Study of the dynamics of size of particles during trinitrotoluene detonation by VEPP-4M synchrotron radiation

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Problem

Acquisition of experimental information on the time history of condensed carbon nanoparticles at detonation of oxygen-deficient high explosives.

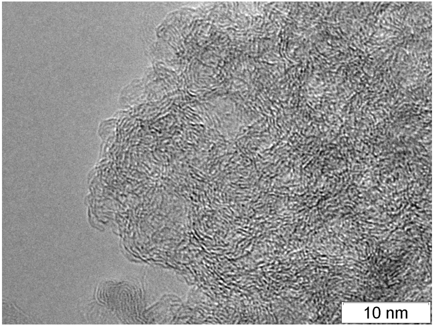
Methods

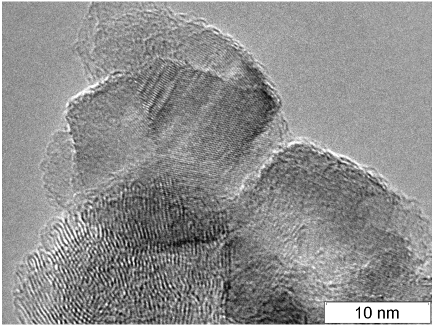
Dynamical recording of small-angle X-ray scattering (SAXS) of synchrotron radiation from the VEPP-4 accelerator. Application of highly-periodic synchrotron radiation (SR) from the accelerator complex VEPP-4 to measuring SAXS with exhibition for 0.1 ns allows tracing development of the signal in the course of detonation of high explosives.

Samples

Cylindrical samples of 30 and 40 mm TNT in diameter were under study.

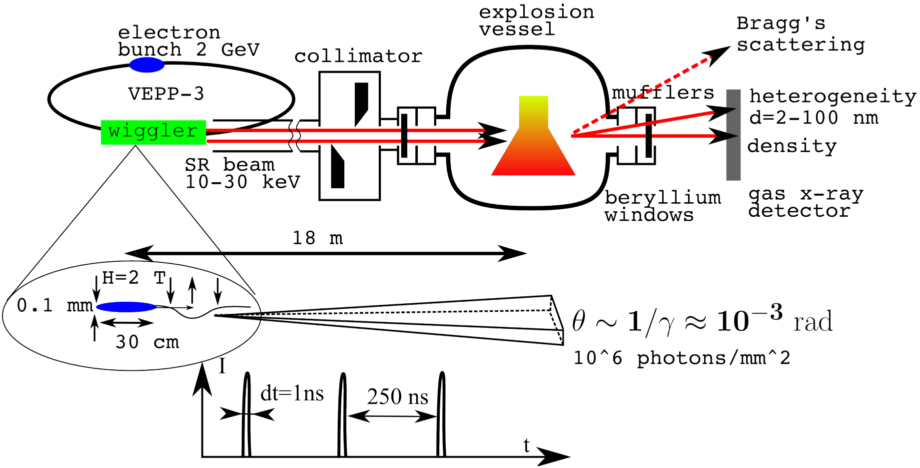
Carbonaceous residue (soot) from the detonation of trinitrotoluene



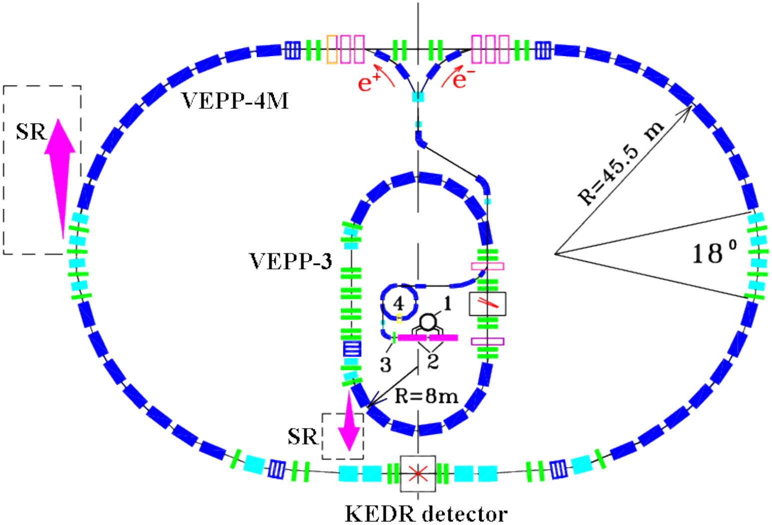


Carbon Photoalbum:
http://ancient.hydro.nsc.ru/srexpl/detcarbon/

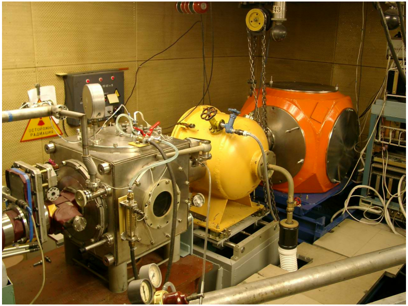
Experimental setup. General scheme



Acceleration complex VEPP-3 – VEPP-4 is the basis of the detonation experiments



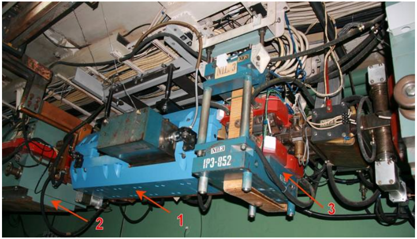
Experimental base in BINP



1999 year – stand for study of detonation process on VEPP-3 beam line 0. Mass of explosion charge is 20 g., time between frames 500 ns. $E_{eff} = 20$ keV.

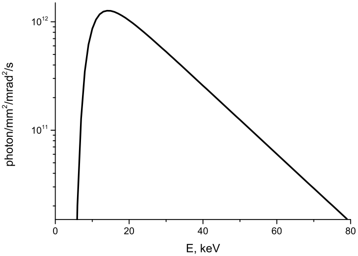
2014 year – new station for study of detonation process on VEPP-4 beam line 8. Mass of explosion charge is 200 g., time between frames 610 ns. $E_{eff} = 36$ keV.

Wiggler radiation at VEPP-4M



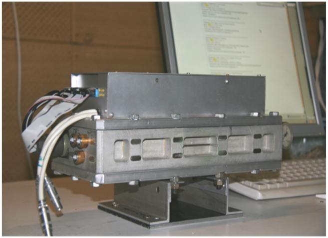
Wiggler (1) located between rotary magnets (2); additional coil (3).

B=1.2 T

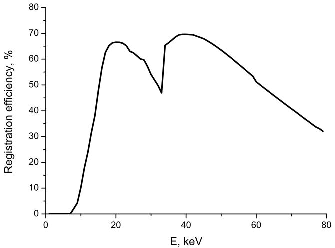


Spectrum of the SR from the VEPP-4 7-poles wiggler

DIMEX – detector for study of the detonation processes

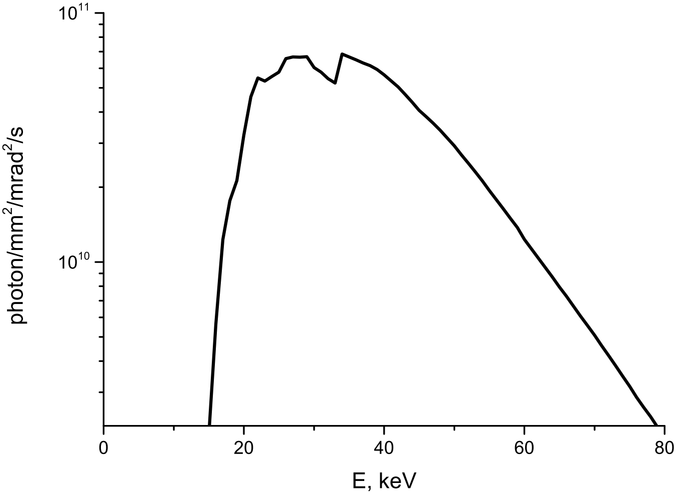


Detector DIMEX-3



Detection efficiency of the detector for photons of different energy

Real radiation spectr at SYRAFEEMA station



SAXS theory

SAXS from spherical particles:

$$I = I_0 \cdot [\frac{\sin(qR) - (qR)\cos(qR)}{(qR)^3}]^2$$

$\vec{q} = \vec{k} - \vec{k_0}, \;\; q = 2k\sin(\theta) = \frac{4\pi\sin(\theta)}{\lambda}$

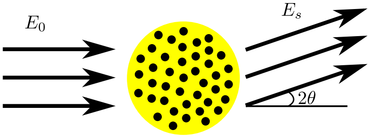
where

R – radius of spherical particles,

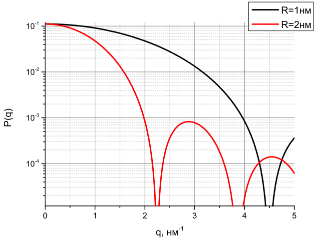
$\vec{q}$ – scattering vector,

2θ – scattering angle,

$\vec{k}$ – wave vector.

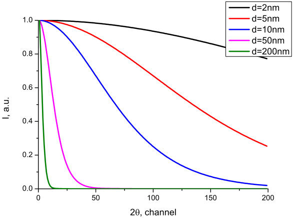


Scattering of monochromatic radiation on a homogeneous spherical particle

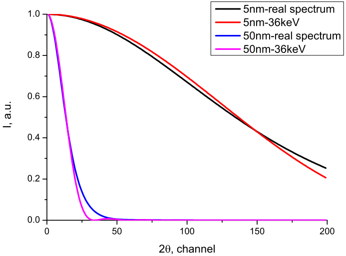


The form factor of the scattering by a spherical particle of 1 nm and 2 nm in diameter

Calculated SAXS signal



SAXS for spherical particles of different sizes with consideration of the real spectrum



SAXS with consideration of the spectrum and effective energy

Guinier approximation

In Guinier approximation

$$I = I_0 \exp(-\frac{(qR)^2}{5})$$

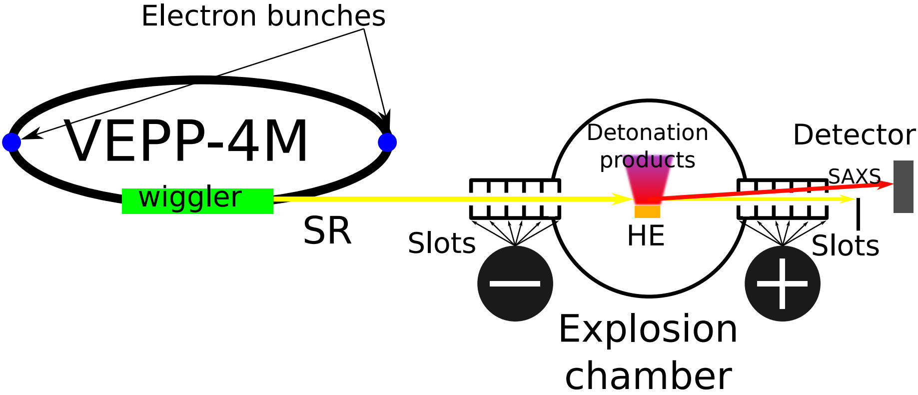
Taking the logarithm of the intensity

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

we obtain a function which decreases linearly versus q^2. We can determine the size of the spherical particle using the slope k of this line.

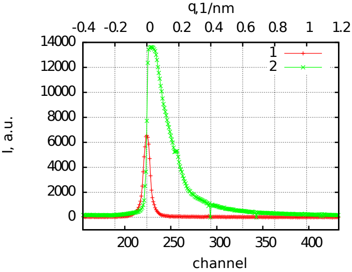
$$D = 2R = 2\sqrt{5|k|}$$

Experimental setup



Experimental assemblies

Setting



1 – attenuated straight beam, 2 – scattering on particles of ultra-fine diamonds (UFD).

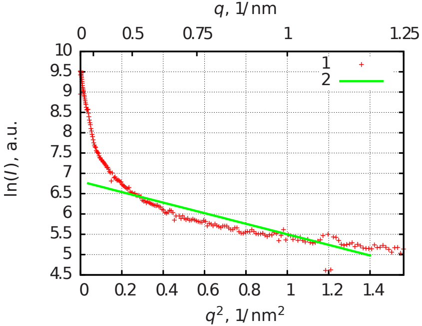
Resolution recovery methods of particle size distribution of SAXS depends on the wavelength of the radiation and the detected scattering angle range $q_{min} \leq q \leq q_{max}$:

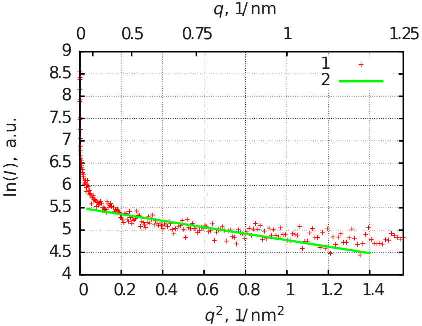
$$d_{min} = \pi/q_{max} = \lambda/4\sin(\theta_{max}) \approx 2 \text{ nm},$$
$$d_{max} = \pi/q_{min} = \lambda/4\sin(\theta_{min}) \approx 100 \text{ nm}.$$

$$0.06 \text{ mrad} \leq 2\theta \leq 5.8 \text{ mrad}$$

Distance from center of charge to detector
L=3432 mm
1 detector channel (0.1 mm) = 0.02914 mrad

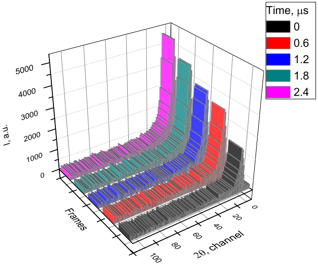
Processing of static experiments in Guinier approximation

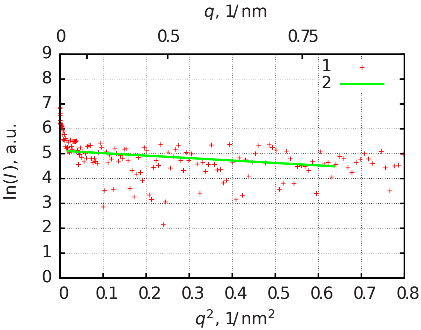




The dependence of ln(I) versus q^2: 1 – ln(I), 2 – approximation by straight line
left: for UFD (k ≈ -1.4, D ≈ 5.4 nm)
right: for aerogel (k ≈ -0.93, D ≈ 4.8 nm).

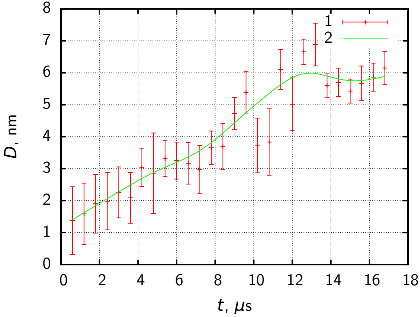
SAXS at trinitrotoluene detonation

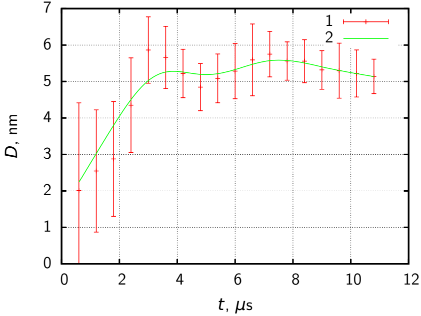




Left: SAXS data during TNT detonation in the first 2.5 μs for one experiment.
Right: 1 – SAXS datd for TNT detonation at 6 μs behind the front,
2 – Guinier approximation.

Experimental results





Average size of carbon particle versus time in detonation of a cylindrical TNT charge of 40 mm diameter (left) and 30 mm diameter (right):
1 – experimental data, 2 – smooth spline.

Thank you for your attention

http://ancient.hydro.nsc.ru/srexpl

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Presentation:

Poster: