Joint ICTP-IAEA Workshop on Monte Carlo Radiation Transport and Associated Data Needs for Medical Applications
28 October – 8 November 2024
ICTP, Trieste, Italy

Lecture 6

Restricted stopping powers, AE and AP

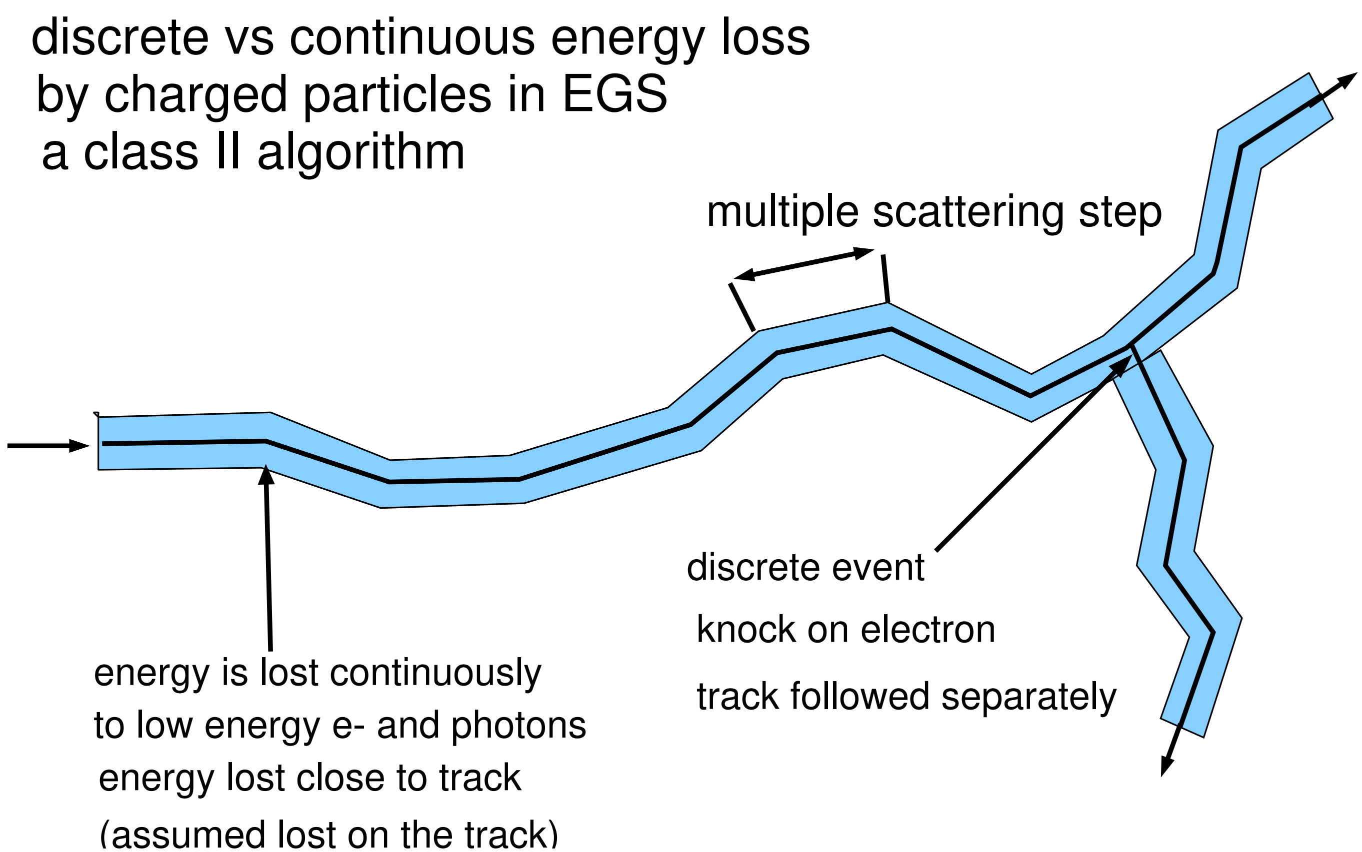
David W.O. Rogers

Carleton Laboratory for Radiotherapy Physics
Physics Department, Carleton University

Government of Canada Gouvernement du Canada

EGS charged particle transport

(see pages 436 – 443 Rogers & Bielajew 1990 review chapter http://www.physics.carleton.ca/∼drogers/pubs/papers/RB90.pdf)



Note: transport mechanics are now more complex, but the AE and AP concepts remain the same.

Definitions of AE and AP

AE: this is related to the creation of secondary electrons or knock-on electrons

- $\mathrm{E}_{\mathrm{sec}} > \mathrm{AE} \Rightarrow$ treat the interactions discretely and follow the secondaries

- $\mathrm{E}_{\mathrm{sec}} \leq \mathrm{AE} \Rightarrow$ treat the interactions as part of the continuous energy loss mechanism and do not follow the secondary particle.

Definitions of AE and AP (cont)

AP: this is related to the creation of bremsstrahlung photons

- E$_{\mathrm{brem}} >$ AP $\Rightarrow$ treat the interactions discretely and follow the bremsstrahlung photon

- E$_{\mathrm{brem}} \leq$ AP $\Rightarrow$ treat the interactions as part of the continuous energy loss mechanism and do not follow the bremsstrahlung photons.

Note that AE and AP are set prior to creating the cross-section data sets. One always has ECUT $\geq$ AE and PCUT $\geq$ AP.

Class II transport

As electrons are transported, creation of low-energy secondaries ($\leq$ AE or AP) is treated as part of the continuous energy loss.

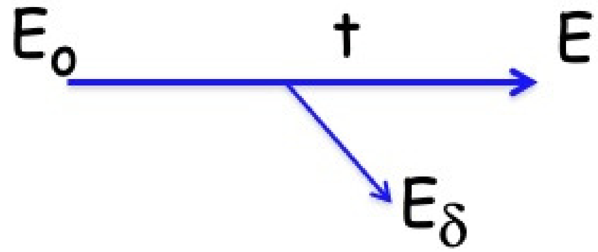
- the energy loss is accounted for in the restricted stopping powers
- the energy is considered deposited on the straight-line track (exact location depends on the user's scoring routine)

Secondary electrons and bremsstrahlung photons created above AE and AP are followed separately.

The energy lost to the secondaries in each discrete event is subtracted from the energy of the primary particle.

Note that in class I Monte Carlo algorithms, the energy lost to secondaries is accounted for independently of the creation of secondaries.

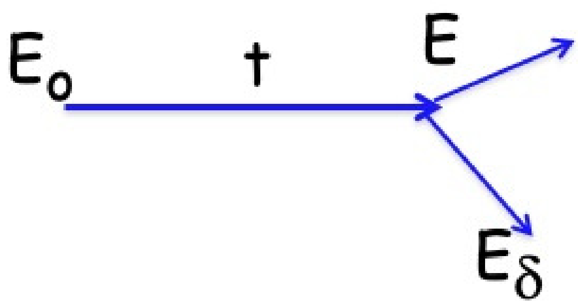
Class I
Uncorrelated energy loss



$$E = E_o - \Delta E(t)$$

$$E_{dep} = \Delta E(t) - E_\delta$$

Class II
Correlated energy loss



$$E = E_o - t\,L^{AE,AP} - E_\delta$$

$$E_{dep} = t\,L^{AE,AP}$$

In Class I, energy loss is sampled from an energy loss distribution, $\Delta E(t)$. Energy is not conserved on every step whereas it is conserved in Class II.

Restricted stopping power

Restricted radiative stopping power:

$$L_{\mathrm{rad}}(E, k_c) = \int_0^{k_c} k \frac{\mathrm{d}\Sigma_{\mathrm{brem}}(E, k)}{\mathrm{d}k} \mathrm{d}k \tag{1.1}$$

Restricted electronic stopping power:

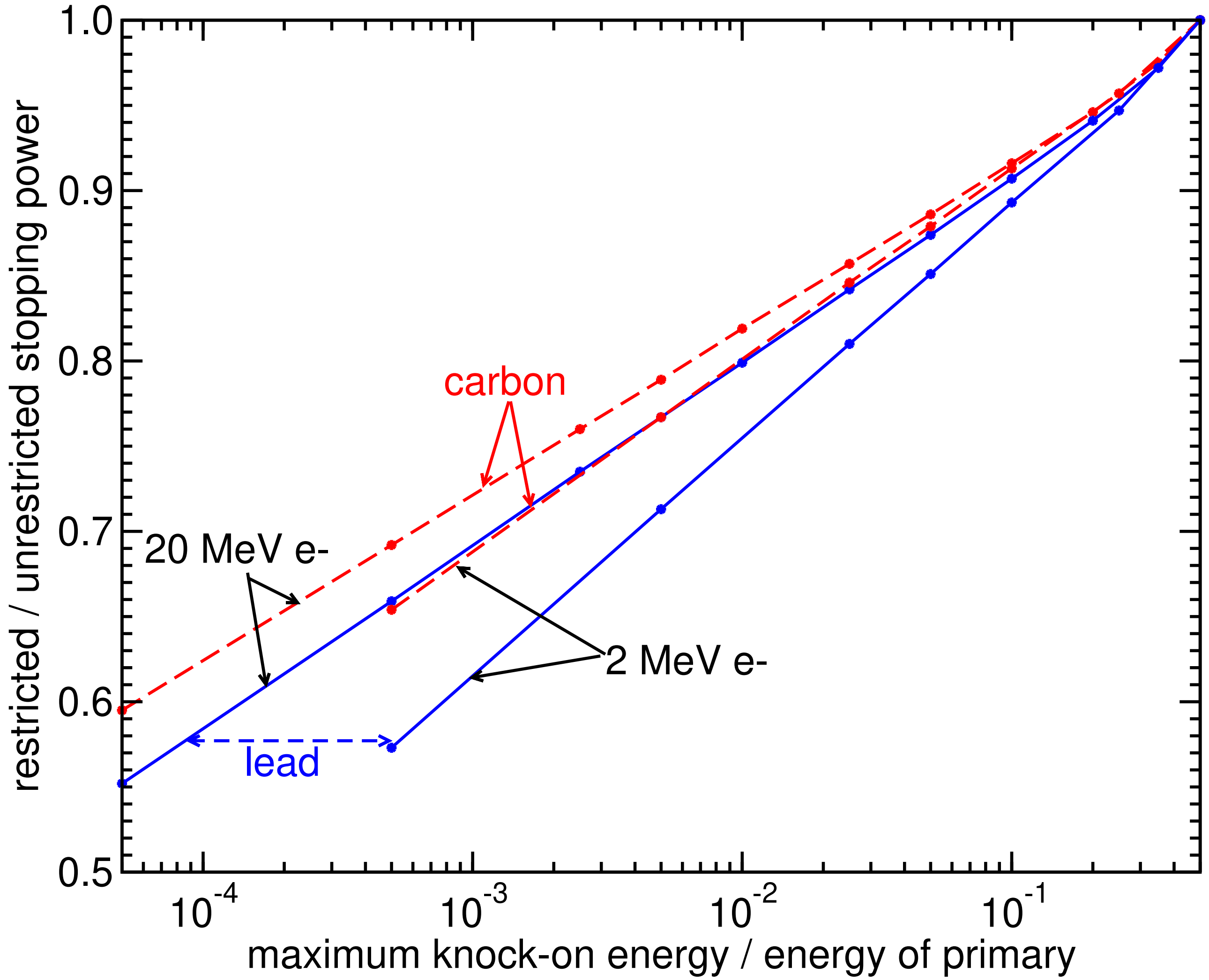
$$L_{\mathrm{el}}(E, E_c) = \int_0^{E_c} E' \frac{\mathrm{d}\Sigma_{\mathrm{el}}(E, E')}{\mathrm{d}E'} \mathrm{d}E' \tag{1.2}$$

Restricted stopping power:

$$L(E, E_c, k_c) = L_{\mathrm{rad}}(E, k_c) + L_{\mathrm{el}}(E, E_c) \tag{1.3}$$

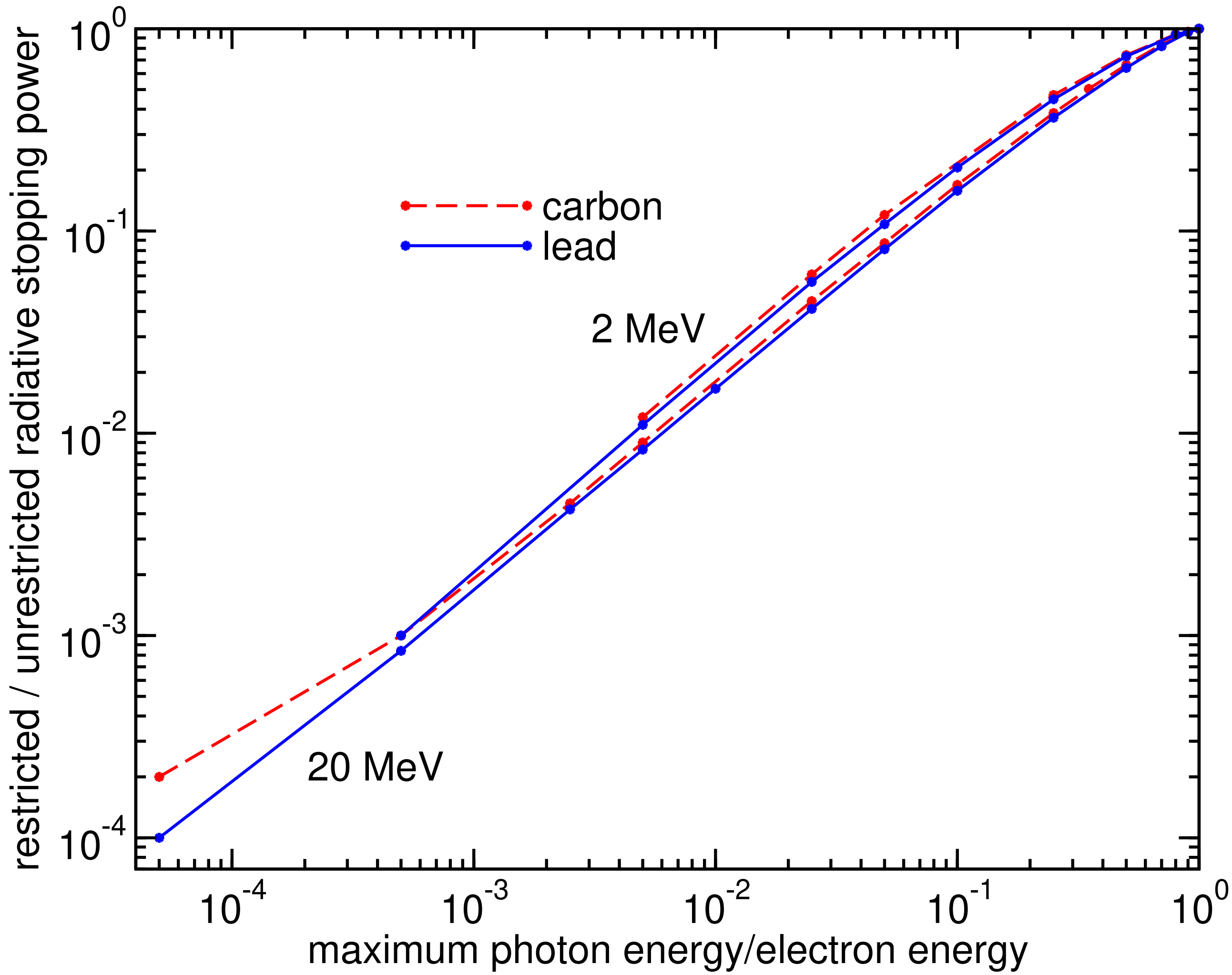
average energy lost to sub-threshold collisions per unit length

Restricted/unrestricted electronic sp

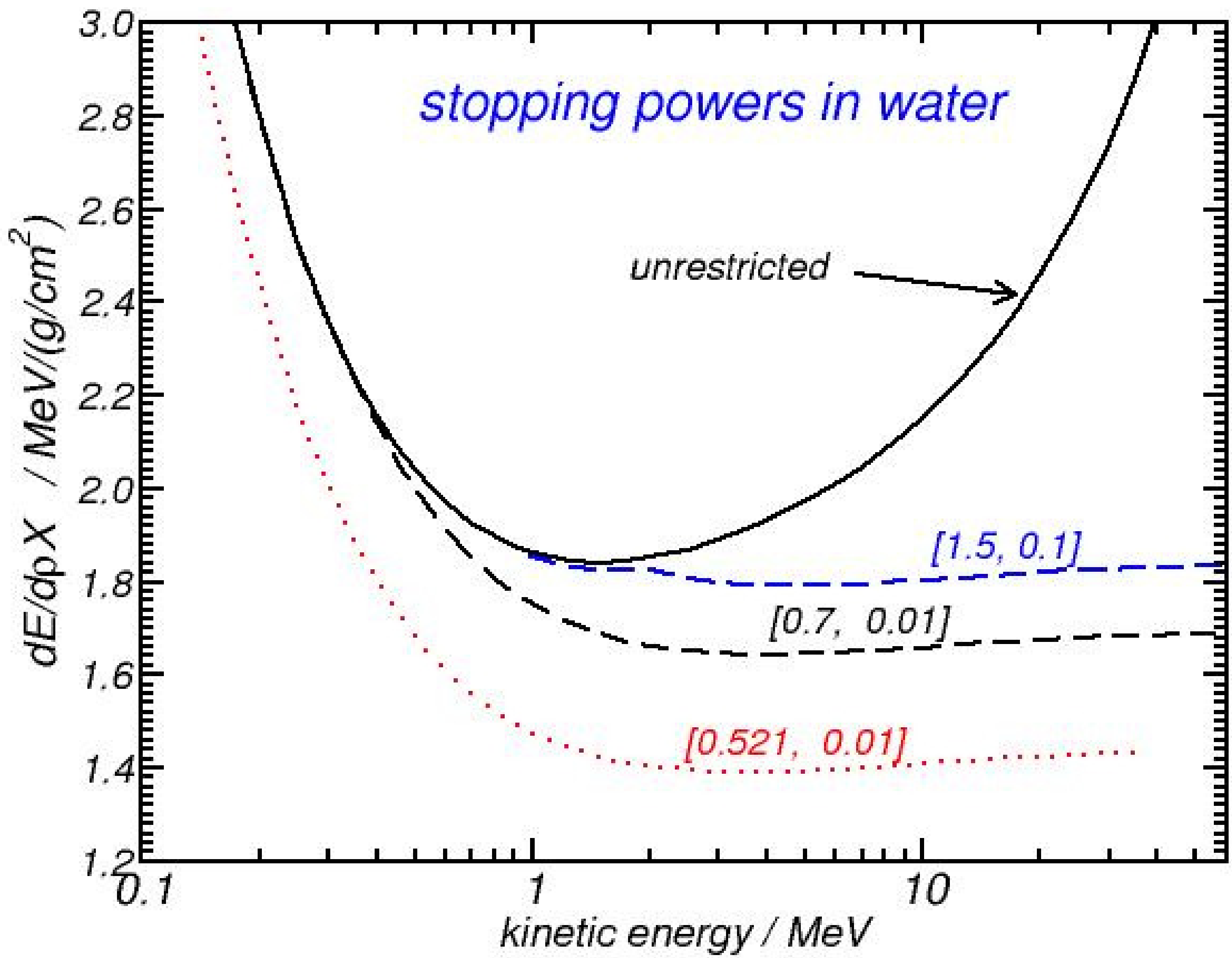


Even for AE=0.512 MeV, $> 55\%$ of stopping power is from sub-threshold events. From 1990 MC review chapter.

Restricted/unrestricted radiative sp

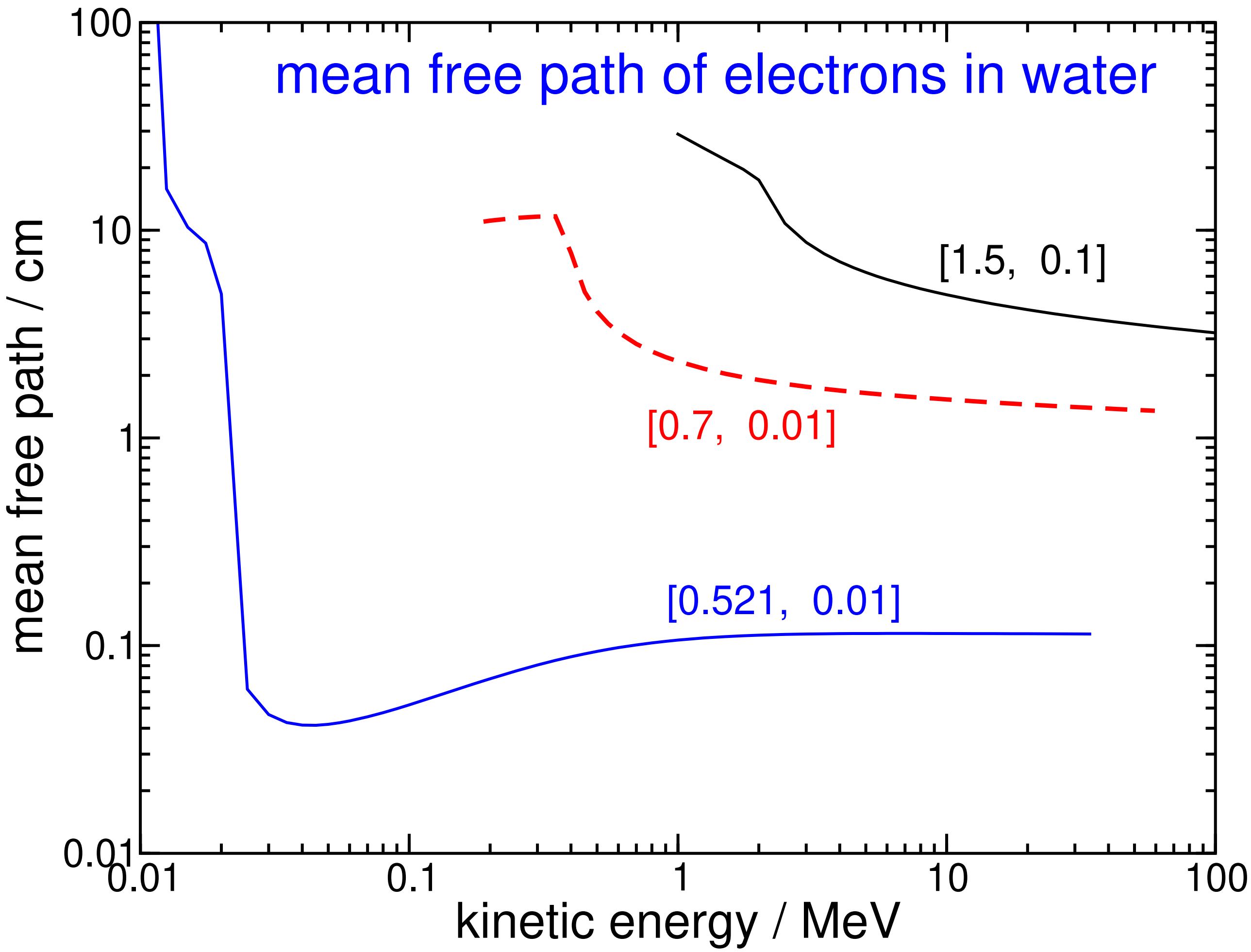


For AP=0.512 MeV, $< 1\%$ of radiative stopping power is from sub-threshold events (often much less). From 1990 MC review chapter.



Stopping power of water for various [AE,AP] values. Be sure you understand the various shapes and relative values.

Effects of AE, AP on step size

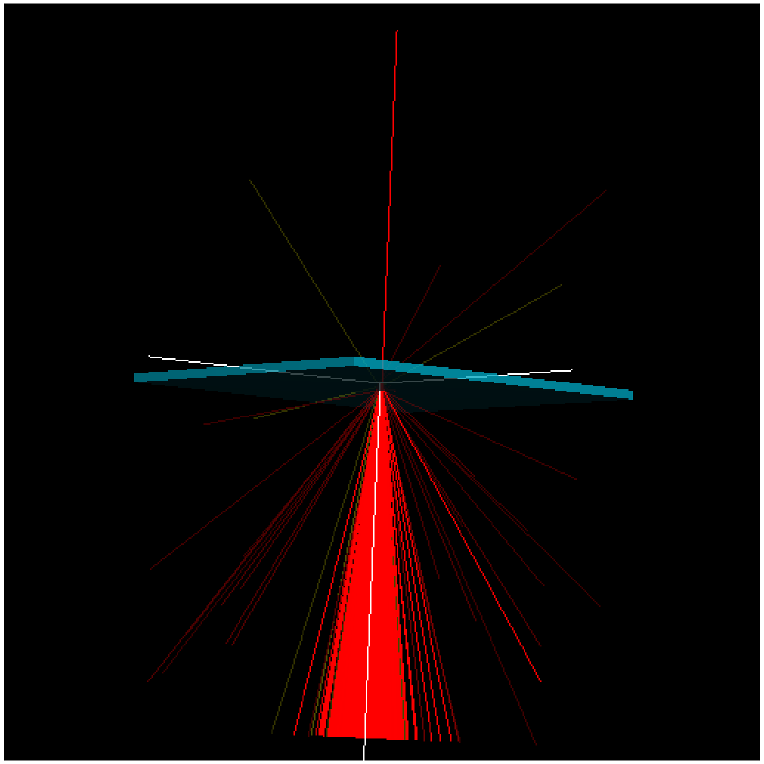


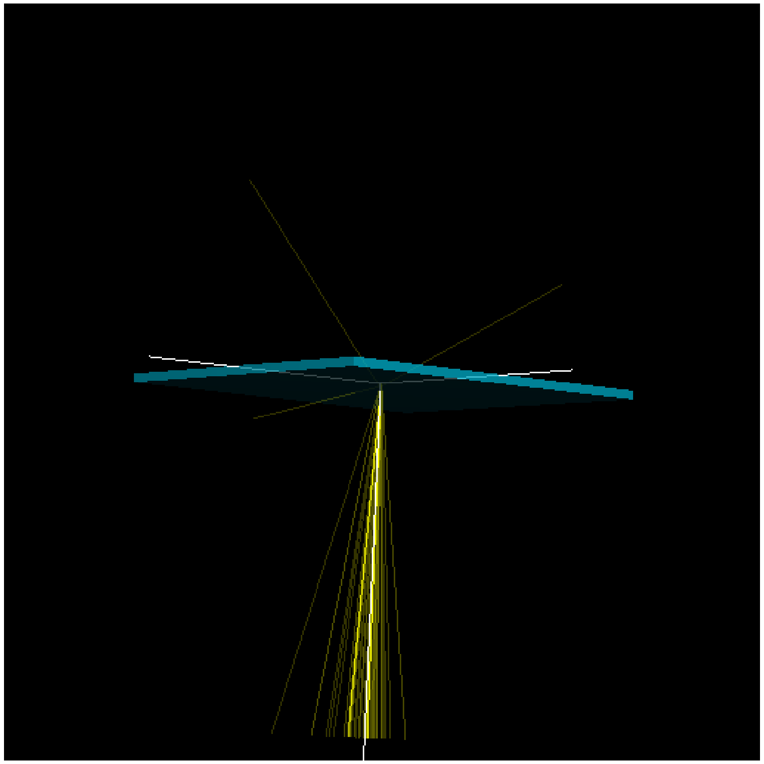
Mean free path of e — to discrete interactions in water for various [AE,AP] datasets.

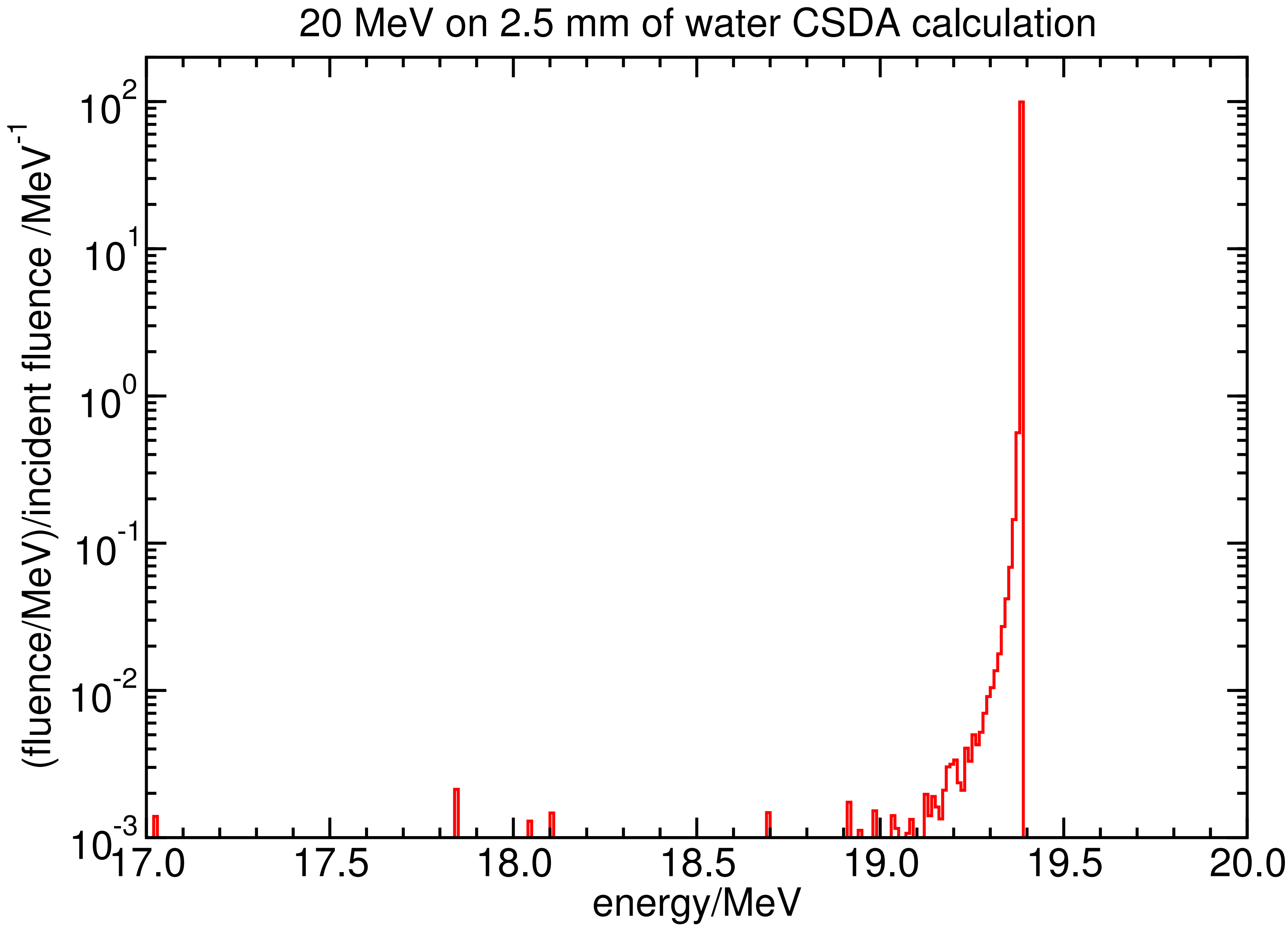
Example: 20 MeV electrons

Look at spectra of all electrons after passing through a 2.5 mm slab of water.
Initial energy 20 MeV in a broad parallel beam.

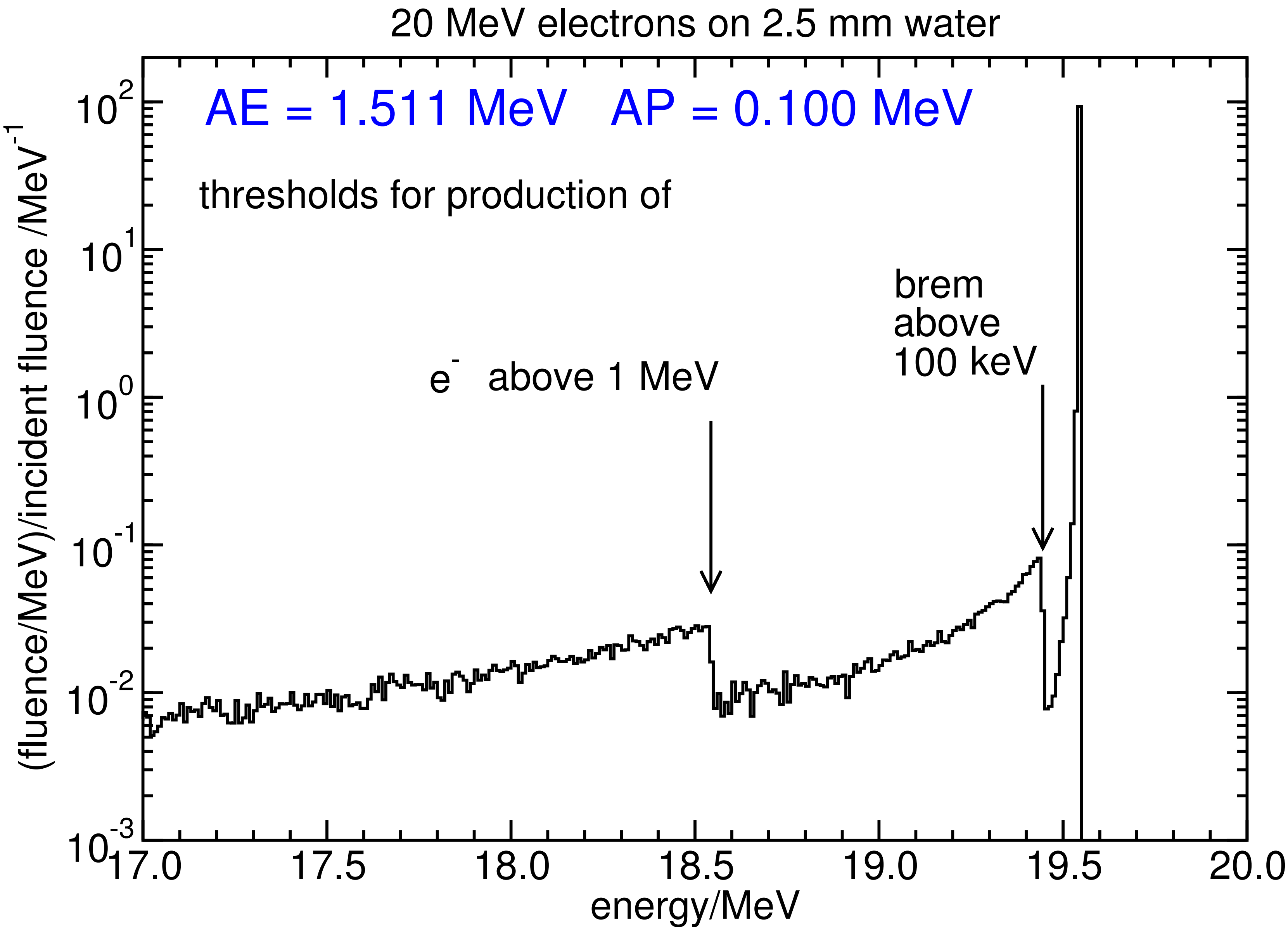
Here: pencil beam, red is e–, yellow is photons thru water slab.



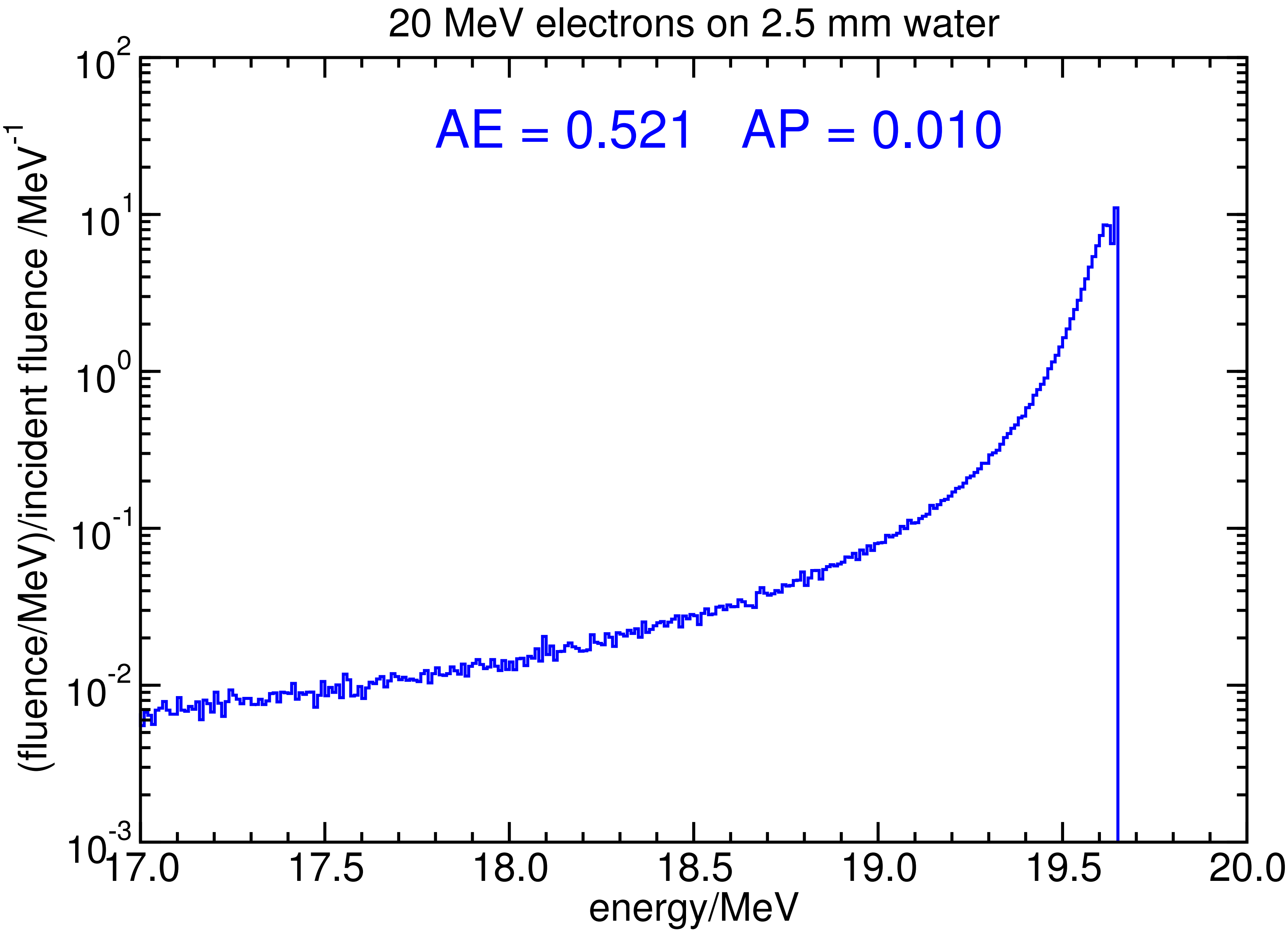




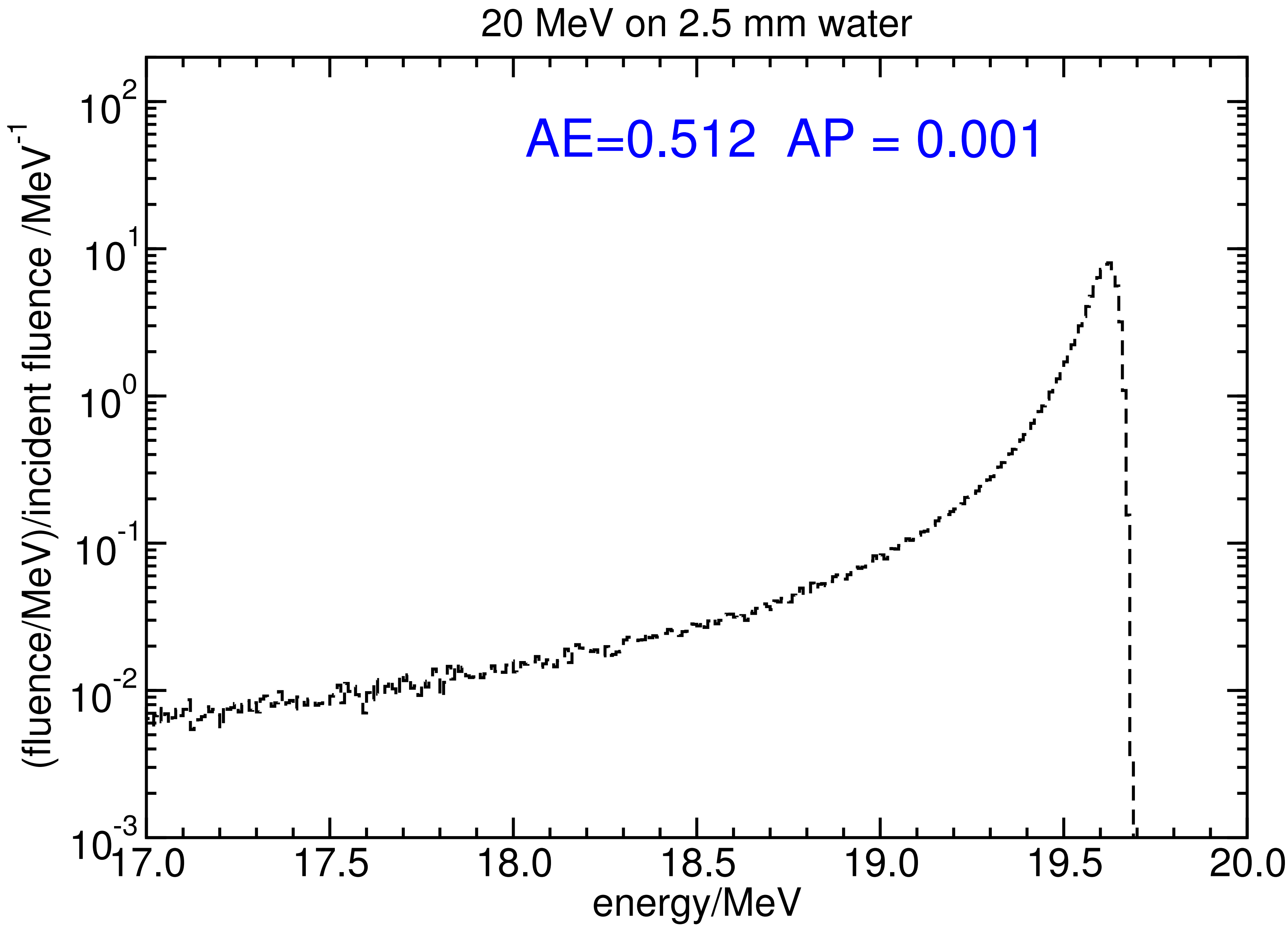
Spectrum of 20 MeV electrons after passing through a 2.5 mm slab of water. Mean energy loss of primaries is 618 keV. Tail (0.5%) is from angulation of a few particles.



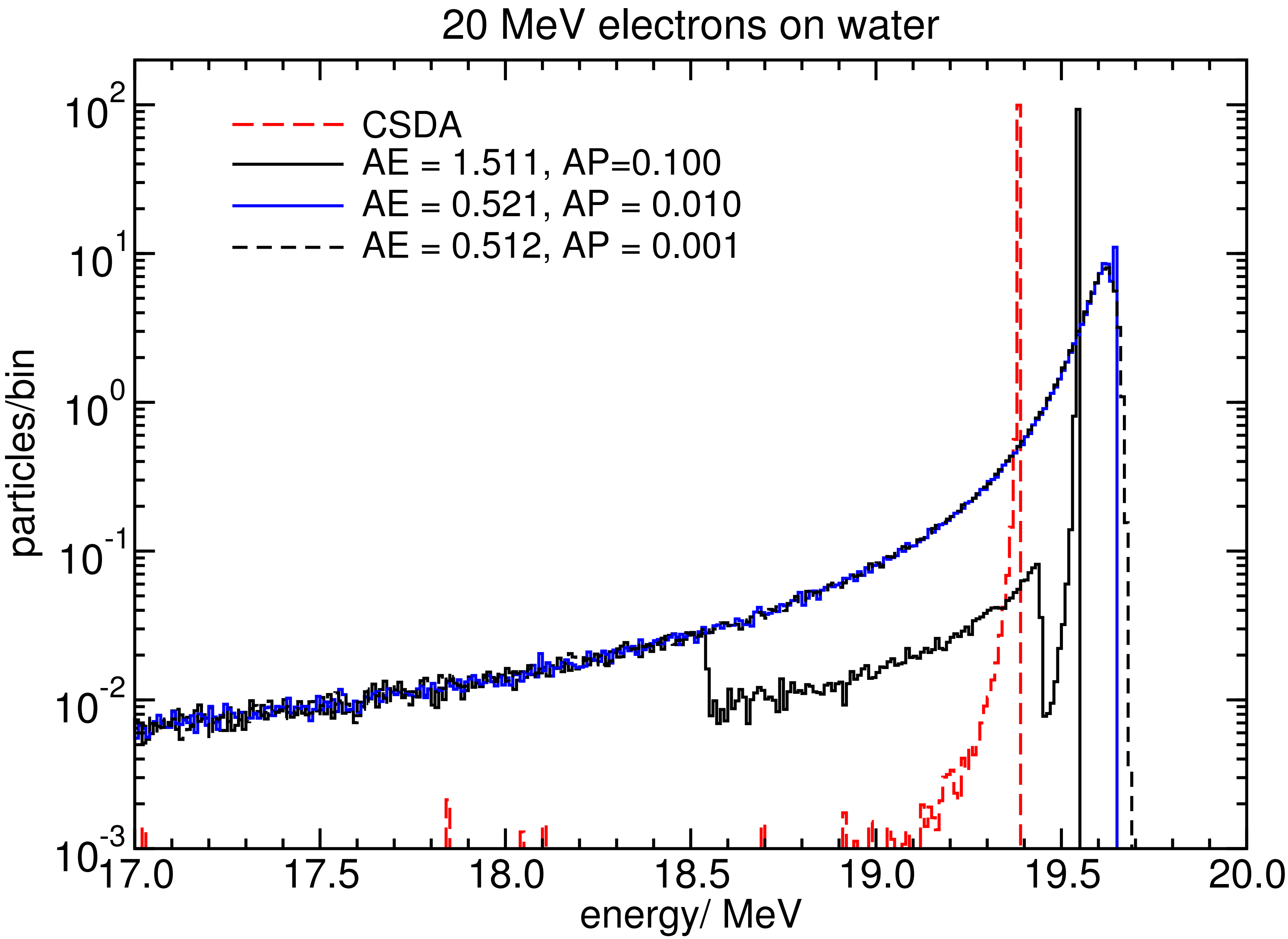
Spectrum of 20 MeV electrons after passing through a 2.5 mm slab of water. Mean energy loss of primaries is 618 keV. 92% of particles are in peak.



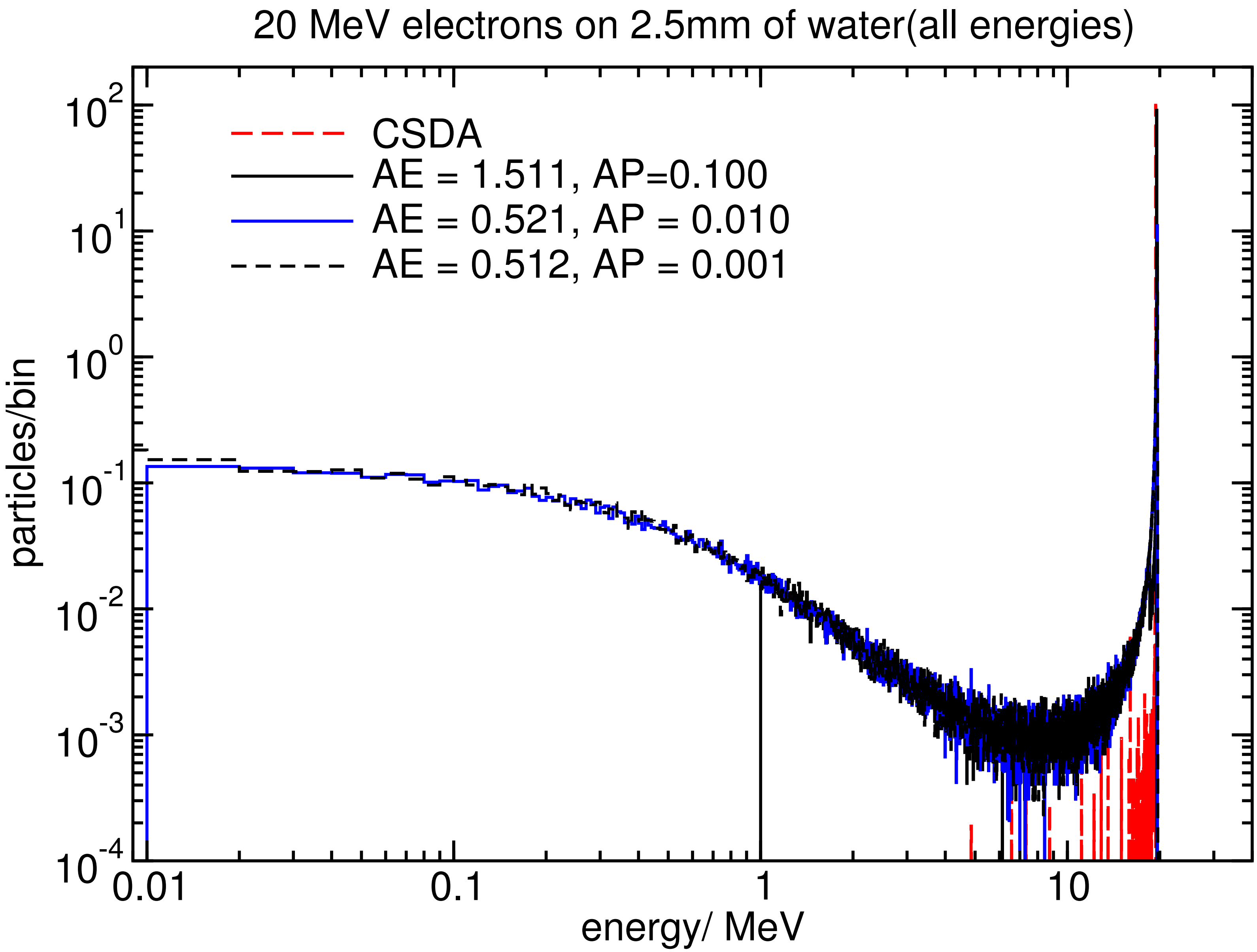
Spectrum of 20 MeV e– after passing through a 2.5 mm slab of water. Mean energy loss of primaries is 618 keV.



Spectrum of 20 MeV e– after passing through a 2.5 mm slab of water. Mean energy loss of primaries is 618 keV.

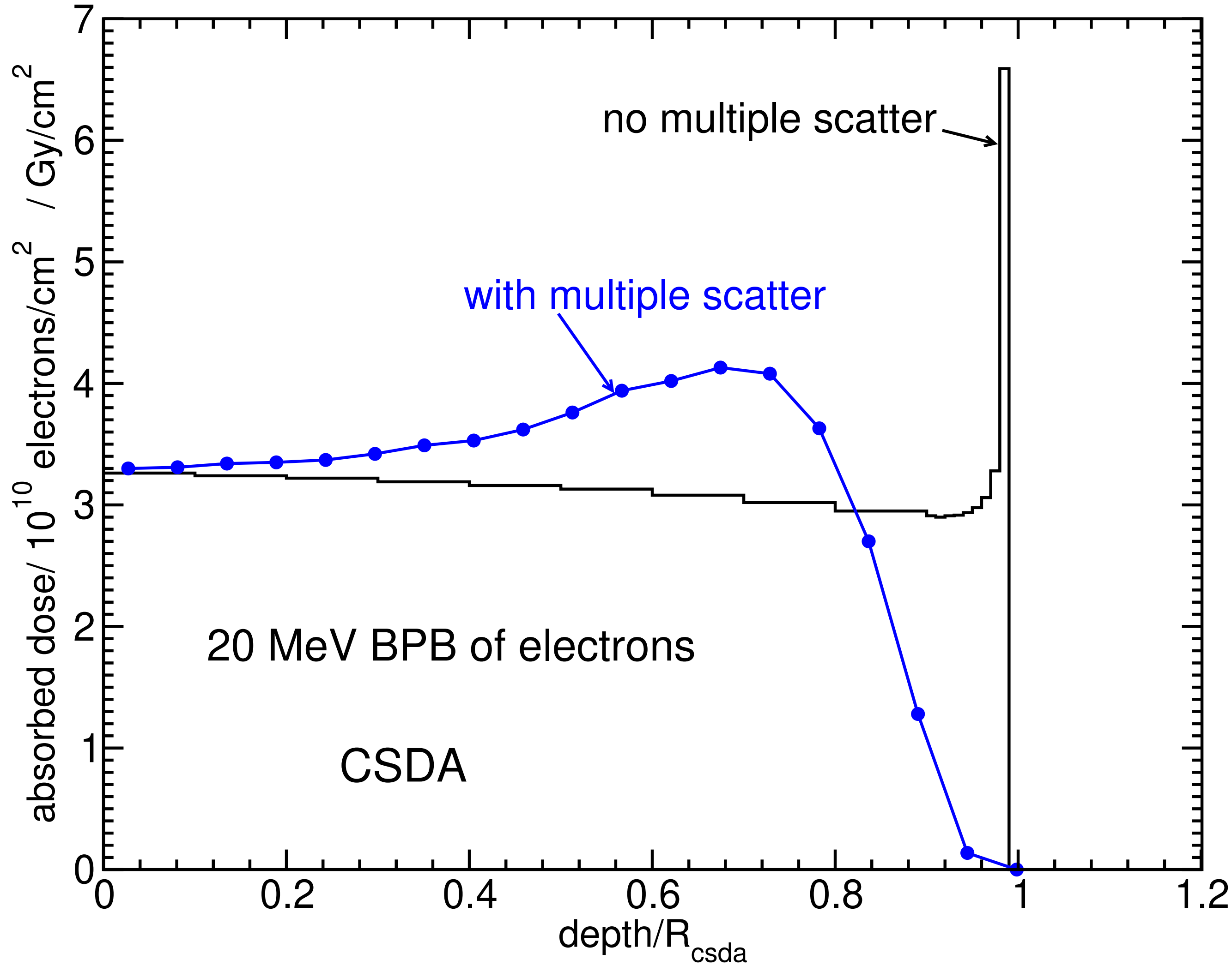


Spectra of 20 MeV e− after 2.5 mm water. Mean energy loss of primaries is 618 keV. Times 77, 84, 144, 1130 s.



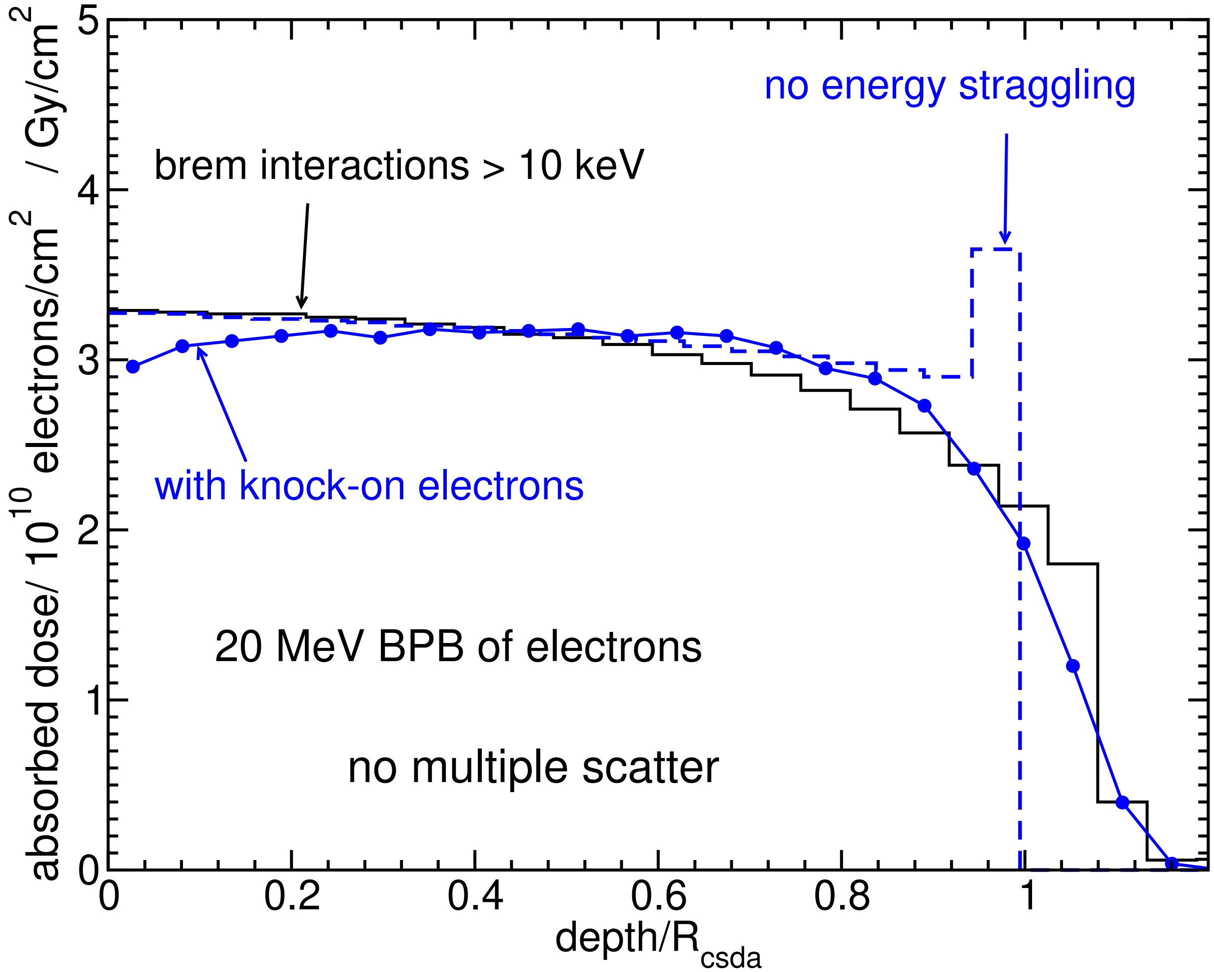
Spectra of 20 MeV e— after 2.5 mm water. Mean energy loss of primaries is 618 keV. Times 77, 84, 144, 1130 s.

Effects of multiple scatter



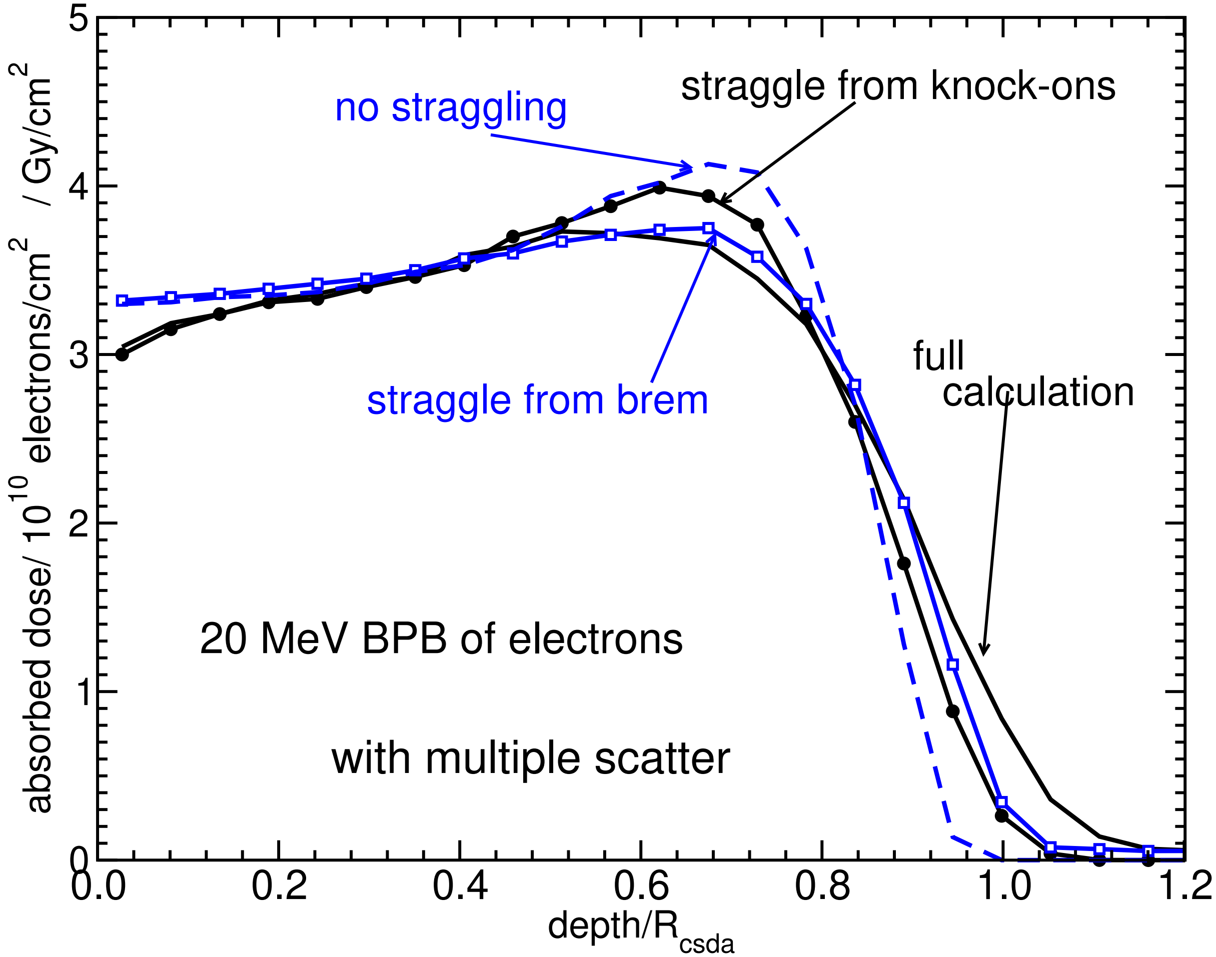
CSDA calculation of 20 MeV e— on water with and without multiple scattering.

Effects of brem & knock-on e− creation: no multiple scatter



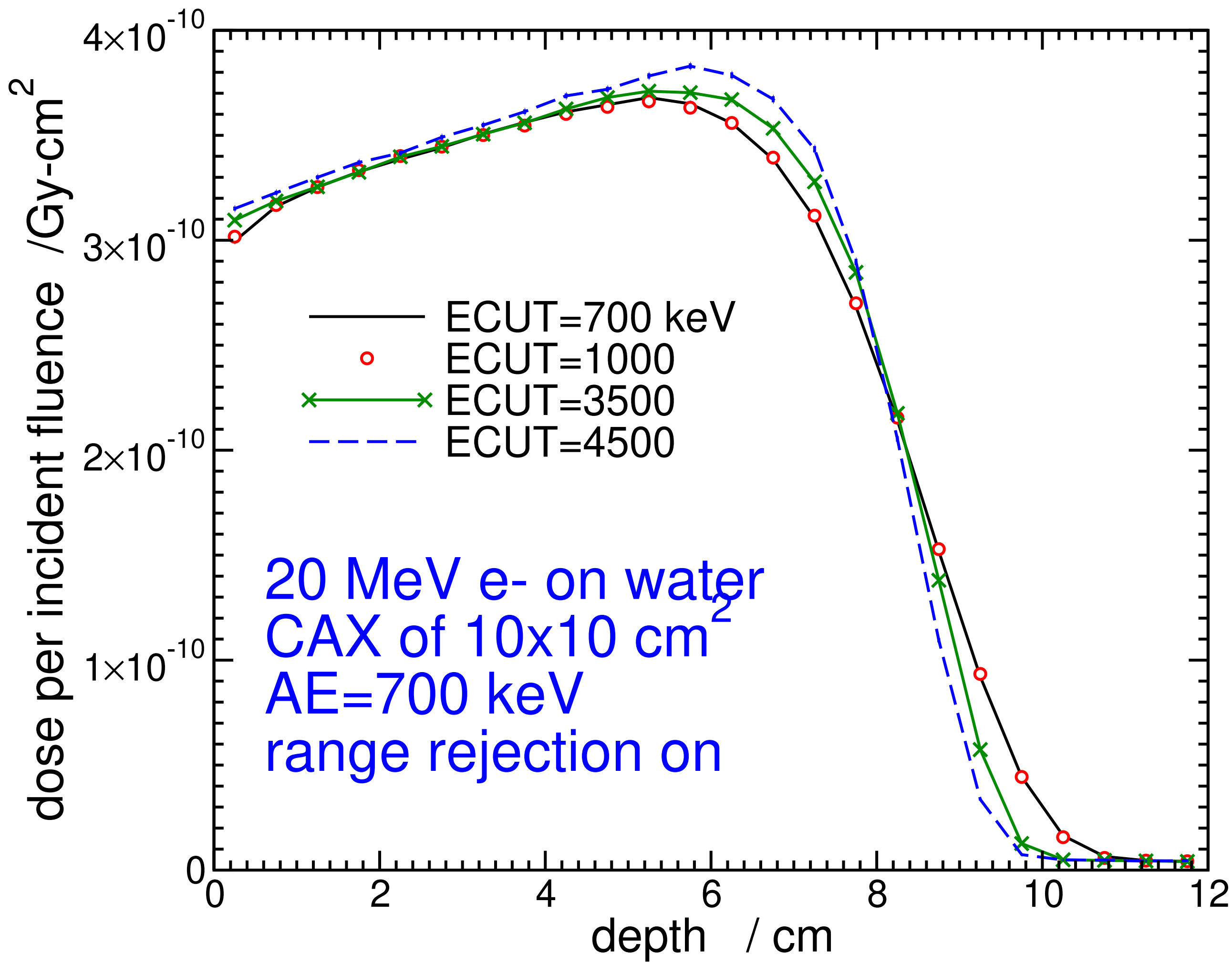
20 MeV e− on water, no multiple scatter. Brem or knock-on e− above 10 keV created.

Effects of brem & knock-on e— creation with multiple scatter



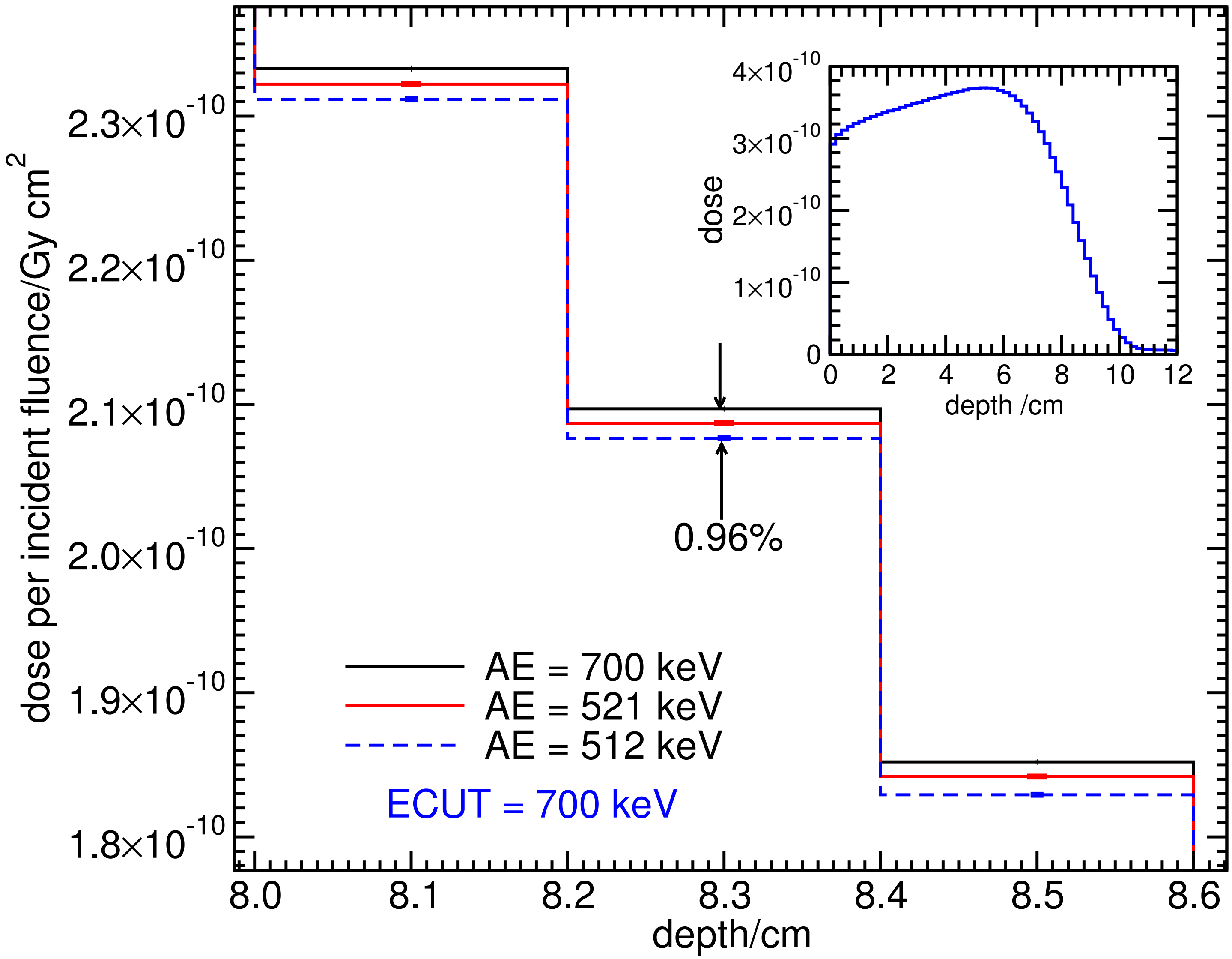
20 MeV e— on water with multiple scatter. Brem or knock-on e— or both above 10 keV created.

Understanding ECUT



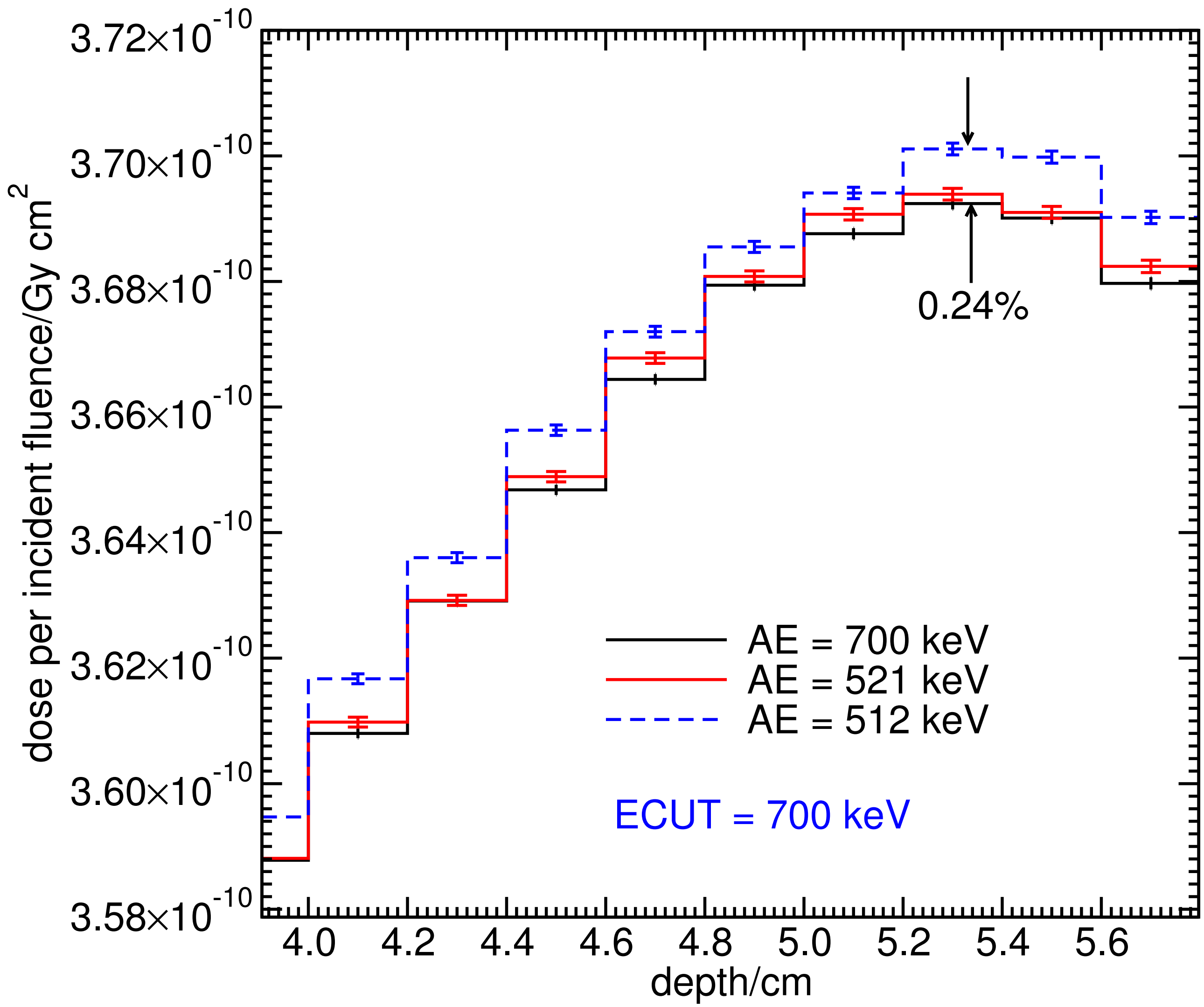
Curves with ECUT = 700 or 512 keV are identical (both AE=512 keV). ECUT=512 keV takes 12% longer with range rejection on and 3.0 times as long if off.

Effects of changing AE value on 20 MeV electron depth-dose curve



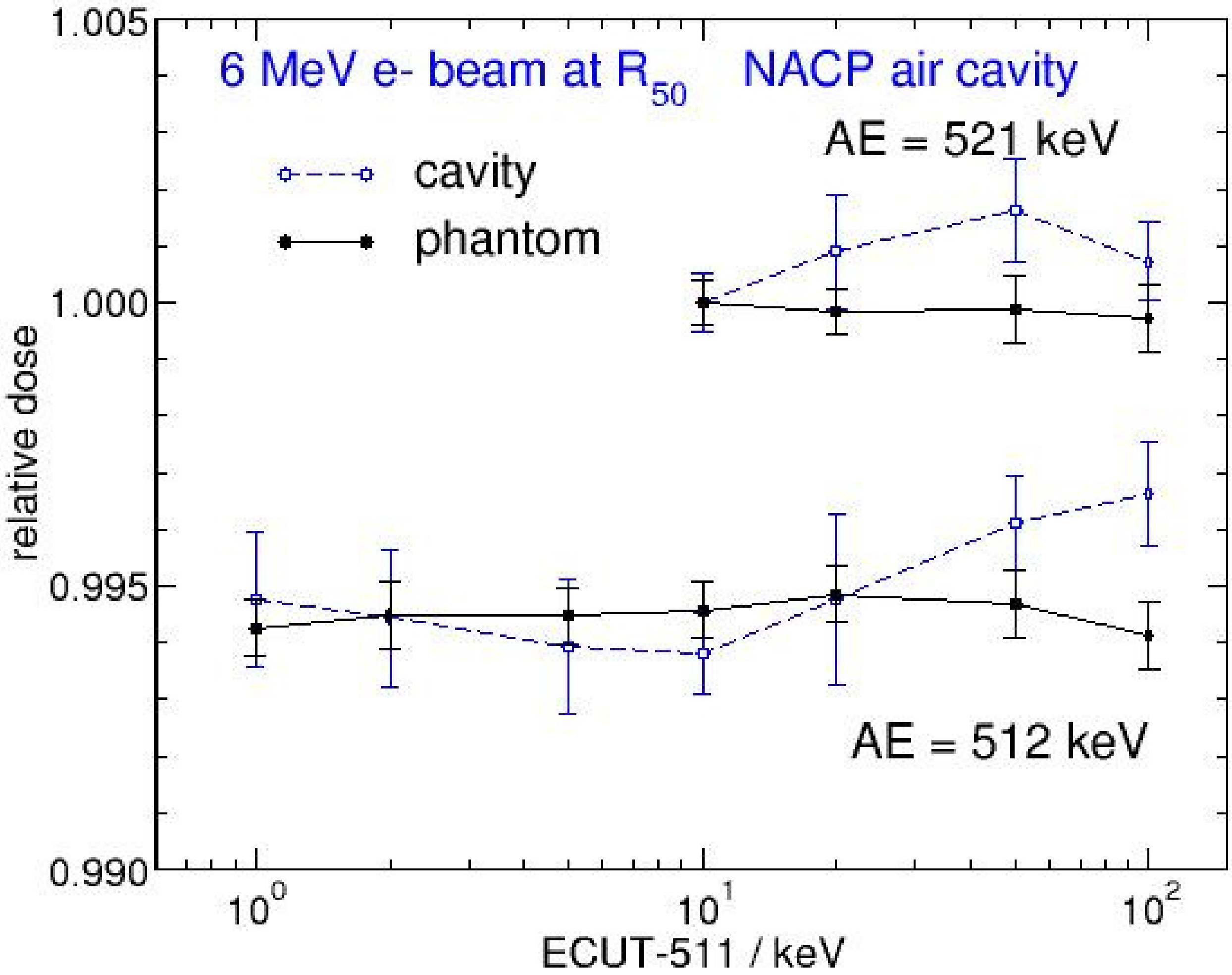
20 MeV e− on water. ECUT = 0.700 MeV. Various AE.

Effects of changing AE value on 20 MeV electron depth-dose curve



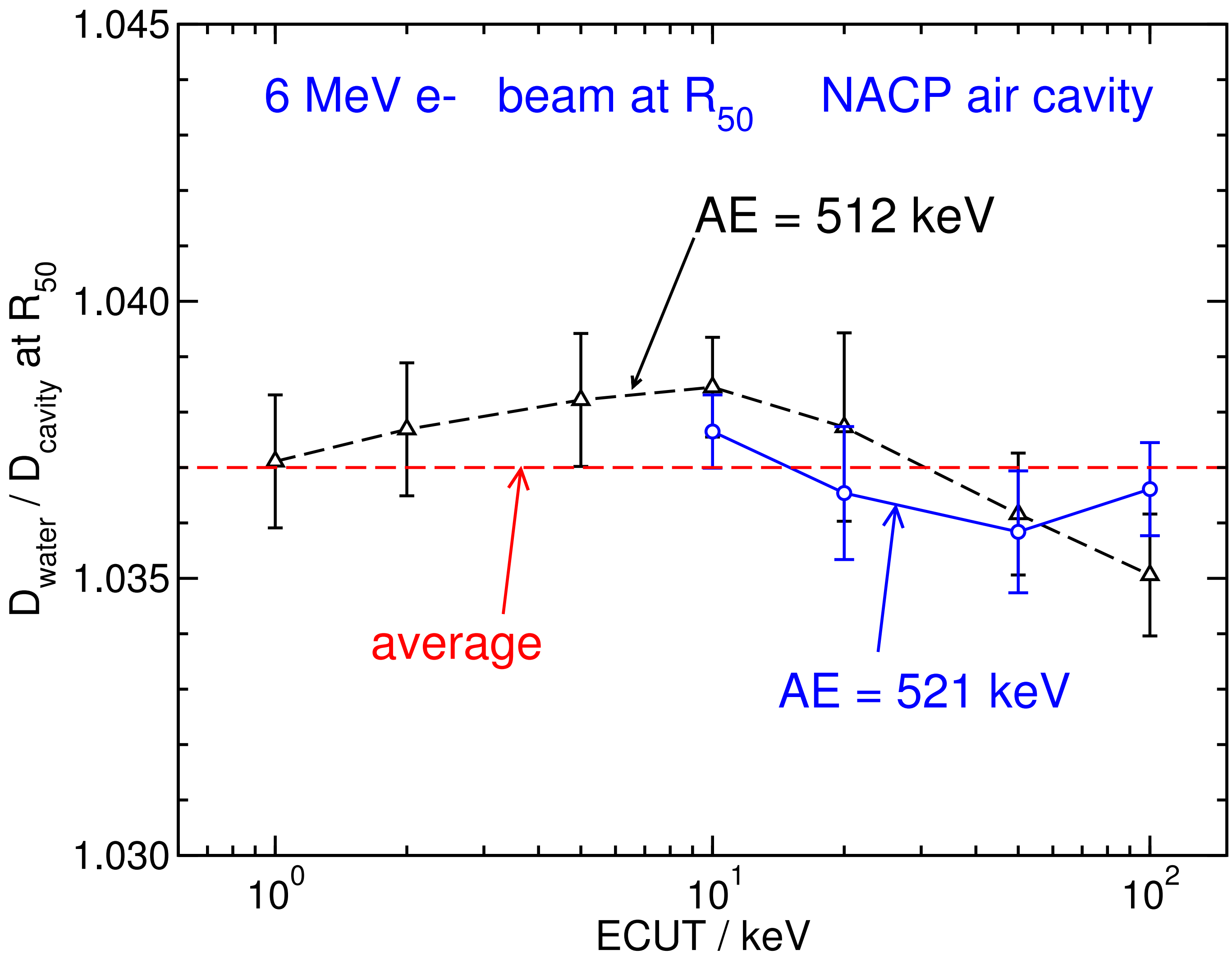
20 MeV e$-$ on water. ECUT = 0.700 MeV. Various AE.
Note reversal of trend vs R_{60} case on previous slide.

Effects of changing AE and ECUT value



Doses normalized in cavity & phantom at AE=ECUT=521 keV. Note ratio of cavity to phantom dose does not change significantly. From Wang and Rogers Med Phys 35(2008)1747.

Effects of changing AE and ECUT value on dose ratio



Ratio of doses shown in previous figure. Independent of AE and ECUT. From Wang and Rogers Med Phys 35(2008)1747.

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