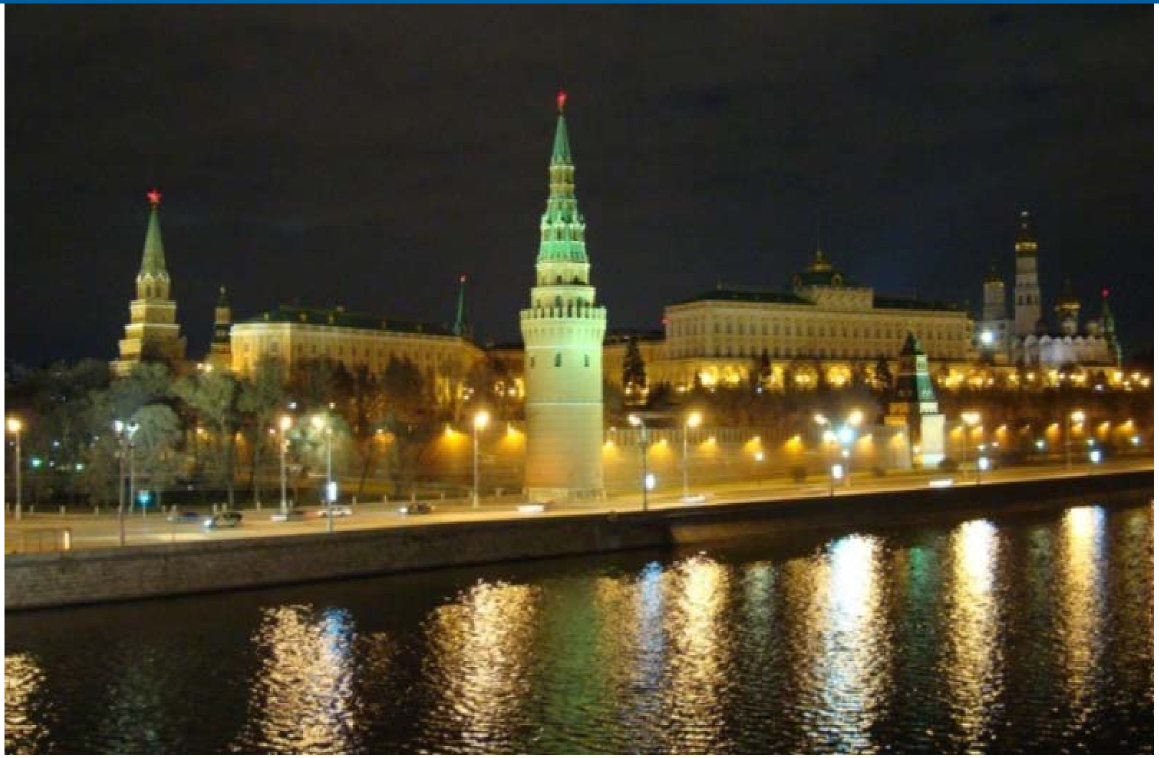
Workshop on Plasma Physics with Intense Laser and Heavy Ion Beams

May 20 - 21, 2010 - Moscow, Russia

GSI

VNIIEF, Sarov

P.N.Lebedev Physical Institute of the Russian Academy of Science



EMMI

IMP, Lanzhou

Uni-Remagen

Experiments on the indirect heating of low Z foam targets

Olga Rosmej

Gesellschaft für Schwerionenforschung, Darmstadt, Germany

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with Intense Laser and Heavy Ion Beams
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Experiments on the indirect heating of low Z foam targets

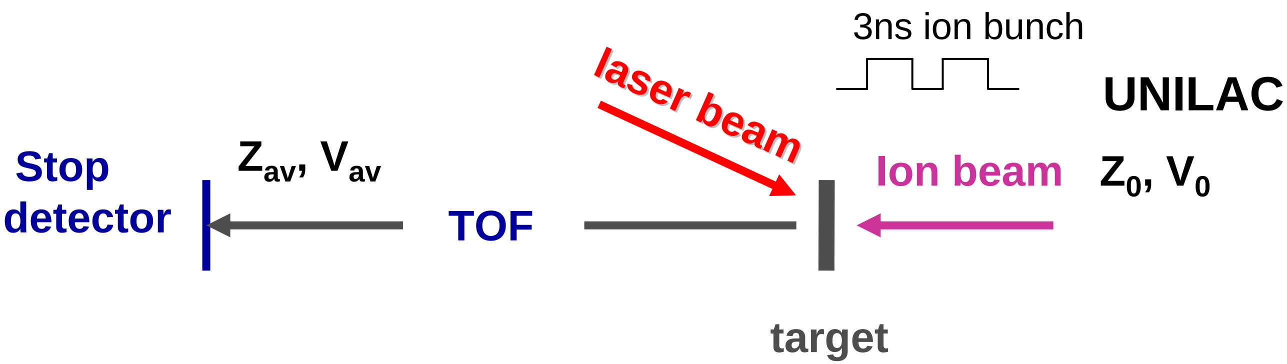
A. Blazevic, N. Zhidkov, V. Vatulin, N. Suslov, A. Kunin, A. Pinegin, D. Schäfer, Th. Nisius,

Y. Zhao, U. Eisenbarth, V. Bagnout, N. Orlov,

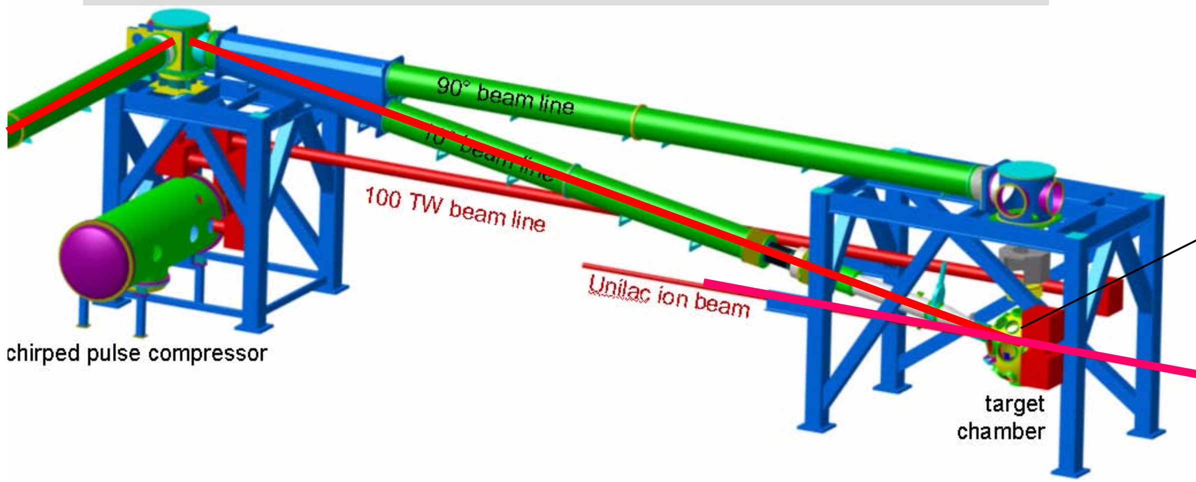
N. Borisenko, G. Vergunova, Th. Wilhein, Th. Stoehlker; V. Fortov

Laser – Heavy Ion Beam Combined Experiments

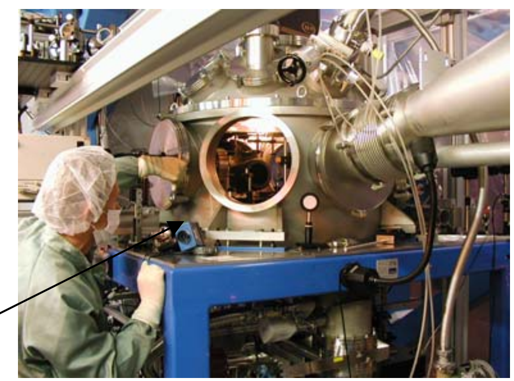
Interaction of heavy ions with ionized matter : increased plasma stopping power



PHELIX-laser : 0.3 kJ @ 1-15 ns, 1ω, 2ω (2011)



Target chamber



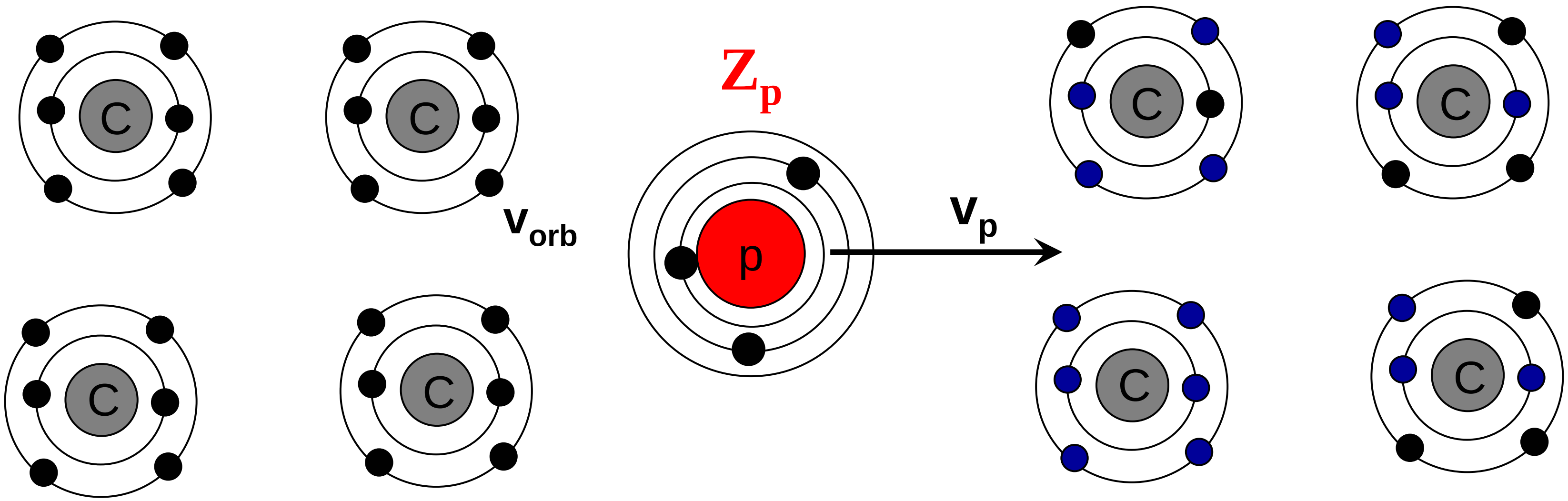
Heavy ion beam:
3<Z<92, E=3–13 MeV/u,
RF: 108/36 MHz

Projectile ion energy loss in partially ionized matter

cold matter

$dE/dx \sim Z_p^2/V_p^2$

plasma



$Z_{solid} < Z_{plasma}$

since $\sigma_{RR} << \sigma_{bec}$

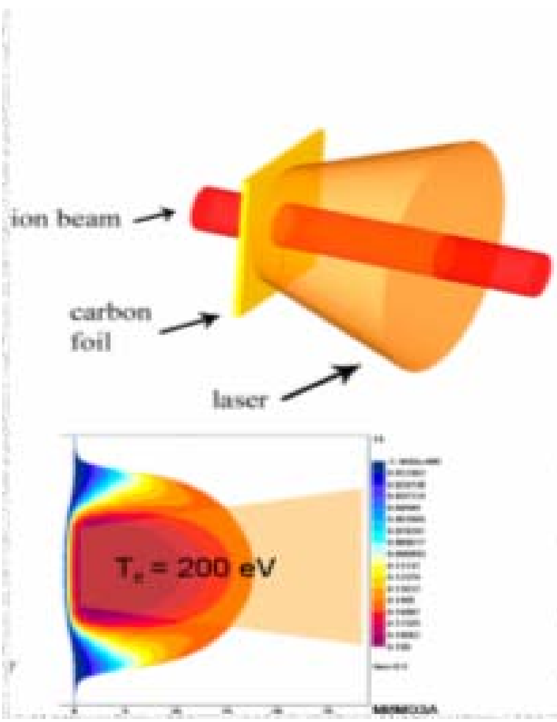
More effective energy transfer to free electrons

Increase of the ion energy loss in plasma

Schemes of the plasma target production

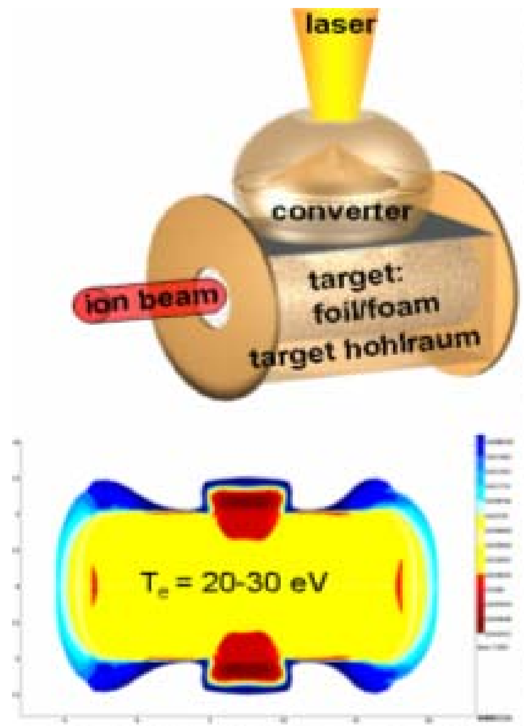
Direct laser heating

Ideal plasma:
Te~ 200 eV, fully ionized



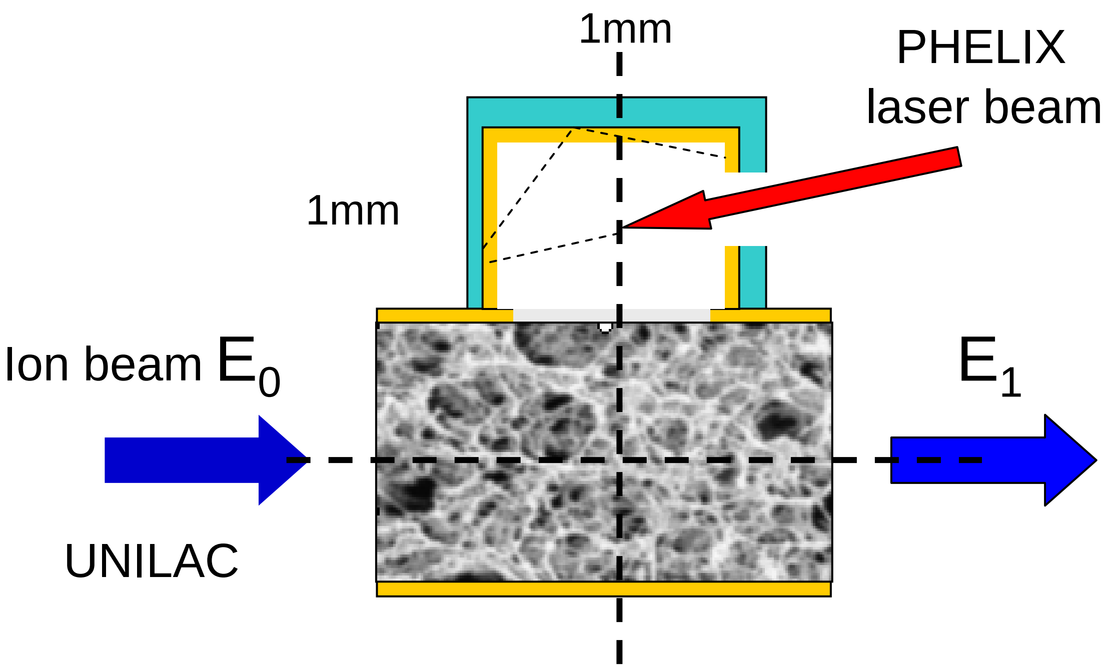
Heating with hohlraum radiation

homogeneous plasma:
Te~ 30 eV, partially ionized

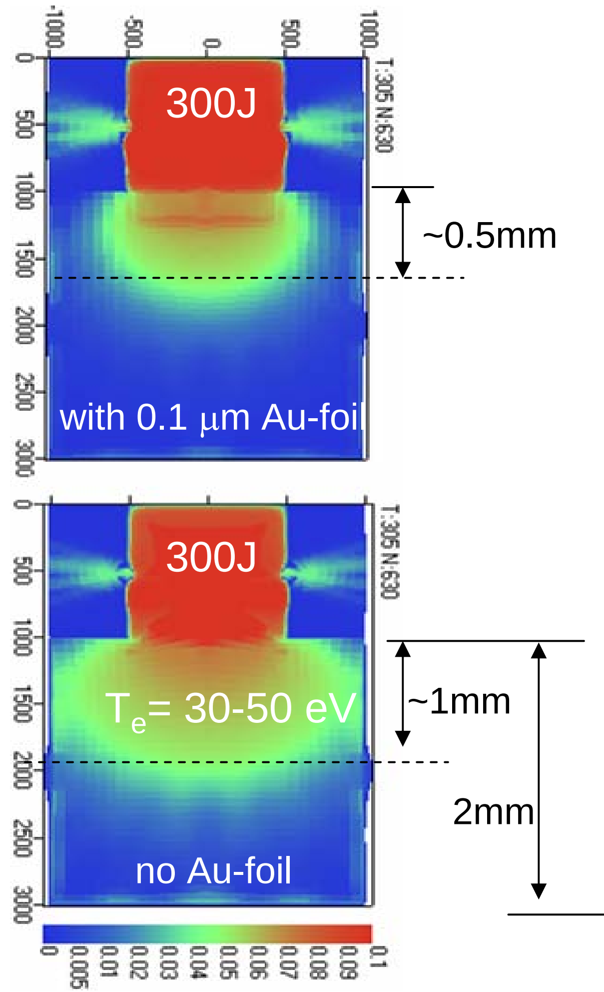


Numerical optimization of the hohlraum target geometry

Calculations for the current PHELIX parameters
300J, 1 ns, 250μm, 1ω, 10 degree beam-line



2-D hydrodynamics combined with
2-D multi group radiation transport

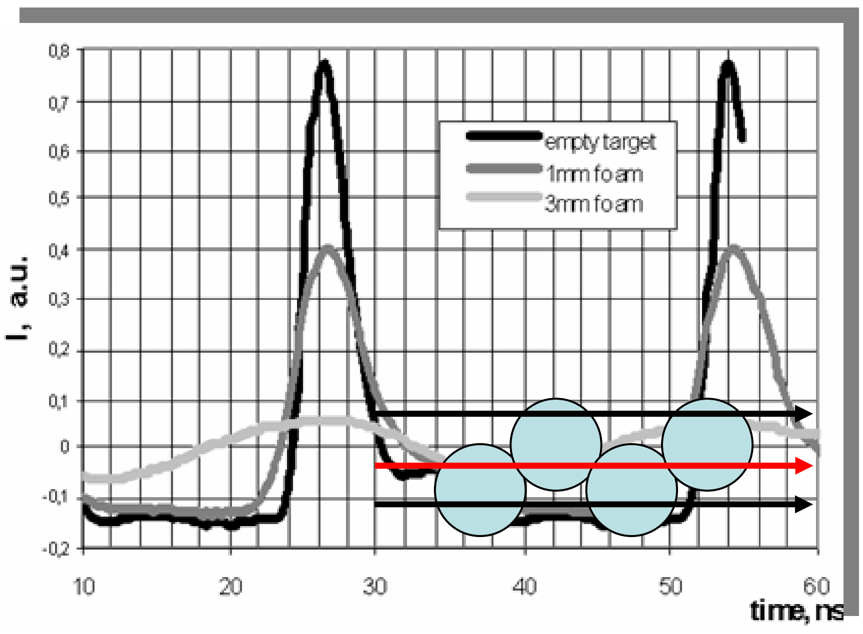


VNIIEF, Sarov, Nov. 2009

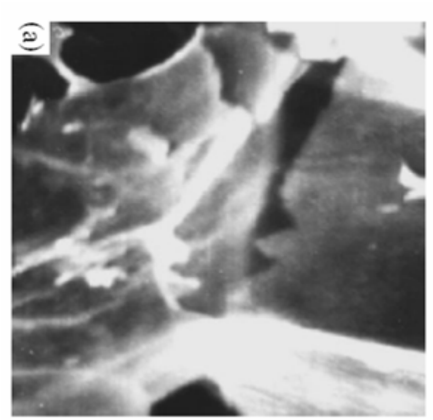
Why foams?

Properties under the ion and laser beam:

1. Effective conversion of the laser energy into Te
2. Slow dynamics of expansion (ρ, T ~ const over ns)
3. Fast (~sub ns) homogenization after the laser heating
4. Energy broadening of the ion bunch caused by the porous structure has to be acceptable (no merging of the subsequent ion bunches)



Variety of low Z foam structures

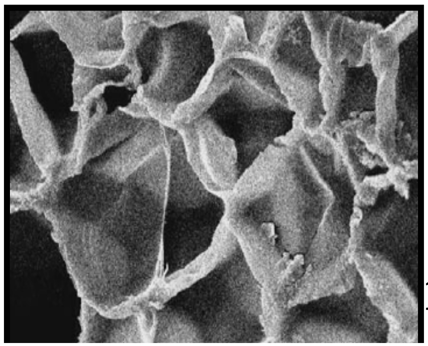


10µm

$C_8H_8O_3$ foam (agar-agar) of 1-20 mg/cm^3

Randomly distributed thin fibers

TRINITI, Mishen, VNIIEF-Sarov Iskra 5

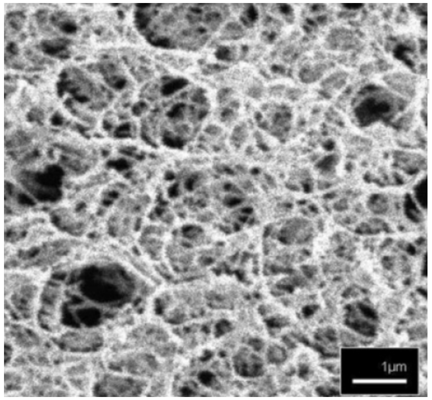


10µm

Polystyrene $(CH)_n$ 1-20 mg/cm^3

Quasi regular sponge like structure (3D network)

TRINITI, Mishen



1µm

TAC - cellulose triacetate $C_{12}H_{16}O_8$ 1-30 mg/cm^3

3-D regular network with open cell structure,
The most fine pore structure (~ 1µm)
remains stable up to 220C

PALS, LIL, GSI

Experimental Goal

Goal of the project:

creation of homogeneous long leaving (>3 ns - the length of the ion bunch) partially ionized plasma of 10^{20}-10^{21} electron density

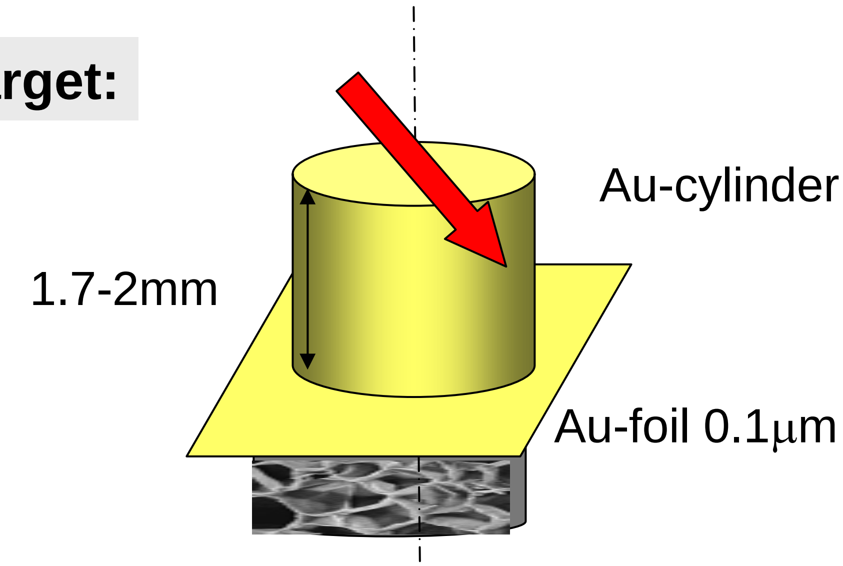
Approaches:

- Indirect heating of low Z foams by means of hohlraum radiation
- Direct heating of the low Z foams with undercritical density/supersonic ionization

Heating of low Z foams with Au-hohlraum radiation

PHELIX Laser: 1ω, 1.4 ns, 200-270 J, d~200μm, >10^{14} W/cm², contrast 10^{-6}

Target:



CHO-foam 2-20 mg/cm³

areal density ρx~ 150-500 μg/cm²

International collaboration

Participants:

•VNIIEF-Sarov, Russia;

Numerical optimization of the target design, experimental support

•Joint Institute for High Temperatures, Moscow,

carbon plasma opacities calculations

• Lebedev Physical Institute, Moscow, Russia;

foam target production, calculations of the foam hydrodynamics

• Institute of Modern Physics, Lanzhou, China

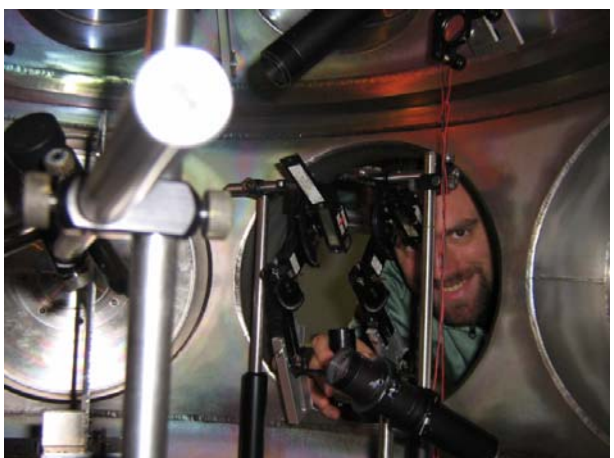
experimental support (x-ray diagnostics)

• Rhein-Ahr-Campus Remagen, University of Applied Sciences, Germany;

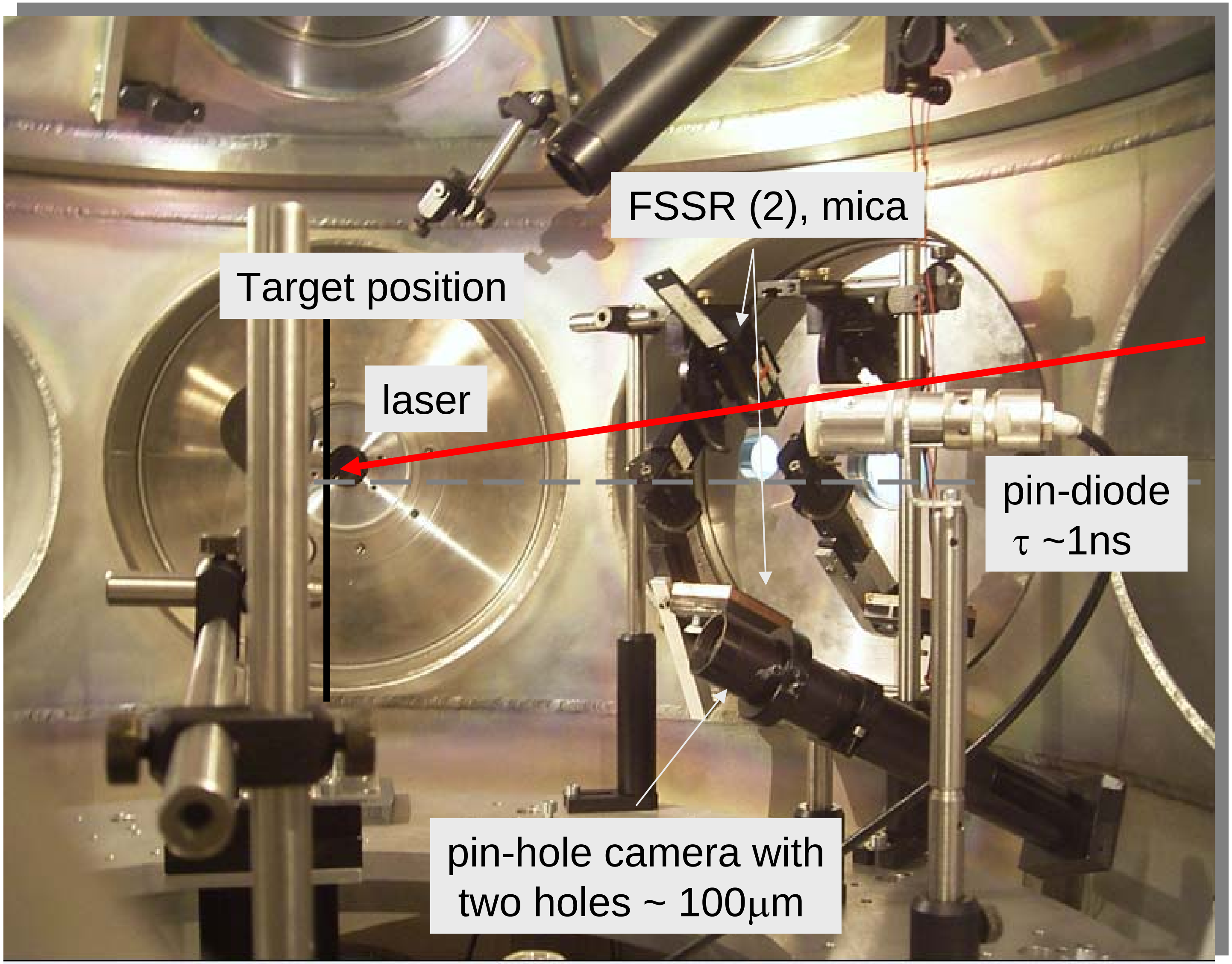
•*experimental support (absolute calibrated transmission grating)*

Plasma Physics Division GSI

Last experimental campaign on February 2010

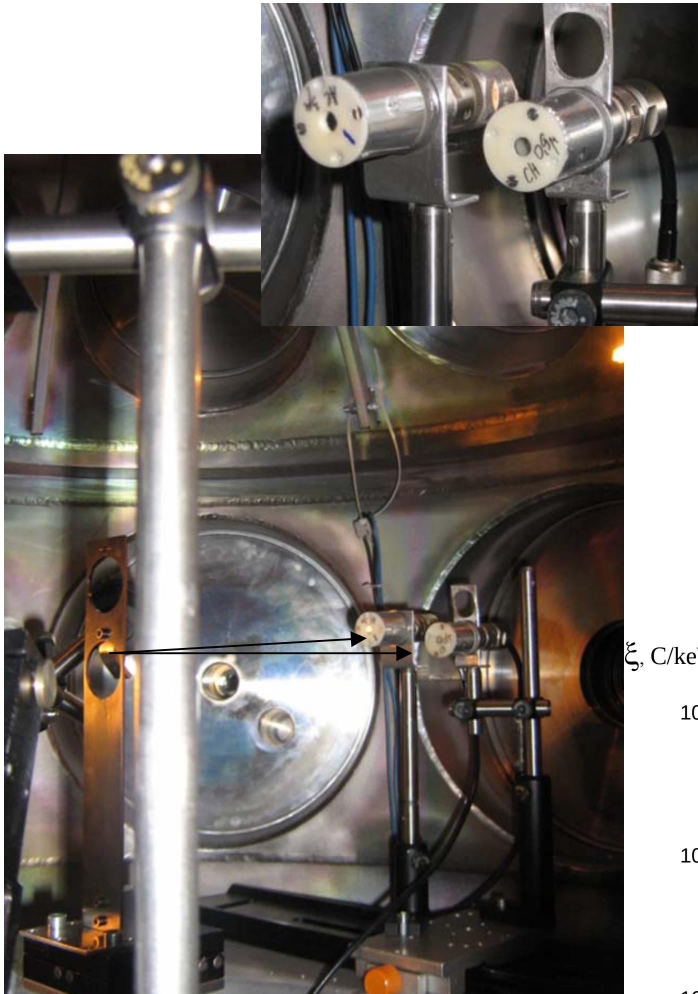


Front-side diagnostics in experiment on the February 2010

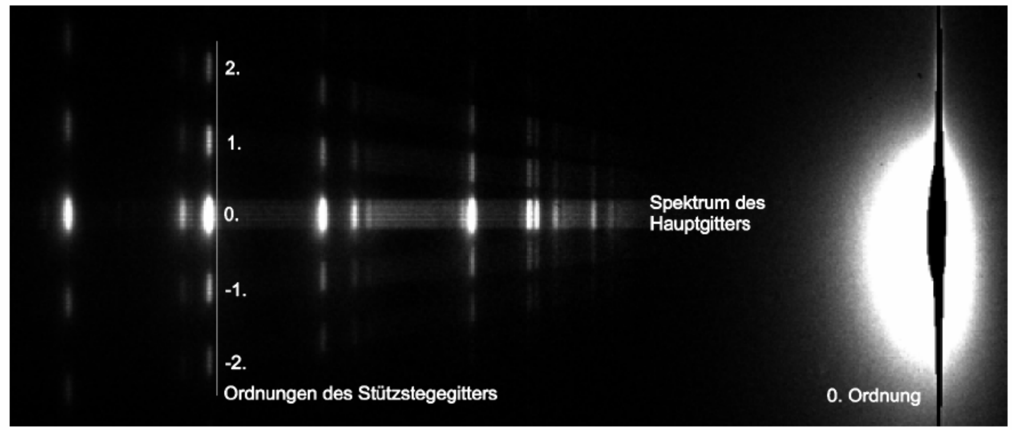


Back-side diagnostics in experiment on the February 2010

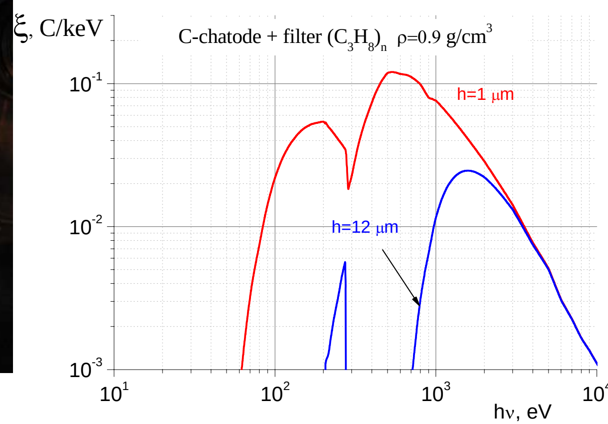
Pin-diodes : temporal evolution of the X-ray signal



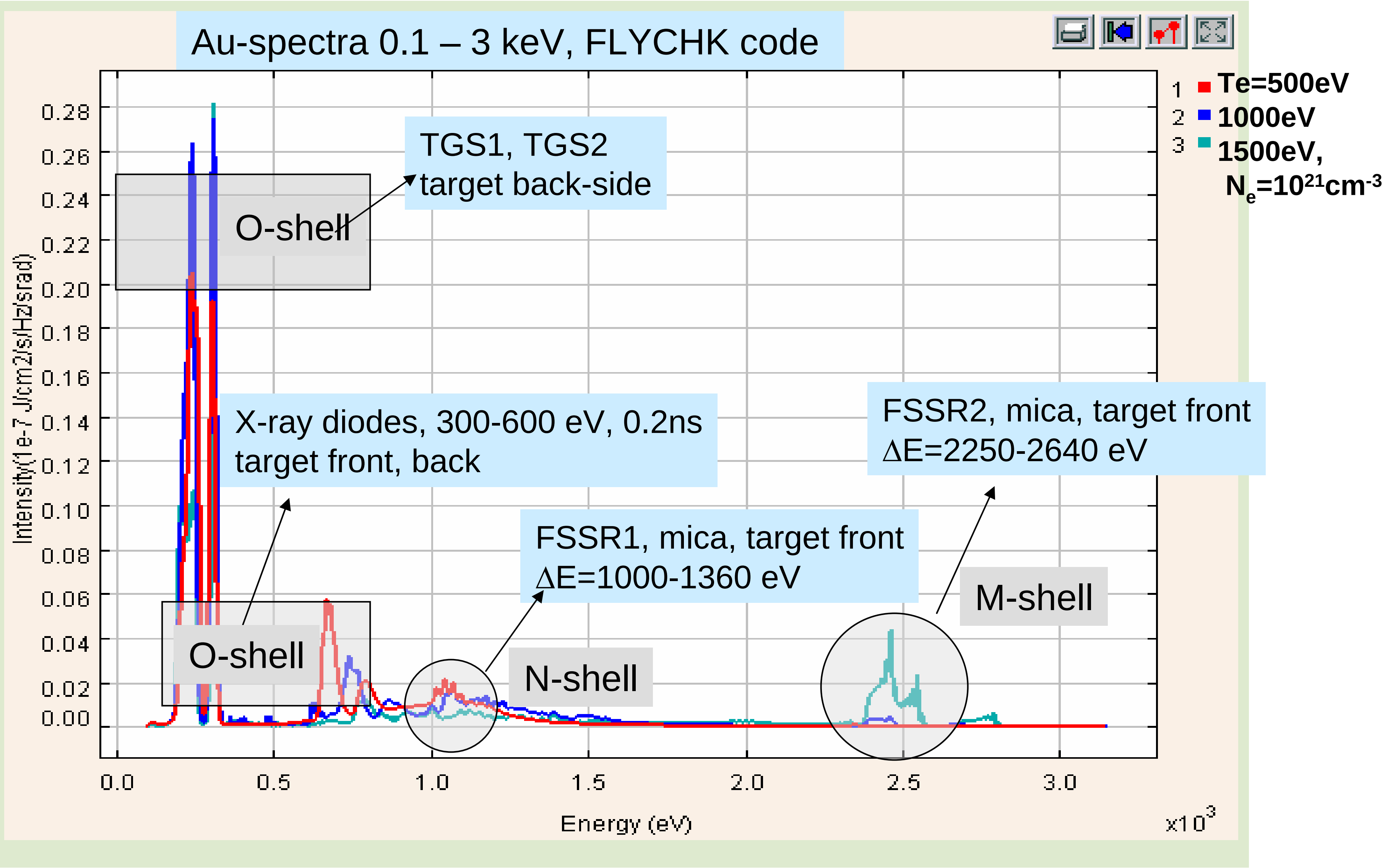
Transmission grating spectrometer (2):
Spectral analysis of the radiation field (1-20nm)



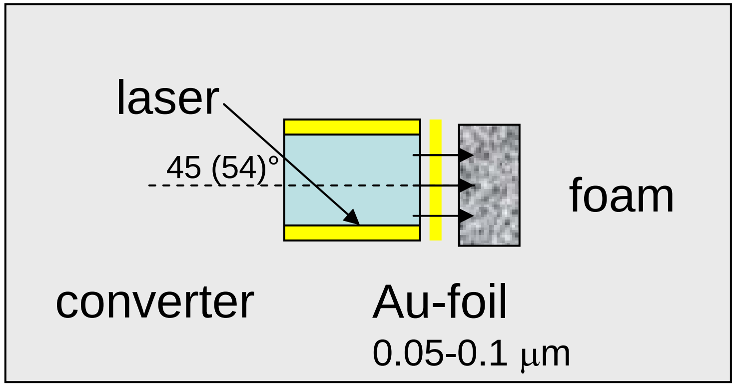
Recorders: UF4 and CCD-camera



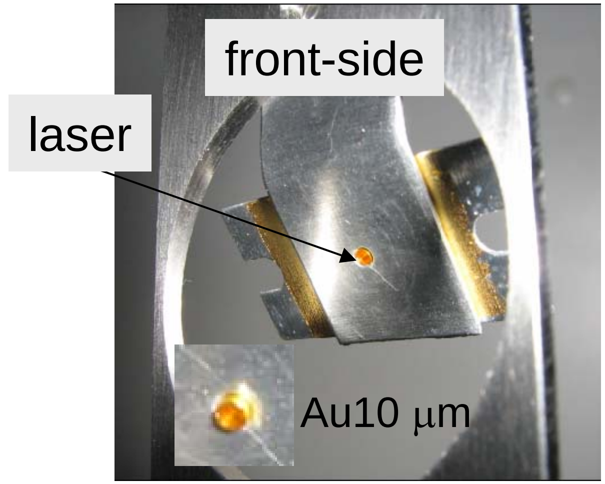
Radiation of Au-plasma observed with different diagnostic tools



Combined targets: converter + foam/foil



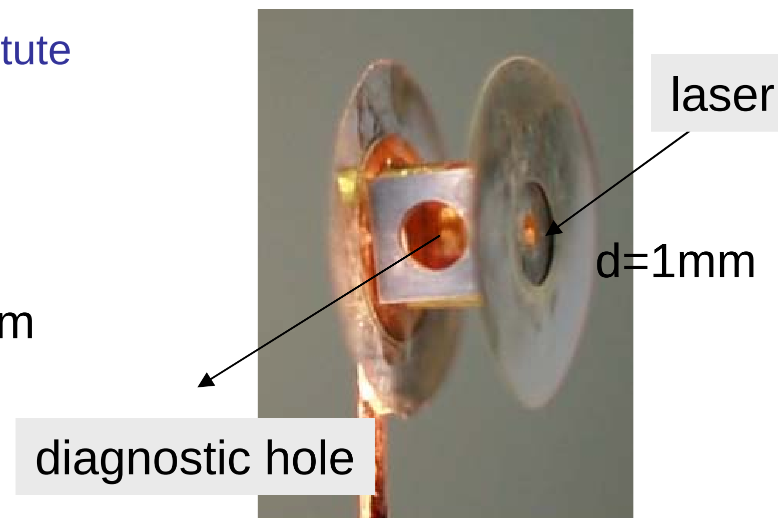
GSI-converter

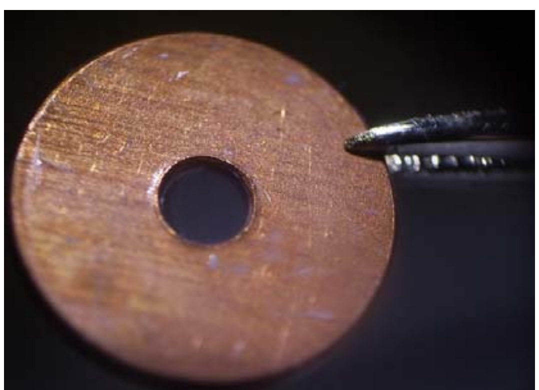


GSI-converter+foam

1. $(CH)_n$, foils / $(C_8H_8O_3)$ foams, A. Pinegin, VNIEF Sarov
   ρ = 1.1g/cc, 0.9 μm; ρ=0.1g/cc 90 μm; ρ=0.01g/cc 900μm
2. TAC $(C_8O_6H_{12})$, N. Borisenko, Lebedev Physical Institute

Sarov-converter

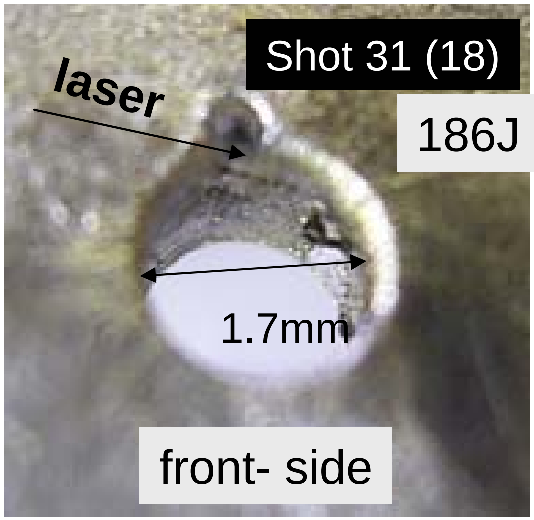


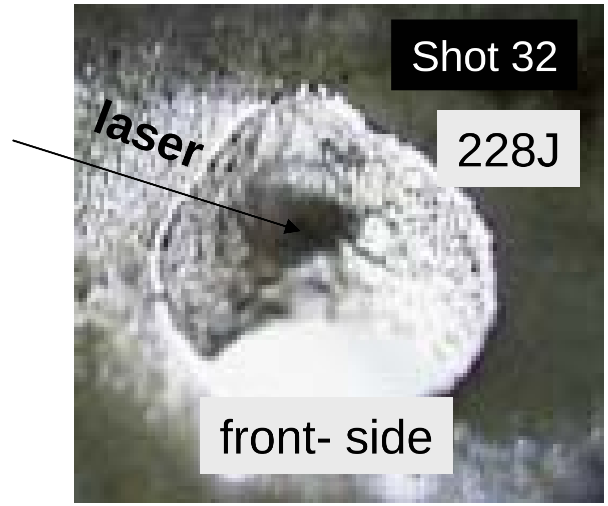


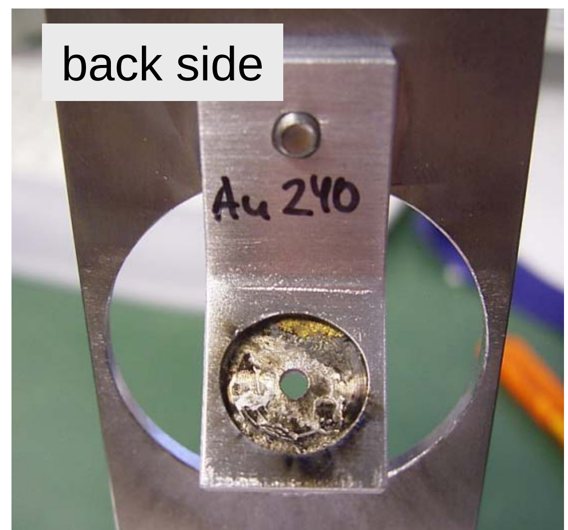
TAC($C_8H_{12}O_6$):

2mg/cc 800-1000μm

Hohlraum targets after shots

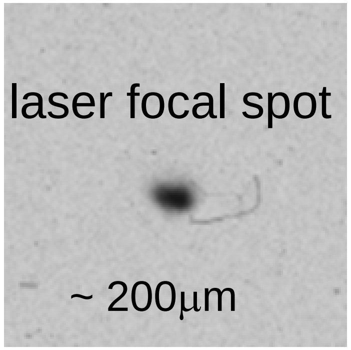


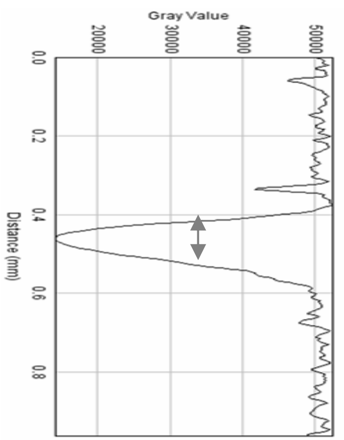


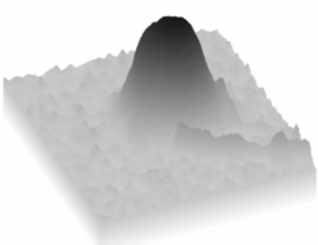


Pin-hole images of hohlraum plasma at low laser energies

Pin-hole images N5 (d=100 μm, M~1, δx~d(M+1)/M~200μm)

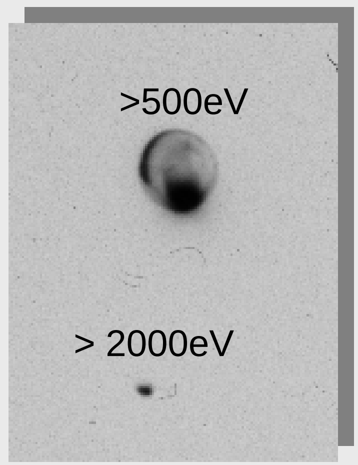


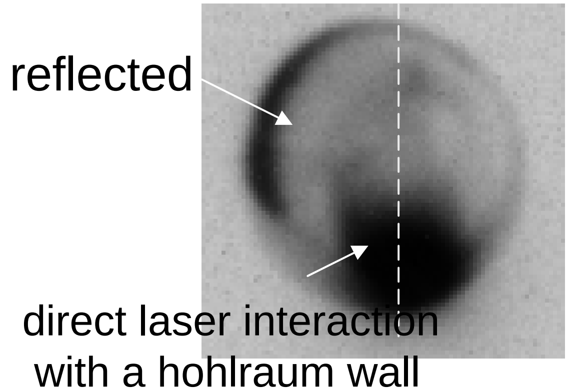


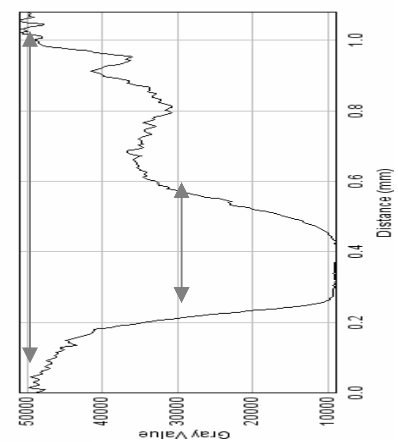


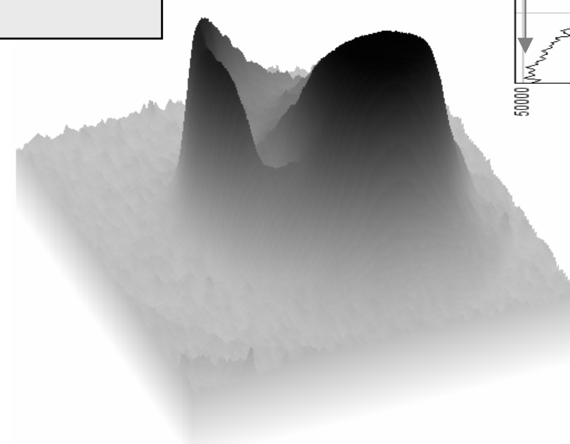
Shot 11 16.02.2010

E=120J, 1.4 ns, 1w



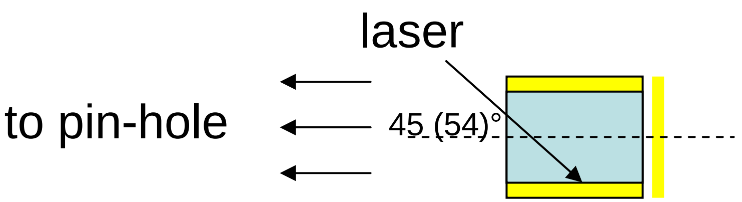




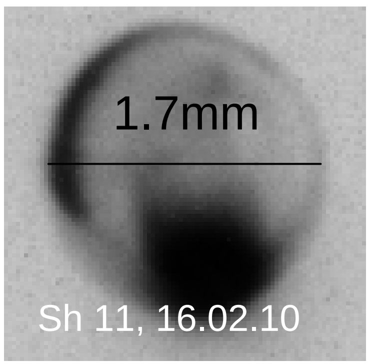


Hohlraum plasma radiation depending on the laser energy

Pin-hole images of the hohlraum plasma radiating hν>0.5 keV **(front)**

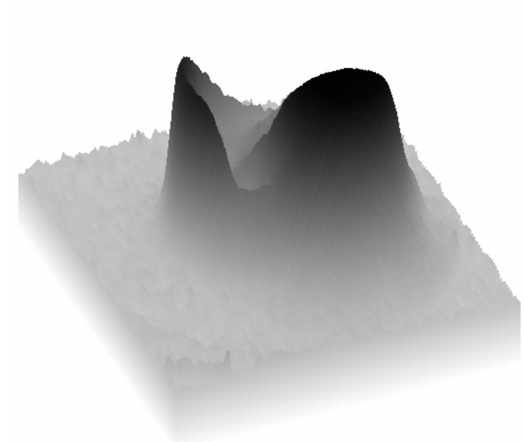


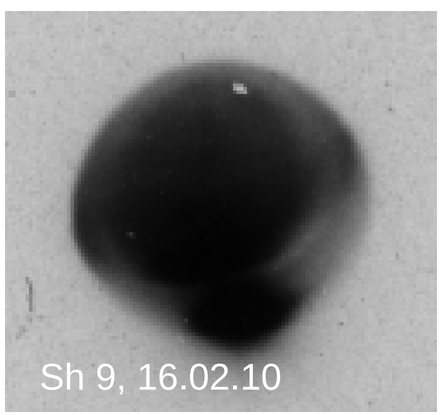
d=100 μm, M~1, dx~d(M+1)/M~200μm



Inhomogeneous

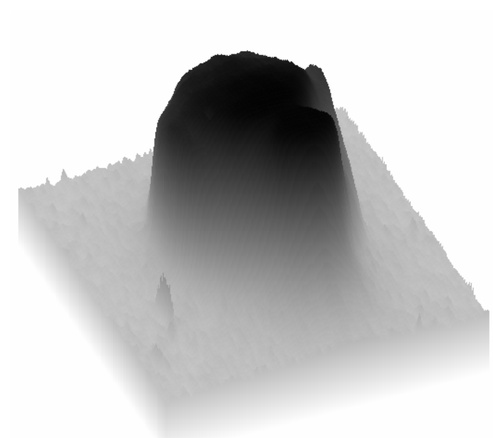
E_{las}=117J





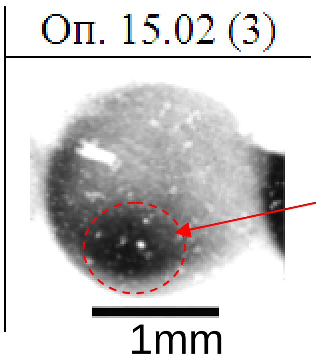
Homogeneous

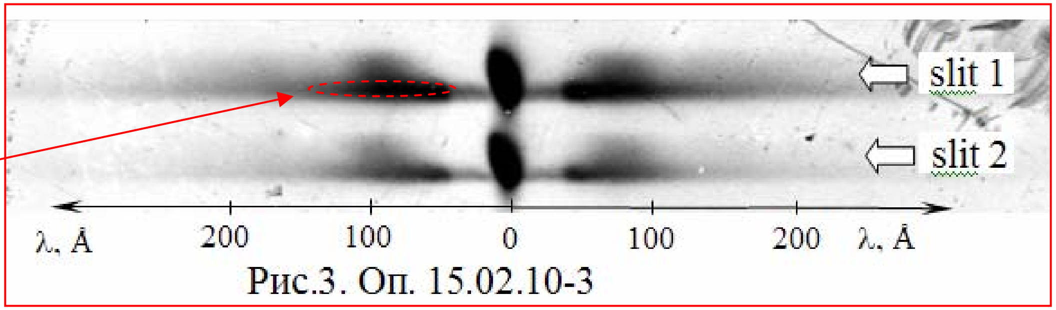
E_{las}=170J



At low laser energies radiation from the focal spot dominates in the spectrum.

E=77J,
target: GSI-converter d=1.9 h=1.9mm, wall 10 μm Au ; bottom: Au -170μg/cm^2

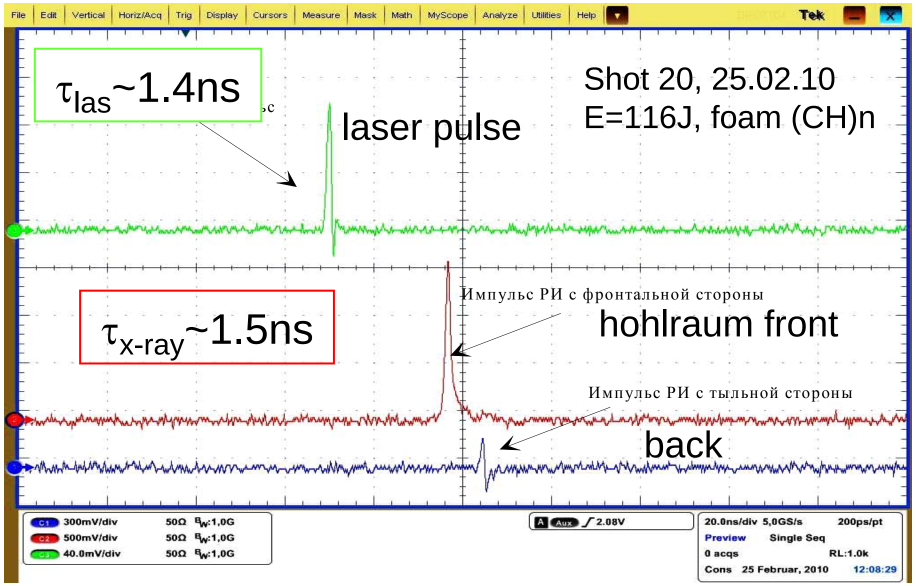




Pin-hole image (~0.2 keV, back)
strongly inhomogeneous

Transmission grating spectrometer: (hohlraum back)
overlapping of the hohlraum and focal spot radiation

Temporal evolution of the hohlraum radiation (pin-diode) →



τ-resolution ~1ns
Energy range: 0.3-0.6 keV

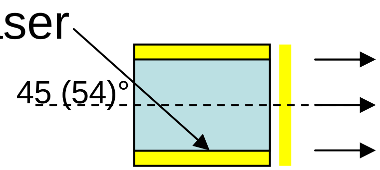
X-ray duration ~ laser pulse

Hohlraum radiation temperature 40 eV at laser energy of 240J

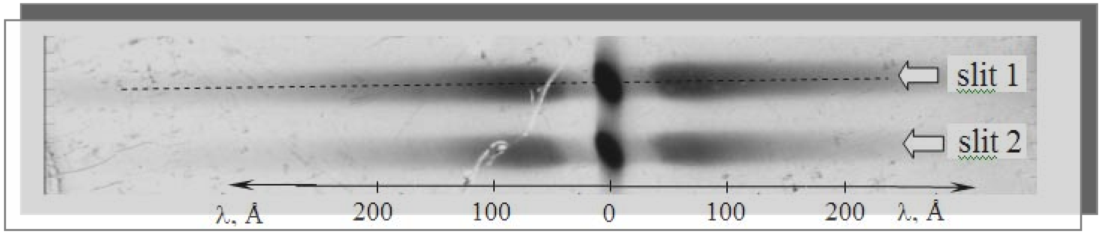
E_{las}=200J

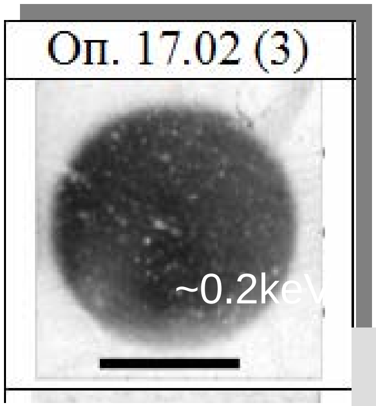
target – GSI-converter

TGS-Sarov

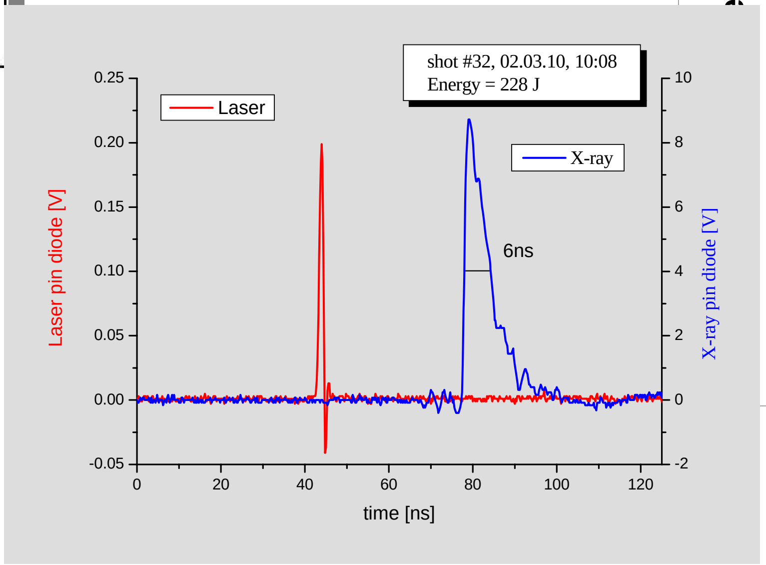


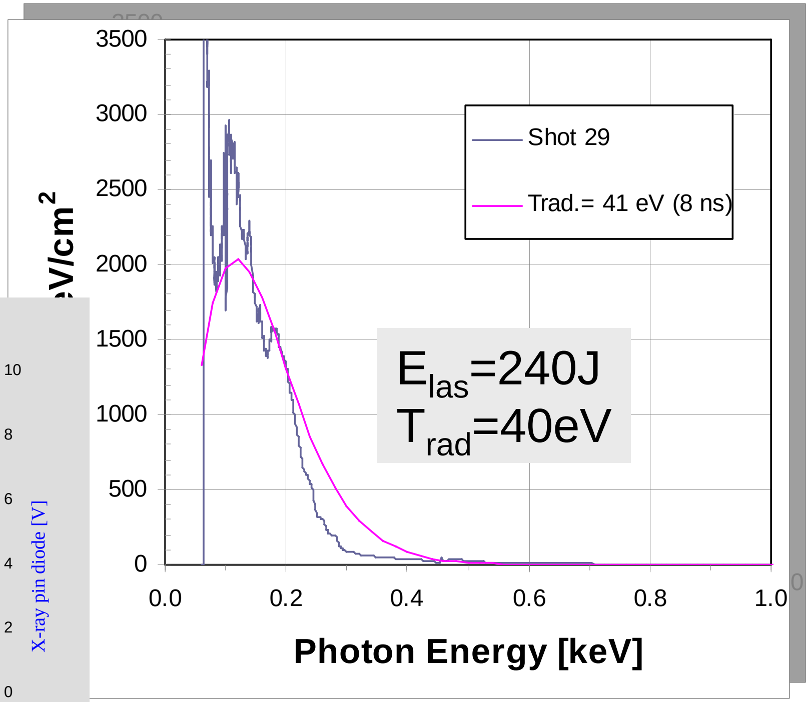
to pin-hole and TGS





pin-hole image

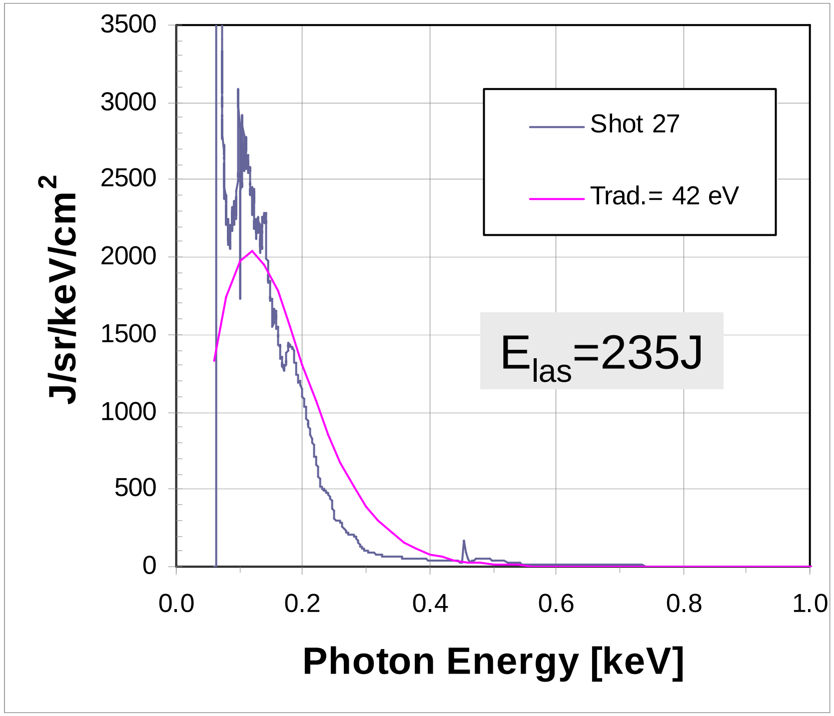


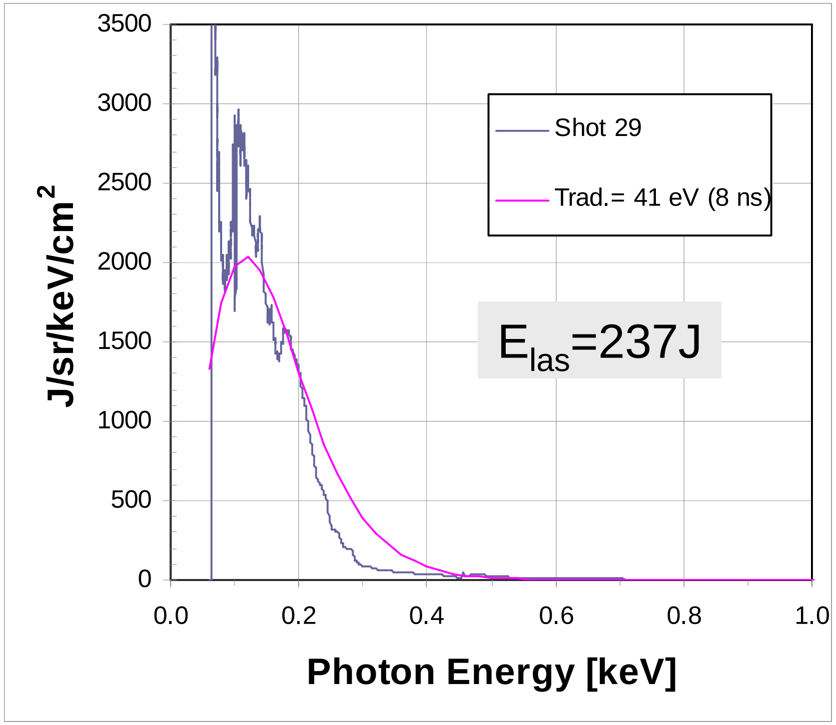


Up to 17%! conversion of the laser energy into soft X-rays

40 J in soft X-rays!

Hohlraum radiation temperature 40 eV at laser energy of 240J

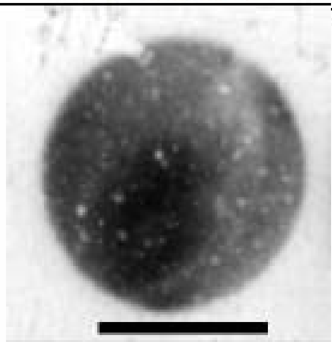
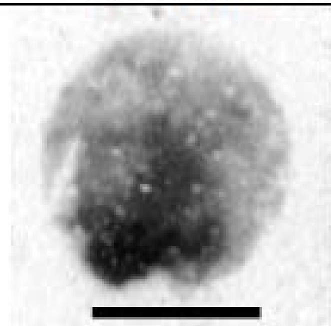
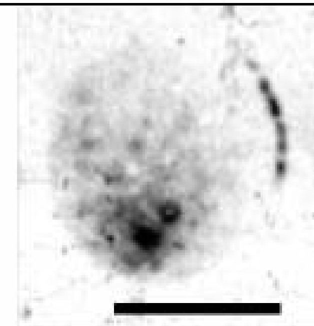
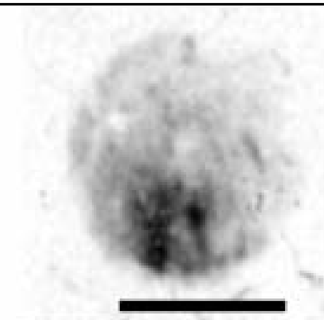




Absorption of soft-X-rays in foam targets

Hohlraum X-ray image (back) in 0.2-0.27 keV photon energy

Increased absorption at E_{las}>200J

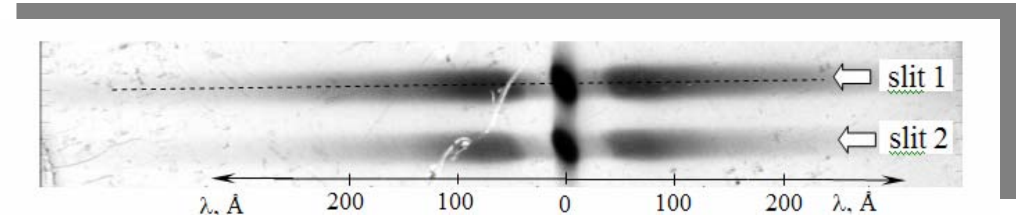
24.02 (1) E=127J	25.02 (2) E=116J	24.02 (3) E=218J	25.02 (1) E=216J
			
Converter d=1.7mm bottom Au~ 150 $\mu g/cm^2$ No foam!	Converter d=1.7mm bottom Au~150 $\mu g/cm^2$ Foam: $(CH)_n$ 0.01g/cc; 300 μm $\rho x = 300 \mu g/cm^2$	Converter d=1.7mm bottom Au~ 150? $\mu g/cm^2$ Foam: $(CH)_n$ 0.1g/cc; 90 μm $\rho x = 900 \mu g/cm^2$	Converter d=1.7mm bottom Au~ 160 $\mu g/cm^2$ Foam: $(CH)_n$ 0.1g/cc; 45 μm $\rho x = 450 \mu g/cm^2$

results N. Suslov, VNIEF, Sarov

75% absorption of the hohlraum radiation in the foam target

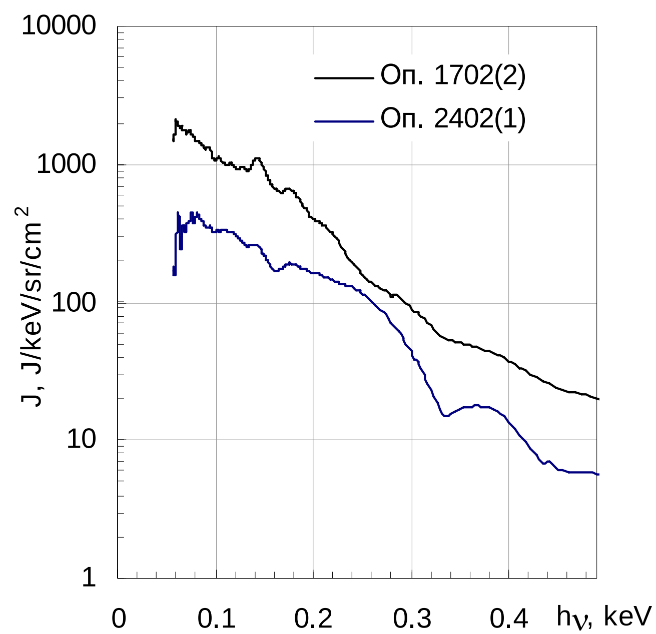
Shot 17.02.10(2) E=120J

Target: converter d=1.7mm,h=1.7mm, wall 10 μm Au, bottom Au 168μg/cm^2



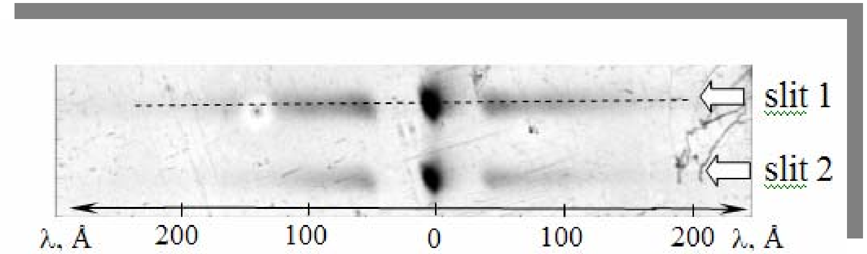
60eV 120eV 120eV 60eV

4 times absorption



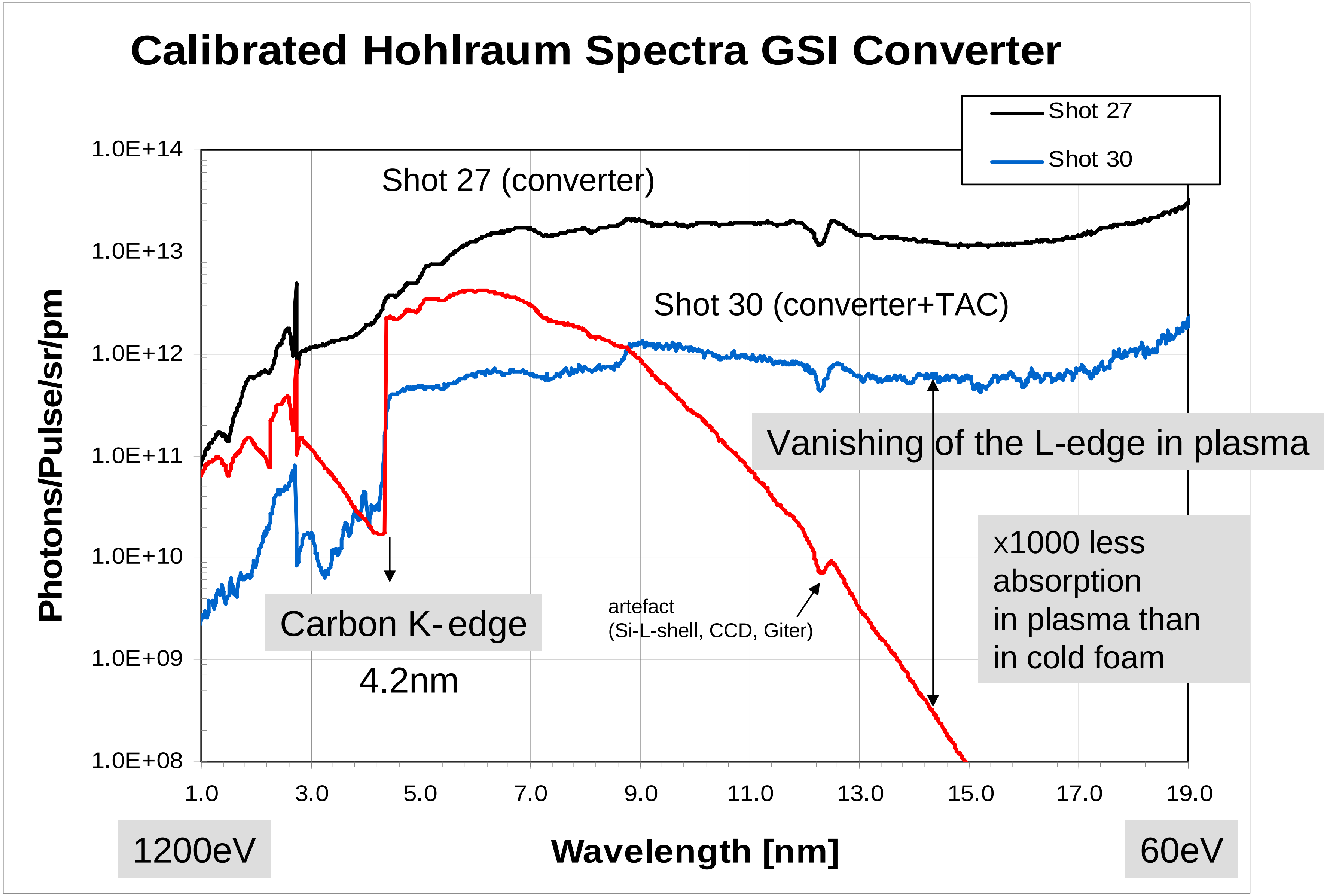
Shot 24.02.10(1) E=130J

Target: converter+ 0.002g/cc 800mm TAC

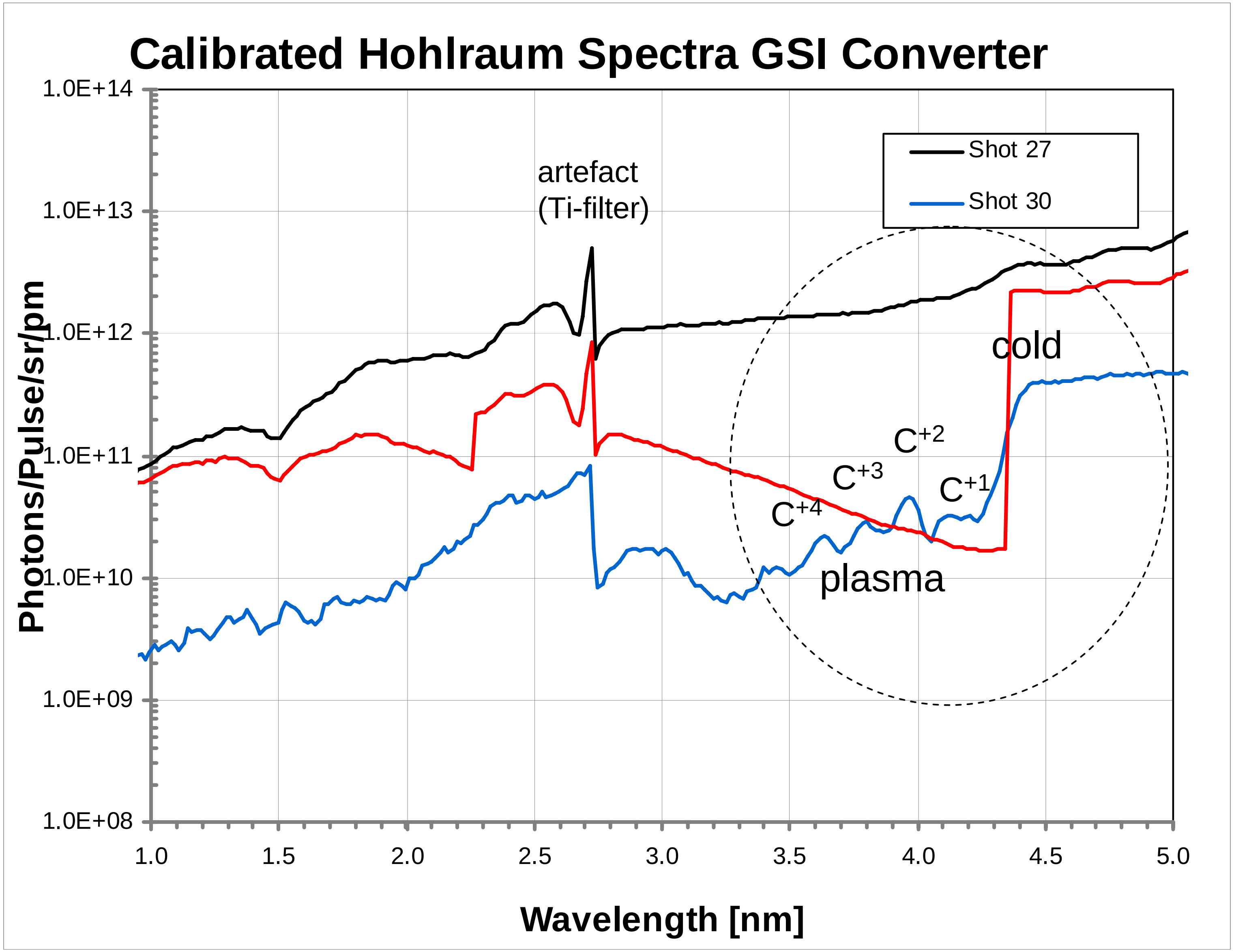


results N. Suslov, VNIEF, Sarov

Absorption properties of heated to plasma foams

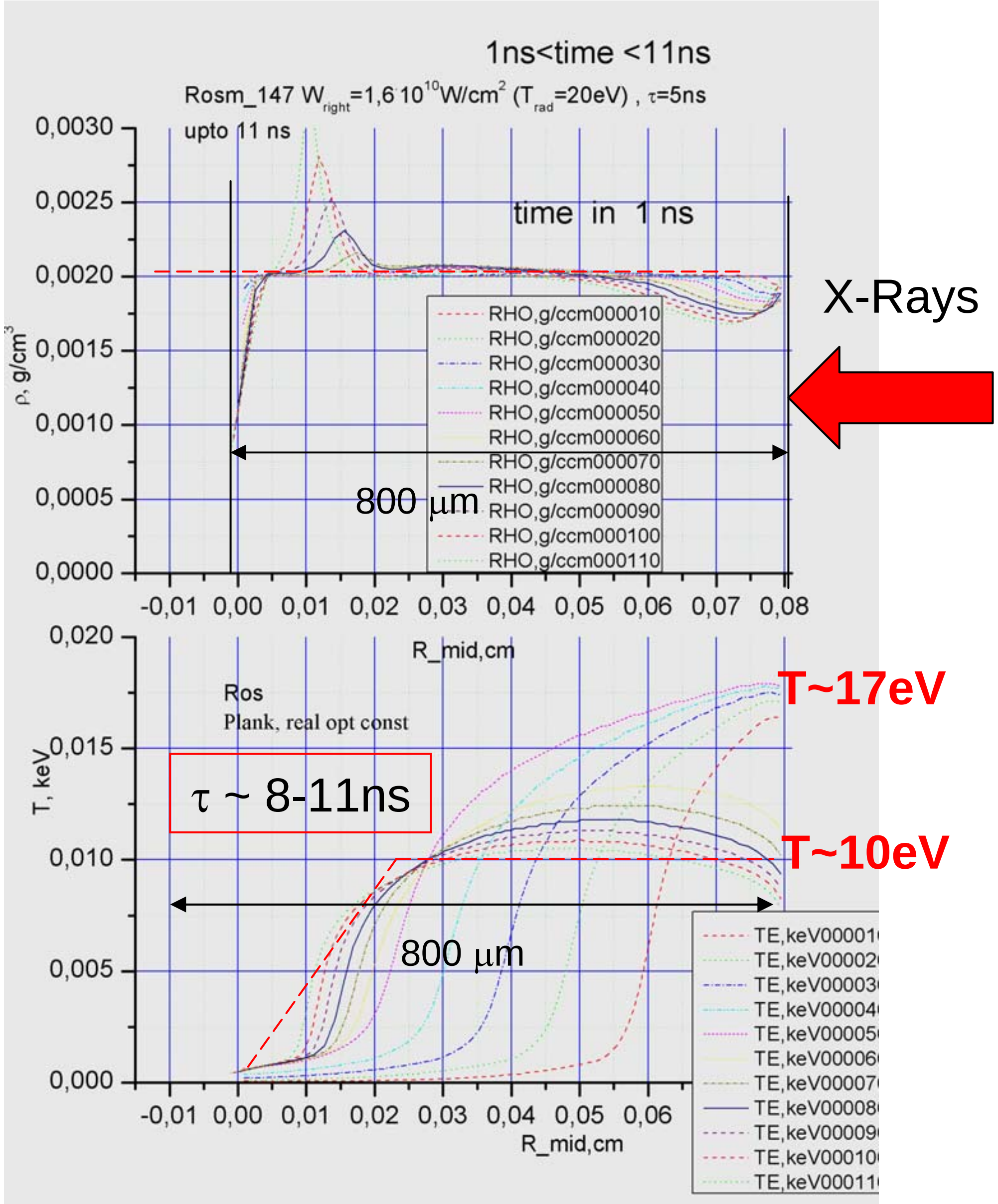


Deformation of Carbon K-edge in plasma

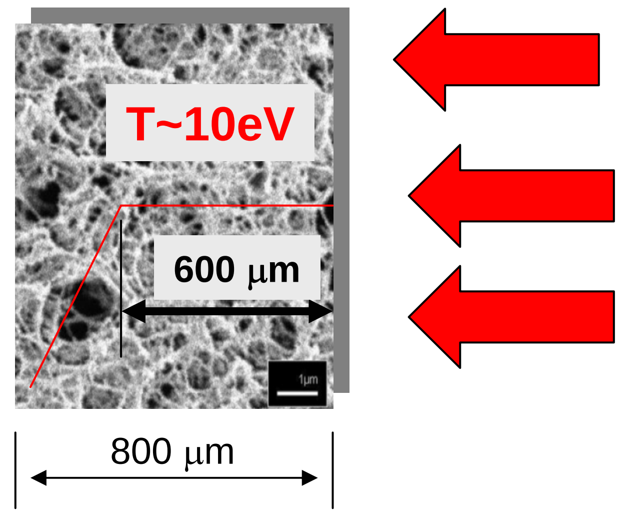


D. Schäfer, Th. Nisius, Th. Wilhein, Remegen

Hydrodynamics of TAC-foam heated with Planck radiation



T_{rad}=20eV
τ=5ns



TAC-foam ($C_8H_{12}O_6$)
0.002g/cc , 800μm thick
ρx=1.6mg/cm²

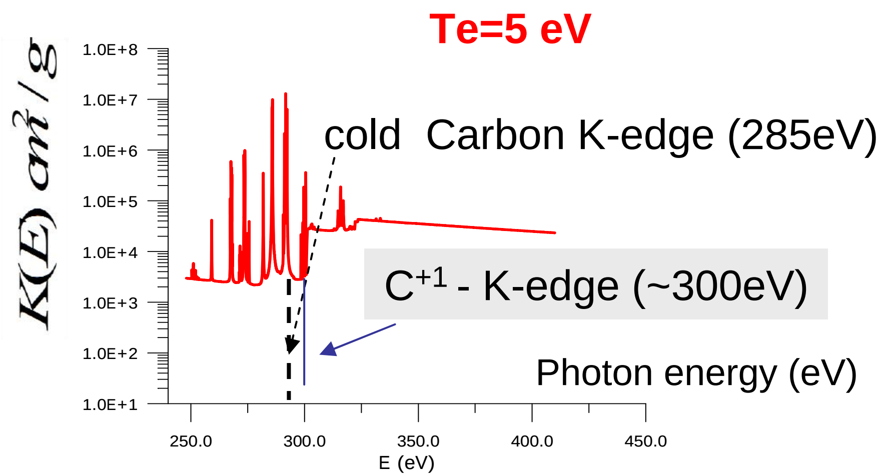
3-D network,
1 μm pore-size
0.1 μm solid wall

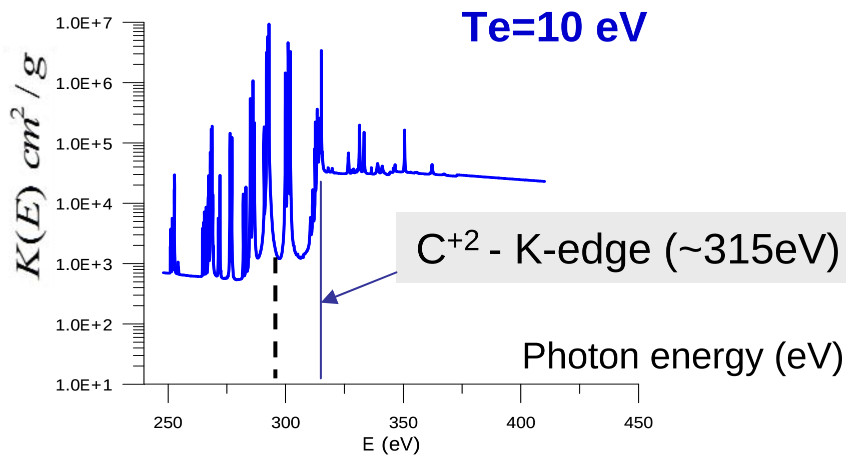
Calculations G. Vergunova, S. Guskov, Lebedev Physical Institute, Moscow

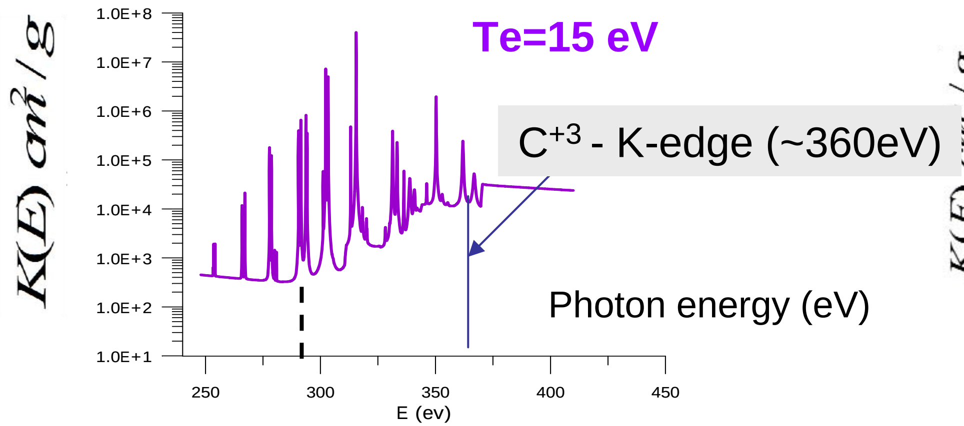
The spectral coefficient for x-ray absorption K(E) in Carbon plasma
Dependence on the electron temperature and density

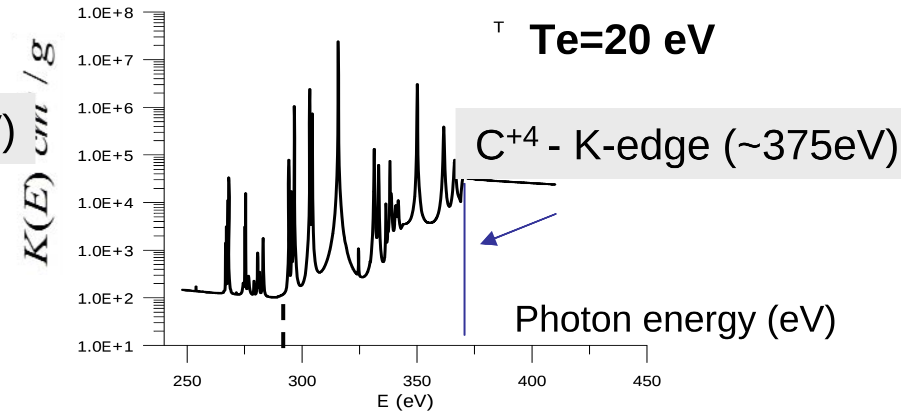
Absorption of 0.003 g/cc carbon plasma

Ion Model, Nikolay Orlov, JIHT, Moscow, 26.12.2009









N. Yu. Orlov “Ion model of a hot dense plasma.” Laser Part. Beams 15 (1997),

Experiments on the indirect heating of foam targets

Converter:

- T_{rad}= 30 - 40eV   d=1.7mm τ = 5-8ns
- $E_{x\text{-}rays}$~10 - 40J ; 5-17% of the laser energy
- $I_{x\text{-}rays}$= 0.5 - 2. 10^{11} W/cm^2

Foam:

- Effective (10 fold) absorption of soft x-rays
- Vanishing of the Carbon L-edge in Plasma, deformation of K-edge: diagnostic of the plasma temperature and ionization degree .
- Rich experimental data on the hohlraum radiation field and opacities of plasma with a coupling parameter

$$\Gamma \sim 0.3 - 0.5 \;;\; z = 2 - 4$$

$$n_i = 10^{20} - 10^{21} cm^{-3}$$