On the Deflection of High-Energy Negatively Charged Particles by Means of Bent Crystals

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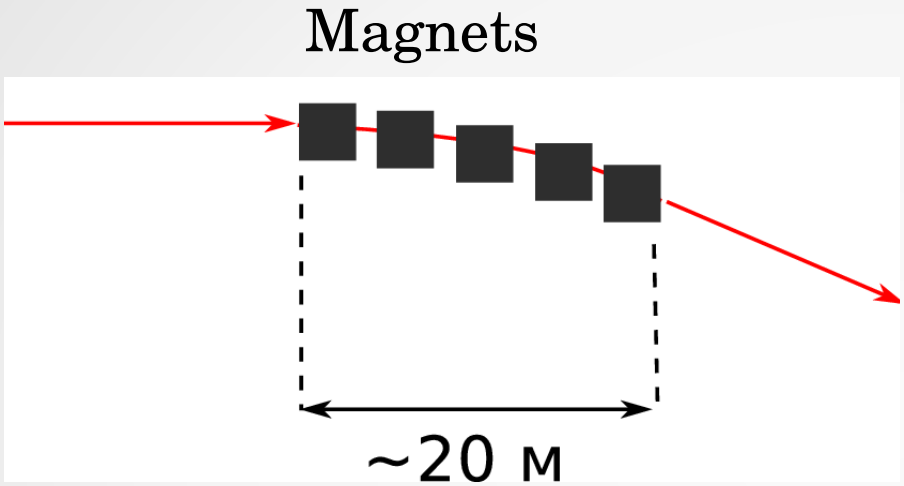
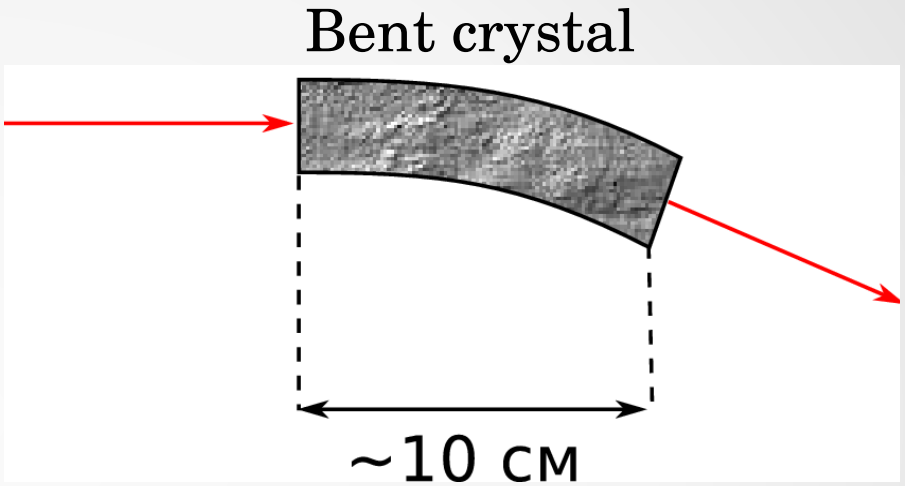
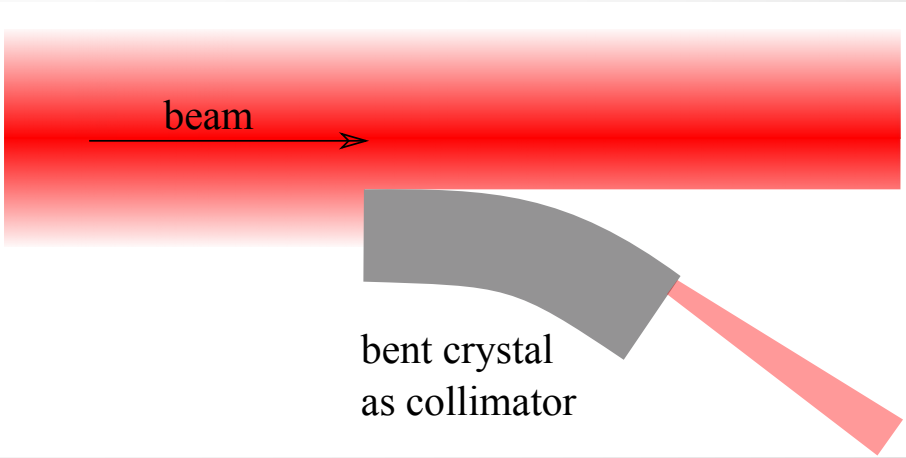
Charged particle beam deflection



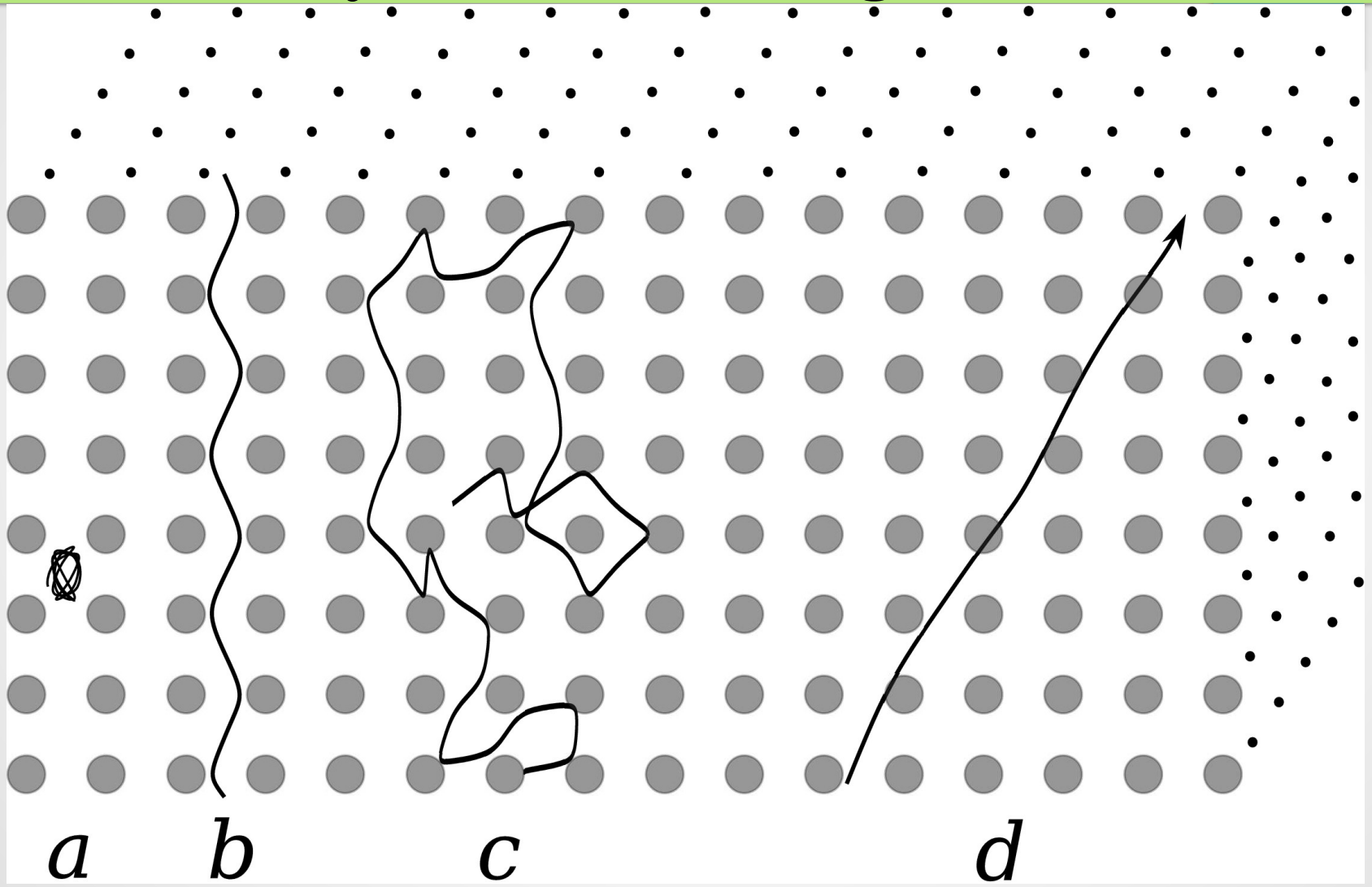


Advantages of bent crystals in front of magnets:

- compact size
- do not need electric power consumption
- do not need cooling



Regimes of charged-particle motion in the field of crystal atomic strings



a) axial channeling

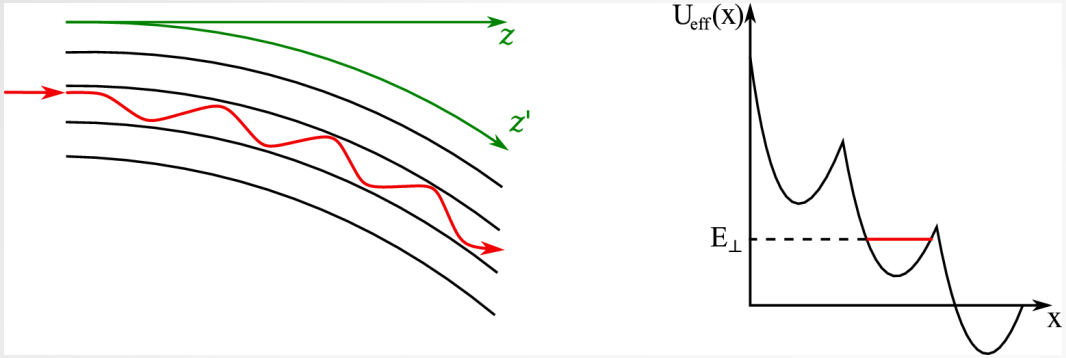
b) planar channeling

c) stochastic scattering

d) strongly above-barrier motion

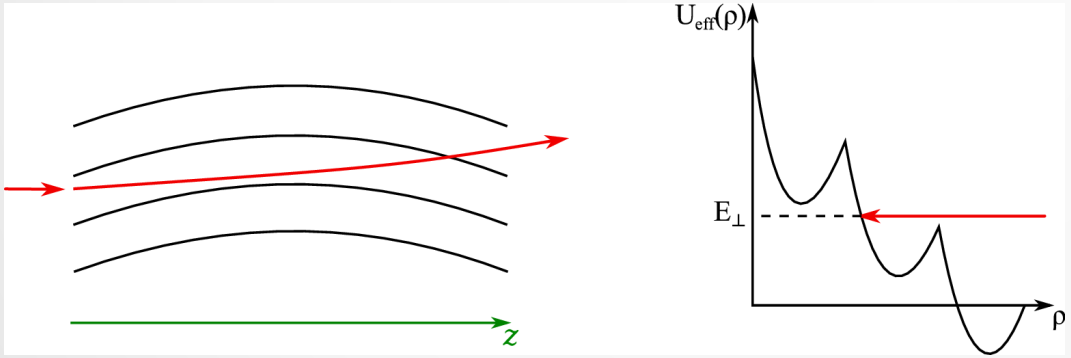
Mechanisms of deflection of charged particles by a bent crystal

- Planar channeling (*E.N. Tsyganov, 1976*)



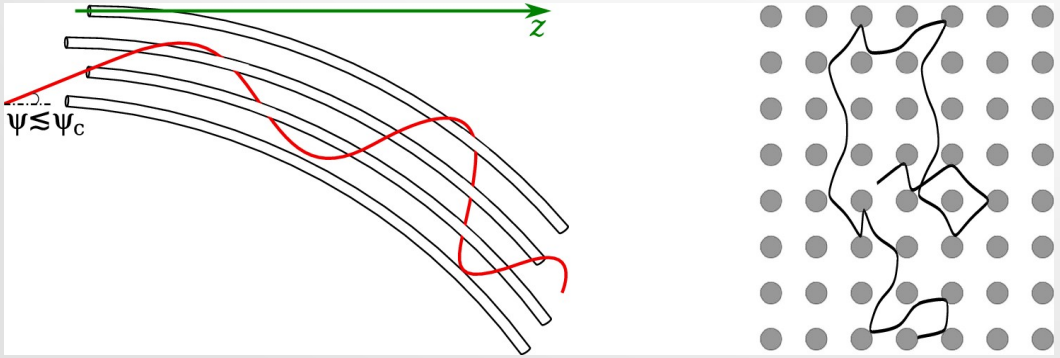
1979 — JINR
1980 — CERN

- Volume reflection (*A.M. Taratin, S.A. Vorobiev, 1987*)



2006 — IHEP
2006 — PNPI
2007 — CERN

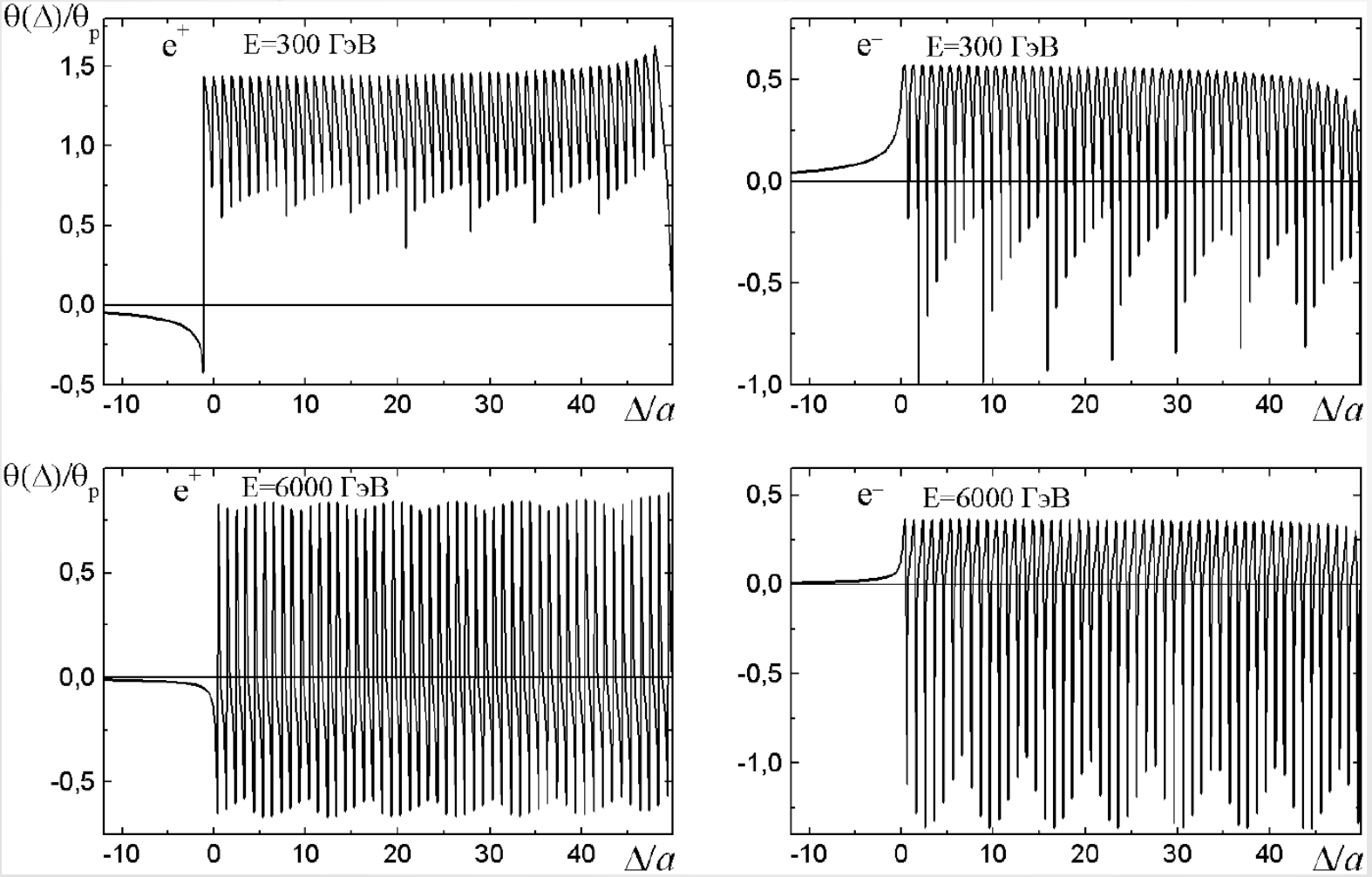
- Stochastic deflection mechanism (*A.A. Grinenko, N.F. Shul'ga, 1991*)



2008 — CERN, protons
2009 — CERN, π^--mesons

Volume reflection

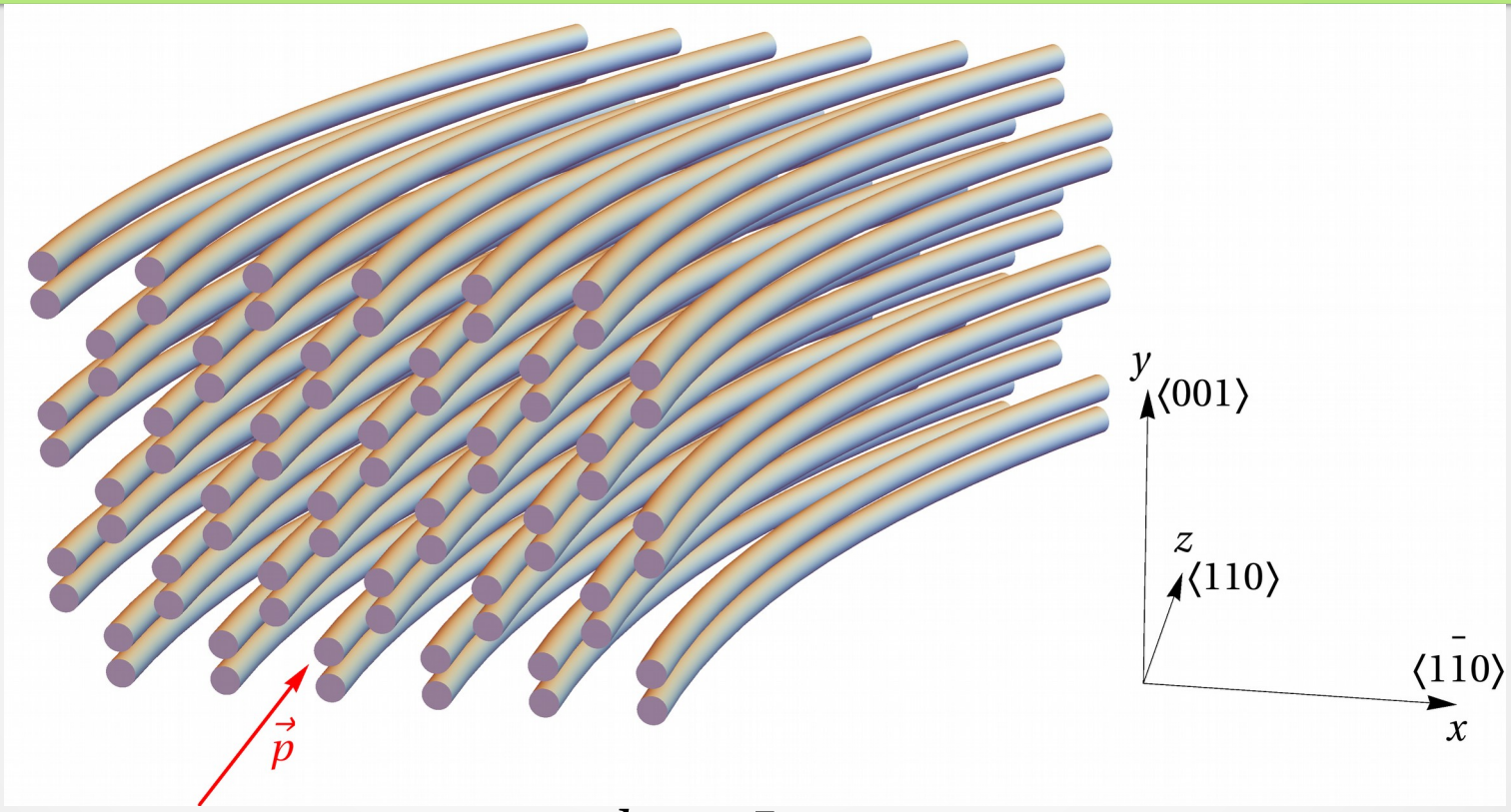
- *V.A. Maisheev, PRSTAB 10 (2007) 84701.*
- *M.V. Bondarenco, Phys. Rev. A 82 (2010) 42902.*
- *N.F. Shul'ga, V.I. Truten', V.V. Boyko, Visn. Khark. Nat. Univ. 916 (2010) 42.*



$$\frac{R}{R_c} \gg 1$$

$$\frac{R}{R_c} < 1$$

Stochastic deflection mechanism



Greenenko-Shul'ga criterion: $\frac{l}{R\psi_c}\frac{L}{R\psi_c}<1$

R is crystal curvature radius;

ψ_c is the critical angle of axial channeling;

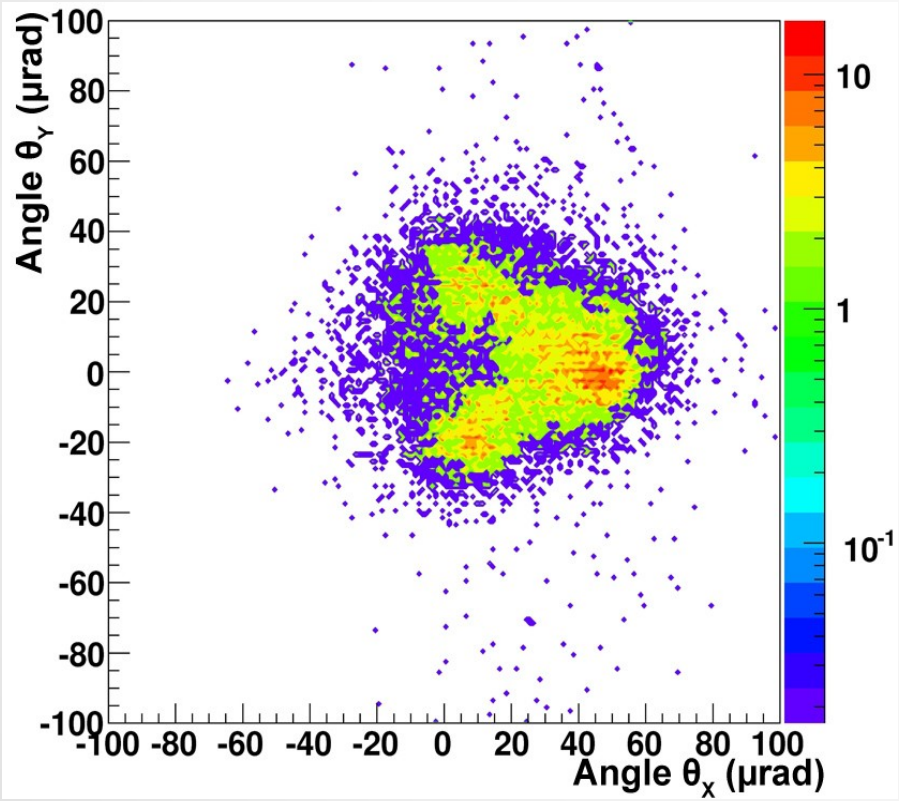
l is the mean free path between successive collisions with atomic strings;

L is the thickness of the crystal.

Stochastic mechanism of high energy charged particles deflection by bent Si crystal with R=40 m

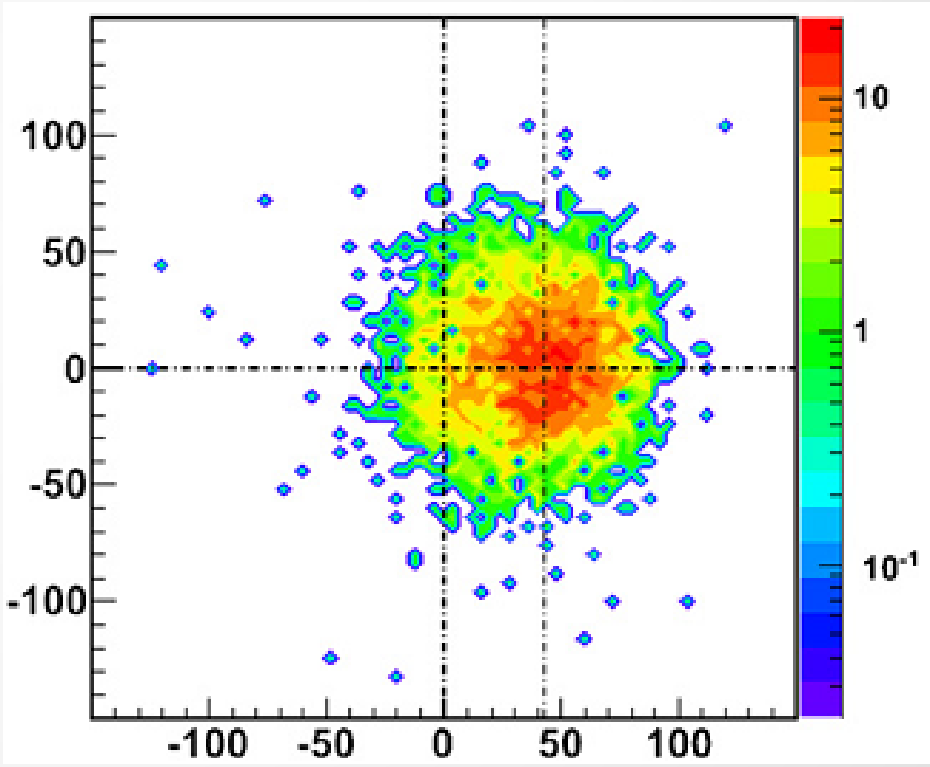
CERN experiment, UA9 collaboration

p^+, E=400 GeV



W. Scandale et al. Phys. Rev. Lett. 101 (2008), 164801

π^-, E=150 GeV



W. Scandale et al. Physics Letters B 680 (2009) 301

Influence of incoherent scattering on stochastic deflection of high-energy negative particle beams in bent crystals

$$\frac{d}{dz}\overline{\psi^2} = \frac{l}{R^2} + \frac{d}{dz}\overline{\psi_{inc}^2}$$

For $U_{str}(\rho) = U_0\left(\frac{a}{\rho}\right)^2$ $\quad l \approx \frac{1}{4\,n\,d\,a}\sqrt{\frac{E}{U_0}}$ $\quad \Rightarrow$ $\quad \overline{\psi^2} = \frac{l\,L}{R^2} + \overline{\psi_{inc}^2}$

$$\overline{\psi_{inc}^2} = \xi\,L$$

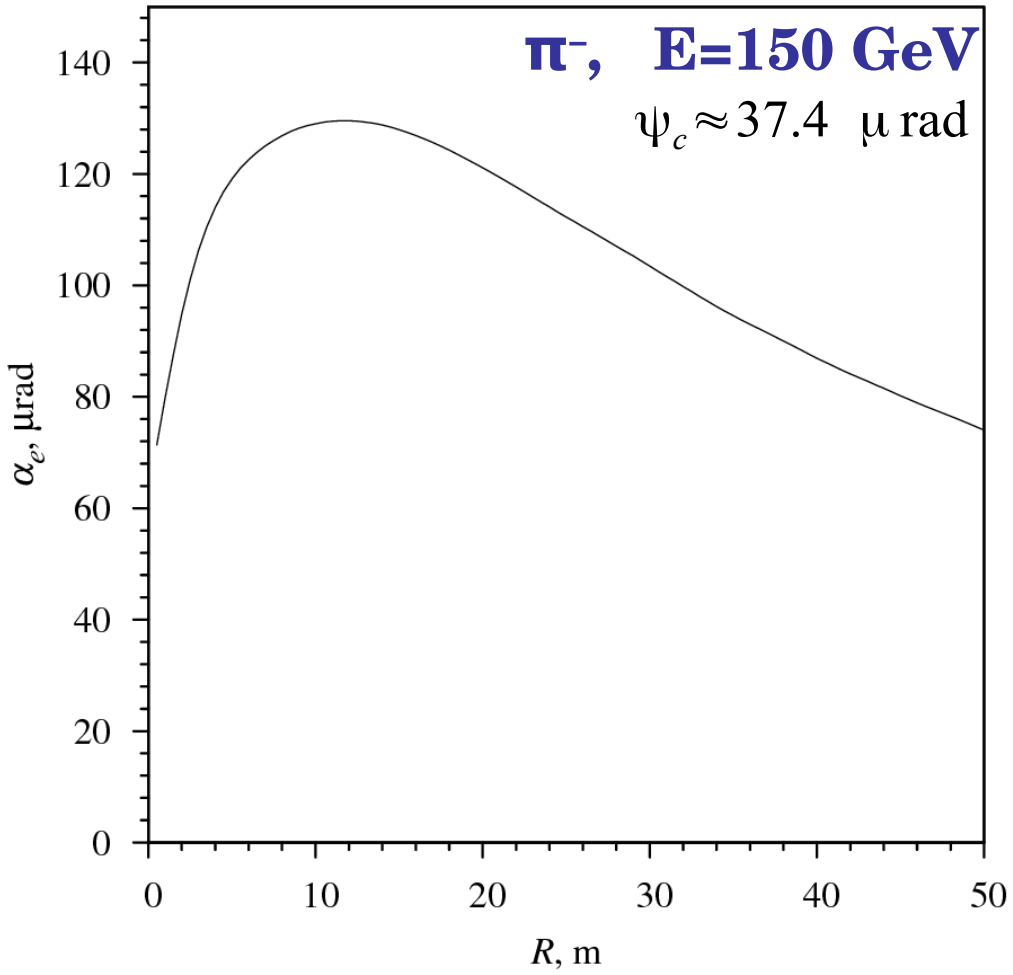
$$L_{st} = \frac{\psi_m^2}{l/R^2 + \xi}$$

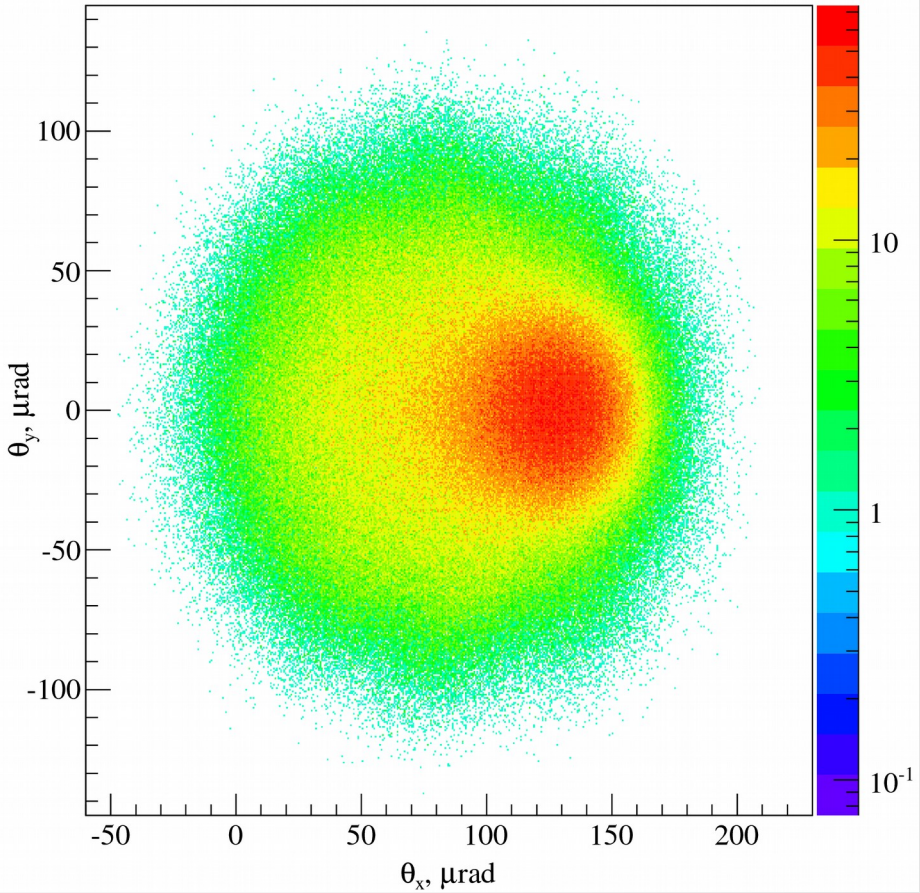
$$\alpha_{st} = \frac{L_{st}}{R} = \frac{\psi_m^2}{l/R + \xi\,R}$$

For $U_{str}(\rho) = U_0\left(\frac{a}{\rho}\right)^2$ $\quad R_{opt} = \sqrt{\frac{l}{\xi}}$

I.V. Kirillin, N.F. Shul'ga, L. Bandiera, V. Guidi, A. Mazzolari
Eur. Phys. J. C 77 (2017) 117

Influence of incoherent scattering on stochastic deflection of high-energy negative particle beams in bent crystals





π⁻, E=150 GeV, Si <110>, L=1.52 mm, R=11.7 m

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Dependence of the efficiency of stochastic mechanism of charged particle beam deflection on the particle energy

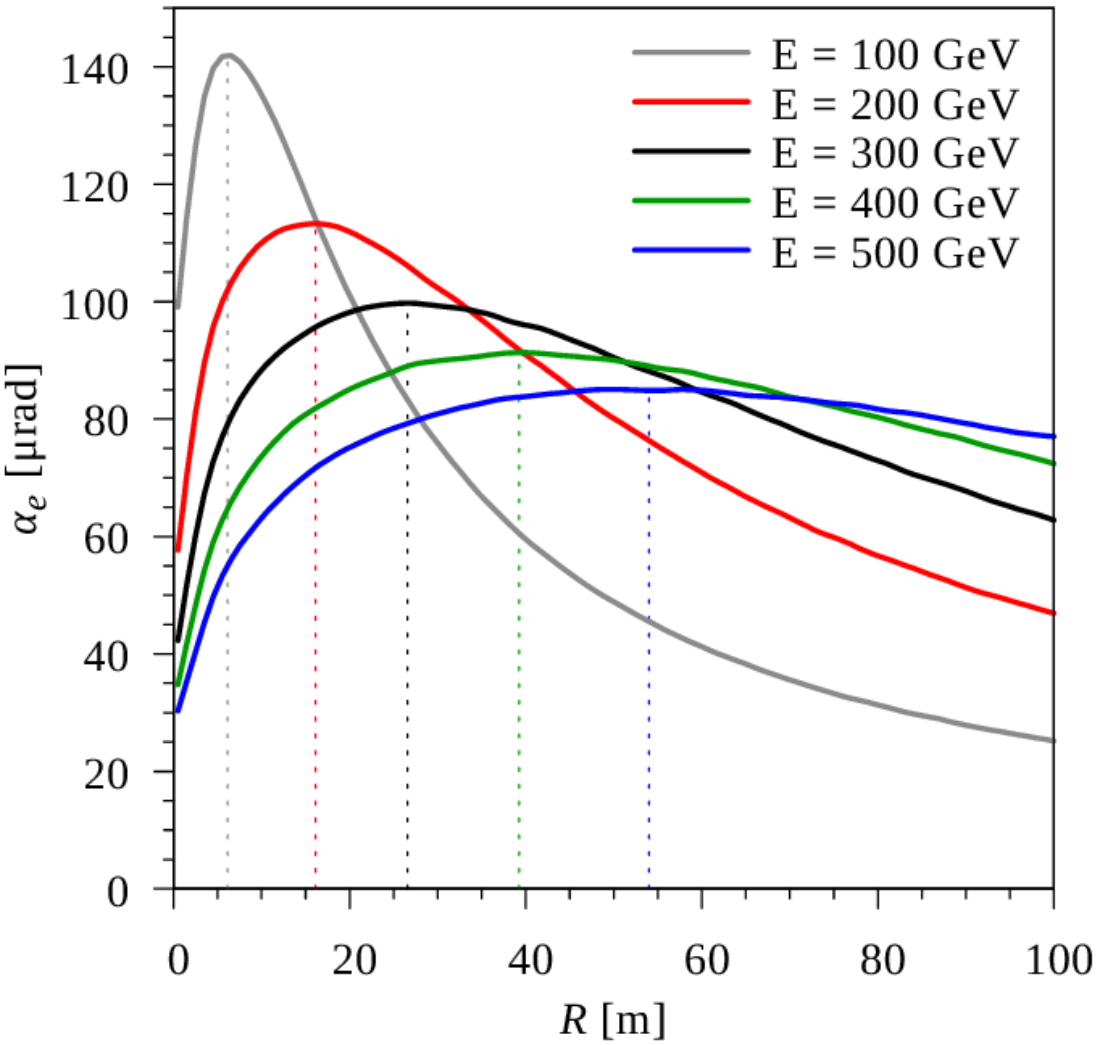
$$\alpha_{st} = \frac{\psi_m^2}{l/R + \xi R}$$

$$\psi_m^2 \propto \frac{1}{E}, \qquad \xi \propto \frac{1}{E^2}$$

For $U_{str}(\rho) = U_0 \left(\frac{a}{\rho}\right)^2$ $\qquad l \propto \sqrt{E}$

$$R_{opt} \propto \sqrt{\frac{l}{\xi}} \propto E^{5/4}$$

$$\alpha_e \propto \frac{E^{-1}}{E^{-3/4}} \propto E^{-1/4}$$

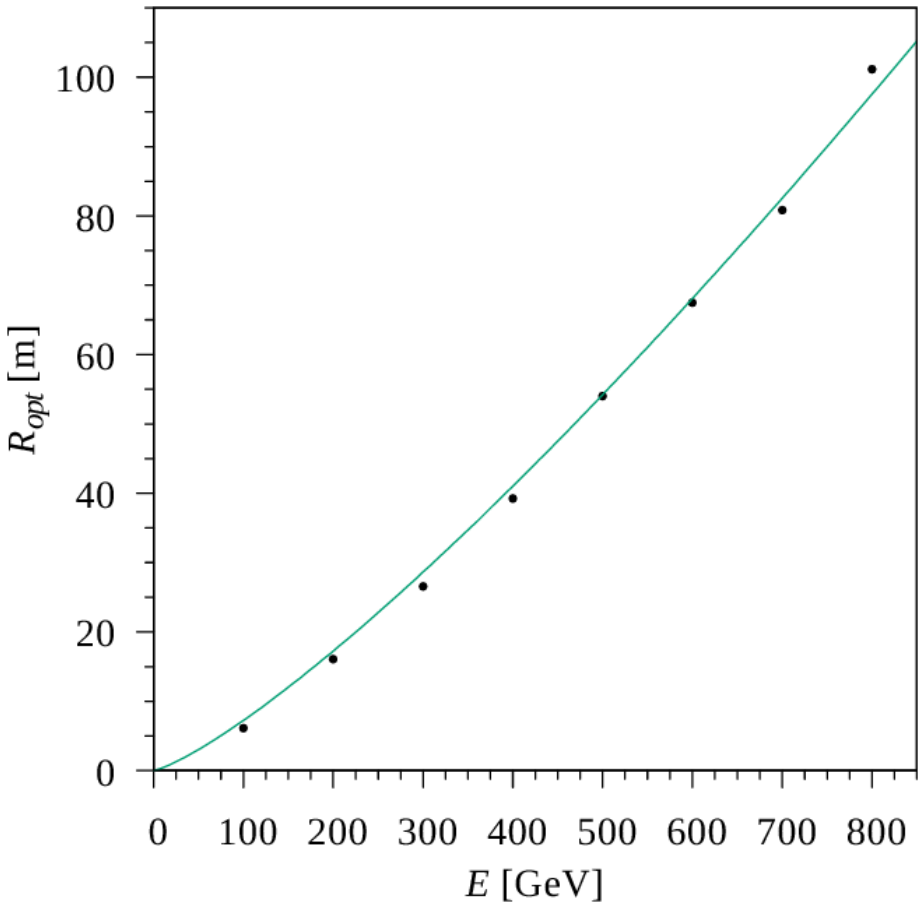


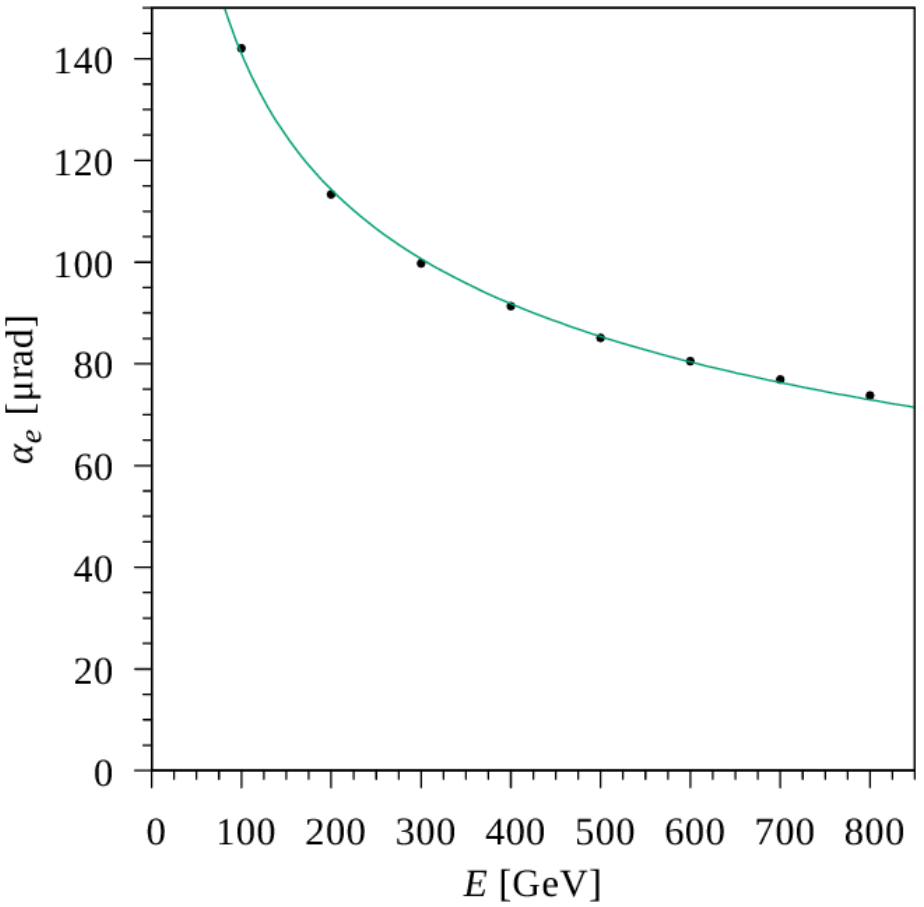
I.V. Kirillin, Probl. Atom. Sci. Tech. 68 (2017) 67

Dependence of the efficiency of stochastic mechanism of charged particle beam deflection on the particle energy

$$R_{opt} \propto \sqrt{\frac{l}{\xi}} \propto E^{5/4}$$

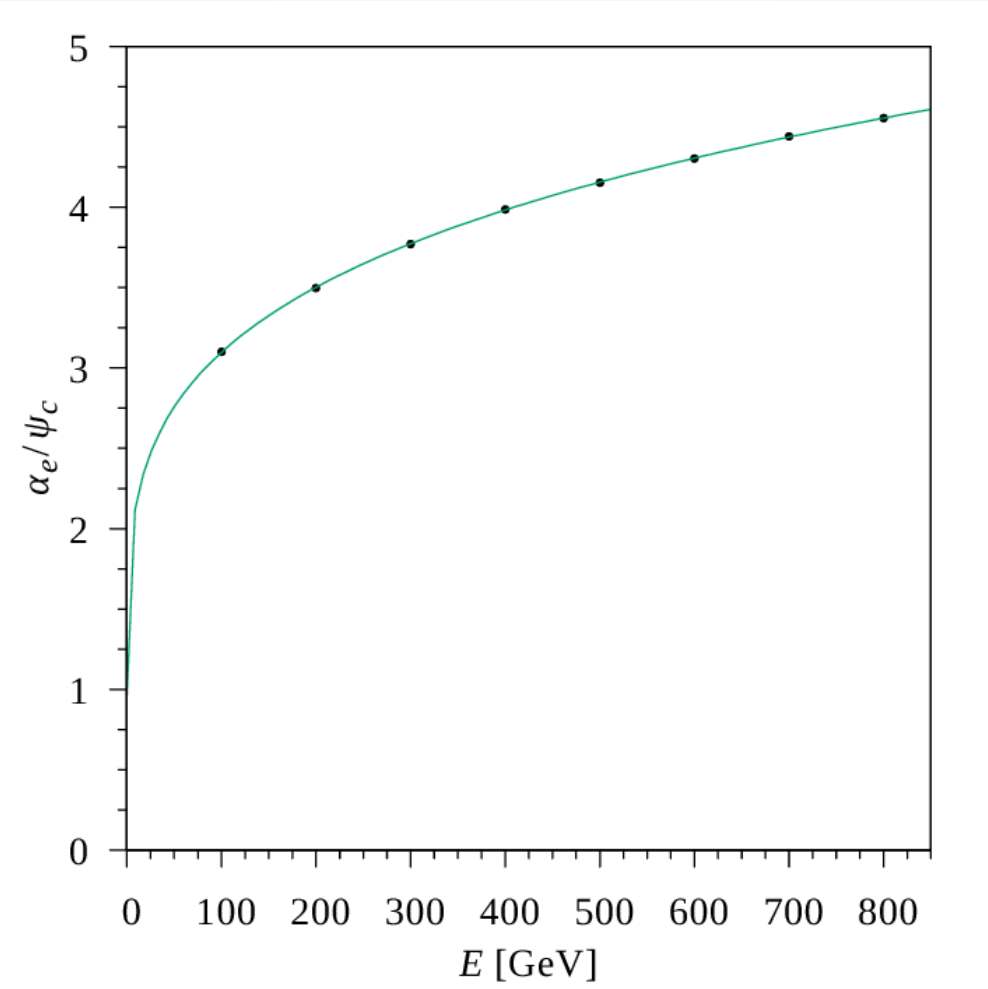
$$\alpha_e \propto E^{-1/4}$$





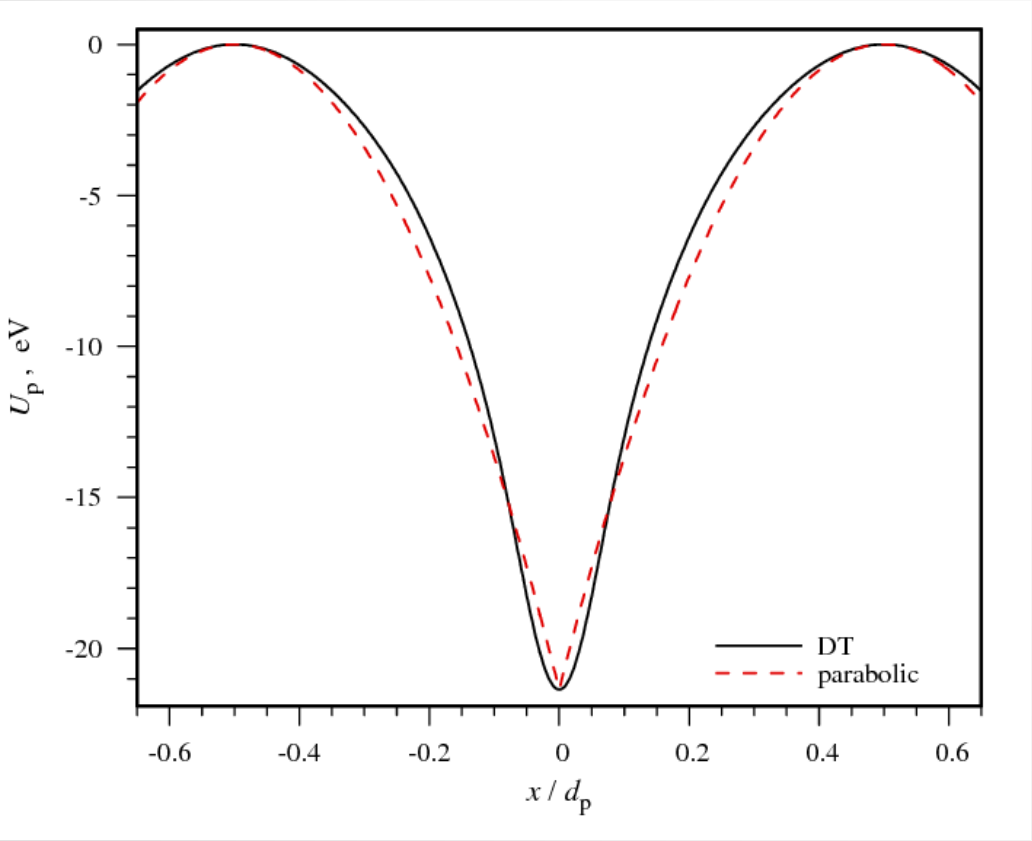
Dependence of the efficiency of stochastic mechanism of charged particle beam deflection on the particle energy

$$\alpha_e/\psi_c \propto E^{1/4}$$



Influence of incoherent scattering on planar channeling of high-energy negative particle beams in bent crystals

$$\frac{d^2x}{dt^2} = -\frac{c^2}{E}\frac{d}{dx}\left(U_p(x) + E\frac{x}{R}\right)$$



$$f = \left(1 - \sqrt{\frac{R}{R_c}}\right)\frac{1}{\sqrt{2\pi}\,\theta_0}\int_{-\theta_c}^{\theta_c}\exp\left(-\frac{\theta^2}{2\theta_0^2}\right)d\theta =$$

$$= \left(1 - \sqrt{\frac{R}{R_c}}\right)\mathrm{erf}\left(-\frac{\theta_c}{\sqrt{2}\,\theta_0}\right)$$

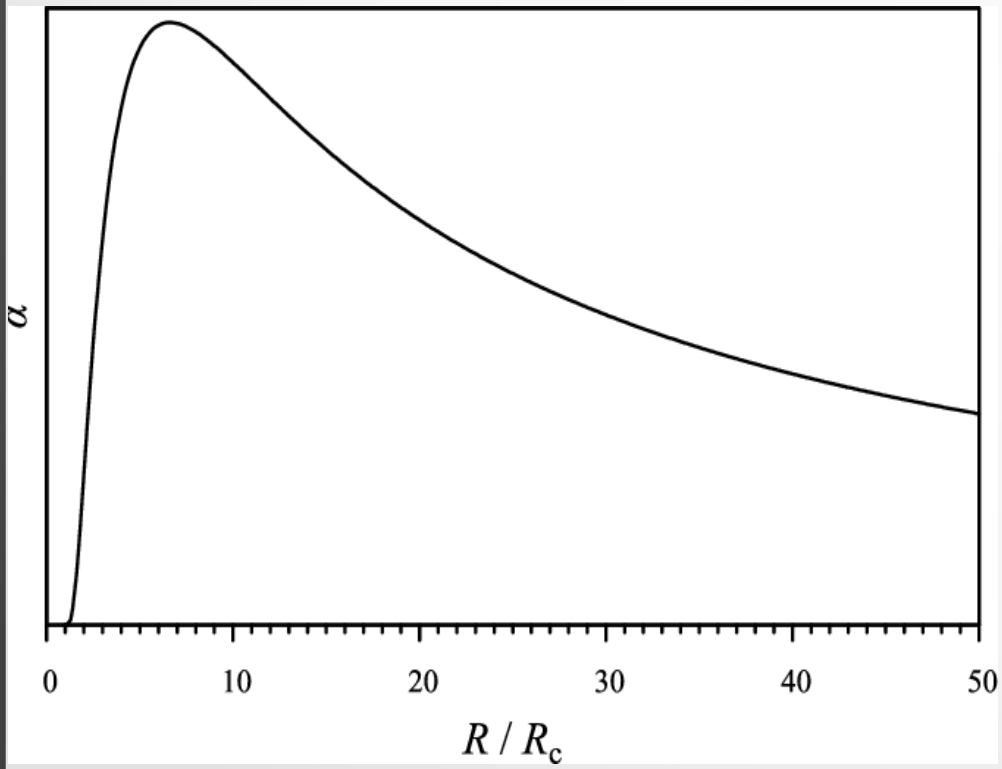
if $\theta_0 = \xi\sqrt{L}$, then

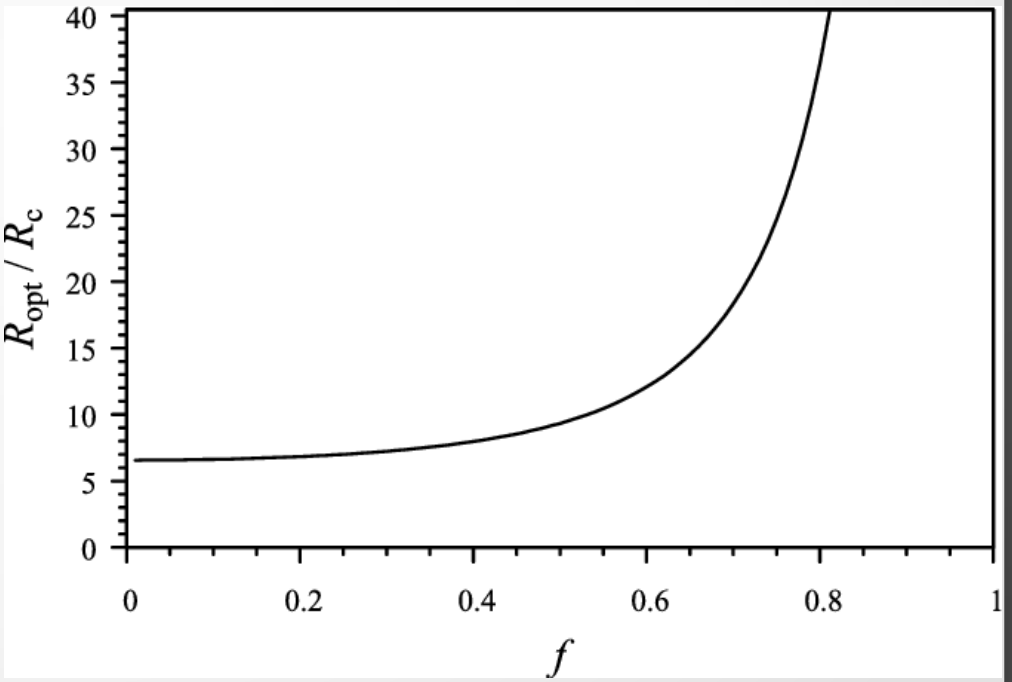
$$L = \frac{\theta_c^2}{2\xi^2\left(\mathrm{erf}^{-1}\left(\dfrac{f}{1-\sqrt{\dfrac{R_c}{R}}}\right)\right)^2}$$

Influence of incoherent scattering on planar channeling of high-energy negative particle beams in bent crystals

$$\alpha = \frac{L}{R} = \frac{\theta_c^2}{2\xi^2 R\left(\mathrm{erf}^{-1}\left(\frac{f}{1-\sqrt{\frac{R_c}{R}}}\right)\right)^2}, \qquad \theta_c = \sqrt{\frac{2U_0}{E}}\left(1-\frac{R_c}{R}\right)$$

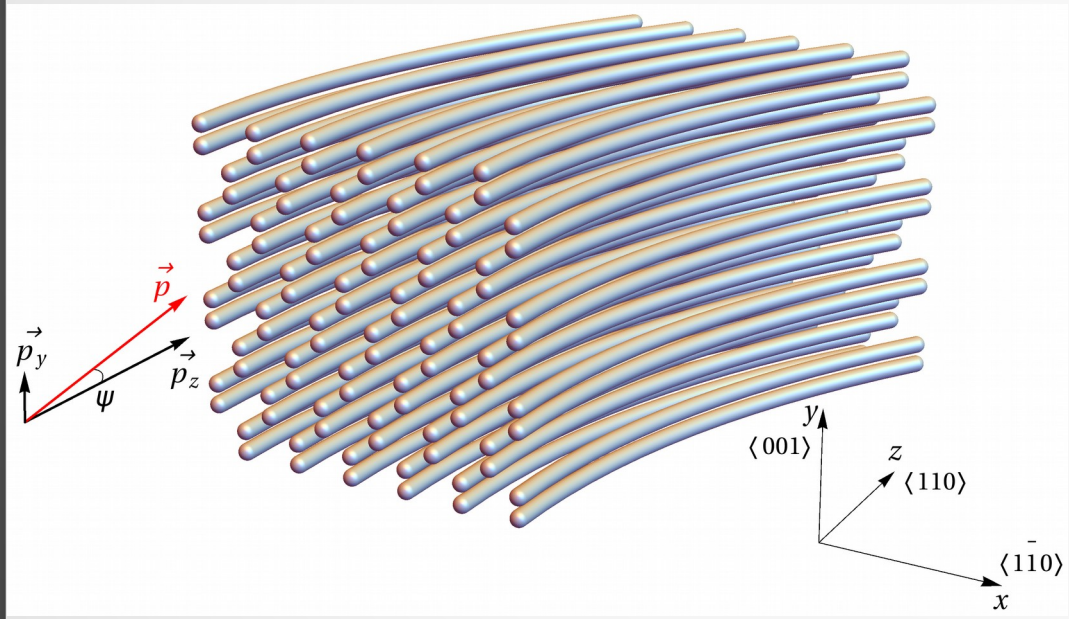
$$R = R_{\mathrm{opt}} \quad \Rightarrow \quad \frac{d\alpha}{dR} = 0$$

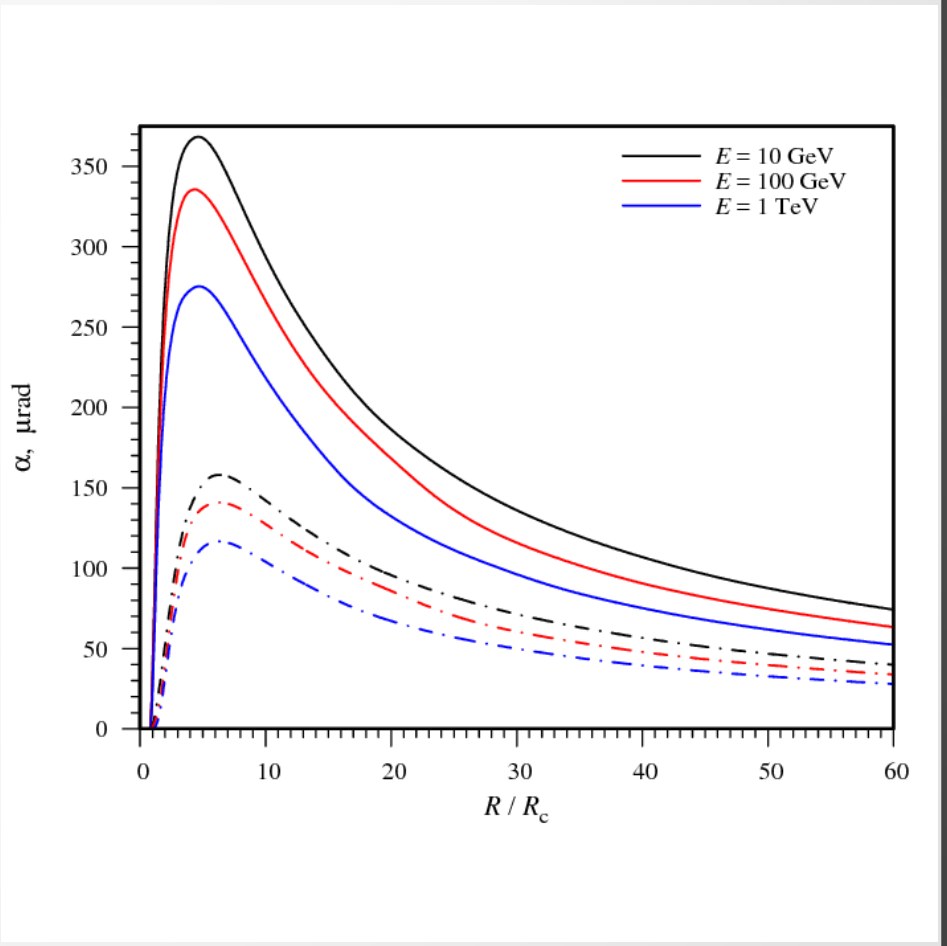




Influence of incoherent scattering on planar channeling of high-energy negative particle beams in bent crystals

π^-, Si (110)





Thank you for your attention!