Channeling 2016
Desenzano del Garda, September 27, 2016

Observation of independence of the nuclear de-channeling length on the particle charge sign

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Motivations

Manipulation of particle beams is a hot topic in accelerator physics

Channeling efficieny is strictly correlated to the dechanneling length.

Study of dechanneling helps design suitable crystals for high performance channeling deflection.

We undertook research plan aimed to a comparative study of dechanneling length for positive and negative particles

Channeling & Dechanneling

Channeling: particle transverse energy remains lower than the potential well depth

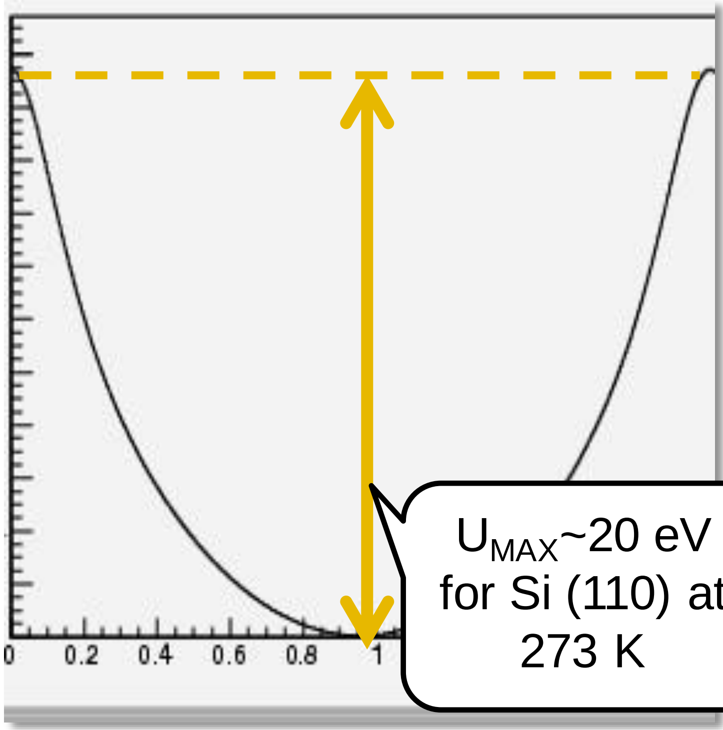
Dechanneling: particle transverse energy grows up and exceed potential well depth

θ = Incoming angle

x =Impact point

Straight crystal

$$E_{\mathrm{T}} = \frac{pv}{2}\theta^2 + U(x)$$



U_{MAX}~20 eV for Si (110) at 273 K

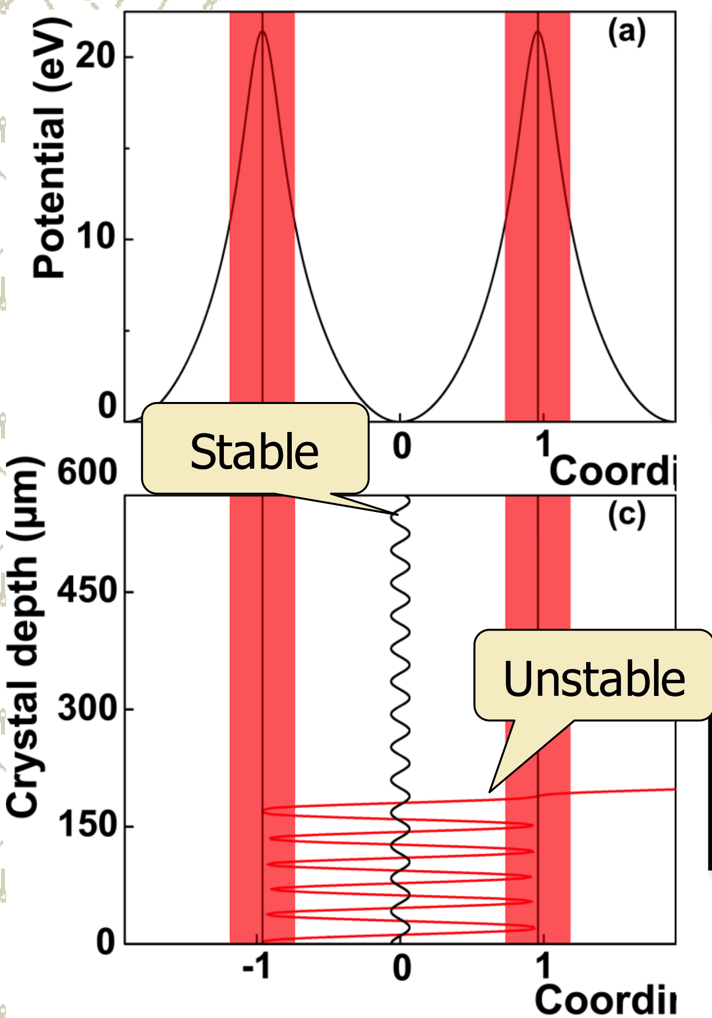
Bent crystal

$$E_{\mathrm{T}} = \frac{pv}{2}\theta^2 + U_{\mathrm{eff}}(x) \ .$$

$$U_{\mathrm{eff}}(x) = U(x) + \frac{pv}{R}x$$

Centrifugal term in the particle reference frame

Dechanneling of positive particles



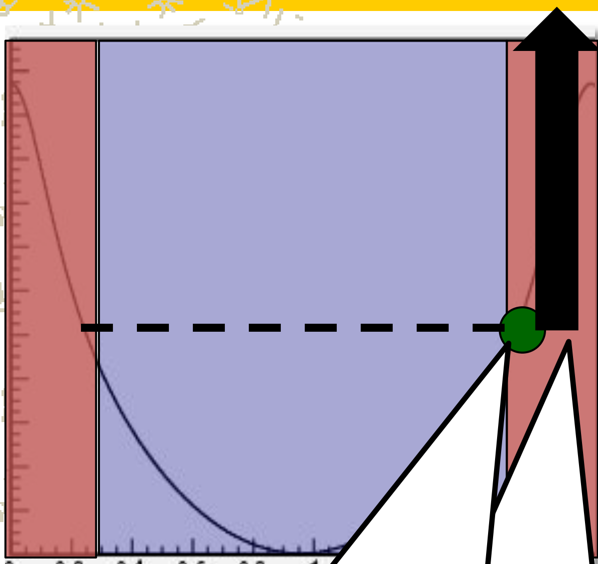
Two mechanisms of dechanneling for positive particles:

- Electronic dechanneling
- Nuclear dechanneling

Exponential approximation for the dechanneling processes:

$$N_{ch}(z) \approx N_u e^{-z/L_n} + N_s e^{-z/L_e}$$

Nuclear dechanneling



Unstable channeling state

Particles impinging close to the atomic planes are are dechanneled by interaction with nuclei traversing a short distance in the crystal.

Nuclear corridor

3 times the thermal vibration amplitude

Positive particle

Transverse energy increase

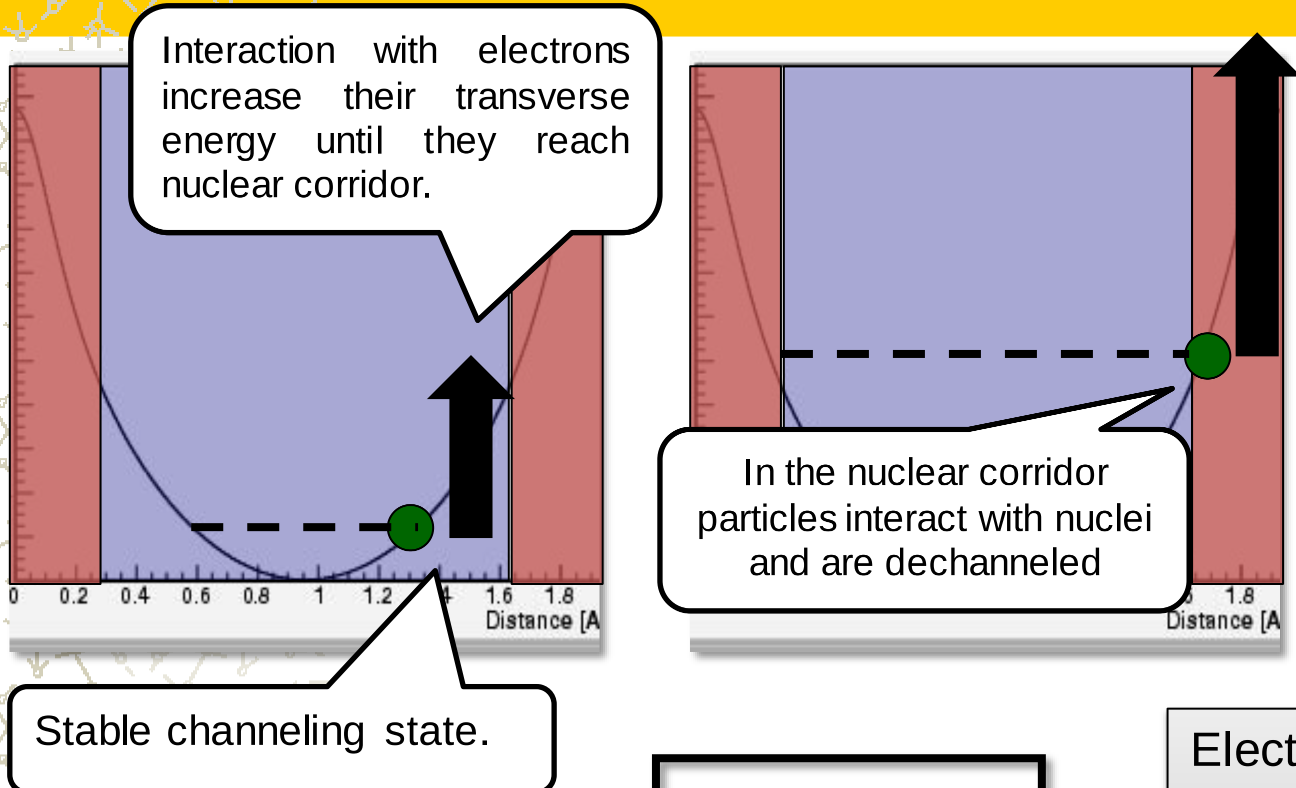
$$N_u e^{-z/L_n}$$

Nuclear dechanneling length for a proton channeled in the Si (110) at 273 K [1] is

$$L_n^+ = 1.5\ \text{mm}$$

[1] W. Scandale, et al., Physics Letters B 680, 129 (2009).

Electronic dechanneling



Nuclear corridor

Positive particle

Transverse energy increase

$$N_s e^{-z/L_e}$$

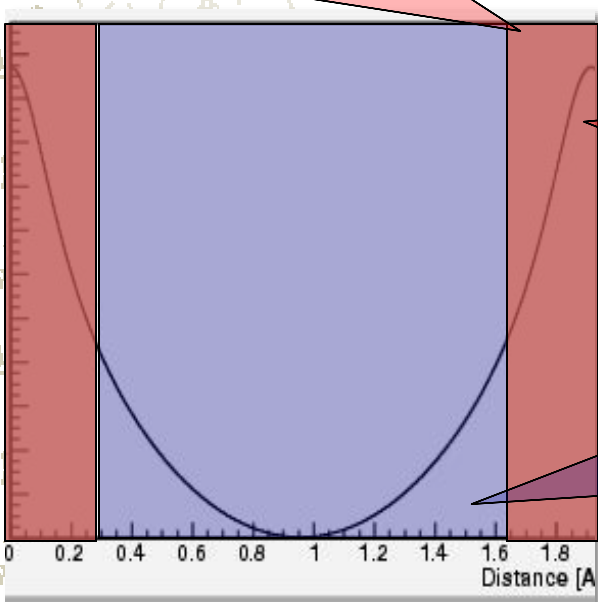
Electronic dechanneling length for a proton channeled in the Si (110) at 273 K [1] is

$$L_e^+ = 220 \text{ mm}$$

[1] V. Biryukov, Y. Chesnekov, and V. Kotov, Crystal Channeling and Its Applications at High-Energy Accelerators (Springer, 1996).

Channeling efficiency

Oscillation amplitude of atomic planes due to thermal vibration = 0.075 A for Si (110) at 273 K



Particle in unstable channeling state ~ 0.23

Particles in stable channeling state ~ 0.77

Maximum predicted channeling efficiency protons channeled in the Si (110) at 273 K [1] was

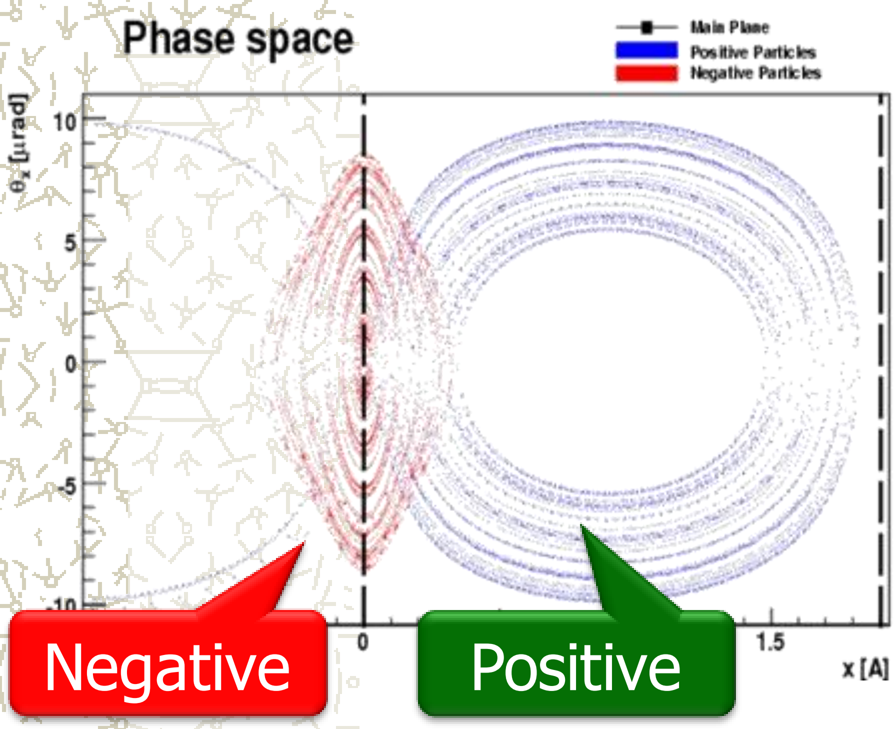
77 %

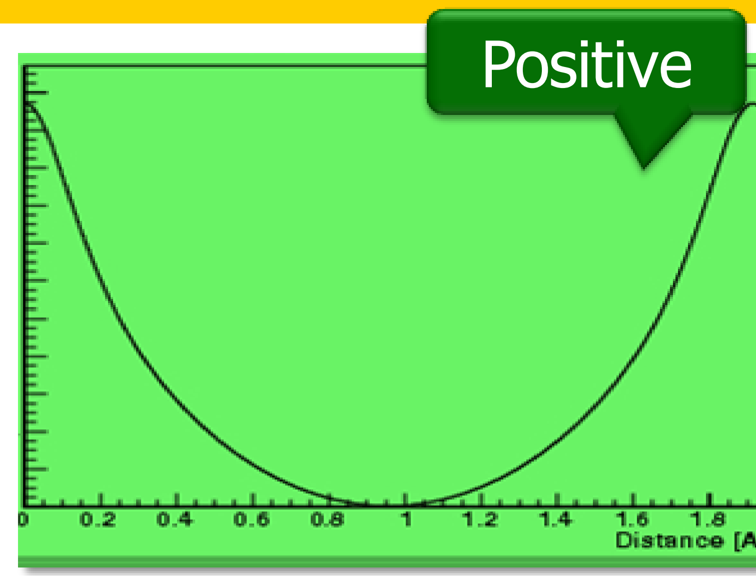
Using crystal shorter than the nuclear dechanneling length it was possible to reach [2]

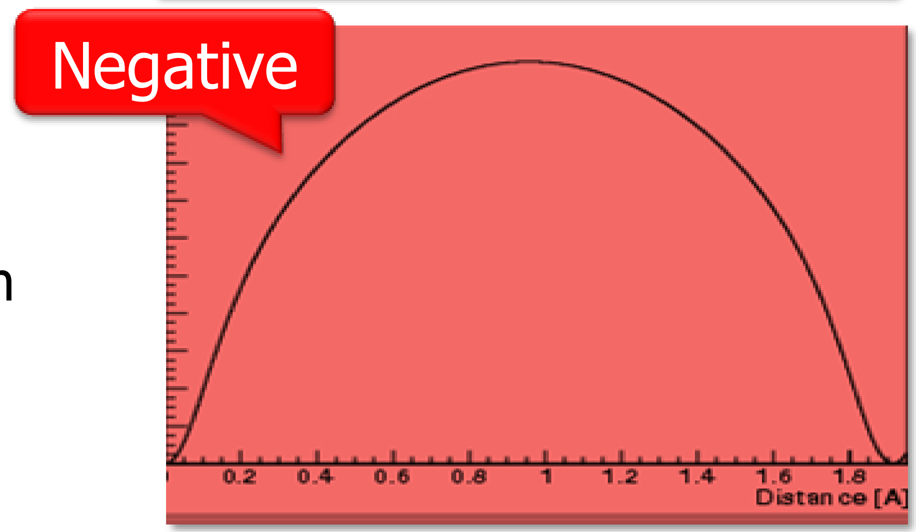
81 %

[1] V. Biryukov, Y. Chesnekov, and V. Kotov, Crystal Channeling and Its Applications at High-Energy Accelerators (Springer, 1996).
[2] W. Scandale, et al., Physics Letters B 680, 129 (2009).

Positive vs negative particles

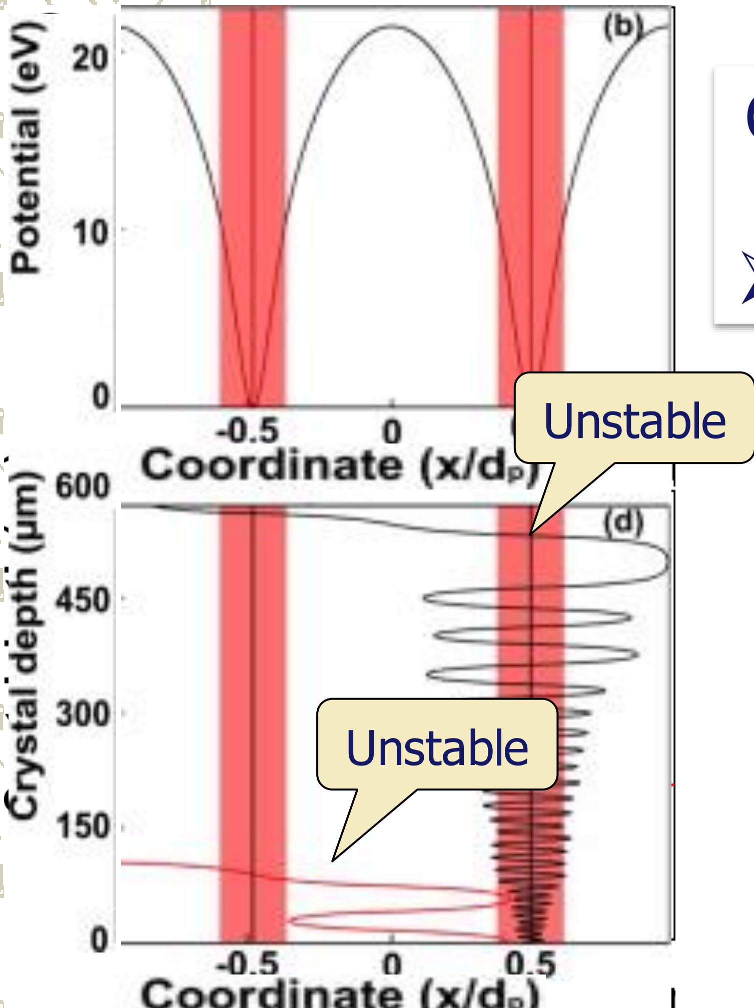






Positive particles oscillate between atomic planes; negative particles repeatedly cross them.

Dechanneling of negative particles



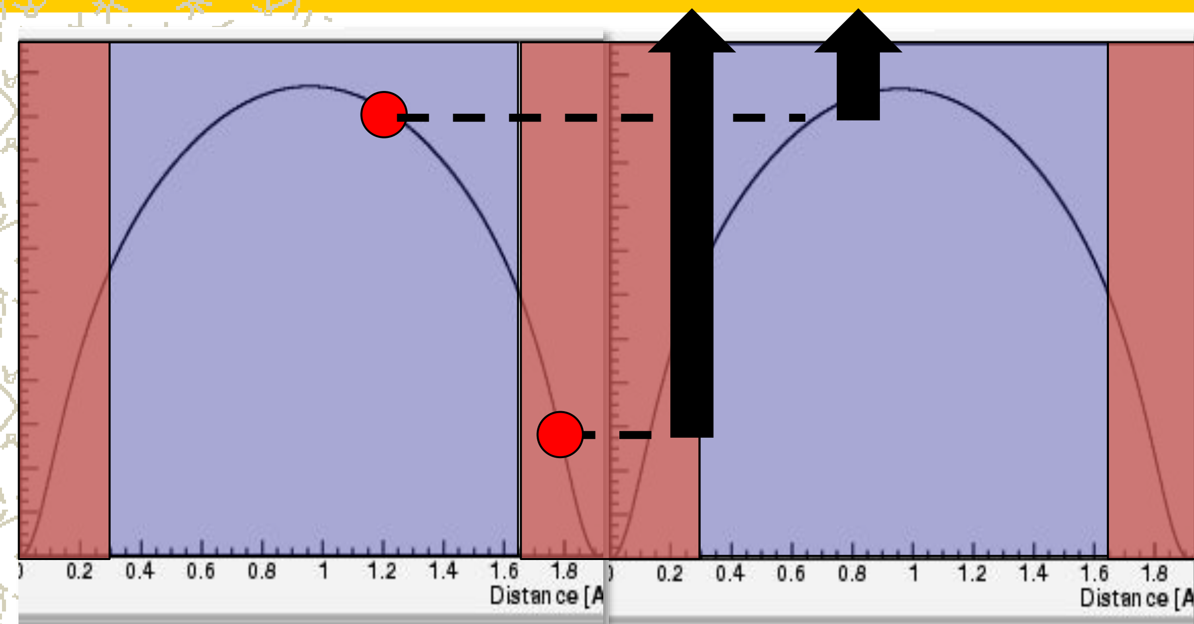
One mechanism of dechanneling for negative particles:

- Nuclear dechanneling

Exponential approximation for the dechanneling processes:

$$N_{ch}(z) \approx N_u e^{-z/L_n}$$

Dechanneling of negative particles



Nuclear corridor

Negative particle

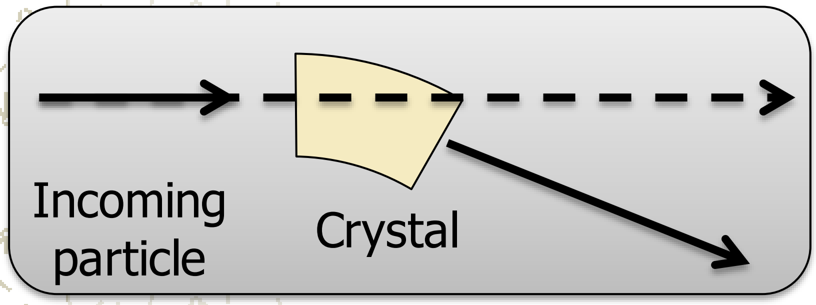
Transverse energy increase

Both particles which impinge far and near the nuclear corridor interact with nuclei and suffer nuclear dechanneling.

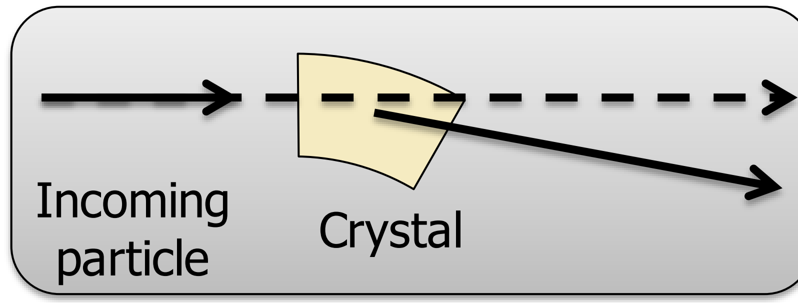
$$N_{ch}(z) \approx N_u e^{-z/L_n}$$

Method of measurement of nuclear dechanneling

Channeled particle =
Full bending angle deflection



Dehanneled particle =
Partial bending angle deflection



$$z = R\,\alpha$$

- z: Crossed crystal length
- R: Crystal radius
- α: Deflection angle

Liner correlation between outgoing deflection angle and exiting point from the channeling state

Method of measurement of nuclear dechanneling

Transverse energy for particle channeled in bent crystal

$$E_T = \cancel{\frac{pv}{2}\theta^2} + U_{eff}(x)$$

$$U_{eff}(x) = U(x) + \cancel{\frac{pv}{R}x}$$

If particle parallel to atomic planes (|θ|<1 urad)

$$\frac{pv}{2}\theta^2 \sim \frac{150GeV}{2} 1\mu rad^2 < 1eV$$

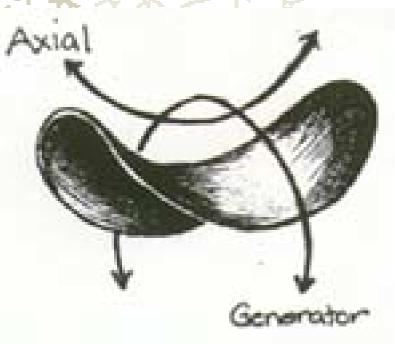
R >> Rc (0.63 m)

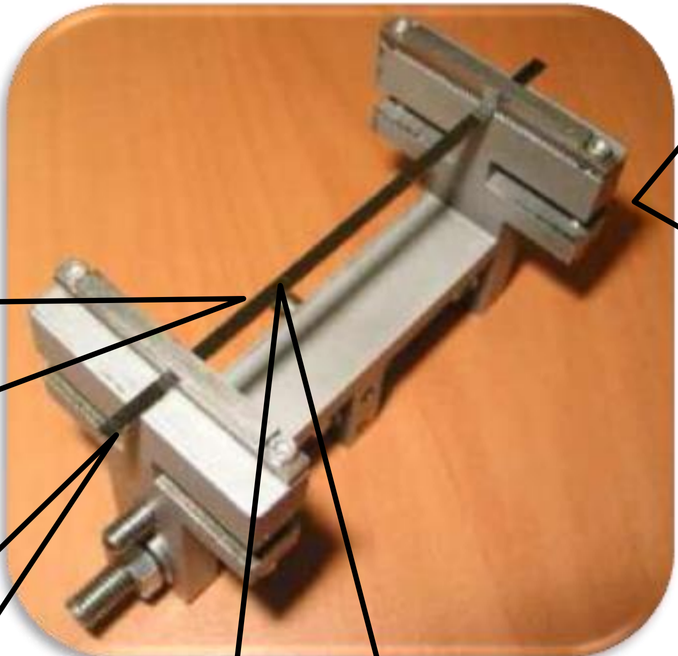
$$\frac{pv}{R}x \sim \frac{150GeV}{20m} 1A < 1eV$$

We can use bent crystal to measure dechanneling length

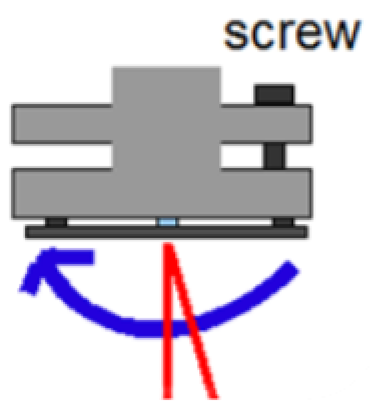
Silicon strip crystal

Anticlastic bending

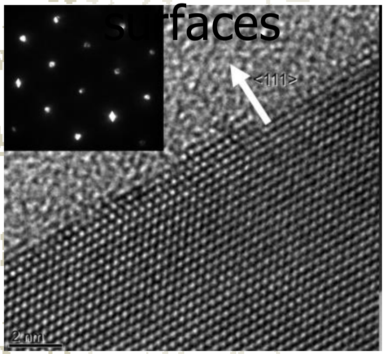




Torsion correction mechanism



High-quality crystalline surfaces



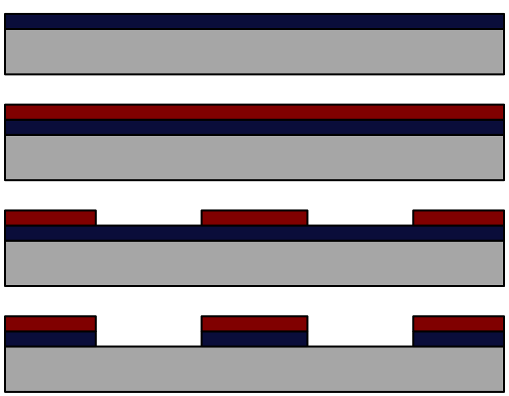
Low-defect silicon wafer

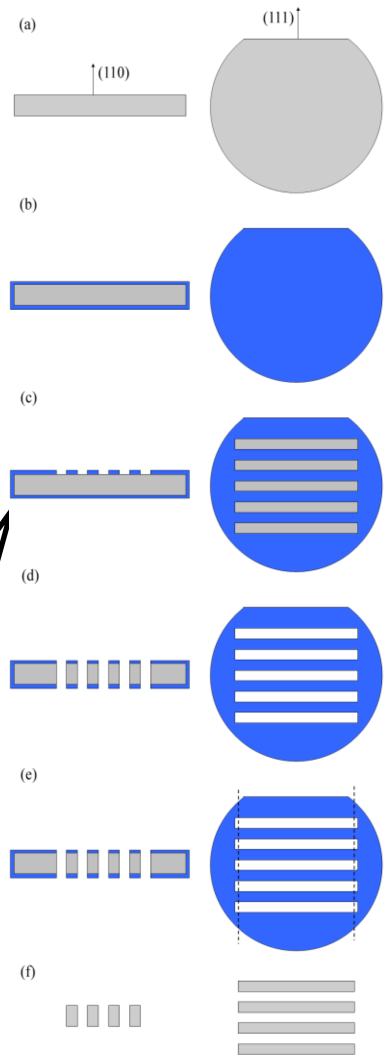
Parameter	Value
Length	1.91 mm
Radius	~ 20 m
Width	0.9 mm
Height	70 mm

Crystal production method

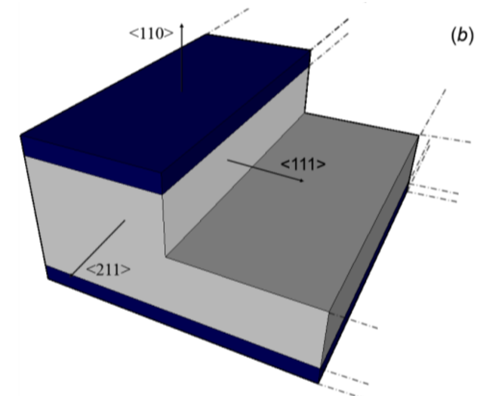
LPCVD deposition of silicon nitride thin layer

Silicon nitride patterning

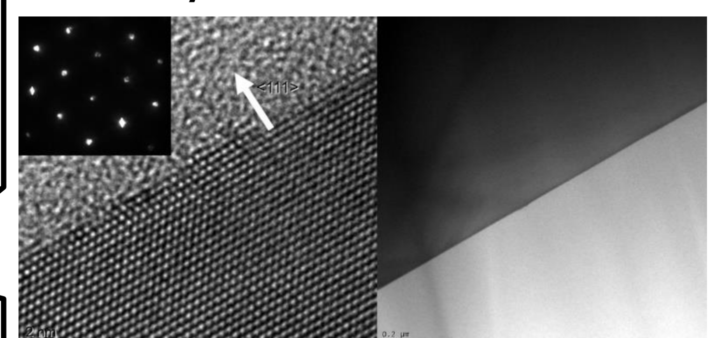




Anisotropic etching:
Etching rate on different silicon planes for KOH 20% at 40 °C



Crystalline surfaces



H4 – π^- 150 GeV/c

Variable	Value
Incoming Horizontal Beam Divergence	30.9 ± 0.2 μrad
Incoming Vertical Beam Divergence	25.4 ± 0.2 μrad

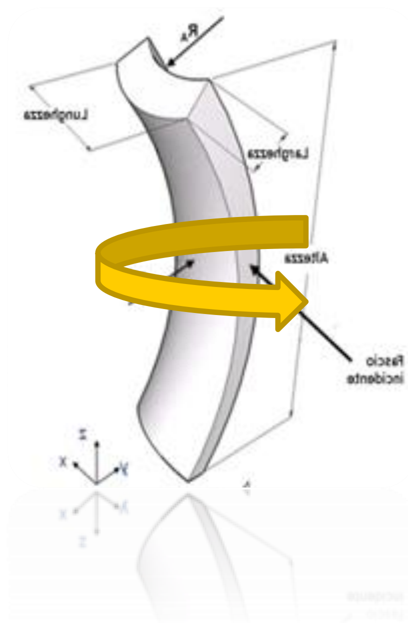
W. Scandale et al. Phys Lett. B 719 (2013) 70-73

Experimental setup

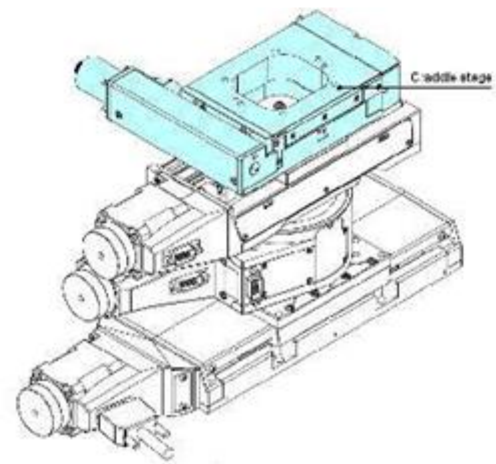
Silicon strip detectors

Spatial resolution
~5 µm

Angular Resolution
~0.5 µrad

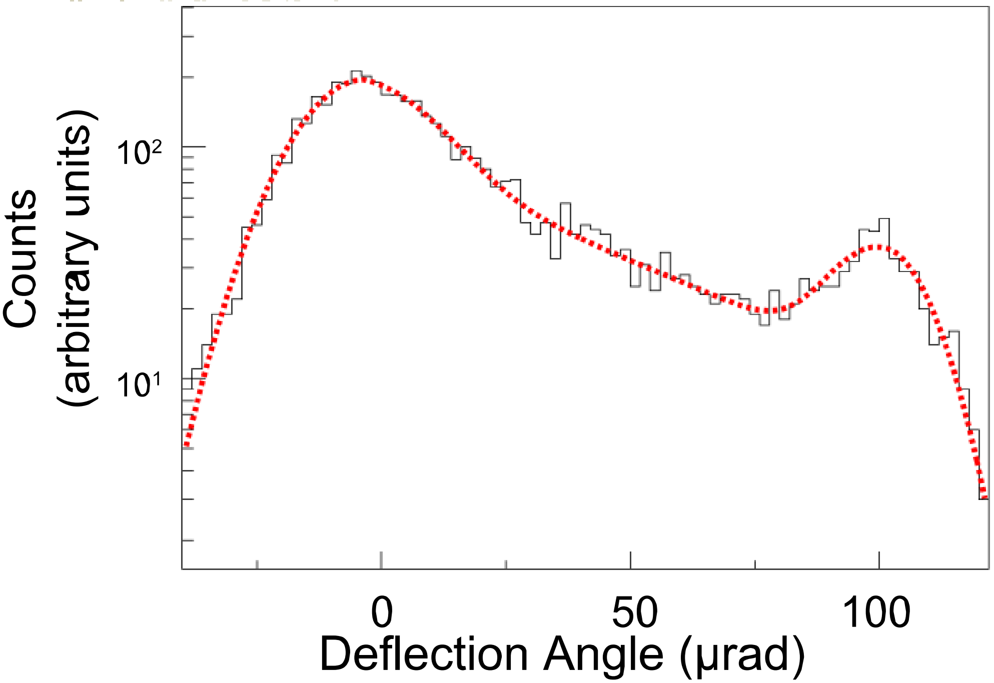


Crystal goniometer



Goniometer resolution
~1 µrad

Measurement of the dechanneling length

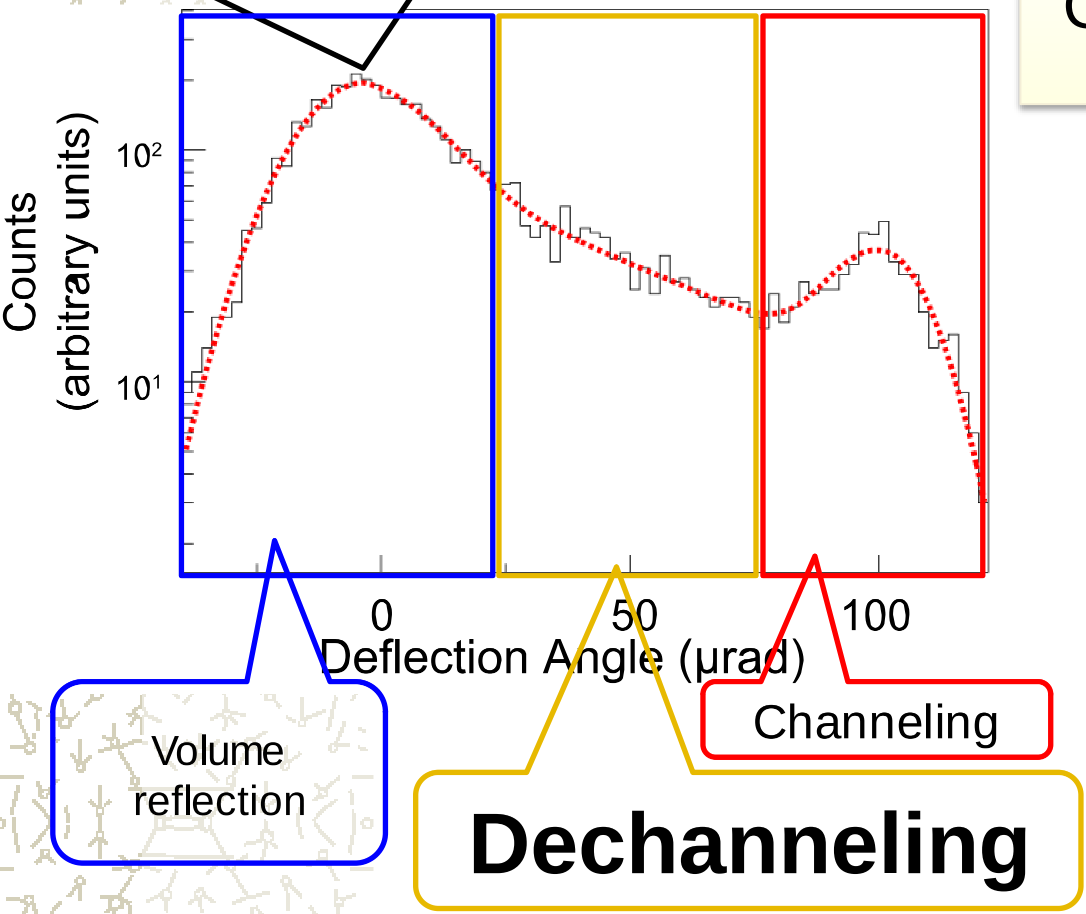


Outgoing angular distribution

| Incoming angle | < 1 μrad

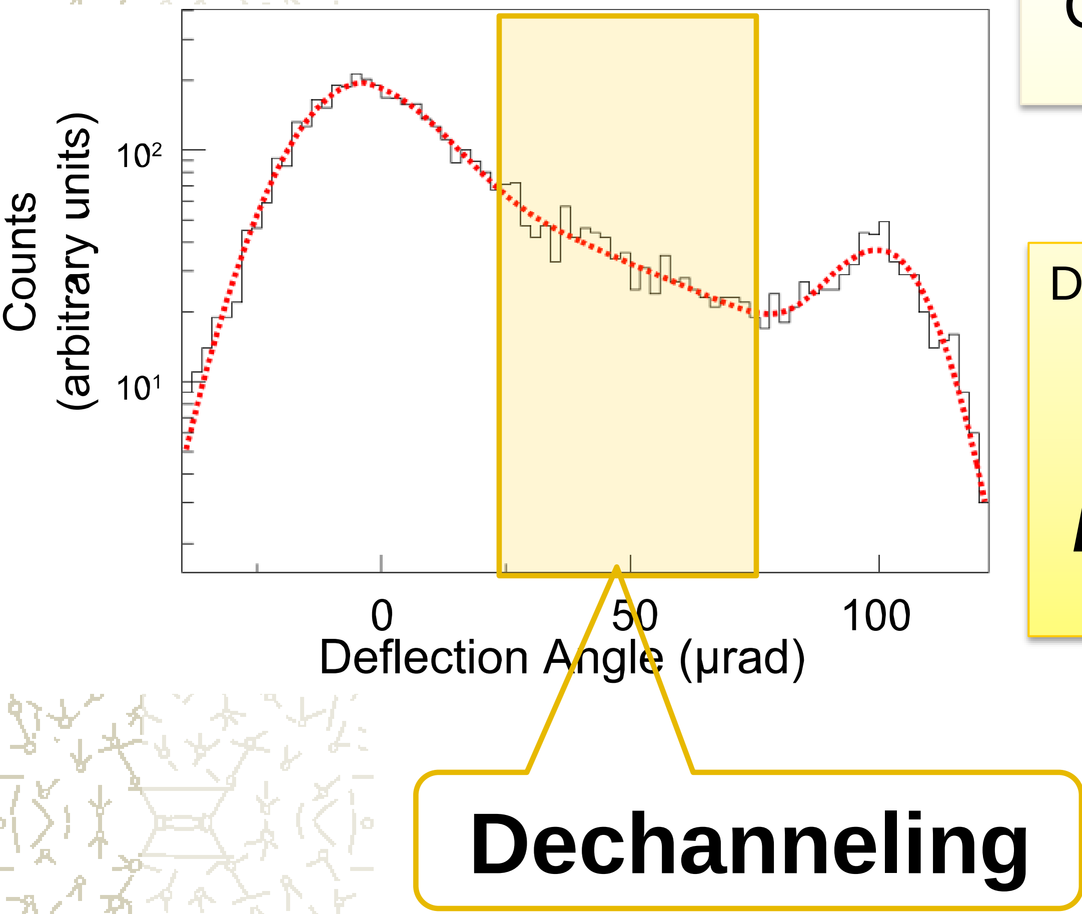
Measurement of the dechanneling length

Fit functions:
two gaussians and an exponential



Outgoing angular distribution
| Incoming angle | < 1 μrad

Measurement of the dechanneling length



Outgoing angular distribution

| Incoming angle | < 1 μrad

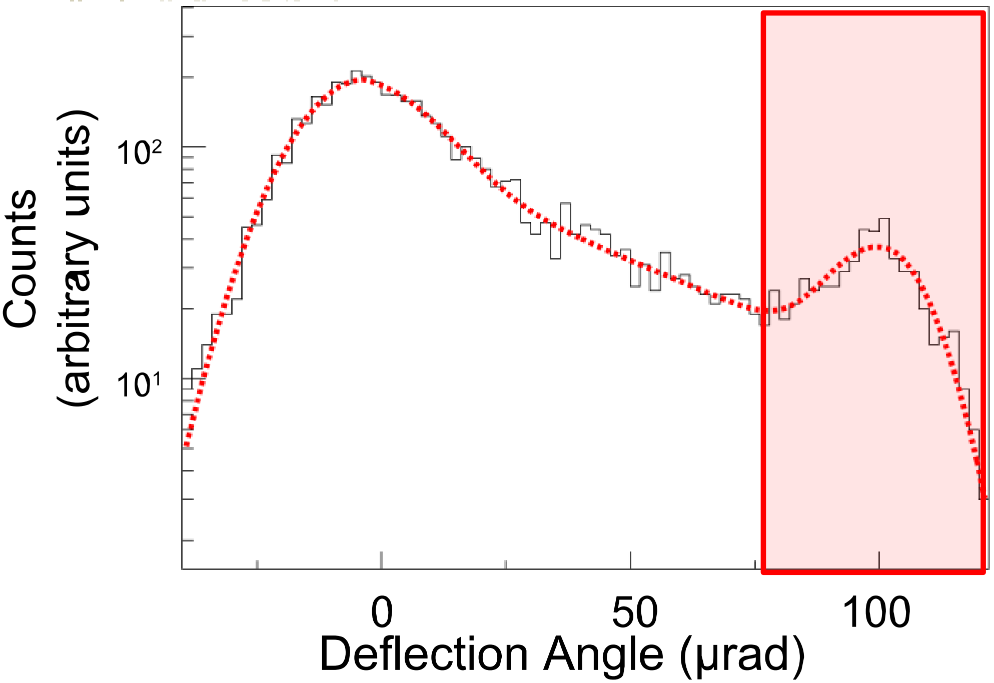
Dechanneling length for a π- channeled in the Si (110) at 273 K [1] is

$$L_n^- = (0.93 \pm 0.05)\ \text{mm}$$

Simulation

$$L_n^- = (0.95 \pm 0.03)\ \text{mm}$$

Measurement of the dechanneling length



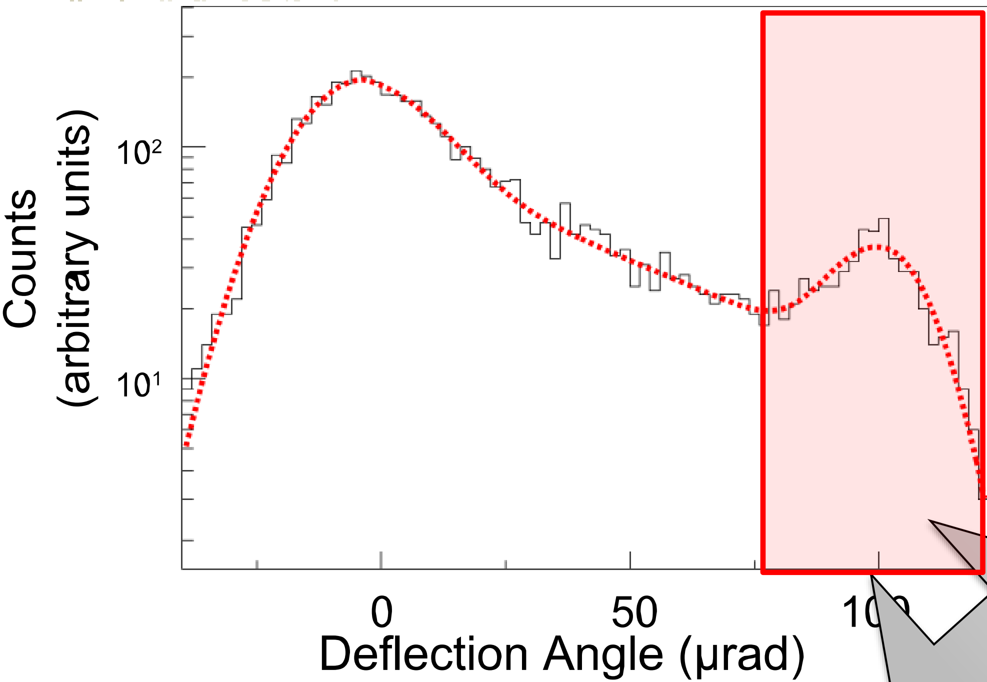
Outgoing angular distribution

| Incoming angle | < 1 μrad

Dechanneling efficiency for a π- channeled in the Si (110) at 273 K [1] is

$$e = (12.5 \pm 1)\ \%$$

Measurement of the dechanneling length



Outgoing angular distribution

| Incoming angle | < 1 μrad

Dechanneling efficiency for a π- channeled in the Si (110) at 273 K [1] is

$$e = (12.5 \pm 1)\ \%$$

Simulation

$$e = (14.3 \pm 0.3)\ \%$$

Using only dechanneling length

$$e \sim e^{-L/L_n} = e^{-1.91/0.96} = 13.7\%$$

Experimental setup of Chanel experiment

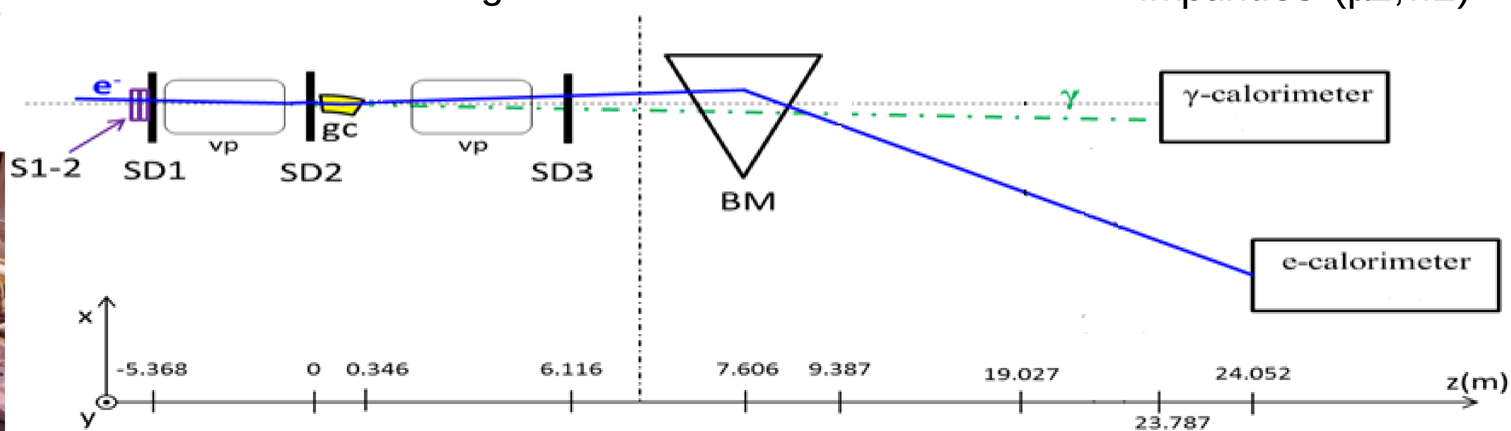
Double sided silicon detectors SDi
(300μm thick)
[5-μm spatial resolution]

2.01 mm long strip crystal
Bent at R=11.5 m
channeling along (110) planes

γ-beam and e-beam calorimeters to measure the emitted photons and to discriminate e± from impurities (μ±,π±)

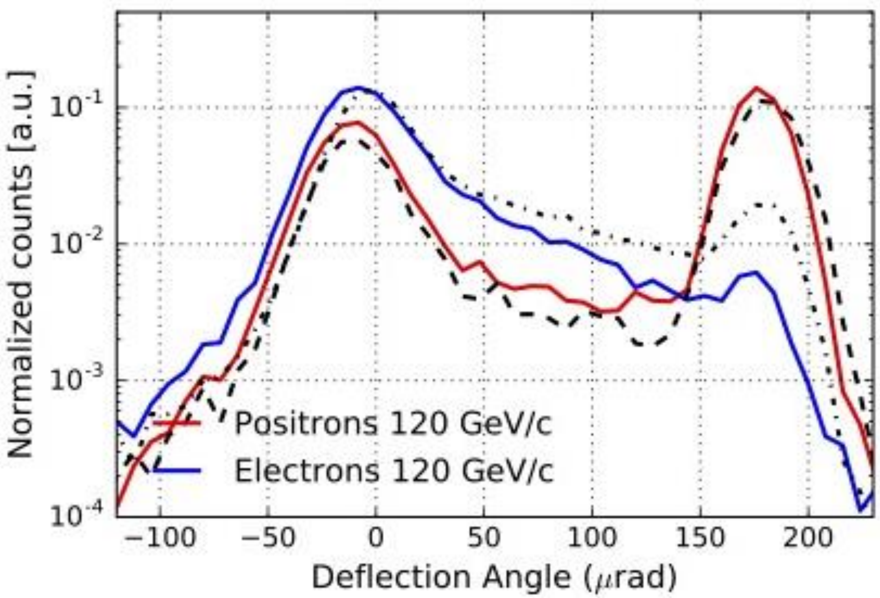
Crystal mounted on a high-precision goniometer (gc)

Bending magnet (BM) to separate charged and neutral beams



External line H4 at CERN SPS

Deflection of positrons and electrons

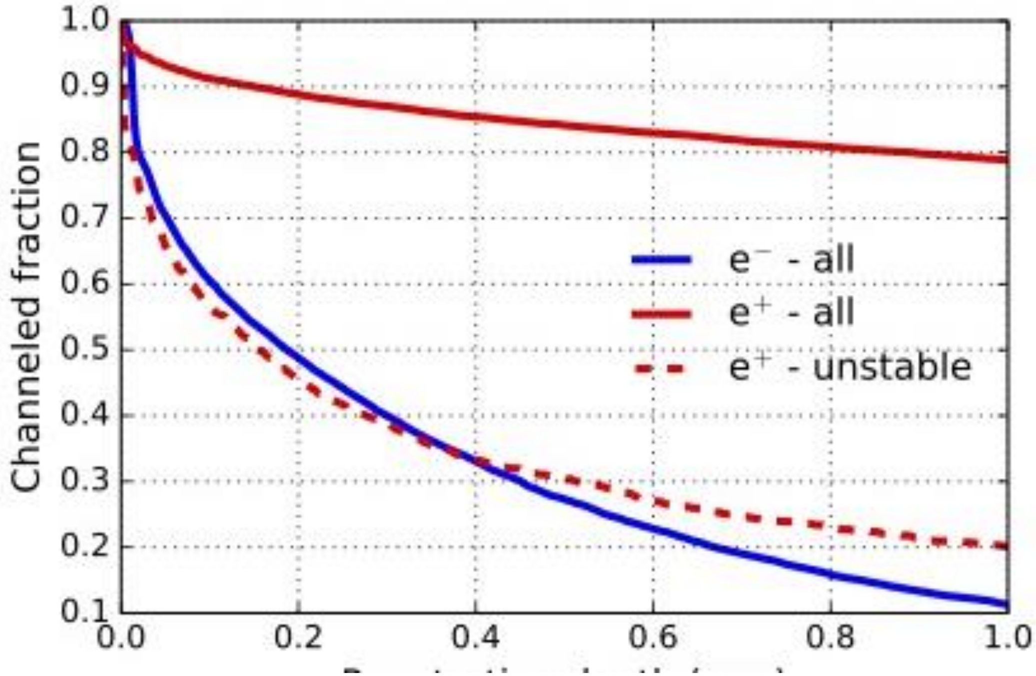


- Deflection patterns of 120 GeV/c electrons and positrons under same experimental conditions
- Channeling efficiency of (53 ± 2)% for positrons and (4 ± 2)% for electrons
- Nuclear dechanneling lengths were comparable as a sign of similar dynamics

$L_n^- = (0.7 \pm 0.1)$ mm

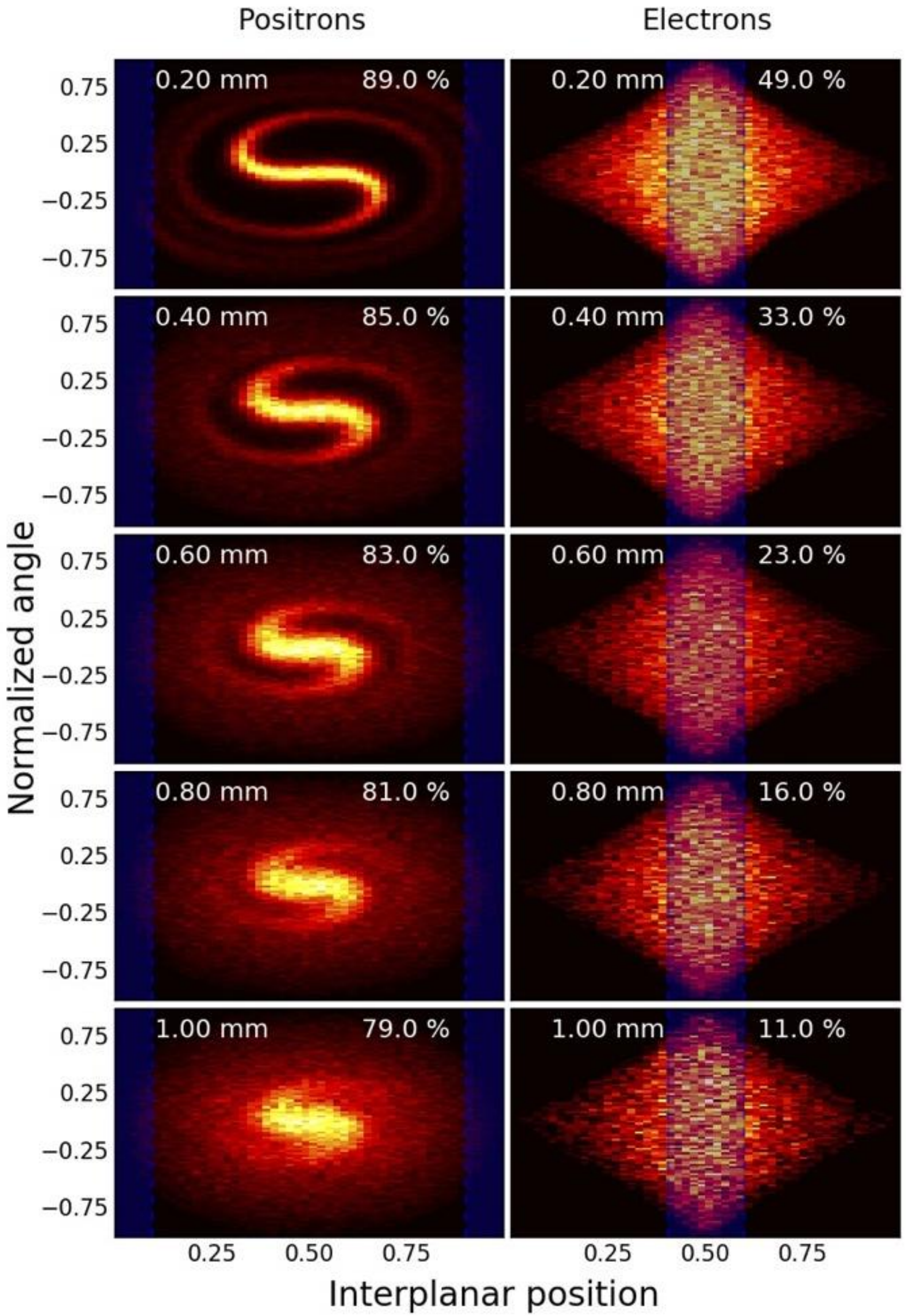
$L_n^+ = (0.85 \pm 0.15)$ mm

Simulation



Distance from the surface (mm)

Simulation of electron and positron dynamics in the crystal via DYNECHARM++

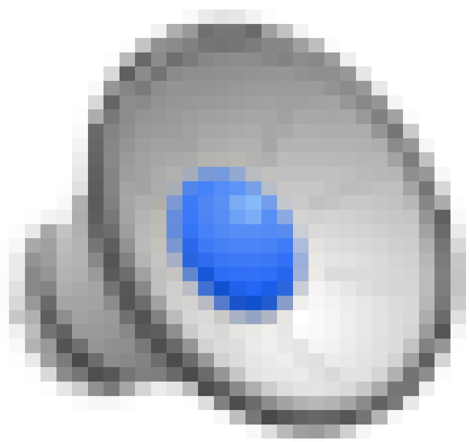


Simulation

Phase-space evolution for positrons (left) electrons (right)

Snapshots taken at some distances from the surface

Simulation



Positrons Electrons

Thank you for your attention