Status of the MACE telescope

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for HiGRO collaboration

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Hanle, Ladakh (32.7°N, 79° E, 4200m asl)
HiGRO: Himalayan Gamma Ray Observatory

New Indian initiative in GeV gamma-ray astronomy

- Collaborators as of now: IIA, TIFR, BARC & SINP
- 7 element HAGAR wave-front sampling array - operating
- Stereo MACE (Major Atmospheric Cherenkov Experiment) imaging telescope
- First element installation in progress
Site characteristics

- Altitude *4200 m asl*
- Number of Spectroscopic Nights: $\sim 260/yr$ (few clouds)
- Number of Photometric Nights: $\sim 190/yr$ (no clouds)
- Extinction
  - $U = 0.353 \pm 0.037$
  - $B = 0.209 \pm 0.029$
  - $V = 0.121 \pm 0.032$
- Night Sky Brightness (mag/sq.arcsec): 21.5 V
- Uniform distribution of useful nights
- Longitudinal Advantage:
  - HESS: $16^\circ E$
  - MACE & HAGAR: $79^\circ E$
  - CANGAROO: $138^\circ E$
  - MAGIC: $20^\circ W$
  - VERITAS: $110^\circ W$
Extensive Air Showers at Hanle

(a) 100 GeV gamma
(b) 300 GeV proton

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MACE telescope: Design parameters

- Lower the energy threshold to $< 50$ GeV by using all possible parameters like Observatory altitude, light collector area, fast coincidence gate width, appropriate pixel size, CPCs, intelligent trigger generation scheme.
- Employ GHz signal processing for better discrimination particularly at energies $< 80$ GeV.
- Use a $f\#=1.2$ instead of the $f\#=1.0$ design for improving PSF.
- Improve detection sensitivity at $> 100$ GeV by using coincident HAGAR data so that muon background can be rejected substantially. Using coincident data should also lead to improved energy resolution.
- Use modified instrumentation for the central pixel so that it can be used for optical monitoring of the source-photometric observations (final sensitivity will depend on the PSF of the light collector).
- Fast repositioning of the telescope for observing high energy tails of GRBs.
- Improve detection sensitivity to milli Crab level flux by employing multi-telescope system in a phased manner.
MACE telescope

MACE structure concept

- Diameter: 21 m (large collector area)
- Focal Distance: 25 m
- Telescope weight: \( \sim 167 T \)

Major sub-systems

- Mechanical structure
- Drive system
- Light collector & mirror alignment
- Camera electronics
- Solar power plant
MACE light collector details

- Total light Collector Area: $337 \, m^2$
- Facet Size: $500 \, mm \times 500 \, mm$
- Number of Facets: $\sim 1500$
- Panel Size: $984 \, mm \times 984 \, mm$
- Number of Panels: 352
- Light collector configuration: Paraboloid with graded FL

<table>
<thead>
<tr>
<th>Light collector design</th>
<th>$D_{80@\theta = 0.0^\circ}$ (mm)</th>
<th>$D_{80@\theta = 1.0^\circ}$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolithic Paraboloid</td>
<td>—</td>
<td>38.48 (0.088°)</td>
</tr>
<tr>
<td>Tessellated Paraboloid (same f) $f=25000 , mm$</td>
<td>31.38 (0.072°)</td>
<td>45.39 (0.104°)</td>
</tr>
<tr>
<td>Tessellated Paraboloid (same f) $f=25490 , mm$</td>
<td>17.99 (0.041°)</td>
<td>44.17 (0.101°)</td>
</tr>
<tr>
<td>Tessellated Paraboloid (graded f)</td>
<td>14.24 (0.033°)</td>
<td>40.54 (0.093°)</td>
</tr>
<tr>
<td>Device Cotton</td>
<td>15.26 (0.035°)</td>
<td>37.92 (0.087°)</td>
</tr>
</tbody>
</table>
Mirror facet manufacture & panel alignment

1030 mirrors accepted as on 01.03.2013
Mirror Alignment control system

- Prototype unit for one panel tested (laser diode based system)
- Picture acquisition rate $\sim 20 \text{ Hz}$
- 50Ncm Stepper motor/car window motor/ BLDC motor based actuators
- Image Processing algorithms developed for star image based system
  * Multiple overlaps
  * Vibrating structure
- 2 motorised actuators for each mirror panel
- absolute encoder based actuators
- 704 actuators
Feasibility of one time alignment (Optimization of basket design)

Alignment at $z=30^\circ$

- Pixel dia
- Acceptable $D_{80}$
- PDR close-out
- Present Design
- $D_{80}$ for ideal design

Zenith angle (deg)

$D_{80}$ (mm)
MACE drive control system

Parameter | Value
--- | ---
Total weight Mass | 167 tonnes approx.
Angle Coverage in AZ | \( \pm 270^\circ \)
Angle Coverage in EL | -26° to 165°
Min Tracking speed (AZ & EL) | 0.03 °/minute
Max Tracking speed (AZ & EL) | 30 °/minute
Tracking acceleration (AZ & EL) | 0.02 °/sec²
Slew speed (AZ & EL) | 180 °/minute
SLEW acceleration | 0.3°/sec²
Pointing accuracy | 1 arc min
Tracking accuracy | 1 arc min
Position measurement accuracy | 0.5 arc min
Position sensor resolution | 27 bit (10 arc second)

Credits : Control Instrumentation Division
Compound Parabolic concentrator (CPC) design and testing results

- Dia of circumscribed circle $\sim 62.35$ mm
- Dia of inscribed circle $\sim 55.0$ mm
- Max. acceptance angle $\sim 33.04^\circ$

- Height $\sim 74.06$ mm
- 6 faces parallel to the optic axis of CPC

CPC testing results

![Graph showing CPC testing results]
MACE camera

- **Pixel size at CPC entry**: 55 mm (0.125°)
- **Photo-cathode dia**: 38 mm
- **Spectral range**: 280 – 600 nm

**Integrated Camera** (all signal processing instrumentation housed within the camera structure of 2 m × 2 m × 1.2 m size)

- **Temperature control** of the camera during operation and standby condition.
- **16 channel CIM module**
- **Total PMTs**: 1088 (68 CIM)
- **PMTs in the trigger region**: 576 (36 CIM)
Implementation of trigger algorithm

**SLT hardware**

- Two level trigger generation
- FLT: within the CIM
- SLT: system level trigger

**Diagram:**
- PMT signals after suitable amplification
- Programable threshold
- Option for triggering 3, 4, 5, or 6 PMT clusters
- **First Level Trigger (FLT) Generator**
  - CGW 5 ns
  - Prop. Time 20 ns
- **Central Second Level Trigger (SLT) Generator**
  - CGW 10 ns
  - Prop. Time 20 ns
- L0_1
- FLT_1
- SLT

**FLT_n consists of 4 signals from each CIM**
- FLT_n_1 :: F (4) trigger
- FLT_n_1 :: S (3) trigger
- FLT_n_1 :: N (2) trigger
- FLT_n_1 :: W (1) trigger
Trigger configuration 4NN tight cluster

Undesired combinations are recognized and rejected at SLT

Combinations retained $\frac{1414}{1541} = 91.88\%$

No individual connection

Table: Number of combinations

<table>
<thead>
<tr>
<th>Trigger Mode</th>
<th>Desired</th>
<th>desired + undesired</th>
</tr>
</thead>
<tbody>
<tr>
<td>FULL single CIM</td>
<td>756</td>
<td>756</td>
</tr>
<tr>
<td>N+N two CIM</td>
<td>240</td>
<td>6588</td>
</tr>
<tr>
<td>S+W two CIM</td>
<td>210</td>
<td>5582</td>
</tr>
<tr>
<td>W+S two CIM</td>
<td>210</td>
<td>5612</td>
</tr>
<tr>
<td>N+2W three CIM</td>
<td>100</td>
<td>ignored</td>
</tr>
<tr>
<td>4W four CIM</td>
<td>25</td>
<td>ignored</td>
</tr>
</tbody>
</table>

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Estimates of chance trigger rates

- **Chance rate due to desired combinations**
  1. **Full triggers:**
     \[36 \times 21 \times 4 \times R^4 \tau_{flt}^3\]
  2. **N+N triggers:**
     \[240 \times 2 \times (2R^2 \tau_{flt})^2 (2R^2 \tau_{flt}) \tau_{slt}\]
  3. **W+S triggers:**
     \[420 \times 2 \times (3R^3 \tau_{flt}^2)(R) \tau_{slt}\]

- **Total chance rate due to implementation**
  1. **N+N triggers:**
     \[6588 \times 2 \times (2R^2 \tau_{flt})^2 (2R^2 \tau_{flt}) \tau_{slt}\]
  2. **W+S triggers:**
     \[11194 \times 2 \times (3R^3 \tau_{flt}^2)(R) \tau_{slt}\]

**TRIGGER INFORMATION IN TWO PHASES!**
EAS generation summary

- CORSIKA ver. 6.990
- Hadronic Interaction Models – Fluka, QGSJet01
- Leptonic Interaction Model – EGS4
- Atmosphere Model – US standard
- Observation Level – Hanle site
- EAS core scatter radius – 250m
- zenith angle – 0°
- $10^5$ EAS generated for $\gamma$-rays at 12 different energies,
  - between 10 GeV to 100 GeV, in step of 10
  - between 100 GeV to 190 GeV, in step of 30
- $10^6$ EAS generated for proton at different energies
Trigger Efficiency and effective area

- Framework for checking valid triggers

- Effective area

- Trigger probability depends on Cherenkov photon density, trigger FOV, trigger multiplicity and single pixel threshold

- These parameters can be programmed
Gamma-ray trigger rates at various single pixel thresholds

**Differential rate:**
Number of particles (E and E+dE) trigger the telescope per unit time

\[ D(E) \, dE = A_{eff} \times N(E) \, dE \]

Peak of differential trigger rate determines the energy threshold

\[ N_{\gamma}(E) = 2.79 \times 10^{-7} \left( \frac{E}{GeV} \right)^{-2.59} \text{ ph m}^{-2} \text{ s}^{-1} \text{ GeV}^{-1} \]

<table>
<thead>
<tr>
<th>Trigger Mode</th>
<th>Threshold Energy (GeV)</th>
<th>Integral Rate (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5peFC</td>
<td>16</td>
<td>8.0</td>
</tr>
<tr>
<td>7peFC</td>
<td>21</td>
<td>3.4</td>
</tr>
<tr>
<td>7peF</td>
<td>23</td>
<td>2.2</td>
</tr>
<tr>
<td>10peFC</td>
<td>30</td>
<td>1.5</td>
</tr>
</tbody>
</table>

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Effective area and trigger rates for gamma ray and protons

- **Effective area**

  - For γ-ray (4NN, 7 pe)
    - Threshold energy: ∼ 21 GeV
    - Integral rate: ∼ 3.4 Hz

- **Differential rates**

  - For Proton (4NN, 7pe)
    - Threshold energy: ∼ 139.81 GeV
    - Integral rate: ∼ 184.57 Hz
Salient features of event acquisition

- Continuous sampling at 1GSPS using DRS4 (Domino Ring Sampler ASIC)
- Triggered mode of event acquisition: All the 1088 channels are digitized continuously but data is acquired based on a common Master Trigger
- ROI mode of operation using “Trigger delay loop mechanism” and sampling the trigger signal on the 9th channel of DRS4.
- Online offset voltage and timing jitter correction for all the channels of DRS4.
- 1 kHz Sustained event rate. Event Dead time of 75 us.
CIM testing

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CIM testing

- Development Camera electronics and operator console: completed
- Testing of integrated electronics of CIM with 16 PMTs: completed
- CIM has been housed in a 64 ch camera housing and LED: test setup established
- Entire chain of functions from loading configuration – up event acquisition and archiving: tested
- Performance related tests are in progress
MACE trial assembly in progress at Hyderabad

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VHEPU, Rencontres de Moriond
9-16 March, 2013
Time-line

- Trial installation at Hyderabad: Jan 12- May 13
- Testing of Drive and mirror alignment system: Jun- Jul 13
- Camera installation and testing: Oct-Dec 13
- Dismantling and packing: Jan - Mar 14
- Transportation to Hanle: April-May 14
- Installation at Hanle: June-Sept 14
- Engg. & Science Trials at Hanle: Oct-Dec 14
Summary

- TACTIC telescope has observed the Crab Nebula and a number of AGN & determined their spectrum
- MACE is the next logical step
- Hanle as a site for GRA offers major scientific advantages and many challenges also !!!
- Technical expertise for setting up the MACE telescope is available in the country
- When operational by 2014 the MACE telescope will be a state of the art instrument
- There is need to expand the HiGRO collaboration to derive maximum scientific benefits
Acknowledgements

- Astrophysical Sciences Division
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Thank you!