Applications of crystals in intensive beams at IHEP Protvino Accelerator

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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.

1.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)

Schemes of crystal channeling extraction

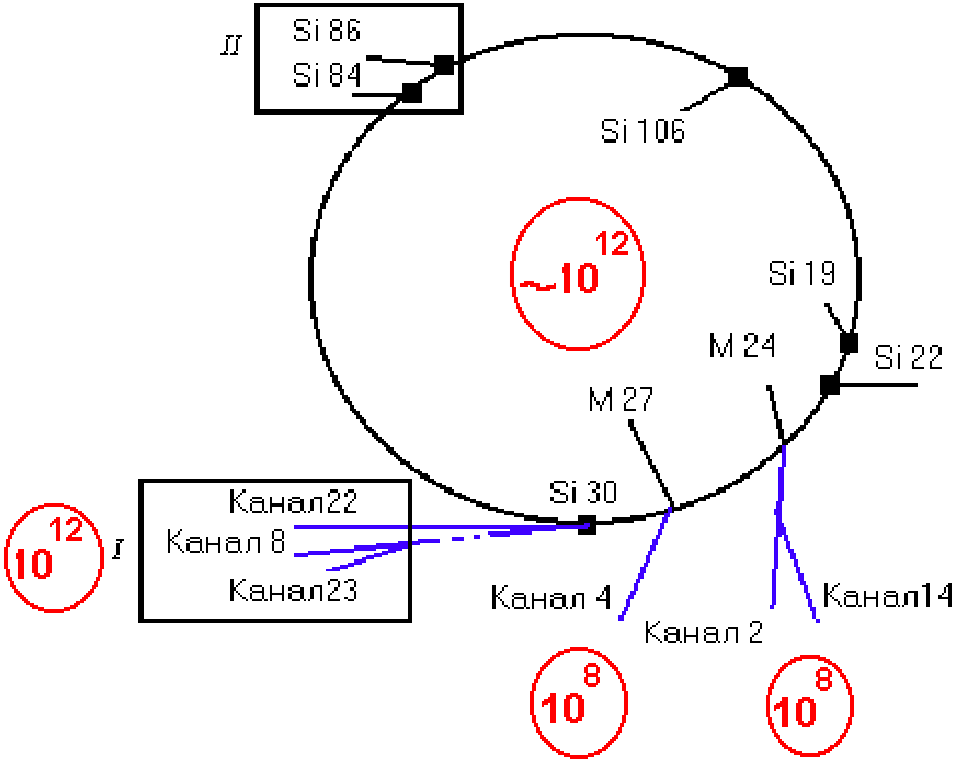
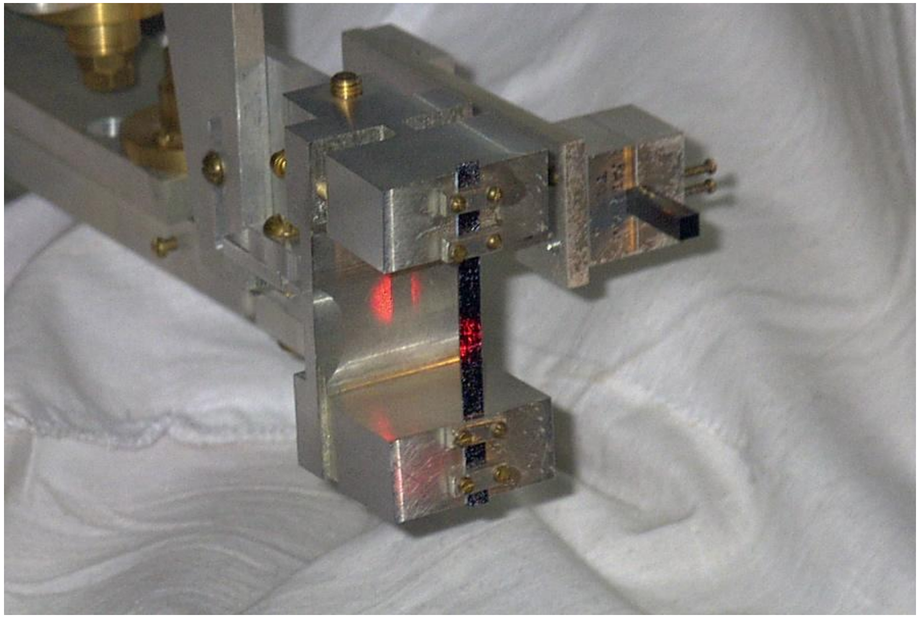


Схема вывода пучков из У-70: Si 19, Si 22, Si 30, Si 84, Si 106 – изогнутые кристаллы; M 24, M 27 – внутренние мишени; *I* – зона экспериментальных установок; II – *зона исследований кристаллов.*

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

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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 ± 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.

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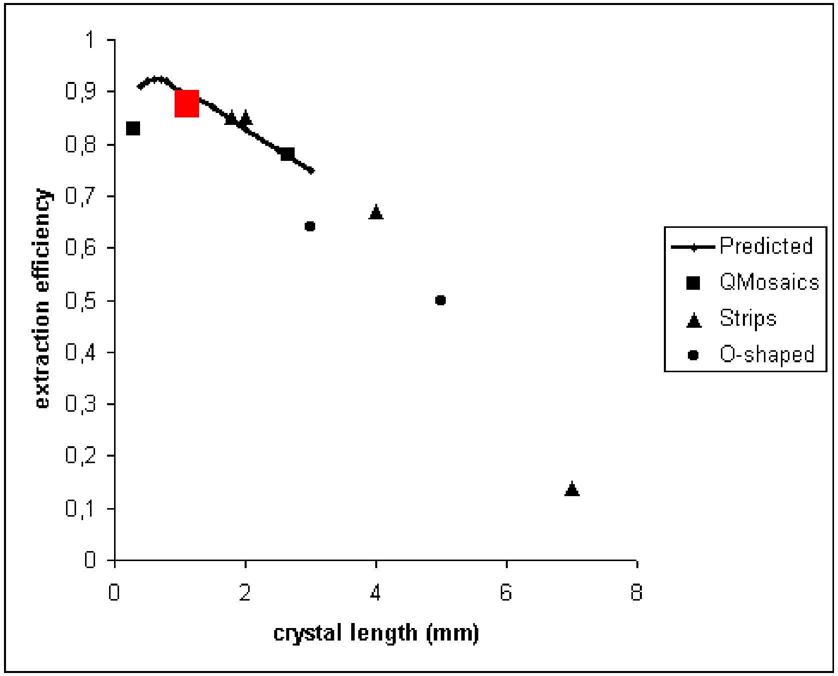
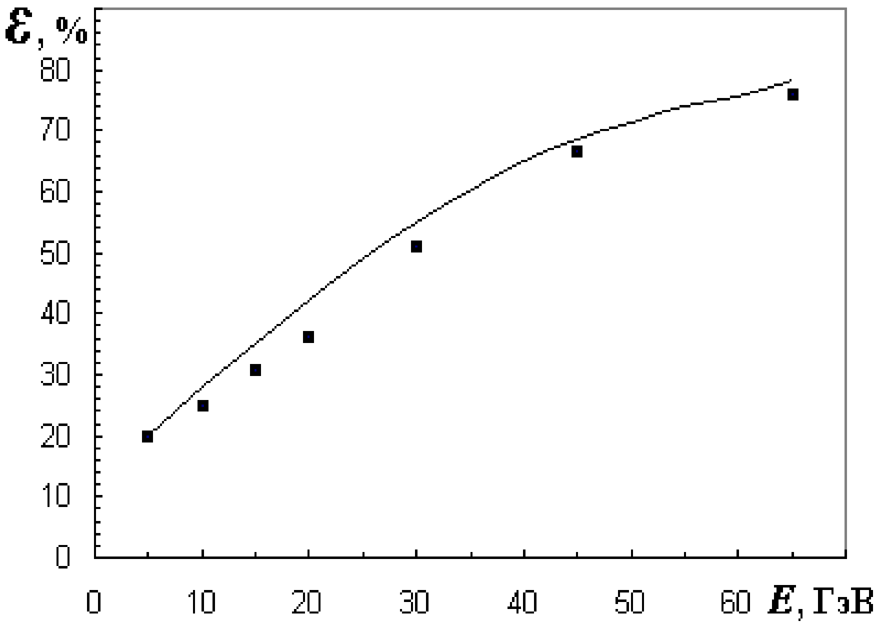
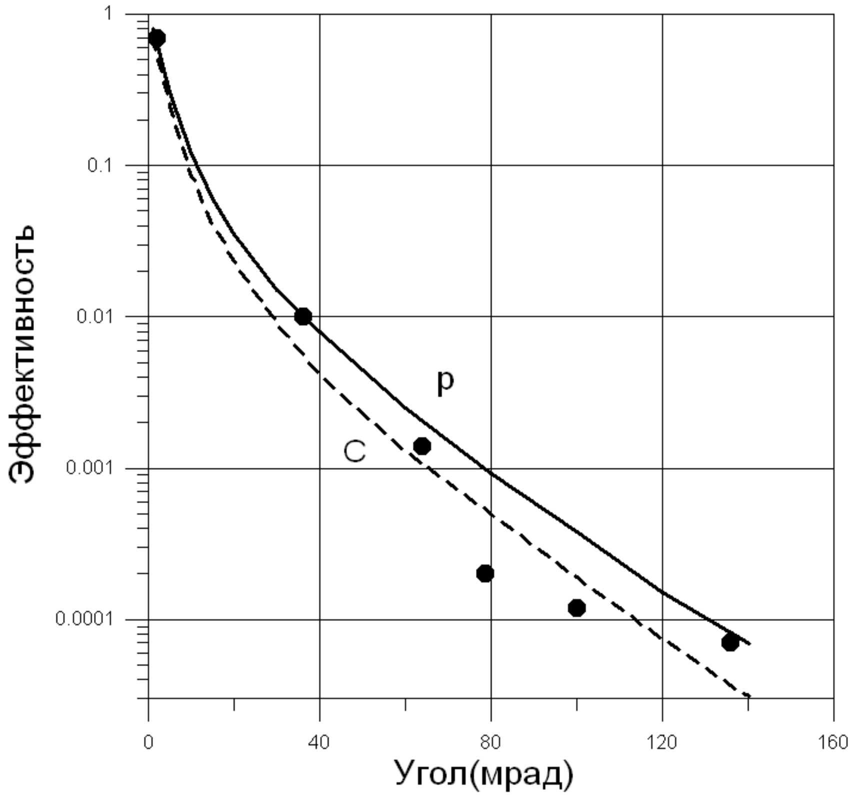
Parameters of crystal extraction



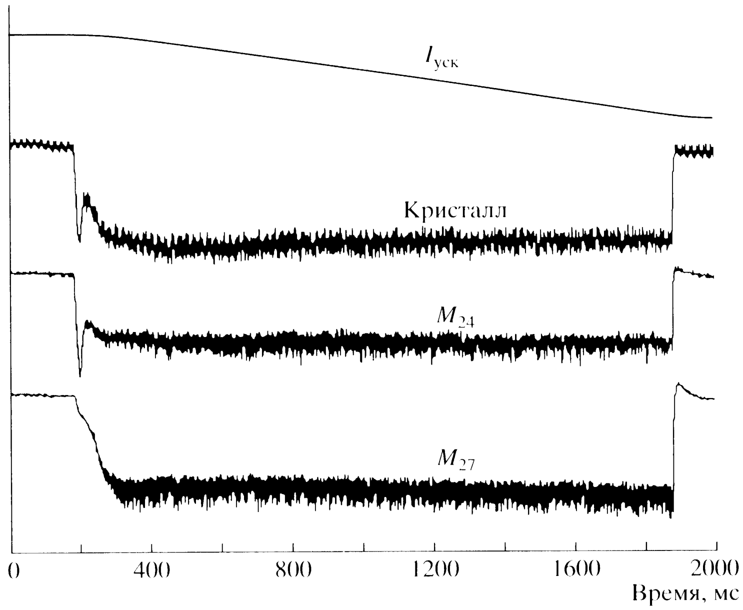
Efficiency dependence versus crystal length



Crystal efficiency versus proton energy



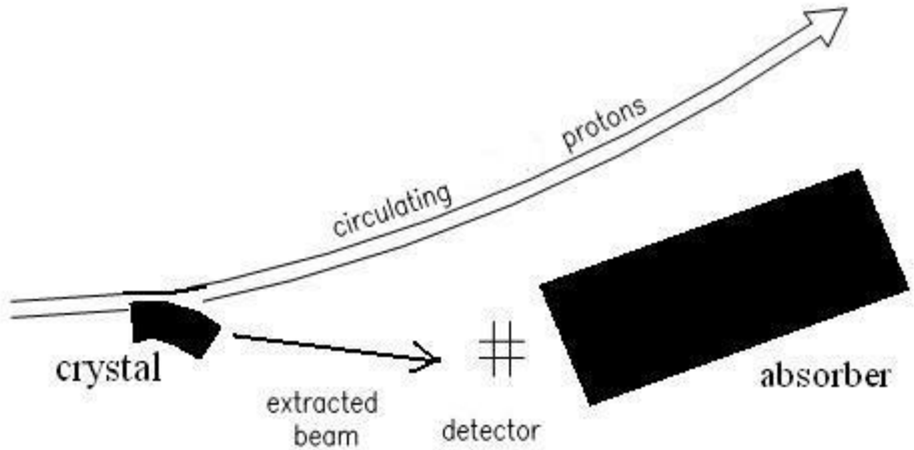
Efficiency dependence versus crystal bend angle



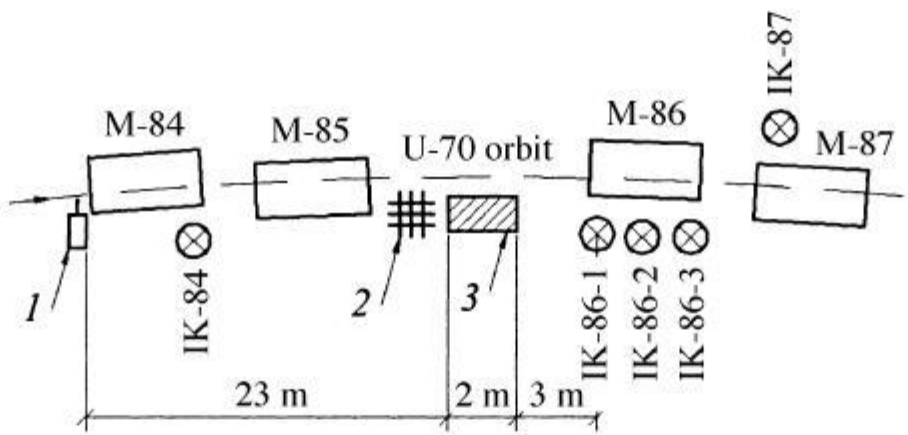
Time structure at Simultaneously operation

Extraction with large bending

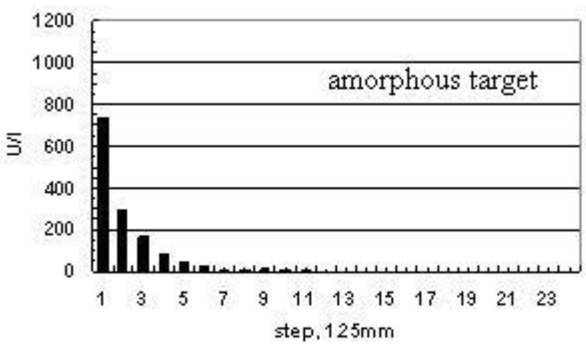
2.Use of crystals to improve beam collimation in U-70.

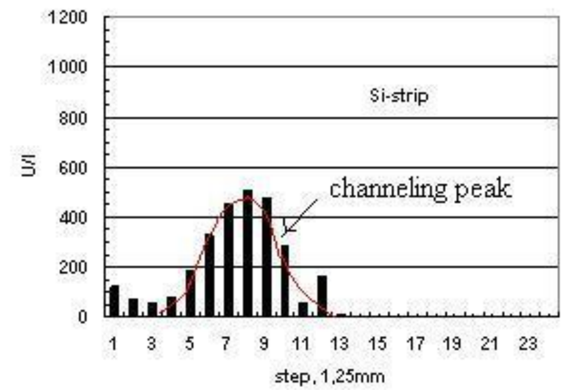


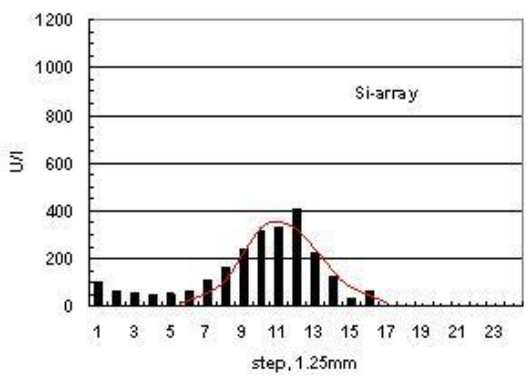
BLM

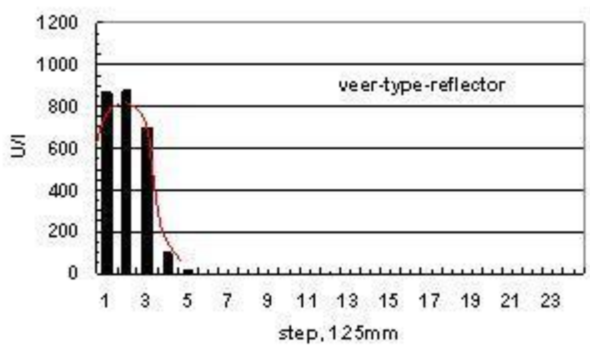


Beam profiles at collimator entry: channeling in 3 different crystals compared to amorphous target (50 GeV protons).

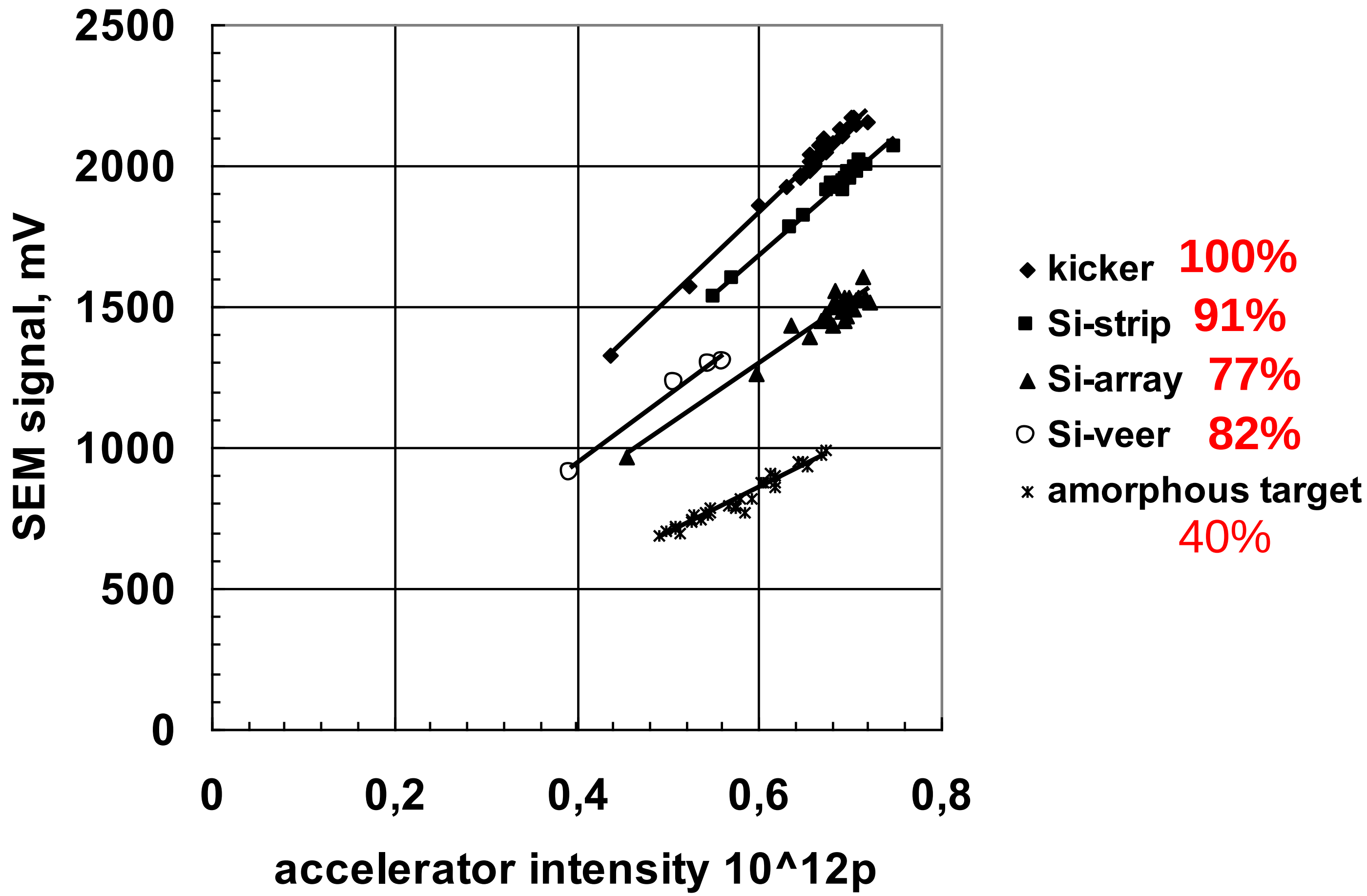




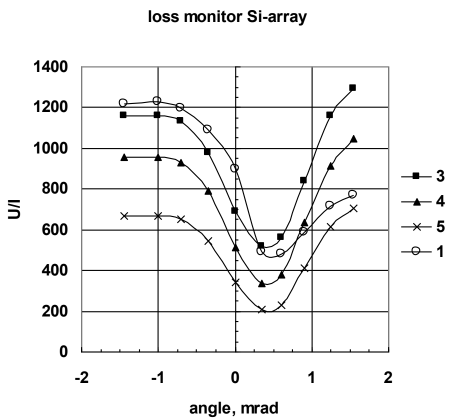


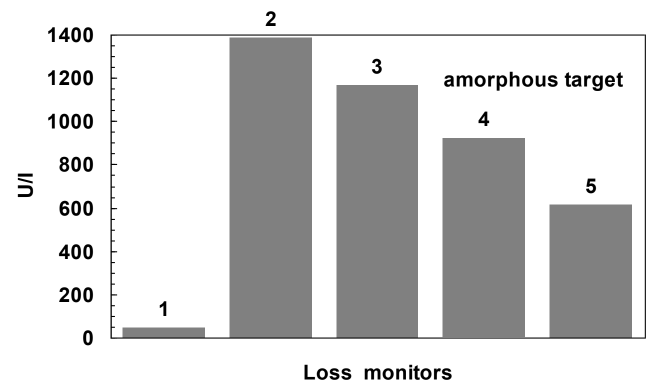


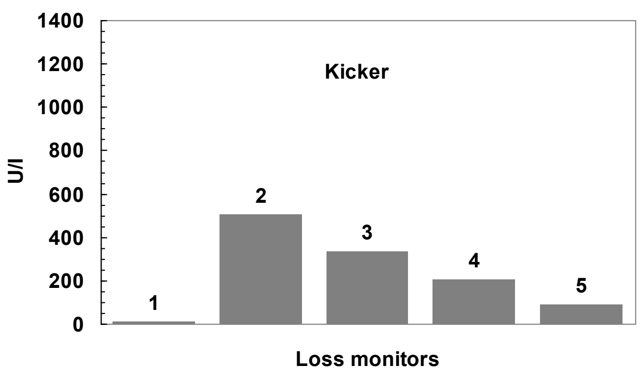
Collimation efficiency measurement by comparison with kicker effect.

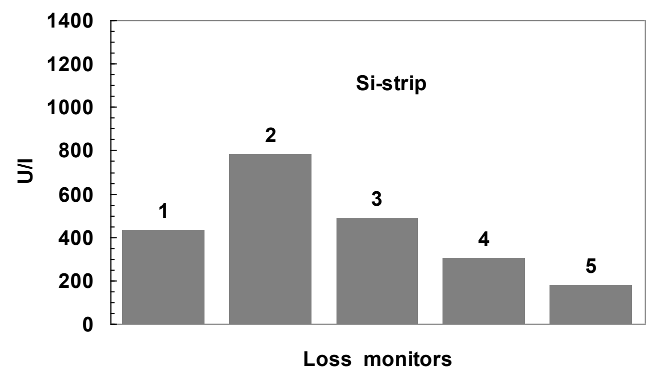


Reduction of losses, factor 2-3.





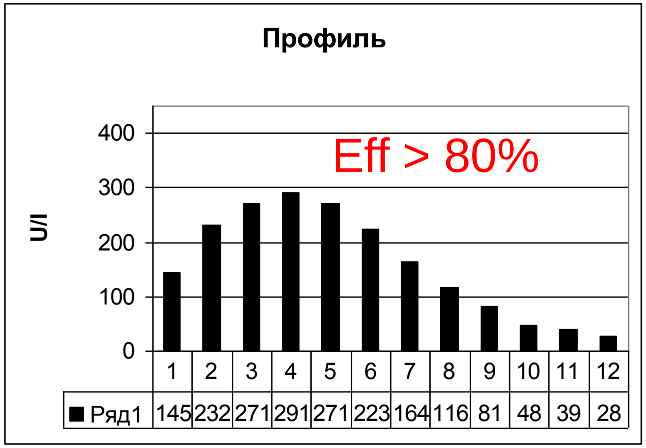




Testing of multistrips: measured beam profiles at absorber entry (2008). Efficiency is good, but deflection is small – next step – axial reflections.

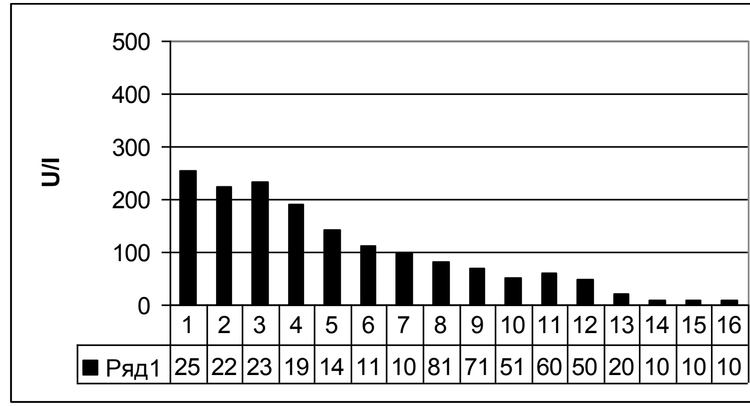
Multiple reflection

a)

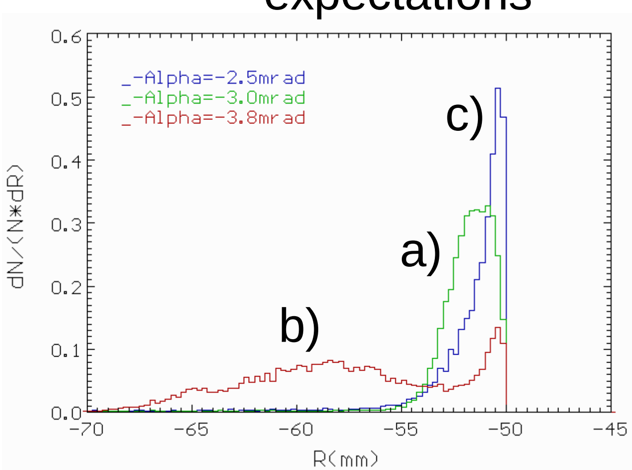


Multiple channeling

b)

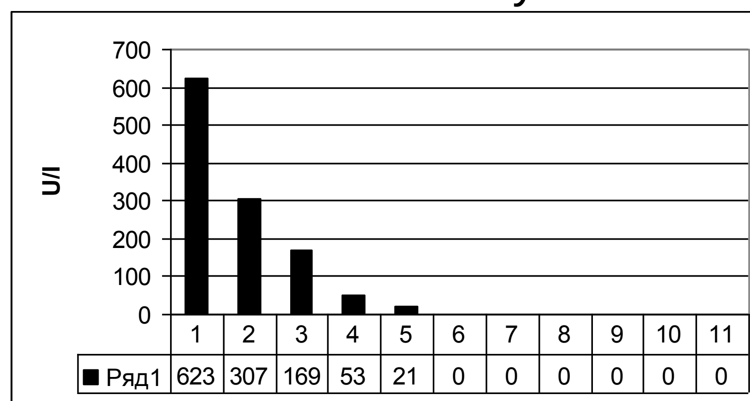


expectations



Disoriented crystal

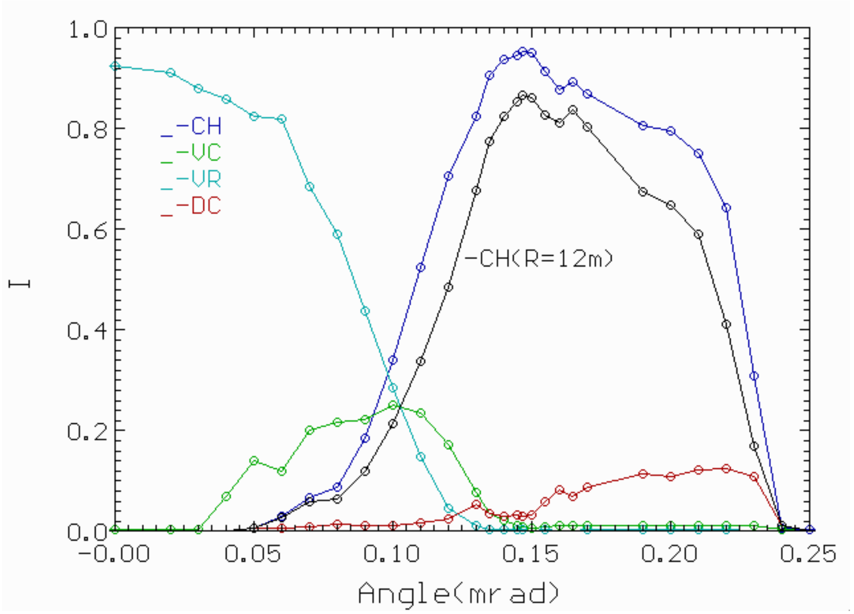
c)



Instead of conclusion: our recommendation for the SPS:

Simulation results for optimization of crystal for channeling collimation in the SPS (120 GeV): Optimal crystal has 0.8mm length and 270 urad angle. Existing 2mm crystals are not ideal choice! (It is optimal exactly for the Tevatron)

- Fig. :Orientation curves of any fractions protons out from the crystal and put on the TAL.
- Simulation for crystal with R=3m, L=0.8 mm, with amorphous layer (blue curve).
- Maximum efficiency fore pure crystal I = 95.7%, with amorphous layer I = 95.0%,
- that is amorphous layer practically don’t influence on the efficiency.
- The range of good efficiency is increase in two times.



Possibilities of using the crystalline target for beam collimation in the LHC

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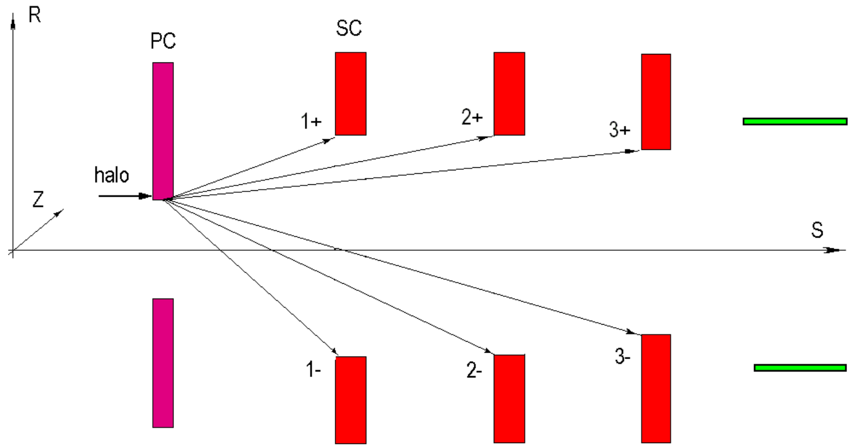
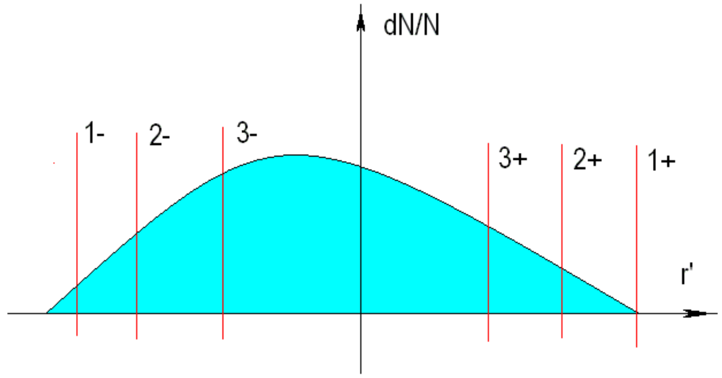
Outline

- The estimation inefficiency of beam cleaning system from any factors was considered.
- The possible variants of application the crystalline targets for beam cleaning in LHC were investigated.
- The use of crystal (channeling effect) with usual collimator gaps.
-

Principal sketch of beam cleaning system





Main collimation systems in LHC:

- Betatron cleaning (IR7).
- Momentum cleaning (IR3).
- Shielding of interaction region.

8 main radiation sources for two systems (R+-,Z+-,…).

In the Pic. of angular beam distribution we can see 6 added sources.

With using crystalline target the distribution changes -> efficiency changes.

The distribution depends also on impact parameter, alignment, substance, …

Inefficiency LHC beam cleaning system

- It are defined as the number of protons that go out from collimation system with an amplitude larger than the acceptance of the accelerator over the total number of localization protons.

$$\eta = I_{lost} / I_0$$

Main sources of scattered protons:

- Primary collimators - η_{pc}
- Secondary collimators – η_{sc}
- Tertiary collimators - η_{tc} $\eta = \eta_{pc} + \eta_{sc} + \eta_{tc}$

- Investigation of system by computer simulation:

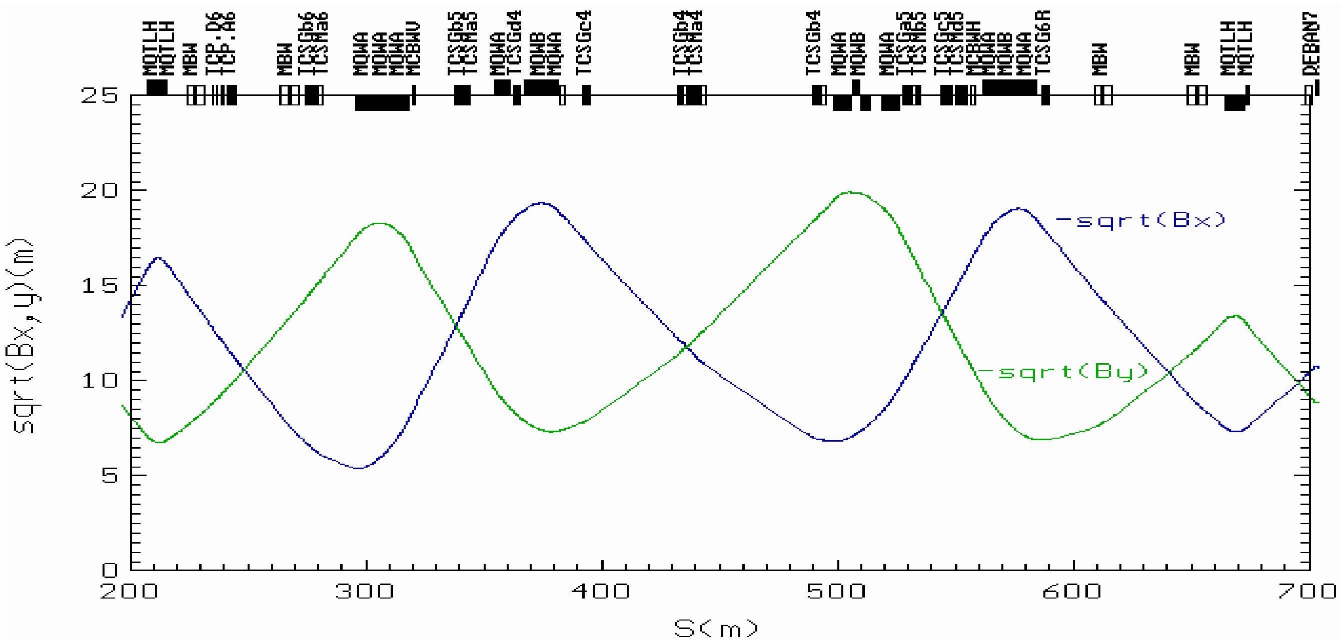
With use of absolute collimators the contribution of each radiation source can be defined:

- η_{pc} – defined when absolute secondary collimators $\eta_{pc} = \eta_{a\_sc}$
- η_{tc} – defined from full losses and variant when absolute tertiary collimators $\eta_{tc} = \eta - \eta_{a\_tc}$
- η_{sc} - defined from $\eta_{sc} = \eta - \eta_{tc} - \eta_{pc}$

- With use of target (crystal) we can defined losses from it:

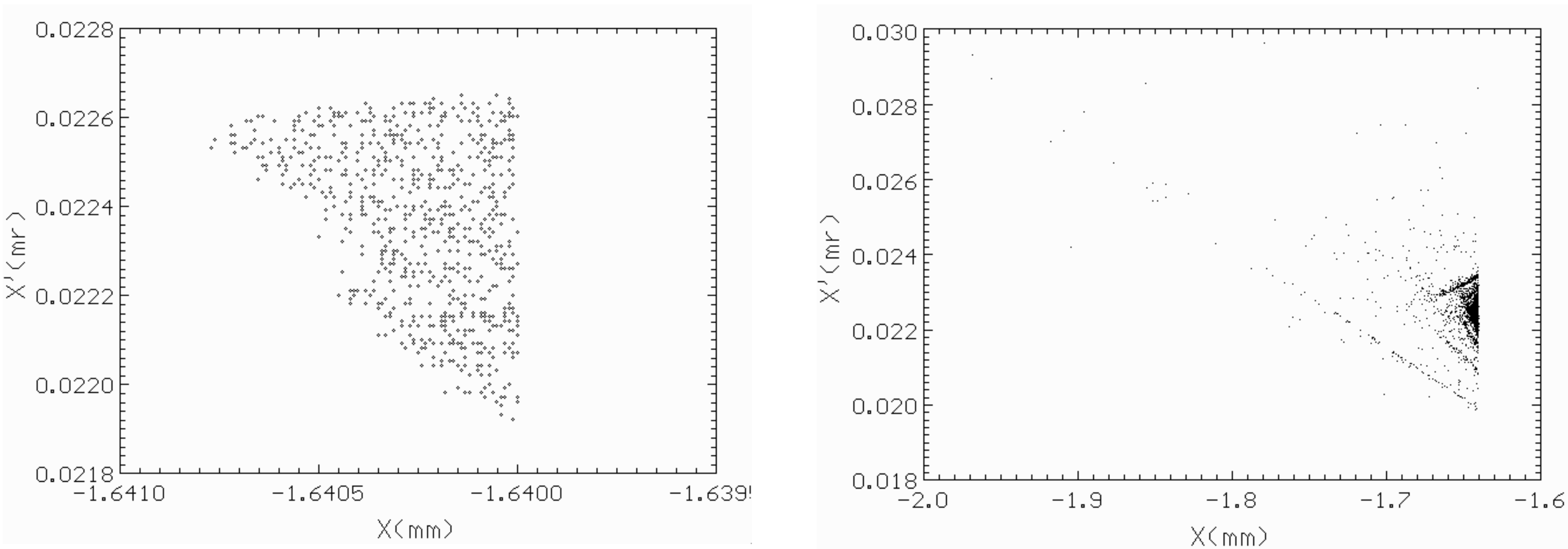
$\eta_{tar} = \eta_{a\_allcoll}$

Structure of LHC beam cleaning system



- Amplitude functions $\sqrt{\beta_{r,z}}$ in **IR7**
- Circle beam sizes $R_b, Z_b = n\sqrt{\beta_{r,z}\varepsilon_{r,z}}$
- For primary collimators n=6, for secondary n=7

Beam distribution at the input of PC for absolute and real collimators



- Mean number of crossings of PC by proton is 3.4 times assuming a velocity of dV=0.05μm/turn,
- Impact parameters dR=0.3 μm.
- Angular width of beam 0.6 μrad.

Calculation inefficiency of system

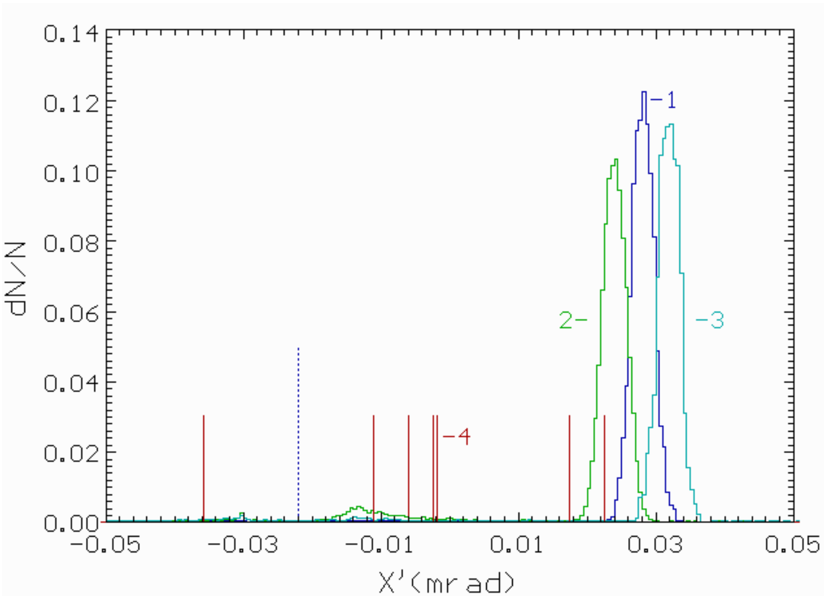
Collision energy E=7000 GeV, R_0'=-0.023 mrad

R_0,mm	Z_0,mm	η_0%	η_1%	η_2%
1.7	0.0	0.091	0.112	0.098

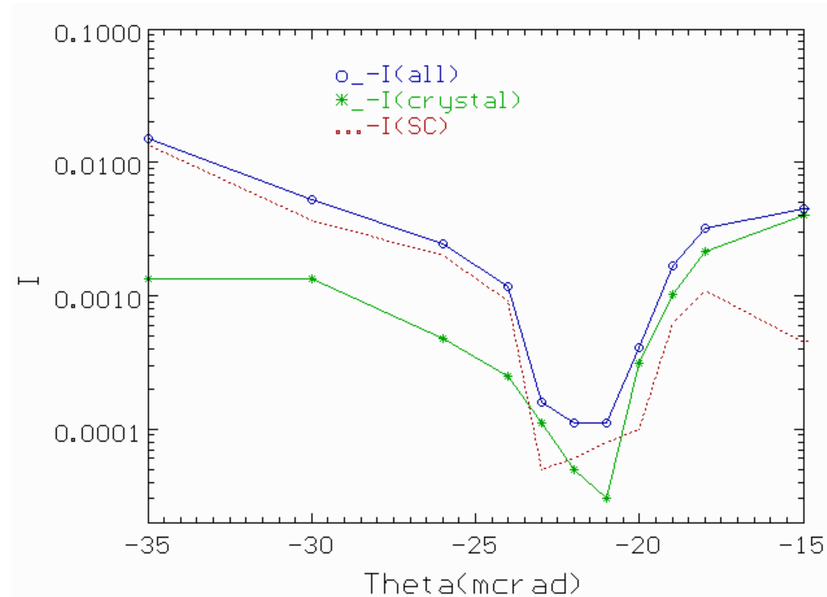
0 - absolutely secondary collimators
1- carbon secondary collimators (phase 1)
2 - secondary + tertiary (Cu) collimators (phase 2)

- First coefficient defined losses only from primary collimators $\eta_{pc} = \eta_0 = 0.091\ \%$
- Losses from secondary collimators $\eta_{sc} = \eta_1 - \eta_0 = 0.021\ \%$
- Part losses catch by tertiary collimators $\Delta\eta_{tc} = \eta_1 - \eta_2 = 0.014\ \%$
- From table we can see that main losses at E=7T defined by particles escaping from PC.

Using channeling effect at LHC in case of phase 1



1



2

Fig.1: Angular beam distribution with any orientation of crystal 1-3: $\vartheta_0 = -22, -26, -18\ \mu rad$
4-images of collimator edges (V=1μm/turn, E= 7TeV, R=80m)

Bend angle of crystal = 0.05 mrad for case of phase 1 (sizes of collimator gaps).

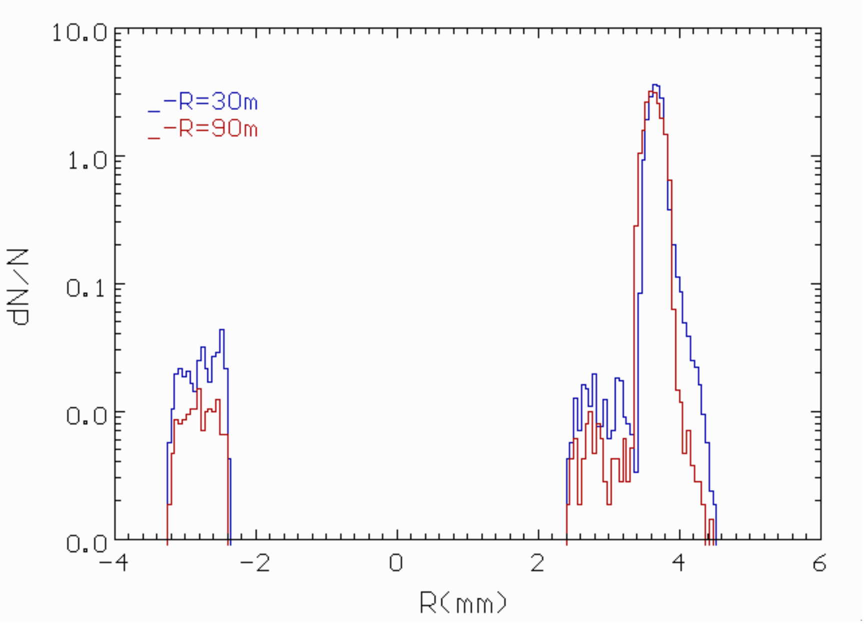
Crystal stand in place of primary collimator and deflect in radial plane.

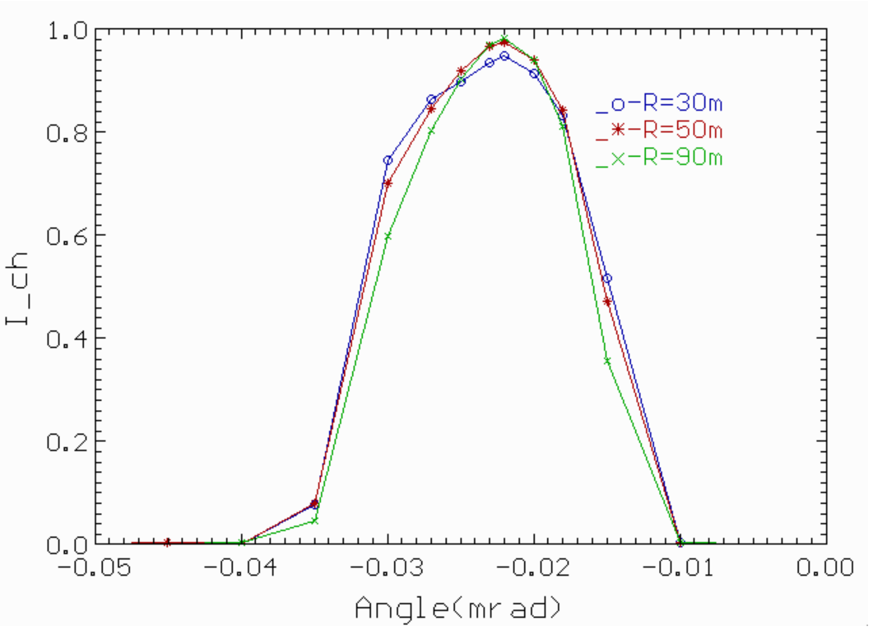
Fig2.: Inefficiency versus alignment of crystal. (E=7 TeV)

- Increase efficiency of system in ~10-15 times
- Range of good efficiency -20.5:-23.5 urad

With using the 2 crystals the working range increase in twice.

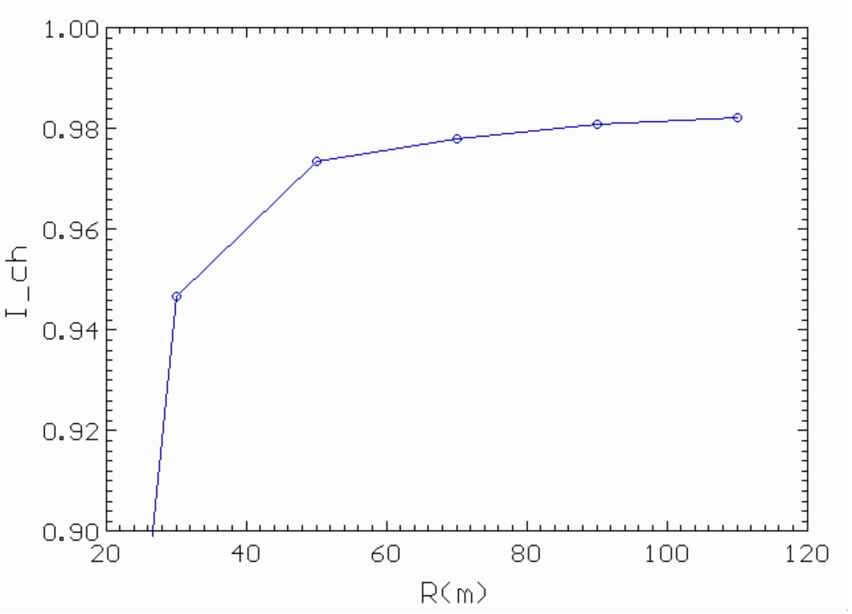
Using channeling effect at LHC in case of some changing gaps



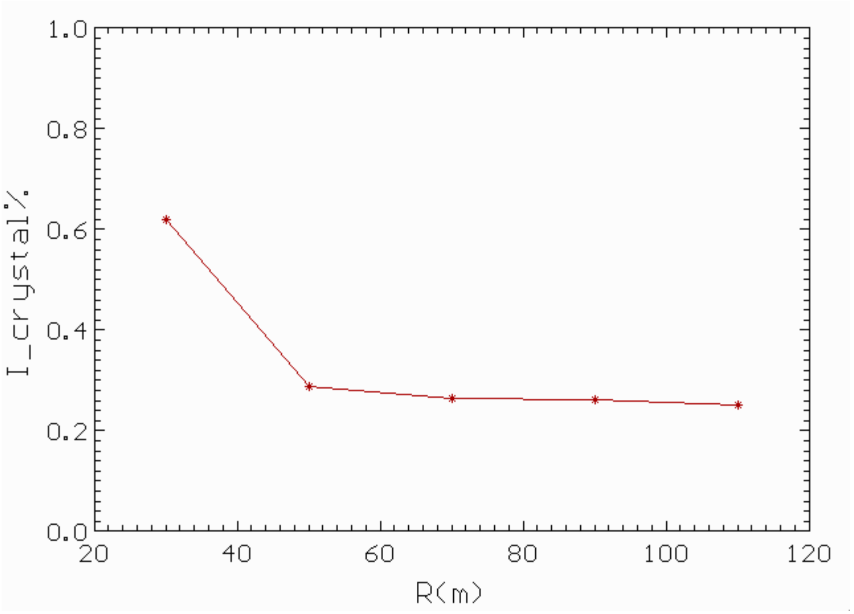


- Beam distribution on the collimator TCSGb5 and orientation curve for channeling fraction.
- Bend angle of crystal (Si110) = 0.03 mrad, gap of collimator=2mm
- Beam size at crystal Rb=1.64mm, Zb=1.23mm

Choice of curve radius



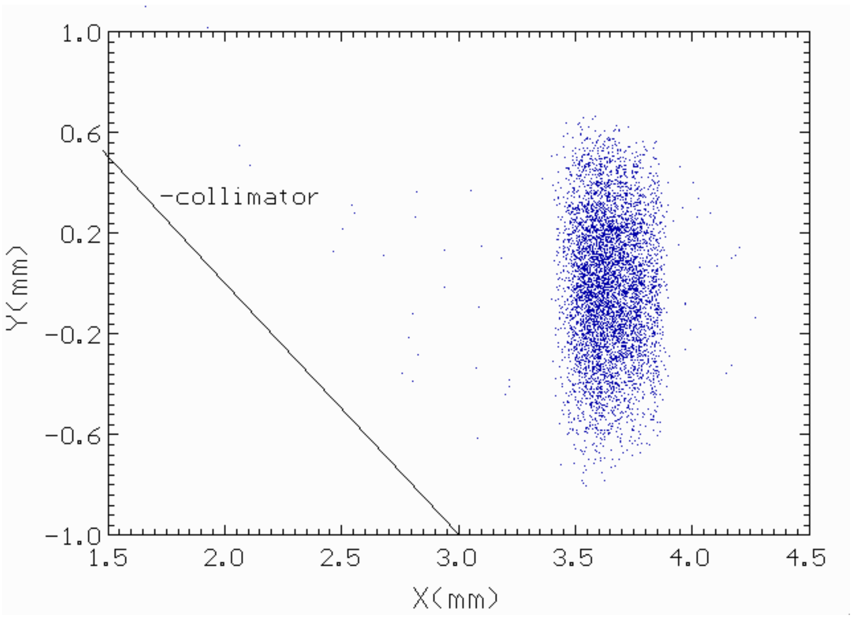
1



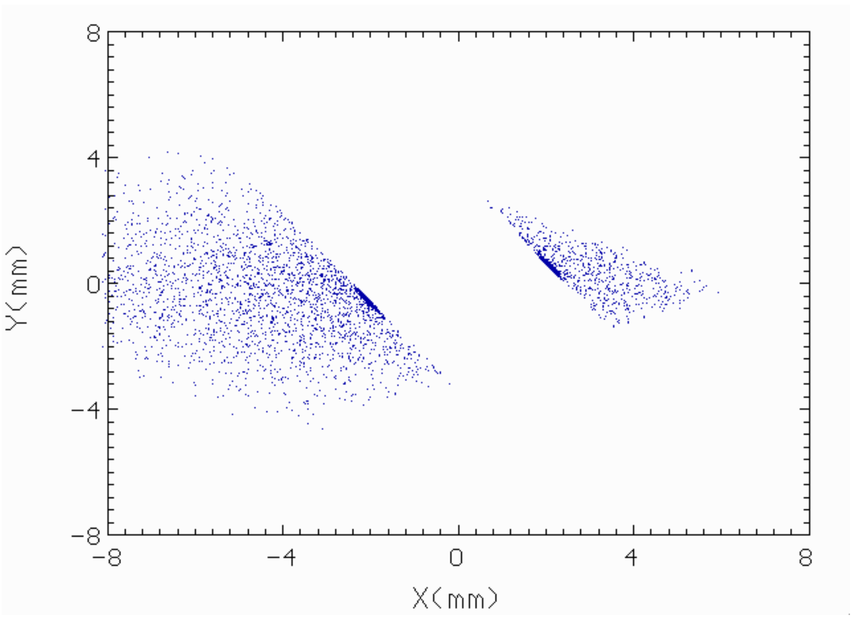
2

- 1 - Channeling fraction from curve radius.
- 2 – Losses on the crystal, Bend angle of crystal = 0.03 mrad
- Optimum curve radius R~ 70m, length = 2.1mm

Phase plane of beam on the collimator TSCb5

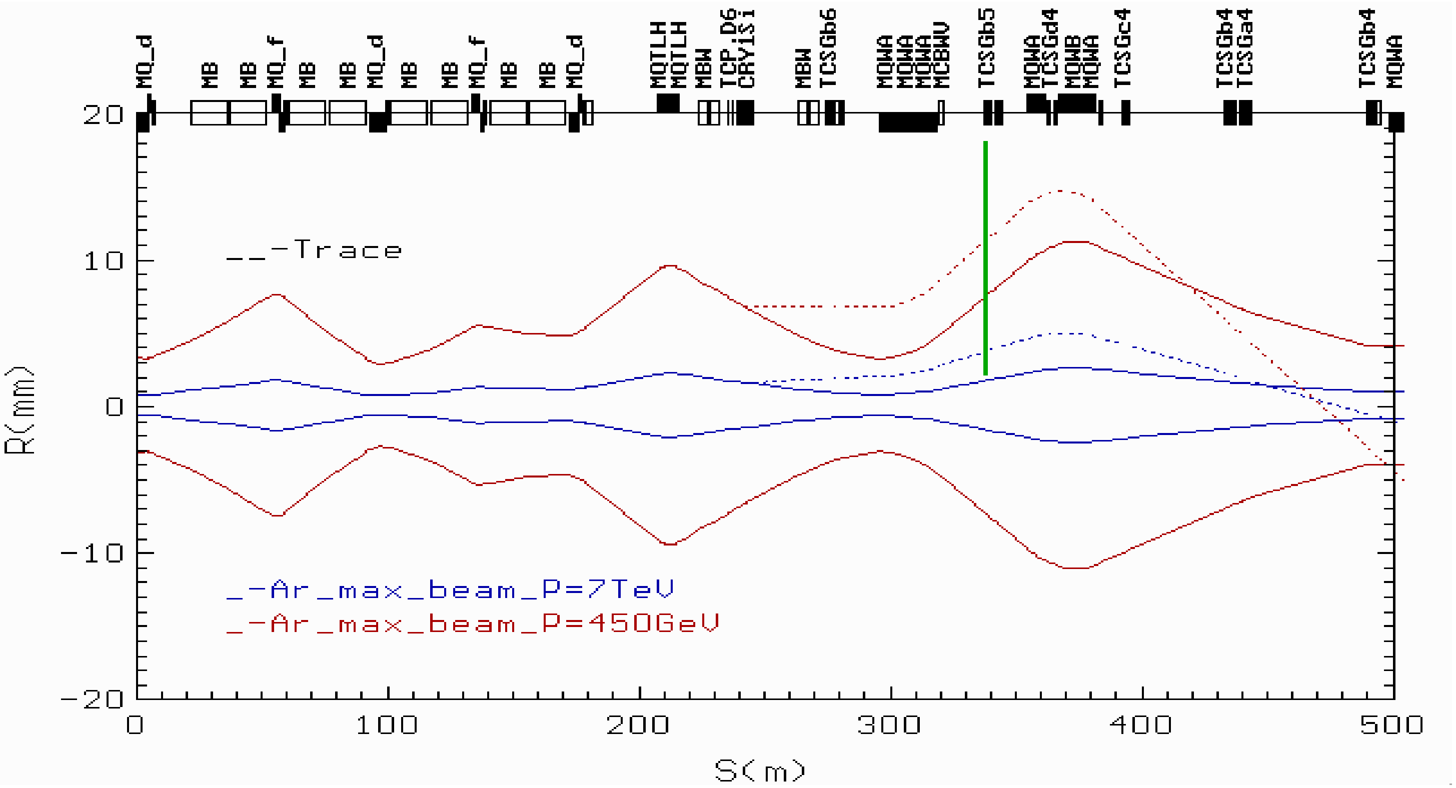


1



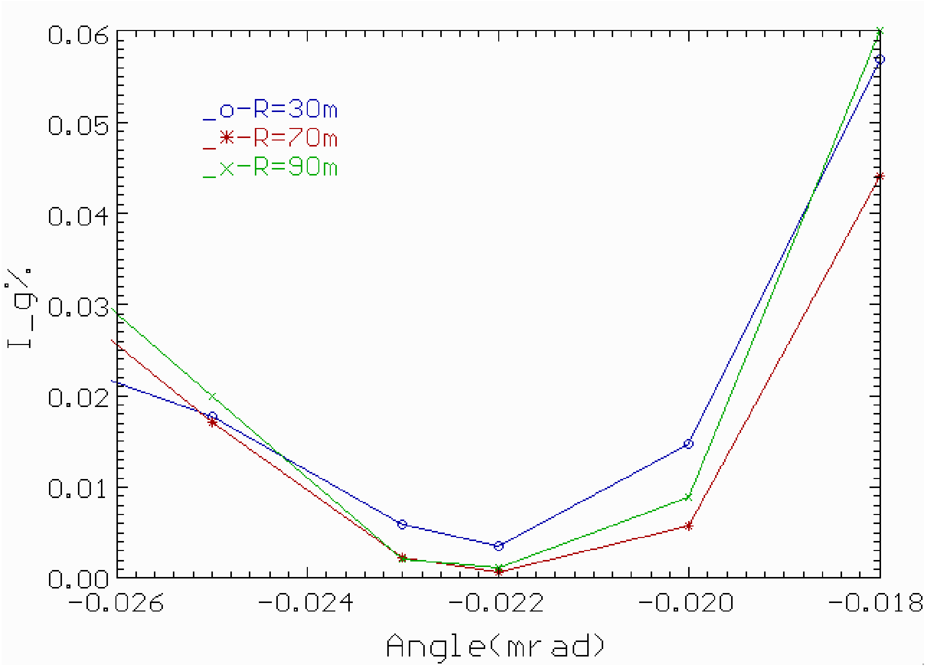
2

- 1 – Optimal orientation (Angle = -22 urad) (R~ 70m, length = 2.1mm).
- 2 – Bad orientation (Angle = 0 urad).
- Density of beam on the edge of collimator decrease in ~1000 times
- Losses on the crystal = 0.26% (losses on primary collim. ~50%)
- Efficiency of collimation system increase in 50-100 times



- Beam sizes and traces protons from crystal for two energies.

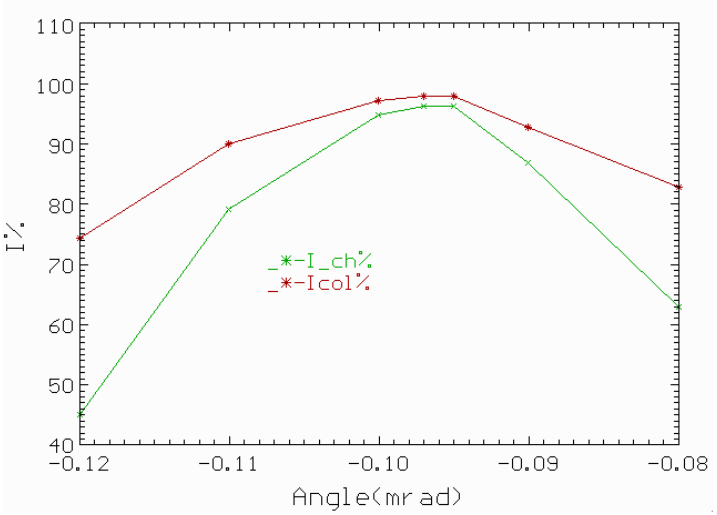
Global inefficiency of system P=7TeV



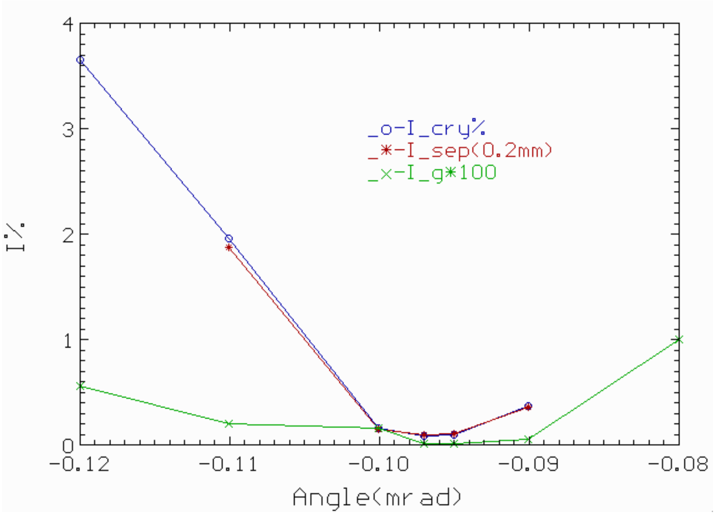
- Orientation curve of full proton losses in accelerator for some curve radiuses of crystal.
- Minimum losses is in case R=70m, Ig=0.0006%,

That in 150 times smaller than usual collimation.

Efficiency of system P=450GeV



1



2

- 1 - Orientation curves for channeling fraction I_ch an for losses on collimator TSGb5 (R = 10m, length = 1.4 mm).
- 2 - Orientation curves of global losses and losses on the crystal.
- Minimum losses is in case Angle=-95urad, Ig=0.0002%,

That in 200 times smaller than usual collimation.