



## A Linear Accelerator for TA-FD calibration

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**Abstract:** The energy of the primary cosmic ray can be calculated from fluorescence photons detected by fluorescence telescope. However, since we can not know the true energy of primary cosmic ray, it is difficult to calibrate between number of photons and energy directly. In the Telescope Array project, we proposed to create pseudo cosmic ray events by using accelerated electron beam which is injected in the air. We are developing a small linear accelerator at KEK in Japan. The maximum energy is 40MeV, and the intensity is 6.4mJ/pulse. We studied the electron beam dynamics and interaction, and evaluated the accuracy of the determining beam energy, beam current, air shower, detector response by using PARMELA and GEANT4.

## Introduction

The Telescope Array project(TA) is one of the large scale experiment which observes extremely high energy cosmic ray. It consists of Fluorescence Detectors(FD) and Surface Detectors(SD). FD observes ultraviolet photons emitted from nitrogen molecule in the air excited with electrons in air shower. Since the total number of generated fluorescence photons is in proportion with energy of mother electron, the energy of primary particle can be calculated from number of photons. However, since the yield of fluorescence photons depend on density, temperature, pressure, and humidity of the air, and the distance from fluorescence detector to core axis of air shower is  $\sim 10$ km, the reconstructed energy of primary particle has large uncertainties. For example, the total systematic error of Hires and Pierre Auger Observation are 17%[5] and 26%[2][1], respectively. We estimated that of TA FD is  $\sim 23\%$ . It is impossible to calibrate between energy of cosmic ray and number of detected photons directly, because we don't know the true energy of that. We can expect that the calibration by using accelerator beam is useful for absolute energy calibration of FD.

## A Linear Accelerator system

We proposed that we develop a small electron linear accelerator for calibration of FD, we call this as "TA-LINAC". The maximum energy is 40MeV, the beam intensity is 6.4mJ/pulse and the pulse width is  $1\mu\text{sec}$ <sup>1</sup>. TA-LINAC will be set up from FD to the distance of 100m. The 40MeV electron beam is injected into the air. Since the total energy of one pulse loses by ionization, the fluorescence photons are generated from  $10^{16}\text{eV}$  energy loss. The number of photons generated with electron beam,  $10^{16}\text{eV}$  energy loss, left from FD by 100m can do the scale to the number generated with cosmic ray,  $10^{20}\text{eV}$  energy loss, away at 10km. Above all, we can calibrate with electron beam as pseudo cosmic ray event whose energy is  $10^{20}\text{eV}$ . TA-LINAC can be used for end to end calibration, that means we can calibrate some parameters collectively, except attenuation coefficient of the air. The attenuation coefficient will be calibrated by laser system. In the TA experiment, we use LIDAR system and central laser facility(CLF). If the accuracy of determining of beam energy

1. The time scale of air shower by cosmic ray is  $\sim 500\text{nsec}$

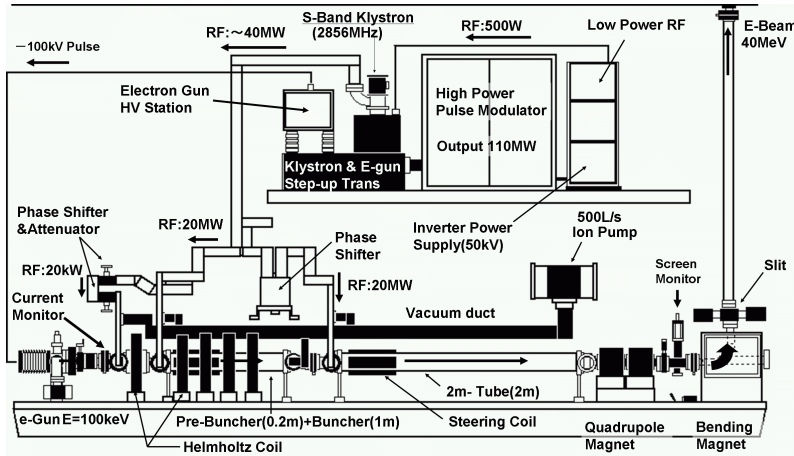


Figure 1: The outline of TA-LINAC which is based on S-band RF acceleration system. The feature of TA-LINAC is recycle Linac, that means almost all of components except high power pulse modulator are the removal equipments to KEKB at the up-grade. The high power pulse modulator was developed for C-band Linear Collider system at KEK[4]

and current can be less than 1%, we can modify the systematic error less than 20%.

Development of TA-LINAC was started from Apr.2005 at High Energy Accelerator Research and Organization(KEK) in Japan as joint research. Almost all of main components of accelerator system were supported from KEK. The construction will be completed until the end of July, and we plan to test of beam operation. After beam test, TA-LINAC will be stored in a 40 feet high cube container and will be moved to Utah, US.

Fig.1 shows the illustration of TA-LINAC. The main components are electron gun, pre-buncher, buncher, main accelerator tube, magnetic lens, helmholtz coil and quadrupole magnet for focusing, 90-deg bending magnet, slit for collimator, high power S-band(2856MHz) klystron and high power pulse modulator as RF source. The electron gun is thermal field emission type which uses oxide cathode, and the maximum peak current is 20A. We determined the output voltage as -100kV pulse. The output current can be adjusted by voltage of grid pulse as trigger. The electron beam is focused by magnetic lens whose maximum magnetic field is 1~2kG. The uniform electron beam just after magnetic lens is made into bunching structure which matches with a period of 2856MHz RF

in pre-buncher and buncher. The maximum accelerating gradients of pre-buncher and buncher are 2MV/m and ~17MV/m, respectively. The electron beam is accelerated in main accelerator tube(2m-tube). The 2m-tube is S-band  $2/3\pi$  mode Quasi-Constant Gradient type which has 55 cavities, whose length is 2m. We can obtain the accelerating gradient as 18MV/m with 20MW input RF. The energy of output electron beam from the 2m-tube achieves 40MeV, moreover, we can change the output energy from 10MeV to 40MeV continuity using by phase shifter of input RF. We use some magnet for focusing and bending the electron beam. The main focus magnet is helmholtz coil, which consists of five solenoid coils, and it is set up outside of pre-buncher and buncher. The maximum magnetic field is about ~500G. The direction of electron beam is turned to vertical by 90-deg bending magnet whose magnetic field is 0.67T@40MeV. In finally, the beam is collimated by slit, whose collimator is made by tantalum, 50mm thickness. By using 90-deg bending magnet and slit, we can obtain the 40MeV energy whose accuracy is less than 1%.

The RF system consists of high power pulse modulator, stepup trans(stepup ratio is 1:15), high power S-band klystron, low power S-band RF source(500W) for input to klystron, and waveg-

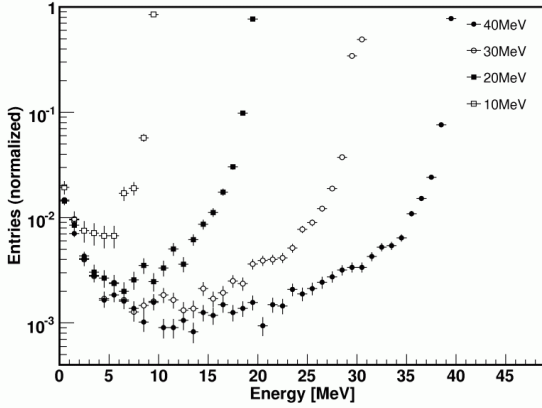


Figure 2: Distribution of output energy in case of 10MeV,20MeV,30MeV,40MeV.

guides. The output pulse from modulator, whose maximum power is 110MW(22kV $\times$ 5000A) and pulse width is  $\sim 2.5\mu\text{sec}$ , is input to the klystron, after transformed by stepup trans. The maximum output power from klystron is 50MW. We can change the initial phase of high power RF by adjustment of input low power RF phase. The waveguides, which are made by oxygen-free copper, propagates high power RF to pre-buncher, buncher and 2m-tube. We can adjust the input phase of pre-buncher, 2m-tube input parts by using phase shifter.

### Simulation of beam dynamics and interaction

We studied the performance of electron beam dynamics, air shower generated by 40MeV electron, and FD response by using PARMELA and GEANT4. PARMELA(Phase And Radial Motion in Electron Linear Accelerator) was developed for studying the transversal and longitudinal electron beam dynamics at Los Alamos Laboratory. We simulated helmoltz coil, pre-buncher, buncher, 2m-tube by using PARMELA. We determined the best power of input RF and relative phase, based on buncher, to obtain 10MeV, 20MeV, 30MeV, 40MeV beam. These values are summarised in Table.1. The dynamics of electron beam in the quadrupole magnet, the 90-deg bending magnet

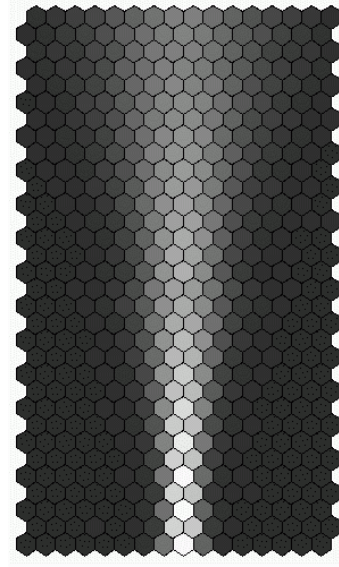


Figure 3: Distribution of fluorescence photons detected by FD(used two telescopes).

and the slit were simulated by GEANT4. We determined the best magnetic field of quadrupole magnet as 1.5T/m and the best width of slit as 7mm to obtain the 1% accuracy of beam energy. In finally, the  $\sim 1\%$  of electron beam loss their energy by ionization and bremsstrahlung in  $100\mu\text{m}$  thickness stainless window. We estimated the ratio of output beam and input beam from electron gun in case of 10MeV,20MeV,30MeV,40MeV as 0.51, 0.42, 0.21, 0.05, respectively.

The interaction of 40MeV electron beam in the air and FD response were simulated by GEANT4. We used photon yield parameters measured by M.Nagano[3]. The point of beam injection was defined in a point 100m away from center of mirror of one telescope. We found that the shower maximum from injection point is about 0.35 radiation length and almost all of electrons contributed to generate fluorescence photons and the total number of generated fluorescence photons was  $6.6 \times 10^{11}$ . Fig.2 shows the distribution of fluorescence photons which were detected by FD. Since the field of view along vertical direction at beam injection position is from  $\sim 10\text{m}$  to  $\sim 68\text{m}$ , the air shower has extended to the entire viewv. We estimated the number

Beam energy(MeV)	10	20	30	40
Pre-Buncher power(MW)	0.0064			
phase(deg)	150			
Buncher power(MW)	14.9			
phase(deg)	0			
2m-Tube power(MW)	15.0			
phase(deg)	60	40	15	340

Table 1: Summary of best power and relative phase. From this results, we found the best RF power from Klystron is  $\sim 30$  MW.

of detected photons as  $7.7 \times 10^5$ . The maximum number of detected photons per one PMT was  $1.6 \times 10^5 (=32,000 \text{ p.e.} @ 20\% \text{ Q.E.} \otimes \text{C.E.})$ . Since the width of beam pulse is  $1 \mu\text{sec}$ , we could estimate the maximum ADC counts detected by SDF<sup>2</sup> is  $\sim 8000$  counts/100nsec.

We discussed systematic error of detected photons by using these simulations. We considered the error of photon yield, weather conditions, the error of detector parameters. The uncertainty of detected photons from the error of detector parameters were  $\sim 5\%$ , and from the error of photon yield are  $\sim 8\%$ . Above all, we can expect that the total systematics is modified from 23% to  $\sim 17\%$ .

## Beam test in KEK and Future

The construction of TA-LINAC was started from Jan.2007, and will be completed in this summer. Since TA-LINAC will be stored in a 40 feet container, it is constructed on the  $11.5\text{m} \times 2.3\text{m} \times 30\text{cm}$  thickness base made by iron to keep its level. Total weight included base is  $\sim 20$  ton, this is lighter than maximum load of a container, 26 ton. After construction, we plan to beam test in KEK. At this test, we will confirm the accuracy of output beam energy and measure the beam current by a Faraday cup, which is located at end of beam line, and some core monitors. Anyway, we will also measure radiation level of gamma ray, X-ray, and neutron around the beam line to determine the detail of sheilding at Utah site. After beam test in KEK, we will export TA-LINAC to Utah, US, and will start beam operation in this winter.

## Conclusion

A small electron Linac, TA-LINAC, is developing for energy calibration of FD at KEK in Japan, and will complete in this summer. The performance of electron beam dynamics and air shower and FD response were studied by using PARMELA and GEANT4, and we estimated the uncertainties as  $\sim 17\%$ . The beam operation in Utah will be started in this winter.

## Acknowledgements

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## References

- [1] K. Arisaka, D. Barnhill, A. Tripathi, A. Ohnuki, J. Lee, W. Slater, A. Chou, and G.R. Fernandez. Determination of absolute energy composition with minimum systematic uncertainties.
- [2] Karl-Heinz Kampert. Cosmic Rays at the Highest Energies – First Data from the Pierre Auger Observatory –. *arXiv:astro-ph/0608136*.
- [3] M. Nagano, K. Kobayakawa, N. Sakaki, and K. Ando. New measurement on photon yields from air and the application to the energy estimation of primary cosmic rays. *Astropart.Phys.*, 22:235–248, 2004.
- [4] T. Shintake, H. Matsumoto, and C band RandD Group. PHASE-I RandD SUMMARY AND PHASE-II REPORT ON C-BAND LINAC FOR 500 GeV e+e- LINEAR COLLIDER. In *Proceeding of the 25th Linear Accelerator Meeting in Japan*, pages 12C–04, 2000.
- [5] G.B. Thomson. Observation of the GZK Cut-off by the HiRes Experiment. *arXiv:astro-ph/0609403*.

2. SDF(Signal Digitizer and Finder) is readout electronics of FD.