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FOR NUCLEAR RESEARCH

Frank Laboratory of Neutron Physics
Лаборатория нейтронной физики им. И.М. Франка

A new experiment on study non-stationary neutron diffraction by surface acoustic waves

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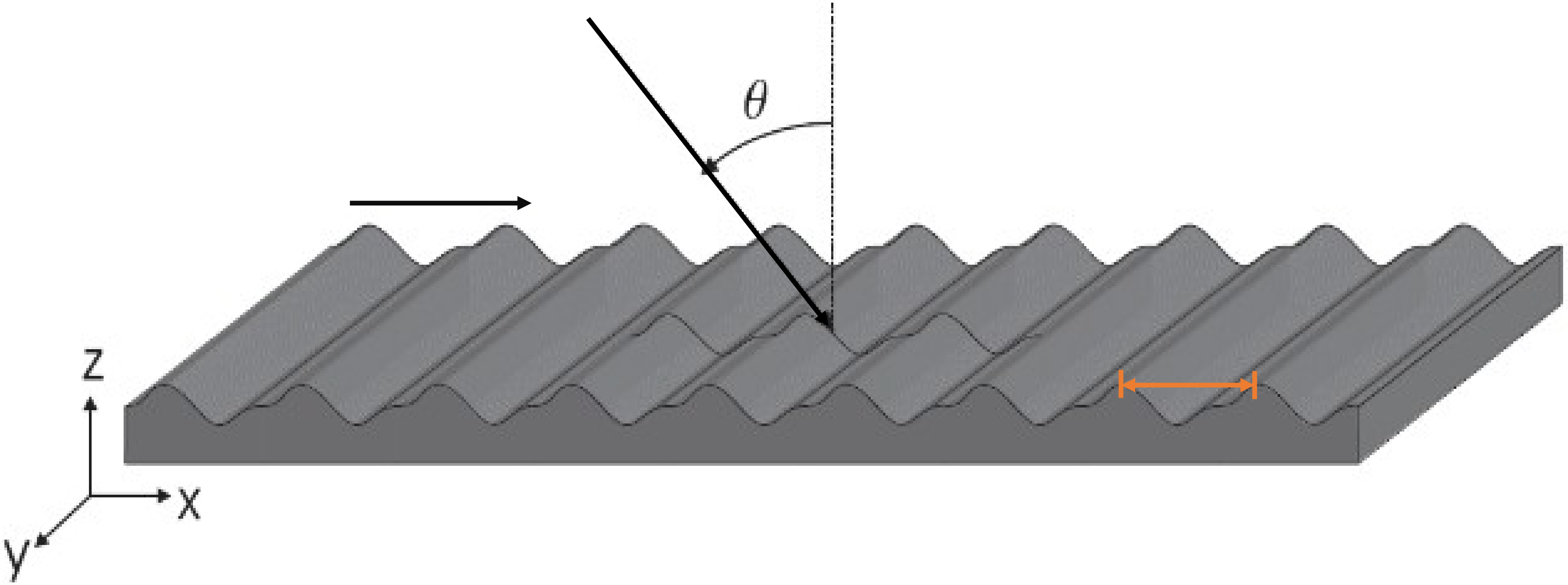
International Seminar on Interaction of Neutrons with Nuclei.

Non-stationary neutron diffraction by surface acoustic waves (SAW)

Non-stationary diffraction is a quantum phenomenon in which a quantum of energy is transferred to neutron

Initial neutron beam



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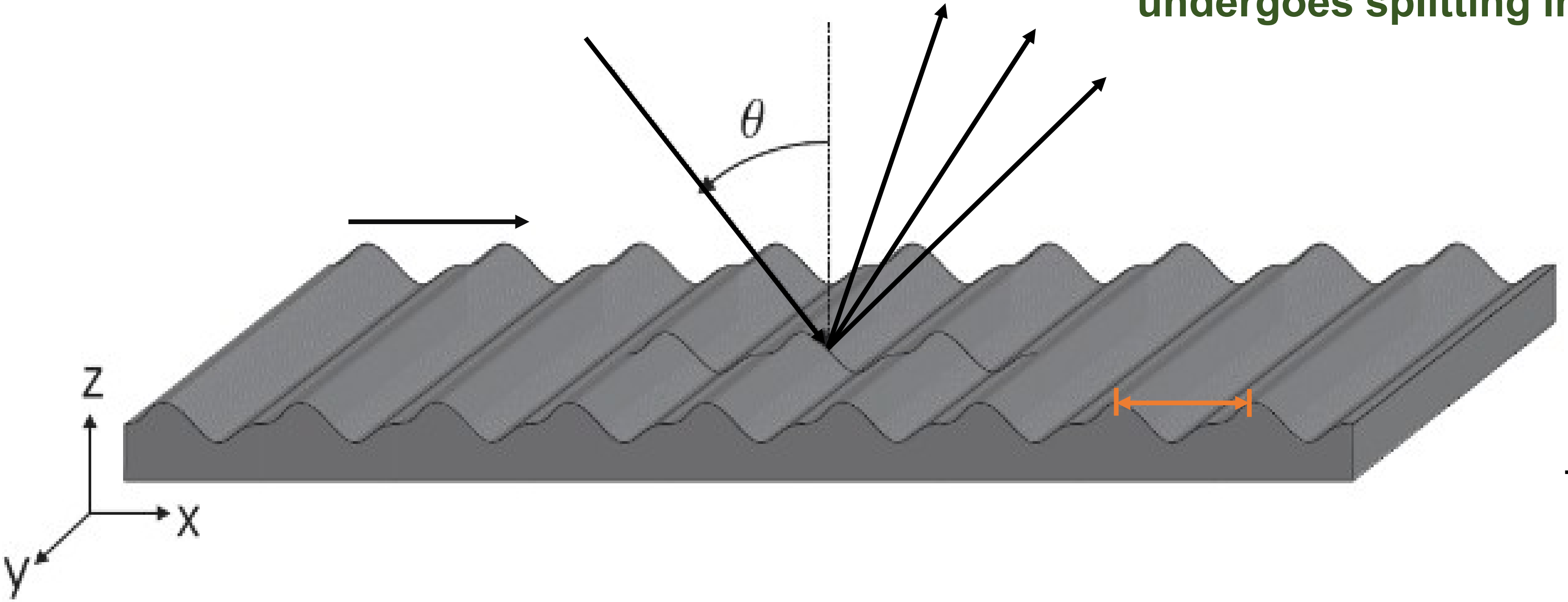
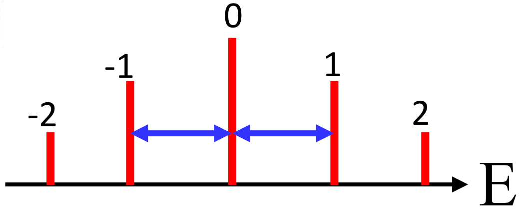
The neutron beam after interaction with SAW undergoes splitting in angles and energy



Energy spectrum



SAW modulation frequency

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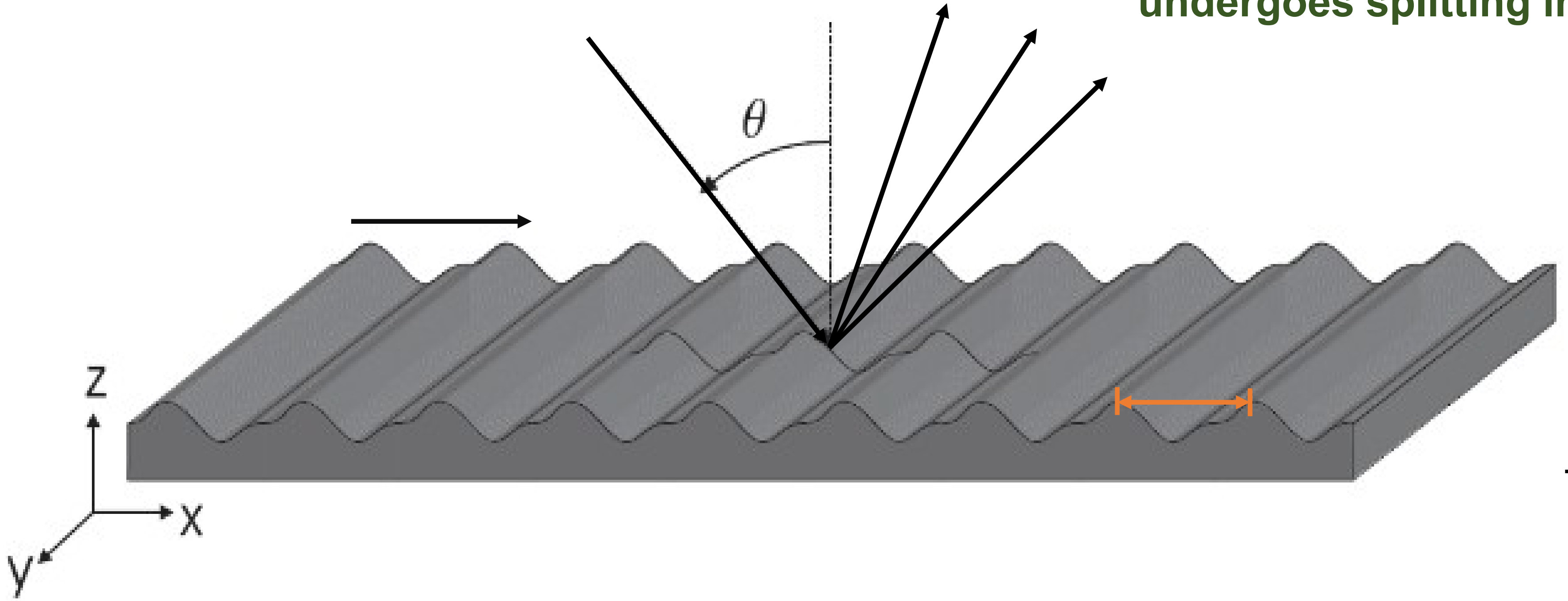
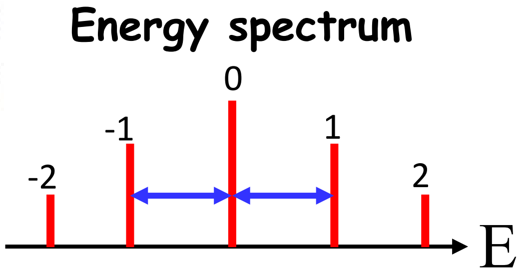




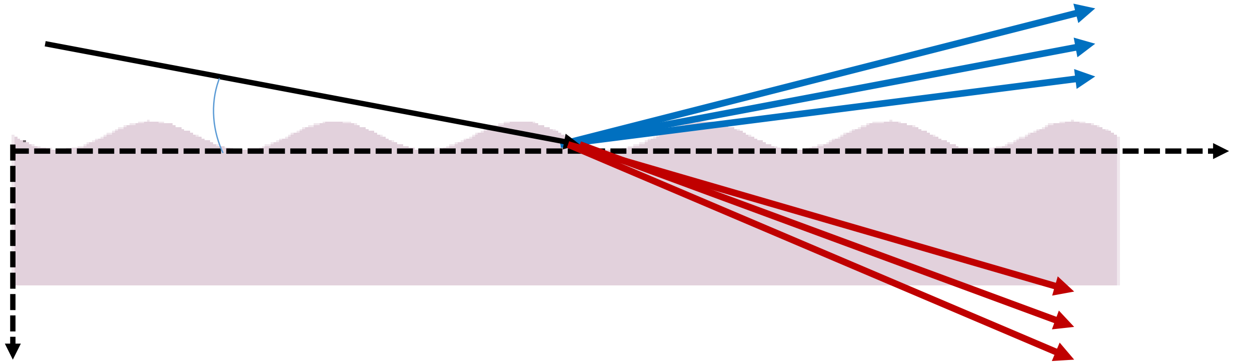
SAW modulation frequency

I. M. Frank JINR Comm. R4-8851 (1975) — possibility of inelastic process of neutron diffraction on surface (Rayleigh) waves in connection with the so-called UCN storage anomaly.

W. A. Hamilton, A. G. Klein, G. I. Opat and P. A. Timmins. Phys. Rev. Lett. 58, 2770 (1987) – first experimental observation.

G. V. Kulin, A. I. Frank, V. A. Bushuev et al. Phys. Rev. B 101 (2020) – previous experiment to study non-stationary neutron diffraction by SAW.

Theory of non-stationary neutron diffraction by SAW



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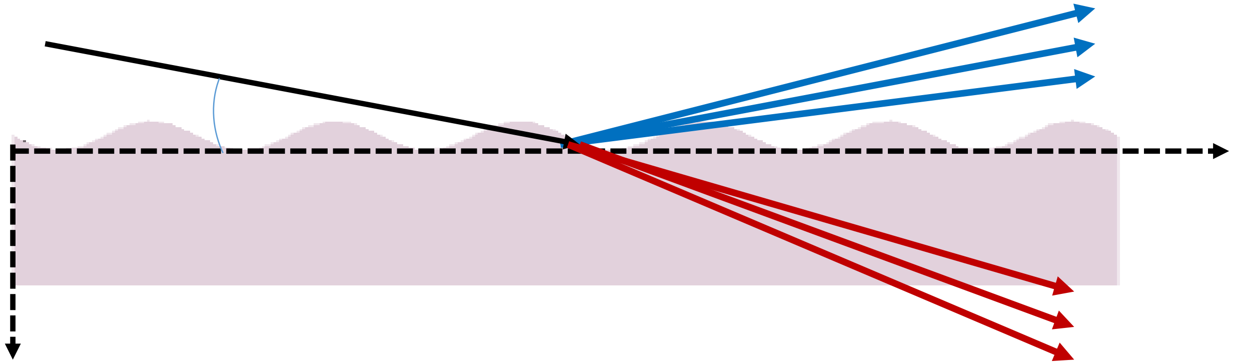
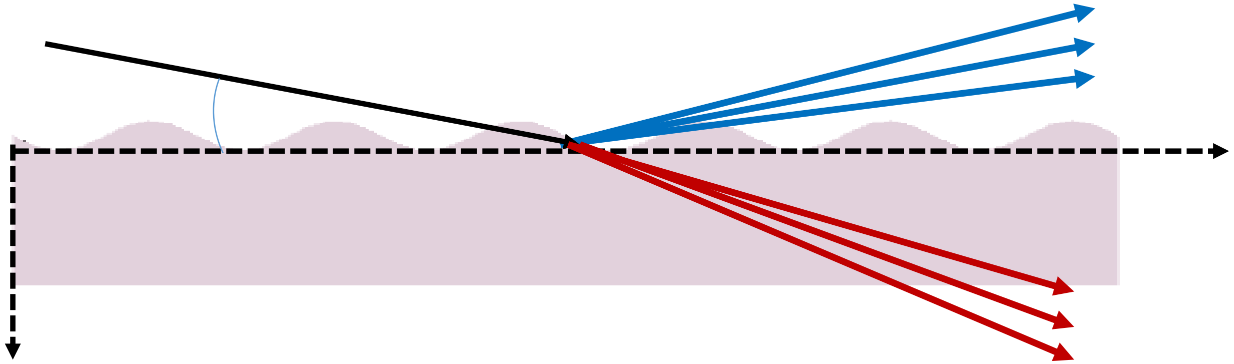


Continuity equations at the interface z_s (boundary conditions)

G. V. Kulin, A. I. Frank, V. A. Bushuev et al. Phys. Rev. B 101 (2020)

Theory of non-stationary neutron diffraction by SAW



Continuity equations at the interface z_s (boundary conditions)

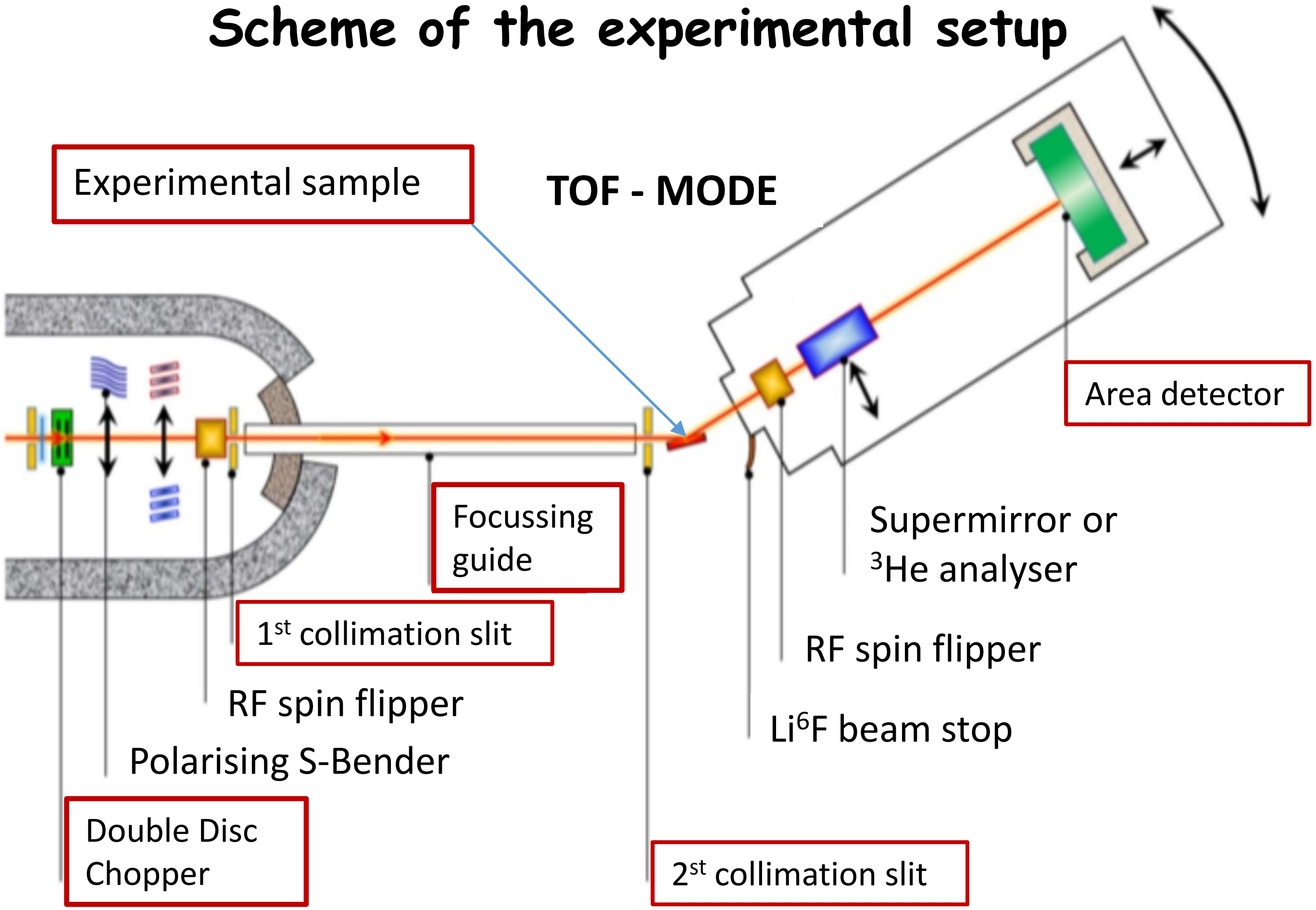
Intensities of diffraction orders (for 0 and ±1):

Diffraction angles:

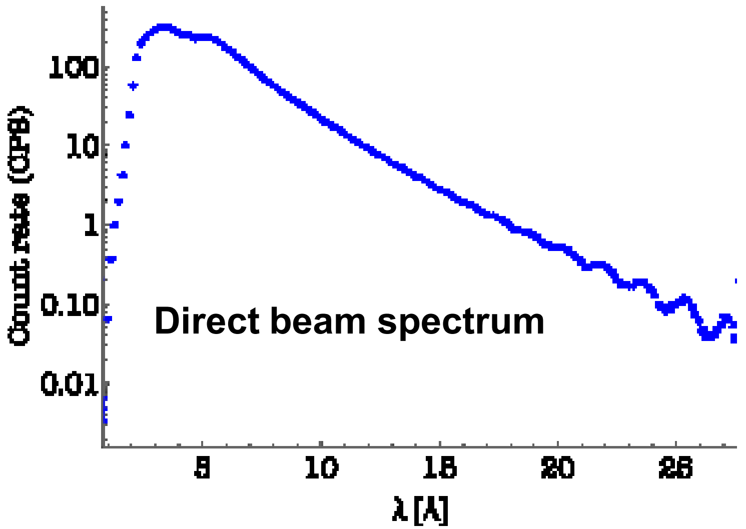
G. V. Kulin, A. I. Frank, V. A. Bushuev et al. Phys. Rev. B 101 (2020)

Neutron diffraction by SAW. TOF mode @D17 (ILL, Grenoble)

Scheme of the experimental setup

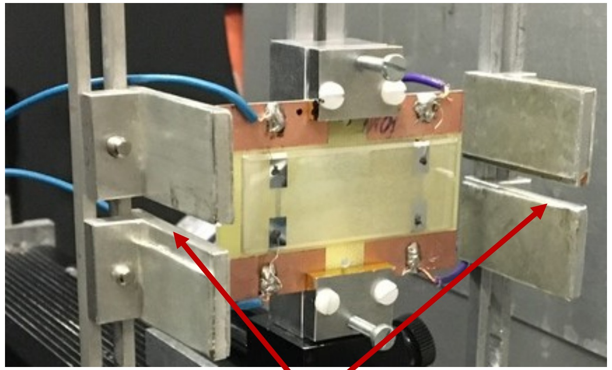


Measurement accuracy of the experimental setup



Neutron diffraction by SAW. TOF mode @D17 (ILL, Grenoble)

Experimental sample - Lithium niobate single crystal ($LiNbO_3$)



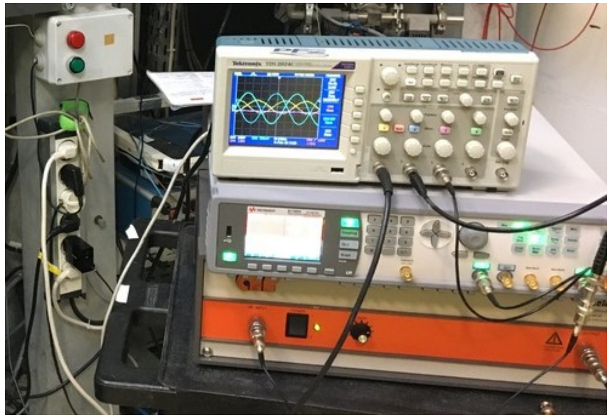
Slits forming the profile of the incident beam.

The experiment was performed with three samples, designed for frequencies of 35, 70 and 117 MHz

and the energy transferred to the neutron was ±145, ± 290 and ±485 neV respectively.

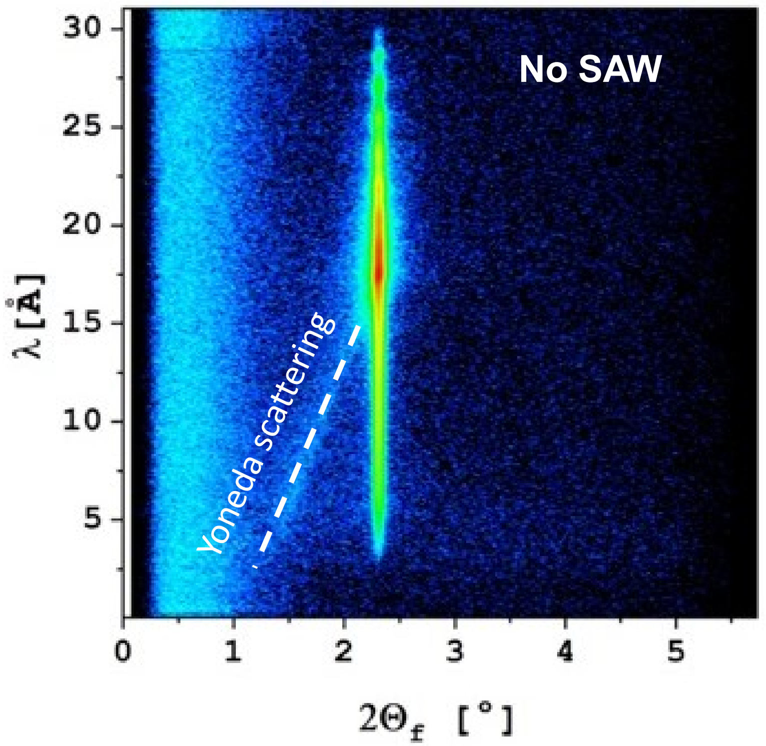
Measurements was perform for several value of SAW amplitudes.

SAW velocity 3490 m/sec > $\mathbf{V_n}$ = 920 m/sec (4.3 Å)

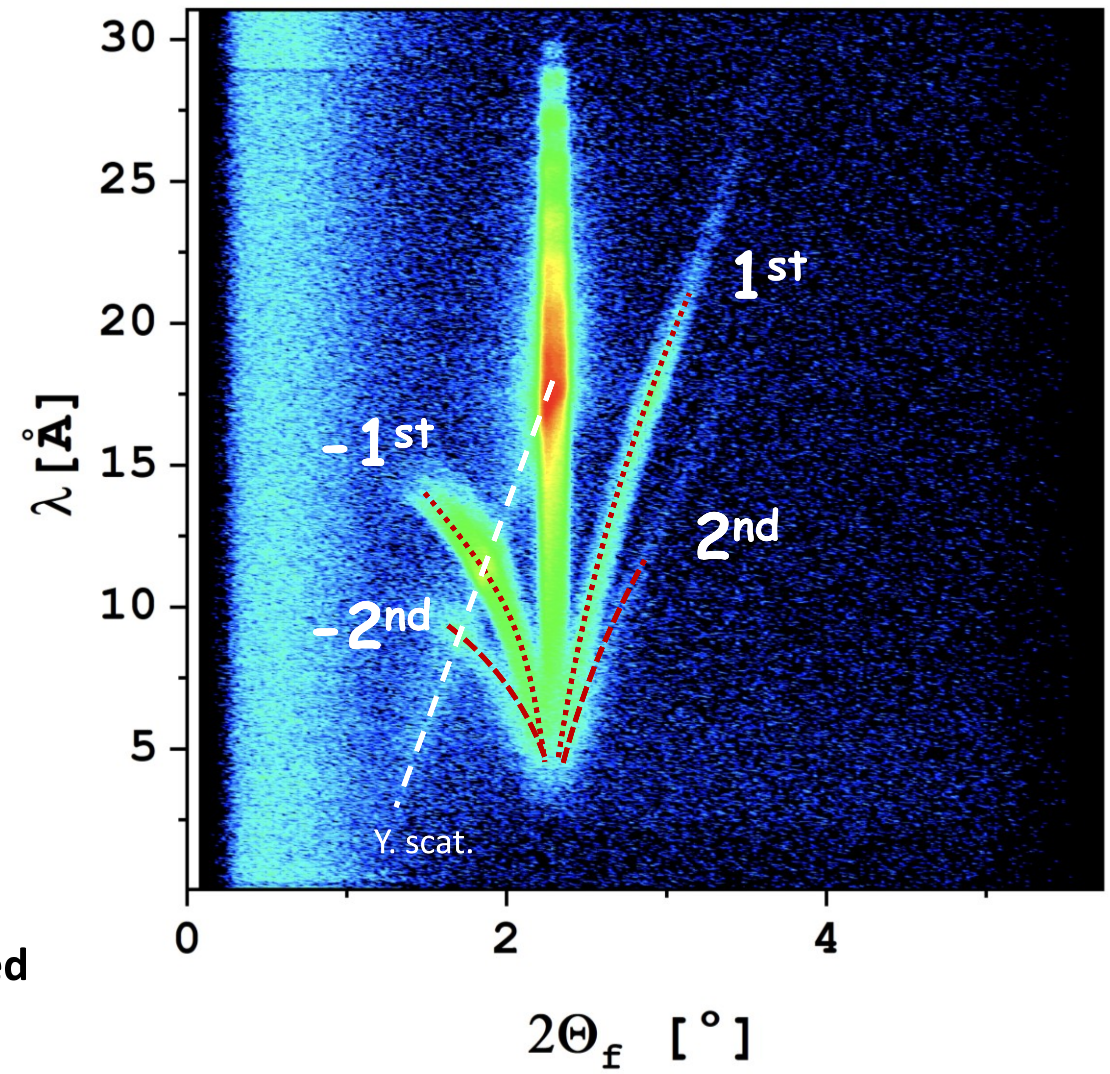


- The signal from the passive electrode is directly proportional to the amplitude of the excited SAW (monitoring and measuring by oscilloscope).
- The correspondence between the value of the signal and the SAW amplitude was measured in a separate optical experiment.

Results of the experiment.



SAW frequency 34.9 MHz
SAW amplitude 40 Å (U_{out}=40.4V)



Angular distributions of diffracted beams

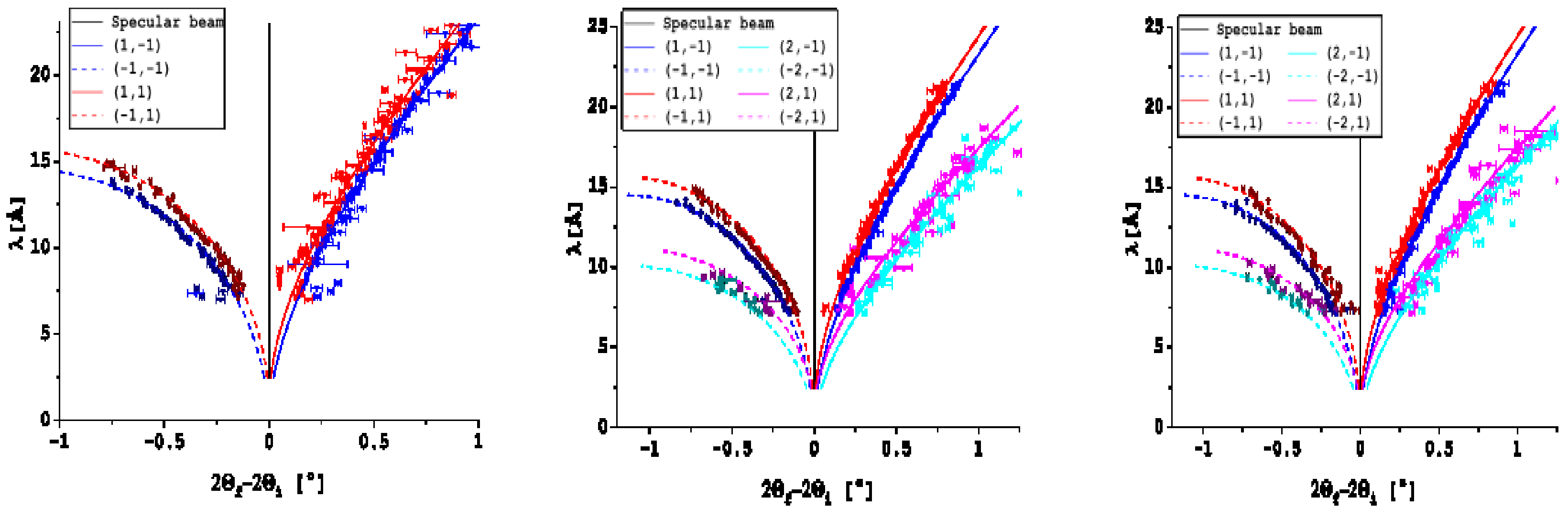
and

Intensity of diffracted beams

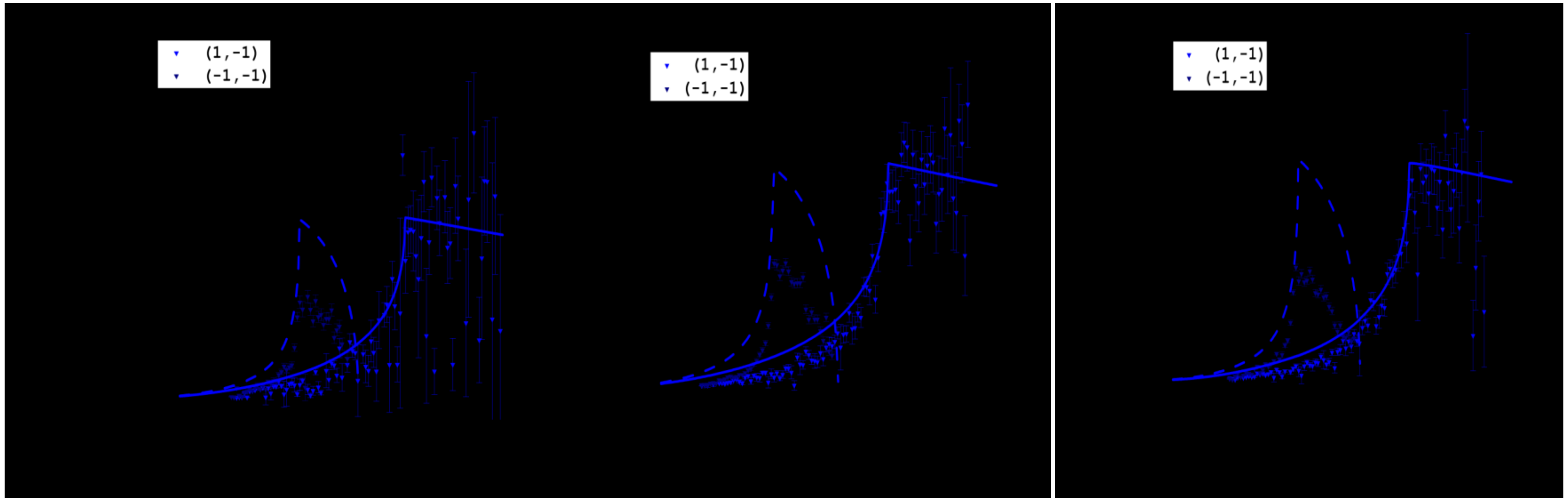
was analyzed

34.9 MHz

- Angular distributions of diffracted beams are in good agreement with calculations



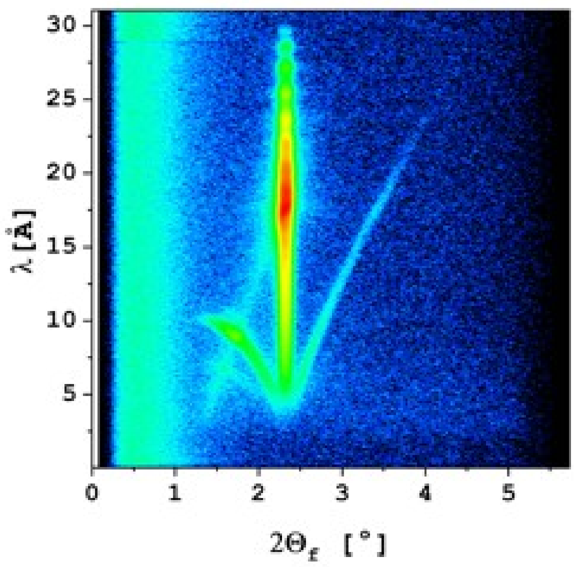
SAW amplitude 20 Å SAW amplitude 31 Å SAW amplitude 40 Å

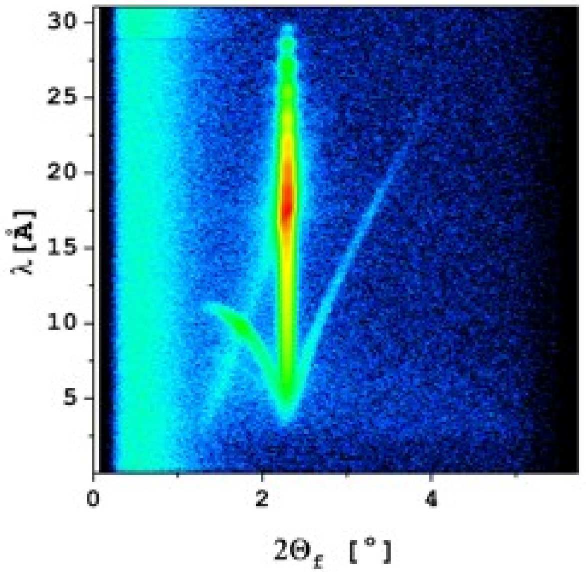


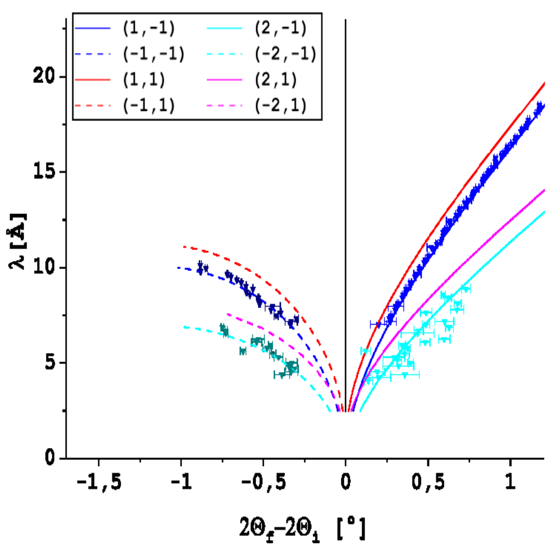
- The diffraction efficiency increases quadratically with increase of SAW amplitude

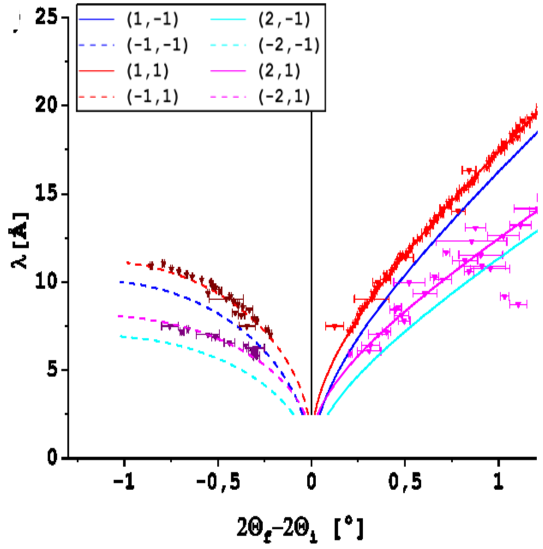
- There is a significant deficit in the intensity of the -1 diffraction order

70 MHz

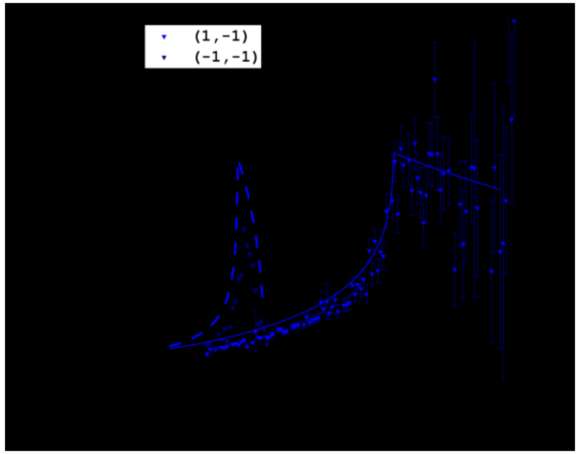




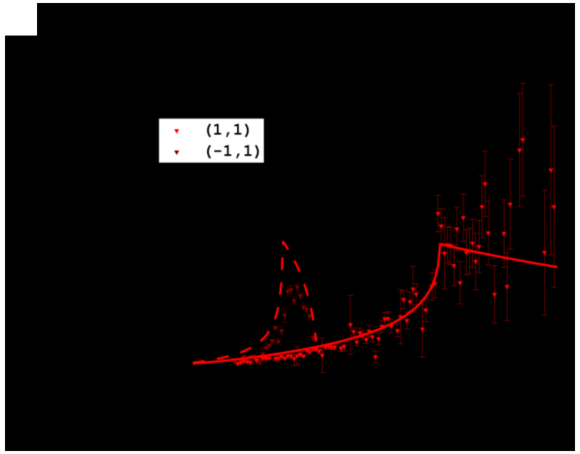




SAW moved towards the beam



SAW moved co-directed to the beam



- There is also the deficit in the intensity of the -1 diffraction order

Possible reasons for the discrepancy between theory and experimental results

1. Problems in the experiment

(Systematic errors)

2. Insufficiently rigorous theory

(do not take into account all known effects)

3. The presence of currently unknown effects

(new physics?)

Problems in the experiment

For reflectometer

spectral and geometry parameters of incident neutron beam
and reflectivity curve of the samples
was measured individual.

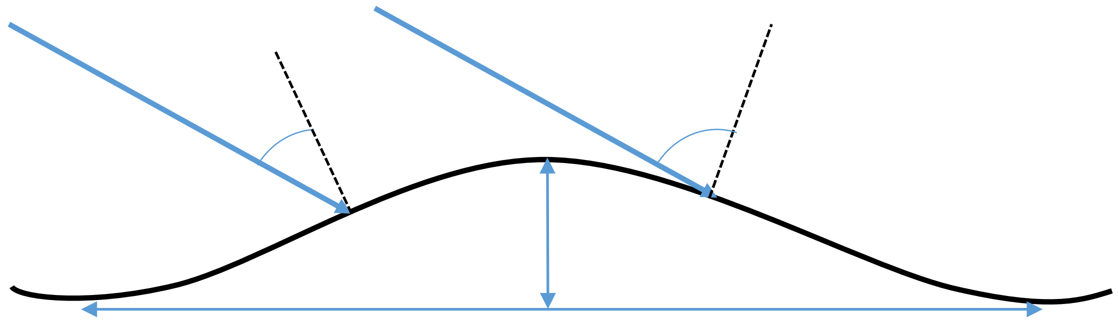
The discrepancy between theory and experimental results
is systematic and was observed in measurements with
different samples operating at
different amplitudes,
different frequencies,
and with different crystal cuts
from different batches.

This may not be a problem of some individual samples.

Non-stationary neutron diffraction by SAW theory

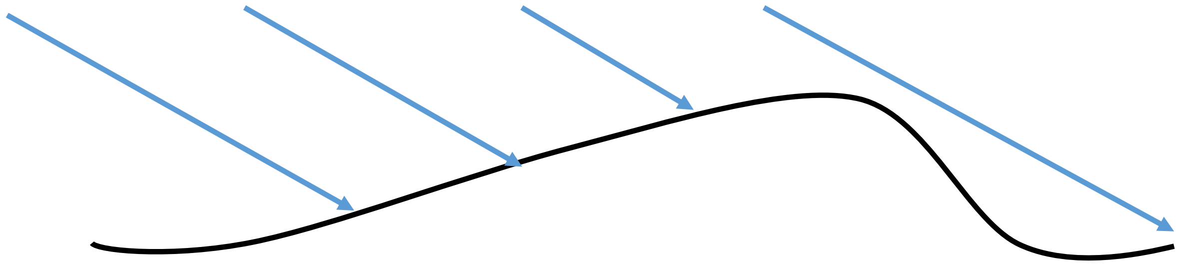
What factors does the previous theory not take into account?

Surface normal variation



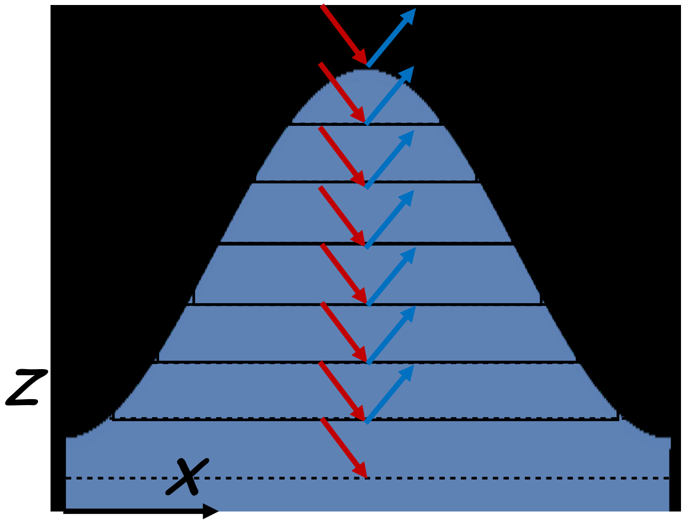
There must be a wavenumber variation

Waveform distortion

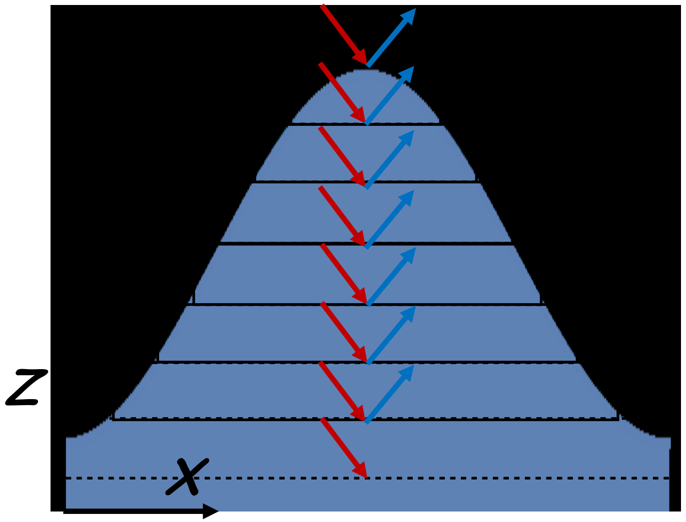


This can influence on
the intensity of diffraction orders

Rigorous coupled-wave analysis

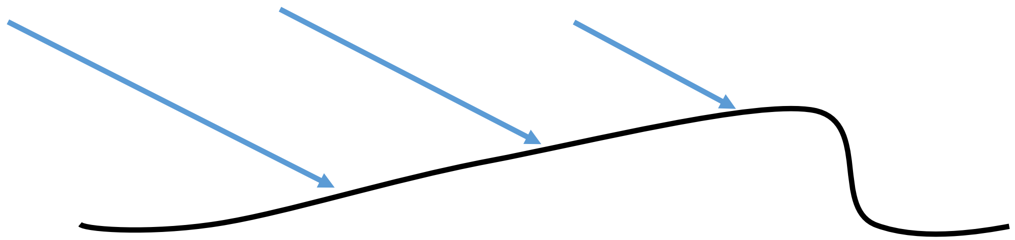


Rigorous coupled-wave analysis



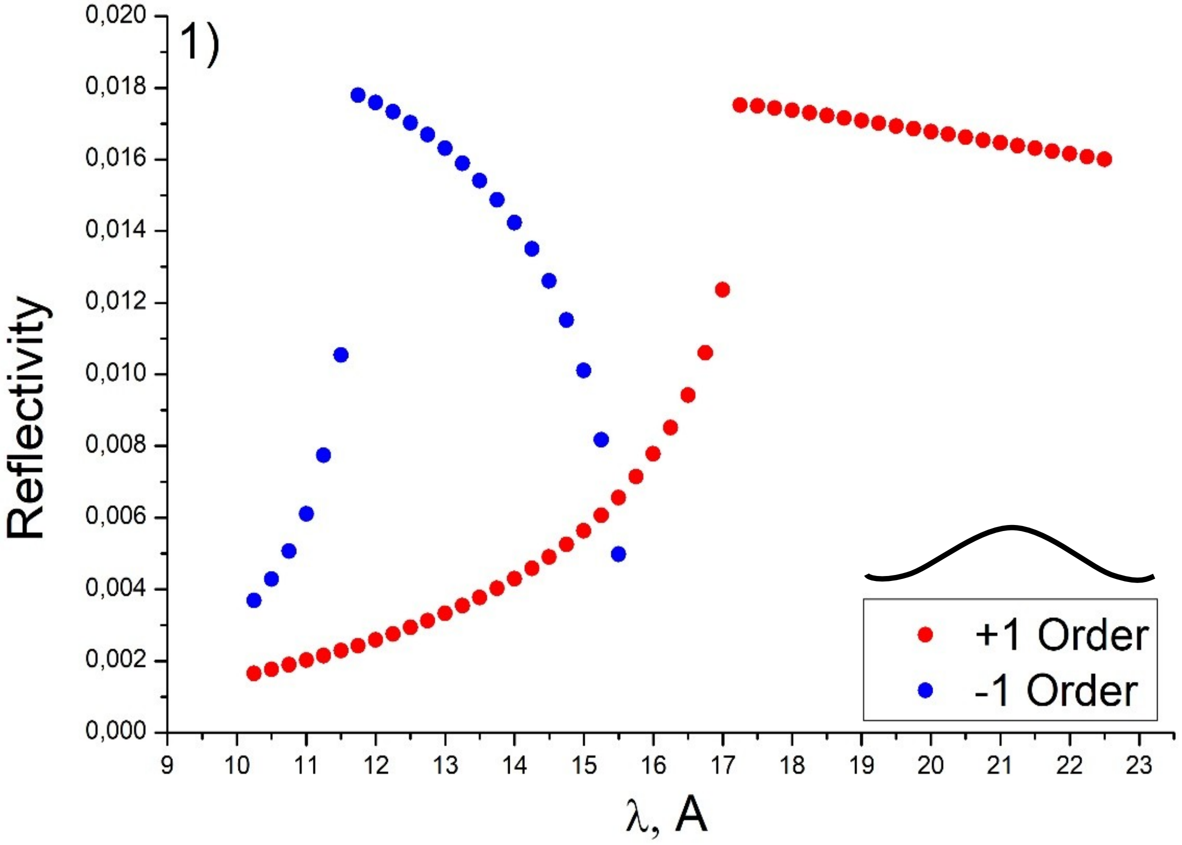
System of 2(2N+1)(2K+1) equations
K – number of considered diffraction orders
N – number of layers

Influence of the waveform distortion

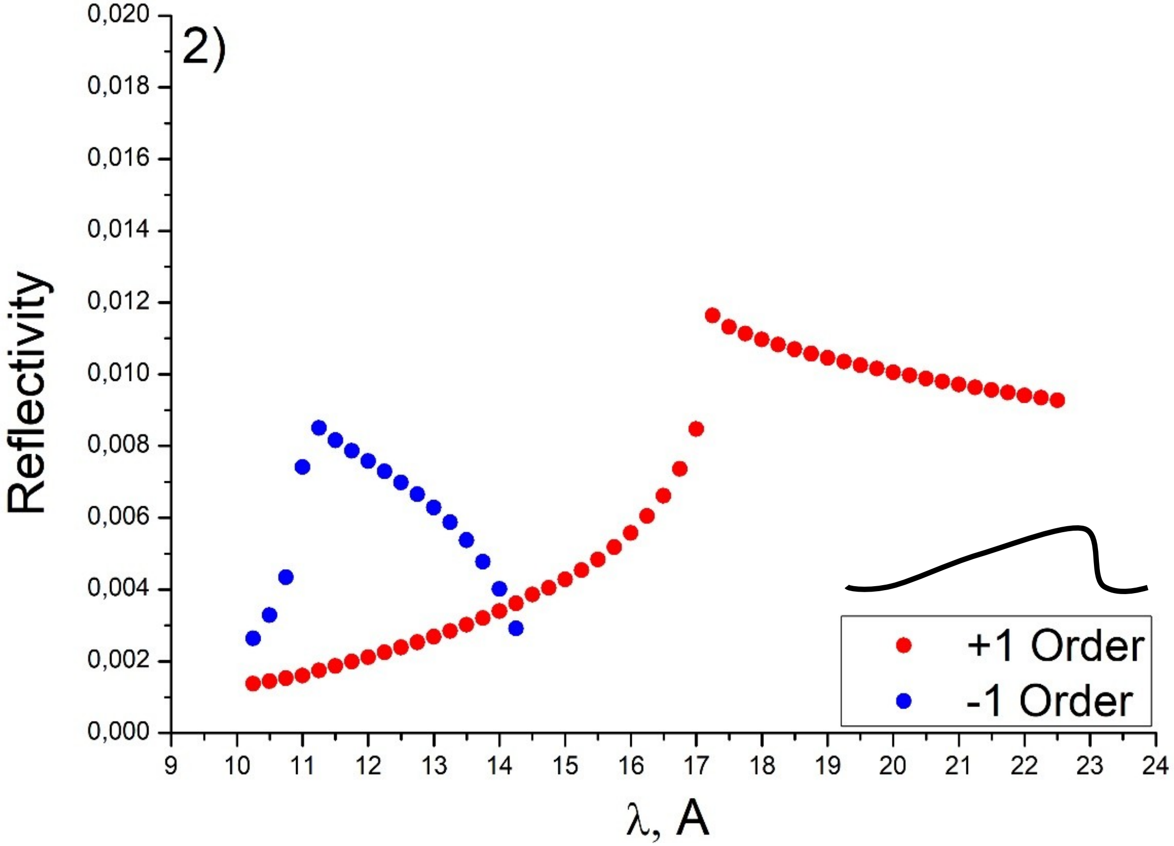


Waveform distortion leads to a change in the shape of the reflectivity function, but cannot quantitatively explain the result of the experiment.

Case of symmetric shape

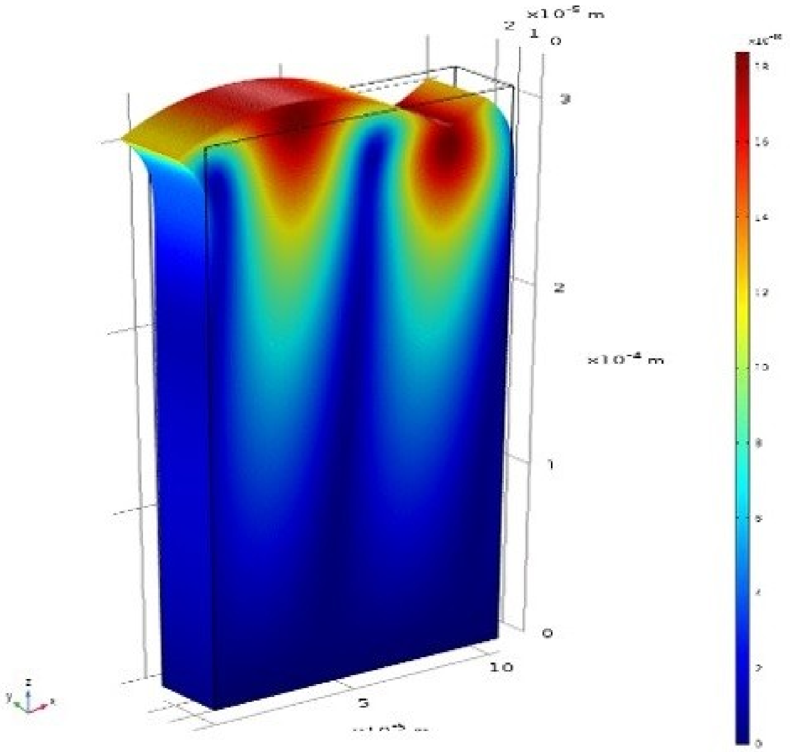


Case of distorted shape



Giant accelerate of nuclei in sample matter

Distribution of atom's acceleration in a medium



Calculated in COMSOL by S.V. Goryunov

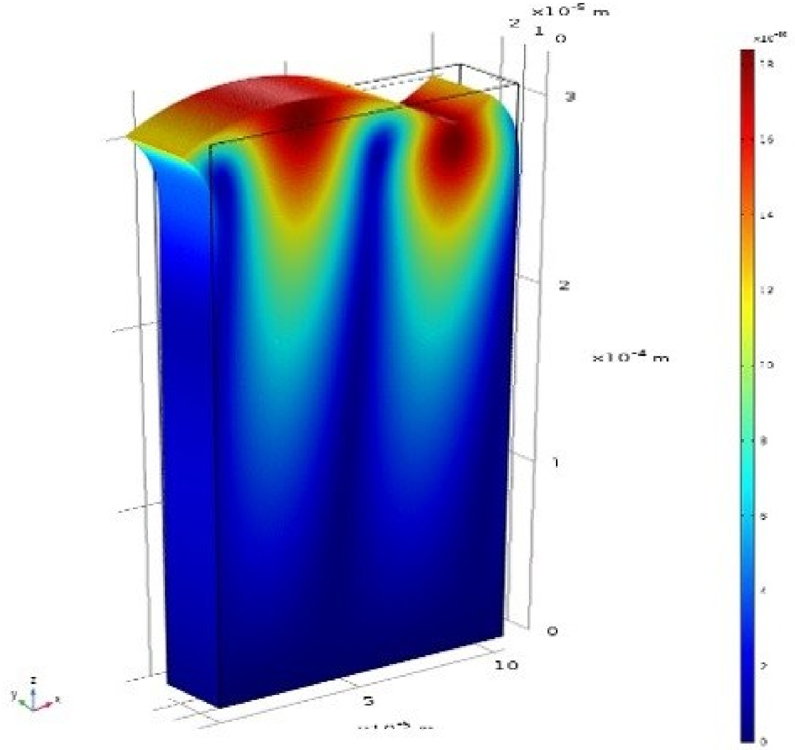
Atoms in the surface layer of the sample move with variable speed and acceleration.

The depth of penetration of the oscillatory motion of atoms into the substance reaches the order of the SAW wavelength

Atoms in a wave move with colossal accelerations

Giant accelerate of nuclei in sample matter

Distribution of atom's acceleration in a medium



Calculated in COMSOL by S.V. Goryunov

Intensities of diffraction orders

Atoms in the surface layer of the sample move with variable speed and acceleration.

The depth of penetration of the oscillatory motion of atoms into the substance reaches the order of the SAW wavelength

Atoms in a wave move with colossal accelerations

There is a hypothesis that in a medium whose atoms move with high acceleration, the behavior of a neutron wave may differ from the predictions of dispersion theory.

*A. Frank, **Physics-Uspeckhi**, **63**, 500 (2020)*
M.A. Zakharov, G.V. Kulin and A.I.Frank. **Eur. Phys. *J. D* 75**, 47 (2021).

All existing theories of nonstationary neutron diffraction are based on the assumption that the theory of neutron dispersion is valid.

Conclusion

Study of non-stationary neutron diffraction by SAW may be interested not only as experimental investigation of non-stationary quantum phenomenon

it also can be suitable for the test of the concept of effective potential in case of giant acceleration

Diffraction on moving surface acoustic waves was observed:

1. The quanta energy transfer to neutron was detected in all cases.

2. Angular distributions of diffracted beams are in good agreement with calculations.

3. The deficit in the intensity of the -1 diffraction order was found.

The application of a more rigorous theory to refine the results did not give agreement with the experiment

The obtained results reliability requires independent experimental confirmation.

Thank you