Baseline Design for a Next Generation Wide-Field-of-View Very-High-Energy Gamma-Ray Observatory

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Future of VHE Gamma Ray detection on the Southern Hemisphere

Wide Field of View, Continuous Operations

Satellite Detector

Extensive Air Shower Detector

Imaging Atmospheric Cherenkov Telescope

TeV Sensitivity

slide concept: B. Dingus
Example of parameter distributions for vertical simulated air showers at 5000m

Energy that reaches ground usually contained in $\mu^\pm / e^\pm / \gamma$

Typically detectors measure:

Electromagnetic energy $E_{em} = E(e^\pm, \gamma)$

Number of muons $N_\mu$

Ideal Uniform Air Shower Particle Detector Arrays

Detection Unit

- Perfect muon counter
- Perfect Calorimeter, above fixed threshold
- Perfect Timing

Default array:

- Unit threshold 20 MeV, Trigger multiplicity 20
- Elevation 5km, 75% filled
- Array size 200m x 200m, unit size 4x4m

*absolutely not to scale*
Varying ideal uniform array properties

Unit Size
Fill Factor
Elevation

Unit Threshold
Trigger multiplicity
Array size
Simulation and reconstruction

CORSIKA* Simulated air showers:
- Proton and Gamma
- Zenith angle 20°
- Energy 50 GeV-100 TeV
- Uniformly distributed within the array

Default array:
Unit threshold 20 MeV,
Trigger multiplicity 20,
Elevation 5km, 75% filled,
Array size 200mx200m, unit size 4x4m

\[ \gamma \text{-ray efficiency} \]
\[ \text{angular resolution} \]
\[ \text{proton efficiency} \]

\[ \text{trigger multiplicity} \]
\[ \text{Likelihood fit} \]
\[ \text{trigger multiplicity} \]
\[ \text{& muon cut} \]

Better = Higher, Bigger & Denser
Better = Higher, Bigger & Denser

Building larger arrays is better for proton rejection.

Recommendation
1) Performance might be better for a lower but larger array than a smaller but higher array
2) Arrays should be larger than 100mx100m to perform sufficiently as γ ray observatory
Smaller unit size leads to better angular resolution

Recommendation
3) Improvement from 4mx4m to 2mx2m is marginal. … no need for detector units smaller than 4mx4m
Lower unit threshold and trigger multiplicity improves $\gamma$ ray efficiency

**Observation**

4) Lowering trigger multiplicity and threshold increases $\gamma$ ray efficiency, but decreases angular resolution in same energy range.

**Recommendation**

5) Improvements below unit threshold of 10 MeV is marginal.
Summary

Derived observatory performances for a variety of design choices

Recommendations for observatory design without hardware simulation

To Do:
More advanced hadronic shower rejections
Realistic Noise model (single muons, small showers)
THANK YOU
Cost remarks

detectors shouldn’t be high-tech

Water is cheap:
detection medium + conversion in one

Site (elevation, existing infrastructure local support):
difficult to optimize

Low multiplicity trigger might be cost efficient to improve lower energy gamma-ray efficiency

High energy augmentation is feasible
**Science Case**

**Monitoring large fraction of the sky:**

Transient events
- receive and send alerts (GRB, FRB, ν, GW, ??)
- Monitor ALL variable sources in FoV
- Unbiased sky maps

**High energy reach**
Atmospheric density, Slant depth
Fraction of showers above a fixed threshold

\begin{align*}
\text{Fraction of } E_{\text{em}}>10 \text{ GeV} \\
\end{align*}

\begin{align*}
\text{Slant Depth } [g/cm^2] \\
\end{align*}

\begin{align*}
\gamma & - E_{\gamma}=5 \text{ TeV} \quad E_{\gamma}=1 \text{ TeV} \quad E_{\gamma}=0.5 \text{ TeV} \\
\gamma & - E_{\gamma}=0.1 \text{ TeV} \quad E_{\gamma}=0.05 \text{ TeV} \\
\end{align*}

\begin{align*}
\text{proton} & - E_{p}=5 \text{ TeV} \quad E_{p}=1 \text{ TeV} \quad E_{p}=0.5 \text{ TeV} \\
\text{proton} & - E_{p}=0.1 \text{ TeV} \quad E_{p}=0.05 \text{ TeV} \\
\end{align*}
Muons:
*at least two muons within a radius from the core

\[ \frac{N}{N_{p,50}} \geq 2 \]

within 50 from core

\[ \frac{N}{N_{p,200}} \geq 2 \]

within 200 from core
Proton showers of same energy generate less $E_{em}$ than gamma showers.

Variations are larger in proton showers.

Roughly Gaussian in log-space.
Parameterization of $E_{em}$ as a function of atmospheric depth of observatory

Dependencies can parameterized with simple 2nd order polynomials.

Protons showers are less sensitive to atmospheric depth.
Equivalent gamma ray energy $E'_\gamma$ and proton rejection

Relation between $E_{\text{det}}$ and $E_\gamma$, to calculate $E'_\gamma$ for proton showers

Cut on the number of muons

Fiducial cut

At least 2 muons or 90% $\gamma$ efficiency
Shower size as function of slant depth and energy

\[ r_{50} \text{ [m]} \]

Slant Depth [g/cm$^2$]
Muons:
*at least two muons within a radius from the core*
Better = Higher, Bigger, Denser
Gamma ray efficiency

Fill factor

Array Size

Elevation

Unit Size

Unit Threshold

Trigger Multiplicity
Proton efficiency