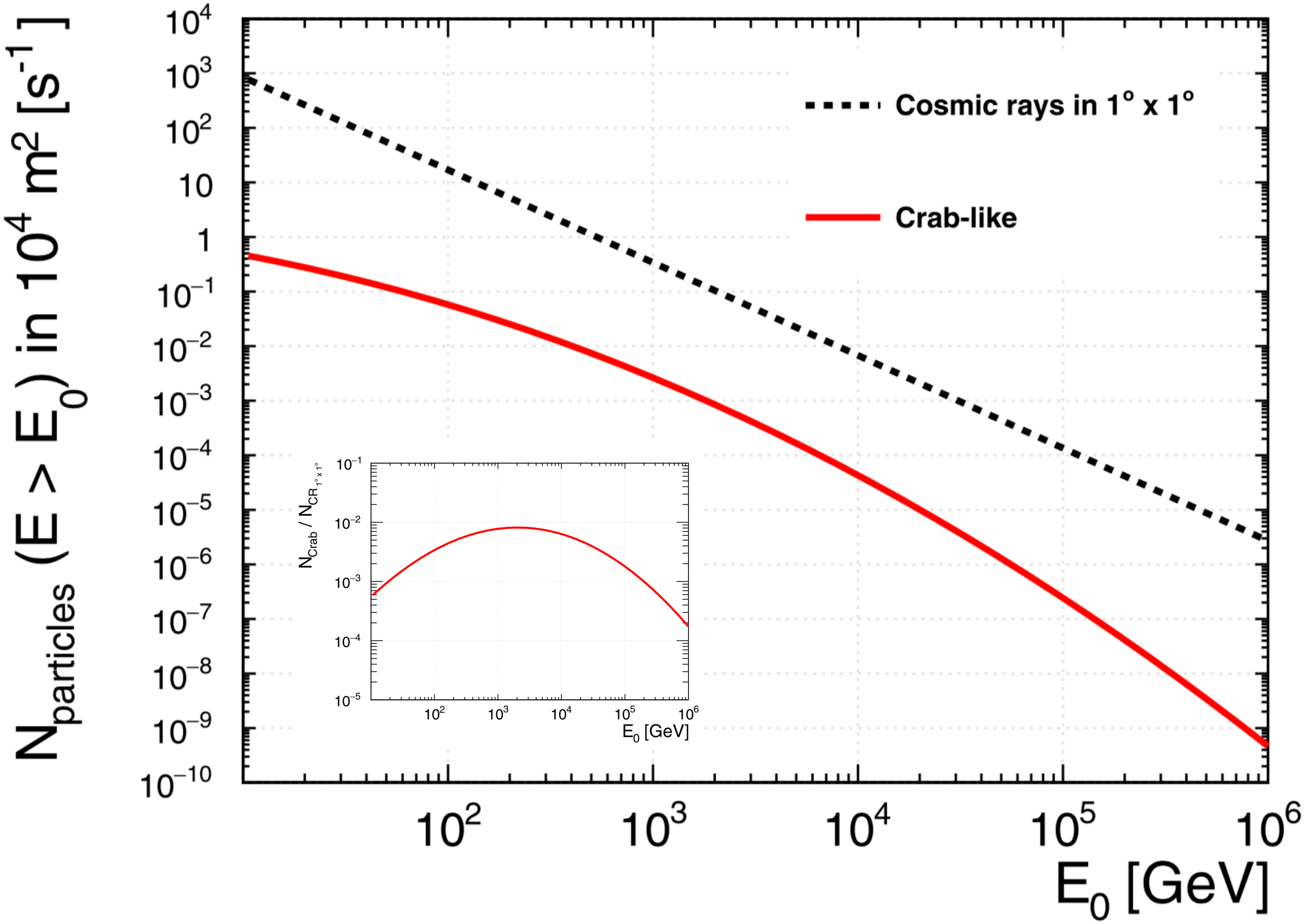
LATTES
Gamma/Hadron Discrimination

Ruben Conceição

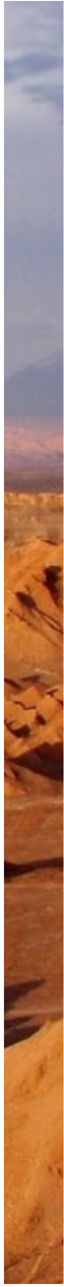
on behalf of the LATTES team

LIP

The problem…

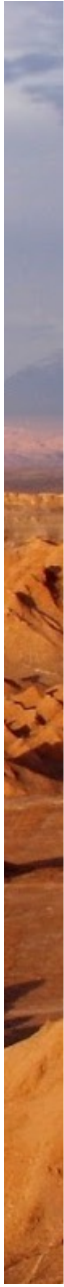


The number of hadrons overwhelms the gammas by several orders of magnitude



Possible solutions…

- If a gamma source emits continuously then increase the acquisition time
- Increase angular resolution
- Increase the energy reconstruction
- Take advantage of shower characteristics to distinguish between a gamma/hadron induced shower



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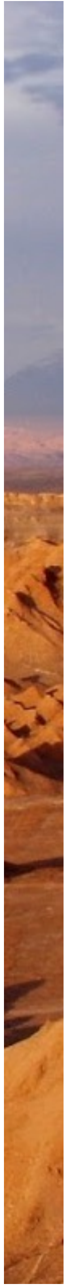
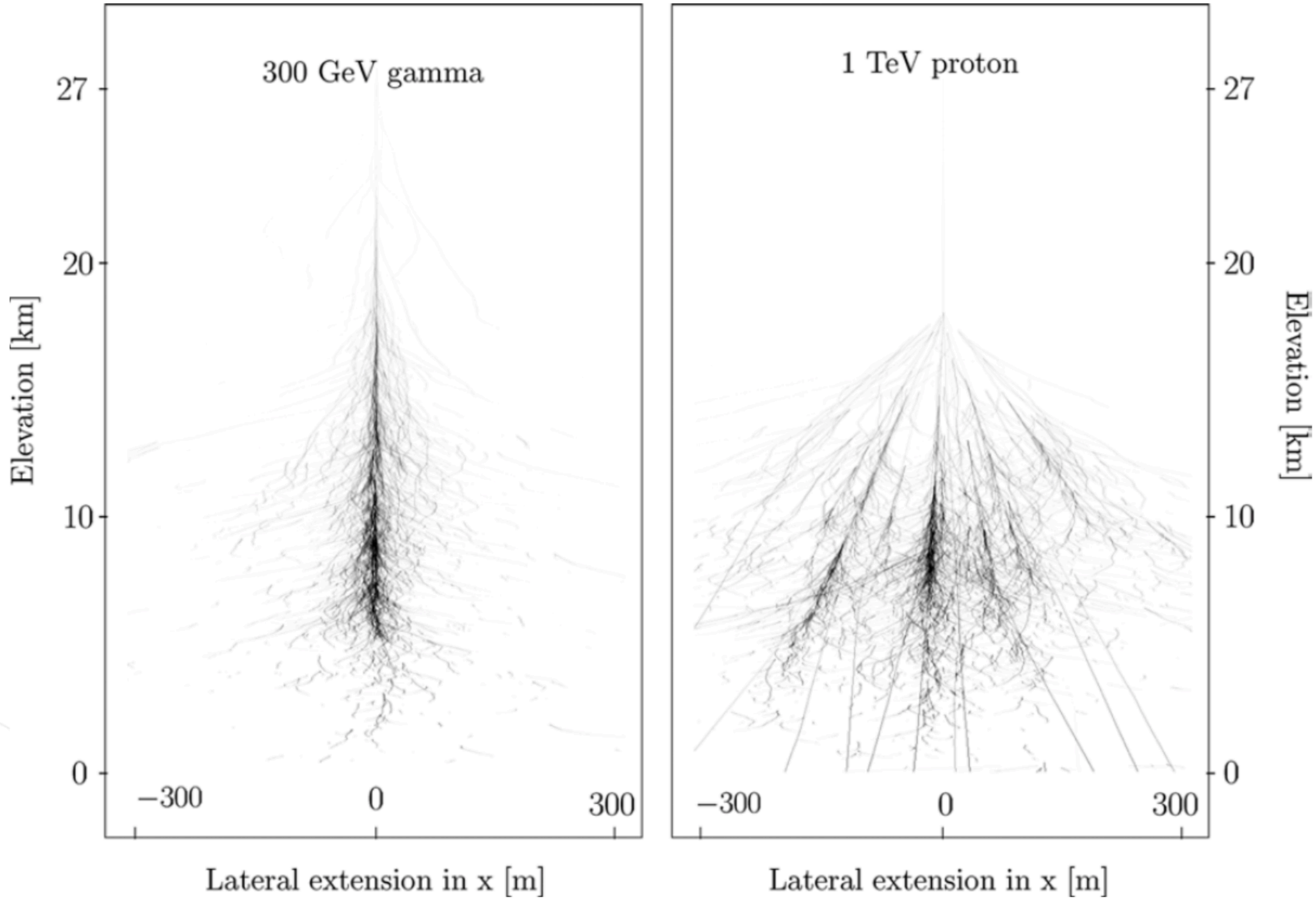
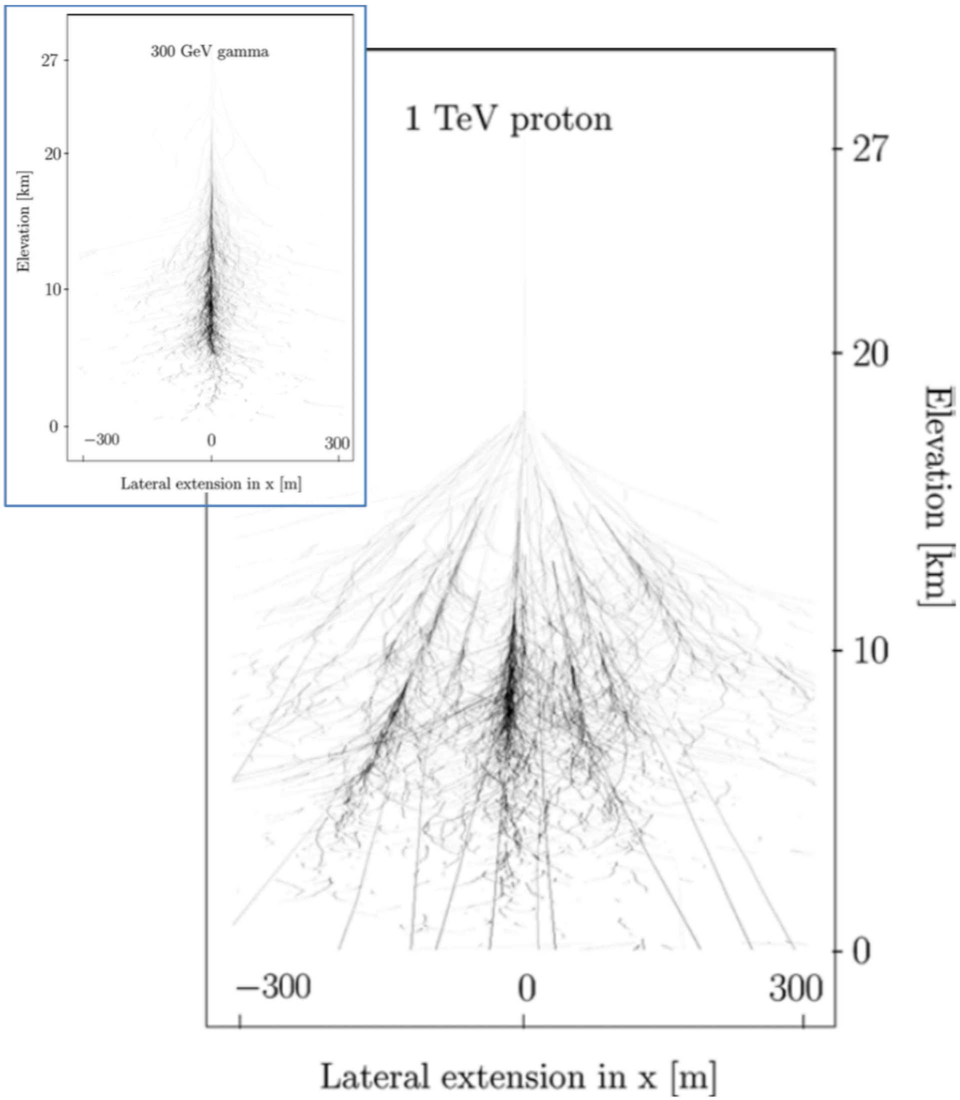


Shower characteristics

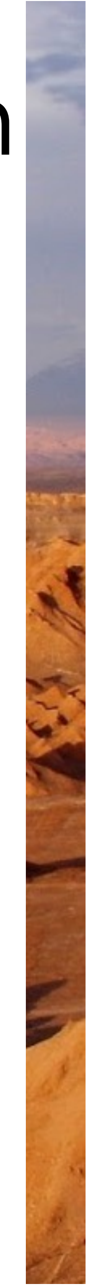


A pure electromagnetic shower (gamma) has distinct features from a shower with an hadronic component (hadron)

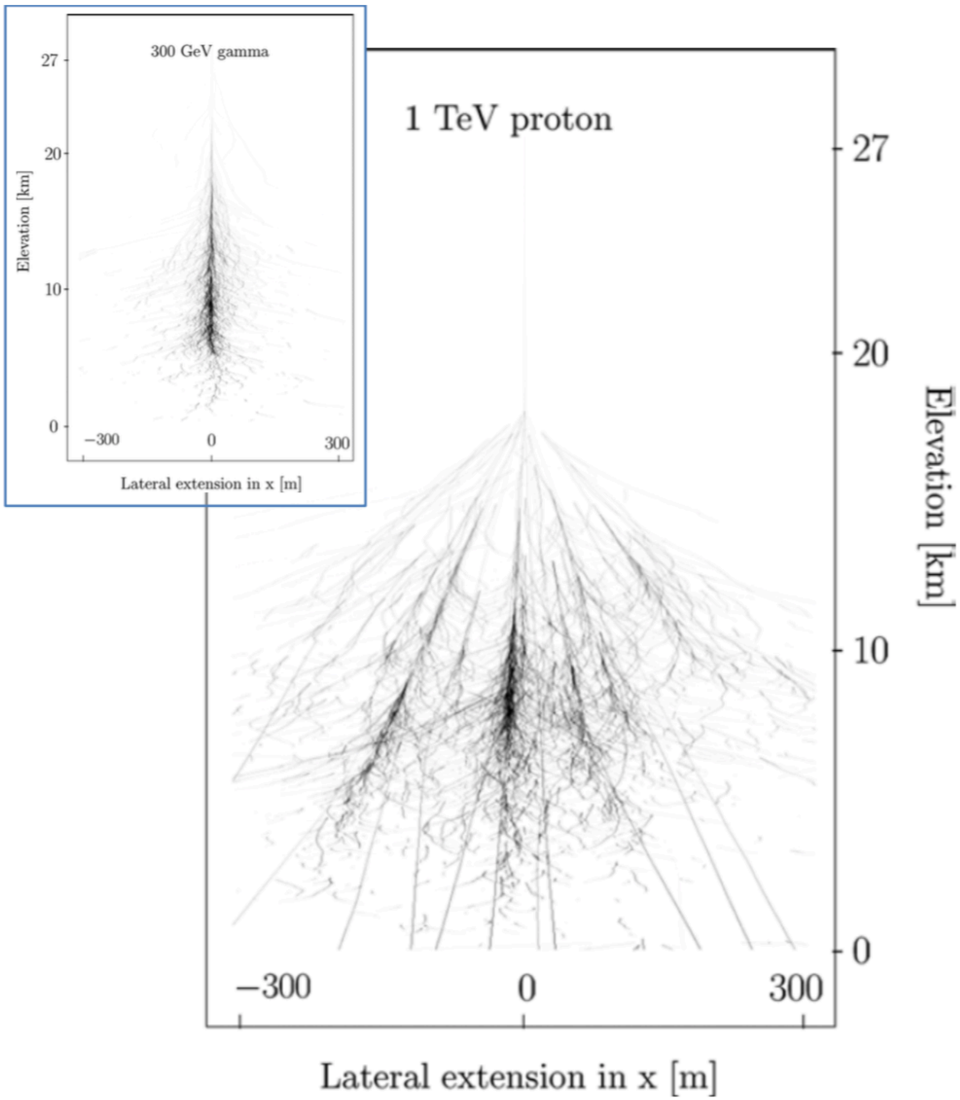
Strategies for primary discrimination



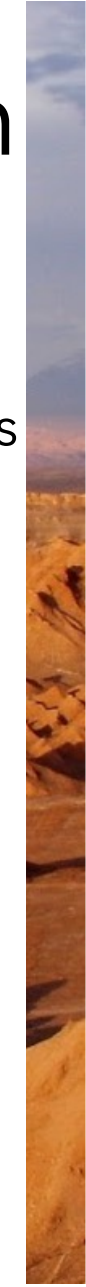
- ✧ Hit pattern at ground
- ✧ Calorimetric information at ground



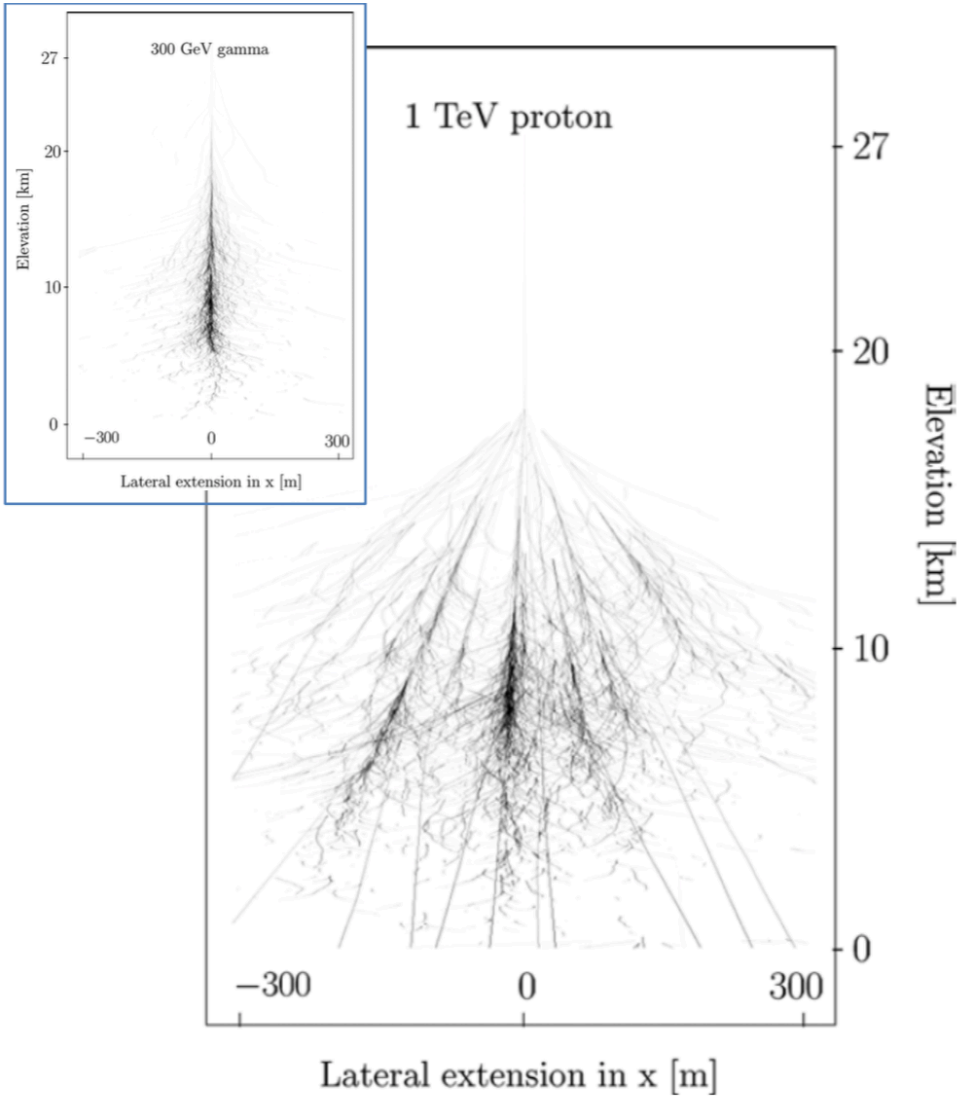
Strategies for primary discrimination



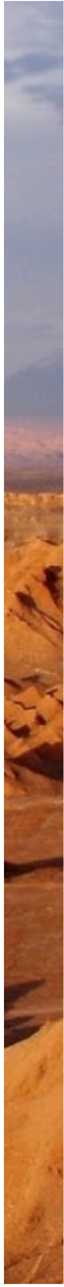
- **Hit pattern at ground**
  - Hits from hadronic showers are more sparse than in gamma induced showers
  - **RPC detectors**
  - Explored by the **ARGO** collaboration
  - Not yet explored for LATTES
    - complex pattern recognition problem



Strategies for primary discrimination

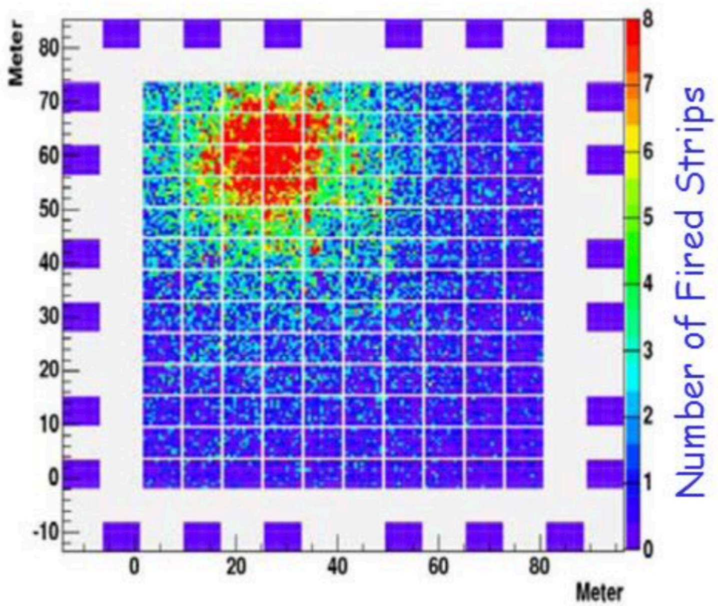


- **Calorimetric information at ground**
  - Search for energetic clusters far from the shower core
  - Lateral Distribution Function (LDF) steepness
  - **Water Cherenkov Detectors**
  - Explored by **HAWC**

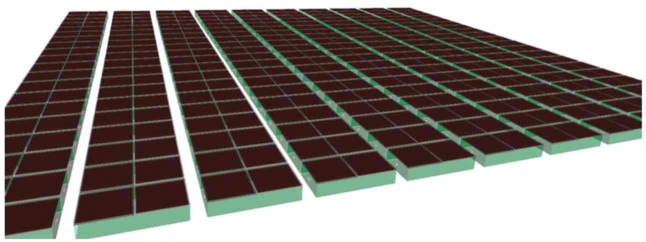


ARGO vs LATTES

ARGO

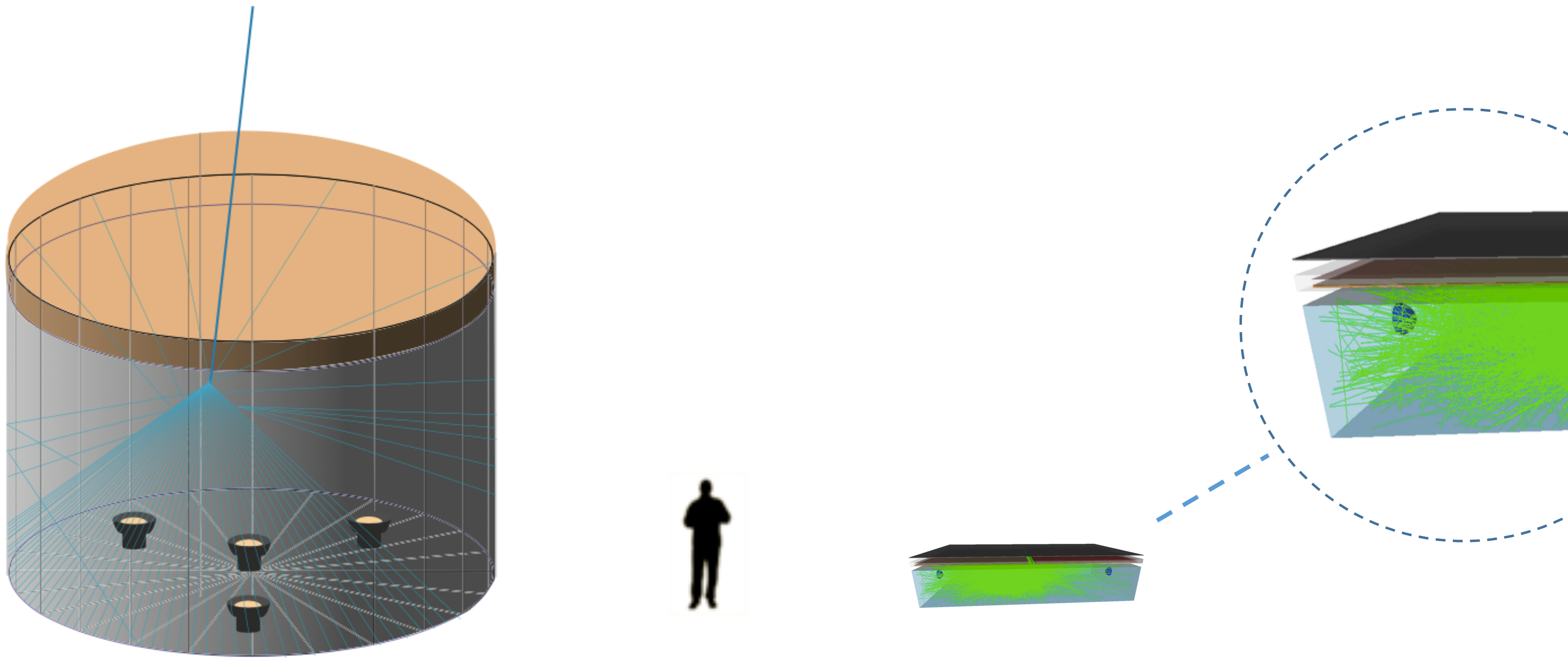


LATTES



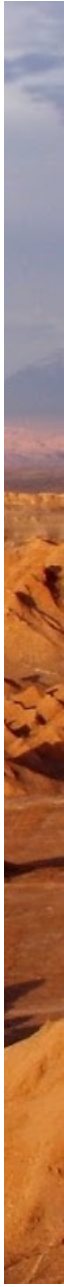
- ARGO has a higher granularity (too much?)
- Similar concept so ARGO g/h discrimination analysis should be importable to LATTES

HAWC vs LATTES



- Take advantage of hybrid detector
  - RPCs: timing and segmentation
  - WCD: calorimetry

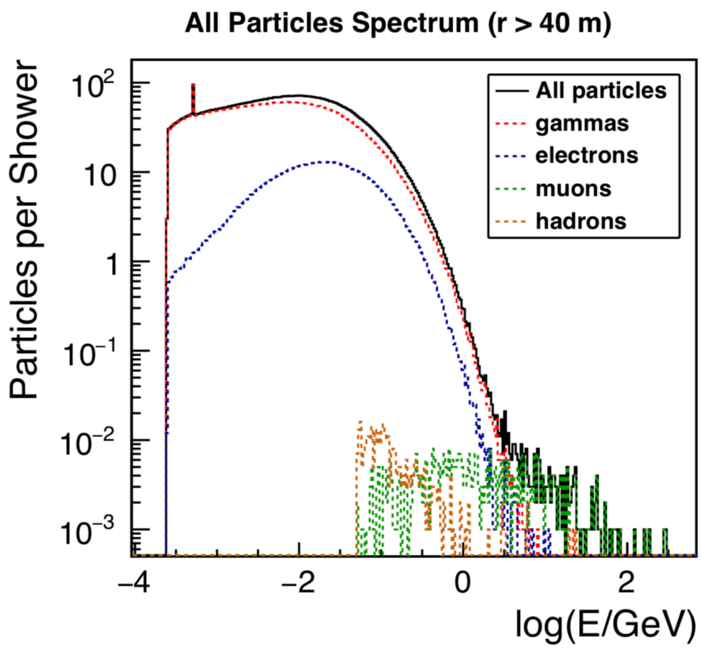
Energetic clusters far away from the shower core



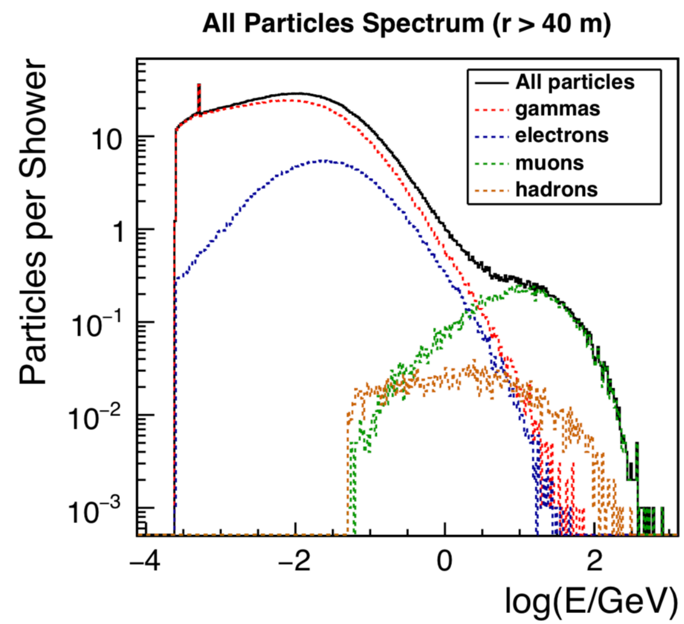
Shower calorimetric information

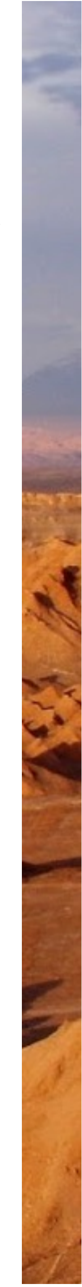
E=5 TeV

Gamma induced showers



Proton induced showers

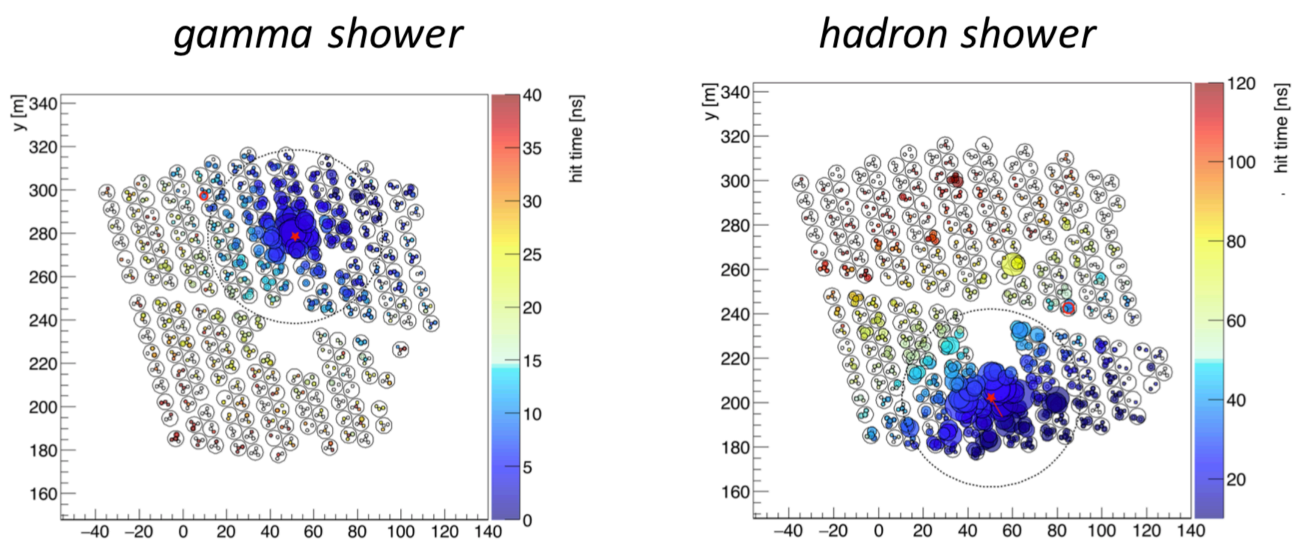




- High pT sub-shower carry large amounts of energy
- Look for energetic clusters far from the shower core (> 40 m)
  - Muons and high-energy photons/electrons

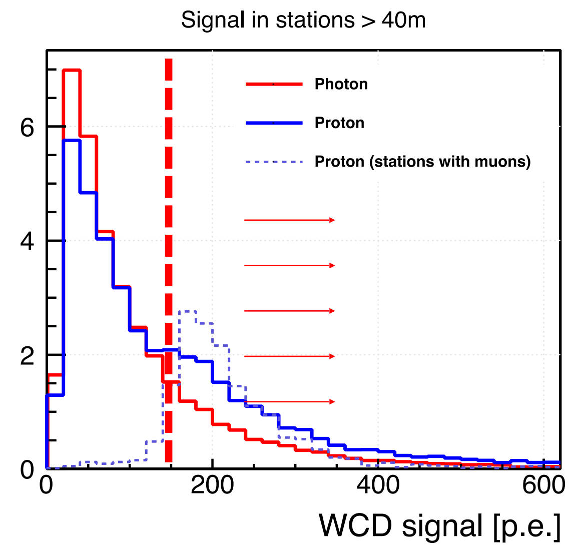
Looking for high-p_T sub-showers

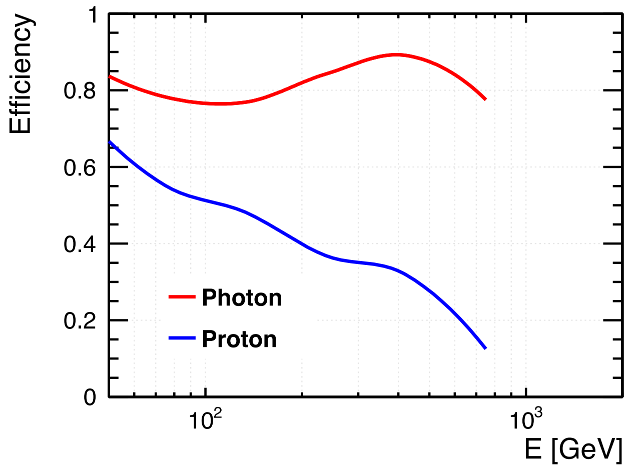
- HAWC g/h discrimination
  - Look for high signal far away from the shower core (> 40 m)
  - Take advantage of height of the tank to distinguish muons from electrons

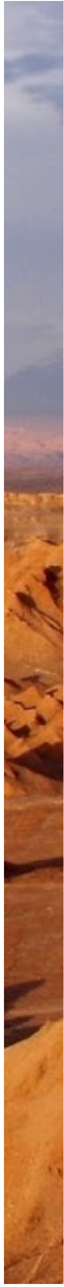


Looking for high p_t sub-showers

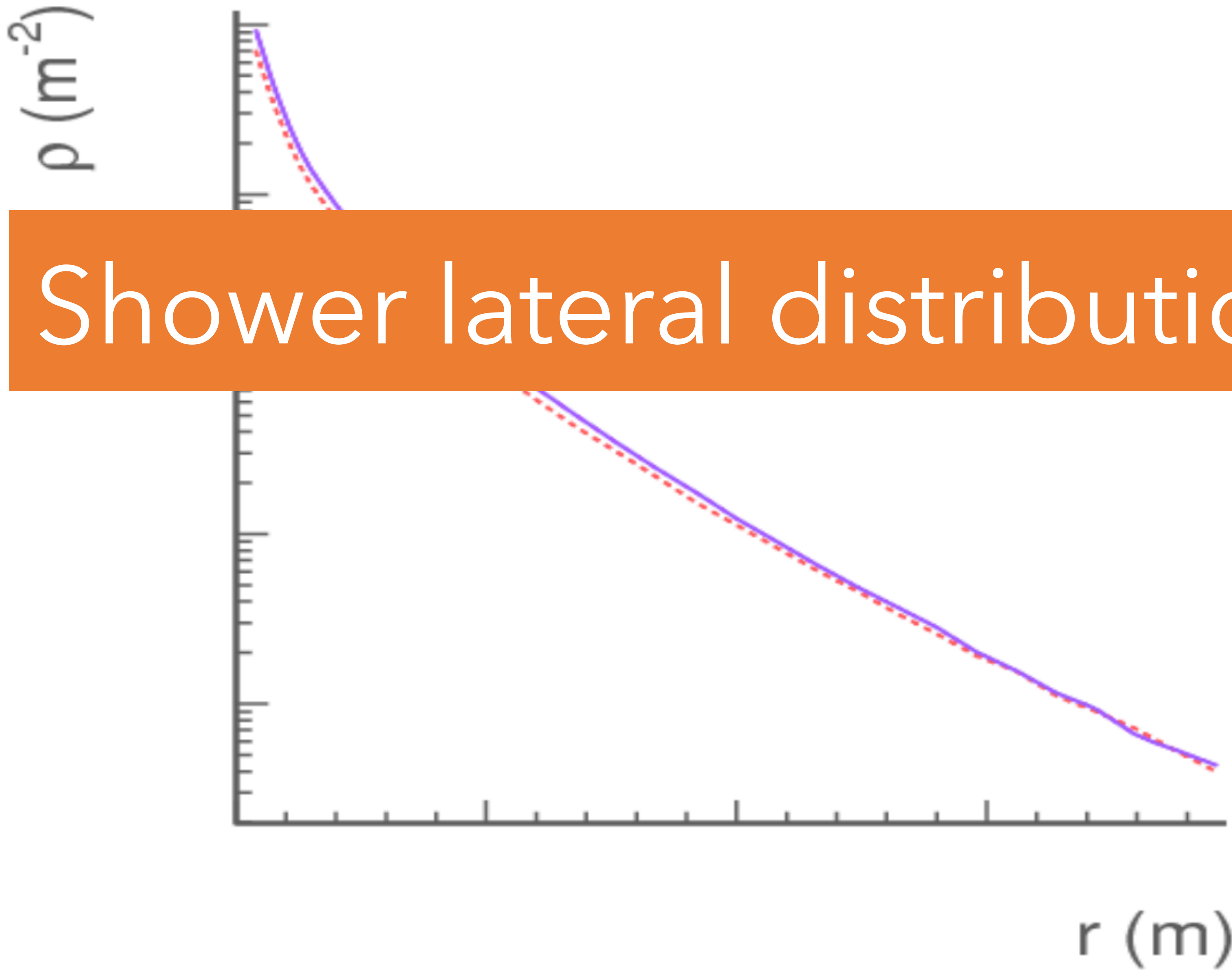
- ✧ LATTES g/h discrimination
  - ✧ Use only stations with a distance above 40 m
  - ✧ S40: sum all WCD stations signal
  - ✧ S40_high: sum all WCD stations that have a signal above the muon energy threshold
  - ✧ Compute S40_high / S40
  - ✧ Not optimized…

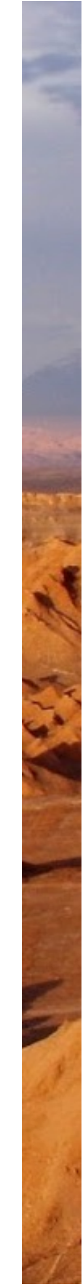




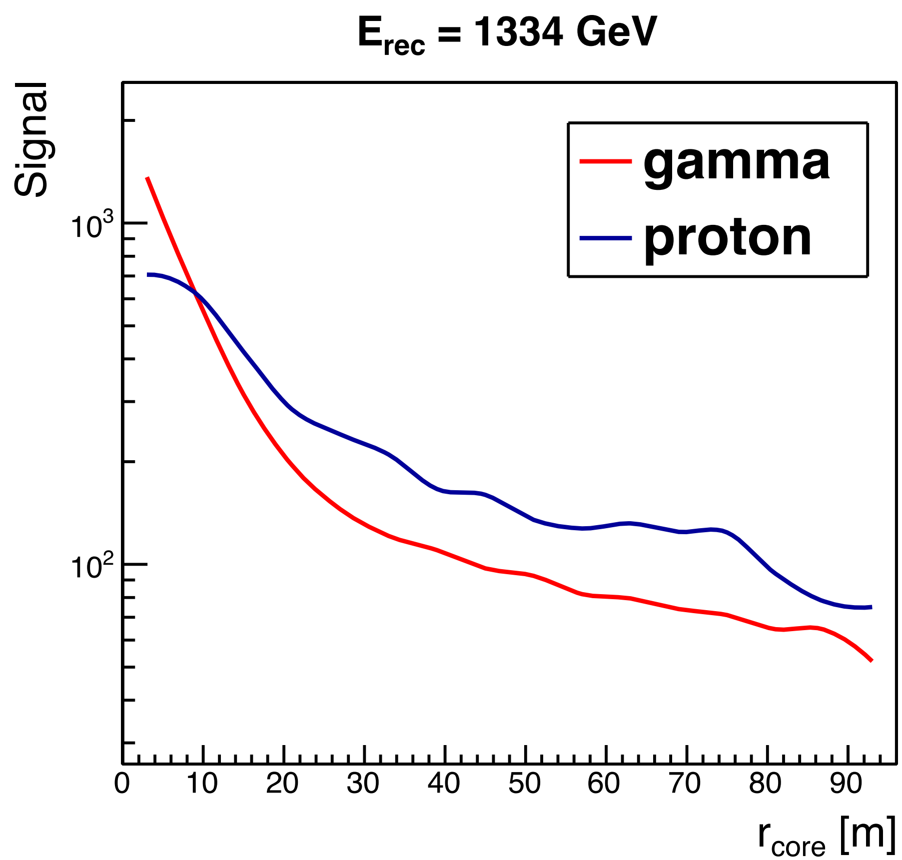


Shower lateral distribution





High-energy discrimination strategy

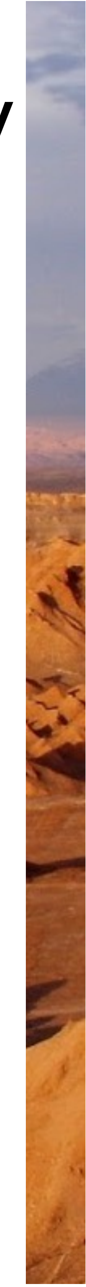


- Lateral distribution function (LDF)
  - LDF of gamma showers is more steep than the LDF of hadron showers

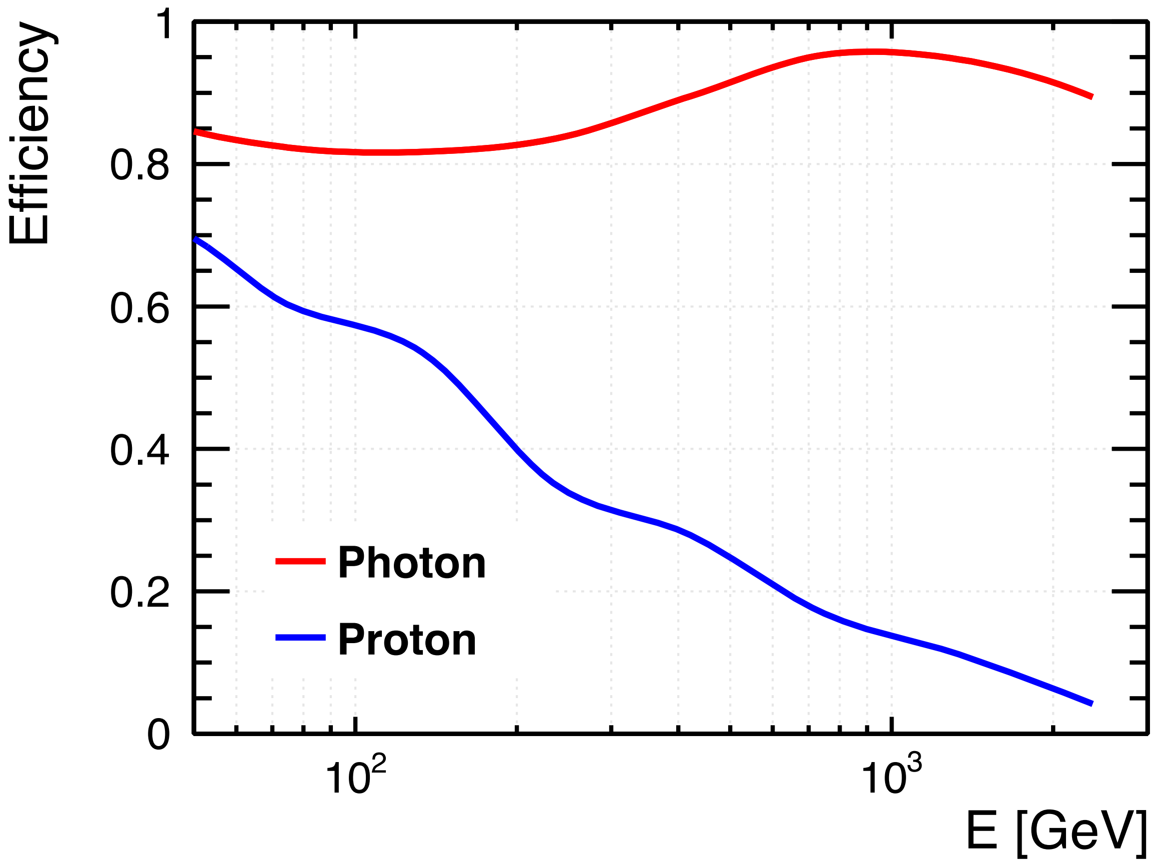
High-energy discrimination strategy

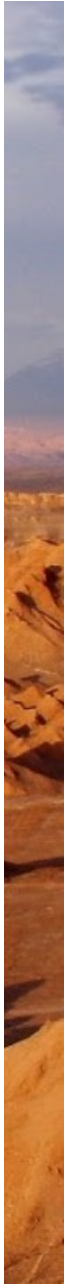
- Get the gamma average LDF for each reconstructed energy bin
- Fit the average LDF to each single event
  - Absorb the normalization factor
- Compute the shower compactness
  - Event LDF “distance” to the gamma average LDF

$$\text{Compactness} = \log_{10}\left(\sum_{i}^{n}\left(\langle LDF\rangle(r_i) - y(r_i)\right)^2\right)$$



High-energy discrimination strategy

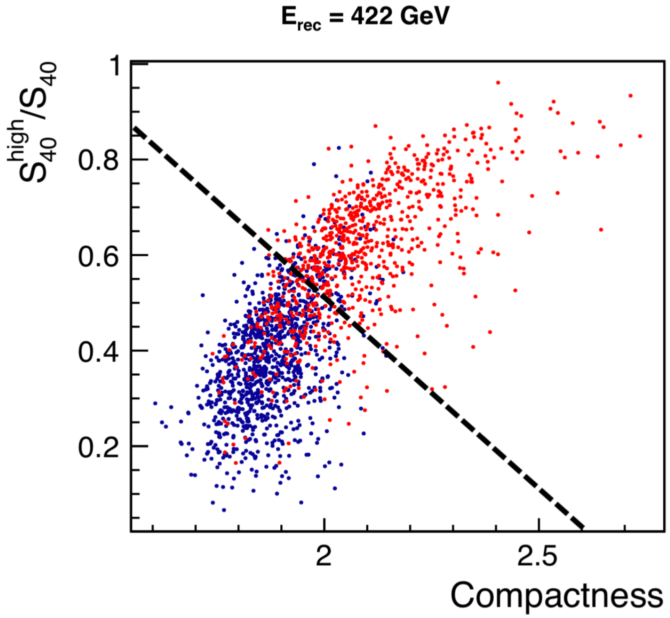




Shower compactness discrimination variable allows for a good background rejection which increases with energy

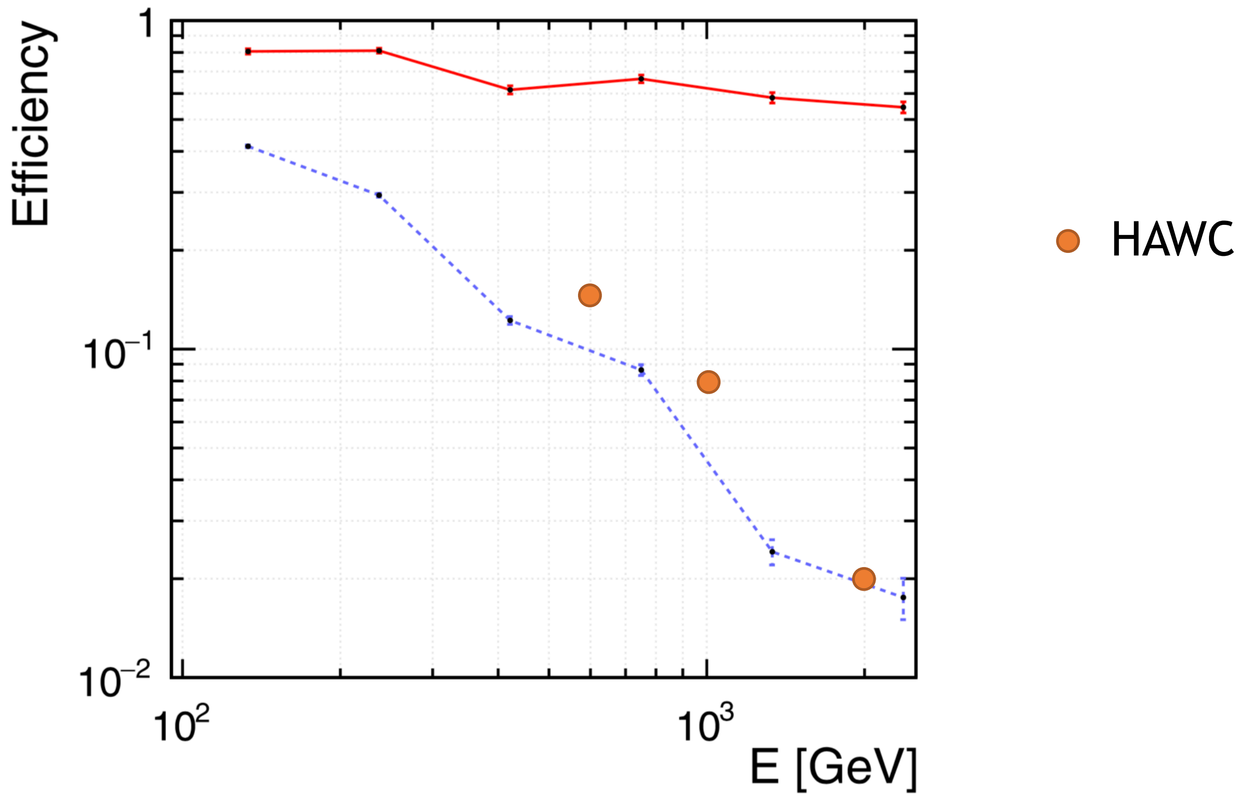
Combine information

- Fisher discriminant analysis to combine the two variables
  - S40high/S40
  - Compactness
  - $S/\sqrt{B} = 6$ (at 2 TeV)



- LATTES MVA toolkit created
  - ROOT::TMVA
  - TinyXML
  - Python / C++
- Can easily be extended to:
  - add more discrimination variable
  - use higher-order methods BDT, ANN…

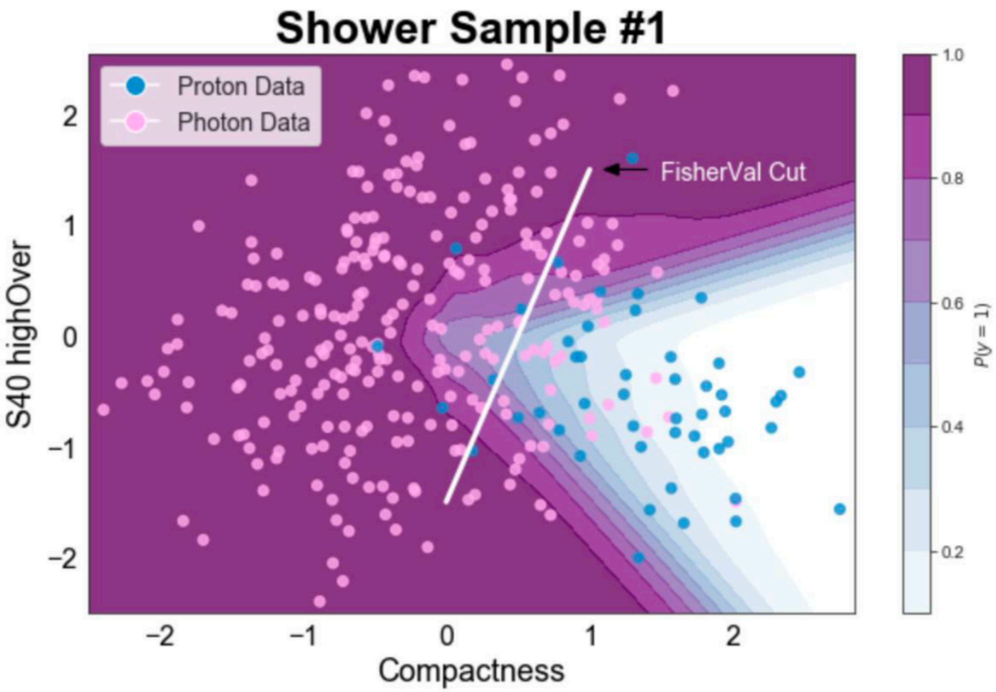
LATTES g/h discrimination



Although not optimized the gamma/hadron discrimination results are already very encouraging

Towards the use of ANN…

- Simple artificial neural network
- ANN with 3 layers: Keras + Scikit-learn
- LATTES summer student work

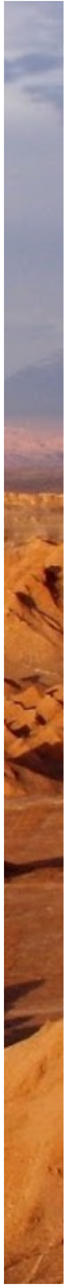


- Encouraging results but need more simulations
- Simulation time recently considerably improved

Summary

- LATTES WCDs can be used to distinguish between gamma and hadron induced showers
  - First results are very encouraging
    - Analysis not optimized
    - More variables (ideas) can be easily added and tested

  - LATTES RPCs still to be explored in g/h discrimination
  - The combination of both techniques shower further improve LATTES discrimination



Acknowledgements

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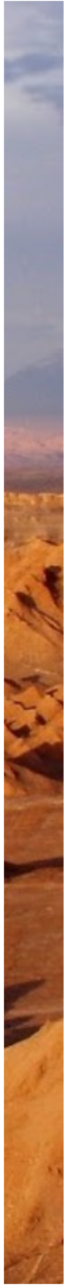
REPÚBLICA PORTUGUESA

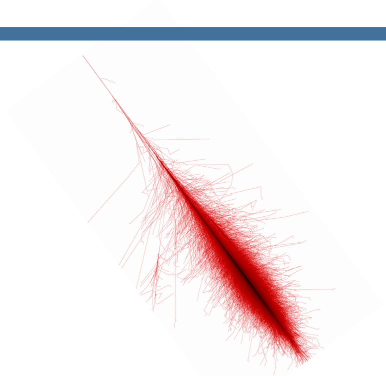
LIP

TÉCNICO LISBOA

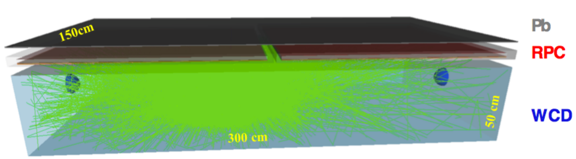
Backup slides



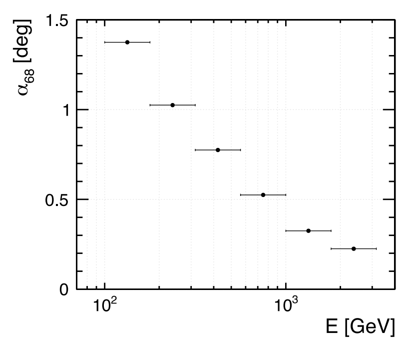
Towards LATTES sensitivity…



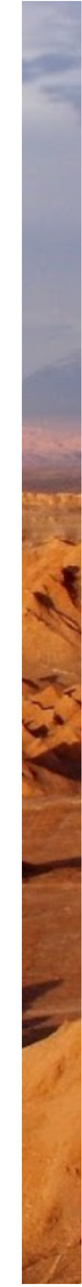
Shower simulation
(CORSIKA)



Detector simulation
(Geant4)



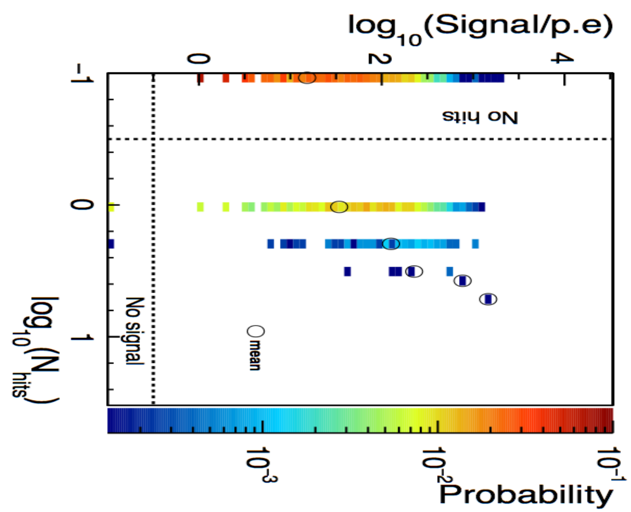
Shower reconstruction
(LATTESrec)

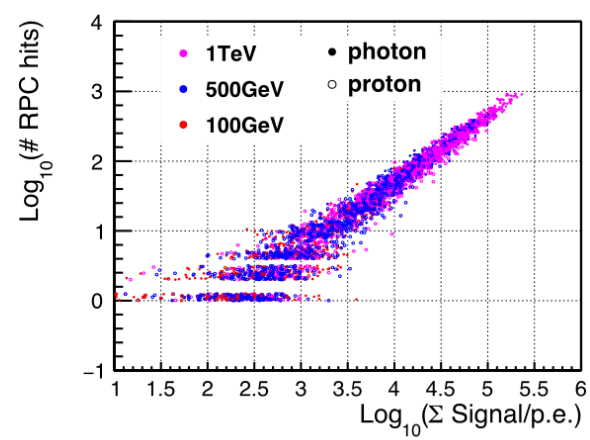


LATTES: a hybrid detector

- Thin lead plate
  - To convert the secondary photons
  - Improve geometric reconstruction
- Resistive Plates Chamber
  - Sensitive to charged particles
  - Good time and spatial resolution
  - Improve geometric reconstruction
  - Explore shower particle patterns at ground
- Water Cherenkov Detector
  - Sensitive to secondary photons and charged particles
  - Measure energy flow at ground
  - Improve trigger capability
  - Improve gamma/hadron discrimination

WCD vs RPC (station level)

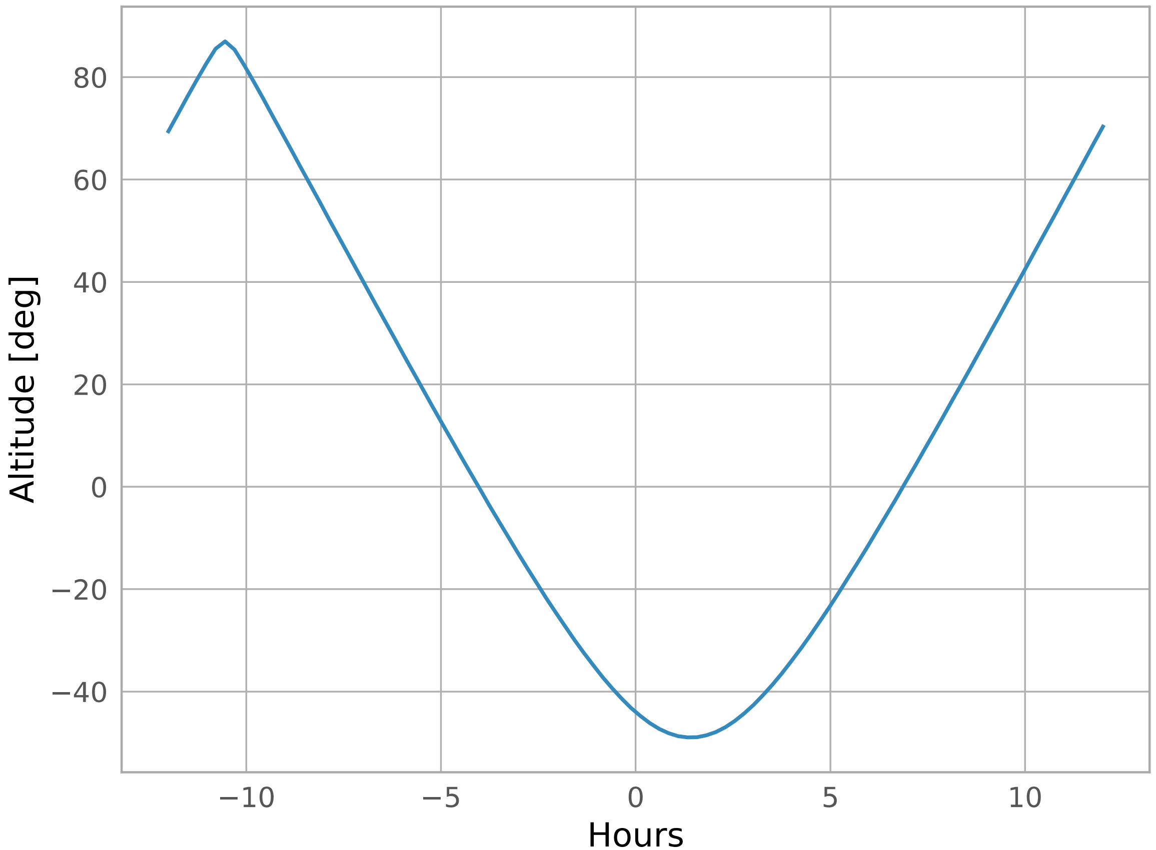


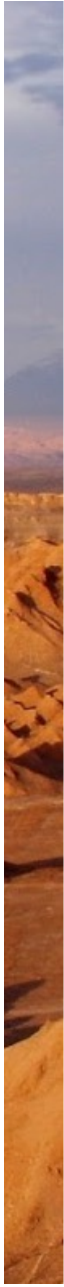


Complementarity

Inter-calibration

Crab





Accidentals contamination

Considering a time window D, the mean number of stations that randomly trigger within D is :

$$n_S = N_s \times R \times D$$

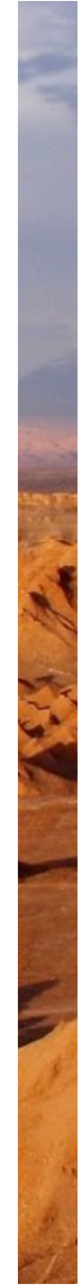
with N_s the # of stations in the array and R the single station trigger rate.

For LATTES N_s = 3600 and R was estimated from MC simulations to be of the order of 500 Hz; taking D ~ 200 ns yields :

$$n_S \sim 0.4$$

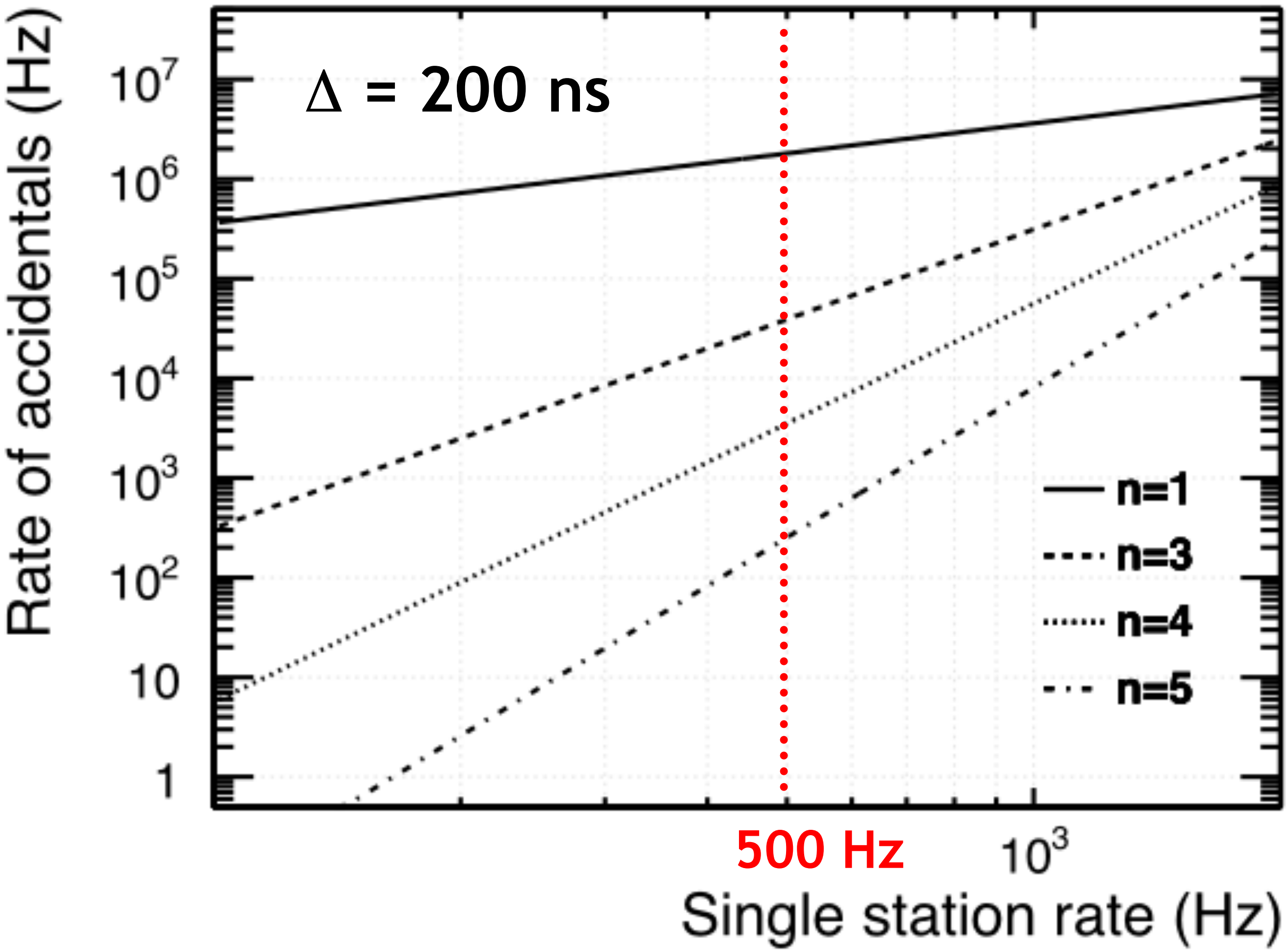
to be compared with the minimum of stations required in a shower trigger, n_S=3.

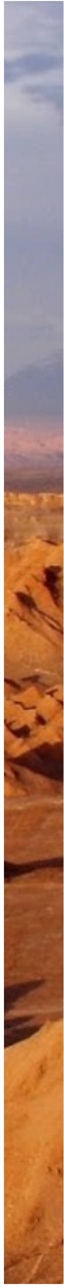
In any case a detailed MC simulation of the impact of the accidentals should be performed !



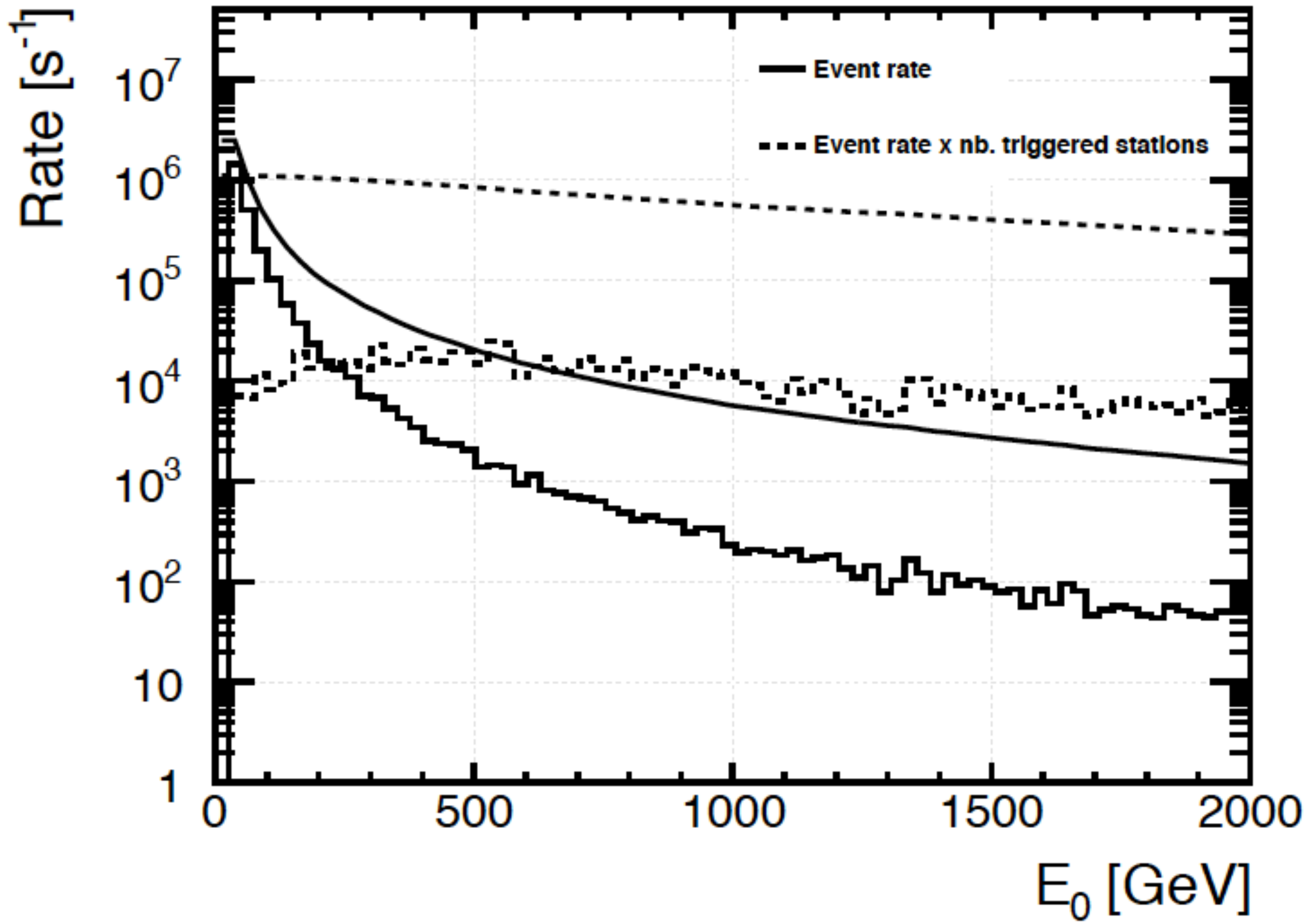
Random triggers

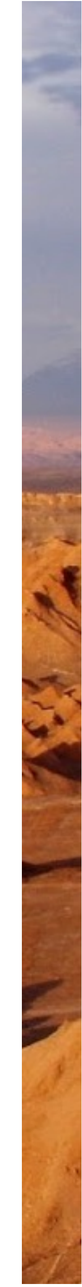
Rate of n-fold random coincidences in LATTES as a function of the single station trigger rate



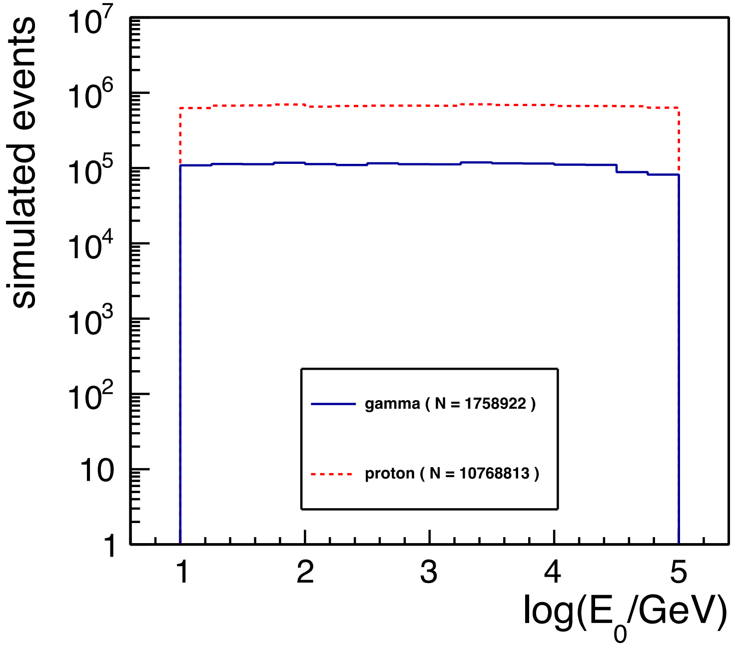


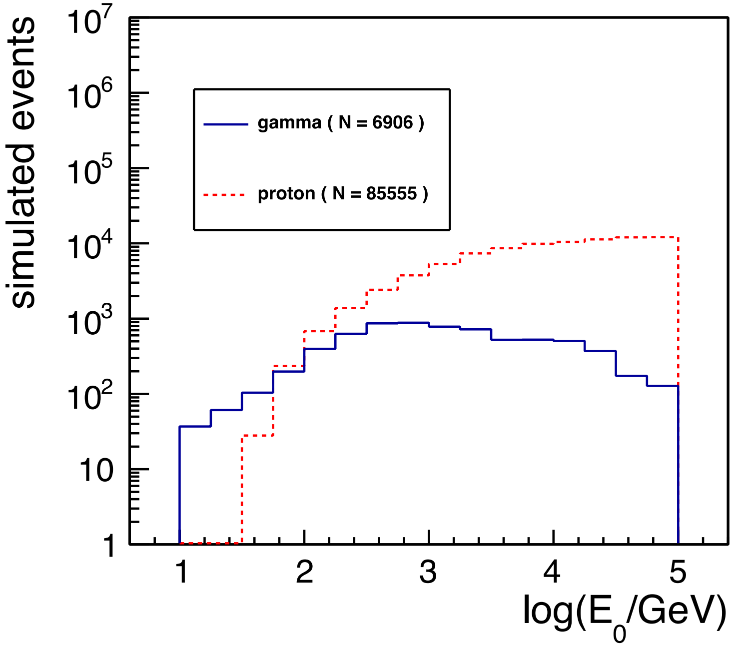
Cosmic rays and station trigger rate





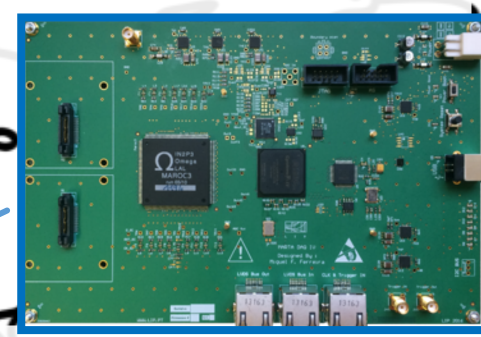
Reconstruction efficiency





Ongoing developments and tests on RPCs, electronics and read-out systems

RPC developments



DAQ Engineering prototype

RPC based muon hodoscope for precise studies of the Auger WCD

Top RPC

Gianni Navarra WCD

Bottom RPC

Construction and Assembling

RPC hodoscope

RPCs in the field @ Auger