A detailed investigation of thunderstorm events recorded in GRAPES-3 experiment

B. Hariharan, CRL, TIFR
DAE-BRNS HEP SYMPOSIUM 2020
Thunderstorm

- Dipolar structure (actual structure is complex)
- $V > 1$ billion volts (predicted by C.T.R. Wilson 90 years ago)

- Measurements?
Muon Telescope
- 3712 PRCs
- 16 Modules
- Area 560 m²
- 169 Directions
- Sec(θ) GeV
- 4 billion muons/day
- 40-50 events/year

GRAPES-3 Experiment, Cosmic Ray Laboratory, Ooty
Muon image of event 1\textsuperscript{st} Dec 2014

18 minutes

45 directions
Muon intensity variation on 1\textsuperscript{st} Dec 2014

![Graph showing muon intensity variation with a significant drop at 11:00 UT, indicated by 20 $\sigma$.]
Monte Carlo simulation

- CORSIKA and in-house
- 169 direction simulation (accuracy of ~0.1%)
- Cloud model inside CORSIKA
Monte Carlo simulation

- $\Delta I_{\mu(\text{Peak})} = (-2 \pm 0.2)\%$
- $V_{\text{Peak}} = (0.90 \pm 0.08)\text{ GV}$
Cloud movement

• Mean V = 1.3 GV
• Angular Velocity = 6.2° min⁻¹
Electrical properties of the cloud

- Mean V = 1.3 GV
- Lin. Vel. = 60 km hr\(^{-1}\)
- Ang. Vel. = 6.2° min\(^{-1}\)
- Height = 11.4 km amsl
- Radius ≥ 11 km
- Area ≥ 380 km\(^2\)
- C ≥ 0.85 µF
- Q ≥ 1100 C
- E ≥ 720 GJ
- P ≥ 2 GW

- Comparable to biggest nuclear reactor / hydroelectric / thermal power plants
- Enough to power a big town

B. Hariharan et al.,
(Focus article & Editors’ suggestion)

Giga-Volt natural particle accelerator above our head !!!
## Event statistics

<table>
<thead>
<tr>
<th>Year</th>
<th># of events</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>49</td>
</tr>
<tr>
<td>2012</td>
<td>43</td>
</tr>
<tr>
<td>2013</td>
<td>40</td>
</tr>
<tr>
<td>2014</td>
<td>52</td>
</tr>
<tr>
<td>Total</td>
<td>184</td>
</tr>
</tbody>
</table>
Distribution of events

<table>
<thead>
<tr>
<th>NW</th>
<th>N</th>
<th>NE</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>V</td>
<td>E</td>
</tr>
<tr>
<td>SW</td>
<td>S</td>
<td>SE</td>
</tr>
</tbody>
</table>

8.1  3.0  29.3
0.5  0.5  3.5
8.1  3.5  43.4

(% of events)
Simulation of 9-direction
Muon charge ratio
Thank You
Backup Slides
Monte Carlo simulation

![Graph showing variation vs. electric potential (MV)]
Electric Field Mills

- 4 Monitors
- Maximum distance of 6 km

- Velocity = 60 km hr$^{-1}$