On possibilities of antiproton beam extraction from HESR storage ring and strongly charged ions from FAIR experiment with the help of bent crystals

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Kharkov, 2014

Experiments with the polarized antiproton beam and with polarized targets

G.Gurevich[1], A.Lukhanin[2], Yu.Plis[3], Yu.Usov[3], A.Thomas[4], F.Maas[5]

1. Institute for Nuclear Research, Russian Academy of Science, Moscow, Russia
2. Kharkov Institute of Physics and Technology, Kharkov, Ukraine
3. Joint Institute for Nuclear Research, Dubna, Russia
4. Institute fur Kernphysik, Universitat Mainz, Germany
5. Helmholtz-Institut Mainz, Universitat Mainz, Germany

Collaboration FAIR (PANDA Experiment)

(GSI, Germany – JNRS, Dubna, Russia – …)

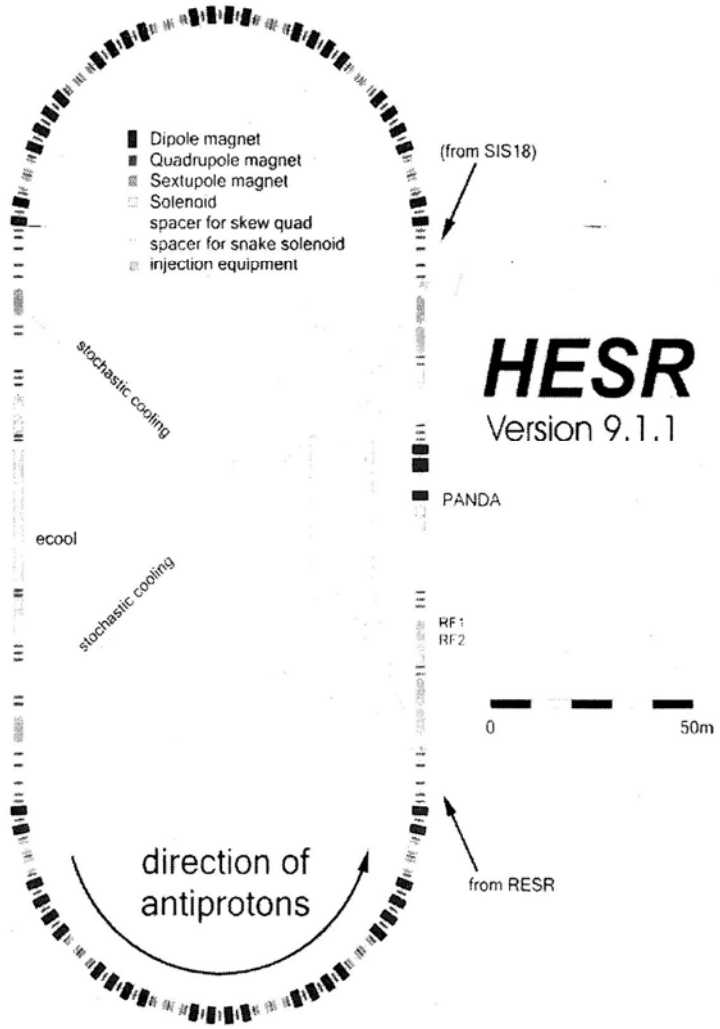
- Production rate 2×10^7/sec
- P_{beam} = 1 - 15 GeV/c
- N_{stored} = 5×10^{10} p^-
- Internal Target

High resolution mode

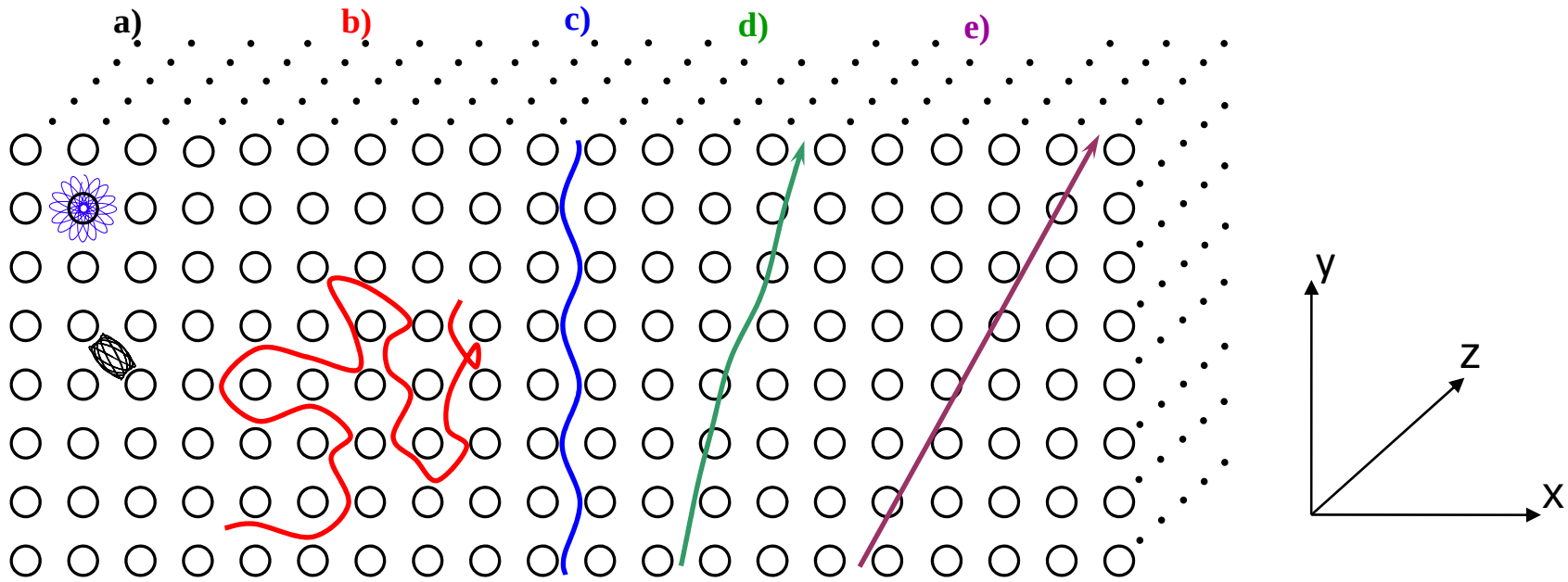
- $\delta p/p \sim 10^{-5}$ (electron cooling)
- Lumin. = 10^{31} cm^{-2} s^{-1}

High luminosity mode

- Lumin. = 2×10^{32} cm^{-2} s^{-1}
- $\delta p/p \sim 10^{-4}$ (stochastic cooling)



Mechanisms of Charged Particles Motion near <100> Axis



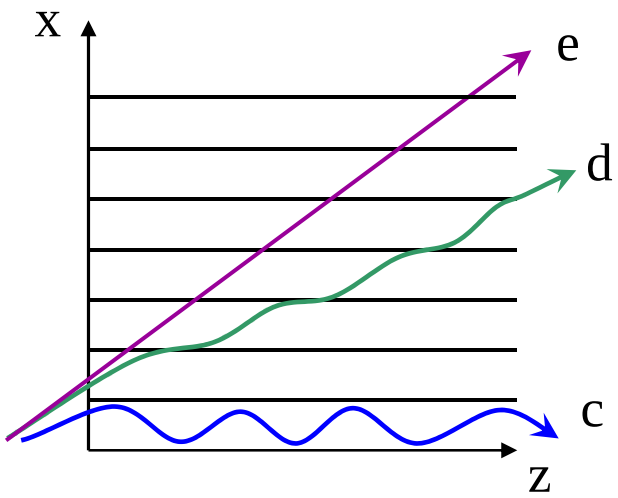
a) Hyperchanneling (e^+, e^-)

b) Stochastic multiple scattering

c) Planar channeling

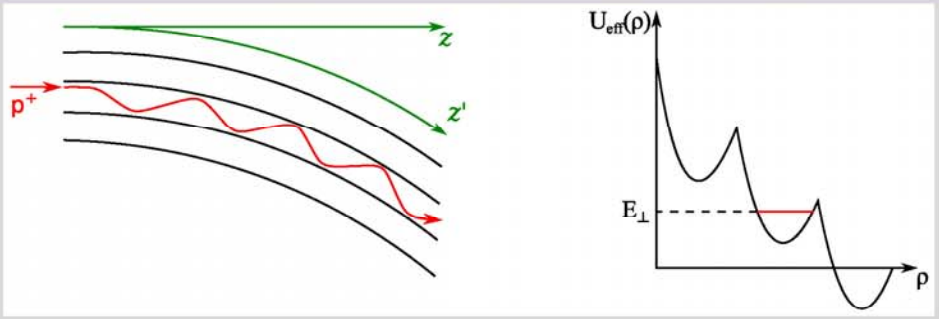
d) Above barrier motion $\varepsilon_\perp \sim U_{pl\,\max}$

e) Above barrier motion $\varepsilon_\perp >> U_{pl\,\max}$



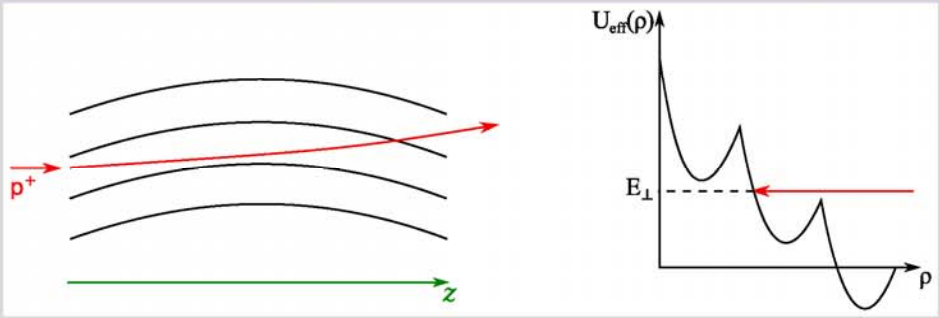
MECHANISMS OF HIGH-ENERGY CHARGED PARTICLE DEFLECTION BY BENT CRYSTALS

Planar channeling in bent crystal (*E.N. Tsyganov, 1976*)



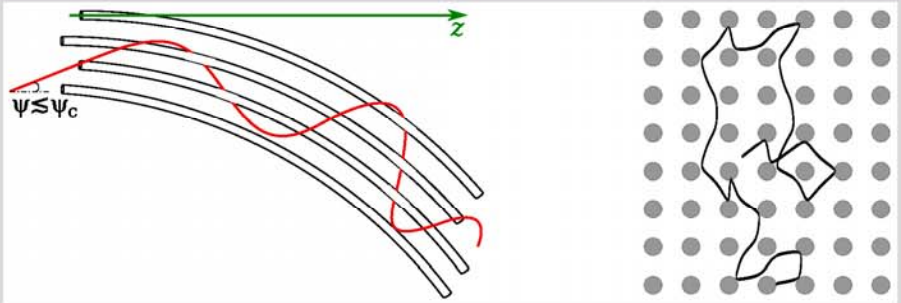
1979 — IHEP (Russia)
1980 — CERN

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



2006 — IHEP (Russia)
2006 — PNPI (Russia)
2007 — CERN

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

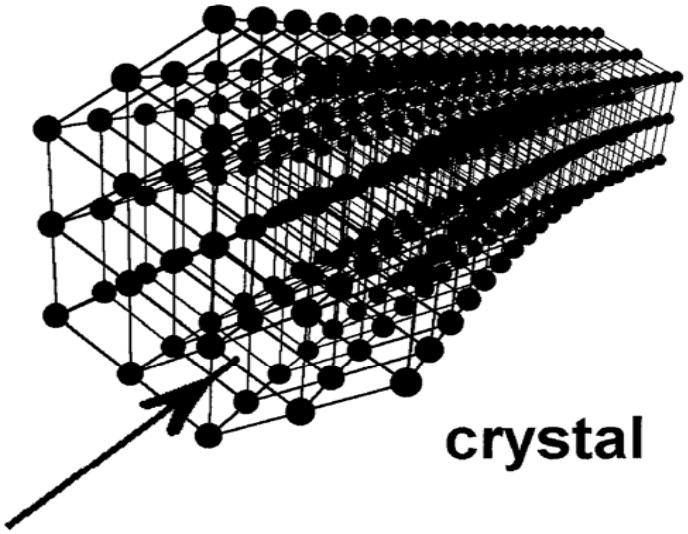


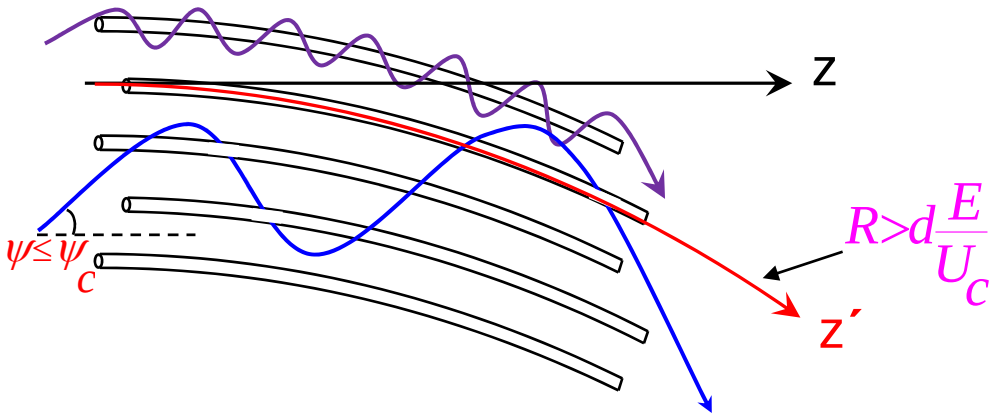
2008 — CERN, protons
2009 — CERN, π^--mesons

N. Shul'ga, V. Truten', I. Kirillin J. of Phys. 236 (2010) 012030; Phys. Lett. B 702 (2011) 100

Stochastic Mechanism of Beam Deflection by Bent Crystal

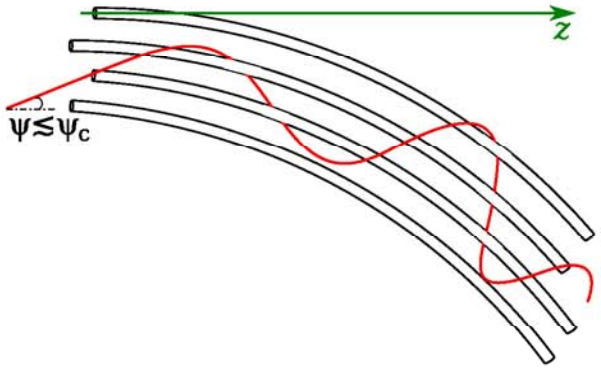
N.F. Shul'ga, V.I. Truten', I.V. Kirillin (2008-2013)

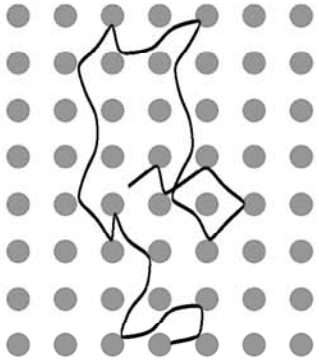




N. Shul'ga, A.Greenenko, JETP Lett., 1991.

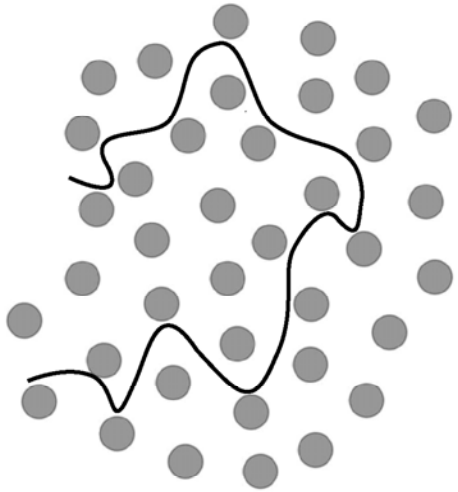
STOCHASTIC DEFLECTION MECHANISM (DYNAMICAL CHAOS)





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

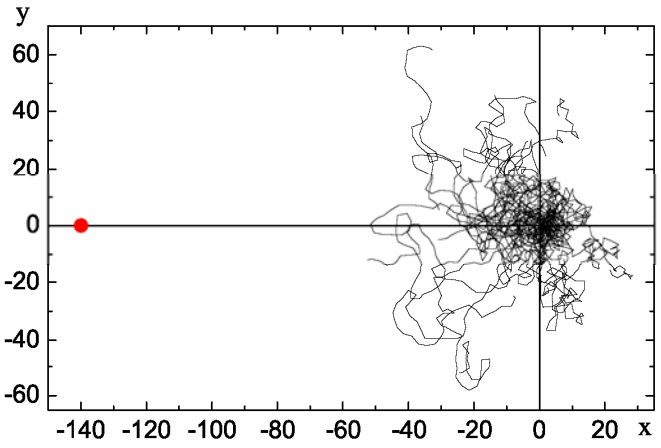
Analogy with particle scattering in random string approximation:

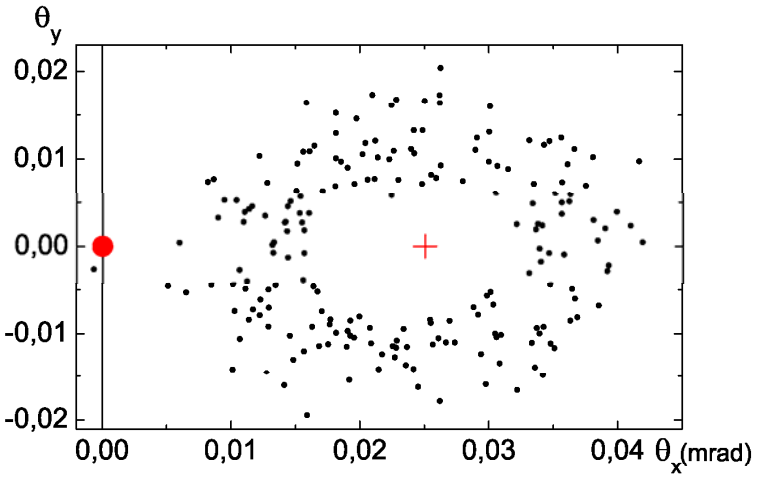


STOCHASTIC MECHANISM OF HIGH-ENERGY CHARGED PARTICLE DEFLECTION BY A BENT CRYSTAL

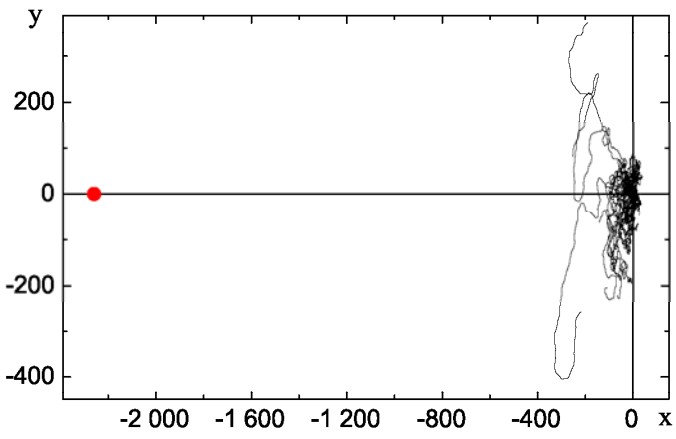
e^-

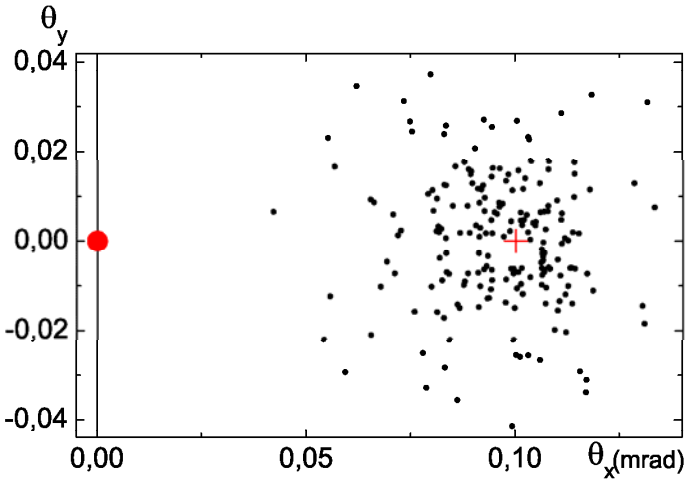
L=0.25 cm



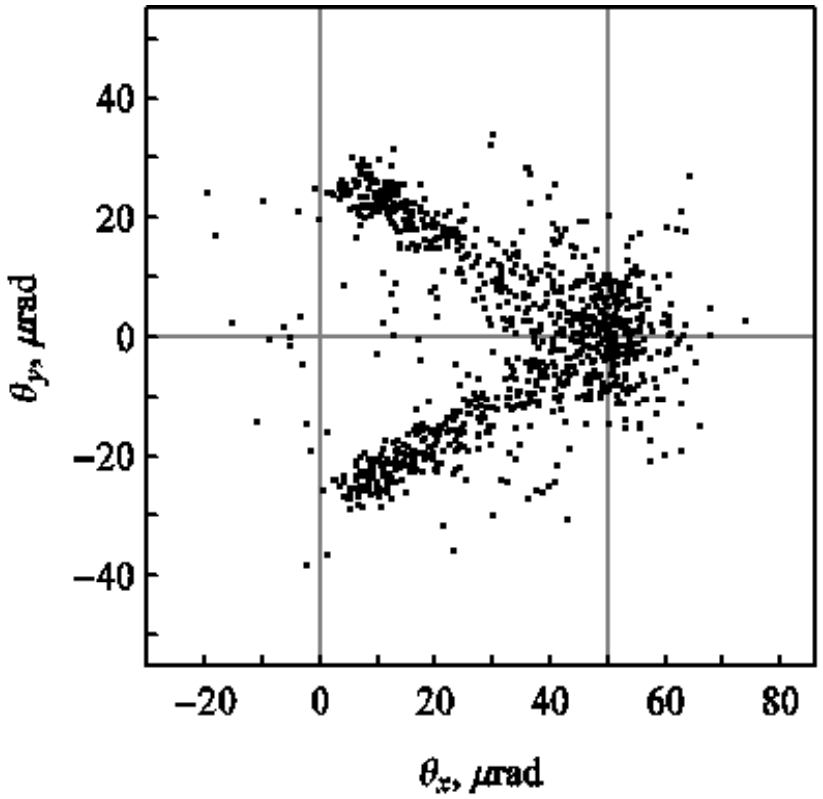


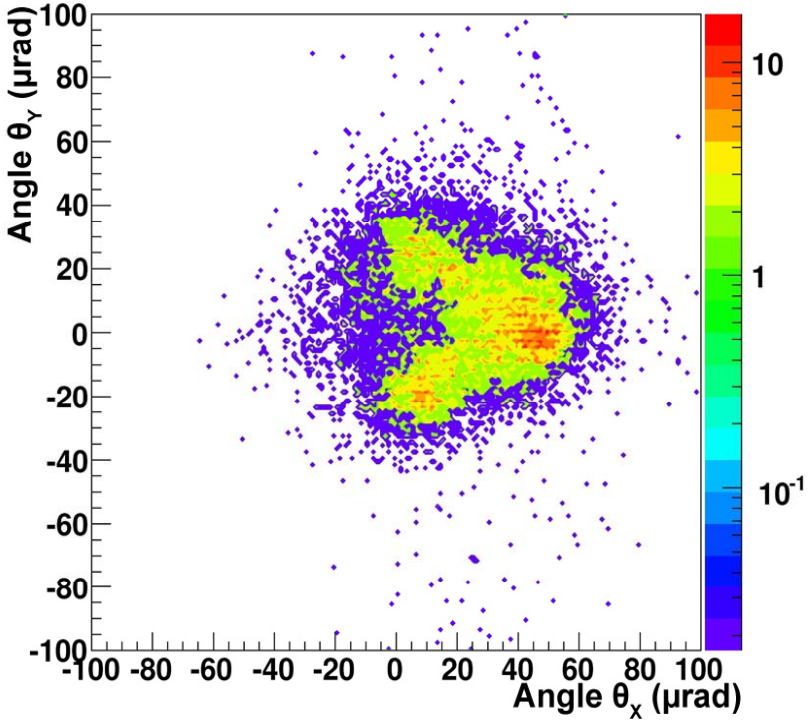
L=1 cm





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



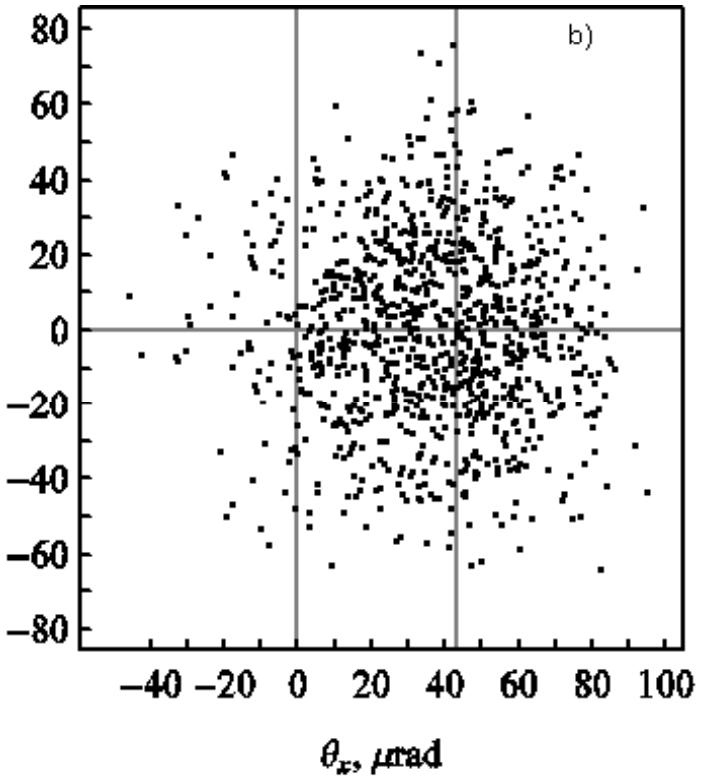


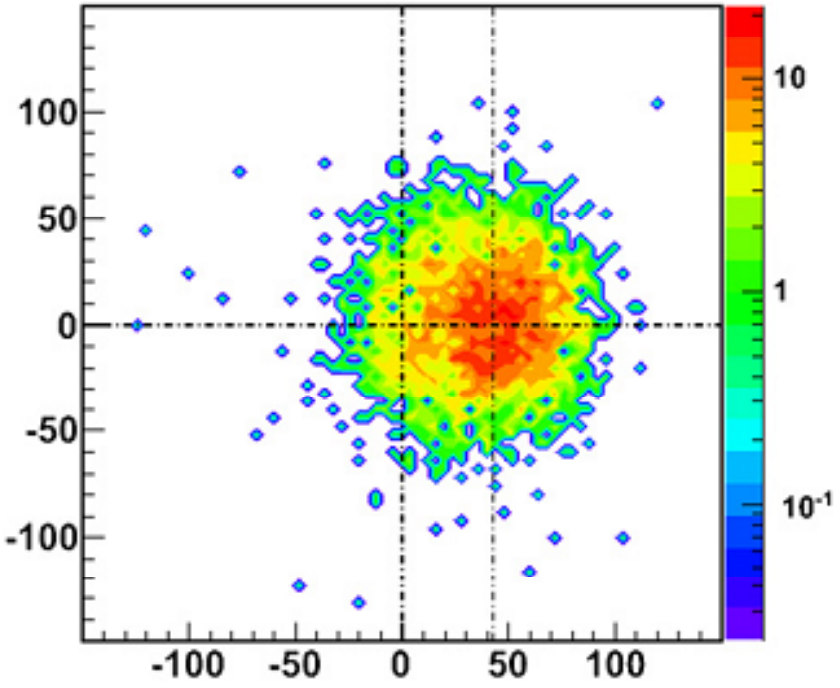
Simulation results

CERN experiment

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

CERN experiment

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

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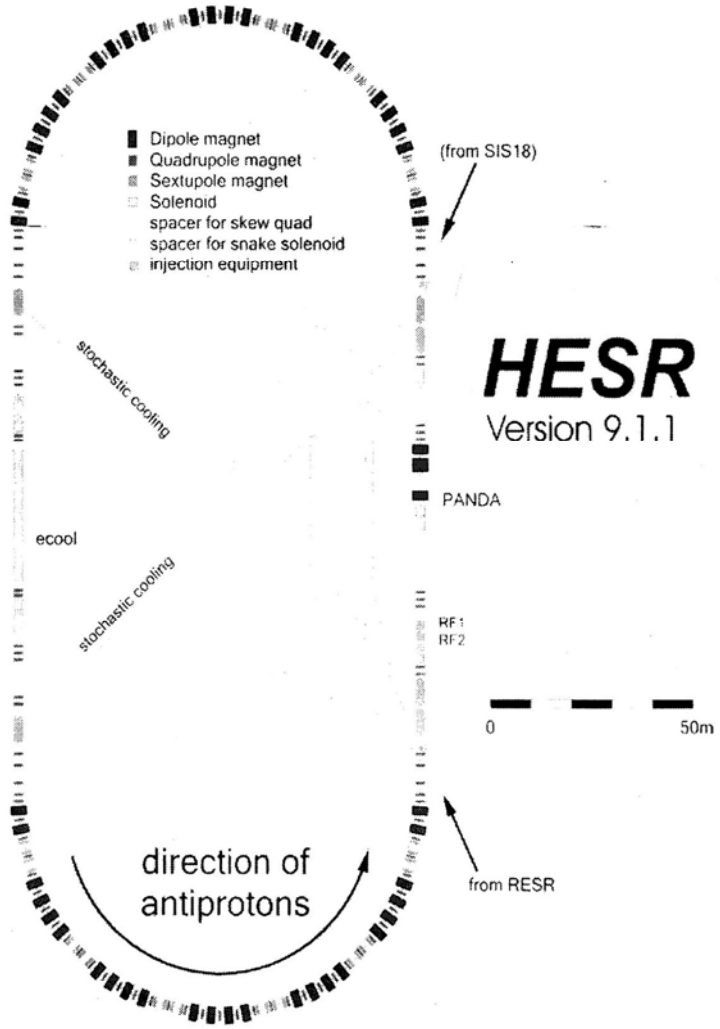
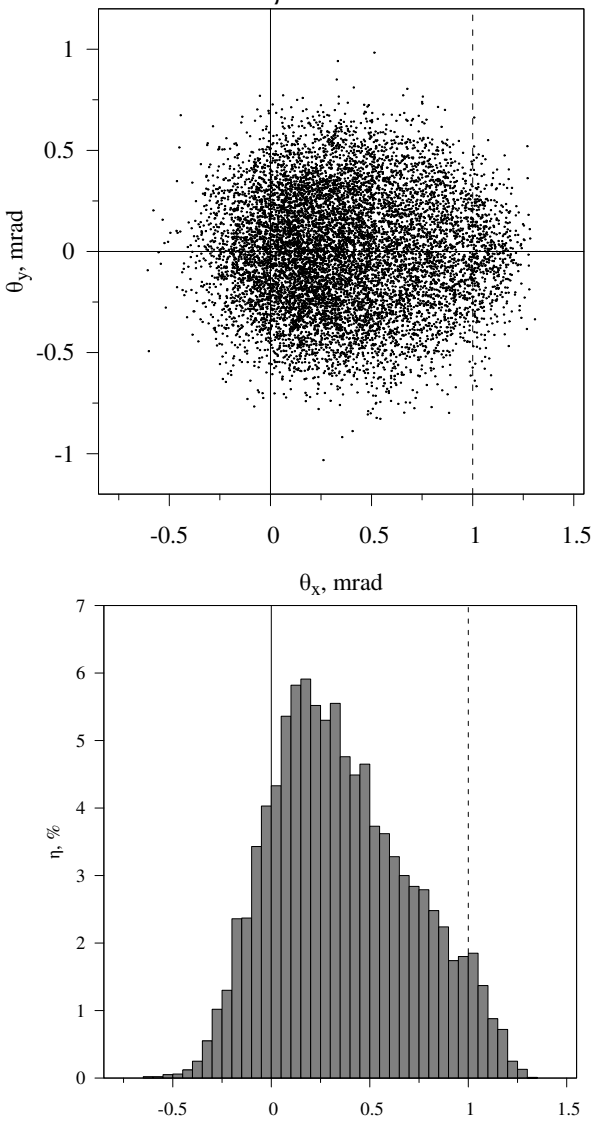


Simulation for HESR antiproton beams

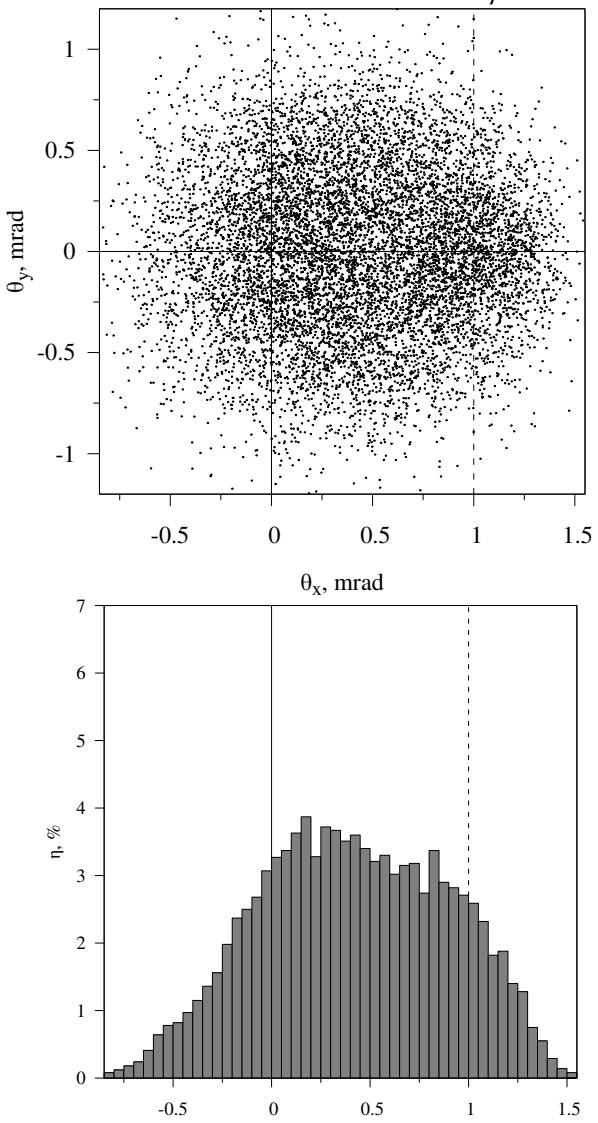
(N. Shul'ga, I. Kirillin, V. Truten' – 2014)

E_{kin} =10 GeV, Si <110>

L=1 mm, *R*=1 m



L=4 mm, *R*=4 m



Beam deflection of high-energy protons and strongly charged ions by bent crystals

CERN Experiment (1996) on 450 GeV Proton Beam by a Bent Crystal

particles are obtained, but no particles are deflected by the full bending angle.

Deflection of a 450 GeV/c proton beam by means of a crystal heavier than silicon, namely germanium, has for the first time been performed. Although the efficiency for large deflection angles is higher for germanium than for silicon, the overall advantage of germanium is not as large as expected.

Finally, the first observation with a high-energy beam of a deterioration of the deflection efficiency of an irradiated crystal has been made. The required fluence to reach such an inefficiency is very large, allowing crystal applications even in intense beams for many years of running time.

Now that bending of positive beams using planar channeling in a bent crystal is well understood and high efficiencies have been proven, the research in the future should be directed towards larger curvatures using heavy

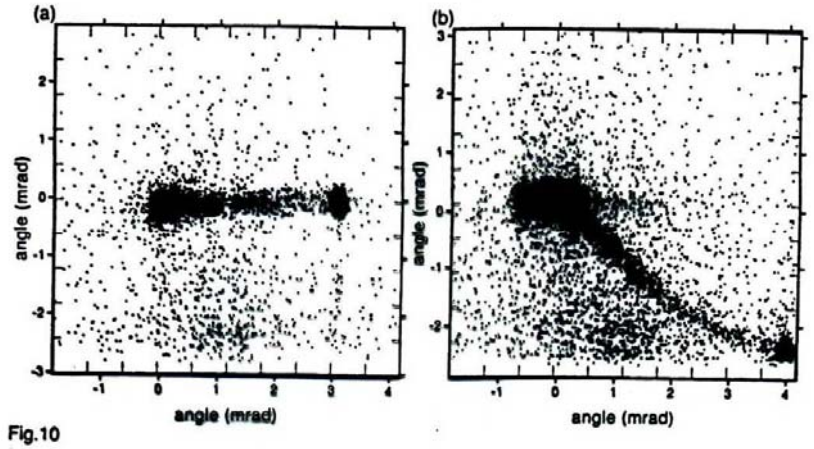


Fig.10

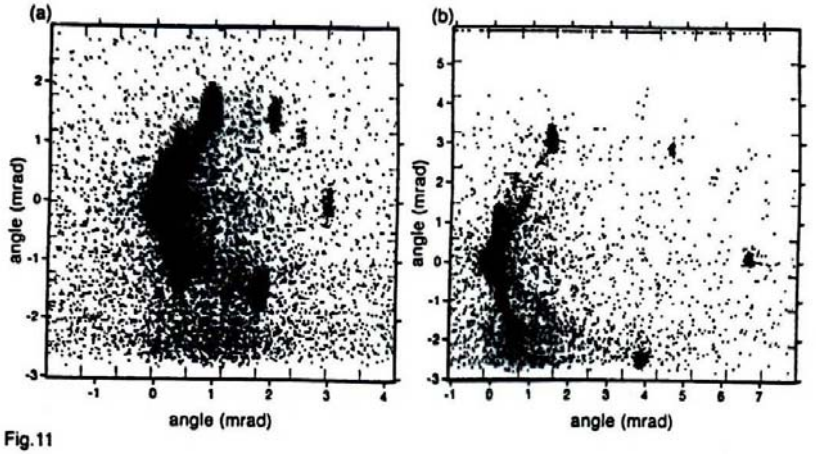


Fig.11

$$Si \ <110> \ \varepsilon = 450 \quad GeV$$

$$L = 3\,cm, \quad R = 10\,m$$

$$\frac{l_0}{R\psi_c} < 1$$

$$\alpha_p = \frac{L}{R\psi_c}\frac{l_0}{R\psi_c} \approx 80 \text{ !!!}$$

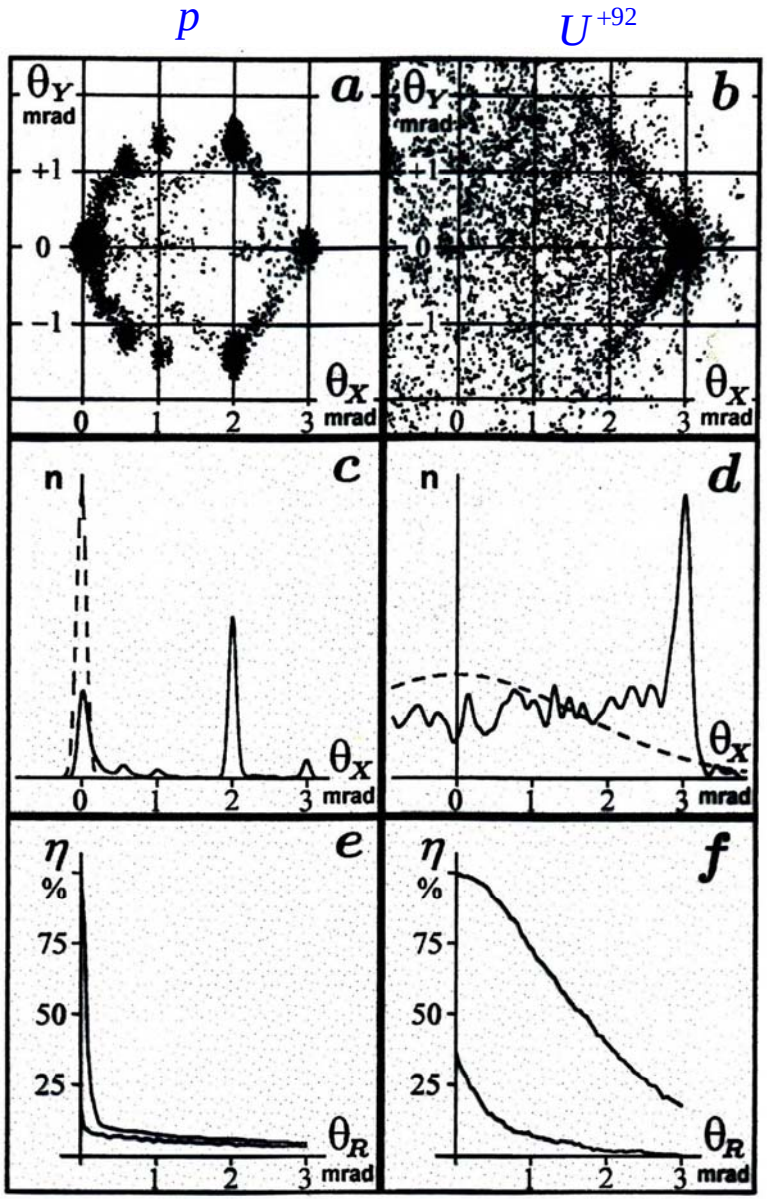
$$l_0 \sim \frac{1}{n\,a\,R\,\psi_c}$$

Simulation for CERN Experiment Experimental Situation

A.Greenenko, N. Shul'ga (1999)

$\varepsilon = 450\,GeV,\ L = 3\,cm,$

$R = 10\,m,\ Si,\ <110>$



$\alpha_p = 80$ $\alpha_{U^{+92}} = 0.1$

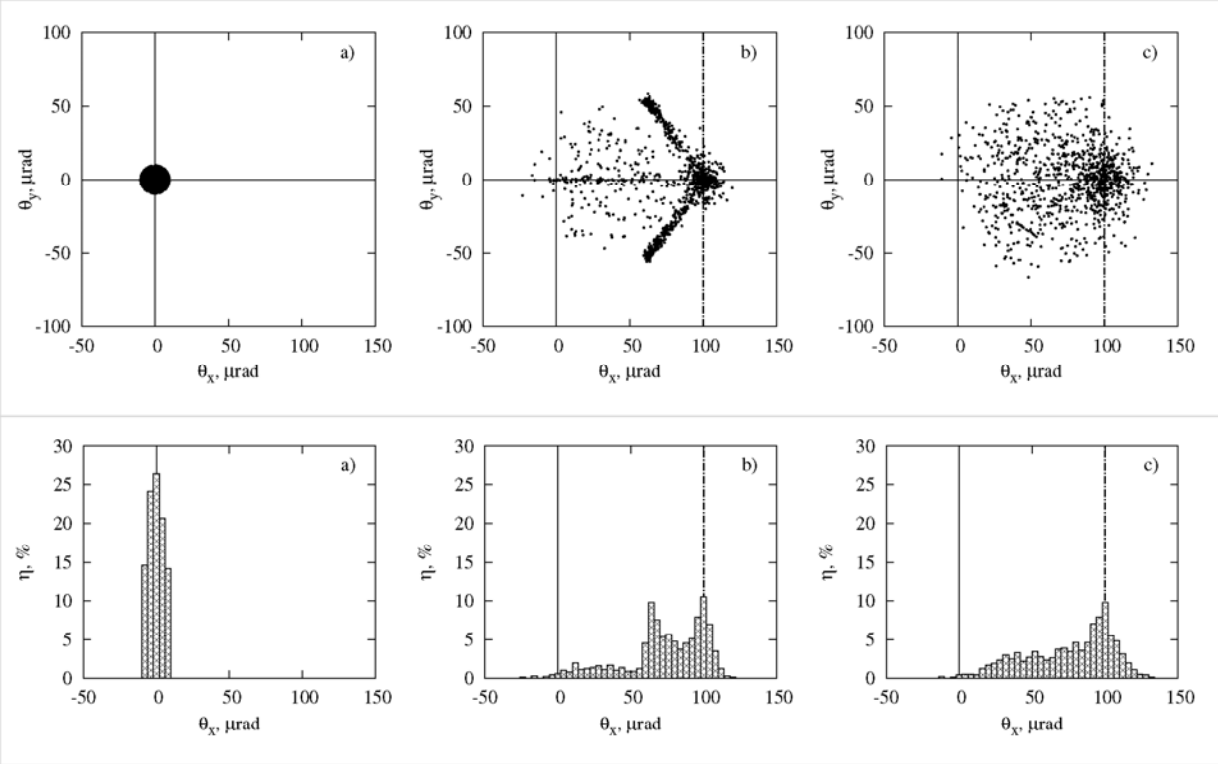
SIMULATION RESULTS

Stochastic deflection mechanism

particle beam before entering the crystal

protons

π^--mesons



Beam center before entering the crystal had the same angular coordinates as the ⟨110⟩ crystal axis

E=1 TeV, L=2 cm, R=200 m

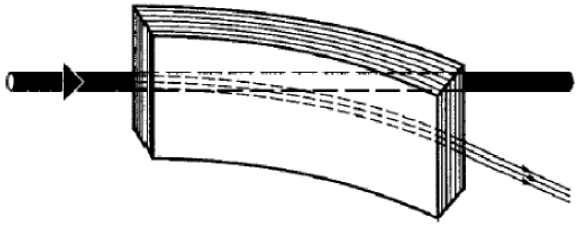
Collaboration AFTER
(A Fixed Target ExpeRiments)
Orsay, France; CERN

AFTER @ LHC

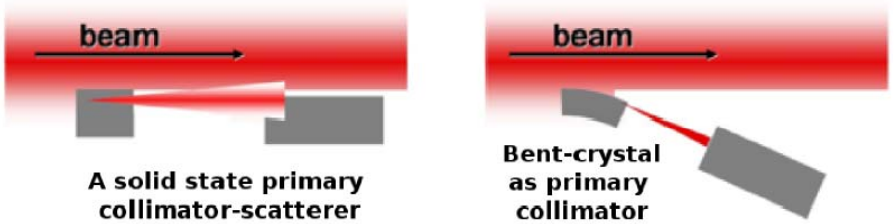
The beam extraction

★ The LHC beam may be extracted using “Strong crystalline f eld”
without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



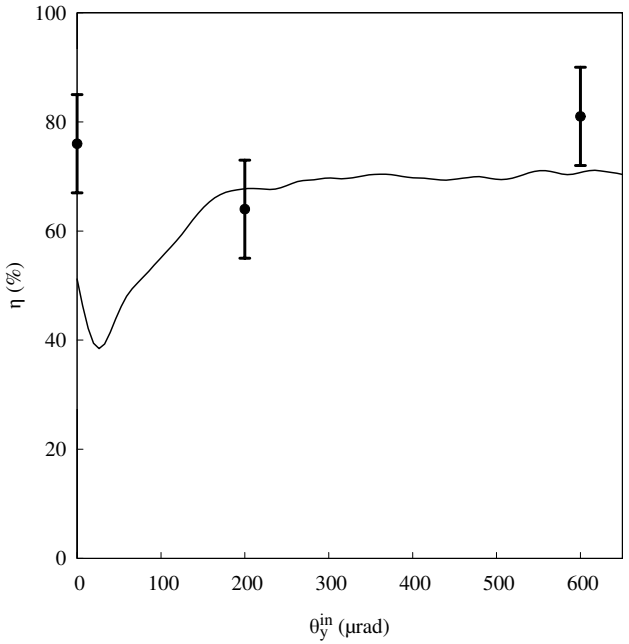
★ Illustration for collimation



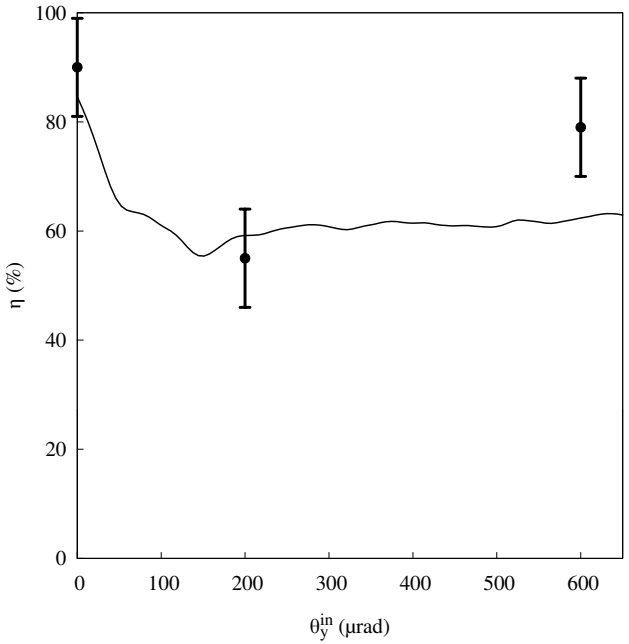
★ Tests will be performed on the LHC beam:
LUA9 proposal approved by the LHCC

Joint with IHEP (Protvino, Russia) work on comparative analysis of different mechanisms of proton beam deflection by means of a bent crystal

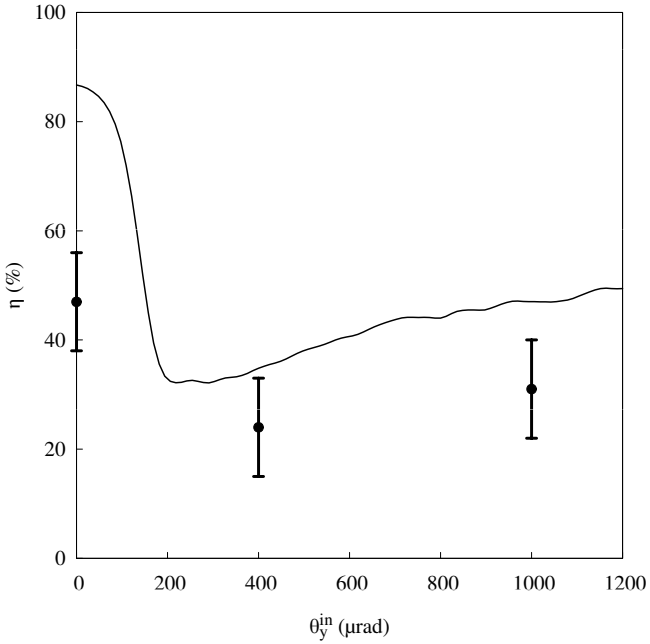
E_{kin}=50 GeV



E_{kin}=15 GeV



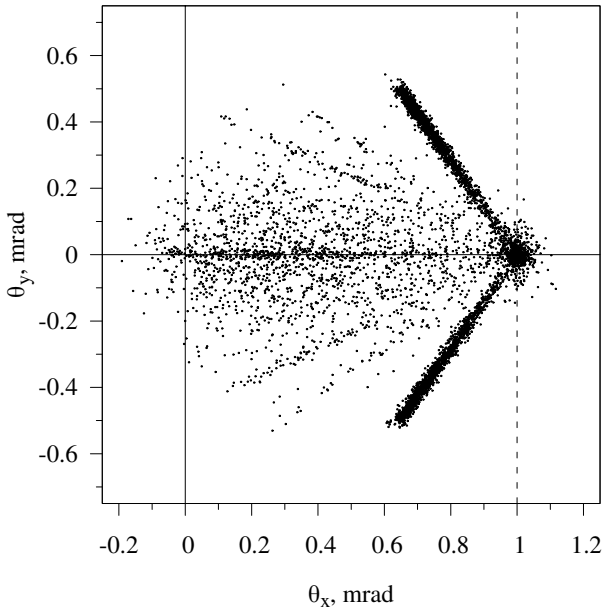
E_{kin}=1 GeV

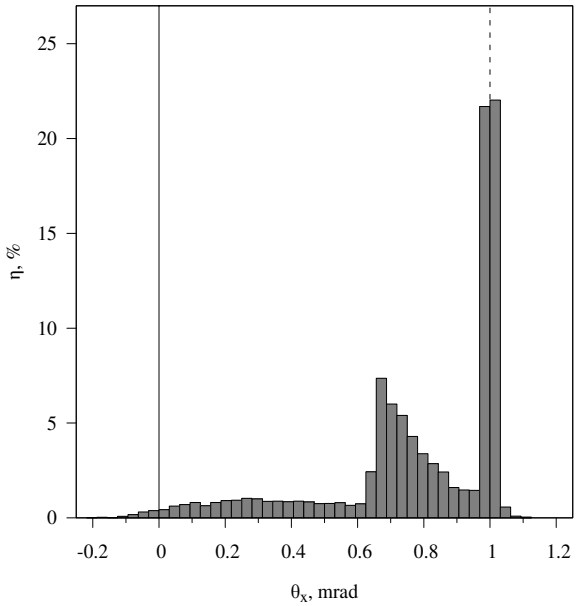


N. Shul'ga, I. Kirillin, V. Truten', V. Ganenko et al.
JETP Letters, 2014, Vol. 99, No. 4, pp. 179–181.

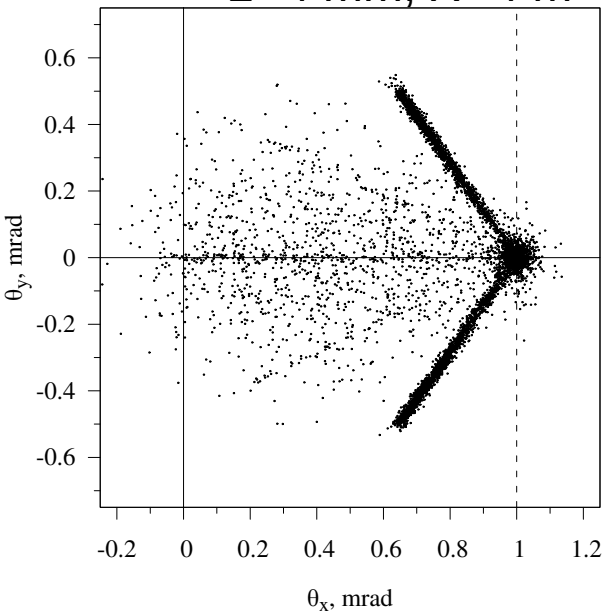
Proton beam deflection, E_{kin} =29 GeV, Si <110>

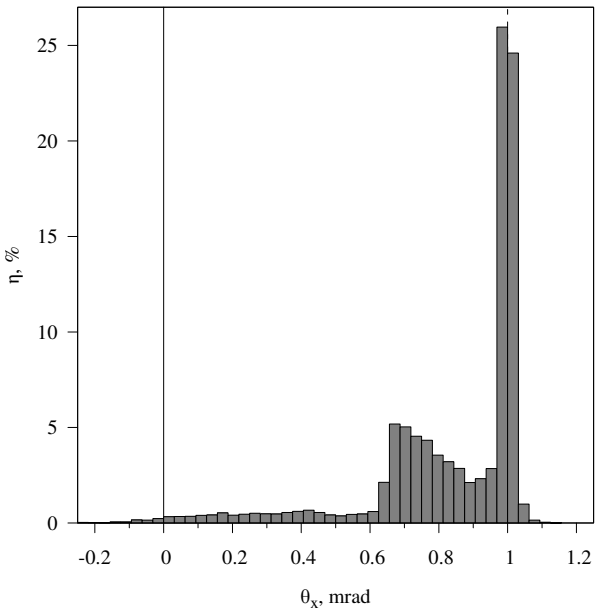
L=2 mm, *R*=2 m





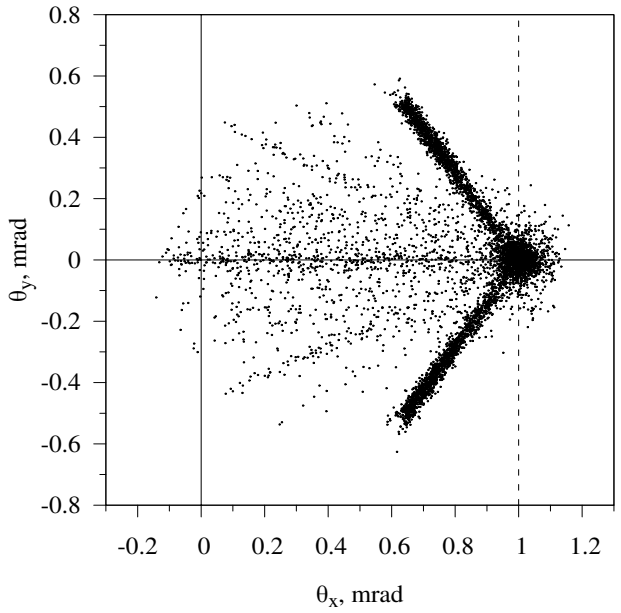
L=4 mm, *R*=4 m



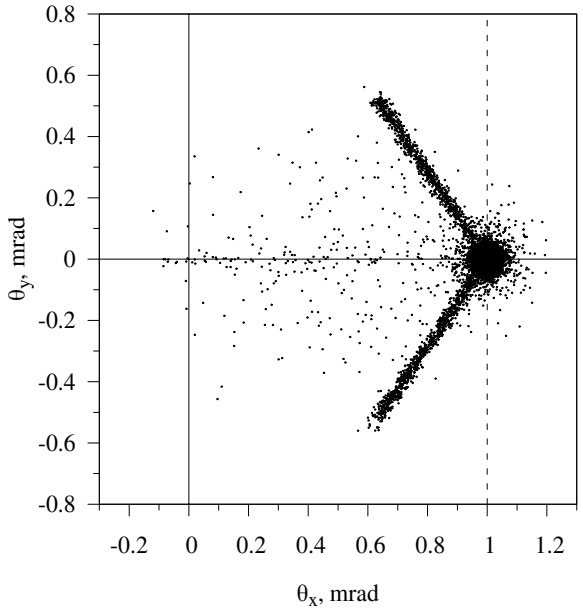


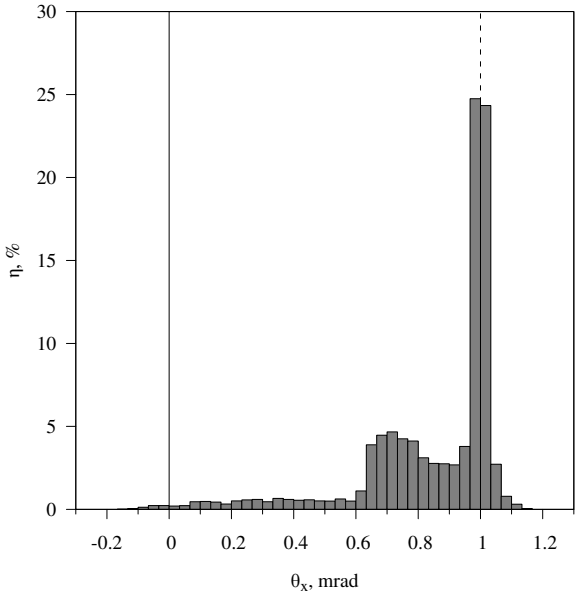
$^{238}U^{28+}$ ions, Ekin =1 GeV / nucl., L=1 mm, R=1 m, Si <110>

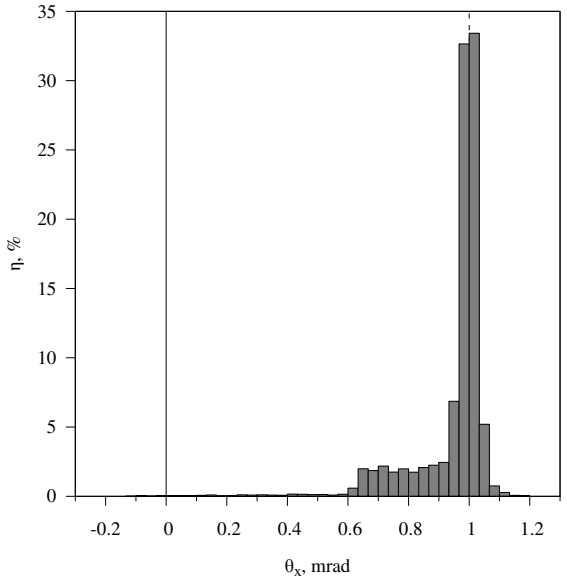
L=1 mm, *R*=1 m



L=5 mm, *R*=5 m







CONCLUSIONS

Antiproton beam from HESR

1. Physical background
   Simulation
   Optimization
   Proposal

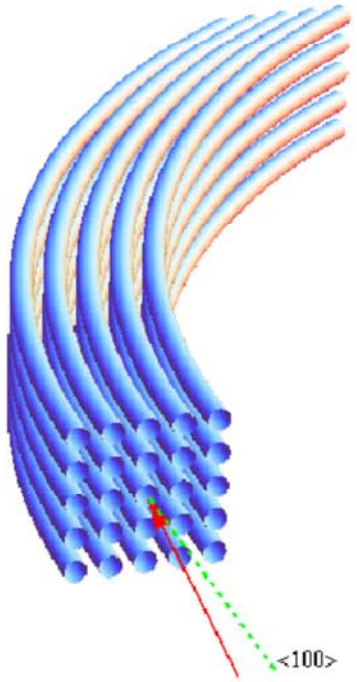
National Science Center “Kharkov Institute of Physics and Technology“

2. Experiment

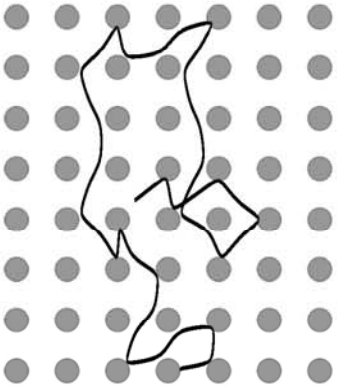
LAL (Orsay, France)
Ferrara University (Italy)
CERN collaboration UA9
IHEP (Protvino, Russia)
JINR (Dubna, Russia)

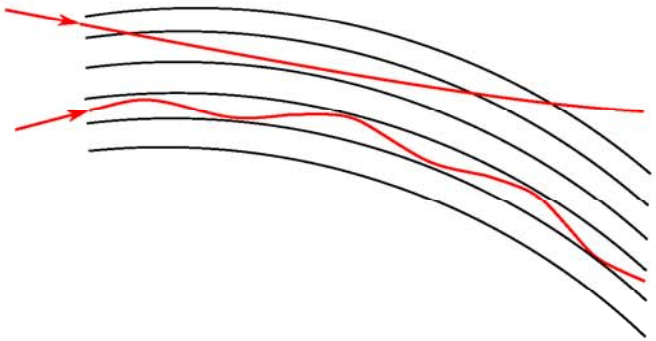
Protons, strongly charged ions. GSI

Thank you for your attention!



SIMULATION METHOD





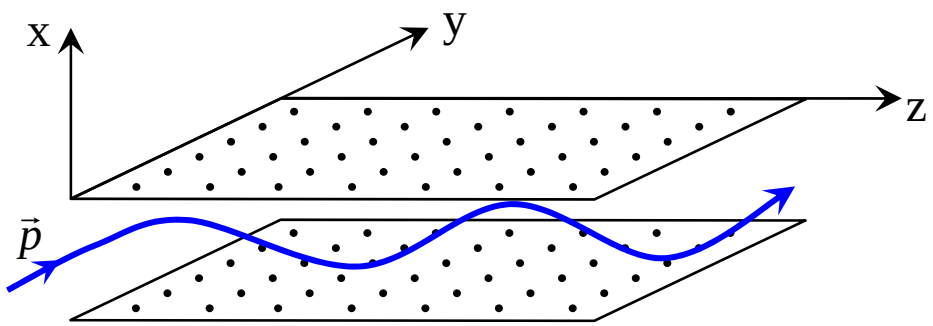
- particle motion in the field of crystal atomic strings
- incoherent scattering

- axial channeling
- multiple scattering by atomic strings
- planar channeling
- reflection from planes
- transitions between these processes

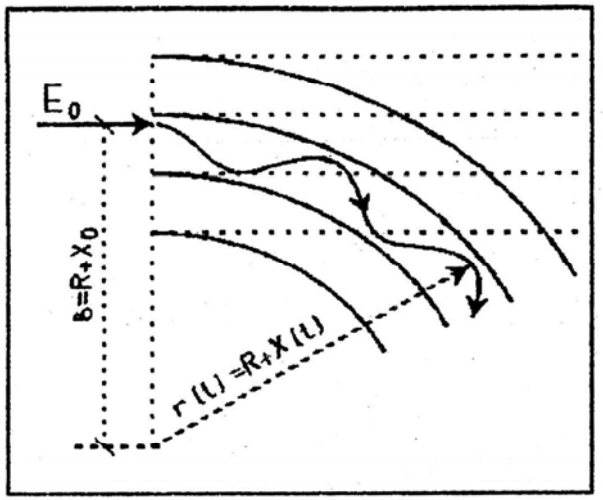
N. Shul'ga, V. Truten' and I. Kirillin. Journ. of Phys.: Conf. Ser. 236 (2010) 012030
N. Shul'ga, I. Kirillin and V. Truten'. Phys. Lett. B 702 (2011) 100

Beam Deflection of fast Charged Particles due to Plane Channeling Effect in Bent Crystal

E.Tsyganov (1976)



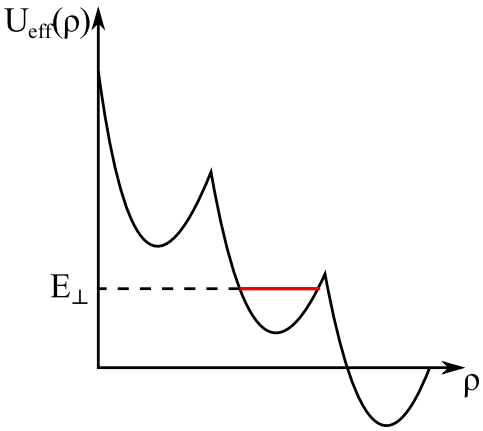
Plane channeling, Lindhard 1965



$$\frac{d^2x}{dt^2} = -\frac{c^2}{E}\frac{\partial}{\partial x}U_{eff}$$

$$U_{eff}(x) = U(x) - x\frac{E}{R}$$

$$R_c = d\frac{E}{4U_{\max}}$$



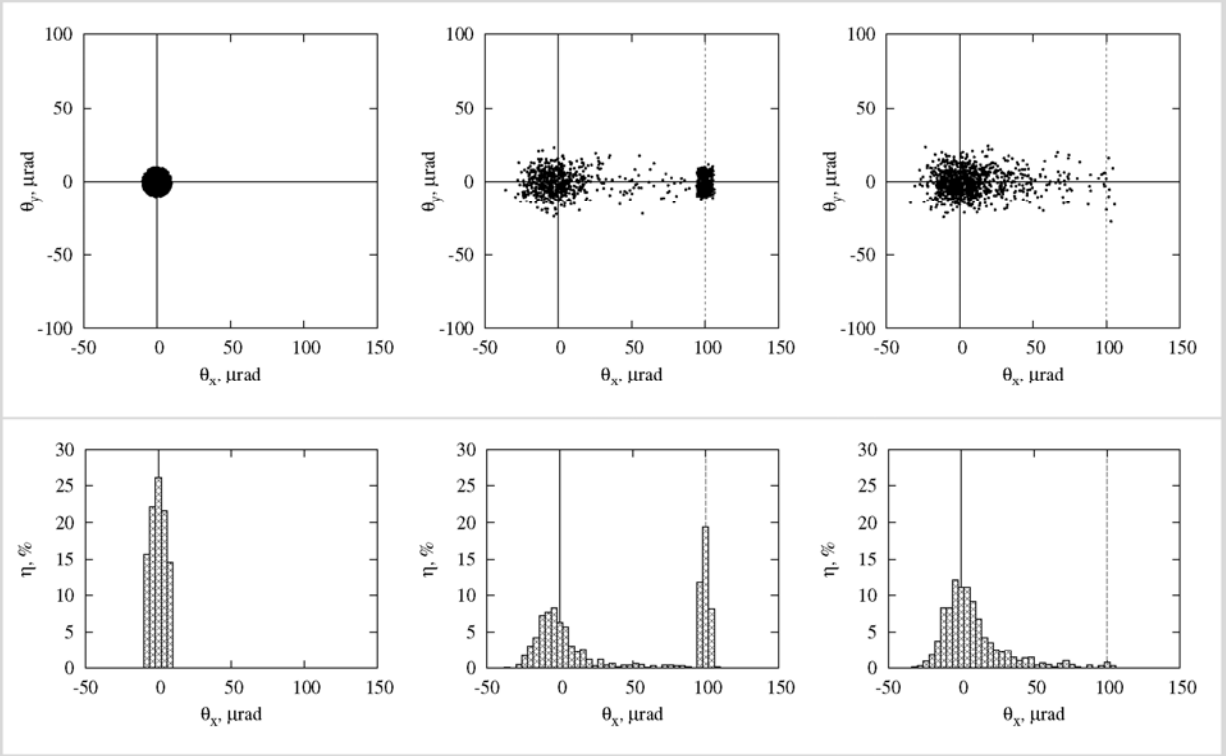
SIMULATION RESULTS

Planar channeling in bent crystal

particle beam before entering the crystal

protons

π^--mesons



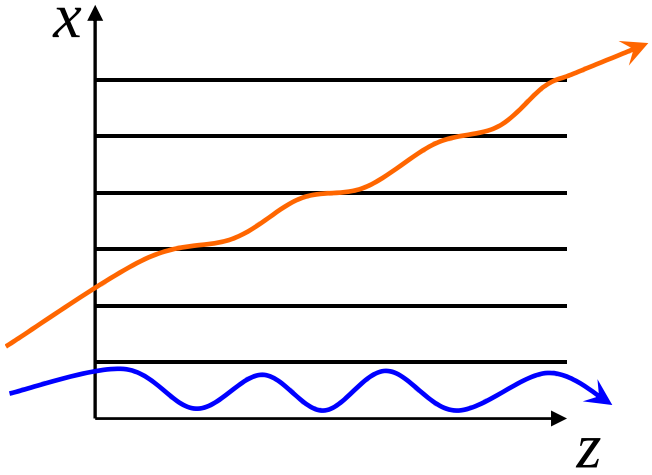
Beam center before entering the crystal had angular coordinates (0,500) μrad with relative to the $\langle 110 \rangle$ crystal axis

($500\ \mu\text{rad} \approx 50\ \theta_c$)

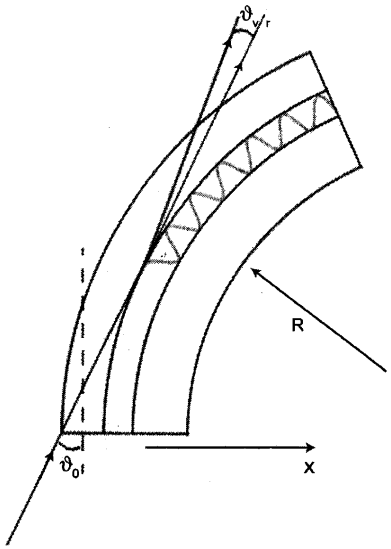
E=1 TeV, L=2 cm, R=200 m

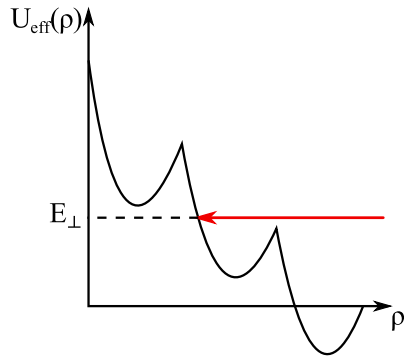
“Volume reflection” effect

A. Taratin, S. Vorobiev 1987



Above barrier motion
Akhiezer, Shul’ga 1978





N.F. Shul’ga, V.I. Truten’, et al. Phys. Lett. A 376 (2012) 2617

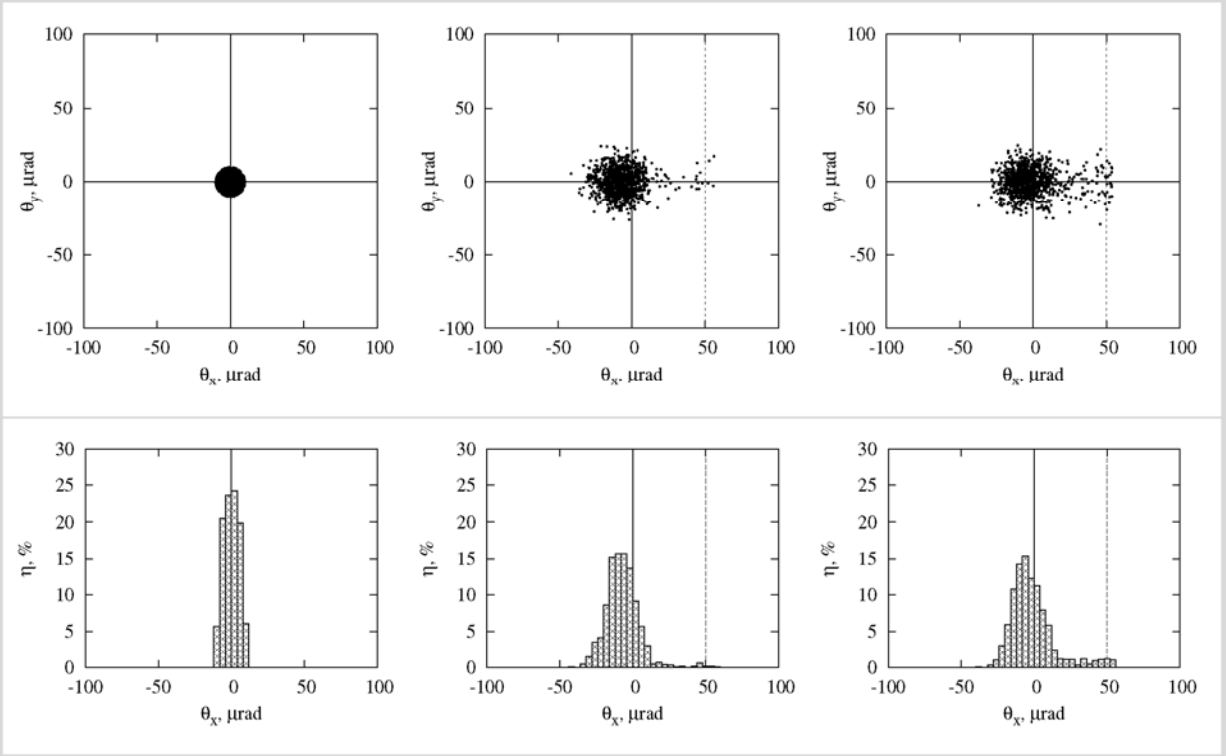
SIMULATION RESULTS

Charged particle reflection from bent crystal atomic planes

particle beam before entering the crystal

protons

π^--mesons



Beam center before entering the crystal had angular coordinates (50,500) μrad with relative to the $\langle 110 \rangle$ crystal axis

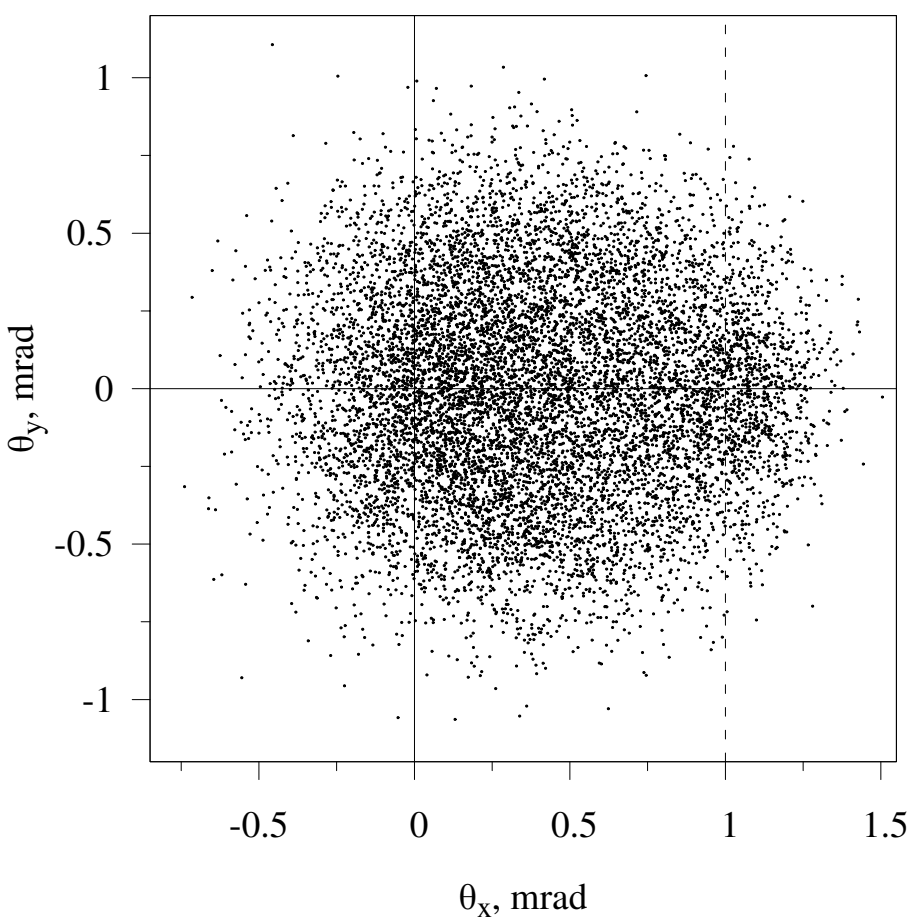
($500\ \mu\text{rad} \approx 50\ \theta_c$)

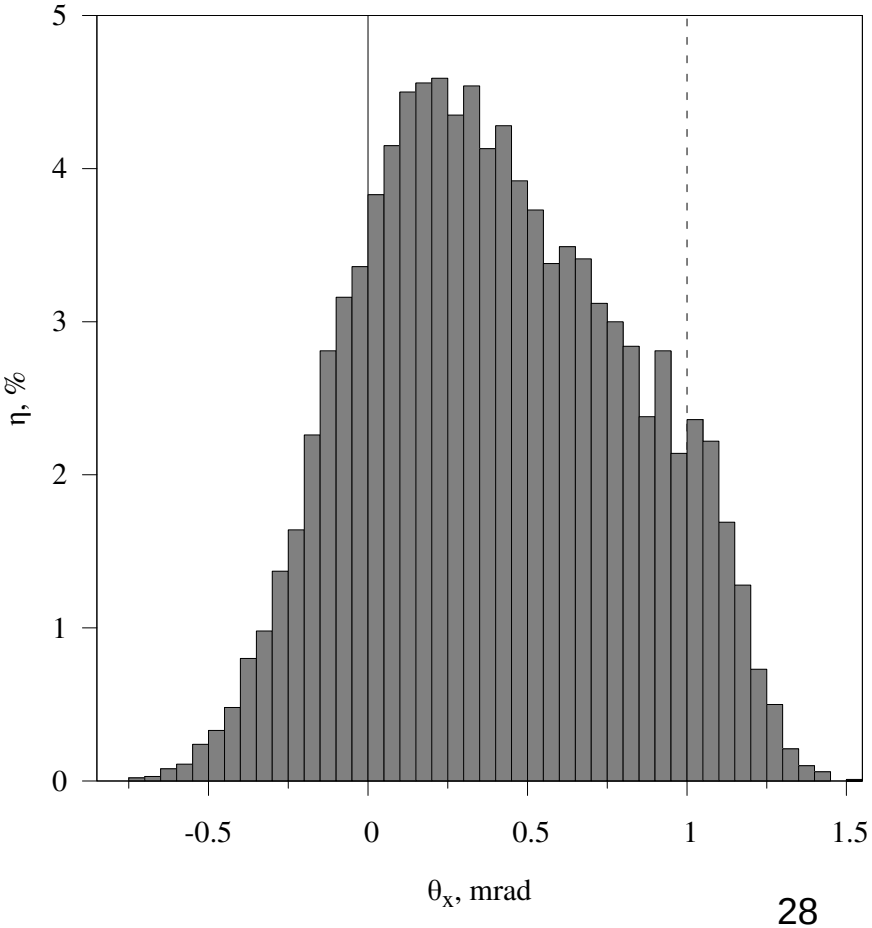
E=1 TeV, L=2 cm, R=200 m

Collaboration FAIR (PANDA Experiment)

(GSI, Germany – JNRS, Dubna, Russia – …)

Antiprotons, E_{kin} =10 GeV, L=2 mm, R=2 m, Si <110>

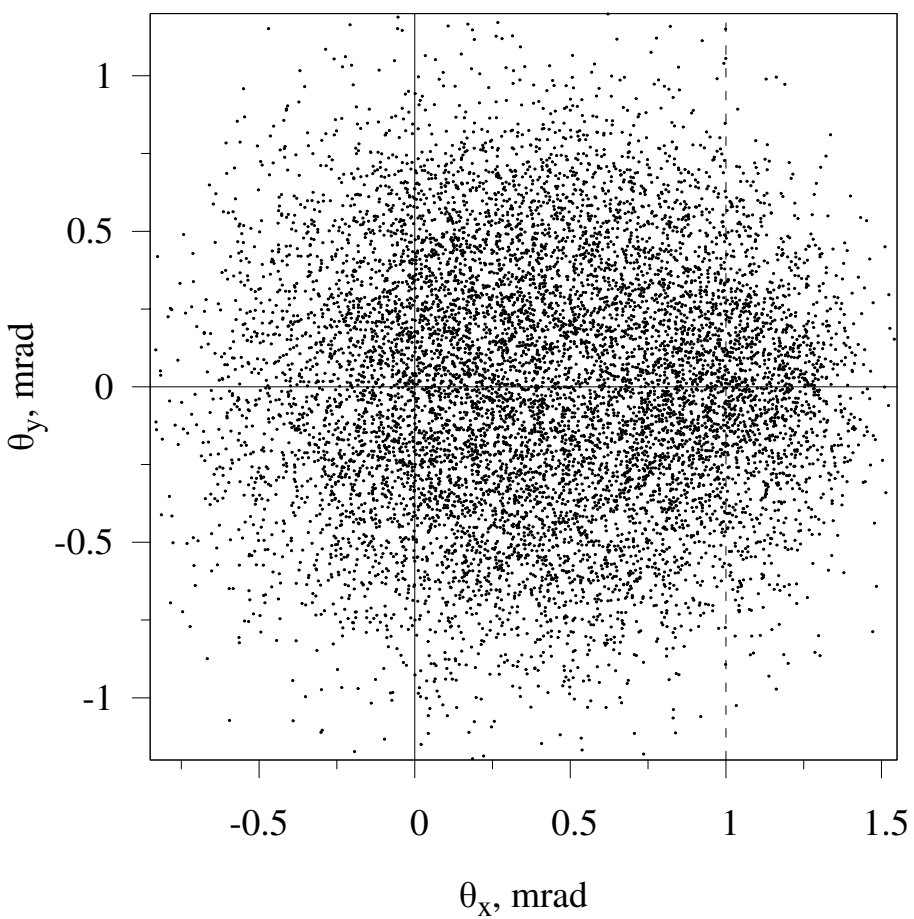


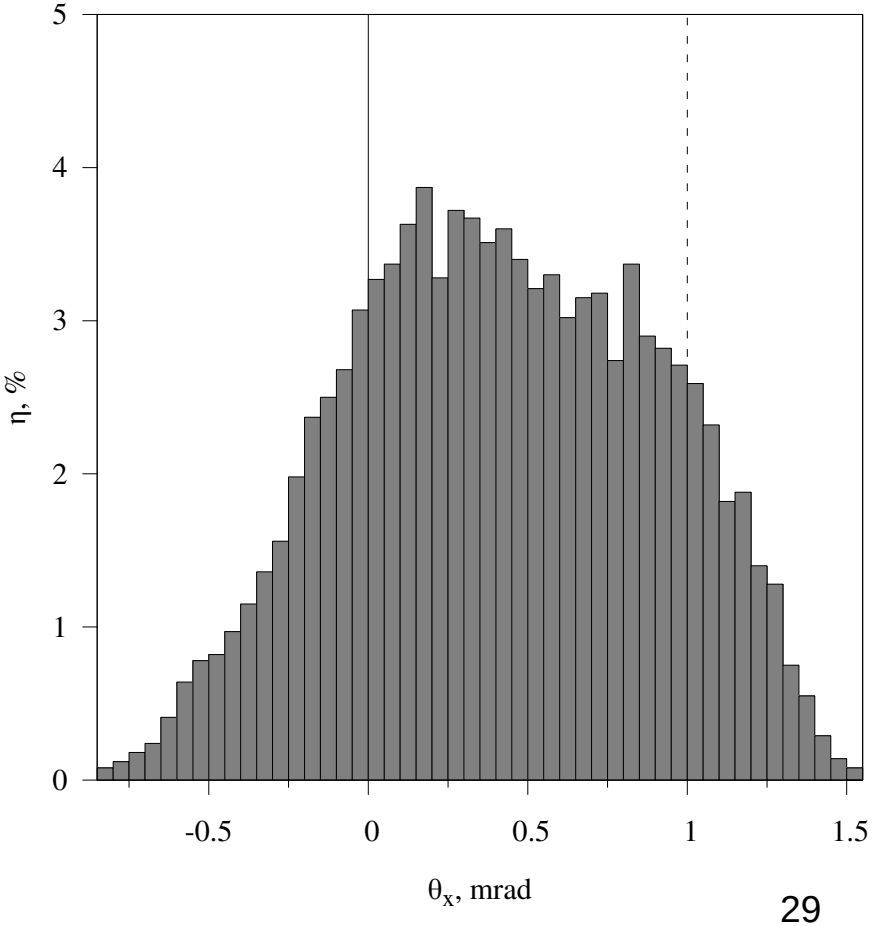


Collaboration FAIR (PANDA Experiment)

(GSI, Germany – JNRS, Dubna, Russia – …)

Antiprotons, E_{kin} =10 GeV, L=4 mm, R=4 m, Si <110>



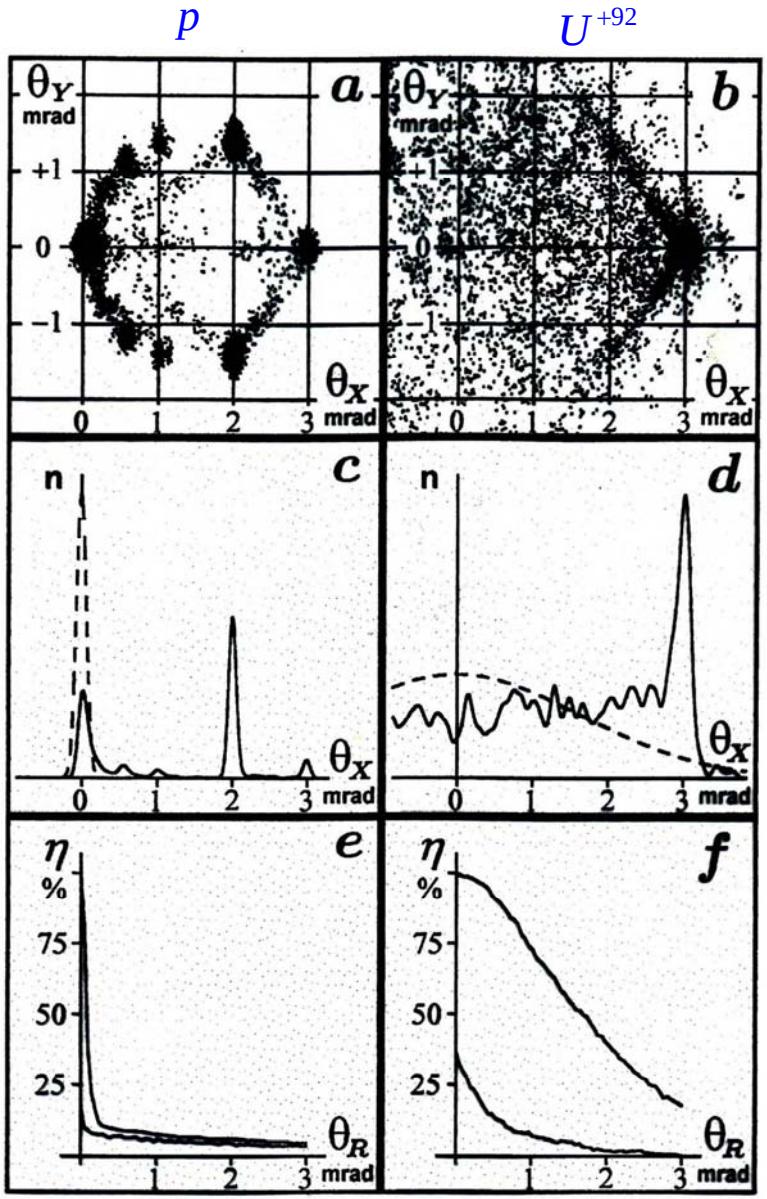


Simulation for CERN Experiment Experimental Situation

A.Greenenko, N. Shul'ga (1999)

$\varepsilon = 450\,GeV,\ L = 3\,cm,$

$R = 10\,m,\ Si,\ <110>$



$\alpha_p = 80$ $\alpha_{U^{+92}} = 0.1$