Max-Planck-Institut für extraterrestrische Physik

The Application of the List-Mode MLEM Algorithm to the Tracking Compton and Pair Telescope MEGA

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Abstract

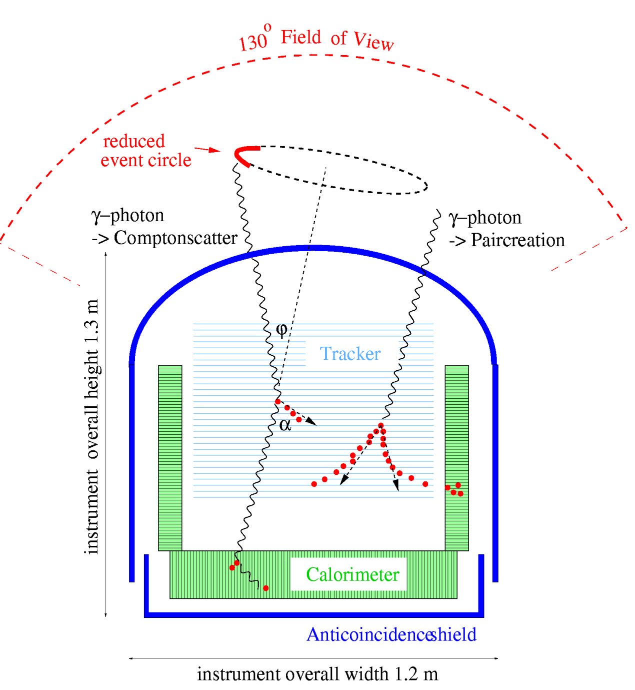
Combined Compton scattering and pair creation telescopes like MEGA (Medium Energy Gamma-ray Astronomy) measure a large amount of event parameters to a high accuracy. Using a list-mode likelihood algorithm (LM-MLEM) in combination with a basic detector response, it is possible to accurately locate sources, resolve extended sources as well as sources on high background as it would be expected in a space environment.

The MEGA Telescope

The MEGA telescope detects gamma-rays via Compton scattering and via pair creation in the energy range from 400 keV up to 50 MeV. It consist of two different detector systems:

(1) A tracker, where the initial interaction takes place and where the direction of the electrons is determined.

(2) A calorimeter, where most of the secondary particles are stopped.

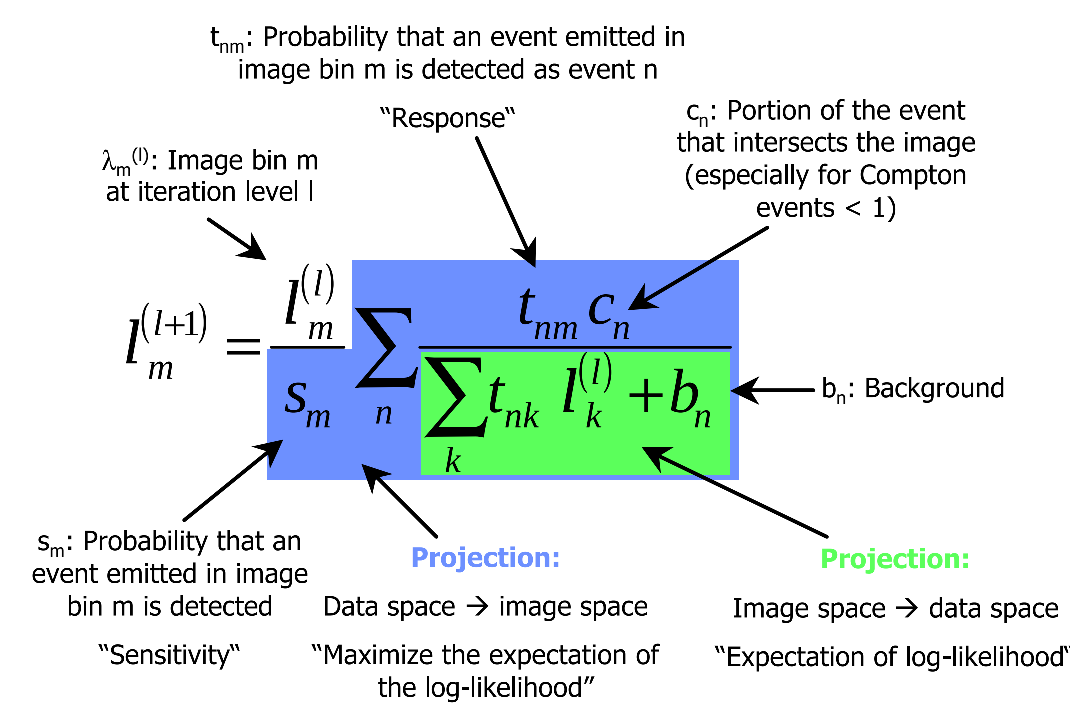


Measurement principle

The List-Mode MLEM for Astrophysics

Using the **L**ist-**M**ode **M**aximum-**L**ikelihood **E**xpectation-**M**aximization (LM-MLEM) algorithm for image reconstruction means that all events are stored in a list instead of a multi-dimensional data space and that the response has to be **calculated** for each of these events. The basic iterative reconstruction algorithm is illustrated on the **right** side. To adopt the standard LM-MLEM algorithm, which has been originally developed for medical imaging, to the needs of the MEGA telescope, three important changes where necessary:

- The response t_{nm} has to cover all event types.
- The algorithm must be able to take into account background (factor b_n).
- It has to take care of objects (e.g. background) that are larger than the reconstructed image (factor c_n).

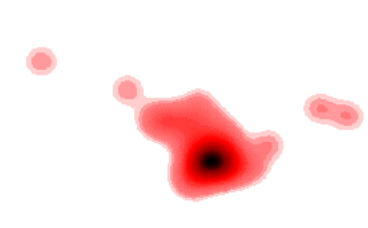


$$l_m^{(l+1)} = \frac{l_m^{(l)}}{s_m} \sum_n \frac{t_{nm} c_n}{\sum_k t_{nk} l_k^{(l)} + b_n}$$

LM-MLEM iterative reconstruction algorithm (similar to the Richardson-Lucy algorithm)

The MEGA Event Types

Untracked Compton events



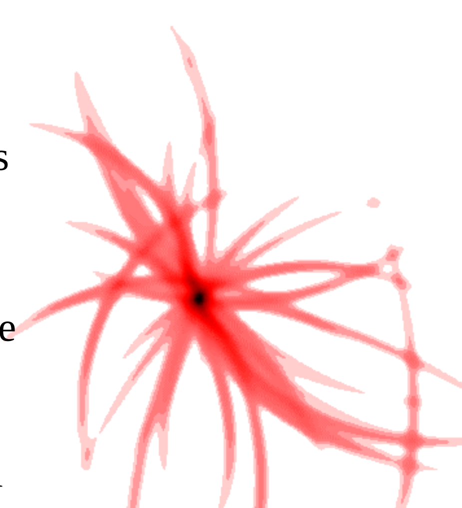
Pair events

Untracked Compton events (< 2 MeV): The energy transferred to the Compton recoil electron is not sufficient to produce a track. Therefore the origin can only be restricted to a cone.

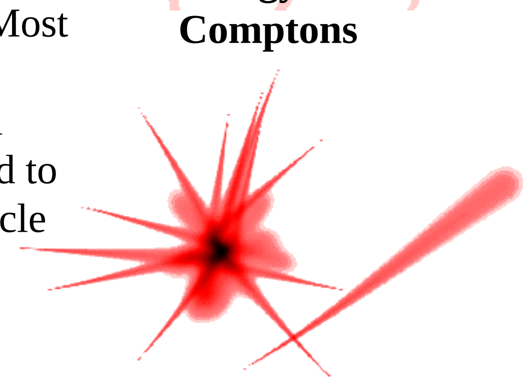
Low energy tracked Comptons (2 - 10 MeV): The events have an electron track and most of them are completely absorbed. The origin is restricted to an arc of the cone-section, whose length is determined by Molière scattering.

High energy tracked Comptons (> 10 MeV): Most of the events are incompletely absorbed, but the direction of electron and scattered photon is well known. The origin of the photon can be restricted to the scattering plane and therefore to the great circle between (reverse) electron and photon direction. Measured energies further restrict this arc.

Pair events: Their origin is the bisecting line between electron and positron direction.



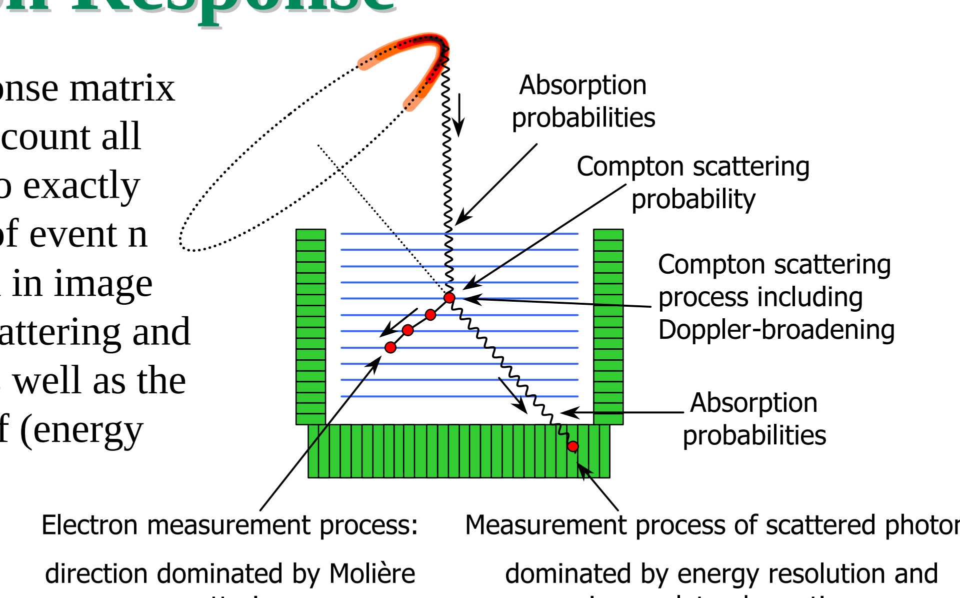
Low energy tracked Comptons

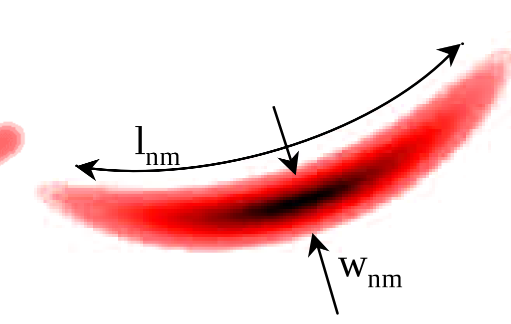


High energy tracked Comptons

The Compton Response

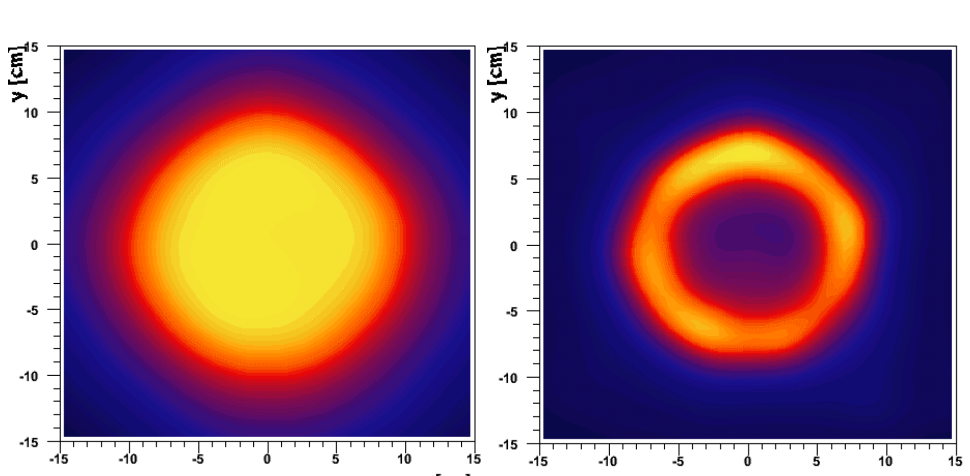
Right: Calculating a response matrix $\{t_{nm}\}$ means taking into account all probabilities, which lead to exactly the measured parameters of event n after a photon was emitted in image bin m. This includes all scattering and interaction probabilities as well as the measurement process itself (energy resolution, etc.).





Left: Beside the Compton process, two factors dominate the response: The width and shift of the cone section w_{nm}, which is mainly determined by the energy and position measurement and, for tracked Comptons, the length of the cone section l_{nm}, which is mainly determined by the direction and energy of the electron and therefore by Molière-scattering.

Selected Results



Lab measurements with the Mega prototype

A "radioactive" ring, produced by ^{88}Y on a rotating propeller with radius 7.5 cm in the near-field, has been measured.

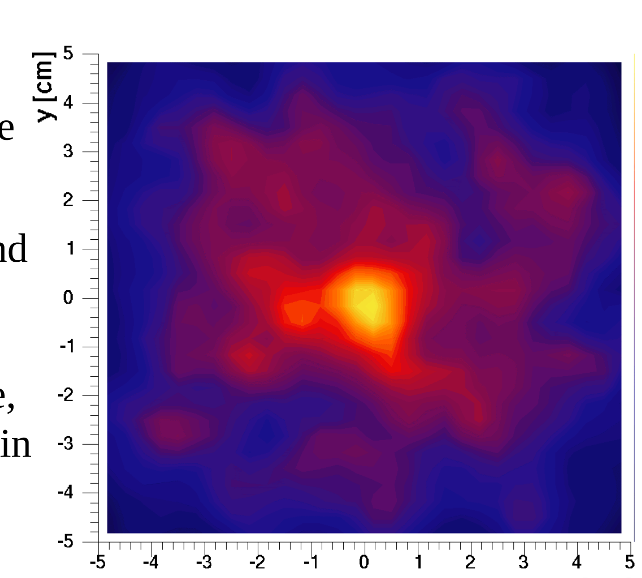
Top Left: Image obtained by a simple back projection of the events in the energy band 0.8-1.0 MeV: The overlapping cone-circles and arcs hide the ring structure.

Top Right: Image after 50 iterations with the list-mode algorithm: The ring structure is clearly visible.

Right: High background simulation

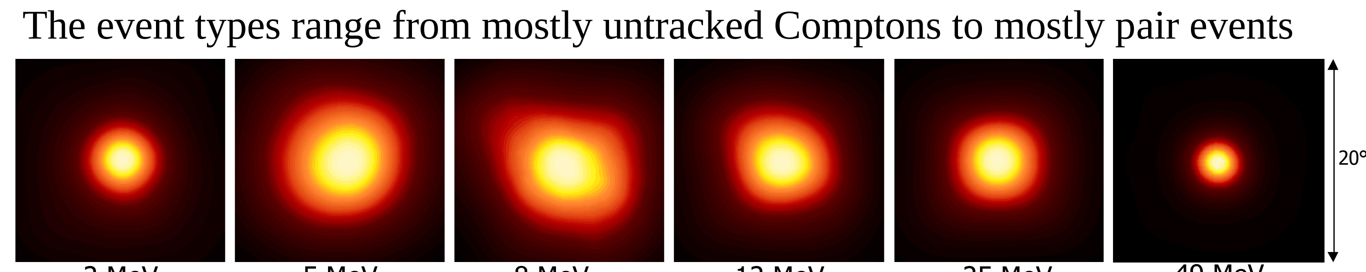
In a real space environment a signal to background ratio of roughly 1 : 100 can be expected as seen by COMPTEL.

1.85 Mio uniformly distributed background events intersect the reconstructed image. 286?000 events are within 3σ of the point spread function of the central point source, which contains 2 200 events. This results in a signal to noise ratio of 1 : 130. No background estimation was applied. The reconstruction took 50 min on a 2.4 GHz Xeon processor.



Bottom: Reconstructed images of a calibration beam from 2 to 49 MeV

The event types range from mostly untracked Comptons to mostly pair events



Conclusions

It has been shown that the List-Mode MLEM algorithm in combination with a basic response of the MEGA telescope allows to:

- ✓ Accurately retrieve positions of point sources
- ✓ Recover extended sources
- ✓ Retrieve point sources on high background
- ✓ Reproduce relative intensities

Furthermore the high flexibility of the implementation allows to easily exchange the detector geometry as well as to switch between near and far field. Thus, the algorithm is well suited for calibration measurements as well as for astrophysical purposes.

References

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