LATTES baseline performance

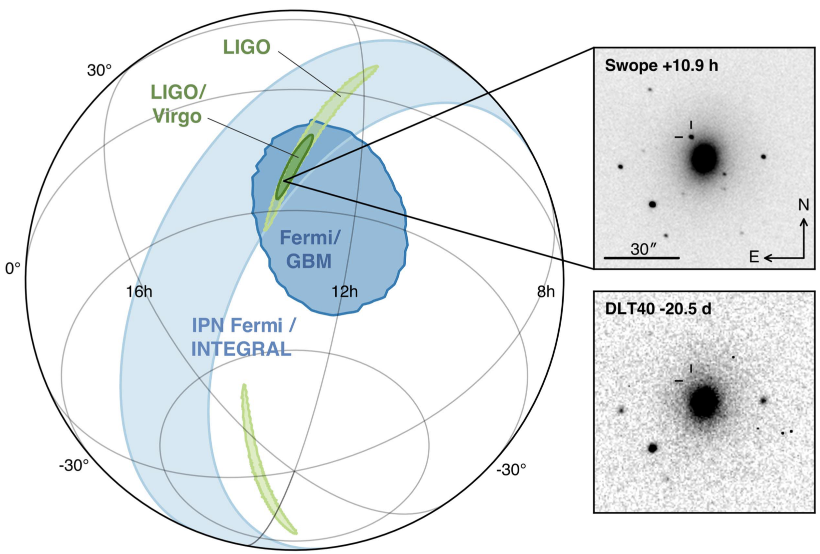
Ruben Conceição

on behalf of the LATTES team

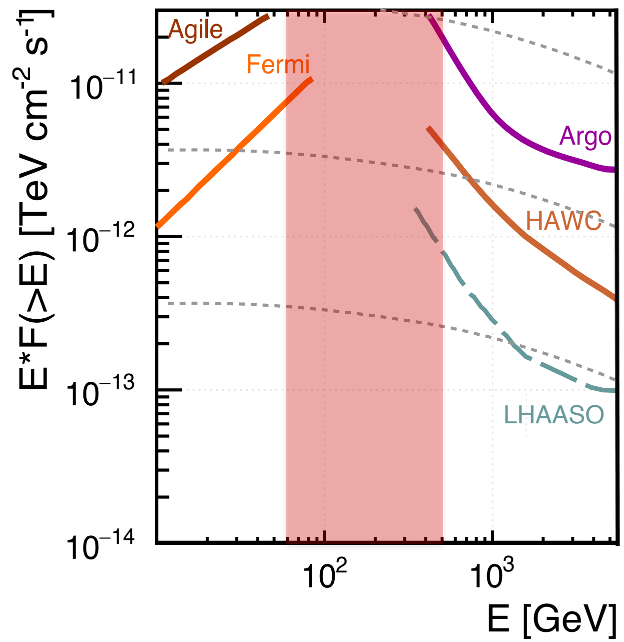
The era of multi-messenger observations

physicsworld BREAKTHROUGH OF THE YEAR 2017

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

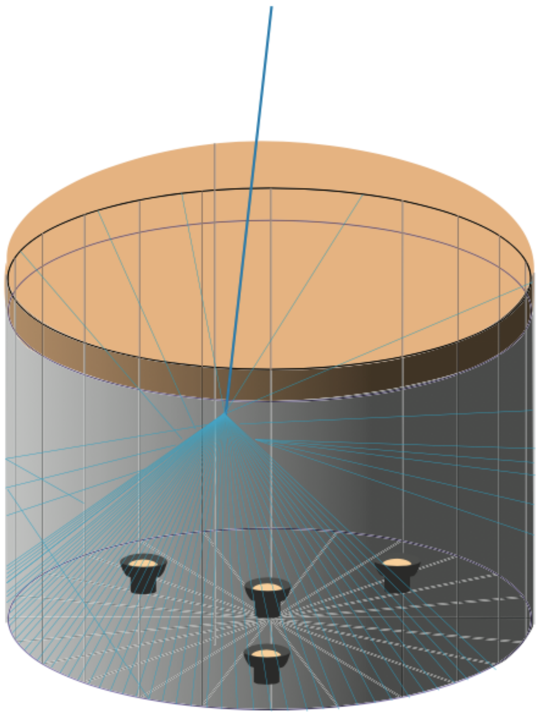


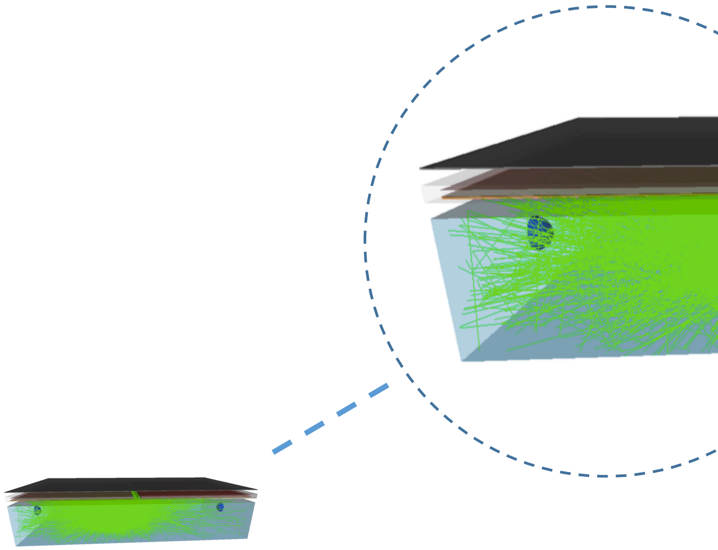
Current wide FoV gamma-ray observatories



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

Station: HAWC vs LATTES





HAWC
(present detector)

LATTES
(next generation)

Station: HAWC vs LATTES

HAWC
(present detector)

LATTES
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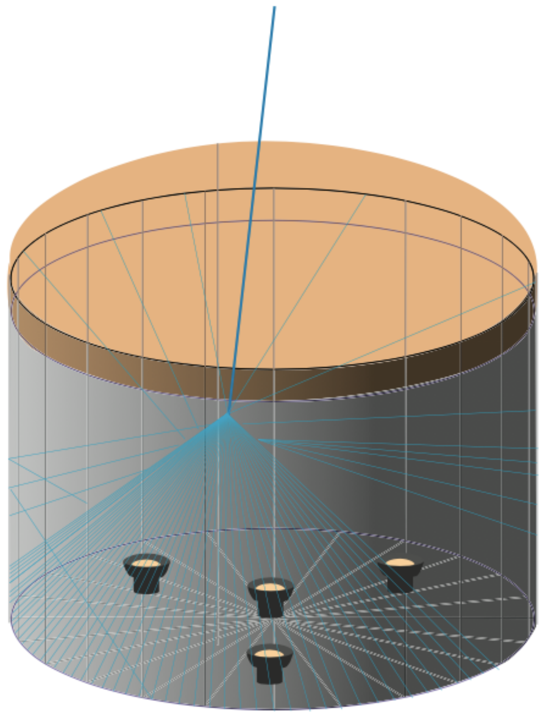
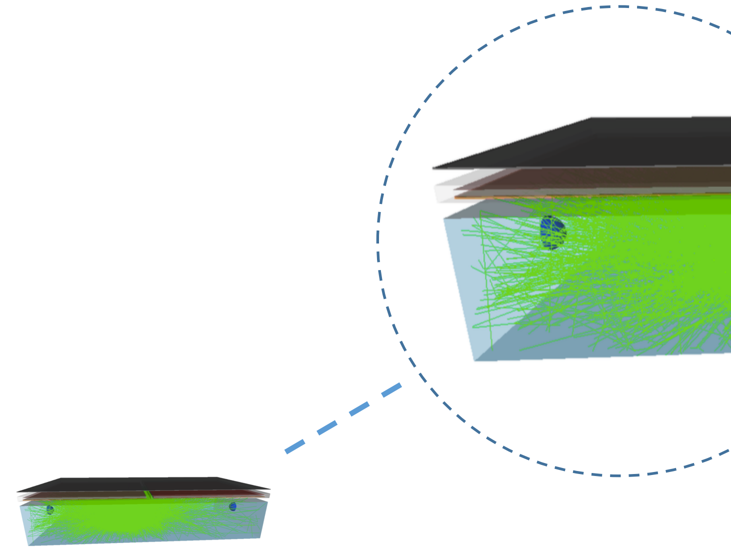
Station: HAWC vs LATTES



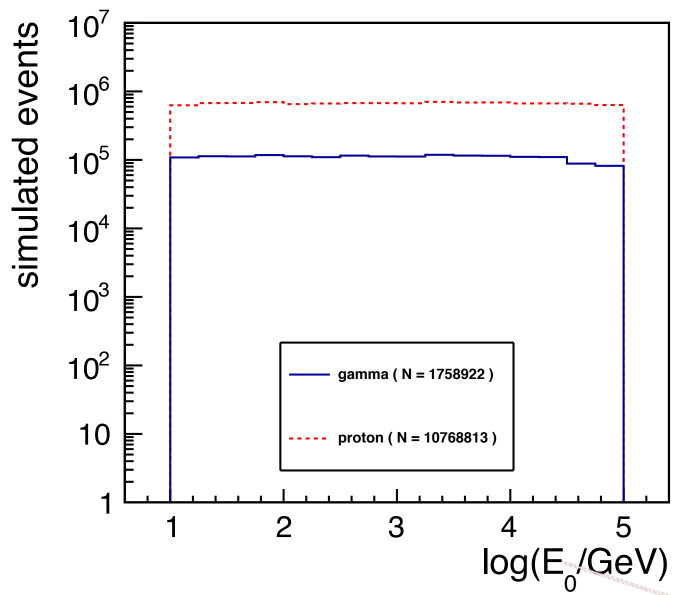


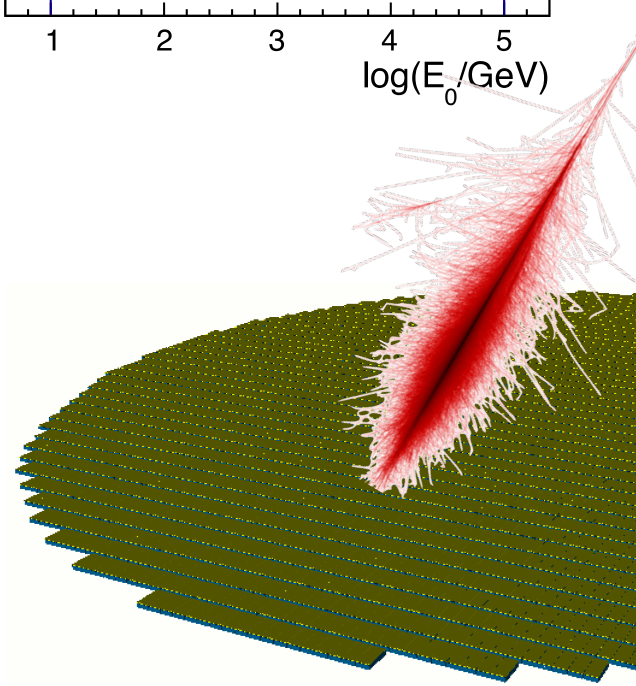
HAWC
(present detector)

LATTES
(next generation)

Simulation Framework

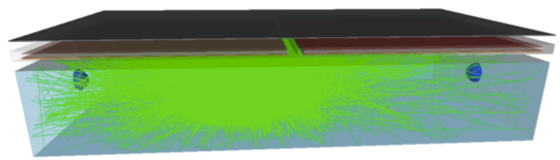
- End-to-end realistic simulation
  - Extensive Air Showers: CORSIKA
    - v7.6400 with Fluka2011.2c
    - More than 50 000 gamma/proton shower simulated randomly between 10 GeV – 300 TeV
    - Gammas have a fixed zenith angle of 10 degrees
    - Observation level at 5200 m of altitude
  - Detector simulation: Geant4
    - v10.1.3
    - Core array 20 000 m^2
    - 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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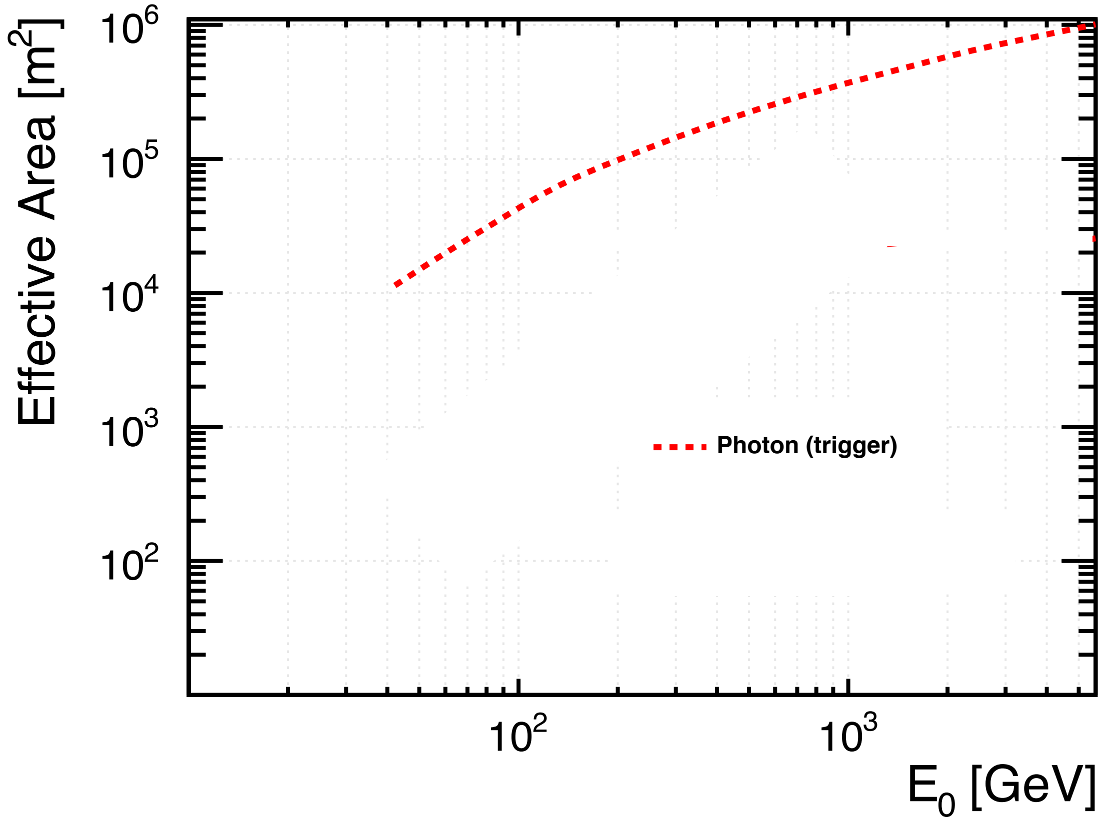
LATTES expected performance

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

LATTES expected performance

- **Trigger and effective area**
- Core reconstruction
- Energy reconstruction
- Geometry reconstruction
- 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

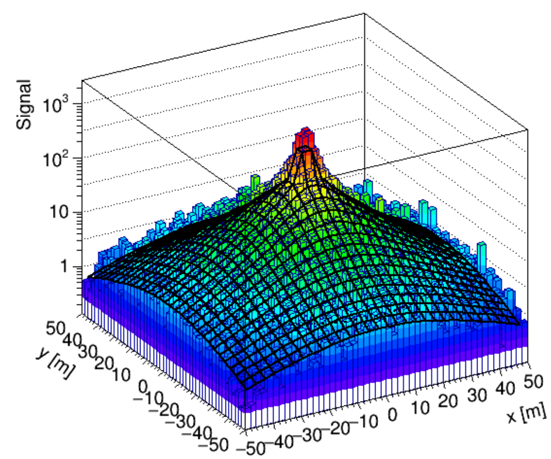
LATTES expected performance

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

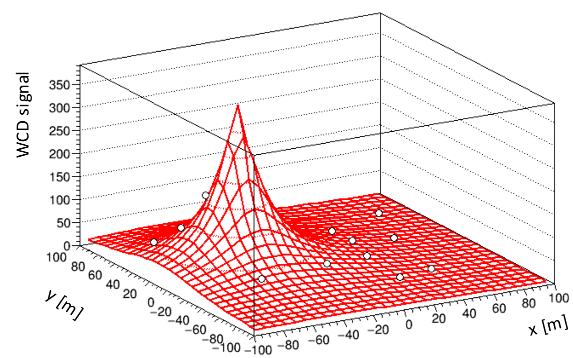
Shower core reconstruction

- 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



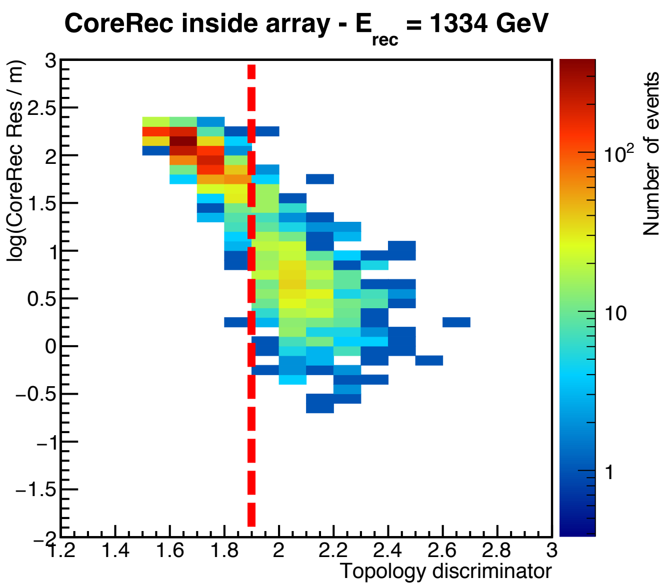
Single event

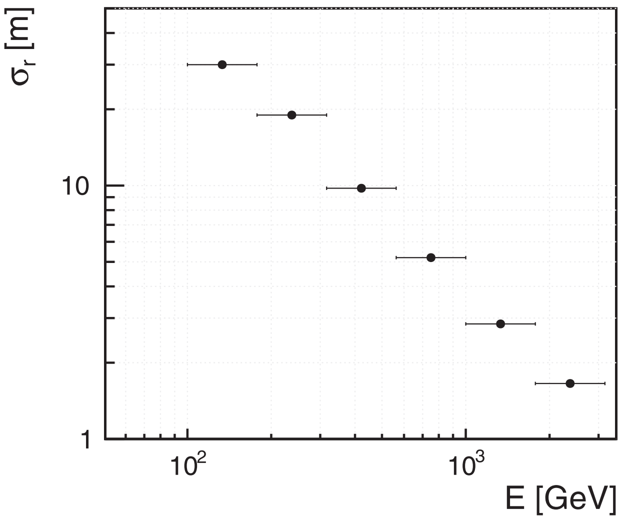


$$S_i = S(A, \vec{x}, \vec{x}_i) = A\left(\frac{1}{2\pi\sigma^2} e^{-|\vec{x}_i - \vec{x}|^2/2\sigma^2} + \frac{N}{(0.5 + |\vec{x}_i - \vec{x}|/R_m)^3}\right)$$

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





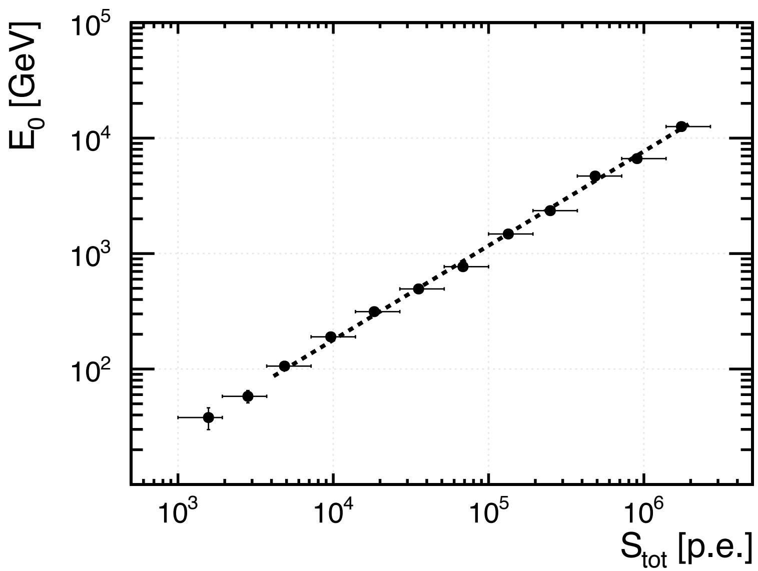
LATTES expected performance

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

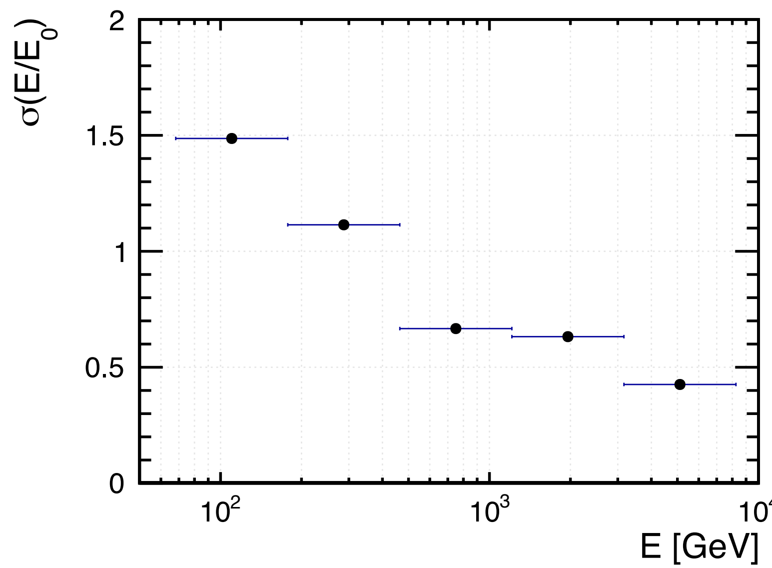
Energy reconstruction

$E_0 \rightarrow$ Simulated energy
$E \rightarrow$ Reconstructed energy

Energy Calibration



Energy Resolution

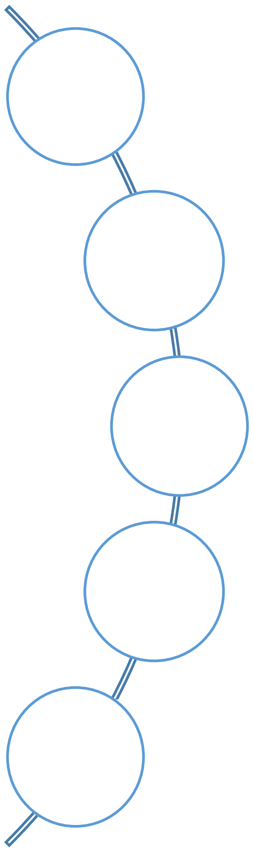


- Use as energy estimator the total signal recorded by WCDs
  - Use only shower cores reconstructed inside array
- Energy resolution at low energy dominated by shower fluctuations

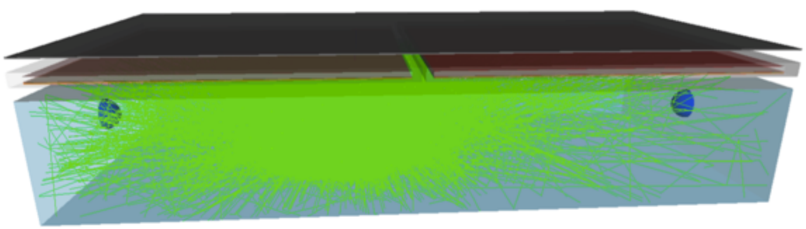
LATTES expected performance

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

Reconstruction of shower geometry

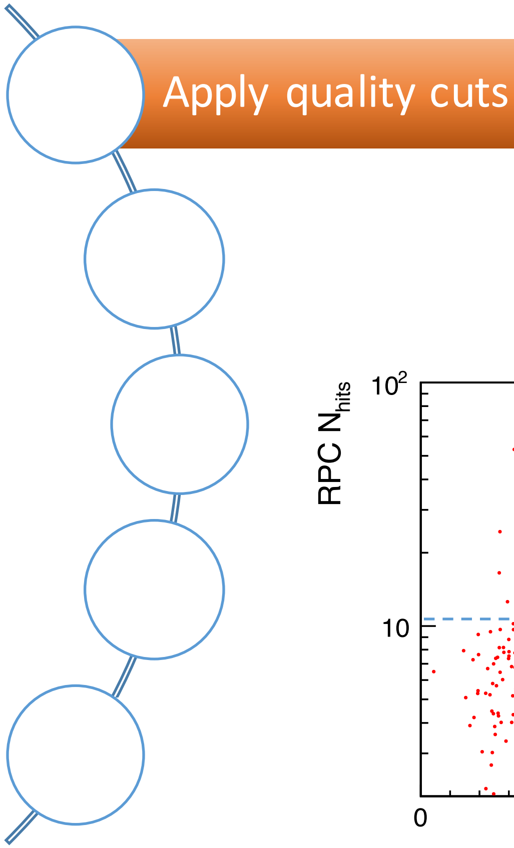


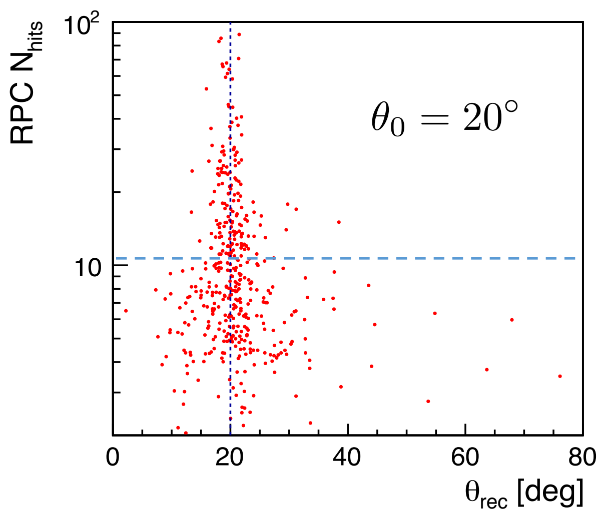
- Use RPC hit time information
  - Take advantage of high spatial and time resolution
  - Used time resolution of 1 ns



R. Conceição

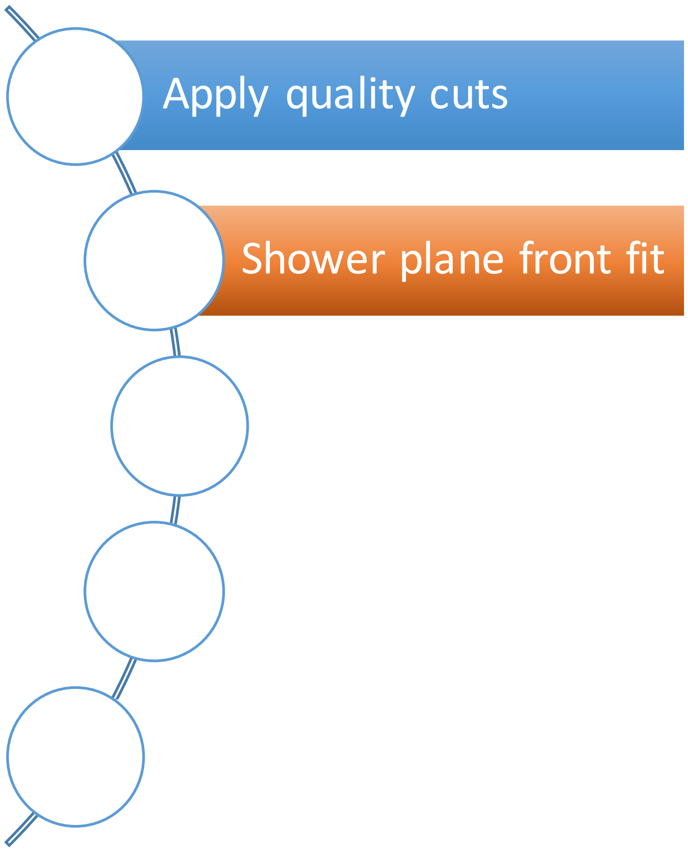
Reconstruction of shower geometry



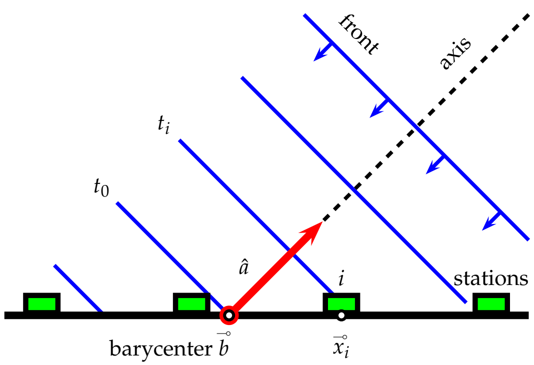


- Use RPC hit time information
  - Apply previous shower rec quality cuts
  - Apply cuts on the number of registered hits on the RPCs
  - Consider only RPCs in triggered WCD stations

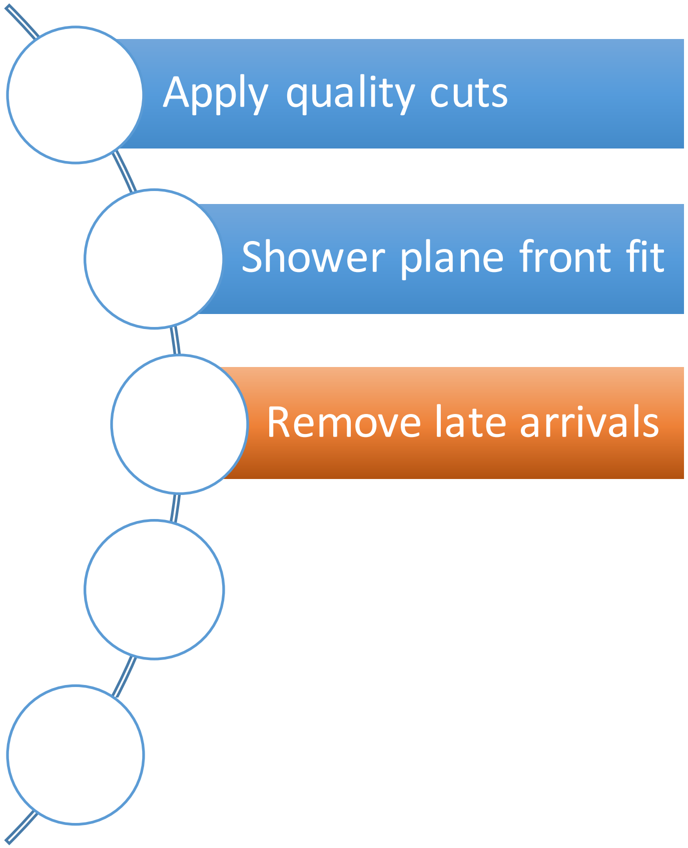
Reconstruction of shower geometry



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



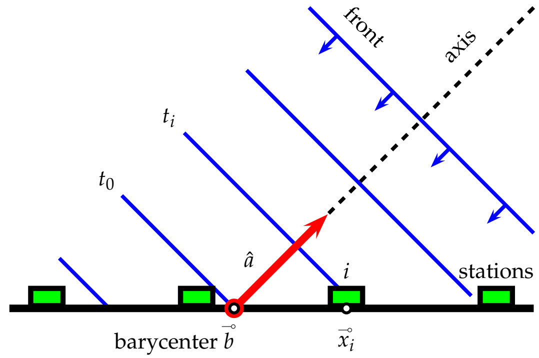
Reconstruction of shower geometry

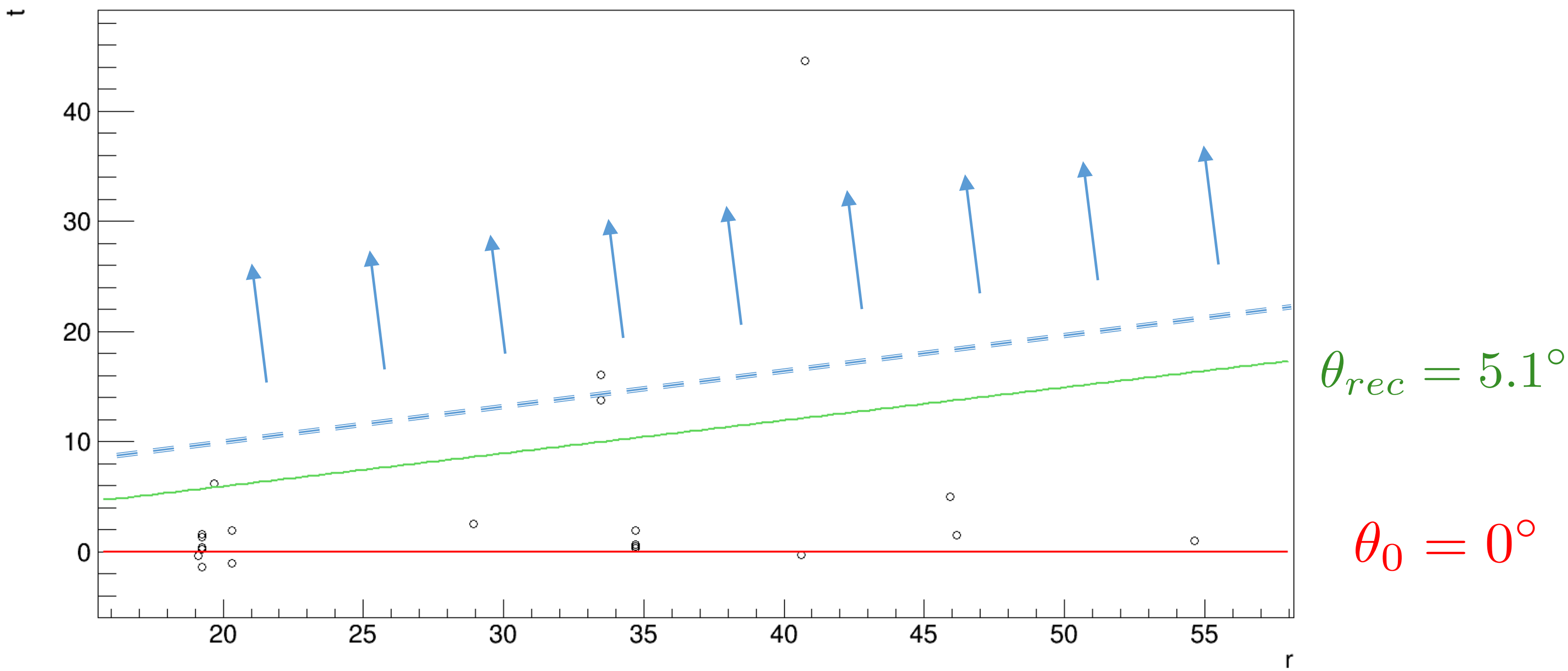


- Use RPC hit time information
  - Identify late arrivals with respect to Rec Shower Front
  - Mainly low energy electrons that lost correlation with shower front

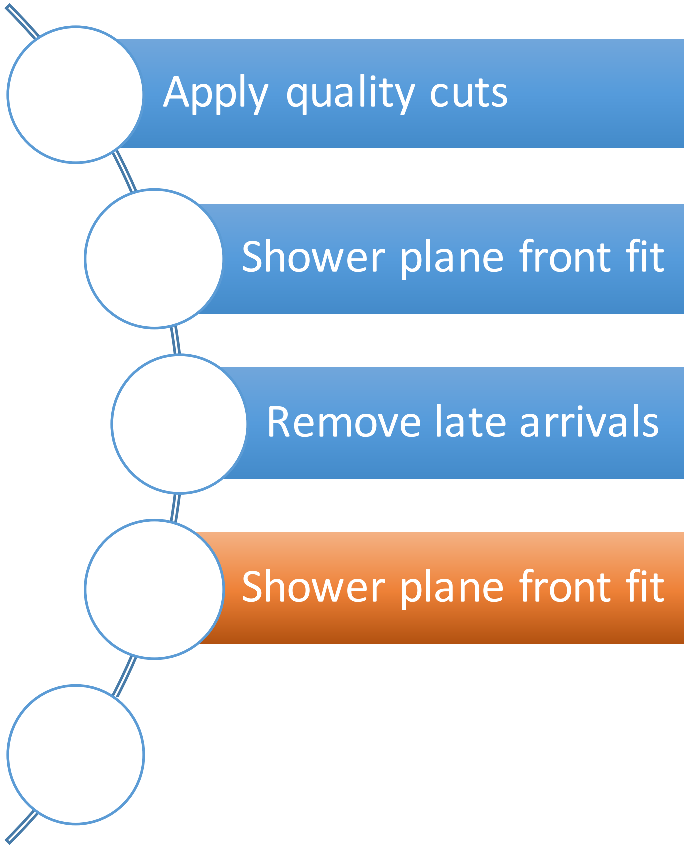
Removal of late arrivals

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



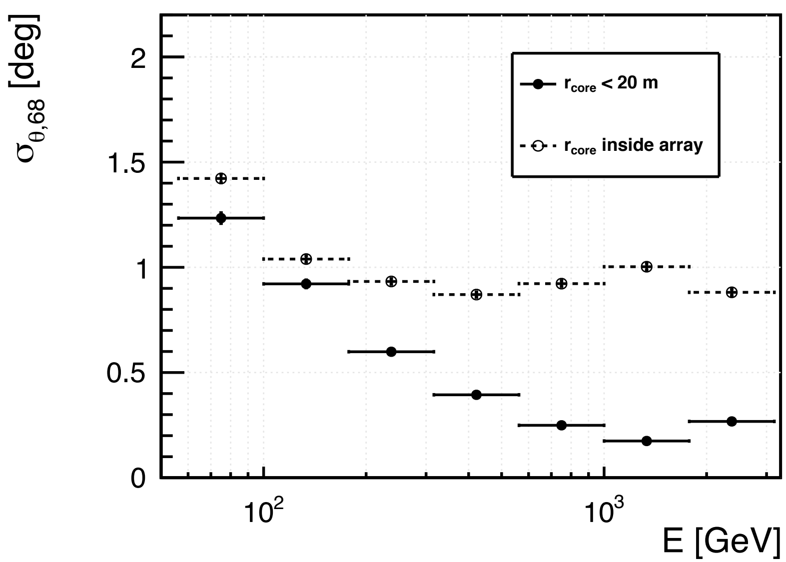


Reconstruction of shower geometry

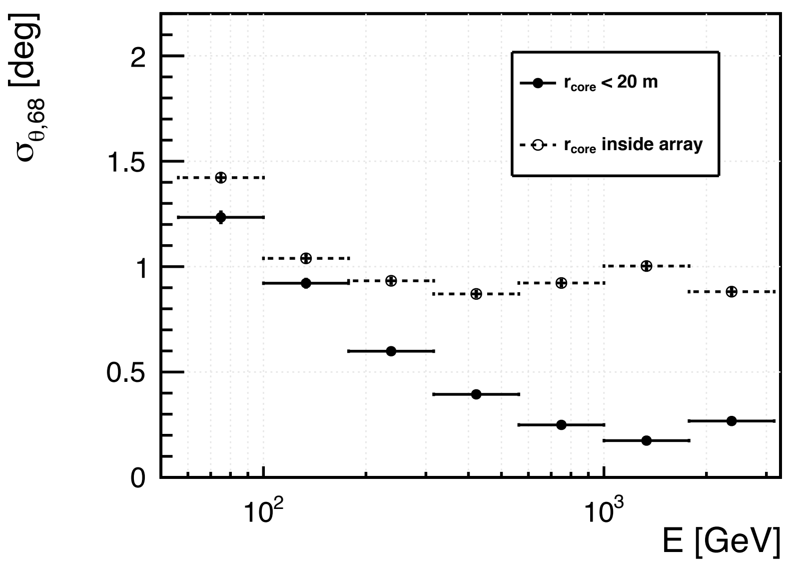


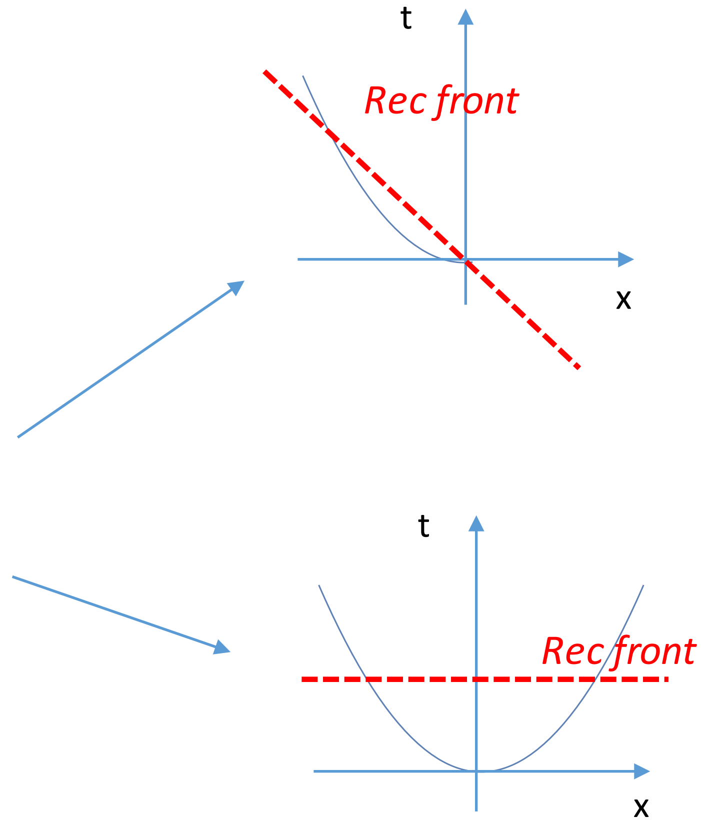
- Use RPC hit time information
  - Repeat fit without arrivals
  - Initial guess for next step

$\gamma - \text{showers}; \theta = 10^{\circ}$



Impact of shower curvature





Border of the array

Center of the array

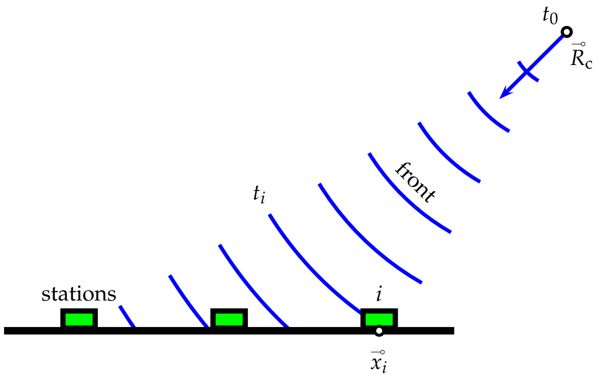
Solution: implement a conic fit instead of fitting a plane

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

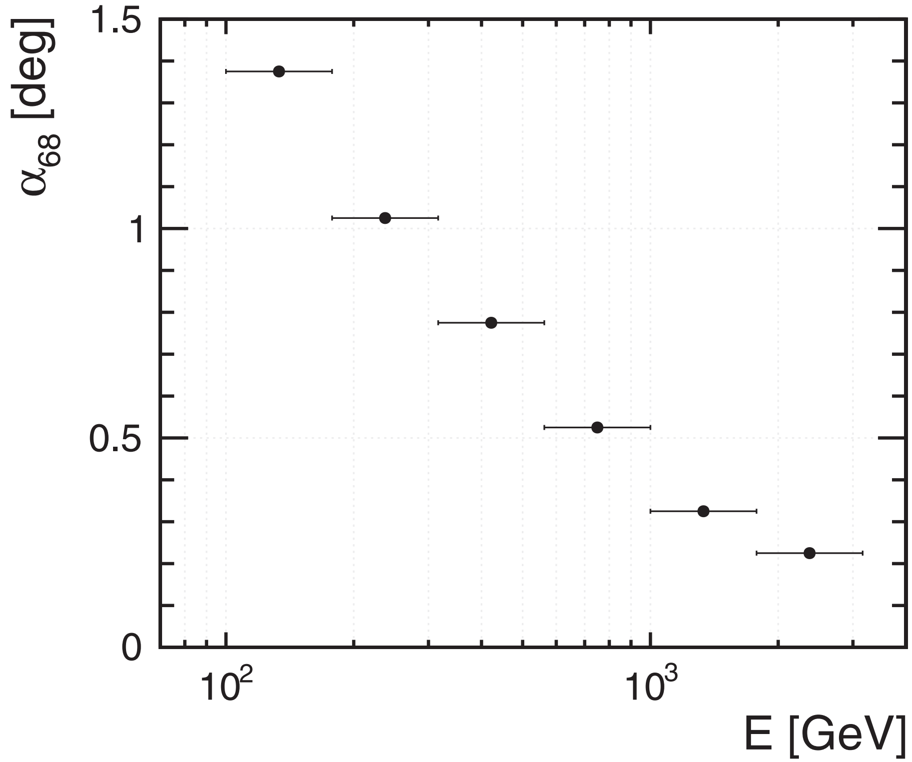
Reconstruction of shower geometry

- Apply quality cuts
- Shower plane front fit
- Remove late arrivals
- Shower plane front fit
- Shower conic front fit

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



Shower geometry reconstruction

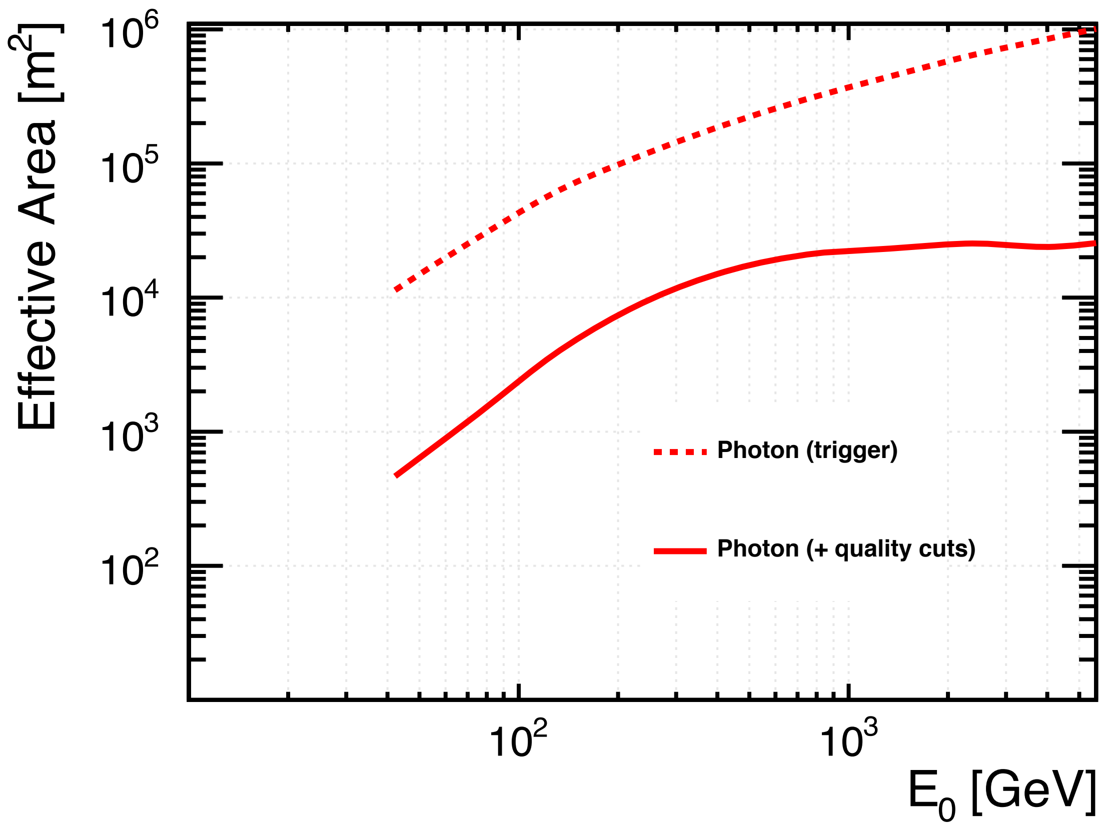


A good angular resolution can be achieved for all events reconstructed inside the array

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

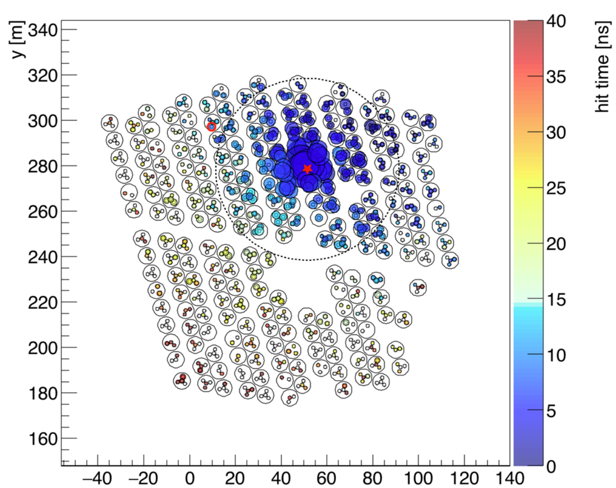
LATTES expected performance

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

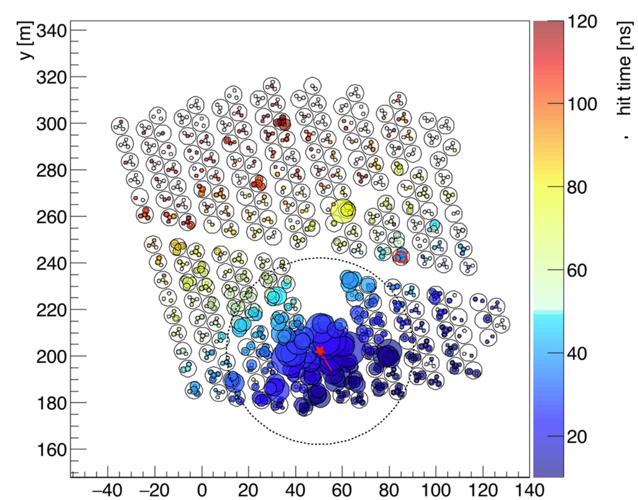
Looking for high-p_T sub-showers

- 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

gamma shower

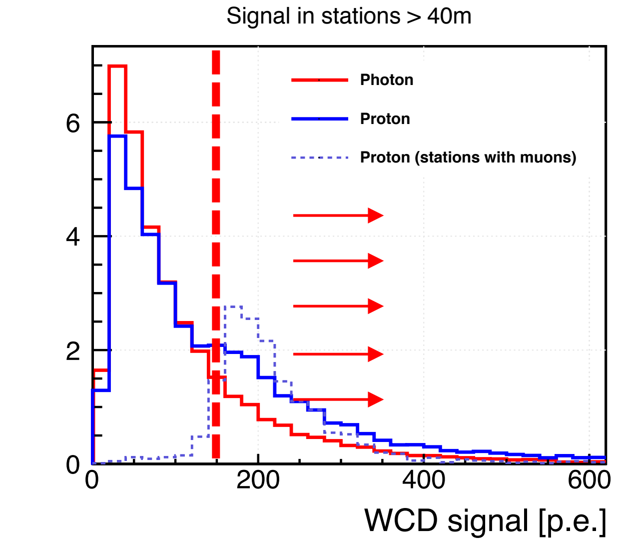


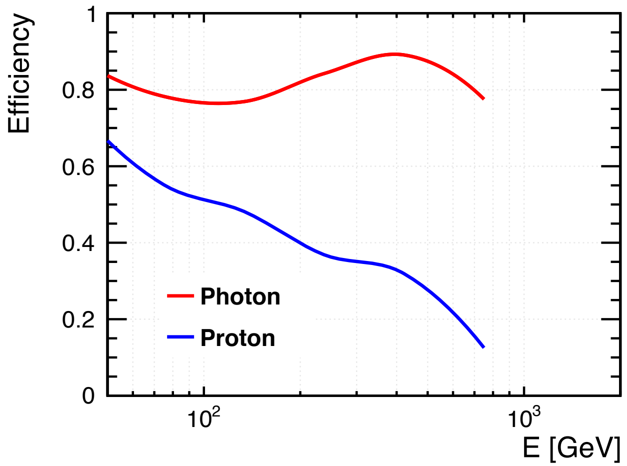
hadron shower



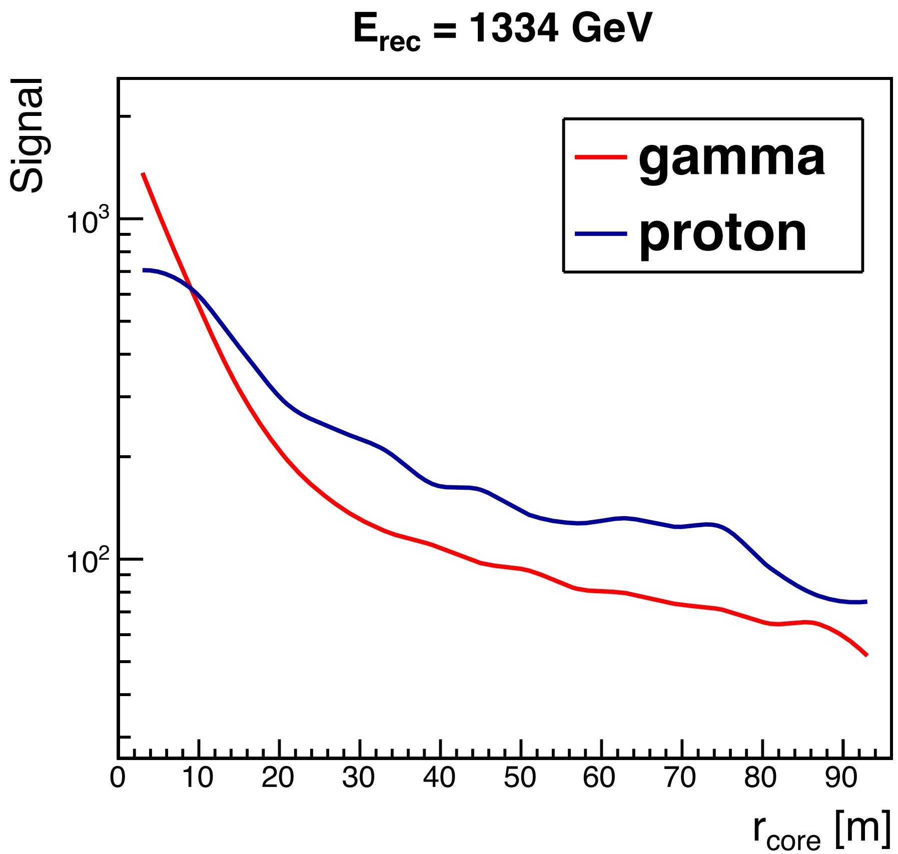
Looking for high p_t sub-showers

- 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…



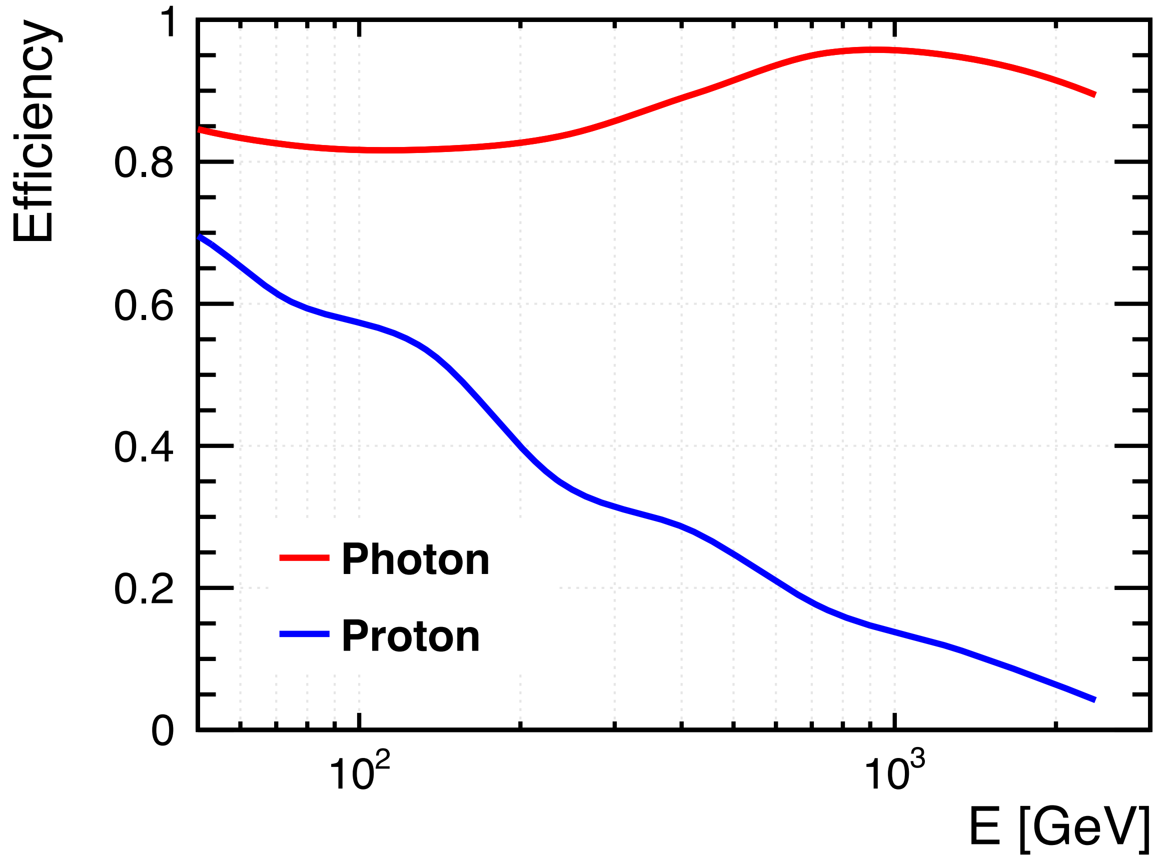


High-energy discrimination strategy



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

High-energy discrimination strategy

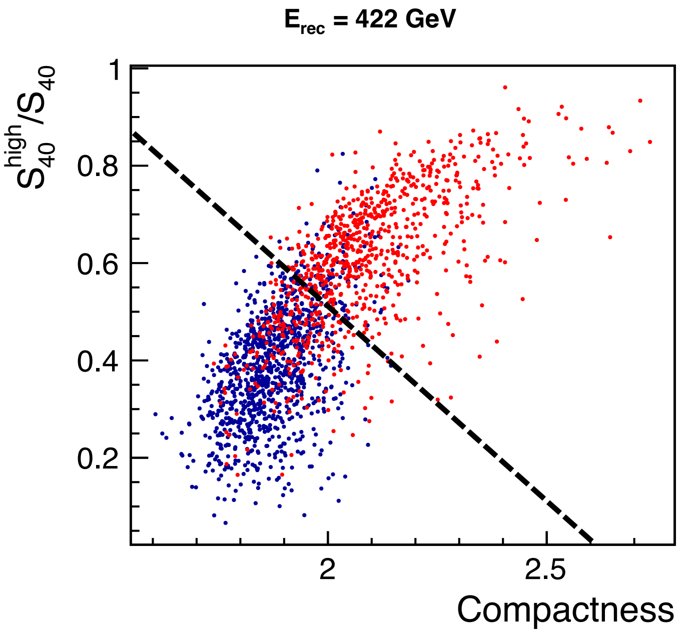


Shower compactness discrimination variable allows for a good background rejection which increases with energy

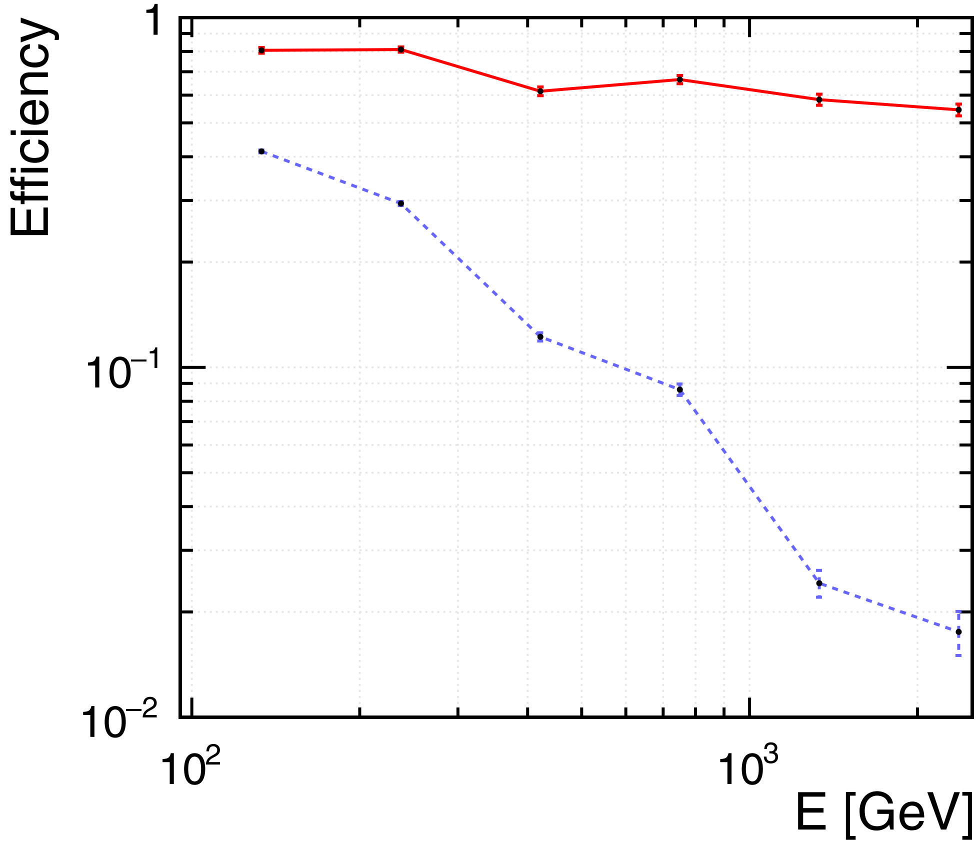
Combine information

- 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 gamma/discrimination results are already very encouraging

LATTES expected performance

✧ Trigger and effective area

✧ Core reconstruction

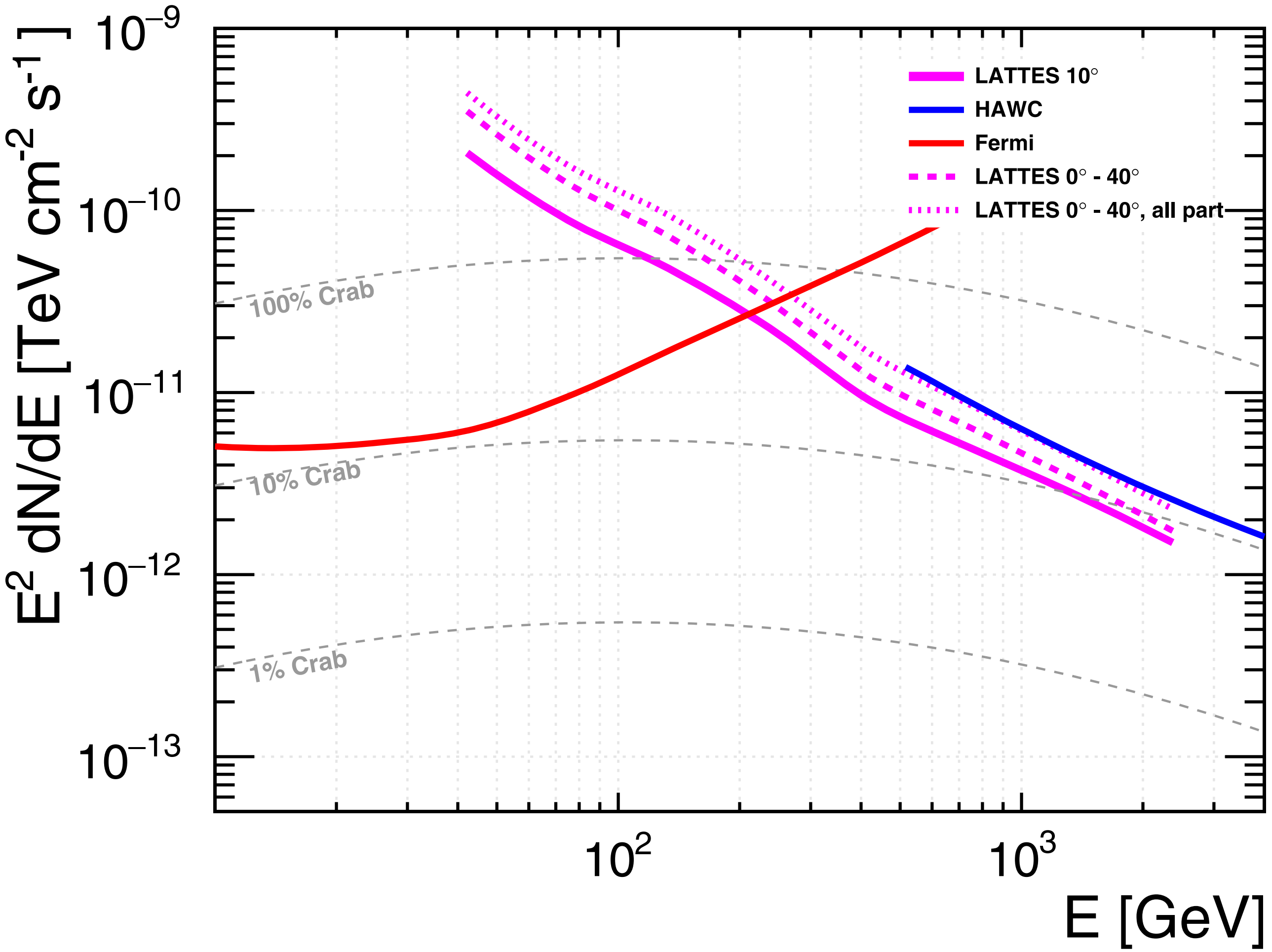
✧ Energy reconstruction

✧ Geometry reconstruction

✧ Gamma/hadron discrimination

✧ **Sensitivity to steady sources**

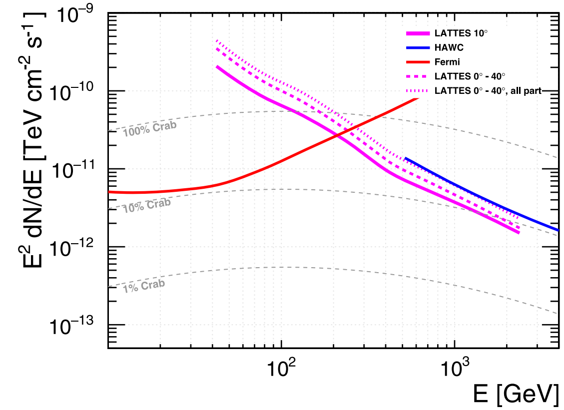
Sensitivity to steady sources

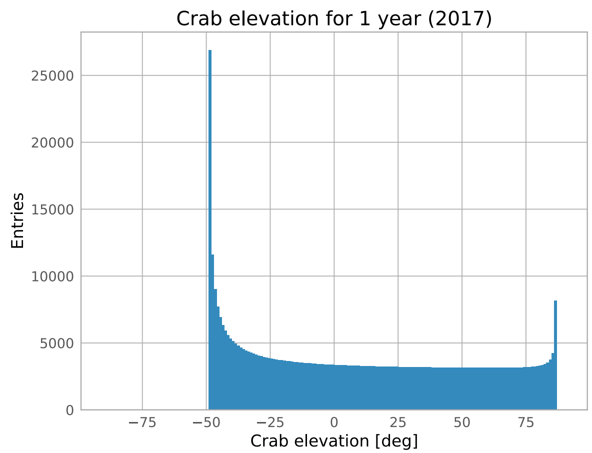


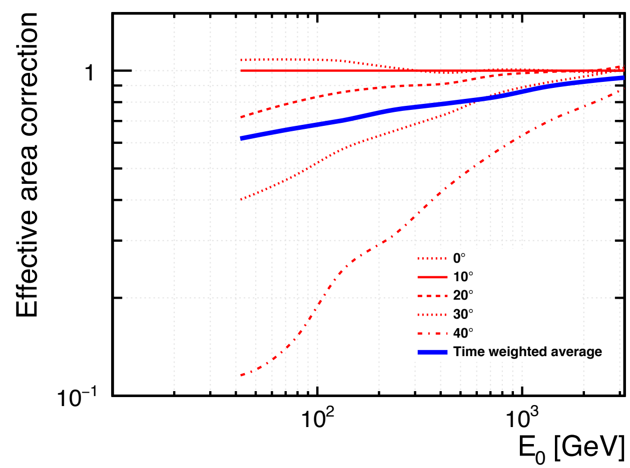
✧ *Full line*: full MC calculation for a source at 10 degrees in zenith

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

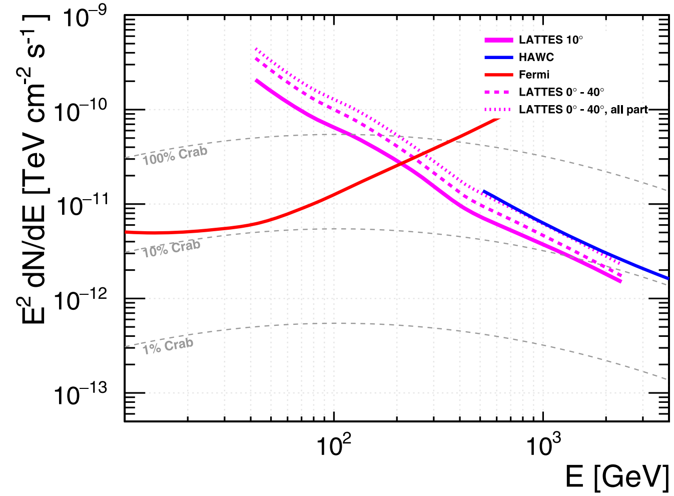


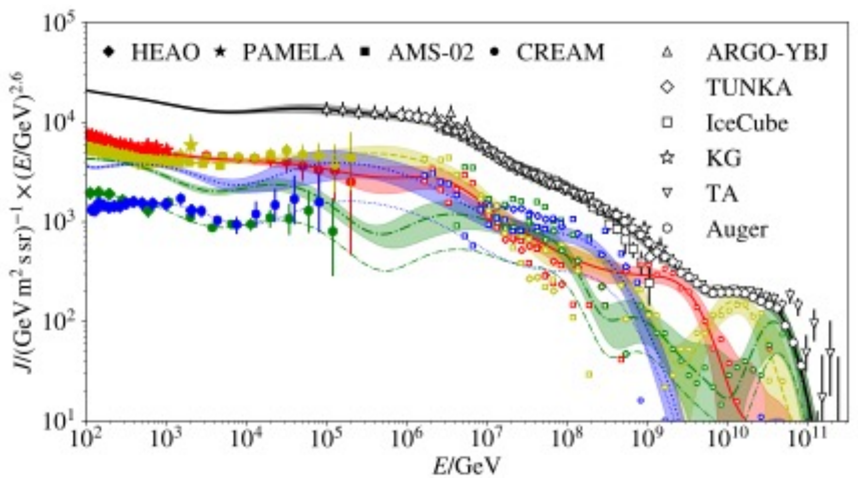




Sensitivity to steady sources

- *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) – see Bernardo's Talk
    - Use RPC patterns to discriminate g/h
    - Better assess LATTES ability to reconstruct
      - Inclined showers
      - Heavier primaries induced showers
    - …

Acknowledgements

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA EDUCAÇÃO E CIÊNCIA

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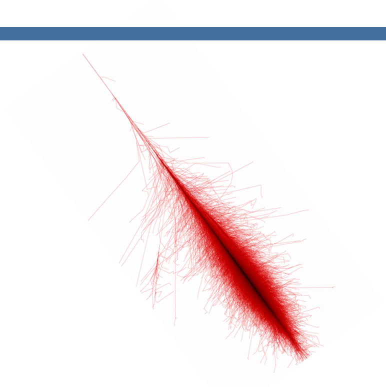
LIP

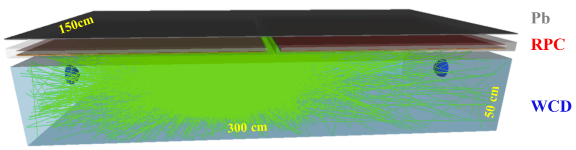
TÉCNICO LISBOA

Backup slides

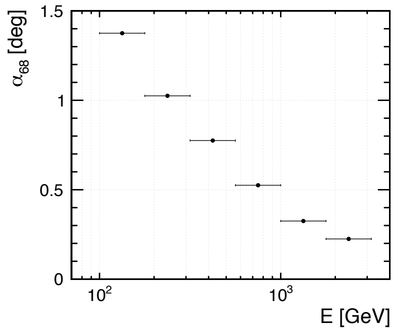
Towards LATTES sensitivity…



Shower simulation (CORSIKA)



Detector simulation (Geant4)

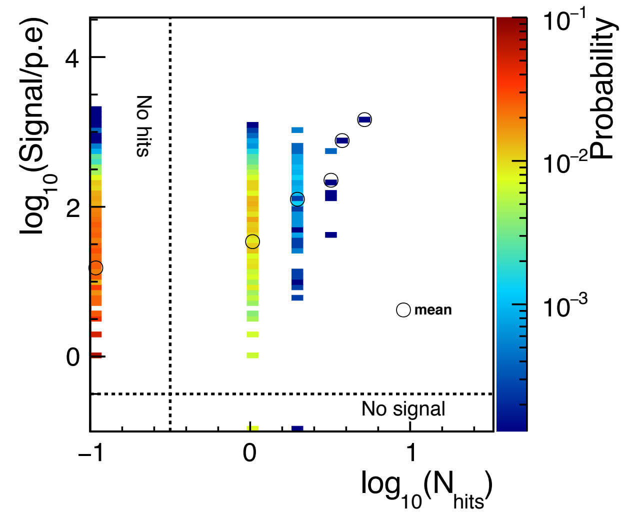


Shower reconstruction (LATTESrec)

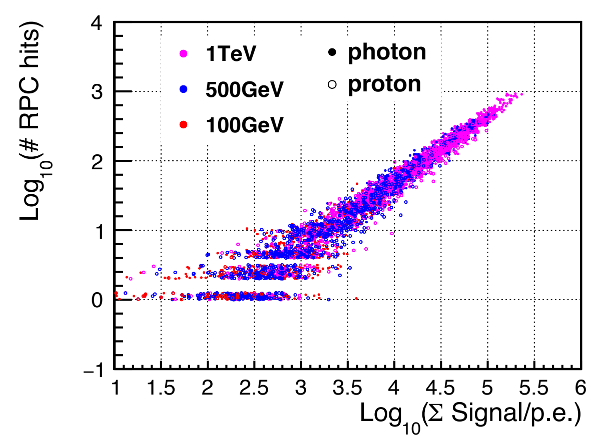
LATTES: a hybrid detector

- 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)

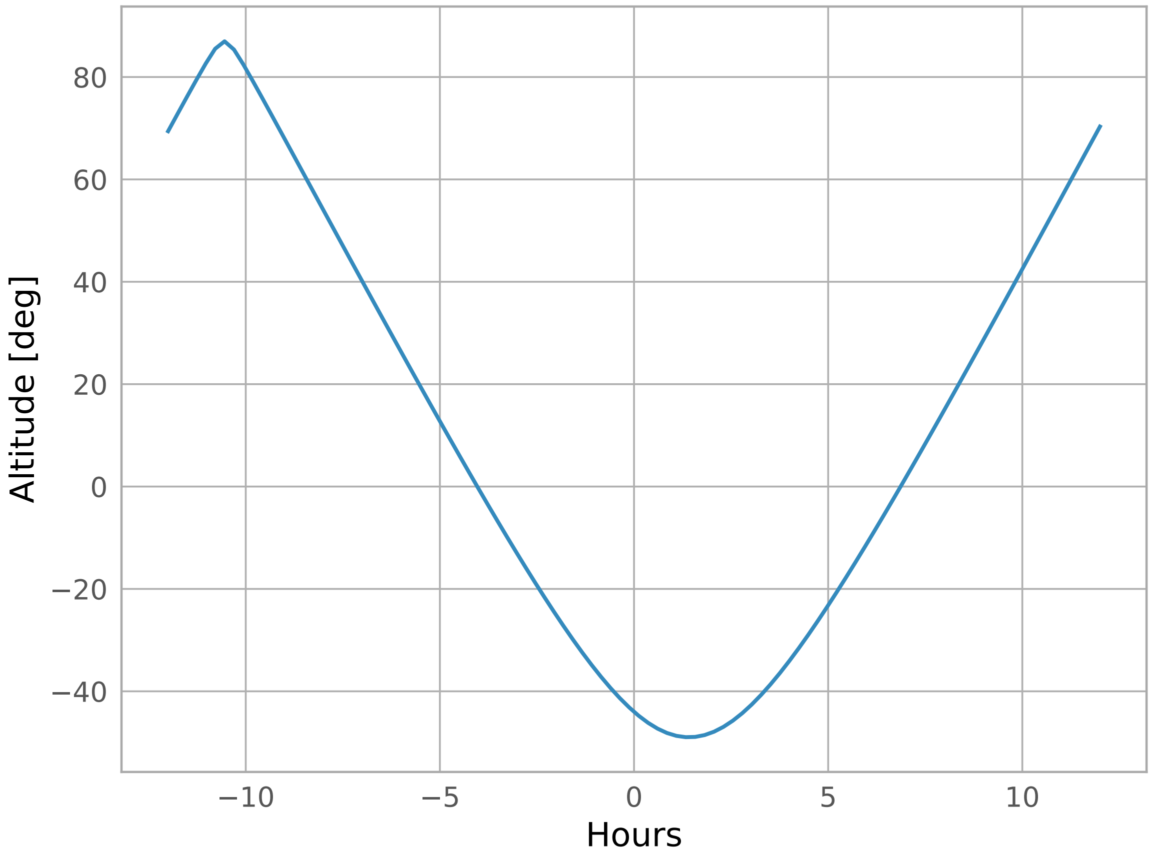


Complementarity



Inter-calibration

Crab



R. Conceição

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 :

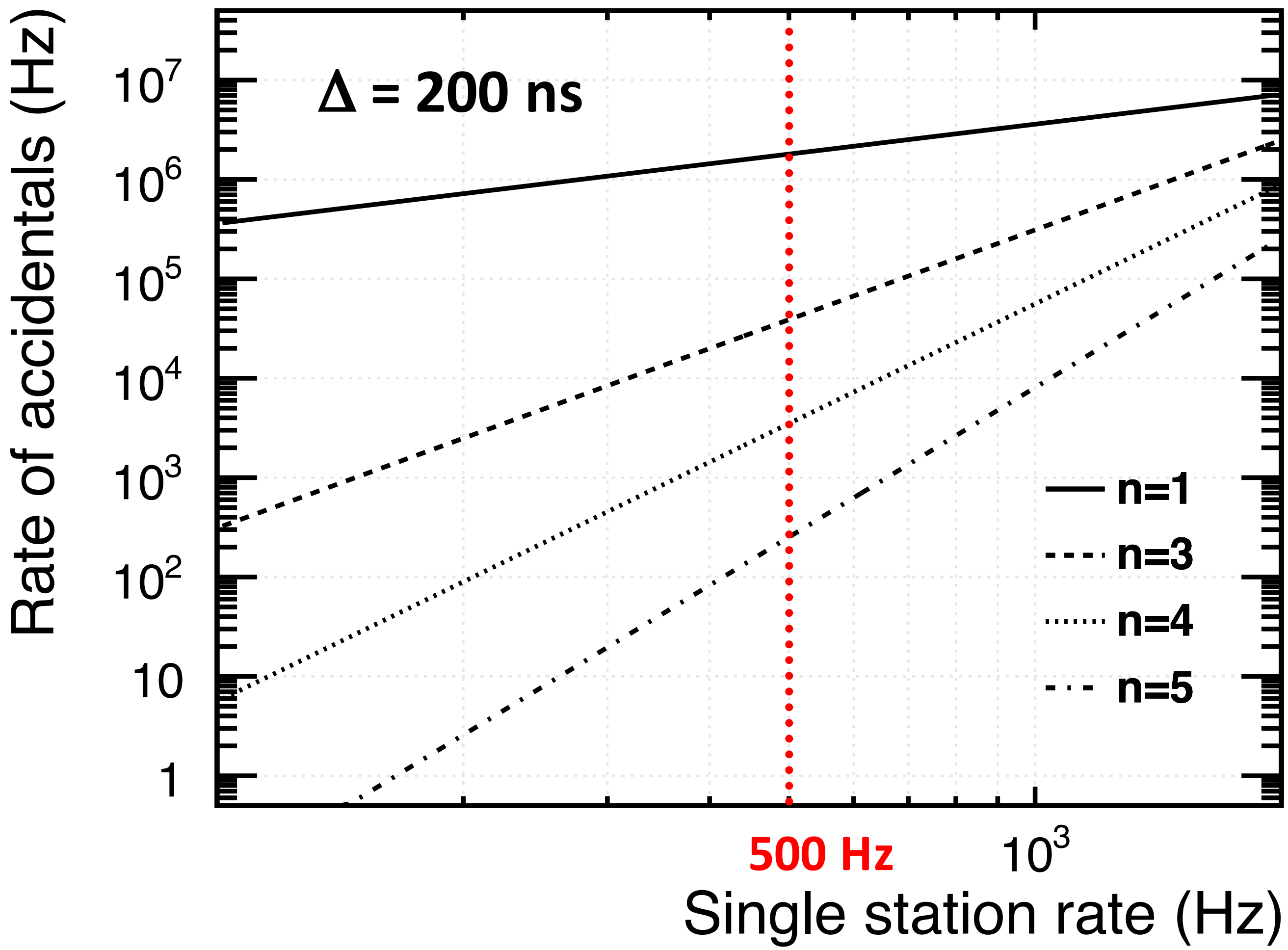
$$n_S \sim 0.4$$

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

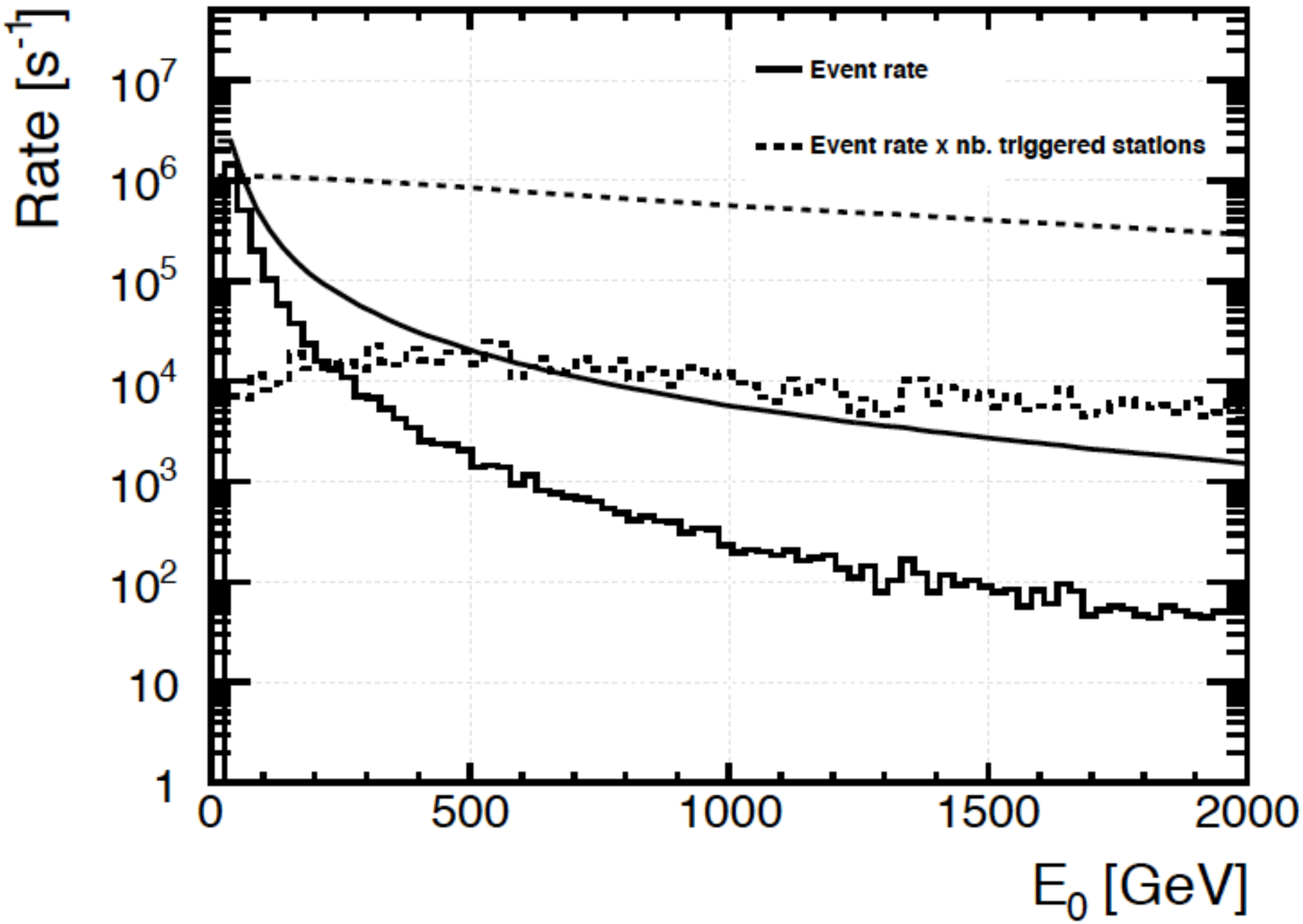
In any case a detailed MC simulation of the impact of the accidentals should be performed !

Random triggers

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

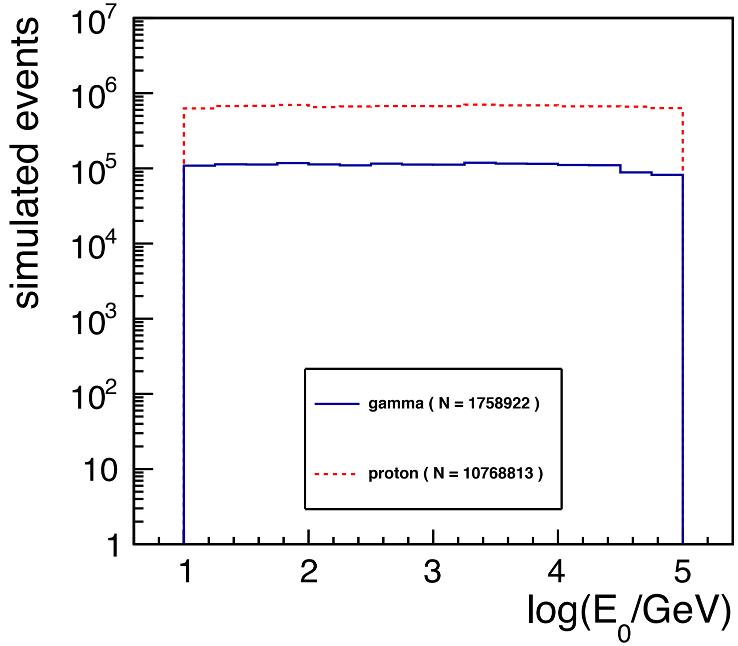


Cosmic rays and station trigger rate

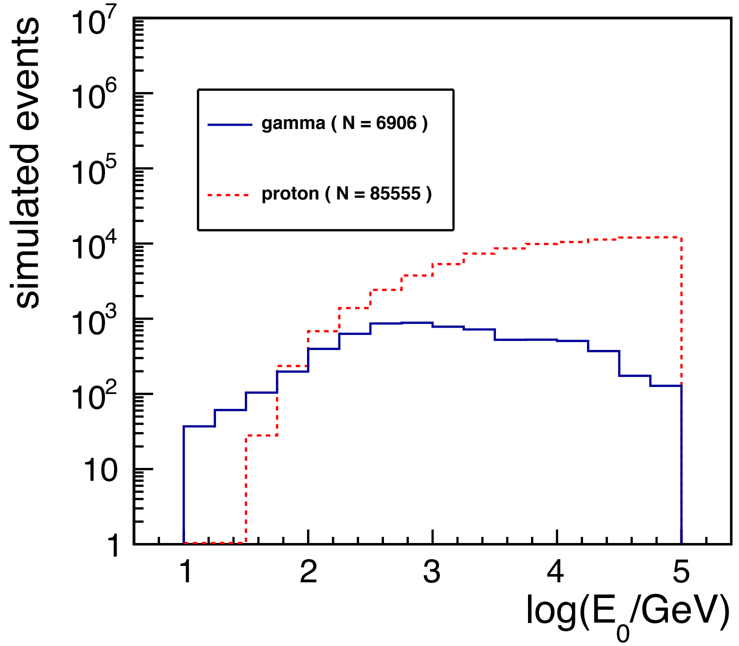


Reconstruction efficiency

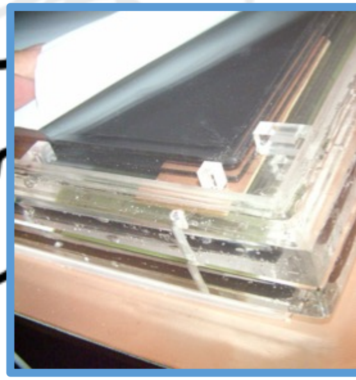
Before quality cuts



After quality cuts



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



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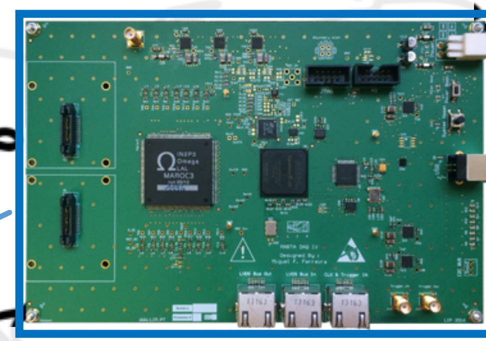

DAQ Engineering prototype

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