THE NANOSECOND TIME RESOLVED X-RAY DIFFRACTOMETRY WITH SYNCHROTRON RADIATION FOR EXPLORATION OF FAST PROCESSES IN SOLIDS

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BUDKER INSTITUTE OF NUCLEAR PHYSICS SB RAS

INSTITUTE OF HYDRODYNAMICS SB RAS

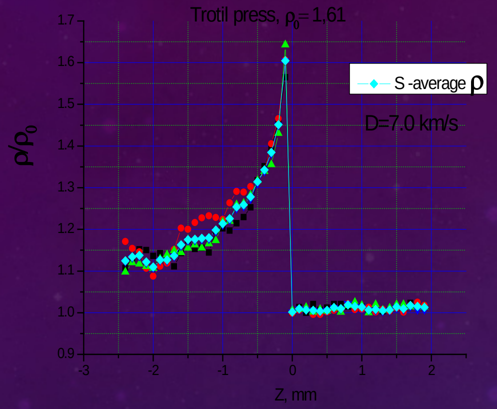
MOTIVATION: NEW LIFE IN SPACE NEED NEW MATERIALS

- Preparation of new materials at extremely high temperatures and pressures (10000 C, 300 kbar).
- Protect materials from the effects of shock compression v=11 km/s.
- Diamond synthesis

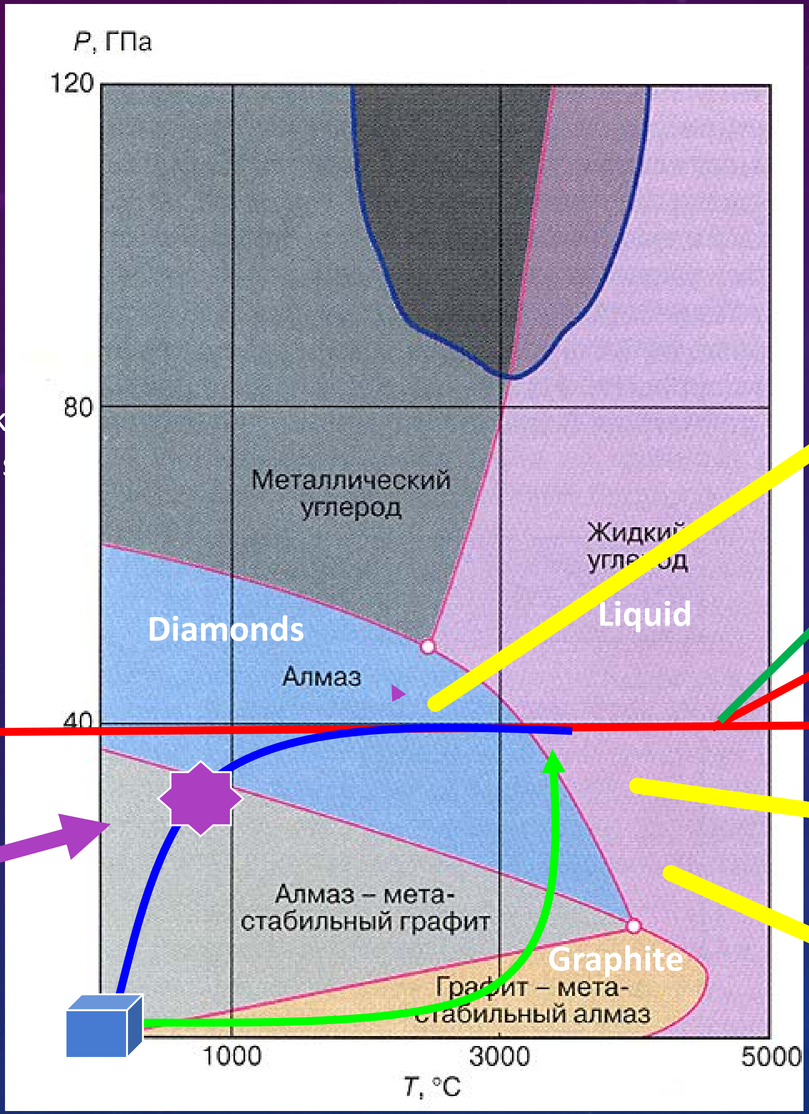
EXPERIMENTAL CONDITIONS

- **New wigglers – new spectrum range, high intensity**
- **New detectors – picosecond time resolution**
- **High energy at VEPP-4 (4,7 GeV) – new spectrum range**
- **LASER 100 J, 100 μs**
- **Explosion chamber for 200 g of TNT**
- **X-ray focusing optics**
- **BINP support (director, laboratories heads, scientific council)**

THE IDEA OF EXPERIMENT



Density distribution in TNT shock wave. 0.1 mm corresponding 13 n



Carbon phase diagram and load-reload model.

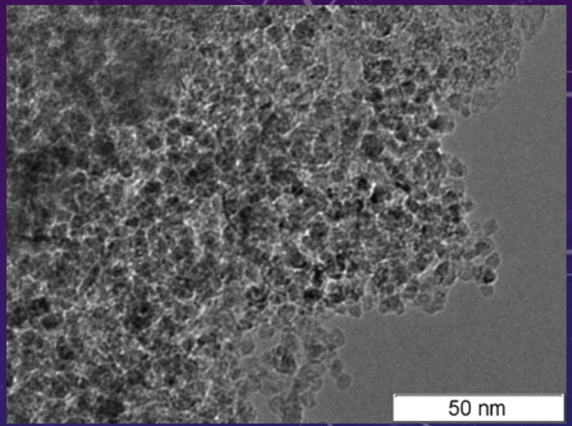
Scientific results

WAXS

SAXS

Absorbsion, XAFS (?)

?

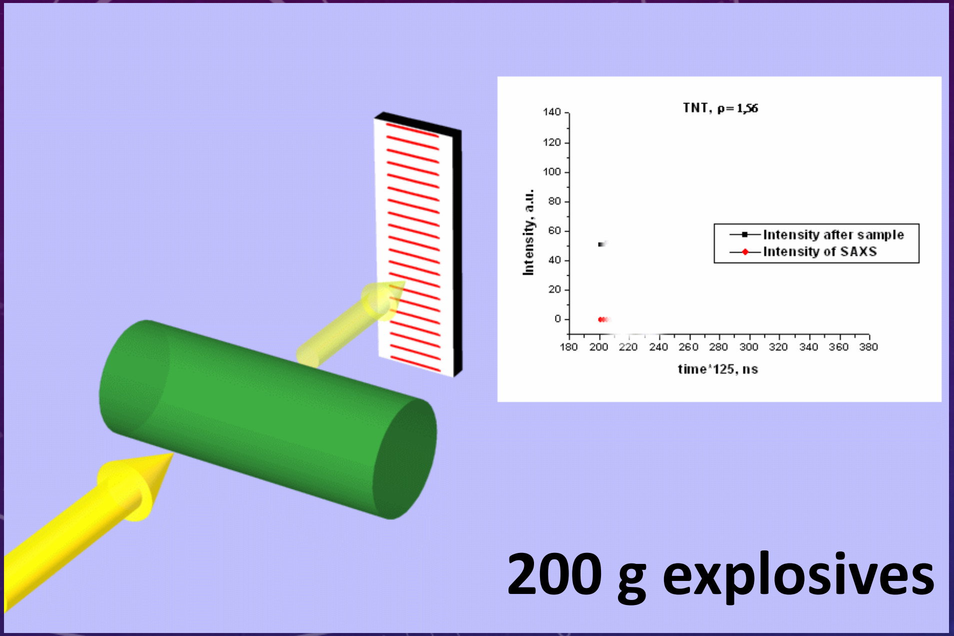


Diamond powder 5 nm

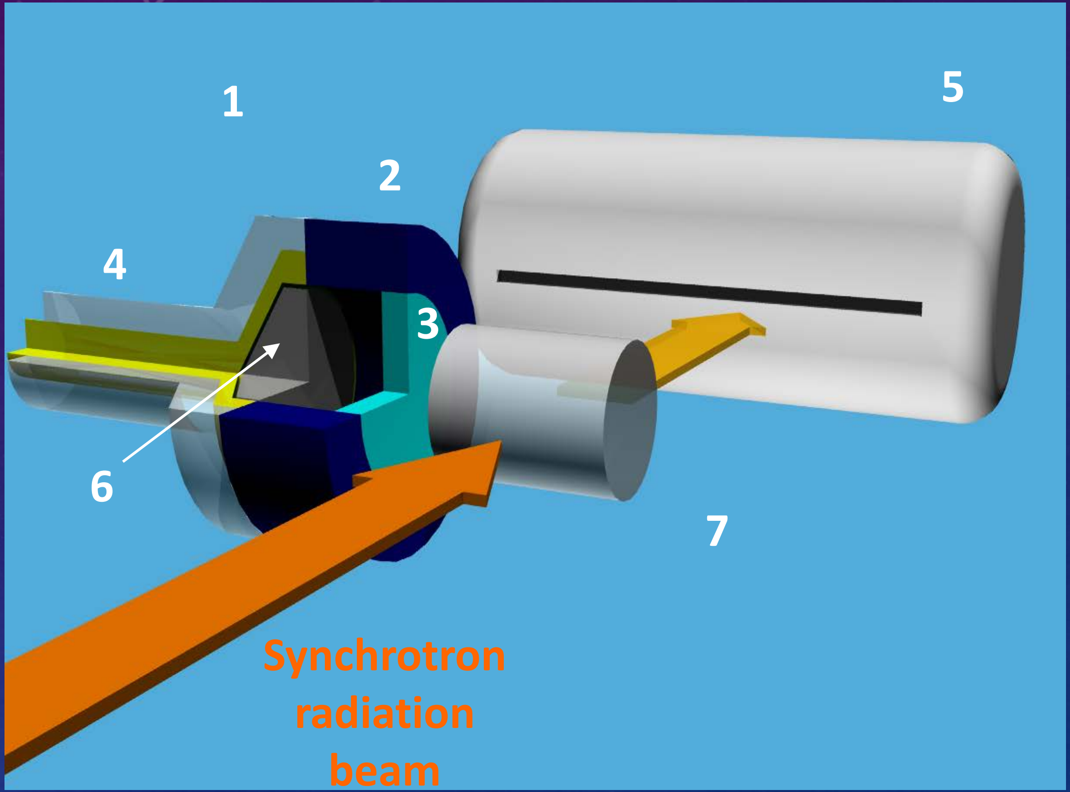
Diamond monolith 1000 nm

Dream: diamond 1 mm

HOW RECEIVE HIGH PRESSURE AND TEMPERATURE ?
BY USING DETONATION, SHOCK WAVES AND LASER



100 J
100 µs
1 mm^2



Shock wave adiabatic heating: 1- flat wave generator, 2-gun tube, 3-plunger, 4-detonator, 5-detector, 6- explosive, 7-sample.

EXPERIMENTAL CONDITIONS

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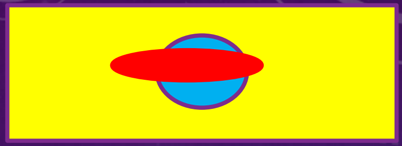
SYNCHROTRON RADIATION GENERATION

SR



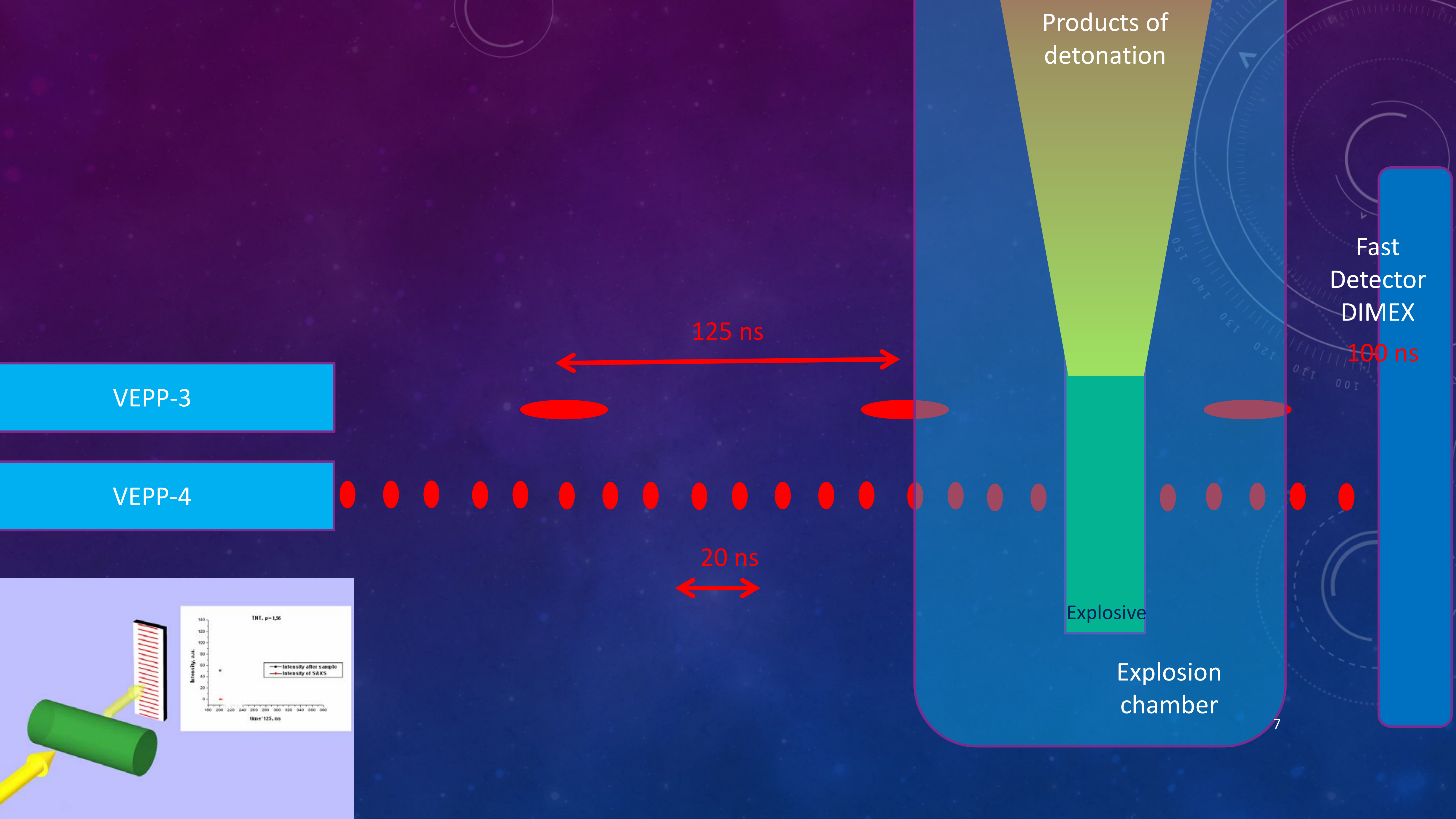
wiggler

Storage ring VEPP-4:

Period – 1200 ns
interval – 5 ns
interval – 10 ns
interval – 15 ns
interval – 20 ns
exposure 73 ps

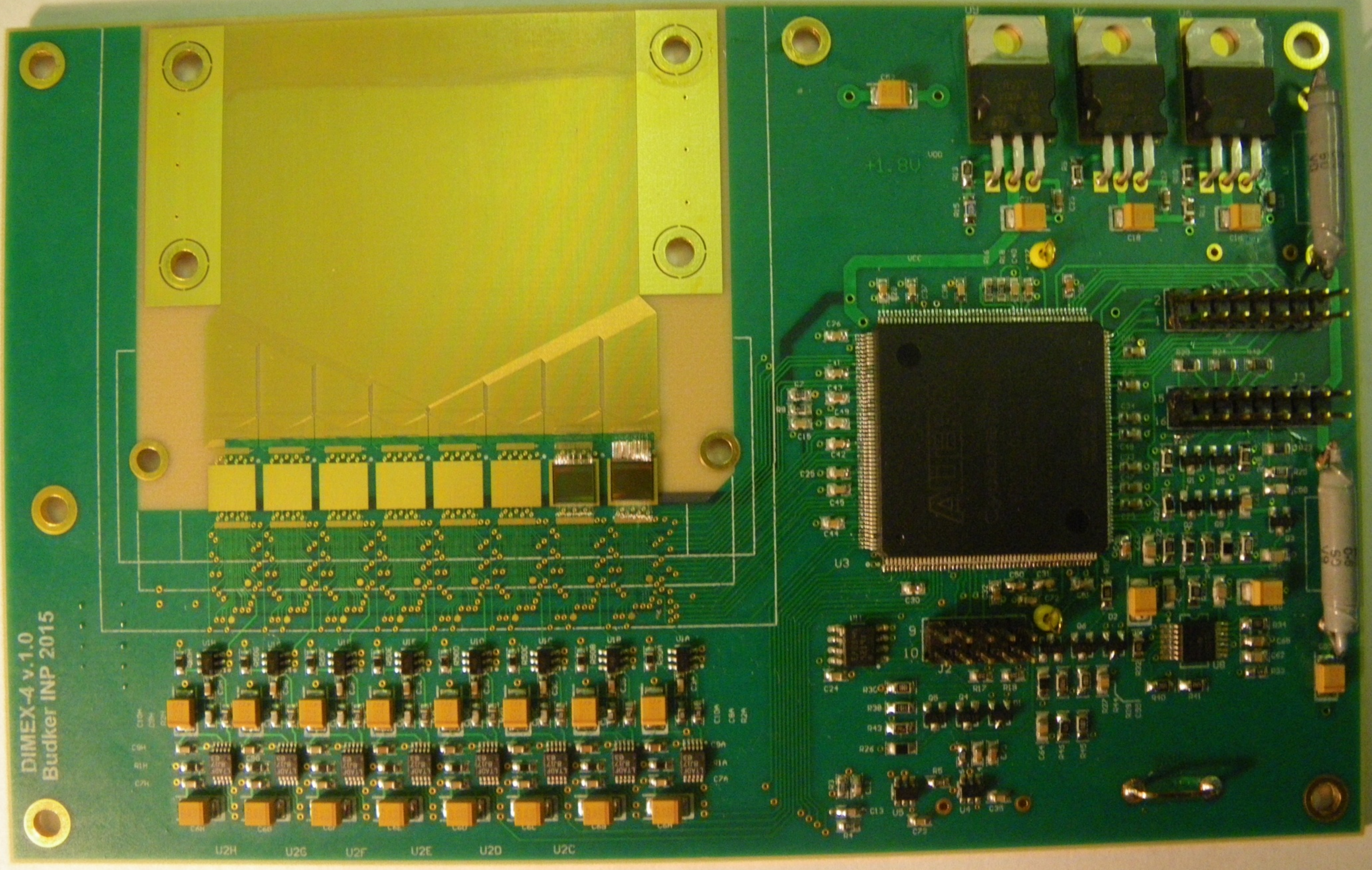
STORAGE RING VEPP-3:

Period – 250 ns
Interval – 250 ns
Interval* – 125 ns
Exposure - 1000 ps


Products of detonation
Fast Detector DIMEX
100 ns
125 ns
VEPP-3
VEPP-4
20 ns
Explosive
Explosion chamber
TNT, ρ=1,56
Intensity, a.u.
Intensity after sample
Intensity of SAXS
time*125, ns

EXPERIMENTAL CONDITIONS

- New wigglers – new spectrum range, high intensity
- High energy at VEPP-4 (4,7 GeV) – new spectrum range
- New detectors – picosecond time resolution (exposure time), interval 100 ns
- LASER 100 J, 100 μs
- Explosion chamber for 200 g of TNT
- X-ray focusing optics
- BINP support (director, laboratories heads, scientific council)



DIMEX-G

Strip structure for DIMEX-Si

EXPERIMENTAL CONDITIONS

- **New wigglers – new spectrum range, high intensity**
- **High energy at VEPP-4 (4,7 GeV) – new spectrum range**
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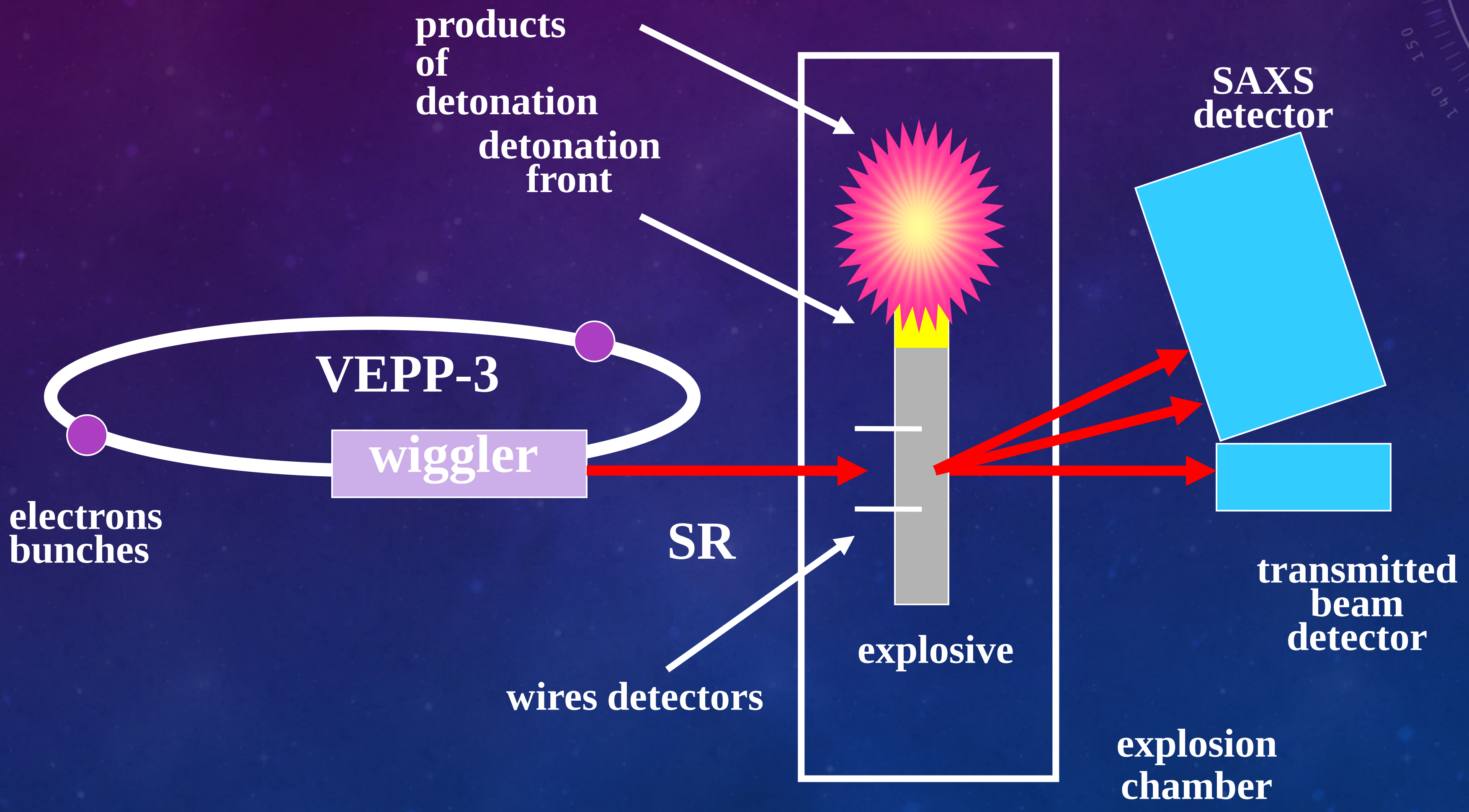
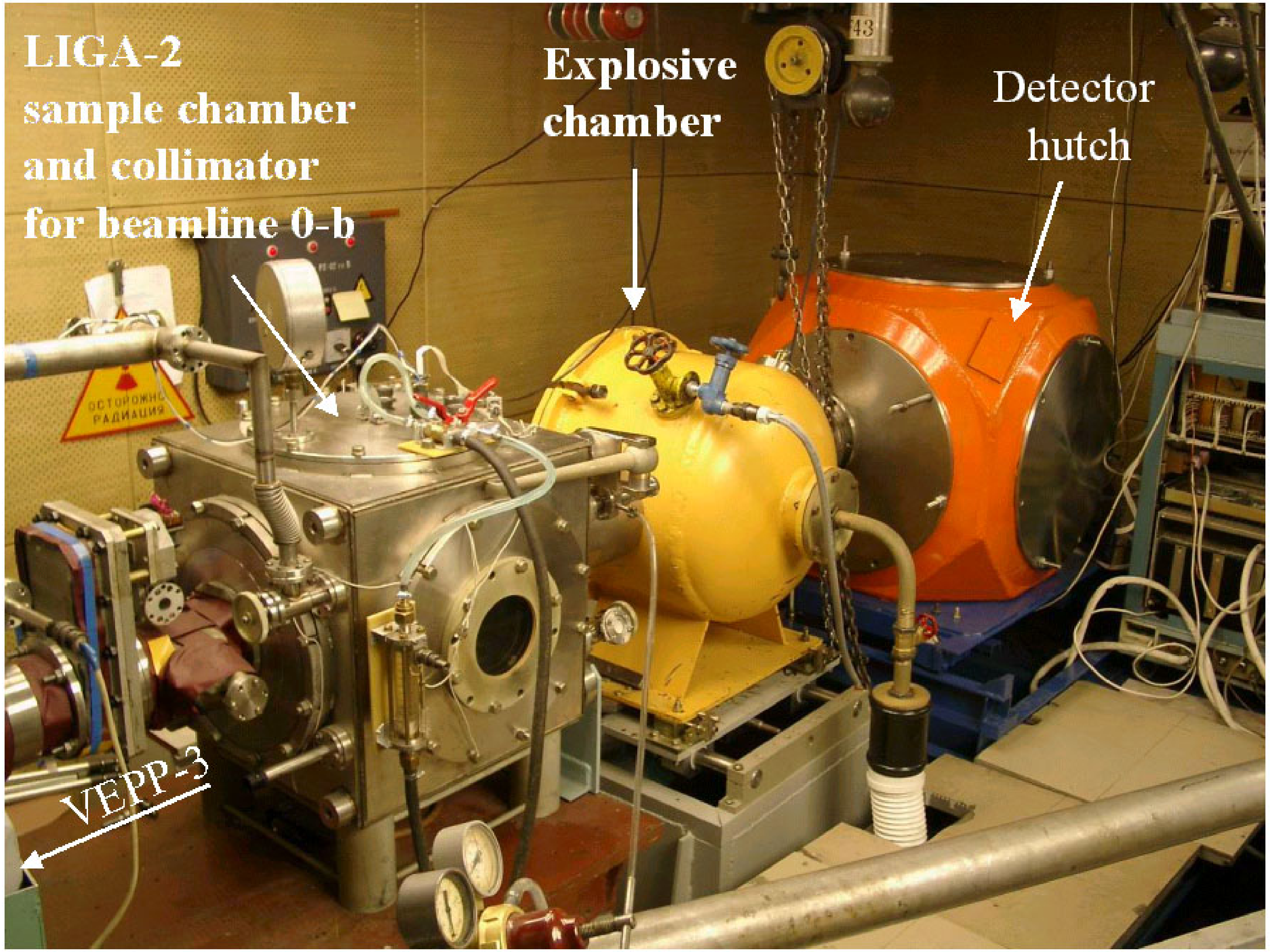
Experimental setup of explosion experiment at VEPP-3

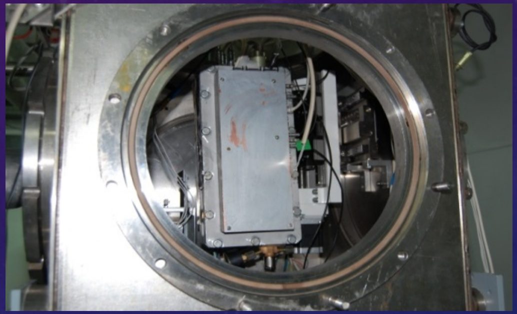


SYNCHROTRON RADIATION EXPERIMENTAL STATION FOR EXPLOSION INVESTIGATION

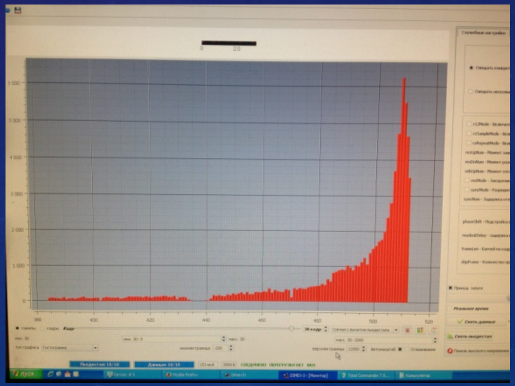


EXPERIMENTAL STATION "DETONATION" AT VEPP-4

Explosive diameter 40 mm
Weight 200 g



Detector
DIMEX



SAXS with
exposure 73 ps

EXPERIMENTAL CONDITIONS

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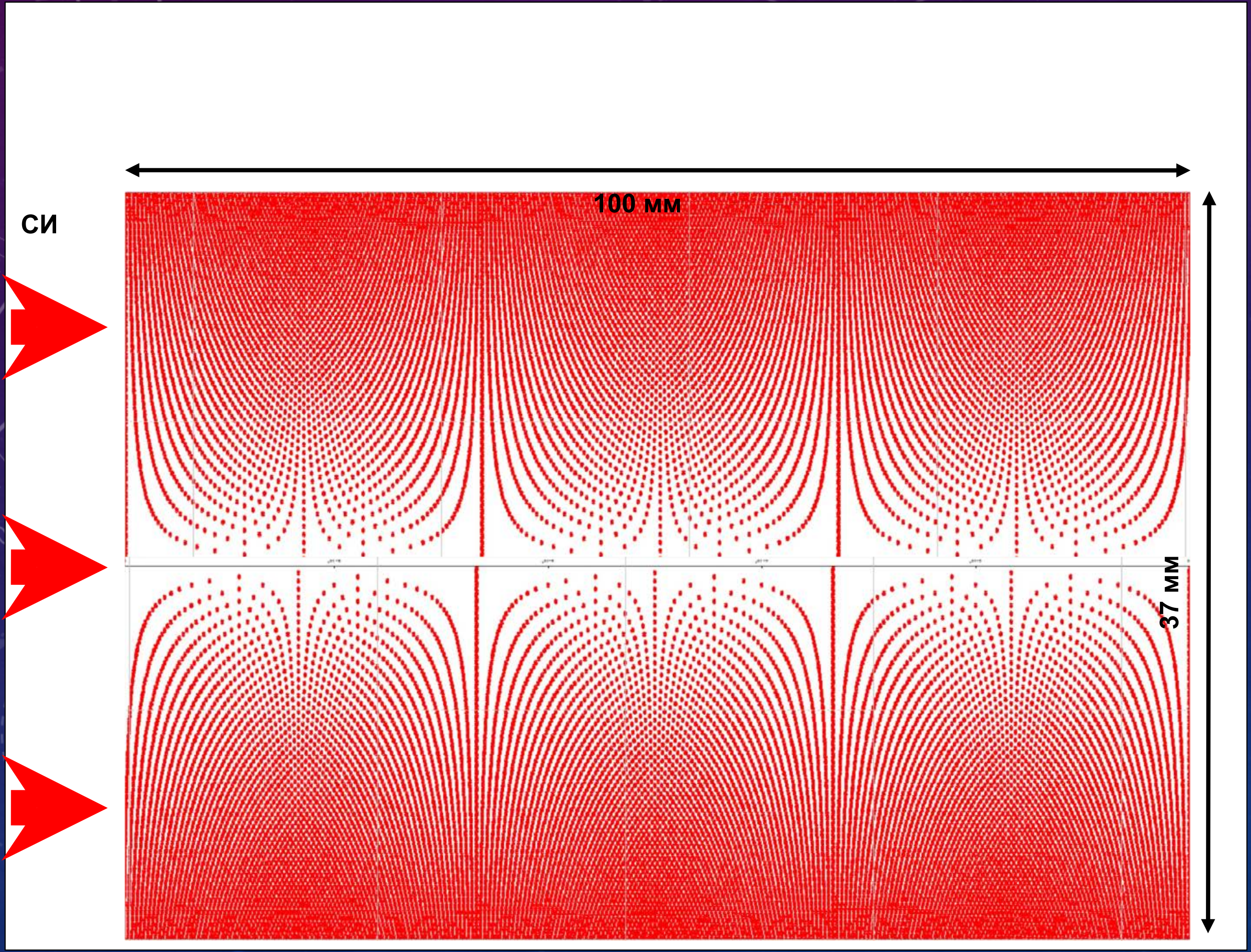
X-RAY OPTIC

150000 ELEMENTS

MATERIALS: PMMA, SU-8, NI

V.NAZMOV REPORT



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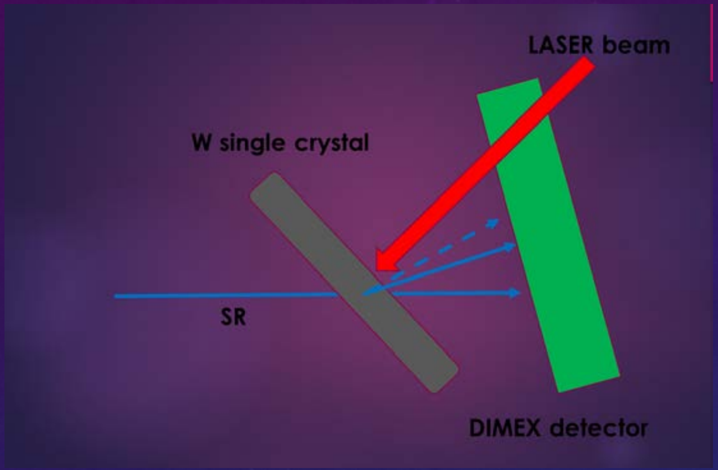
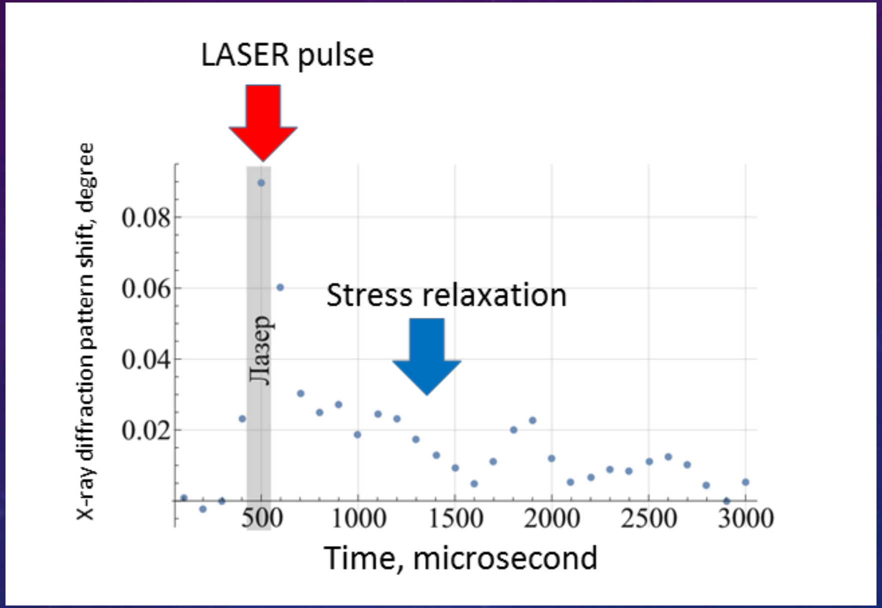
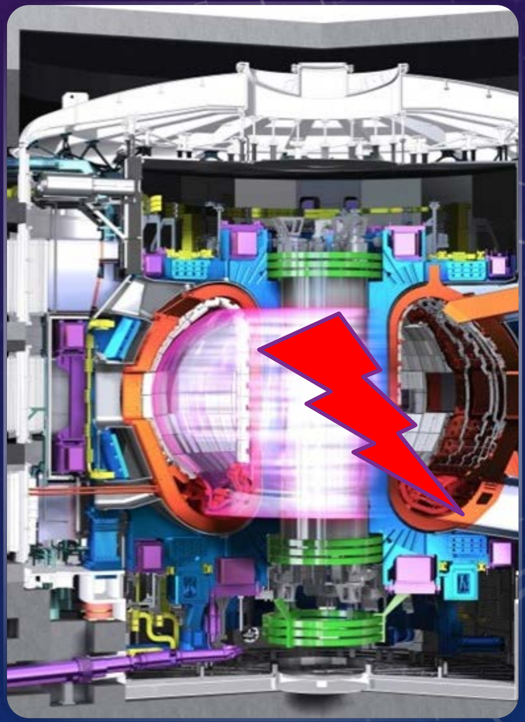
ITER: PLASMA DISCHARGE ON THE DIVERTER. MATERIAL BEHAVIOR. MODEL EXPERIMENT WITH LASER PULSE HEATING. NEED NEW MATERIALS



The scheme of model experiment with LASER pulse heating during 100 microseconds.



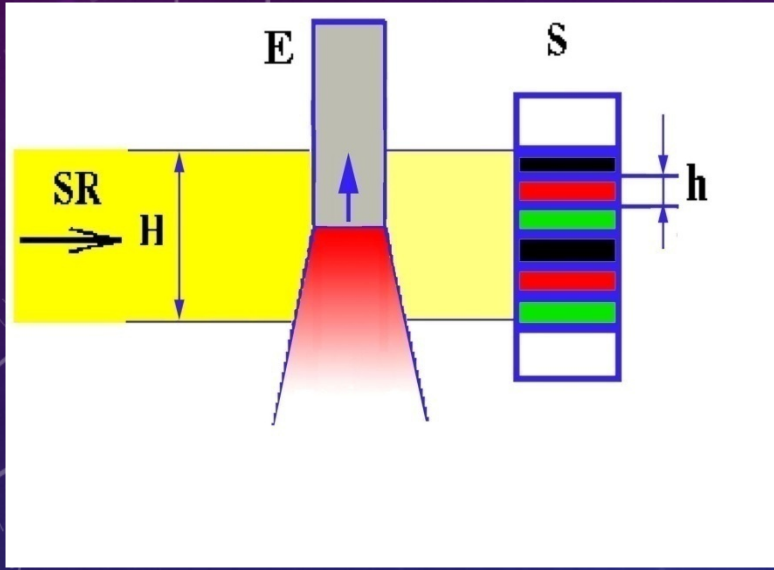
The experimental data of model experiment with LASER pulse heating .

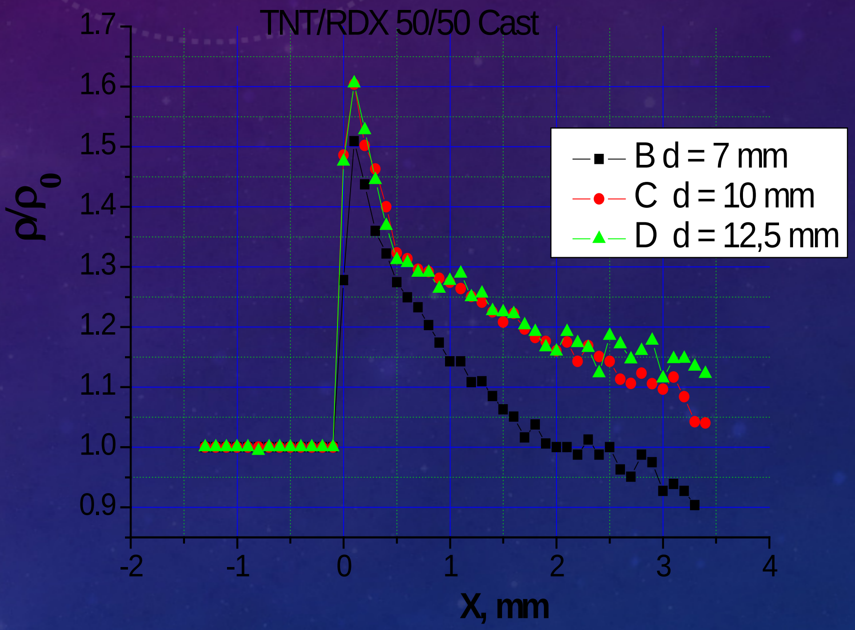


- Now we are preparing an experiment to study the behavior of the crystal lattice of the material of the fusion reactor first wall in a plasma discharge on the diverter

SCIENTIFIC RESULTS

Detonation front structure measurements with using SR

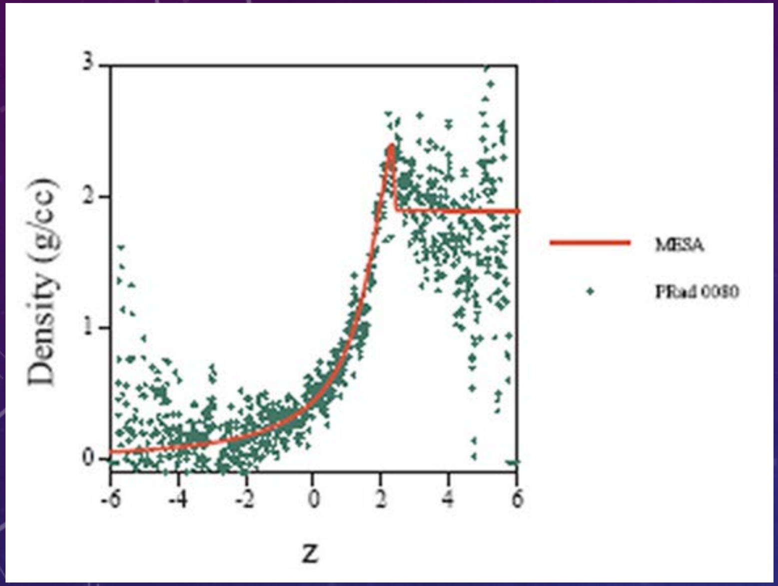


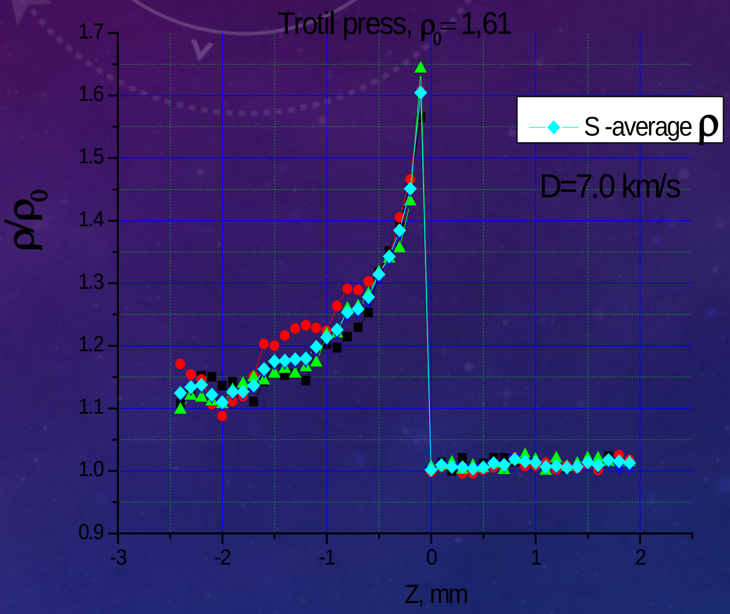


Experimental setup on SR beam. Beam width H=18 mm, thickness 0,4 mm. Exposure time 1 ns. DIMEX detector strip width h=0,1 mm.

Relatively density at detonation front of explosives TNT/RDX 50/50, diameter 7 mm, 10 mm and 12,5 mm, 13 ns time resolution

Las Alamos (LANL, protons) and Novosibirsk (BINP, synchrotron radiation) experimental of density measurements at detonation front





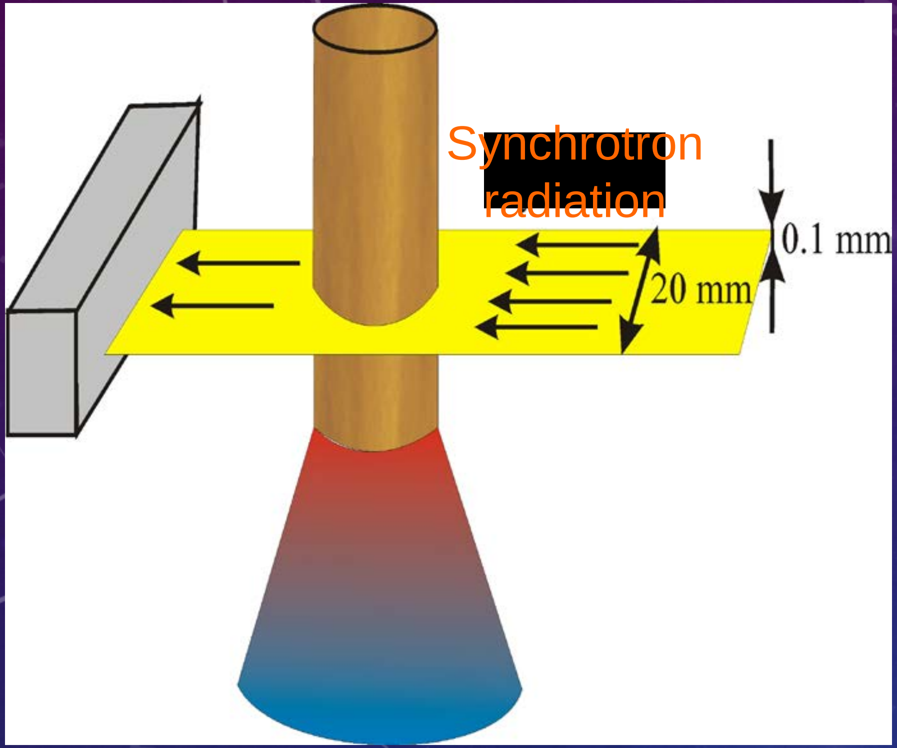
Las Alamos. Proton experiment.

Comparison of the density on axis from the MESA calculation density (red line) estimated from a single frame in green points for PBX9502.

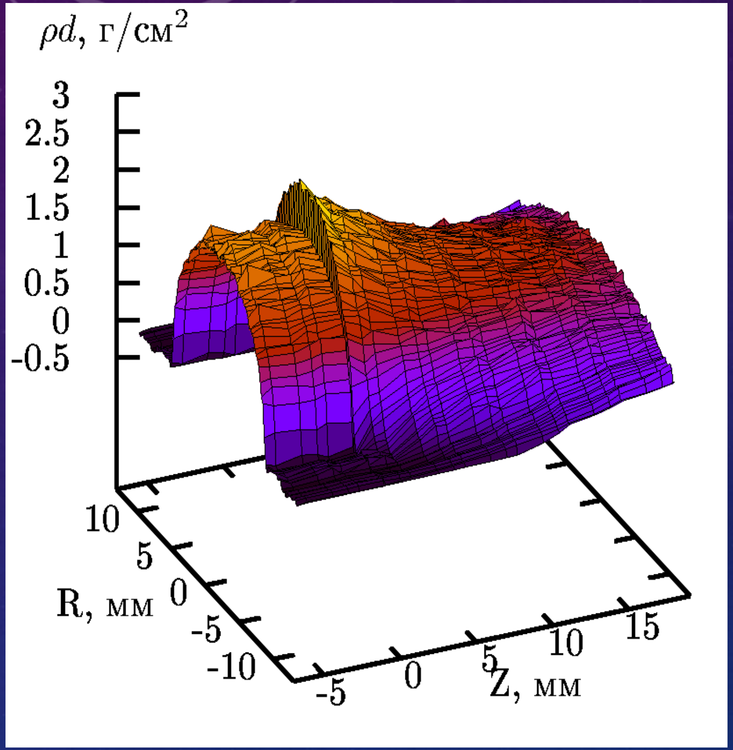
BINP. SR experiment

Experimental date received in explosion experiment of TNT.

DENSITY MEASUREMENT OF EXPLOSION PRODUCTS AFTER DETONATION FRONT WITH USING SYNCHROTRON RADIATION

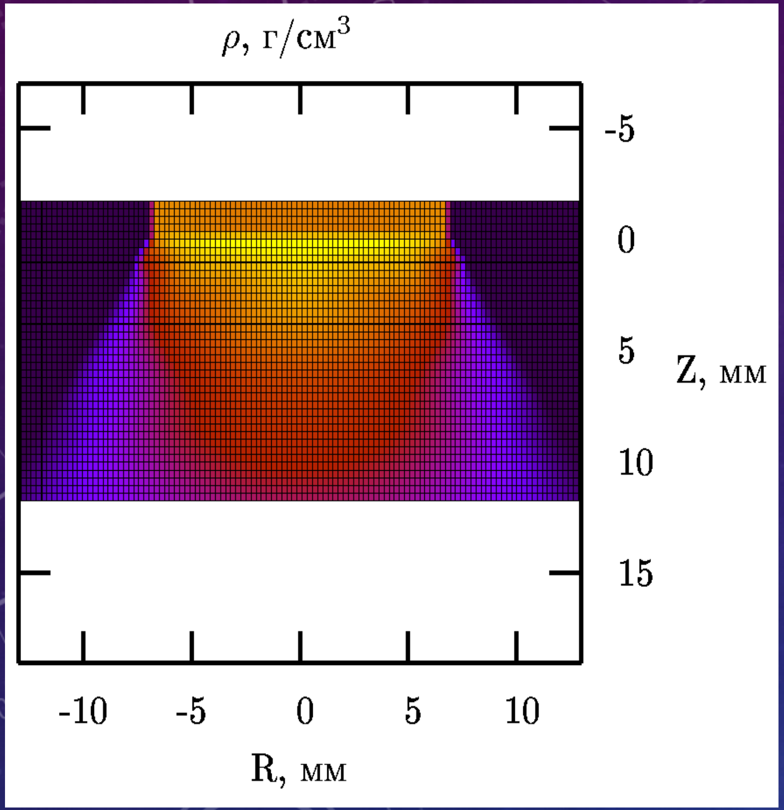


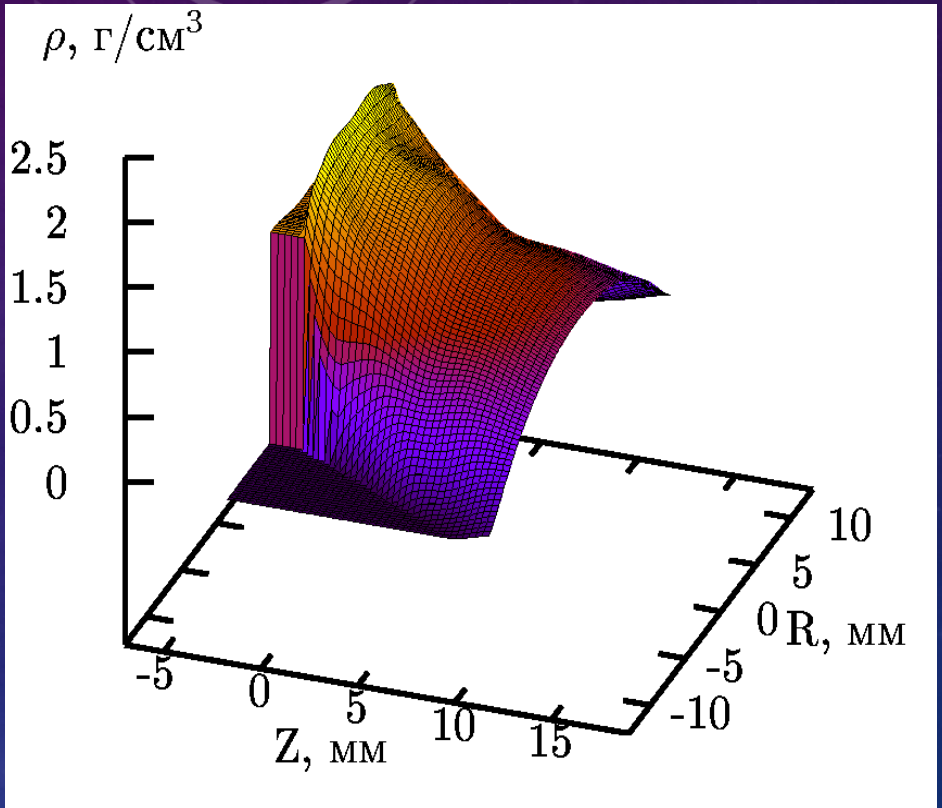
Experiment setup.



Density distribution.

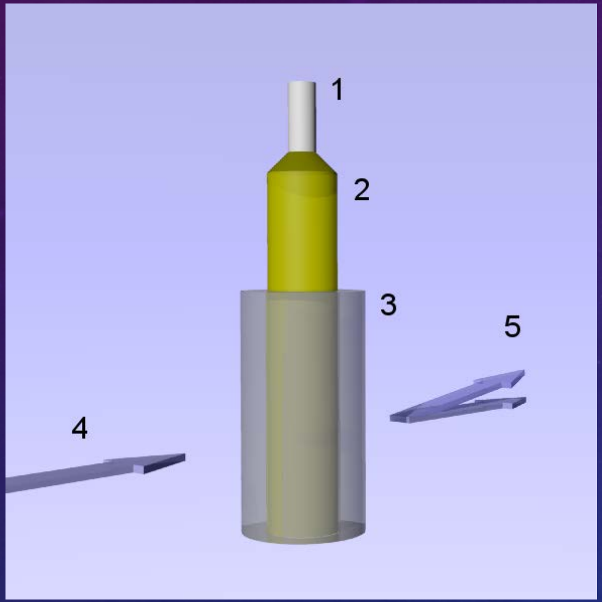
Density measurement of explosion products after detonation front with using synchrotron radiation. Precision 1 % !

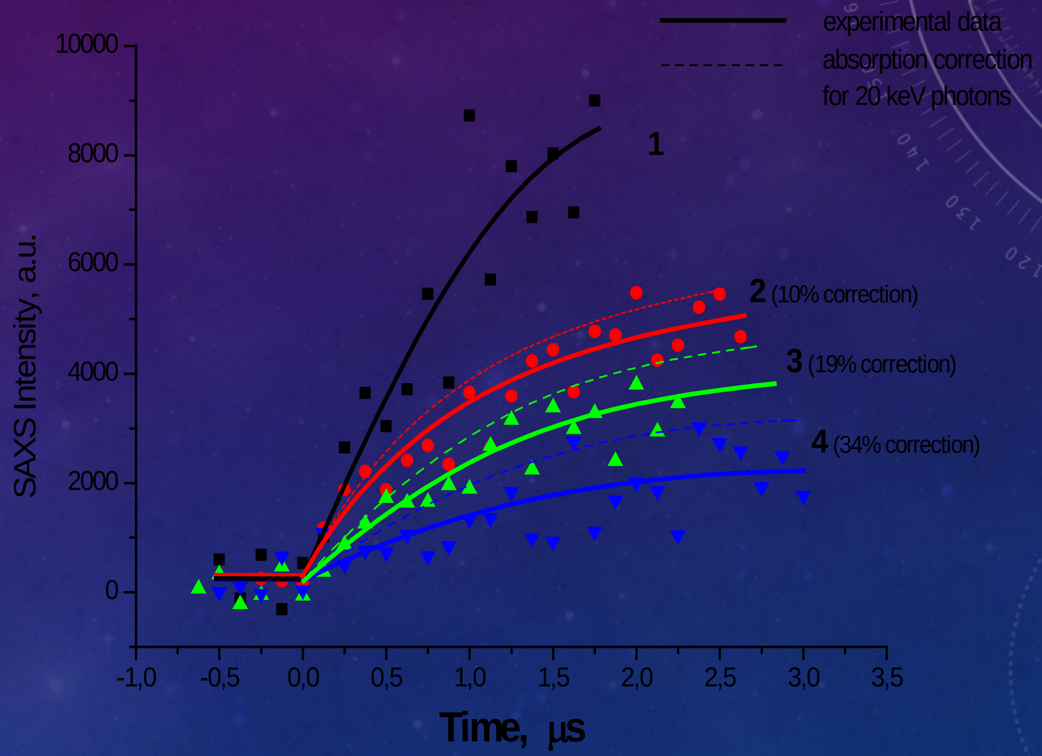




Density reconstruction of explosion product of TNT.

INFLUENCE OF DISPERSION CONDITION OF DETONATION PRODUCTS AT NANODIAMOND NUCLEATION

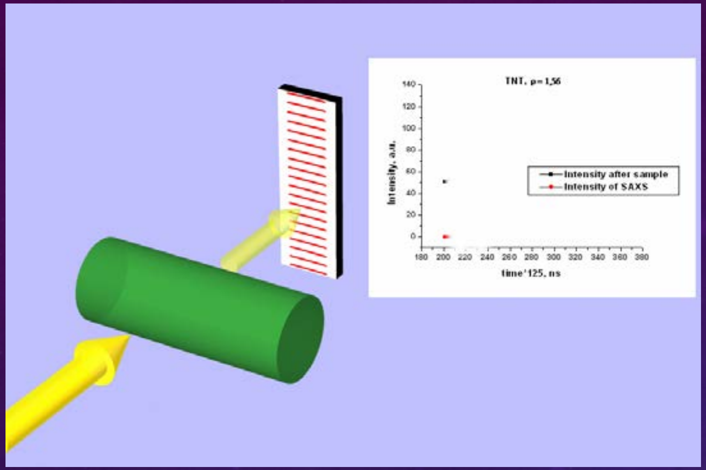




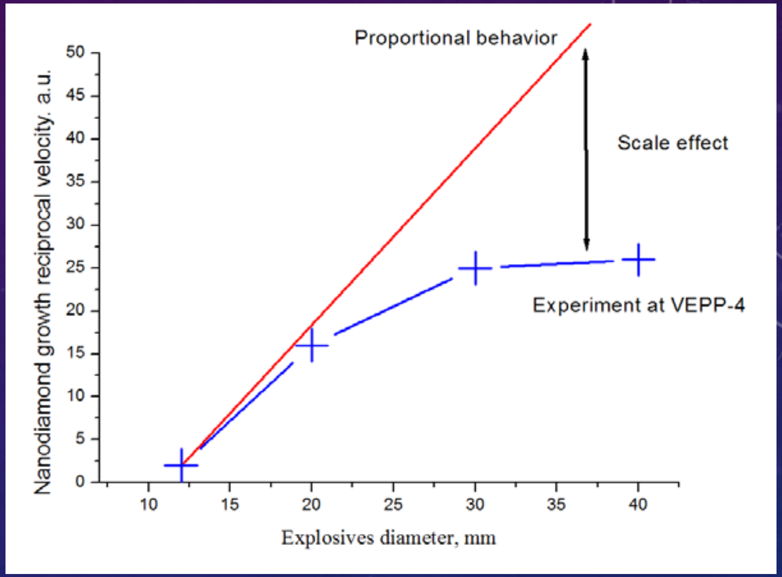
The experiment setup for changing of dispersion condition of detonation products. Detonator – (2), Explosive – (2), PMMA muff – (3), SR beam – (4), SAXS – (5).

The SAXS signal time dependence from RDX-TNT (50/50) with using PMMA tube with thickness: no tube - (1), 1,5 mm - (2), 3 mm - (3), 6 mm - (4).

DETONATION DIAMOND NUCLEATION : SCALE EFFECT



- The scheme of SAXS experiment during detonation of explosive trotyl/hexogen.



- The scheme of SAXS experiment during detonation of explosive trotyl/hexogen.

- It was found that an increase the mass of explosives leads to increases of produced diamonds mass. Accordingly, increases the rate of formation of diamonds. However, the dependence of the diamonds mass versus the mass of explosive is nonlinear. Also there is non-linear dependence of the formation rate of diamonds versus the weight of the explosives. Thus we observe a scale effect.

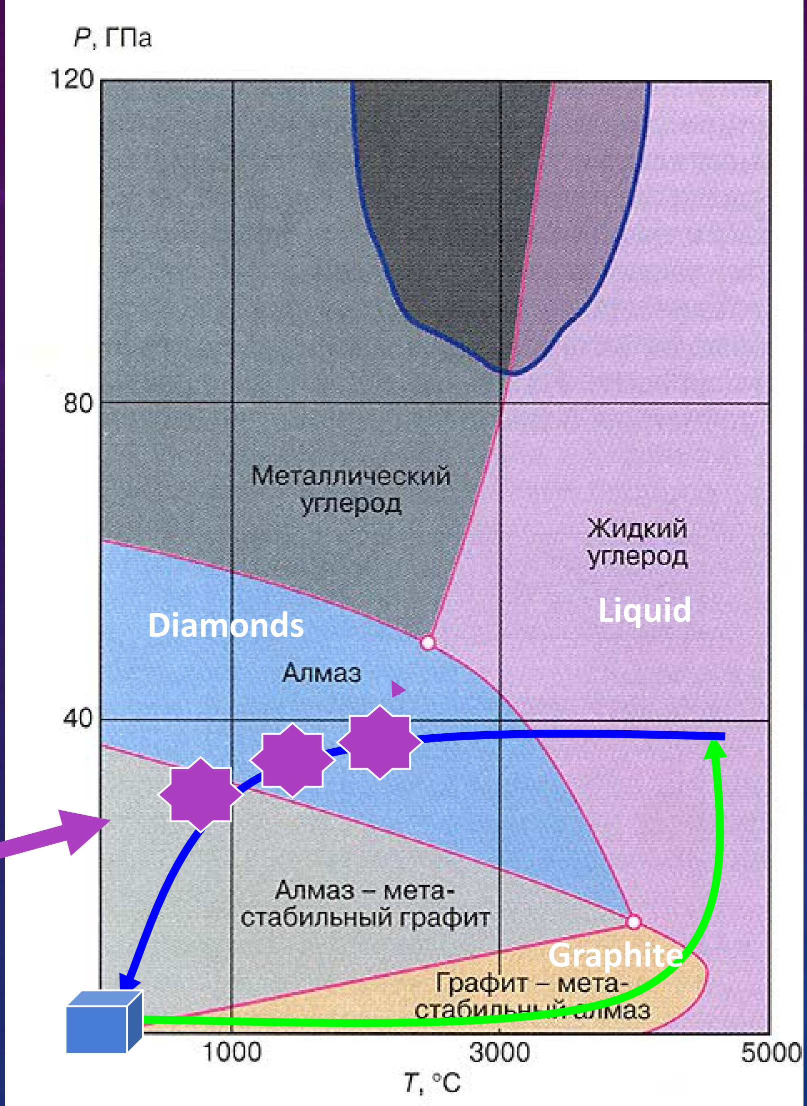
- Interpretation: the dependence of chemical reactions from the detonation conditions (diameter), the formation of larger diamonds in the detonation of explosives with large diameters.

CONTROL OF THE DIAMOND NUCLEATION PROCESS

Correction of Zeldovich theory and textbooks for university

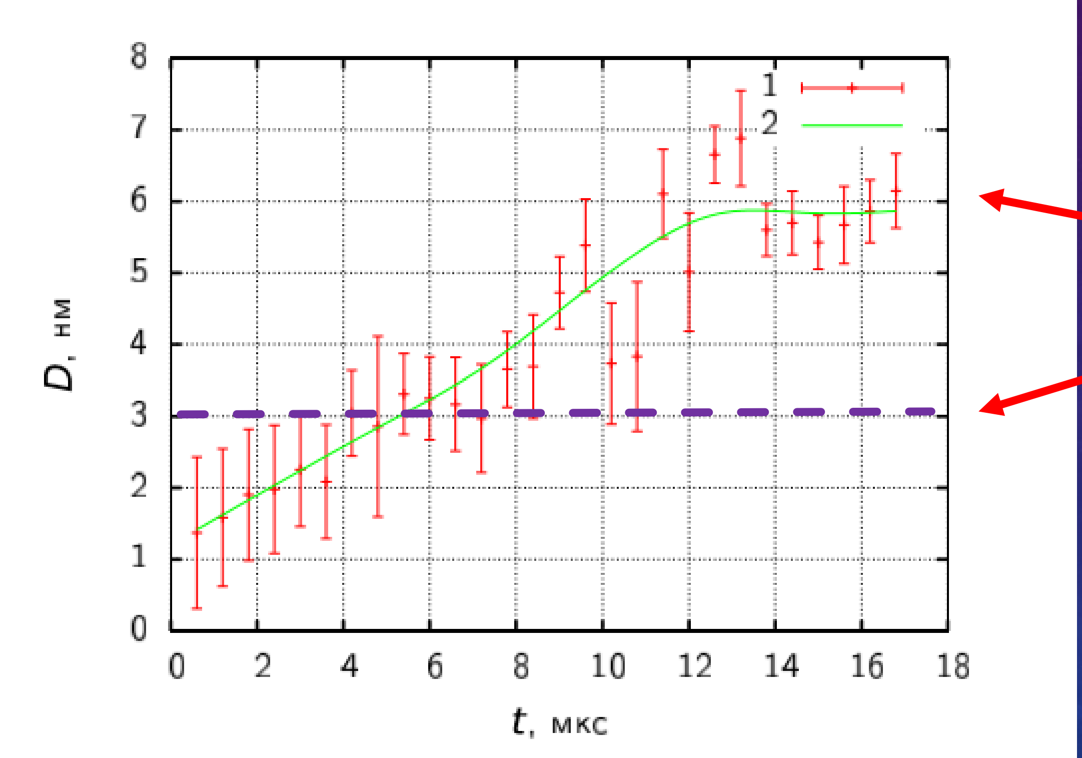
Control the area in PD and velocity of nucleation

Scientific results



Carbon phase diagram and load-reload model.

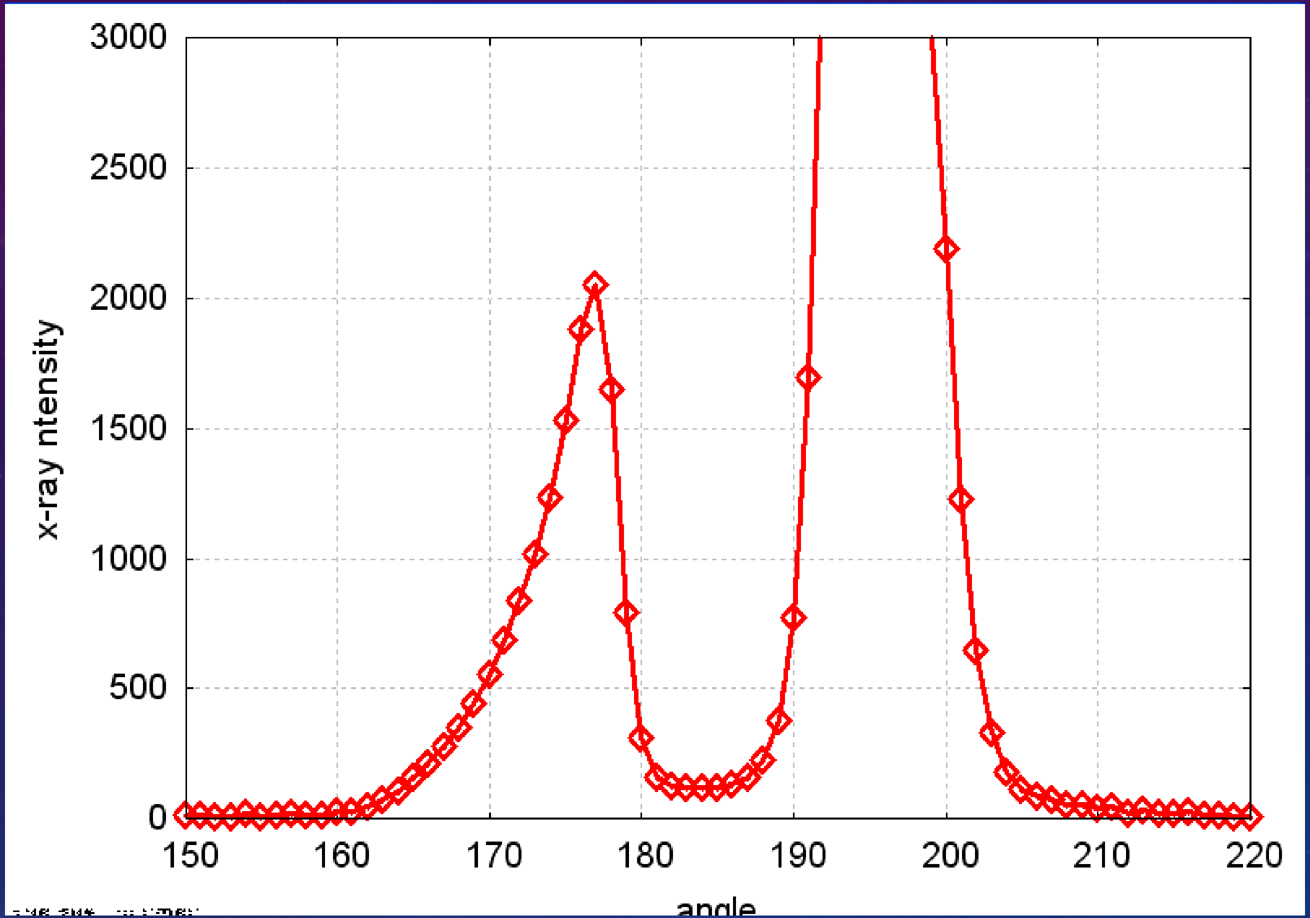
DIAMOND SIZE GROUSE DURING TNT DETONATION



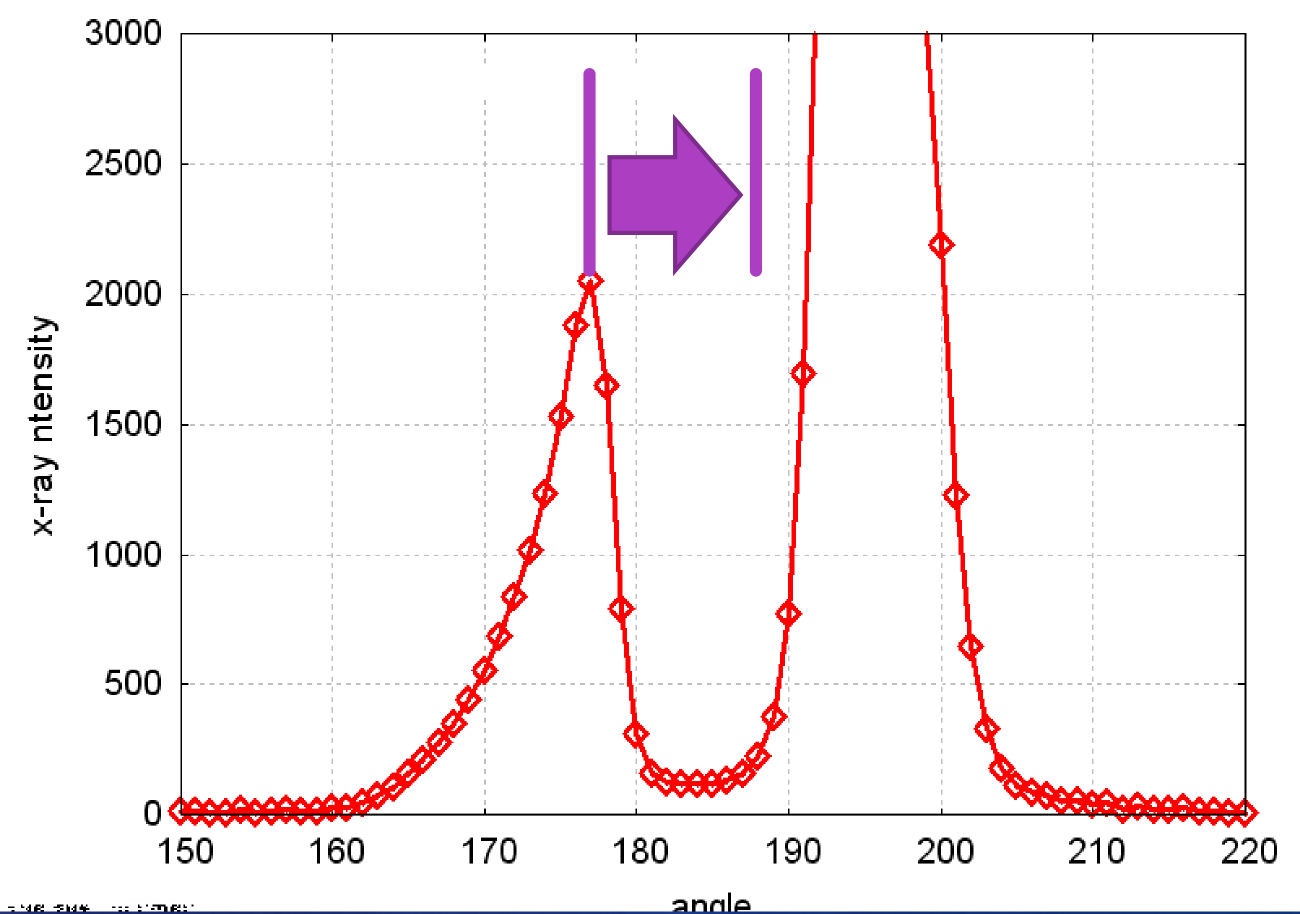
- Rubtsov Ivan – student Novosibirsk University
- Argonne National Laboratory - APS

THANK YOU FOR ATTENTION

SAXS with 1 ns exposure



SAXS with 1 ns exposure



НОВЫЕ ВОЗМОЖНОСТИ ДЛЯ МУРР

- **ВЭПП-3:**

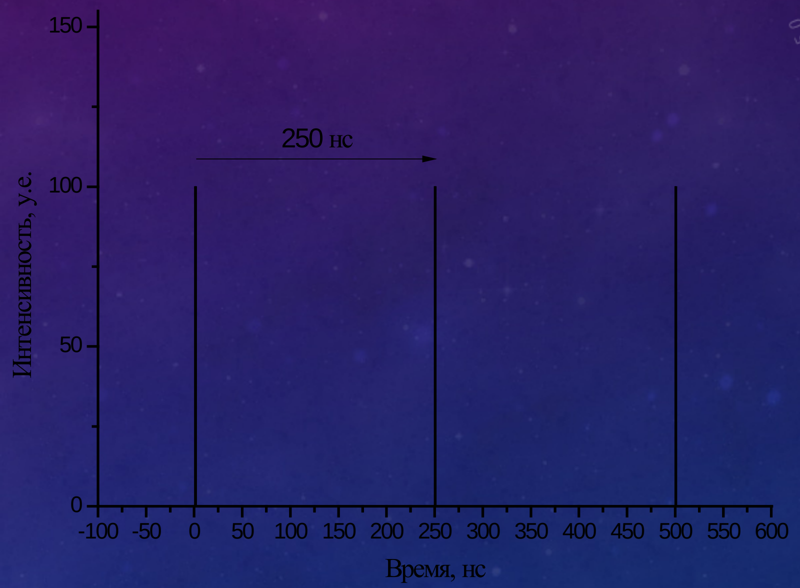
Количество наночастиц
Размер наночастиц в диапазоне 1-100 нм

- **ВЭПП-4**

Формфоктор наночастиц (кристаллическая структура, распределение плотности внутри частицы)
Размер наночастиц в диапазоне 1-1000 нм

Возможность исследования откольных иявлений (пыление)

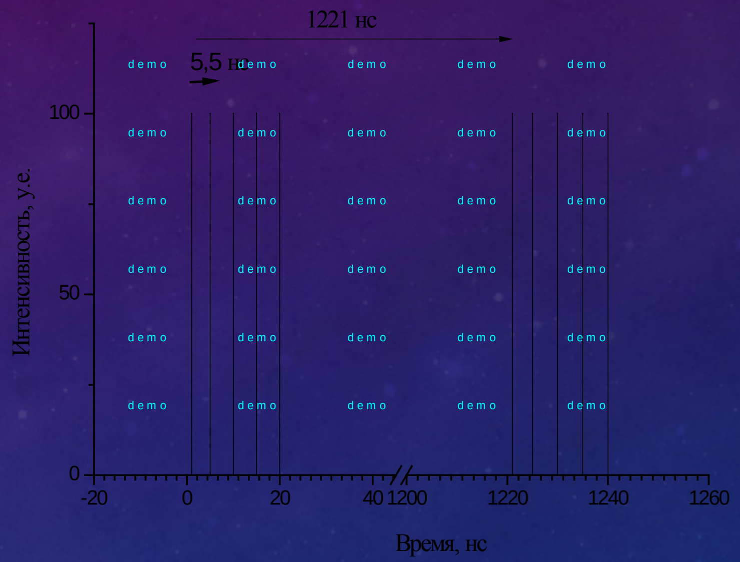
ВОЗМОЖНАЯ СТРУКТУРА РАСПОЛОЖЕНИЯ БАНЧЕЙ НА ОРБИТЕ ВЭПП-3 И ВЭПП-4



Расположение сгустка электронов на орбите ВЭПП-3 в однобанчевом режиме. Периметр орбиты 74.39 м, длина сгустка порядка 30 см.

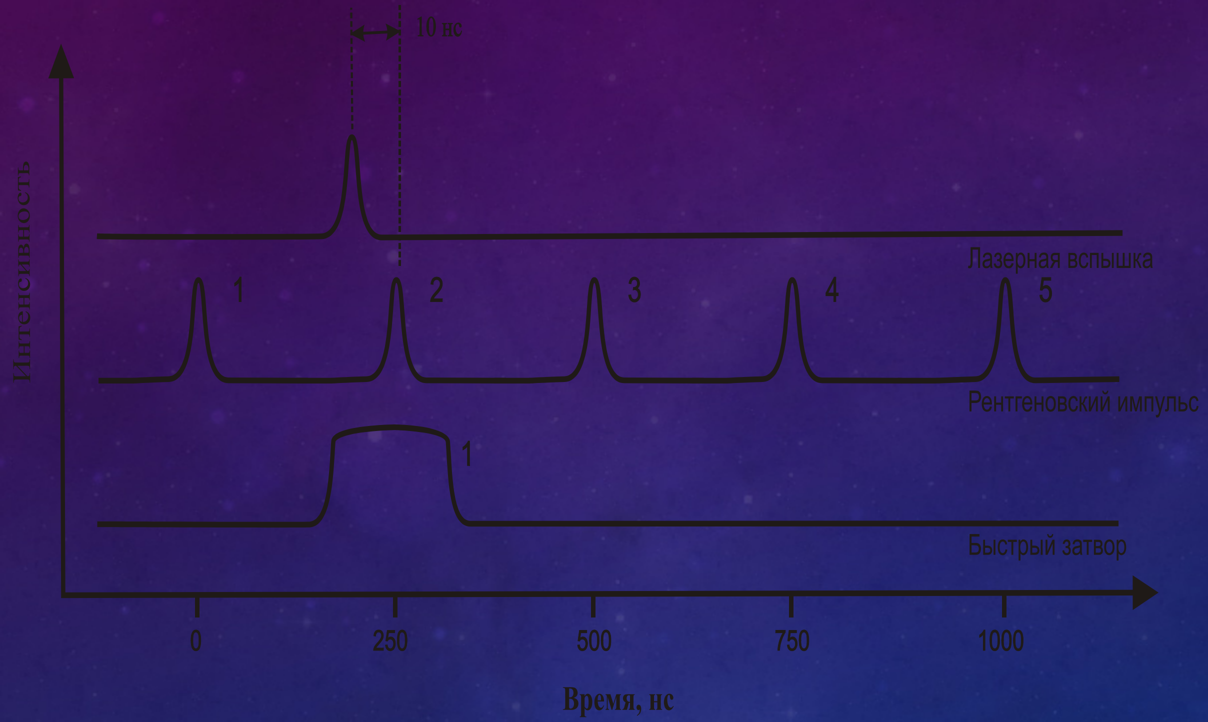
Временная структура синхротронного излучения из ВЭПП-3 в однобанчевом режиме. Период между импульсами рентгеновского излучения равен 250 нс. Длительность импульса равен 1 нс.

ВОЗМОЖНАЯ СТРУКТУРА РАСПОЛОЖЕНИЯ БАНЧЕЙ НА ОРБИТЕ ВЭПП-4

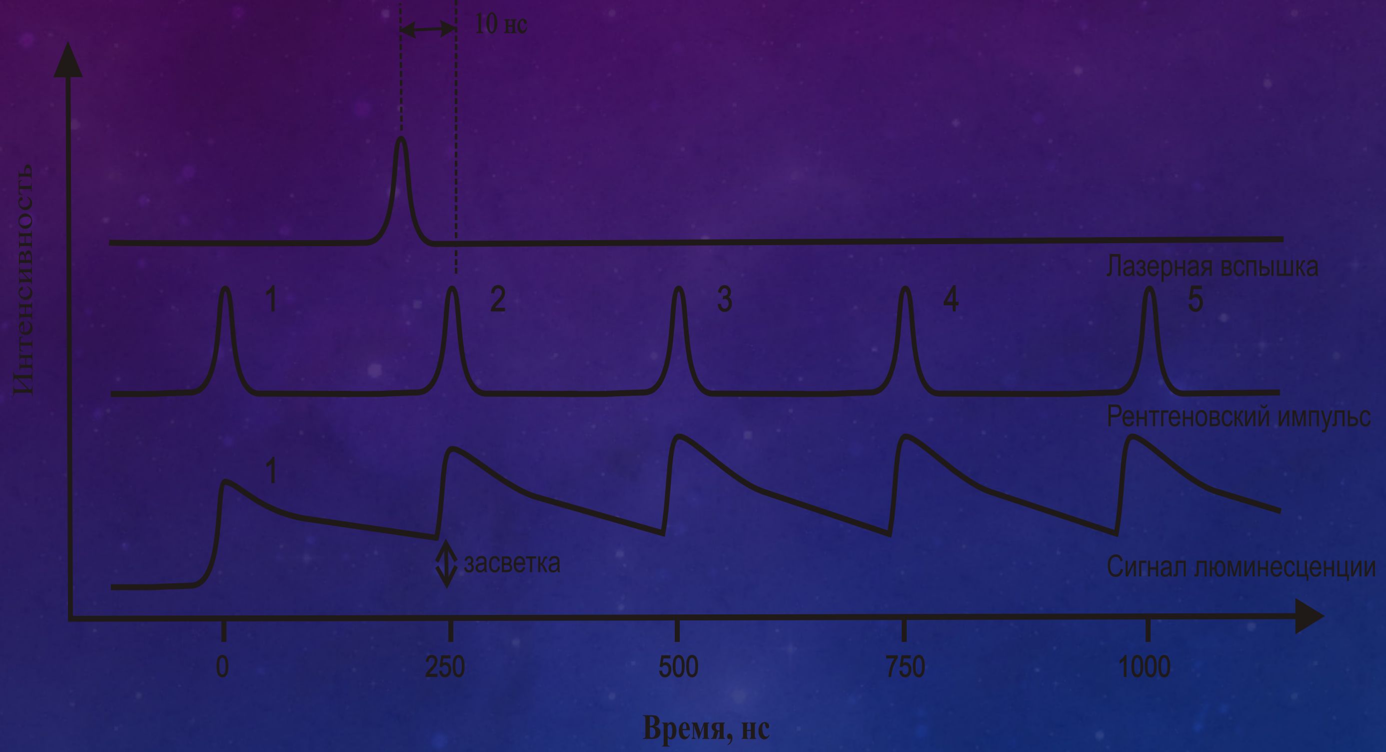


5-ти банчевый режим - один из теоретически возможных вариантов расположения сгустков электронов на орбите ВЭПП-4 при непрерывном заполнении сепаратрис. Периметр орбиты 366.075 , расстояние между сгустками 165 см, длина сгустка порядка 3 см. Однако практически удается расположить банчи на расстоянии не менее 1650 см, что определяется параметрами системы инжекции.

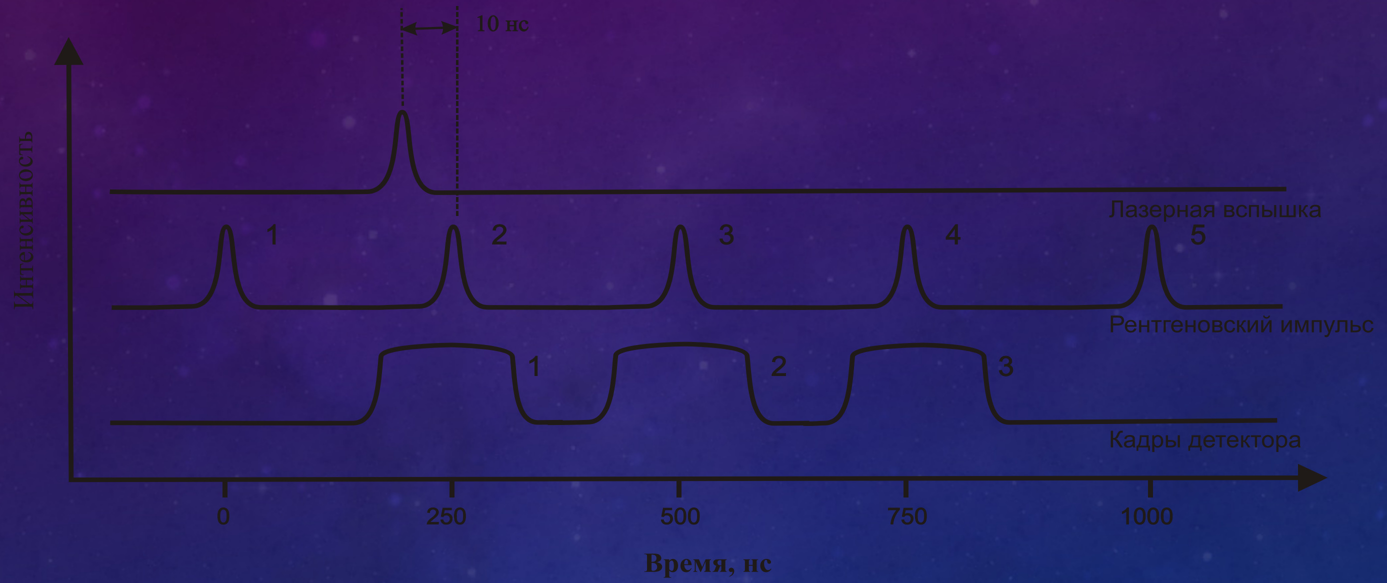
Теоретически возможная временная структура рентгеновских импульсов СИ при 5-ти банчевом режиме ВЭПП-4. Расстояние между импульсами 5,5 нс, длительность импульса 0,1 нс. Однако практически удается получать минимальное время между импульсами 55 нс..



Временная диаграмма однократного стробоскопического дифракционного эксперимента на ВЭПП-3 в однобанчевом режиме. Основная информация о возбужденной структуре образца через 10 нс после облучения лазером содержится в дифрагированном излучении от импульса № 2. Остальные импульсы создают фоновую засветку. Чтобы убрать фоновую засветку, необходимо перекрыть рентгеновские импульсы № 1, 3,4 и 5. Либо включить детектор только для регистрации дифракции от рентгеновского импульса № 2.



Влияние большого времени затухания люминисценции люминофора от рентгеновского импульса № 1 , в конверторе рентген – свет на фоновые условия регистрации дифракции рентгеновского импульса № 2. Именно дифракция излучения импульса № 2 содержит информацию о структуре вещества через 10 нс после возбуждения ее лазерным излучением.



Временная диаграмма однократного дифракционного эксперимента в режиме «дифракционного кино». Цель эксперимента – зафиксировать дифрагированное излучение банчей № 2, 3, 4, 5.

ОПРЕДЕЛЯЮЩИЕ ФАКТОРЫ РАЗВИТИЯ РАБОТ С СИНХРОТРОННЫМ ИЗЛУЧЕНИЕМ НА ВЭПП-4

Изменение фундаментальных параметров синхротронного излучения при увеличении энергии

Критическая энергия

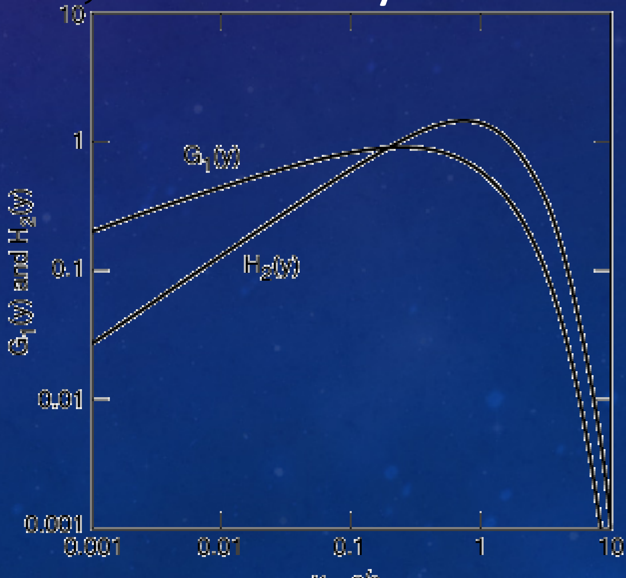
ε_c [keV] = 0.665 E^2 [GeV] B[T])

Расходимость пучка СИ

$1/\gamma$ γ = electron energy/$m_e c^2$ (m_e = electron mass, c = velocity of light)

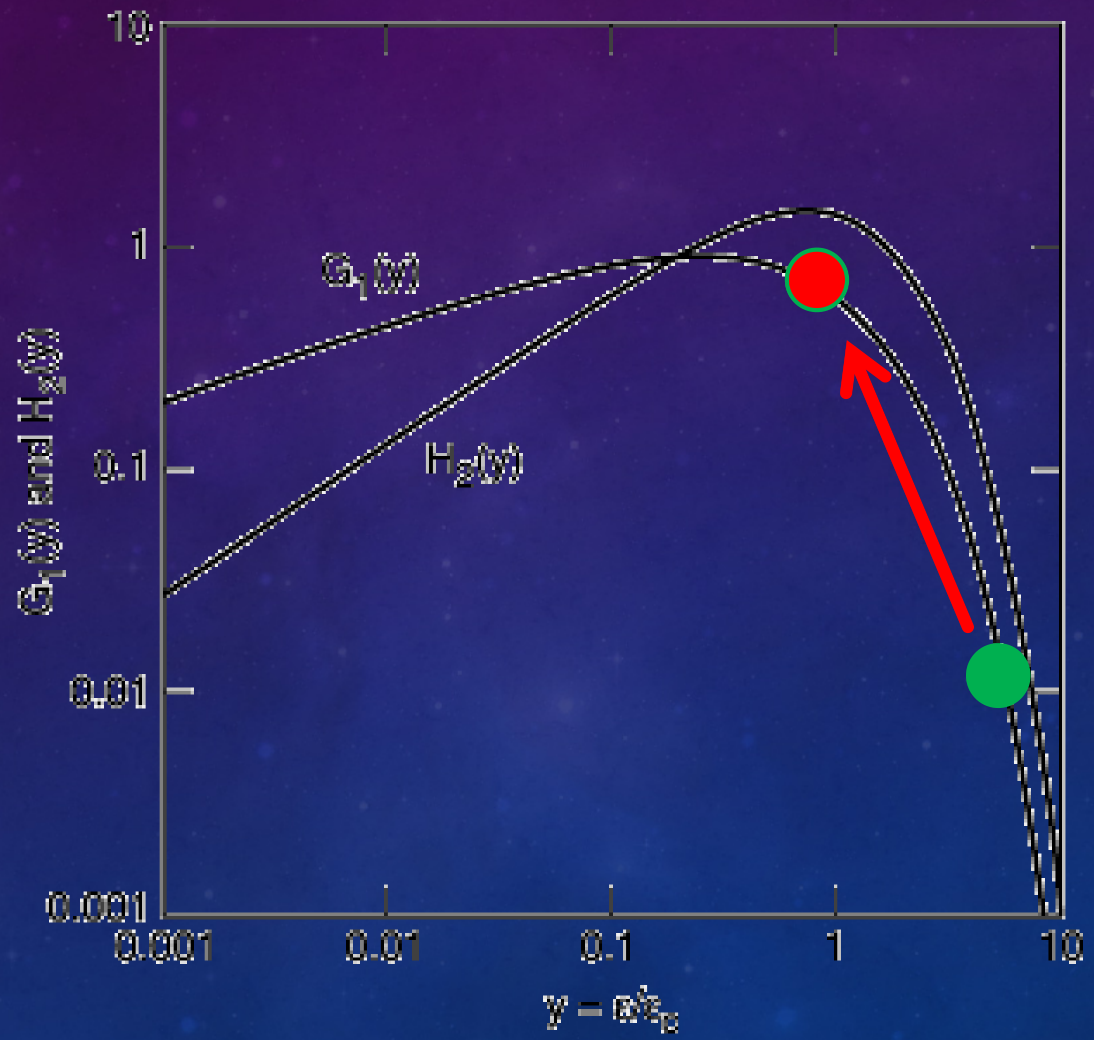
Яркость [photons·s^{-1}·mr^{-2}·(0.1% bandwidth)$^{-1}$],

$$\frac{dS_B}{d\theta} = 2.457 \times 10^{13} E[\mathrm{GeV}]\, I[\mathrm{A}]\, G_1(y)$$

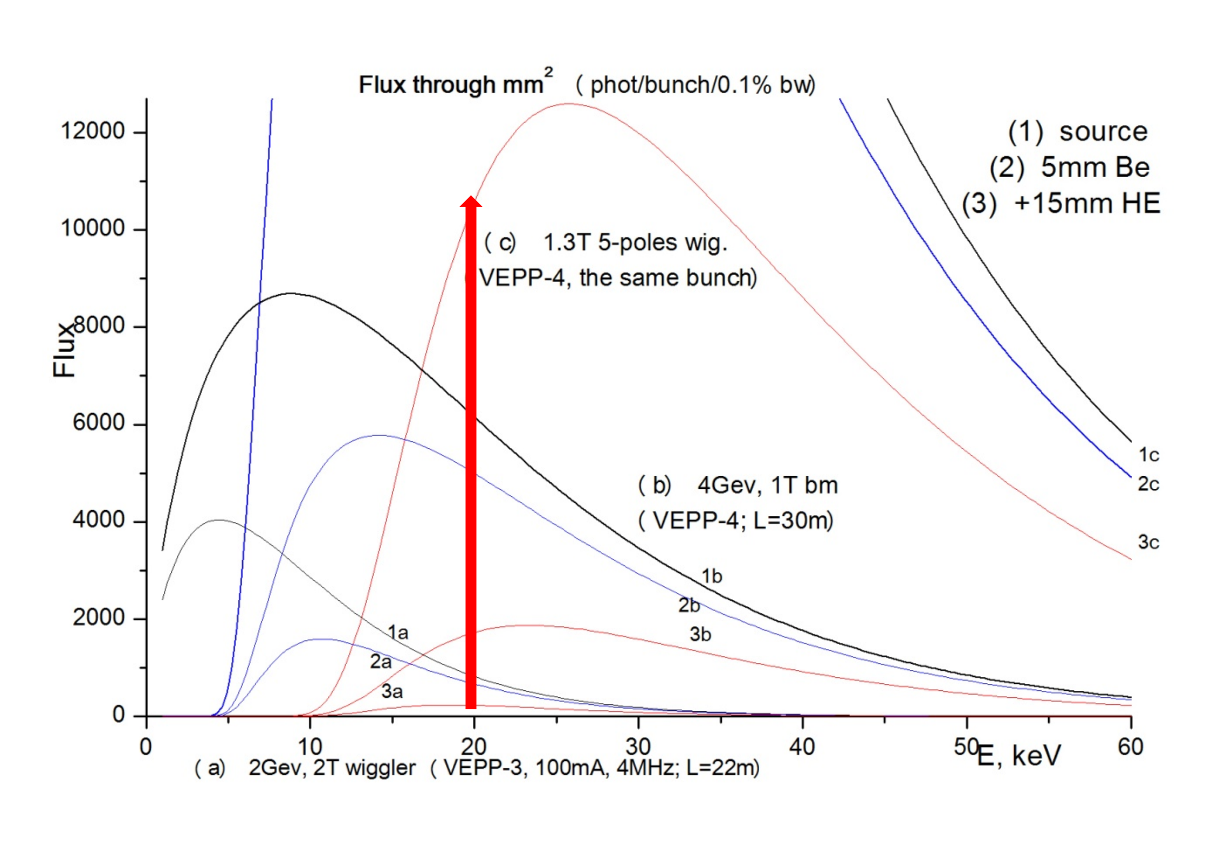


ЯРКОСТЬ [PHOTONS·S^{-1}·MR^{-2}·(0.1% BANDWIDTH)$^{-1}$]

$$\frac{d\dot{N}}{d\theta} = 2.457 \times 10^{13} E[\mathrm{GeV}]\, I[\mathrm{A}]\, G_1(y)$$

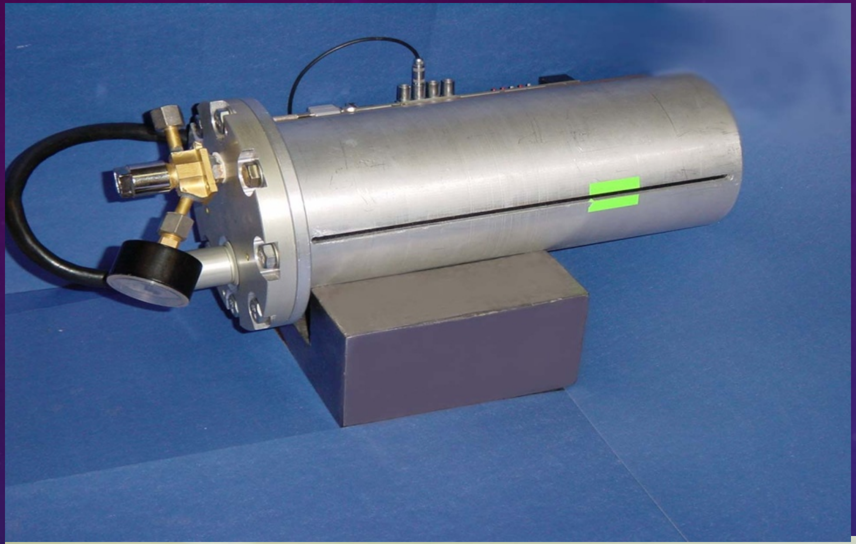


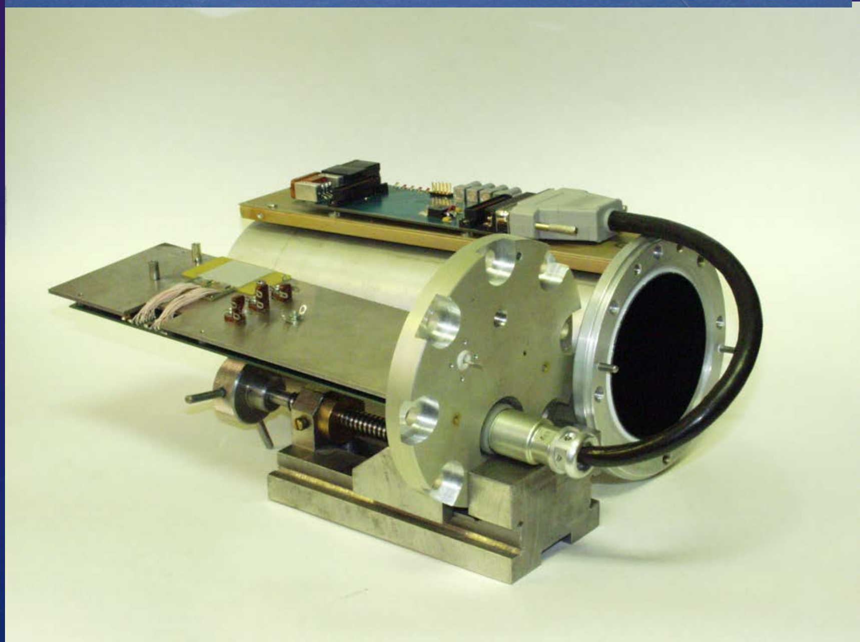
НОВЫЕ ВОЗМОЖНОСТИ НА ВЭПП-4



- Спектры излучения на ВЭПП-3 и ВЭПП-4 за 1 нс

Position sensitive X-ray detector DIMEX with time resolution 100 ns (prototype)



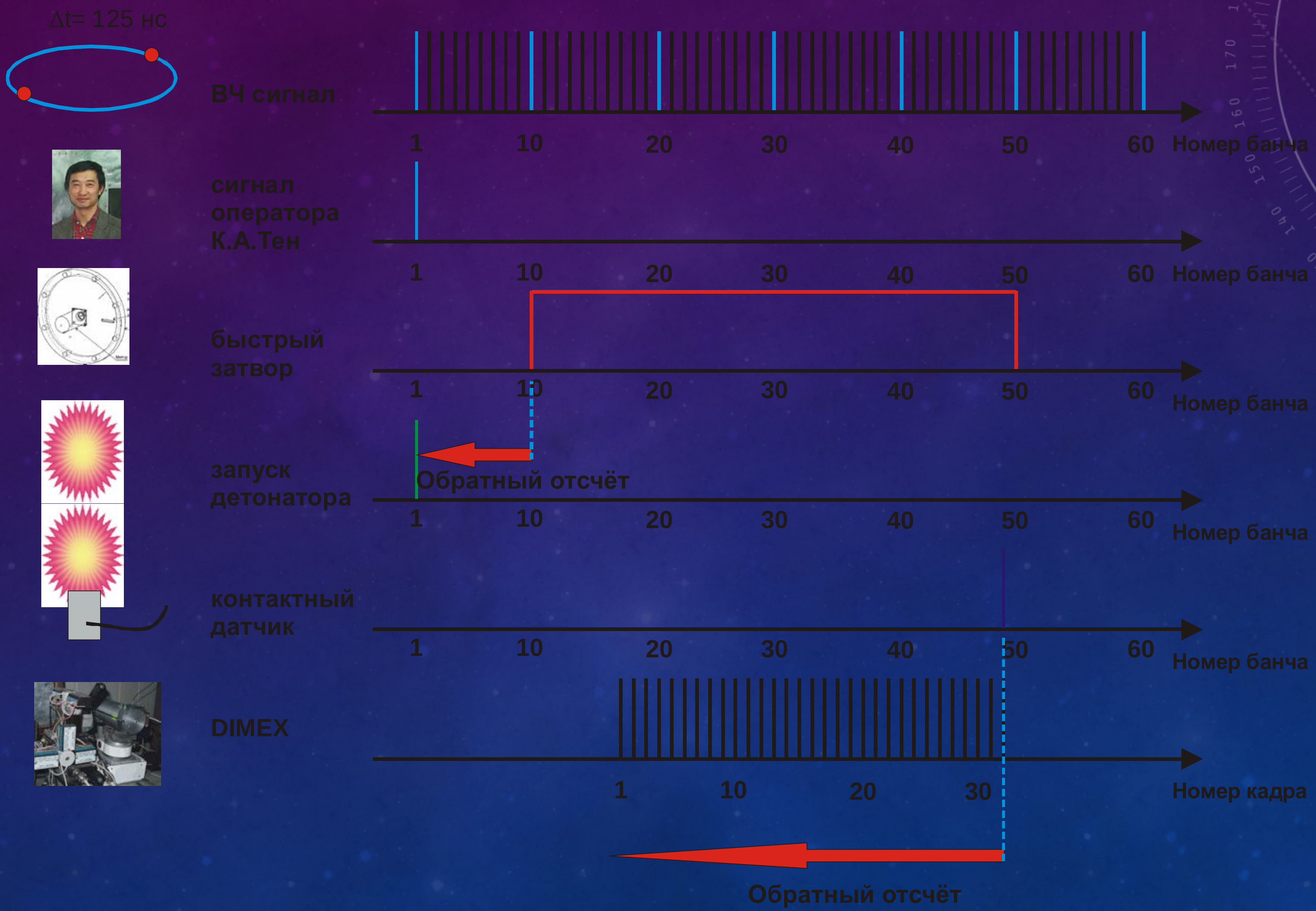


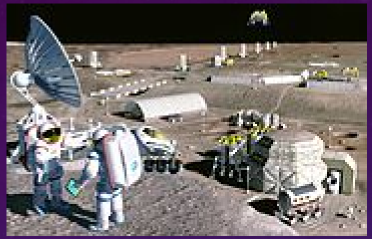
DIMEX is the **D**etector for **IM**aging of **EX**plosions

Goal: perform dynamic imaging synchronously with SR flashes from individual bunches

Design:
- GEM with drift gap and microstrip signal PCB
- gas mixture: Xe/20%CO_2 at 7 bar
- readout and DAQ: based on PSI's IC APC128 provided 32 x 100 ns frame-by-frame measurements

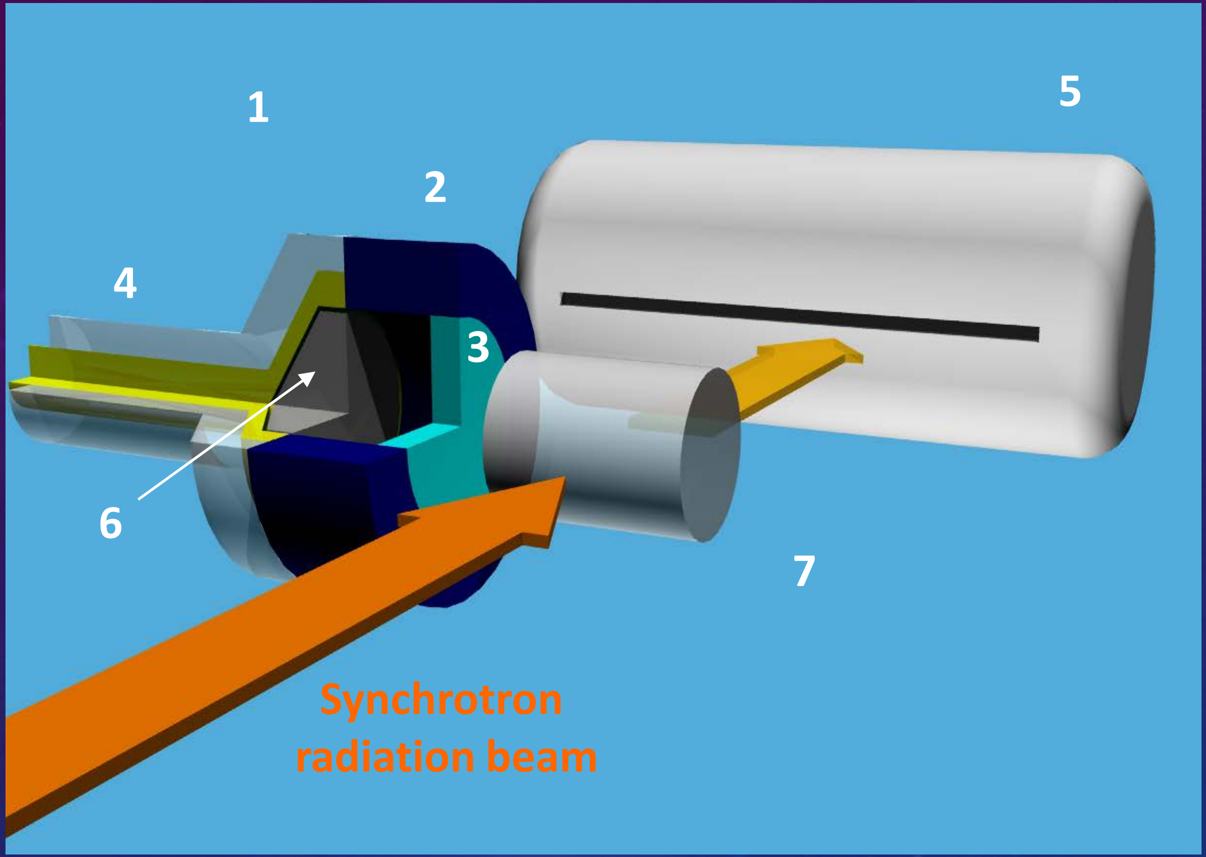
ВРЕМЕННАЯ СТРУКТУРА ЭКСПЕРИМЕНТА





THANK YOU FOR A

Shock-wave experiments at synchrotron radiation beam line



Experiment set up: 1- flat wave generator, 2- gun tube, 3-plunger, 4-detonator, 5-detector, 6- explosive, 7- sample.