Hybrid concept of detection for a wide-field gamma-ray observatory using Cherenkov telescopes

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Abstract

We present a study on the hybrid detection concept for the future Southern Wide-field Gamma-ray Observatory (SWGO), integrating multiple Cherenkov telescopes represented in the analysis by Single-Mirror Small-Size imaging atmospheric Cherenkov Telescopes (SST-1M) located inside the surface array of water Cherenkov detectors (WCDs). We discuss the mutual benefits of this hybrid approach and present simulation-based results on key performances. Our findings show a significant improvement of the gamma-hadron discrimination capabilities of the SST-1M telescope when additional gamma/hadron (γ/h) discriminator variables from the ground array of surface detectors are implemented into the reconstruction chain.

1. Simulated experimental layout

Altitude 4700 m a.s.l. at Pampa la Bola site in the Atacama Astronomical Park, Chile

Ground array of WCDs
- WCDs: 12.6 m^2 with 3 PMTs
- 9997 WCDs on area of 1 km^2 with fill factor 12.5 %

Imaging Air Cherenkov Telescopes
- Two identical **SST-1M** telescopes [1] 110 m apart in stereo mode
- Pointing direction 20° zenith angle

2. Simulation setup

Shower simulations

`CORSIKA v7.7402` [2]
→ `UrQMD` [3]
→ `QGSJet II-04` [4]

γ showers: 200 GeV – 631 TeV
p showers: 400 GeV – 1100 TeV

$$\frac{dN}{dE} \propto E^{-2}$$

Response of the SST-1M

Attenuation of light and response of the telescopes
`sim_telarray v2021-12-25` [5]

Response of the ground array

simplified code from [6]
γ/h discriminator variables
→ $\boldsymbol{LCm}$ [6,7] (above 10 TeV)
→ $\boldsymbol{p^{\alpha}_{tail}}$ [8]
→ $\boldsymbol{N_{\mu}}$ (reference ideal case)

Shower reconstruction

`sst1mpipe` [9]

γ/h Random Forests classifier
↓
Reconstruction of the showers

3. Gamma hadron separation performance

- Significant improvement of γ/h separation performance with additional γ/h discriminators → represented by area under curve (AUC) of the Receiver Operating Characteristics curve

SST-1M only: AUC = 0.963
↓
SST-1M + LCm + p^{α}_{tail}: AUC = 0.998

- Gini importance of reconstruction parameters for different γ/h classifiers
  → $\boldsymbol{N_{\mu}}$: decision heavily based on it when used (over the whole energy range)
  → $\boldsymbol{LCm}$ and $\boldsymbol{p^{\alpha}_{tail}}$: dominate the decision logic when used (only evaluated above 10 TeV)

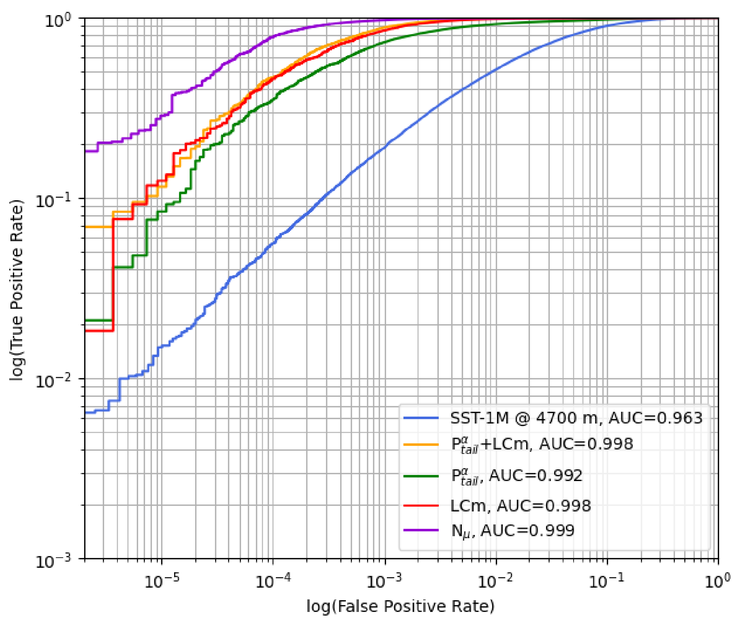

Figure 1: Receiver Operating Characteristics for SST-1M telescopes alone (blue) and with γ/h discrimination parameters obtained from the ground array added into the `sst1mpipe`.

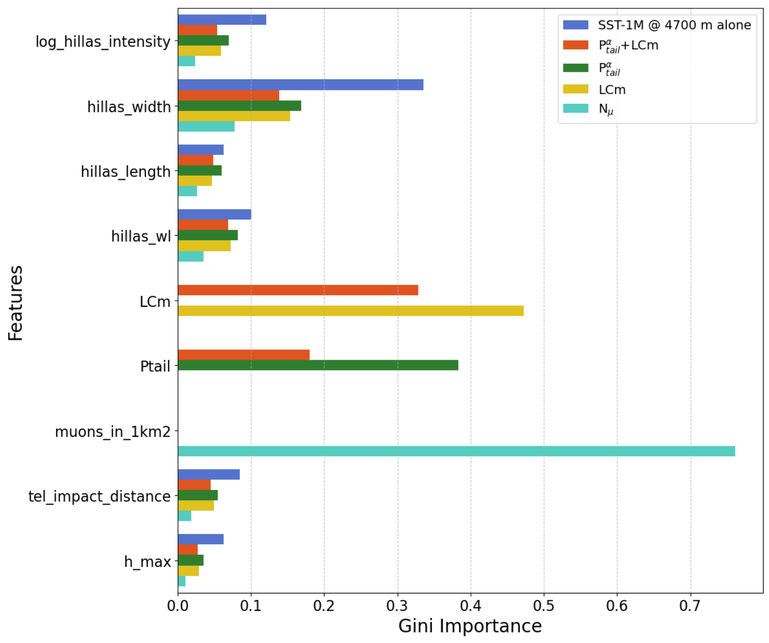

Figure 2: The Gini importance of selected features for γ/h Random Forests classifier for the SST-1M telescopes alone (blue) and with the additional information from the ground array.

4. Sensitivity curve

Including γ/h discriminator variables from the ground array leads to **flux sensitivity improvement by ~ 30 % above 10 TeV.**

LCm surpasses in efficiency N_{μ} [10]
→ visible in the energy bins around 100 TeV, where calculation of LCm was optimized

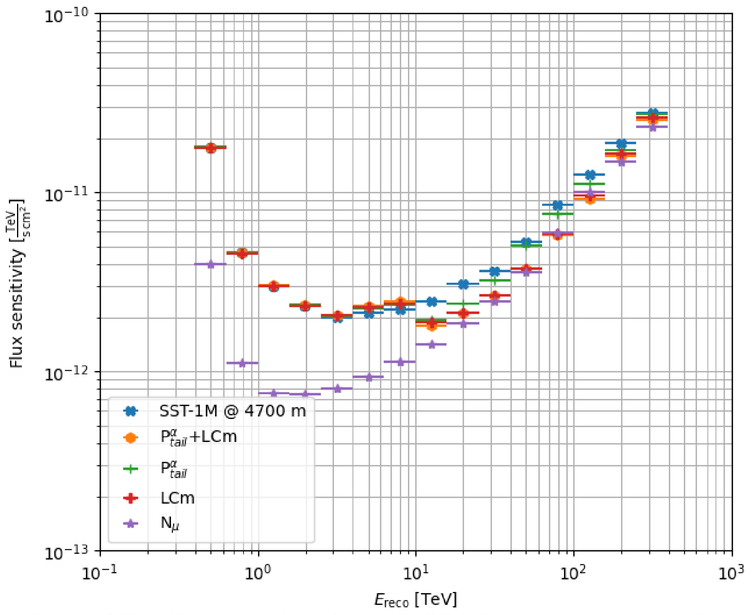

Figure 3 The flux sensitivity for the SST-1M telescopes alone (blue) and with γ/h discrimination parameters obtained from the ground array added into the sst1mpipe.

5. Angular and energy resolution

- Selection effect indirectly influences also angular and energy resolution

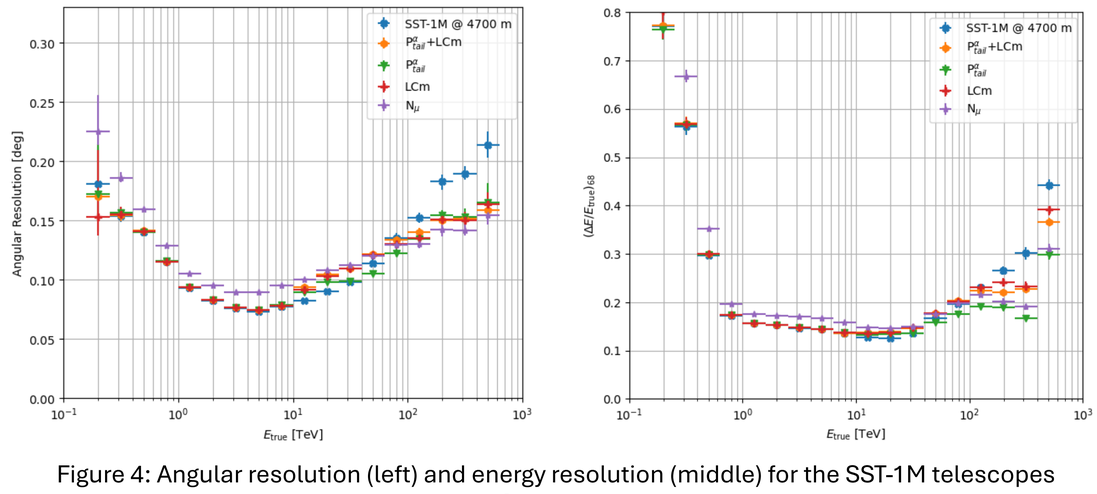

Figure 4: Angular resolution (left) and energy resolution (middle) for the SST-1M telescopes alone (blue) and with the additional γ/h separation parameters from the ground array .

References

[1] Alispach et al., JCAP02 (2025) 047. [2] Heck et al., Report FZKA 6019 (1998) [3] Bleicher et al., J. Phys. G 25 (1999) 1859. [4] Ostapchenko, PRD 83, 014018 (2011). [5] Bernlöhr, Astroparticle Physics 30 (2008) 149. [6] Conceição et al., JCAP10 (2022) 086202. [7] Conceição et al., EPJC 83 (2023) 932. [8] Conceição et al., PRD 110 (2024) 023033. [9] Jurysek et al., 10.5281/zenodo.14808846. [10] Bakalova et al., PRDD 111 (2025) 083036.

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