X-ray and THz generation from metal foil irradiated by laser pulses.

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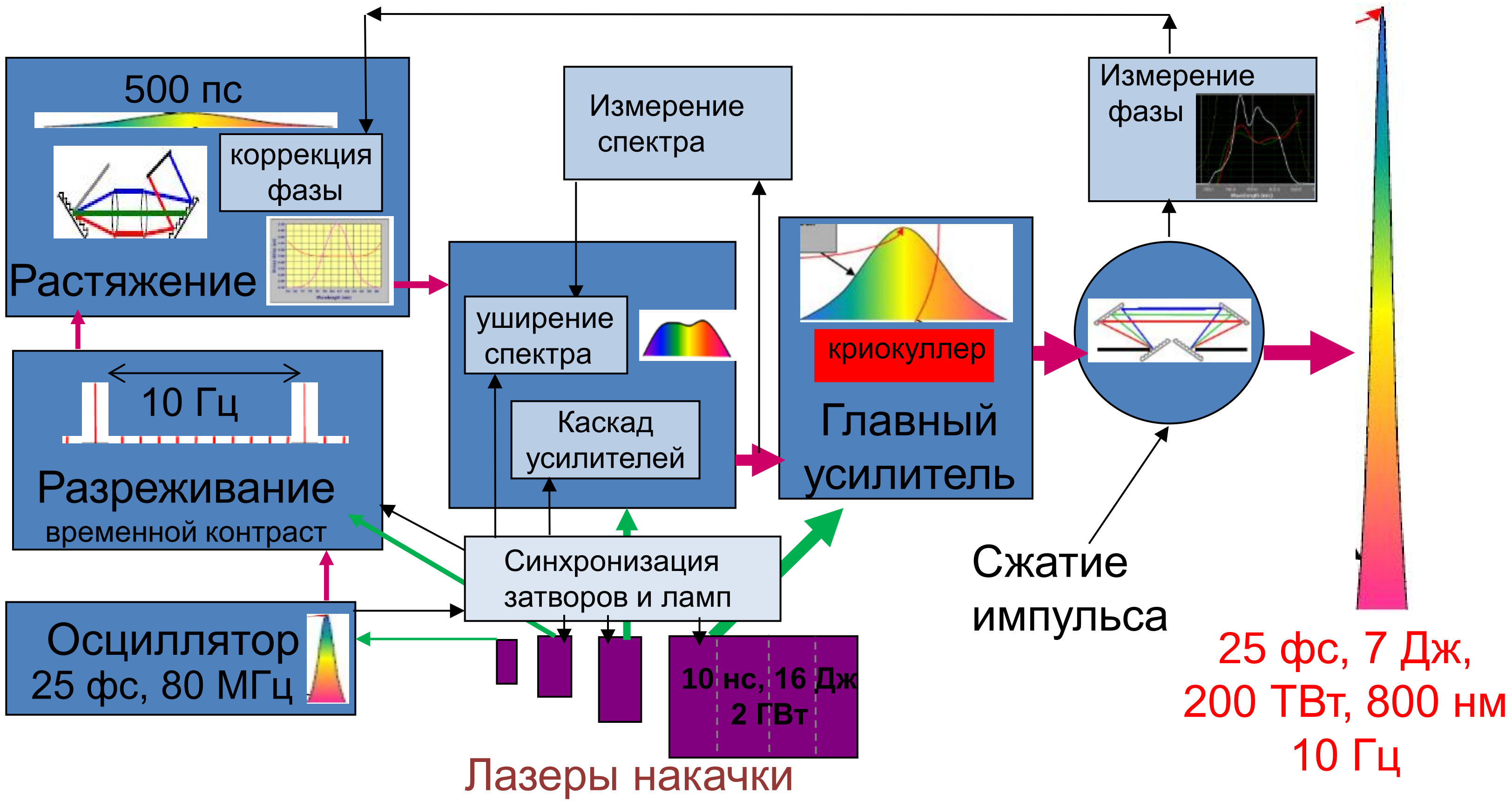
Motivation

- Strong THz fields are requested for matter manipulation. We obtain THz pulses by conversion of TW laser pulses.
- For relativistic laser intensities THz generation from thin metal foil can be more efficient than from other media..
- We observed THz generation from metal at subrelativistic intensity with efficiency higher than expected.
- Synchronized femtosecond x-ray pulses are required for lattice diagnostics, they are generated on the same matal.

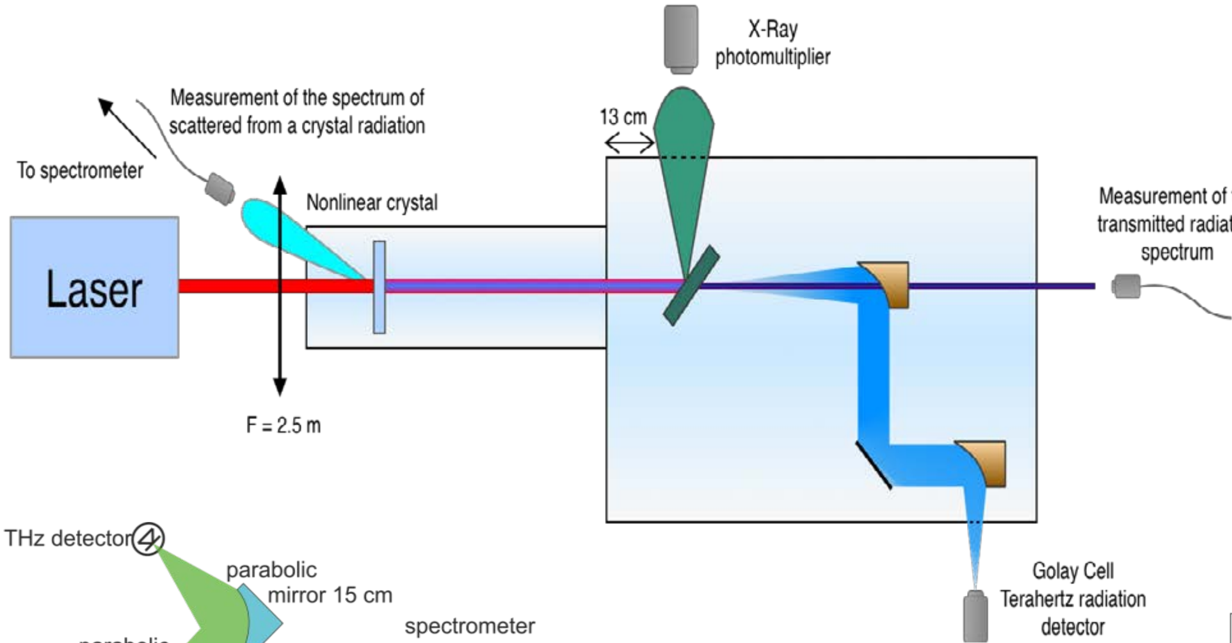
“National research center “Kurchatov Institute"

Laser Terawatt Femtosecond Complex

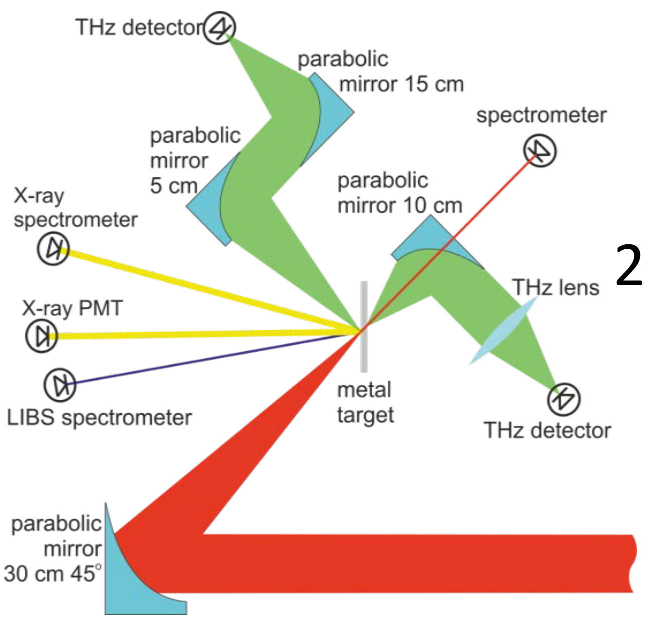


2019 г. -80 мДж
2020 г- 250 мДж
2021 г. - 600 мДж

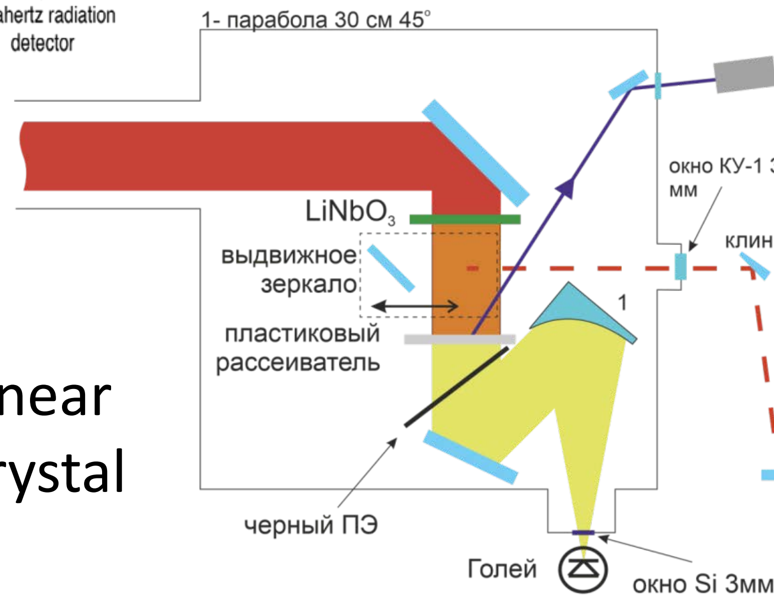
Experimental schemes



1 – filament



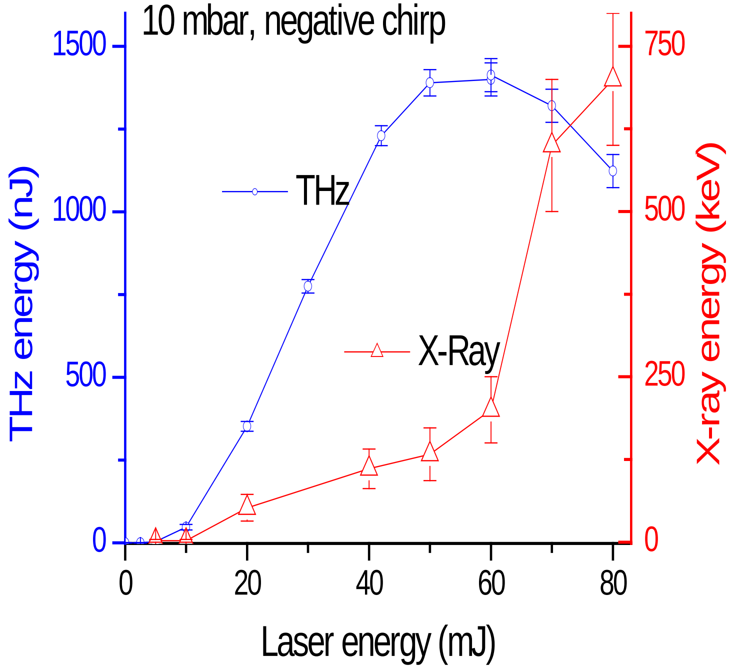
2 – short focus



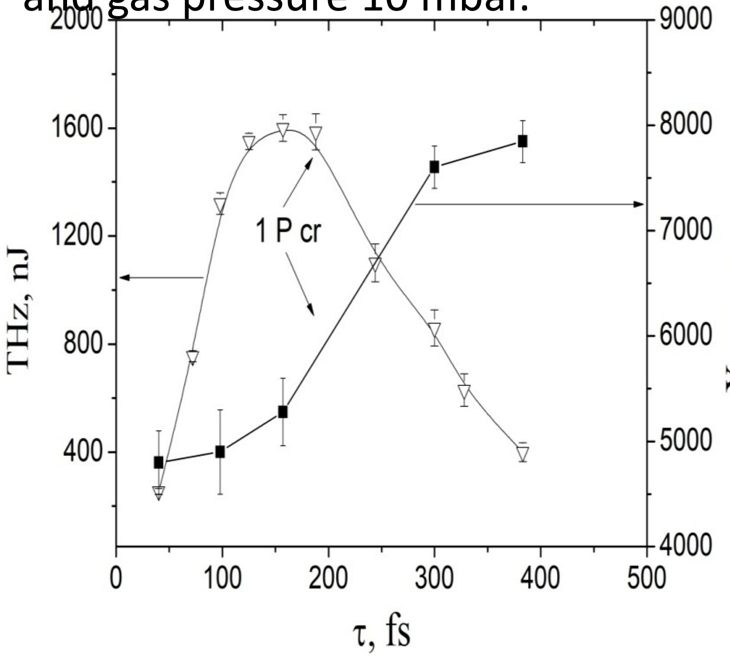
3 – nonlinear
crystal

Experimet-1. THz and x-ray optimization in filament

THz energy (open circles) and X-ray yield (triangle) versus laser energy at nitrogen pressure P=10 mbar



THz energy (open triangles) and X-ray energy (square) versus chirped pulse duration induced at laser energy 60 mJ and gas pressure 10 mbar.

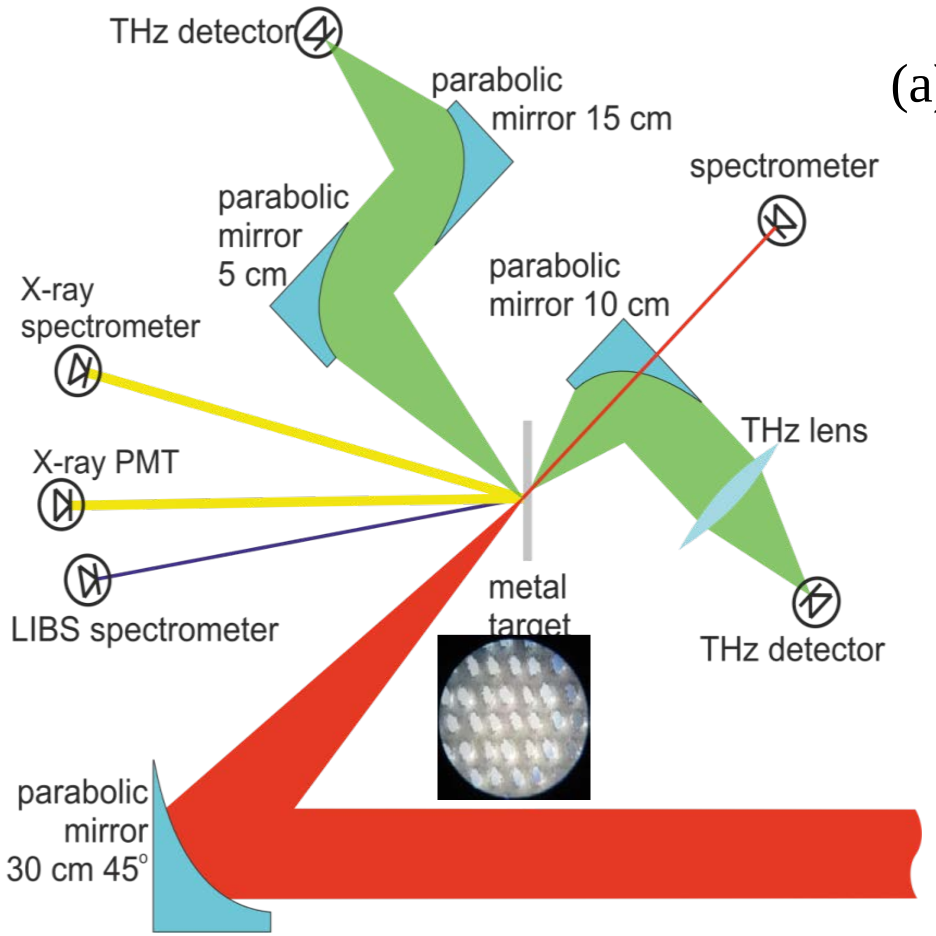


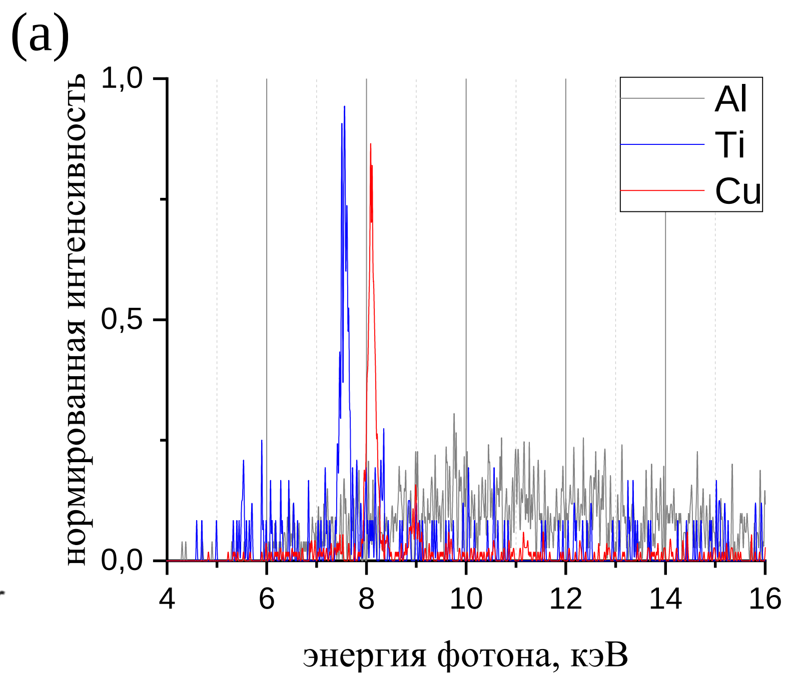
Maximal THz energy in gas - 2 μJ - is obtained at:
Intensity is $2.5*10^{14} W/cm^2$, Pressure 20 mbar, P=1 TW, Efficiency $<10^{-4}$

Let us go to vacuum

Experiment-2

We decrease focal length from 250 to 30 cm, decrease pressure below 0.2 mbar, increased X-ray yield two orders



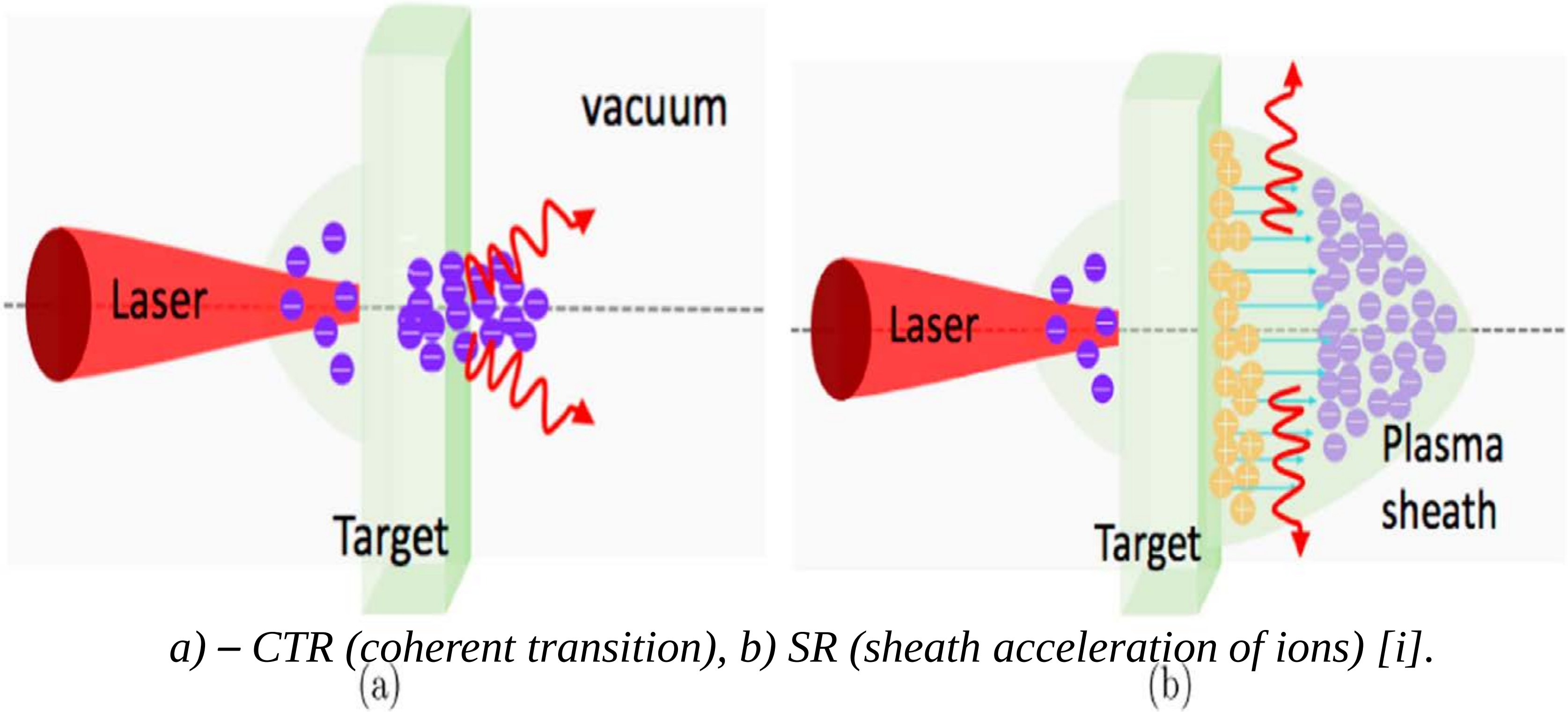


I=0.5*10^17 Вт/см^2

Поток к_альфа фотонов

10^8 фот/(2*Пи*стерадиан*сек)

For relativistic intensities there are two known mechanisms of THz emission

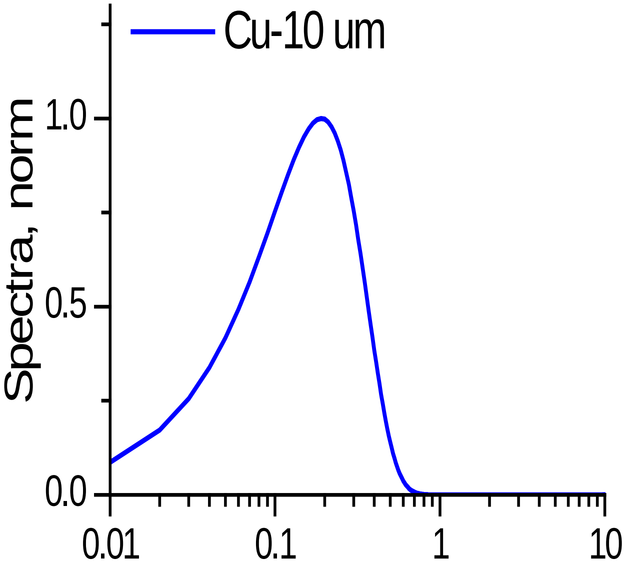


a) – CTR (coherent transition), b) SR (sheath acceleration of ions) [i].

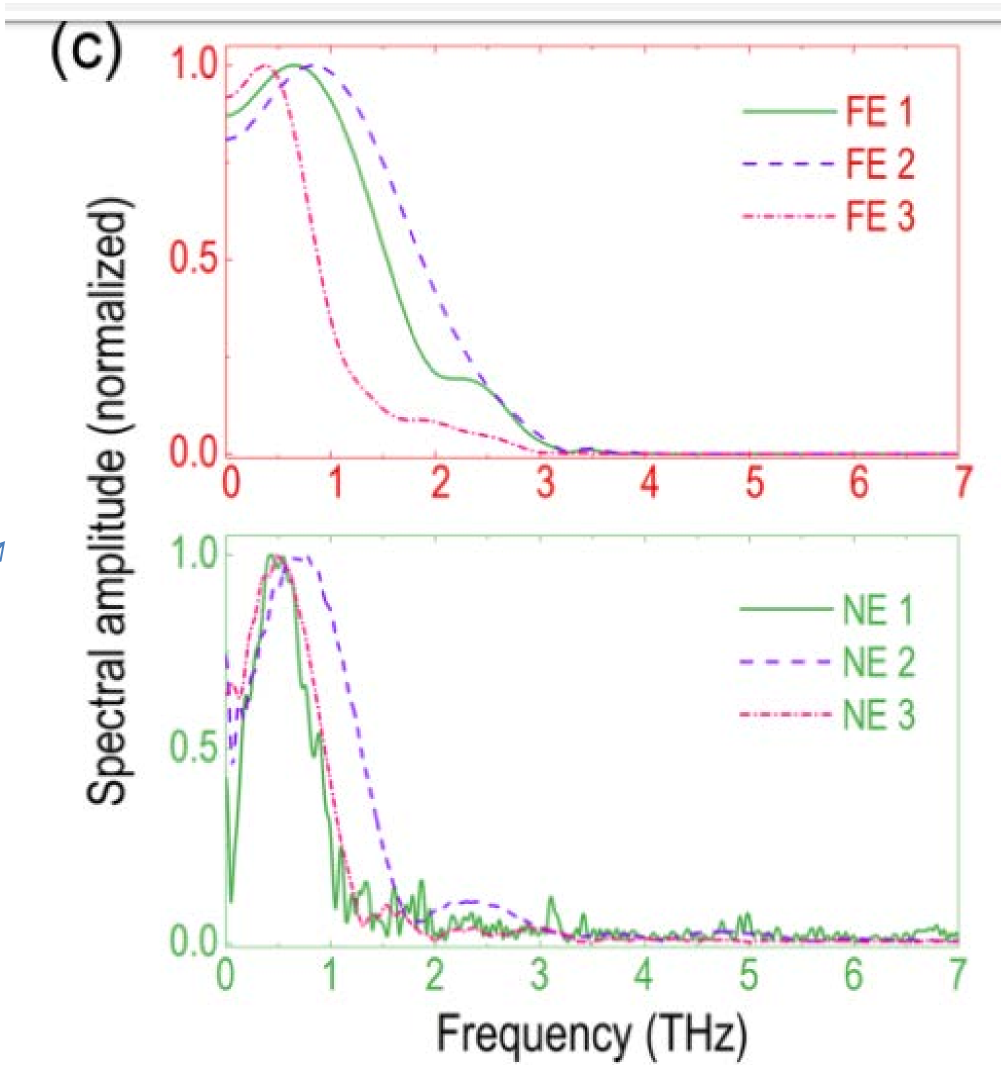
Для дорелятивистких интенсивностей эффективность преобразования в ТГц на несколько порядков ниже. В работе [2] получили 0.2 нДж в ТГц от 2.5 мДж *Ti:Sapphire* (эффективность 10^{-7}),

[i] Herzer S, Woldegeorgis A, Polz J, Reinhard A, Almassarani M, Beleites B, Ronneberger F, Grosse R, Paulus GG, Hübner U, May T. An investigation on THz yield from laser-produced solid density plasmas at relativistic laser intensities. New Journal of Physics. (2018);20(6) p.063019.
[2] Akhmedzhanov, R. A., et. al. “Generation of Terahertz Radiation by Interaction of Intense Femtosecond Laser Pulses with a Metal Surface” *Radiophysics and Quantum Electronics*, *57*(11), 807-820. (2015)

Spectra of THz radiation from metal

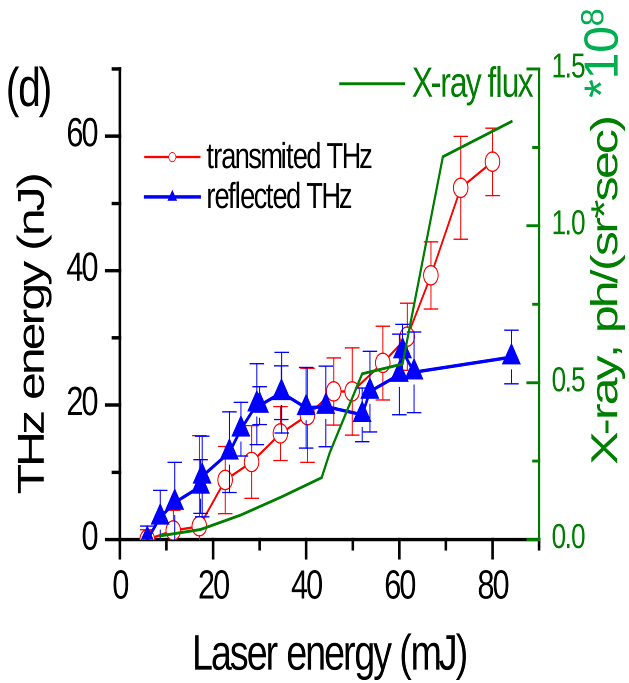


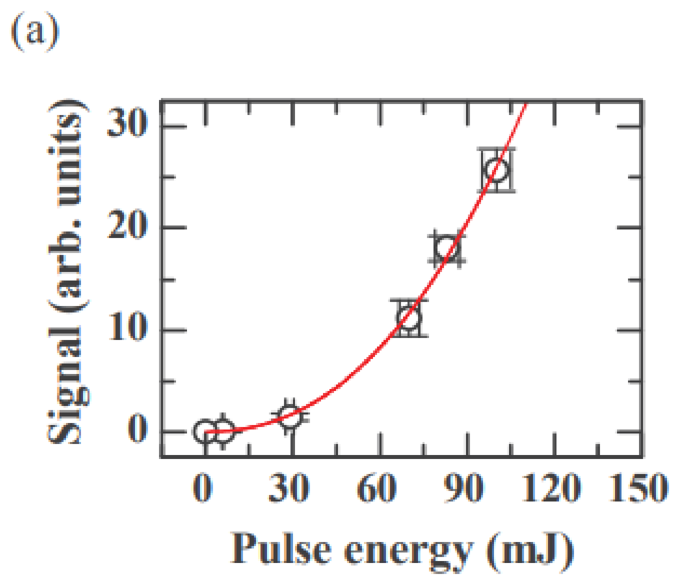
(b)



THz spectra for CTR mechanism (upper plot), and for SH mechanism (lower plot) [Gopal, A., et al. Spatiotemporal visualization of the terahertz emission during high-power laser-matter interaction. Phys. Rev. E, 100(5), 053203. (2019)]

Power dependence



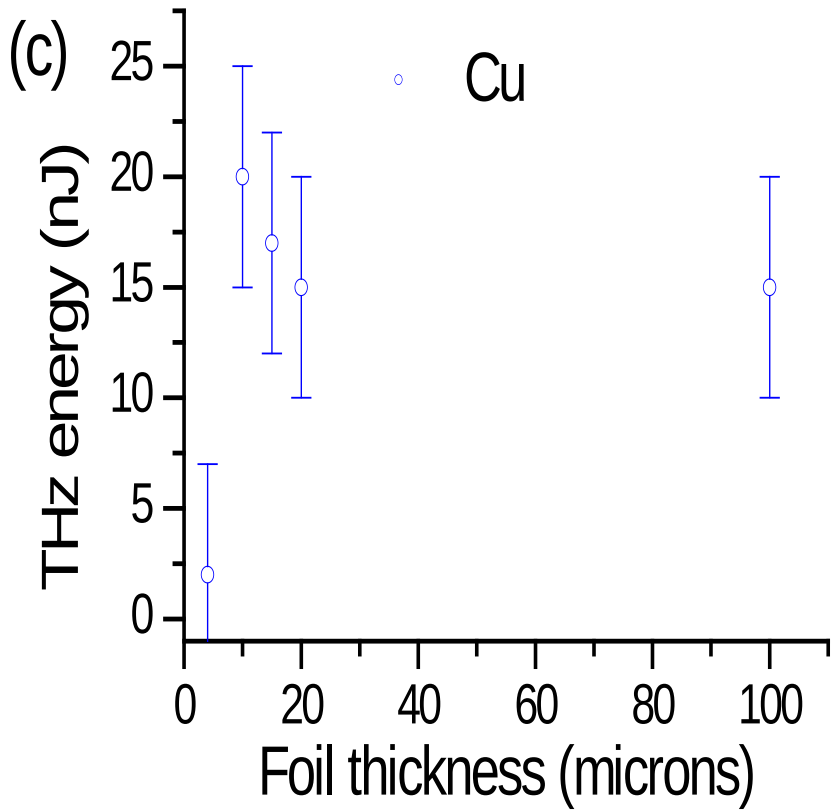


Похожие на наши параметры использовали в работе [1], интенсивность >10^{17} Вт/см^2, *Ti:Sa* система, 3 ТВ, 35 фс, 5 мкм титановая фольга, отражение, 45 град. падения. Механизм ТГц генерации– пакет релятивистских электронов и его дипольный момент.

[1] – “Radially polarized terahertz radiation from relativistic laser plasma of metal foil target” (2010)

No saturation!
Perspective for 10^18 W/cm^2 –relativistic intensities. Efficiency is expected two orders higher and we can get 100 mkJ in THz range

Foil thickness influence



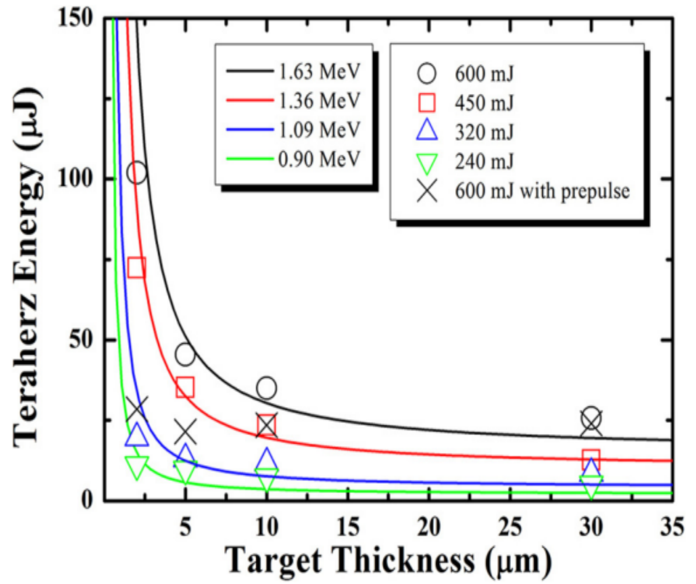
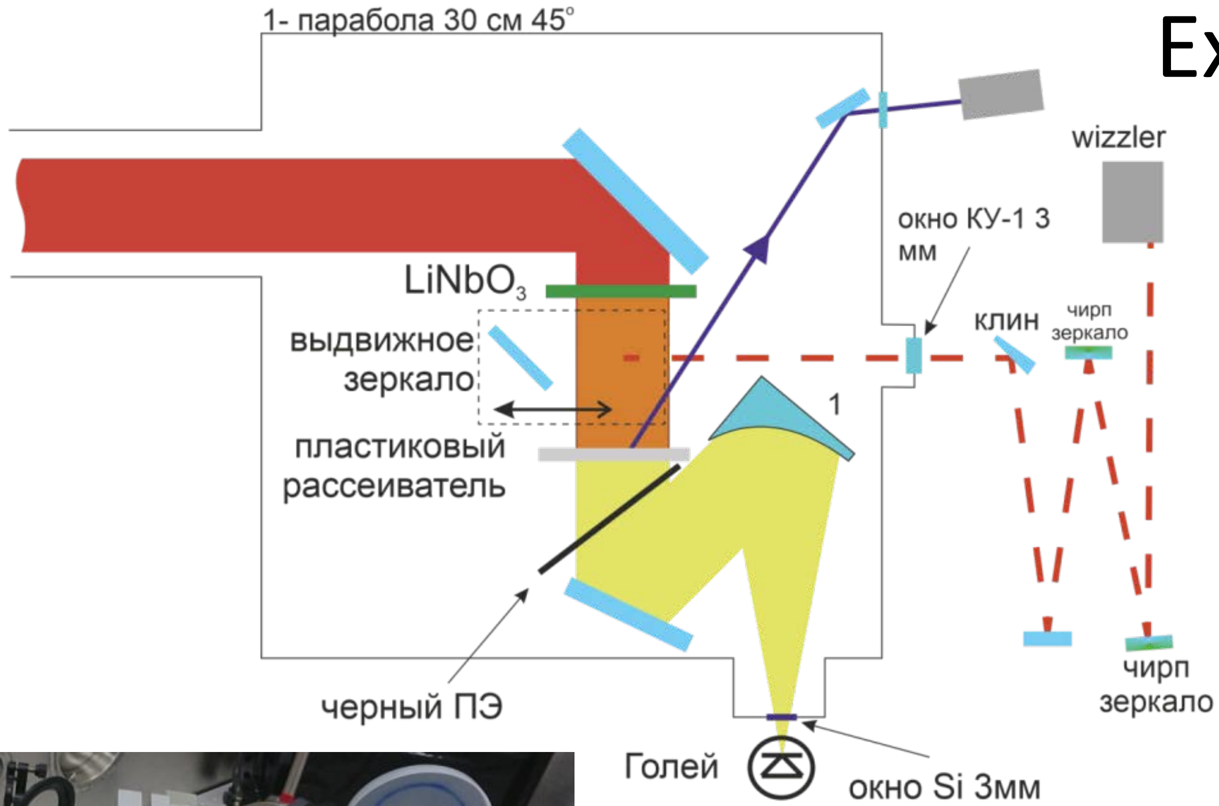


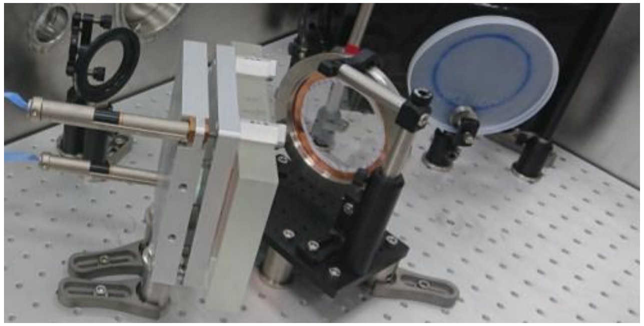
FIG. 2. Terahertz radiated energy versus target thickness for different electron temperatures. The solid curves are from the theoretical model.

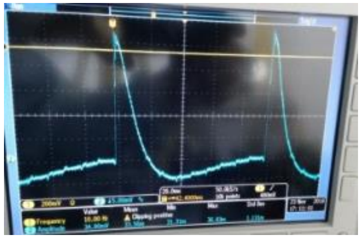
Jin Z, Zhuo HB, Nakazawa T, Shin JH, Wakamatsu S, Yugami N, Hosokai T, Zou DB, Yu MY, Sheng ZM, Kodama R. Highly efficient terahertz radiation from a thin foil irradiated by a high-contrast laser pulse. Physical Review E. 2016 Sep 21;94(3):033206.

Experiment-3

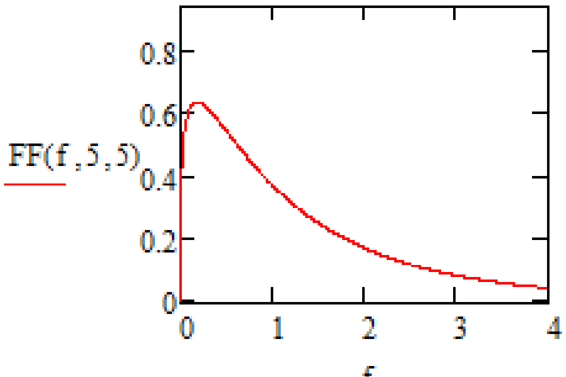


Кристалл LiNbO3
Нет синхронизма,
Lc=50 um,la=100 um
Но,
 высокая прочность,
Доступны большие
размер





7 В=4 мкДж
Эф=2*10^-5

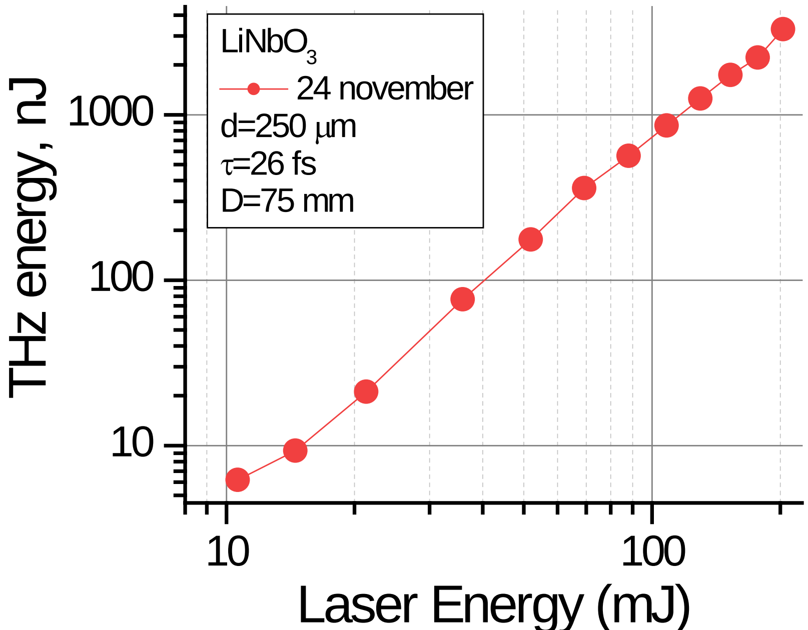


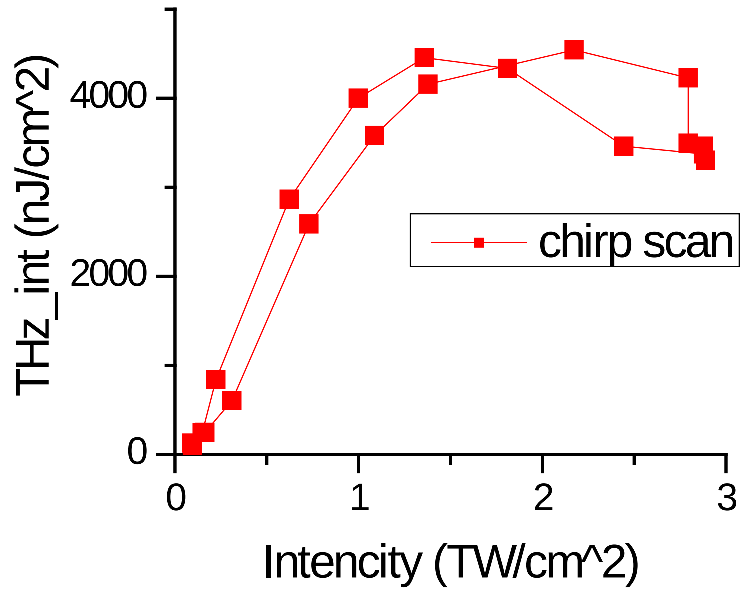
Jang D, Kang C, Lee SK, Sung JH, Kee CS, Kang SW, Kim KY. Scalable terahertz generation by large-area optical rectification at 80 TW laser power. Optics letters. 2019 Nov 15;44(22):5634-7.

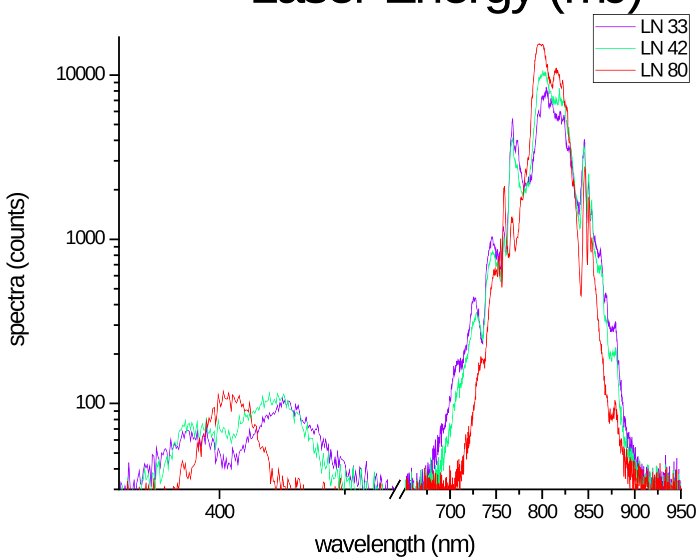
arXiv:2003.11715v1 [physics.optics] 26 Mar 2020

ТГц Энергия - 4 мкДж при широком пучке

Интенсивность накачки: 0.2 ГВт/см^2, мощность 9 ТВт, пл.эн.=5.6 мДж/см^2





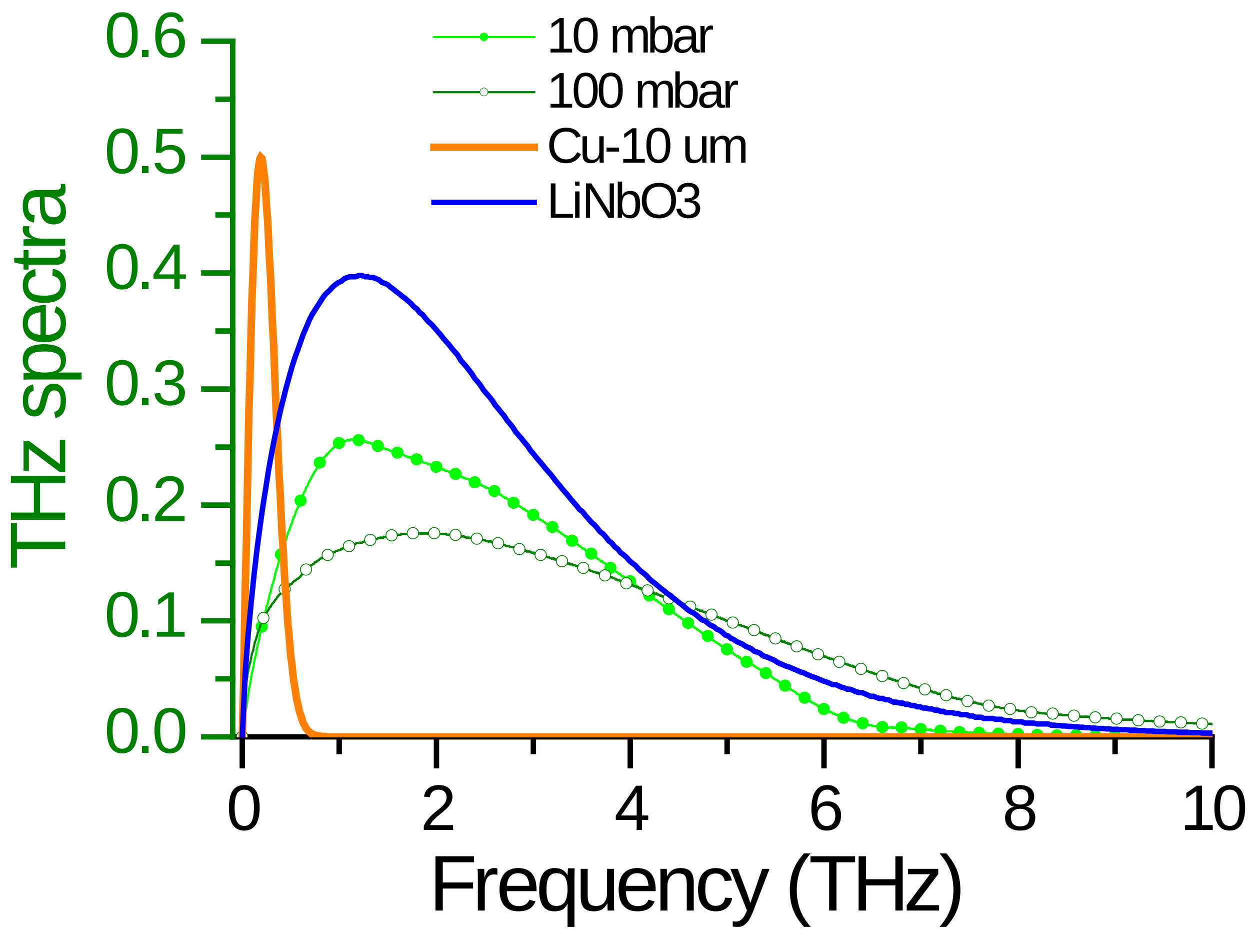


Если сжать пучёк, эффективность возрастает до 10^-4,

От 100 см^2 LN можно получить

Сотни мкДж в ТГц при 100 ТВт

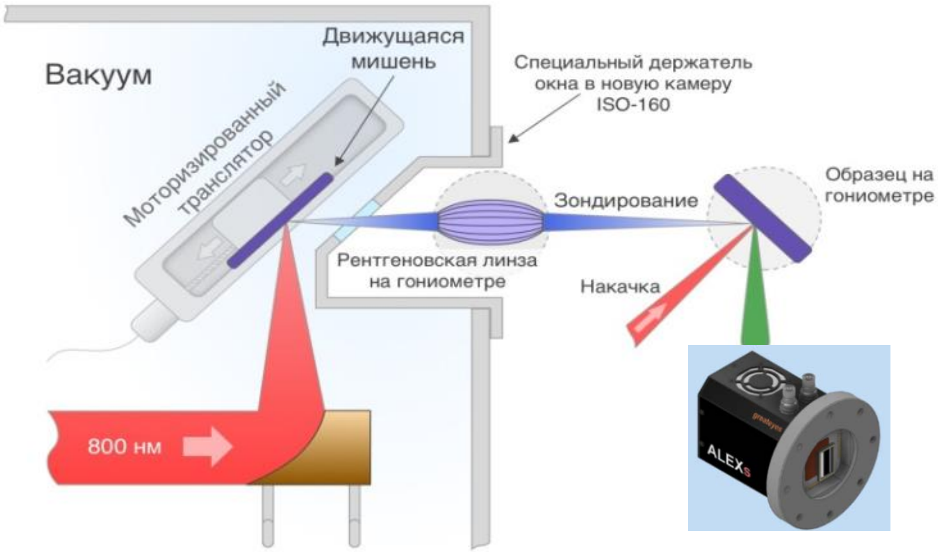
THz spectra from three methods



By pressure or energy spectra bandwidth can be tuned in gas

By pulse duration – in LN

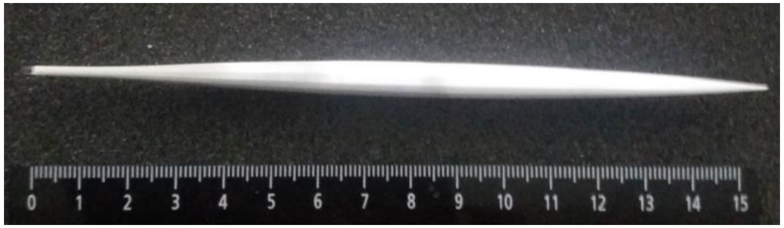
изменение решетки Δd/d на 0.1% приведет к сдвигу Kα – линий на 2’

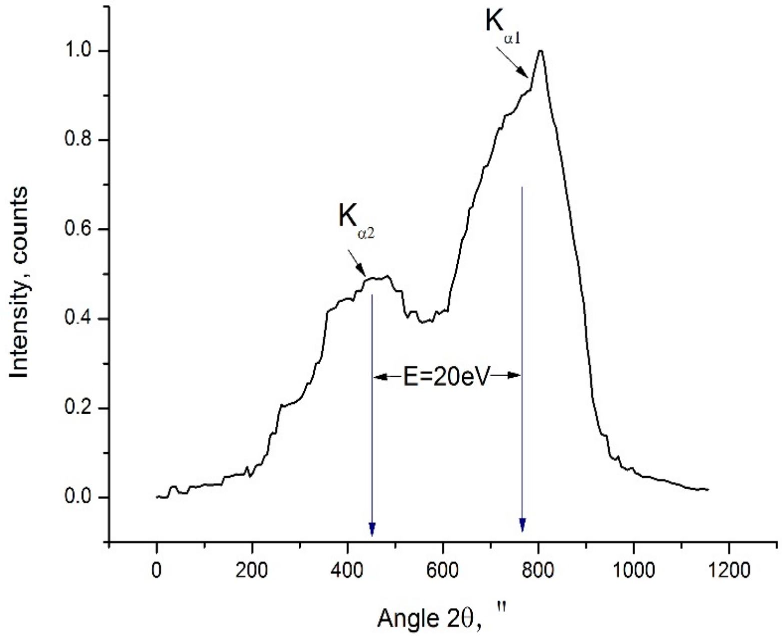


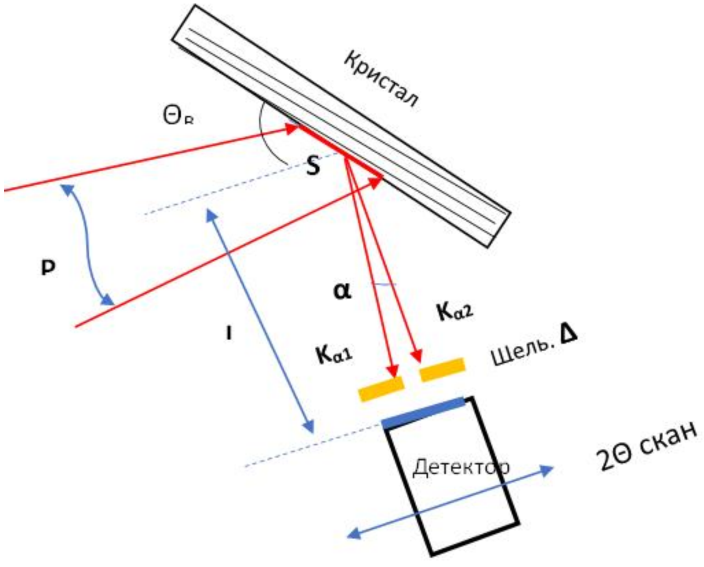
Параметры рентгеновского излучения на мишени **– 10^9 k_alfa фот/(импульс*2*Пи*стер.)**

параметры на образце
10^5 k_alfa фот./имп (в угол 2 град), диаметр 100 мкм.

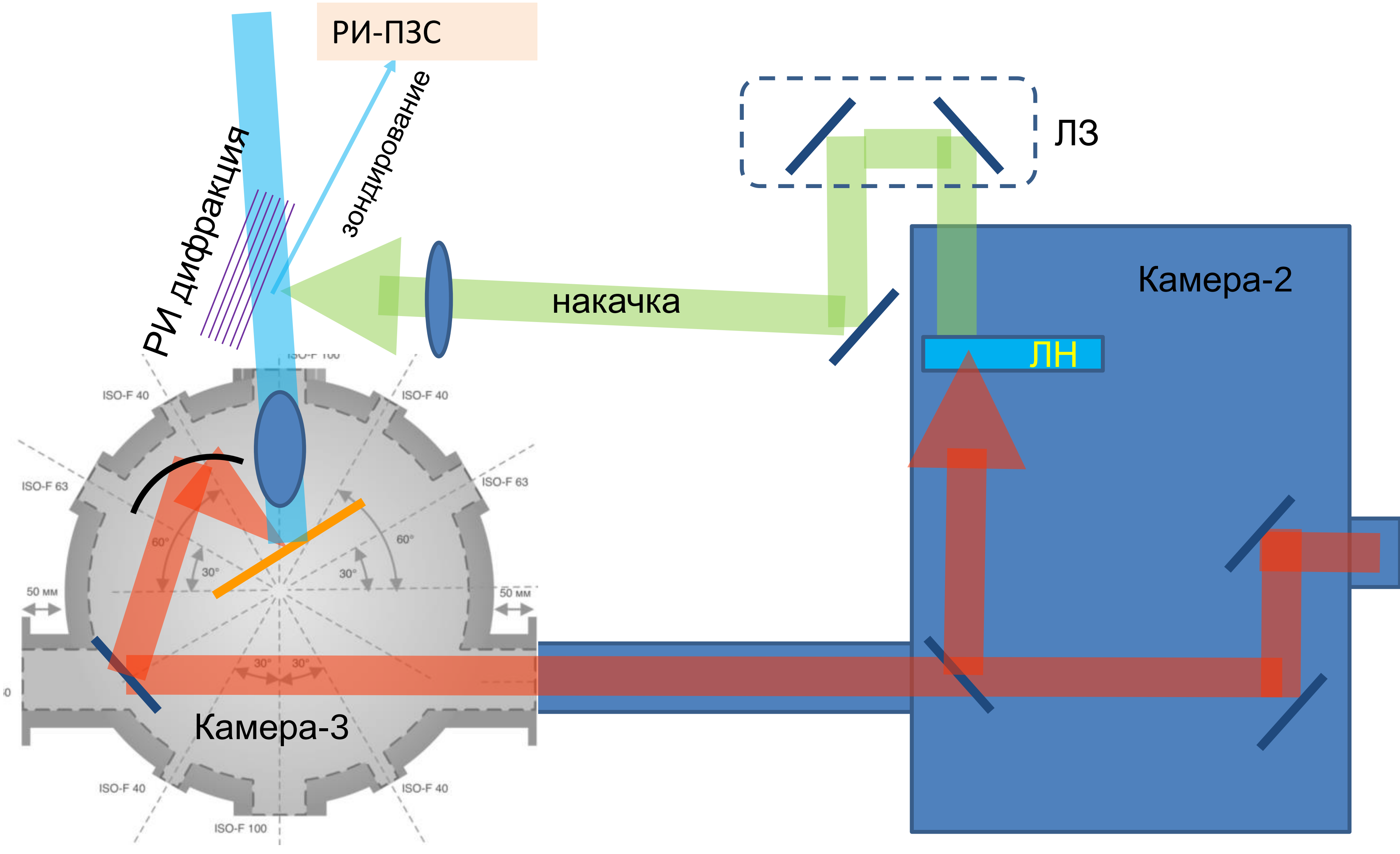
Расстояние до детектора – **1 м**







A scheme for THz pump - x-ray probe



Conclusions:

- Intensity of 10^{16} W/cm^2 and 20 mJ energy is enough to observe THz emission from rear side of metal foil.
- Observed efficiency of THz generation from metal is higher than predicted by known theories for sub-relativistic intensities.
- Dependence of film thickness and on pulse energy do not confirm relativistic processes of CTR or SR. The main mechanism of THz generation should still be discovered for this energy range
- The advantage THz generation in metal – is the absence of saturation at energy increase above TW level. We expect 10^{-3} THz efficiency at 10 TW in this scheme
- Simultaneously fs x-ray pulses are generated for diagnostics.
- Each of three methods of THz generation provides its own spectra. Saturation threshold is different.

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