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

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AB-ABP Group

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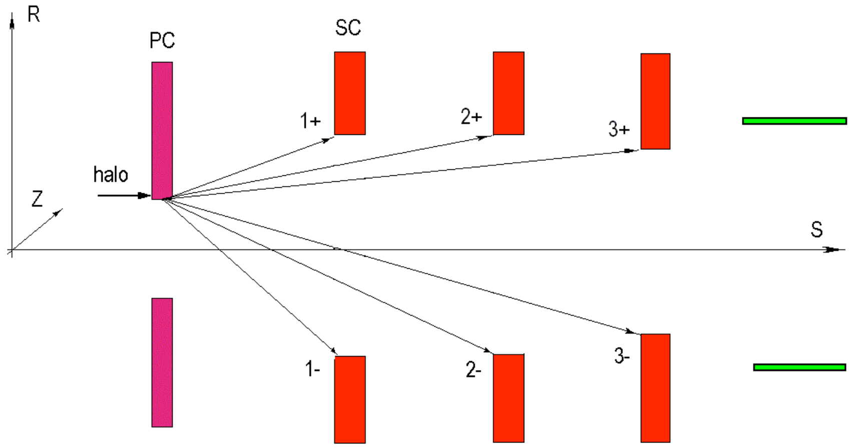
Outline

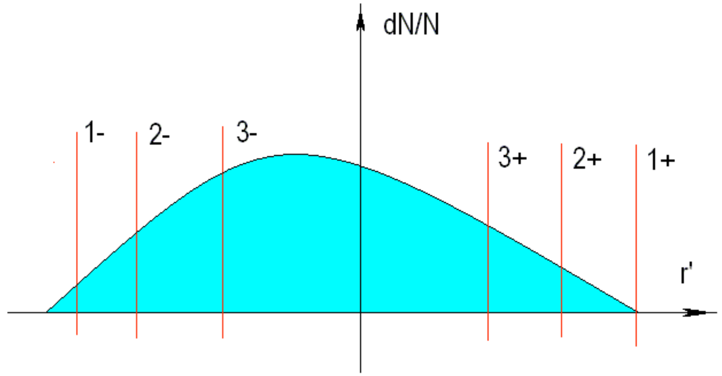
- The estimation inefficiency of beam cleaning system from any factors was considered.
- The possible variants of application the crystalline targets for beam cleaning in LHC were investigated.

1. The channeling,
2. multi channeling
3. multiple reflection effects in crystals.

- The heating of crystal and limitation of beam intensity for beam cleaning system was considered.

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:

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

Calculation inefficiency of system

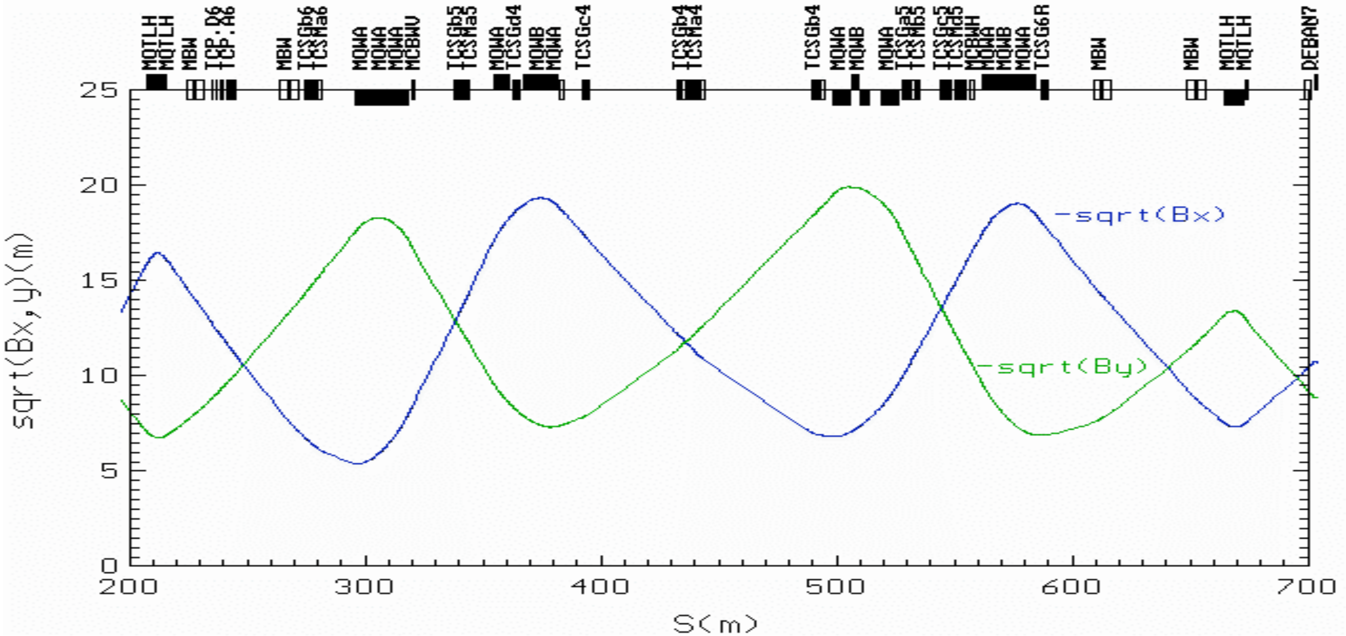
Collision energy E=7000 GeV, R_0'=-0.023 mrad

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)

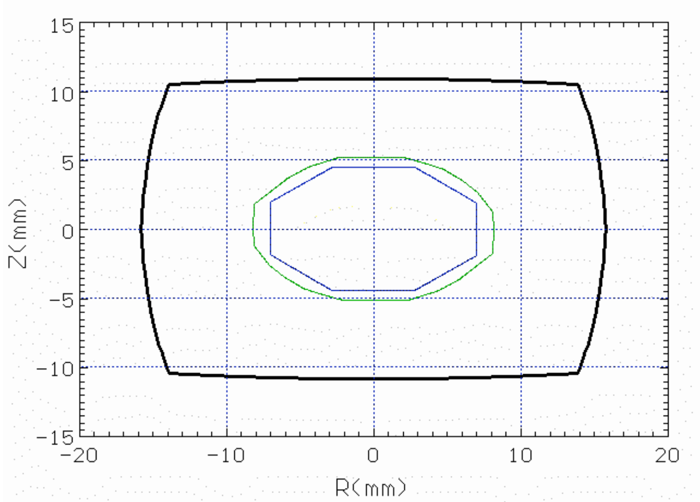
- First coefficient defined losses only from primary collimators $\eta_{pc} = \eta_0 = 0.091\%$
- Losses from secondary collimators $\eta_{sc} = \eta_1 - \eta_0 = 0.021\%$
- Part losses catch by tertiary collimators $\Delta\eta_{tc} = \eta_1 - \eta_2 = 0.014\%$
- From table we can see that main losses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

Structure of LHC beam cleaning system

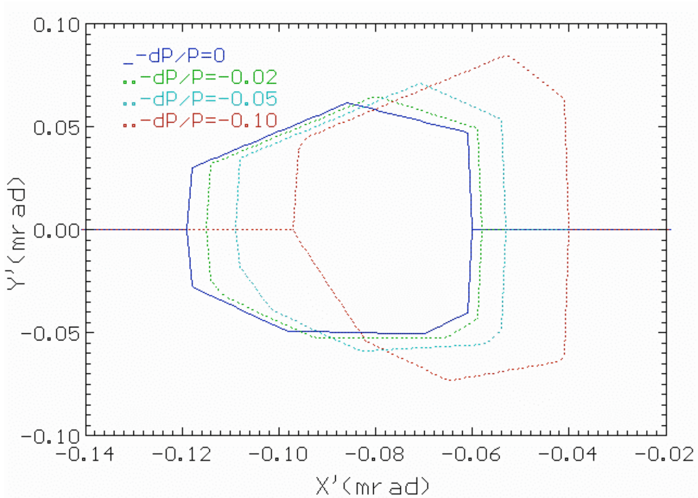


- Amplitude functions $\sqrt{\beta_{r,z}}$ in IR7
- Circle beam sizes $R_b, Z_b = n\sqrt{\beta_{r,z}\varepsilon_{r,z}}$
- For primary collimators n=6, for secondary n=7

Modeling LHC beam cleaning system



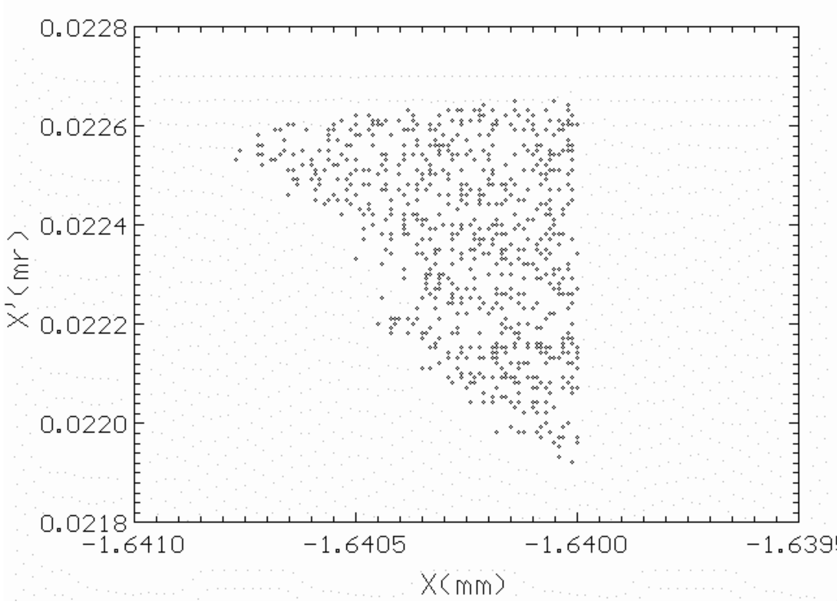
Images of primary (blue), secondary (green) collimators and vacuum chamber (black) at the location of the PC (E = 450 GeV).

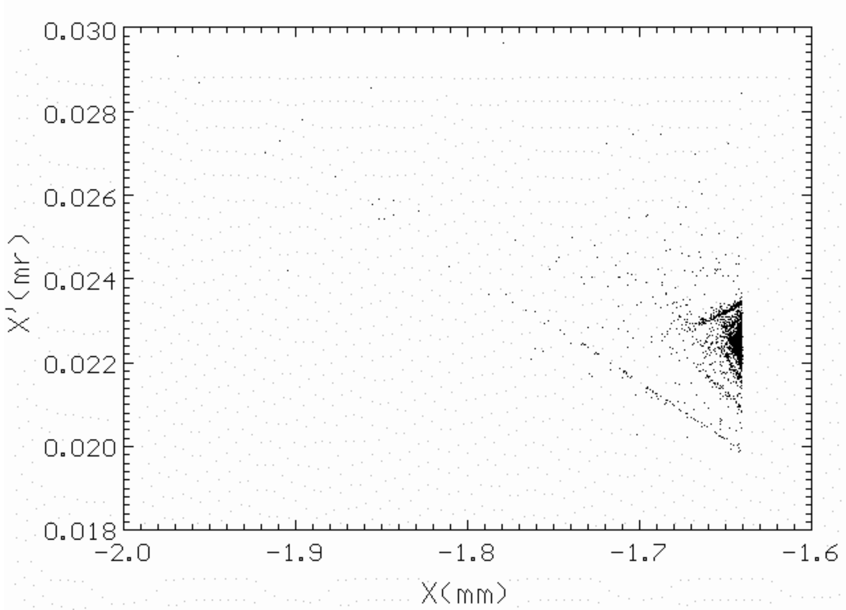


Images of secondary collimators at location of horizontal PC.

- Initial coordinates of the beam: R0=6.7mm, Z0=0, 1PC
- It defined from motion of scattered protons in 3D space.
- $x = x_0 X_{11}(p) + x_0' X_{12}(p) + \delta X_{13}(p)$ X_{ij}- elements of transfer matrixes

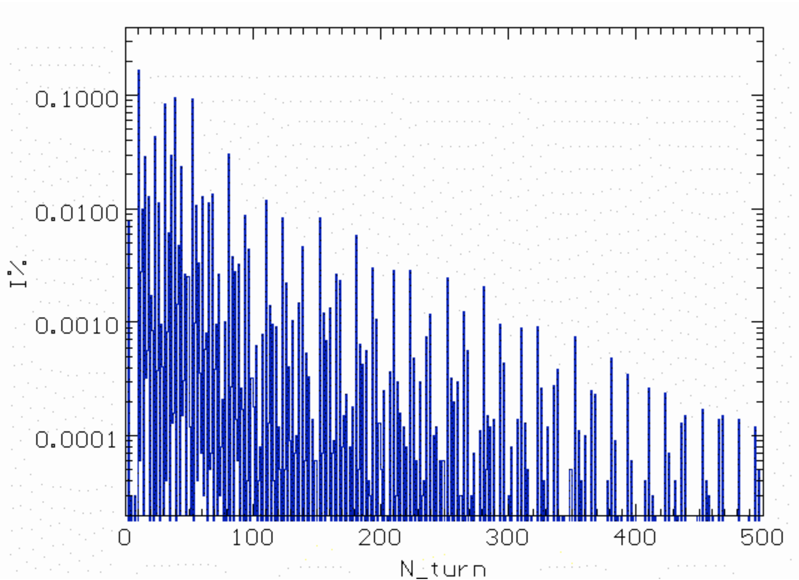
Beam distribution at the input of PC for absolute and real collimators

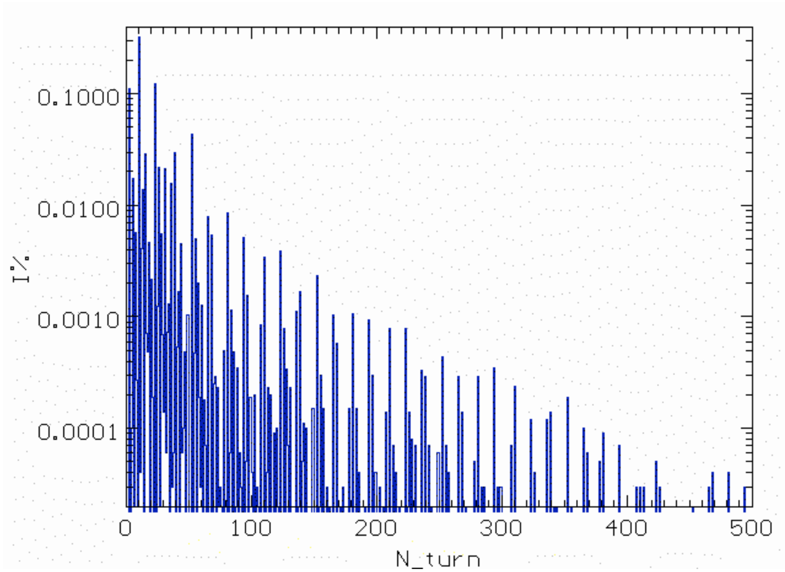




- Mean number of crossings of PC by proton is 3.4 times assuming a velocity of dV=0.05μm/turn,
- Impact parameters dR=0.3,20 μm.
- Angular width of beam 0.6, 4 μrad.

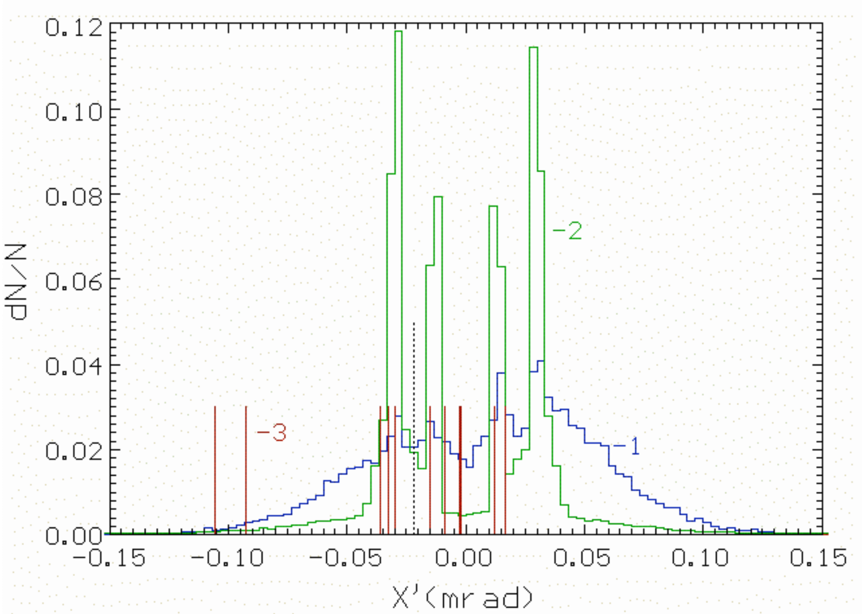
Intensity of cleaning versus turn of proton in accelerator for two impact parameters

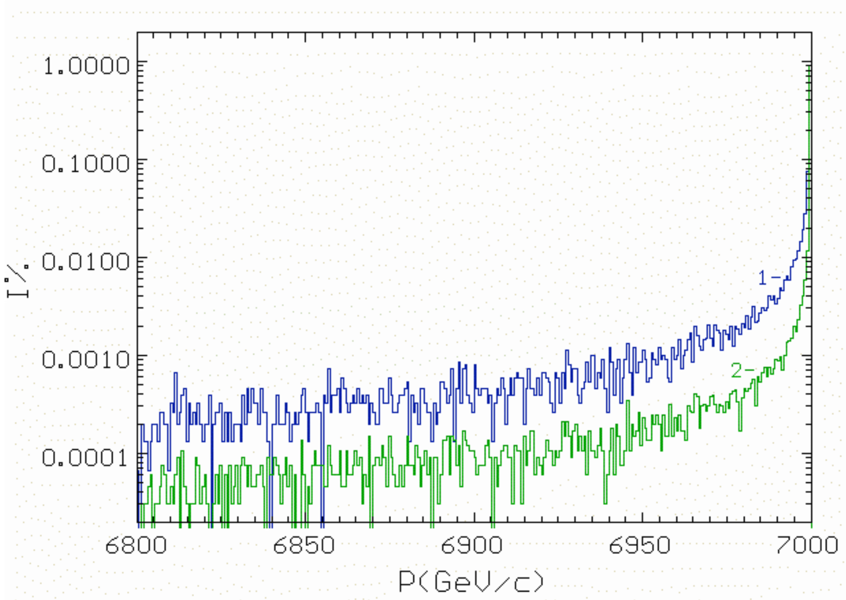




- a) dR=0.050 μm ($\overline{N} = 51.6$), b) dR = 1 μm ($\overline{N} = 23.7$),
- For calculation must Nt>500, with consider beam halo 5000.
- Function of intensity may approximated by exponent function. $I(N) = \frac{1}{\overline{N}}\exp(-N/\overline{N})$
- Needed really simulated changing beam amplitude

Beam distribution after horizontal PC





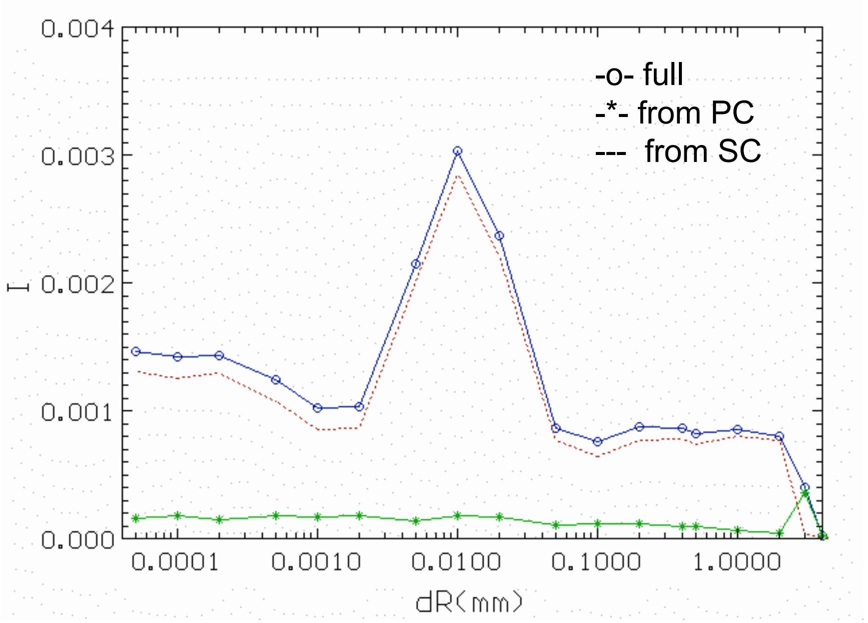
- Angular Momentum

1- V=1μm/turn, 2- V=300 μm/turn, 3-images of edges

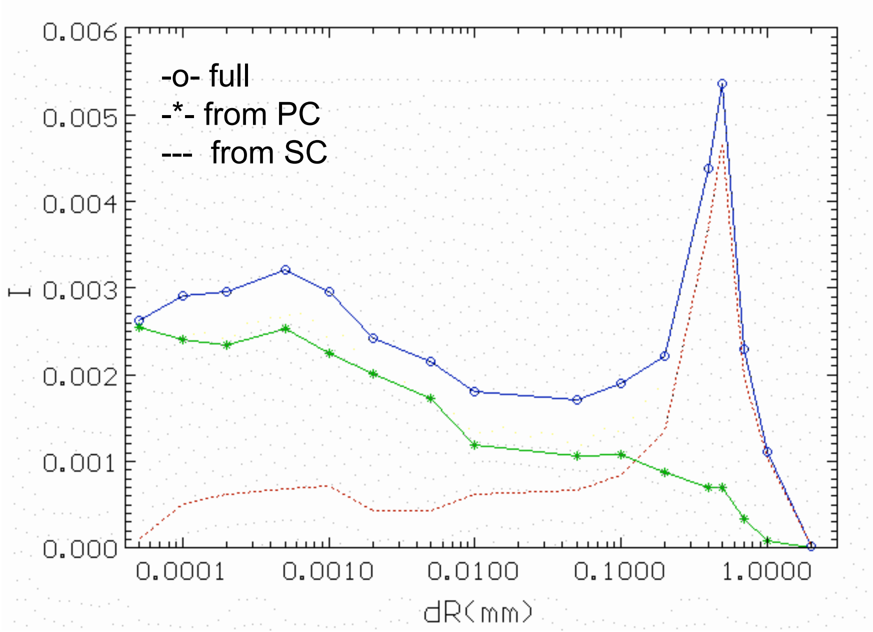
1. Losses at PC at small impact parameters ~85%
2. At big (2) = 66% and large density at SC ->losses mean number of crossing ~ 1.

* Losses defined at 7sigma

Inefficiency versus impact parameter (dR) of protons at horizontal PC



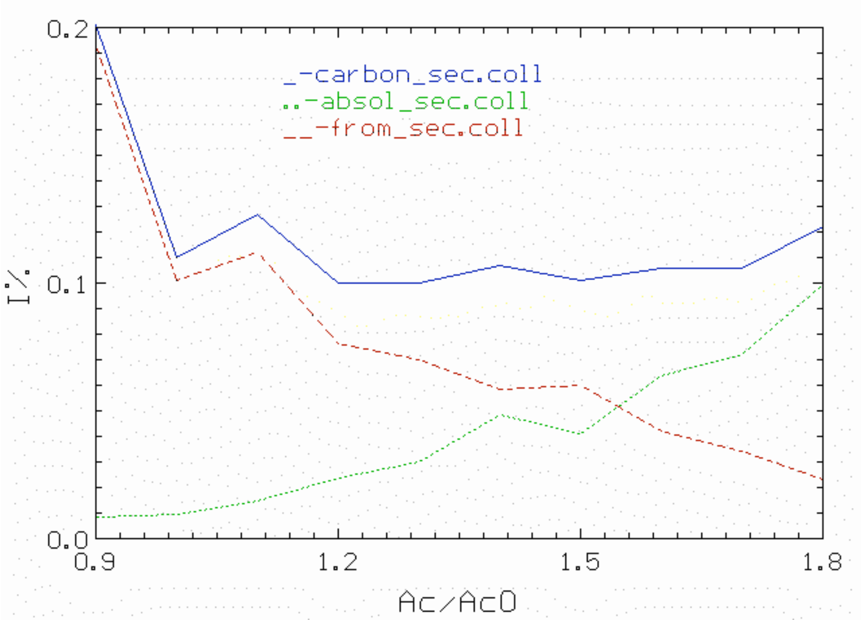
(E=450 GeV)

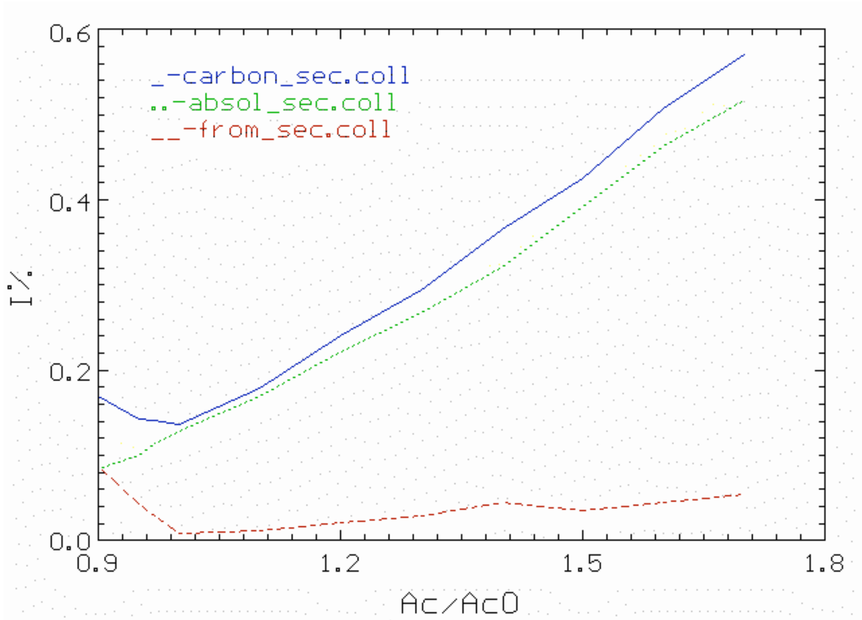


(E=7000 GeV)

- At the small dR < 1 μm, that occur for main real processes of beam cleaning, the inefficiency can be considered practically constant for small amplitude changes.
- For injection energy the losses are mainly due to protons going out from secondary collimators (diffraction and elastic processes) and at maximum energy the biggest part of losses are given by protons going out from primary collimators (diffraction p, green).
- At big dR (0.3-0.8mm) most of the scattered protons at PC go to edge of SC that gives losses.

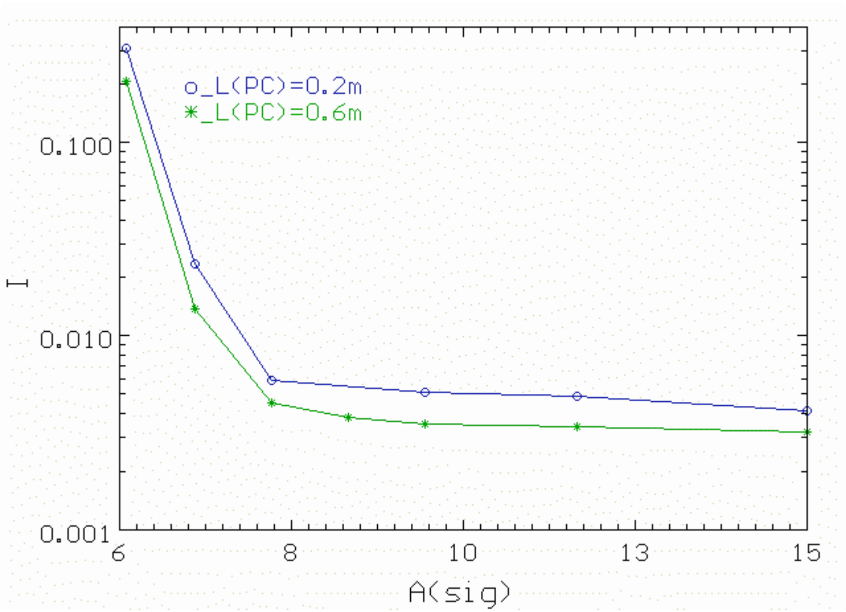
Modeling LHC beam cleaning system

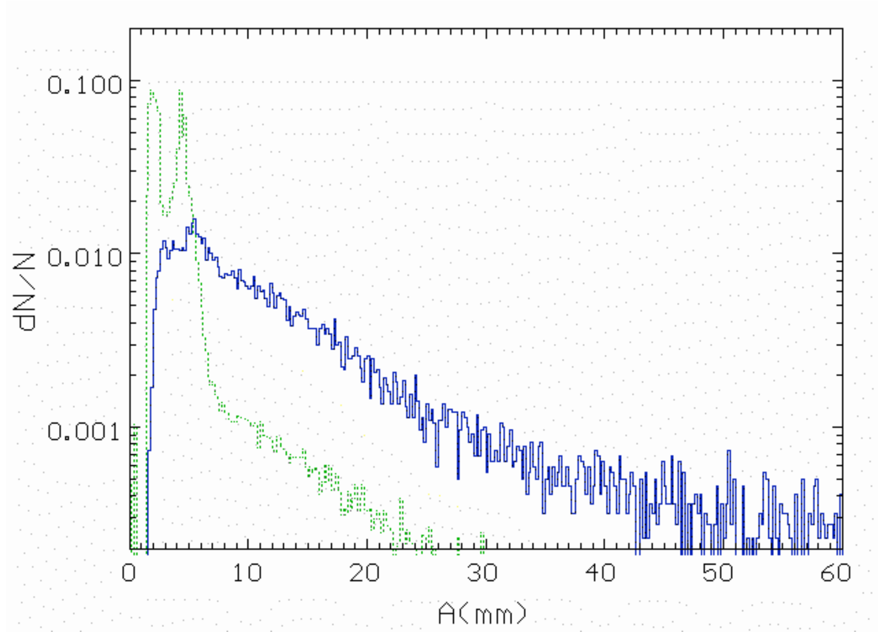




- Inefficiency of the system versus secondary collimator aperture
- 1) E = 450 GeV, 2) E=7TeV.
- CONCLUSIONS
- optimum aperture of secondary collimators $A_c = A_{c0} = 7\sigma$
- minimum inefficiency for E=450GeV, 7 TeV: $I_{out} = 0.10, 0.14\%$

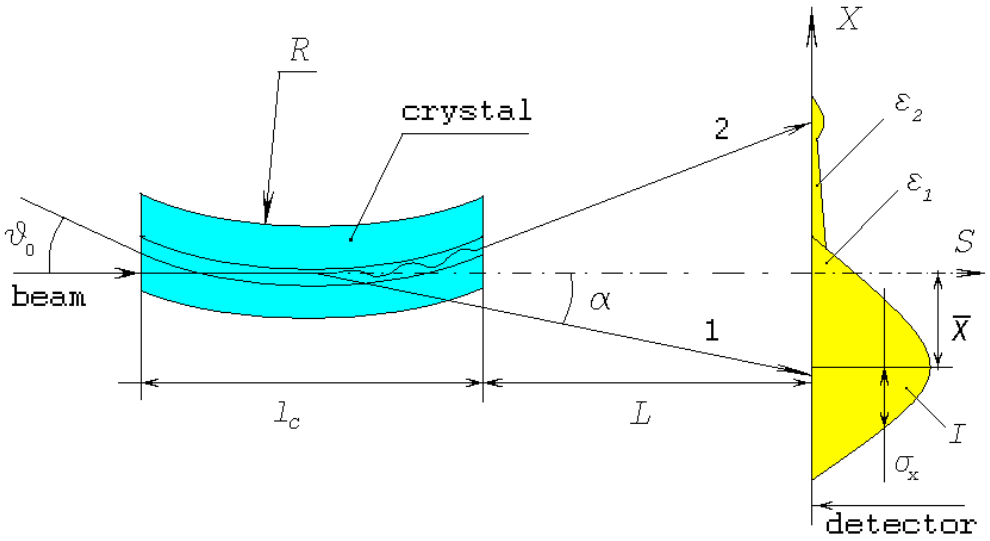
Inefficiency versus of accelerator aperture





- Consider 2 variants of length the PC (E=7 TeV)
- If aperture greater then 8sigma the inefficiency slowly decreases that explains the wide amplitude distribution of outgoing protons (2nd picture).
- Second variant more prefer.

Investigation of deflection p by crystals

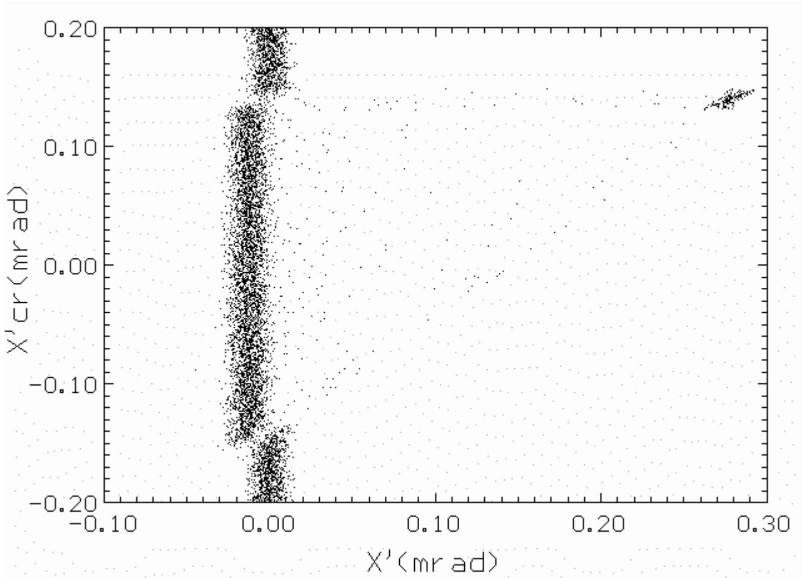


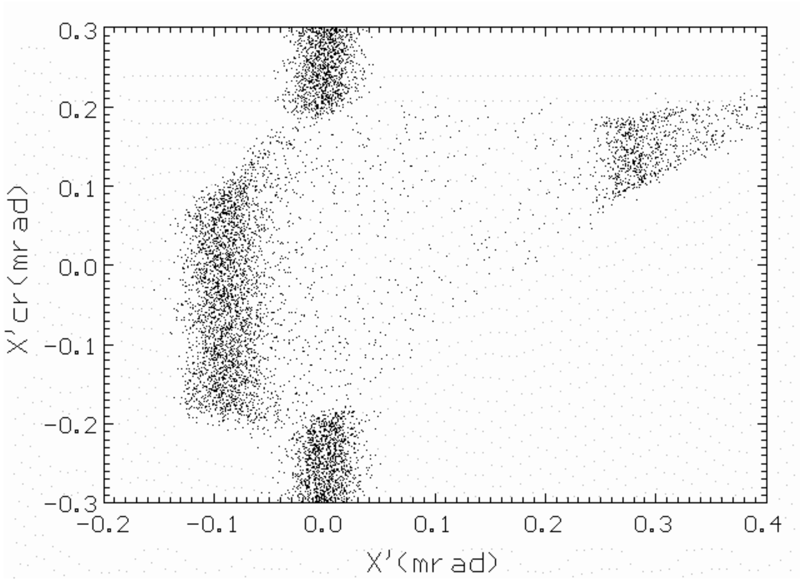
- Three main coherent effects:
- Channeling (2)
- Volume reflection (1)
- Volume capture

Main parameters

1. mean deflection angle – $\overline{\alpha}$,
2. width of the beam angular distribution – σ (rms),
3. beam deflection efficiency – $I = 1 - \varepsilon$

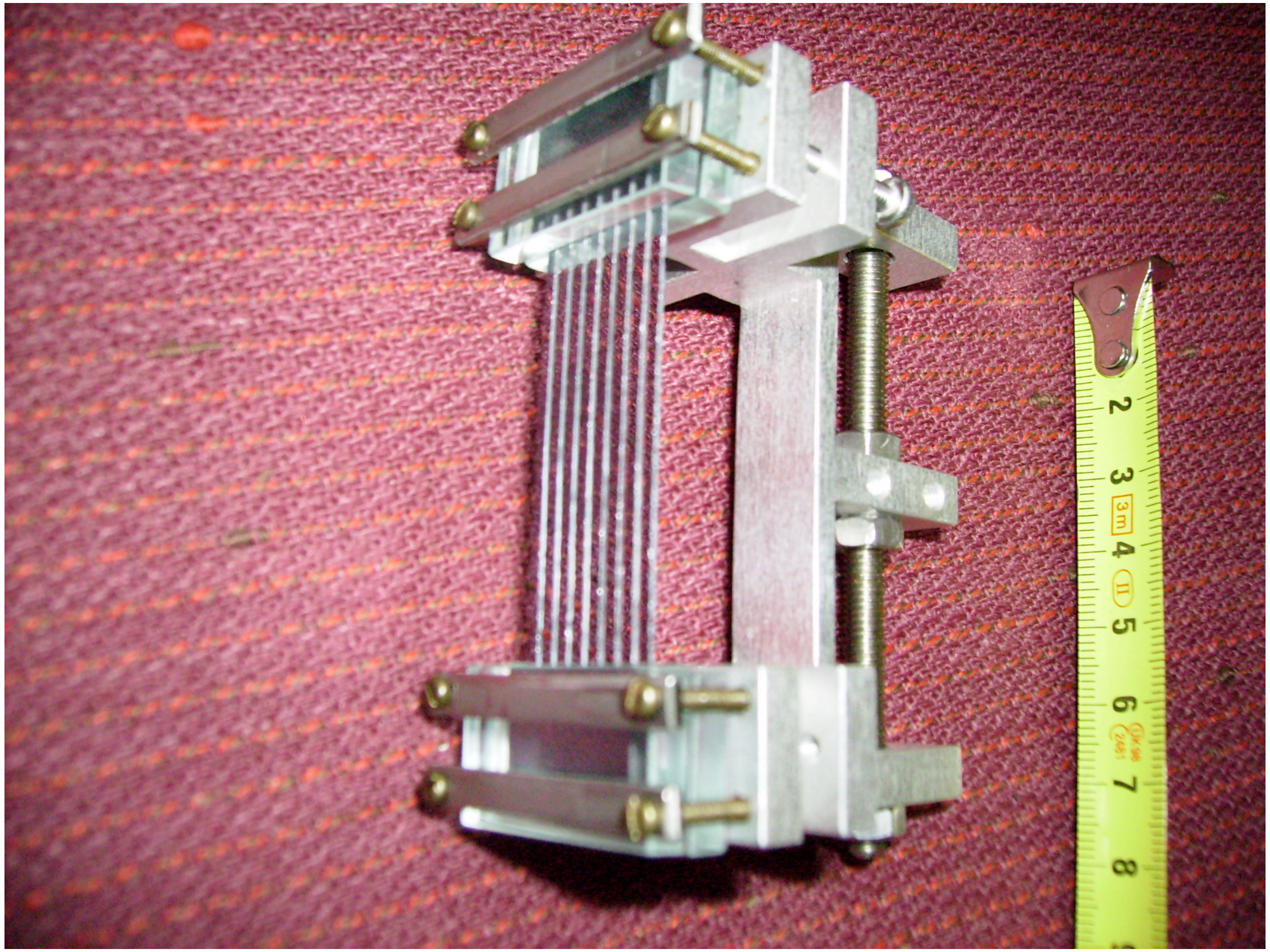
Scattering protons on 1 and multi crystal



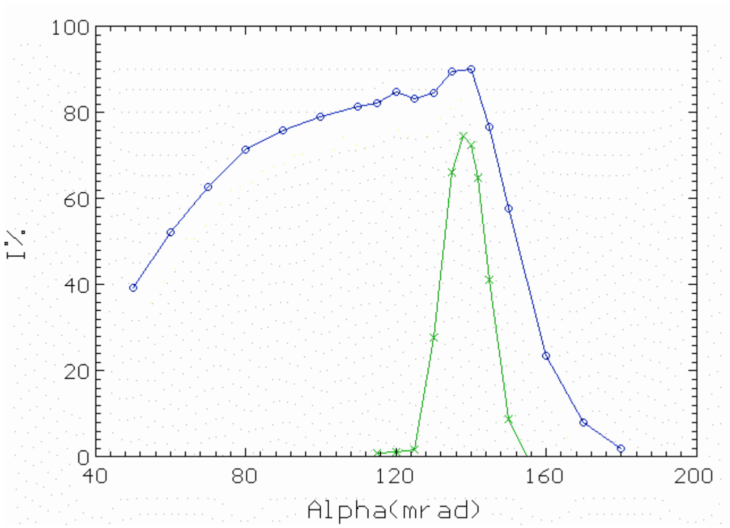


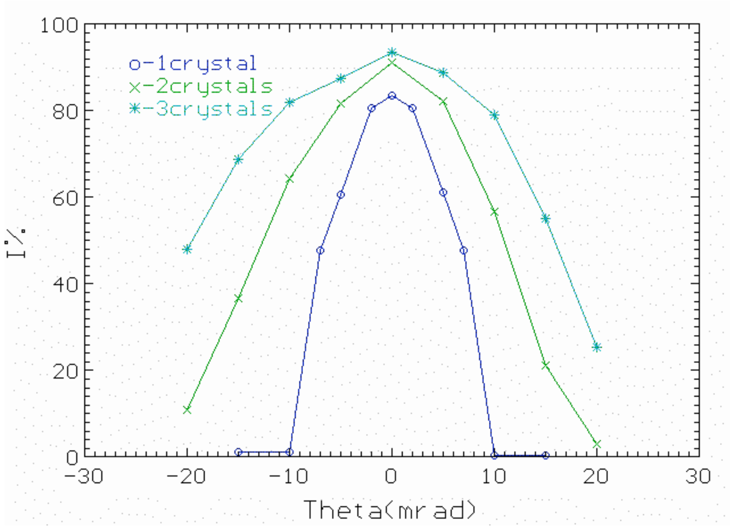
- Fig. : Beam distribution at the plane (X',X'_{cry}) with initial zero angle beam divergence, E=400 ГэВ, for 1 and 8 crystals
- Increasing range of channeling and efficiency
- Mean angle deviation increase at number crystal times $\overline{\alpha} = 8 \cdot \overline{\alpha}_1$
- Some decreasing range of VR
- Two decision: multistrip and quasimosaic (Ivanov Gatchina)

Possible design of multistrip crystal device (Protvino – Ferrara collaboration)



Advantages of multicrystal channeling



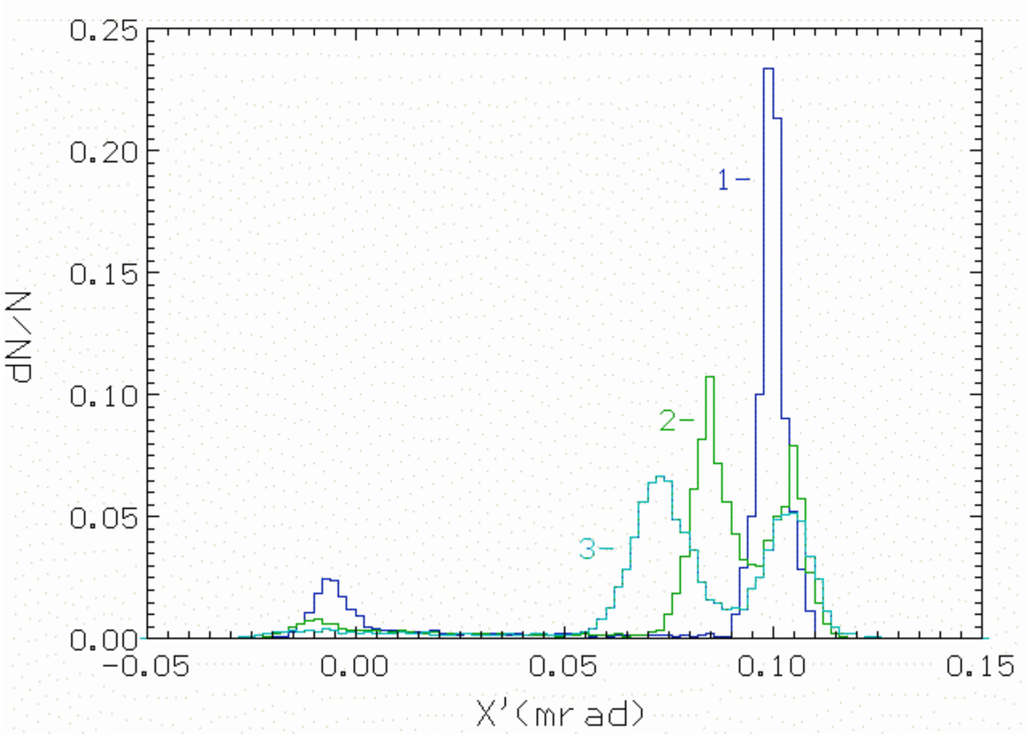


- Efficiency of channeling versus alignment of target for 8 (I=90%) and 1 crystal (I=75%).
- Efficiency of channeling versus alignment of target (E=400 GeV, dRP=-0.005mrad)

lc=1mm, R=10m,

increase range of good efficiency ~ number of crystal

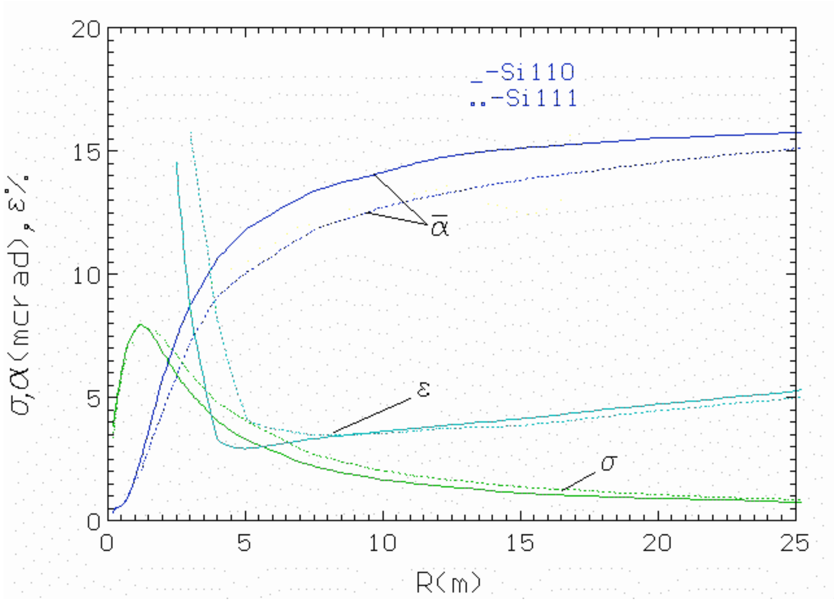
Beam distribution after multicrystal

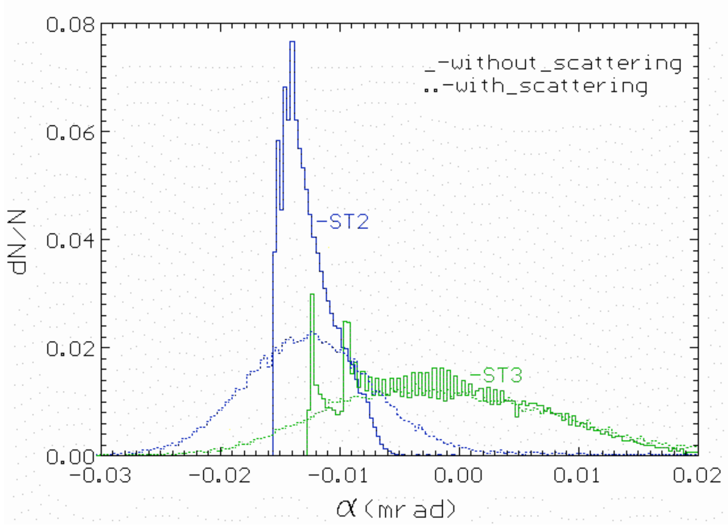


Beam angular distributions after 1,2 and 3 crystals.

- Increase efficiency W(>0.05mrad)=83, 91, 94%
- Decrease number crossing p throw crystal -> heating target down.
- Increase output radial angular beam size:
- May good for decrease of heating of collimator (dump).

Investigation parameters of beam volume reflection by crystal

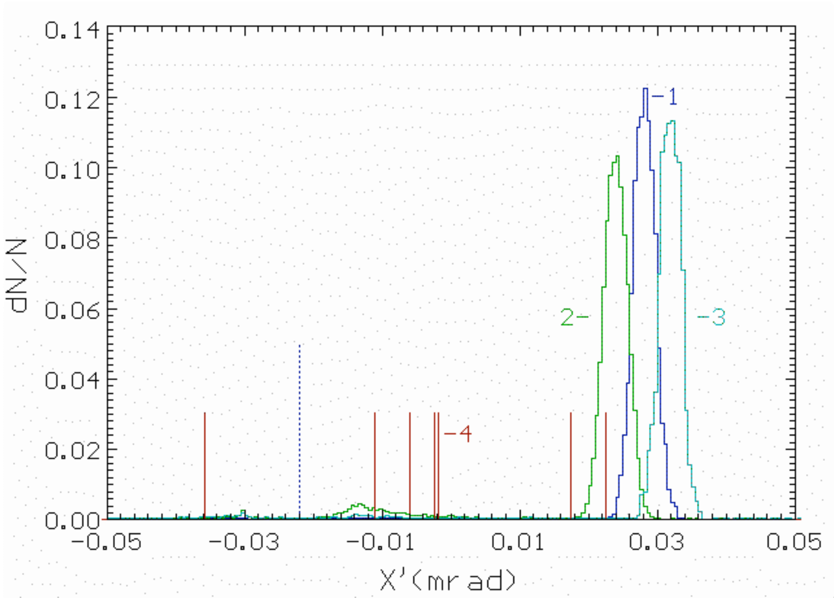




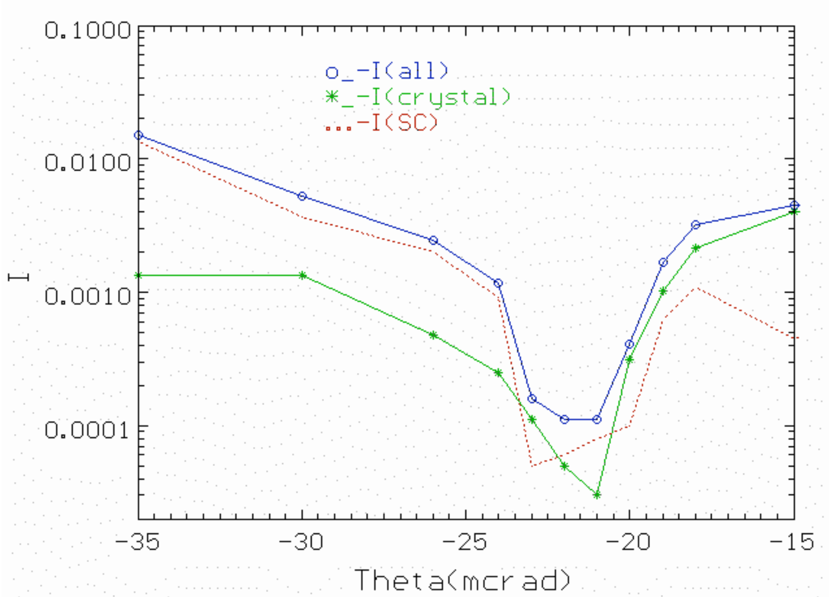
- Fig. 1. Dependences of average reflection angle (blue line) and rms scattering (green line) versus crystal bending radius in Si(110), E=400 GeV.
- Fig. 2:Angular distribution narrow beam after interaction with crystals (ST2,ST3 R=1, 9.25 m).

- Crystal has added potential scattering on the nuclear planes than amorphous.
- Two variants of using crystals
- 1) Small curve radius $R_c \leq R_{cr}$ - big rms scattering
- 2) Big curve radius $R_c > 3R_{cr}$ - big average refection ! Optimal for LHC

Using channeling effect at LHC



1



2

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

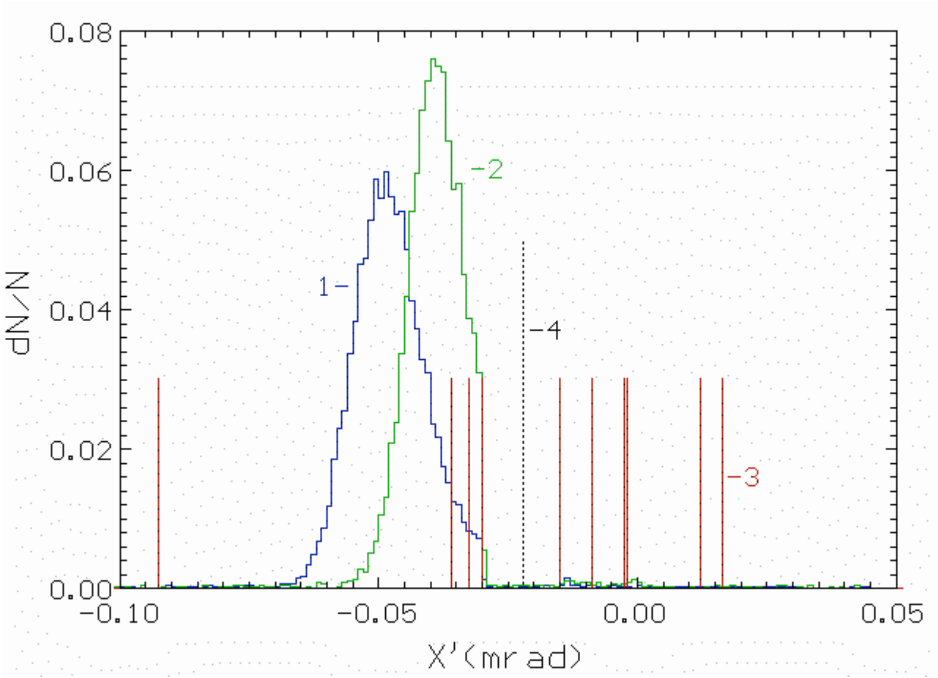
Bend angle of crystal must be ~0.05 mrad.

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

- Increase efficiency of system in ~15 times
- Range of good efficiency 20.5-24 mcrad

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

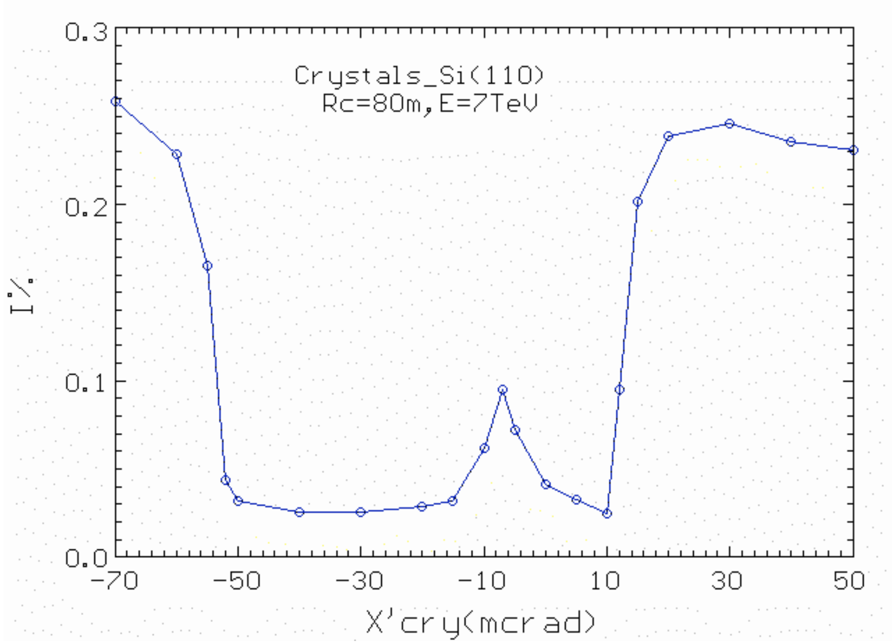
Using VR effect



- Angular beam distribution with crystalline target (E = 7 TeV, V=1mcm/turn)
- 1-15 crystals, 2 - 10 crystals, 3-images of coll. edges, 4 – zero point.
- For decreasing losses was changed gaps 2 collimators

That have images more left then minimum left collimator.

Inefficiency versus angular alignment of crystalline target



- Increasing efficiency of system achieved 10 times with multicrystal.
- We can see two region of good efficiency: multi VR and channeling
- Size of VR ΔX'=35 mcrad, for multi channeling Δ X'=10 mcrad
- Losses at target defined $I_c \approx 1 - \exp(-\overline{n} l_t / L_n)$ l=48mm(12crystals)
- For good efficiency I_{cry}= 0.11, n = 1.1
- Bad efficiency (analog amorphous Si target) I_{cry}= 0.72, n = 11.7
  Mean number of crossings defined heating the crystal!

Heating crystal at localization process

- There are possible three modes of heating

1. Instantaneous (lower heating border) $\Delta T_1 = \frac{dE}{dz}\frac{1}{\rho C_p}\cdot\frac{\overline{N}\Delta I}{S}$
2. Stationary (upper heating border)
3. Dynamic (intermediate heating)

- Energy deposition in crystal $\Delta E \approx dE/dz \cdot I_c \cdot l_c$

$I_c = \Delta I \cdot \overline{N}$ - number protons hit the crystal

dE/dz – beam stopping energy, N – average passing of p through the crystal.

	C	Si
1 I_{max}	10^{13}	$4\cdot 10^{12}$
2 $I_{max/t}$	$15\cdot 10^{14}$	$4\cdot 10^{14}$

CONCLUSIONS

- Using crystals has advantages for beam cleaning system :

1. Efficiency increase in ~10-20 times at E = 400-7000GeV
2. Limit for instantaneous intensity ~ 1.5% of full in LHC. For stationary case there are not limit. With use carbon crystal limit increase in 10 times.
3. For using VR effect it is simple adaptation and construction of target (practically is not depended on alignment, surface, purity)