Differences in Electron and Gamma Induced Air Showers

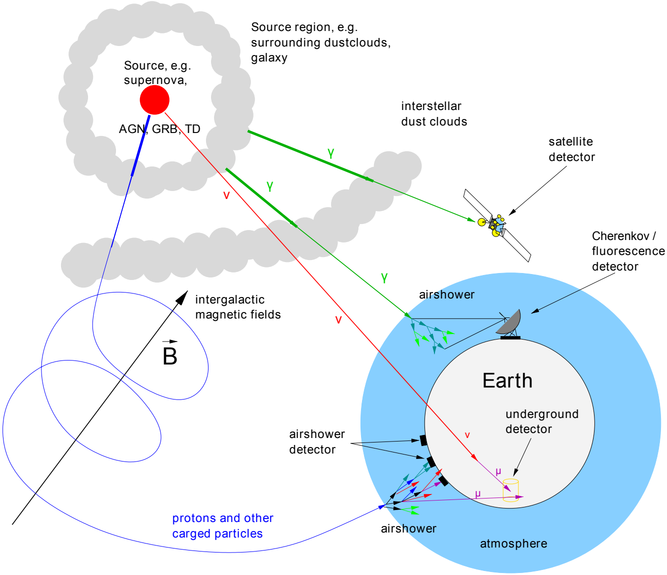
Marcel C. Strzys

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Astroteilchenschule Obertrubach-Bärnfels

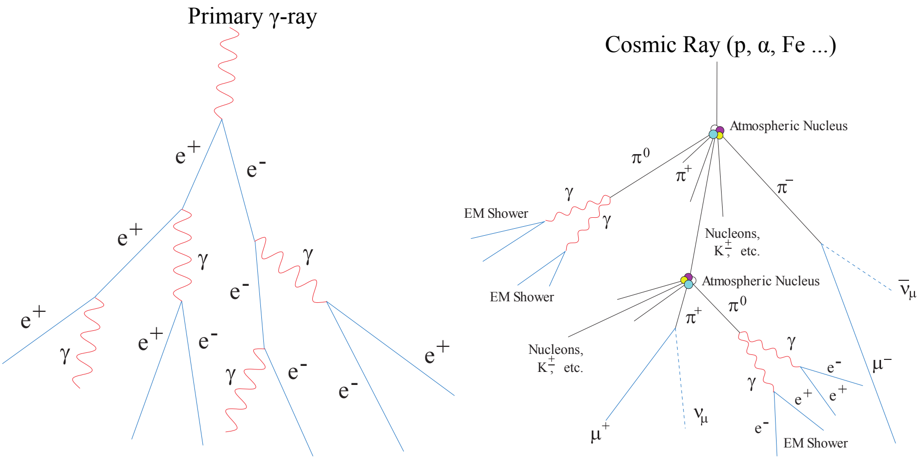
7 October 2013

Background in gamma ray astronomy



[Wag04]

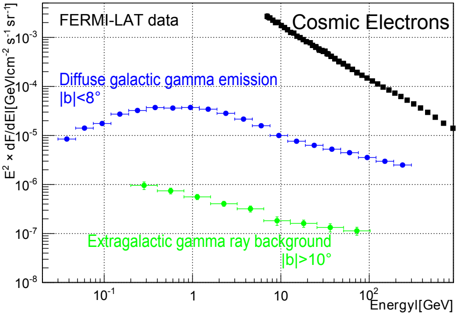
Background in gamma ray astronomy



[Wag06]

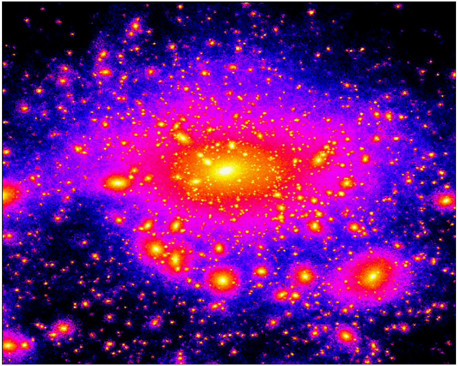
What can be studied if we had another discrimination tool than arrival direction

- Galactic and extragalactic diffuse gamma rays (data points from Fermi-LAT)
- Extended sources, e.g. galactic gamma ray halo from Dark Matter annihilation or galaxy cluster



What can be studied if we had another discrimination tool than arrival direction

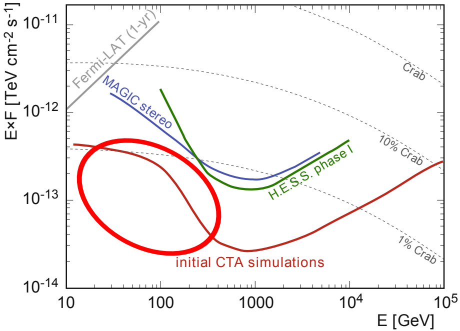
- Galactic and extragalactic diffuse gamma rays (data points from Fermi-LAT)
- Extended sources, e.g. galactic gamma ray halo from Dark Matter annihilation or galaxy cluster
- Sensitivity of Cherenkov telescopes for low energies



[MK07]

What can be studied if we had another discrimination tool than arrival direction

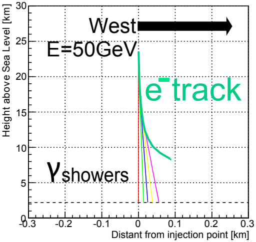
- Galactic and extragalactic diffuse gamma rays (data points from Fermi-LAT)
- Extended sources, e.g. galactic gamma ray halo from Dark Matter annihilation or galaxy cluster
- Sensitivity of Cherenkov telescopes for low energies

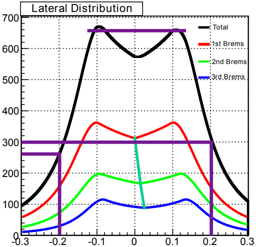


[LW12]

Methods to discriminate γ/e^-

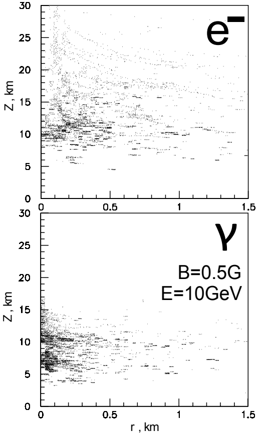
1. Geomagnetic effect





Very small effect

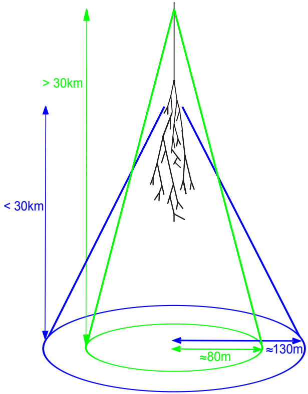
2. Height of the shower maximum



[SAA06]

Some separation power

3. Cherenkov light at high altitude



Most promising effect

Effect of geomagnetic field

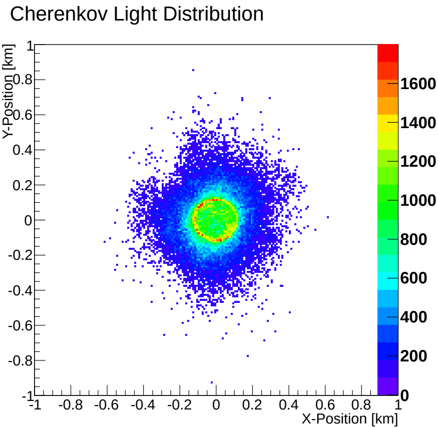
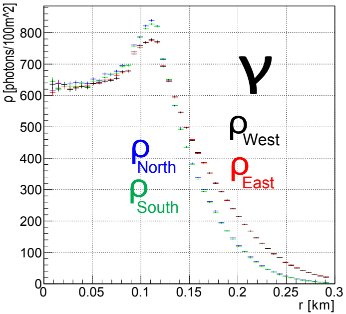


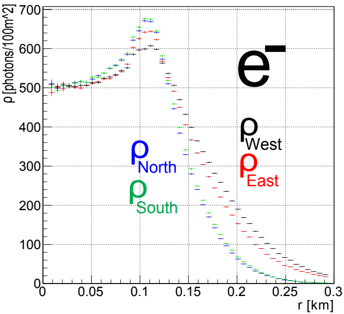
Figure: Single 50 GeV γ event

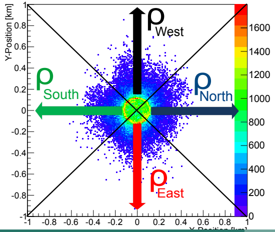
Air shower simulation studies with CORSIKA

- Observing the Cherenkov photon distribution (x,y-coordinate)
- Obsl. of MAGIC Telescope (2200 m) and magnetic field over La Palma
- 10m x 10m pixel
- Primaries injected from zenith
- 1000 events for each particle and energy

Lateral distribution of $\rho_{\text{East, South, West, North}}$ for 50 GeV showers





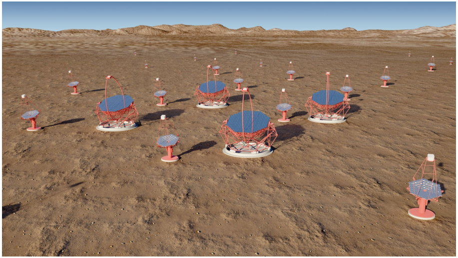


- Electron showers show asymmetry in East-West direction: Higher hump in east, more intensive slope in west.
- Effect very small, even at low energies

Height of the shower maximum

Simulation for CTA

- 200 000 events for each shower type simulated with CORSIKA and sim_telarray
- 2000m observation level
- magnetic field mixture of La Palma and Namibia
- Configuration E

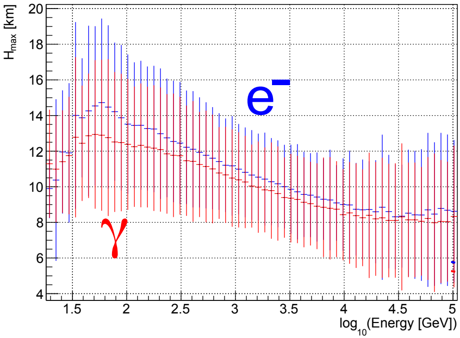


[Pér12]

Height of the shower maximum

Results

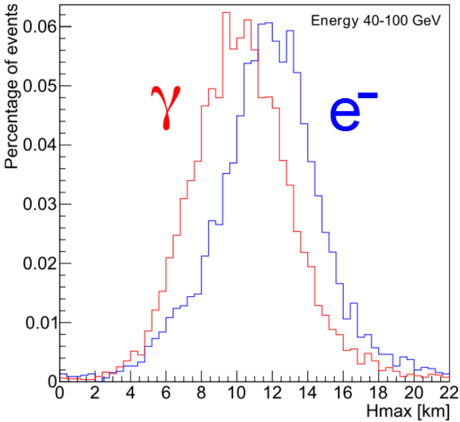
- ⇒ Difference decreases logarithmically with energy
- ⇒ Just some separation power even at optimal range
- ⇒ Q-factor $= N_{signal}/\sqrt{N_{bg}}$ maximal 1.04



Height of the shower maximum

Results

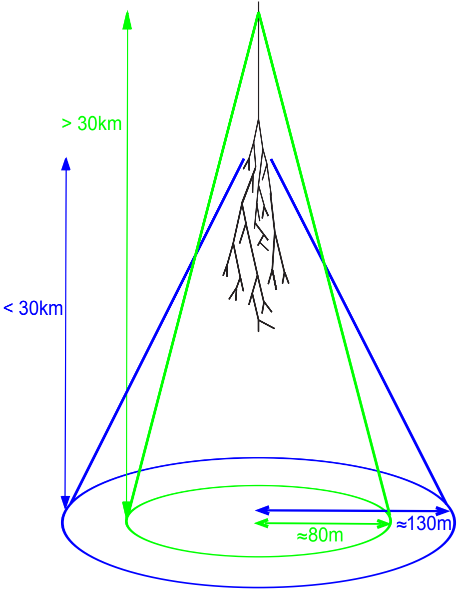
- ⇒ Difference decreases logarithmically with energy
- ⇒ Just some separation power even at optimal range
- ⇒ Q-factor $= N_{signal} / \sqrt{N_{bg}}$ maximal 1.04



Direct Cherenkov Light - DCL

Simulation with Corsika

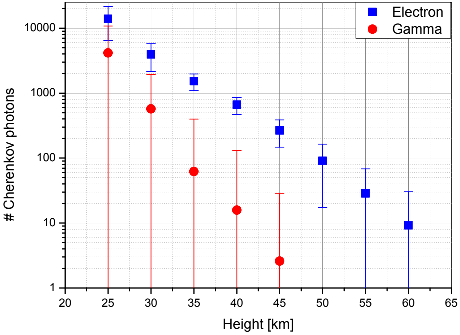
- In contrast to hadronic and γ-ray events e^- have not clear first interaction point
- Optimal height may be around 30 km
- Photon vs. Height: averaged over 1000 events per particle of 200 GeV, but similar for different energies
- DCL arrives in very small time slot and under small angle



Direct Cherenkov Light - DCL

Simulation with Corsika

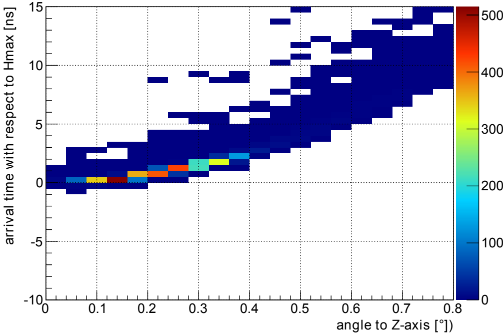
- In contrast to hadronic and γ-ray events e^- have not clear first interaction point
- Optimal height may be around 30 km
- Photon vs. Height: averaged over 1000 events per particle of 200 GeV, but similar for different energies
- DCL arrives in very small time slot and under small angle



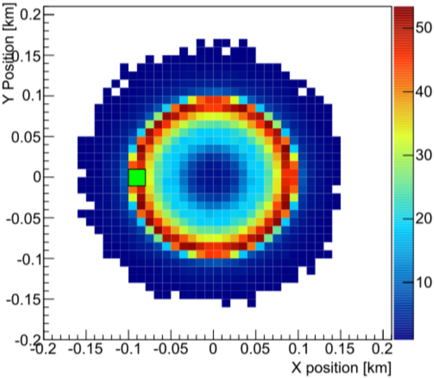
Direct Cherenkov Light - DCL

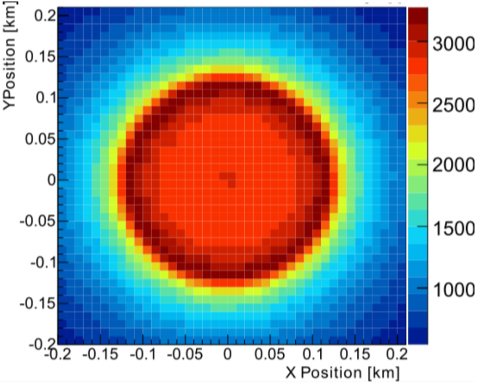
Simulation with Corsika

- In contrast to hadronic and γ-ray events e^{-} have not clear first interaction point
- Optimal height may be around 30 km
- Photon vs. Height: averaged over 1000 events per particle of 200 GeV, but similar for different energies
- DCL arrives in very small time slot and under small angle



Direct Cherenkov Light

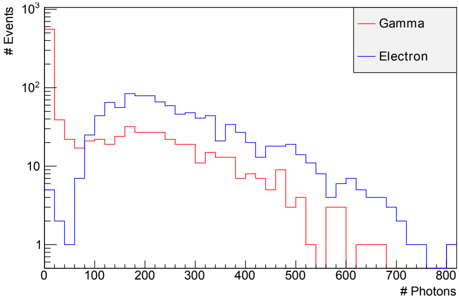




Direct Cherenkov Light - Toy model

Toy model

- Only photons arriving 2 ns before and after the shower maximum
- Arriving within an "dish" (20 m diameter) placed at 100m from core
- Arrival angle $< 25^\circ$
- Without magnetic field effects



Summary

Methods for gamma/e^{-} separation:

- Asymmetry due to magnetic field too small
- Separation by Hmax is low,
  but may work on statistical basis or with better reconstruction
- Direct Cherenkov Light shows promising hints,
  worth to be investigated further

Thank you for your attention and interest!

Backup Slides

Lateral distribution of Cherenkov photons

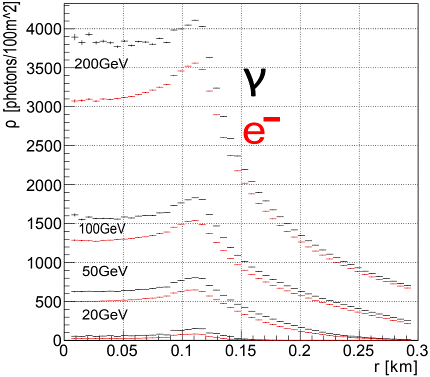


Figure: Averaged lateral distribution of 1000 events for several energies.

- Intensity for gamma shower is higher than that for electron shower with the same energy
- Feature not usable as shower energy is unknown
- Shape of the lateral distribution is similar for both shower types

Height of the shower maximum

$$t_{max}(E) = 1.01 X_0 \left[\ln\left(\frac{E}{E_c}\right) - n \right], \text{ with } n = \begin{cases} -0.5, & \text{for } \gamma \\ 0.5, & \text{for } e^{\pm} \end{cases}$$

$$z_{max} = -h_s \ln\left(\frac{X_0\, t_{max}}{h_0\, \rho_0}\right)$$

$$\Rightarrow \Delta(E) = h_s \ln\left[1 + \frac{1}{2\left(\ln\left(\frac{E}{E_c}\right) - 1\right)}\right] \approx \frac{h_s}{2\left(\ln\left(\frac{E}{E_c}\right) - 1\right)}$$

$\Rightarrow$ Difference descrease logaritmically with energy

Bibliography I

LORENZ, E. ; WAGNER, R.:
Very-high energy gamma-ray astronomy - A 23-year success story in high-energy astroparticle physics.
In: *EPJ H (The European Physical Journal H)* 37 (2012), Nr. 3, S. 459–513.
http://dx.doi.org/10.1140/epjh/e2012-30016-x. –
DOI 10.1140/epjh/e2012–30016–x

MAYER, Lucio ; KAZANTZIDIS, Stelios:
Simulations show how the darkest galaxies in the universe get that way and appear to resolve a serious problem with the prevailing theory of how the universe evolves.
http://www.psc.edu/science/2007/darkgalaxies/.
Version: 2007. –
Latest date of access 07. Oct 2013

Bibliography II

Pérez, Gabriel:
Conceptional Images of CTA.
Instituto de Astrofísica de Canarias (Servicio Multimedia).
http://www.observatorio-cta.es/index.php?option=com_content&view=article&id=82&Itemid=82.
Version: 2012. –
Latest date of access 25. Apr 2013

Sahakian, V. ; Aharonian, F. ; Akhperjanian, A.:
Cherenkov light in electron-induced air showers.
In: *Astroparticle Physics* 25 (2006), Nr. 4, 233 - 241.
http://dx.doi.org/10.1016/j.astropartphys.2006.02.003. –
DOI 10.1016/j.astropartphys.2006.02.003. –
ISSN 0927–6505

Bibliography III

WAGNER, Wolfgang:
Design and Realisation of a new AMANDA Data Acquisition System with Transient Waveform Recorders.
Dortmund, Germany, Universität Dortmund (now TU Dortmund), Diss., October 2004

WAGNER, Robert M.:
Measurement of Very High Enery Gamma-Ray Emission from Four Blazars Using the MAGIC Telescope and a Comparative Blazar Study.
Munich, Germany, Technische Universität München, Diss., 2006