DECHANNELING MECHANISMS

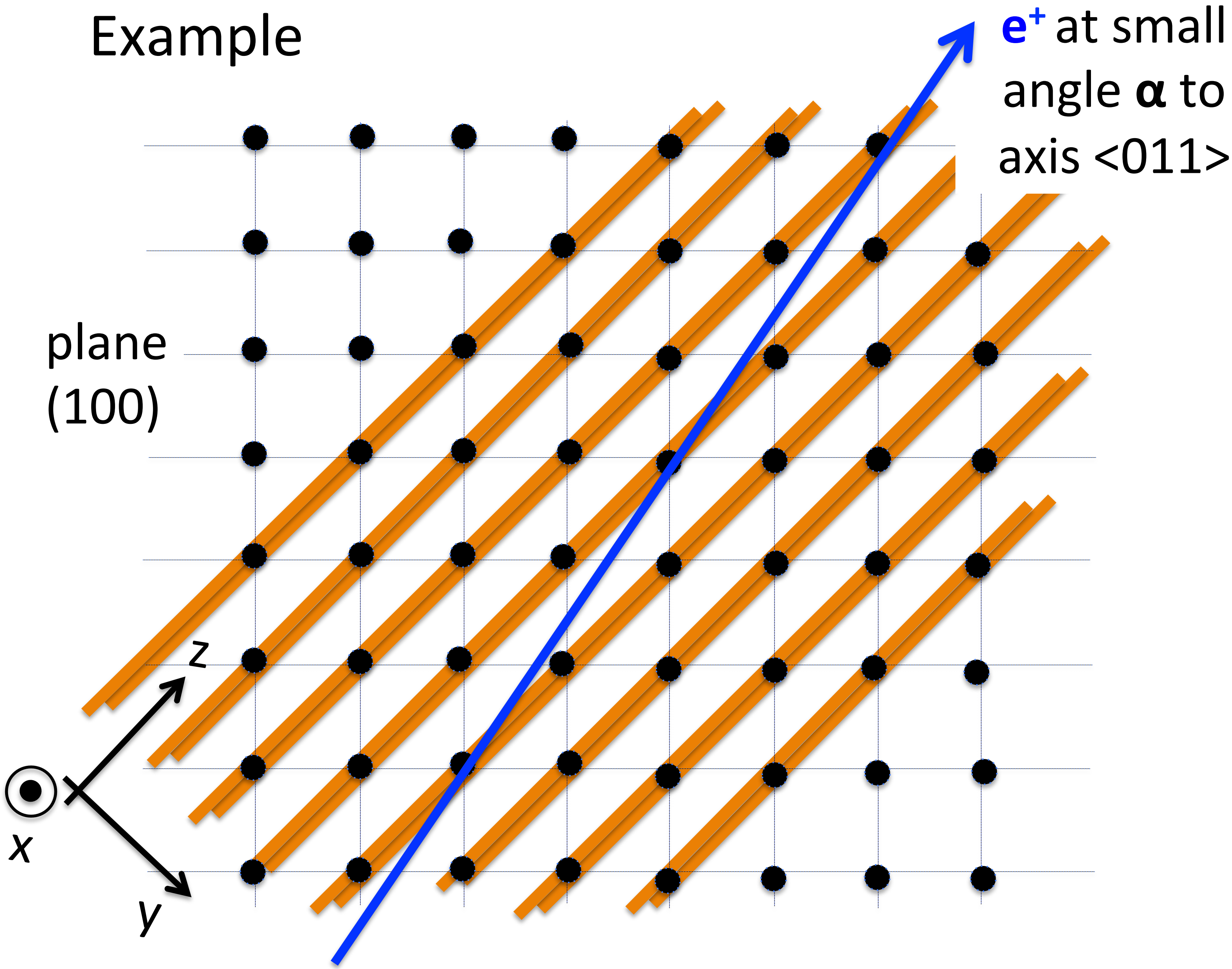
- Planar dechanneling by the potentials of nearby axes
- The correlation between atom displacements can influence axial dechanneling
- Quantum versus classical aspects of axial dechanneling

Planar dechanneling by the potentials of nearby axes

- Experimental results by Yu. V. Bulgakov and V. I. Shulga

- Simulation results (work with Nabil Boutassetta, unpublished) and interpretation

Example



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TRANSPARENCY OSCILLATIONS OF A SILICON SINGLE CRYSTAL IN PASSING FROM AXIAL TO PLANAR CHANNELLING

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(*Received May 2, 1975*)

The transparency coefficient, T, of thin (2.5 μ) Si single crystals relative to a well collimated 8.16 MeV He ion beam has been measured as a function of angle α between the beam direction and the [110] axis of crystals rotated in the $(1\bar{1}0)$ plane. Curve $T(\alpha)$ has been found to display minima at $\alpha = 0.15°$, $0.34°$ and $0.5°$. Computer simulation of experimental conditions has shown that the first minimum is a result of competition of two processes: increase of the radius of ring-shaped angular distribution with increasing α and ion capture in the $(1\bar{1}0)$ planar channel. The remaining two minima are due to particle dechannelling from channel $(1\bar{1}0)$ resulting from resonance enhancement of transverse particle oscillations in the channel. Similar calculations have been carried out for the transition from axial [110] to planar (001) channelling. It has been shown that in this case the difference in the conditions resonance result in spatial separation of the ion beams that have passed through channels (001) with and without displaced arrangement of rows [110].

I INTRODUCTION

The problems associated with the motion of charged particles in axial and planar channels of the crystal lattice have been considered in a large number of both theoretical and experimental works.[1,2] Recently, there has been a growing interest in the intermediate case which corresponds to the transition from axial channelling to the planar channelling. Under these conditions, the transverse (relative to atomic rows) ion energy is

respect to a well-collimated beam of He ions incident upon the crystal at small angles to the [110] axis parallel to the $(1\bar{1}0)$ and (001) planes. The study involved both experiments and calculations by computer simulations of trajectories of individual particles. The results obtained suggest that in passing from axial to planar channelling there takes place a resonance enhancement of the transverse ion vibrations which results from the interference of the row and plane mechanisms and which leads to dechannelling of

Bugakov & Shulga's result

Transparency versus α

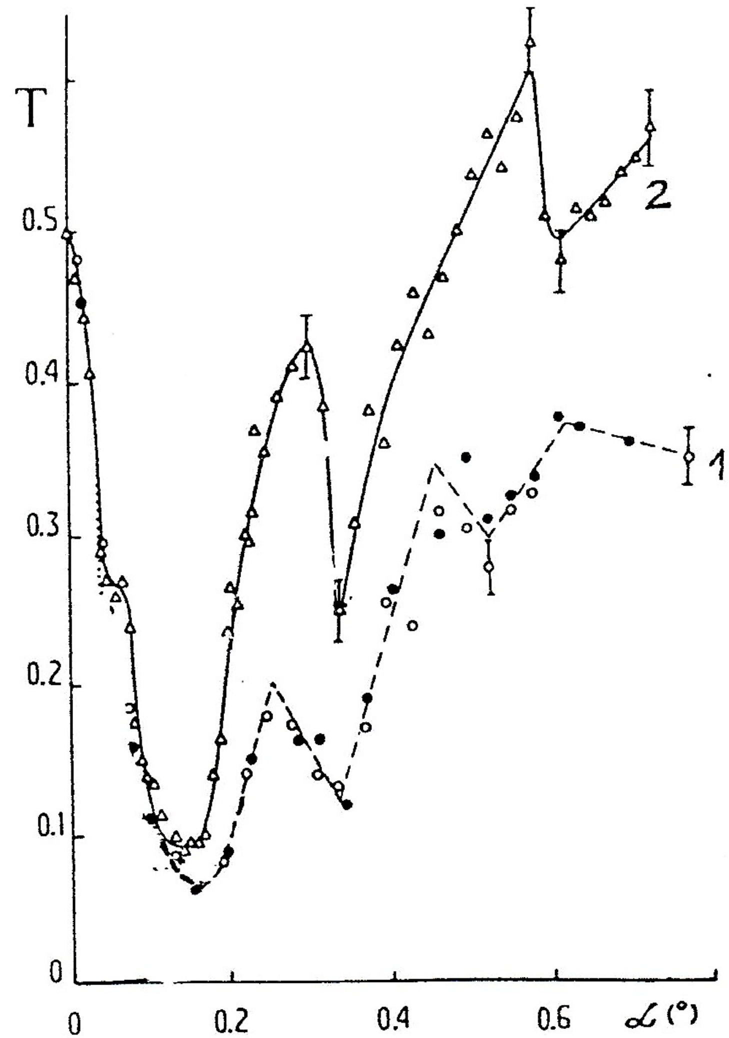


fig.4 : Coefficient de tranparence T en fonction de l' angle, dans la transition de la canalisation suivant l' axe < 110 > à celle suivant le plan (1$\bar{1}$0) .

Year 1992-1993

RAPPORT DE STAGE

de

BOUTASSETTA Nabil

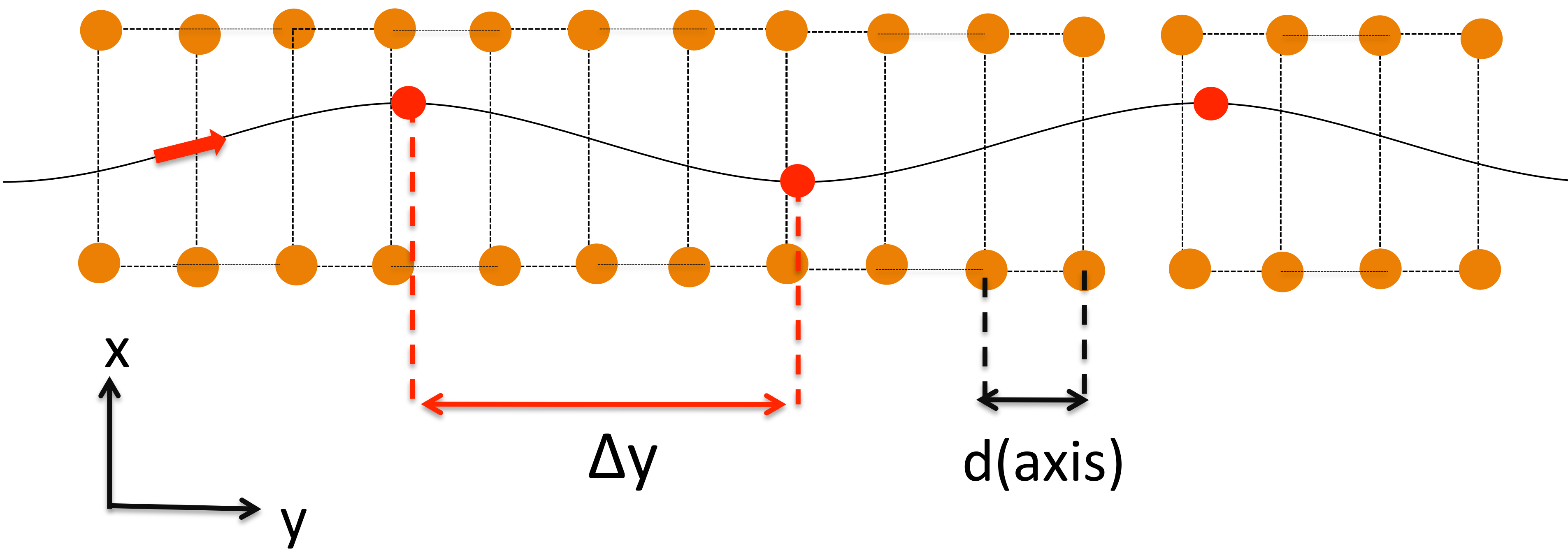
INFLUENCE D'AXES SECONDAIRES SUR LA STABILITE DE LA CANALISATION PLANAIRE DANS UN CRISTAL

Responsable de stage : Pr. X. ARTRU

English : *Influence of secondary axes on the stability of planar channeling in a crystal*

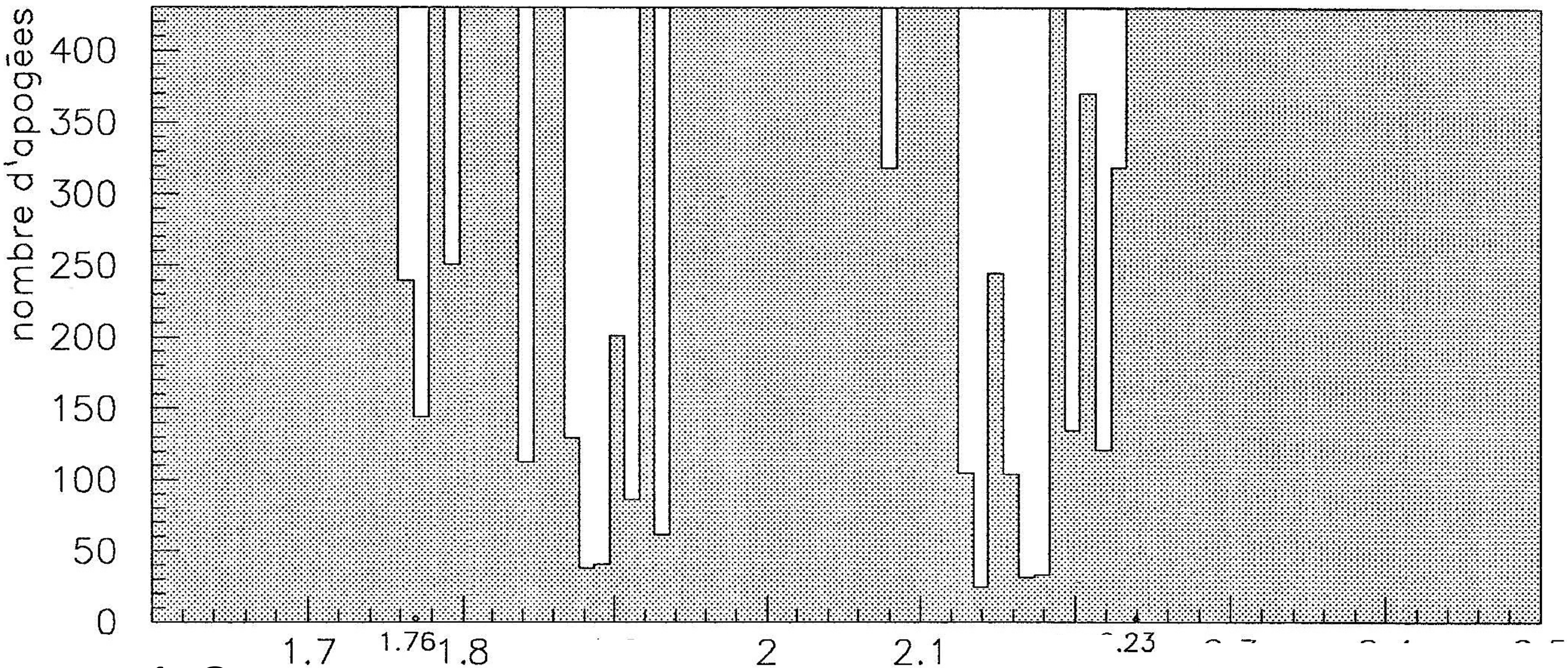
Université Claude Bernard Lyon-I
Institut des Sciences de la Matière

Projection on a plane ⊥ to the string axes



$\Delta y / d(\text{axis})$ = **Δ(phase)** = number of crossed cell in the half-period of channeling motion

Number of half-oscillations before dechanneling
(*limited to 400*)



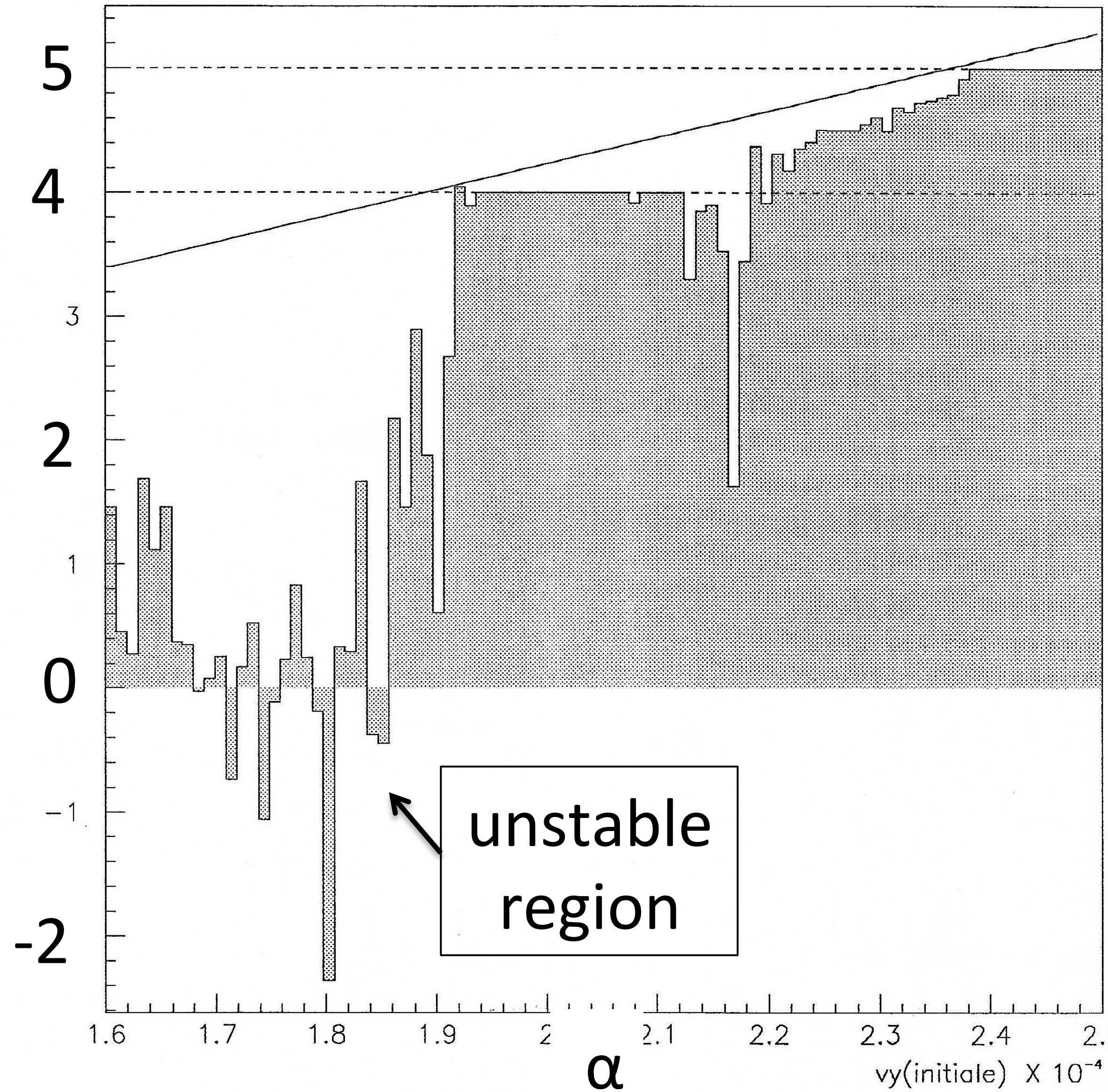
1.6 1.9 2.2 $\times 10^{-4}$

initial $v_y \approx \sin\alpha \approx \alpha$ ⟶

unstable region

$< \Delta_{phase} >$

= average number of crossed cells per 1/2 period of channeling motion

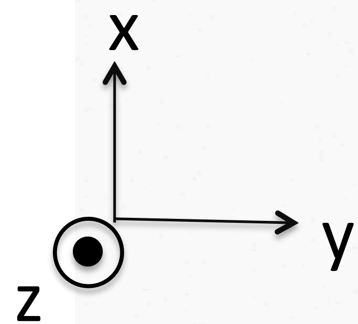


Note :

In stable motion,

< Δ(phase) > ***is locked at integer values***

Dechanneling
➔ chaotic motions



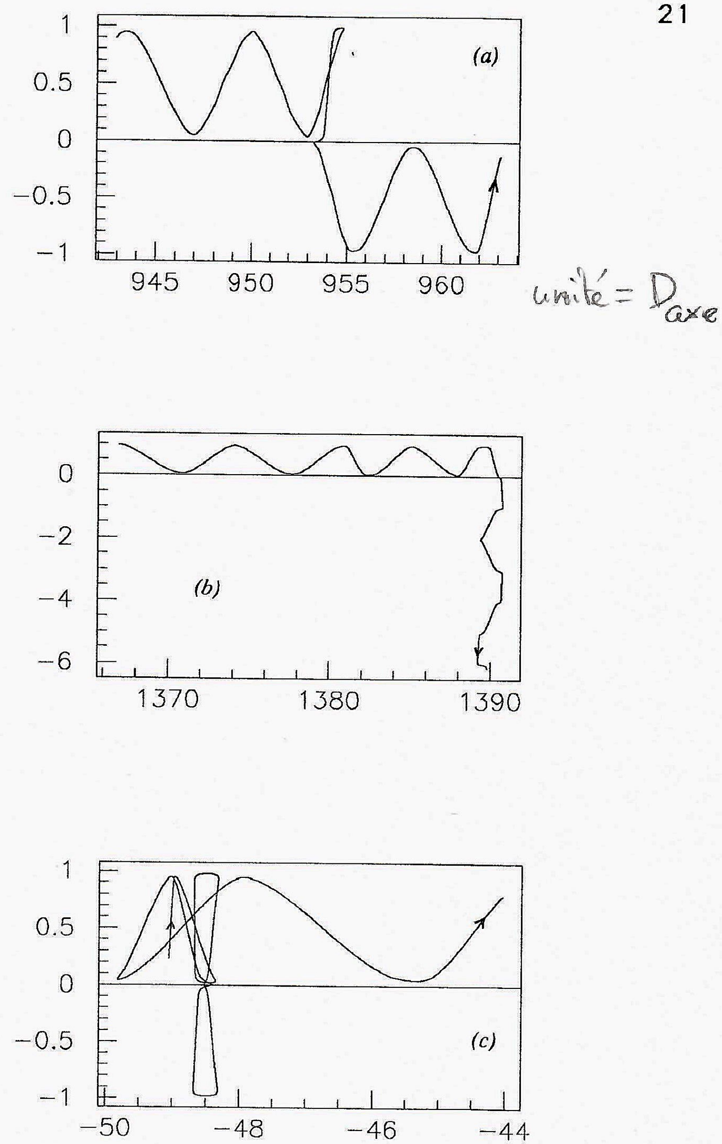


fig.9 : Mouvement après la décanalisation :

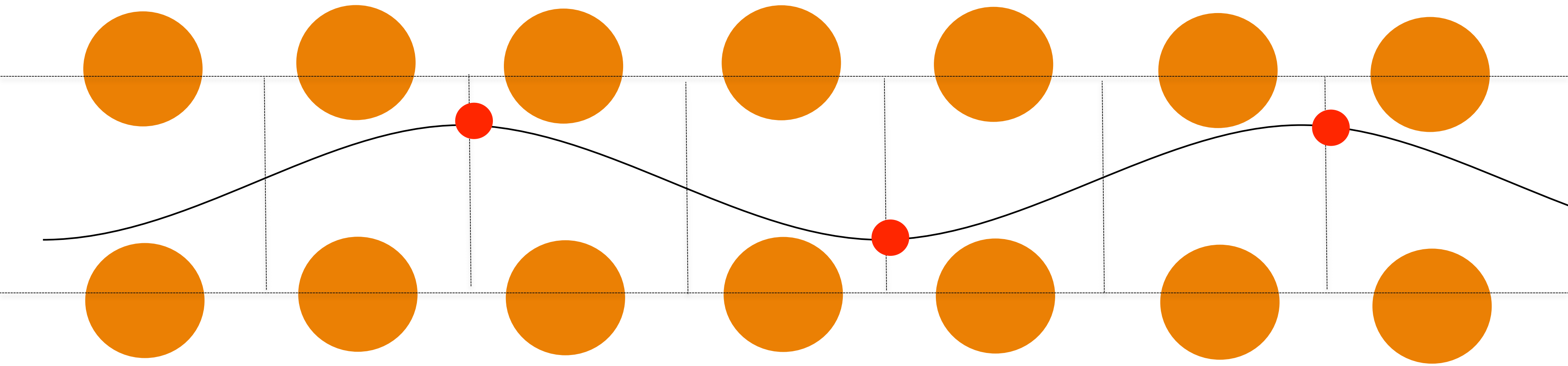
(a) la particule oscille entre les plans 0 et -1 ($v_{y0} = 2.13\ 10^{-4}$)

(b) la particule oscille entre deux plans perpendiculaires aux plans initiaux ($v_{y0} = 2.23\ 10^{-4}$)

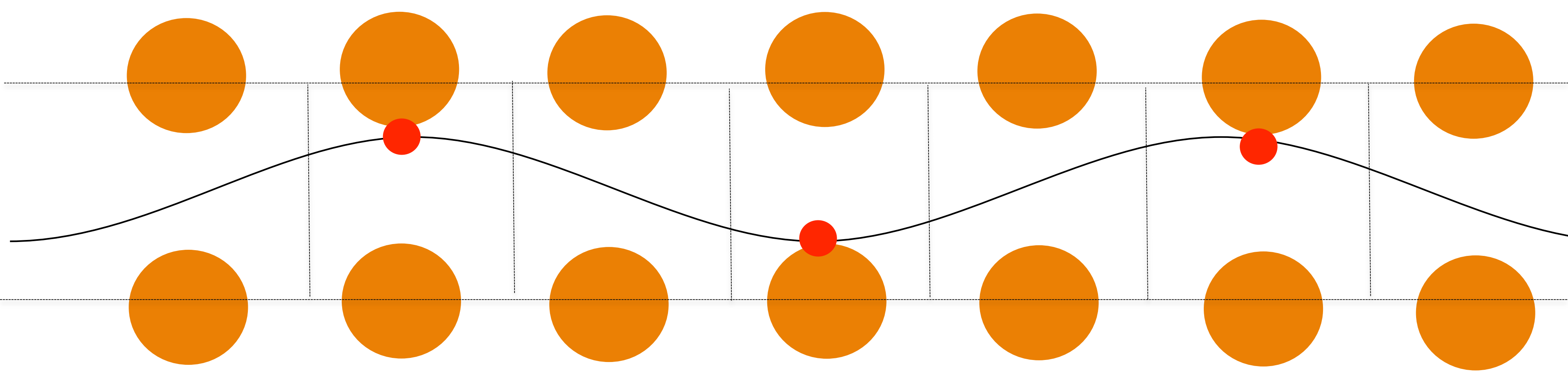
(c) la particule est dans un mouvement chaotique ($v_{y0} = 2.15\ 10^{-4}$)

Condition of stable motion

perfectly stable motion

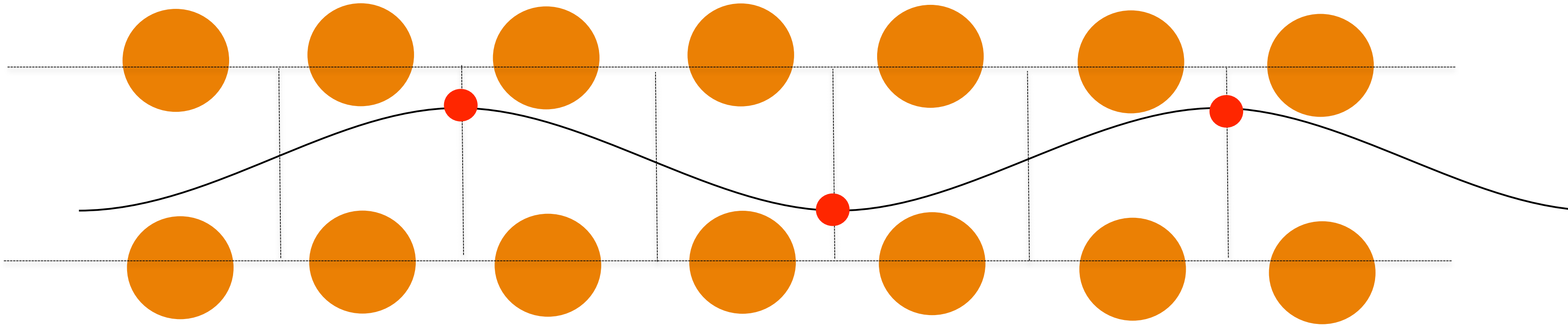


Unstable motion

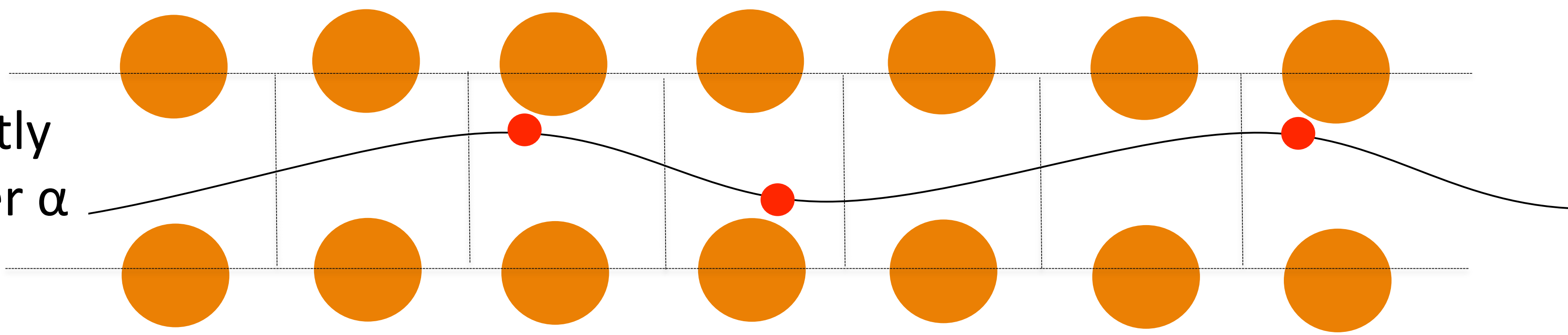


Why is Δ(phase) locked at integers?

perfect stable motion



slightly
larger α



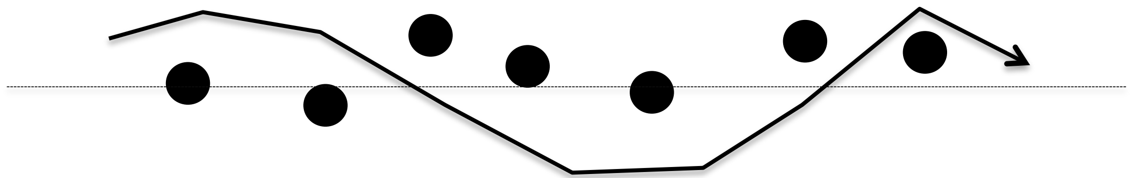
a too *fast* v_y is followed by a too *slow* v_y

=> Δ(phase) *oscillates about* < Δ(phase) >

Axial dechanneling

- Atom displacements
- Residual potential
- Correlations
- Classical or quantum treatment ?

Atom displacements



Position of the n^{th} atom of the string : $\langle \mathbf{R}_n \rangle = (0,0,nd) + \mathbf{u}_n(t)$

$\mathbf{u}_n(t)$ = *displacement* (quantum + thermal)

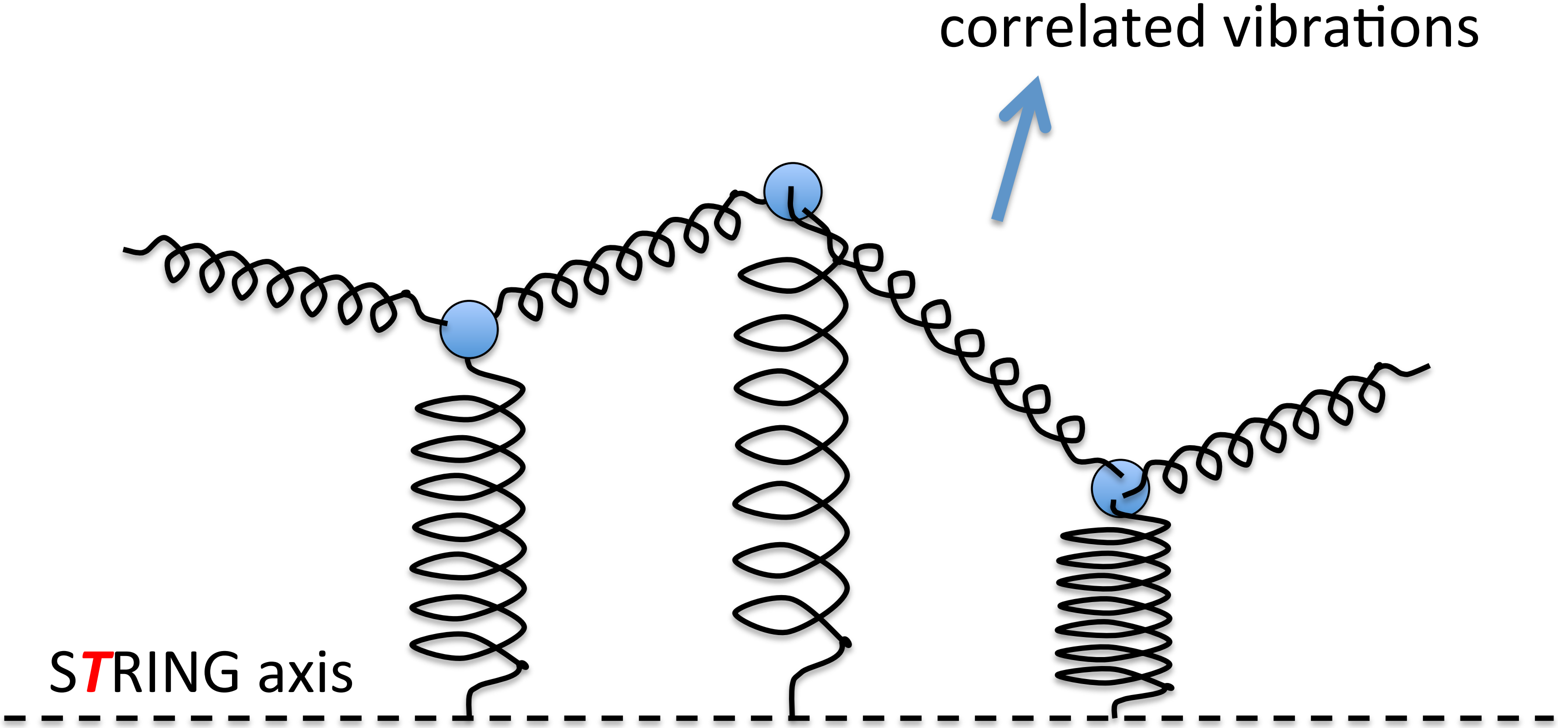
=> convolution by $\exp(-\mathbf{r}^2 / \langle \mathbf{u}^2 \rangle)$ for the string potential

⇒ increases dechanneling.

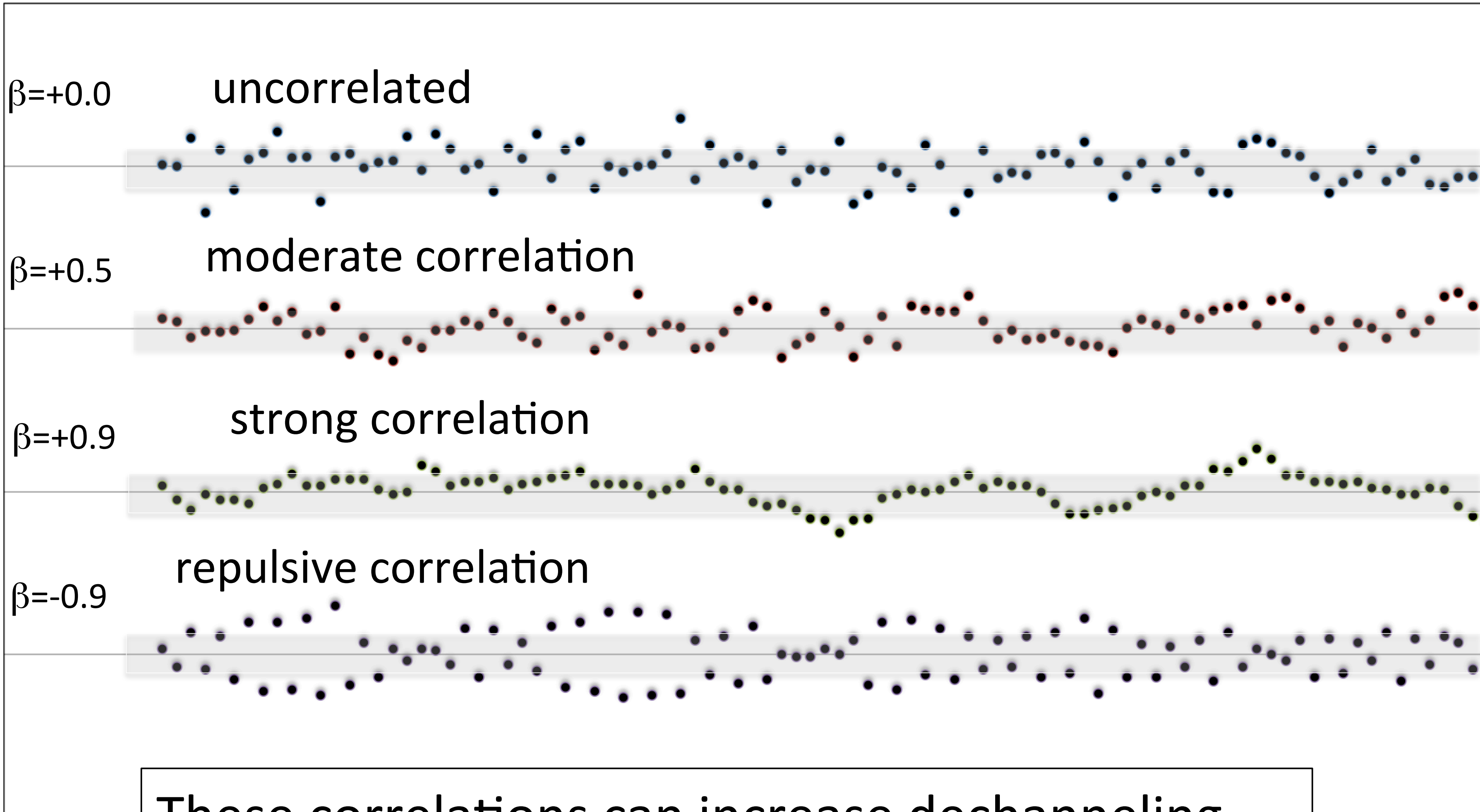
In a ***brutal*** and ***naive*** computer simulation, the particle trajectory is built with *binary collisions*, with $\mathbf{u}_n$ distribution $\simeq \exp(-\mathbf{u}^2 / \langle \mathbf{u}^2 \rangle)$.

=> This ignores ***correlations*** between the displacements of neighbouring atoms [*X. A. Nucl. Instr. Meth (2017)*]

S*P*RING picture of correlated displacements



Correlated atom displacements (simulated)



These correlations can increase dechanneling and, by coherence effects, *channeling radiation*

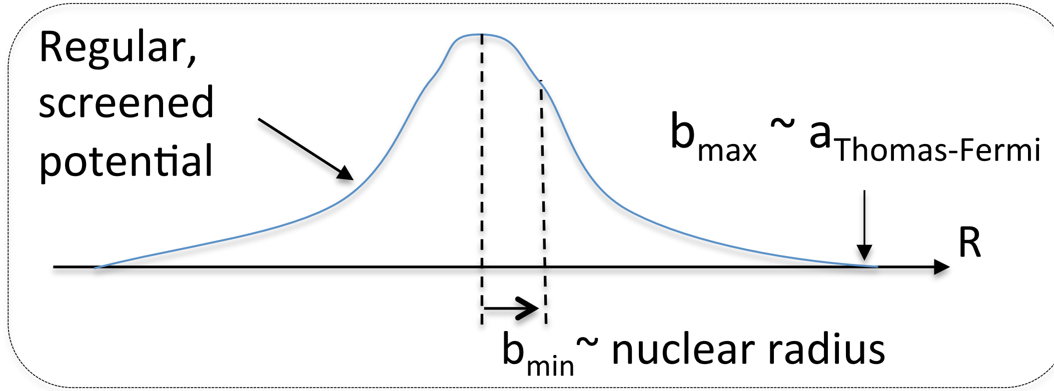
Quantum versus classical de-channeling

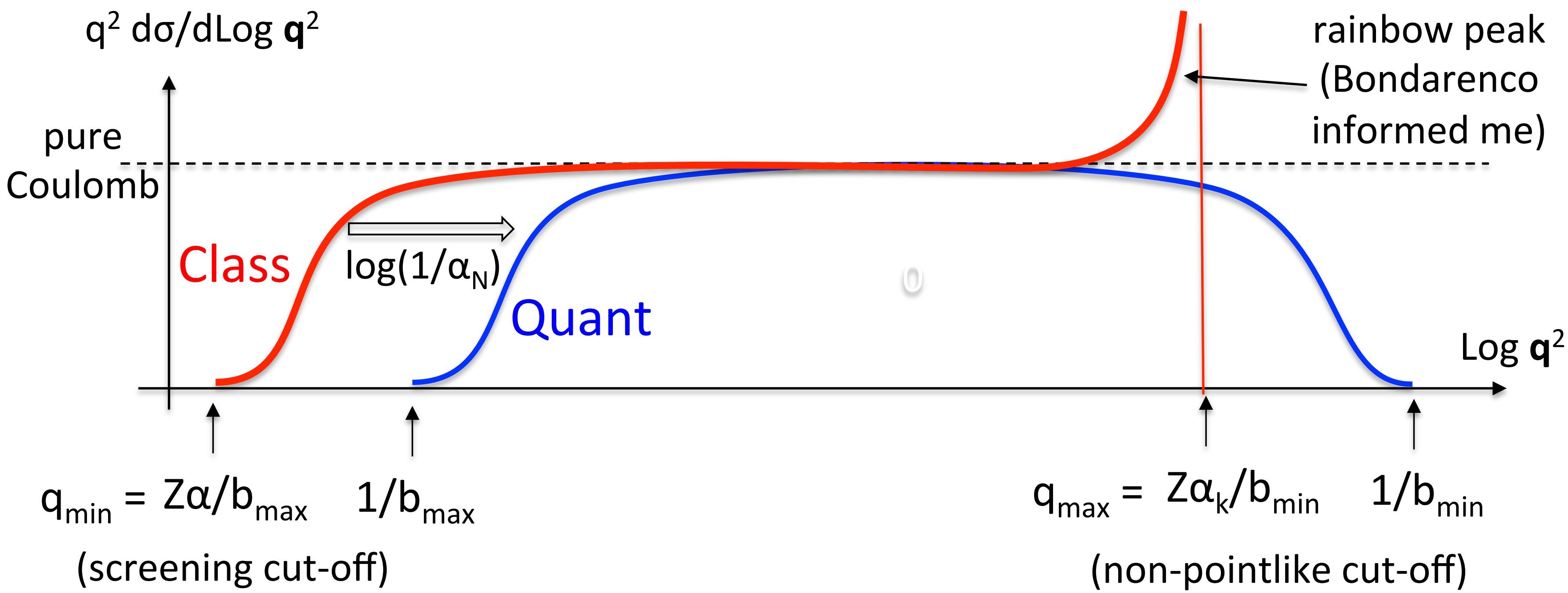
- Comparison classical and quantum cross sections in scattering on an isolated atom

- Residual atomic potentials or « remnant atom »

[*X. A. JINST* ***15*** *C 04010 (2020)*]

Scattering on an isolated atom

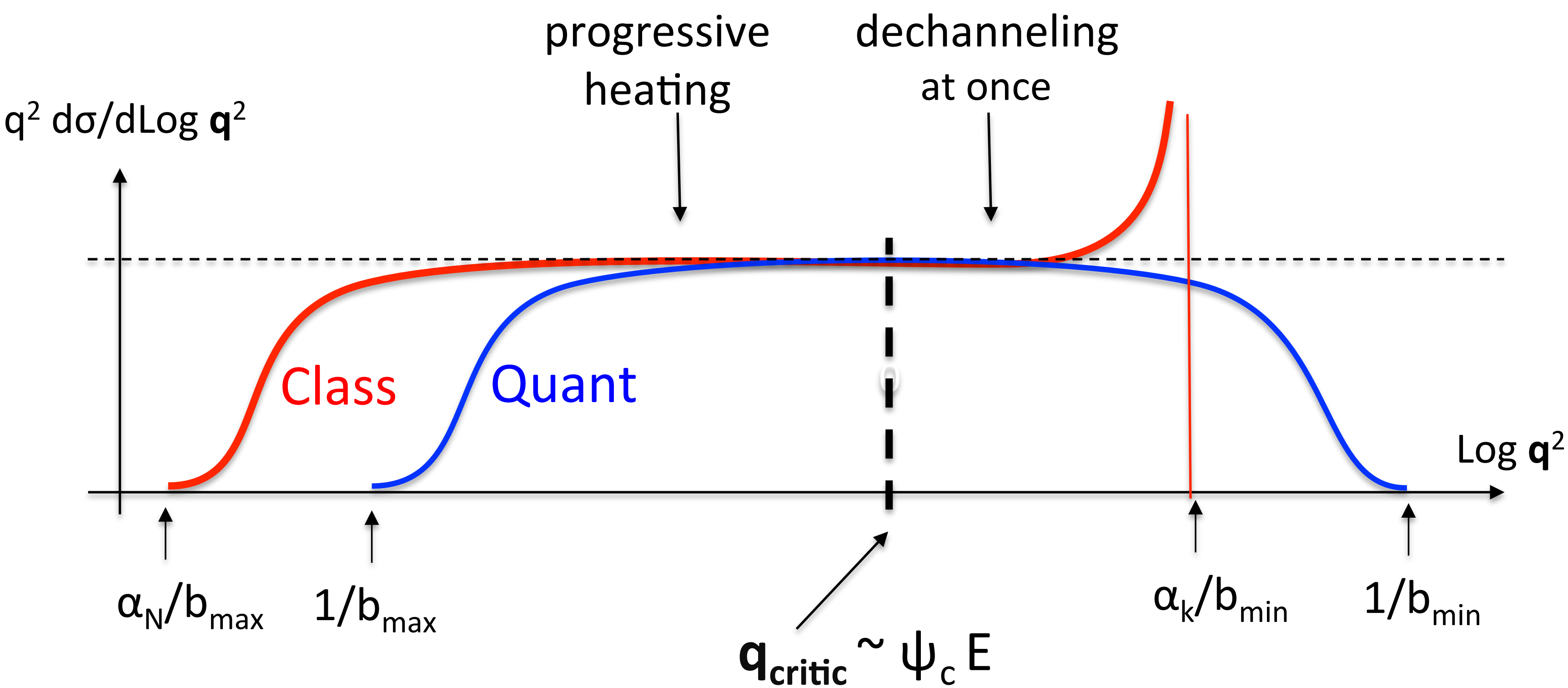




Classical and quantum predict *equal* heating of transverse energy

$$\Delta E_T \approx E^{-1} \int q^2 \, d\sigma$$

Efficiency for dechanneling



Classical de-channeling is *faster* than quantum de-channeling.

Residual potential δV_A (with respect to the Lindhard potential)

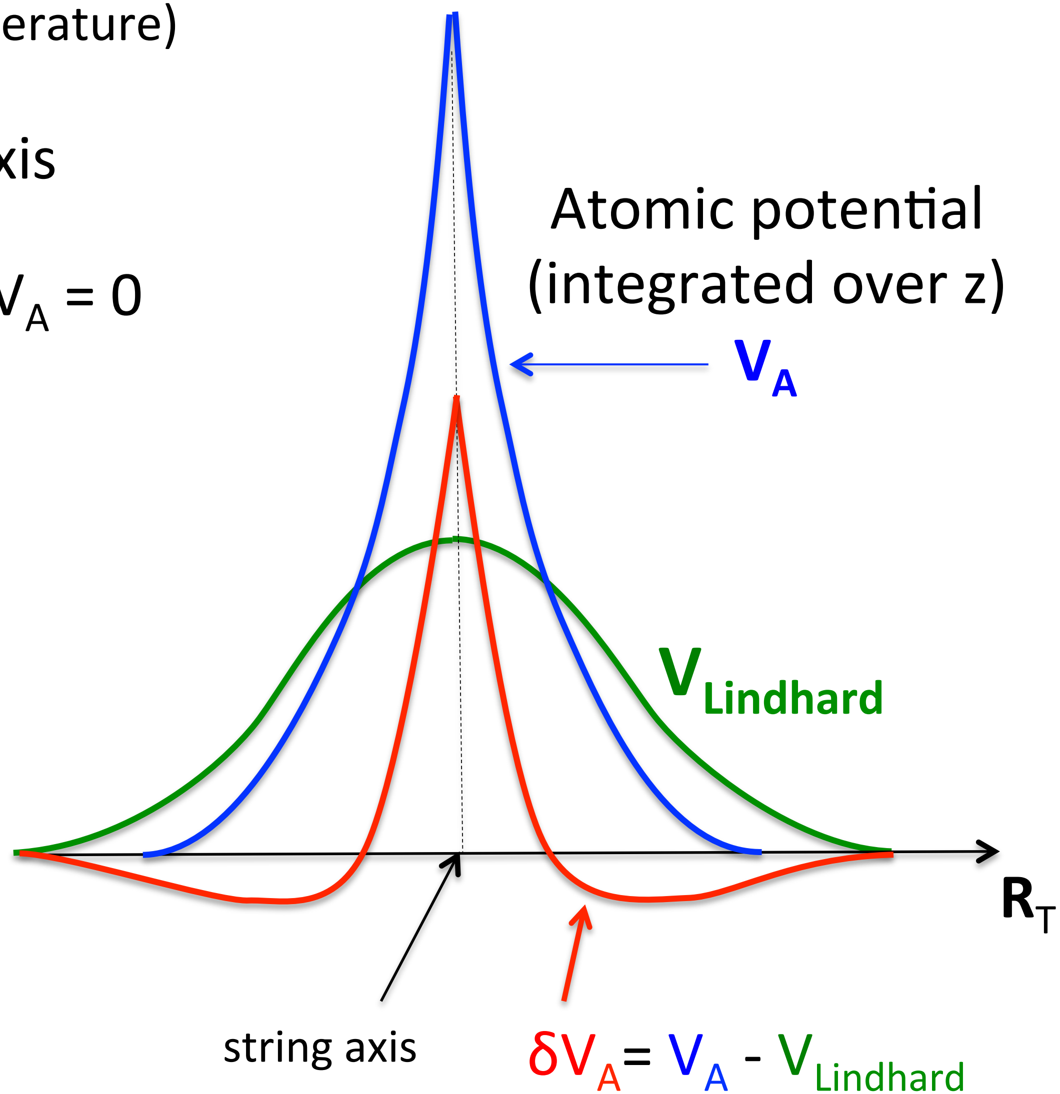
(« remnant atom » in russian litterature)

1) Atom *on* the string axis

Zero mean value : $\int d^3\mathbf{r}\, \delta V_A = 0$

↓

$d\sigma / d\mathbf{q}^2$ *vanishes* at zero momentum transfer $\mathbf{q}$ (instead of finite limit for an isolated atom, or $1/\mathbf{q}^4$ divergence for unscreened charge)



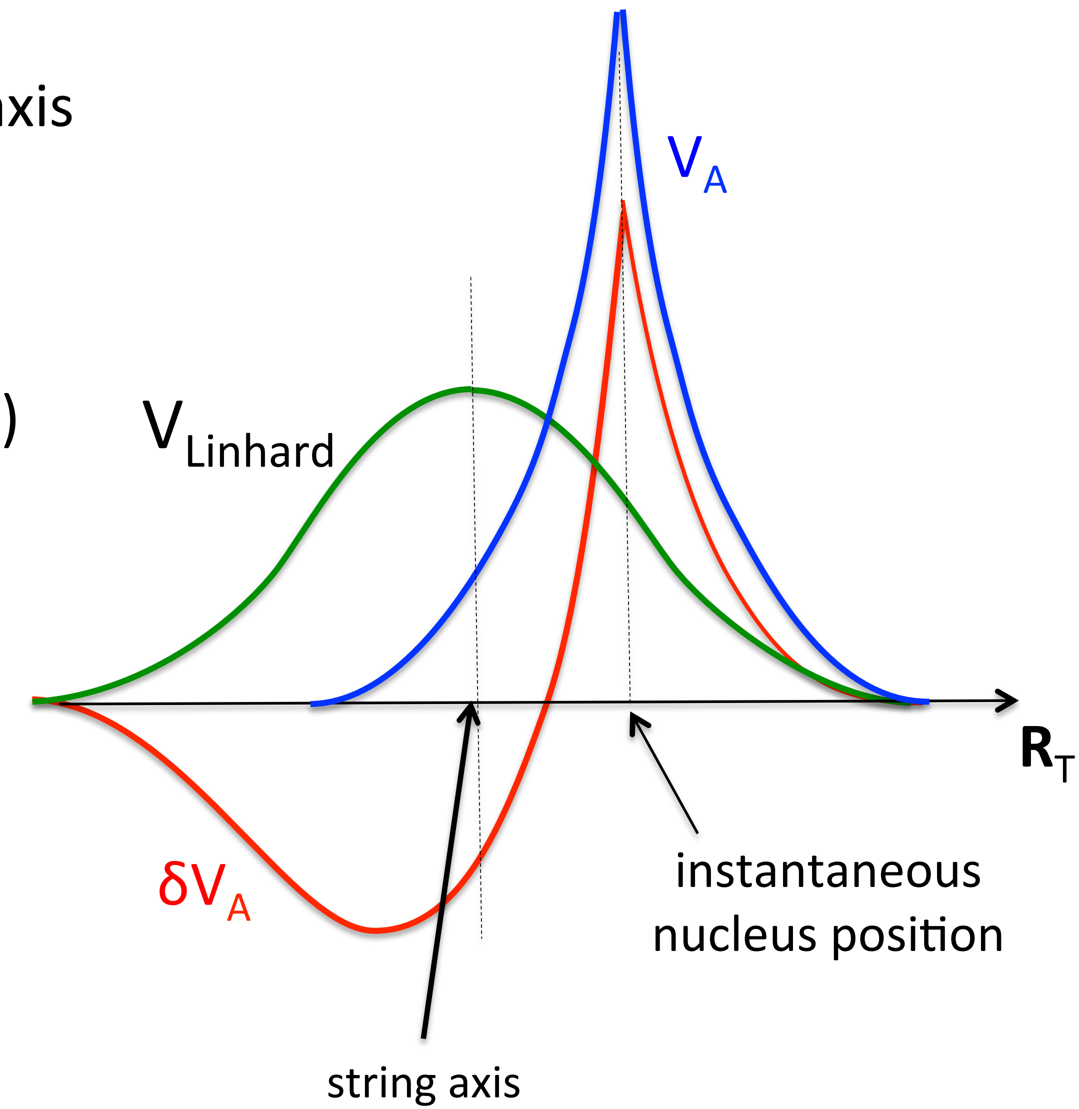
Residual potential δV_A

2) Atom off the string axis

↓

δV_A is asymmetrical

(but $d\sigma/d\mathbf{q}^2$ is symmetrical)

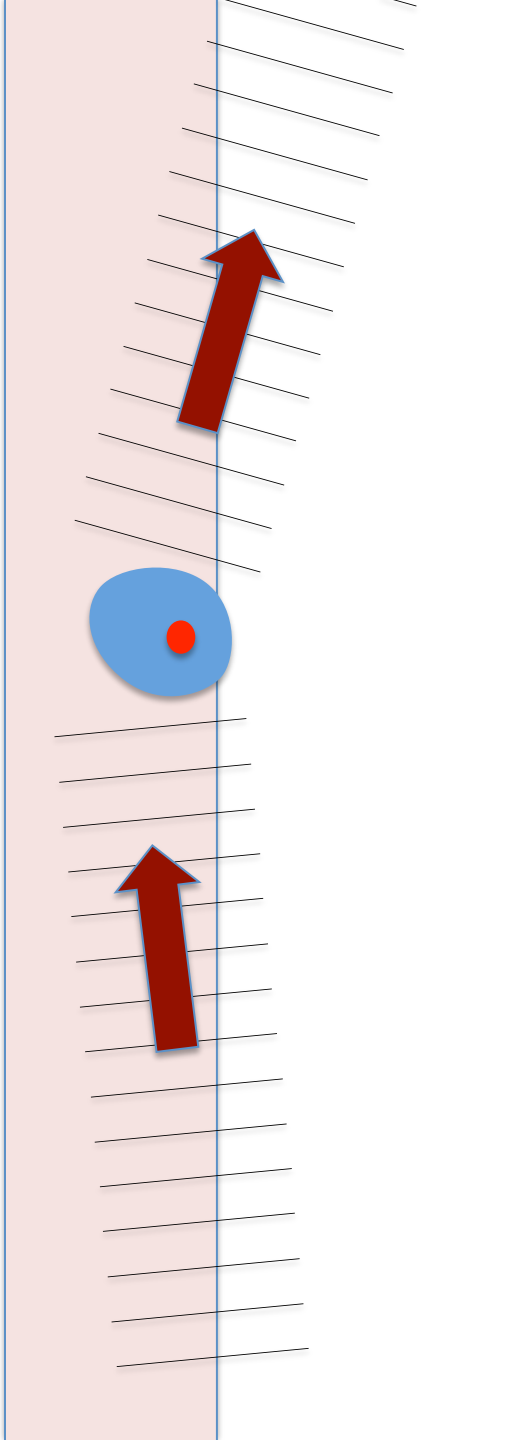


The scattering on a remnant atom should be treated quantum mechanically.
But how ?

- The (Born) quantum cross section
$d^2\sigma/d^2\mathbf{q} \sim |\int \delta V_A(\mathbf{r})\, e^{-iq.r}|^2$
applies to initial and final **plane waves**,
but the particle wave function **is not** a plane wave.

- if we assume the wave packet has a transverse size Δr,
then the use of quantum cross section needs
$\Delta r >> \text{size of } \delta V_A \sim a_{TF} \text{ or } u_1$.

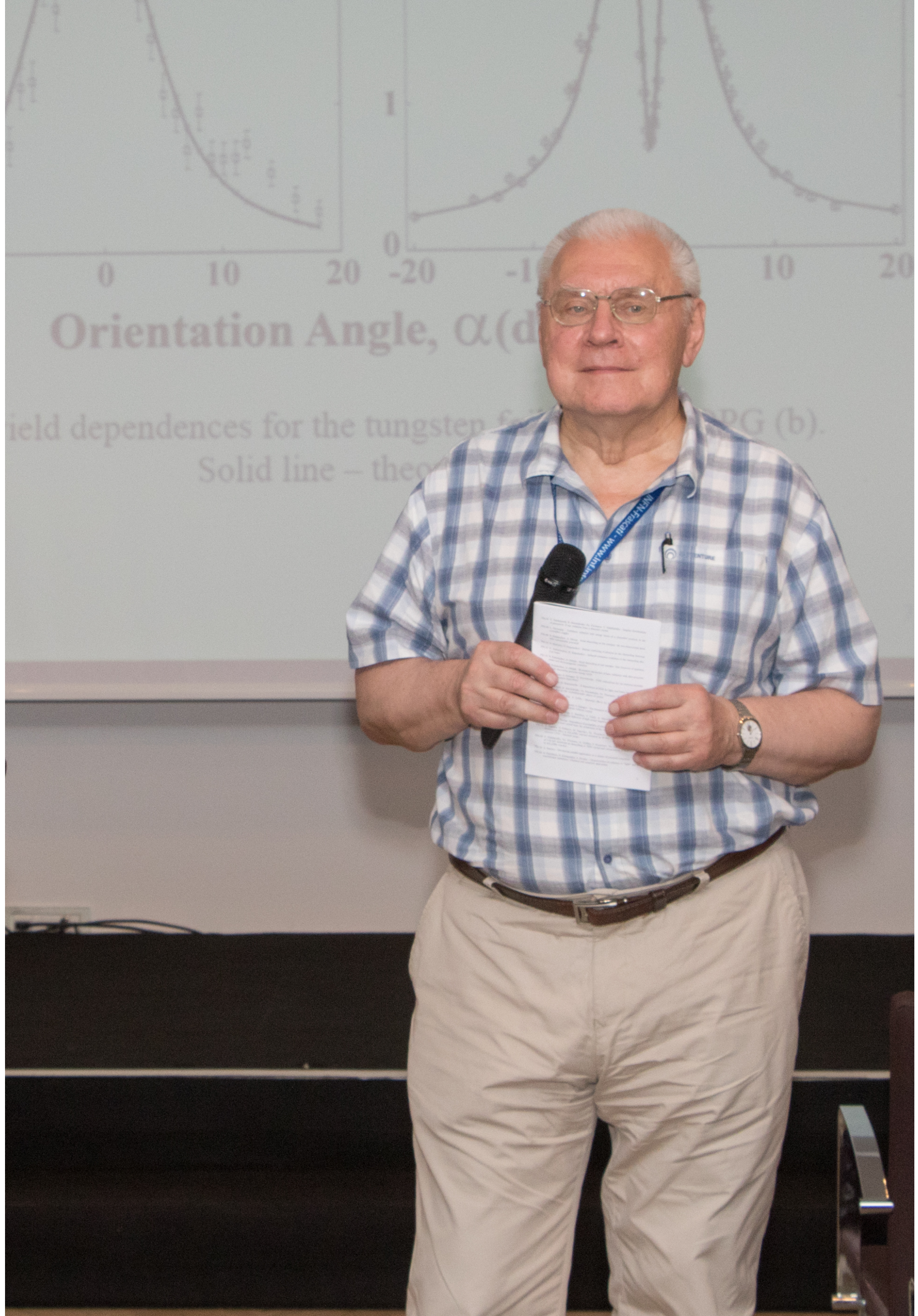
➔ we must give up simulations based on classical trajectories.
Solution : *Wigner distributions ?* [V.V Tikhomirov, 2019]



Conclusions (some of which are well known)

- The axial potentials of atomic strings can destabilize the channeling motion of particles (of positive charge) at small angle **α** w.r.t. these strings.
  But there are islands in **α** of stability. Here, the **average** number of crossed cells per channeling period is *locked* at integer values.
- The thermal motions of atoms along a string are *correlated*. It can increase channeling radiation and de-channeling
- The classical scattering differential cross section predicts a *faster* de-channeling than the quantum one.
- The incoherent scattering on atoms is due to a *residual potential* δV_A .
  The scattering at *small angle* is inhibited due to $\int d^3\mathbf{r}\ \delta V_A = 0$
  (~ Landau-Pomeranchuk effect).
- It is not easy to find a good phenomenological model including a *quantum* treatment of incoherent scattering by δV_A and *classical* particle trajectories.

THANK YOU FOR YOUR ATTENTION !
THANKS TO THE ORGANIZERS !
THANKS TO NIKOLAI FOR HIS INFATIGABLE WORKS AND MANAGING ACTIVITIES !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