New Analysis methods for stereo

Project *16*

A “new” analysis method for stereo data

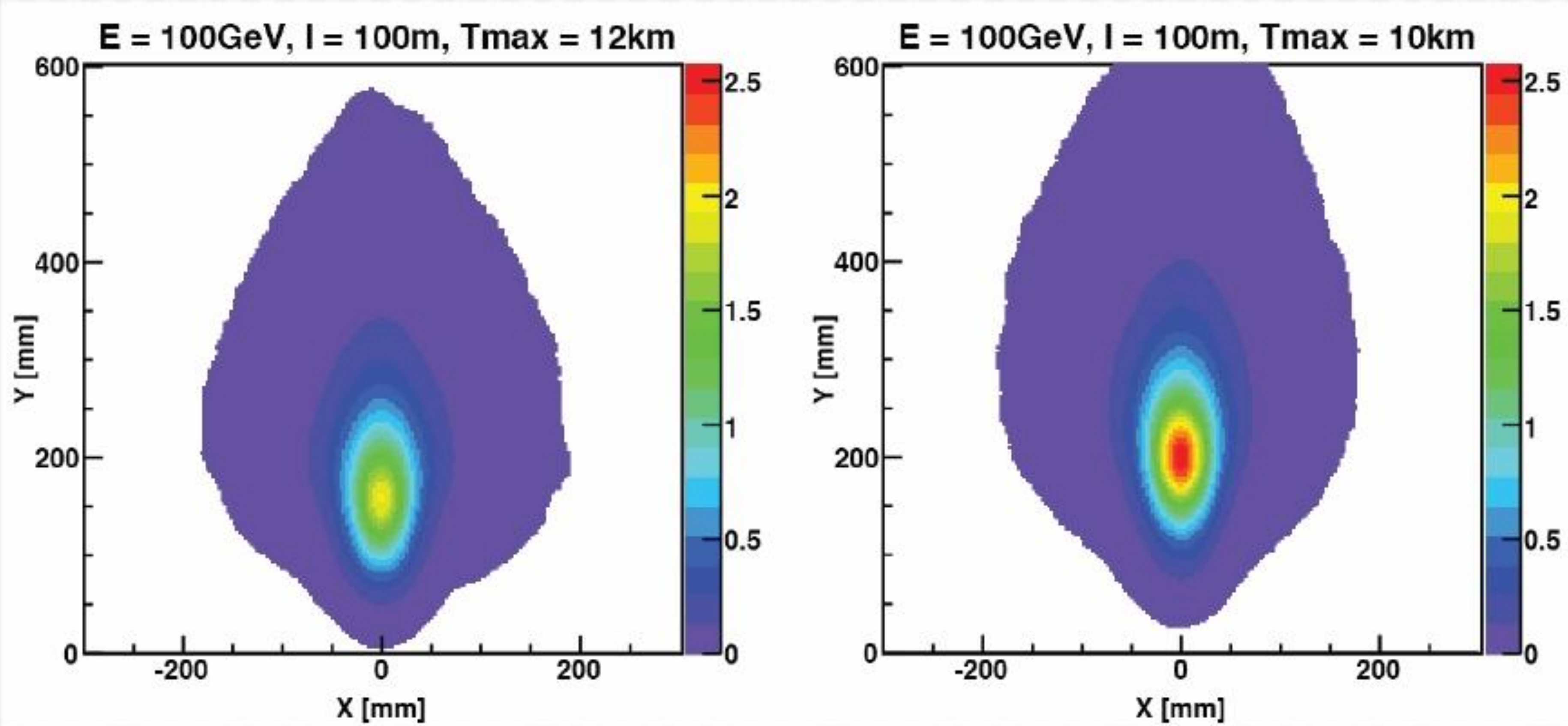
Already known approach: Model analysis

- Pioneered by CAT
- Picked up by H.E.S.S. -> Daniel Mazin tried implementation for MAGIC
- First iteration already showed improvements compared to standard Hillas analysis
- New and improved version by H.E.S.S. collaborators is vastly superior to the Hillas analysis
- Improves sensitivity by factor of 2
- In total H.E.S.S. I now needs *16 times* less observation time than MAGIC 1.5!!!
- Ergo: We are lost ☹

Model analysis – general idea

- Overlay several simulated shower images to get an "average" signal distribution in a "perfect" camera (infinite resolution)
- Advantages in MAGIC: We can use the timing additionally, our pixels are very small – we have a good resolution of the shower images
- Problem: outer large pixels in M1 have to be taken into account properly, in M2 large electronic noise

Shower maximum



clear differences: Tmax binning needed!

Im
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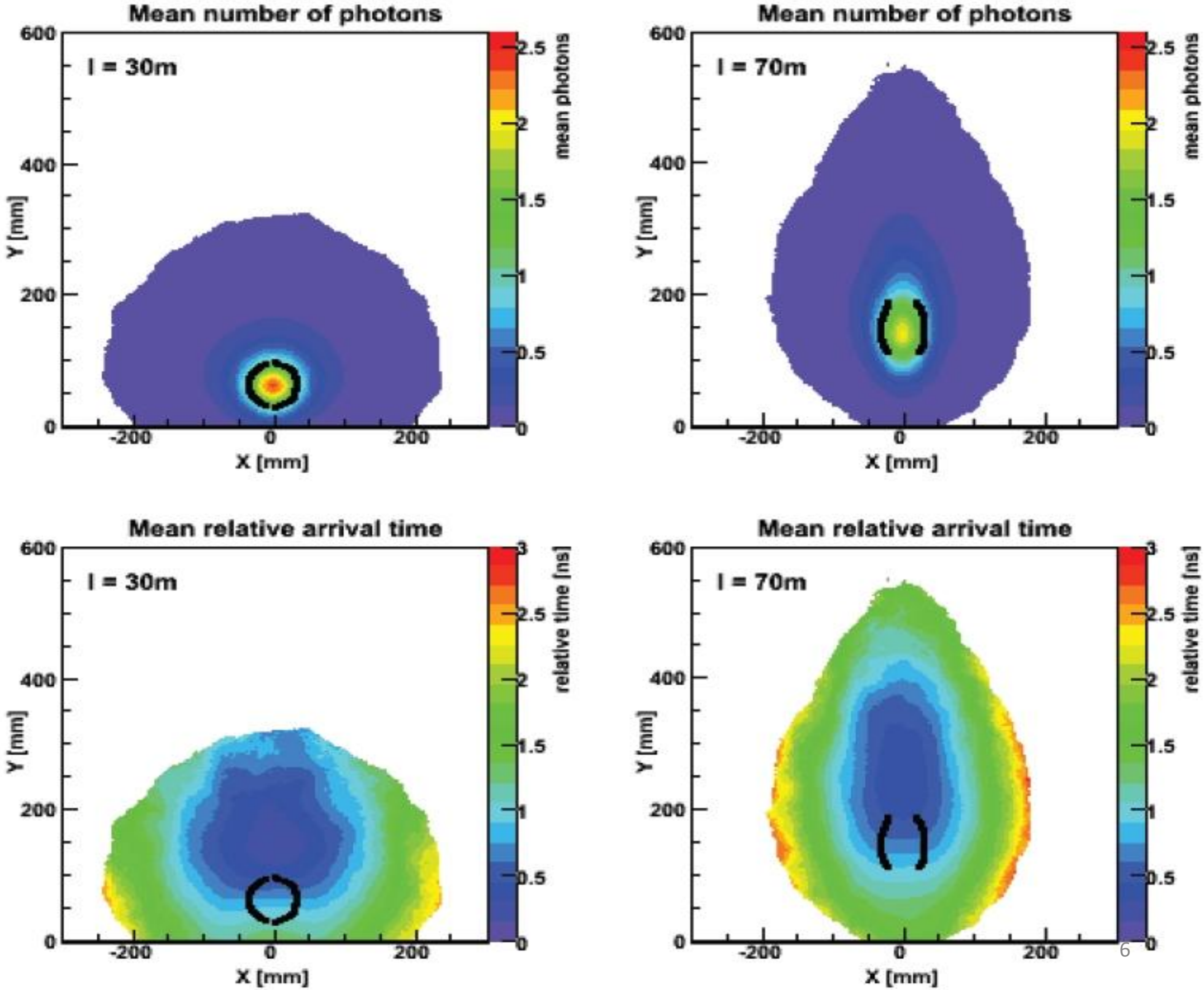
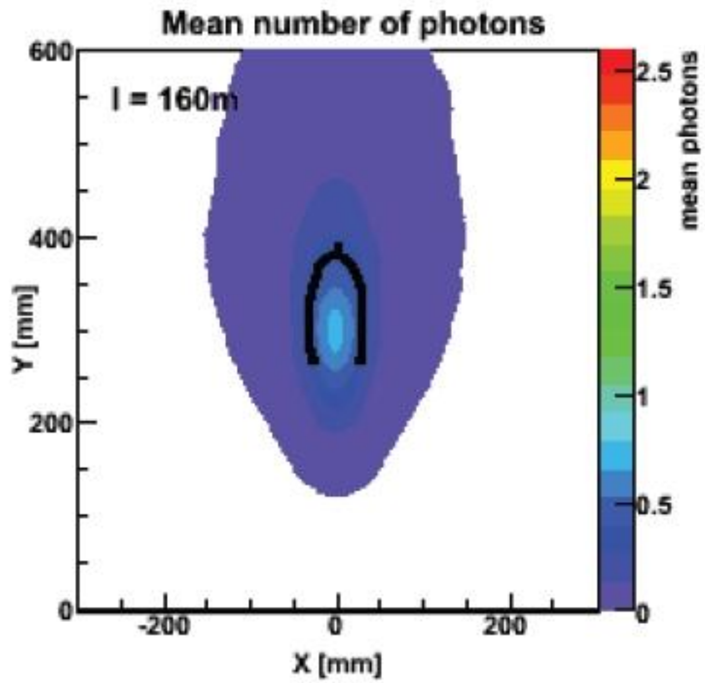
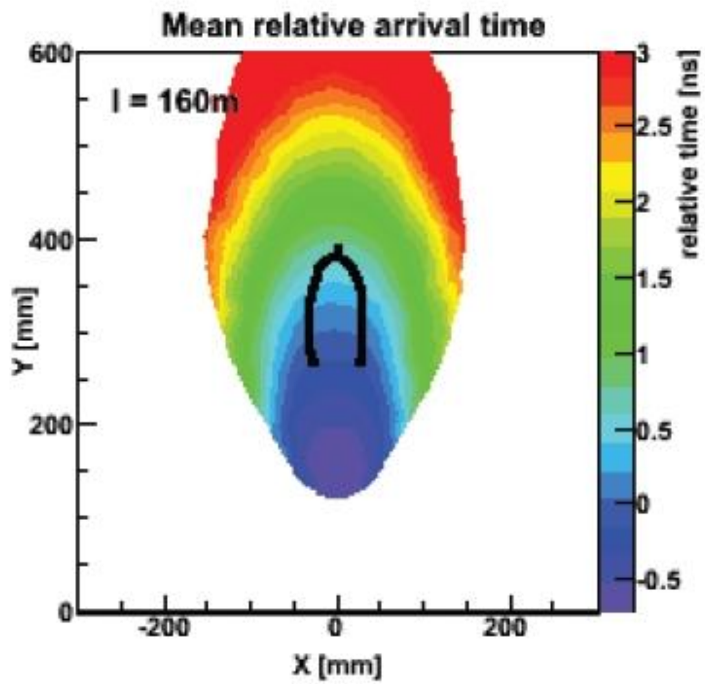
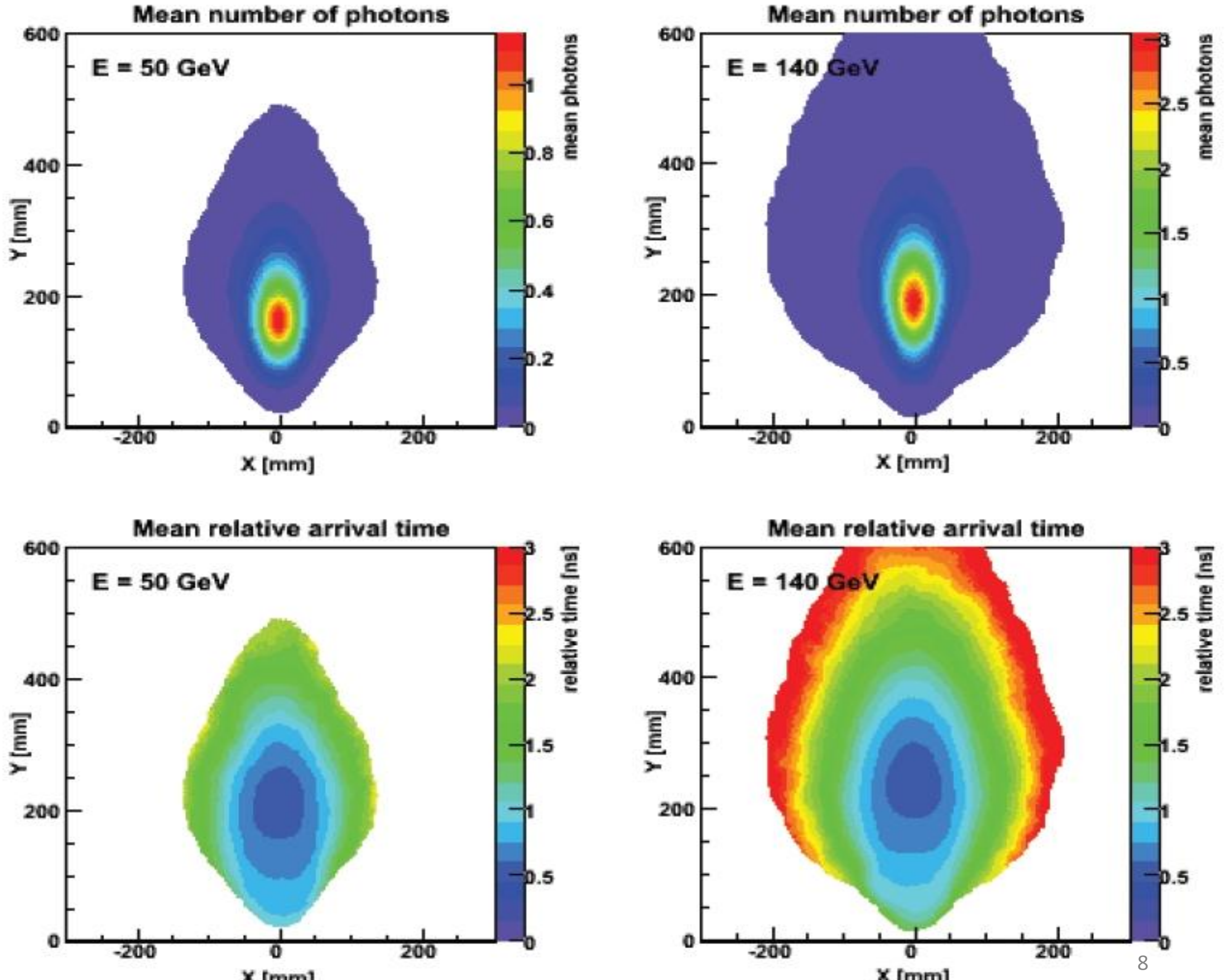


Famous Cherenkov “bump” at 120m: maximum number of photons
Beyond 160m shower fades and spreads out quickly -> sumtrigger would be very useful here!!!





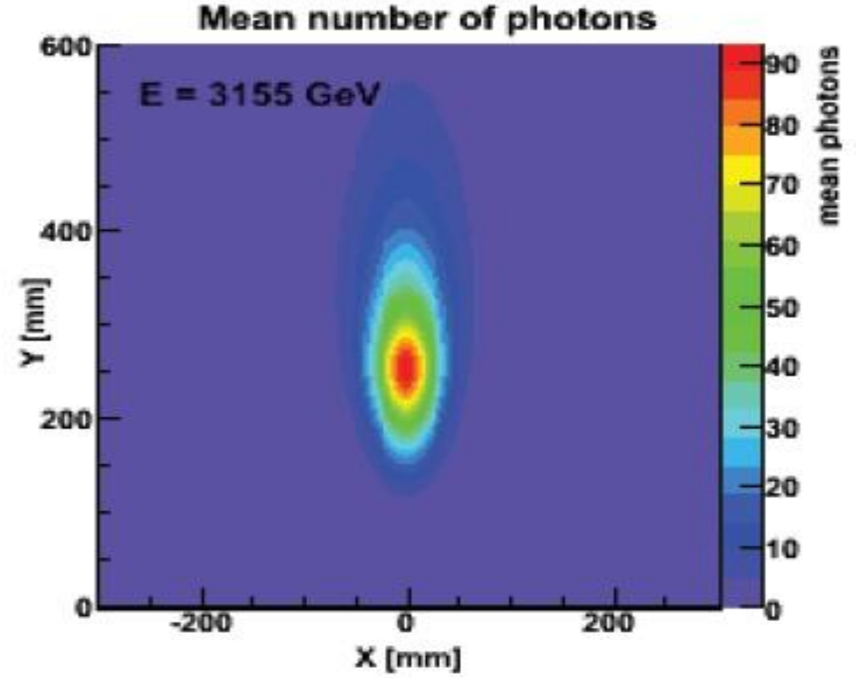
Energy dependence

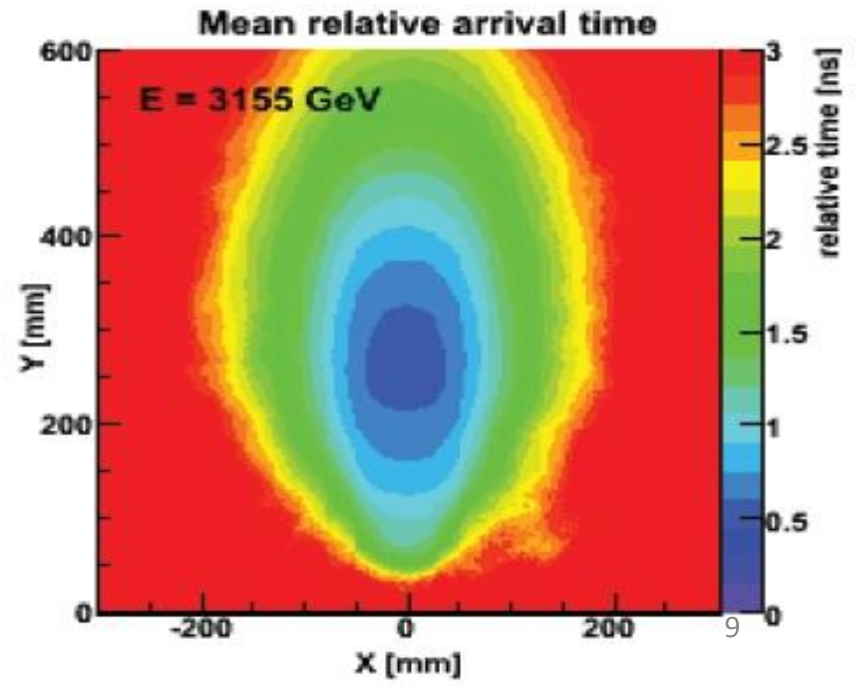


As expected higher energy γ-rays produce more signal in the camera (at same impact) and accordingly more pixels can be used!

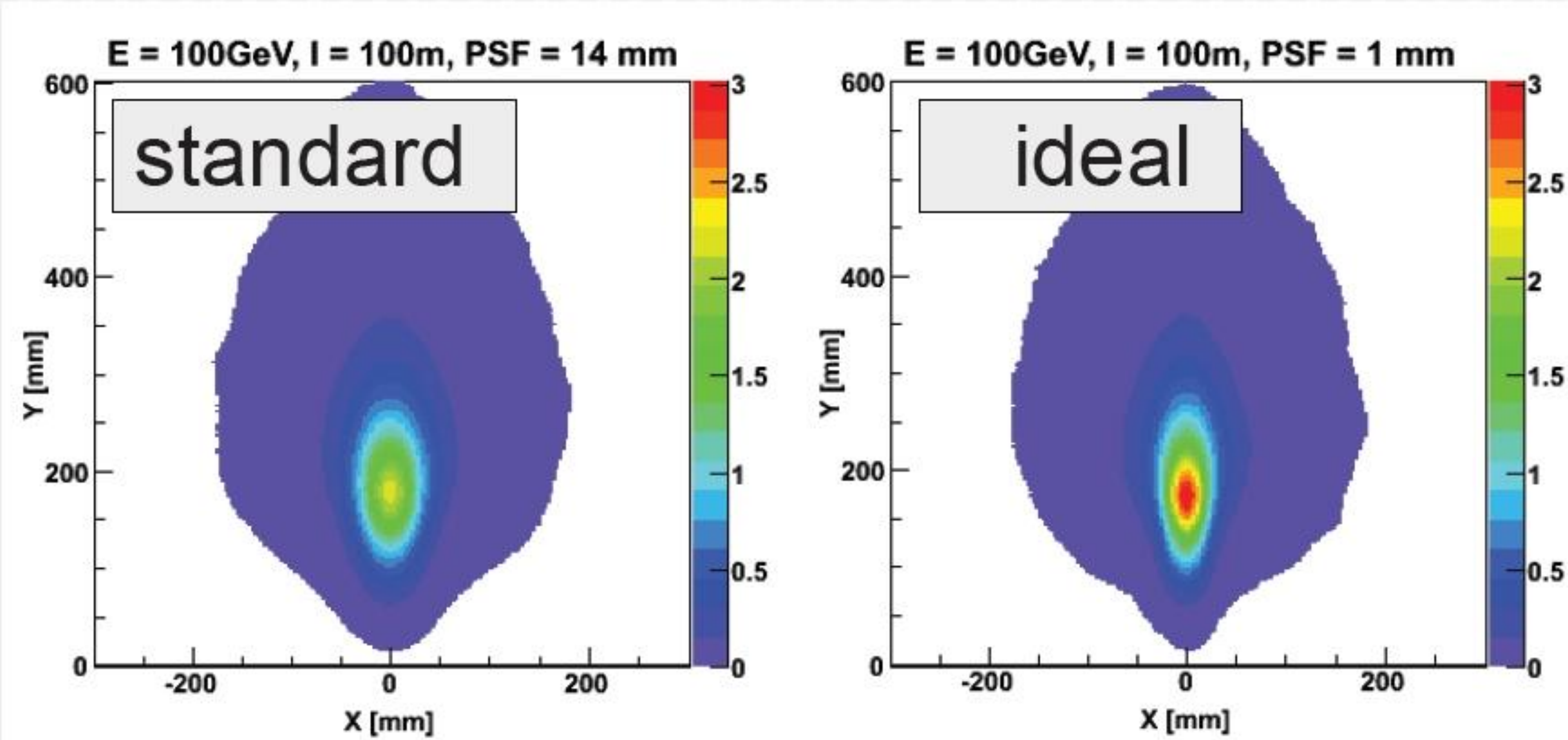
Higher energy showers move outwards in the camera (different Tmax)

Different Impact parameters make energy identification difficult for a single telescope!!!



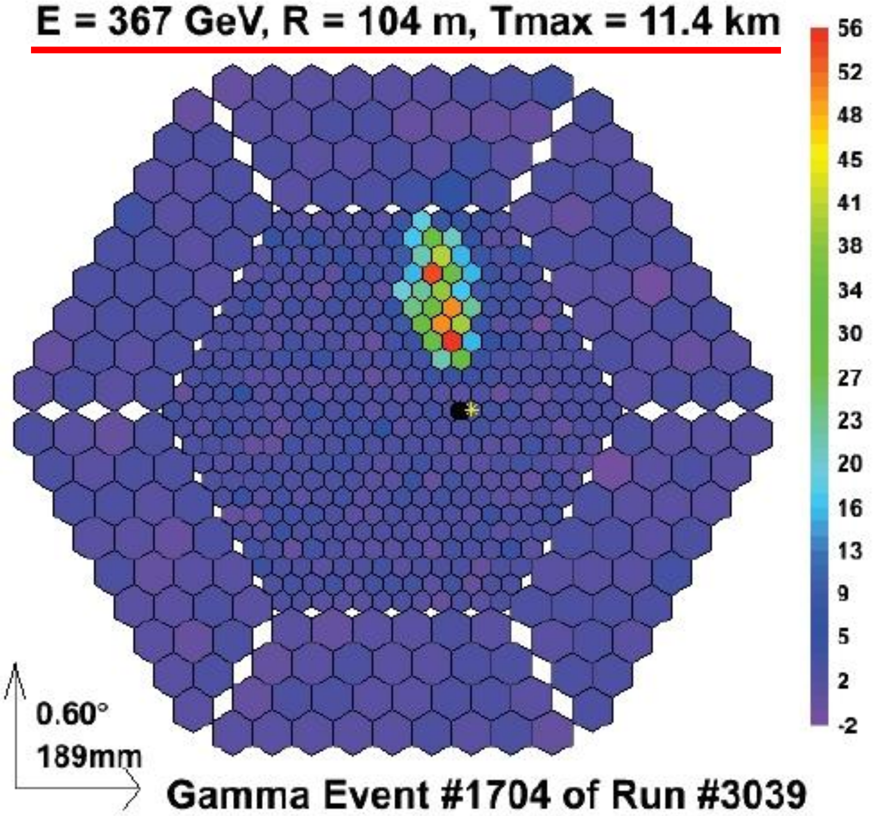


Point Spread Function

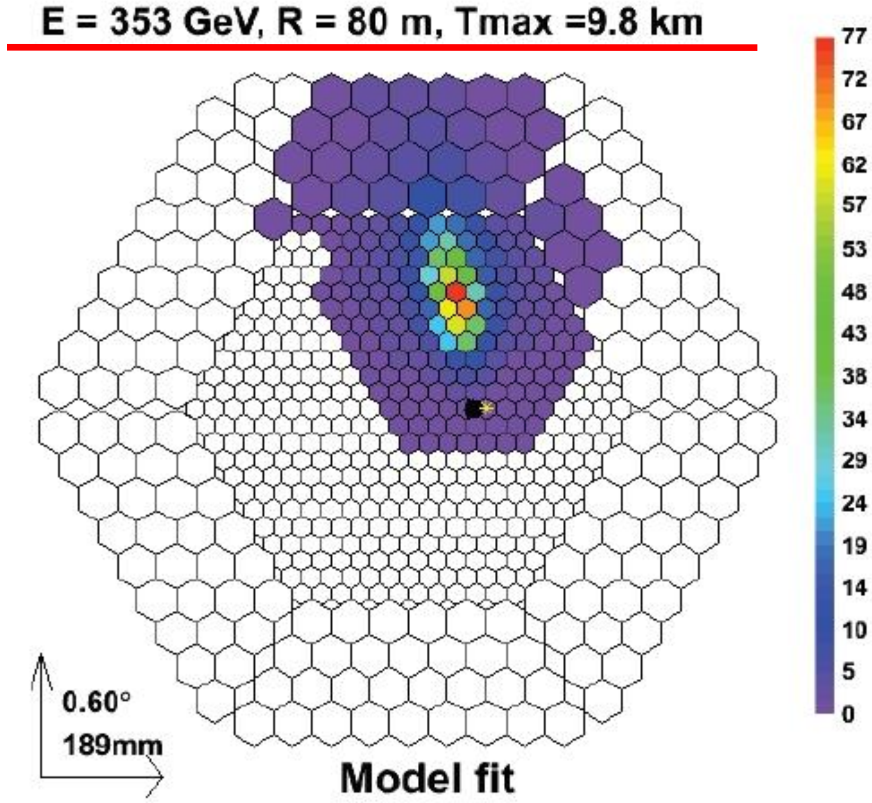


40% less charge in the center!

Fitting example (wobble)

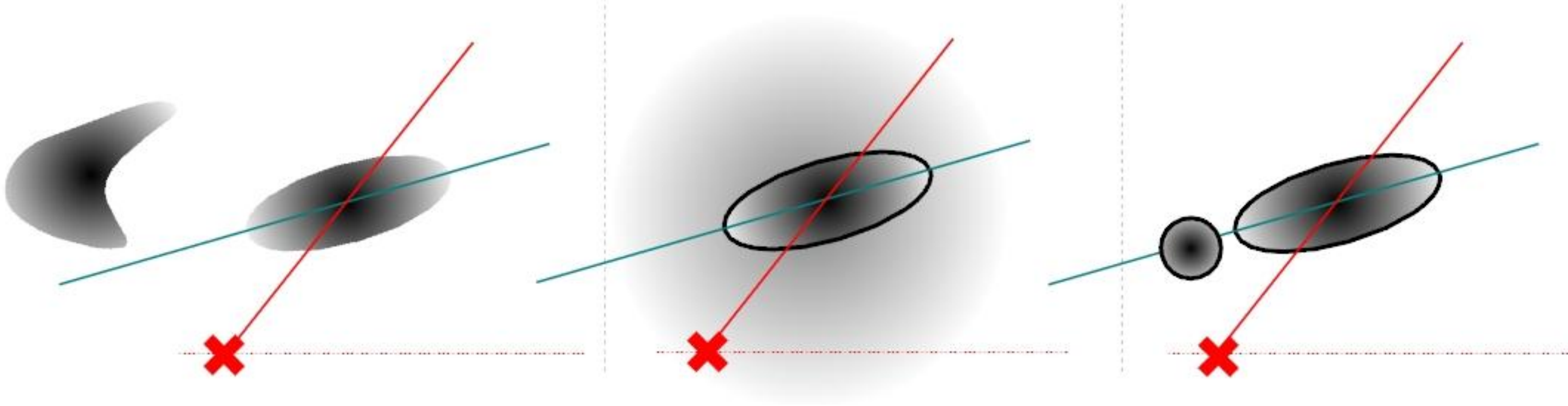


mc γ-event



template

Model analysis – what is it good for?



Islands | Cherenkov rain | Direct Cherenkov light

- Usage of ALL camera pixels allows to check for small islands, Cherenkov rain or direct Cherenkov light (here the timing is again important!) -> shower goodness (pixels belonging to the shower) and background goodness (pixels outside the shower)

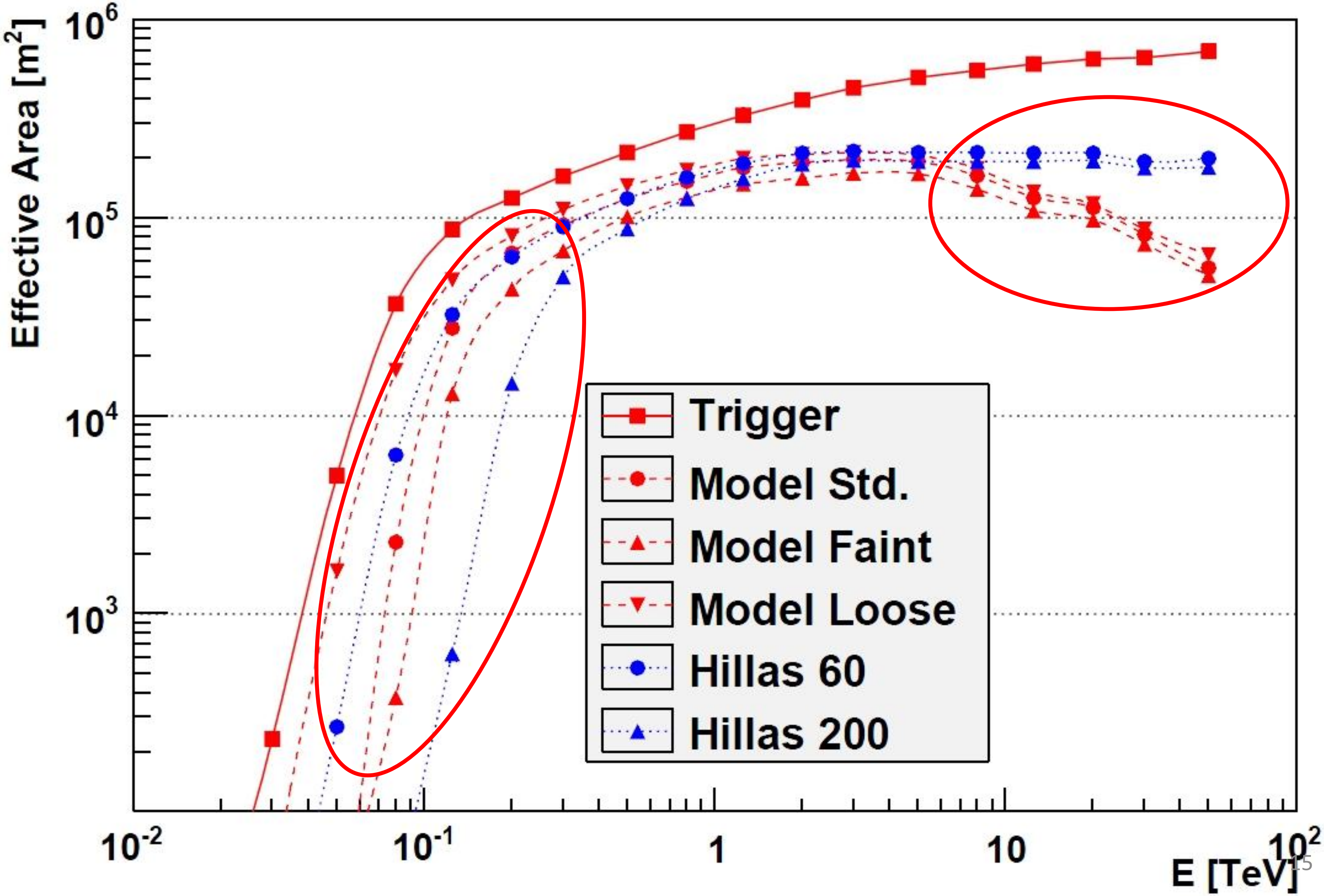
Results? Improvements? Many!

- Testing on real data -> samples with large significance (PKS 2155 and Crab)
- This is the way to do it!!! Any improvement should show up $>5\sigma$! Otherwise it may just be a fluctuation
- They get 100σ improvement! Very significant...
- We can check e.g. on Crab and Mrk421

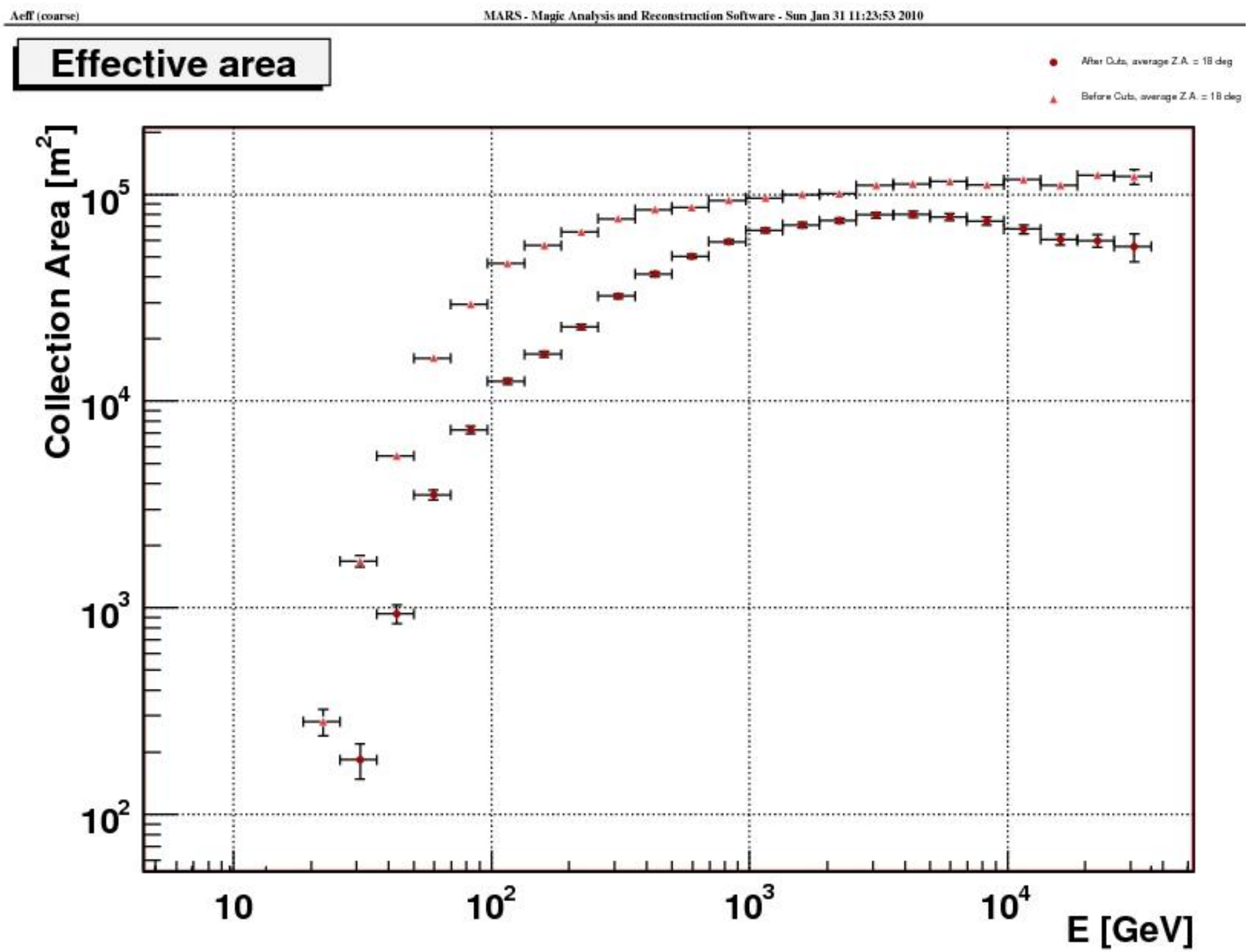
Results? Improvements? Many!

Data Set	Analysis	ON	OFF	$1/\alpha$	γ	σ	S/B
Crab Full	Hillas 60	12768	26154	16.2	11148.6	162.6	6.9
Crab Full	Hillas 200	3742	1435	16.9	3657.1	125.0	43.1
Crab Full	Model Std	10249	3848	18.2	10037	210.7	47.3
Crab Full	Model Faint	5920	1605	25.8	5857.7	176.8	94.0
Crab Full	Model Loose	20107	22137	16.7	18782.3	244.3	14.2
PKS Flare	Hillas 60	24964	7025	10.9	24320.4	302.1	37.8
PKS Flare	Hillas 200	5148	490	12.7	5109.3	153.9	132.1
PKS Flare	Model Std	24388	1303	12.7	24285.4	342.9	236.7
PKS Flare	Model Faint	11047	427	18.1	11023.4	248.1	466.5
PKS Flare	Model Loose	38308	3676	11.0	37972.7	407.2	113

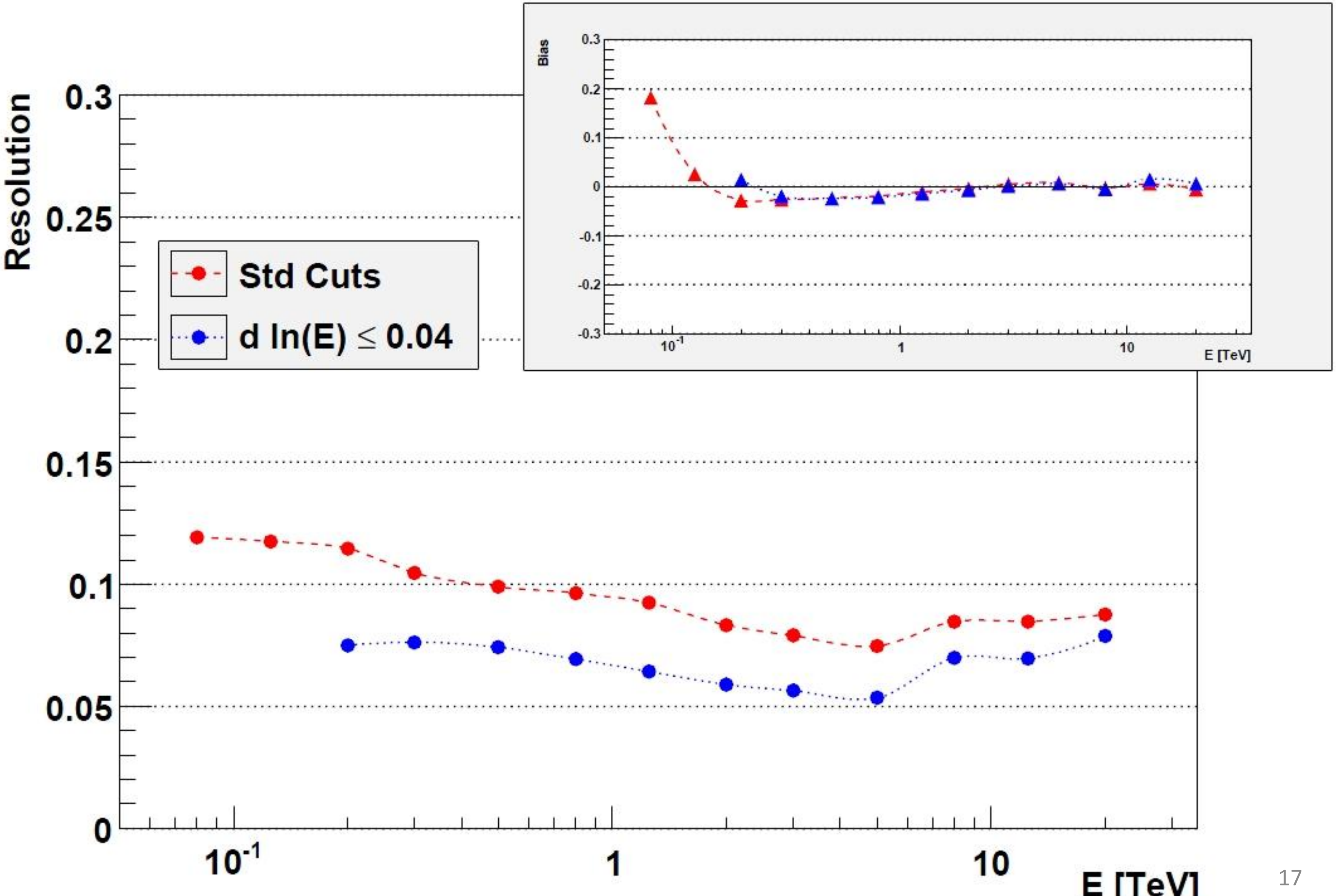
Effective area



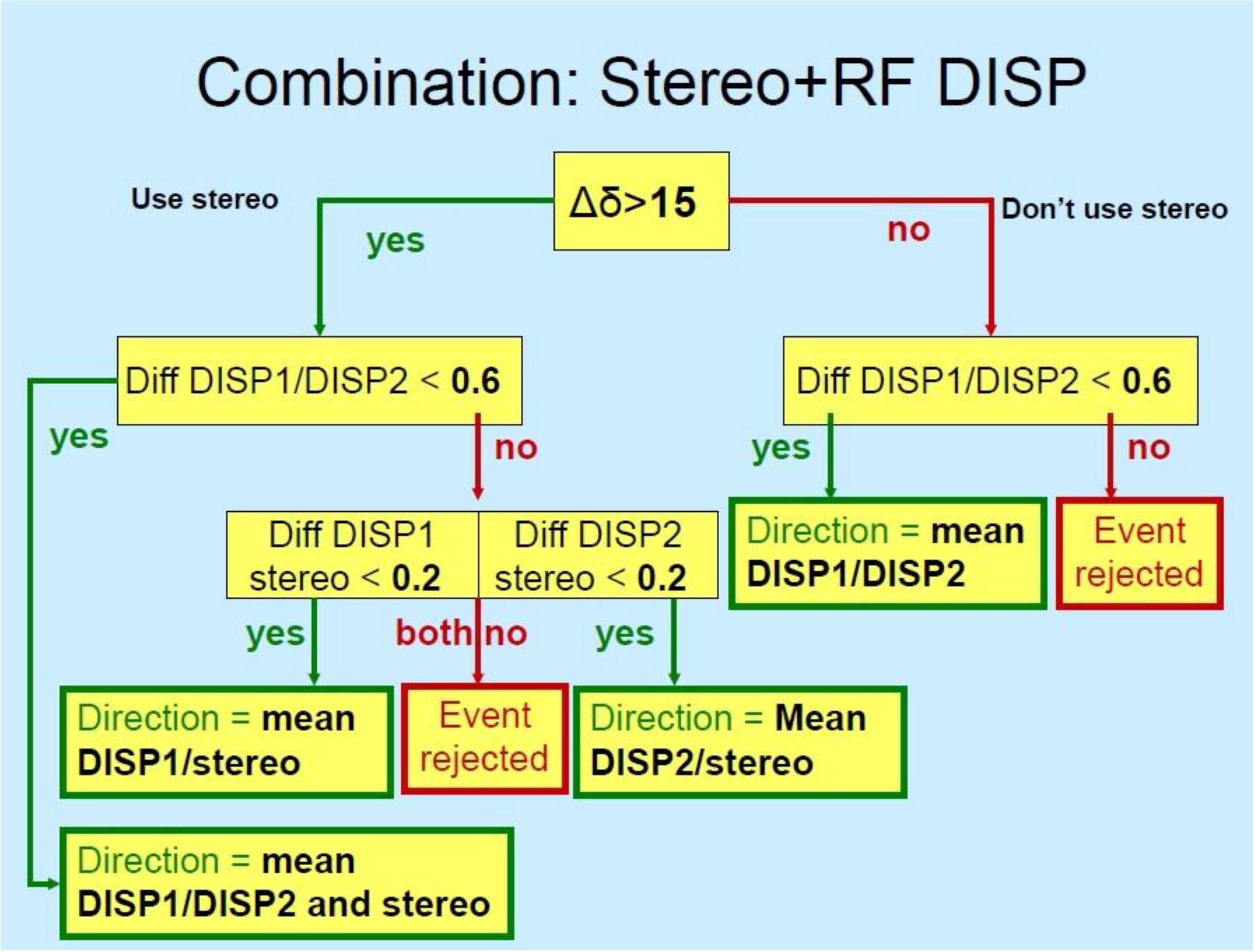
Effective area: MAGIC stereo



energy resolution “golden events”

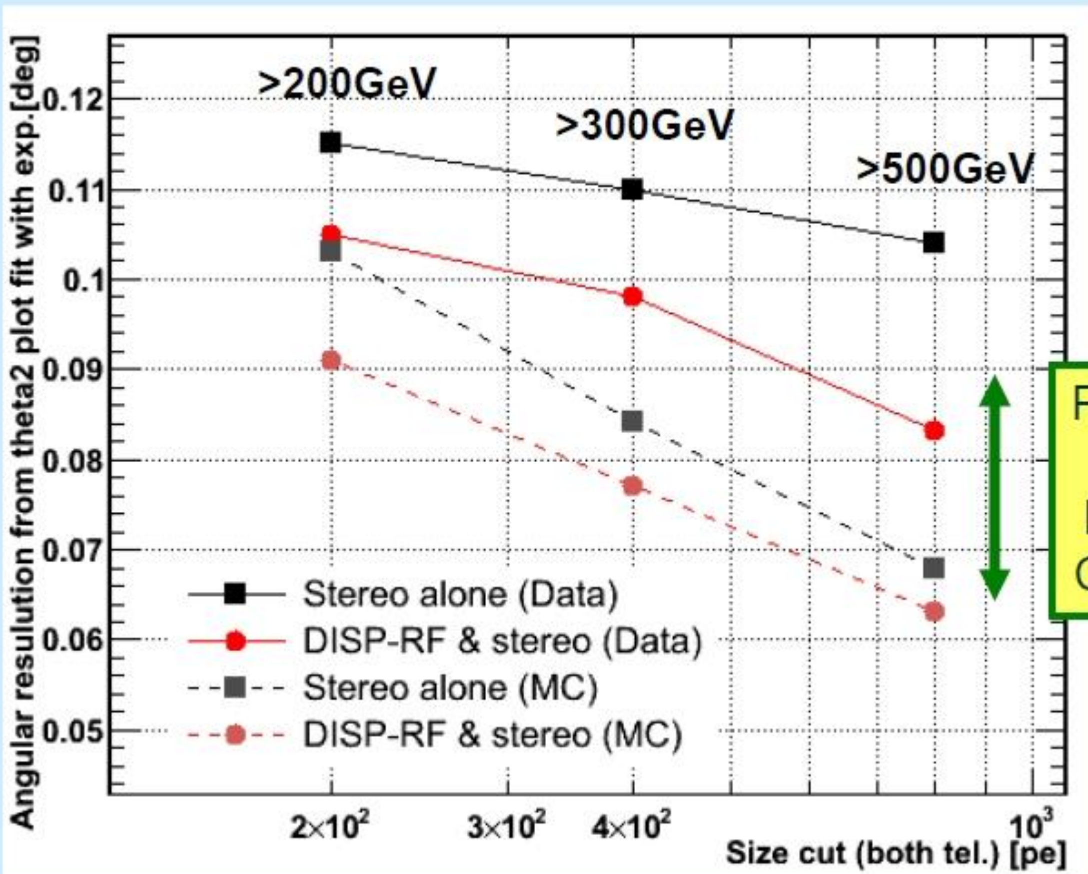


MAGIC stereo angular res.



MAGIC stereo angular res.

Comparison with simulation



Angular resolution
From crab is worth
Than expected.

Pointing uncertainty?
(σ =0.05)
Larger optical PSF?
Calibration problem?

Energy bias sumtrigger

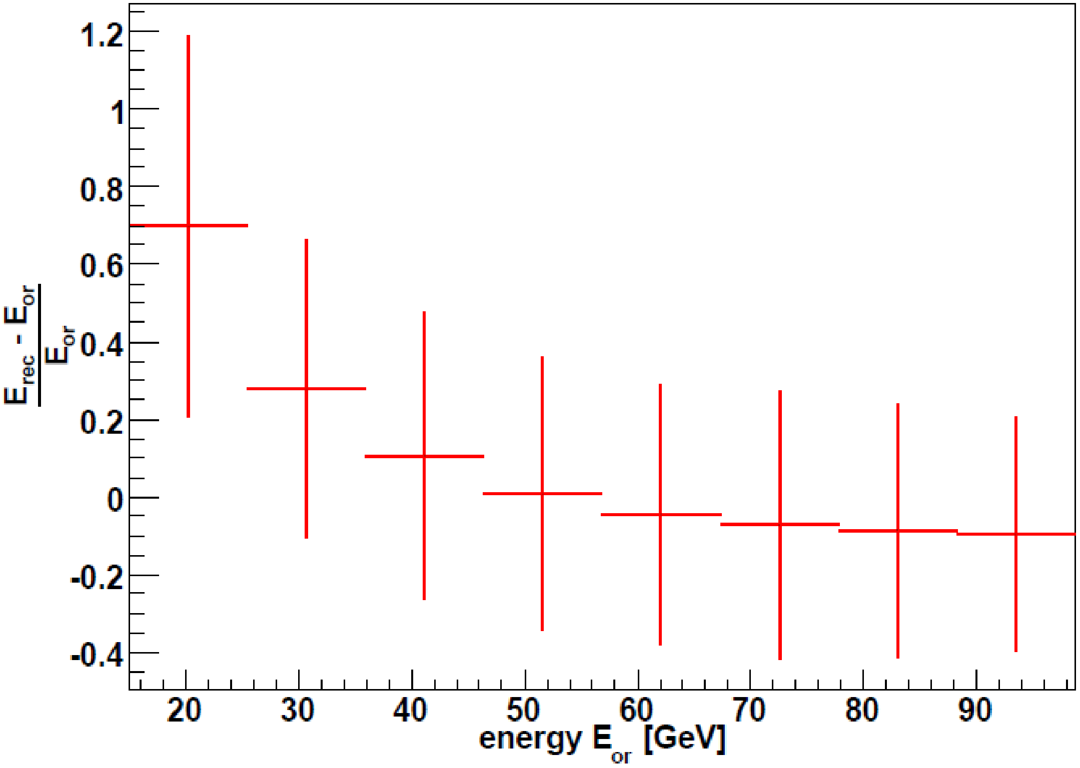


Figure 6.24: The bias of the reconstructed energy between 15 – 100 GeV.

Energy res. sumtrigger

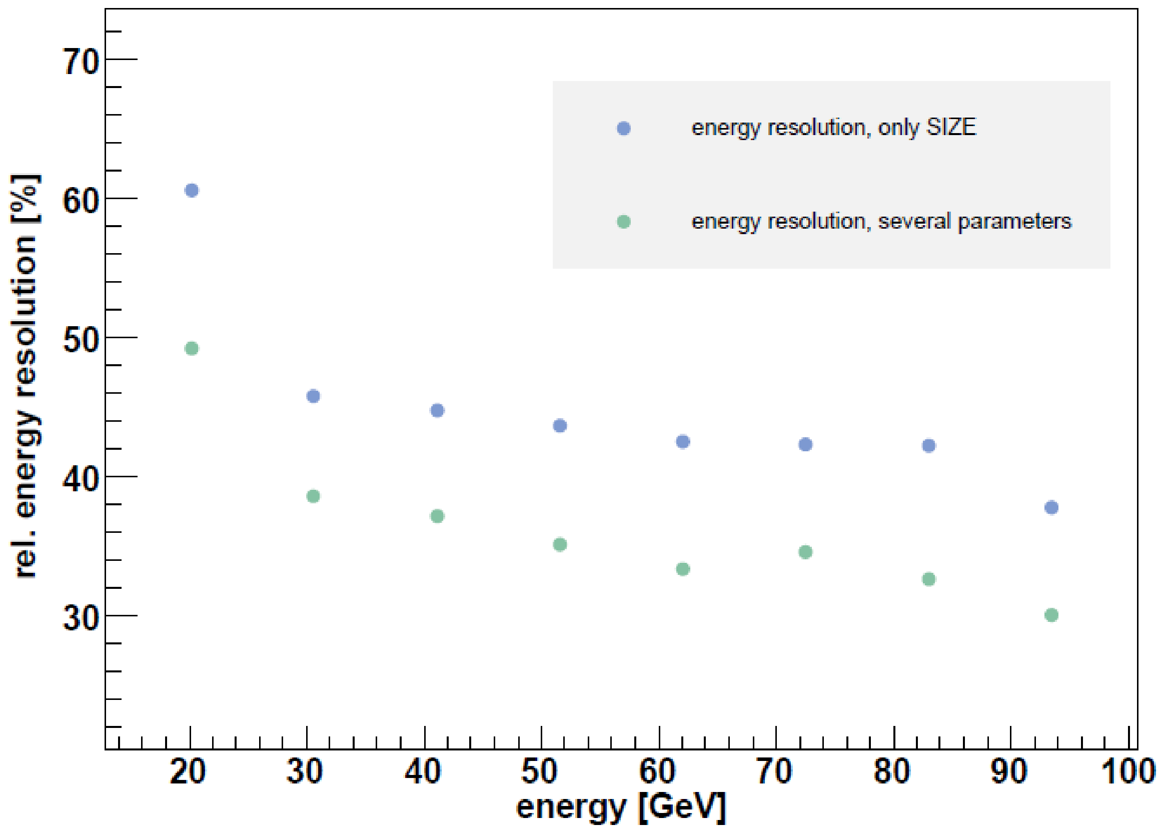
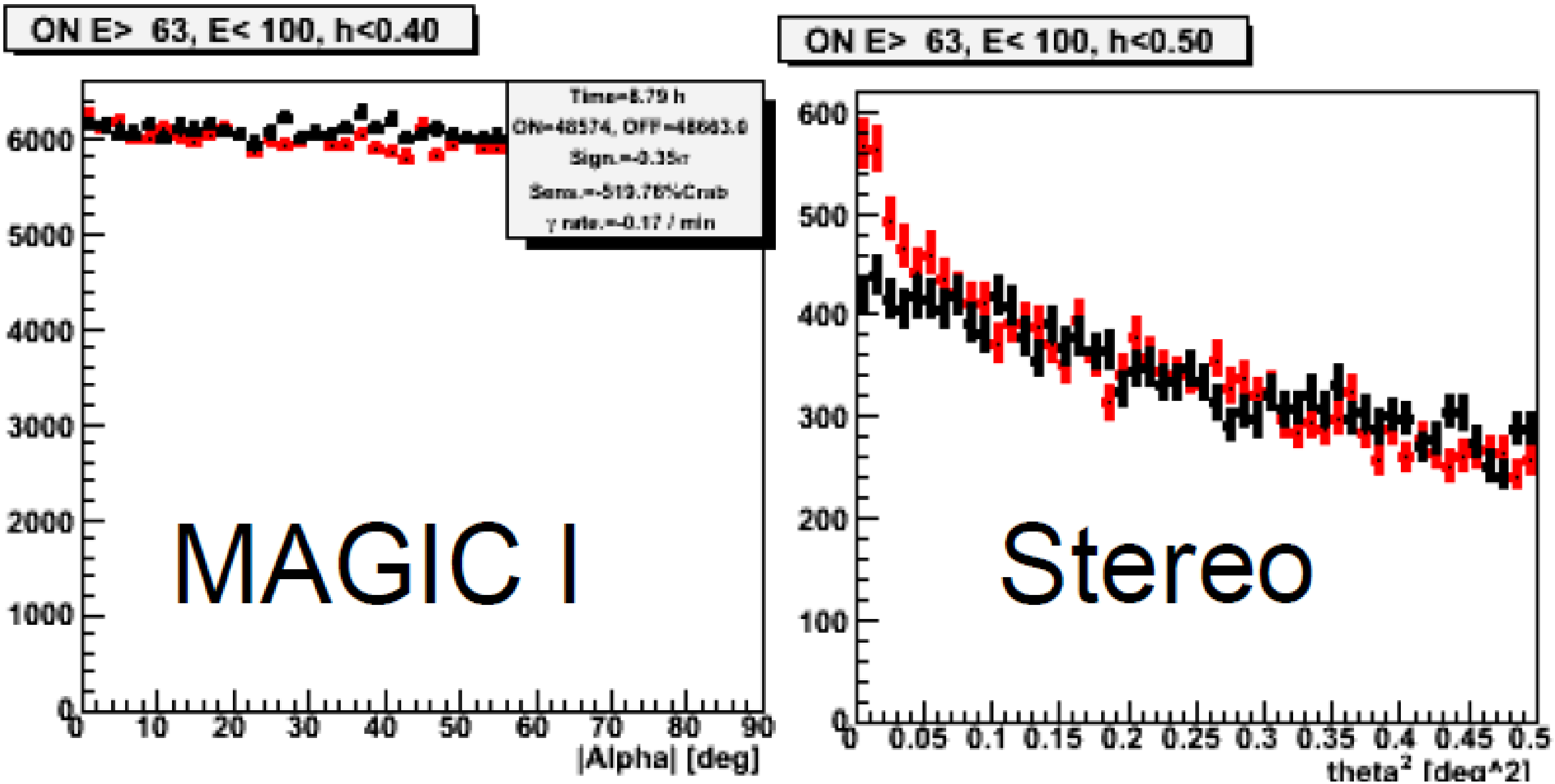
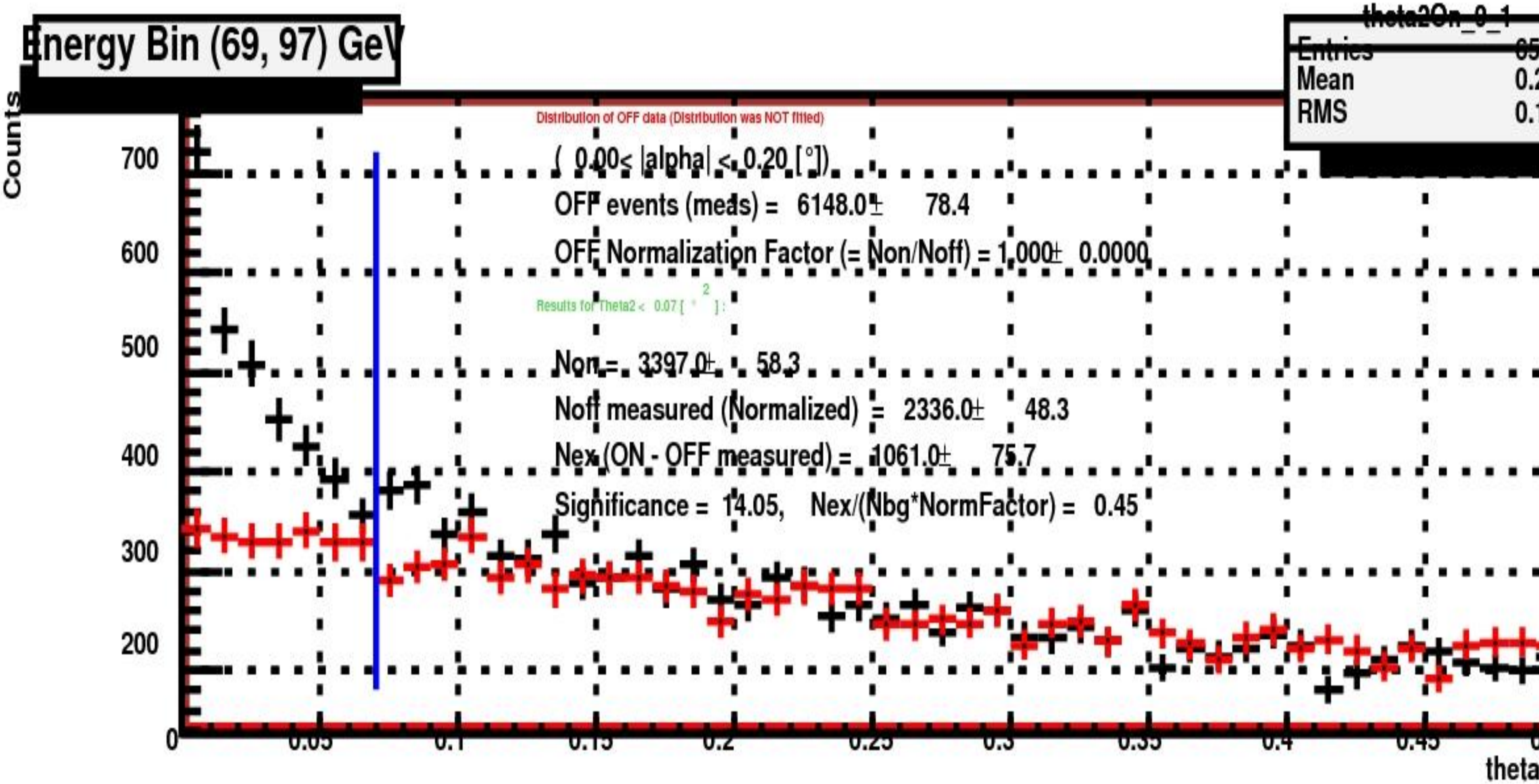


Figure 6.25: The energy resolution at low energies. The energy was estimated using only SIZE (blue circles), or with additional parameters denoted in the text (green circles)

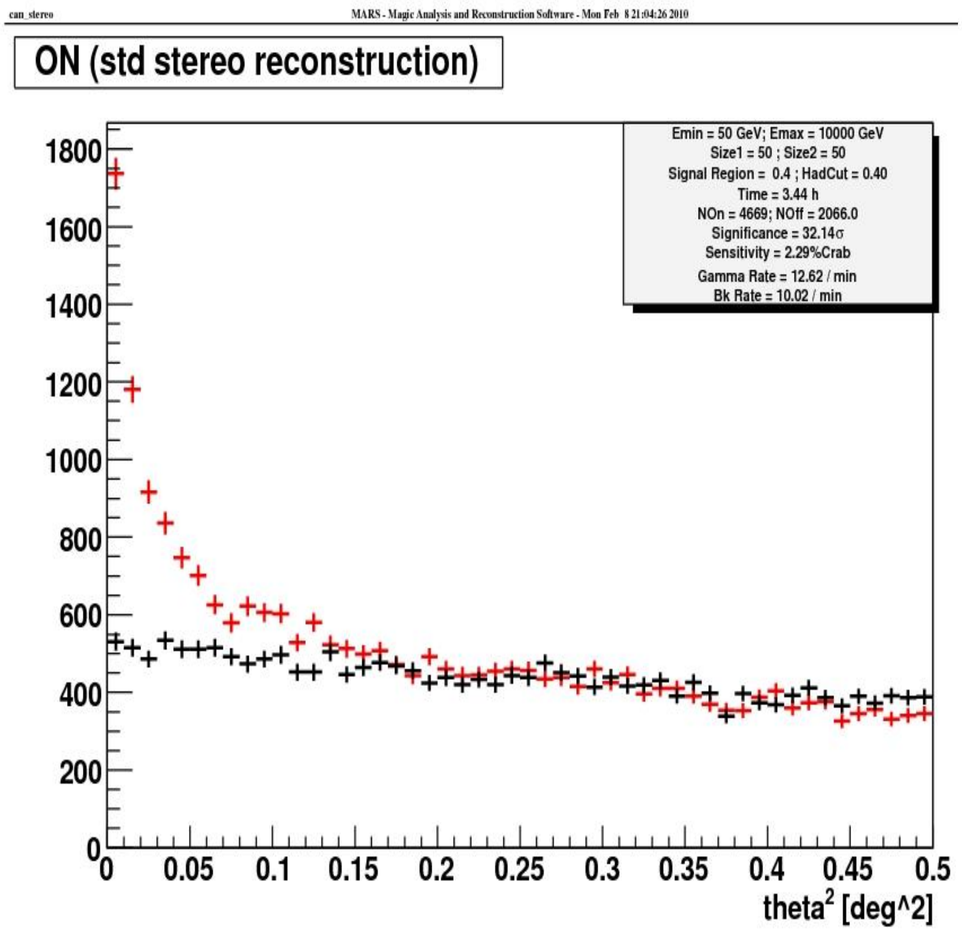
Improvements at E<100GeV

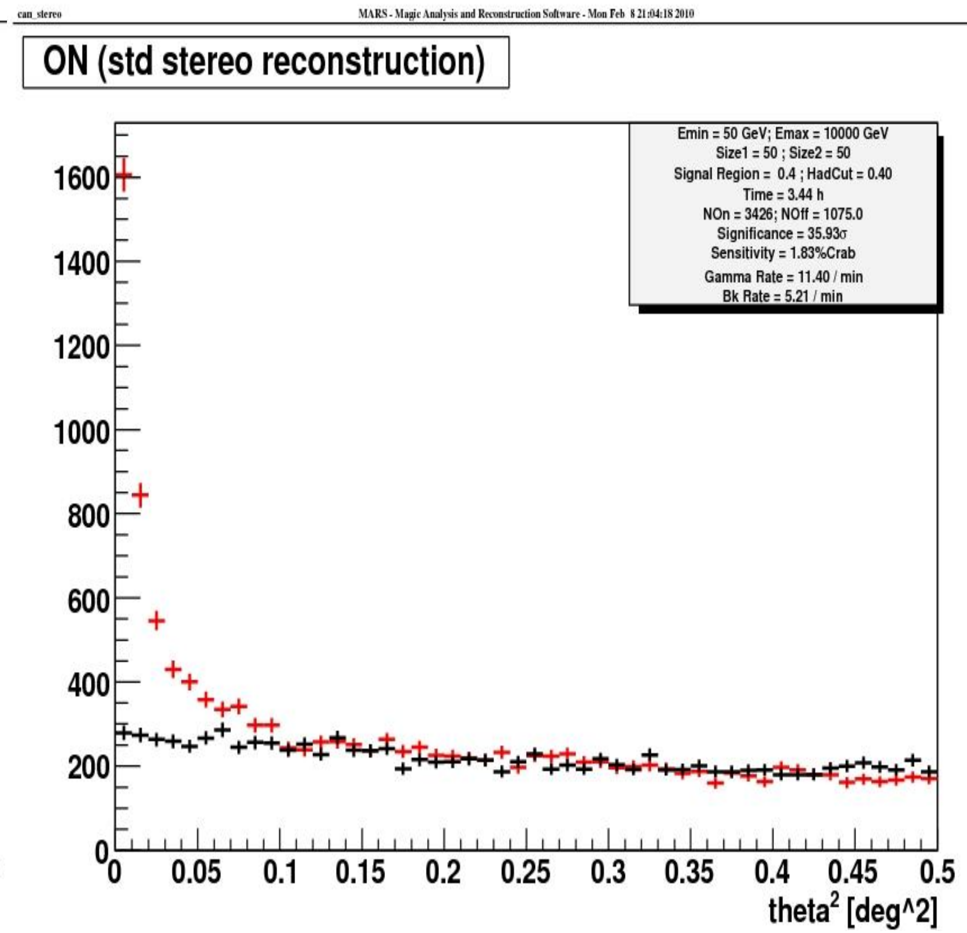


And it adds up…



Stereo DISP also improves background impression





Auto Correlation function

A.1 General Idea

Assuming that the NSB causes Poissonian signal fluctuations in a PMT, one wants to distinguish these signals from the ones caused by the shower itself. A robust method to do so is the image cleaning algorithm, described above in section 4.4.2. This algorithm, however, removes not only NSB fluctuations, but also the small signals coming from subshowers. Assuming that these subshowers are correlated in time with the main shower, I used the autocorrelation function $A_f(x, y, t)$ to identify those. For a given function $f(x, y, t)$, its autocorrelation function $A_f(x, y, t)$ is defined as:

$$A_f(x, y, t) = \int\int\int f(x + x', y + y', t + t') \cdot f(x', y', t')\, dx'\, dy'\, dt' \tag{A.1}$$

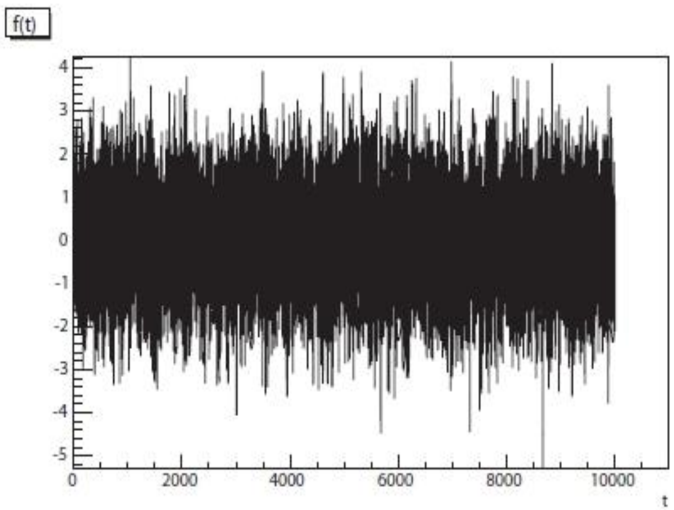
The function f is thus used as a filter for itself. An important property of the autocorrelation function is that it follows a δ-distribution if $f(x, y, t)$ is Poissonian or Gaussian noise:

$$A_{f,\text{ noise}}(x, y, t) = \delta(x, y, t) \tag{A.2}$$

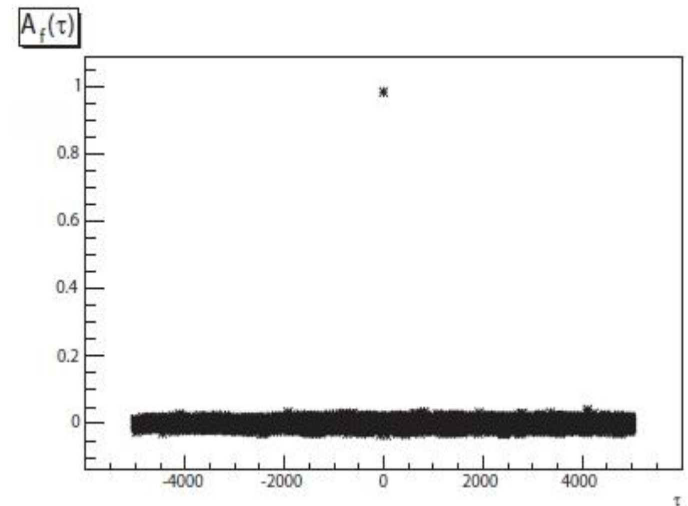
displayed in 1D in figure A.1. If $f(\tau)$ consists of noise and two signal peaks, the autocorrelation function can be used as an efficient noise filter. This is displayed in figure A.2.

The function $f(x, y, t)$ corresponds to the FADC value in each slice (time t) and pixel (spatial coordinate (x, y)). With the main axis (LENGTH) of the shower as abscissa and the minor axis (WIDTH) as the ordinate, I introduced cartesian coordinates along the shower main axis. The

A C F



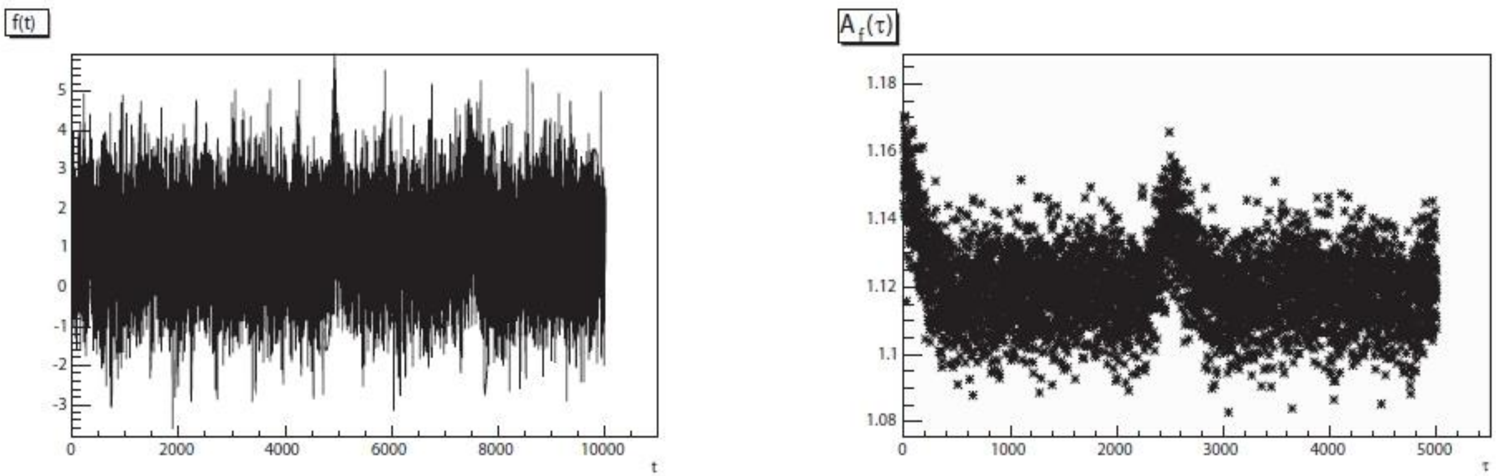
(a) $f(\tau)$: Gaussian Noise



(b) $A_f(\tau)$

Figure A.1: Figure (a) shows an example of Gaussian noise $f(\tau)$ and figure (b) its auto-correlation function $A_f(\tau)$.

A C F

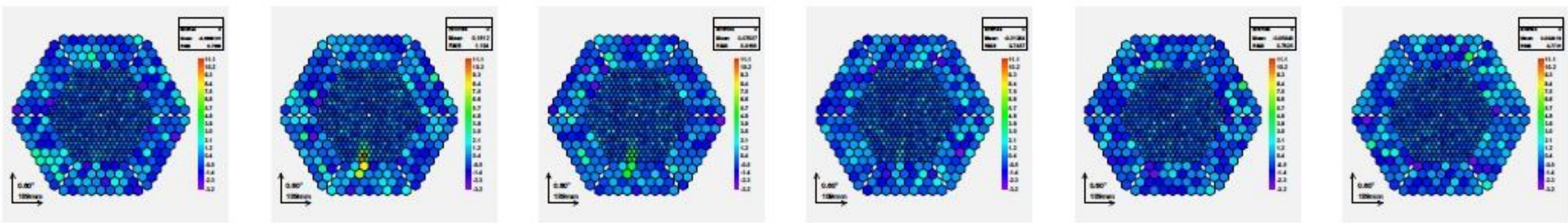


(a) $f(\tau)$: Noise and two signals

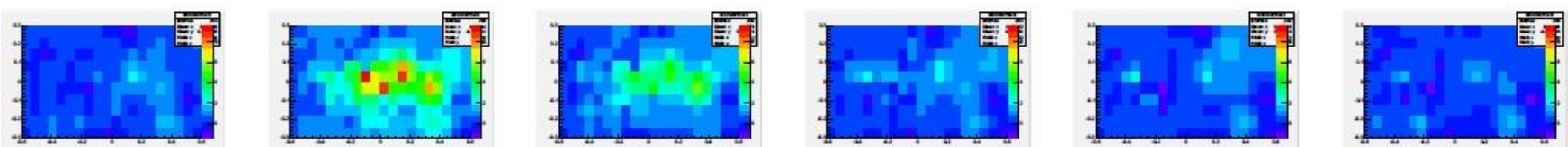
(b) $A_f(\tau)$

Figure A.2: The function $f(\tau)$ consists of Gaussian noise and two hardly visible peaks at the positions $\tau = 5000$ and $\tau = 7500$. Its autocorrelation function shows a clear peak at $\tau = 0$ at $\tau = 2500$, coming from the hardly visible two peaks in $f(\tau)$. Because the shape of the two signal peaks is similar, the autocorrelation function filters the noise.

A C F showers



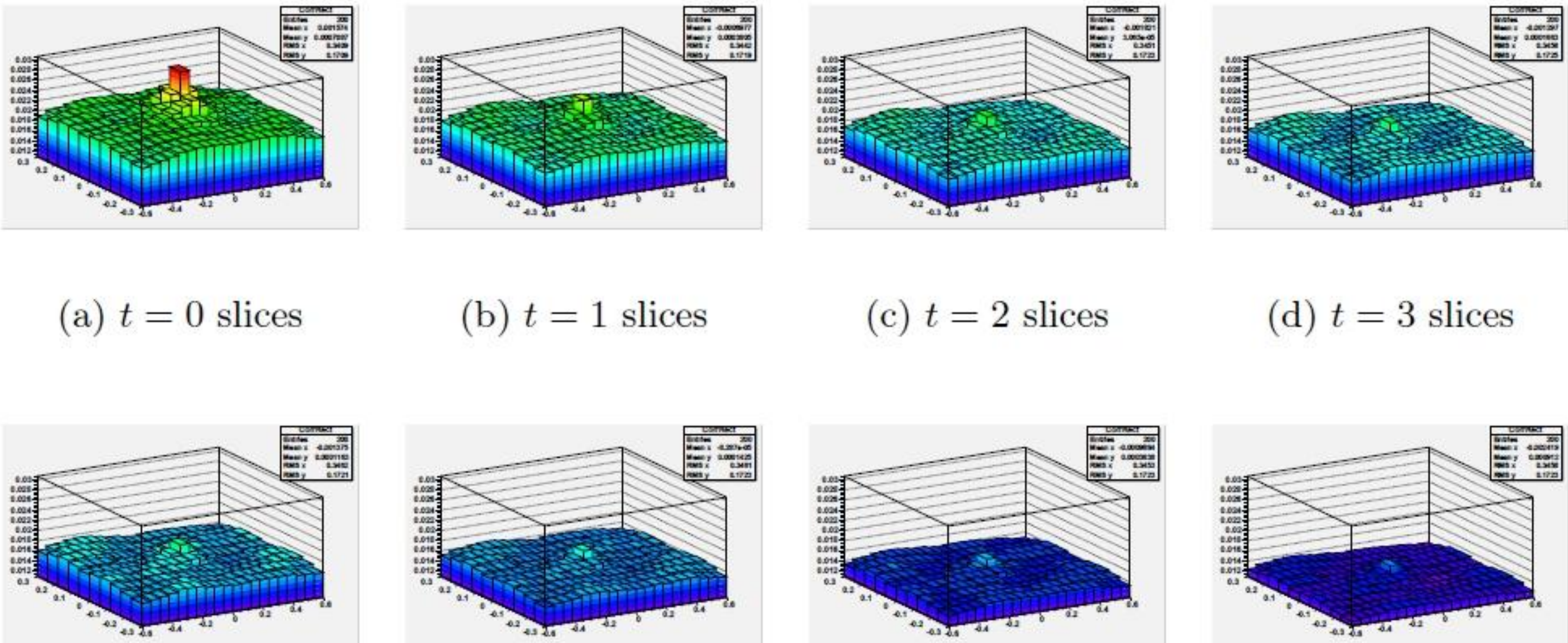
(a) $t = 0$ slices
(b) $t = 1$ slices
(c) $t = 2$ slices
(d) $t = 3$ slices
(e) $t = 4$ slices
(f) $t = 5$ slices



(g) $t = 0$ slices
(h) $t = 1$ slices
(i) $t = 2$ slices
(j) $t = 3$ slices
(k) $t = 4$ slices
(l) $t = 5$ slices

Figure A.3: A shower in time slices in Camera and Rectangular coordinates.

A C F showers

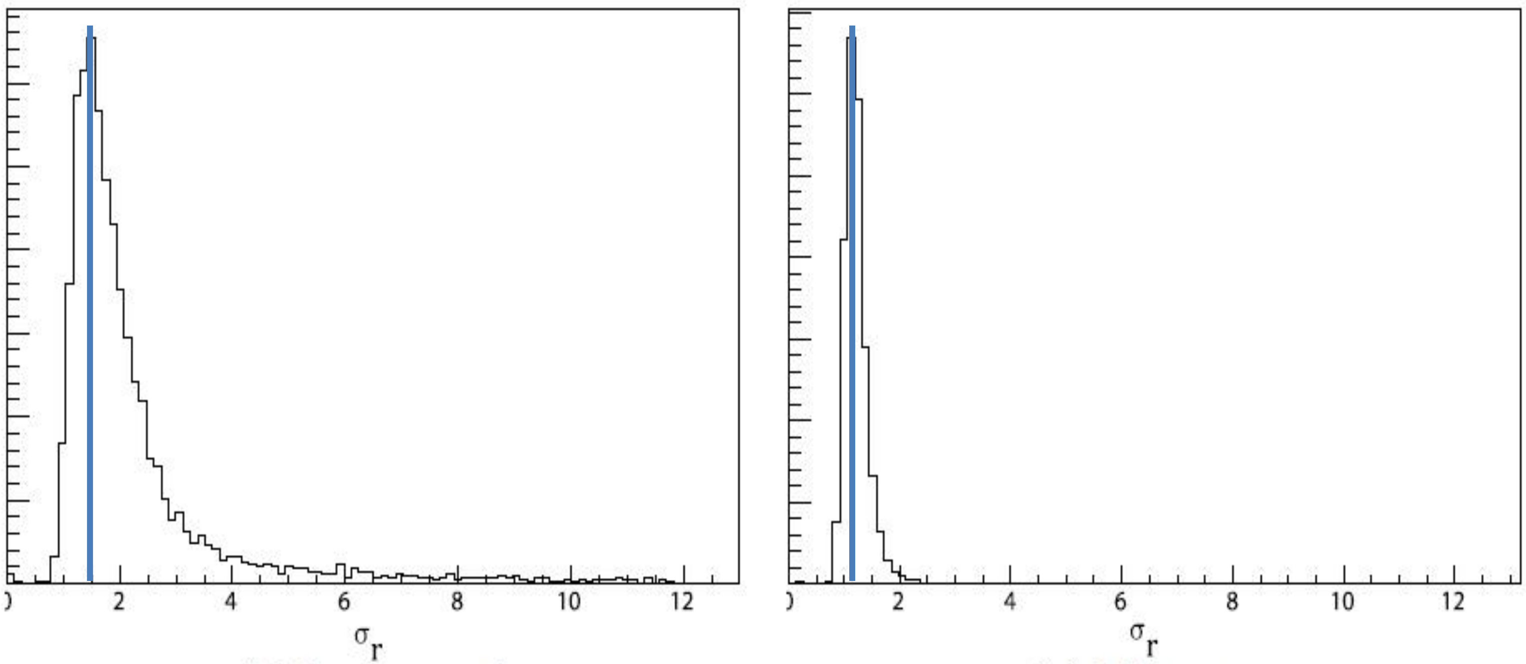


(a) $t = 0$ slices (b) $t = 1$ slices (c) $t = 2$ slices (d) $t = 3$ slices

(e) $t = 4$ slices (f) $t = 5$ slices (g) $t = 6$ slices (h) $t = 7$ slices

Figure A.4: The autocorrelation function of the shower displayed in figure A.3. It peaks at the time slice 0. In this example, after $t = 4$ slices, the autocorrelation function at $(x, y) = (0, 0)$ is reduced to $1/e$ of its value at $t = 0$. In the spatial direction $r = \sqrt{x^2 + y^2}$, $A_f(r, t = 0)$ is reduced to $1/e$ at a distance of $r = 0.14°$ of the value at $r = 0$.

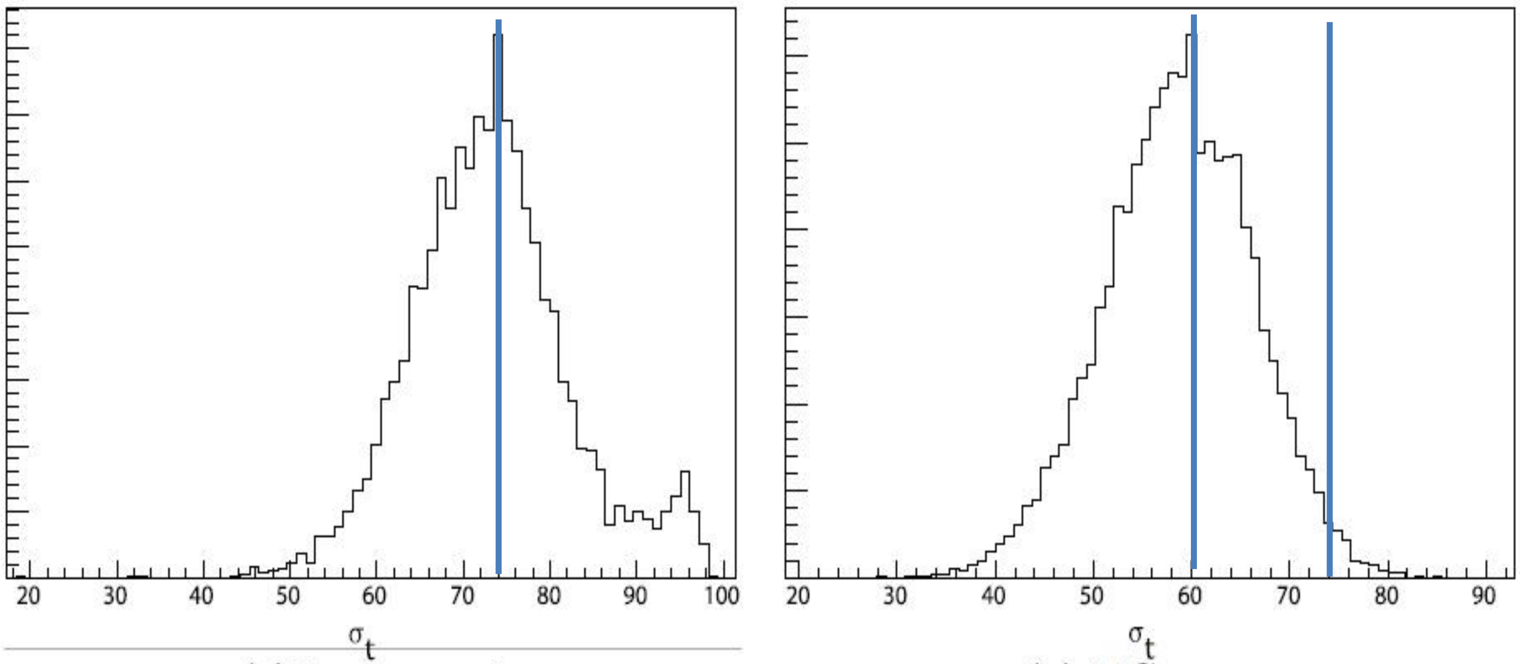
Autocorrelation function: with Hadroness Cut!



(a) background (b) MC γ-rays

Figure A.5: The spatial variance $\sigma_r = \sqrt{\sigma_x^2 + \sigma_y^2}$ of the autocorrelation function $A_f(x, y, t)$. The unit on the x-axis is arbitrary, the y-axis denotes the number of counts per bin. The σ_r for background reaches higher values.

Autocorrelation function: with Hadroness Cut!



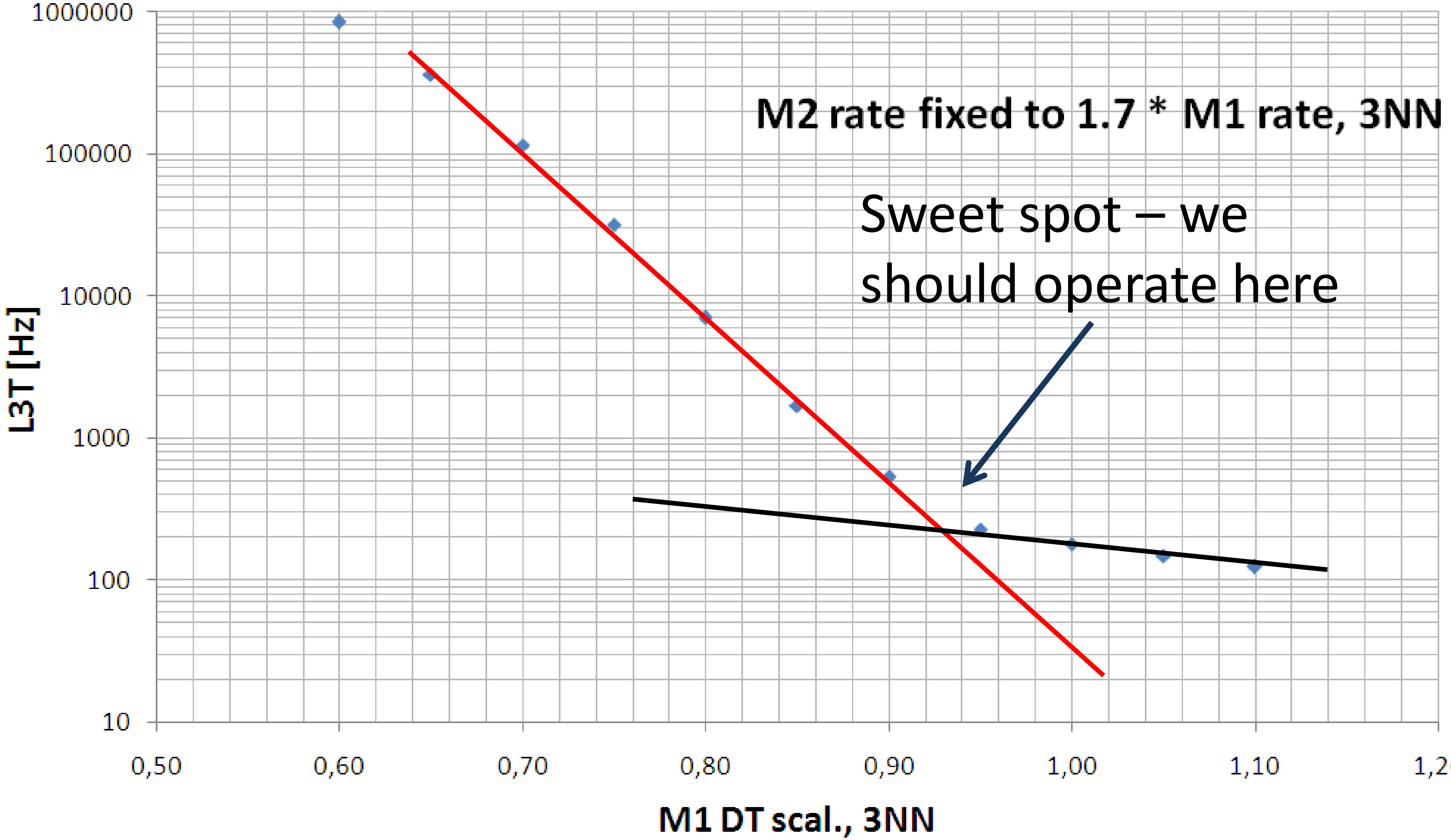
(a) background (b) MC γ-rays

Figure A.6: The variance in time σ_t of the autocorrelation function, measured at $(x, y) = (0, 0)$. The unit on the x-axis is arbitrary, the y-axis denotes the number of counts per bin. The autocorrelation of hadronic background is in average larger than for γ-rays.

Stereo trigger status

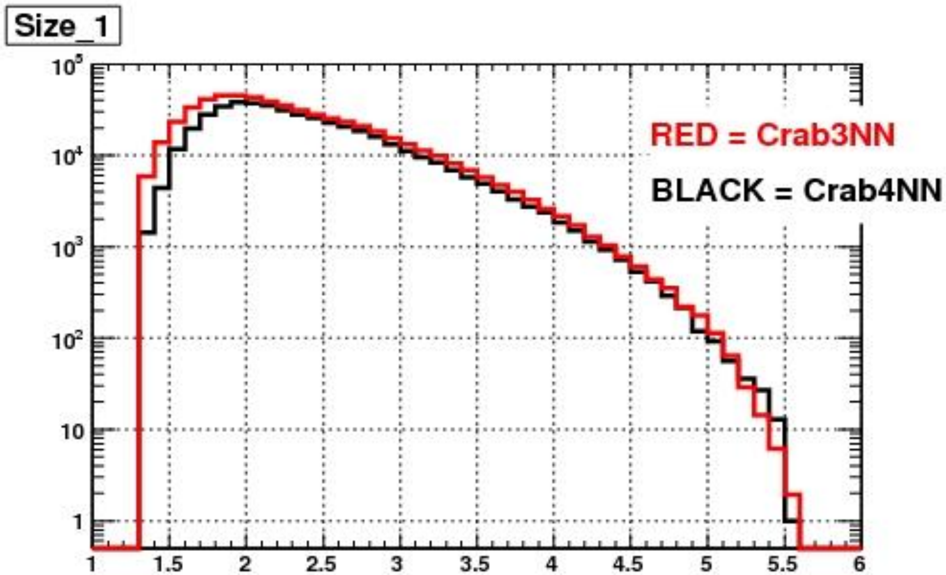
- Reminder: L1 L1 stereo trigger

3NN

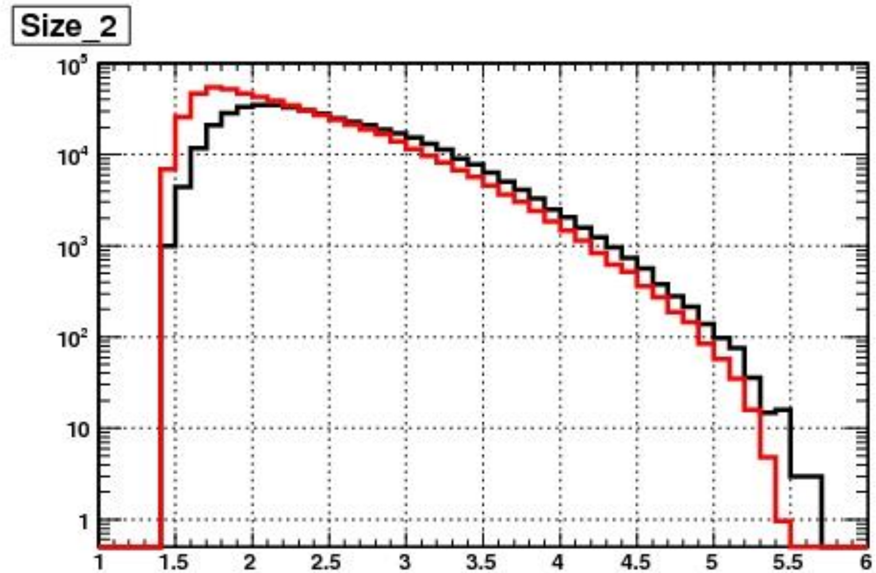


1000000
100000
10000
1000
100
10
L3T [Hz]
0,50
0,60
0,70
0,80
0,90
1,00
1,10
1,20
M1 DT scal., 3NN
M2 rate fixed to 1.7 * M1 rate, 3NN
Sweet spot – we should operate here

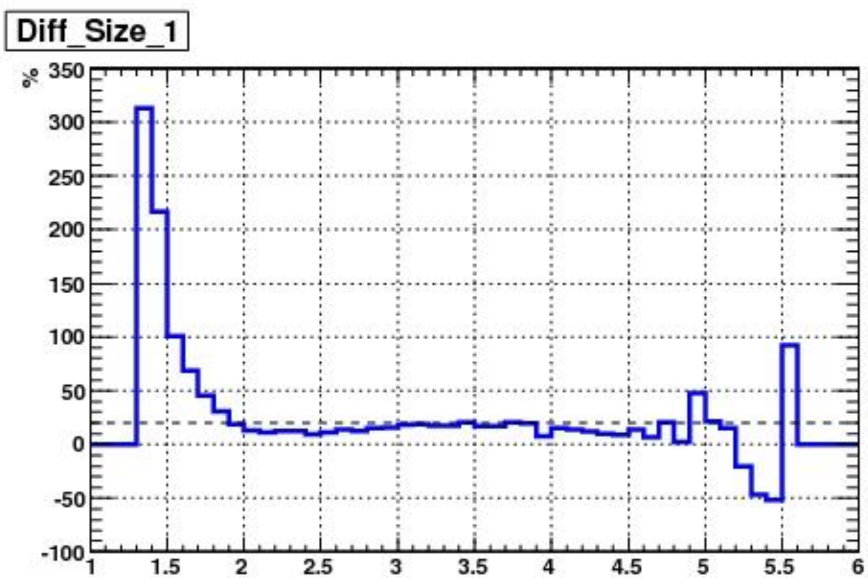
3NN vs 4NN



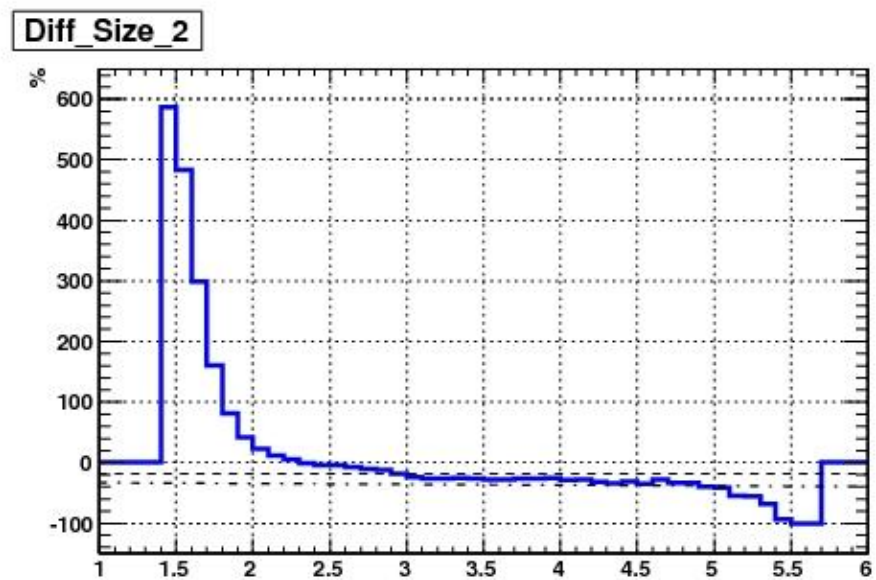
Size_1
RED = Crab3NN
BLACK = Crab4NN
10^5
10^4
10^3
10^2
10
1
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6



Size_2
10^5
10^4
10^3
10^2
10
1
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6

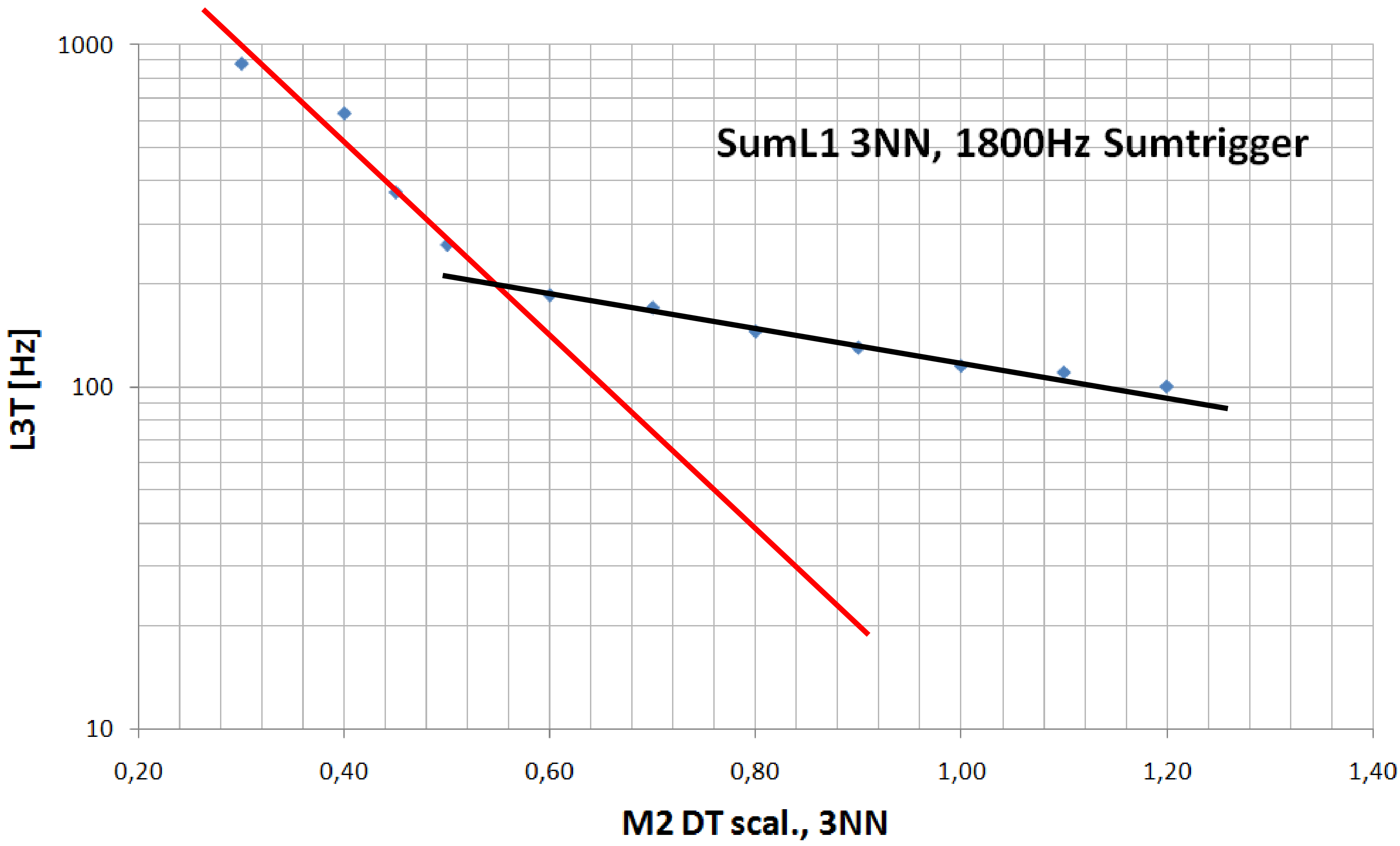


Diff_Size_1
%
350
300
250
200
150
100
50
0
-50
-100
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6

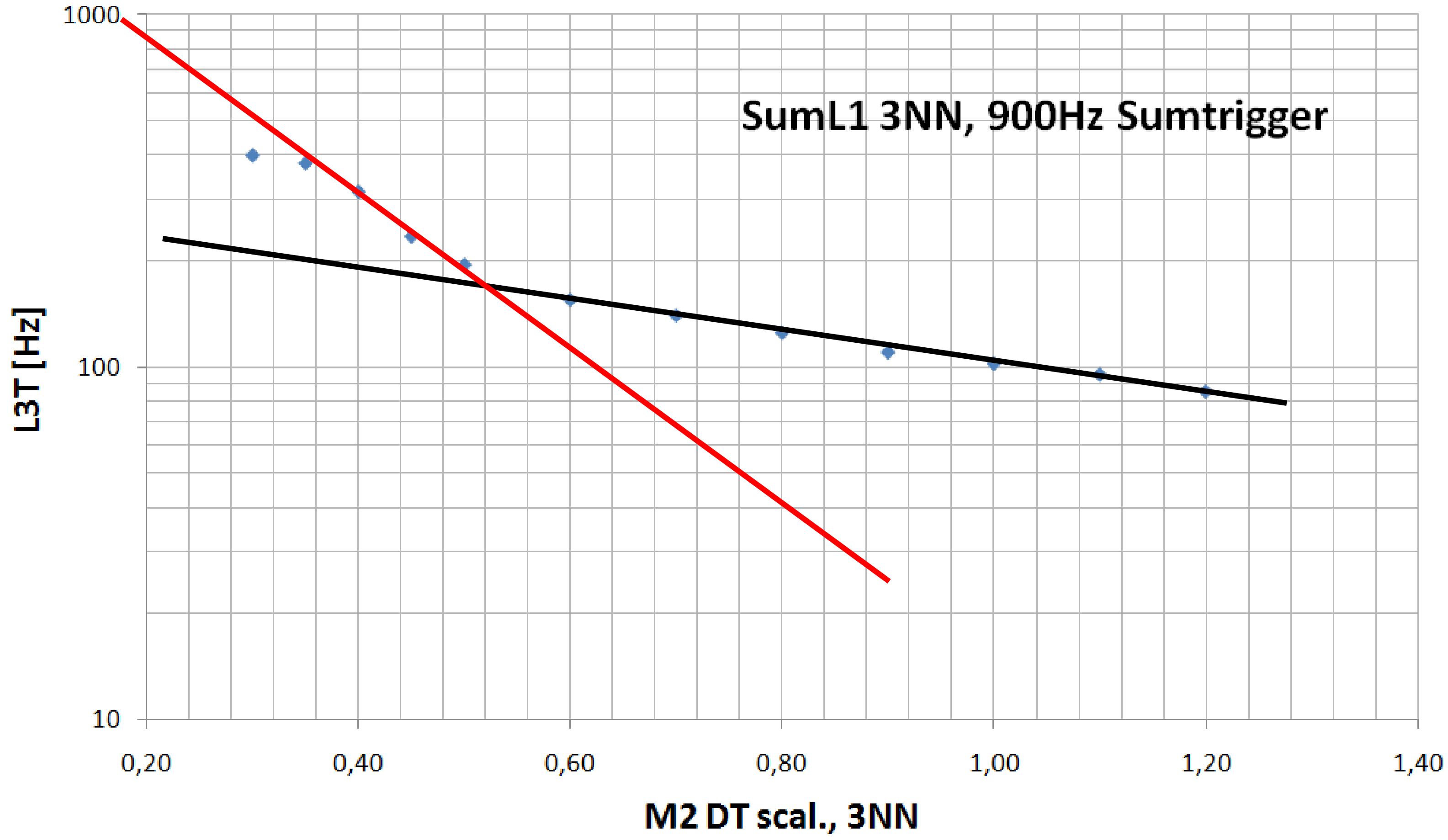


Diff_Size_2
%
600
500
400
300
200
100
0
-100
1 1.5 2 2.5 3 3.5 4 4.5 5 5.5 6

Coincidence Sum M1 – L1 M2



Coincidence Sum M1 – L1 M2



COG

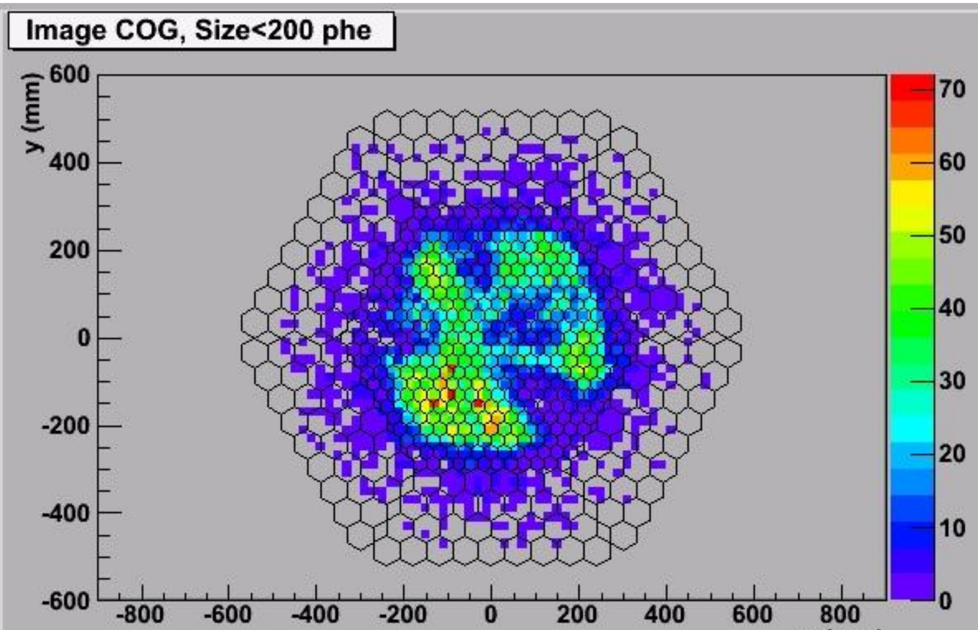
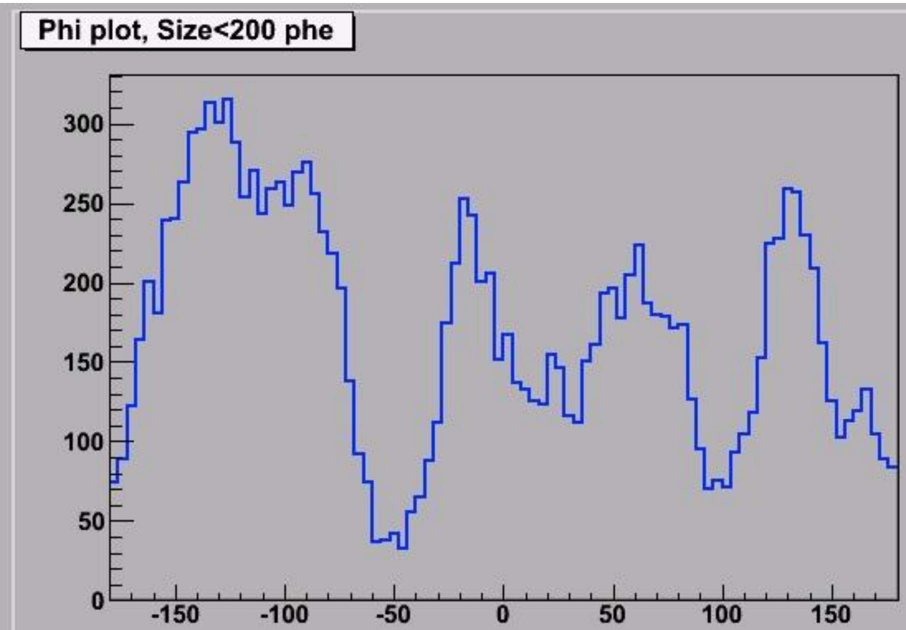


Image COG, Size<200 phe
y (mm)



Phi plot, Size<200 phe

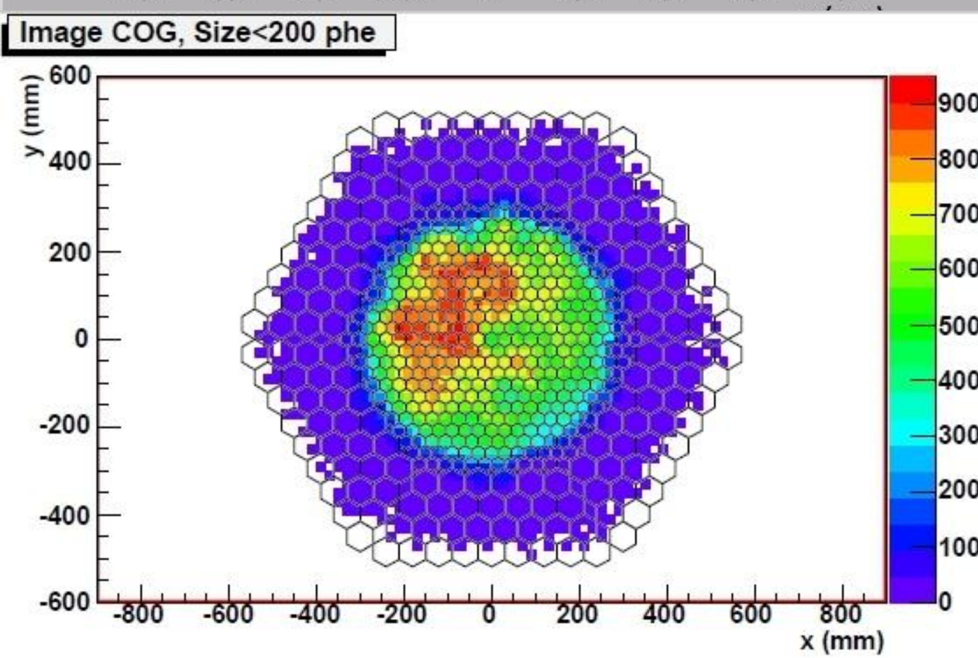
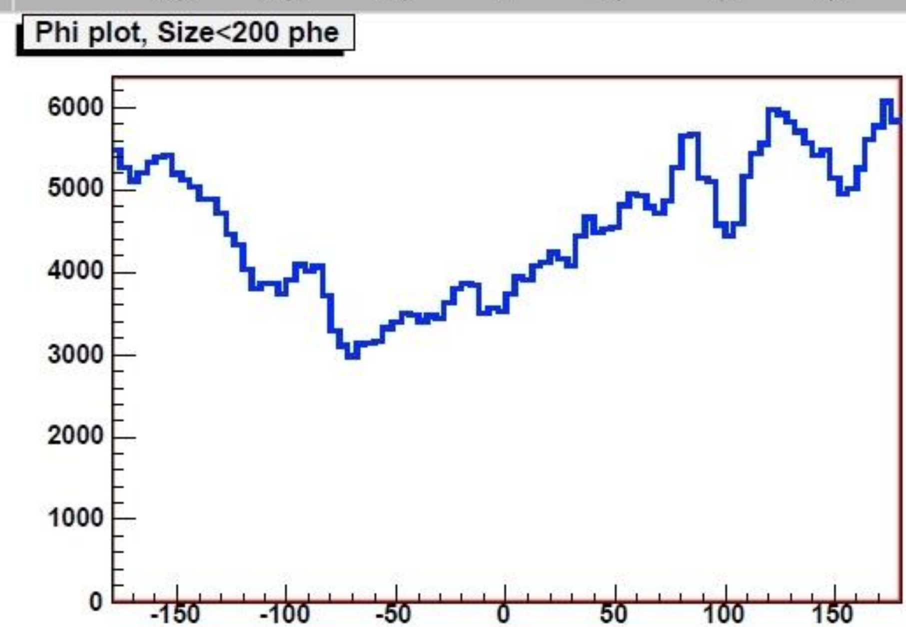


Image COG, Size<200 phe
y (mm)
x (mm)



Phi plot, Size<200 phe

Coincidence Sum L1 – L1 M2

- Coincidence rate rather low (low overlap of collection areas? Holes in the COG???)
- Suspicion: Problem with the timing.
- Expected rate ~60% lower than sumtrigger rate (extrapolating from our experience with standard L3 data) ->300Hz showers expected
- Threshold?
- Problems with the timing: after shifting delay by 6ns we got ~230Hz rate (higher!)
- Measurements have to be repeated!!!

Dorota

The background from single electromagnetic subcascades for a stereo system of air Cherenkov telescopes

Dorota Sobczyńska

University of Łódź, Department of Astrophysics, Pomorska 149/153, 90-236 Łódź, Poland

E-mail: ds@kfd2.phys.uni.lodz.pl

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Dorota Sobczyńska

University of Łódź, Department of Astrophysics, Pomorska 149/153, 90-236 Łódź, Poland

E-mail: ds@kfd2.phys.uni.lodz.pl

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obtained. The ratio of the expected number of both false γ and one π^0 images to that of primary γ-rays is approximately eight times lower for the stereo system than for a single telescope. Using the stereo imaging technique measurement one may expect a significant reduction of this kind of background in comparison to a single telescope.