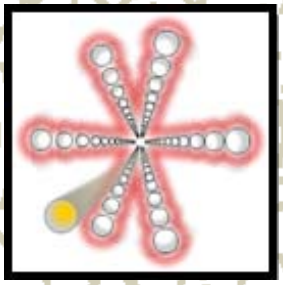

Channeling 2014

Backscattering/transmission of 2 MeV He^{++} ions quantitative correlation study

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Outline

- Planar channeling for positive ions
- Correlations
- Low energy channeling apparatus
- Experimental setup
- Comparison with simulations
- Summary and conclusions
- Future outlook

Planar channeling

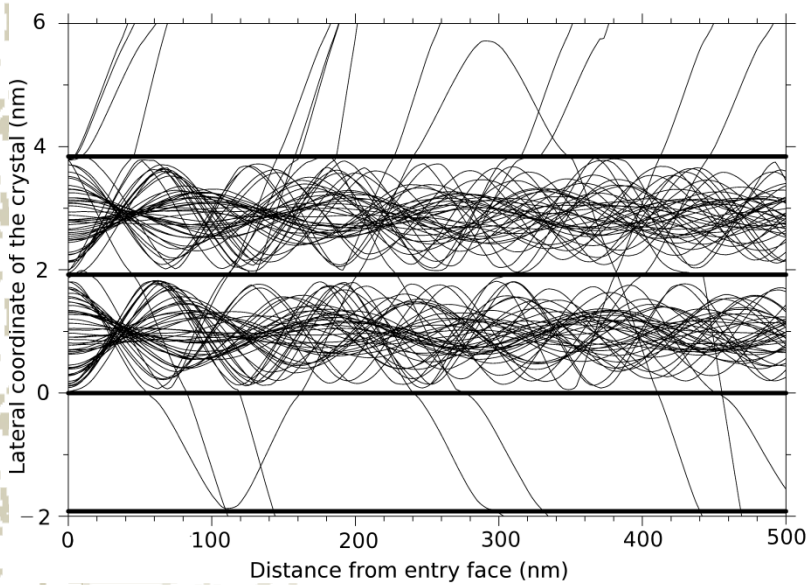


Figure: Simulated trajectories of 2 MeV He^{++} ions between (110) planes of a Si crystal

- Beam impinges at an angle lower than θ_c -> planar channeling
- Collisions with atoms are correlated
- Oscillations between planes
- Wavelength weakly depends on the impact parameter
- -> coherence between the trajectories of the channeled particles
- Multiple scattering on core electrons and atomic nuclei -> loss of coherence

Correlation

Arises when the particles traverse a sufficient distance in the crystal at constant velocity along a near-linear trajectory.

Three types of correlations are considered:

- **1. Superposition of Coulomb potential energy, waked by interaction of He^{++} ions with harmonic crystal potential, with exchange-correlation potential due to multiple scattering effect on electrons. Exchange-correlation potential becomes predominant as channeling trajectory increases its distance path from the entry face of the crystal.**
- **2. Superposition of coherent radiation of the crystal lattice atoms itself induced by backscattered/channeled He^{++} ions, and radiation field secondary emitted by projectiles (He^{++} ions).**
- **3. Interference effects exhibited in neighboring (110) Si planar stacking sequences between coherent He^{++} channeled trajectories.**

Coherence and channeling

- **The effect of coherence arises during the interaction of charged particle with a crystal potential when the interaction amplitudes of the emitted/channeled particles are summing up in the phase with individual lattice atoms.**

- **Coherence being the central part of the interference phenomena, produces phase summing, identifying an interferential multiplier in the scattering cross–section, which leads to appearance of coherent peaks when the transferred momentum coincides (it is in resonance) with one of the reciprocal lattice vectors.**

- **This happens due to periodical arrangement of the crystal atoms, at selected parameters (beam energy, angles of incidence with respect to crystallographic axes or planes).**

✓ Channeling and coherence can occur simultaneously producing a joint effect.

Low energy channeling apparatus

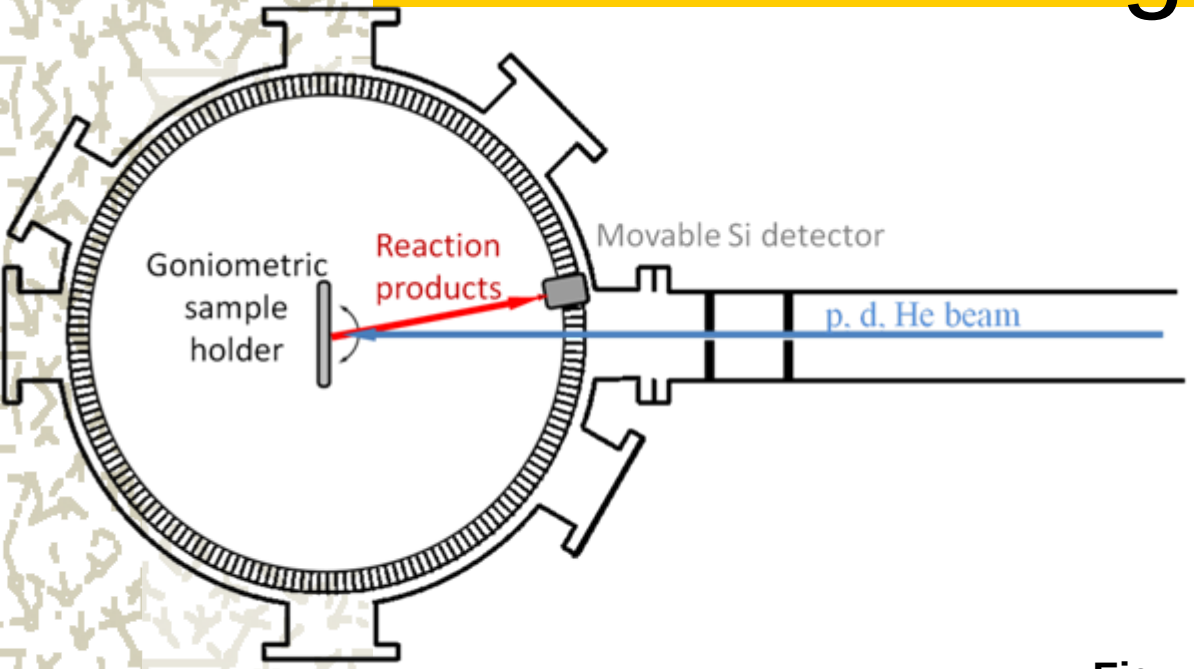


Figure: Experimental apparatus

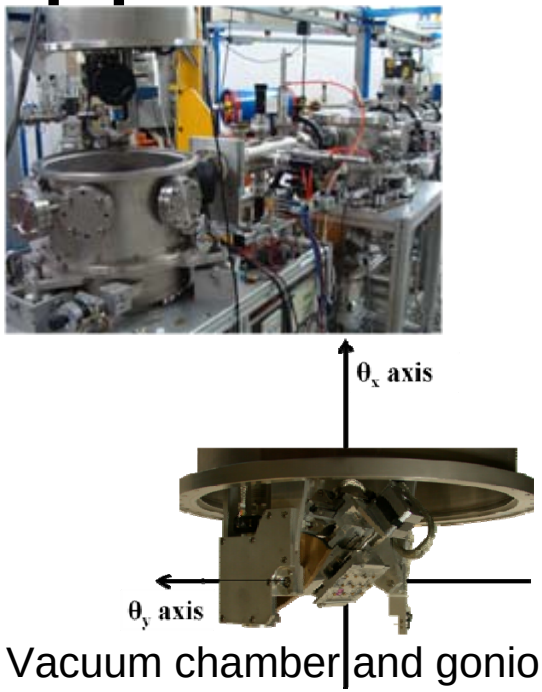


Figure: Vacuum chamber and goniometer

Channeling chamber at LNL-AN2000 accelerator:

- α or p^+ beams available
- Energies: from 2 to 7 MeV
- 2 rotational degrees of freedom for the goniometer, 1 for the Si detector

Experimental setup

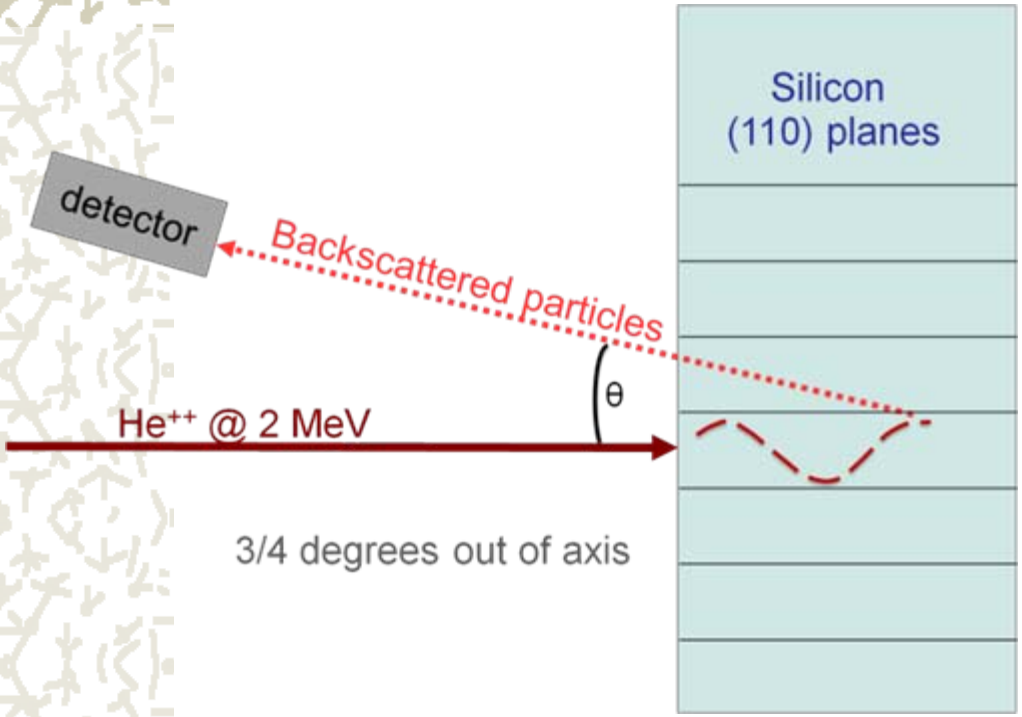


Figure: Scheme of the experimental apparatus.

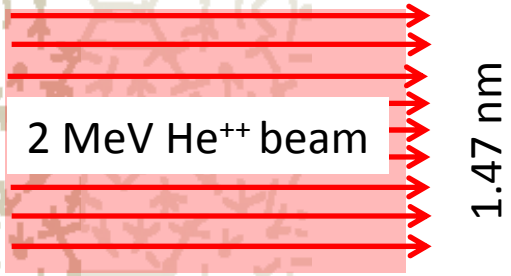
- 2.0 MeV He++ ions delivered to a (100)-oriented Si wafer
- To avoid <100> axial channeling, beam set to be a few degrees out of axis
- 3 different angles chosen for the detector (108°, 115°,170°)
- Energy spectrum of backscattered particles recorded

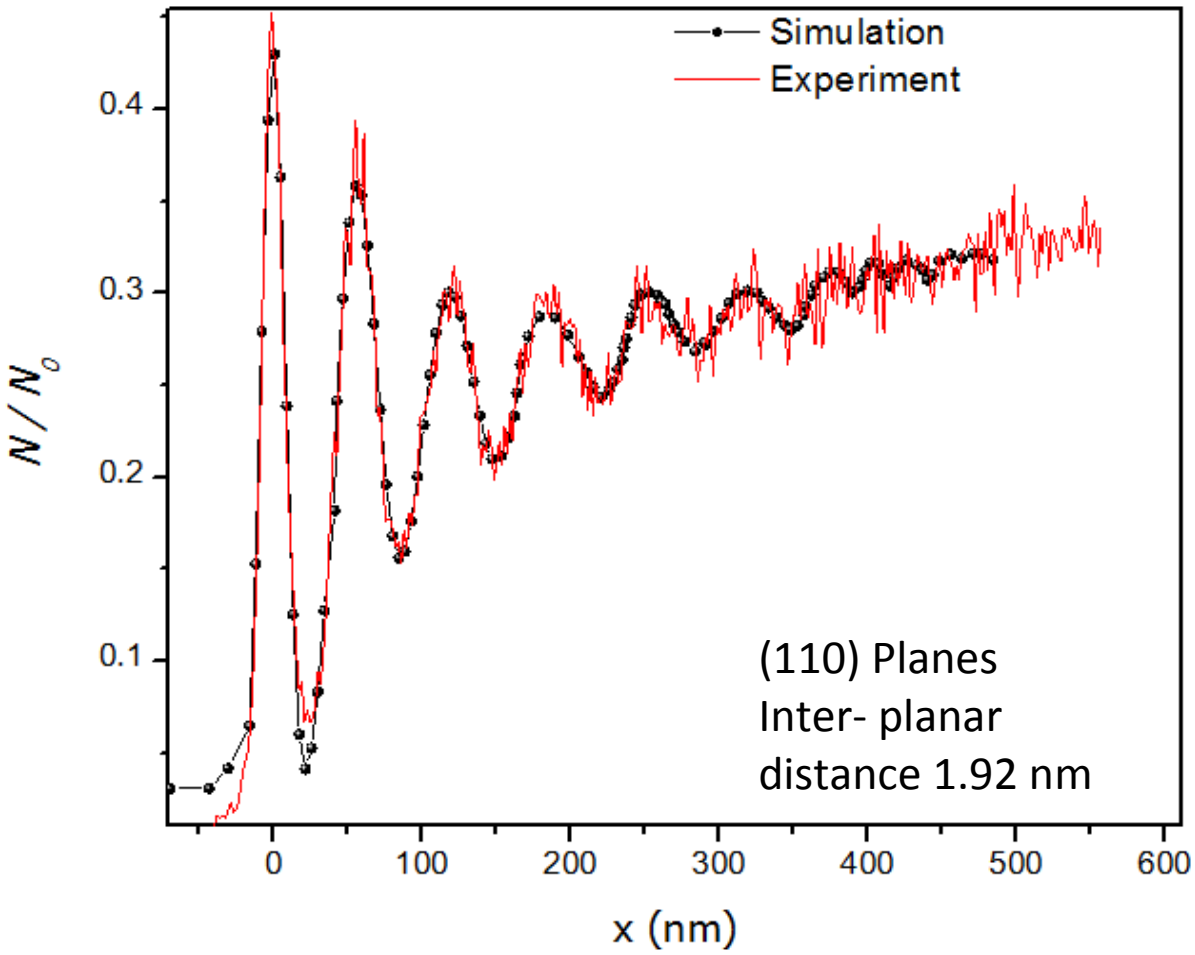
Comparison with simulations

Simulation input parameters

- Beam: 2 MeV He^{++} particles.
- Beam divergence: 0 degrees.

- Target: Silicon crystal, (110) Planes.
- Beam impinging parallely to atomic planes.





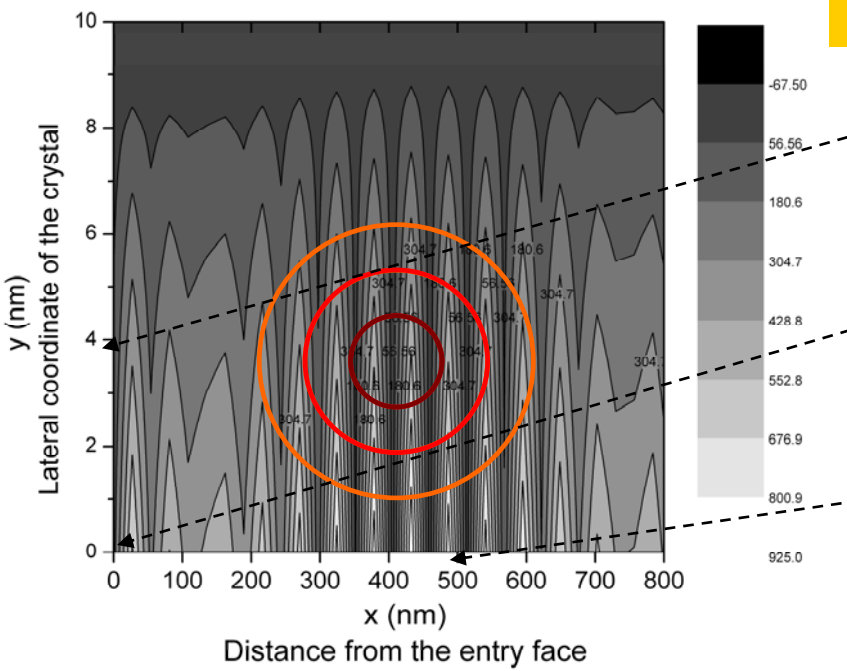
Coherence effect and correlation

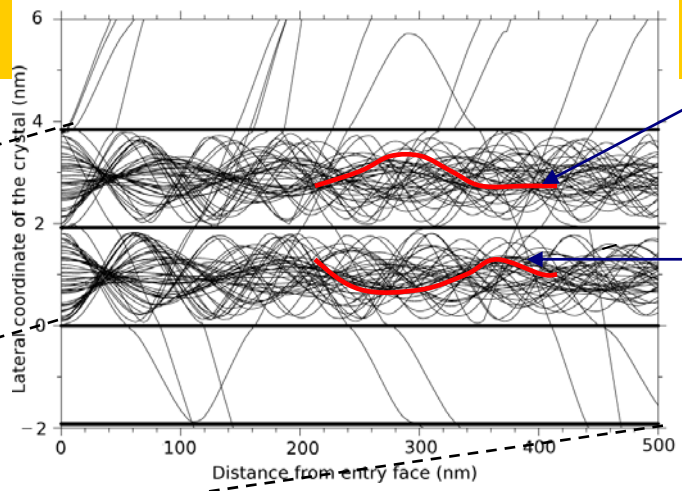
- Assuming the lattice periodicity within the of Bloch's model we express coherence effect, induced by correlation of the ion soft collisions over electron density of states and the waked potential, in terms of a Fourier spectral decomposition:

$$\phi_k = \sum_x e^{ikx} \phi_x$$

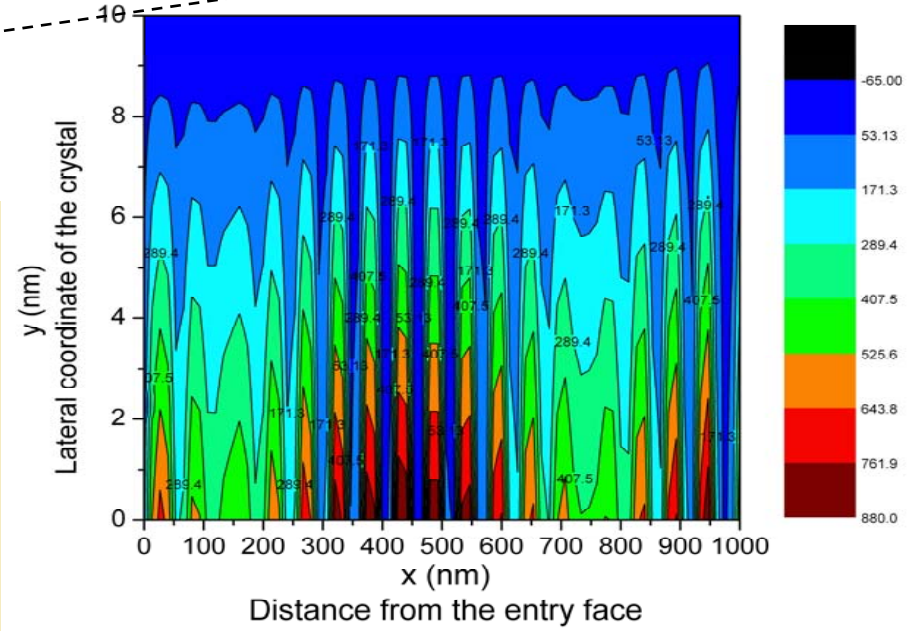
- In order to perform numerical simulation of channeled ion trajectories, coherent in spacetime with a lattice, we apply path integral formalism over a system ((100)Si crystal plane) whose degrees of freedom consist of effective potential field variable φ_x at each lattice site x.

Correlated He^{++} trajectories





interference effects exhibited between correlated channeled He++ trajectories



Effect of coherence, established over channeled He^{++} trajectories, becomes predominant at 200-600 nm distances from the entry face of crystal. Coherent motion of channeled He^{++} ions is precisely guided through (110) planar stacking sequence of silicon atoms using simultaneous correlation, i.e. superposition of Coulomb potential energy caused by interaction of He^{++} ions with harmonic crystal potential, and exchange-correlation potential due to multiple scattering effect on electrons.

Summary and conclusions

- **We reported a detailed description of planar channeling oscillations of 2 MeV He^{++} particles channeled between (110) atomic planes of a silicon crystal.**
- **Backscattering/transmission experiments with 2 MeV He^{++} ions were performed to study the exact correlation between the confined particles oscillating trajectories.**
- **Regular patterns of channeled ion planar oscillations are shown to be dominated by the crystal harmonic-oscillator potential and multiple scattering effects. Quantitative estimation of channeling efficiency and electronic dechanneling length were performed.**
- **Correlation and combined coherence effect for 2 MeV He^{++} particles in backscattering/transmission geometry are analyzed.**

Future outlook

- **Comparative analysis between 2 MeV protons and 2 MeV He^{++} particles, channeled between (110) atomic planes of a silicon crystal, considering quantitative and qualitative analysis of:**

  - **Electron dechanneling length;**
  - **Coherence effect and interference between neighboring planar stacking sequences;**
  - **Correlation due to multiple scattering effect on electrons..**