Mimrec

<u>M</u>EGAlib <u>im</u>age <u>rec</u>onstruction and more …

Version of 23 July 2018

1. Prelude

What is Mimrec?

Mimrec is MEGAlib's main tool for advanced data analysis. It enables event selections on various parameters of single-site, Compton, and pair events. It allows coded mask, Compton, and pair image reconstruction using list-mode maximum-likelihood (ordered-subsets) expectation maximization using different accuracy levels for the response representation. In addition it provides functions to look at energy spectra, ARM distribution, and many more parameters of Compton telescopes.

Installation

Since Mimrec is part of MEGAlib, please see the MEGAlib installation instructions for a complete step by step installation guide.

Bug reports

If you find a bug or other problem, please email it to me: Andreas Zoglauer, zog@ssl.berkeley.edu

2. Invocation

```
mimrec <options> -f <tra file>
```

Mimrec can be started with a variety of command line options. The tra file is always given via the "-f" parameter. The command line options are not mandatory, since everything can be set via the GUI, and since Mimrec will remember the options (file names, etc.) it has used last.

The other options are:

-g/--geometry <file name> or -f/--filename <file name>	Give the geometry file name usually ending with *.geo.setup
-d/--debug	Activate debug mode for more detailed command line output
-c/--configuration <file name>	Use this Geomega configuration file containing a previously stored GUI configuration. Using the option –g (or –f) overwrites the geometry file name stored in the configuration file.

3. The tra file format

Common keywords

Keyword marked with (*) are mandatory. However not giving some of the parameters disables the possibility too do event selections on them.

Key: SE *

Parameters: None

Description: Indicates the start of an event description

Key: EN *

Parameters: None

Description: Indicates the end of all events in the file

Key: ID *

Parameters: 1: event ID

Description: A numerical ID (integer) of the events

Key: TI *

Parameters: 1: Time in seconds

Description: The event time in seconds. The zero point is instrument specific

Key: RX & RZ

Parameters: 1: x-value [cm] of the detector orientation vector
2: y-value [cm] of the detector orientation vector
3: z-value [cm] of the detector orientation vector

Description: Describes the x and z-axis of the orientation of the detector in Cartesian coordinates. Use either (RX & RZ) or (GX & GZ), not both!

Key: GX & GZ

Parameters: 1: longitude [deg] of the detector orientation vector in Galactic coordinates
2: latitude [deg] of the detector orientation vector in Galactic coordinates

Description: Describes the x and z-axis of the orientation of the detector in Galactic coordinates. Use either (RX & RZ) or (GX & GZ), not both!

Key: HX & HZ

Parameters: 1: longitude [deg] of the detector orientation vector in Galactic coordinates
2: latitude [deg] of the detector orientation vector in Galactic coordinates

Description: Describes the x and z-axis of the orientation of the detector in a Horizon coordinates system. HX and HZ are different from (RX & RZ) and (GX & GZ), because they are not used for imaging, but for the Earth horizon cut.

Key: `CC`

Parameters: 1: Just text

Description: Nothing but a comment belonging to the event, which is kept throughout the MEGAlib pipeline

Key: `ET *`

Parameters: 1: One of CO (Compton event), PA (pair event), PH (photo effect event = single hit event), MU (Muon or any other high-energy charged particle events), UN (Unknown)

Description: Indicates the type of the event.
Attention: No special event type specific keyword is recognized if it appears before the ET keyword!

Keywords specific for Compton events (ET CO)

Key: `CE *`

Parameters:
1: Energy of scattered gamma-ray in keV
2: Energy uncertainty as one sigma of scattered gamma-ray in keV
3: Energy of recoil electron in keV
4: Energy uncertainty as one sigma of recoil electron in keV

Description: Energy of electron and scattered gamma-ray as identified during the event reconstruction and their uncertainties.

Key: `CD *`

Parameters:
1: x position of first interaction in cm
2: y position of first interaction in cm
3: z position of first interaction in cm
4: x position uncertainty as one sigma of first interaction in cm
5: y position uncertainty as one sigma of first interaction in cm
6: z position uncertainty as one sigma of first interaction in cm
7: x position of second interaction in cm
8: y position of second interaction in cm
9: z position of second interaction in cm
10: x position uncertainty as one sigma of second interaction in cm
11: y position uncertainty as one sigma of second interaction in cm
12: z position uncertainty as one sigma of second interaction in cm
13: Electron direction x
14: Electron direction y
15: Electron direction z
16: Uncertainty as one sigma of electron direction x
17: Uncertainty as one sigma of electron direction y
18: Uncertainty as one sigma of electron direction z

Description: Position of the first and second interaction as identified during the event reconstruction as well as the direction of the recoil electron (if measured) plus the uncertainties.

Key: `SQ *`

Parameters: 1: Compton sequence length

Description: Gives the length of the Compton sequence in detected/resolved interaction positions
For a two-side event this is 2, for a three-site event this is 3.

Key: `CT`

Parameters: 1: First Compton quality factor
2: Second Compton quality factor

Description: The Compton quality factors from event reconstruction.

Key: `TQ`

Parameters: 1: First quality factor
2: Second quality factor

Description: The electron track quality factors from event reconstruction.

Key: `PQ`

Parameters: 1: Clustering quality factor

Description: The quality factors from clustering. NCT specific.

Key: `TL`

Parameters: 1: Length of the first track

Description: Gives the length of the electron track in hits layers, NOT as a distance. For an event without a track this value is 1.

Key: `TE`

Parameters: 1: energy deposit in keV

Description: The energy deposited in the first layer of the electron track

Key: `LA`

Parameters: 1: Length in cm

Description: The shortest length between any two interaction within the Compton sequence

Key: `TF`

Parameters: 1: Time of flight usually in seconds

Description: The time-of-flight between the first and second interaction. For COMPTEL it’s the TOF channel number.

Key: `PD`

Parameters: 1: PSD value

Description: COMPTEL only: PSD channel number

Keywords specific for pair events (ET PA)

Key: PC *

Parameters: 1: x-position in cm
2: y-position in cm
3: z-position in cm

Description: Position of the gamma conversion

Key: PE *

Parameters: 1: Energy of electron in keV
2: Energy uncertainty of electron in keV
3: x-direction of electron
4: y-direction of electron
5: z-direction of electron

Description: Energy and direction of the electron

Key: PP *

Parameters: 1: Energy of positron in keV
2: Energy uncertainty of positron in keV
3: x-direction of positron
4: y-direction of positron
5: z-direction of positron

Description: Energy and direction of the positron

Key: PI

Parameters: 1: Energy in keV
2: Energy uncertainty of electron in keV
3: x-direction of electron
4: y-direction of electron
5: z-direction of electron

Description: Energy deposition in the first layer

Keywords specific for photo effect events/single-site events (ET PH)

Key: PE *

Parameters: 1: Energy deposit in keV
2: Energy error of scattered gamma-ray in keV

Description: Energy deposit of the gamma ray

Key: PP *

Parameters: 1: x-position in cm
2: y-position in cm
3: z-position in cm

Description: Position of the energy deposit

Keywords specific for single charged particle events, e.g. muons (ET MU)

Key: `ME *`

Parameters: 1: Energy deposit in keV

Description: Total energy deposit of the particle

Key: `MD *`

Parameters: 1: x-direction
2: y-direction
3: z-direction

Description: Direction of the particle

Key: `MG *`

Parameters: 1: x-position in cm
2: y-position in cm
3: z-position in cm

Description: Position for the path reconstruction of the particle

Keywords specific for unidentifiable events (ET UN)

Key: `BD *`

Parameters: 1: String

Description: Unique string explaining why the identification might have failed.

Key: `PE *`

Parameters: 1: Energy deposit in keV

Description: Total energy deposit of the particle

Special keywords

Key: `OI`

Parameters: 1: x-value of the start position in cm
2: y-value of the start position in cm
3: z-value of the start position in cm
4: x-value of the start direction
5: y-value of the start direction
6: z-value of the start direction

Description: Original start parameters of the photon. This keyword is usually not part of the data set, except for special calibrations

4. The Mimrec UI

The mimrec menu system is split into four sections. The menu file takes care of loading tra, geometry, and configuration files. The menu “Selections” enables event and coordinate system selection. Those are used for all other operations, in the “Imaging” and “Analysis/Response” menu.

The menu “File”

The menu “Selections”

Event selection

This UI enables various event selections on most of the parameters of the events.
It consists of 7 sections or tabs.

Coordinate system

Choose the coordinate system. Options are Cartesian 2D and 3D, spherical and galactic. This determines the coordinate system for image reconstruction as well as the positional information of the source origin for e.g. ARM selections, etc.

Show event selections

This loops through the events and dumps the selections into the console. It also gives a summary of which events selection have been applied how often at the end. This function is especially helpful to determine why no events passed the event selections.

Extract events

The creates a new tra file containing only those events which pass the event selections. If the original file is name Name.tra then the new file name is Name.extracted.tra

The menu “Imaging”

This menu provides all options for list-mode image reconstruction

Start image reconstruction

Starts the image reconstruction, which consists of two parts: First, the

Image dimensions

This mask allows to set the image dimension and bin numbers for each axis of the coordinate system. The UI is different for all possible coordinate systems.

Image drawing options

Reconstruction algorithm

Response type selection

Response parameter (for the above selected type)

Memory, accuracy, thread management

The menu “Analysis/Response”

5. Frequent tasks

In the following section the procedure to achieve some frequent tasks are described, such as determining resolution and efficiencies.

Basic telescope performance parameters

The following three topics describe how you can determine some common characteristics of a Compton telescope, its energy resolution, its angular resolution (ARM), and its effective area. The prerequisites are simulations of point sources with mono-energetic beams (of course you can also determine angular resolution or effective area for source power law spectrum, but this is not part of this introduction). An example for such a simulation can be found in the Cosima example run “EffectiveArea.source” utilizing the (old) MEGA satellite geometry (setup file: “mpesatellitebaseline/Satellite.geo.setup”). From now on we assume you performed the above simulation and you reconstructed the events with revan (using the revan configuration file “EffectiveArea.revan.cfg” from the revan example directory).

Determine the energy resolution

The first step is to set reasonable event selections and the correct coordinate system (here: spherical coordinates). In our case, we want to make as few event selections as possible, but only look at tracked events (you can do not-tracked events as an additional exercise). The only additional event selection which we want to make is an energy window of +-5% around the input energy of 2 MeV. The window has to be large enough to contain the complete photo-peak, but not too much else. Take a look at the “EffectiveArea.mimrec.cfg” file in the mimrec example directory, to load the defaults GUI settings.
Now click on menu option “Energy spectra” in the “Response” menu. The energy spectra GUI will appear (see Figure 1).

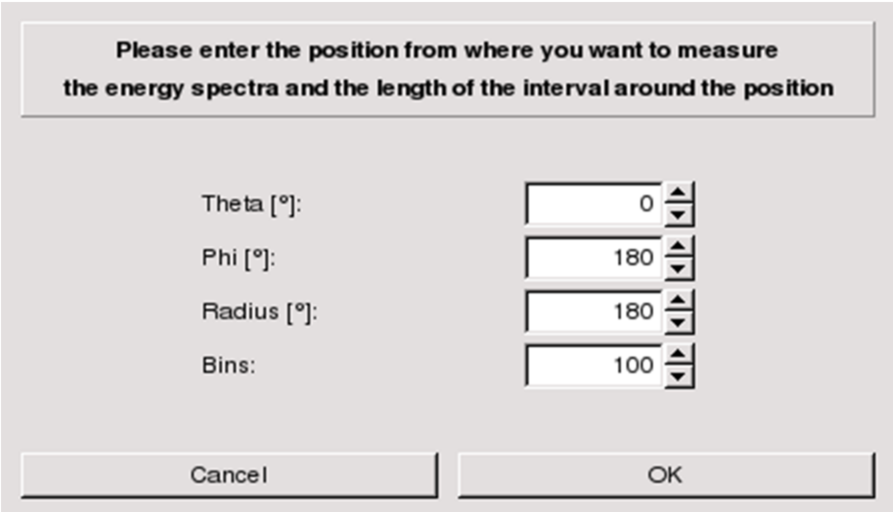

Figure 1: The energy spectra GUI: Set the radius to 180 degrees to not select a window around the source.

For the given task we do not want to restrict the selected events to a window around the source position. Thus set a radius of 180 degrees. Use 100 bins for the spectrum. Press the OK to start the generation of the spectrum. As soon as the canvas appears, right click on the spectrum (make sure to really hit the drawn spectrum, not the filling and not the white area) and a context menu will appear (Figure 2).

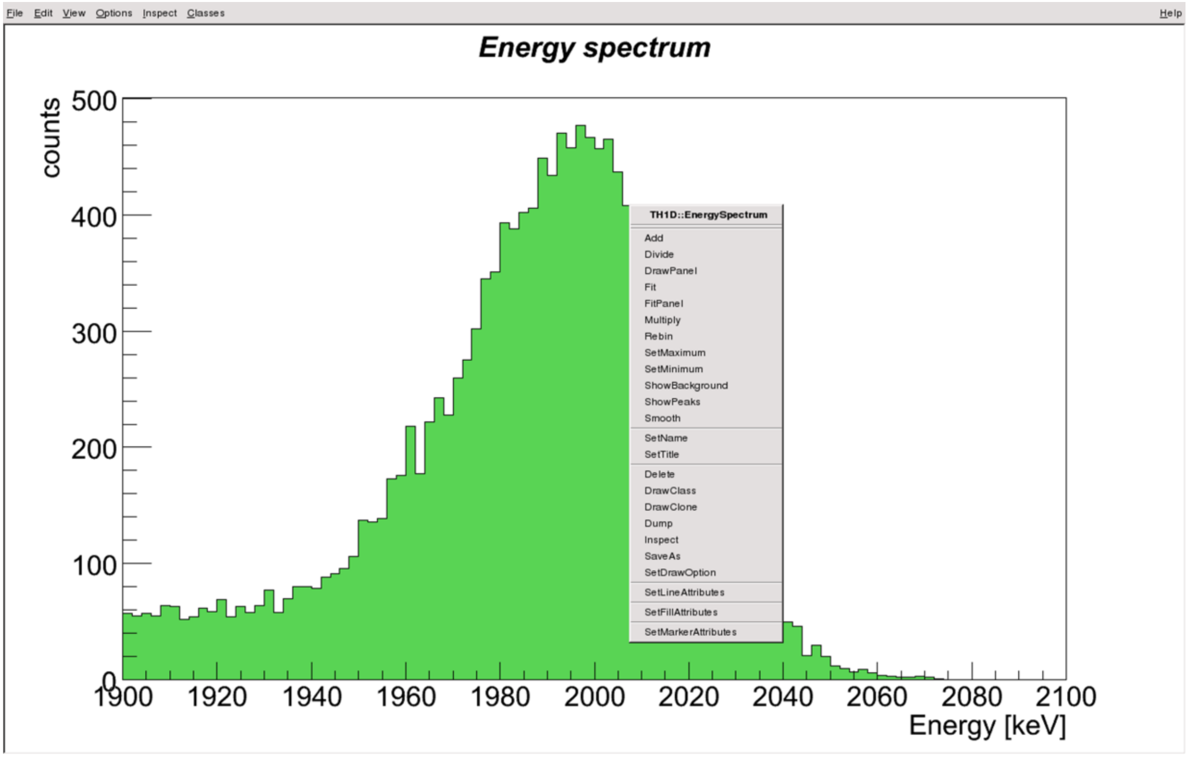

Figure 2: Energy spectrum with context menu: To get the menu, make sure to click on the black spectrum line, not the green fill area.

This menu is a default ROOT menu and gives you a lot of options. Take a look into the ROOT manual if you are interested in more information about the other options in the context menu. We are interested in the "Fit panel", thus right click on it:

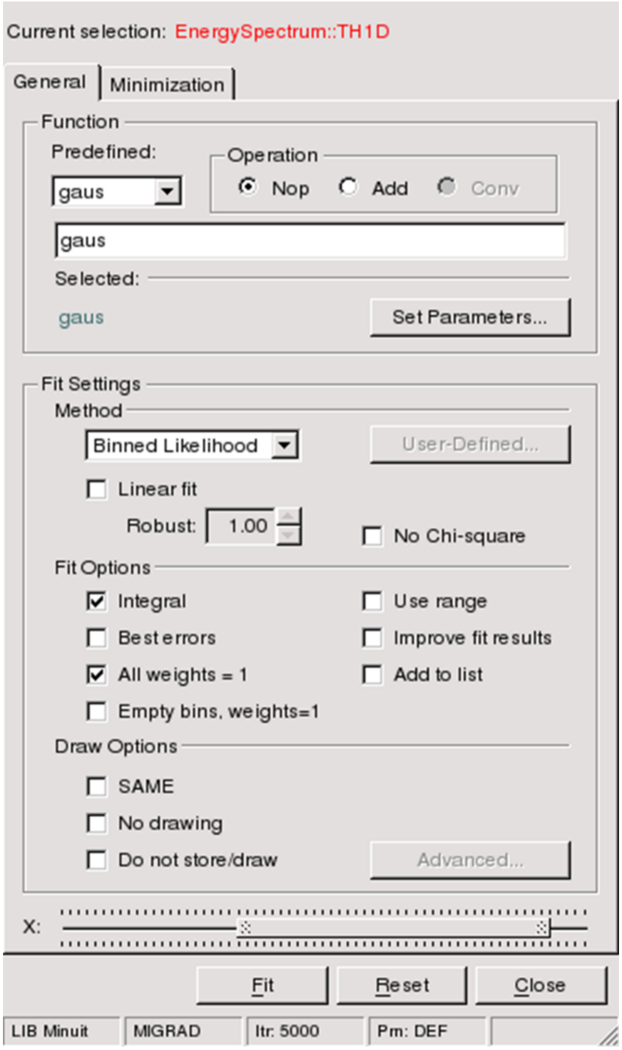

Figure 3: The fit panel: Make sure to select a Gaussian as fit function. In addition, in the fit options section, select "Integral" and "All weights = 1". Furthermore use the bottom slider to optimize the energy range on which the fit happens.

Make sure to select a Gauss fit, as seen in. In addition you might want to use the bottom slider to restrict the fit to the area around the peak (e.g. move the left slider to ~1975 keV). See the ROOT manual for all the other fitting options. After clicking “Fit” the Gauss fit should appear in the histogram, along with the fit parameters dumped to the console. Look for the number after “3 Sigma” to get the 1-sigma energy resolution of the telescope, which is in this case ~21 keV.

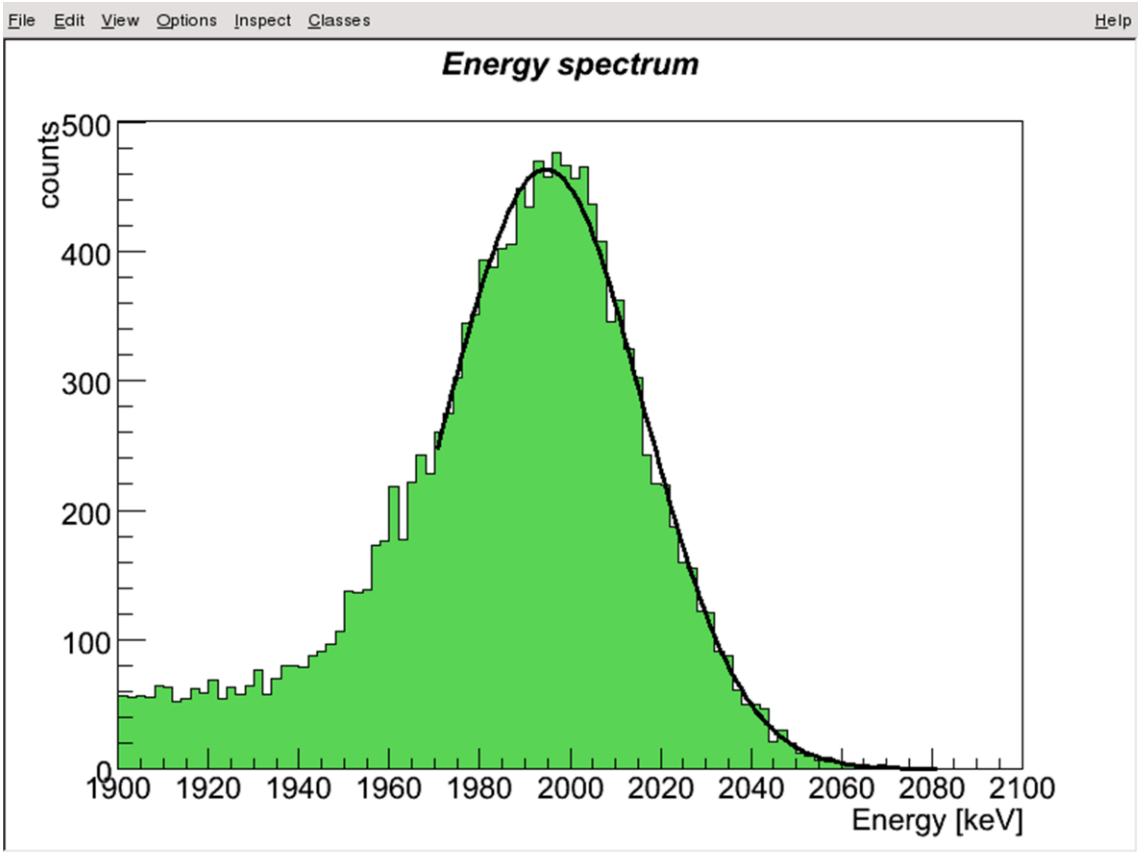

Figure 4: That's how the final gauss-fit should look like.

Determine the angular resolution (ARM) of a point source

Now we want to determine the angular resolution for the events in the photo peak. We begin be setting the energy window in the event selector to a +-2 sigma interval around the known input energy. In out case the energy window is 1958 – 2042 keV.
The chosen example is for a point source in the far field (i.e. at infinite distance, thus you get a plain wave). When you are in the near field please make sure to set the correct coordinate system via Mimrec's Coordinate system GUI (2D or 3D Cartesian) before you continue. This will give you the option in the ARM dialog window to choose the position in Cartesian instead of spherical or Galactic coordinates.

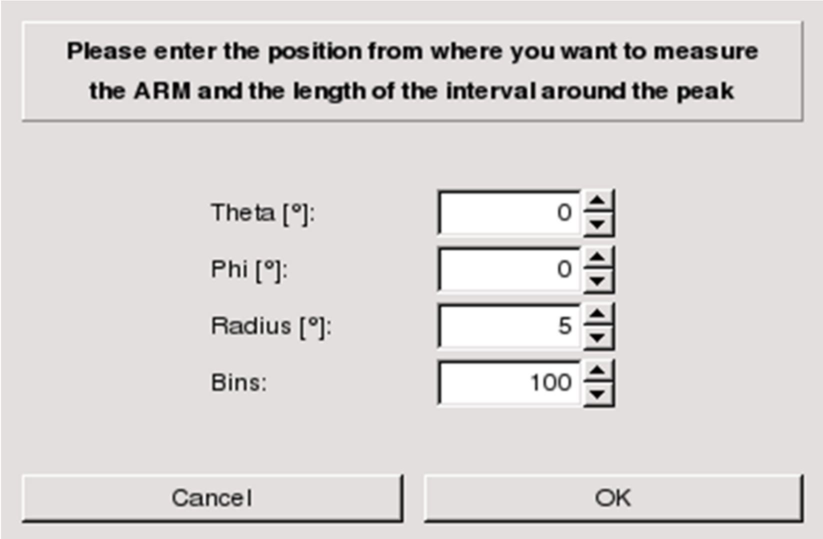

Figure 5: ARM dialog: Select the correct source position theta and phi, as well as the radius around the source position, which is large enough to cover the whole ARM peak.

In the ARM dialog window (see Figure 5) select the correct source position: in our case the source in the zenith, i.e. theta and phi are zero. The Radius around the source position should cover the whole ARM peak, but not too much else to give a good ARM fit. In our case 5 degrees is a good choice. The chosen number of bins is 100. Then click OK.

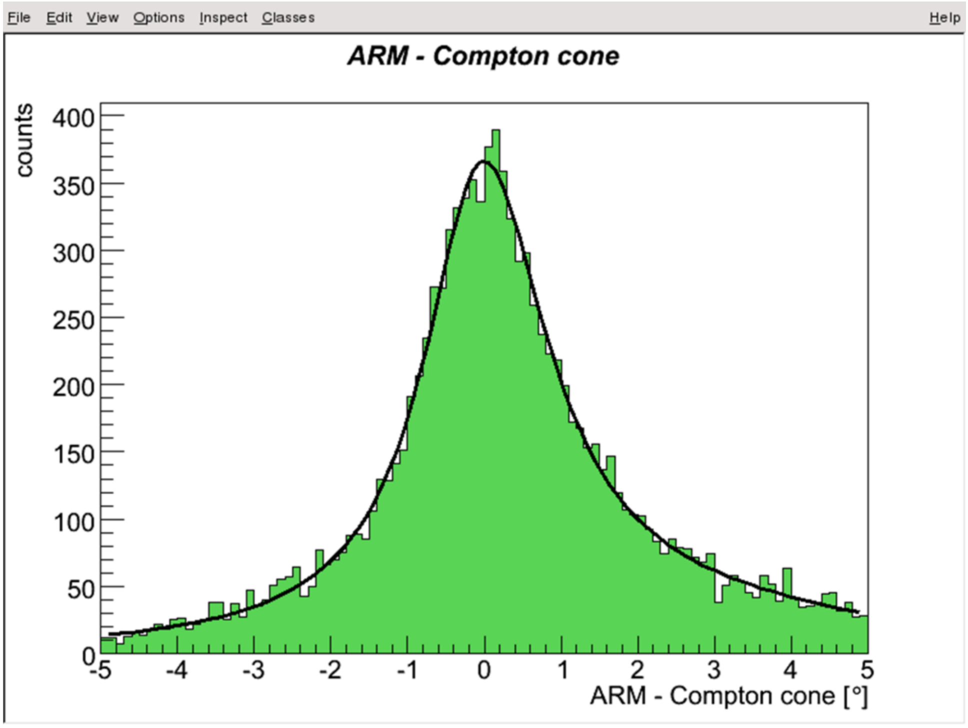

Figure 6: ARM distribution with a fit

The ARM spectrum with a fit should appear. The fit function consists of two Lorentz-functions and one asymmetric Gauss (right and left wing can have different sigmas). The FWHM of the fit is printed on the console. In this case the width should be around 2 degrees.
In some cases the fit may fail. Then try to make the radius larger or smaller, or change the number of bins.

Determine the effective area of the telescope

The effective area A_{eff} is defined in the following way:

$$A_{eff} = A_{start} \frac{N_{measured}}{N_{started}}$$

Here A_{start} is the area from which the photons are started. For simulations with Cosima the start area is defined by the surrounding sphere (see Cosima or Geomega manual), which can be found in the geometry file. For the given example look for the keyword **SurroundingSphere** in the file "mpesatellitebaseline/Satellite.geo.setup". It is the first number: r=50 cm. Since this is the radius of the sphere, the start area is $A_{start} = \pi \cdot r^2$.

The number of started photons can be found in the simulation file: Look at the last event. Find the **ID** keyword. The second number is the one you look for. Its value should be around ~3,460,000.

For the number of measured events we want the number of events with the above chosen 2-sigma energy window, and a 1-FWHM window around the source position. To determine the later, redo the angular resolution step, but now use the previously determined FWHM (e.g. 2.0 degree) as "Radius" in the ARM dialog. After running through your data, mimrec will dump the number of photons within the ARM window to the console ("Compton and pair events in histogram"). In our case we have 8486 photons.

Thus finally we get an effective area of 19.3 cm^2 for the chosen event selections.