LATTES: shower reconstruction

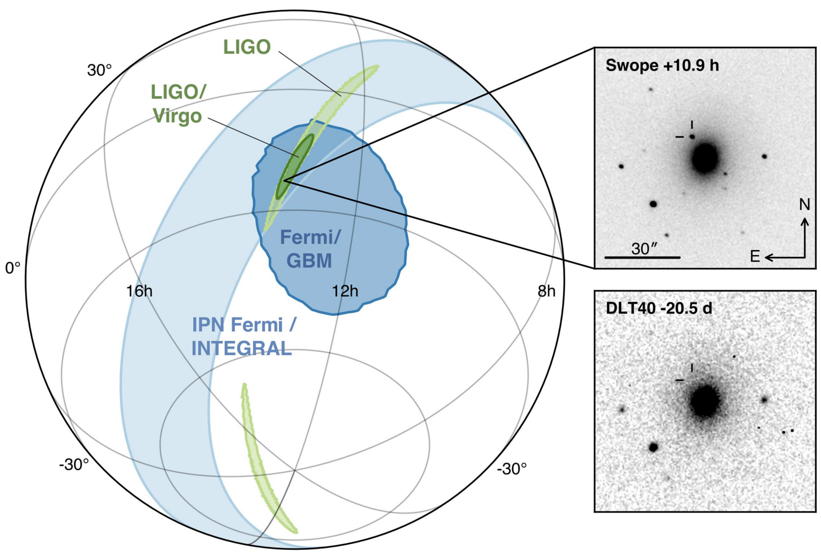
Ruben Conceição

on behalf of the LATTES team

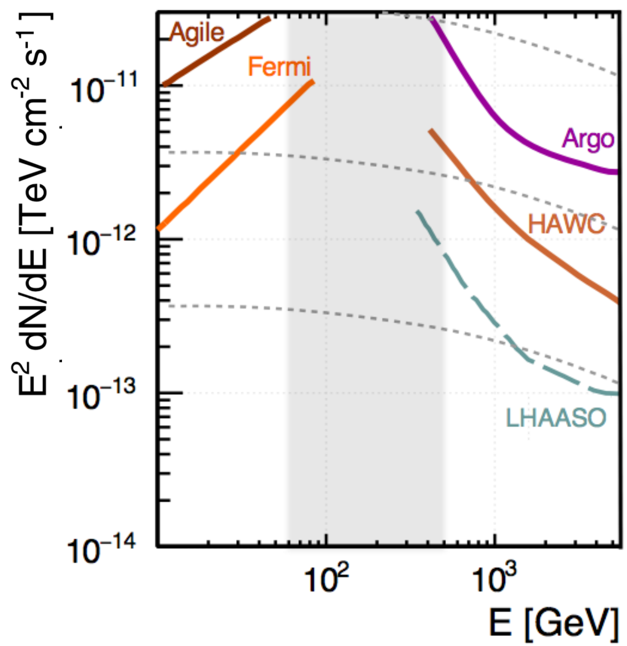
LIP

The era of multi-messenger observations

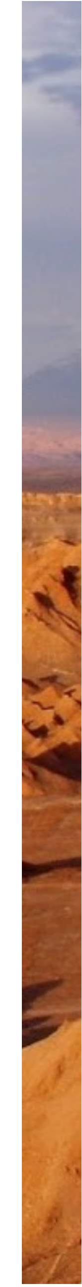
Joint publication of LIGO, VIRGO, INTEGRAL, Fermi, IceCube, Pierre Auger …



Current wide FoV gamma-ray observatories

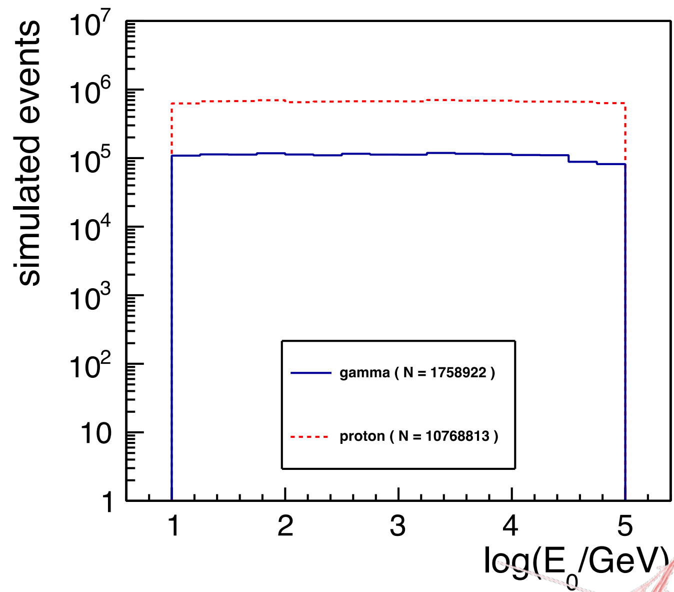


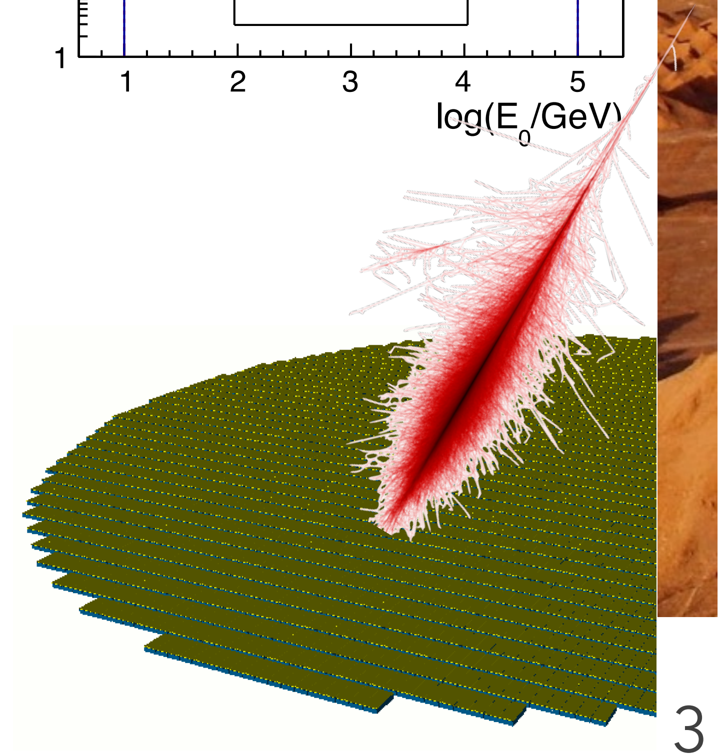
- Simultaneous observation of a Gravitational Wave + electromagnetic counterparts
- Study of transient phenomena in all energy windows is one of the main ingredients



Simulation Framework

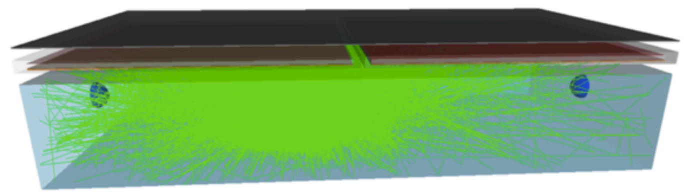
- End-to-end realistic simulation
  - Extensive Air Showers: CORSIKA
    - v7.6400 with Fluka2011.2c
    - More than 50 000 gamma/proton shower simulated randomly between 10 GeV – 300 TeV
    - Gammas have a fixed zenith angle of 10 degrees
    - Observation level at 5200 m of altitude
  - Detector simulation: Geant4
    - v10.1.3
    - Core array 20 000 m²
    - Each shower is resampled 100 times over a big area containing all the array



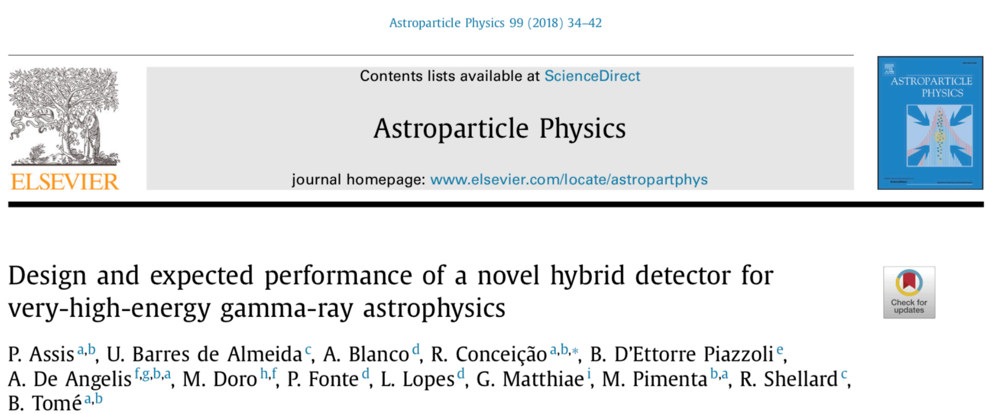


Simulation Framework

- Reconstruction
  - First order analyses with little optimization only to demonstrate principle



- Performance and sensitivity



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Design and expected performance of a novel hybrid detector for very-high-energy gamma-ray astrophysics

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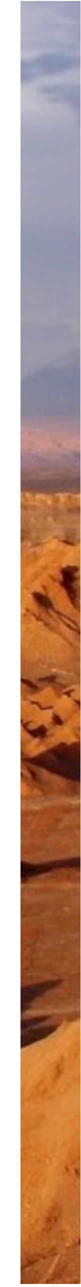
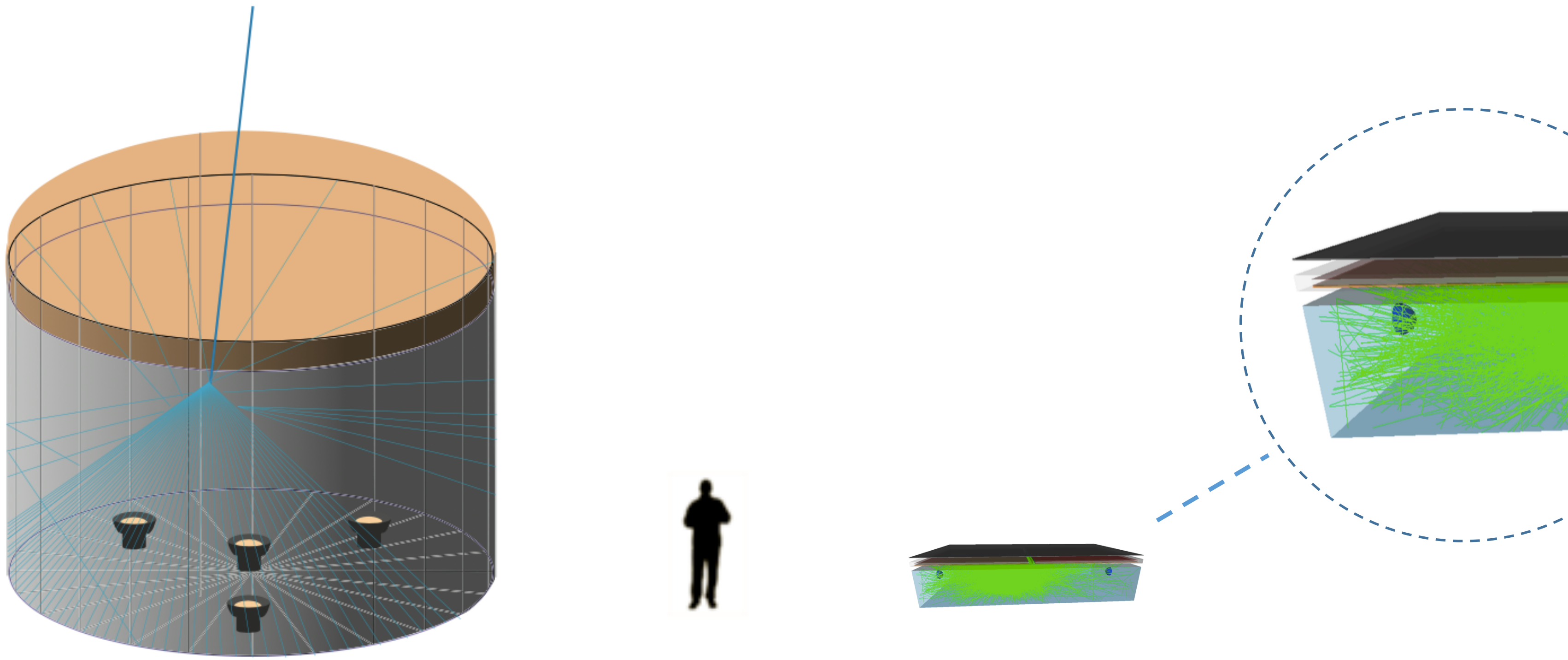


LATTES expected performance

- Trigger and effective area
- Core reconstruction
- Energy reconstruction
- Geometry reconstruction
- Gamma/hadron discrimination
- Sensitivity to steady sources

Station: HAWC vs LATTES



HAWC
(present detector)

LATTES
(next generation)

LATTES expected performance

- **Trigger and effective area**
- Core reconstruction
- Energy reconstruction
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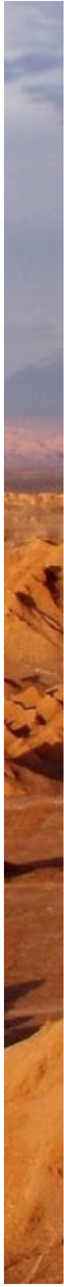
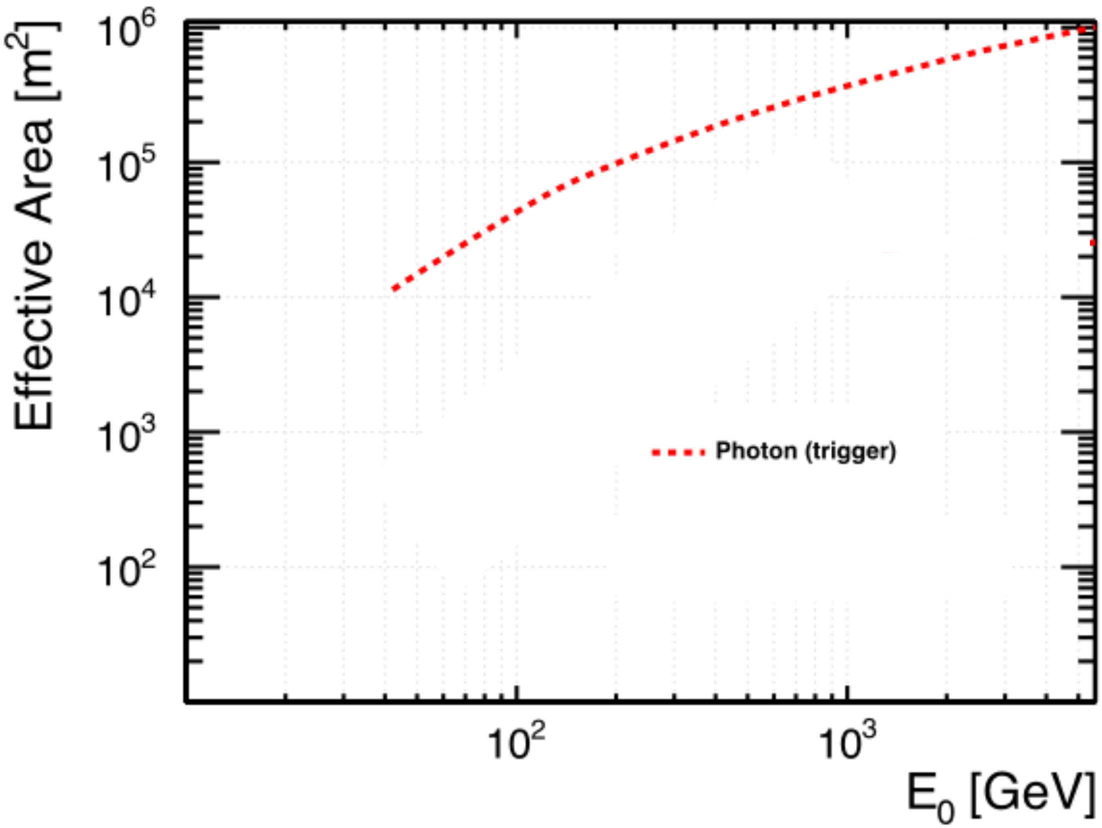
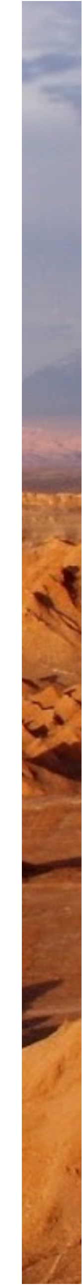
- Gamma/hadron discrimination
- Sensitivity to steady sources



Trigger efficiency



- Use WCD stations to trigger at low energies
  - Trigger condition
    - Station: require more than 5 p.e. in each PMT
    - Event: require 3 triggered stations



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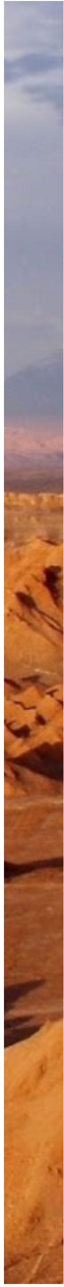
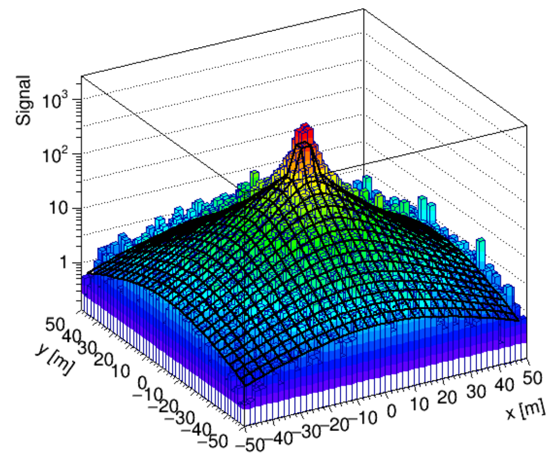


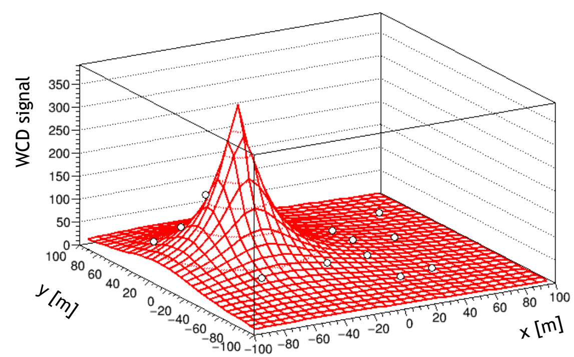
Shower core reconstruction

- Use the WCD signal
- Barycenter
  - Initial guess
  - Works but the core is always reconstructed inside the array
- Fit the WCD LDF
  - Fit photon average LDF to fix the shape
    - Function inspired in HAWC
    - Nearly no evolution with energy
  - Use this form to find the maximum, i.e. the shower core

Average LDF



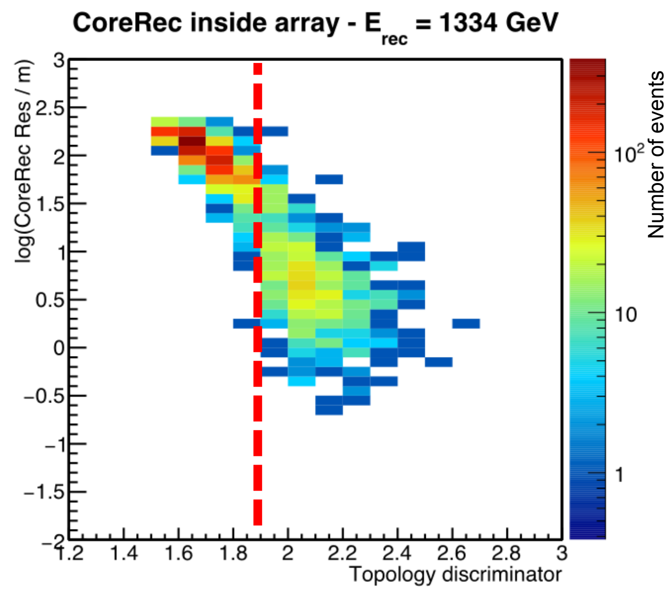
Single event

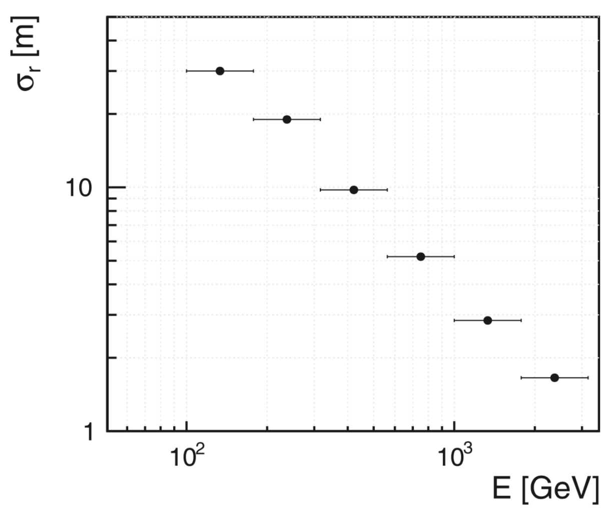


$$S_i = S(A, \vec{x}, \vec{x}_i) = A\left(\frac{1}{2\pi\sigma^2} e^{-|\vec{x}_i - \vec{x}|^2/2\sigma^2} + \frac{N}{(0.5 + |\vec{x}_i - \vec{x}|/R_m)^3}\right)$$

Shower core reconstruction

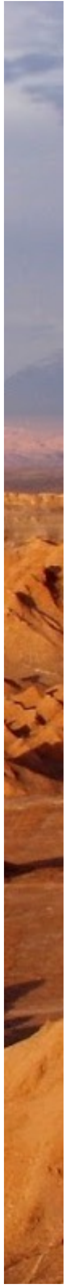
- Test whether the shower is inside/outside the array
  - Explore LDF topology
  - Is maximum observed inside of array?
  - Currently exploring the quality of the fit
  - Fixed cut for all energies
- Resolution better than 10 meters for showers above 300 GeV





LATTES expected performance

- ✧ Trigger and effective area
- ✧ Core reconstruction
- ✧ **Energy reconstruction**
- ✧ Geometry reconstruction
- ✧ Gamma/hadron discrimination
- ✧ Sensitivity to steady sources

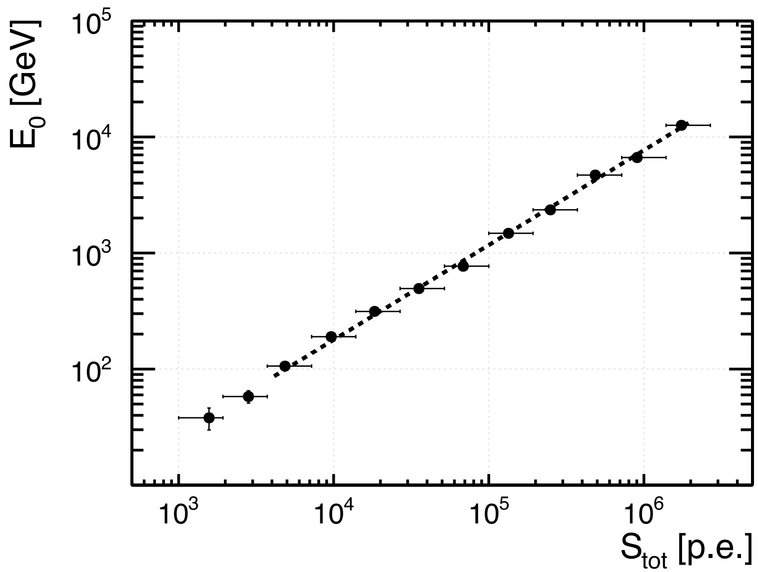


Energy reconstruction

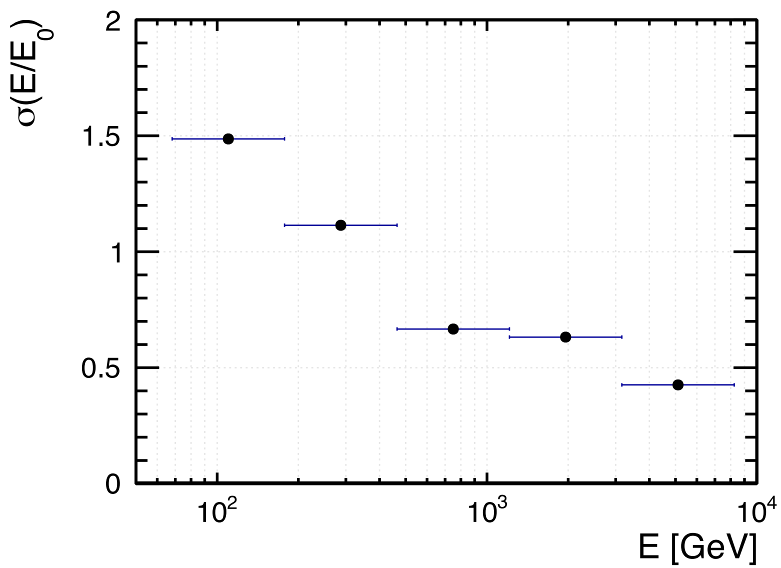
$E_0 \rightarrow$ Simulated energy

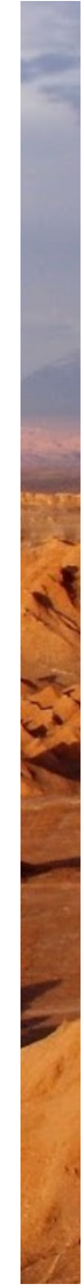
$E \rightarrow$ Reconstructed energy

Energy Calibration



Energy Resolution





- Use as energy estimator the total signal recorded by WCDs
  - Use only shower cores reconstructed inside array
- Energy resolution at low energy dominated by shower fluctuations

LATTES expected performance

- ✧ Trigger and effective area
- ✧ Core reconstruction
- ✧ Energy reconstruction
- ✧ **Geometry reconstruction**
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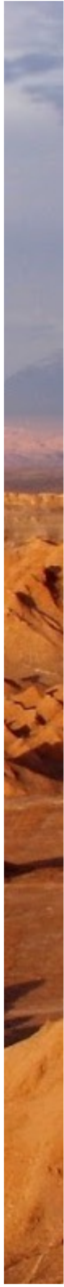
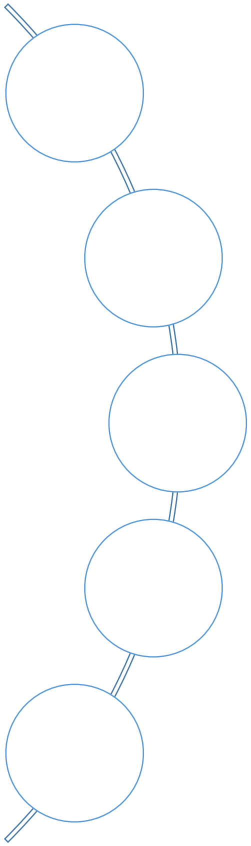
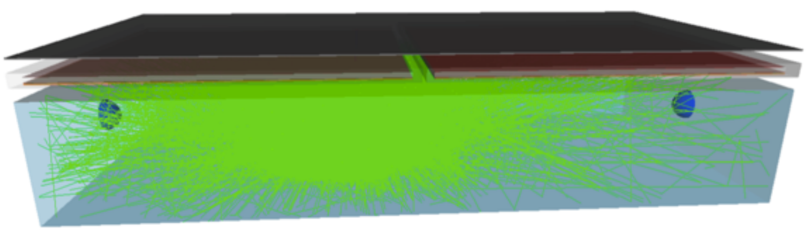
- ✧ Sensitivity to steady sources



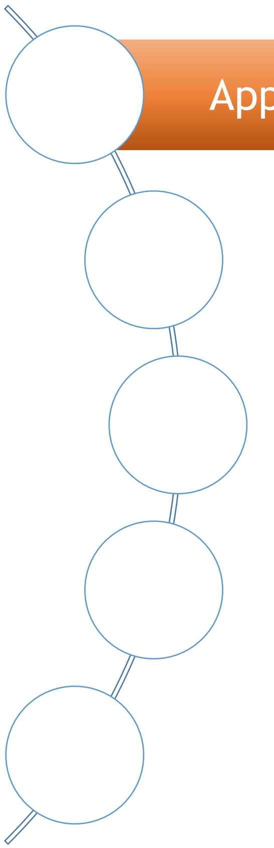
Reconstruction of shower geometry

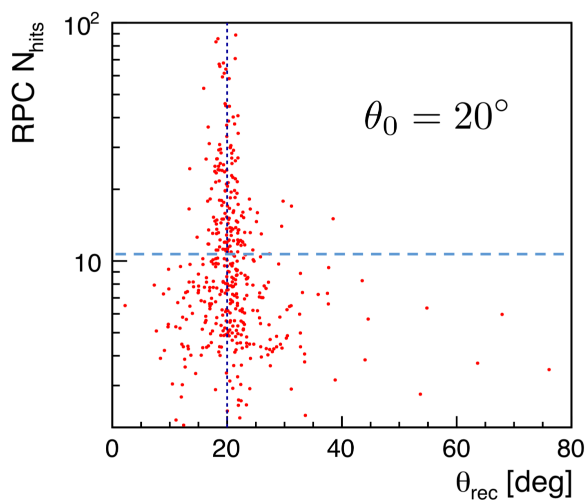


- Use RPC hit time information
  - Take advantage of high spatial and time resolution
  - Used time resolution of 1 ns

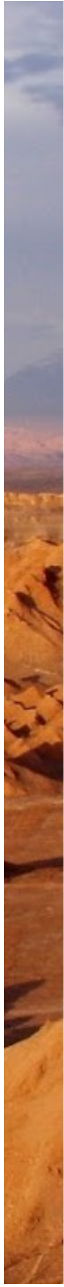


Reconstruction of shower geometry





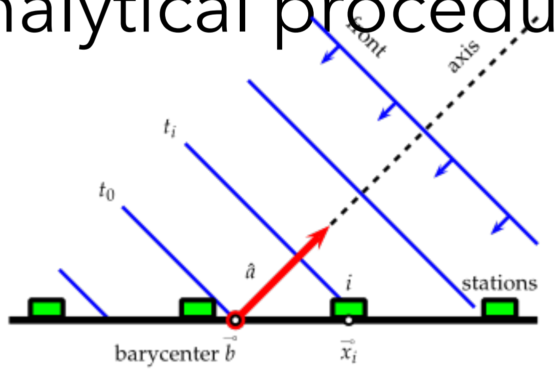
- ✧ Use RPC hit time information
  - ✧ Apply previous shower rec quality cuts
  - ✧ Apply cuts on the number of registered hits on the RPCs
  - ✧ Consider only RPCs in triggered WCD stations

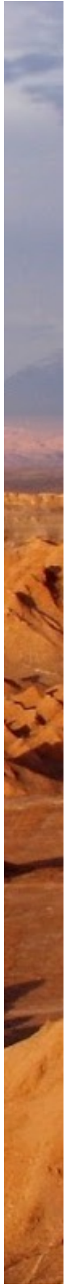


Reconstruction of shower geometry

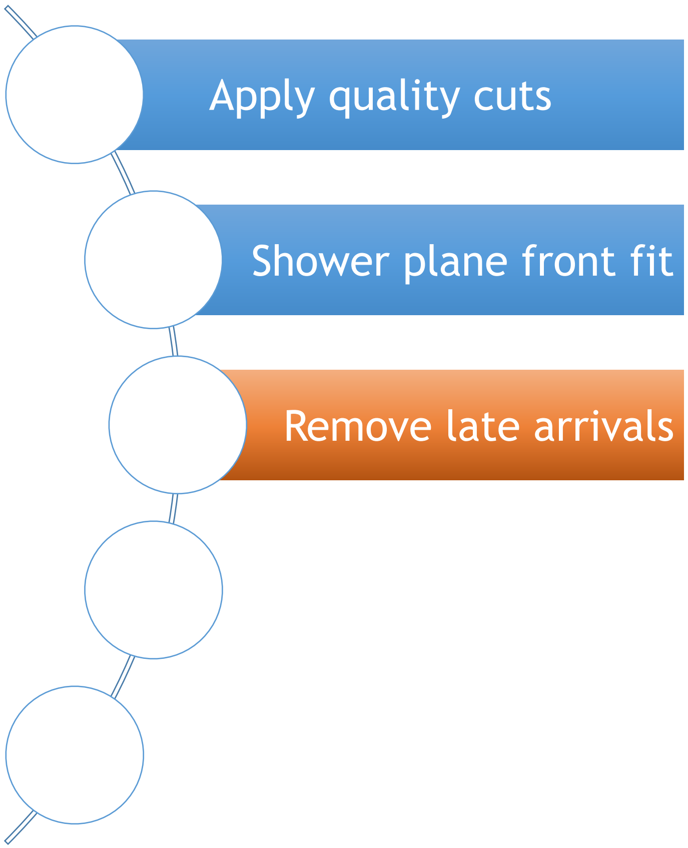
- Apply quality cuts
- Shower plane front fit

- Use RPC hit time information
- Perform shower reconstruction
- Use shower front plane approximation
- Analytical procedure

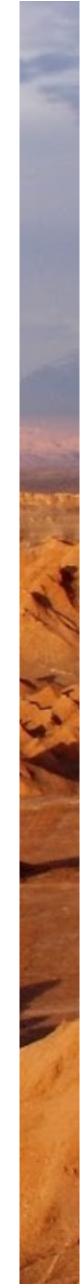




Reconstruction of shower geometry

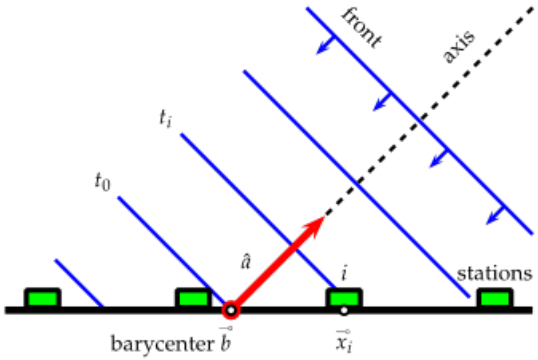


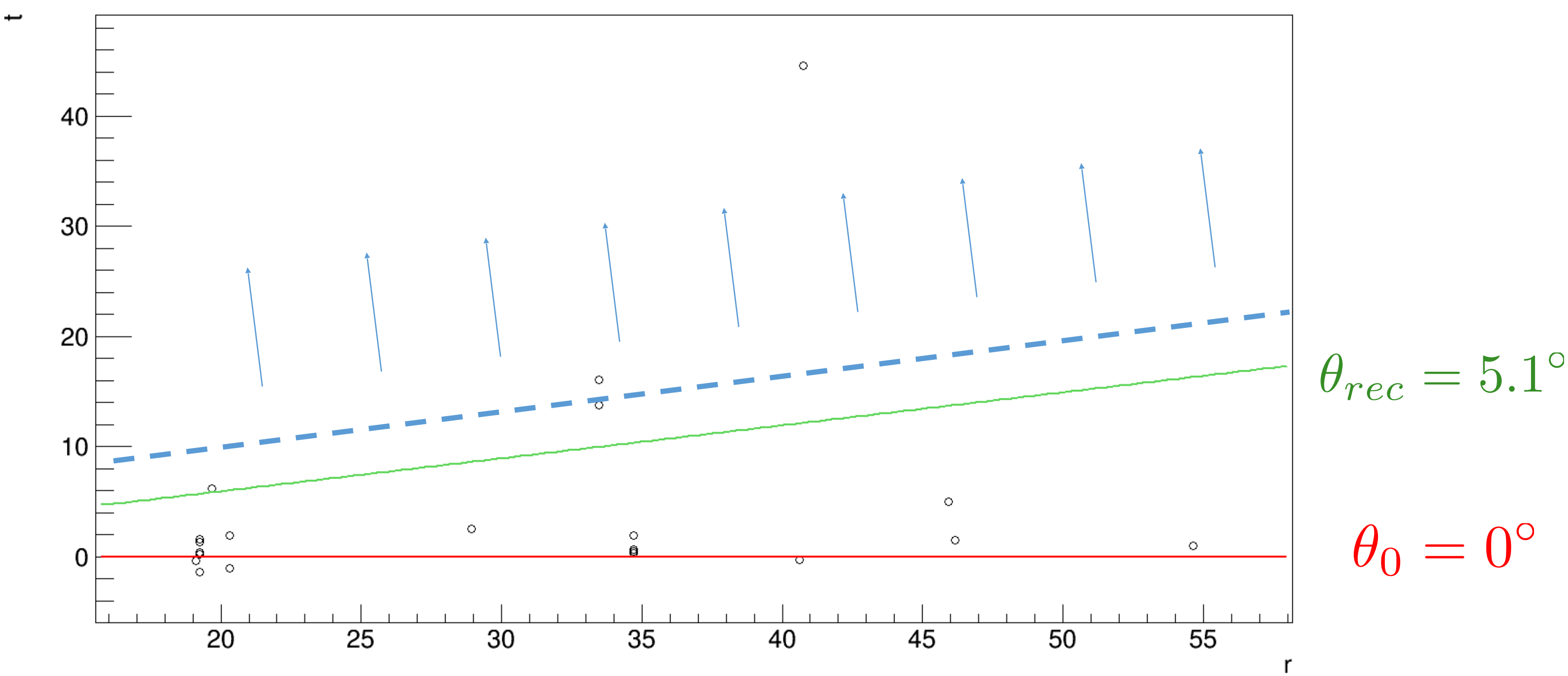
- Use RPC hit time information
  - Identify late arrivals with respect to Rec Shower Front
  - Mainly low energy electrons that lost correlation with shower front

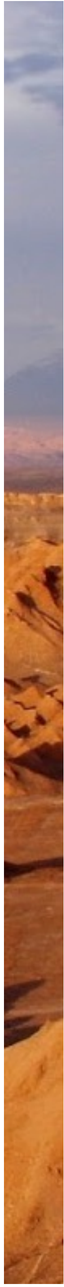


Removal of late arrivals

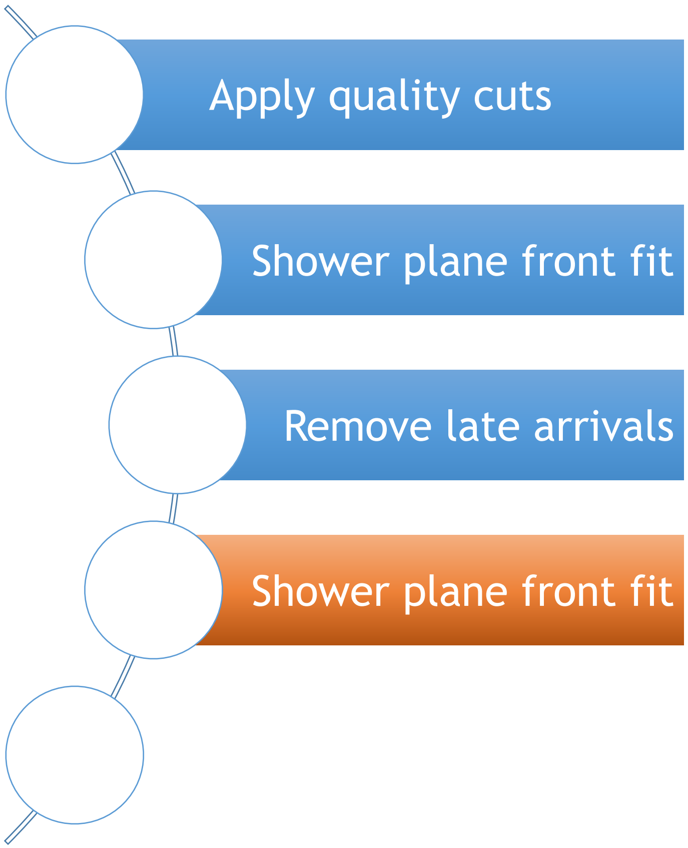
- Example of a vertical gamma shower
- Plot depicts arrival time (ns) distance to simulated shower core (m)



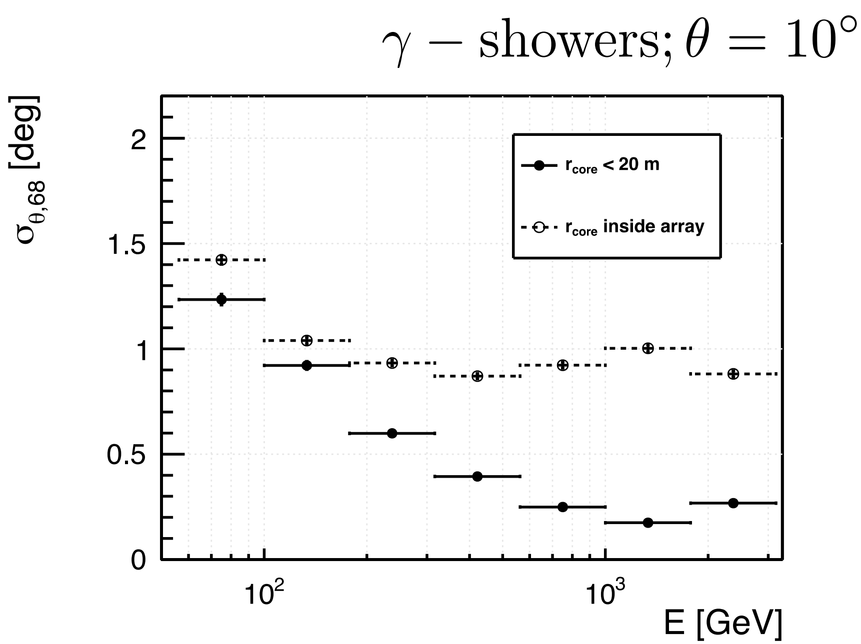




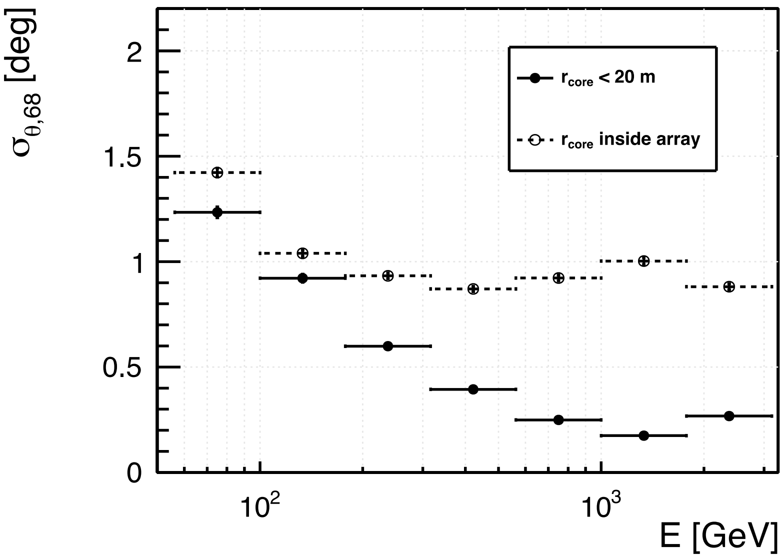
Reconstruction of shower geometry

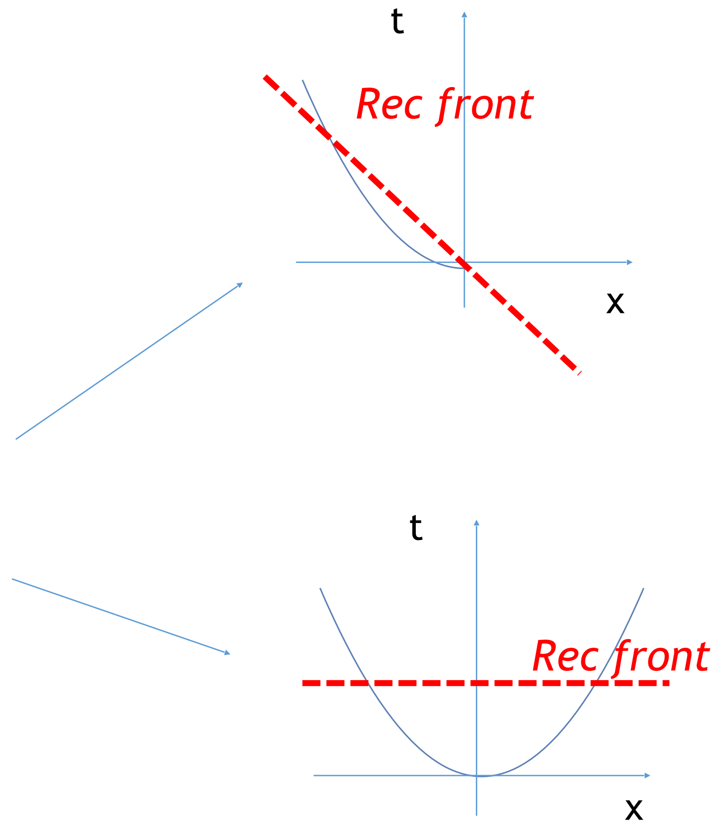


- Use RPC hit time information
  - Repeat fit without arrivals
  - Initial guess for next step



Impact of shower curvature





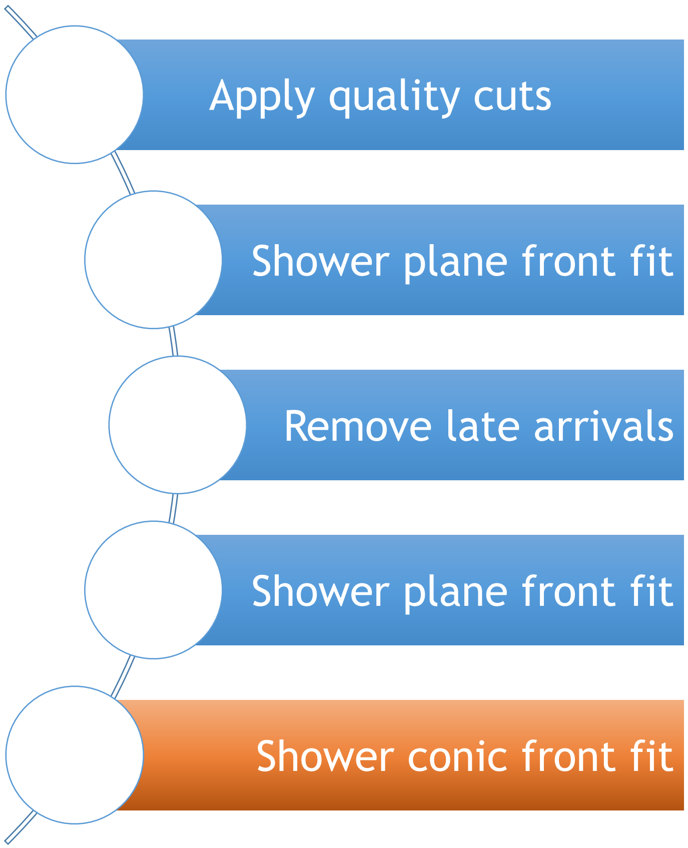
Border of the array

Center of the array

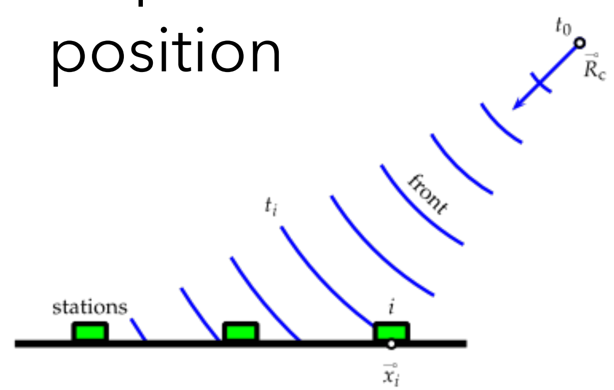
Solution: implement a conic fit instead of fitting a plane

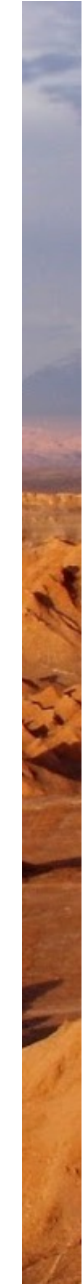
$$\chi^2 = \sum (c \cdot (T_n - T_0) - X_n \cdot - Y_n \cdot m - R_n \cdot \alpha)^2$$

Reconstruction of shower geometry

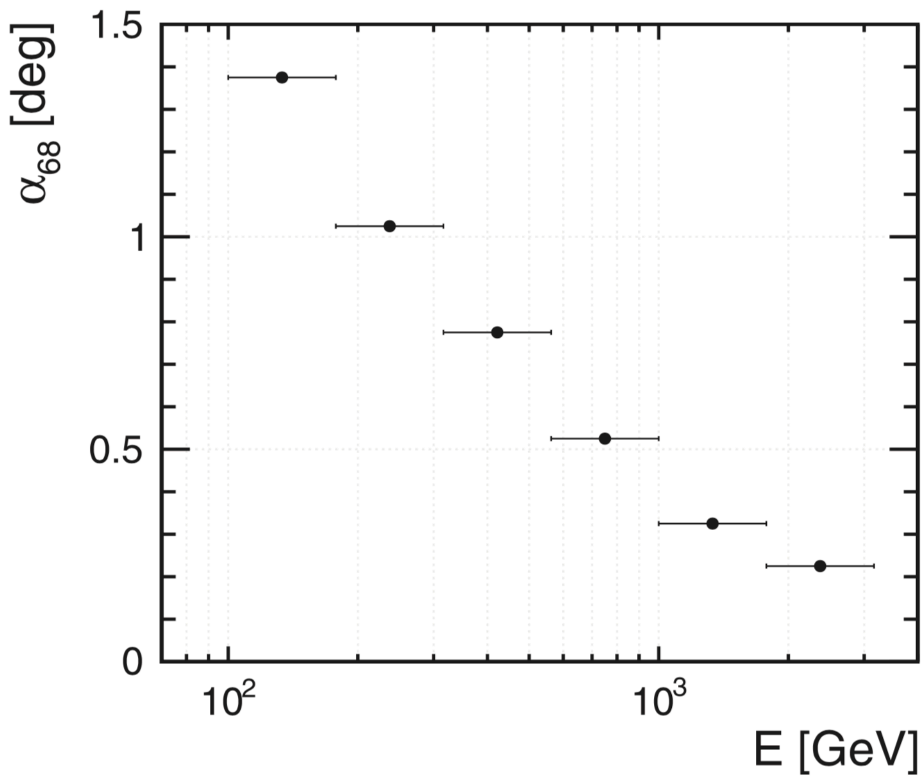


- Use RPC hit time information
  - Fit the shower geometry using a shower conic front model
  - Depends on core position

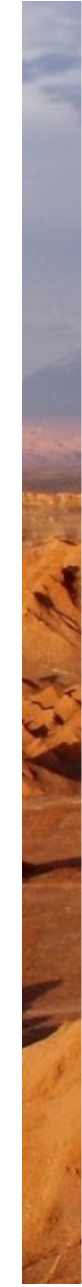




Shower geometry reconstruction

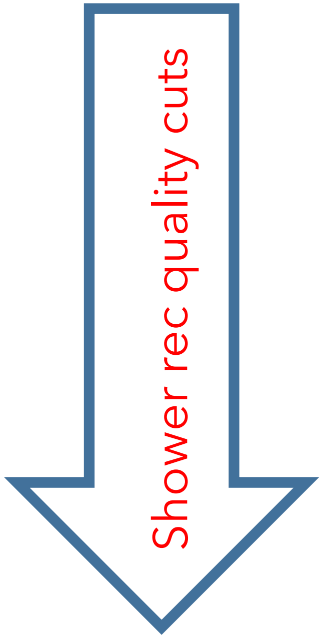


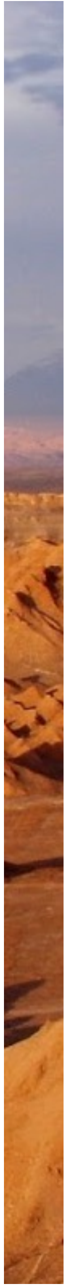
A good angular resolution can be achieved for all events reconstructed inside the array



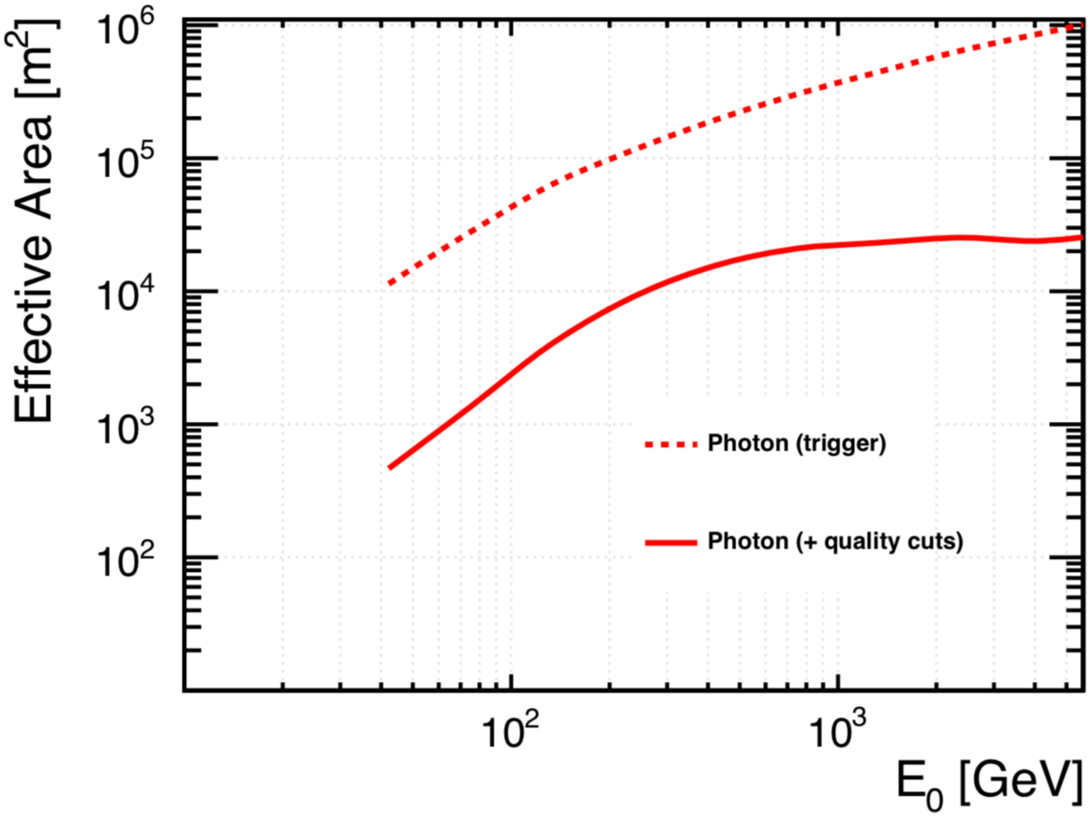
LATTES expected performance

- ✧ Trigger and effective area
- ✧ Core reconstruction
- ✧ Energy reconstruction
- ✧ Geometry reconstruction
- ✧ Gamma/hadron discrimination
- ✧ Sensitivity to steady sources



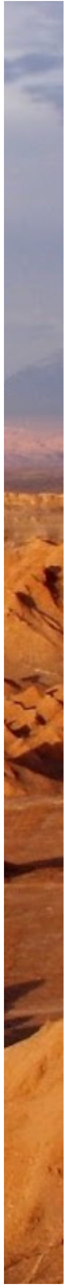


Effective Area



Even applying all quality cuts LATTES

gets an effective area of ~1000 m^2 for E = 100 GeV



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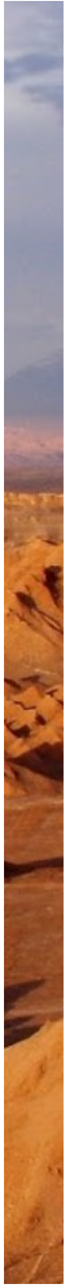
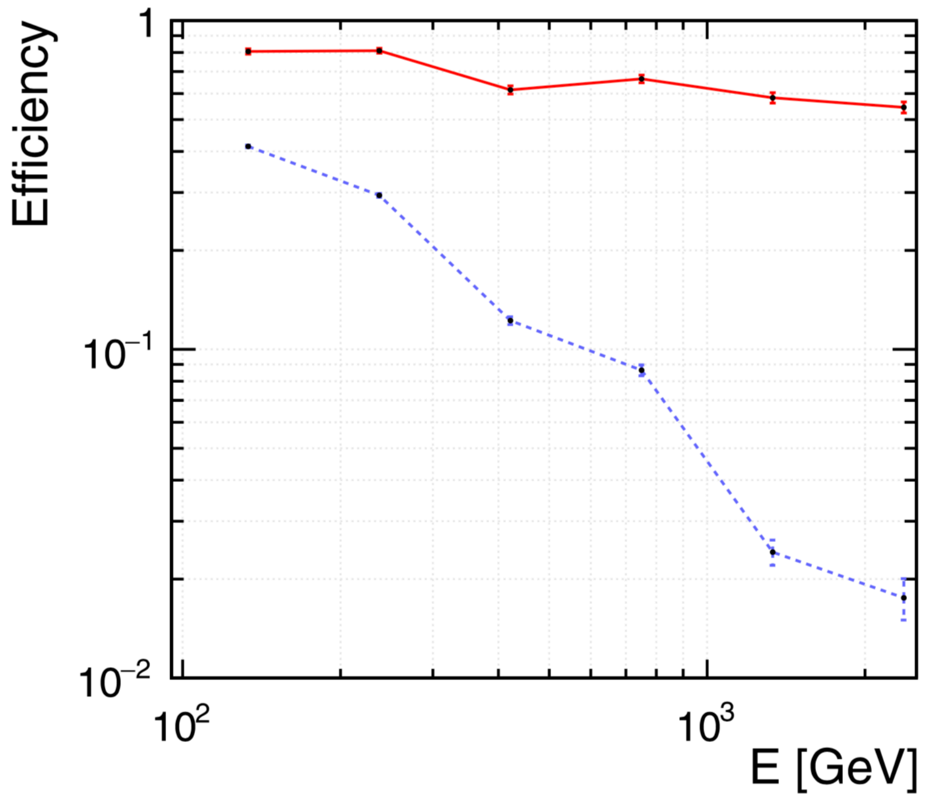


LATTES g/h discrimination

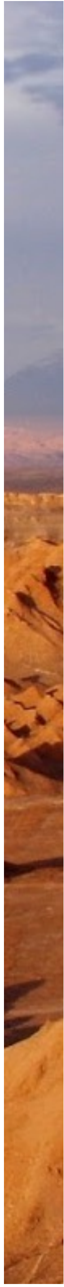


(see next talk)

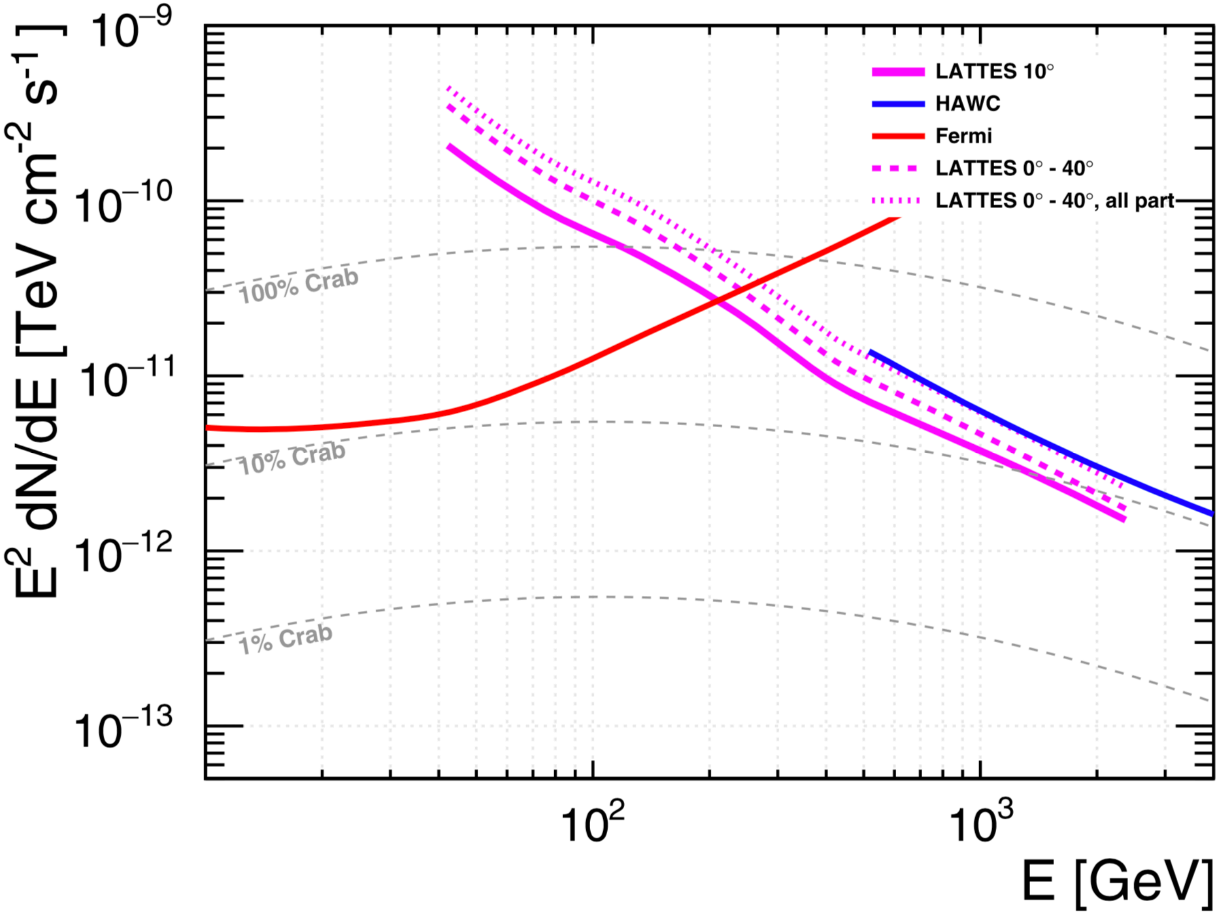
Although not optimized the gamma/hadron discrimination results are already very encouraging

LATTES expected performance

- ✧ Trigger and effective area
- ✧ Core reconstruction
- ✧ Energy reconstruction
- ✧ Geometry reconstruction
- ✧ Gamma/hadron discrimination
- ✧ **Sensitivity to steady sources**



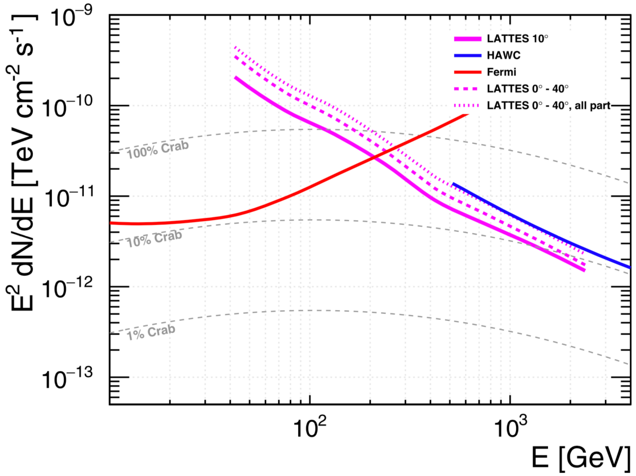
Sensitivity to steady sources

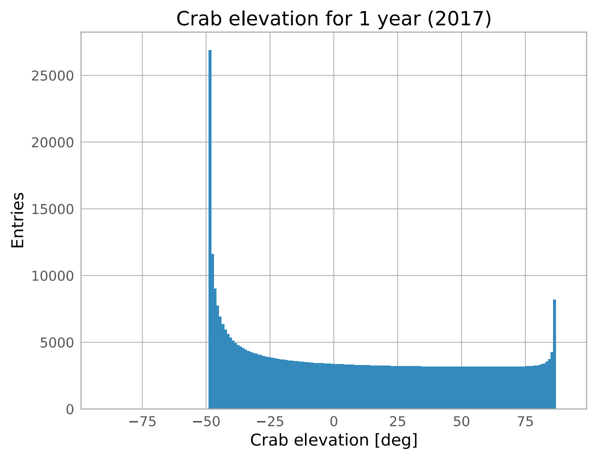


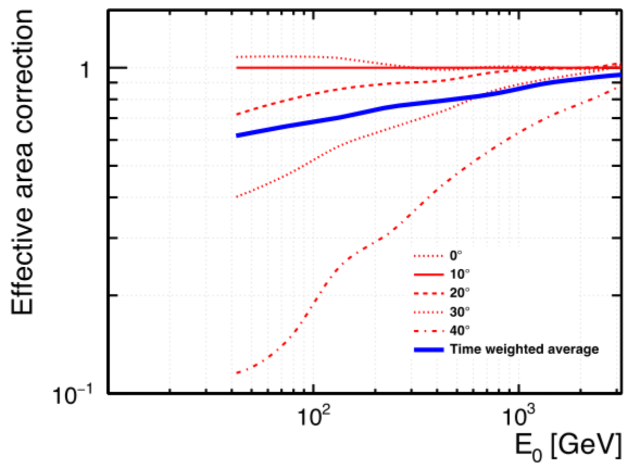
✧ *Full line*: full MC calculation for a source at 10 degrees in zenith

Sensitivity to steady sources

- *Dashed line*: Crab transit as seen by HAWC
  - Degradation of effective area with zenith angle estimated from electromagnetic energy at ground

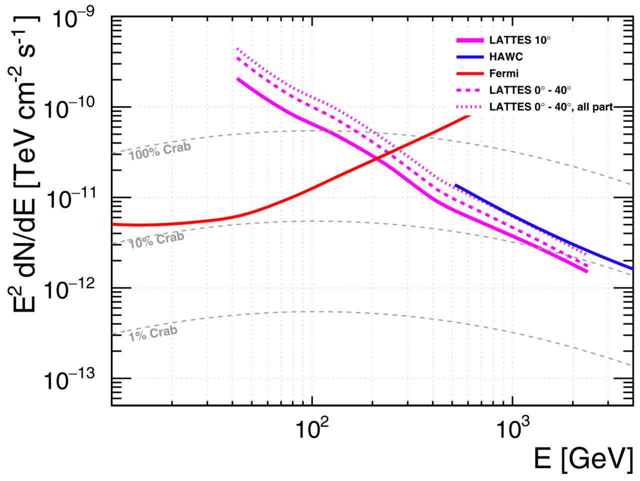


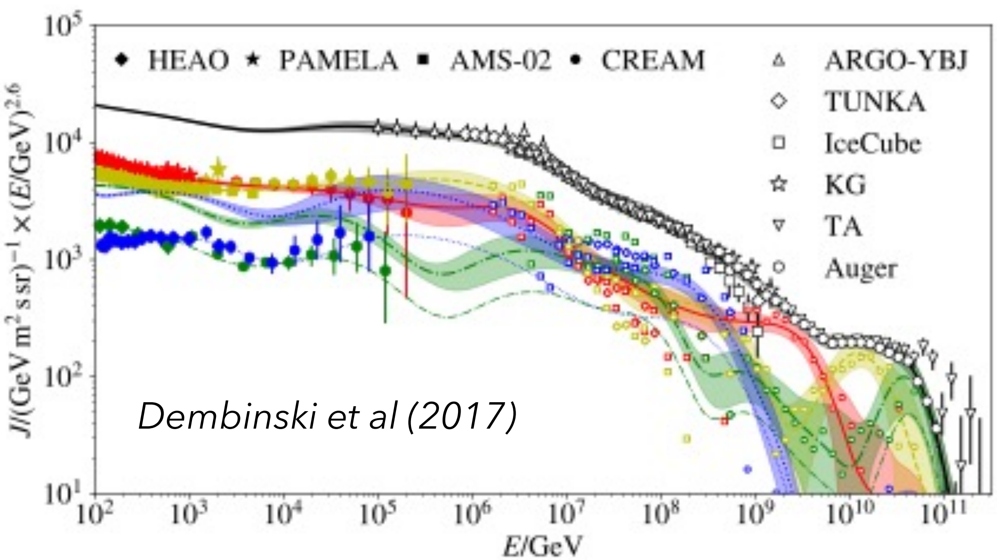




Sensitivity to steady sources

- *Dotted line:* CR all-spectrum
  - Additional elements (He, N, Fe…)
  - Assume that LATTES cannot distinguish gammas from irons

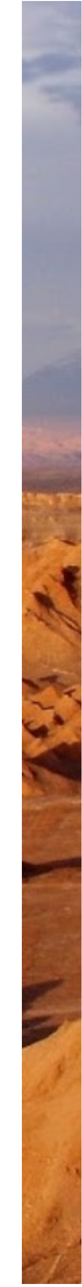




Dembinski et al (2017)

Summary

- LATTES shower reconstruction performance has been evaluated yielding very good results
  - Shower trigger (effective area)
  - Shower core reconstruction
  - Shower energy reconstruction
  - Shower geometry reconstruction
  - Gamma/hadron discrimination
- LATTES capabilities are far from being fully explored
  - Possible improvements already identified
    - Sparse array to veto far away high-energy showers (main background source)
    - Use RPC patterns to discriminate g/h
    - Better assess LATTES ability to reconstruct
      - Inclined showers
      - Heavier primaries induced showers
    - …



Acknowledgements

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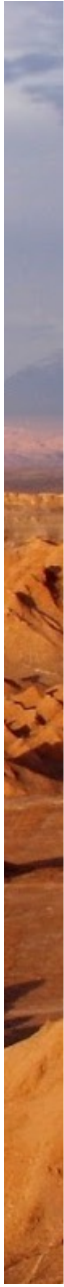
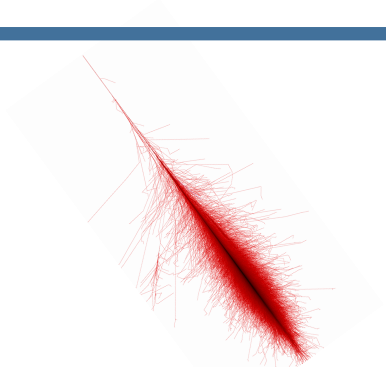
TÉCNICO LISBOA

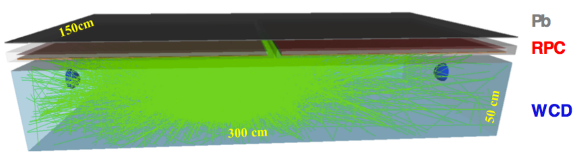
Backup slides



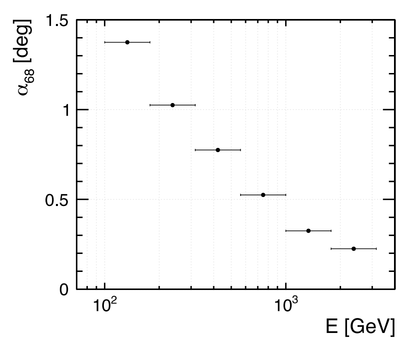
Towards LATTES sensitivity…



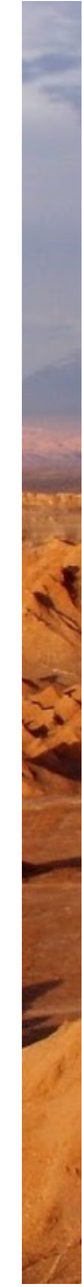
Shower simulation
(CORSIKA)



Detector simulation
(Geant4)



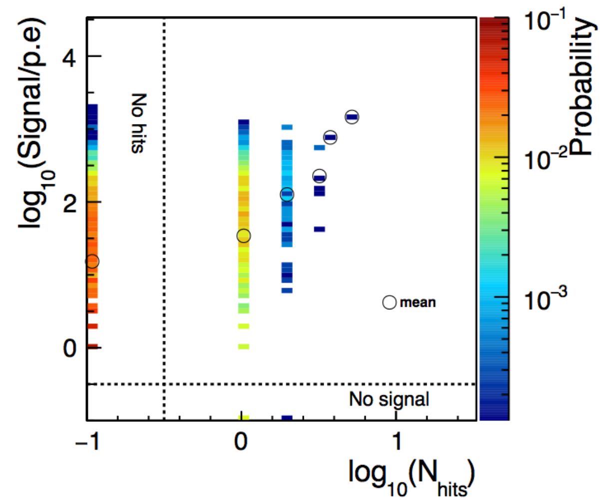
Shower reconstruction
(LATTESrec)



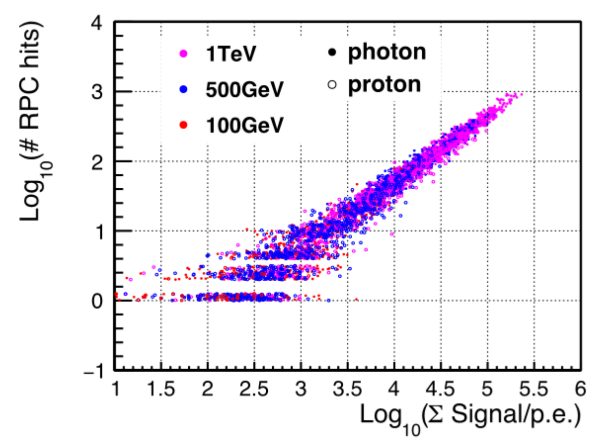
LATTES: a hybrid detector

- 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)

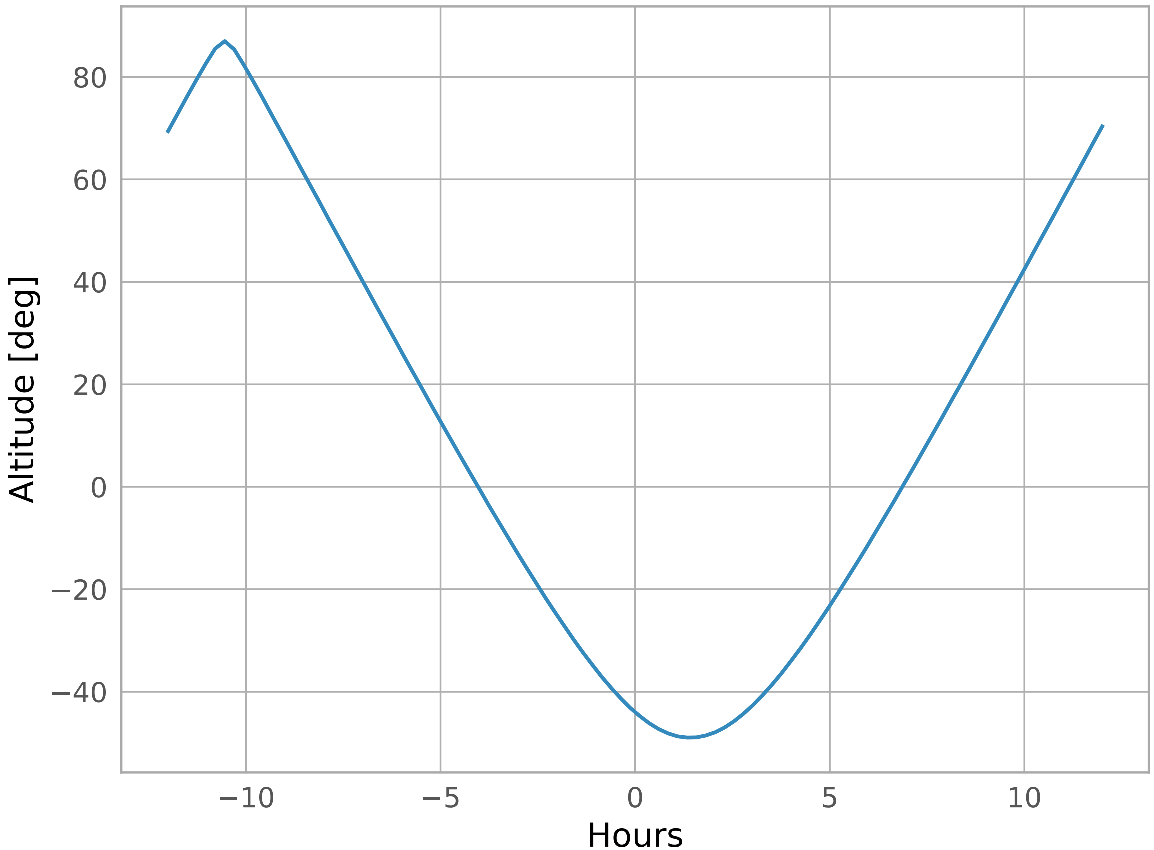


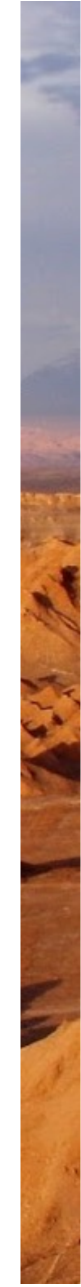
Complementarity



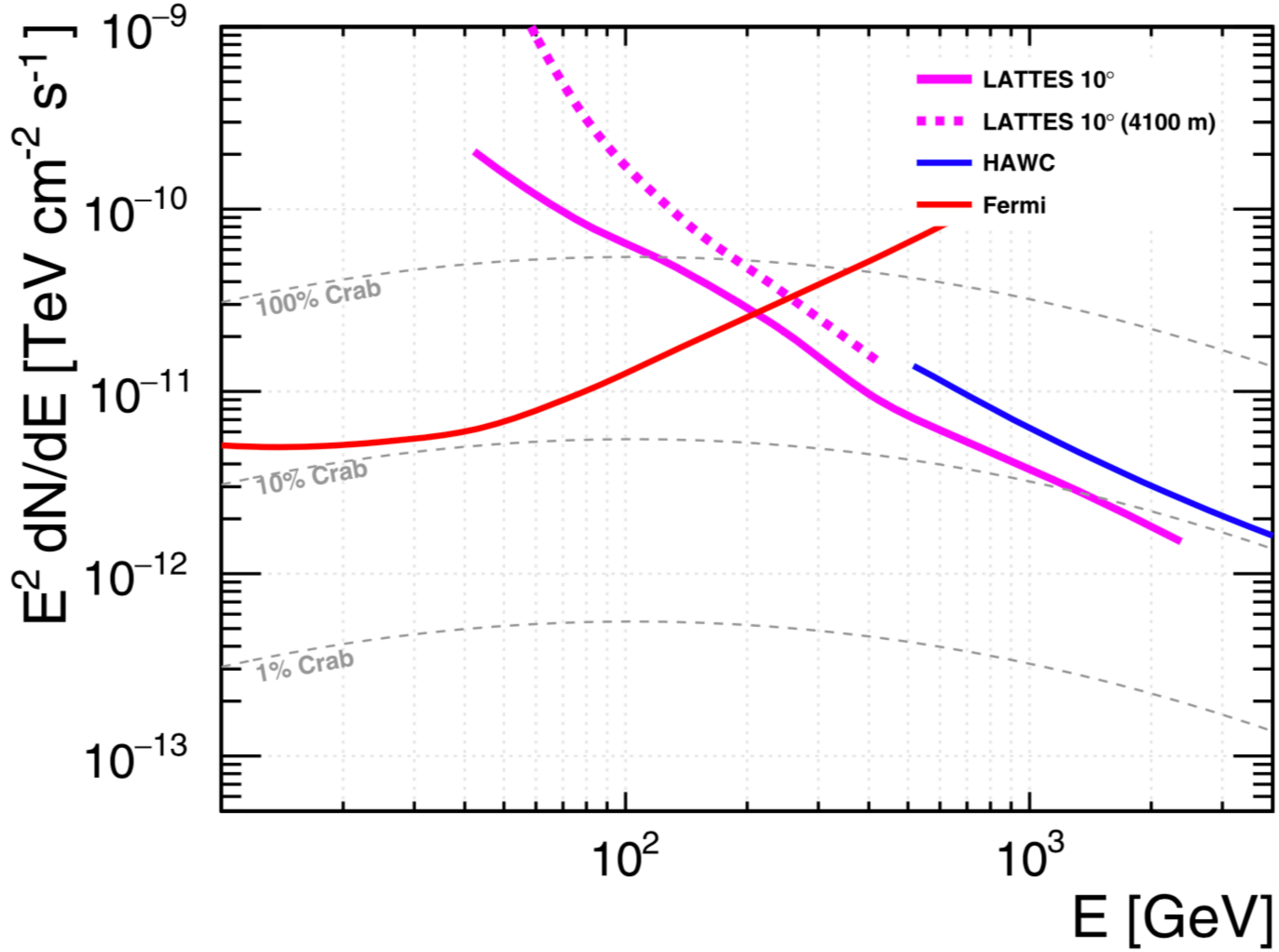
Inter-calibration

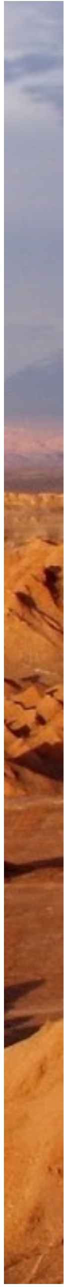
Crab





Impact of altitude





Accidentals contamination

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

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

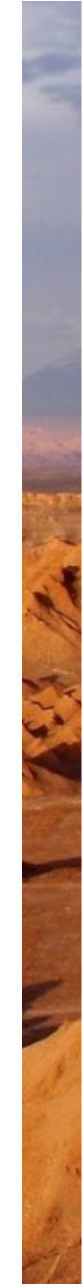
with N_s the # of stations in the array and R the single station trigger rate.

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 :

$$n_S \sim 0.4$$

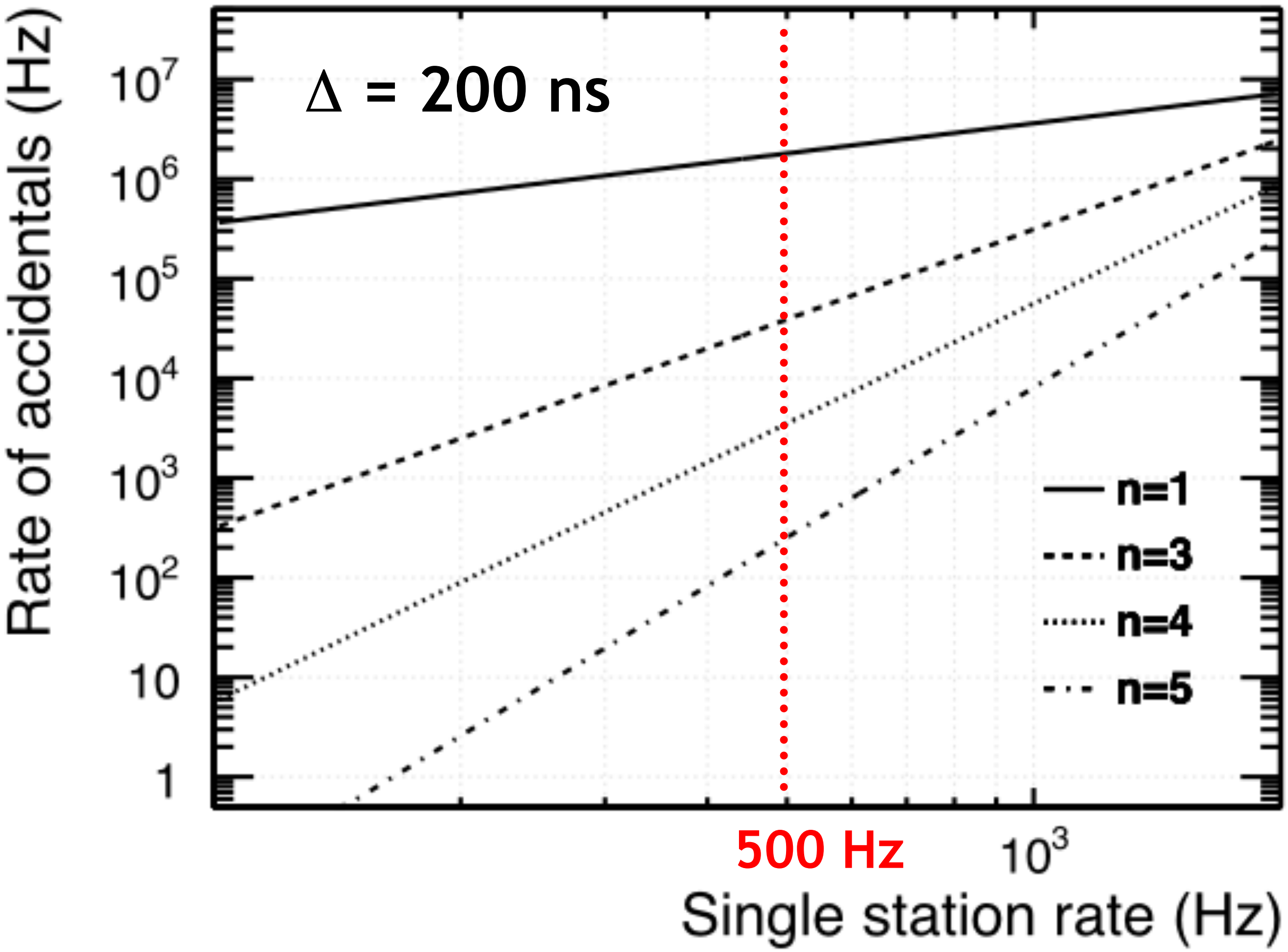
to be compared with the minimum of stations required in a shower trigger, n_S=3.

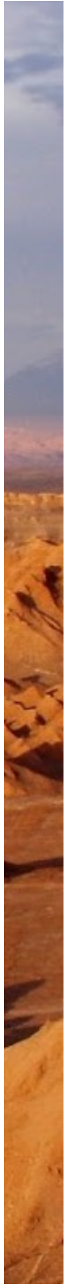
In any case a detailed MC simulation of the impact of the accidentals should be performed !



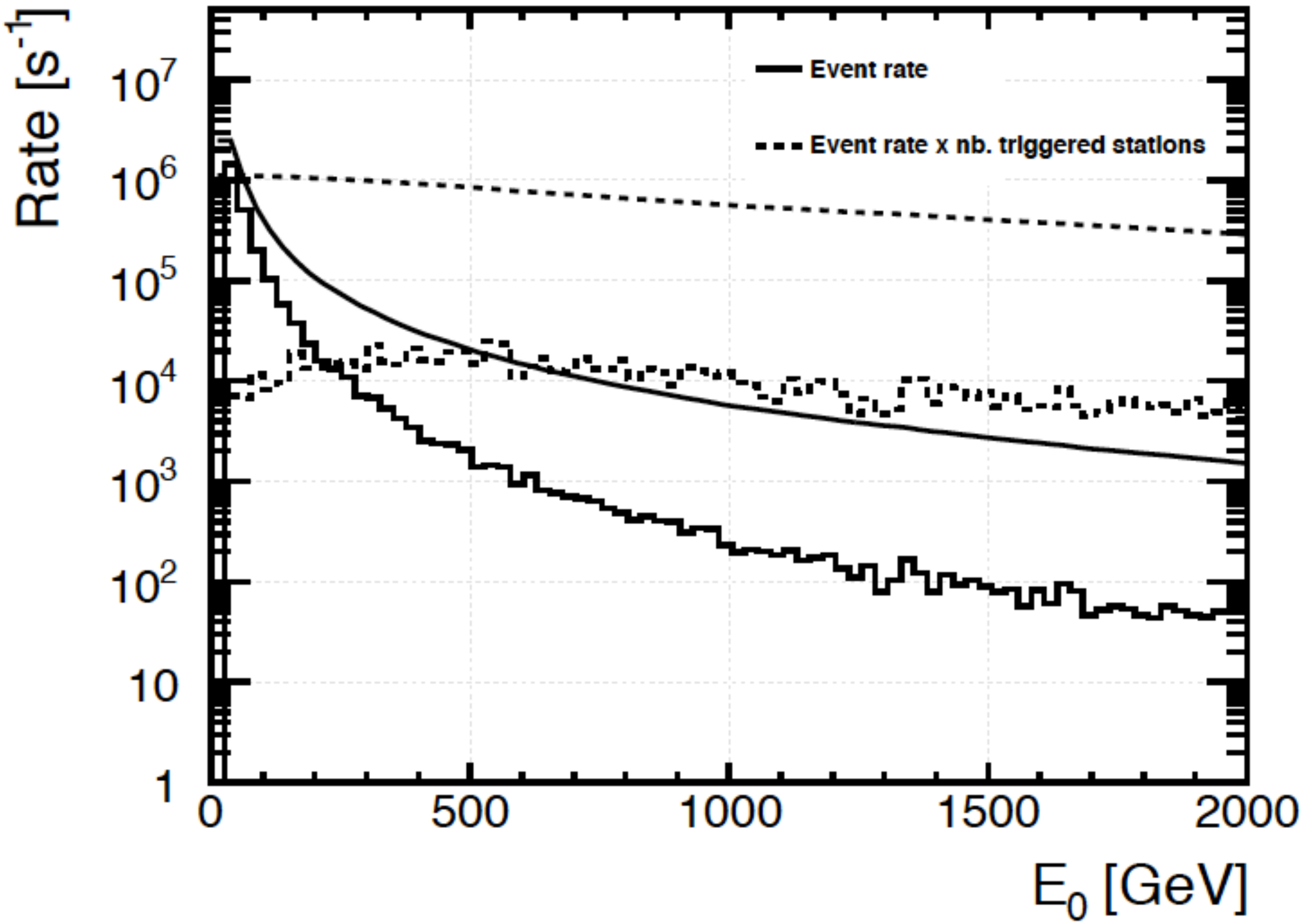
Random triggers

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

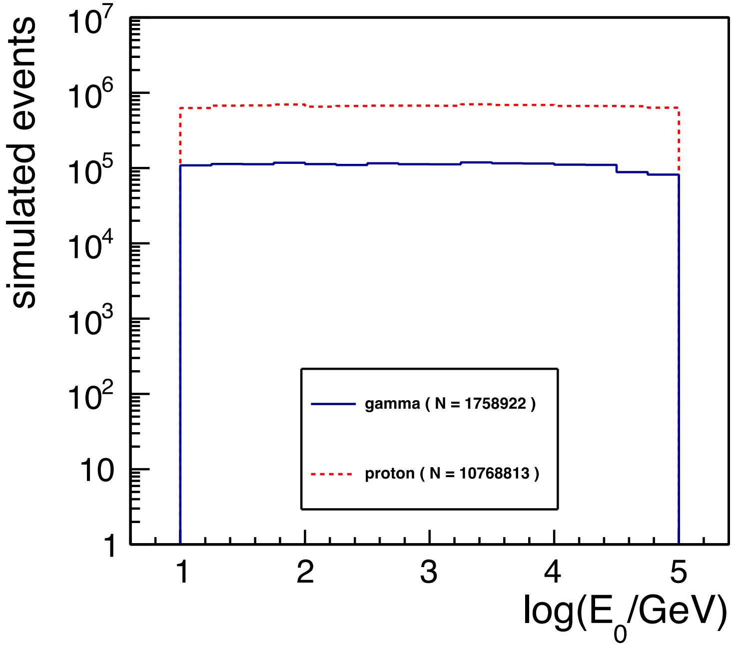


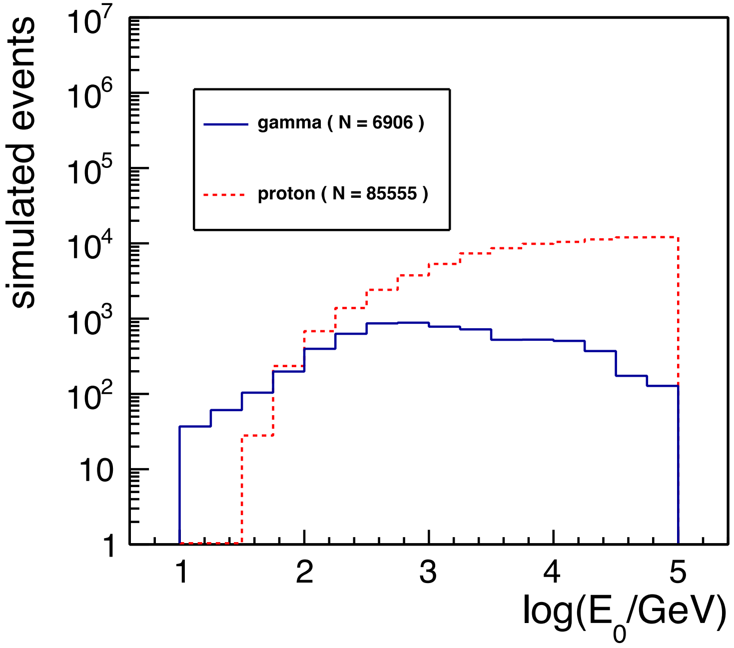


Cosmic rays and station trigger rate

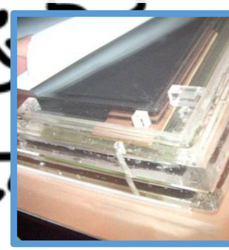


Reconstruction efficiency

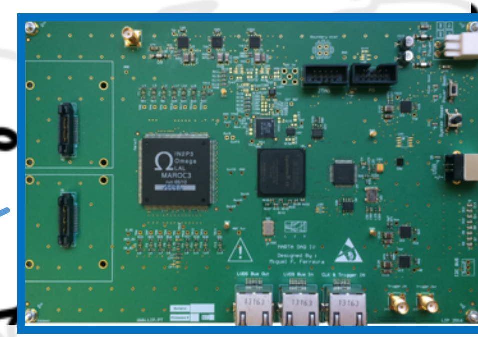




Ongoing developments and tests on RPCs, electronics and read-out systems



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