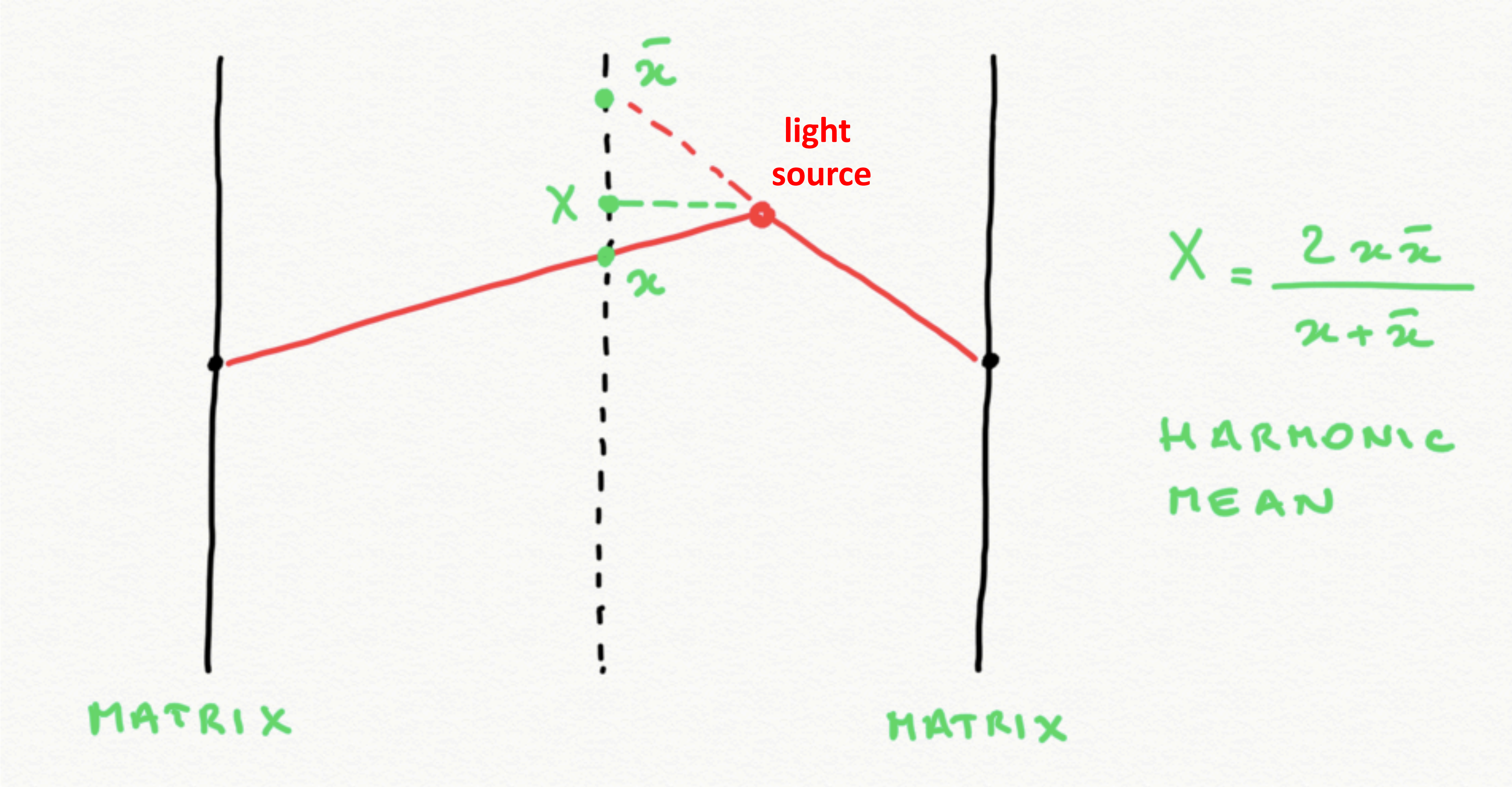
Report on the activity in Lecce

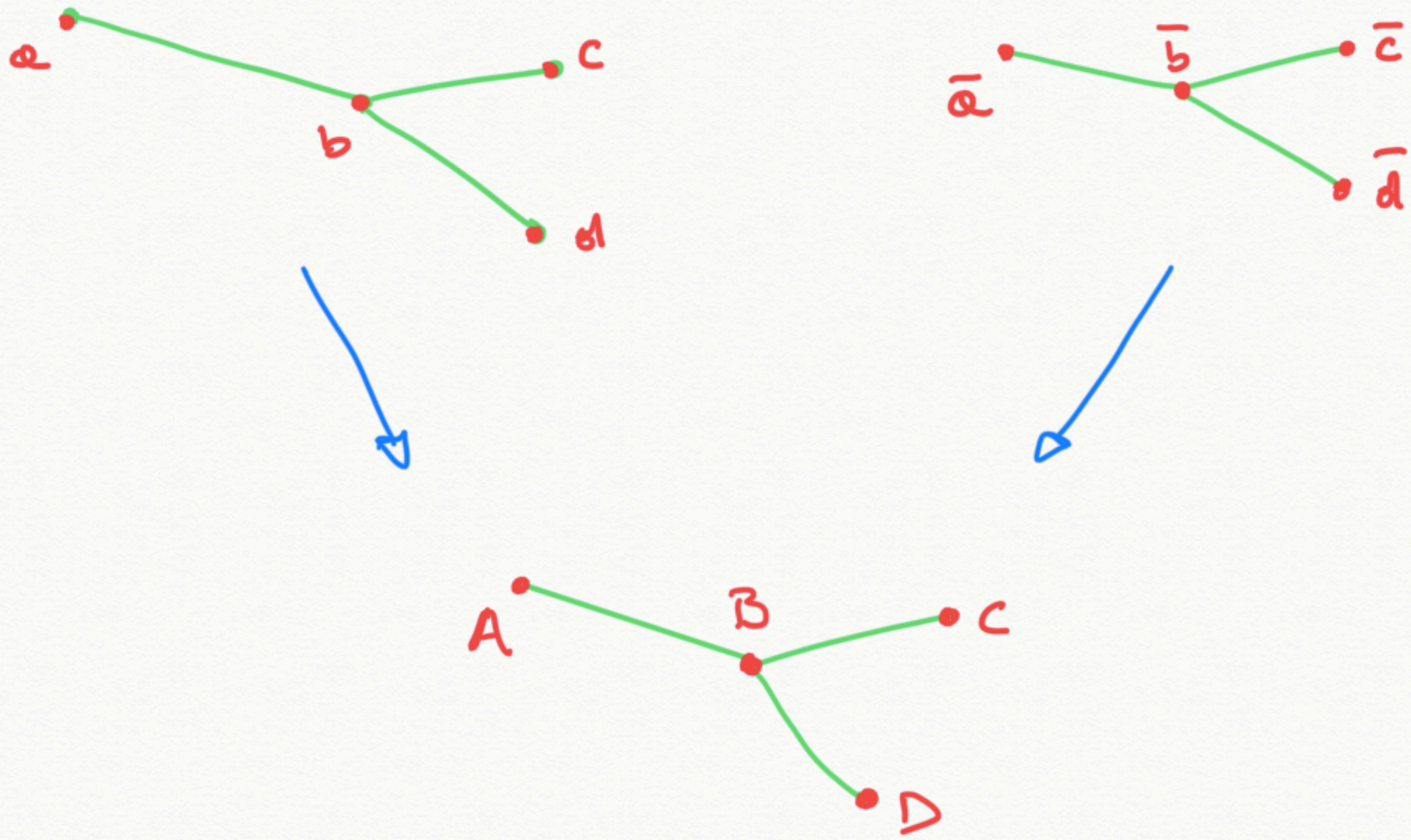
December 23, 2020
zoom meeting

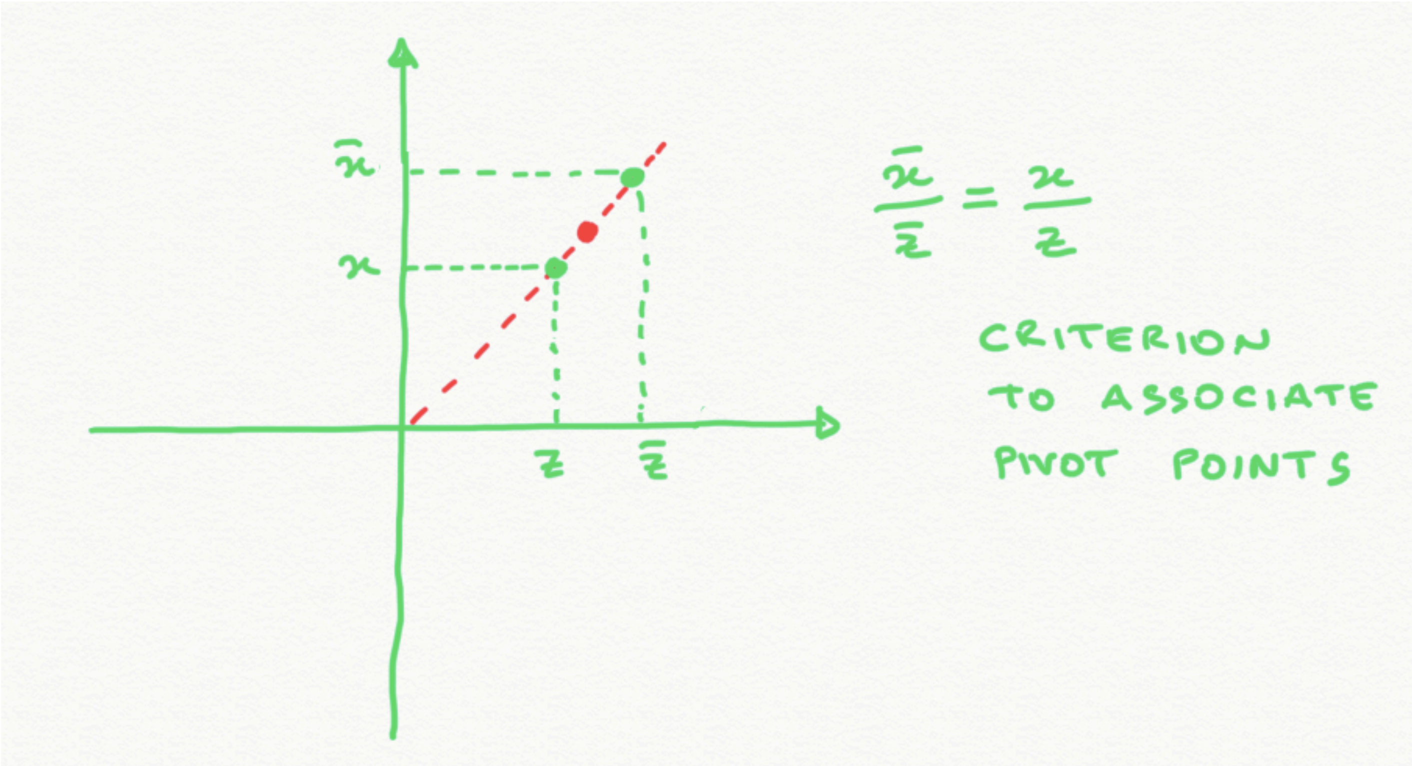
- Theoretical studies about the properties of the coded masks
- Geometrical simulation to check the theoretical results
- Definition of proper setup and fiducial volume
- Track reconstruction by means of DBSCAN

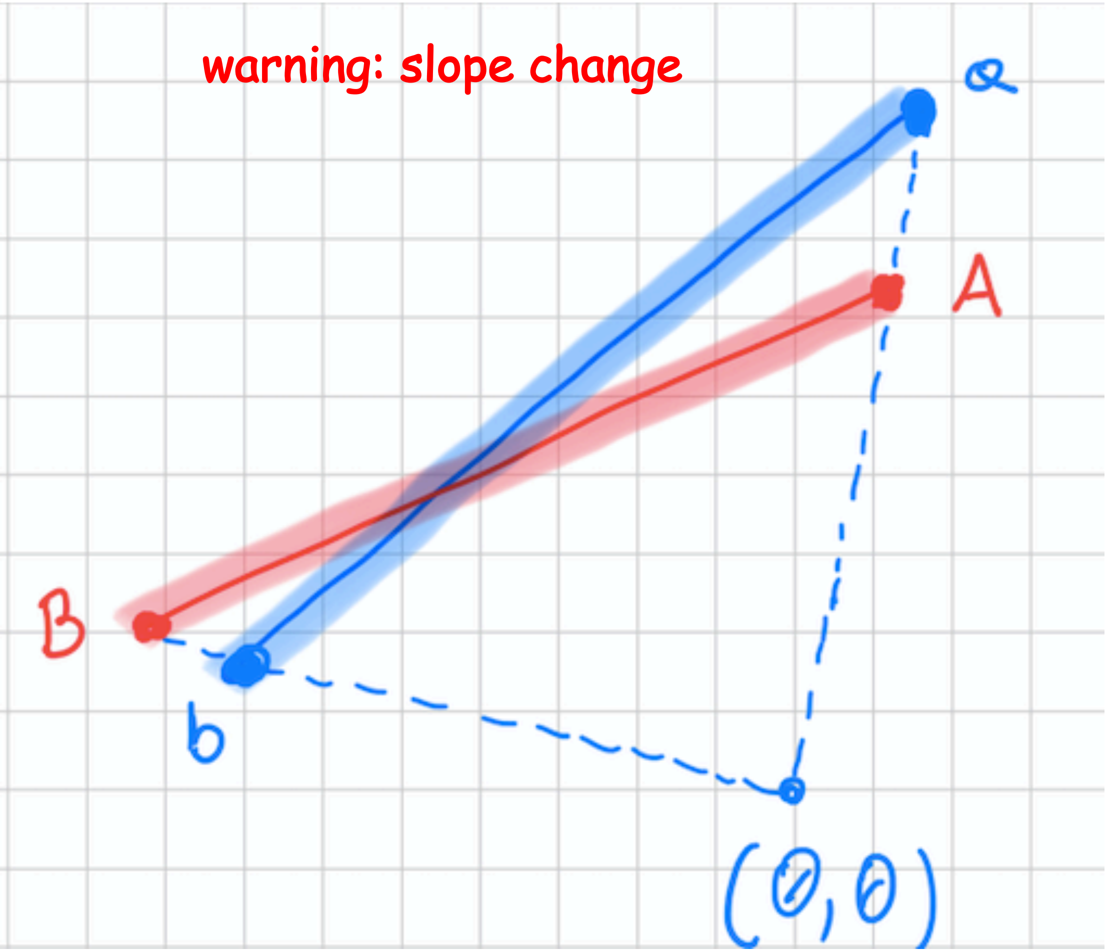
Double measurement of the same view and method of the **harmonic mean**



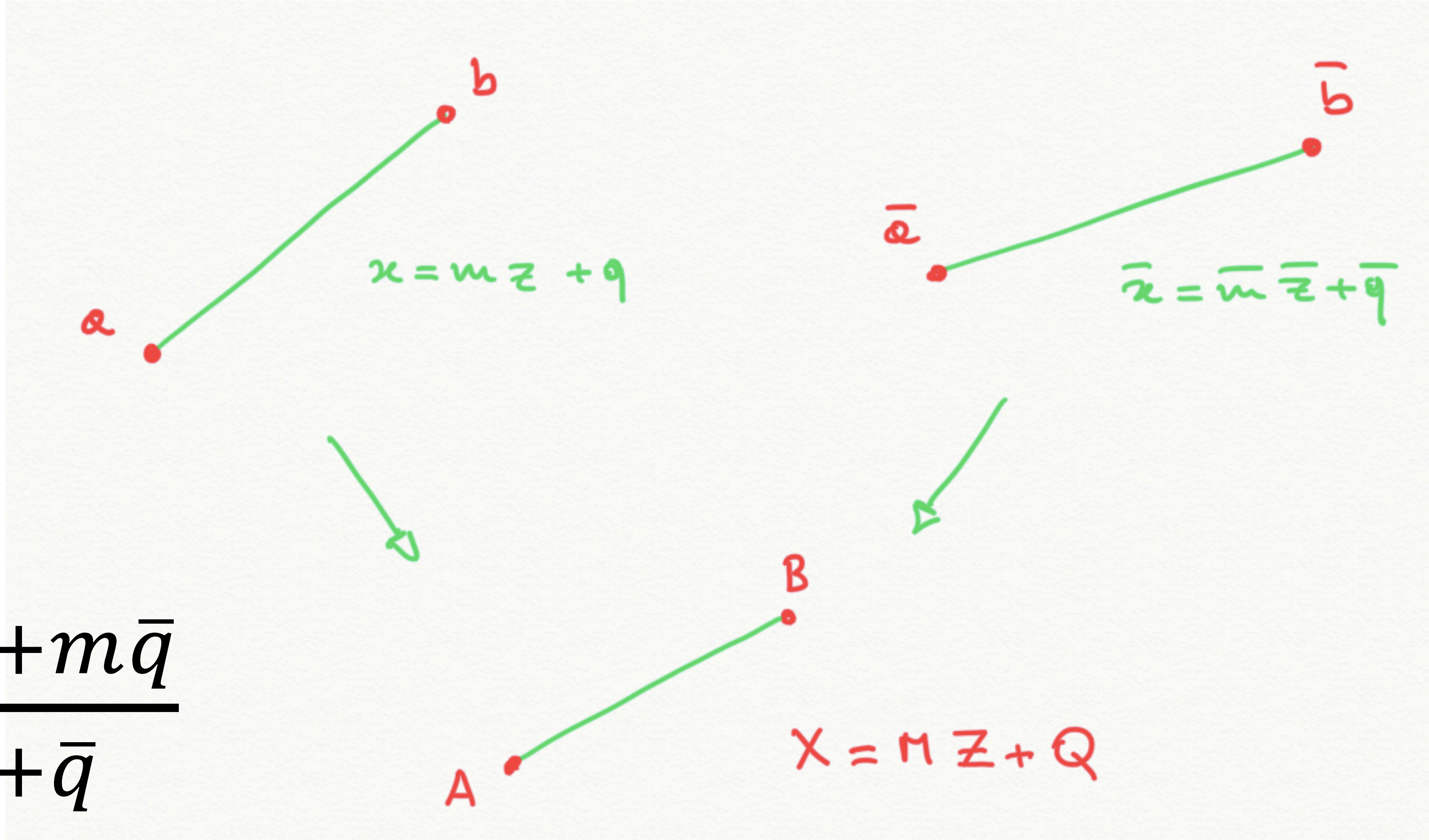
METHOD OF THE PIVOTS POINTS



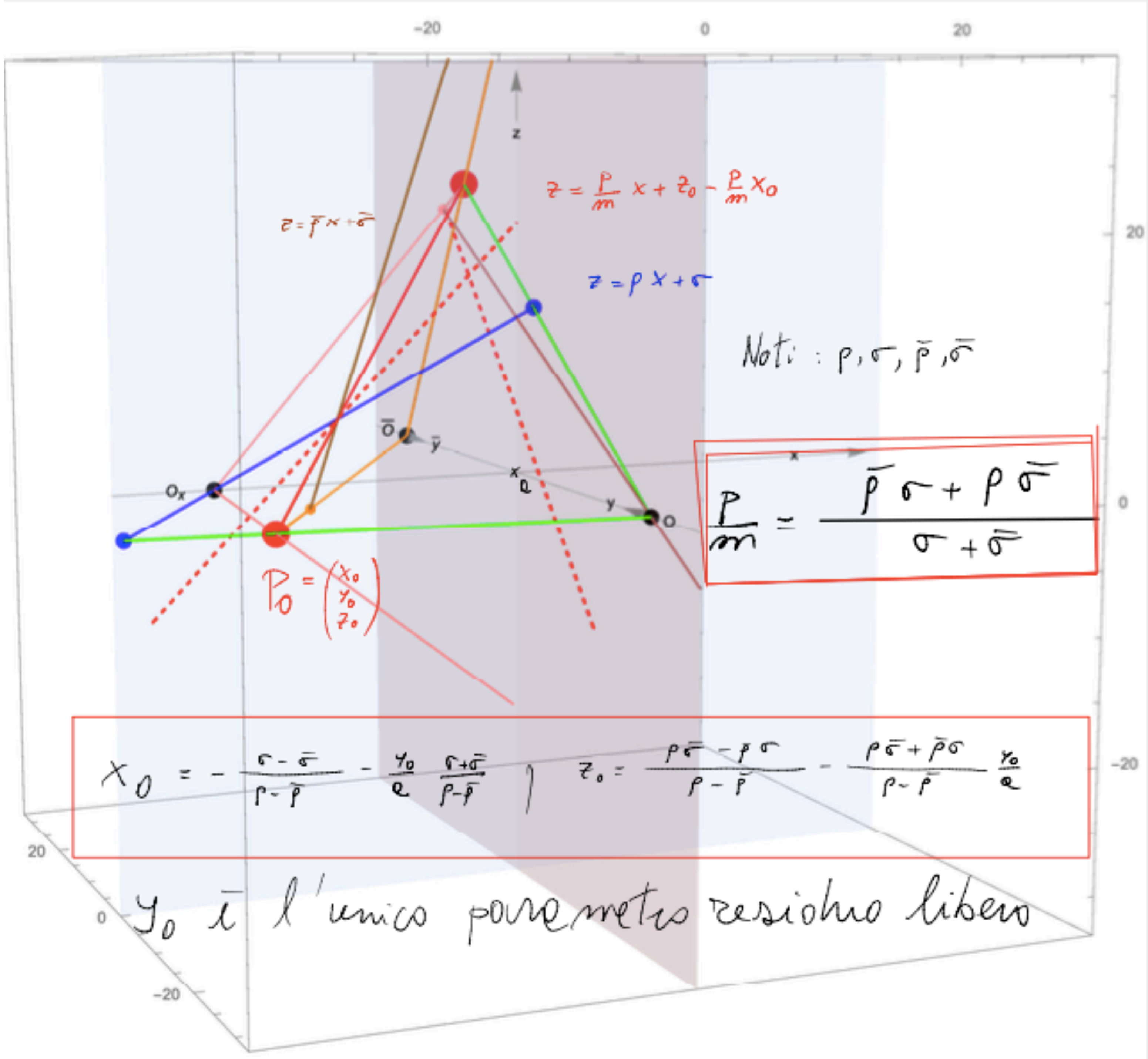

x̄
x
z
z̄
x̄/z̄ = x/z
CRITERION TO ASSOCIATE PIVOT POINTS


warning: slope change
a
A
B
b
(0,0)

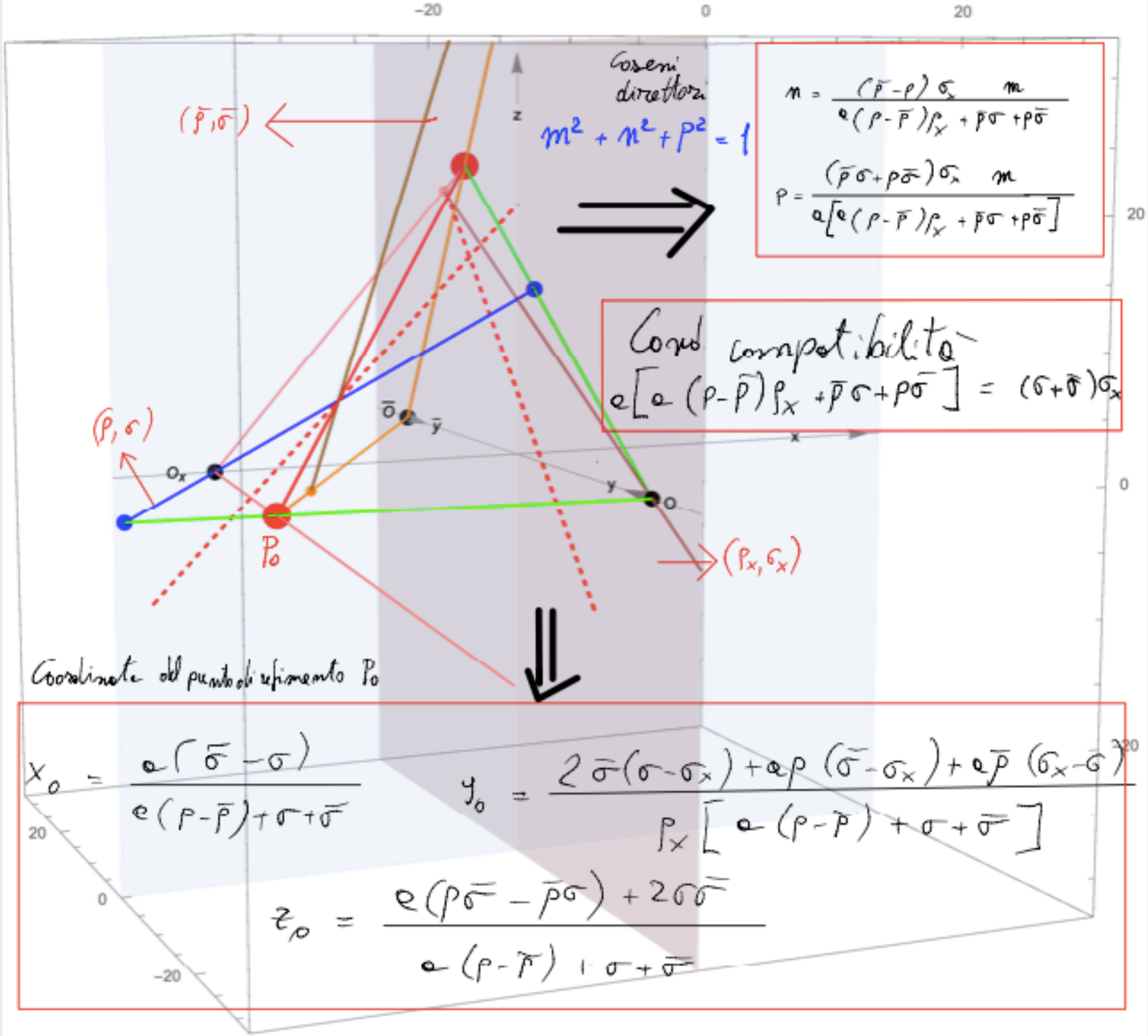
A possible check – the true track is reconstructed from the deformed tracks



$$M = \frac{\bar{m}q + m\bar{q}}{q + \bar{q}}$$



-20
0
20
z
$z = \frac{p}{m} x + z_0 - \frac{p}{m} x_0$
$z = \bar{\rho} x + \bar{\sigma}$
$z = \rho x + \sigma$
Noti : $\rho, \sigma, \bar{\rho}, \bar{\sigma}$
$\bar{O}$
$\bar{y}$
O_x
x_e
y
O
x
$P_0 = \begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix}$
$\frac{p}{m} = \frac{\bar{\rho}\sigma + \rho\bar{\sigma}}{\sigma + \bar{\sigma}}$
$x_0 = -\frac{\sigma - \bar{\sigma}}{\rho - \bar{\rho}} - \frac{y_0}{e}\frac{\sigma + \bar{\sigma}}{\rho - \bar{\rho}}$ | $z_0 = \frac{\rho\bar{\sigma} - \bar{\rho}\sigma}{\rho - \bar{\rho}} - \frac{\rho\bar{\sigma} + \bar{\rho}\sigma}{\rho - \bar{\rho}} \frac{y_0}{e}$
y_0 è l'unico parametro residuo libero



Coseni direttori

$$m^2 + n^2 + p^2 = 1$$

$\Longrightarrow$

$$n = \frac{(\bar{\rho} - \rho)\,\sigma_x\, m}{e(\rho - \bar{\rho})\rho_x + \bar{\rho}\sigma + \rho\bar{\sigma}}$$

$$p = \frac{(\bar{\rho}\sigma + \rho\bar{\sigma})\,\sigma_x\, m}{e\left[e(\rho - \bar{\rho})\rho_x + \bar{\rho}\sigma + \rho\bar{\sigma}\right]}$$

Cond compatibilità

$$e\left[e(\rho - \bar{\rho})\rho_x + \bar{\rho}\sigma + \rho\bar{\sigma}\right] = (\sigma + \bar{\sigma})\sigma_x$$

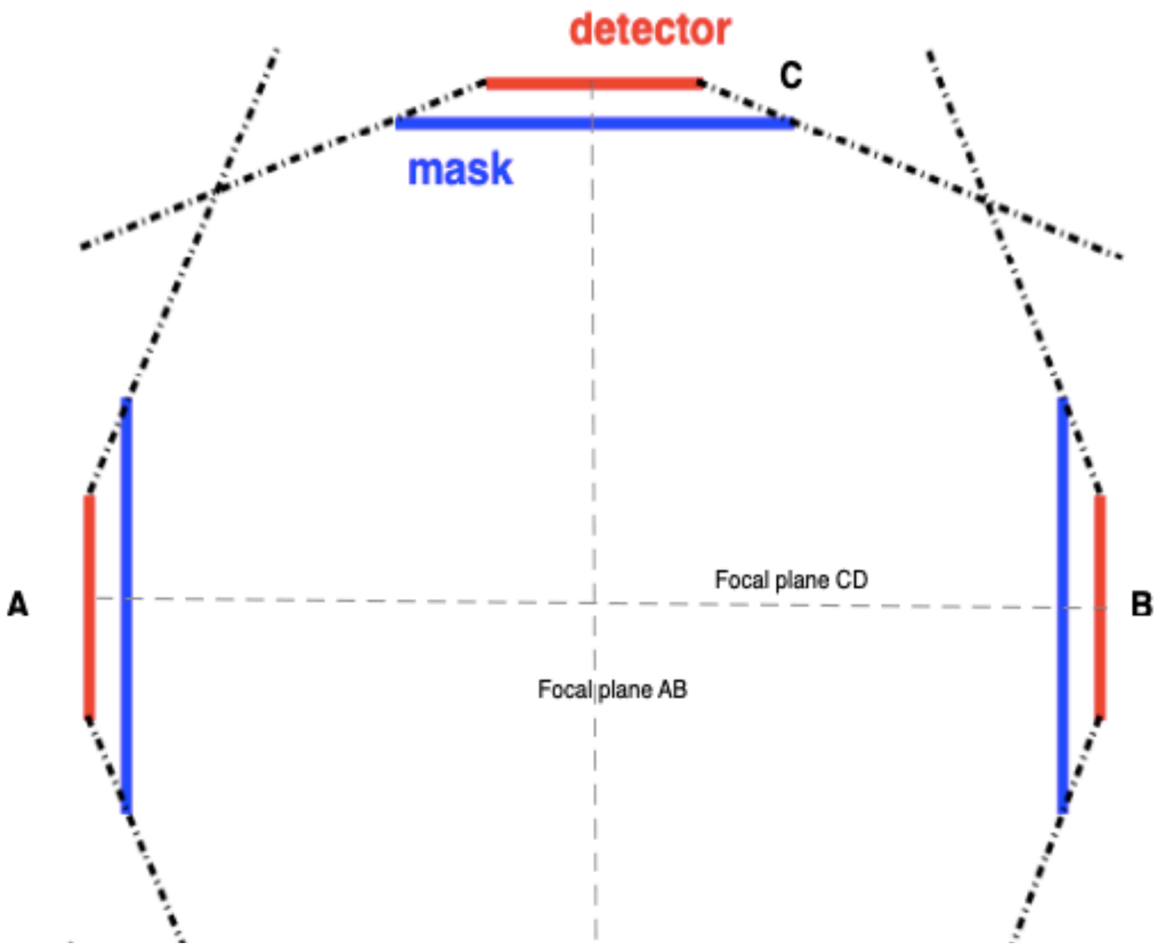
$\Downarrow$

Coordinate del punto di riferimento P_0

$$x_0 = \frac{e(\bar{\sigma} - \sigma)}{e(\rho - \bar{\rho}) + \sigma + \bar{\sigma}}$$

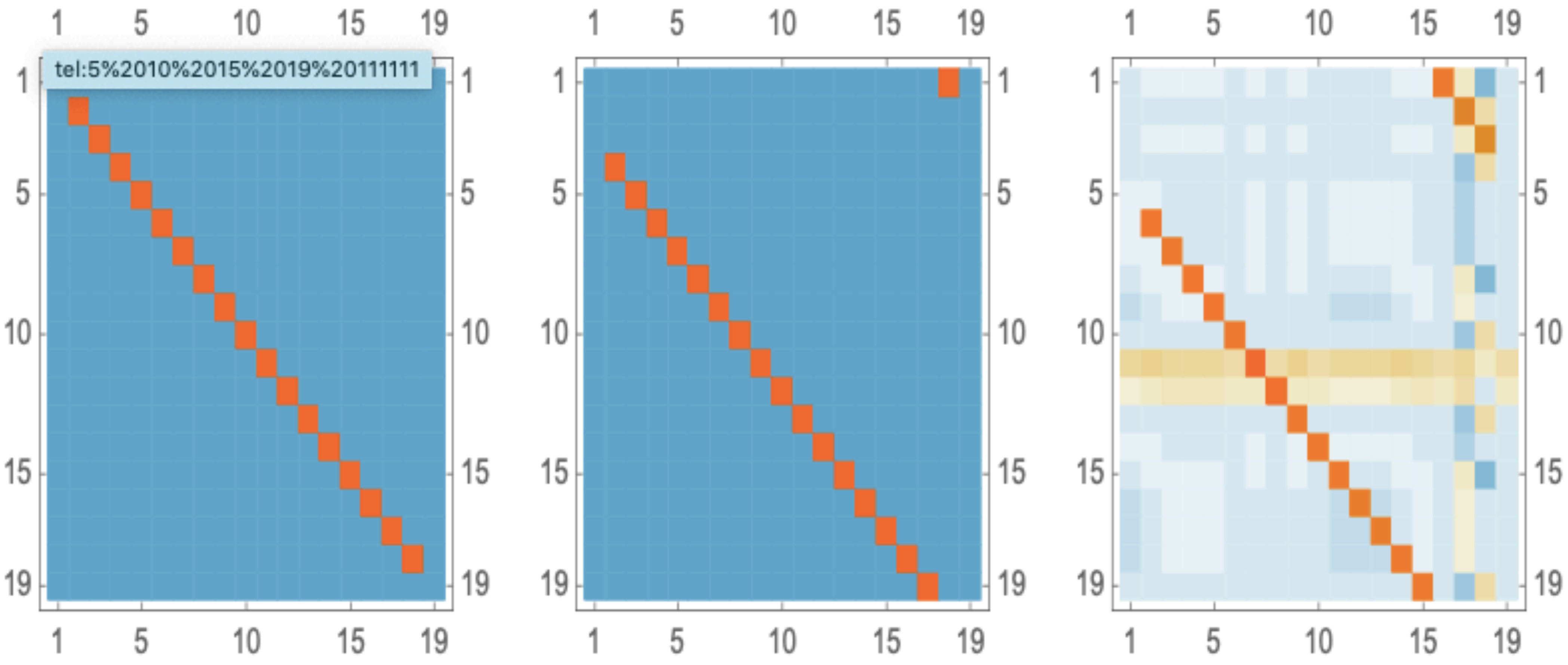
$$y_0 = \frac{2\bar{\sigma}(\sigma - \sigma_x) + e\rho(\bar{\sigma} - \sigma_x) + e\bar{\rho}(\sigma_x - \sigma)}{\rho_x\left[e(\rho - \bar{\rho}) + \sigma + \bar{\sigma}\right]}$$

$$z_0 = \frac{e(\rho\bar{\sigma} - \bar{\rho}\sigma) + 2\sigma\bar{\sigma}}{e(\rho - \bar{\rho}) + \sigma + \bar{\sigma}}$$



3 dectectors can be enough

Toric features of the reconstruction



A paper in progress

Abstract

1 Introduction

The aim of this work is to introduce a possible implementation of the technology of the *Coded Masks*, for the image capturing and their manipulation addressed to the *Deep Underground Neutrino Experiment* (DUNE) experiment [1], devoted to the study of the neutrino Physics. The concept under the device we are trying to develop is to capture the scintillation light emitted by liquid Argon under the excitations of μ particles emitted after a collision of high energy neutrinos on Argon nuclei. Differently from other type of measurements, we would like to localize the vertex of the interaction and the trajectory of the muon. The typical energies of the ejected muon are sufficiently high to generate $\approx 10^4 \frac{photons}{sr\,cm}$ at the typical light wavelength of 127 nm. One might reasonably wonder if such a photon stream cannot be used for a direct visualization of the muon trace by a camera, like in a bubble chamber. However, Collecting and focusing enough light is a challenging problem and the exploitation of the coded masks have been proposed, in order to avoid lenses and have sufficiently high luminosity. In the following we will discuss the basic features of the imagers we are thinking about.

2 Imaging by Coded Masks

It is well understood that a small pinhole is required to achieve high spatial resolution, but the small pinhole also dims the light in the image. Multiple pinholes increase light intensity, but they made image reconstruction more involved, and this approach had to exploit fast numerical methods [4, 5]. Each bright point of a scene deposits a shadow-image of the pinhole array on the viewing screen. They improve brightness where lenses are difficult or not applicable as in the X or gamma-rays case. In the case of the VUV they can be seen as an alternative to the use of special materials transparent to such wavelengths. Knowledge of the geometry of the pinhole array (the *coded mask*) allows for numerical recovery of the image [6]. Initially, random arrays of pinholes were used in X-ray astronomy [7, 8] and these were eventually replaced by binary uniformly redundant arrays [9, 10] (URAs), which were shown to be optimal for imaging [11, 21]. The multitude of sharp open features contain equal amounts of all possible spatial frequencies, thereby allowing high spatial resolution without sacrificing image brightness. Depth information about the object is encoded in the scaling of the shadow image of the object points. URA-based coded masks are now commonly used in hard X-ray astronomy [22, 27], medical imaging [28, 37], plasma research [32], homeland security [33] and spectroscopy [34]. The technology of the coded mask is well established in the astrophysical domain (for a fast review see [2]) and for medical diagnostic imaging [48]. Since in the experiment we are interested in the light sources are posited at length scales of the optical apparata (meters vs centimeters) (see for details [1] Vol. 2), we concentrate to the *Near Field* geometrical settings. They imply important geometrical effects, leading to distortions in the data and the presence of arte-facts in reconstruction of the image. Thus this situations has to be attentively considered largely improving the reconstruction techniques. Entering in the details and the concrete designing of a mask applicable to the considered experiment, we assume that the size of the apertures (all identical) are well beyond that the diffraction effects becomes important and geometrical optics is still a good approximation. Also the interference effects of the light coming from the different apertures is neglected. These are strong assumptions and possibly the main sources of noise in the image. Further, we assume the light to be monochromatic, disregarding at the first stage the effects of a finite band width of the emitted spectrum.

2.1 Physical Settings

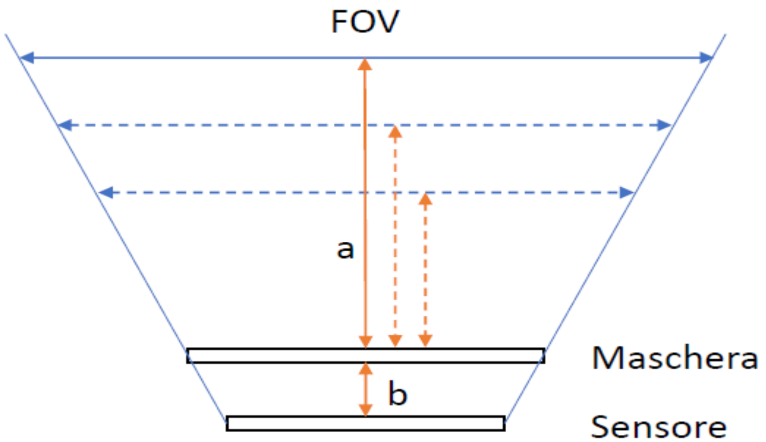
The geometrical setting of light source, mask and detector plane are deoicted in Fig. (1). We assume that the size of the apertures (all identical) are well beyond that the diffraction effects becomes important and geometrical optics is still a good approximation. Also the interference effects of the light coming from the different apertures is neglected. These are strong assumptions and possibly the main sources of noise in the image. Further, we assume the light to be monochromatic, disregarding at the first stage the effects of a finite band width of the emitted spectrum.

Other matrices have been tested

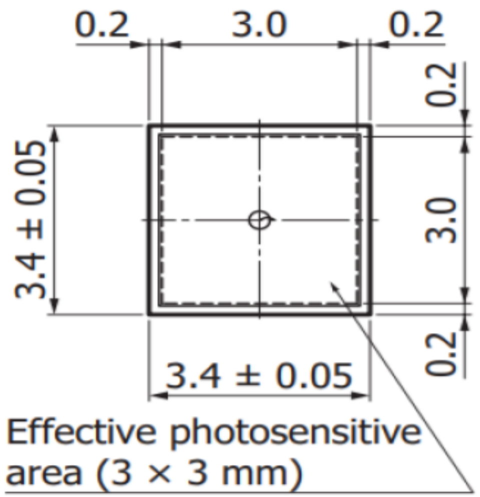
NTHT
PNP
MLS
Quasi-random series

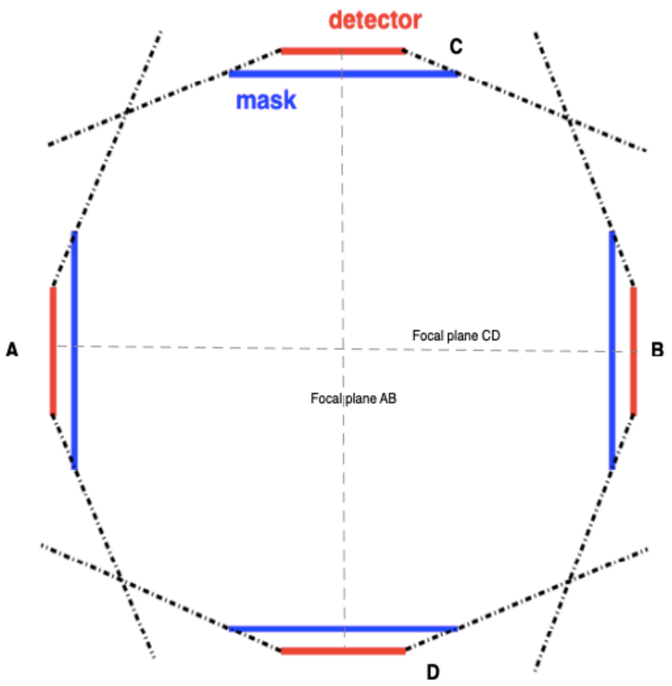
results similar to MURA

Setup Parameters



Rango matrice	17
Rango maschera	17
Lato pixel	3.4 mm
Pitch maschera	3.15 mm
Distanza maschera-sensore (b)	20 mm
Distanza maschera-oggetto (a)	250 mm
FOV	723 mm

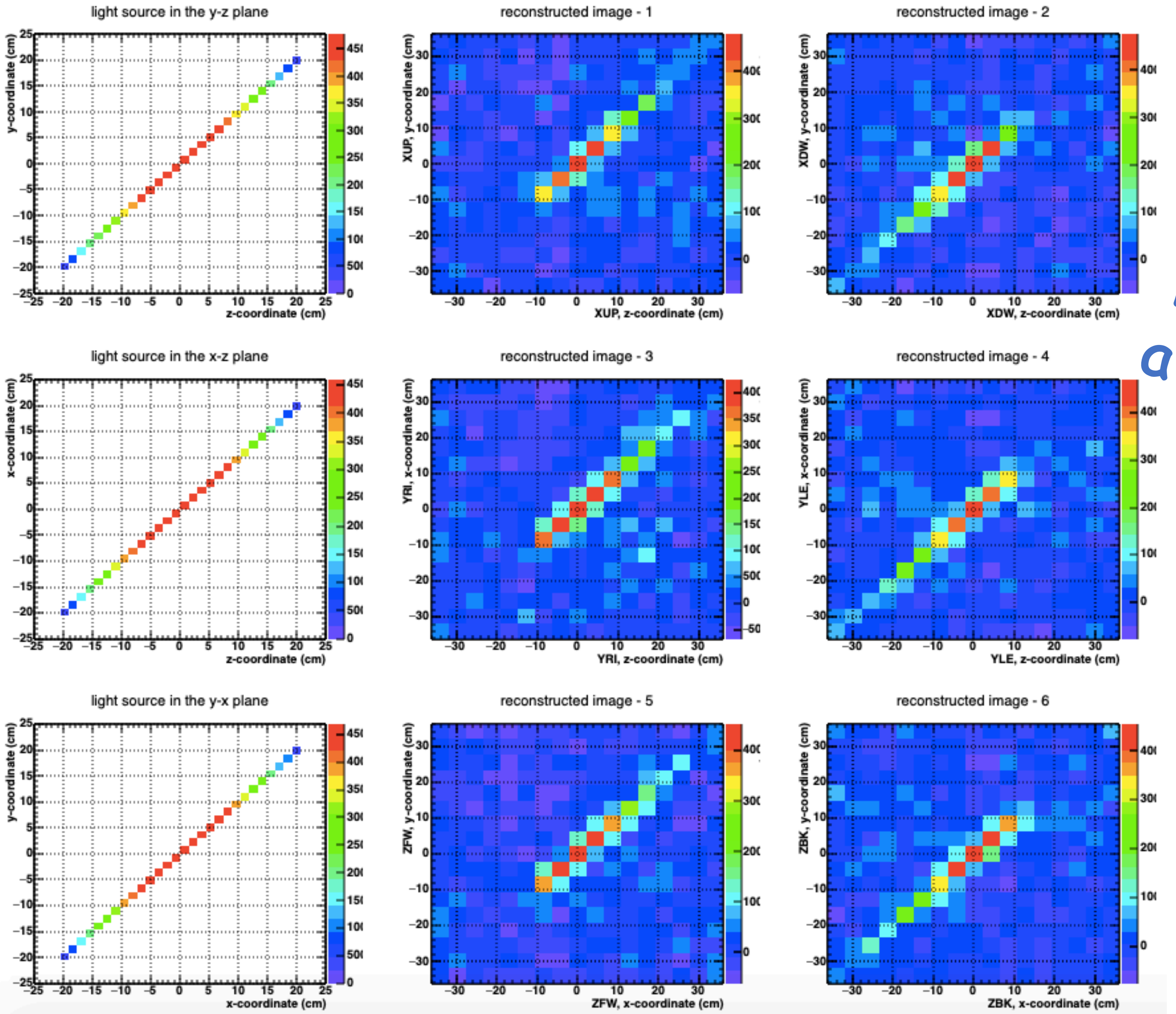




MURA 17x17

enhanced (x5)

B = 2 cm

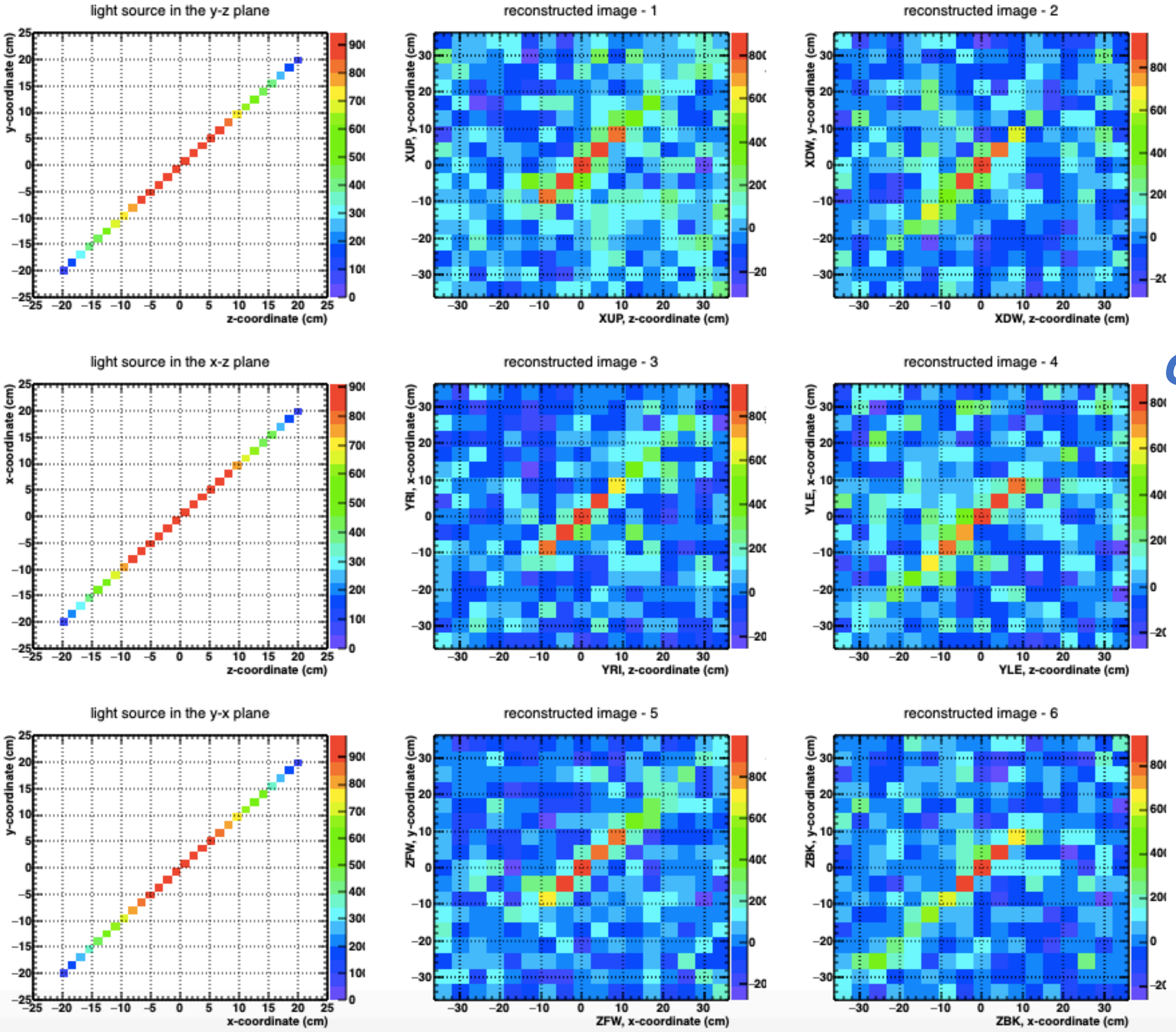


bisector as a benchmark

MURA 17x17

B = 2 cm

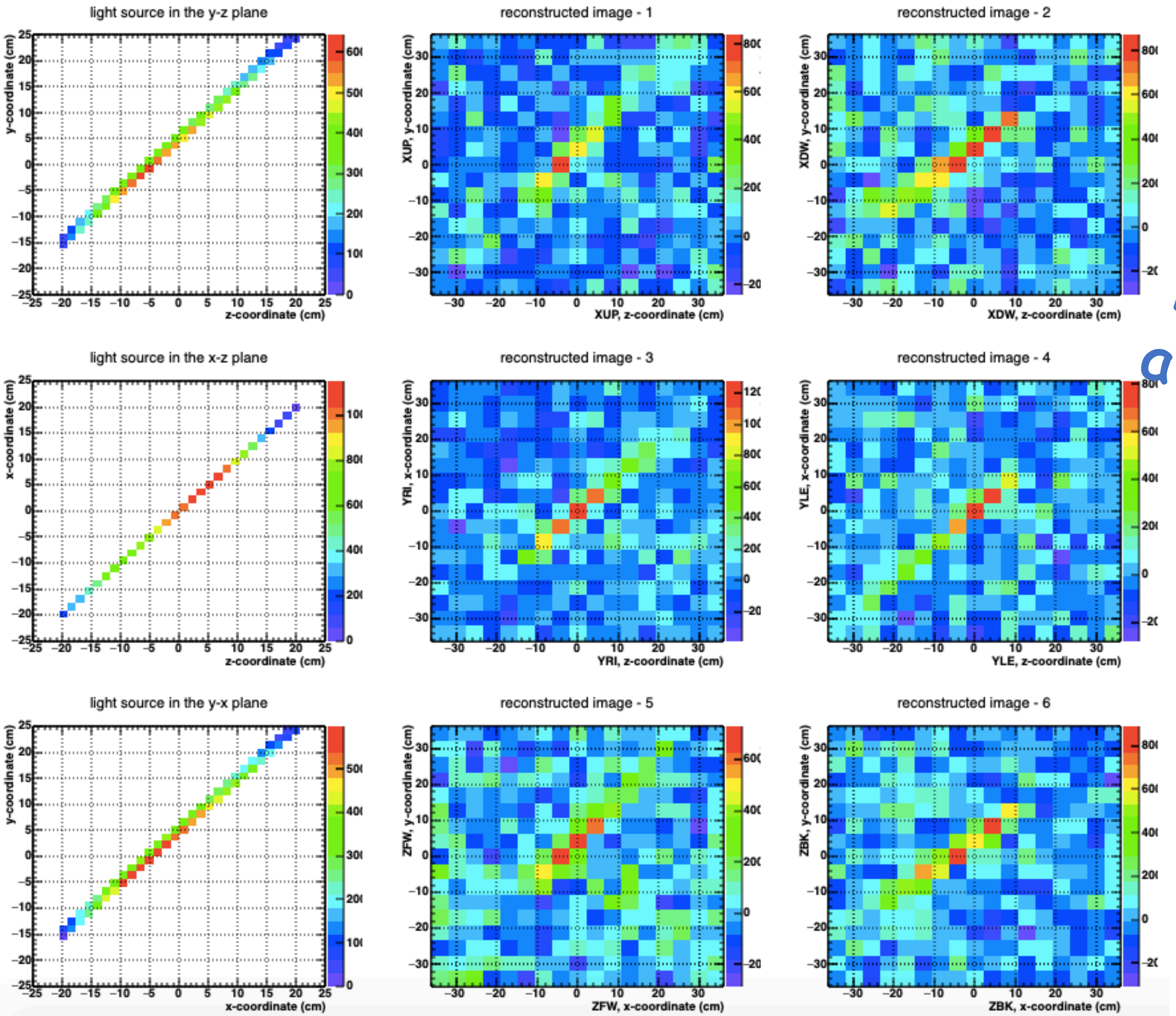
y-offset 0.0



bisector as a benchmark

MURA 17x17

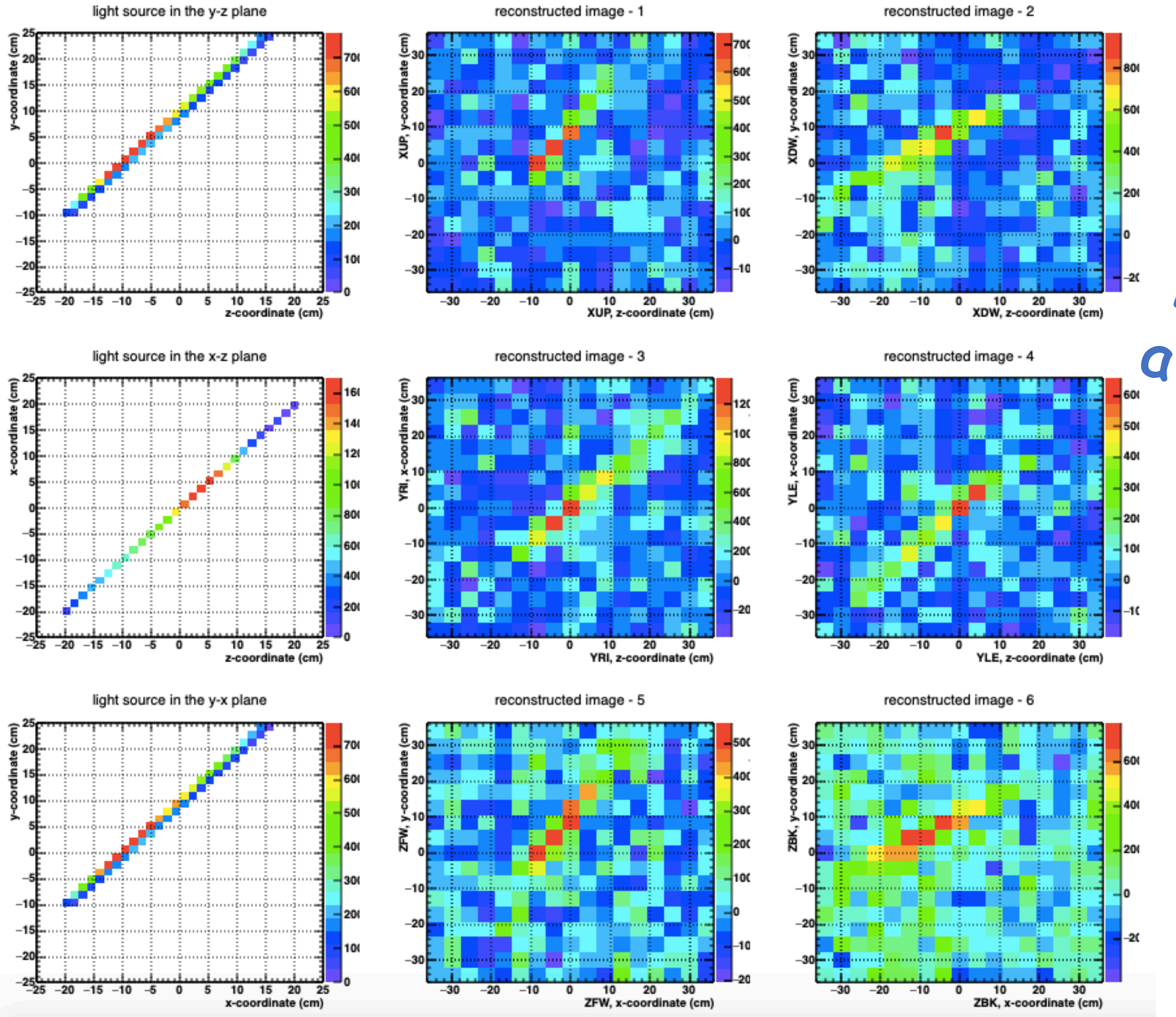
y-offset 5 cm



bisector as a benchmark

MURA 17x17

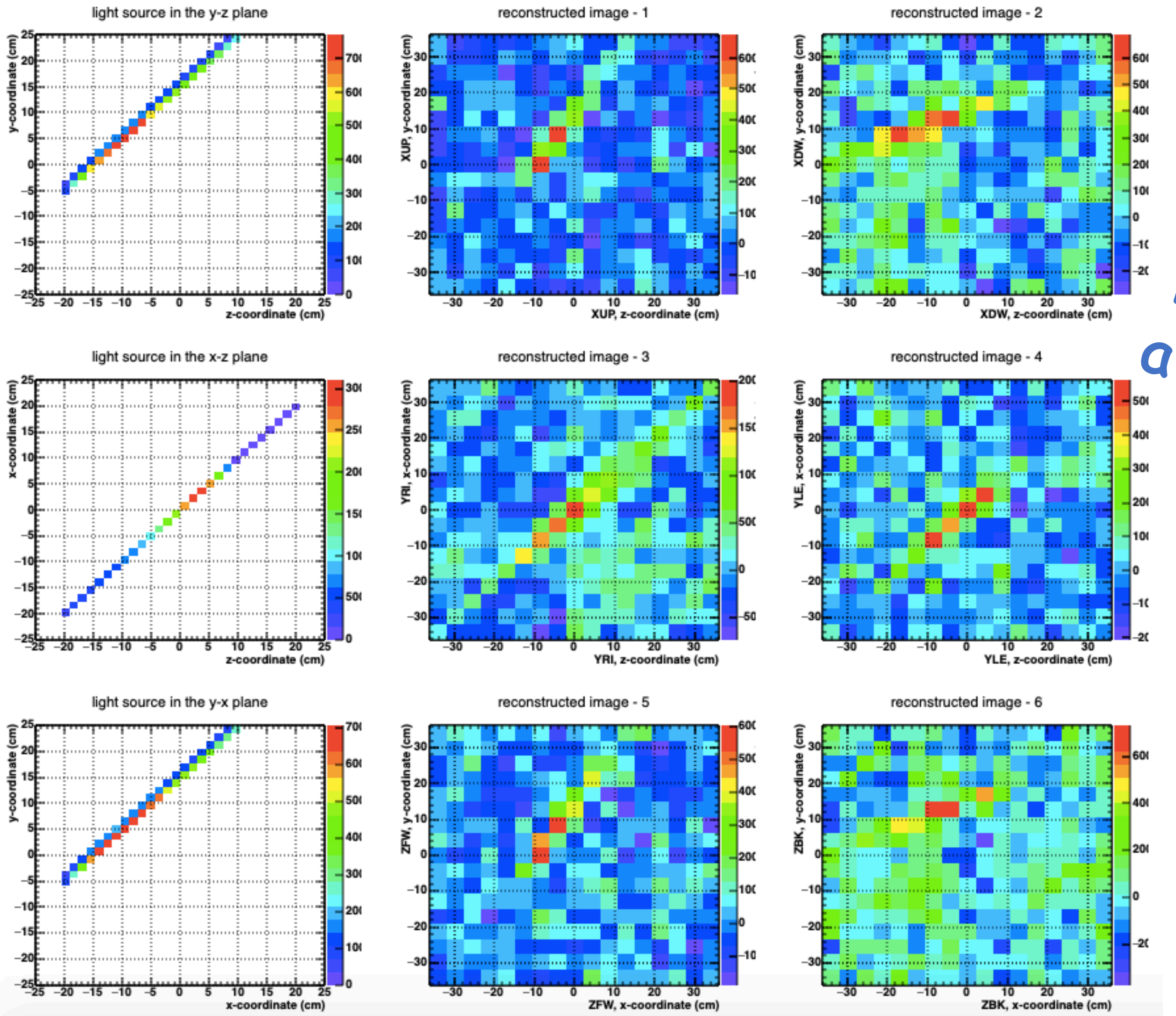
y-offset 10 cm



bisector as a benchmark

MURA 17x17

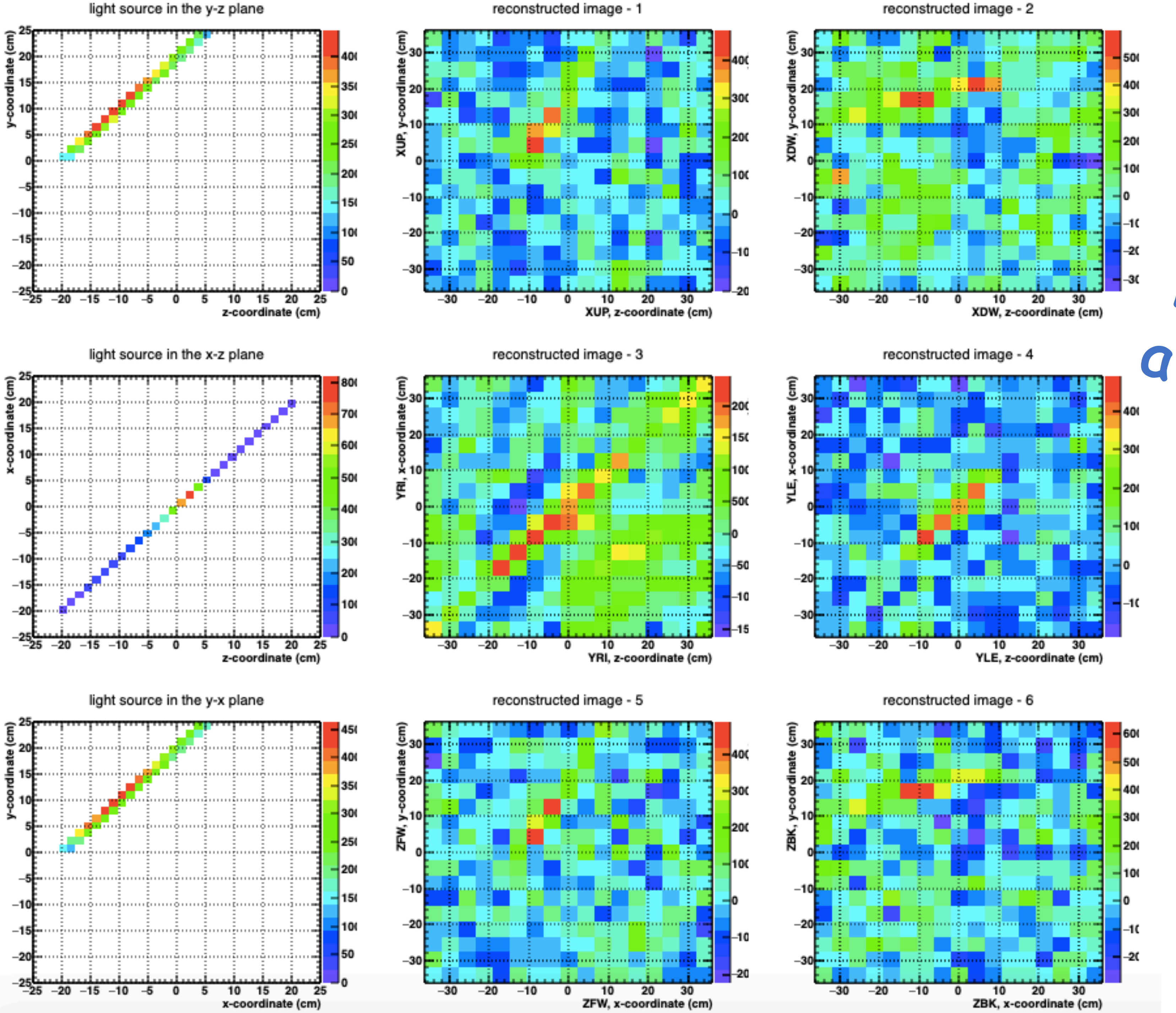
y-offset 15 cm



bisector as a benchmark

MURA 17x17

y-offset 20 cm



bisector as a benchmark

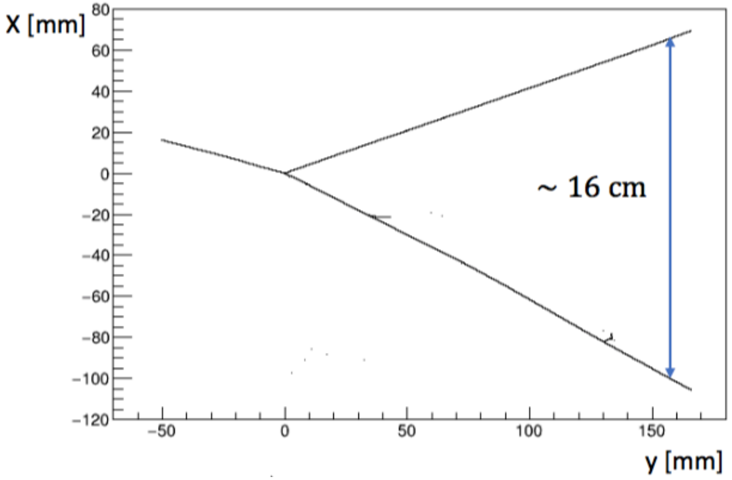
A simple procedure to detect the signal

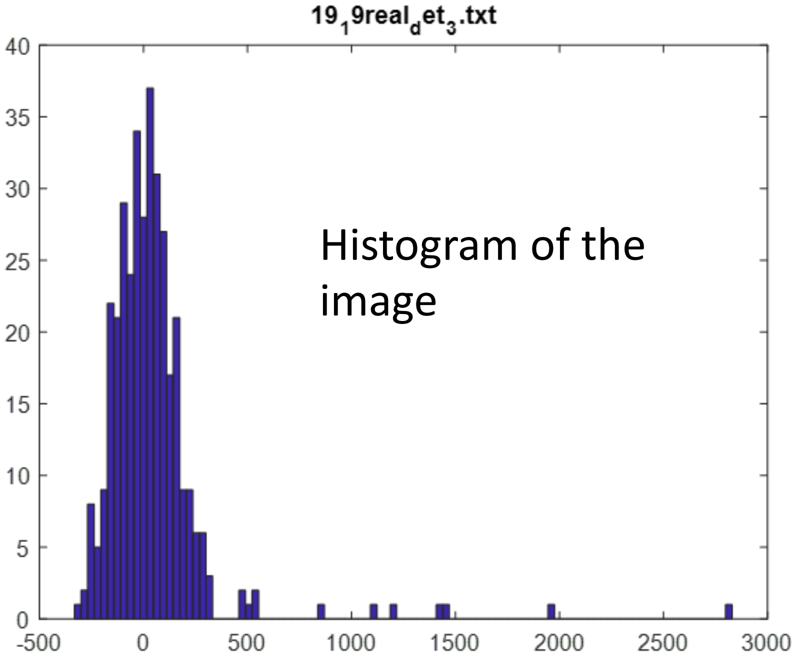
A simple procedure was developed in order to **automatically** extract the spatial extent of the signal from the noisy images on the detectors.

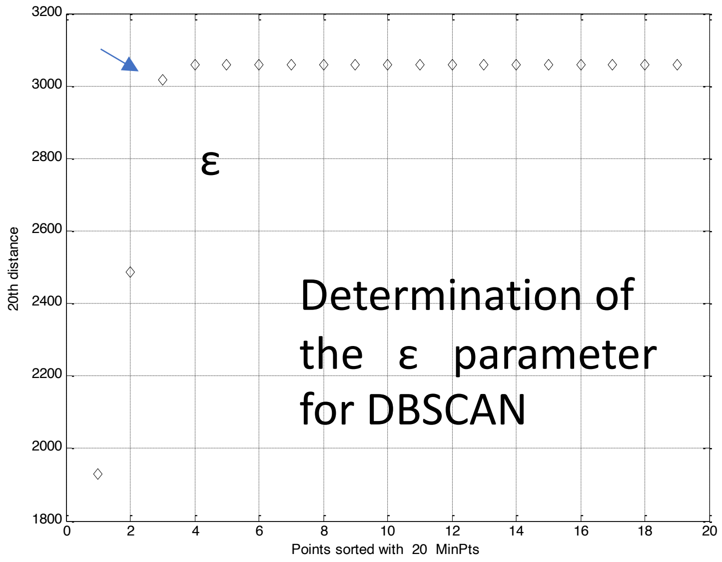
It consists of :

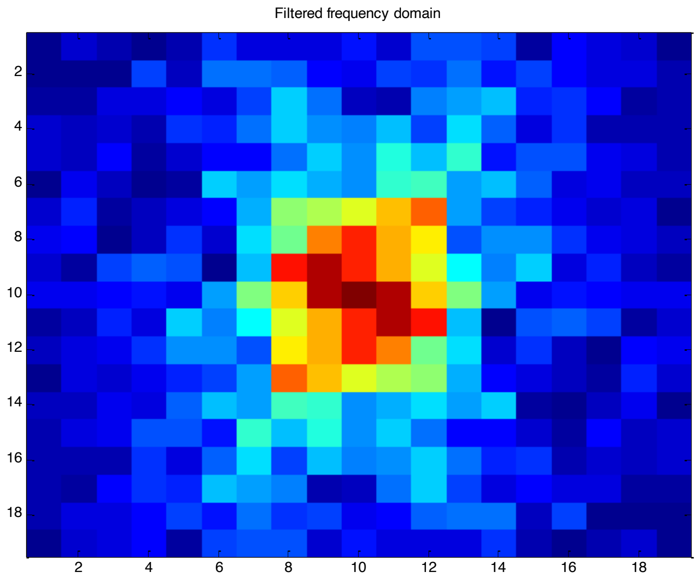
- a pre-processing stage, where, taking into account the shape of the image histogram, a better separation between noise and signal was performed, by using a Gaussian low-pass filter (Czako et al., 2019);

- the search of the points belonging to the signal, by means of the Density-based Spatial Clustering of Applications with Noise (DBSCAN), widely used in many fields of research, spanning from network security, data mining, geospatial data, until biomedical images (Ester et al., 1996, Heris et al., 2015).

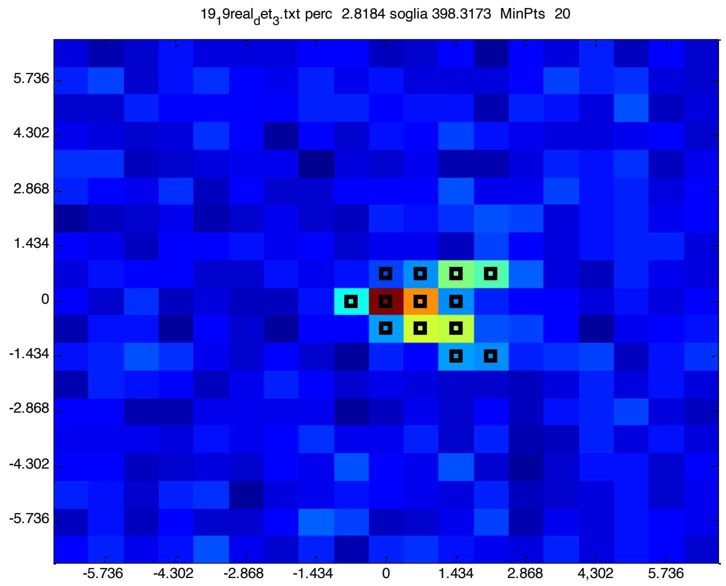




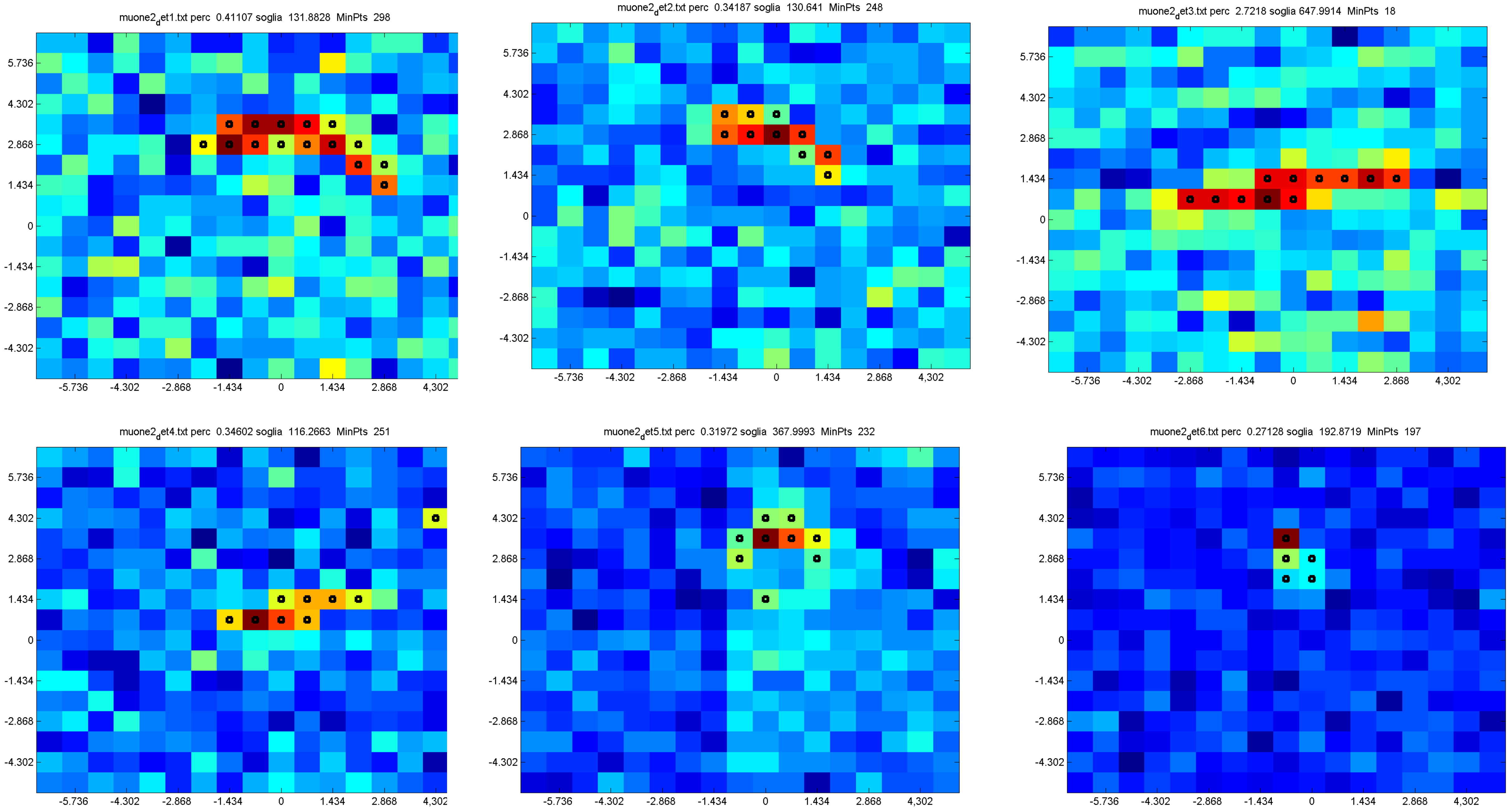




Gaussian filter

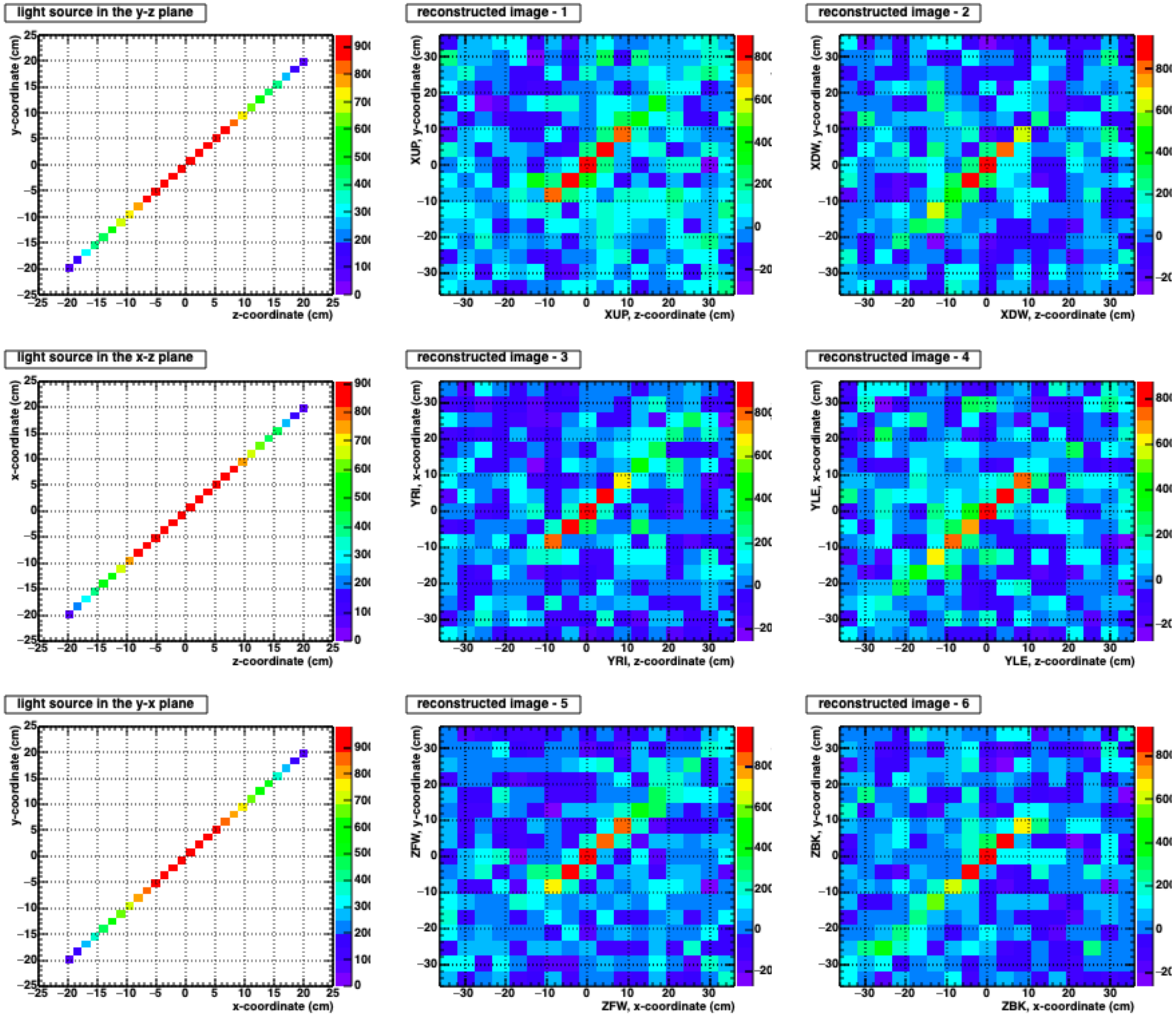


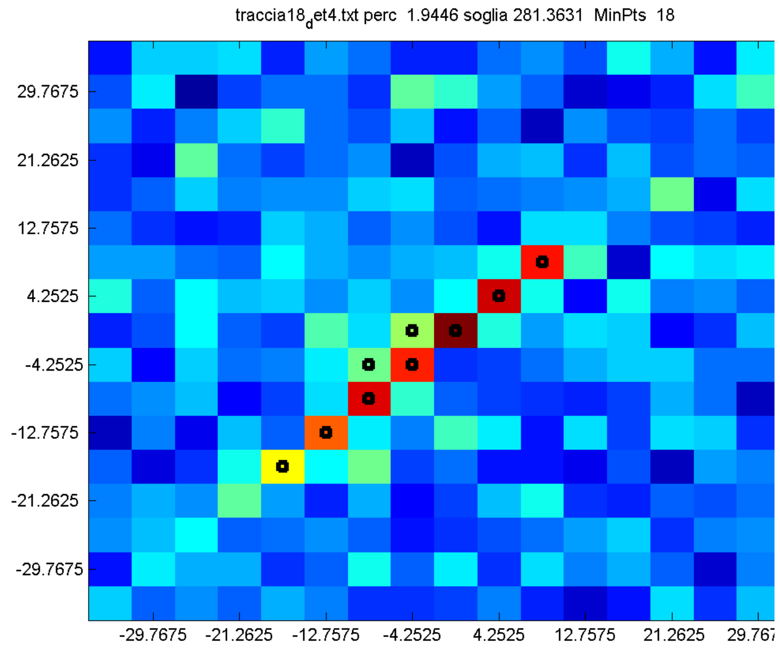
Final detection

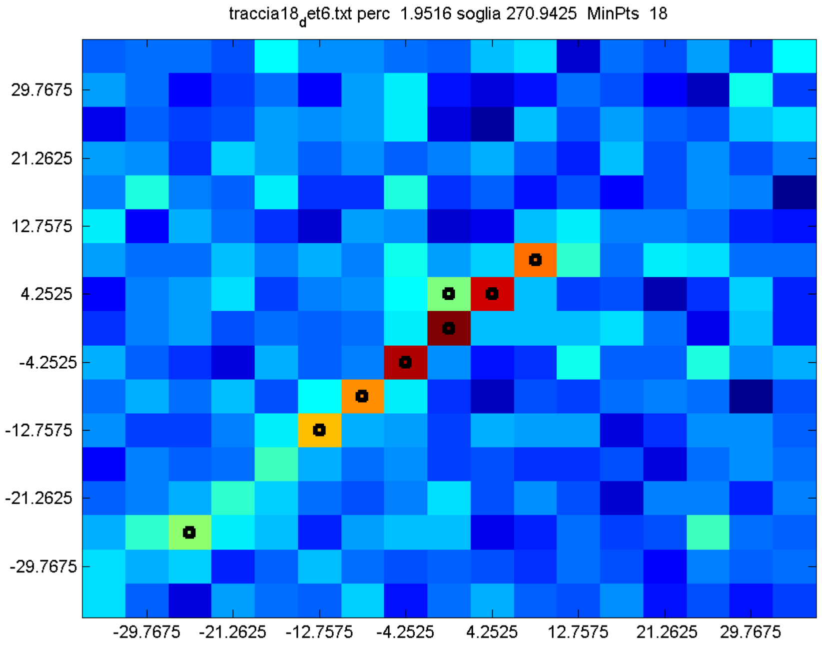


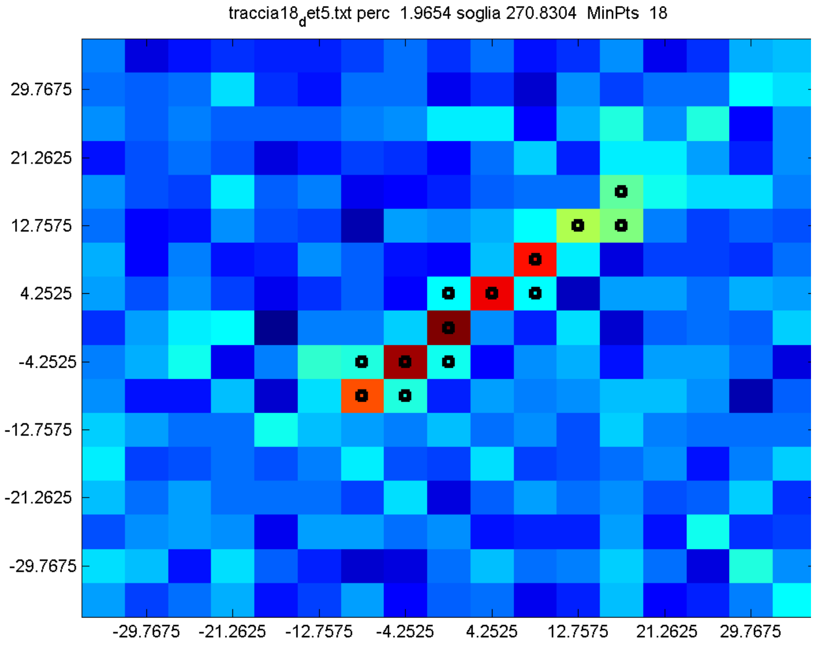
muone2_det1.txt perc 0.41107 soglia 131.8828 MinPts 298
muone2_det2.txt perc 0.34187 soglia 130.641 MinPts 248
muone2_det3.txt perc 2.7218 soglia 647.9914 MinPts 18
muone2_det4.txt perc 0.34602 soglia 116.2663 MinPts 251
muone2_det5.txt perc 0.31972 soglia 367.9993 MinPts 232
muone2_det6.txt perc 0.27128 soglia 192.8719 MinPts 197
5.736
4.302
2.868
1.434
0
-1.434
-2.868
-4.302
-5.736
4.302

Images on the detectors

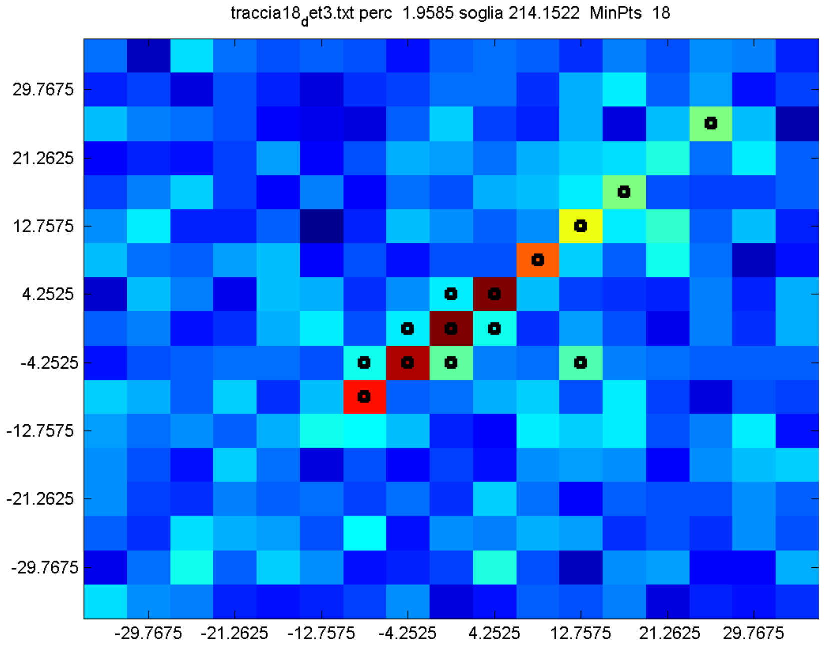


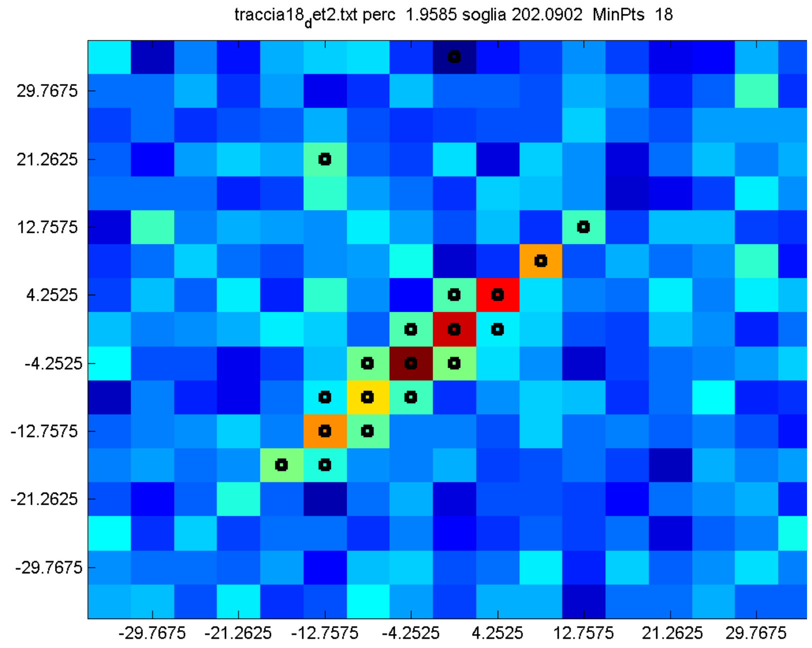


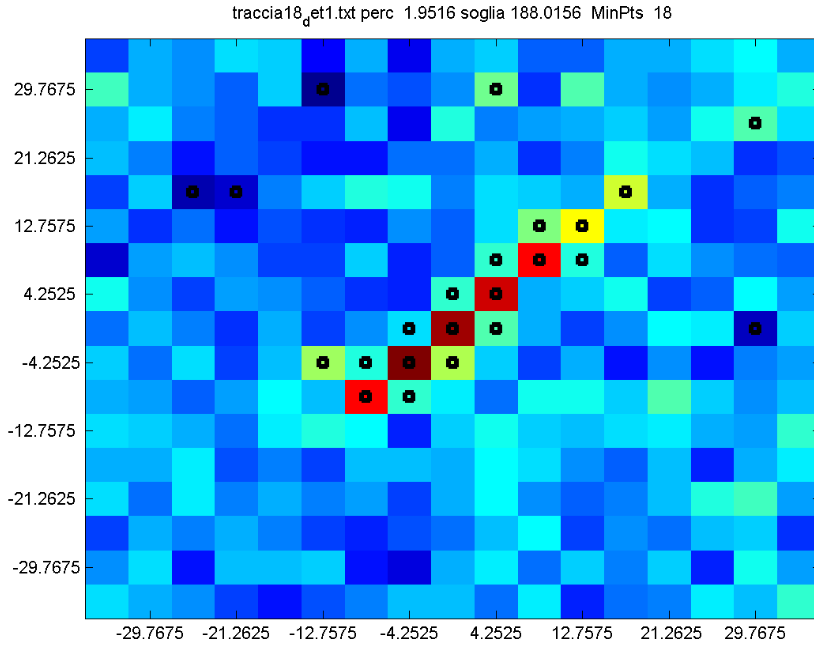




RECONSTRUCTED SIGNAL





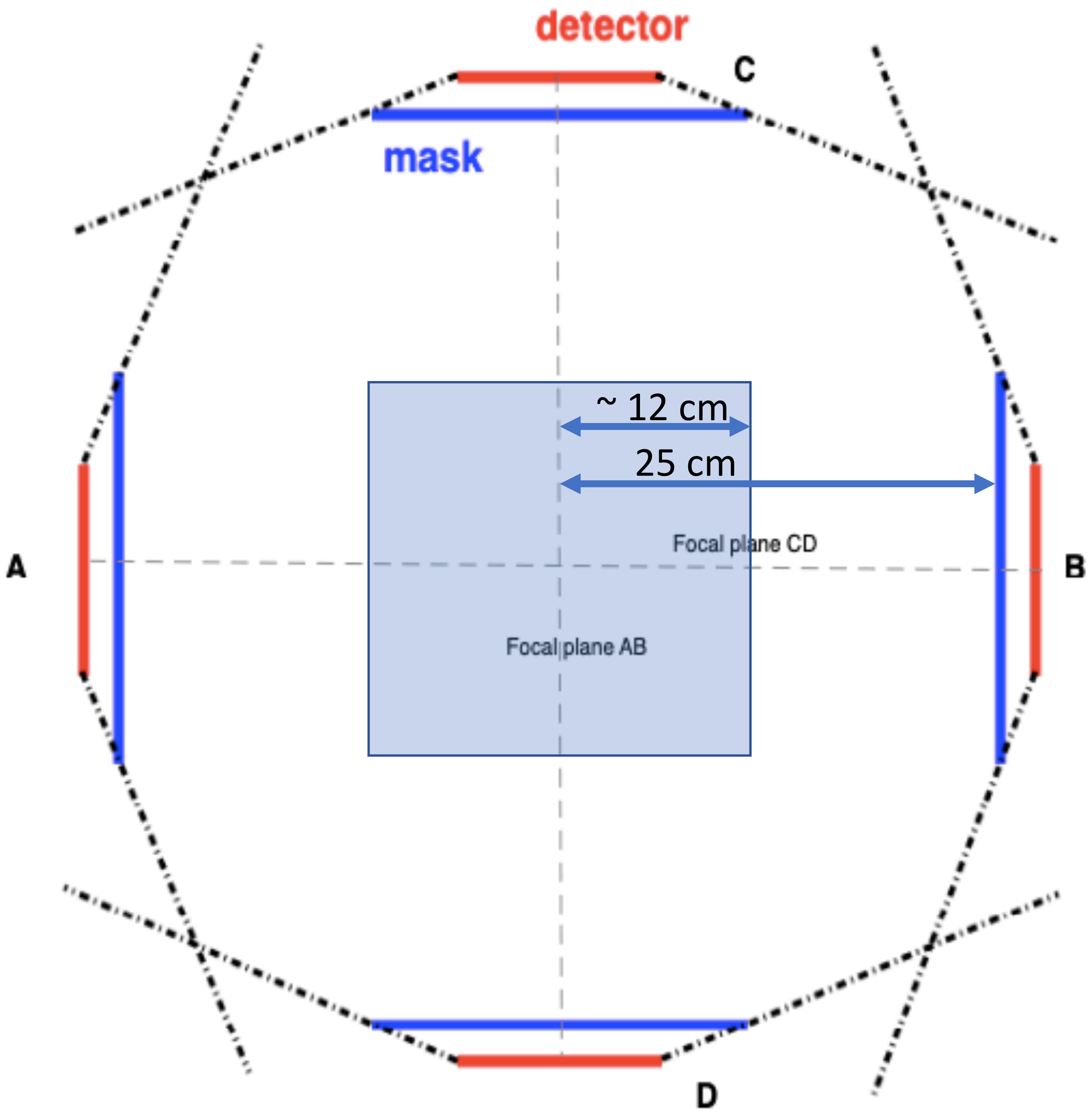


ESTIMATE OF THE PIVOT COORDINATES

Truth	AX= -20 cm AY= -20 cm AZ= -20 cm	BX =20 cm BY =20 cm BZ =20 cm
DIRECTLY FROM THE ORIGINAL SIGNAL	AX = -14.0 AY = -12.1 AZ = -14.0	BX =15.1 BY =12.0 BZ =17.0
FROM DBSCAN CLUSTER ELEMENTS	AX= -12.0 AY= - 12.0 AZ= -11.3	BX = 11.3 BY = 13.0 BZ = 13.0

Fiducial volume for image reconstruction

~ 25 x 25 x 25 cm^3



Conclusions

- Analytical formulas to reconstruct linear tracks in 3-D are available
- A setup with only 3 masks (2 parallel, 1 orthogonal) can be enough for image reconstruction
- Definition of proper setup and fiducial volume (~ 25 x 25 x 25 cm^3)
- Track reconstruction by means of DBSCAN

BUFFER

Check on the distance B (SiPM - matrix)

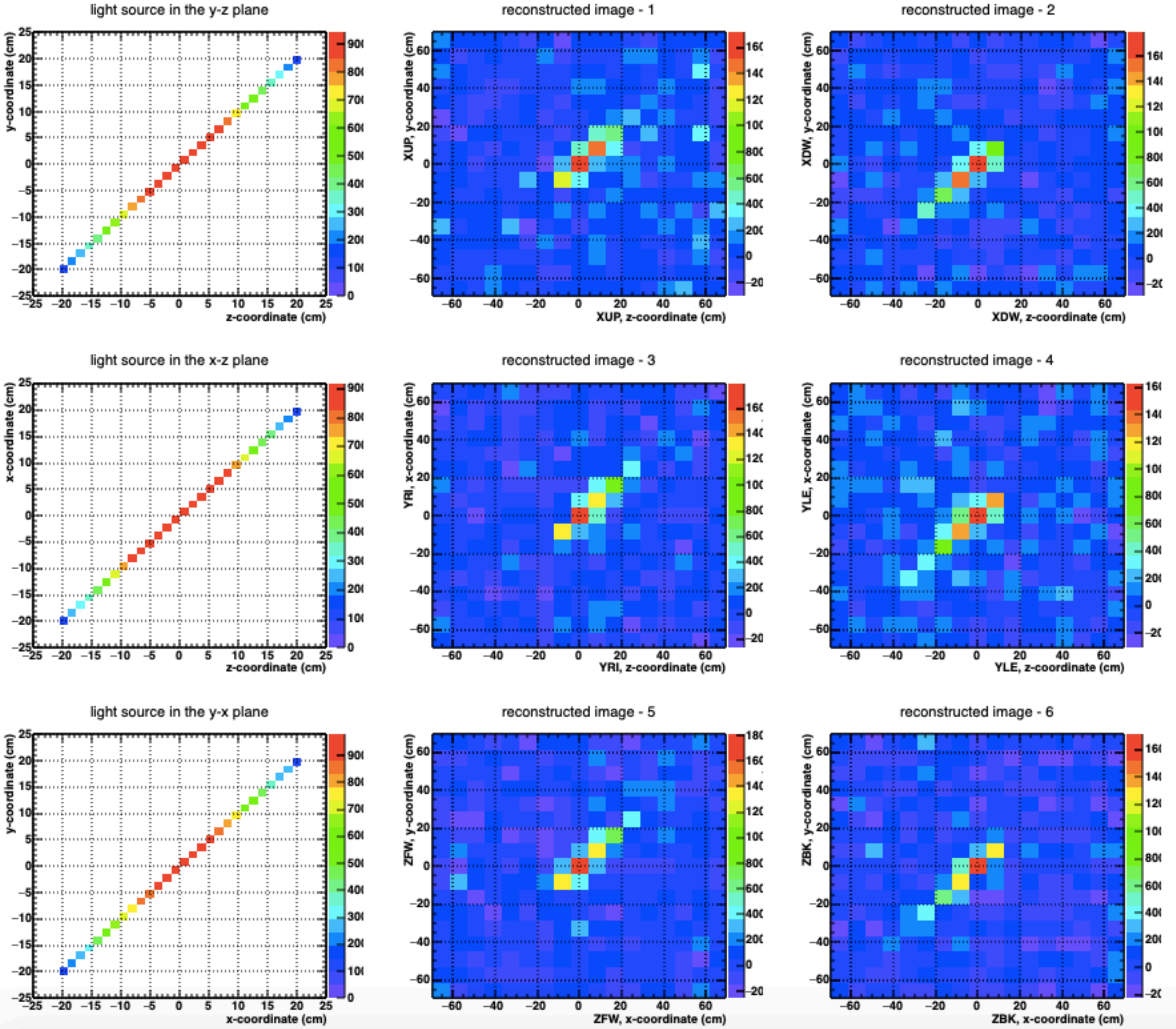
MURA 17x17

B = 1 cm

A = 25 cm

Δ_{mask} = 0.315 cm

Δ_{SiPM} = 0.328 cm



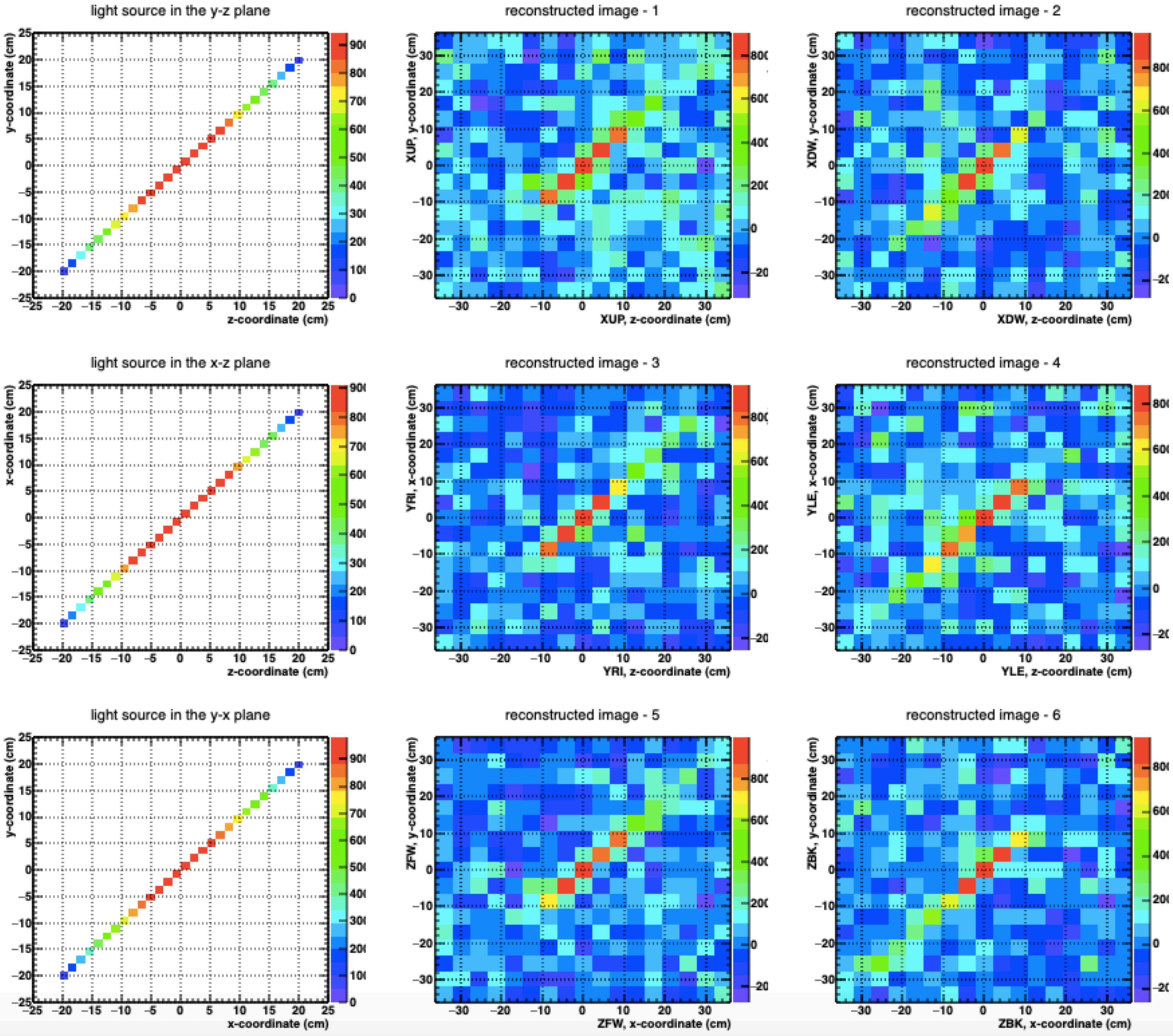
MURA 17x17

B = 2 cm

A = 25 cm

Δ_{mask} = 0.315 cm

Δ_{SiPM} = 0.340 cm



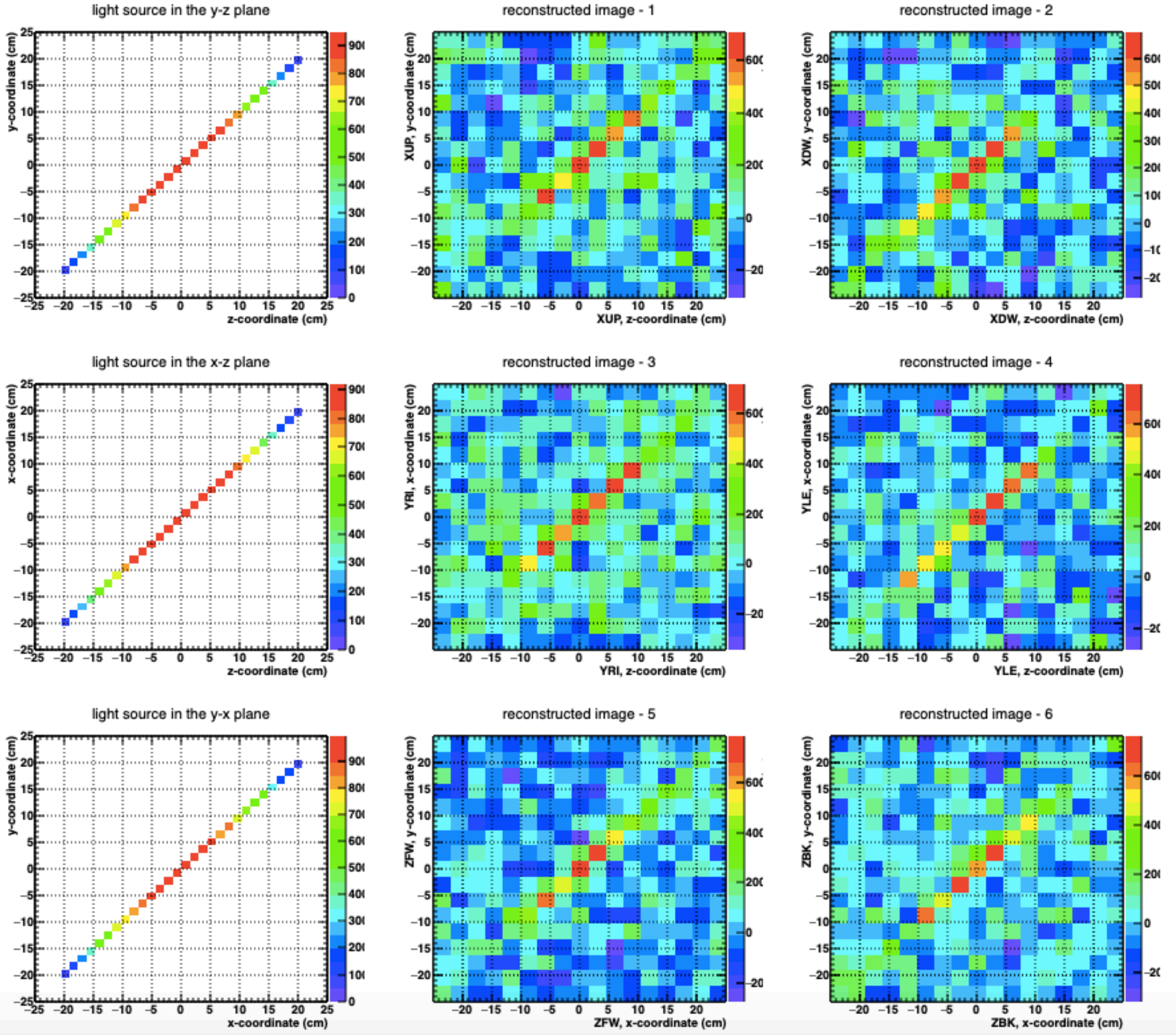
MURA 17x17

B = 3 cm

A = 25 cm

Δ_{mask} = 0.315 cm

Δ_{SiPM} = 0.353 cm



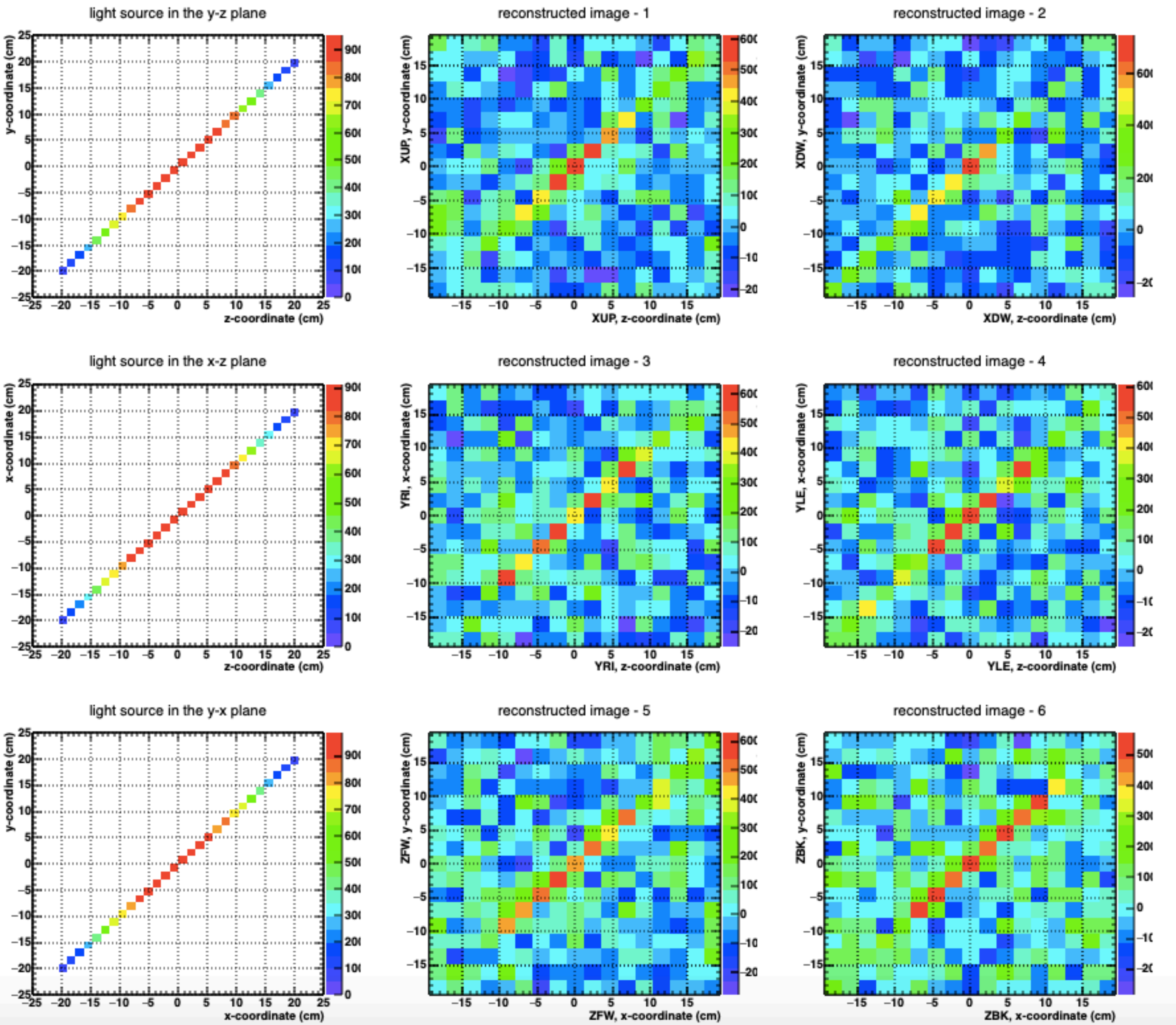
MURA 17x17

B = 4 cm

A = 25 cm

Δ_{mask} = 0.315 cm

Δ_{SiPM} = 0.365 cm



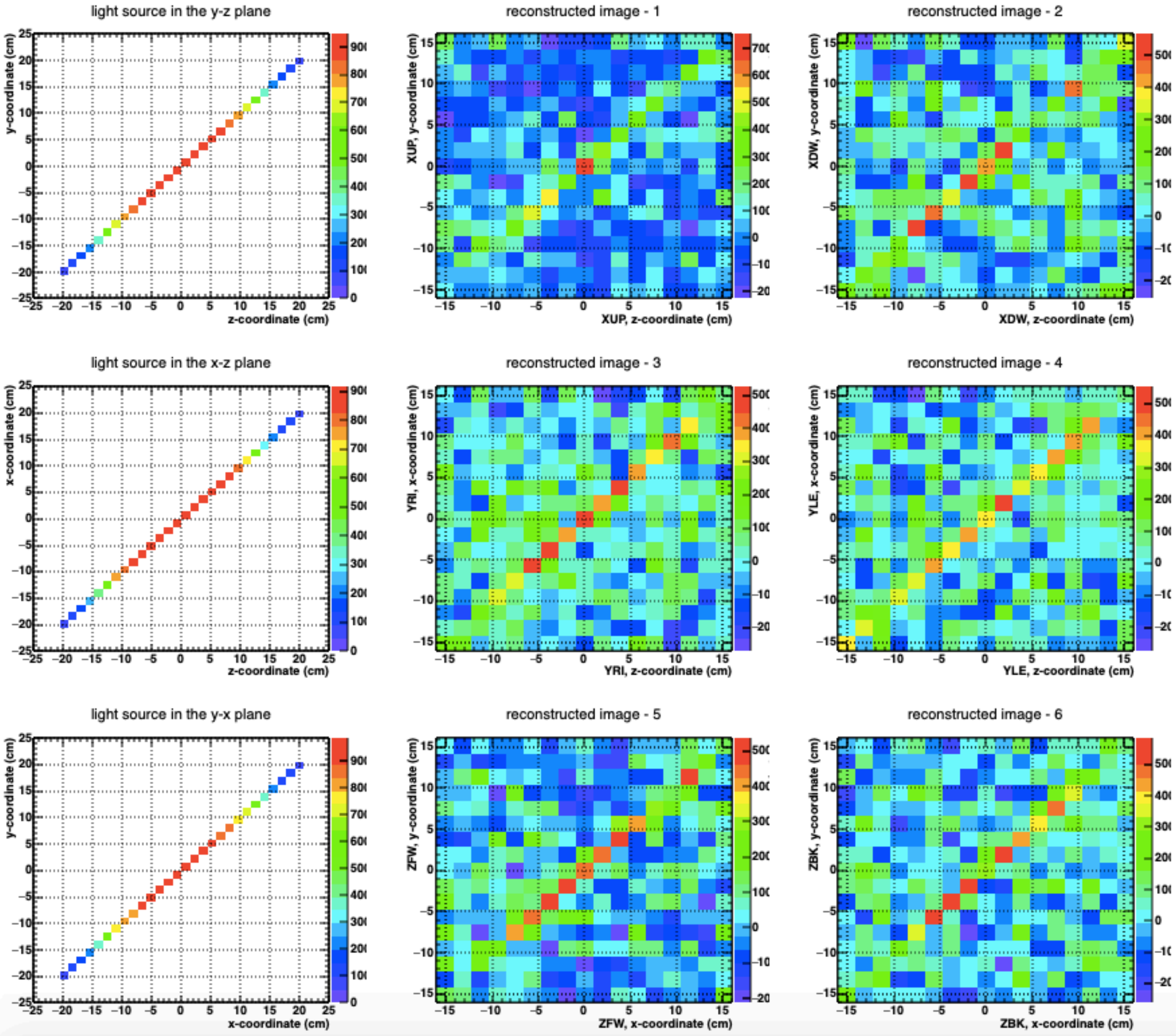
MURA 17x17

B = 5 cm

A = 25 cm

Δ_{mask} = 0.315 cm

Δ_{SiPM} = 0.378 cm



MLS 15x17

B = 2 cm