Deflection of positively charged heavy particles by the crystal miscut surface

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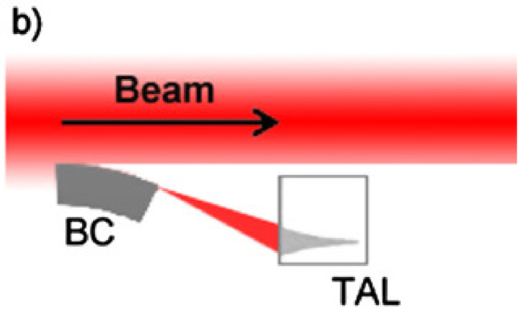
A.A Babaev, S.B. Dabagov,
Deflection of proton beams by crystal miscut surface, *LNF Preprint INFN 14-05/LNF*

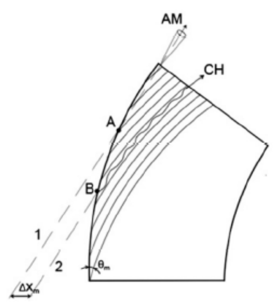
Channeling-2014, 5-10 October 2014, Capri, Italy

1. Origin of the task



- Using of bent crystal (BC) for beam collimation: BC as a primary collimator. Halo particles are deflected and directed onto the absorber (TAL).

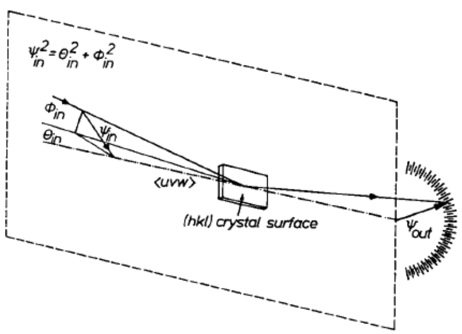
[1] W. Scandale et al. *Phys. Lett. B* **692** (2010)



- At small impact parameters halo particles hit the lateral surface that are characterized by miscut angle between surface and crystallographic planes.

[2] W. Scandale et al. *Phys. Lett. B* **703** (2011)

Shortens channels and stair-step planes form terrace-like structure of surface layer



- We know, the single-plane crystal surface reflection as well as the surface channeling are well known phenomena

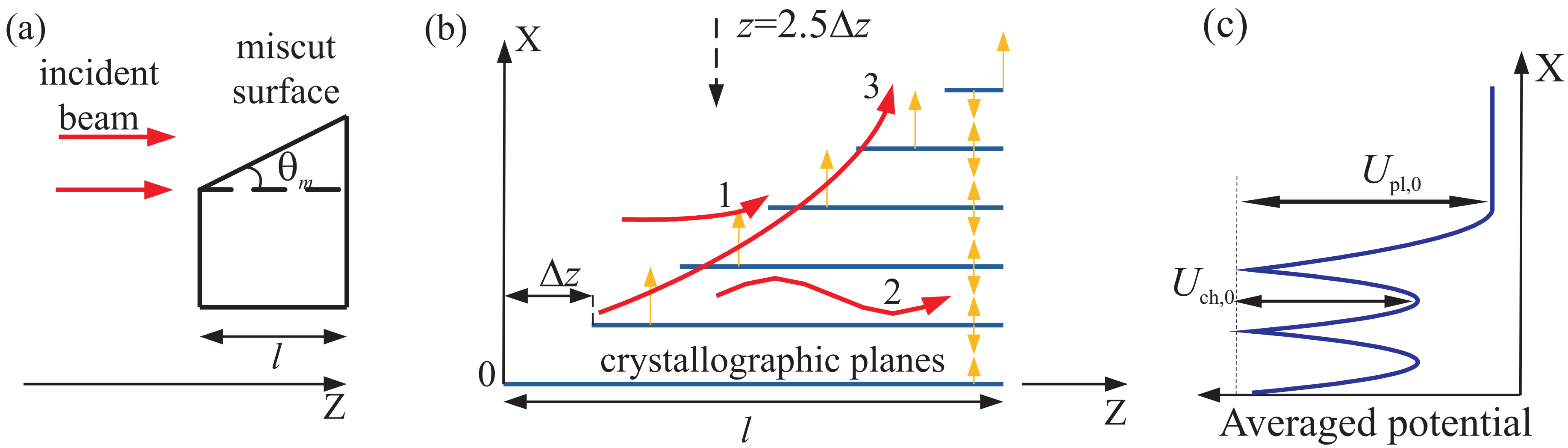
[3] R. Sizmann and C. Varelas, *NIM* **132** (1976)

The idea: the deflection by miscut surface could be more effective than the deflection by single-plane surface

2. Miscut surface

Crystallographic planes are oriented along beam direction

Miscut angle θ_m is the angle between lateral crystal surface and crystallographic planes.



(a) Particles penetrates into the crystal through the lateral miscut surface;
(b) It can be considered as terraces formed by crystallographic planes;
(c) Averaged field near the surface is the deflecting terrace field or channel field

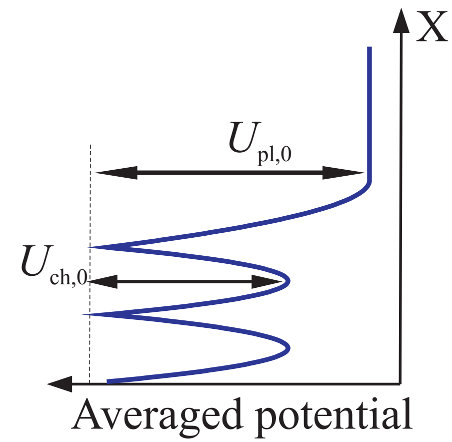
Kinds of motion:

1. Deflection by single terrace field;
2. Channeling;
3. Multiple terrace deflection due to quasichanneling.

The multiple terrace deflection can deflect particles over noticeable angles

3. Estimations

Nondivergent beam penetrates into the crystal along planes.



Critical channeling angles:

$$\theta_{ch} = \sqrt{\frac{2U_{0,ch}}{p_z c}}$$ - Lindhard angle

$$\theta_{pl} = \sqrt{\frac{2U_{0,pl}}{p_z c}}$$ -Critical angle for vacuum-surface penetration

Critical miscut angles:

$\theta_{m1} = \dfrac{2\theta_{pl}}{\pi}$ and $\theta_{m2} = \arctan \dfrac{\theta_{pl}}{\alpha}$ where $\dfrac{\cos\alpha}{\cos^2\alpha + \dfrac{\theta_{pl}^2}{4\theta_{ch}^2}\sin^2\alpha} = 1$

$\theta_m < \theta_{m1}$ -single terrace deflection (1), maximal deflection angle $\theta_{max}=\theta_{pl}$

$\theta_{m1} < \theta_m < \theta_{m2}$ -channeling & quasichanneling (2+3)
- multiply terrace deflection deflection angles $\theta>\theta_{pl}$

$\theta_m > \theta_{m2}$ - channeling (2)

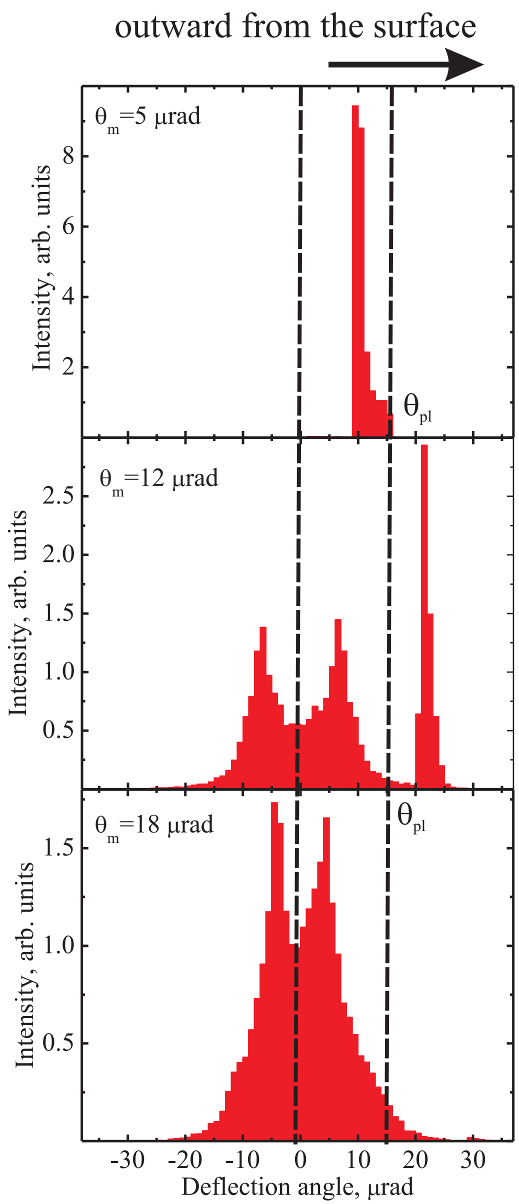
Pb nuclei: $p_z c$, (GeV/c per unit charge)

Angles (μrad)

	270	400
θ_{ch}	12.7	10.5
θ_{pl}	15.3	12.6
θ_{m1}	9.7	8.0
θ_{m2}	15.7	13.0

* for (110) Si

4. Deflection by miscut surface



(110)Si crystal; Pb nuclei beam:

270 GeV/c per unit charge

400 GeV/c per unit charge

At small miscut angle particles form sharp peak at $\theta<\theta_{pl}$ due to single terrace deflection; channeling is absent

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At moderate miscut angle the deflection angle increases ($\theta>\theta_{pl}$) due to multiple terrace deflection; channeling appears

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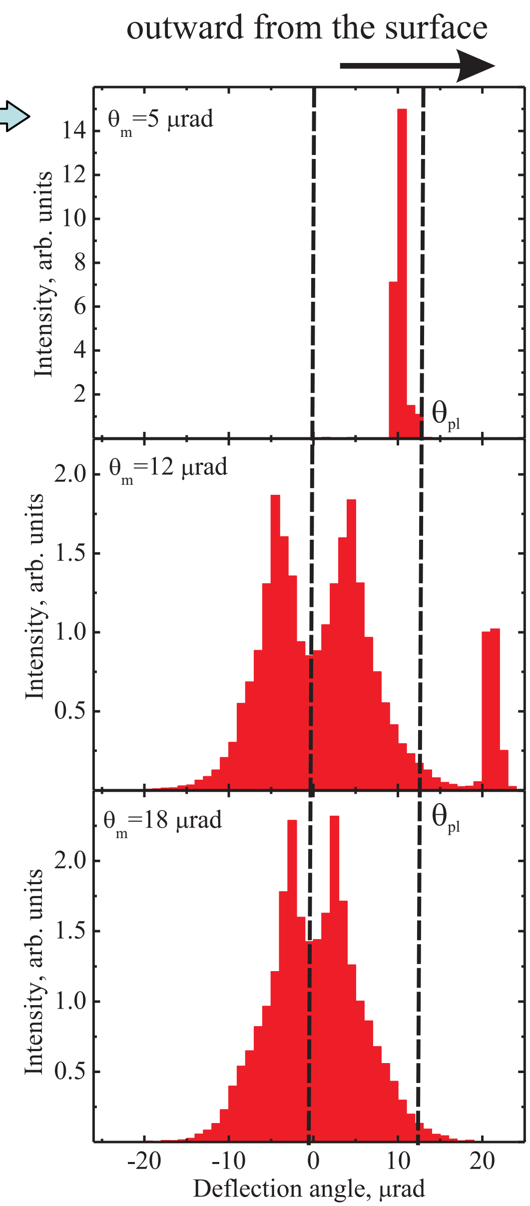
At large miscut angle the deflection outward from the surface dissapears; only channeling exists

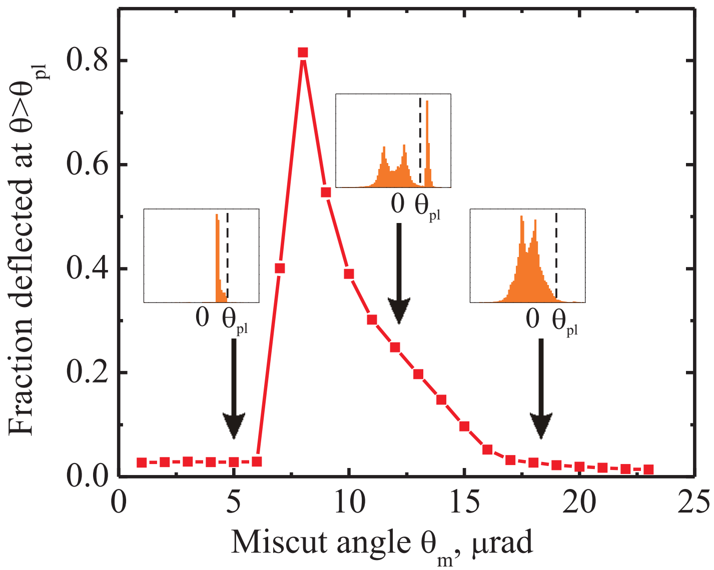


5. Multiple terrace deflection

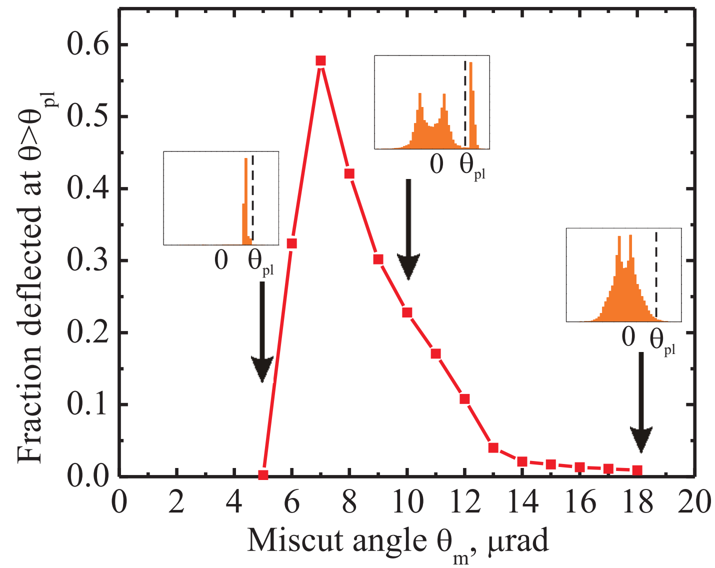
Theory: maximal deflection angle at single terrace deflection $\theta = \theta_{pl}$
deflection angles at multiple terrace deflection $\theta > \theta_{pl}$

(110) Si crystal; Pb nuclei beam

270 GeV/c per unit charge
$\theta_{pl} \approx 15$ µrad



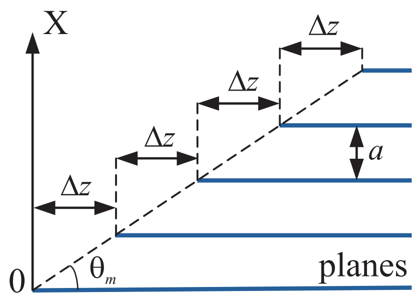
400 GeV/c per unit charge
$\theta_{pl} \approx 13$ µrad



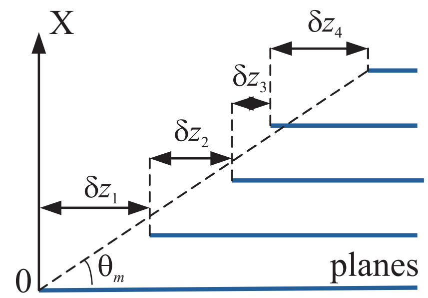
- Multiple terrace deflection exists [approximately] for $\theta_{m1} < \theta_m < \theta_{m2}$: it is provided mainly by quasichanneling.
- Multiple terrace deflection could be very effective: the deflected fraction exceeds 50%

6. Imperfect miscut surface

Perfect surface:



Imperfect surface:



Terrace length for perfect surface:

$$\Delta z = a / \tan \theta_m$$

Terrace length for imperfect surface:

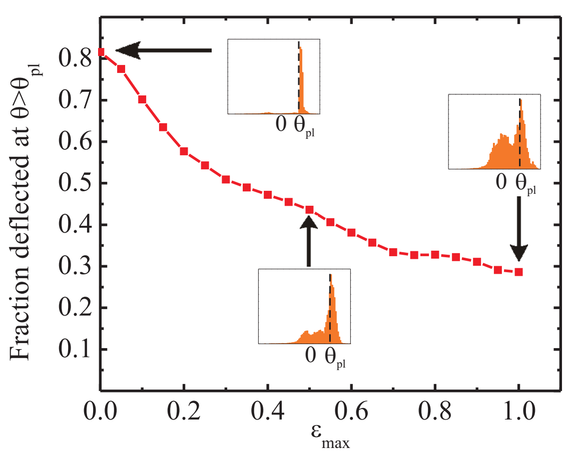
$$\delta z = (1+\varepsilon)\Delta z$$

ε – random distributed within

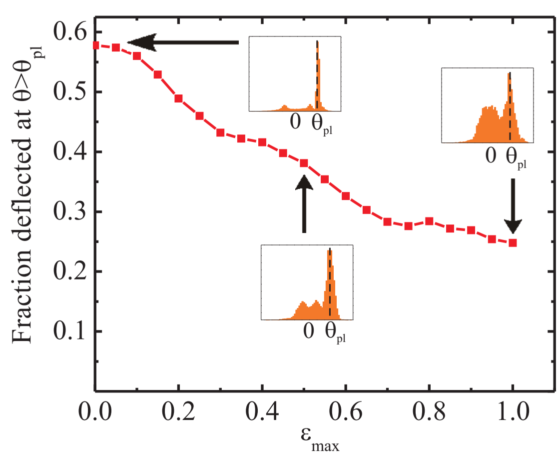
$$\varepsilon \in (-\varepsilon_{\max}, \varepsilon_{\max})$$

(110) Si crystal; Pb nuclei beam

270 GeV/c per unit charge
$\theta_{pl} \approx 15$ μrad, θ_m=8 μrad



400 GeV/c per unit charge
$\theta_{pl} \approx 13$ μrad, θ_m=7 μrad

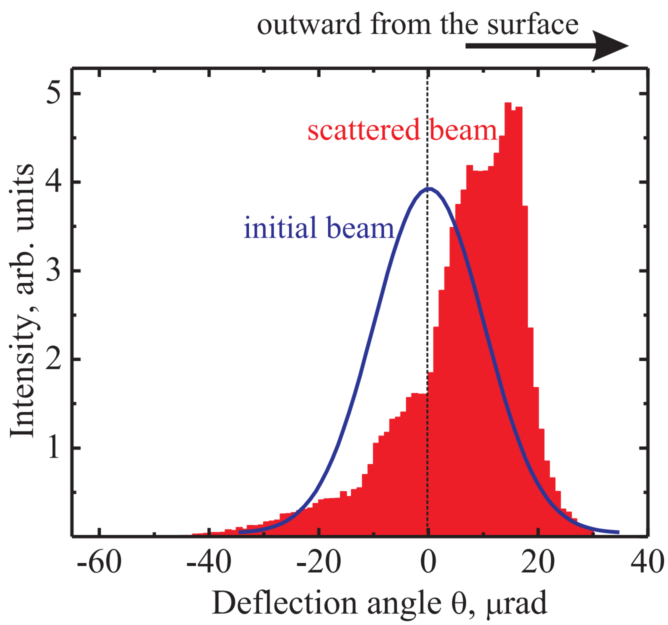


- Peak of deflected particles remains at large ε_{max}
- Multiple terrace deflection is still effective at large ε_{max}: about 20% at ε_{max}=1

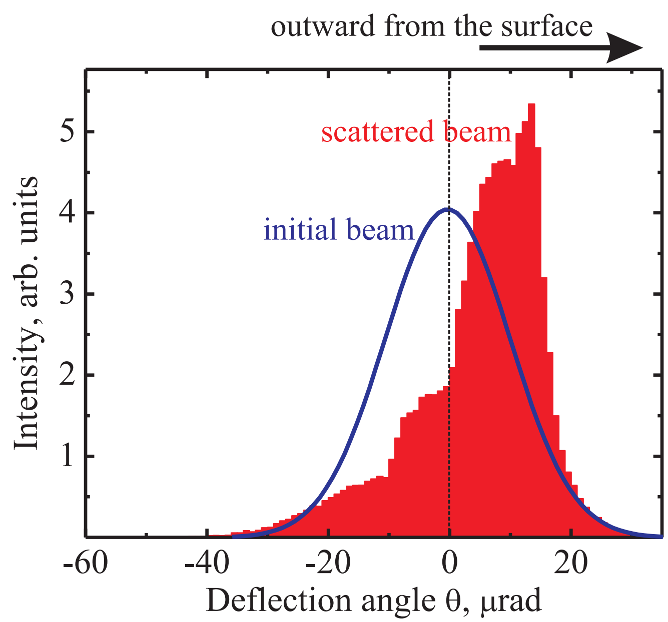
7. Beam divergence

(110) Si crystal
Pb nuclei beam: σ=10 μrad, comparable with θ_{pl}

270 GeV/c per unit charge
θ_m=8 μrad



400 GeV/c per unit charge
θ_m=7 μrad



- There is not clearly visible peak of terrace deflected particles
- Nevertheless one can see the shift of intensity maximum

8. Finally

What is negative:

- For considered energies it requires very small miscut angles: ~10 μrad whereas usually crystals have θ_m~100 μrad.
- The initial beam divergence can cover up the effect if the divergence ~θ_{pl}. For considered energies θ_{pl}~10 μrad and slight divergent beams are required.

What is positive:

- The multiple terrace deflection could be effective way of beam deflection: more than 50% of non-divergent beam hitting the miscut surface.
- The effect remains even for imperfect miscut surface.
- Particles interact only with very thin surface layer.

For ~100 MeV/c positrons multiple terrace deflection takes place at θ_m~100 μrad:
A.A. Babaev, G. Cavoto, S.B. Dabagov, *JETP Letters*, accepted for publication
Simulations are based on the code:
A Babaev, *Computer Physics Communications*, **185** (2014)

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