Nuclear reactions and accompanying physical phenomena in plasma of laser-induced discharges

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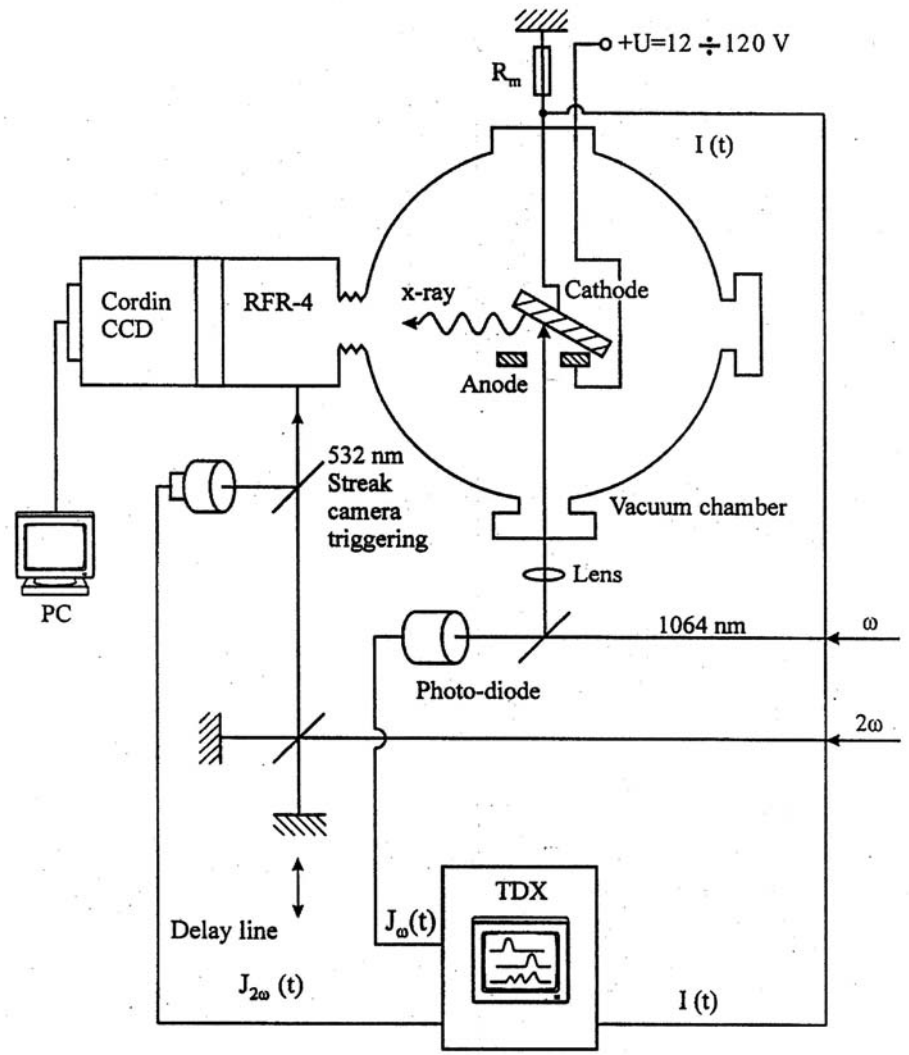
Main topics

*Generation and diagnostics of super strong magnetic fields in laser-induced discharges

* Generation and diagnostics α-particles and gamma-ray radiation in LID
* Transmutation of Ta→Tm
* Detection of high energy particles by means of nuclear detectors
* Theoretical model of nuclear reactions
* Computer simulation MHD-processes in laser-produced plasmas
* Summary

Схема экспериментальной установки



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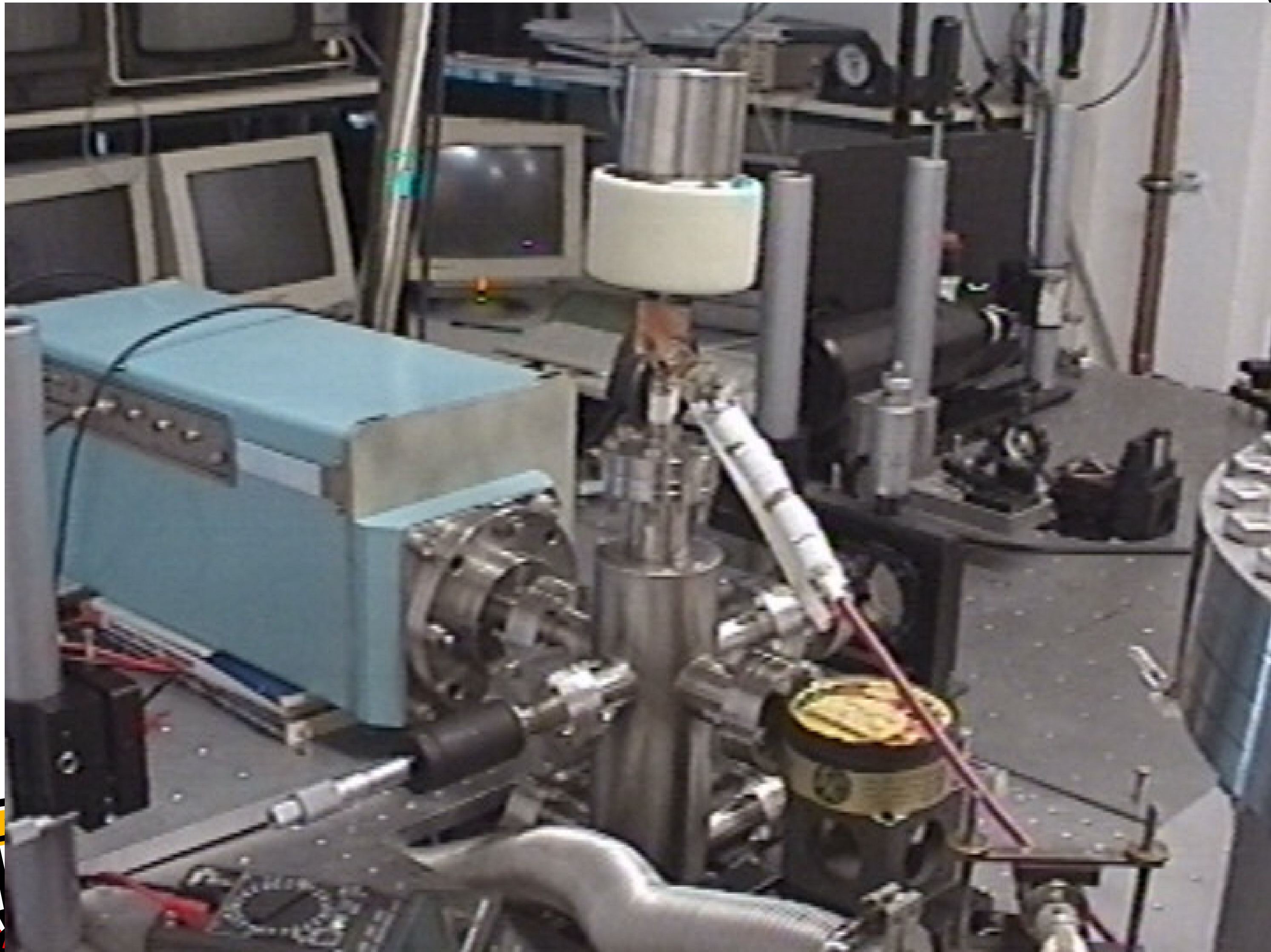
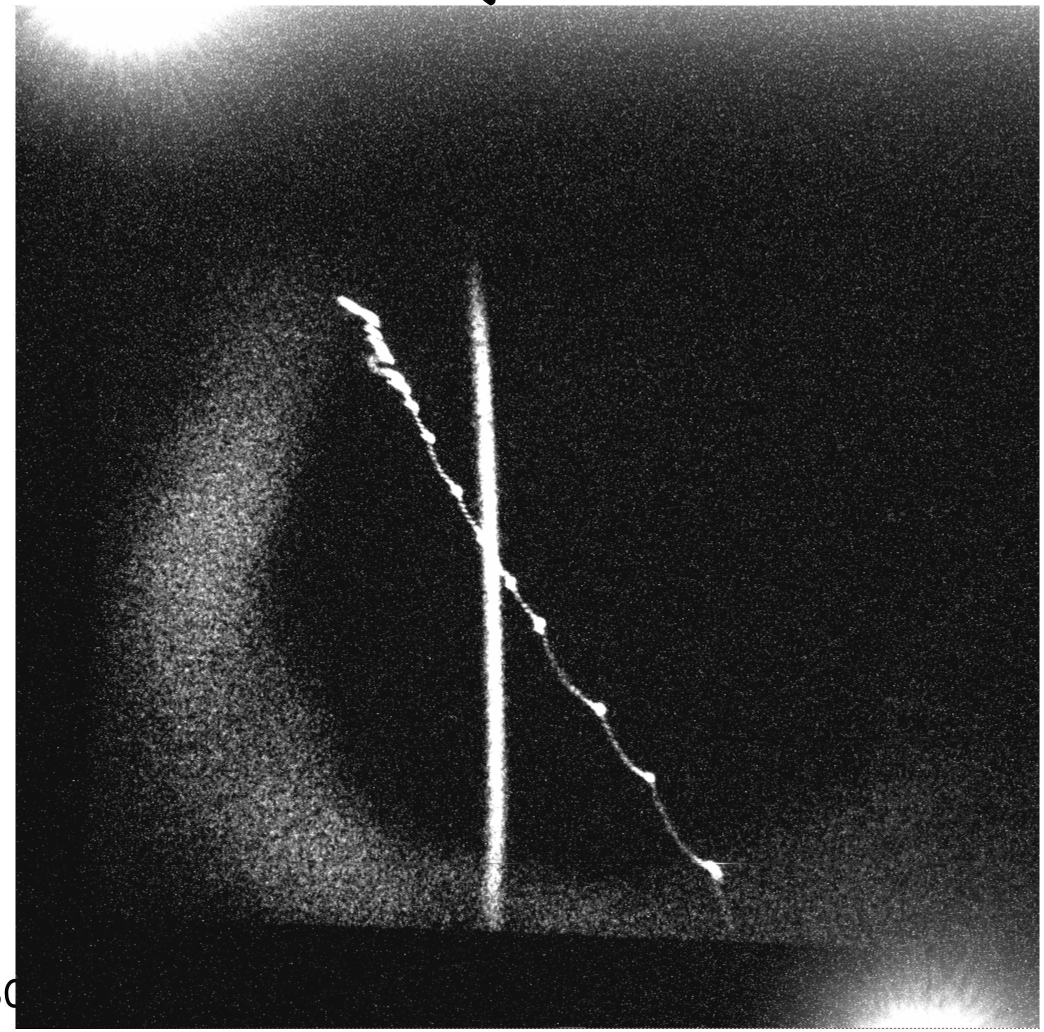
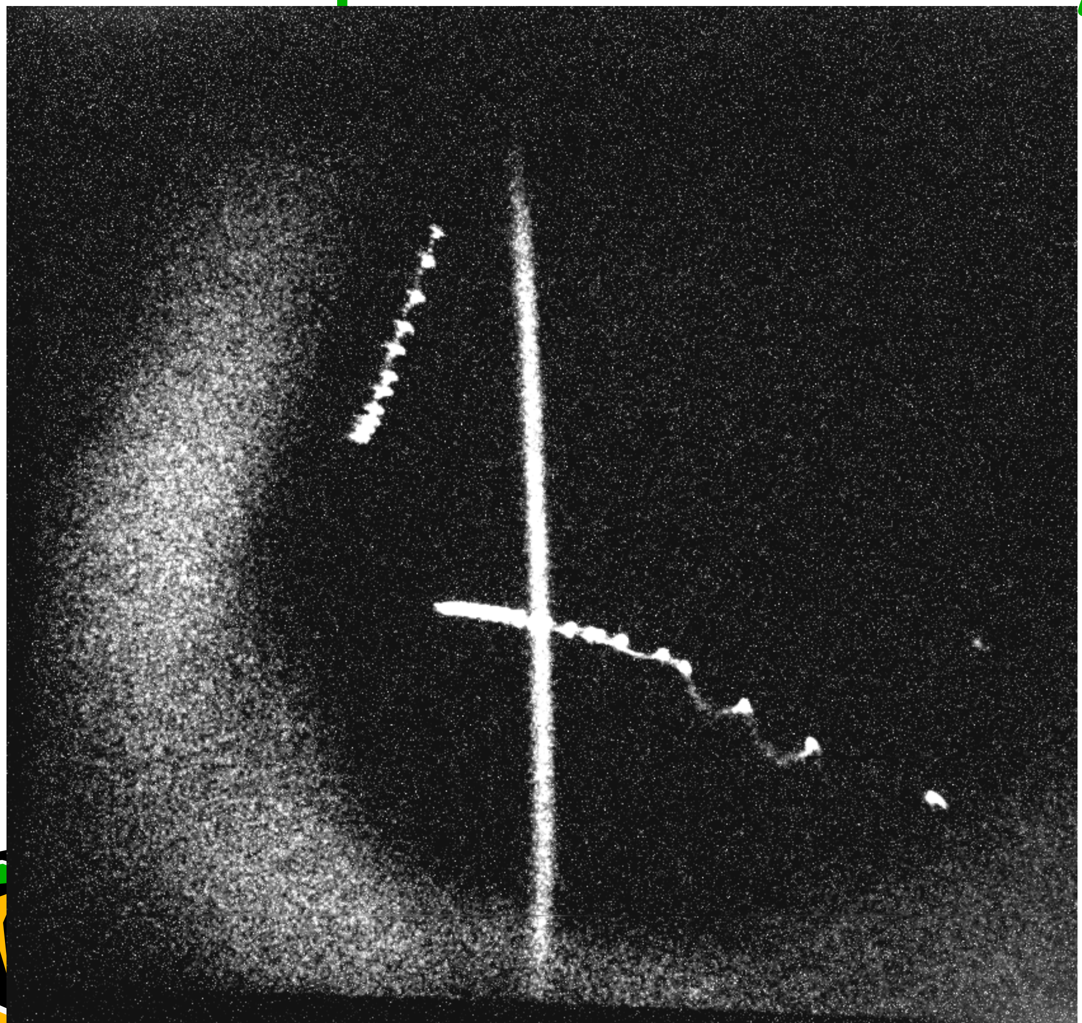
Внешний вид экспериментальной установки

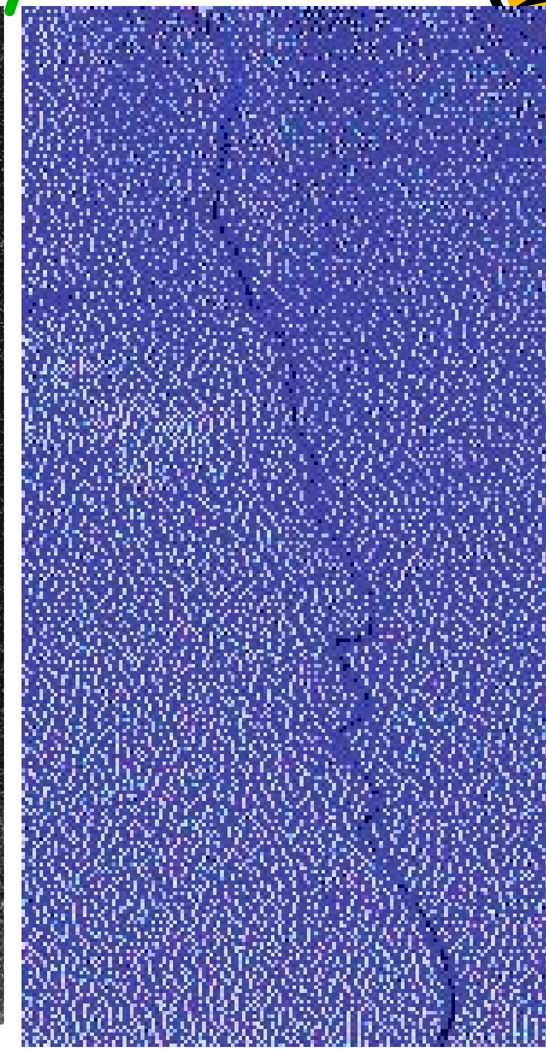


Излучение от вращающейся QP

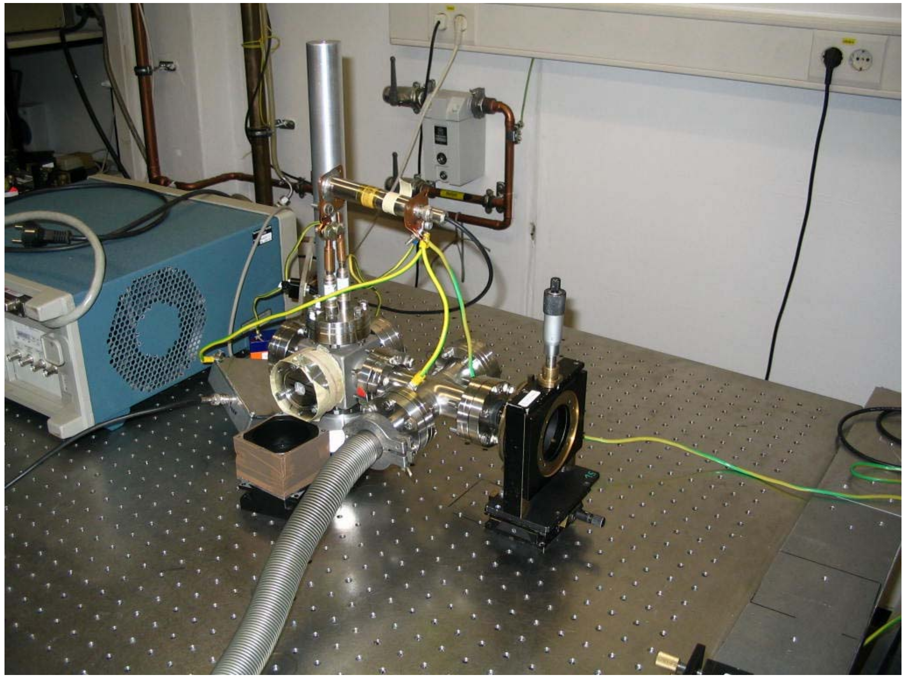


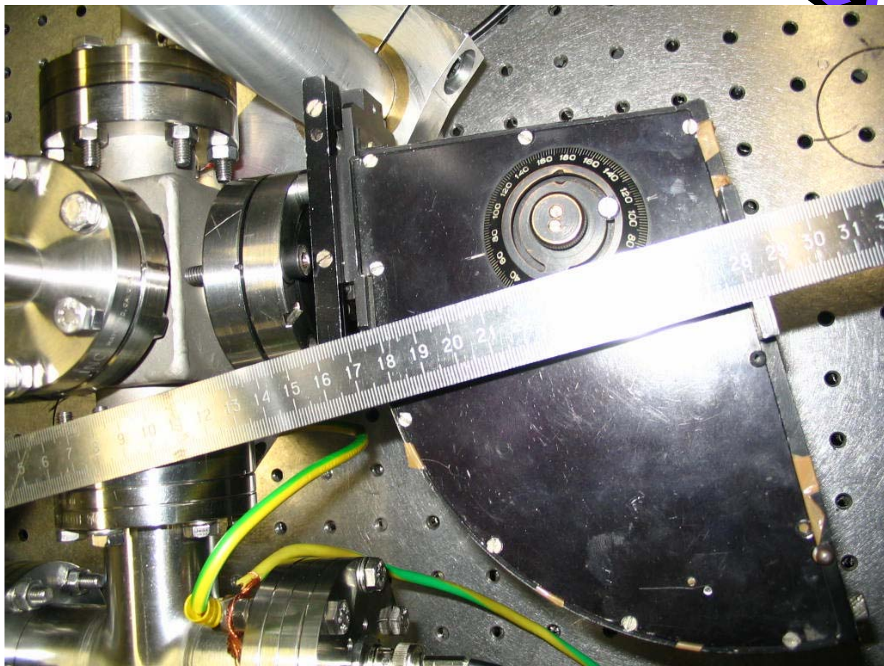
Электронное и фото-изображение в X-лучах



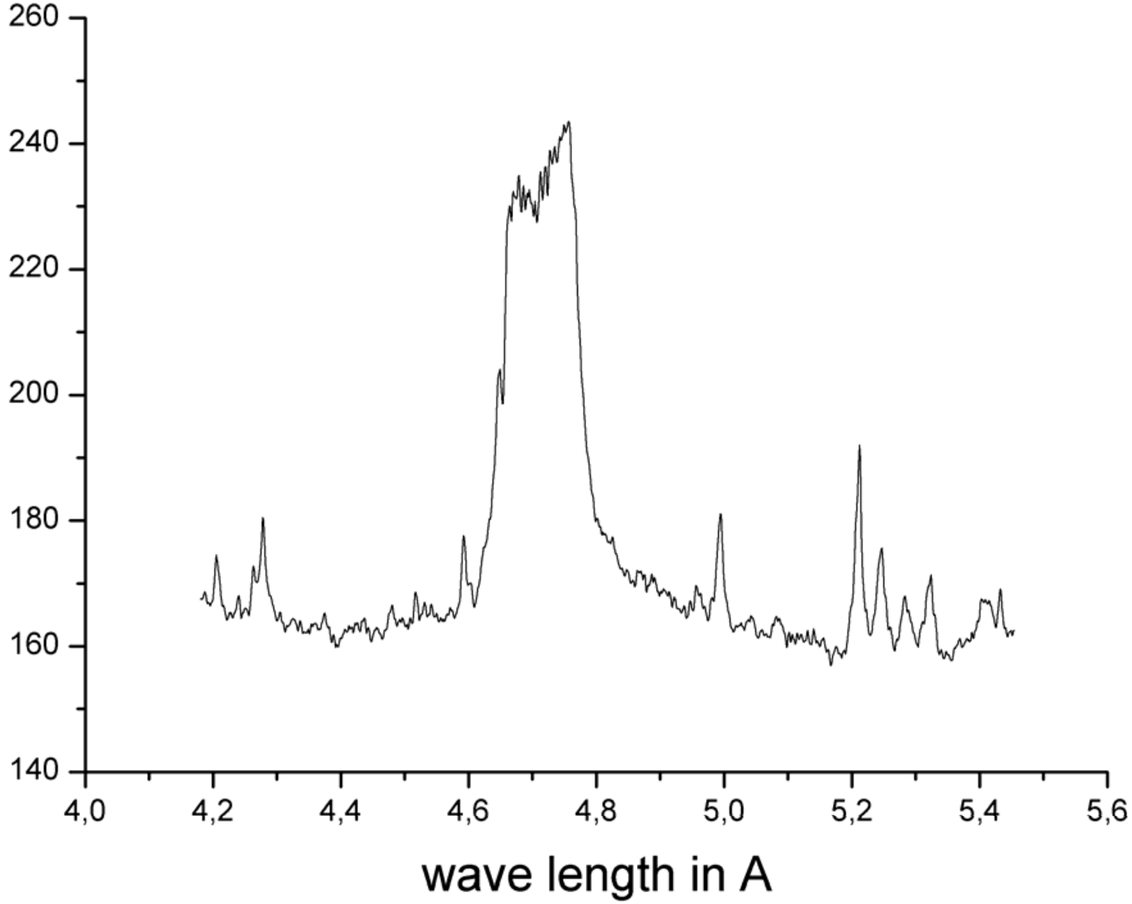


Измерения снаружи вакуумной камеры.

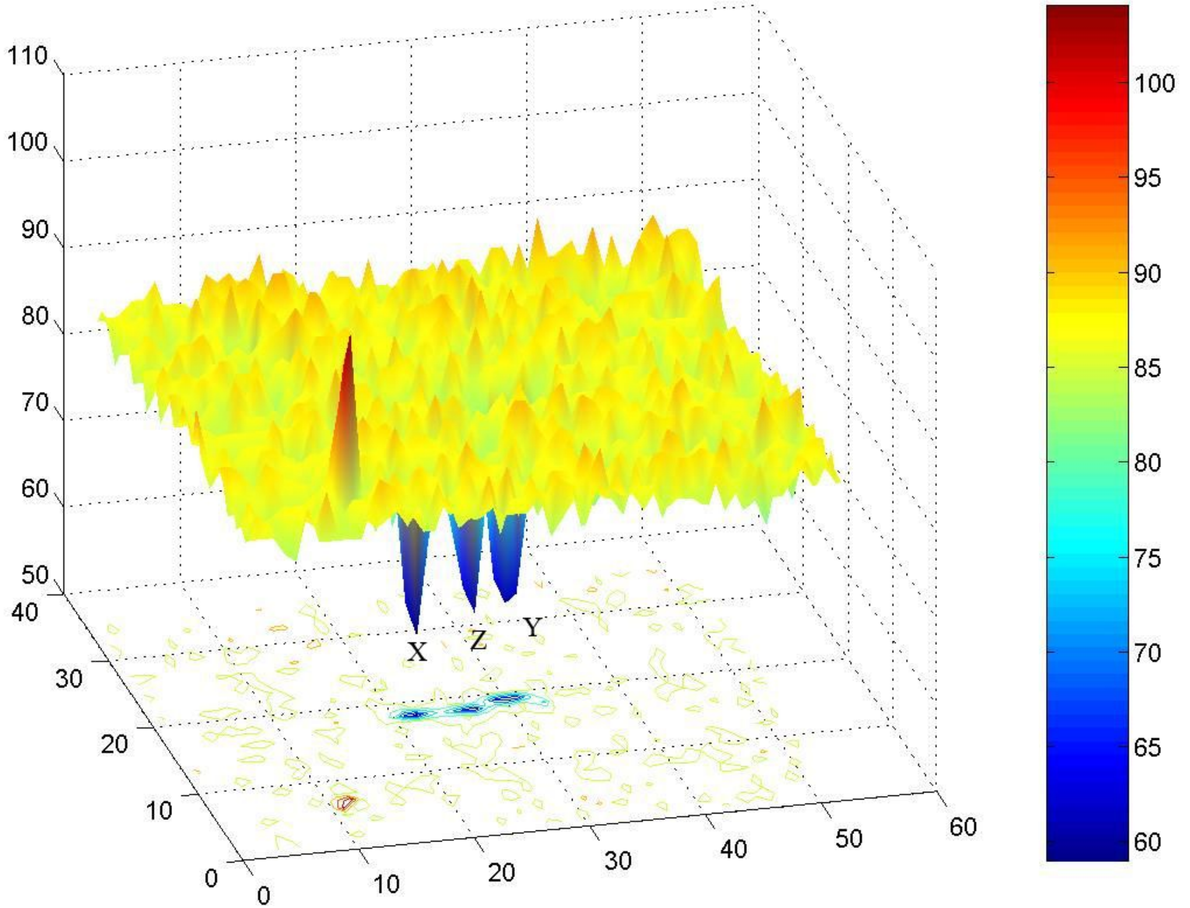




Спектр рентгеновского излучения, (Ni-подобные ионы Ta XLVI, а также Cu, Zn, Ga, Ge –подобные ионы Ta).



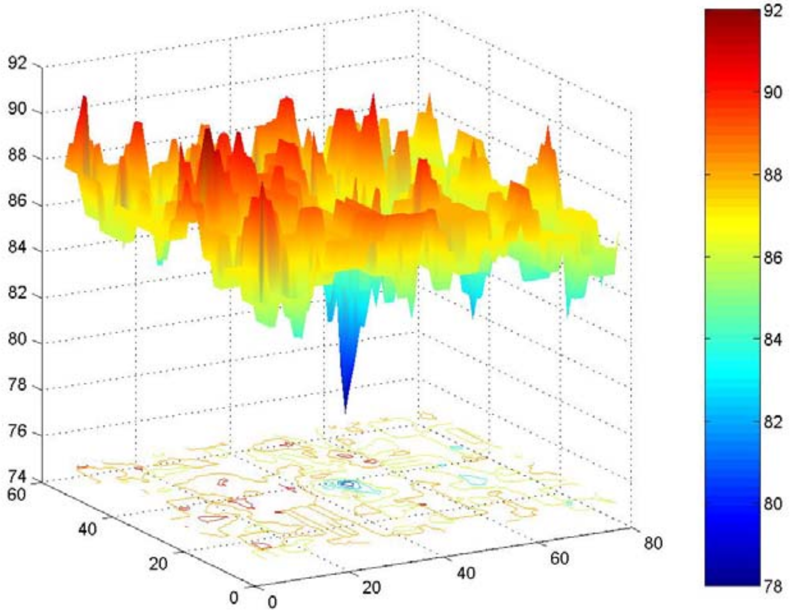
Расщепление линий Ni-подобных ионов Ta XLVI
λ =5.20 A; X (5.184 A), У (5.216 A), Z (5.20 A).

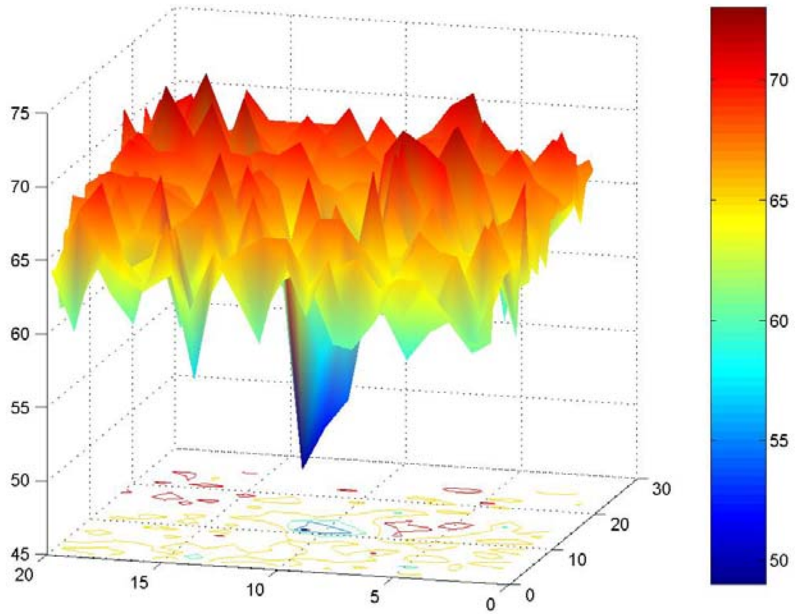


Пример из студенческой лаборатории МФТИ

Спектральная линия γ-излучения Ta -181,

$E\gamma \approx 6.24$ keV.





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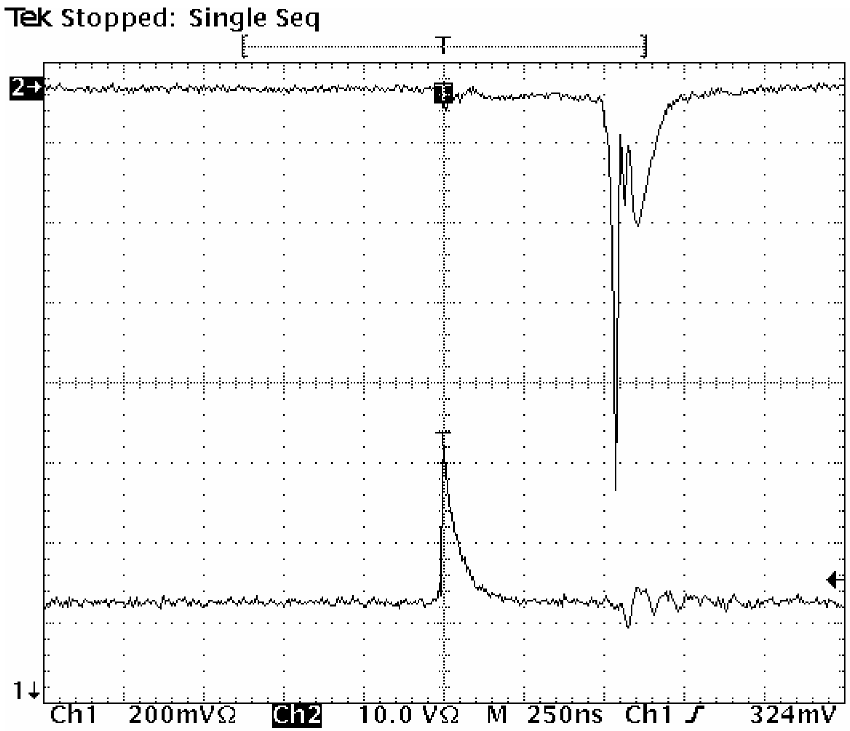
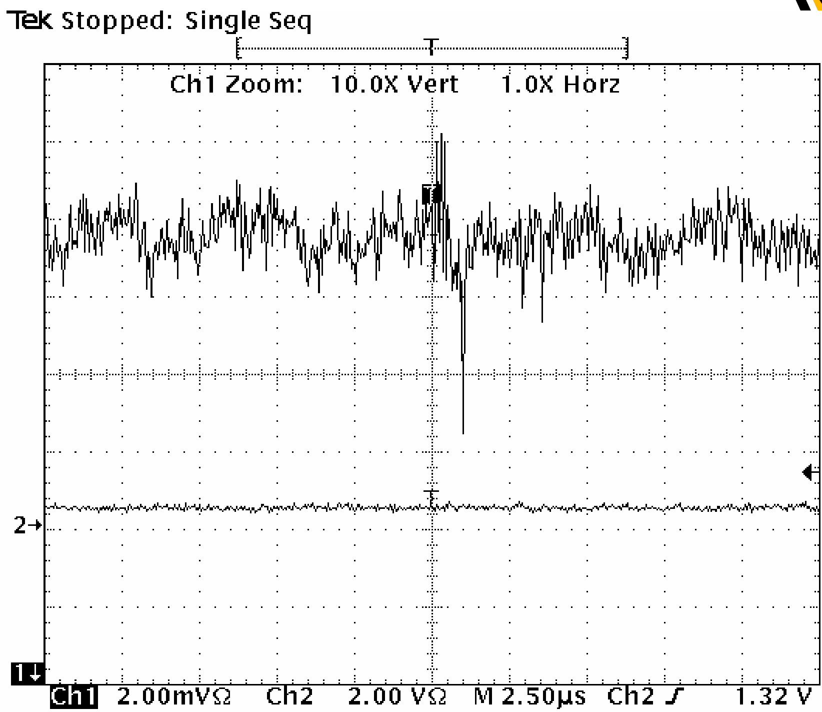
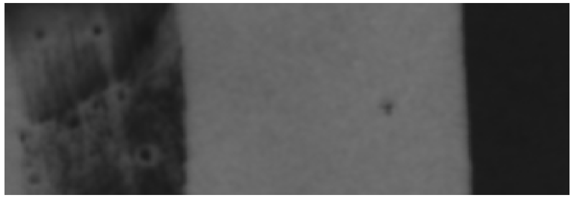
Сигналы от МКП-датчиков



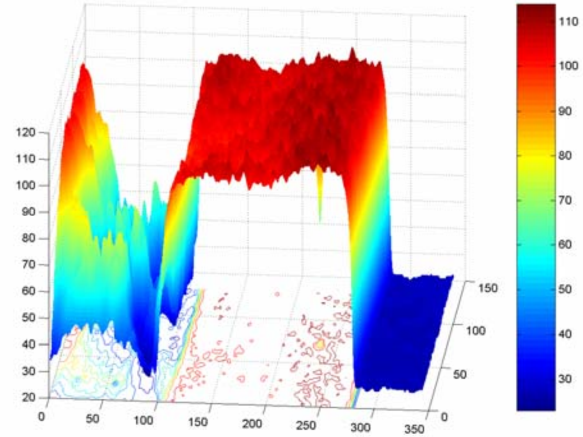


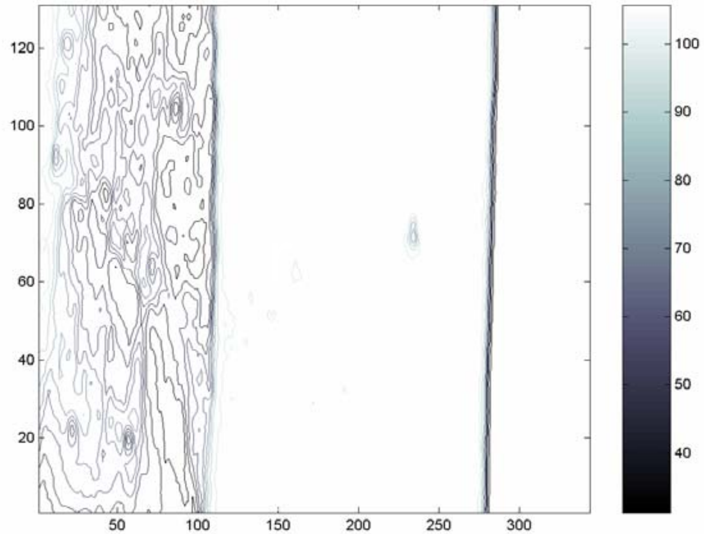
≈4.9 Вт/см^2 на расстоянии 13.5 см имеем : $I \approx 1.8\ 10^{-3}$ Вт/см^2, а на расстоянии в 3 см - $I \approx 36.5$ мВт/см^2. Т.о. направленное излучение по интенсивности в 135 раз (а иногда почти и в 1000 раз) выше, чем изотропное излучение. Так работает только лазерная система.

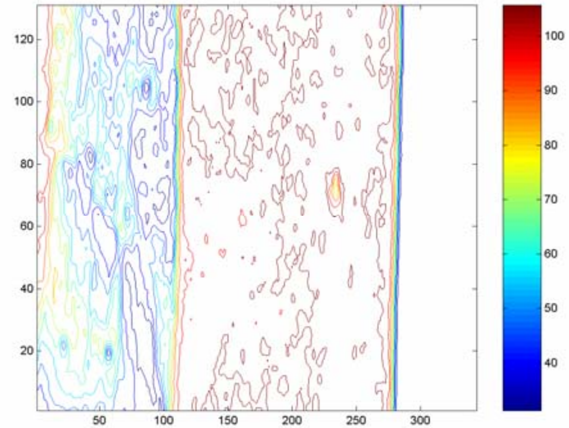
Диагностика с помощью фильтров



Fe 7.19 μm | **Cr** 10.53 μm | **Be** 100 μm

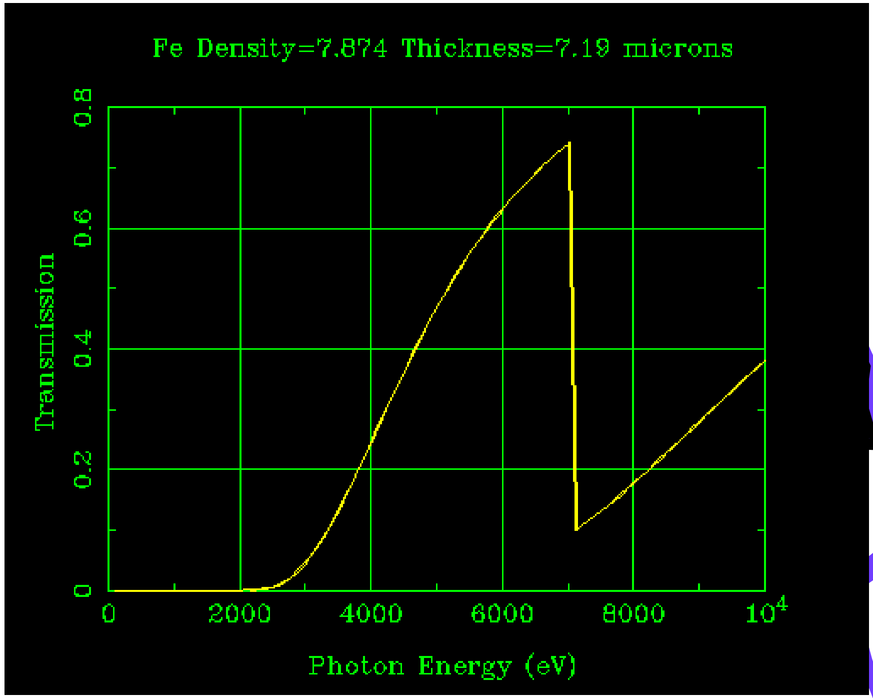




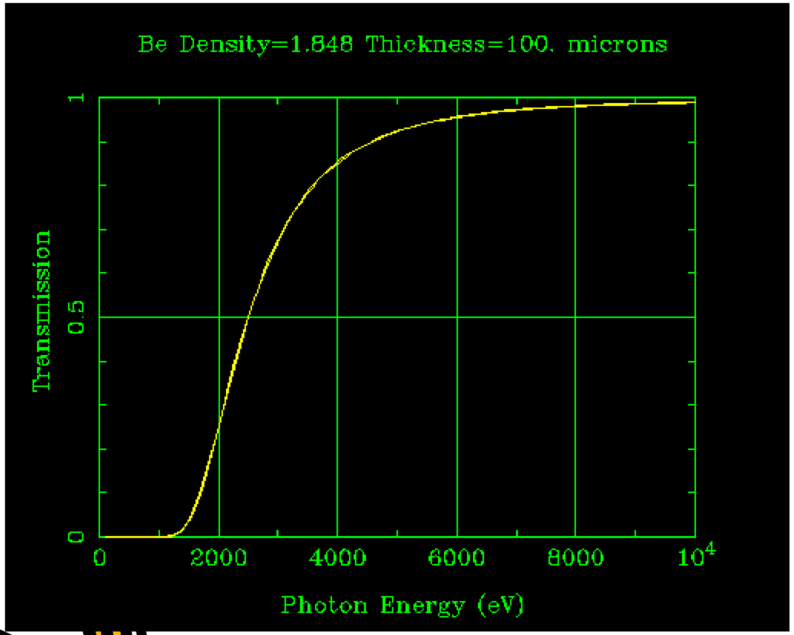


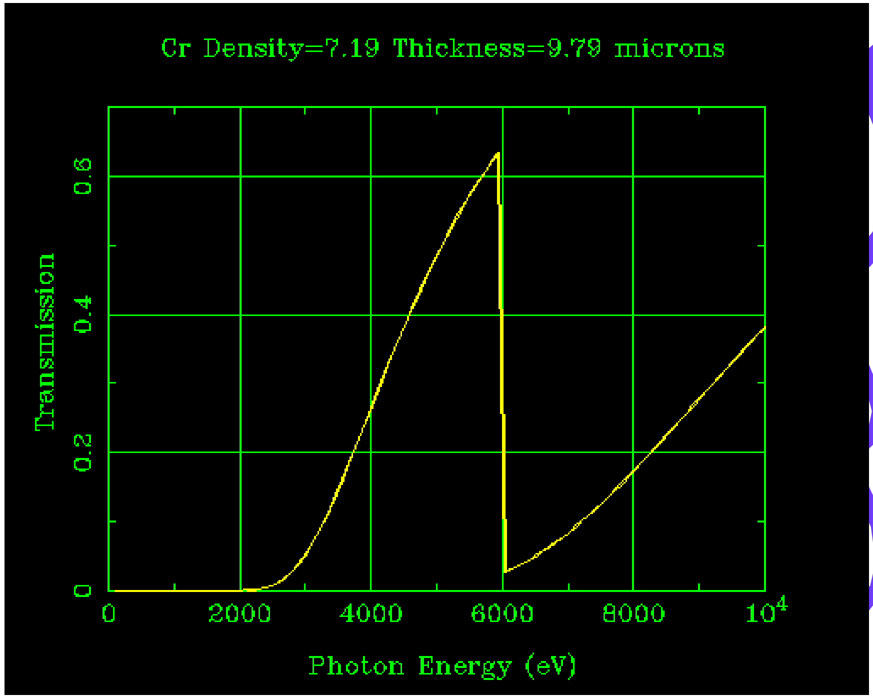
Пропускание фильтров Be, Fe, Cr

Fe



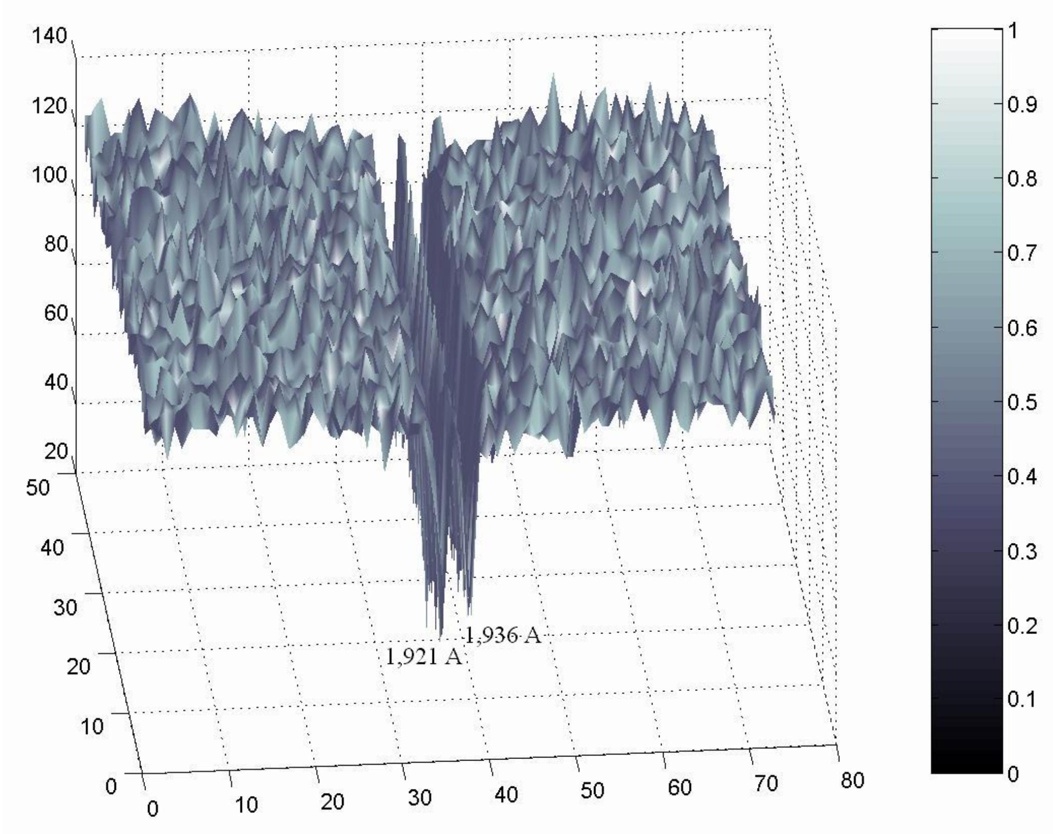
Be





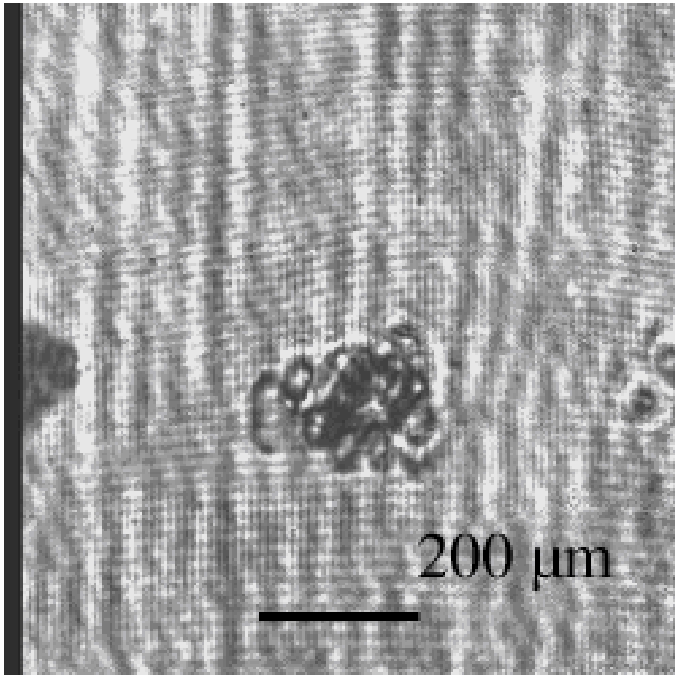
Расщепление спектральной линии γ-излучения Ta -181, Eγ ≈ 6.24 keV.

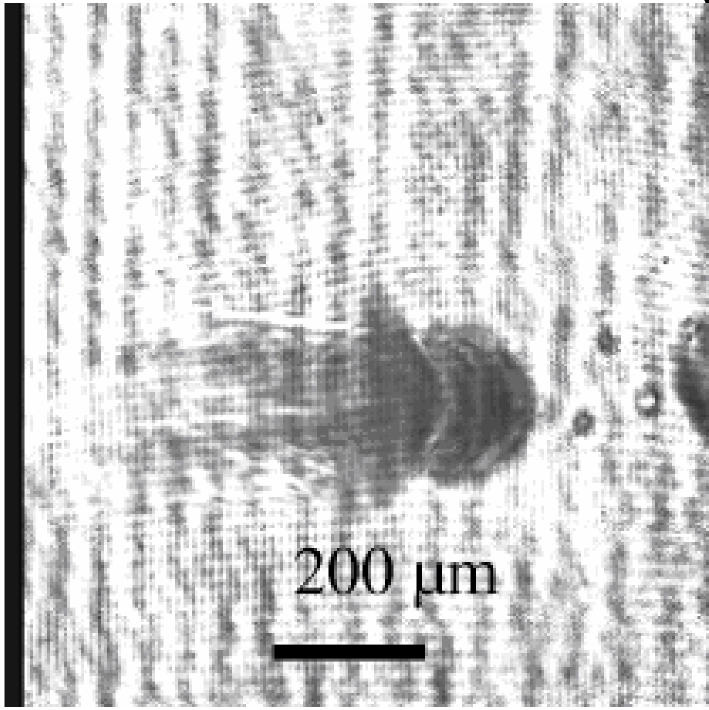
B=15.2 TG
E≈2.2 GeV



Plasma droplets with freezing magnetic fields

Ar

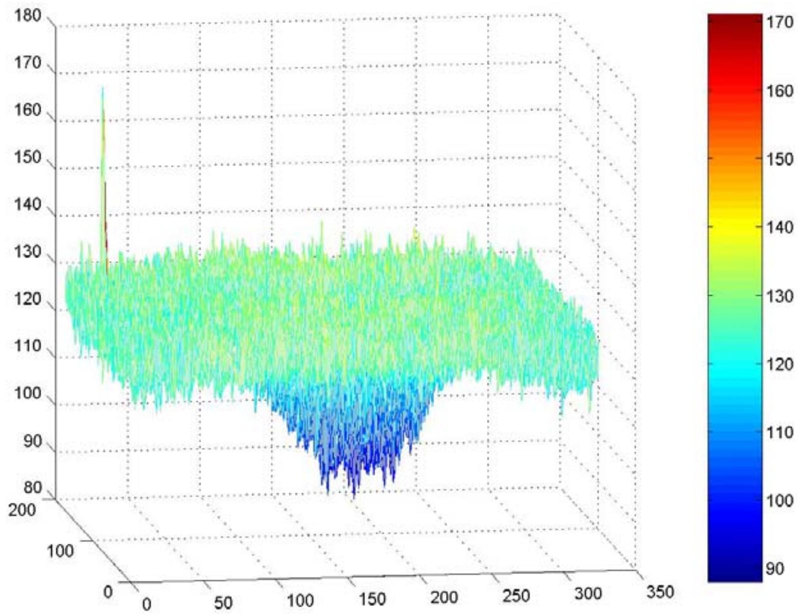




For t = +60 ps.Al-target, air. Due to effect Faraday (angle rotation 43°). V sgustke plasmi v scharikach vidni svetlie tochki i temnie. Diametr micro droplets - 3 mkm, density of plasma Ne= 20e+20 cm-3, wavelength - 532 nm, so B=357 MG. For r=3 mkm. q≈30 SGSE

Gamma-ray generation and diagnostics

The observed triplet: 104.648, 104.775 104.902 keV (ΔE=0.127 keV) can be connected with Zeeman effect for nuclear transition. Hence we have B$\approx$40 TG. For measured doublet 105.156, 105.537 keV (ΔE=0.381 keV), B$\approx$121 TG. Such super high magnetic fields can be in the vicinity of observed magnetic monopoles only [4, 5] which in turn can be generated owing to quantum evaporation (or decay) of laser-induced miniature black halls (or very similar system) [11]. It is well known[12] that β-decay of neutron with high probability take place under influence of strong magnetic filed with B=118 TG.



[12] L.I. Korovina. Izv. VUZov. Fizika.No.6, pp.86-92 (1964)

Generation and diagnostics of gamma-ray radiation

The γ-ray spectre of Hf-176 had been measured too, by using spectrograph provided a spectral resolution of 3000. Instead of Kodak-Insight X-ray photographic film it was better to use ILFORD 3200 (UK black and white film with thin scintillating cover film) protected from visible light by 3 μm Al- filter. The data are represented in Table 1 (energy of γ-quanta, in [keV], upper level –is our data, lower level from work [10]). These results are in a good agreements with the results of [10].

Table 1.

207.2	124.28	88.99	62.48	56.86	48.22	41.89	31.61
207.5	125.4	88.35	~60	56.8		~40	30.76

[10]. E.P.Grigoriev. Nuclear Physics (in Russ.), 2005

Two possible mechanisms of generation such superstrong magnetic fields

1. The collisions of heavy ions which can be accelerated up to 4.4 GeV (the propagation Ta-ions throw 90 micrometers of Cu-foil had been detected).

The theory of such mechanism was considered at first in ANL by J. Rafelski and B. MullerPRL. V.36.No.10. P.517 (1976)

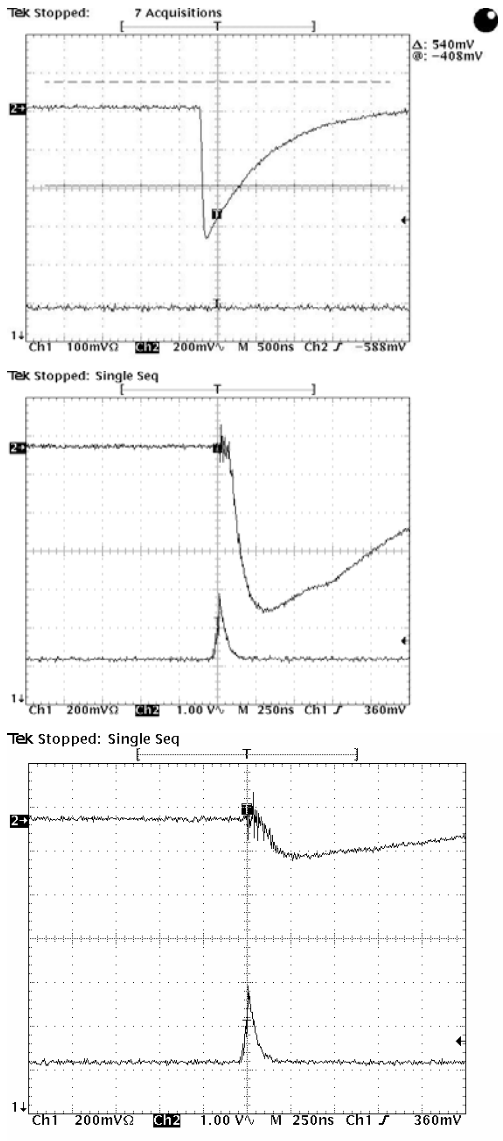
«In sub-Coulomb-barrier heavy-ion collisions the magnetic field created in the vicinity of the colliding nuclei is of the order of 1.E14 G. »

2. The inductance of magnetic fields in the vicinity (r~ 1-10 A) of an exotic quasiparticles can rich up to 1.E16-2.E18 G as had been estimated by V. Skvortsov and N. Vogel:
   Electromagnetic waves and electronoc systems. V.7. No.7.P.65- (2002).

(In accordence with the estimations produced by L. Korovina :
neutron betta-decay takes place at B=1.18E14 G, and proton decay - at B=1.23E17 G)

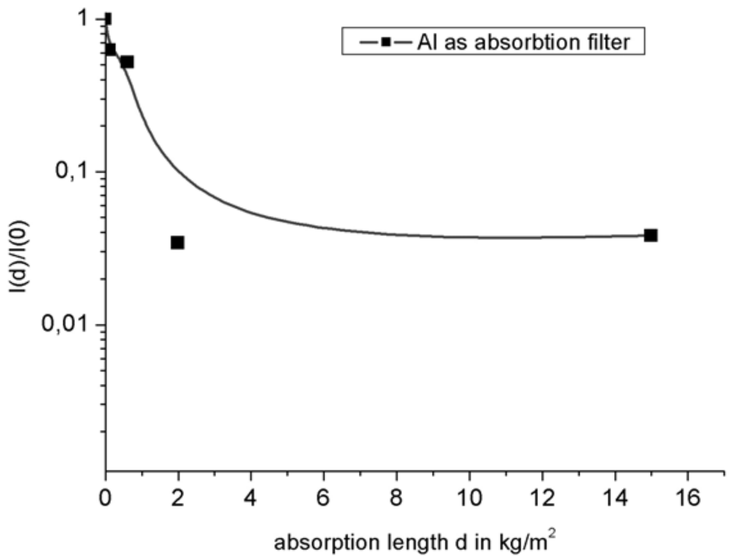
Gamma-ray generation and diagnostics

The very precisely experiments for investigation of gamma-ray radiation were produced by using different gamma-ray detectors. We detected a flux of γ-quanta with energy E=0.9-3.0 MeV. Fig.7 demonstrates testing signals and signals from tantalum target illuminated by picosecond laser beams (in batch mode). We can see, that signal is decreased in approximately 5 times when we used a 25 mm filter of Pb. Such behavior of signals is very similar to that of γ-quanta with E ≈ 0.9 MeV [9].



[9] Physical values. Reference book.. Ed. By I.S. Grigoriev, E.Z. Meilikhov. Moscow. Energoatomizdat. (1991).

Generation and diagnostics of Gamma-ray and β-ray radiation

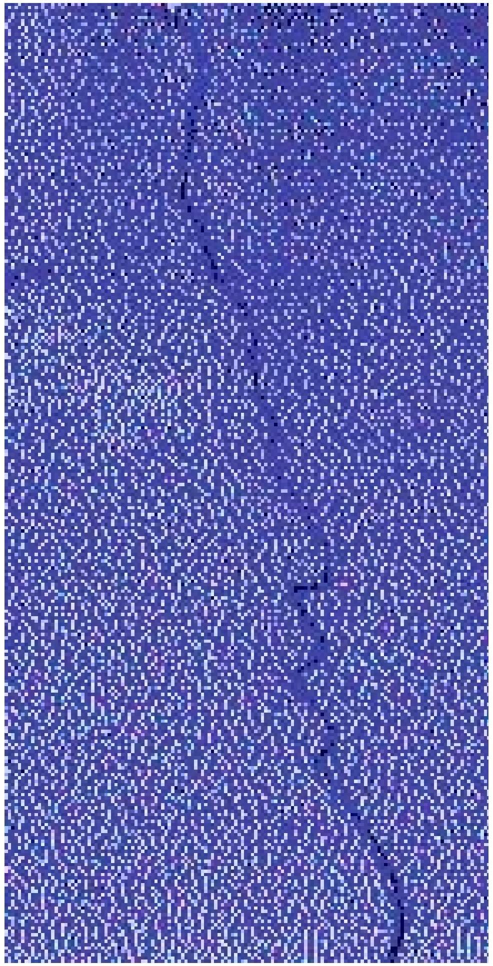


By using standard methodic of Al- filters [8] we determine also that we have γ-radiation with E=3.0 MeV as well as β-rays with E=250 keV and 1,26 MeV (see fig.8).

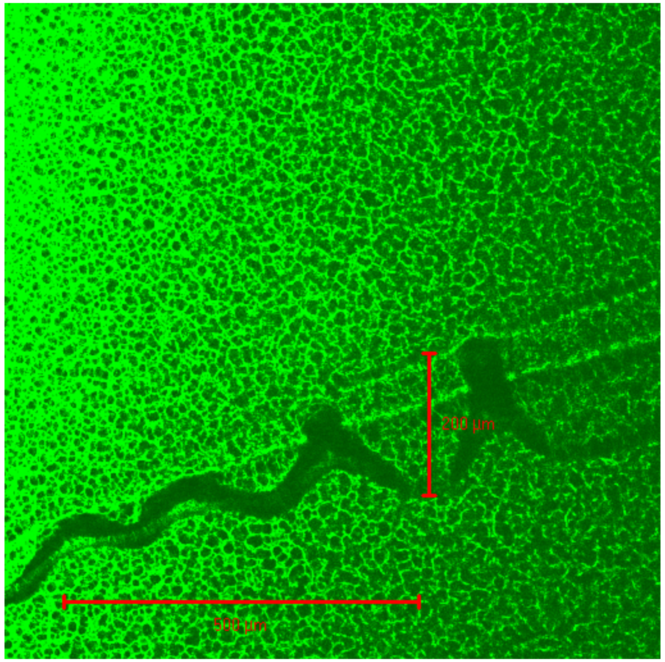
[8] L. Herforth, H. Koch. Praktikum der Angewandten radioaktivitat. VEB Deutsher der Wissenschaften, Berlin, (1972).

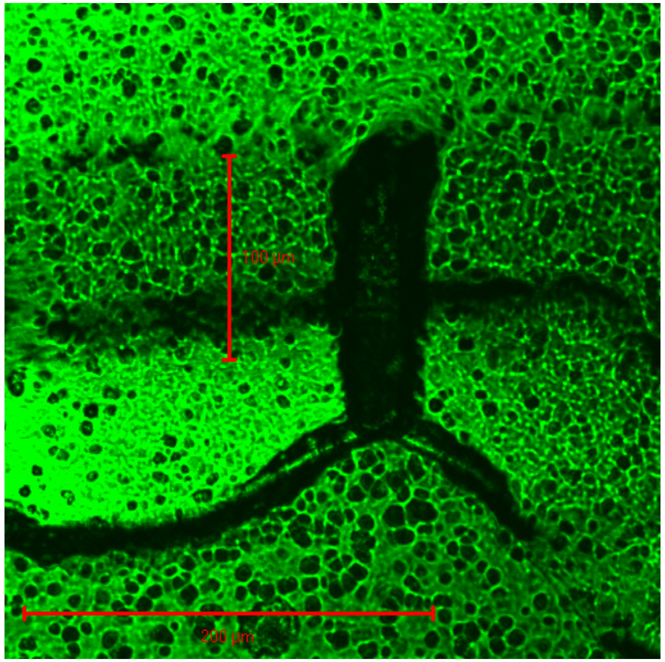
Generation and diagnostics of gamma-ray radiation

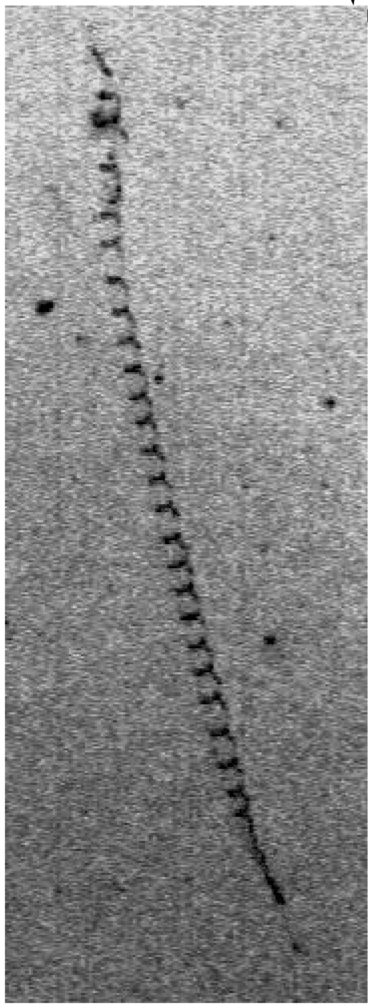
След на фотопленке (фрагмент, размер по вертикали – 25 мм, мишень из Al).

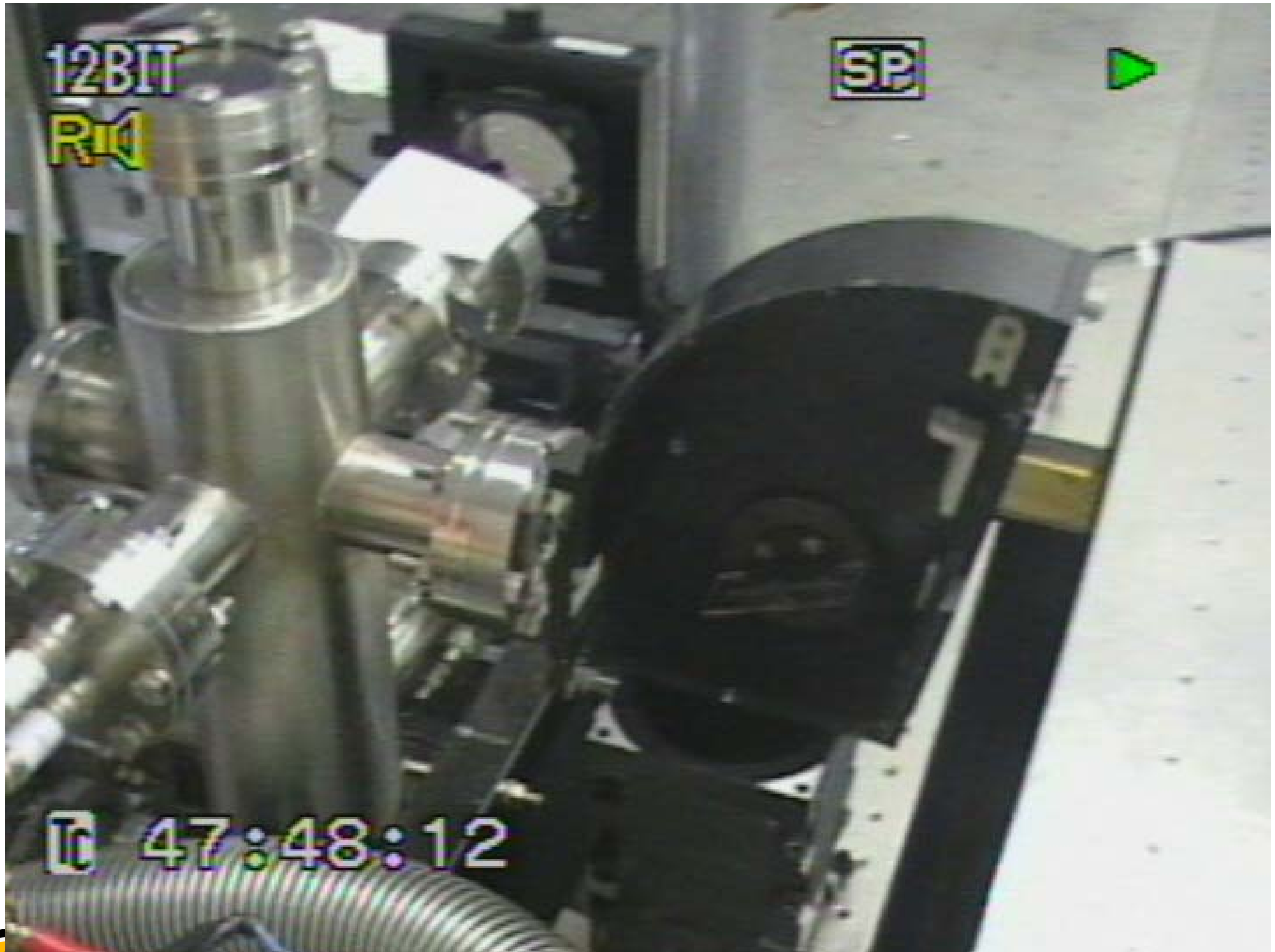


След на фотопленке (фрагмент, размер по вертикали – 10.25 мм, мишень из Ta-181).









The angle of slipping ≈ 20 degrees

One of simplest explanation

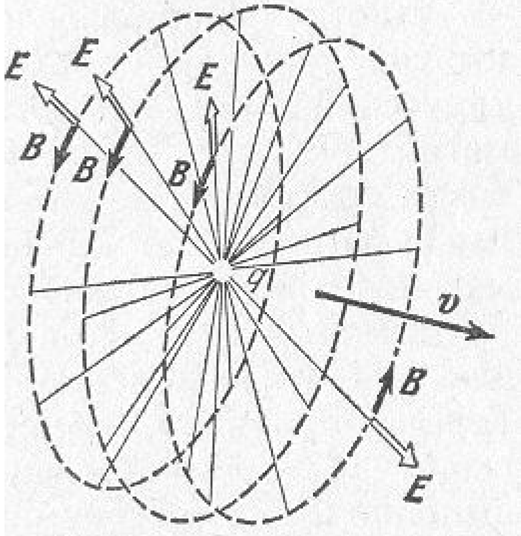


Рис. 6.26. Электрические и магнитные поля заряда, находящегося в состоянии равномерного движения, в данный момент времени.

For case (*)
E= -[v,B]/c;

B= [v,E]/c

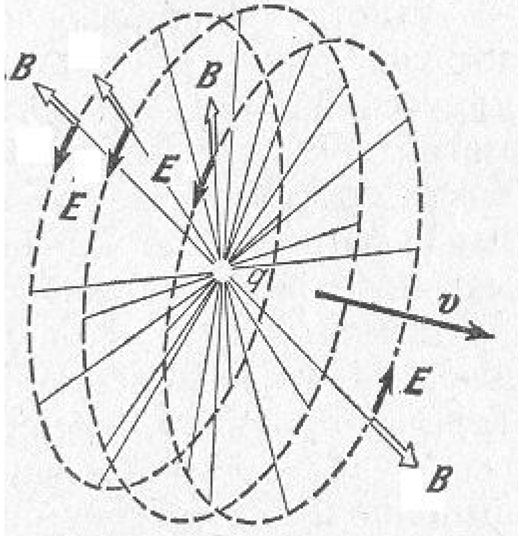
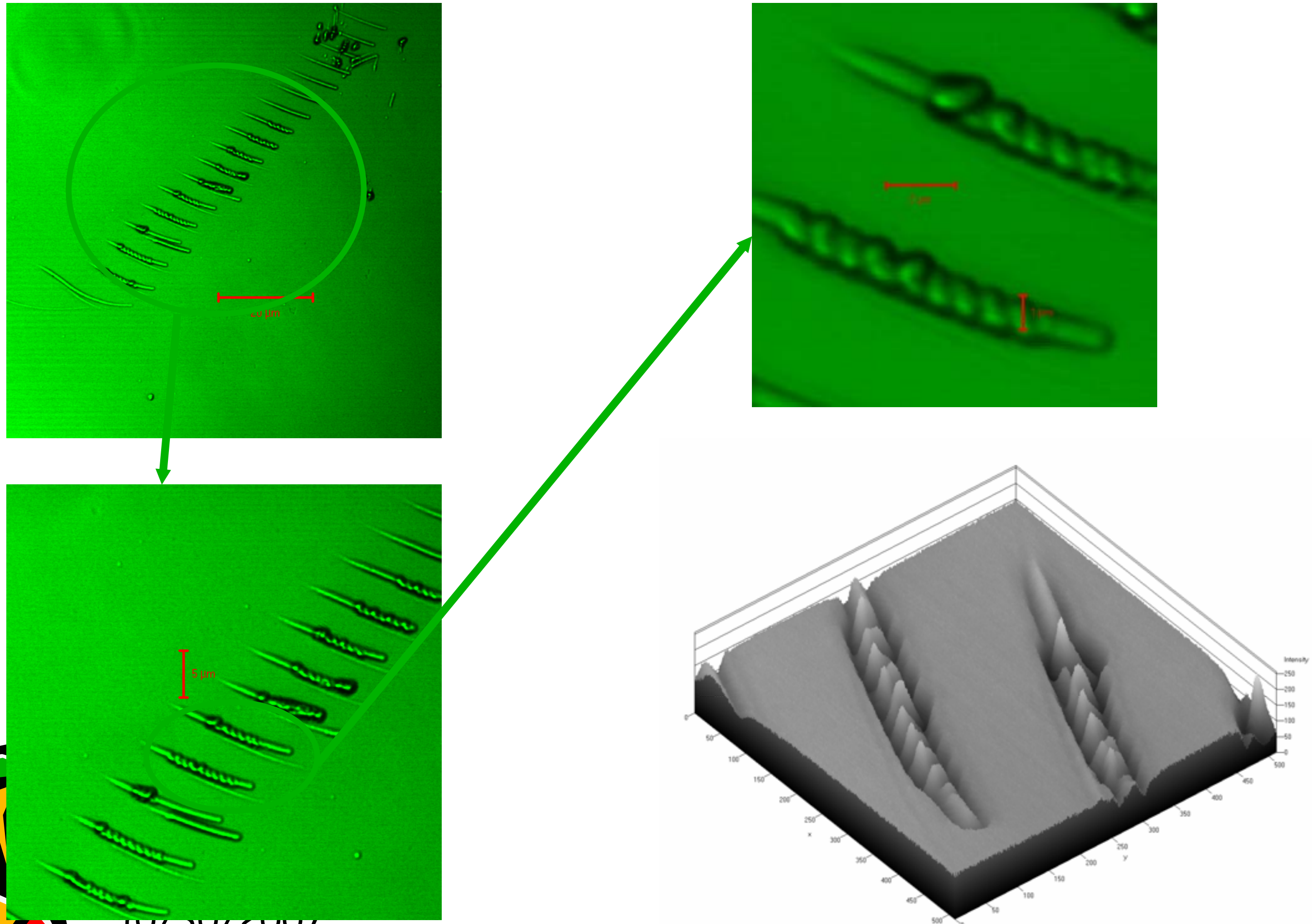


Рис. Электрические и магнитные поля заряда, находящегося в состоянии равномерного движения, в данный момент времени.

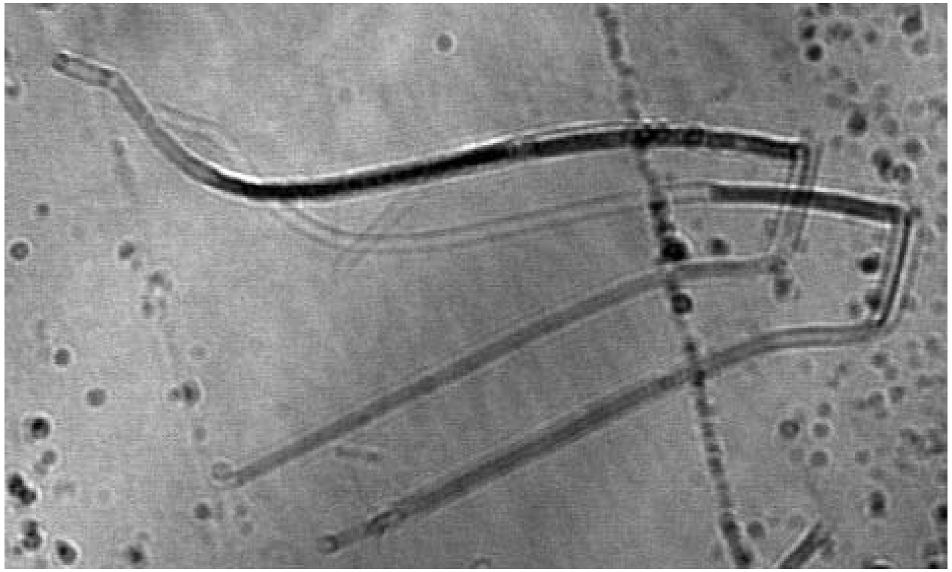
Fe=eE + e[V,B]/c; B=q/r2; E= [v,B]/c;
V=6.E7(Ee)**1/2≈1.8 E10 cm/s for 100 keV electrons passing 100 mkm of foil.
ω≈1.76 E7 B(G)=1.76 q/r2. ωr=V=1.76E7q/r
q = vr/1.76E7 ≈10 if r≈1.E-2 cm and V ≈v
then E ≈ 0.5 H ≈ 500 SGSE, or 150 kV/cm

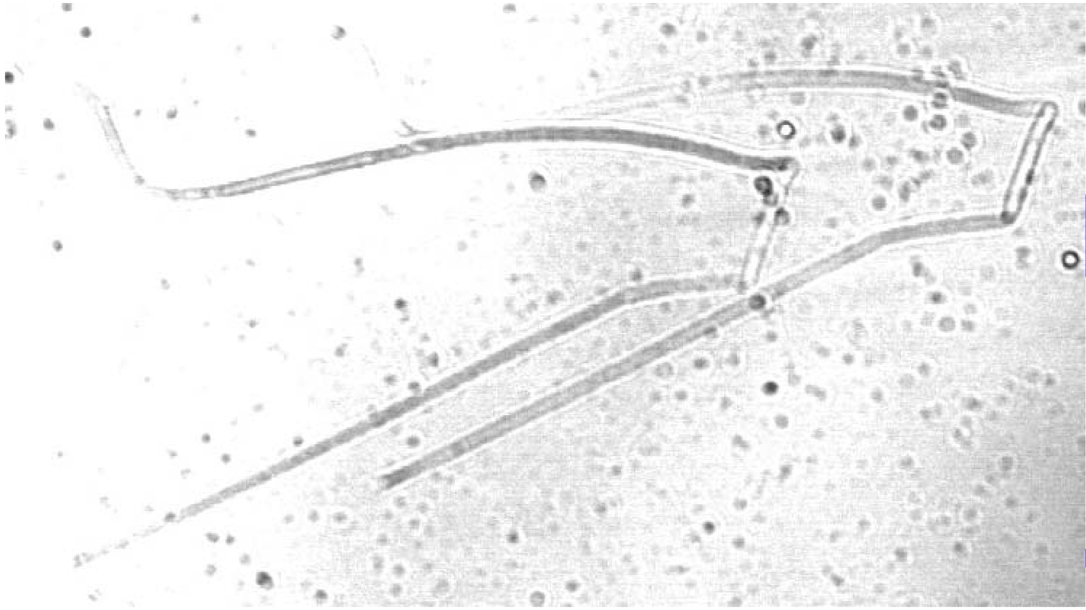
* E.Purcel. Electricity and Magnetism.Berkeley Physics Course. Vol.2.

Tracks on CR-39

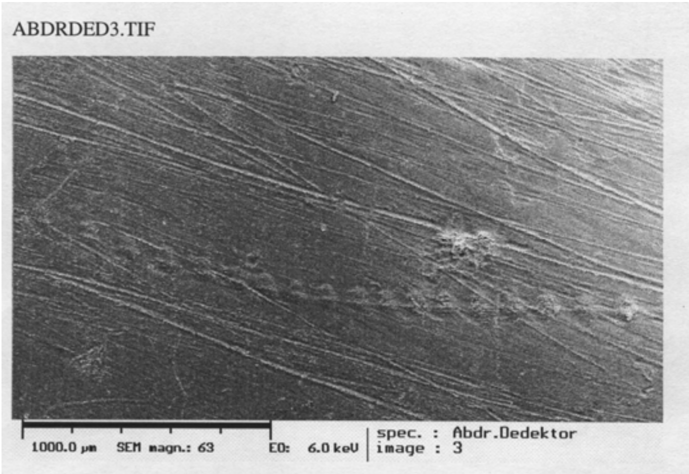


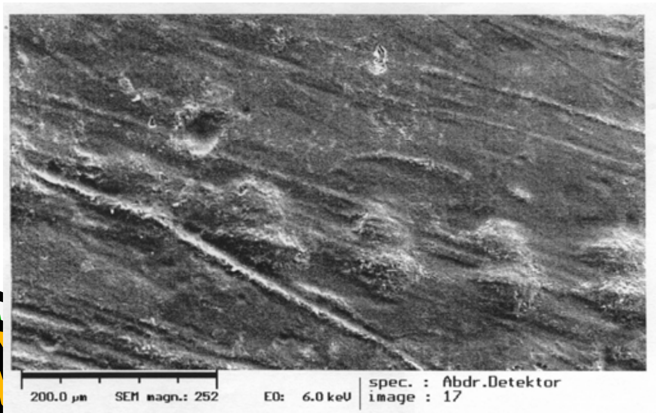
Следы на CR-39 в электрических полях

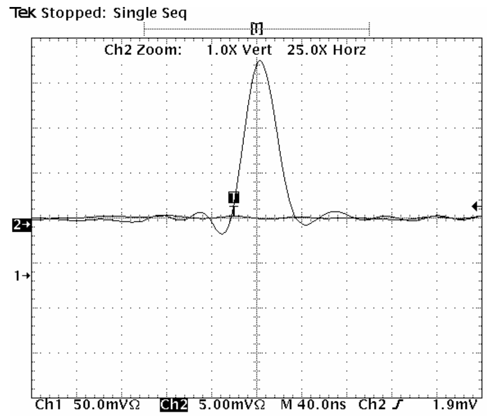




Tracks on metallic surface





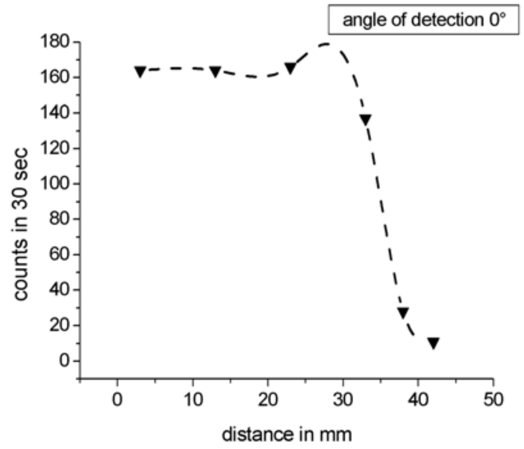


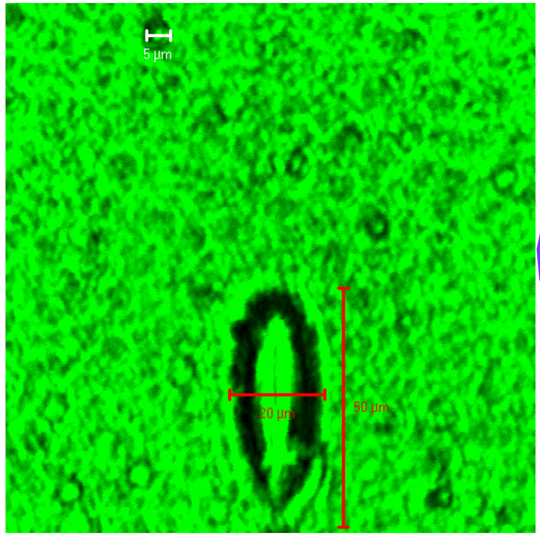
Signal of x-ray radiation registrated by absolutly calibrated semiconductor x-ray detector Photon flux $2x10^{12}/cm^2s$ (energy range 50 keV - 1.5 MeV

SEM -images of long tracks on the surface of x-ray detector

Generation and diagnostics of α-particles in laser-induced discharges

The measured value of α-particles energy is 6.39±0.1 MeV, which had been determined by method of particle stopping in air (in parallel with α-particles identification by using CR39 nuclear detector). Fig.1. shows a classical curve for monoenergetic α–particles extracted from very pure Ta-181 target. Here we took into account some an additional correction owing energy losses in window of used detector. The determined laser-induced radioactivity is equal ≈1.5-3*1.E3 Bq , which approximately in two order of magnitude lower then the using Am-241 radioactivity source (for calibration and testing of our devices). Such flux of α-particles had been observed in the vicinity of Ta-target. So we have reactions Ta-181→….→Ta-157+α (6.380 MeV).



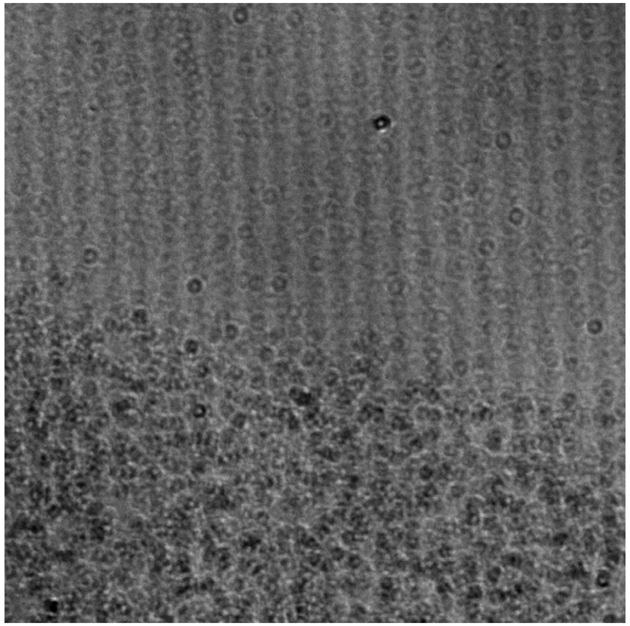


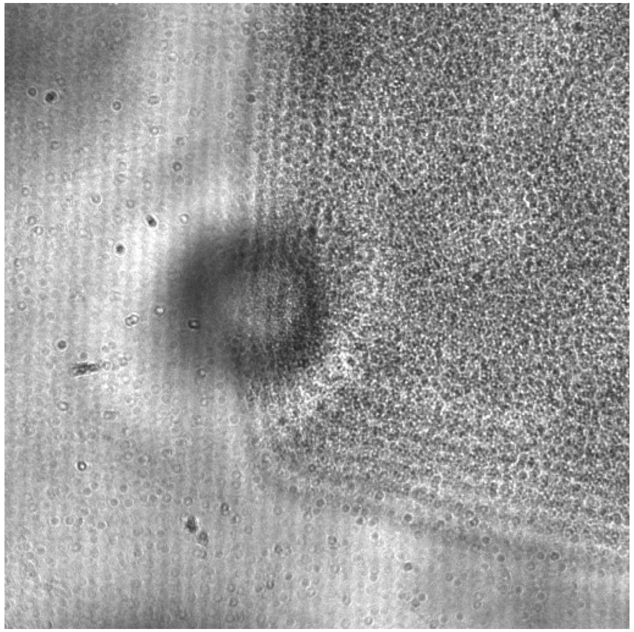
- For its explanation it is not sufficiently to propose the possible bombing Ta-target by accelerated ions (including tantalum ions like as in scheme [6]). We must take into account an exotic quasiparticles [4,5]. Fig.2 shows a typical track in CR39. The general view in microscope of eliminated surface of CR39 by α-particles a shown in Fig.3 a,b for standard sources of radioactivity Am-241 and our laser-produced α-particles. For 50 μm range in such dielectrics (with normal density 1.1 g/cc) we can estimate the energy of observed α-particle: E=6.4 MeV (with correction on loss energy in air), by using data [7]. We also measured other values of α-particle energies : 8.5 MeV and 8.9 MeV but with more high error (about of 30 %) for case of Ta-181 target

- [4]. V.Skvortsov., N. Vogel. The electromagnetic waves and electronic systems.V.**7**, No.7, pp. 64-73 (2002).
- [5]. V.A. Skvortsov, N.I Vogel. In book: Particles Physics in Laboratory, Space and Universe. World Scientific Co., Singapore. 2005, pp. 373-382.
- [6]. V.A Bushuev., A.V. Kolpakov, R.N Kuz'min., E.M Saprykin., D.A. Shalabaev. Vestnik Moscow State Uni., Ser. Physics and Astronomy., V.**19**. No.3. pp. 101-103 (1978).

Fig.3a The α-particle tracks from 241Am after 20 min etching in NaOH at 70 C (left)

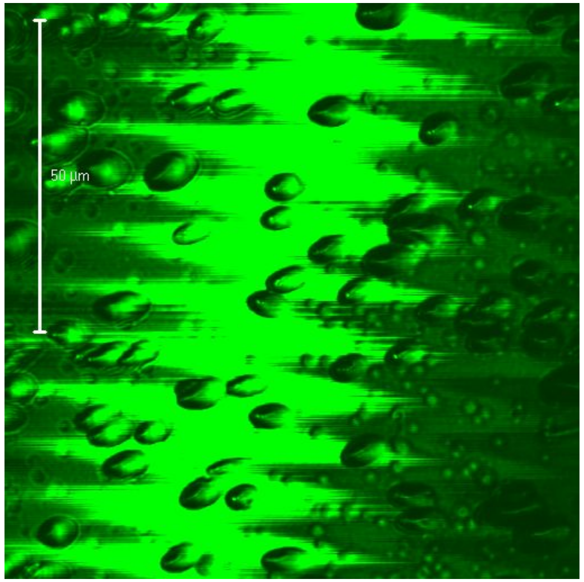
Fig.3b. The α-particle tracks from laser-induced discharge after 20 min etching in NaOH at 70 C (right)

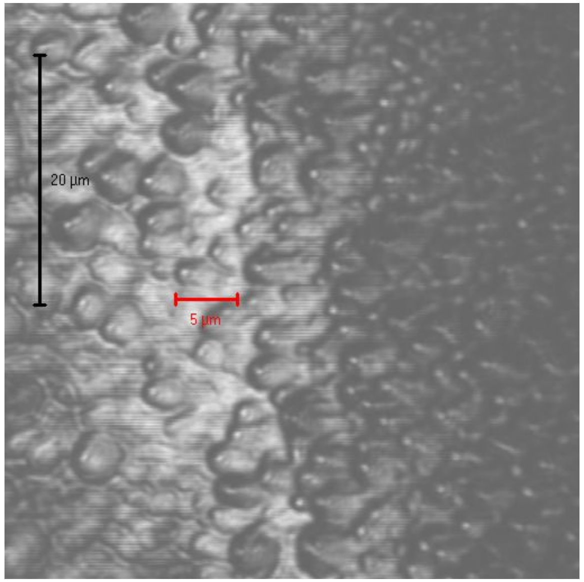




The general views of CR39 detectors (in partially closed by Al-filters with 45 μm thickness) which were illuminated by α-particles are shown in Fig.3 a,b. For comparison see Figures 4, 5 with more higher enlargement.

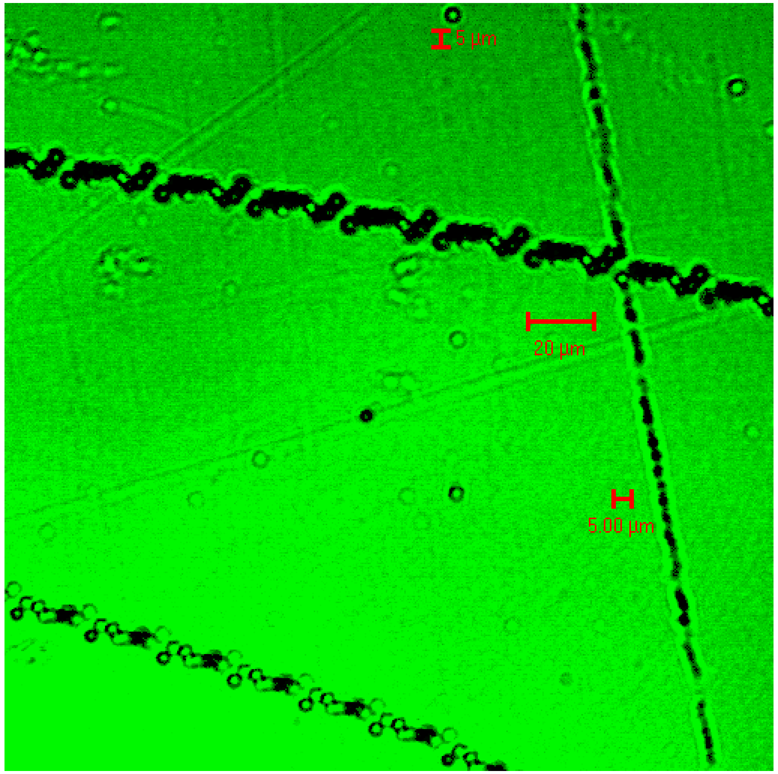
Fig. 4. The α-particles tracks for testing 241Am radioactivity source. Time of etching in NaOH was 60 min at 70 C (left). Fig.5.(right) The α-particles tracks for our laser-induced radioactivity source, based on Ta-181. Time of etching in NaOH was 60 min. CR39 was arranged in air at the same distance from source as in testing case (Fig.4).



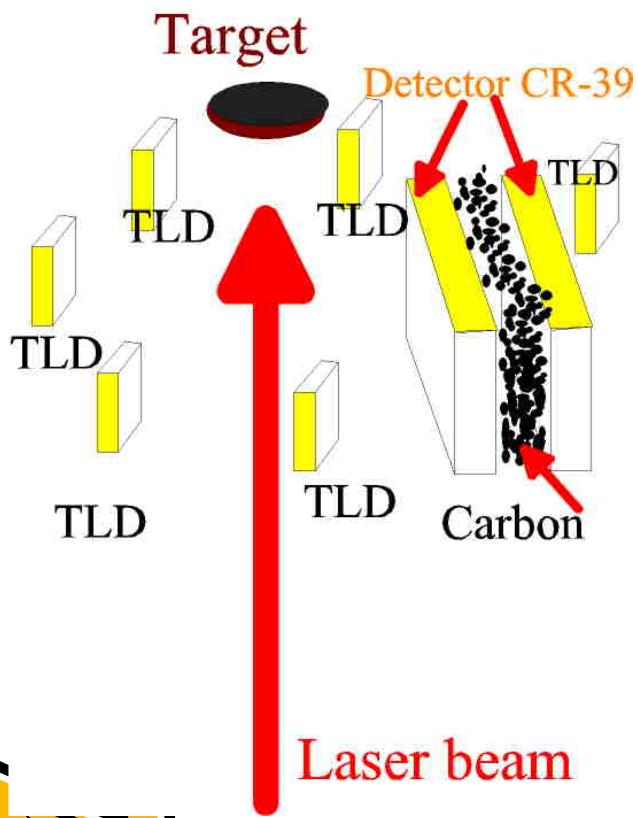


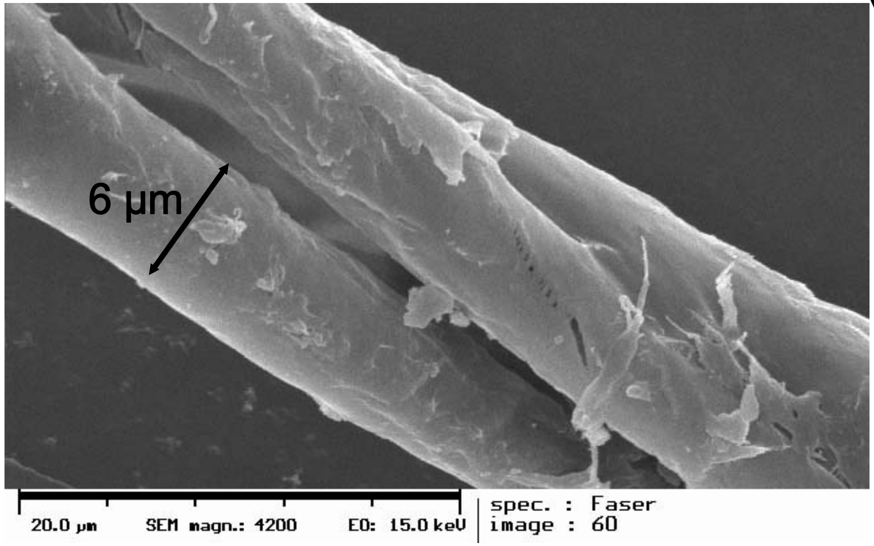
way of exotic quasiparticles the nuclear reaction take place.

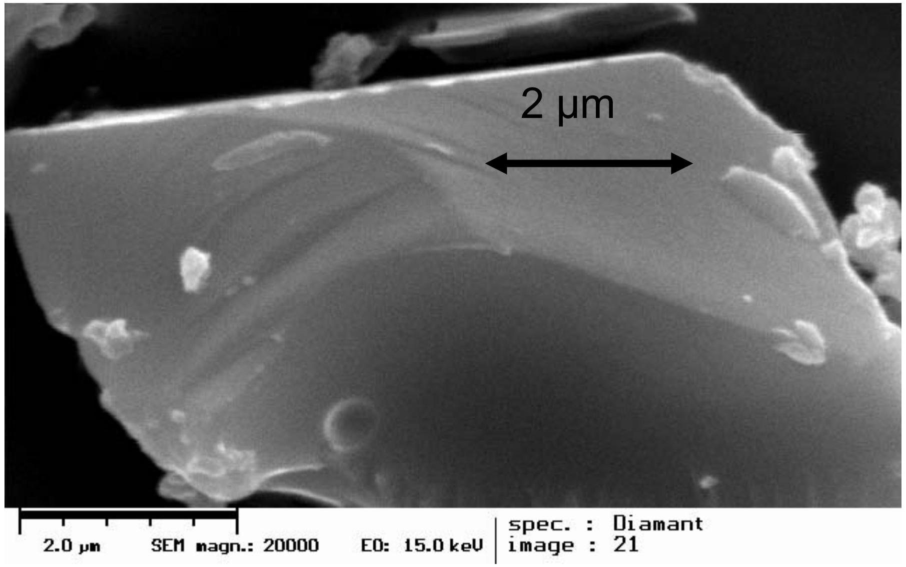
Our an exotic quasiparticles some times demonstrate properties which are very similar to properties of neutrons: at low energy they can reflected from metallic plates and under high energy can penetrates throw massive block of different metallic constructions. In addition they very like to slip along surfaces of dielectrics and metals.



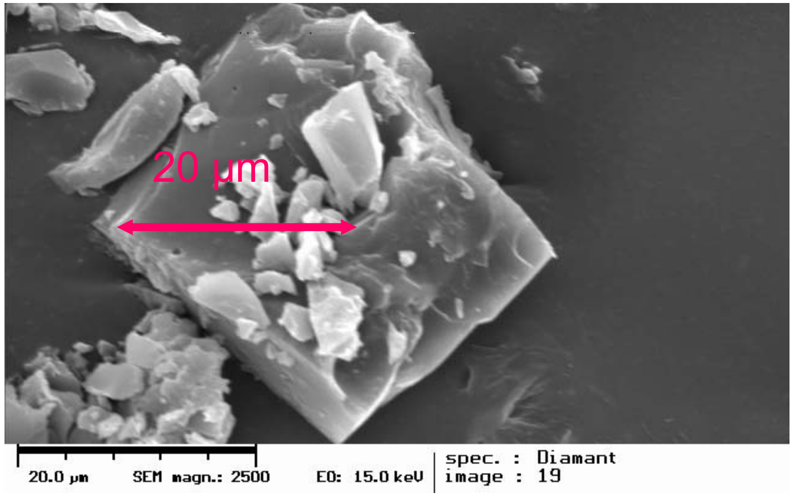
Experiments with carbon



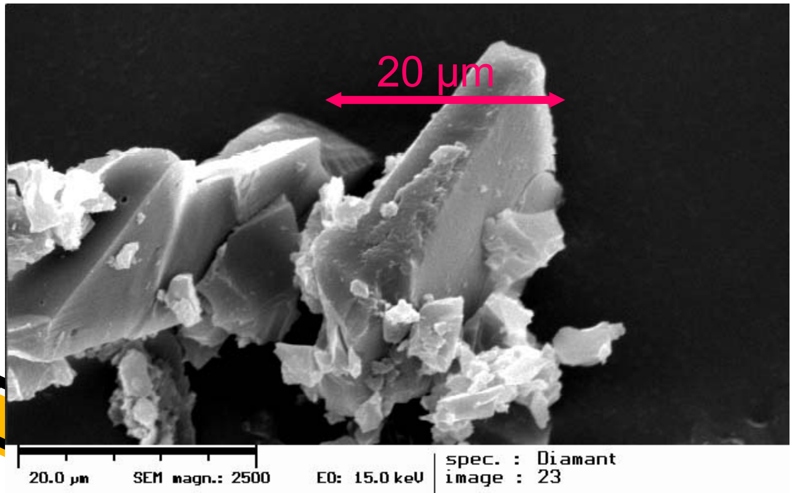


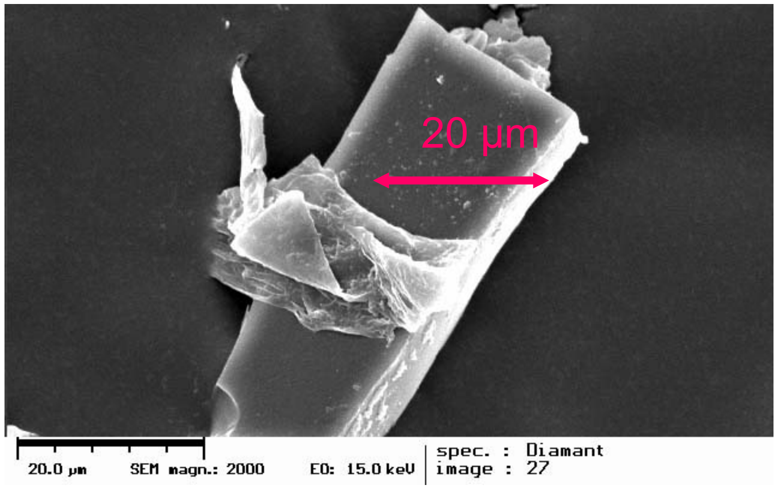


Experiments with carbon - SEM images and LEED



[123] a = 0.356
simple cubic
diamond lattice





Transmutation Ta→Tm

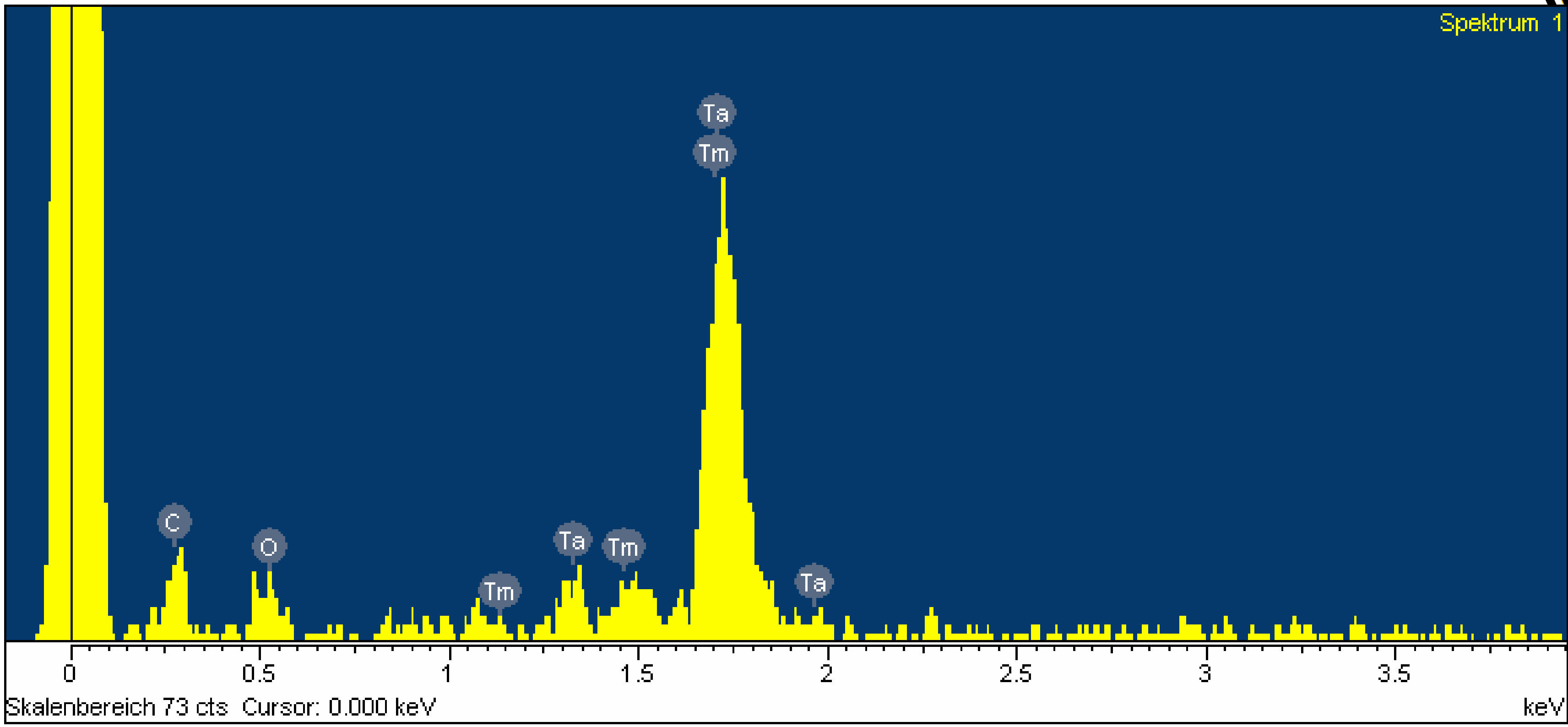
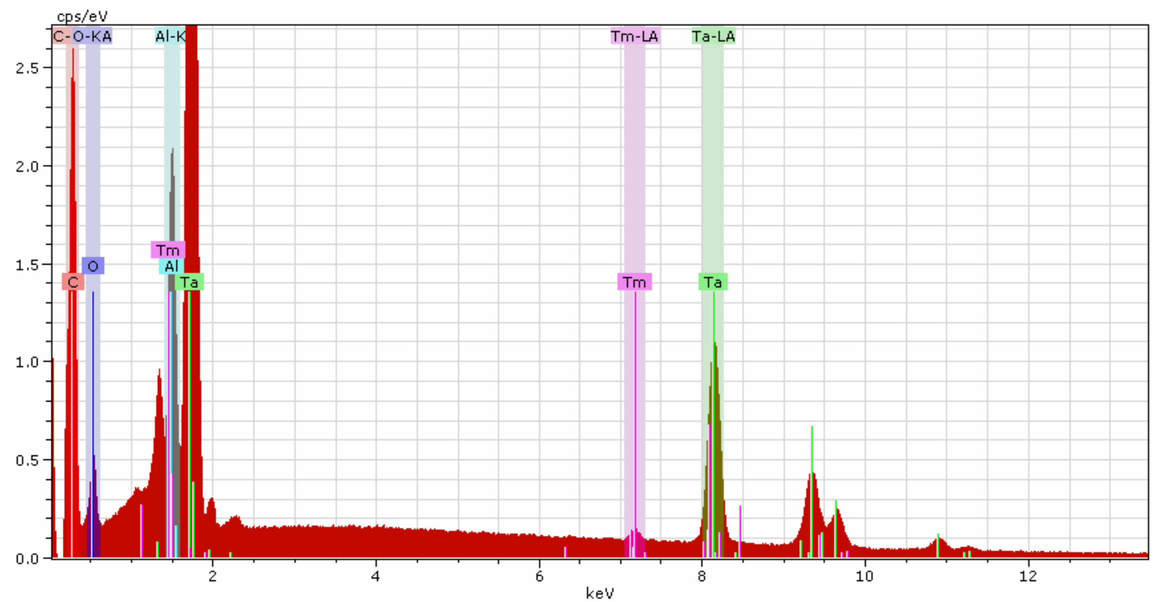
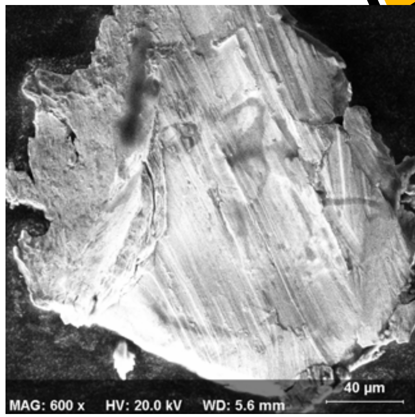


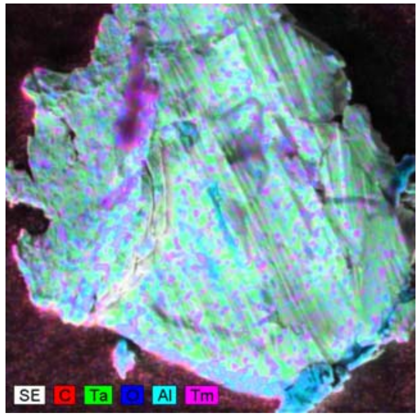
Table 2.

Element	Gewichts%	Atom%
CK	0.19	61.90
OK	0.11	26.97
Tm L	0.01	0.21
Ta M	0.49	10.91
Insgesamt	0.80	

Transmutation Ta→Tm







After that the magnetic properties of new material had been investigated by using SQUID microscope [14]. In deference from other particles of tantalum the particle with Tm has very distinct magnetic image.

SQUID microscope messuremts

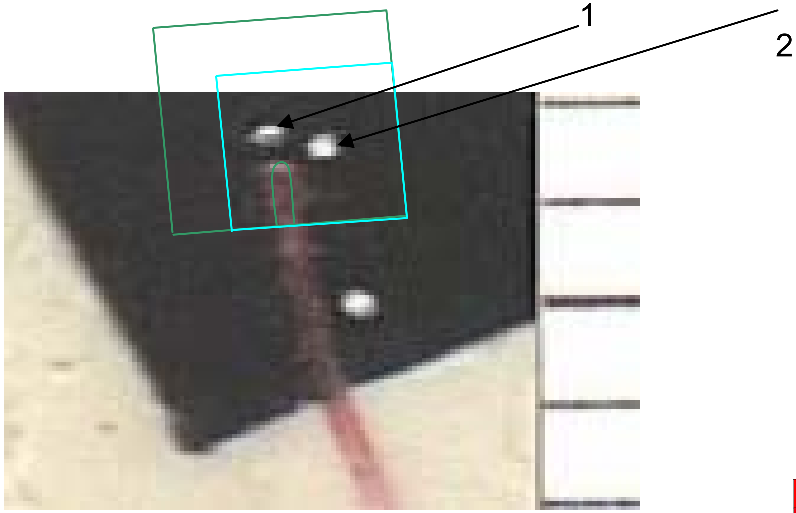
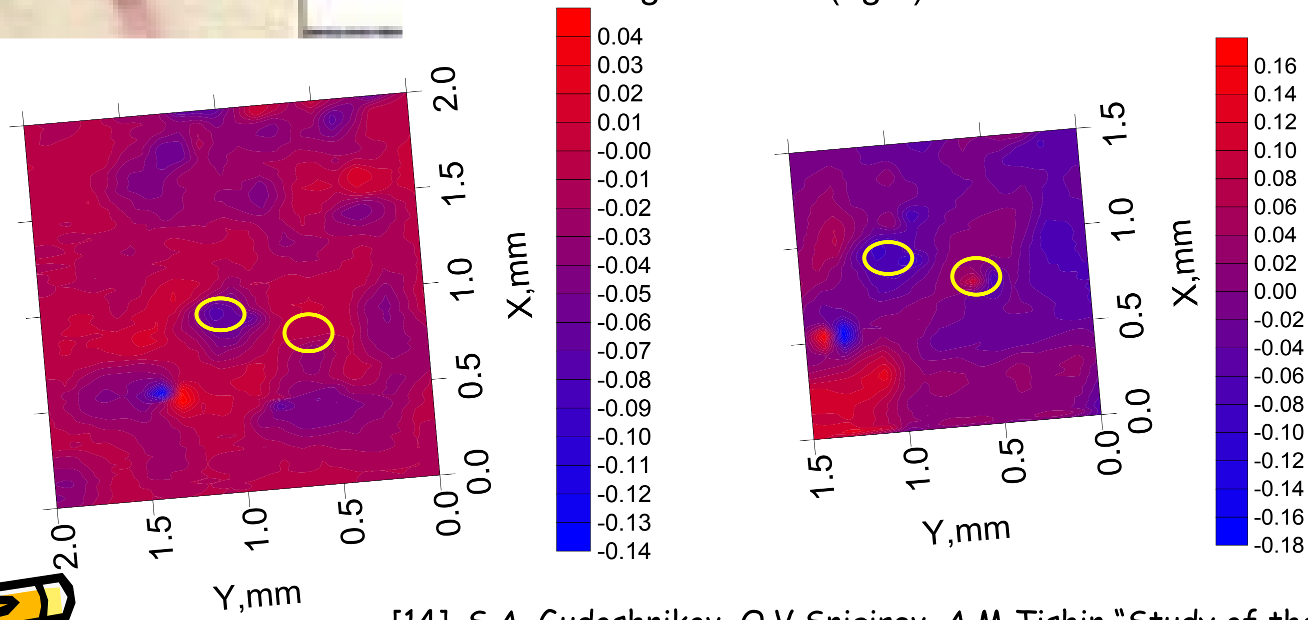


Fig.14. Photographic image of example with mark 1 and 2. The scanning regions are signed by quadratic frames.

Fig.15. The magnetic image of sample in residual magnetic field (left) and in parallel magnetic field (right)



[14]. S.A. Gudoshnikov, O.V Snigirev, A.M Tishin,"Study of the magnetic recording media using a scanning SQUID microscope". European Conference on Applied Superconductivity (EUCAS'99), Barselona, Spain, September 14-17, 1999

The theoretical model of observed nuclear reactions

In accordance with theory of tunnelling transitions and α-decay [15,16] we can write for α-particle penetrability in the form $W \approx \exp[(-\pi zZe2/\hbar)(2m\alpha/E)1/2\ ]$,

here E, $m\alpha$, z - are the energy, mass, charge of α-particle, Z|e|-charge of nuclear. In our case instead of $m\alpha$ we must take a relative mass $mp = mq * m\alpha/(m\alpha + mq)$, which for case $mp \ll m\alpha$ can be $mp \cong mq$. In accordance with our measurements $mq \cong 2*10$ -35 g (in [5] we named an exotic quasipaticle as "monopolino"). So the value of W is very close to 1 not only for α-particle but also for C, O,...(see Fig.10,12). In principal in our type of nuclear reactions together with α-particles another nuclears can be ejected from target atom.

[15]. G.A. Gamov, Zs. Fur Physik, **51**, 204; **52**, 510 (1928).
[16]. A.I. Baz', Za.B. Zeldovich, A.M. Perelomov. Scattering, reactions and decays in non-relativistic quantum mechanics. M. Nauka, 1966.-309 p.

Few Examples of nuclear reactions

Ta181 + q.p. $\rightarrow$Tm174 +He3+ He4 + q.p. + Q($\approx$9 MeV)

Ta181 + q.p. $\rightarrow$Hf176 +p +4n + γ + q.p. + Q ?!

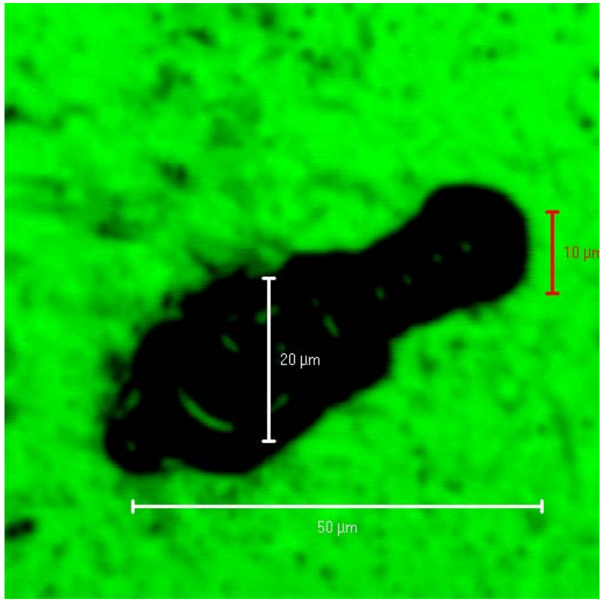
F. Wilczeck also has discussed the fact that monopoles should catalyze nuclear reactions. Phys. Rev. Lett. V.48.p.1146 (1982).

C12 + C12 $\rightarrow$Ne20 + He4 + 4.617 MeV
$\rightarrow$Na23 + p + 2.241 MeV
For «Gamov window» at E=2.42 Tg**2/3 in MeV, Tg$\approx$1 $\pm$ 0.2
E.E. Salpeter. Astrophys. J. V.115. P326. (1952).
Or O16 +O16 $\rightarrow$S31 + n + 1.50 MeV
for E=3.91 Tg**2/3 MeV, Tg ~ 2.

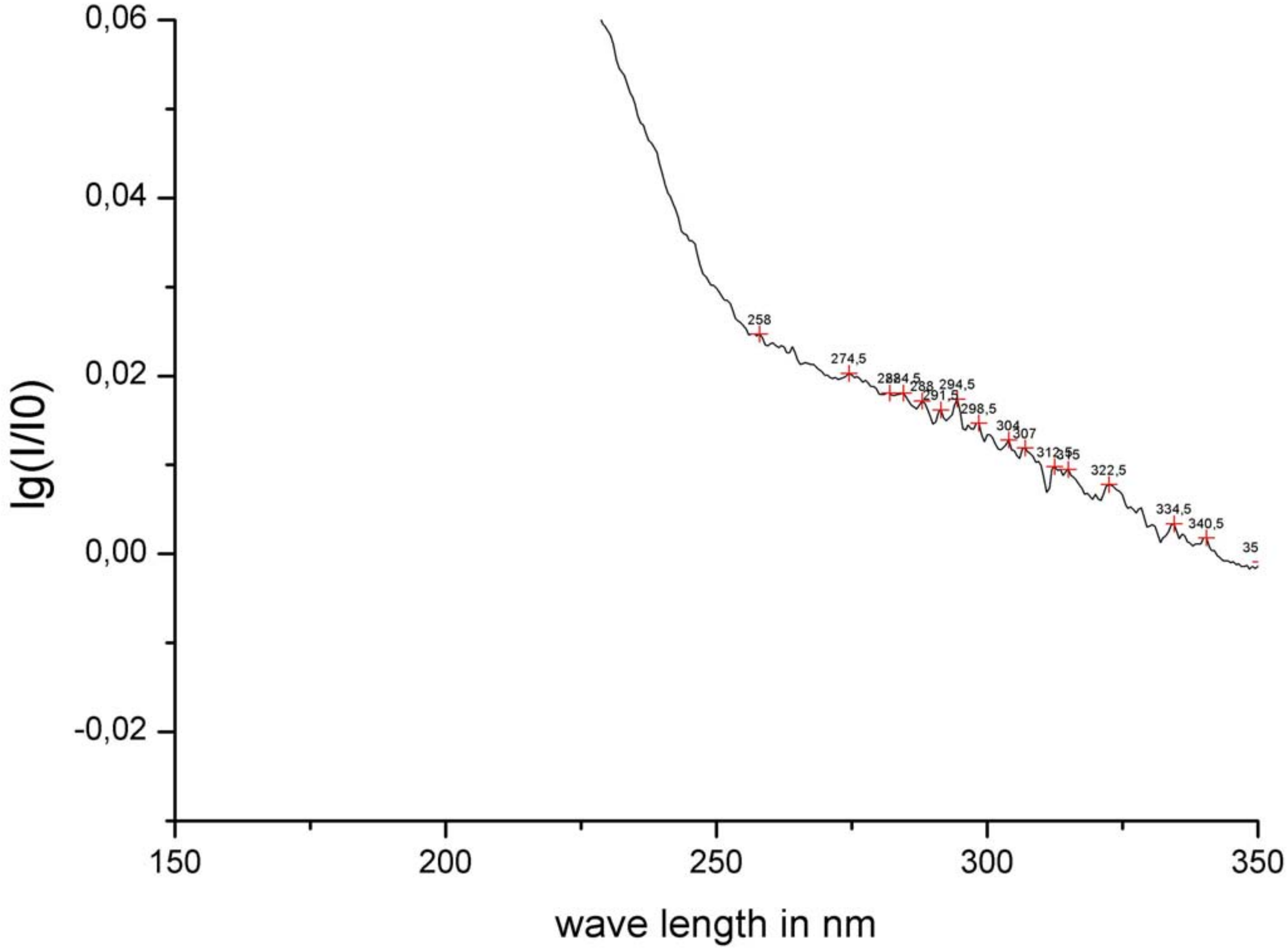
Low-temperature superfusion !?...

Note that analogous increasing of probability can be for reactions of nuclear synthesis (not only for light elements D,T..., but practically for all elements). The corresponding relationship for penetrability $W_{synth} \sim \exp\{-4eZ(2mq R)^{1/2} / \hbar\} \cong 1 - 2*1.E\text{-}4*Z \cong 1$, (for $R \cong 5*1.E\text{-}9$ cm).

We have already observed such reactions of "low-temperature" superfusion when instead of Ta-target we used an Al-target. In this case we had not observed of α-particles. We detected by means of mica particle detector a very energetic ions of Fe with an energy of $E \approx 675$ MeV (see Fig.13). Mica is insensitive to light nuclei with mass number A less than about 30 [17]. So only for elements with $A > 30$ we can see tracks on mica detector, and Al-ions must be excluded from the consideration. For our opinion such element can be $^{54}Fe_{26}$ due to reaction Al + Al + q.p.$\rightarrow$ Fe + q.p..



Low-temperature superfusion !?...

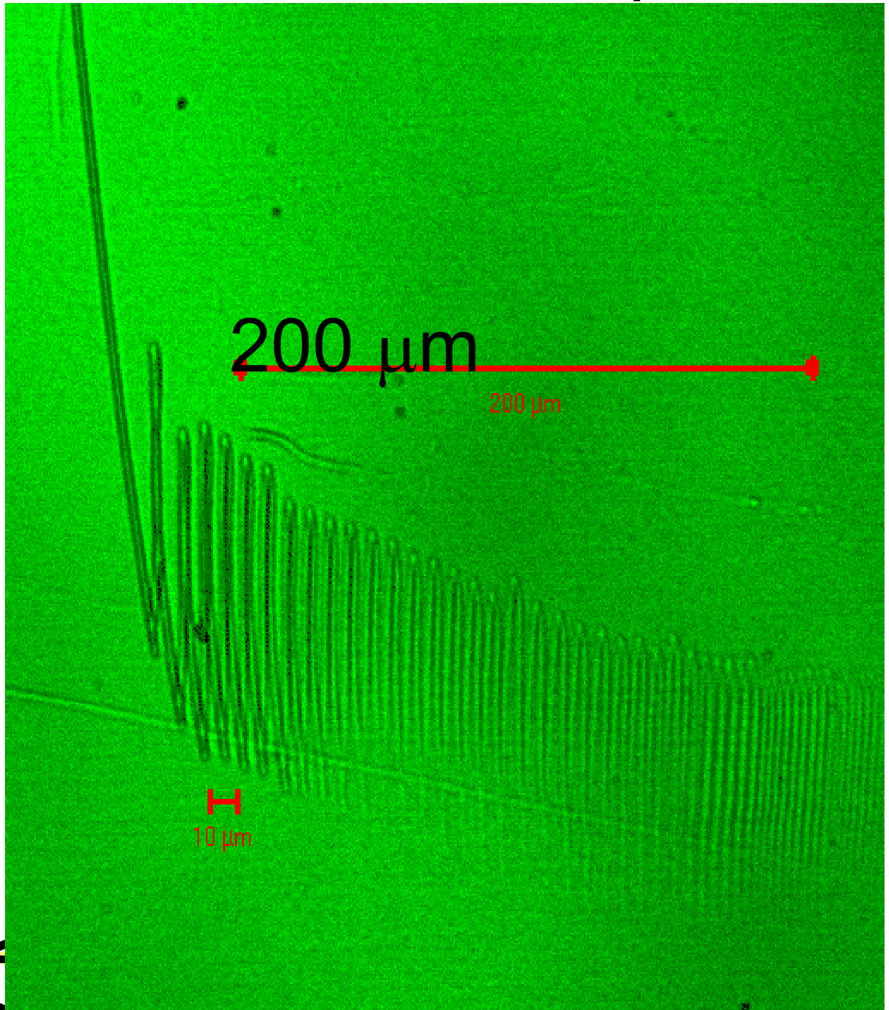


The main physycal parameters of the first microreactor of nuclear fusion

Al27 + Al27 (+ q.p.) → Fe54 + (q.p.)+ 65.1 MeV;

Energy yield: 0.4- 4 mJ per laser pulse (100 mJ);
Number ions of Fe : 4.E7-4.E8 per pulse;
radius : R ~ 1 micrometer;
coeff. K=1.5 E-9 cc/s, cross section : 1.5 E-17 cm-2.
The penetration of l=3.E-3 cm of mica had been detected. Such range of propagation is tipical for Fe- ions with energy E≥ 65 MeV.

Shredinger's "Zitterbewegung" of Dirac's particle



- $2\delta r \approx 100\ \mu m$
- $m = (h/2\pi)/(2\delta r c) \approx 2.0\ \ 10^{-35}\ g.$

Математическое моделирование МГД-процессов

- $\partial \rho / \partial t + div(\rho \mathbf{u}) = 0$; $\rho d\mathbf{u}/dt = -grad P + [\mathbf{j} \times \mathbf{B}]/c$;
- $\rho d\varepsilon_e / dt = -P_e \, div \, \mathbf{u} - div \, W_e + G_j - G_e + Q_{ei}$; $\rho d\varepsilon_i / dt = -P_i \, div \, \mathbf{u} - div \, W_i - Q_{ei}$;
- $rot \, \mathbf{B} = (4\pi/c)\mathbf{j} + (1/c)\partial \mathbf{E}/\partial t$; $rot \, \mathbf{E} = -(1/c)\partial \mathbf{B}/\partial t$;
- $div \, \mathbf{B} = 0$; $\mathbf{j}/\sigma = \mathbf{E}^* + \zeta \nabla T_e + \nabla Pe/ne$; $\mathbf{E}^* = \mathbf{E} + [\mathbf{uB}]/c$;
- $P = P_e(\rho, T_e) + P_i(\rho, T_i)$;
- $G_e = G_{rad} + G_s(\rho, T_e, \mathbf{B}, t)$; $G_j = \mathbf{j}\mathbf{E}^*$; $\mathbf{W}_{e,i} = -\kappa_{e,i} \, grad \, T_{e,i}$.
- Здесь ρ - плотность вещества, ε - удельная внутренняя энергия, P – давление вещества, $P_{e,i}$- электронное и ионное давление, **u**- массовая скорость, **B** - индукция магнитного поля, **E** - напряженность электрического поля, **j**- плотность тока, $W_{e,i}$- электронные и ионные тепловые потоки, $\kappa_{e,i}$ – коэффициенты теплопроводности, $T_{e,i}$ - электронная и ионная температура, $Q_{e,i}$ - обмен энергией между электронами и ионами, G_e- поток энергии (тепловой) за счет эмиссии или поглощения электронов (источники и стоки энергии) , ζ - удельный термомагнитный тензор, σ - удельная электропроводность. Член $\zeta \nabla T_e$ играет принципиальную роль в решении задачи.

Прохождение и поглощение лазерного излучения в плазме

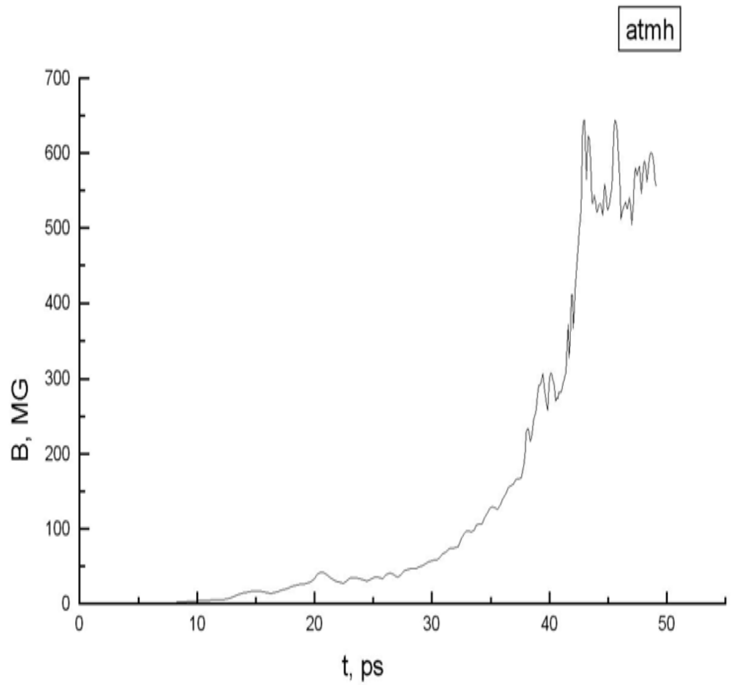
Расчет переноса и поглощения лазерного излучения проводился в приближении геометрической оптики (рассеяние излучения не учитывалось) с использованием простой формулы

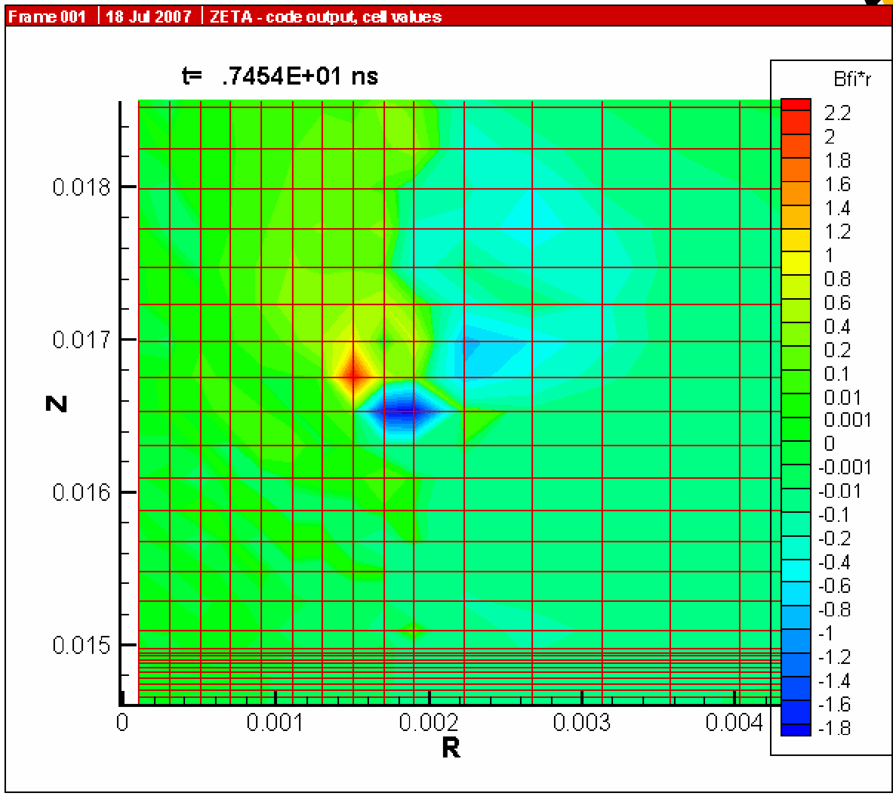
$$\mathbf{dI(r,y)/dz=-\mu\,(r,z)I(r,z)}$$

μ **(r,z)** - коэффициент поглощения. Зависит от Te, Ne, Z -плазмы.

В области резонансного поглощения. Предполагалось, что отражения излучения нет и вся «оставшаяся» энергия лазерного излучения поглощается на толщине скин-слоя.

B max (t) (Al в Ar и H)





Stamper J.A. et al./ /Phys.Rev. Lett. 1971.V. **26**. P.1012
B~ (1-10) кГс /R (см). Имеем 10-100 МГс. R=1 мкм

Термомагнитная неустойчивость сильного МГД-разрыва в лазерной плазме

$$E_r \simeq (\dots) - \alpha \frac{\partial P_e}{\partial r} - 3\beta \frac{\partial T_e}{\partial r}$$

$$E_z \simeq (\dots) - \alpha \frac{\partial P_e}{\partial z} - (3+\xi)\beta \frac{\partial T_e}{\partial z}$$

$$\alpha \simeq 10^{-4} A/(\rho Z) = 10^{-4}(N_A/n_e)$$

$$n_e = (\rho Z)\cdot N_A/A$$

N_A → число Авогадро

$$\beta = K (T_e/n_e)$$

$$\xi = 3 - \Lambda_{ei}^{-1}$$

Λ_{ei} ↓ кулоновский логарифм

$$P_e = n_e T_e$$

Если $P_e \simeq const$

$$n_e = P_e/T_e$$

$$\beta \simeq K(T_e^2/P_e) \sim T_e^2$$

Если T_e растет, n_e – падает, β растет как T_e^2

А.А. Рухадзе и др. Письма в ЖЭТФ. 1974. Т.19. №5. С.291-294.

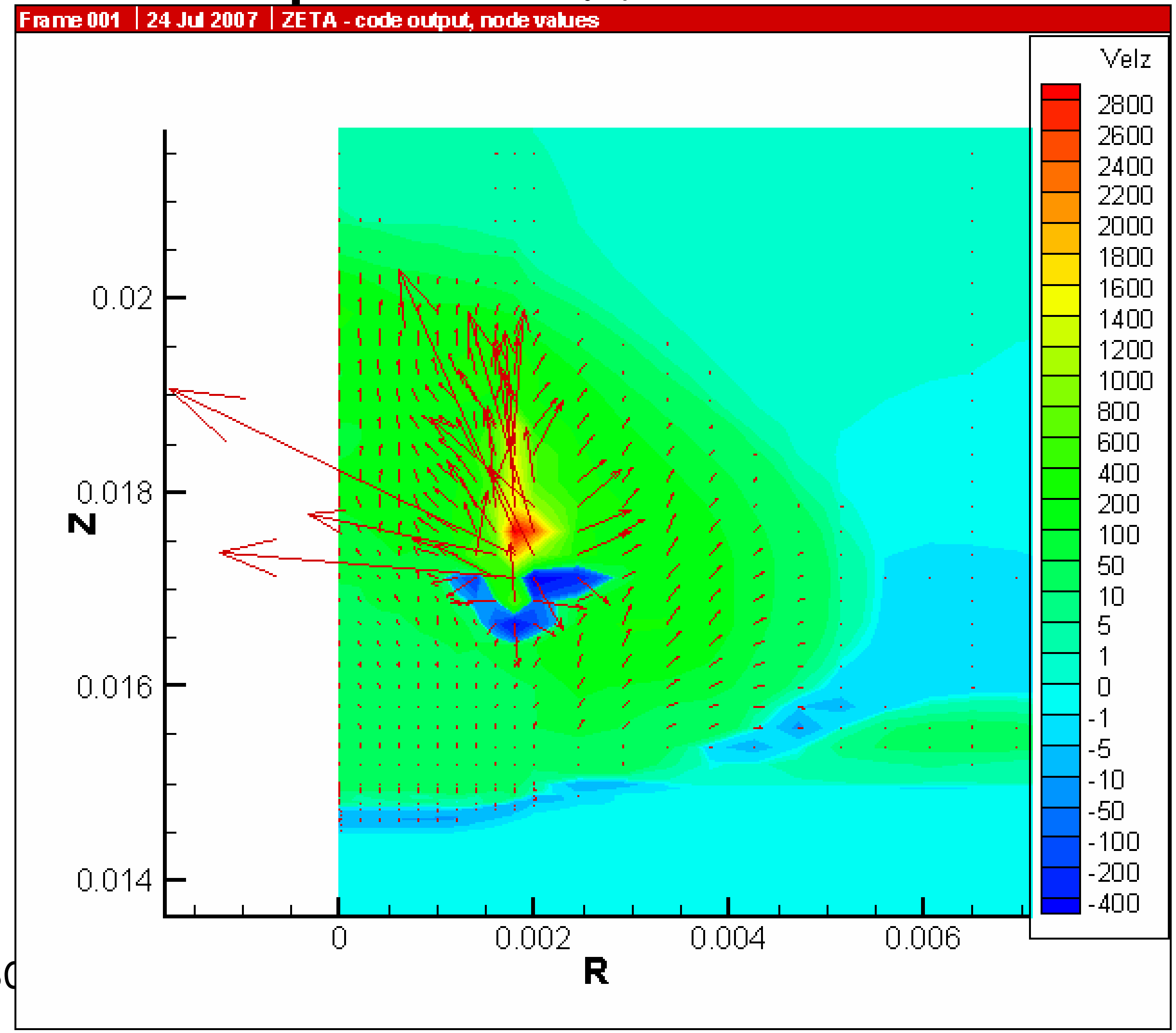
+ гирорелаксационный нагрев :

$$Q_{вязк} \sim \eta\, [(dB/dt)/B]^2,$$

Коэффициент β : **В.А. Урпин. «Термомагнитные явления и остывания звезд с магнитным полем». Астрономический журнал. 1985. Т.62. №2. С.258-267.**

Поле скоростей для t=53.77 пс

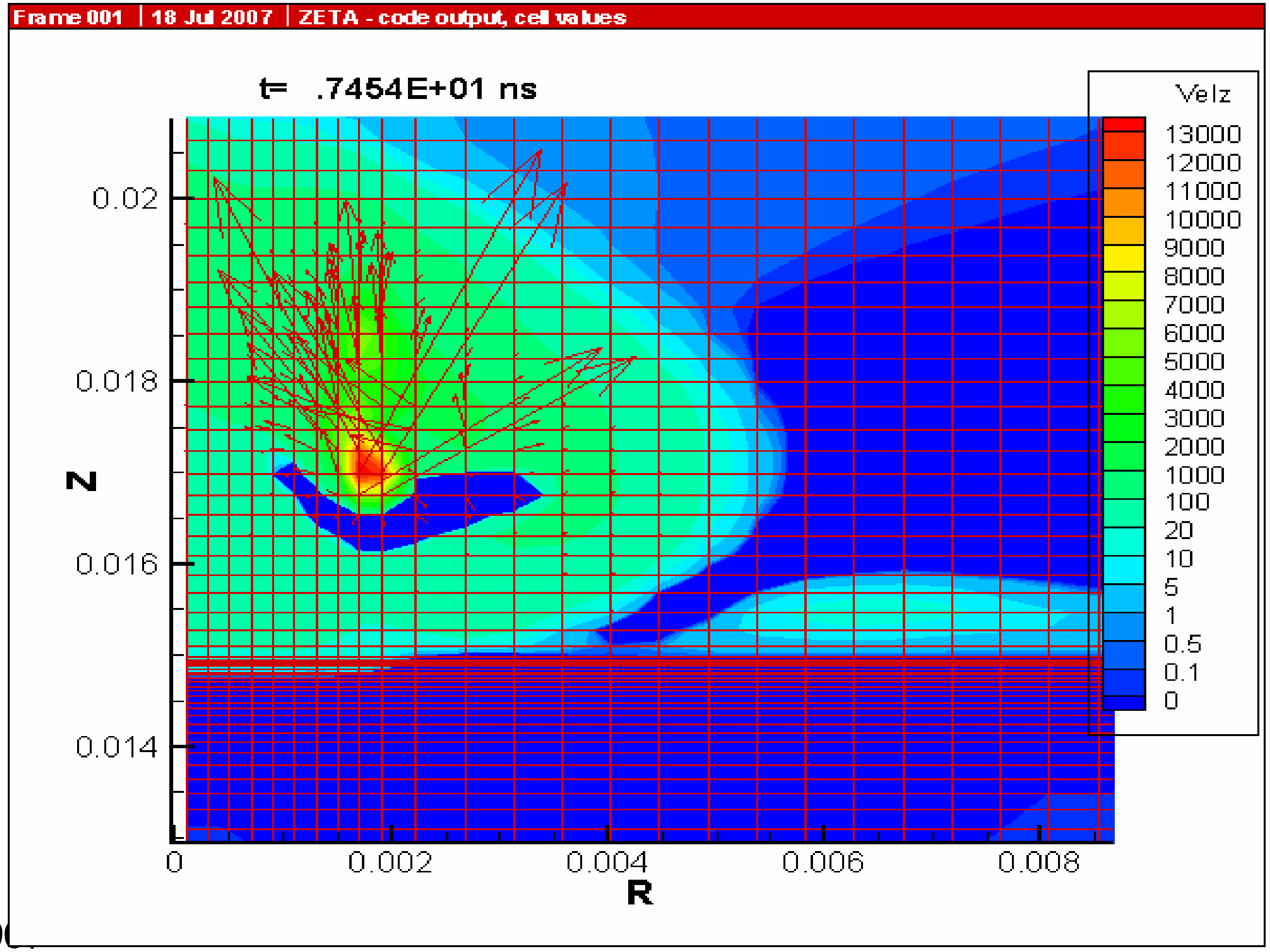
E=100-150 MeV. For Al and Ar-ions



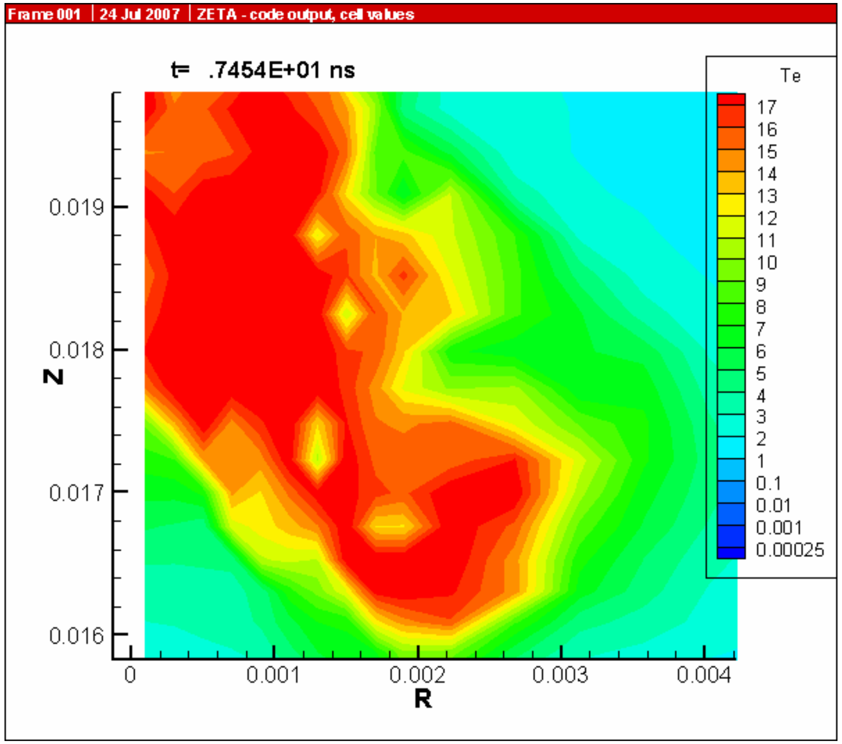
Поле скоростей для t=54.47 пс

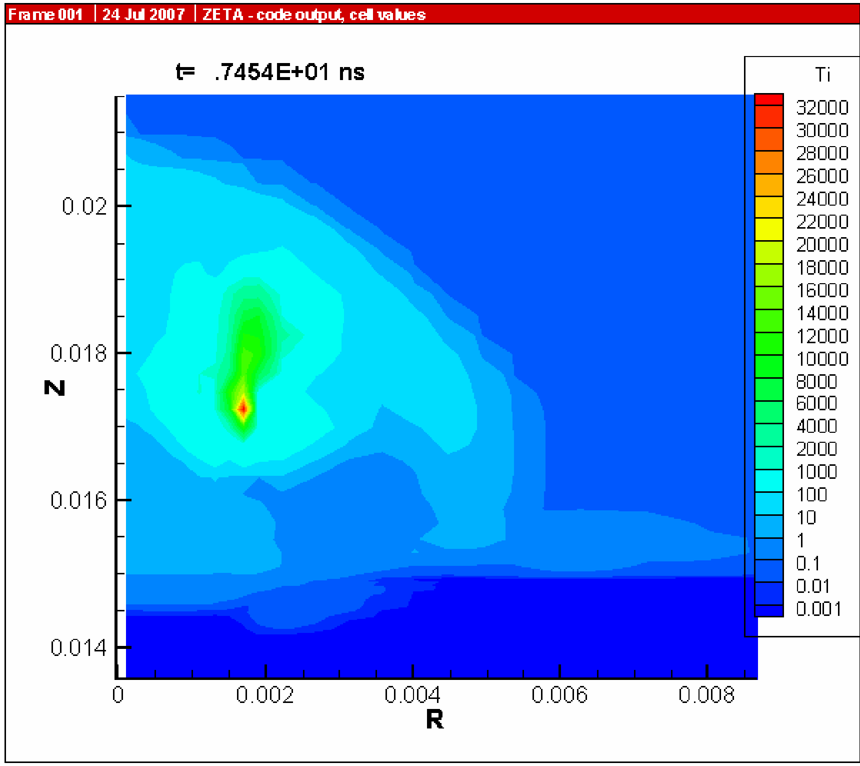
E≈2.4-3.6 ГэВ.
Для ионов
Al и Ar.

Эксперимент
дает
E≈ 2-4 ГэВ !
Для ионов Ta.

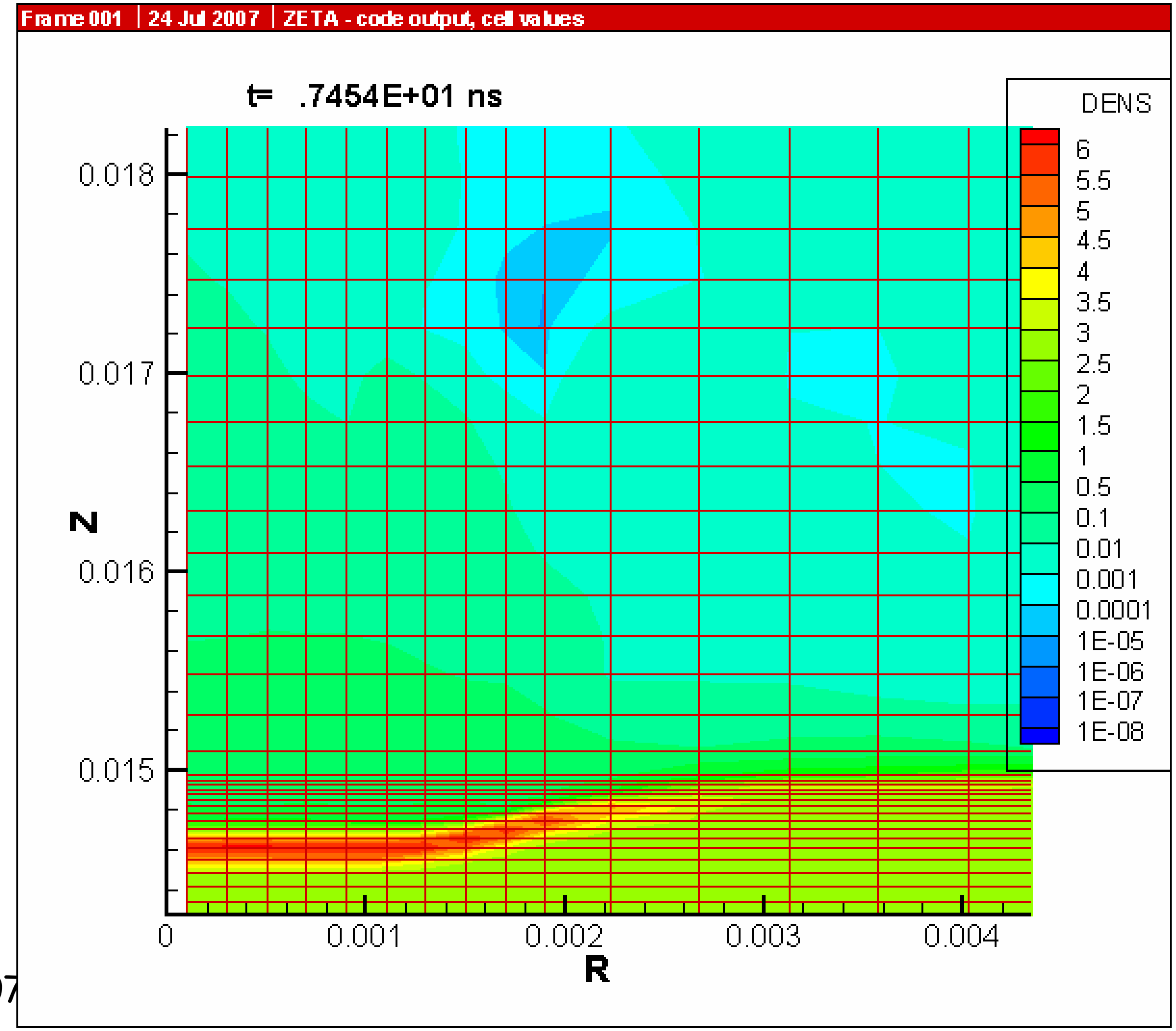


Te и Ti для t=53.77 пс

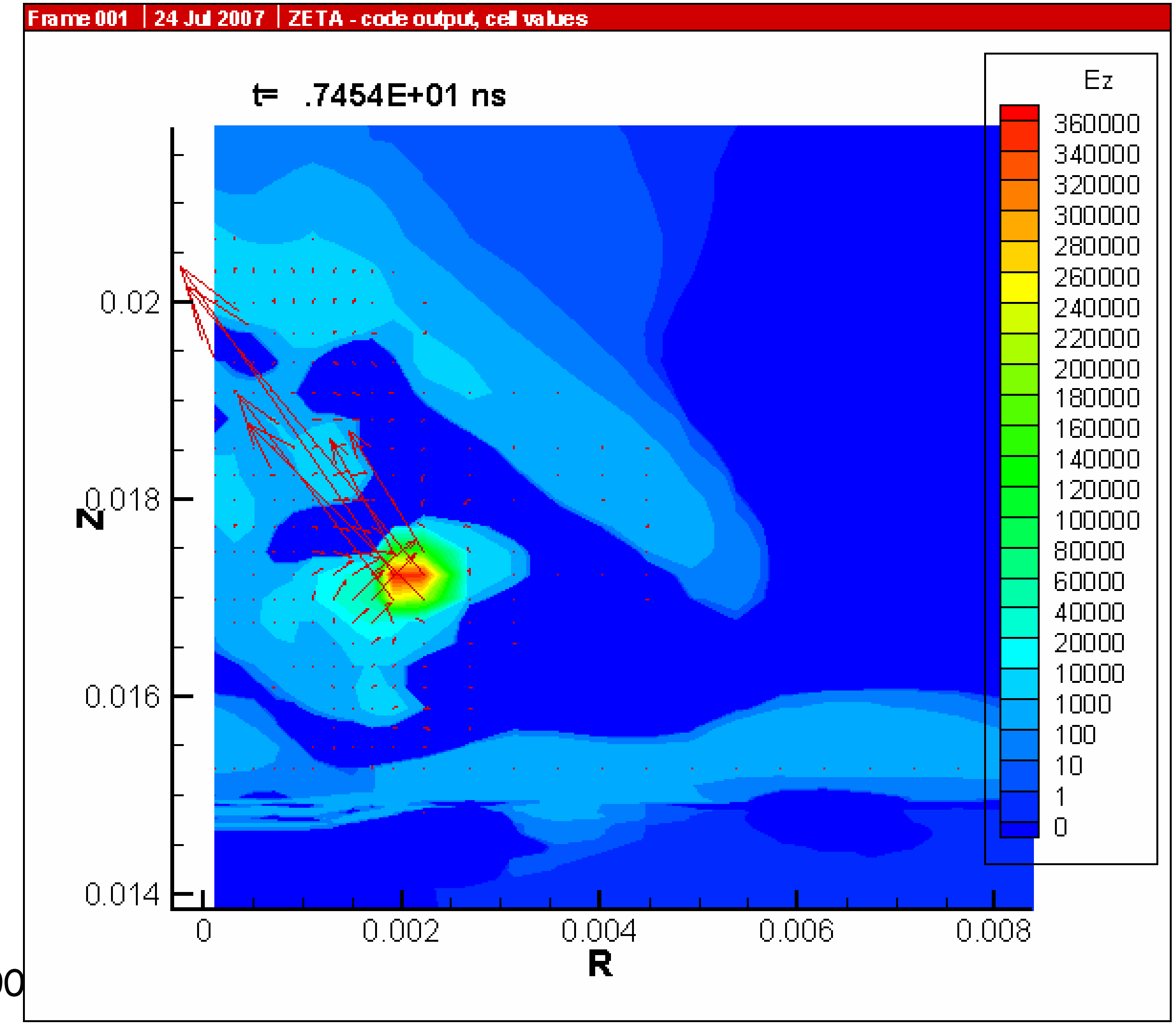




Плотность для t=53.77 пс



Напряженность электрического поля для t=53.77 пс



Summary

- The α-decay in laser-induced discharges had been observed under moderate initial intensities of picosecond laser beams I =1.E14 – 1.E15 W/cm2.

- The superstrong magnetic fields with B≈1 GG -121 TG are detected which can be in the vicinity of an exotic quasiparticles (with magnetic charge q ≈ 100 SGSE).
- Most probably that confinement reactions of nuclear decay and nuclear synthesis catalyzed by an exotic quasiparticles having mass of m ≈ 2* 1.E-35 g have been carried out.

Acknowledgements

We are very obliged to S. Gudoshnikov and O. Snigirev for a precisely measurement
of magnetic properties of investigated examples on SQUID-microscope.

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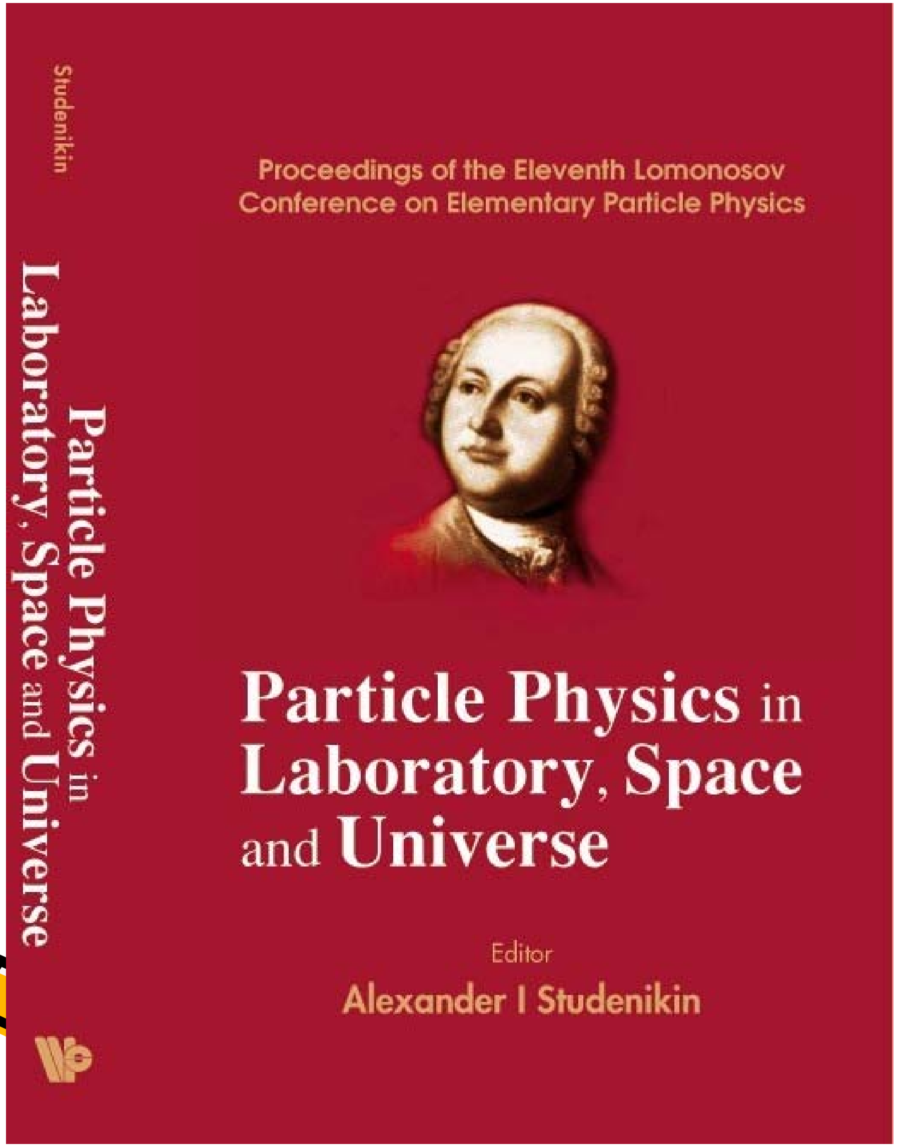
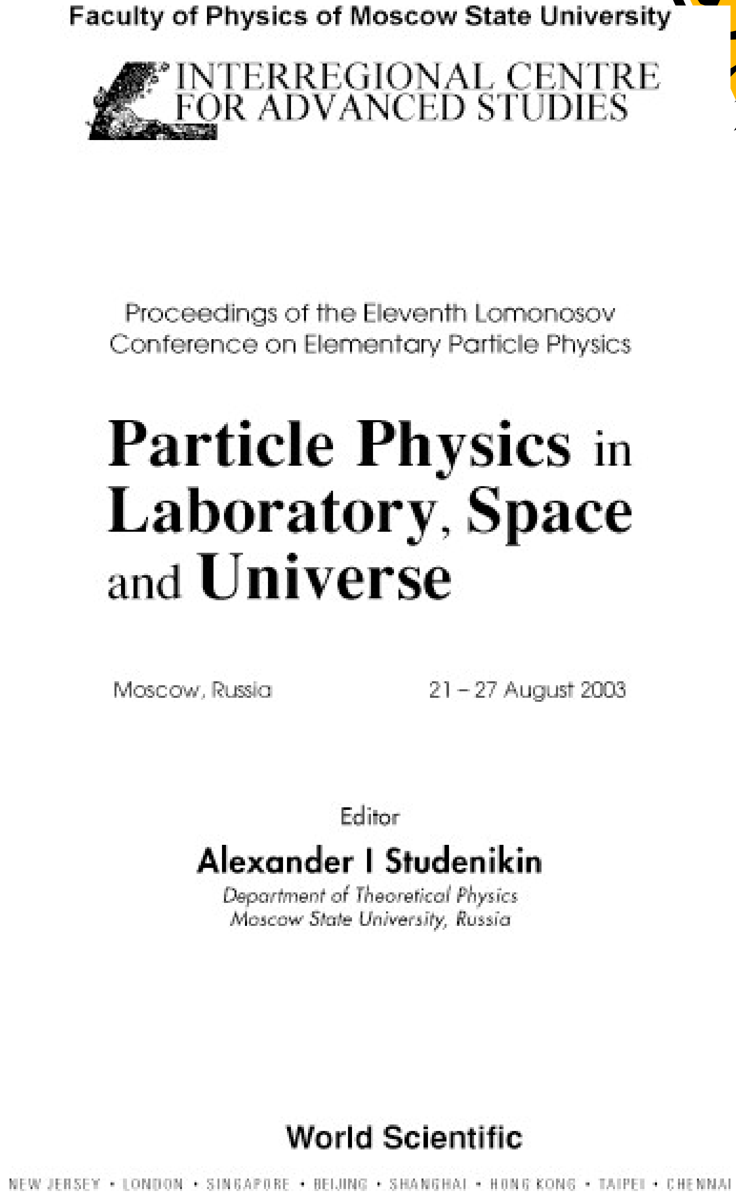
The Generation of Exotic Quasiparticles

V.Skvortsov, N.Vogel   *pp.373-382*

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