# Design of a small Cosmic Ray Air Shower array to study atmospheric effects

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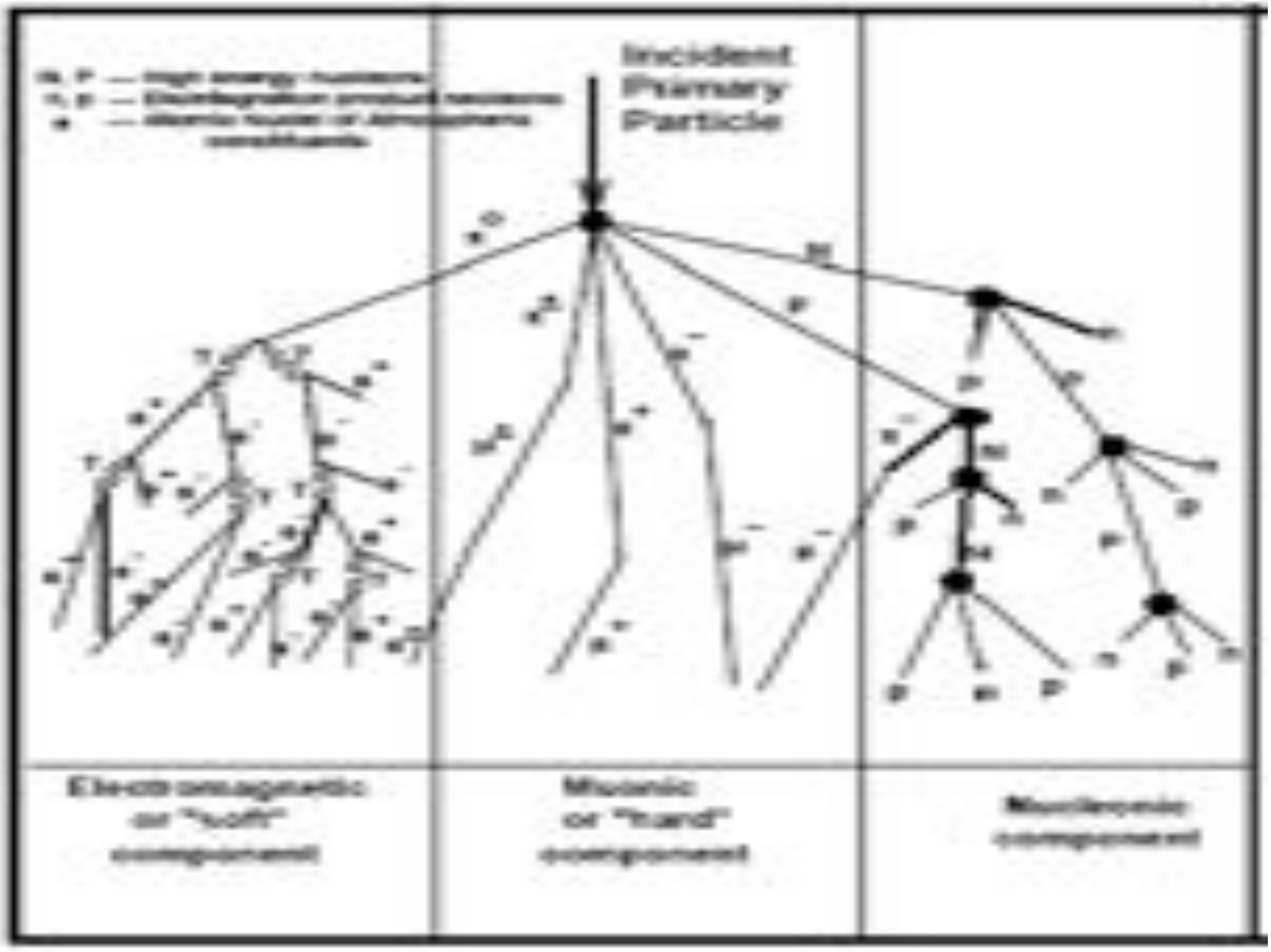
# Plan of my talk

1. Introduction : Cosmic ray air shower
2. Shower detection methods : Ground based EAS array
3. Lateral distribution of charged particles
4. CORSIKA Code
5. Proposed array layout and Electronics
6. Reconstruction of zenith and azimuth angles
7. Artificial shower simulation and threshold parameters
8. Atmospheric effects

# Introduction : Cosmic Ray Extensive Air Showers (EAS)

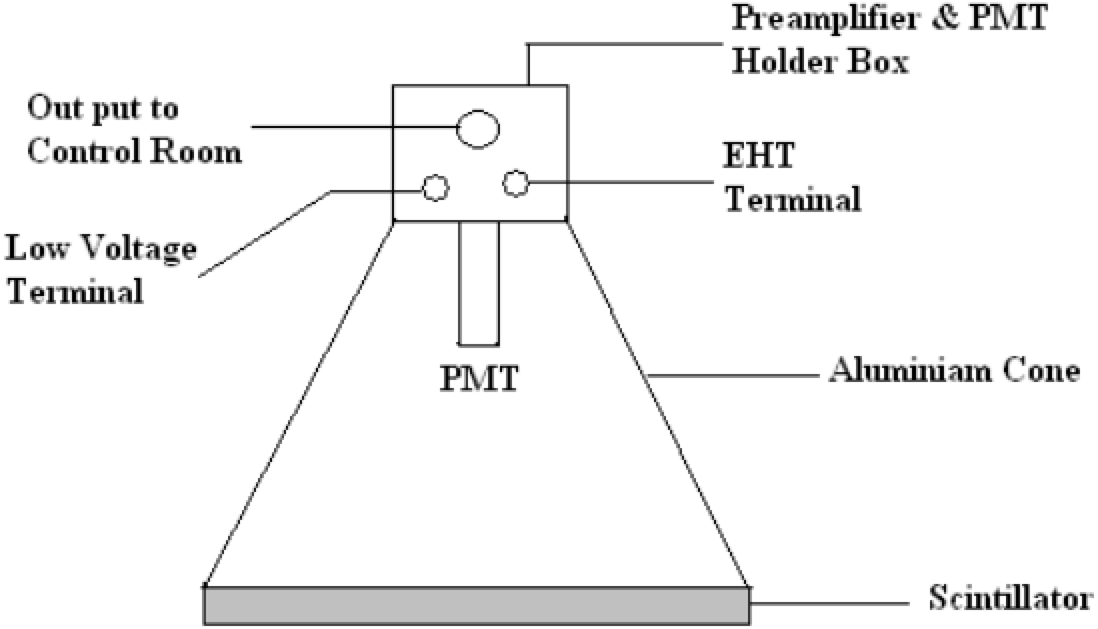
- EAS particles are produced when a high energy (>10TeV) cosmic ray undergoes nuclear collision with atmospheric $O_2$ or $N_2$ nucleus.
- In the first collision, hadrons (**p,n,pions,kaons**) are produced, which further interact or decay producing cascade of secondary particles, spread over very large area.
- At sea level, about 90% are electrons ($\mathbf{e}^-$) and positrons ($\mathbf{e}^+$) and about 10% are muons ($\boldsymbol{\mu}^+$, $\boldsymbol{\mu}^-$)

# Hadron shower development



GRAPES-3 Experiment at Ooty

# Plastic Scintillation Counter



# Water Cerenkov Detector

# Objective

To design and to setup :

- Four particle detectors at the corners of a square of adjustable size at the roof top of Physics building, GU.
- Cosmic ray air shower to be detected by coincidence technique designed to record arrival time and particle density.
- Effective area and threshold parameters are estimated using Monte Carlo Simulation using CORSIKA code.

# Lateral Distribution of charged particles

Analytical formula (NKG) for charged particle density at Core distance ‘r’m and at atmospheric depth ‘X’ g/sq cm,

$$\rho_e(r,X) = N_e(X)\frac{C(s)}{rr_1}\left(\frac{r}{r_1}\right)^{s-1}\left(1+\frac{r}{r_1}\right)^{s-9/2}$$

Where, ‘s’ is the age parameter, ‘r1’ is the lateral distribution Parameter and Ne is the shower size at depth ‘X’.
For comparison with CORSIKA simulation, Greisen lateral distribution function is used,

$$\rho(r) = \frac{N_0}{2\pi}\frac{\exp(-r/r_0)}{r_0(1+r)}$$

Where, No and r0 are fitted parameters.

# Simulation : CORSIKA code

In order to derive primary parameters from experimental observations, method of simulation is widely used. **CORSIKA (COsmic Ray SImulation for KAscade)** is a detailed Monte Carlo program to study the evolution of EAS in the atmosphere initiated by different Cosmic Ray particles.

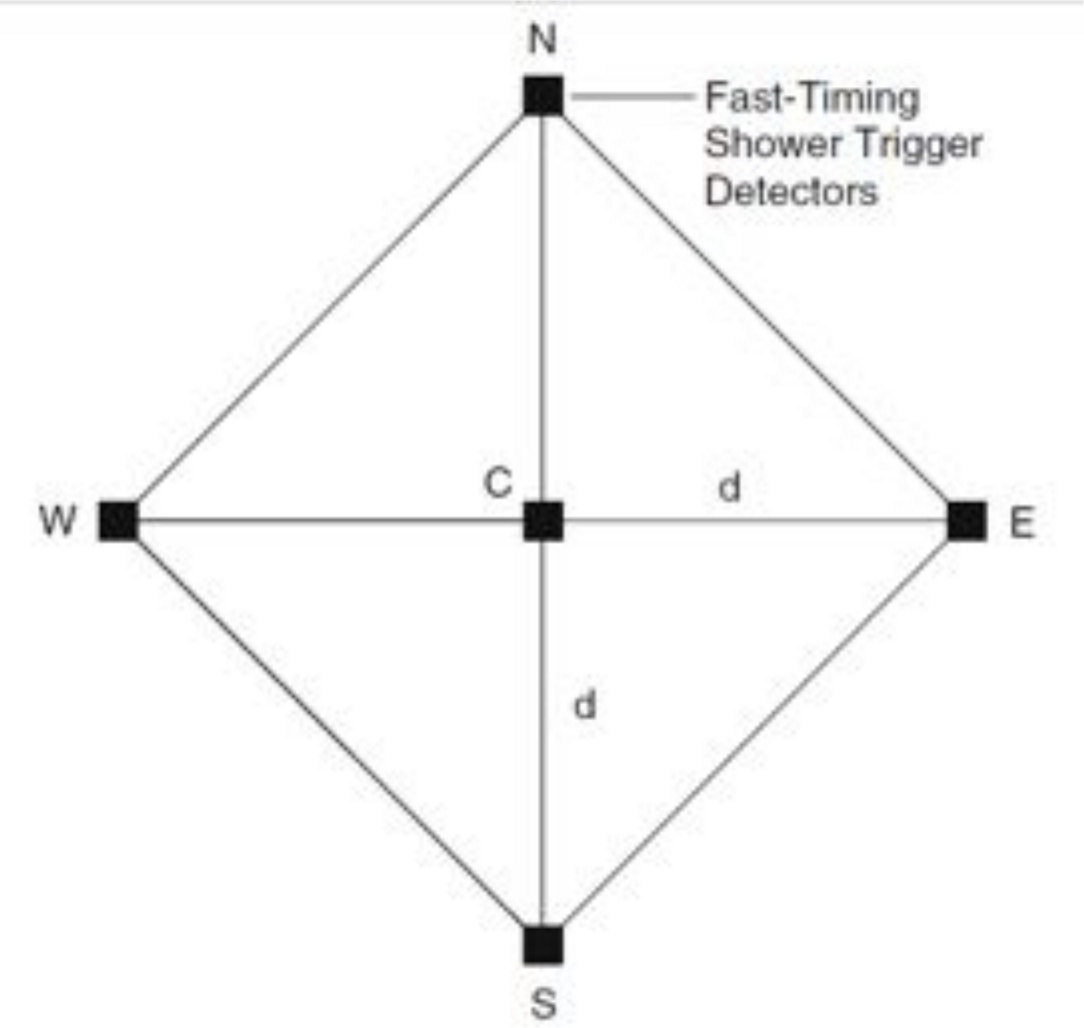
Also, prediction of particle energy spectra, densities, and arrival times to be observed in EAS experiments, can be made effectively using CORSIKA Simulation.

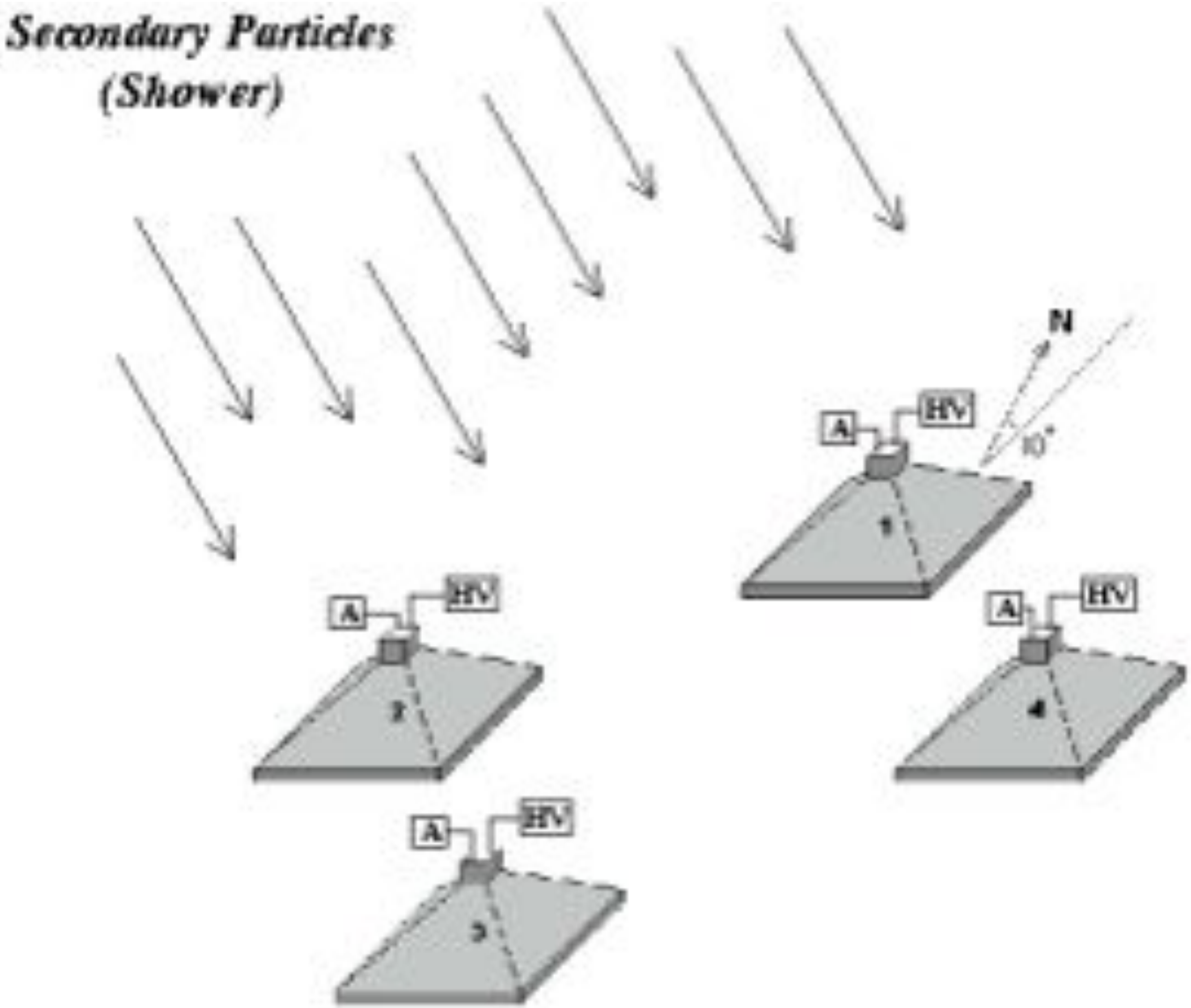
# CORSIKA code

- The CORSIKA program recognizes more than 50 elementary particles: γ,e±,μ±; πo,π±,K±, KoS/L,η,baryons,antibaryons,resonance,anti resonance states and nuclei up to A ≤ 56.
- It gives type, energy, momentum, location, direction and arrival times of all secondary particles that pass a selected observation level.
- Particle output is a binary file, which is first decoded to produce a file ‘fort.8’ (ASCII), containing the following information,

$$id,\ p_x\ ,\ p_y\ ,\ \ p_z\ ,\ x,\ y,\ t$$

# Proposed Array Layout



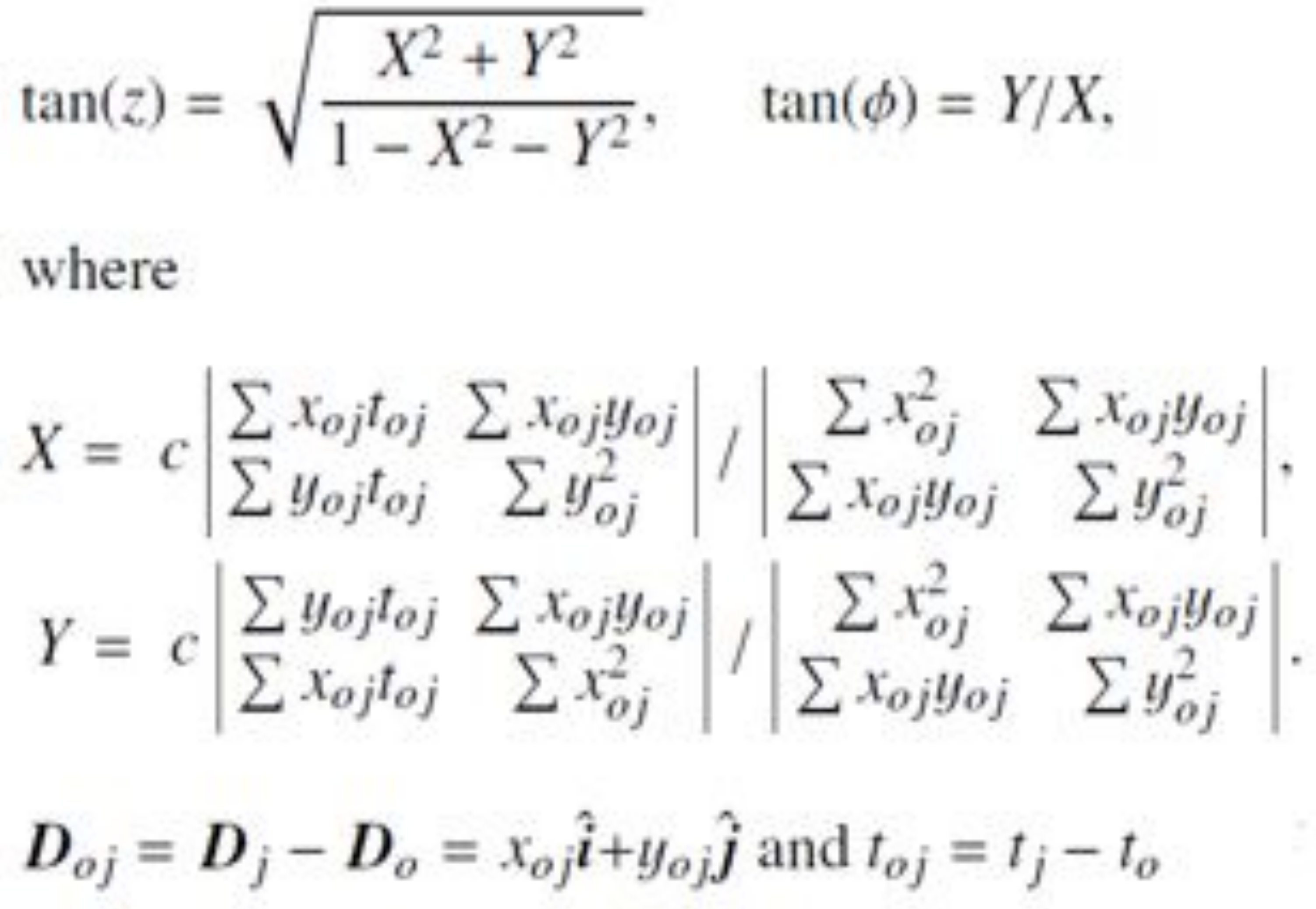

Secondary Particles
(Shower)
N
10°
A
HV
1
A
HV
2
A
HV
4
A
HV
3

# Reconstruction of zenith and azimuth angles using simulated data

CORSIKA output (fort.8) is read using a fortran file and the coordinates of the charged particles are transformed to the origin at the array centre.

The number of charged particles and their arrival times at each detector positions are recorded for random locations of the EAS core.

The first particle arrival times are used to estimate Zenith (*z*) and azimuth (φ) angles using least square method,



$$\tan(z) = \sqrt{\frac{X^2 + Y^2}{1 - X^2 - Y^2}}, \qquad \tan(\phi) = Y/X,$$

where

$$X = c \begin{vmatrix} \sum x_{oj} t_{oj} & \sum x_{oj} y_{oj} \\ \sum y_{oj} t_{oj} & \sum y_{oj}^2 \end{vmatrix} \Big/ \begin{vmatrix} \sum x_{oj}^2 & \sum x_{oj} y_{oj} \\ \sum x_{oj} y_{oj} & \sum y_{oj}^2 \end{vmatrix},$$

$$Y = c \begin{vmatrix} \sum y_{oj} t_{oj} & \sum x_{oj} y_{oj} \\ \sum x_{oj} t_{oj} & \sum x_{oj}^2 \end{vmatrix} \Big/ \begin{vmatrix} \sum x_{oj}^2 & \sum x_{oj} y_{oj} \\ \sum x_{oj} y_{oj} & \sum y_{oj}^2 \end{vmatrix}.$$

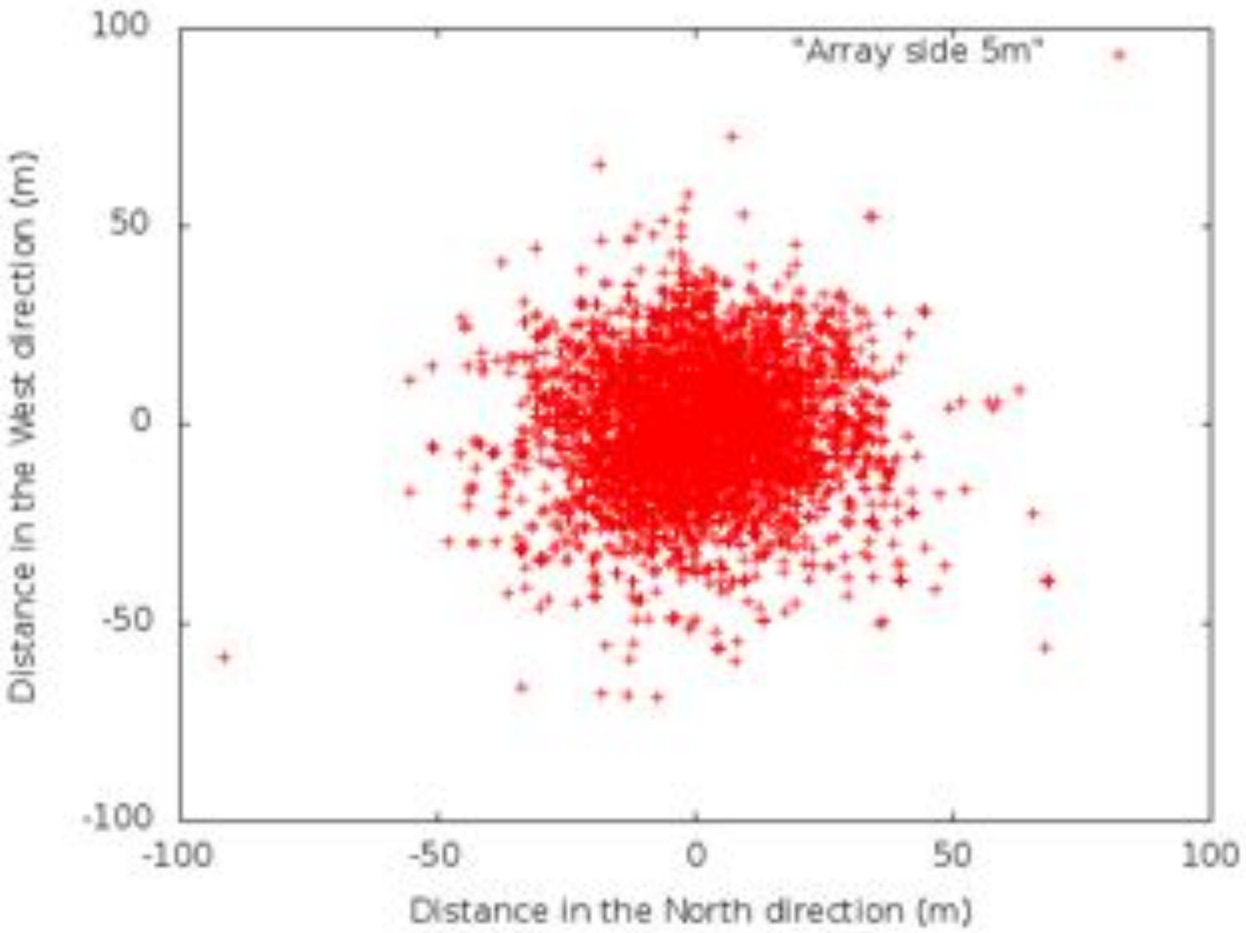
$\boldsymbol{D}_{oj} = \boldsymbol{D}_j - \boldsymbol{D}_o = x_{oj}\hat{\boldsymbol{i}} + y_{oj}\hat{\boldsymbol{j}}$ and $t_{oj} = t_j - t_o$

‘***D****oj*’ is the coordinate vector, ‘*toj’* is the time lag of *j*-th detector with respect to the reference one and ‘*c*’ is the velocity of light.

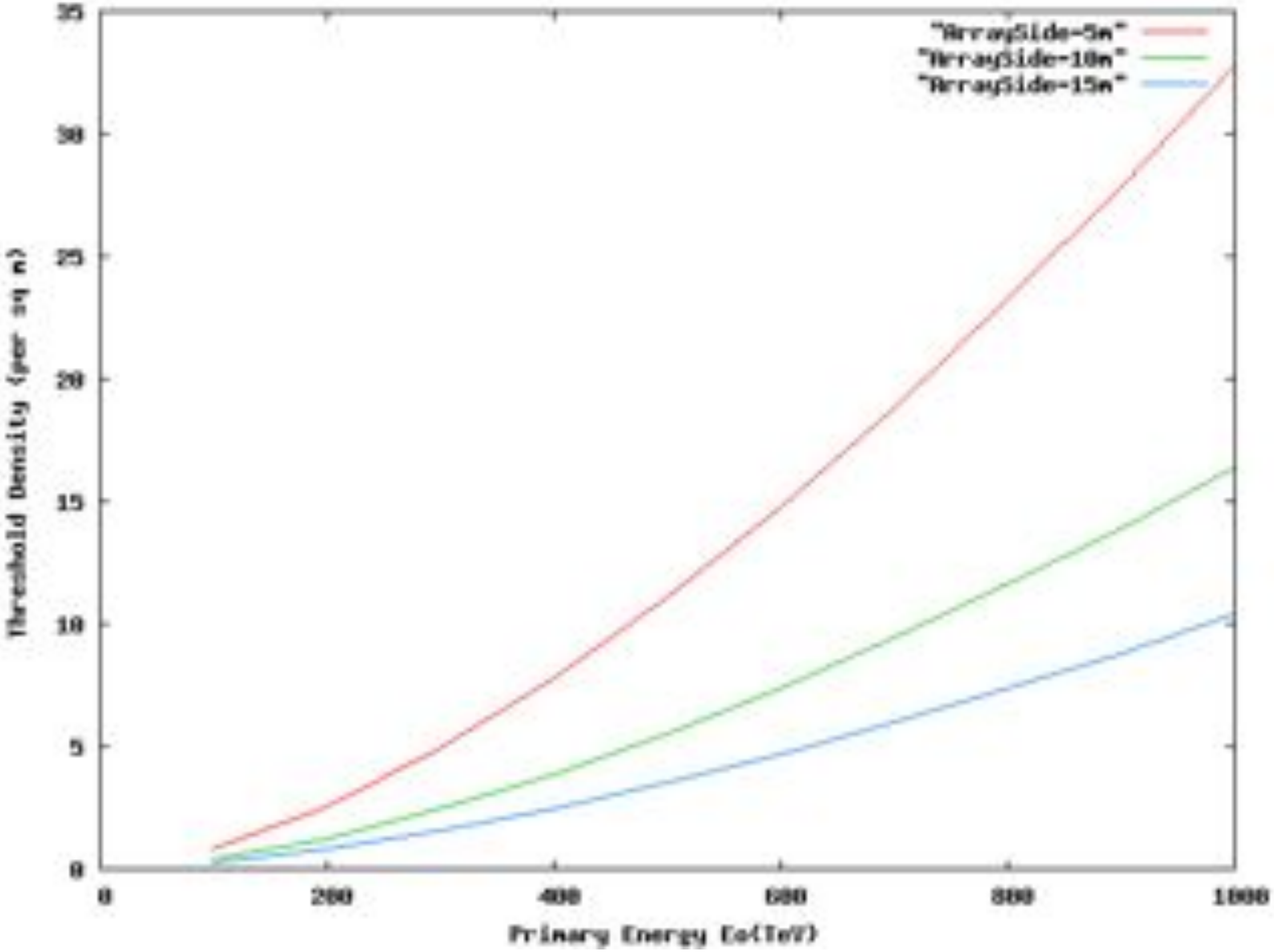
# Array Design

- Array is designed in terms of threshold parameters, using analytical formula and these are tested using artificial simulation of random projection of cores using CORSIKA simulation results.

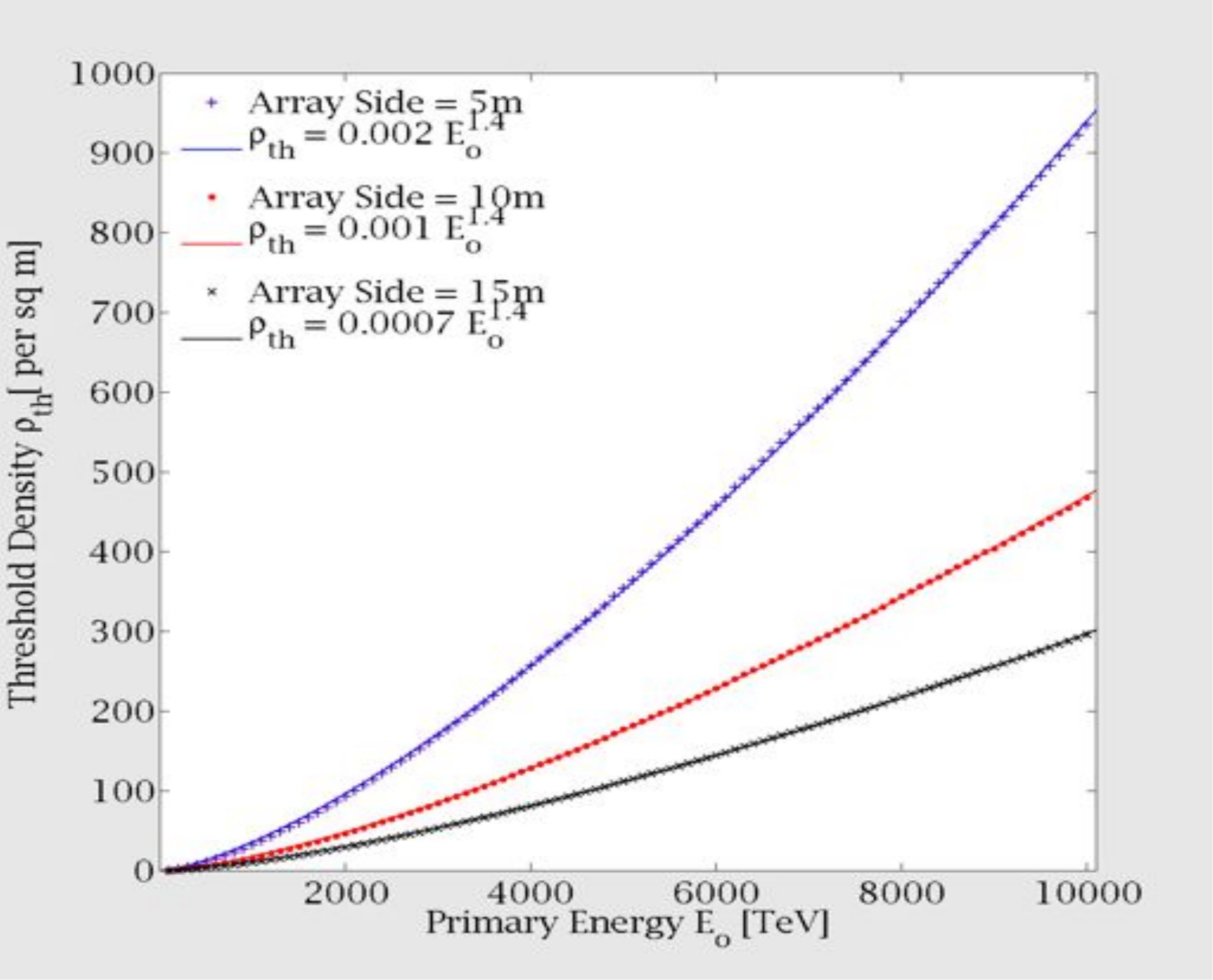
# Scatter plot of acceptable random cores in a 5mx5m array for 1 PeV vertical proton shower



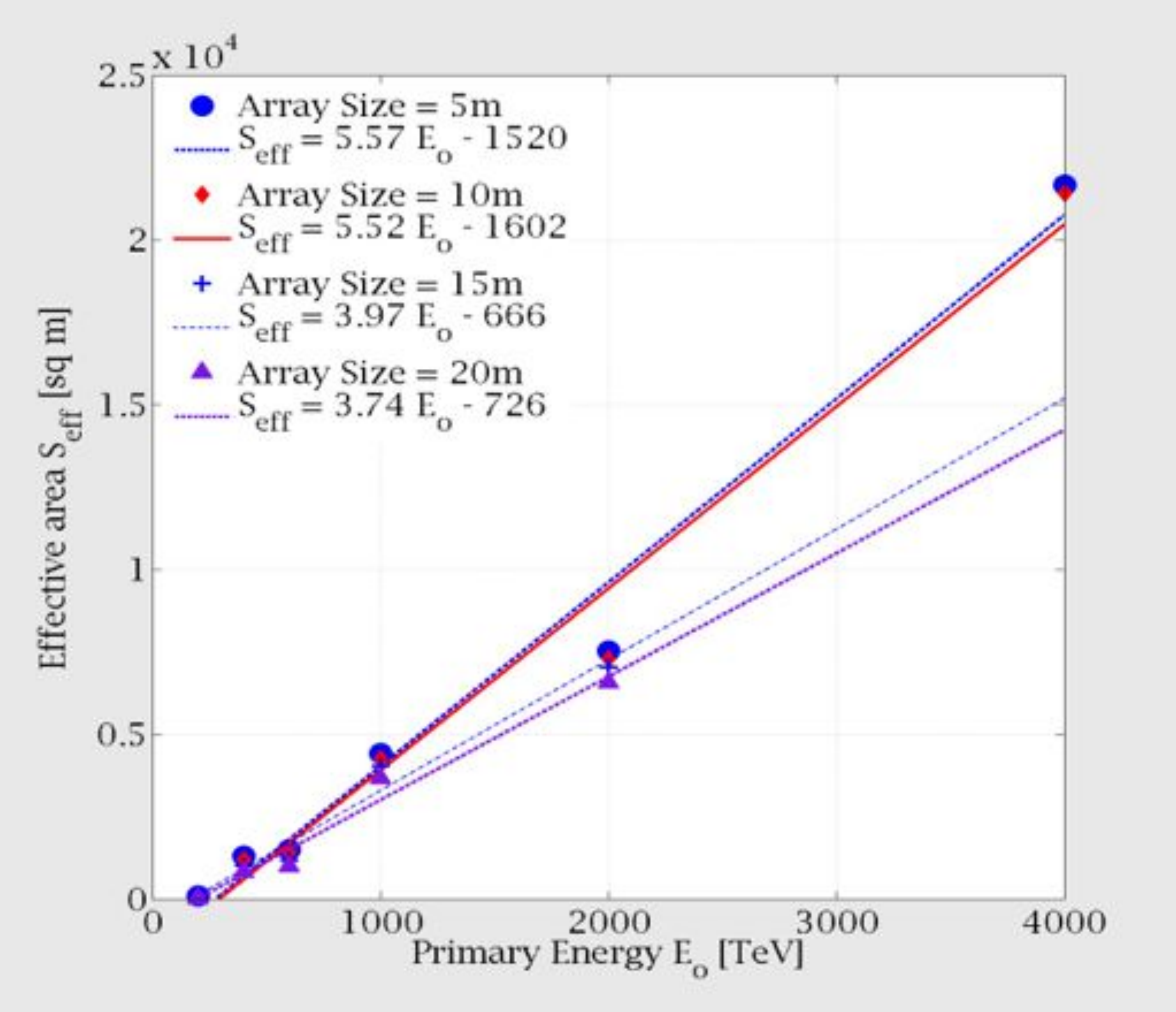
# Threshold density vs primary energy for 1m$^2$ scintillation detector



# Threshold density vs primary energy for a 1m$^2$ scintillation detector



# Effective area vs primary energy for a 1m² scintillation detector

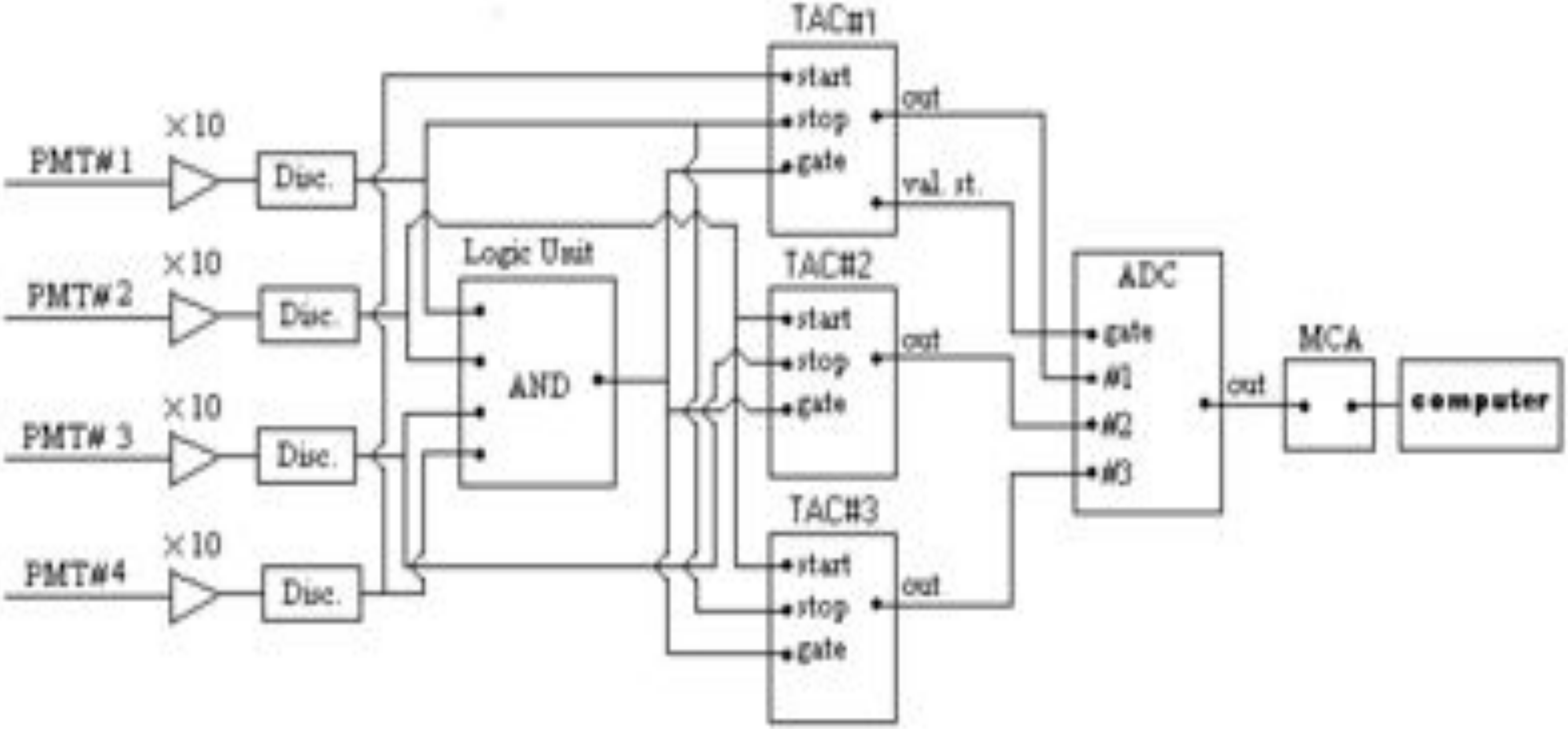


# Triggering Criterion and data acquisition

The signal output from the PMTs are to be discriminated for suitable trigger and connected to Time to Amplitude Converter(TAC). The time lag of three of the detectors with reference to the fourth one are to be recorded.

These data are used for measuring zenith and azimuth angles for each event.

The acceptance area and threshold energy  depends on the size of the square area and the selection of minimum triggering condition (threshold density).


PMT#1
×10
Disc.
PMT#2
×10
Disc.
PMT#3
×10
Disc.
PMT#4
×10
Disc.
Logic Unit
AND
TAC#1
start
stop
gate
out
val. st.
TAC#2
start
stop
gate
out
TAC#3
start
stop
gate
out
ADC
gate
#1
#2
#3
out
MCA
computer

# Atmospheric Effect

- Ground based arrays observe EAS past shower maximum and therefore, atmospheric absorption effect is dominant.
- The atmosphere acts as a part of the detector recording data and therefore affects EAS events.
- Since the thickness of the atmosphere increases with increasing zenith angle, the number of EAS events is strongly related to the zenith angle of the arrival direction.

# Atmospheric effect on count rate

- The rate of shower detections depends on zenith angle variation due to atmospheric thickness effect.
- Along with recording of particle number and arrival time, parameters like temperature, pressure and humidity may be recorded simultaneously. A multiple regression analysis of event rate against these parameters will help to study atmospheric effects.
- solar diurnal and seasonal changes affecting the atmospheric temperature and pressure may be studied.

# References

1. B. D'Ettorre Piazzoli et al., Astroparticle Physics, vol.2, (1994) 199-214.
2. S. M. H. Halataei et al., Physical Review D 77, 083001 (2008)
3. D.Heck et al., Report FZKA 6019, Forschungszentrum Karlsruhe, 1998.
4. M. Khakian Ghomi et al., 30th ICRC, V.4, P.15-18, HE0263 (2007)
5. Khakian Ghomi, M., Bahmanabadi, M.,Samimi, J., 2005, A&A, 434, 459
6. F. J. M Farley, and J. R. Storey, Proc. phys. Soc. , 996 (1954)
7. T. Antoni et al., ApJ , 687 (2004)
8. J. Linsley, Phys. Rev. Letts. , 1530 (1975)

# Thanks for your attention