LHCB UPGRADE I CALORIMETER RECONSTRUCTION

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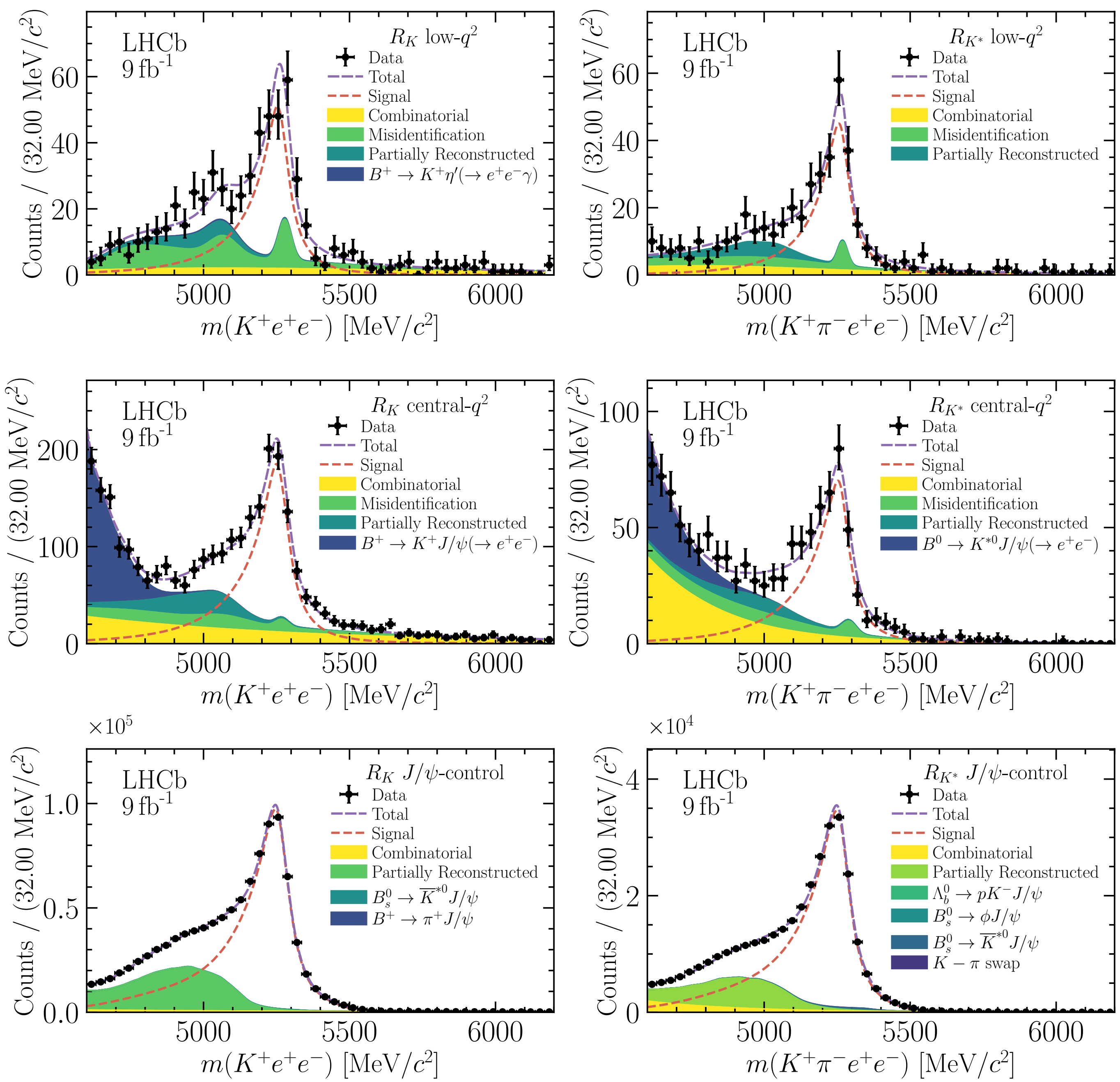
Physics motivation

- Extending searches of **Lepton Flavour Universality** (LFU) particularly in $b \to s\ell^+\ell^-$ is one of the main goals
- Have an efficient and precise e (and γ) identification is **fundamental**



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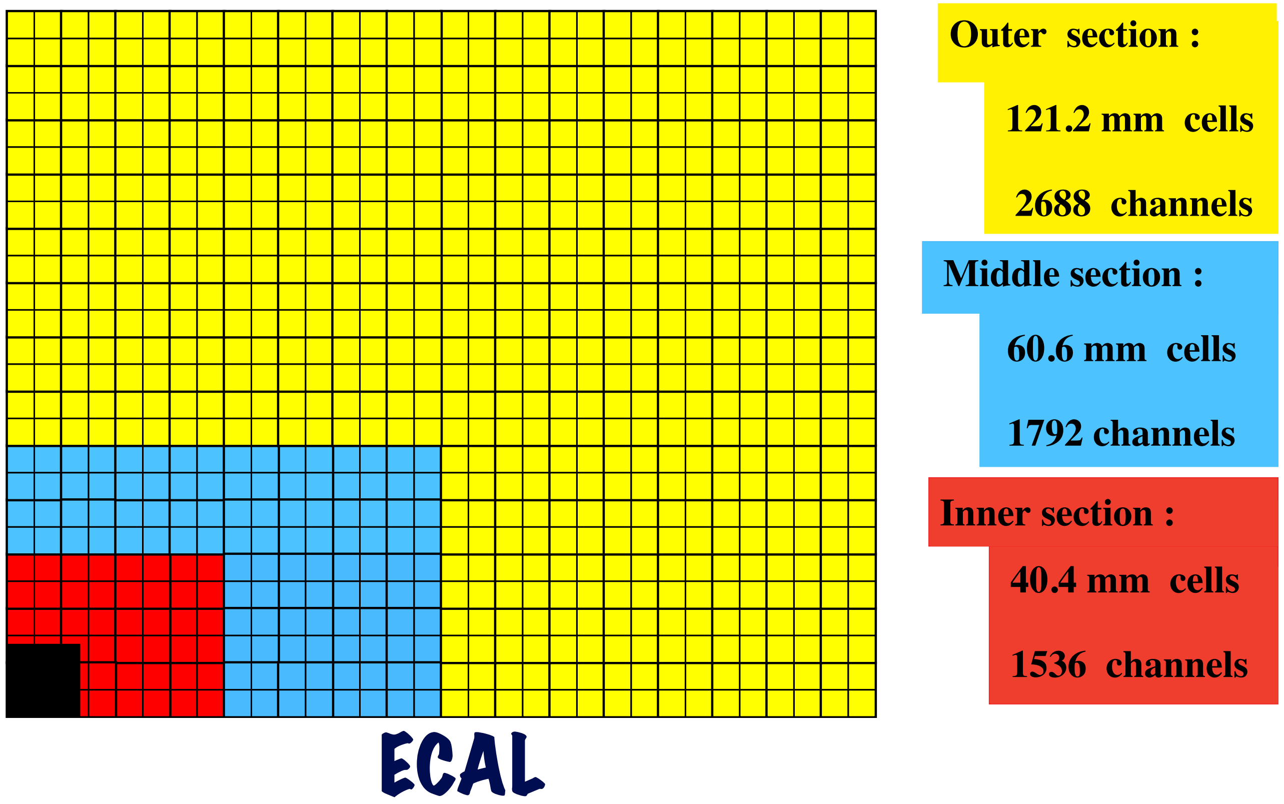
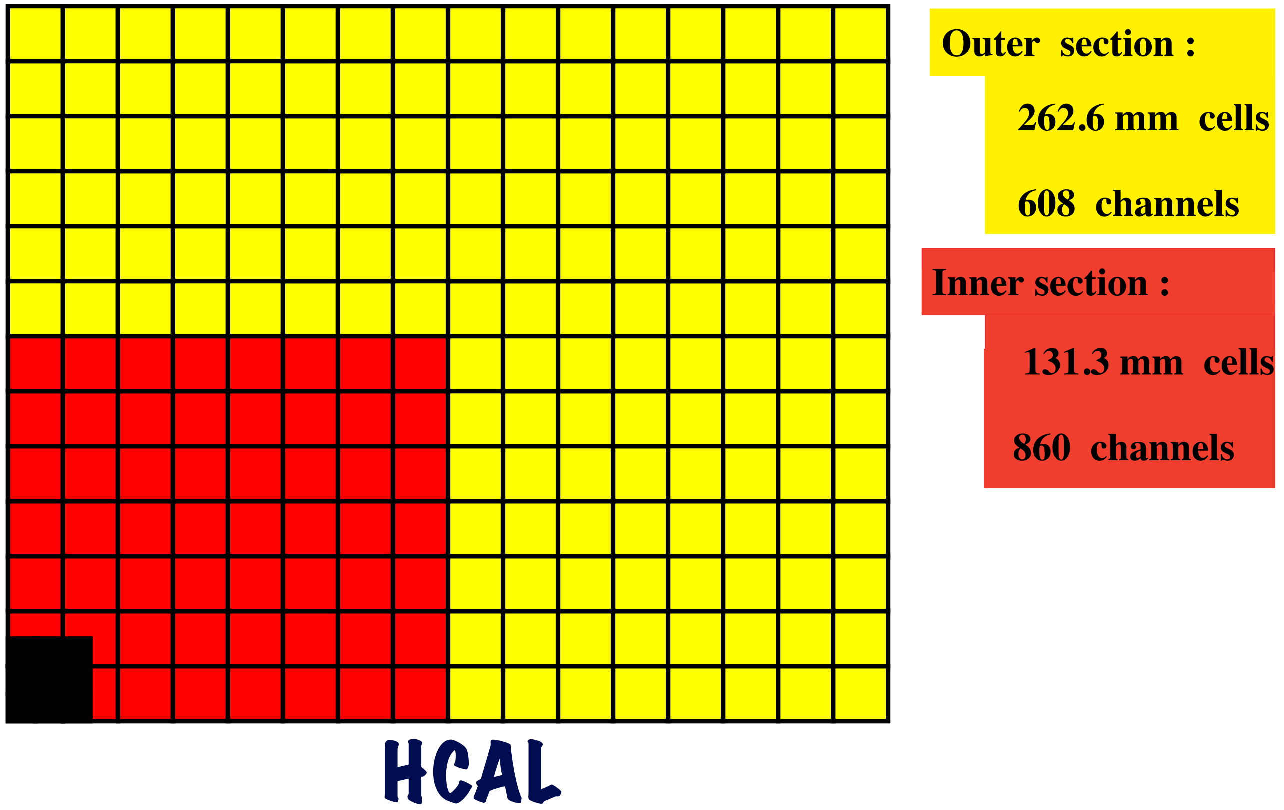
LHCb Upgrade I calorimeters

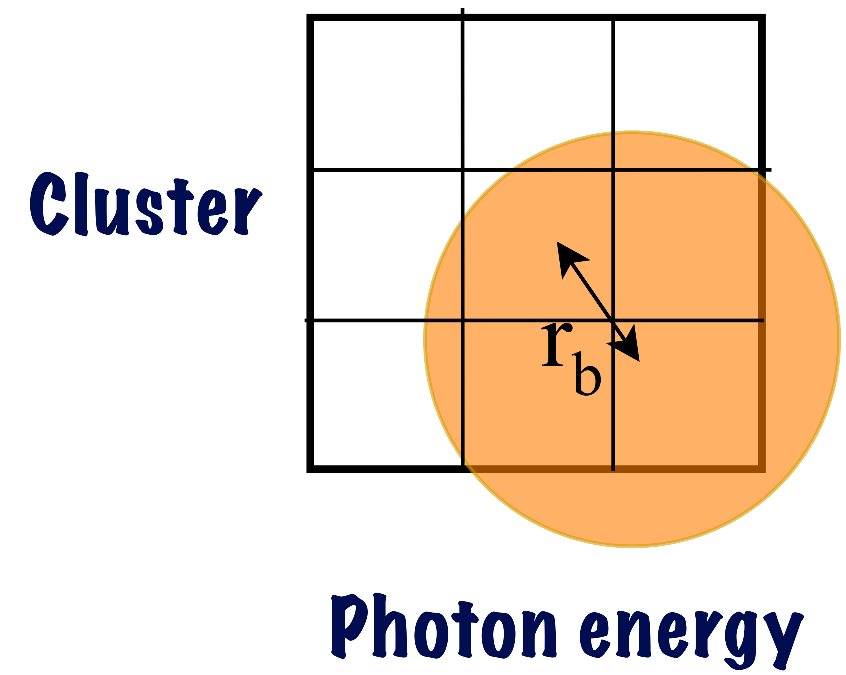
- The electronic calorimeter (ECAL) is composed by modules of lead absorber and plastic scintillator
- Considering the cell size, the ECAL is divided in three regions
  - The hadronic (HCAL) one has only two regions





LHCb calorimeter reconstruction

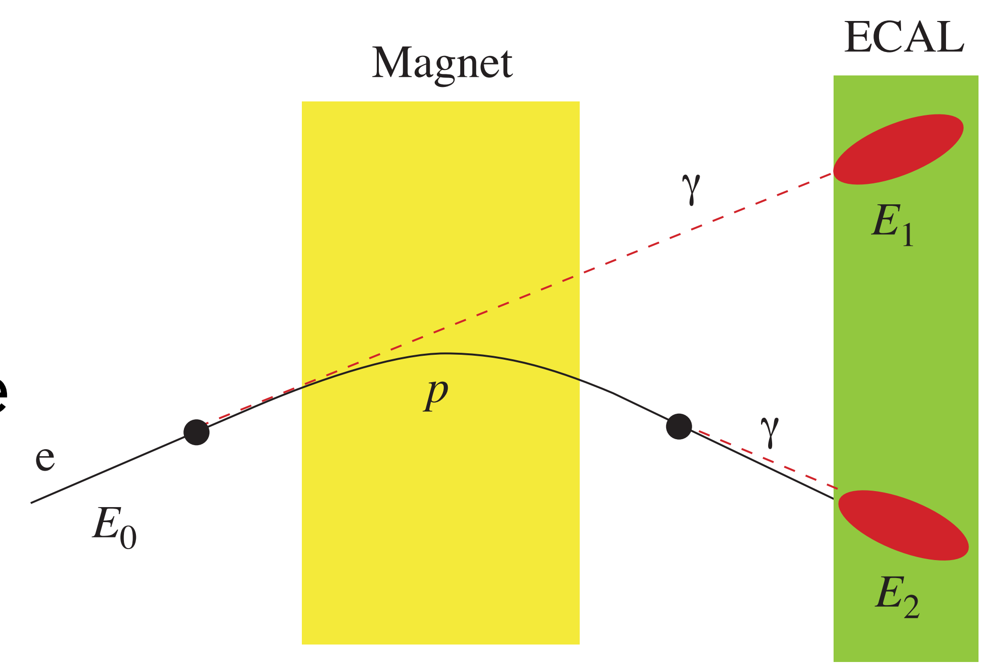
- Energy deposits are clusterised using Cellular Automaton algorithm
  - Choose cell with the highest energy deposit → **cluster barycenter**



- Obtain cluster energy and position as

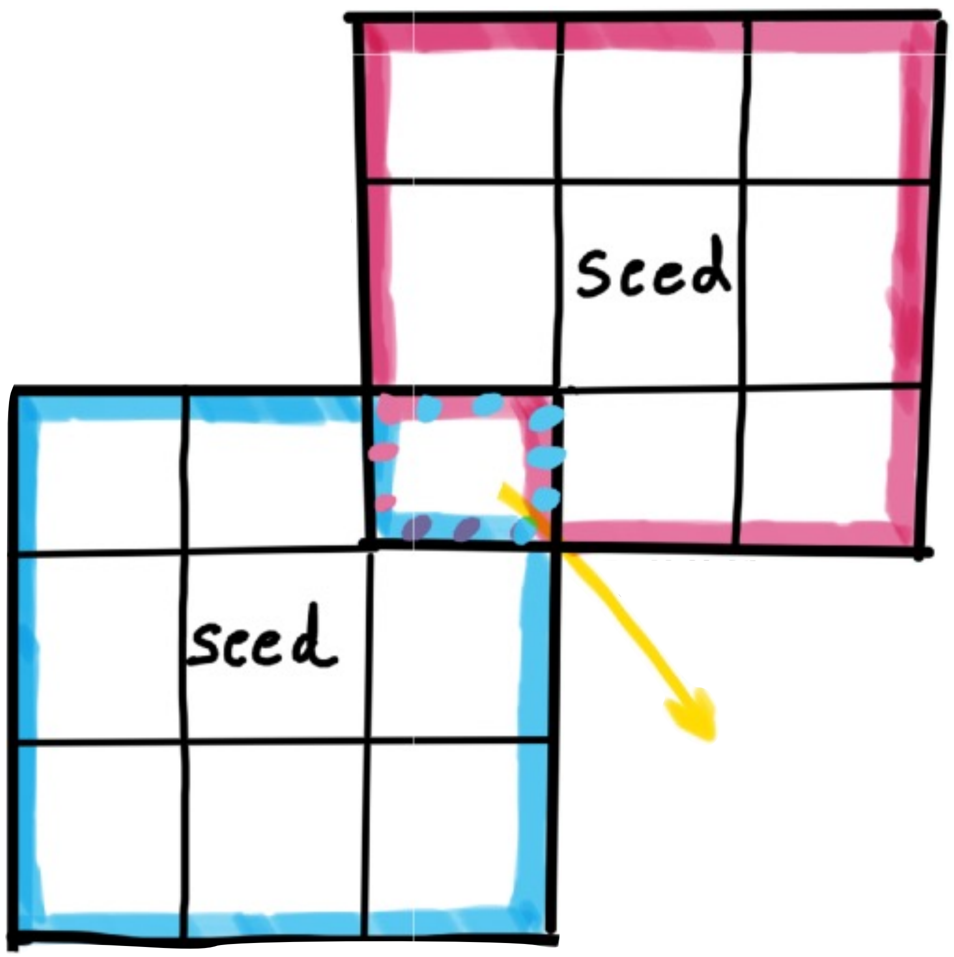
$$\varepsilon = \sum \varepsilon_i \qquad x_b = \frac{1}{\varepsilon} \sum x_i \varepsilon_i \qquad y_b = \frac{1}{\varepsilon} \sum y_i \varepsilon_i$$

- Photon clusters are selected matching *e* tracks
- Tracks extrapolated to the CALO reference plane and then matched with the reconstructed clusters



CALO reconstruction in Run 3

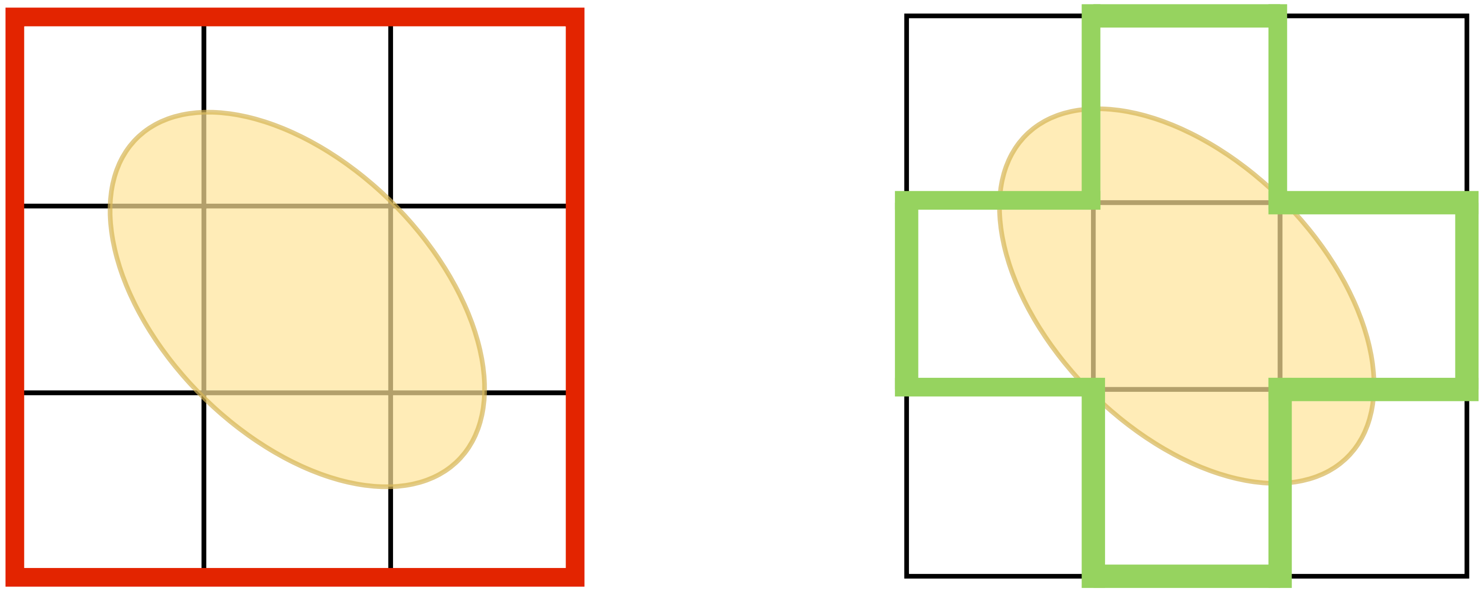
- Higher luminosity in Run 3:
    1. Higher occupancy → more overlap between neighbour clusters
    2. Pile-up effects → more hits in the detector cells increasing read-out



- Study different shapes of clusters for the reconstruction

Cluster masks

- Study different mask shapes for the cluster reconstruction



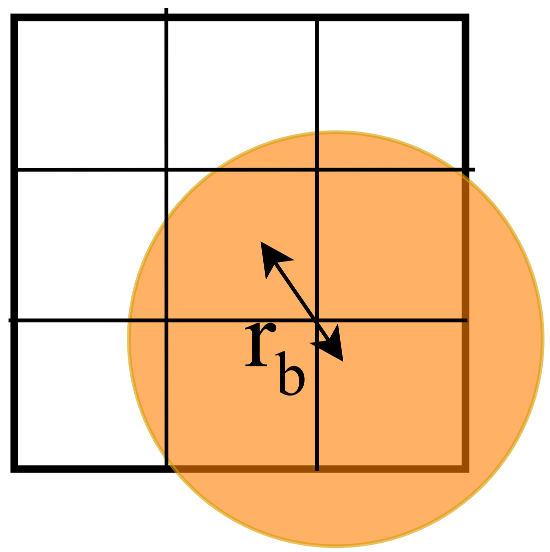
3x3 Swiss Cross (SC)

- Study energy and position resolution for each mask shape
  - ParticleGun MC = 1 photon per event pointing to the barycenter of the shower → **This presentation**
  - Then using $B \to K^{*}\gamma$ 2024 MC (WIP)

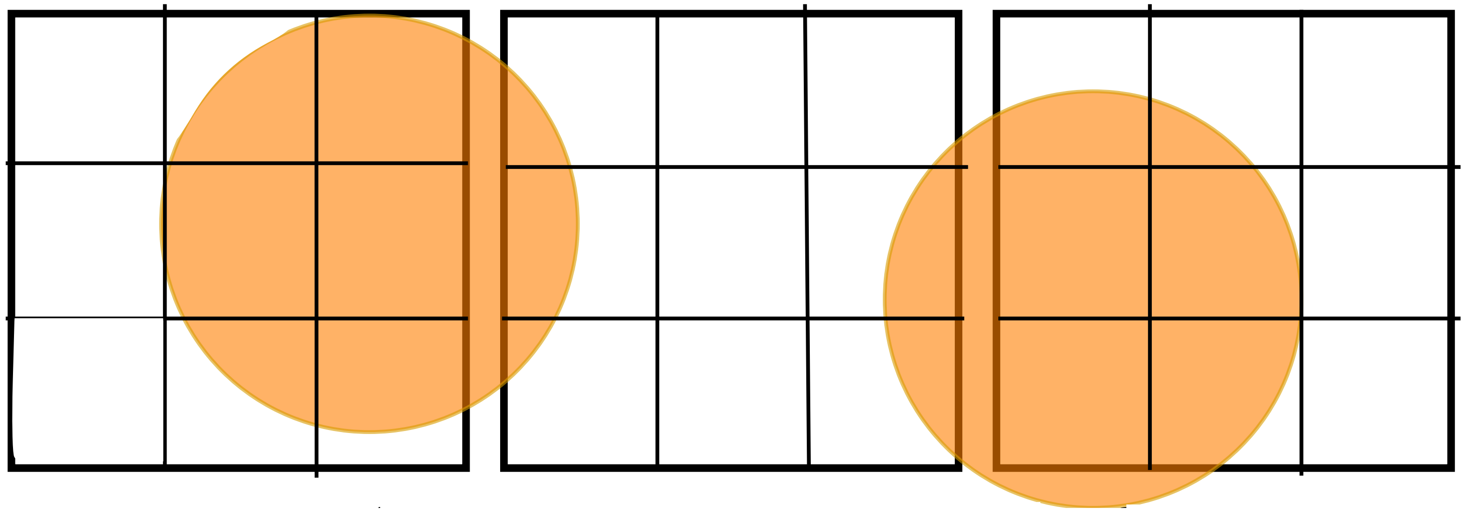
Energy corrections

- The γ/e shower is evaluated from the total energy of the cluster $E_{cluster}$
- However, there can be some leakage due to the shower position w.r.t. to the cluster $\rightarrow E_{corr} = \alpha E_{cluster}$

Shower outside the cluster α_2



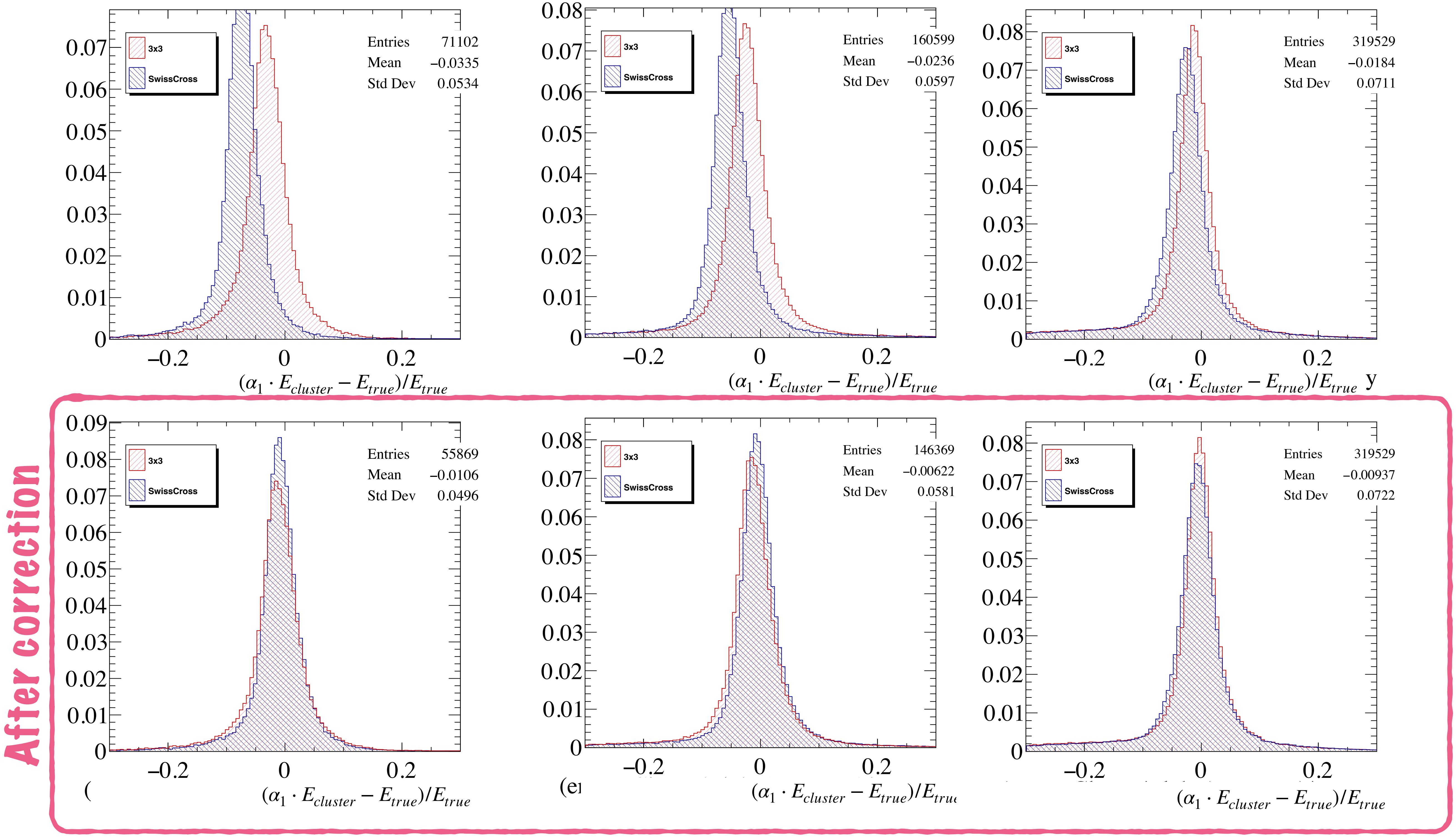
Dead material between modules α_3



$$E_{corr} = \alpha_1 E_{cluster} + \alpha_2(\frac{r_{baricenter}}{cluster}) + \alpha_3(\frac{r_{baricenter}}{module})$$

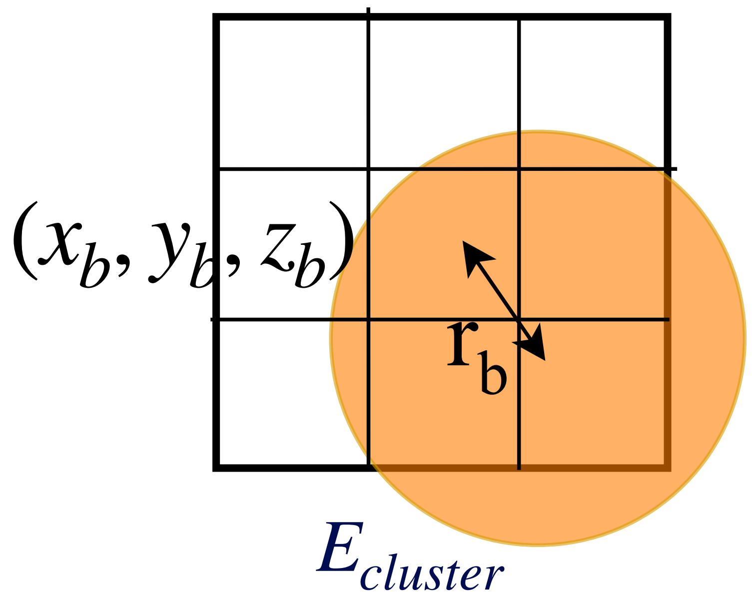
Energy resolution after correction

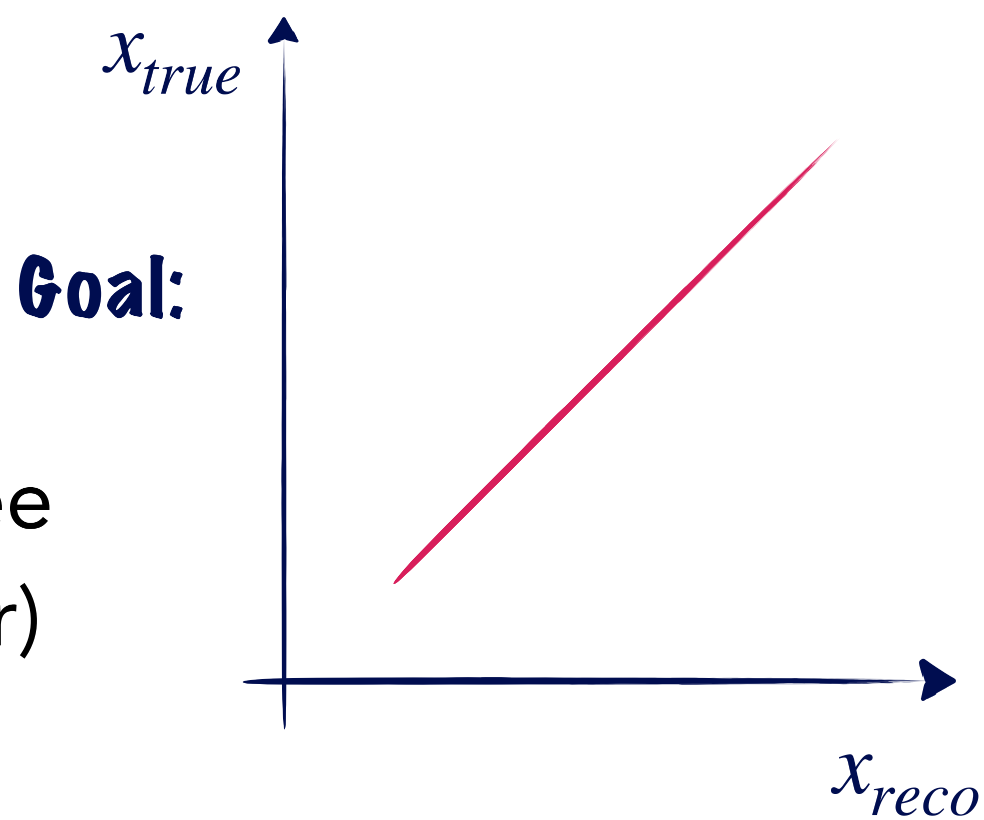
Inner | Middle | Outer



Position reconstruction

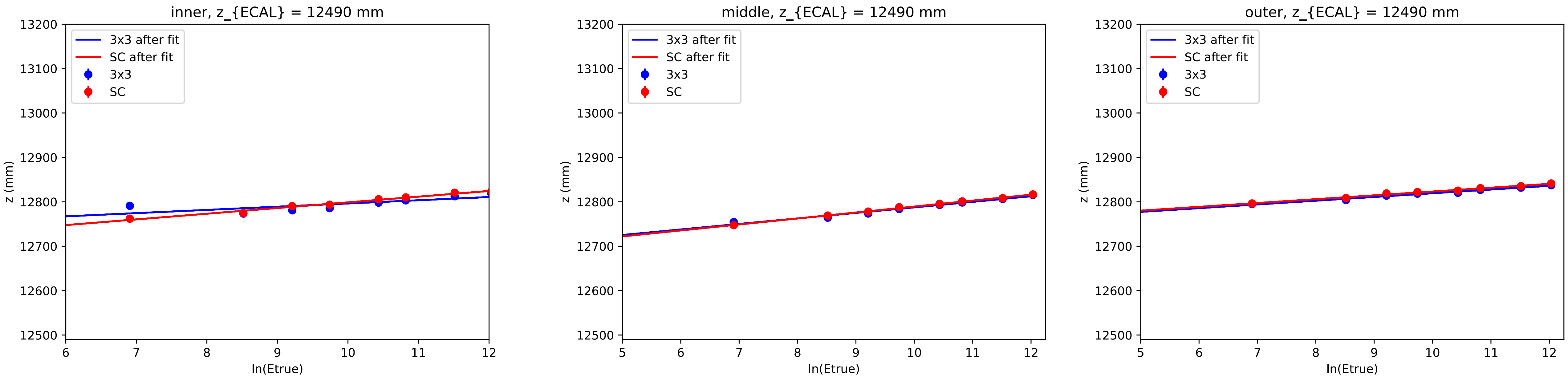
- The barycenter position is extrapolated from the tracks and the ECAL plane
- The reconstructed position has to match the simulation
- Different steps of corrections:
  - **Longitudinal (L) correction**
  - **S shape corrections**
- Correct all coordinates for the three CALO regions (inner, middle, outer) and the two masks (3x3 and SC)





Longitudinal correction (L)

- The longitudinal position is obtained as the ECAL position z_{ECAL} scaled for the penetration depth of the photon as
  - $z^L = \gamma_0 \ln E + \delta_0$



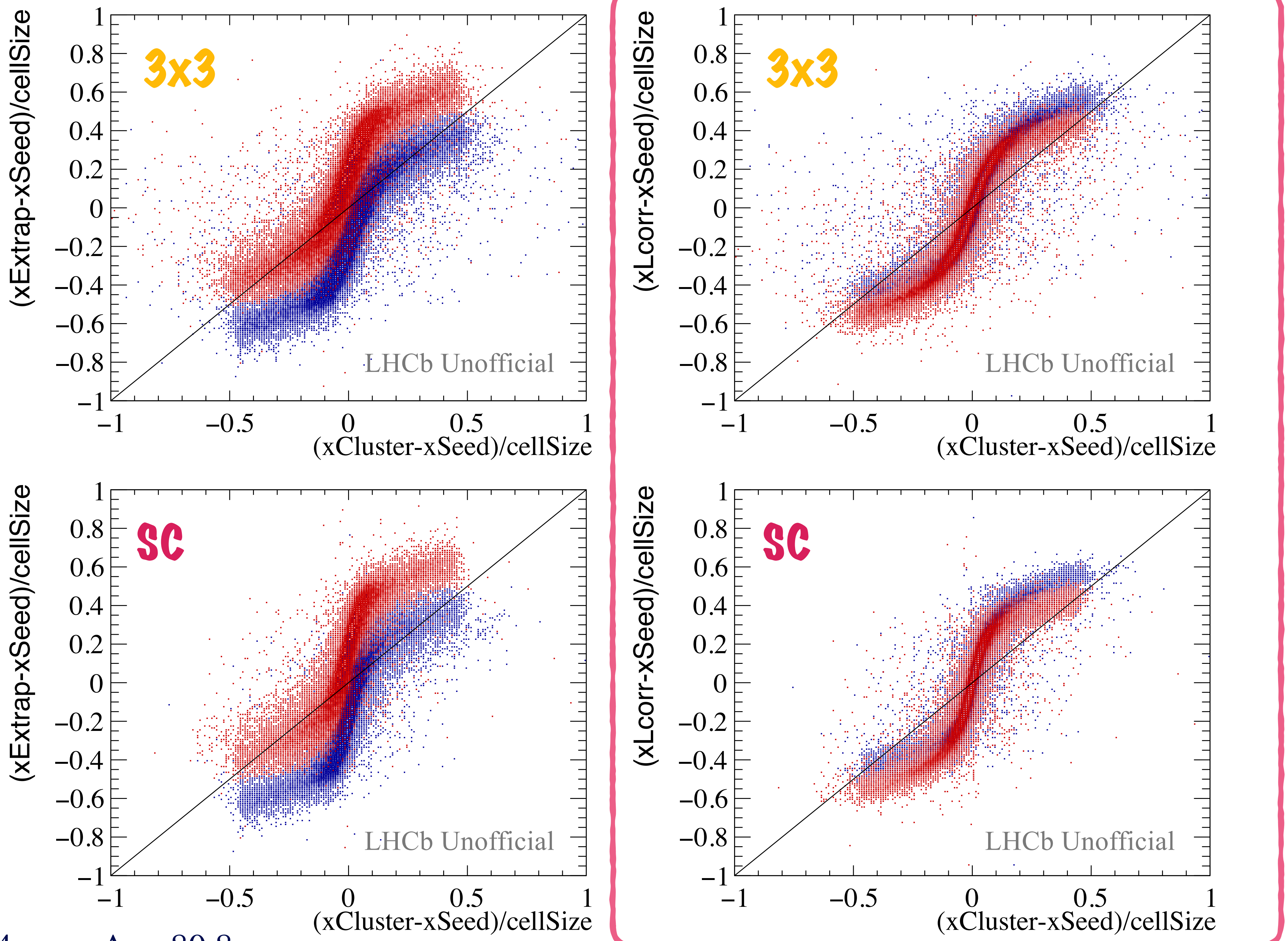
- Then the extrapolated value of the transversal coordinates $x_i\ (= x, y)$ has to be corrected as
  - $$(x_i)^L = (x_i)_{\mathrm{extrap}} + \frac{p_{x_i}}{p_z}(z^L - z_{\mathrm{vertex}})$$

Longitudinal correction (L)

After L correction

$x < 0$
$x > 0$

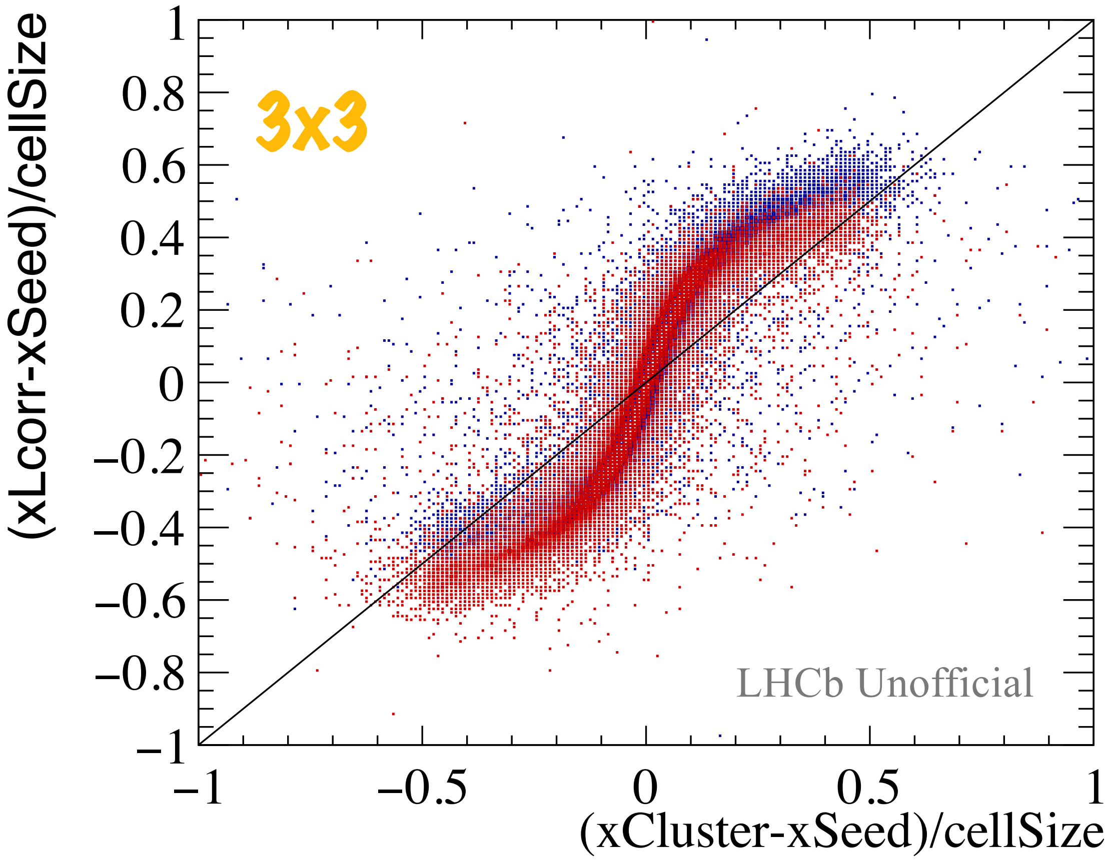
Inner



Cell size = 40.4 mm, Δ = 80.8 mm

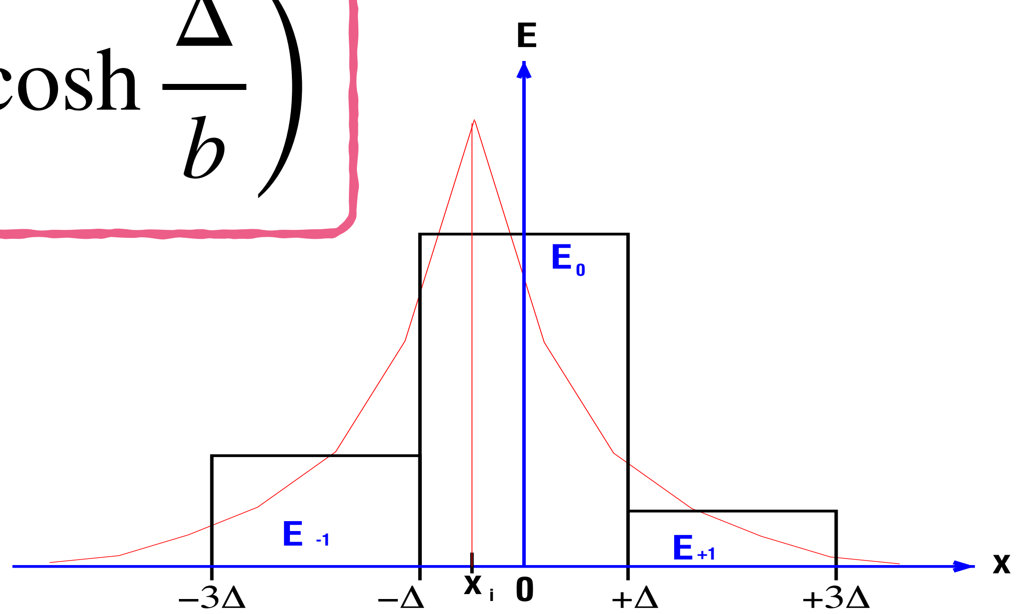
S corrections

- "Straighten" the S shape by correcting the reconstructed x_i variables
- Assuming the transversal profile to decrease exponentially, it is corrected by



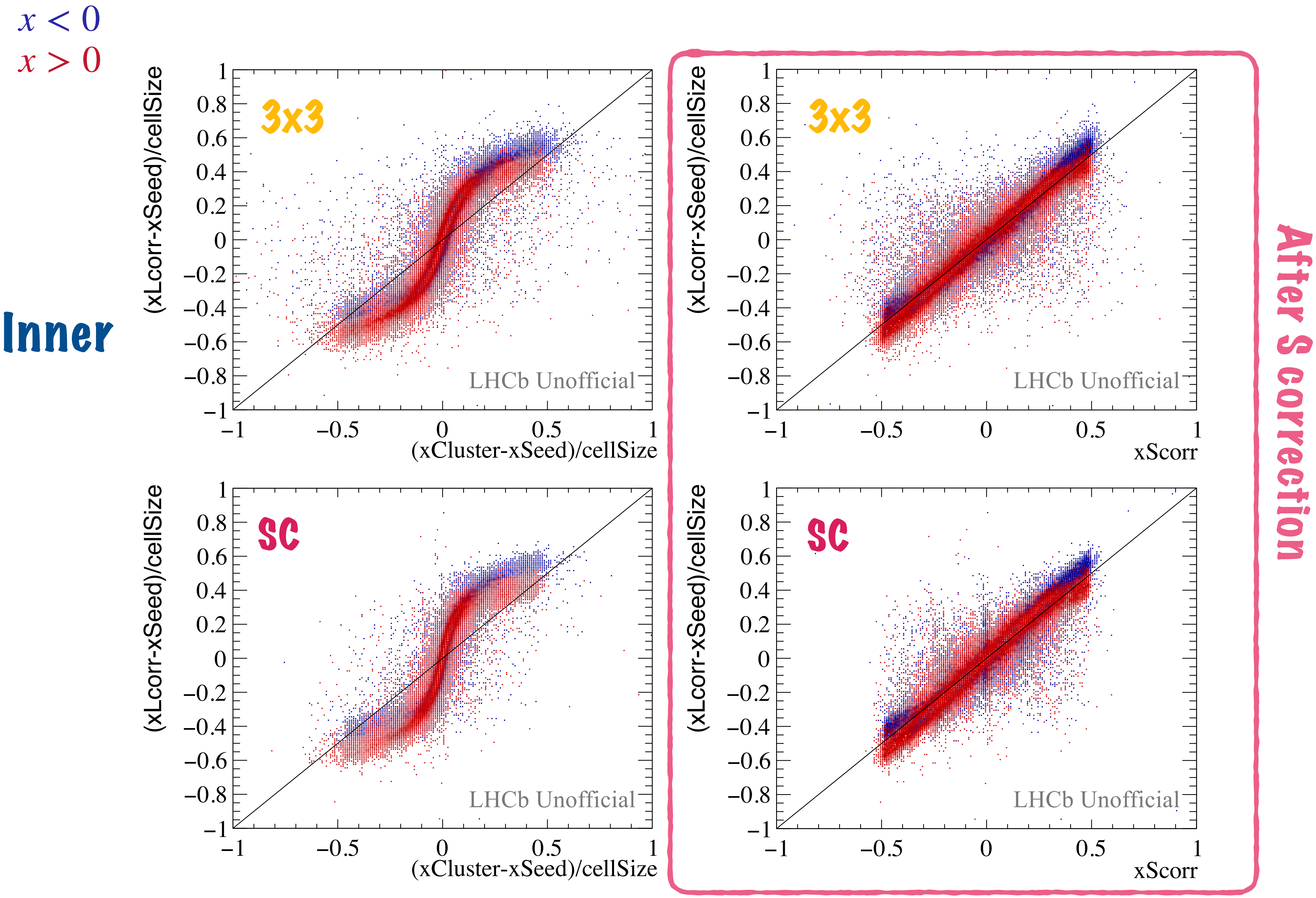
$$(x_i)^S_{\mathrm{reco}} = b \sinh^{-1}\left(\frac{(x_i)_{\mathrm{Cluster}} - (x_i)_{\mathrm{seed}}}{\Delta} \cosh\frac{\Delta}{b}\right)$$

that solve the system
$$\begin{cases} \varepsilon(x) = \varepsilon_0 e^{\frac{-\|x-x_i\|}{\mathbf{b}}} \\ x_b = \frac{2\Delta E_{+1} - 2\Delta E_{-1}}{E_{-1}+E_0+E_{+1}} \\ E_{-1} = \int_{-3\Delta}^{-\Delta} \varepsilon(x)dx \\ E_0 = \int_{-\Delta}^{\Delta} \varepsilon(x)dx \\ E_{+1} = \int_{\Delta}^{3\Delta} \varepsilon(x)dx \end{cases}$$



$\Delta = 2 \times$ cell size

S corrections



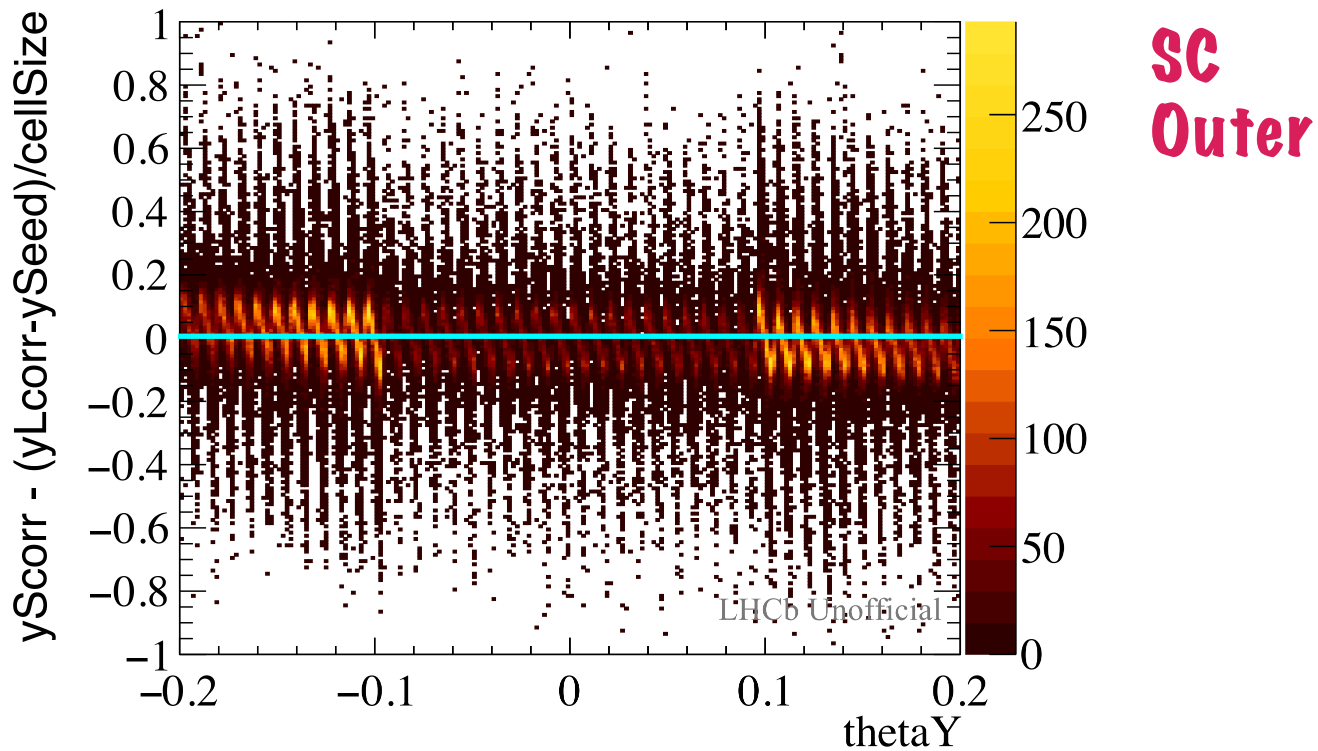
Angular correction

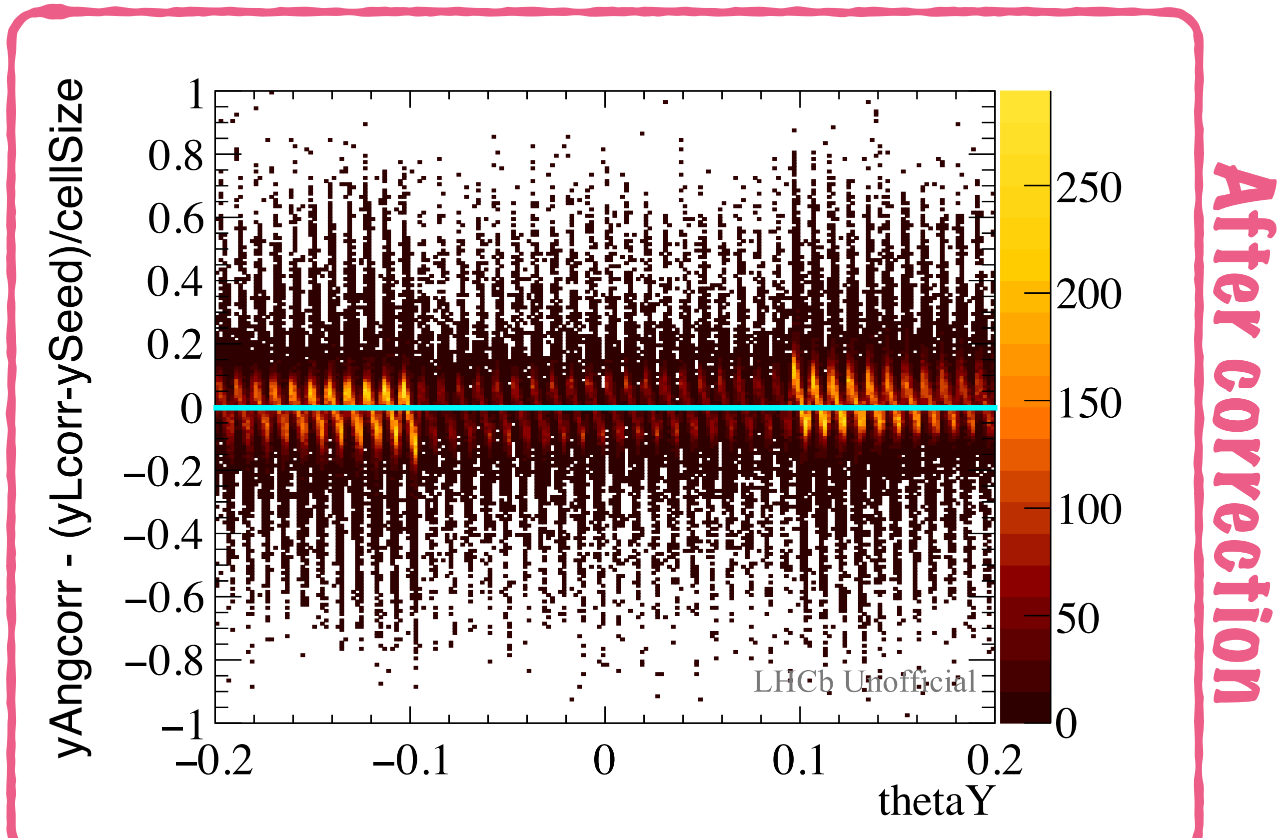
- The cluster position depends also on the incidence angle, so it must be corrected accordingly.
- The residual $x^S_{reco} - x^L_{true}$ is studied w.r.t. to

$$\theta_{x_i} = \tan^{-1}\left(\frac{p_{x_i}}{p_z}\right)$$

- The reconstructed coordinate is corrected as

$$x_i^{ang} = x_i^S - a_1\theta_{x_i}$$

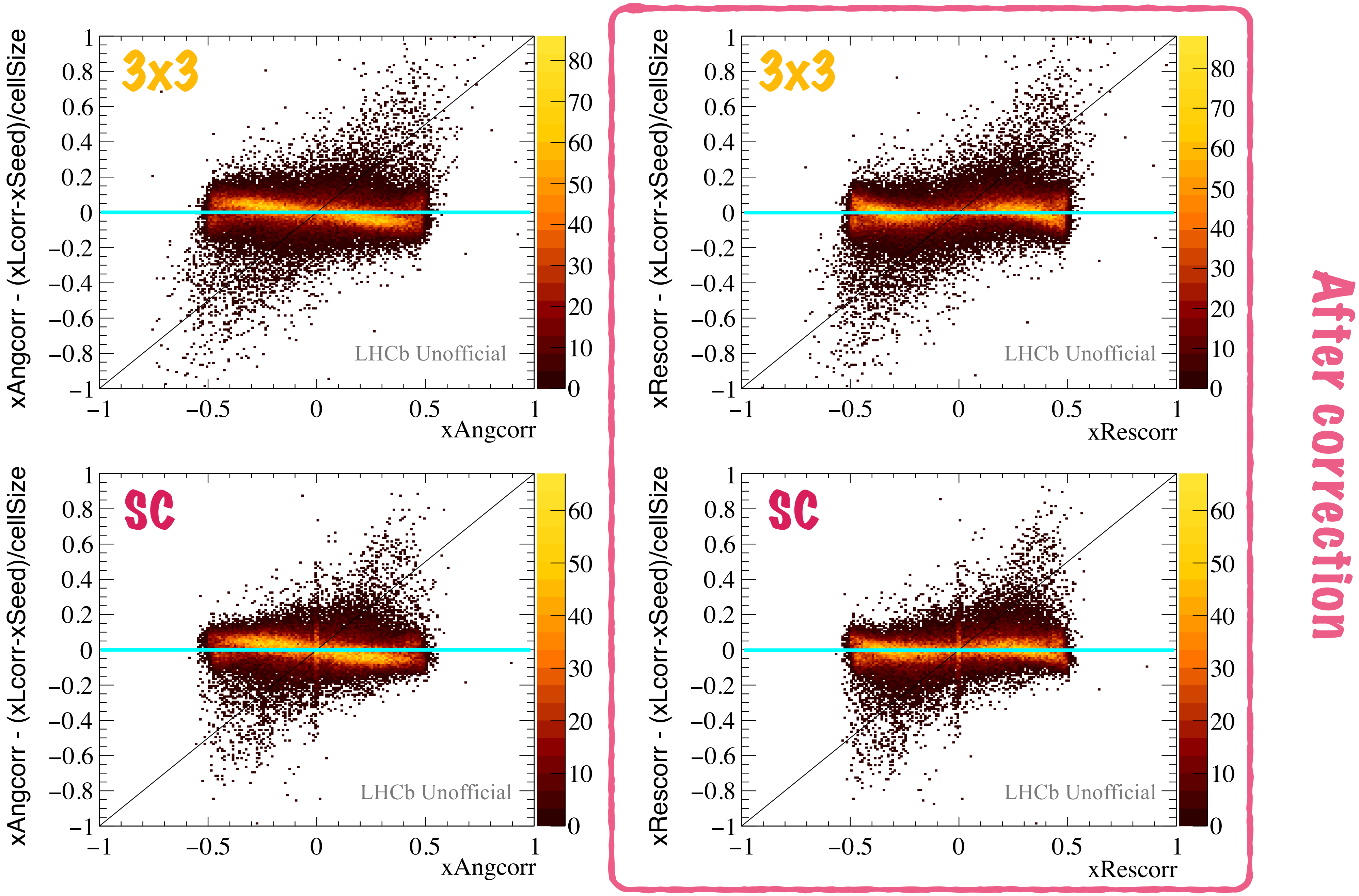




Inner

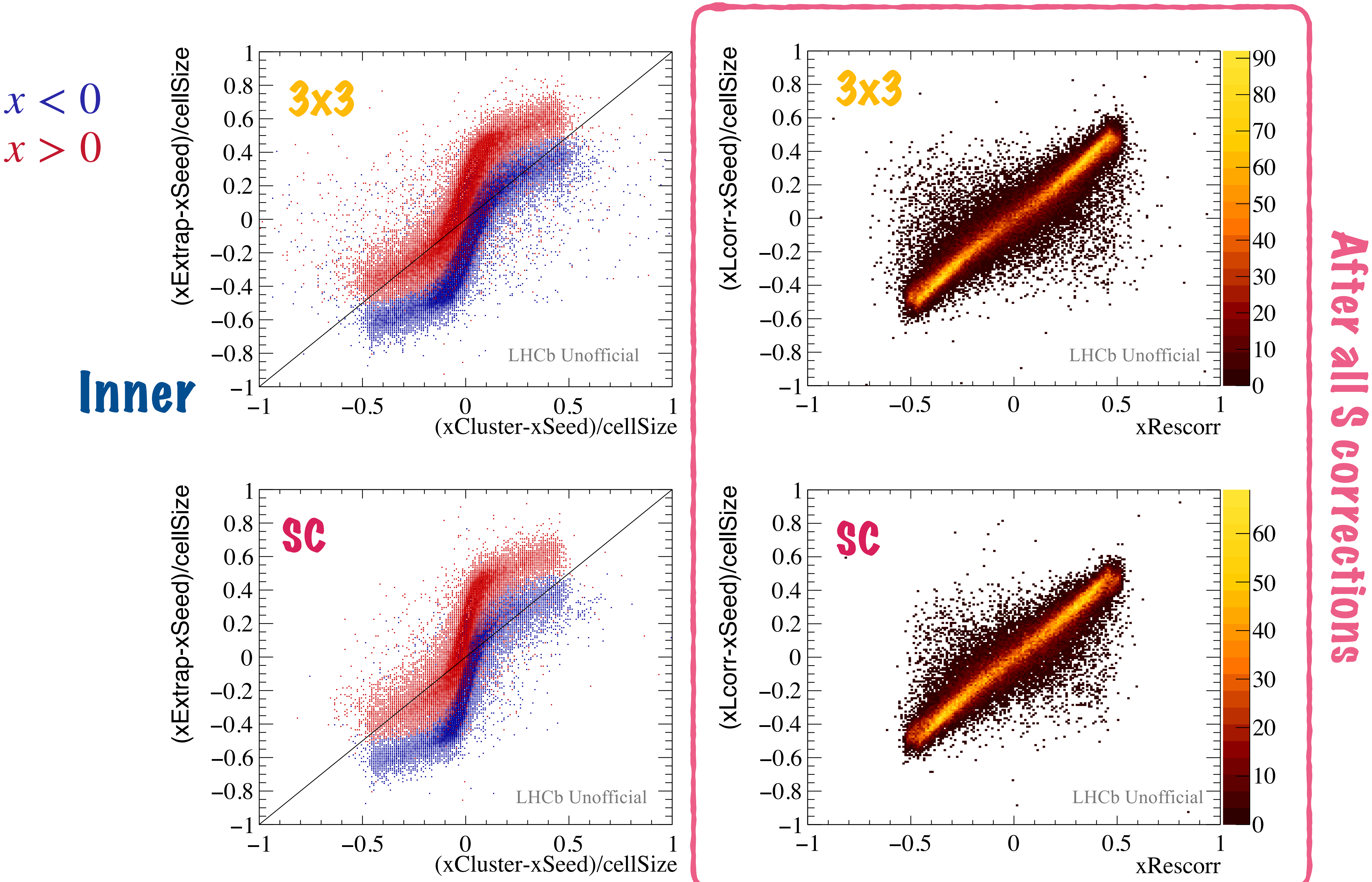
Residual correction

- Looking the residual $x_i^{ang} - x_i^{L}$ correction needed
- Correct using $$x_i^{res} = x_i^{ang} - A_1 \sin(2\pi \cdot x_i^{ang})$$



Final result

- Reconstructed position after applying all corrections

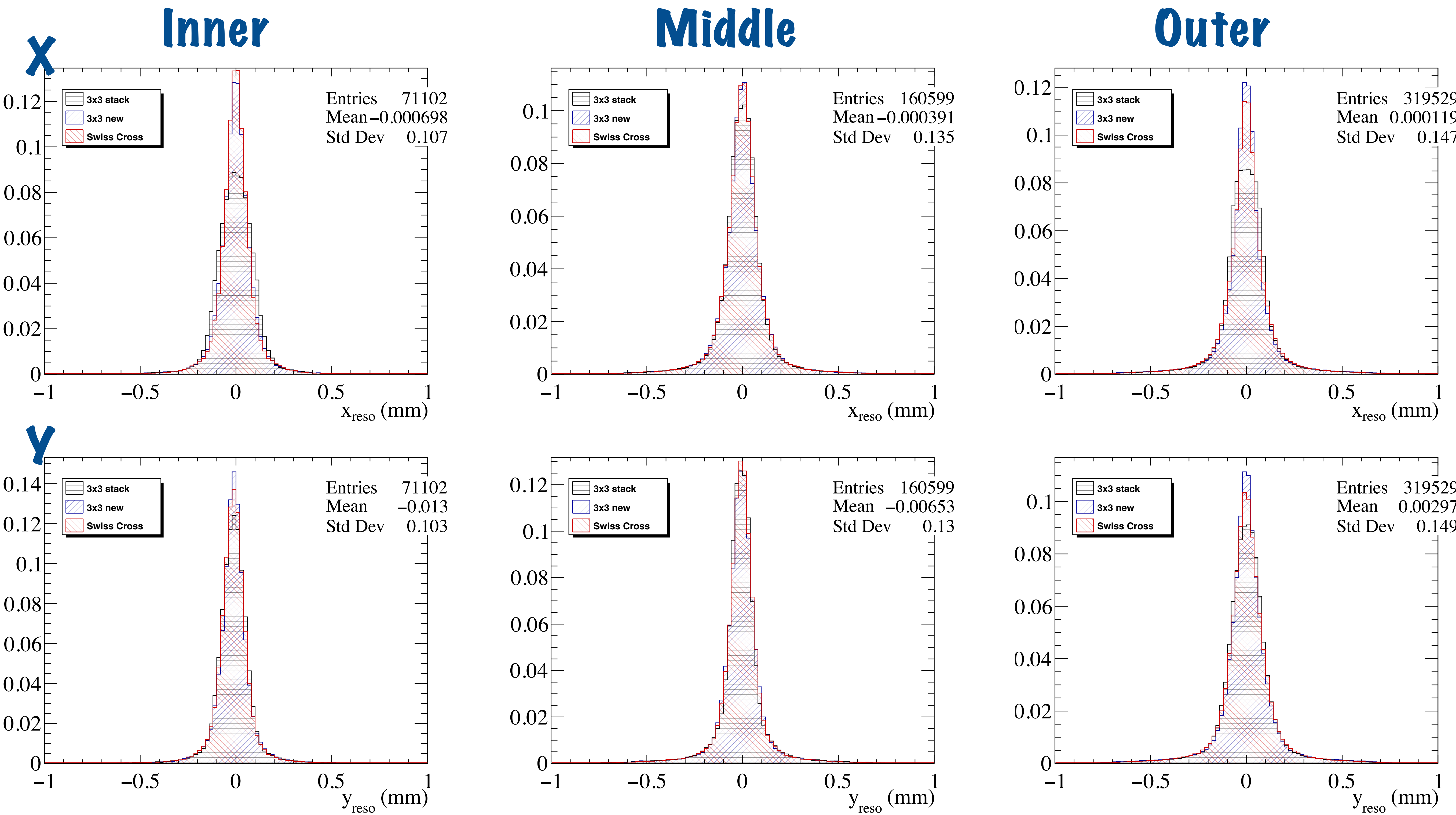


Position resolution

- Once obtained and applied the corrections, check the position resolution
- Swiss Cross mask: expecting higher resolution for higher multiplicities

	ECAL region	3x3 stack (%)	3x3 new (%)	SC new (%)
x	inner	11.27 ± 0.03	10.74 ± 0.03	9.86 ± 0.03
	middle	13.05 ± 0.02	13.45 ± 0.02	12.63 ± 0.02
	outer	14.00 ± 0.02	14.67 ± 0.02	13.94 ± 0.02
y	inner	10.34 ± 0.03	10.28 ± 0.03	9.58 ± 0.03
	middle	12.81 ± 0.02	13.00 ± 0.02	12.20 ± 0.02
	outer	14.05 ± 0.02	14.89 ± 0.02	14.06 ± 0.02

Position resolution after corrections



Prospects and conclusions

- Electrons (and photons) have an important role in the LHCb Upgrade I physics program → **efficient CALO reconstruction needed**

- Run 3 conditions with higher multiplicity and pile-up → study new cluster mask shape: Swiss Cross (SC)

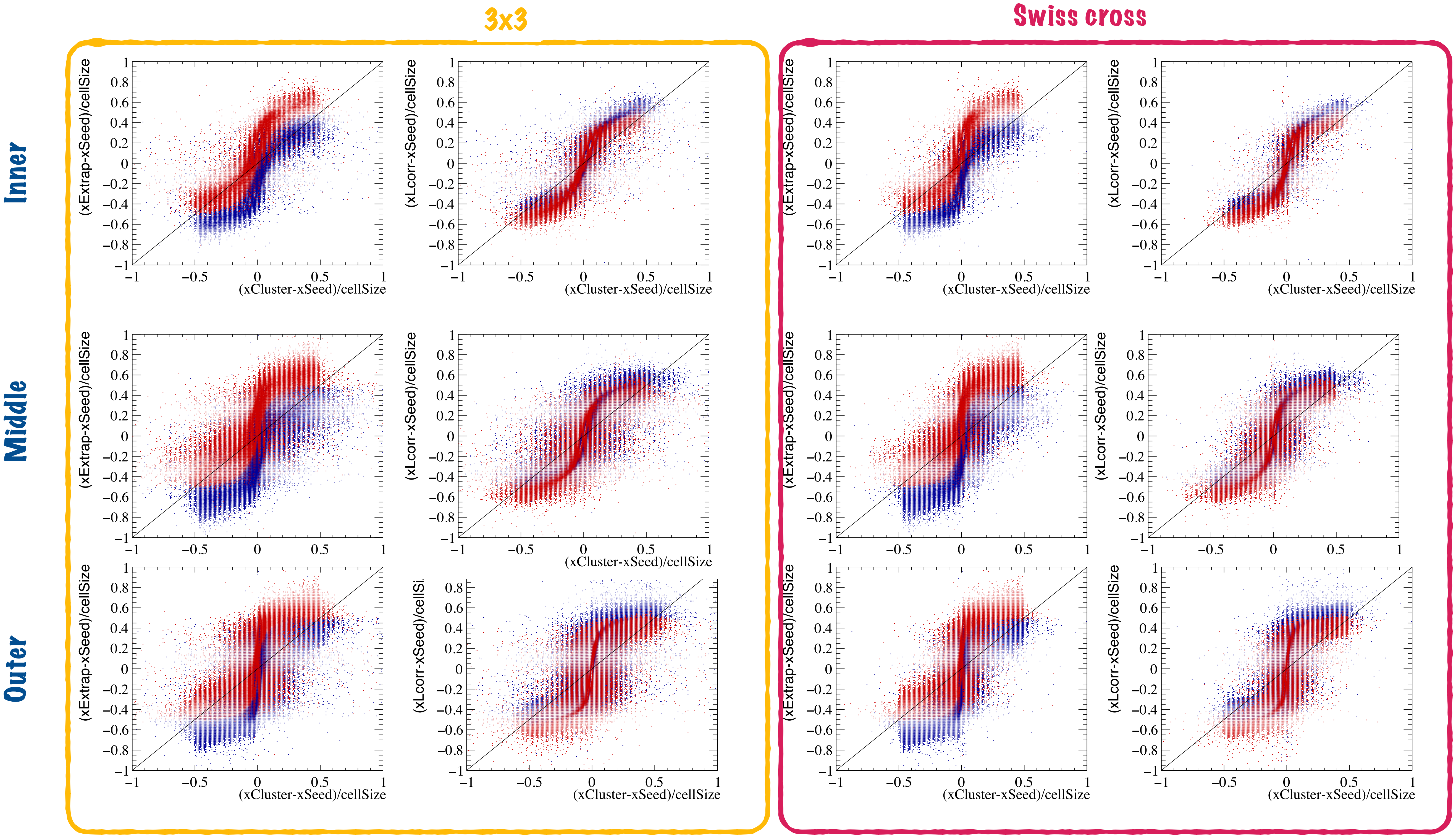
- Considering only one photon per event the two shapes has very similar position resolutions → improvements in new corrections

- Studies with higher multiplicity ongoing → expect the SC shape to have a **better resolution**

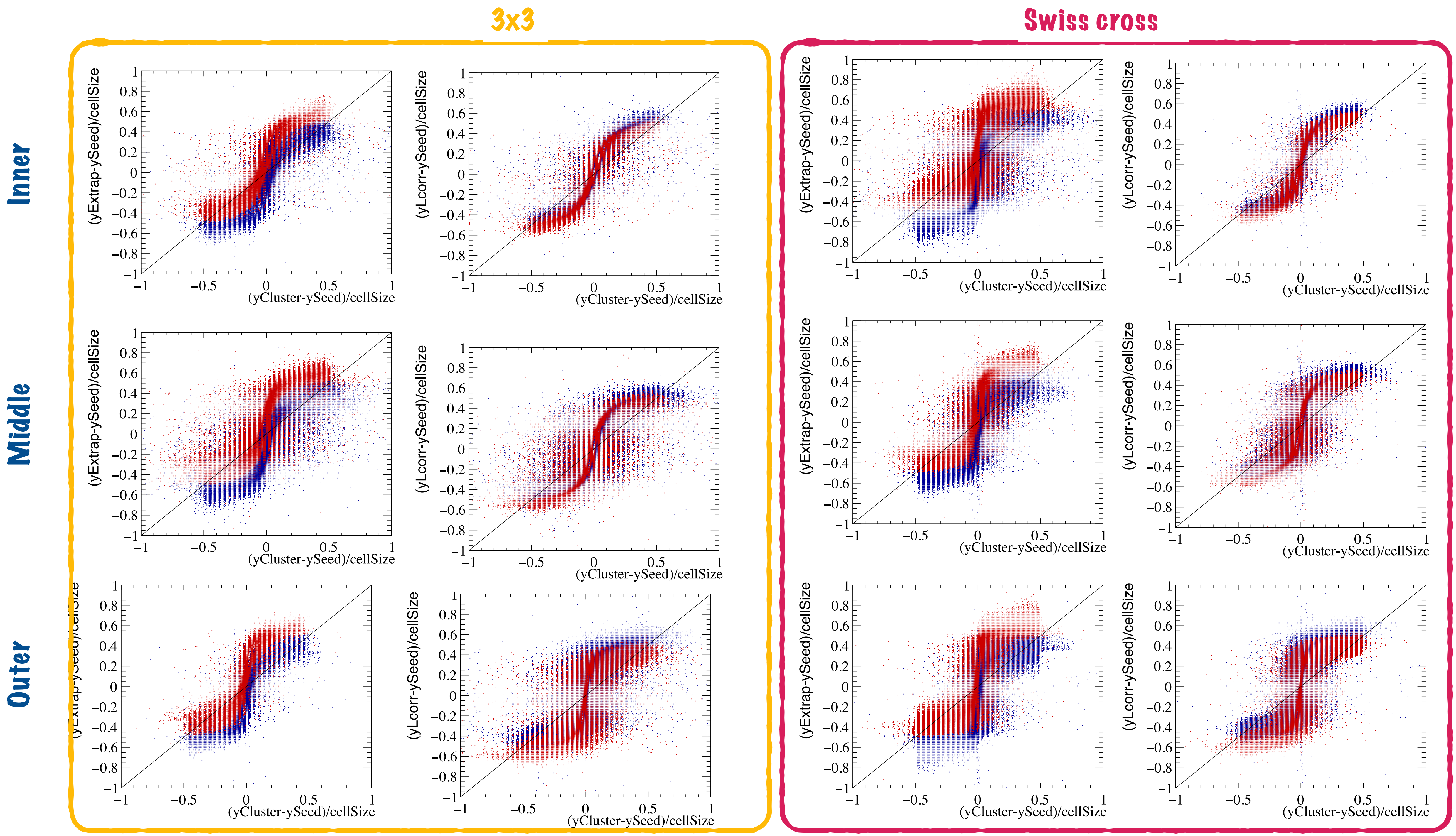
THANK YOU

BACKUP

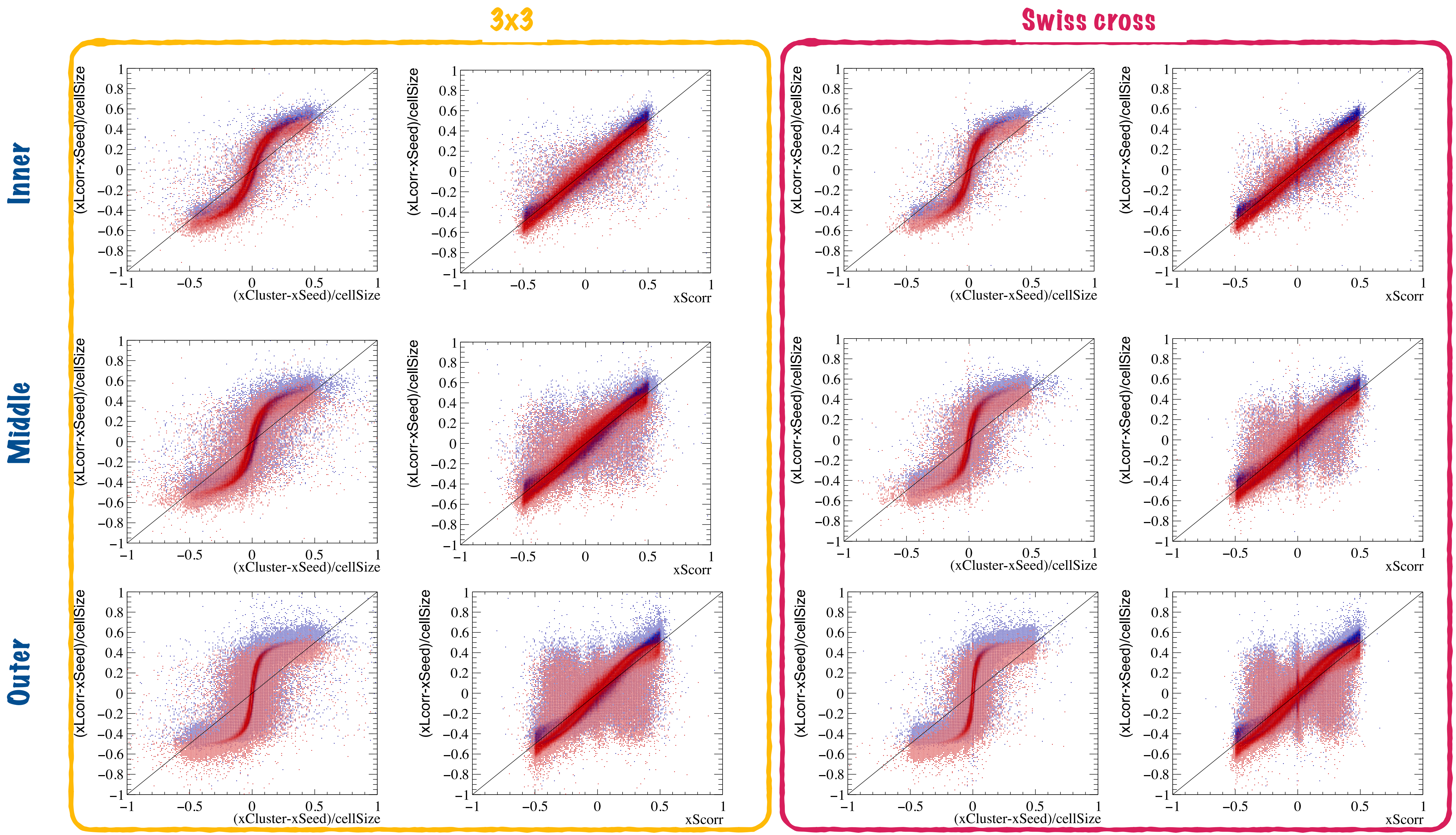
L correction x



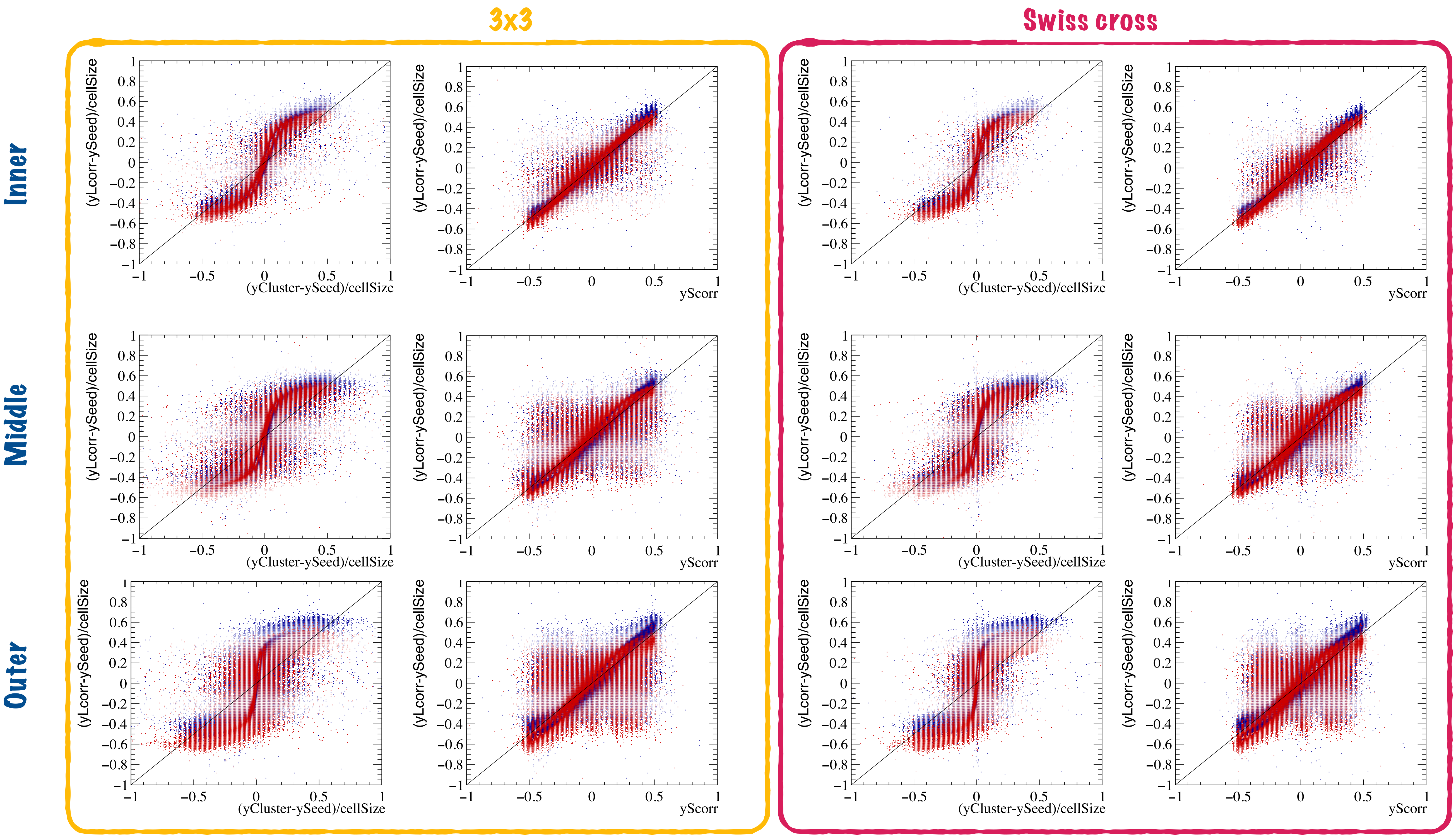
L correction y



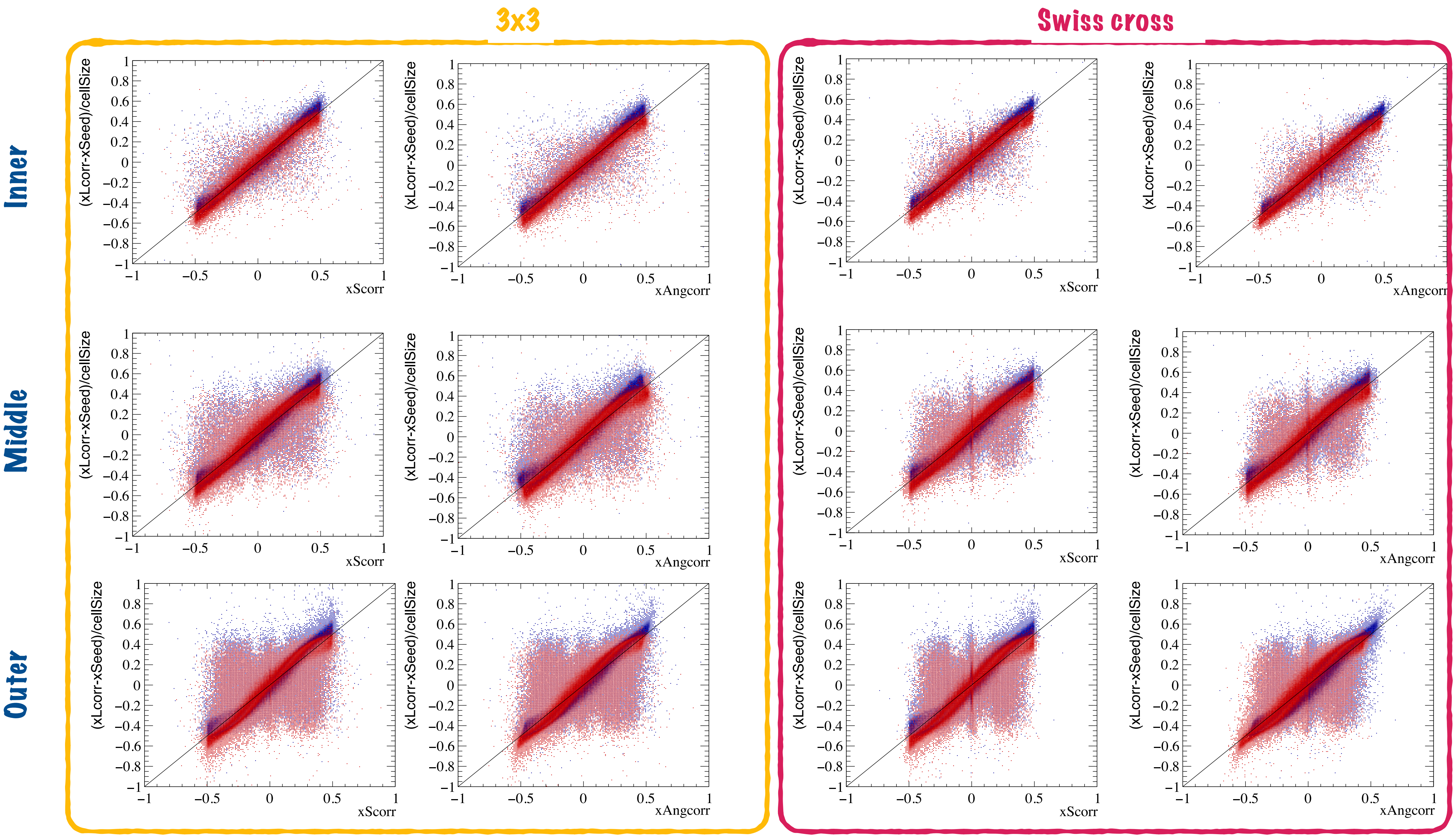
S correction x



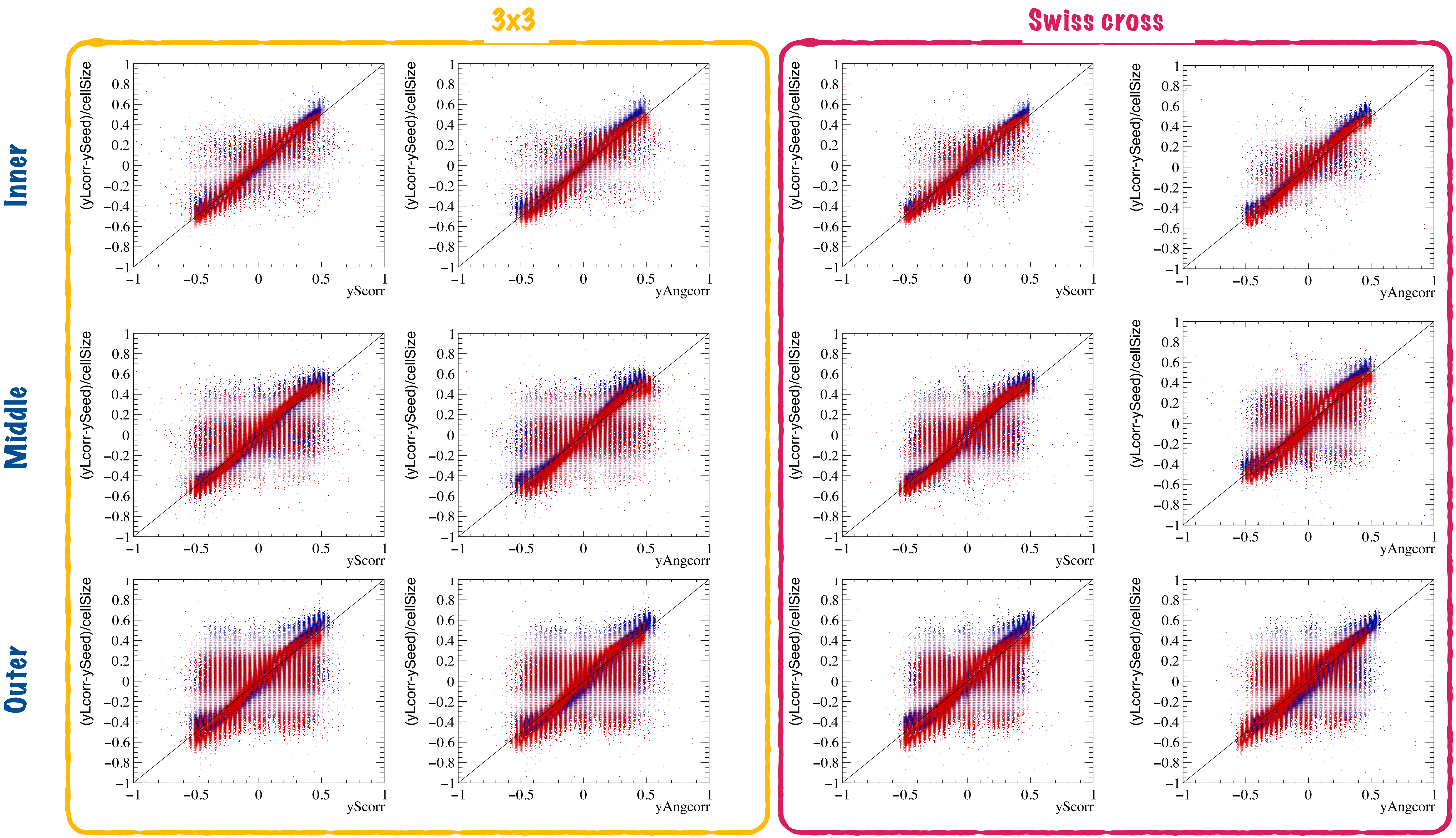
S correction y



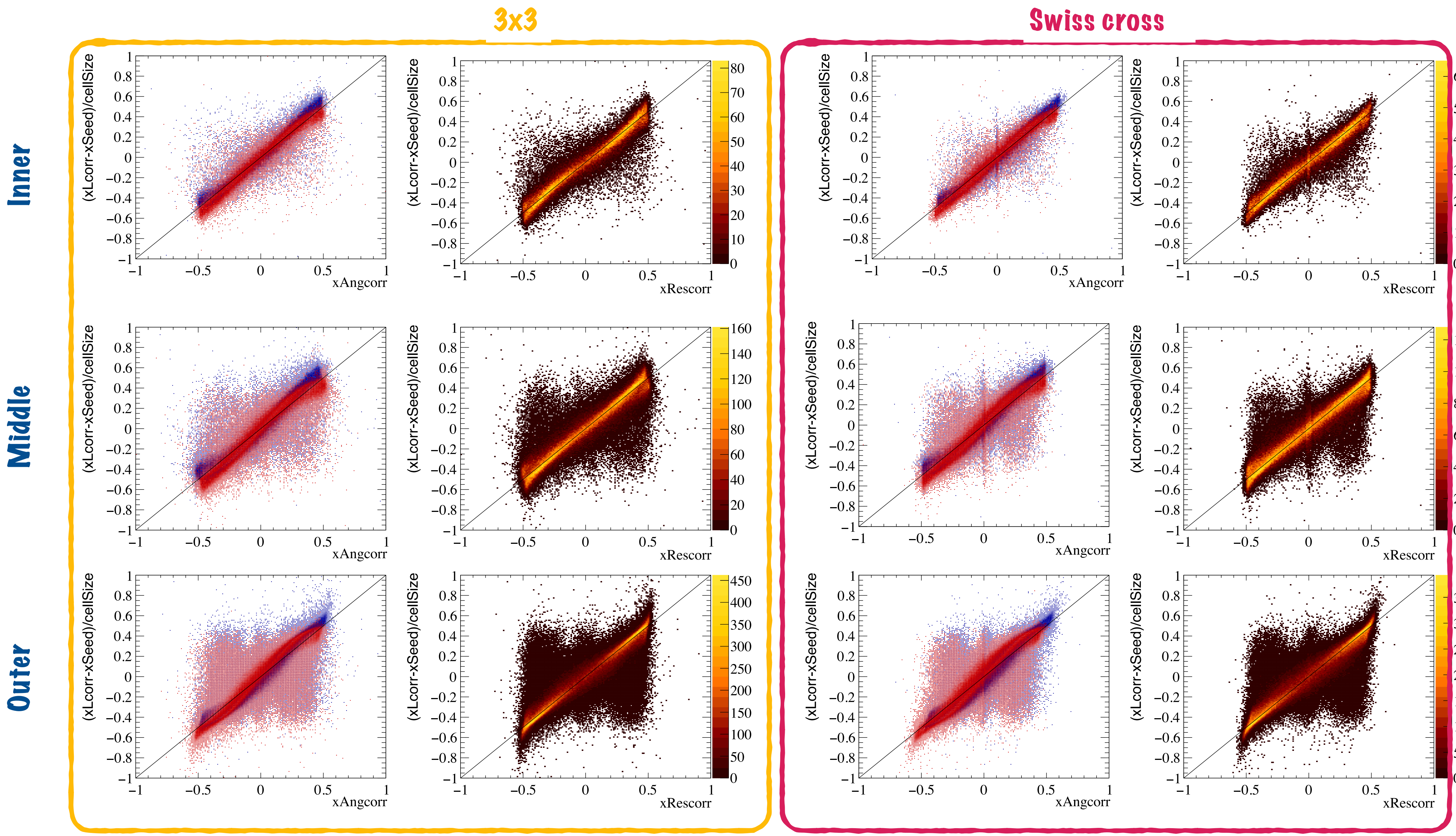
S correction x - angular



S correction y - angular



S correction x - residual



S correction y - residual