ENERGY ESTIMATOR OF ULTRA-HIGH ENERGY COSMIC RAYS(UHECRS) USING GEANT4 SIMULATION

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UHECRs(Ultra-High Energy Cosmic Rays)

- Intensity of UHECRs

  1 event

  per 1km^2 area per century

  for particles with energies *$E_0 > 10^{18}$eV

  * E_0 is primary cosmic ray energy

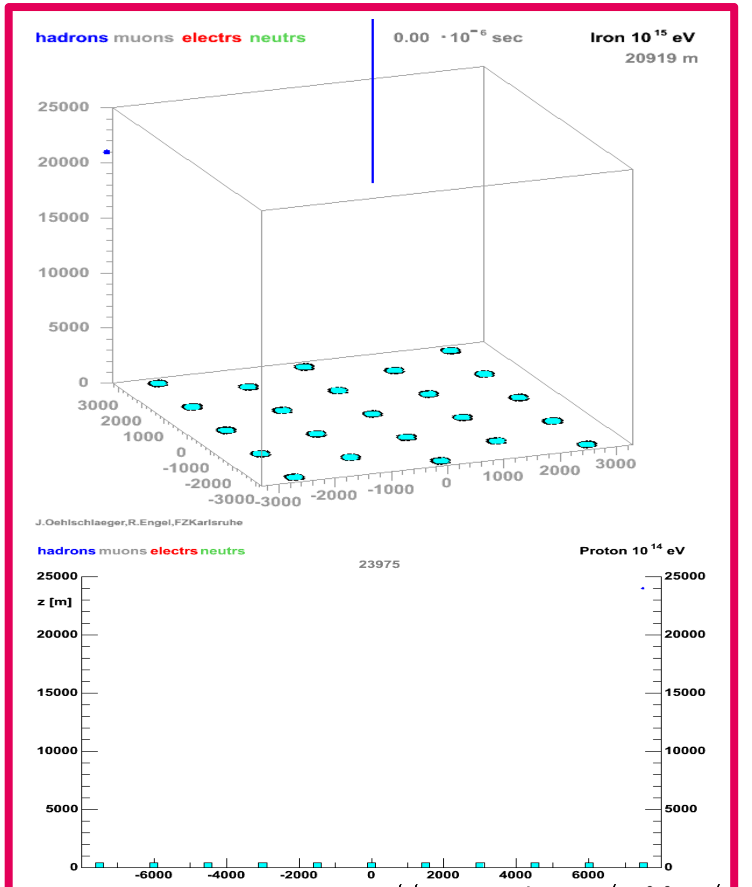
- However,

  the shower cascade in air

  → Extensive Air shower(EAS)

  → billions of sub-particles

  on the ground



http://www-ik.fzk.de/corsika/

Ground Array Method

- Sample the charged secondary shower particles as they reach the ground
  → distributed surface detectors measure the energy loss generated by particles
  → the primary energy from the particle density

Ground Array ? - TA Surface Detectors

A Good Energy Estimator, S(800)

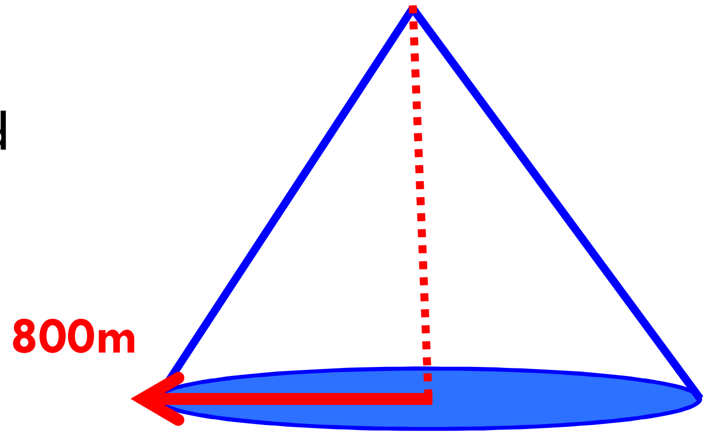
- **S(800)** means the particle density at 800m from the shower core!

⇒ by measuring energy deposition on surface detector

- **S(distance from shower core), for example, S(800)**

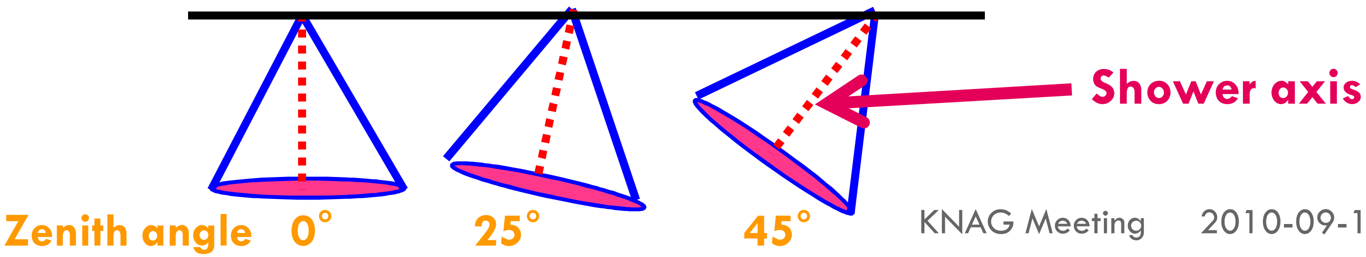
  - Fluctuation of the local number density of shower particles far from the core is significantly small.

- The past cosmic ray experiments used
  - S(600) in AGASA
  - S(1000) in Auger
  - **S(800) in TA ?**



Monte Carlo Simulations

- CORSIKA and COSMOS simulation
- Hadronic Interaction Model
- Cut energies
  - EM component 500 keV
  - The other component 50 MeV
- **Generate AS event (p, Fe)**
  - Primary energy $10^{18.5} \sim 10^{20.25}$eV 0.25 step in $\log_{10}$
  - Zenith angle 1.00 ~ 0.70 0.05 steps in cosine



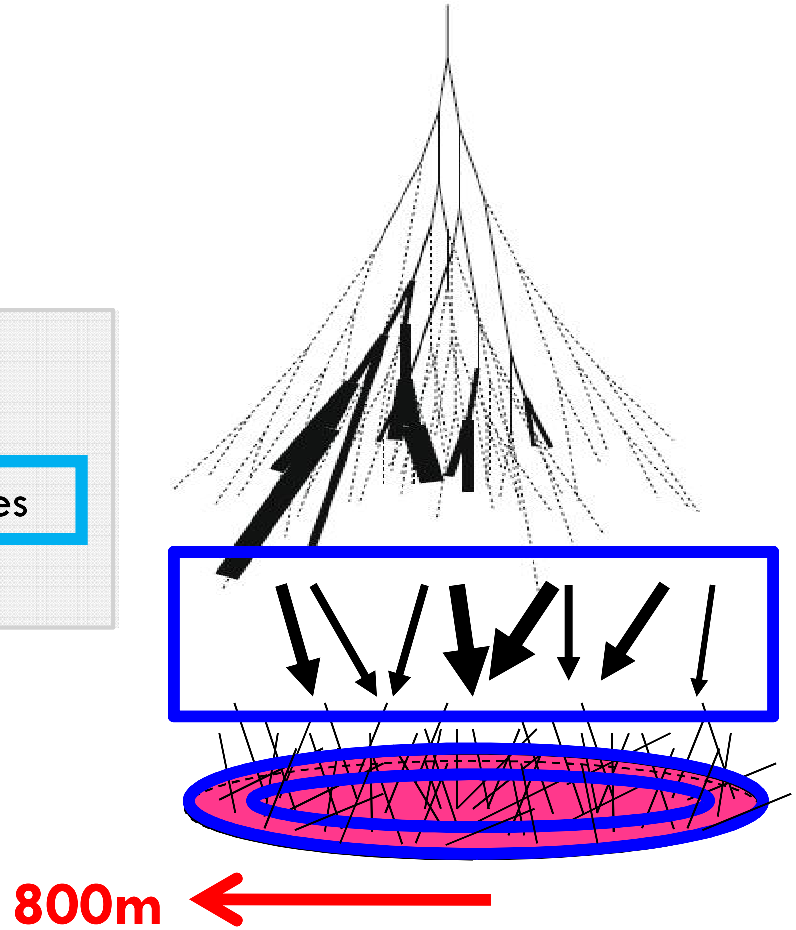
Particle Energy Spectrum

- Generate Air shower
  - "thinning method"
- Using sub-particles

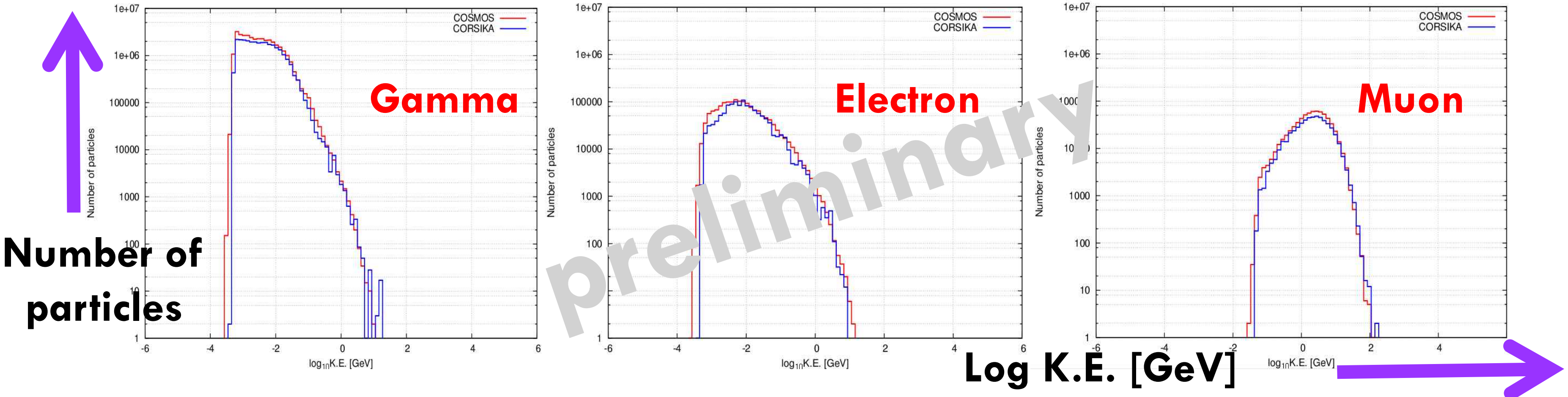
Using Weighted particles → Reproduce particles

"Dethins" method

- Acquire the particles falling in the ring (near 800m)

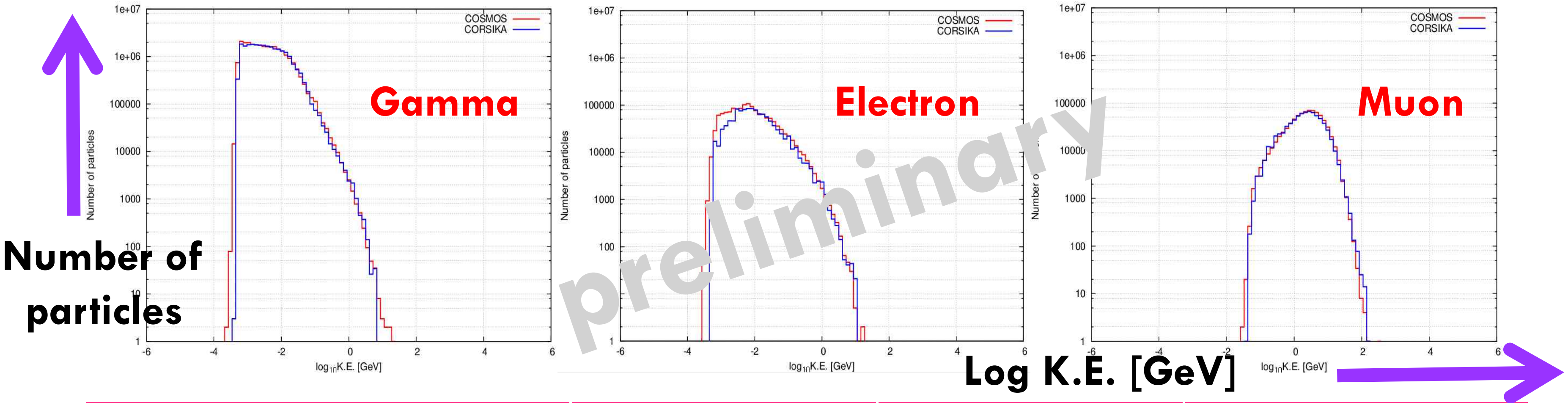


Particle Energy Spectrum in the ring(750~850m)



Proton Primaries		COSMOS Sim.	CORSIKA Sim.	Difference
Gamma	Total energy	2.618819e+05	2.202126e+05	19%
	Total no. of particles	3.498243e+07	2.936467e+07	19%
Electron	Total energy	3.895400e+04	3.075245e+04	27%
	Total no. of particles	1.516596e+06	1.226405e+06	24%
Muon	Total energy	1.906912e+06	1.613041e+06	18%
	Total no. of particles	6.532425e+05	5.301190e+05	23%

Particle Energy Spectrum in the ring(750~850m)

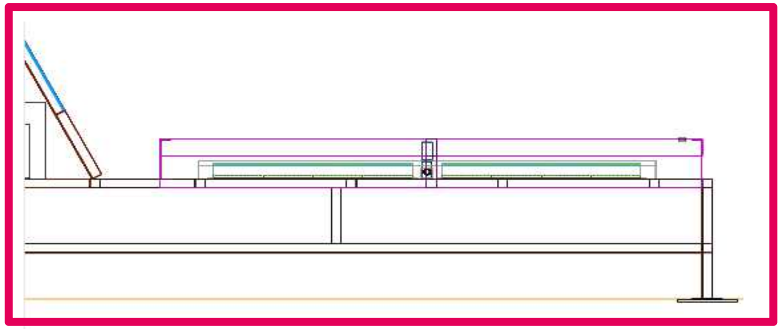


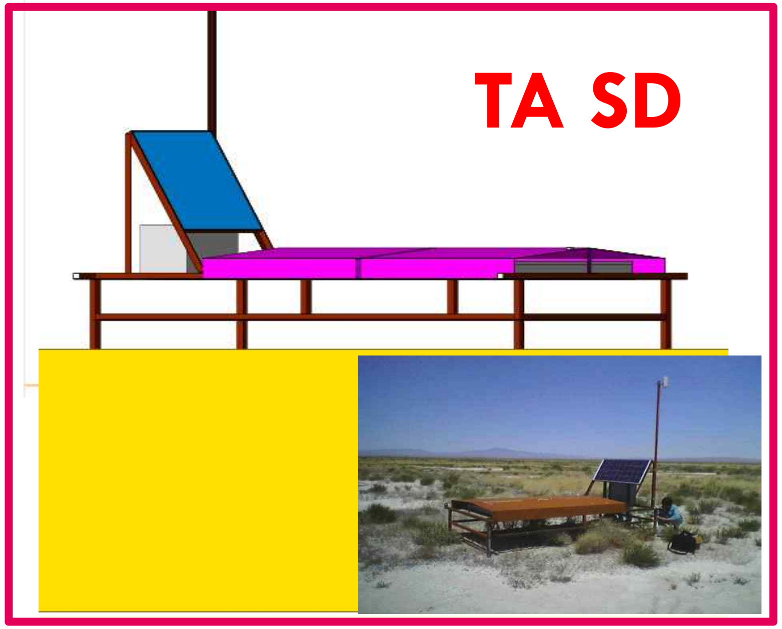
Iron Primaries		COSMOS Sim.	CORSIKA Sim.	Difference
Gamma	Total energy	2.043813e+05	2.095098e+05	2.5%
	Total no. of particles	2.382721e+07	2.493880e+07	4.5%
Electron	Total energy	3.913562e+04	3.568663e+04	9.7%
	Total no. of particles	1.303323e+06	1.167950e+06	1.2%
Muon	Total energy	2.569609e+06	2.249879e+06	1.4%
	Total no. of particles	7.453085e+05	7.046200e+05	5.8%

Geant4 Simulations

- I used TA(Telescope Array) SD(Surface Detector) set

  which is made by one of our TA group collaborators

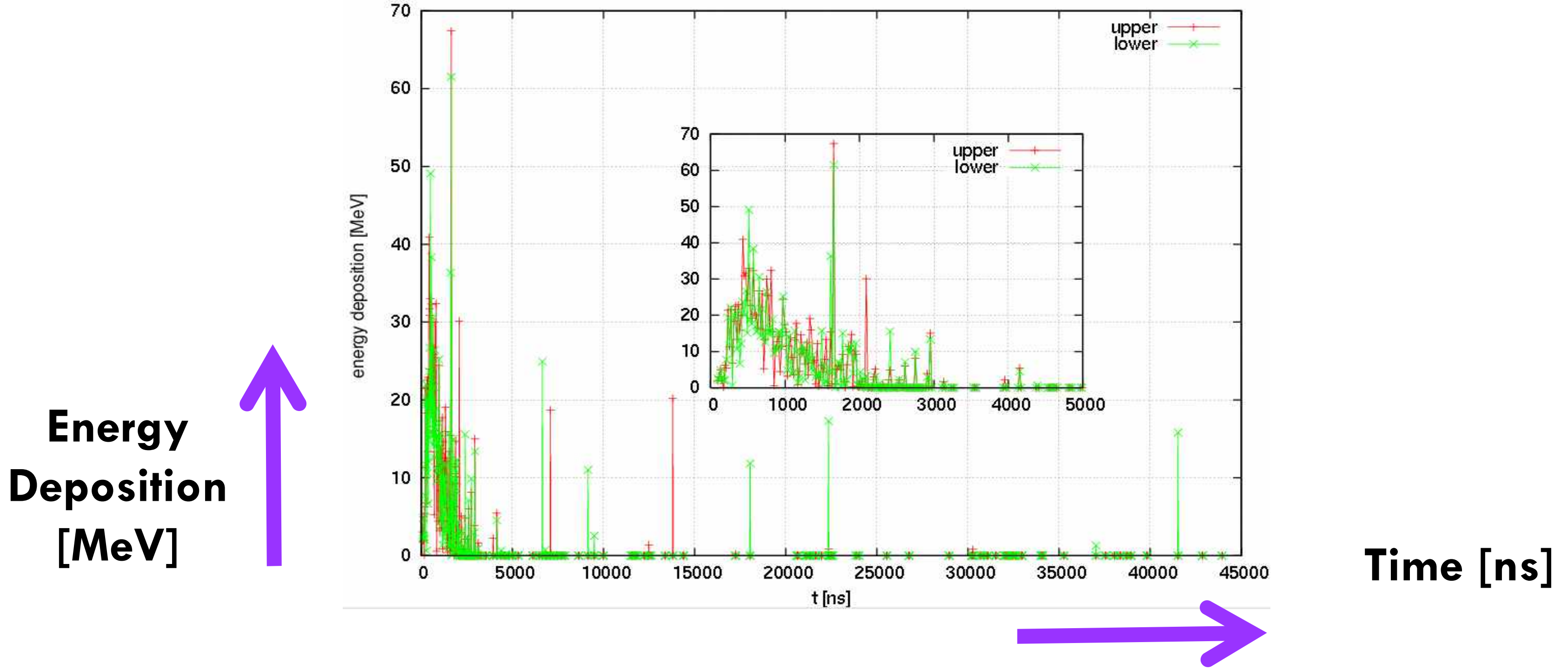




- What we need
  - ✓ Particle ID
  - ✓ charge of particle
  - ✓ arrival time
  - ✓ momentum
  - ✓ energy of particle
  - ✓ position
  - ✓ incident angle

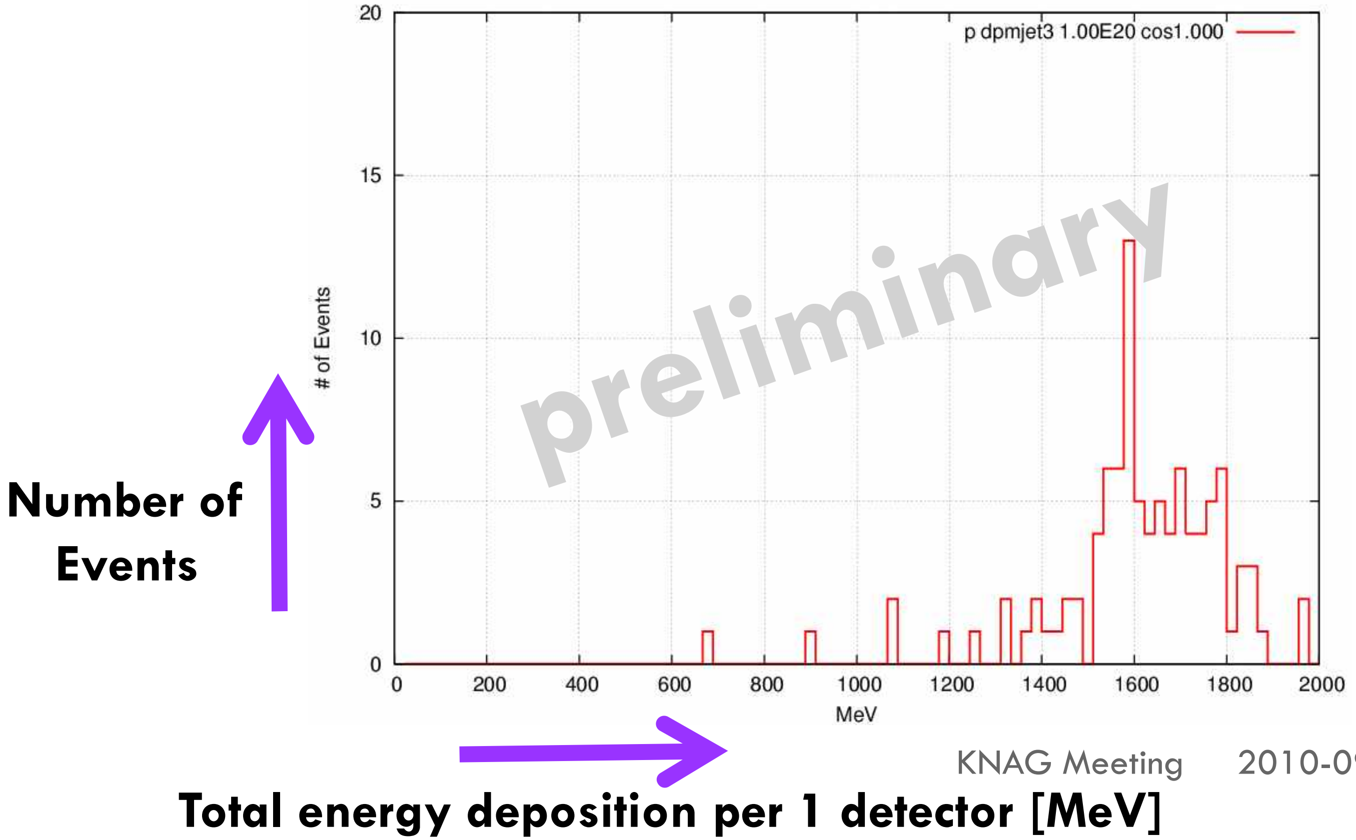
Detector Response

- 3 m^2 area, 2 layers
- Upper & Lower layer are separated optically
  ← Using GEANT4 simulation



Energy Deposition　S(800)

- Proton primaries
- 10^{20}eV with a zenith angle of 0°



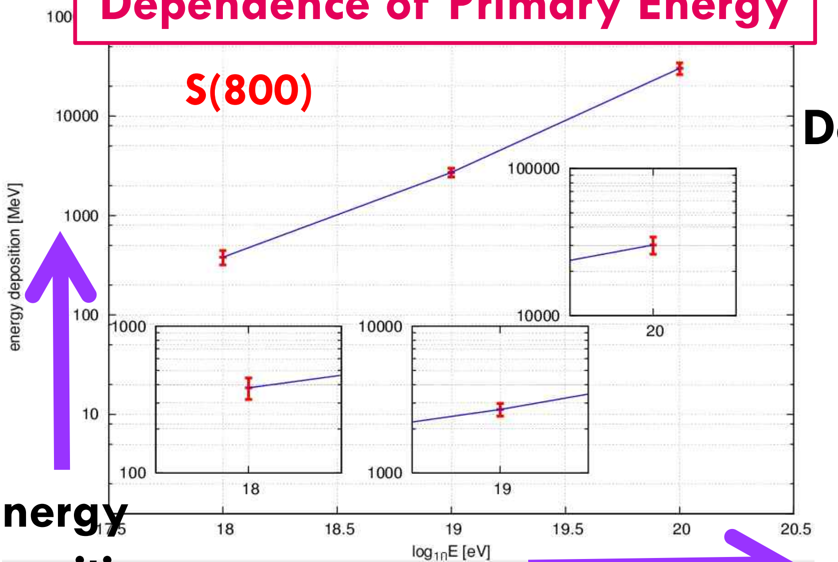
Energy Deposition

- A high-energy particle → A larger air shower and particles
- Shower particles far from the core

  ← produced at early stage of the shower cascading

  & scattered out by the Coulomb process

Dependence of Primary Energy

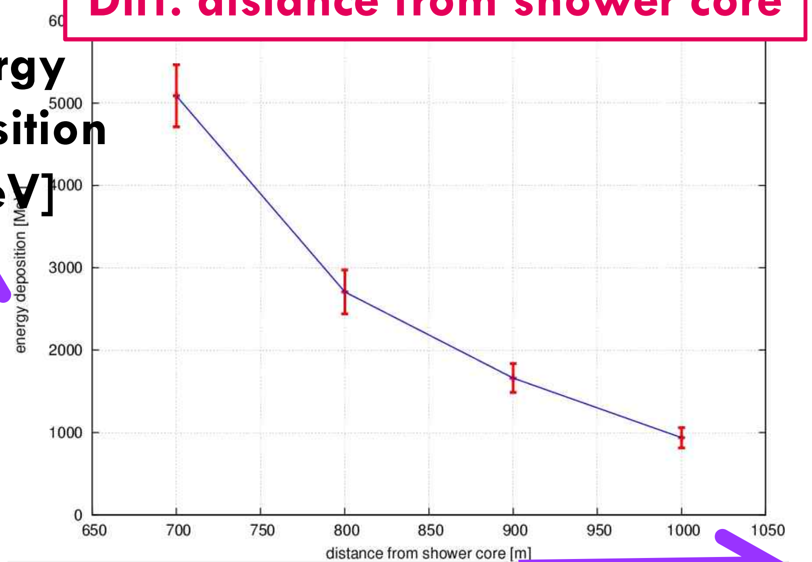


Energy Deposition [MeV]

Primary Energy [eV]

Diff. distance from shower core

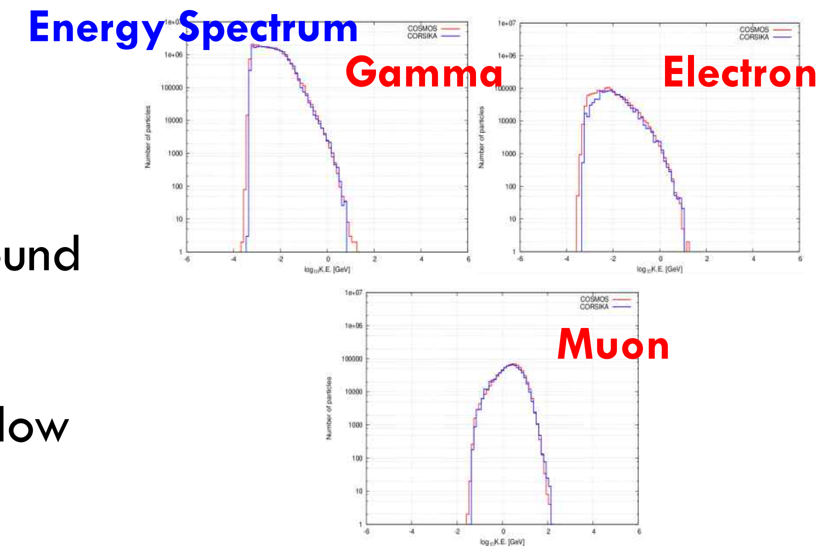
Energy Deposition [MeV]



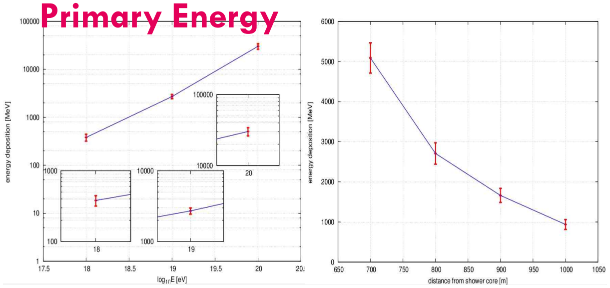
Distance from shower core [m]

Summary

- Particle Energy Spectrum near 800m from core
  - ✓ Energy of particle arriving at the ground COSMOS Sim. > CORSIKA Sim.
  - ✓ In Iron shower, CORSIKA has a lot of low energy particles than COSMOS.



Dependence of Primary Energy



Diff. distance from shower core

- Energy Deposition
  - ✓ The energy deposition far from the core is indeed stably proportional to primary energy.
  - ✓ The fluctuation of the local energy deposition far from the core is significantly small.

Back-Up Slides

- ✓ Current CORSIKA/COSMOS simulation library

Current CORSIKA/COSMOS simulation library

Table1. CORSIKA simulation library
Table2. COSMOS simulation library

Table 1

Cos(Zenith angle) \ Primary energy	$10^{18.5}$eV	$10^{18.75}$eV	10^{19}eV	$10^{19.25}$eV	$10^{19.50}$eV	$10^{19.75}$eV	10^{20}eV	$10^{20.25}$eV
1.00	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe
0.95								
0.90								
0.85								
0.80								
0.75								
0.70	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe

Table 2

Cos(Zenith angle) \ Primary energy	$10^{18.5}$eV	$10^{18.75}$eV	10^{19}eV	$10^{19.25}$eV	$10^{19.50}$eV	$10^{19.75}$eV	10^{20}eV	$10^{20.25}$eV
1.00	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe
0.95					10p			
0.90	50p,50Fe	40p	40p	40p	40p	30p	30p	8p
0.85					10p			
0.80	10p,10Fe	10p,10Fe	10p,10Fe	10p,10Fe	10p,10Fe	10p,10Fe	10p,10Fe	10p,10Fe
0.75		50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe		50p,50Fe	
0.70	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe	50p,50Fe