Complex Dynamic Study of ejection of the of Particles from Shock-Loaded Tin by SR methods, a PDV laser complex, and optical and piezoelectric sensors.

Комплексное исследование динамики пылевого облака в газовых средах методами СИ, лазерным комплексом PDV и пьезодатчиками.

Konstantin A. Ten[1], Edward R. Pruuel[1], Aleksey O. Kashkarov[1], Ivan A. Rubtsov[1], Dmitriy V. Petrov[2], Aleksandr Yu. Garmashev[2], Evgeniy B. Smirnov[2], Mikhail Yu. Stolbikov[2], Victor V. Malev, Artem E. Shirobokov, Vladimir V. Sekretarchuk, Lev I. Shekhtman[3] , Vladimir V. Zhulanov[3], Boris P. Tolochko[4]

[1]*Lavrentyev Institute of Hydrodynamics SB RAS*

[2]*Russian Federal Nuclear Center Zababakhin All—Russia Research Institute of Technical Physics*

[3]*Budker Institute of Nuclear Physics SB RAS*

[4]*Institute of Solid State Chemistry and Mechanochemistry SB RAS*

SFR-2020,13-16 July 2020, Budker INP

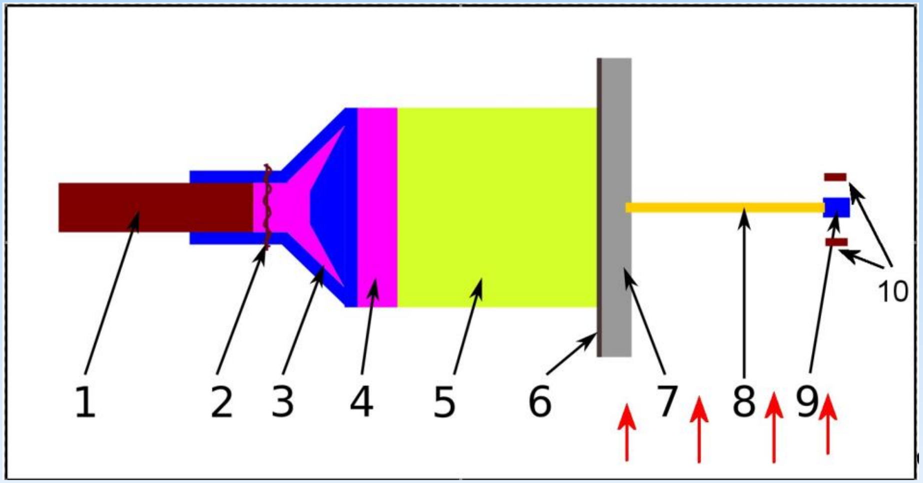
The importance of using SR for recording micro and nanoparticle flows.

1. *At high accelerations, a flows of microparticles (dust cloud) appears in front of the free surface (FS). Particle detachment is associated with the development of instabilities under conditions of high strain rates and high tensile strength of materials on a micron scale. An interest in this phenomenon is also associated with the influence of the "dust" emission on the results of measurements of surface motion using shadow, electrocontact, and laser methods for detecting motion, as well as the importance of inertial thermonuclear fusion in plasma compression.*
2. *Existing registration techniques do not allow the registration of microparticle flows with a linear density of less than 0.01 g / cm^2. Synchrotron radiation can be useful due to the soft energy spectrum (up to 30 keV), good time resolution (124 ns), a large number of frames (100 frames) and the possibility of synchronous use of other (PDV, piezoelectric sensors) techniques.*

Objectives.

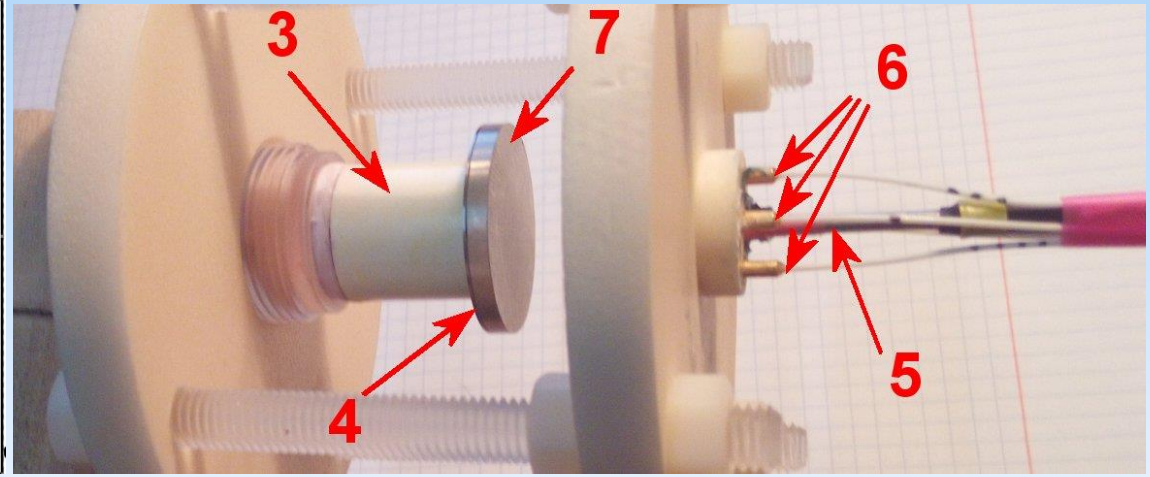
1. ***Using the registration of SRs, investigate the flows of a cloud of particles from the FS of tin with a different degree of roughness (Rz 5 - 80).***
2. ***Measure the dynamics of the density distribution along the dust cloud in vacuum and at atmospheric pressure.***
3. ***Perform simultaneous recording of X-ray cinema SR, readings of PDV and piezosensor.***

Experiment setup.



The basic statement on the study of dusting processes

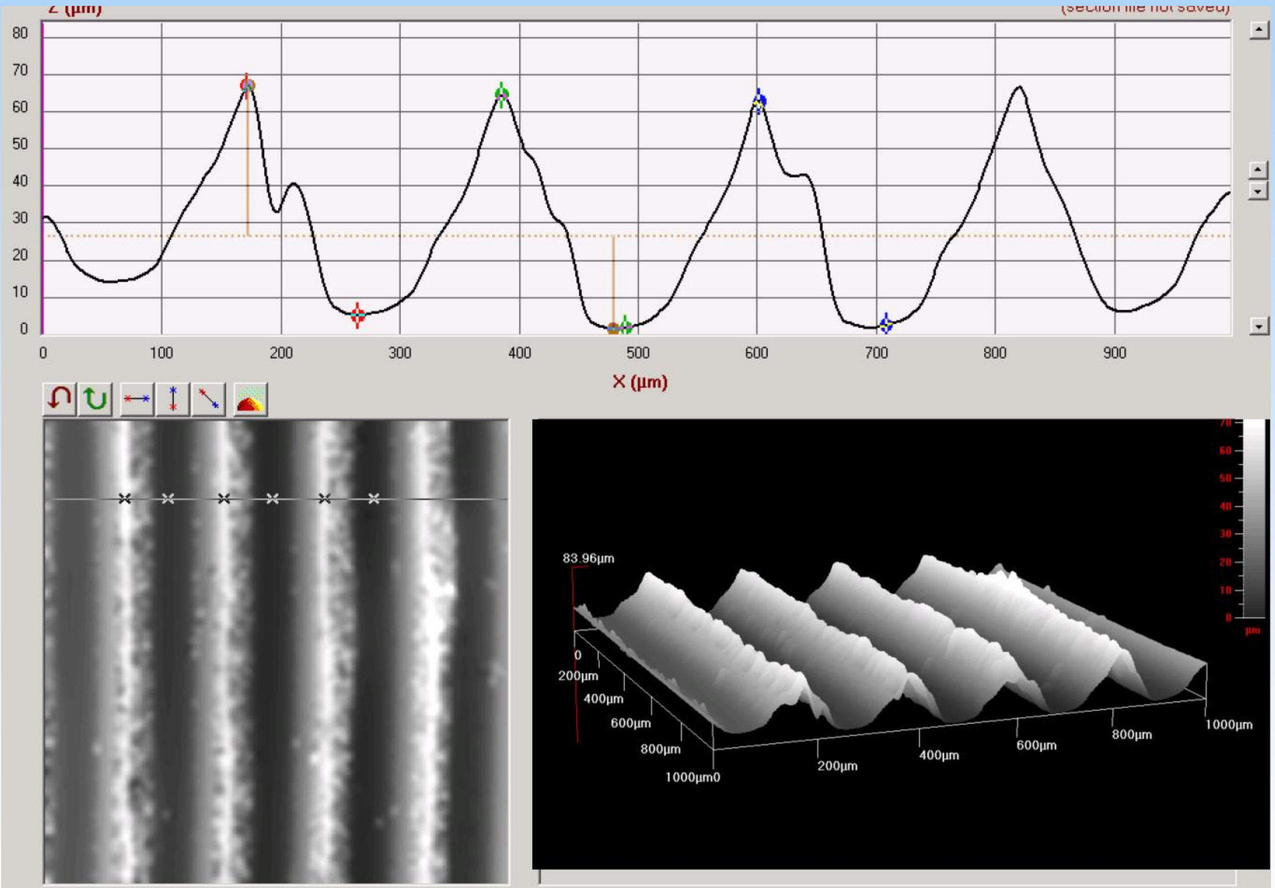
1 - detonator, 2 - contact sensor for synchronizing three techniques, 3 - plane wave generator, 4 - plastic explosive based on PETN, 5 - loading explosive charge with a diameter of 20 mm and a length of 20 mm, 6 - steel disk, 7 - tin disk 30 mm in diameter, 8 — a synchrotron radiation beam, 9 — a piezoelectric transducer, 10 — PDV collimators.



Experimental assembly.

3 - explosive charge, 4 - steel disk (h = 0.5mm), 5 - piezoelectric transducer, 6 - PDV collimators (4 pcs), 7 - tin disk (h = 3 mm)

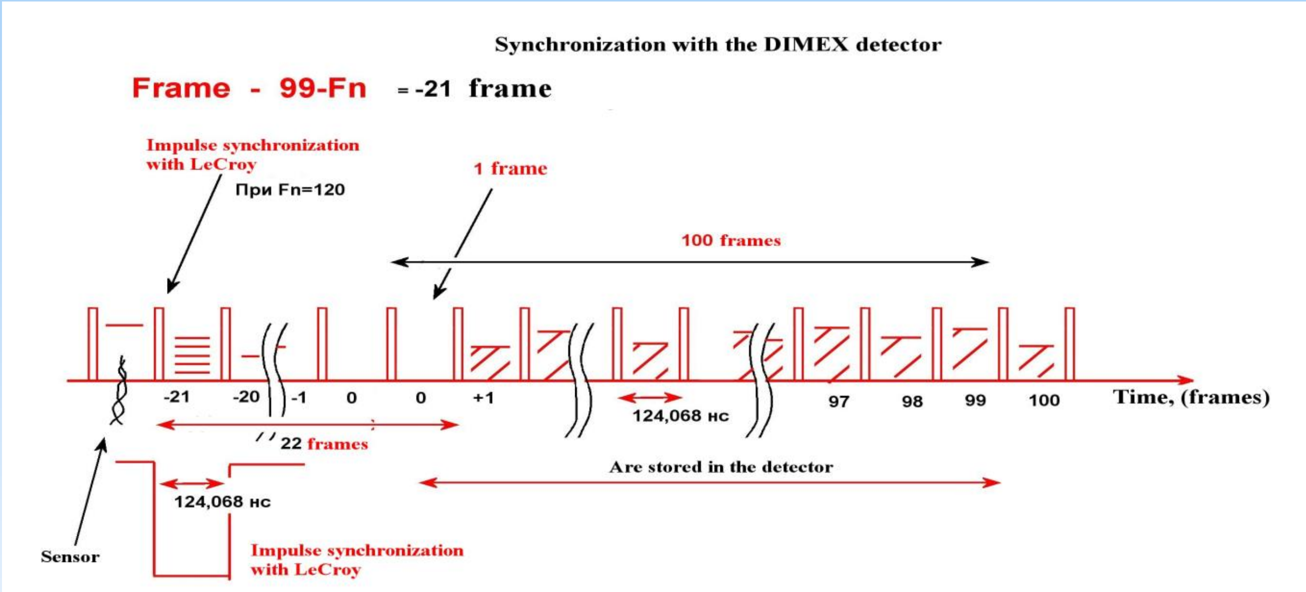
Profile of grooves (tin).

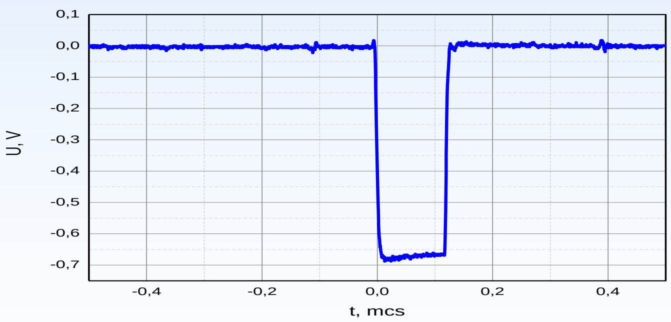


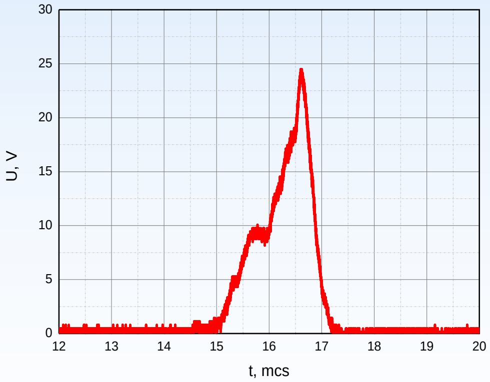
Profile of grooves in free surface.

№ version	The roughness parameters FS			The pressure in the explosion chamber, barr
	A, мкм	λ, мкм		
1	5	50		0.01
2	62	250		0.01
a – the depth of the groove roughness, λ – the distance between the grooves				

DIMEX detector synchronization with a LeCroy oscilloscope.

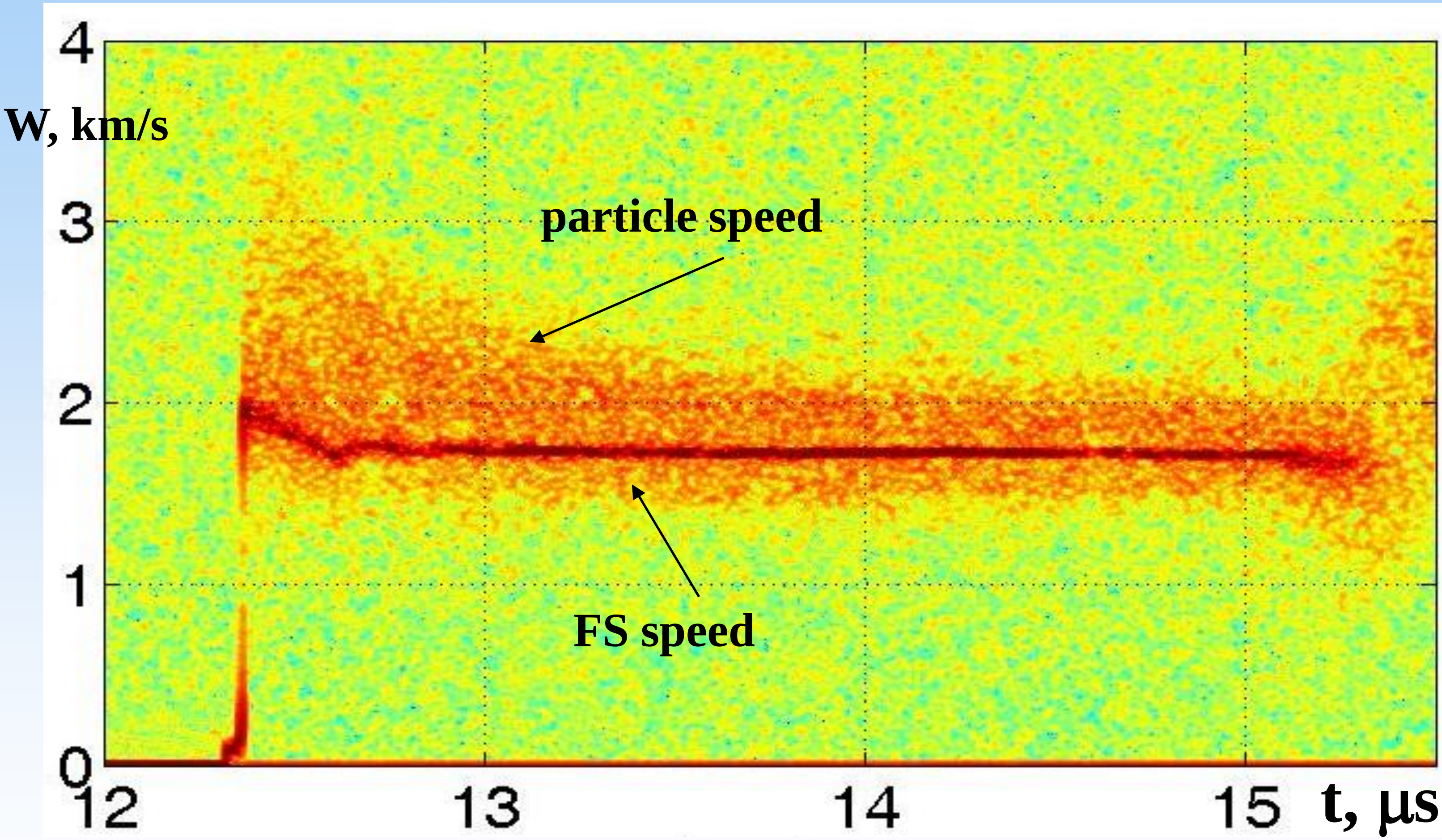






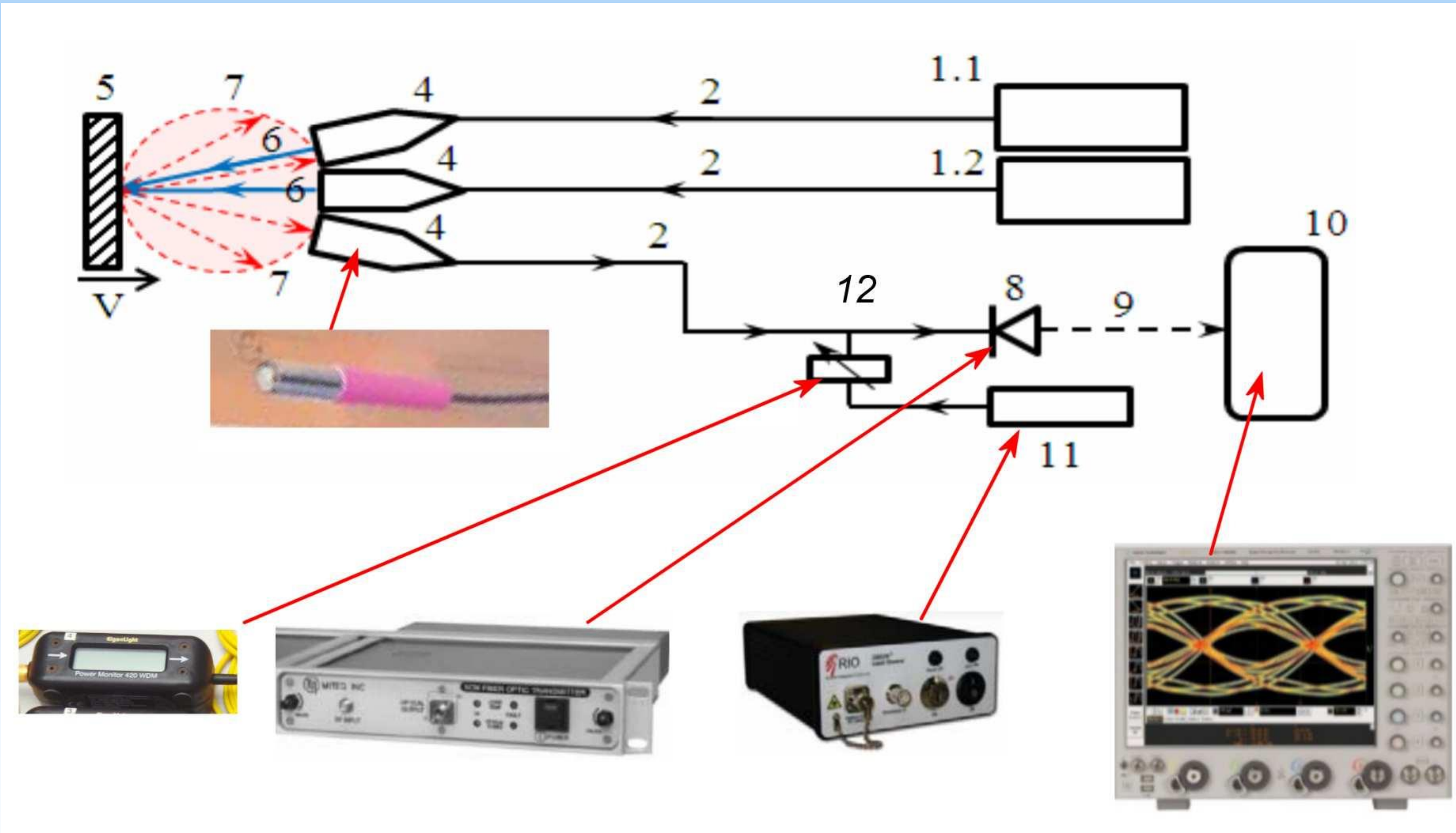
The synchronization signal from the DIMEX detector (left) and the signal from a piezoelectric sensor (LeCroy) (right)

Registration of a spectrum of particles speeds



A. Fedorov, A. Mikhailov, S. Finjushin at al.

Measuring complex PDV
(Photon Doppler Velocimetry)



2006 – LANL

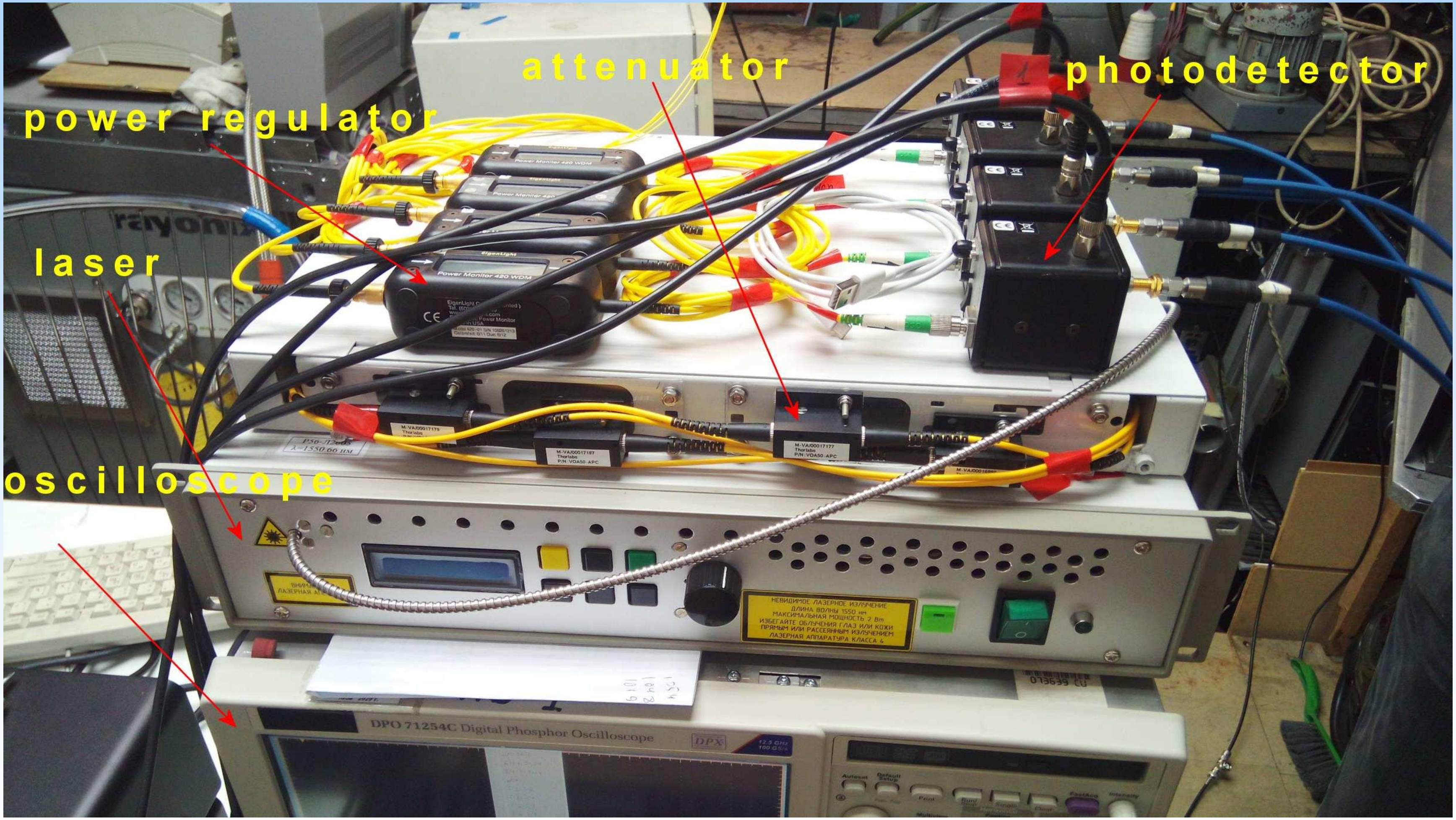
2010- VNIIEF

2016 - VNIITF

2019 – BINP

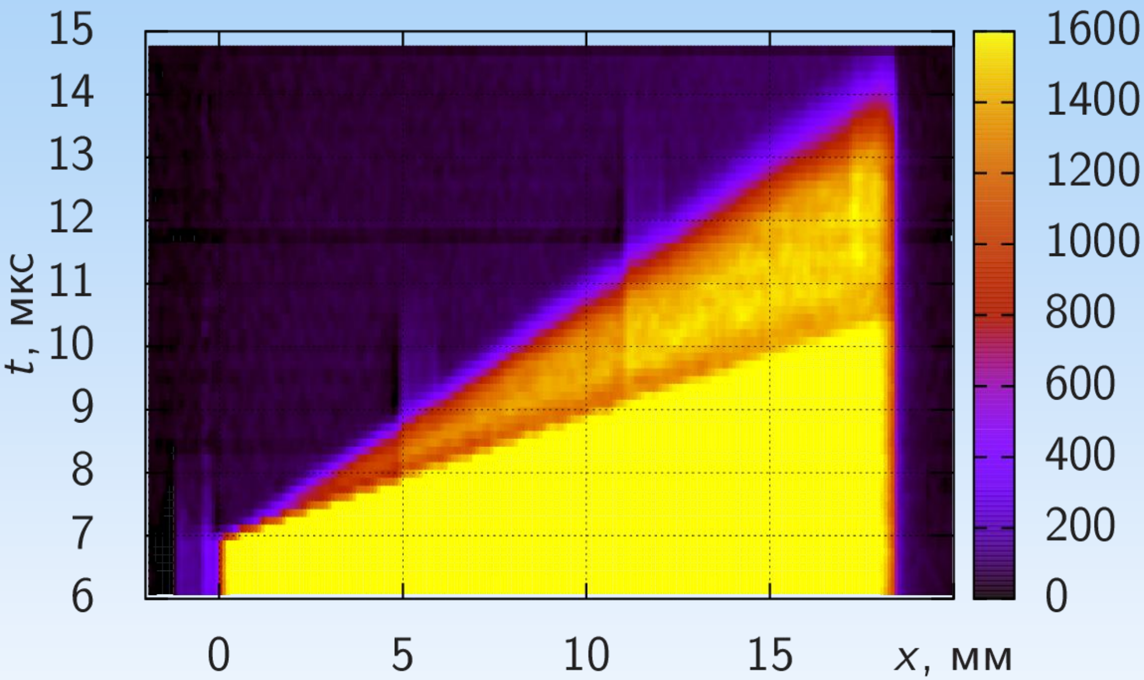
Elements of the 1st PDV channel: 2 - optical fiber, 4 - collimator, 8 - photodetector, 10 - oscilloscope, 11 - laser, 12 - power regulator (meter)

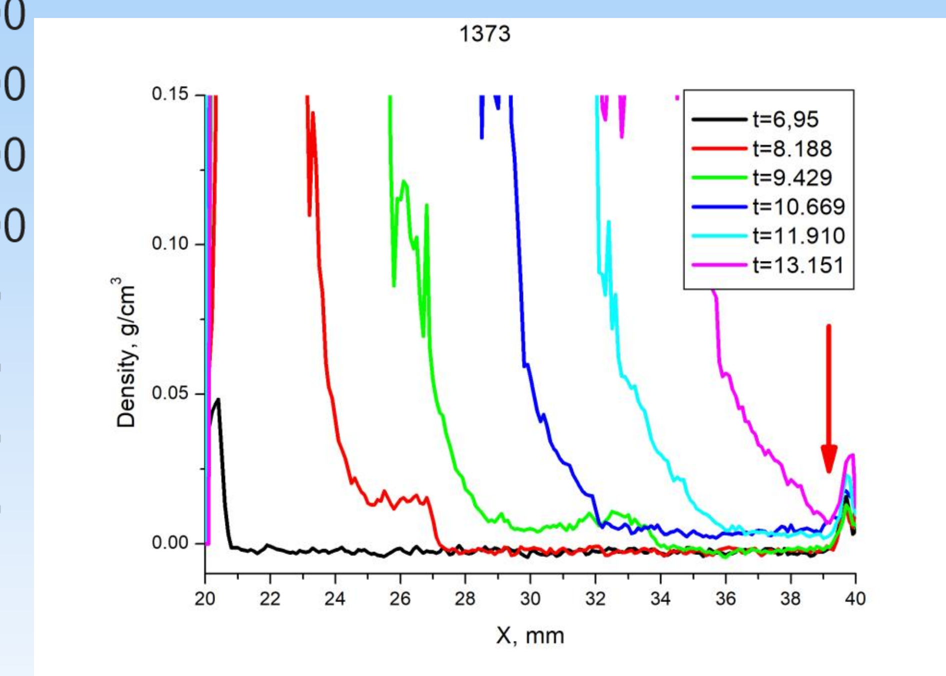
Setting up experiments.



PDV measuring complex.

The dynamic of a dust cloud of tin.
Rz62, vacuum

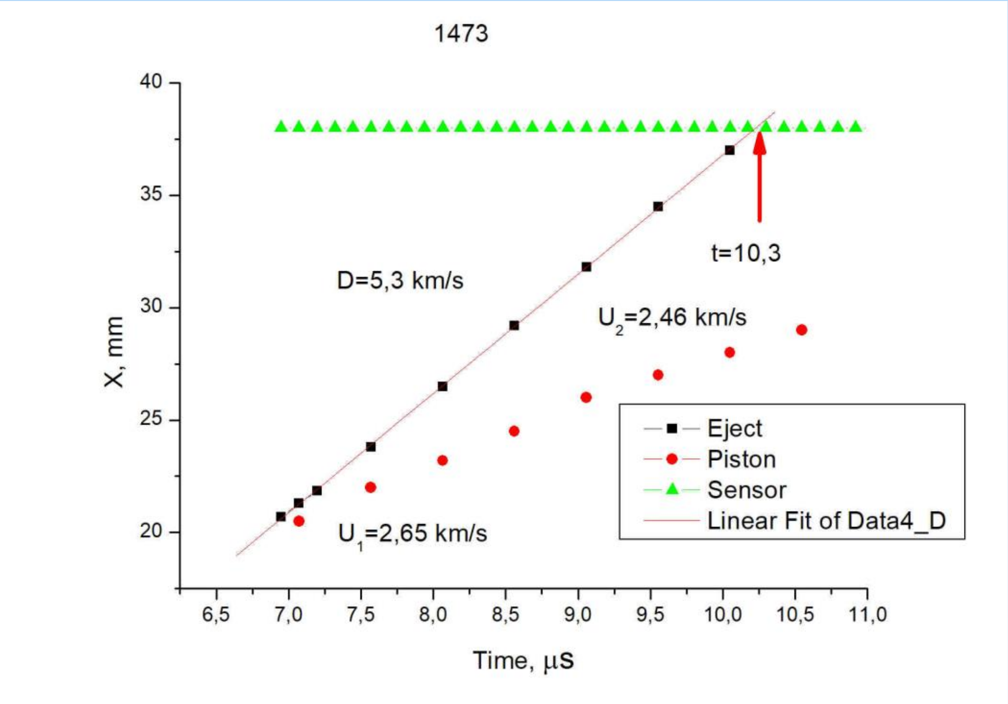




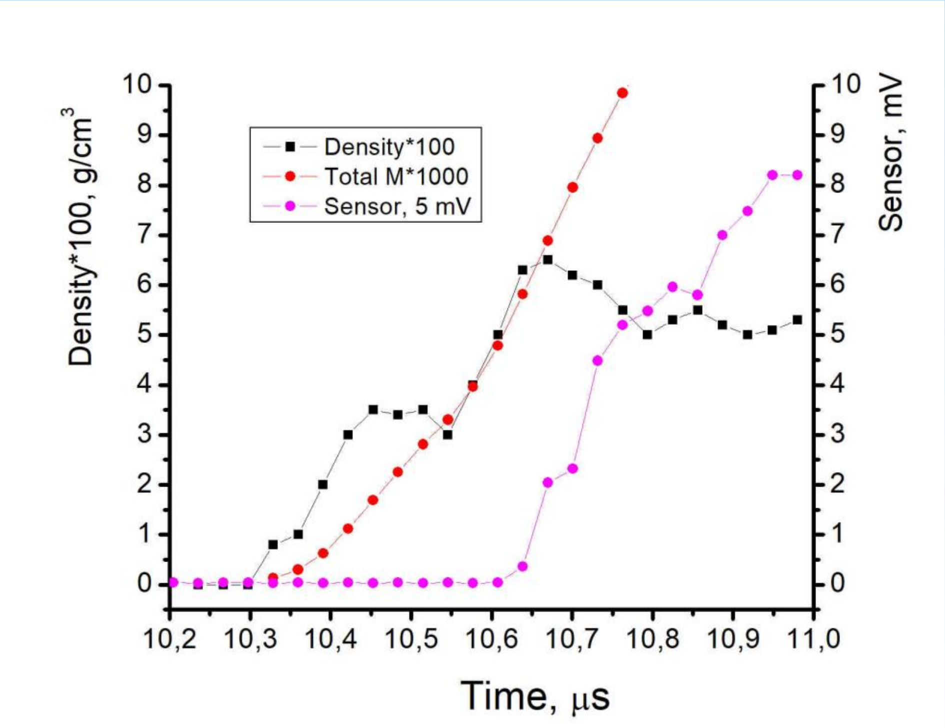
The dynamics of relative intensity. Dust speed - 5.30 km/s, FS speed - 2.46 km/s.

The dynamics of mass distributions. Time between graphs -1.24 µs.

Dust Cloud Dynamics (Rz62).

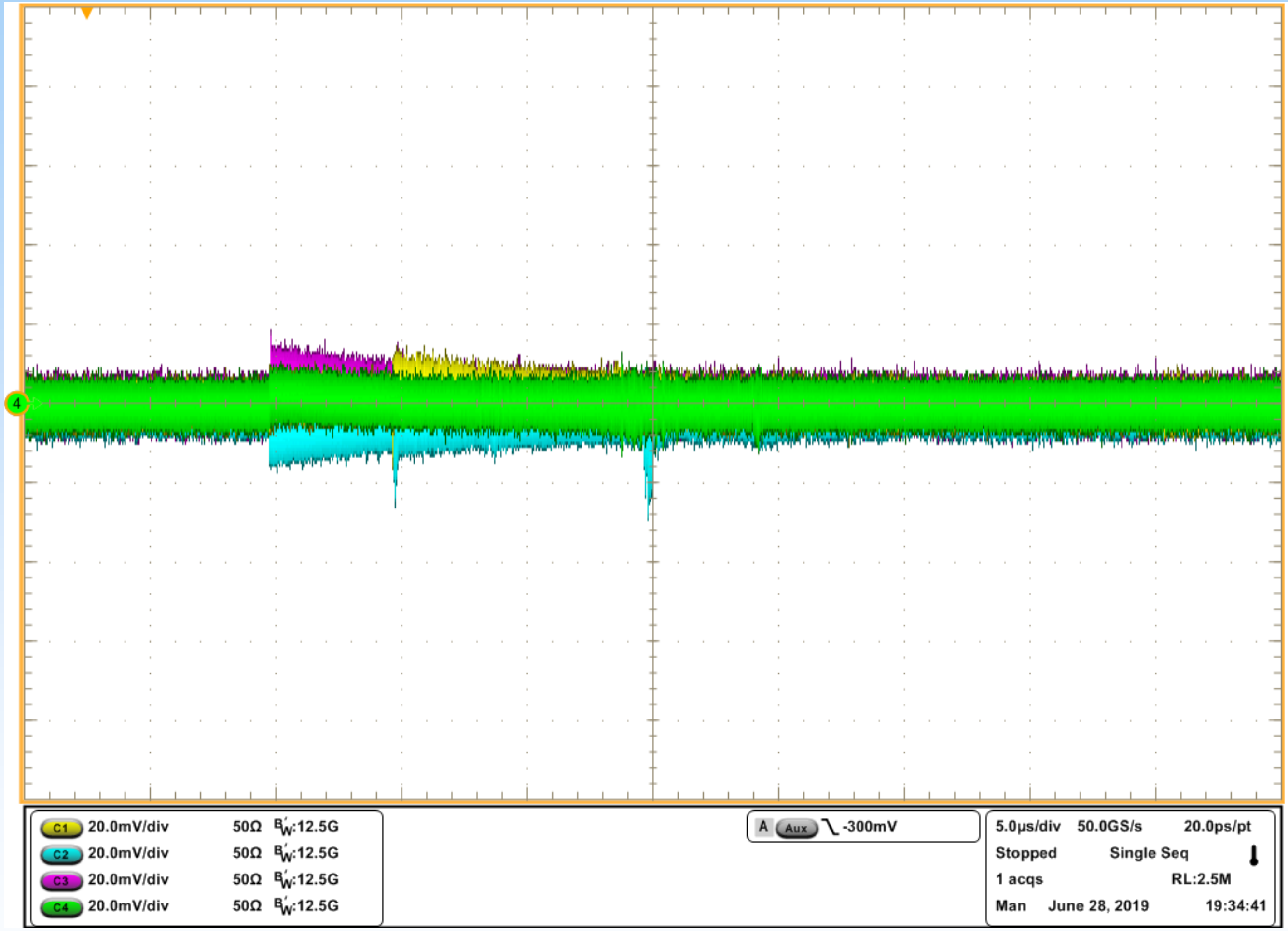


Eject motion graph (black spots). The red arrow shows the moment of impact on the piezosensor.



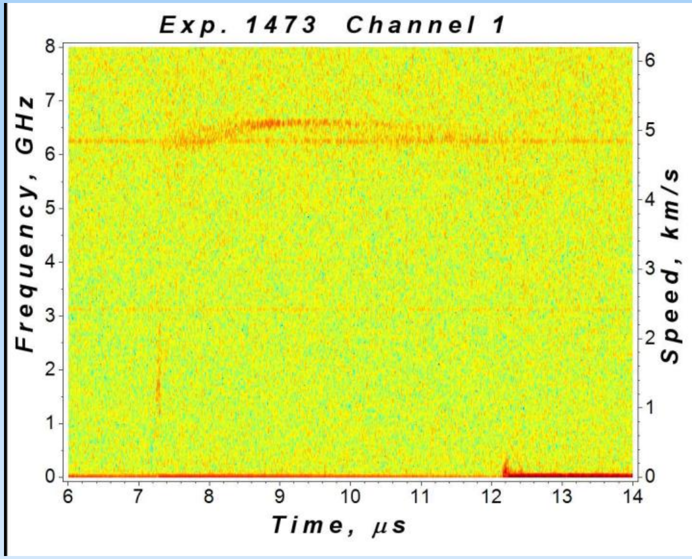
Piezosensor readings (violet) and densit y dynamics (black) and dust mass (red) depending on time.

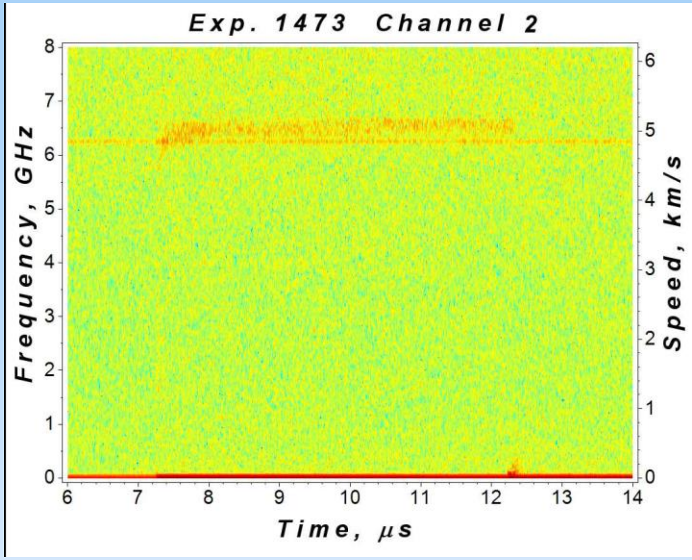
Dust Cloud Dynamics (Rz62).

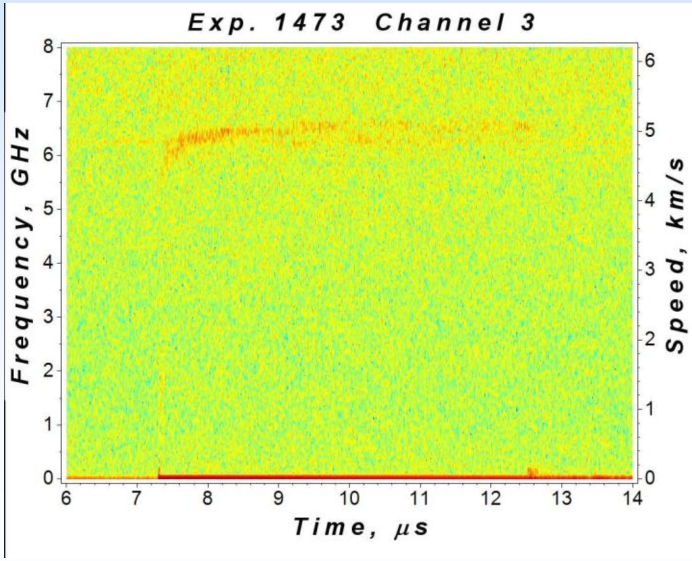


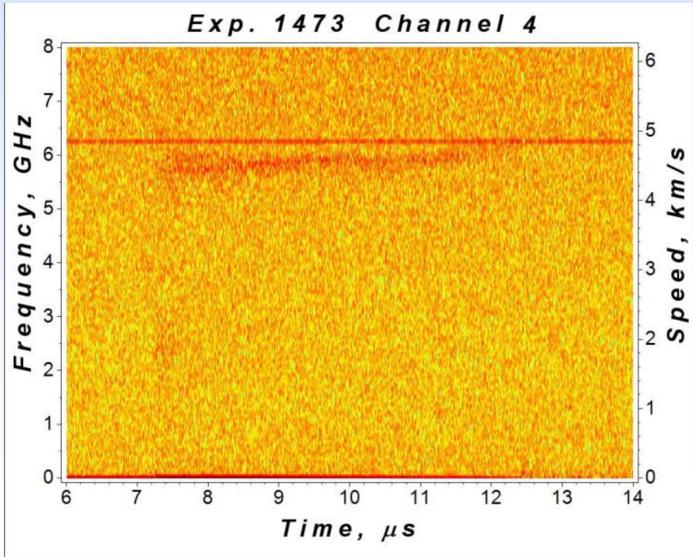
data from 4 PDV channels

Dust Cloud Dynamics (Rz62).



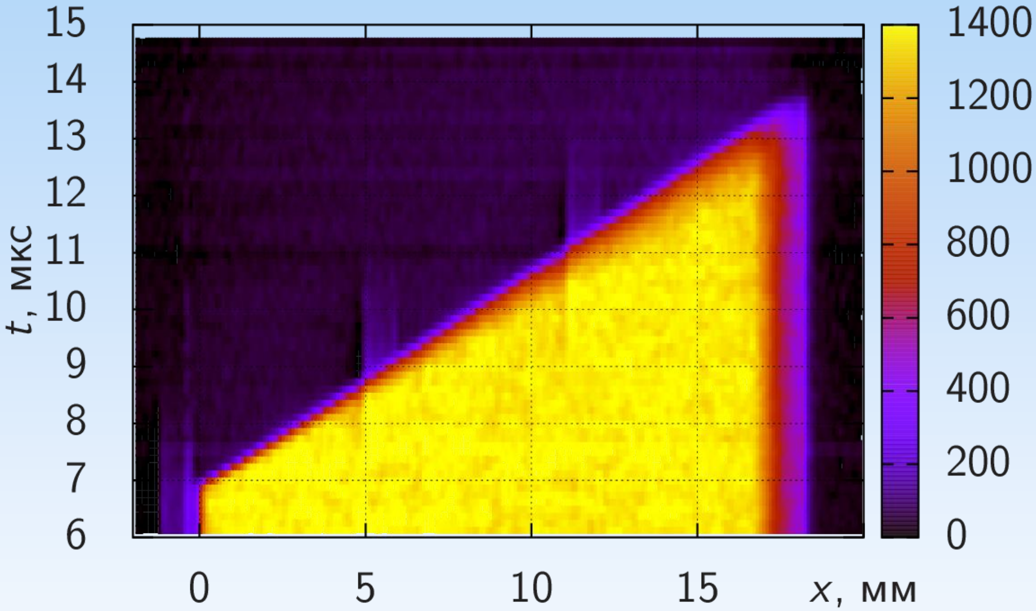


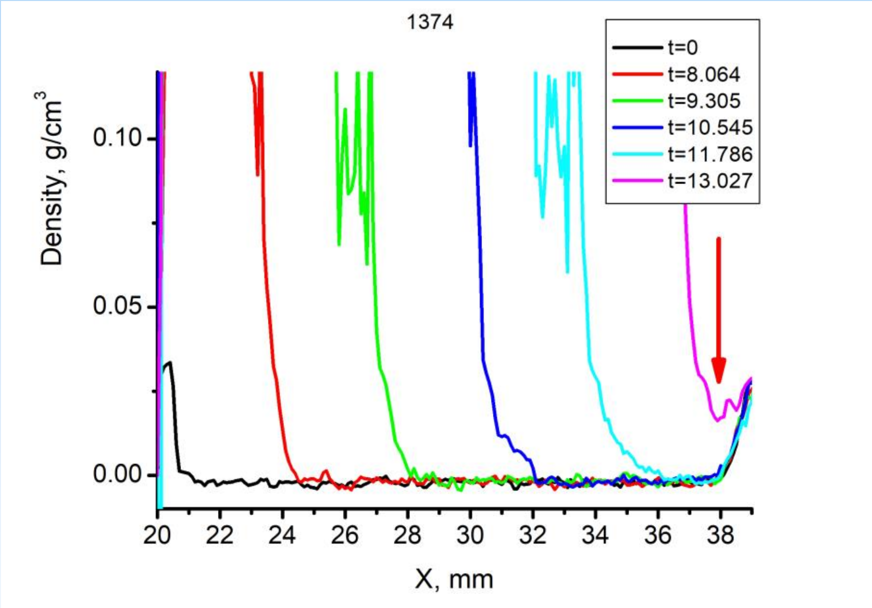




Dust Cloud Velocity Dynamics (PDV, Rz62)
The speed of the FS is visible only on channel 1

The dynamic of a dust cloud of tin.
Rz 5, vacuum

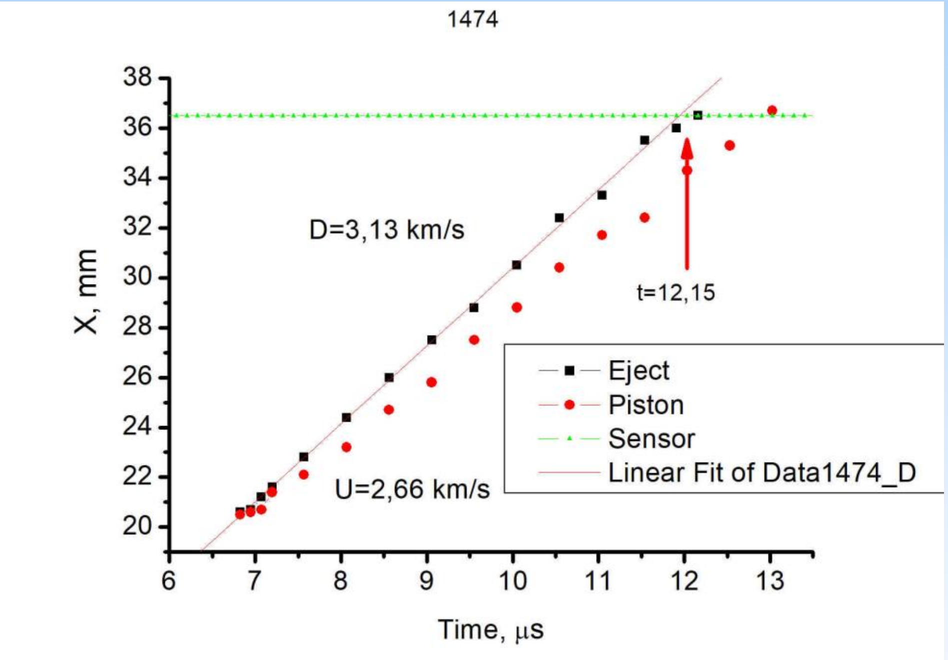


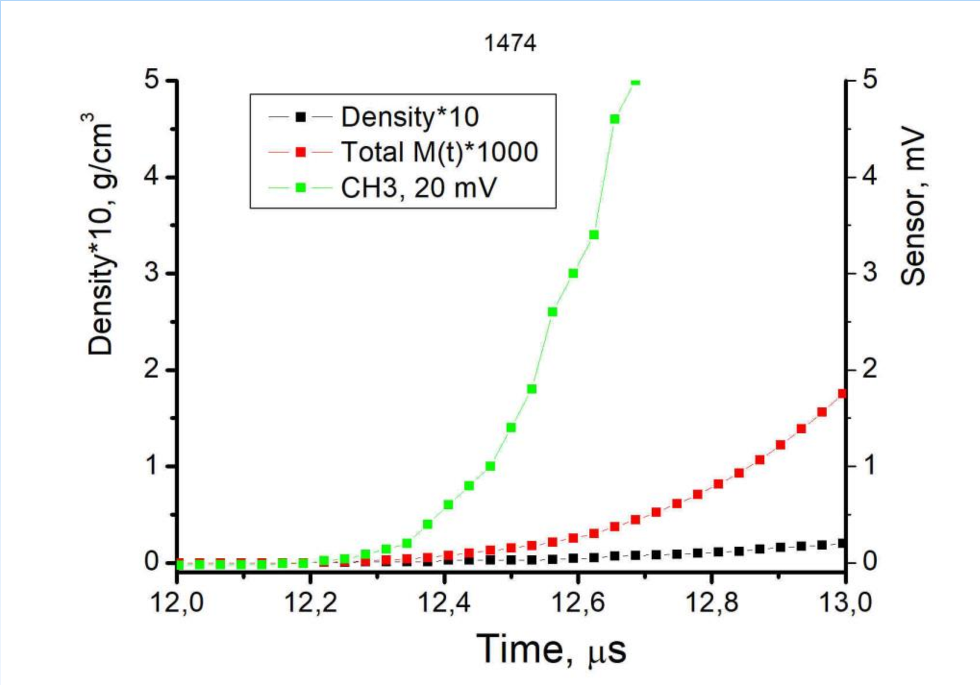


**The dynamics of relative intensity.
Dust speed - 3.13 km/s, FS speed - 2.66 km/s.**

**The dynamics of mass distributions.
Time between graphs -1.24 µs.**

The dynamic of a dust cloud.
Rz 5, vacuum

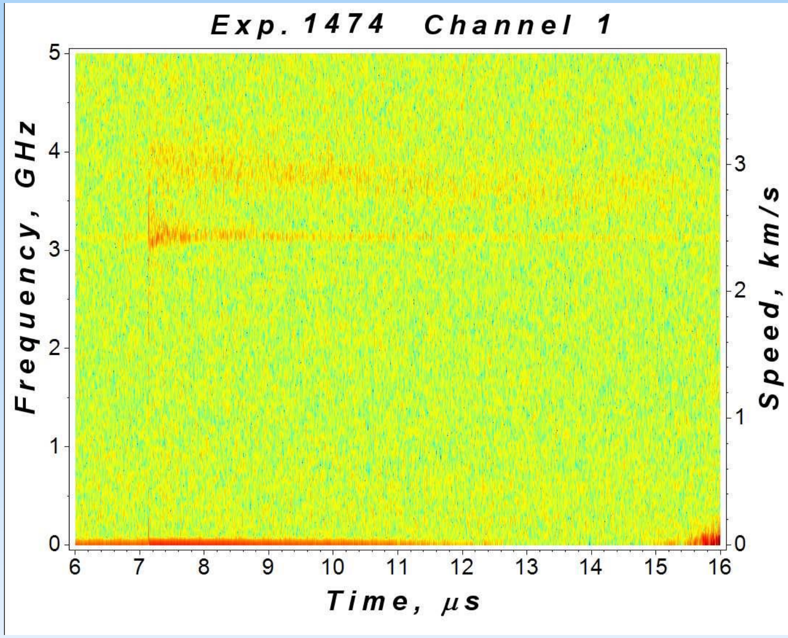


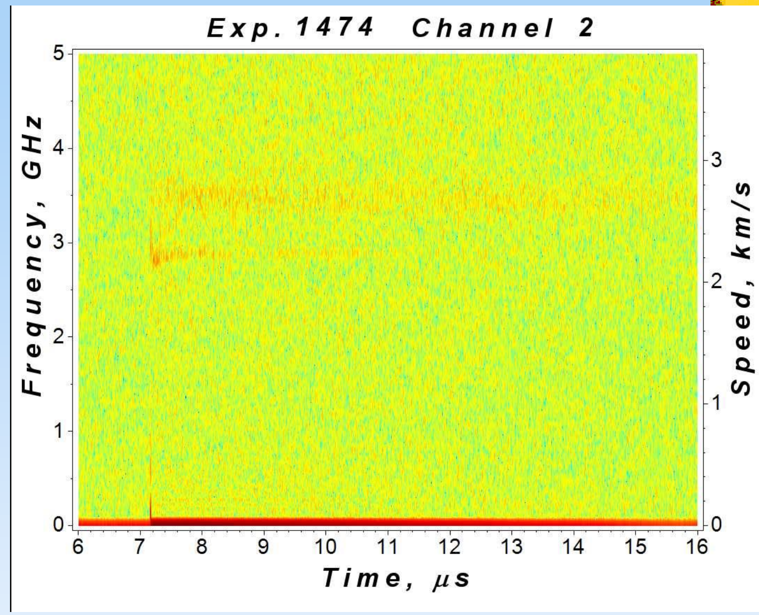


Eject motion graph (black spots). The red arrow shows the moment of impact on the piezosensor.

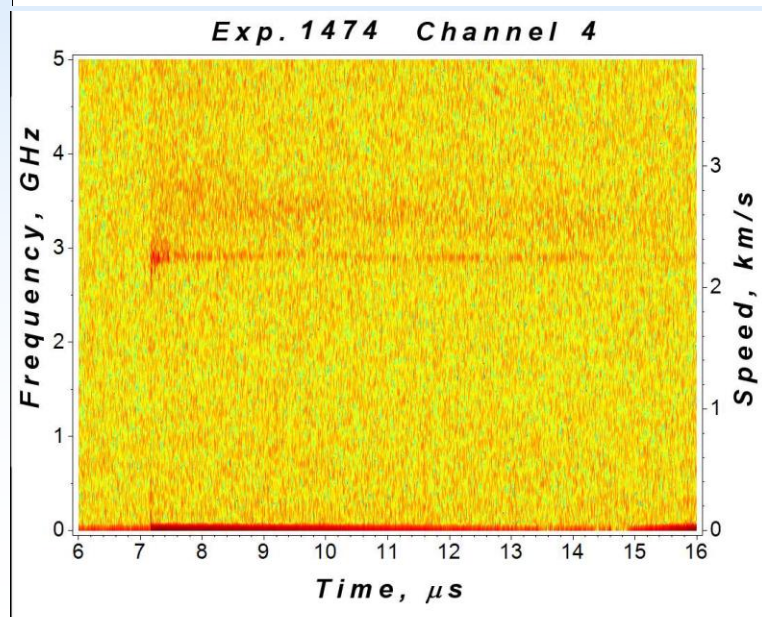
Piezosensor readings (green) and densit y dynamics (black) and dust mass (red) d epending on time.

Dust Cloud Dynamics (Rz5).

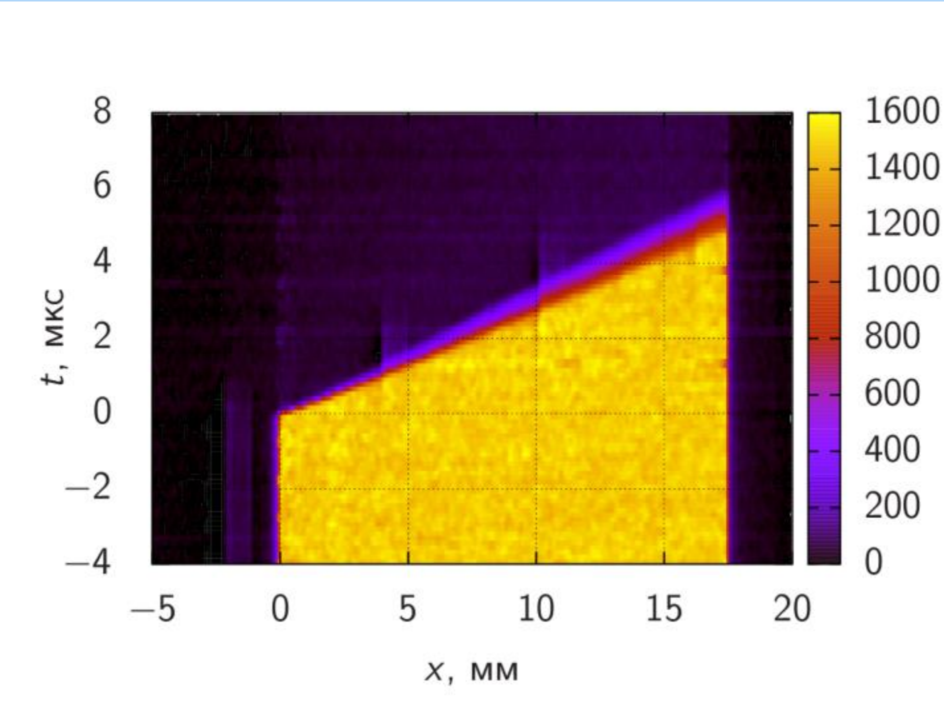


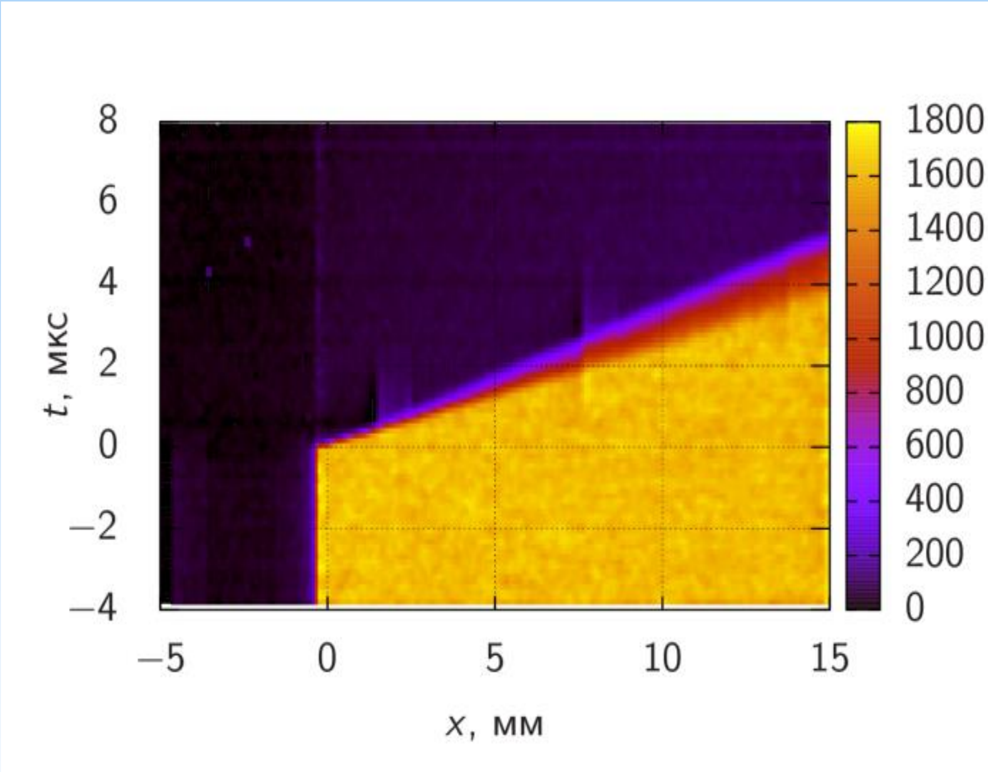


Dust Cloud Velocity Dynamics (PDV). Visible FS speed - 2.4 km / s.



The dynamics of a dust cloud in helium (Rz20).

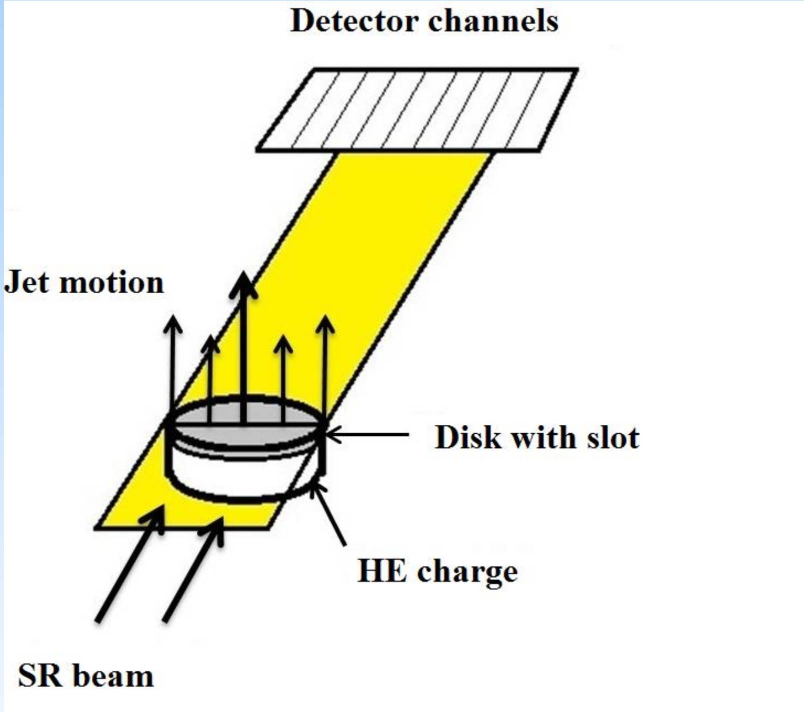


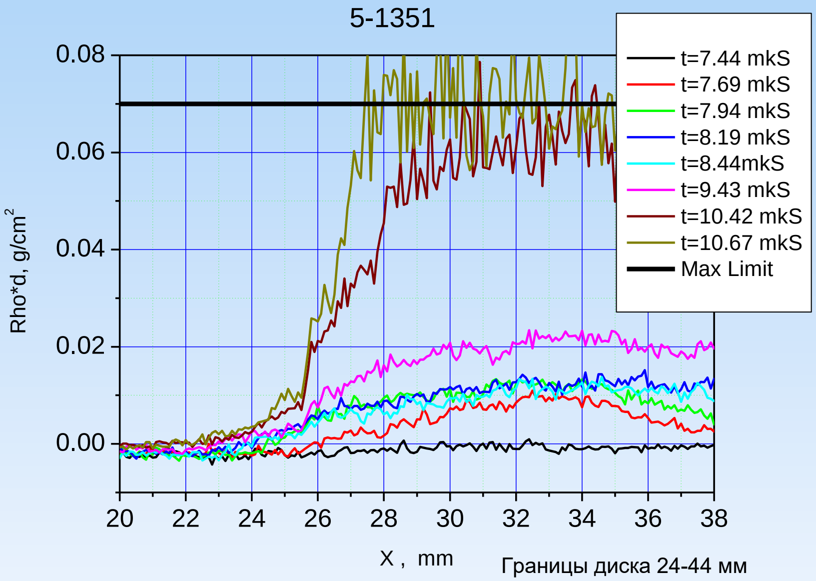


Record the relative intensity of SR. Helium - 8 atm. Eject speed - 3.49 km/s, FS speed - 3.11 km/s

The dynamics of the distribution of mass on the SR beam. Helium, 1 atm Eject velocity - 4.21 km/s, FS plate speed - 3.13 km/s

Dust cloud movement - side view.

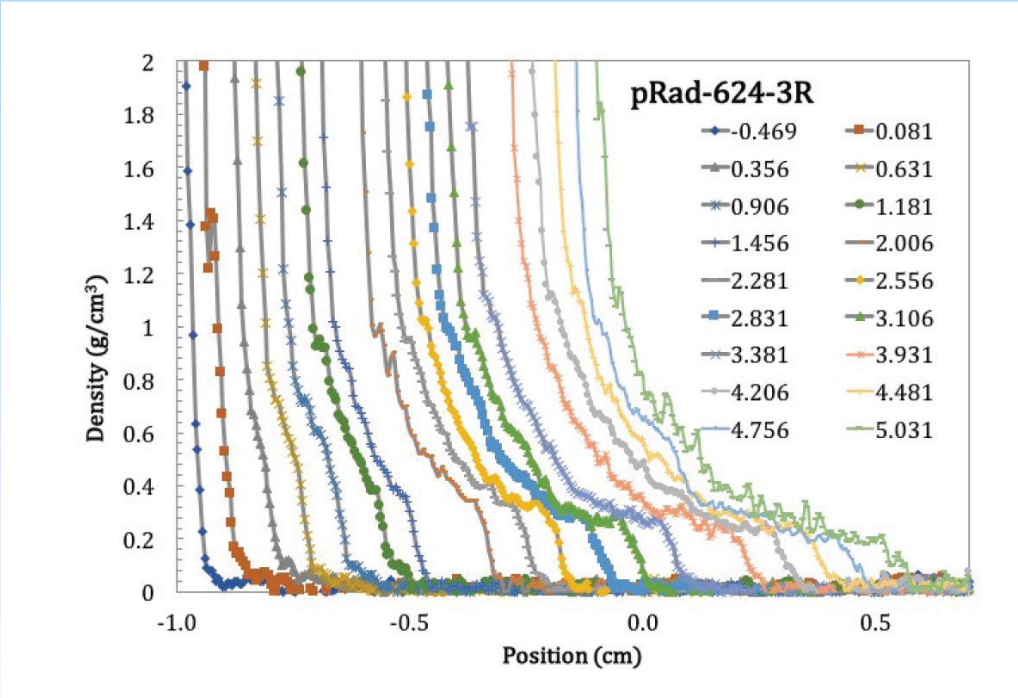




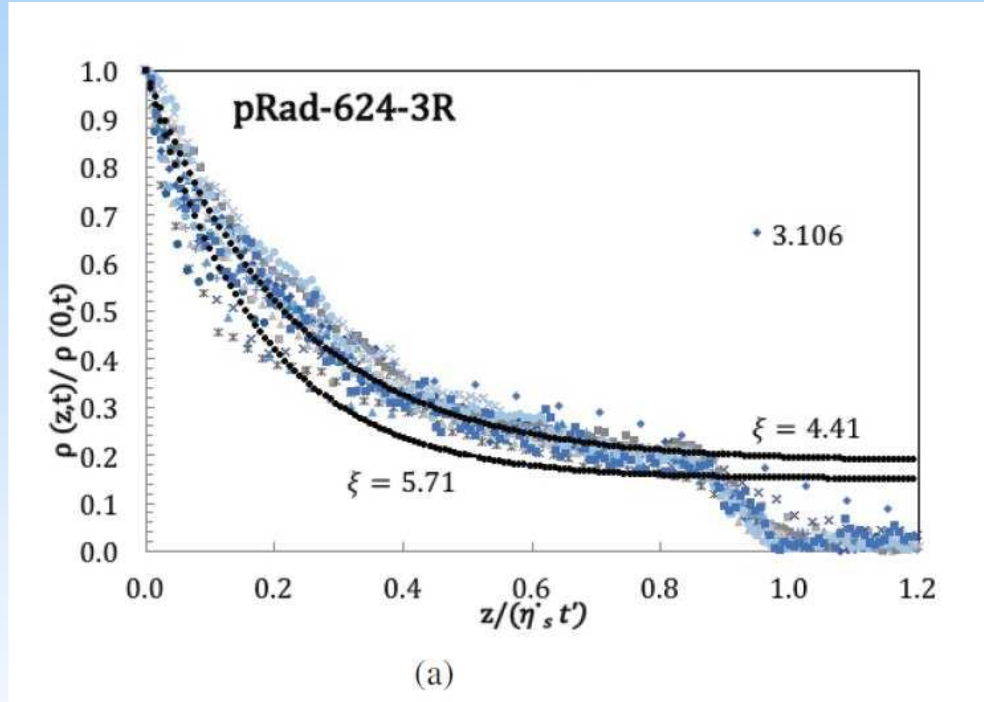
Setting up experiments to study expansion to the side

Dynamics of density distributions at a distance of 10 mm from the FS plate.

The dynamics of the dust cloud. Protonography LANL.



The density distribution of dust clouds and tin surface versus time. The initial position of the plate is -1 cm.



Density distribution data (t = 3.106 μs) and their interpolation.

Conclusions

1. ***For the first time in the world, experiments were carried out with synchronous registration of a dust cloud using SR, a PDV laser complex, and piezoelectric sensors.***

2. The cloud speed readings at Rz 62 for PDV are somewhat lower (SR - 5.3 km/s, PDV - 5.15 km/s), while Rz 5 the readings coincide (SR - 3.13 km/s, PDV – 3,00 km/s). At low Rz (5), the plate velocity can be measured (SR- 2.65 km/s, PDV - 2.40 km/s).

3. At Rz 62, the readings of the piezosensor are delayed relative to x-ray by 0.3 µs.

4. PDV does not see the FS plate hit the sensor.

Literature.

- K A Ten, E R Pruuel, A O Kashkarov, I A Rubtsov, M V Antipov, A B Georgievskaya, A L Mikhailov, I A Spirin, L I Shekhtman, V V Zhulanov and B P Tolochko. Dynamic registration of ejection from shock-loaded metals // Journal of Physics: Conference Series, Volume 1147, (2019) 012020 doi:10.1088/1742-6596/1147/1/012020
- K. Ten, E. Pruuel, A. Kashkarov, I. Rubtsov, A. Muzyrya, K. Prosvirnin, G. Rykovanov, E. Smirnov, M. Stolbikov, L. Shekhtman, V. Zhulanov, and B. Tolochko. Experimental Study of Ejection of Particles from Shock-Loaded Metals // Fundamentals of 31st International Symposium on Shock Waves. Editors: Akihiro Sasoh, Toshiyuki Aoki, Masahide Katayama. Springer, Switzerland, 2019, Pp. 953-959. ISBN 978-3-319-91019-2, ISBN 978-3-319-91020-8 (eBook) https://doi.org/10.1007/978-3-319-91020-8,
- Регистрация выброса частиц из ударно-нагруженных металлов методами СИ. К.А. Тен, Э.Р. Прууэл, А.О. Кашкаров, И.А. Рубцов, М.В. Антипов, А.Б. Георгиевская, А.Л. Михайлов, И. А. Спирин, В.М. Аульченко, Л.И. Шехтман, В.В. Жуланов, Б.П. Толочко. //ФГВ, 2018, т.54, № 5, стр. 103-111
- DETECTION OF MICROPARTICLES IN DYNAMIC PROCESSES *Ten K.A., Pruuel E.R., Kashkarov A.O., Rubtsov I.A., Shechtman L.I., Zhulanov V.V., Tolochko B.P., Rykovanov G.N., Muzyrya A.K., Smirnov E.B., Stolbikov M.Y., Prosvirnin K.M. //*
Journal of Physics: Conference Series. 2016. Т. 774. № 1. С. 012070.
- . SYNCHROTRON RADIATION METHODS FOR REGISTRATION OF PARTICLES EJECTED FROM FREE SURFACE OF SHOCK-LOADED METALS *Ten K.A., Pruuel E.R., Kashkarov A.O., Rubtsov I.A., Kosov A.V., Shechtman L.I., Zhulanov V.V., Tolochko B.P., Rykovanov G.N., Muzyrya A.K., Smirnov E.B., Stolbikov M.Y., Prosvirnin K.M. //* Physics Procedia. Сер. 2016. С. 366-373.

Спасибо за внимание.