SPS collimation simulation → requirements for crystals

Limitation on the crystal imperfections

1. Amorphous layer

Mechanically disrupted layer can be avoided

Thickness of native Si oxide layer due to contact with air is about 2 nm
Native layer can be also chemically removed before the installation

2. Crystal miscut

Angle between the crystal planes and surface

3. Anticlastic bending

It is parasitic one for QM crystal

4. Crystal torsion

Orientation of crystal planes is changed along vertical direction

Simulation scenario

For particle tracking → (1) liner approach was used for SPS

(2) the only aperture restrictions are in the crystal collimation area

We transport particles along SPS through two azimuths

BC → TAL → BC using two transfer matrices M(6,6)

Start point → BC azimuth

Final points → (1) absorption in TAL

(2) Inelastic interaction in BC

Collimation efficiency losses only due to inelastic nuclear interactions

Initial distribution of halo particles

Normalized betatron amplitude at BC $\rightarrow x_m = x_{bc} + \Delta x_m$

Amplitude increase Δx_m is a random value

$$P(\Delta x_m) = \exp(-\Delta x_m/\lambda),\ \ \lambda = 0.1\ \mu\text{m},\ \ \Delta x_m = -\lambda \cdot \ln(\xi_1)$$

Interval betatron phases of particles hit BC

$$\Delta\varphi = \arccos(1/(1+\Delta x_m/x_{bc}))$$

Random phase from this interval

$$\Phi(\xi_2) = 2\cdot\Delta\varphi(\xi_2 - 0.5)$$

Horizontal coordinates

$$x(\xi_1,\xi_2) = x_m(\xi_1)\cdot\cos(\varphi(\xi_2))$$

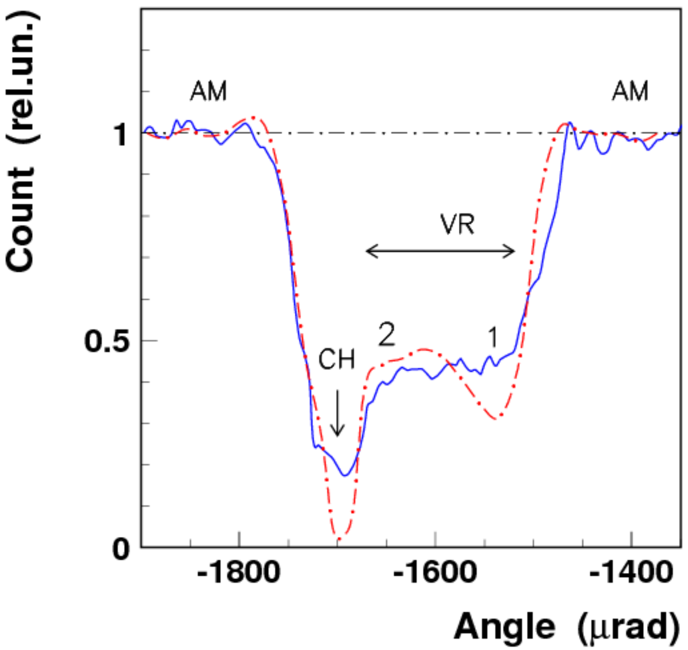
$$x'(\xi_1,\xi_2) = -x_m(\xi_1)/\beta_x\ (\sin(\varphi(\xi_2)) + \alpha\cdot\cos(\varphi(\xi_2)))$$

Distributions of vertical coordinates (y, y´) and momentum deviation $\delta = \Delta p/p_o$

$$P(y) = P(y') = P(\delta) = \delta(0)$$

Results for Strip Crystal 1 in 2009

Straight comparison can be made only for the angular dependence of beam losses in crystal



Alignment positions BC and TAL are about $4\sigma_x$

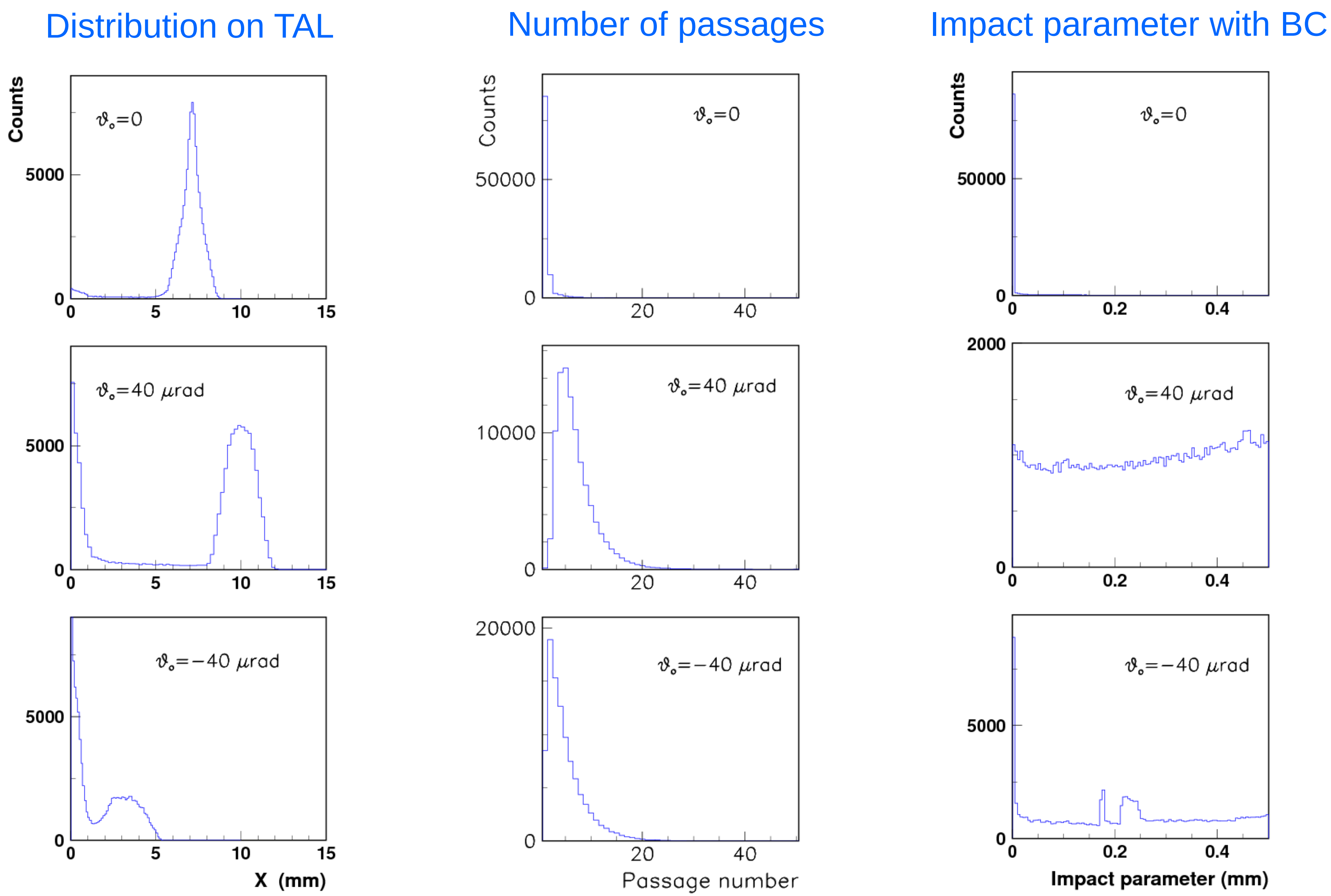
Collimation positions
BC → - 0.5 mm, TAL → +1.5 mm

Loss reduction in channeling experiment → 5, simulation → 36

Discrepancy reason → Strip crystal has a large torsion + goniometer inaccuracy

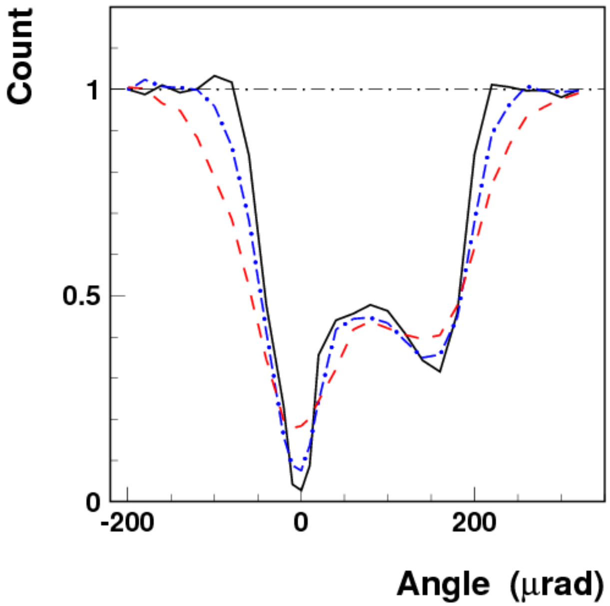
Results for Strip Crystal 1 in 2009

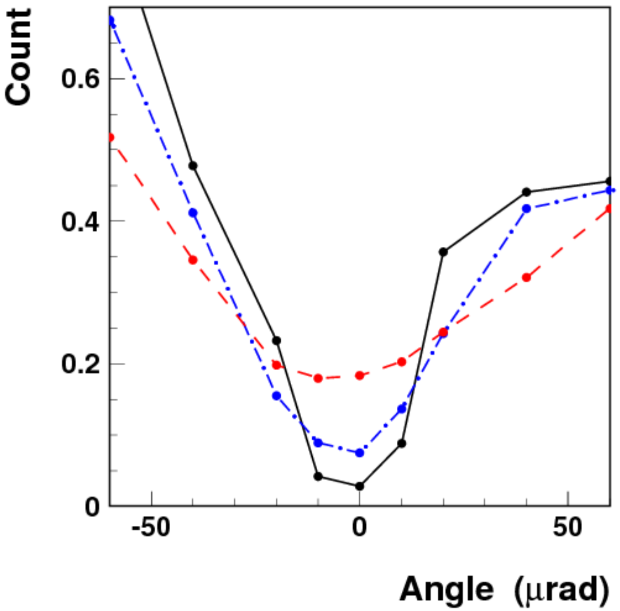
Different shift, width and efficiency of deflected beam were caused by different orientations of the crystal



Simulation for Strip Crystal 1 with torsion

Torsion values → 20 μrad/mm (1) and 40 μrad/mm (2)
Critical angle → θ_c=19.5 μrad





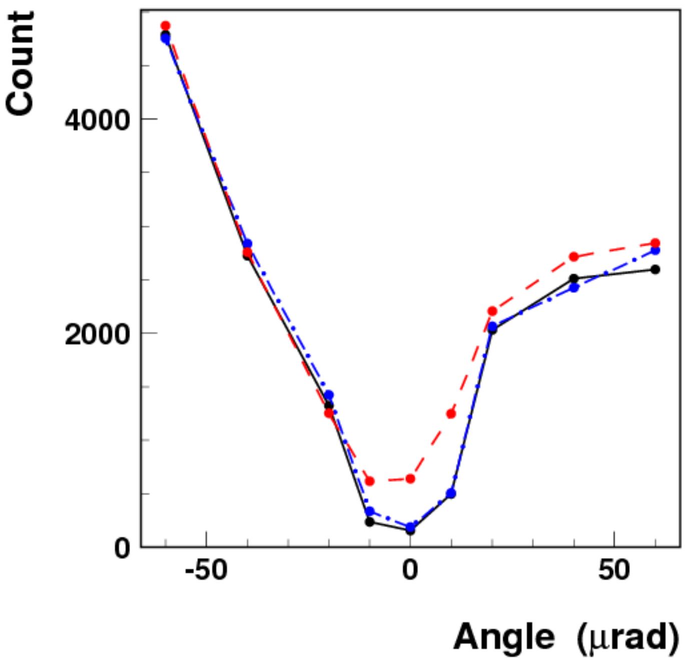
Particle losses at θ_o=0 are increased by 2.7 for torsion 1 and by 6.6 for torsion2

Torsion for Strip Crystal 1 can be about 20 μrad/mm + goniometer inaccuracy → larger than 20 μrad

Simulation for Strip Crystal 1 with amorphous layer

(1) Native amorphous layer thickness – 2 nm, λ=0.5 nm

(2) Amorphous layer thickness – 1 µm, λ=0.1 µm



Loss increase at θ_o=10 µrad
(1) 41% , (2) 158%

Loss increase at θ_o=0
(1) 16% , (2) 300%

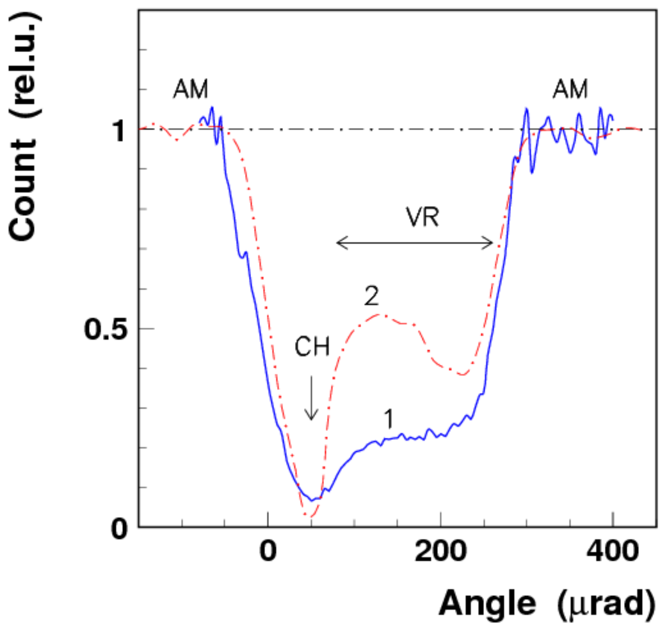
Loss increase at θ_o=-10 µrad
(1) 1.8% , (2) 150%

First passage is unsuccessful
Difference in the crystal length passed in the cases (1) and (2)

Loss value for the ideal crystal at θ_o=0 → 2.8% of amorphous
0.16% of all beam halo

Results for QM Crystal 3 in 2010

Data of the run in September 1-2



Distances from the orbit for BC and TAL were about two times larger

Offset between BC and TAL was about 1.55 mm

Loss reduction in channeling experiment → 16-20, simulation → 33

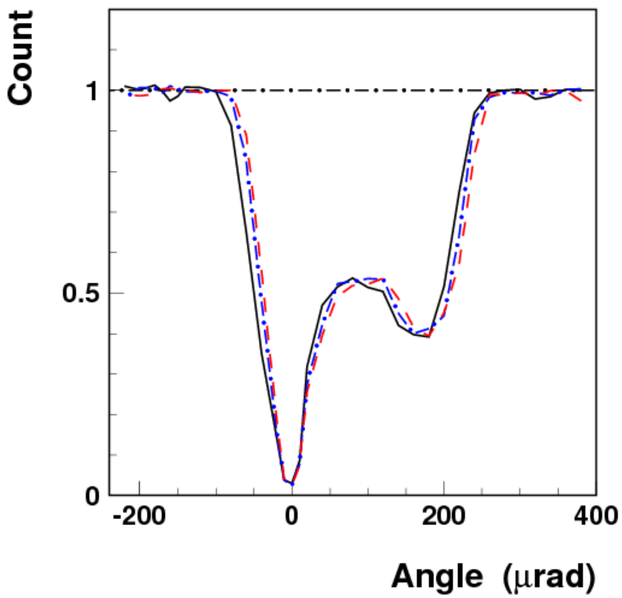
Discrepancy at θ_o=0 was decreased
New IHEP goniometer has smaller inaccuracy → 10 μrad
+ good QM crystal

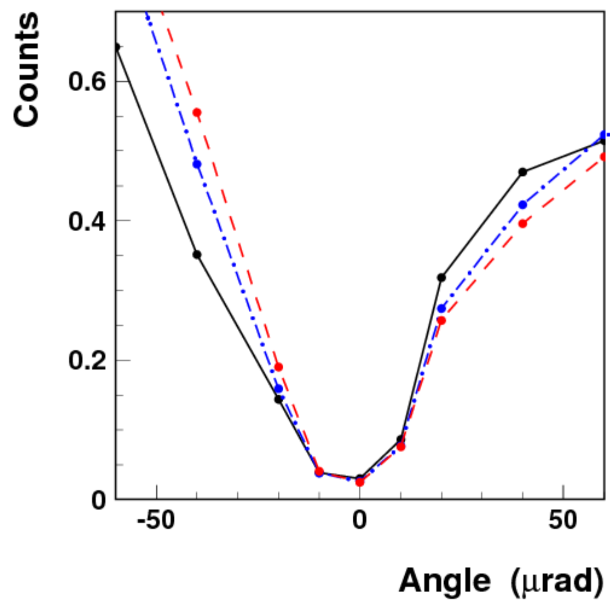
However, discrepancy with experiment is observed in VR area

Simulation for QM Crystal 3 with anticlastic bending

Anticlastic curvature → 25.6 μrad/mm (1) and 43 μrad/mm (2)
Critical angle → θ_c=19.5 μrad

(1) is corresponded to the change rate of the beam envelop direction → $-\alpha/\beta$



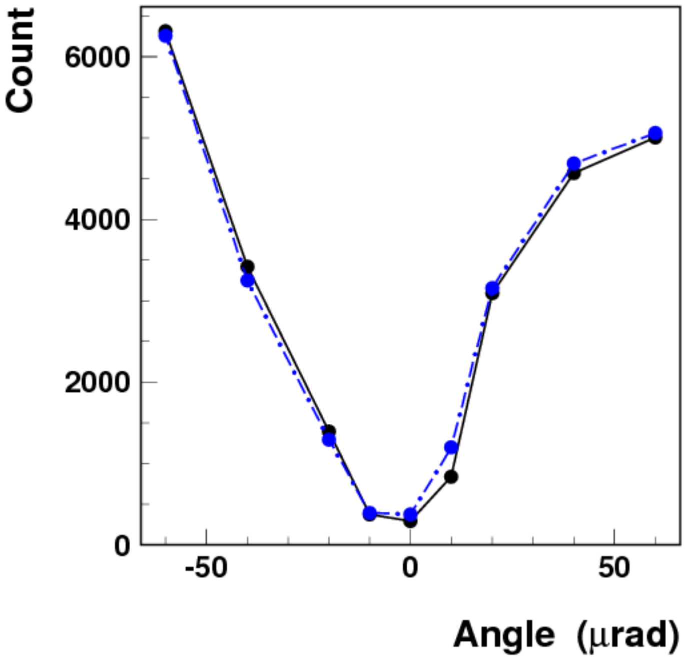


Anticlastic reduces the losses for negative angles and increases for positive ones near θ_o=0   10 μrad the losses are about the same

Loss increase at θ_o=0 → (1) -14% , (2) -17%

Simulation for QM Crystal 3 with miscut

Miscut angle for QM crystal 3 → θ_m=92 μrad



Loss increase at θ_o=10 μrad
5.6%

Loss increase at θ_o=0
29%

Loss increase at θ_o=-10 μrad
44%

Loss value for the ideal crystal at θ_o=0 → 3% of amorphous
0.3% of all beam halo