Russian Research Center " Kurchatov Institute"

Calculations of radiation damage near 7 TeV proton beam in LHC collimator materials

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Aims of Investigations:

- Development of theoretical models for the investigations of radiation damage formation in the collimator materials: Cu and C under irradiation by a 7 TeV proton beam taking into account elastic and inelastic collisions, ionization, electronic excitation and physical properties of materials used data from FLUKA program .

- Calculations of radiation damage: point defects, cascades and subcascades in collimator materials: Cu and graphite irradiated by a 7 TeV proton beam taking into account elastic and inelastic collisions, electronic excitation and energy transfer from electronic subsystem to ionic one in these materials.

- Simulation and modeling of radiation formation and microstructure change in different collimator materials: Cu and C produced by a 7 TeV proton beam.

Development of theoretical models for the calculations of radiation damage near 7 TeV proton beam in LHC collimator materials.

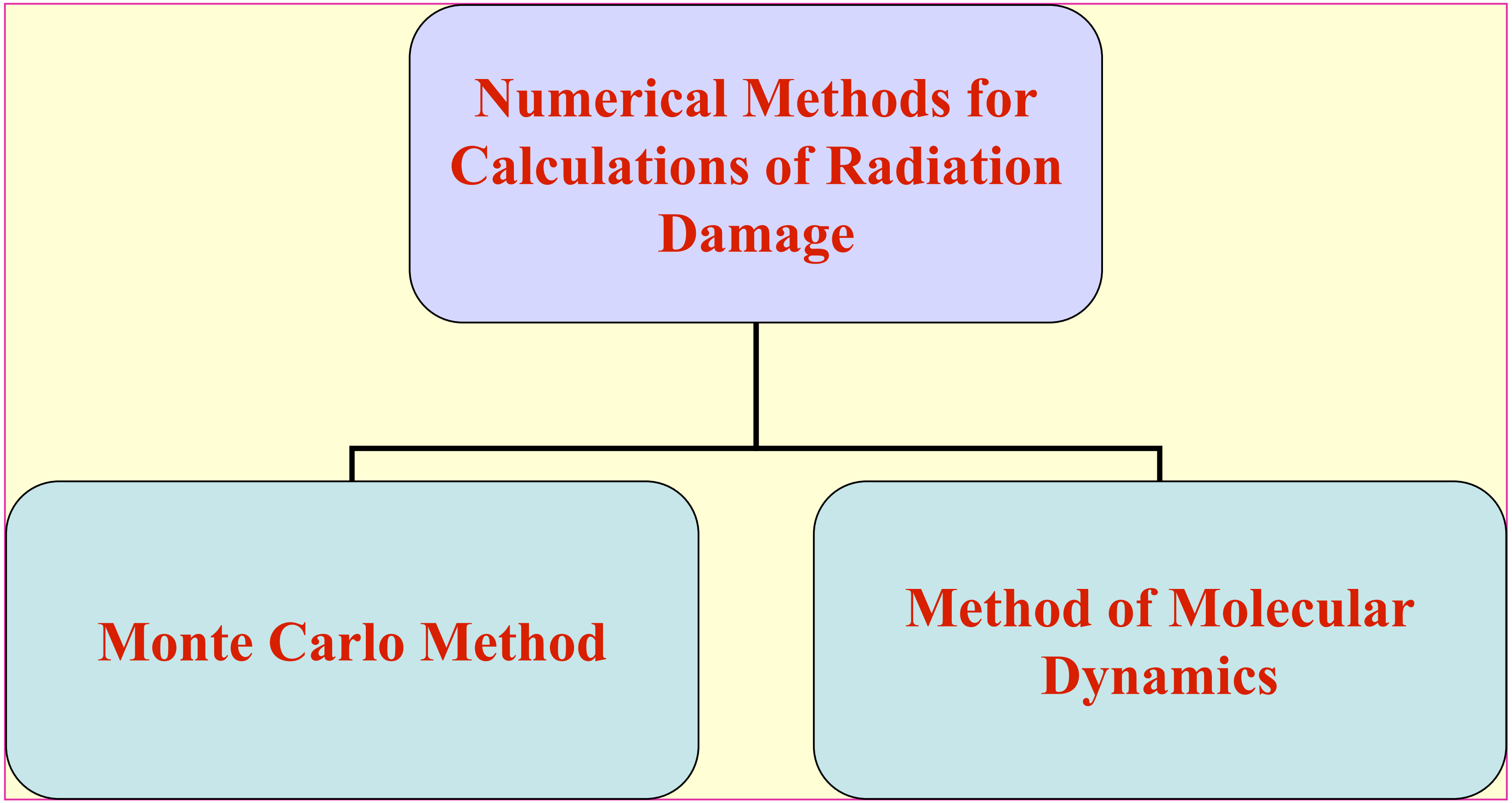
Materials:

- Copper
- Graphite

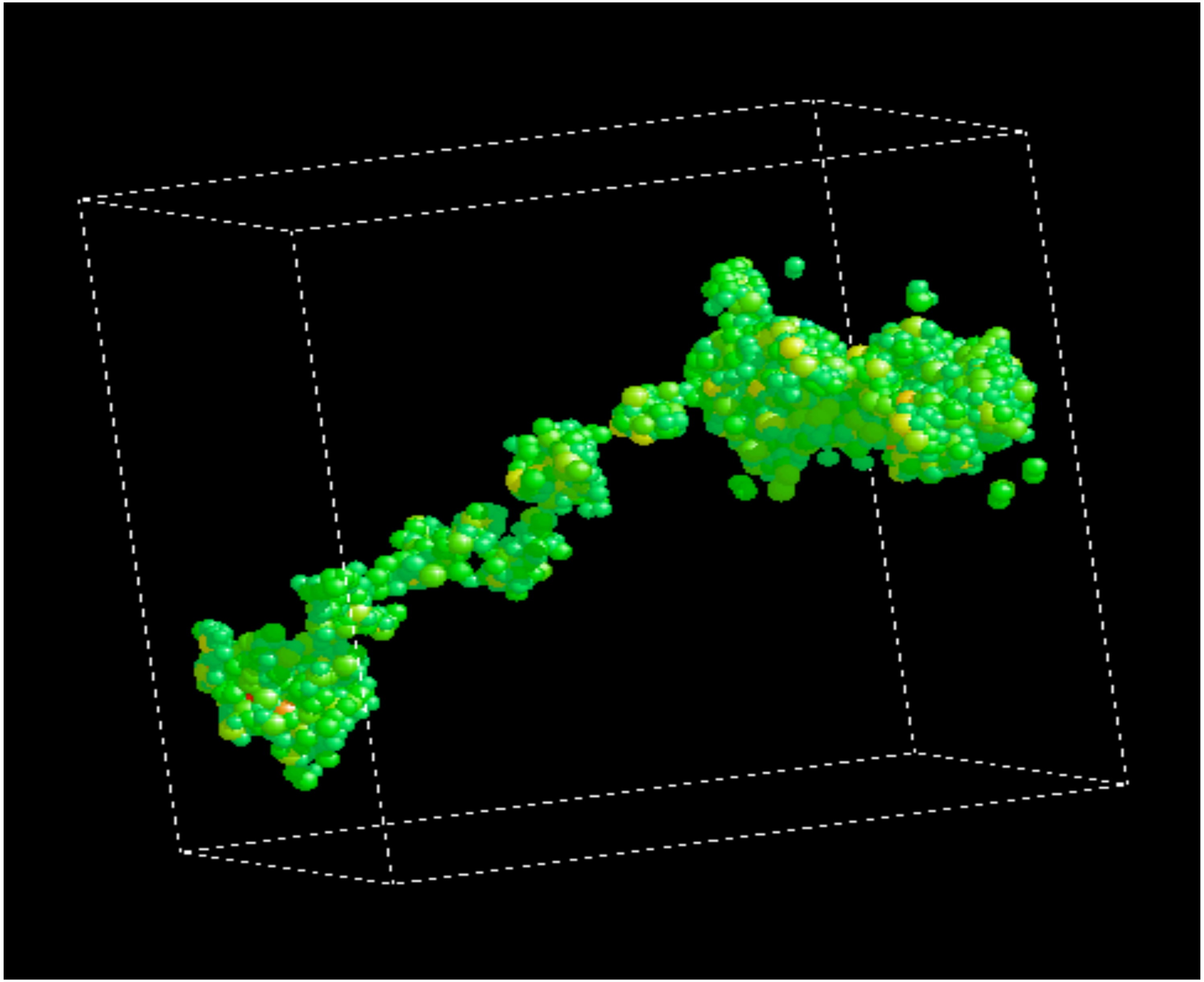
Physical Processes:

- Production of fission products and secondary particles under irradiation of collimator materials by 7 TeV proton beam.
- Electronic excitation of electronic subsystem of materials
- Elastic and inelastic collisions in materials
- Production of PKA energy spectrum and point radiation defects
- Cascade and subcascade formation
- Electron-phonon coupling in materials

Methods for Calculations of Radiation Damage



Cascades in Al PKA energy E = 10KeV



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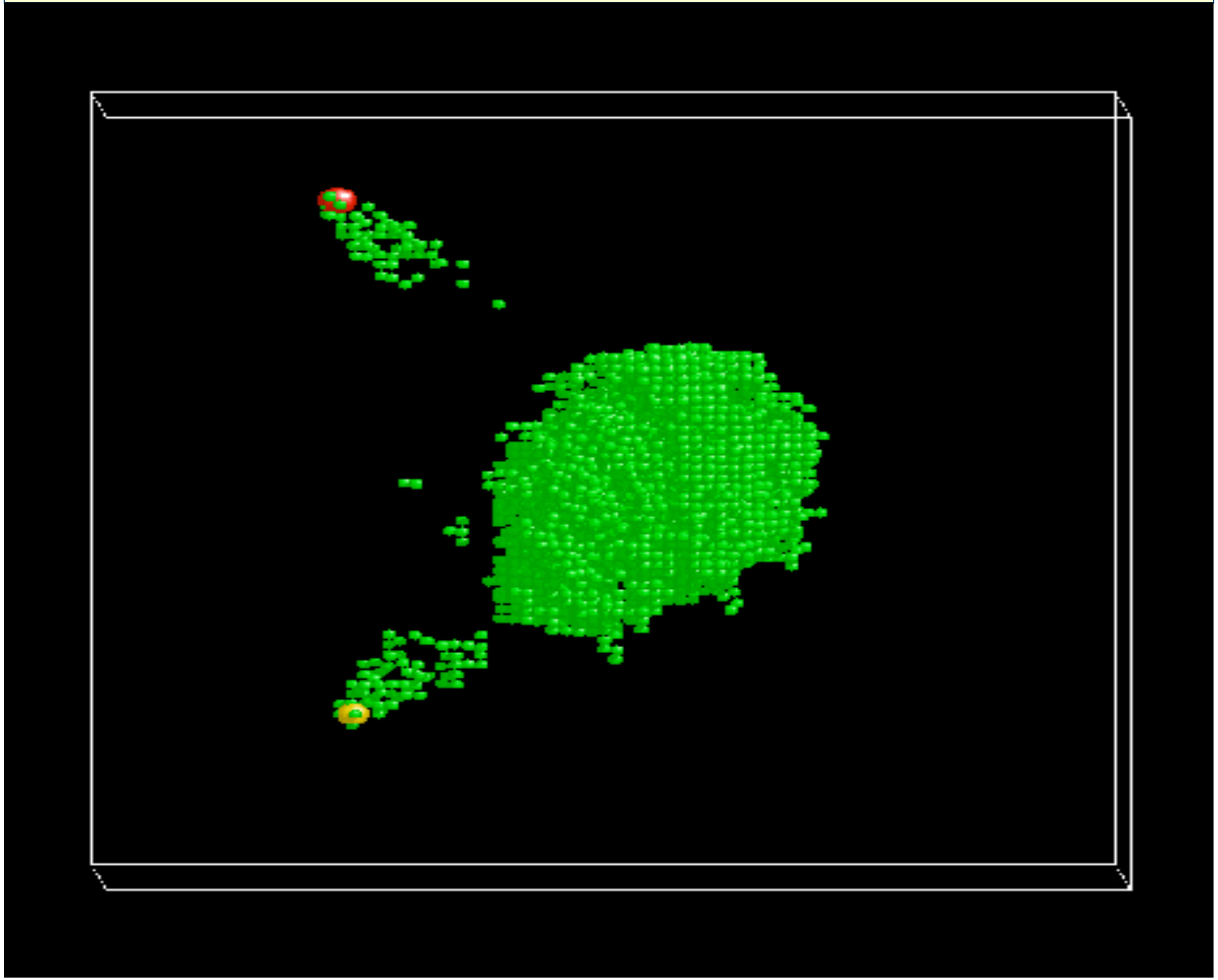
Cascades in Au PKA energy E = 10KeV



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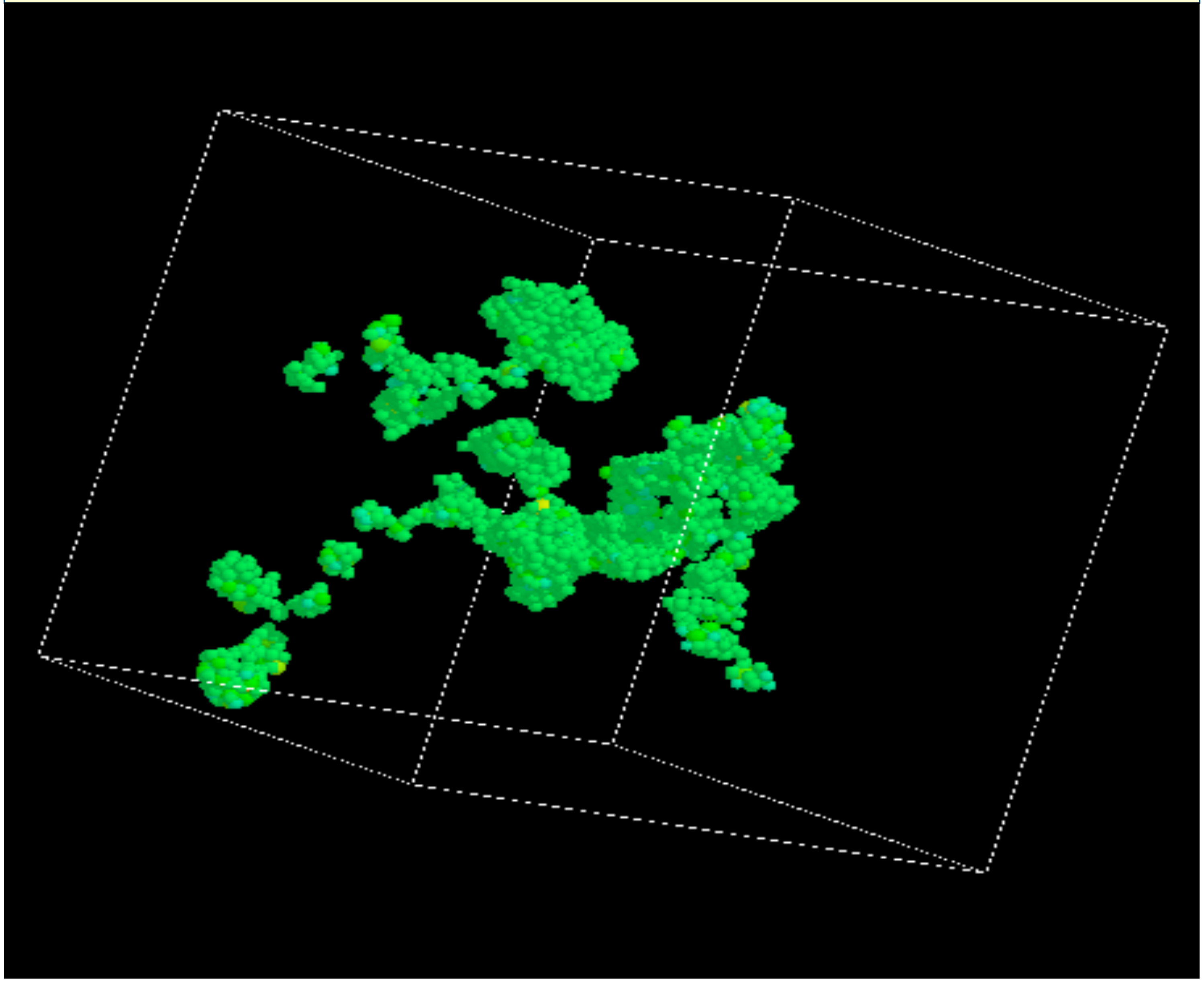
Cascades in Si PKA energy E = 10KeV



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Theoretical Model of Point Defects Production

Cross Section for Point Defect Production

$$\sigma_d = \sum_i \alpha_i \int \frac{d\sigma_{PKA}(E,E_n)}{dE} \nu_i(E)\,dE$$

α_i **is the yield of** ***i*** **type of fission product,** $\frac{d\sigma_{PKA}(E,E_n)}{dE}$ **is the cross-section of energy transfer to recoil atom,**

$\nu_i(E)$ **is the cascade function NRT-standard:**

$$\nu_i(E) = 0.8\frac{\hat{T}_i(E)}{2E_d}$$

$$\hat{T}_i(E) = \frac{E}{1 + k(3.4008\varepsilon_i^{1/6} + 0.40244\varepsilon_i^{3/4} + \varepsilon_i)}$$

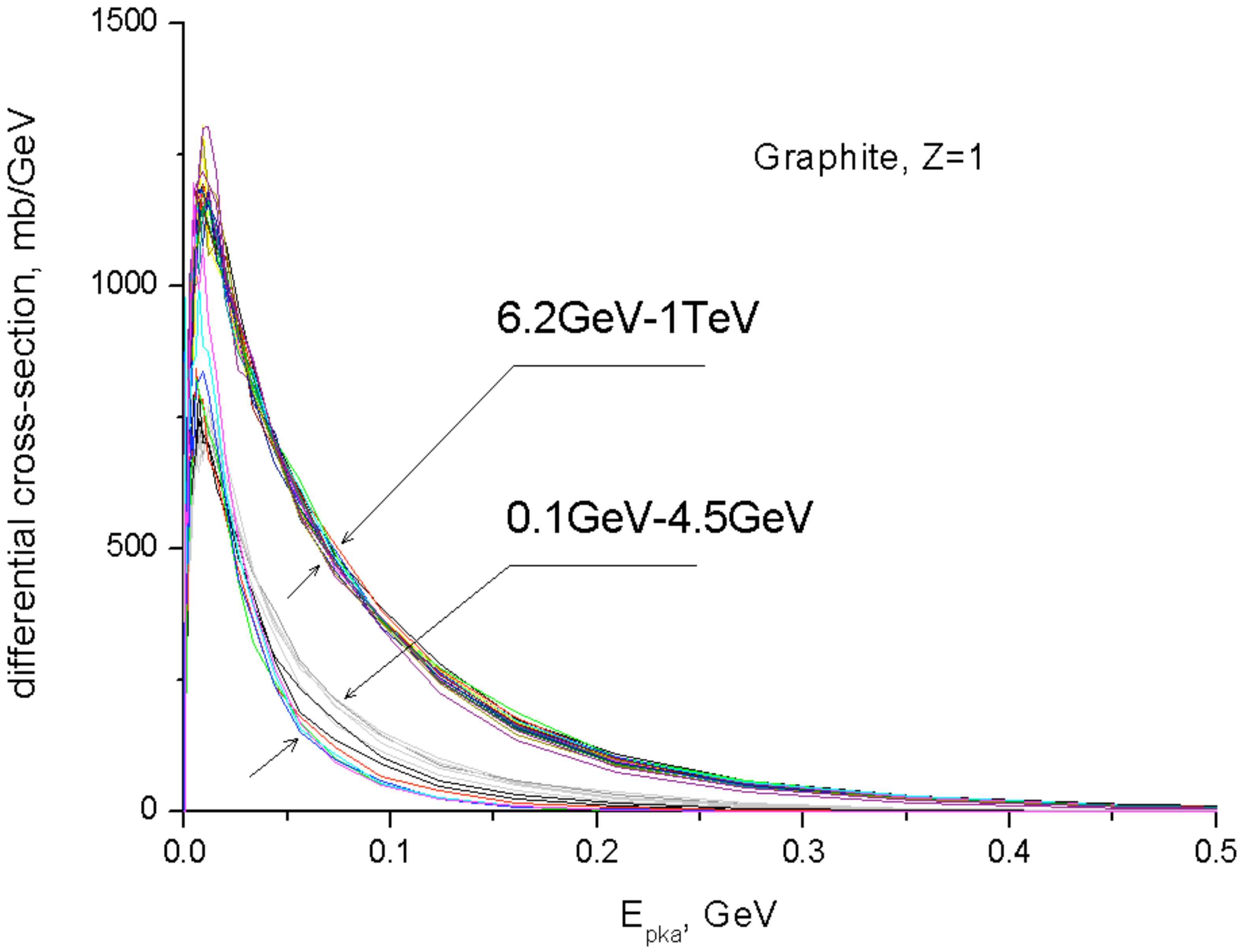
$$k = \frac{32}{3\pi}\left(\frac{m_e}{M_T}\right)^{1/2} \frac{(A_i + A_T)^{3/2} Z_i^{2/3} Z_T^{1/2}}{A_i^{3/2}(Z_i^{2/3} + Z_T^{2/3})^{3/4}} \qquad \varepsilon_i = \frac{A_T E}{(A_i + A_T)} \frac{a}{Z_i Z_T e^2} \qquad a = \frac{a_0 (9\pi^2/128)^{1/3}}{(Z_i^{2/3} + Z_T^{2/3})^{1/2}}$$

a_0 **is the Bohr radius;** Z_i **and** Z_T **are the charges of recoil and target atoms;**

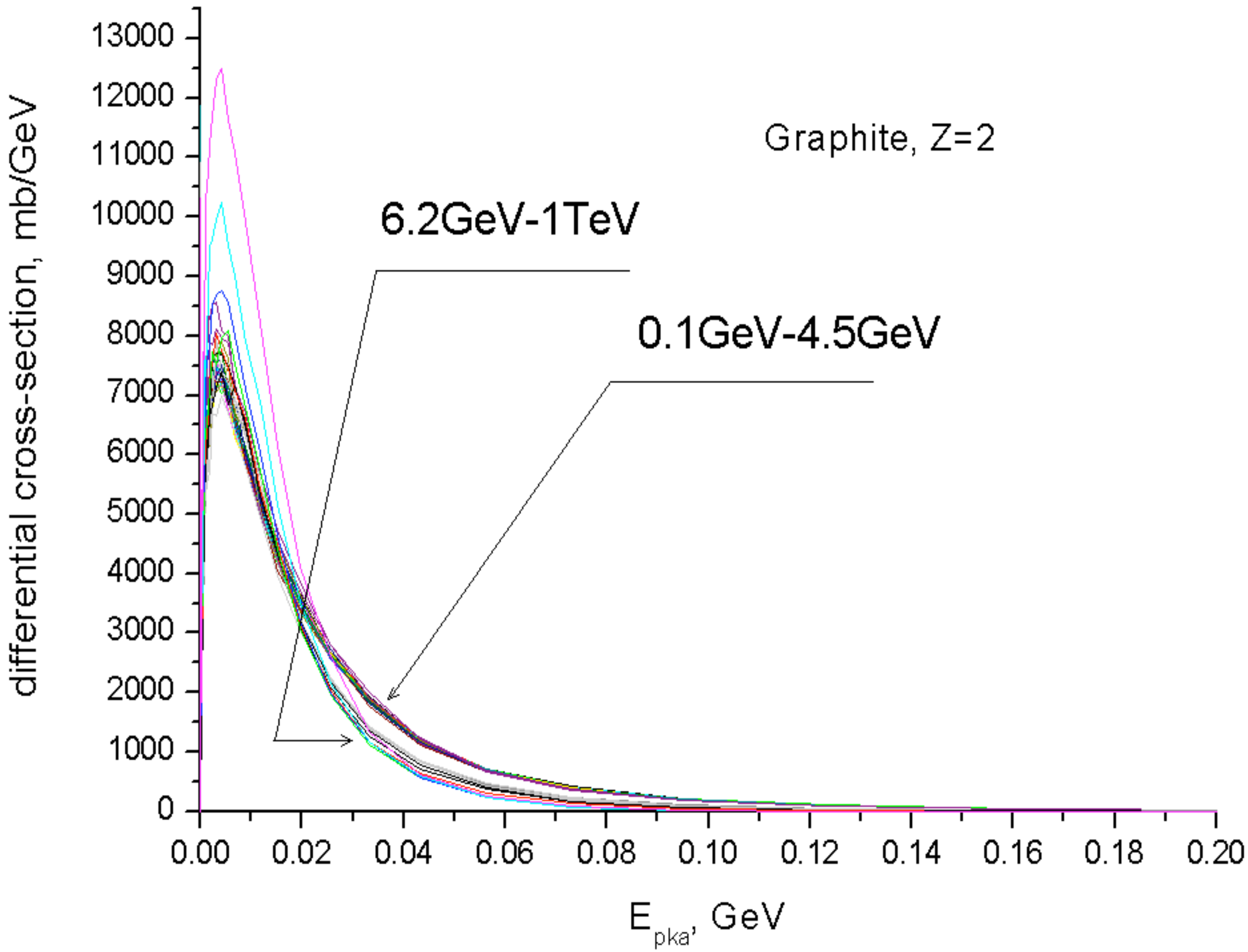
A_i **and** A_T **are the mass number of recoil and target atoms,**

m_e **and** ***e*** **are the mass and charge of electron,** E_d **is the threshold energy**

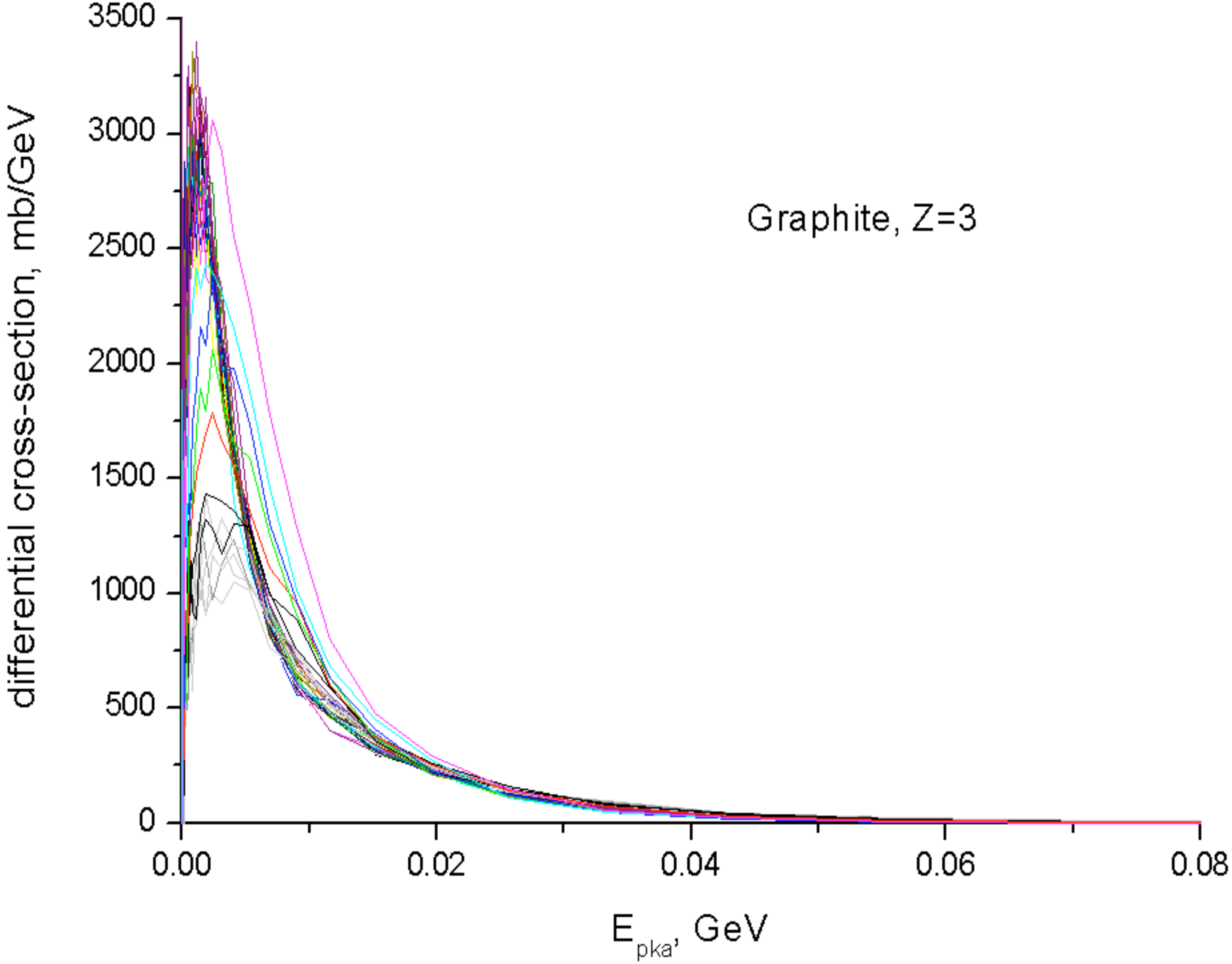
Differential cross-section of energy transfer to recoil atom



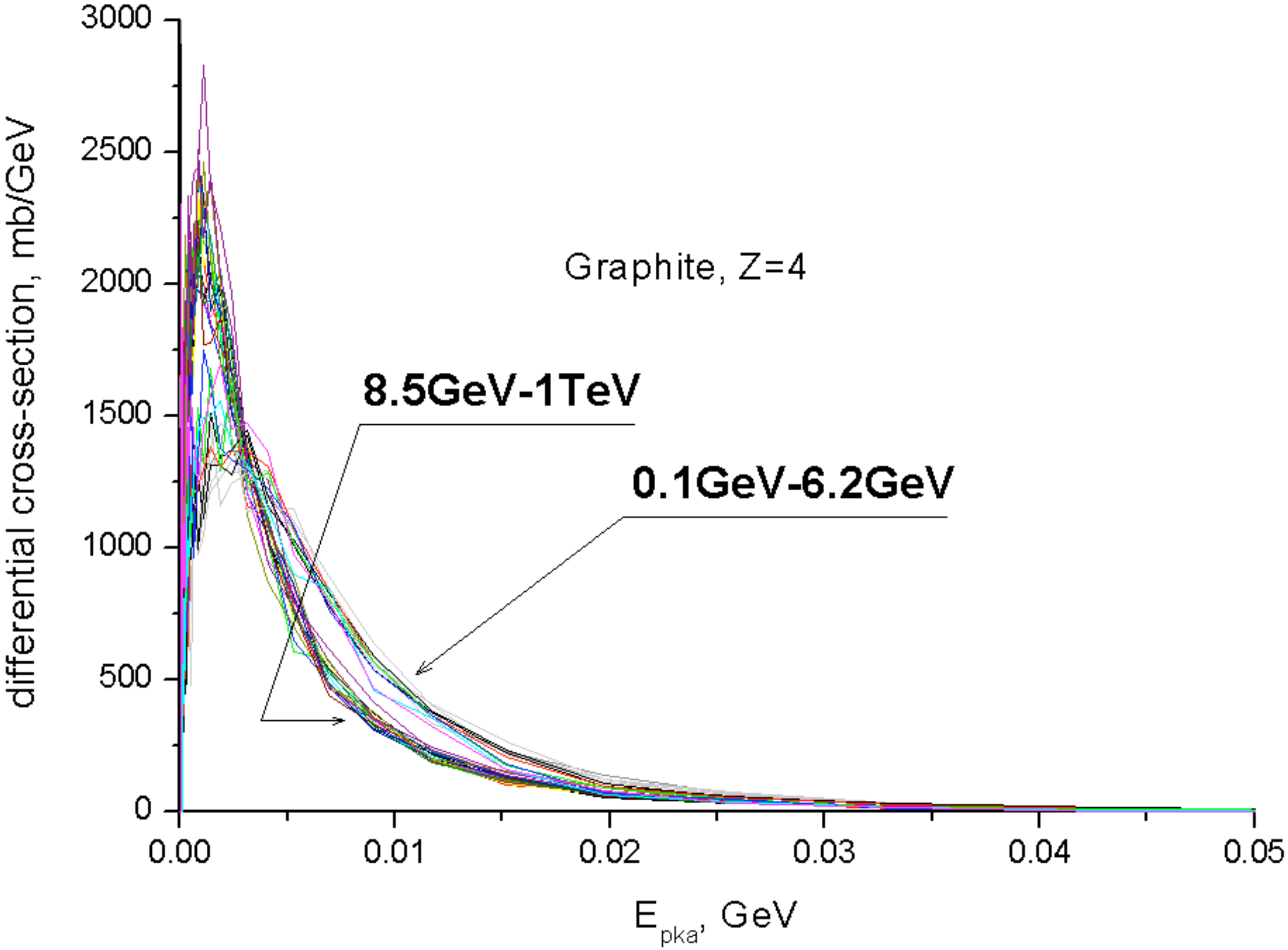
Differential cross-section of energy transfer to recoil atom



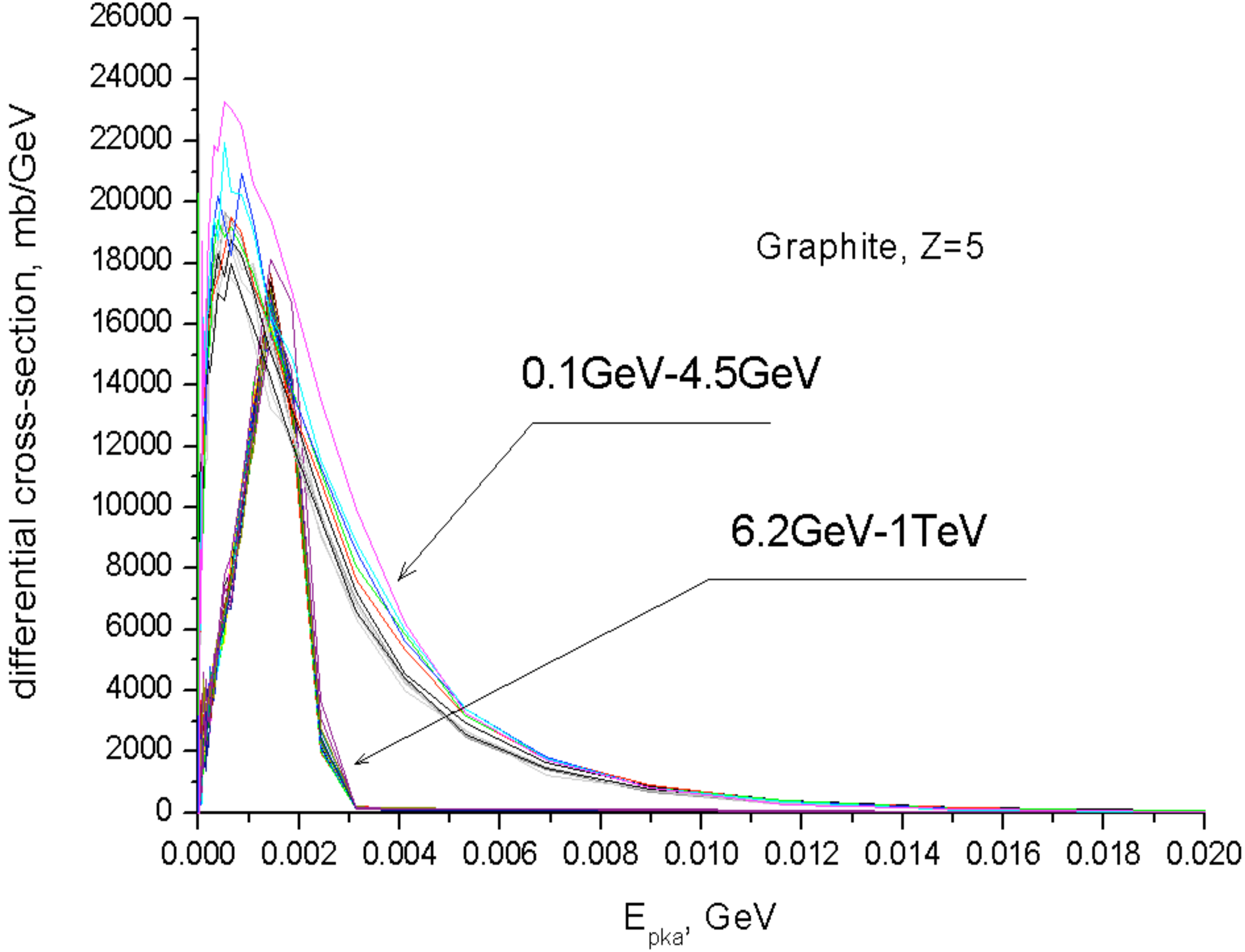
Differential cross-section of energy transfer to recoil atom



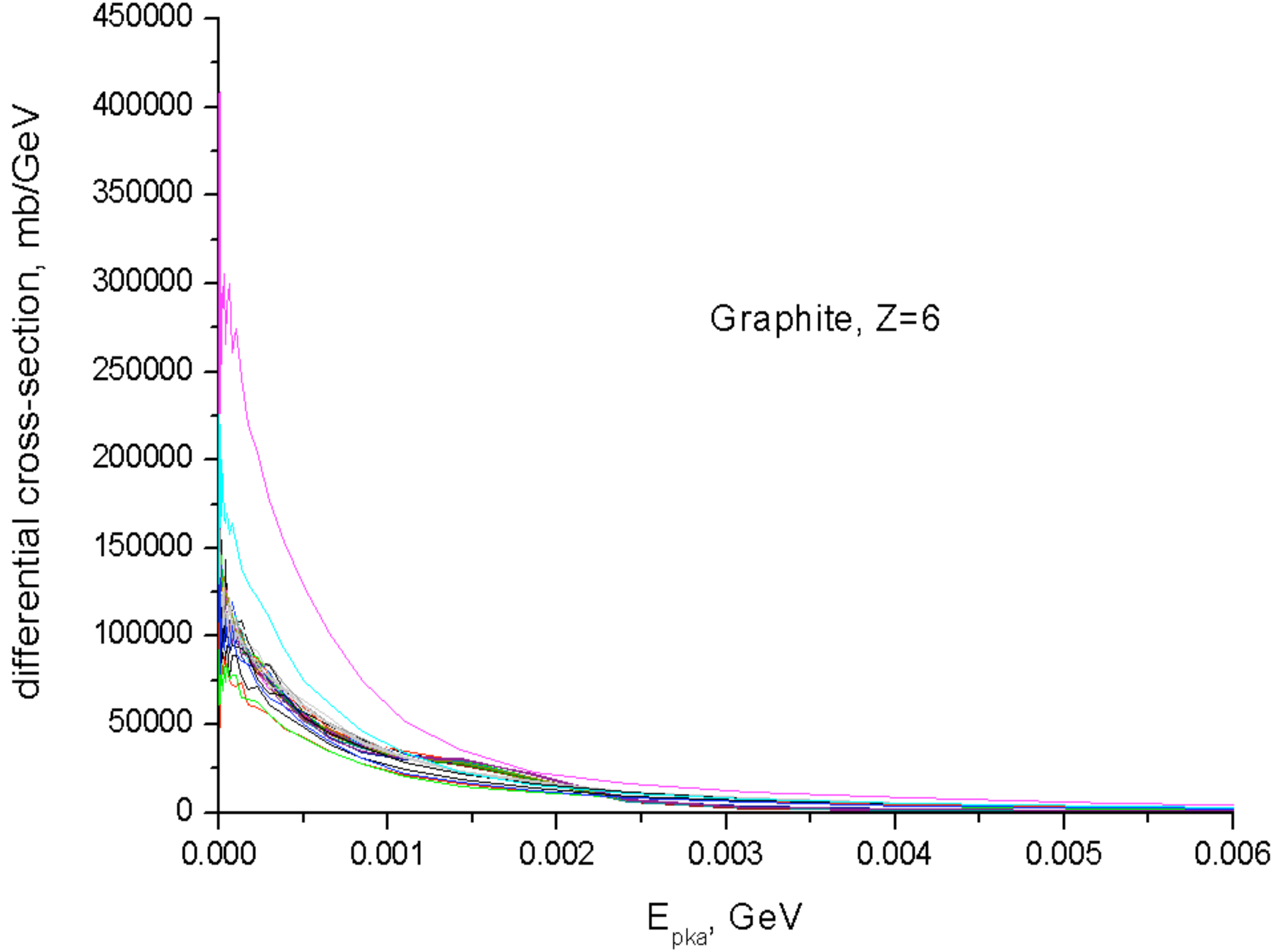
Differential cross-section of energy transfer to recoil atom



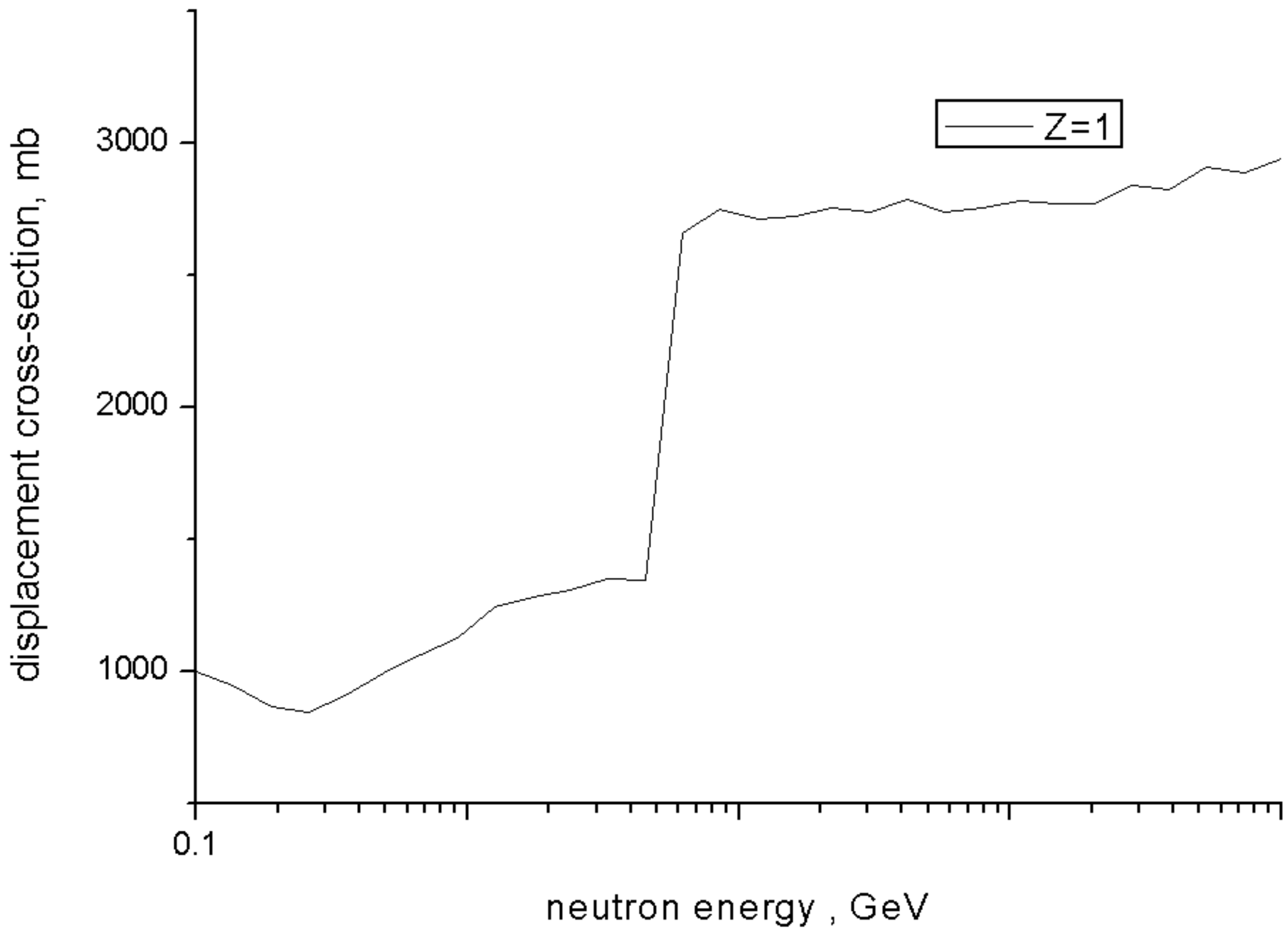
Differential cross-section of energy transfer to recoil atom



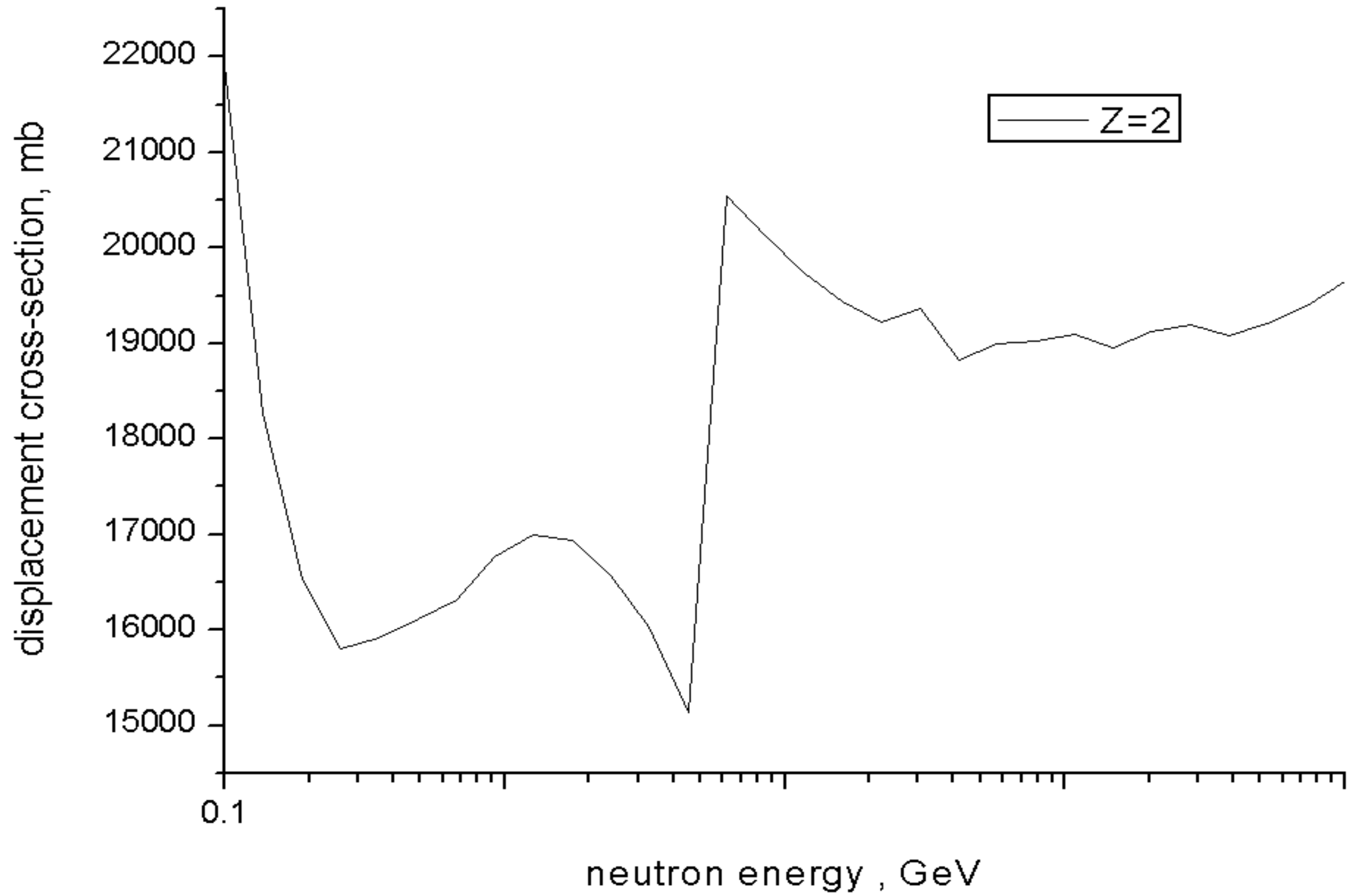
Differential cross-section of energy transfer to recoil atom



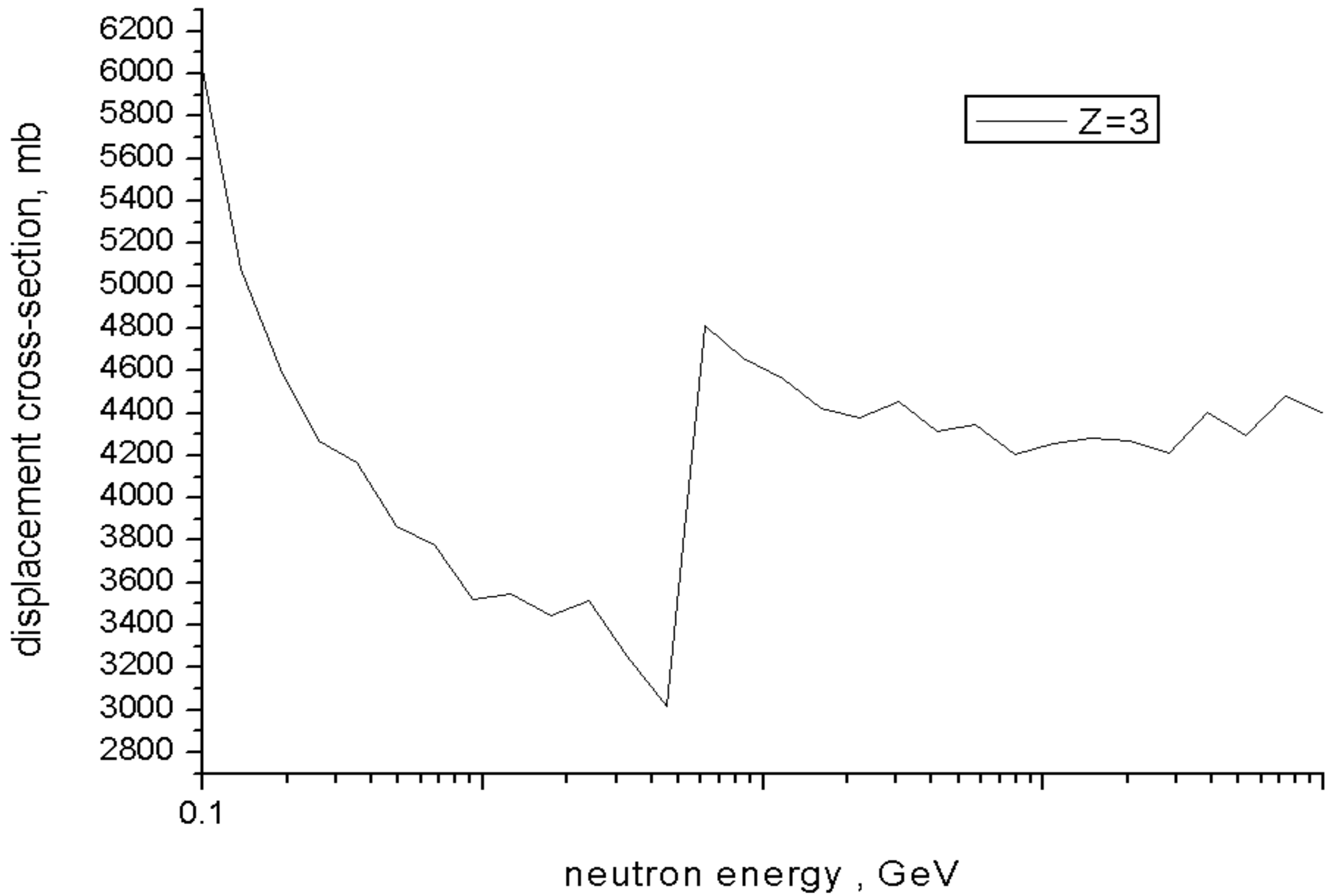
Displacement Cross Section in C for fission product (Z = 1)



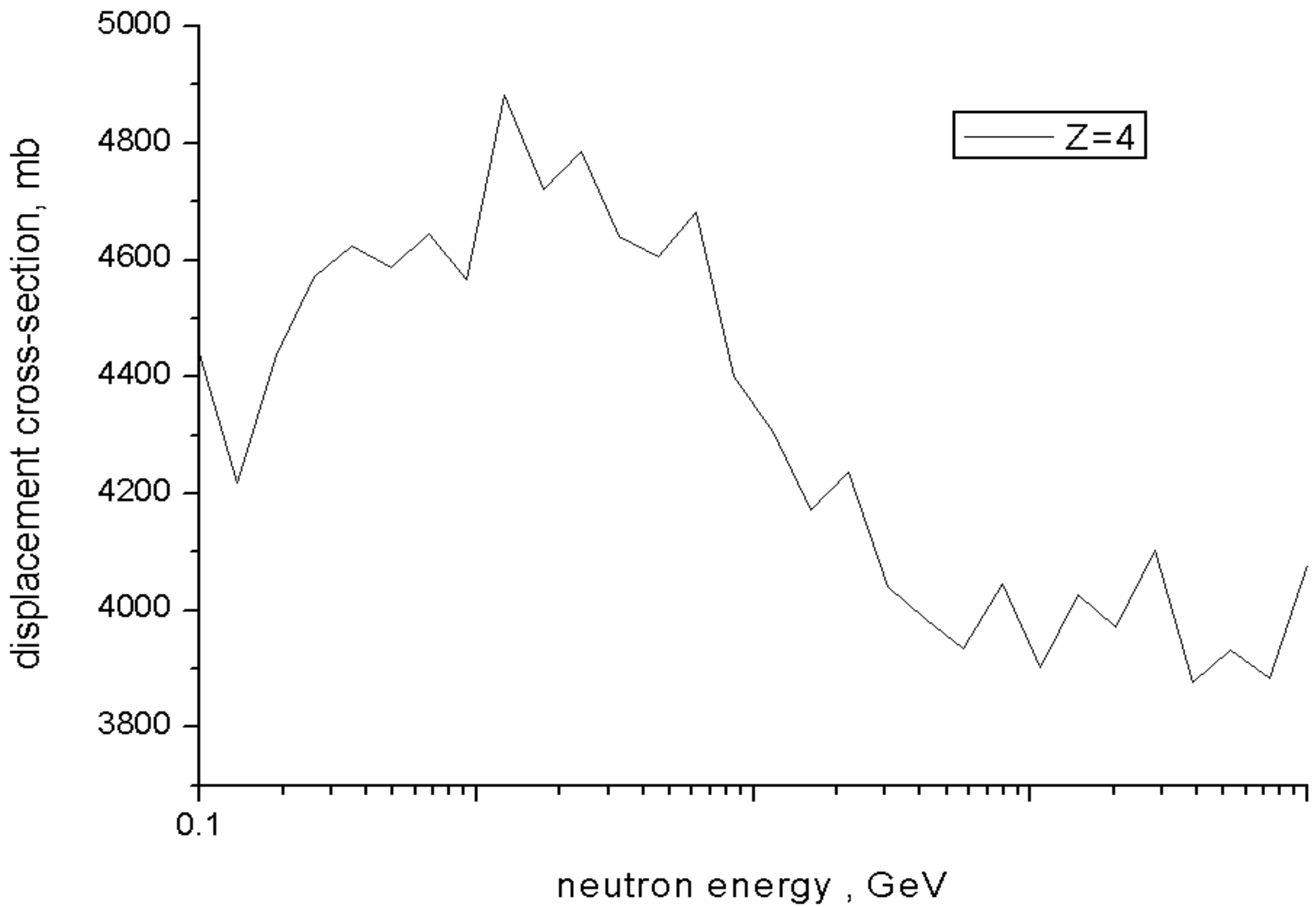
Displacement Cross Section in C for fission product (Z = 2)



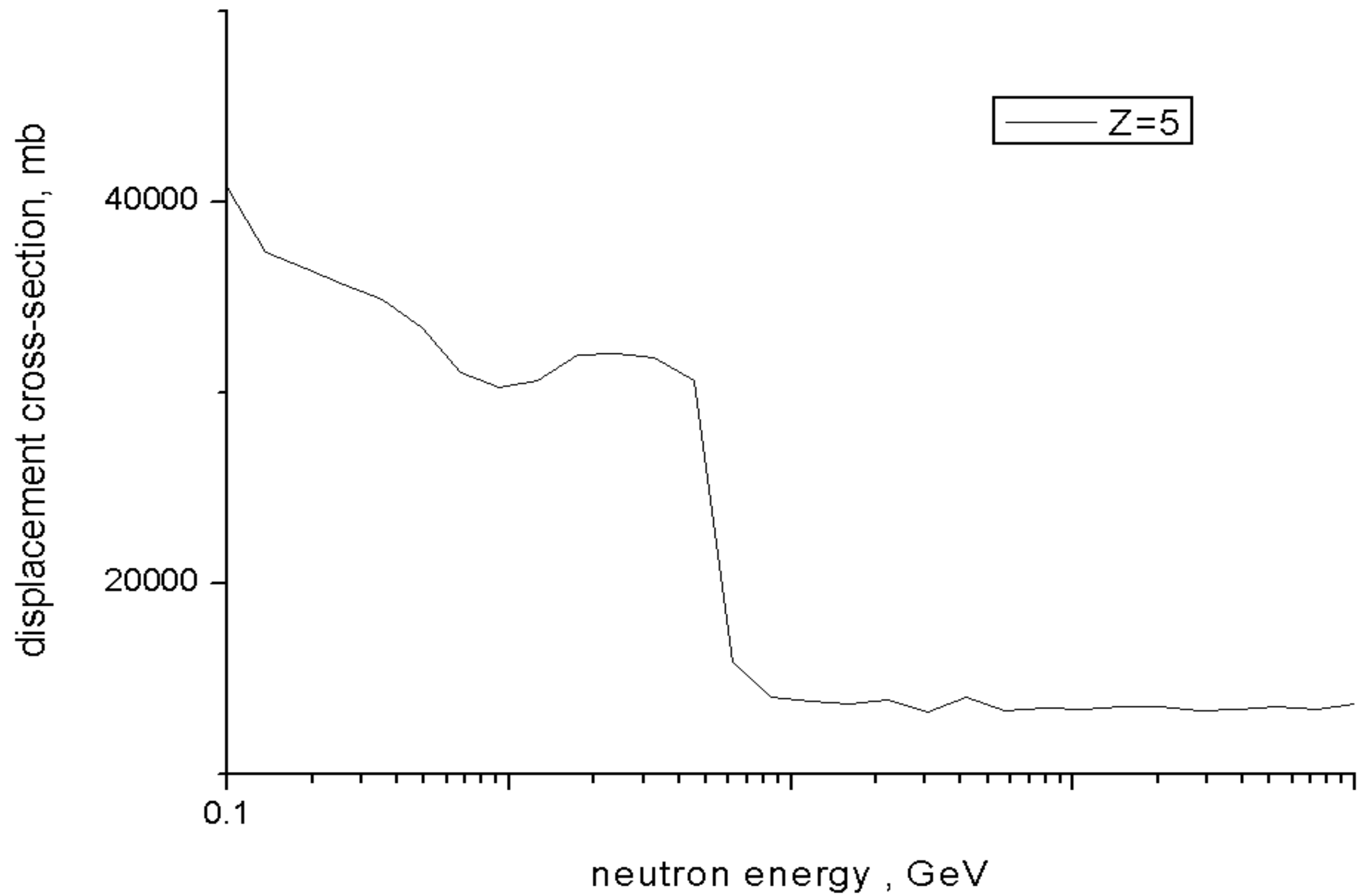
Displacement Cross Section in C for fission product (Z = 3)



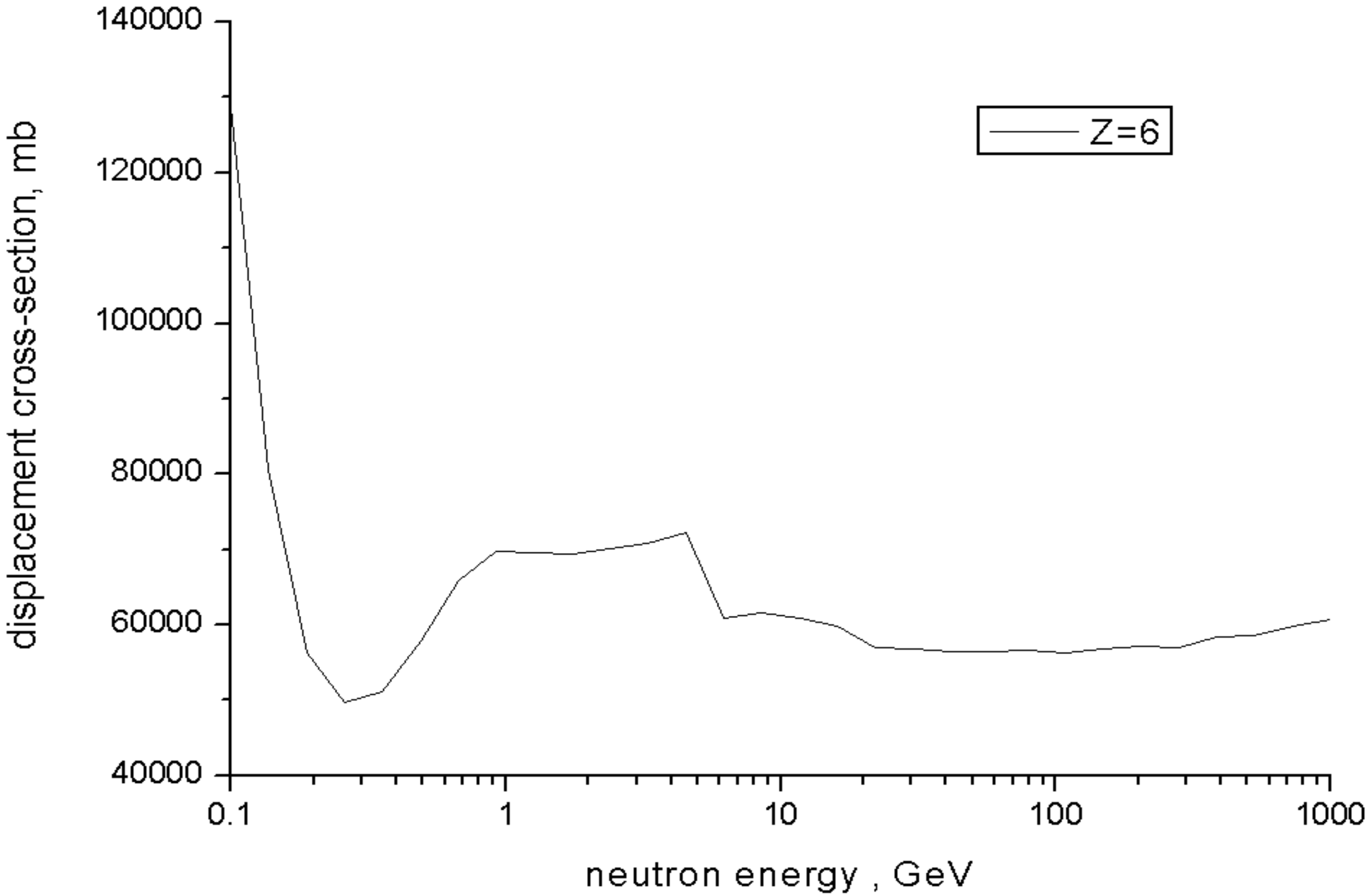
Displacement Cross Section in C for fission product (Z = 4)



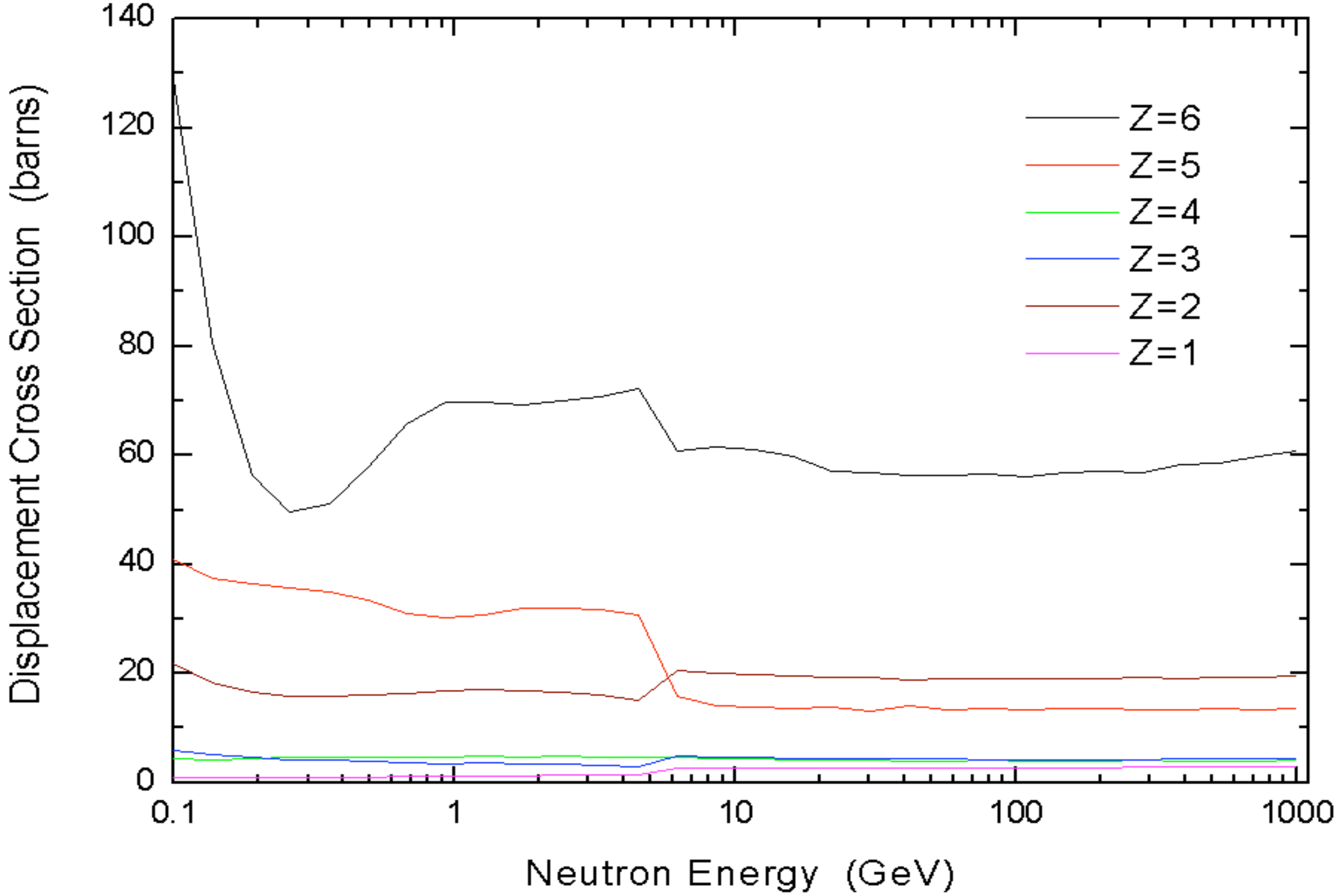
Displacement Cross Section in C for fission product (Z = 5)



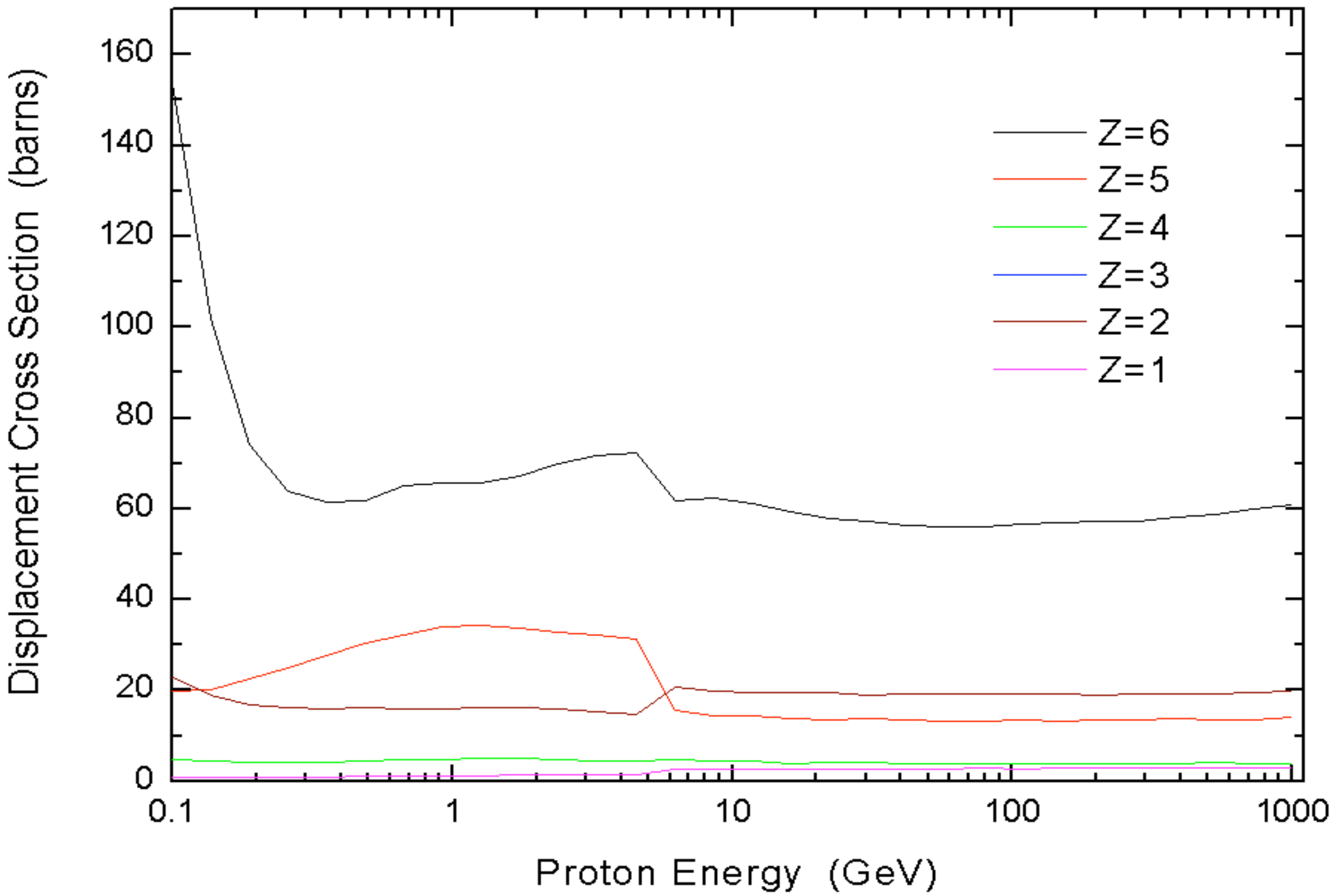
Displacement Cross Section in C for fission product (Z = 6)



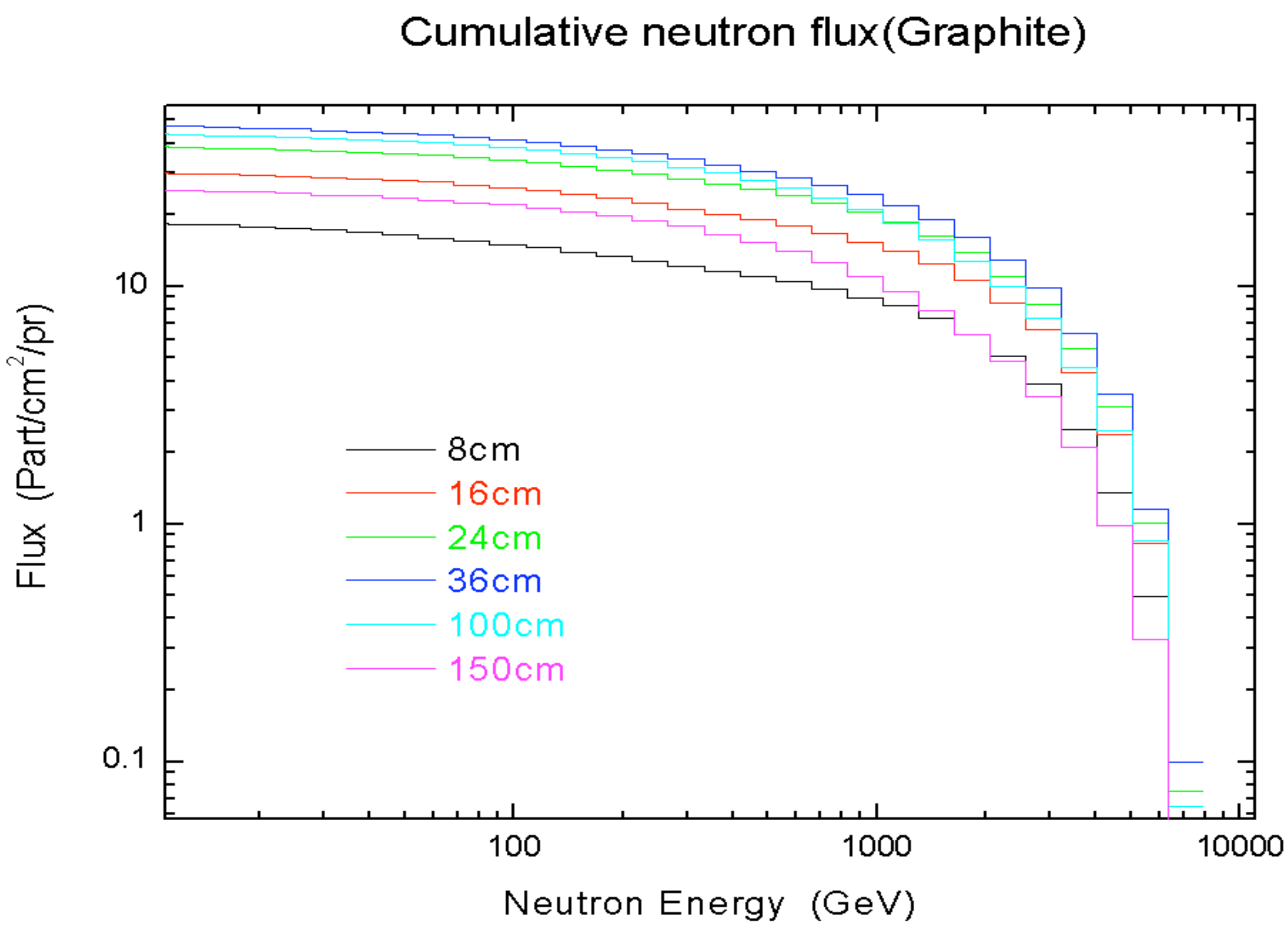
Displacement Cross Section in C for different fission products (z)



Displacement Cross Section in C for different fission product (z)

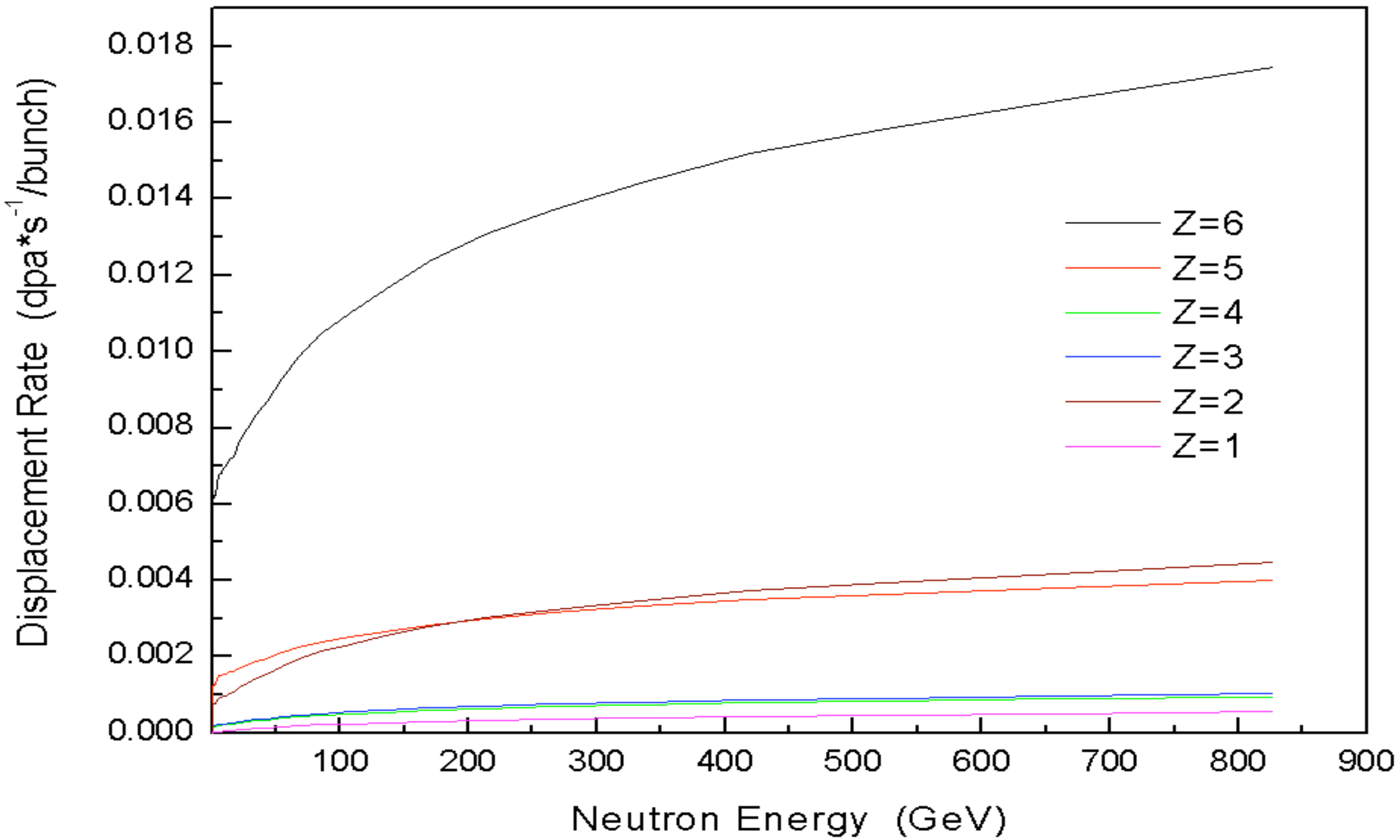


Neutron Energy Spectrum in Graphite near 7 TeV proton beam

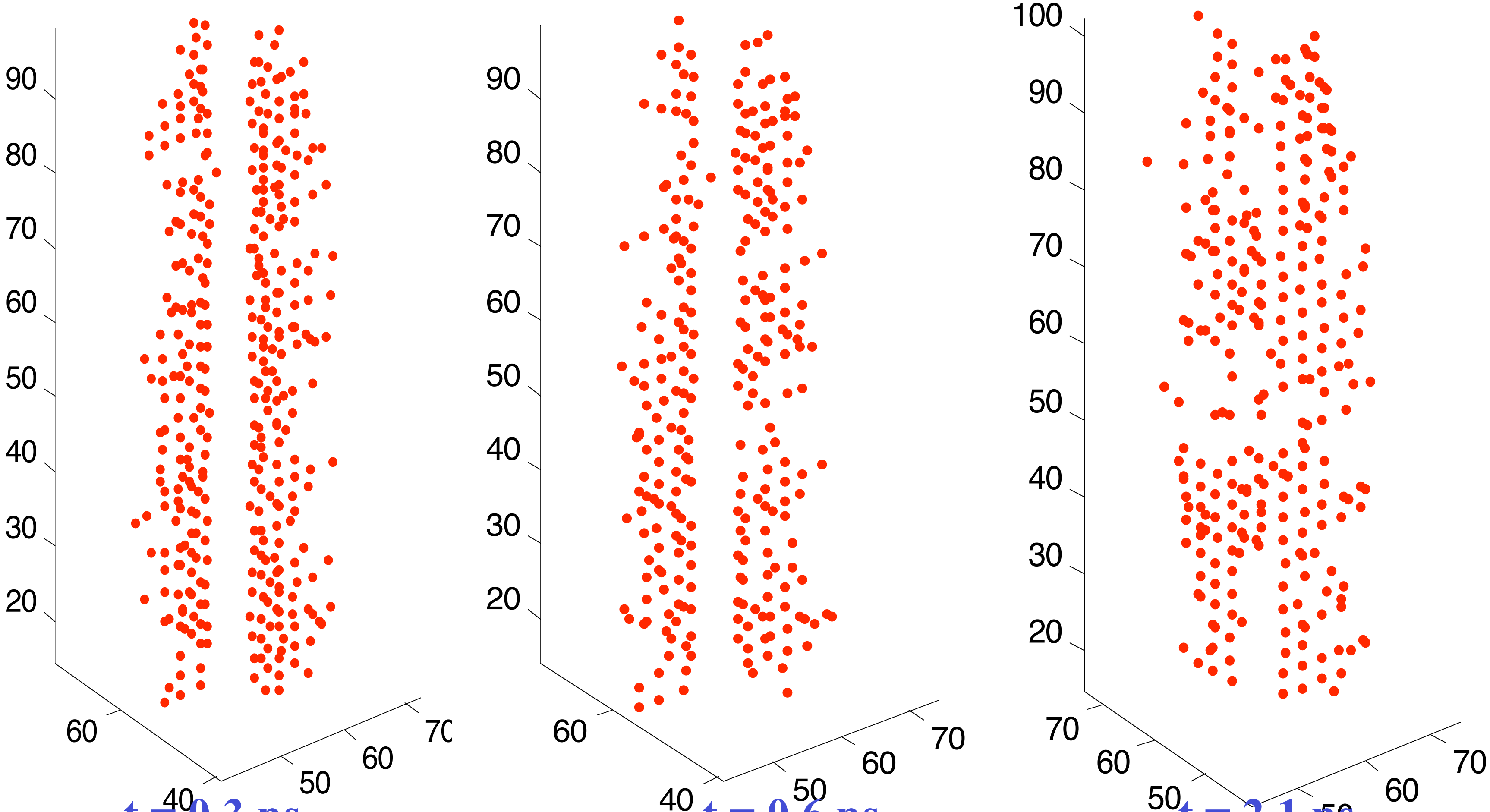


Displacement Generation Rate for Point Defects in C near 7 TeV Proton Beam per one bunch on L=8 cm

1 bunch = 1.1*10E11 pr., τ =26 ns



The results of numerical simulations for the spatial distribution of displaced point defects produced in proton beam area by the shock wave initiated by an ionization at the temperature T=300K at the three different simulation times: t1 =0.3 ps, t2 = 0.6 ps and t3 = 2.1 ps.



t = 0.3 ps   t = 0.6 ps   t = 2.1 ps

Summary

Theoretical models and computer tools are developed for investigations of radiation damage formation: **point defects, cascades and sub-cascades** near a 7 TeV proton beam in collimator materials: Cu and Graphite, taking into account electronic excitation, energy loss, elastic and inelastic collisions in materials induced by interaction of 7 TeV proton beam with collimator materials and data obtained from FLUKA program.