Review of Studies and Application of Bent Crystals for Beam Steering at U70

Yu.A. Chesnokov, A.G. Afonin, V.T. Baranov, G.I. Britvich,
V.N. Chepegin, V.I. Kotov, V.A. Maisheev,
V.I.Terekhov, I.A. Yazynin

SRC IHEP, 142281, Protvino Moscow region

This report overviews studies accomplished in the U70 proton synchrotron of IHEP-Protvino during the recent two decades. Major attention is paid to a routine application of bent crystals for beam extraction from the machine. It has been confirmed experimentally that efficiency of beam extraction with a crystal deflector of around 85% is well feasible for a proton beam with intensity up to 10^12 protons per cycle. Another trend is to use bent crystals for halo collimation in a high energy collider. New promising options emerge for, say, LHC and ILC based on the “volume reflection” effect, which has been discovered recently in machine study runs at U70 of IHEP (50 GeV) and SPS of CERN (400 GeV). Perspectives to use bent crystals for extraction of light ions from the U70 accelerator are also disclosed.

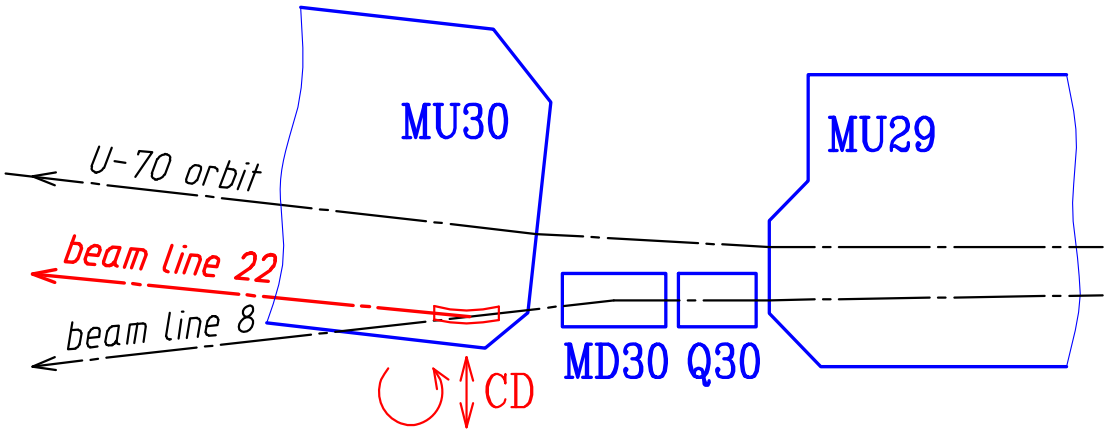
Ideas of use the particle channeling in bent crystals for steer the beams have been checked up and advanced in many experiments. This method has found the widest practical application on U-70 accelerator of SRC IHEP, where crystals are used in regular runs for beam extraction and forming.

Beam splitting.

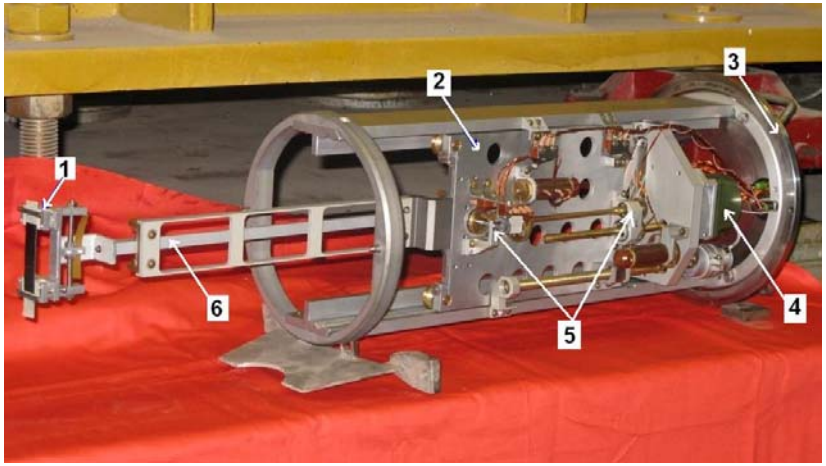
Usually a beam is split by an electrostatic or a magnetic splitter. This is a technically fairly complex approach requiring considerable space, since the angles of deflection of a beam by a conventional splitter are very limited. The use of crystals provides a simple means for beam splitting, which is unattainable by conventional techniques. The first crystal beam-splitting station began to operate since 1988.

IHEP new splitting station

Crystal location

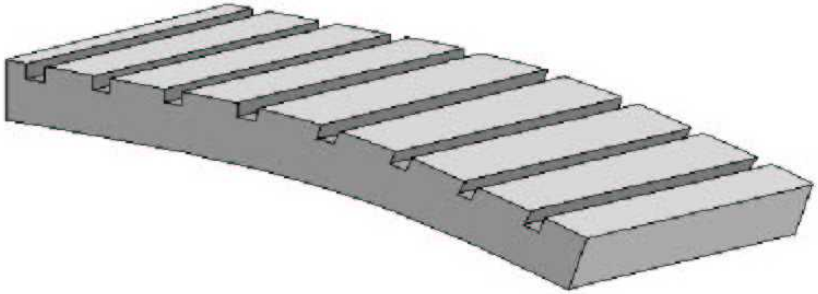


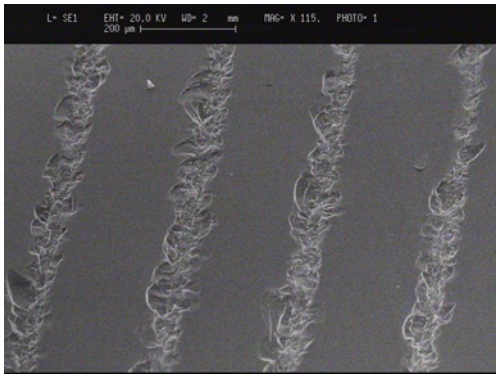
Construction of goniometer

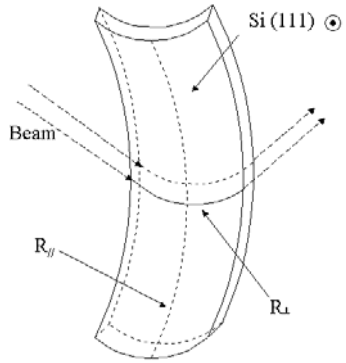


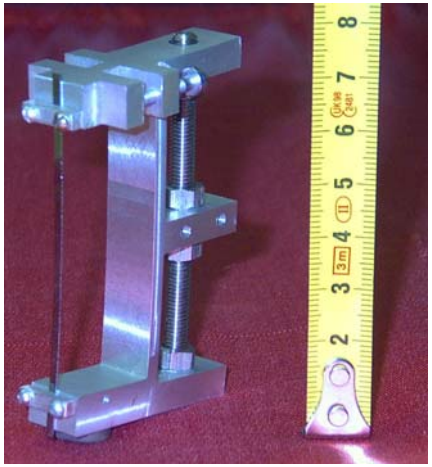
Preparation of the bent crystal with use of two original methods has allowed to lower losses of particles

at splitting up to 0.01 %

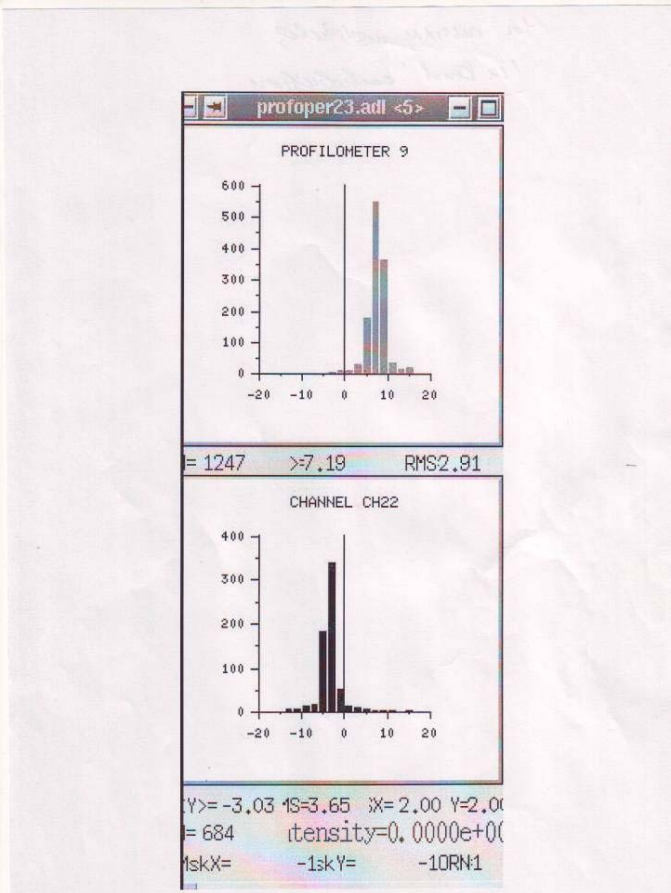






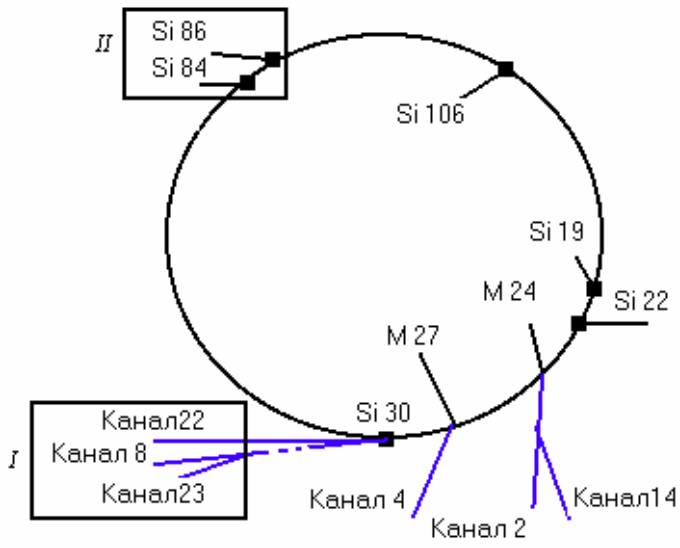


Deflected by crystal beam near the target



Beam extraction from U-70 ring by means of bent crystals

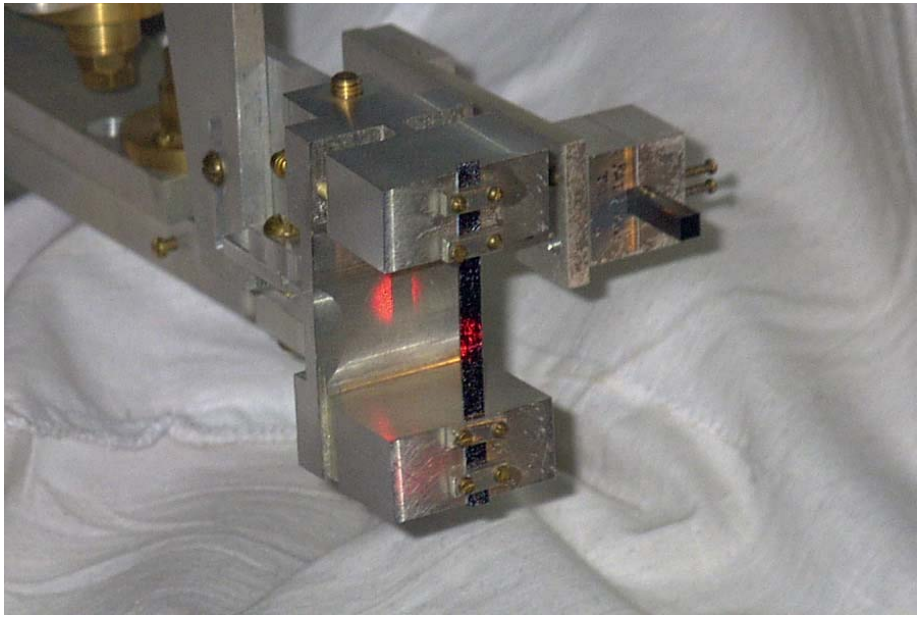
Different types of extraction schemes were realized by bent crystal. In first case high efficiency of extraction up to 85% is reached applying short silicon crystals Si 19,22,106 (Fig.3)



Different types of short crystals were installed in ring

. Станция кристаллических дефлекторов,
смонтированная на ускорителе У-70.

. Изогнутые кристаллы, установленные на станции.



High-Efficiency Beam Extraction and Collimation Using Channeling in Very Short Bent Crystals

A. G. Afonin,[1] V. T. Baranov,[1] V. M. Biryukov,[1] M. B. H. Breese,[2] V. N. Chepegin,[1] Yu. A. Chesnokov,[1] V. Guidi,[3] Yu. M. Ivanov,[5] V. I. Kotov,[1] G. Martinelli,[4] W. Scandale,[6] M. Stefancich,[4] V. I. Terekhov,[1] D. Trbojevic,[7] E. F. Troyanov,[1] and D. Vincenzi[4]

[1]*Institute for High Energy Physics, Protvino, 142281, Russia*
[2]*Surrey University, Guildford, GU2 5XH, United Kingdom*
[3]*Ferrara University, Department of Physics and INFN, I-44100, Italy*
[4]*Ferrara University, Department of Physics and INFM, I-44100, Italy*
[5]*Petersburg Nuclear Physics Institute, Gatchina, 188350, Russia*
[6]*CERN, Geneva 23, CH-1211, Switzerland*
[7]*Brookhaven National Laboratory, Upton, New York 11973*
(Received 12 April 2001; published 14 August 2001)

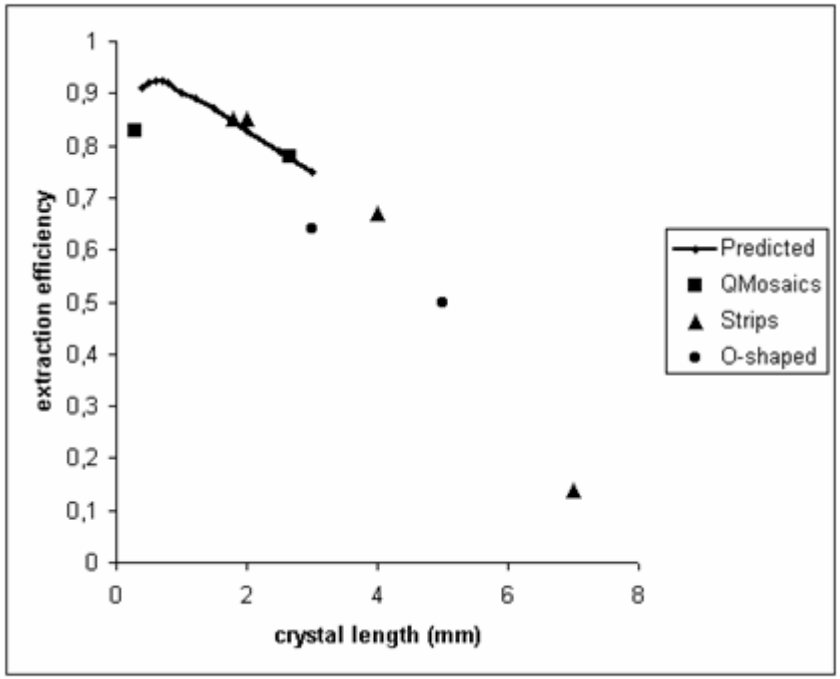
A silicon crystal was used to channel and extract 70 GeV protons from the U-70 accelerator with an efficiency of 85.3 ± 2.8%, as measured for a beam of $\sim 10^{12}$ protons directed towards crystals of ~2 mm length in spills of ~2 s duration. The experimental data follow very well the prediction of Monte Carlo simulations. This demonstration is important in devising a more efficient use of the U-70 accelerator in Protvino and provides crucial support for implementing crystal-assisted slow extraction and collimation in other machines, such as the Tevatron, RHIC, the AGS, the SNS, COSY, and the LHC.

DOI: 10.1103/PhysRevLett.87.094802 PACS numbers: 41.85.−p

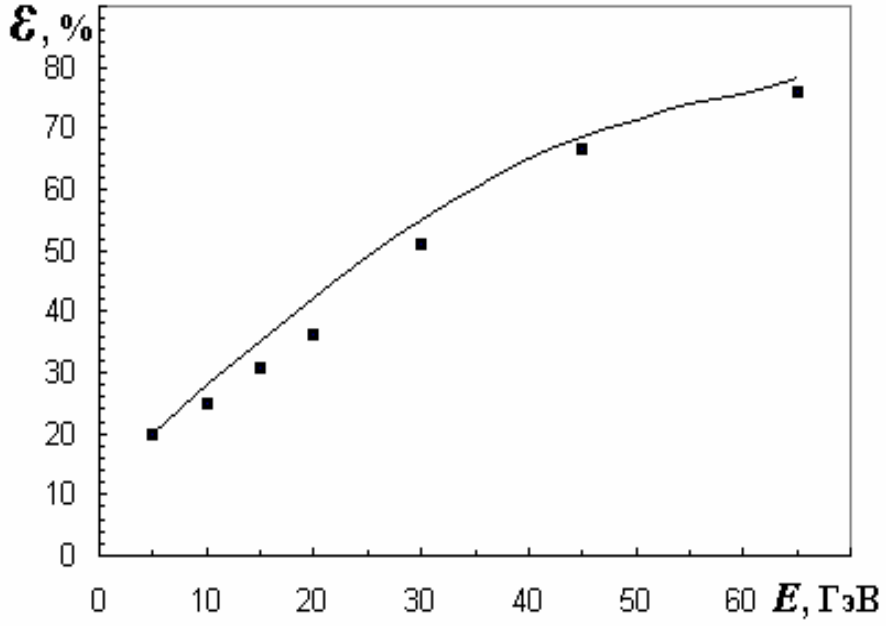
Использование
изогнутых кристаллов в сеансе 2007г:

Из 9 основных экспериментов, предусмотренных расписанием, 6 установок работали в режиме МВК:

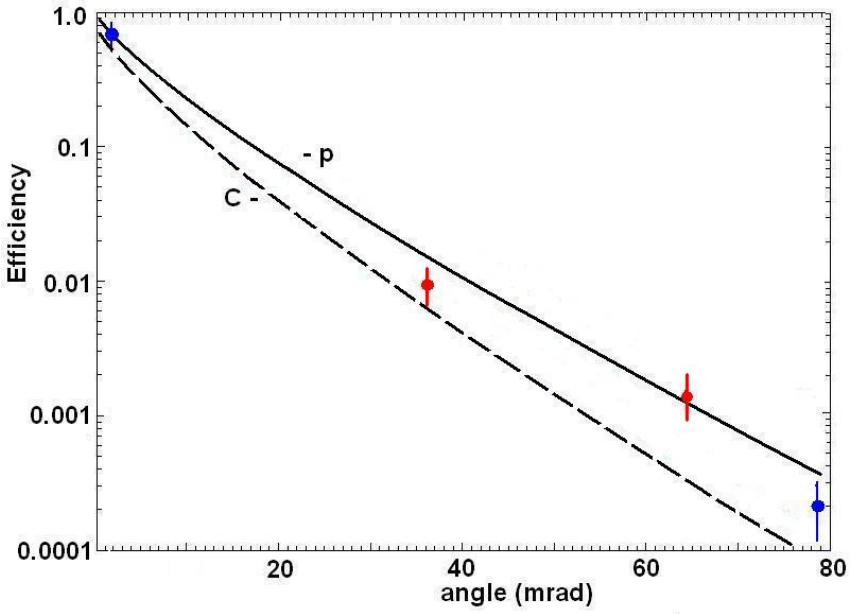
- **23 канал- КМН 32 смены СКД 19**
- **22 канал- ФОДС 16 смен СКД 19**
- **22 канал- Кристалл 20 смен СКД 19**
- **22 канал СВД 56 смены КД 30/СКД 19**
- **2Б канал- СИГМА 32(36) смен СКД 24/25**
- **14 канал- ПРОЗА 88 смен СКД 24/25.**



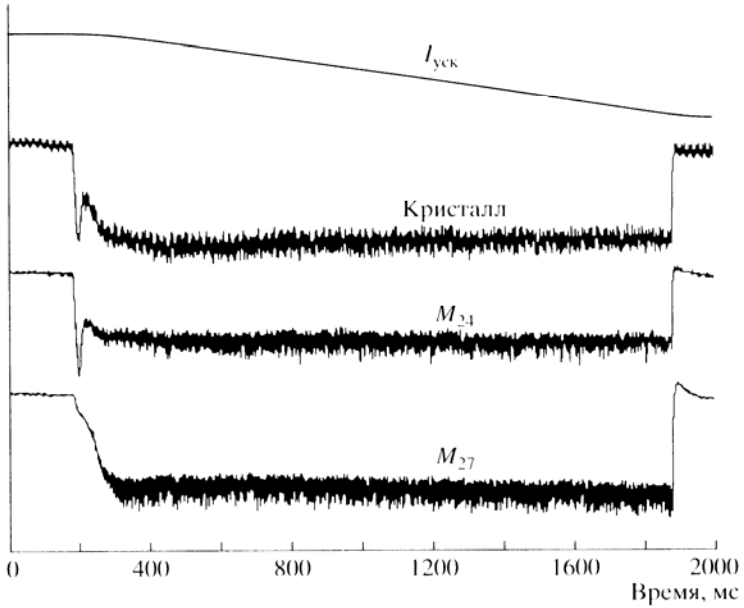
Efficiency dependence versus crystal length



Crystal efficiency versus proton energy



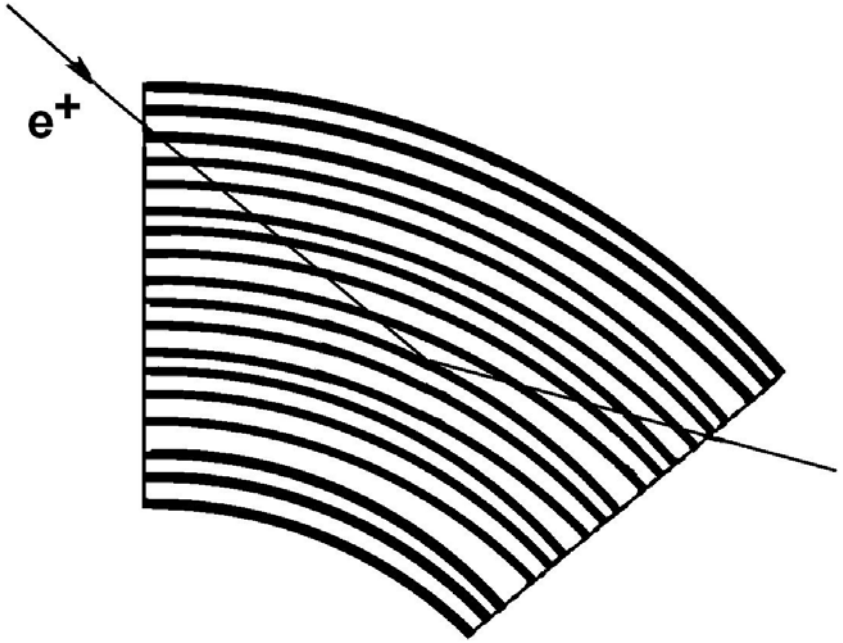
Efficiency dependence versus crystal bend angle



Time structure at Simultaneously operation

Reflections offer new way to steer the particle trajectories.

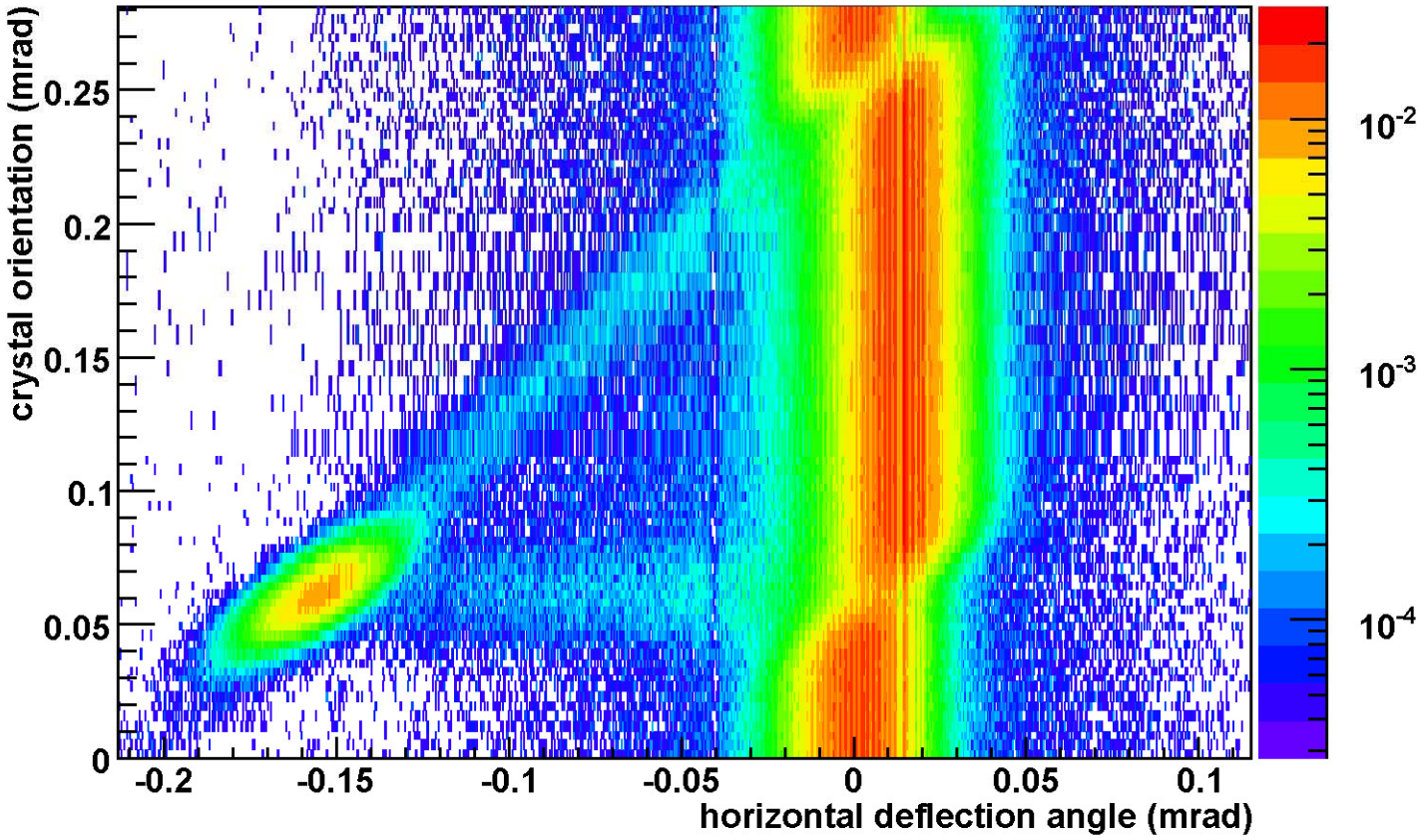
The phenomenon of reflection occurs in wide area of angles and is more effective, than usual channeling



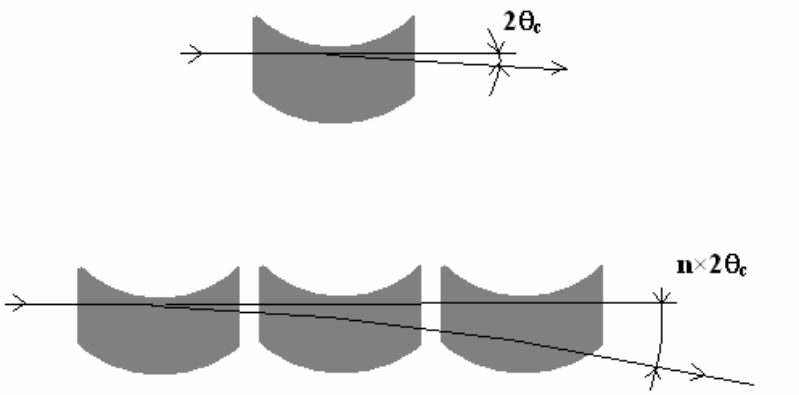
Observation of reflection of 400 GeV protons at CERN SPS

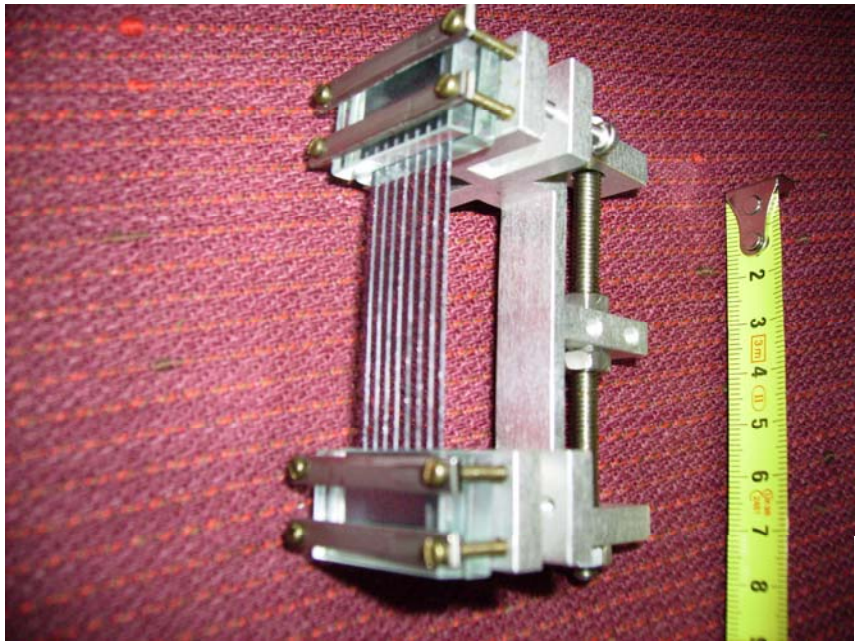
W. Scandale *et al.* Phys.Rev.Lett.98:154801,2007

(CERN-INFN-IHEP-PNPI-JINR)



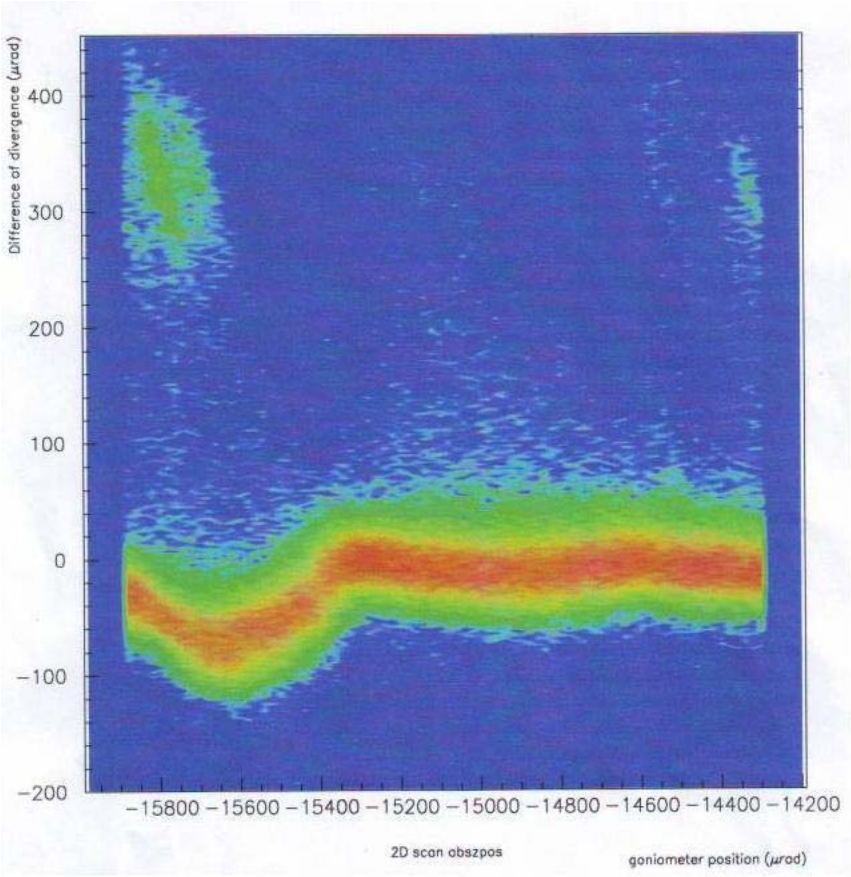
Enhancement of reflection angle in multi-crystals

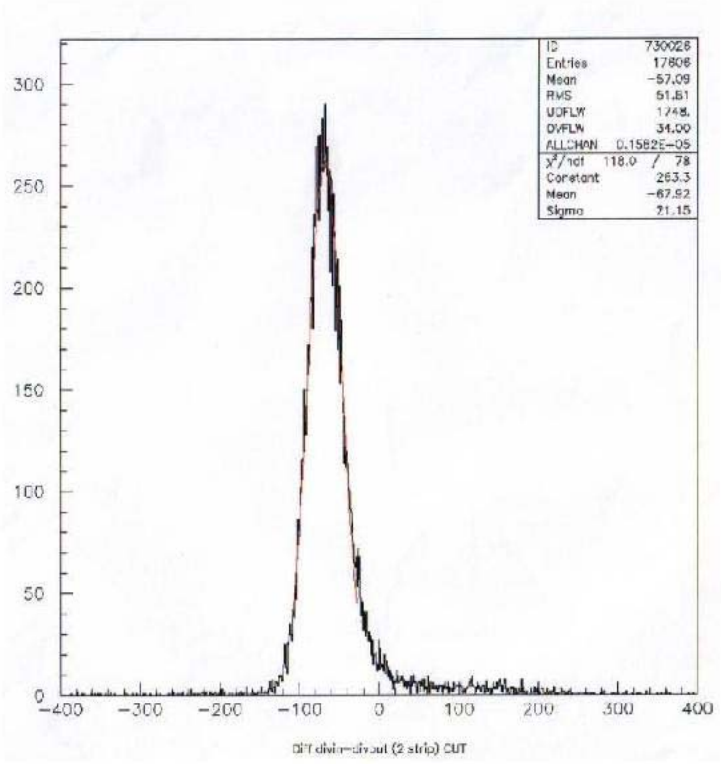




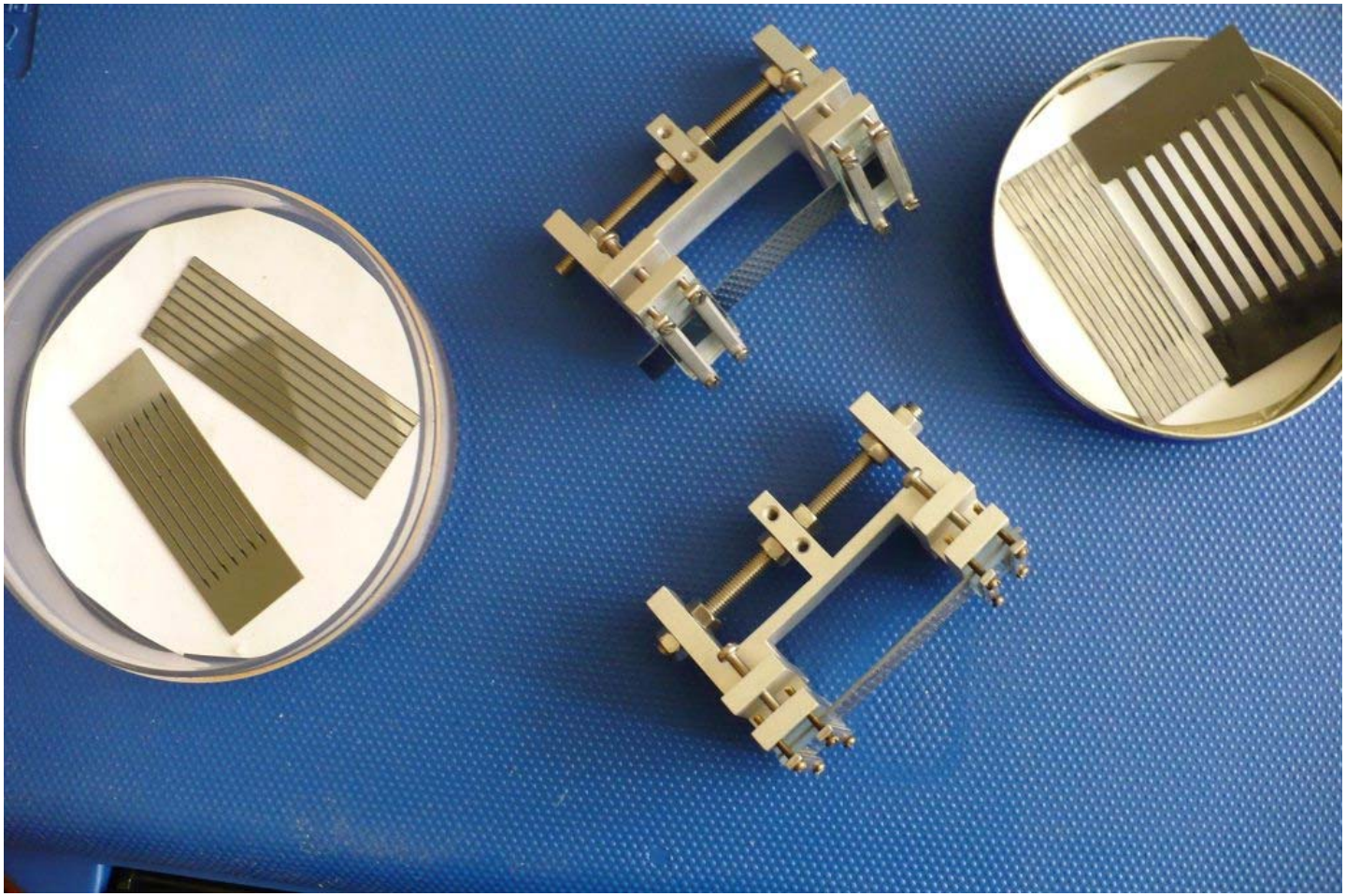
Multi-crystal testing on 400 GeV proton beam

H8-RD22 (CERN-INFN-IHEP-PNPI-JINR)

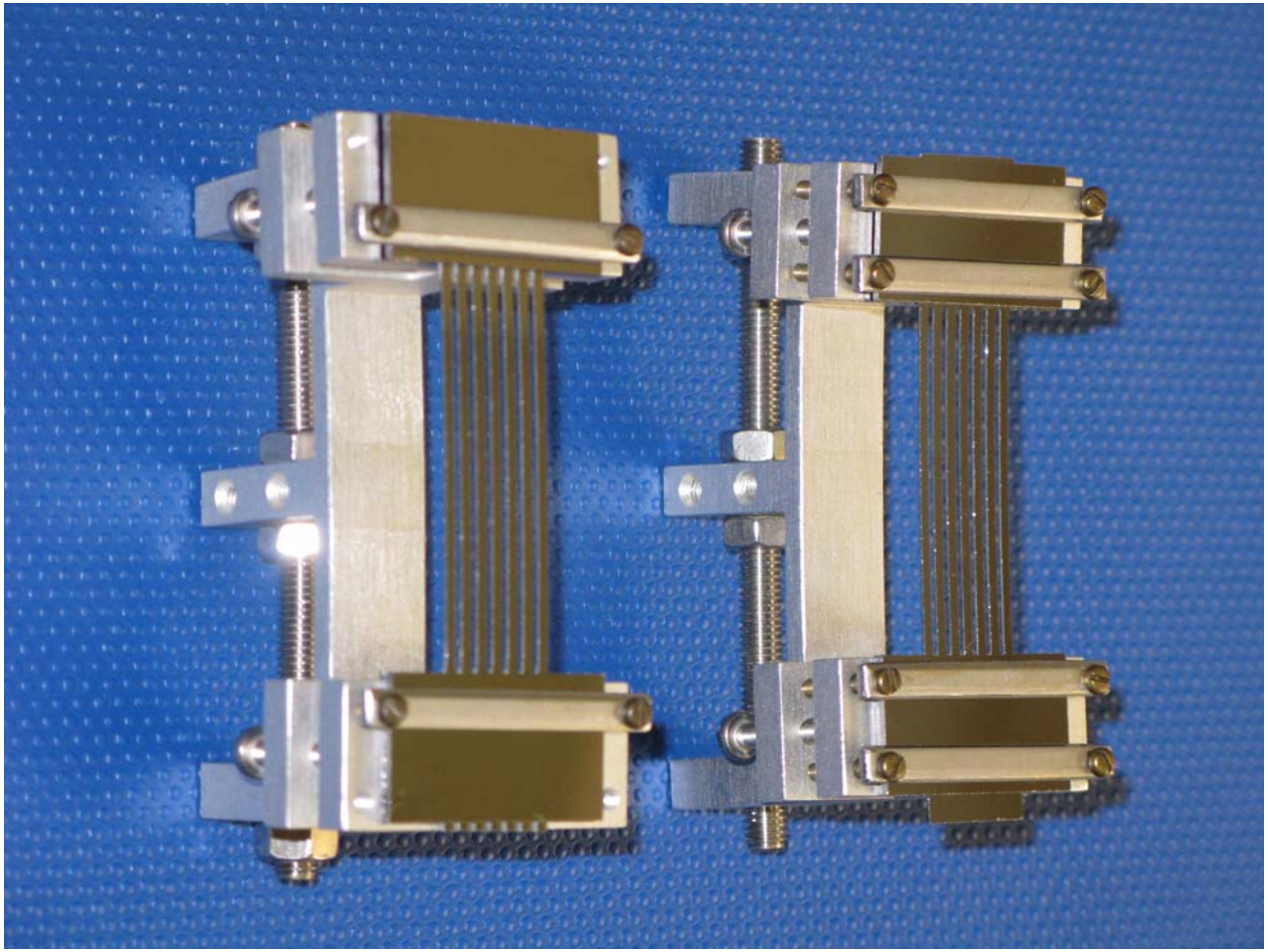




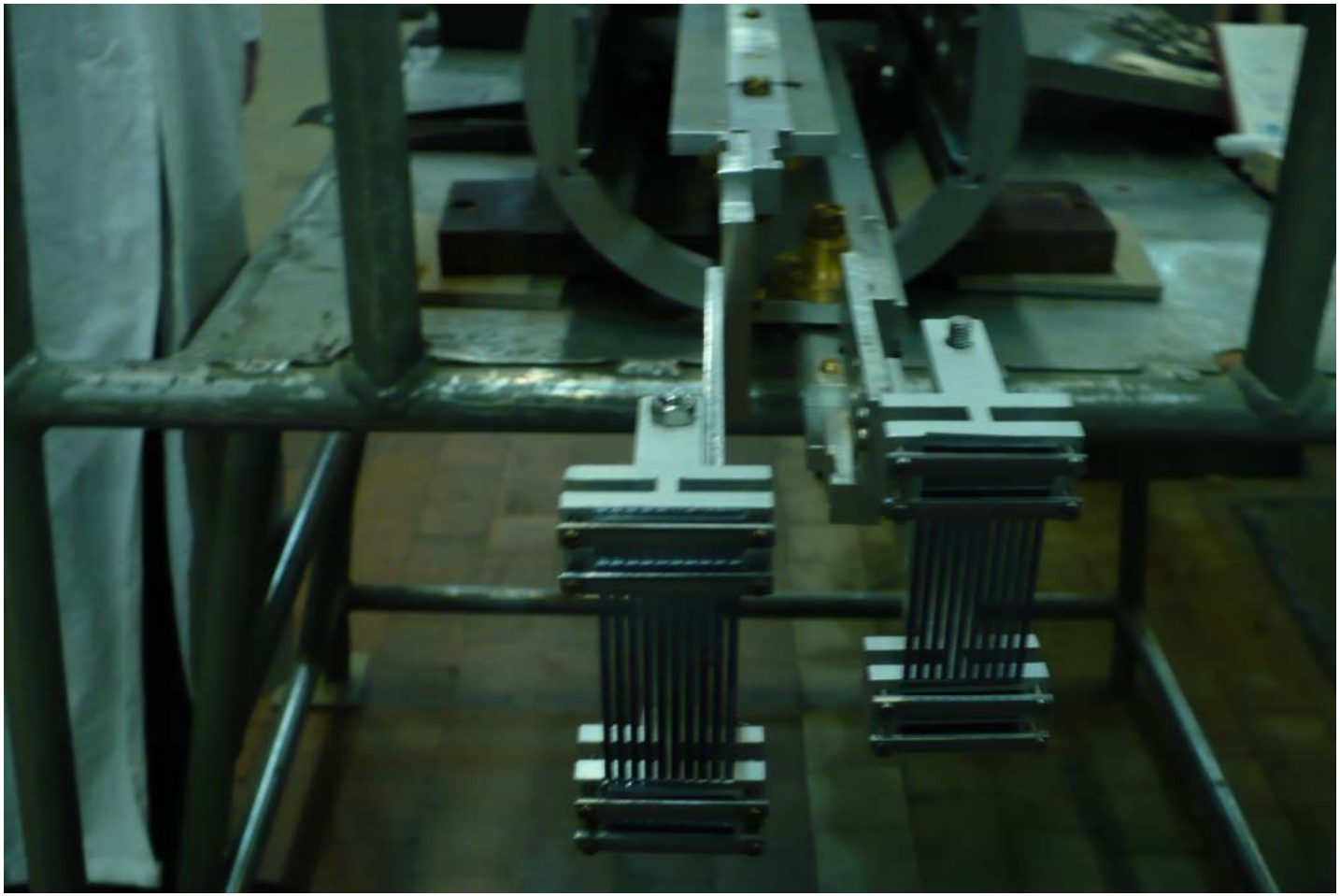
Technology of creation of multi-structures



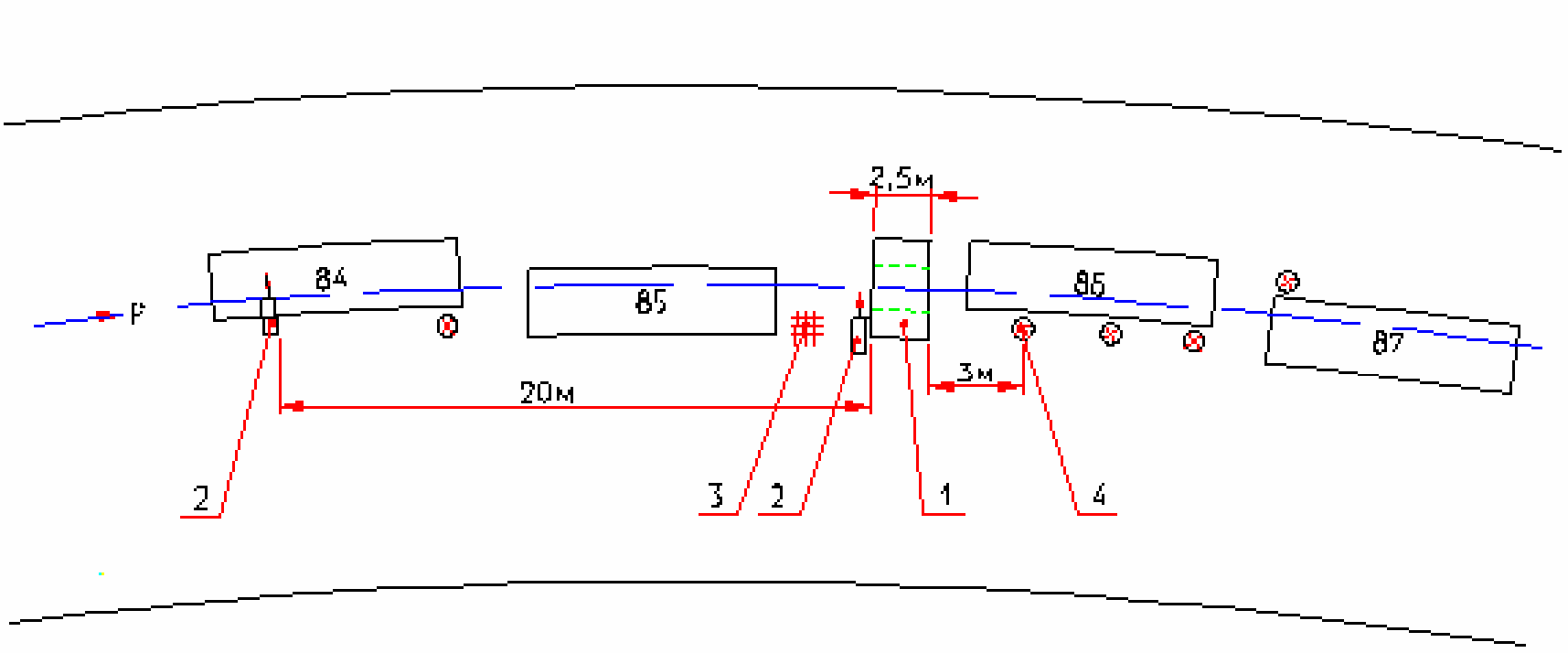
New IHEP devices



Installation in U-70 goniometer.



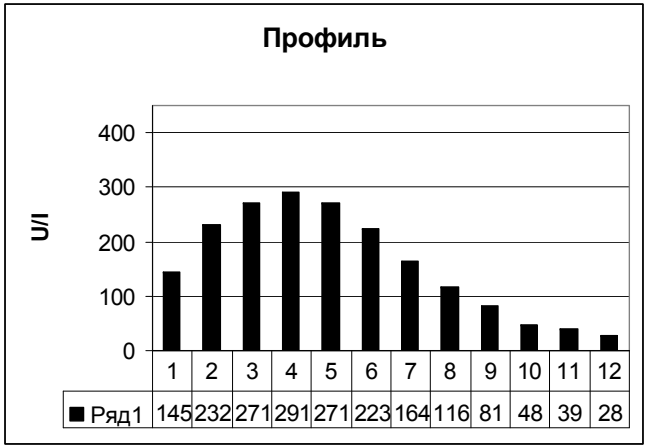
The crystal test area in main ring:
1 – beam absorber, 2 – crystal stations, 3 – profile meter,
4 – ionization chambers (loss monitors),
84-87 – magnet blocks.



Measured beam profiles at absorber entry run april-2008.

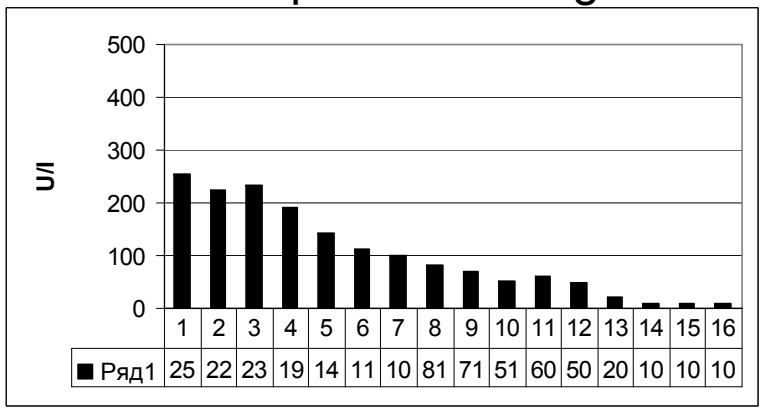
Multiple reflection

a)

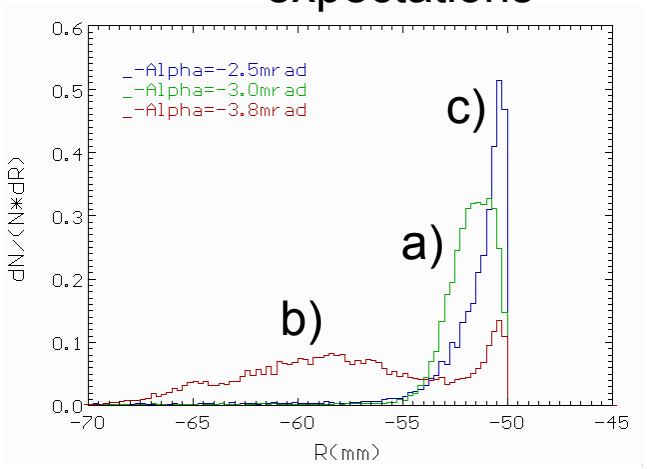


Multiple channeling

b)

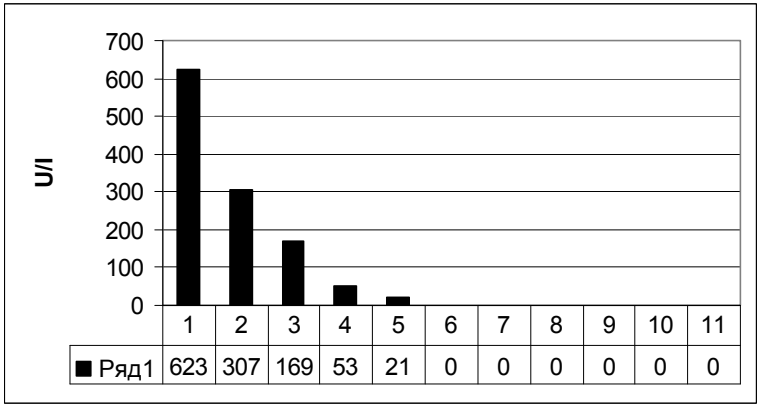


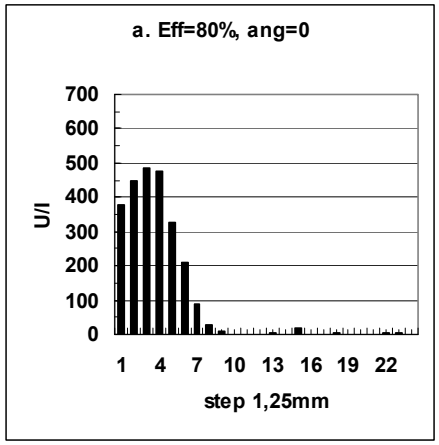
expectations

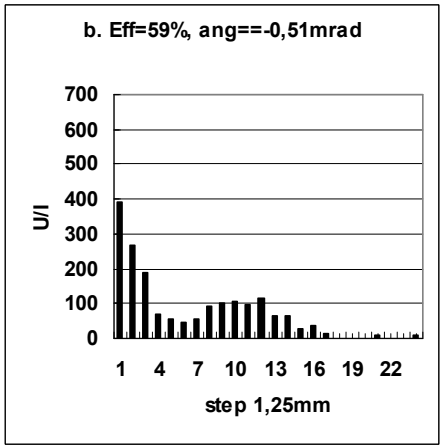


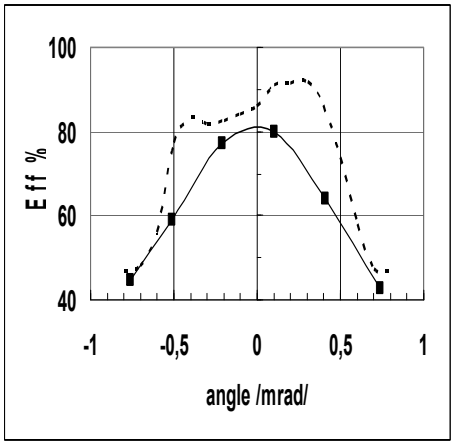
Disoriented crystal

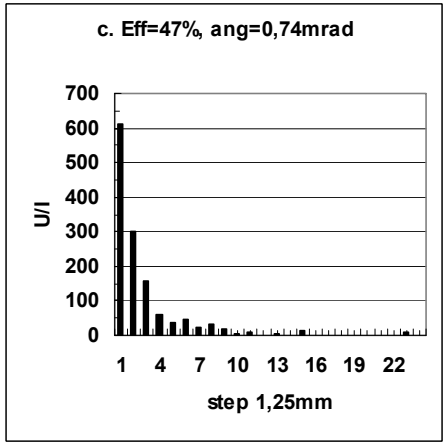
c)

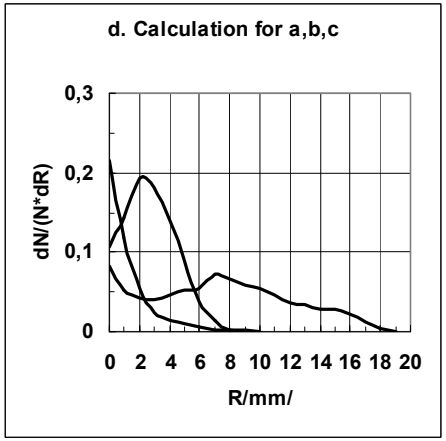


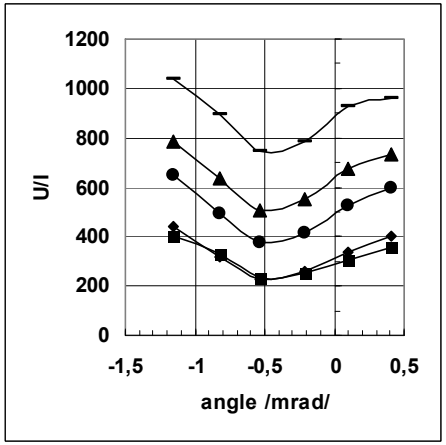

a. Eff=80%, ang=0
U/I
700
600
500
400
300
200
100
0
1 4 7 10 13 16 19 22
step 1,25mm


b. Eff=59%, ang==-0,51mrad
U/I
700
600
500
400
300
200
100
0
1 4 7 10 13 16 19 22
step 1,25mm


Eff %
100
80
60
40
-1 -0,5 0 0,5 1
angle /mrad/

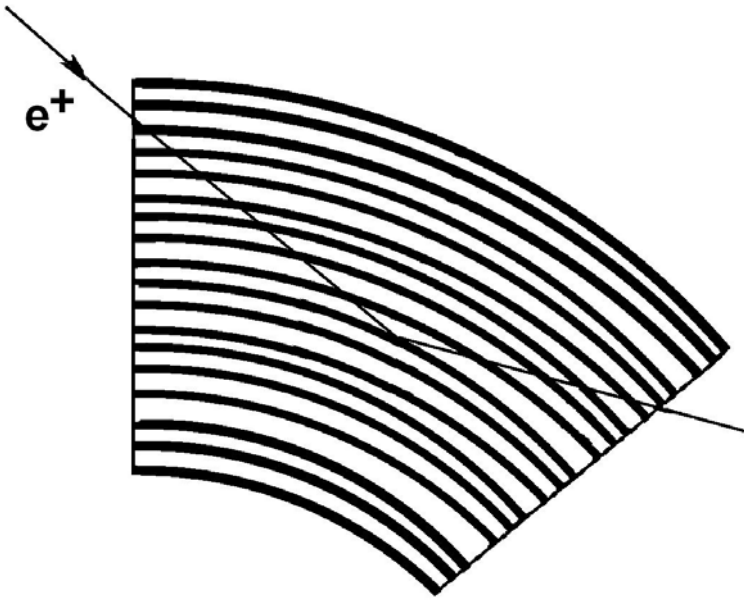

c. Eff=47%, ang=0,74mrad
U/I
700
600
500
400
300
200
100
0
1 4 7 10 13 16 19 22
step 1,25mm

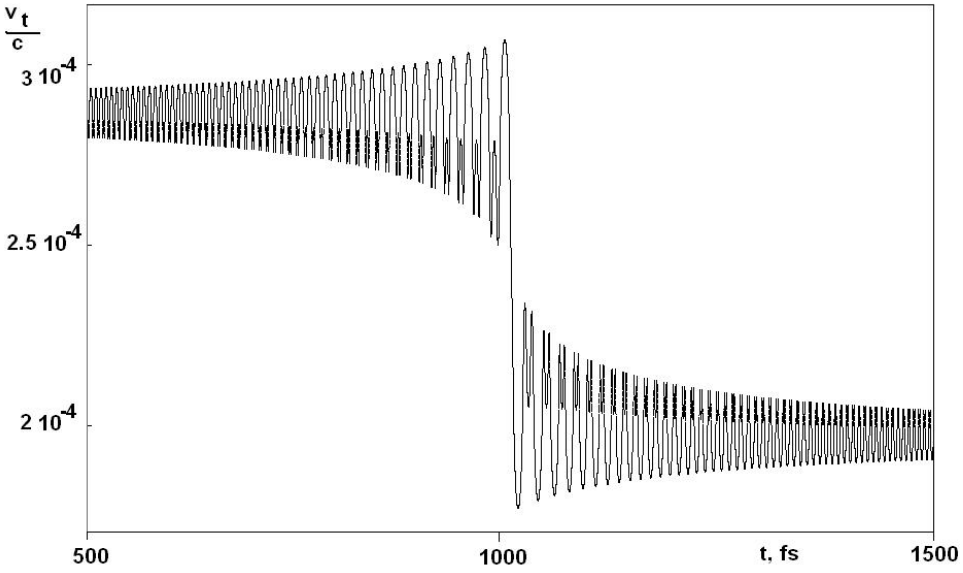

d. Calculation for a,b,c
dN/(N*dR)
0,3
0,2
0,1
0
0 2 4 6 8 10 12 14 16 18 20
R/mm/


U/I
1200
1000
800
600
400
200
0
-1,5 -1 -0,5 0 0,5
angle /mrad/

Over 80 % of particles were reflected in a crystal and were deserted in absorber on distance over 1 mm from the edge. It is expected, that over 90 % of circulated particles can be reflected by crystal in thin-walled electrostatic deflection for extraction from the U-70 ring.

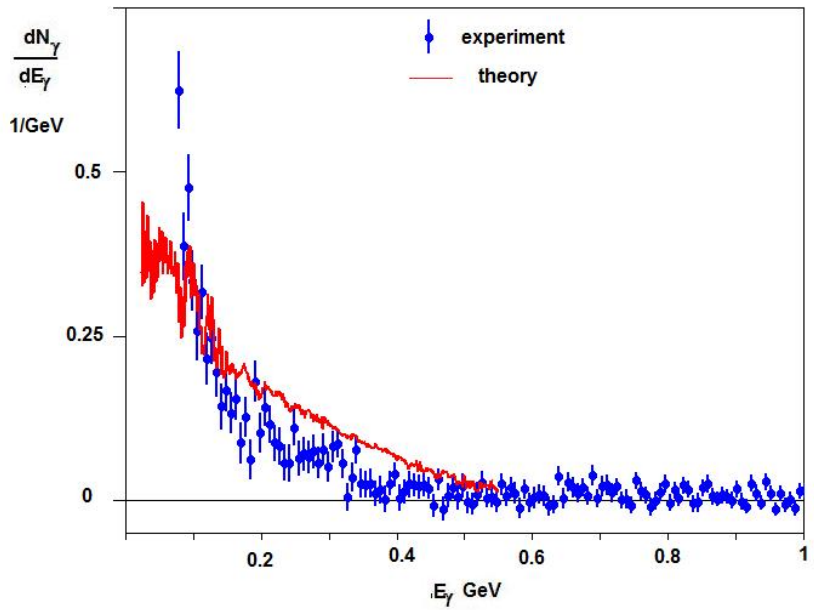
Radiation of photons from particles at volume reflection

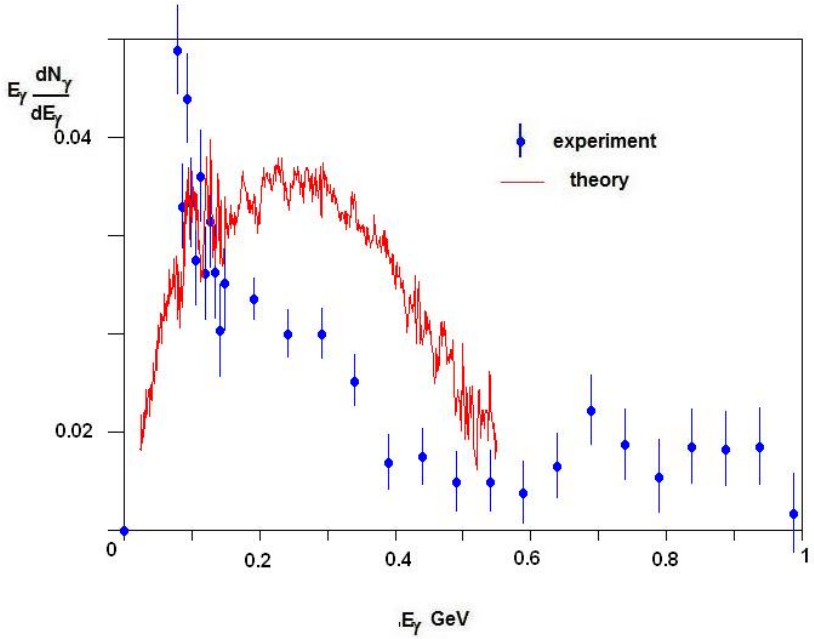




Behavior of transversal velocity near reflection point.

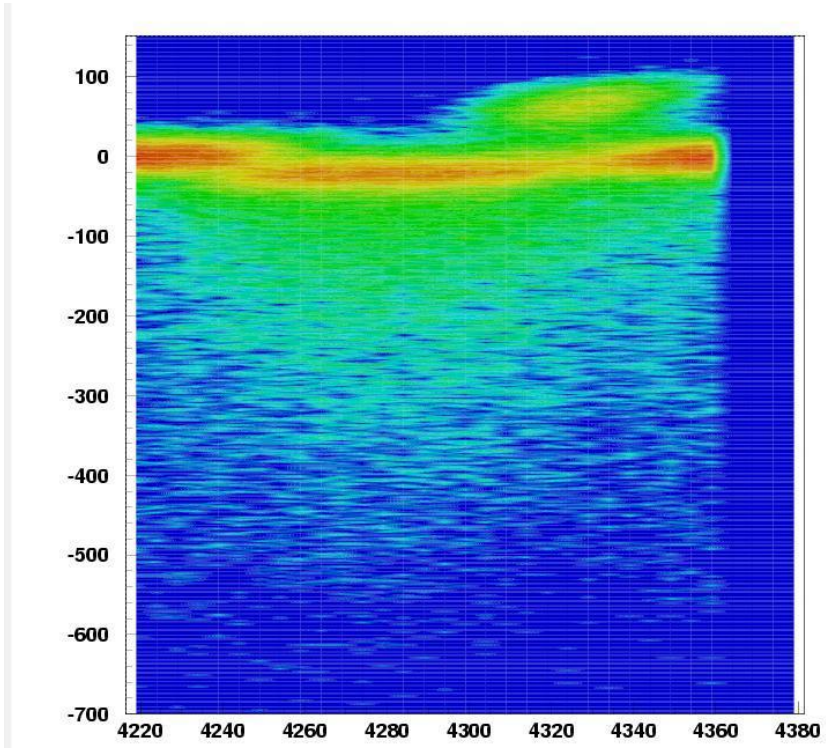
Measured spectra of photons and energy losses from 10GeV positron beam in silicon crystal: 0.7mm length, 0.5mrad bend at 22 IHEP beamline.



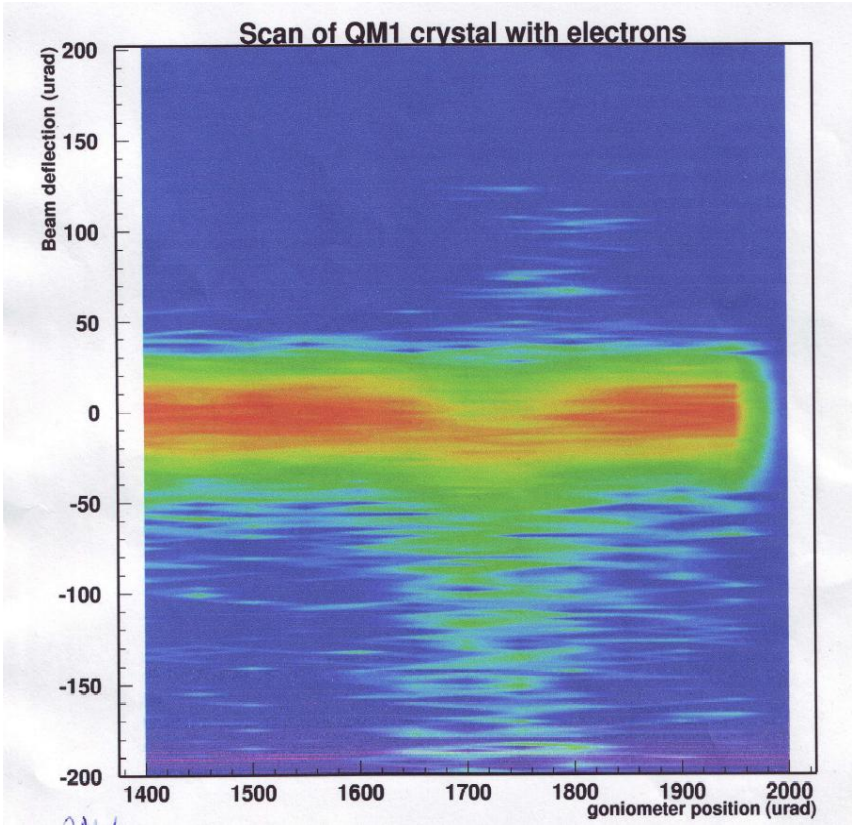


Energy losses of 180 GeV positrons and electrons in 1mm bent crystal

H8-RD22 (CERN-INFN-IHEP-PNPI-JINR)



positrons



electrons

Literature:

- [1] A.F. Elishev *et al.* Phys.Lett.B88:387,1979, JETP Lett.30:442,1979.
- [2]R.P. Fliller, A. Drees, D. Gassner et al Phys.Rev.ST Accel.Beams 9:013501,2006.
- [3] W. Scandale *et al.* Phys.Rev.Lett.98:154801,2007.
- [4] Crystal channeling and its application at high-energy accelerators. V.M. Biryukov, Yu.A. Chesnokov, V.I. Kotov (Serpukhov, IHEP) . 1997. 219pp. Berlin, Germany: Springer (1997) 219 p.
- [5] Proton beam extraction from the IHEP accelerator using short silicon crystals. A.G. Afonin *et al.* Phys.Part.Nucl.36:21-50,2005, Fiz.Elem.Chast.Atom.Yadra 36:43-99,2005.
- [6] M.D. Bavizhev et al, IHEP preprint 1989-77, Protvino, 1989.
- [7] A.A.Arhipenko et al, IHEP preprint 2008-8, Protvino, 2008
- [8] Afonin A. G. *et al.* Nucl.Instrum.Meth.B234:122-127,2005.
- [9] V. M. Biryukov, Yu. A. Chesnokov, V. I. Kotov et al Rev.Sci.Instrum.73:3170-3173,2002.
- [10] A.A. Aseev et al Nucl.Instrum.Meth.A309:1-4,1991.
- [11] A.A.Arhipenko et al, JETP Letters, 88(4),265 (2008)
- [12] I.A. Yazynin et al Proc.SPIE Int.Soc.Opt.Eng.6634:66340H,2007
- [13] Yu.A. Chesnokov et al JINST 3:P02005,2008.
- [14] A.G.Afonin et al, JETP Letters, 88(7),486, (2008)

conclusion

Bent crystals are very promising for application at accelerators for beam extraction/collimation and generation of powerful photon radiation.

This work is supported by
IHEP Directorate,
State corporation Rosatom
and RFBR grants