LATTES: a next generation gamma-ray detector concept

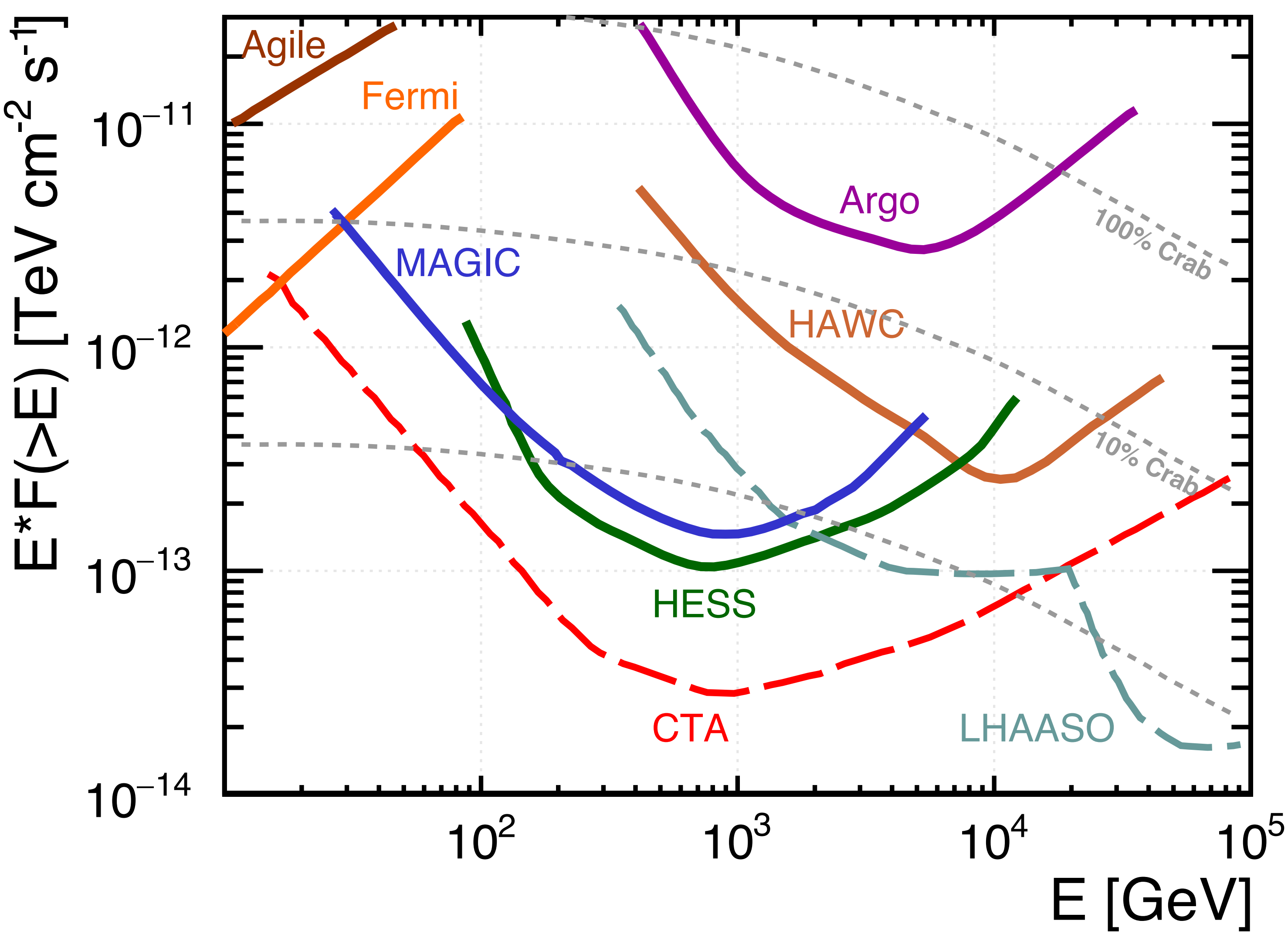
Ruben Conceição

on behalf of the LATTES team

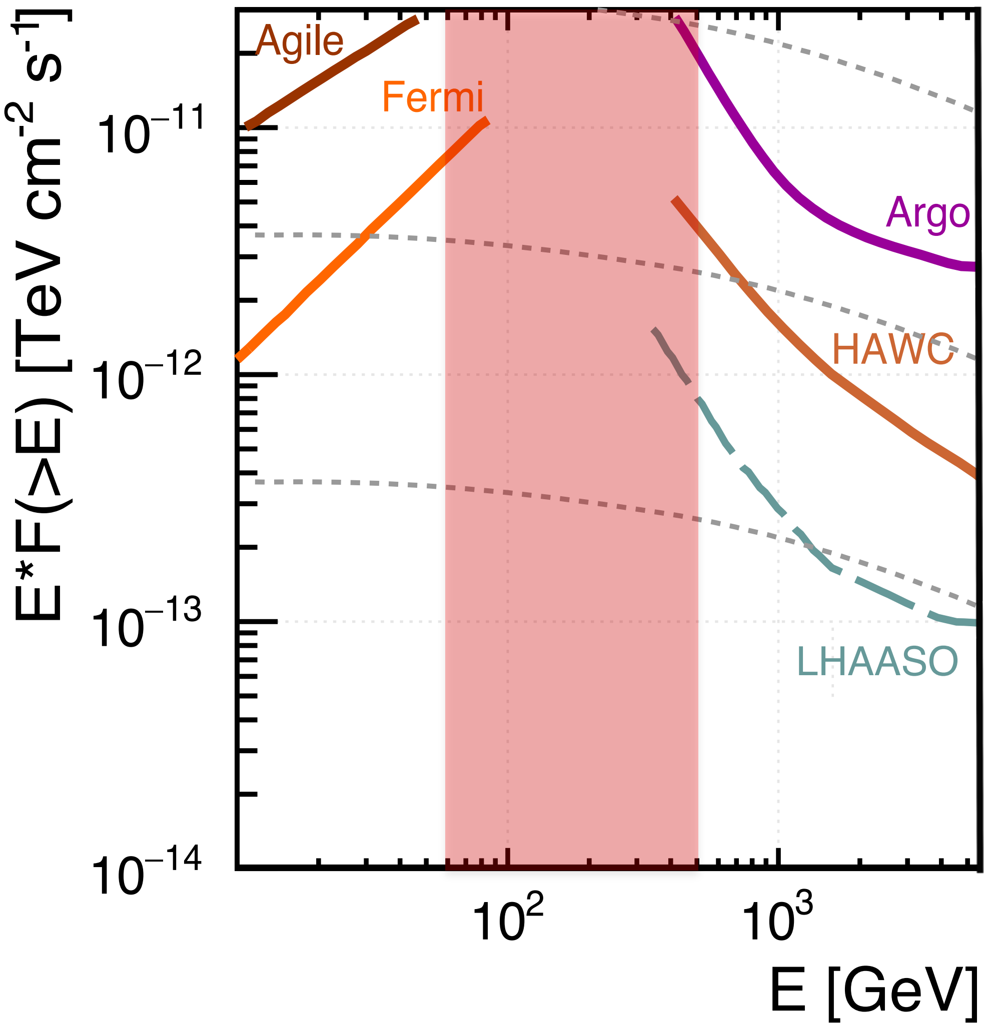
L I P

Workshop on wide FoV Southern hemisphere TeV gamma-ray observatory, Rome, Puebla 10th 2016

Current experimental status

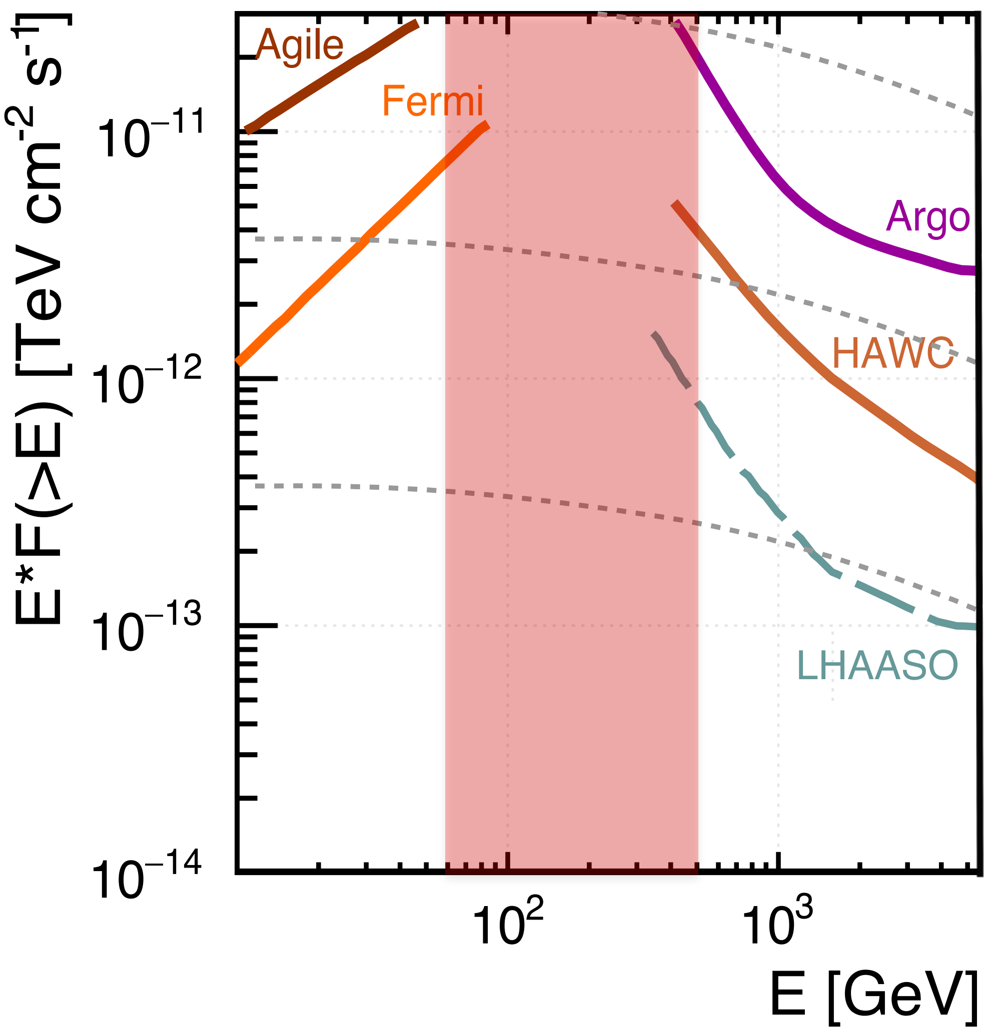


Current Situation



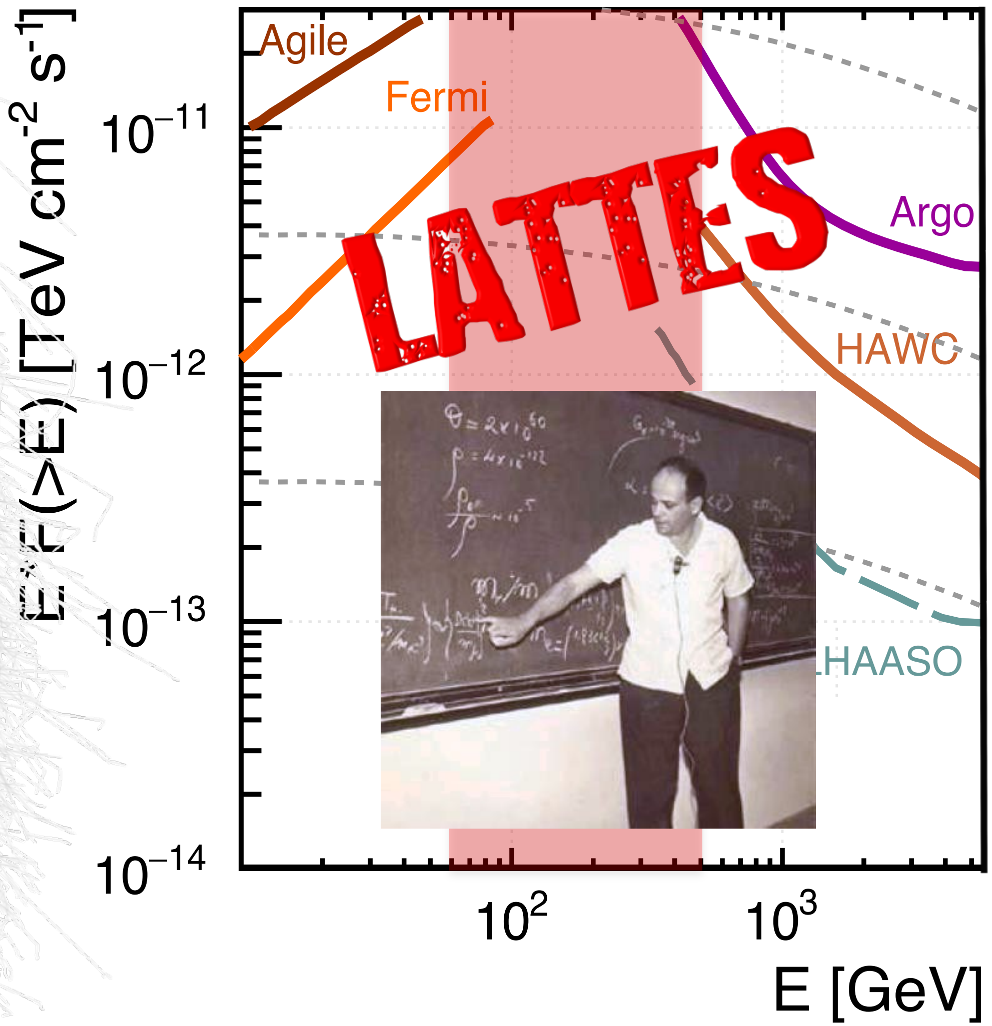
- No wide FoV experiment to:
  - Survey the Galactic Center (GC)
  - Explore the energy region of 100 GeV
    - Cover the gap between satellite and ground based observations;
    - Trigger observations of variable sources (finder for CTA);
    - Detect extragalactic transients/flaring activity.

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 ✓

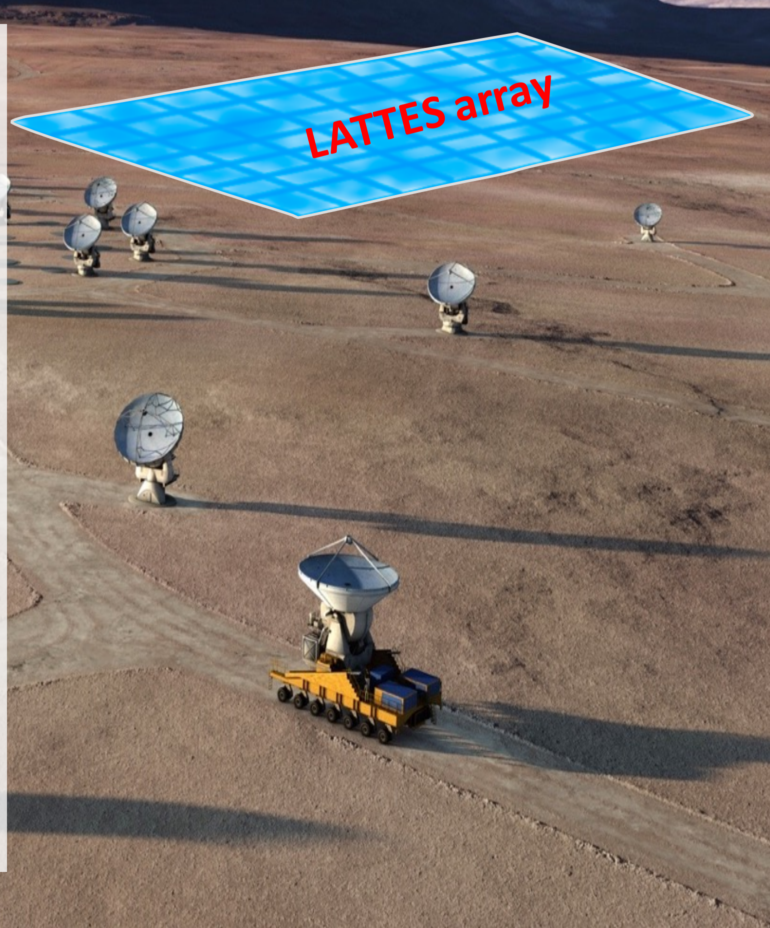
Who we are…

- Several meetings to discuss LATTES progress
  - 30 persons in last meeting
    - Brazil, Czech Republic, Italy, Portugal, Spain

LATTES @ ALMA site

Large Array Telescope for Tracking Energetic Sources

- **Planned site:**
  - **Atacama Large Millimeter Array site**
    - **Chajnantor plateau**
    - **Good position to survey the Galactic Center**
- **LATTES array baseline**
  - **Compact core array**
    - **Area: 20 000m^2**
    - **Target lowest energies (E_{min} < 100 GeV)**
  - **Sparse array**
    - **Area: 100 000 m^2**
    - **Cover energies up to 100 TeV**



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

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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

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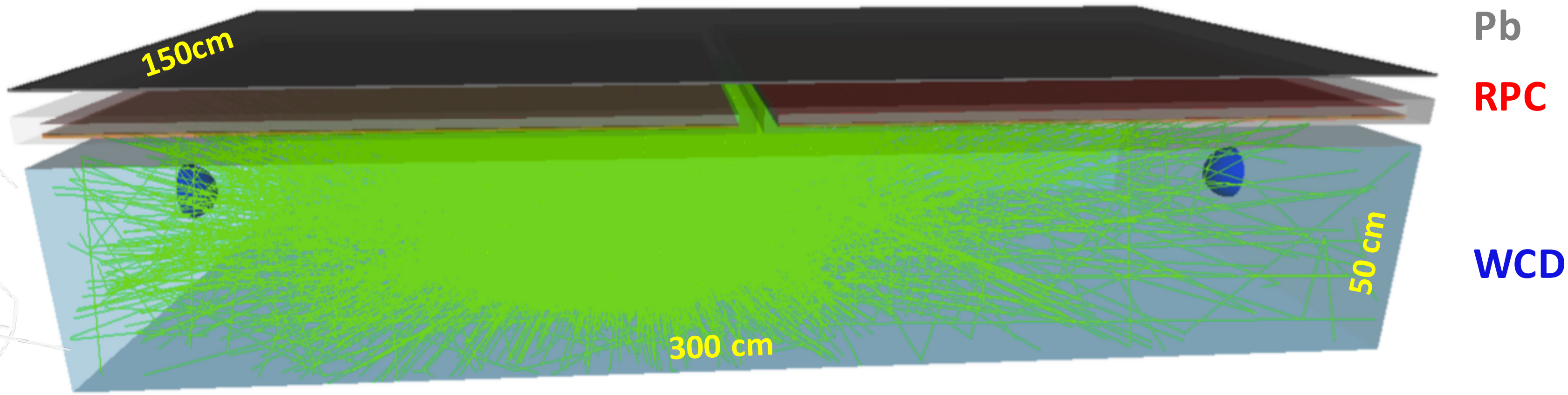
Investigate the **performance** of LATTES at **low energy**

Use only a Compact Core Array – Area: **10 000 m²**

Submitted to Astropart. Phys.

LATTES concept

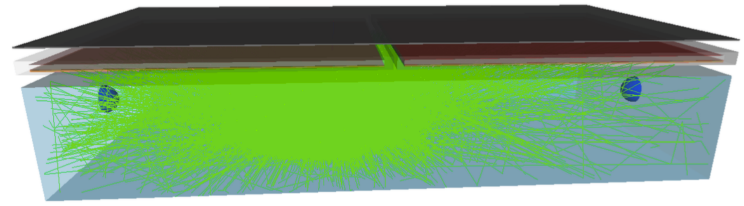
LATTES STATION



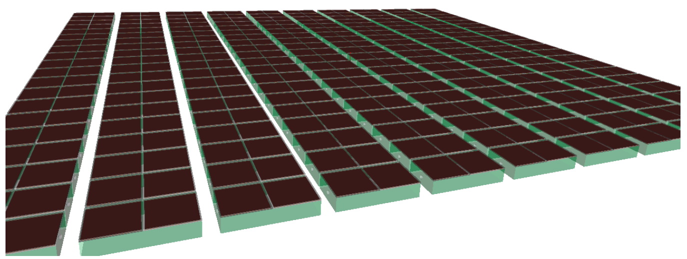
- Thin lead plate (Pb)
  - 5.6 mm (one radiation lenght)
- Resistive Plate Chambers (**RPC**)
  - 2 RPCs per station
  - Each RPC with 4x4 readout pads
- Water Cherenkov Detector (**WCD**)
  - 2 PMTs (diameter: 15 cm)
  - Inner walls covered with white diffusing paint

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



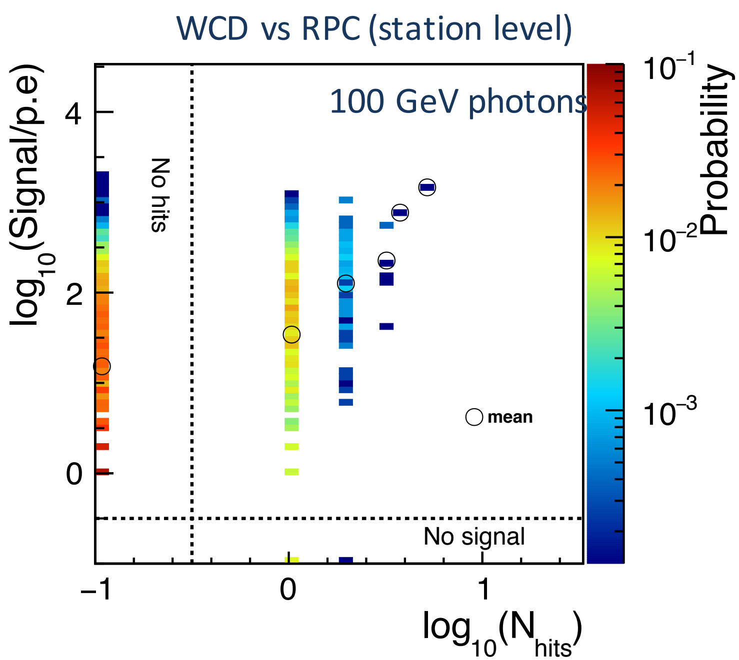
LATTES station
1.5 m x 3 m x 0.5 m

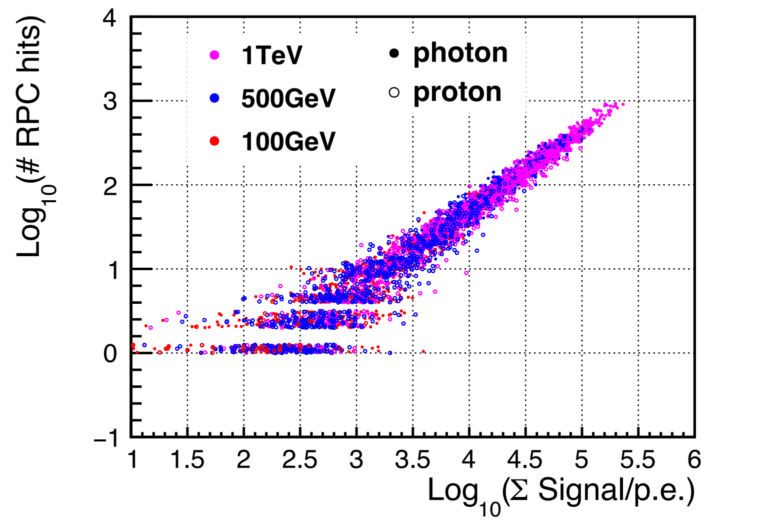


LATTES core array
30 x 60 stations
100 x 100 m^2

LATTES: complementary

- 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



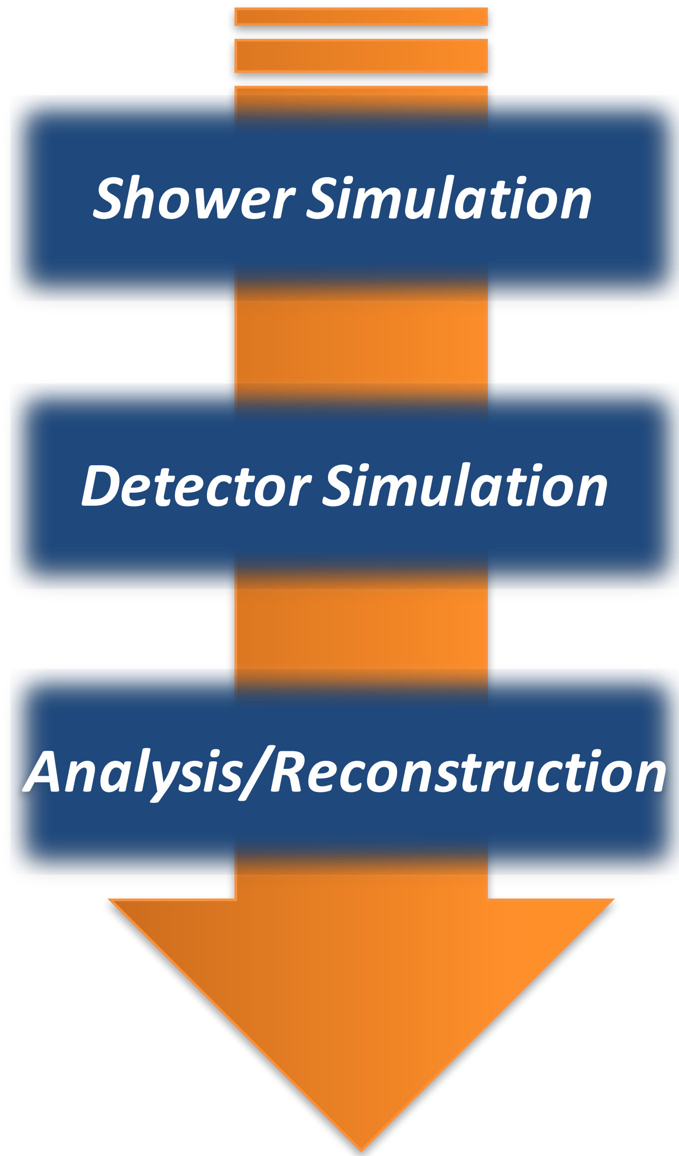


- **LATTES perfomance:**
  - Trigger efficiency
  - Energy Reconstruction
  - Geometric Reconstruction
  - Gamma-hadron discrimination

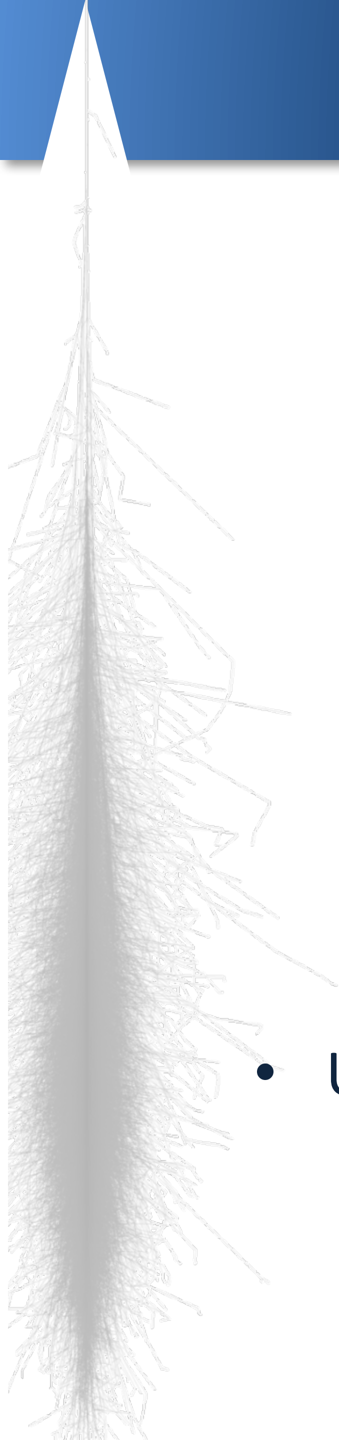
- LATTES sensitivity

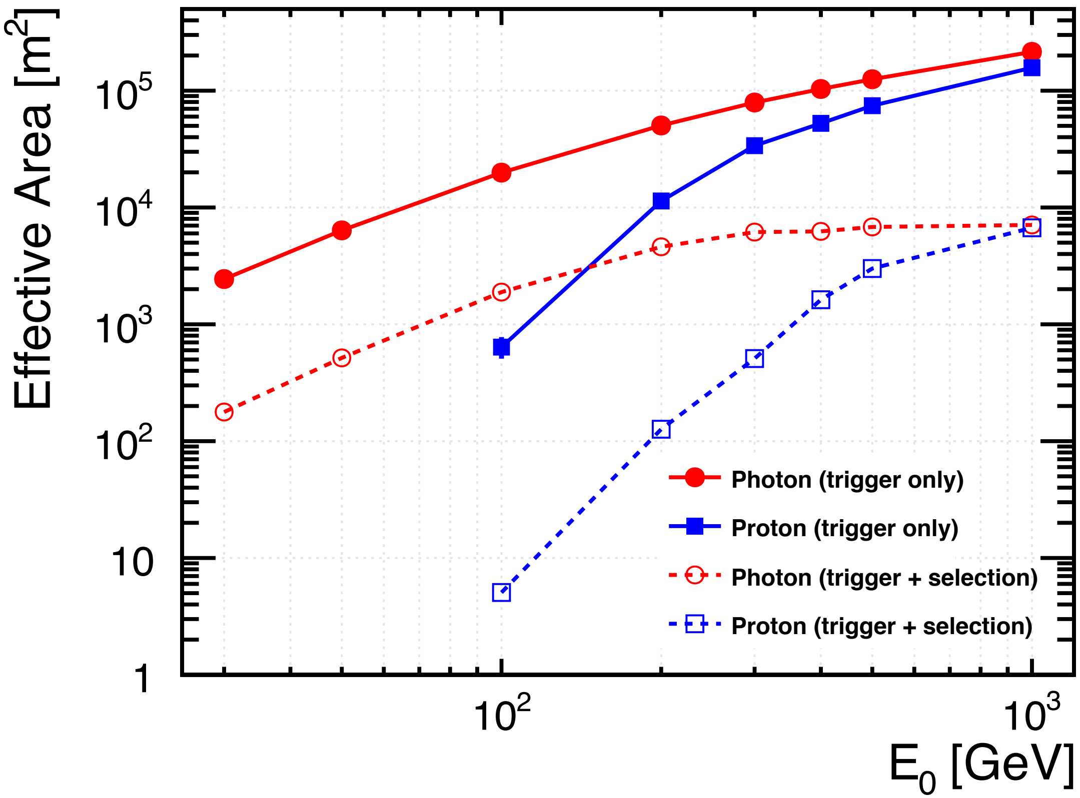
Simulation Framework

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



Trigger efficiency





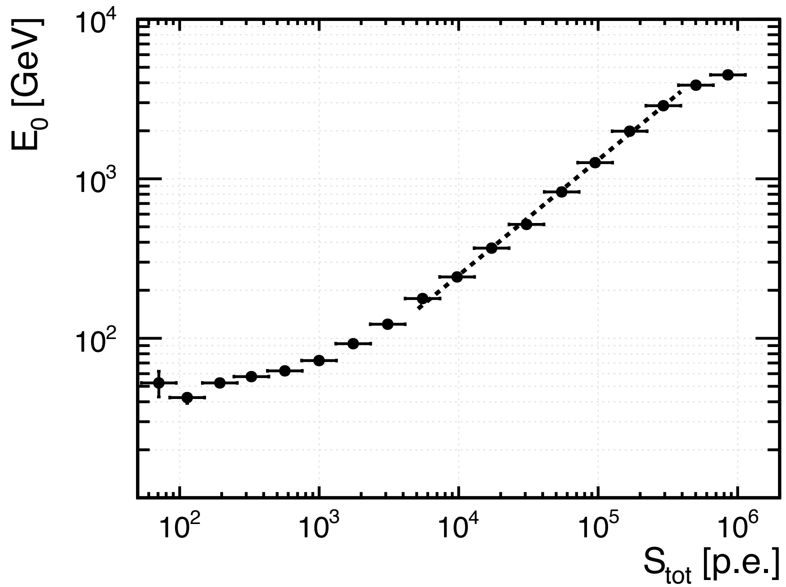
- Use WCD stations to trigger at low energies
  - Trigger condition
    - Station: require more than 5 p.e. in each PMT
    - Event: require 3 triggered stations
  - *Effective Area of 1000 m^2 at 100 GeV! (after quality cuts)*

Energy reconstruction

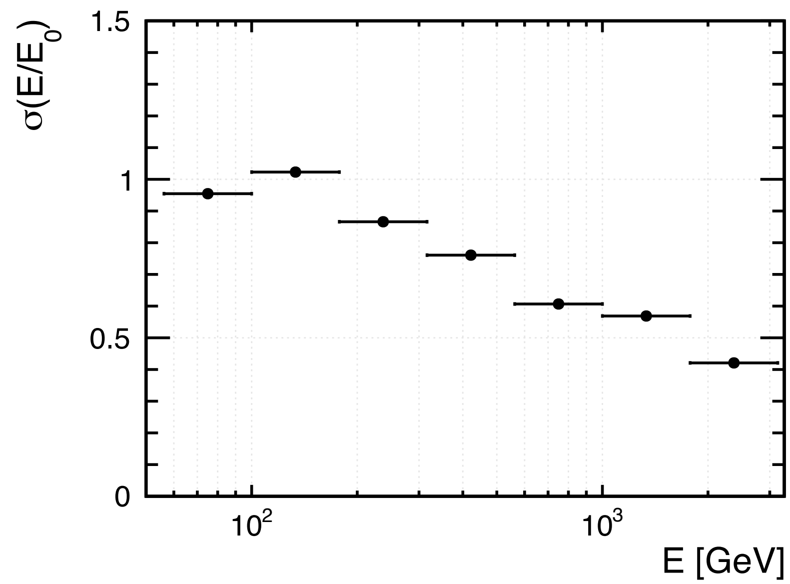
$E_0 \rightarrow$ Simulated energy

$E \rightarrow$ Reconstructed energy

Energy Calibration



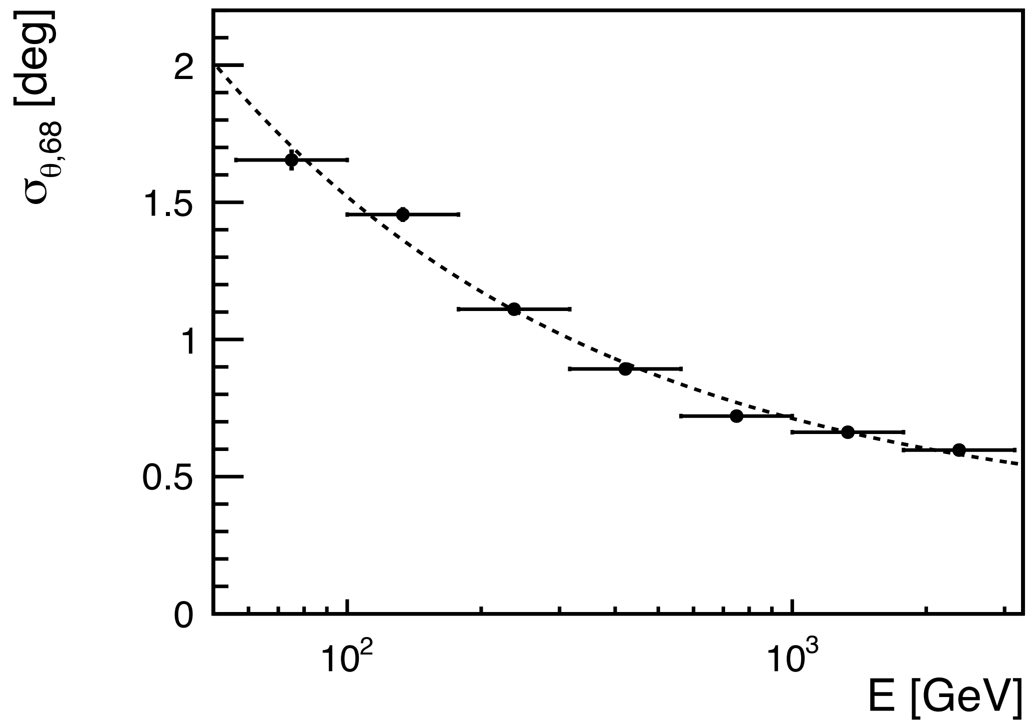
Energy Resolution



- 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

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

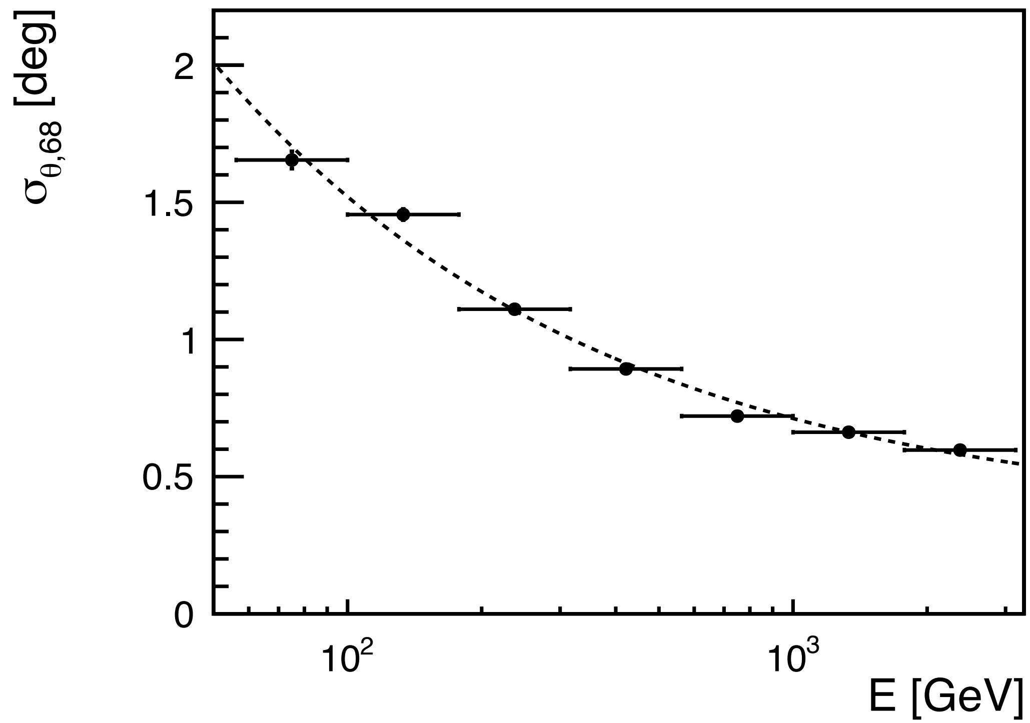


- Shower **geometry reconstruction** done using **RPC hit time**
  - Take advantage of RPCs **high spatial and time resolution**
    - Consider a time resolution of 1 ns
  - Use shower front plane approximation
  - Require more that 10 hits in the RPCs

– *Angular resolution below 2 deg even for 50 GeV showers*

Geometric reconstruction

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

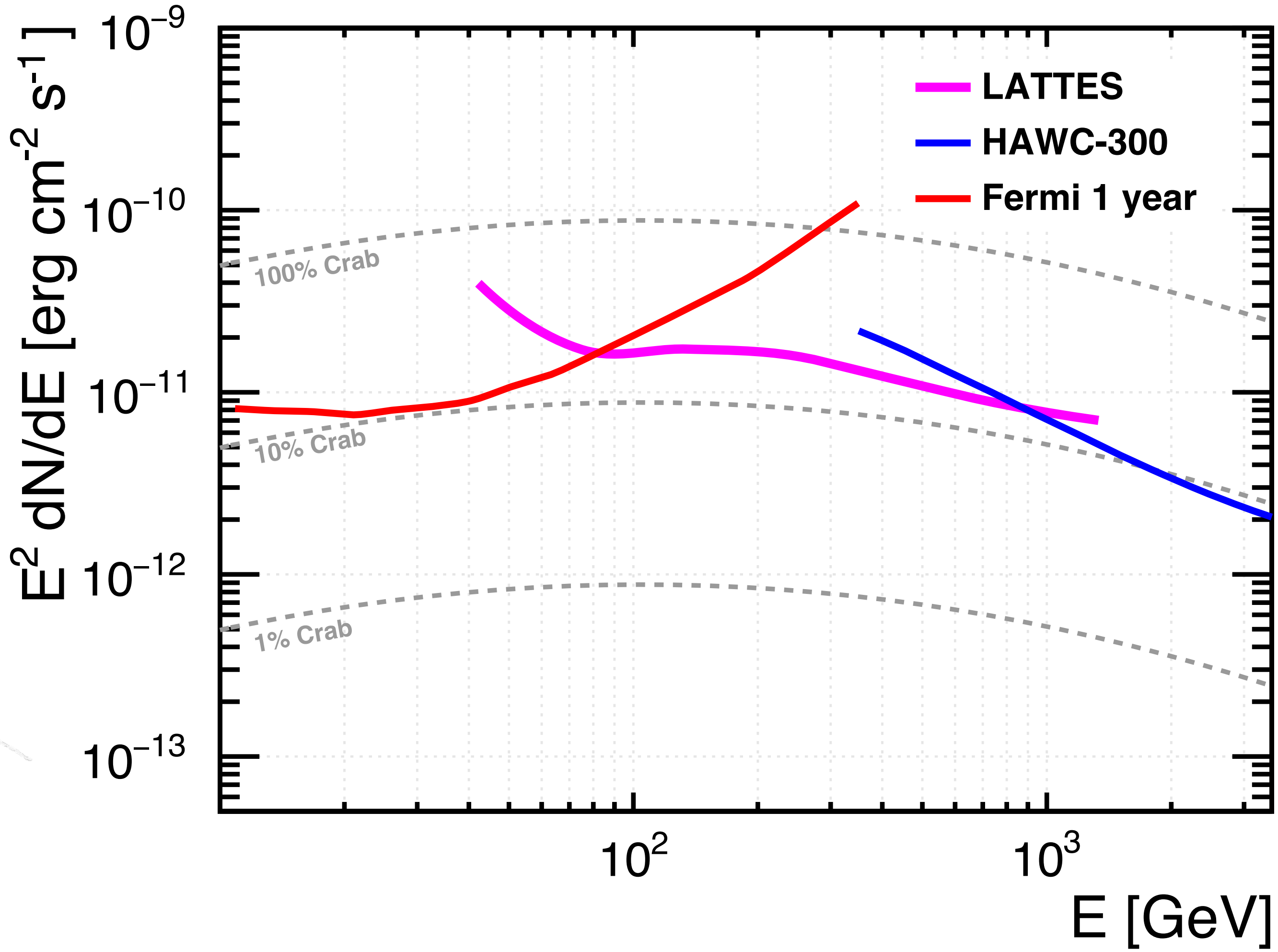


– Expected improvements:
- Account for shower front curvature
- Weight each RPC by WCD signal

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

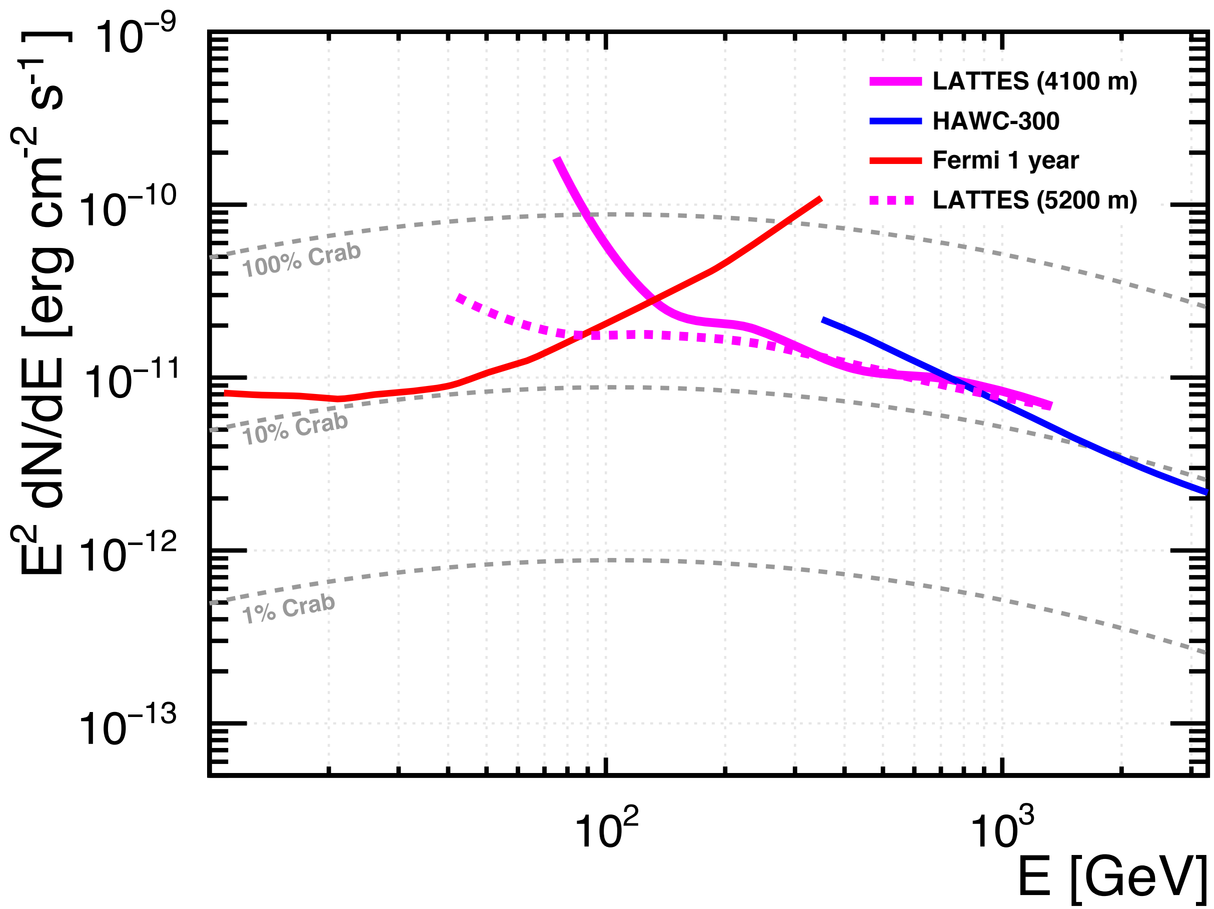
    - For now use a conservative approach:
      - Below 300 GeV don’t consider any discrimination
      - Above 300 GeV use HAWC discrimination curve
- **LATTES sensitivity**

LATTES sensitivity



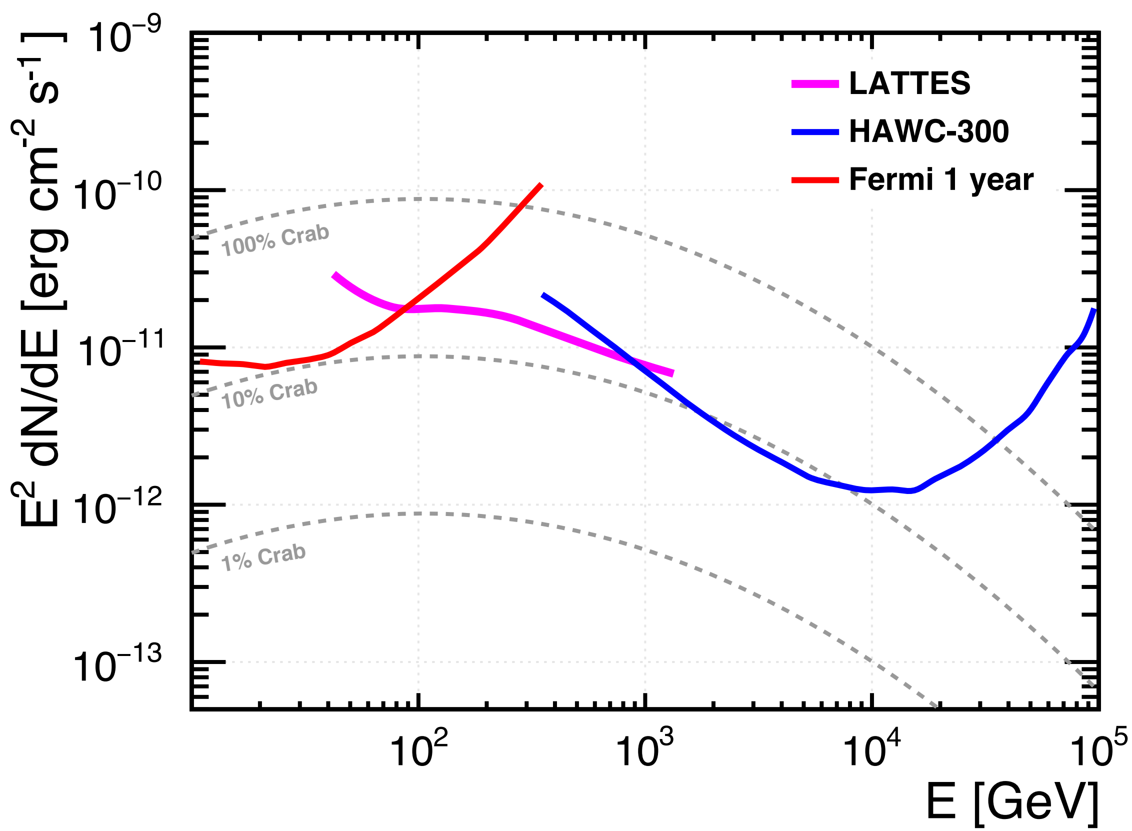
Differential sensitivity to steady sources in one year

The impact of altitude



- *The ability to reach the lowest energies does not depend only on the altitude*
- *Difference is related with the detector concept*

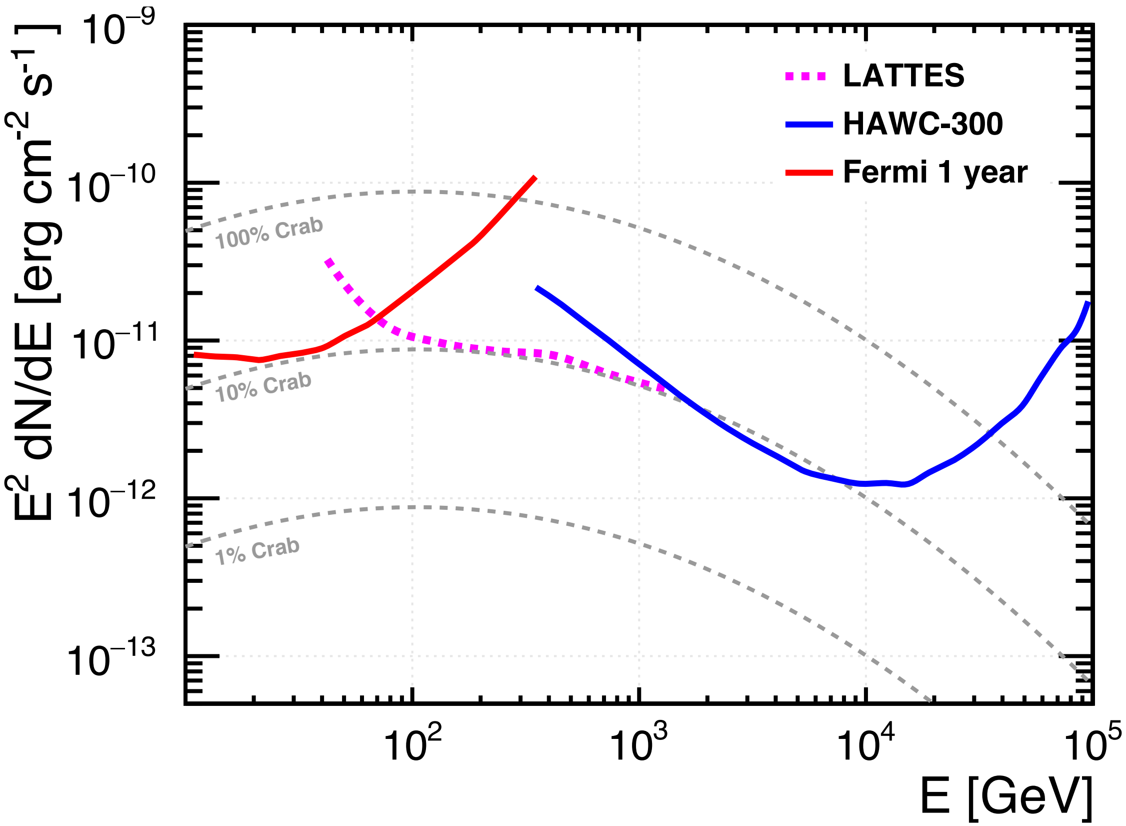
LATTES full array



- LATTES core array (10 000 m2)
  - Sensitivity evaluated using and end-to-end realistic simulation

10 x 10^3 m^2

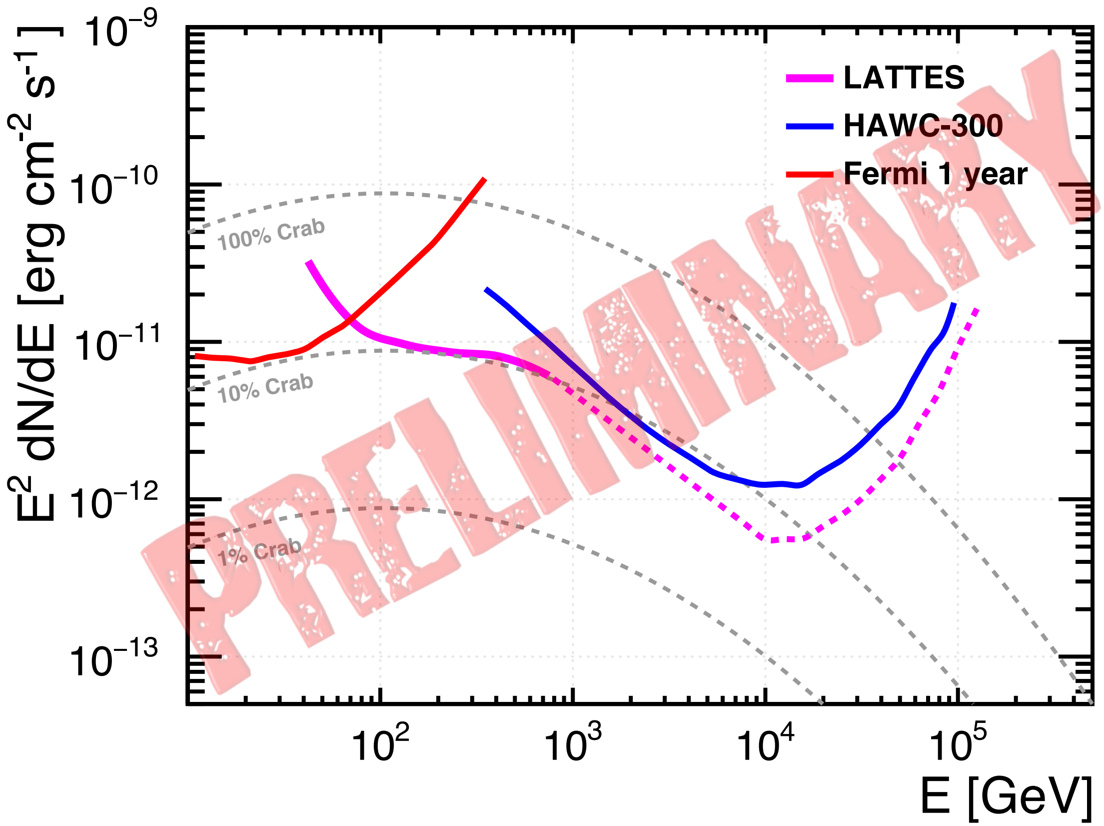
LATTES full array (projection)



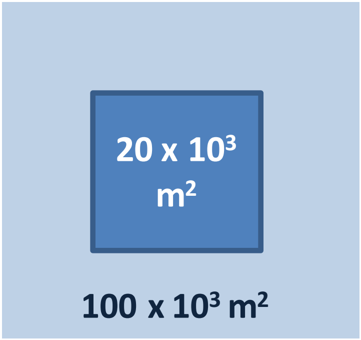
- LATTES core array (20 000 m^2)
  - Projected sensitivity @ low energy:
    - Scale by area;
    - Preliminary g/h discrimination studies (RPC+WCD)

20×10^3 m^2

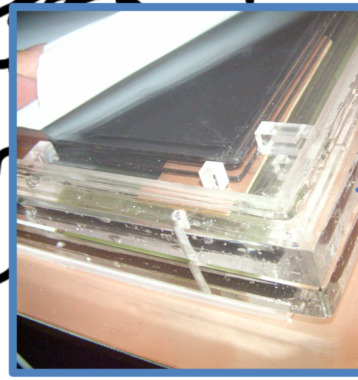
LATTES full array (projection)



- LATTES sparse detectors array (100 000 m^2)
  - Add about 500 stations
  - Preliminary studies indicate that 95% of showers at 1 TeV would be reconstructed
- On-going simulations to assess performance at high-energies



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



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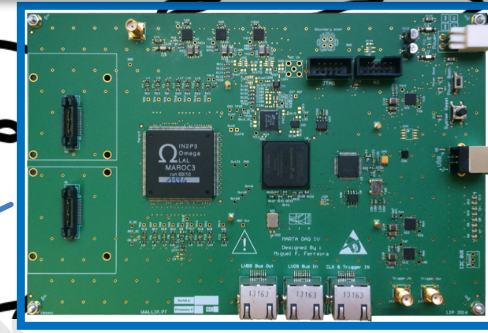


DAQ Engineering prototype

RPC based muon hodoscope for precise studies of the Auger WCD

Top RPC

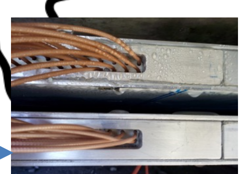
Gianni Navarra WCD

Bottom RPC

Construction and Assembling

RPC hodoscope

RPCs in the field @ Auger



Summary

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

Acknowledgments

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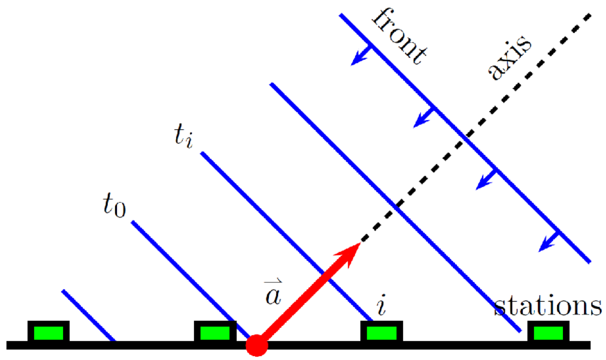
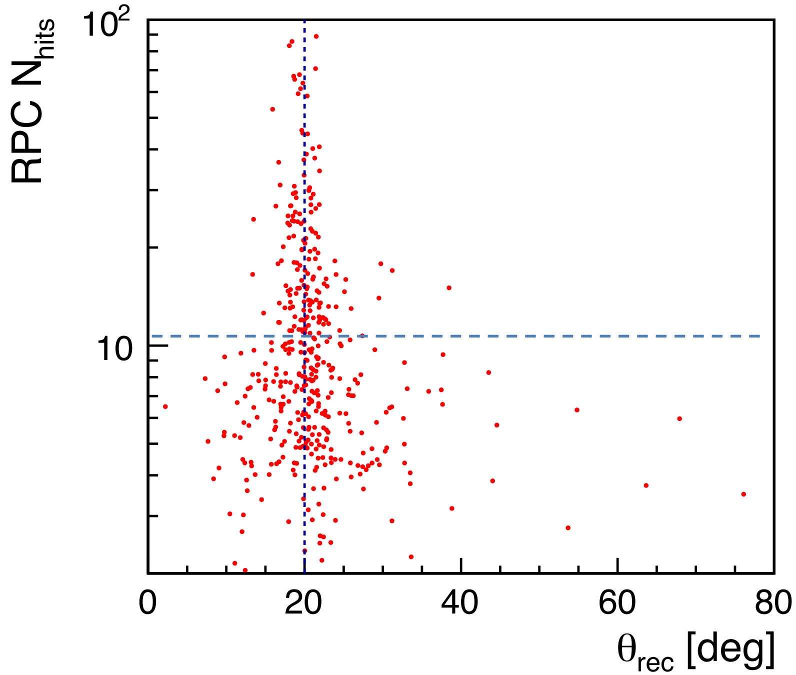
BACKUP SLIDES

Reconstruction of shower geometry

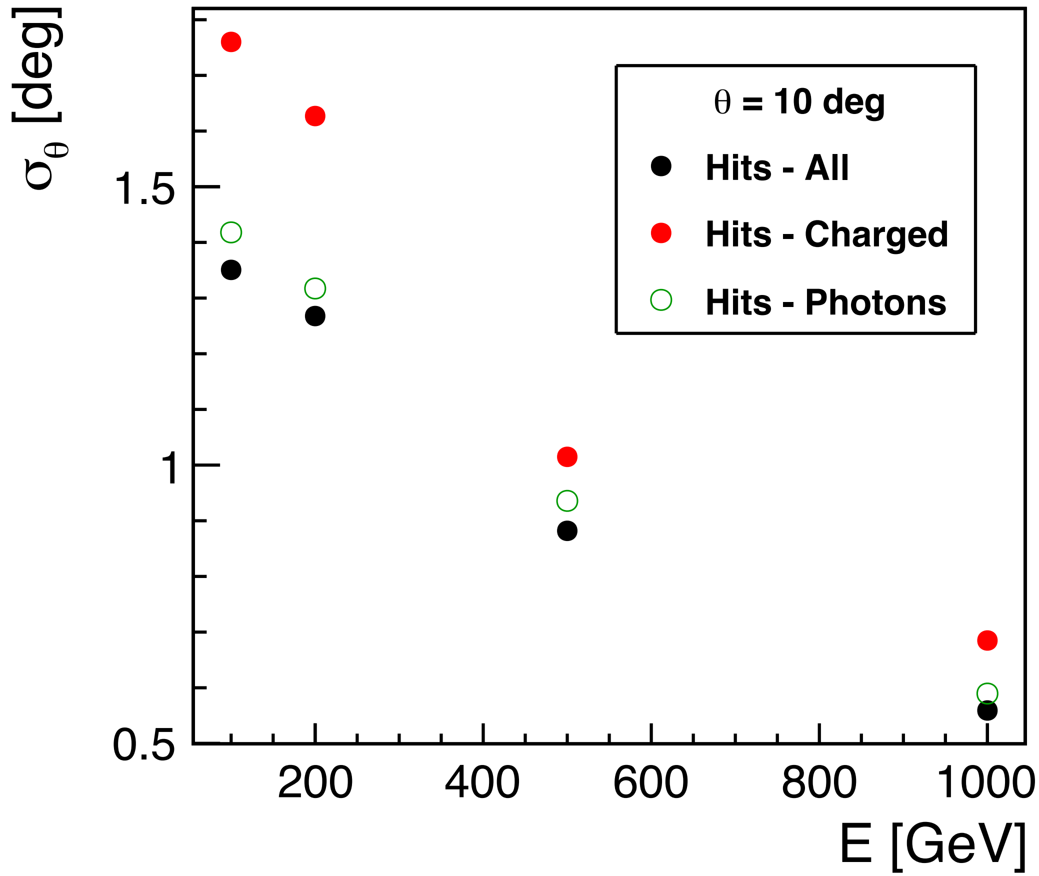
- Use RPC hit time information to reconstruct the shower
  - Take advantage of high spatial and time resolution



- Shower geometry reconstruction:
  - Use shower front plane approximation
  - Analytical procedure
  - Apply trigger conditions
  - Apply cut on the number of registered hits by the RPCs

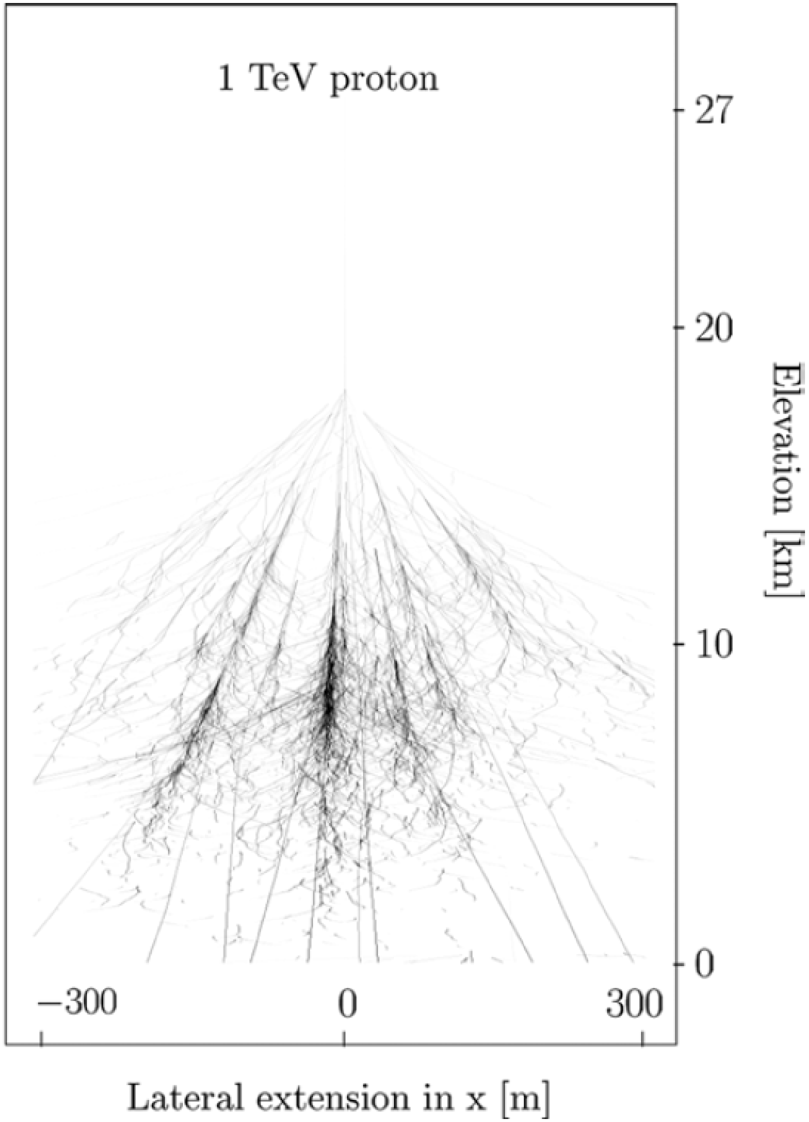


Contributions to the geometric reconstruction



- **Photons** retain a **higher correlation** with the **shower geometry** than charged particles
- Could we measure photons with the RPC instead?

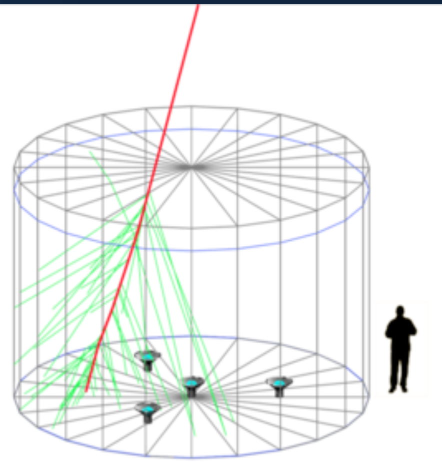
Strategies for primary discrimination



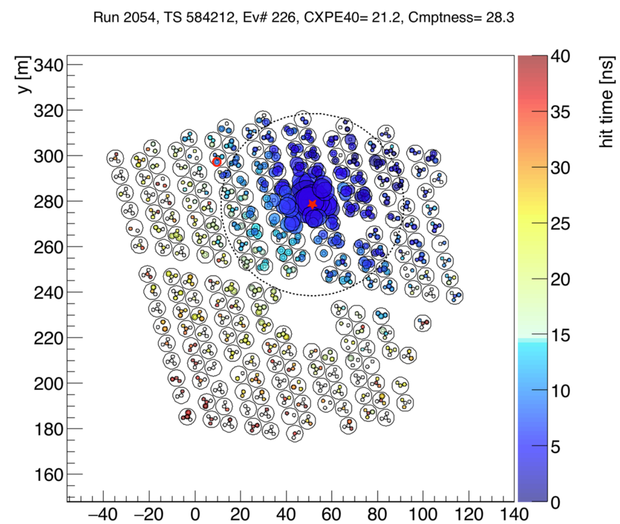
- **Hit pattern at ground**
  - Hits from hadronic showers are more sparse than in gamma induced showers
  - RPC detectors
  - Explored by the ARGO collaboration
- **Search for energetic clusters far from the shower core**
  - Present only in hadronic showers
  - Water Cherenkov Detectors
  - Explored by the HAWC collaboration
- ***Combine both strategies using an hybrid detector: LATTES***
  - *Work on-going…*
  - *See Gonçalo's talk*

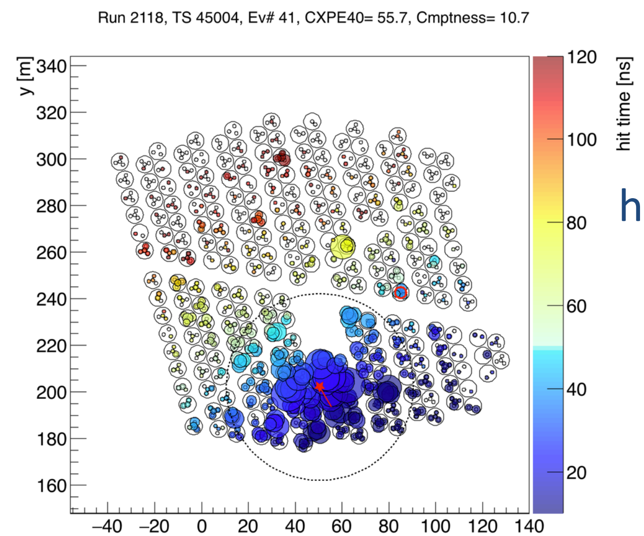
Looking for that special muon…

- 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



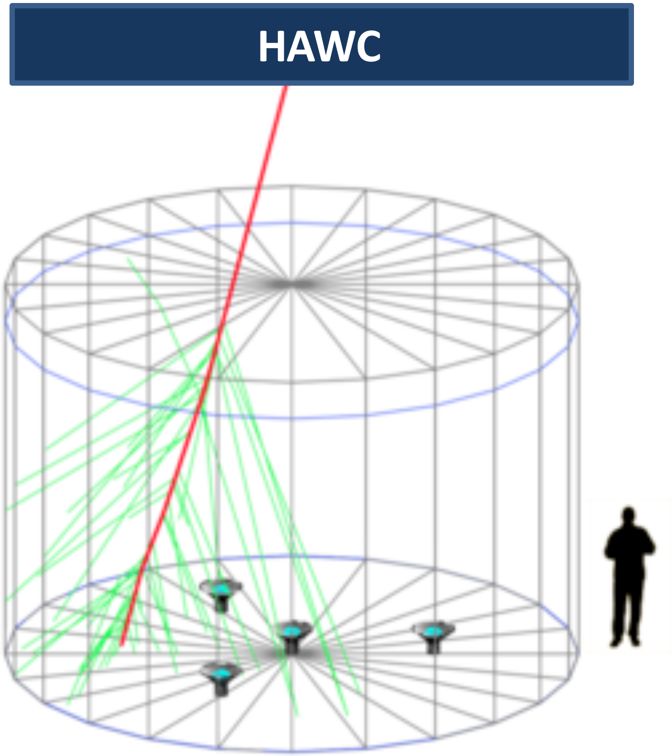
gamma

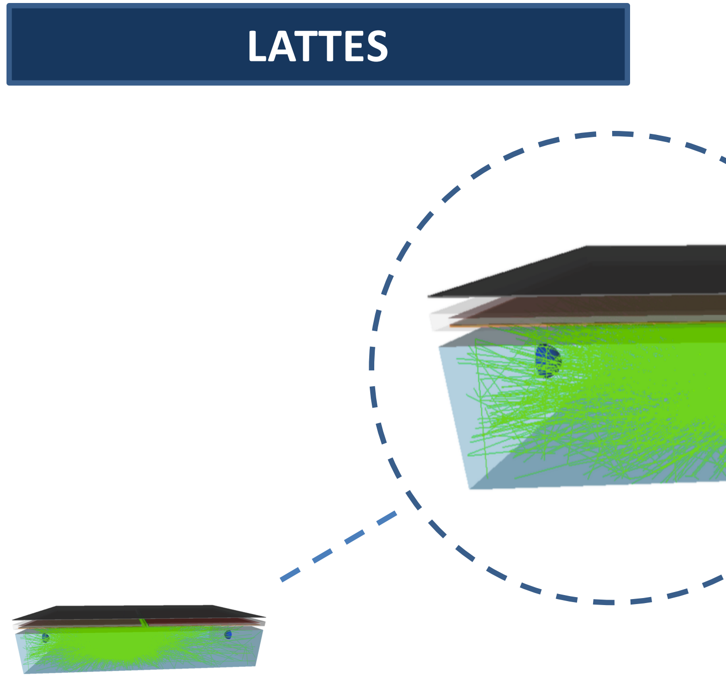




hadron

Looking for that special muon…

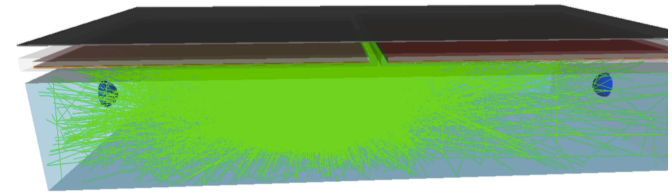


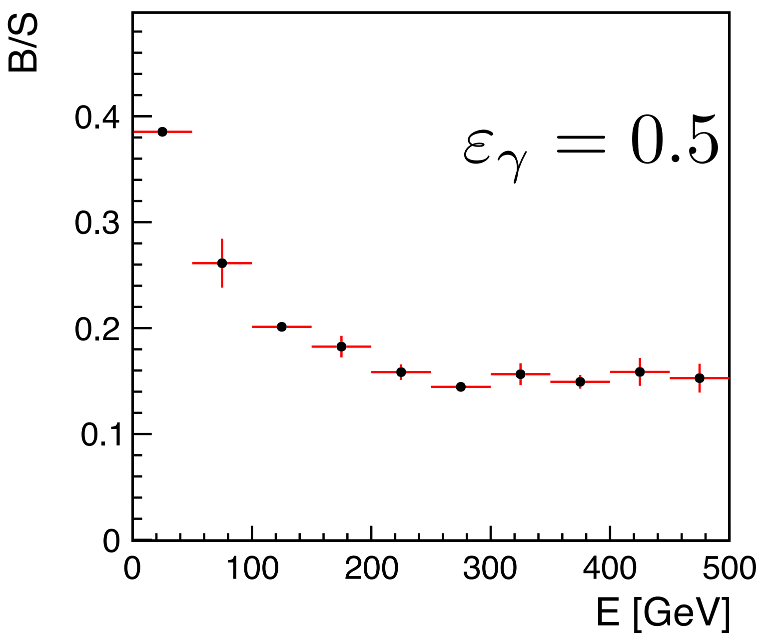


- Detect high energy muons far away from the shower core
  - LATTES: take advantage of the RPC segmentation

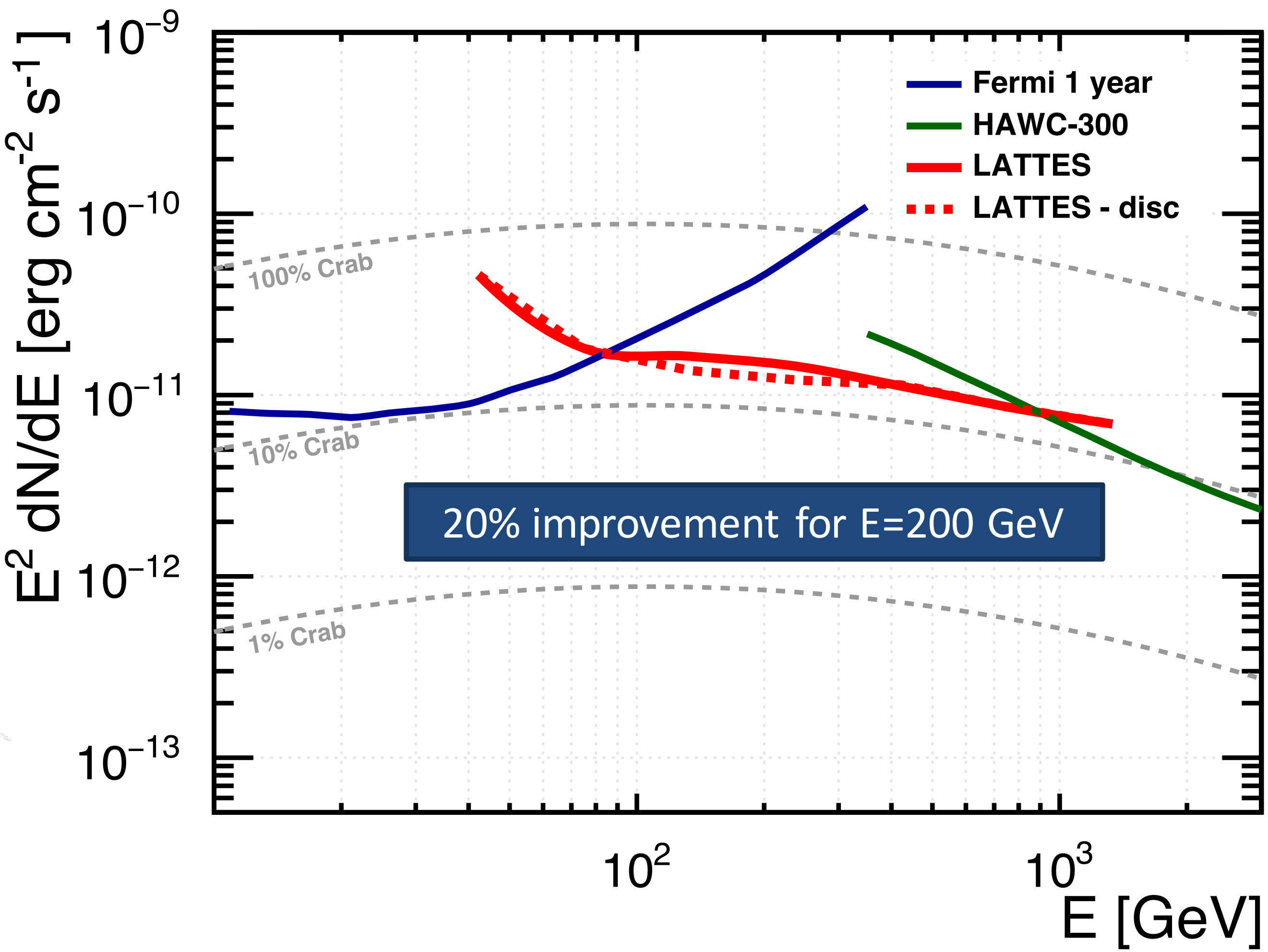
Looking for that special muon…

- LATTES g/h discrimination
  - A first try! (see Goncalo's talk for details)
  - Look for an energetic cluster far away from the core
  - Require one single hit in the RPC
  - B/S ≃ 0.2



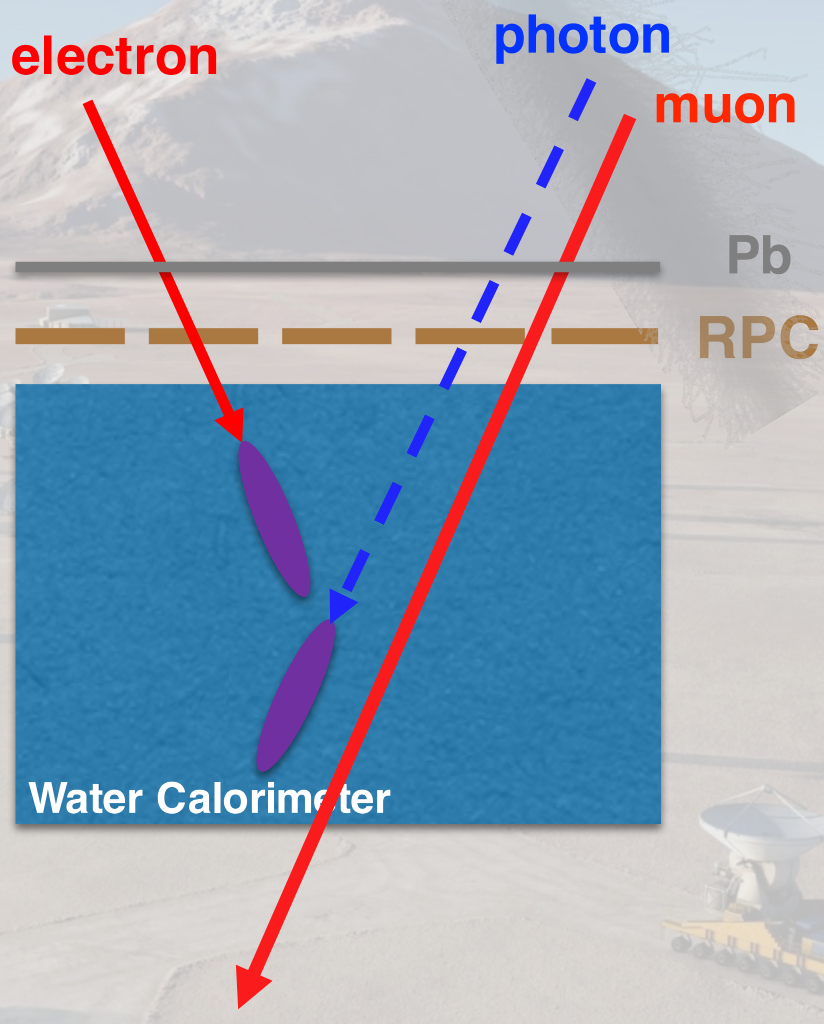


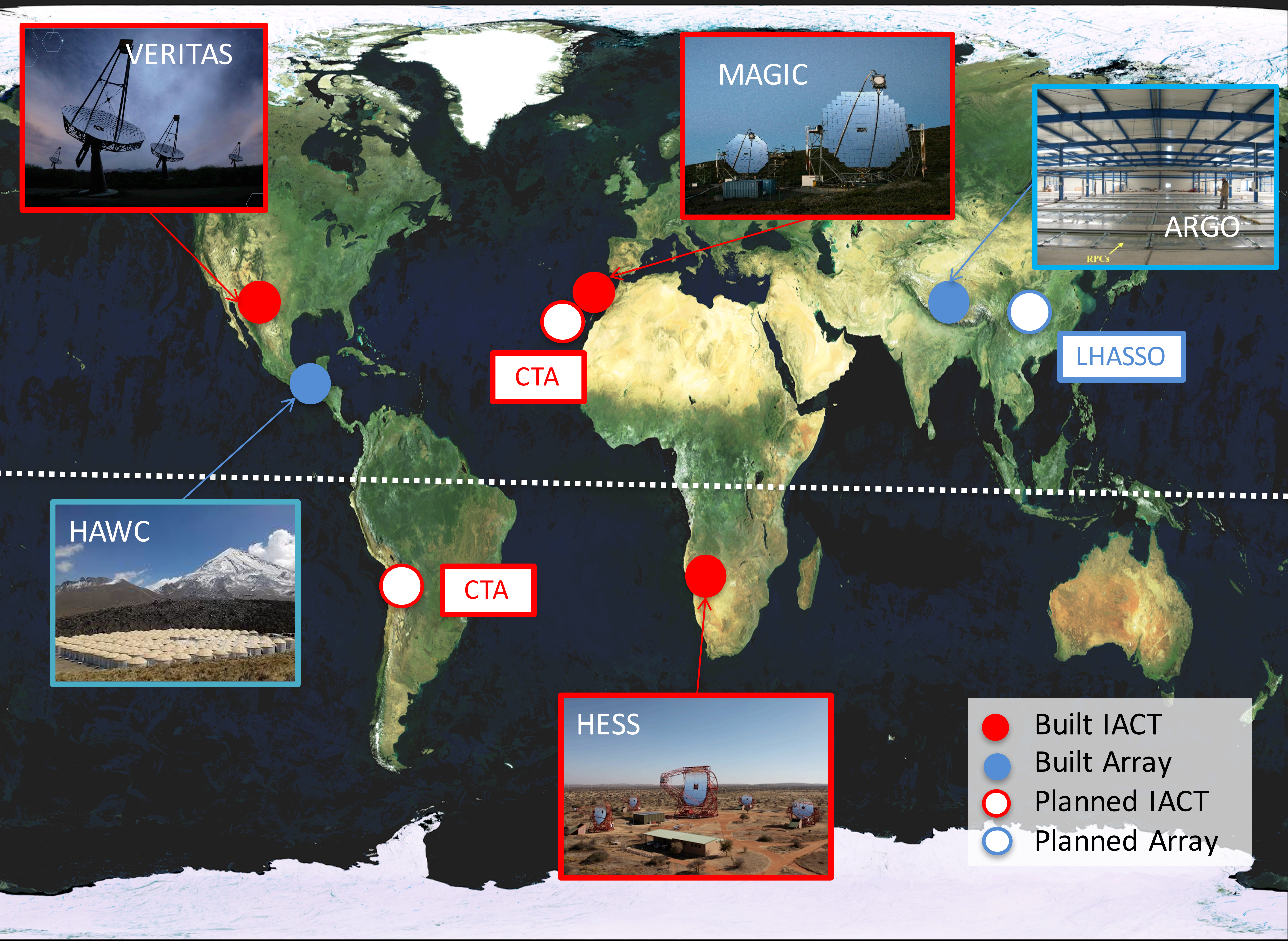
LATTES sensitivity (g/h discrimination)

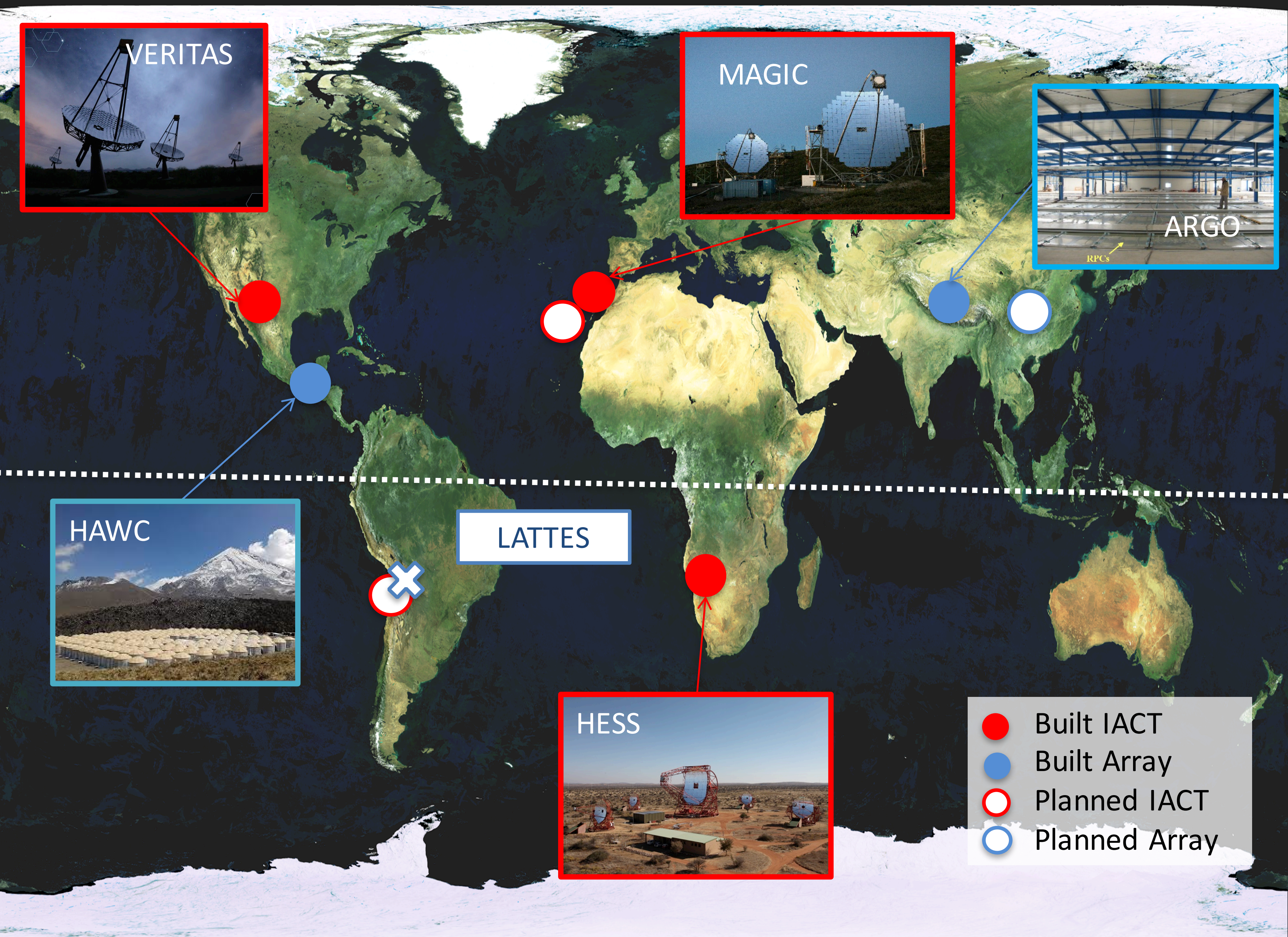


Differential sensitivity to steady sources in one year

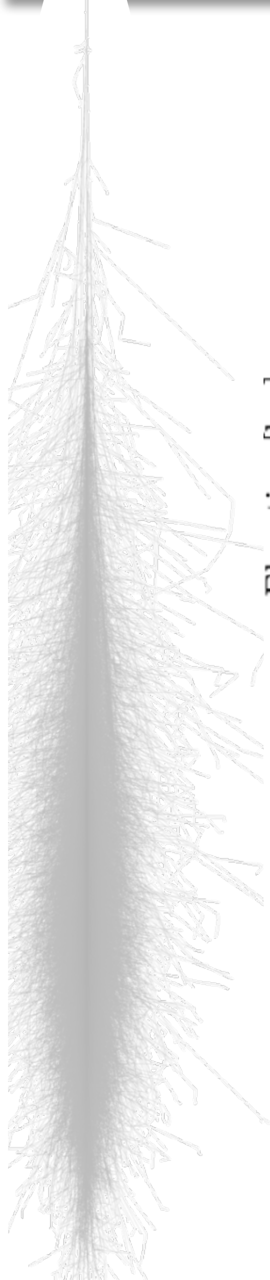
LATTES station baseline concept

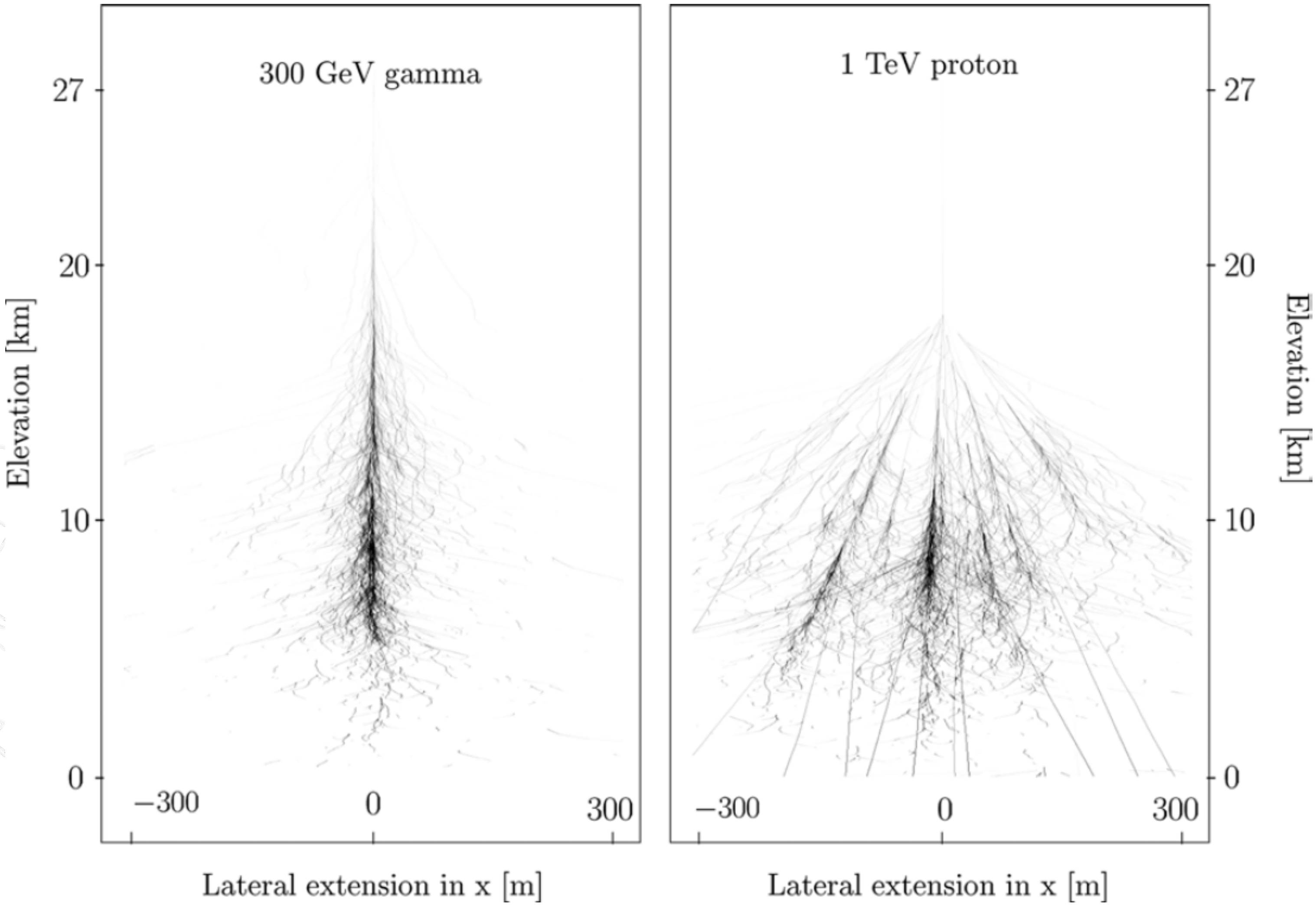



VERITAS
MAGIC
ARGO
RPCs
LHASSO
CTA
CTA
HAWC
HESS
Built IACT
Built Array
Planned IACT
Planned Array


VERITAS
MAGIC
ARGO
RPCs
HAWC
LATTES
HESS
Built IACT
Built Array
Planned IACT
Planned Array

Strategies for primary discrimination



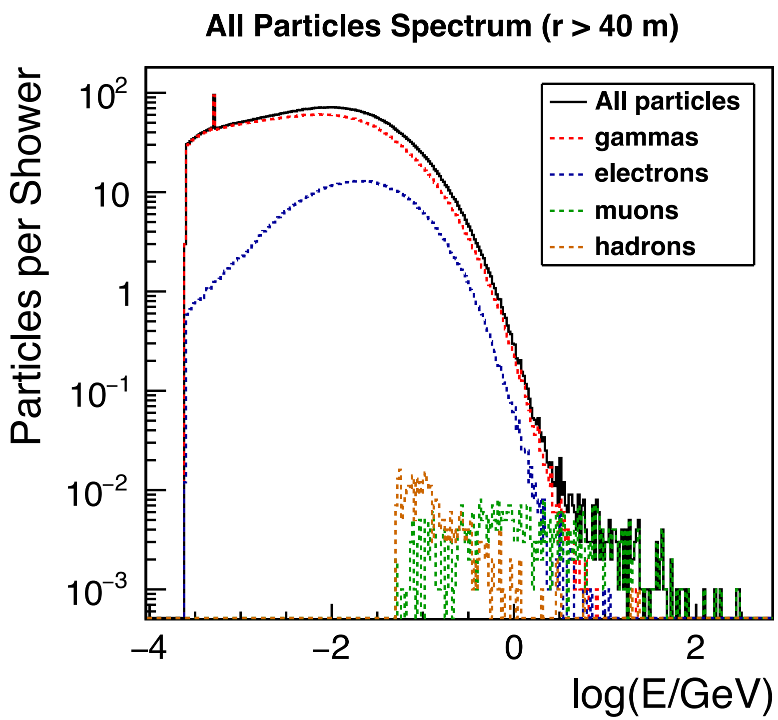


Explore differences in shower development

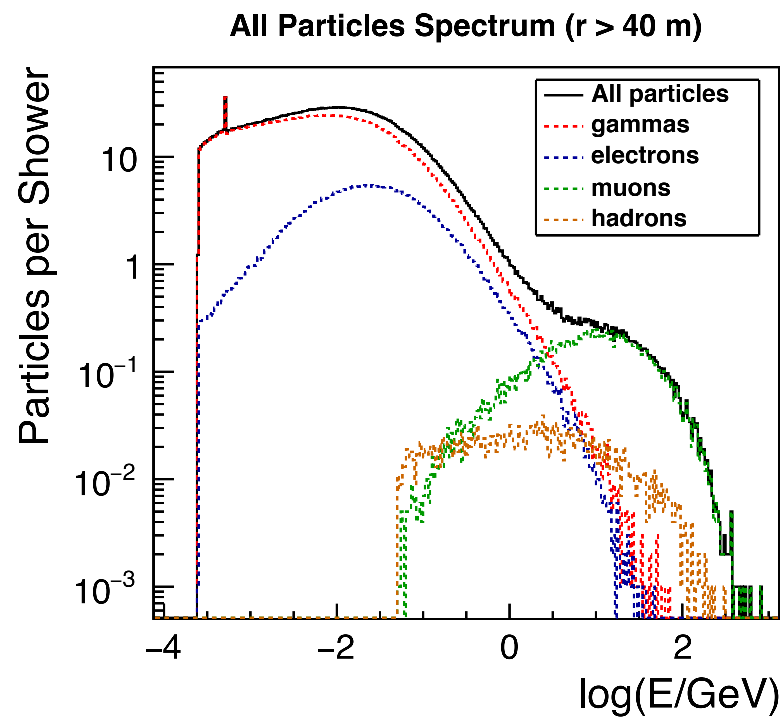
Exploring the WCD

5 TeV

Gamma showers



Proton showers



- What should we look for?
  - Look for energetic clusters far from the shower core
  - Above 40 m

LATTES integrated sensitivity

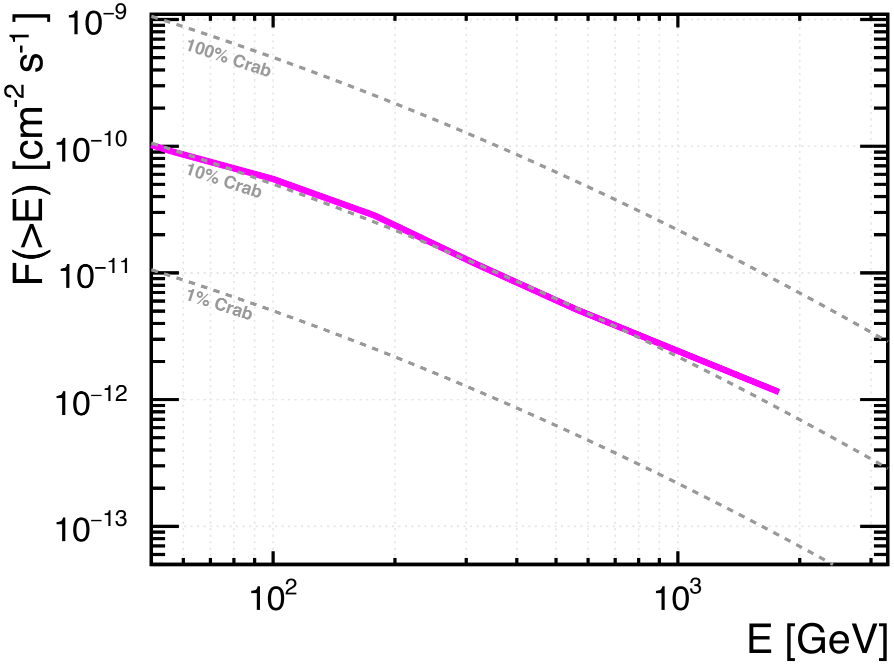
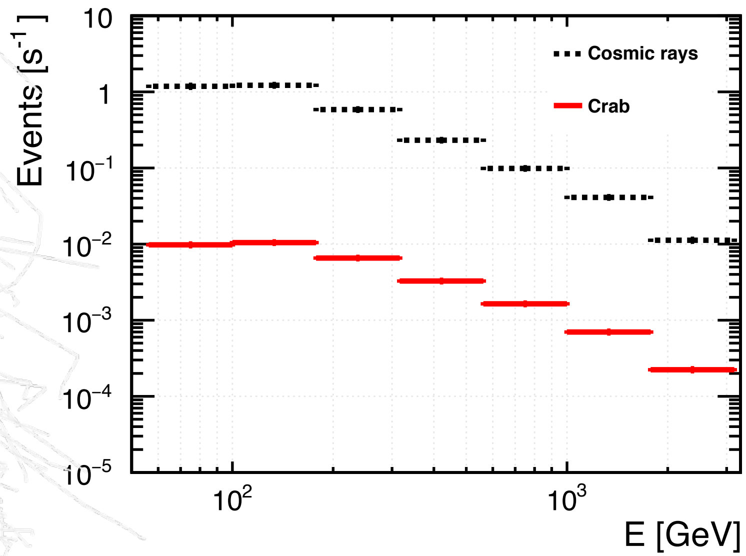
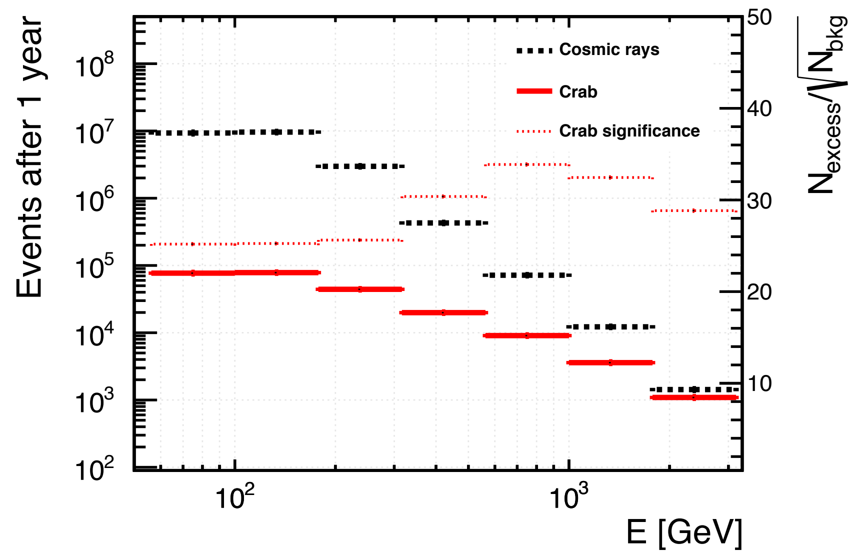


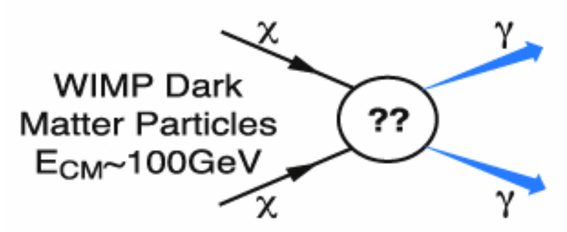
Figure 10: Integral sensitivity, defined as the flux of a source above a given energy for which $N_{\text{excess}}/\sqrt{N_{\text{bkg}}} = 5$ after 1 year; it is assumed that the SED is proportional to the SED of Crab Nebula. For comparison, fractions of the integral Crab Nebula spectrum are plotted with the thin, dashed, gray lines.

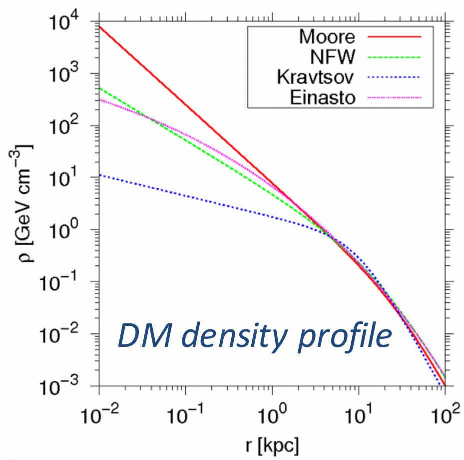
LATTES expect events from Crab

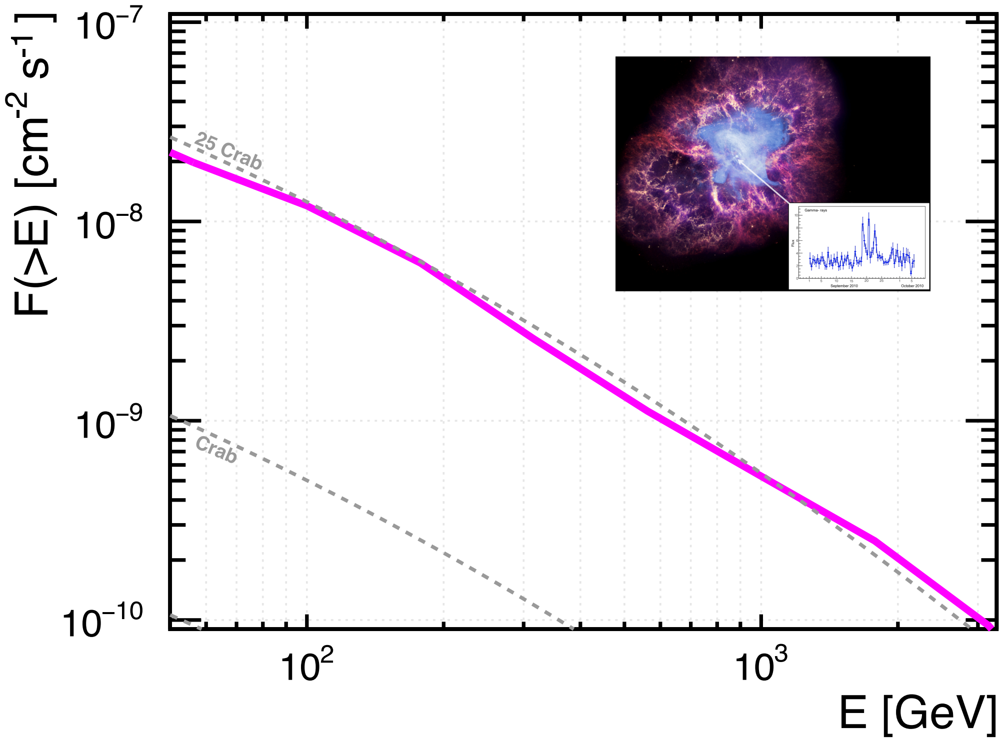




LATTES physics opportunities



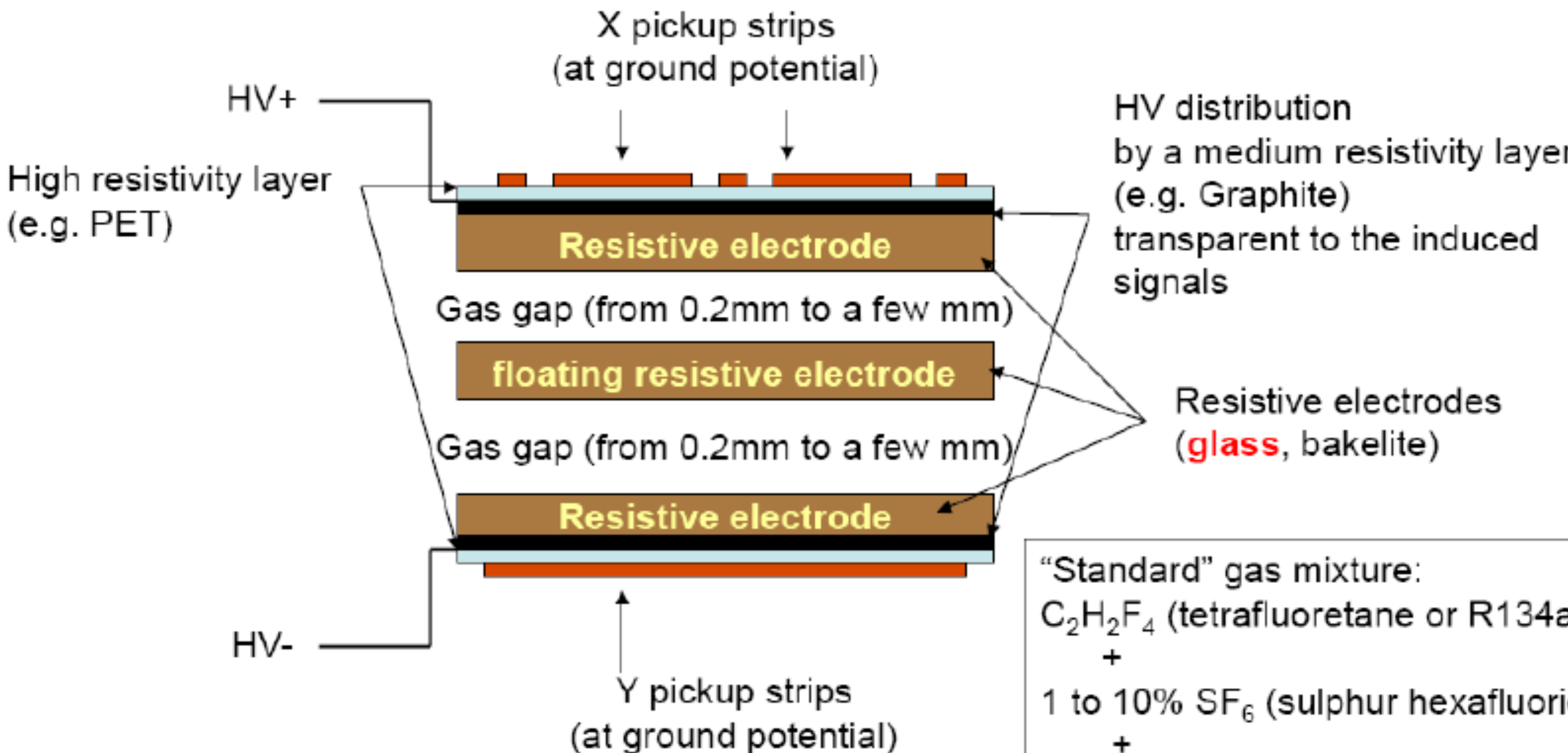




- Many interesting scientific goals:
  - Dark matter searches at the center of the galaxy
  - Study transient phenomena
    - LATTES can detect a 25 Crab source at 3 sigma in 1 minute

RPCs – basic structure

Many variations allowed



"Standard" gas mixture:
$C_2H_2F_4$ (tetrafluoretane or R134a)
+
1 to 10% SF_6 (sulphur hexafluoride)
+
0 to 5% C_4H_{10} (isobutane)

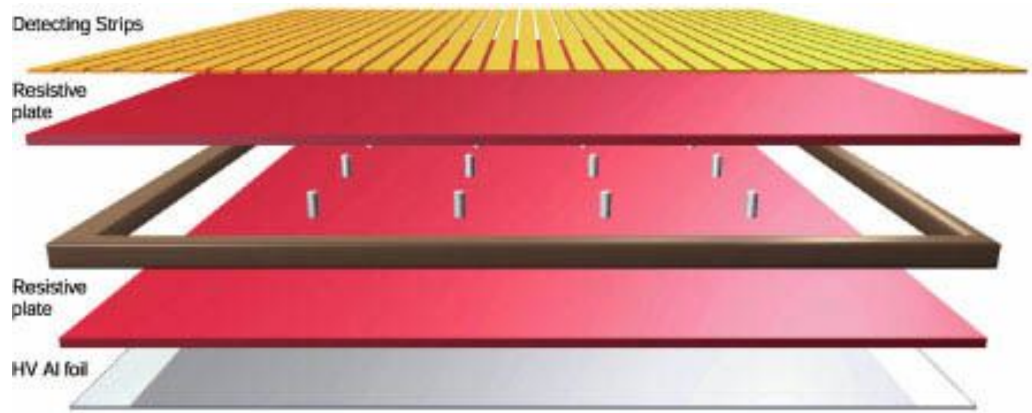
The current is limited by the resistive electrodes: no sparks by construction

Þ very safe detector, although limited to low particle rates (~2kHz/cm^2)

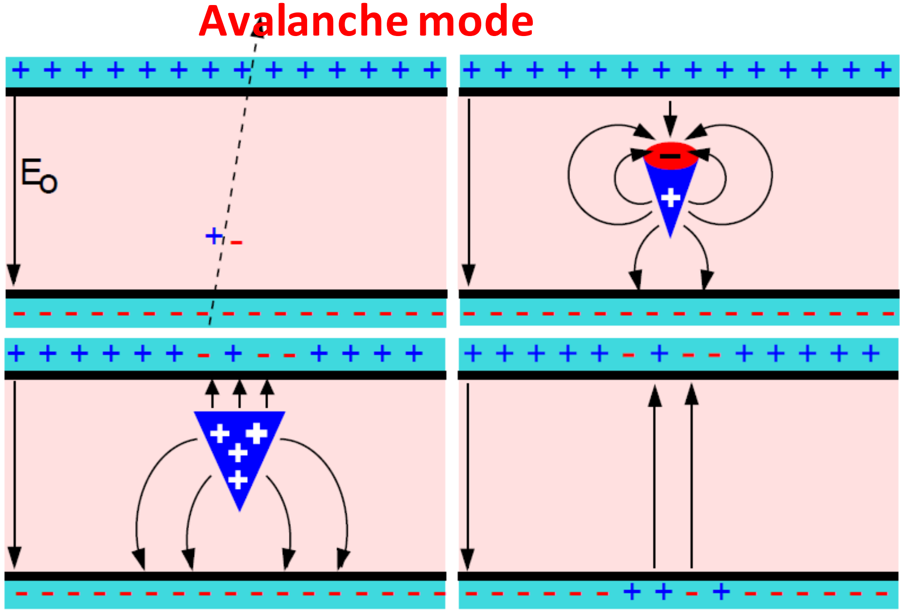
Þ excellent efficiency (99%), time (~50 ps) and position resolution (~100μm)

RPCs Resistive Plate Chamber

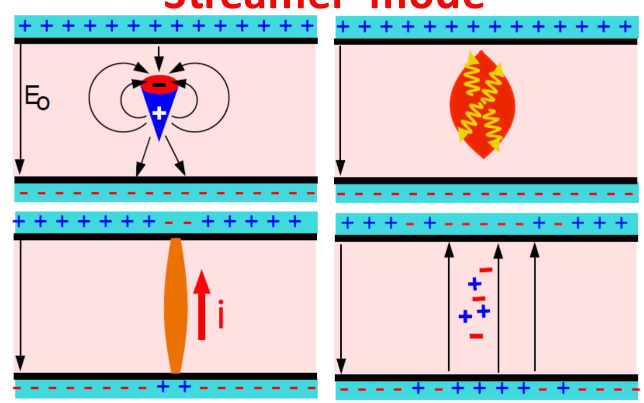
- Gaseous detector
- Planar geometry
- uniform electrical field imposed.
- High resistive plates in between the electrodes limit the avalanche current.
- Signal is picked up by the induction of the avalanche in the readout pads.



Avalanche mode

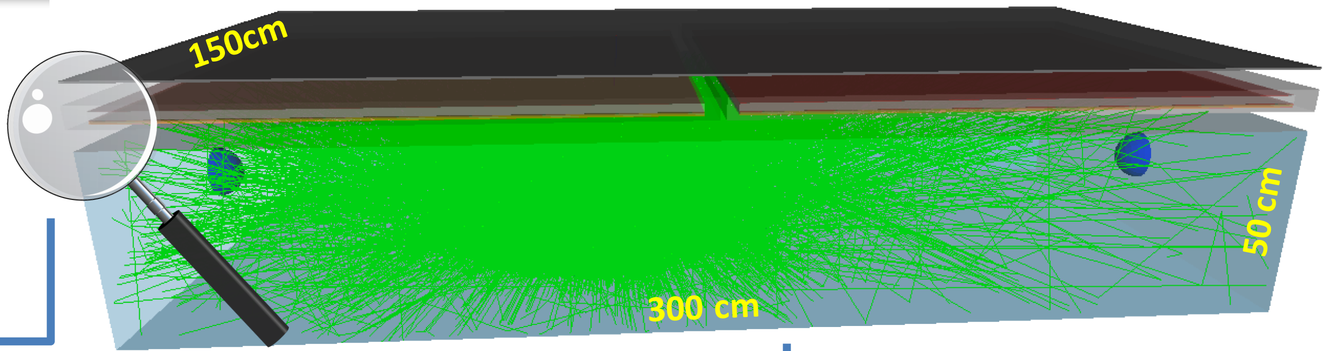


Streamer mode

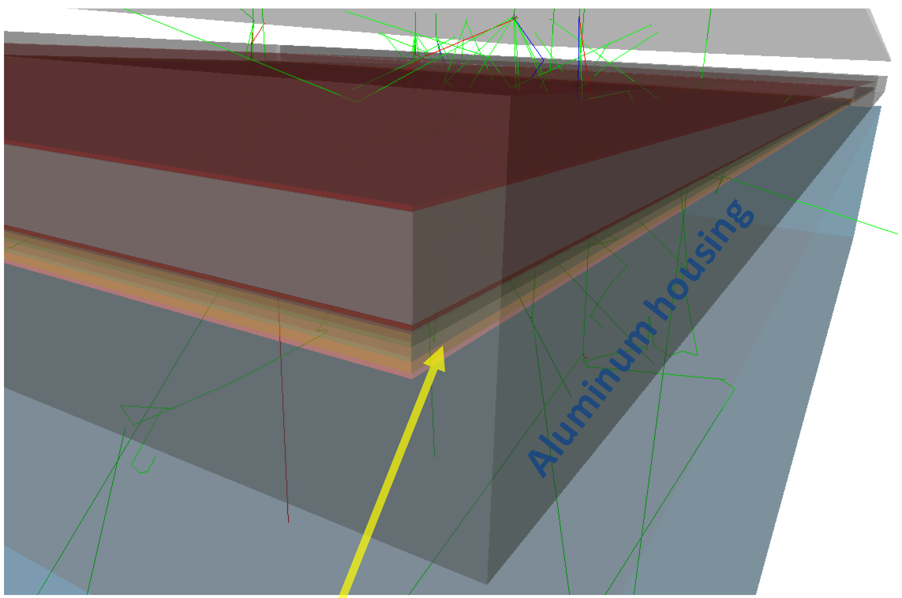


LATTES station in Geant4

- **Realistic description**



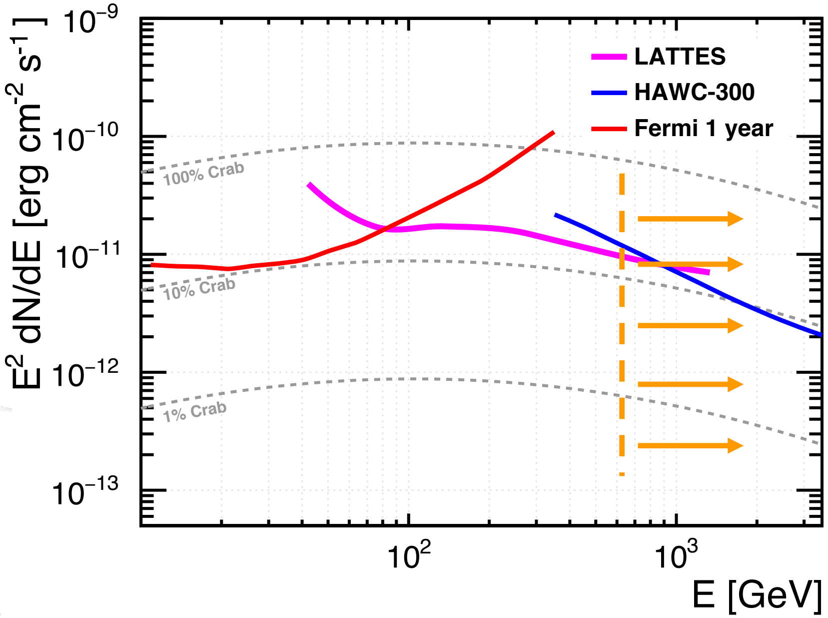
Detailed RPC structure

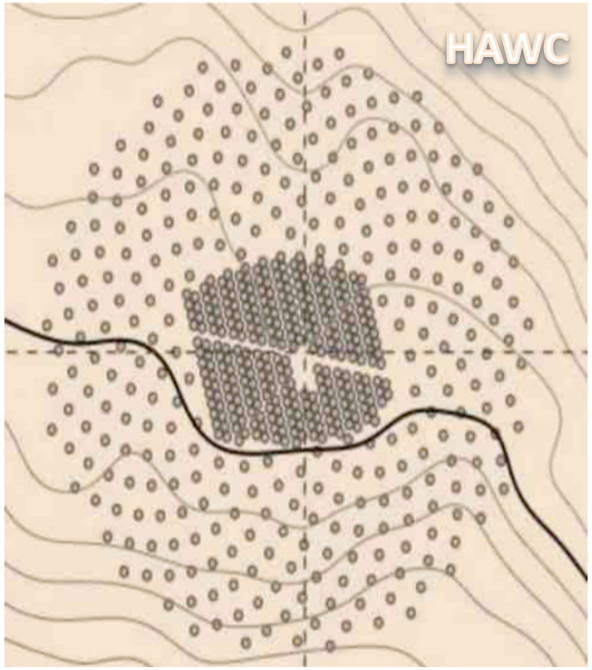


Acrylic box with glass electrodes and 1 mm gas gaps

- **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

LATTES at higher energies





- The sensitivity scales with the array area
- It could be extended to reach higher energies with an external corona of sparse detectors