Carbon Condensation during Detonation of High Explosives of Various Diameters

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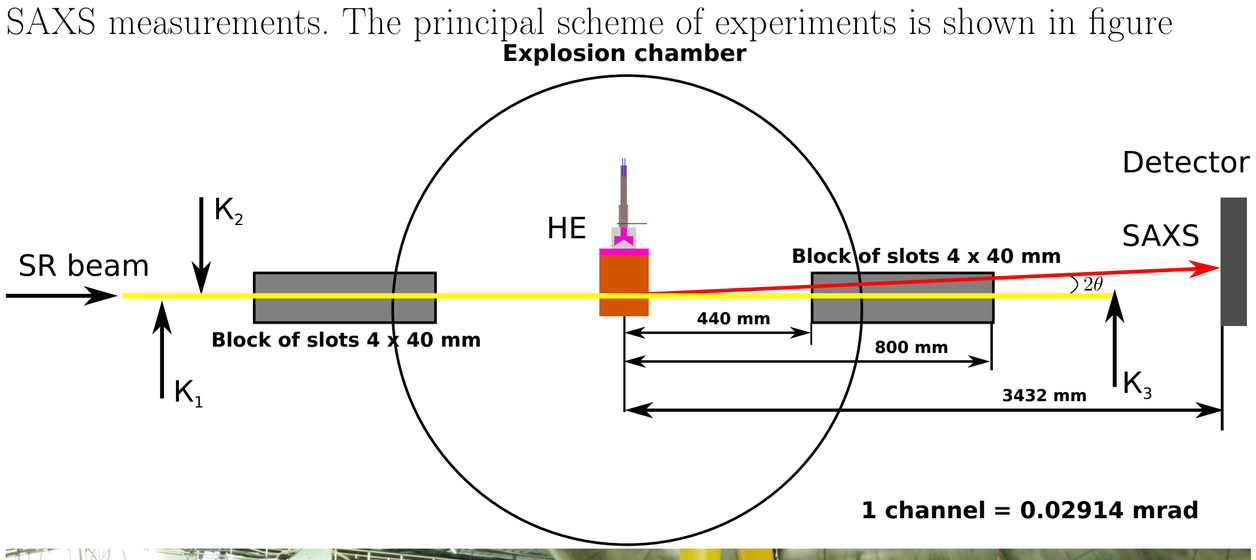
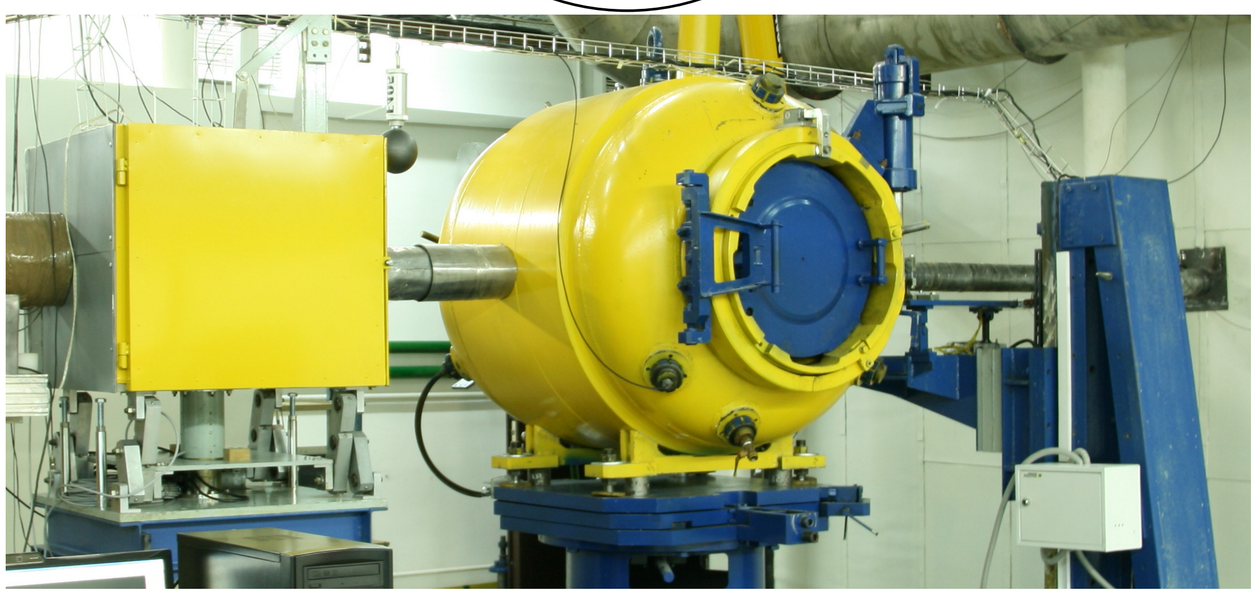
Abstract

We present the results of experimental studies of the process of formation of condensed carbon particles during the detonation of TNT/RDX charges with diameters of 20, 30 and 40 mm. The particle sizes are determined by the method of small-angle X-ray scattering of the synchrotron radiation beam. At present, this method is perhaps the only direct method for recording the particle sizes during detonation. Due to the high frequency of pulses of synchrotron radiation and their high stability, the usage of this method also makes it possible to track the dynamics of particle sizes.

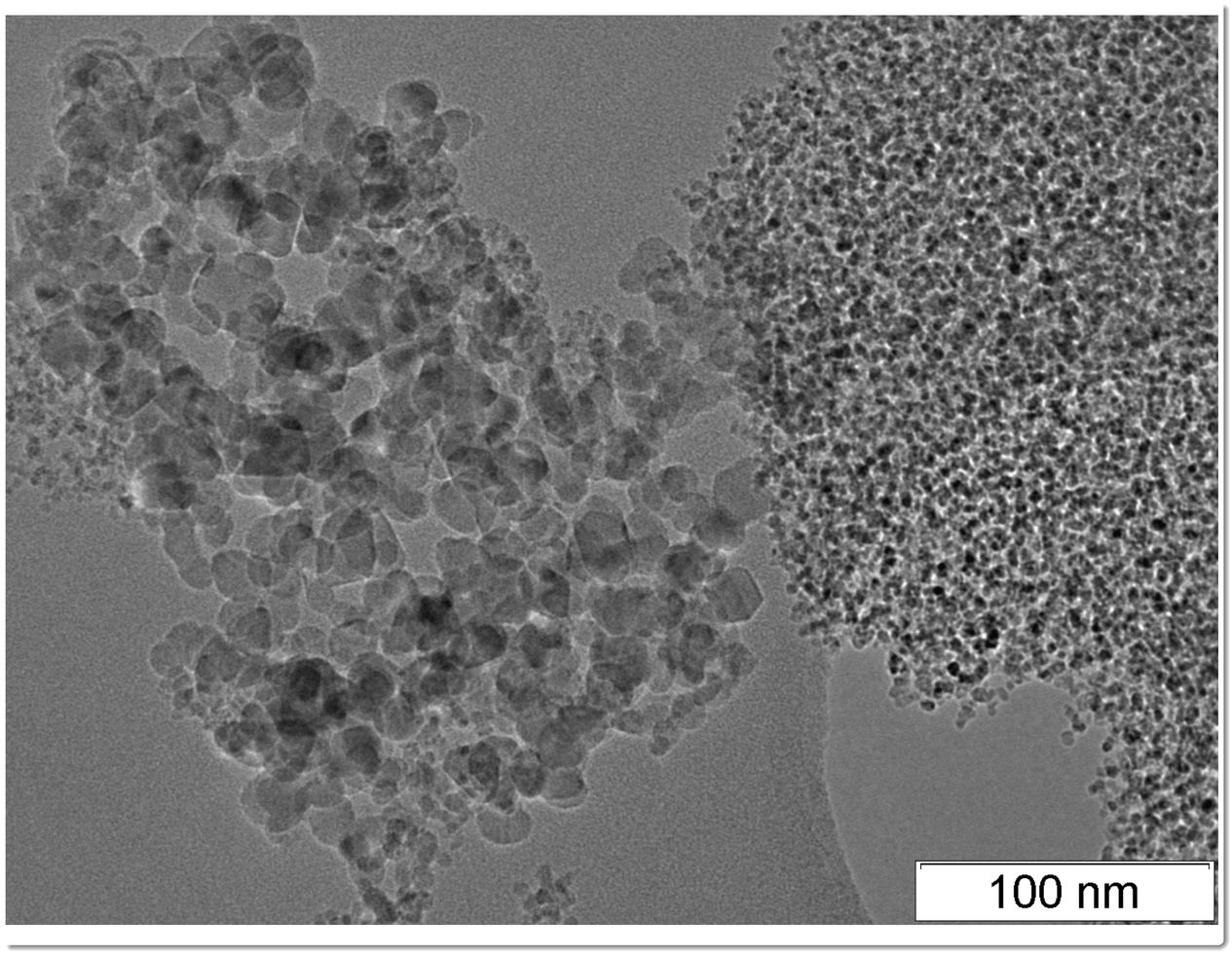
Experimental setup

We use the VEPP-4M accelerator complex (BINP SB RAS) facilities for dynamic SAXS measurements. The principal scheme of experiments is shown in figure



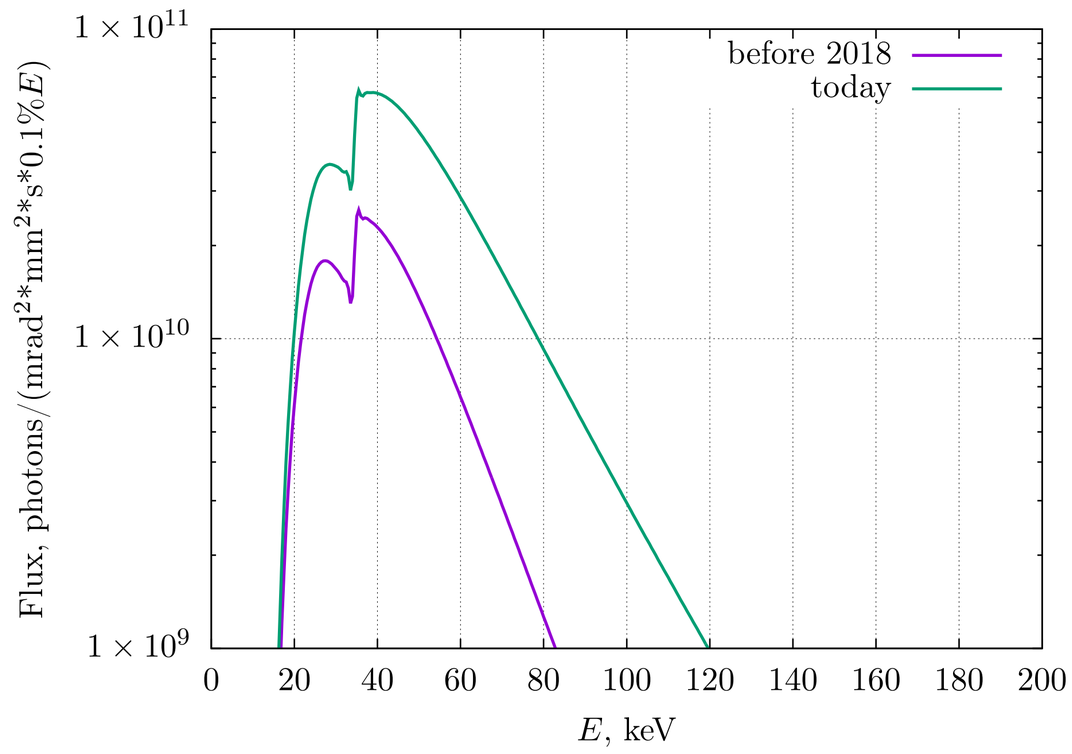


Detonation soot



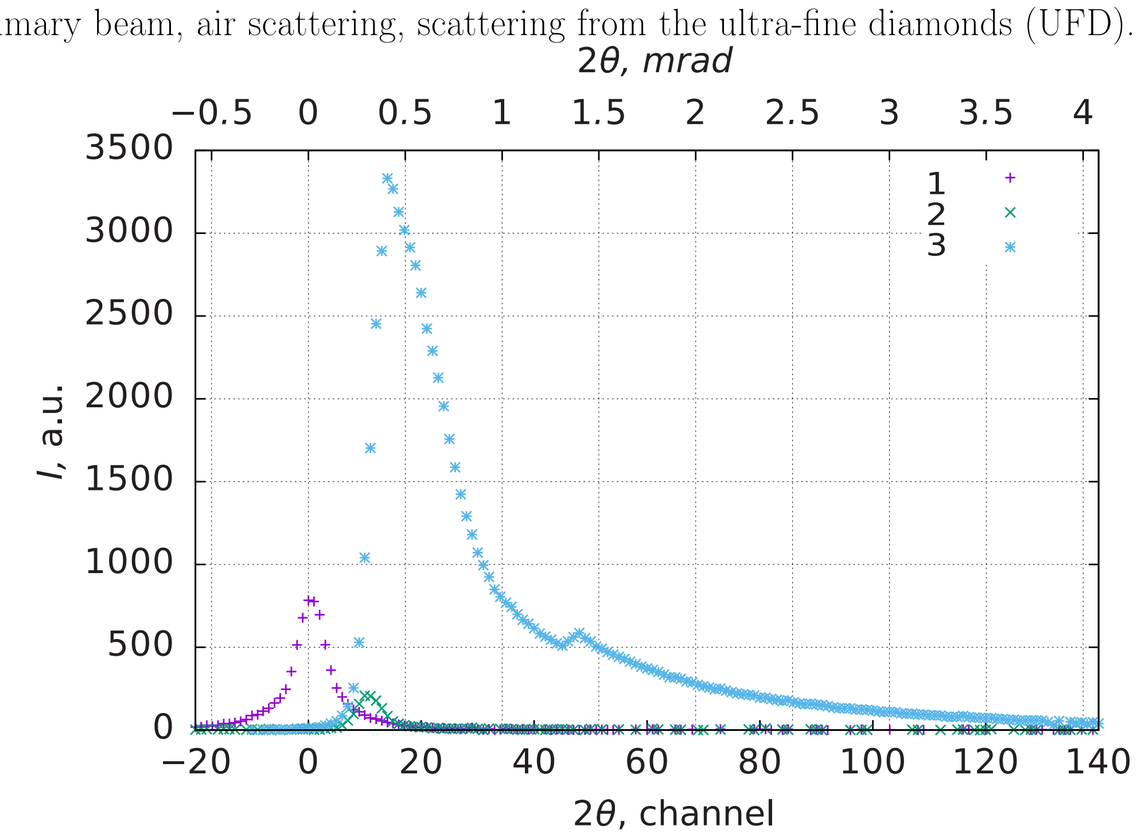
SAXS measurement experiments

The accelerator was operated in a standard two-bunch mode with a current of 10 mA, yielding SR pulses of 73 ps and 611 ns spacing between bunches. We used a new 9-pole wiggler with a non-monochromatic spectrum to generate the SR beam. The real spectrum (including wiggler spectrum, sample absorption and registration efficiency of the detector) at the station is shown in figure



The possibility of using such pink SR beam for determination of the size of scattering centers by replacement spectrum to effective monochromatic energy was shown in previous works.

Before the start of the experiment, calibration measurements was made: attenuated primary beam, air scattering, scattering from the ultra-fine diamonds (UFD).



1 – attenuated straight beam, 2 – air scattering, 3 – scattering on particles of UFD.

First, a SR primary beam was formed by Kratky collimator with 1 mm vertical size (≈10 channels, curve 1). Then, beam stop K_3 blocks the primary SR beam (curve 2). The amplitude of this signal corresponds to the scattering in the air and is taken as the zero signal. Scattering experiments at UFD are extremely important to check the readiness of equipment for an experiment, evaluating the expected signal from explosives during detonation, as well as to produce a SAXS calibration curve.

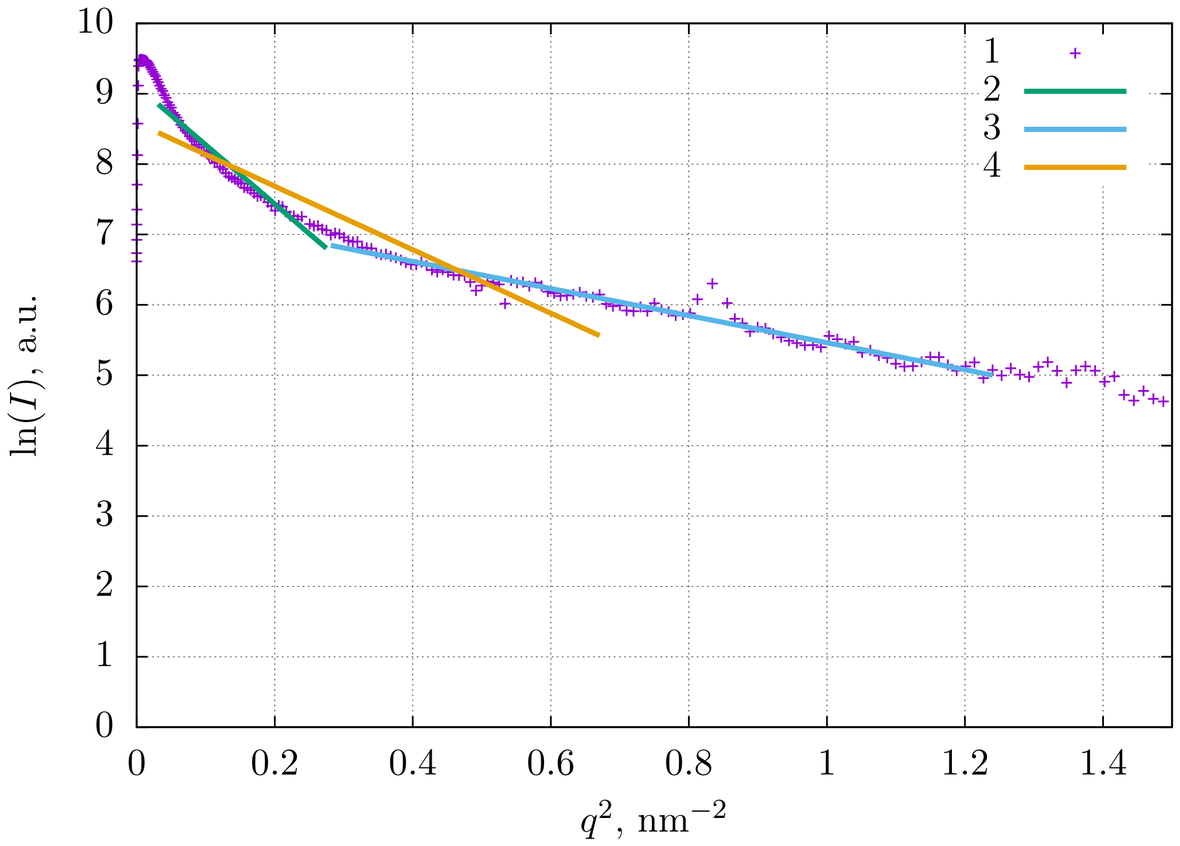
The size of the scattering centers were determine using the Guinier approximation

$$I(q, R) = I_0 \exp(-q^2 R_g^2/5)$$

Taking the logarithm of the intensity $\ln(I(q, R)) = \ln(I_0) - q^2R^2/5$, we obtain a function which decreases linearly versus q^2. Here, $q = 4\pi \sin(\theta)/\lambda$ is the scattering vector, and 2θ is the scattering angle.

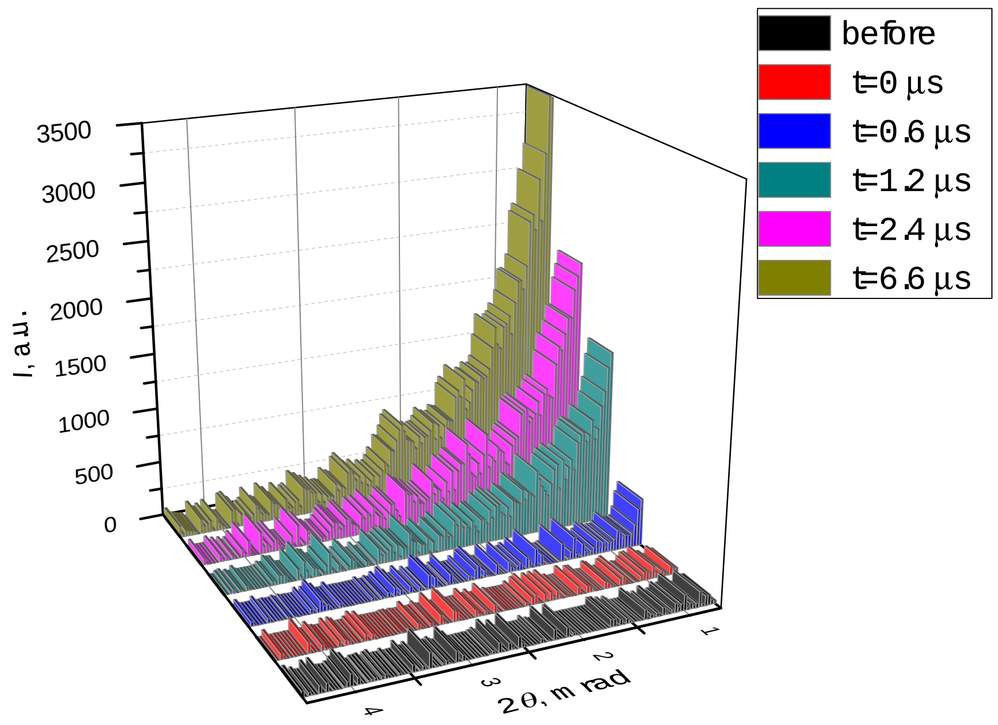
We can determine the size of the spherical particle $D = 2R = 2\sqrt{5|k|}$ using the slope k of this line.

SAXS measurement experiments

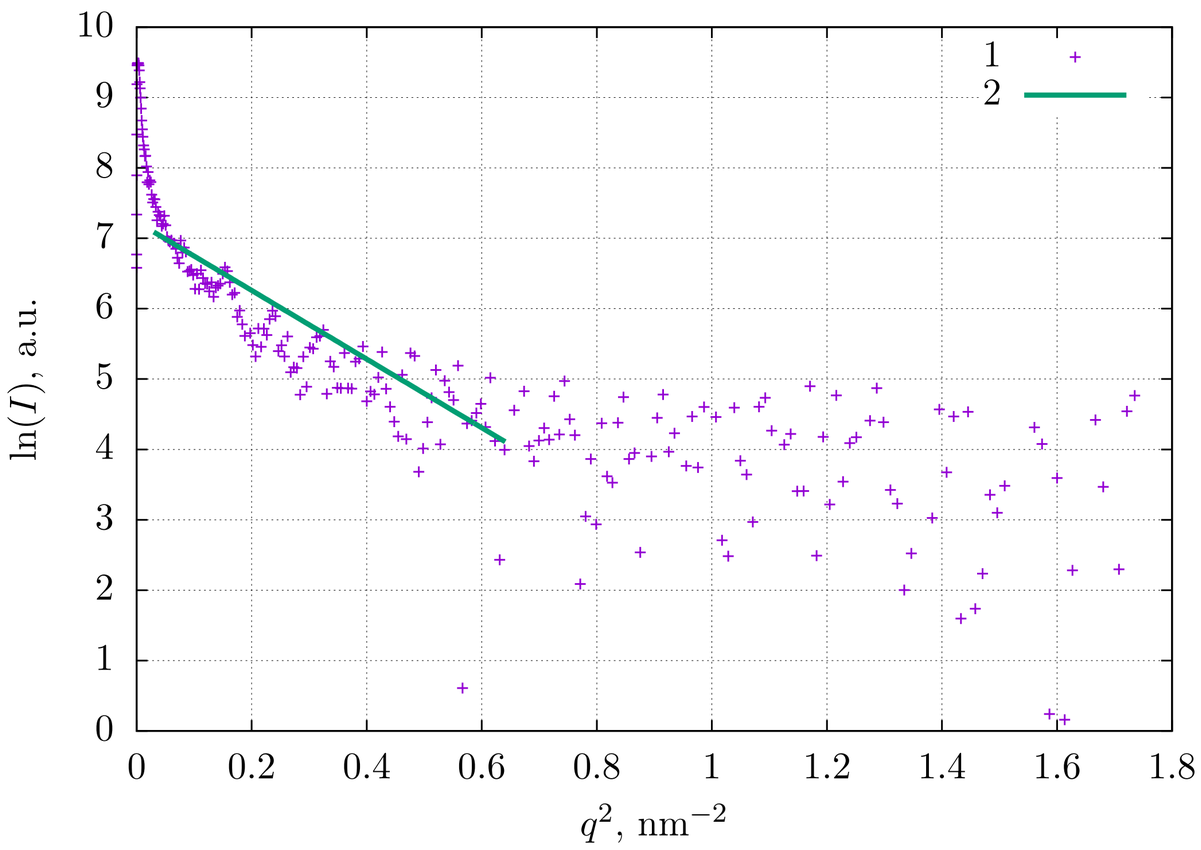


The range of approximation. 1 – experimental data scattering on particles of UFD; 2 – approximation at small angles (a); 3 – approximation at large angles (b); 4 – range of approximation used (c).

a) 2θ=0.9–2.6 mrad	b) 2θ=2.6–5.5 mrad	c) 2θ=0.9–4.1 mrad
D =13 nm	D =6.2 nm	D =9.5 nm

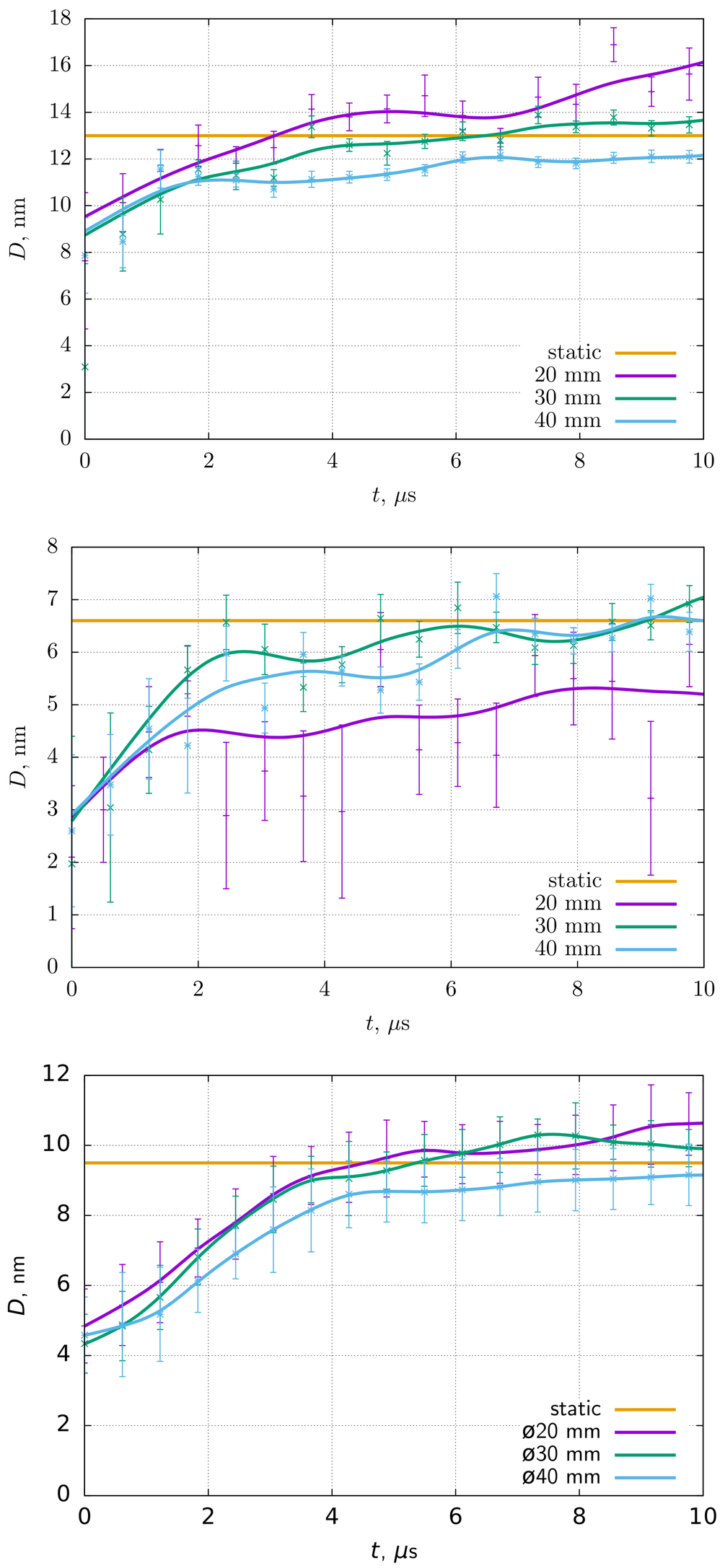


The SAXS dynamics of detonation of cast TNT/RDX charges 30 mm in diameter



The dependence of ln(I) on q^2: 1 – SAXS for TNT/RDX detonation at 6 μs behind the front, 2 – Guinier approximation.

Results



Average size of carbon particle versus time of detonation of TNT/RDX charges recovered by Guinier method at scattering angles 2θ=0.9–2.6 mrad (a), 2θ=2.6–5.5 mrad (b), 2θ=0.9–4.1 mrad (c).

The dynamics of SAXS signal during the detonation of cast TNT/RDX charges of 20, 30 and 40 mm diameter was measured. The average size of the condensed carbon nanoparticles behind a chemical reaction zone was obtained by Guinier approximation. The minimal size of particles is 4 nm. This particles are registered immediately behind the detonation front. After a while, the average size of particles increases. The time of fast growth of scattering centers up to 9 nm is 3–4 microseconds.

It was found that the dynamics of the average size of carbon particles is essentially independent of the charge diameter. At the same time, according to the electron microscopy and SAXS measurements data, we see that the actual particle size distribution is not monodisperse. Therefore, there is a reason to suppose that determination of the scale factor of the carbon condensation process requires the determination of the particle size distribution and their phase state.

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