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

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Current experimental status

The graph illustrates the energy flux density ($E F(\geq E)$) in $[\text{TeV/cm}^2 \text{s}]$ as a function of energy ($E$) in $[\text{GeV}]$. The data is plotted for various detectors and observatories, including Agile, Fermi, Argo, MAGIC, HAWC, HESS, CTA, and LHAASO. The Crab is also indicated on the graph.
Current Situation

- No wide FoV experiment to:
  - Survey the Galactic Center (GC)
  - Explore the energy region of 100 GeV
• Build an EAS array experiment:
  – Located in the South Hemisphere
  – Low energy threshold:
    • High altitude
    • Next generation detector concept
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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

LATTES STATION

– Thin lead plate (Pb)
  • 5.6 mm (one radiation length)

– Resistive Plate Chambers (RPC)
  • 2 RPCs per station
  • Each RPC with 4x4 readout pads

– Water Cherenkov Detector (WCD)
  • 2 PMTs (diameter: 15 cm)
  • Dimensions: 1.5 m x 3 m x 0.5 m
• 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: 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 Argo/HAWC discrimination techniques
• LATTES performance:
  • Trigger efficiency
  • Energy Reconstruction
  • Geometric Reconstruction
  • Gamma-hadron discrimination

• LATTES sensitivity
• Complete end-to-end simulation chain to evaluate LATTES performance
  – Showers simulated using CORSIKA
  – Detector layout and simulation performed by Geant4
  – LATTESsim: Integrated toolkit to study and optimize LATTES performance
• 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 m² at 100 GeV! (after quality cuts)**
Energy reconstruction

\[ E_0 \rightarrow \text{Simulated energy} \]
\[ E \rightarrow \text{Reconstructed energy} \]

- Use as energy estimator the total signal recorded by WCDs
- Energy resolution below 100% even at 100 GeV
  - Dominated by the shower fluctuations
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 than 10 hits in the RPCs
  - Angular resolution below 2 deg even for 50 GeV showers
• 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**
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
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
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 satellite and ground based measurements
- Powerful tool to trigger observations of variable source and to detect transients
Acknowledgments
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?
LATTES station baseline concept

- electron
- photon
- muon
- Pb
- RPC
- Water Calorimeter
Explore differences in shower development

1.1 The Physics of Air Showers

Fig. 1.3: Comparison of the shower development for a leptonic and a hadronic shower (taken from \[3\]). While the electromagnetic shower (left side) shows only a small lateral spread compared to its longitudinal extension, the hadronic shower (right side) is quite a lot more extended and also more irregular in shape.

1.1.3 Cherenkov Emission

Cherenkov photons are emitted whenever a charged particle moves through a medium with a velocity \(v\) greater than the local speed of light \(c_0 = c/n\) (where \(n\) denotes the refractive index of the medium). The charged particle polarizes the atoms along its path which emit photons when returning to their equilibrium state. For velocities smaller than the speed of light the electromagnetic radiation interferes destructively, while for \(v > c_0\) the interference is additive (See Figure 1.4). This effect is equivalent to the shock front of a supersonic boom. All photons are emitted in a cone with an opening angle of:

\[
\Theta_C = \arccos \left( \frac{c_0}{v} \right) = \arccos \left( \frac{1}{n} \right)
\]

with:

\[
\Theta_C = \frac{v}{c_0}
\]

Since the particles in air showers travel at highly relativistic velocities they emit Cherenkov light which can be measured by ground-based telescopes. The requirement \(v > c_0\) leads to a threshold energy, above which particles with mass \(m_0\) emit Cherenkov photons:

\[
E_{\text{th}} = \frac{m_0 c^2}{p_1 n^2}
\]

Since \(E_{\text{th}}/m_0\), most of the Cherenkov radiation is emitted by lightweight particles such as electrons and positrons. Concerning the opening angle of the Cherenkov cone emitted by a shower, one has to take into account that the refractive index of air varies with its density \(\rho\), which is a function of the height above sea level \(z\). The deviation \(\Delta\) of the refractive index from 1 (\(\Delta = n - 1\)) is proportional to the density:

\[
\Delta / \rho(z) \approx \Delta \exp \left( \frac{z}{\Delta z} \right)
\]

9
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...
Exploring the WCD

**What should we look for?**
- Look for energetic clusters far from the shower core
- Above 40 m
• Signal of the hottest WCD station
  – above 40 m from the shower core
  – with only one hit in the RPC
Figure 10: Integral sensitivity, defined as the flux of a source above a given energy for which \( \frac{N_{\text{excess}}}{\sqrt{N_{\text{bkg}}}} = 5 \) 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
RPCs – basic structure

Many variations allowed

HV distribution by a medium resistivity layer (e.g. Graphite) transparent to the induced signals

Resistive electrodes (glass, bakelite)

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

- very safe detector, although limited to low particle rates (~2kHz/cm²)
- 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.