Derivation of Secondary Electron Energy Spectrum at Different Atmospheric Depth

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Abstract— **The all particle primary nucleon spectrum has been estimated on the basis of the latest PAMELLA, CREAM, ATIC-2 BALLOON BORNE EXPERIMENTAL DATA. The concept of nuclear fragmentation has been used to estimate the nucleon flux from nuclei spectra. Using this spectra, we have calculated analytically the energy spectra of the secondary electrons originated from the decay of charged and neutral pions initiated on the upper atmosphere from the primary nucleon-air collision in the energy (4-1000) GeV. The calculations are valid up to an atmospheric depth of about (3.8-7.4) gm-cm-2. The derived results are compared with the experimental electron fluxes available from Boezio et al., Torri et al., Aguilar et al. Chang et al. and Yoshida et al. using PPB-BETS detector.**

I. INTRODUCTION

The investigation on primary cosmic rays is necessary in the study of cosmic ray acceleration and propagation through the atmosphere and also in testing the validity of models in high energy interactions with the interstellar matter. The secondary component electron is the lowest mass constituents of the cosmic rays. In contrast to heavier cosmic rays, acceleration and propagation process for electrons are affected by synchrotron energy loss and inverse Compton scattering. Consequently, electron flux observations can be compared with other cosmic ray measurement to yield insight into cosmic ray acceleration and propagation process. It has been recognized that the spectra of electrons give us unique information about the propagation acceleration of cosmic rays in ISM. Muller et al. [1] have suggested that the containment volume of electrons includes regions beyond the disk of the galaxy, the spectrum at the acceleration site has a power law exponent 2.65 and the time scale of containment in the galaxy is independent of the energy of the electrons. They have used radio data from the galactic anti-center direction for analysis. Mauger et al. [2] have shown a truncated path-length distribution due to lack of nearby sources could be responsible for the additional steepening of the electron spectrum. Van der Walt [3] has investigated the validity of the Thomson limit for inverse Compton scattering up to electron energies of 1000 GeV. Nishimura et al. [4] have estimated the possible contribution of nearby sources to the high energy electrons.

Ptuskin and Ormes [5] have discussed the anisotropy of very high-energy electrons based on the diffusion from local SNRs. They have given an extremely high anisotropy amplitude. However, it is not easy to obtain the electron spectrum in the high energy region above 1TeV, because we need a rejection power of more than 104 against protons, which exceeds the limit of current emulsion technology with microscopes. To solve the problem,Yoshida et al. [6] have observed the cosmic ray electrons in the energy range 10 GeV to 1 TeV at the top of the atmosphere with the PPB-BETS detector consisting of 36 scintillating fiber belts, 9 plastic scintillation counters, and 14 lead plates with a total thickness of 9 radiation lengths. The basic structure is similar to that of BETS detector of Torri et al. [7], but several improvements have been adopted to observe high energy electrons. Recently Chang et al. [8] have achieved the electron observations in the energy region from 20 GeV to 1TeV using ATIC-2 balloon experiment.

In the present work, the flux of secondary electrons has been derived from the decay of charged and neutral pions initiated by primary p-air collisions in the energy range 10 to 1000 GeV at different atmospheric - depth 3.8 , 5.6 and 7.4 gm- cm-2 . The derived result has been compared with experimental data of Boezio et al. [9], Torri et al. Aguilar et al. [10], Chang et al. and Yoshida et al

II. NUCLEAR PHYSICS AND KINEMATICS

Bhadhwar et al. [11] have modified the formulation of e-energy spectrum obtained from charged π meson decays which obeys the formula.

$$J_{e^-}(E)dE_p = \frac{2(\gamma+6)}{(\gamma+1)(\gamma+3)(\gamma+4)}\left(\frac{m_\mu}{m_\pi}\right)\frac{Am}{m_p}\int_E^\infty \frac{d\sigma_{\pi^-}(E,E_p)}{dE}E_p^{(\gamma+1)}dE_p \quad (1)$$

where $AE_p^{-(\gamma+1)}$ is the all particle primary nucleon spectrum with the spectral amplitude A and integral index γ; m is the matter traversed by primary nucleons in air; m_P = 1.67×10-24gm is the proton mass in gm, m_μ =0.10566GeV, m_π= 0.13957 GeV are the rest energies of muon and pion respectively; $\frac{d\sigma_{\pi^-}}{dE}$ is the invariant cross section taken from the fit to the accelerator data of the $pp \to \pi^- X$ inclusive reaction.
Verma [12] has given the e-spectrum obtained from neutral π meson.

$$J(E,m) = \frac{4F(E_\pi)}{\Lambda_i\Lambda_\gamma}m^2\left[1 - \frac{m(\Lambda_p + \Lambda_\gamma)}{3\Lambda_p\Lambda_\gamma}\right] \quad (2)$$

where

$$F(E_\pi) - \frac{1}{2}(Z_{p\pi+} + Z_{p\pi-})AE_p^{-(\gamma+1)} \quad (3)$$

is the production spectrum of chargedπ- meson, Λ_i is the interaction mean free path of protons, Λ_γ is the characteristic length for pair production, m is atmospheric depth, Λ_p is the absorption mean free path of proton in air in gm – cm-2.

III. Result and Discussion

Several balloon and satellite borne active and passive detector experiments on the determination of primary cosmic nuclei fluxes viz., H, He, C, N, O, Ne, Mg, Si, and Fe have been performed by PAMALLA collaboration [13], CREAM [14], ATIC-2 [15], HEAO [16] and are displayed in Figs. 1-8.

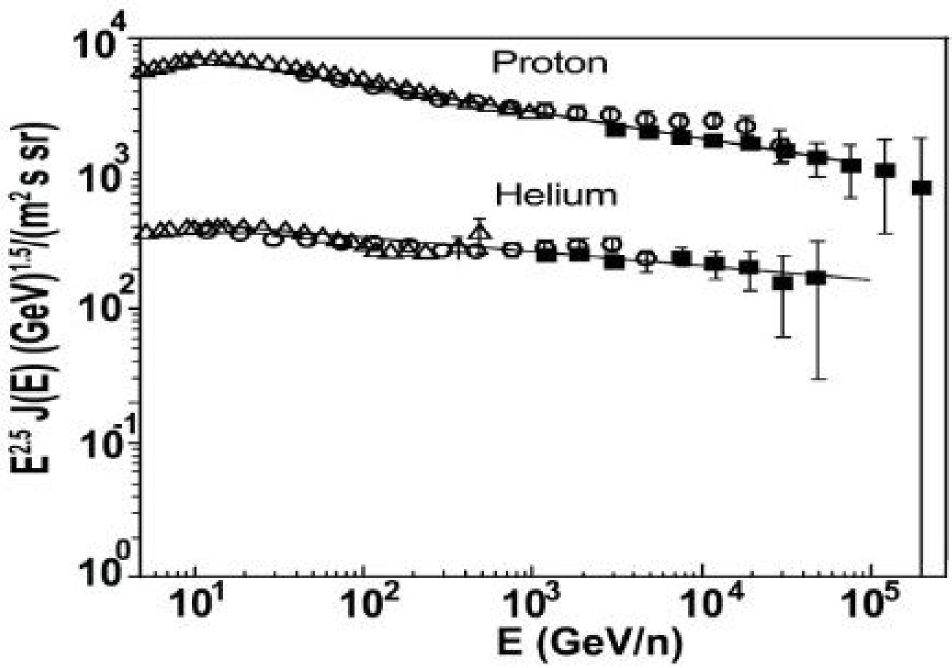

FIGURE 1 :
△ : PAMELLA – 2013
■ : CREAM – 2011
○ : ATIC2 – 2009
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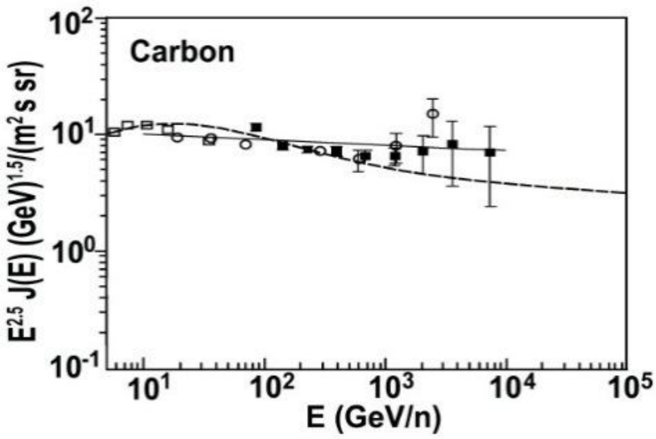

Fig.2

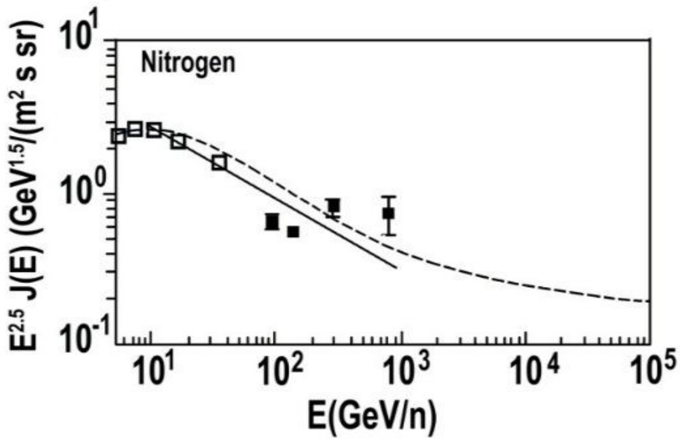

Fig.3

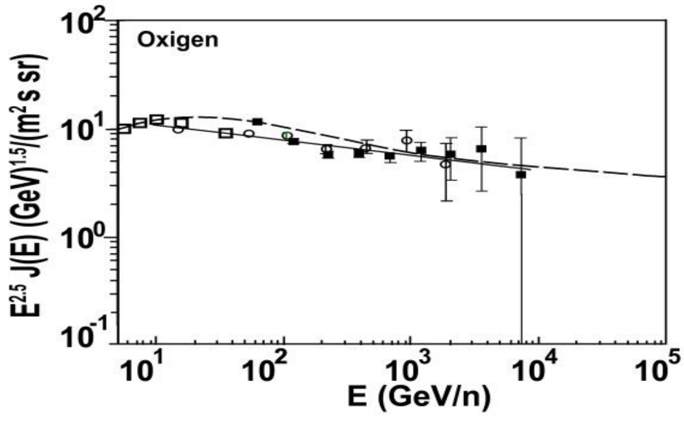

Fig.4

○ : HEAO – 1990 ■ : CREAM - 2011
□ : ATIC2 – 2009

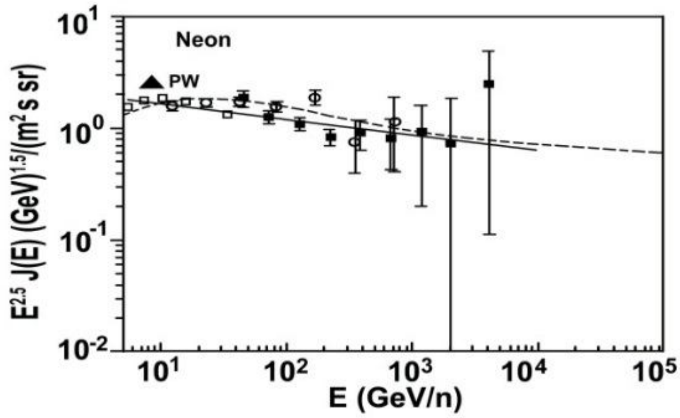

Fig.5

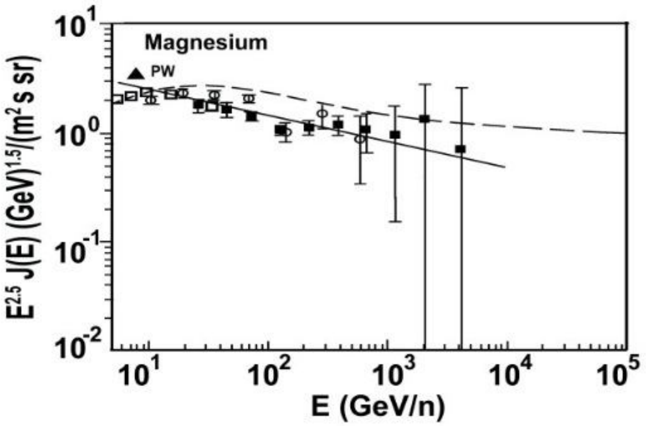

Fig.6

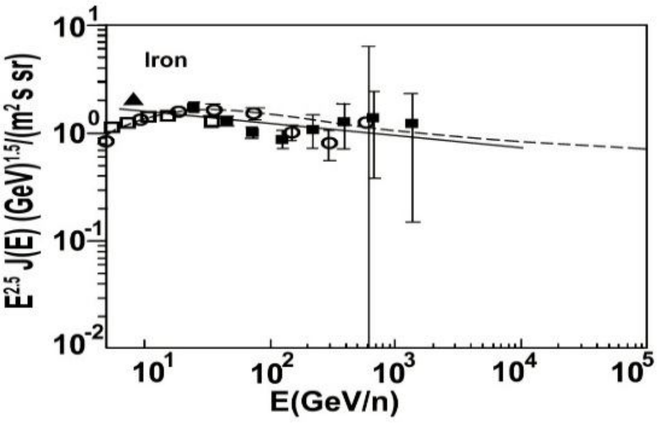

Fig.7

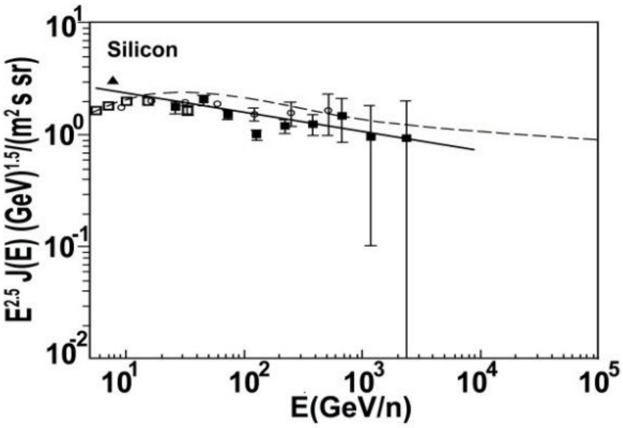

Fig.8

○ : HEAO – 1990 ■: CREAM - 2011

□ : ATIC2 – 2009 ▲: PW (1995)

—— : PRESENT WORK (FITTED)

The fit to these data are exhibited in those plots and follows the power law form for energy range between 10-10^4GeV and the parametric values are shown in Table-1.

TABLE-1

Element (i)	**Mass number(A_i)**	**Differential spectral amplitudes K_i in (cm^2sec sr GeV/n)$^{-1}$**	**Spectral Index (γ)**
P	1	1.24	2.71
He	4	5.25×10^{-2}	2.61
C	12	9.6×10^{-4}	2.53
N	14	8.18×10^{-4}	2.96
O	16	1.52×10^{-3}	2.64
Ne	20	2.1×10^{-4}	2.56
Mg	24	4.3×10^{-4}	2.73
Si	28	3.356×10^{-4}	2.66
Fe	56	2.05×10^{-4}	2.61

The latest all particle primary nucleon spectrum in the energy range EP = (10-10^4) GeV has been found to follow the form

$$J_{p+n} = 1.53\ E^{-2.7} dE \qquad (4)$$

The CERN ISR data on the pp→ π ^- X inclusive reaction cross-section can be fitted by the power law

$$\left(x\frac{d\sigma}{dx}\right)_{\pi^-} = 23.3963\ (1-x)^{5.02mb} \qquad (5)$$

for 0.1<x< 0.6.

The flux of electrons originated from the decay of charged π^- meson at different depths have been estimated from the relation (1) in the energy range (4-10^2) GeV and follows the power law

$$J_{e^-} = K(m)\ E^{-2.7}\ (m^2\ s.\ sr.\ GeV)^{-1} \qquad (6)$$

for K(m) = 4.79, 7.06, 9.33 (for m = 3.8, 5.6,7.4 gm-cm-2 respectively.

Table-2 shows the parametric values of interaction mean free path of protons (Λ_j), the absorption length of protons in air (Λ_p), the characteristic length of protons for pair production (Λ_γ) in gm – cm^{-2} air, fractional energy moments in p-air collision for π^- and π^+ productions, $Z_{p\pi^-}$and $Z_{p\pi^+}$ respectably.

The estimated parametric values ofΛ_j,Λ_p, $\Lambda_\gamma$in g-cm^{-2} air and Z- factors are displayed in table 2.

Λ_j	Λ_p	Λ_γ	$Z_{p\pi^+}$	$Z_{p\pi^-}$
70	110	38	0.04099	0.0283

The estimated Z- factors [17] for p-p collision have been corrected for p-air collision by adopting the conventional procedure of DAR [18]. The Z factors provide a good measure of the shape of the inclusive reaction cross-section which gives an estimate of the primary energy flow to secondaries generated in air showers.

Using these parametric values, the fluxes of electrons obtained from neutral π meson can be estimated from (2) at different atmospheric depths and the corresponding power law becomes

$$J_{e^-} = T(m)\ E^{-2.7}\ (m^2\ .\ s.\ sr.\ GeV)^{-1} \qquad (7)$$

for T(m) = 23.38,32.28,45.54 for m = 3.8, 5.6, 7.4 gm-cm^{-2} respectively.

In the present investigation we have adopted the scaling hypothesis of Feynman[19] for the estimation of meson spectrum initiated by p-p collision in the upper atmosphere. The scaling hypothesis is assumed to be valid at relativistic energies above 6 GeV. So the minimum threshold of electron energy should be above 4 GeV which is free from Albedo electrons [20,21]. Therefore the derived electron spectrum has been compared with data measured above 4 GeV.

Now the total secondary electron spectrum is obtained by accounting the contributions from the sum of (1) and (2) and is plotted in Fig.9.

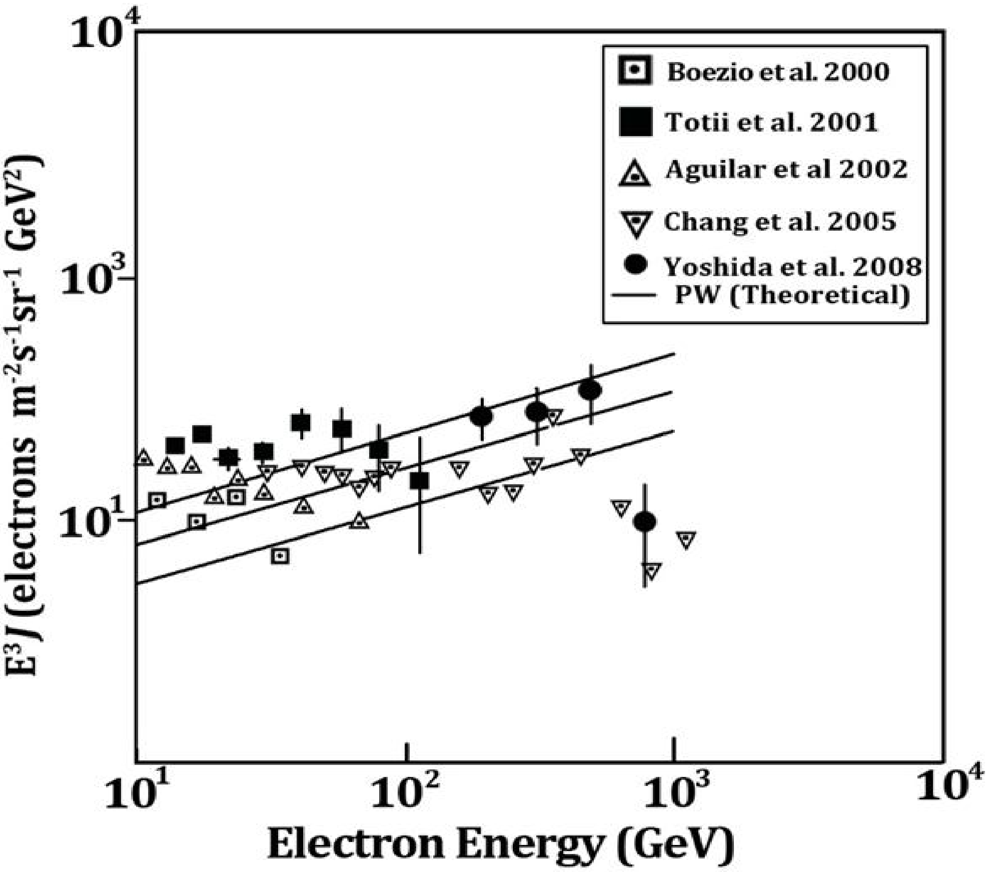

Fig-9

IV. CONCLUSIONS

Using the latest primary nucleon spectrum and CERN differential cross section data, the energy spectra of cosmic ray secondary electron spectra at different atmospheric depths (3.8 – 7.4)g/cm2 have been calculated. The derived spectra have been found comparable with experimental data of Boezio et al., Torii et al., Aguilar et al., Chang et al. and Yoshida et al.

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