Monte Carlo Simulation on Charge-deposition Distribution for Electron Beam Energy Determination

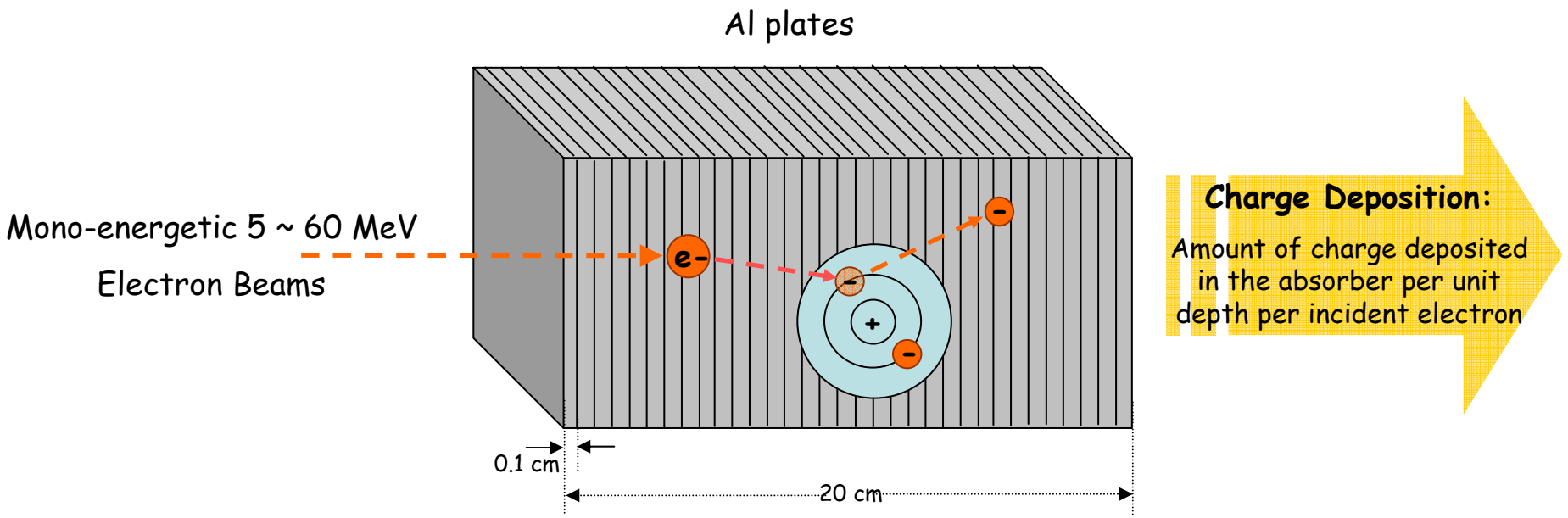
길영미, 오영도[1], 김상훈, 문성익, 조무현, 남궁원

포항공과대학교. [1]포항가속기연구소

Abstract

The electron energy is one of principal parameters influencing the charge-deposition distribution (abbreviated as CDD) within a material penetrated by electron beams. The CDDs of electrons with energies from 5 to 60 MeV passing through aluminum absorbers have been calculated by MCNPX 2.4 codes and the experiments were performed for electron beams with 50, 55, and 60 MeV passing through aluminum absorbers, consisting of 4 plates separated by air gaps at Pohang Accelerator Laboratory (PAL). To develop a useful device for measurements of the electron beam energy, the most probable charge-deposition depth, x_m and the maximum charge deposition, y_m have been determined from both the MCNP and experimental CDDs. The relative errors between MCNP and experimental results were 3-6 % for x_m, and 2 % for y_m.

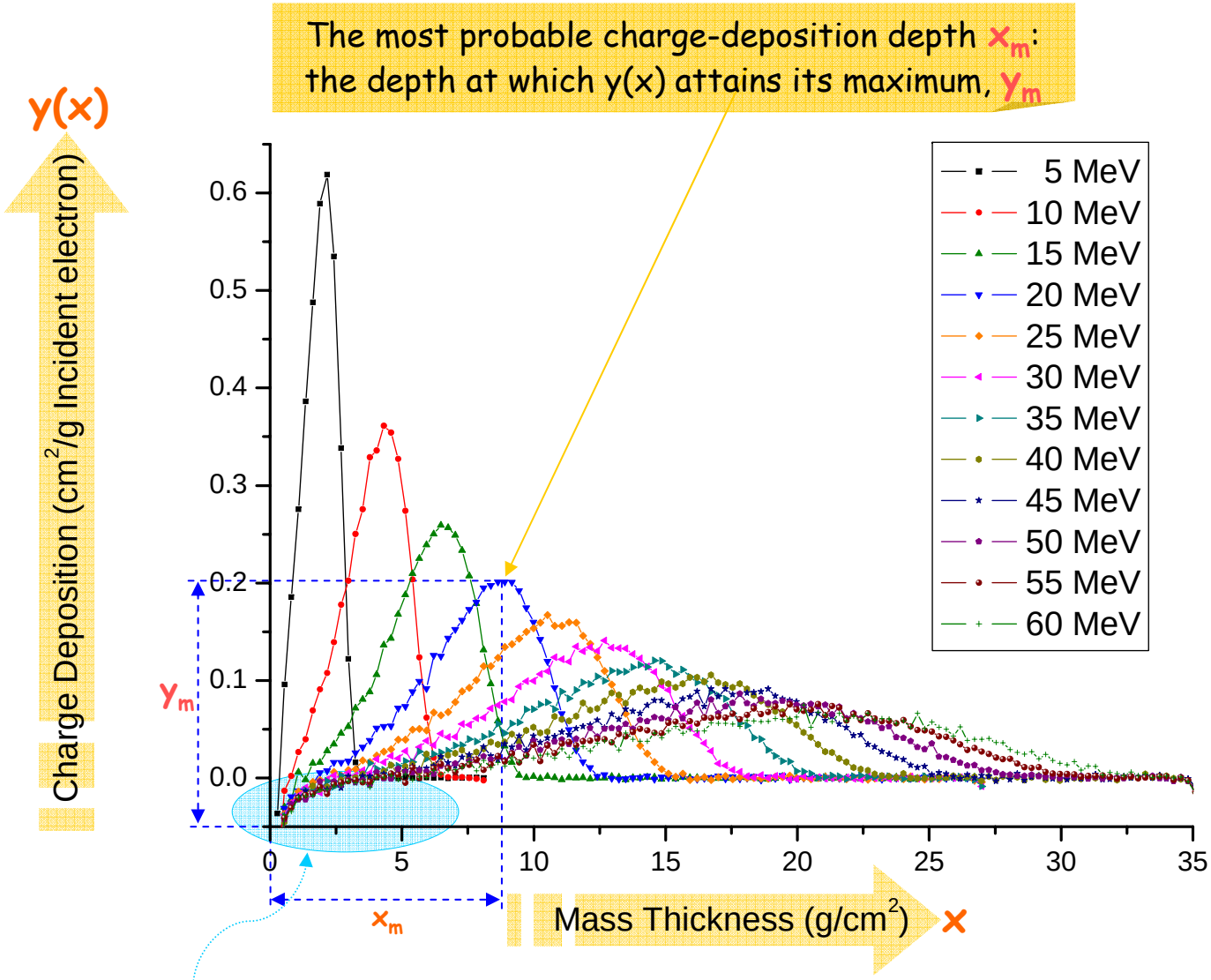
Condition of MCNP Simulation



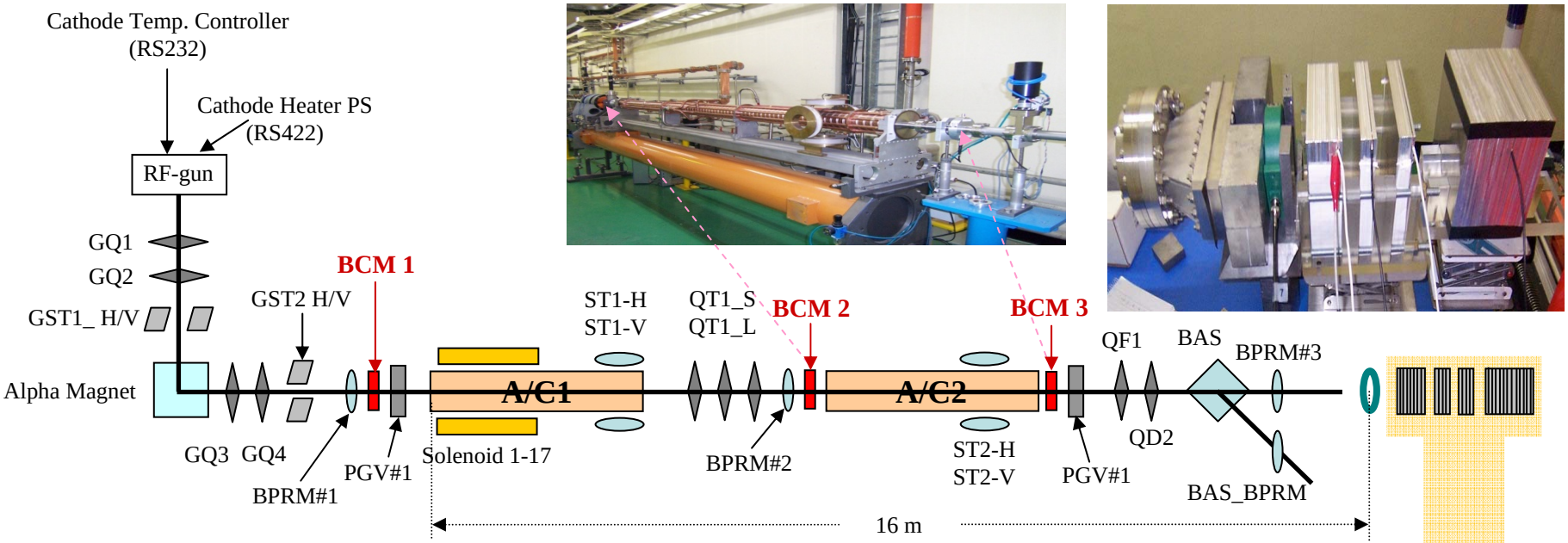
Depositing their negative charges by collision with atomic electrons and by the bremsstrahlung process in the Coulomb field of atoms.

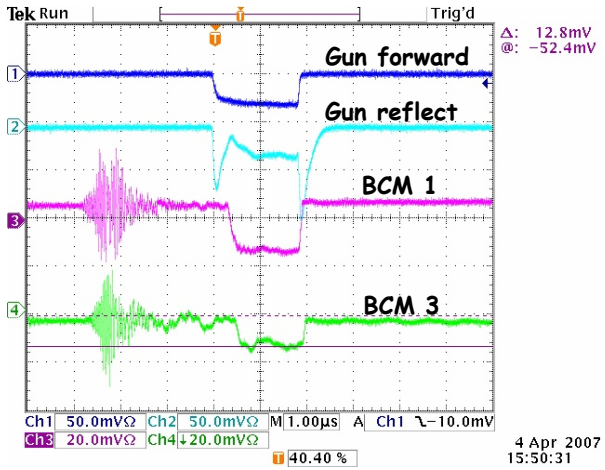
(Secondary electrons and bremsstrahlung photons leave the positive charges, and deposit their own charges at the end of their tracks.)

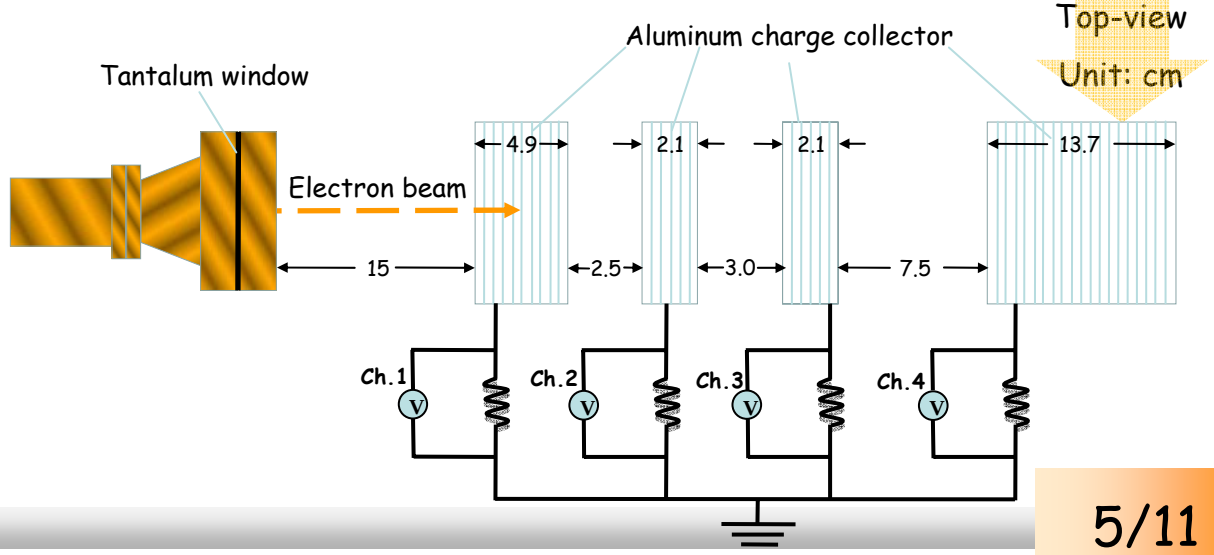
Charge Deposition Distribution (CDD)



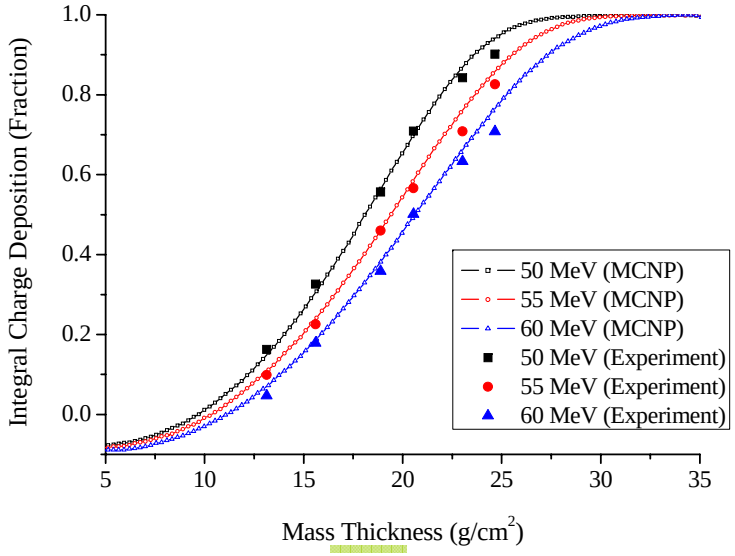
Experimental Condition of Test Linac @ PAL



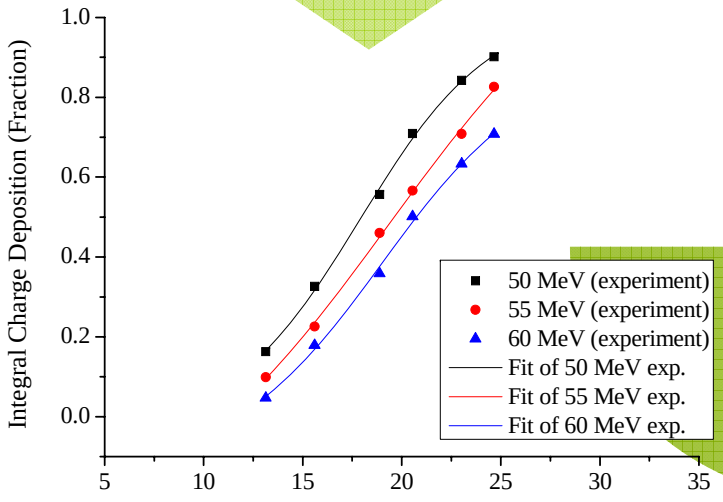




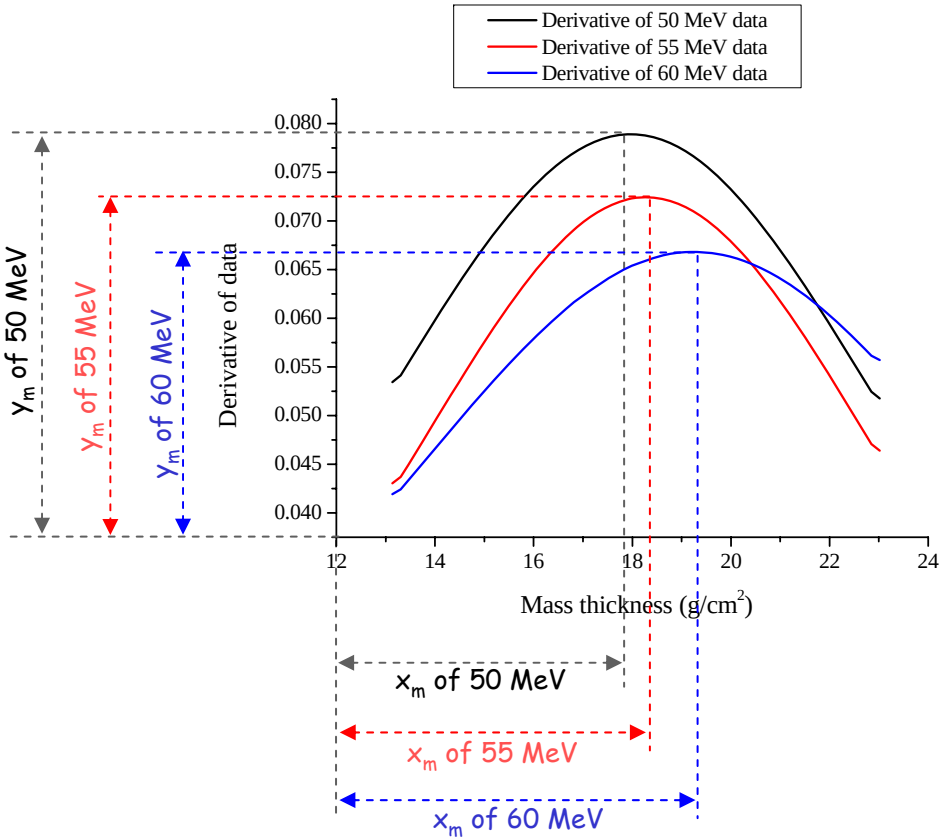
x_m and y_m derived from Integral CDD



Fitting of experimental data



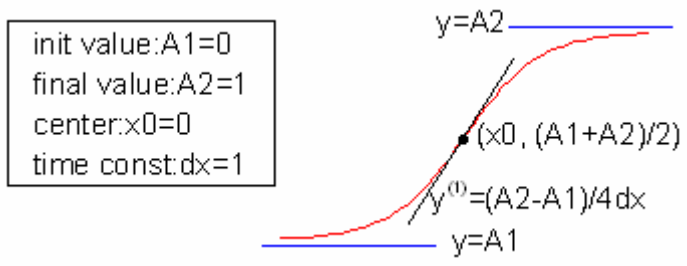
Derivative of fitting equation



Fitting function for Integral CDD and its parameters

Integral CDD can be fitted by Boltzmann function of mass thick.

$$y = \frac{A_1 - A_2}{1 + e^{(x - x_0)/dx}} + A_2 \qquad (1)$$



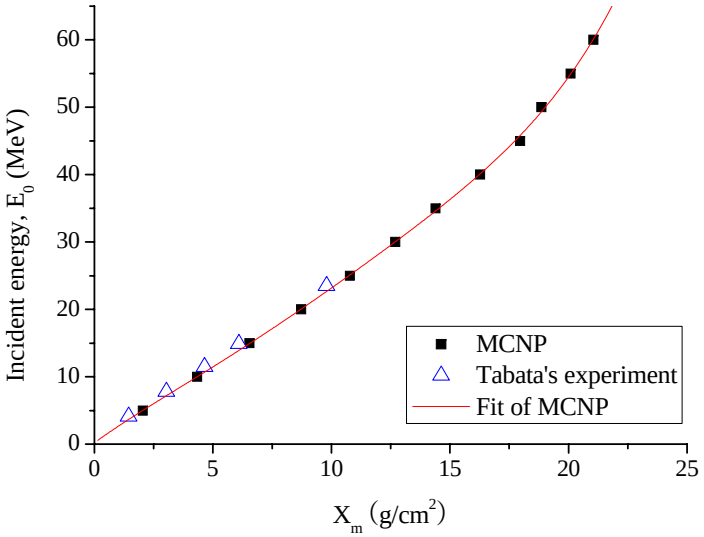
Parameters of Boltzmann function for fitting **simulation** data:

Energy (MeV)	A_1	A_2	x_0	dx
50	-0.082 ±0.276	1.082 ±0.247	17.974 ±0.987	3.687 ±2.009
55	-0.152 ±0.128	1.108 ±0.138	19.240 ±0.427	4.362 ±1.138
60	-0.218 ±0.282	1.052 ±0.391	19.664 ±1.482	4.955 ±3.031

Parameters of Boltzmann function for fitting **experimental** data:

Energy (MeV)	A_1	A_2	x_0	dx
50	-0.104 ±0.006	1.174 ±0.008	18.529 ±0.023	3.863 ±0.048
55	-0.140 ±0.008	1.214 ±0.017	19.893 ±0.069	4.526 ±0.089
60	-0.186 ±0.009	1.237 ±0.024	21.007 ±0.122	5.200 ±0.114

E_0 fitted as function of x_m



Incident energy, E_0 is fitted as a function of x_m:

$$E_0 = 0.210 + 6.88x_m - 0.966x_m^2 + 0.391x_m^3 - 0.0631x_m^4 + 0.00389x_m^5 \quad (2)$$

Where x_m is cm and E_0 is in MeV. This equation is applied to the electron passing through the aluminum absorbers.

x_m^a (g/cm^2)	E_0^a (MeV)	E_0^b (MeV)
1.45	4.09	3.74
3.04	7.79	7.61
4.65	11.5	11.53
6.1	14.9	15.06
9.8	23.5	24.07

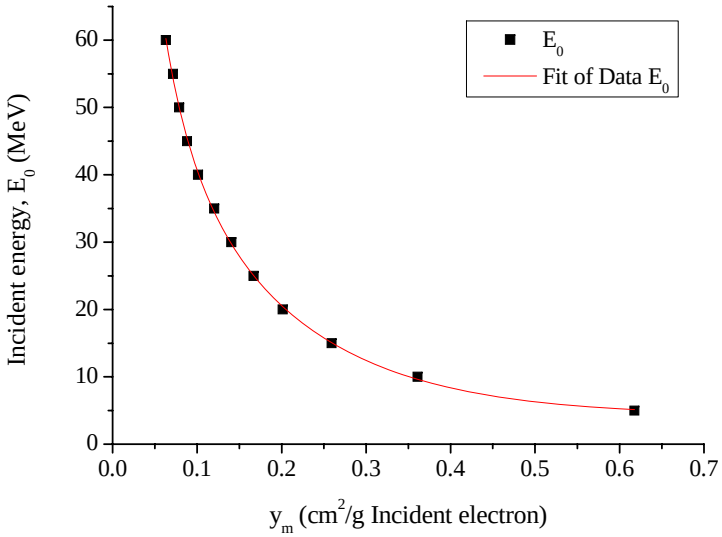
[a]Values described in Tabata et al [1].
[b]Values calculated from equation (2).

Comparing of the energy described in Tabata et al's experiment and the energy calculated from equation (2):

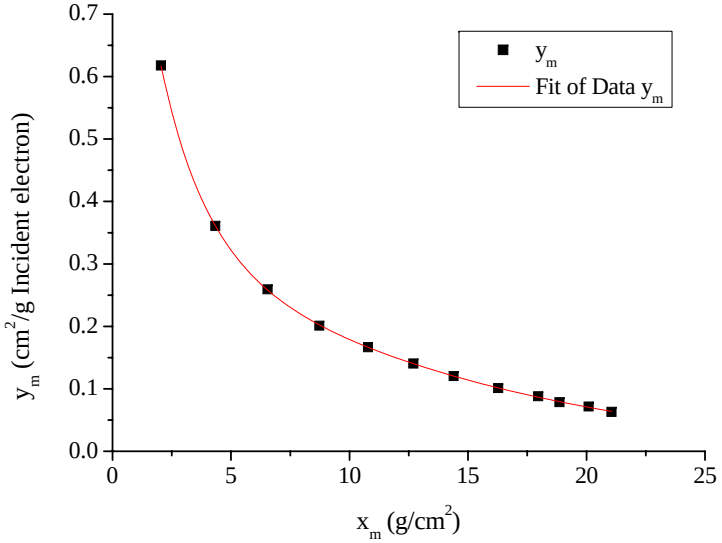
- Tabata et al derived the x_m^a from E_0^a of 4.09, 7.79, 11.5, 14.9, and 23.5 MeV. The E_0^b was calculated from substituting the x_m^a for the x_m in equation (2).
- For each x_m, the relative errors between E_0^a and E_0^b are 8.6, 2.3, 0.3, 1.1, and 2.4 % respectively.

[1] T. Tabata, R. Ito, S. Okabe, and Y. Fujita, Phys. Rev. B 3, 572 (1971)

y_m : additional parameter for determining energy



Incident energy E_0 fitted as a function of y_m.



y_m fitted as a function of x_m.

In addition to the x_m, the y_m was adopted as the parameter for determining the electron energy. The incident energy E_0 fitted as a function of y_m and y_m fitted as a function of x_m. Using these relationships, we can determine the electron energy from x_m and y_m derived by the electron beam with unknown energy.

Comparison of Simulation and Experimental values

Energy (MeV)	x_m (g/cm^2)	
	MCNP	Experiments
50	18.53	17.97 ± 0.99
55	19.89	19.24 ± 0.43
60	21.01	19.66 ± 1.48

Energy (MeV)	y_m (cm^2/g Incident electron)	
	MCNP	Experiments
50	0.079	0.079 ± 0.050
55	0.072	0.072 ± 0.022
60	0.063	0.064 ± 0.046

In the case of x_m, the results of MCNP simulation are larger than the experimental results by 3-6 %, and in the case of y_m, the results of experiments are in fairly good agreement with the results of MCNP simulation within 2 % error.

Conclusion

We performed the MCNP simulation for CDDs, and derived the x_m and y_m from the CDDs. Tatsuo Tabata et al. used the x_m derived from CDDs for determining the electron energy [1, 2]. In addition to the x_m, we adopted the y_m as the parameter for determining the electron energy. Thus it is possible to determine the electron beam energy with an improved accuracy. In the present work, mono-energetic electron beam was considered. Further work is planned to extend to beams with the energy spreads.

[2] T. Tabata, P. Andreo, K. Shinoda, and R. Ito, Nucl. Instr. And Meth. B 95, 289 (1995)