A Level 2 Trigger for H.E.S.S. Phase 2

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Martin Tluczykont\textsuperscript{1}, M. Ouchrif\textsuperscript{2}, J.-C. Prévotet\textsuperscript{3}, F. Verdier\textsuperscript{3}
\textsuperscript{1} LLR Ecole Polytechnique, H.E.S.S. Collaboration
\textsuperscript{2} LPNHE Université Paris VI/VII, H.E.S.S. Collaboration
\textsuperscript{3} Université Cergy-Pontoise

- From H.E.S.S. phase 1 to phase 2
- Performance: expectations
- Optimizing low energies: L2 trigger
  - Purpose & constraints
  - L2 Simulation: results
Observations with Cherenkov Telescopes

- Proton 6 TeV
- Photon 1 TeV

HEGRA

- Hadron
- Photon

Kamera

- Cherenkov light
- direction
- camera plane
- observation level / reflector
- shower axis
- reflector front view
Hofmann algorithm nr. 3

≥ 2 images → superposition:
  • ... in the camera → direction ($\theta$)
  • ... observation level
    → position d’impact (core)

Hadrons rejection:
core + amplitude + zenith angle
→ mean scaled width (mscw)

Crab Nebula

signal region ($N_{\text{in}}$)
background region ($N_{\text{off}}$)

tracking direction
reconstructed shower direction

0 0.02 0.04 0.06 0.08 0.1
squared angular distance $\Delta \theta^2$ [deg$^2$]

0 500 1000 1500 2000 2500 3000
events

Crab Nebula
$\Delta \theta^2 < 0.05$ deg$^2$

signal region (photons + hadrons)
background region (hadrons)
signal - background = photons
Gauß fit to photons

Constant 634.9 ± 17.63
Mean 0.9987 ± 0.2422E-02
Sigma 0.9499E-01 ± 0.2023E-02

CT−System

photons
hadrons

tracking direction
reconstructed shower direction

0 0.25 0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5
mscw

0 100 200 300 400 500 600 700
frequency

3/25 Martin Tluczykont for the H.E.S.S. Collaboration – Martin.Tluczykont@poly.in2p3.fr
H.E.S.S. – Phase 1 Completed

First light telescope 1 : June 2002
Two telescopes : February 2003
Stereoscopy : July 2003
Three telescopes : September 2003
Four telescopes : December 2003

Phase 1 completed & fully operational !

- 0.01 Crab in 25 h (20 deg zenith)
- $E_{thr} = 100 \text{ GeV}$

Many physics results already shown/published

4/25 Martin Tluczykont for the H.E.S.S. Collaboration – Martin.Tluczykont@poly.in2p3.fr
H.E.S.S. Phase 2 = H.E.S.S. 1 + Very Large Cherenkov Telescope

**Very Large Cherenkov Telescope:**
- **Reflector:** 28 m Ø (≈ 600 m²)
- **Focal distance:** ≈ 36 m
- **Camera:** 2 m Ø (< 3 t)
- **2048 PMTs** (0.07°/pixel)
- **FoV:** 3.17° Ø

- **Trigger rate:** 2-20 kHz
- **Faster analogue memories needed**
- **Optimize data flow:** 2nd level trigger

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From Phase 1 to Phase 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Phase 1</th>
<th>Phase 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflector</td>
<td>13 mØ / 107 m²</td>
<td>28 mØ / &gt;600 m²</td>
</tr>
<tr>
<td>Davies-Cotton</td>
<td>→</td>
<td>Parabolic</td>
</tr>
<tr>
<td>Mirror facets</td>
<td>15 m f</td>
<td>35 m f</td>
</tr>
<tr>
<td>Circular</td>
<td>60 cm</td>
<td>90 cm</td>
</tr>
<tr>
<td>Hexagonal</td>
<td>→</td>
<td></td>
</tr>
<tr>
<td>Camera</td>
<td>960 PMTs</td>
<td>2048 PMTs</td>
</tr>
<tr>
<td>Pixel</td>
<td>0.16deg / pixel</td>
<td>0.07deg / pix</td>
</tr>
<tr>
<td>Field of View</td>
<td>5 deg Ø</td>
<td>3.0 deg Ø</td>
</tr>
</tbody>
</table>

Martin Tluczykont for the H.E.S.S. Collaboration – Martin.Tluczykont@poly.in2p3.fr
Telescope Mechanics

Huge telescope:

- Steel mount 500 t
- camera: 2 m × 2.5 m (<3 t)

technical modifications/challenges

- improved Winston cones
- stronger drive units
- mirror facets / alignment
- camera: heat evacuation (cool dry air)
H.E.S.S. Camera electronics

modular concept, all inside camera

Phase 1 & 2
- large dynamic range, good linearity
- single photoelectron peak resolution
- GHz sampling
- signal storage in analogue memory → trigger formation → memory readout

Improvements Phase 2
- 2-20 kHz trigger rate → faster analogue memories
- acquisition rate limited (≈ 3 kHz) → Second Level trigger
The Camera Trigger (L1)

- $A_{pix}$ amplitude threshold of PMs (photoelectrons)
- $N_{pix}$ number threshold of PMs in one sector

L1 trigger: at least $N_{pix}$ PMs with amplitude $>A_{pix}$ in one sector

LCT (Phase I)

- 38 sectors (64 PMs)
- $N_{pix} = 4, A_{pix} = 3$
- trigger rate mono : $R < 2$ kHz
- dead time : $T \approx 20\%$ (current ARS)
- trigger rate stereo : 350 Hz (total DAQ)

VLCT

- 96 sectors (64 PMs)
- new analog memories (SAM $\approx2\mu s$)
- $T < 10\% @ R < 50$ kHz L1
- $T < 1\% @ R = 3$ kHz Data acquisition
Trigger configuration & Energy ranges

- > 100 GeV
  - stereoscopy \( \geq 2 \) LCT + VLCT
  - improved resolutions
  - improved sensitivity

- 50 GeV - 100 GeV
  - stereoscopy LCT + VLCT
  - "new" event class

- 10 GeV - 50 GeV
  - monoscopie VLCT
  - new event class

Ferdi  Jade  Cléa  Jenny

each camera contains L1 trigger

Zora

H.E.S.S. Phase II

DAQ

L1 && L2

#Telescopes \( \geq 2 \)

L1 L1 L1 L1

Telescope 1
Telescope 2
Telescope 3
Telescope 4
Telescope 5

LCT1
LCT2
LCT3
LCT4

VLCT

L1 & L2

Central Trigger

mono
stereo

10/25 Martin Tluczykont for the H.E.S.S. Collaboration – Martin.Tluczykont@poly.in2p3.fr
Event Display – Simulation

10 GeV γ-ray shower

Monoscopic event class
10 GeV < E < 50 GeV
Event Display – Simulation

70 GeV γ-ray shower

New stereoscopic event class
50 GeV < E < 100 GeV
Event Display – Simulation

100 GeV $\gamma$-ray shower

Stereoscopic event class
$E > 100$ GeV
Event Display – Simulation

1 TeV $\gamma$-ray shower

Stereoscopic event class $E > 100$ GeV
Simulation of H.E.S.S. Phase 2 on trigger level

Parallel operation in monoscopic & stereoscopic mode

H.E.S.S. Phase II stereoscopy + monoscopy

- stereoscopy phase 1
- hybrid stereoscopy phase 2
- monoscopy phase 2

- $E_{\text{thres}} \approx 20$ GeV
- $\# \text{ events } \gamma \times 25$ (peak)
- trigger rate : 2.5 kHz
- dead time < 1%

Further improvement: lower energy threshold & better low-energy efficiency

Lower PM thresholds $\Leftrightarrow$ Level 2 Trigger

15/25 Martin Tluczykont for the H.E.S.S. Collaboration – Martin.Tluczykont@poly.in2p3.fr
Purpose of L2: optimize lowest energies / reduce trigger rate

- Pulsars (low energy cutoff)
- Microquasars
- AGN at high $z$
- unidentified sources (EGRET & H.E.S.S.)

loosen L1 conditions (lower thresholds)

$\rightarrow$ Lower energy threshold
$\rightarrow$ More low energy events
$\rightarrow$ Higher $\gamma$ sensitivity
$\rightarrow$ Higher trigger rate
- Night Sky Background
- Hadronic showers

L2 : reject Night Sky Background & Hadrons & Muons
Constraints on trigger rates

Rate limits:
- L1: < 50 kHz
dead time < 10 %
- L2: < O(4 kHz)
data flow

L1 Trigger

L2 Trigger

< 50 kHz!
deadtime < 10%

< 3.6 kHz

DAQ (PC Farm)
Available information at trigger level

Trigger level image:

- information unit: bloc
- 1 bloc = 4 PMs
- 1 active bloc = 2 PMs triggered

Binary information!
images based on blocks:
\(\gamma, \mu,\) proton, Night sky background
Clustering Condition

1. **L1**: Lower PMT amplitude threshold
   5 ph.e. $\rightarrow$ 3 ph.e. $\rightarrow$ **L1** trigger rate: 5 kHz

2. **L2**: Reject events with 0 clusters
   $\rightarrow$ **L1 + L2** trigger rate: 3.3 kHz
   - low energies: rejection of gammas
   + very good rejection of NSB
   + rejection of hadrons
   + rejected gammas unclustered = bad

   better reconstruction of remaining $\gamma$s

next step: more information, e.g. amplitude

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Event 22 gamma #Clusters: 1

Cluster of EVENT 22

trigger image entries

<table>
<thead>
<tr>
<th>0101xxxxx</th>
<th>0311xxxxx</th>
<th>0102xxxxx</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0212xxxxx</td>
<td>0</td>
</tr>
</tbody>
</table>
L2 clustering: loss & gain in performance ($\gamma$)

- **loss**: $\gamma$ efficiency of L2 clustering condition
- **gains**: # of triggered events due to lower threshold

**Gamma-ray efficiency with activated clustering condition**

- Loose L1 conditions + L2 clustering condition
- Standard L1 trigger conditions, no L2

**Lowering L1 conditions: gain factor in # of triggered events**

- Loose L1 trigger conditions + L2 clustering
- Standard L1 trigger conditions, no L2

**Total gain positive ?**
L2 clustering: Total positive gain

\[
gain \text{ after lowering PM thresholds } + \text{ L2 activation} \\
gain = \text{flux}_0 \times \text{efficiency} \times \text{gain} \times (1 - \text{dead time})
\]

![Graph showing Effective Gamma-Ray flux gain L2=clustering](image)

**Standard L1 trigger conditions, no L2**

**Lower PM thresholds + L2**
Other simple criteria

Reject high image amplitudes: small effect
- reject high energies
- keep low energies
  \[\rightarrow\] possible for steep source spectra (Pulsars)
  \[\rightarrow\] bad idea for hard spectra

Second moment analysis (Hillas)
loose analysis cuts on trigger level
(width, length, distance, length/size, etc.)
\(\sum\) of individual cuts, potential O(50%)
finer amplitude information is useful
Complex algorithms

currently under study: Neural networks, Hough transform (μ-ring tagging)

neural network architecture

extracting small zones of interest
Cascade of criteria from most simple to complex
Summary

- **L2: Optimize data flow**
  - Low energy threshold
  - Low acquisition rate

- **Simple criteria show positive results**
  - Clustering
  - Hillas analysis

- **Complex criteria under study**
  - Neural networks
  - Hough transform