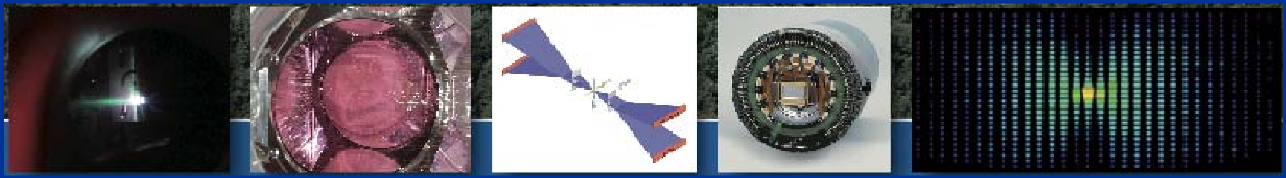
ExtreMe Matter Institute EMM

X-rays as a Tool for Probing Extreme States of Matter

Properties of combined hohlraum targets for probing with heavy ion beams

Olga Rosmej

Plasma physics, GSI



June 7-9, 2010, Darmstadt

ExtreMe Matter Institute EMM

X-rays as a Tool for Probing Extreme States of Matter

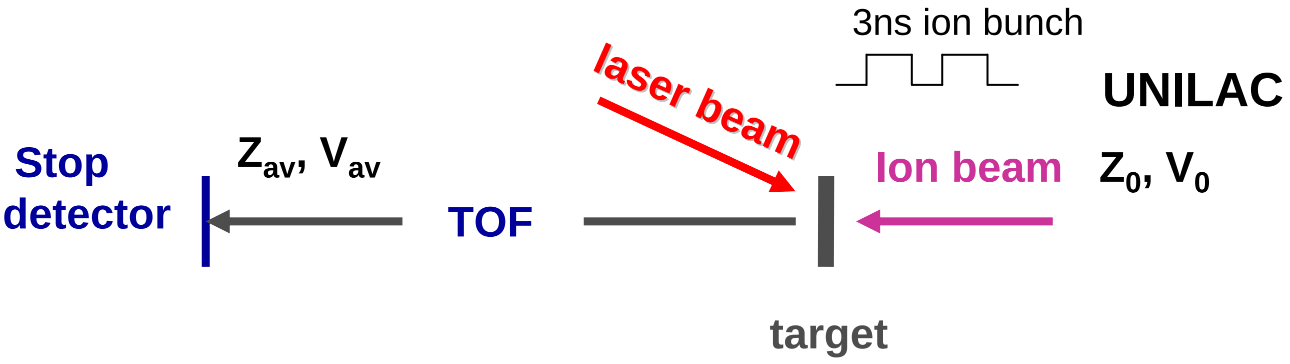
Properties of combined hohlraum targets for probing with heavy ion beams

Experimental and theoretical work was done by:

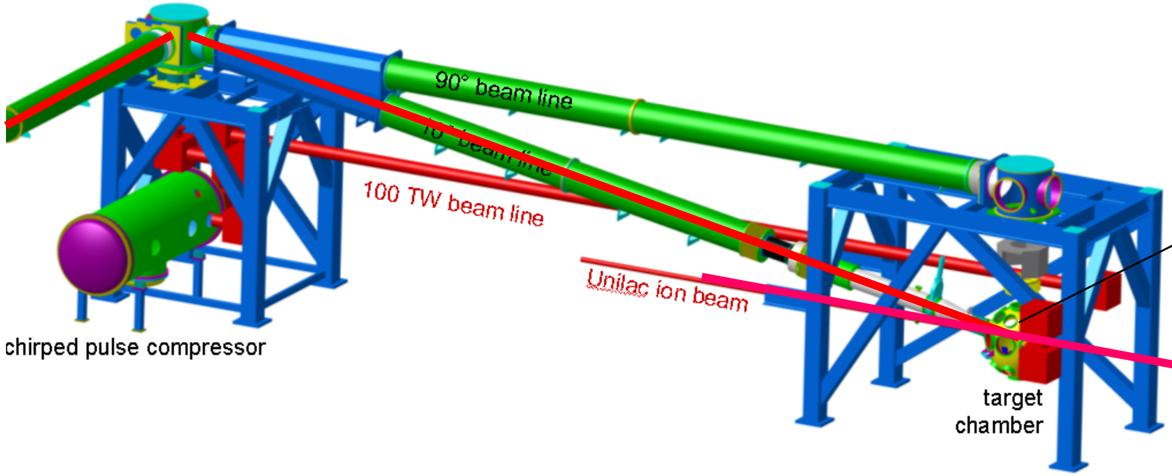
O. Rosmej, A. Blazevic, Th. Hessling, N. Zhidkov, V. Vatulin, N. Suslov,
A. Kunin, A. Pinegin, D. Schäfer, Th. Nisius, Y. Zhao, V. Bagnout
U. Eisenbarth, J. Wichula, T. Rickener, N. Orlov, N. Borisenko,
G. Vergunova, S. Gus´kov, Th. Wilhein

Laser – Heavy Ion Beam Combined Experiments

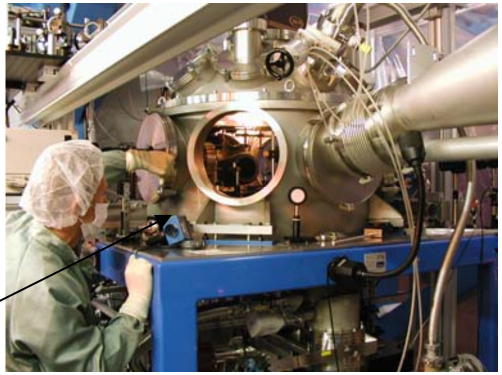
Interaction of heavy ions with ionized matter : increased plasma stopping power



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



Target chamber



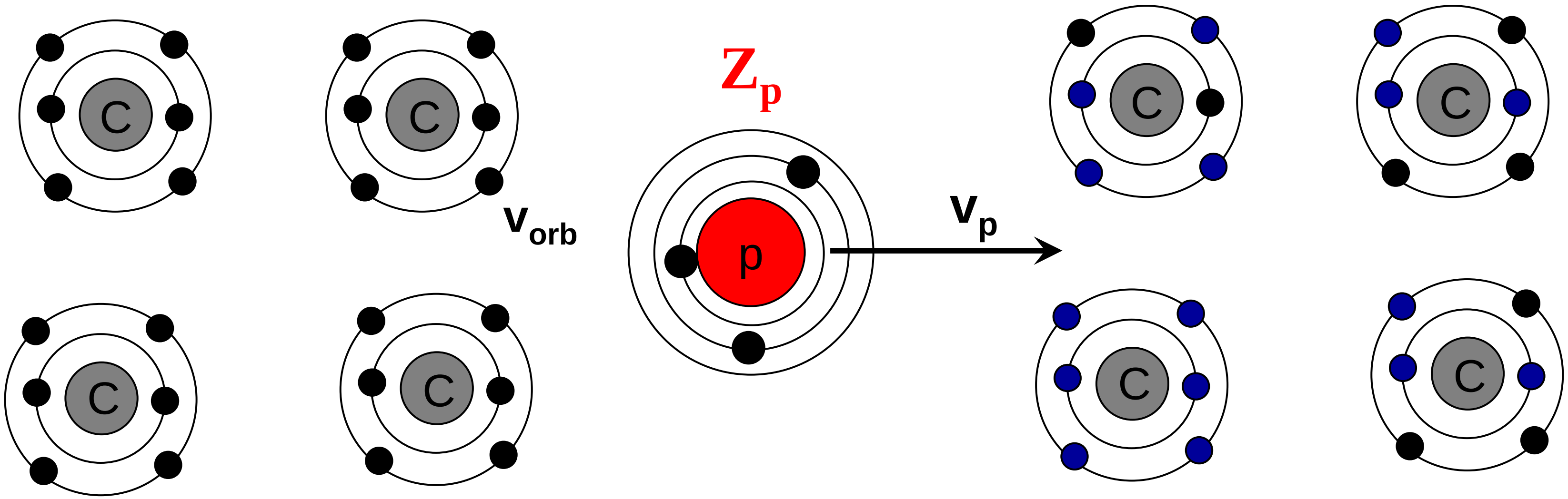
Heavy ion beam:
3<Z<92, E=3–13 MeV/u,
RF: 108/36 MHz

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

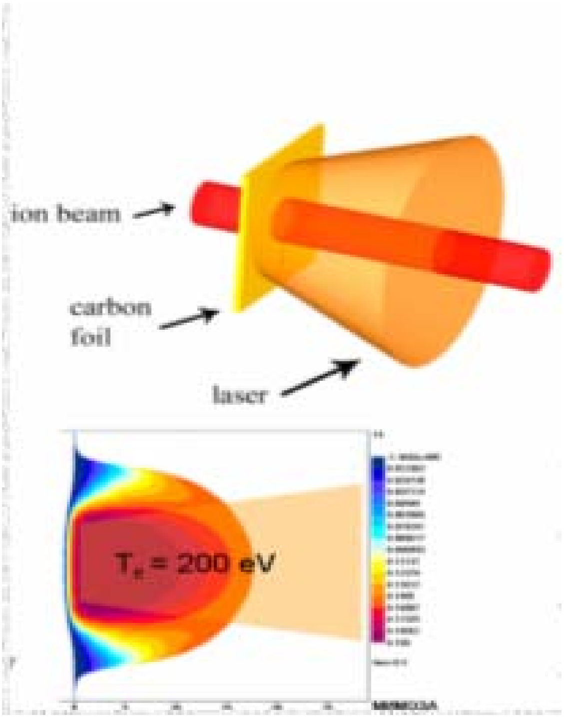
More effective energy transfer to free electrons

Increase of the ion energy loss in plasma

Schemes of the plasma target production

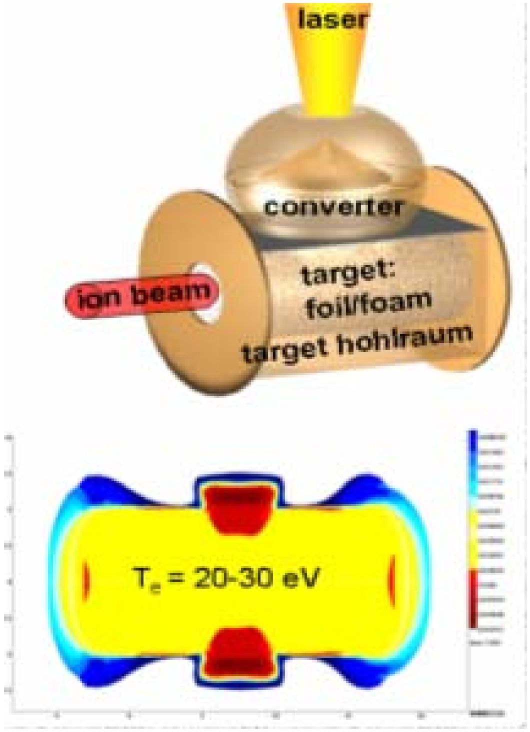
Direct laser heating

Ideal plasma:
Te~ 200 eV, fully ionized



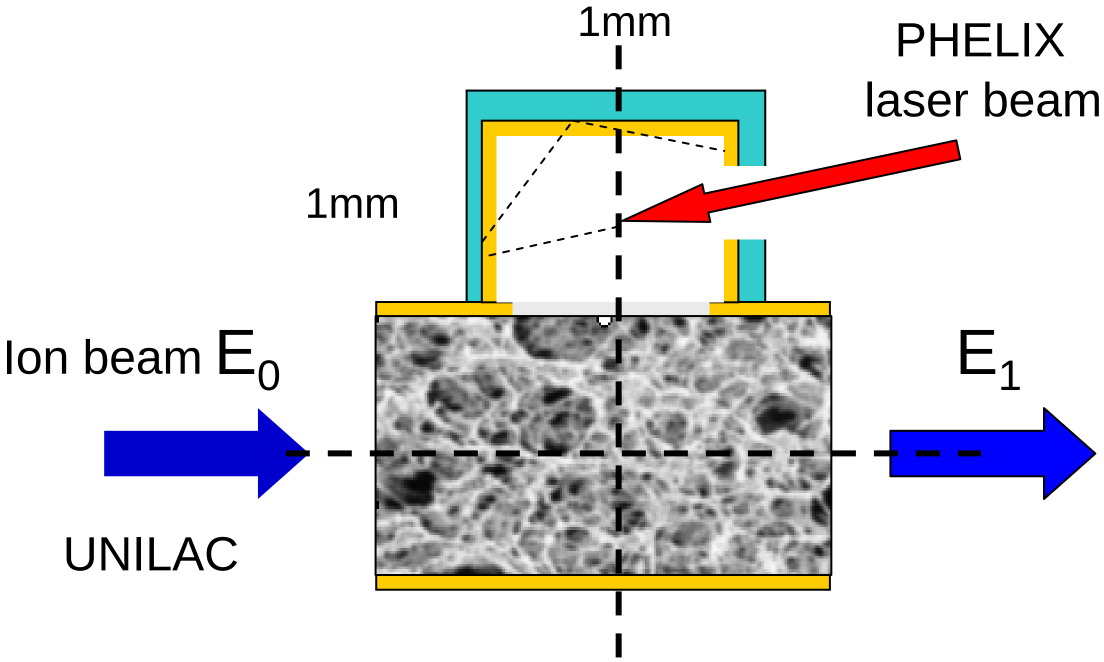
Heating with hohlraum radiation

homogeneous plasma:
Te~ 30 eV, partially ionized



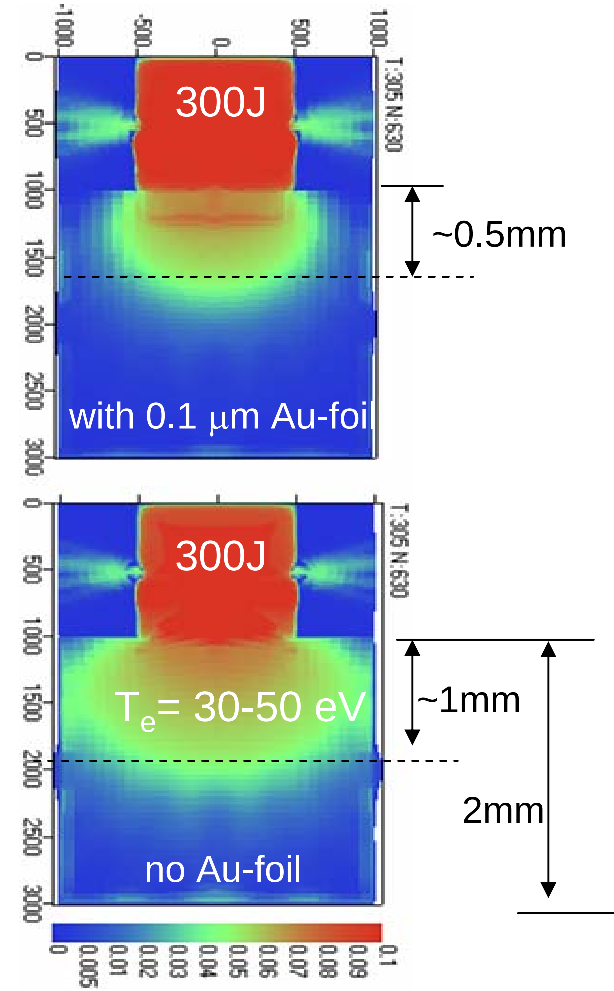
Numerical optimization of the hohlraum target geometry

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



VNIIEF, Sarov, Nov. 2009

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



Why foams?

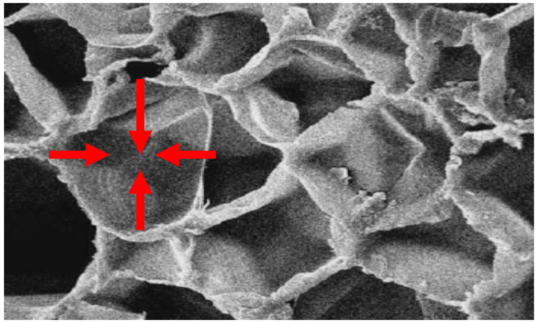
Properties under the ion and laser beam:

1. Higher conversion of laser energy in to the plasma temperature compared to the solid foils

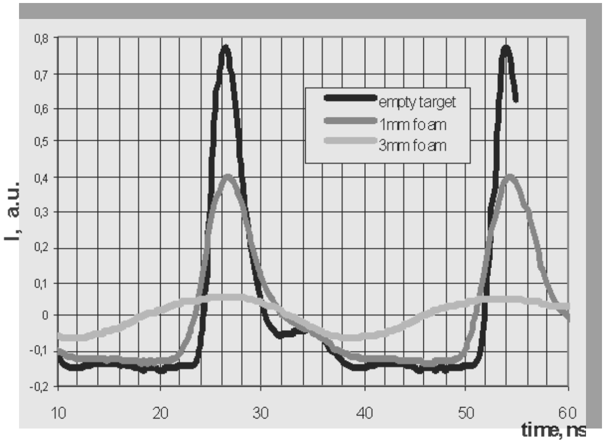
2. Slow dynamics of expansion (ρ, T ~ const over ns)

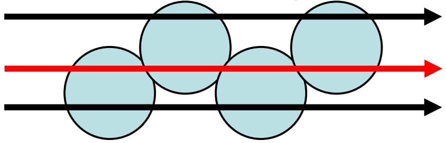
3. Fast (~sub ns) homogenization after the laser heating

4. Energy broadening of the ion bunch caused by the porous structure has to be acceptable (no merging of the subsequent ion bunches)



$mv_i^2 \Rightarrow T_i \Rightarrow T_e$





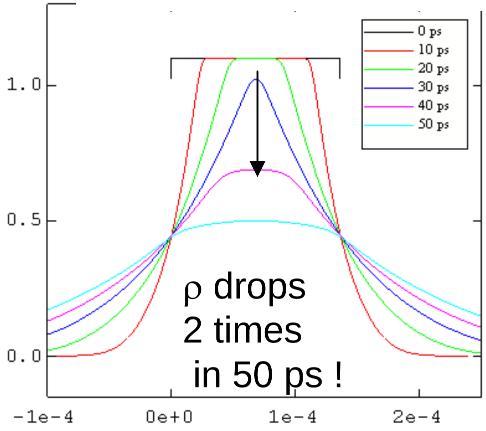
CH- foil and CH-foam expansion dynamics (1-D)

CH-foil 1.1 g/cc 1.36 μm

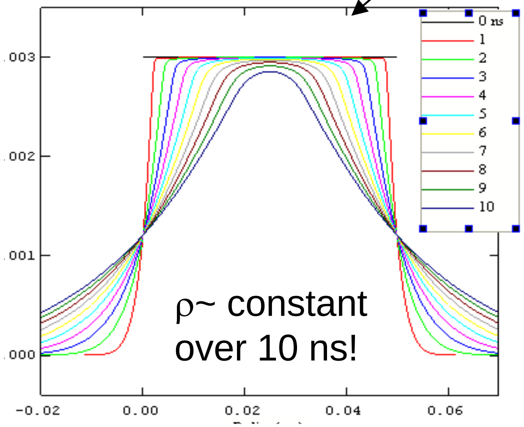
CH-foam 3mg/cc 500 μm

Density versus foil thickness

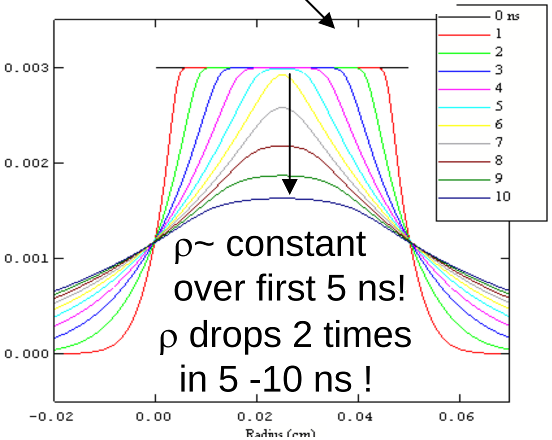
Density g/cc



ρ drops 2 times in 50 ps !



ρ~ constant over 10 ns!



ρ~ constant over first 5 ns!

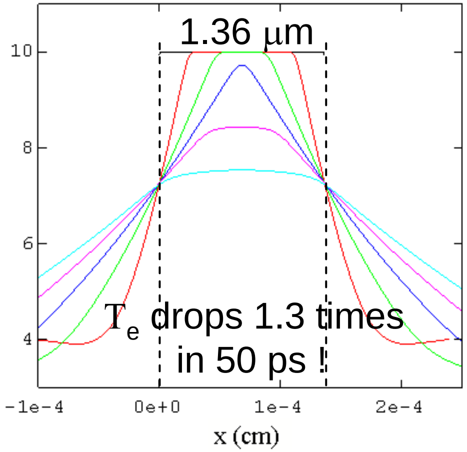
ρ drops 2 times in 5 -10 ns !

$T_e(t=0)=10$ eV

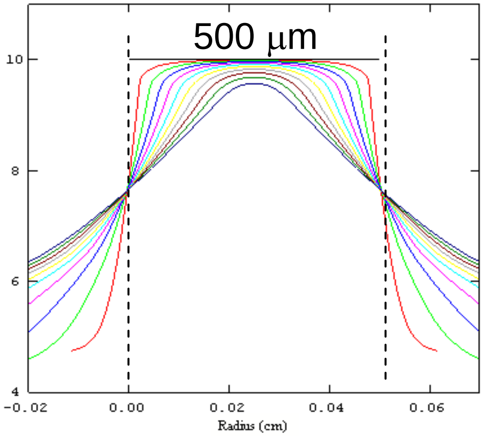
$T_e(t=0)=10$ eV

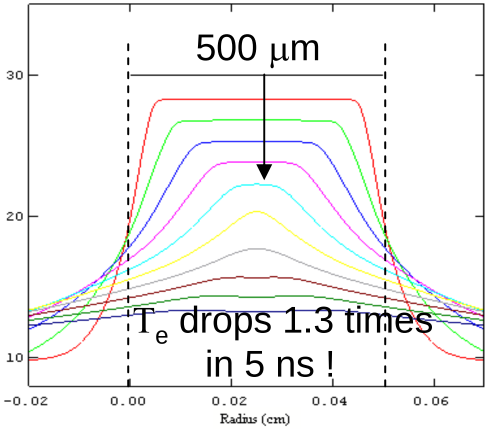
$T_e(t=0)=30$ eV

Electron Temperature (eV)



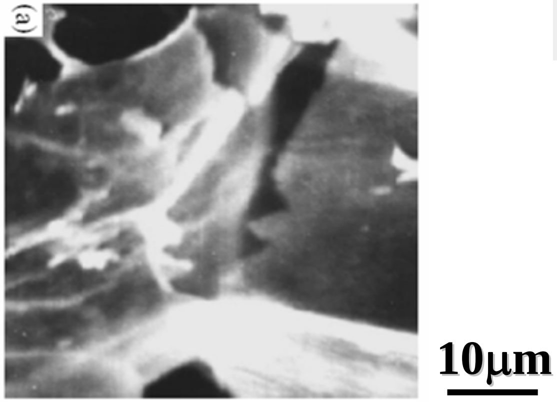
T_e drops 1.3 times in 50 ps !





T_e drops 1.3 times in 5 ns !

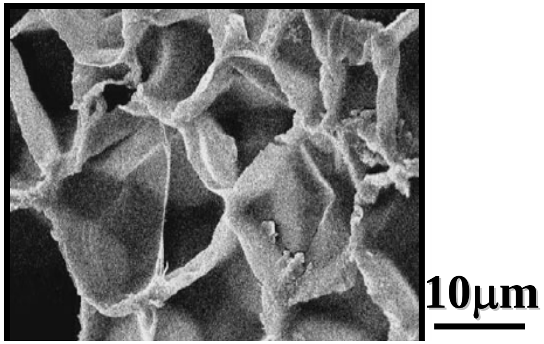
Variety of low Z foam structures



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

Randomly distributed thin fibers

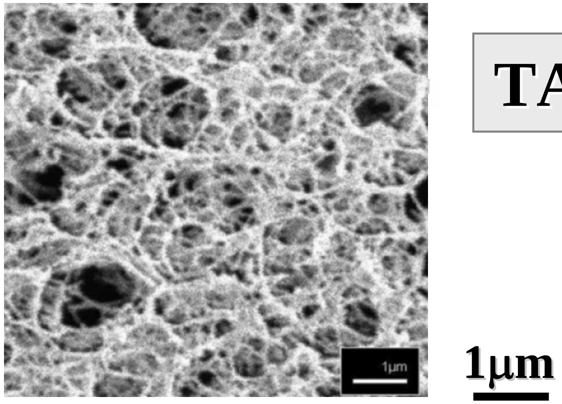
TRINITI, Mishen, VNIIEF-Sarov Iskra 5



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

Quasi regular sponge like structure (3D network)

TRINITI, Mishen



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

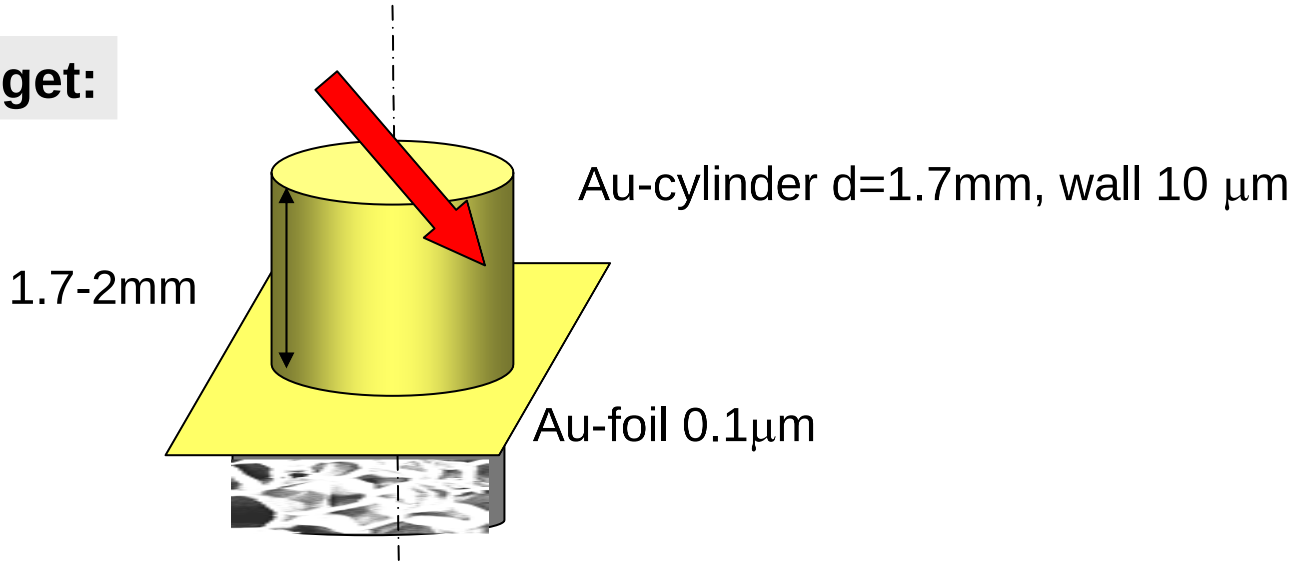
Approaches:

- 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/cm^2, contrast 10^{-6}**

Target:



CHO-foam 2-20 mg/cm^3

areal density ρx~ 150-500 µg/cm^2

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

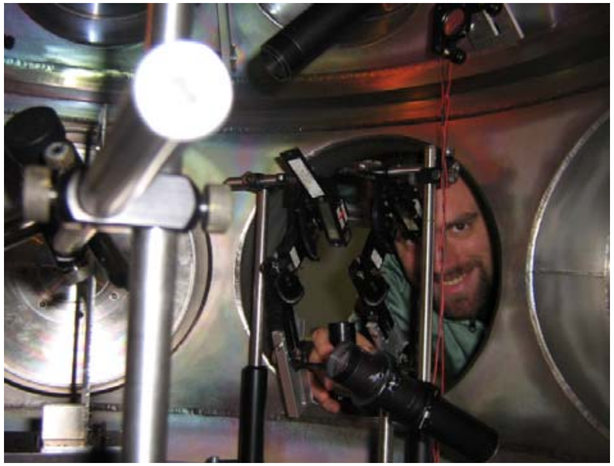
experimental support (x-ray diagnostics)

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

•*experimental support (absolute calibrated transmission grating)*

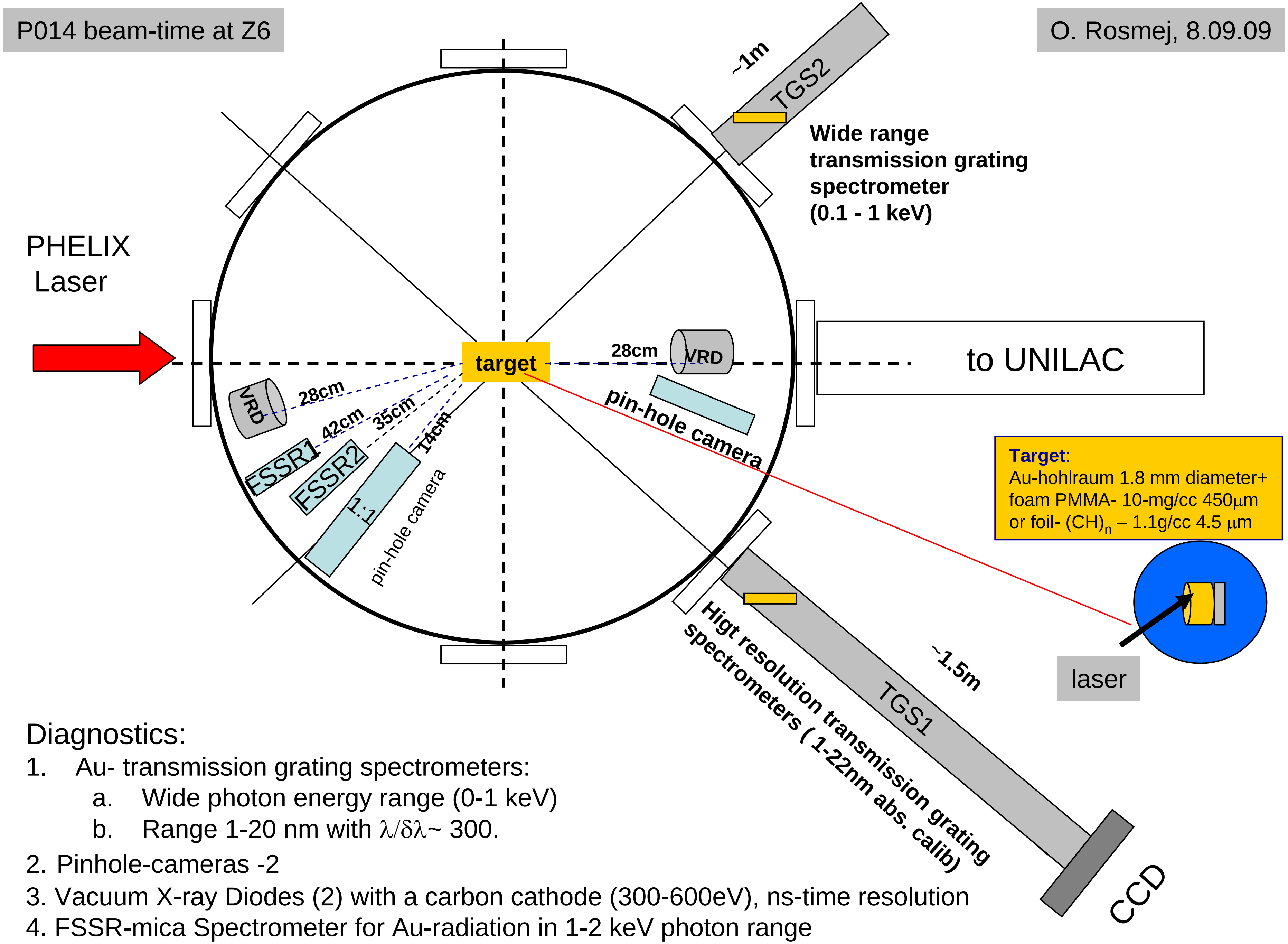
Plasma Physics Division GSI

Last experimental campaign on February 2010



P014 beam-time at Z6

O. Rosmej, 8.09.09

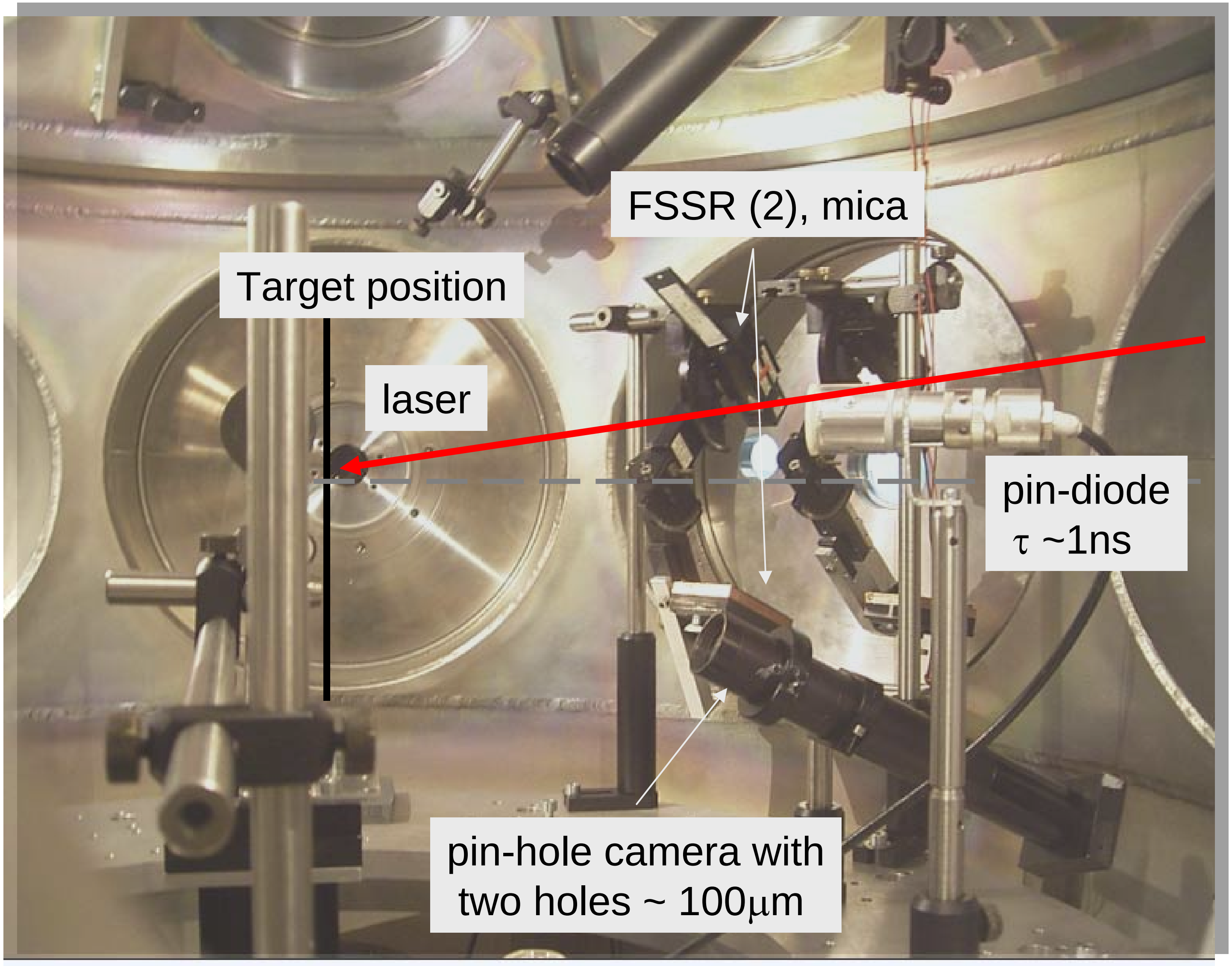


Target:
Au-hohlraum 1.8 mm diameter+
foam PMMA- 10-mg/cc 450µm
or foil- $(CH)_n$ – 1.1g/cc 4.5 µm

Diagnostics:

1. Au- transmission grating spectrometers:
   a. Wide photon energy range (0-1 keV)
   b. Range 1-20 nm with $\lambda/\delta\lambda$~ 300.
2. Pinhole-cameras -2
3. Vacuum X-ray Diodes (2) with a carbon cathode (300-600eV), ns-time resolution
4. FSSR-mica Spectrometer for Au-radiation in 1-2 keV photon range

Front-side diagnostics in experiment on the February 2010



FSSR (2), mica

Target position

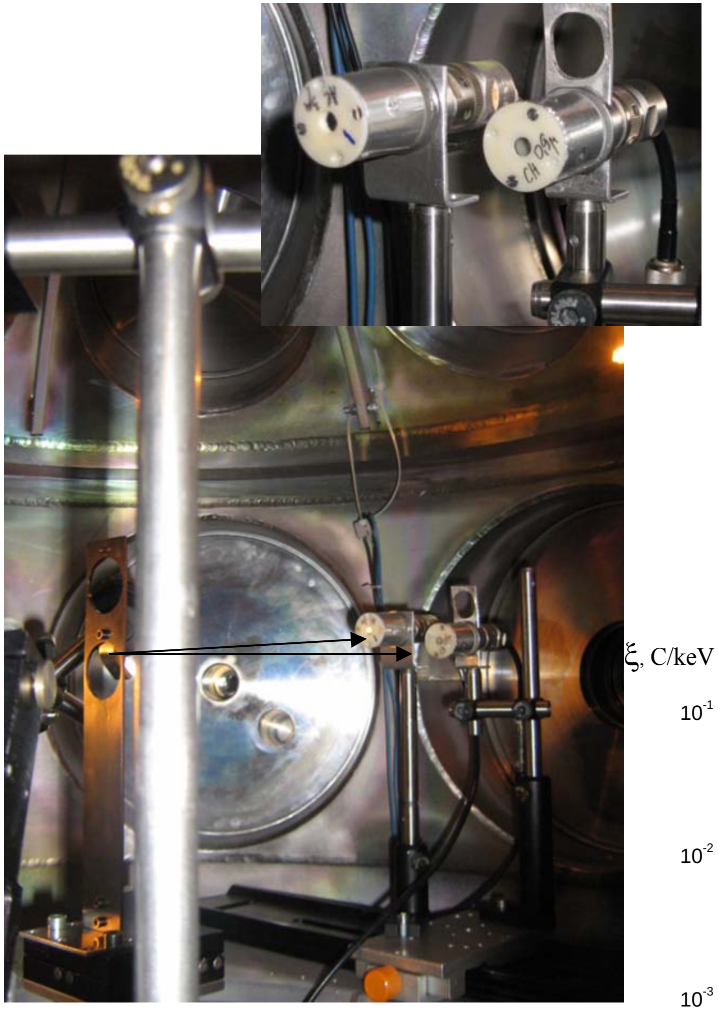
laser

pin-diode
τ ~1ns

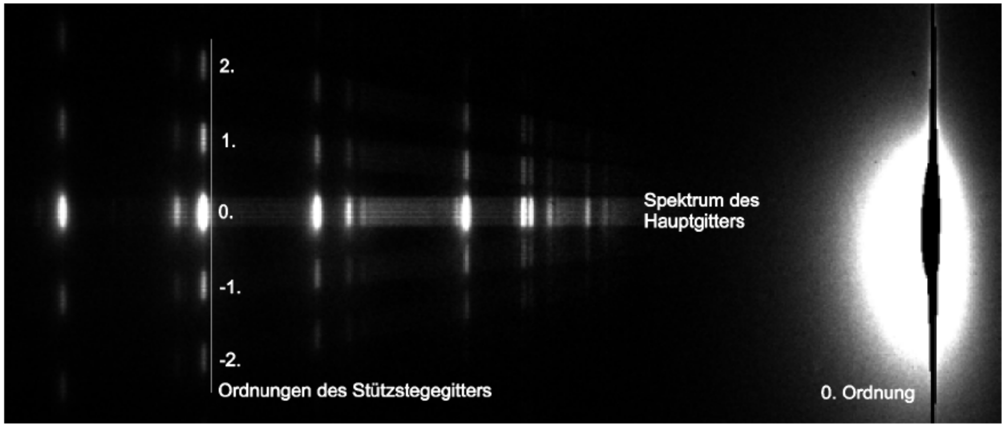
pin-hole camera with
two holes ~ 100μm

Back-side diagnostics in experiment on the February 2010

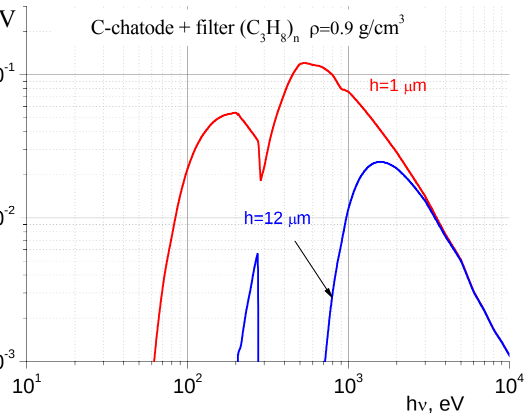
Pin-diodes : temporal evolution of the X-ray signal



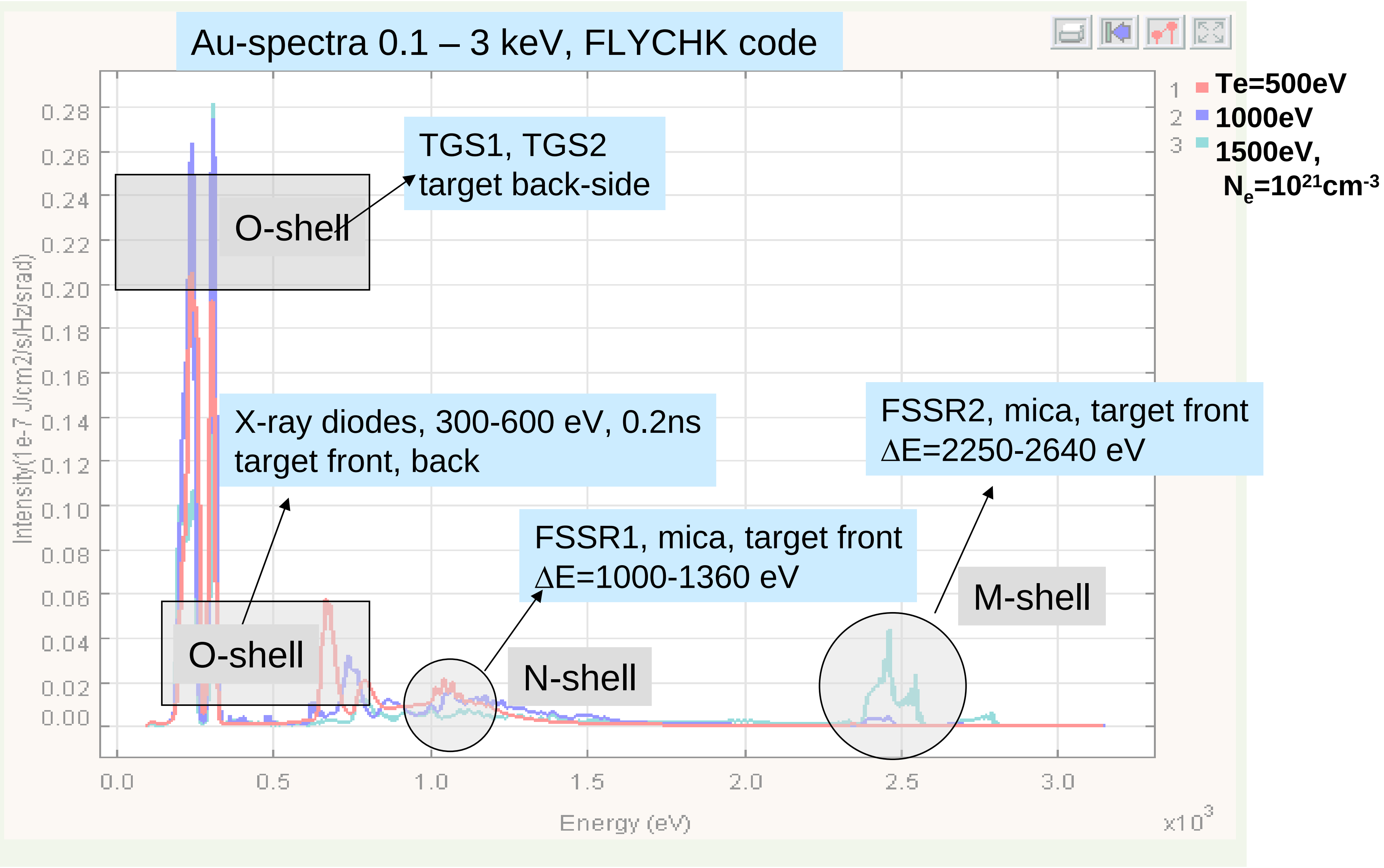
Transmission grating spectrometer (2): Spectral analysis of the radiation field (1-20nm)



Recorders: UF4 and CCD-camera



Radiation of Au-plasma observed with different diagnostic tools



Au-spectra 0.1 – 3 keV, FLYCHK code

TGS1, TGS2
target back-side

O-shell

X-ray diodes, 300-600 eV, 0.2ns
target front, back

O-shell

FSSR1, mica, target front
ΔE=1000-1360 eV

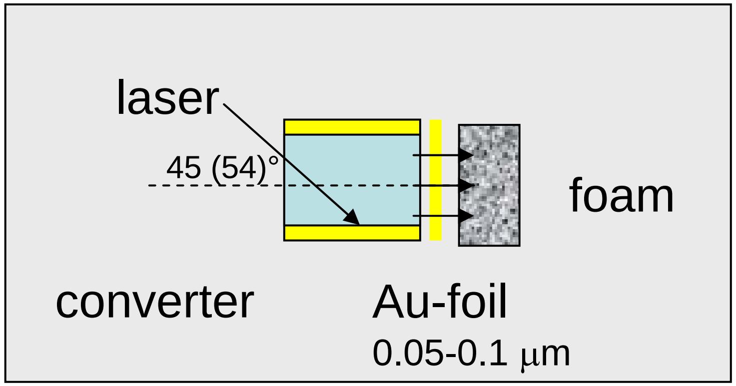
N-shell

FSSR2, mica, target front
ΔE=2250-2640 eV

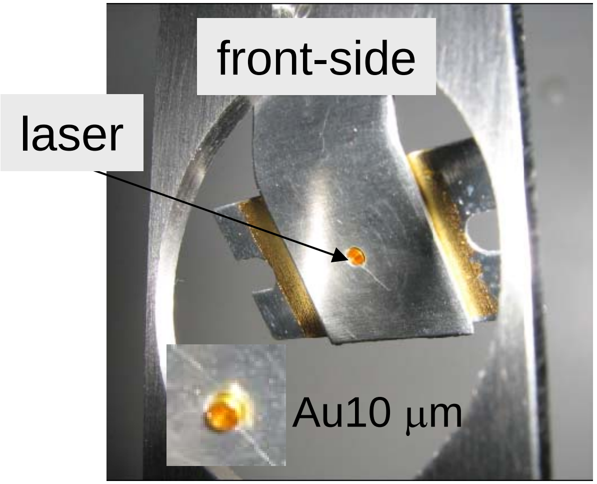
M-shell

Te=500eV
1000eV
1500eV,
$N_e=10^{21} cm^{-3}$

Combined targets: converter + foam/foil

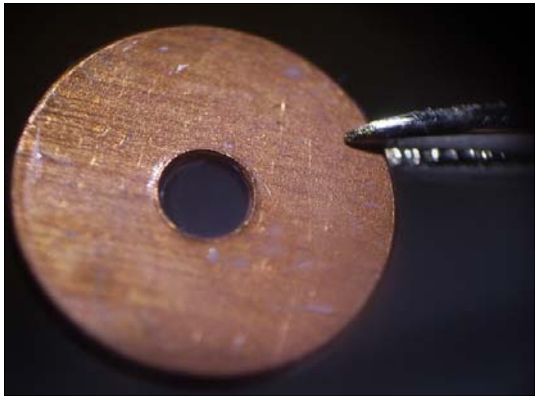


GSI-converter



GSI-converter+foam

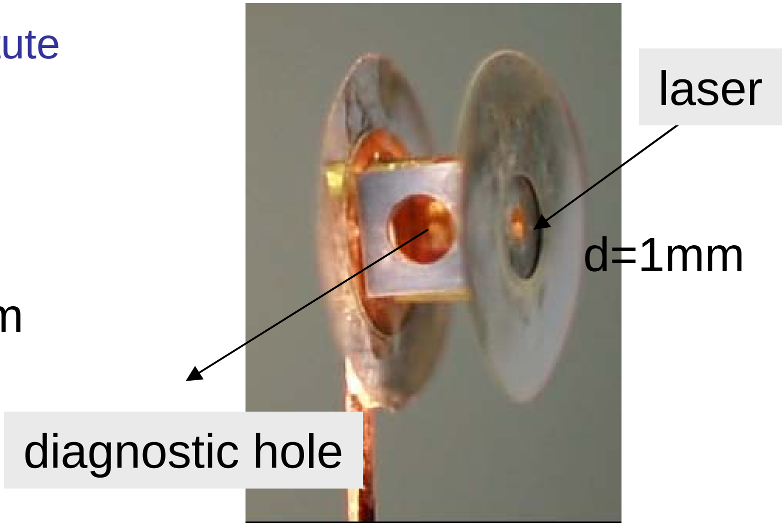
1. $(CH)_n$, foils / $(C_8H_8O_3)$ foams, A. Pinegin, VNIEF Sarov
   ρ = 1.1g/cc, 0.9 μm; ρ=0.1g/cc 90 μm; ρ=0.01g/cc 900μm
2. TAC $(C_8O_6H_{12})$, N. Borisenko, Lebedev Physical Institute



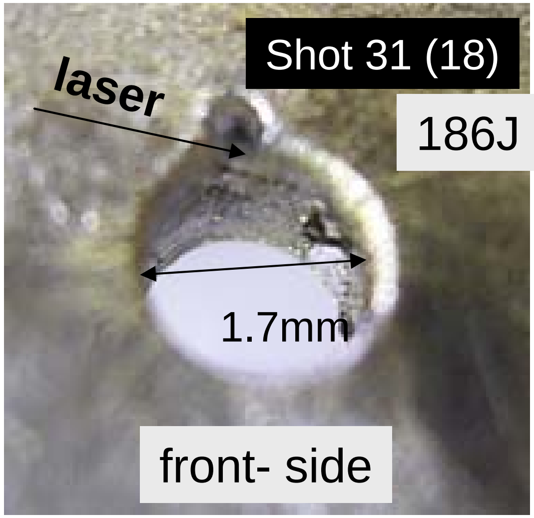
TAC($C_8H_{12}O_6$):

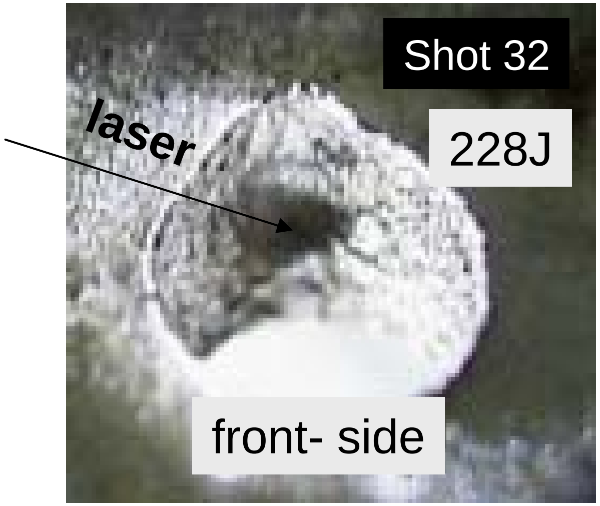
2mg/cc 800-1000μm

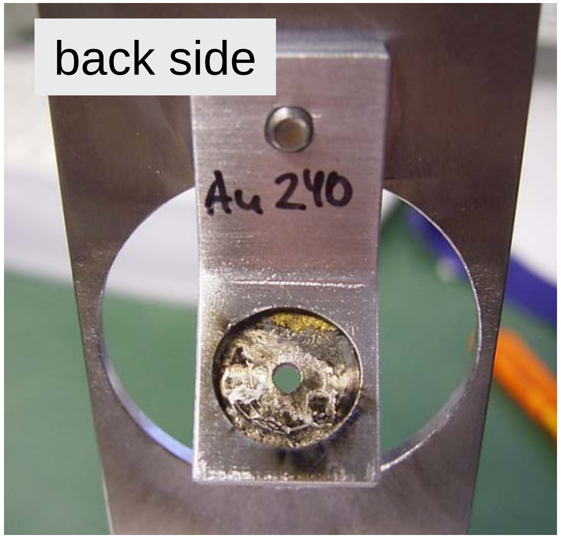
Sarov-converter



Hohlraum targets after shots

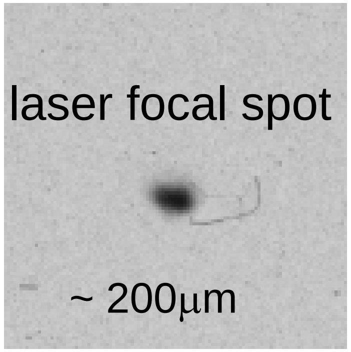






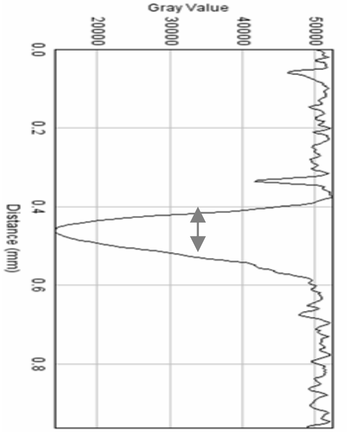
Pin-hole images of hohlraum plasma at low laser energies

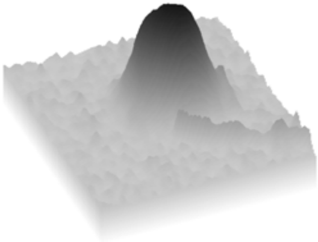
Pin-hole images N5 (d=100 μm, M~1, δx~d(M+1)/M~200μm)



laser focal spot

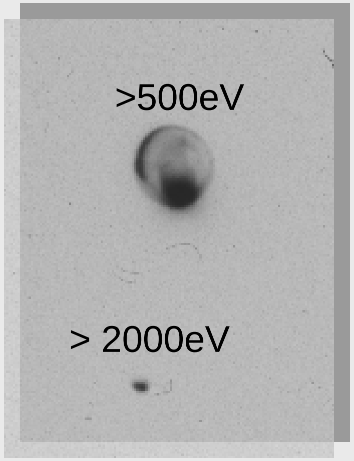
~ 200μm





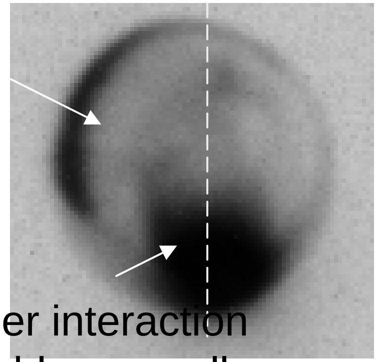
Shot 11 16.02.2010

E=117J, 1.4 ns, 1w



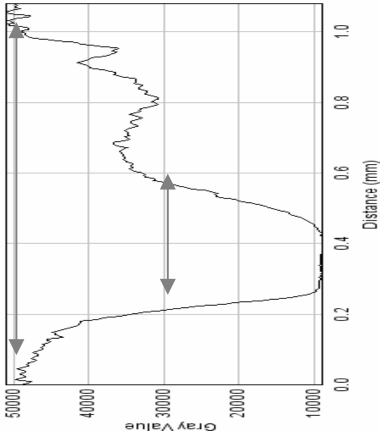
>500eV

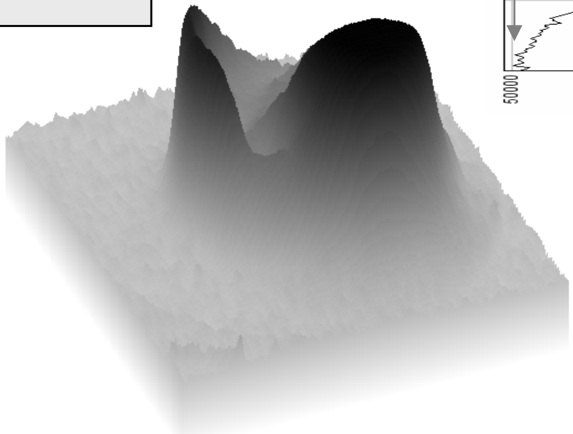
> 2000eV



reflected

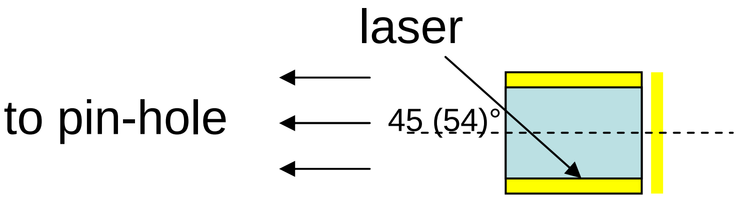
direct laser interaction
with a hohlraum wall



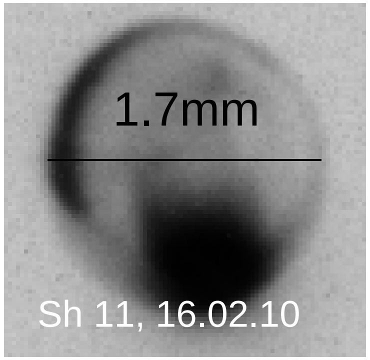


Hohlraum plasma radiation depending on the laser energy

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

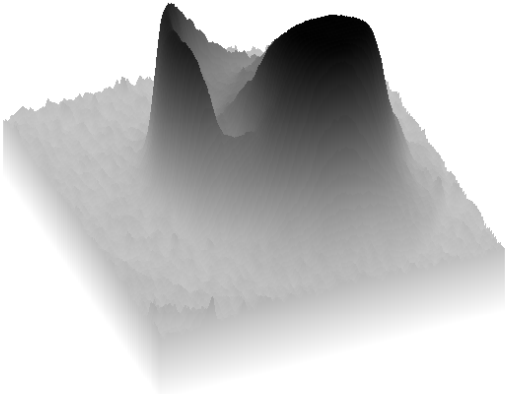


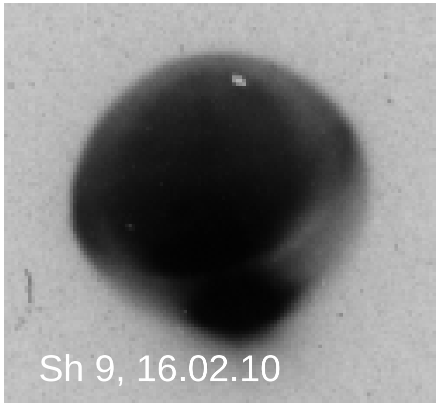
d=100 μm, M~1, dx~d(M+1)/M~200μm



Inhomogeneous

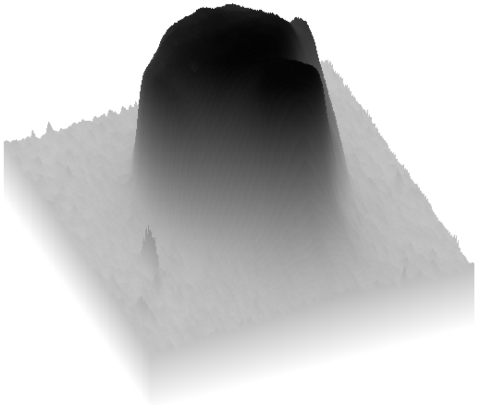
E_{las}=117J



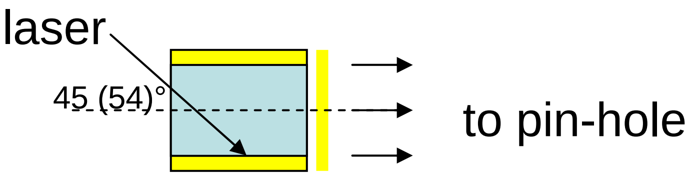


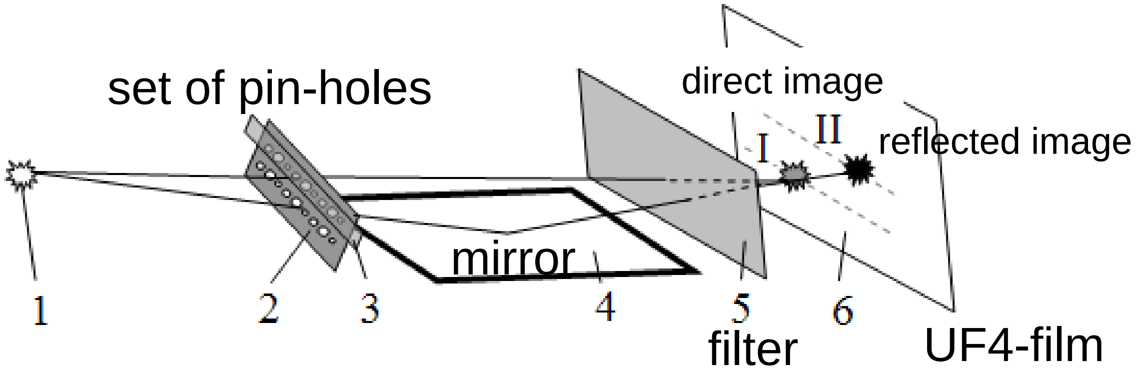
Homogeneous

E_{las}=170J



Pin-hole image of the back-side of the hohlraum





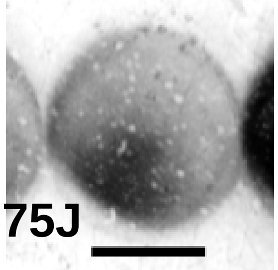
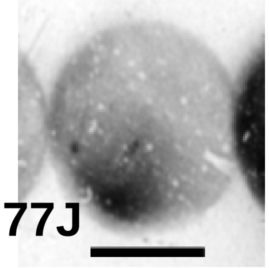
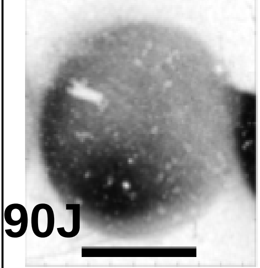
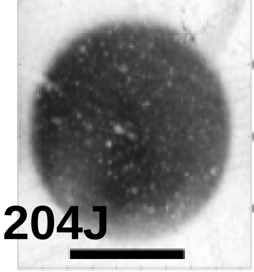
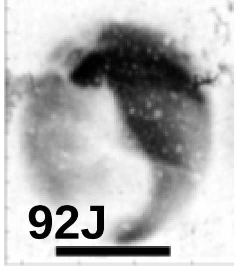
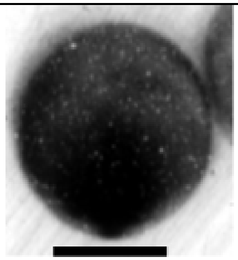
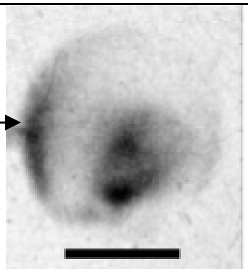
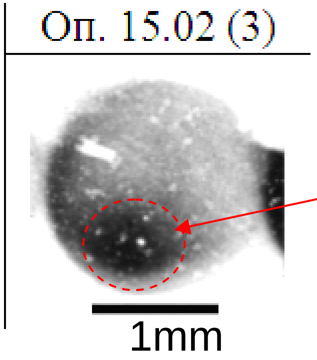
		Оп. 15.02 (1)	Оп. 15.02 (2)	Оп. 15.02 (3)	Оп. 17.02 (3)	Оп. 23.02 (2)
0.2-0.28 keV	reflected image	 **75J**	 **77J**	 **90J**	 **204J**	 **92J**
	direct image	0.9μm CH + 0.1μm Al →		Al 3 μm → (>1.5 keV)		—

Рис.   . Схема камеры обскуры с зеркалом ПВО.
1- источник РИ; 2- диафрагма; 3-фильтр на диафрагме; 4- зеркало ПВО; 5- филь
на кассете; 6- пленка с изображениями: I- прямое изображение, II- отражение от зеркал

results N. Suslov, VNIEF, Sarov

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

E=76.8J,
target: GSI-converter d=1.9 h=1.9mm, wall 10 μm Au ; bottom: Au -170μg/cm^2



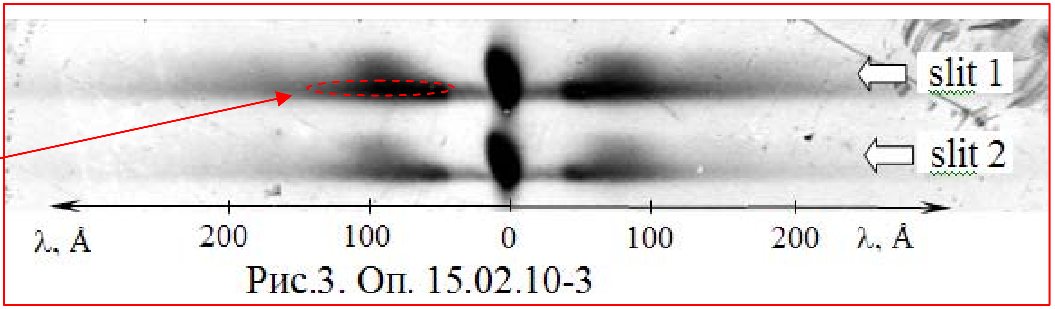
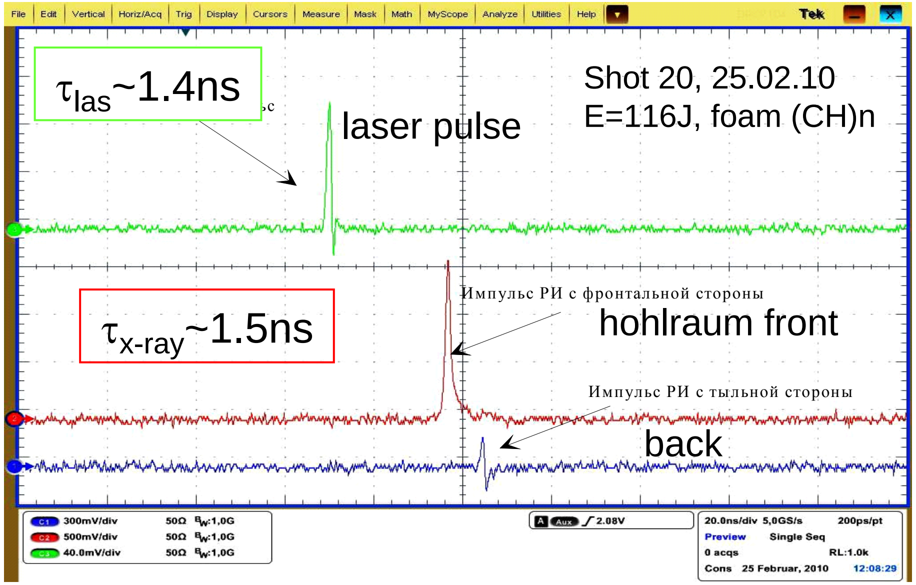


Рис.3. Оп. 15.02.10-3

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_{las}~1.4ns

laser pulse

Shot 20, 25.02.10
E=116J, foam (CH)n

$\tau_{x\text{-}ray}$~1.5ns

Импульс РИ с фронтальной стороны
hohlraum front

Импульс РИ с тыльной стороны
back

C1 300mV/div 50Ω B_W:1,0G
C2 500mV/div 50Ω B_W:1,0G
C3 40.0mV/div 50Ω B_W:1,0G

A Aux ∫ 2.08V

20.0ns/div 5,0GS/s 200ps/pt
Preview Single Seq
0 acqs RL:1.0k
Cons 25 Februar, 2010 12:08:29

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

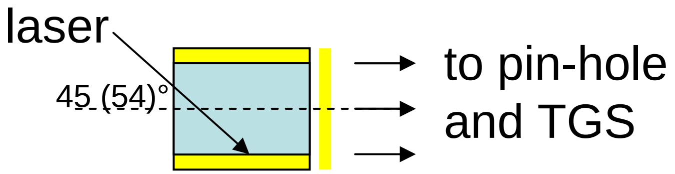
X-ray duration ~ laser pulse

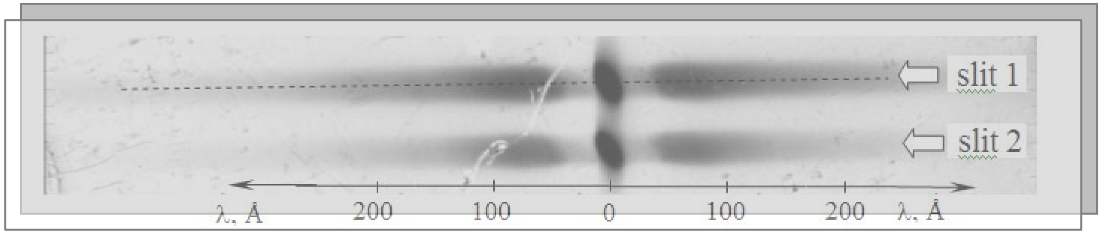
Hohlraum radiation temperature 40 eV at laser energy of 240J

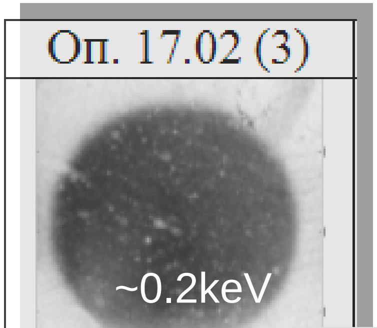
E_{las}=204J

target – GSI-converter

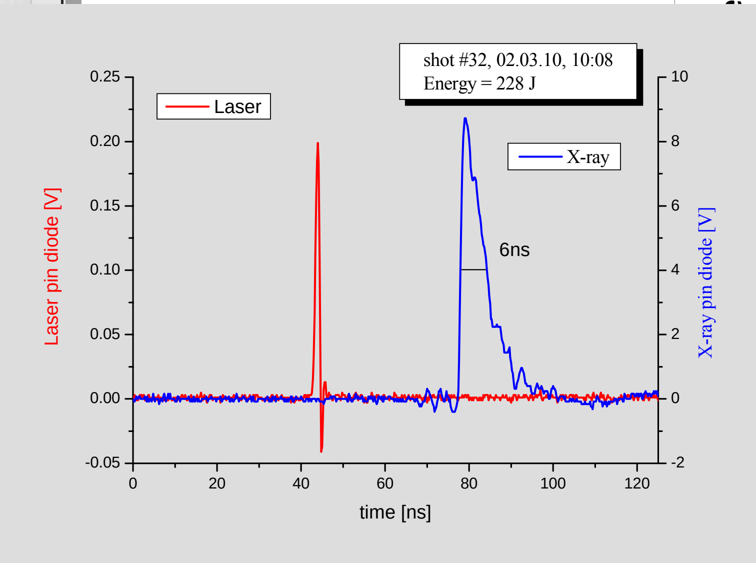
TGS-Sarov

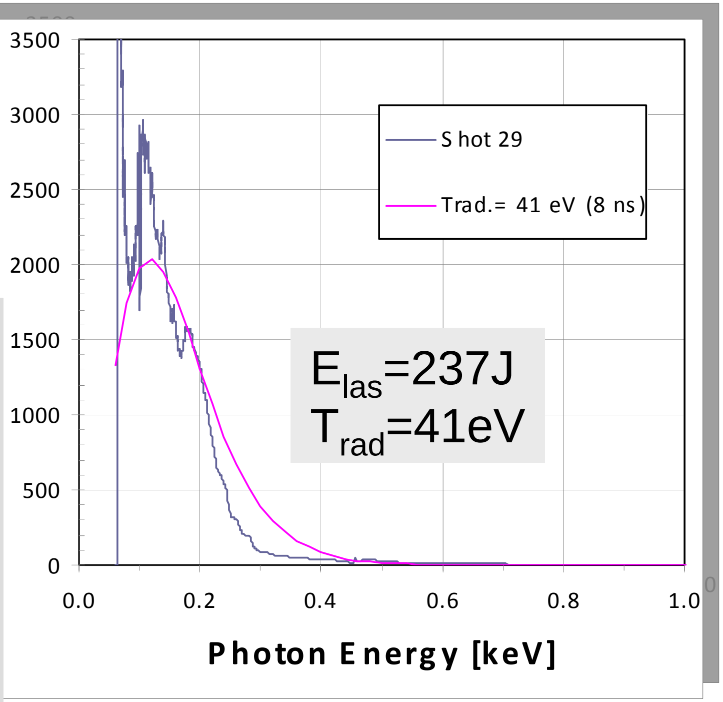






pin-hole imag



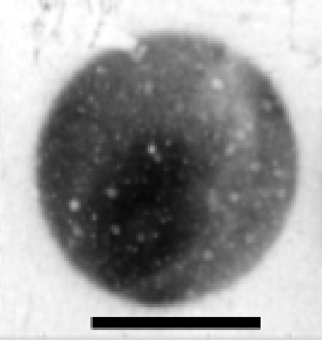
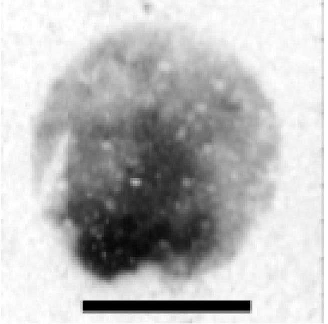


E_{las}=237J

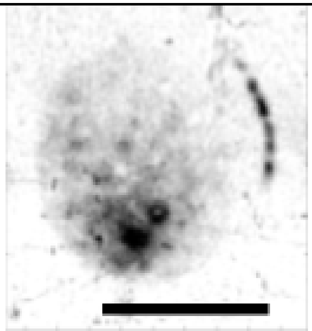
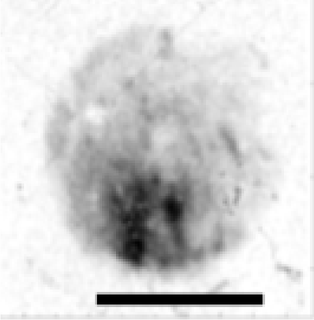
T_{rad}=41eV

Absorption of soft-X-rays in foam targets

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

24.02 (1) E=127J	25.02 (2) E=116J
	
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 $\rho x = 300 \mu g/cm^2$

Increased absorption at $E_{las} > 200J$

24.02 (3) E=218J	25.02 (1) E=216J
	
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 $\rho x = 450 \mu g/cm^2$

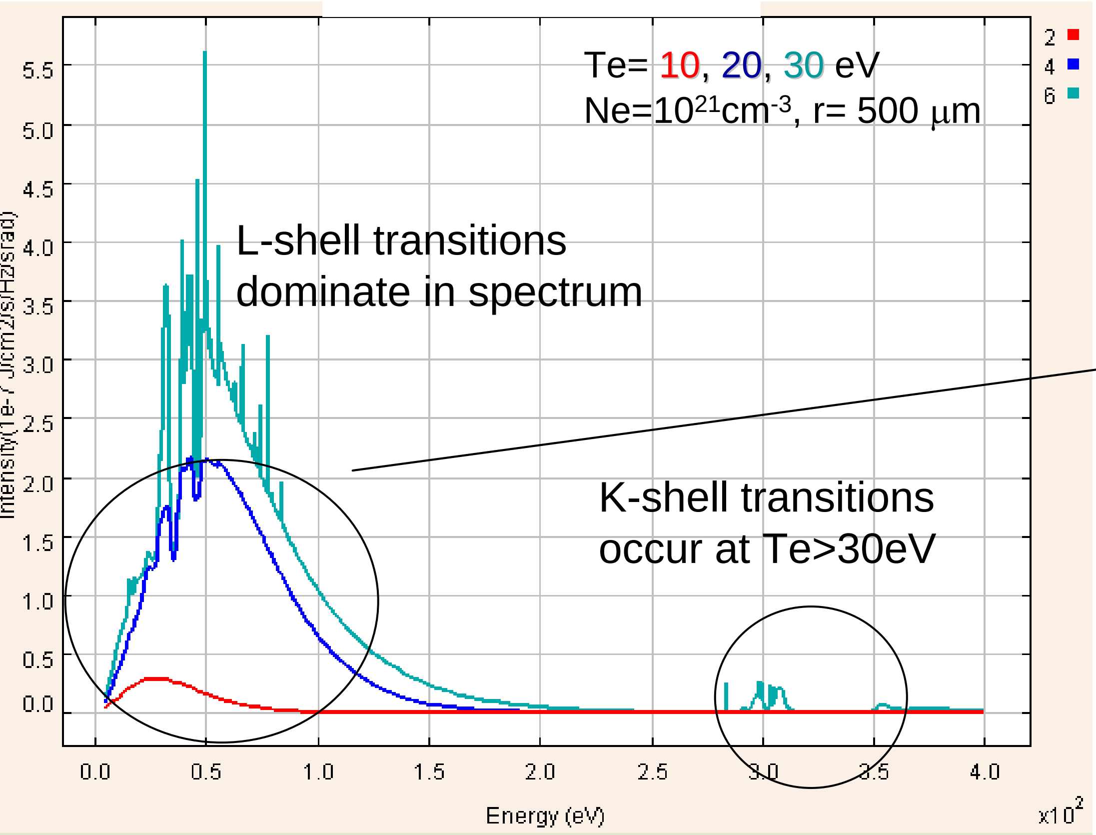
results N. Suslov, VNIEF, Sarov

Spectral properties of CH-targets heated with hohlraum radiation

C-plasma is in thermodynamical equilibrium

Boltzmann – Saha – Planck

(Te =5-15 eV, r = 500μm, ρ = 1/100 ρ_{solid})

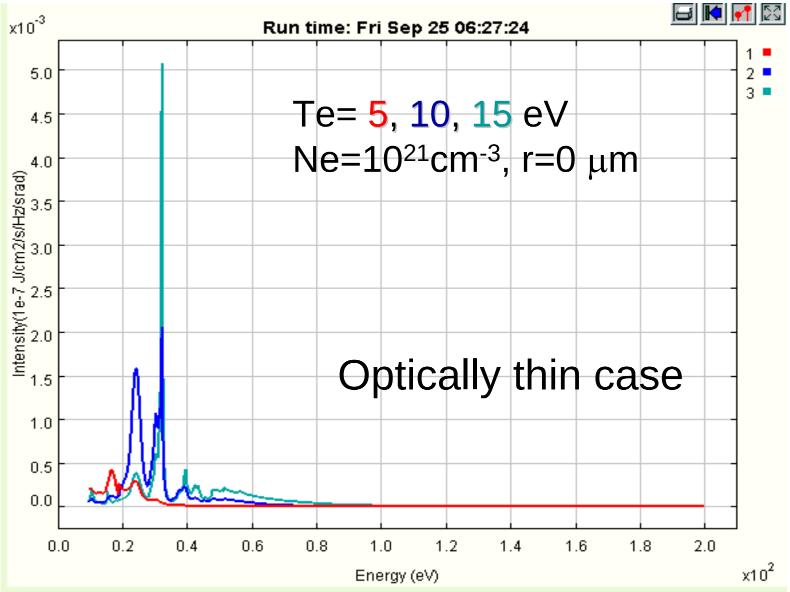


Te= 10, 20, 30 eV

Ne=10^{21}cm^{-3}, r= 500 μm

L-shell transitions dominate in spectrum

K-shell transitions occur at Te>30eV

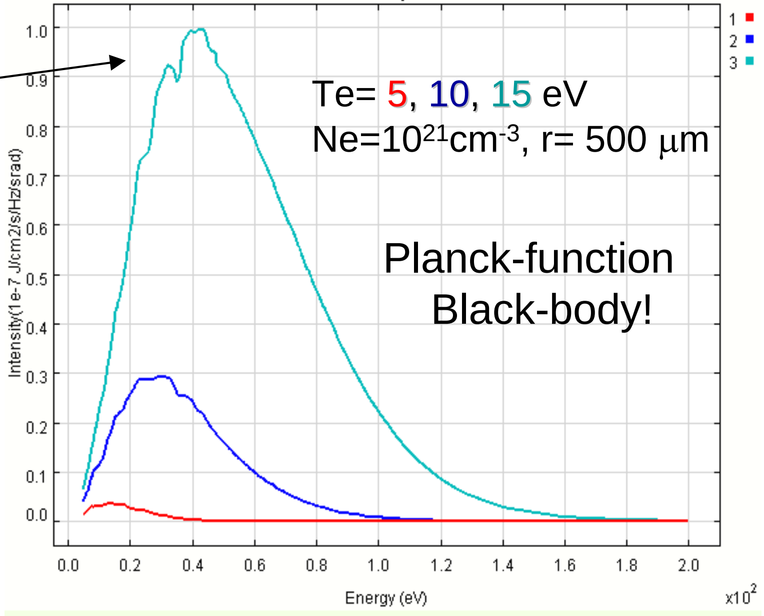


Run time: Fri Sep 25 06:27:24

Te= 5, 10, 15 eV

Ne=10^{21}cm^{-3}, r=0 μm

Optically thin case



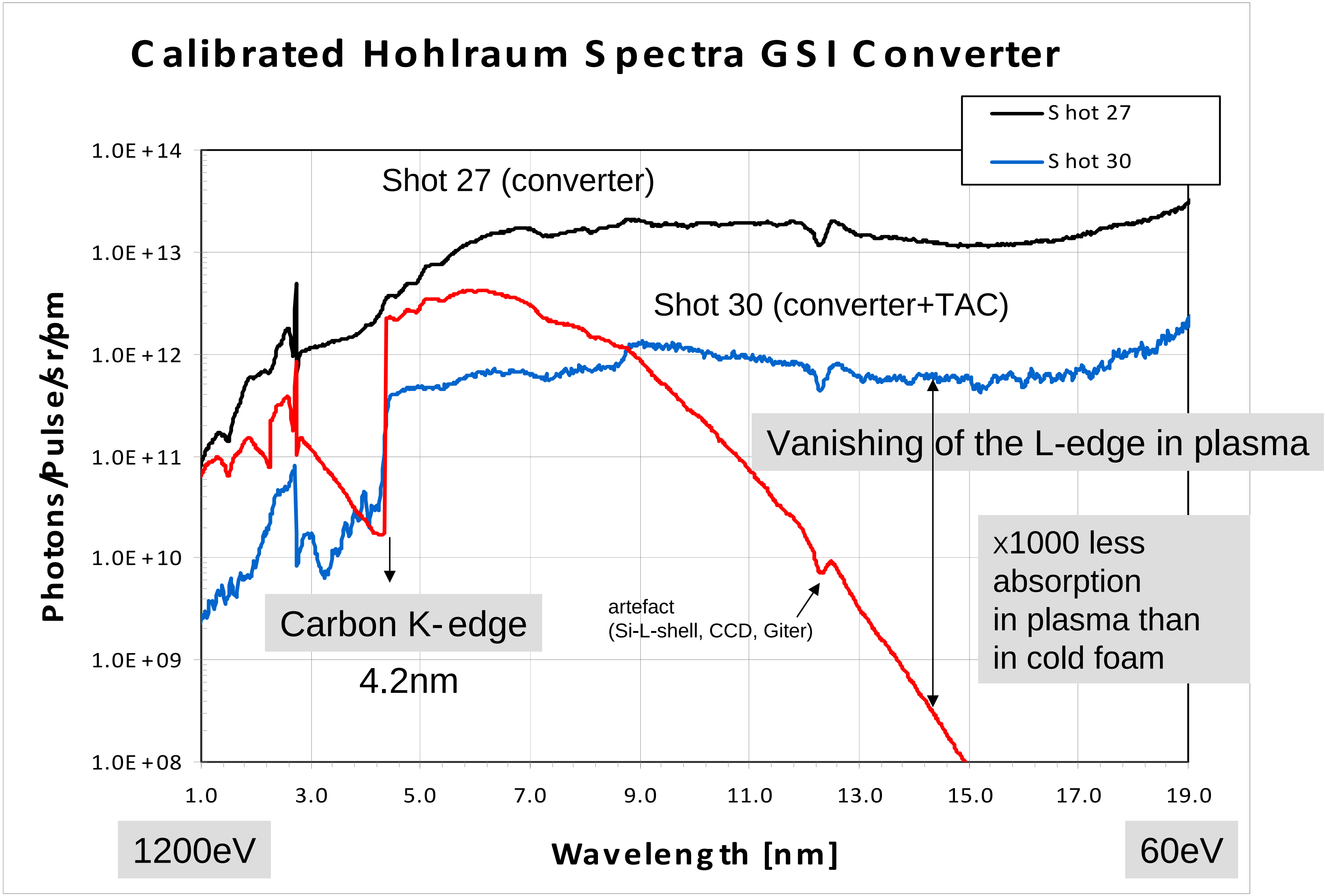
Te= 5, 10, 15 eV

Ne=10^{21}cm^{-3}, r= 500 μm

Planck-function

Black-body!

Absorption properties of heated to plasma foams



Vanishing of the L-edge in plasma

Carbon K-edge

4.2nm

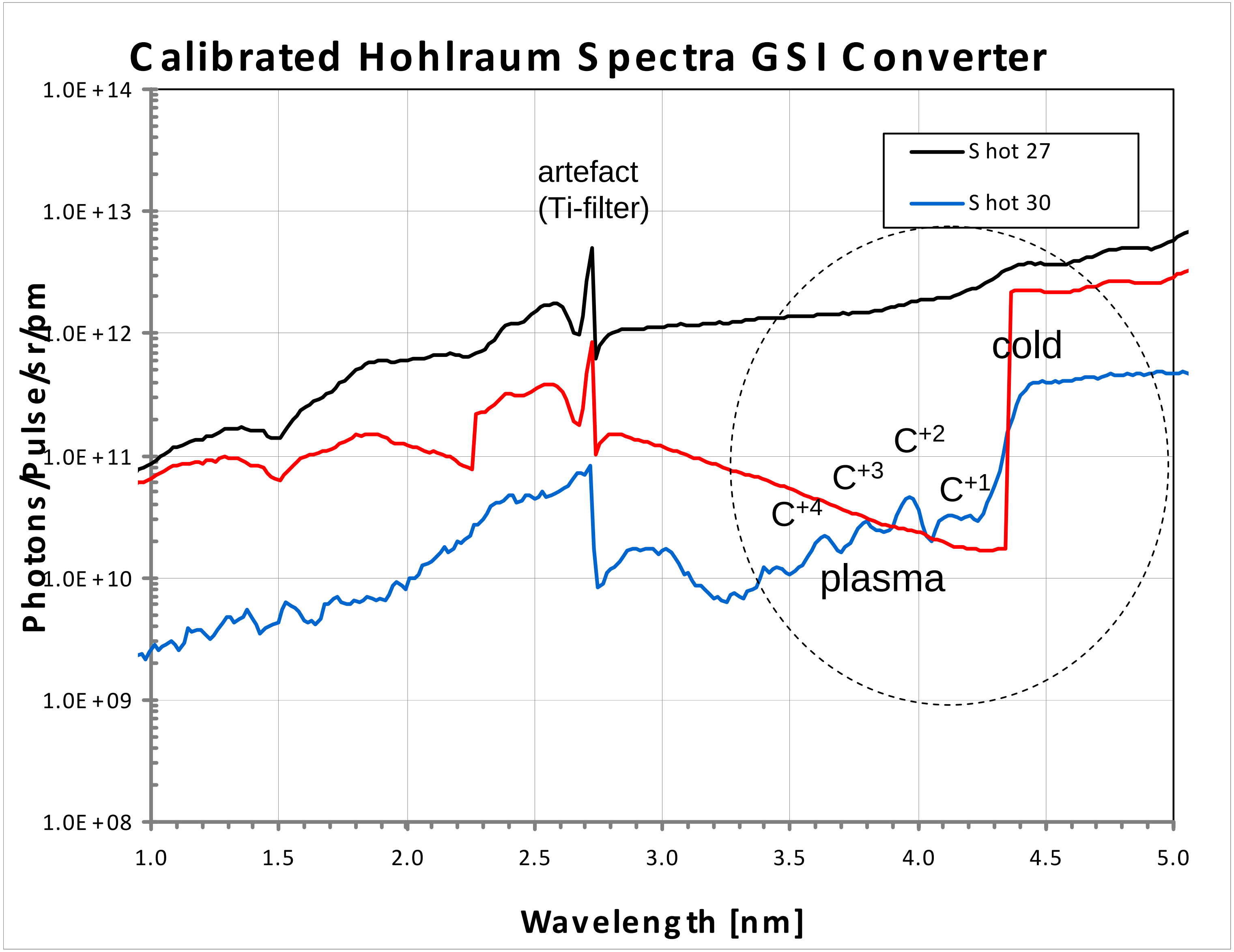
artefact
(Si-L-shell, CCD, Giter)

x1000 less
absorption
in plasma than
in cold foam

1200eV

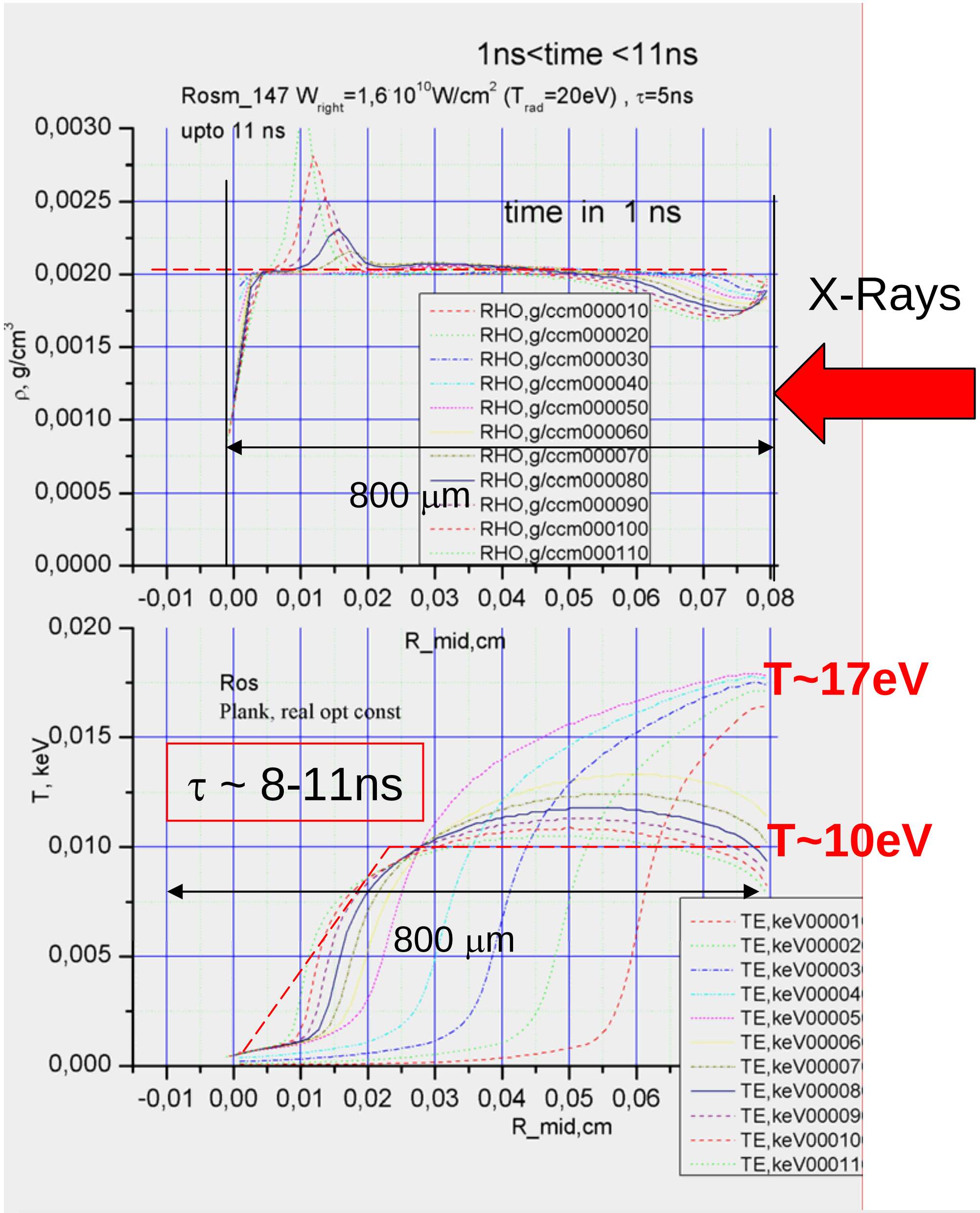
60eV

Deformation of Carbon K-edge in plasma

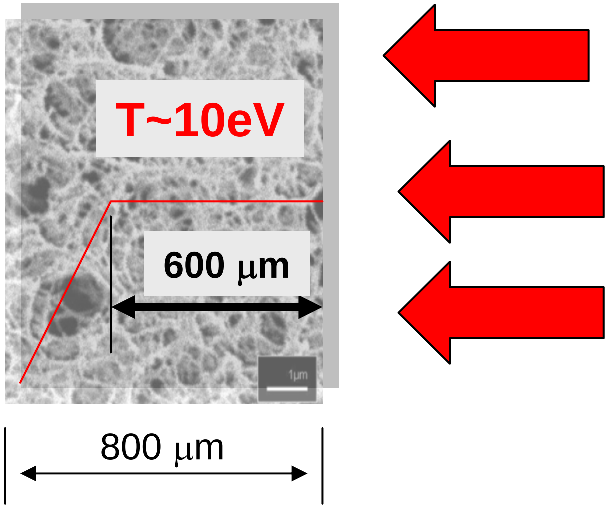


D. Schäfer, Th. Nisius, Th. Wilhein, Remegen

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

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

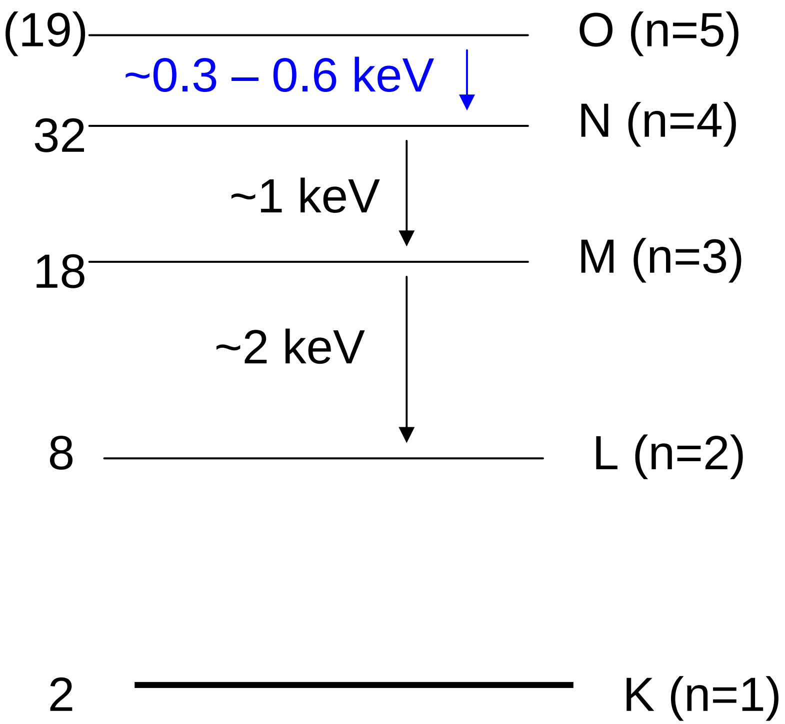
Foam:

- 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 the ionization degree .
- Rich experimental data on the hohlraum radiation field and opacities of plasma with a coupling parameter

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

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

Shell structure of Gold (79)



(19) O (n=5)

~0.3 – 0.6 keV

32 N (n=4)

~1 keV

18 M (n=3)

~2 keV

8 L (n=2)

2 K (n=1)

Radiative transitions with energies of 0.3 -0.6keV are effective for the heating of the target due to high absorption in matter

If plasma is too hot, so that N and O levels are empty (up Cu-like Au $^{51+}$), the radiation in the photon region above 1 keV dominates in Au-spectra. Bed conditions for the target heating due to high transparency of matter .