Time of Flight Fourier spectrometry for precision measurements with UCNs

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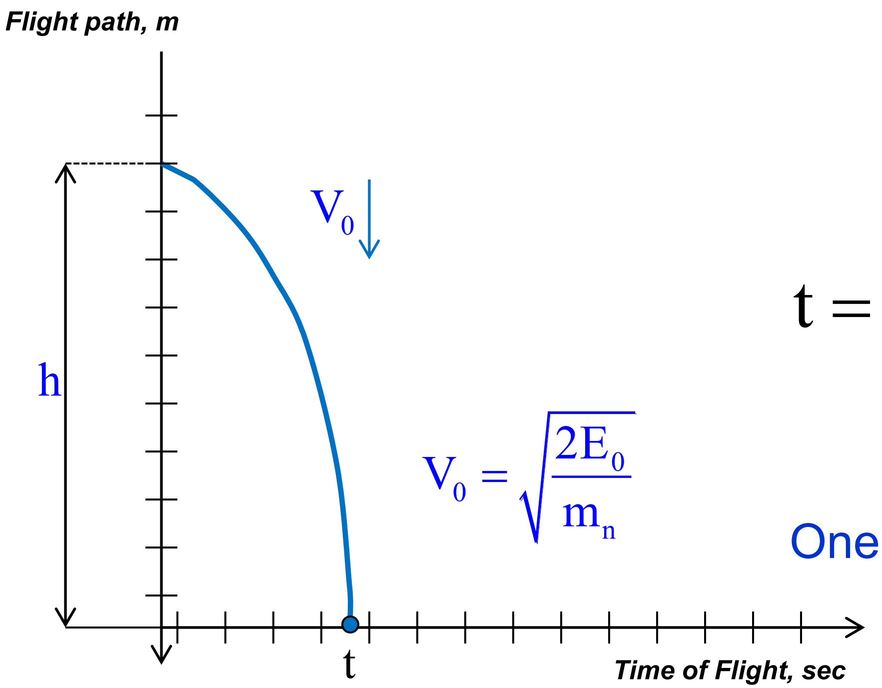
Outline

- Test the weak equivalence principle for neutrons
- Reverse TOF Fourier spectrometry method
- Monte-Carlo simulations
- Nearest plans

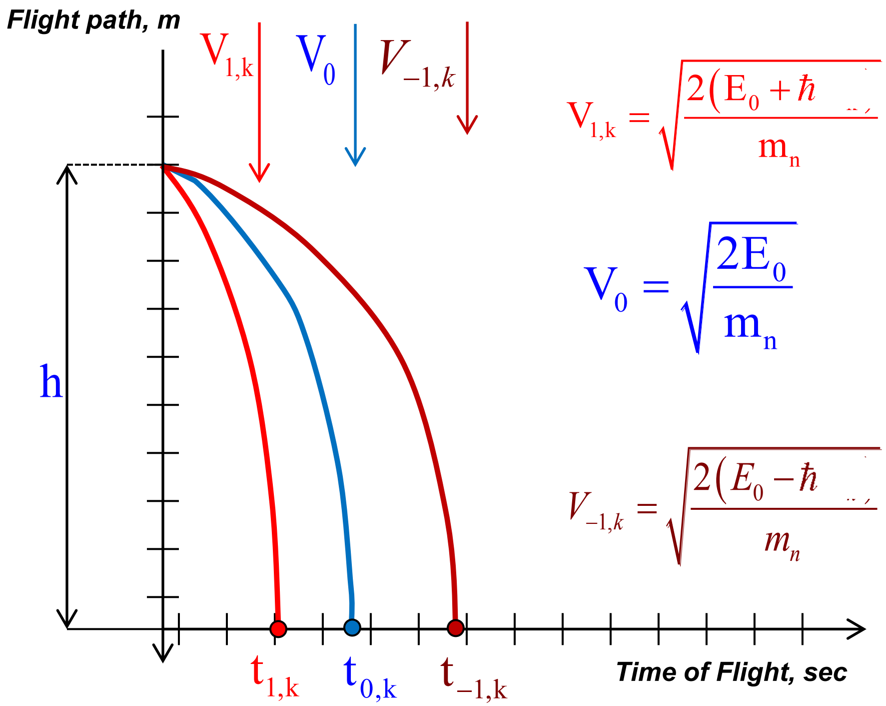
Test of the weak equivalence principle for neutrons



$$t = \frac{1}{g}\sqrt{\frac{2E_0}{m}}\left[\sqrt{1+\frac{mgh}{E_0}}-1\right]$$

One equation with three unknowns

Test of the weak equivalence principle for neutrons



$$V_{1,k} = \sqrt{\frac{2(E_0 + \hbar}{m_n}}$$

$$V_0 = \sqrt{\frac{2E_0}{m_n}}$$

$$V_{-1,k} = \sqrt{\frac{2(E_0 - \hbar}{m_n}}$$

$$\begin{cases} t_1 = \frac{1}{g}\sqrt{\frac{2(E_0 + \hbar}{m}}\left[\sqrt{1 + \frac{mgh}{E_0 + \hbar}} + 1\right] \\ t_0 = \frac{1}{g}\sqrt{\frac{2E_0}{m}}\left[\sqrt{1 + \frac{mgh}{E_0}} + 1\right] \\ t_{-1} = \frac{1}{g}\sqrt{\frac{2(E_0 - \hbar}{m}}\left[\sqrt{1 + \frac{mgh}{E_0 - \hbar}} + 1\right] \end{cases}$$

Three equations with three unknowns

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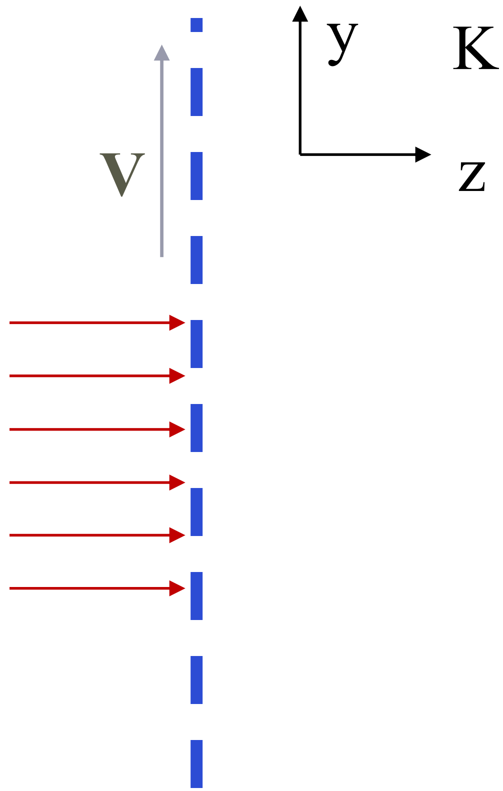
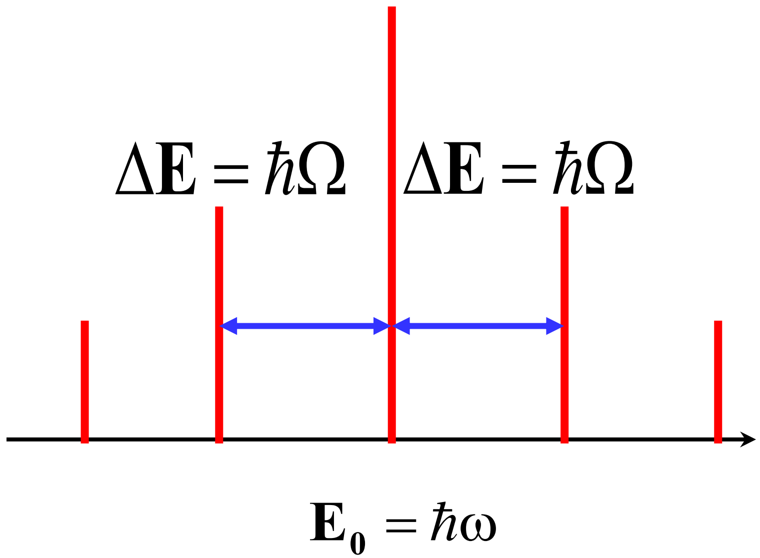
Moving diffraction grating as a non-stationary quantum device





$$\mathbf{\Omega} = 2\pi \frac{\mathbf{V}}{\mathbf{L}}$$

V – ***grating velocity***

L – ***period of the grating***

Requirement for ToF measurements was determined in our latest research

$$\delta t \le 10^{-5}\ \mathrm{sec} \rightarrow \frac{\delta g}{g} \le 10^{-3}$$

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Time of Flight Fourier spectrometry

In the general case the detector response is

$$Z(t) = \int_0^\infty I(t')\theta\left(t - t'\right)dt'$$

If initial flux modulated harmonically

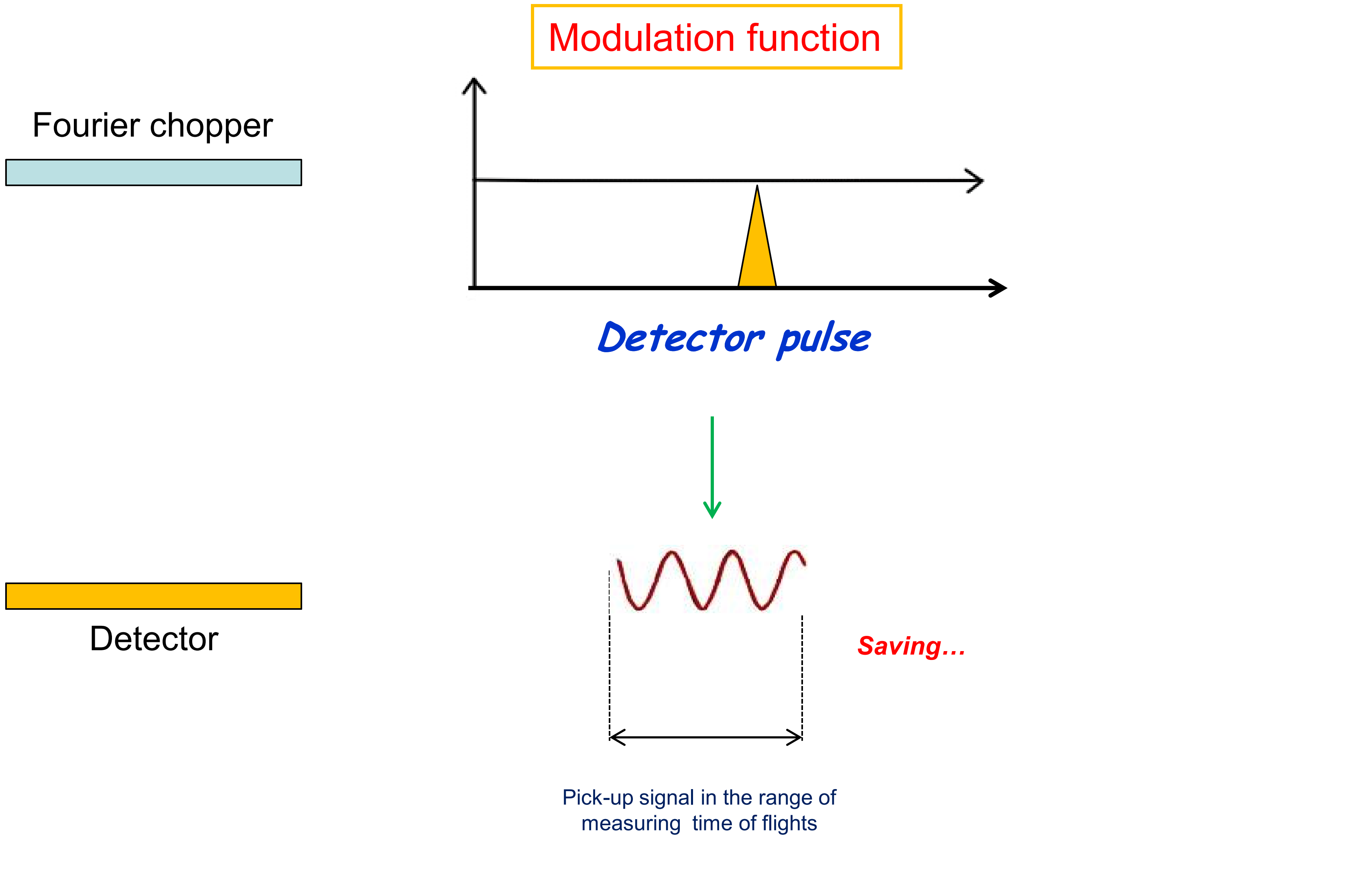
$$Z(t) = \int_0^\infty I(t')\sin\left[\omega\left(t - t'\right)\right]dt'$$

Initial time-of-flight spectrum can be presented as Fourier expansion

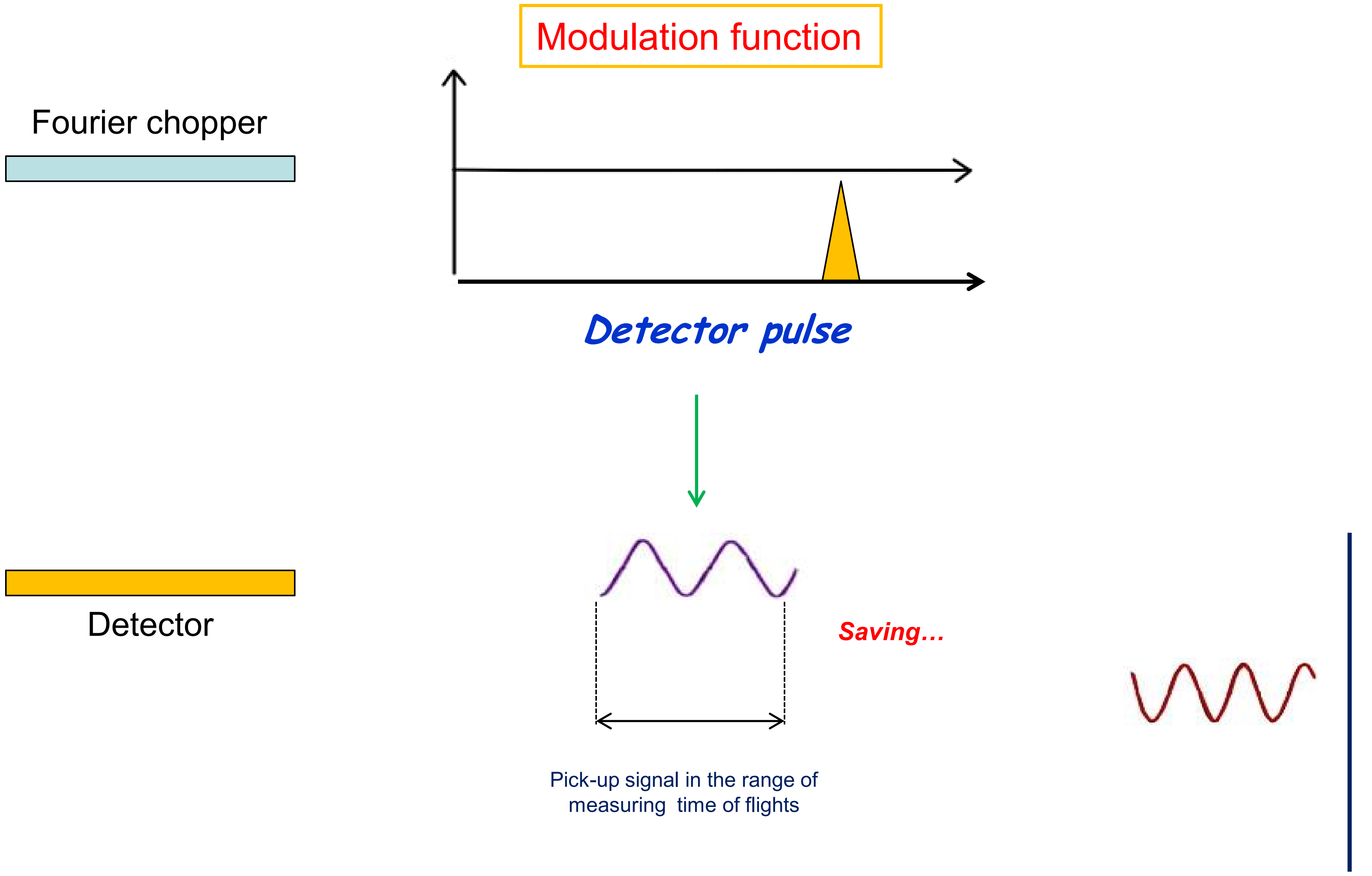
$$I(t) = \int_0^\infty R(\omega)\, sin\left[\omega t - \varphi(\omega)\right]d\omega$$

- ***Z(*ω,t)** **– Fourier harmonic of initial spectrum**
- **It is necessary to find *R*(*ω*) and *φ*(*ω*) in an infinitely large range of frequencies**

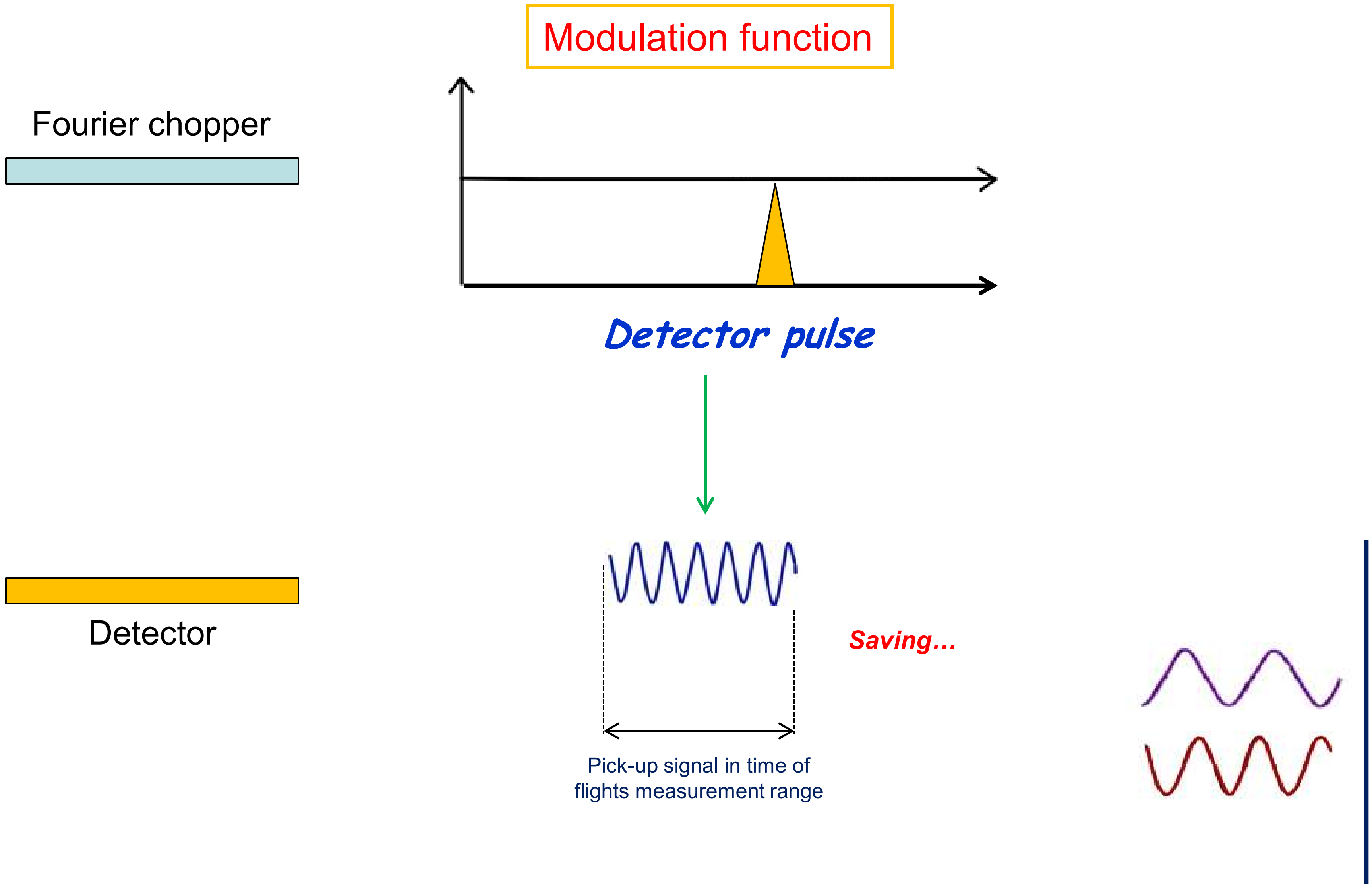
Reverse TOF Fourier spectrometry method



Reverse ToF Fourier spectrometry method

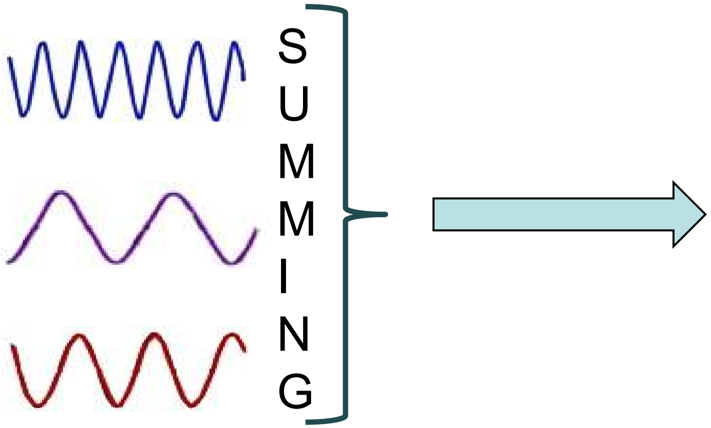


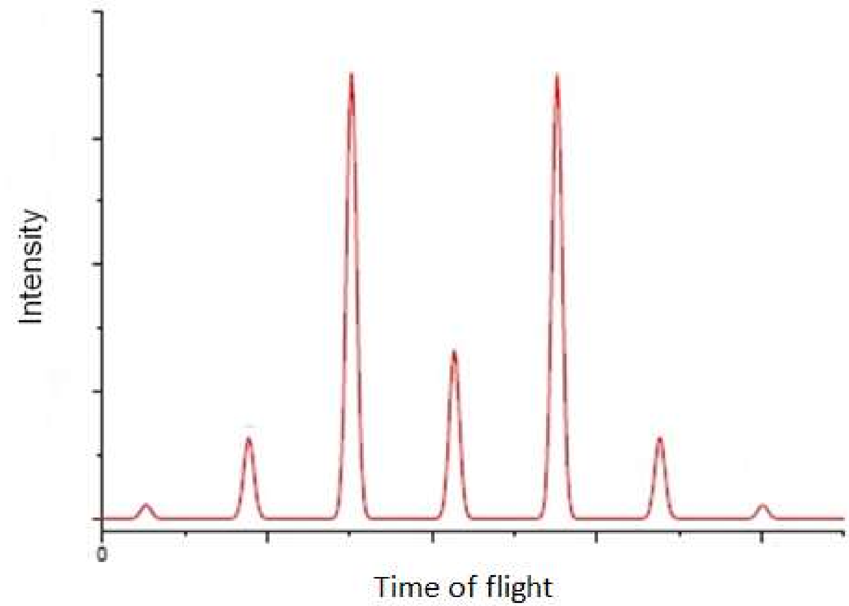
Reverse ToF Fourier spectrometry method



Reverse TOF Fourier spectrometry method

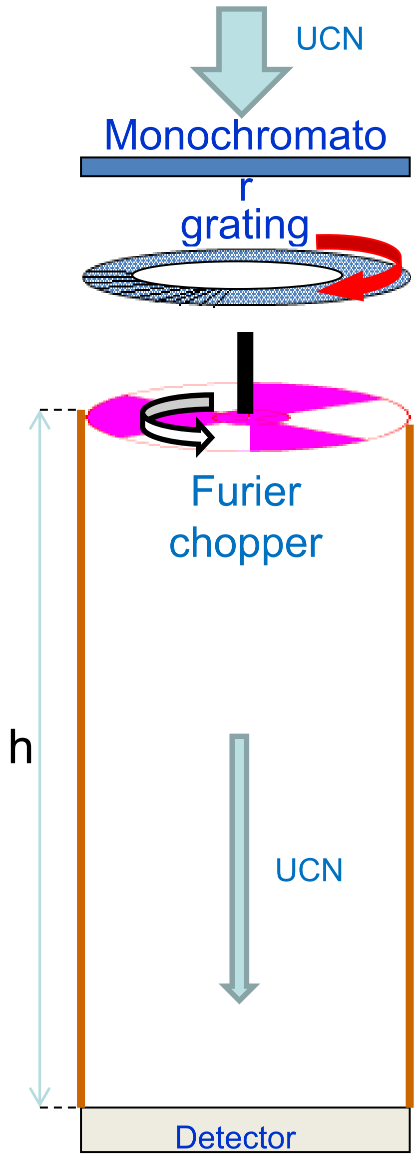
To restore the initial time of flight spectrum it's necessary to sum all given parts of the modulation function

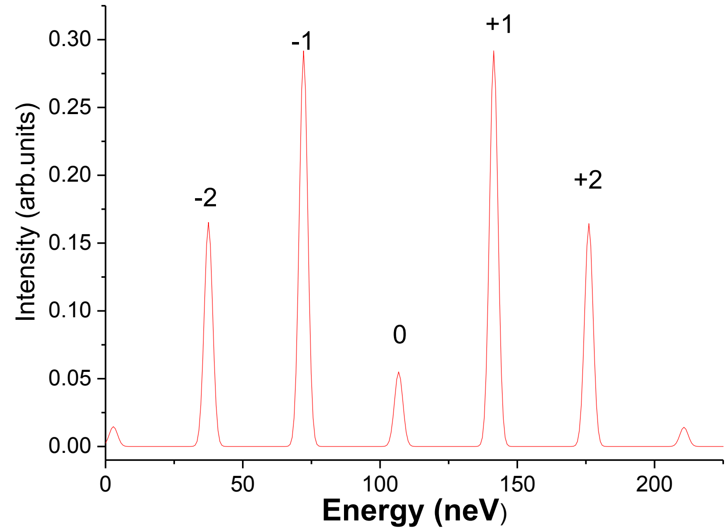




Reconstructed spectrum

Scheme of gravity experiment





$$\delta t \leq 10^{-5}\ \text{sec} \rightarrow \frac{\delta g}{g} \leq 10^{-3}$$

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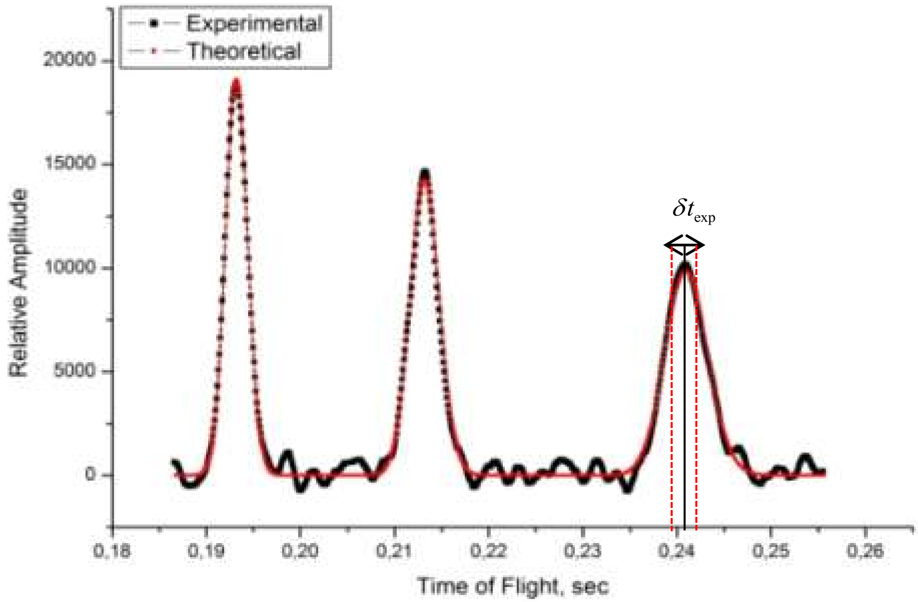
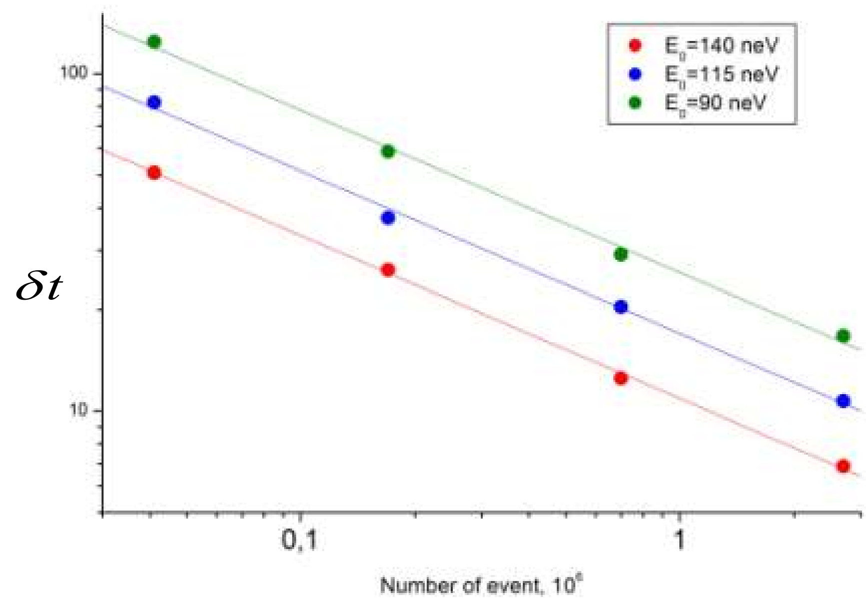
Monte-Carlo simulations



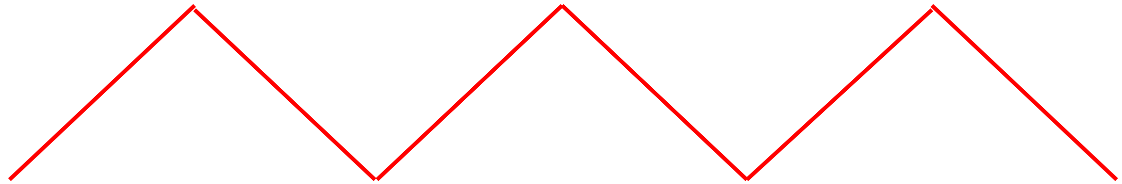
Number of events = 2.6 million Number of runs = 50		
t_{th}, s	$\langle t \rangle_{exp}$, μs	δt_{exp}, μs
0.193219	0.193218	6,7
0.213186	0.213189	10,4
0.240977	0.240978	15,9



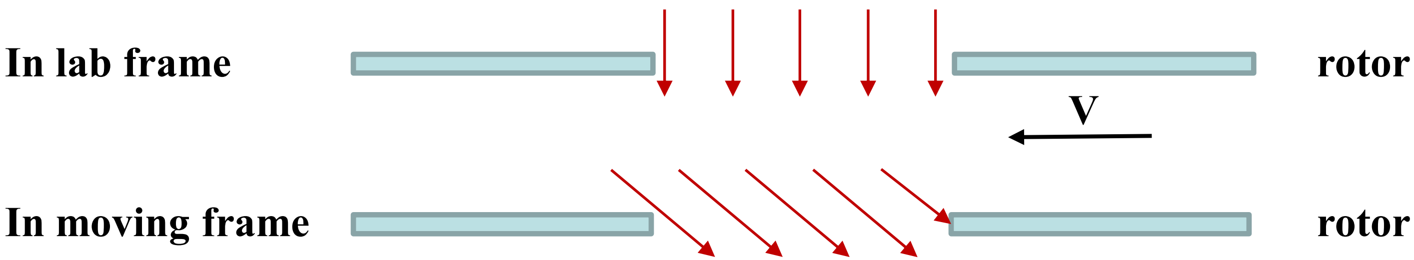
No limitation in accuracy was found

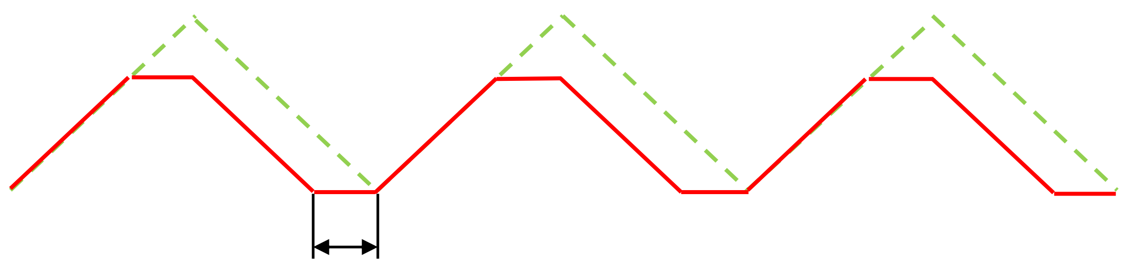
Thick chopper

Modulation function of Fourier chopper with zero thickness



Modulation function of Fourier chopper with non-zero thickness





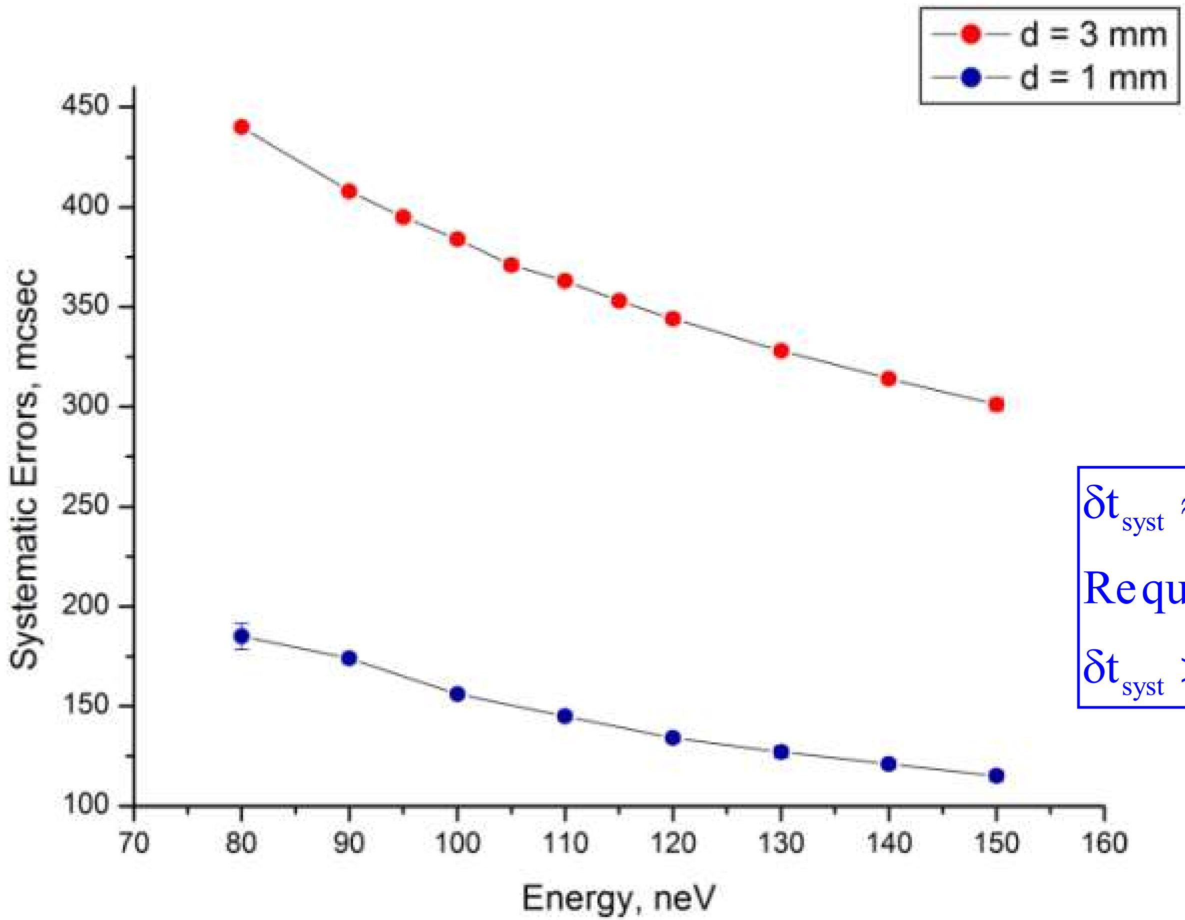
$$2\pi f \frac{d}{v_n}$$

f – modulation frequency

d – chopper thickness

v_n – neutron velocity

Systematic errors

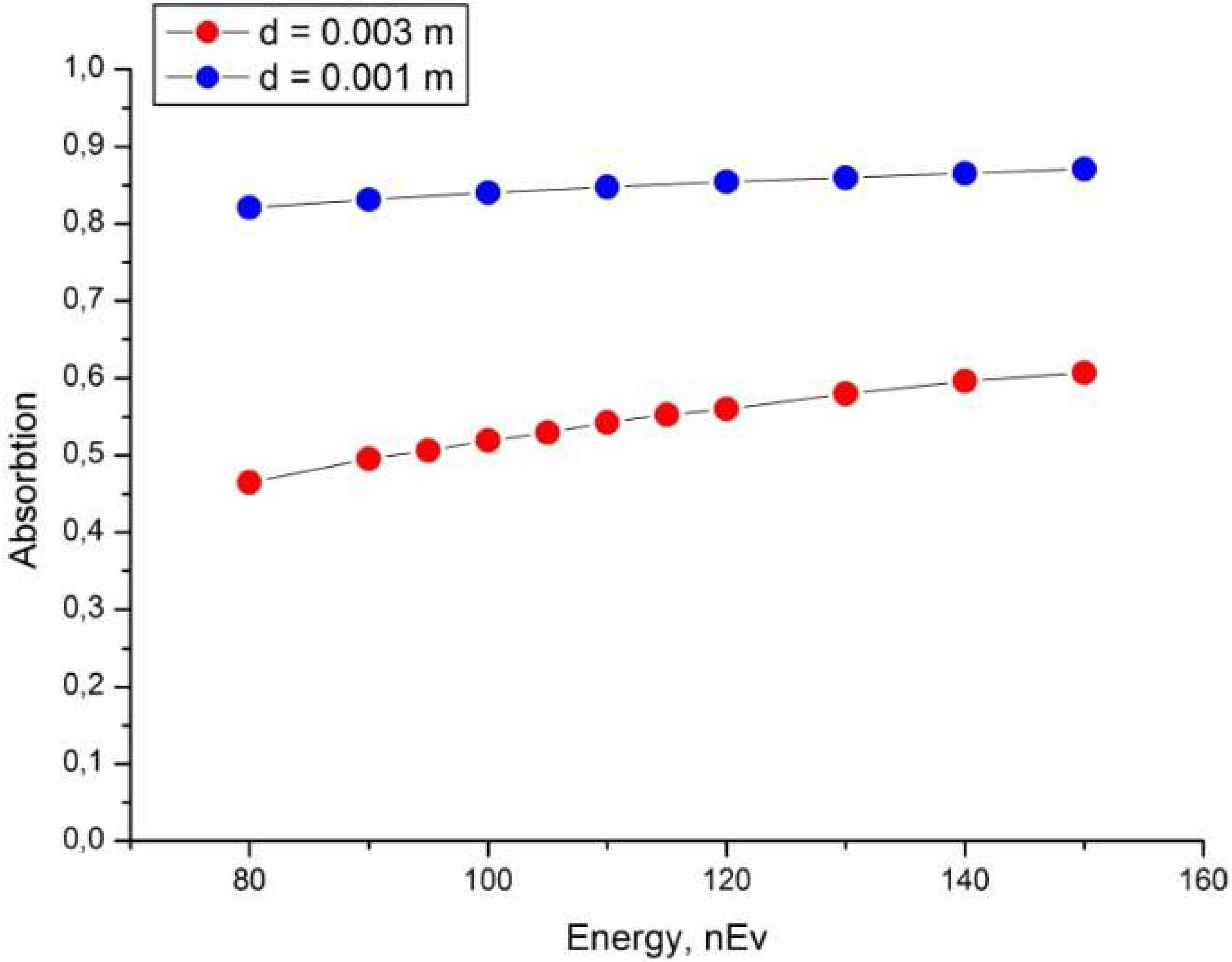


$\delta t_{syst} \approx 10^{-4}$ sec

Required $\delta t_{req} = 10^{-5}$ sec

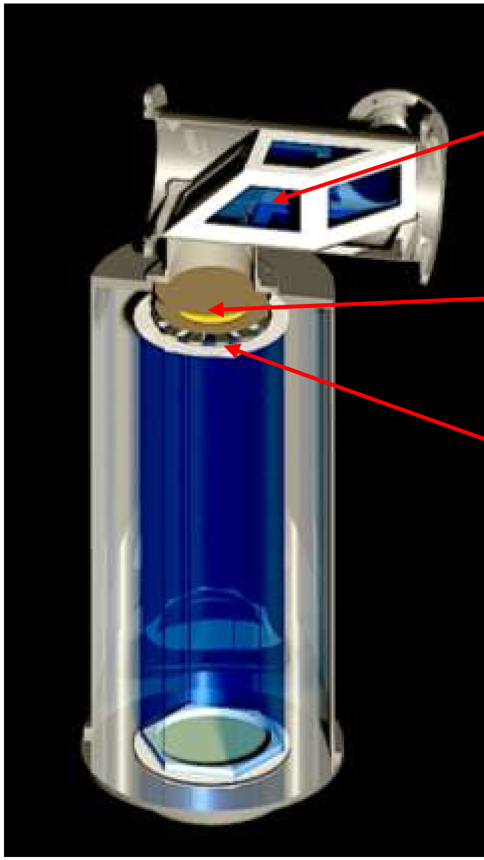
$\delta t_{syst} > \delta t_{req}$

Neutron transmission



On the way to the gravity experiment

- <u>The new TOF Fourier spectrometer</u> (for the free fall experiment with $\Delta g/g \leq 10^{-3}$)



New entrance chamber

Moving grating

Thin Fourier chopper

No systematic effects due to absorption in the moving rotor

Main goal: test of the new approach and comparing with results of Monte-Carlo simulation

Summary

I. The new approach can be used for the test of weak equivalence principle.

II. The reverse TOF Fourier spectrometry has no limitations on precision.

III. Systematic error due to non-zero thickness of the chopper was considered. It exceeds the required precision more than ten times.

<u>Nearest plans:</u>

I. New TOF Fourier spectrometer have to be build

II. Test of the new approach in the free fall geometry

Thank you for your attention!