

Image processing for Cherenkov telescopes

Ramin Marx

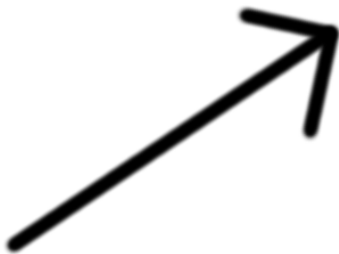
Max-Planck-Institut für Kernphysik, Heidelberg

October 13, 2014



MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

Rätsel des Universums

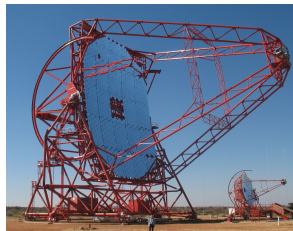


Warum ist dort ein Quadrat?

Gamma Astronomy compared to Optical Astronomy



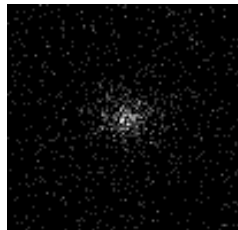
Galileo Galilei with his optical telescope



H.E.S.S. II

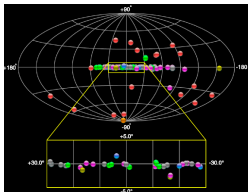


Crab Nebula in visible light

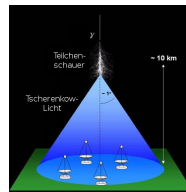


Crab Nebula in gamma rays

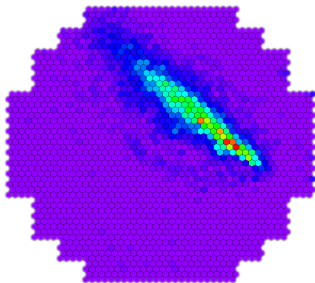
What is different in Gamma Astronomy?



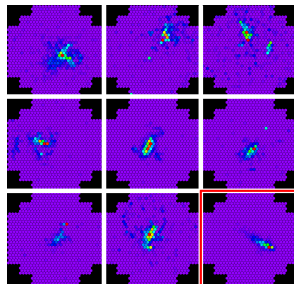
relatively few gamma sources



gamma rays do not pass through the atmosphere, but induce air showers

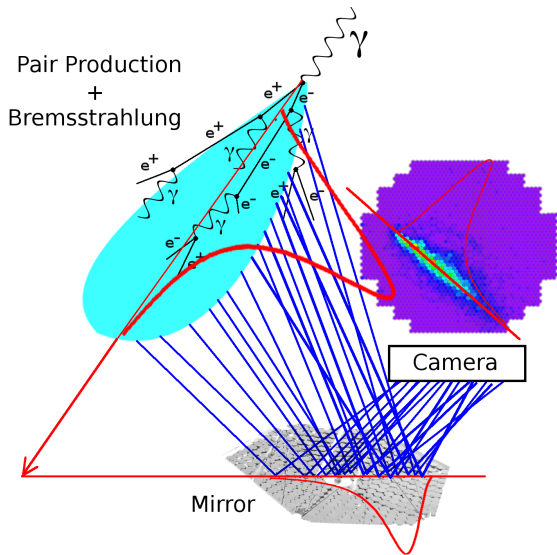


air shower images are taken with the camera and then analysed

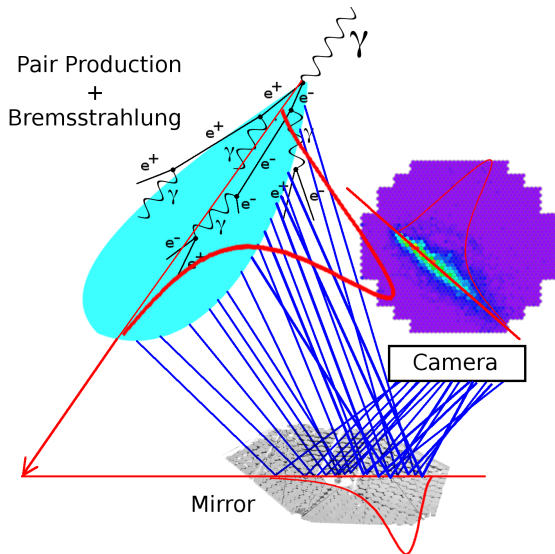


high background level: only 1 of 10^5 events is a gamma, furthermore, it can be difficult to recognize them

Air Showers and Cherenkov Telescopes



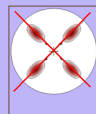
Air Showers and Cherenkov Telescopes



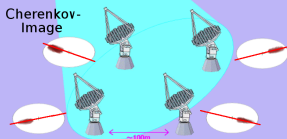
Stereoscopy

Direction reconstruction
with several telescopes

Superposition of
camera images

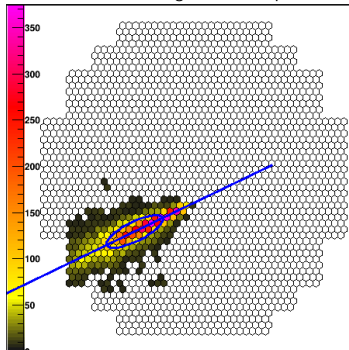


Cherenkov-
Image



Hillas-Analysis of the Air Shower Image

Describe air shower image with an ellipse:



parameters of the Hillas-ellipse:

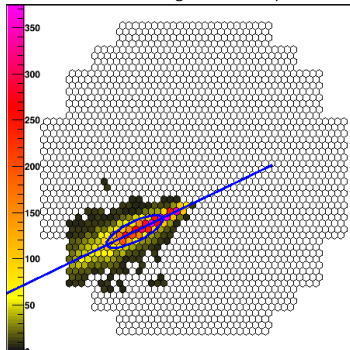
- centre of gravity
- width and length
- amplitude of image

⇒ energy, direction and ...

type of particle

Hillas-Analysis of the Air Shower Image

Describe air shower image with an ellipse:

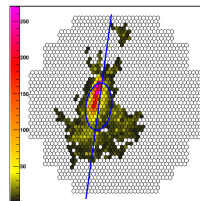
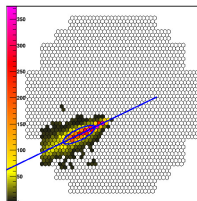
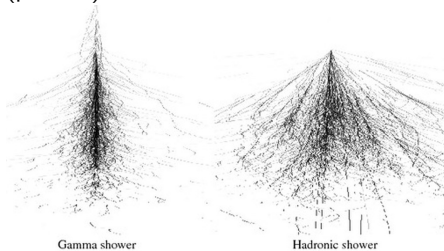


parameters of the Hillas-ellipse:

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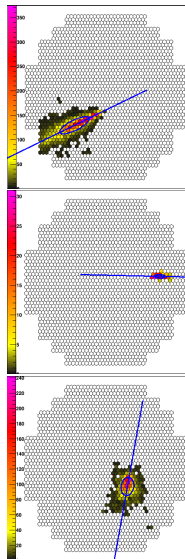
Problem: very high cosmic ray background (protons)



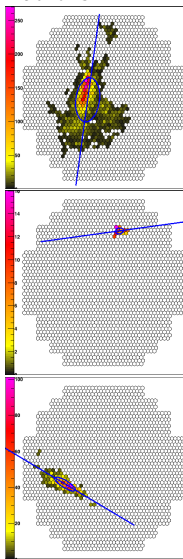
⇒ Gamma-Hadron separation is very important

Gamma-Hadron-Separation using Hillas-Width

Gammas:

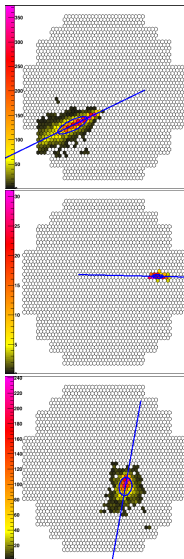


Hadrons:

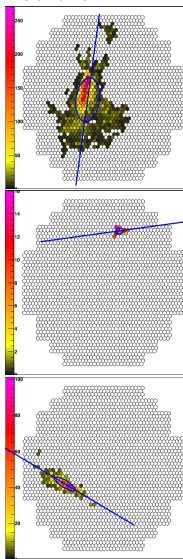


Gamma-Hadron-Separation using Hillas-Width

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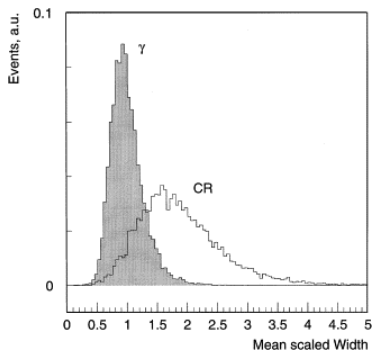


Hadrons:



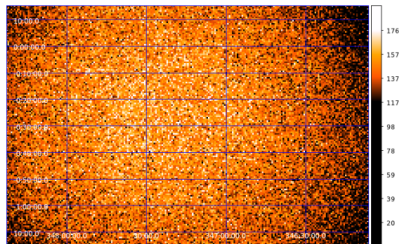
The classical separation method exploits that hadronic images are wider than gamma images.

⇒ cut on Hillas-Width:



Gamma-Hadron Separation - Why?

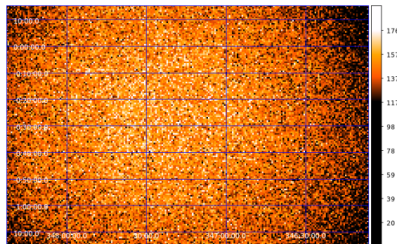
Example: RXJ1713, exposure time: 167 hours, one pixel is $0.01^\circ \times 0.01^\circ$



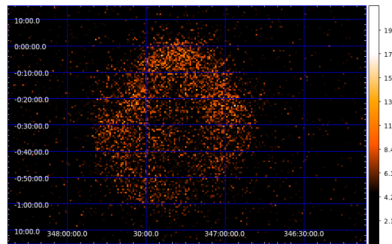
without gamma-hadron separation

Gamma-Hadron Separation - Why?

Example: RXJ1713, exposure time: 167 hours, one pixel is $0.01^\circ \times 0.01^\circ$

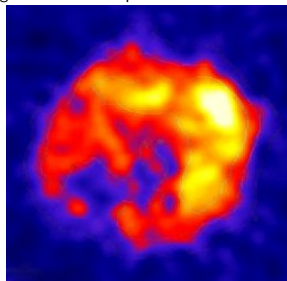


without gamma-hadron separation



with gamma-hadron separation

⇒ gamma-hadron separation is essential



Gamma-Hadron Separation - How?

General Approach

- + simulate many gamma and hadron air showers
- + parameterize shower images
- + gammas and protons show different distributions for the same feature → cut on the distributions to select gamma-like events

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Improve separation power by

- finding new parameterisations that are more sensitive to the differences between gammas and hadrons
- using machine learning algorithms that combine these features optimally

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Improve separation power by

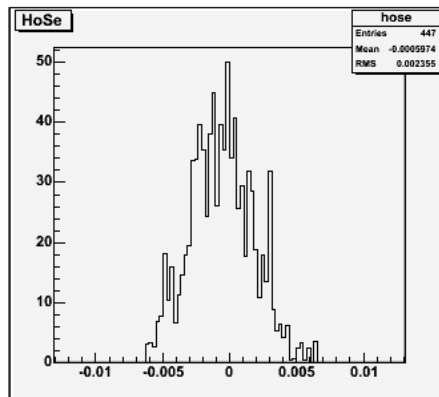
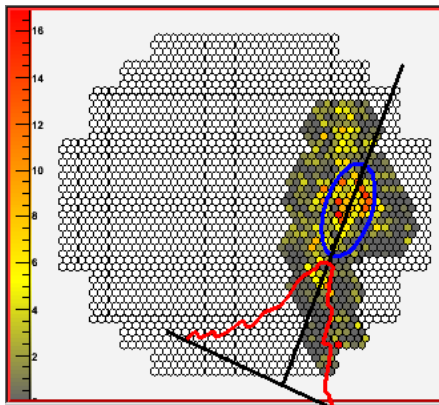
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Some methods we are developing

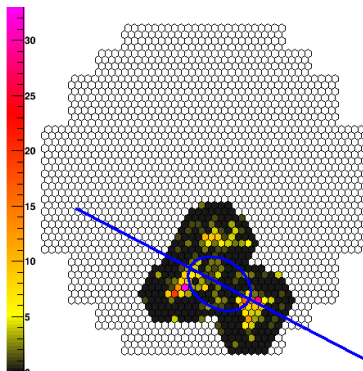
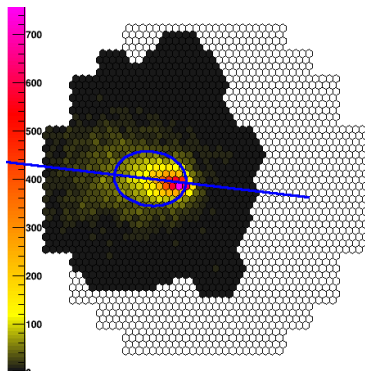
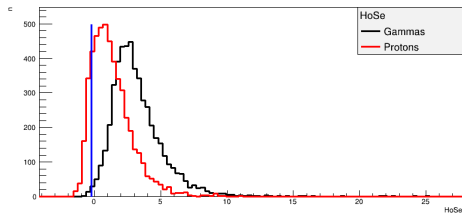
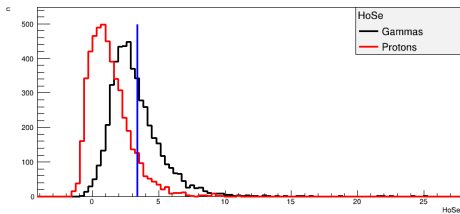
- 1 HoSe (Hofmann Separation)
- 2 Watershed
- 3 Average Intensity in Growing Ellipse
- 4 Cross Correlation

Method 1: HoSe (Hofmann Separation)

- project pixel intensities onto minor axis of Hillas Ellipse
- calculate 4. moment (measure peakedness)

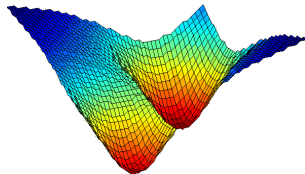
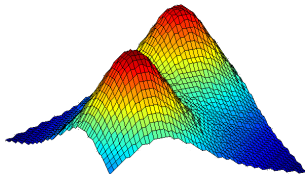
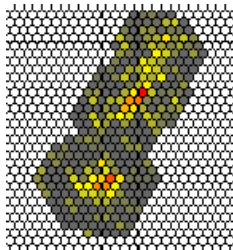


HoSe, 5000 events, Amp ≥ 80 pe

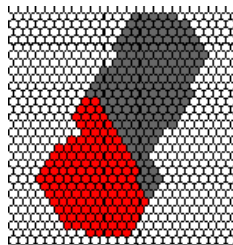
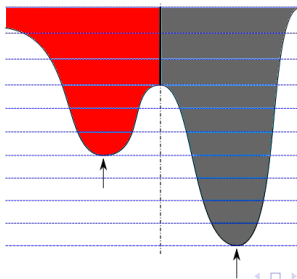
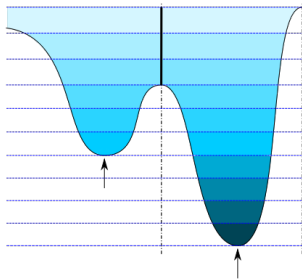


Method 2: Watershed (1/2)

Smooth image, interpret as 3D landscape (intensity \rightarrow elevation), invert:



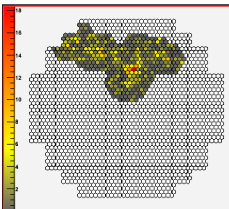
Then flood it and assign every basin a different label



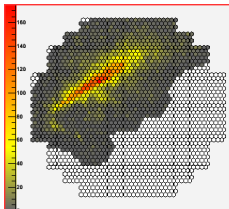
Method 2: Watershed (2/2)

Segmentation results for typical gamma and proton events:

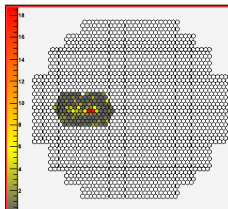
Proton 1



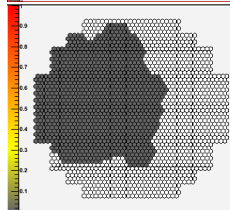
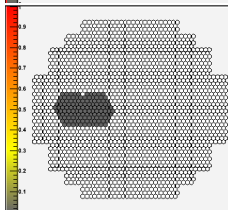
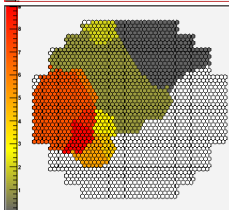
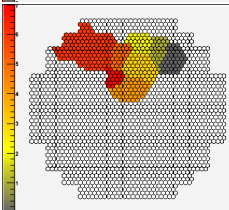
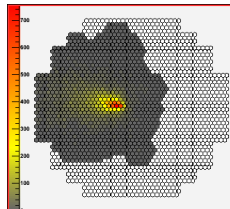
Proton 2



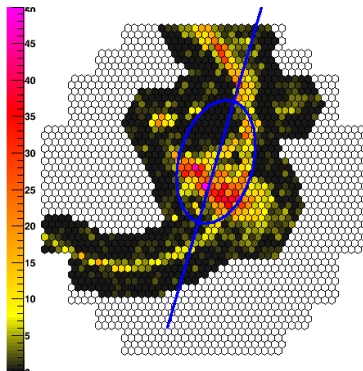
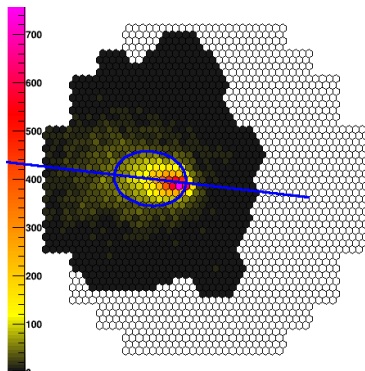
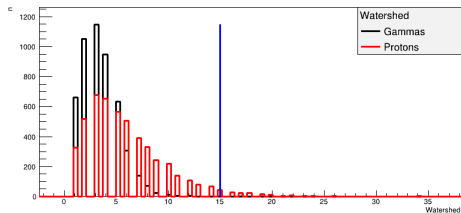
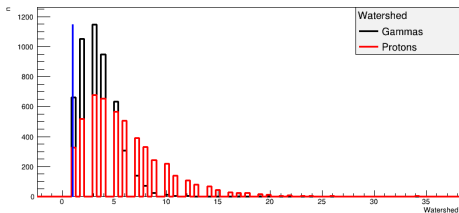
Gamma 1



Gamma 2

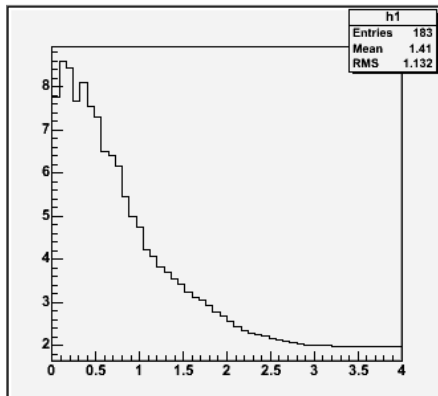
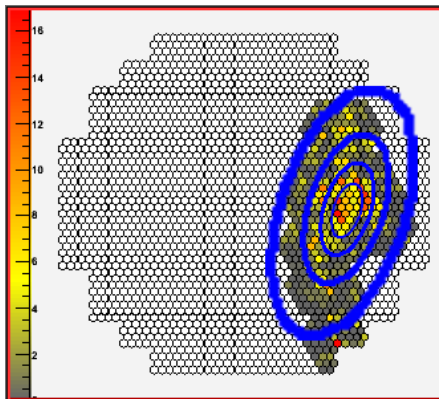


Watershed, 5000 events, Amp ≥ 80 pe

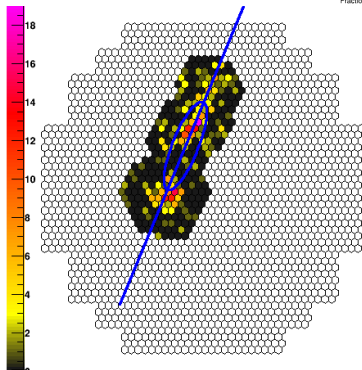
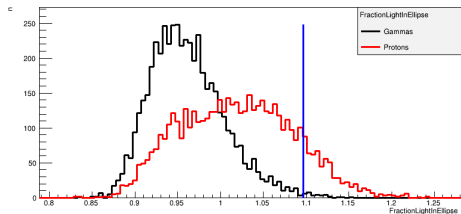
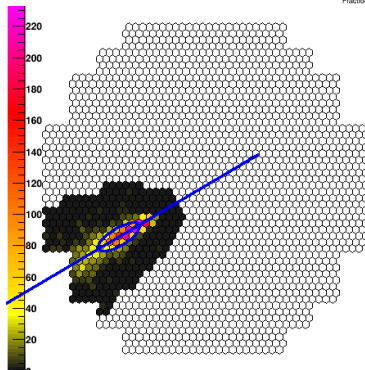
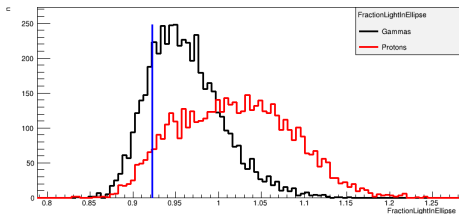


Method 3: Average Intensity in Ellipses

- vary size of Hillas Ellipse
- average intensity in that ellipse
- get RMS

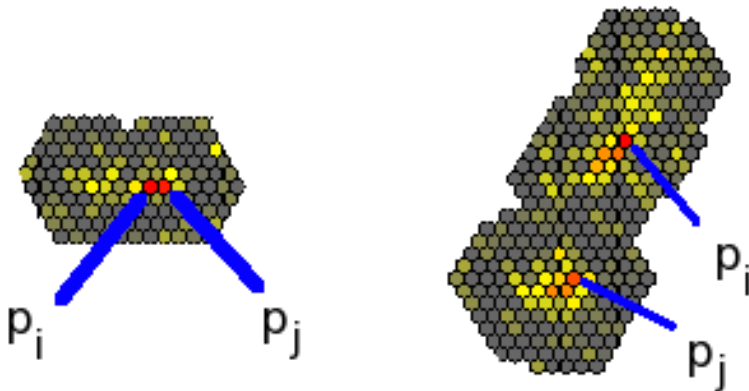


Average Intensity in Ellipses, 5000 events, Amp ≥ 80 pe

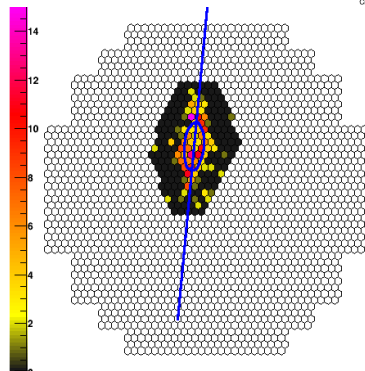
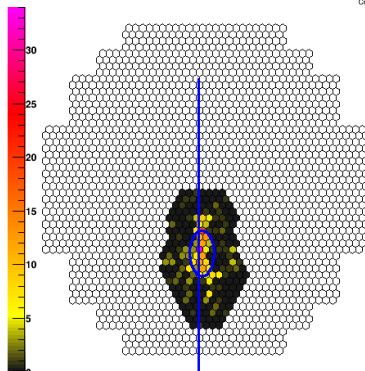
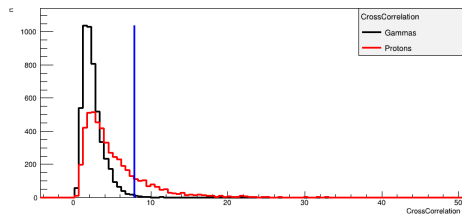
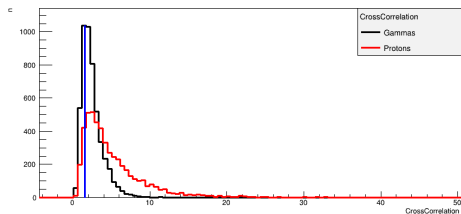


Method 4: Cross Correlation

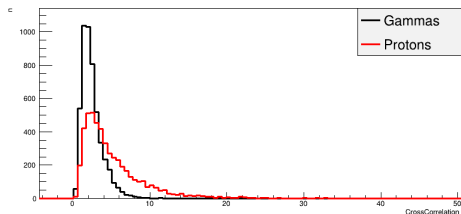
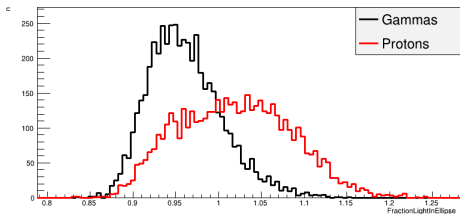
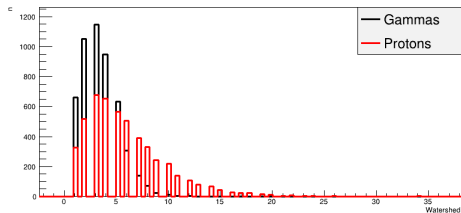
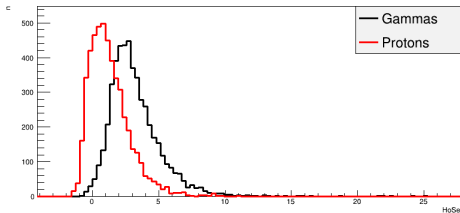
penalize pixel pairs with high intensity and long distance $p = \sum_{i,j} p_i p_j / r$



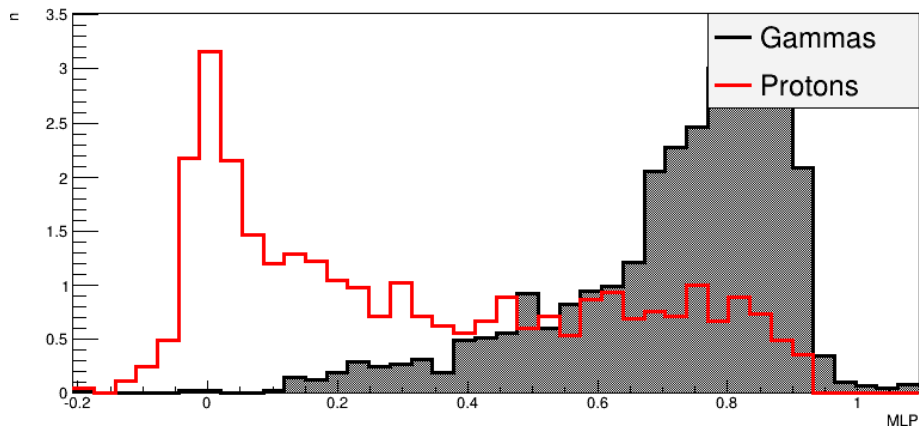
Cross Correlation, 5000 events, Amp ≥ 80 pe



Overview of all Classifiers



Combining all Classifiers in root-TMVA (MLP)



- image analysis is important for gamma-ray astronomy