

## Coincident Observation of Air Showers by the HiRes Prototype and CASA/MIA Experiments

D.J. Bird,<sup>1</sup> A. Borione,<sup>2</sup> J. Boyer,<sup>3</sup> M. Catanese,<sup>4</sup> R.W. Clays,<sup>5</sup> S.C. Corbato,<sup>6</sup> C.E. Covault,<sup>2</sup> J.W. Cronin,<sup>2</sup> H.Y. Dai,<sup>6</sup> B.R. Dawson,<sup>5</sup> R.W. Downing,<sup>1</sup> J.W. Elbert,<sup>6</sup> B.E. Fick,<sup>2</sup> K.G. Gibbs,<sup>2</sup> K.D. Green,<sup>4</sup> M.A. Huang,<sup>6</sup> M.J. Kidd,<sup>1</sup> D.B. Kieda,<sup>6</sup> S. Ko,<sup>6</sup> C.G. Larsen,<sup>6</sup> W. Lee,<sup>3</sup> E.C. Loh,<sup>6</sup> T.A. McKay,<sup>2†</sup> E. Mannel,<sup>3</sup> J. Matthews,<sup>4</sup> B.J. Newport,<sup>2</sup> D. Nitz,<sup>4</sup> T.A. O'Halloran,<sup>1</sup> R.A. Ong,<sup>2</sup> M.H. Salamon,<sup>6</sup> L.J. Rosenberg,<sup>2‡</sup> J.D. Smiths,<sup>6</sup> D. Sinclair,<sup>4</sup> P. Sokolsky,<sup>6</sup> P. Sommers,<sup>6</sup> J.K.K. Tang,<sup>6</sup> S.B. Thomas,<sup>6</sup> and J.C. van der Velde<sup>4</sup>

<sup>1</sup> *Dept. of Physics, University of Illinois at Urbana-Champaign, Urbana, IL 61801 USA*

<sup>2</sup> *Enrico Fermi Institute, University of Chicago, Chicago, IL 60637 USA*

<sup>3</sup> *Nevis Laboratories, Columbia University, Irvington NY 10533 USA*

<sup>4</sup> *Dept. of Physics, University of Michigan, Ann Arbor, MI 48109 USA*

<sup>5</sup> *Dept. of Physics and Mathematical Physics, University of Adelaide, Adelaide, South Australia 5001 Australia*

<sup>6</sup> *High Energy Astrophysics Institute, Dept of Physics, University of Utah, Salt Lake City UT 84112 USA*

<sup>†</sup> *now at Fermi National Accelerator Laboratory, Batavia IL 60510 USA*

<sup>‡</sup> *now at Dept. of Physics, M. I. T, Cambridge, MA 02139 USA*

### ABSTRACT

The HiRes prototype detector is now observing extensive air showers above 50 PeV in coincidence with the CASA extensive air shower and MIA muon arrays. The prospects for energy cross-calibration and cosmic ray composition measurements are discussed. Preliminary analysis of data collected in late 1992 is presented.

### 1. INTRODUCTION

The HiRes prototype detector at Dugway, Utah, has been constructed so that its fourteen mirrors overlook the Chicago/Michigan air shower array complex 3.4 km away ( Figure 1 ). In addition to confirming the anticipated performance of the next generation atmospheric fluorescence detector, the principal physics goals of the prototype are tied to the study of air showers in the energy range primarily between 50 and 200 PeV in coincidence with the Chicago Air Shower Array ( CASA: Ong *et al* 1990 ) and the Michigan Anti ( MIA: Sinclair 1989 ).

The unique experimental arrangement at Dugway provides the opportunity to observe a flux of cosmic rays above the "knee" with both the ground array and atmospheric fluorescence techniques. An energy cross-calibration of both techniques will be performed. Energy estimation for the ground array technique is based on the shower lateral distribution some distance from the core ( 600 m for the EeV energy scale ). Using the observed longitudinal shower development profile, the optical technique provides a more direct estimate of the primary energy. The coordinated operation of these detectors will also serve to test ideas for combining a  $10^4 \text{ km}^2\text{-sr}$  ground array and an air fluorescence detector ( see papers in Boratav *et al.* 1992 ).

The unresolved issue of cosmic ray composition in this energy regime will be studied from several approaches. The arrival directions and core locations determined by the ground arrays will constrain the geometrical reconstruction of coincident HiRes events. The HiRes depth-of-shower-maximum (  $X_{\text{max}}$  ) distribution of these events will be compared with Monte Carlo predictions for different primary nuclei. Simulations have predicted that iron initiated showers ( at fixed energy ) will have 75% higher muon content than proton showers. Using the enhanced energy resolution of the HiRes prototype, we will examine the muon multiplicities of coincident events and later compare these

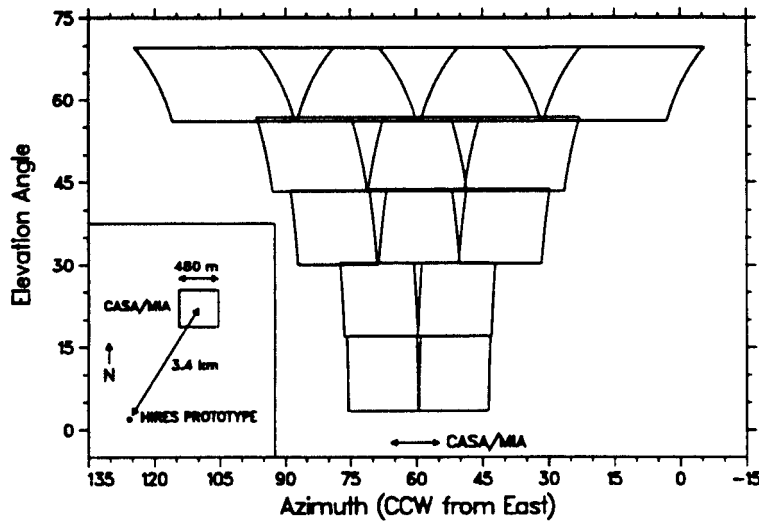


Figure 1: Geometrical arrangement of the HiRes prototype and CASA/MIA experiments, Dugway, Utah. The HiRes prototype is 140 m higher in altitude than the array complex.

results with composition predicted by the  $X_{\max}$  distribution as measured by HiRes.

## 2. COINCIDENT EVENTS

In March, 1993, the HiRes prototype became fully operational with its complement of fourteen mirrors. In the late summer and autumn of 1992, however, a subset ( between 4 and 6 in number ) of HiRes mirrors was utilized to collect data in coincidence with the ground arrays. At the end of each nightly HiRes run, the raw data file was passed through a fitter program to reject nearby Cerenkov blast events and noise triggers. A list of WWVB times for candidate HiRes track events was then transmitted to the CASA data acquisition computer. CASA/MIA events having occurred within 1ms ( this window accounts for variations in clock performance ) of a HiRes track were then flagged. Figure 2 compares the observed CASA alerted station multiplicity distribution for these coincident events with that for events from a standard CASA data run ( a CASA alert is defined as the firing of two of four scintillators in a station within 30 ns ). This multiplicity distribution is then used to define a cut at 250 alerted CASA stations for identifying candidate coincident air showers.

For this paper, we have examined a limited subset of coincident events observed over this period. In particular, we have chosen to focus on one coincident event as a demonstration of the analysis techniques. The selected event occurred at 8:27:45.280 UT on 27 Sep 1992 and was observed in all three detectors. The shower produced alerts in 678 of the 1089 CASA stations ( Figure 3 ) and triggered 619 of the 1024 Michigan muon counters ( each  $2.5 \text{ m}^2$  in area ) buried underneath the CASA array. It also triggered 80 photomultiplier tubes in three HiRes prototype mirrors viewing between  $3^\circ$  and  $44^\circ$  in elevation angle ( Figure 4 ).

Preliminary CASA and HiRes analyses of this event have been conducted. The CASA shower directions were determined by a method intrinsically less precise than the standard CASA analysis ( the angular resolution for this preliminary method is  $1.7^\circ$  for events with a minimum of 100 CASA stations ). The HiRes plane reconstruction method ( Bird *et al.* 1993 ) yielded a fit to the shower-detector plane with a precision of  $0.4^\circ$ . The CASA shower direction vector intersects this plane at angle of  $3.6^\circ$ . Using

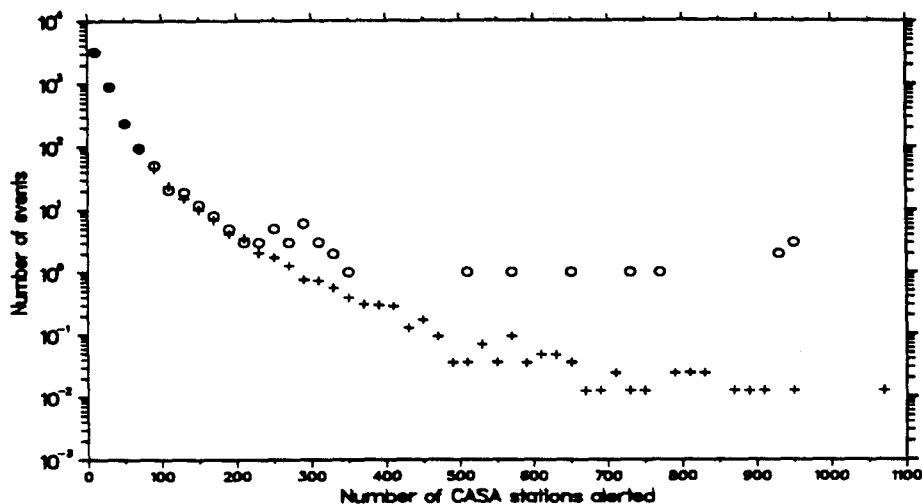


Figure 2: Observed CASA alert multiplicity distributions for 4613 HiRes / CASA coincident events ( $\dot{A}_{t_{\text{WWVB}}}$  1 ms) between 26 Sep and 4 Dec 1992 (circles) and a normalized set of 400,000 CASA events collected 23 Sep 1992 (crosses).

HiRes photomultiplier timing information to determine the event geometry, we have also produced a preliminary shower development curve for this event (Figure 5). From the integration of this curve, the initial estimate for the shower energy is 450 PeV. Its maximum occurred at an estimated depth of  $620 \text{ g-cm}^{-2}$ .

### 3. CONCLUSION

We expect to observe on the order of 700 air showers above 50 PeV in energy annually with the HiRes prototype and CASA/MIA ground arrays. To minimize the accidental coincidence rate, a hardware flag for coincidences with the HiRes prototype (enabled via a light signal over the 3.4 km distance between the two experimental sites) has recently been incorporated in the CASA/MIA data stream. By the time of the Calgary meeting, we will have collected several hundred such events and plan to present a preliminary analysis of these data.

### ACKNOWLEDGMENTS

We are indebted to Colonels Frank Cox and James King and the staff of the Dugway Proving Grounds for their continued cooperation and assistance. S. Voelker at the University of Utah has provided valuable programming assistance for the project. This work has been supported in part by the National Science Foundation (Chicago, Columbia, and Utah) and the U.S. Department of Energy (Illinois and Michigan).

### REFERENCES

- Bird, D.J. *et al.*: 1993, *Reconstruction Techniques and Tests Using the HiRes Prototype*, these proceedings, OG 10.
- Boratav, M., Cronin, J.W. and Watson, A.A., eds.: 1992, *Cosmic Rays above  $10^9 \text{ eV}$* , North-Holland, Amsterdam.
- Ong, R.A.: 1990, *Nucl. Phys. B. (Proc. Suppl)*, **14A** 273.
- Sinclair, D.: 1989, *Nucl. Instr. Meth.*, **A278** 583.

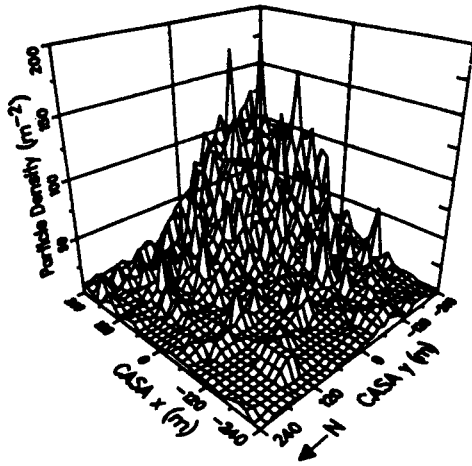


Figure 3: CASA particle density distribution for coincident event at 08:27:45.280 UT, 27 Sep 1992. The shower saturated the ADC's in the CASA Stations near the core, which fell beyond the far southeastern corner of the array.

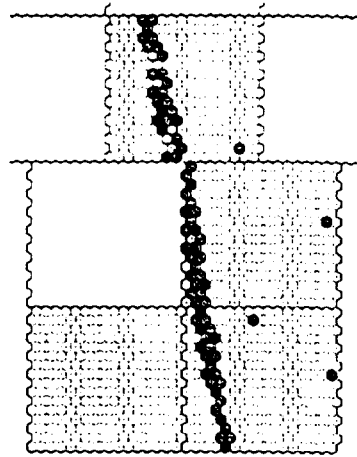


Figure 4: HiRes prototype triggered tube pattern for the same event as in Figure 3.

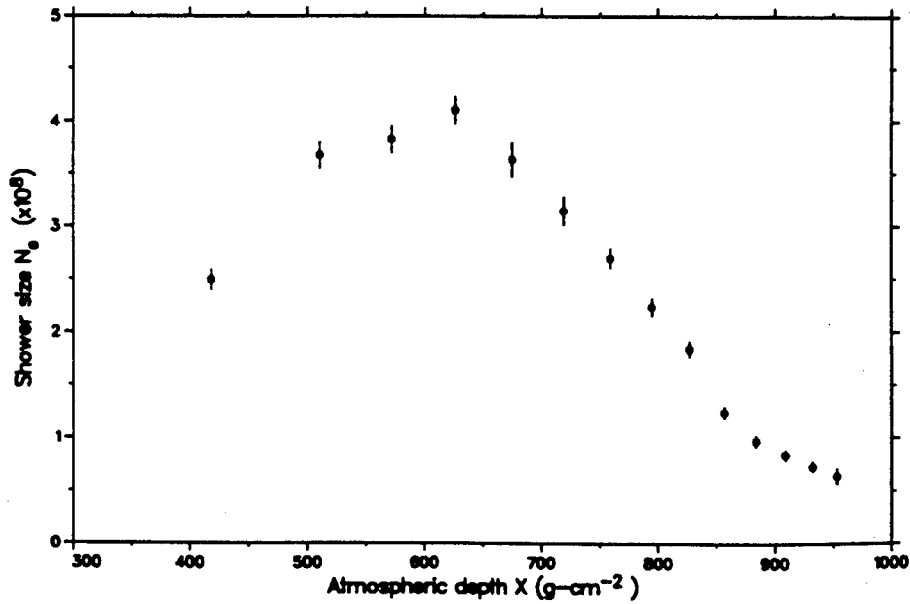


Figure 5: Preliminary HiRes prototype shower longitudinal development curve for the coincident event of 27 Sep 1992. The error bars on  $N_e$  represent the statistical errors on the observed light intensity only.