

# Observation of Variations in Cosmic Ray Showers During Thunderstorms and Implications for Large-Scale Electric Field Changes

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# Balloon-borne electric field measurements



- Violent environment (dangerous and difficult)
- Size scale
- Time scale (rapid change)
- Perturbing the system while observing.

# Cosmic ray EAS Variations



The Baksan Experiment



Mount Norikura cosmic ray observatory



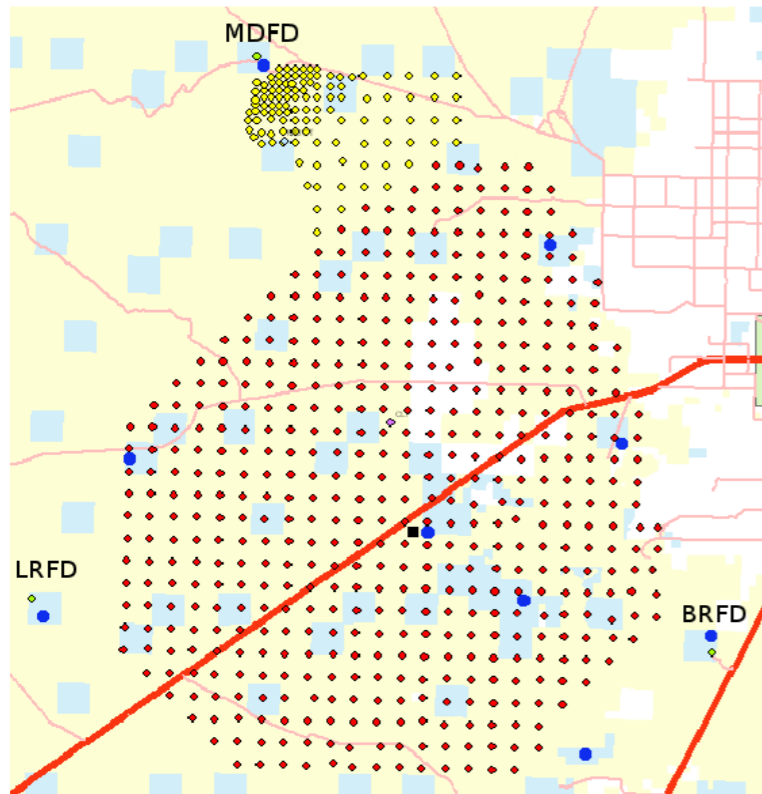
ARGO



GrapesIII-Muon Telescope

- Pre-lightning enhancement
- Variation without lightning effect
- soft component variation up to a few percents
- hard component variation up to one percent

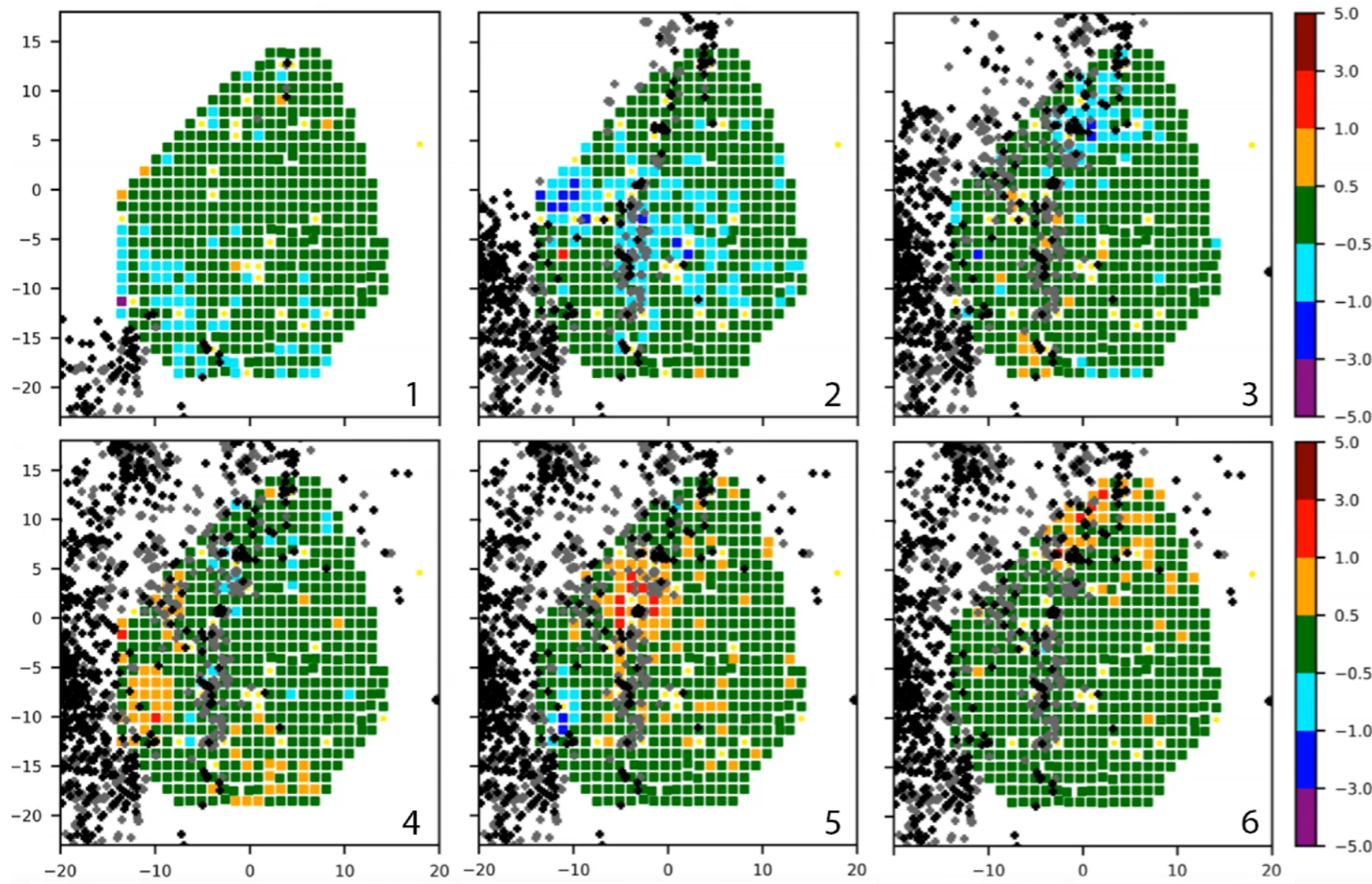
# TELESCOPE ARRAY



- **Signal  $> 0.3$  MIP are stored in Level-0 trigger data.**
- **The local trigger rate for Level-0  $\sim 750$  Hz**
- **Eth  $\sim 0.75$  MeV**
- **Level0 is used for detector monitoring**
- **Trigger rate  $\sim 10$  min resolution**



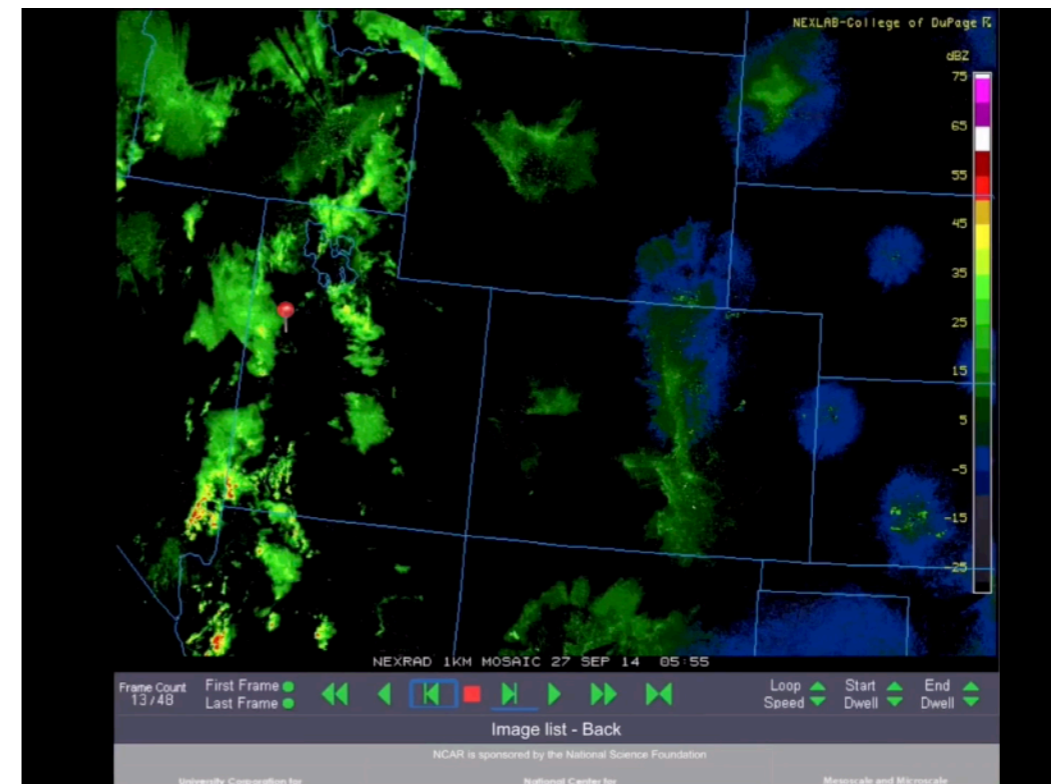
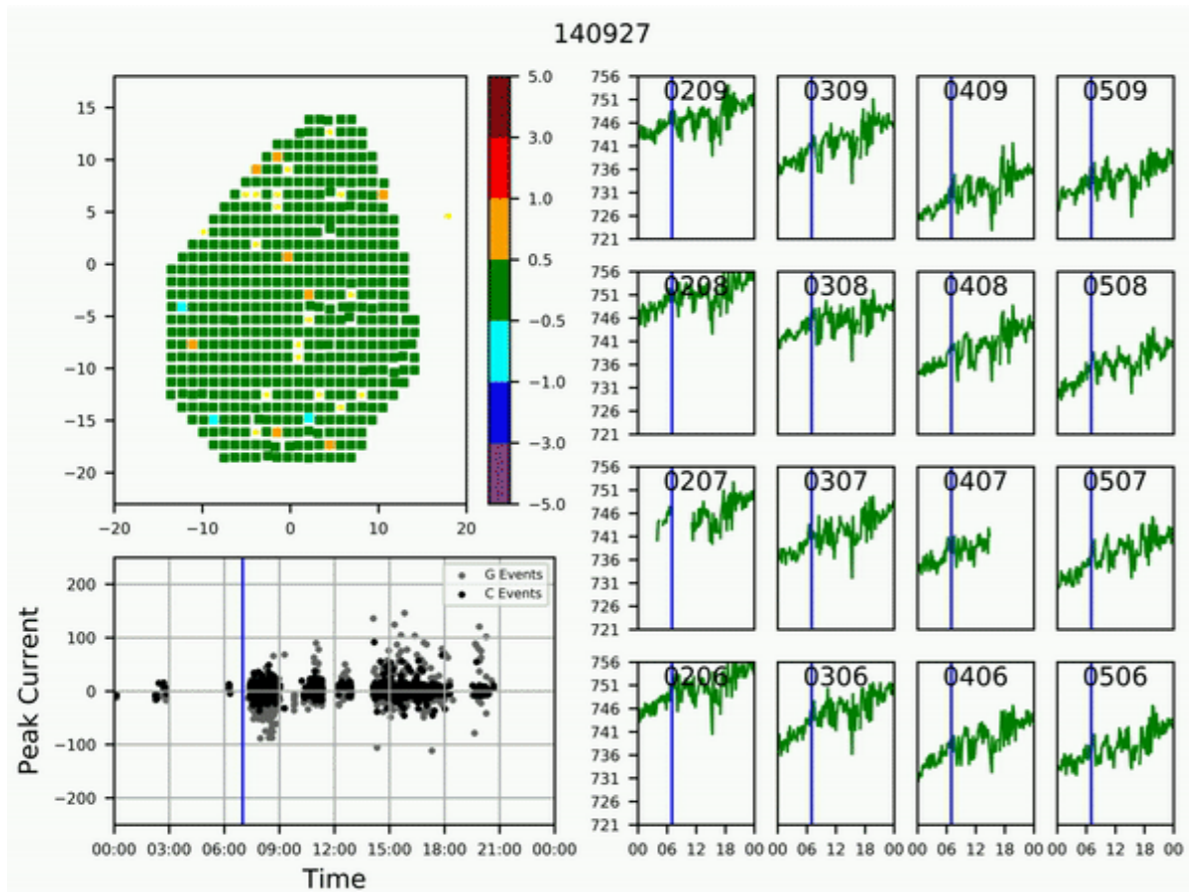
# Shower variation and Thunderstorms



- Shower intensity variations between  $-0.5$  —  $+3.0\%$ .
- Events were found to correlate with lightning reported by the National Lightning Detection Network (NLDN) in both time and location
- Correlation with Thunderstorms
- Footprint size is between 4-20 km in diameter and lasted 10s of minutes.

# Shower variation and Thunderstorms

weakly convective systems



# Monte Carlo simulation

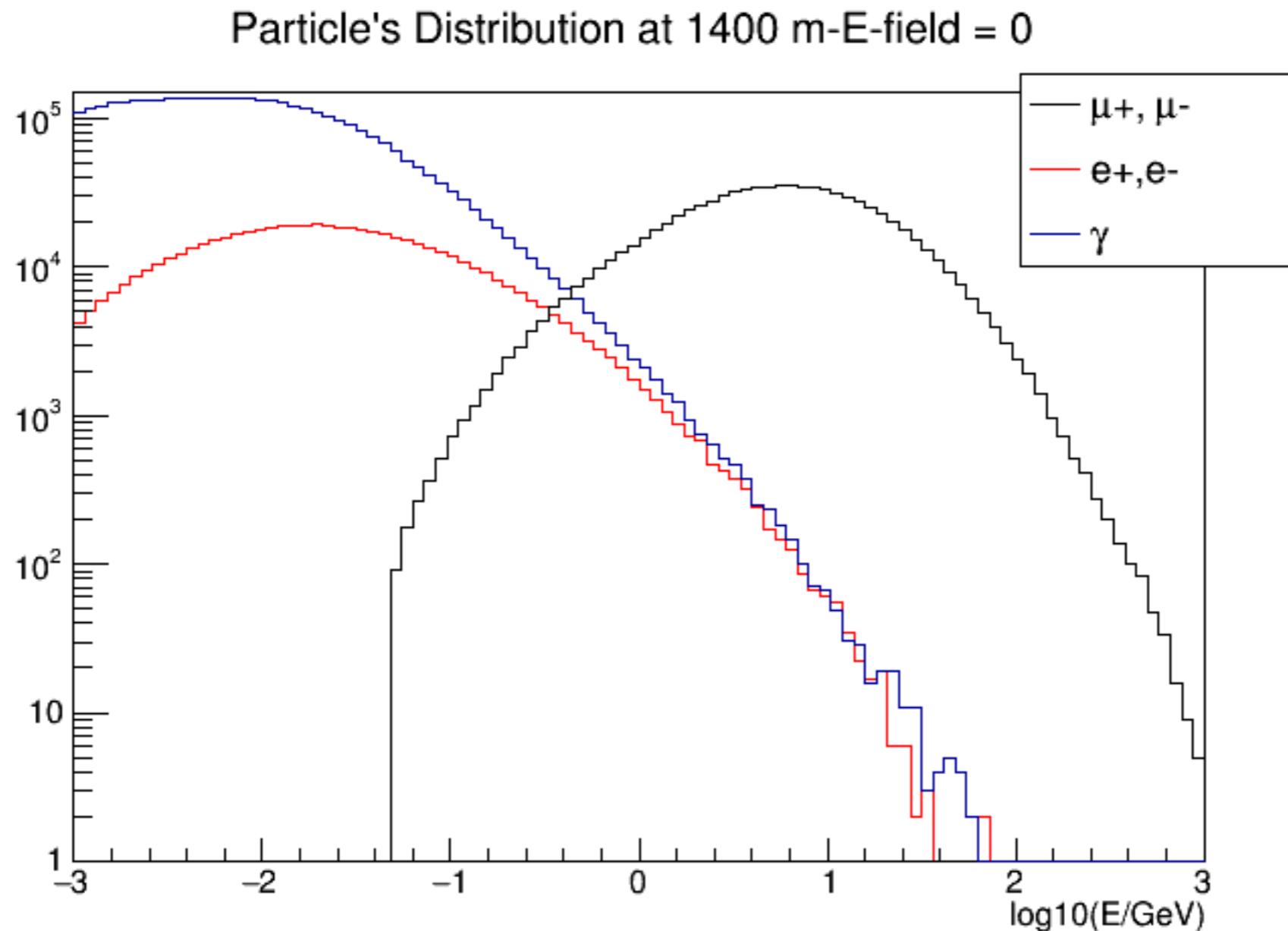
- Corsika v76900 - SIBYLL-GEISHA/URQMD/FLUKA
- $>7.5$  EFIELD in Corsika includes effect not only for positrons/electrons, but also for muonic and charged hadronic particles
- Efield -2000-2000 V/cm - [-200-200 kv/m]
- IC: Height of 3.4-5.4 km asl.
- CG: From 1.4 km-3.4 km asl

# Monte Carlo simulation

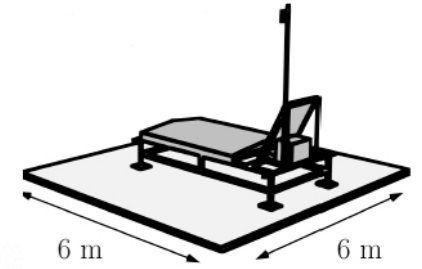
- Corsika v76900 - SIBYLL-GEISHA/URGMD/FLUKA
- 1,00,000 proton showers per data set
- Energy 20 GeV- 10TeV
- Angular range  $0^\circ < \theta < 60^\circ$  and  $0^\circ < \phi < 360^\circ$
- Cuts Hadron 500 MeV/ Muon 50 MeV/ e 1 MeV /Gamma 1 MeV.
- Models: simple uniform (IC,CG) electric field
- sets with changing Efields and one set without for background.



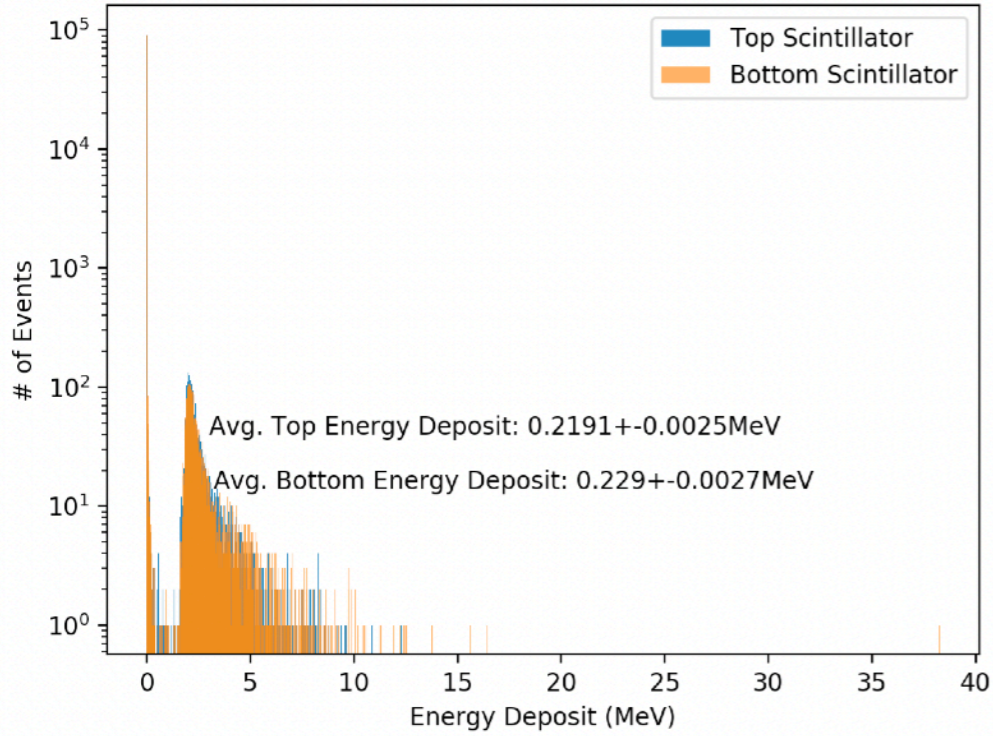
# Energy distribution of muon/ electrons at TA for 20GeV-100TeV



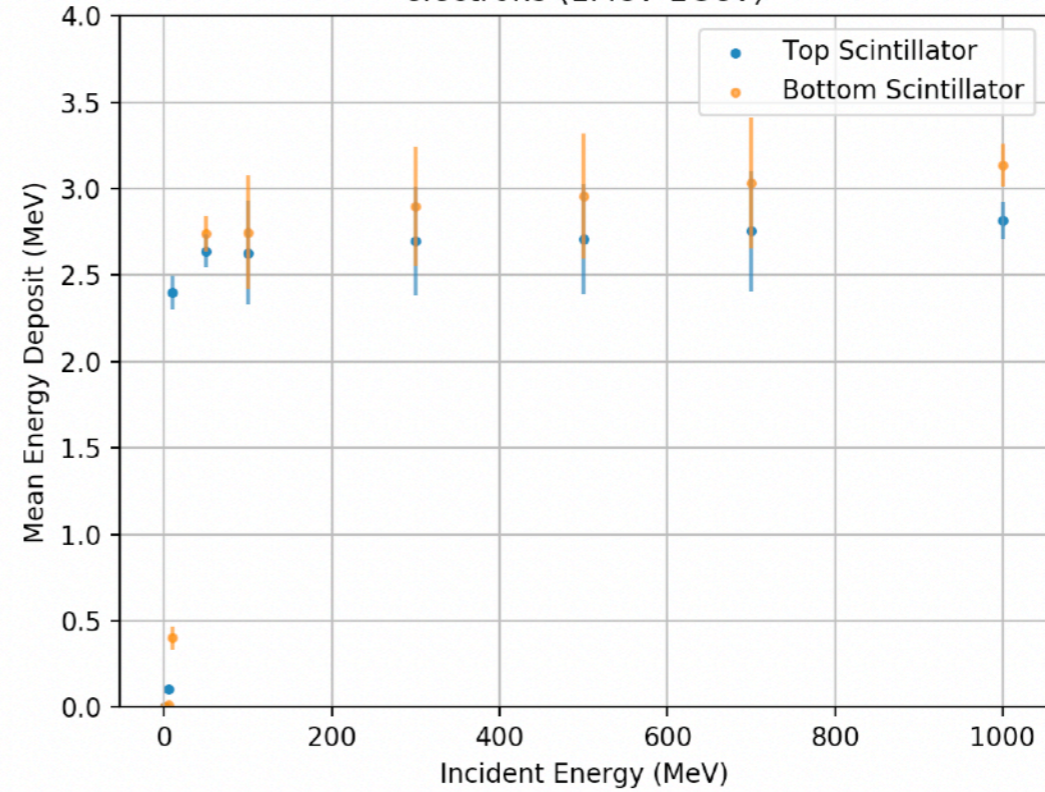
# $e^-$ and $\gamma$ 's Detection



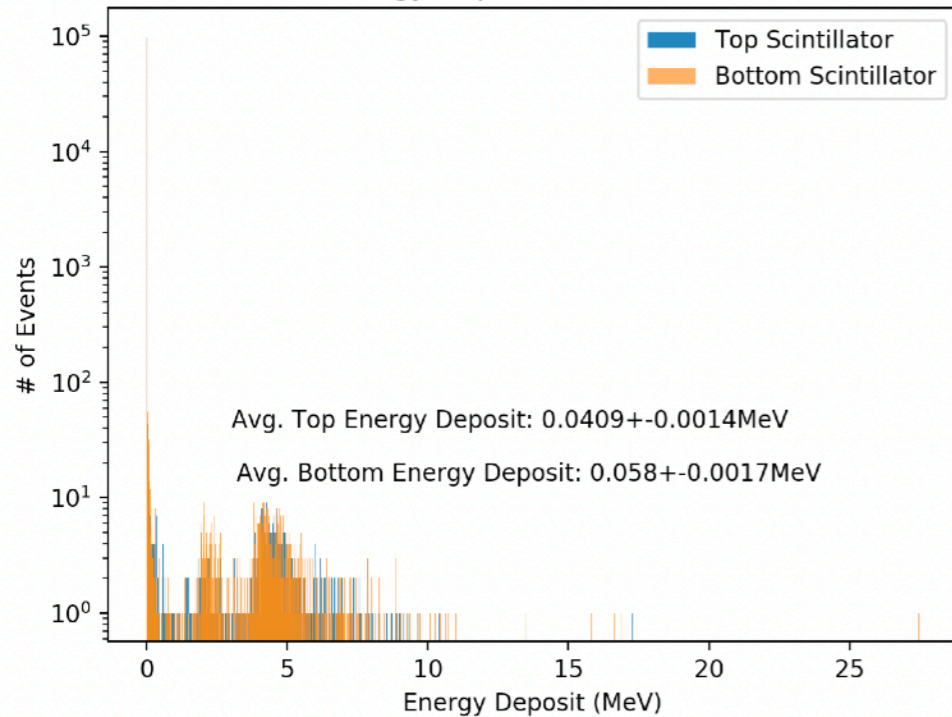
Energy Deposit for 100 MeV



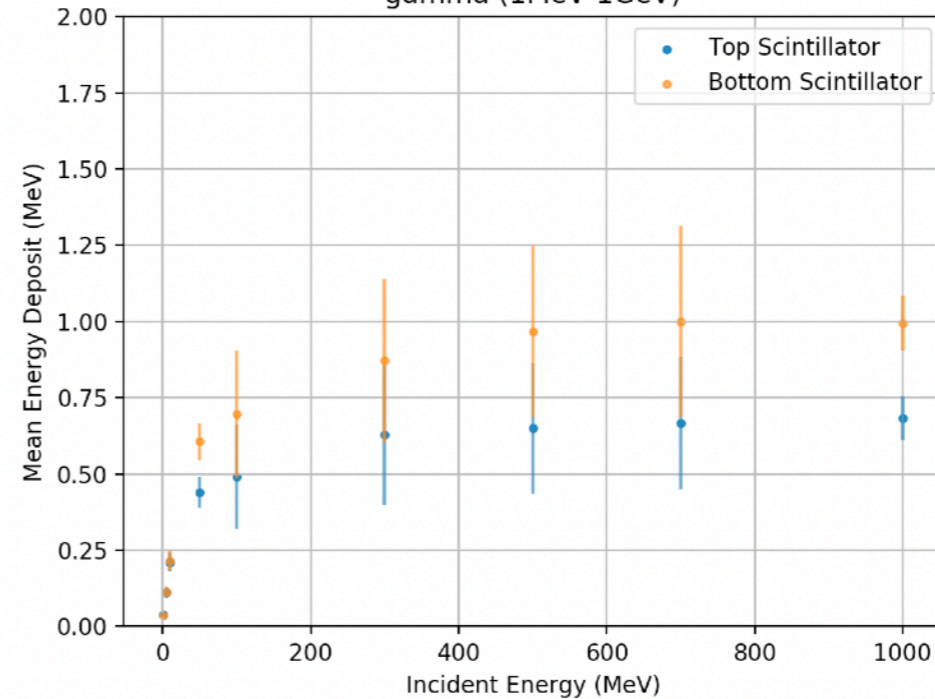
electrons (1MeV-1GeV)



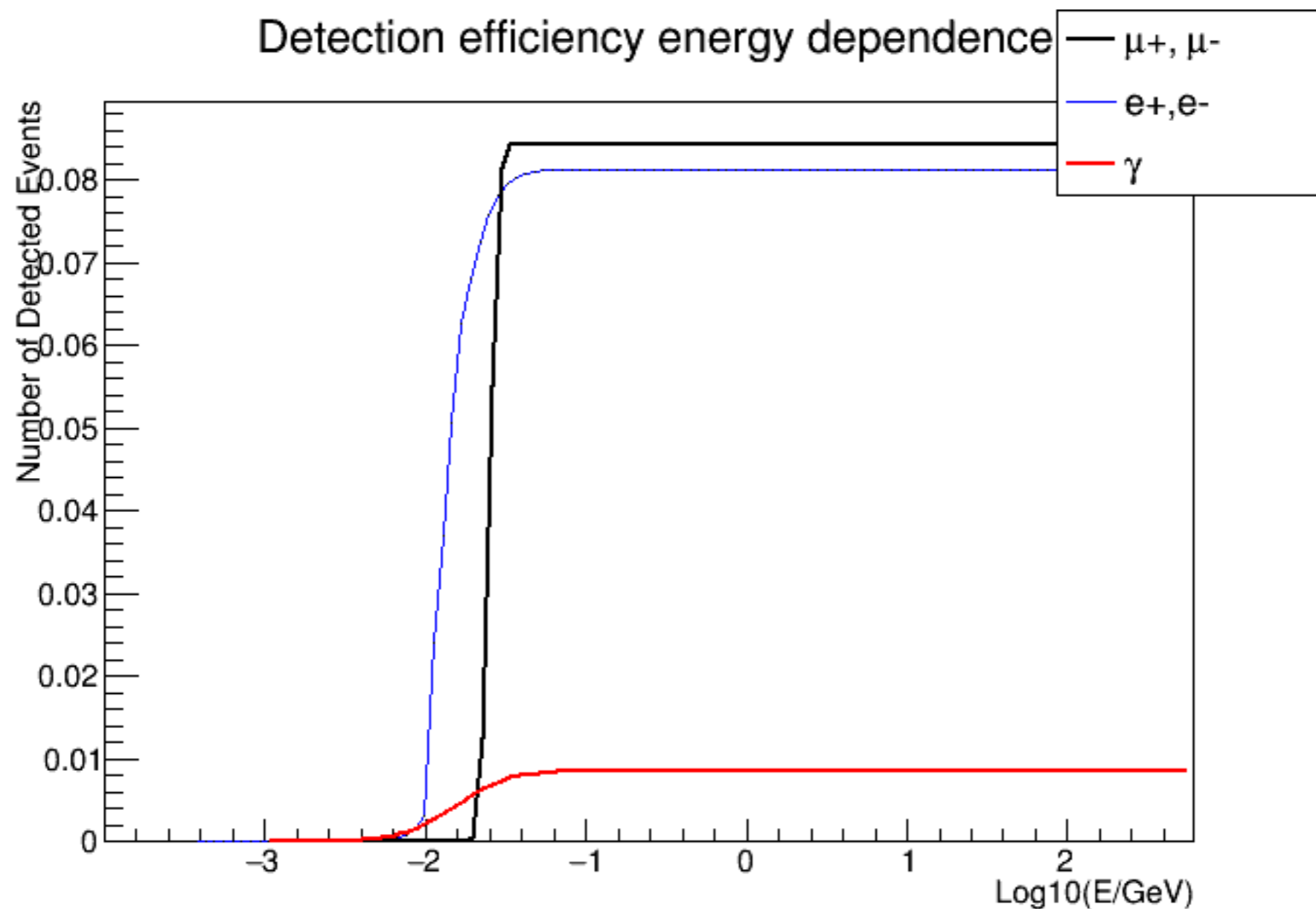
Energy Deposit for 100 MeV



gamma (1MeV-1GeV)

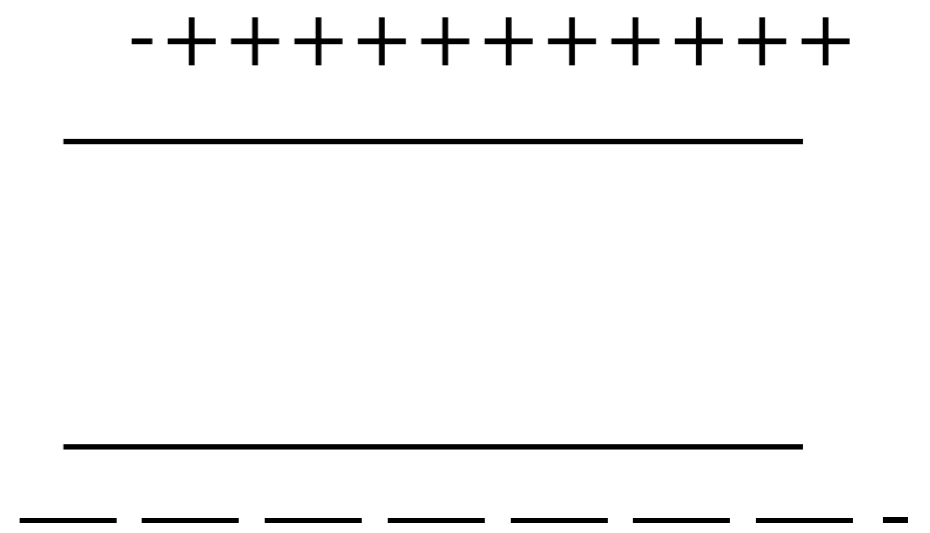
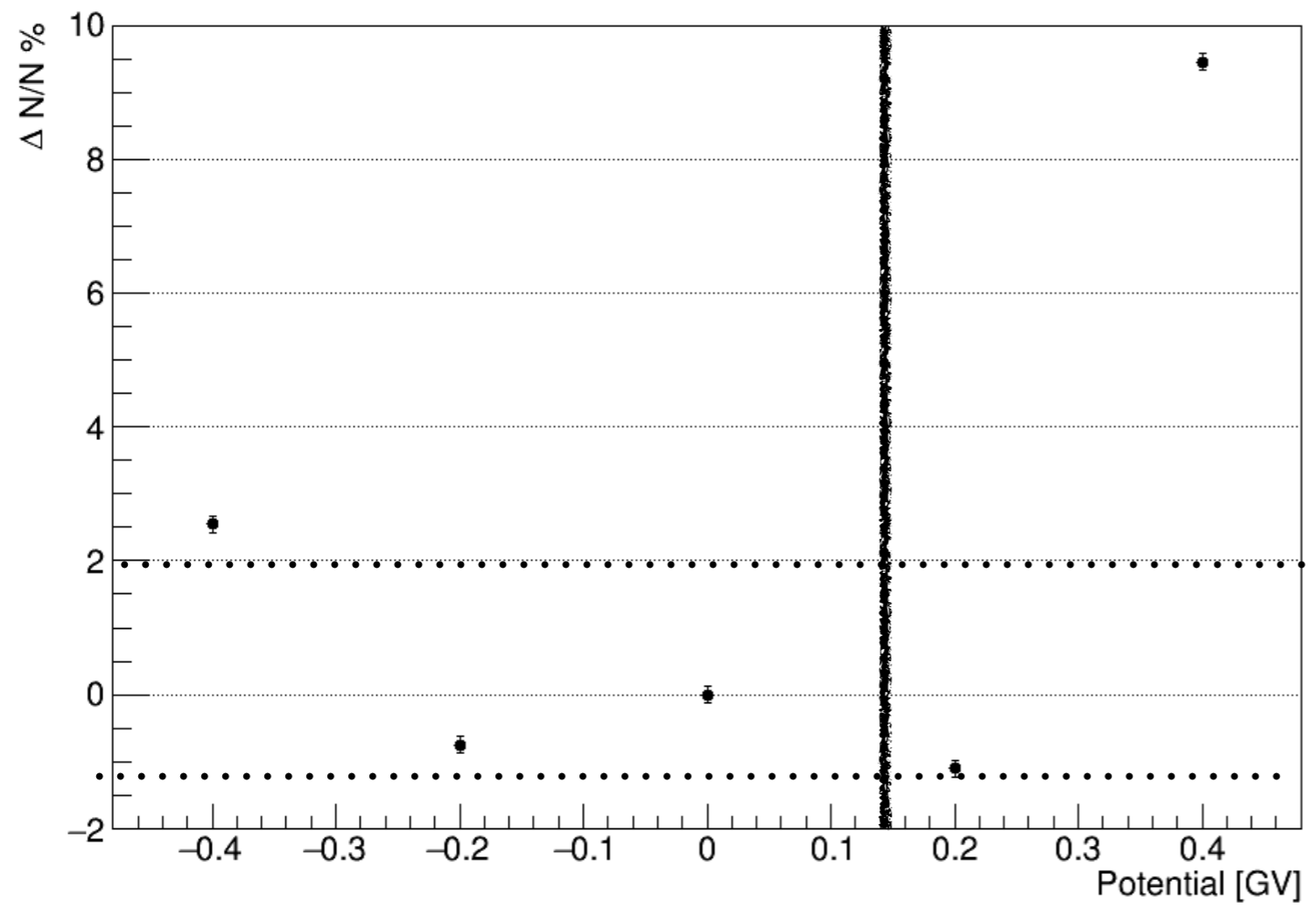


# Detector Efficiency Energy Dependence



Intra-Cloud model

URQMD Model-I



IC: Height of 3.4-5.4 km ASL

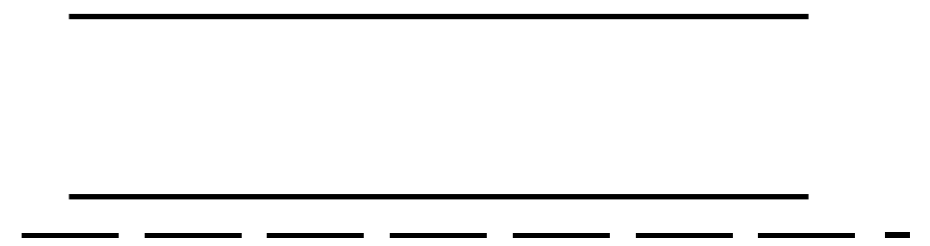
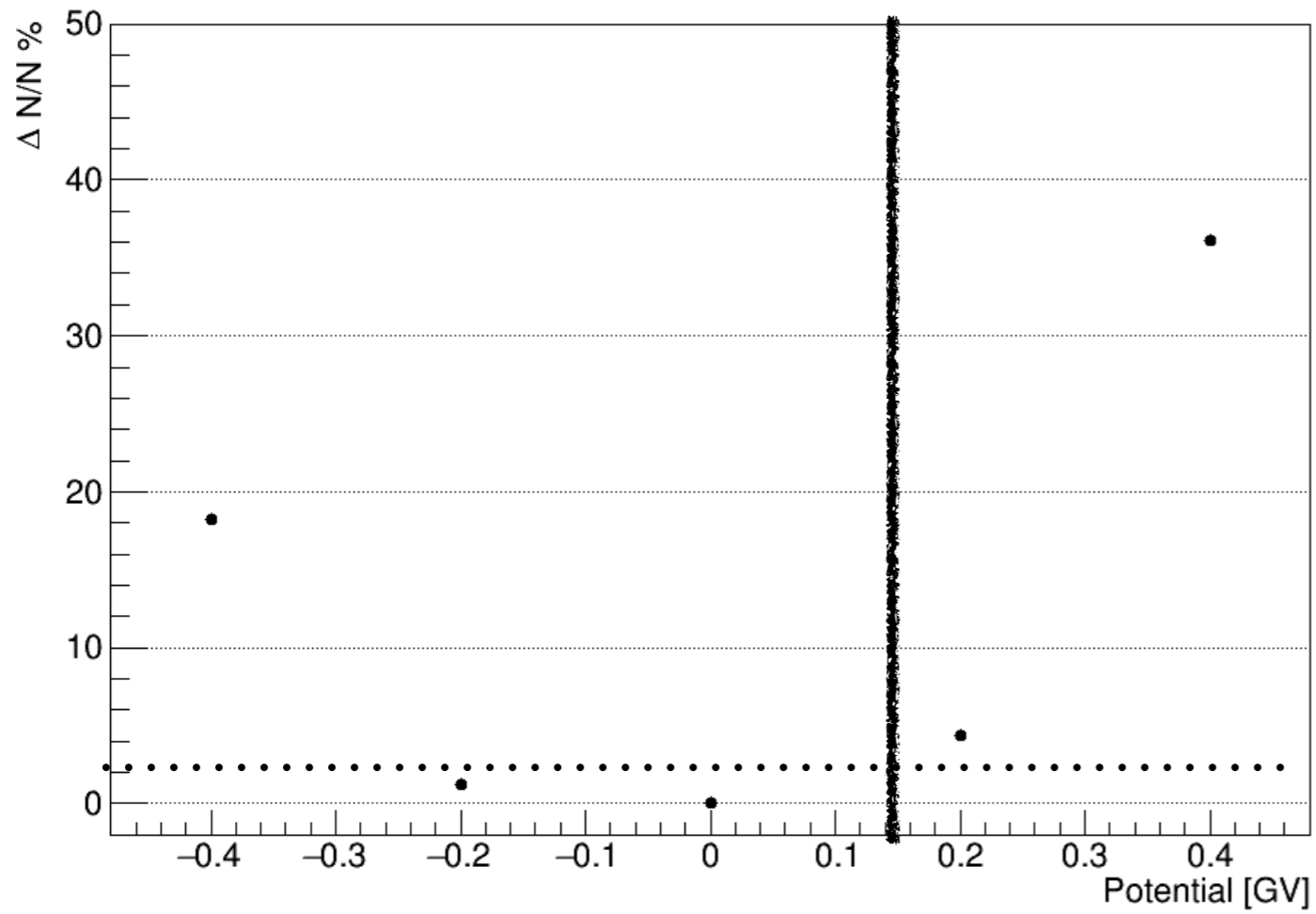
2km in change separation

TA

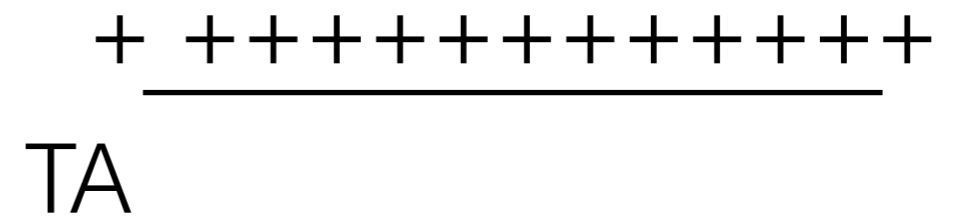


Cloud-Ground model

URQMD Model II



CG: Height of 1.4-3.4 km ASL



# Conclusion

- Observations of variations in the cosmic ray EAS rate (1-3)% in magnitude.
- First observations of thunderstorms progressing in 10s of minutes over 700 km<sup>2</sup>.
- Interpret the observations via simple Corsika simulation electric field model.
- Electric Field Mills array.

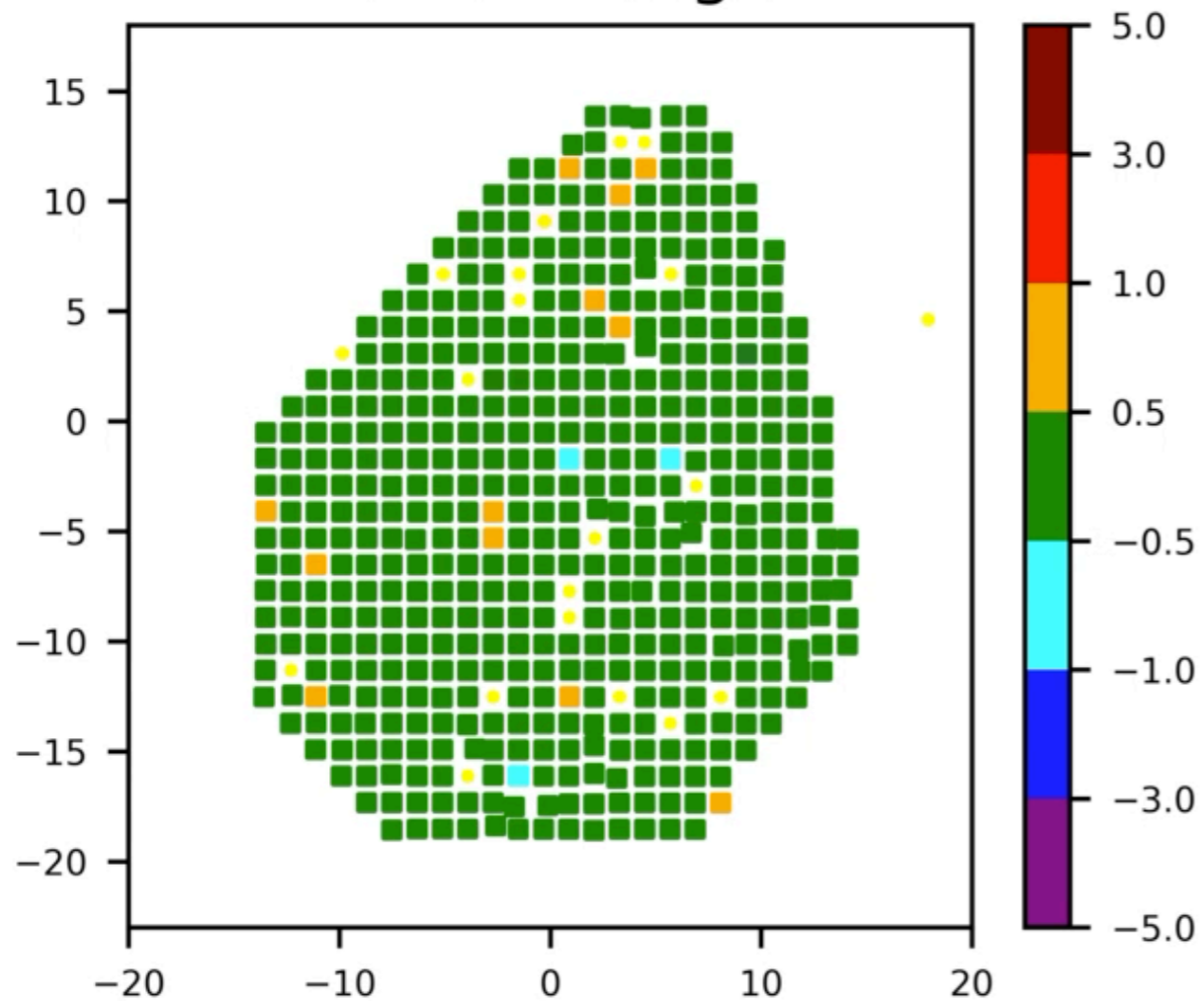


Backup slide

# Shower and Temp variation and Thunderstorms

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## Rate Change



## Temperature Change

