Imaging with Hadamard masks

2021/11/11

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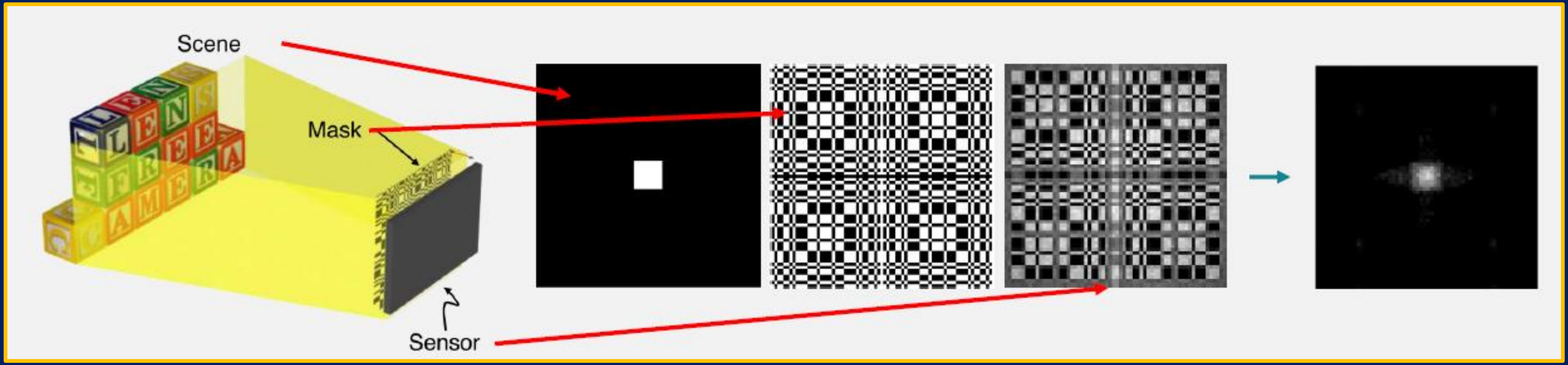
"LAr Optical System Working Group"

Coded Aperture Technique

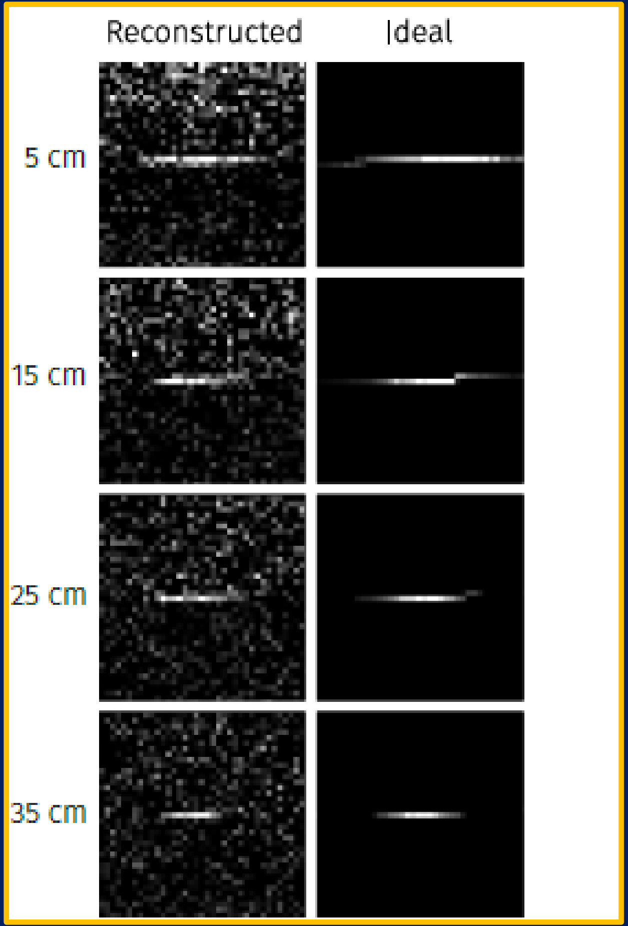
- Single pinhole can be used to reconstruct images with high spatial resolution → requires long exposure time / intense light sources.
- A matrix of multiple pinholes can increase the light collection, but the recorded image is a superimposition of the images from every hole.
- By a proper pinhole arrangement (mask), it is possible to decode the image of the source.

Main Idea

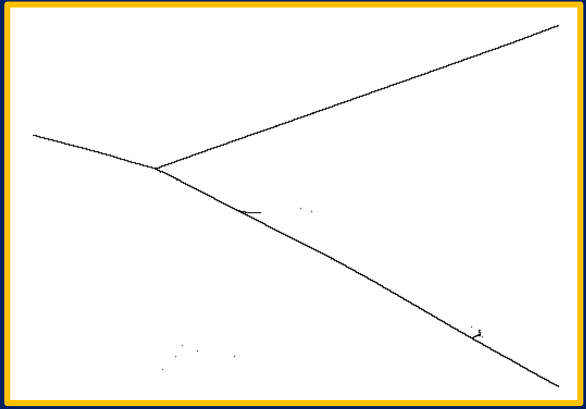


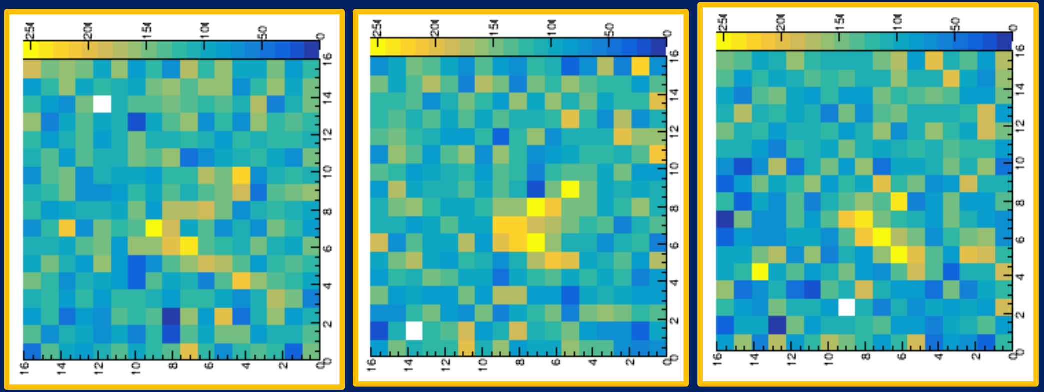
Details can be found in "Coded masks for imaging of neutrino events" → for publication in the European Physical Journal C.
e-Print: 2105.10820

Coded Mask in LAr – MC examples



Muon using a 2.4 mm side pixel for tracks at different depth.



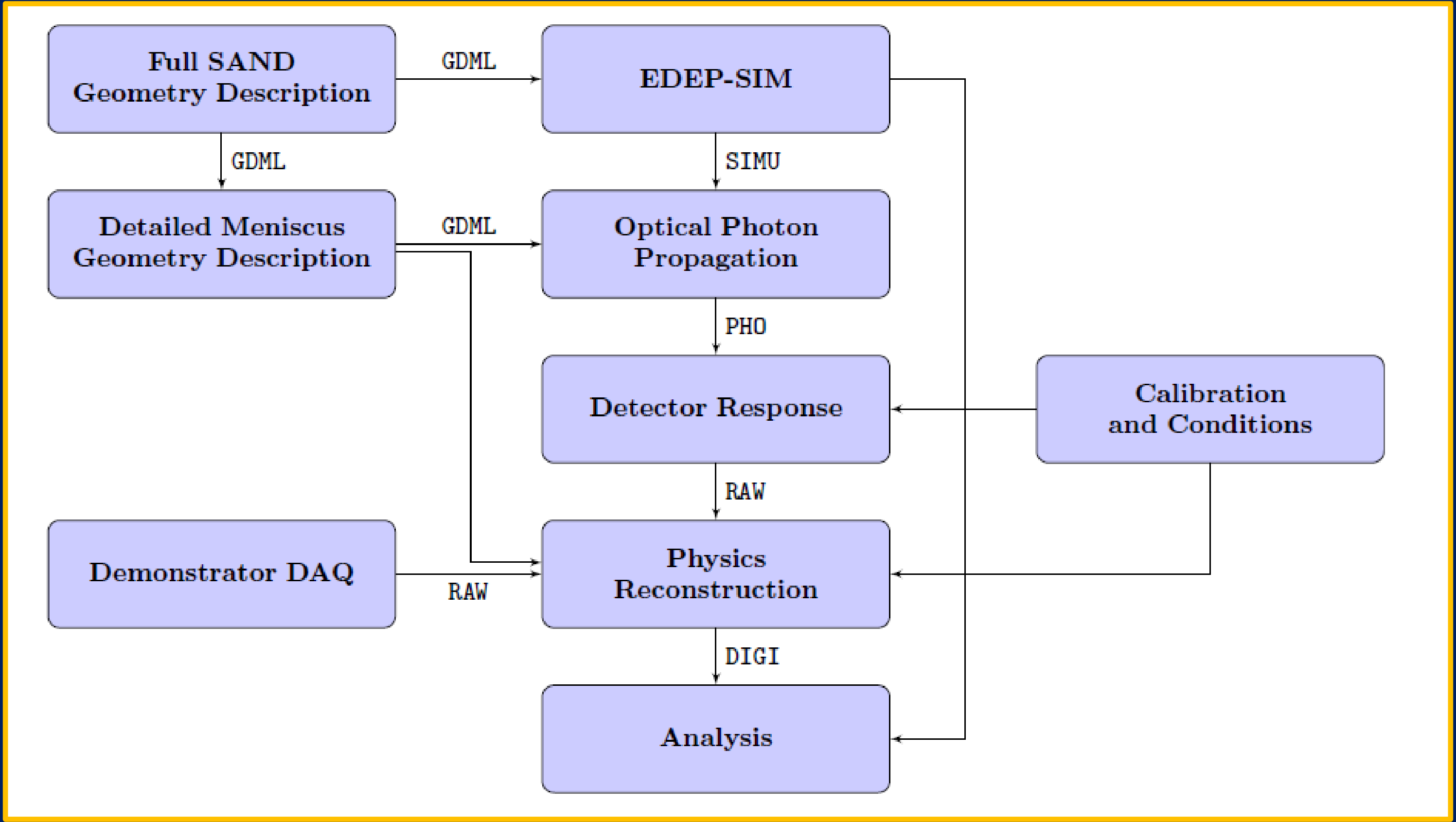


neutrino event using a 3.4 mm side pixel

Issues

- This technique works well when:
  - The source is far away from the mask
  - High light intensity or long exposure time:
    - to produce shadows → "greyscale" is needed
- We have to deal with:
  - LAr:
    - not producing huge light intensity;
    - SiPM quantum efficiency not so high @ λ_{LAr}
  - Tracks from neutrino events:
    - distributed in the whole volume → Near Field Artifacts;
  - Number of channels:
    - limited → cost and readout issues
  - SiPM dimensions:
    - Big (3x3 mm^2 ↔ 6x6 mm^2) → to cope with low light intensity
    - worsen the resolution

Simulation Framework

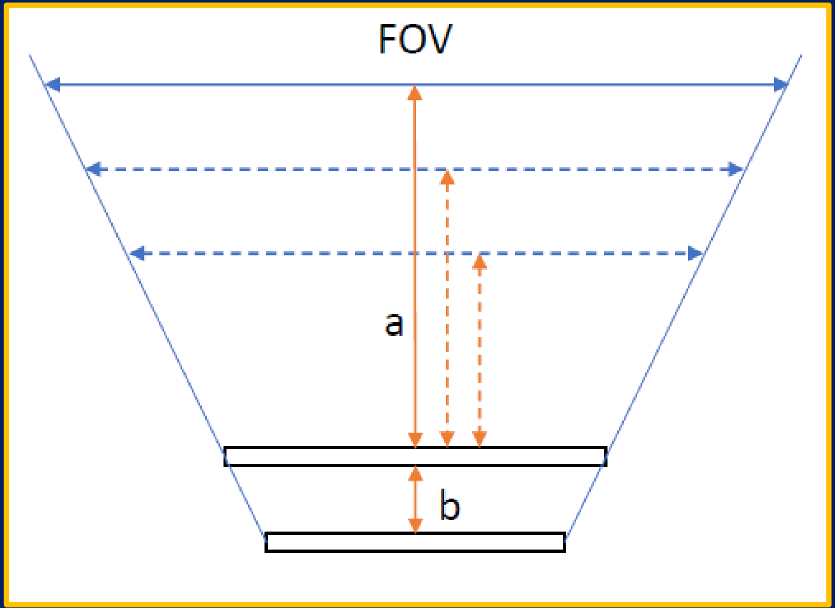


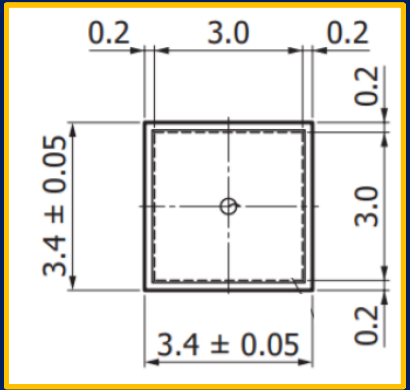
Complete data flow diagram

https://baltig.infn.it/dune/sand-optical

Demonstrator Parameters

- Matrix SiPM Rank: 16
- Mask Rank: 17
- Mask Pitch: 3.15 mm
- Sensor Pitch: 3.4 mm
  - active area 3.0 mm
- Mask to Sensor Distance: b = 2.0 cm
- Focal Plane: a = 25 cm
- SiPM Efficiency: hypothesized 25%





Simulation (at CNAF)

/storage/gpfs_data/neutrino/SAND-LAr/SAND-LAr-OPTICALSIM-PROD/ColdDemonstrator/...
... 4Points/a15/fast_response.root
... 4Points/a25/fast_response.root
... colddemo_17_3_diagonal_muons/output/response.root

SiPM detectors:			
	CAM_NB_X0	CAM_NT_X0	bottom/top
	CAM_NE_X0_Y0	CAM_NW_X0_Y0	east/west
	CAM_NN_Y0	CAM_NS_Y0	north/south

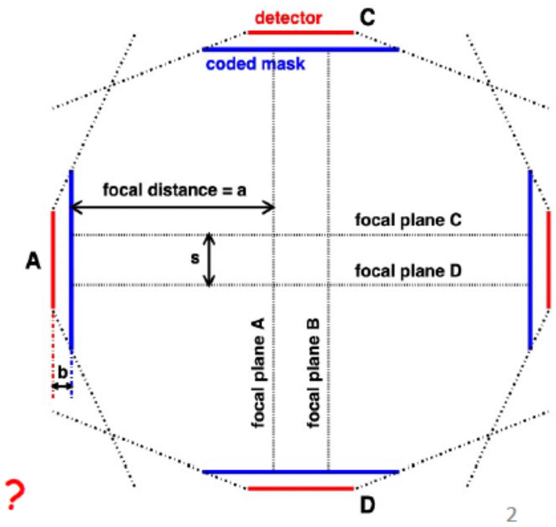
SiPM matrix 17 x 17 (last column and last row = 0)
Coded mask 33 x 33 (according to Bologna style)

Coincident point between SiPM matrix and coded mask ?
16 SiPM center ? 17 SiPM center ? Left corner ?

Focal plane – mask distance a = 25.000 cm
Mask – SiPM distance b = 2.027 cm s = 0

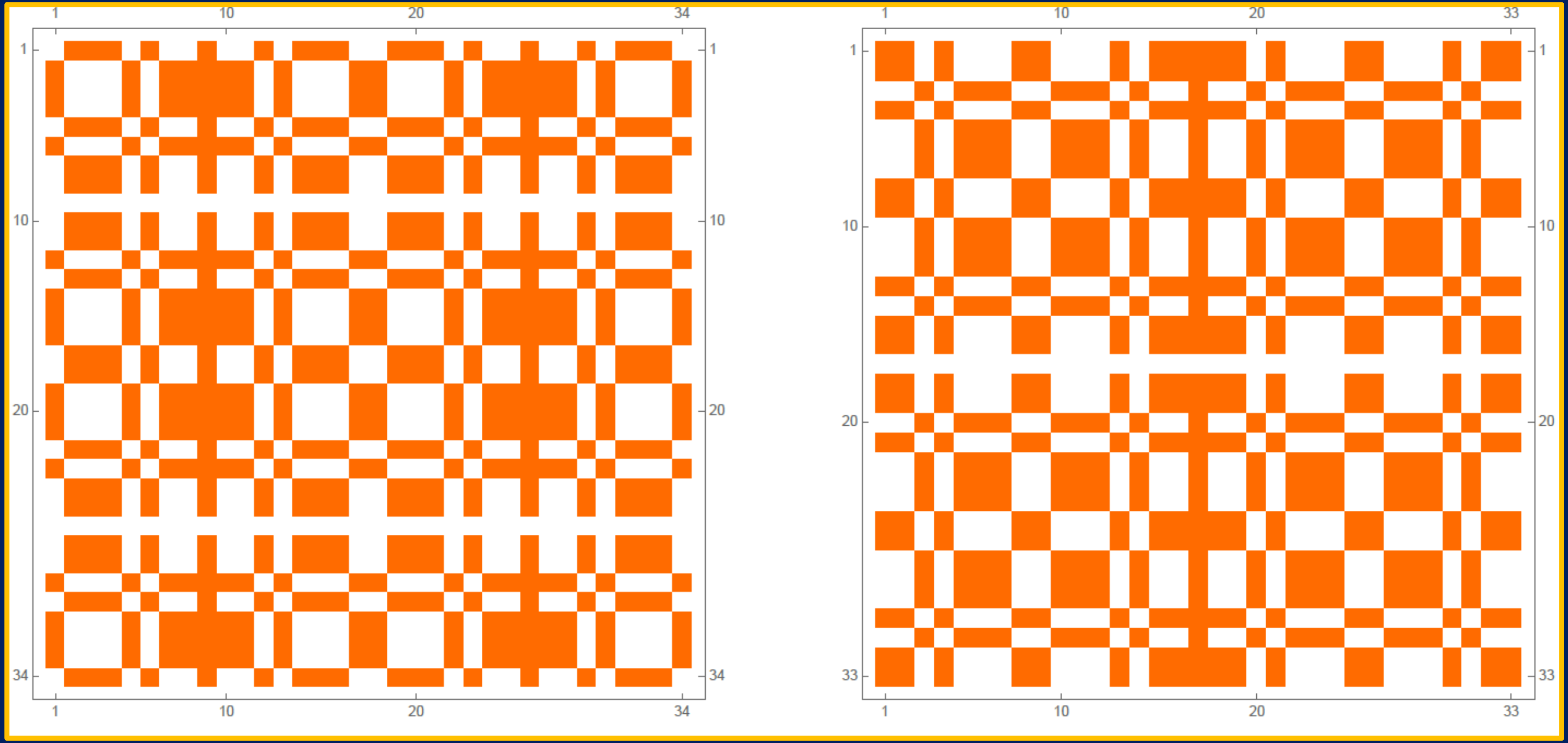
Mask pitch Mapit = 0.296 cm
SiPM pitch Sipit = 0.320 cm

Light source position ?

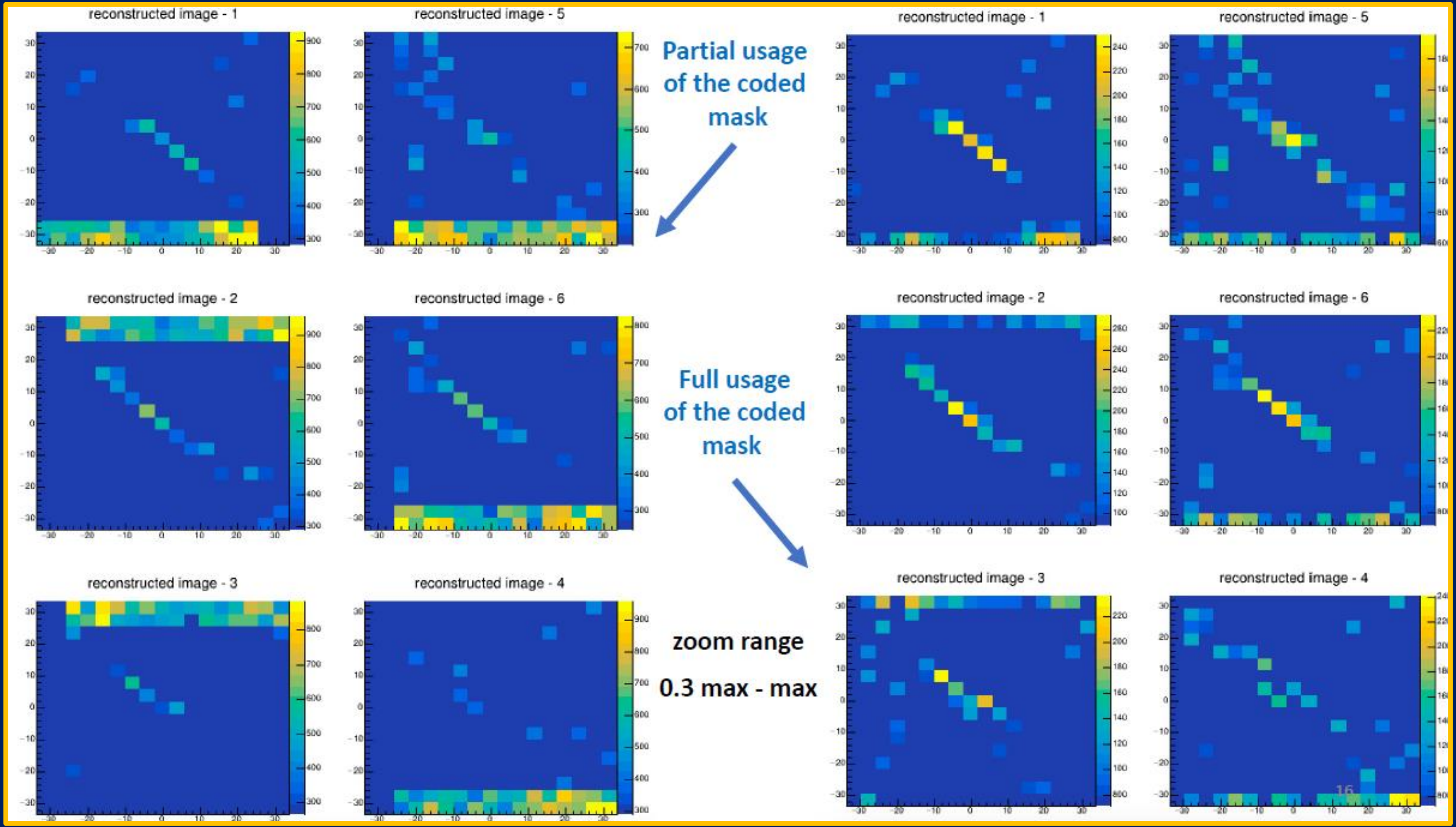


Slide from P. Bernardini

What we have



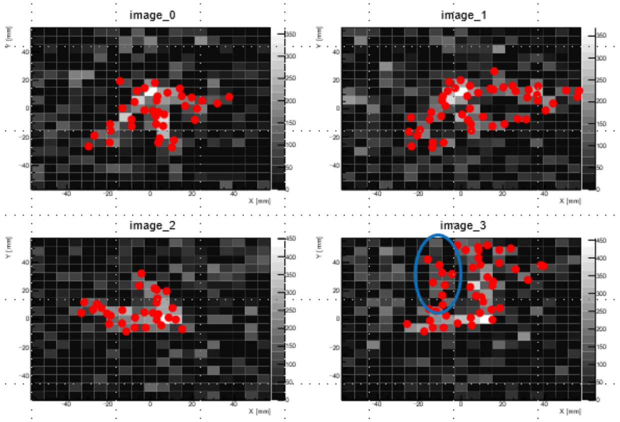
Different ways to generate the mosaic mask



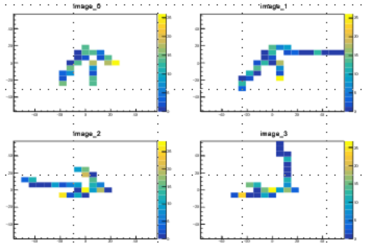
Different ways to reconstruct the 2D image

Clustering 2D

- Algoritmo mDBSCAN (modified DBSCAN): modificato per considerare anche l'intensità dei pixel
- Pixel iniziali selezionati con soglia (intensità >20% rispetto a quella massima nell'immagine)
- Un pixel è seed per l'inizio di un cluster se non è isolato (ha almeno un vicino) ed ha intensità >80% di quella massima
- Ogni punto del cluster può espanderlo ai suoi «vicini» se ne ha più di N



$(0,0,-1910)$



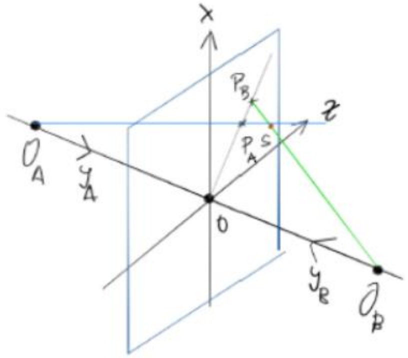
Clustering algorithm
19x19 matrix (6x6 mm^2 each)

11/11/2021

Position reconstruction

The double Pinhole Camera Approximation

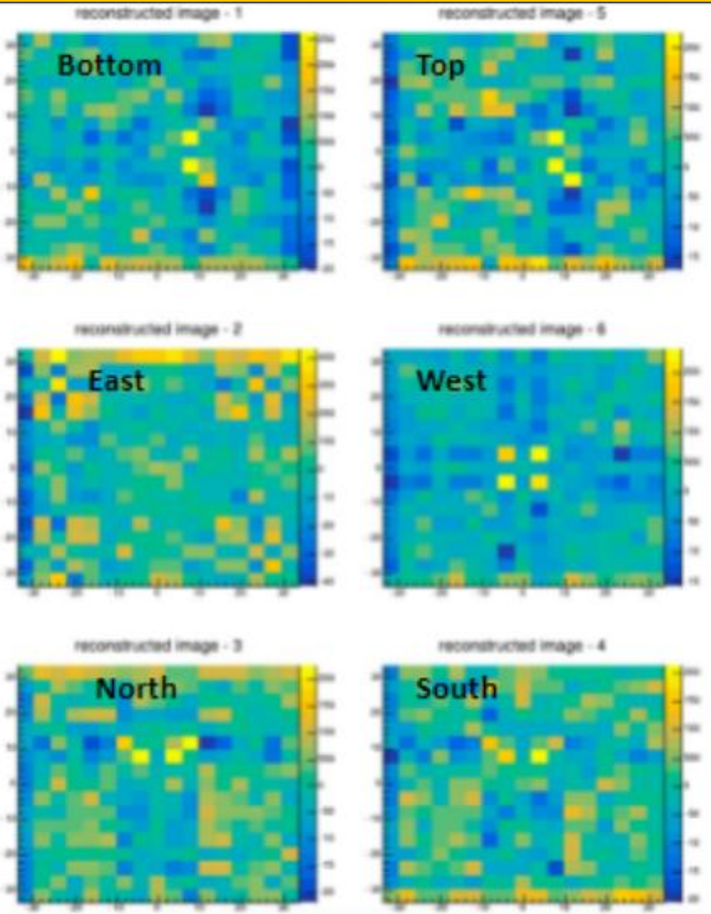
The mask-SiPM system is approximated by a Pinhole Camera, with a pointlike pinhole on the system axis at the mask position. $S = (x_S, y_{S_{A,B}}, z_S)$, $P_A = (x_A, a, z_A)$, $P_B = (x_B, a, z_B)$



$$\begin{cases} x = \frac{x_A}{a} y + x_A & z = \frac{z_A}{a} y + z_A \\ x = -\frac{x_B}{a} y + x_B & z = -\frac{z_B}{a} y + z_B \end{cases} \rightarrow x_S = \frac{2 x_A x_B}{x_A + x_B}, \quad z_S = \frac{2 z_A z_B}{z_A + z_B}, \quad y_S = \frac{x_B - x_A}{x_A + x_B} a.$$

The Harmonic Mean localization (in transverse directions)

Example of coordinate reconstruction - 4 points source



4 points (15 – 35 cm)

photons from 10 “events”

inverted axes

bin offset

usage of the full coded mask

Coordinates from East-West: ± 6.5 cm

True coordinates: ± 6 cm

11

Conclusions – What we have

- Simulation Framework:
  - fully integrated with the SAND MC standard tools;
  - Setup a code repository on baltig:
    - distributed version control system designed to handle everything from small to very large projects with speed and efficiency
  - First geometry based on a realistic demonstrator
  - Fast reconstruction (to have quick look on simulation)
  - Full reconstruction to deal with:
    - electronic noise;
    - SiPM Quantum efficiency;
    - SiPM XT + AP
    - ADC chain

Conclusions - Next Steps

- Optimize and implement / cross check
    - 2D image reconstruction;
    - 2D clustering algorithm;
    - Position reconstruction with double pin-hole camera approximation
- Finalize the implementation of Coded Mask mosaic geometry:
  - Add all the possible way to build the MURA mosaic
    - Python code already done;
    - GDML file ongoing;
- Measure the mask "intrinsic" performance:
  - Autocorrelation matrix (mosaic)
  - Mosaic ⊗ Decode "quality"
- Compare performances on 4 spots-sources with different masks
- Optimize the demonstrator geometry and test with C.R. events
- Move to full GRAIN Geometry