New beam optics on the basis of bent single crystals

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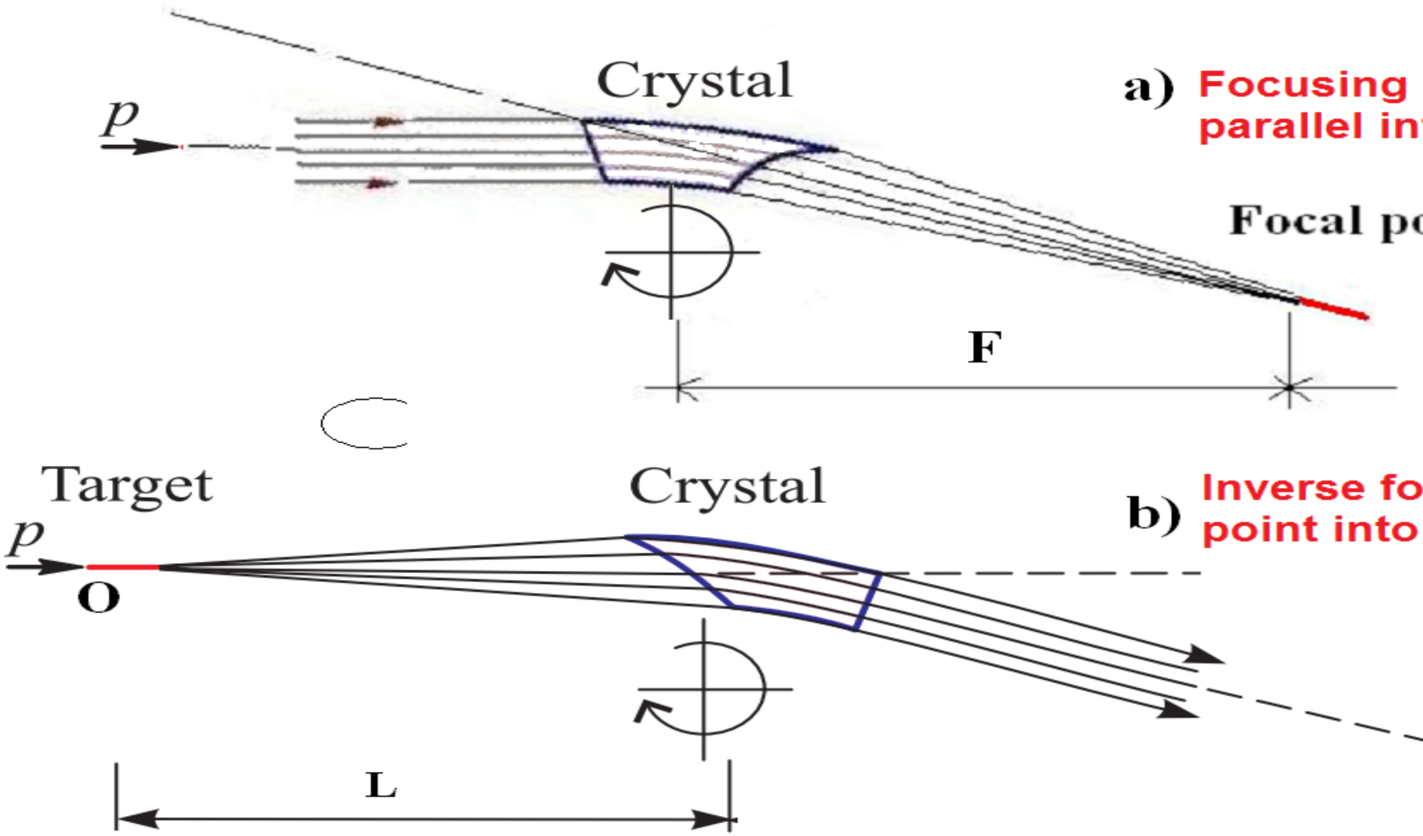
Abstract

The paper is devoted to development of new possibilities in creation of focusing devises for high energy positively charged beams on the basis of special bent single crystals. The focusing effect in such devises takes place only for particles which channeled in bent crystallographic planes. The presented in the paper relations show that the high efficiency of capture of particle beam with wide angle spread (in bending plane) in channeling regime can be achieved in the case of focusing point-like beam into parallel one. However, in the cosidered case some requirements on coordinate size of beam arise. Here we give mathematical analysis of the problem. As result we suggest to create of new optical devices: a) device which focusing a point-like beam into a point-like one; b) device, consistig from two bent single crystals with the aim to obtain the focusing in the both mutually orthogonal planes.The focusing elements can be used in various applications in practice of high energy accelerators. In particulur they can be used for extraction of secondary particle beams from proton accelerator and their effective transport on the fixed target.



a) Focusing parallel into point

W. Scandale et al Phys Lett B 733 (2014) 366.

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b) Inverse focusing point into parallel

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Probability of capture particles in channeling regime and propagation through bent crystal (in this regime)

The beam (in bending plane) may be described with the help of 2 parameters 1- coordinate size and 2-maximal angle in bending plane

Respectively 1) $\pm s_m$

2) $\alpha = \frac{s_c}{L}$

s_c half size of width of crystal

L -distance

The seached probability is equal to the next product:

$$\eta_{Total} = \eta \eta_c$$

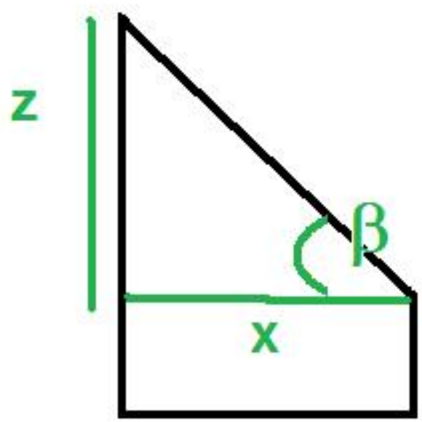
where η is probability of beam particle to move under θ_{pat} angle less than θ_c critical angle of channeling

$$\theta_{pat} < \theta_c$$

$\eta_c \sim 0.5$ is probability to be captured in channeling when $\theta_{pat} < \theta_c$

We find equations for calculation of efficiency η (for case point into parallel focusing)

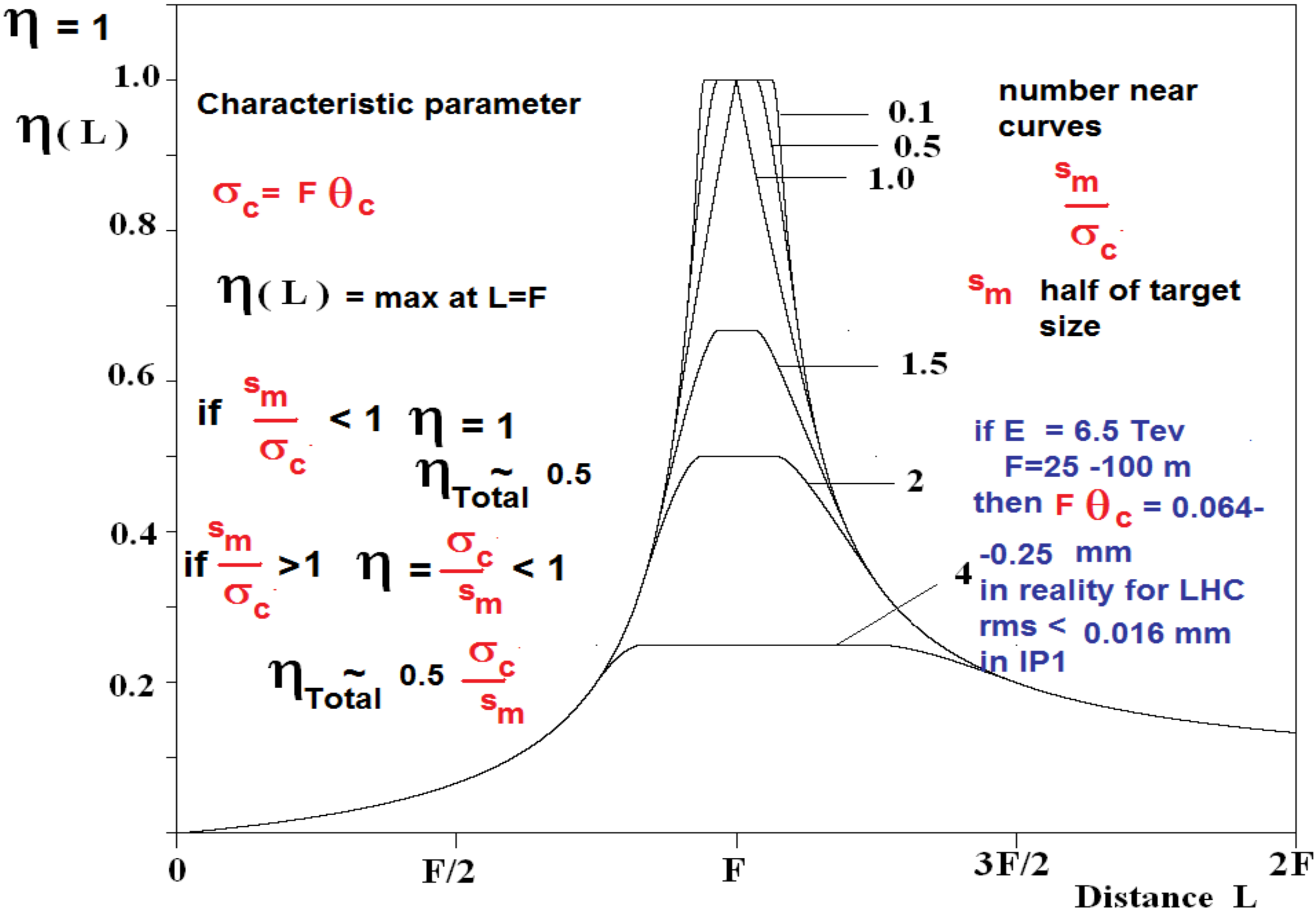
η as function of distance L has maximum at $L = F$ where F is focal length of a crystal



$$F = \frac{R}{K}$$

R is bending radius

$$K = \frac{Z}{X} = tg(\beta)$$



η = 1
1.0
η(L)
Characteristic parameter
σc= F θc
0.8
η(L) = max at L=F
0.6
if sm/σc < 1 η = 1
ηTotal ~ 0.5
0.4
if sm/σc >1 η = σc/sm < 1
ηTotal ~ 0.5 σc/sm
0.2
0
F/2
F
3F/2
2F
Distance L
0.1
0.5
1.0
1.5
2
4
number near curves
sm/σc
sm half of target size
if E = 6.5 Tev
F=25 -100 m
then F θc = 0.064-
-0.25 mm
in reality for LHC
rms < 0.016 mm
in IP1

IHEP experiment on deflection (from point to parallel) of divergent 50 GeV proton beam

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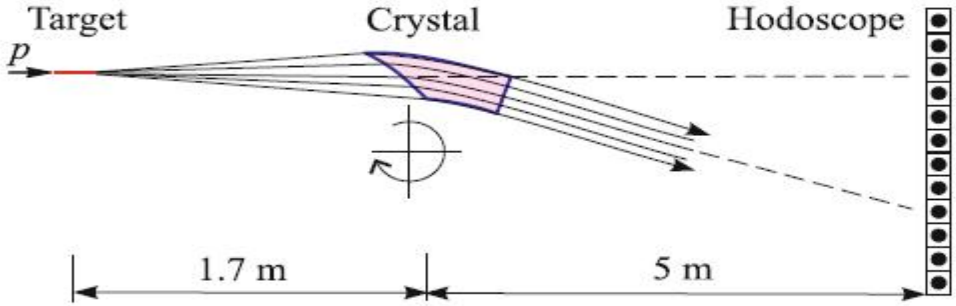


Schematic layout of the experiment.

Target CsI(scintillator) ±0.075 mm

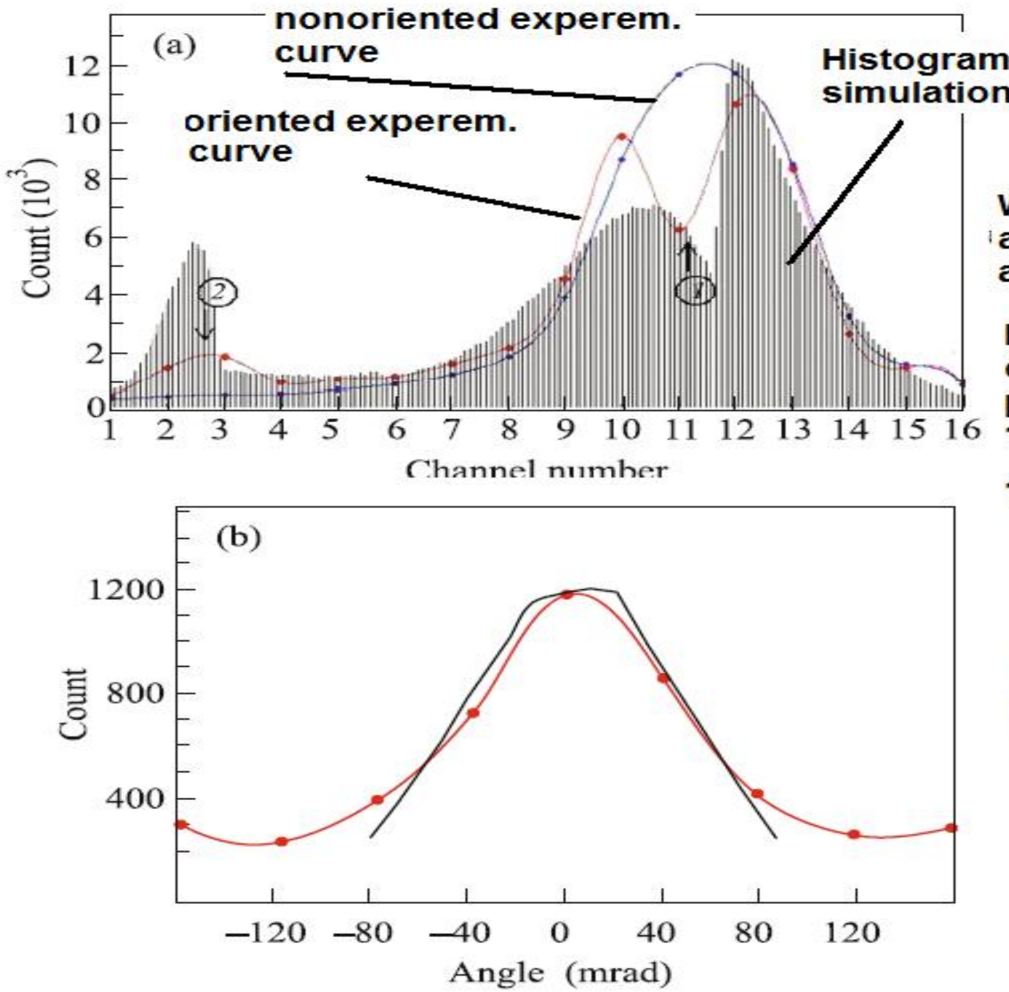
$$\frac{s_m}{\sigma_c} = 1.5$$

Trigger $C_1 C_2$ CsI

mean square devergence of beam = 0.36 mrad

deflection angle 1.8 mrad

Measured beam distributions after crystal



We see satisfactory agreement calculation and measurement

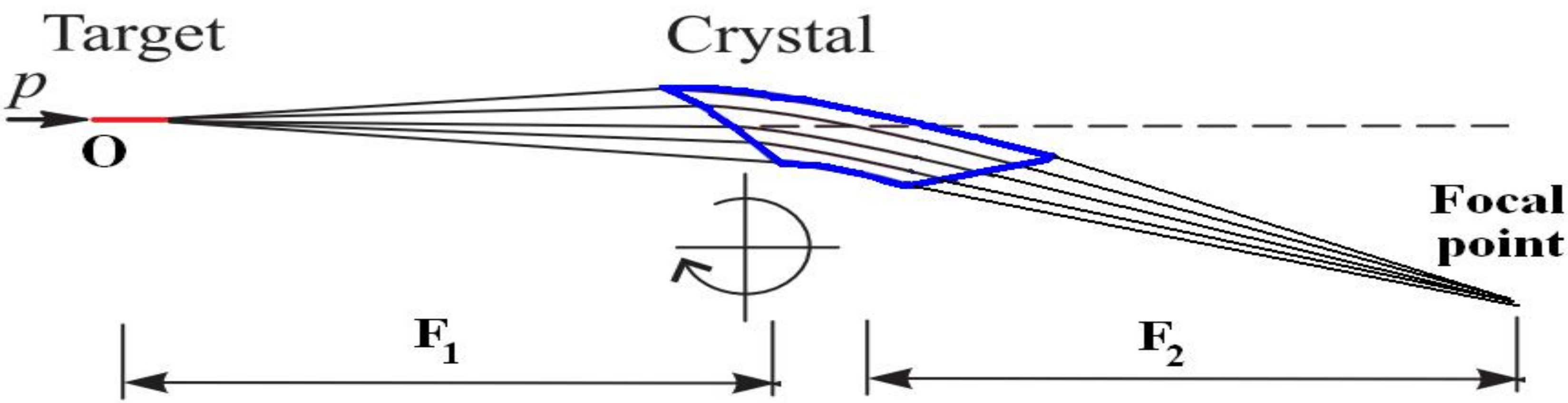
Number channeling particles is 14% experiment

16% simulation

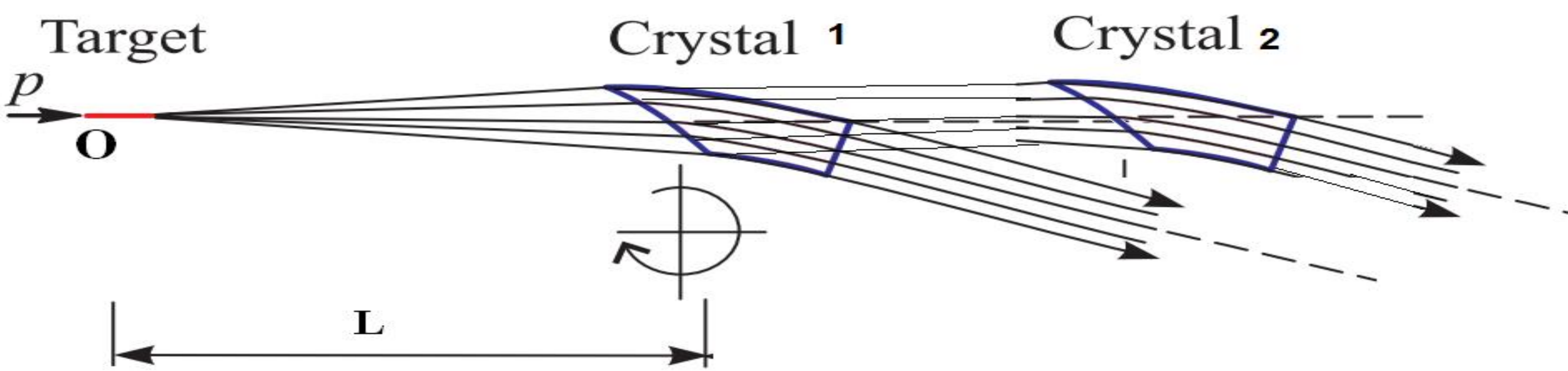
orientation curves
red -experiment
blue - calculation

New possibilities for beam optics

Focusing from point into point (beam lens)



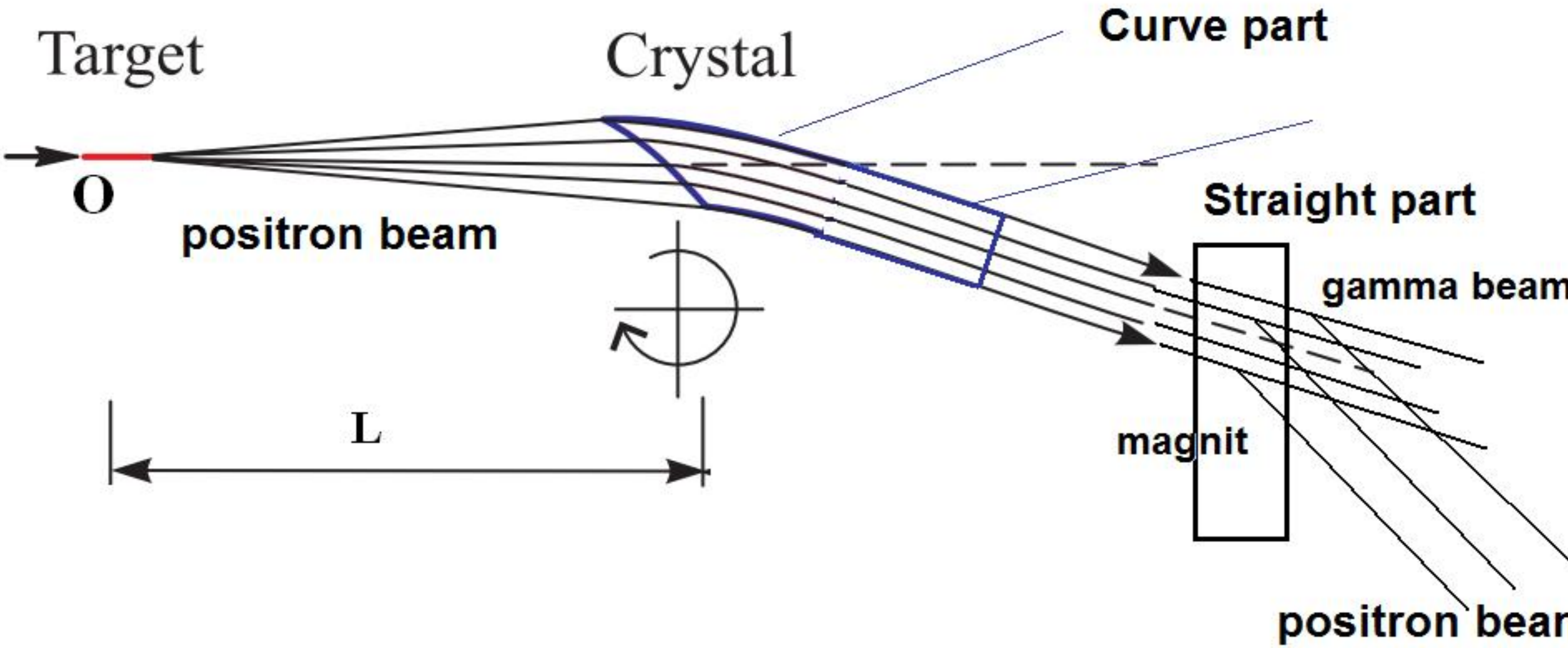
Possibility to increase capture beam



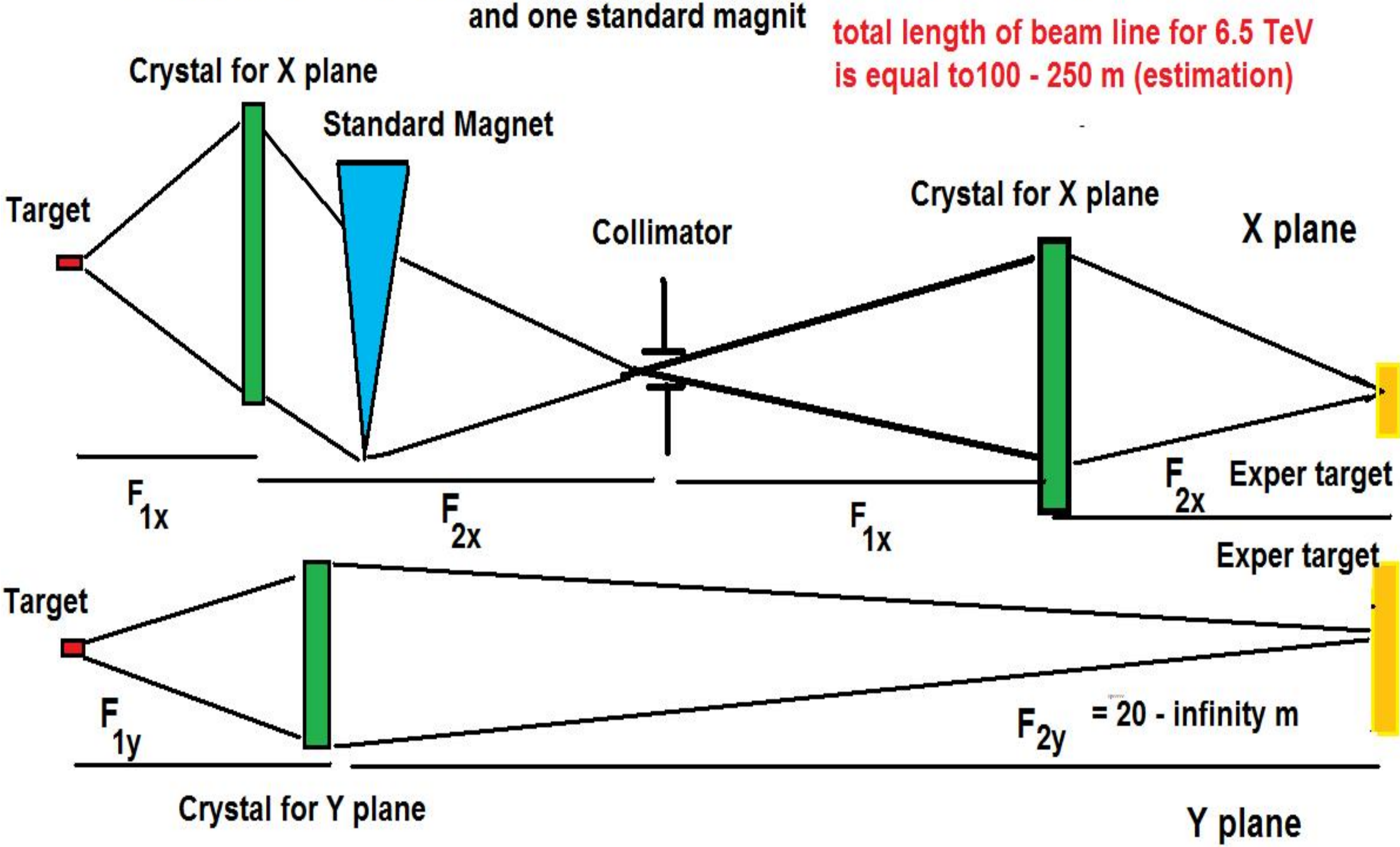
New possibilities for beam optics

It is obvious that focusing crystals can be used independently in the both mutually orthogonal planes

It is possible to capture the beam of high energy positrons with the help of focusing crystals and hence to get high intensity of gamma-beam (channeling radiation) per unit of area.



Formation of secondary monochromatic beam with the usage of focysing crystals and one standard magnit



Conclusion

1) The focusing sheme: point in parallel was studied and equations for efficiency were obtained.

2) The review of new IHEP experiment was done.

3) We propose the new crystal-optical solutions for example crystal with transfomation point to point and others.

4) We show that focusing crystal is transparent for some space area ($\sigma_c = F\,\theta_c$)

5) It was proposed to use focusing crystals in positron beams with the aim to obtain intensive gamma beam

Thank you for attention