Study of the diffuse emissions with the H.E.S.S. experiment

Tania Garrigoux

NWU, Potchefstroom

with Pascal Vincent, LPNHE, UPMC, Paris

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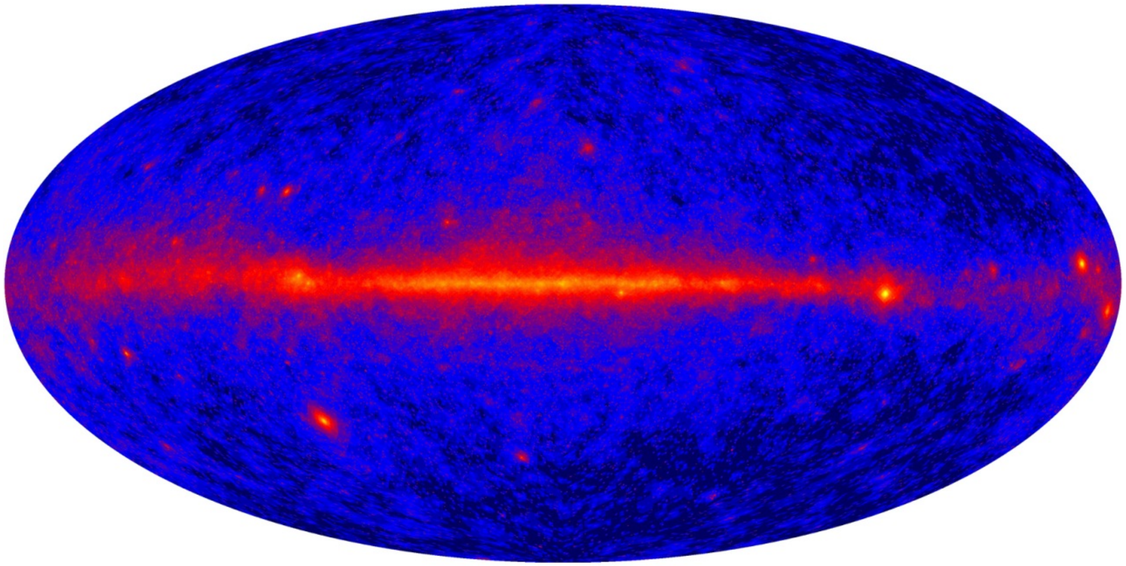
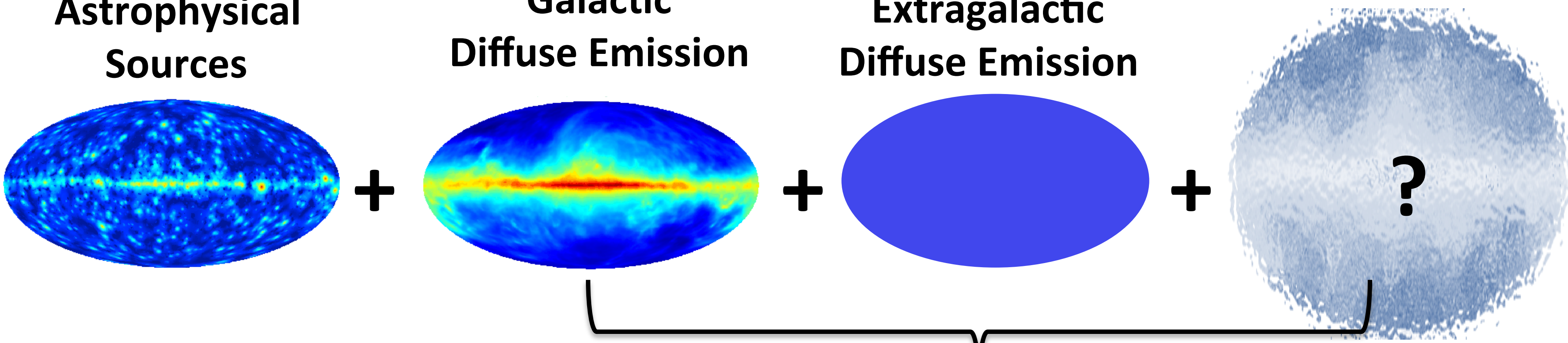
Gamma-rays



Astrophysical Sources | **Galactic Diffuse Emission** | **Extragalactic Diffuse Emission**



Gamma diffuse Emissions

Purpose: search for anomalies

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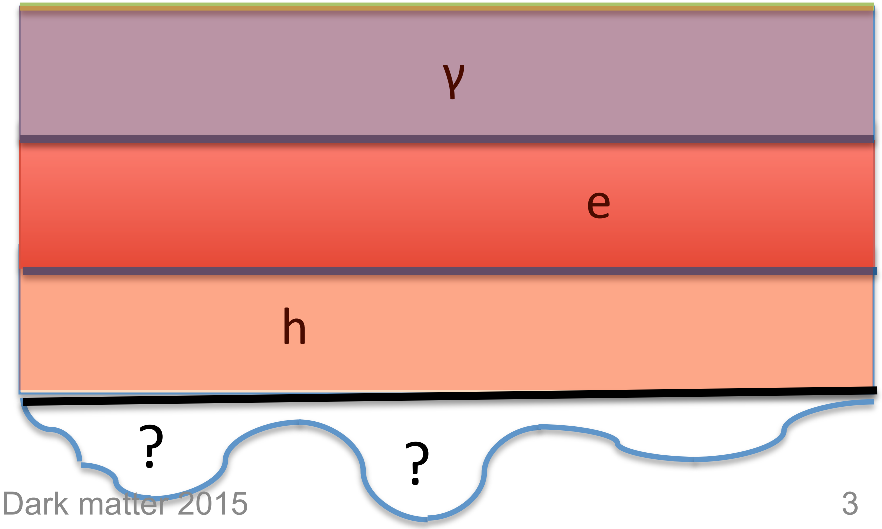
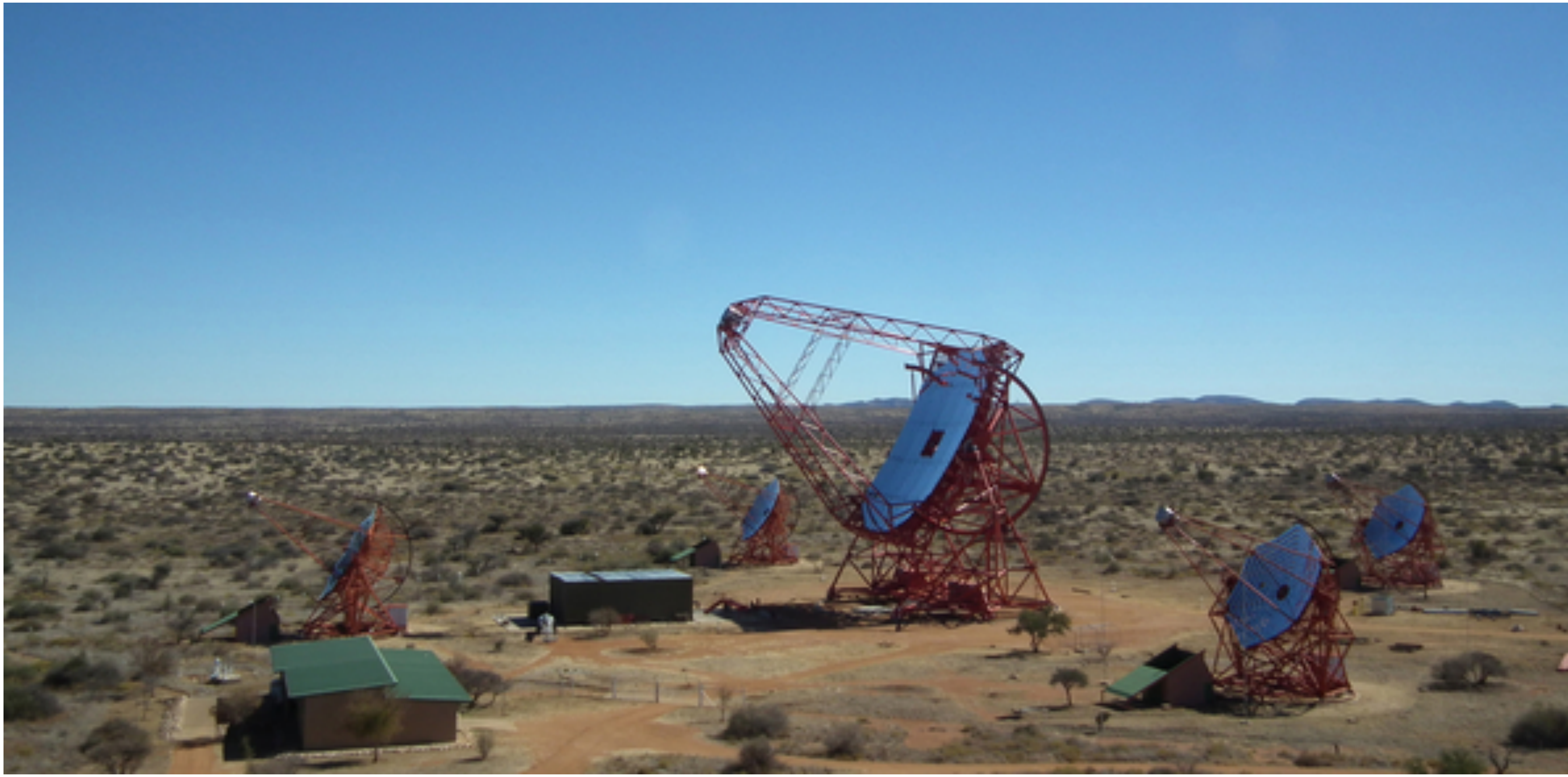
- The hadron flux is estimated to be ~ 10^{-1} m^{-2} s^{-1} sr^{-1} TeV^{-1}
- Electrons flux: protons'/10^3
- Galactic gamma flux: protons'/ 10^{4-5}
- Extragalactic gamma flux: protons'/10^6





Experiment

HESS

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High Energy Stereoscopic System

- 4 small telescopes since 2004 (HESS I)
- + 1 large telescope since 2012 (HESS II)
- Namibia, ~ 1800m
- Form recognition and stereoscopy
- Energy range: 100 GeV (and ~20GeV for the fifth telescope) to a few tens of TeV
- Field of view: 5˚ for small telescopes, 3˚ for the large one
- Resolution: 0,07˚ (HESS I)
- Cherenkov light detected by cameras made of PMTs
- Limited observation time

Studying the diffuse emissions

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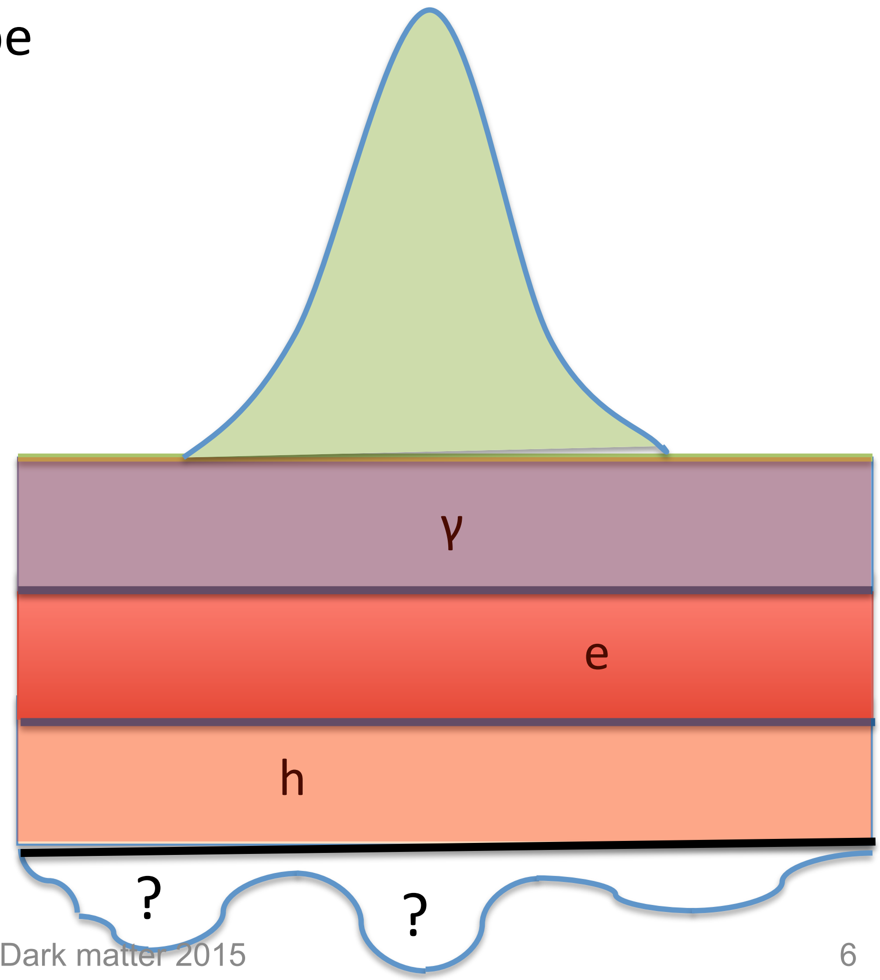
- The hadron flux is estimated to be ~ 10^{-1} m^{-2} s^{-1} sr^{-1} TeV^{-1}
- Electrons flux: protons'/10^3
- Galactic gamma flux: protons'/ 10^{4-5}
- Extragalactic gamma flux: protons'/10^6

Known Astrophysical Source



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Cherenkov

Detection technique

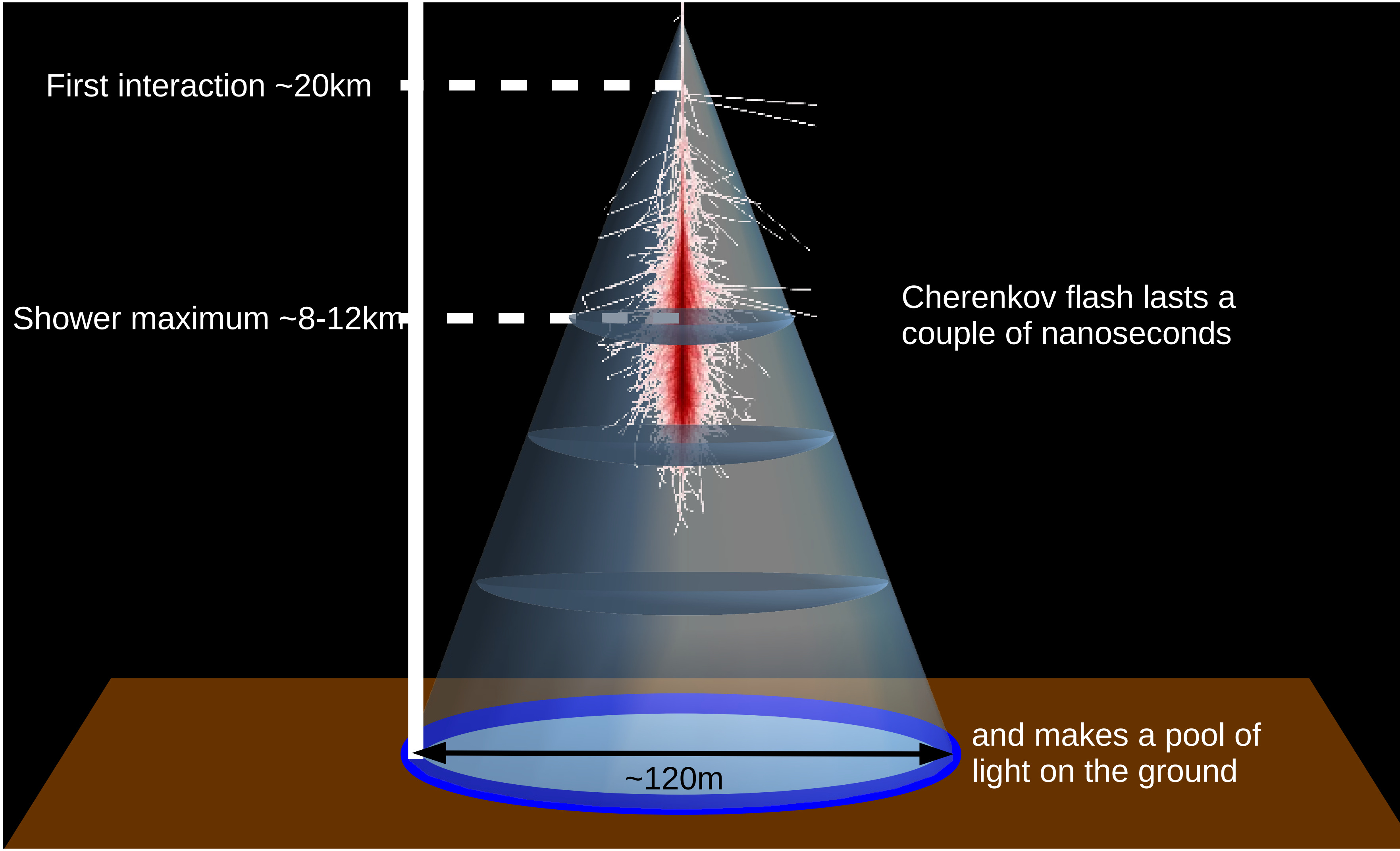
Cherenkov telescopes

http://magic.mppmu.mpg.de

http://veritas.sao.arizona.edu

http://www.mpi-hd.mpg.de/hfm/HESS

Cherenkov detection



Credit: M. Daniel

Event reconstruction

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Shower image on the cameras

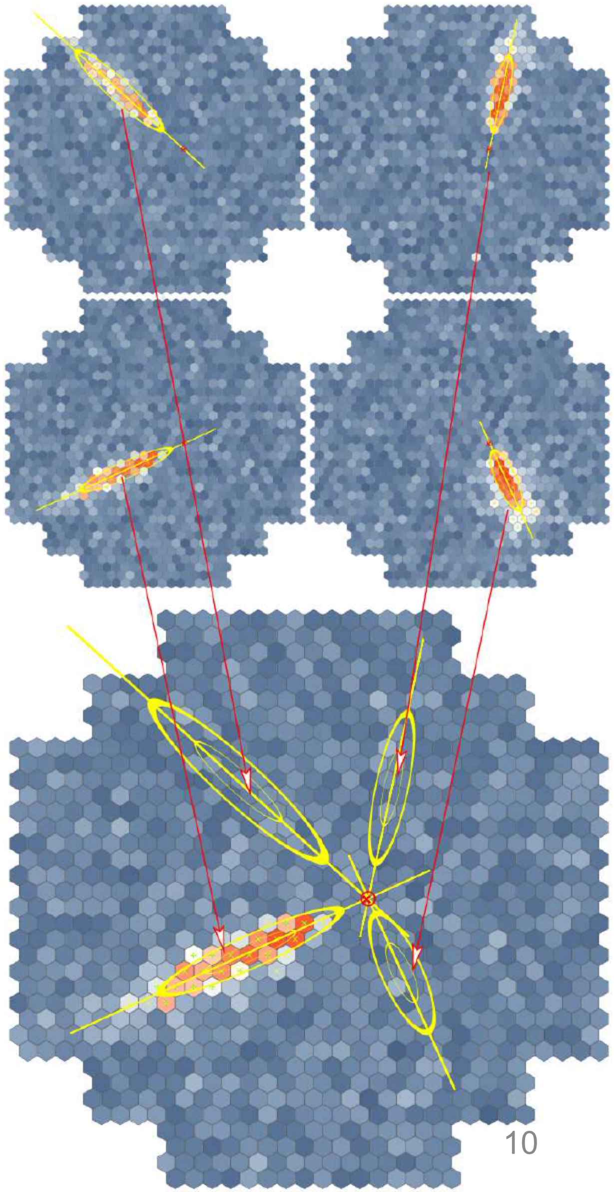
Information on the event is deduced

The shower's number of Cherenkov photons, height of the maximum of development, the primary particle's energy or direction…

Stereoscopy

The position of the source is on the symmetry axis of the image

By combining several images the degeneracy can be lifted



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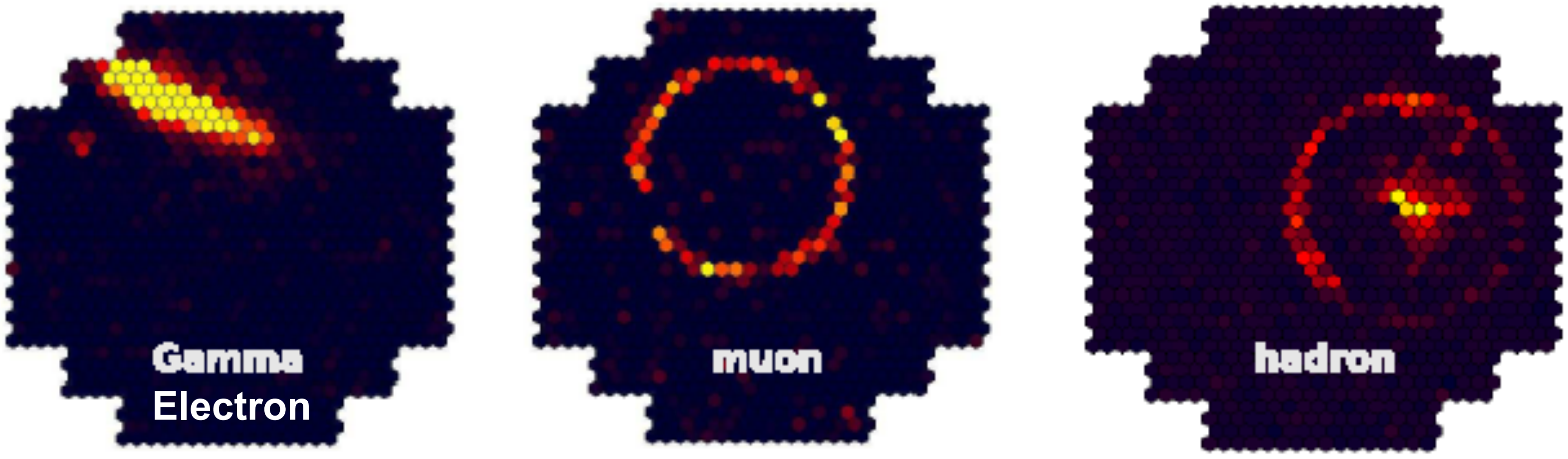

Method

The discriminant variables

The discriminant variables

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Obtained from the shower image :

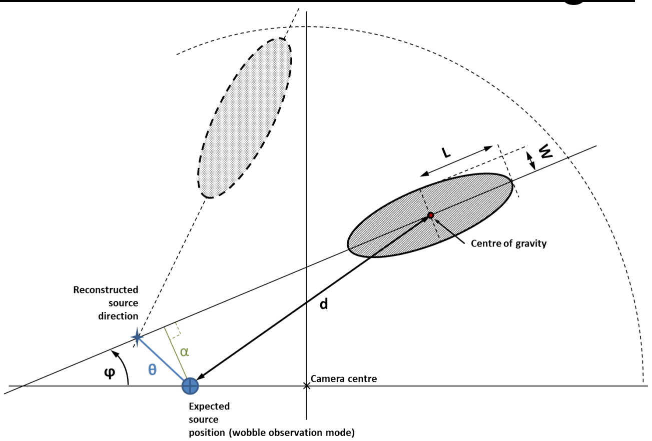
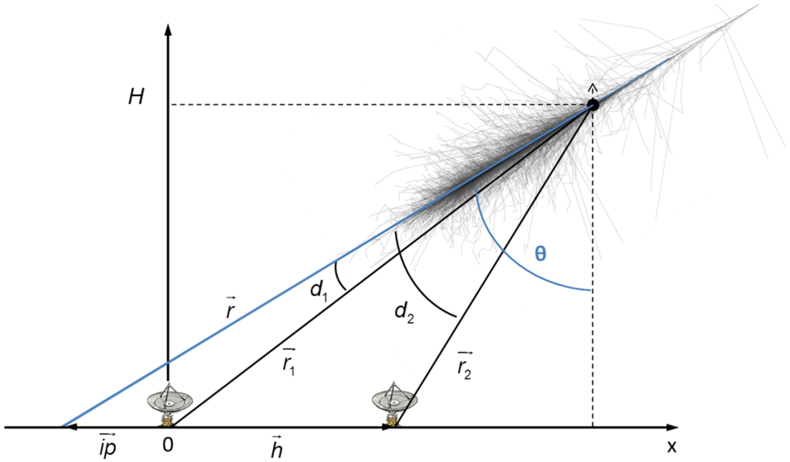


Image length and width

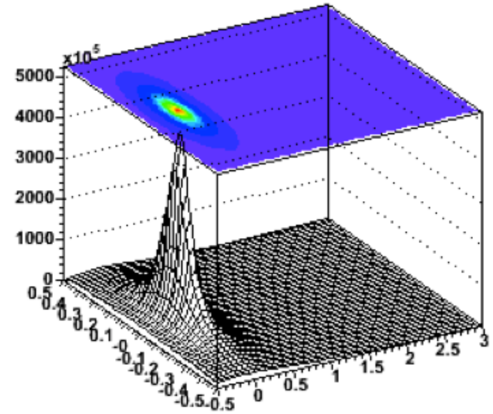


Height of the maximum of the shower development

Obtained from models:

Goodness of fit

First point of interaction in the atmosphere: primary depth



Study of the discriminant variables for all types of particles (on simulations and data samples)

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The discriminant variables

Photons, electrons and protons

Protons vs EM :

MSL

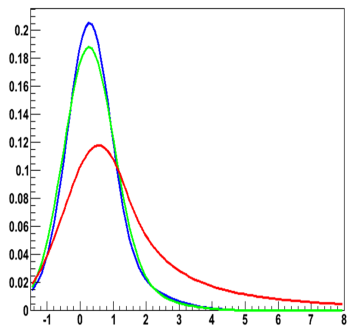


Image length

MSW

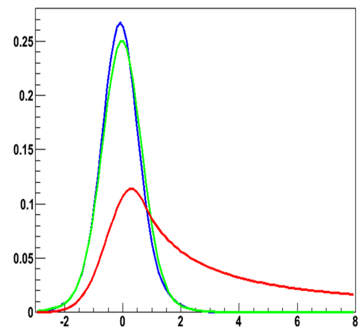
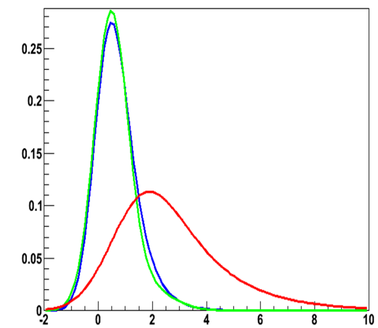


Image width

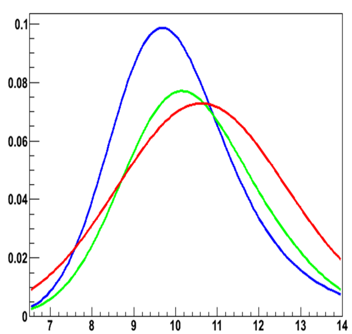
MSG



Goodness of fit

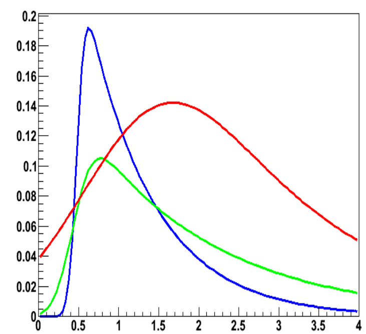
Electrons vs Gamma :

MDH



Maximum of shower development

PDH



Primary depth

The discriminant variables

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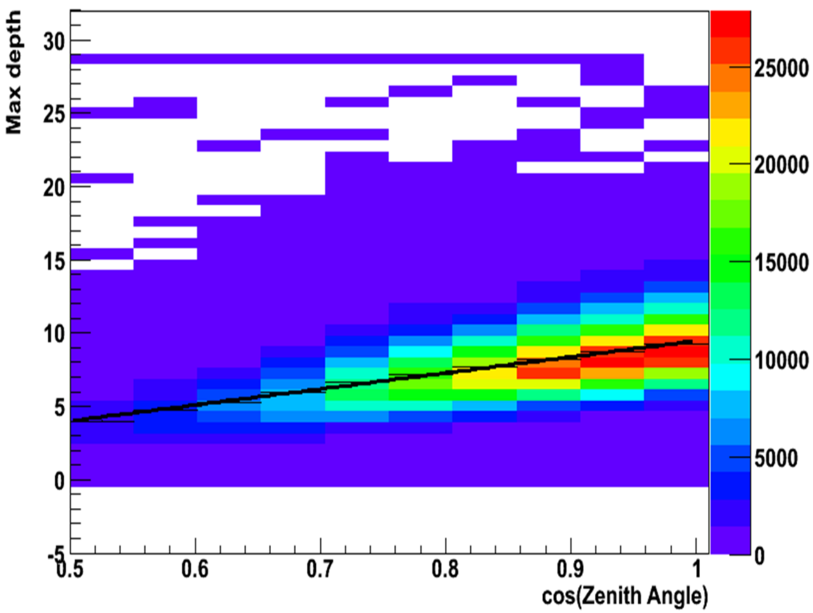
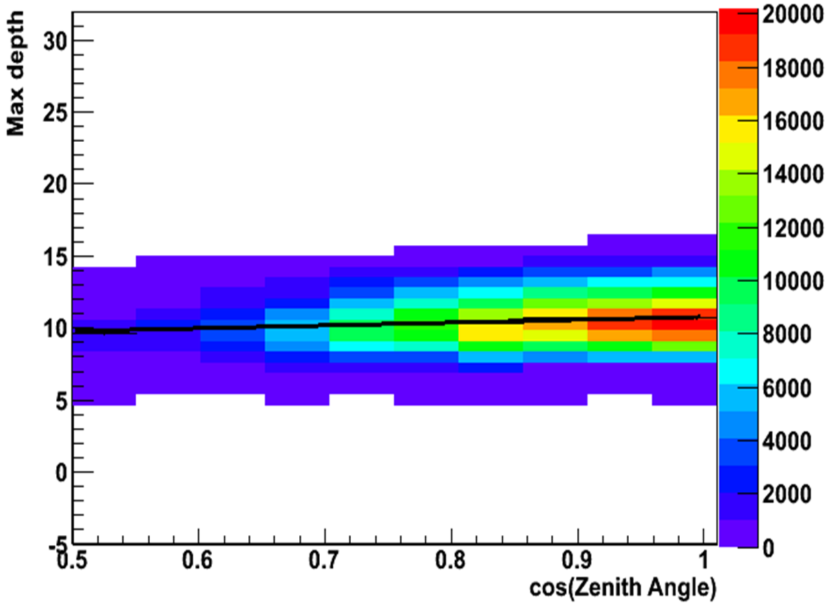
Correcting the discriminant variables: *zenithal angle dependency*





$$MDH = a\cos z + b$$

$$MDH_{corr} = MDH + a*(1-\cos z)$$

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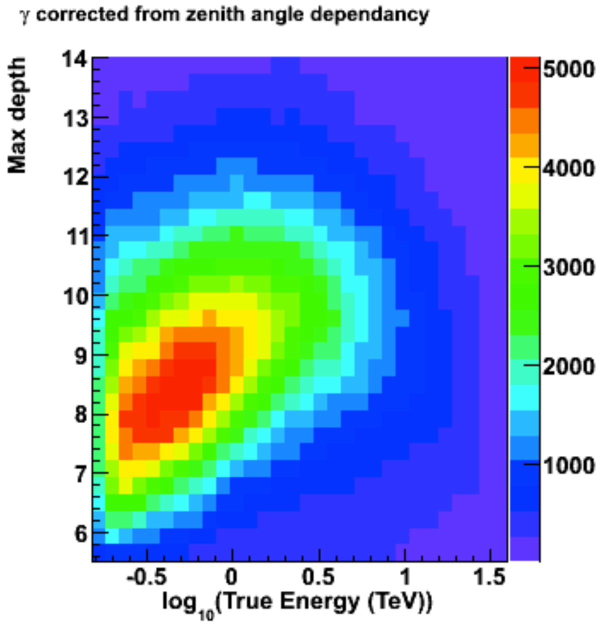
The discriminant variables

Correcting the discriminant variables: *MDH energy dependency*



$$MDH = f(E) = a_0 \log(E) + a_1$$

Longo & Sestili

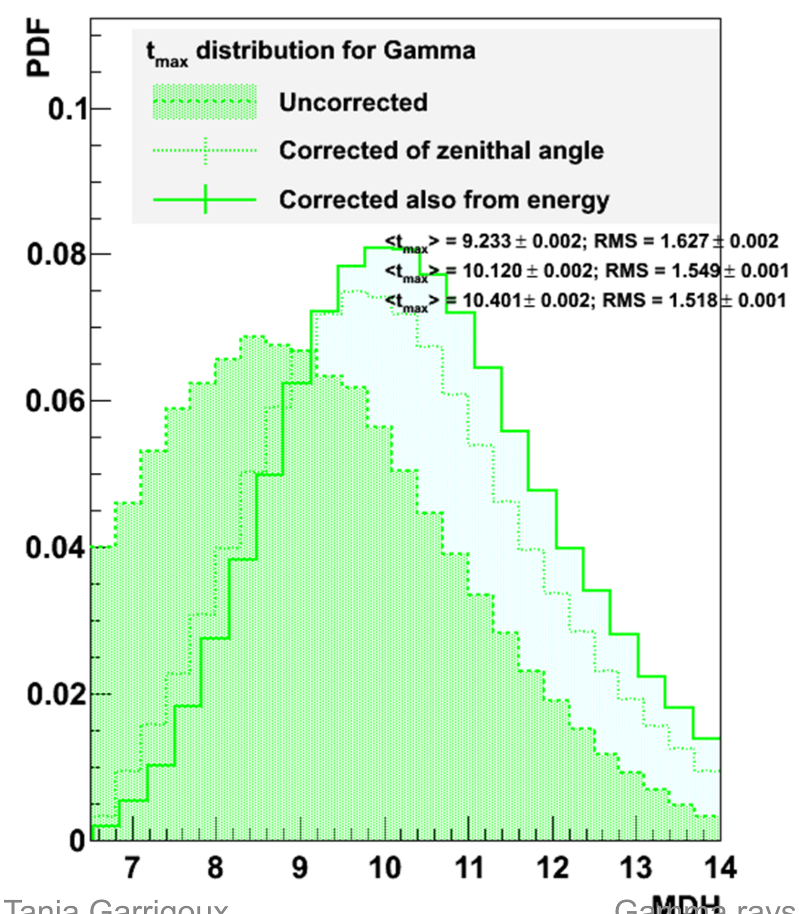
$$t_{max} = 1.0 * (\ln y + C_j)$$

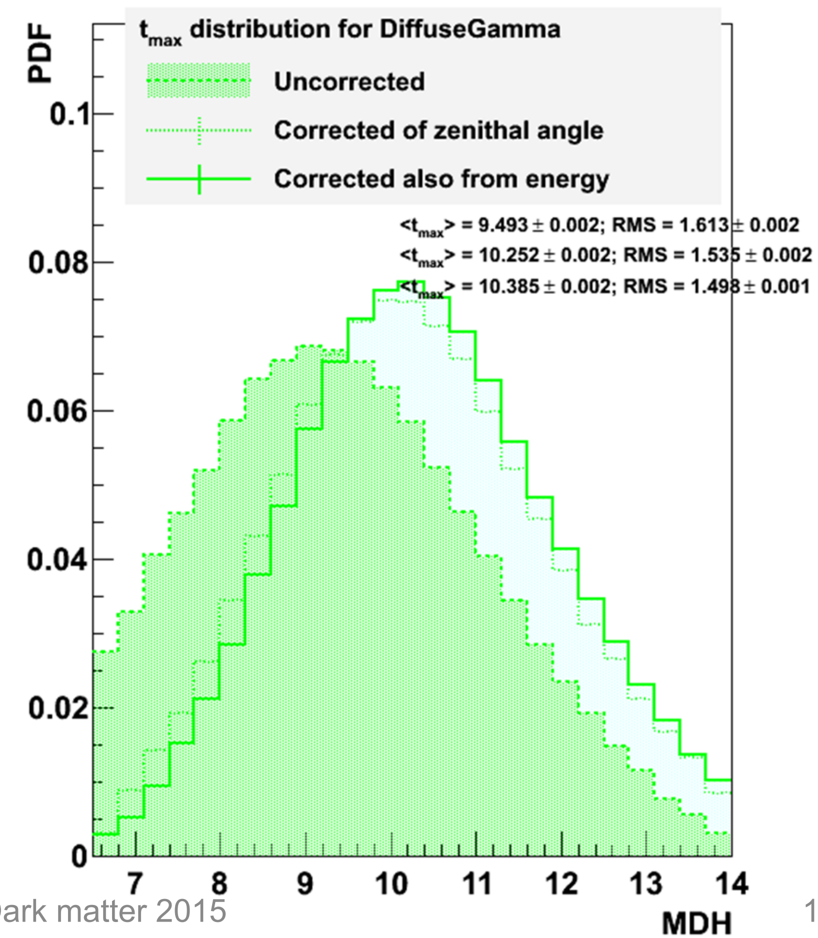
with $C_\gamma = +0.5$, $C_e = -0.5$

$$y = \frac{E}{E_C}; \quad t = \frac{x}{X_0}$$

The discriminant variables

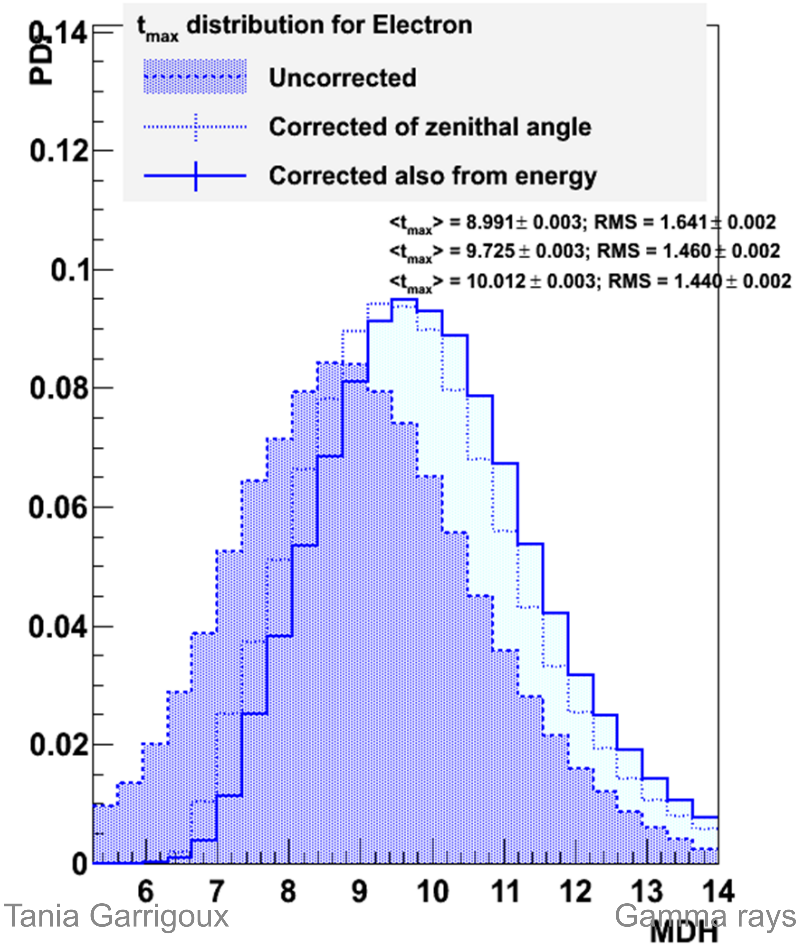
Correcting the discriminant variables: *MDH correction effects*

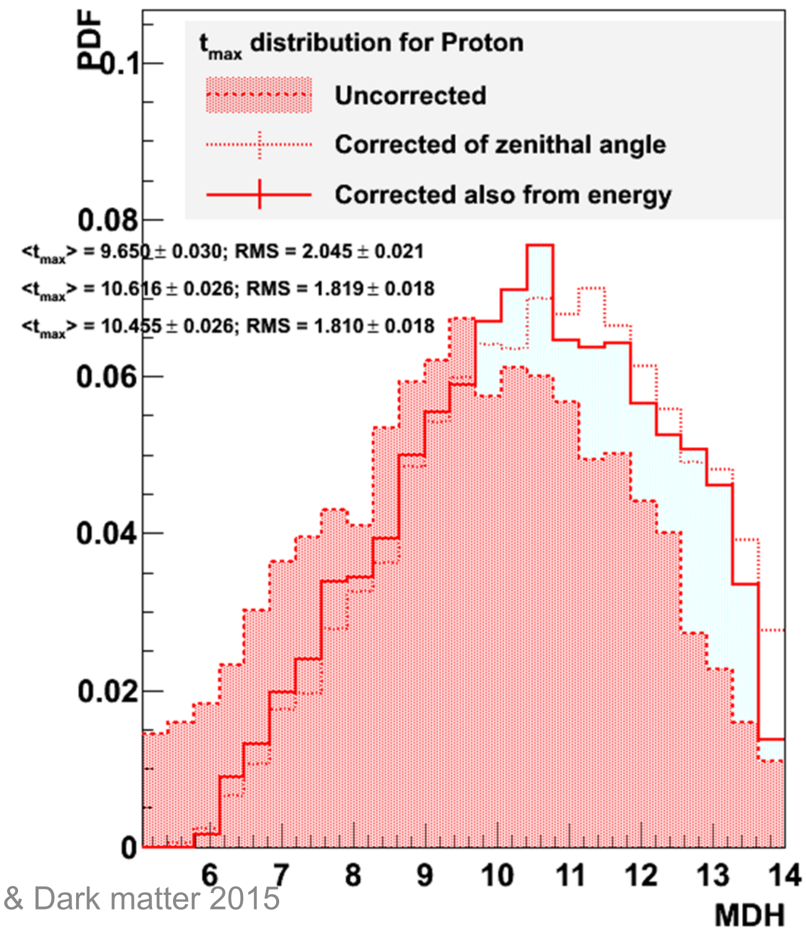




The discriminant variables

Correcting the discriminant variables: *MDH correction effects*





The discriminant variables

Correcting the discriminant variables:

- *zenithal angle dependency*

$$MDH_{corr} = MDH + a * (1 - \cos z)$$

- *MDH energy dependency*

$$MDH_{corr} = MDH - a_0 * \log(E)$$

- *Optical efficiency dependency*

Select PDFs produced for optical efficiency

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The discriminant variables

Correcting the discriminant variables

What about the data?

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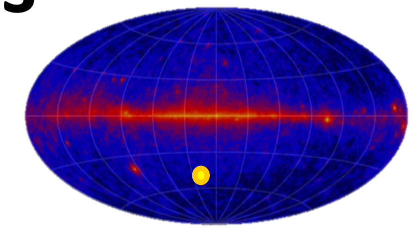
The discriminant variables

Observational data



PKS 2155-304: Active Galactic Nucleus (AGN) at a redhsift of z=0.116, well above the galactic plane ($\delta_{J2000} = -30^{\circ}13'$)

Of interest for different areas, due to its high variability and **flaring activity**, resulting in many observations and publications. Participated in several multi-wavelength campaigns.

Two famous flares in 2006: the **"big" flare** and the **"Chandra" flare**, corresponding to an increased activity of the source, with the gamma clearly dominant in the region of the source. Study of PKS 2155 during these periods allows to have a region enriched in gamma, added to the one of the background with mostly protons

Used runs: the "Chandra" flare's **14 runs (6h32)**. Optical efficiency: 50%

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The discriminant variables

Simulations and data comparison: **purified samples** are needed for each type of particle.

- Source region during flare: enriched in point-like gamma
- Outside the source region: protons predominant

Electrons always present

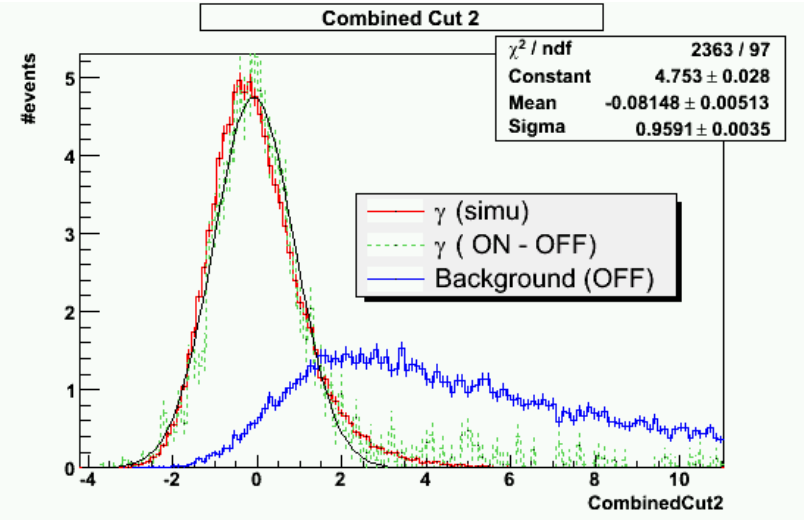
To further purify the samples (for the comparison only) :

$$CombinedCut2 = \left(MSG + \frac{MSL + MSW}{\sqrt{2}} \right) / \sqrt{2}$$

MSL, MSW and MSG are uncorrelated for gamma but not for protons. Cuts on their combination optimize the separation.

- CombinedCut2 < x: protons eliminated. x = 1, 3
- CombinedCut2 > x: EM eliminated. x = 3

The discriminant variables



To further purify the samples (for the comparison only) :

$$\color{red}{CombinedCut2} = \left(MSG + \frac{MSL + MSW}{\sqrt{2}} \right) / \sqrt{2}$$

MSL, MSW and MSG are uncorrelated for gamma but not for protons. Cuts on their combination optimize the separation.

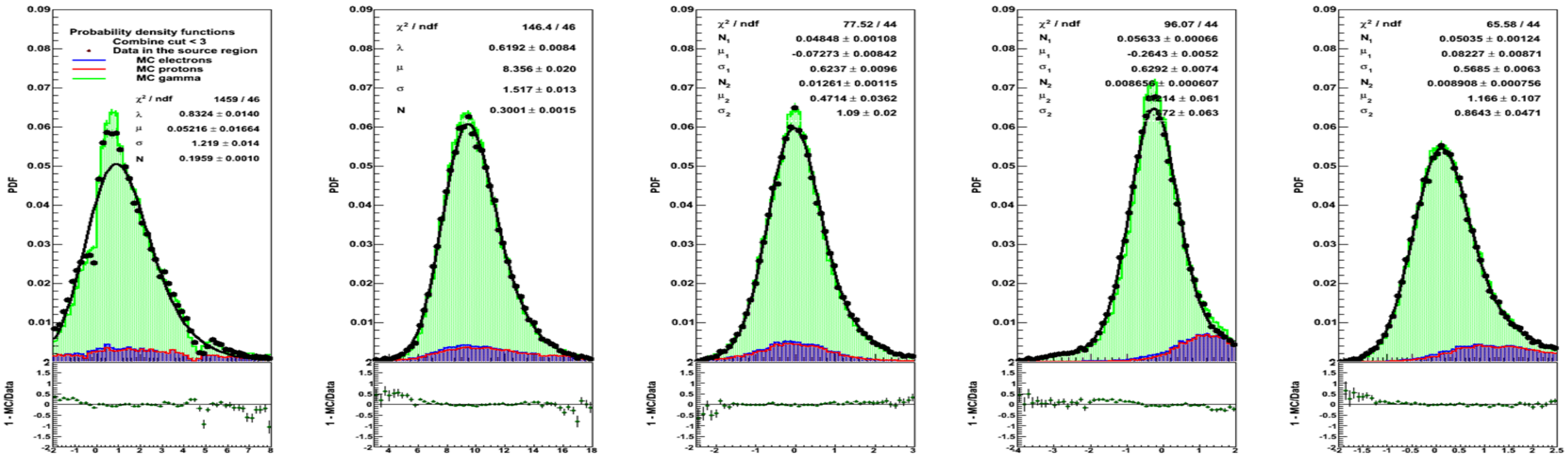
- CombinedCut2 < x: protons eliminated. x = 1, 3
- CombinedCut2 > x: EM eliminated. x = 3

The discriminant variables

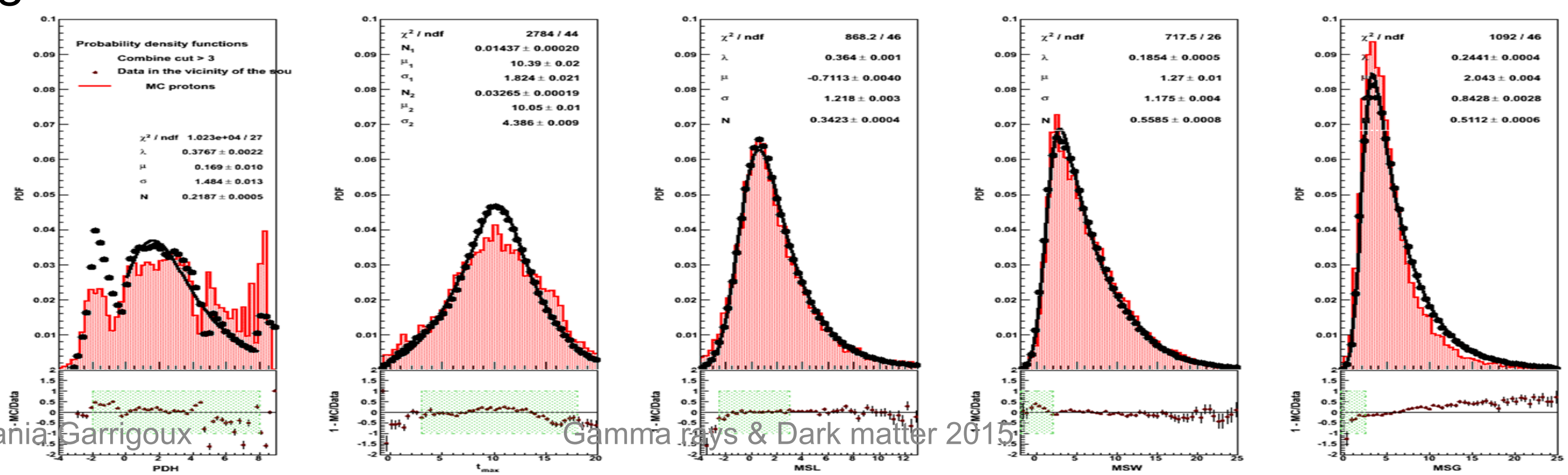
Matching data and simulations:

For the "Chandra" flare

Signal: CombinedCut2<1



Background: CombinedCut2>3



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SPlot

"Unfolding" tool to disentangle the contributions

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The *sPlot* technique

Purpose: disentangle the contribution to the spectrum of the different types of particles detected by HESS

“Unfolding” method which takes into account the correlations between the different contributions through the covariance matrix

Method:

1. Simulated discriminant variables are fitted on the data. The concentration η of each component and its weight in the spectrum are obtained.
2. The spectra are produced and fitted using the weights, acceptance and time of observation, applied on each event

The *sPlot* technique

Test on Toy Montecarlo

The *sPlot* technique

Application on a Toy Montecarlo:

1 000 000 events generated

Simulated concentrations and spectral indices (powerlaw)

$$\varepsilon_\gamma = 0,2\%$$

$$\varepsilon_\mathrm{e} = 2\%$$

$$\varepsilon_\mathrm{p} = 97,8\%$$

$$\Gamma_\gamma = 2$$

$$\Gamma_\mathrm{e} = 4$$

$$\Gamma_\mathrm{p} = 3$$

sPlot →

Obtained number of events:

$$\varepsilon_\gamma = (0,197 \pm 0.003)\%$$

$$\varepsilon_\mathrm{e} = (2.005 \pm 0.010)\%$$

$$\varepsilon_\mathrm{p} = (97,798 \pm 0.070)\%$$

$$\Gamma_\gamma = 2,006 \pm 0,023$$

$$\Gamma_\mathrm{e} = 3,985 \pm 0,016$$

$$\Gamma_\mathrm{p} = 3,001 \pm 0,001$$

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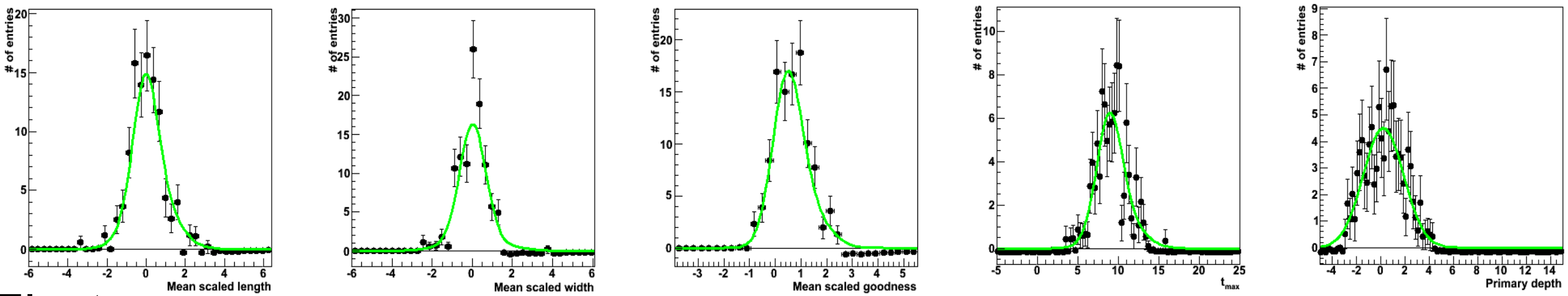
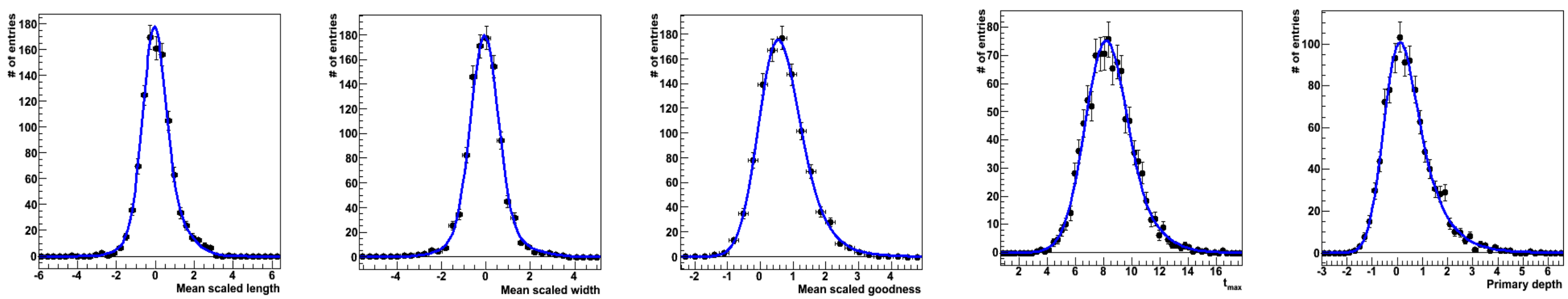
The *sPlot* technique

PDF fit on simulated data

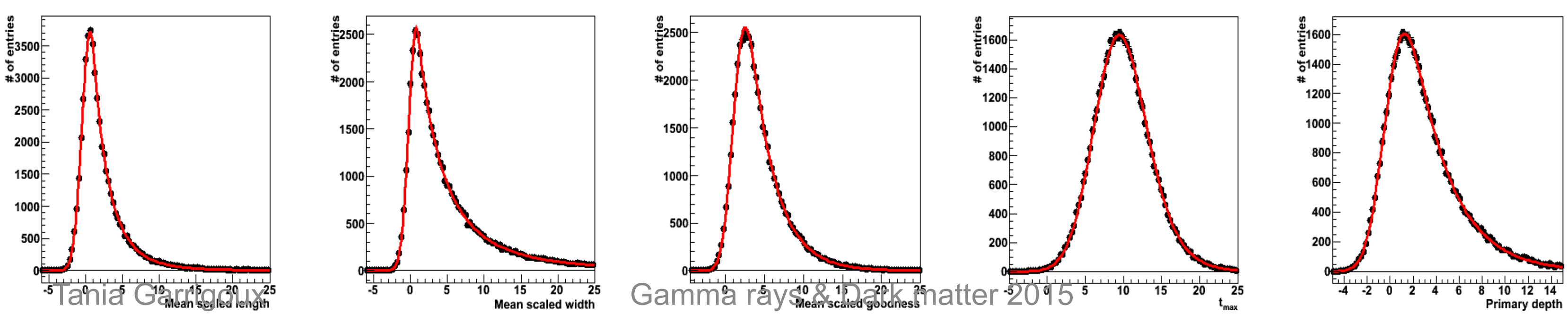
Diffuse γ:



Electrons:



Protons:

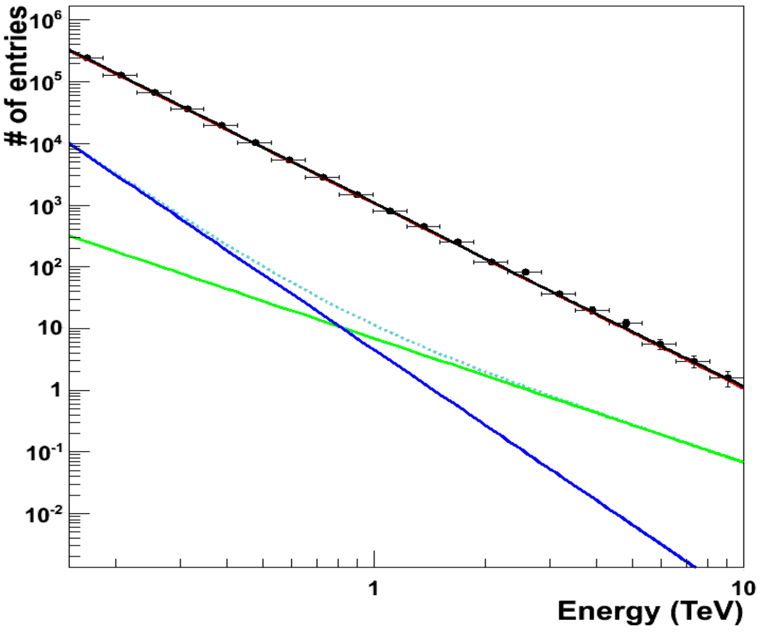


The *sPlot* technique

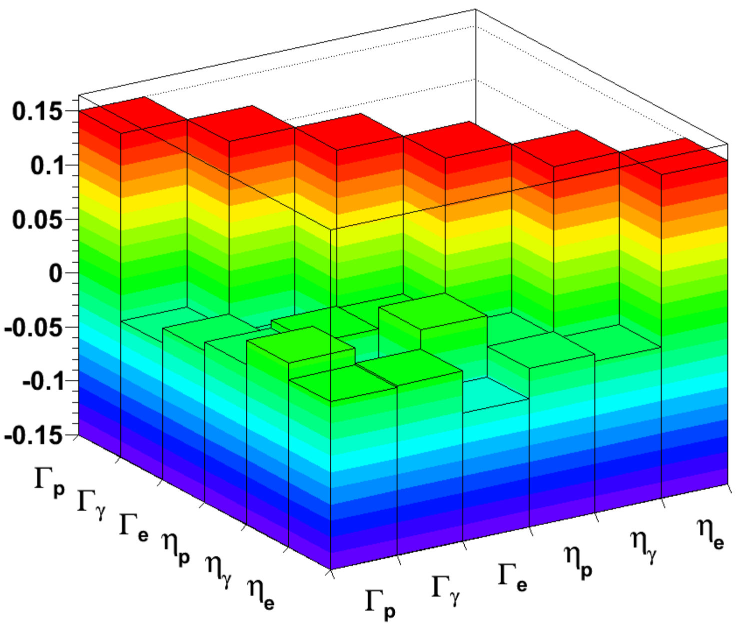
Application on a Toy Montecarlo:

1 000 000 events generated

Obtained spectrum



Correlation matrix



The *sPlot* technique

Test on PKS 2155-304

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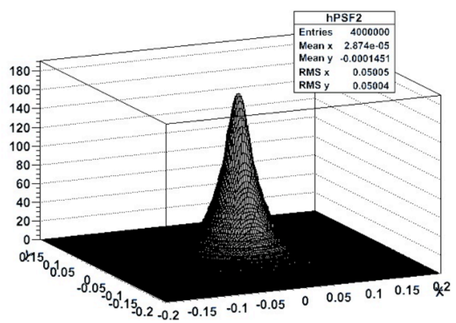
Modelling a point-like source with an enhanced PSF

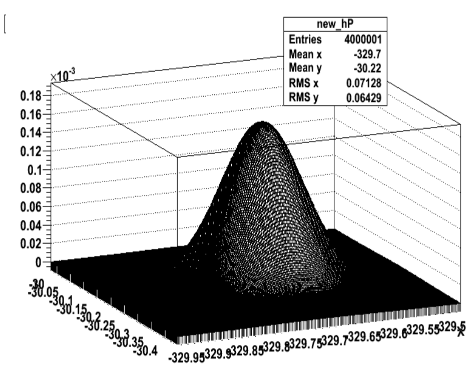
- Keep the global shape of the PSF which is expected to be the best representation of a point like source

- Convoluted with Gaussian distribution to smear the distribution. $PSF(E, Zenith, OffAxis, OpticalEff) \circ Gauss(\sigma)$

- Fit to determine the width (σ_x, σ_y) of the Gaussian function



PSF



Convoluted

Fitting PKS 2155 – 304 during the "Chandra flare" with the PDF

Gamma in source in a radius of 0.3°

Convoluted PSF fitting technique, no cuts used:

$$N_\gamma = 24\,681 \pm 157$$

PDF fit on the data, no cuts used:

$$N_\gamma = 24\,614^{+529}_{-532}$$

Convoluted PSF fitting technique, using standard method cuts:

$$N_\gamma = 22\,553 \pm 150$$

Standard method (ring background):

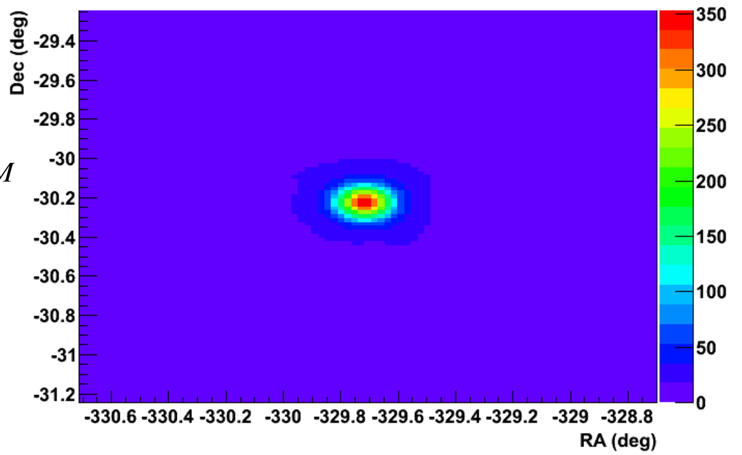
$$N_\gamma = 22\,631 \pm 150$$

PDF fit on the data, using the functions:

$$L' = \eta_p f'_p + \eta_e f'_e + (1 - \eta_e - \eta_p) f'_\gamma \qquad L = \eta_p f_p + \eta_{EM} f_{EM}$$

and minimizing the extended likelihood:

$$\sum_{j=1}^{N_A} -\log(L_A^j) + \sum_{j=1}^{N_B} -\log(L_B^j) + \sum_{k=A}^{B} (N_k^{\exp} - N_k \log(N_k^{\exp}))$$



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Conclusions

- The behaviour of the discriminant variables is understood, and there is a relatively good agreement between simulations and data
- The preliminary results obtained with the *sPlot* technique seem promising

Next steps:

- Helium to be added for characterisation of the hadronic component
- Apply on data: different regions

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Thank you!

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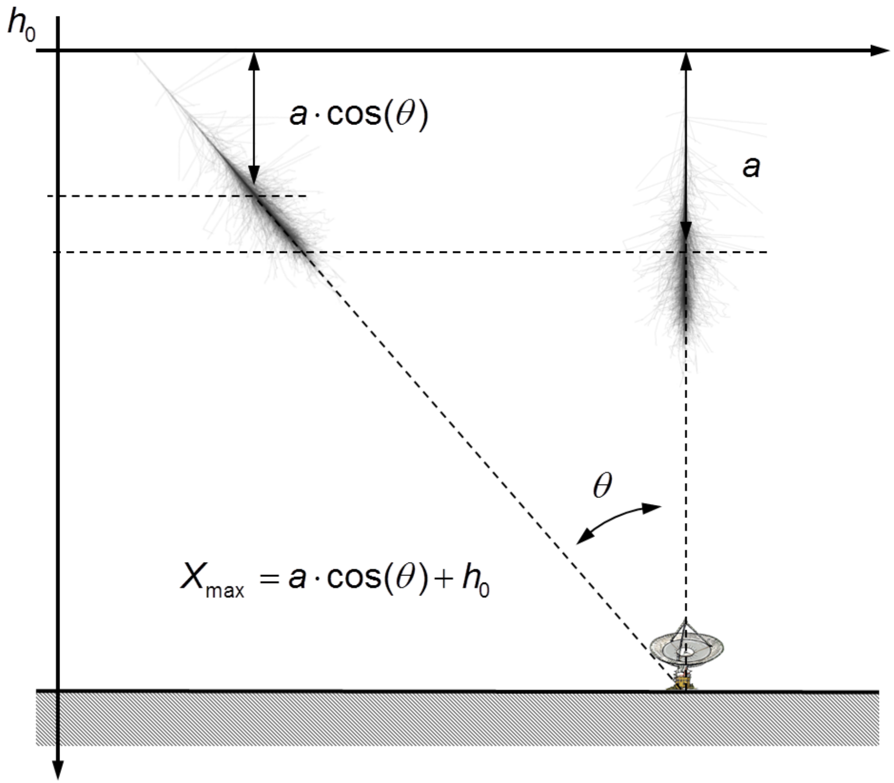
Back up

The discriminant variables

Correcting the discriminant variables:
zenithal angle dependency



The discriminant variables

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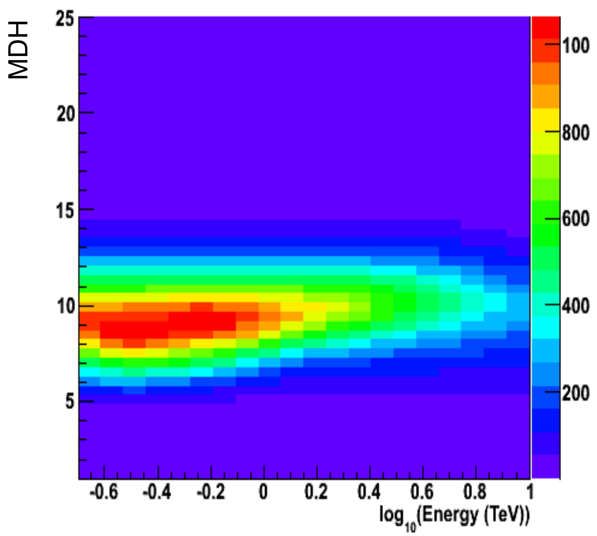
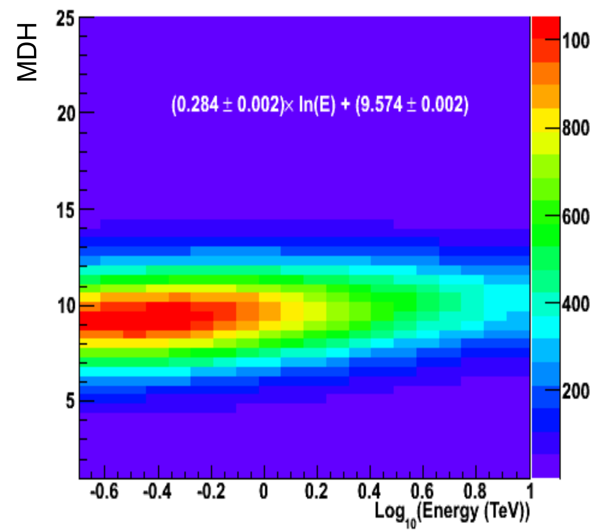
Correcting the discriminant variables: *MDH energy dependency*

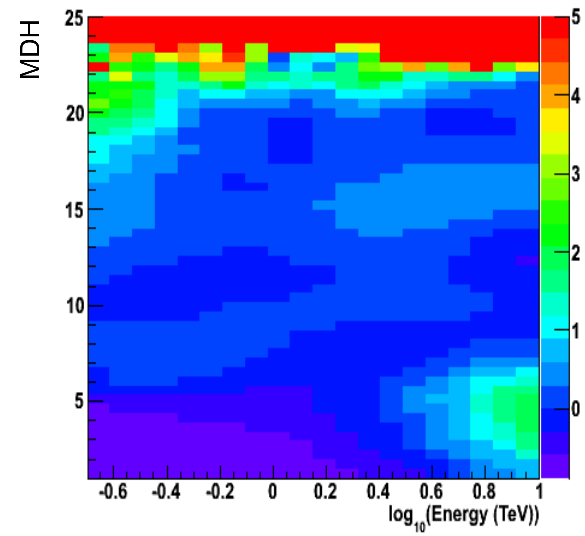
Simulated diffuse photons



Model



Residue



$$MDH = a_0 \log(E) + a_1$$

$$MDH = (0.284 \pm 0.002)\log(E) + (9.574 \pm 0.002)$$

$$MDH_{corr} = MDH - a_0 * \log(E)$$

The discriminant variables

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Correcting the discriminant variables: *Optical efficiency dependency*