DISENTANGLING ATMOSPHERIC CASCADES STARTED BY GAMMA RAYS FROM COSMIC RAYS WITH CORSIKA

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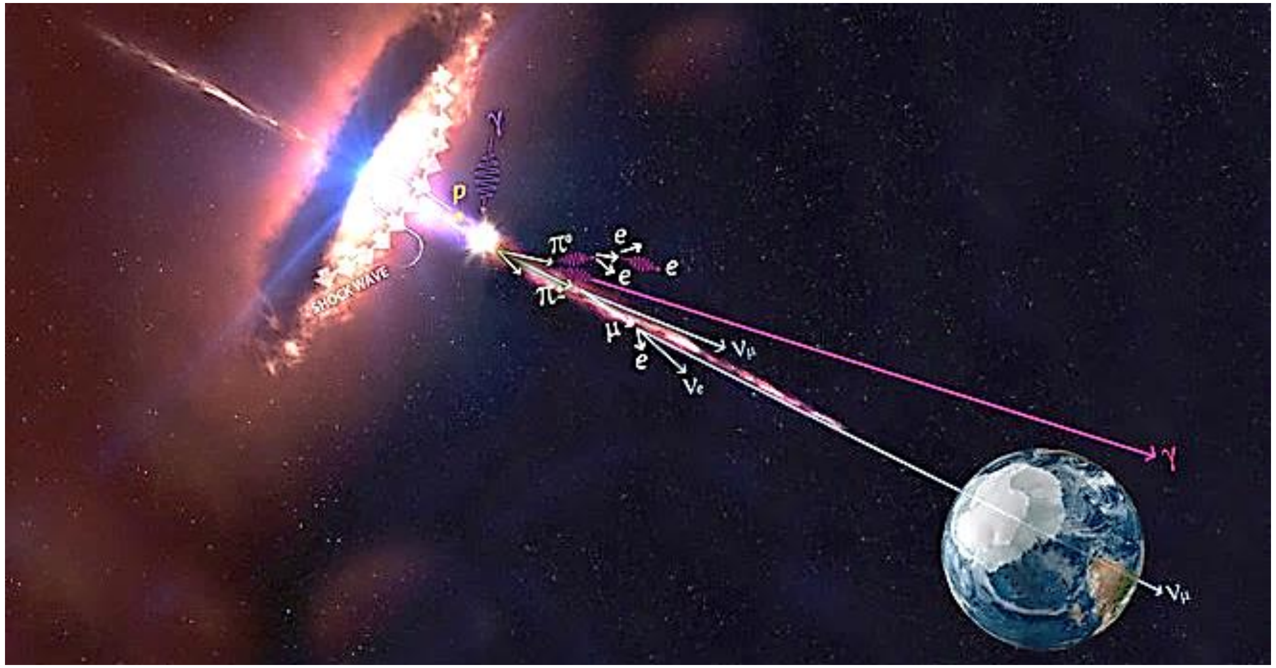
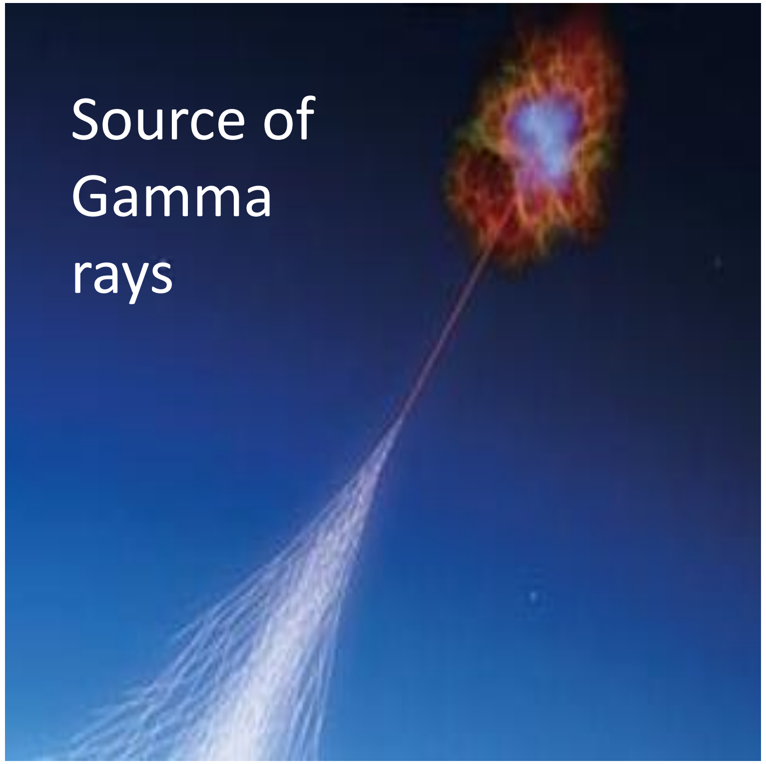
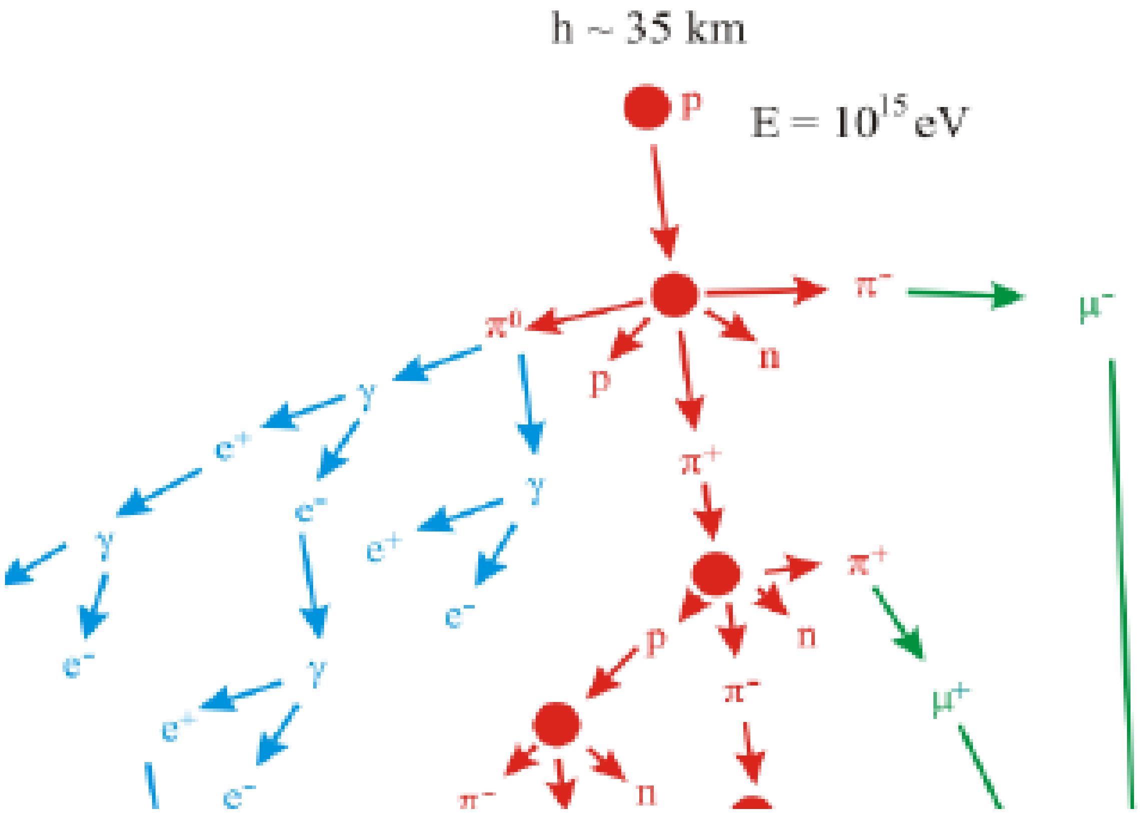


COSMIC RAYS & GAMMA RAYS.

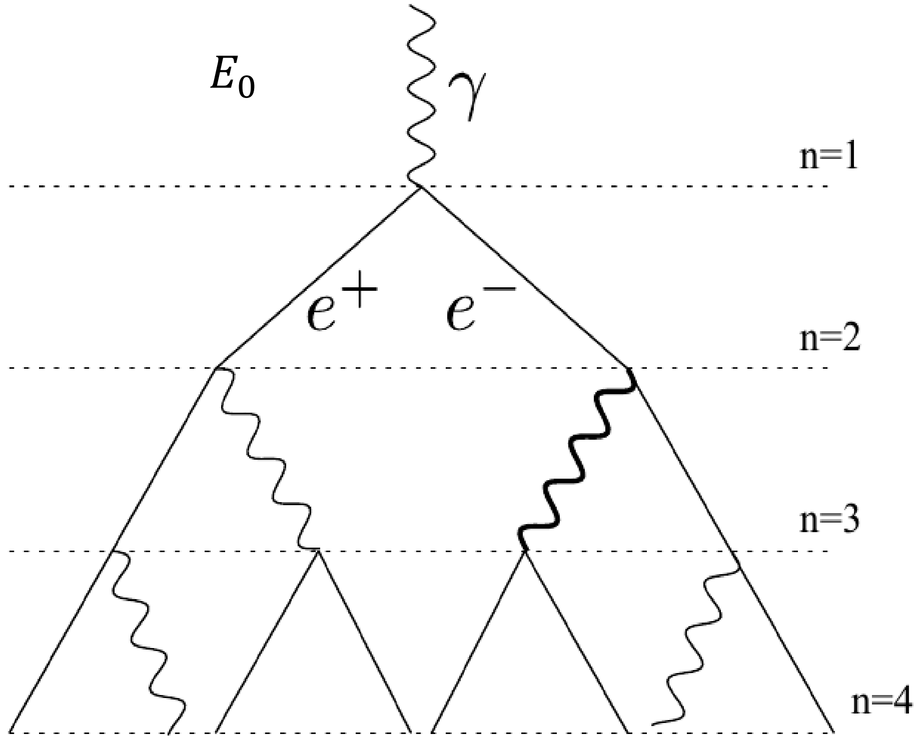




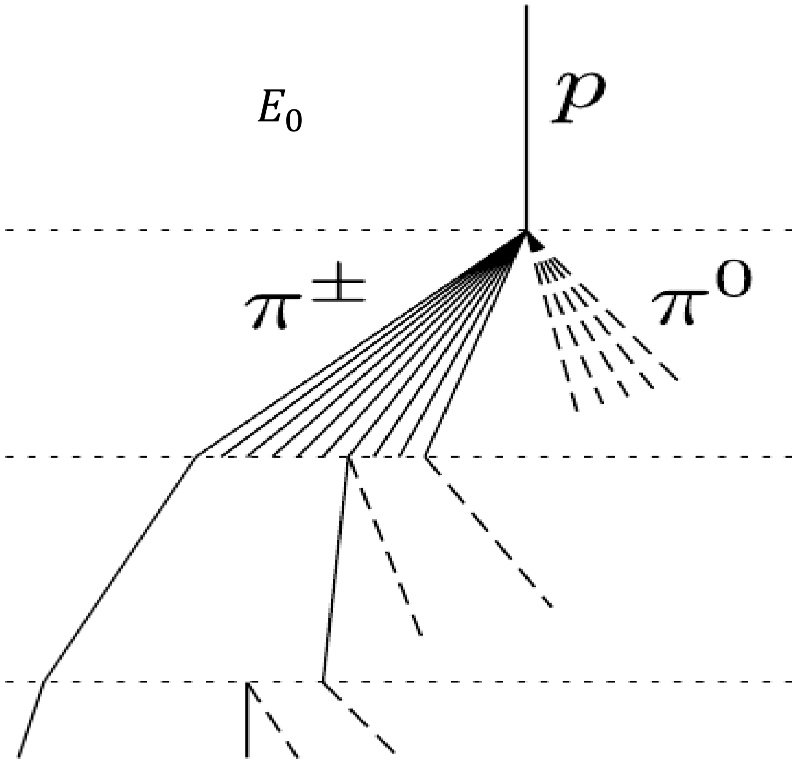
- Electromagnetic Shower ($\bar{e}$, $e^{+}\gamma$).
- Hadronic Shower (p^{+}, Fe, etc.).
- Muonic Shower.

EXTENSIVE AIR SHOWERS (EAS)

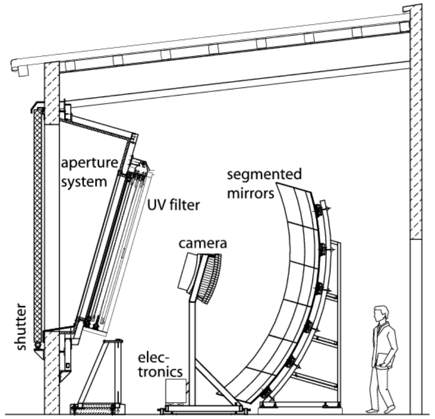
Primary particle:
Photon - Electromagnetic



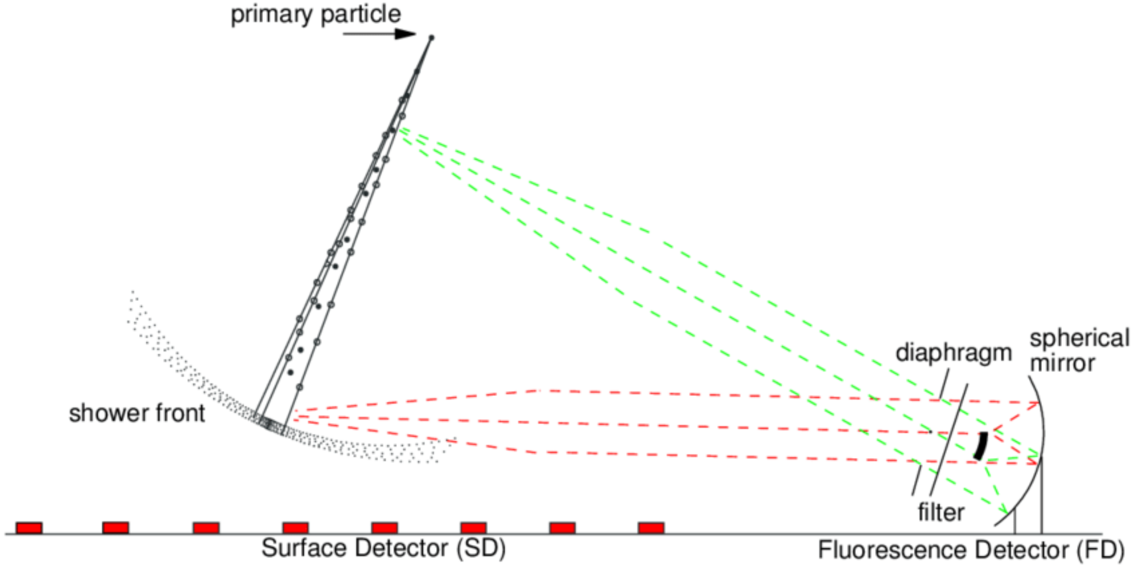
Primary Particle:
Proton - Hadronic.



COSMIC AND GAMMA RAYS DETECTORS

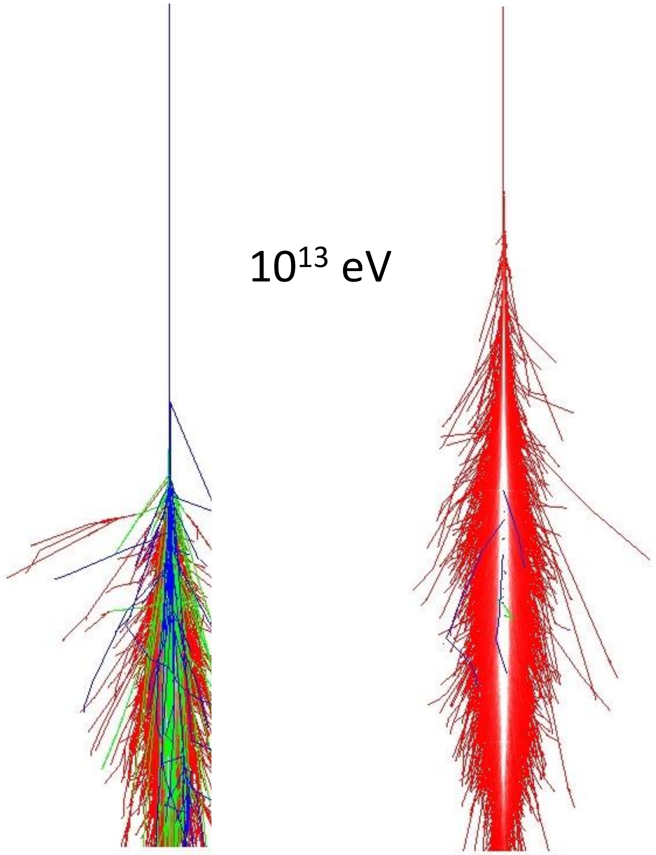


PIERRE AUGER OBSERVATORY



SIMULATION WITH CORSIKA

COsmic Ray SImulation for KAscade: extensive air showers initiated by cosmic ray particles.



Protons — Cosmic rays

Photons — Gamma rays

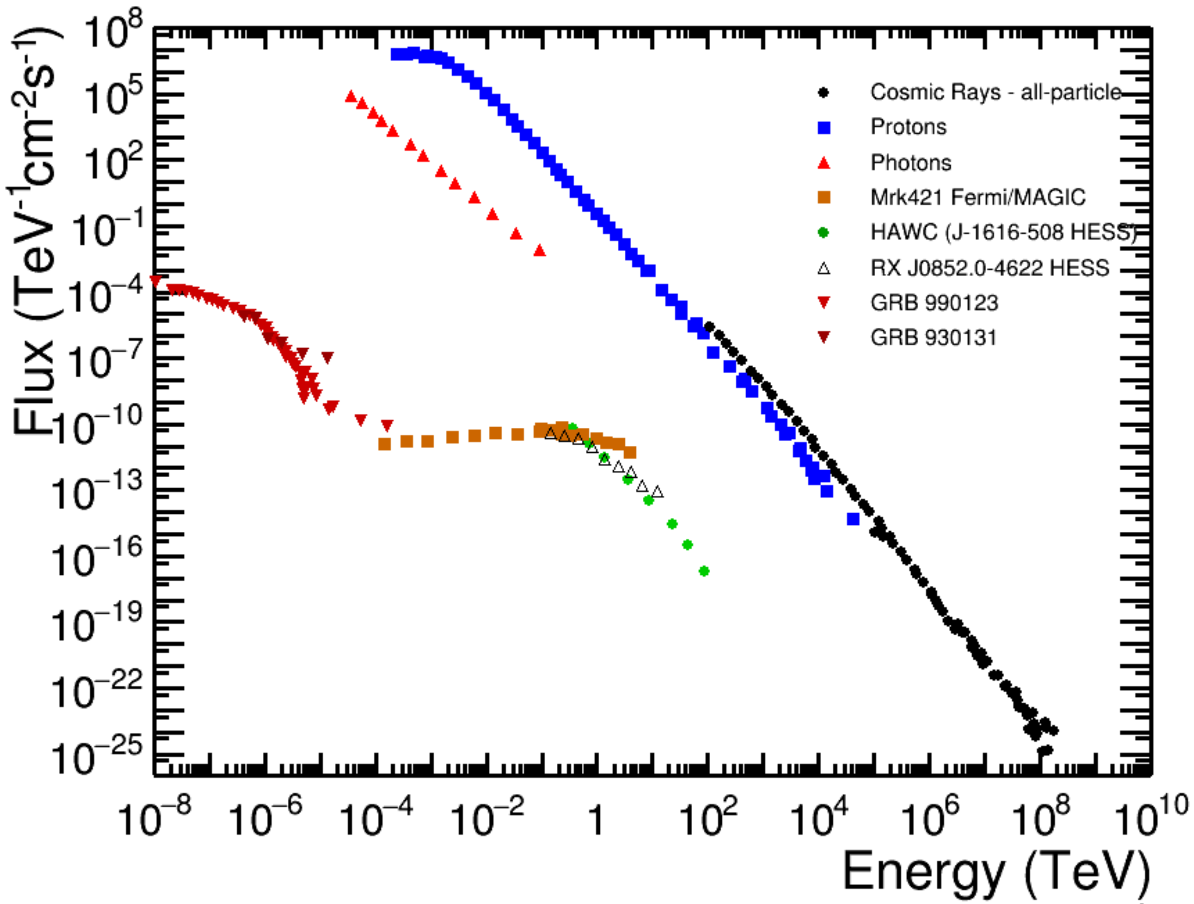
Red:
photons, electrons and positrons.

Green:
muons and antimuon.

Blue:
hadrons.

SIMULATION WITH CORSIKA: Some Considerations

Power Law $F(E) \propto E^{-\alpha}$



Comparison of cosmic ray [11] and gamma-ray fluxes from different sources from [12], [13], [14], [15], [16], [17], [18] and [19].

Cosmic ray flux is 10^6 times greater than gamma rays at 10^1 TeV.

Energy range: $10^2 - 10^5$ GeV.

Inclination: Vertical.

Observation Level: 1400 masl.

We consider:

10^4 photons (gamma rays)

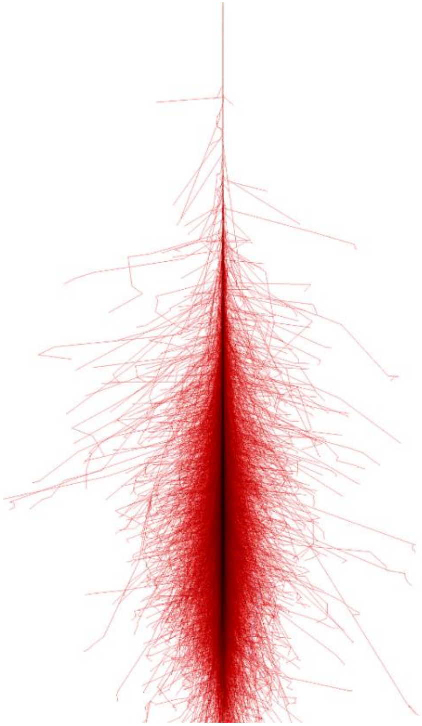
10^6 protons (cosmic rays)

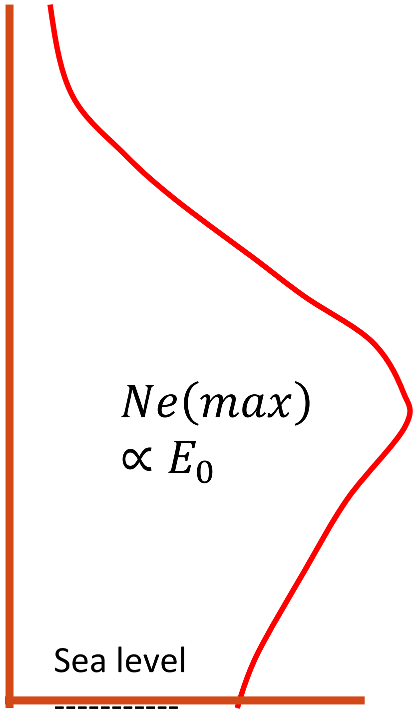
Spectral index:

2 for photon

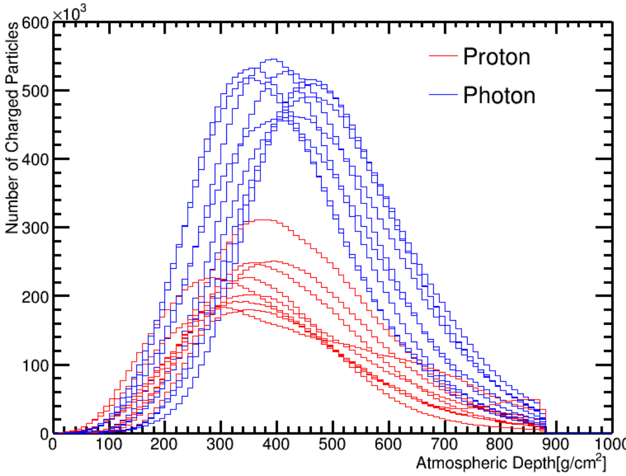
2.7 for proton

SIMULATION WITH CORSIKA: Data Analysis





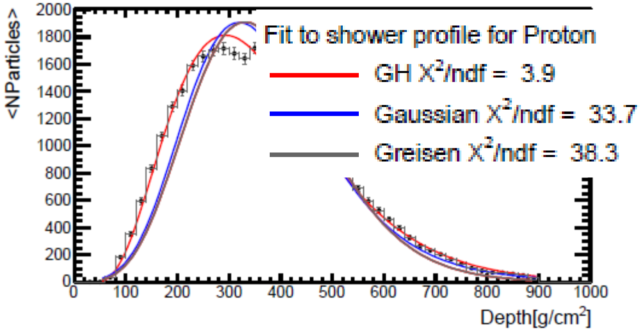
Longitudinal Profile Fitting



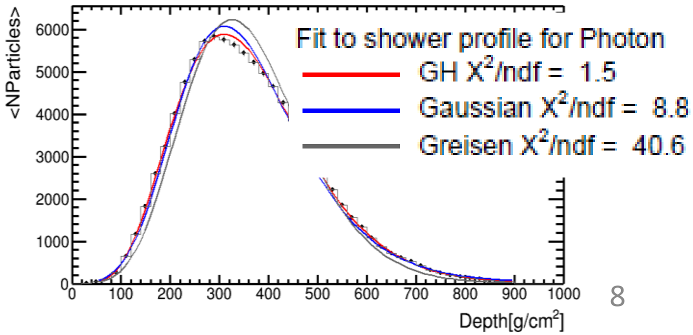
Gaisser-Hillas Function

$$N(X) = N_{max}\left(\frac{X - X_0}{X_{max} - X_0}\right)^{\frac{X_{max}-X_0}{\lambda}} e^{\frac{X_{max}-X}{\lambda}}$$

Proton at 10^2 GeV

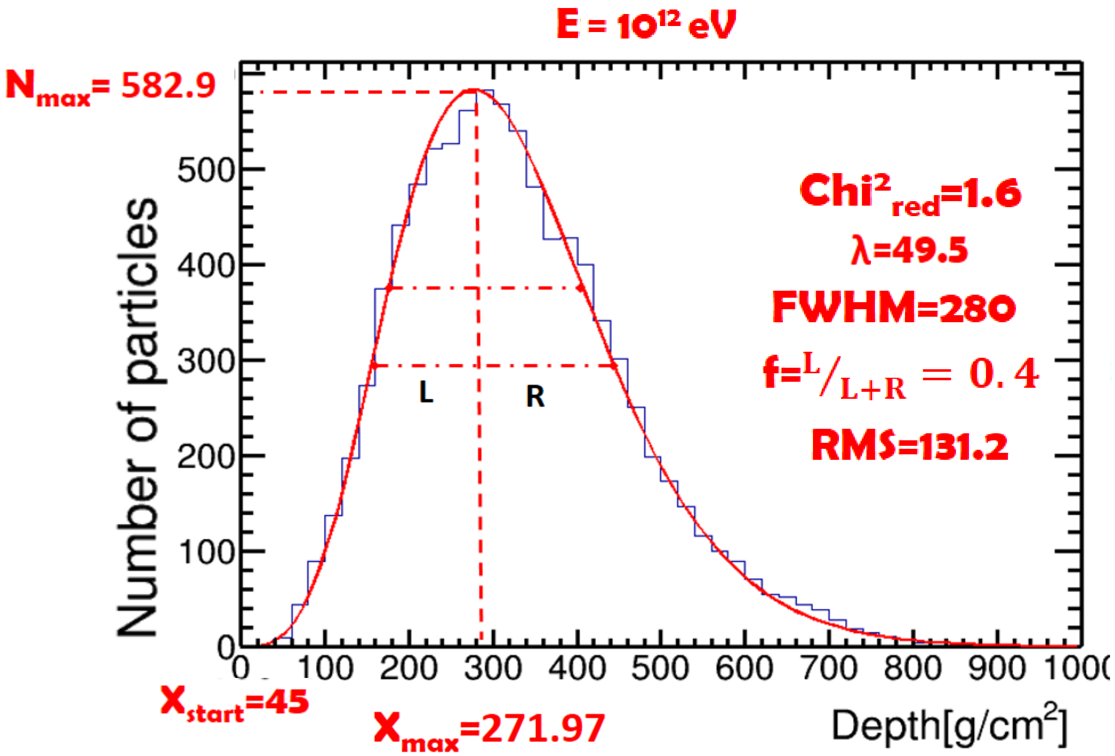


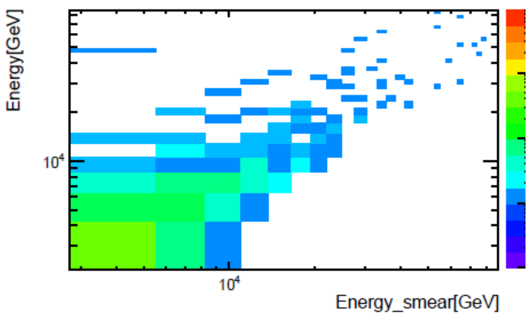
Photon at 10^2 GeV



SIMULATION WITH CORSIKA: Longitudinal Profile Parameters

- Energy E.
- Shower maximum depth X_{max}.
- First point of interaction X_0.
- Maximum number of charged particles N_{max}
- Shower decay length λ.
- Reduce Chi-square of the fit X^2_{red}
- Point of shower start X_{start}.
- Root mean square RMS.
- Shower full width at half-maximum FWHM.
- Shower asymmetry parameter f.

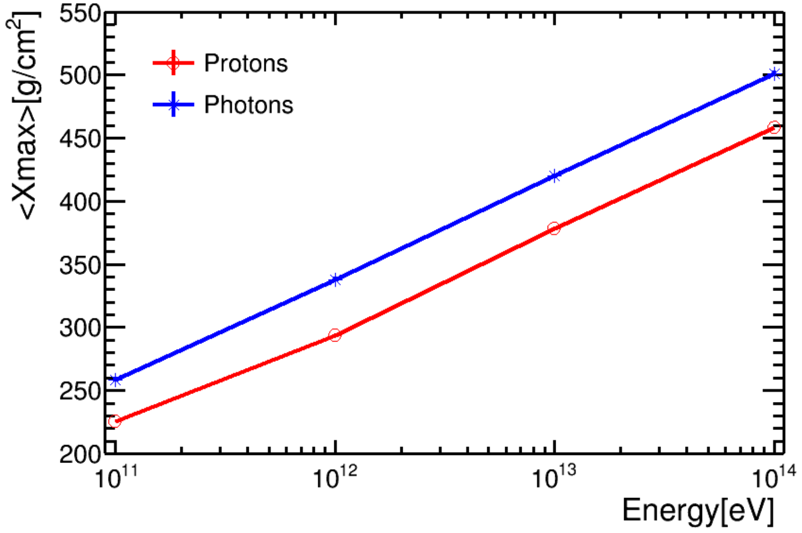


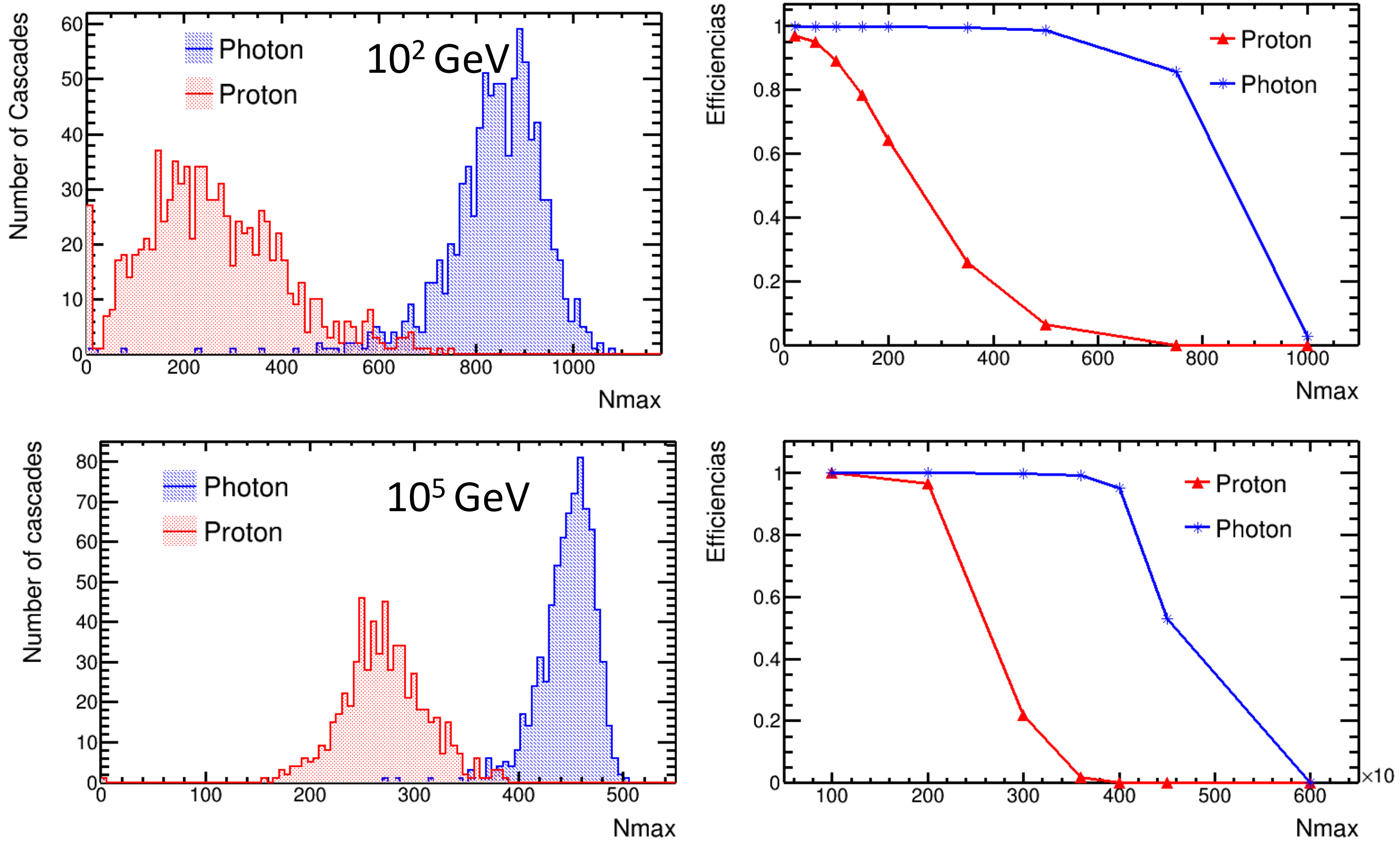


Energy with Smearing vs Energy

SIMULATION WITH CORSIKA: Cuts vs Energy for N_{max}

Shower Maximum: Xmax Parameter

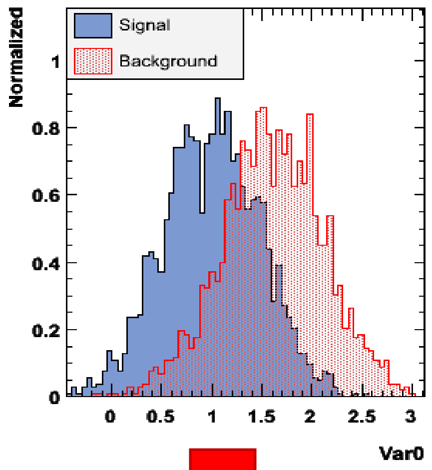




Considering discrete energies

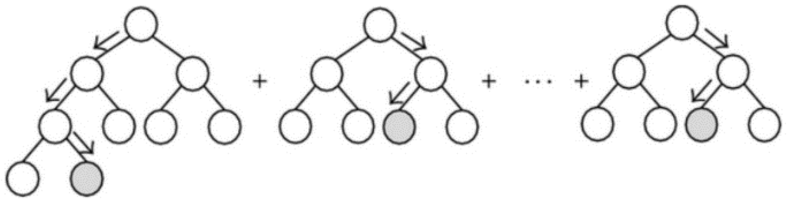
Toolkit for Multivariate Data Analysis with ROOT (TMVA)

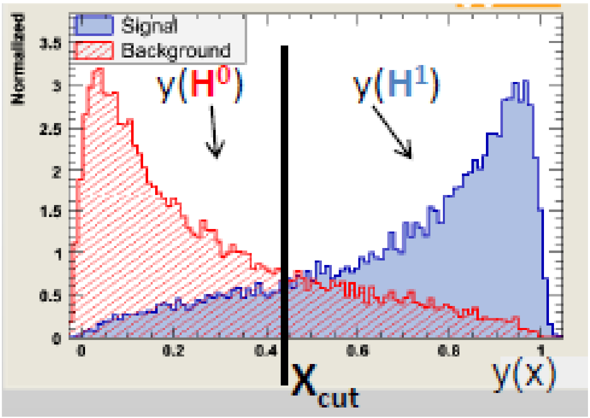
1. Training (subset):
   - ➢ Classification: Signal: Photons
     Background: Protons
   - ➢ Choose the best method and its parameters



- ○ Boosted Decision Trees (**BDT**).

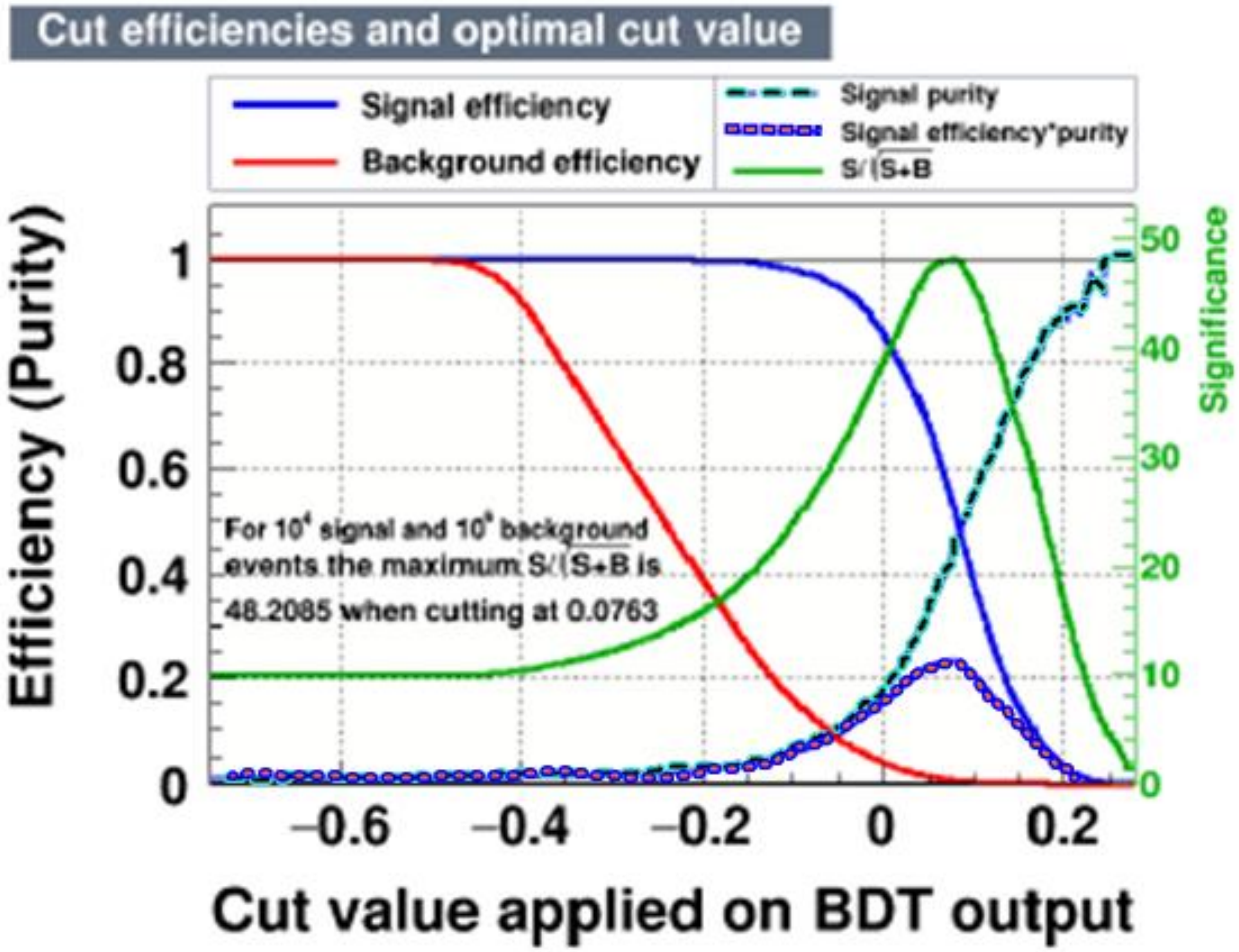
Supervised learning: Extract patterns.



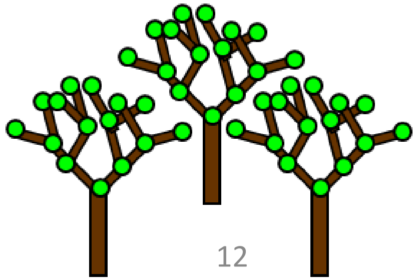


2. Test (subset): Evaluate training

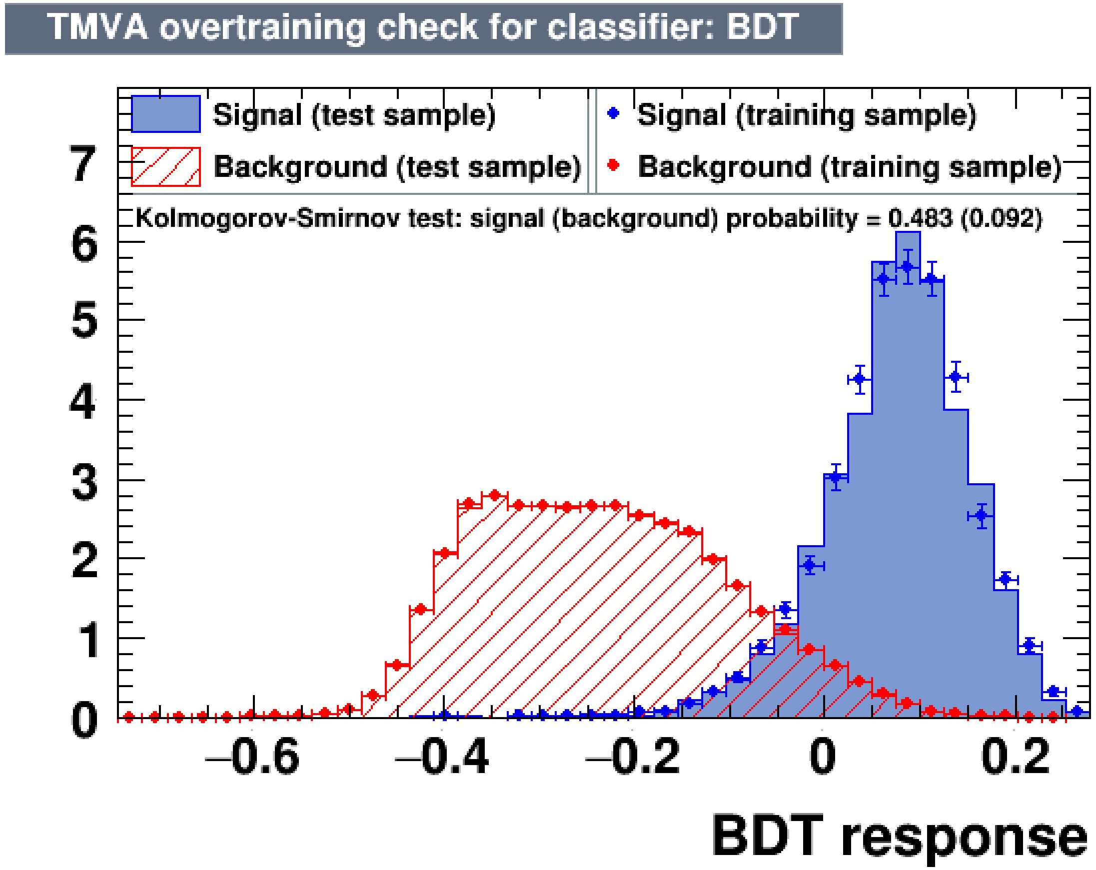
TMVA: BDT Efficiency



Significance $S/\sqrt{S+B}$

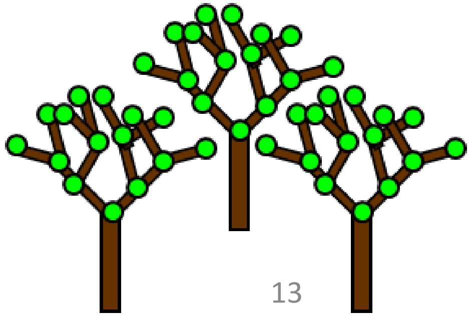


TMVA: BDT Response



Energy with Smearing NT=850

BDT Cut	Signal	Background	$S/\sqrt{S+B}$
0.07	54.4%	0.7%	7.3
0.0095	83.1%	3.4%	8.93



Conclusions

- Distinguish photons (signal) from protons (background) air-showers with CORSIKA.
- Energy range: 10^{12} to 10^{15} eV with vertical events.
- Gaisser-Hillas fit for longitudinal profiles.
- Point-source fluxes: at 10^{13}eV $\frac{\Phi_\gamma}{\Phi_p} \approx 10^{-6}$.

Method	Signal (%)	Background (%)	Significance
TMVA (BDT – Cut 0.07)	$54.4 \pm 1.0 \times 10^{-2}$	$0.7 \pm 1.0 \times 10^{-4}$	**7.3**
TMVA (BDT – Cut 0.02)	$3 \pm 2 \times 10^{-3}$	$3 \times 10^{-3} \pm 8 \times 10^{-6}$.	**1.7**

- Background rejection capability is 10^3
- Feasibility of gamma/hadron separation requires further improvement

50 años CONCYTEC | FONDECYT

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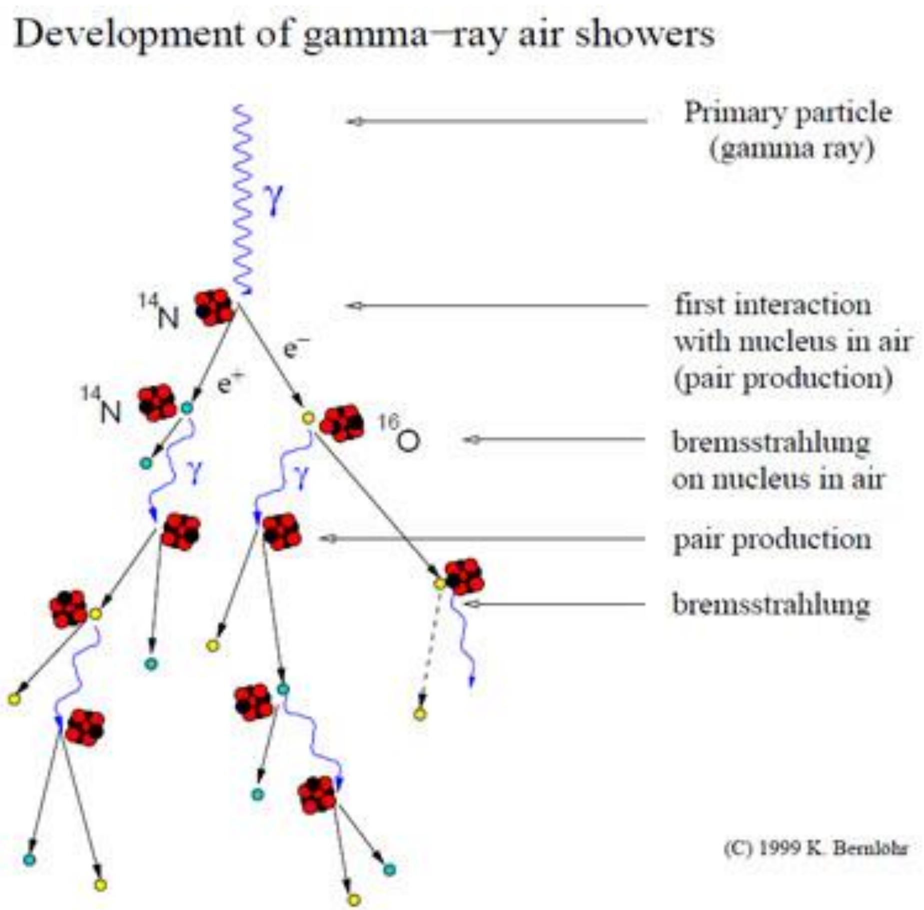
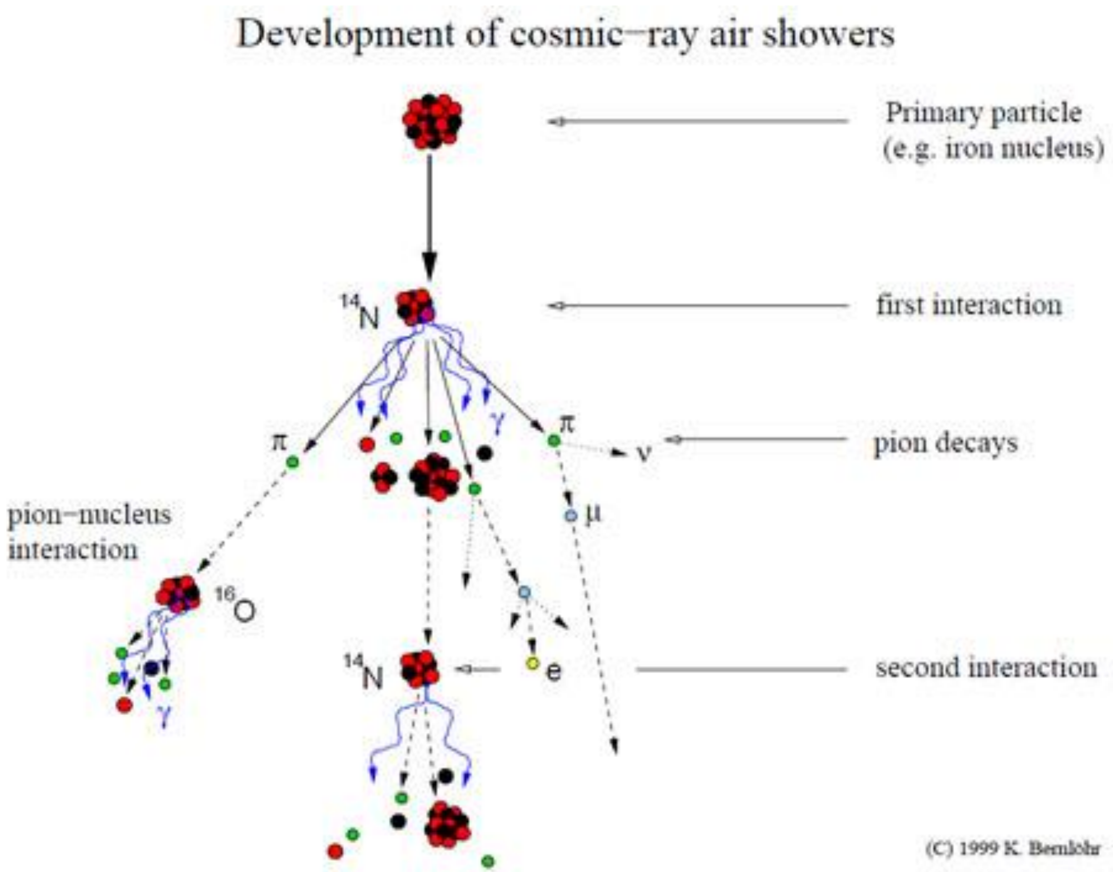
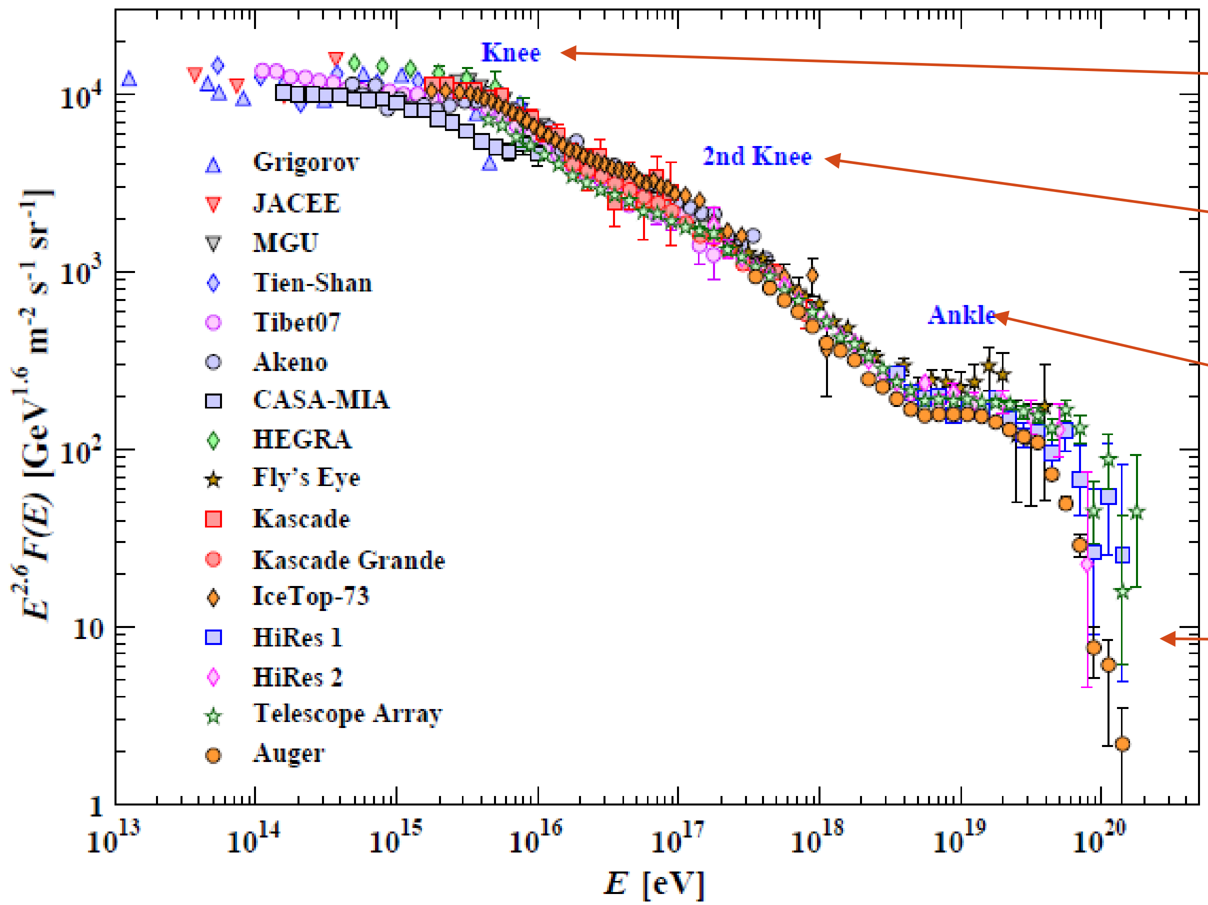
BACKUP SLIDES

Extensive Air Shower with more detail





Cosmic Ray Spectrum



Spectral Index -2.7 a -3 [2]

Spectral Index -3 a -3.3 [3]

Spectral Index -4.2 [4]

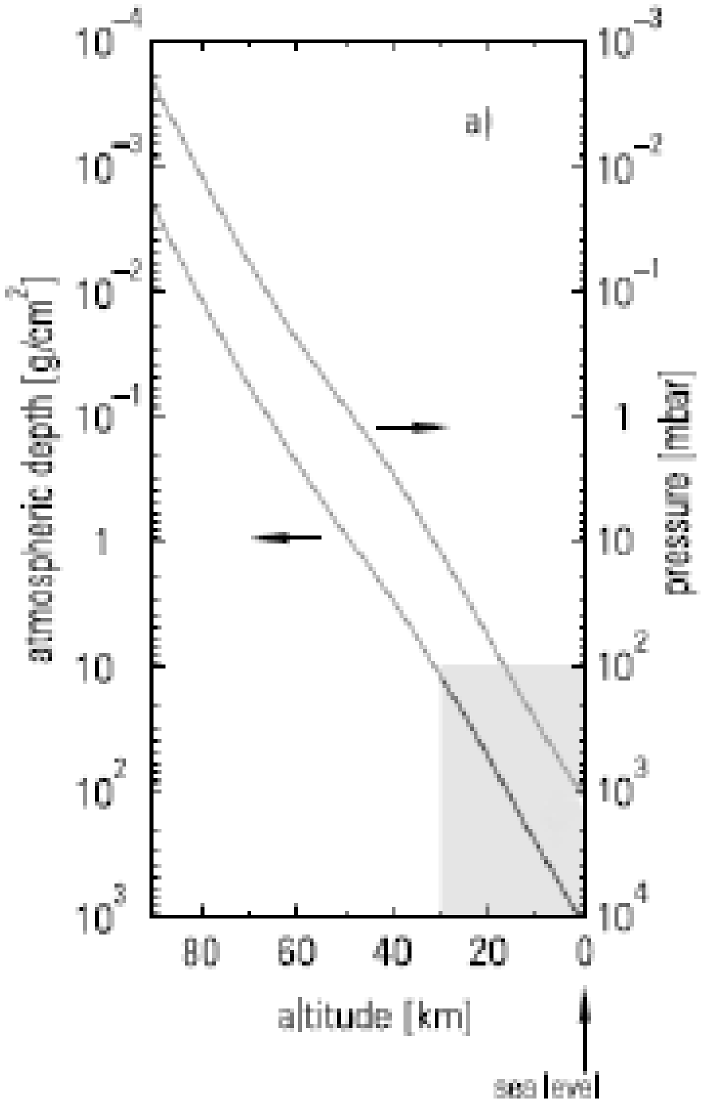
GZK Cut [5]

Cosmic Ray Flux [1]

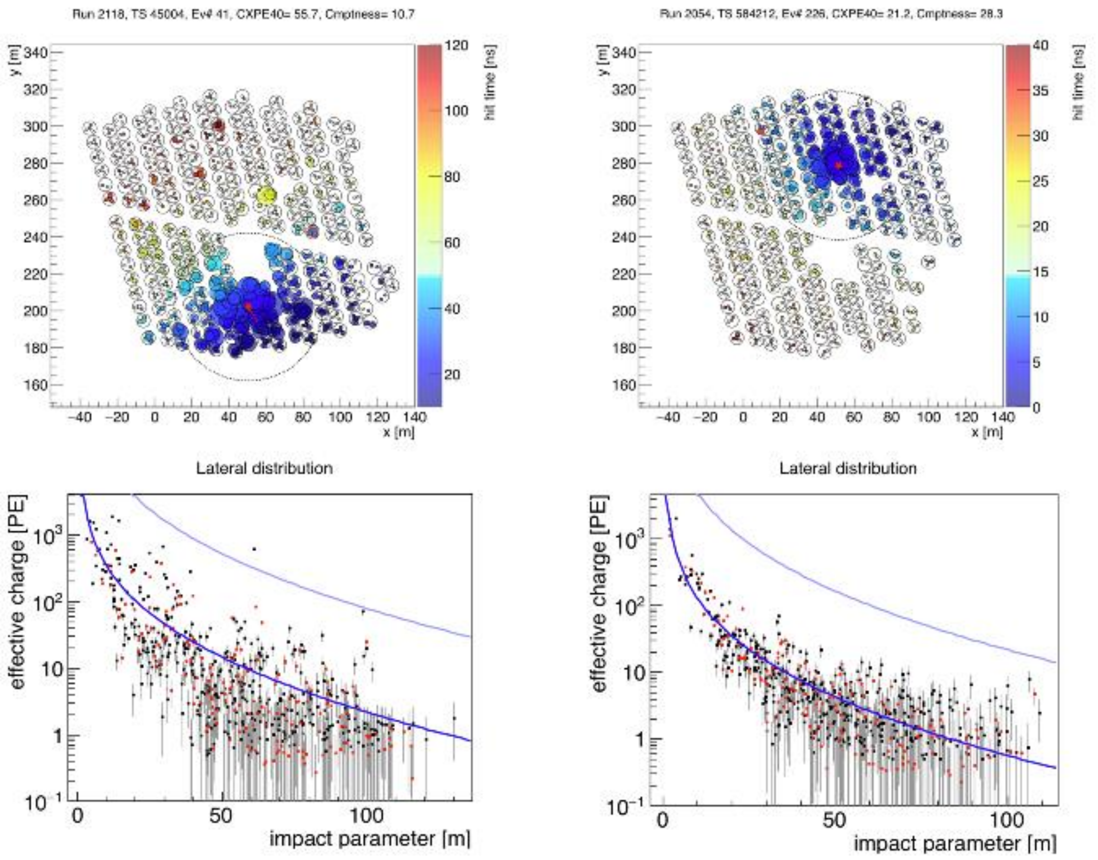
Atmospheric depth vs altitude

The column density of the whole atmosphere amounts to approximately 1000 g/cm2. Scientific balloons: 35 or 40 km

15 to 20 km primary cosmic rays interact with atomic nuclei of the air and initiate depending on energy and particle species electromagnetic and/or hadronic cascades (Grupen, 2005).



Data HAWC

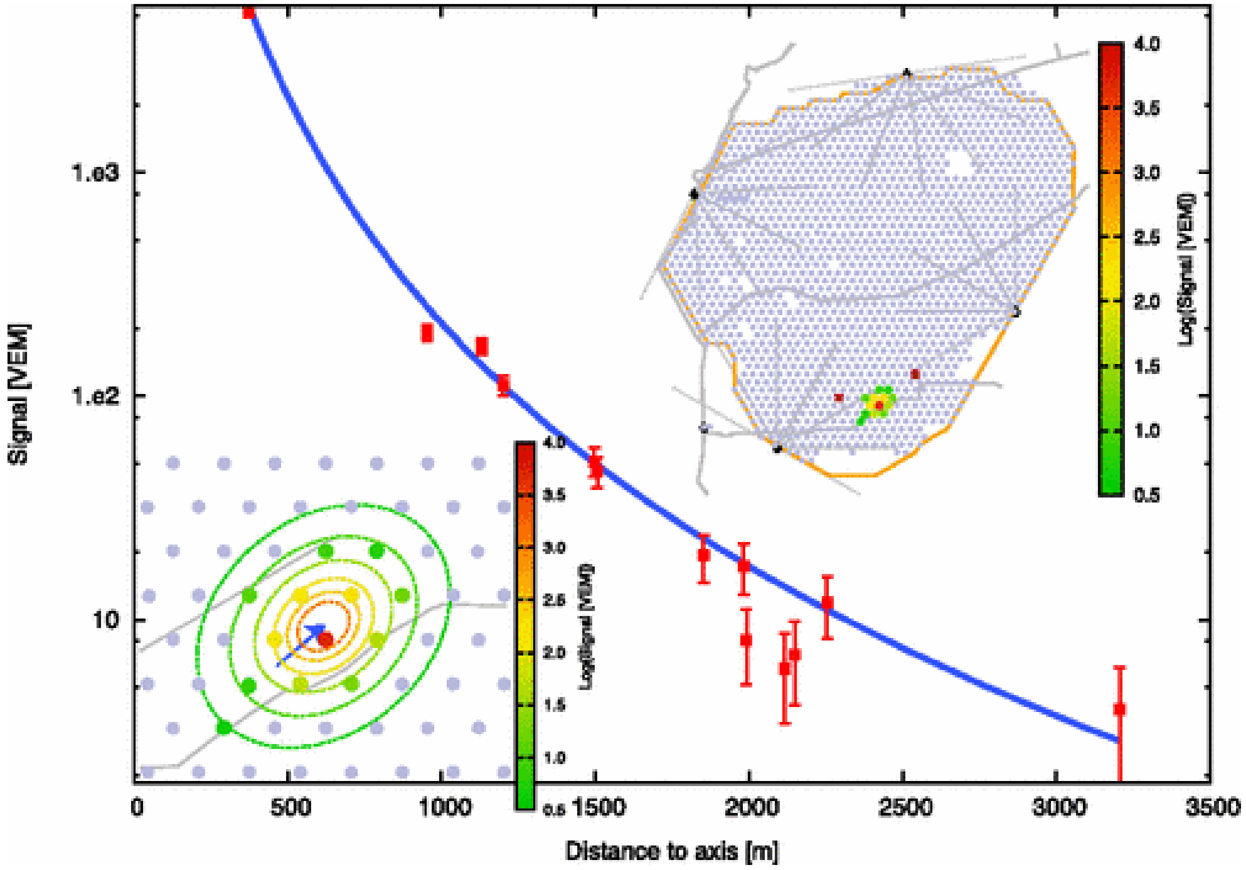


HAWC events of a hadronic shower (left) and an electromagnetic one (right) showing the PMT signals on the array (top row) and as function of the distance from the shower core with the NKG fit (bottom row)

http://www.nucleares.unam.mx/noticias.php?publicacion=HAWC_2016_1&key=5000

https://inspirehep.net/record/1393440/plots

Data Pierre Auger



Example of detection using a surface array. The upper right inset shows the whole Auger surface array and the footprint of the shower, each dot represents a detector and the spacing between them is 1.5 km. The lower inset shows details of this footprint with the estimated contours of the particle density levels. The curve represents the adjusted LDF (lateral distribution function) and the center point represents the measured densities as a function of the distance to the shower core. From the Auger

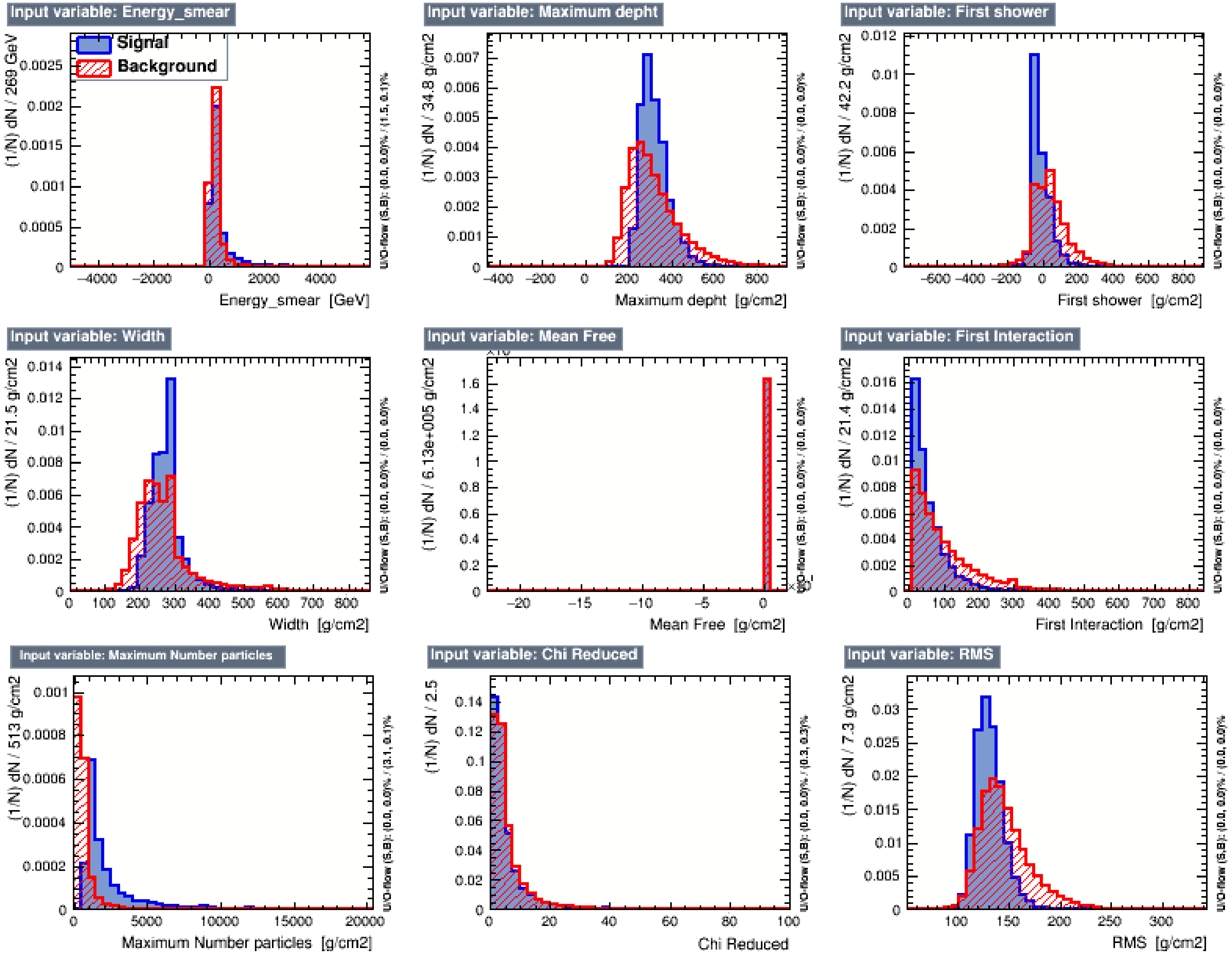
Input and output CORSIKA

```
RUNNR    116                               run number
EVTNR    1                               number of first shower event
NSHOW    100                               number of showers to generate
PRMPAR   14                              particle type of prim. particle
ESLOPE   -2.7                            slope of primary energy spectrum
ERANGE   1.E3  1.E3                      energy range of primary particle
THETAP   0.   0.                       range of zenith angle (degree)
PHIP     -180.  180.                     range of azimuth angle (degree)
SEED     1   0   0                       seed for 1. random number sequence
SEED     2   0   0                       seed for 2. random number sequence
OBSLEV   1400.E2                          observation level (in cm)
FIXCHI   0.                              starting altitude (g/cm**2)
MAGNET   20.0  42.8                      magnetic field centr. Europe
HADFLG   0  0  0  0  0  2                flags hadr.interact.&fragmentation
ECUTS    0.3  0.3  0.003  0.00           energy cuts for particles
MUADDI   T                               additional info for muons
MUMULT   T                               muon multiple scattering angle
ELMFLG   T   T                           em. interaction flags (NKG,EGS)
STEPFC   1.0                             mult. scattering step length fact.
RADNKG   200.E2                          outer radius for NKG lat.dens.distr.
LONGI    T  20.  F  F                    longit.distr. & step size & fit & out
ECTMAP   1.E3                            cut on gamma factor for printout
MAXPRT   100                               max. number of printed events
DIRECT   /home/jrengifo/LAGO/            output directory
PLOTSH   T
USER     jrengifo                              user
DEBUG    F  6  F  1000000                debug flag and log.unit for out
EXIT                                     terminates input
```

Results: File Root called DAT000###.root

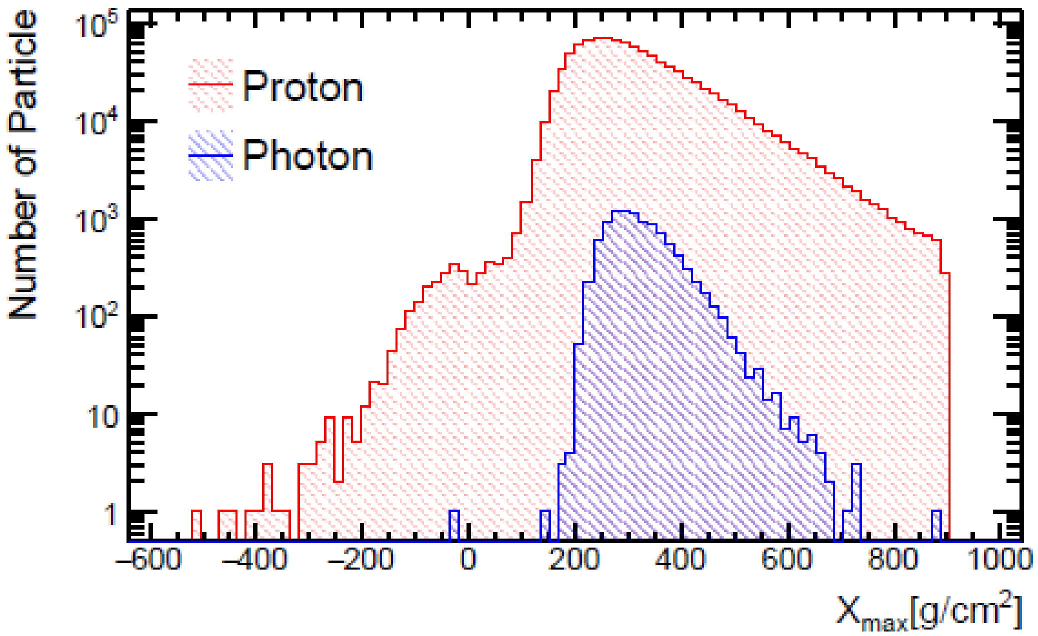
Information about position, momentums and arrive time, number of particles, type of particles, etc.

Input parameters

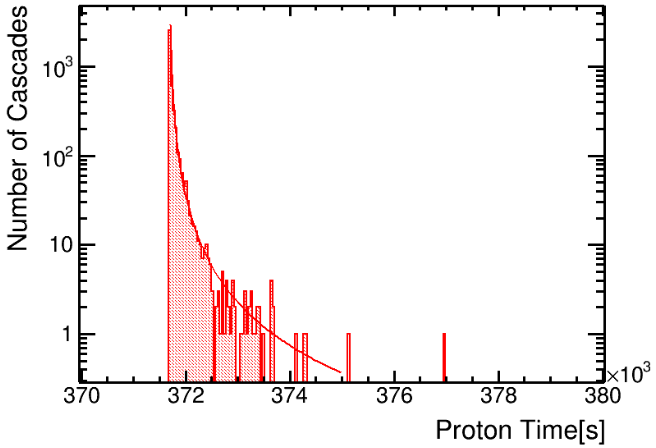


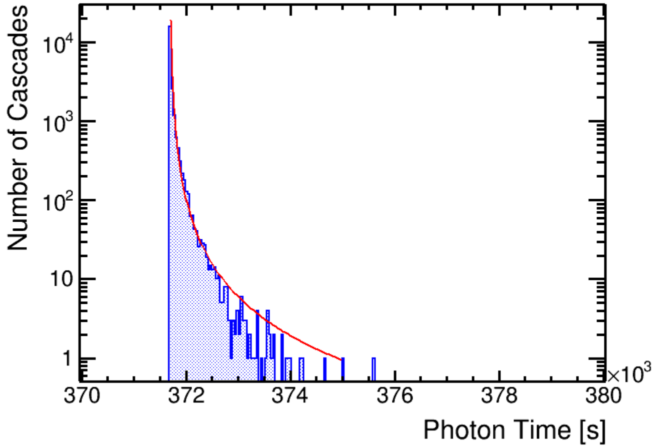
Applying cuts under realistic considerations

Parameters	Cut1	Cut2
X_{max}	> 220	< 415
$FWHM$	> 197.5	< 362
f	> 0.25	< 0.59
RMS	> 112	< 150
X_{start}	–	< 188.2
X_0	> -102	< 74
N_{max}	–	< 150000
λ	> 33.5	< 61
χ^2_{red}	> 0.63	< 6.8
Energy not smearing	$S: 56\%$	$B: 13\%$
Energy smearing	$S: 54\%$	$B: 12\%$



Other parameters

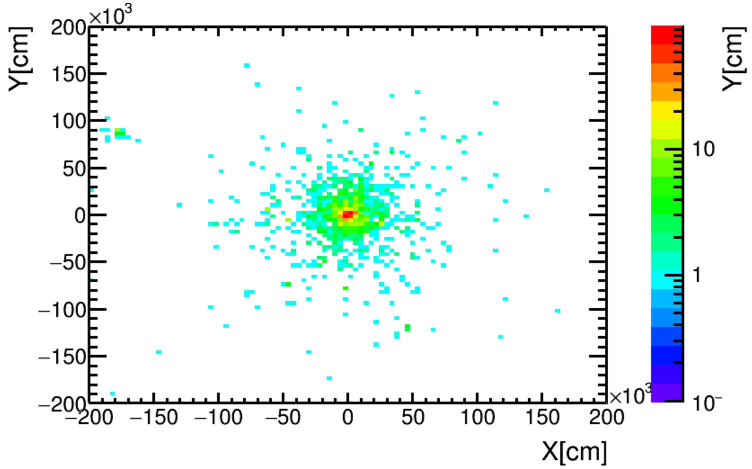


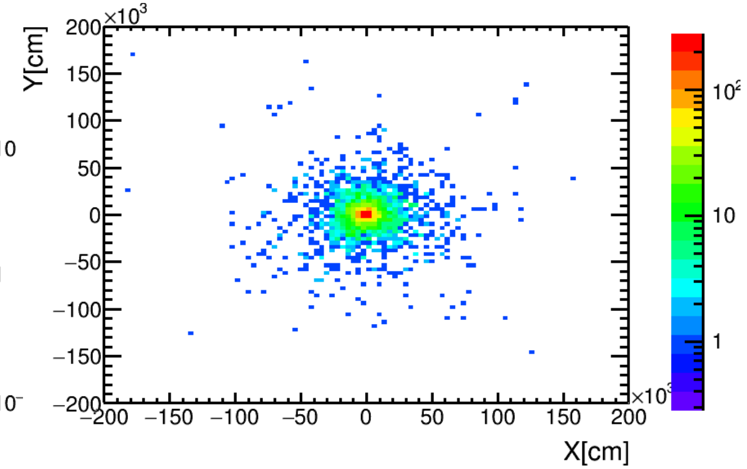


Time distribution

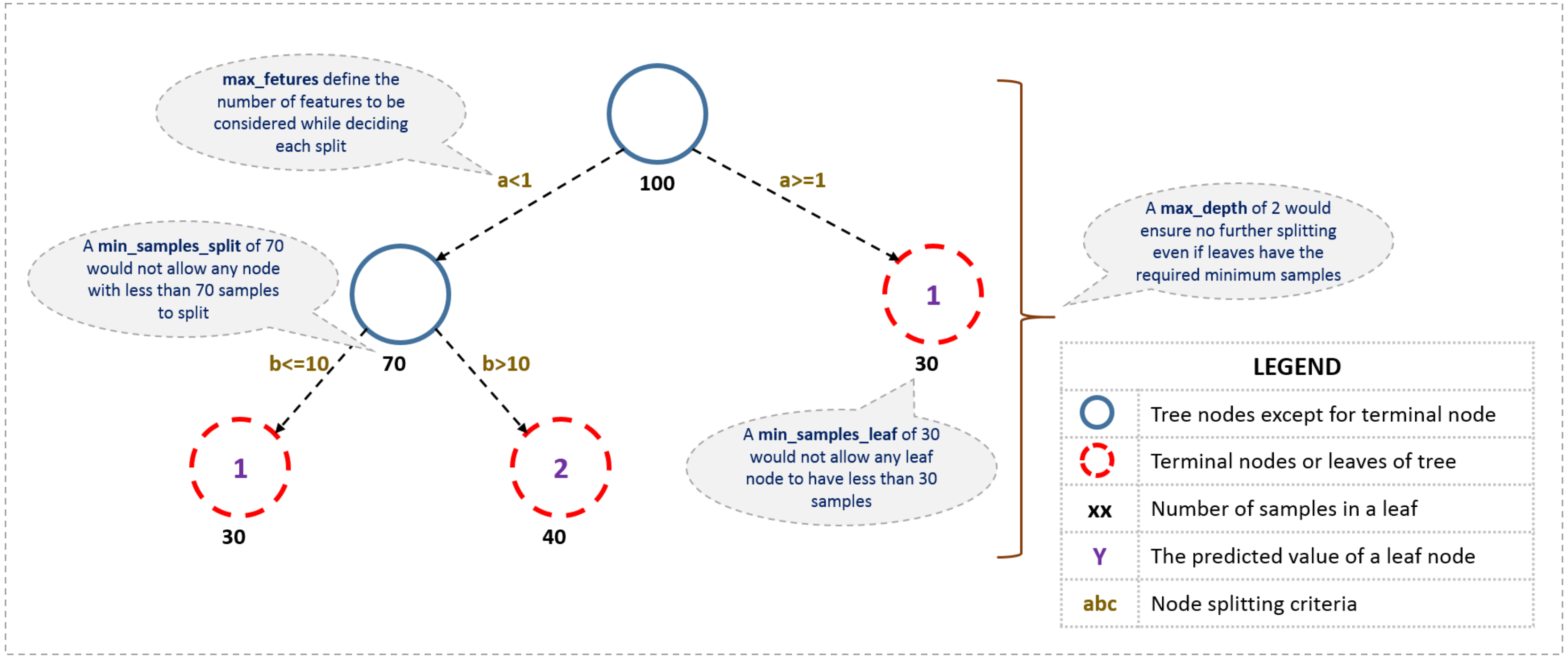
Problems related to low energies and processing time.
Uncorrelated in space/time.

Spatial distribution





Boost Desition Trees (BDT)

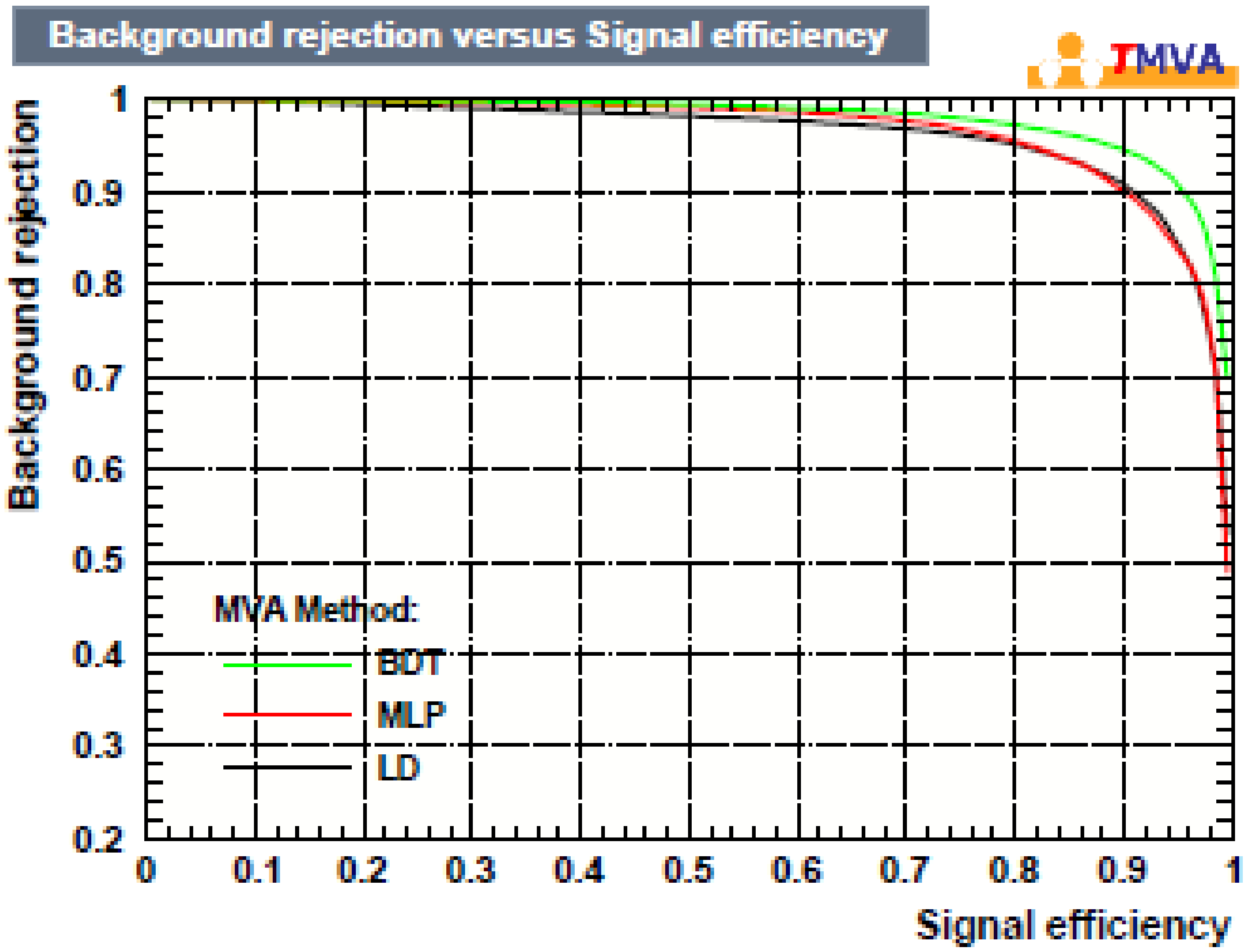


Desition Trees: Sequential application of cuts splits the data into nodes, where the final nodes (leafs) classify an event as signal or background.

BDT: Combine forest DTs, with differently weighted events in each tree (tres can also be weighted).

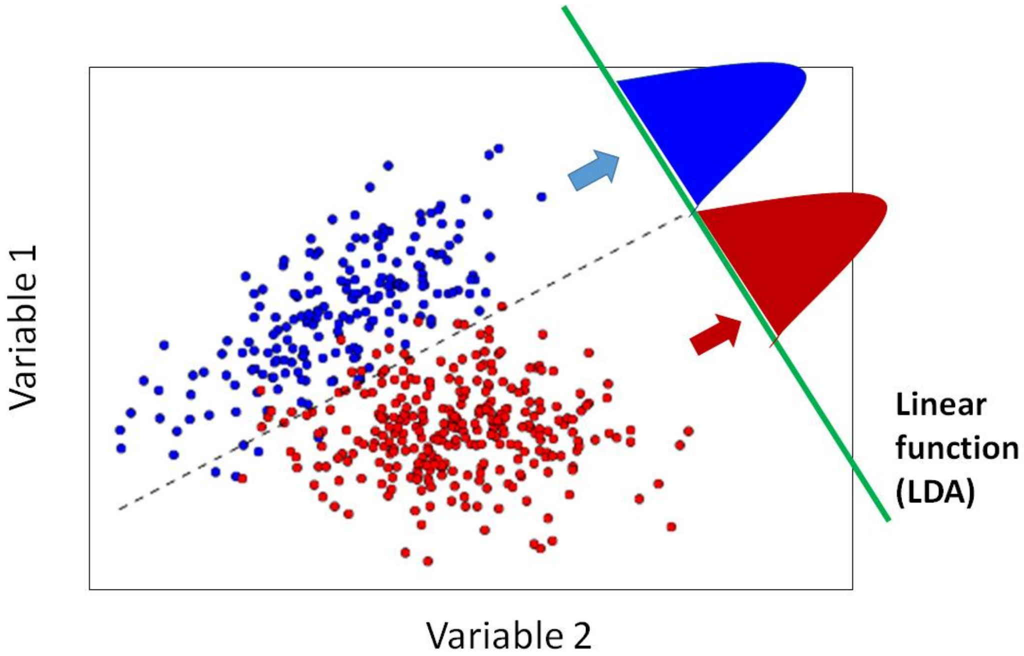
(More weight to misclasification events)

This is what the essence of boosting is, i.e. to add a new classifier to an existing set of classifiers, so that the new classifier can better handle examples that were not handled correctly by the existing classifiers.

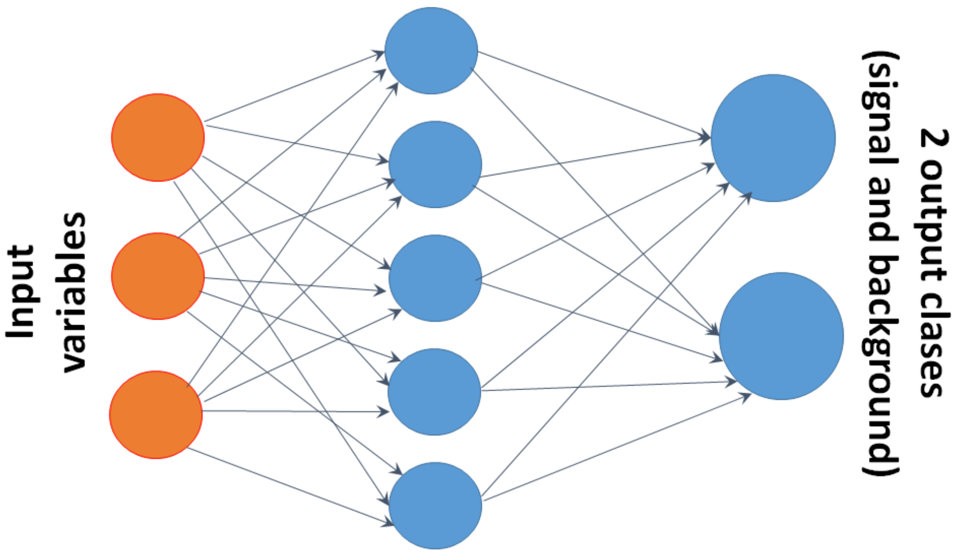

Background rejection versus Signal efficiency
TMVA
Background rejection
Signal efficiency
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
MVA Method:
BDT
MLP
LD

TMVA Methods

Linear Discriminant Analysis (LDA)



Multi-Layer Perceptron- Articial Neural Networks (MLP-ANN)



The number of hidden layers depend of the "activation function"

Variation of Results with other spectral index

- Signal events could decrease.
- Spectral index define the slope of flux.
- If index has more inclination, this could increase the events at more energy.
- But, if all events has the same efficiency, then don´t care.
- If the events depence of the energy. Then, its care.
- SOLUTION: Simulate more events at more energy at different spectral index.

Variation of Results if the shower isn´t Vertical

- The more horizontal events could to pass more atmosphere. Then could less energy. So less particles.
- Could to depend of coverage of Fluorescence Telescope.
- SOLUTION: Simulate events with different inclination angles.