GEANT4 simulation package for the GRAPES-3 muon telescope

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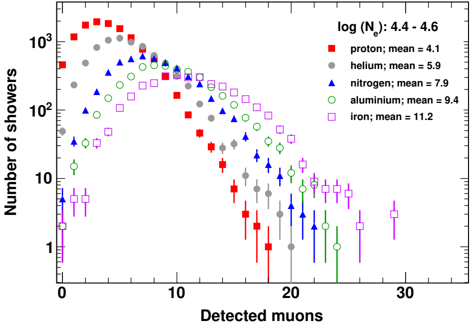
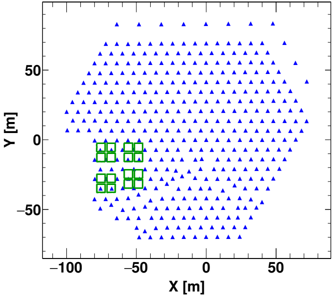
Motivation

- Muon component of EAS is sensitive to the nature of PCRs.
- Plays a vital role in extracting the nuclear composition of the PCRs and separating the $\gamma-$rays from the background of the cosmic ray.
- To achieve the desired precision, a thorough understanding of the response of EAS particles in the GARPES-3 muon telescope (G3MT) is necessary.



- We developed a simulation framework for the G3MT using the GEANT4 toolkit (version 4.10.04) and studied its performance using CORSIKA (version 7.6900) based on the QGSJET-II-04 and FLUKA.

GRAPES-3 experiment



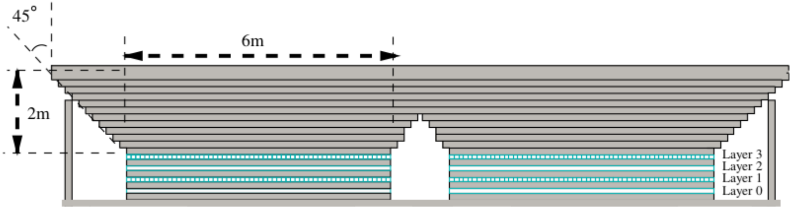
Location:

- Ooty, south India
- 11.4° N, 76.7° E
- 2200 m a.s.l.

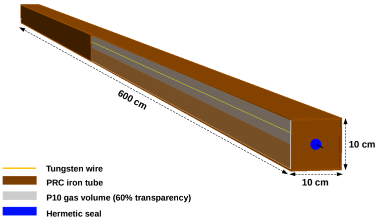
- 400 plastic scintillation detectors (1 m^2 each) cover an area of 25,000 m^2.
- Large area (560 m^2) muon telescope.
- Fraction of detector area covered is 2%.
- Energy range: 1 TeV – 10 PeV.

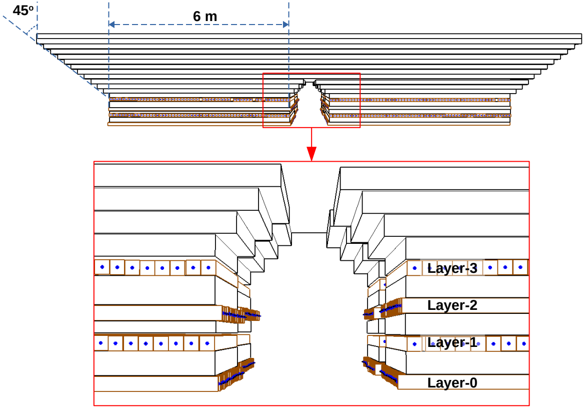
GRAPES-3 muon telescope

- 16 independent modules (each 35 m^2).
- Total effective area: 560 m^2.
- Energy threshold: 1 GeV$\times \sec\theta$.
- Detector unit: proportional counters (PRCs, total 3712) filled with P10 gas.
- Four orthogonal layers of PRCs.
- Concrete absorber (550 $g\,cm^{-2}$): shields electromagnetic & hadronic components.



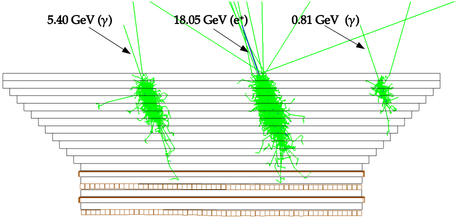
Geant-4 simulation: Geometric reconstruction of GMT

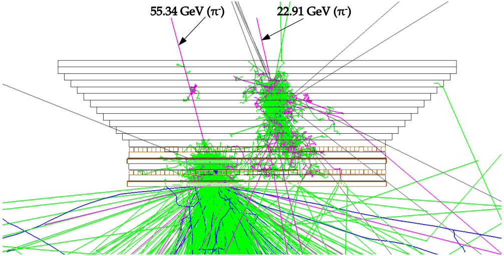




Geant-4 simulation: EAS particles response

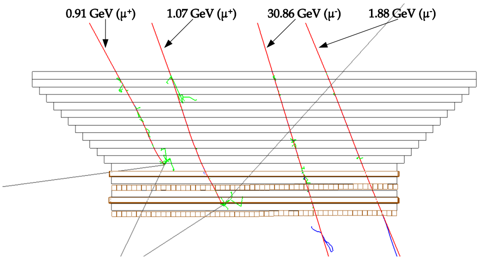
- CORSIKA (version 7.6900) based on the QGSJET-II-04 and FLUKA.

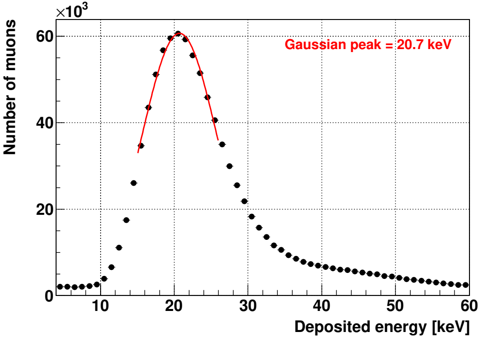




- Electromagnetic (EM) and low energy hadronic components get absorbed.
- High energy hadrons generate an EAS in the absorber and form a cluster of PRCs hit.

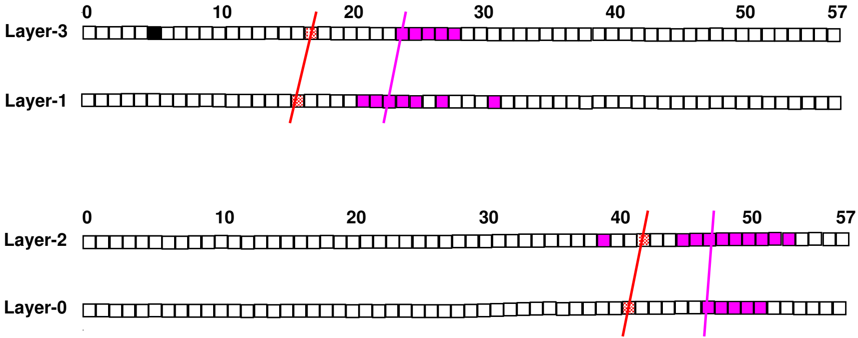
Geant-4 simulation: EAS particles response





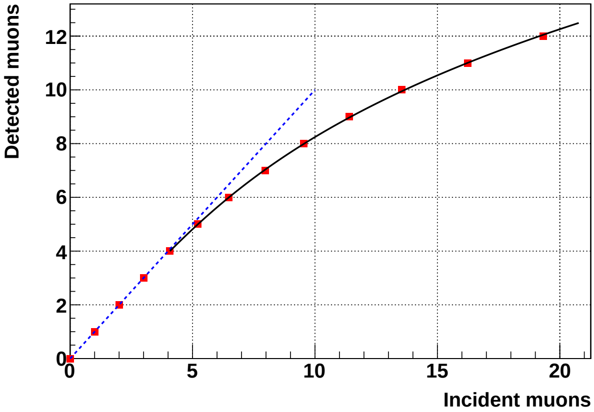
- Muons above 1 GeV$\times \sec\theta$ threshold make a clear passage through the module.
- The energy deposition by single muons in PRC peaks at 20.7 keV, which is consistent with the experimental value of ~20 keV.

Reconstruction of muon tracks



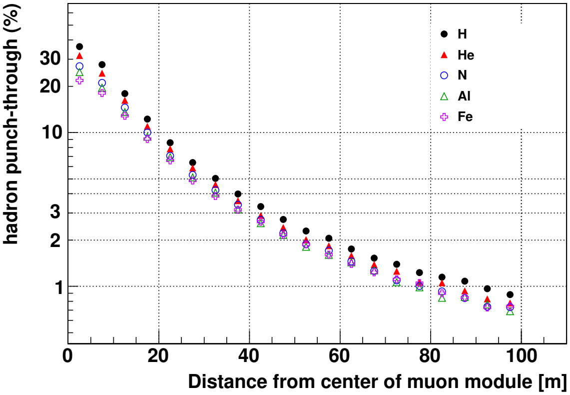
Muon saturation

- The mean value of incident muons is plotted against the given number of detected muons.
- Curve is modeled with the 3^{rd} polynomial and used to correct for the saturation.

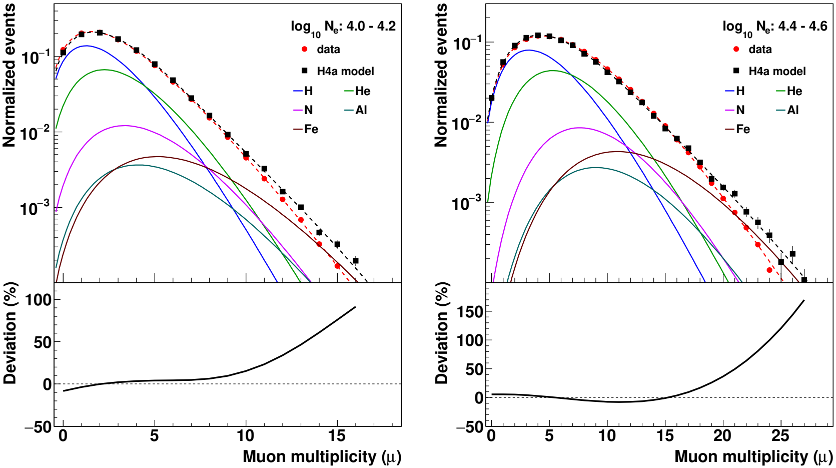


Hadron punch-through

- Quality cuts:
  - Successful reconstruction of direction and NKG parameters.
  - Reconstructed cores within 50 m from the center of array.
  - Shower age (s): [0.2, 1.8].
  - zenith angle : [0°, 25°].
  - Shower size (N_e) ≥ $10^{4.0}$.
- event-by-event basis, fraction of number of tracks by hadron is calculated.
- hadron punch-through per EAS is calculated, followed by averaging for all the 16 modules.
- ~10% at 20 m and reduces to ~2% at 60 m.



Comparison of observed MMD with the H4a composition model

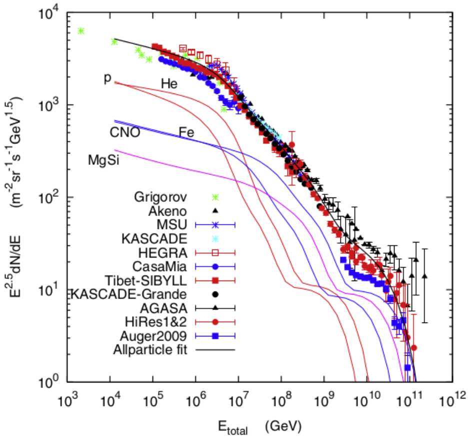


Summary

- We developed a simulation framework for the G3MT using the GEANT4.
- Performance is studied using CORSIKA based on the QGSJET-II-04 and FLUKA.
- Electromagnetic (EM) and low energy hadronic components get absorbed while high energy hadrons generate an EAS in the absorber and form a cluster of PRCs hit.
- Muons above 1 GeV$\times \sec\theta$ threshold make a clear passage through the module.
- The energy deposition by single muons in PRC peaks at 20.7 keV, which is consistent with the experimental value.
- Hadron punch-through is studied and it reduce to less than 2% at 60 m.
- Comparative study shows a reasonably good agreement at lower muon multiplicity and a significant deviation at higher muon multiplicity indicates that the relative composition of heavier nuclei (especially iron) in the H4a model is higher than that expected from the observed data.

Thank you

Backup slides: H4A Model



	p	He	CNO	Mg-Si	Fe
Pop. 1:	7860	3550	2200	1430	2120
$R_c = 4$ PV	1.66	1.58	1.63	1.67	1.63
Pop. 2:	20	20	13.4	13.4	13.4
$R_c = 30$ PV	1.4	1.4	1.4	1.4	1.4
Pop. 3:	1.7	1.7	1.14	1.14	1.14
$R_c = 2$ EV	1.4	1.4	1.4	1.4	1.4
Pop. 3(*):	200	0.0	0.0	0.0	0.0
$R_c = 60$ EV	1.6				

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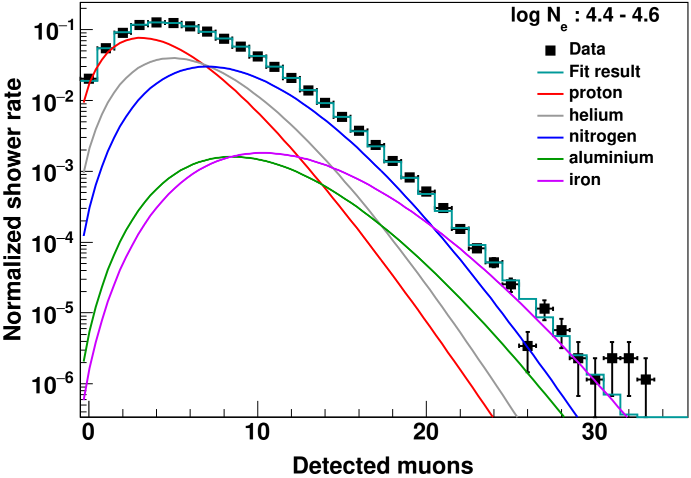
Backup slides: Stats and Composition

$\log N_e$	Energy (E_H)	Number of EAS		Relative composition (%)					Mean of MMD	
Range	Range [TeV]	Data	H4a	H	He	N	Al	Fe	Data	H4a
4.0 - 4.2	35 - 55	4091460	174510	54.7	32.3	7.1	2.4	3.5	2.7	2.8
4.2 – 4.4	55 - 84	2080850	106219	52.3	33.2	7.4	2.7	4.4	4.1	4.1
4.4 – 4.6	84 - 127	1045140	61109	51.1	33.6	7.6	2.7	4.9	6.1	6.0
4.6 – 4.8	127 - 193	527207	35181	50.2	34.4	7.6	2.9	4.9	8.7	8.6
4.8 – 5.0	193 - 294	268389	19729	48.8	35.3	8.1	2.9	4.9	12.3	12.2
5.0 – 5.2	294 - 447	137934	55972	46.4	35.8	8.7	3.3	5.7	17.4	17.7
5.2 – 5.4	447 - 680	71189	31124	43.9	38.4	8.7	3.5	5.4	24.6	25.2
5.4 – 5.6	680 - 1035	37122	17073	43.4	37.7	9.5	3.8	5.6	34.5	35.9

Backup slides: MMD unfolded



H: 45.4%, He: 33.6%, N: 15.5%, Al: 4.2% and Fe: 1.3%