Focusing of high energy particles with help of bent single crystal

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Abstract

This report is continuation of study of the focusing properties of bent single crystals. Resently the transformation of parallel beam into pointlike beam was demonstrated theoretically and experimentally. Here we investigate the inverse problem when a pointlike beam is transformed into parallel one. We show that the application of such focusing case allow one to generate more intensive beams of the secondary particles in the comparison with the traditional method.

The first focusing experiments were carried out in 1991 year. (M.A. Gordeeva, M.P. Gur'ev, A.S. Denisov et. al. JETP Lett., Vol. 54 No. 9, p. 487 (1991).)

The theoretical description of the focusing standed on the geometrical relations.

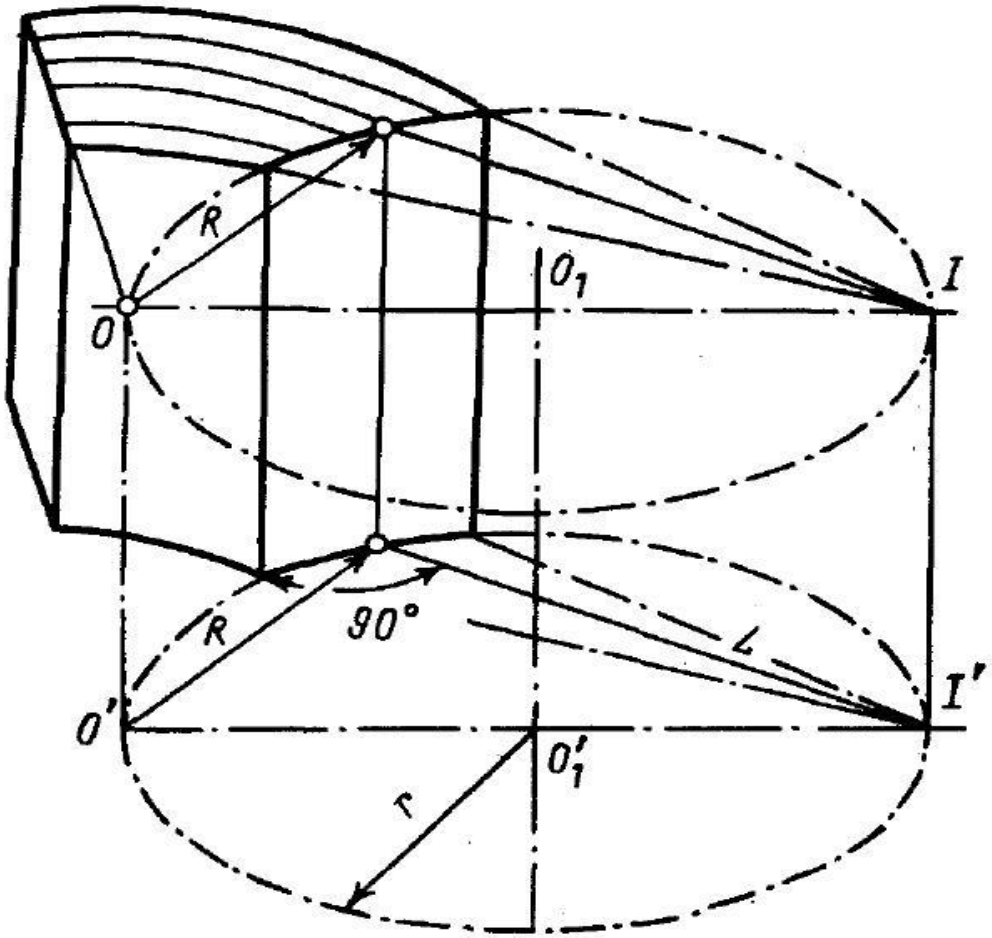
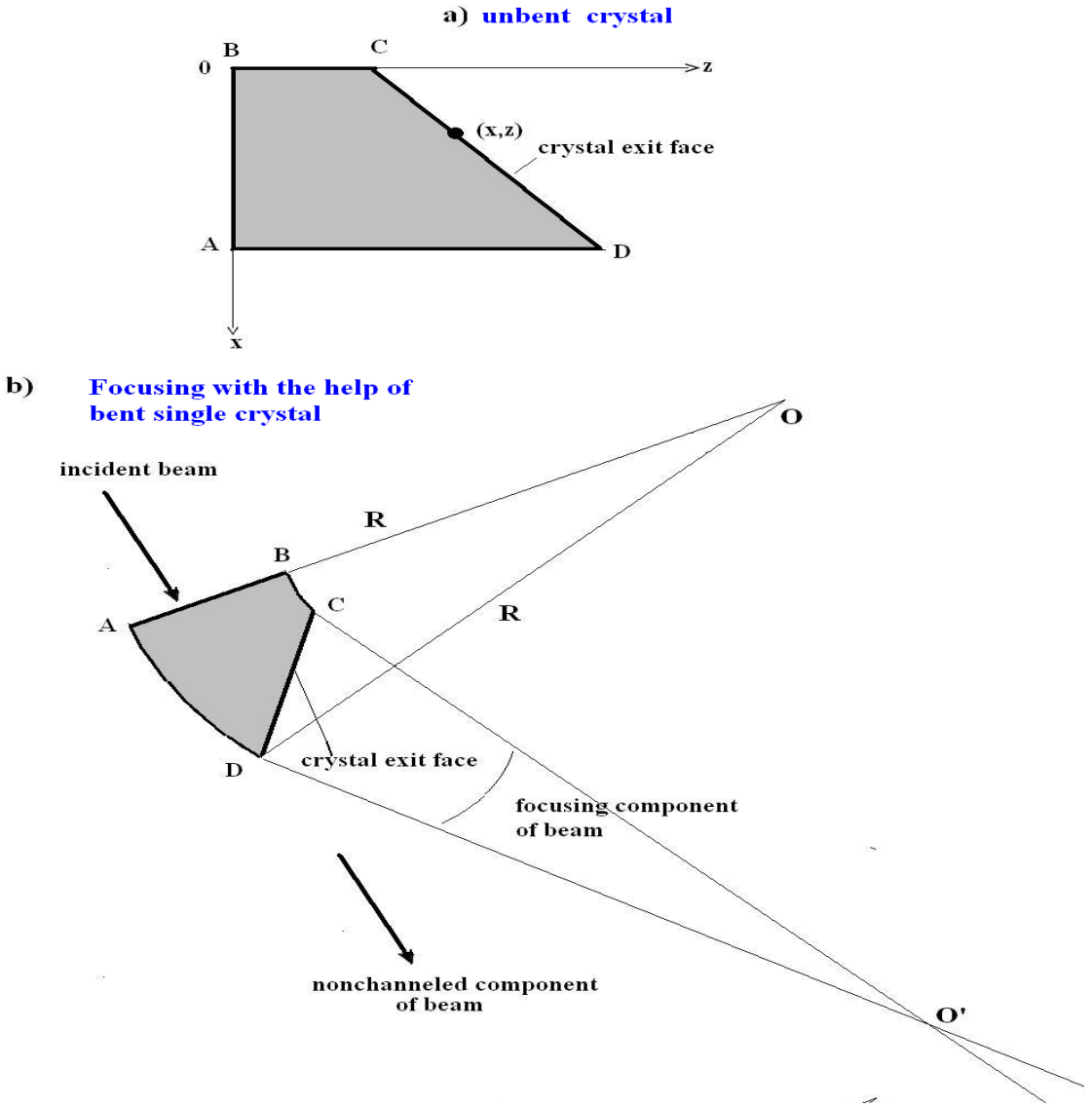
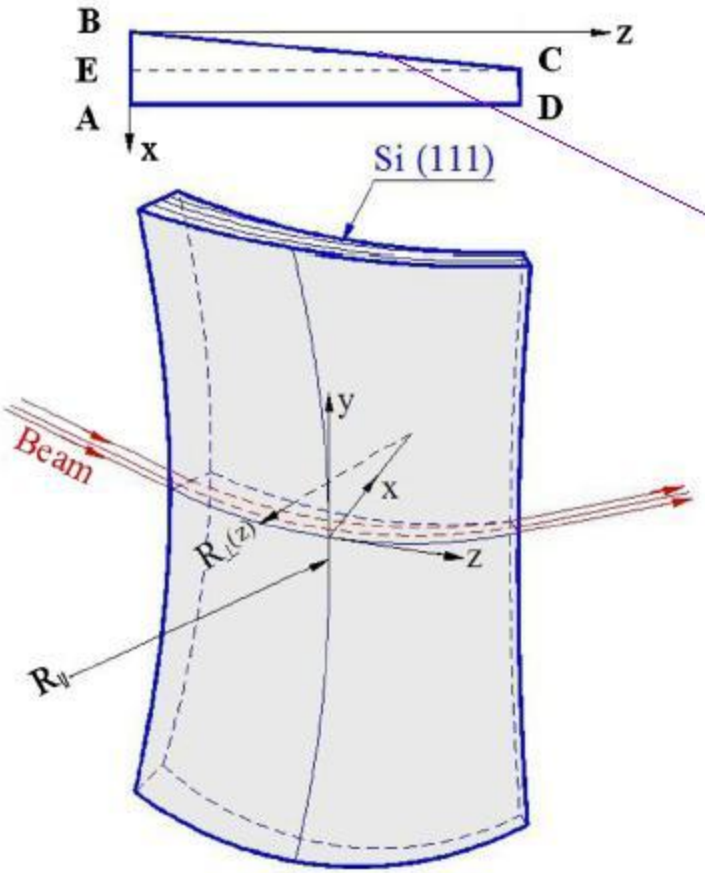


FIG. 1. Principle for focusing a beam by means of a crystal. OO'—The line running through the centers of curvature of the crystallographic planes; O_1O_1'—the axis of the cylinder of radius r in accordance with which the end of the crystal is shaped; II'—focus line, at which the tangents to the curved planes converge according to a known geometric theorem.


a) unbent crystal
B
C
0
z
(x,z)
crystal exit face
A
D
x
b)
Focusing with the help of
bent single crystal
O
incident beam
R
B
C
R
A
D
crystal exit face
focusing component
of beam
nonchanneled component
of beam
O'

Detailed investiganion of focusing properties of the single crystal recently was made in the frame of the UA9 collaboration (at H8 beamline of SPS, CERN).

W.Scandale, G. Arduini, M. Batcher et. al. Phys. Lett. B 733 (2014),366-372



The sample of investigated bent crystal deflector.

Linear cut of the crystal. Only this part has focusing property and was studied.

Two crystals were used for study.

The envelope of the beam as a function of the distance l one can calculate with the help of the following equation

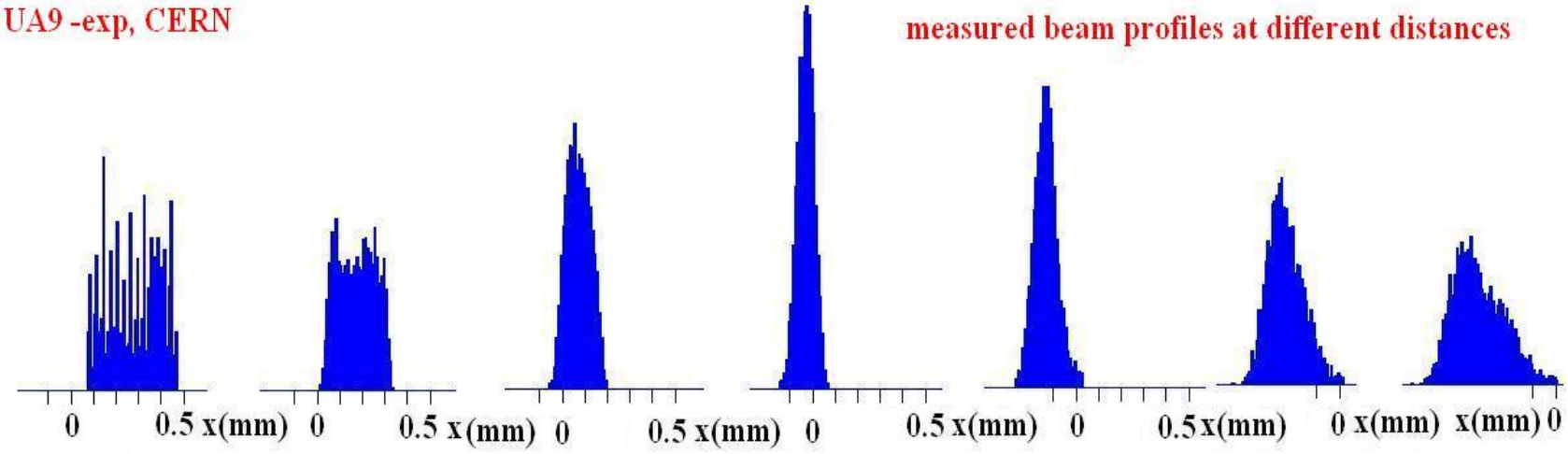
$$\sigma_x(l) = \langle x^2 \rangle - \overline{x}^2 + [(\langle \varphi^2 \rangle - \overline{\varphi}^2) + (\langle \theta^2 \rangle - \overline{\theta}^2)]l^2 + 2(\langle x\varphi \rangle - \overline{x}\,\overline{\varphi})l\,, \tag{1}$$

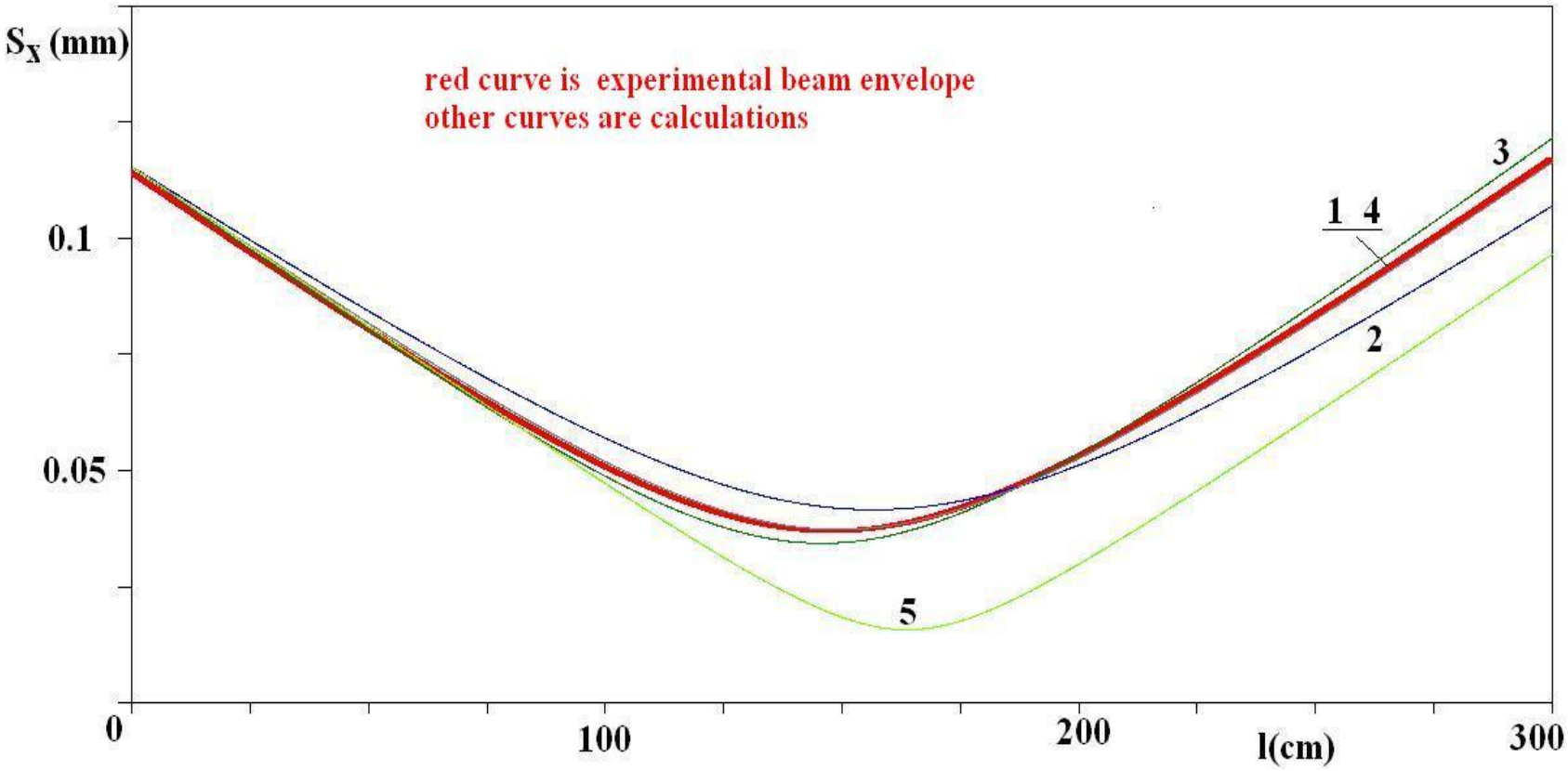
where $\langle x^2 \rangle$ and $\overline{x}$ are the mean square size and mean size of the beam at $l = 0$;
$\langle \varphi^2 \rangle$ and $\overline{\varphi}$ are the square angle of a beam deflection and mean deflection angle;
$\langle \theta^2 \rangle$ and $\overline{\theta}$ are the square angle of a beam deflection and mean deflection angle due to oscillator motion at channeling;
$\langle x\varphi \rangle = \int_0^d x\varphi(x)\rho(x)dx$
$\rho(x)$ is the distribution function over x-coordinate normalized on unity.
The function $\sigma_T(l)$ has a minimum when

$$l = l_f = -\frac{\langle x\varphi \rangle - \overline{x}\,\overline{\varphi}}{\langle \varphi^2 \rangle - \overline{\varphi}^2 + \langle \theta^2 \rangle - \overline{\theta}^2}. \tag{2}$$

UA9 -exp, CERN

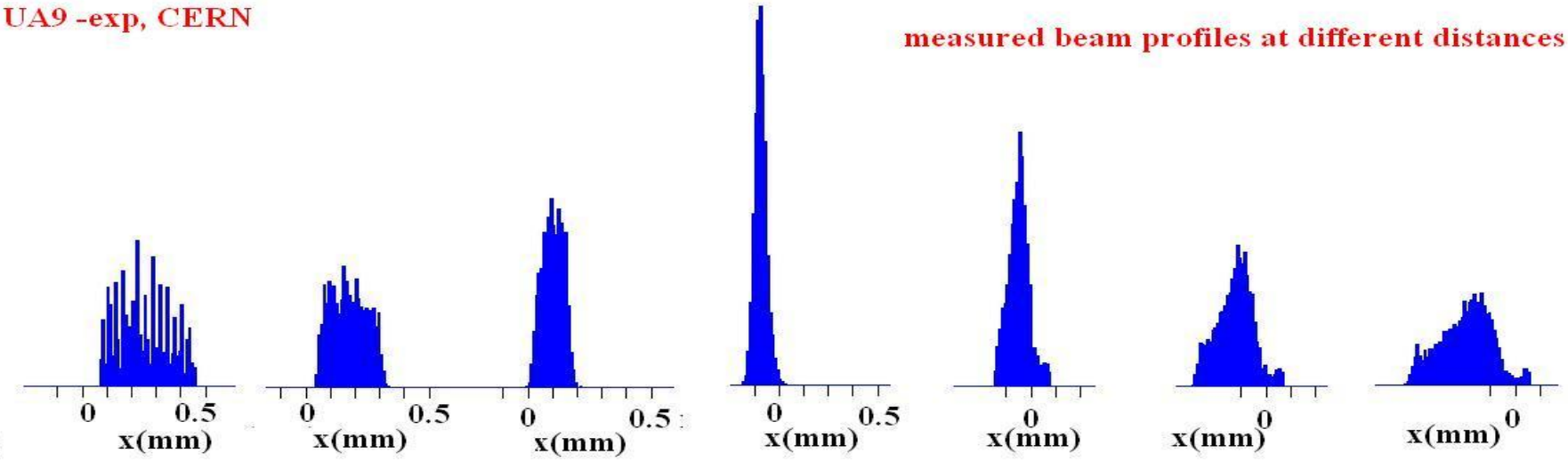
measured beam profiles at different distances

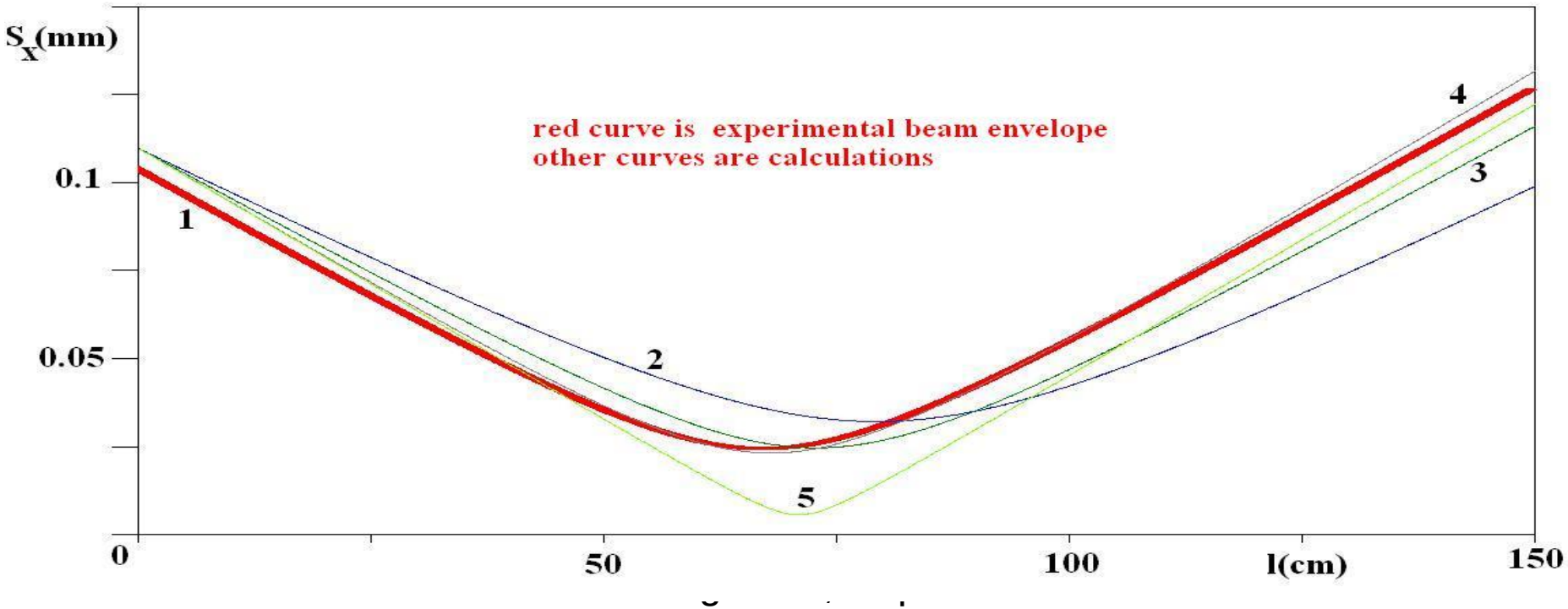


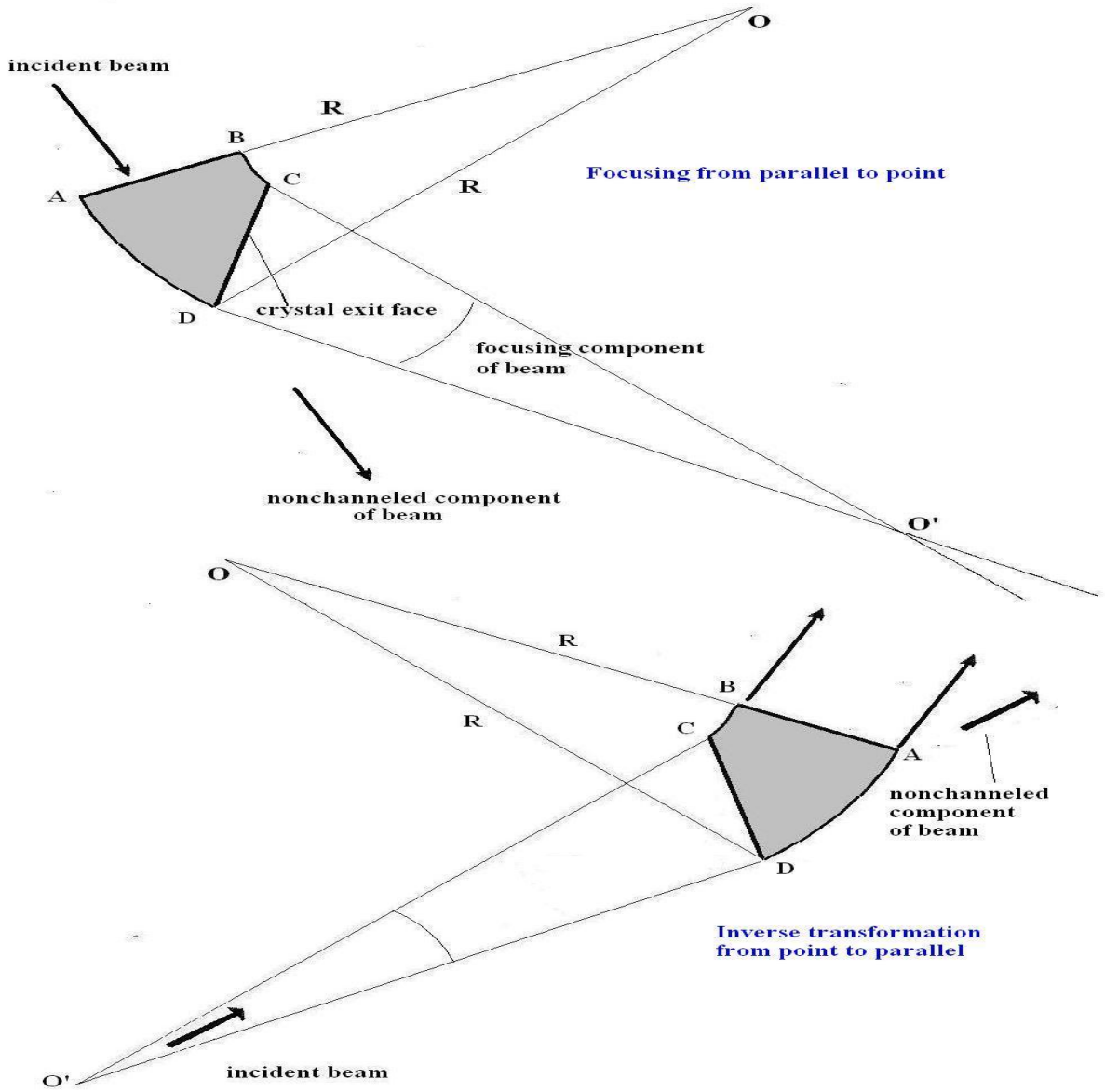


UA9 -exp, CERN

measured beam profiles at different distances

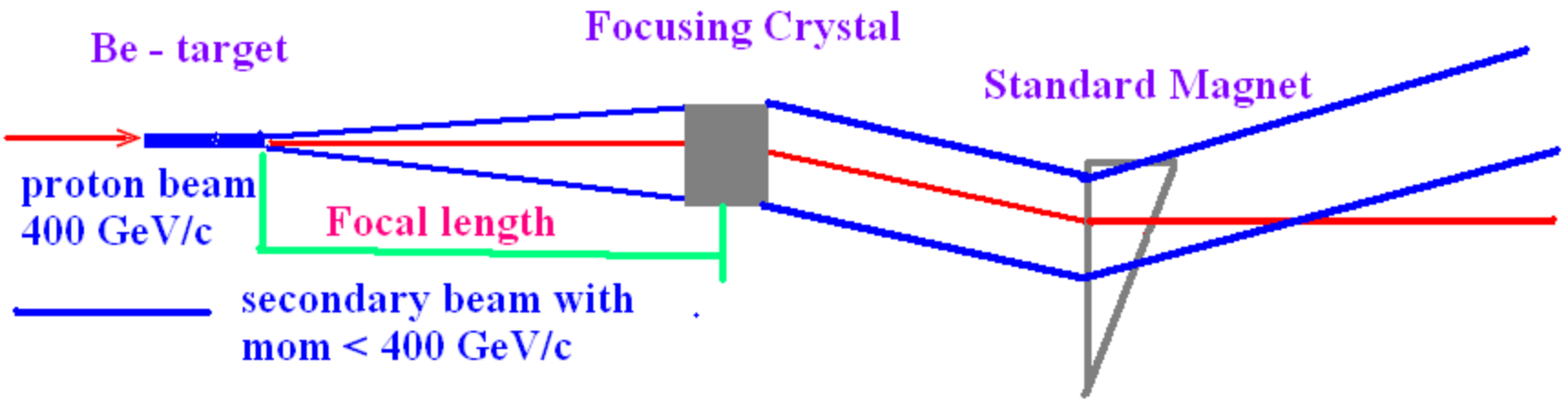




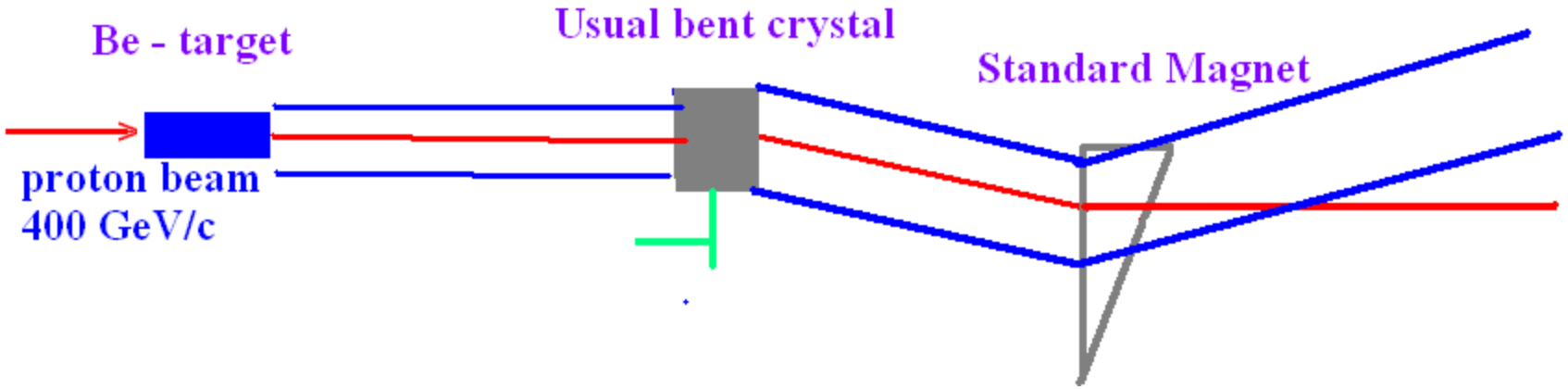

incident beam
O
R
B
C
A
R
Focusing from parallel to point
D
crystal exit face
focusing component
of beam
nonchanneled component
of beam
O'
O
R
R
B
C
A
nonchanneled
component
of beam
D
Inverse transformation
from point to parallel
O'
incident beam

Usage of inverse transformation of beam for obtaining intensive beam of a secondary particles.

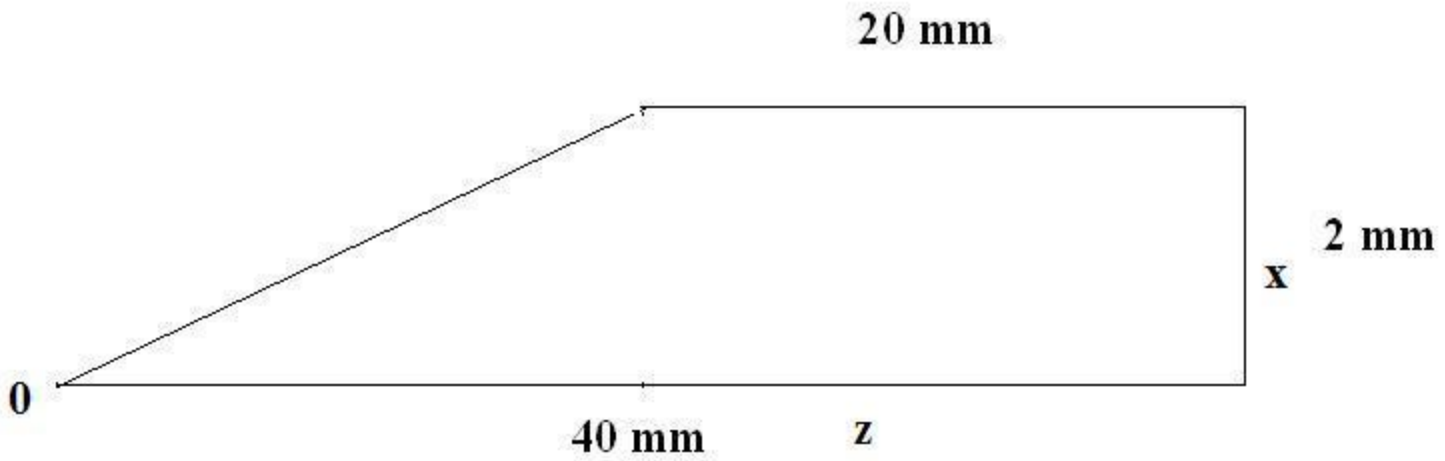
CASE "point to parallel"



CASE "parallel to parallel"



For calculations the sample fabricated in IHEP was used:



The bending radius about 15 m

In calculations we used the linear angle dependence $\varphi(x) = kx/R_0 = z/R_0$

The next calculations of secondary particle fluxes were made at suggestion of 100% capture in the channeling regime incoming in crystal particles. In reality these fluxes should be multiply on this value (about 0.75 or less).

Acceptance of secondary beam

Prodaction angle $\theta^2 = \theta_x^2 + \theta_y^2$ (xz -channeling plane)

At large θ the number of particle is small

We use max angle θ equal 0.0025 or 0.0125 radian in calculations

point to parallel

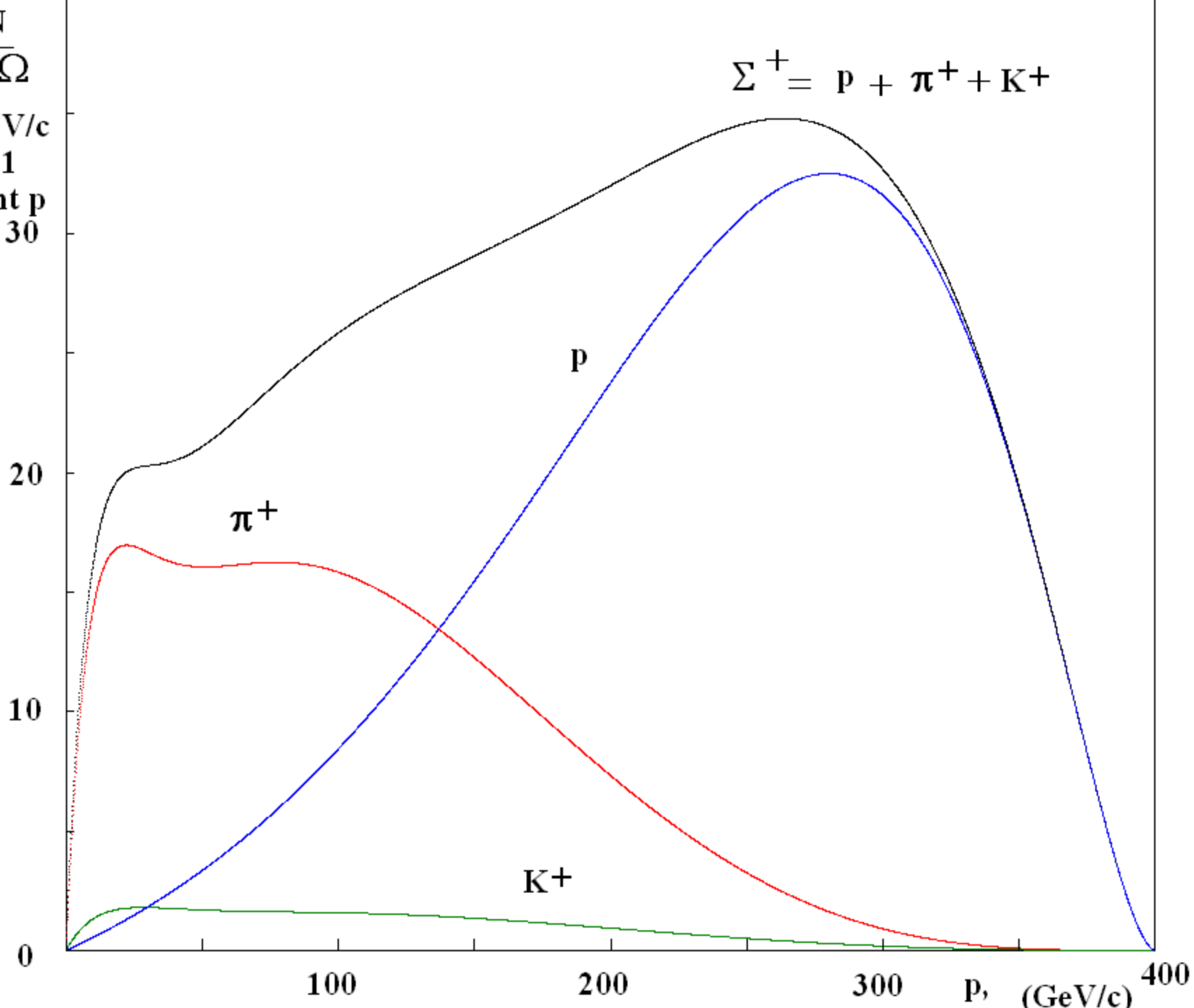
$\theta_{x\,(max)}$ is approx equal to $\pm \frac{d}{2\,l_f}$

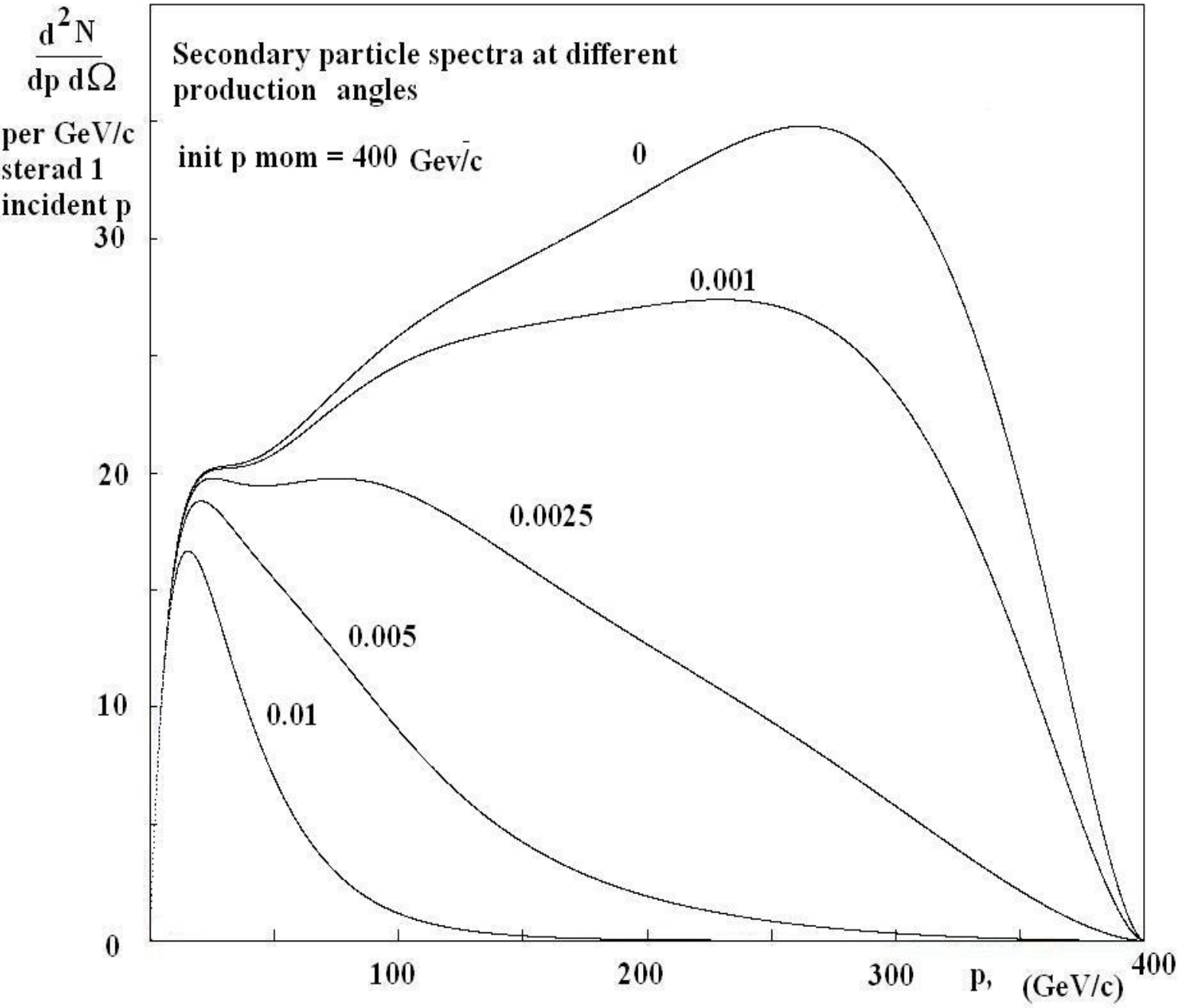
d transversal size of the crystal

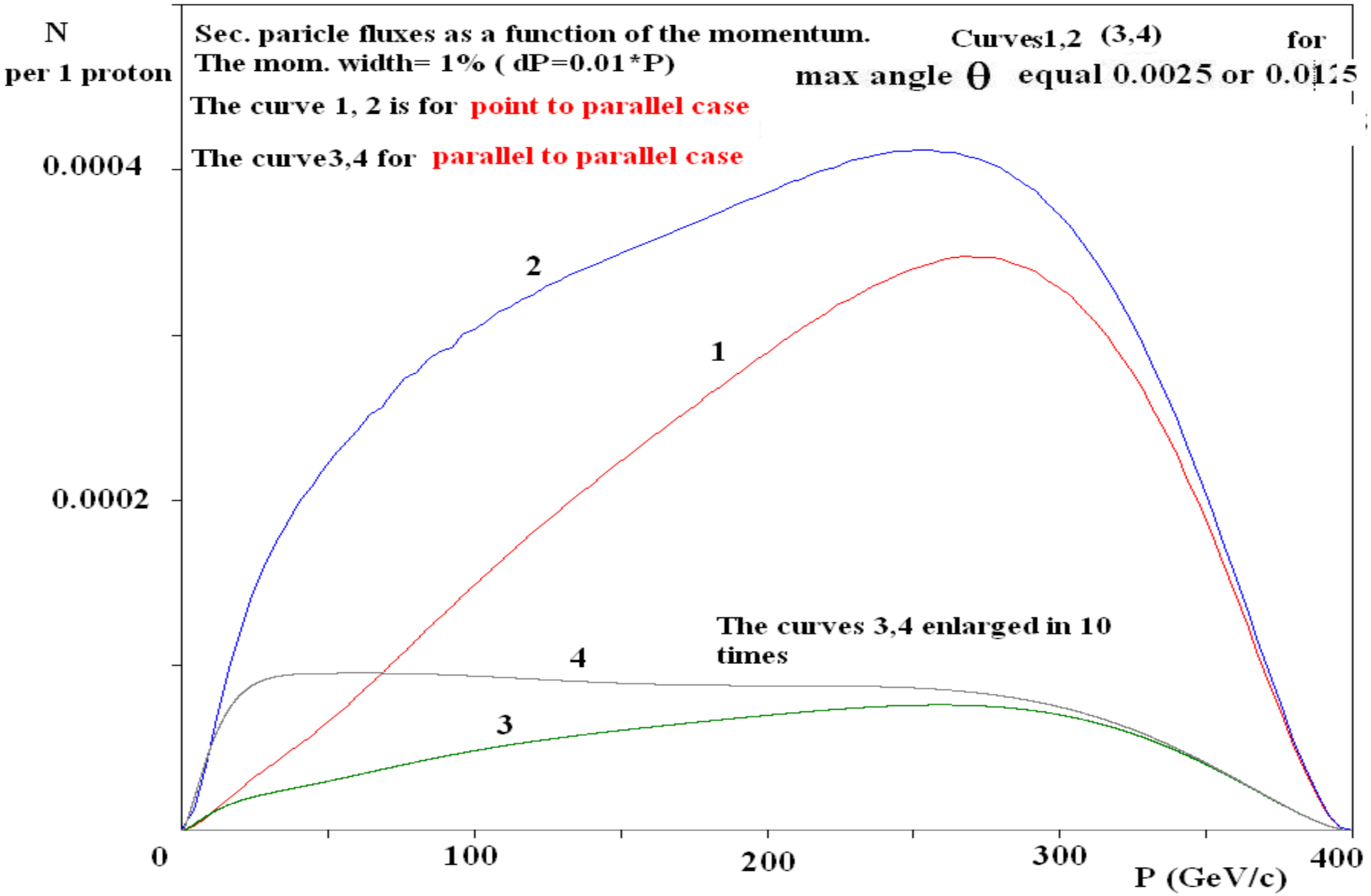
l_f focal length

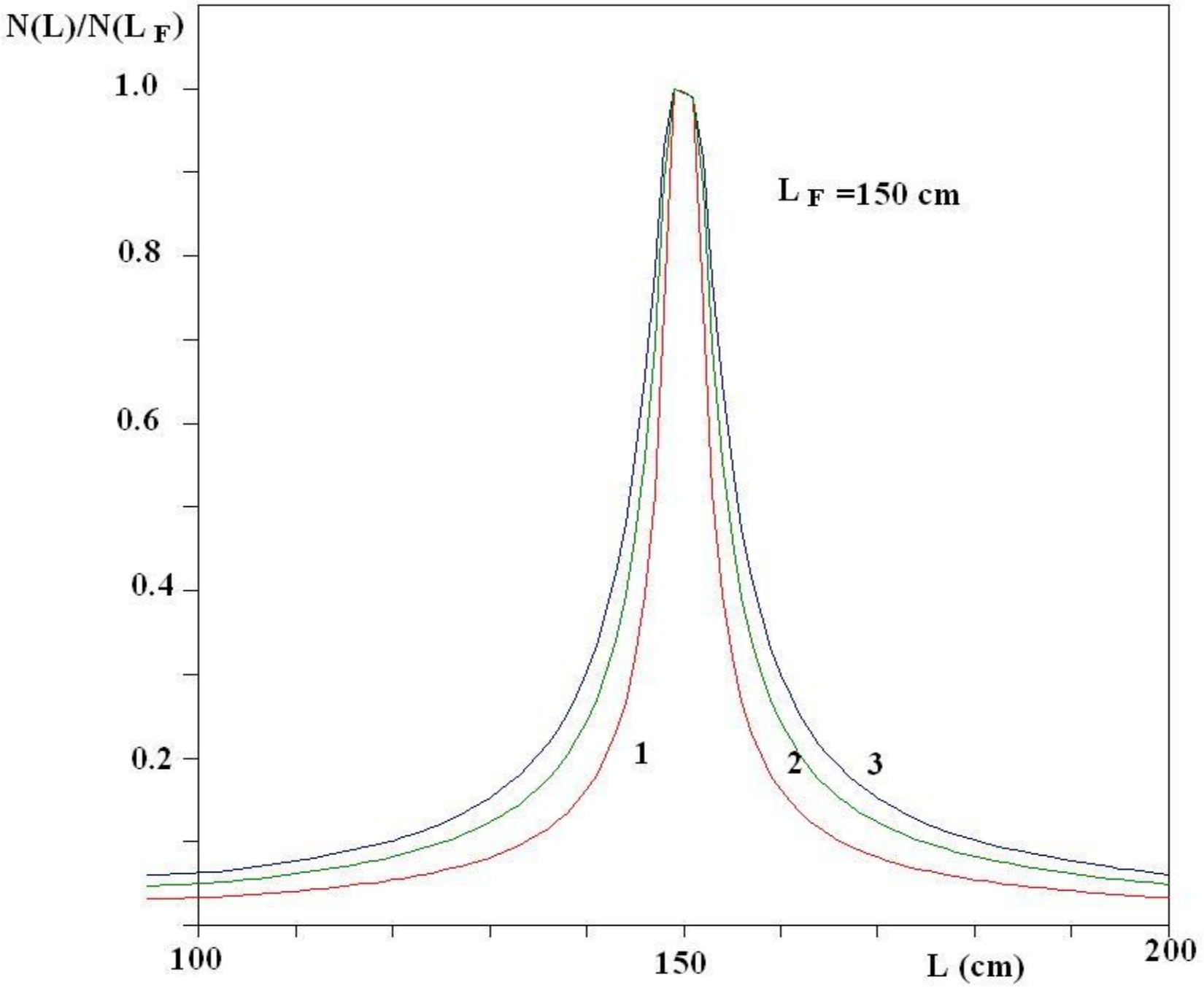
parallel to parallel

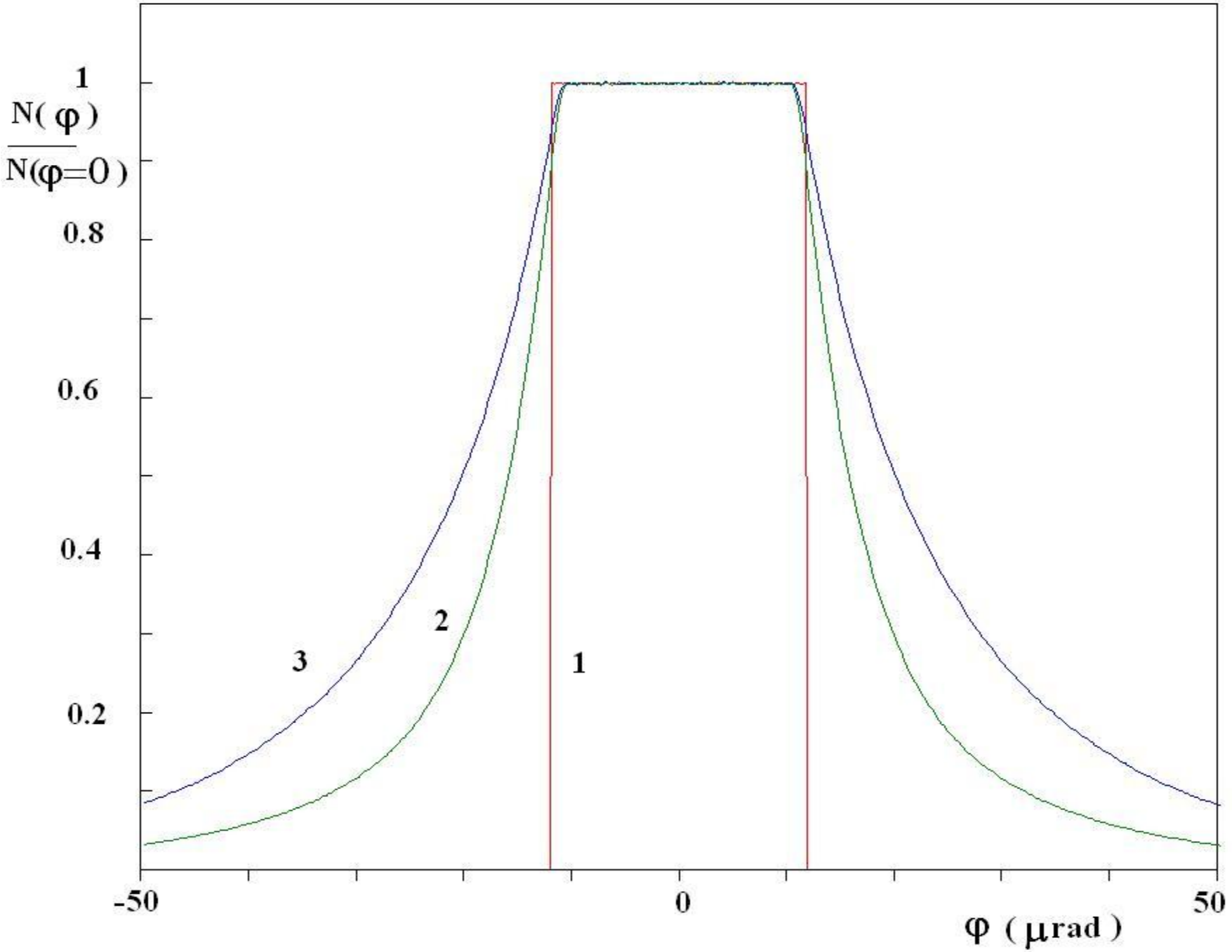
$\theta_{x\,(max)}$ is approx equal to the critical angle of channeling


Σ+ = p + π+ + K+
p
π+
K+
0
10
20
30
100
200
300
400
p, (GeV/c)


$\frac{d^2N}{dp\,d\Omega}$
per GeV/c
sterad 1
incident p
Secondary particle spectra at different
production angles
init p mom = 400 Gev/c
0
0.001
0.0025
0.005
0.01
30
20
10
0
100
200
300
400
p, (GeV/c)


N
per 1 proton
Sec. paricle fluxes as a function of the momentum.
The mom. width= 1% (dP=0.01*P)
Curves1,2 (3,4) for
max angle θ equal 0.0025 or 0.0125
The curve 1, 2 is for point to parallel case
The curve3,4 for parallel to parallel case
0.0004
0.0002
2
1
4
3
The curves 3,4 enlarged in 10 times
0
100
200
300
400
P (GeV/c)


N(L)/N(L F)
1.0
0.8
0.6
0.4
0.2
L F =150 cm
1
2
3
100
150
200
L (cm)


1
N(φ)
N(φ=0)
0.8
0.6
0.4
0.2
3
2
1
-50
0
50
φ (μrad)

Conclusions

1. The focusing by bent single crystals was observed experimentally. The measured characteristics of the process are in a good agreement with theoretical predictions.

2 The inverse focusing was proposed for effective generation of secondary particle beams.

3. We expect that intensity of secondary beams based on inverse focusing is more in 40 times such beams based on a traditional method.

Thank you for attention!