New Approaches to the Crystal Collimation

Vincenzo Guidi, Andrea Mazzolari

Department of Physics and INFN - University of Ferrara

Victor Tikhomirov

Institute for Nuclear Problems Minsk, Republic of Belarus

Channeling 2010, Ferrara, 5 October 2010

Outline

Beam collimation by crystals

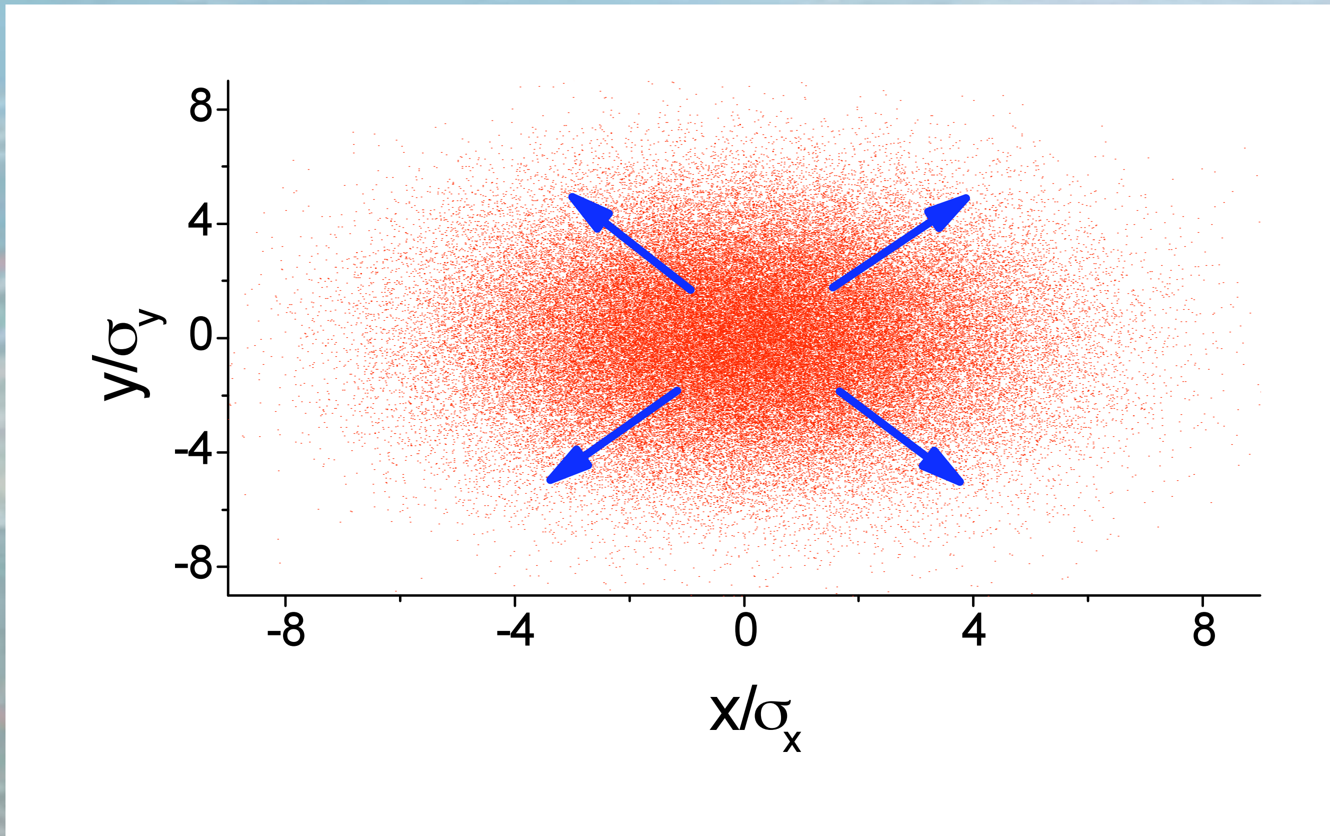
MVROC – Multiple Volume Reflection in One crystal (VR amplification by crystal axes)

Channeling fraction increase by the **crystal cut**

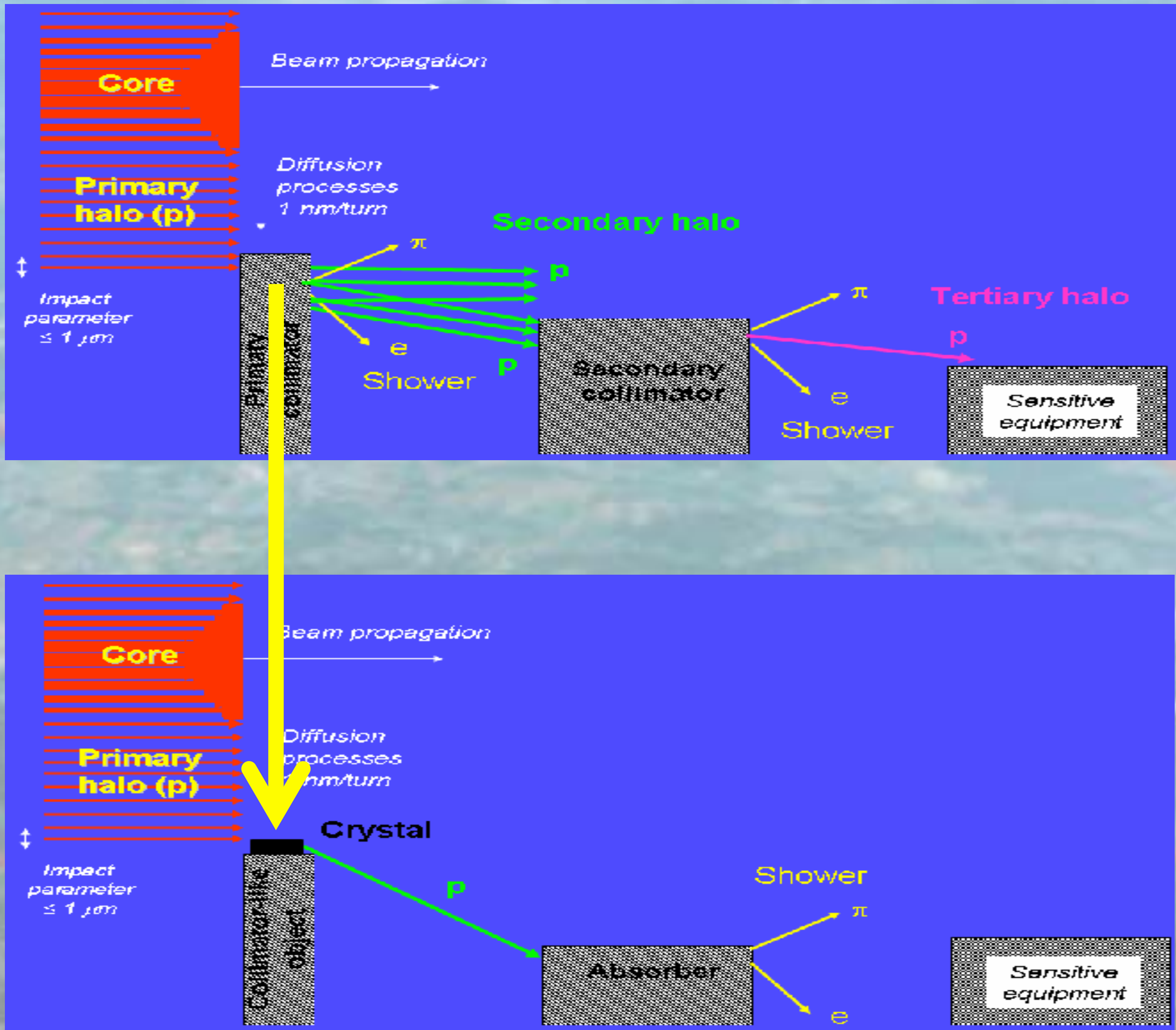
Crystal cut and MVROC **application to crystal collimation**

Conclusions

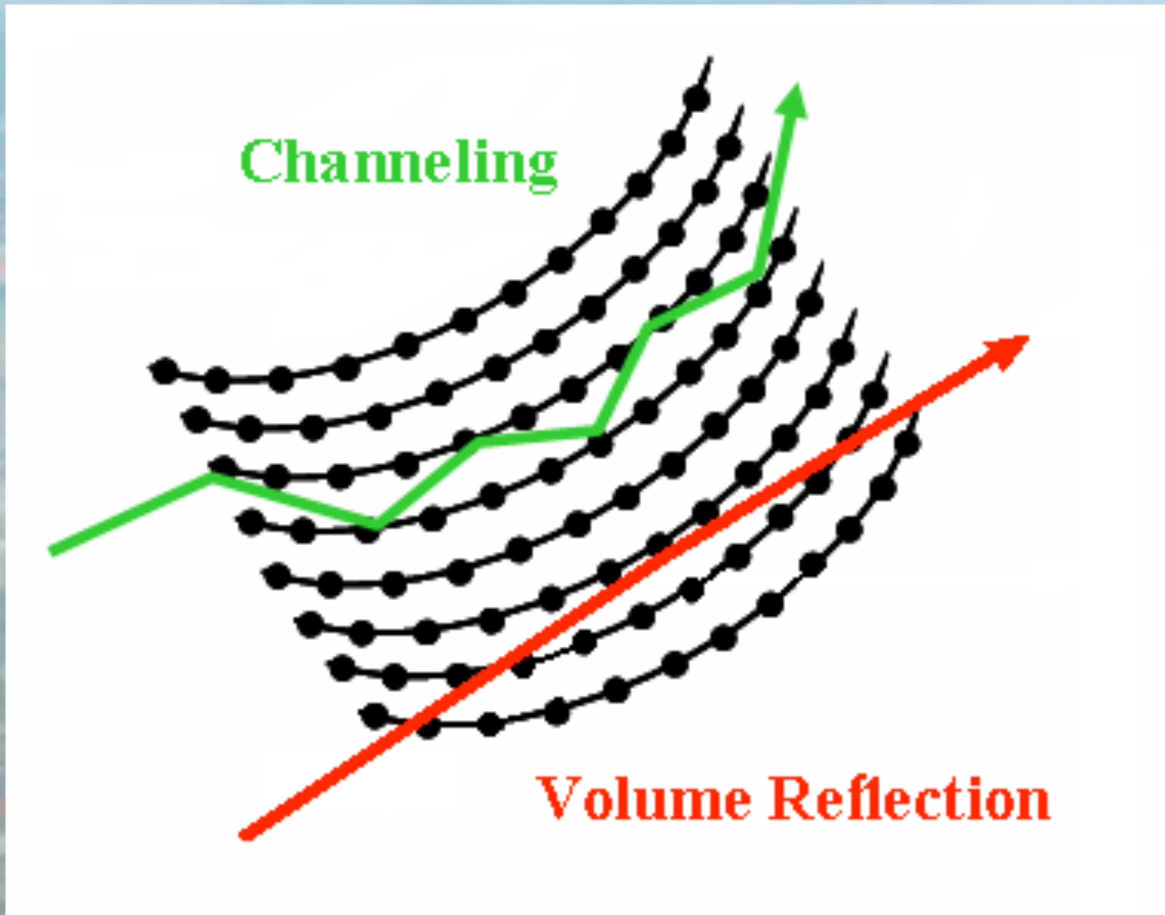
The planned LHC luminosity upgrade will intensify the beam **halo** formation



Crystals improve collimation efficiency



Crystals are used in either *channeling* or *volume reflection* regimes



First results on the SPS beam collimation with bent crystals

W. Scandale et al, PLB 692(2010)78

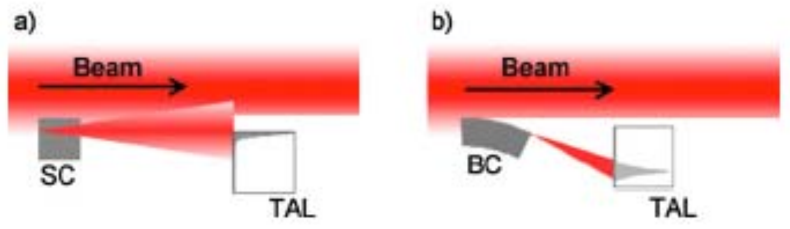


Fig. 1. (Color online.) (a) Collimation scheme using a solid state primary collimator-scatterer (SC). (b) Collimation scheme with a bent crystal (BC) as a primary collimator. Halo particles are deflected and directed onto the absorber (TAL – Target Aperture Limitation) far from its edge.

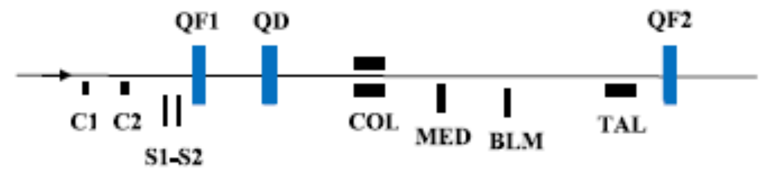


Fig. 2. (Color online.) The UA9 experimental layout. The primary collimators – bent crystals C1 and C2 are located upstream the quadrupole QF518 (QF1). The TAL acting as a secondary collimator (absorber) is upstream the quadrupole QF 520 (QF2).

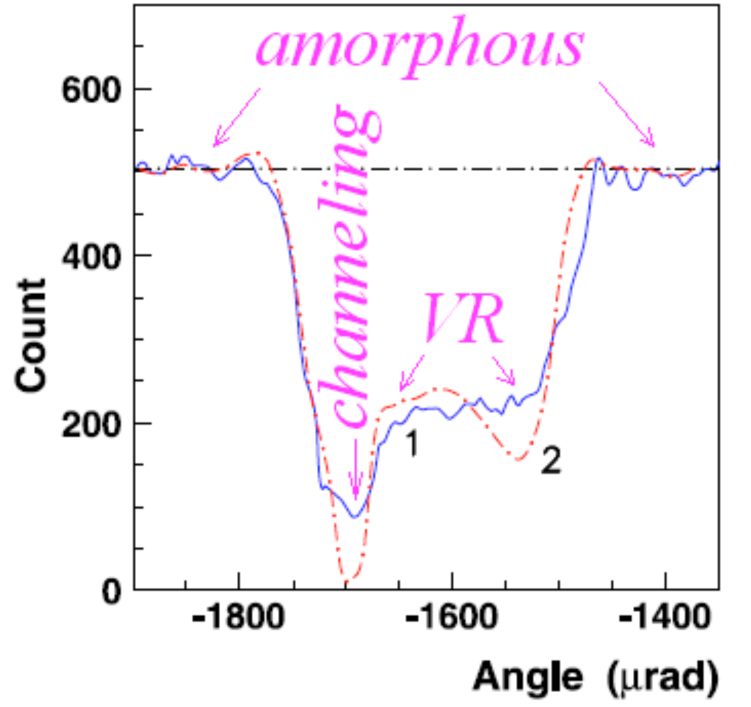


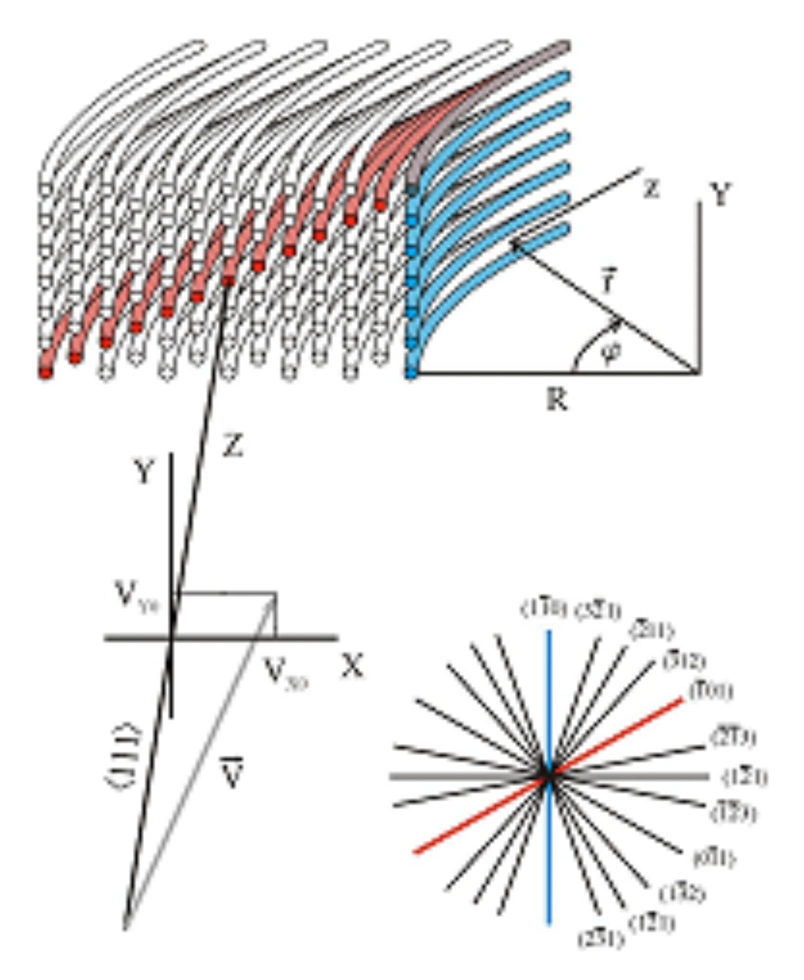
Fig. 3. (Color online.) (1) The dependence of the S1–S2 telescope count on the angular position of the crystal 1; (2) The dependence of the number of inelastic nuclear interactions of protons in the crystal on its orientation angle obtained by simulation. The dot-dashed line shows the level of the beam losses for the amorphous orientation of the crystal.

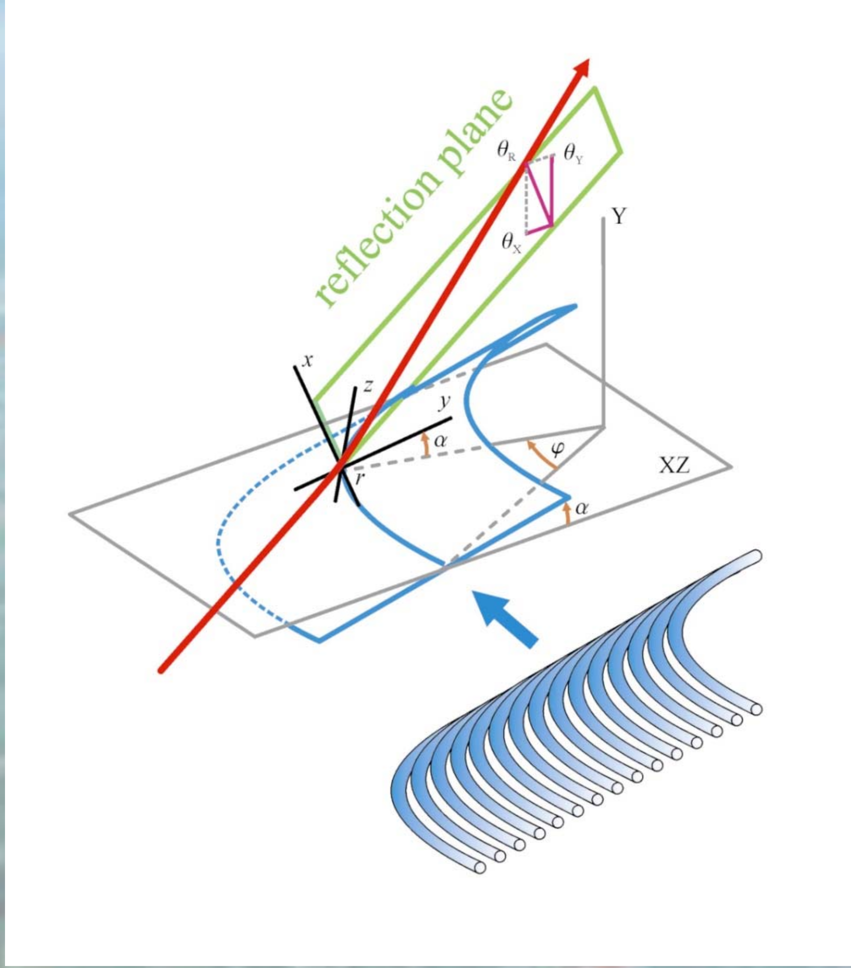
New effects allowing to facilitate crystal collimation

Multiple **V**olume **R**eflection from different inclined planes of **O**ne **C**rystal (**MVROC**)

Multiple Volume Reflection in One Crystal (MVROC)

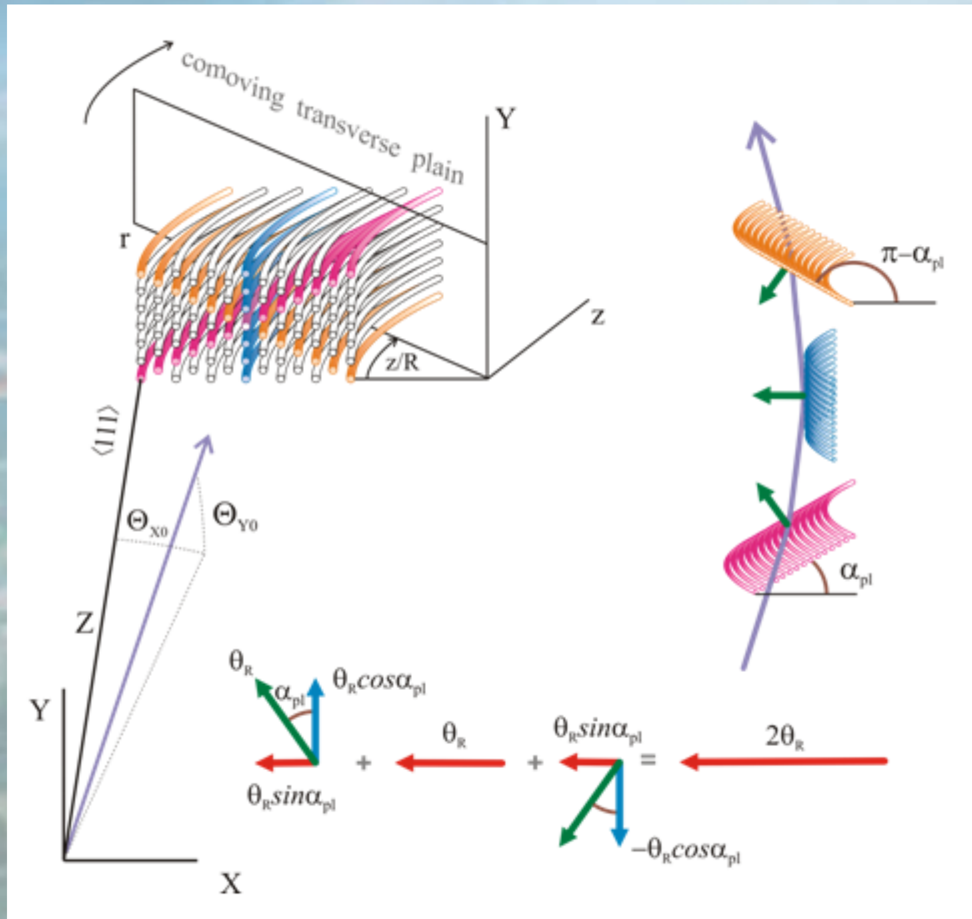
V.V. Tikhomirov, PLB 655(2007)217





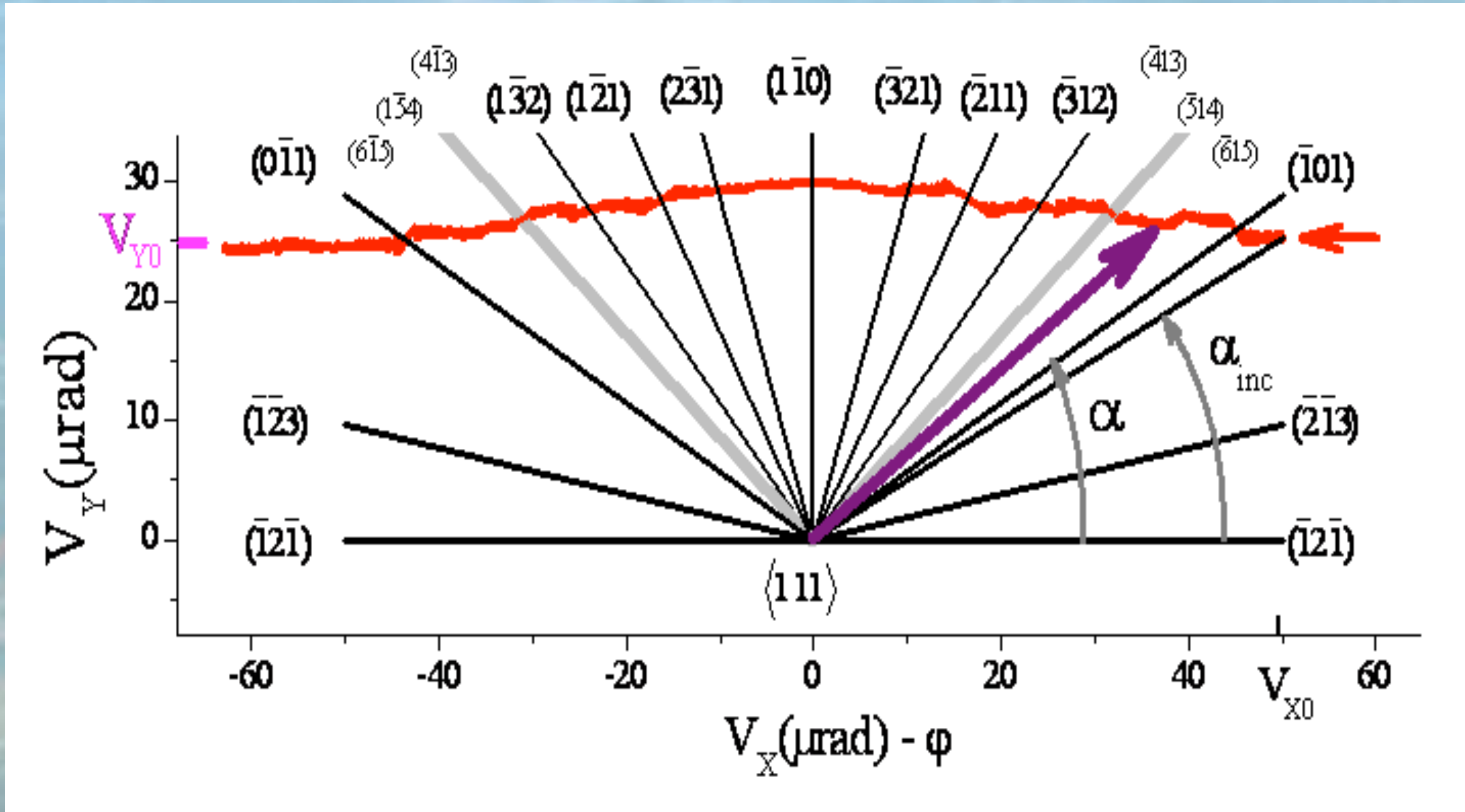
Axes form ***many*** inclined reflecting planes

Horizon projections of the angles of reflection from different skew planes sum up giving rise to the MVROC effect while the vertical angles of reflection from symmetric skew planes, like (-101) and (0-11), mutually compensate.



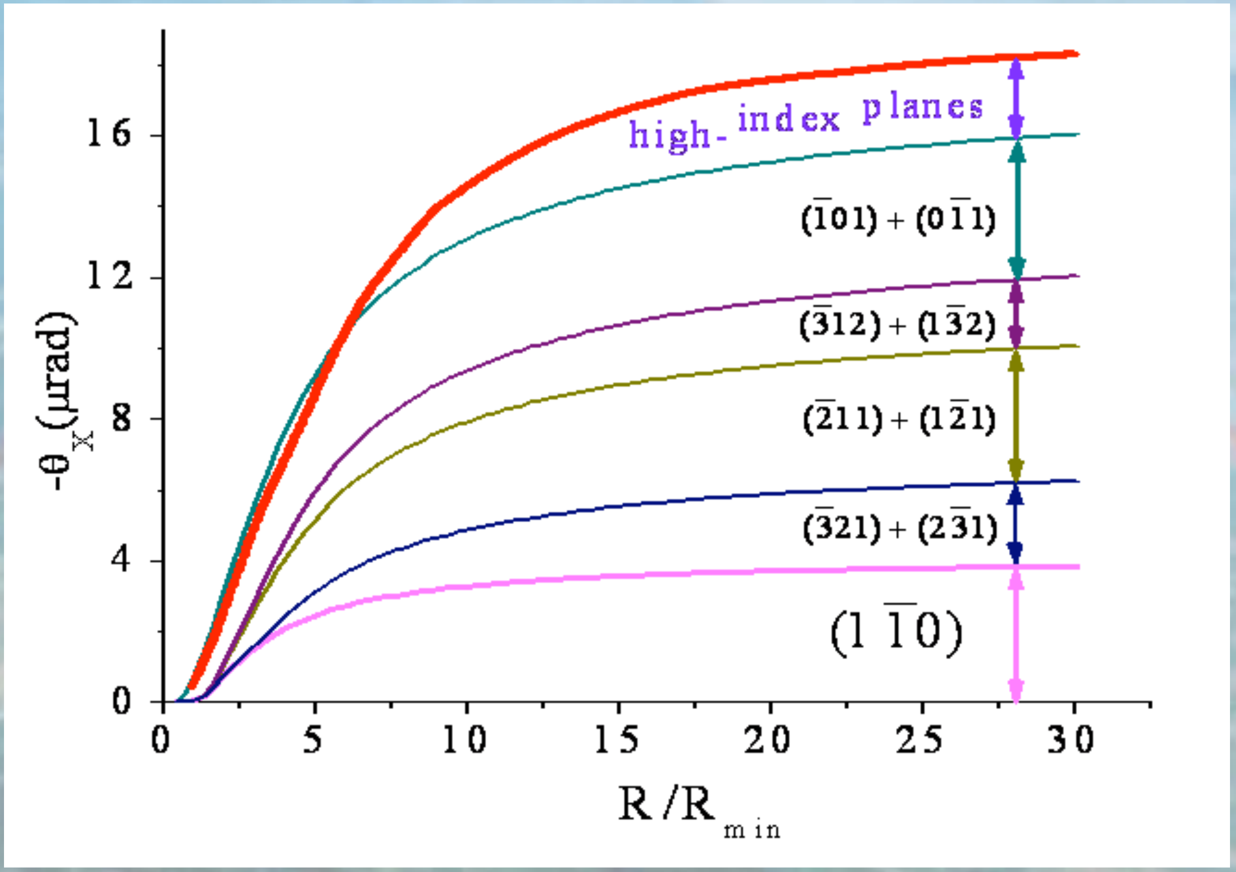
Comoving reference frame rYz rotates with the normak bent axis direction when a particle moves through the crystal.

Proton motion in comoving reference plane



Protons are reflected from ***many*** different crystal plane sets in ***one*** crystal

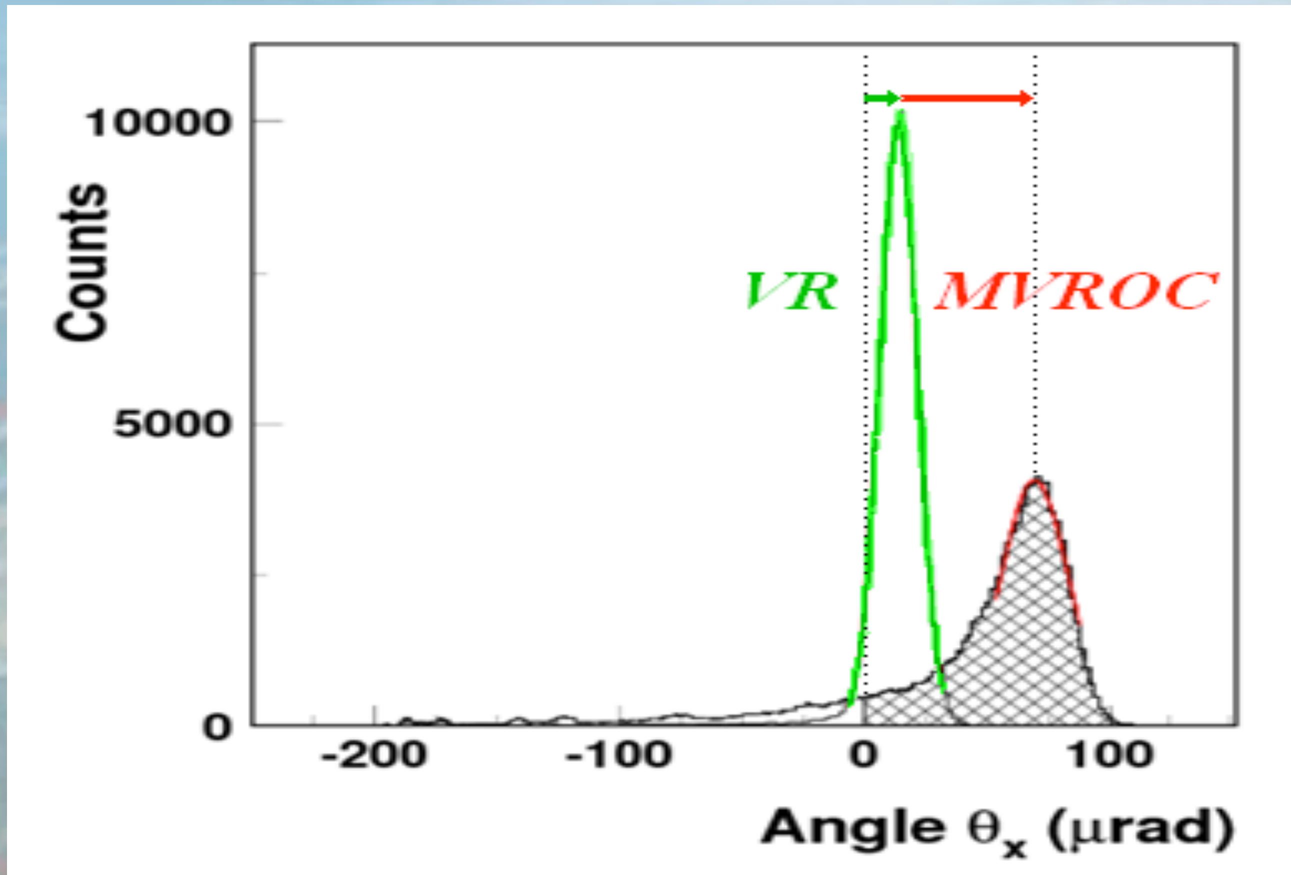
Reflection angles from planes of one crystal *vs* bending radius



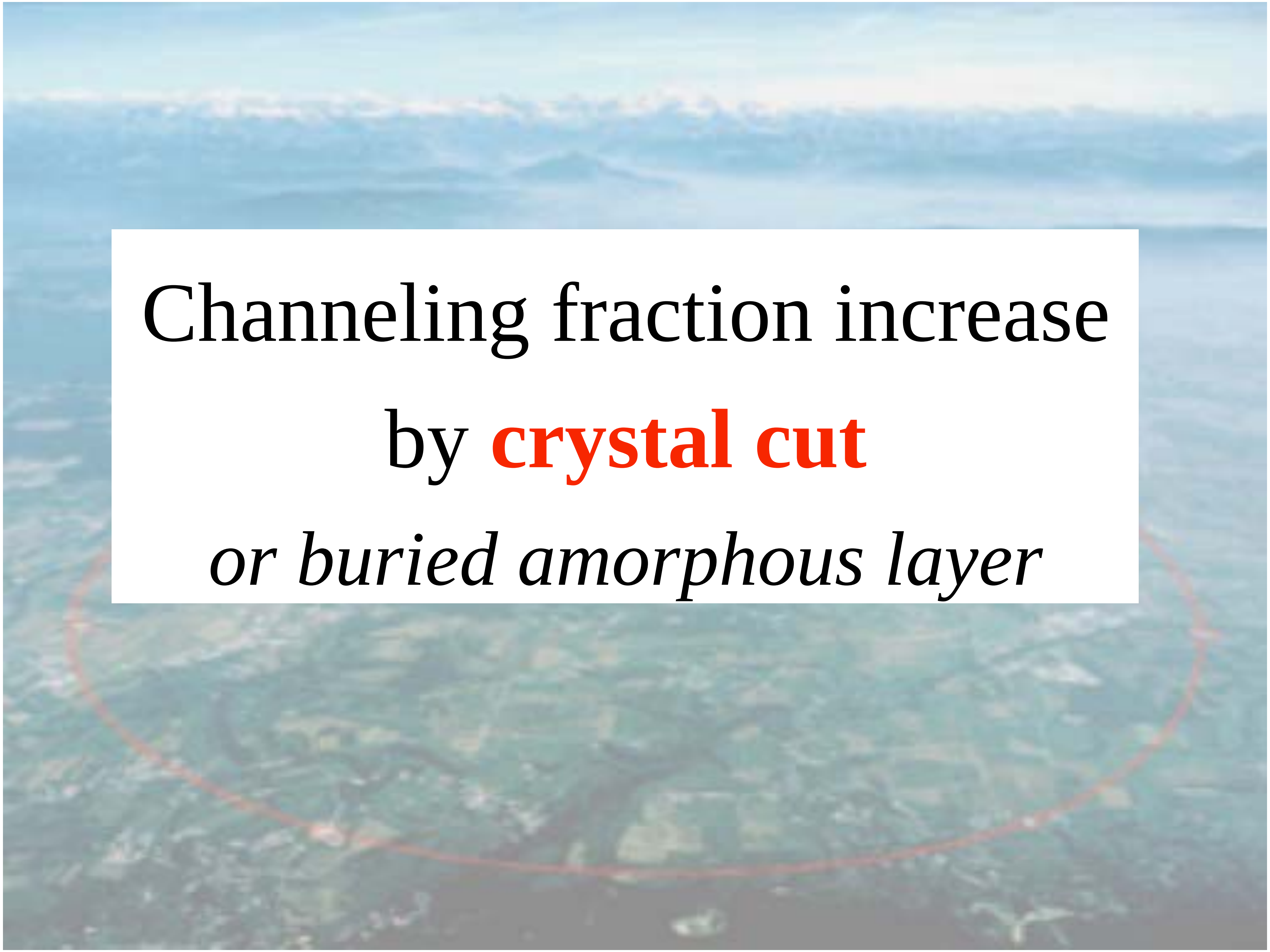
Reflection from different crystal planes increases VR angle about ***5 times***

First MVROC observation

W. Scandale et al, PLB 682(2009)274



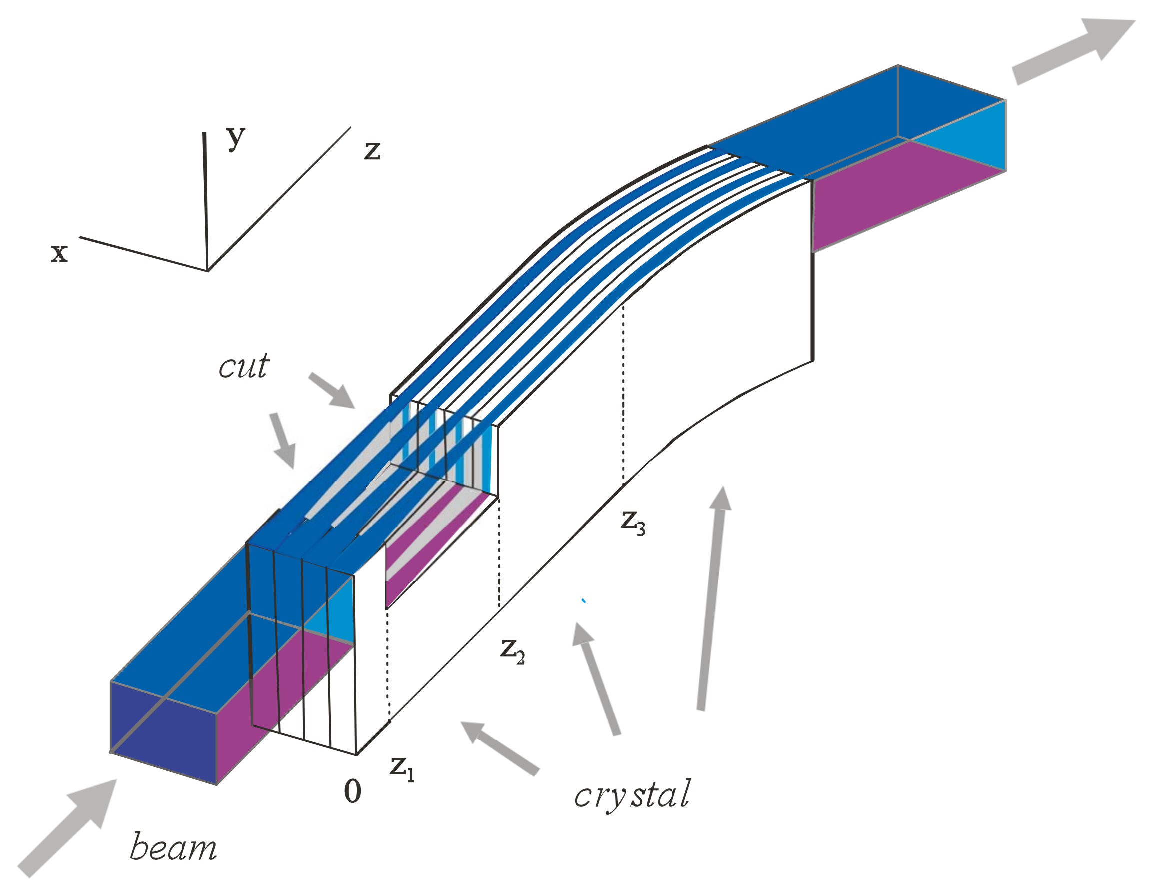
MVROC indeed increases reflection angle **5 times**



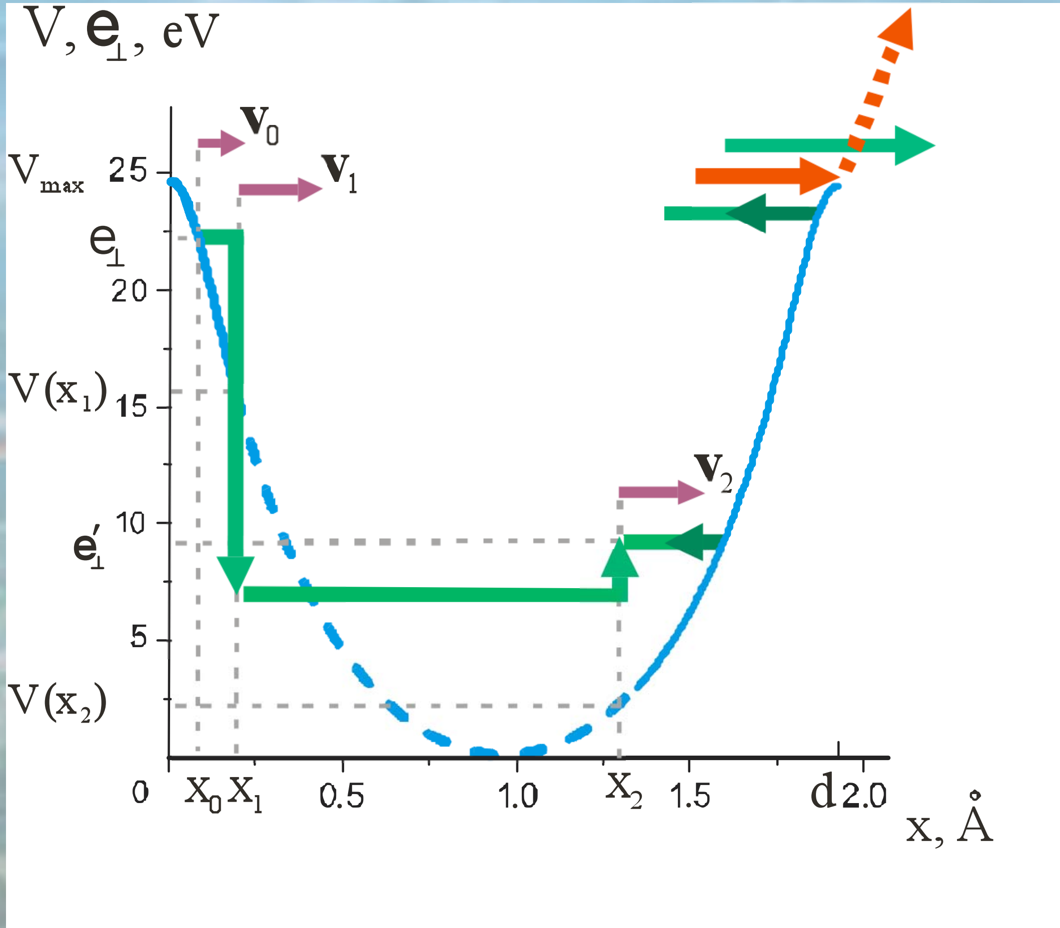
Channeling fraction increase by **crystal cut** *or buried amorphous layer*

The capture probability **increase by crystal cut**

V.V.Tikhomirov, JINST, 2(2007)P08006

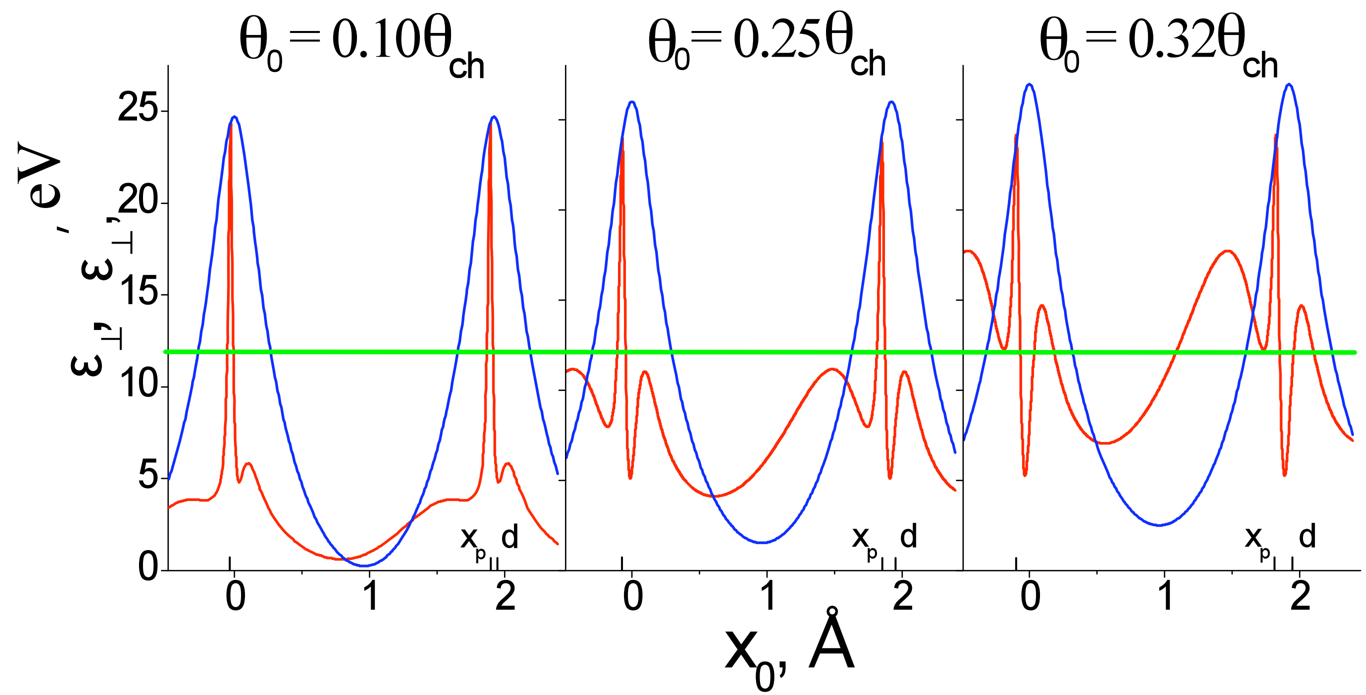


Transverse energy reduction *by the cut - 1*



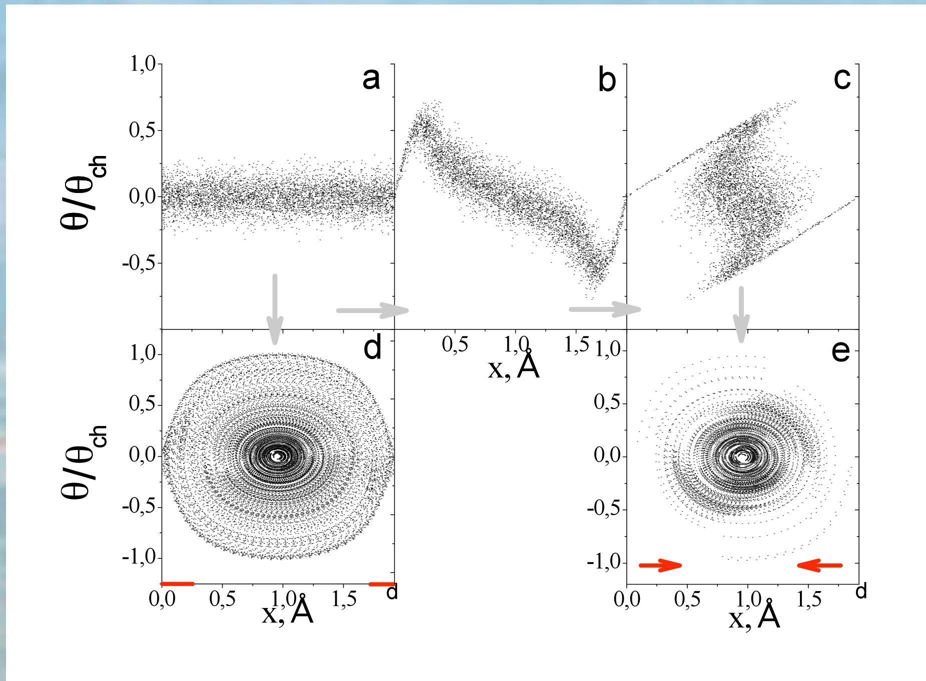
The cut diminishes the potential energy conserving the transverse kinetic one

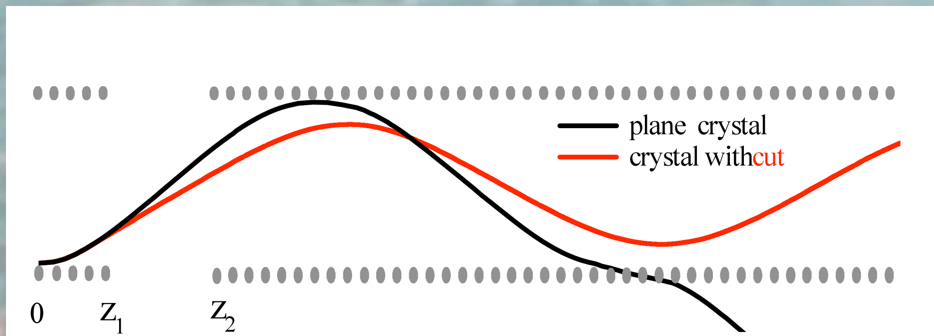
Transverse energy reduction ***by the cut - 2***



Only 1-2% of protons avoid drastic transverse energy reduction by the cut

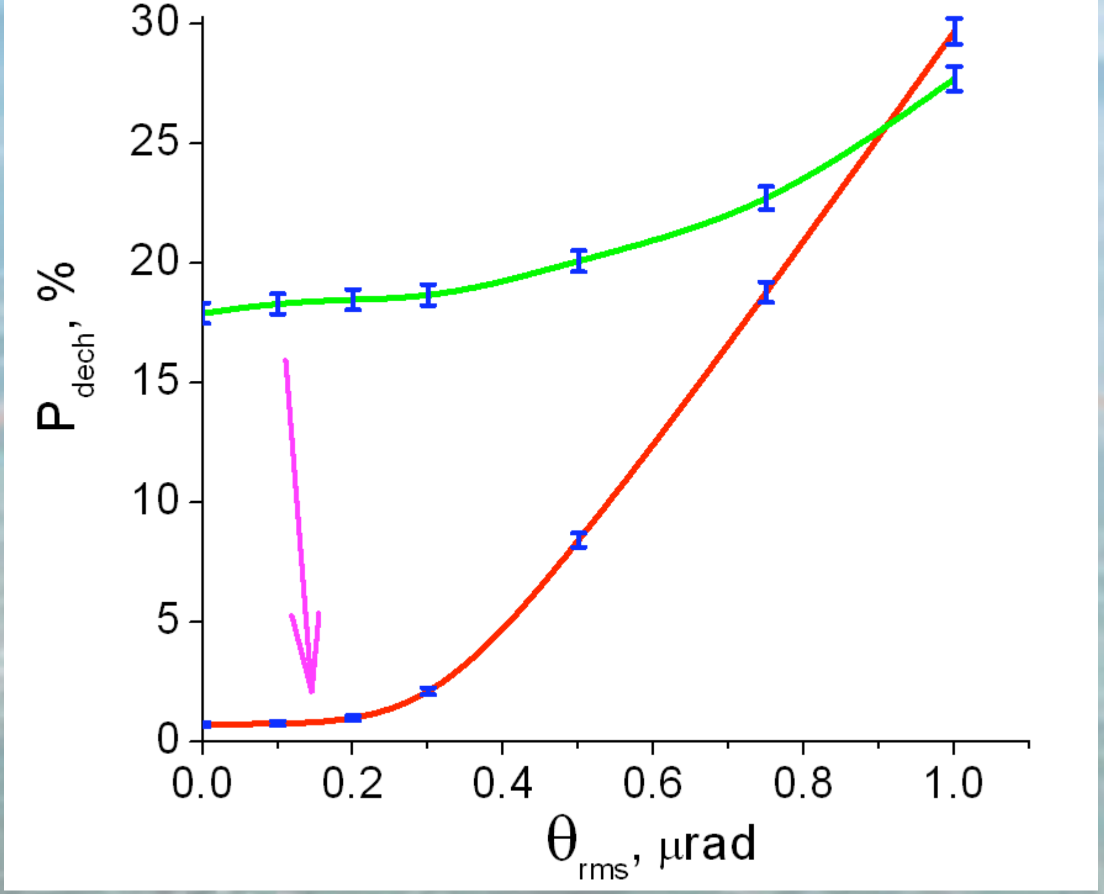
Phase space transformation by the cut





Protons cease to reach the high nuclear density regions

Channeling fraction increase by the cut



The cut increases channeling fraction from 85 to 99%

Cut formation method

(110) Silicon Etching for High Aspect Ratio Comb Structures

*Seong-Hyok Kim, Sang-Hun Lee, Hyung-Taek Lim, and Yong-Kweon Kim
School of Electrical Engineering, Seoul National University
San 56-1 Shilim-dong, Kwanak-gu, Seoul, 151-742, Korea
Seung-Ki Lee
Department of Electrical Engineering, Dankook University
8, Hannam-dong, Yongsan-gu, Seoul 140-714, Korea

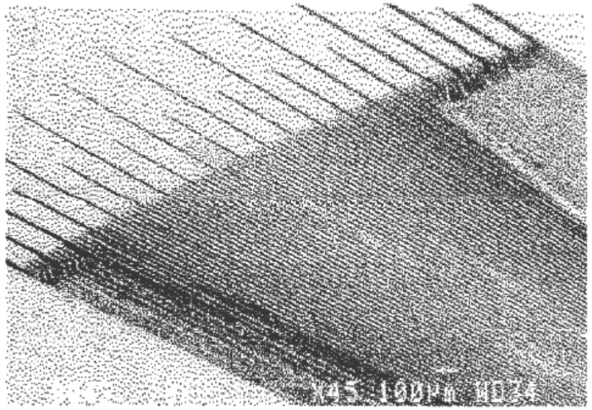


Fig 1. SEM photograph of alignment target after wet etching

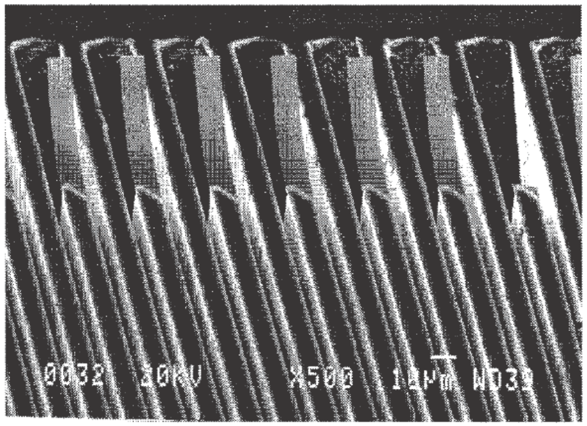
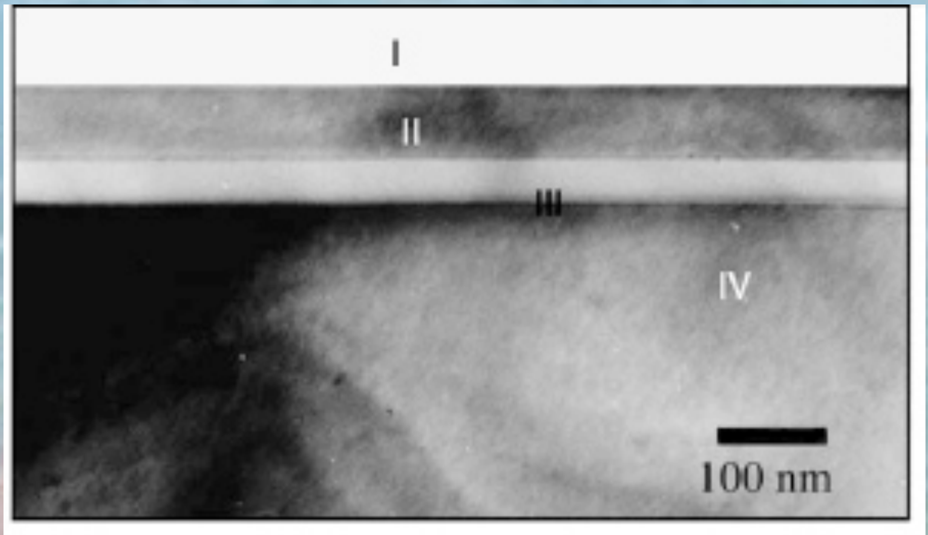


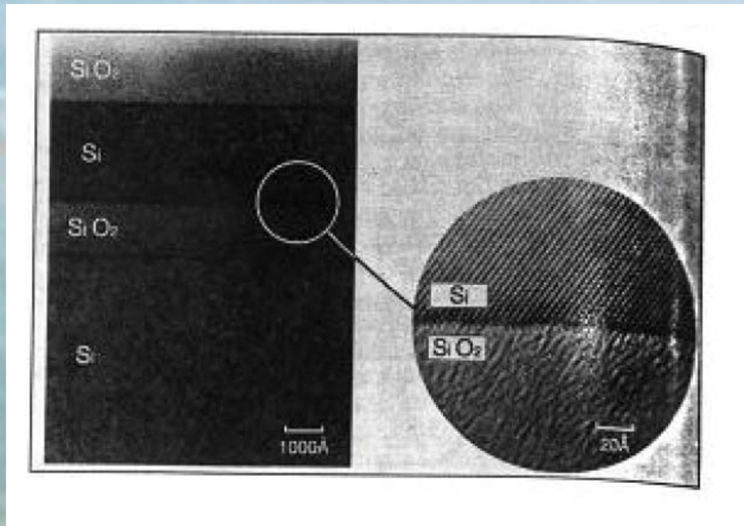
Fig. 12 Fabricated comb structures.
The width is 8㎛, gap is 7㎛ and height is about 150㎛

Crystal cut can be produced by
anisotropic etching

SIMOX Buried Oxide Layer
can be used instead of crystal cut

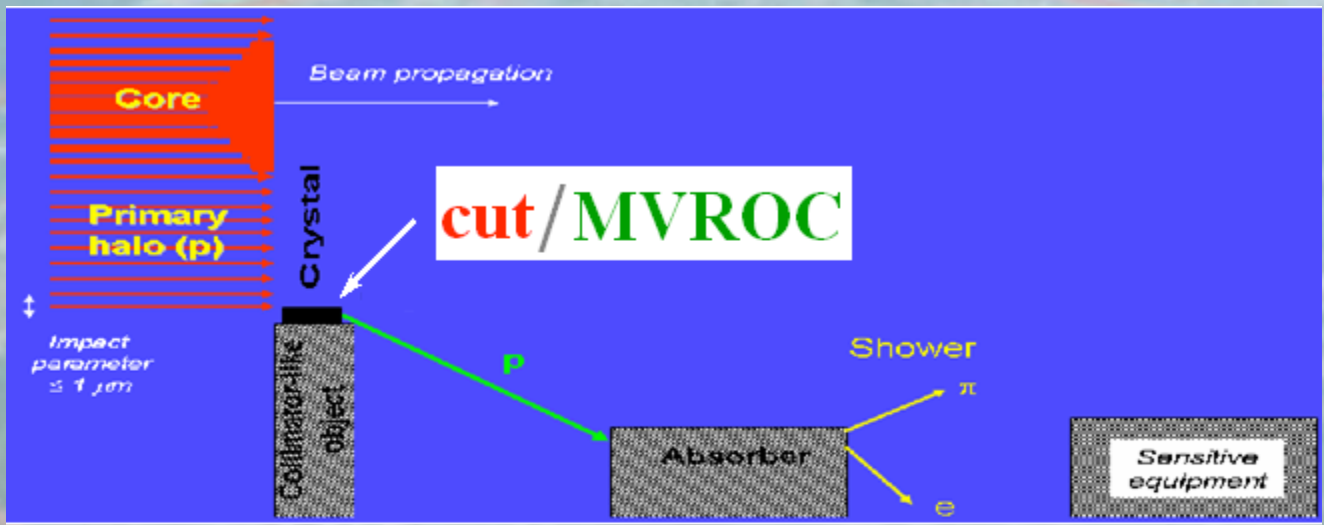
V. Guidi, A. Mazzolari and V.V. Tikhomirov, *J. Phys. D: Appl. Phys.* 42(2009) 165301





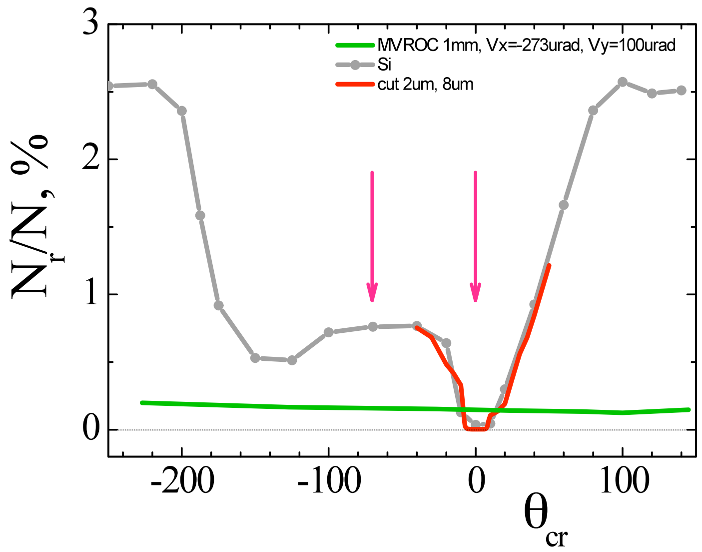
- Thermal annealing restores silicon cristalline quality and creates a buried SiO_2 layer,
- Interfaces between Si and SiO_2 are well terminated,
- Misalignment between silicon layers in available SIMOX structures: less than 0.7 Å/mm.

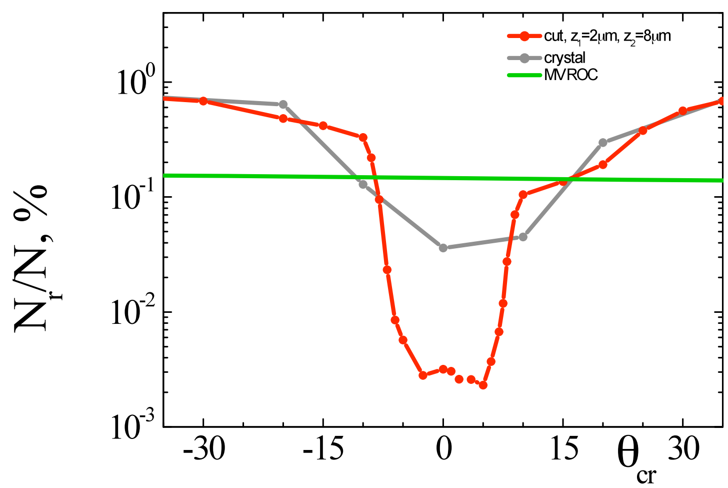
Crystal cut and MVROC application to crystal collimation



Inelastic loss fraction as a function of the crystal orientation

in the **usual crystal**, **crystal with cut** and a **crystal in MVROC orientation***)





Crystal cut decreases inelastic losses

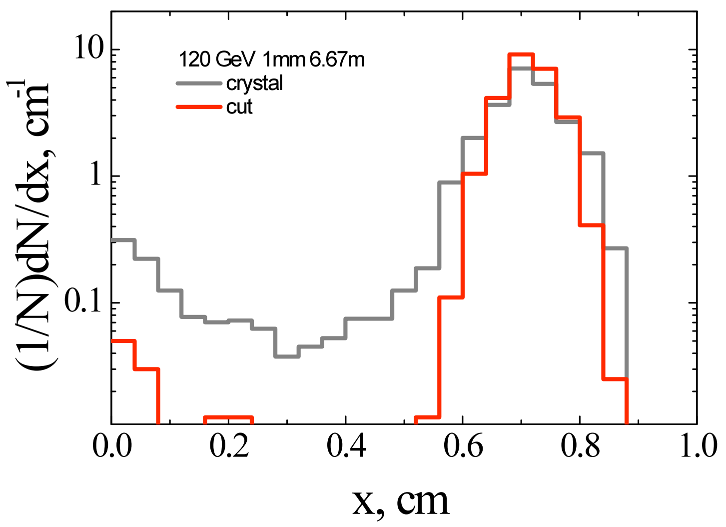
MVROC increases angular acceptance

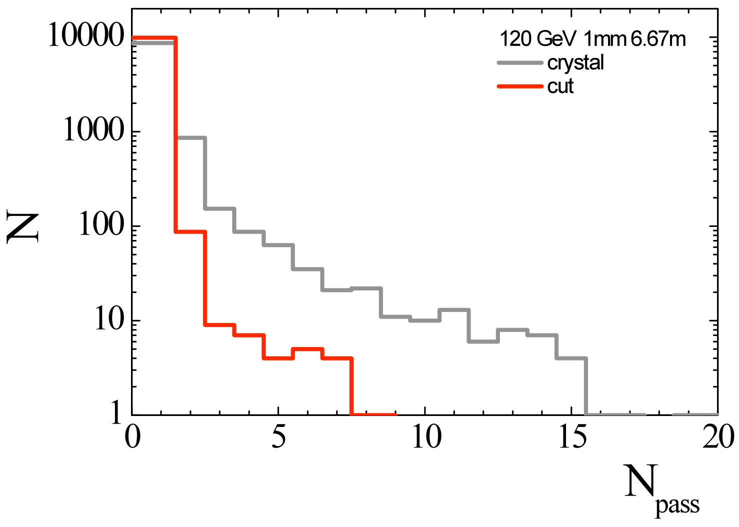
*) MVROC orientation with Θ_{X0} = -273urad, Θ_{Y0} = 100urad and R=2m

Distributions of the impact parameter and number of the crystal transversals

in usual Si crystal and **crystal with cut*)**

at perfect alignment





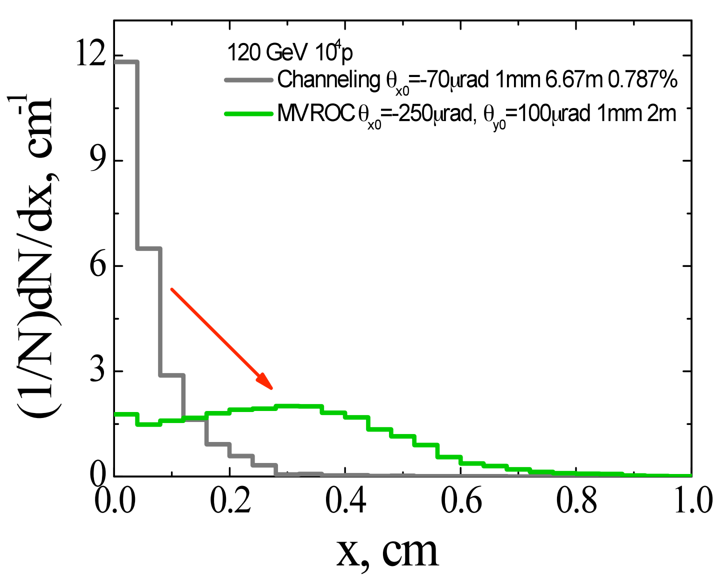
The cut both increases the impact parameter and decreases the crystal transversals number *at perfect alignment*

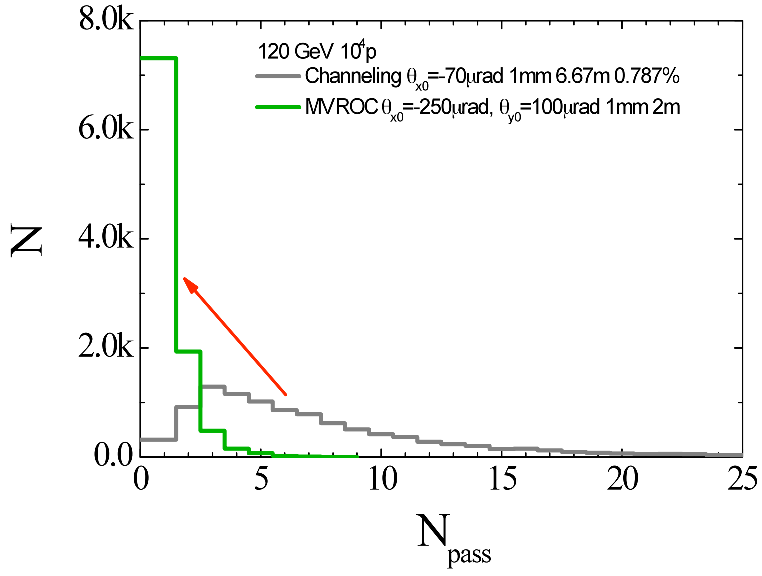
*) cut is between 2 and 8 um. R=6.67m, l=1mm

Distributions of the impact parameter and number of the crystal transversals

in usual Si crystal *) and **crystal in MVROC orientation**+)

at rough alignment





MVROC both increases the impact parameter and decreases the crystal transversals number *at rough alignment*

*) Θ_{X0} = -70urad**!** +) Θ_{X0} = -250urad, Θ_{Y0} = 100urad and R=2m

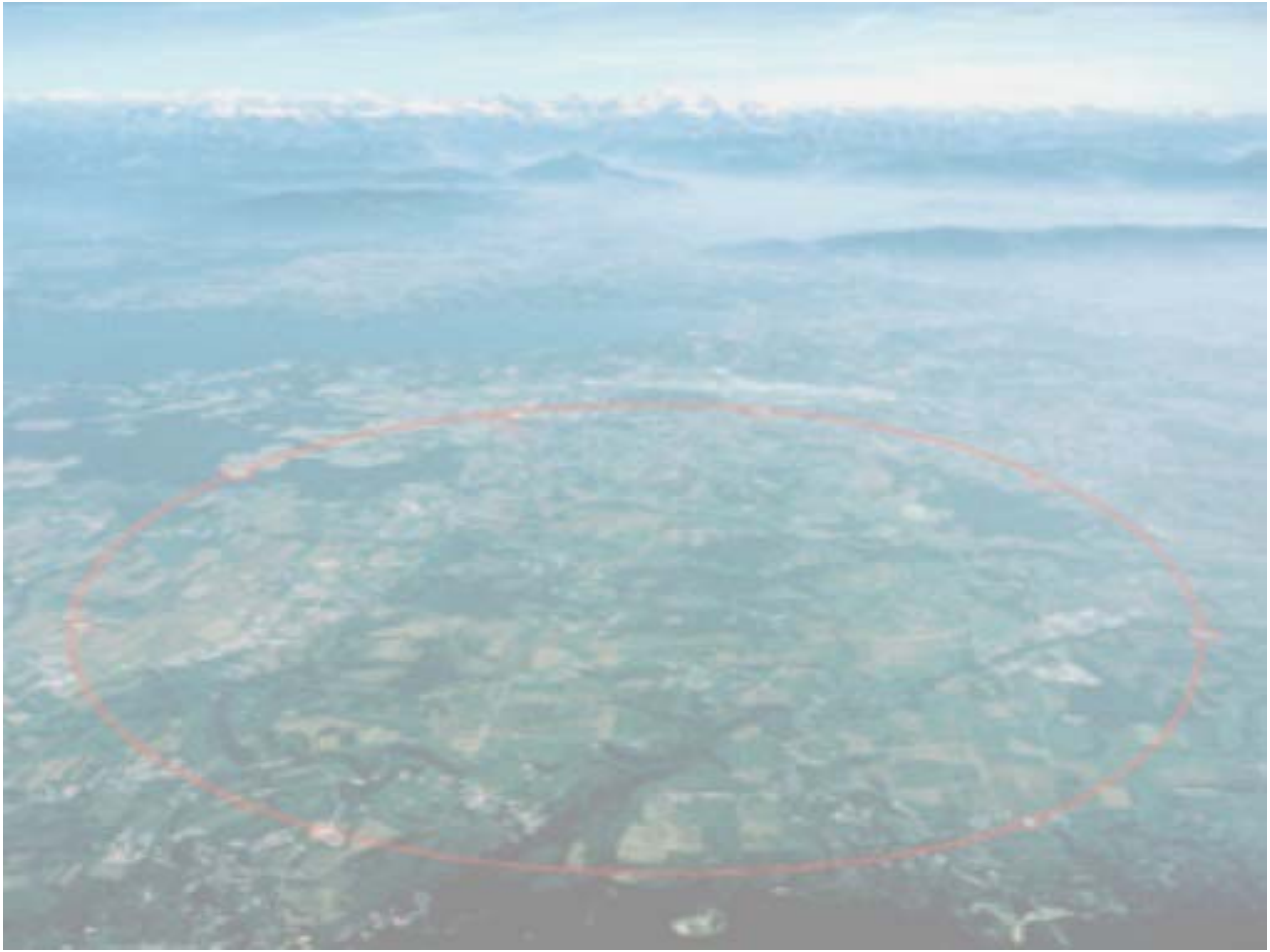
CONCLUSIONS

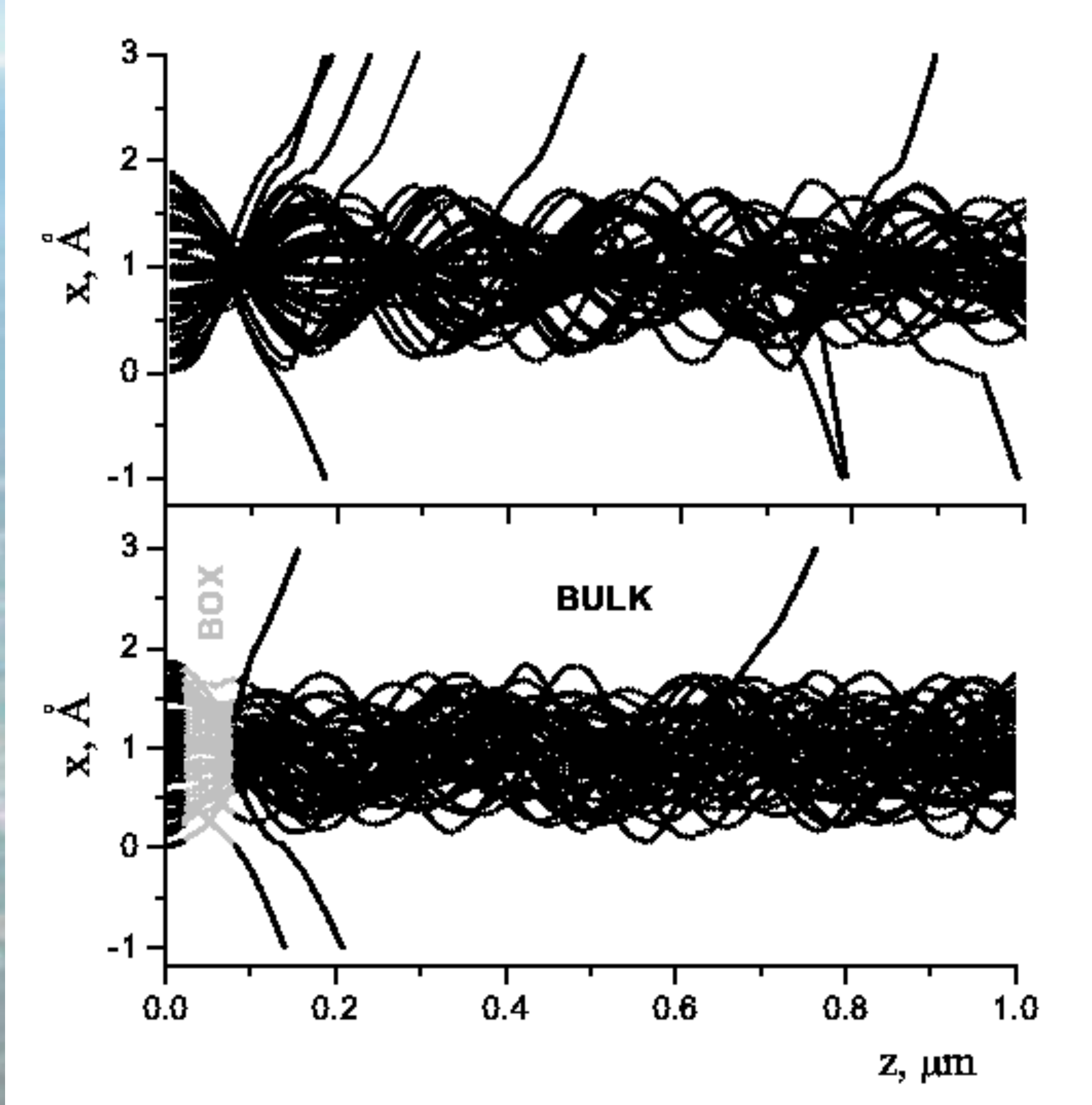
Crystal collimation can be drastically facilitated by both crystal cut and MVROC process, namely:

both the impact parameter can be increased and the crystal transversals number can be decreased

– by crystal cut *at perfect alignment*

– by *MVROC process at rough alignment*

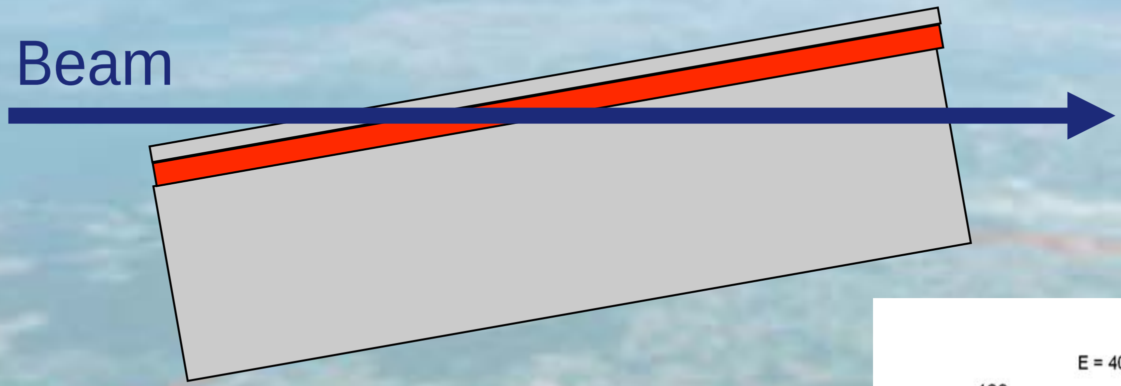


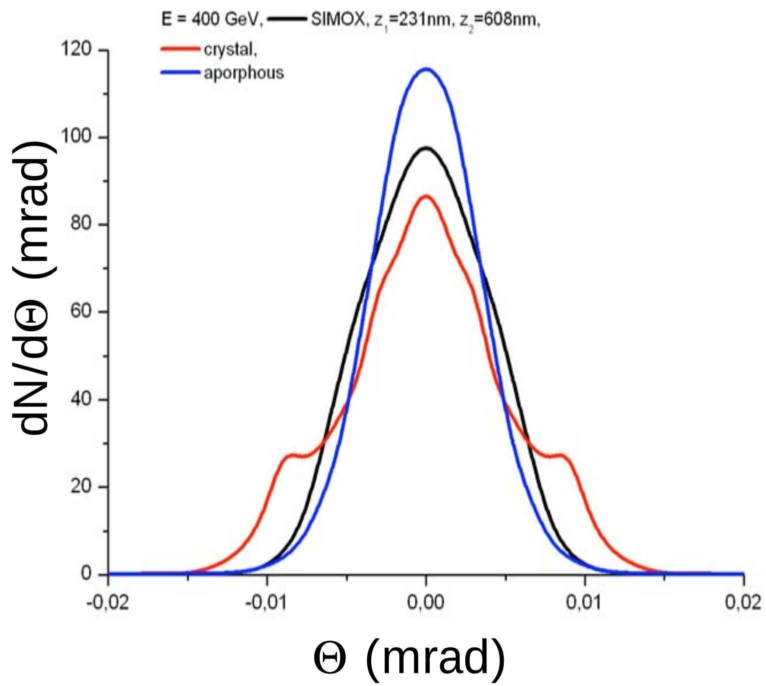


BOX layer
"focuses"
protons
like a ***cut***
diminishing
their
transverse
energy

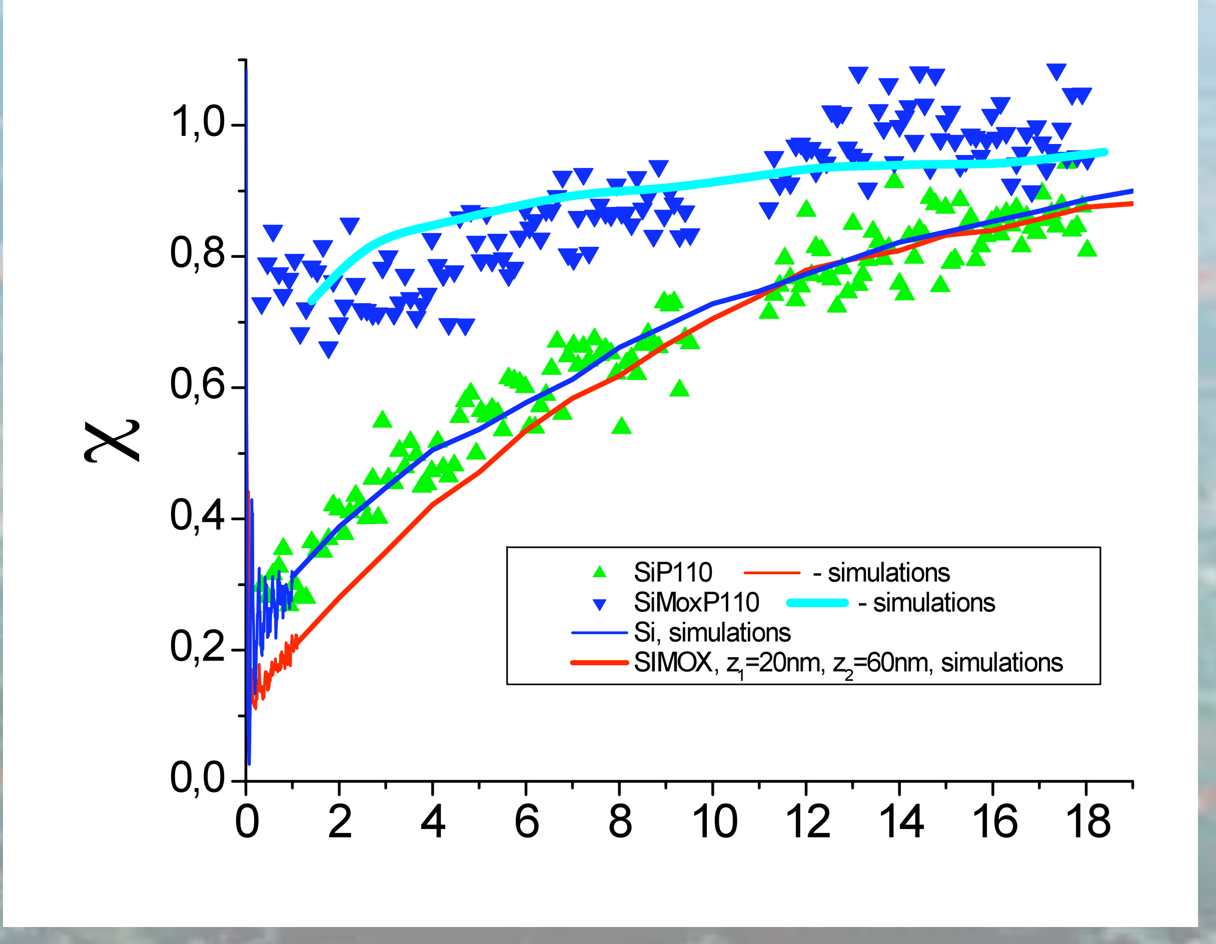
$z_1 = 20\,nm,$
$z_2 = 80\,nm,$
$z_3 = 1\ \mu m,$
$E_p = 7\,MeV$

Grazing proton incidence allows to abserve the channeling eficiency increase at SPS energy of 400 GeV (H8 line)



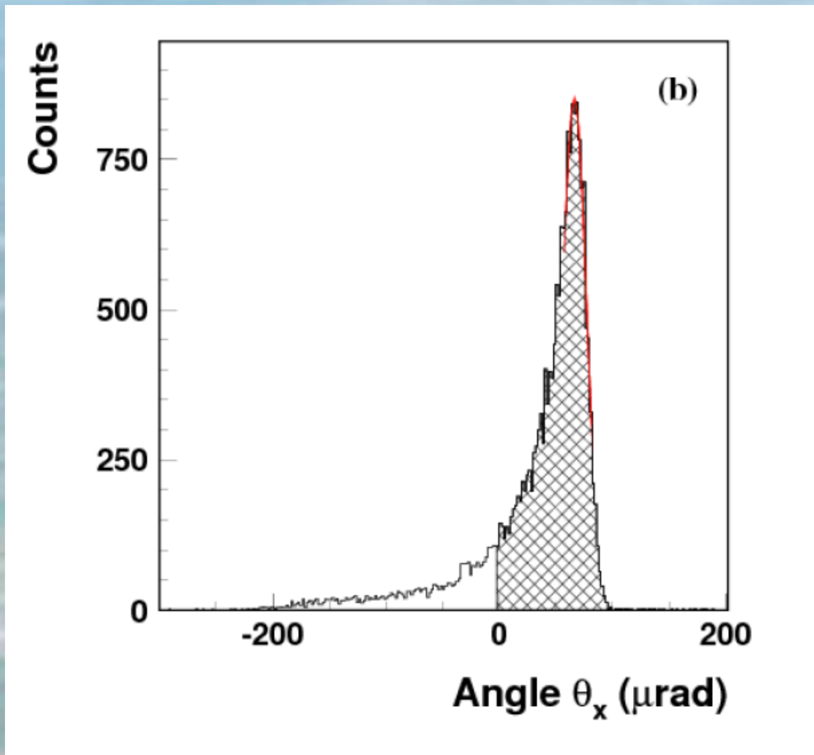


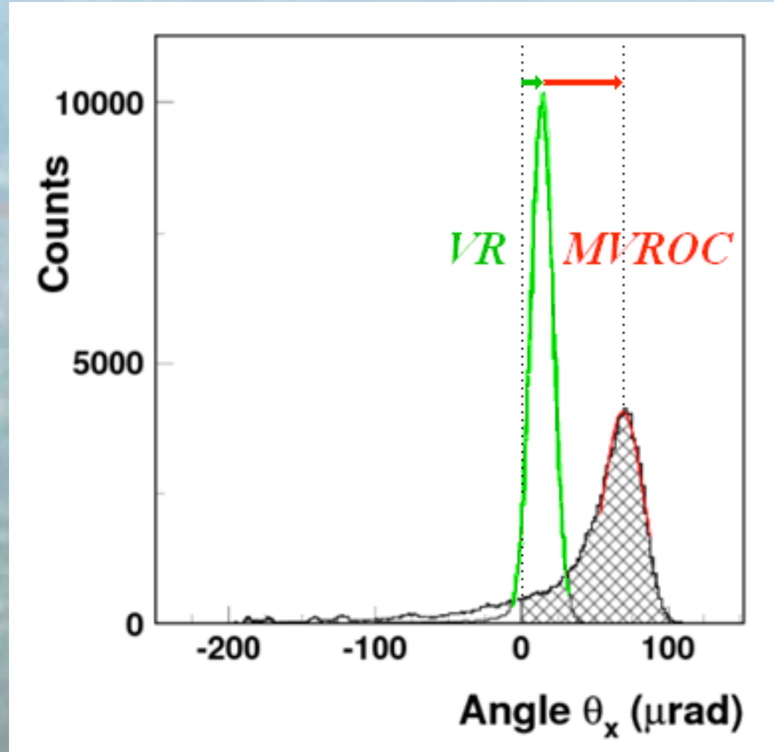
Rutherford Backscattering allows to observe the channeling eficiency increase at low energies (6.1 MeV Legnaro)



First MVROC observation

W. Scandale et al, PLB 682(2009)274





MVROC indeed increases reflection angle 5 times