Spectator Plane Tutorial

O2 Analysis tutorial 5.0

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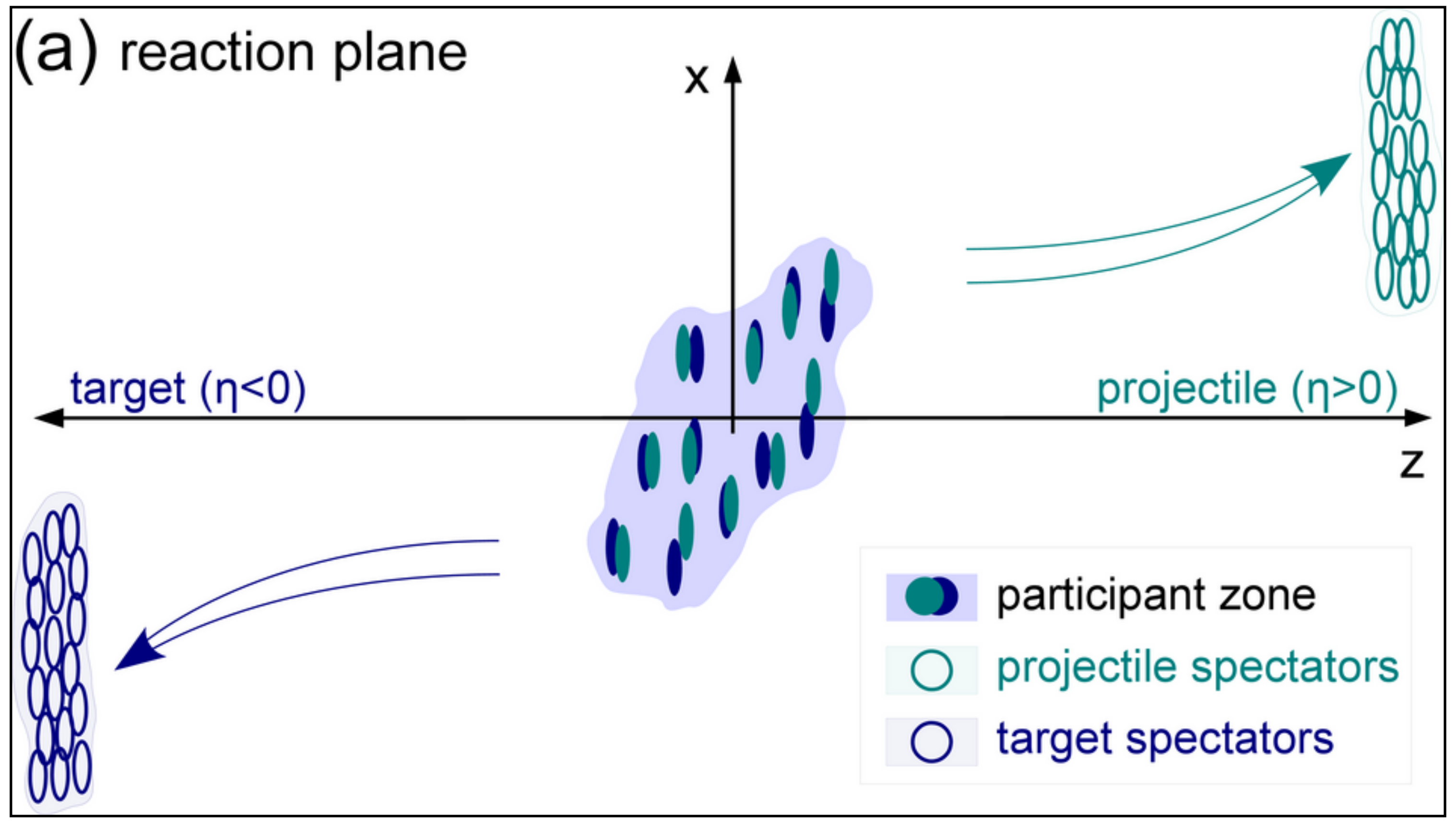
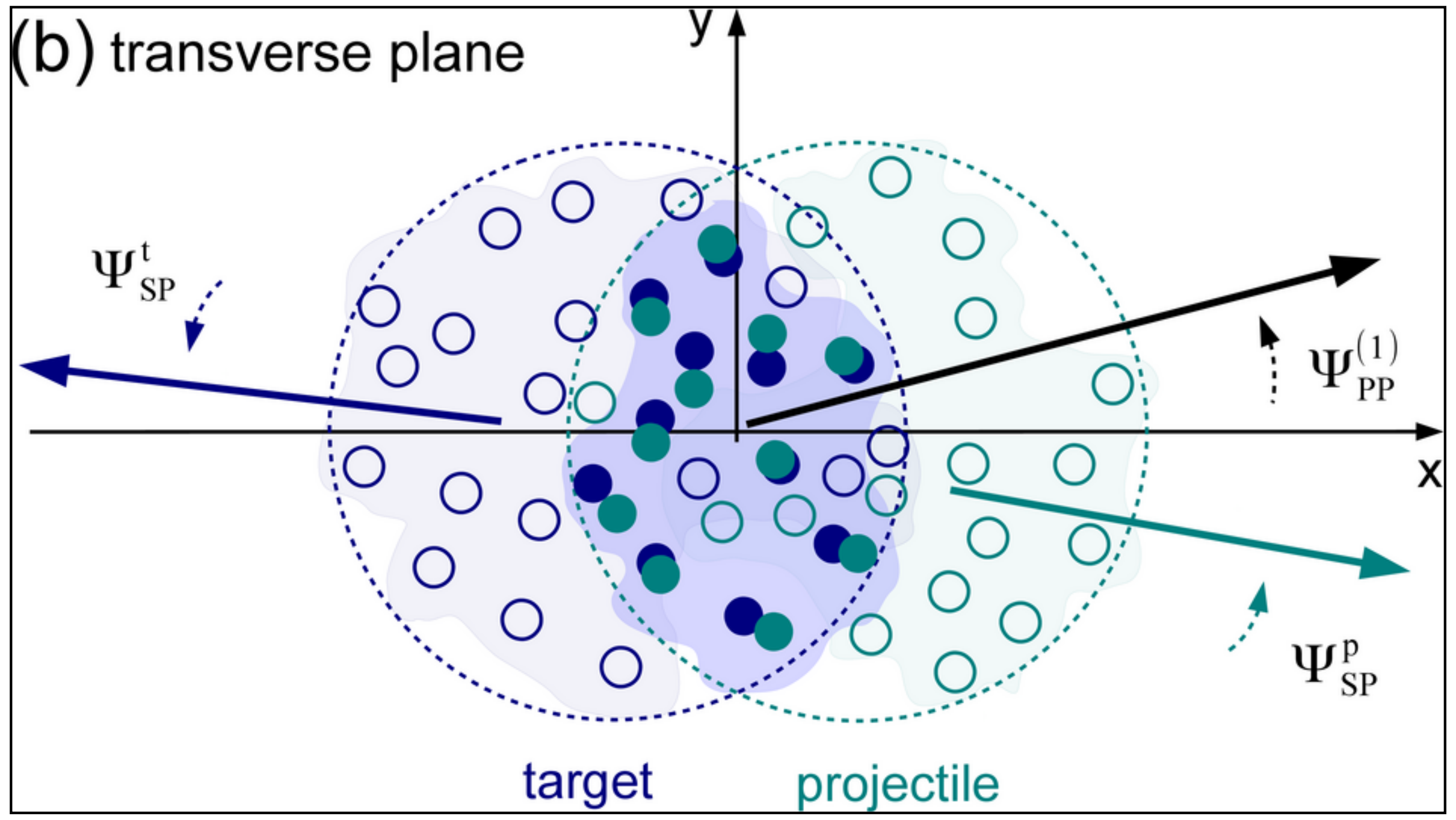
Spectators in Heavy-ion Collisions

- Nucleons that don't participate in the collision
- Correlated with the reaction plane
- Different from participant symmetry plane
- Participants detected with the Zero Degree Calorimeters



Momentum transfer with participants causes deflection of spectators from interaction zone



Two spectator planes from target and projectile nuclei

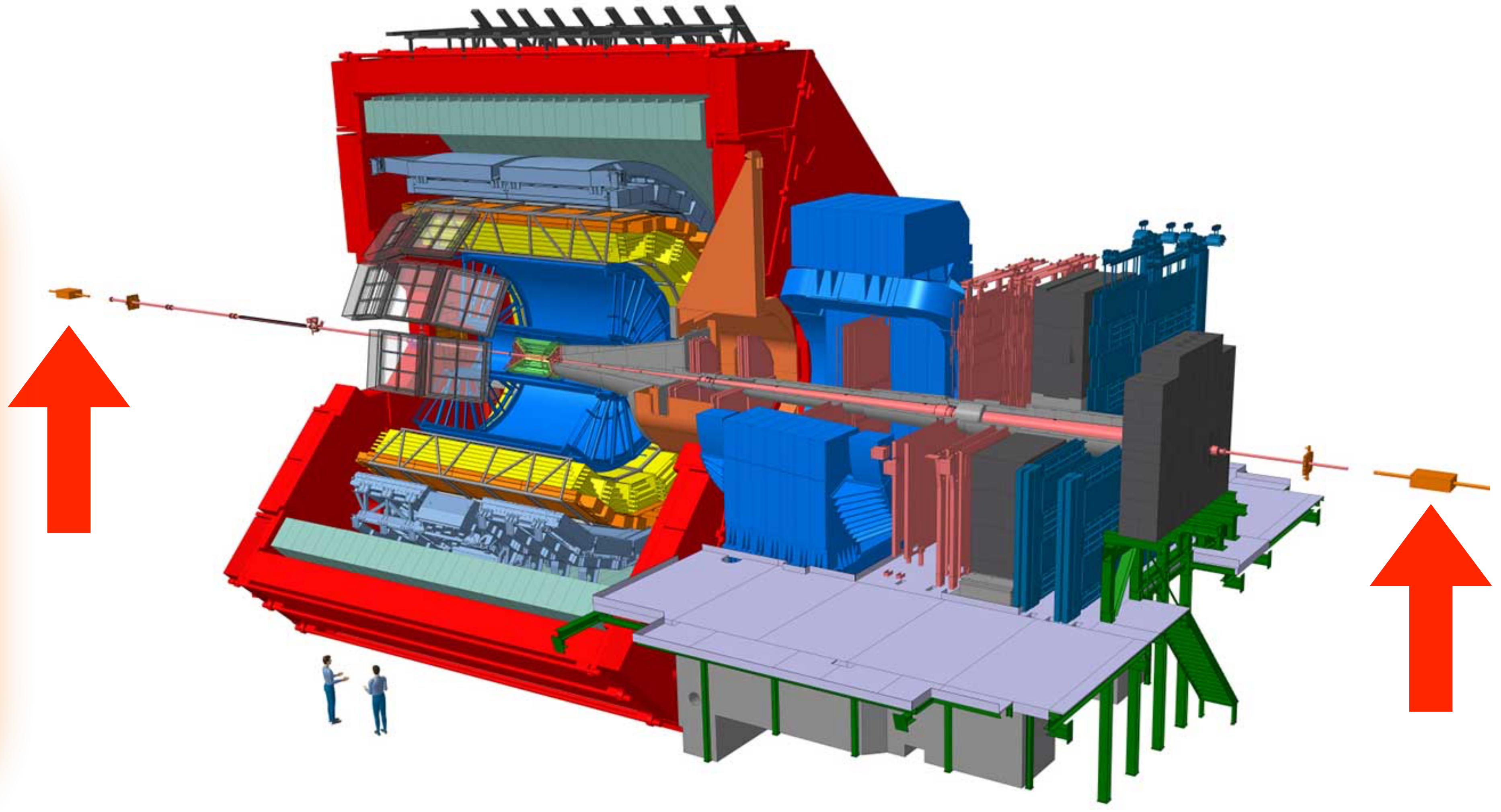
Phys. Rev. Lett. 111 (2013) 232302

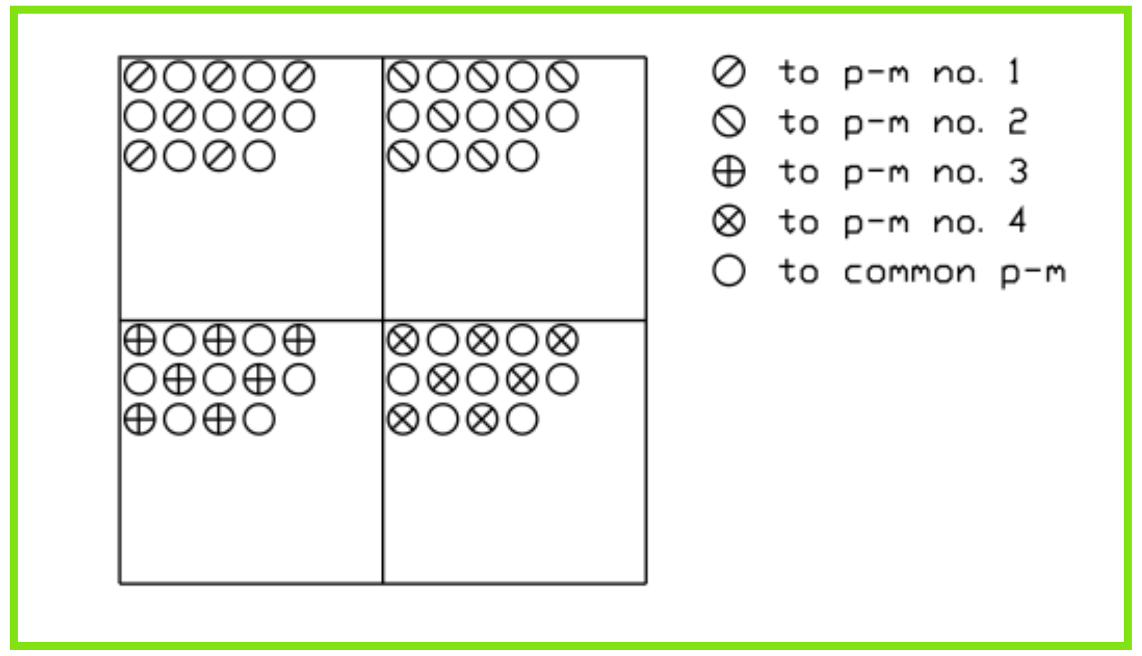
The ALICE Zero Degree Calorimeters

- Charged spectators ca be deflected by magnetic field into proton ZDC
- Neutrons don't feel magnetic field and can be separated from protons in neutron ZDC (ZN)
- Two ZNs consist of 4 towers and 1 common channel
- Spatial resolution to reconstruct spectator plane!

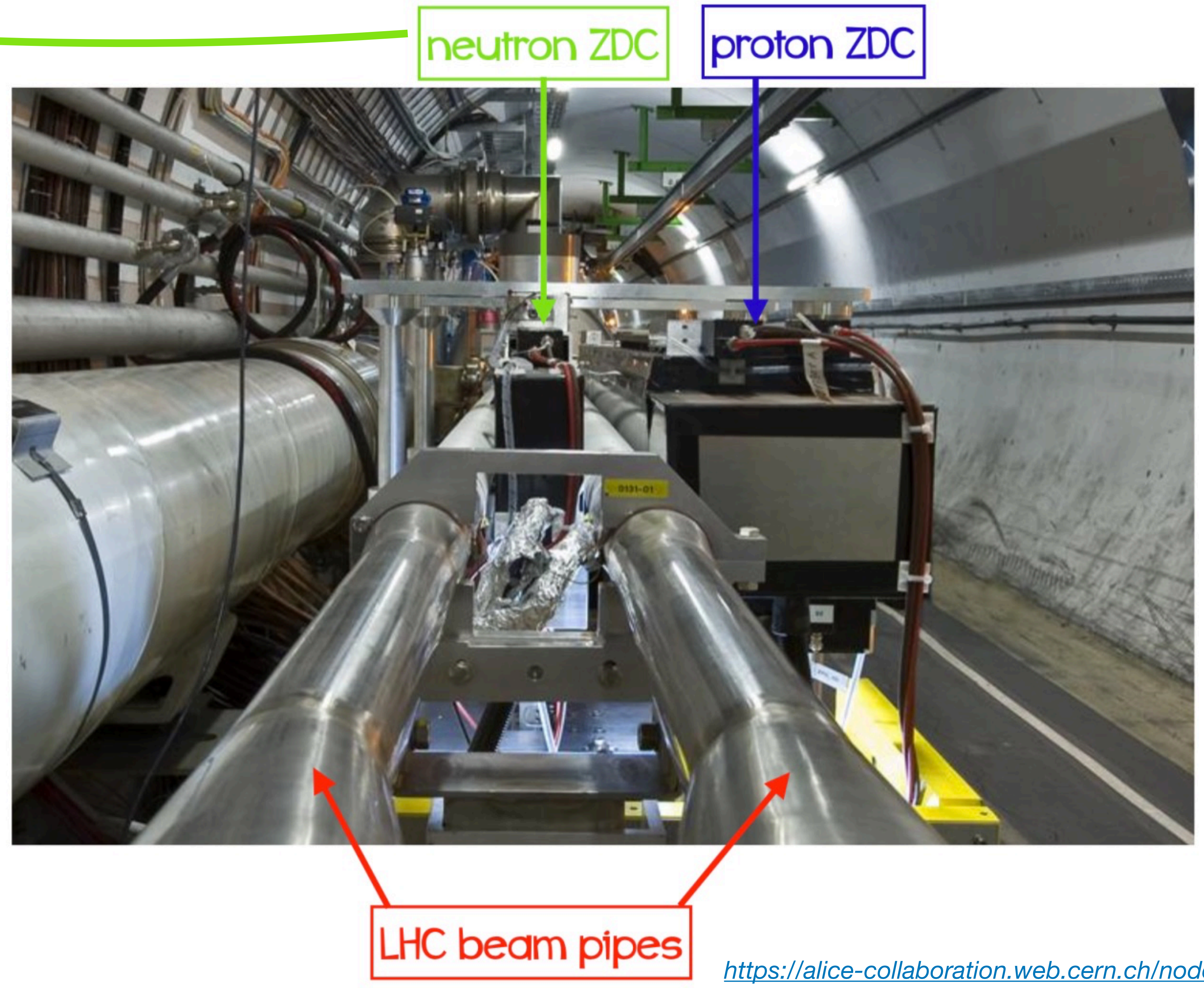
In O2Physics: (link)

- Table: `o2::aod::Zdcs`
- Information is linked to BC
  - Use `bc.has_zdc()`
- Common channels (ZDC-N or ZN)
  - `energyCommonZN(A/C)`
- Four towers -> [E1,…,E4]
  - `energySectorZN(A/C)`
- A ($\eta > 0$) and C ($\eta < 0$) are the different sides of the detector!





https://cds.cern.ch/record/381433/files/Alice-TDR.pdf



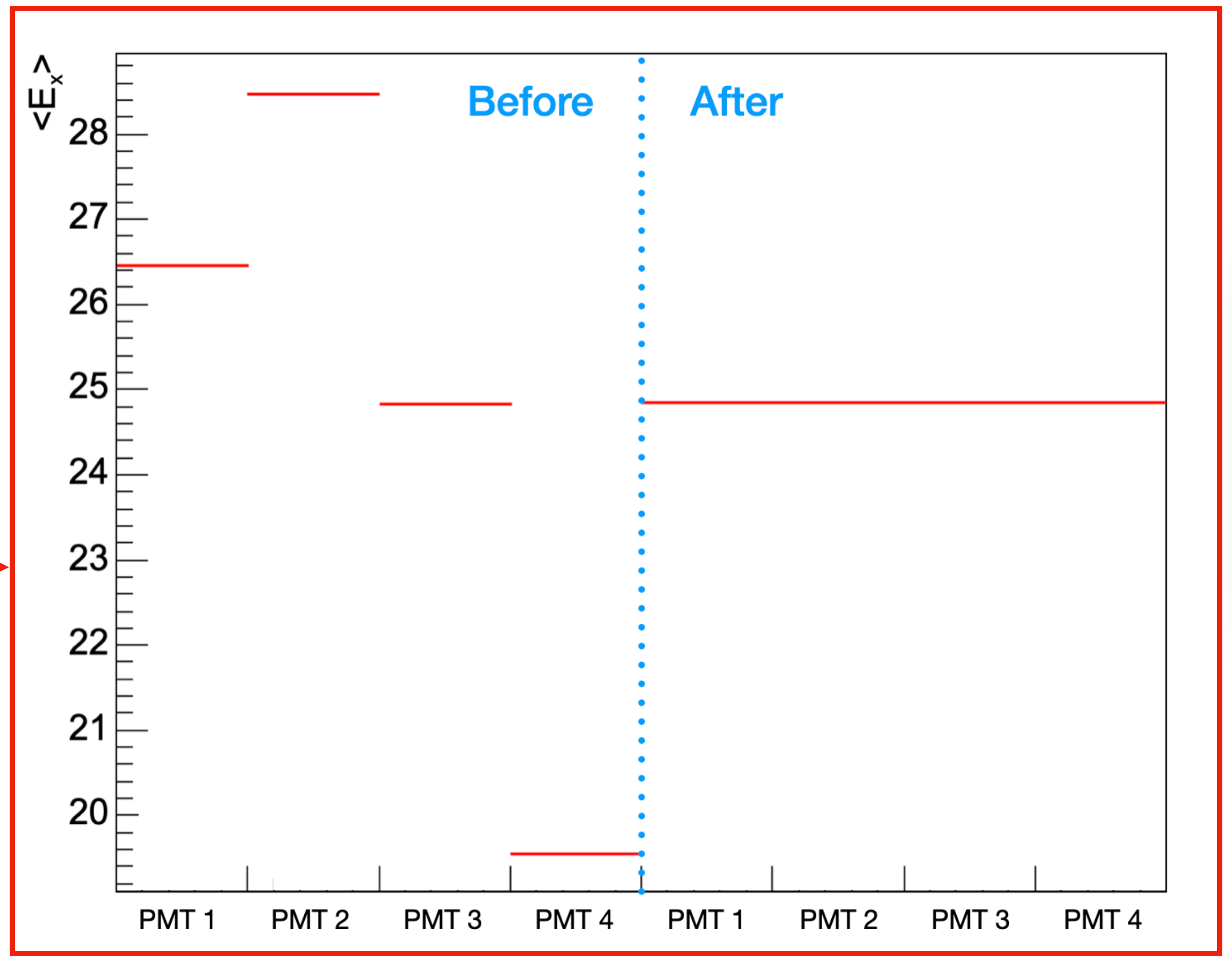
https://alice-collaboration.web.cern.ch/node/34995

Reconstructing the spectator plane

Constructing the ZDC Q-vectors

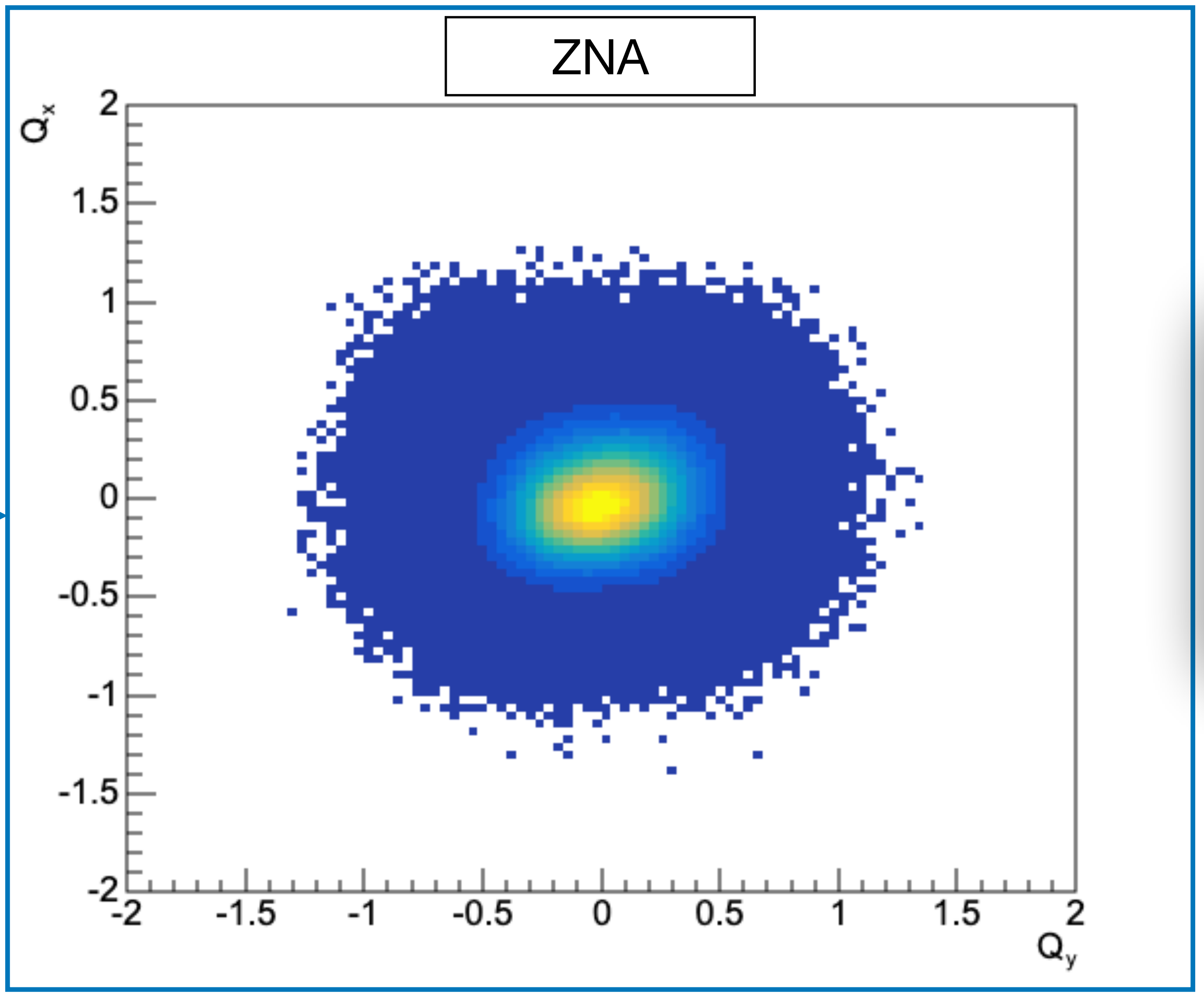
- Information from 8 ZN $(2 \times (4 + \text{Common}))$

1. For each side equalize gain per channel in 1% centrality bins
   - $E_i^{eq} = E_i \times \dfrac{\frac{1}{4}\langle E_{com}\rangle}{\langle E_i\rangle}$



For $\langle E_{com}\rangle$ and $\langle E_i\rangle$ see **L785-799** in **zdcQvectors.cxx**
Average taken in 1% centrality bins

2. Determine Q-vector in ZNA(C)
   - $\vec{Q}_{A,C} = \dfrac{\sum_{i=1}^{4} \vec{p}_i \left(E_{A,C}\right)_i^a}{\sum_{i=1}^{4} \left(E_{A,C}\right)_i^a}$
   - Where $\vec{p}$ are the x,y-coordinates of the tower centers and α is a saturation factor from previous MC studies (link)



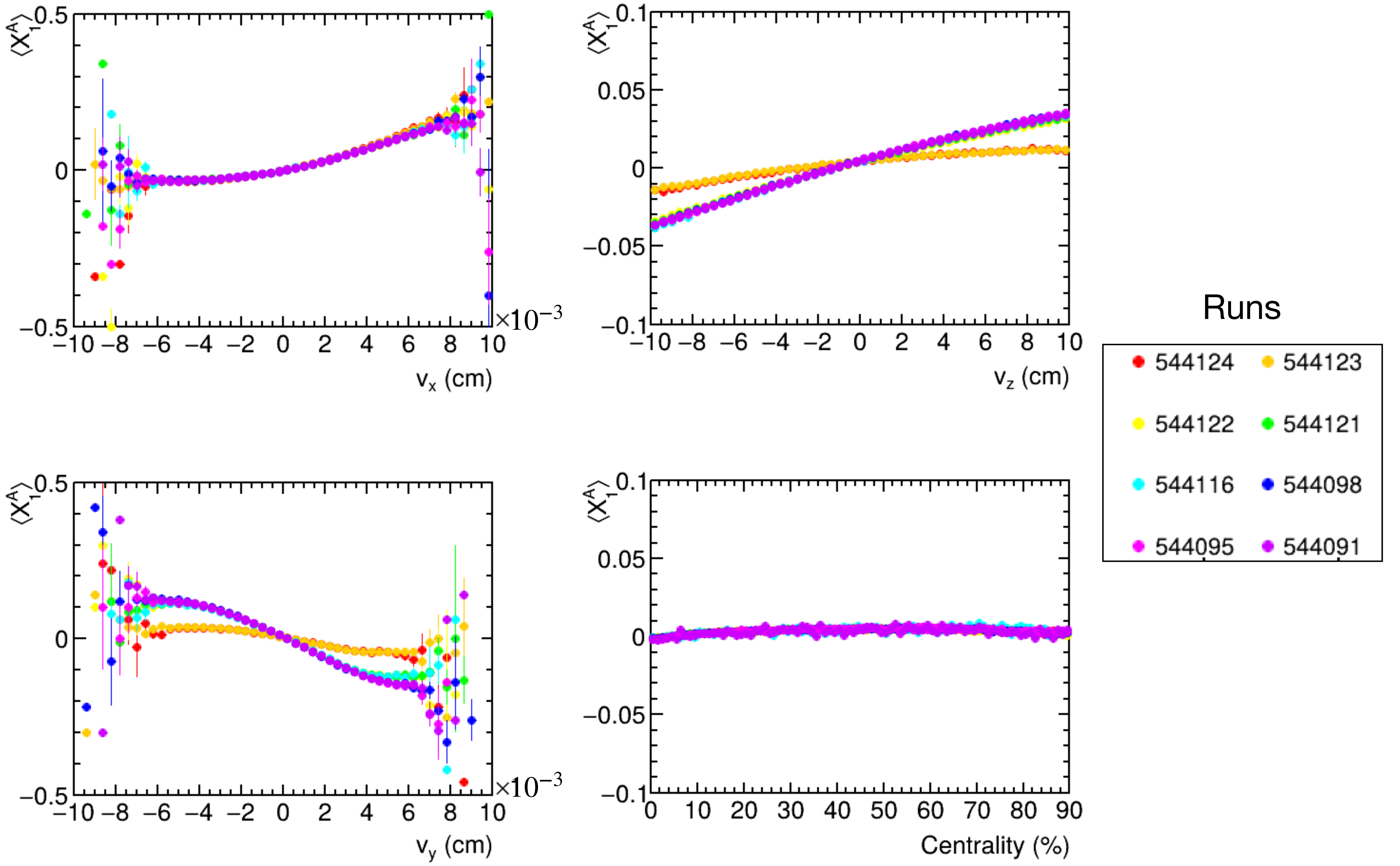
Q-vectors calculated in **L894-921** of **zdcQvectors.cxx**

Recentering the Q-vectors

In histogram registry:
- hQXA_vs_cent
- hQXA_vs_vx
- hQXA_vs_vy
- hQXA_vs_vz

x-component of Q-vector ZNA

- The location of the neutron spot depends on the beam and event properties that vary on a run-by-run and event-by-event basis
  - Individually recenter Q-vectors to get unbiased estimate of spectator plane!
- Recenter Q-vectors per run as a function of
  - Collision vertex (v_x, v_y, v_z)
  - Centrality
- $Q^{rec}_{A,C} = Q_{A,C} - \langle Q_{A,C} \rangle$

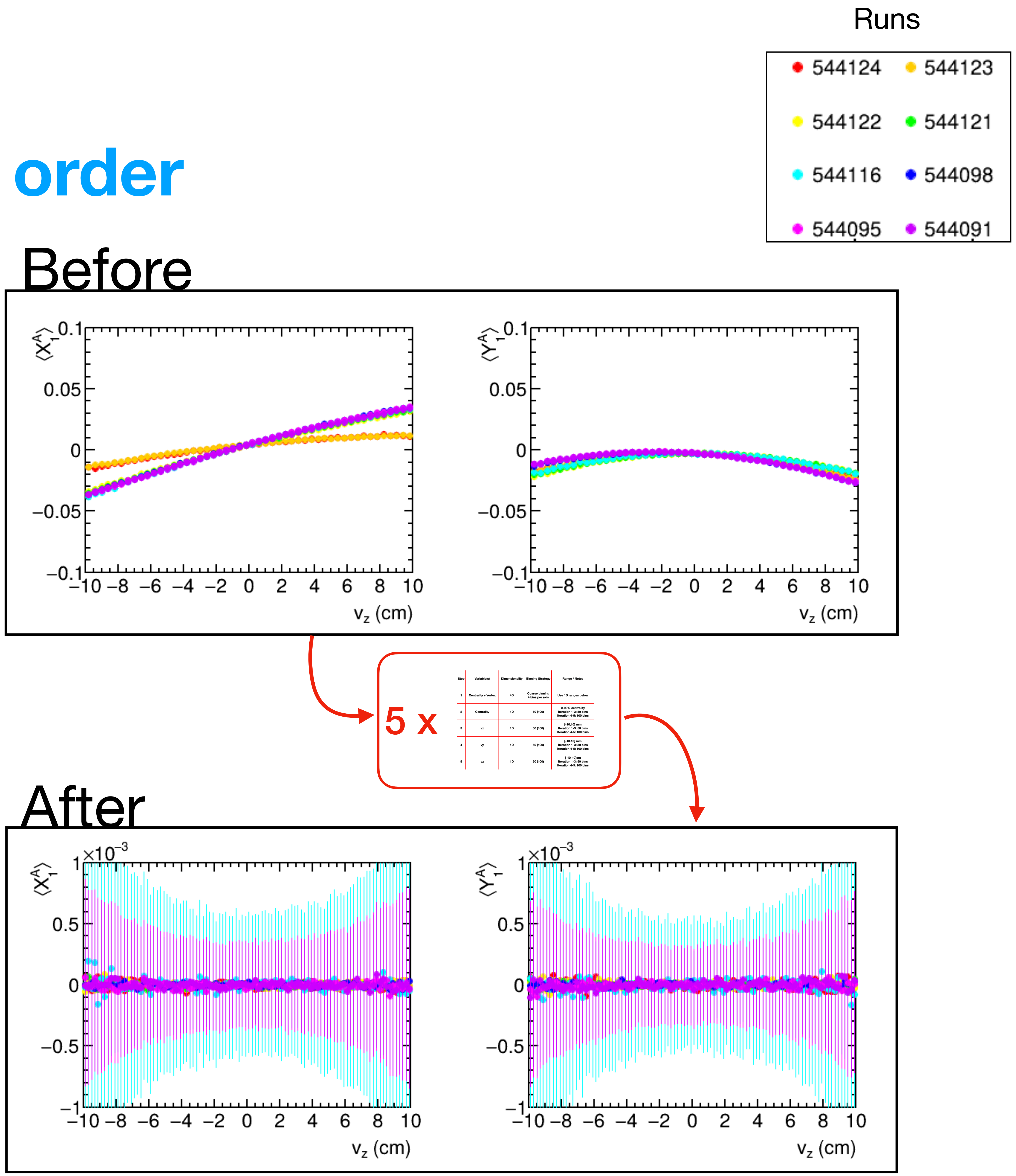


Done offline with derived data! And uploaded to CCDB

Recentering procedure

Perform five iterations in consecutive order

Step	Variable(s)	Dimensionality	Binning Strategy	Range / Notes
1	Centrality + Vertex	4D	Coarse binning 4 bins per axis	Use 1D ranges below
2	Centrality	1D	50 (100)	0-90% centrality Iteration 1-3: 50 bins Iteration 4-5: 100 bins
3	vx	1D	50 (100)	[-10,10] mm Iteration 1-3: 50 bins Iteration 4-5: 100 bins
4	vy	1D	50 (100)	[-10.10] mm Iteration 1-3: 50 bins Iteration 4-5: 100 bins
5	vz	1D	50 (100)	[-10-10]cm Iteration 1-3: 50 bins Iteration 4-5: 100 bins

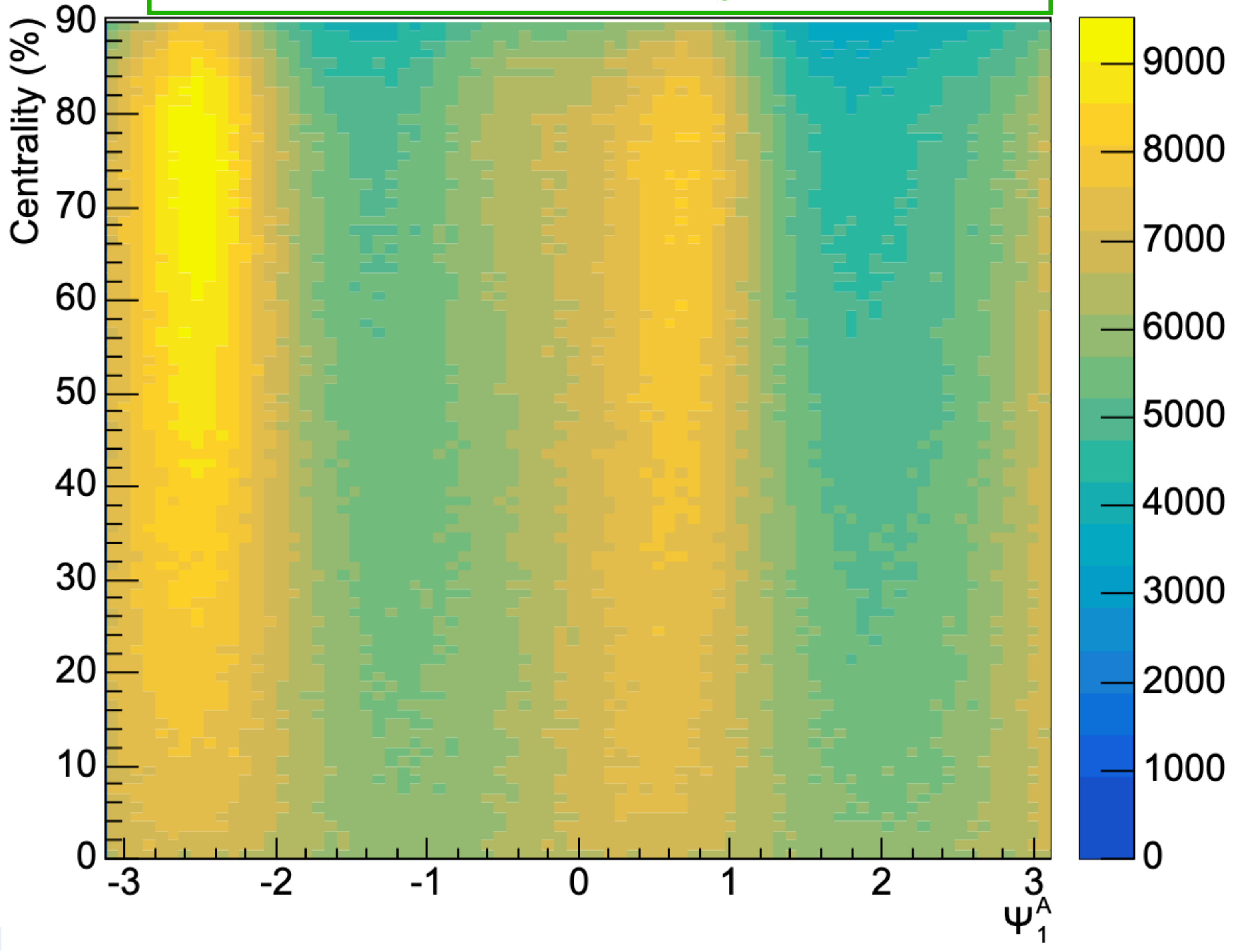


Spectator plane

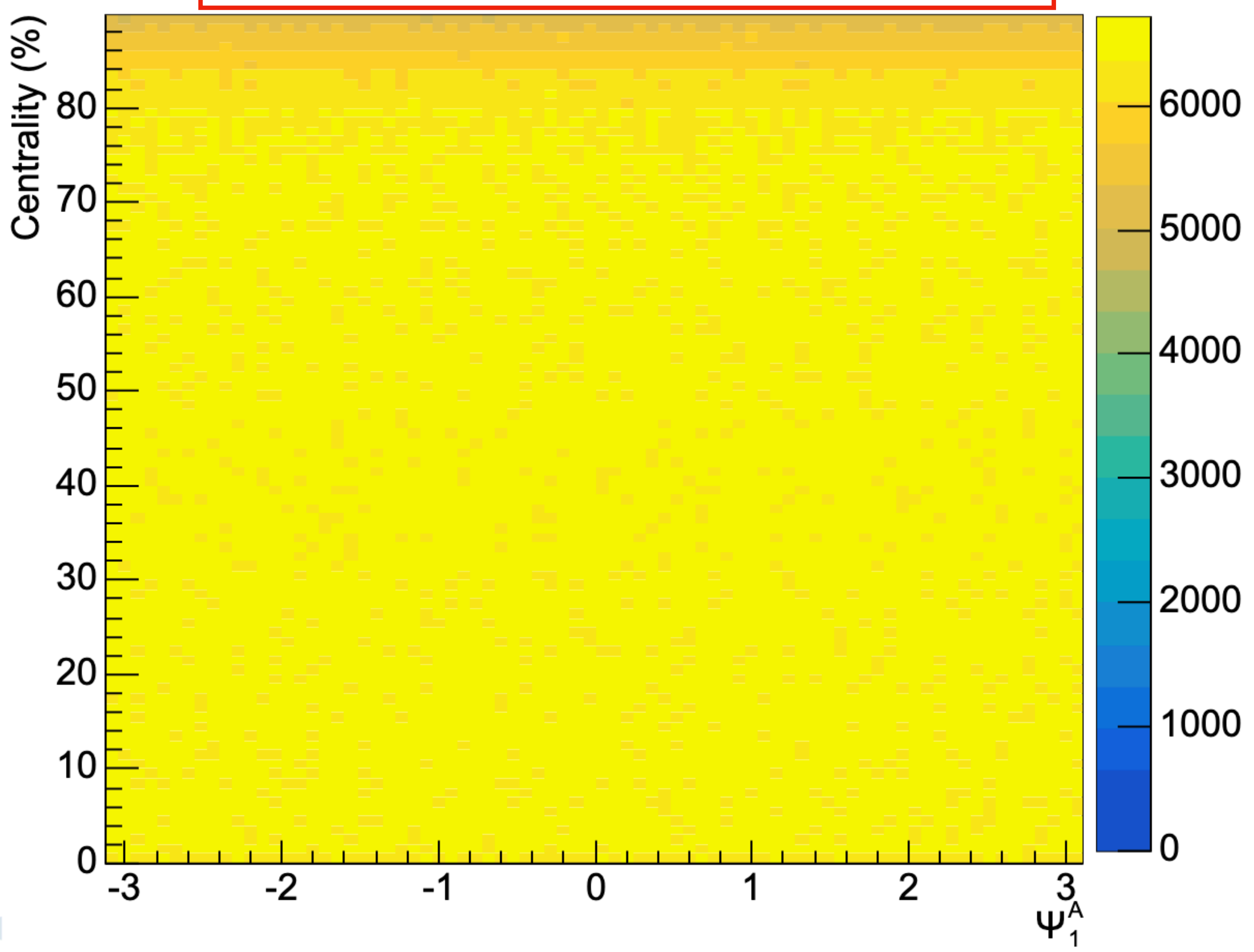
Reconstruct from recentered Q-vectors

- The spectator plane is calculated using
  - $\Psi_1^{A,C} = \operatorname{atan2}\left(Q_y^{A,C}, Q_x^{A,C}\right)$
- Because the orientation of the collisions is random, we expect Ψ to be **flat**
- Use event-by-event **shift correction** to flatten spectator plane distribution (L1035-1098)

Clear modulation remains after recentering

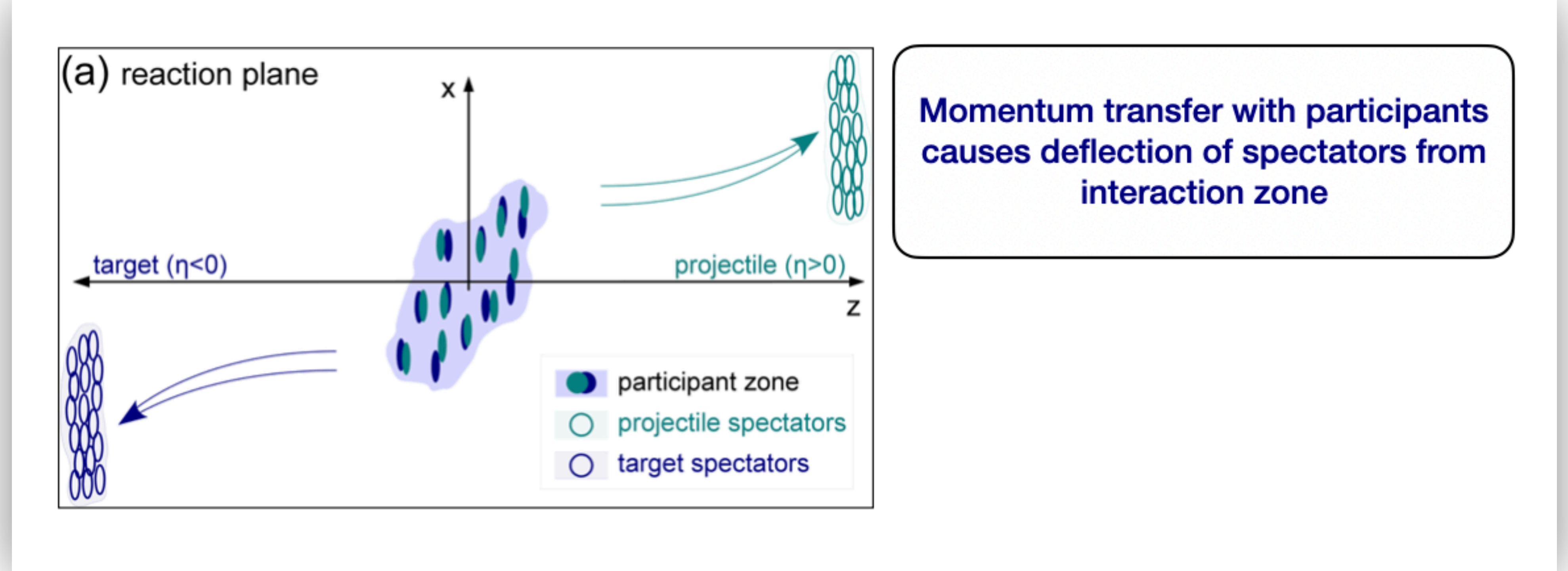


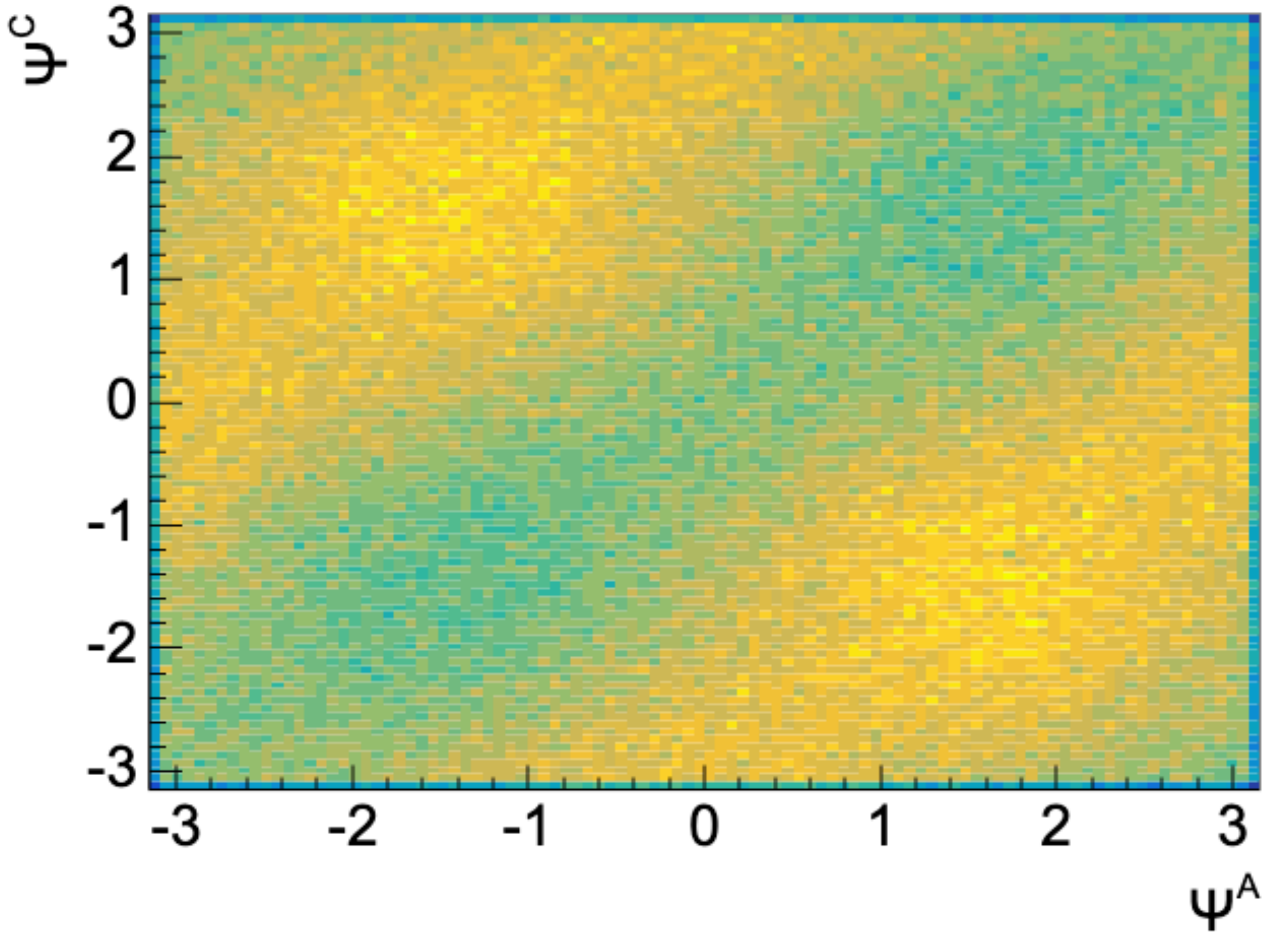
Distribution is flat after shift correction



Correlations between A and C

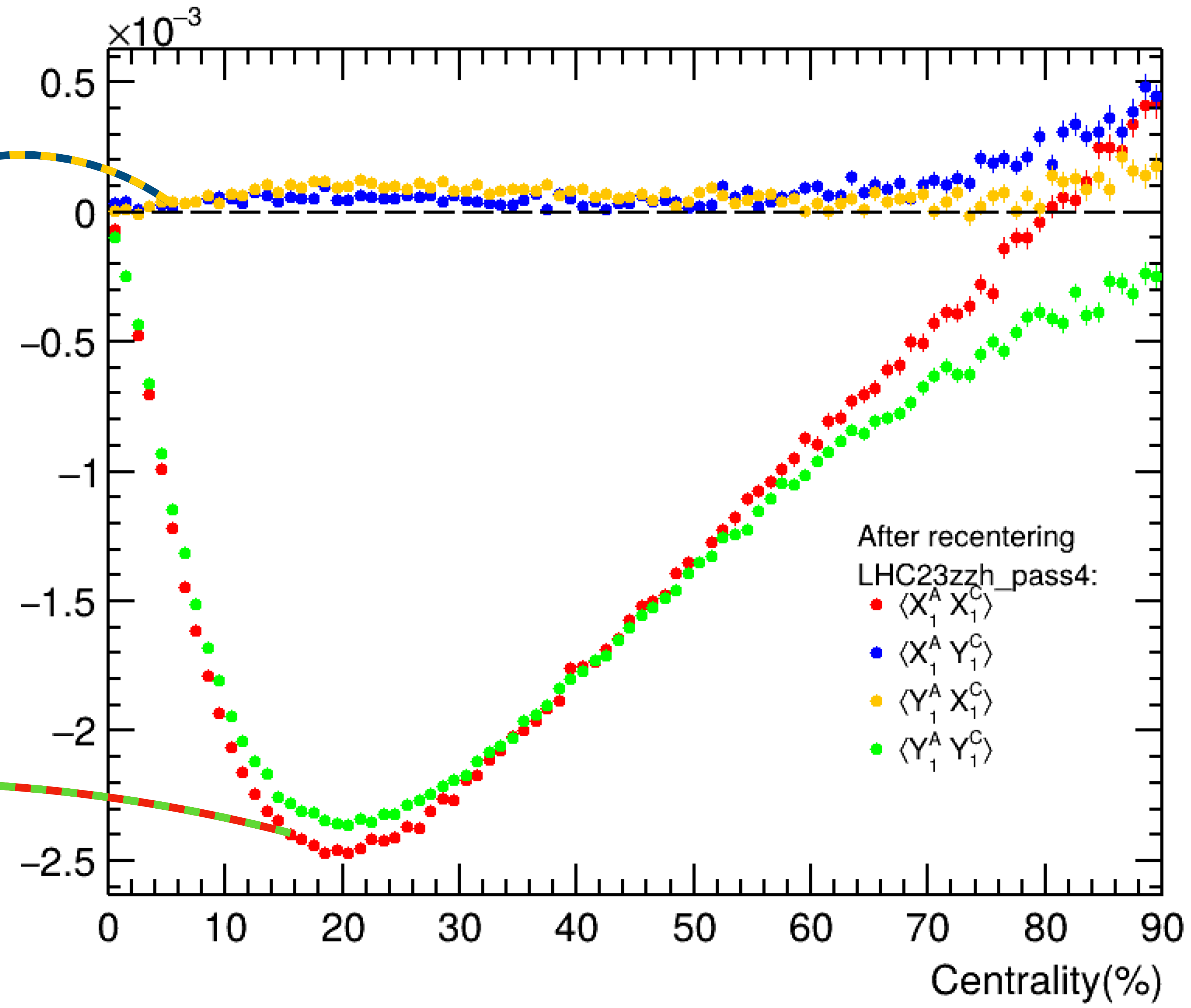
Remember





- Cross terms expected to be zero

- $\langle X_1^A X_1^C \rangle$ and $\langle Y_1^A Y_1^C \rangle$ expected to be the same



Structure of the ZDC Q-vector task + table

PWGCF/DataModel/SPTableZDC.h

- Table contains
  - **Runnumber**
  - **Cents** → vector of floats that can hold multiple centrality estimators
  - **Vertex** → vector with v_x, v_y and v_z
  - **Timestamp**
  - **QxA** → x-component of ZNA Q-vector
  - **QyA** → y-component of ZNA Q-vector
  - **QxC** → x-component of ZNC Q-vector
  - **QyC** → y-component of ZNC Q-vector
  - **IsSelected** → Flag to check if there was signal in the ZNs
  - **EventSelectionFlags** → Bits to hold passed event selections
- For each event iterated over in the table produce, the table needs to be filled. If not, you cannot join it with other tables later in the analysis!
- To create and fill table
  - `#include "PWGCF/DataModel/SPTableZDC.h"`
  - In Struct: `Produces<aod::SPTableZDC> spTableZDC;`
  - `spTableZDC(runnumber, cents, v, foundBC.timestamp(), q[0], q[1], q[2], q[3], isSelected, eventSelectionFlags);`

PWGCF/Flow/TableProducer/zdcQVectors.cxx

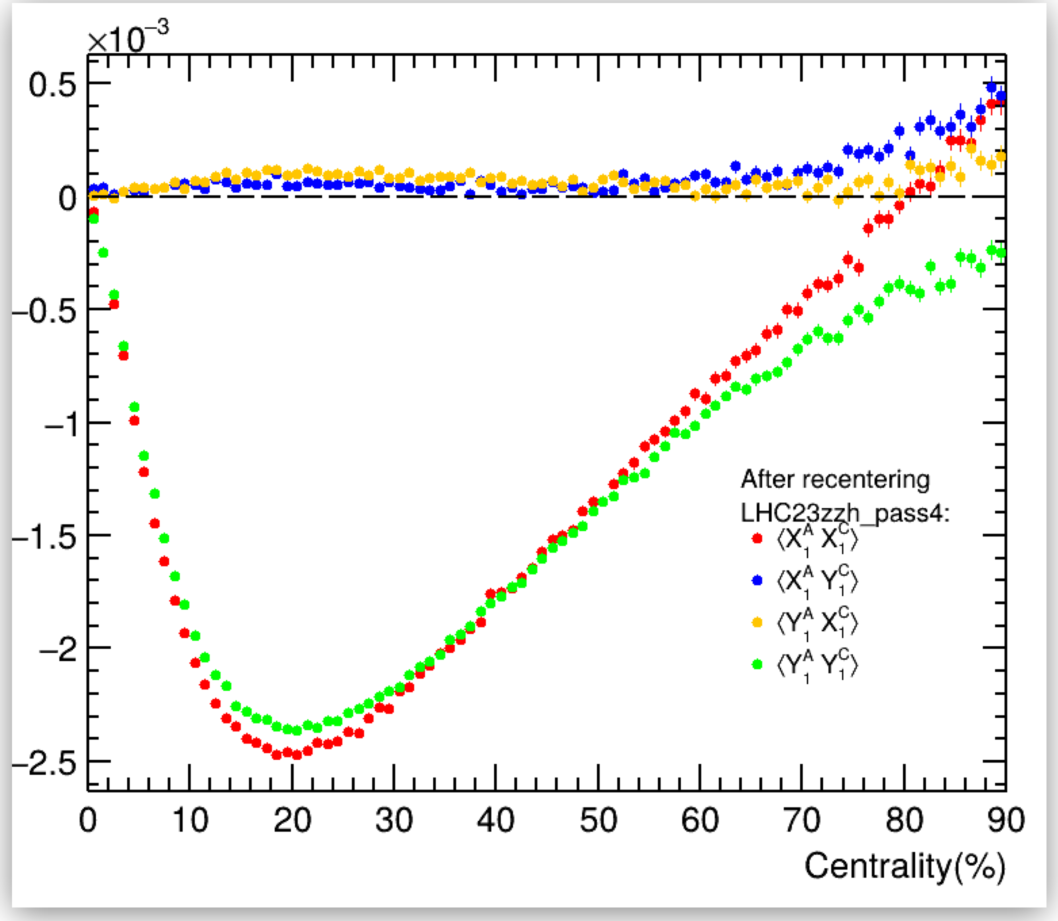
- Important configurables
  - **cfgEnergyCal: “Users/c/ckoster/ZDC/<period>/Energy”**
  - **cfgMeanv: “Users/c/ckoster/ZDC/<period>/Vertex”**
  - **cfgRec: “Users/c/ckoster/ZDC/<period>”**
- These hold the CCDB paths for the calibration histograms, leave them empty and the recentering will NOT be performed! Instead CCDB histograms will be filled.
- Shift correction is applied after the recentering, to include it in the analysis
  - **cfgShift: “Users/c/ckoster/ZDC/<period>/Shift”**
- **IMPORTANT:** Calibrations for 2023 are available, 2024 is still in progress.
- To use table
  - `#include "PWGCF/DataModel/SPTableZDC.h"`
  - `soa::Filtered<soa::Join<aod::Collisions aod::SPTableZDC>>;`
  - Access table contents by using: `collision.<..>()`
  - Example task: `PWGCF/Flow/Tasks/flowSP.cxx`
  - Run `o2-analysis-cf-zdc-q-vectors` as a helper task in your `run.sh`

Using the spectator plane in flow calculations

Scalar Product Method

$\langle x_1^A x_1^C \rangle$ and $\langle y_1^A y_1^C \rangle$ averaged in 1% centrality bins
$\langle x_n^T \ldots \rangle$ and $\langle y_n^T \ldots \rangle$ averaged over all events

- Scalar product methods for Directed Flow
- $$v_1\left\{\Psi_1^{A,C}\right\} = \frac{\left\langle \vec{u_1} \cdot \vec{Q}_1^{A,C} \right\rangle}{\sqrt{\left|\left\langle \vec{Q}_1^A \cdot \vec{Q}_1^C \right\rangle\right|}} = \frac{\left\langle x_1^T x_1^{A,C} + y_1^T y_1^{A,C} \right\rangle}{\sqrt{\left|\left\langle x_1^A x_1^C + y_1^A y_1^C \right\rangle\right|}}$$ [1]
- For elliptic flow we can use the Scalar Product Method for mixed harmonics
- $$v_2\{\Psi_1\} = \frac{2}{3}\left(\frac{\langle x_2^T x_1^A x_1^C \rangle}{\langle x_1^A x_1^C \rangle} - \frac{\langle x_2^T y_1^A y_1^C \rangle}{\langle y_1^A y_1^C \rangle} + \sqrt{\frac{\langle y_2^T x_1^A y_1^C \rangle \langle y_2^T y_1^A x_1^C \rangle}{\langle x_1^A x_1^C \rangle \langle y_1^A y_1^C \rangle}}\right)$$ [2,3]
- Where $\langle \ldots \rangle$ denotes averages over all events, $\vec{u_i} = (x_i^T, y_i^T) = (\cos(i\varphi), sin(i\varphi))$ is the unit flow vector of your particle of interest and $\vec{Q}_1^{A,C} = (x_1^{A,C}, y_1^{A,C})$ the ZN Q-vectors.



Tutorial exercises

Tutorials/PWGCF/EventPlane/src/spectatorPlaneTutorial.cxx

- Run the tutorial task
- Open the AnalysisResults.root file and check the output
- Add the missing histograms to have both A and C side information