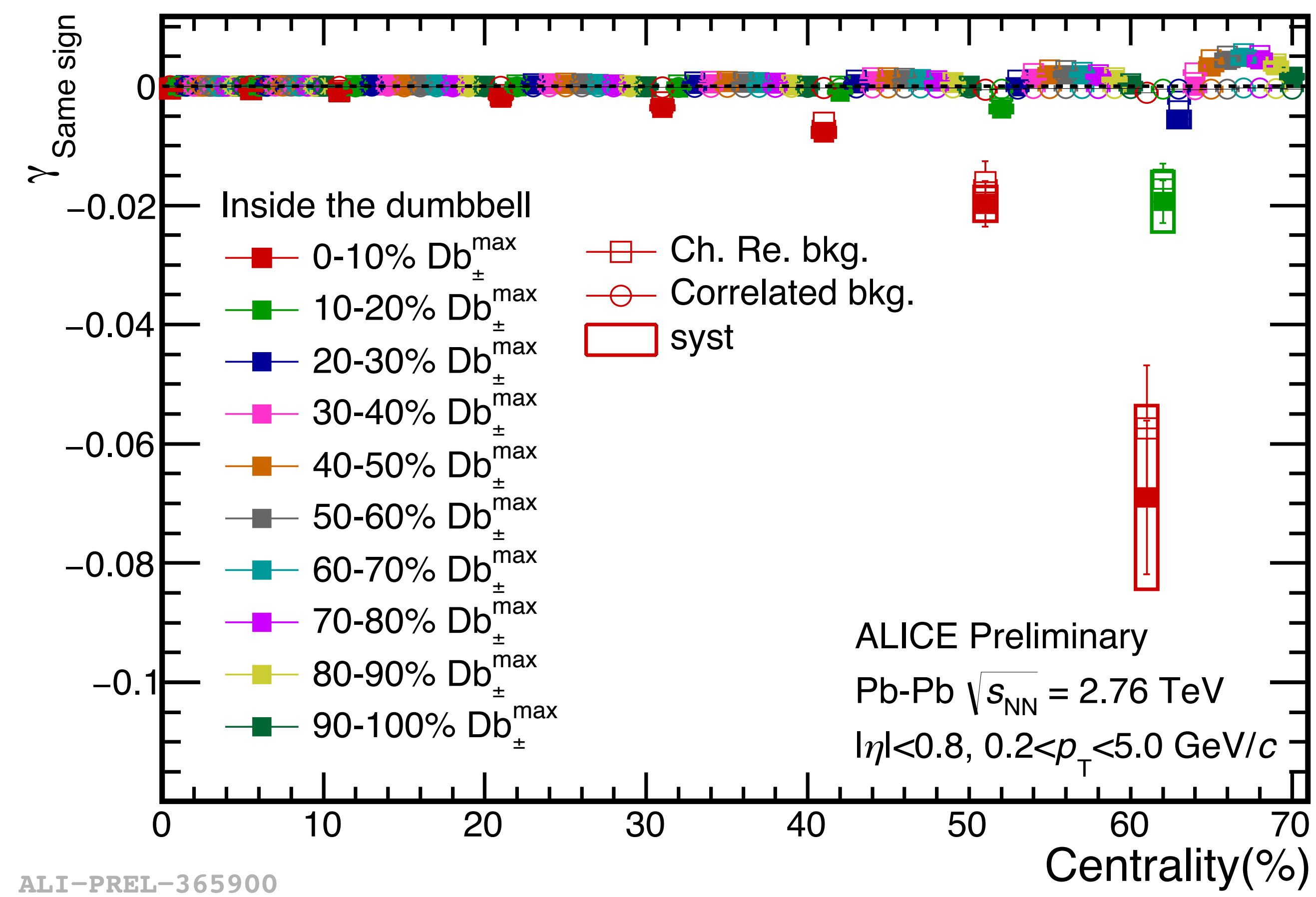


Variation of γ with $Db_{\pm}^{max}$ bins for opposite sign and same sign charged pair combinations for whole event. $|\gamma|$ increases for top $Db_{\pm}^{max}$ bins for both opposite sign and same sign charged pairs.

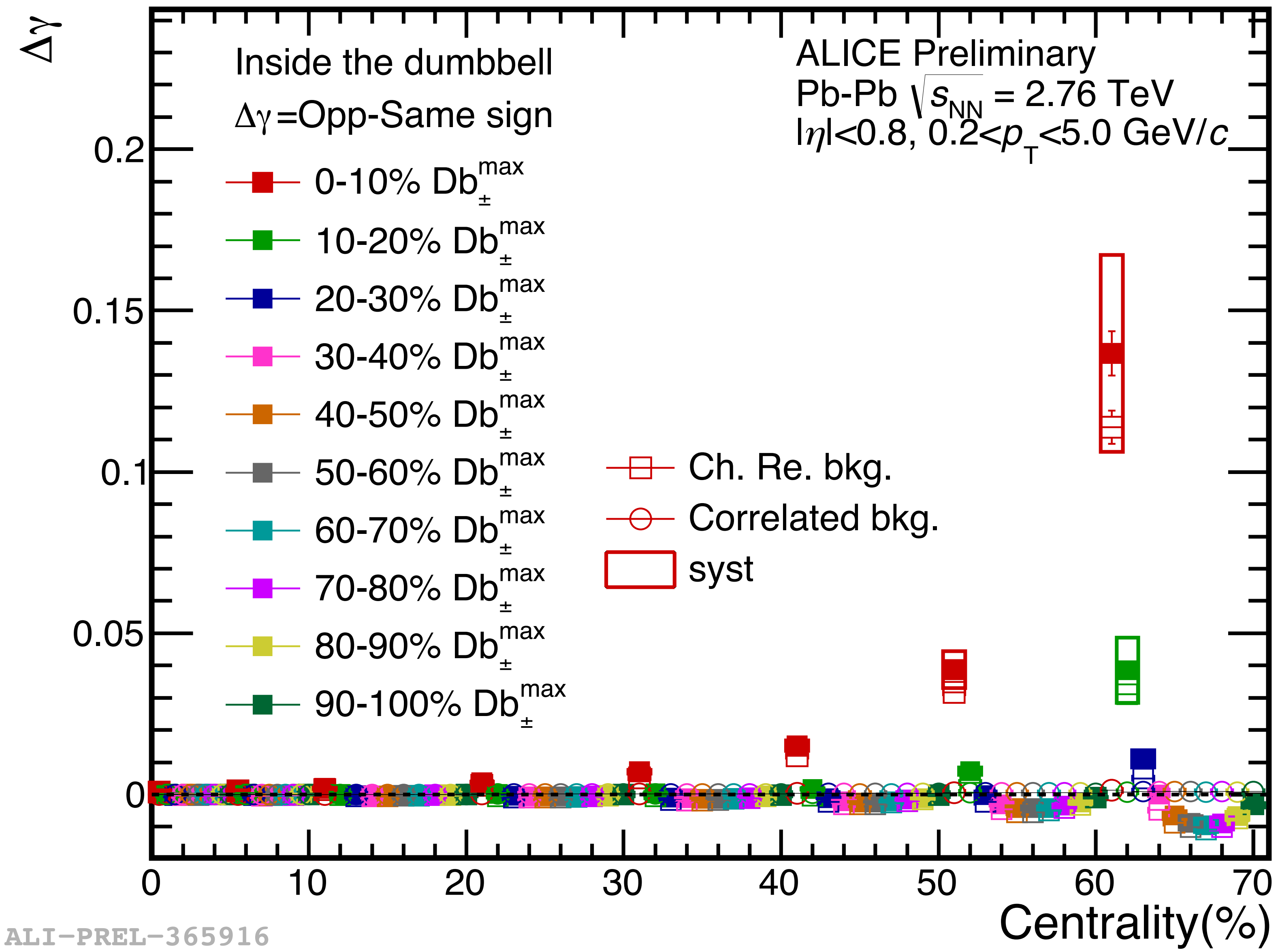
γ Inside dumbbell

Correlator values are further enhanced if we consider the particles inside the dumbbell only. $|\gamma_{OS}| \sim |\gamma_{SS}|$ for top $Db_{\pm}^{max}$ bins as expected for CME-like sample.





$\Delta\gamma = \gamma_{OppSign} - \gamma_{SameSign}$



Large correlation is observed in higher $Db_{\pm}^{max}$ bins where the sample of events with large charge separation has been extracted. Charge reshuffle shows similar dependences but with smaller magnitude while correlated background remains almost constant.

Summary

- It is observed that for top $Db_{\pm}^{max}$ bins $|\gamma_{OS}| \sim |\gamma_{SS}|$ as required for CME-like sample.

- Using SDM, we are able to extract the CME - like events corresponding to top (10-20%) $Db_{\pm}^{max}$ for a given centrality. The CME-like signal is significantly magnified (~40-150 times) if three-particle correlator is computed for particles inside the dumbbell only.

Thanks !

Back up

Background estimation :

Charge Reshuffle:

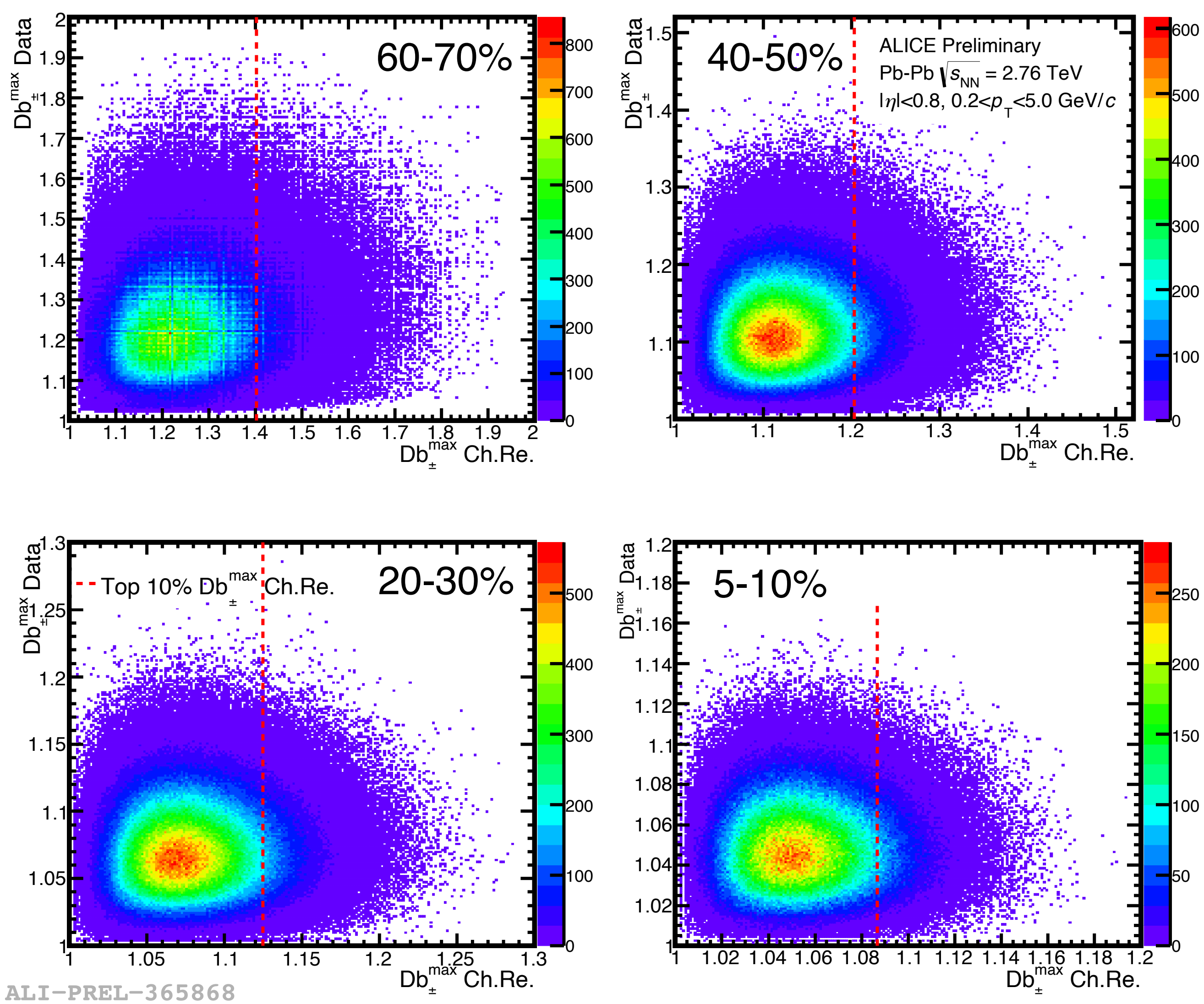
For background estimation, charges of particles are reshuffled randomly keeping (θ, ϕ) same to obtain charge reshuffle background leading to back-to-back charge separation statistically. This data set is treated in the same way as real data set.

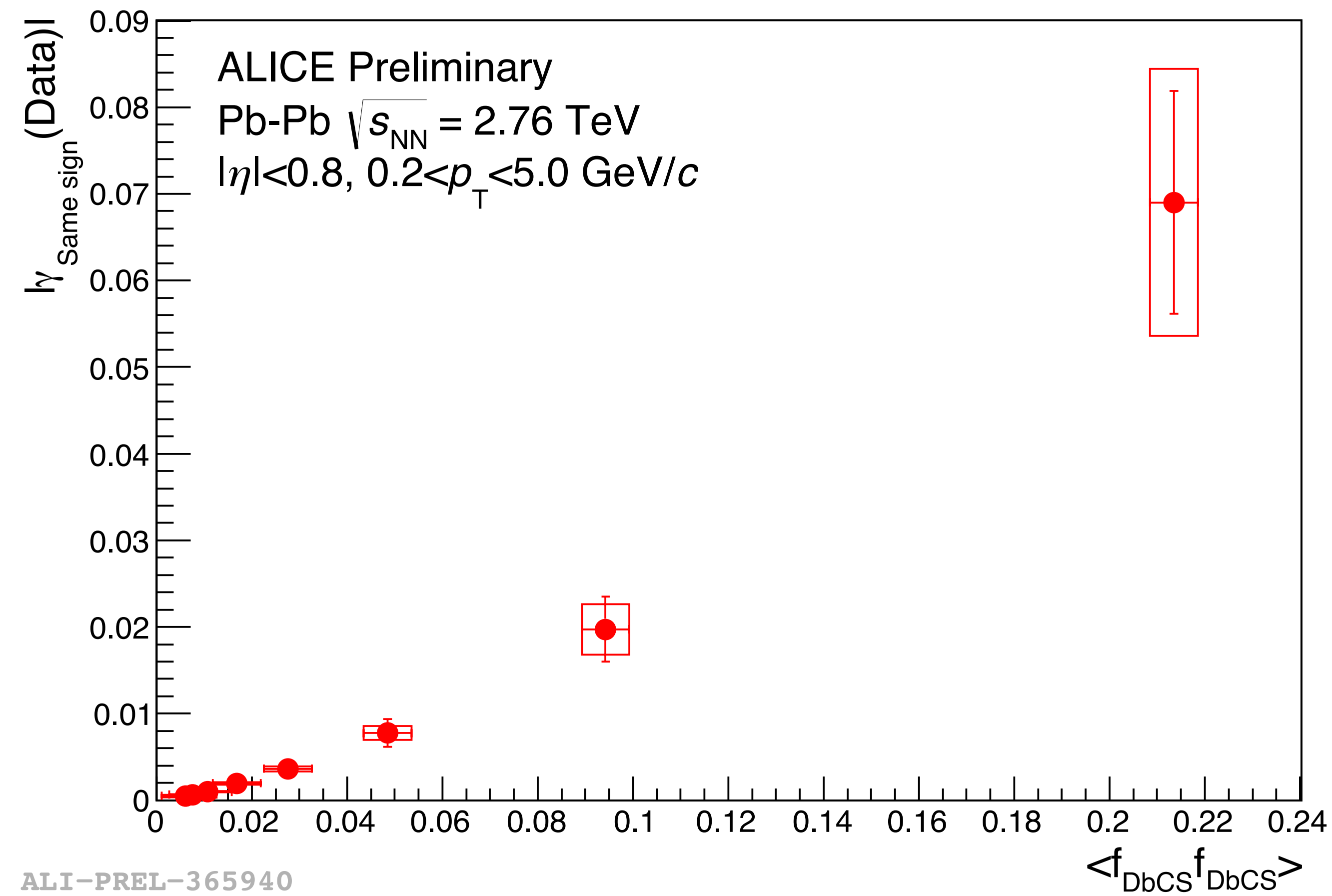
Correlated background:

Charge reshuffling kills not only the CME correlations but also correlations amongst produced particles in a collision. So we have taken the correlated background from original event itself corresponding to charge reshuffle. However, it should be noted that here $Db_{\pm}^{max}$ bins in charge reshuffle is different from $Db_{\pm}^{max}$ original event as will be shown in scatter plot of $Db_{\pm}^{max}$ charge reshuffle vs $Db_{\pm}^{max}$ data.

$$\gamma_{bkg.} = \gamma_{ch.re} + \gamma_{correlated}(original\ event)$$

Results





- **Left plot:** Scatter plot between $Db_{\pm}^{max}$ charge reshuffle versus data, and vertical line is drawn corresponding to top 10% $Db_{\pm}^{max}$ bin of charge reshuffle. From this plot it is clear that for top $Db_{\pm}^{max}$ bin of charge reshuffle, data $Db_{\pm}^{max}$ can take any value.

- **Right Plot :** $|\gamma_{SameSign}(Data)|$ seems to vary approximately linearly with $< f_{DbCS} f_{DbCS} >$.