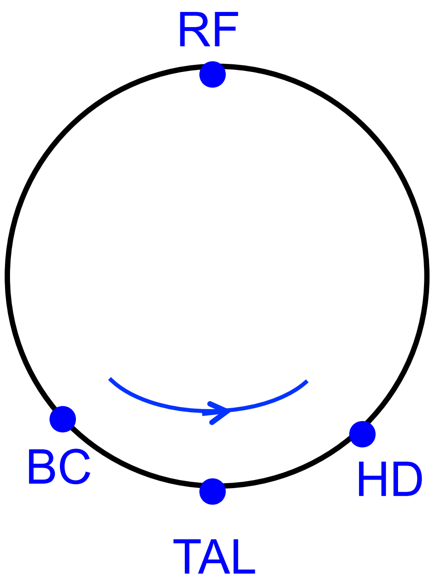
Simulation of the SPS beam collimation



Four points along the ring were considered:

BC - crystal

TAL – absorber

HD – high dispersion area

RF – accelerating system voltage

Particle coordinates – (x, x′, y, y′, l, δ)

Four linear 6-D transfer matrices M(6,6) were used
to transport particles between

BC → TAL
TAL → HD
HD → RF
RF → BC

SPS azimuths characterization

Start point → BC azimuth

Halo generation

Halo particles begin hit BC after some turn numbers

Due to increase of particle oscillation amplitudes

Final points → (1) absorption in TAL

(2) Inelastic interactions in BC

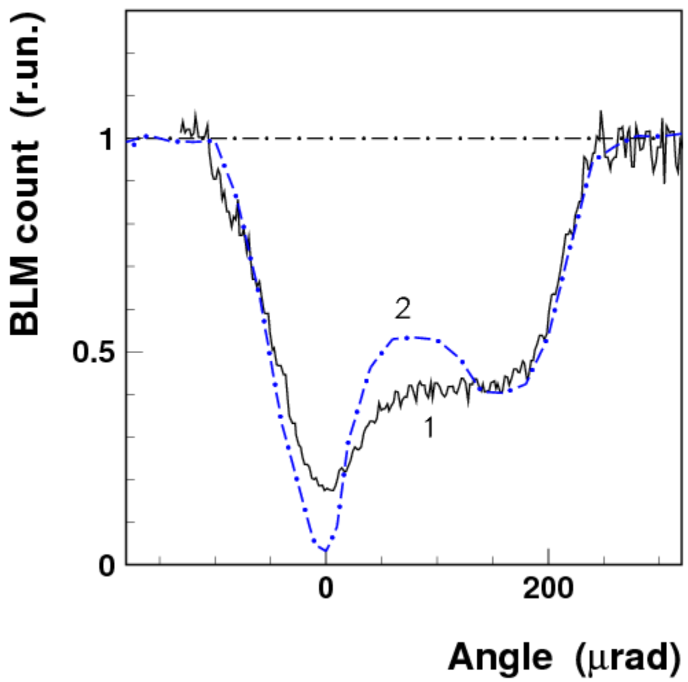
HD azimuth → off-momentum halo registration

RF azimuth → change of particle momentum due to RF voltage V

$$\delta = \delta + \frac{eV}{E_0}\sin(\pi + 2\pi h\frac{l}{C})$$

Beam losses in crystal : experiment ↔ simulation

Observation object → loss dependence on crystal orientation



Good agreement in the dependence character and angular width

Disagreement in loss reduction value R for channeling

Experiment → R≈6
Simulation → R≈30

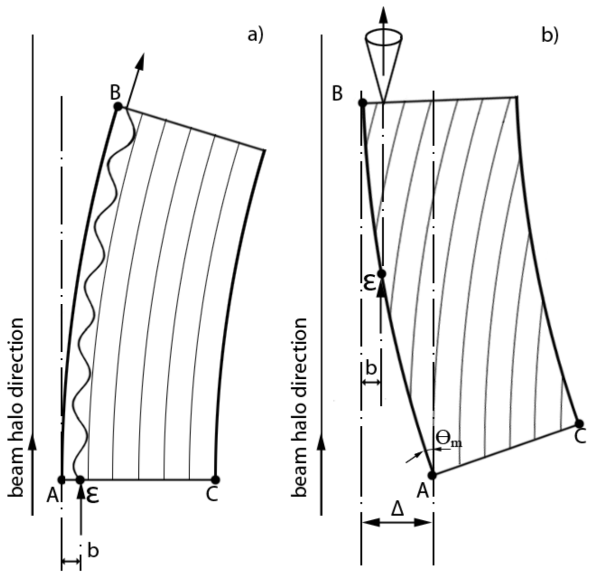
One of possible reasons of this disagreement → crystal miscut

Crystal with miscut

Miscut angle θ_m is between the crystal plane and its surface

When crystal plane direction at its entrance is
parallel to the beam envelope direction

Some particles enter BC through its side face in first hits



This fraction is determined by
the prominent part value Δ
and impact parameters of particles

They pass the crystal as amorphous
substance and some part of them will
be lost due to inelastic interactions

These losses are additional
therefore the total losses for the aligned crystal with miscut will be larger

To estimate the beam losses in the aligned crystal with miscut

Impact parameters of halo particles should be studied

With taking into account

Betatron oscillations
Increase of betatron oscillation amplitudes
Synchrotron oscillations

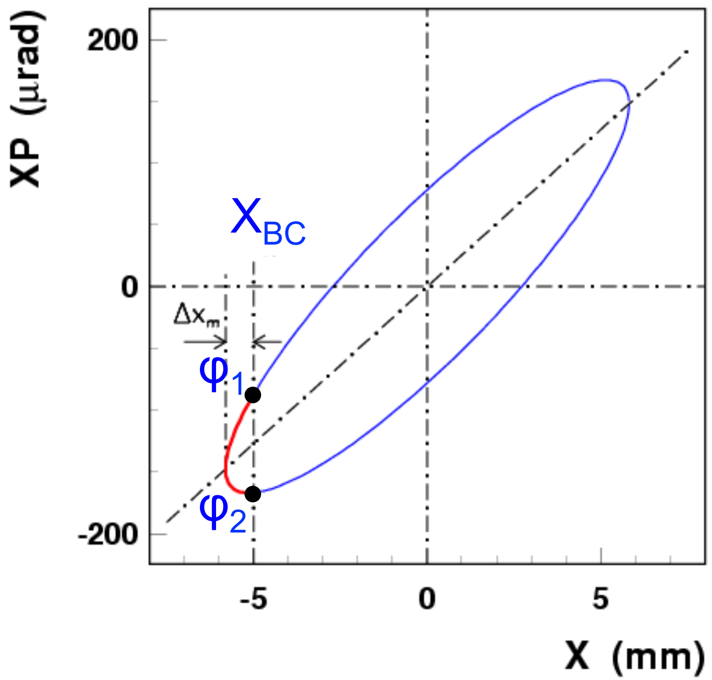
and

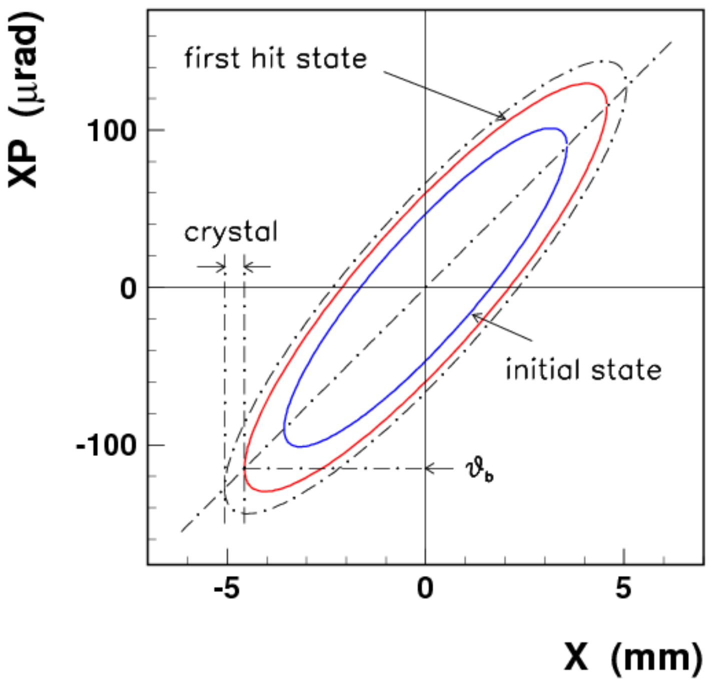
Model of crystal with miscut should be developed

Using the surface potential of the crystal
near the entrance through its side face

Increase of betatron oscillation amplitude per turn Δx_m

Estimation of halo repopulation time in the experiment
gave the average rate of the oscillation amplitude growth λ=2.2 μm/s
That is per turn λ < 1 nm





Assumption → exponential distribution

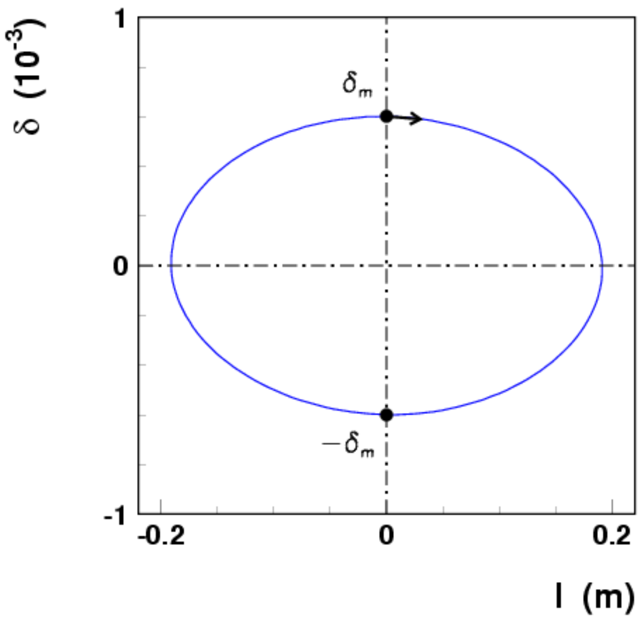
$$P(\Delta x_m)=\exp(-\Delta x_m / \lambda)$$

When a particle touches the crystal?

Gaussian distributions in longitudinal coordinates (l,δ) were considered

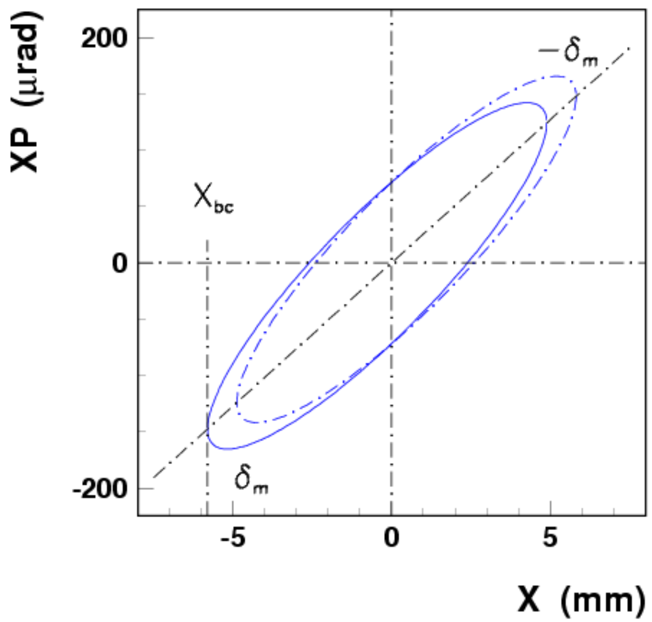
Particles change their momentum due to RF voltage

Trajectory in longitudinal space



→

Horizontal phase ellipse oscillates



Period of longitudinal oscillations is about $T_s=N_s \cdot T_o$ (N_s=150) for $\delta=\sigma$ and orbit shift $X_\varepsilon=D_x\cdot\delta$=0.47 mm >> $N_s\cdot\lambda$ (halo propagation value)

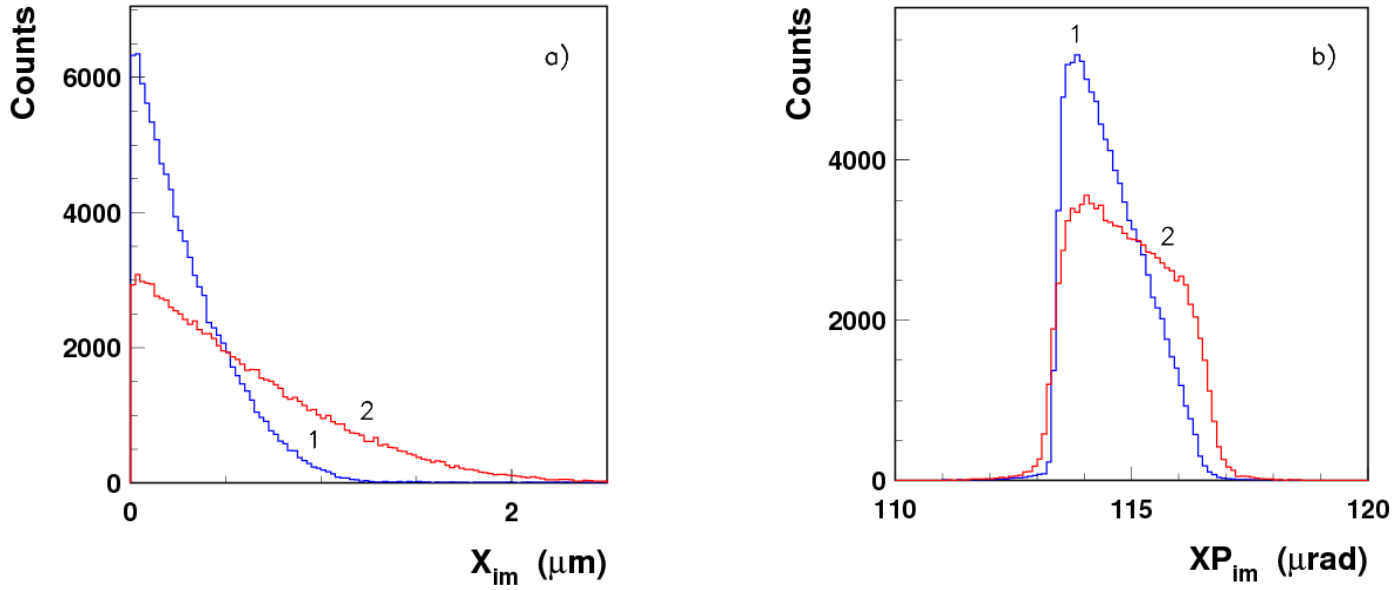
Thus, particles touch BC when their momentum is about its maximum, δ_m

Impact parameters and angles for different λ

To hit BC a particle should have
betatron phase near φ=π and longitudinal position near $(0,\delta_m)$

When particles have already $X_m > X_{BC}$ they will miss the crystal many times

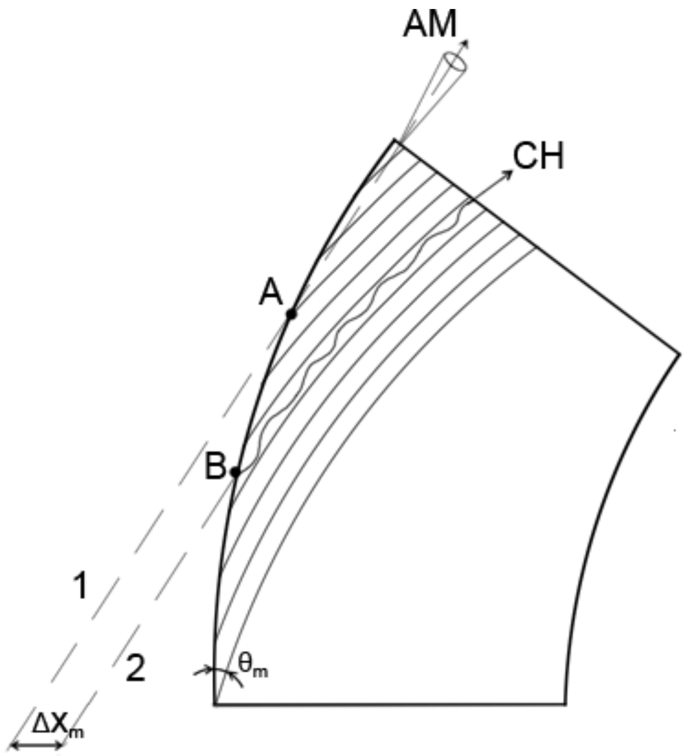
Impact parameters become much larger than λ per turn



Average impact parameter in the experiment b=0.28 μm (1)
The width of impact angle distribution, FWHH=1.9 μrad

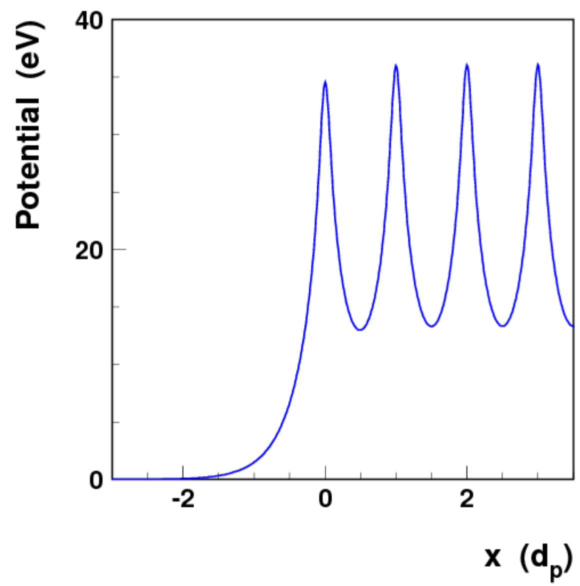
Impact parameters and angles increase with increasing λ

Simulation for crystal with miscut



Conditions for entrance and exit
through the side face
should be correctly taken into account

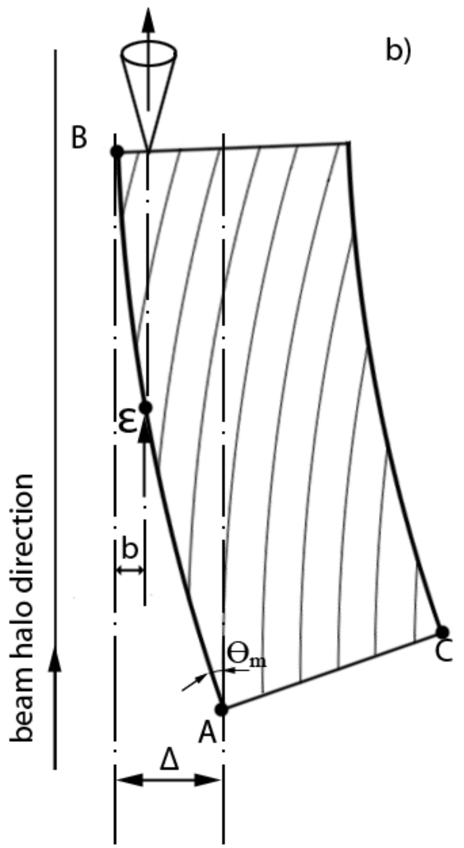
Potential of the crystal surface
was used near the entrance
through the side face



Miscut of the crystal under study

Crystal 4 has miscut angle θ_m=200 μrad

Its length 2 mm and bend angle 176 μrad → R=11.36 m



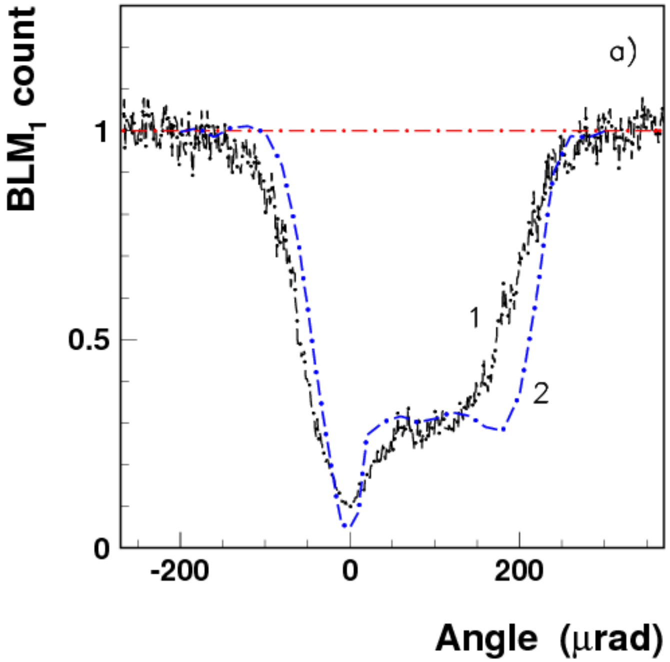
Prominent part of the crystal surface bend
Δ_m=0.23 μm

The average impact parameter
b=0.28 μm

The crystal miscut should visibly affect
beam losses

Loss reduction change for the crystal with miscut

Our simulation results show
the losses of halo particles for the aligned crystal
are really increased by more than 140%



The beam loss reduction in channeling R_{bl}=21
without miscut R_{bl}=50

Whereas, channeling efficiencies are close,
93.2% and 91.4%

The agreement with the experimental value, R_{bl}=10,
becomes much better

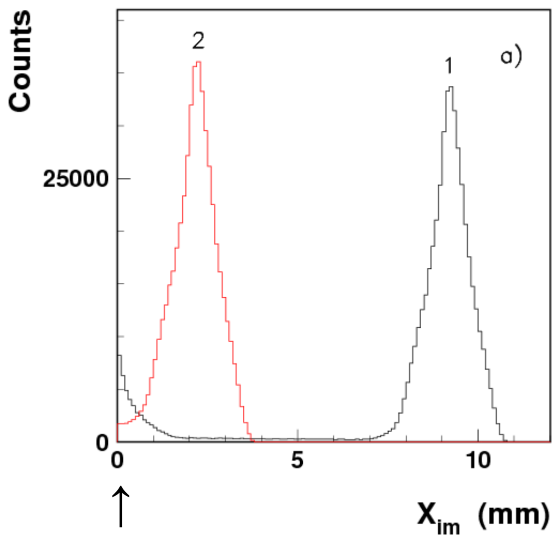
Optimization of gap value between crystal and absorber

Secondary collimator TAL should be far from the orbit, $X_{tal}=X_{cr}+X_{off}$
providing conditions for the multi-turn extraction

Halo particles are absorbed in TAL due to inelastic interactions – N_{tal}
Some halo fraction has inelastic interactions in crystal – N_{cr}

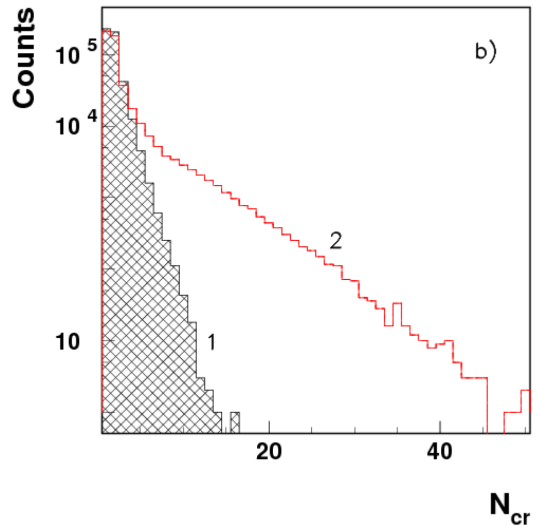
Optimal X_{off} should give a minimal collimation leakage $\Delta=N_{halo}-(N_{cr}+N_{tal})$

Impact parameters with TAL



↑
TAL edge

Number of passages through CR

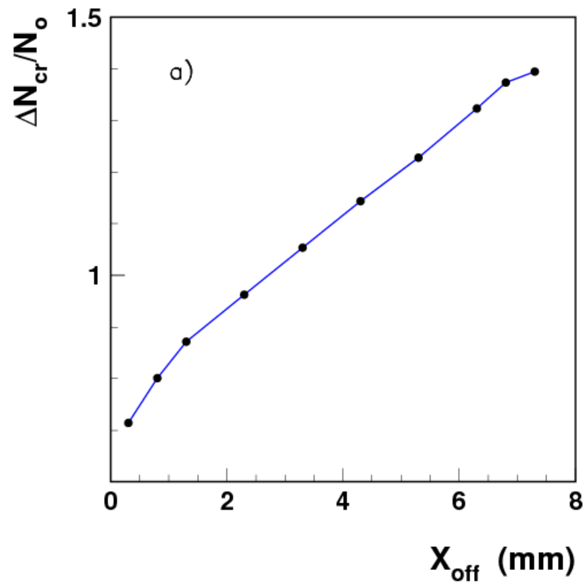


X_{off}
0.3 mm (1)
7.3 mm (2)

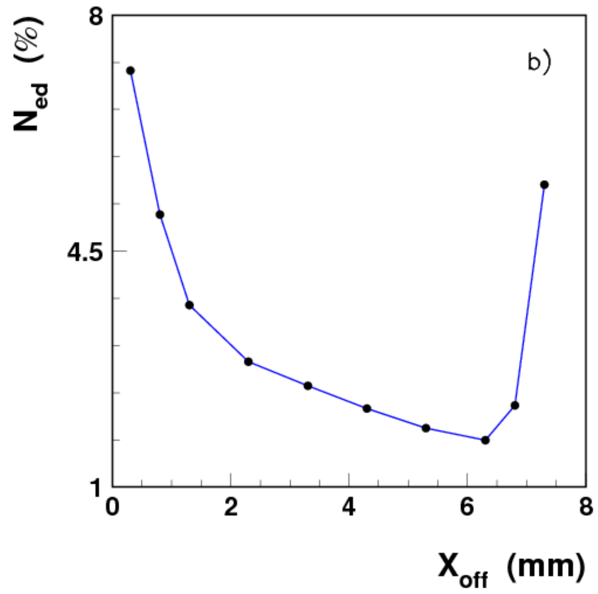
Channeling maximum become closer to the TAL edge
and number of passages through CR increases when X_{off} increases

Dependencies on the gap value between crystal and absorber

Extra passages through CR



TAL edge population (1 mm)



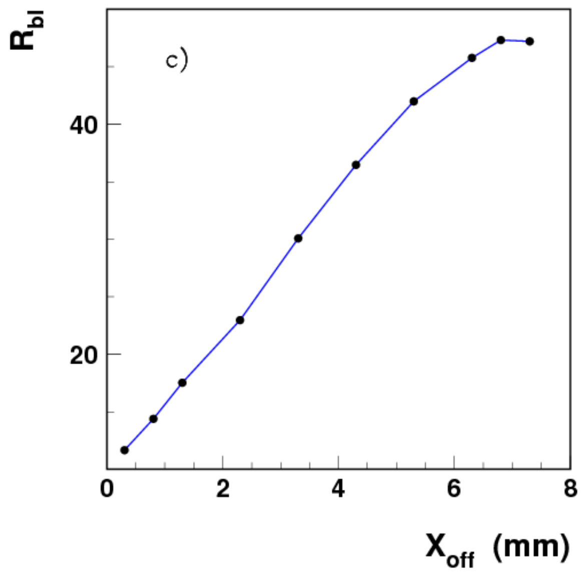
Beam losses in CR (extra passages) increase about twice
for the largest gap value

TAL edge population has minimum where it is 4 times smaller

Dependencies on the gap value between crystal and absorber

Though the beam losses in CR at channeling increase with increasing X_{off}
the losses in AM orientation increase larger
Therefore, the loss reduction increases

Beam loss reduction in CR



The simulation study of the collimation leakage
requires a huge statistics

However, the first experimental results show
that the off-momentum halo population behind the collimation area
becomes smaller with increasing the gap

Conclusion

(1) Miscut really increases beam losses in the aligned crystal
This increase was about 140% in the experiment

(2) Simulation well describes the experiment
Differences of 100% in the loss value
correspond to the difference of the order of 1% in channeling efficiency

(3) Halo propagation rate λ should be measured
to use its correct value in simulations

(4) Optimal gap between crystal and absorber should be found
through the population minimum of the off-momentum halo in HD area