NEW IDEAS FOR CRYSTAL COLLIMATION

Saint-Petesburg, RuPAC 2012, September 25, 2012

VICTOR TIKHOMIROV,

ALEXEI SYTOV

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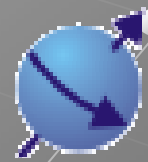
Belarusian State University



BSU *INP*

Outline

UA9 experiment (SPS, CERN) for crystal collimation and **miscut angle** problem

Crystal collimation at the **LHC** with application of **MVROC**

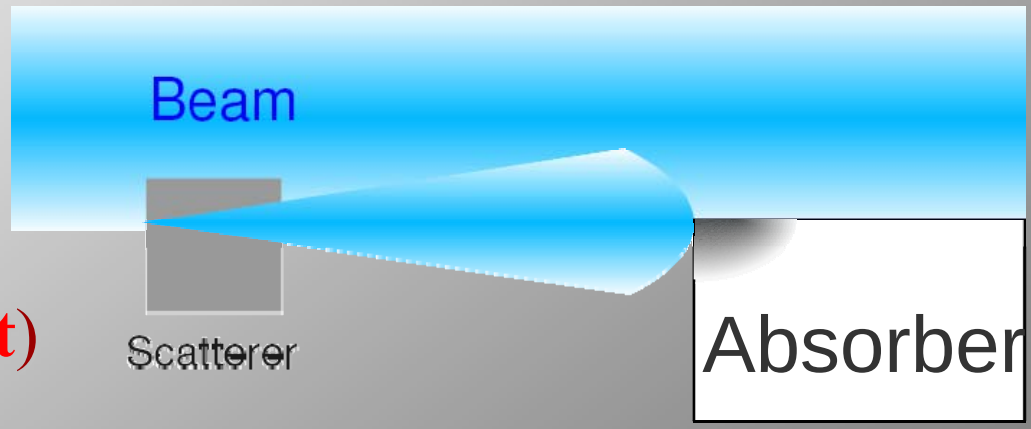
Future experiment of 8 GeV proton beam extraction from the **Recycler Ring** by application of bent crystal and modification by the **crystal cut**

Collimation system for removing halo particles

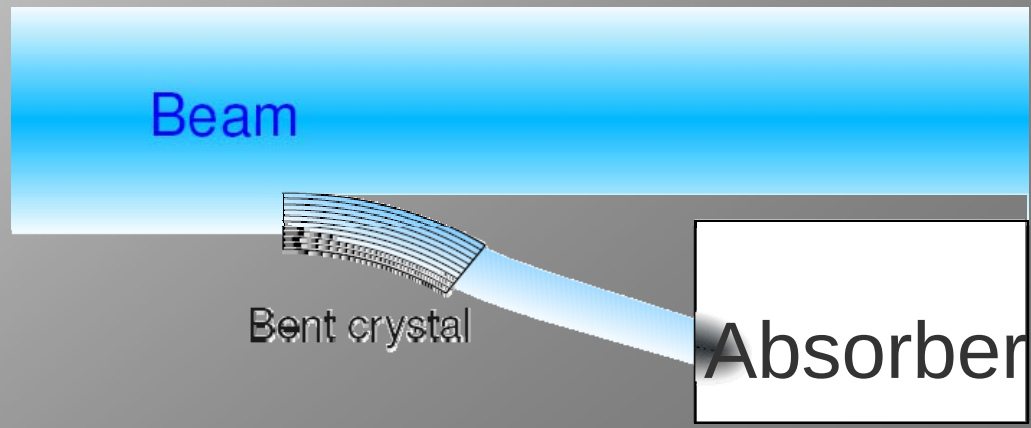
- Halo particles can damage the LHC equipment because of their large amplitude of betatron oscillations. So we should remove them using collimation system:

old collimation system

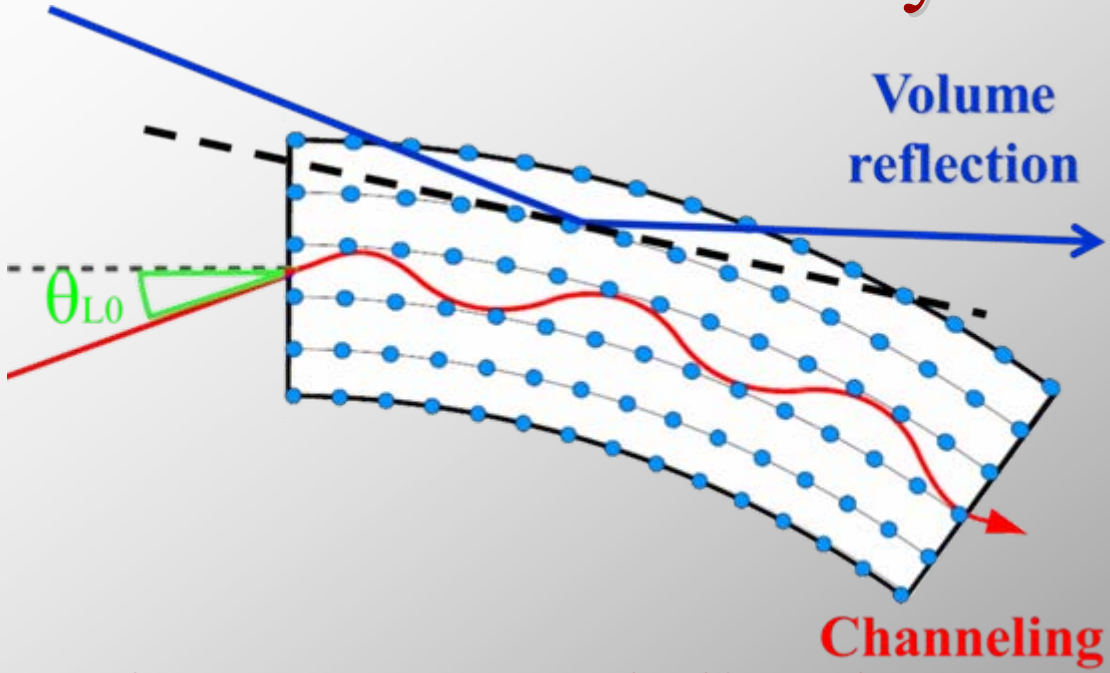
(after the LHC luminosity upgrade becomes **insufficient**)



new collimation system



Effects of beam deflection by bent crystal



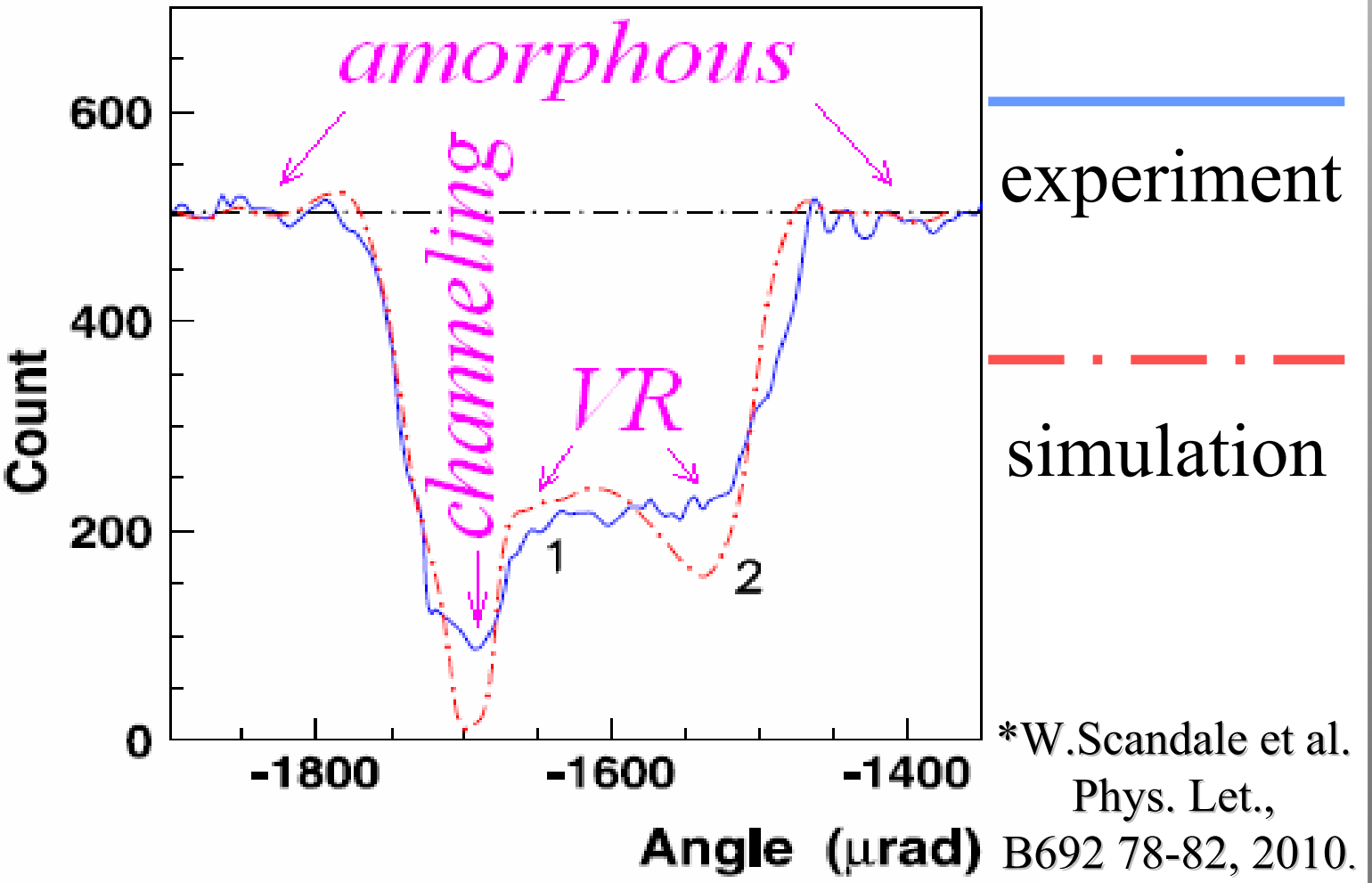
Advantages and disadvantages of different effects

Channeling in Bent crystals — large deflection,
but small acceptance → good for small *angular divergence*

VR — large acceptance,
but small deflection → good for large *angular divergence*

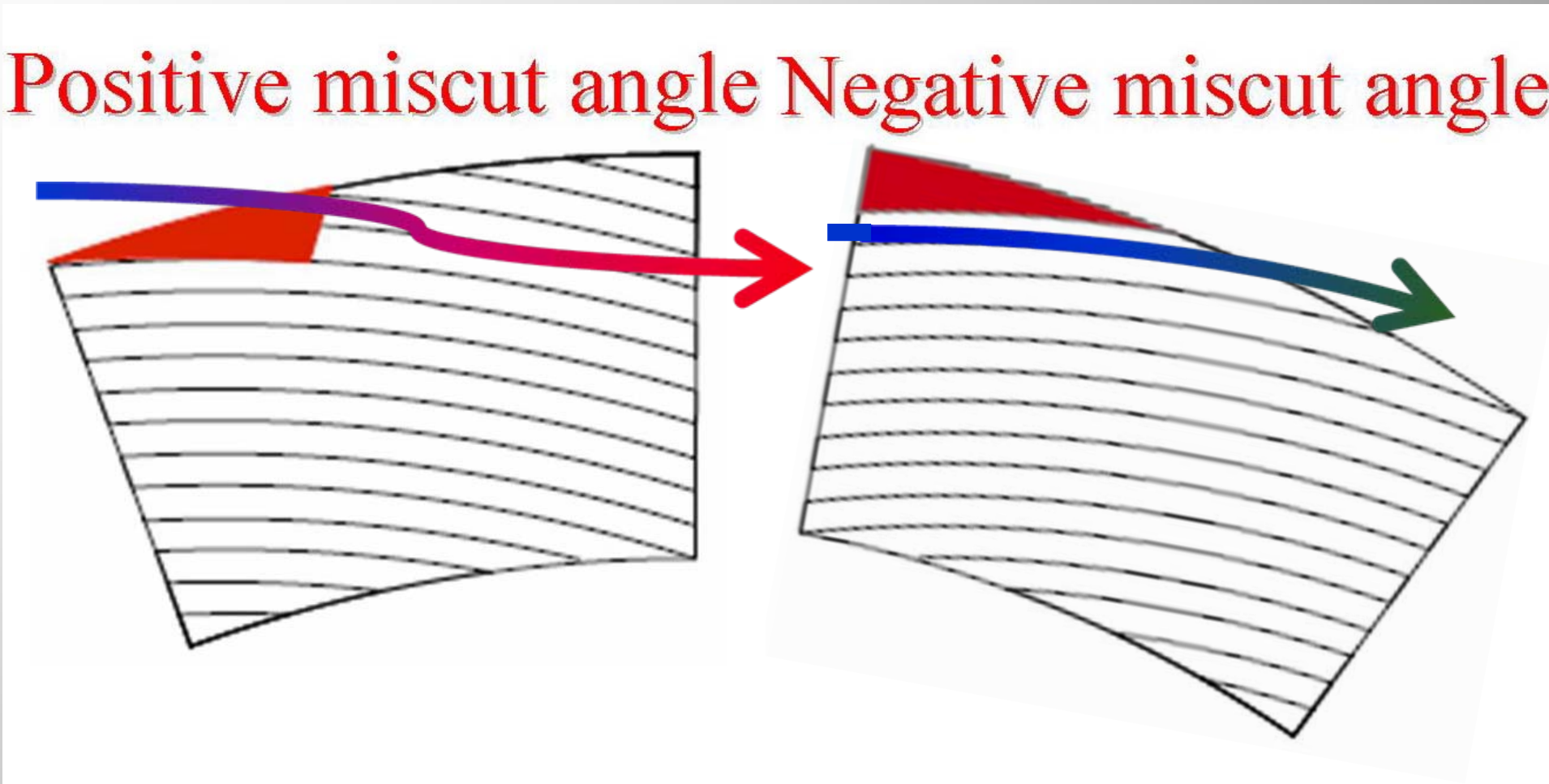
UA9 experiment for crystal collimation at the SPS (CERN)*

- Dependence of inelastic nuclear interaction number of protons on the angular position of the crystal C1:

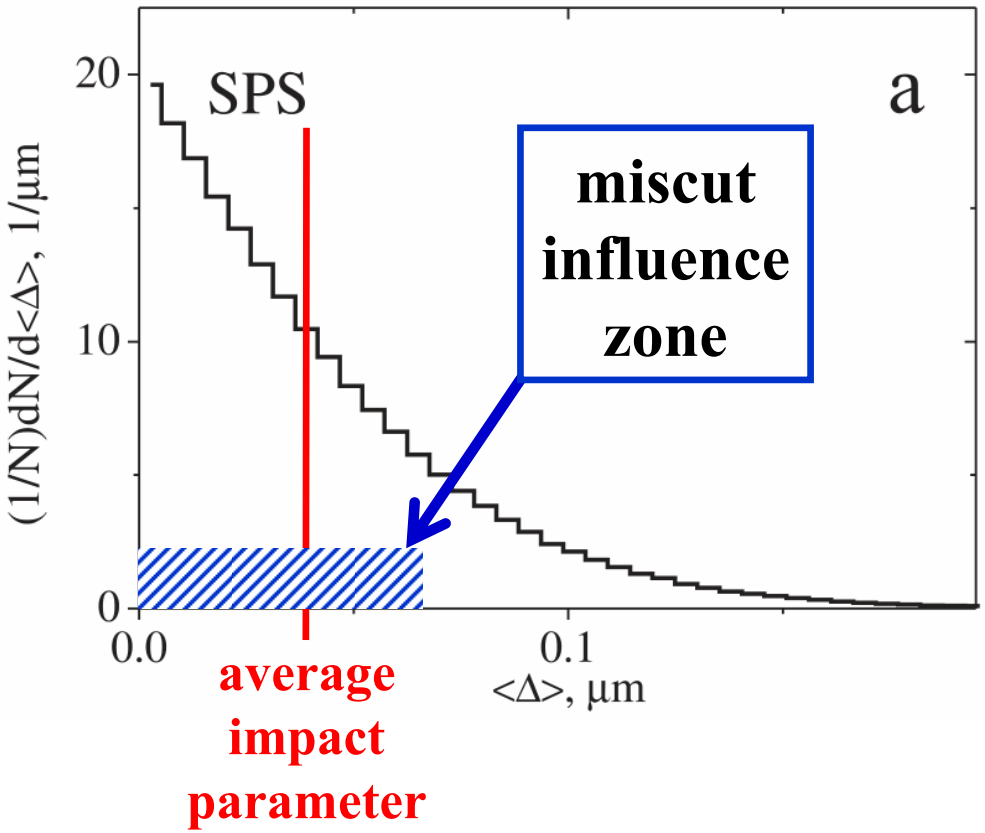


*W.Scandale et al. Phys. Let., B692 78-82, 2010.

Miscut angle problem

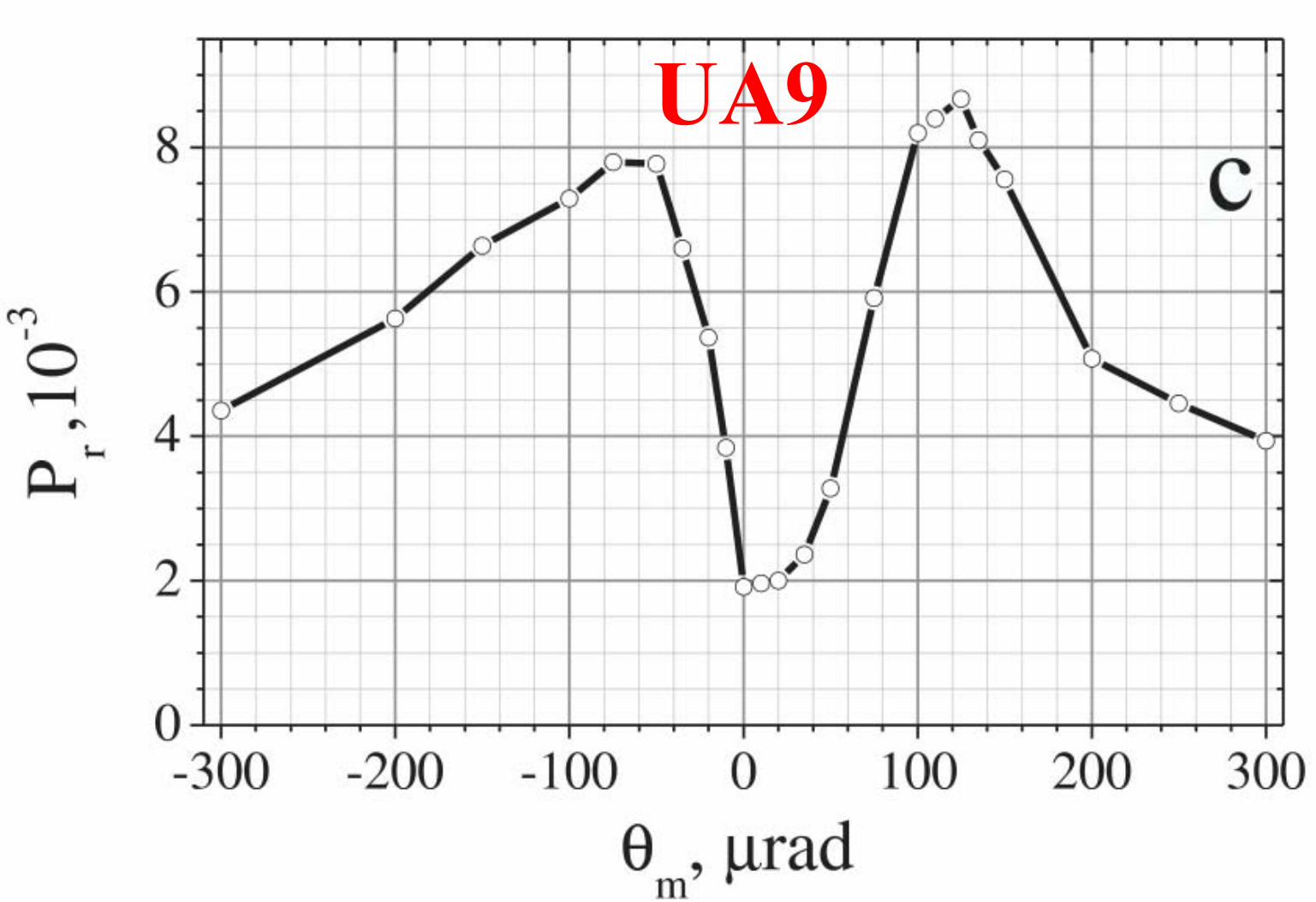


The beam impact parameter influence because of the miscut angle*



*V. Tikhomirov, A. Sytov, "VANT" (57), 2012, N1, p. 88-92; V. Tikhomirov, A. Sytov. arXiv:1109.5051 [physics.acc-ph]

Probability of nuclear reactions in the crystal collimator vs miscut angle at perfect crystal alignment*



*V. Tikhomirov, A. Sytov, "VANT" (57), 2012, N1, p. 88-92;
V. Tikhomirov, A. Sytov. arXiv:1109.5051 [physics.acc-ph]

THE MISCUT ANGLE INFLUENCE ON THE FUTURE LHC CRYSTAL BASED COLLIMATION SYSTEM

V.V. Tikhomirov and A.I. Sytov*

Research Institute for Nuclear Problems, Belarus State University, 220030, Minsk, Belarus

(Received October 25, 2011)

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY, 2012, N 1.
Series: Nuclear Physics Investigations (57), p. 88-92.

To the positive miscut influence on the crystal collimation efficiency

V. V. Tikhomirov, A. I. Sytov*

Research Institute for Nuclear Problems,

Belarus State University, Bobruiskaya 11, 220030 Minsk, Belarus

(Dated: September 26, 2011)

arXiv:1109.5051v1 [physics.acc-ph] 23 Sep 2011

Strong reduction of the off-momentum halo in crystal assisted collimation of the SPS beam

W. Scandale [a,b,e], G. Arduini [a], R. Assmann [a], F. Cerutti [a], S. Gilardoni [a], E. Laface [a], R. Losito [a], A. Masi [a], E. Metral [a], D. Mirarchi [a], S. Montesano [a], V. Previtali [a], S. Redaelli [a], G. Valentino [a], P. Schoofs [a], G. Smirnov [a], E. Bagli [c], S. Baricordi [c], P. Dalpiaz [c], V. Guidi [c], A. Mazzolari [c], D. Vincenzi [c], S. Dabagov [d], F. Murtas [d], G. Claps [d], G. Cavoto [e], F. Iacoangeli [e], L. Ludovici [e], R. Santacesaria [e], P. Valente [e], F. Galluccio [f], A.G. Afonin [g], M.K. Bulgakov [g], Yu.A. Chesnokov [g], V.A. Maisheev [g], I.A. Yazynin [g], A.D. Kovalenko [h], A.M. Taratin [h,*], V.V. Uzhinskiy [h], Yu.A. Gavrikov [i], Yu.M. Ivanov [i], L.P. Lapina [i], V.V. Skorobogatov [i], W. Ferguson [j], J. Fulcher [j], G. Hall [j], M. Pesaresi [j], M. Raymond [j], A. Rose [j], M. Ryan [j], G. Robert-Demolaize [k], T. Markiewicz [l], M. Oriunno [l], U. Wienands [l]

Physics Letters B 714 (2012) 231–236

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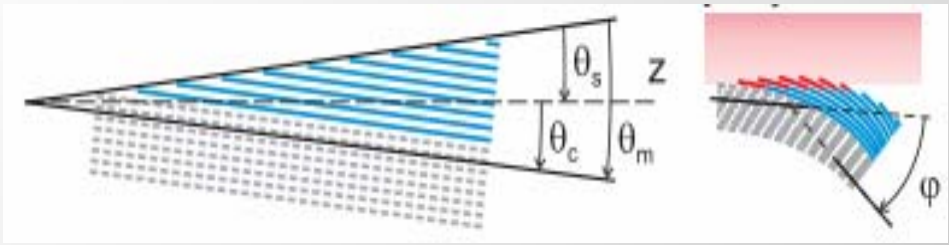

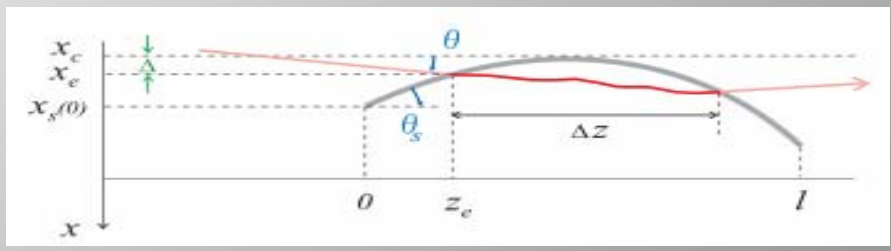

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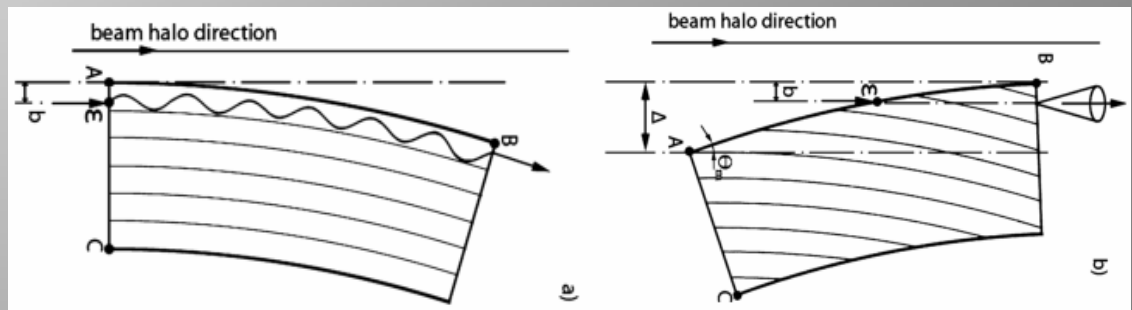

Two opposite cases for channeling and volume reflection

Channeling provides high deflection efficiency for:

- Small *angular divergence* (for capture in the channeling regime)
- Large *impact parameter* (to decrease the miscut angle influence)

Otherwise we should choose the *volume reflection*.

2 opposite examples:

- *Volume reflection* for the crystal-based collimation at the LHC (CERN)
- *Channeling* for the 8 GeV proton beam extraction from the Recycler Ring (FNAL)

Why volume reflection for the LHC?

Crystal collimation at the LHC

Main effects of beam losses at the LHC*

<table>
<tr><th>Effect</th><th colspan="4">Beam life time, h</th></tr>
<tr><td>Inelastic scattering in IP</td><td>108</td><td>108</td><td rowspan="3">70</td><td rowspan="5">41</td></tr>
<tr><td>Elastic scattering in IP</td><td>310</td><td rowspan="2">197</td></tr>
<tr><td>Diffractive scattering in IP</td><td>539</td></tr>
<tr><td>Inelastic scattering on residual gas</td><td>129</td><td colspan="2" rowspan="2">101</td></tr>
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</table>

***M. Lamont, LHC Project Note 375**

Main effects of halo formation at the LHC*

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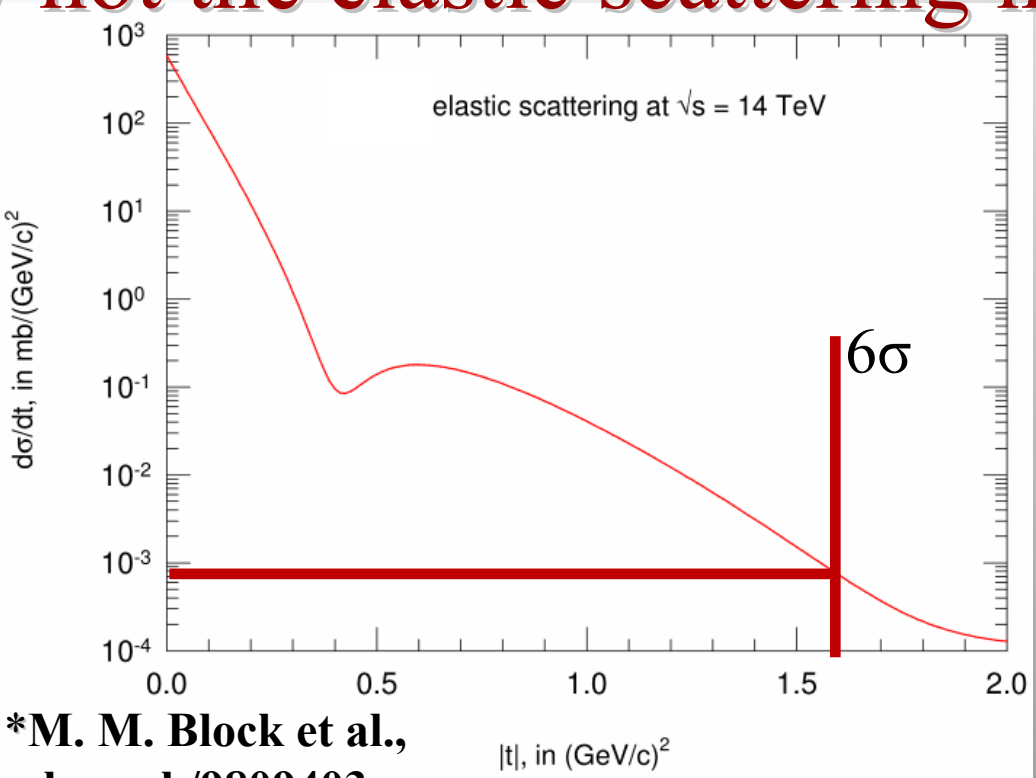
Main effects of halo formation at the LHC*

Effect	Beam life time, h			
Inelastic scattering in IP	108	108	70	41
Elastic scattering in IP	310	197		
Diffractive scattering in IP	539			
Inelastic scattering on residual gas	129	101		
Elastic scattering on residual gas	459			

***M. Lamont, LHC Project Note 375**

Why not the elastic scattering in IP?



***M. M. Block et al., hep-ph/9809403**

$$\frac{x_{gas}}{x_{IP}} = \sqrt{\frac{\beta_{avr}^2\theta^2}{\beta_{IP}\beta_{avr}\theta^2}} = \sqrt{\frac{\beta_{avr}}{\beta_{IP}}} \sim 18 \qquad (1)$$

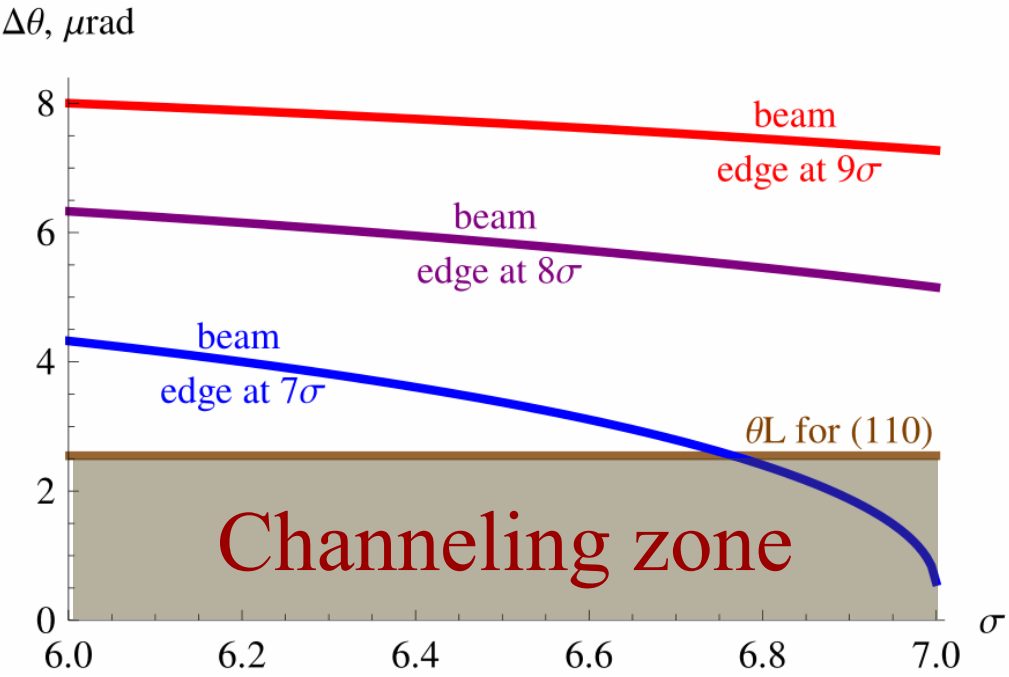
$$p_{6\sigma} \sim 2 \cdot 10^{-6} \Rightarrow \frac{dN}{dt} \sim \frac{M_{beam}N_{beam}}{T_{life}} p_{6\sigma} \sim 2 \cdot 10^4 s^{-1} \qquad (2)$$

***J.B. Jeanneret et al., LHC Project Report 44**

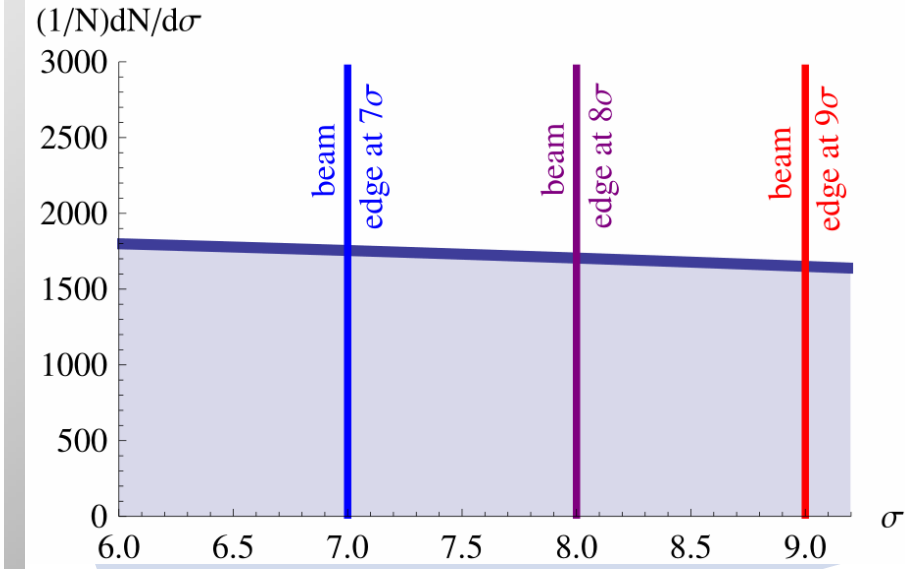
Quench limit*: $\frac{dN_{ql}}{dt} \sim 5 \cdot 10^6 s^{-1}$ (3)

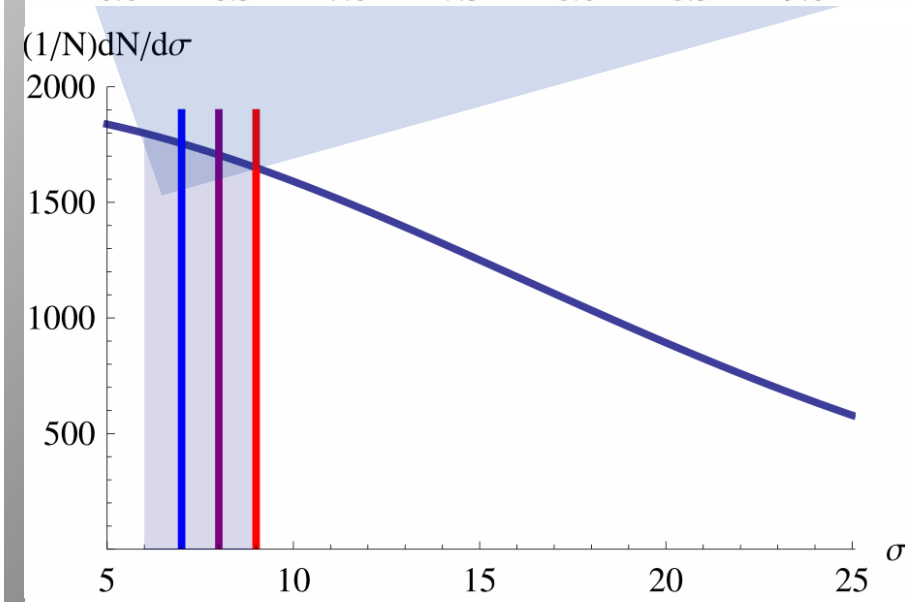
Beam profile and angular divergence for channeling

Average angular divergence vs impact parameter for different beam edges



Beam profile at large σ due to elastic nuclear scattering on the residual gas





Conclusion:

The angular divergence is much larger than the critical angle of capture in the channeling regime.

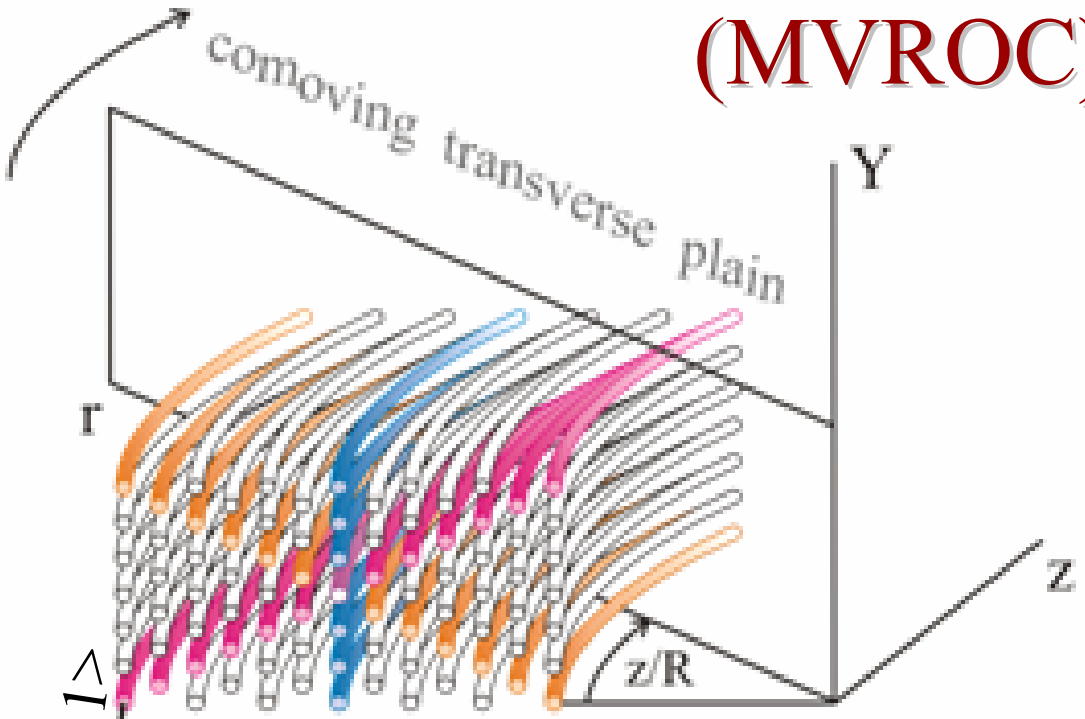
So, the channeling effect is not applicable for the LHC case.

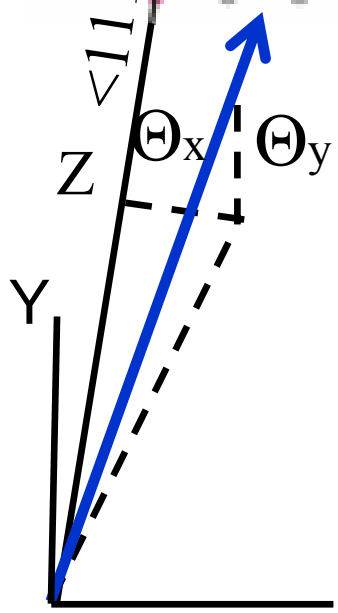
MVROC instead of VR for the LHC

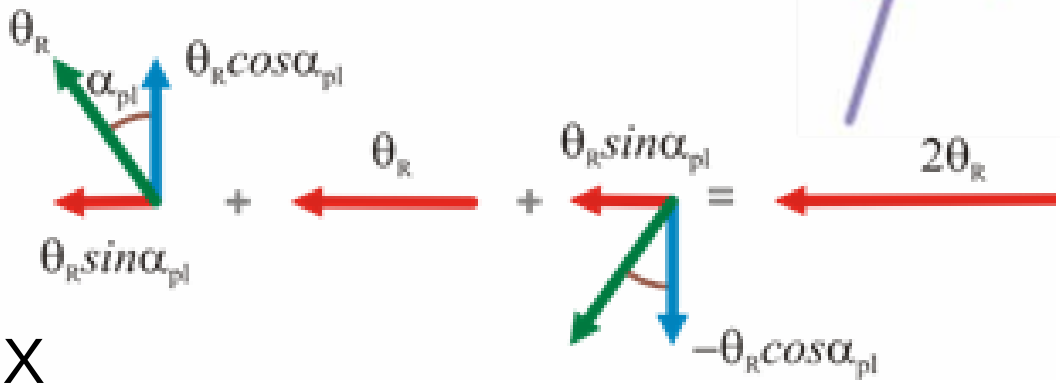
VR — large acceptance,
but small deflection
(7 times smaller than we can expect from channeling for the LHC)

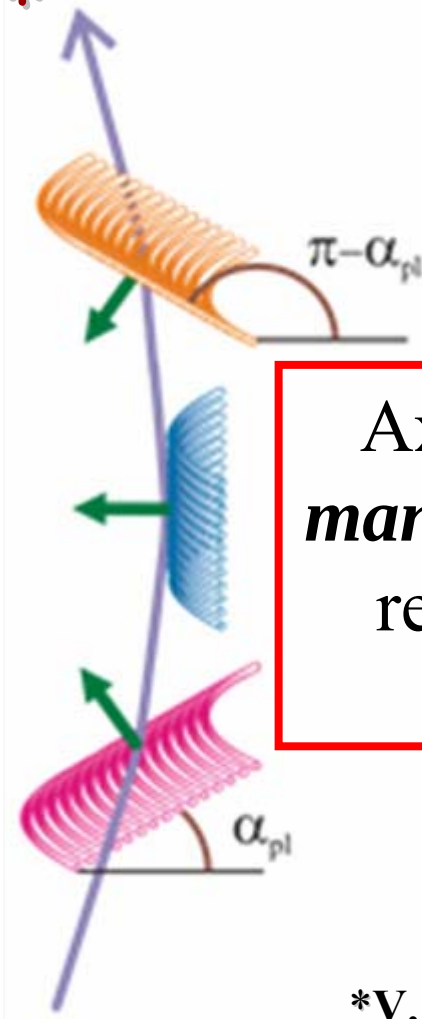
MVROC — very large acceptance,
increased deflection
MVROC indeed increases reflection angle
5 times *in comparison with VR*

Multiple Volume Reflection in one bent crystal (MVROC)*





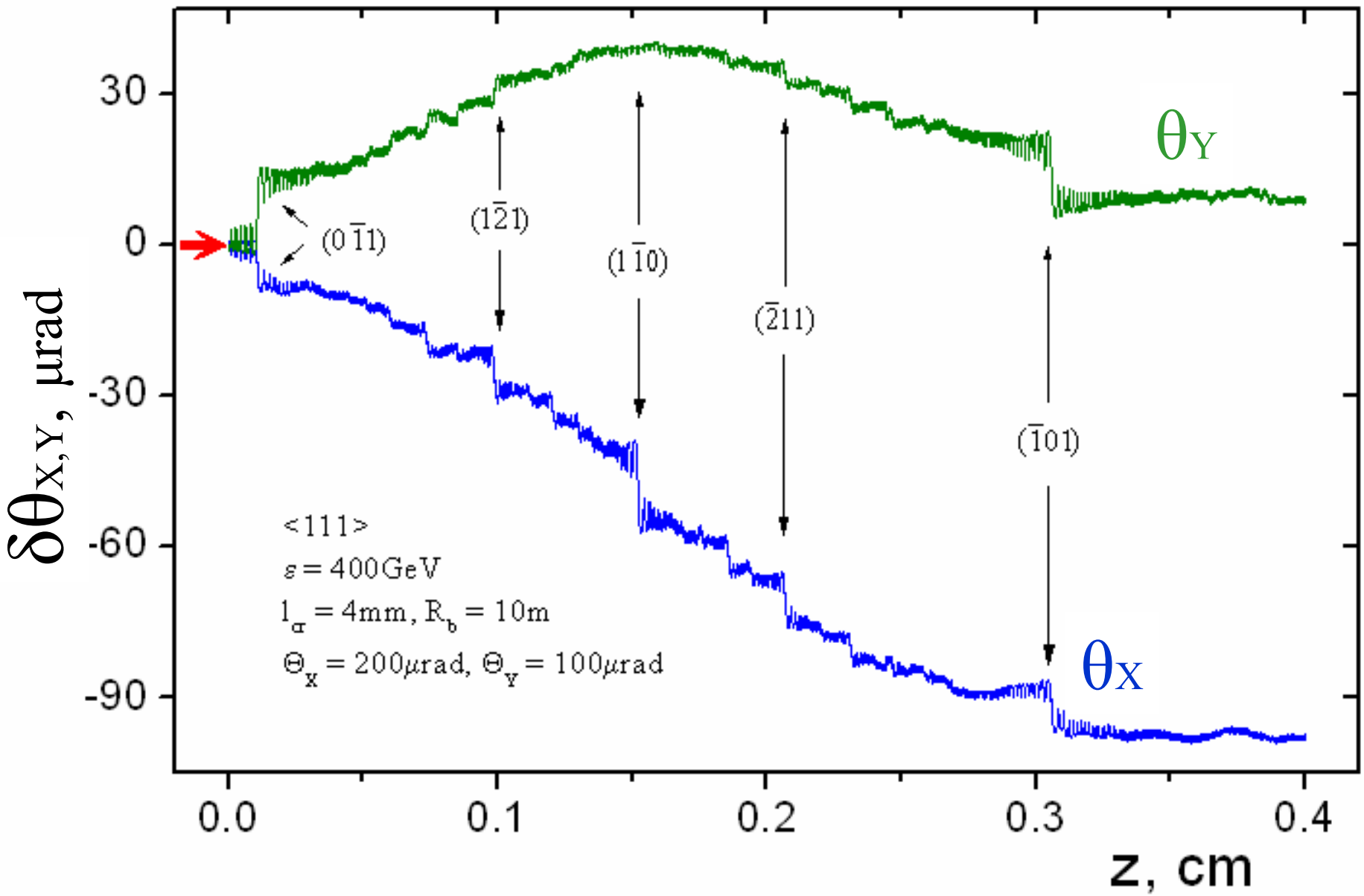




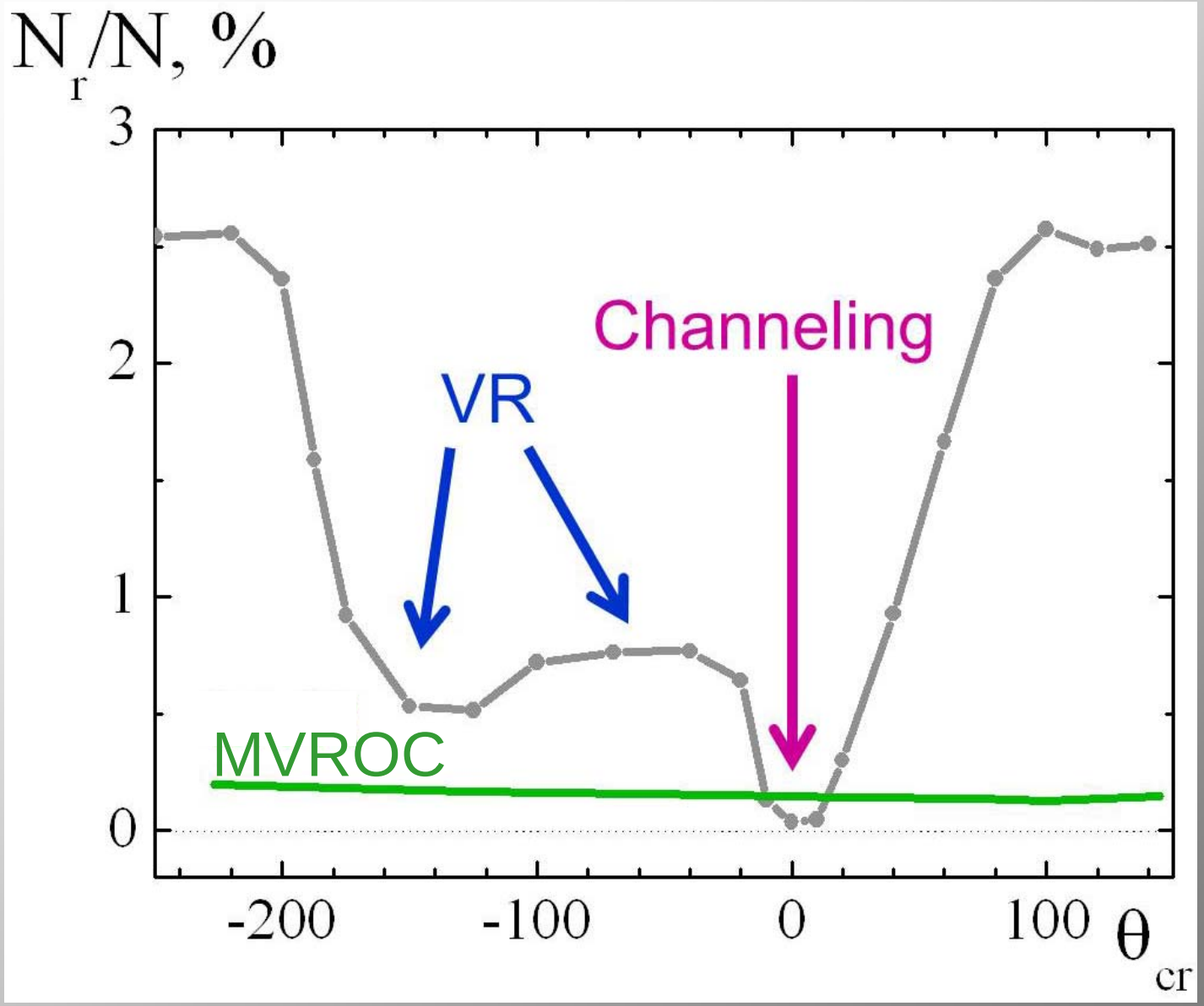
Axes form ***many*** inclined reflecting planes

***V. Tikhomirov, PLB 655 (2007) 217; V. Guidi, A. Mazzolari and V. Tikhomirov, JAP 107 (2010) 114908**

A trajectory



Angular acceptance increase by MVROC*



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

Письма в ЖЭТФ, том 93, вып. 4, с. 205 – 208 © 2011 г. 25 февраля

Коллимация циркулирующего пучка в синхротроне У-70 с помощью отражения частиц в кристаллах с осевой ориентацией

А. Г. Афонин, В. Т. Баранов, М. К. Булгаков, И. С. Войнов, В. Н. Горлов, И. В. Иванова, Д. М. Крылов, А. Н. Лунёков, В. А. Маишеев, С. Ф. Решетников, Д. А. Савин, Е. А. Сыщиков, В. И. Терехов, Ю. А. Чесноков, П. Н. Чирков, И. А. Язынин

Государственный научный центр "Институт физики высоких энергий", Протвино, 142281 Московская обл., Россия

Поступила в редакцию 18 января 2011 г.

First observation of multiple volume reflection by different planes in one bent silicon crystal for high-energy protons

W. Scandale[a], A. Vomiero[b], E. Bagli[c], S. Baricordi[c], P. Dalpiaz[c], M. Fiorini[c], V. Guidi[c], A. Mazzolari[c], D. Vincenzi[c], R. Milan[d], Gianantonio Della Mea[e], E. Vallazza[f], A.G. Afonin[g], Yu.A. Chesnokov[g], V.A. Maisheev[g], I.A. Yazynin[g], V.M. Golovatyuk[h], A.D. Kovalenko[h], A.M. Taratin[h,*], A.S. Denisov[i], Yu.A. Gavrikov[i], Yu.M. Ivanov[i], L.P. Lapina[i], L.G. Malyarenko[i], V.V. Skorobogatov[i], V.M. Suvorov[i], S.A. Vavilov[i], D. Bolognini[j,k], S. Hasan[j,k], A. Mattera[j,k], M. Prest[j,k], V.V. Tikhomirov[l]

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March 2011

EPL, 93 (2011) 56002
doi: 10.1209/0295-5075/93/56002

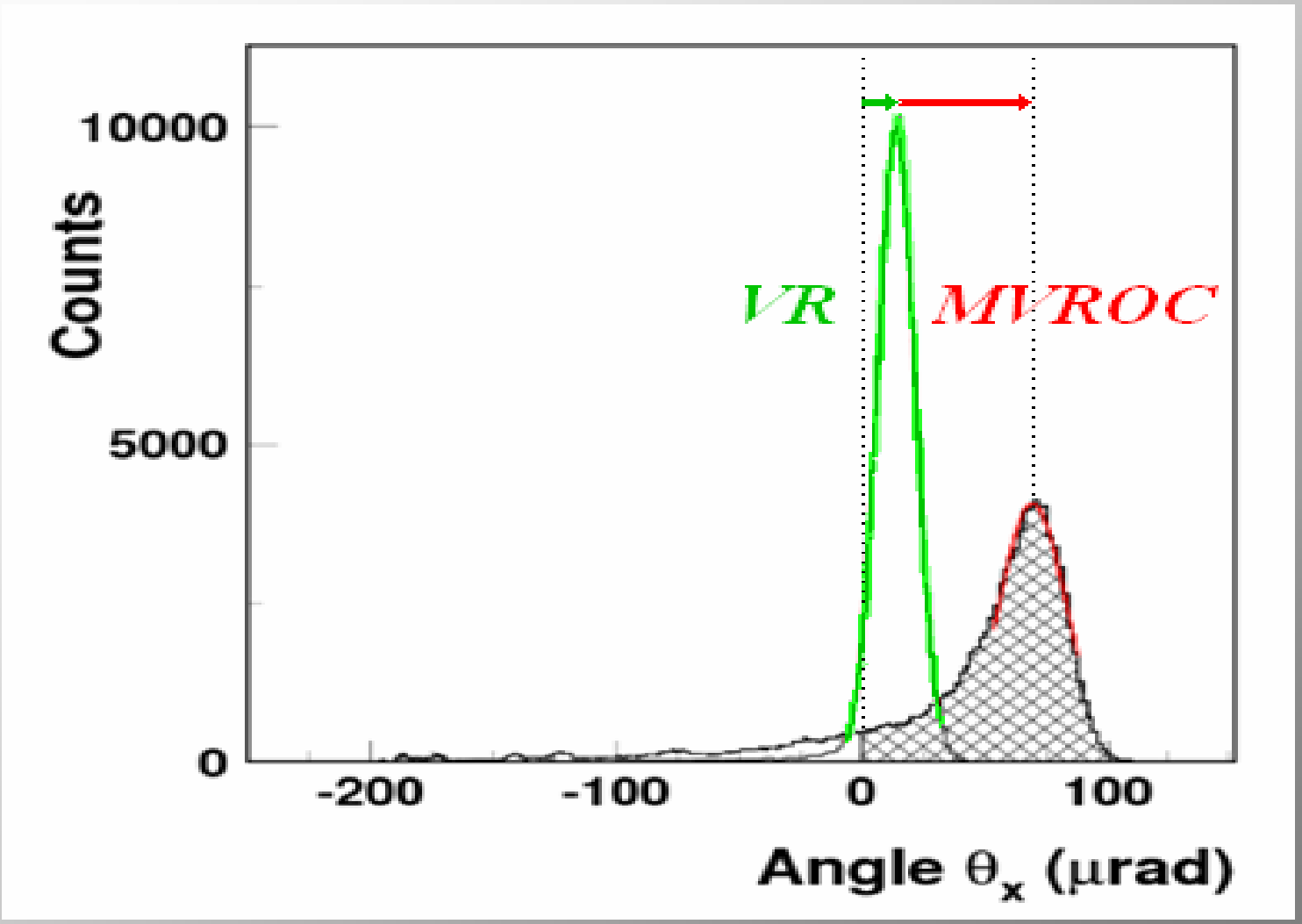
www.epljournal.org

Observation of multiple volume reflection by different planes in one bent silicon crystal for high-energy negative particles

W. Scandale[1], A. Vomiero[2], E. Bagli[3], S. Baricordi[3], P. Dalpiaz[3], M. Fiorini[3], V. Guidi[3], A. Mazzolari[3], D. Vincenzi[3], R. Milan[4], G. Della Mea[5], E. Vallazza[6], A. G. Afonin[7], Yu. A. Chesnokov[7], V. A. Maisheev[7], I. A. Yazynin[7], A. D. Kovalenko[8], A. M. Taratin[8(a)], A. S. Denisov[9], Yu. A. Gavrikov[9], Yu. M. Ivanov[9], L. P. Lapina[9], L. G. Malyarenko[9], V. V. Skorobogatov[9], V. M. Suvorov[9], S. A. Vavilov[9], D. Bolognini[10,11], S. Hasan[10,11], A. Mattera[10,11], M. Prest[10,11] and V. V. Tikhomirov[12]

First MVROC observation

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



*MVROC indeed increases reflection angle **5 times***

Beam extraction from the Recycler Ring (Fermilab)

Fermilab, Accelerator Physics Center (APC)

Vladimir Shiltsev
Director of Accelerator Physics Center
at Fermi National Accelerator Lab

Nikolai Mokhov
Head of the Energy Deposition Department
in the Accelerator Physics Center

Tevatron beam halo collimation system: design, operational experience and new methods[1]

N. Mokhov,[2] **J. Annala, R. Carrigan, M. Church, A. Drozhdin, T. Johnson, R. Reilly, V. Shiltsev, G. Stancari,**[3] **D. Still, A. Valishev, X.-L. Zhang and V. Zvoda**

Fermi National Accelerator Laboratory,
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E-mail: mokhov@fnal.gov

2011 JINST

APC Fermilab

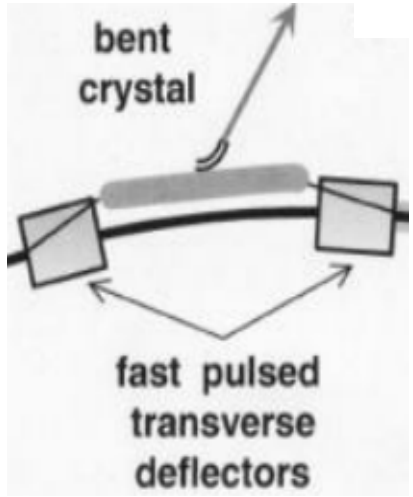
Beam extraction from the Recycler Ring*

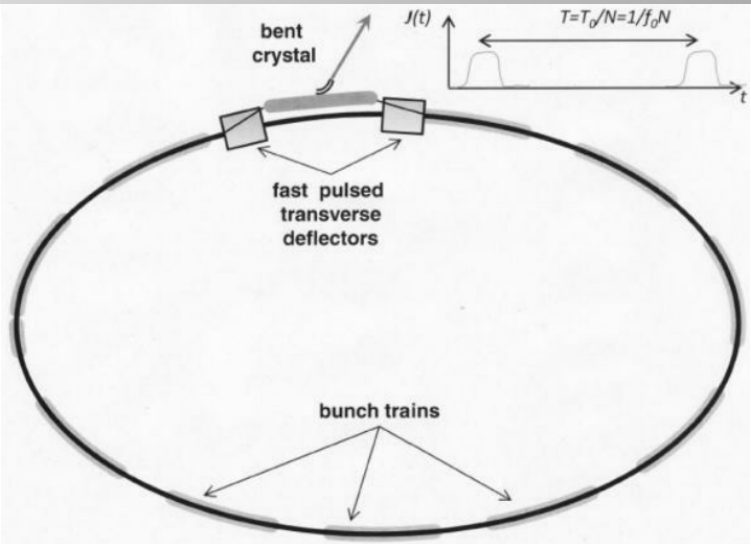
NOVEL SLOW EXTRACTION SCHEME FOR PROTON ACCELERATORS USING PULSED DIPOLE CORRECTORS AND CRYSTALS*

V. Shiltsev#, FNAL, Batavia, IL 60510, USA

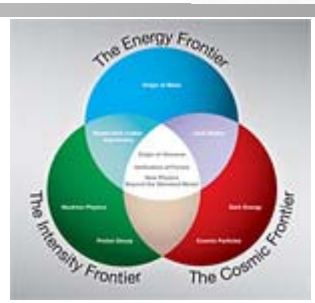
Crystal and beam parameters**:

- E = 8 GeV
- Crystal length = 1mm
- Crystal thickness = 1mm
- Bending angle = 0.5mrad





Intensity Frontier



Possible application:

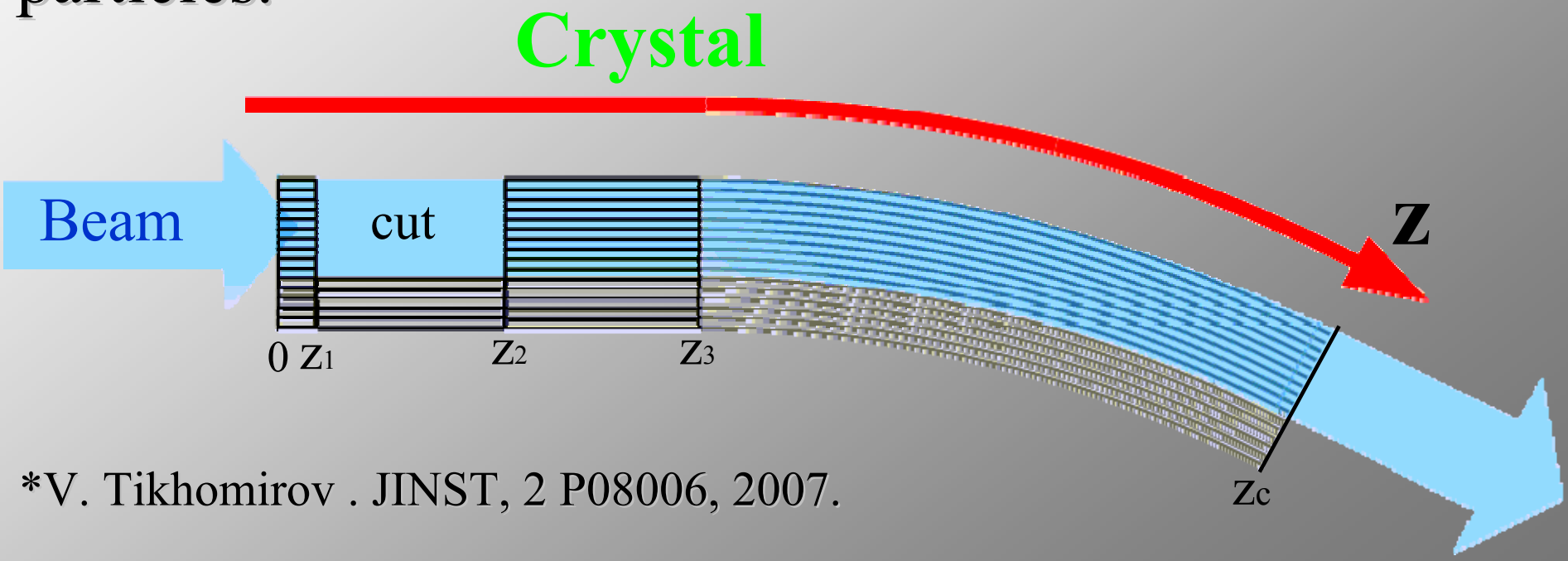
Extraction of *very intensive beam* for:

- **Neutrino experiments** (ArgoNeuT, MINERvA, MiniBooNE, MINOS, NOvA, LBNE)
- **Experiments with muons** (Mu2e, MICE)

*V. Shiltsev, FNAL, No. DE-AC02-07CH11359;
**A.I. Drozhdin, FNAL, No. DE-AC02-07CH11359.

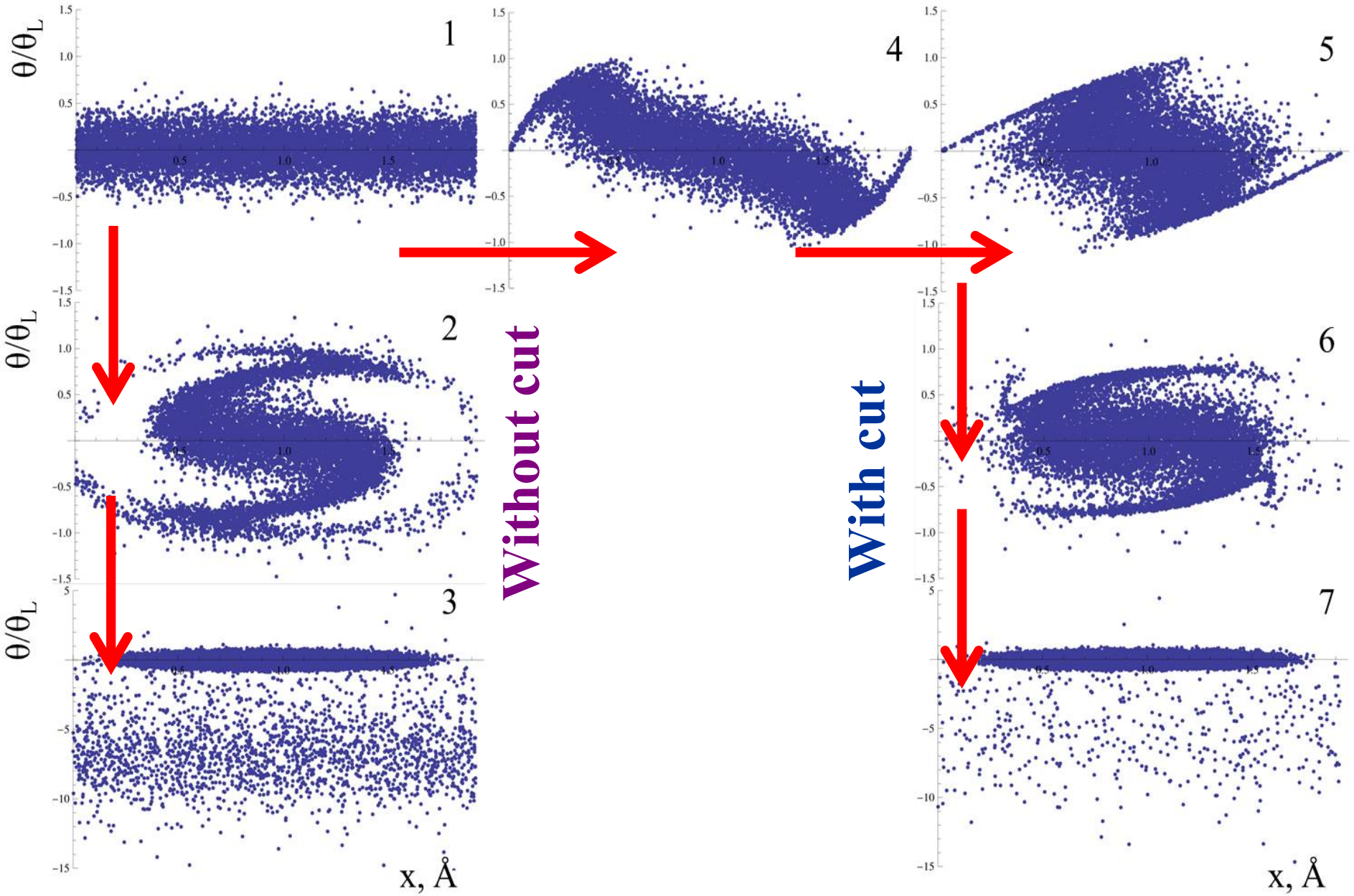
A technique to improve crystal channeling efficiency of charged particles up to 99%*

- A narrow plane cut near the crystal surface considerably increases the probability of capture into the stable channeling motion of positively charged particles.



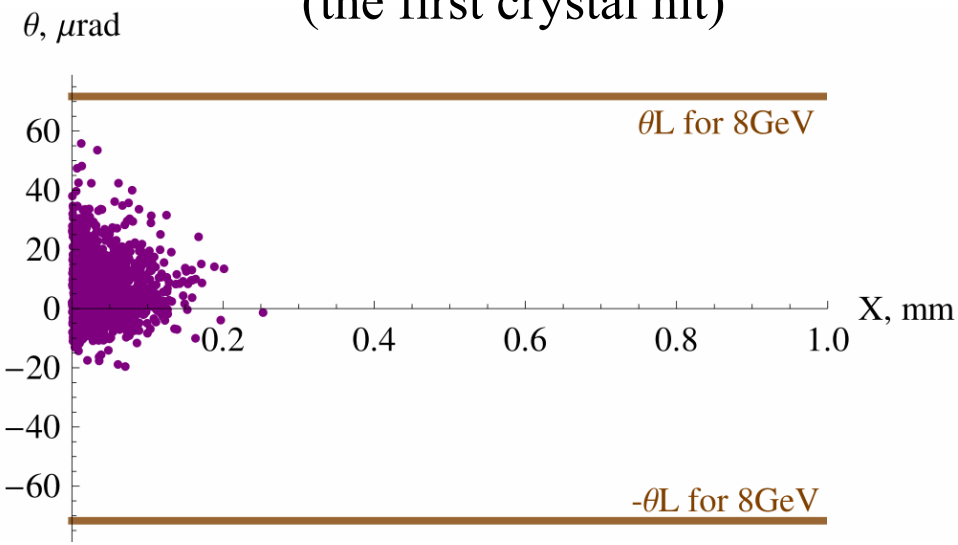
*V. Tikhomirov . JINST, 2 P08006, 2007.

Phase spaces

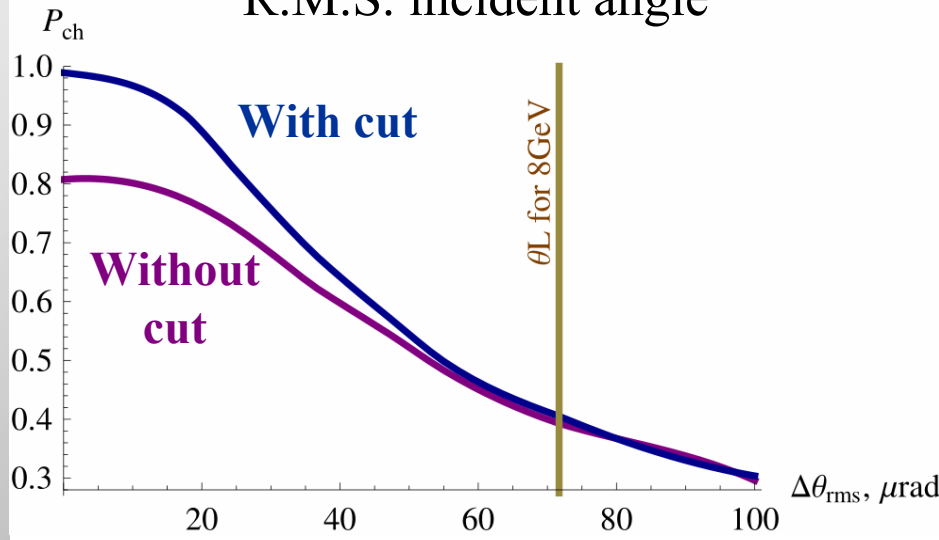


Cut modification for Recycler Ring

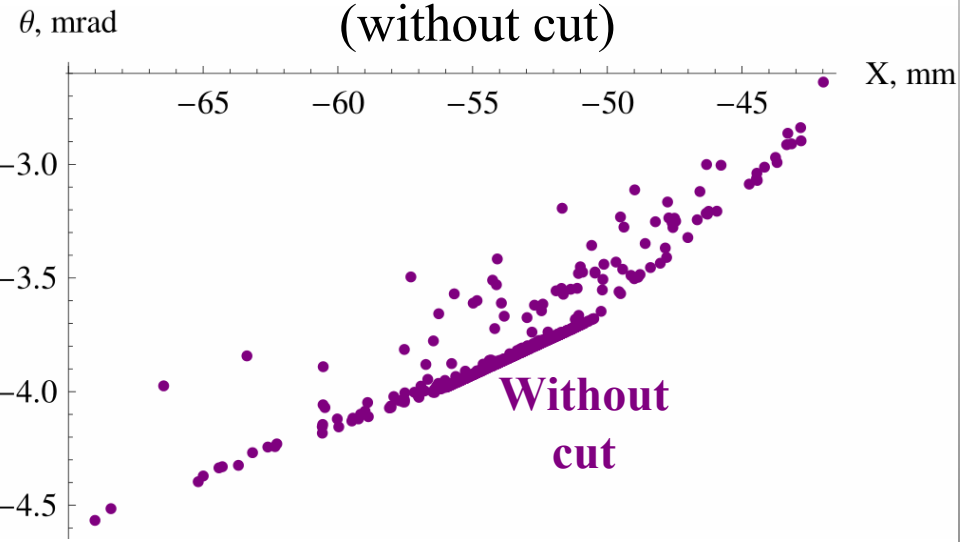
Phase space at the crystal entrance (the first crystal hit)



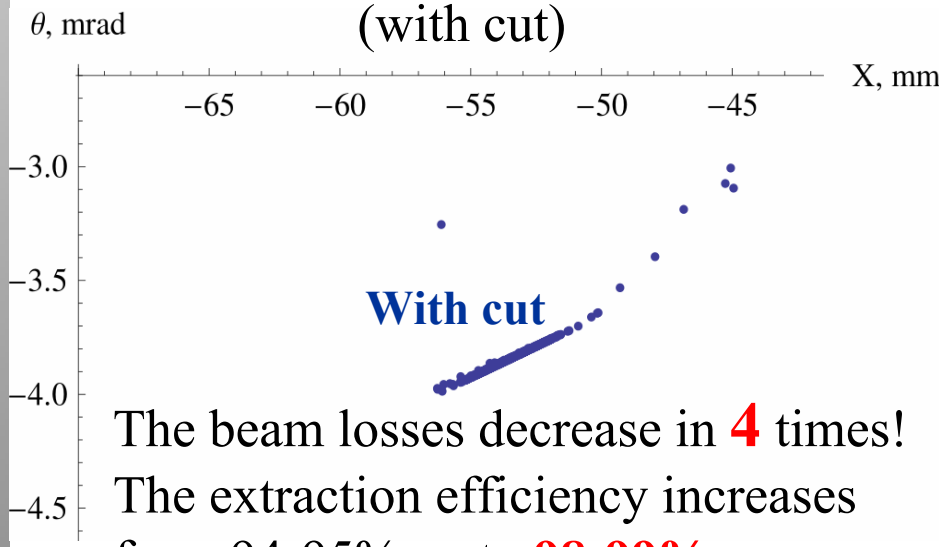
Channeling efficiency *vs* R.M.S. incident angle



Phase space of the extracted beam (without cut)



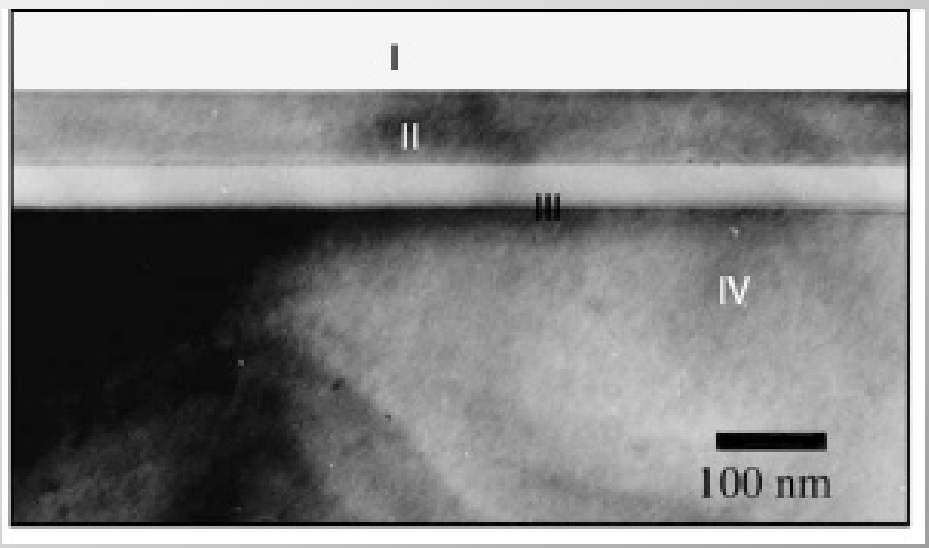
Phase space of the extracted beam (with cut)

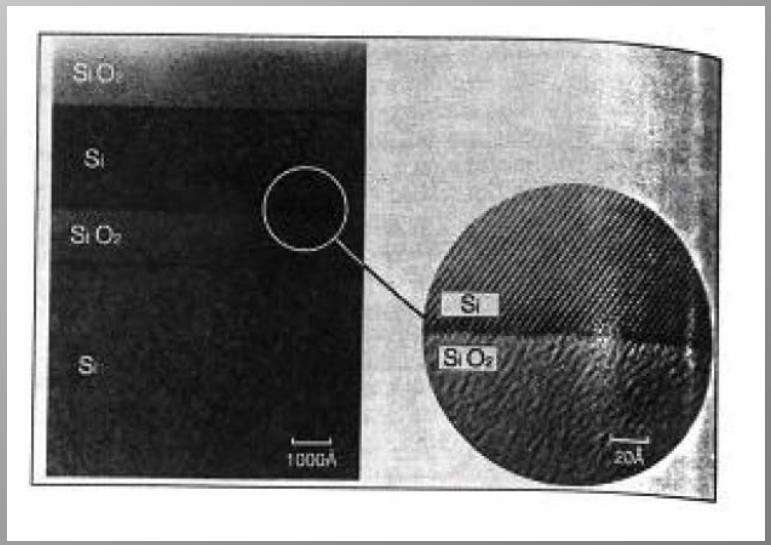


The beam losses decrease in **4** times!
The extraction efficiency increases from 94-95% up to **98-99%**.

SIMOX Buried Oxide Layer can be used instead of crystal cut*

The optimal thickness of the cut at beam energy of 8 GeV will be ~ 1μm.
So, much technologically simpler to fabricate the amorphous layer instead of the cut.





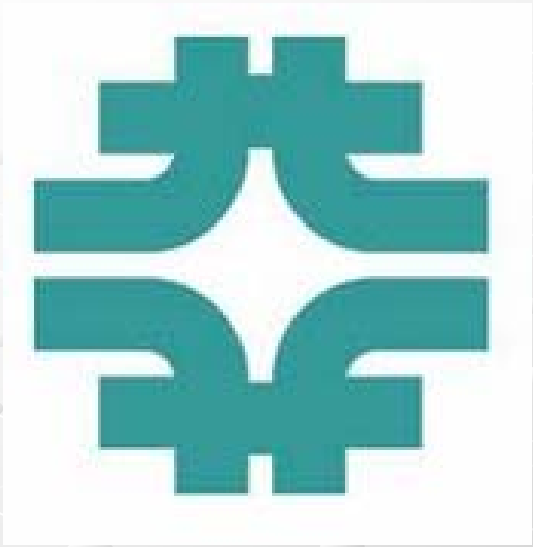
V. Guidi, A. Mazzolari and V.V. Tikhomirov, J. Phys. D: Appl. Phys. 42(2009) 165301

Summary

- The UA9 experiment for crystal collimation provides the good conditions for the miscut angle influence.

- The channeling effect is not applicable for the crystal-based collimation at the LHC because of large angular divergence of the incident beam.
- However, MVROC can provide sufficient collimation efficiency at the LHC due to both large deflection angle and angular acceptance.

- The beam parameters at the Recycler Ring are very good for the channeling application with cut modification.
- The beam losses decrease in **4** times while the extraction efficiency increases from 94-95% up to **98-99%** by application of the crystal cut.
- For simplification of fabrication one can use the amorphous layer instead of the cut.



Fermilab ***INP***

Thank you for attention!

The miscut angle influence on the future LHC crystal based collimation system