Fast MC simulations for J-PET

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Simposium on Positrion Emission Tomography
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Motivation

- Input data for testing of reconstruction algorithms:
  - geometry setups
  - different phantoms
  - detector response
- ”Feed-back” for the experimental group to provide estimates and tests for:
  - geometry setups
  - time parameters

Developed tools

We developed several tools:

- event display for detector geometry and track visualization with the graphical user interface
- fast MC simulations
- simple image reconstruction algorithms
- application to compare the quality of the reconstructed images

Reconstruction methods

We use several reconstruction algorithms:

- simple but fast summation algorithm (can be treated as a backprojection from the projection space, 1/r smearing effect remains)
- summation algorithm + TOF techniques (two versions)
- 3-D MLEM algorithm (Z. Rudy and A.Słomski implementation)

Reconstruction methods

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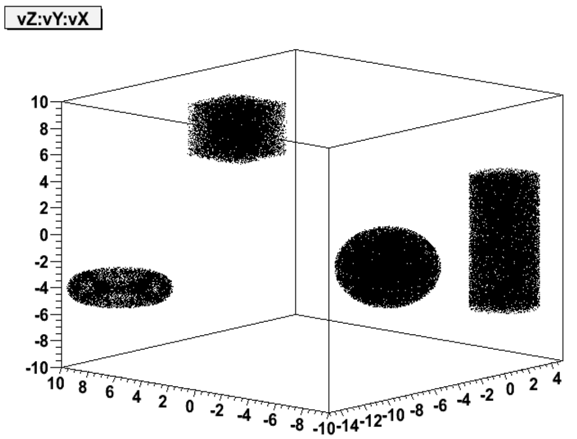
M. Bała's talk „"Simple image reconstruction with TOF" , Sunday 12:50

- 3-D MLEM algorithm (Z. Rudy and A.Słomski implementation)

Z. Rudy, and A. Słomski's talk
"3D PET reconstruction based on the MLEM algorithm" , Saturday 11:10

Phantoms

- geometrical shapes with uniform distribution of points:
  - point sources
  - spheres,
  - cylinders.
  - elipsoids
  - ....
- phantom generator (M. Bała)



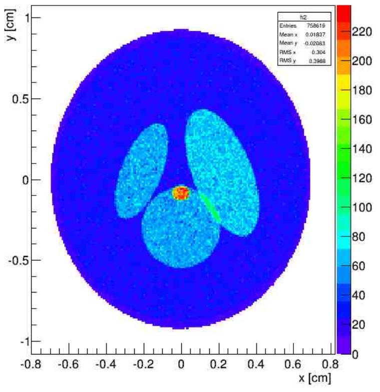


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Image metrics

$$\mathrm{MSE}(X,Y) = \frac{1}{N} \cdot \sum_{k=1}^{N} (x_k - y_k)^2$$

$$\mathrm{PSNR}(X,Y) = 10 \cdot \log_{10}(\frac{L(Y)^2}{\mathrm{MSE}(X,Y)})$$

$$\mathrm{NRMSE}(X,Y) = \frac{\sum_{k=1}^{N}(x_k - y_k)^2}{\sum_{k=1}^{N} x_k^2}$$

$$L(X) = max(X) - min(X)$$

$$\mathrm{NRMSE}(X,Y) = \frac{\sum_{k=1}^{N}(x_k - \alpha \cdot y_k)^2}{\sum_{k=1}^{N} x_k^2}$$

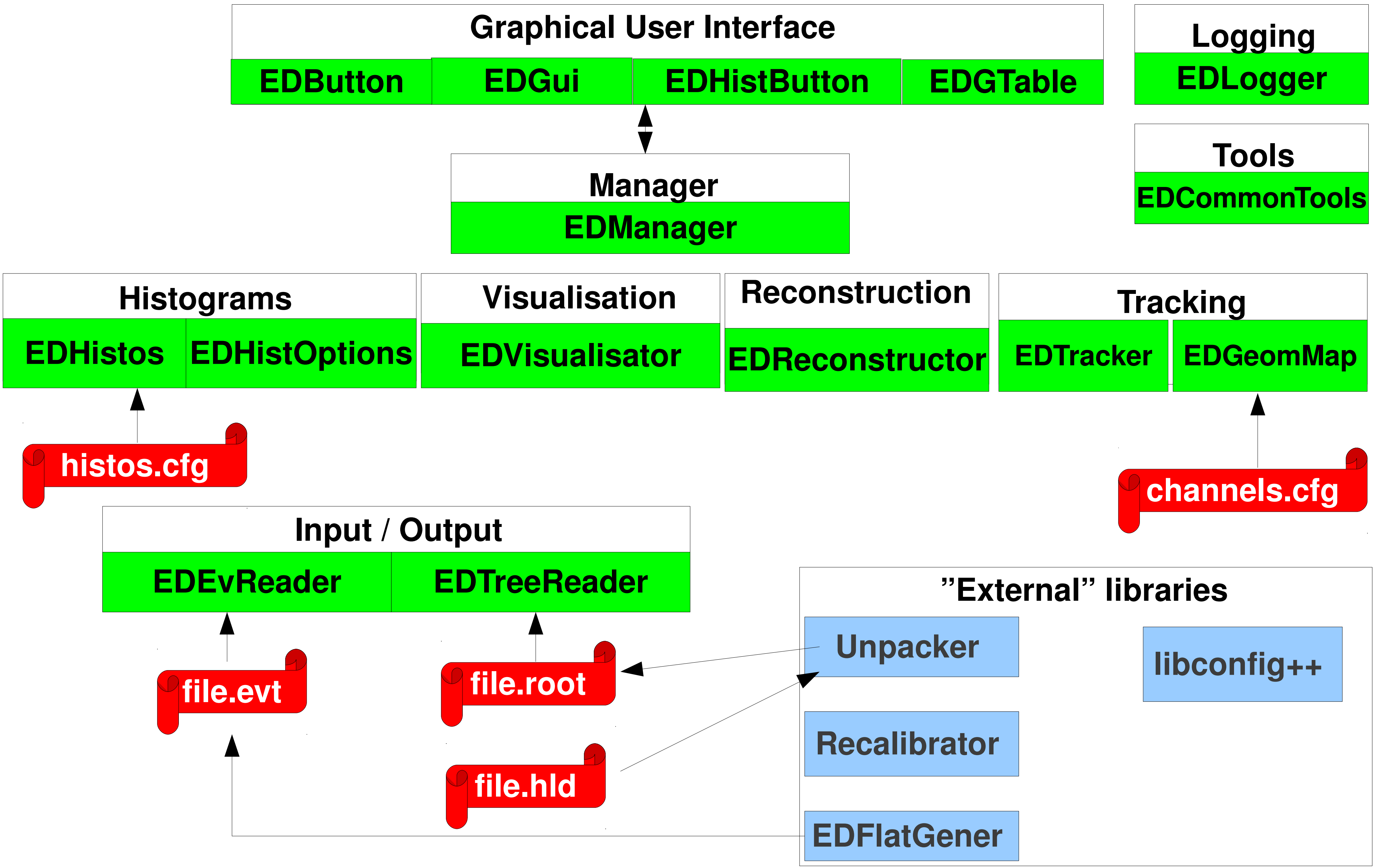
$$\alpha = \sum_{k=1}^{N} \frac{x_k \cdot y_k}{\sum_{k=1}^{N} y_k^2}$$

$$SSIM(x,y) = \frac{2\overline{xy} + c_1}{\overline{x}^2 + \overline{y}^2 + c_1} \cdot \frac{2\sigma_x\sigma_y + c_2}{\sigma_x^2 + \sigma_y^2 + c_2} \cdot \frac{\sigma xy + c_3}{\sigma_x + \sigma_y + c_3}$$

Fast MC simulations

- Independent application based on the ROOT geometry package.
- Included effects:
  - Penetration depth of gamma quanta in the material
  - Smearing of the time measurement in the photomultipliers
- Not included:
  - energy dependence
  - propagation of light in the scintillator

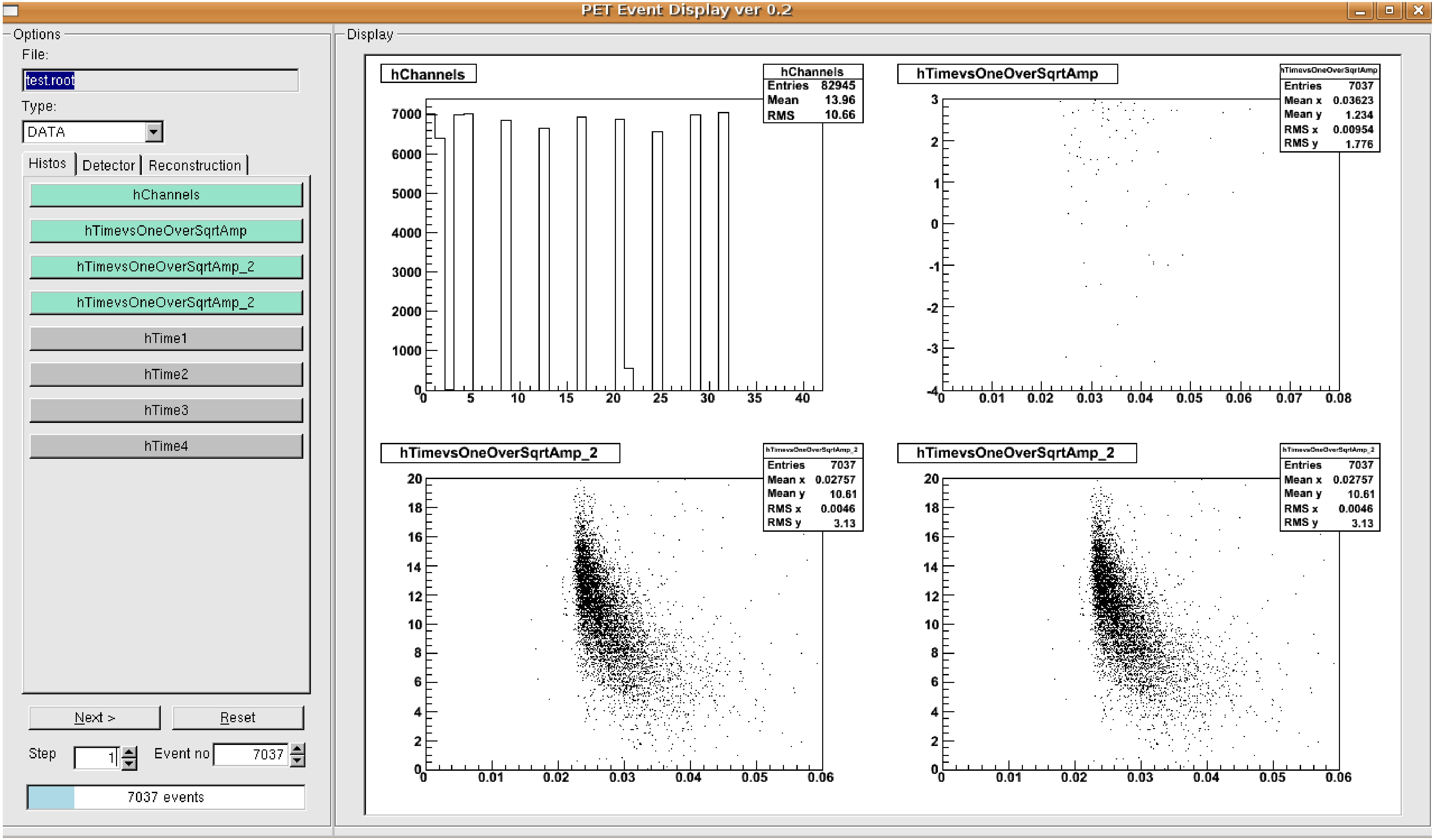
Internal architecture



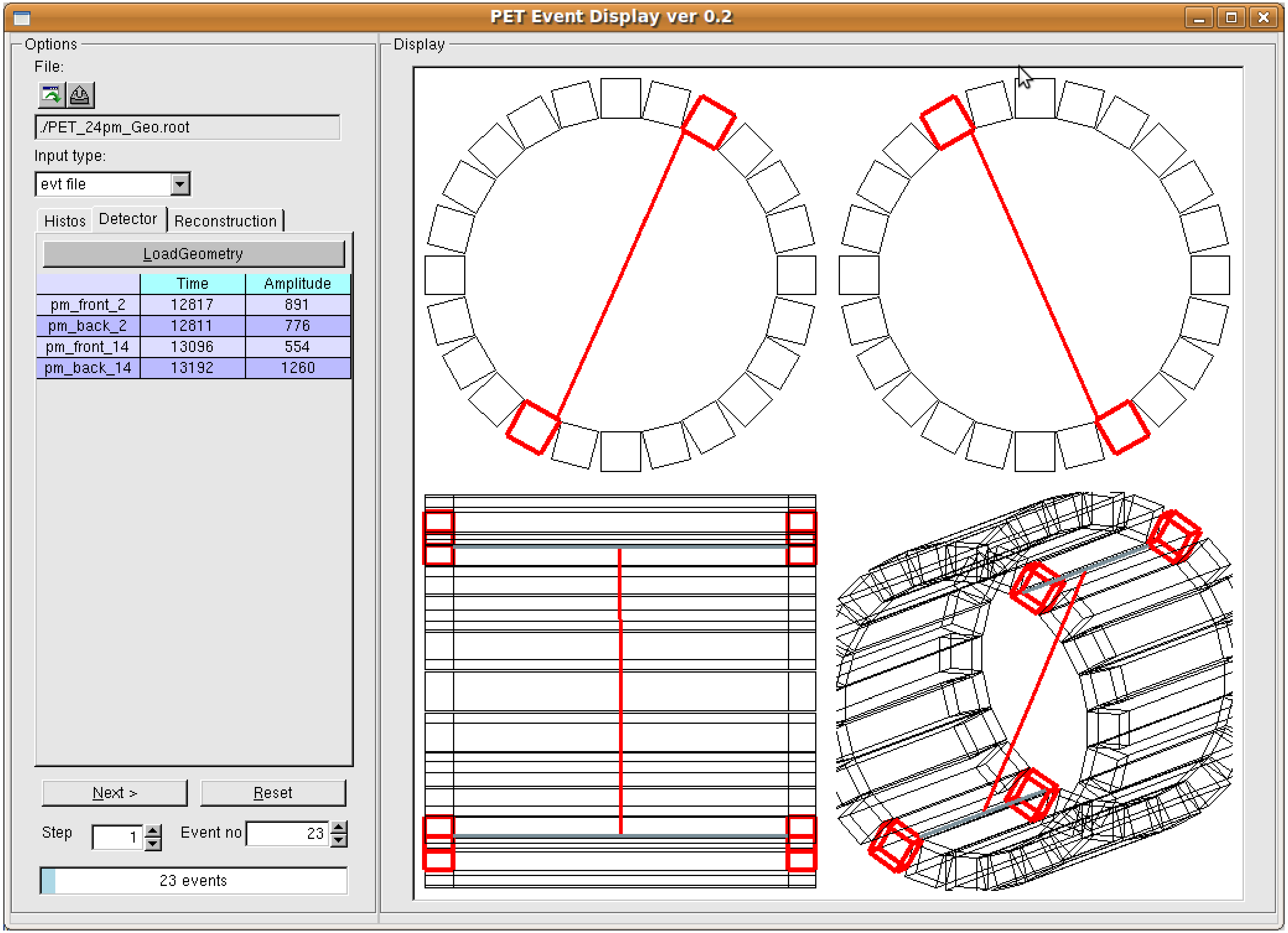
Technical details

- Developed in C++, STL.
- Modularity – possibility to add independent modules (analysis, recalibration, ...) in the future.
- Graphical User Interface based on WIN95 widgets (external library from ROOT).
- Signal-slot mecanism (like in Qt).
- HTML/Latex documentation of the whole code (Doxygen).

Graphical user interface

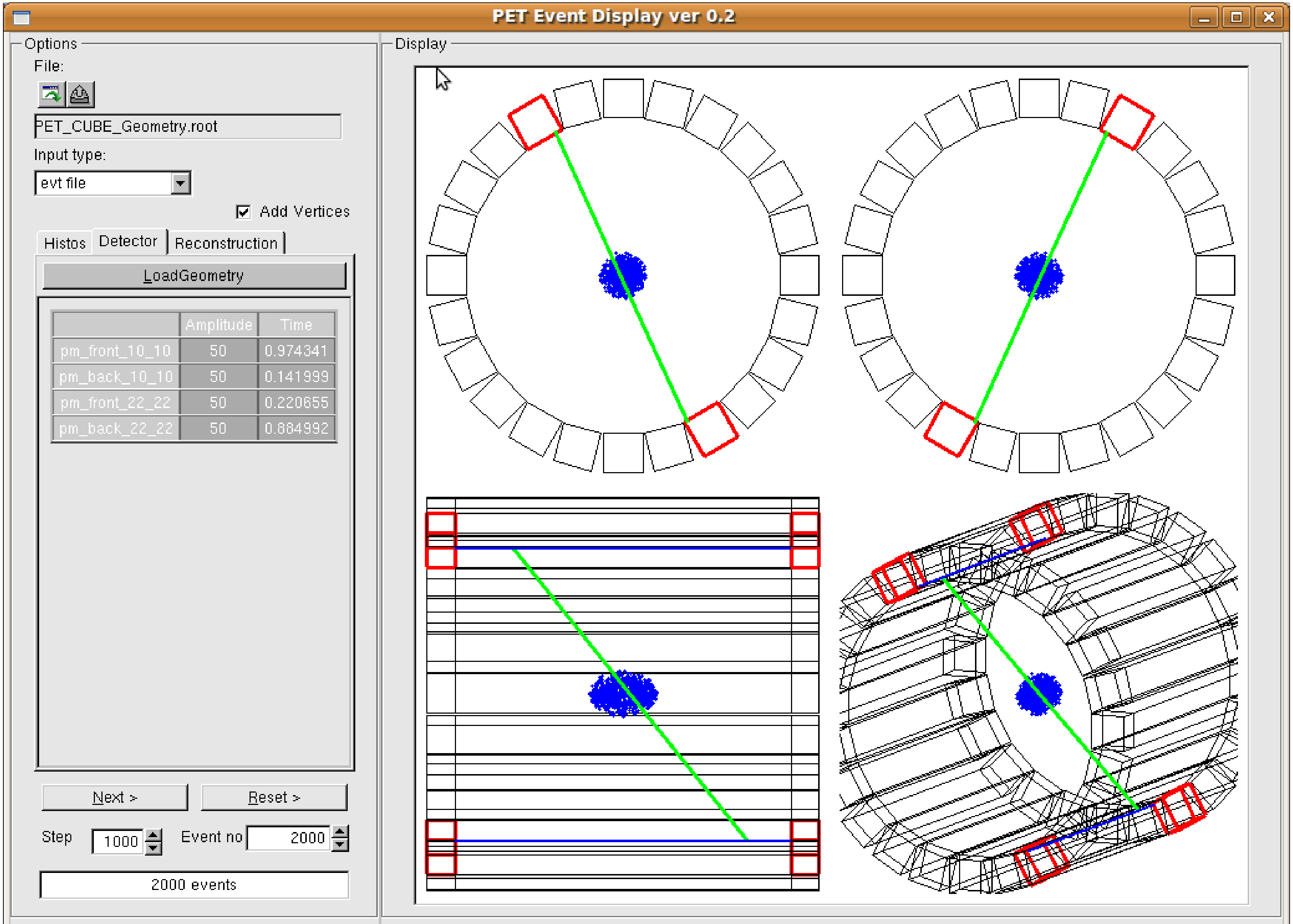


Detector visualization

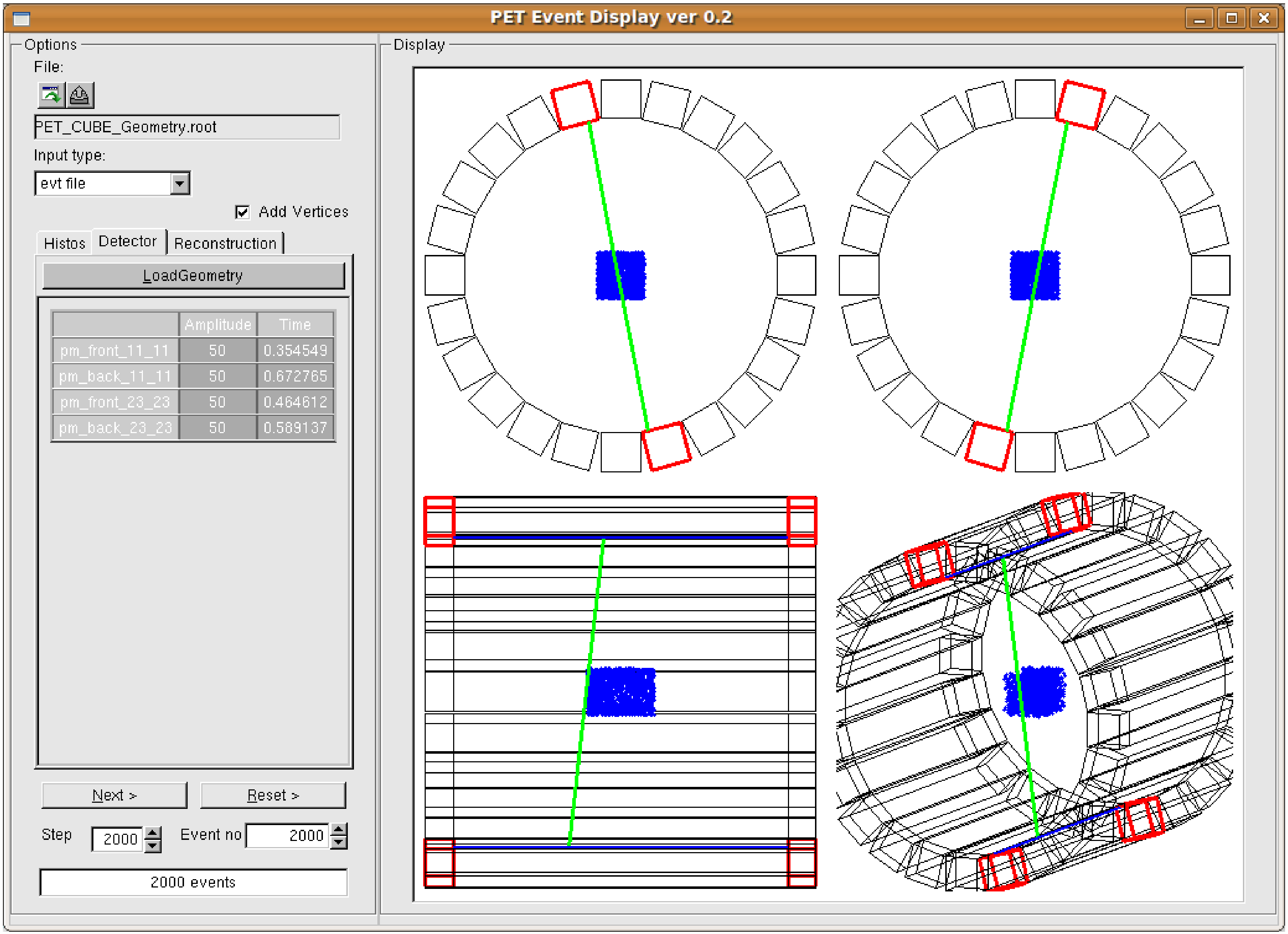


24 x rectangular-shape: 5 cm x 5 cm x 30 cm

Phantoms visualization



Phantoms visualization

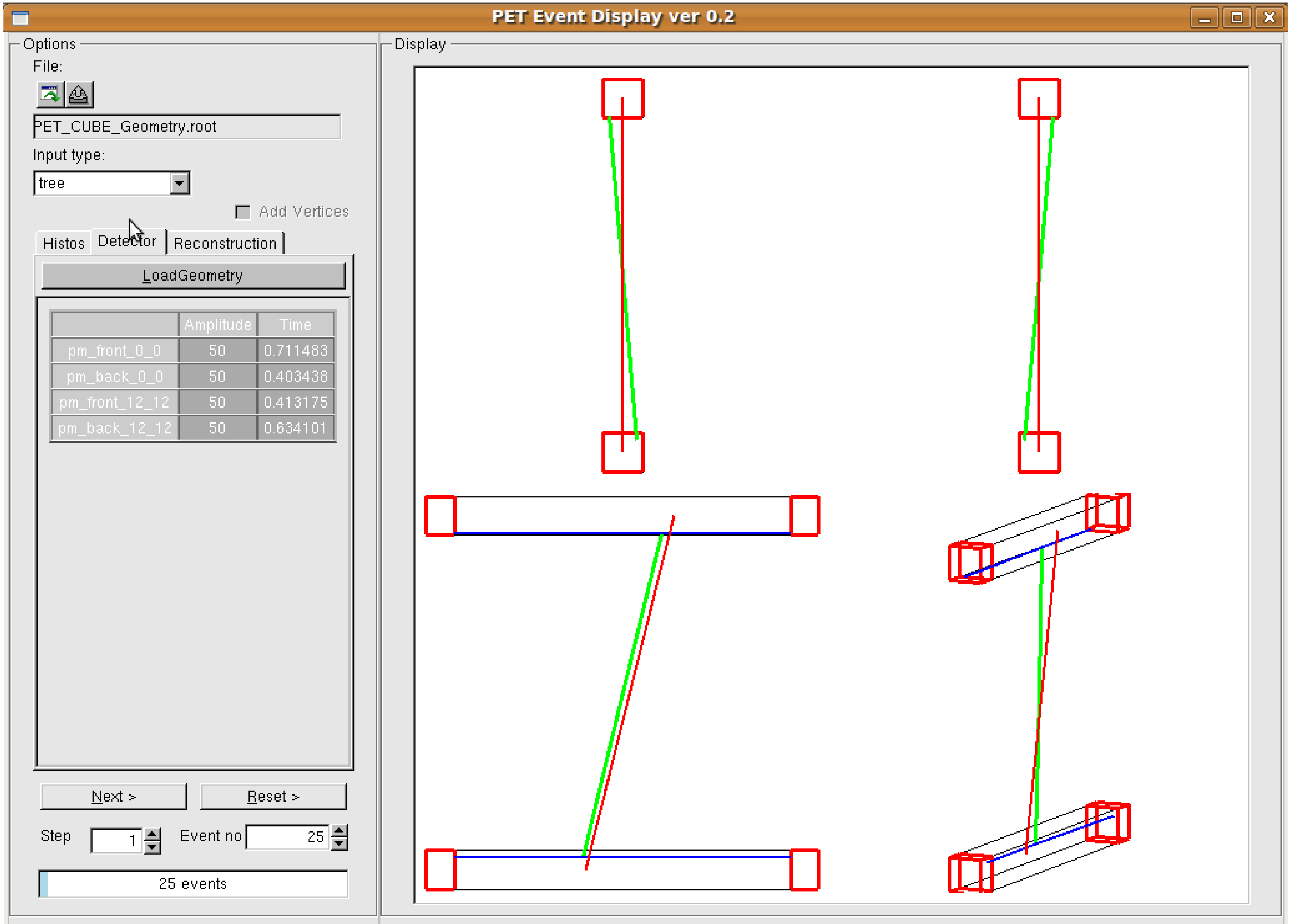


Detector response simulation

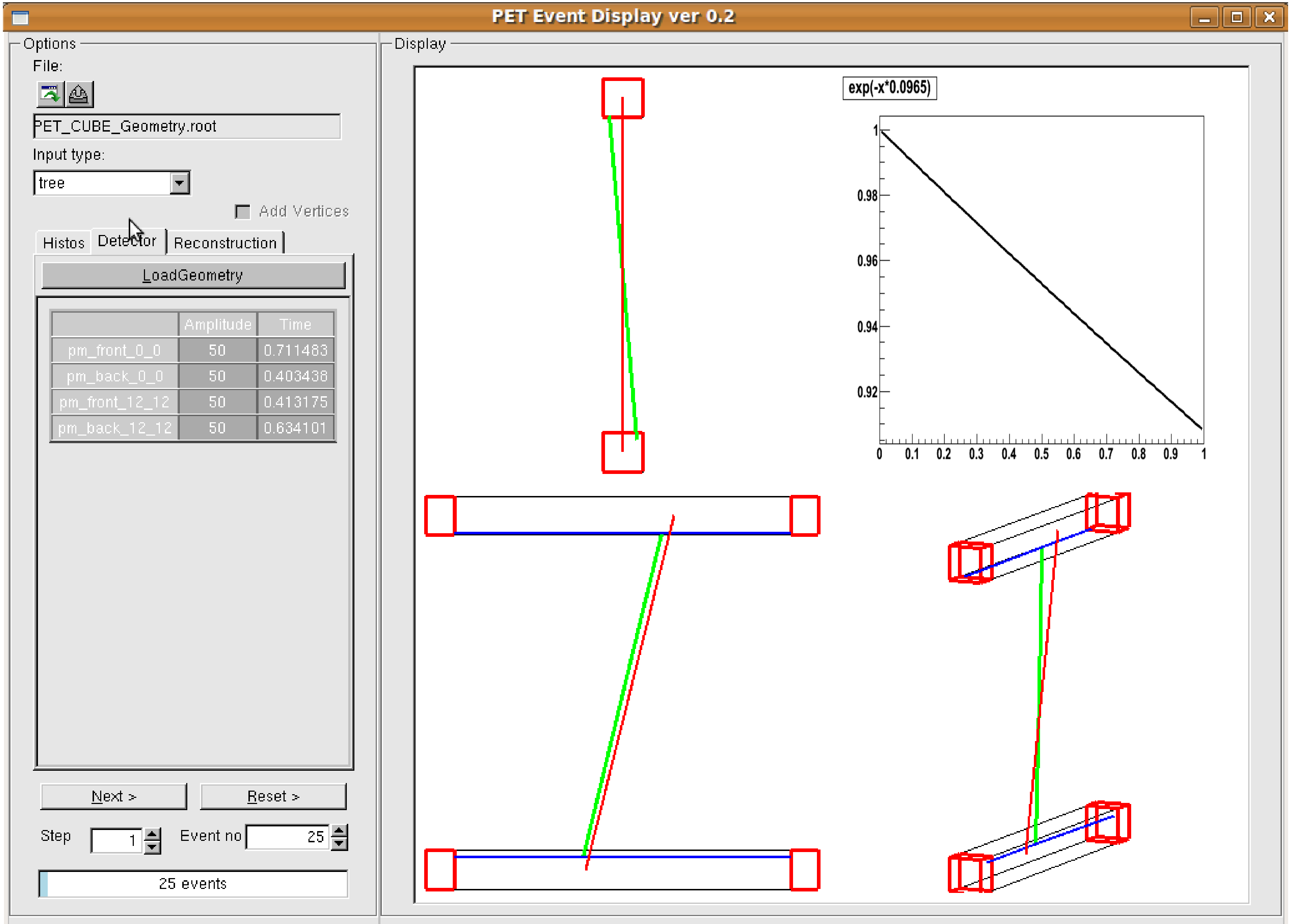
- Propagation of light in the scintillator treated as a straight line
- Ideal propagation times smeared under the assumption that the time error follows a Gaussian distribution

- Interaction point reconstructed from the time difference

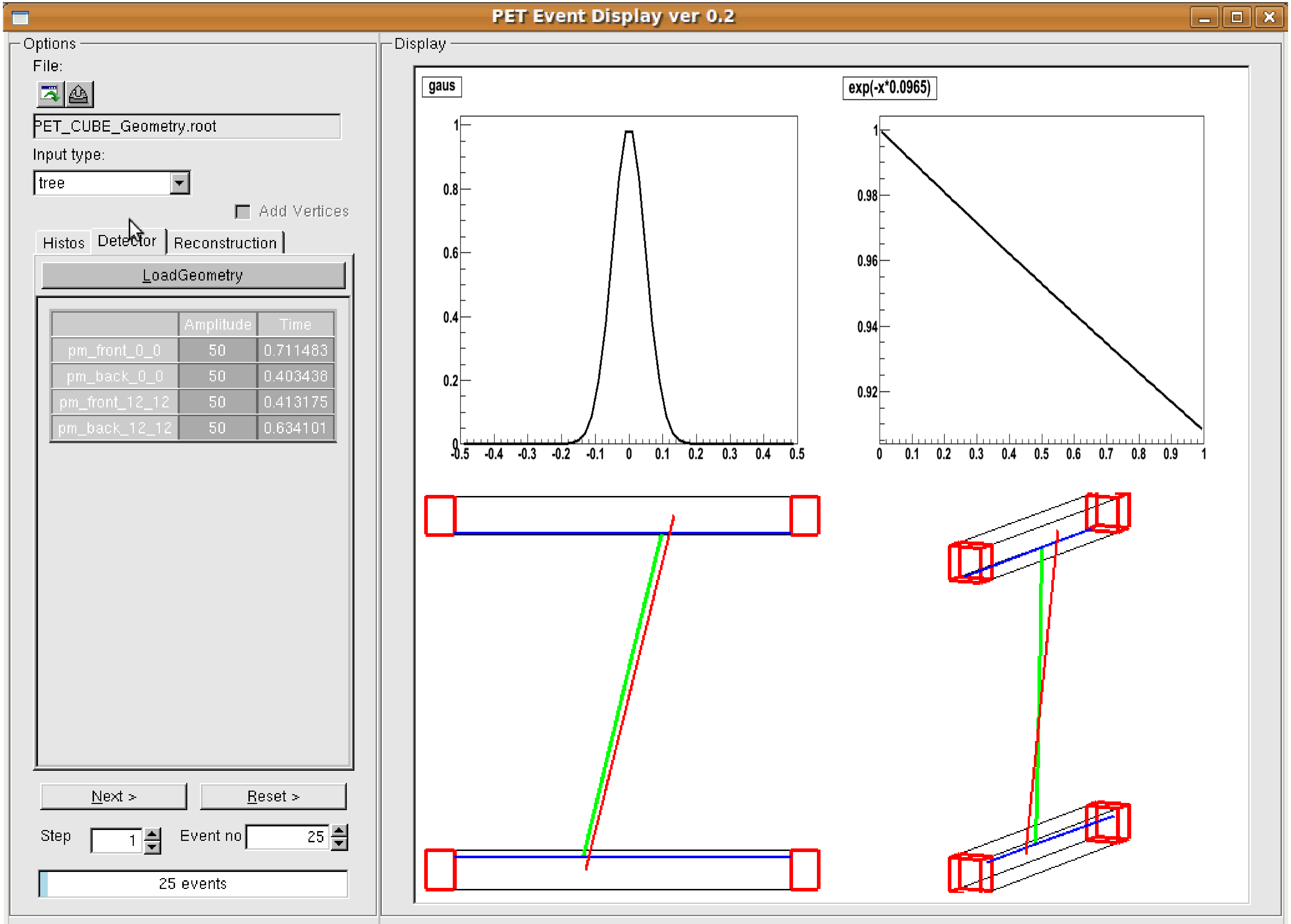
Detector response simulation



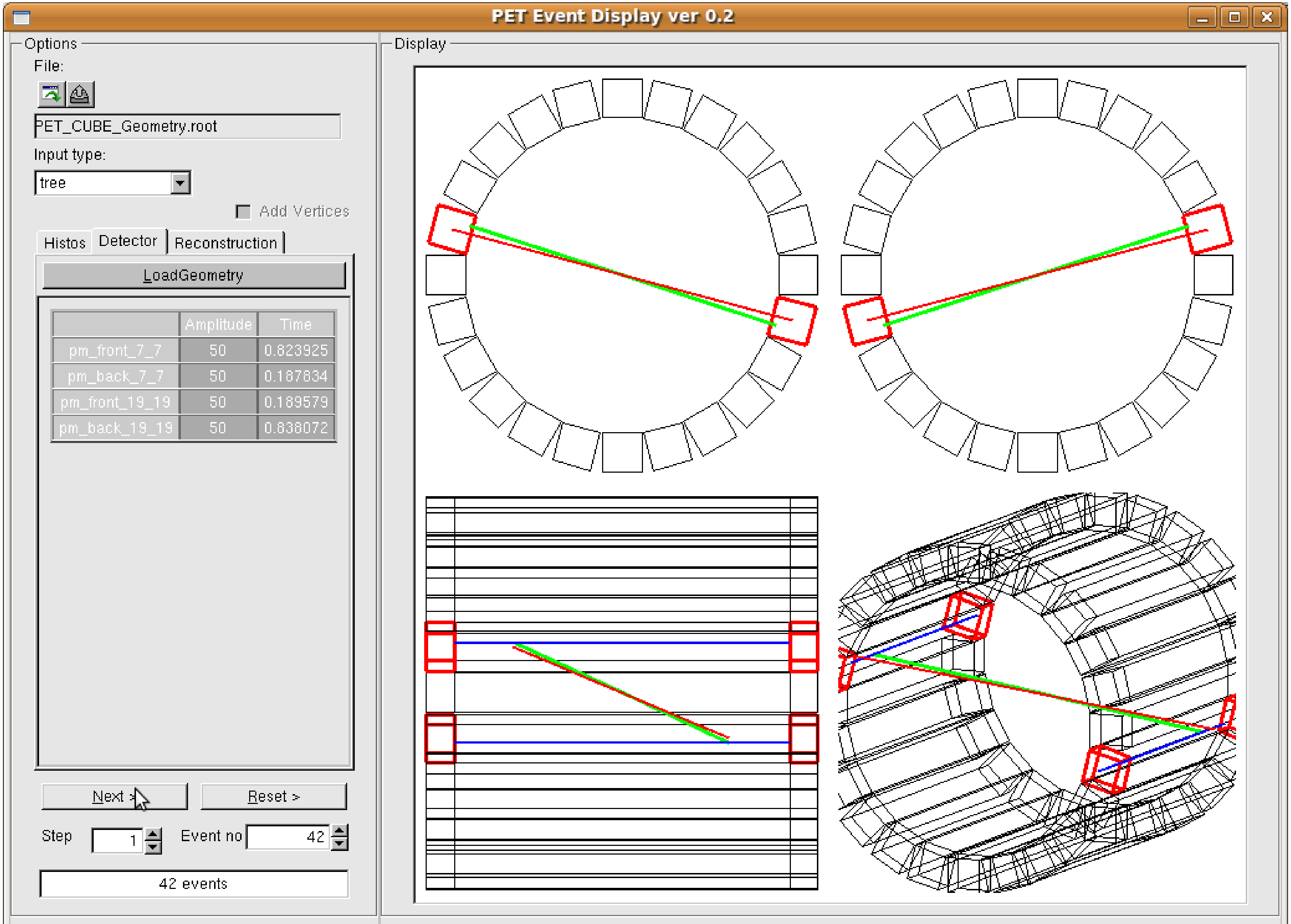
Detector response simulation



Detector response simulation



Detector response simulation



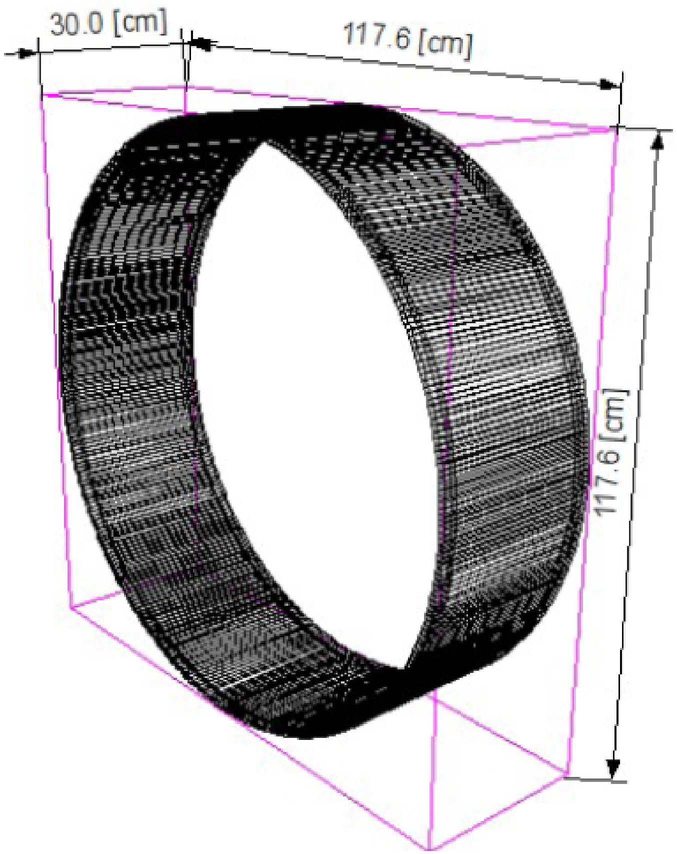
MC tests – QA plots

toy detector:

- 360 strip scintillators distributed symmetrically on a circle (R =57 cm)
- Module dimensions 1 x 1 x 30 cm

- Two simple phantoms:

Emitting point (0,0,0)
Sphere (0,0,0) R=3 cm



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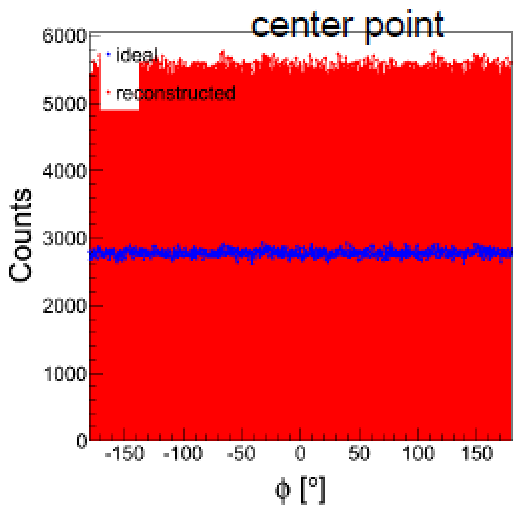
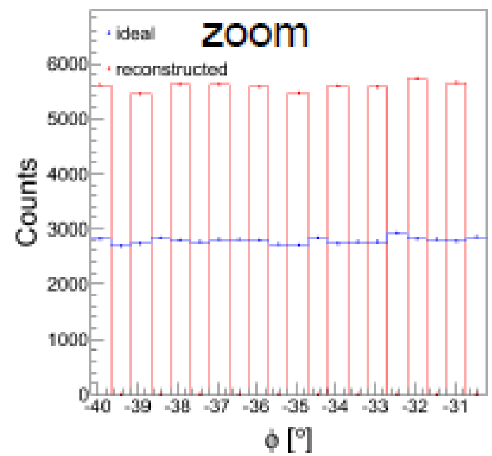
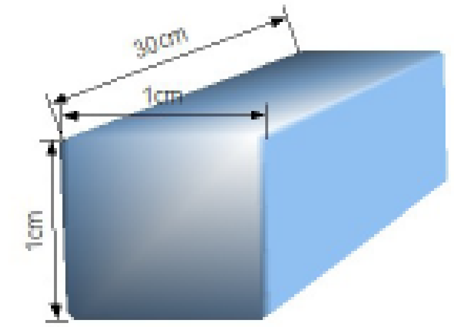
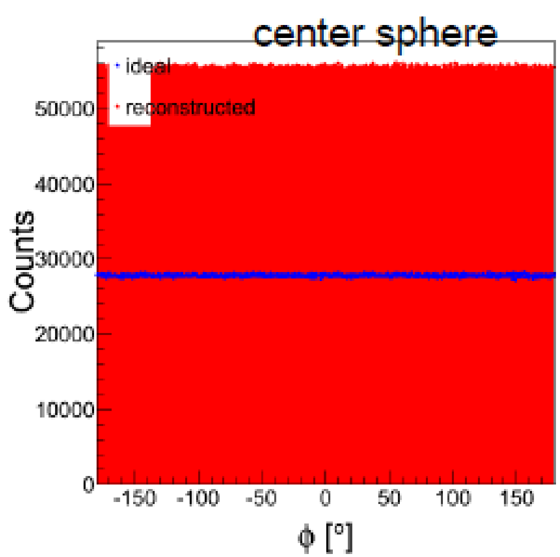
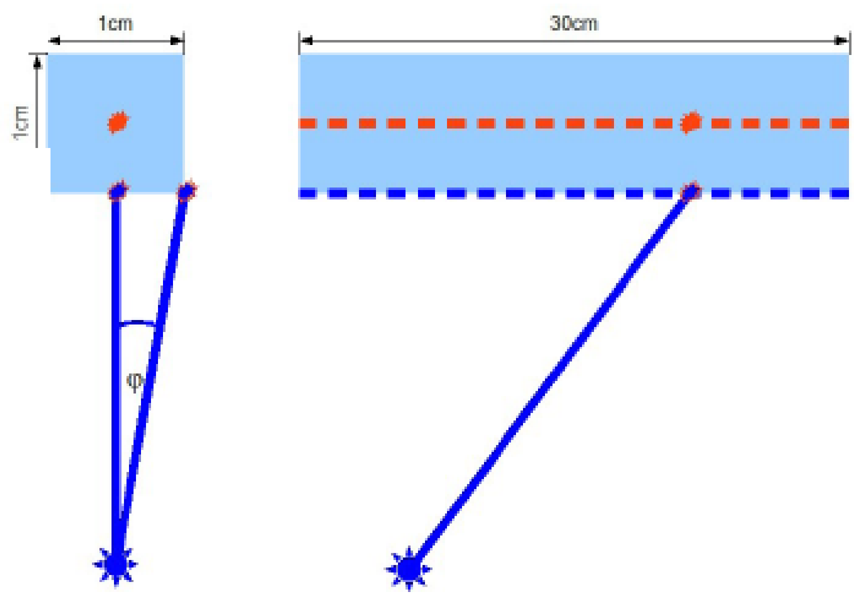


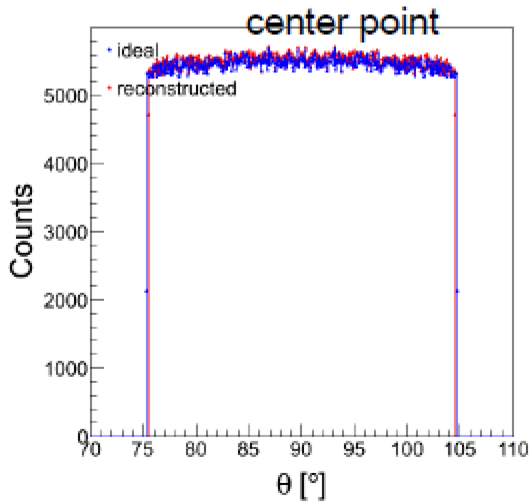


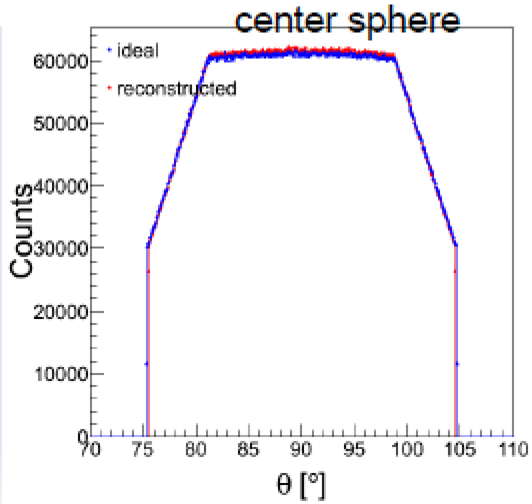


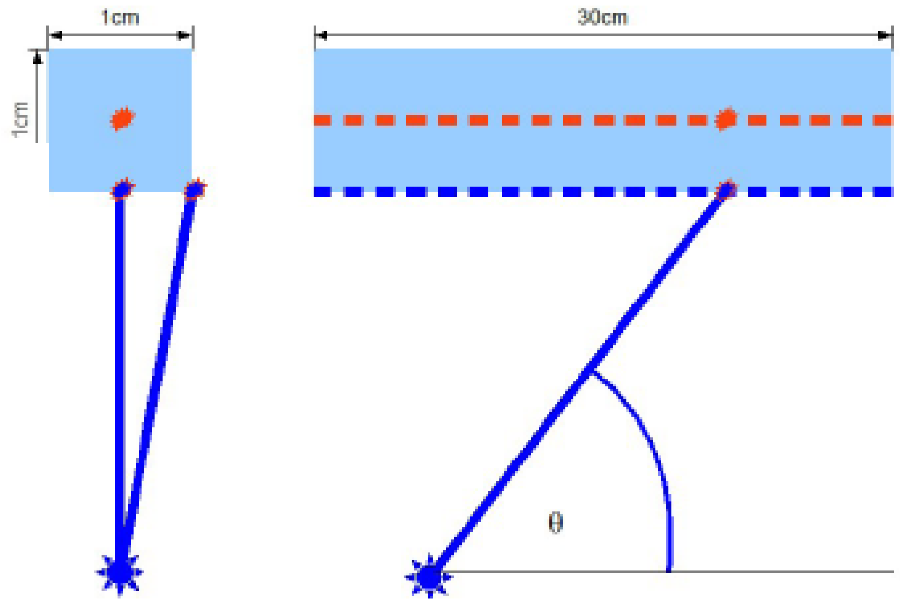




MC tests – QA plots







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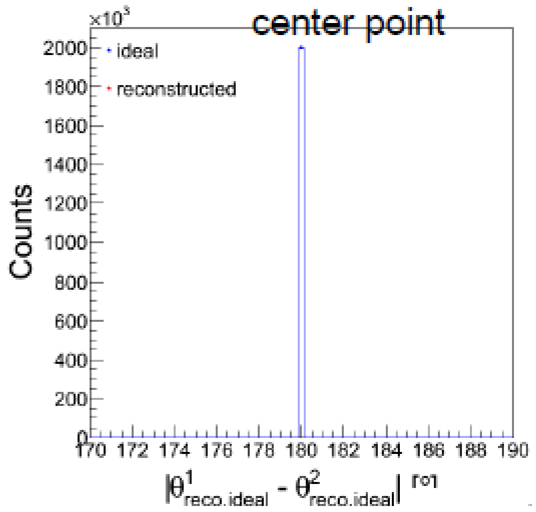

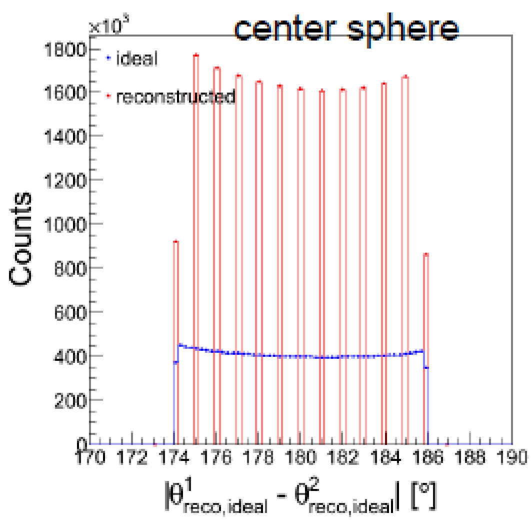

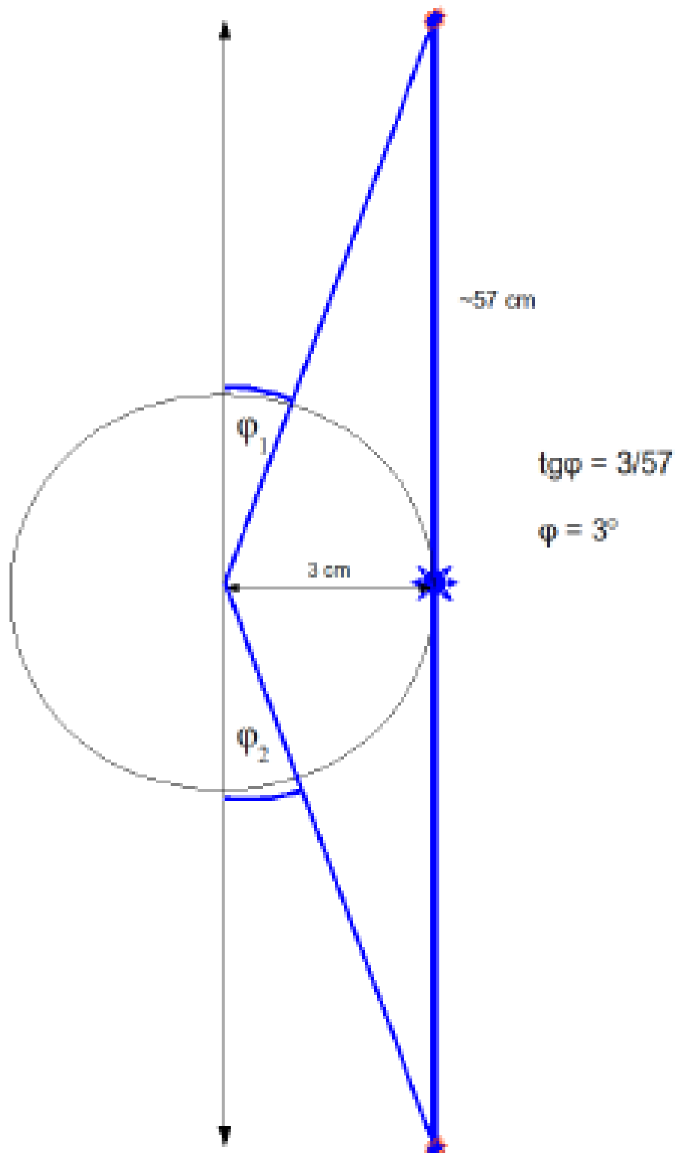

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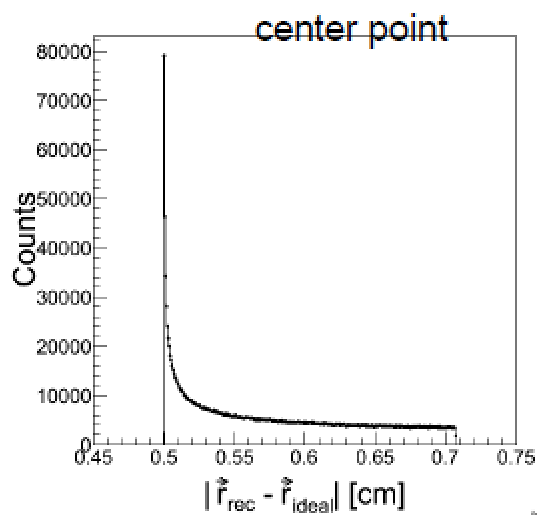

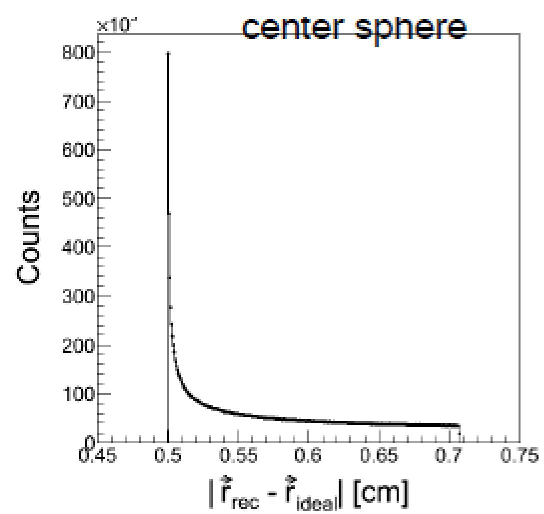

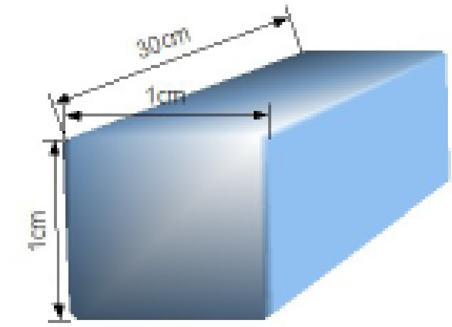

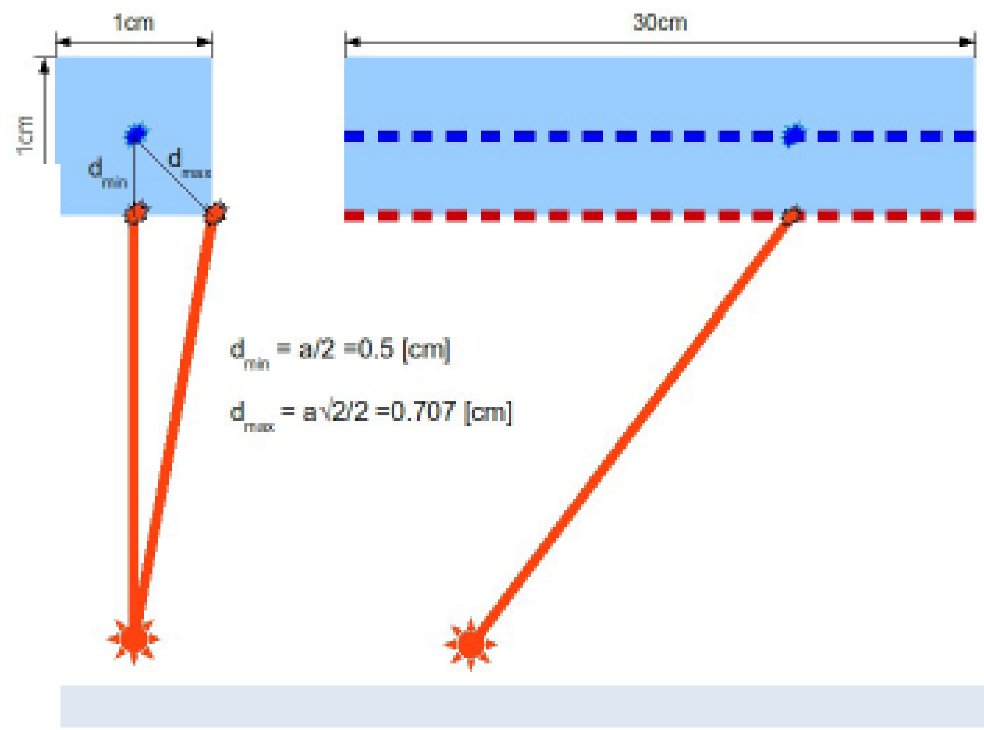

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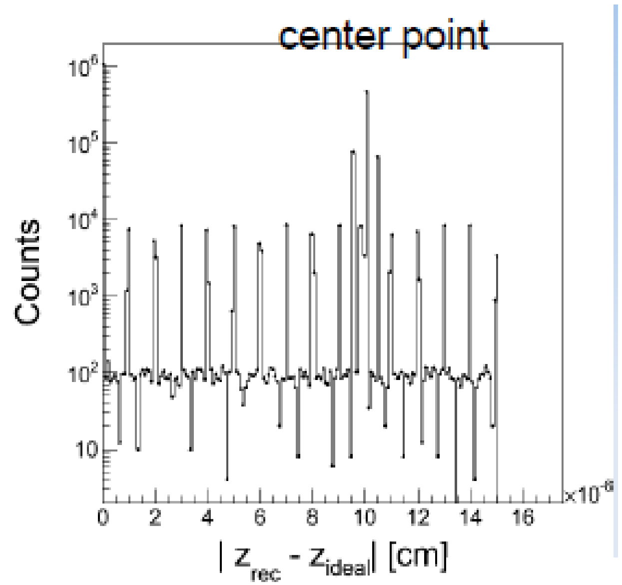

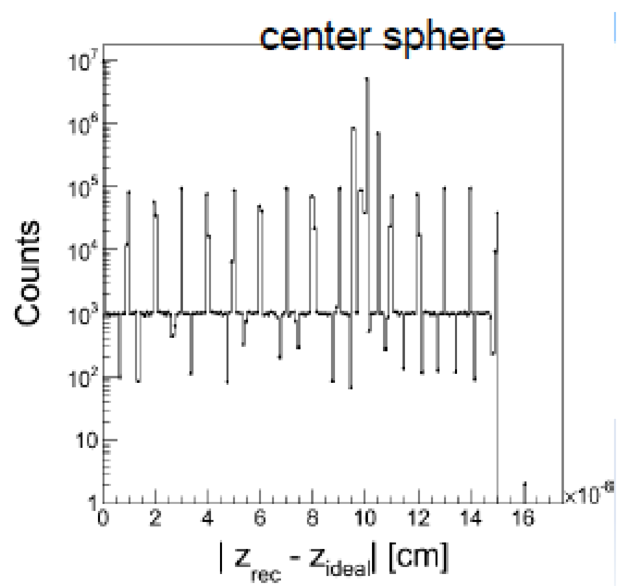

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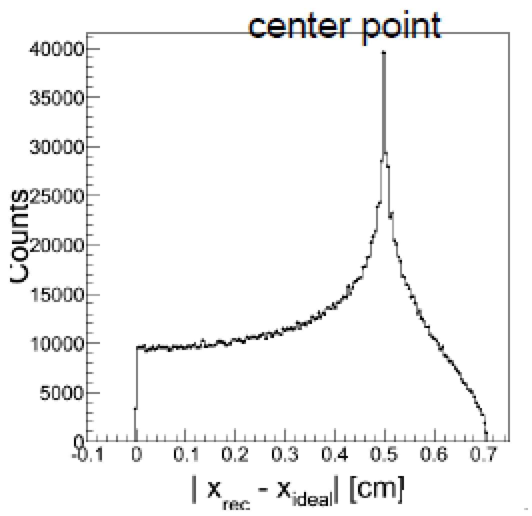
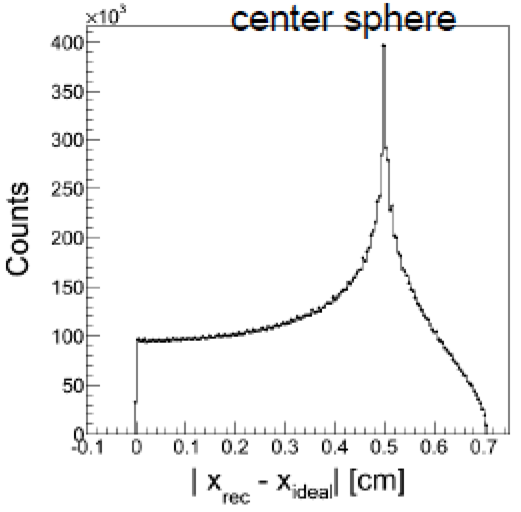
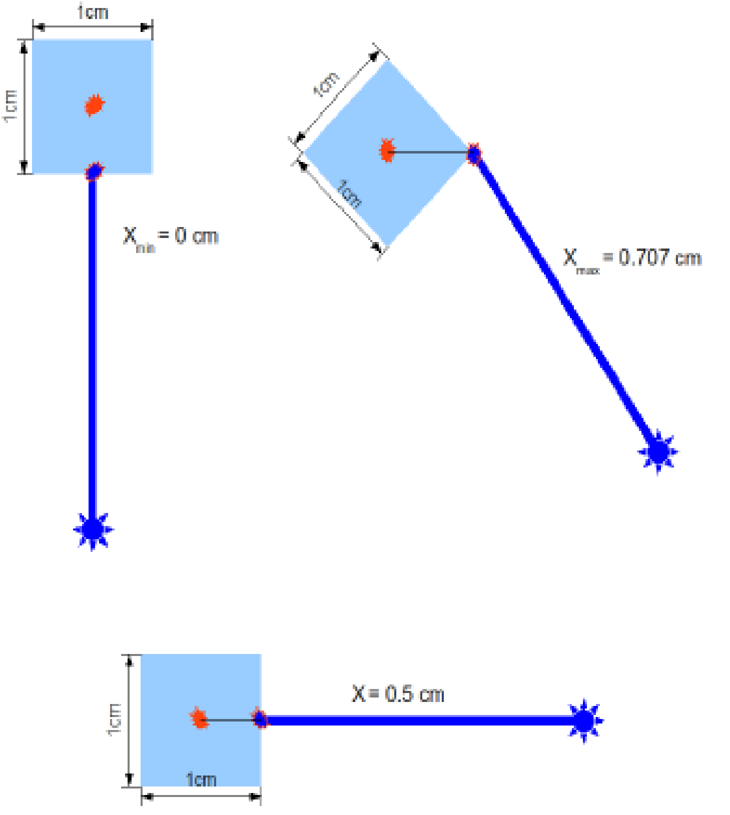
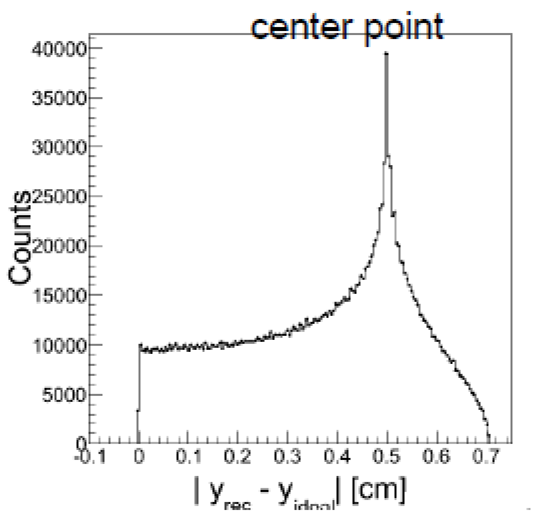
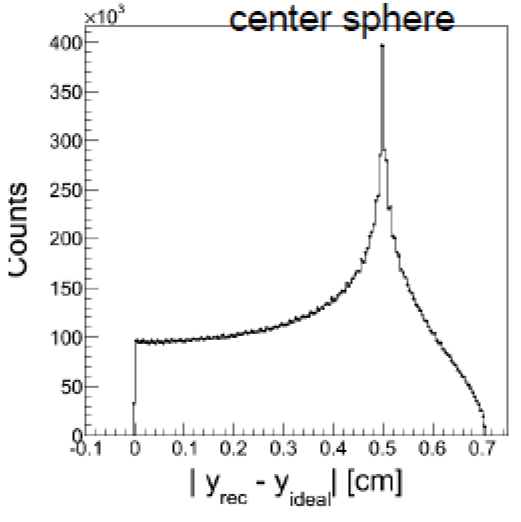






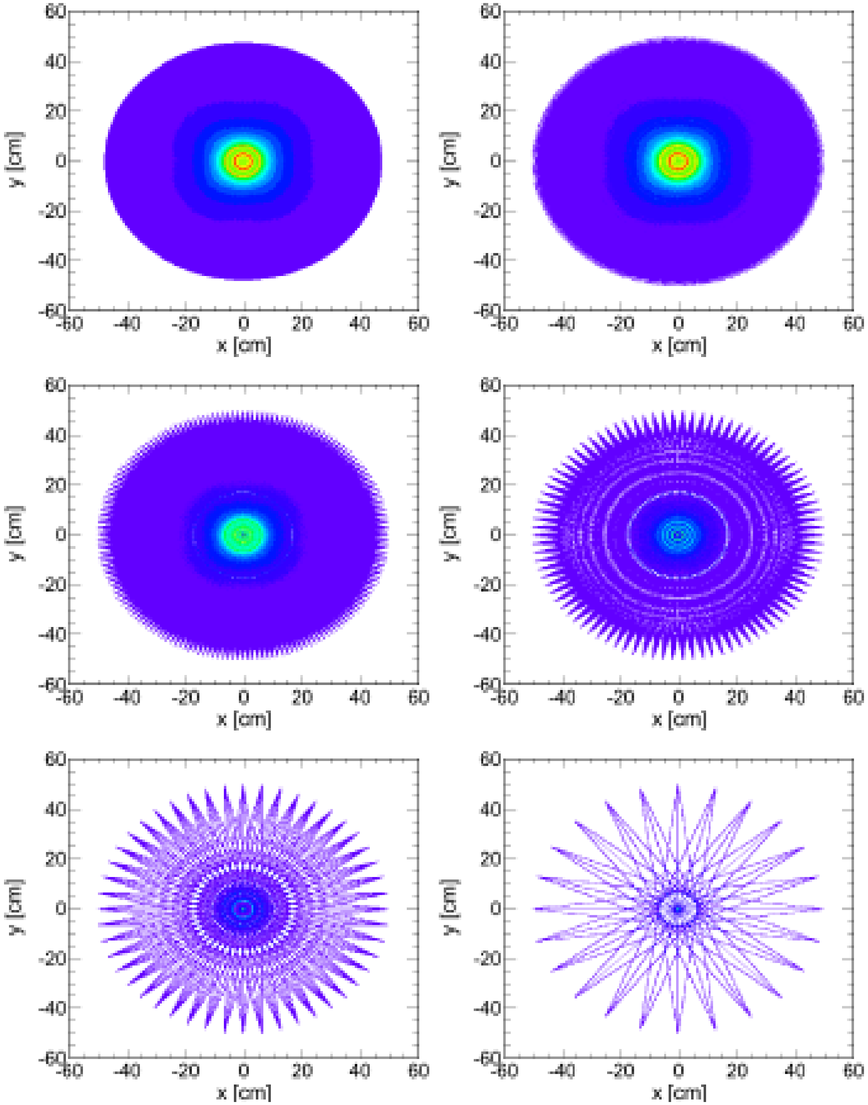


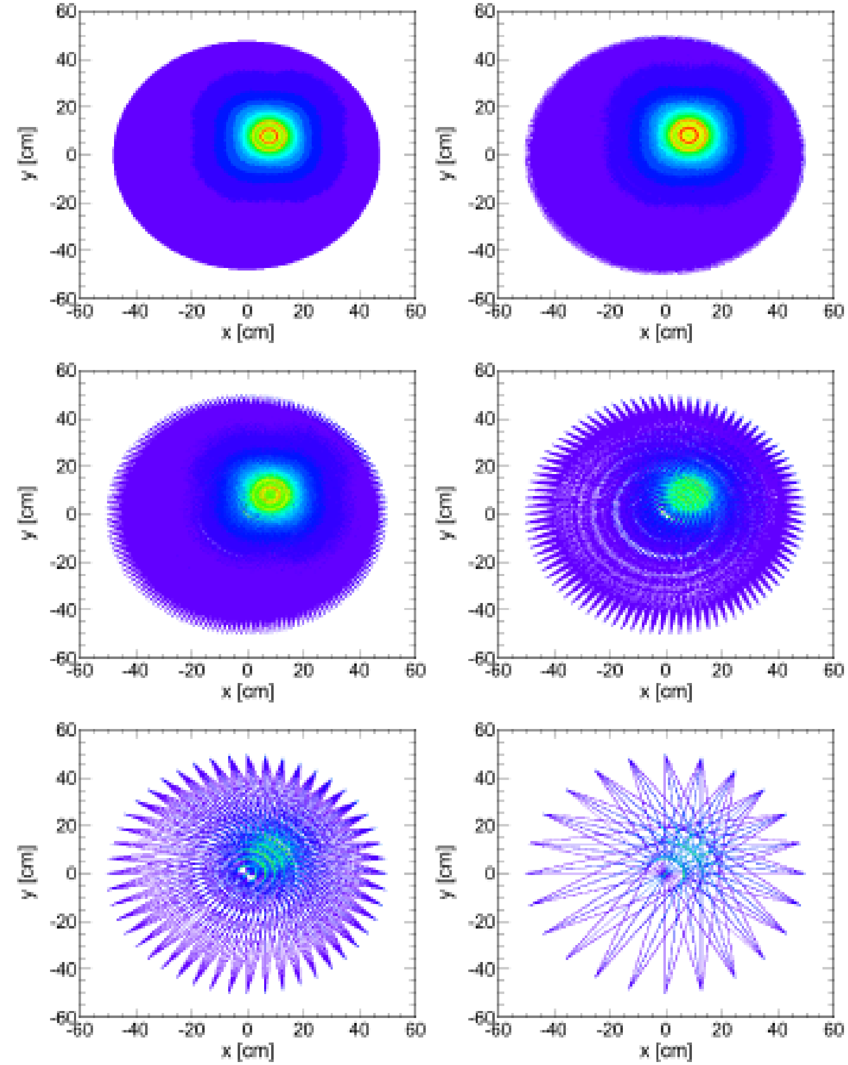


Simple reconstruction example

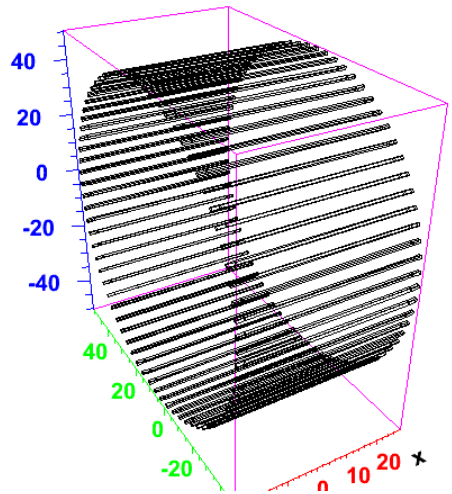
- Uniformly distributed sphere within a sphere (r1 =3 cm, r2 = 6 cm).
- Two cases:
  - position of the center: in (0,0,0)
  - position of the center: in (8,8,8) cm.
- Detector is a cylindrical barrel with strip modules distributed symetrically on the circle (R =50 cm).
- Dimensions: 50 cm x 2,5 x 2 cm
- We change the number of modules in the detector:

Examples of reco (cross-sections z = 0, 5 mln events registered)

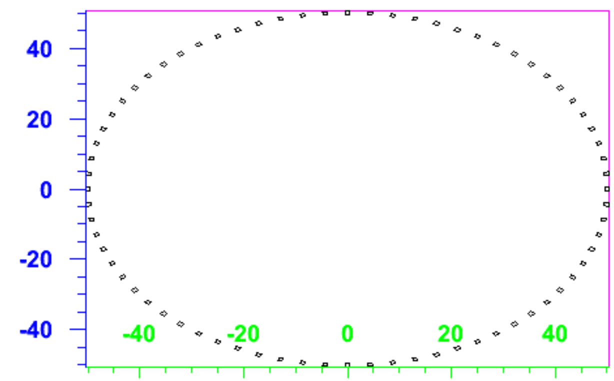


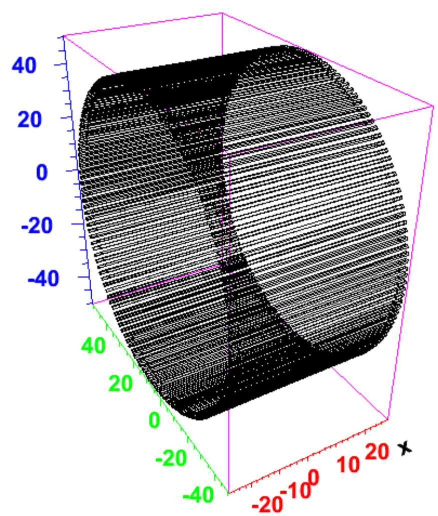


Different number of detectors (uniformly distributed 20% -100%) (R=50cm, L=50cm)

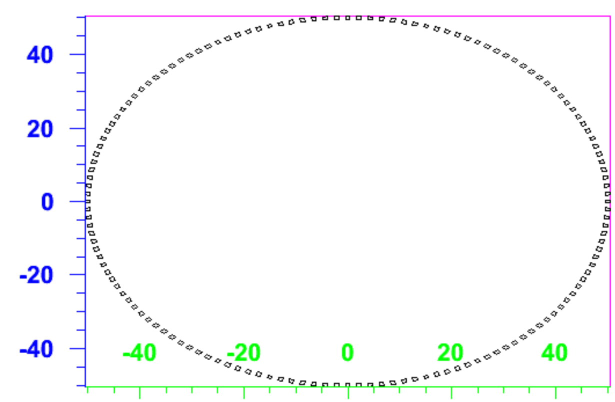


20%

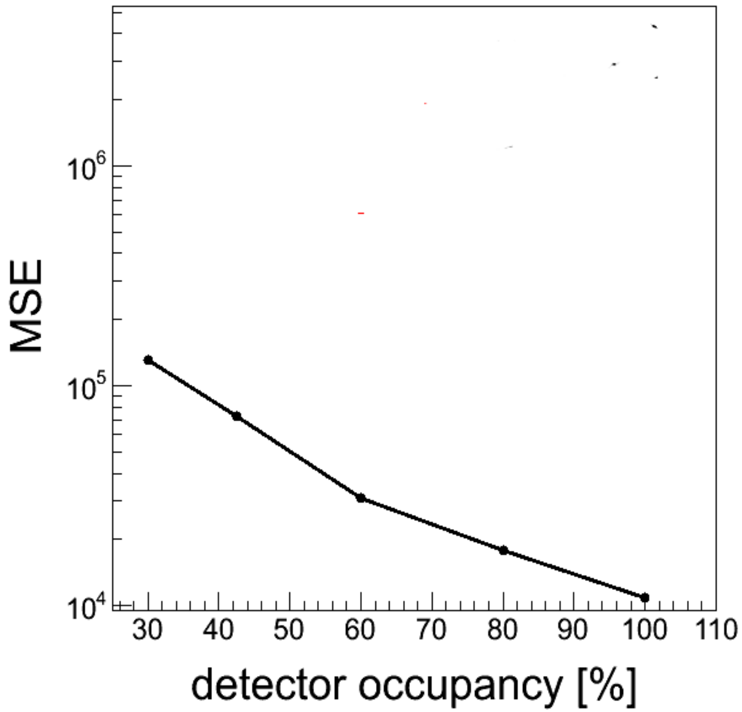


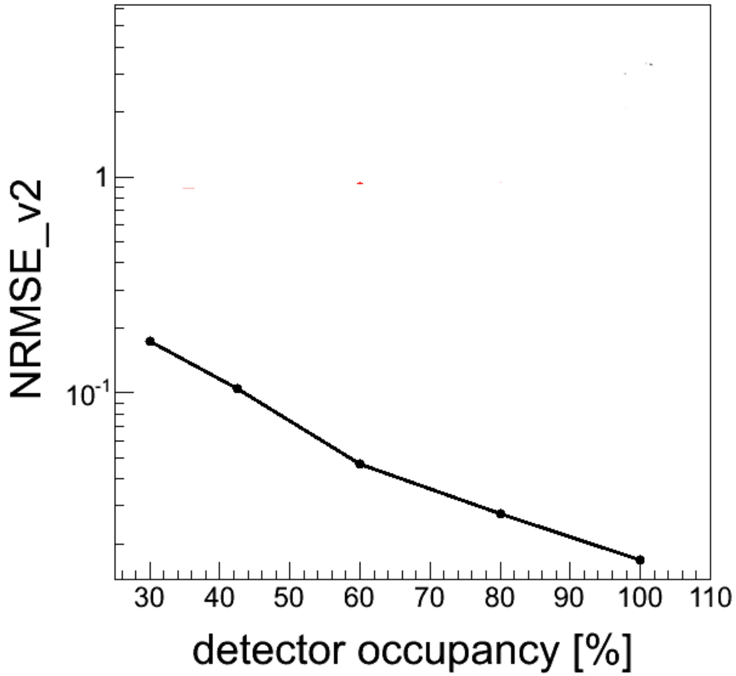


40%

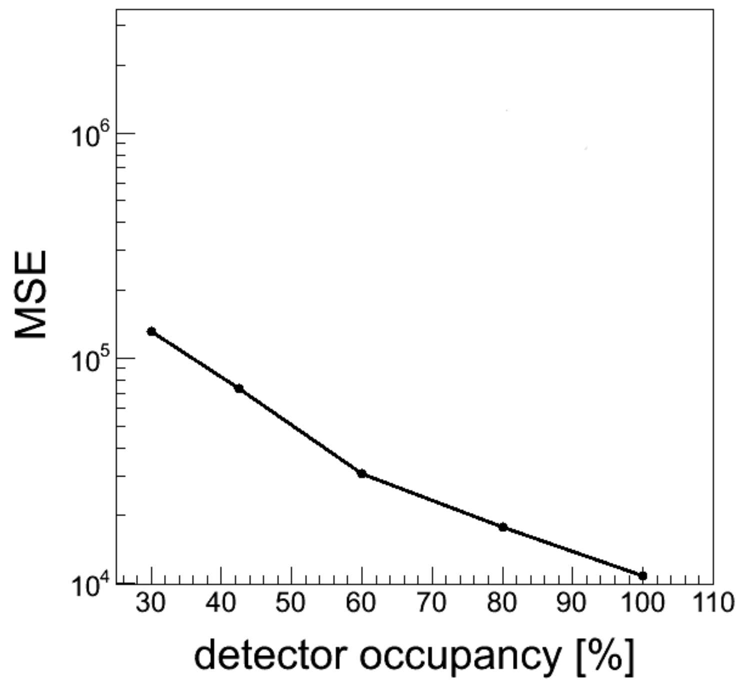


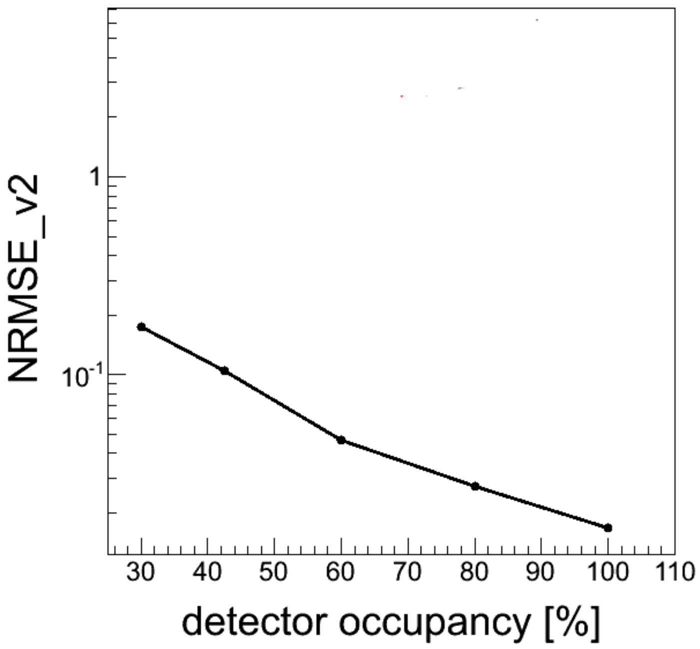
Same number of LORs accepted (same # of LORs for every case)



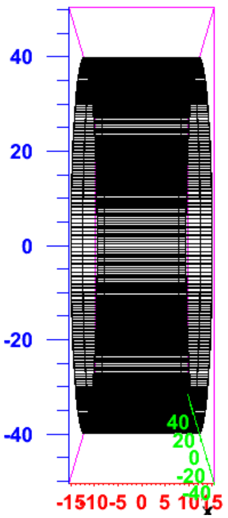


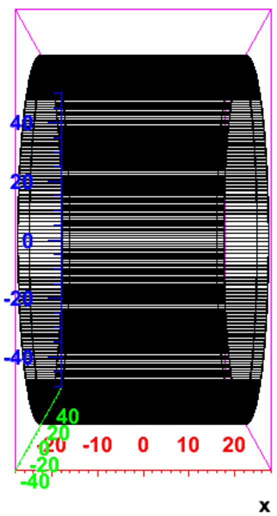
Same number of LORs emitted (different # of LORs due to acceptance)

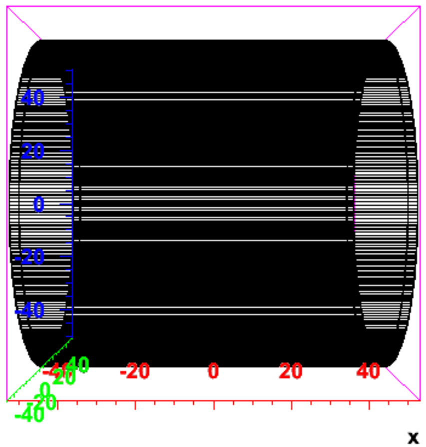




Different detector length
(R=50 cm, L =25, 50, 100 cm)







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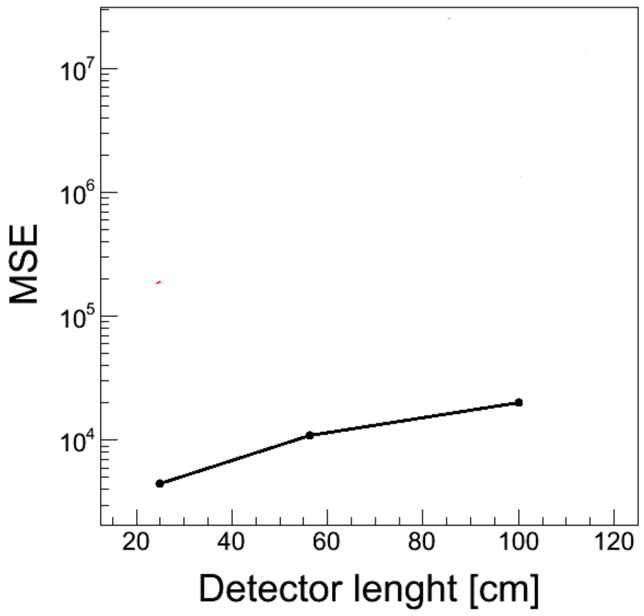
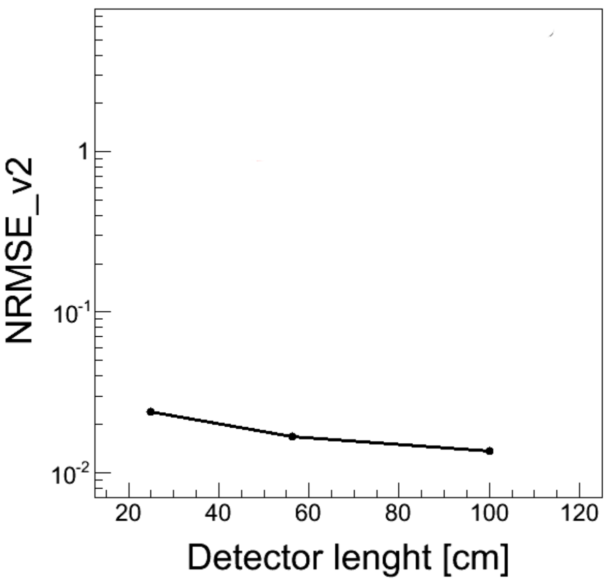
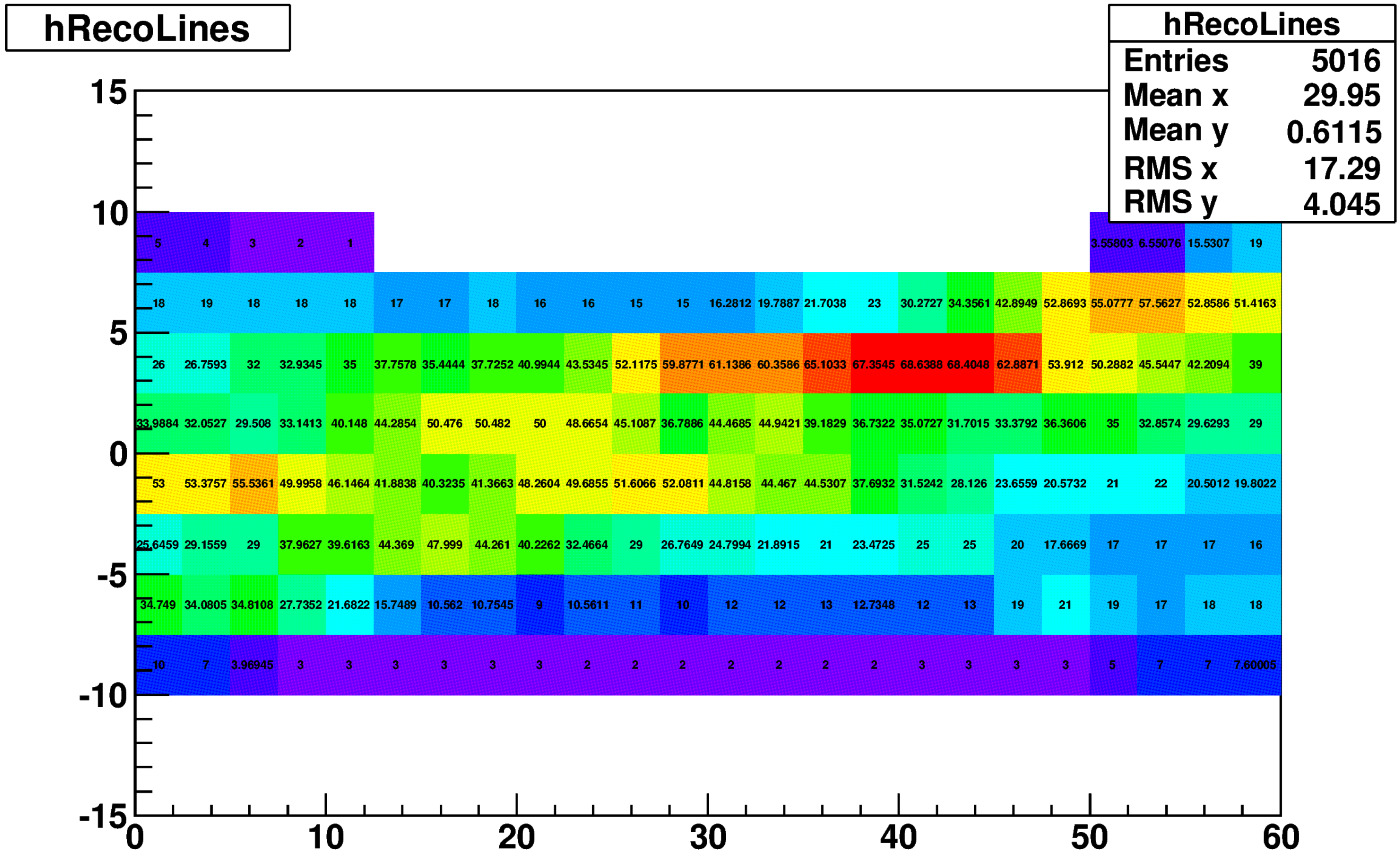




Outlook

- Using the developed software we can investigate the quality of the image reconstruction, changing:
  - dimensions of the scintillators
  - number of detectors
  - shape of the detectors
- We plan to repeat the studies using:
  - More complicated phantoms
  - Simple algorithms with TOF
  - MLEM algoritm (in cooperation with A. Słomski and Z. Rudy)
  - TOF resolution as an additional parameter

Very first „image reconstruction”



Chosen phantoms

- Sphere (3cm radius)
- Sphere in a sphere (3 cm, 6 cm)
- Shepp-Logan phantom 2-D
- Shepp-Logan phantom 3-D version
- Two emitting points separated by a distance d