LATTES: a new gamma-ray detector concept for South America

Bernardo Tomé

on behalf of the LATTES team

LIP

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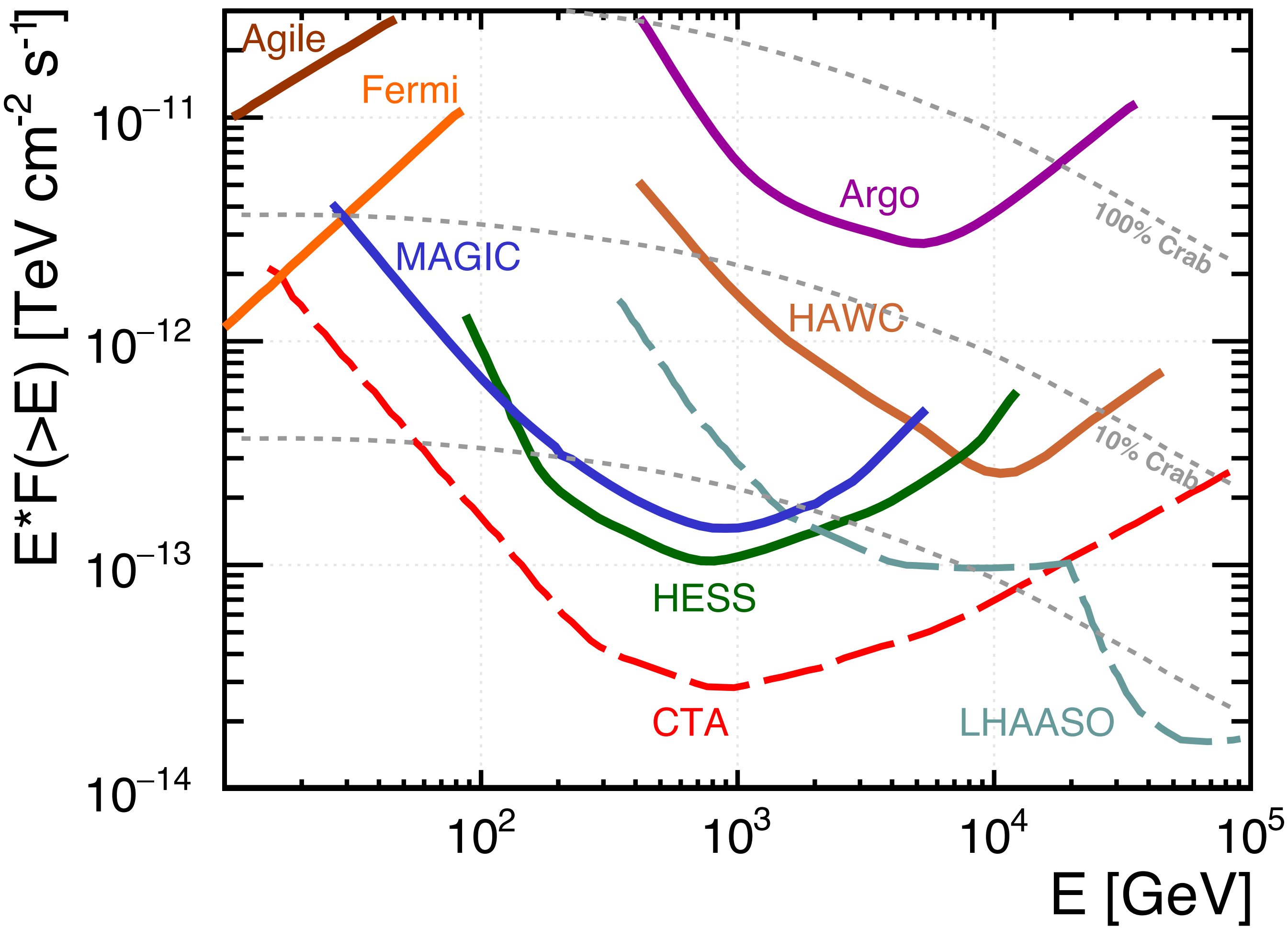
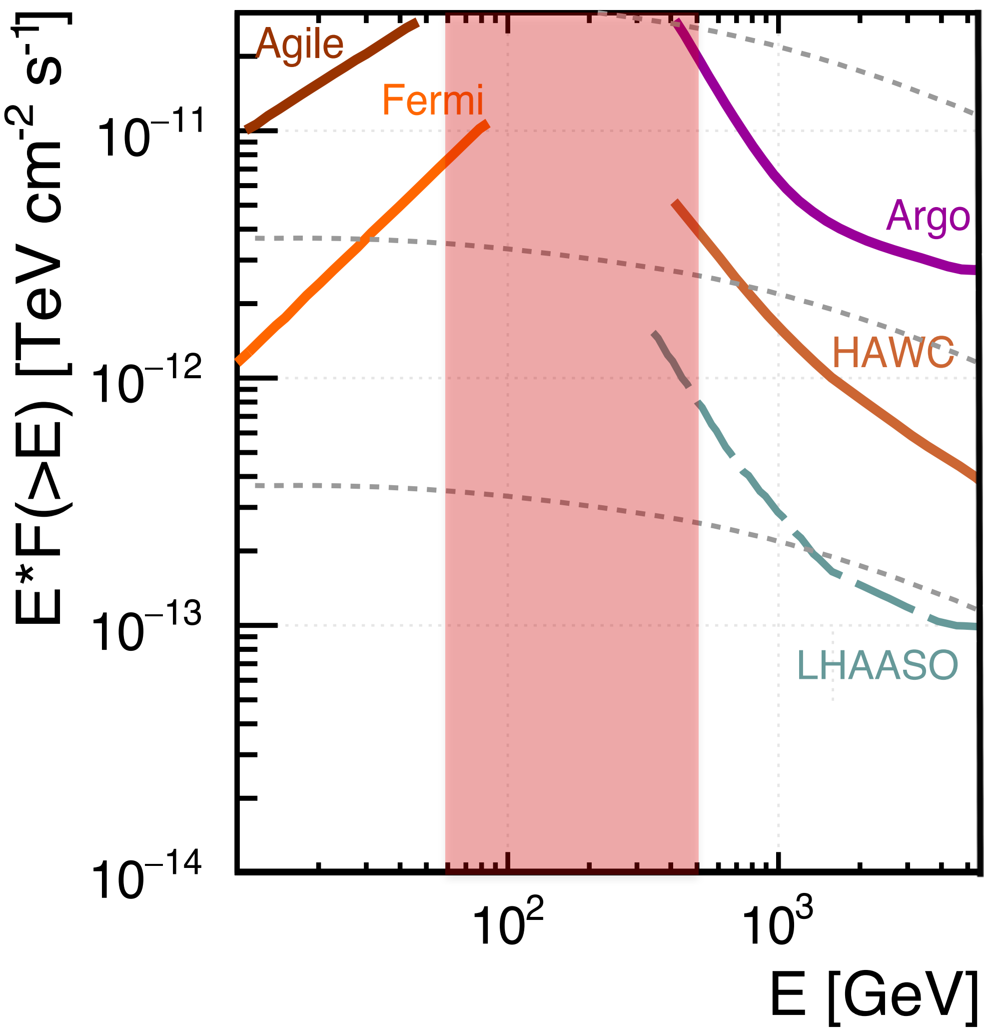
Current experimental status

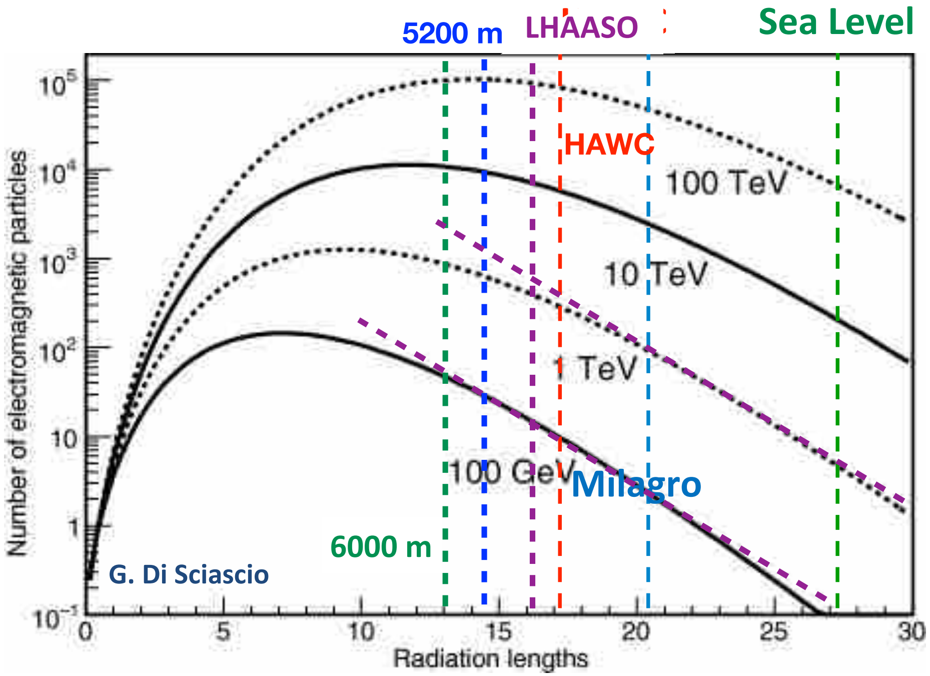


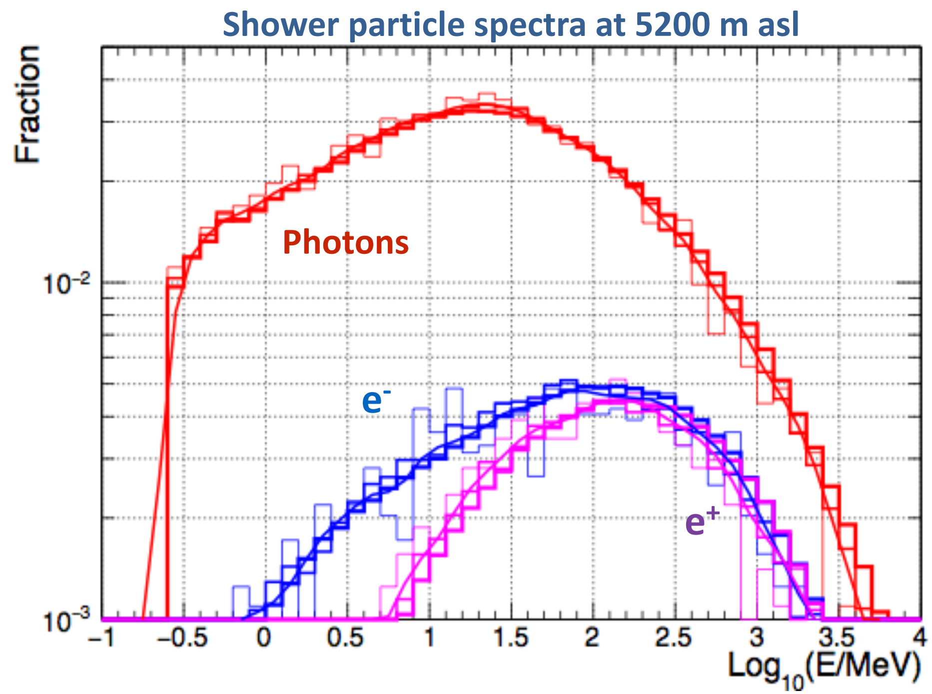
Current Situation



- No wide FoV experiment to:
  - Survey the Galactic Center
  - Explore the energy region of 100 GeV :
    - Cover the gap between satellite and ground based observations;
    - Trigger observations of variable sources (finder for CTA);
    - Detect extragalactic transients/flaring activity.

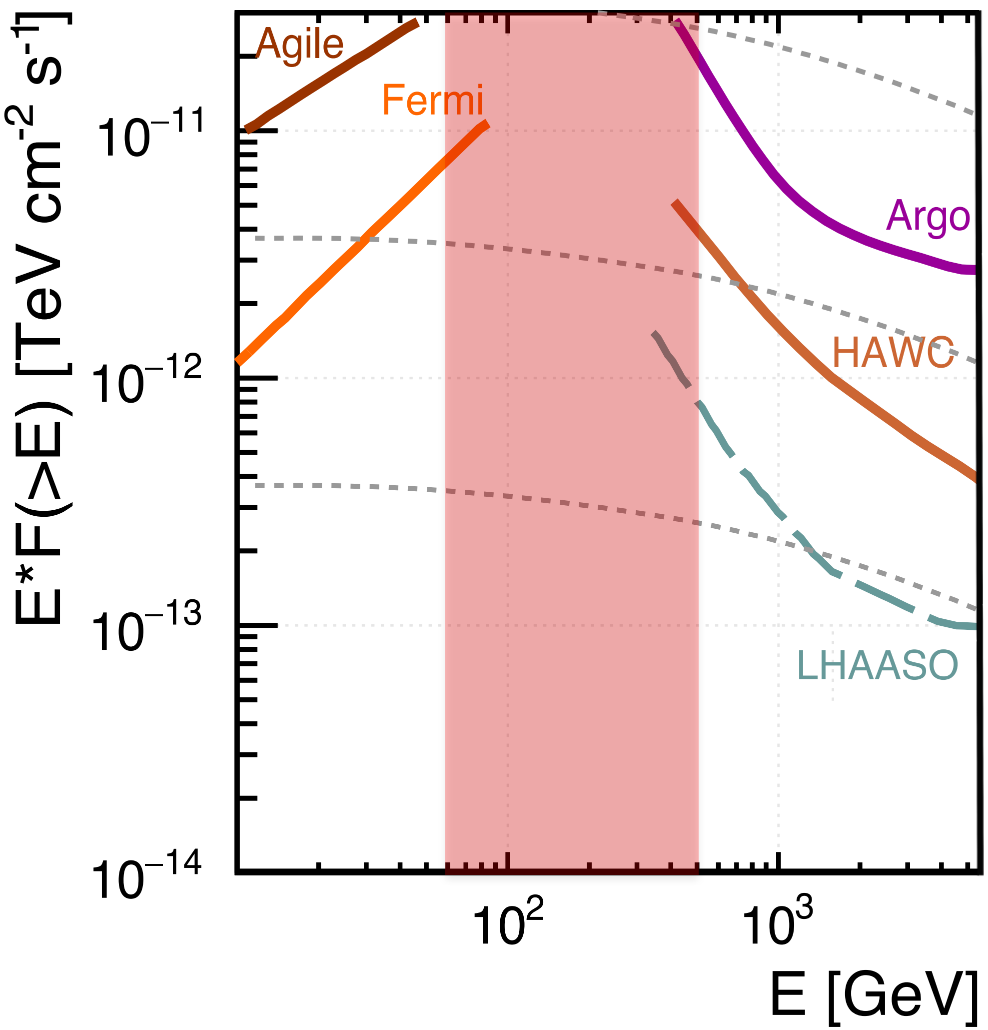
The low energy challenge





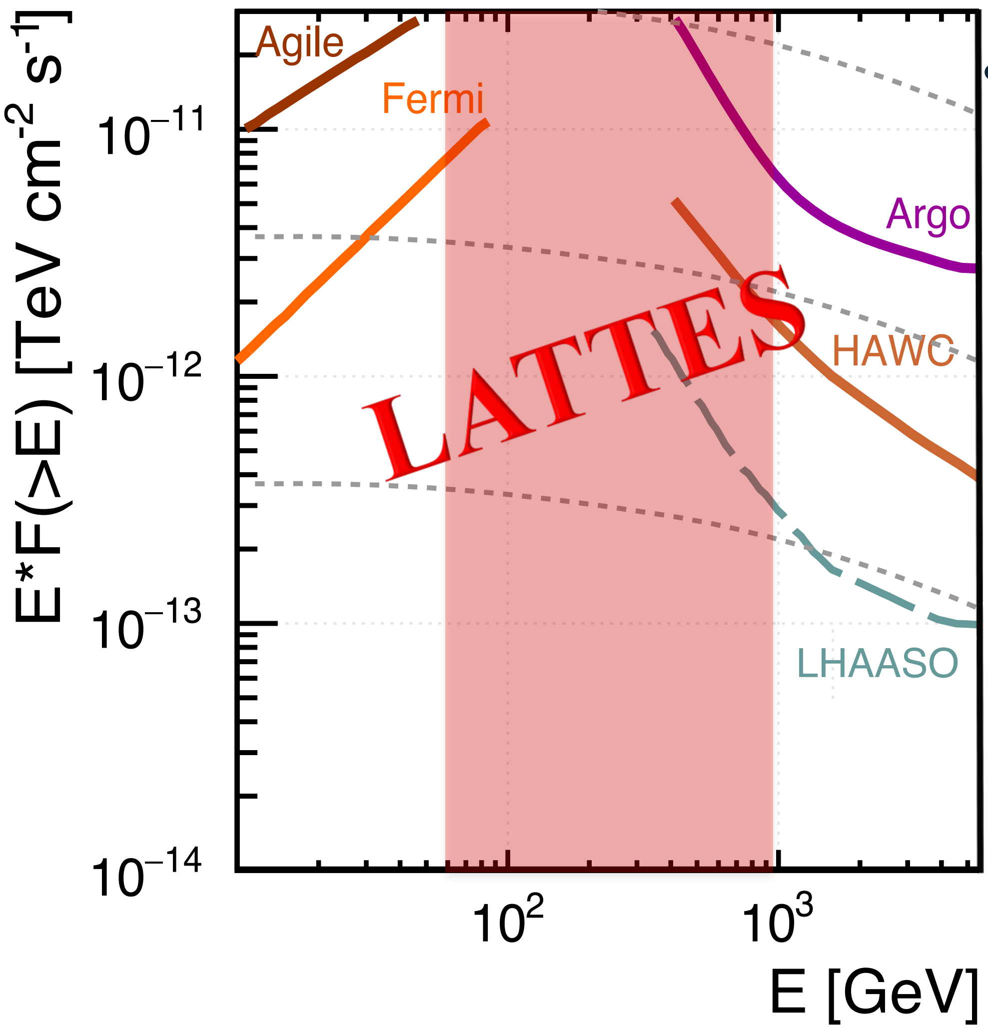
- Need to:
  - Go to high altitude;
  - Convert the shower photons;
  - Measure energy flow.

Requirements



- Build an EAS array experiment:
  - Located in the South Hemisphere
  - Low energy threshold:
    - High altitude
    - Next generation detector concept

Solution



- Build an EAS array experiment:
  - Located in the South Hemisphere ✓
  - Low energy threshold:
    - High altitude ✓
    - Next generation detector concept ✓

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

P. Assis[a,b], U. Barres de Almeida[c], A. Blanco[d], R. Conceição[a,b], B. D'Ettorre Piazzoli[e], A. De Angelis[f,g,b,a], M. Doro[h,f], P. Fonte[d], L. Lopes[d], G. Matthiae[i], M. Pimenta[b,a], R. Shellard[c], B. Tomé[a,b]

[a]LIP Lisboa, Portugal
[b]IST Lisboa, Portugal
[c]CBPF, Rio de Janeiro, Brazil
[d]LIP Coimbra and University of Coimbra, Portugal
[e]Università di Napoli "Federico II" and INFN Roma Tor Vergata, Italy
[f]INFN Padova, Italy
[g]Università di Udine, Italy
[h]Università di Padova, Italy
[i]INFN and Università di Roma Tor Vergata, Roma, Italy

with a 5σ significance a source as faint as 10% of the Crab Nebula in one year, and able to survey half of the sky. The instrument can detect a source with the luminosity of 25 Crab at 3σ in 1 minute, making it a very powerful tool to trigger observations of variable sources and to detect transients coupled to gravitational waves and gamma-ray bursts.

Keywords: Gamma-ray astronomy, Extensive air shower detectors, Transient sources, Gamma-ray bursts

1. Introduction

High energy gamma rays are important probes of extreme, non thermal, events taking place in the universe. Being neutral, they can cover large distances without being deflected by galactic and extragalactic magnetic fields. This feature enables the direct study of their emission sources. The gamma emission is also connected to the acceleration of charged cosmic rays and to the production of cosmic neutrinos. Gamma-rays can also signal the existence of new physics at the fundamental scales, namely by the annihilation or decay of new types of particles, as it is the case for dark matter particles in many models. This motivation, associated to the advances of technology, has promoted a vigorous program of study of high energy gamma rays, with important scientific results (see [1, 2, 3, 4] for a summary of the main achievements).

The detected sources of cosmic gamma-rays above 30 MeV are concentrated around the disk of the Milky Way; in addition there is a set of extragalactic emitters. About 3000 sources emitting above 30 MeV were discovered, mostly by the Large Area Telescope (LAT) detector [5] onboard the *Fermi* satellite, and some 200 of them emit as well above 30 GeV [6] (see Fig. 1) - the region which is labeled the Very High Energy (VHE) region.

Our Galaxy hosts about half of the VHE gamma-ray emitters [7] and most of them are associated to supernova remnants of various classes (shell supernova remnants, pulsar-wind nebulae, etc.). The remaining emitters are extragalactic. The angular resolution of current detectors, which is slightly better than 0.1°, does not allow to assign the identified extragalactic emitters to any particular region in the host galaxies; however, there is some consensus that the signals detected from the Earth must originate in the proximity of supermassive black holes at the center of the galaxies [8].

Still, many problems remain open, of which we may mention:

- *The origin of cosmic rays* – supernova remnants (SNRs) are accepted to be the sites for the acceleration of protons up to few PeV. However, the mechanism of acceleration of particles to energies of that order is still to be established experimentally. The study of the photon yield from Galactic sources for energies larger than 100 GeV and all the way up to PeV, might solve the problem (see for example [9]). Actually photons, which come from π^0 decay, correspond to hadronic cascades initiated at energies at least an order of magnitude larger.

- *The propagation of gamma-rays* – tells us about their interaction with the cosmic background radiation and is a

*Corresponding authors
Email addresses: ruben@lip.pt (R. Conceição), alessandro.deangelis@pd.infn.it (A. De Angelis), shellard@cbpf.br (R. Shellard)

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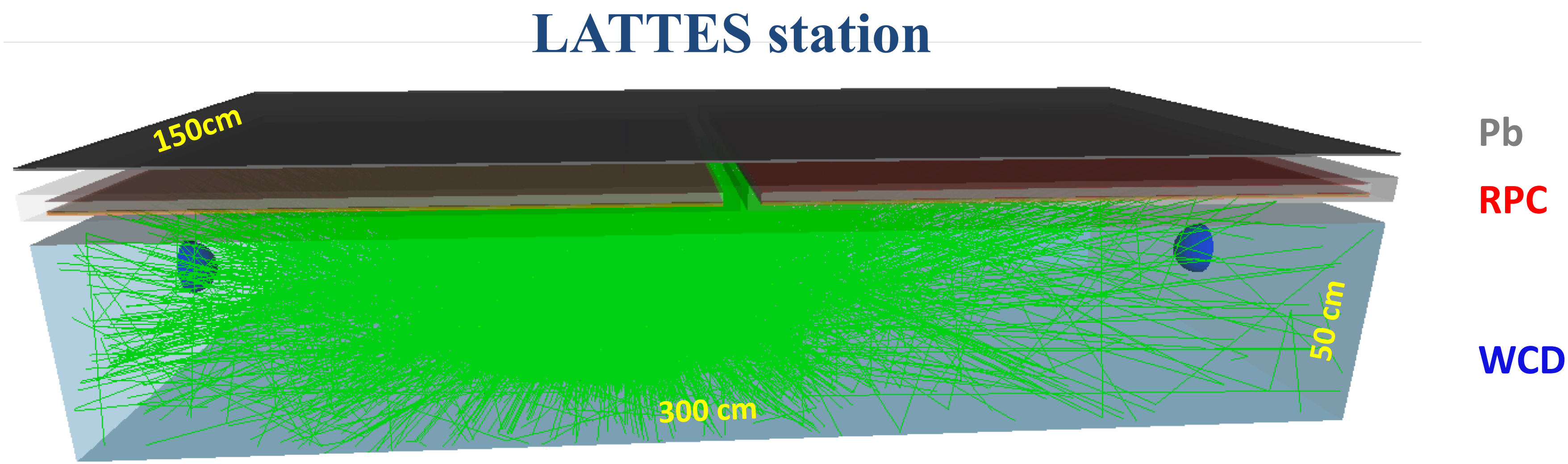
LATTES @ ALMA site

Large Array Telescope for Tracking Energetic Sources

- **Planned site:**
    - **Atacama Large Millimeter Array site**
        - **Chajnantor plateau**
        - **5200 meters altitude in north Chile**
        - **Good position to survey the Galactic Center**

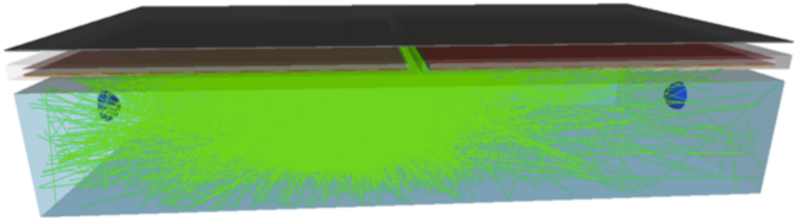
LATTES concept



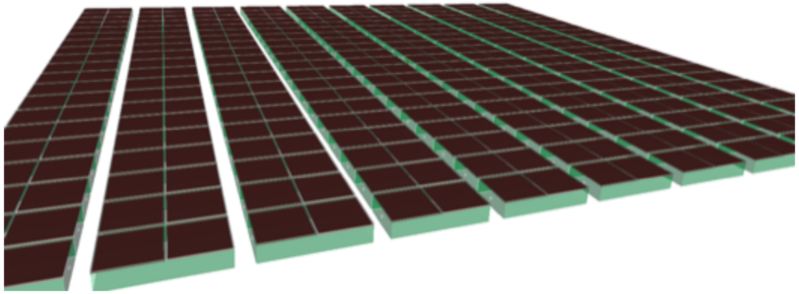
– Thin lead plate (Pb)
  - 5.6 mm (one radiation lenght)
– Resistive Plate Chambers (**RPC**)
  - 2 RPCs per station
  - Each RPC with 4x4 readout pads
– Water Cherenkov Detector (**WCD**)
  - 2 PMTs; 15 cm diameter
  - inner walls covered with white diffusing Tyvek

LATTES concept

- 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



LATTES station

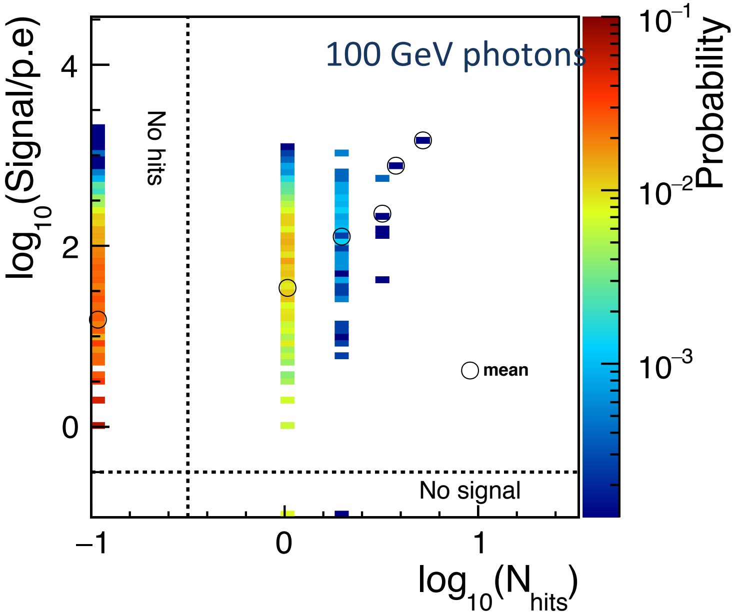


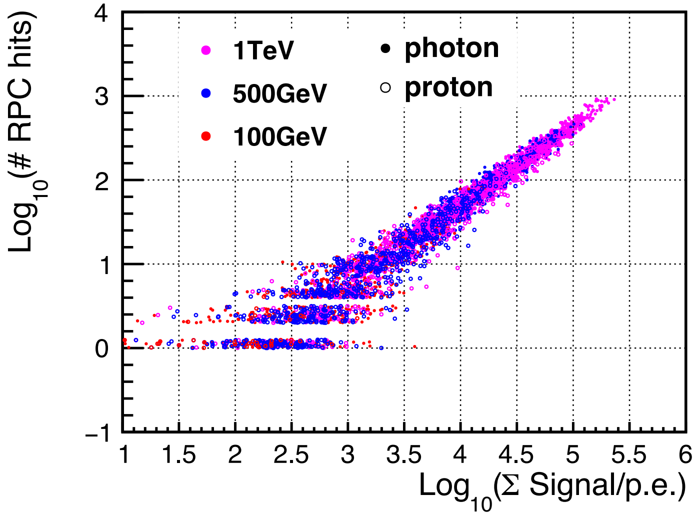
LATTES core array

LATTES: complementarity

- Combined detection:
  - Lower the **energy threshold**
    - Improve the trigger conditions (WCD)
  - Enable detector **inter-calibrations**
    - Energy calibration can be used to control detector systematic uncertainties
    - Check Monte Carlo simulations performance
  - Enhance **gamma/hadron discrimination**
    - Explore shower characteristics
    - Access to combined Argo/HAWC discrimination techniques

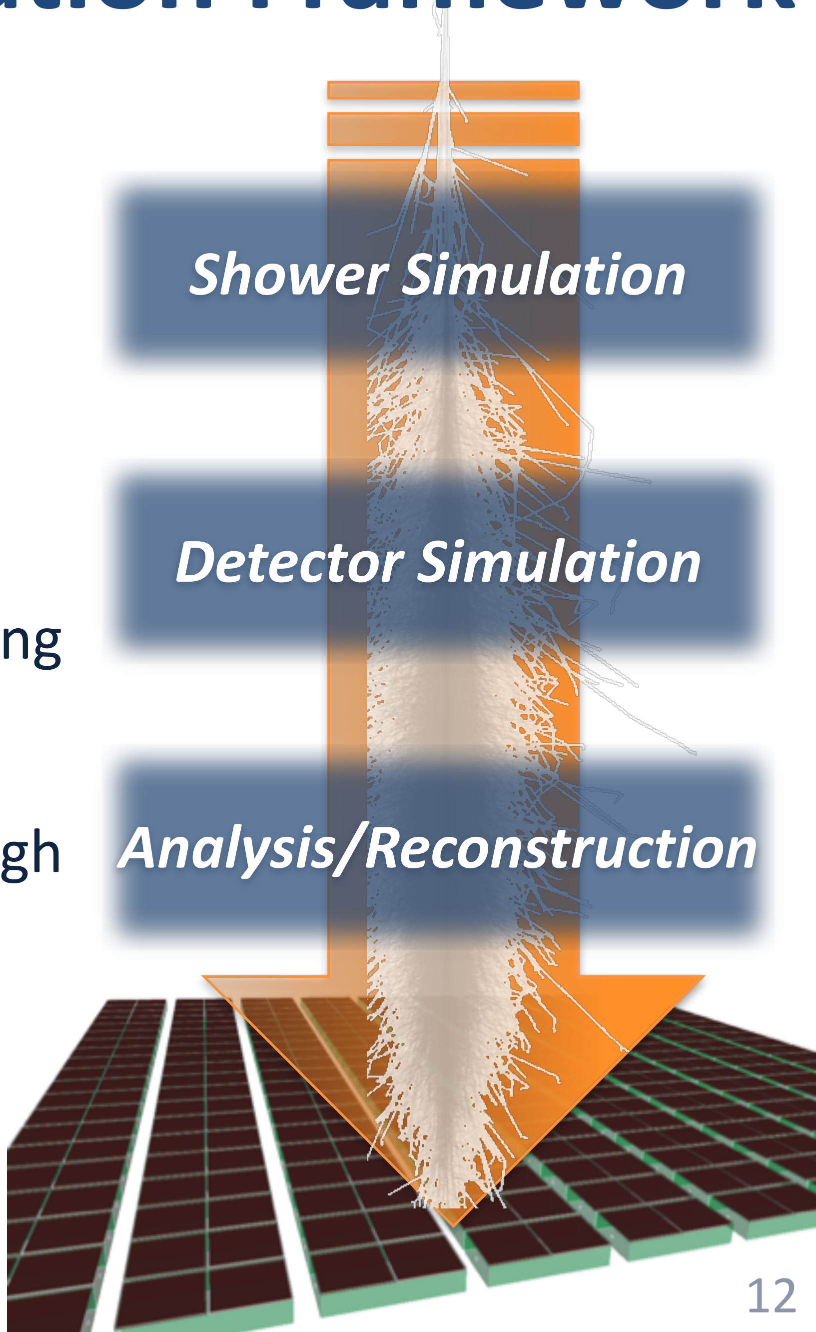
WCD vs RPC (station level)





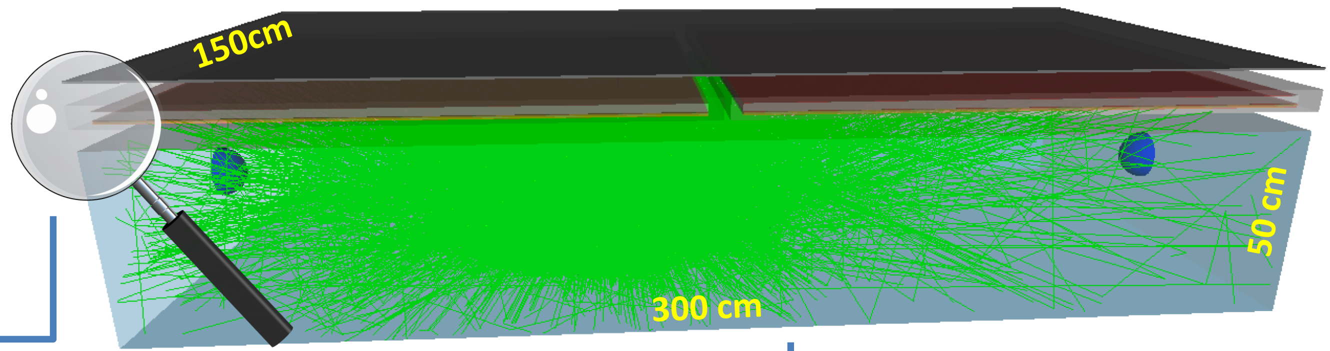
Simulation Framework

- Complete end-to-end simulation chain to evaluate LATTES performance:
  - Showers simulated using **CORSIKA**
    - **Photon** and **proton** showers
    - ~ 8 million showers fully processed
  - Detector layout and simulation using **Geant4**
  - **ROOT** based reconstruction and high level analysis
  - Integrated tool to study and optimize LATTES performance

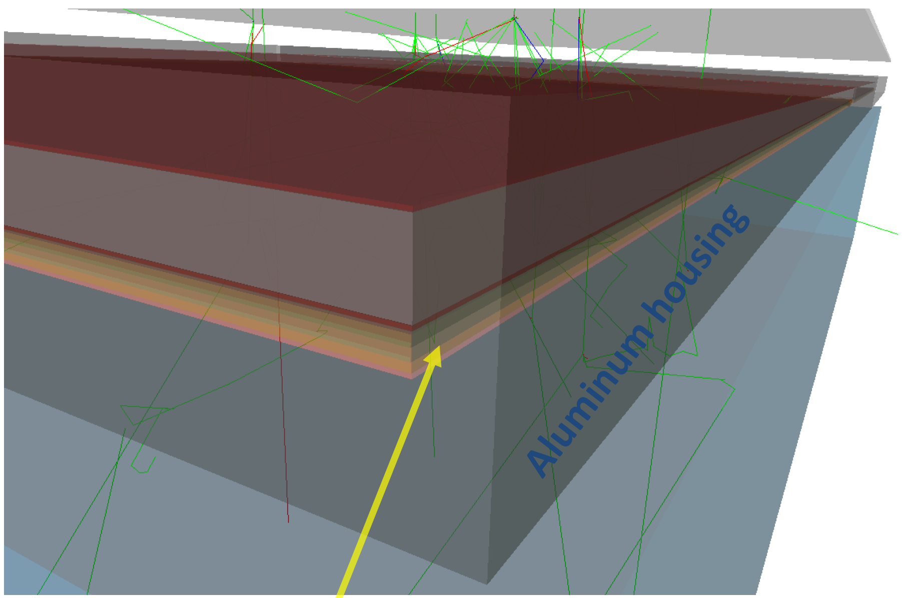


LATTES station in Geant4

- **Realistic description**



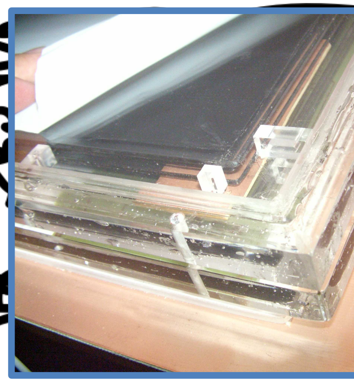
Detailed RPC structure



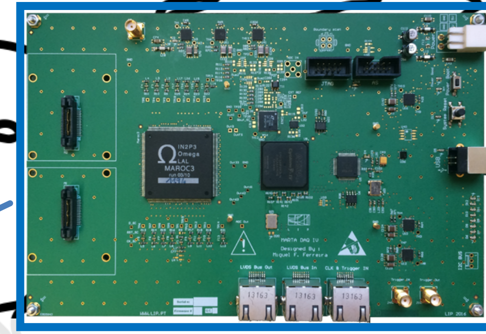
Acrylic box with glass electrodes and 1 mm gas gaps

- **Explore Geant4 capabilities to simulate optical photon propagation;**
- λ dependence of all relevant processes/materials taken into account;
- **Water**
  - Attenuation length ~ 80 m @ λ = 400 nm
- **PMT**
  - Q.E.$_{max}$ ~ 30% @ λ = 420 nm
- **Tyvek**
  - Described using the G4 UNIFIED optical model;
  - Specular and diffusive properties;
  - R ~ 95%, for λ > 450 nm

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



RPC developments



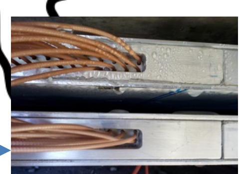
DAQ Engineering prototype

RPC based muon hodoscope for precise studies of the Auger WCD

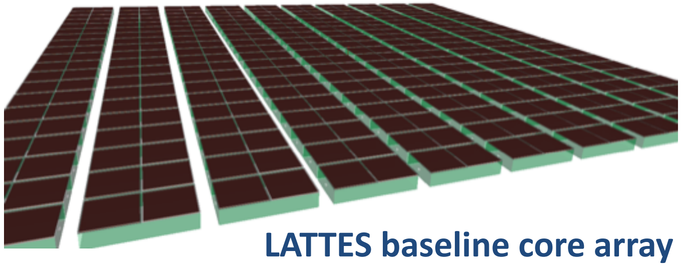
Construction and Assembling

RPC hodoscope

RPCs in the field @ Auger

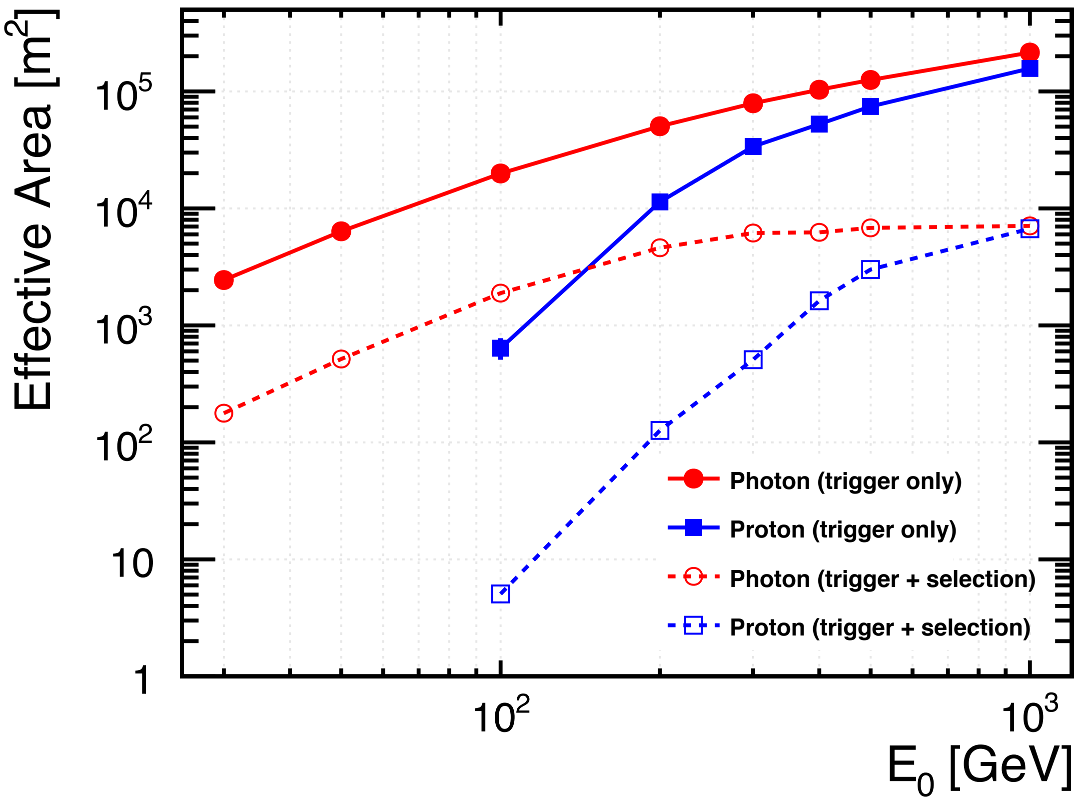


- **LATTES perfomance:**
  - Trigger efficiency
  - Energy Reconstruction
  - Geometric Reconstruction
  - Gamma-hadron discrimination
- LATTES sensitivity



LATTES baseline core array
30 x 60 stations
100×100 m^2

Trigger efficiency

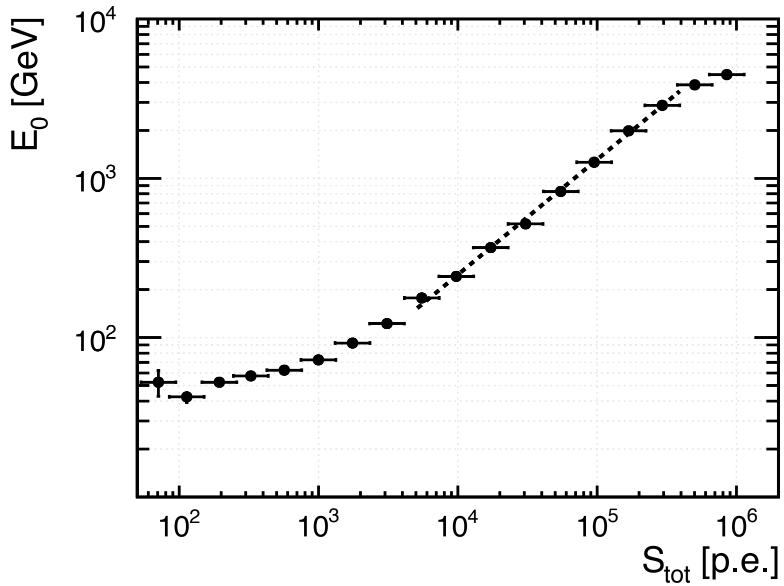


- Use WCD stations to trigger at low energies
  - Trigger condition
    - Station: require more than 5 p.e. in each PMT
    - Event: require 3 triggered stations
  - *Effective Area of 1000 m^2 at 100 GeV! (after quality cuts)*

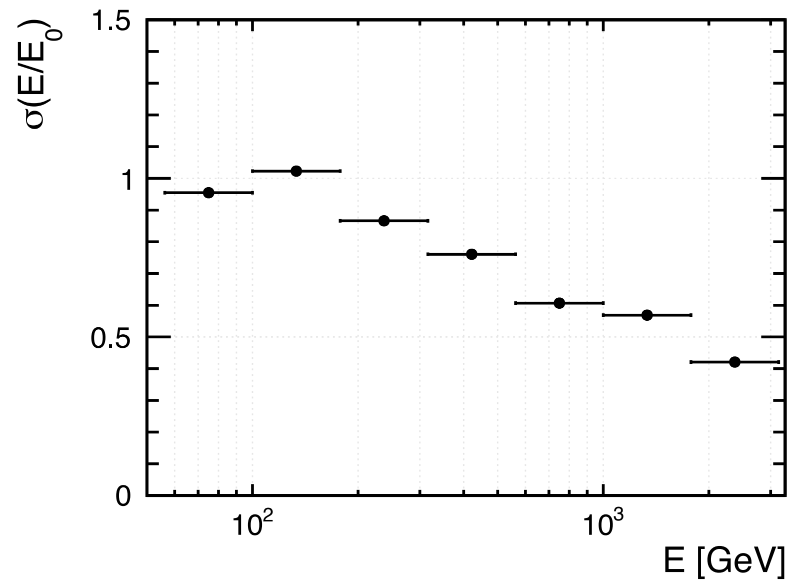
Energy reconstruction

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

Energy Calibration



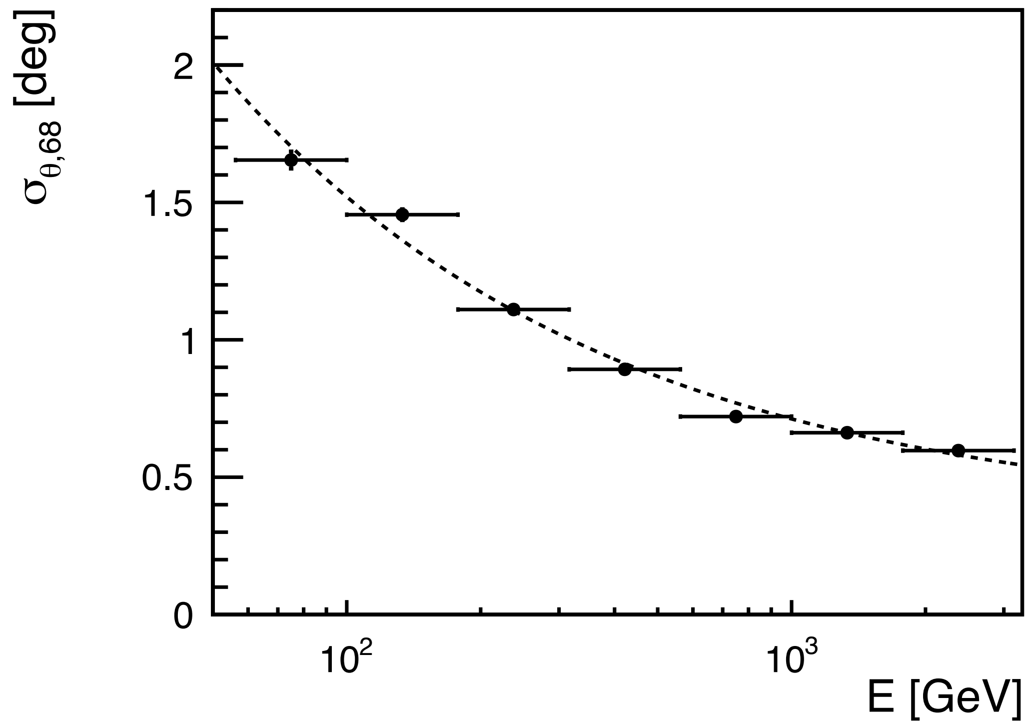
Energy Resolution



- Use as energy estimator the total signal recorded by WCDs
- Energy resolution below 100% even at 100 GeV
  - Dominated by the shower fluctuations

Geometric reconstruction

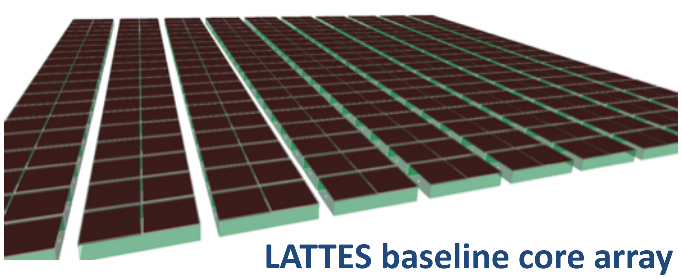
$\gamma - \text{showers}; \theta = 10^\circ$



- Shower **geometry reconstruction** using **RPC hit time**
  - Take advantage of RPCs **high spatial and time resolution (~ 1 ns)**
  - Use shower front plane approximation
- – *Angular resolution below 2^o even for 50 GeV showers*
- – Expected improvements:
  - ***Account for shower front curvature;***
  - ***Weight each RPC by WCD signal;***

- LATTES performance:
  - Trigger efficiency ✓
  - Energy Reconstruction ✓
  - Geometric Reconstruction ✓
  - Gamma-hadron discrimination

    - For now use a conservative approach:
      - Below 300 GeV don't consider any discrimination
      - Above 300 GeV use HAWC discrimination curve
- **LATTES sensitivity**



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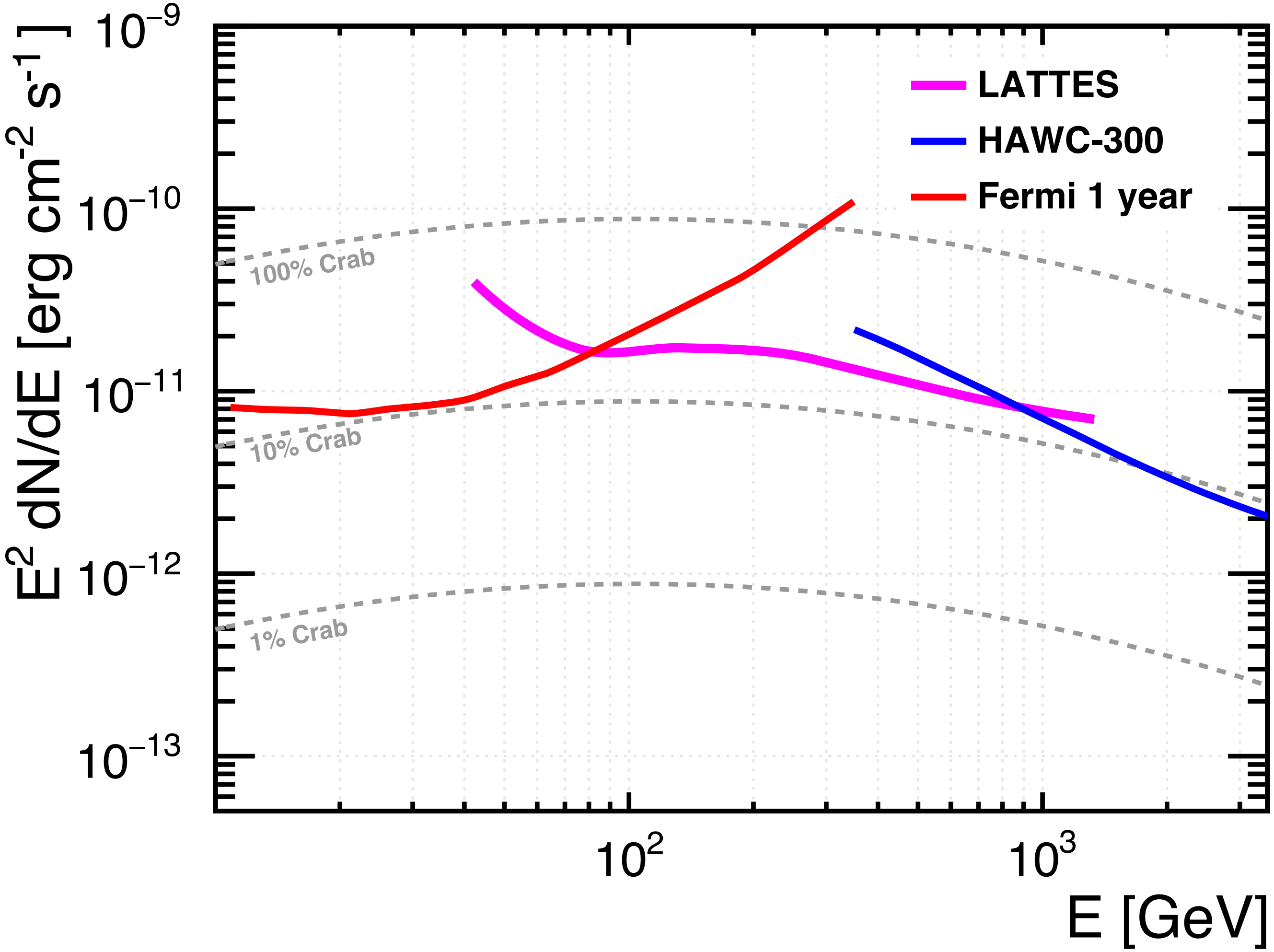
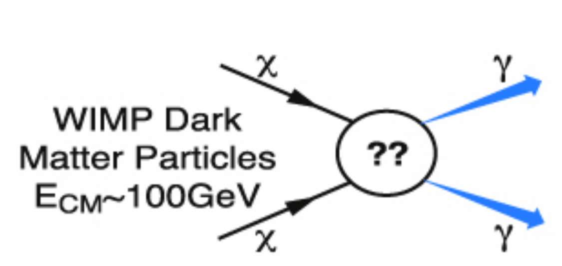
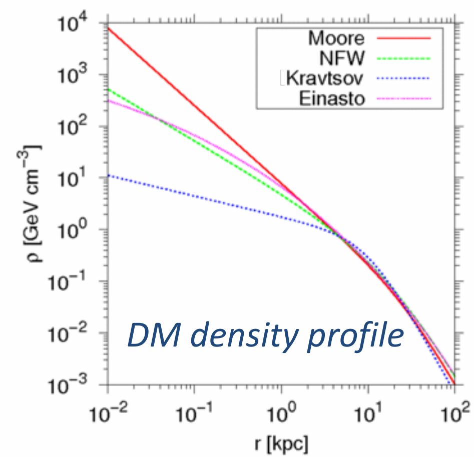
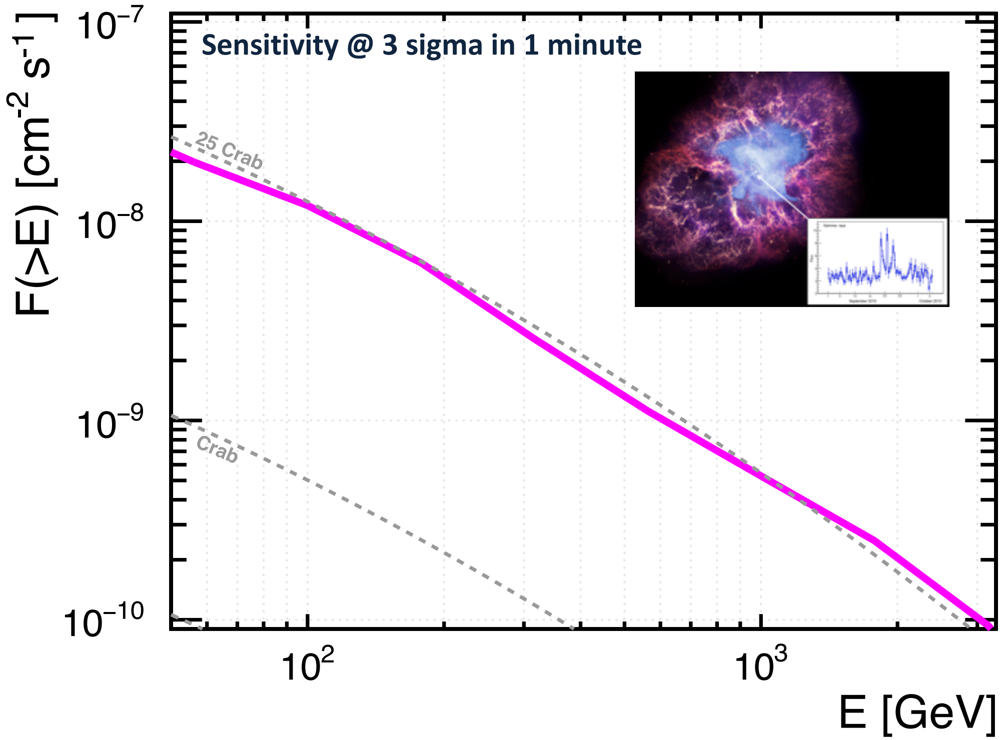


Differential sensitivity to steady sources in one year

LATTES physics opportunities



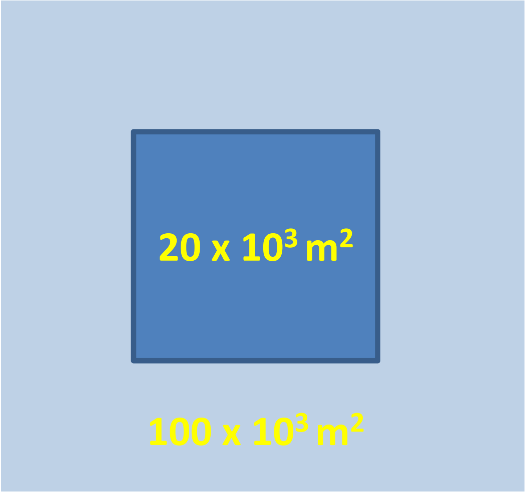




- Many interesting scientific goals:
  - Dark matter searches at the center of the galaxy
  - Study transient phenomena
    - LATTES can detect a 25 Crab source at 3 sigma in 1 minute

Towards the LATTES full array

- Sensitivity studies using a baseline 10000 m^2 core array



- Final LATTES design should consist of:
  - 20 x 10^3 m^2 core for improved sensitivity @ low energy;
  - 100 x 10^3 m^2 of sparse detectors outrigger;

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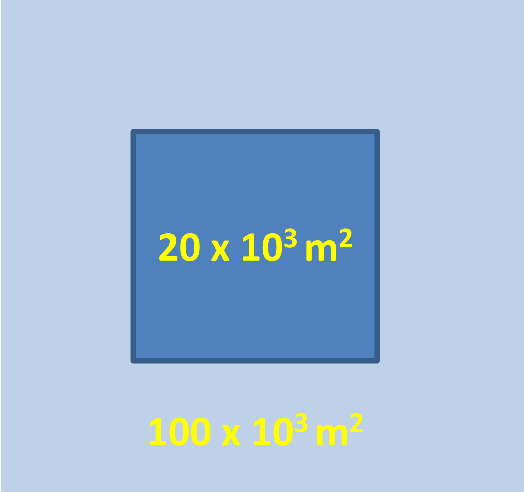

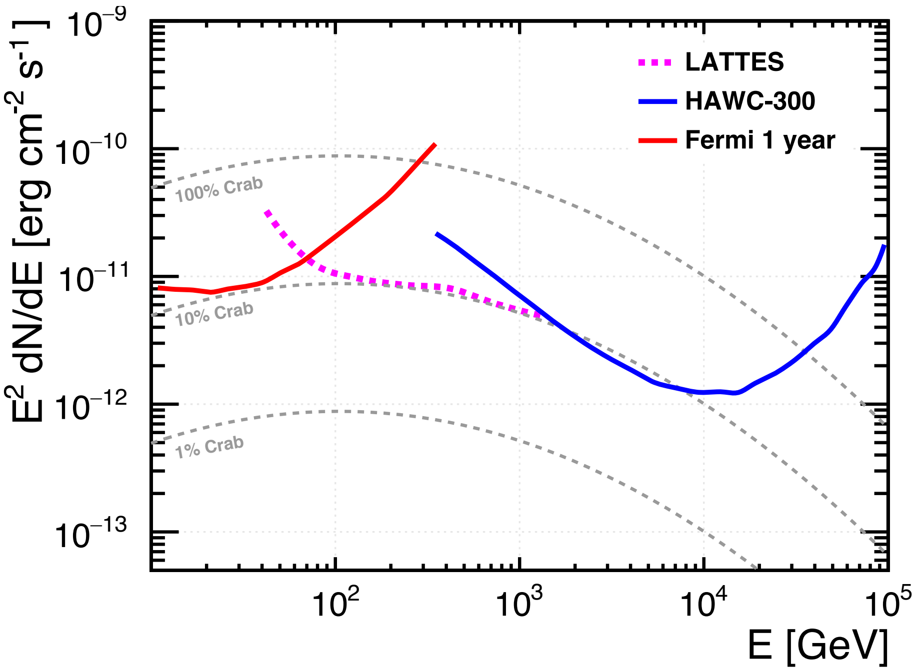

- Projected sensitivity @ low energy:
  - Scale by area;
  - Preliminary γ/h discrimination studies (RPC+WCD)
- Ongoing simulations to assess performance at high energy

Summary

- LATTES: gamma ray wide field of view experiment at South America
  - Complementary project to CTA to survey the southern sky, in particular the center of the galaxy;
  - Next generation hybrid gamma-ray experiment;
  - Good sensitivity at low energies (100 GeV)
    - Cover the gap between satellite and ground based measurements
  - Powerful tool to trigger observations of variable sources and to detect transients

Acknowledgements

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PORTUGAL 2007.2013

UNIÃO EUROPEIA
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LIP

TÉCNICO LISBOA