

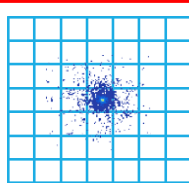
# Crystal Ecal reconstrcutio

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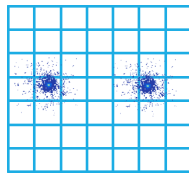
# Reconstruction

Key issue for crystal bar Ecal design: pattern multiplicity and their confusion when multiple particles hit at one module(ghost hits).

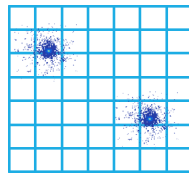
- 1 particle



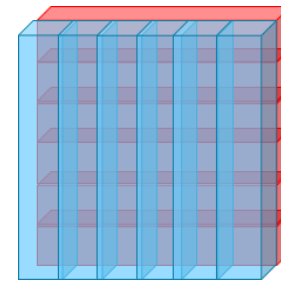
- 2 particles



2\*1

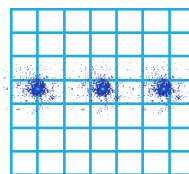


2\*2



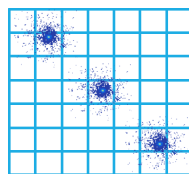
Basic module in long bar design

- 3 particles



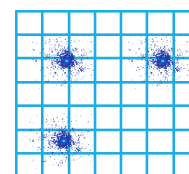
3\*1

Case1

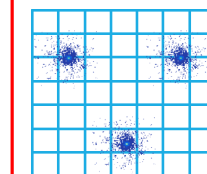


3\*3

Case2



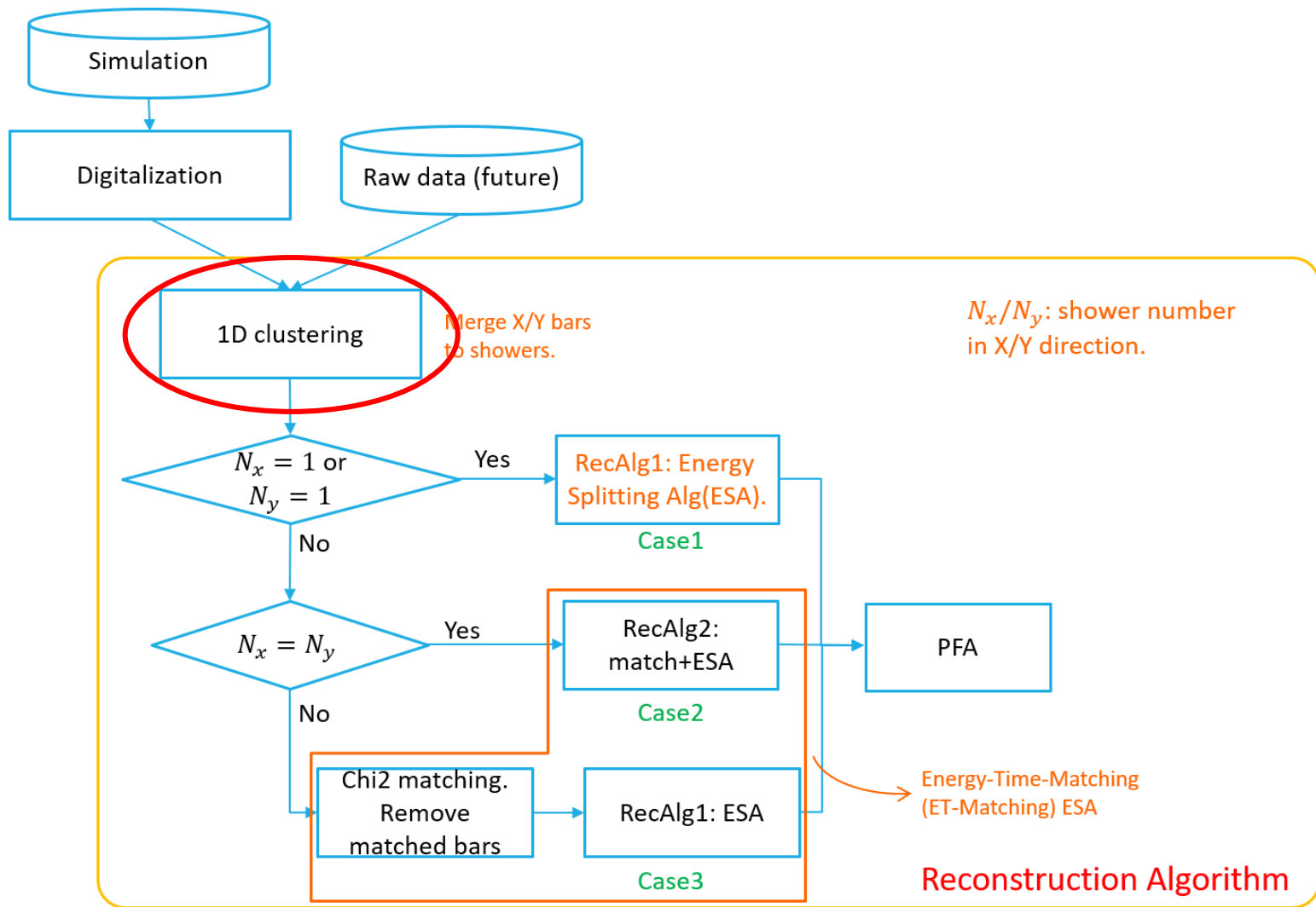
2\*2



3\*2

Case3

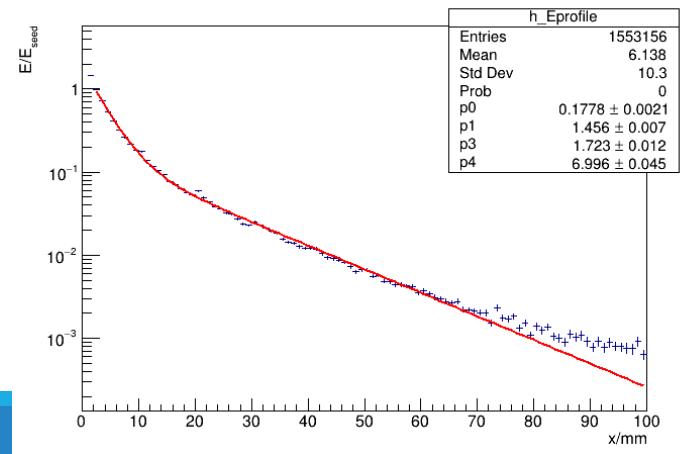
# Hit Reconstruction



# 1D Clustering

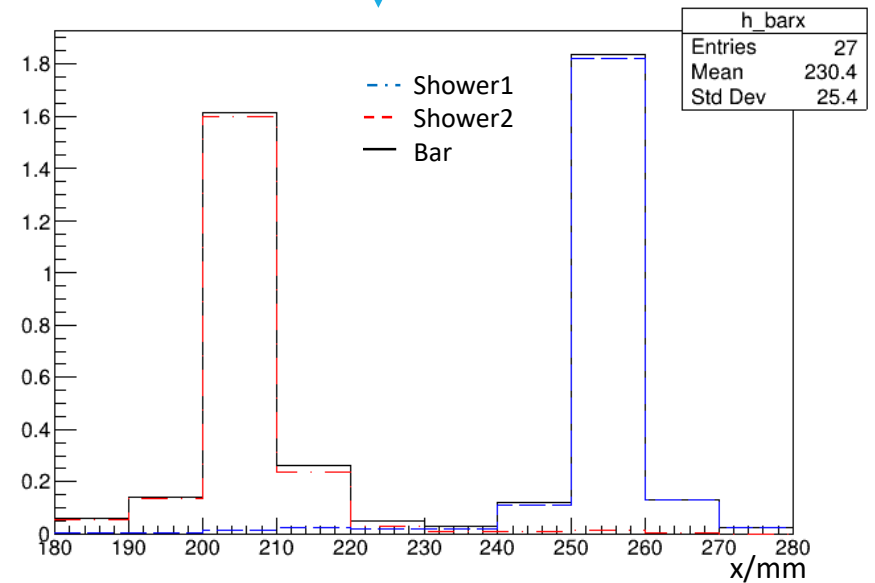
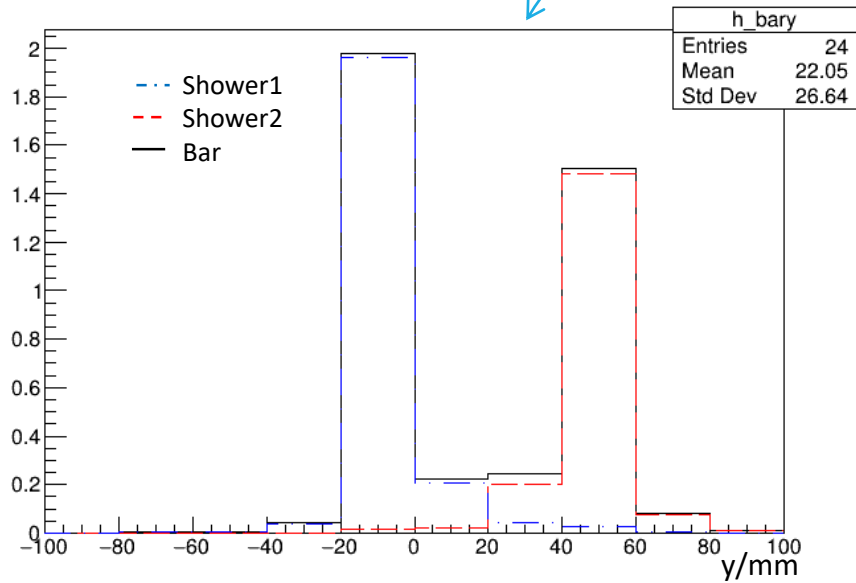
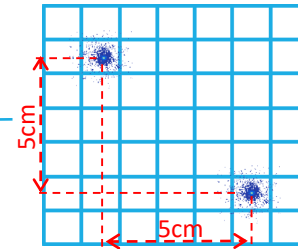
## Pattern recognition

- Bar energy threshold: 200keV (0.1MIP)
- Neighbor clustering
- Seed candidate:  $E > E_{th}^{seed}$  and local max. Calculate second moment  $S$ .
- Splitting:  $N_{seed} \geq 2$  &&  $S > S_{th}$  (0 now).
  - $N_{shower} = N_{seed}$ . Each shower contains all bars in the cluster, but with different weight.
  - For bar  $i$ , energy belongs to shower  $\mu$  is  $E_{i\mu}^{exp} = E_{\mu}^{seed} \times f(|x_i - x_c|)$ .
  - $f(x) = p_0 \exp\left(-\frac{p_1 * x}{R_M}\right) + p_3 \exp\left(-\frac{p_4 * x}{R_M}\right)$  from fitting shower profile to truth MC.
  - Weight  $w_{i\mu} = \frac{E_{i\mu}^{exp}}{\sum_{\mu} E_{i\mu}^{exp}}$
  - Iterate until shower position converge or  $\geq 20$  times.



# 1D clustering

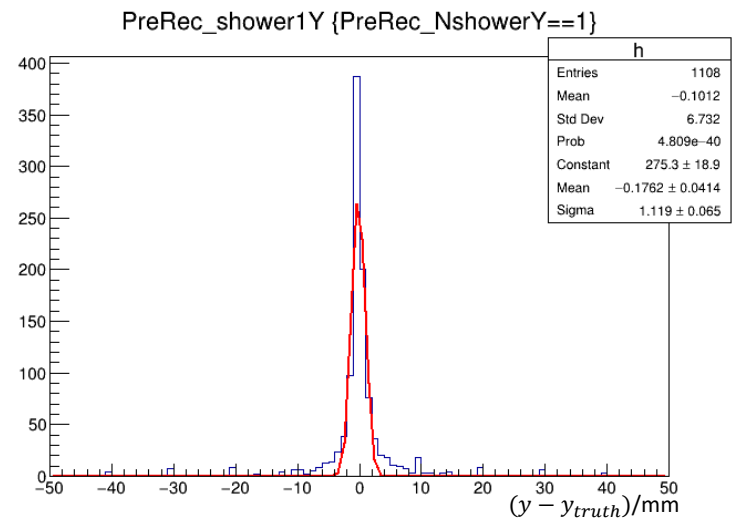
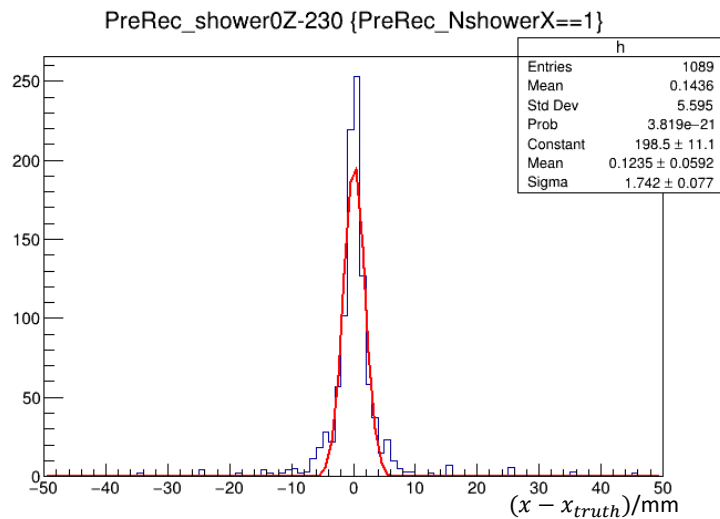
## Shower splitting



# 1D clustering

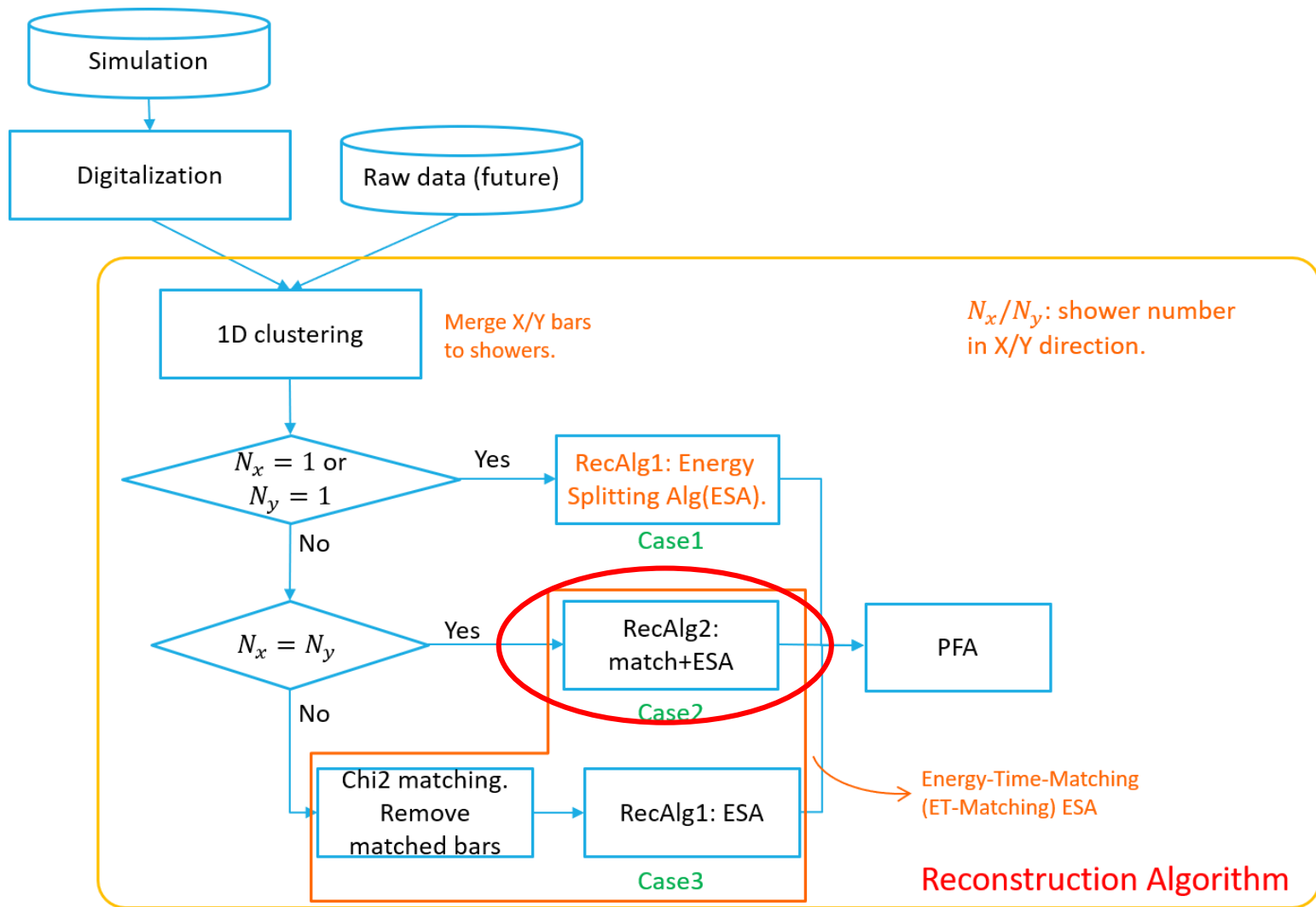
## Shower position resolution

- 1 single 10GeV photon, requiring only 1 shower.



- Resolution depends on shower position:
  - Shooting at the edge of 2 bars will have better resolution.
  - Expect to see a wave curve of  $\sigma_x - x$  between 1.2mm and 1.8mm.

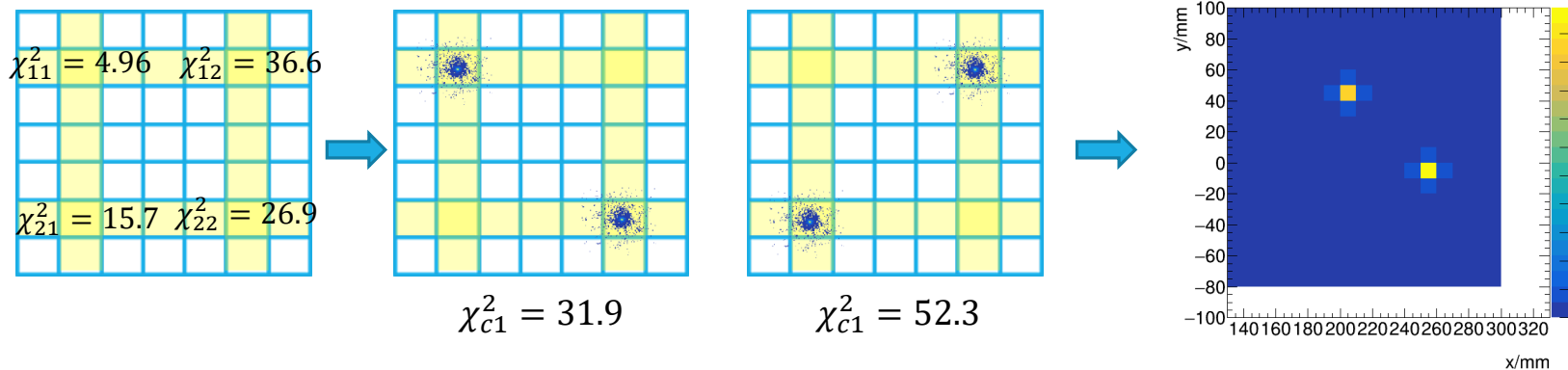
# Hit Reconstruction



# 2D matching

- Basic concept: shower in X/Y bars comes from one photon.
- Define  $\chi^2$  from energy:  $\chi_E^2 = \frac{(E_X - E_Y)^2}{\sigma_E^2}$ .  $\chi_T^2$  from time:  $\chi_T^2 = \frac{(z_T - z_Y)^2}{\sigma_S^2 + \sigma_Z^2(t)}$
- Define  $\chi_{point}^2 = w i_E * \chi_E^2 + \frac{w i_T}{2} * (\chi_{Tx}^2 + \chi_{Ty}^2)$ . (for each shower X/Y).
- Totally N! combinations.  $\chi^2$  for combination:  $\chi_c^2 = \sum_{i=1}^N \chi_{point}^2$ .
- Time resolution is 500ps.

E.g. (one layer)

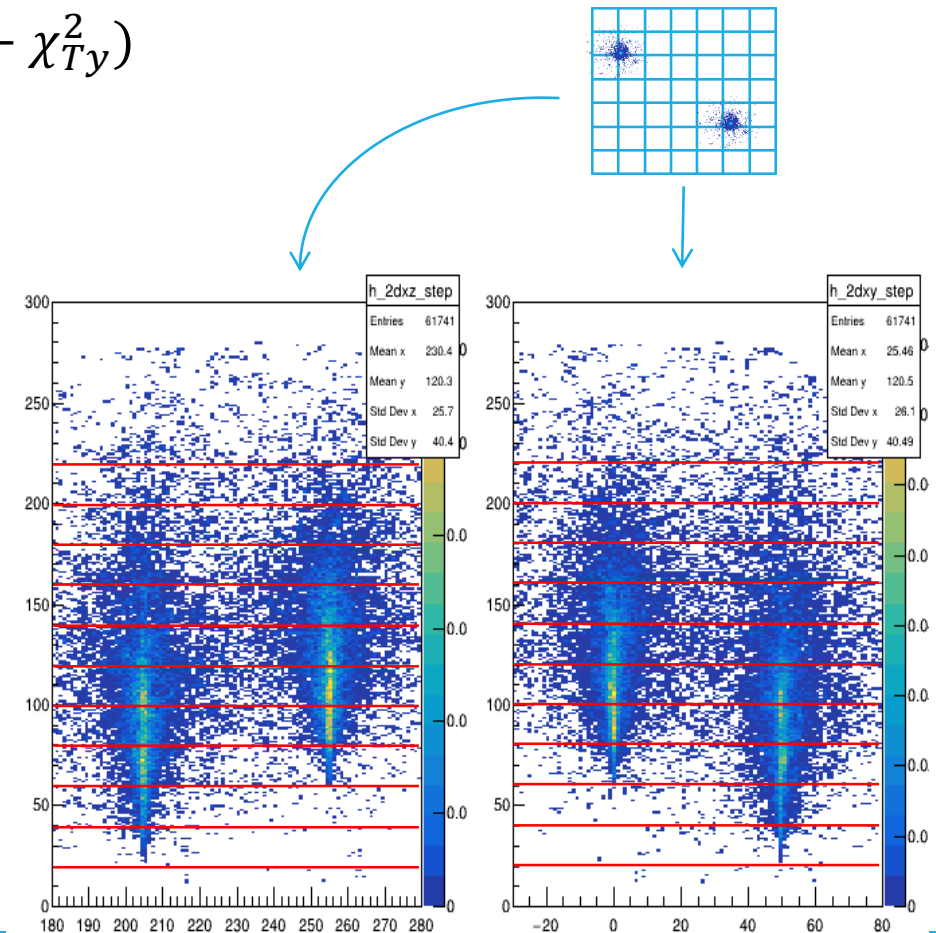




# 2D matching---energy

$$\chi_{point}^2 = w_{iE} * \chi_E^2 + \frac{w_{iT}}{2} * (\chi_{Tx}^2 + \chi_{Ty}^2)$$

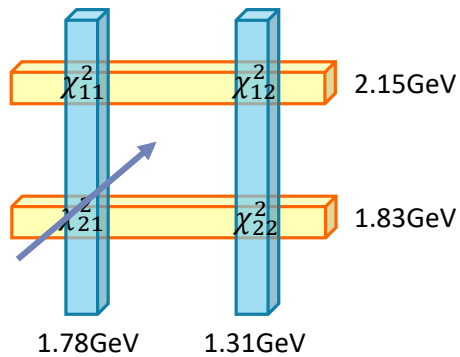
| Depth/mm | Nshower | Eshower1 | Eshower2 |
|----------|---------|----------|----------|
| 20       | 1       | 0.051    |          |
| 40       | 1       | 0.527    |          |
| 60       | 2       | 1.378    | 0.135    |
| 80       | 2       | 1.781    | 1.313    |
| 100      | 2       | 2.138    | 2.192    |
| 120      | 2       | 1.507    | 2.252    |
| 140      | 2       | 0.715    | 2.070    |
| 160      | 2       | 0.547    | 1.171    |
| 180      | 2       | 0.314    | 0.540    |
| 200      | 2       | 0.218    | 0.346    |
| 220      | 1       |          | 0.275    |
| 240      | 1       |          | 0.146    |
| 260      | 1       |          | 0.067    |



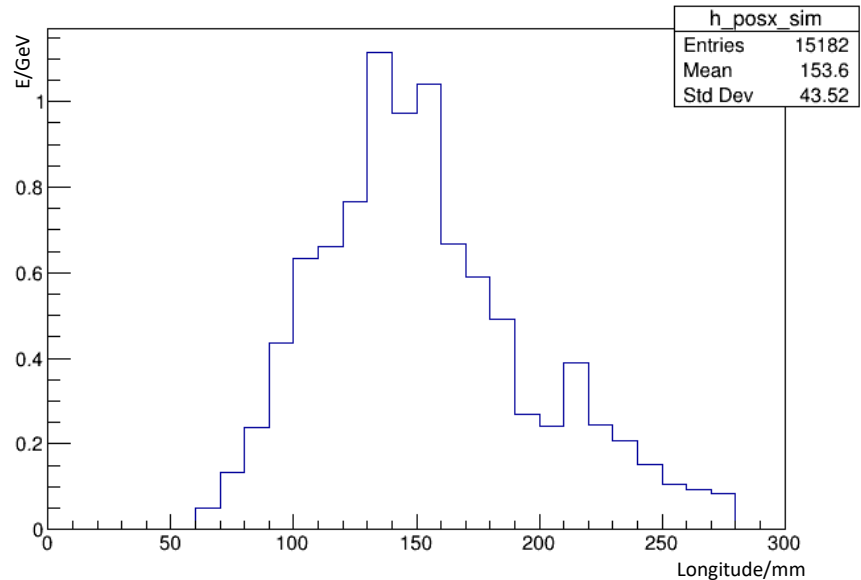
# 2D matching---energy

Check energy and time in one super-layer

- $\chi_E^2$ : energy deposition is difference in X/Y layer due to longitude profile.



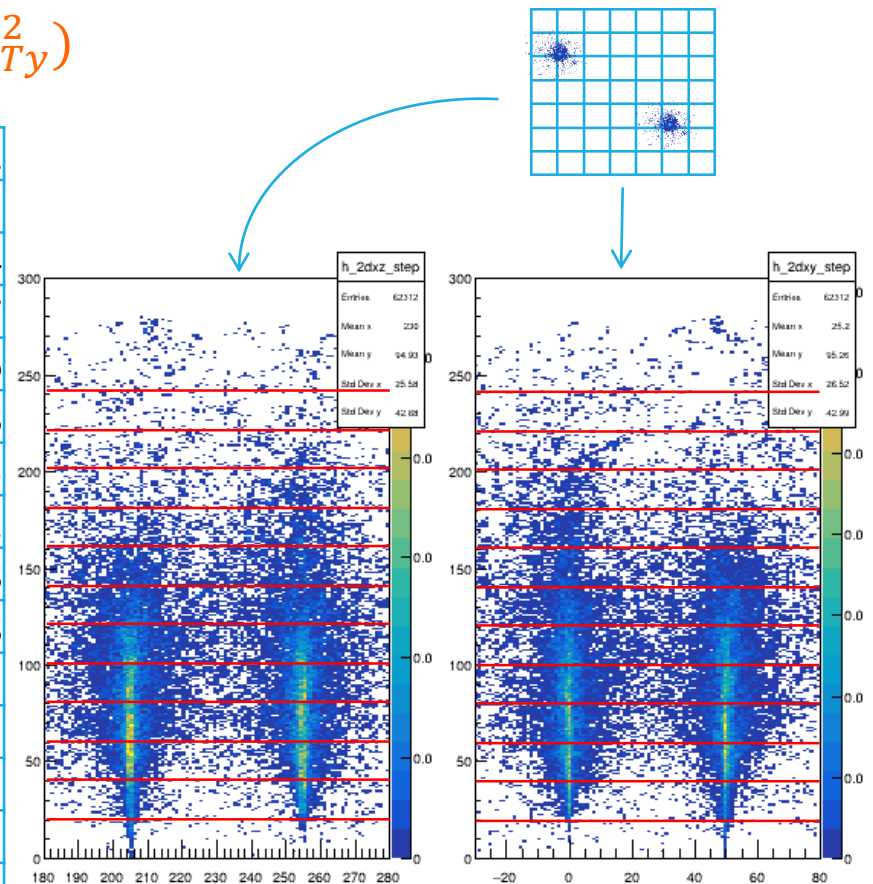
$$\begin{aligned}\chi_{11}^2 &= 107 \\ \chi_{12}^2 &= 284 \\ \chi_{21}^2 &= 1.1 \\ \chi_{22}^2 &= 57.1\end{aligned}$$



# 2D matching---time

$$\chi_{point}^2 = w i_E * \chi_E^2 + \frac{w i_T}{2} * (\chi_{Tx}^2 + \chi_{Ty}^2)$$

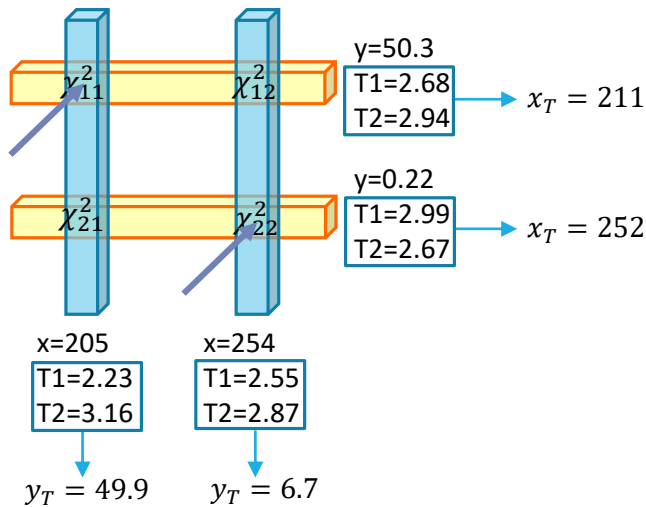
| Depth/mm | Nshower | Eshower1 | Eshower2 |
|----------|---------|----------|----------|
| 0        | 1       | 0.018    |          |
| 20       | 2       | 0.402    | 0.404    |
| 40       | 2       | 1.242    | 1.127    |
| 60       | 2       | 1.667    | 1.96     |
| 80       | 2       | 1.886    | 1.808    |
| 100      | 2       | 1.72     | 1.823    |
| 120      | 2       | 1.137    | 1.201    |
| 140      | 2       | 0.645    | 0.698    |
| 160      | 2       | 0.493    | 0.28     |
| 180      | 1       | 0.511    |          |
| 200      | 1       | 0.351    |          |
| 220      | 1       | 0.099    |          |
| 240      | 3       |          |          |
| 260      | 2       |          |          |



# 2D matching---time

Check energy and time in one super-layer

- $\chi_T^2$ : small chi2 due to large position resolution.



From  $x_T$

$$\chi_{11}^2 = 0.034$$

$$\chi_{12}^2 = 1.49$$

$$\chi_{21}^2 = 1.82$$

$$\chi_{22}^2 = 0.003$$

From  $y_T$

$$\chi_{11}^2 = 10^{-4}$$

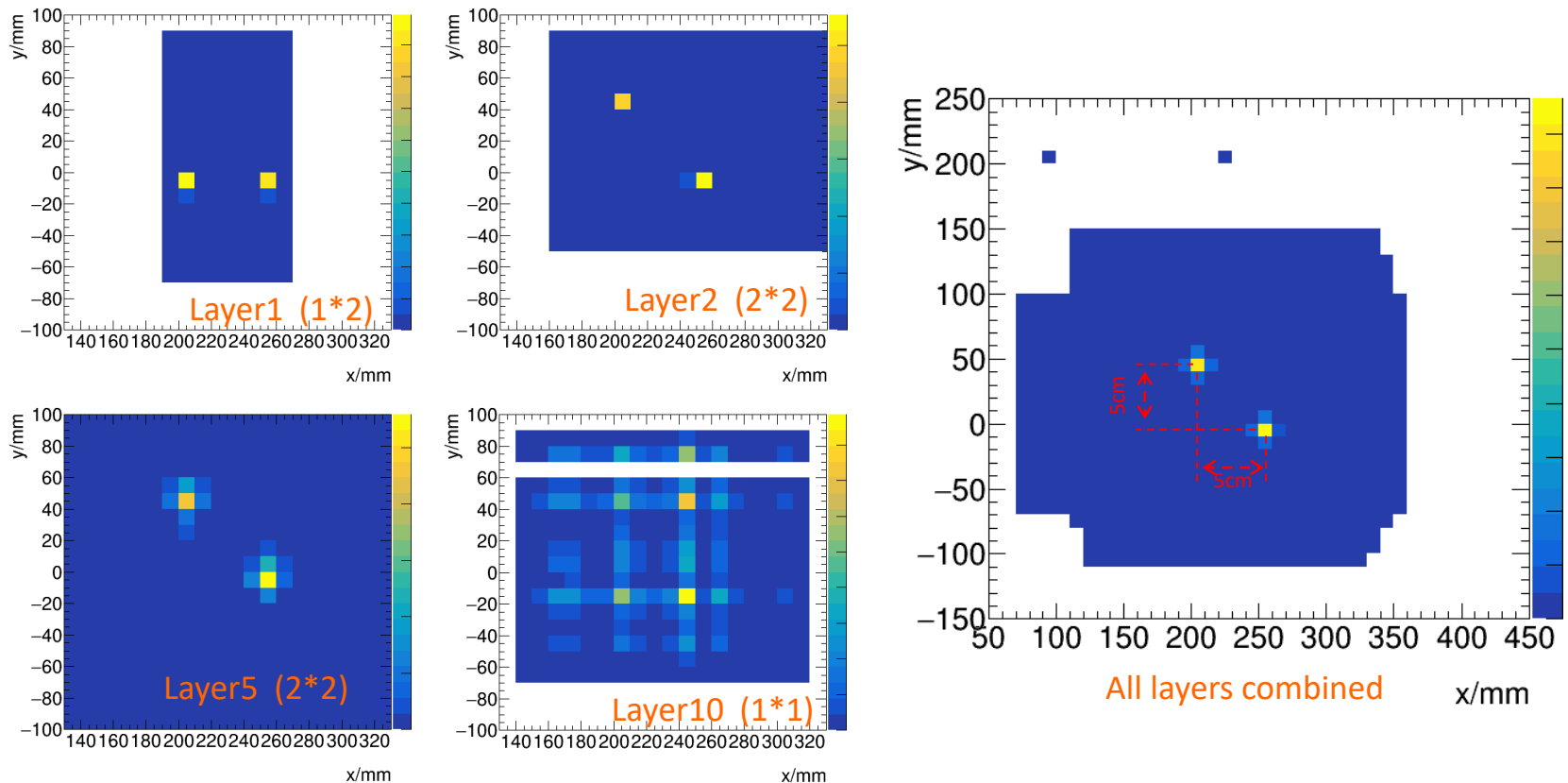
$$\chi_{12}^2 = 1.55$$

$$\chi_{21}^2 = 2.01$$

$$\chi_{22}^2 = 0.034$$

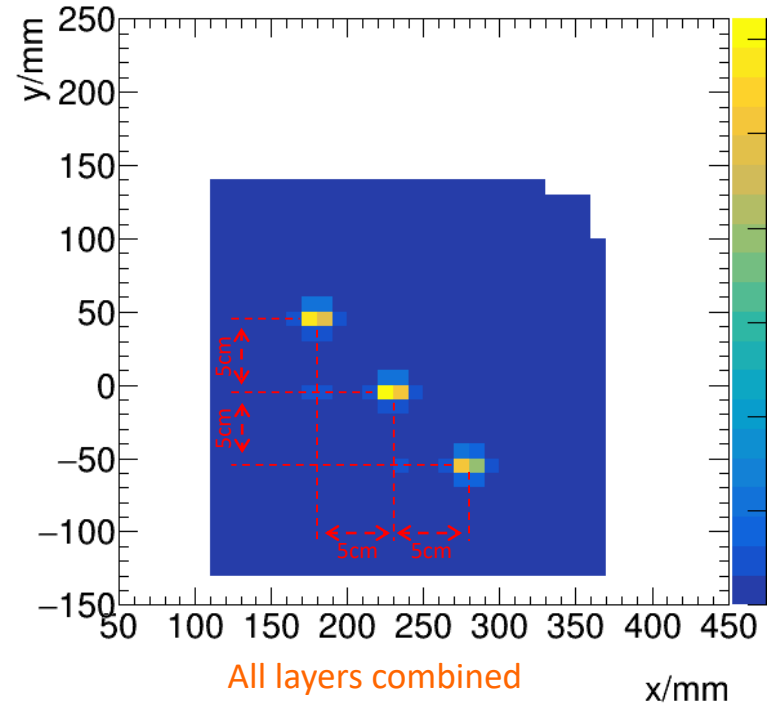
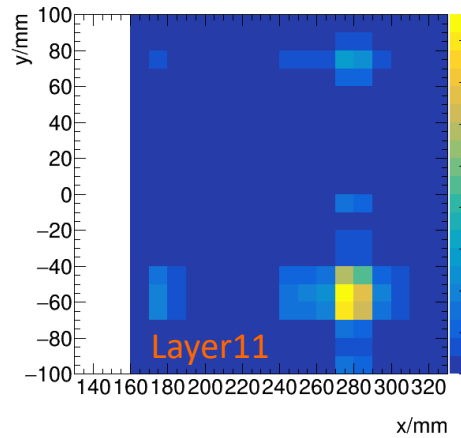
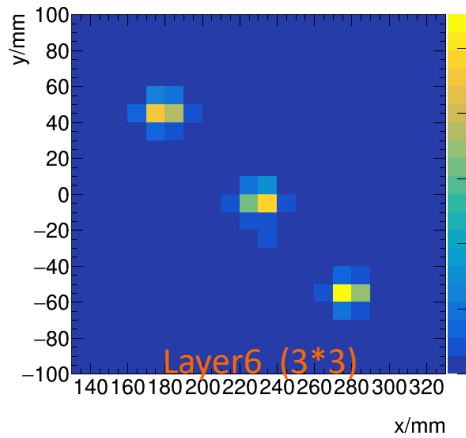
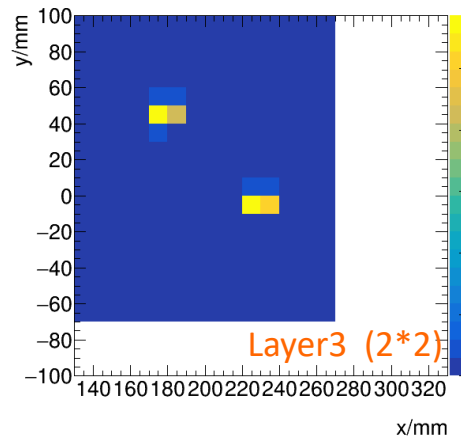
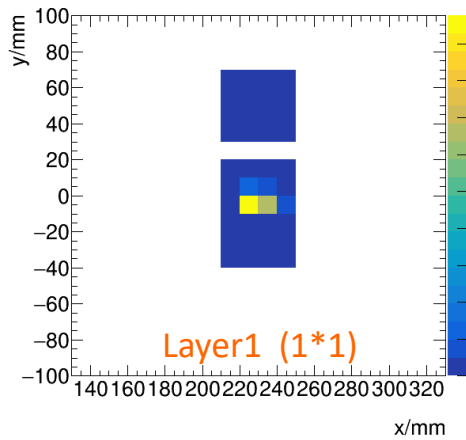
# 2D matching

## 2 hits in one module



# 2D matching

## 3 hits in one module

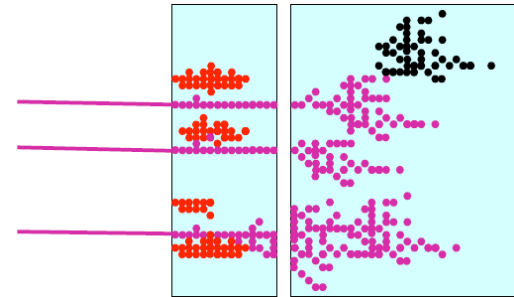


# Summary

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Ghost hit problem can be solved:

- Shower pattern can be recognized from 1D clustering.
- It's possible to use energy + time matching to remove ghost hits.
- Only few cases need time information. Track + energy can deal with most cases in jets.



Next step:

- Get a statistical result.
- Parameters in the algorithm need optimization.
- Consider the longitude shower profile for energy matching and splitting.
- See jet energy resolution and BMR.

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backup



# Hit Reconstruction

Hit reconstruction: cross locating of bars.

- Position:  $(x_i, y_j, \frac{(z_i+z_j)}{2})$
- Energy: use energy distribution in cross bars as fraction:

$$E_{rec} = E_i \times f_i + E_j \times f_j,$$

$$f_i = \frac{E_j}{\Sigma E_j}, \quad f_j = \frac{E_i}{\Sigma E_i}$$

Truth-level Simulated hit: merge G4steps in each  $1*1*1 \text{ cm}^3$  cube as a truth hit.

Time information:  $x_T = x_{bar} + \frac{T1-T2}{2} v$ . Match  $x_T$  with  $x_i$  to veto ghost hits.

