High energy electron and gamma-ray observation by TANSUO mission

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***Abstract*. We are proposing the TANSUO mission for high energy electron and gamma-ray observation in the space. Major goal of the mission is the investigation of high energy phenomena in universe by observing electrons and gamma-rays from 10 GeV to10 TeV with high energy resolution and large acceptance. TANSUO will feature a deep BGO calorimeter to follow the details of shower development and a neutron detector to enhance discrimination between electron and hadron. Details of TANSUO will be discussed along with its expected performance and flight expectations.**

***Keywords*: High energygy electron, High energy Gamma-ray, Space Mission**

I. INTRODUCTION

High energy electron detection is very important to understand the cosmic ray origin, acceleration, and propagation. Since last year, several experiments such as Pamela[1], ATIC[2], H.E.S.S.[3], PPB-BETS[4] and FERMI[5] have reported deviations of high energy electron spectra from the present cosmic ray model by GALPROP[6]. Pamela measures an increase of positrons with respect to electrons at energies above a few GeV; ATIC and PPB-BETS detect a prominent spectral feature at around 500 GeV in the total electron plus positron spectrum; H.E.S.S. result shows significant steepening of the spectrum above 600 GeV. FERMI found an 'excess' but not so high compared to ATIC & PPB-BETS. All these results may indicate the presence of a nearby primary source of electrons and positrons. However such measurements can not agree with each other very well. TANSUO mission is proposed for high energy electron and gamma-ray measurement with high energy resolution and large background rejection.

II. SIGNIFICANCE OF HIGH ENERGY ELECTRON AND GAMMA-RAY OBSERVATIONS

Cosmic ray transport through the galaxy is understood to be a diffusion process, where the GCR hadronic component may traverse the distance equivalent of hundreds of galactic diameters during their lifetime, thereby randomizing their trajectory and losing connection with their original source. Thus, 'imaging' a cosmic ray source in high energy particles is very likely impossible. High energy electrons, however, have radiative energy losses that limit their lifetime and, consequently, the distance they can diffuse away from their source. As a result, the highest energy electrons that we see at Earth very likely originate from sources younger than 100 thousands years and less than 1 kpc from the Solar System. The cosmic ray electron spectrum 'feature' observed by ATIC is the first time such a feature has been identified at high energy, implying that there must be a source of energetic particles relatively near our solar system. The exact nature of this source is currently subject to much debate and, to date, more than 170 papers have been submitted to arXiv that propose explanations ranging from the mundane (e.g. standard SNR acceleration using an inhomogeneous source distribution), to more interesting sources such as pulsars [7], [8] to the most exotic explanations: Dark Matter of various types[9].

Today, we believe that only about 5% of the universe is made up of baryonic, 'ordinary matter' such as cosmic rays, while 70% of the universe is composed of an unknown substance called 'dark energy' and the remaining 25% is made up of some form of gravitating matter that is not directly observable, i.e. 'dark matter'. The identity of this 'dark matter' has remained a major physics mystery since Zwicky first identified the problem more than 70 years ago, and a myriad of investigations over the decades have essentially eliminated all known particles as dark matter candidates. Remaining choices include exotic weakly interacting species and particles that emerge from theories with extra dimensions[9], [10], [11], [12]. Such particles can annihilate into electron-positron pairs and produce structure in the observed cosmic ray electron spectrum for energies in excess of 300 GeV[10].

Present dark matter models also predict that dark matter particle annihilations will create gamma rays. There will be some 'Features' in the gamma-ray energy spectrum and 'photoes'.

If one detector will observe high energy electron and gamma-ray with high energy resolution in the same time, it will play an important role in future cosmic-ray physics and 'new physics' such as dark matter.

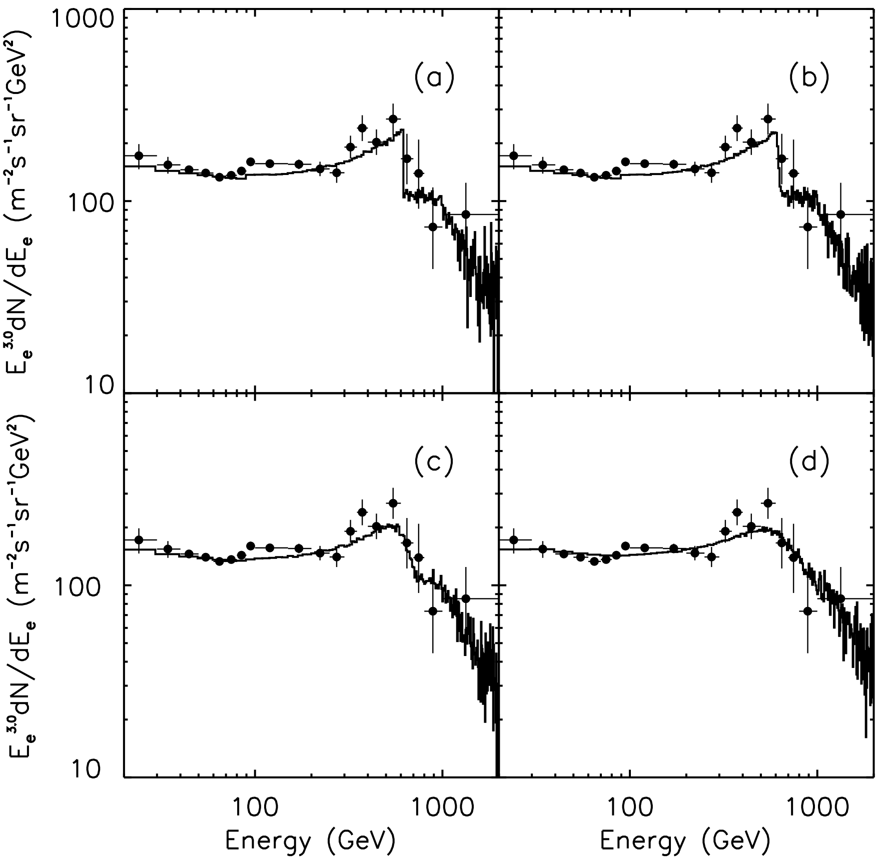

Fig. 1. The simulated high energy electron spectra observed by instruments with different energy resolution, a:input spectrum,, b: energy resolution =1.5%,c: energy resolution =10%, d: energy resolution =25%.

III. Scientific Requirements for TANSUO

Present high energy electron spectra observed by ATIC and FERMI can not agree with each other very well. The difference may come from the systematic error of two different instruments. FERMI uses the thin calorimeter with high space resolution tracking detector to observe electron by measuring the shower image. ATIC uses the thick BGO calorimeter with high energy resolution to observe electron by measuring the shower tail and spread. The energy resolution, proton rejection power, and electron event selection methods of two instruments are different. However ATIC is a polar balloon mission where atmospheric background could cause systematic error. FERMI is a space mission, but its rejection power is not enough for high energy electron observation. New instrument such as TANSUO with high energy resolution and large proton rejection power could distinguish this difference.

The energy resolution of present high energy gamma-ray observations including ground and space instruments are very poor, normally above 10%. High energy resolution gamma-ray observations are very important for 'new' physics such as dark matter.

The scientific requirements of TANSUO are as following:

A. High energy resolution.

High energy resolution is very important for spectrum 'feature' observation. Here we show some simulations for a 'feature' observed by instruments with different energy resolution. We assume the cosmic-ray electron background spectrum is a power law spectrum with index =-3.1. Above 1 TeV, the spectrum is changed to a soft spectrum with index=-4.5. The results are in figure 1. It can be seen that if energy resolution decreases, the feature will decrease, and the spectrum will get flat.

B. Large acceptance and high background rejection power

The expected electron flux is very small, and the amount of background protons exceeds electrons in flux by more than 100 to 1000 times in the high energy. As a result, the detector should require a large acceptance and

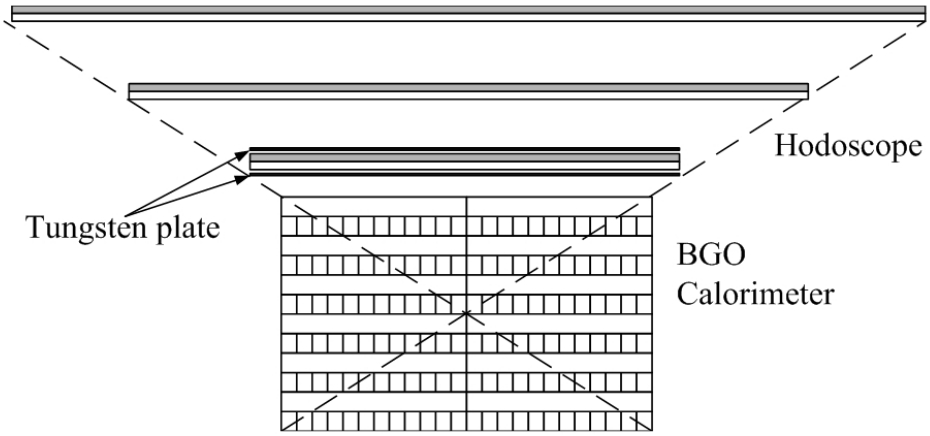

Fig. 2. Scematic configuration of the TANSUO detector

an excellent rejection power better than 100,000 against the background protons.

C. In-Flight calibration

The high energy electron detector is very complicated, normally there are more than 10,000 channels. We need flight calibration for energy measurement and background rejection. In TANSUO we propose the measurement of high energy electron and gamma-ray in the same time. Because the shower development of gamma-ray and electron are almost the same, gamma-ray is a good 'ruler' for flight calibration.

IV. DETECTOR CONCEPT

Transition Radiation Detector (TRD), Cherenkov Detecor (CD), Magnet Spectrometer (MS), high space resolution Imaging Calorimeter (IMC) and high energy resolution calorimeter (HERC) are usually used for high energy electron observation. But above 100 GeV, the rejection power by TRD, CD, MS and IMC will decrease very quickly, only High energy resolution calorimeter can work above 1 TeV. Such a detector observes high energy electron by measuring the shower lateral distribution (at the top of calorimeter) and shower tail (at the bottom of calorimeter).

In order to understand the reason why the shower lateral image can be useful for electron identification while the shower difference between electron and proton will get small with energy increases. Table 1 lists the numbers of multiplicities and the median angles of secondary particles at different energies which are simulated by FLUKA 2006. The median angle of protons is smaller than electron. As a result, proton showers have larger lateral distribution than electron showers. The median angle of proton will change with energy, from 69.6 degree at 10 GeV to 13.5 degree at 10 TeV. It makes the difference between electron shower and proton shower get smaller with energy increase. If we only use lateral distribution to distinguish electron and proton, the rejection power will be getting smaller, PPB-BETS and BETS experiment have confirmed this by beam test and flight data [4].

TABLE I
MULTIPLICITIES, ANGULAR DEPENDENCE OF PROTON-LEAD NUCLEAR INTERACTION

Energy (GeV)	10	10^2	10^3	10^4
Multiplicity	43.8	67.0	101.0	142.7
Median angle (deg.)	69.6	56.4	36.5	13.5

The TANSUO detector not only measures the lateral distribution but also the shower tail. It is composed of an imaging calorimeter(IMC), a BGO calorimeter and a neutron detector. The Imaging Calorimeter is used for the identification of gamma-ray and electron, and the BGO calorimeter is for the proton rejection and energy measurement. A schematic configuration of the TANSUO detector is presented in Fig.2. The IMC is a sampling-type tracking calorimeter using scintillating hodoscope as sensitive layers and tungsten as absorber. Since back-scattered particles in shower increases considerably when the incident energy becomes higher, a highly granulated imaging capability is crucial for identification of the incident particle. Therefore, the IMC has 3 layers which are set in x and y direction alternatively. The cross section of each hodoscope is 1 cm square. The area of detector is 100×100 cm^2 in the top , and the total thickness of lead is 2 r.l. The BGO caloimeter, with a cross section of 2.5 cm $\times$ 2.5 cm, which are aligned in x and y direction layer by layer. By simulation study, the thickness of BGO is optimized to be 27 r.l for the rejection power of nearly 10^5 . The required dynamic range of the read-out system of BGO will be established by the PMT and specified electronics. The total thickness of absorber is 29 r.l and the interaction mean free path of protons is

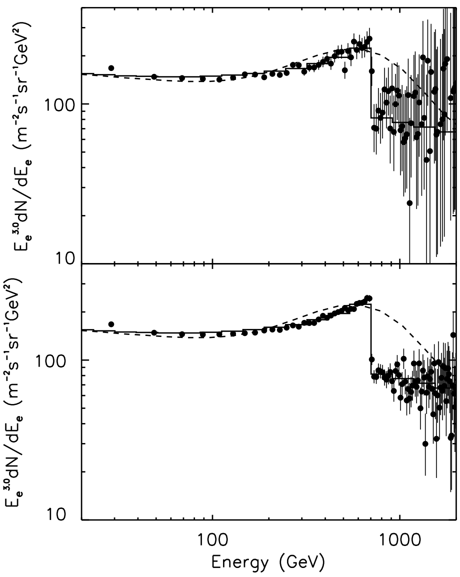

Fig. 3. TANSUO expected results by different exposure. (a): 100 days, (b):1000 days

nearly 1.6.

V. Expected performance

By simulation we find that primary electrons deposit about 98% of their energy in the BGO calorimeter, dependent weakly on energy, while protons on average deposit about 41%Ṫhe energy resolution is better than 1% at 100 GeV.

The expected results for TANSUO are shown in figure 3a and figure 3b for a geometrical factor of 0.4 m^2.sr and a minimum exposure of 100 days and a maxisum exposure of 1000 days. The solid curve is simulation results according to the dark matter model by ATIC results. The dashed curve is pulsar model. The vertical bar is the statistical uncertainty. As can be seen in the figure TANSUO should be able to distinguish between different models.

VI. Summary

The TANSUO has a capability to observe the electrons and gamma-rays in 5 GeV to 10 TeV with high statistical precision and excellent energy resolution of 1% at 100 GeV. This capability makes possible for us to observe the spectrum features in high energy electron and gamma-ray.

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