STOCHASTIC MECHANISM OF 1-100 GeV/c CHARGED PARTICLES DEFLECTION BY A BENT CRYSTAL

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Radiation from Relativistic Electrons in Periodic Structures

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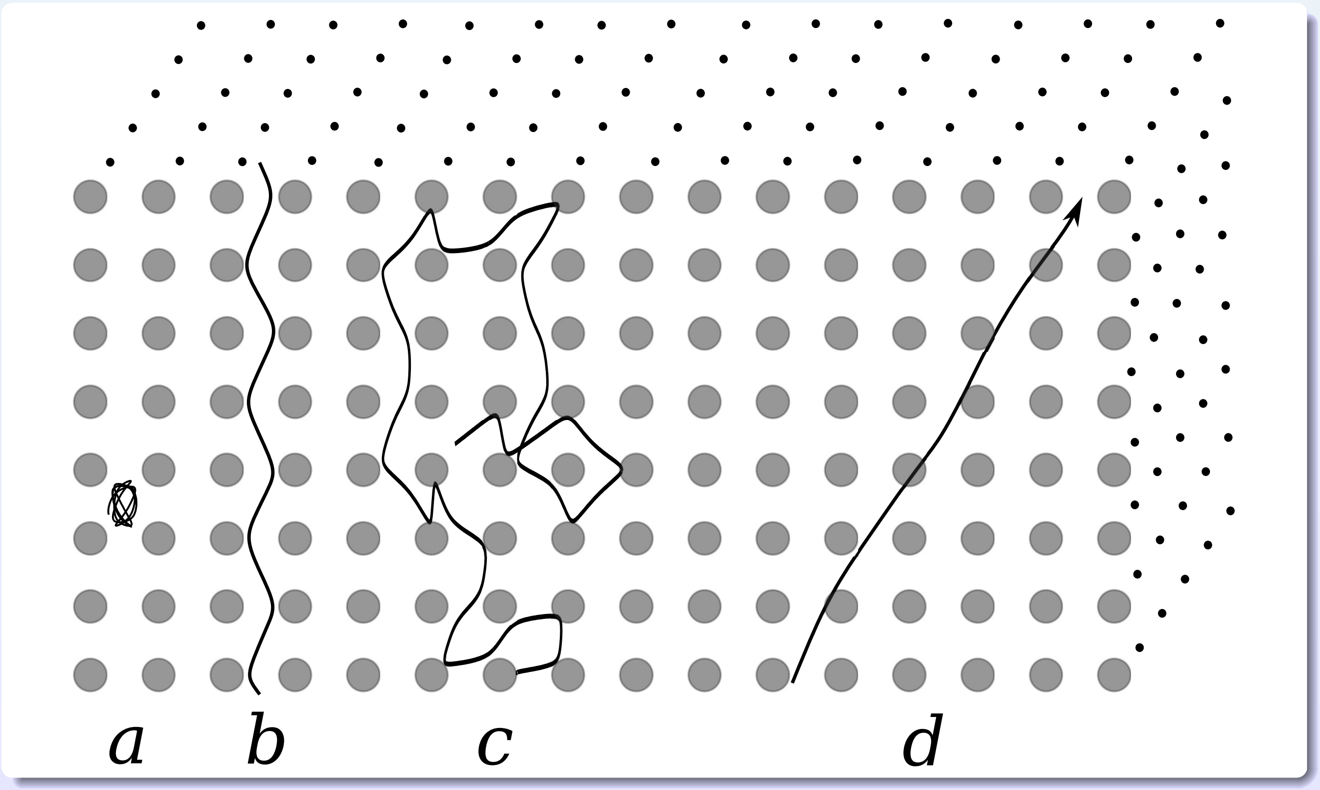
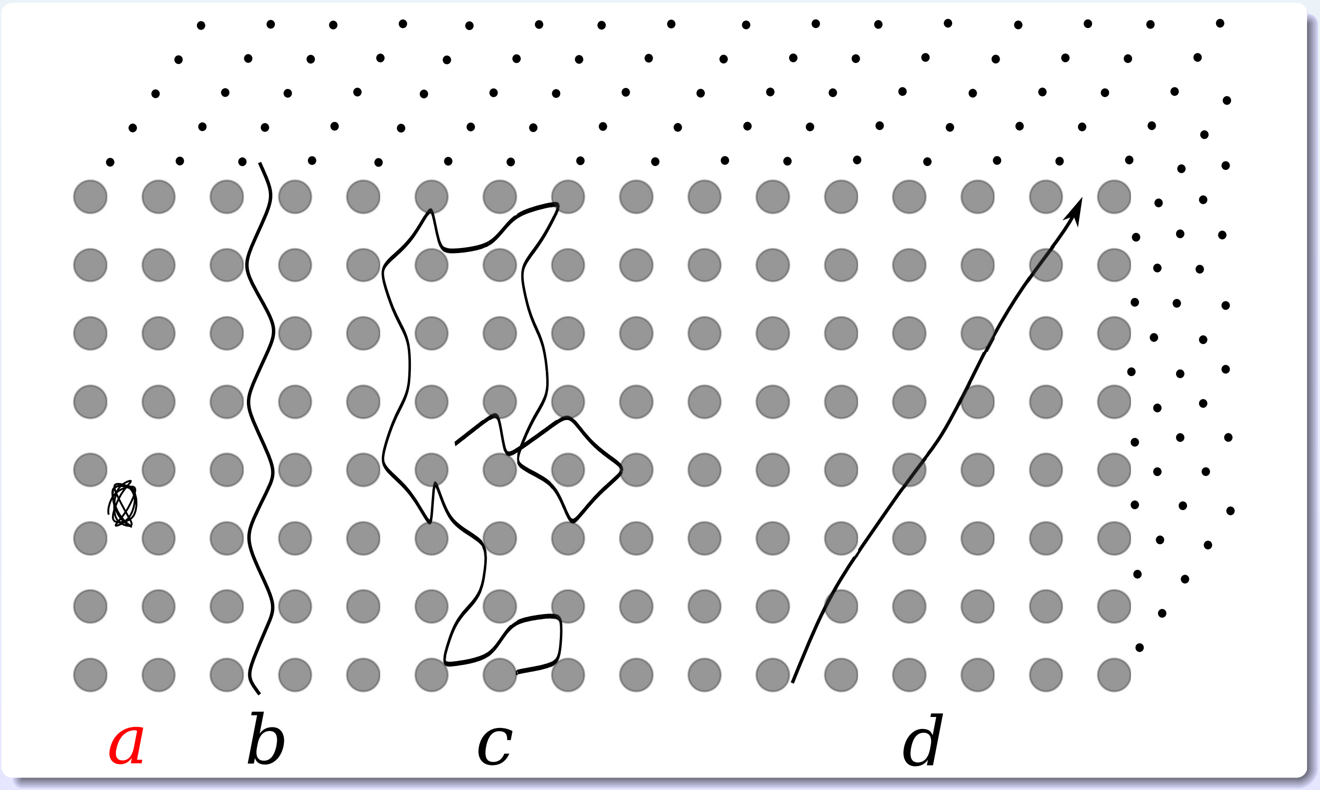
Mechanisms of fast charged particle motion in a crystal near one of crystal axes



Mechanisms of fast charged particle motion in a crystal near one of crystal axes

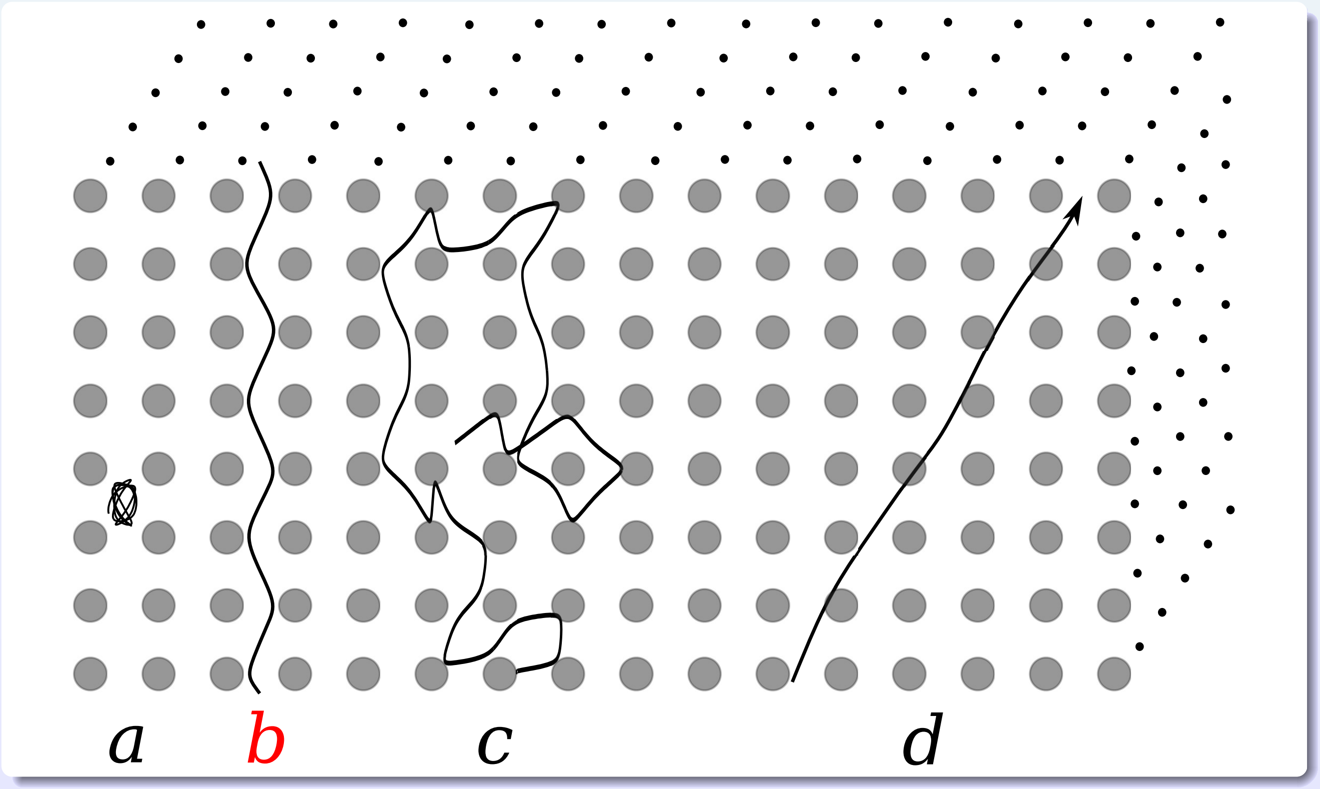
a) axial channeling;



Mechanisms of fast charged particle motion in a crystal near one of crystal axes

a) axial channeling;

b) planar channeling;

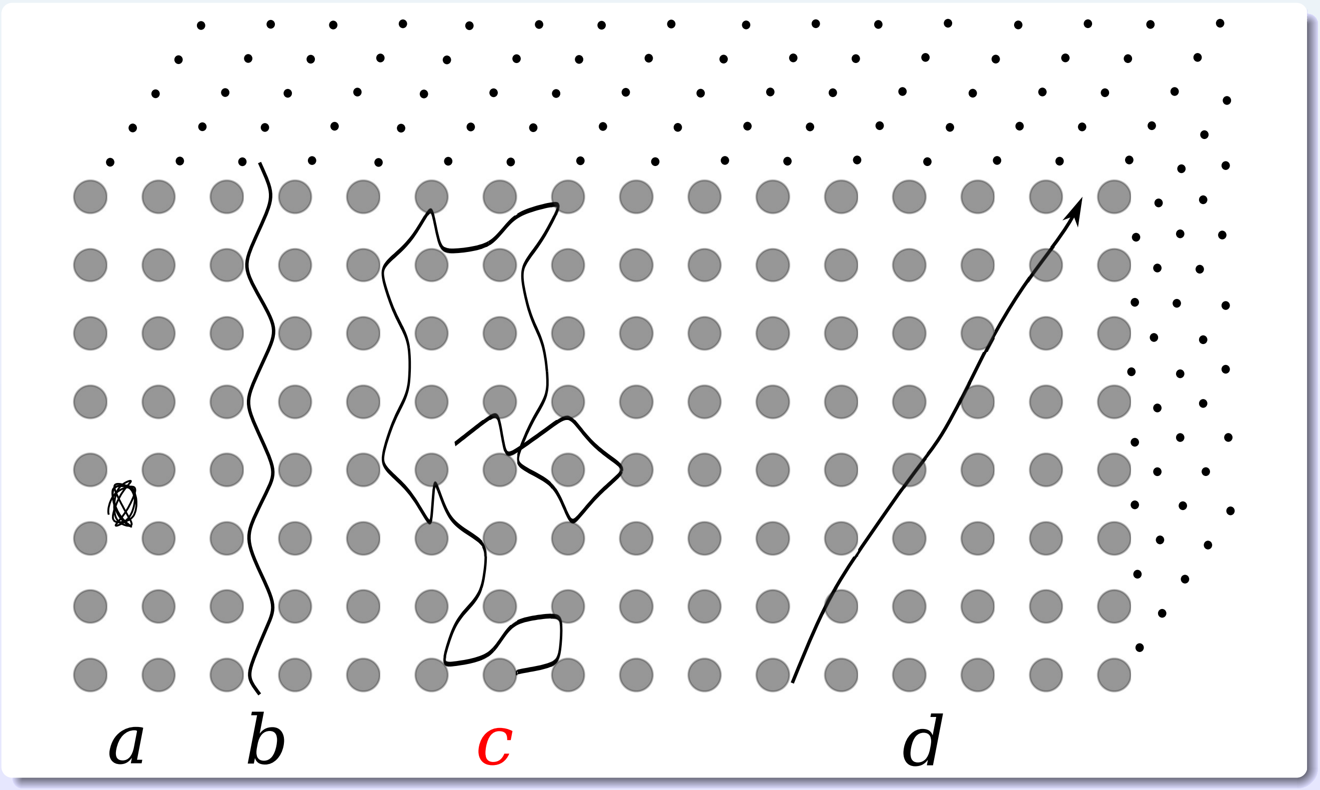


Mechanisms of fast charged particle motion in a crystal near one of crystal axes

a) **axial channeling;**

b) **planar channeling;**

c) **stochastic scattering;**



Mechanisms of fast charged particle motion in a crystal near one of crystal axes

a) **axial channeling;**

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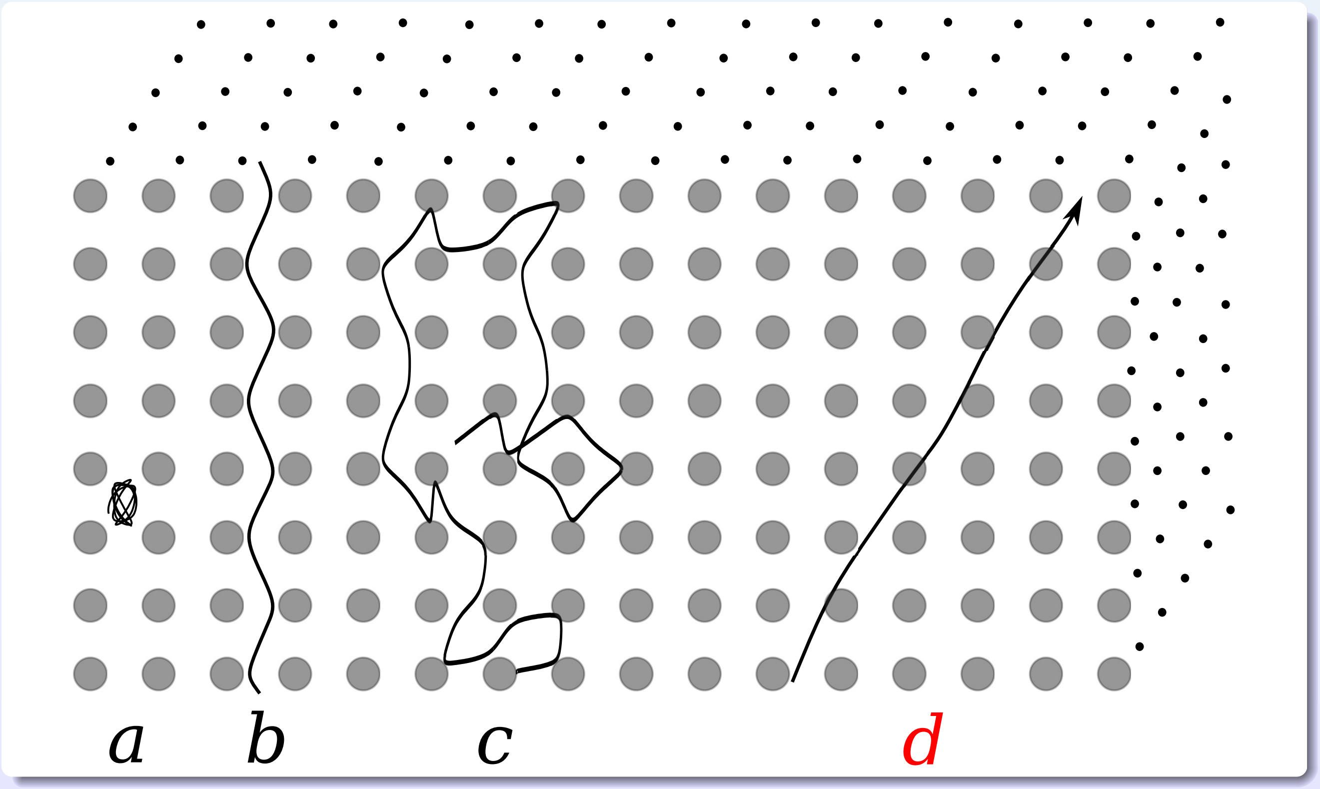
d) **above-barrier motion.**



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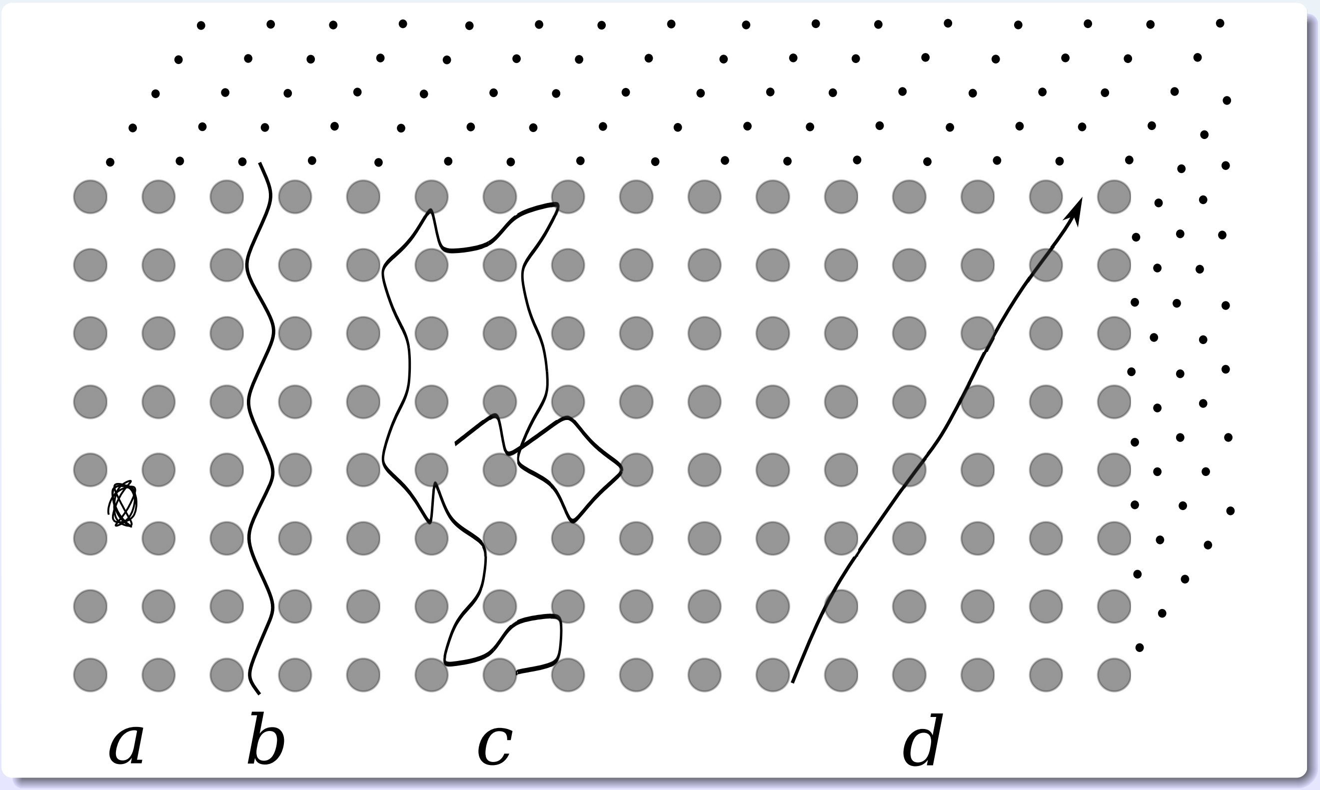
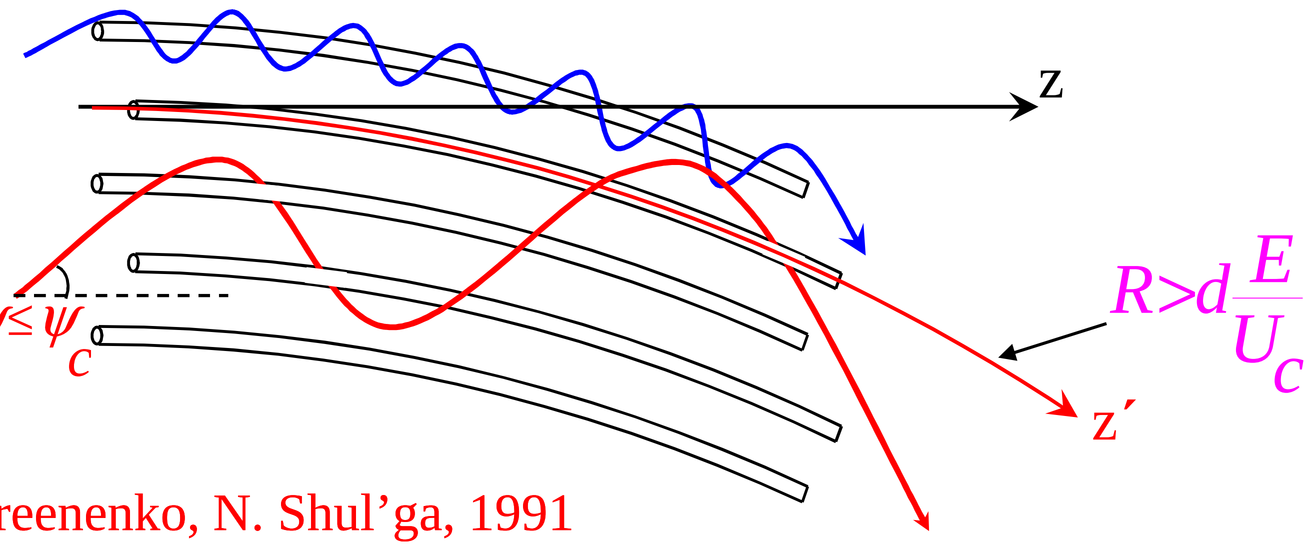


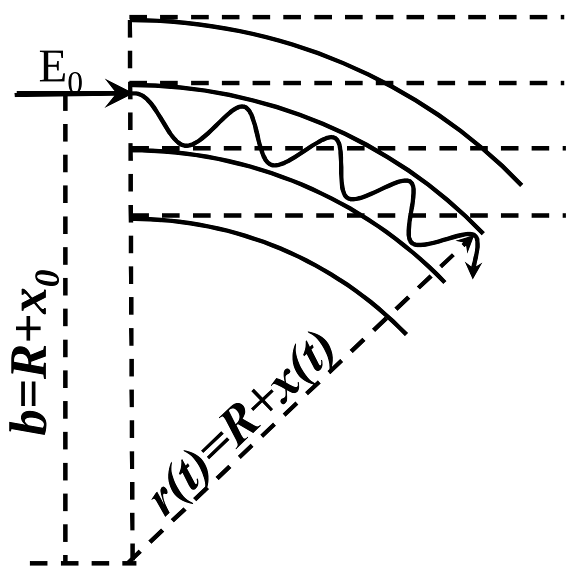
Axial channeling and stochastic mechanism

$\psi_x \approx \psi_y \leq \psi_c$



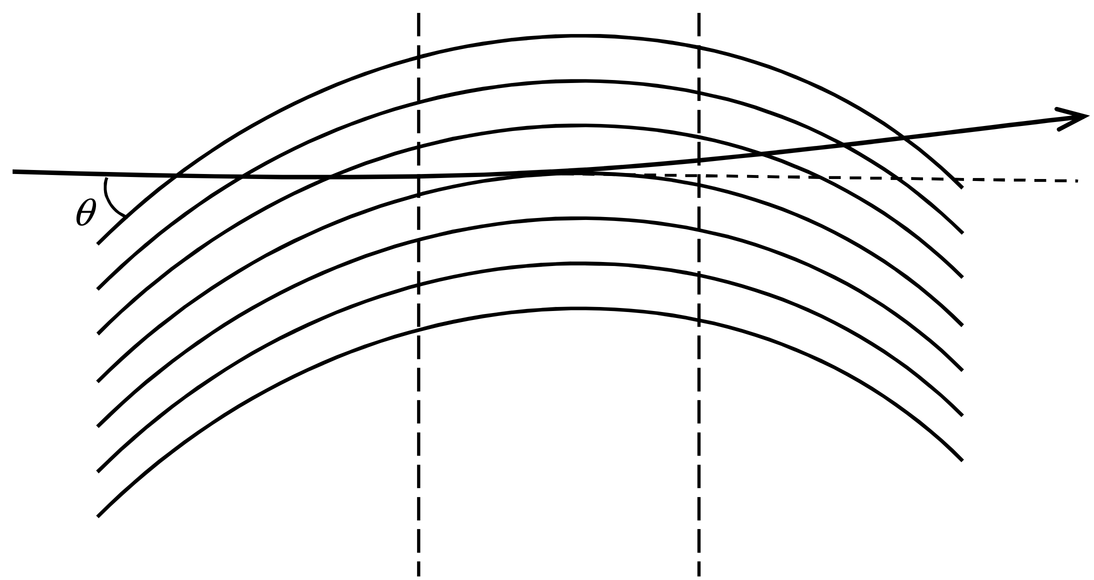
A.Greenenko, N. Shul’ga, 1991

Planar channeling



Tsyganov E.N., 1976 Preprint
Fermilab TM-682, TM-684

Volume reflection



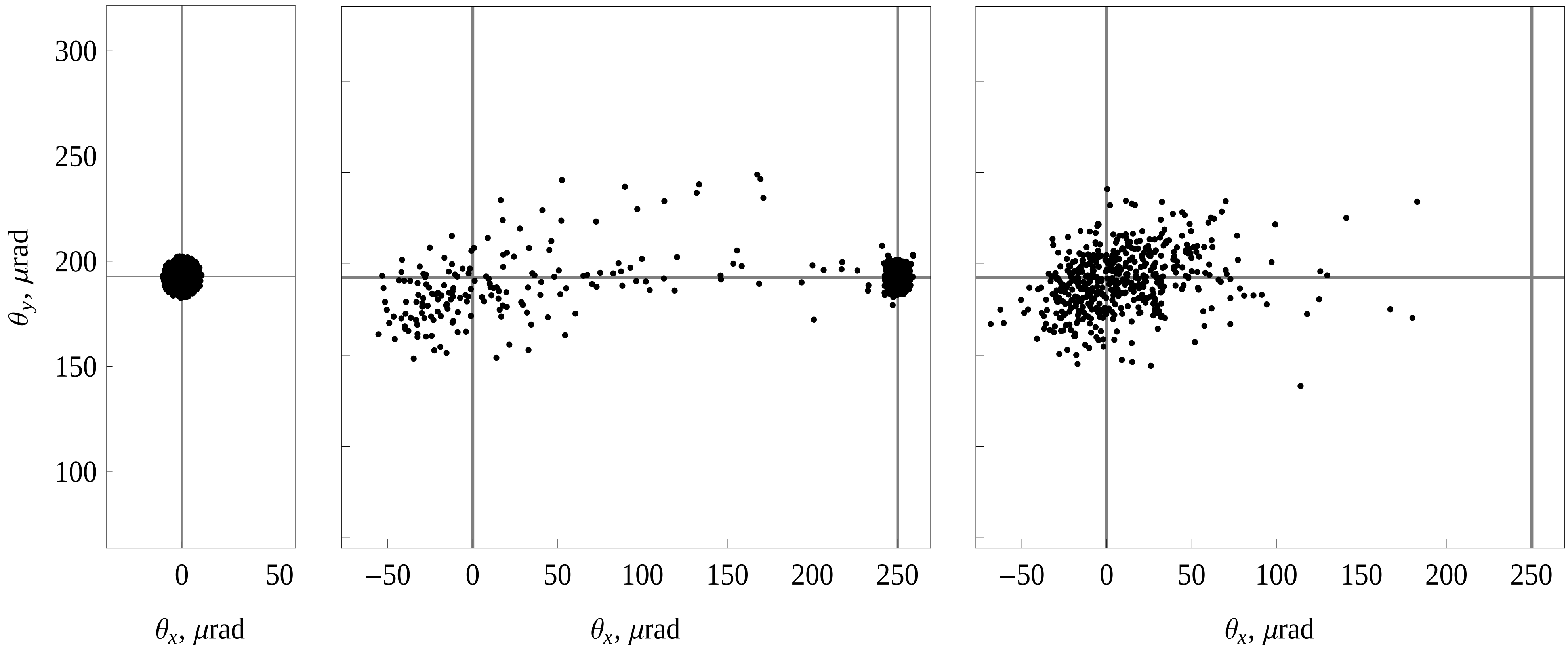
A. Taratin, S. Vorobiev, 1987

Angular distributions of charged 400 GeV/c particles before and after passing 1 cm of bent Si crystal in the conditions of planar channeling

initial conditions

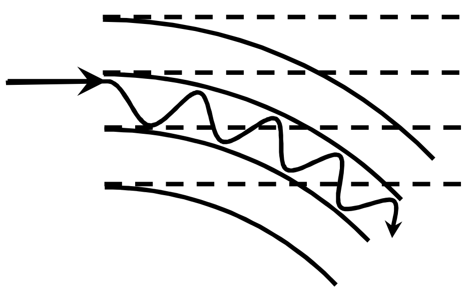
after passing bent Si crystal
positively charged particles

after passing bent Si crystal
negatively charged particles



The main part of the beam follows bent crystal planes

Weak deflection



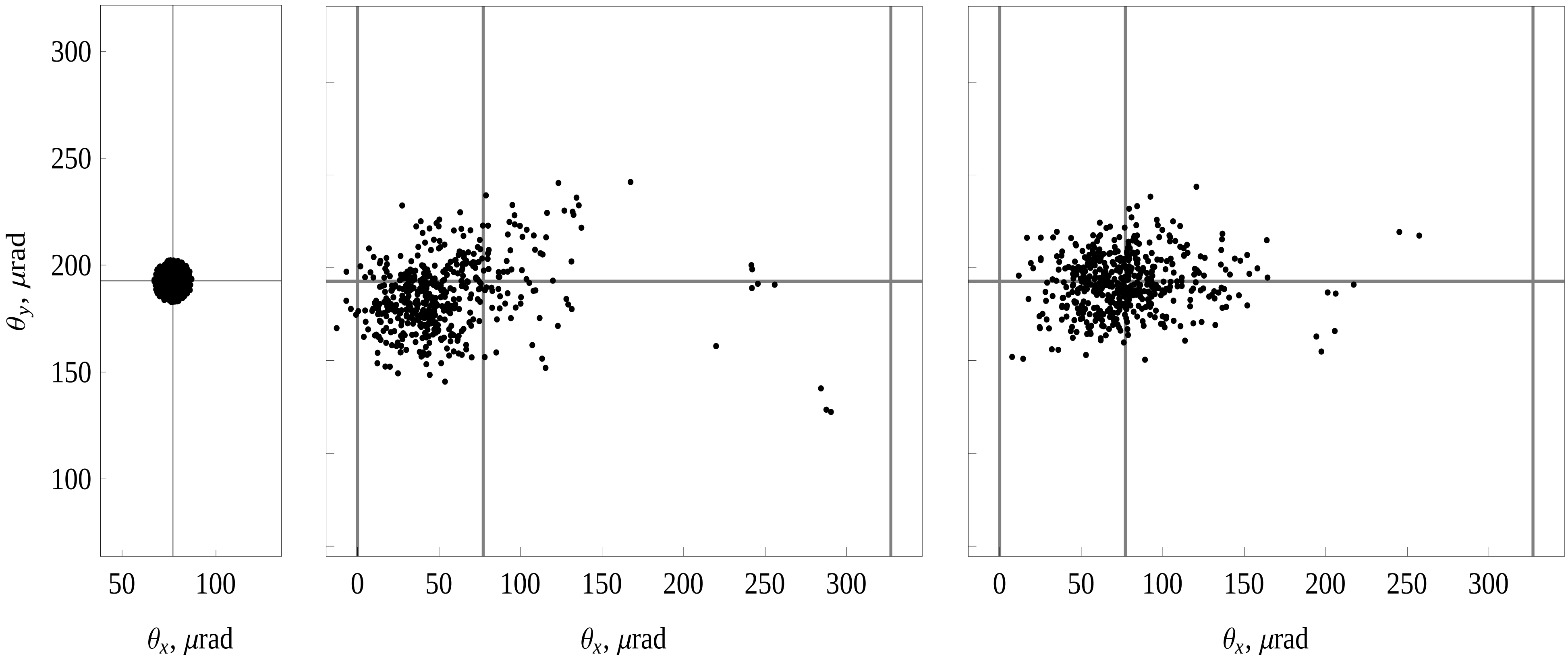
Good for positively charged particles, but ineffective for negatively charged ones

Angular distributions of charged 400 GeV/*c* particles before and after passing 1 cm of bent Si crystal in the conditions of volume reflection

initial conditions

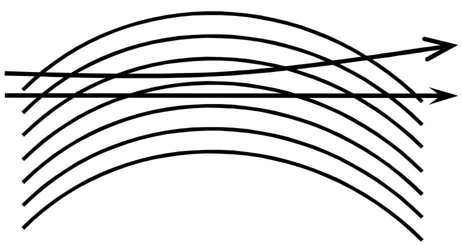
after passing bent Si crystal
positively charged particles

after passing bent Si crystal
negatively charged particles



Particles are deflected in the direction opposite to the direction of crystal bend. Deflection angle ~ 50 μrad

Weak deflection



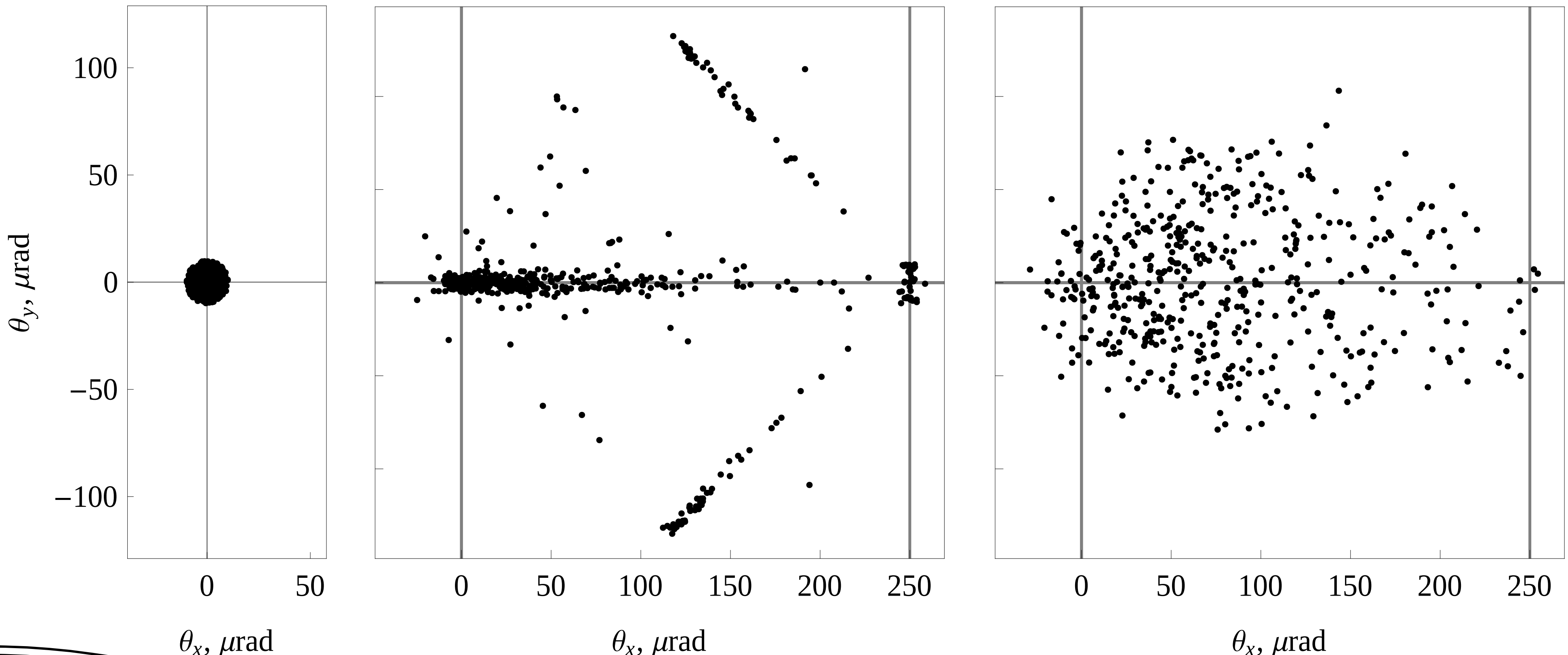
Less useful for positively charged particles and ineffective for negatively charged ones

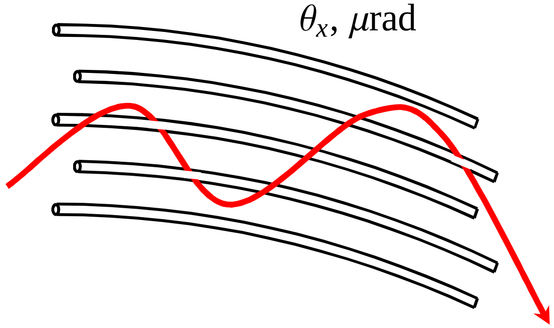
Angular distributions of charged 400 GeV/*c* particles before and after passing 1 cm of bent Si crystal in the conditions of stochastic deflection mechanism

initial conditions

after passing bent Si crystal
positively charged particles

after passing bent Si crystal
negatively charged particles





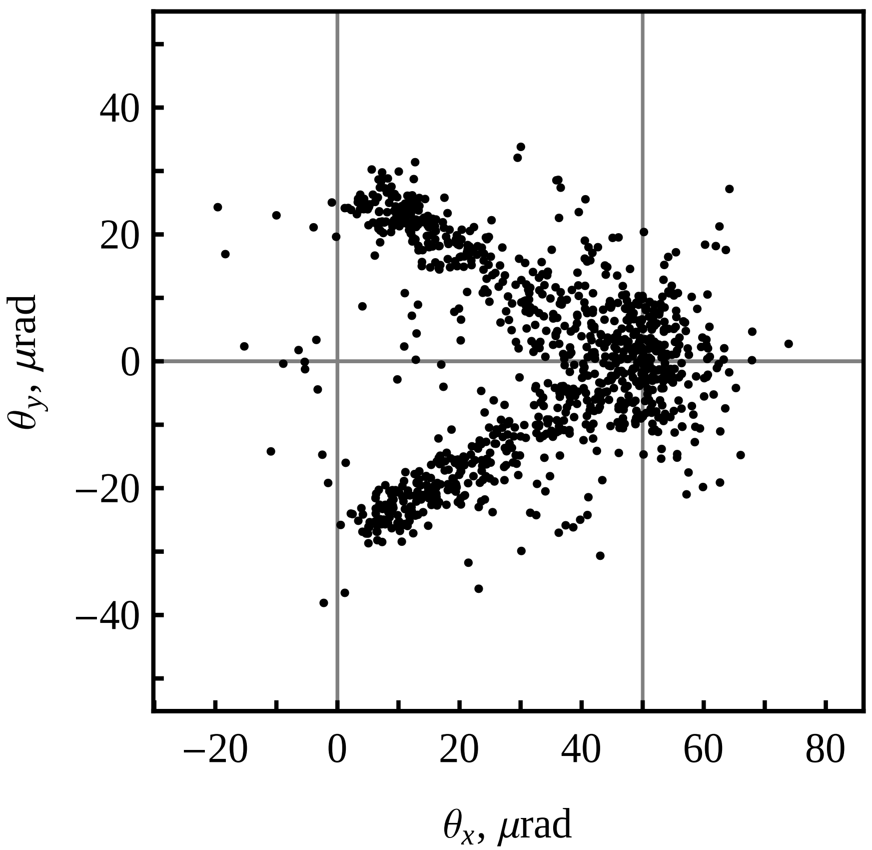
•Deflection of particles in the direction of crystal bent
•Escape into planar channels
•Beam splitting

Deflection of particles
in the direction of crystal bent

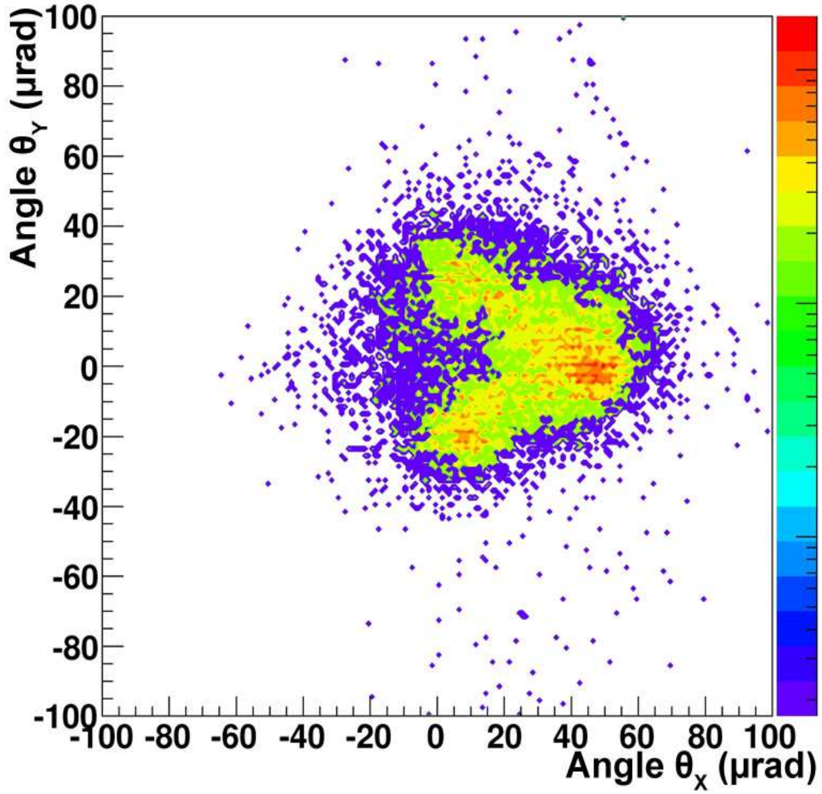
Effective for both positively and negatively charged particles

Angular distribution of 400 GeV protons after passing 2 mm of bent Si crystal with R=40 m

Simulation results



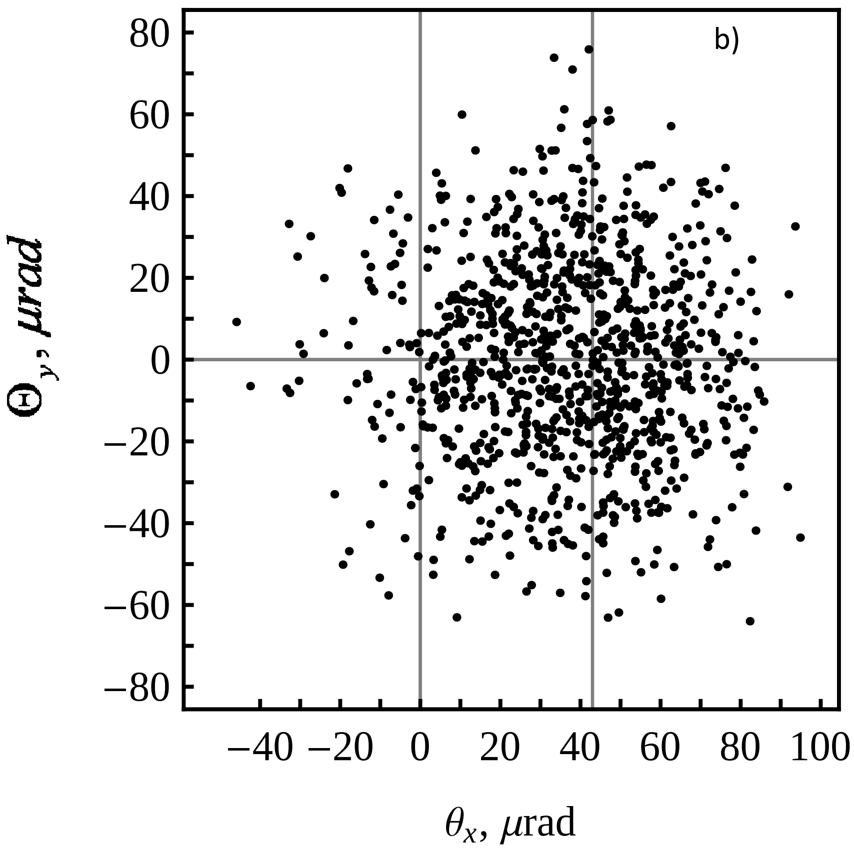
Experimental results



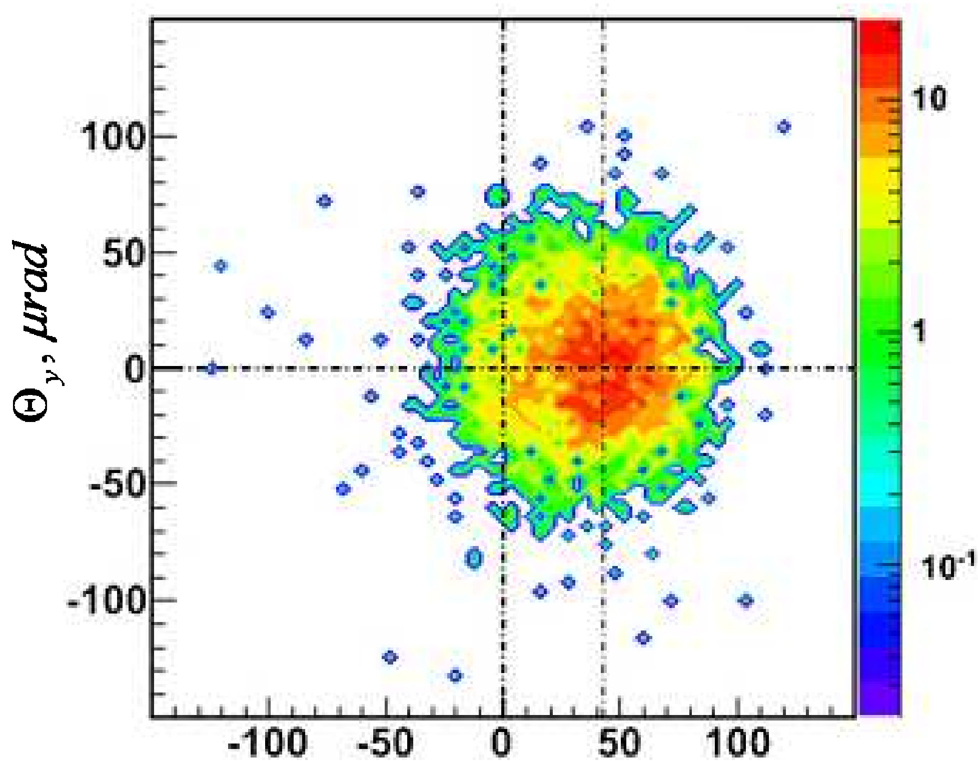
W. Scandale et al. Phys. Rev. Lett. 101 (2008), 164801

Angular distribution of 150 GeV π⁻-mesons after passing 1.172 mm of bent Si crystal with R=40 m

Simulation results



Experimental results



W. Scandale et al. Physics Letters B 680 (2009) 301-304

Stochastic mechanism of fast charged particle deflection by a bent crystal

Greenenko-Shul'ga condition (N.F. Shul'ga, A.A. Greenenko, *Phys. Lett.* B 353, 1995)

$$\frac{l_\perp}{R\psi_c}\frac{L}{R\psi_c} < \mathbf{1}$$

R – **crystal curvature radius;**

$\psi_c = \sqrt{4Z\,|qe|\,/(pvd)}$ – **critical angle of axial channeling;**

$Z\,|e|$ – **atomic charge;**

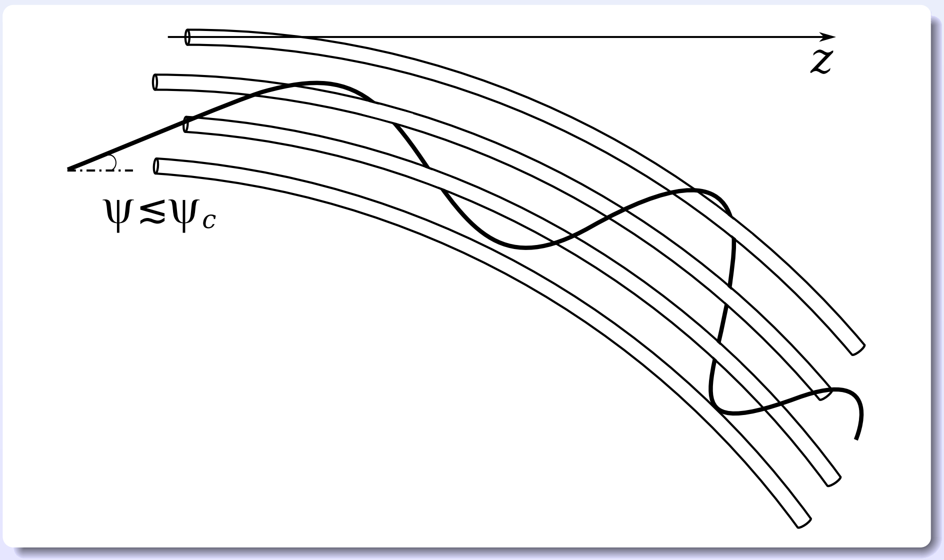
q – **particle charge;**

v **and** p – **particle velocity and momentum;**

d – **the distance between neighboring atoms in the atomic string parallel to the selected axis;**

$l_\perp$ – **mean free path of a particle between successive collisions with crystal atomic strings;**

L – **crystal thickness.**



Stochastic mechanism of fast charged particle deflection by a bent crystal

Without the account of the scattering on thermal oscillations of crystal atoms

According to the Greenenko-Shul'ga criterion $L_{max} = \frac{(R\psi_c)^2}{l_\perp}$

If $R \to \infty$**, then** $L_{max} \to \infty$ **and** $\alpha_{max} = \frac{L_{max}}{R} \to \infty$

With the account of the scattering on thermal oscillations of crystal atoms

$$L_{max} = \frac{\psi_c^2}{\frac{l_\perp}{R^2} + \frac{\varepsilon_s^2}{E^2 L_{rad}}} \qquad \Rightarrow \qquad \alpha_{max} = \frac{\psi_c^2}{\frac{l_\perp}{R} + \frac{\varepsilon_s^2 R}{E^2 L_{rad}}}$$

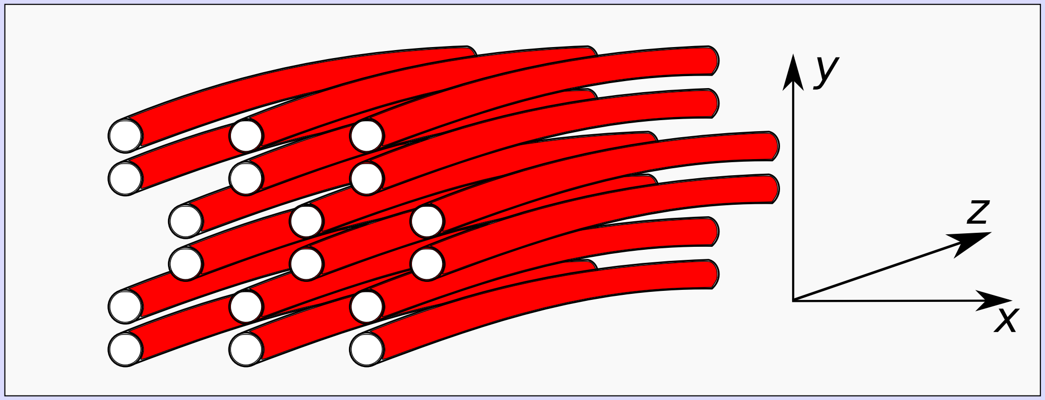
$\varepsilon_s \approx 20$ **MeV,** L_{rad} **– radiation length.**

if $R \to \infty$**, then** $L_{max} = \frac{\psi_c^2 E^2 L_{rad}}{\varepsilon_s^2}$ **and maximum possible angle of beam deflection by a bent crystal** α_{max} **is finite.**

Initial conditions

Bent Si crystal with thickness L=1,5 mm and radius of curvature R=1,5 m. Crystal bend angle $\alpha = \frac{L}{R}$=1 mrad.

Crystal is bent in the (001) crystal plane (in which axes x and z are located) in the direction of increasing x.



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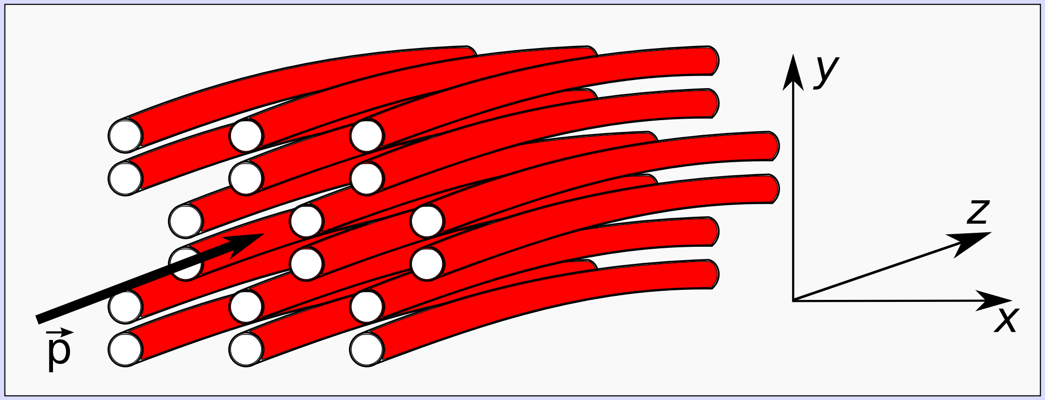
Crystal is bent in the (001) crystal plane (in which axes x and z are located) in the direction of increasing x.

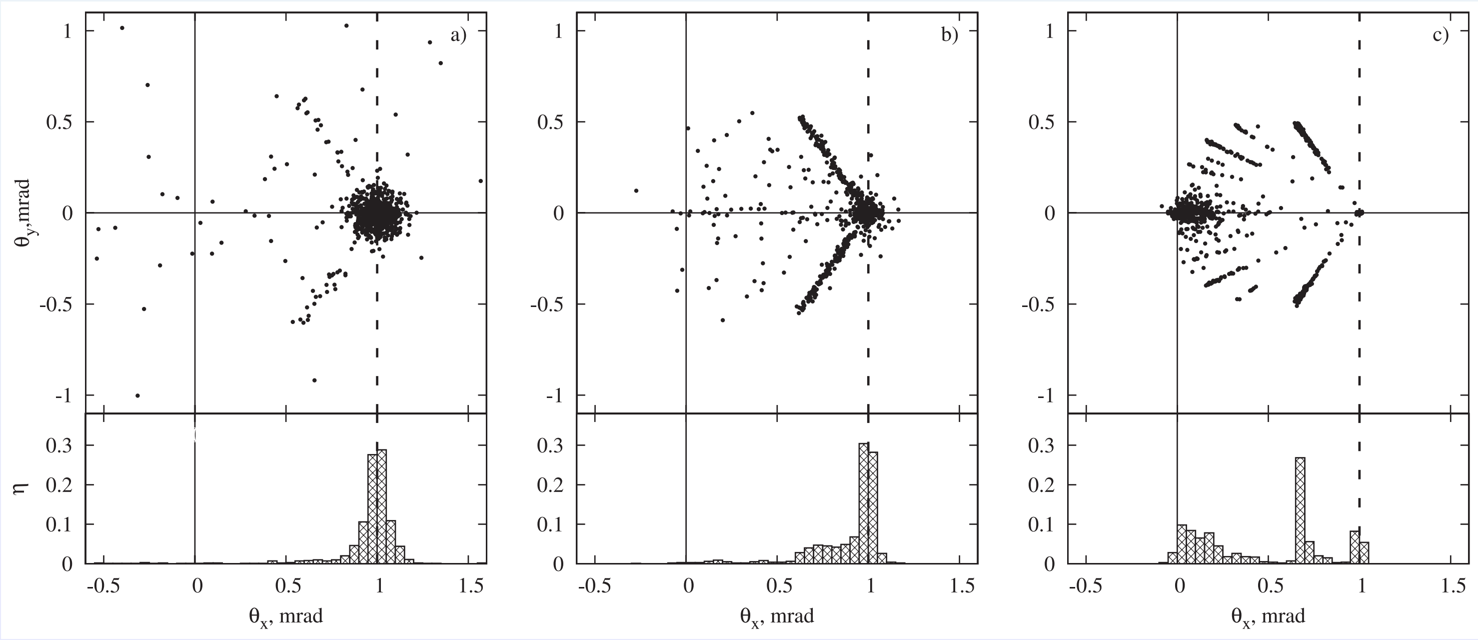
Particle beam impinges on the crystal along the $\langle 110 \rangle$ crystal axis (coinciding with the z axis). Beam divergence is 10 μrad.



Proton beam deflection by a bent crystal

- **With decreasing particle energy the maximum possible angle of beam deflection by the crystal increases**

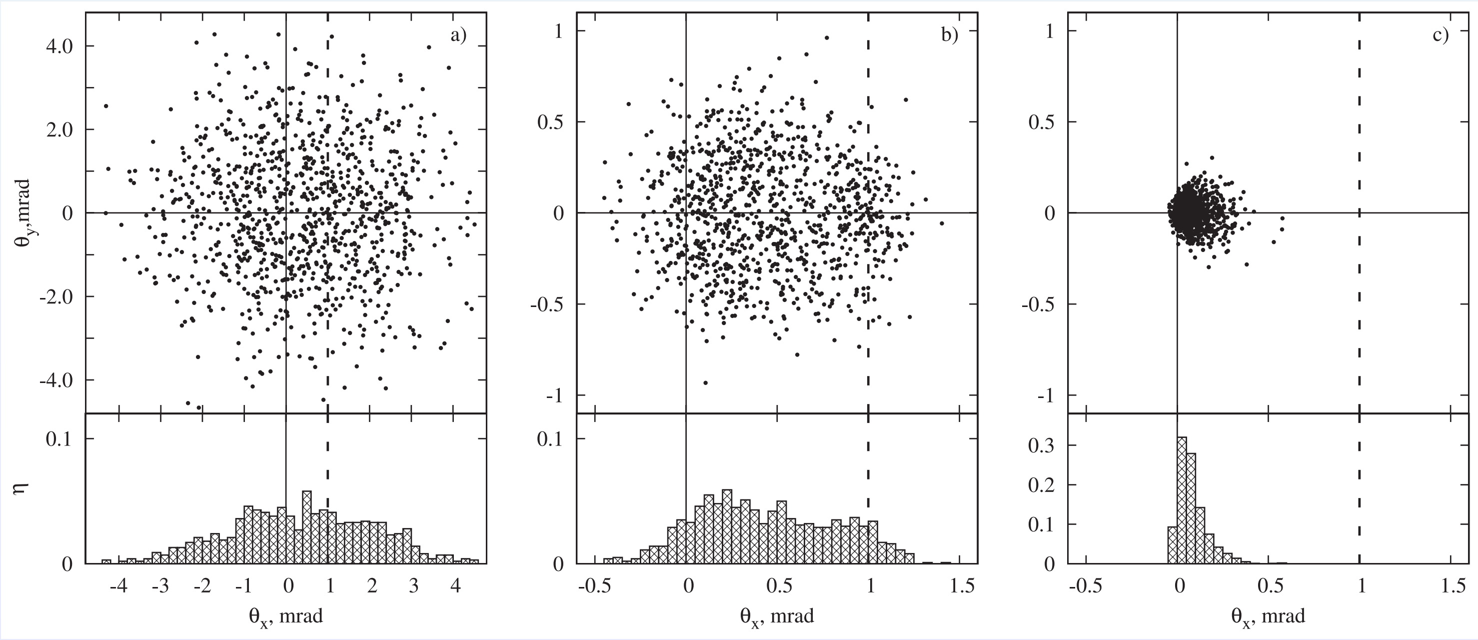
1 GeV **10 GeV** **100 GeV**



π^--meson beam deflection by a bent crystal

- **In the case of negatively charged particles scattering on crystal atoms thermal oscillations is more intense**

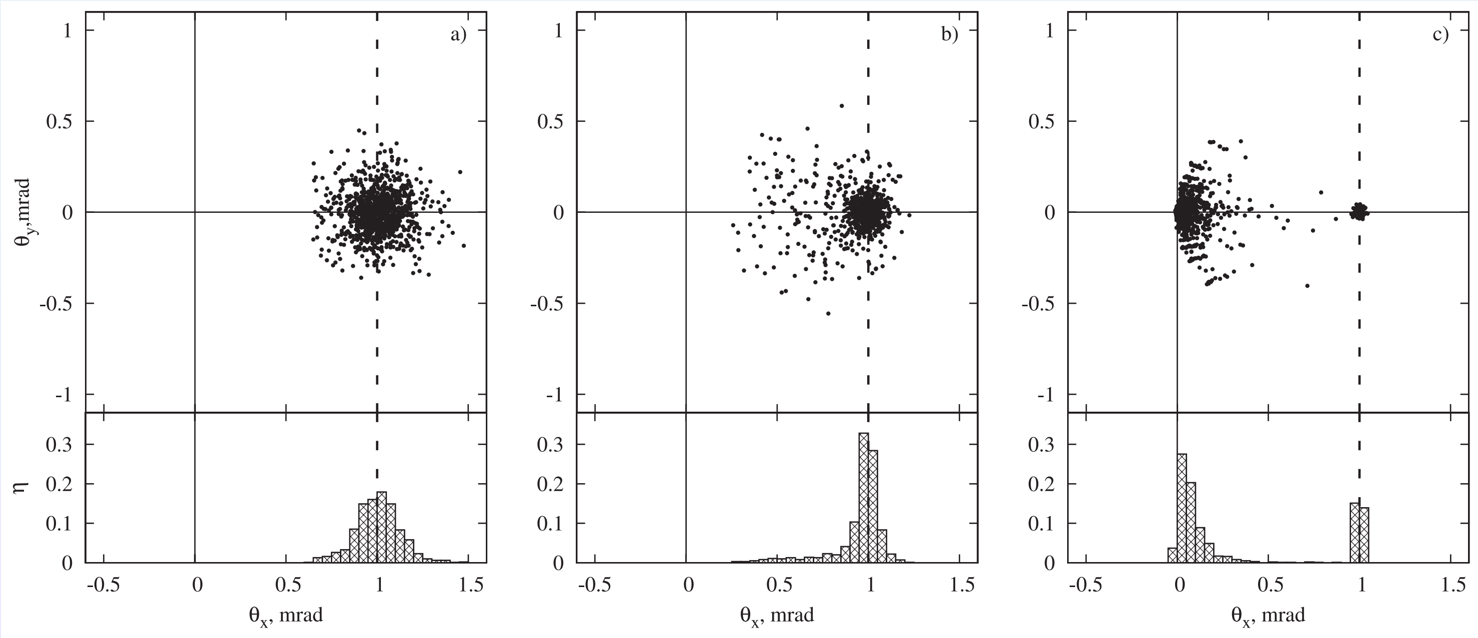
1 GeV **10 GeV** **100 GeV**



π^--meson beam deflection by a bent crystal without the account of scattering on crystal atoms thermal oscillations and electronic subsystem

- **Without the account of scattering on crystal atoms thermal oscillations the evolution of the negatively charged particle beam in a crystal is almost identical to the evolution of positively charged particle beam**

1 GeV **10 GeV** **100 GeV**

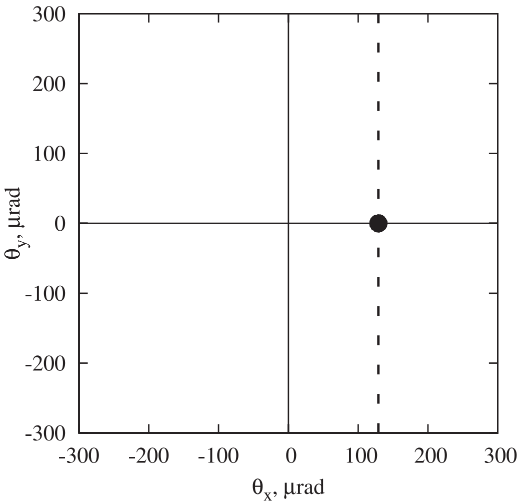


Conclusions

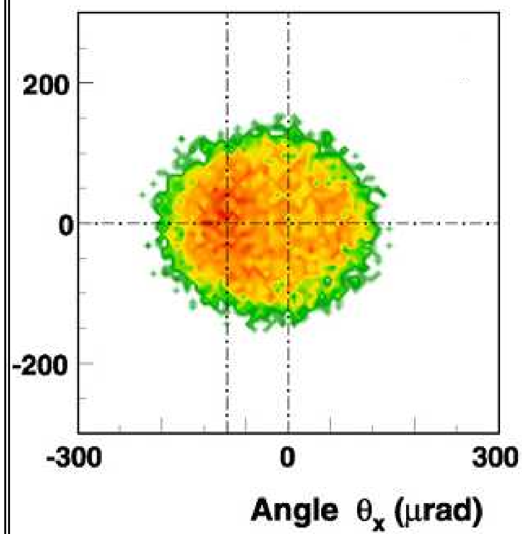
- **In the energy area 1÷10 GeV the stochastic mechanism of beam deflection gives the opportunity to deflect beams of both positively and negatively charged particles at an angle of about 1 mrad**
- **For negatively charged particles the account of scattering on crystal atoms thermal oscillations in the specified energy range is crucial for the analysis of beam dynamics**
- **The simulation shows that the stochastic mechanism of deflection can be successfully used to solve some technical problems (charged particle beam output from accelerators, beam collimation, etc.)**

DYNAMICAL CHAOS IN NEGATIVELY CHARGED PARTICLE BEAM SCATTERING BY A BENT CRYSTAL

Initial beam:

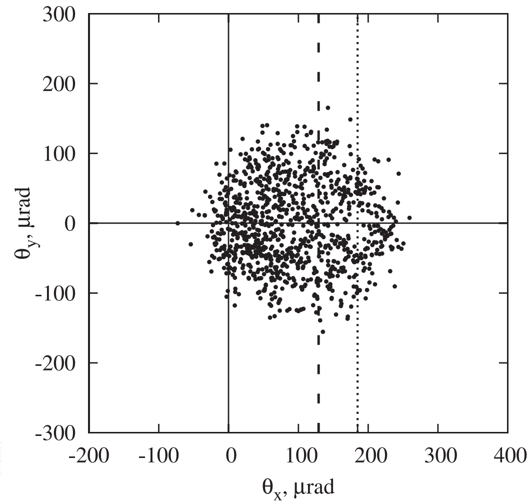


The beam after passing of 8 mm of Si bent crystal with R=185μrad:

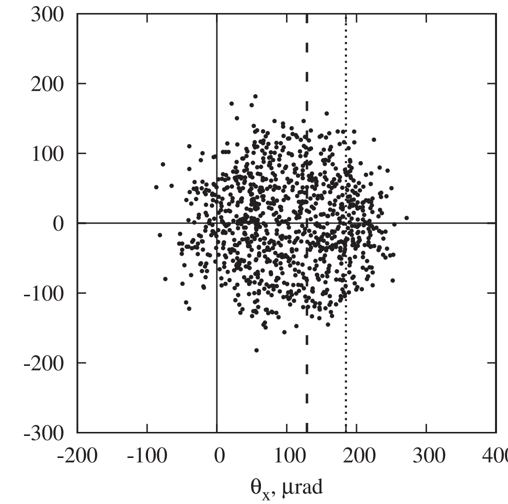


Experiment

(W. Scandale, A. Vomiero et al., Phys. Lett. B, v. 693, 2010, p. 545)

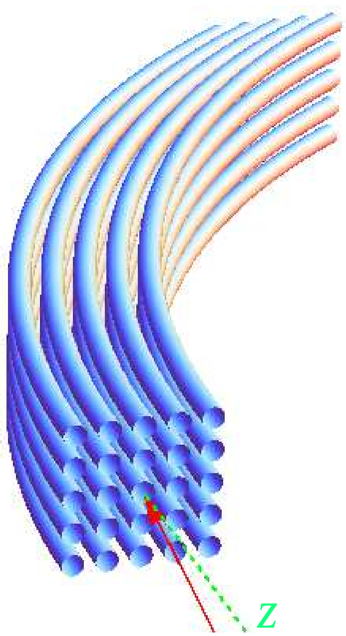


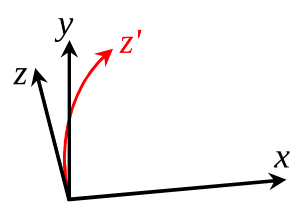
Simulation of beam motion in a crystal

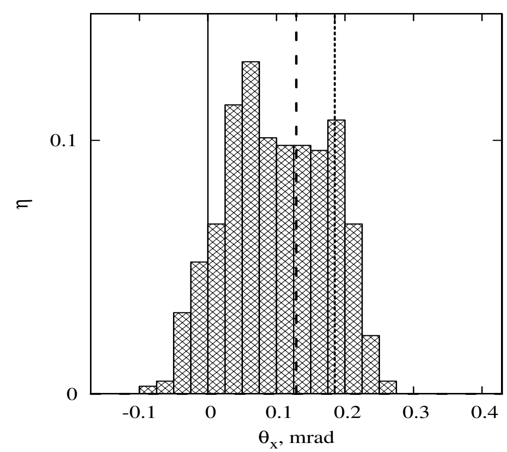


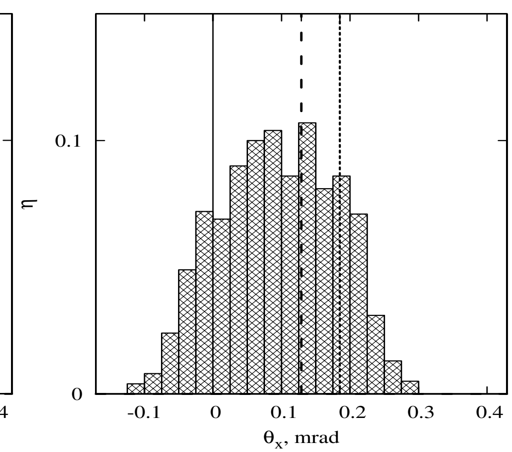
Simulation of beam motion in random strings approximation

(N.F. Shul'ga, I.V. Kirillin, and V.I. Truten, Phys. Lett. B, v.702, 2011, p. 100)









Beam consists of 150 GeV/c π^--mesons


Thank you for your attention!