

# **Crystal devices for beam steering in the IHEP accelerator.**

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P.N.Chirkov, V.A. Maisheev, V.I.Terekhov, I.A. Yazynin

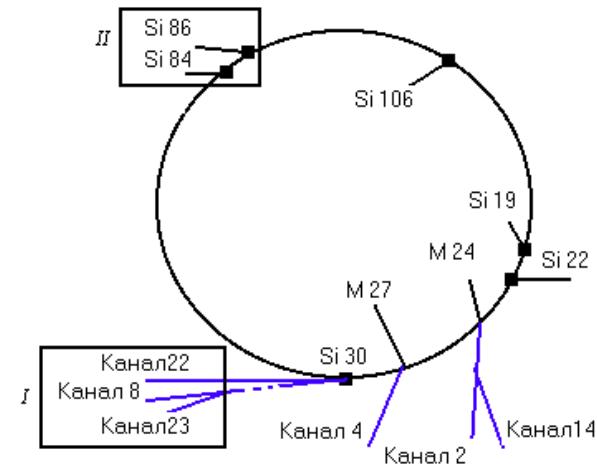
SRC IHEP, 142281, Protvino Moscow region

Yu.Chesnokov, RREPS13 and  
Meghri13

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.

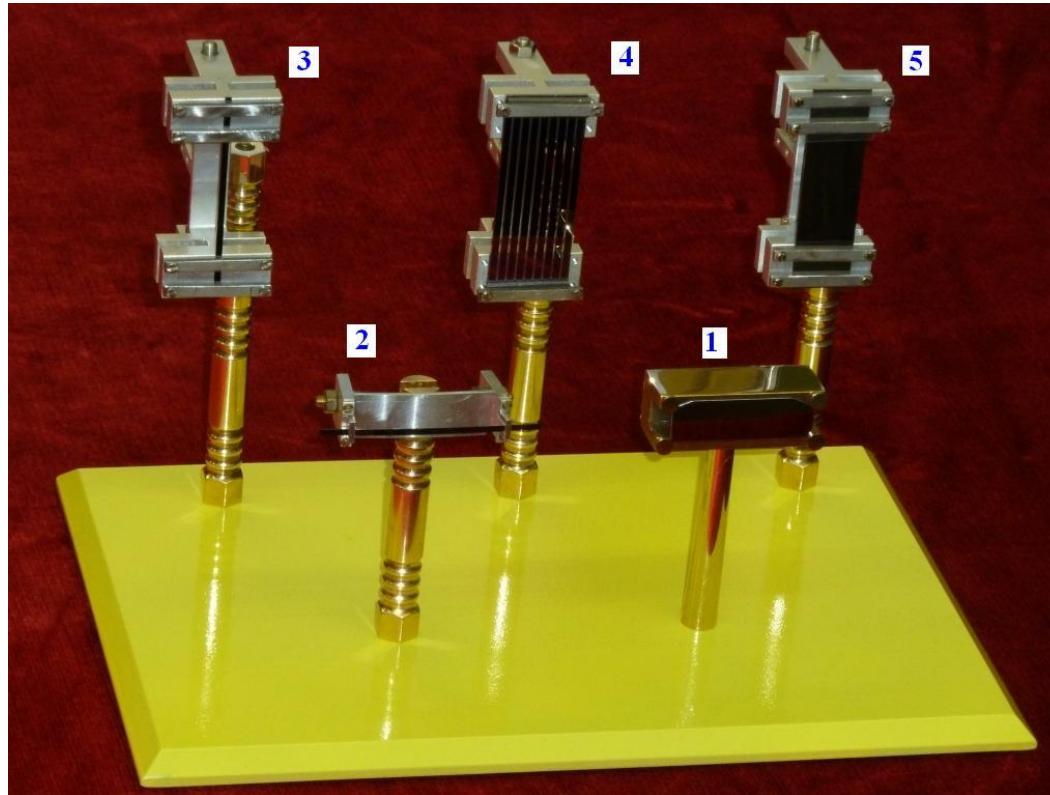
Different types of extraction schemes were realized by bent crystal. In first case high efficiency of extraction up to 85% is reached applying

short silicon crystals Si 19,22,106 (Fig.3)



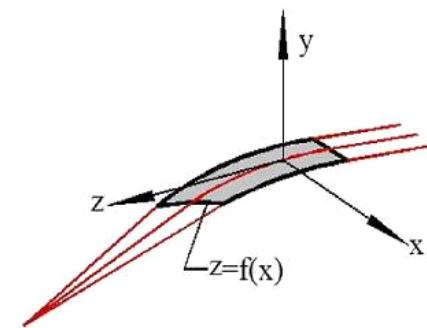
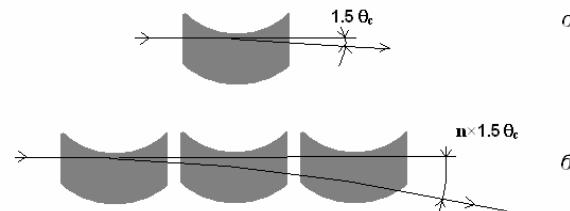
In a photo few developed crystal devices for beam steering are presented:

1. The first long bent crystal for beam splitting in U-70 beam lines (1987).
2. The working model of the bent crystal for beam extraction in beam lines N2 and N4.
3. A thin crystal of a strip-type for a highly-efficient crystal extraction of a beam in beam line N8.
4. The device for beam collimation, based on multiple reflection on a chain of the bent crystals.
5. The device for focusing of particle trajectories in ultrahigh energy region.

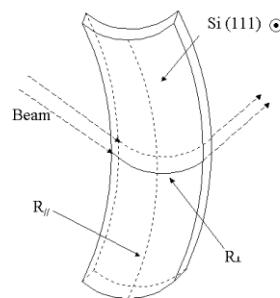


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Amplification of deflection angle by multiple reflection of the particles on a chain of the bent crystals (the device 4).



the Principle of beam focusing by the device 5.



the Principle of a bend of a strip-type crystal (the device 3). The necessary cross-section bend is created by a longitudinal bend of a plate due to anisotropy of a crystal.



the extraction of a beam from U-70 ring by crystals 1 and 2 in a direction of beam lines N2 and N4.

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

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A silicon crystal was used to channel and extract 70 GeV protons from the U-70 accelerator with an efficiency of  $85.3 \pm 2.8\%$ , as measured for a beam of  $\sim 10^{12}$  protons directed towards crystals of  $\sim 2$  mm length in spills of  $\sim 2$  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.

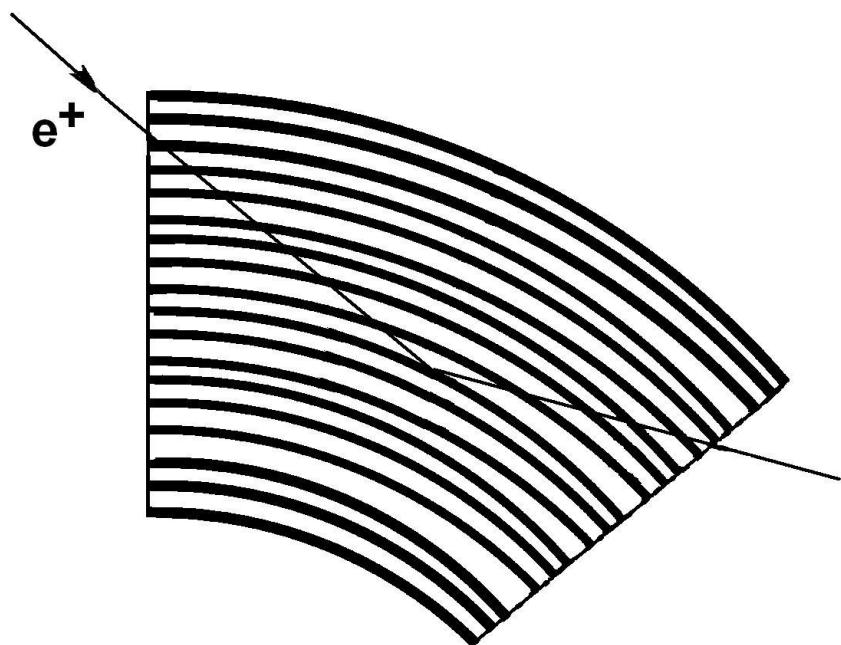
DOI: 10.1103/PhysRevLett.87.094802

PACS numbers: 41.85.-p

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# Reflections offer new way to steer the particle trajectories.

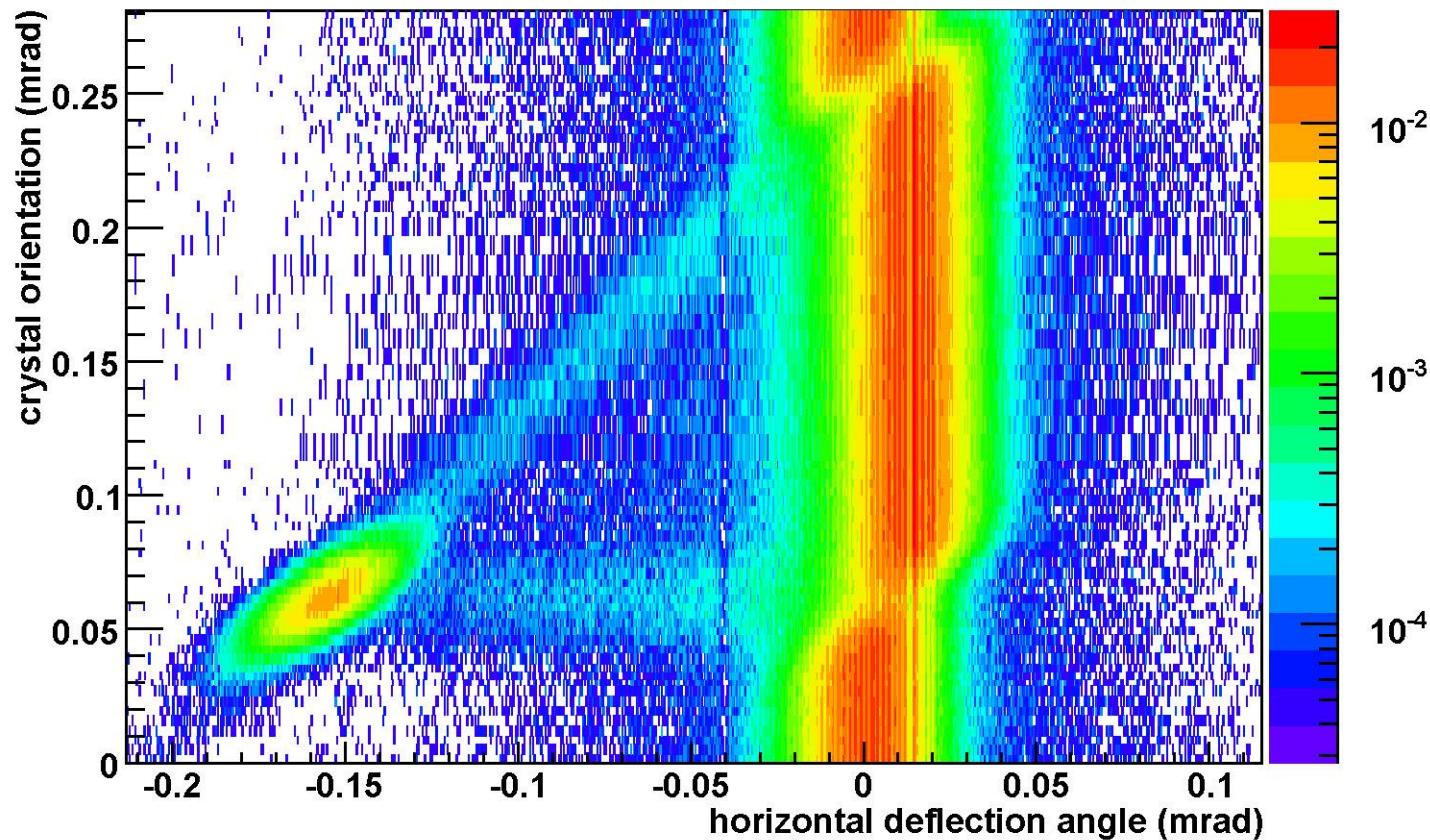
The phenomenon of reflection occurs in wide area of angles and is more effective, than usual channeling



# 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)



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## Radiation of photons in process of charged particle volume reflection in bent monocrystal

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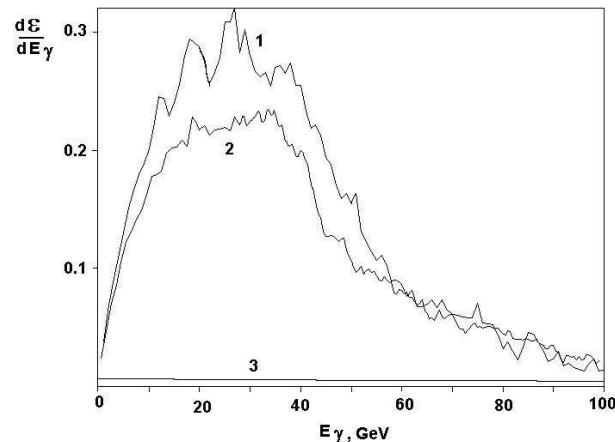
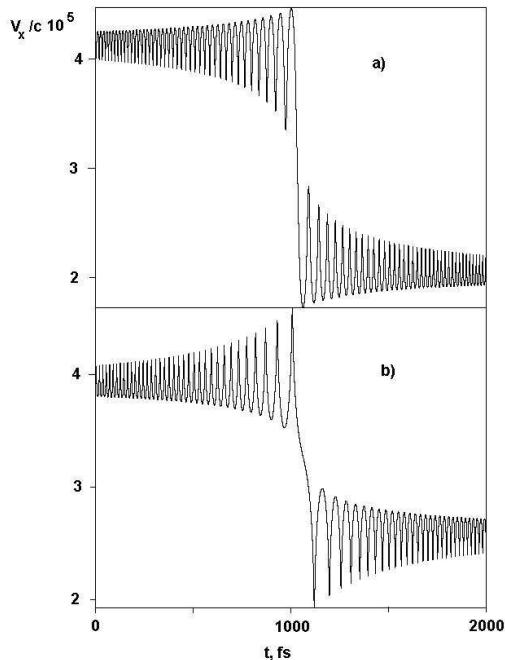
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**ABSTRACT:** New type of radiation in crystals is predicted and investigated in computer simulation. It is shown that process of volume reflection of electrons and positrons in bent crystals is accomplished with high-power radiation of photons. Volume reflection radiation has intensity comparable with known channeling radiation, but it is less sensitive to entrance angle and sign of charge of a particle. Simulated spectra of radiation power are presented for 10 GeV and 200 GeV particles.

**KEYWORDS:** Interaction of radiation with matter; Radiation calculations.

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# Investigation of the Emission of Photons Induced in the Volume Reflection of 10-GeV Positrons in a Bent Silicon Single Crystal

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The emission of photons in the motion of a 10-GeV positron beam in bent silicon crystals has been experimentally investigated. The experimental data are compared with the theoretical calculations.

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DOI: 10.1134/S0021364008190028

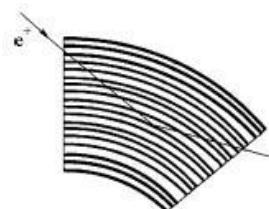
The volume reflection of charge particles in bent crystals [1, 2], which is coherent scattering, was observed for proton beams in the experiments in the last three years (see [3] and references therein). These experiments demonstrate a good agreement between the predicted and measured characteristics of the process [4]. Particles undergoing volume reflection intersect bent crystallographic planes. For this reason, their transverse velocity has the character of aperiodic oscillations. On the basis of the consideration of this motion, a new type of intense coherent radiation was predicted in [5]. This radiation for light leptons is more intense than that for other particles owing to a large Lorentz factor  $\gamma$ .

Figure 1 illustrates the volume reflection of an ultrarelativistic particle moving in a system of bent crystallographic planes. Approaching the tangency point, the transverse velocity of the particle approaches zero and the particle undergoes reflection (coherent scattering). Moreover, the particle moving in this region intersects a number of crystallographic planes at small angles; for this reason, its velocity undergoes significant aperiodic oscillations (see Fig. 2). As a result, such motion of electrons and positrons undergoing volume reflection is accompanied by intense gamma radiation.

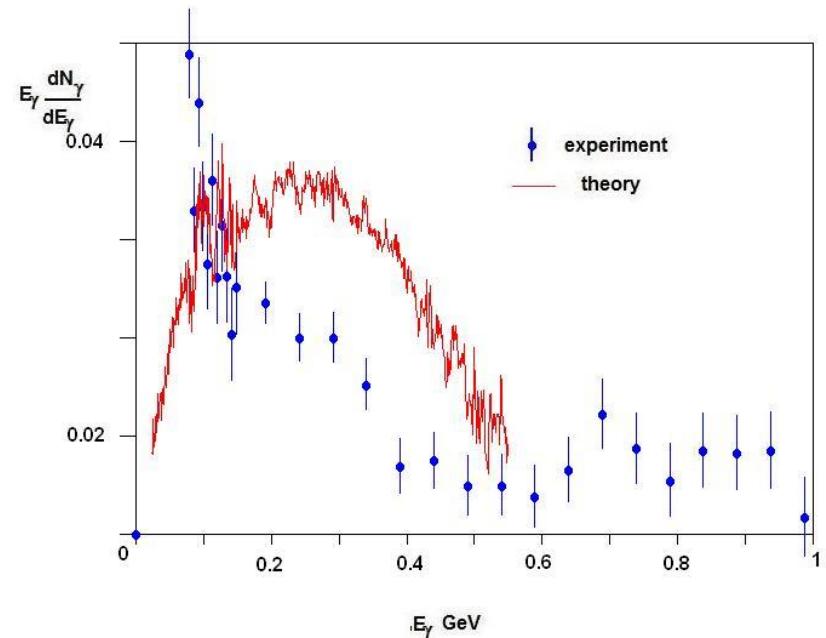
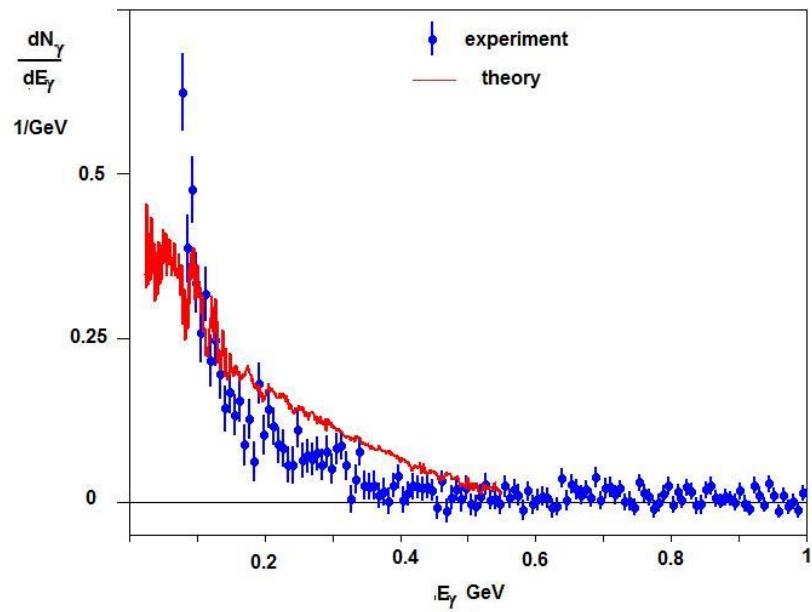
In an unbent crystal with the plane orientation, the character of the radiation of electrons and positrons depends primarily on the emission angle with respect to the crystallographic planes. When  $\theta \gg \theta_b = U/m_e c^2$ ,

synchrotron (magnetic bremsstrahlung). The type of radiation can also be described by the parameter  $\rho = 2\gamma^2(v_t^2 - v_m^2)/c^2$ , where  $\langle v_t^2 - v_m^2 \rangle$  is the rms deviation of the transverse velocity from its mean value. Thus, coherent bremsstrahlung and synchrotron radiation correspond to the cases when  $\rho \ll 1$  and  $\rho \gg 1$ , respectively. In the intermediate case,  $\rho \sim 1$ , one type of radiation transfers to the other type. The type of the radiation of a particle in unbent thin crystals is determined by the input angle  $\theta$ , which remains almost unchanged during the motion of the particle.

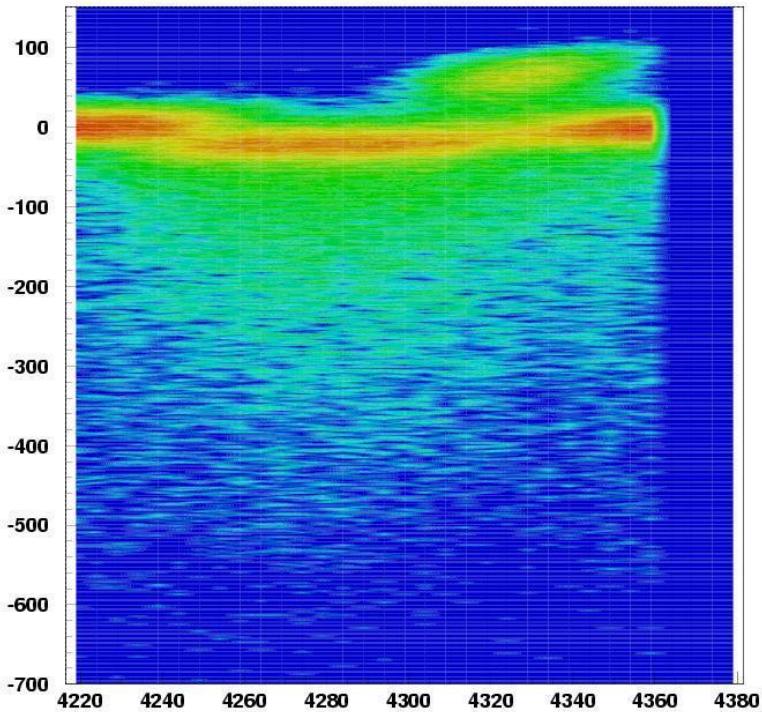
However, the angle with respect to the crystallographic planes in a bent crystal varies during the motion of the particle; therefore, the type of radiation also changes. Far from the tangency point, where  $\rho \ll 1$ , the radiation of the particle is a coherent bremsstrahlung



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

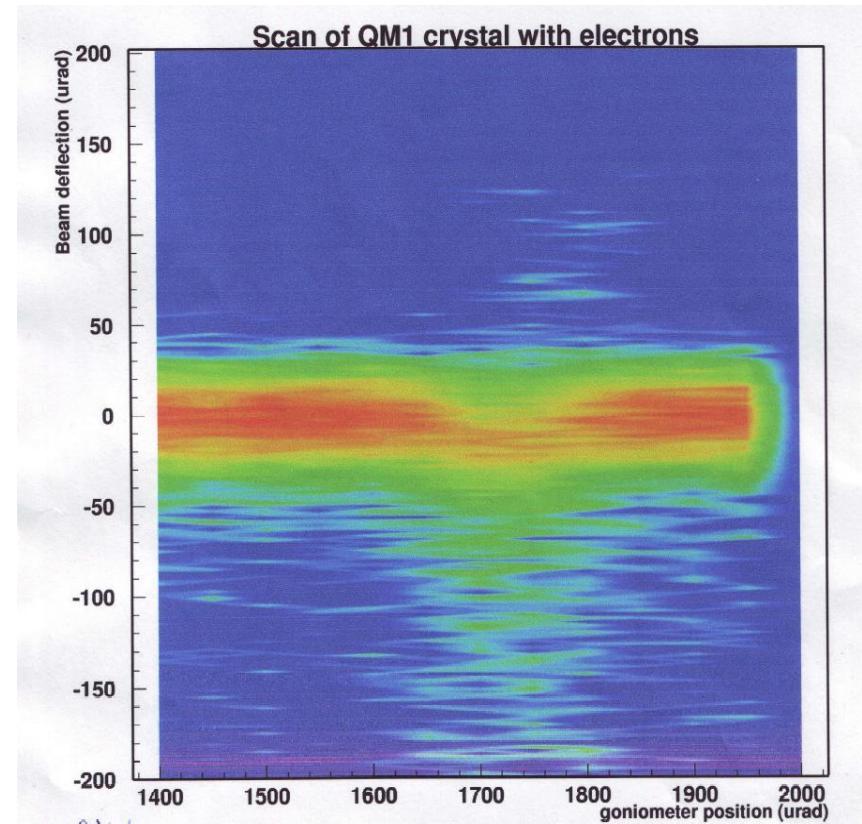


**Energy losses of 180 GeV positrons and electrons in 1mm bent crystal**  
**H8-RD22 (CERN-INFN-IHEP-PNPI-JINR) W.Scandale et al,**  
**PHYSICAL REVIEW A 79, 012903 2009**



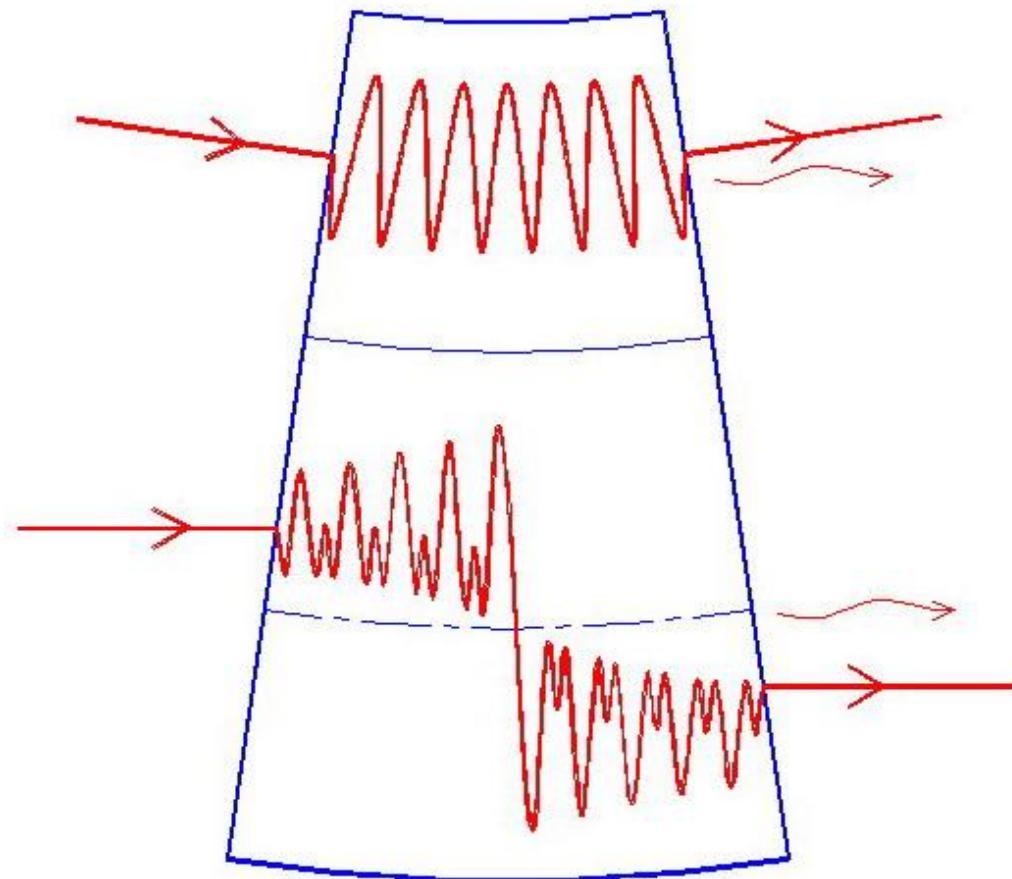
positrons

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electrons

Main positive feature of VRR radiation compared to Channeling radiation is wide angular region which is equal the crystal bend angle.



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# conclusion

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

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