Japan-Korea Joint Summer School on Radiation Science and Engineering
Kitakyusyu International Conference Center (15 Jul 2009)

EGS code and reaction between electrons and photons

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Last modified on 2009.7.9

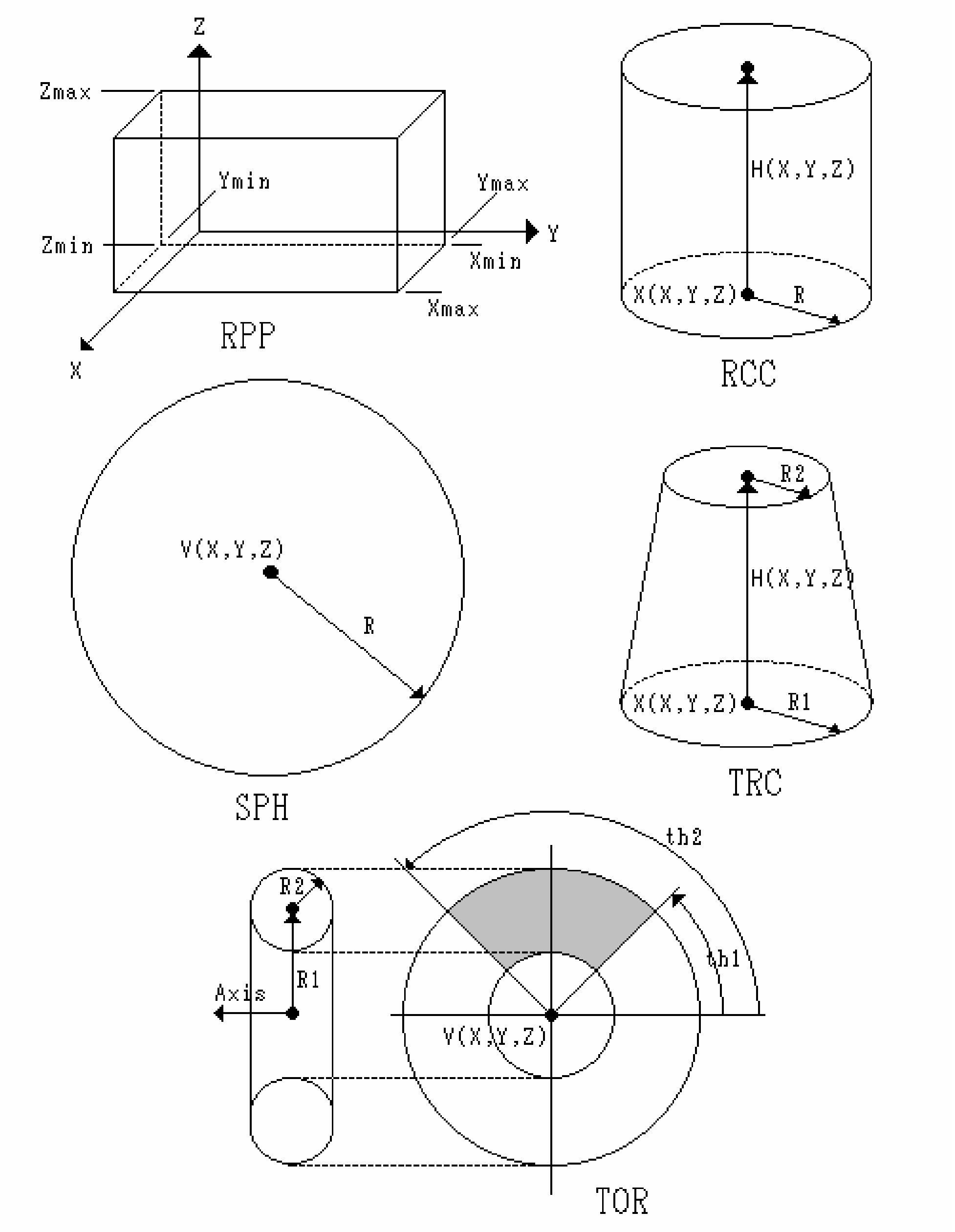
History of EGS system

Period	Program	Languag e	Authors
1963～1965	SHOWER1	Fortran	Nagel
1966	SHOWER2	Fortran	Nicoli
1967～1972	SHOWER3/PREPRO	Fortran	Ryder, Talwar, Nelson
1970～1972	SHOWER4/SHINP	Fortran	Ford
1974	EGS1/PEGS1	Fortran	Ford, Nelson
1975	EGS2/PEGS2	Mortran 2	Ford, Nelson
1976～1977	EGS3/PEGS3(SLAC-210)	Mortran 2	Ford, Nelson
1982～1985	EGS4/PEGS4(SLAC-265)	Mortran 3	Nelson, Hirayama, Rogers
2006	EGS5(SLAC-R-730 and KEK Report 2005-8)	Fortran	Hirayama, Namito, Bielajew, Wilderman and Nelson

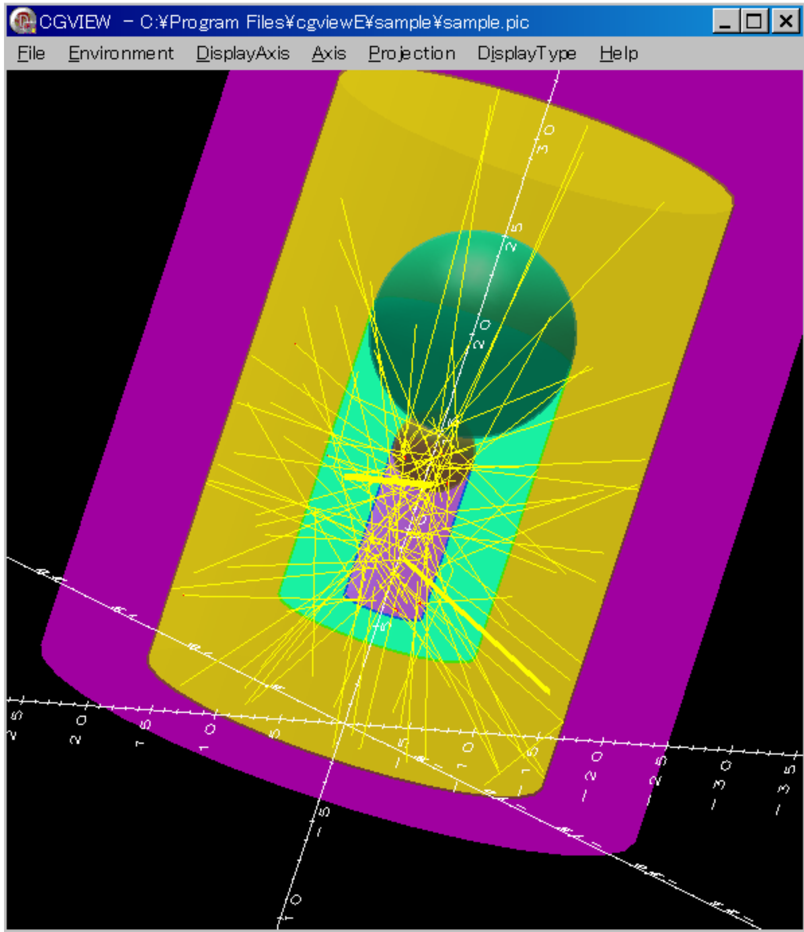
About EGS

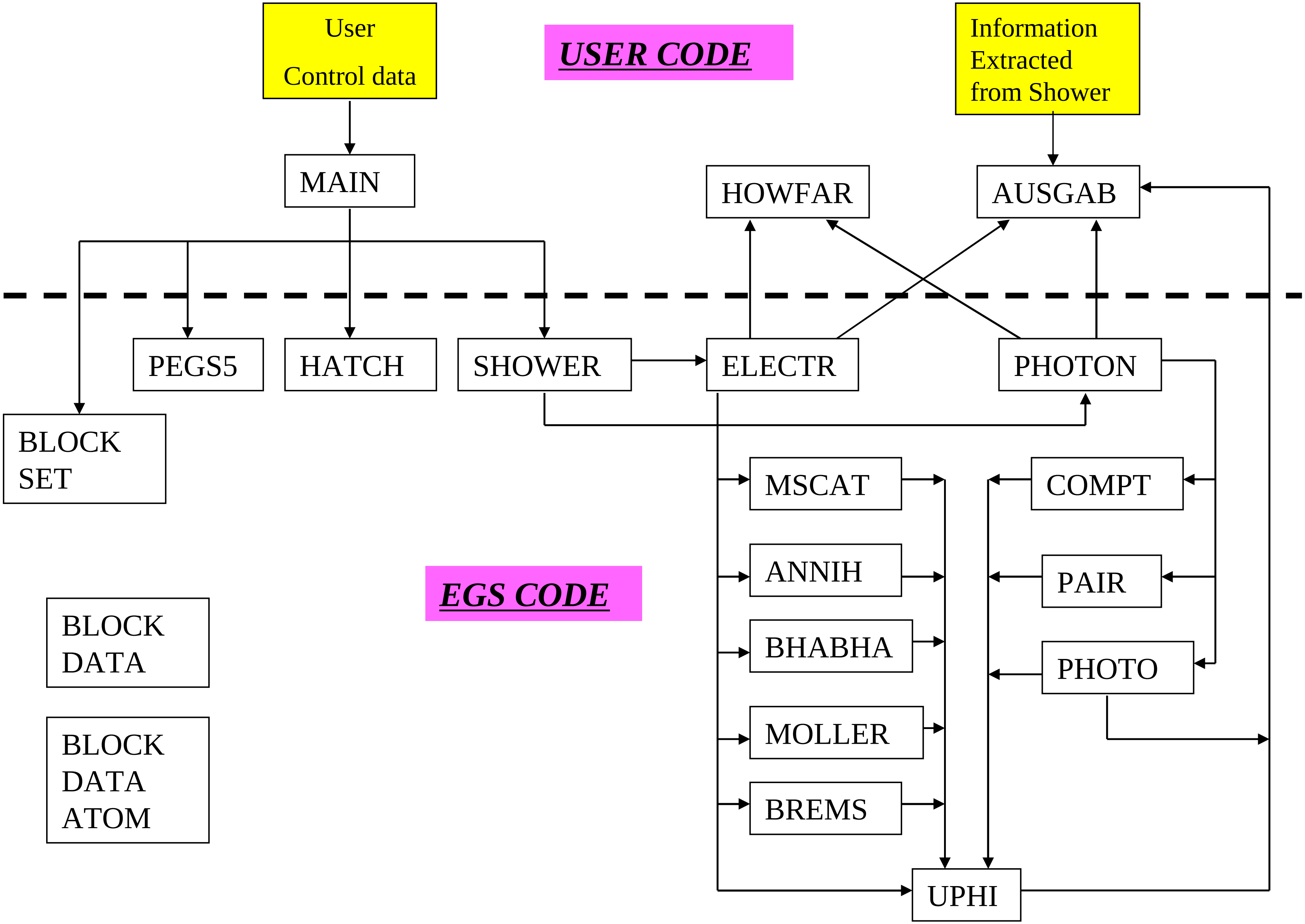
- Monte Carlo particle transport simulation code.
- Interaction of electron and photon with matter.
- Energy range: 10^3eV - 10^{12}eV.
- EGS5: Released in 2006. Authors: Hirayama, Namito, Bielajew, Wilderman, and Nelson.
- Runs on Linux, Cygwin and Windows-PC.
- Combinatorial geometry is available.
  - Geometry check program (CGVIEW) is available.
  - Separation of geometry and other preparation.
- Transport in EM field.

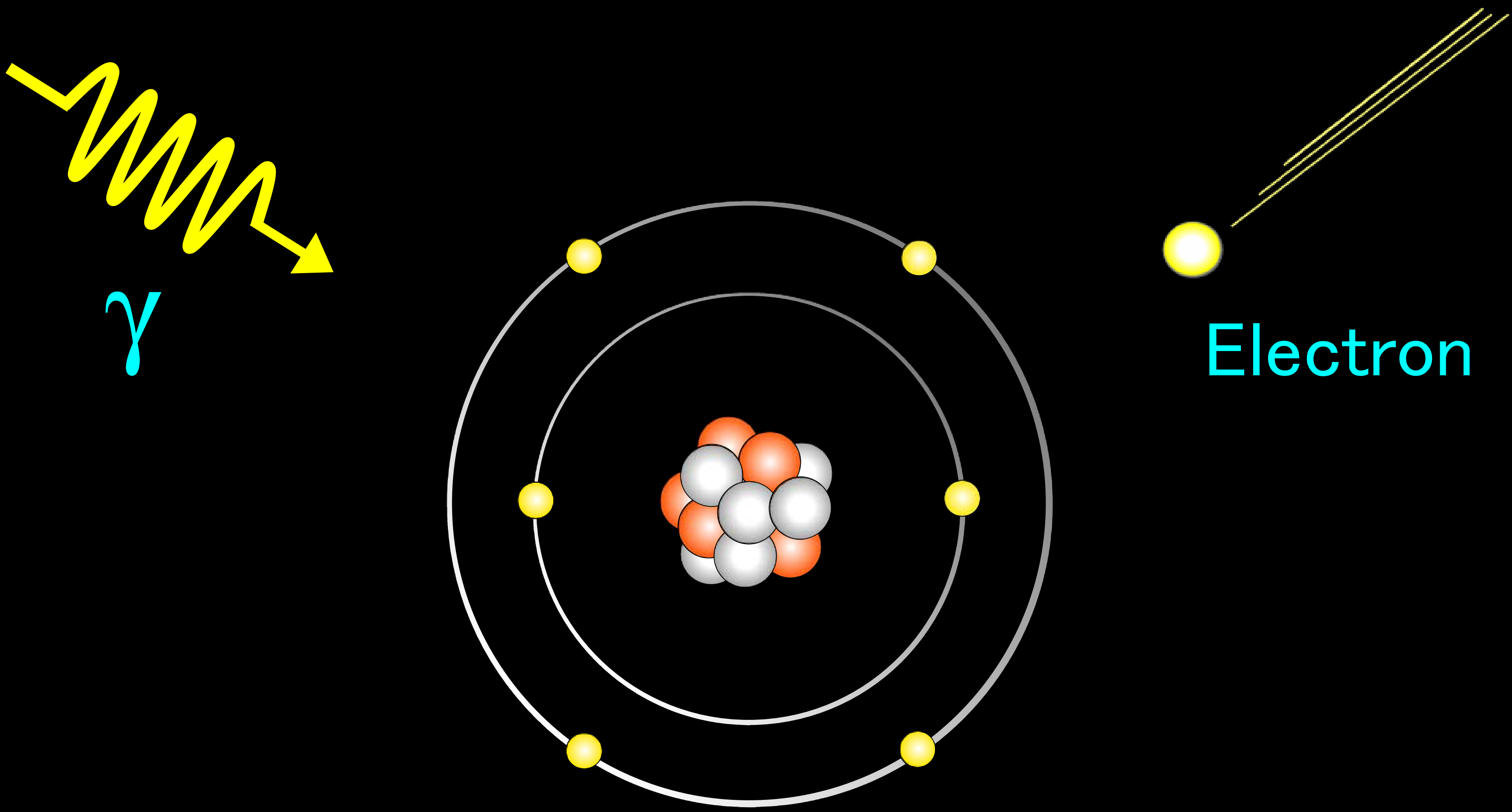
Combinatorial Geometry CG



1. Specify BODY using parameters.
2. Specify ZONE by operation (AND, OR, OUTSIDE) of bodies.
3. Specify material for ZONE




User
Control data
USER CODE
Information
Extracted
from Shower
MAIN
HOWFAR
AUSGAB
PEGS5
HATCH
SHOWER
ELECTR
PHOTON
BLOCK
SET
MSCAT
COMPT
ANNIH
PAIR
EGS CODE
BHABHA
PHOTO
BLOCK
DATA
MOLLER
BLOCK
DATA
ATOM
BREMS
UPHI

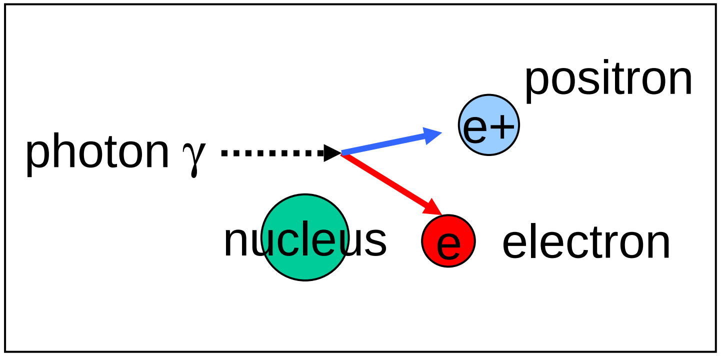


What is interact with photon and electron ?

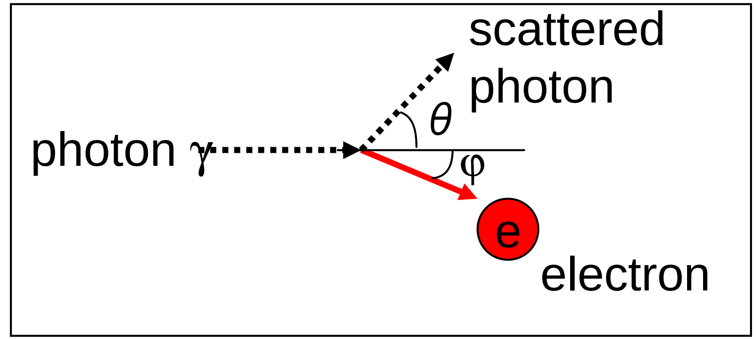
Whole One Atom? Electron? Nucleus?

Photon Monte Carlo Simulation

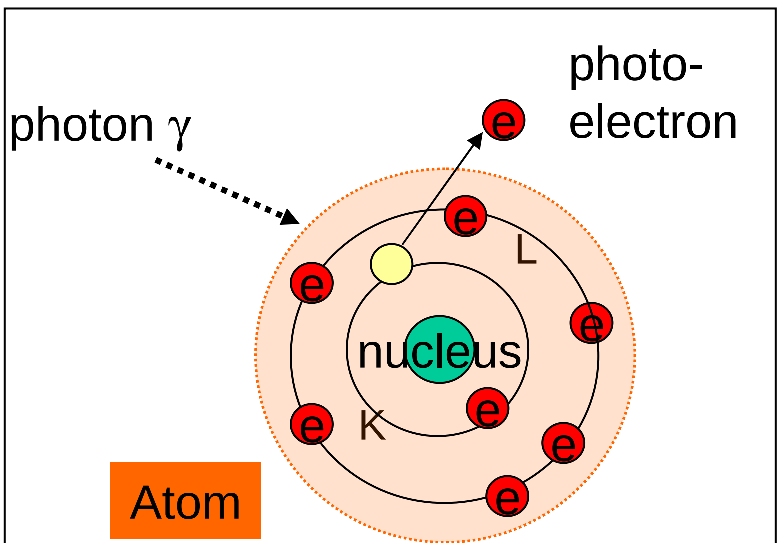
Photon Interaction with Matter



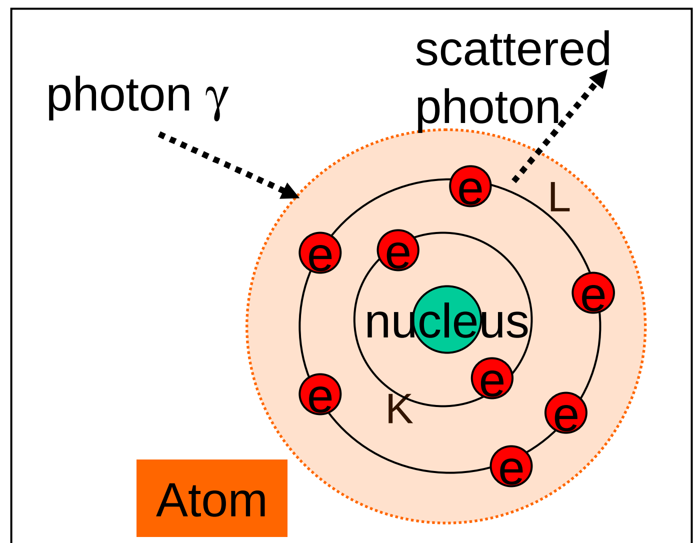
Pair Production



Compton scattering

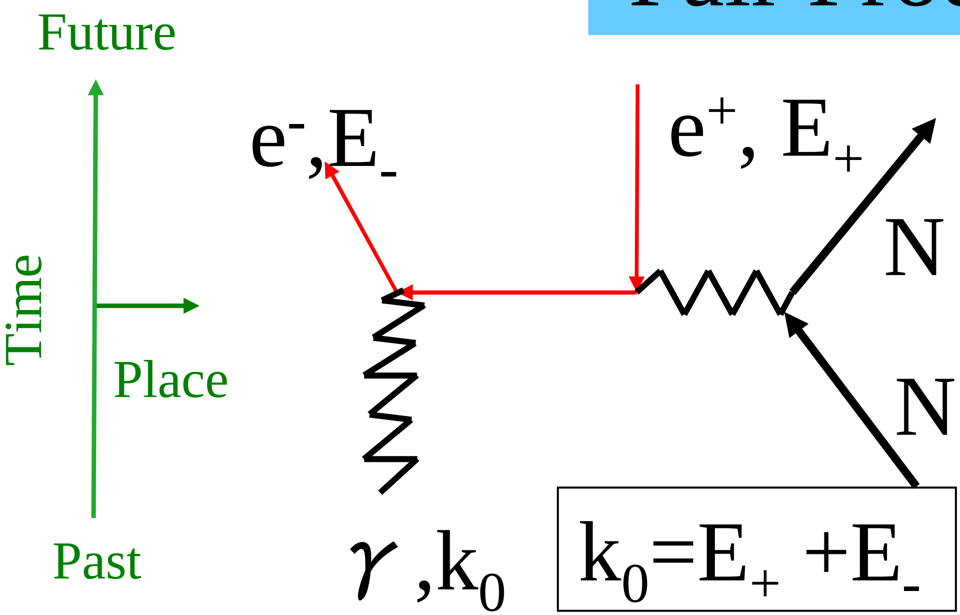


Photoelectric effect

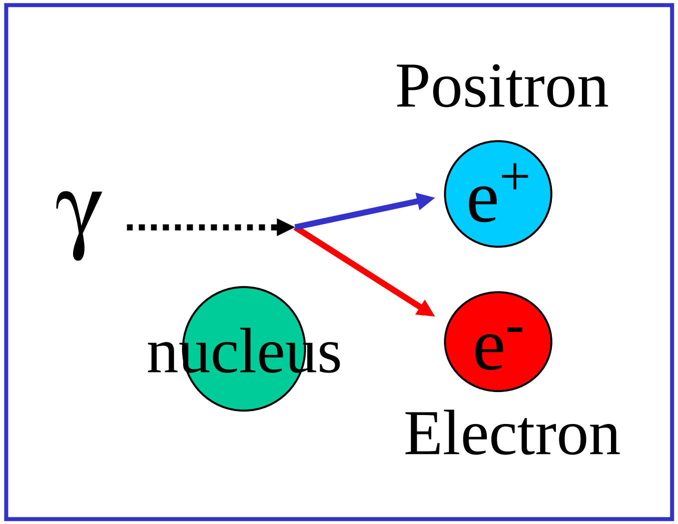


Rayleigh scattering

Pair Production



Feynman diagram



sketch

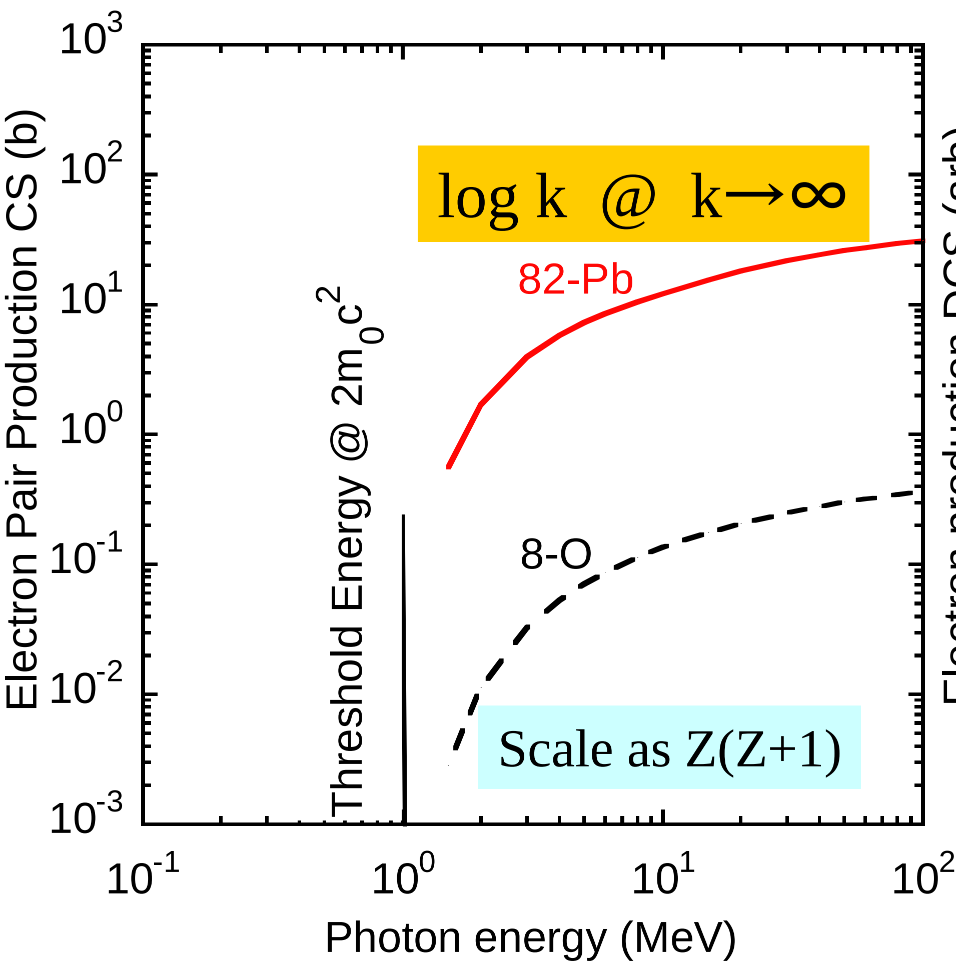
- Interact in the field of a nucleus
- Annihilate and produce e^+ - e^- pair
- triplet distribution ignored,

  incl. in total σ_{pair}

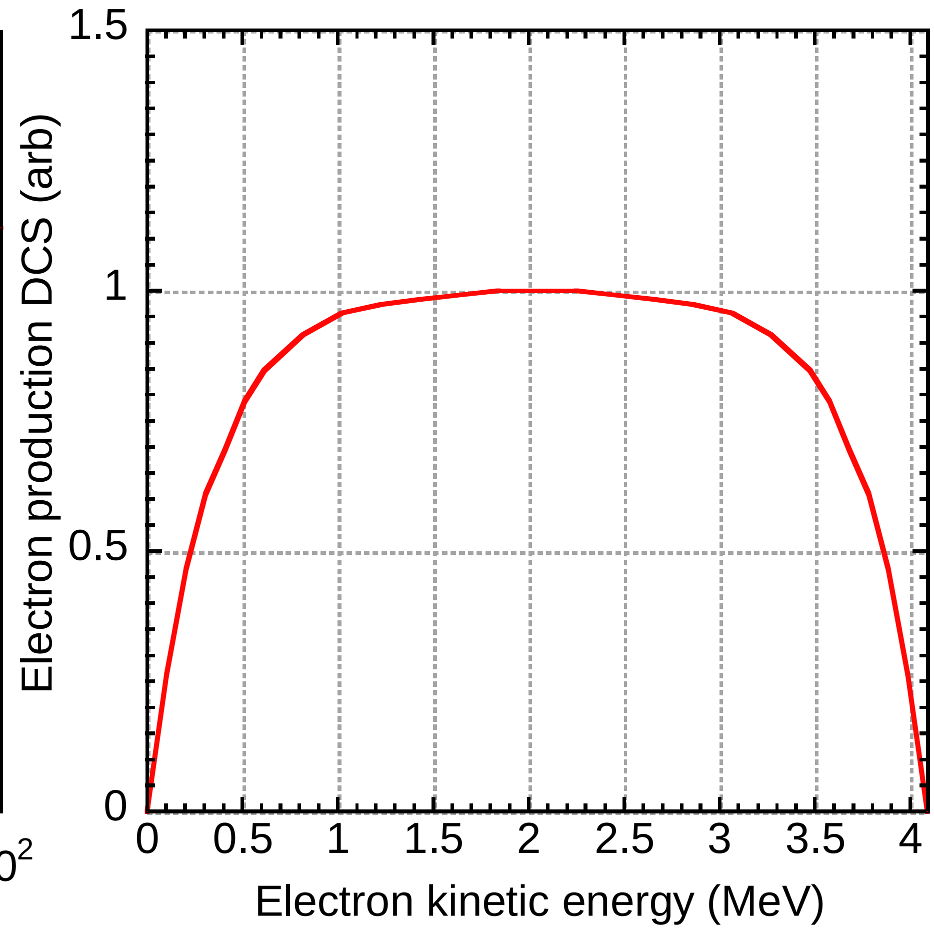
- PHOTX CS
- default $\theta = m_0c^2/k_0$
  - Realistic angle. dist.: optional

Pair Production (Cont')

Electron-positron pair production cross section

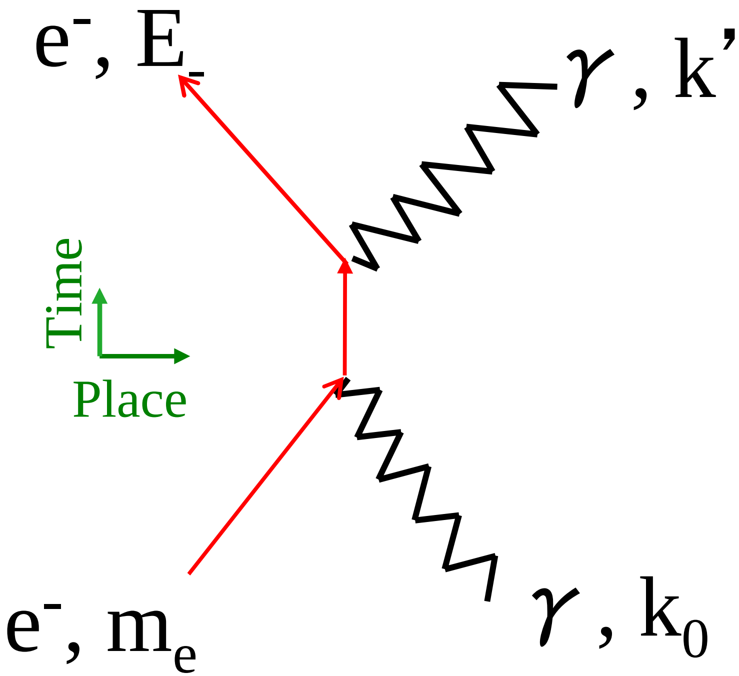


Electron energy dist of Pair Production for 5.11 MeV γ

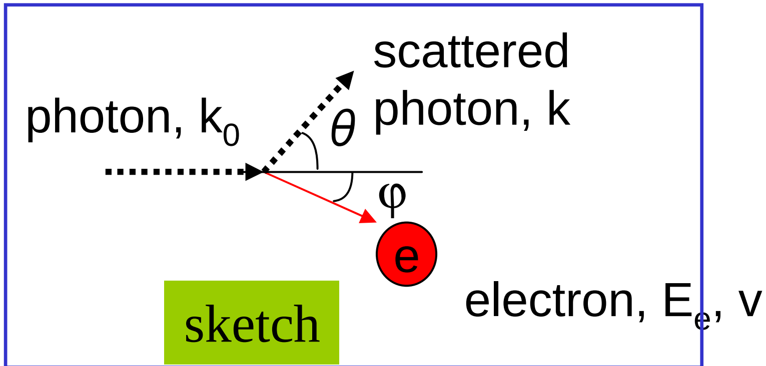


Compton scattering

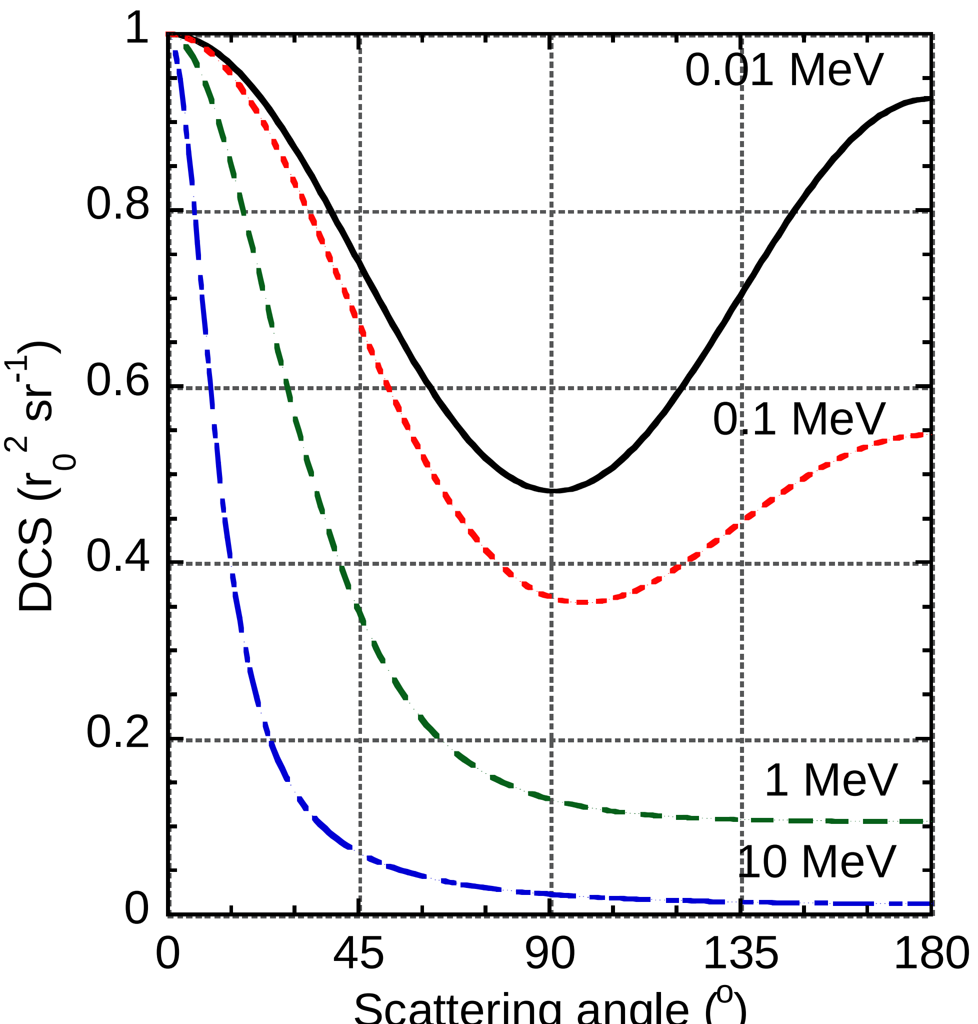
$$k_0 + m_e = k' + E_-$$



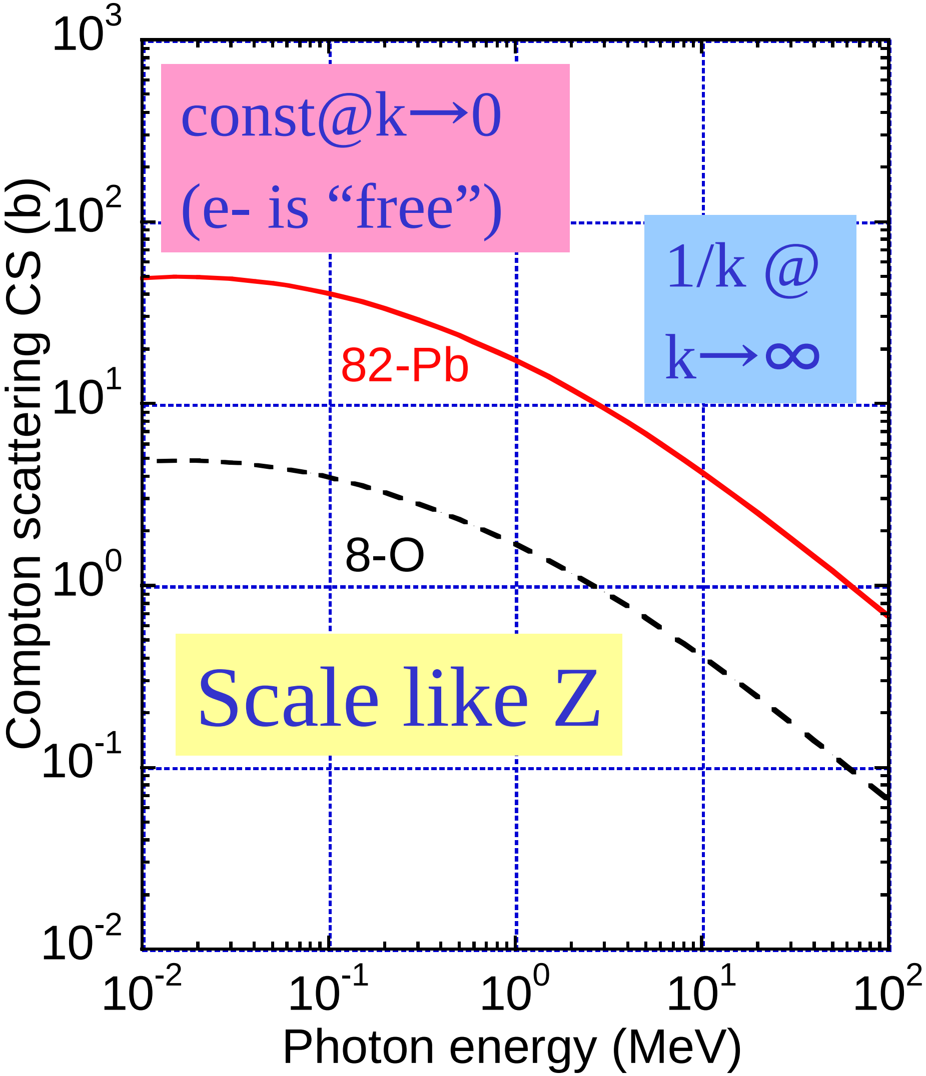
Feynman diagram



Klein- Nishina d σ



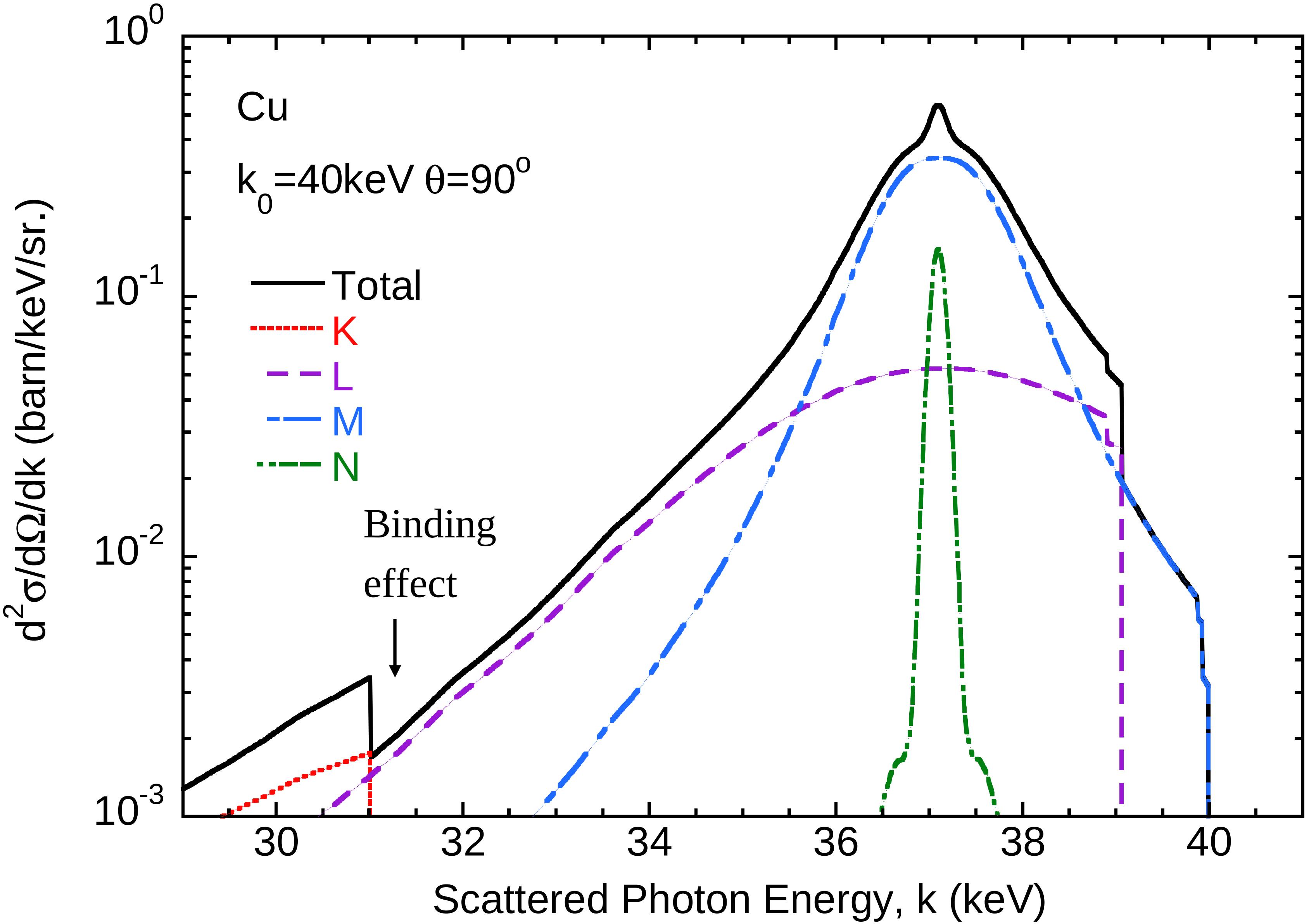
Compton scattering (Cont')



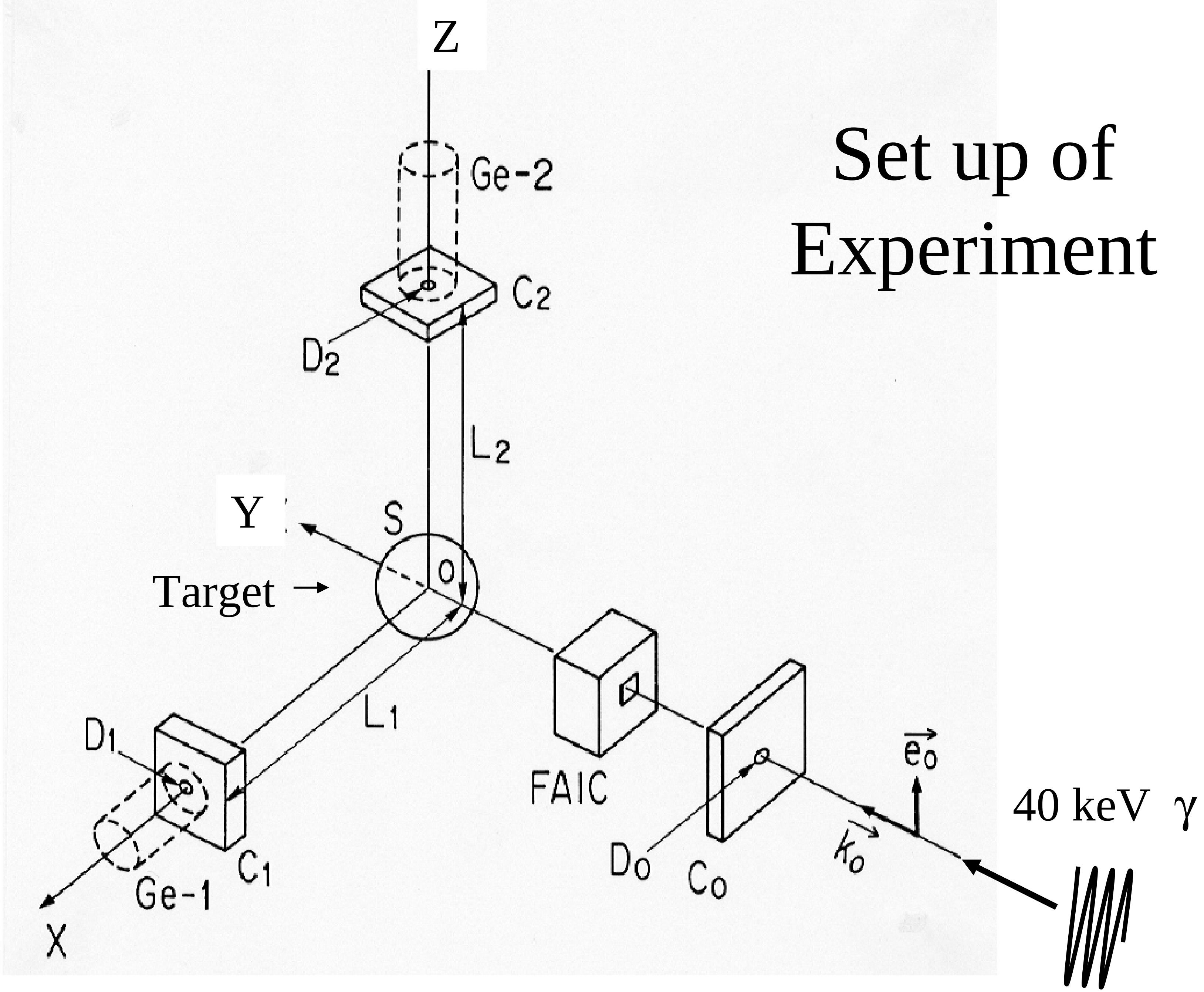
Optional treatment in egs5

- Binding effect (0 @ k⟶0)
- Doppler Broadening
  - e^- pre-collision motion
- Linearly polarized photon scattering

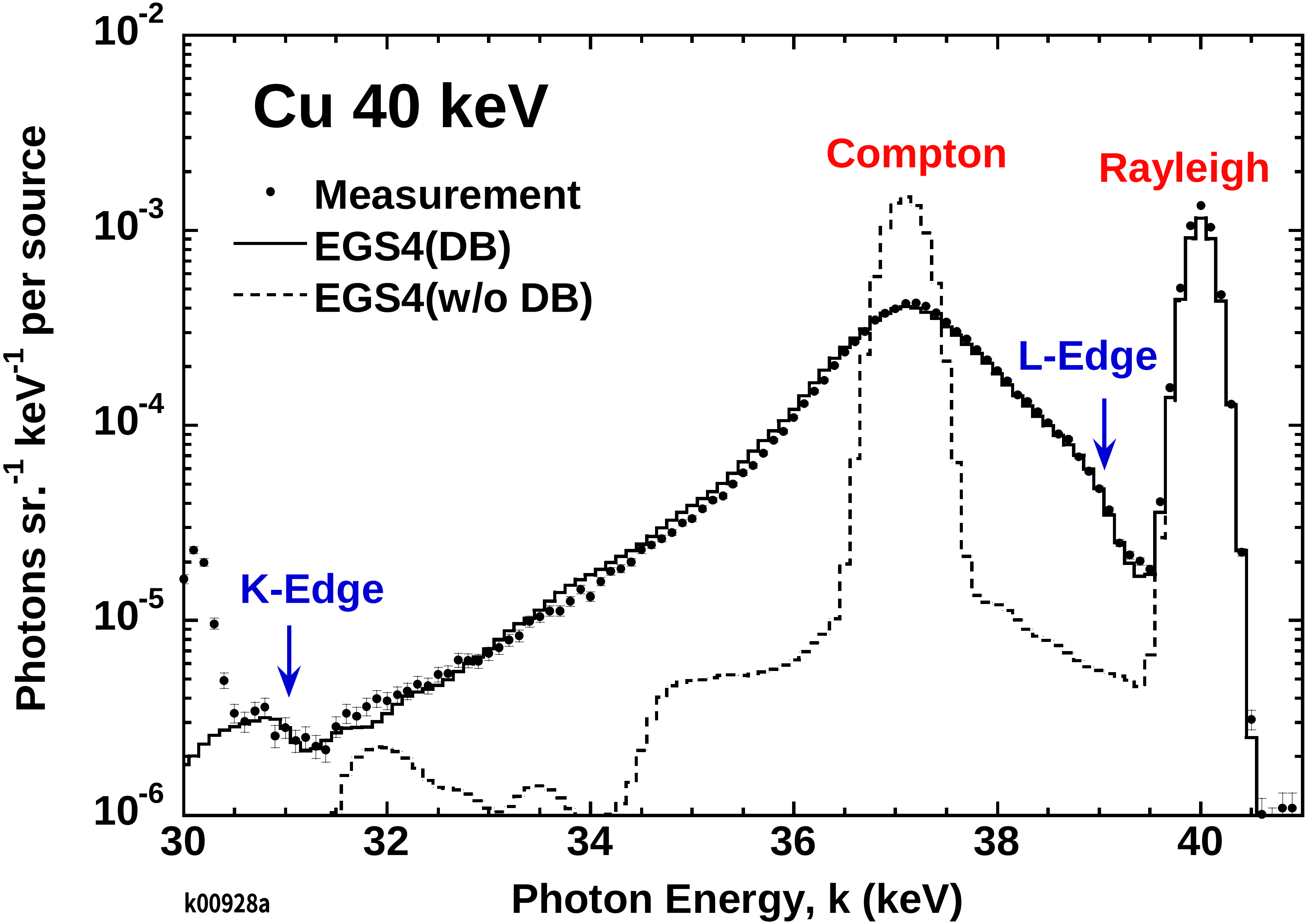
Double Differential Compton Cross Section



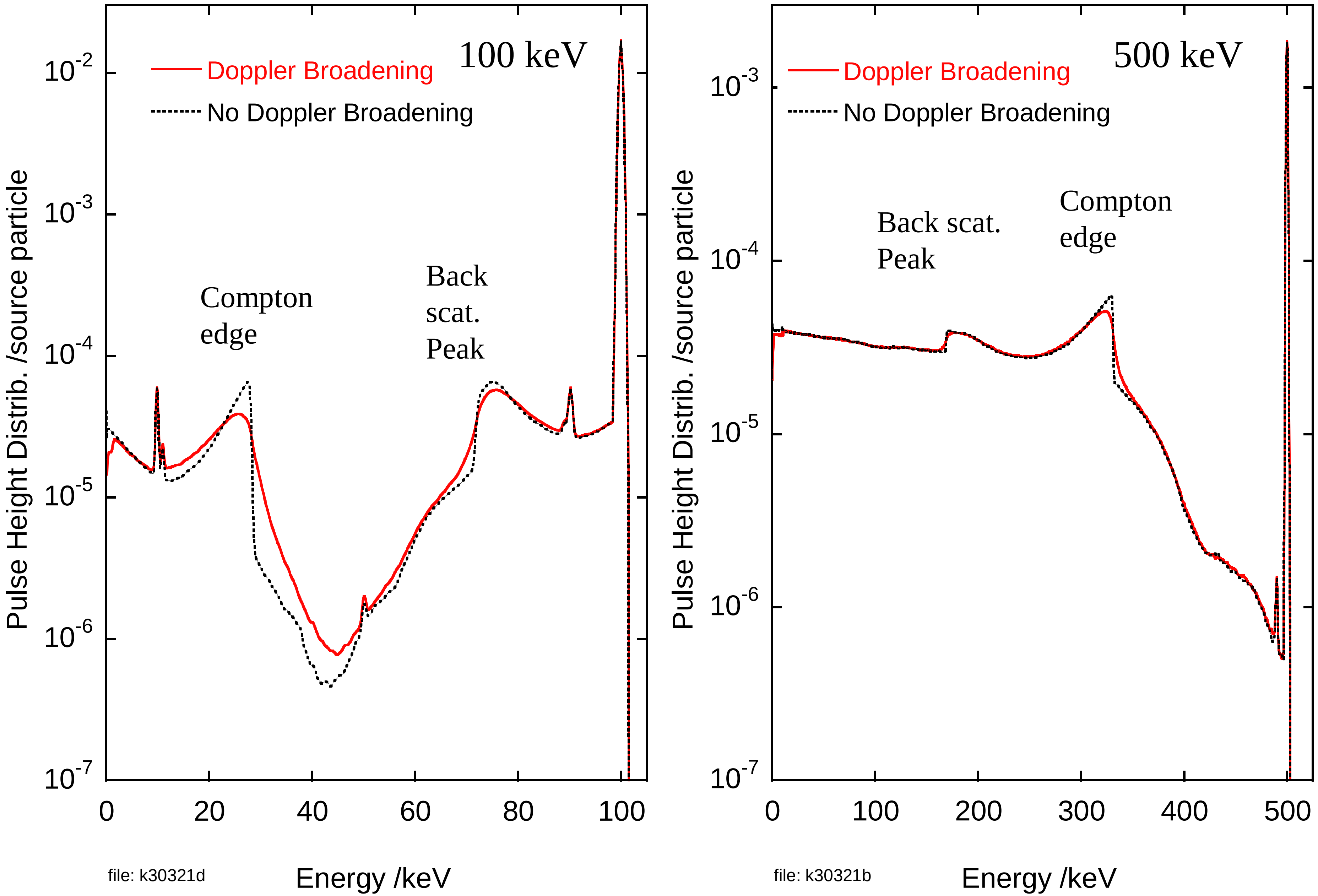
Set up of Experiment



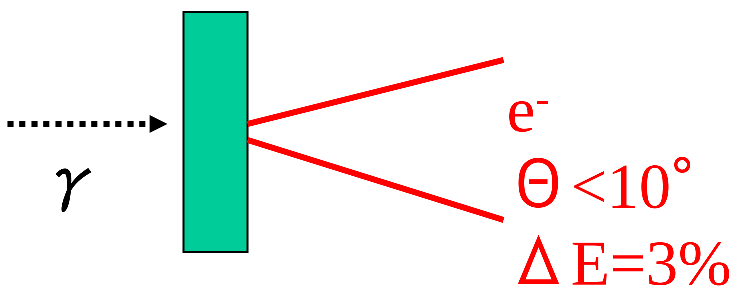
Cu,40 keV(EGS4+LP+DB=EGS5)



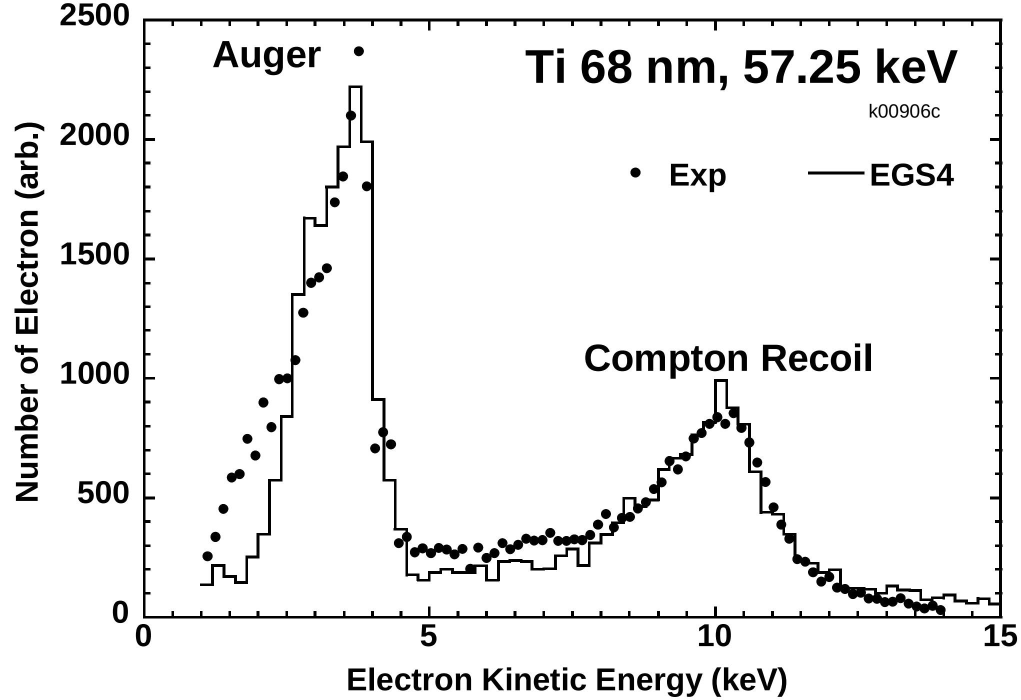
Effect of Doppler to Ge detector response

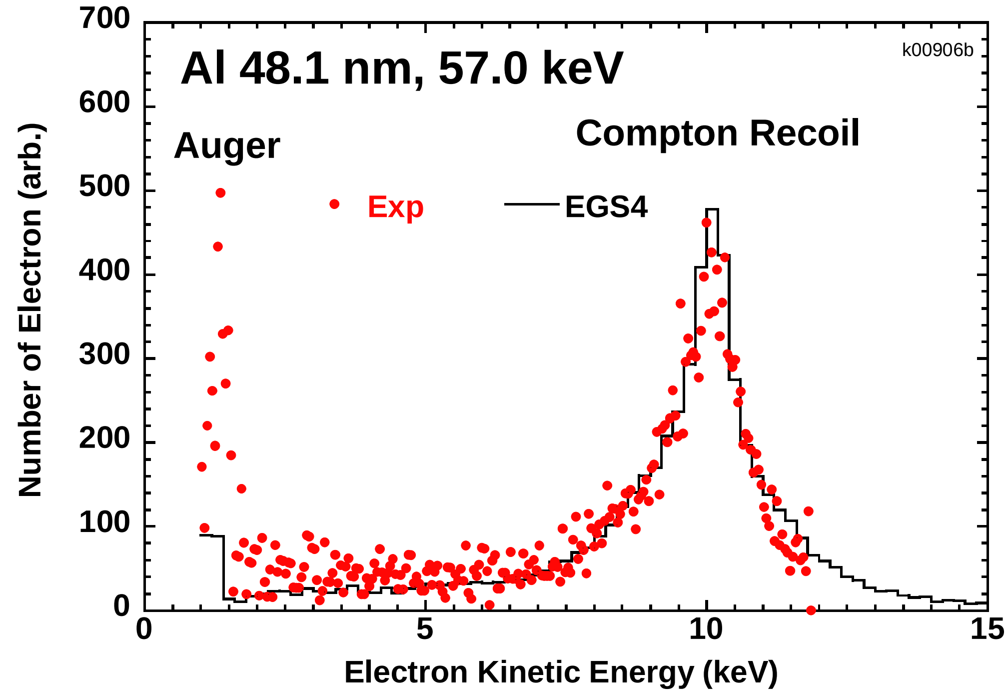


Example of Compton and Auger electron spectrum



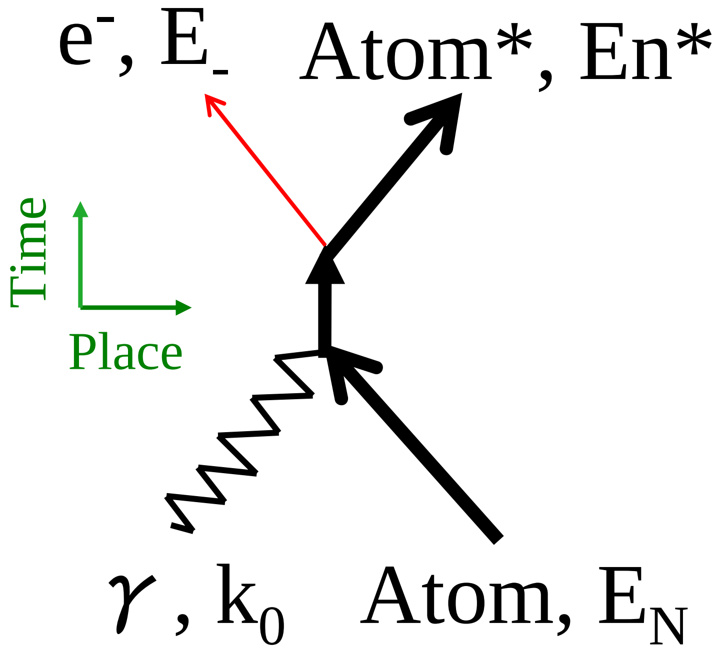
Guadala,Land&Price's exp

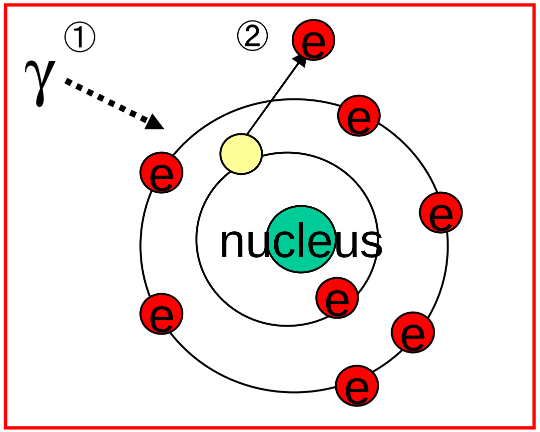


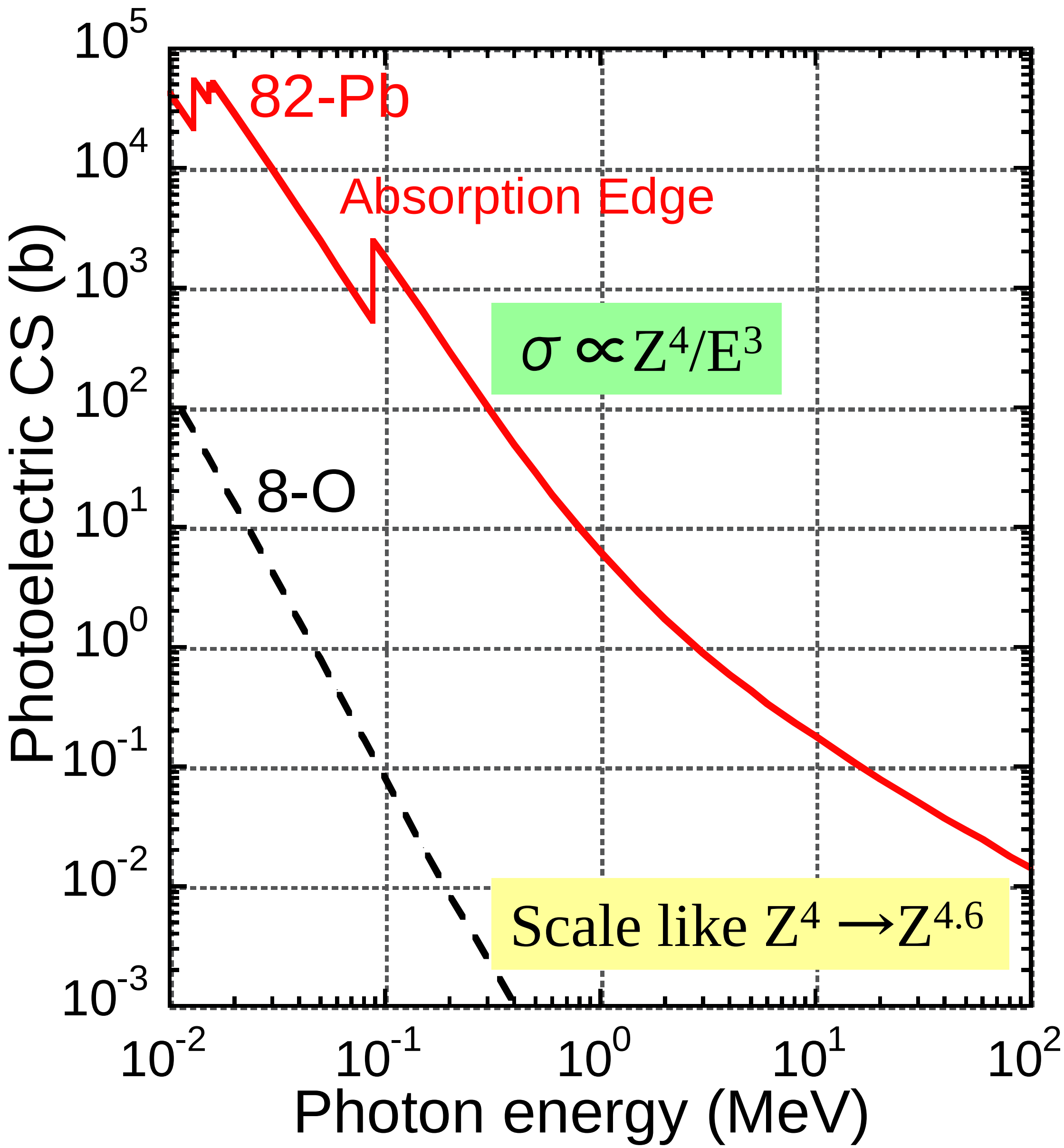


Photoelectric effect

$$k_0 + E_N = E_- + E_N{}^*$$

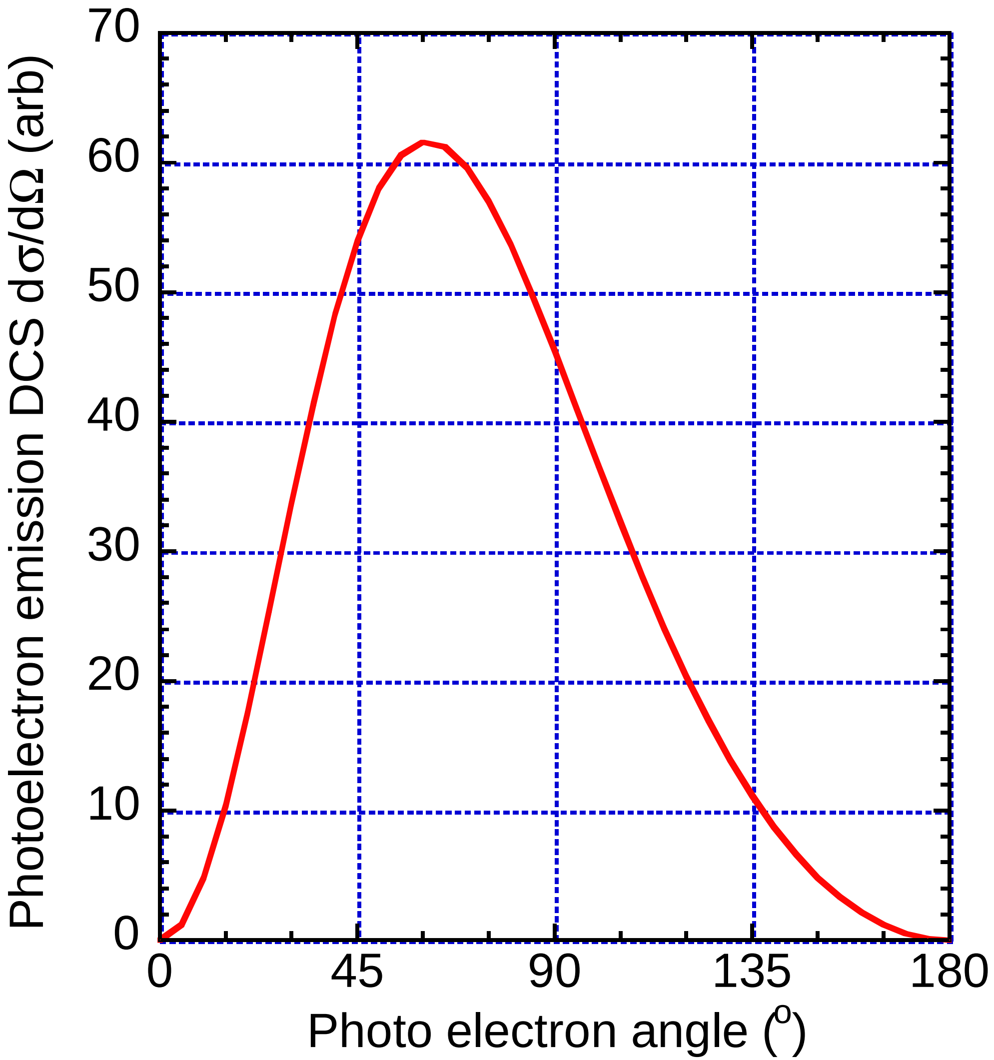






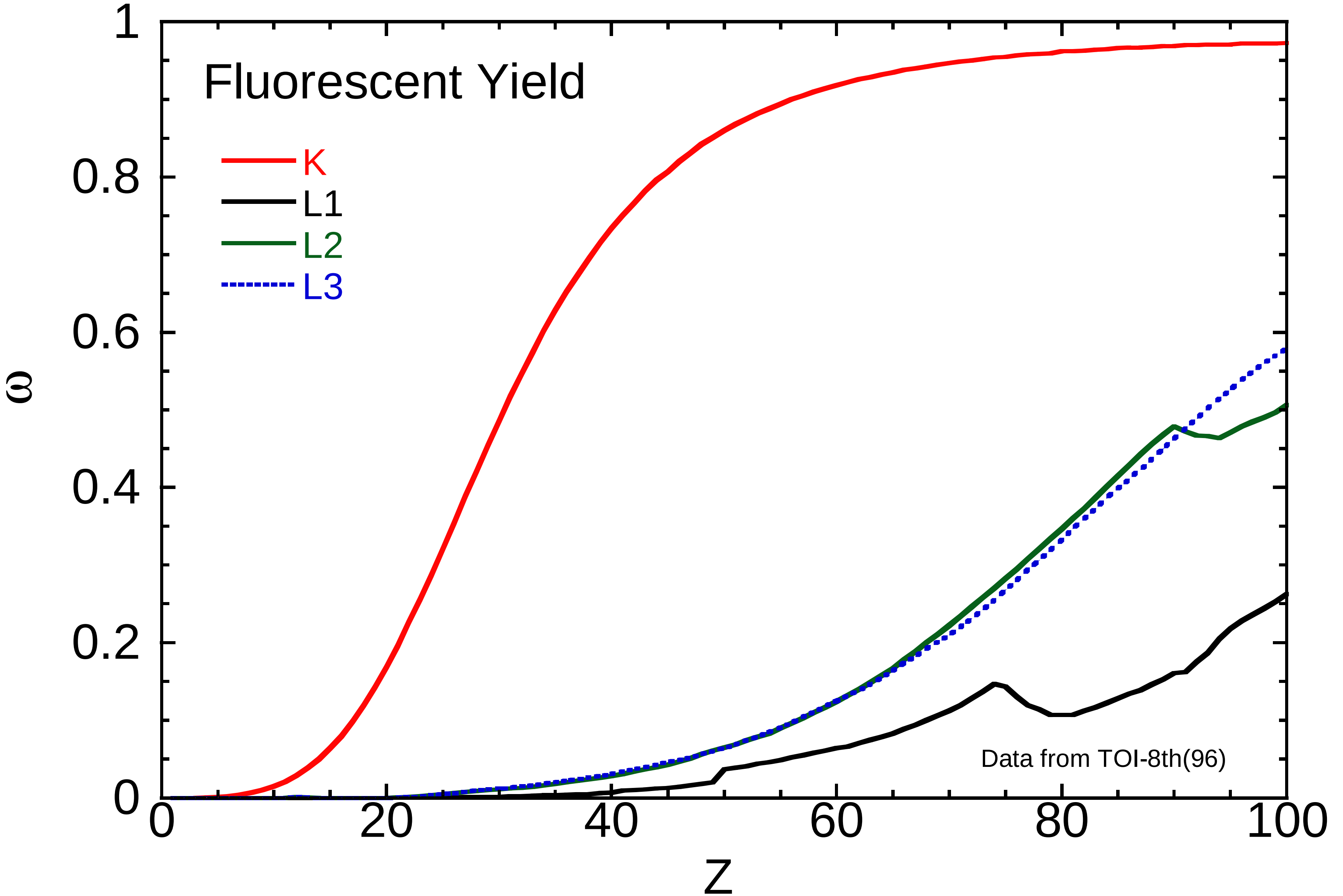
Photoelectric effect (Cont')

θ=0! (Realistic dist. optional)

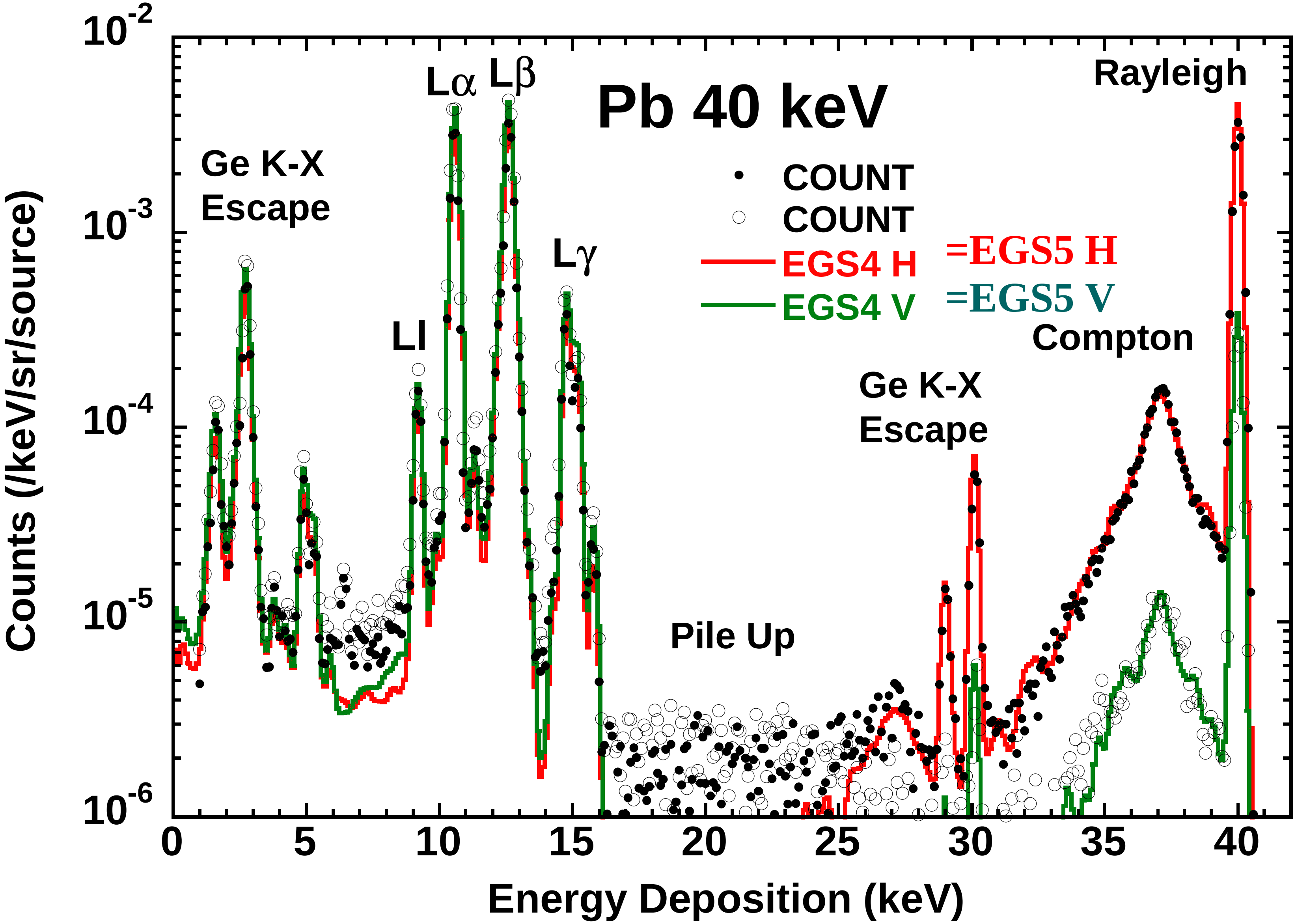


Relaxation of atom (option in egs5)

- Fluorescent X ray and Auger electron from K and L shell

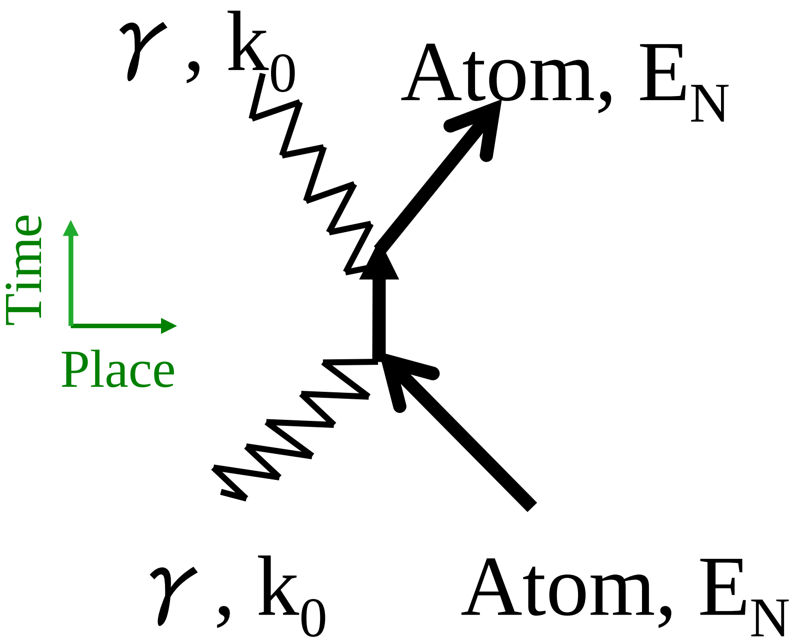


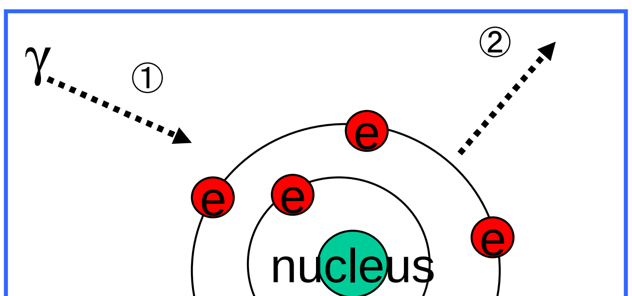
Photon spectrum from Pb target
EGS4 (General Treatment of PE) = EGS5



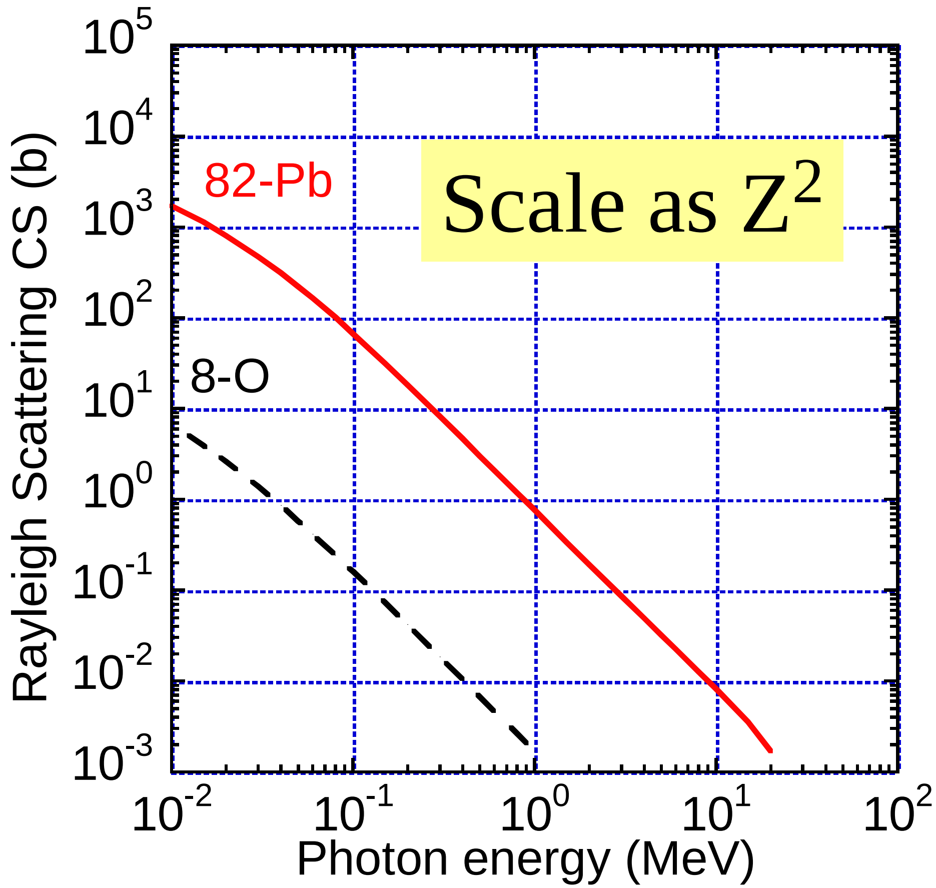
Rayleigh Scattering

$$k_0 + E_N = k_0 + E_N$$





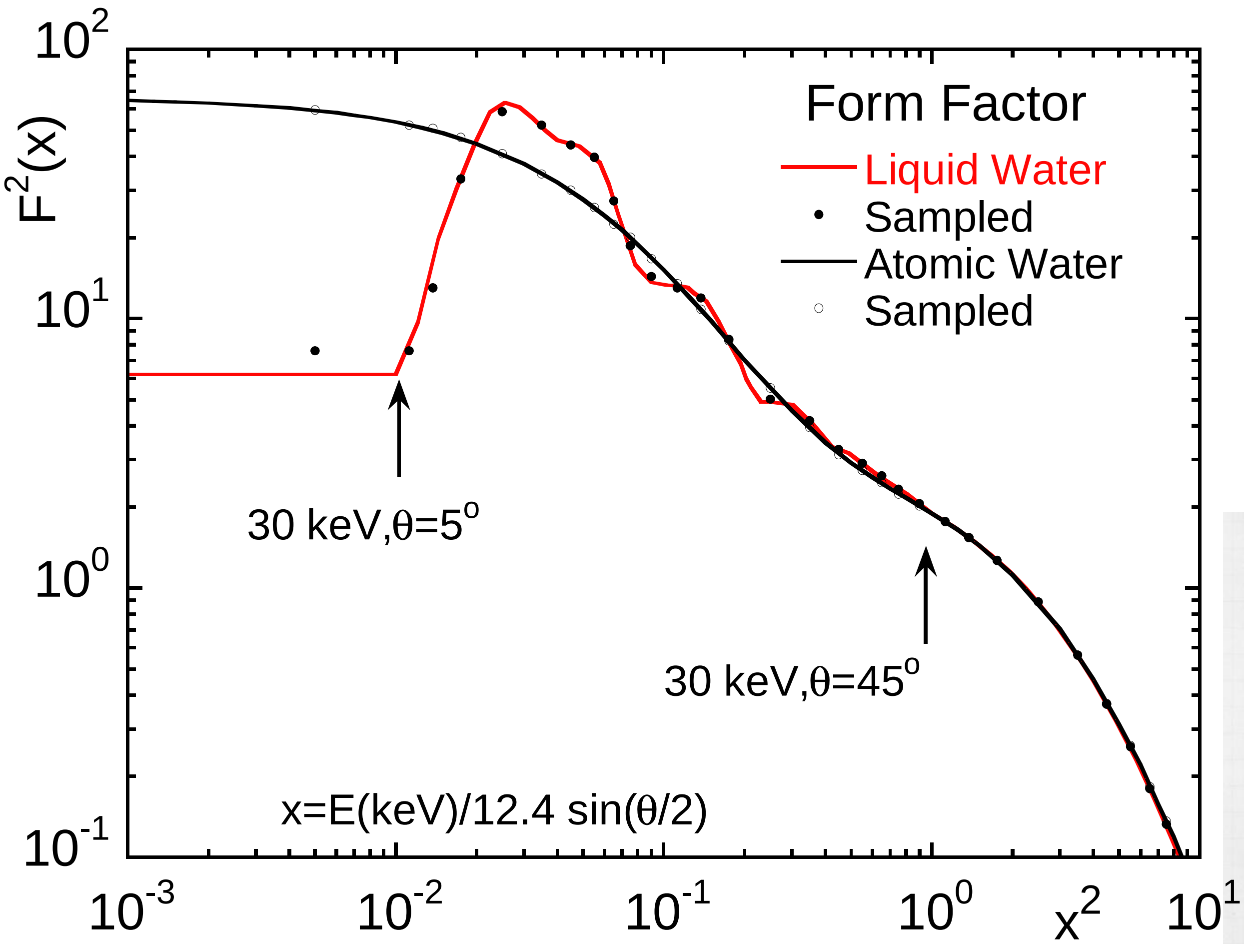
- elastic process
- independent atom approx.

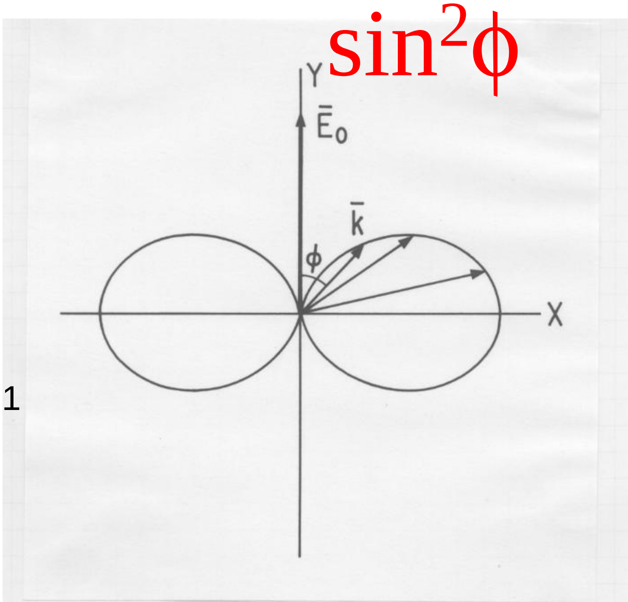


Rayleigh Scattering (Cont')

Optional treatment in egs5

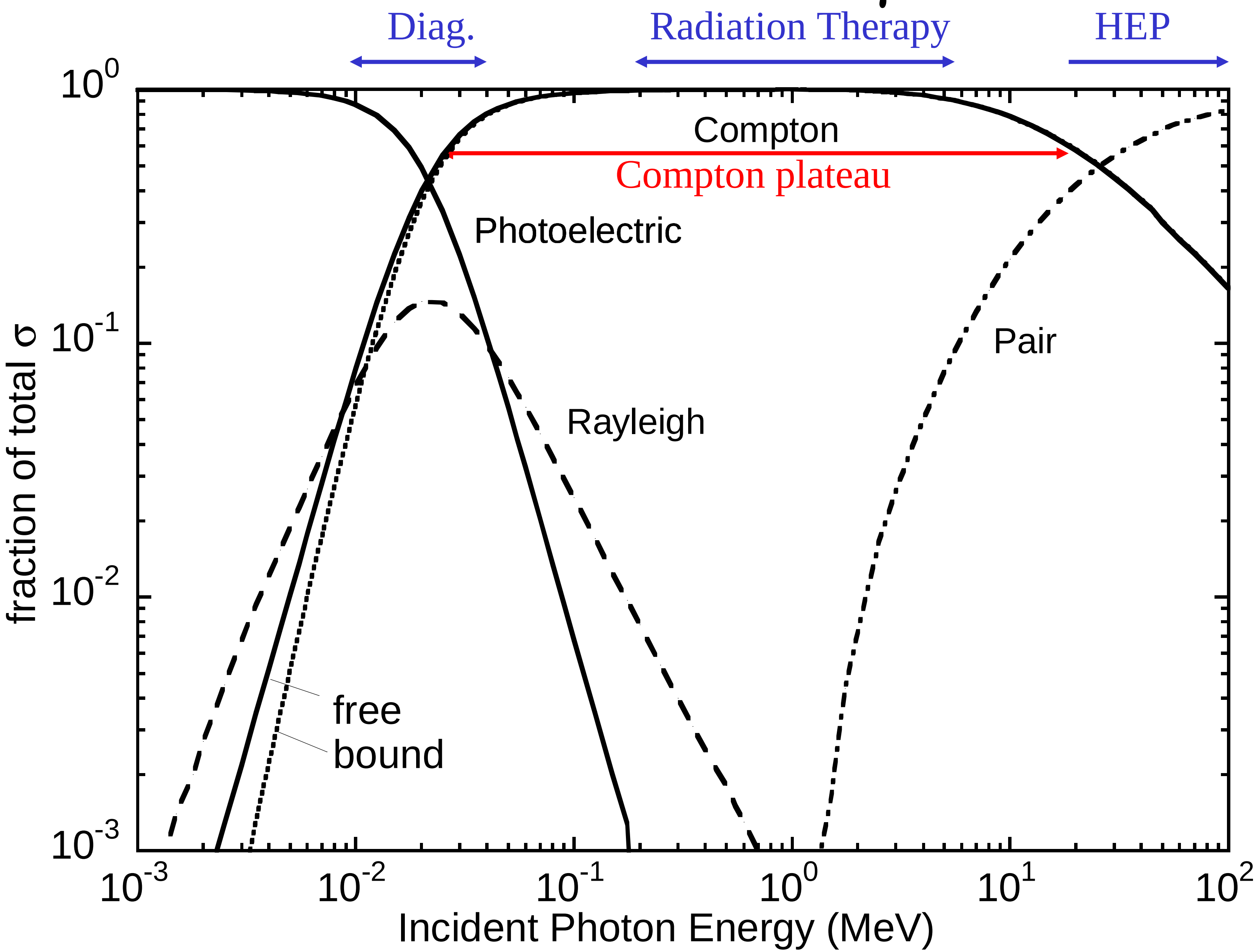
- Interference effect between nearby atoms

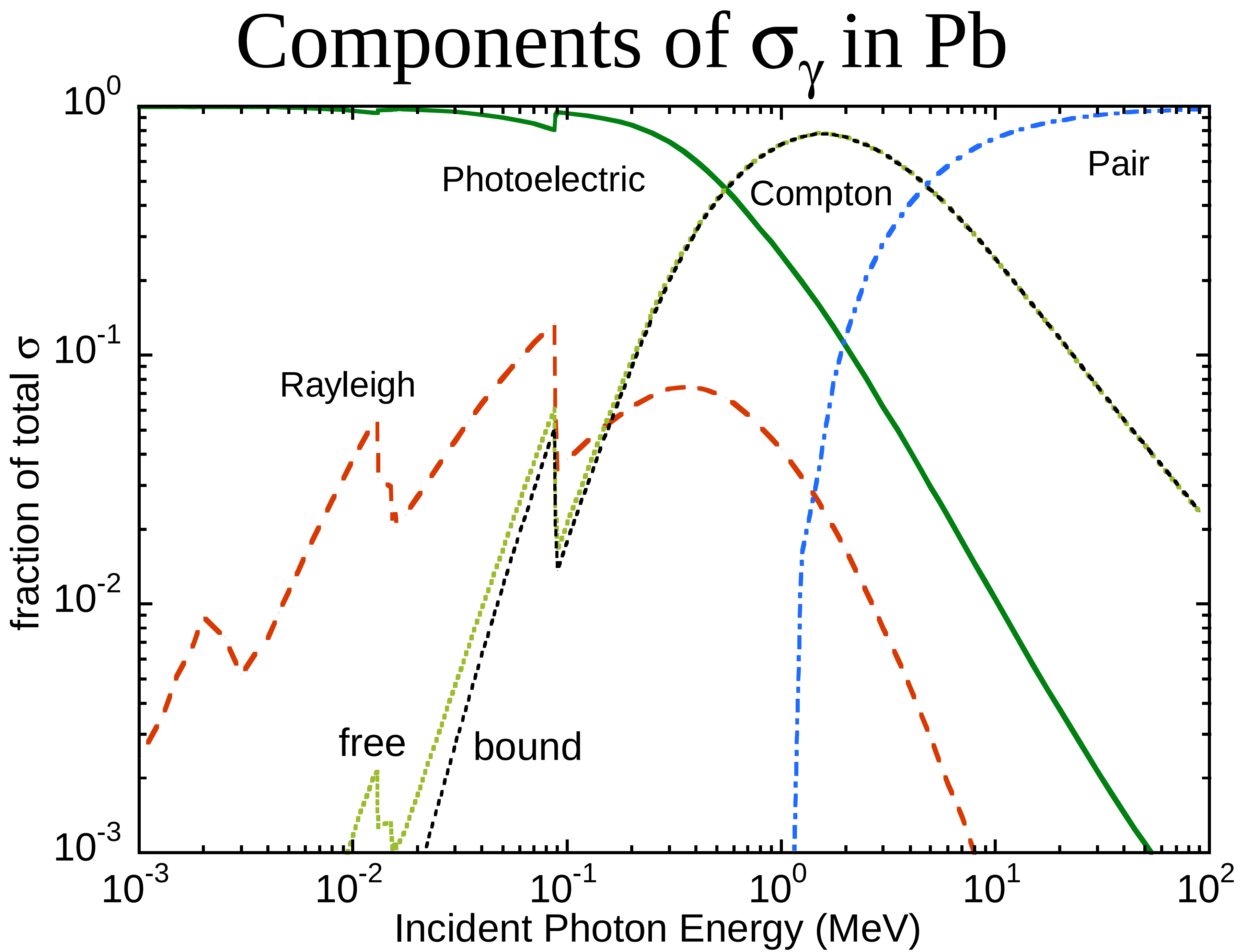




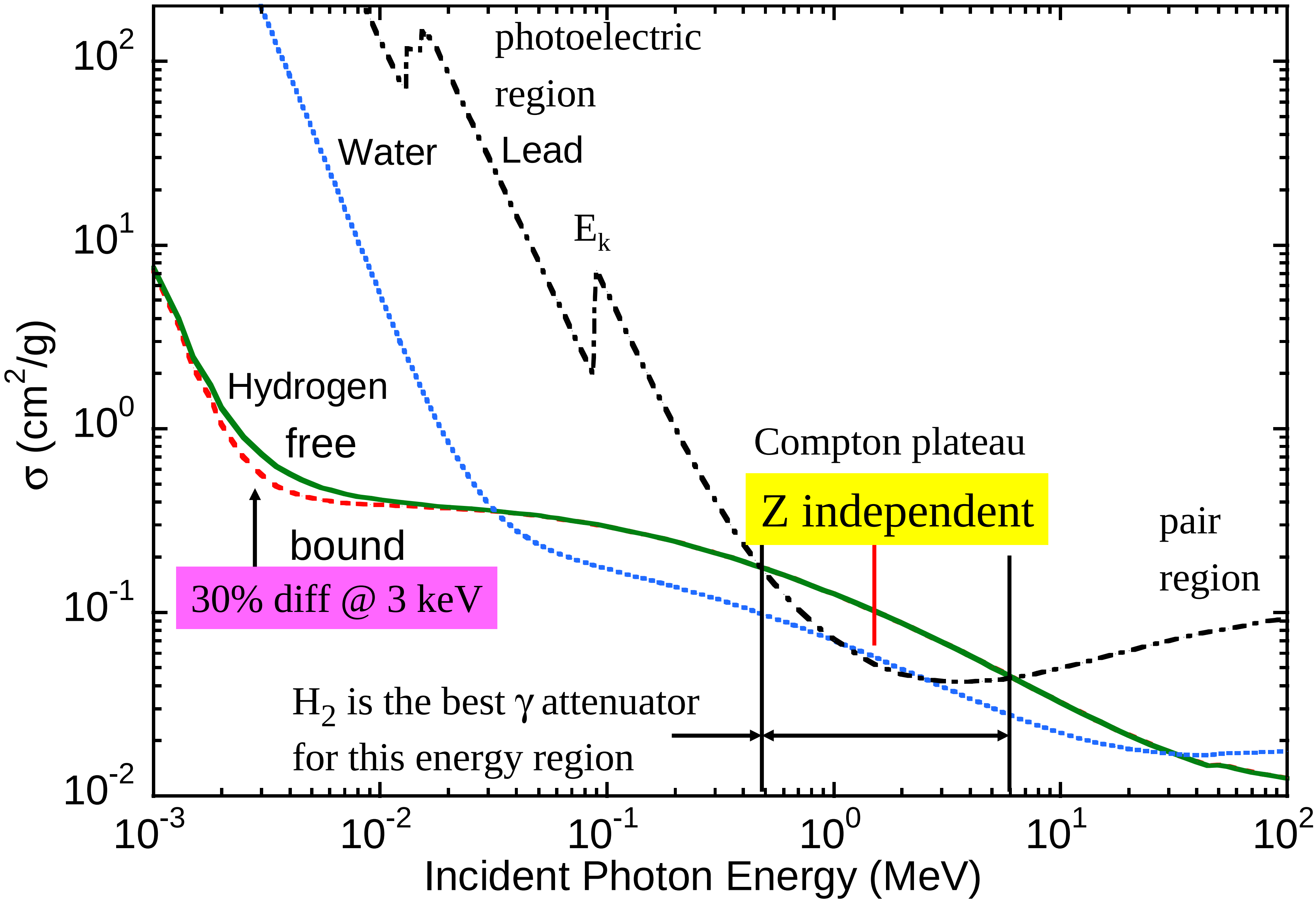
- Linearly polarized photon scattering

Components of σ_γ in C



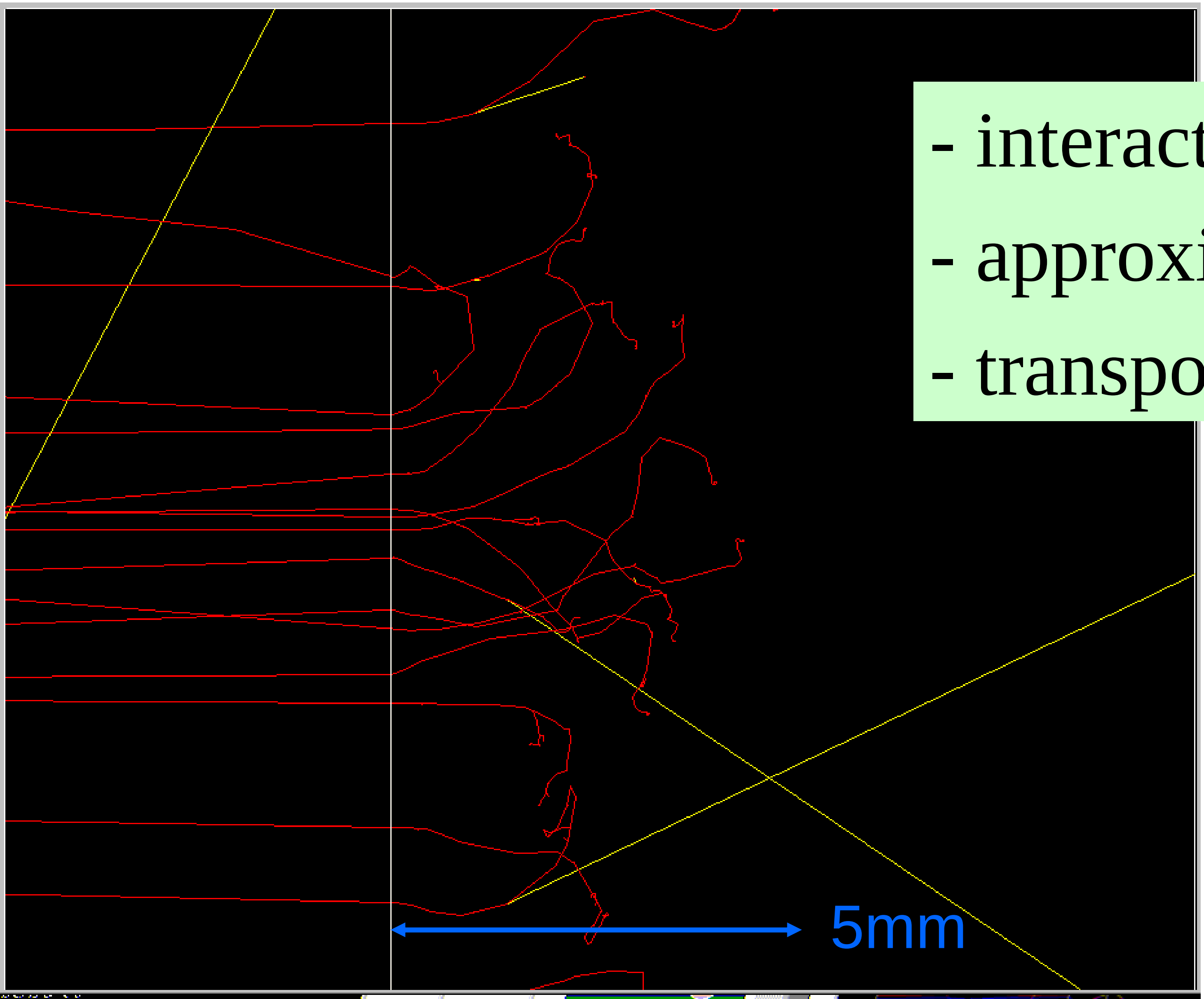

Components of σ_γ in Pb
10^0
10^{-1}
10^{-2}
10^{-3}
fraction of total σ
Photoelectric
Compton
Pair
Rayleigh
free
bound
10^{-3}
10^{-2}
10^{-1}
10^0
10^1
10^2
Incident Photon Energy (MeV)

Total photon Σ *vs* γ-energy



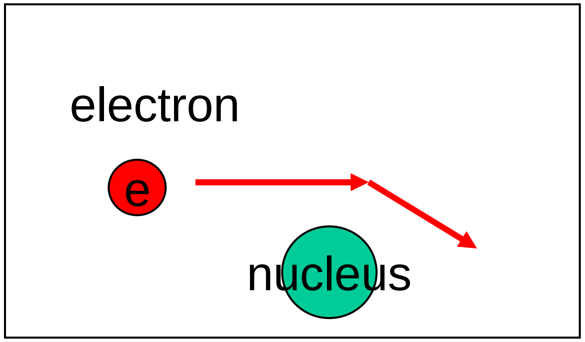
End of Photon Monte Carlo Simulation

Electron Monte Carlo Simulation

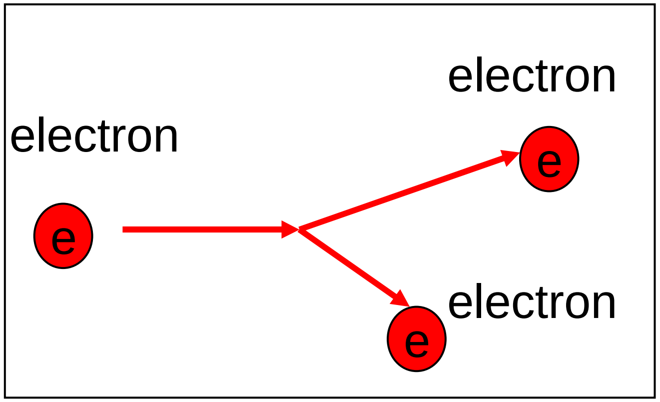


- interaction
- approximations
- transport methods

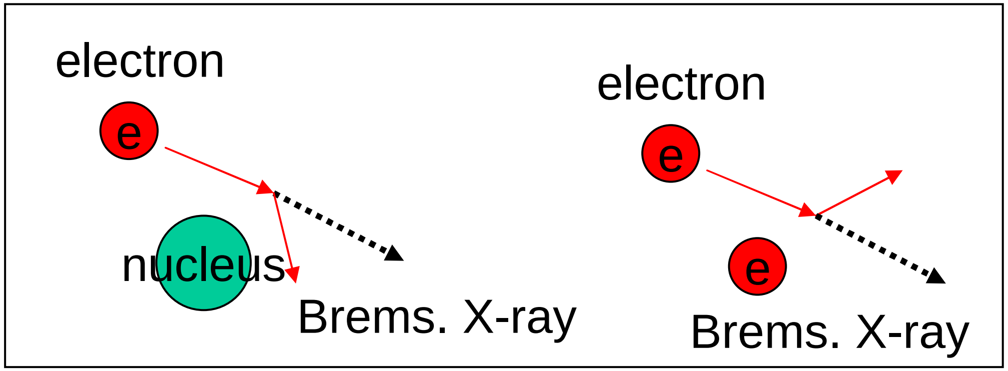
Electron interaction with matter



1. Electron scattering by nucleus (Rutherford scattering): Change direction

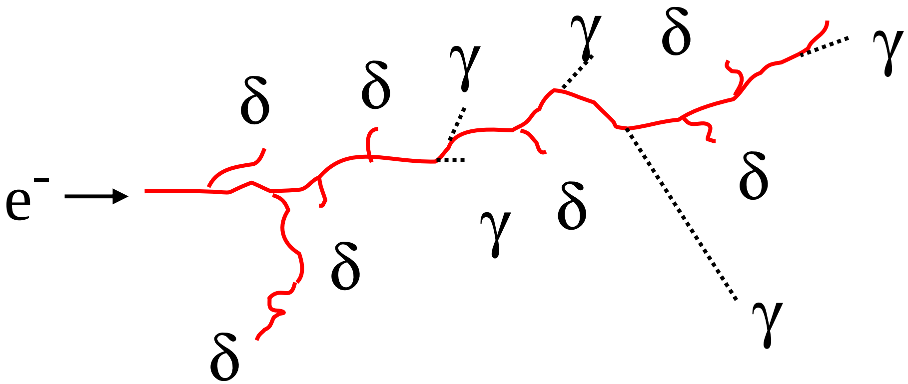


2. Inelastic scattering of electron and electron: Loose energy

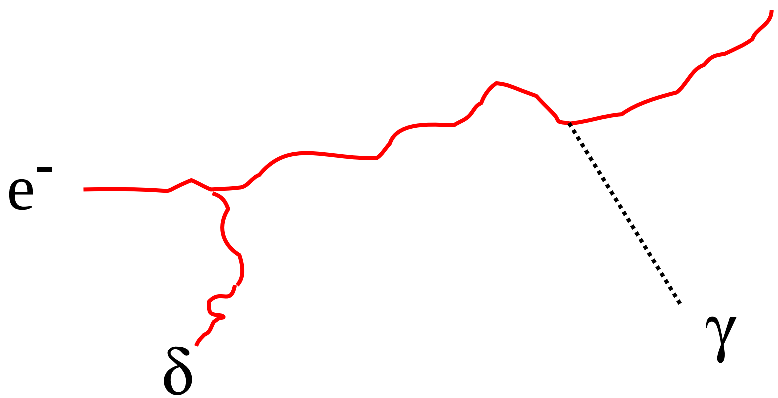


3. Generation of bremsstrahlung x ray

Condensed Random Walk



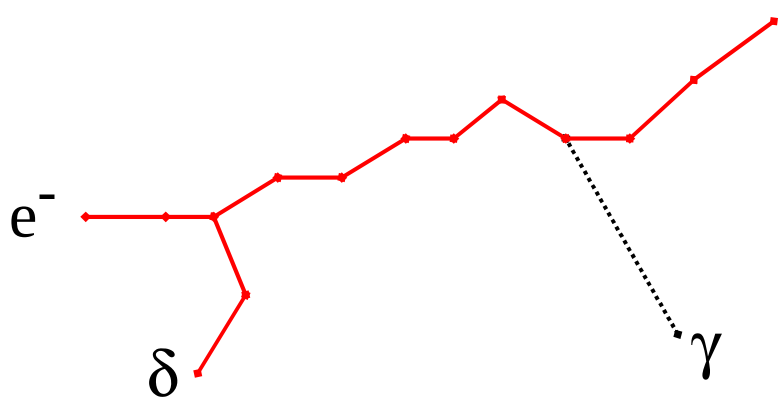
In Reality, mean free path is in nm or μm unit.



Continuous slowing down

δray, brems: Treated only if,

2nd particle energy > threshold



Multiple scattering

M.S. Angle $\theta_{ms}(E,Z,t)$

Moliere theory

GS theory

How do we treat both hard interaction and continuous approximation consistently?

↓

Use Threshold energy (AE, AP) by User's choice

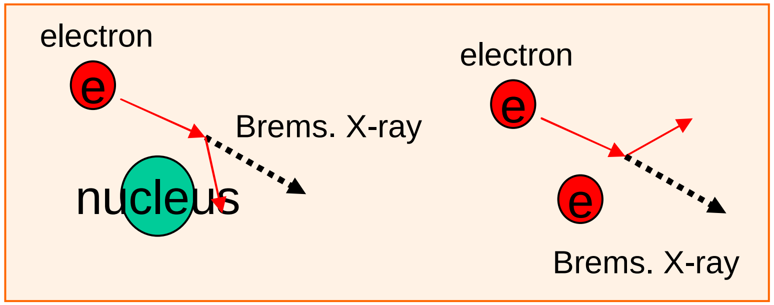
- "Hard" interaction: Discrete sampling
  - –large ΔE Moller/Bhabha (2nd particle energy>AE)
  - –large ΔE bremsstrahlung (photon energy>AP)
  - –annihilation "in flight" & at rest
- "Soft" interaction
  - –small ΔE Moller/Bhabha
  - –atomic excitation
  - –soft bremsstrahlung

  } Energy Absorption

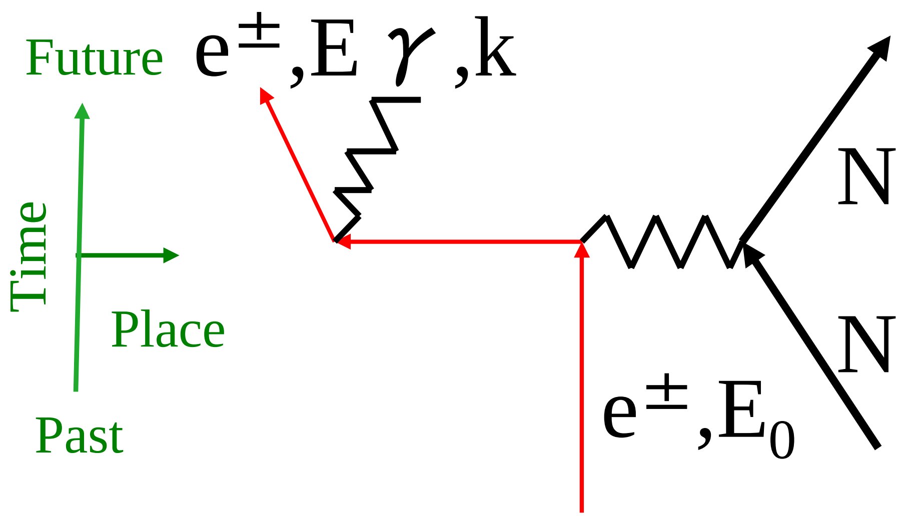
  - –multiple $e^{\pm}$ Coulomb scattering

Hard Interaction

Bremsstrahlung



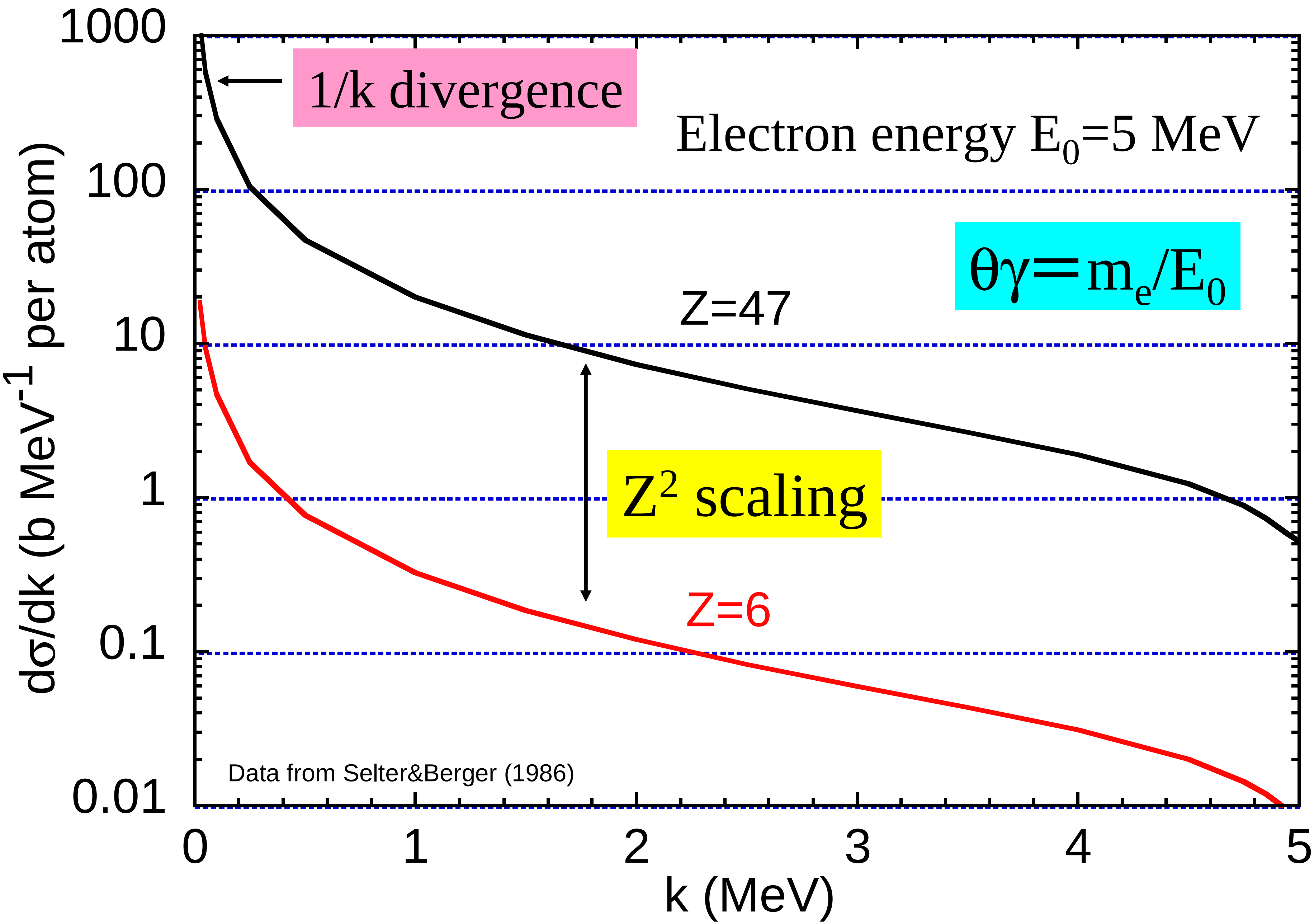
$$E_0 = E + k$$



Feynman diagram

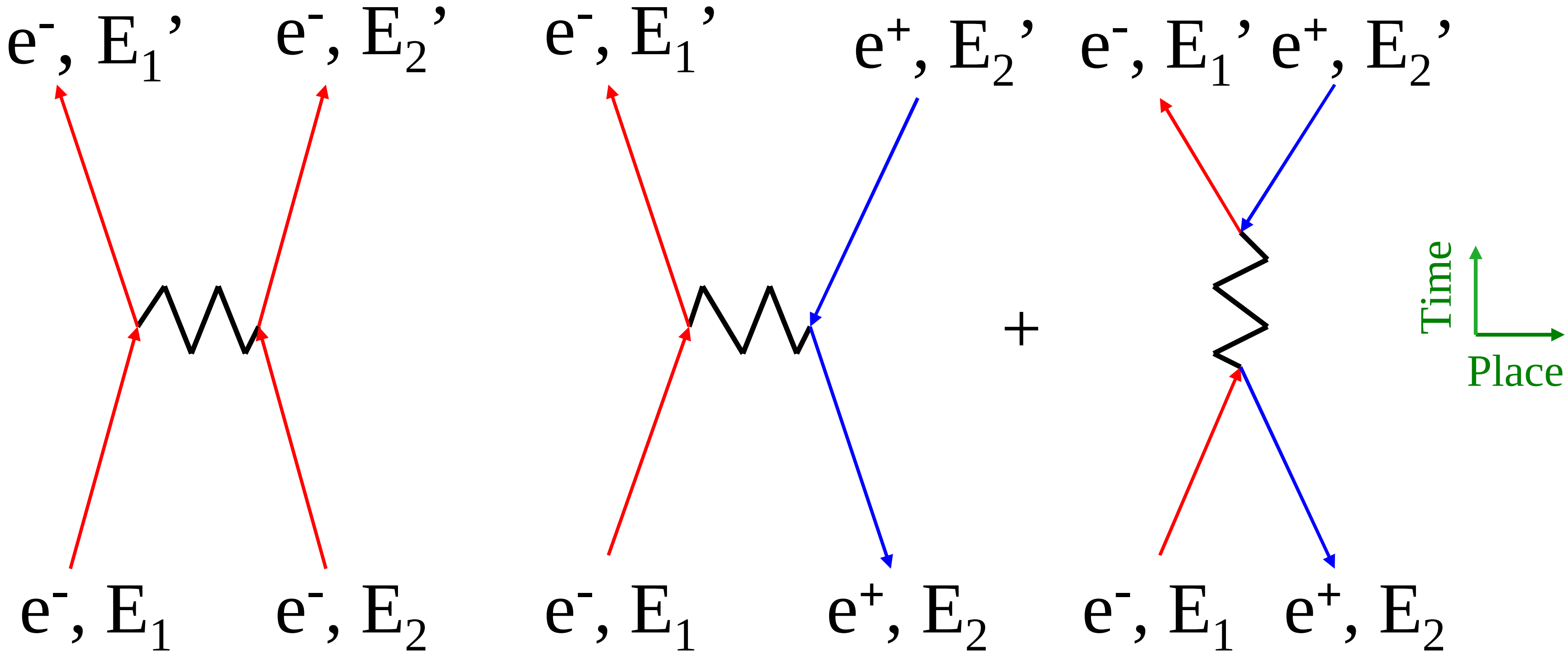
- Z^2 scaling
- 3 body angular dist'n ignored
  - $Z^2 \longrightarrow Z(Z+\xi(Z))$
- <50 MeV Normalize to ICRU-37
- >50 MeV ERL
- Migdal ignored >10 GeV
- TF screening
- e^-, e^+ treated as same
- $e^{\pm}$ not deflected

Example of brems photon spectrum



Moller

Bhabha



identical particles

- threshold 2(AE-RM)

different particles

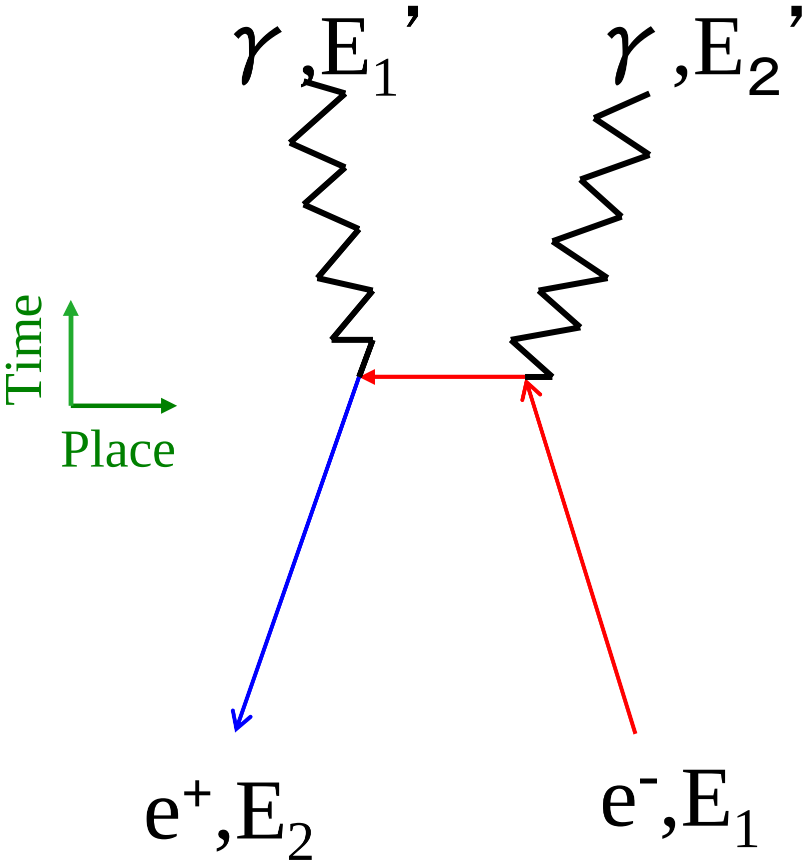
- threshold AE-RM

- goes like $1/v^2$
- scale like Z
- Target e^- is “free”

Optional treatment in EGS5

- K-X ray production in Moller
  (Electron Impact Ionization)

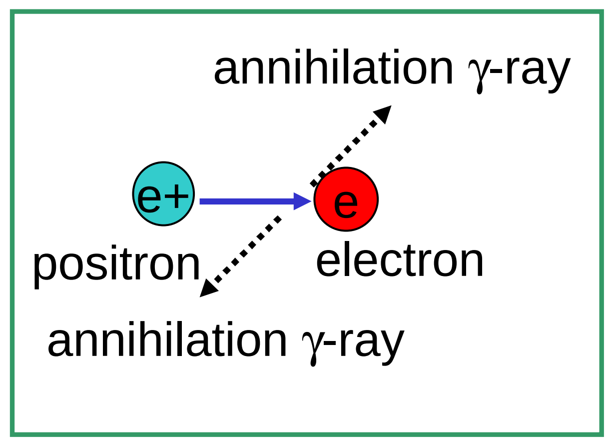
Annihilation



- in flight and at rest
- $e^+ e^- \rightarrow n\,\gamma$ (n>2) ignored
- $e^+ e^- \rightarrow \gamma$ N* ignored
- at ECUT e^+ annihilates

Residual drift is ignored

- no binding



Statistically grouped interactions (Soft Interaction)

- Continuous energy loss
- Multiple scattering

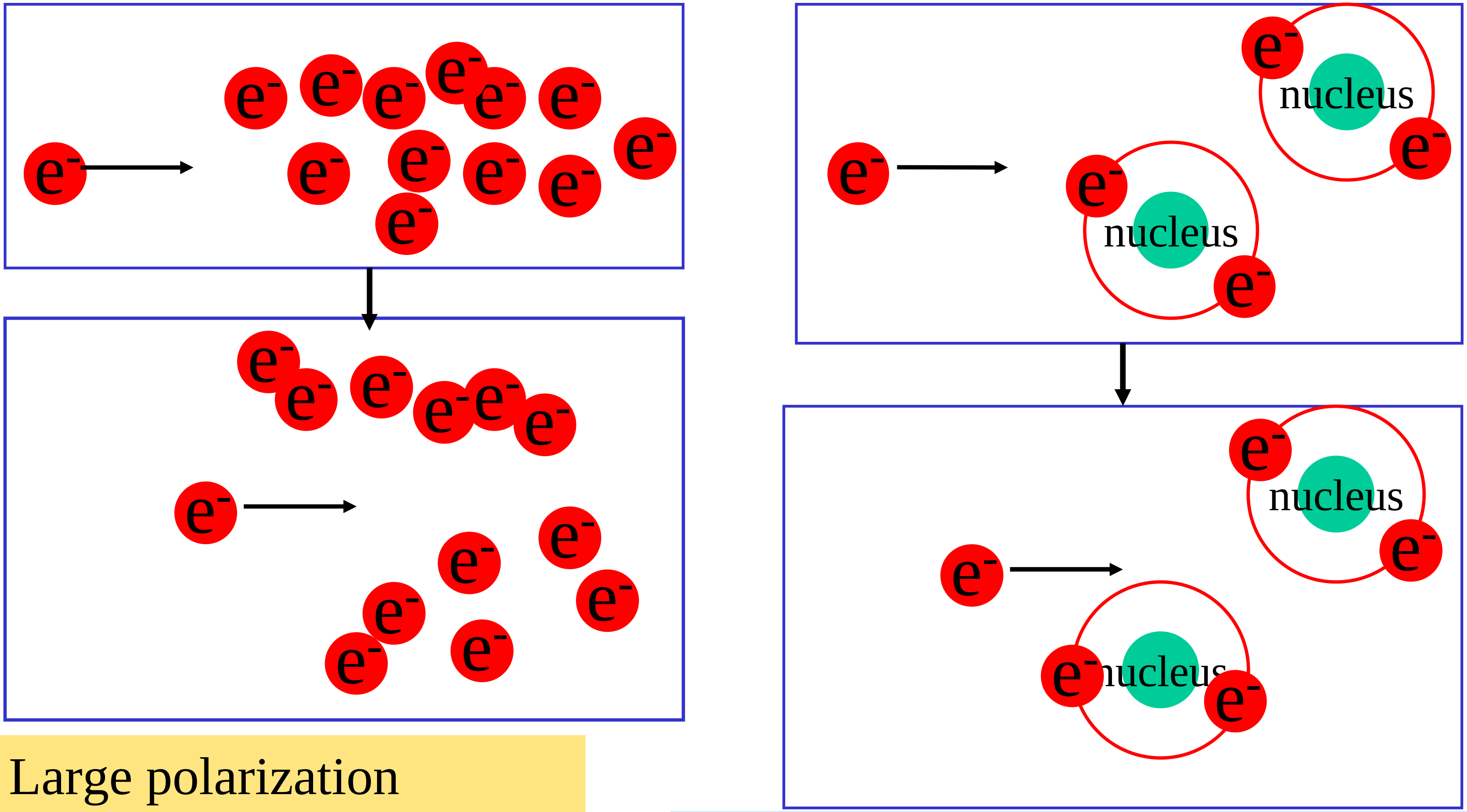
"Continuous" energy loss

1. collisional energy loss（$e^{\pm}$ different)
   1. Bethe-Bloch theory density effect
   2. well-above K shell energy
   3. many electron atoms $\propto$ Zav

2. radiative energy loss（$e^{\pm}$ treated same)
   1. integration of bremsstrahlung cross sections
   2. same approximations
   3. e^+, e^- treated as identical

Density effect

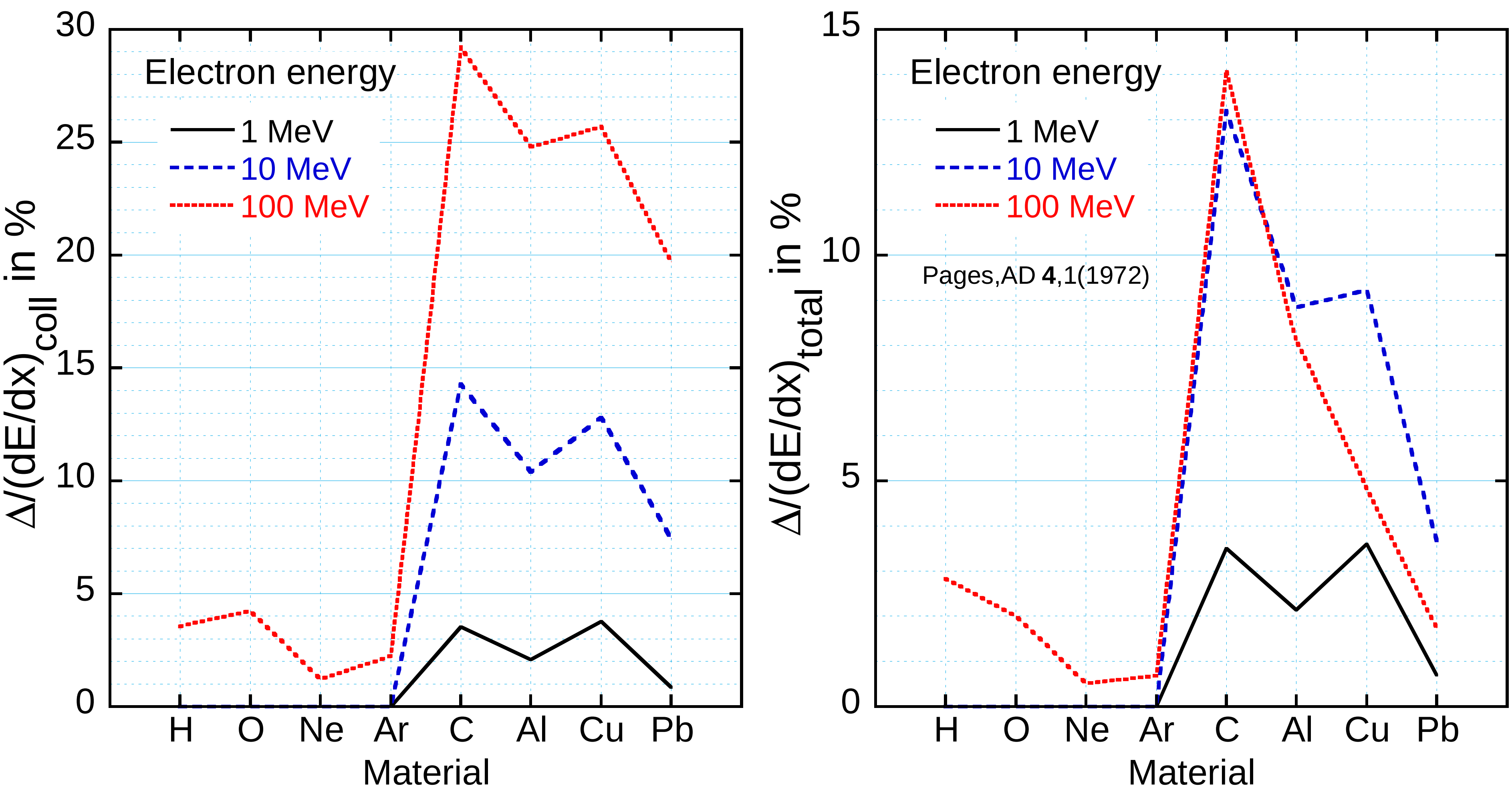
Reduction of the collision stopping power due to the polarization of the medium by the incident electron.



Large polarization
in Conductor (ex. Carbon)

Small polarization in Rare Gas (ex. Ar)

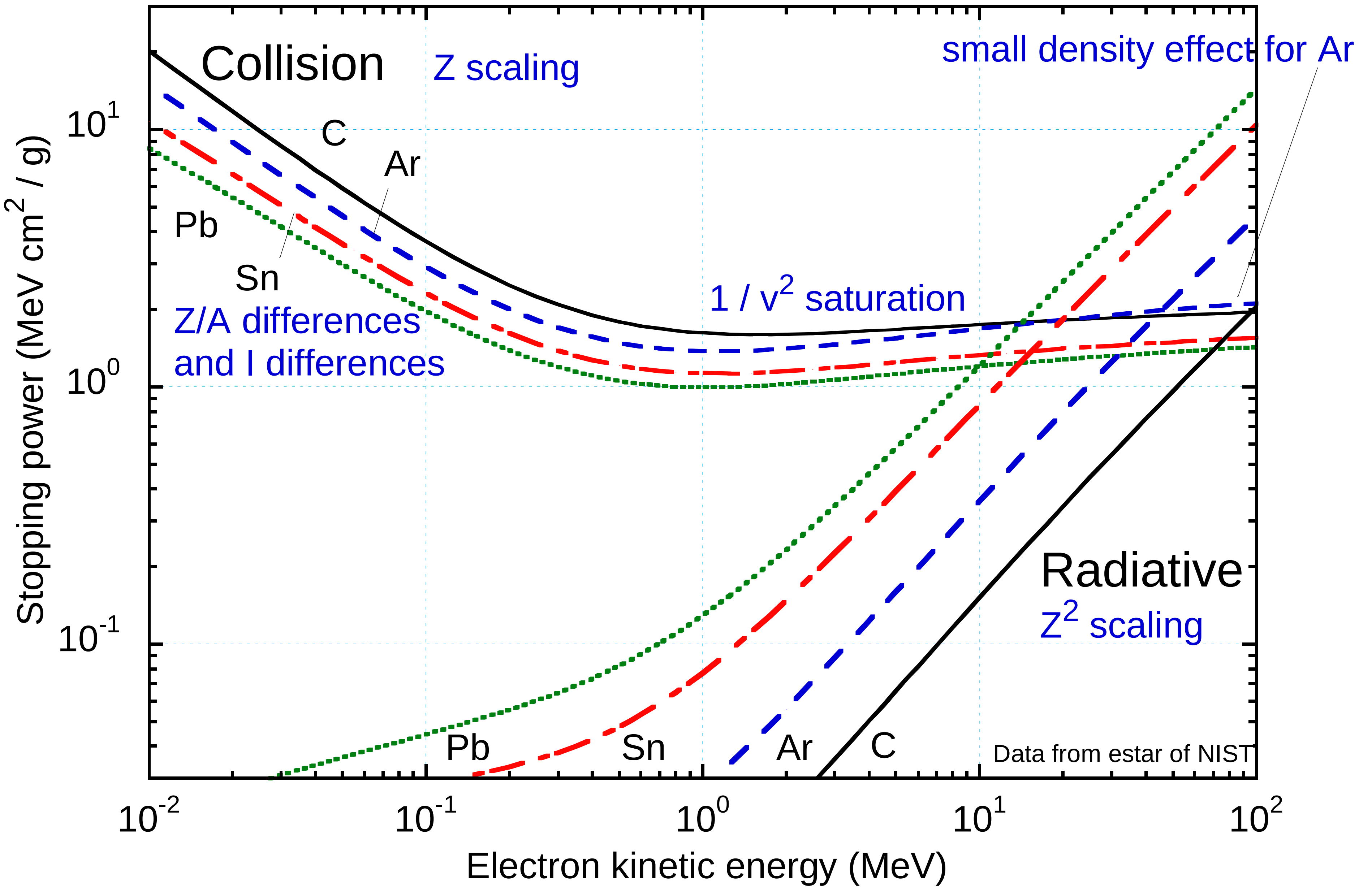
Density effect (2)



Density effect in egs5

- Berger, Seltzer, and Sternheimer
  - Parameters for 278 materials
- Sternheimer and Peierls
  - general treatment
    - Less precise, Needs only Z and ρ

Electron stopping power (unrestricted)



Energy absorption

energy absorption for $e^{\pm}$ transport of t

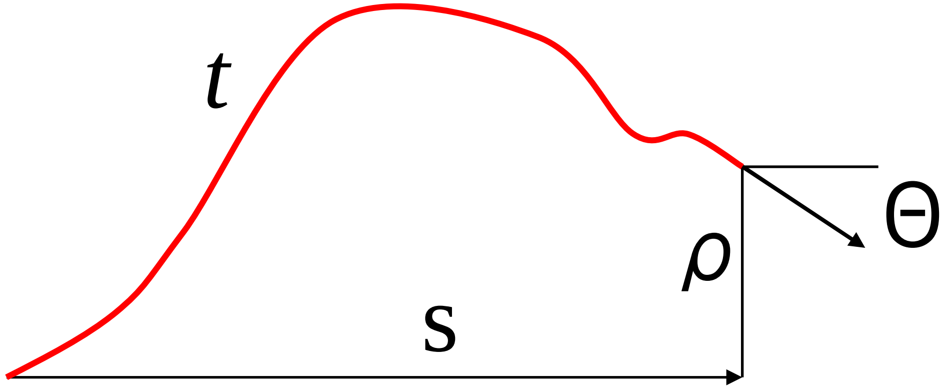
$$= -(dE_{\pm}/dx)^{\text{restricted stopping power}} \times t$$

$$-(dE_{\pm}/dx)^{\text{restricted stopping power}} = -(dE_{\pm}/dx)^{\text{Radiative sub cutoff}} - (dE_{\pm}/dx)^{\text{Collision sub cutoff}}$$

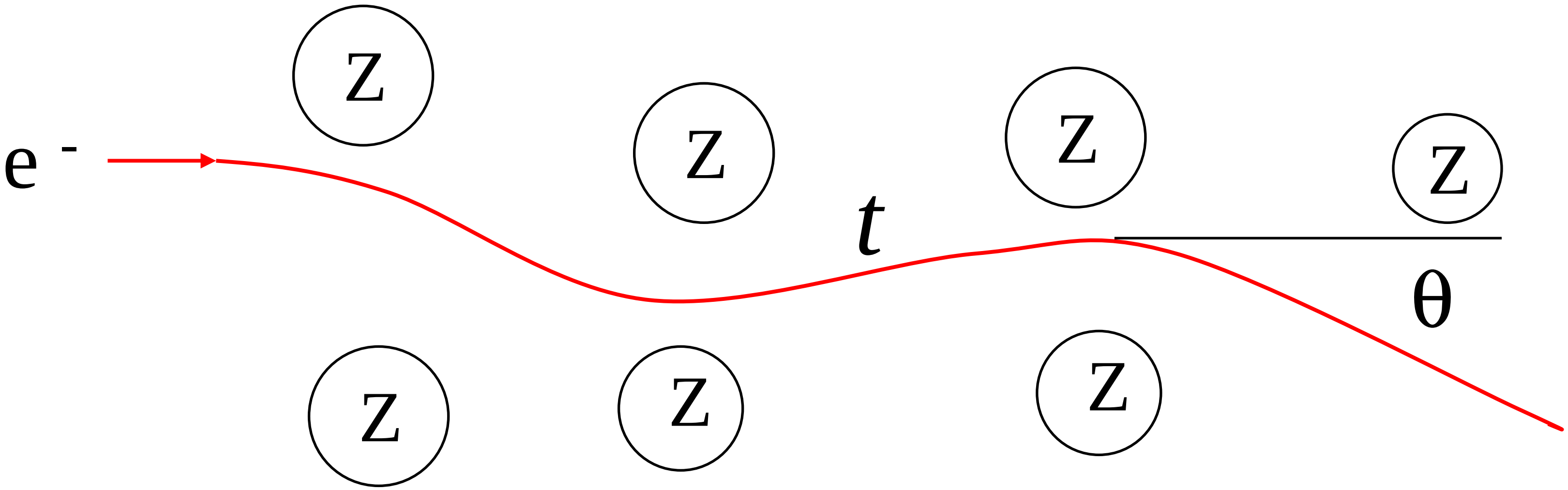
Mean energy loss from Gaussian distribution

Needs Landau's distribution for thin geometry

Absorption Dose (Gy) = Energy absorption (J) / mass(kg)



Multiple Scattering

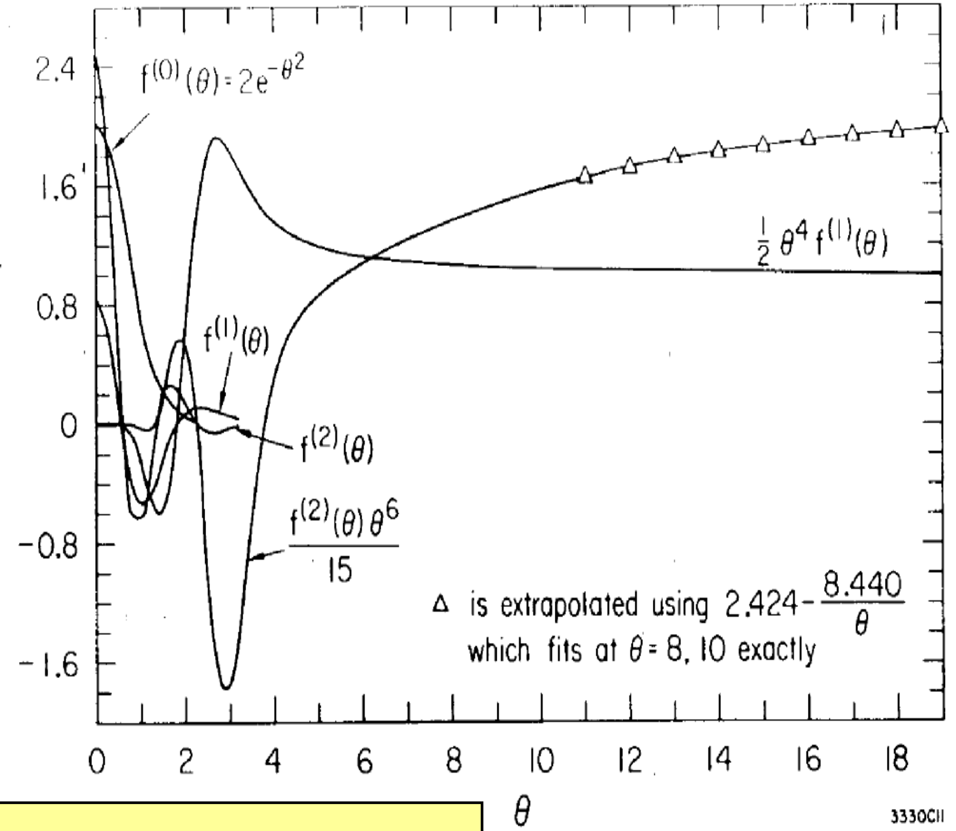


f(θ)=? : after path length t

- Fermi-Eyges theory
- Goudsmit-Saunderson theory: EGS5
- Moliere’s small angle large pathlength theory:EGS5

Moliere theory
(Middle precision, Middle restriction, Simple)

- Convert scattering angle
  Θ (E,Z,t) to reduced angle θ
- Use single set of $f^{(n)}(\theta)$ → Simple
- Good for small angle (<20°)
- Needs long t (>100 elastic mfp)

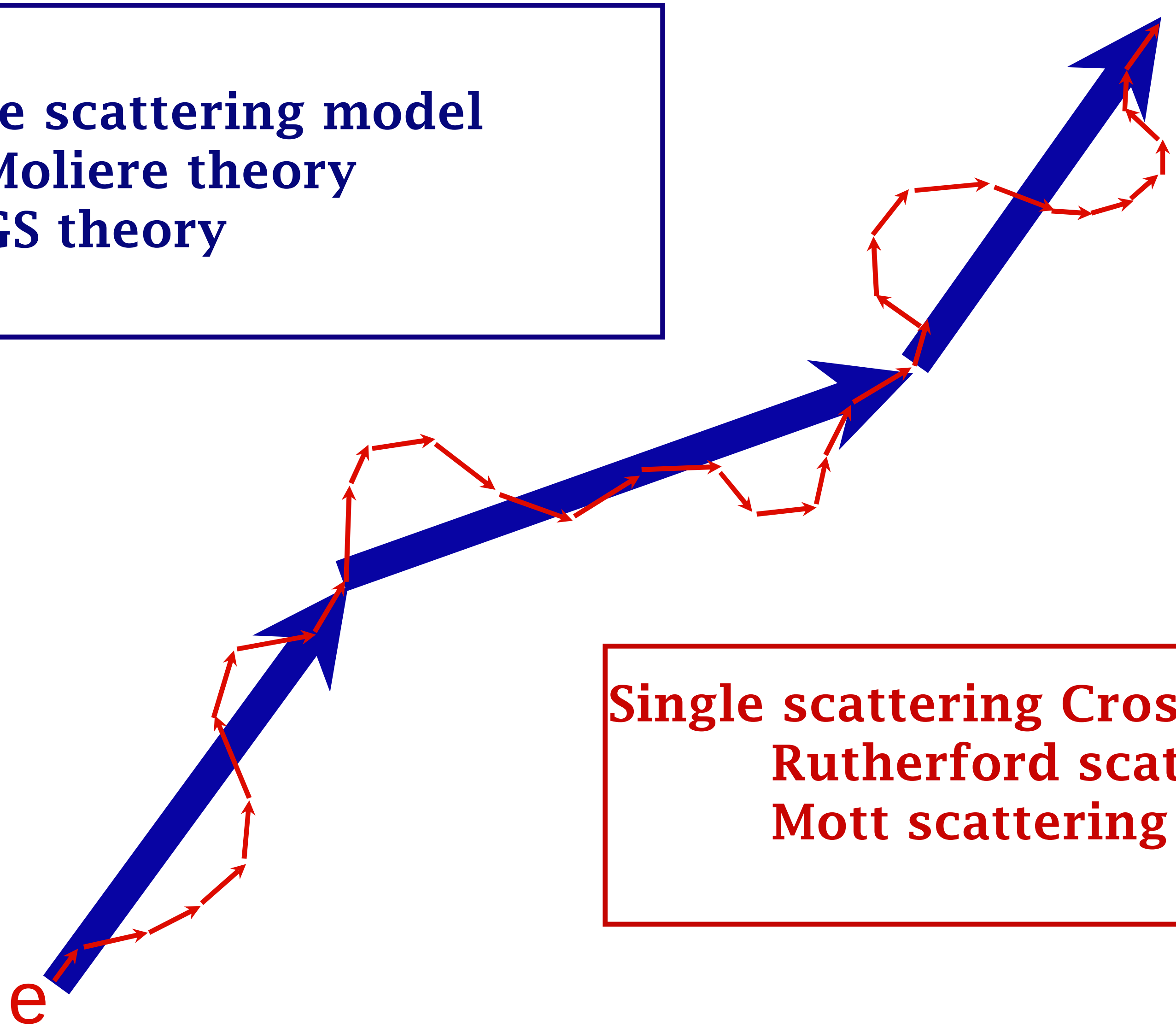


Goudsmit-Saunderson (GS) theory
(High precision, Little restriction, Cumbersome)

- Expand scattering CS by Legendre function
- Coefficient f (E, Z, t, θ) → Need large Data Base
- Good for all scattering angle without restriction

Concept figure for single scattering and multiple scattering

Multiple scattering model
- **Moliere theory**
- **GS theory**



Single scattering Cross section
- **Rutherford scattering**
- **Mott scattering**

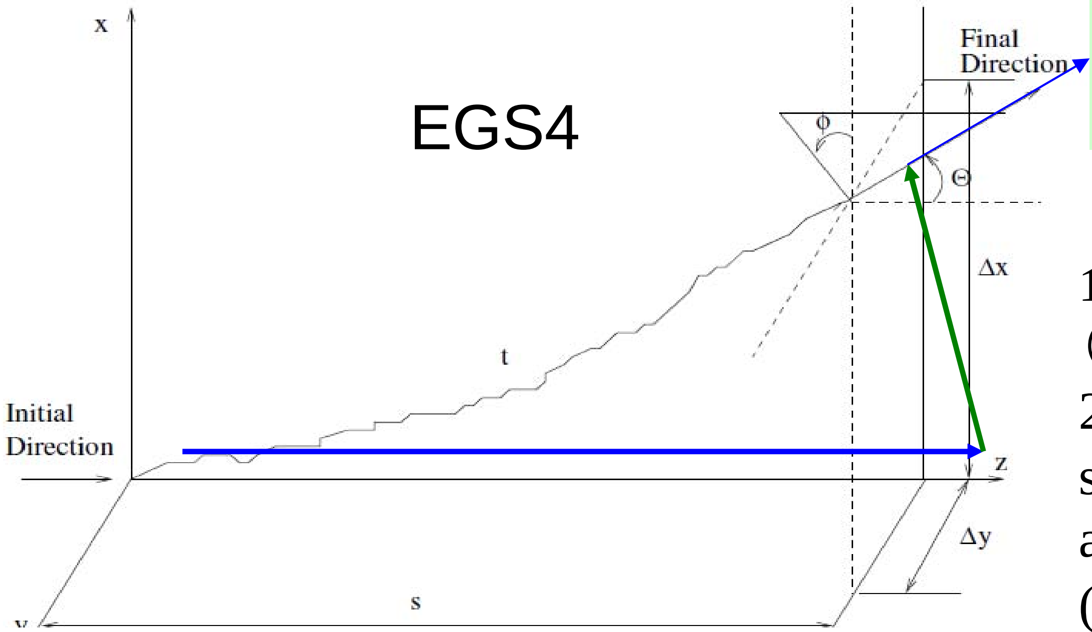
Electron transport in EGS5

- Elastic scattering cross section
  - Rutherford CS（Default)(=EGS4)
    - Coulomb interaction between nucleus and electron. Nucleus is treated as a point.
  - Mott CS
    - Consider spin relativistic effect
- Multiple scattering
  - Moliere theory (Default)(=EGS4)
  - Goudsmit-Saunderson theory (GS)
- Transport mechanics inside m.s. step
  - Dual Hinge

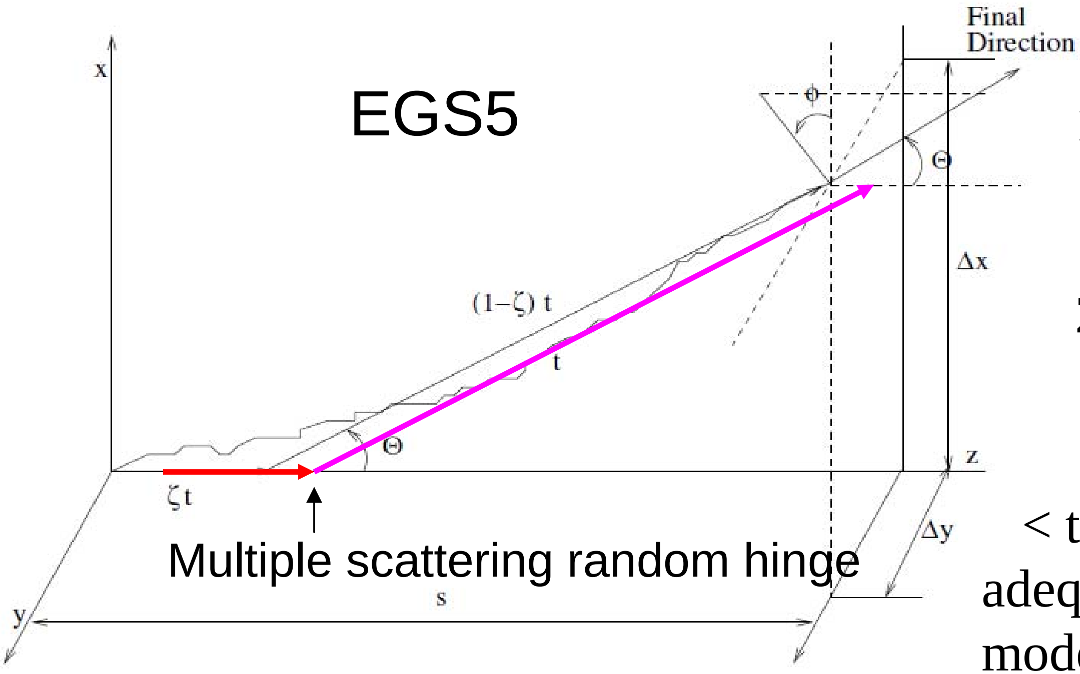
Transport Mechanics inside step

Transport mechanics inside m.s. step of EGS5 (1)

Developed at U.Mich and U.Barcelona



1. Sampling m.s. step s (straight step size)
2. Evaluate curved length (t), scattering angle (τ) and lateral displacement $(\Delta x^2+\Delta y^2)$



1. Sampling multiple scattering hinge point inside curved length t
2. Change electron direction at that point based on m.s. model

$<t/s>$ and $<\Delta x^2+\Delta y^2>$ are adequately calculated in this hinge model as long as energy loss is ignored.

Transport mechanis inside m.s. hinge in EGS5 (2)

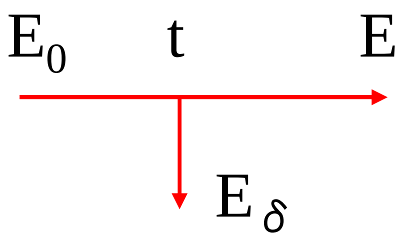
- Instead of hinge model of ζt and $(1-\zeta)t$, hinge model based on scattering strength is used. $\zeta \boldsymbol{K_1}(t)$ and $(1-\zeta)\boldsymbol{K_1}(t)$.
  - To account for energy loss.
- Introduce "**Energy loss hinge** " to simplify integral of G_1 to evaluate K_1.
  - Energy is constant between energy loss hinge.
- Introduce "**Characteristic dimension**" to make setting of adequate step length easy.

Simple

Accurate

Class I (ITS,MCNP)

Energy loss without correlation

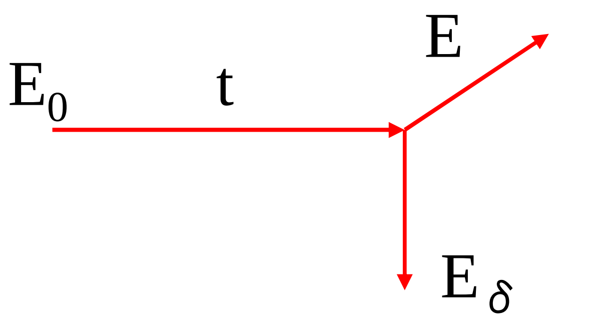


$$E = E_0 - \Delta E(t)$$

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

Class II (EGS,Penelope)

Energy loss with correlation



$$E = E_0 - t\, L_{col}^{AE} - E_\delta$$

$$E_{dep} = t\, L_{col}^{AE}$$

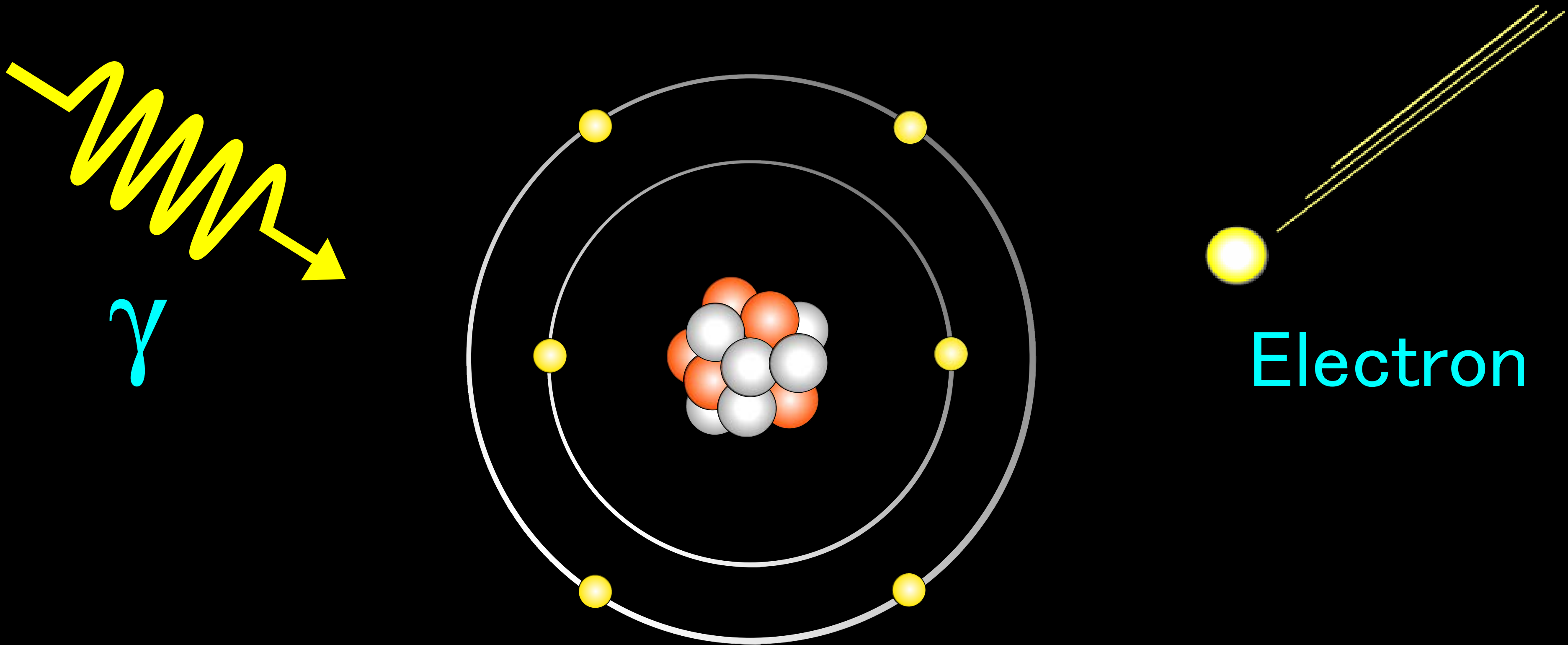
- $\Delta E(t)$: energy loss sampled from energy loss distribution (Straggling considered)
- L_{col}^{AE} : restricted stopping power for 2nd particle (<AE)

t : Fixed length (Function of Max energy) @ITS,
Variable @ EGS, Penelope

Comparison of Electron transport model

Code	Spin	M.S. model	Class	Transport mechanism in step
EGS5	×	Moliere	2	Dual Hinge Characteristic dimension
	○	GS		
EGSnrc	○	GS	2	Separate single scatt.
Penelope	○	GS	2	Dual Hinge Separate large θ scatt.
ITS 3.0 #	○	GS	1	

Adopted as electron transport of MCNP



Photon and electron interact with

Whole One Atom, Electron, and Nucleus

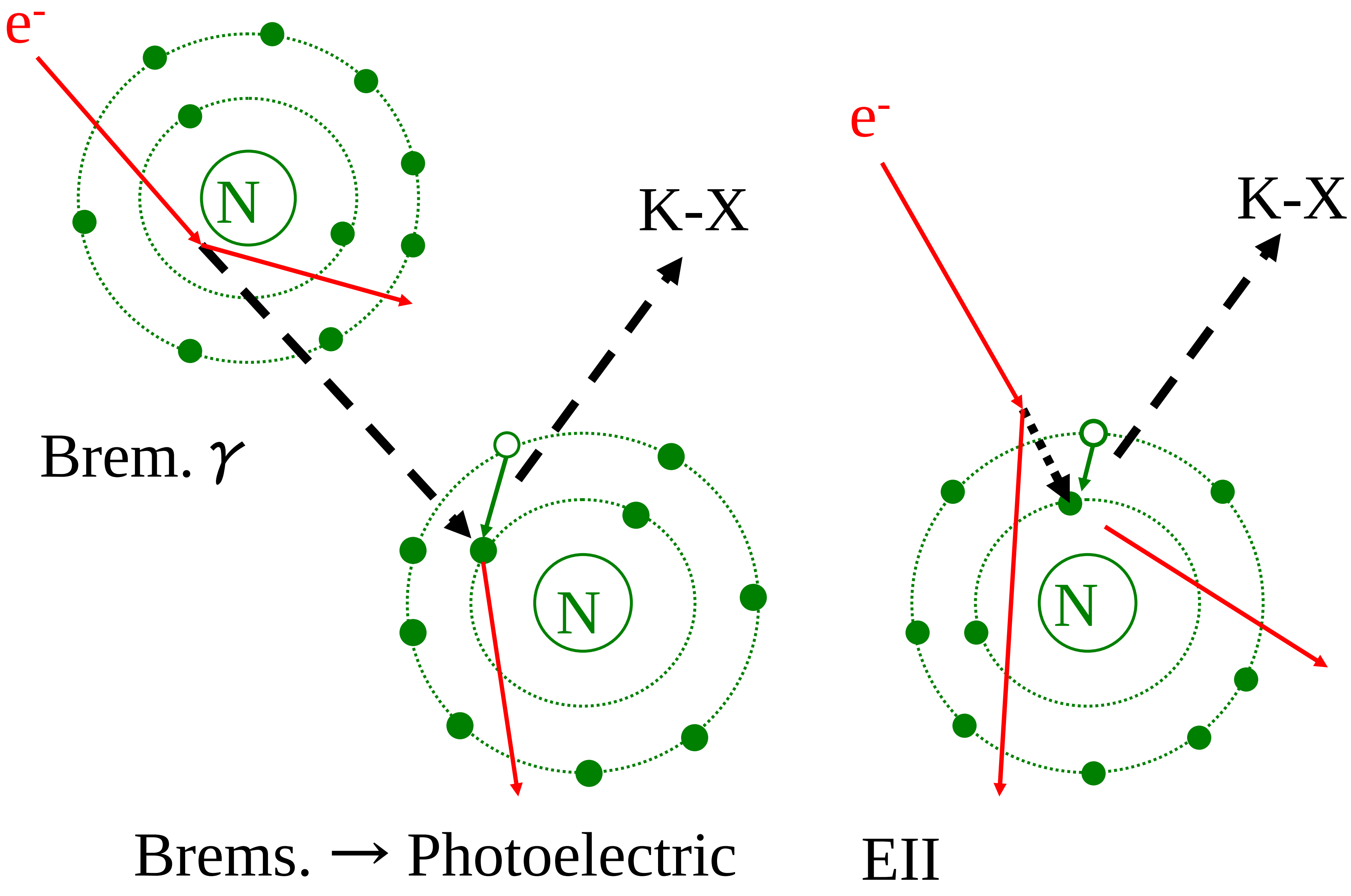
Exception

- Density effect
- Interference in Rayleigh scattering

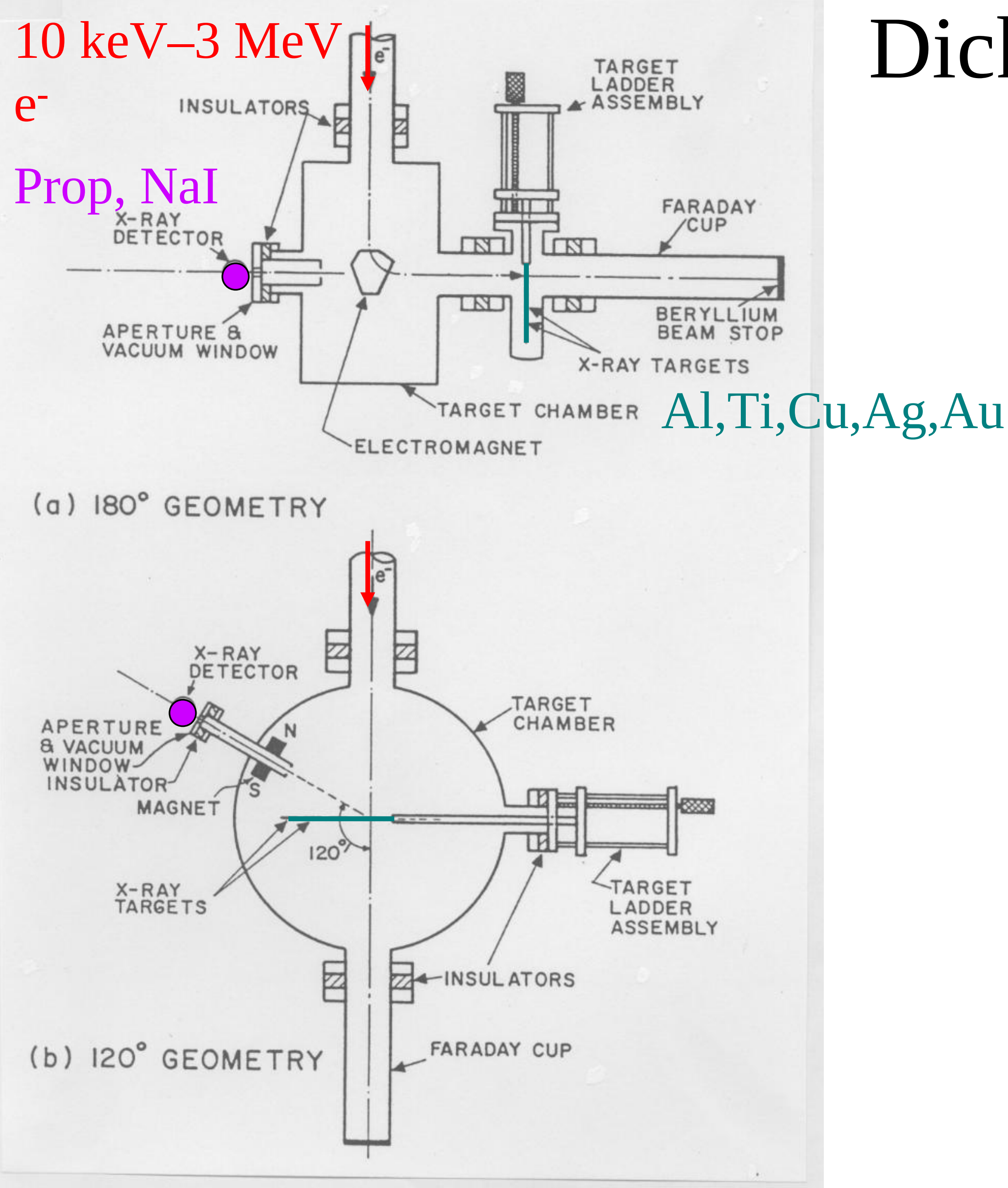
Complement

- Electron impact ionzation
- Shielding of α,β,γ ray

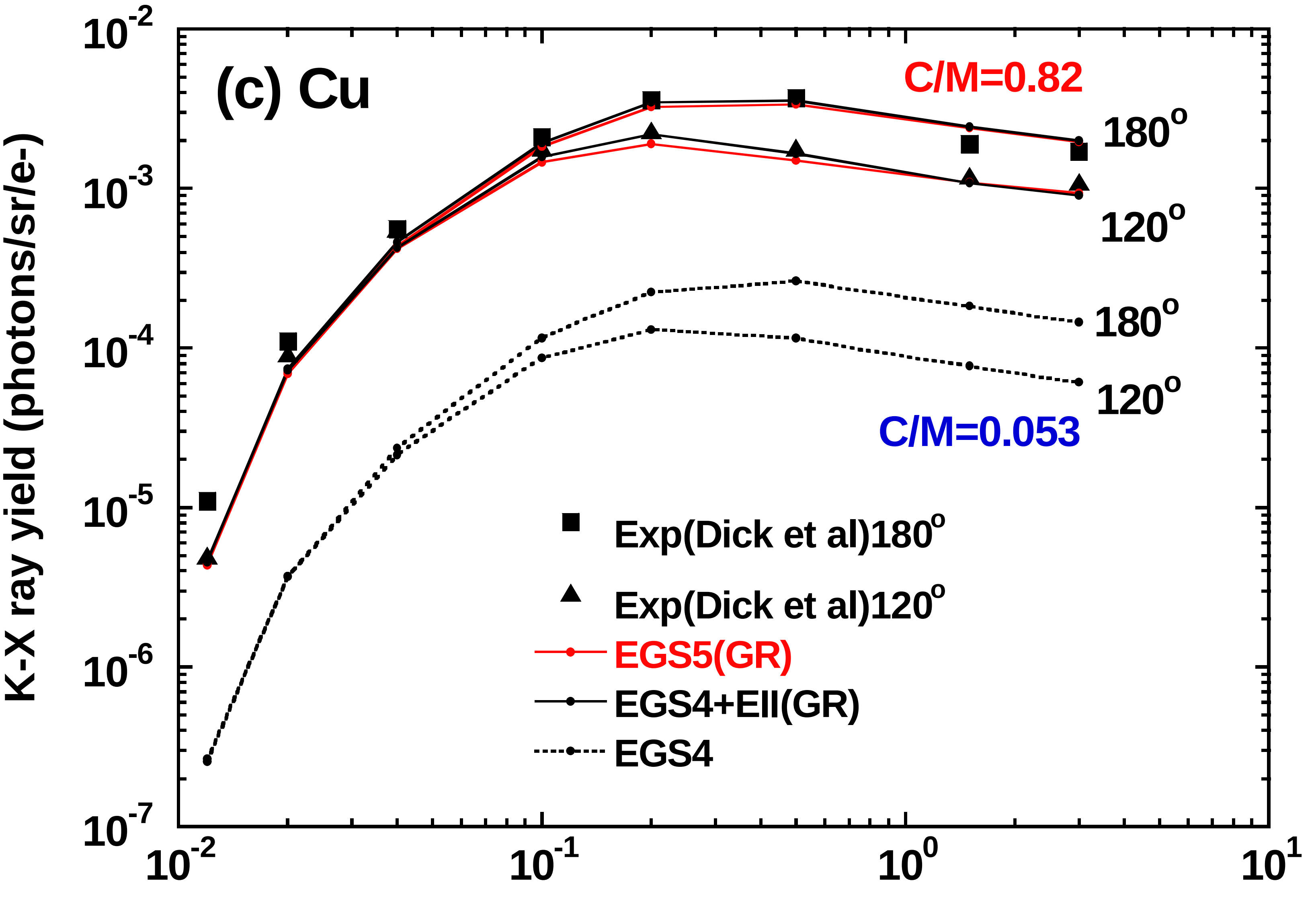
Electron Impact Ionization (EII)



Dick et al (1973)'s exp set up



K X-ray yield for Cu



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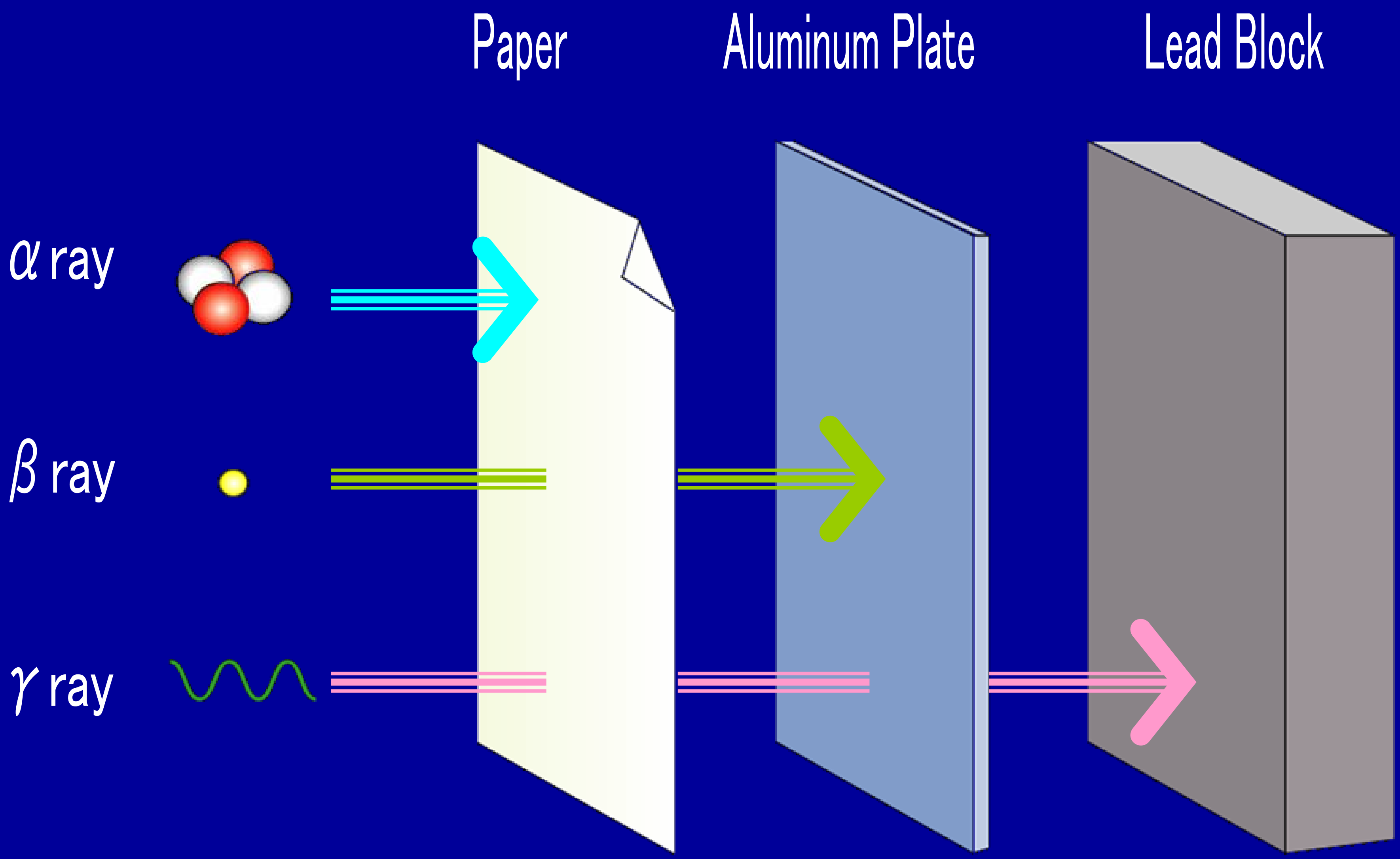
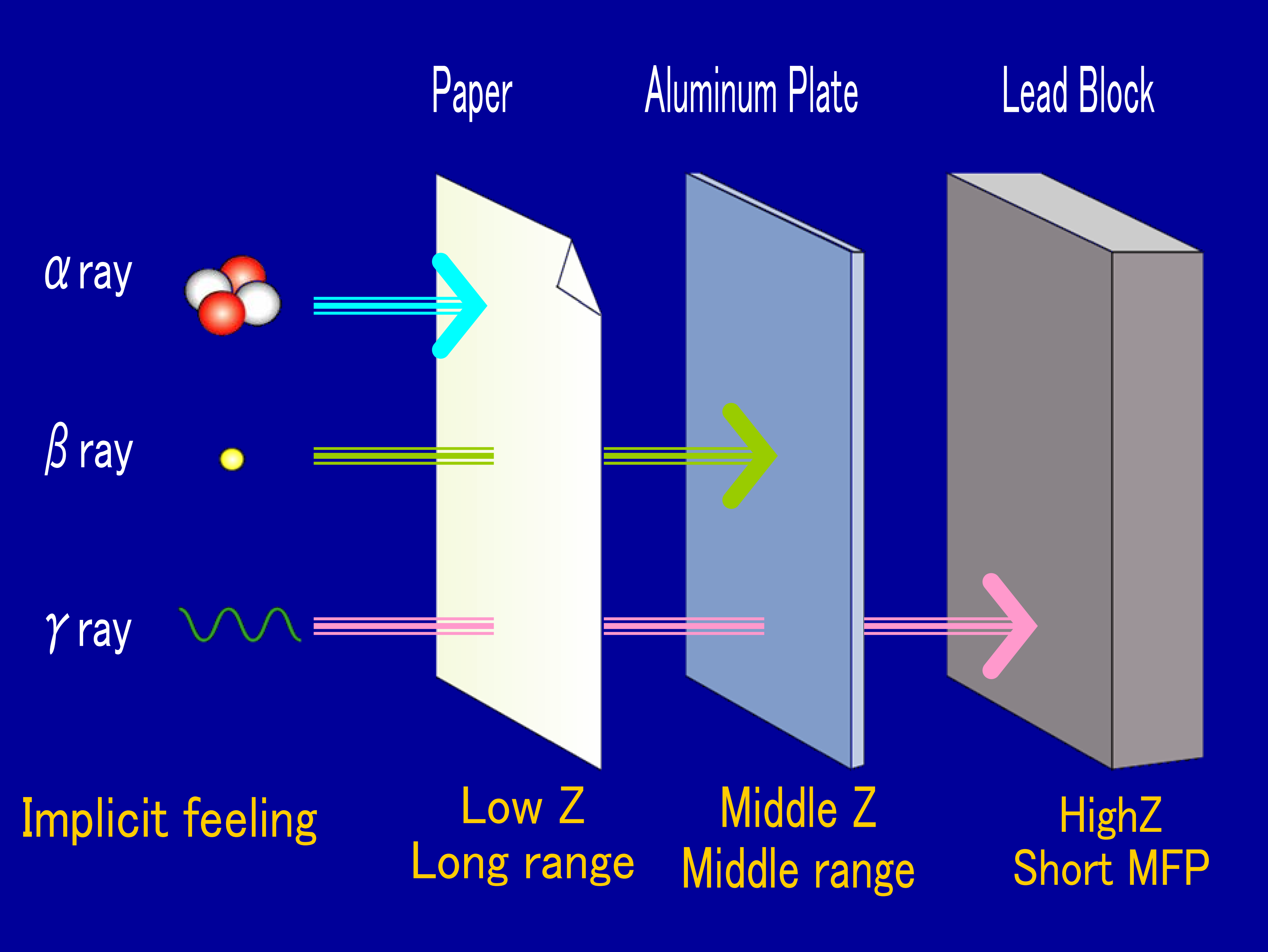
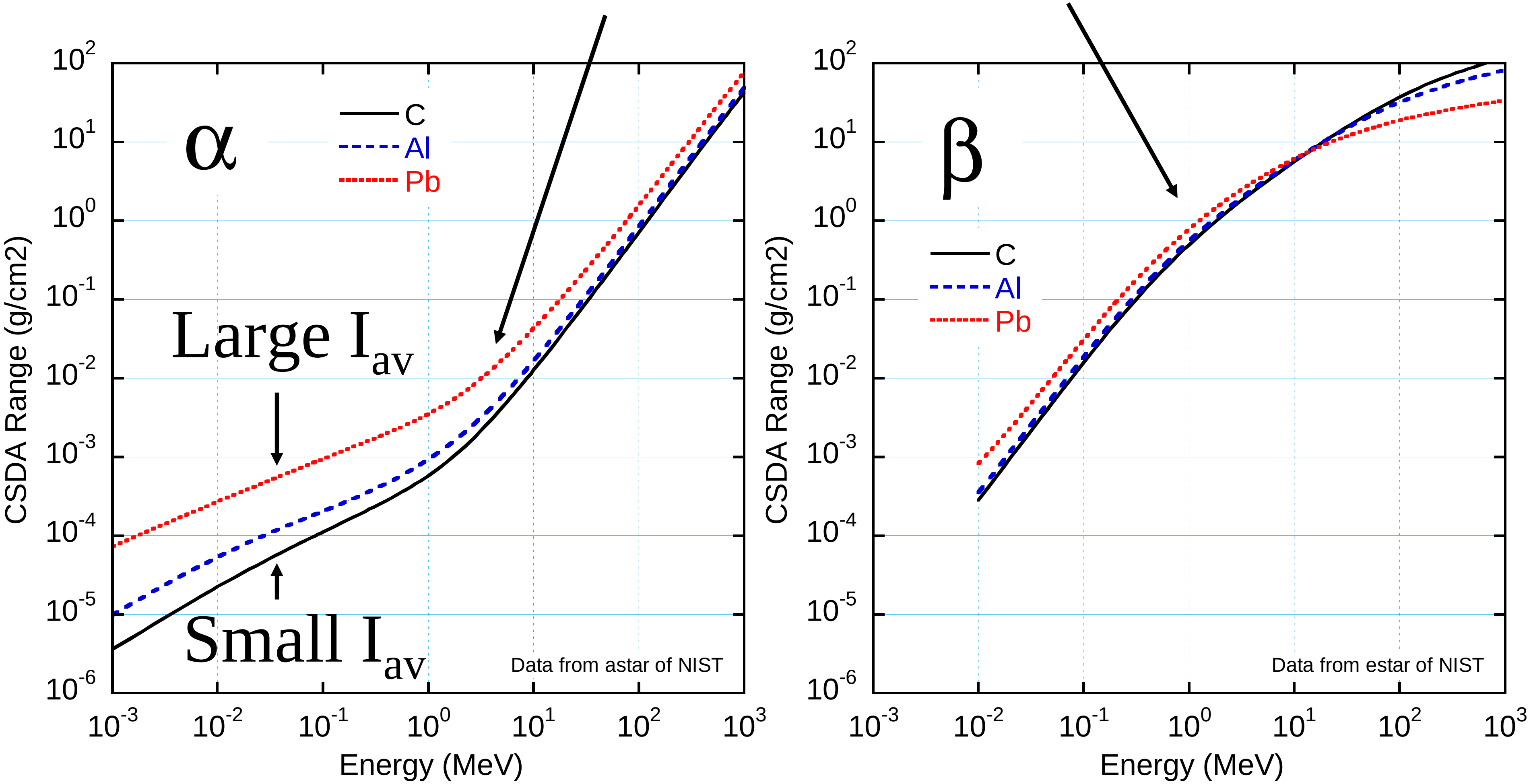


Penetration of radiation

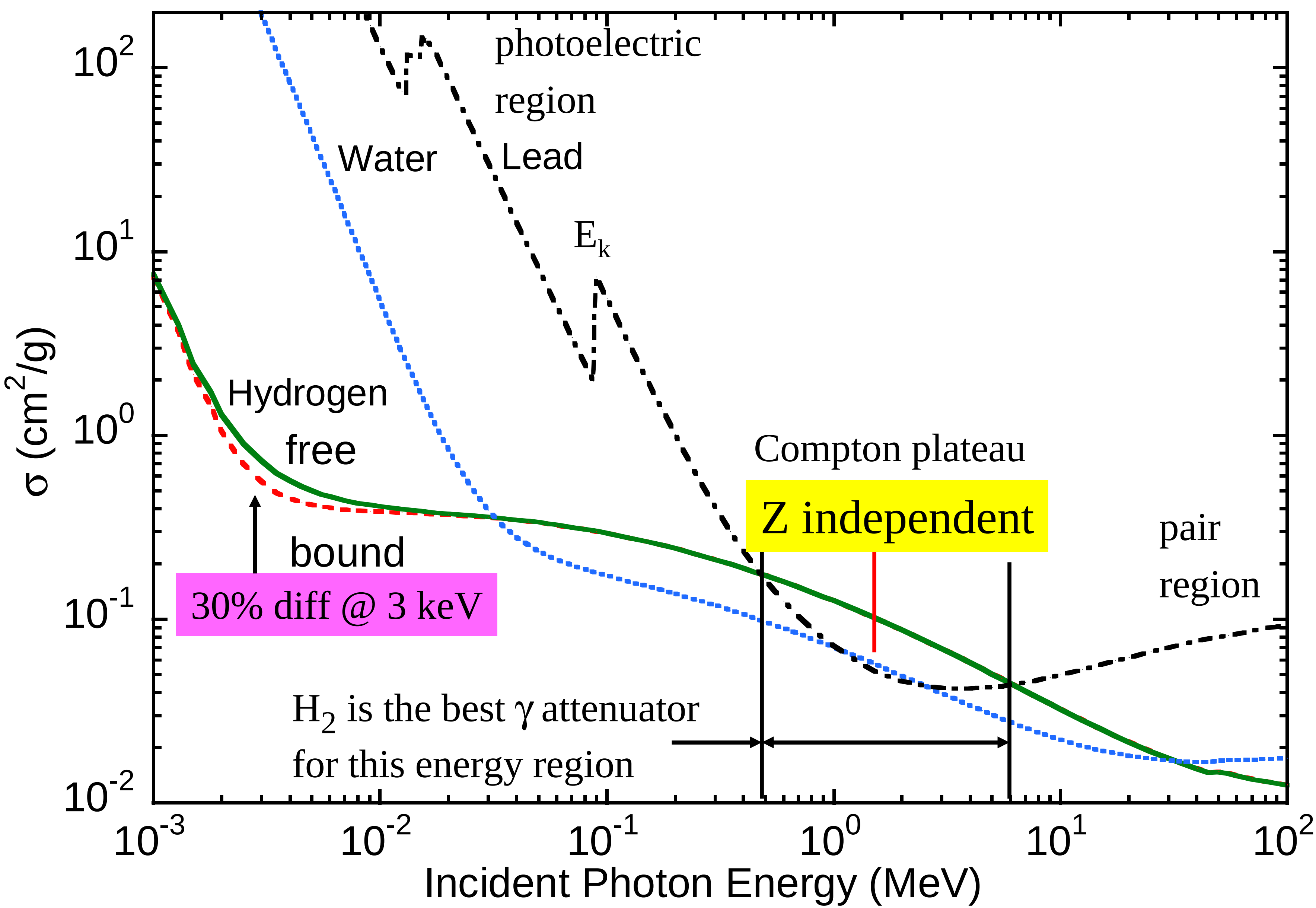

Paper
Aluminum Plate
Lead Block
α ray
β ray
γ ray
Implicit feeling
Low Z
Long range
Middle Z
Middle range
HighZ
Short MFP

CSDA range of α and β ray

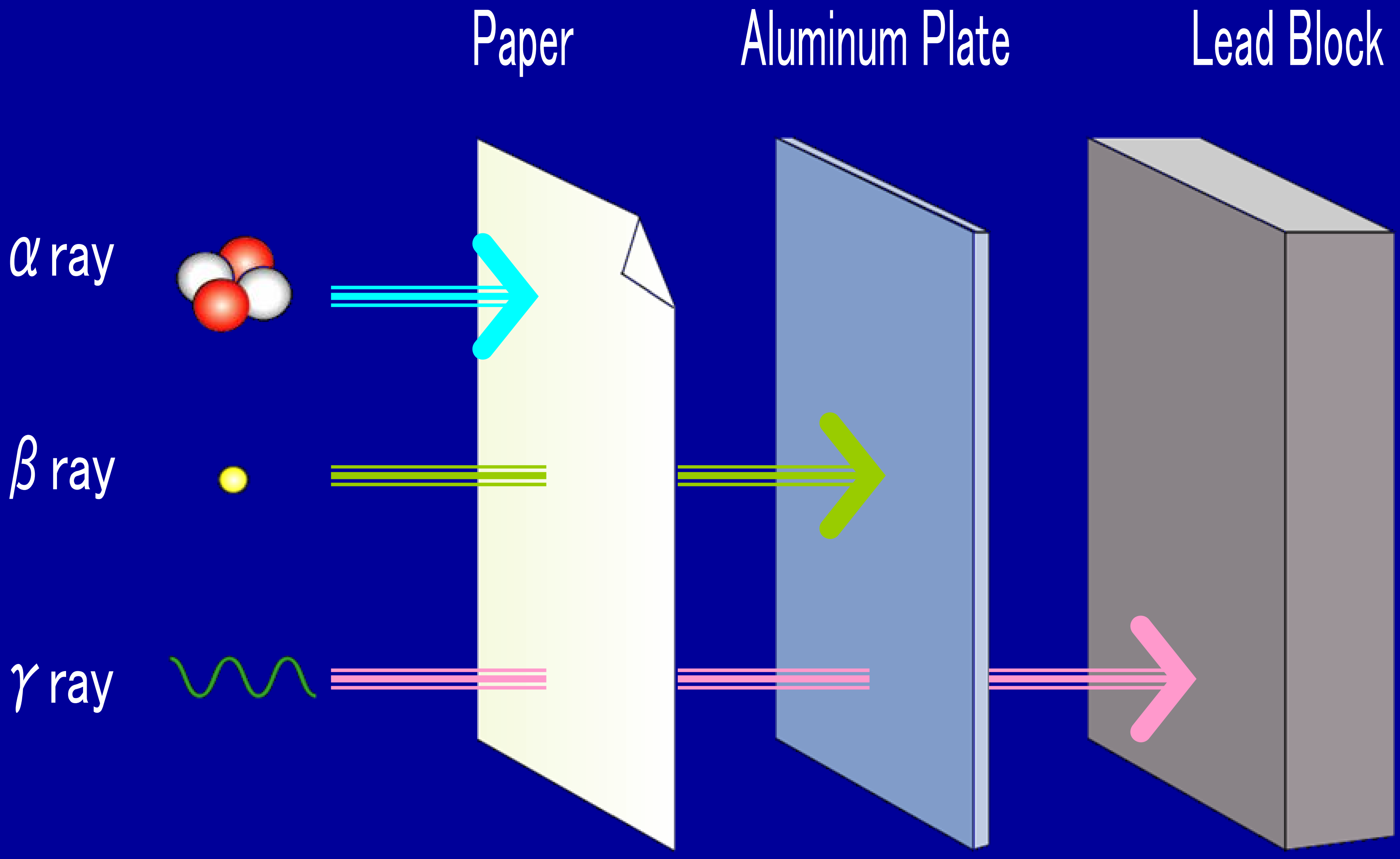
(Almost) independent of Z



Total photon Σ *vs* γ-energy



Penetration of radiation



In reality, α ray and β ray range (g/cm^2) or γ ray MFP is (almost) independent of Z!

End of Electron Monte Carlo Simulation