A brief history of the Czech-French collaboration about X-UV lasers at PALS

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PALS 10th anniversary, Prague, September 22-24, 2010

Academic affiliation : LSAI - LIXAM

Laboratoire de Spectroscopie Atomique et Ionique,
(CNRS and Université Paris-Sud)

→ **2002**

Laboratoire d'Interaction des rayonnements X avec la Matière
(CNRS and Université Paris-Sud)

→ **2009**

Group of atomic physics of highly-ionised atoms (Pierre Jaeglé)

- New line identifications - emission and absorption
- Doppler broadening and shift
- Linear and quadratic Stark effect
- Radiative transfer
- Populations, X-UV amplification and X-UV lasers

In 1969 : **Nd-glass laser 3 J, 30 ns**

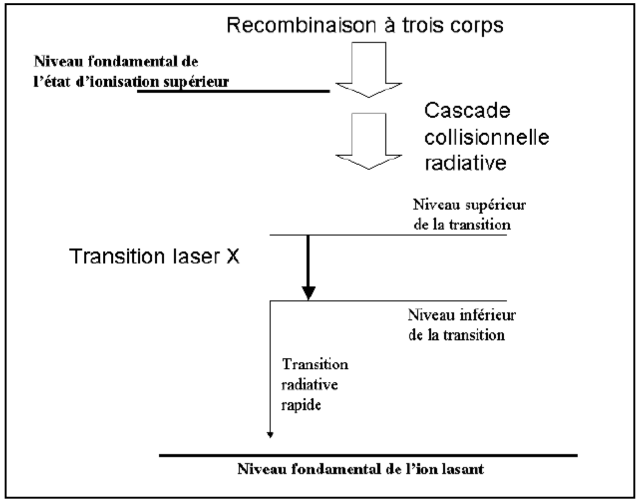
Summary

- French prehistory of PALS 1991 - 1995
- Contribution of LSAI/LIXAM to the PALS X-UV laser
  - Interaction facilities
  - The zinc X-UV laser of PALS 21.2 nm
  - X-UV interferometry : an efficient tool for plasma physics and surface testing
  - Interaction between X-UV laser and matter : application to biology irradiation of DNA.
- Conclusions

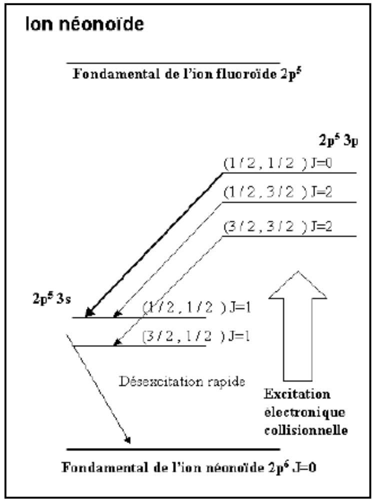
State of the art of X-UV lasers in 1990

Two main processes responsible for X-UV lasers.

- Dielectronic recombination in fast cooling plasmas
  H-like, Li-like ions, "moderate" driving laser energy (RAL, LULI, Asterix, …) (< kJ)
- Excitation by electron-ion collisions in hot dense plasmas
  Ne-like Se (LLNL), high-energy driving lasers (> kJ)



Recombination scheme



Collisional scheme

"French" prehistory of the PALS

1991 : PhD thesis proposal by LSAI.

Subject : collisional X-UV laser with the LULI driver (≤ 500 J, 600 ps).

Excitation Ne-like Zn X-UV laser (21.2 nm).

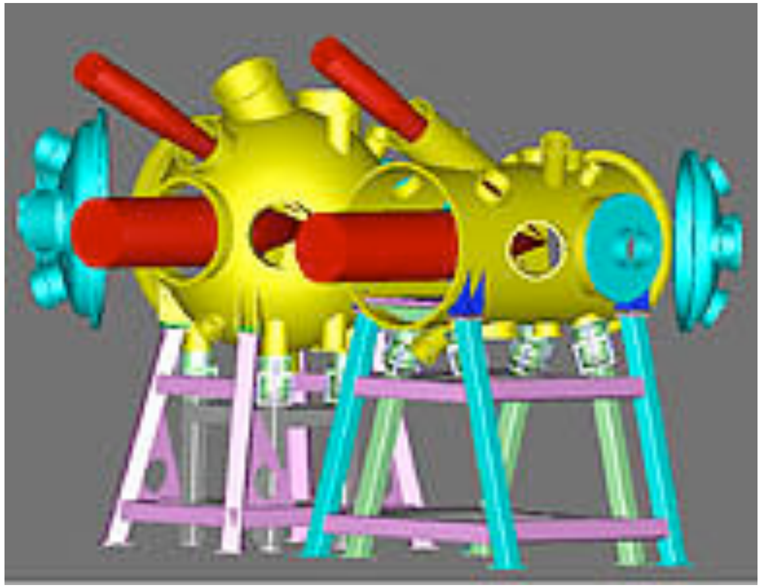
Double - pass amplification.

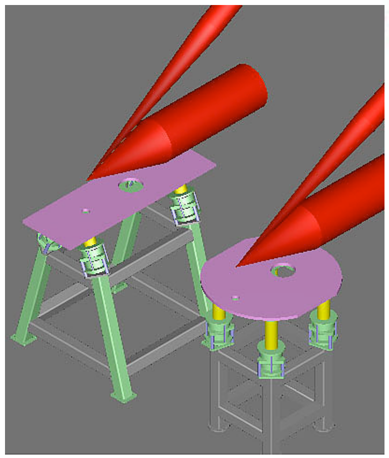
1991 - 1994 : observation and progressive enhancement of the laser lines

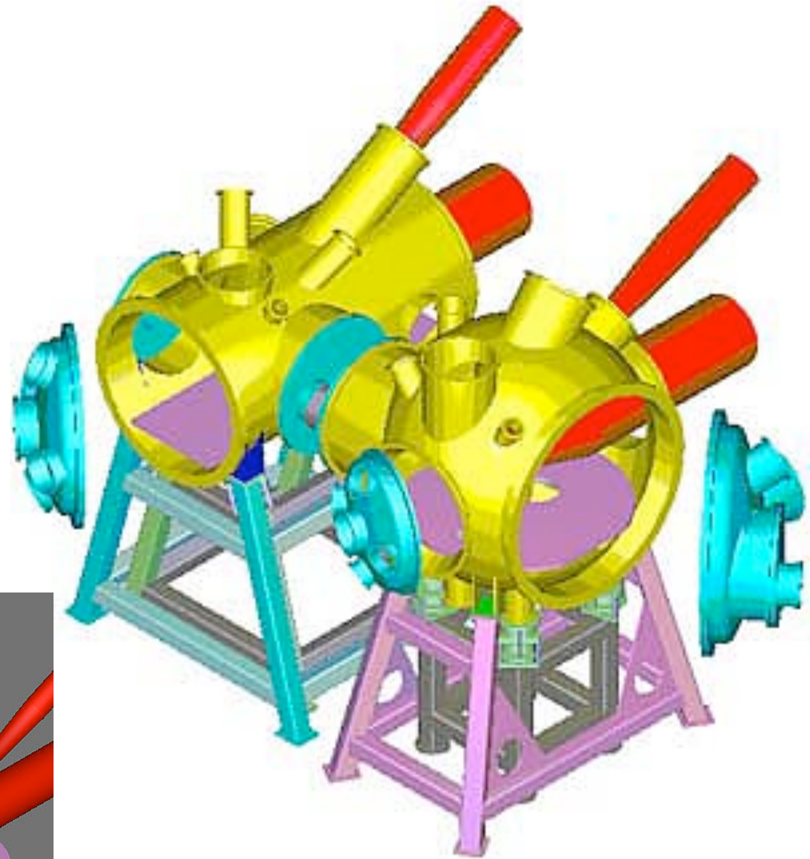
- **Important role of a very low (10 mJ) pre-pulse 10 ns previously to the main driving pulse (500 J).** The prepulse enhances the plasma volume, decreases the density gradient, and consequently the refraction of the amplified X-UV beam.
- Saturated X-UV laser in double - pass operation using a X-UV mirror (half cavity).
- Amplification by the plasma keeps X-UV laser polarisation unchanged (collaboration with RAL)
- First developments of X-UV laser applications

Design of PALS interaction facilities

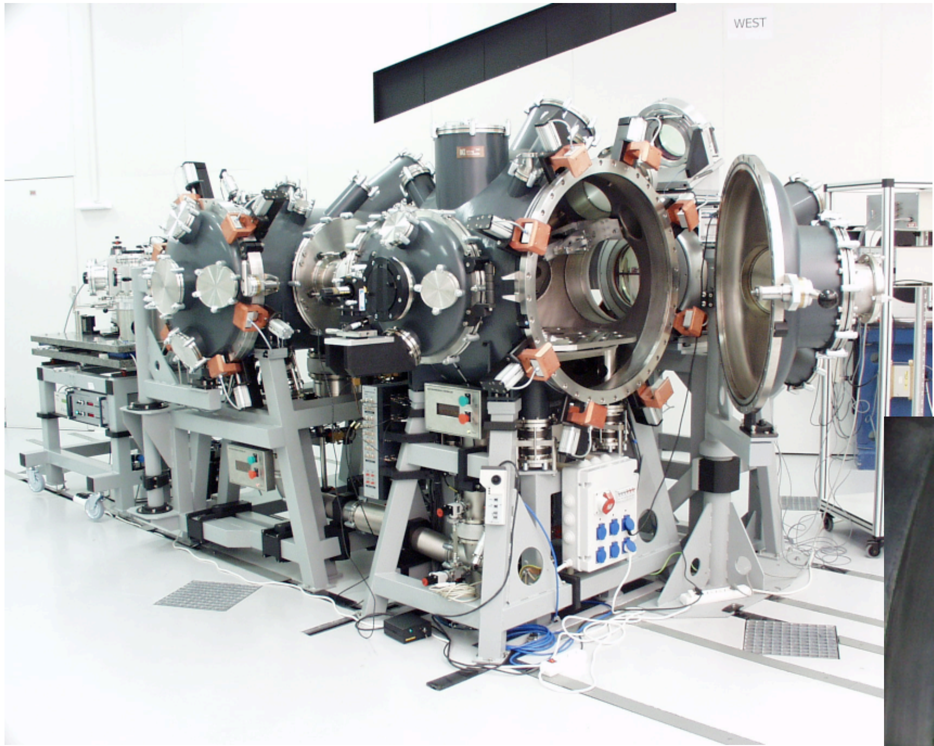
1997 → 2000 : FZU - LSAI project of an experimental device intended for the new location of Asterix IV in Prague (Lagron, Hudeček, Rus, + LSAI)

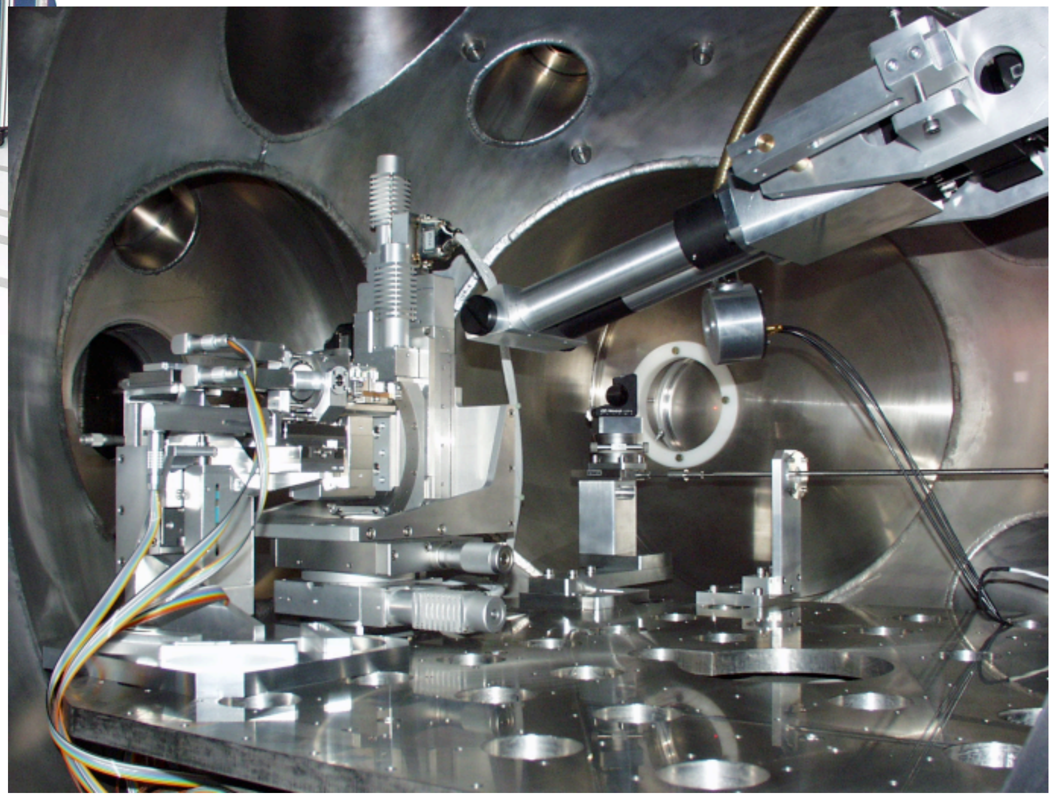






Interaction facilities of the PALS

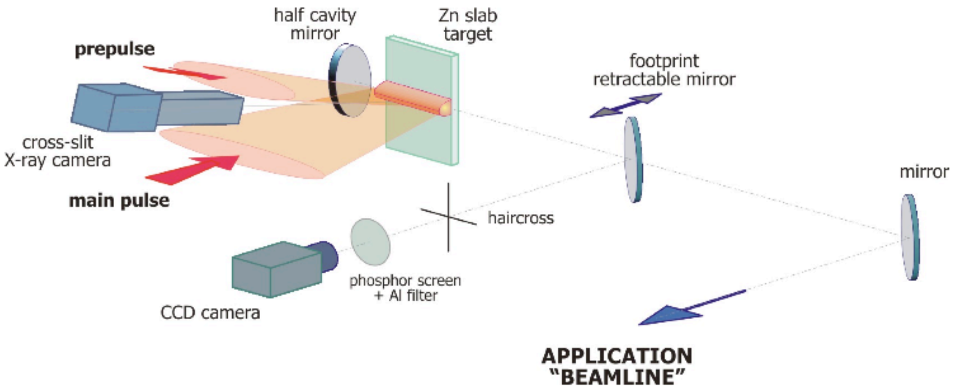




July 2001

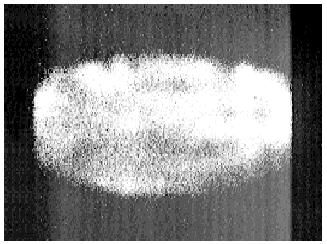
The zinc laser of PALS @ 21.2 nm

First experiments : summer 2001

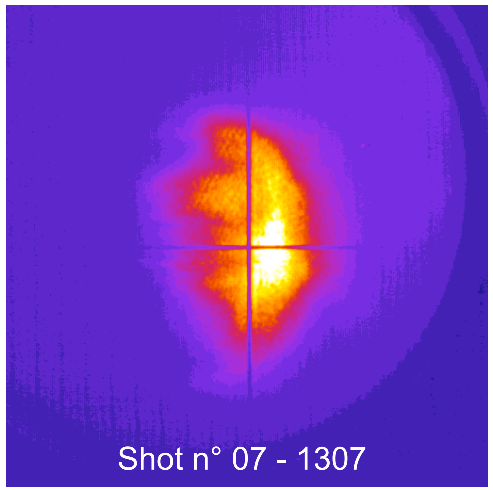


	LULI 1996	PALS 2001
Pumping energy	450 J	500-600 J
Target	2 cm	3 cm
Gain value	5 cm^{-1}	6.5 cm^{-1}
Nb photons/pulse	10^{14}	4 10^{14}
X-UV Energy	1 mJ	4 mJ
Power	15 MW	≈ 60 MW
Solid angle	≈ 2.5 10^{-5} stéradian	≈ 10^{-5} stéradian

Prepulse



Main pulse

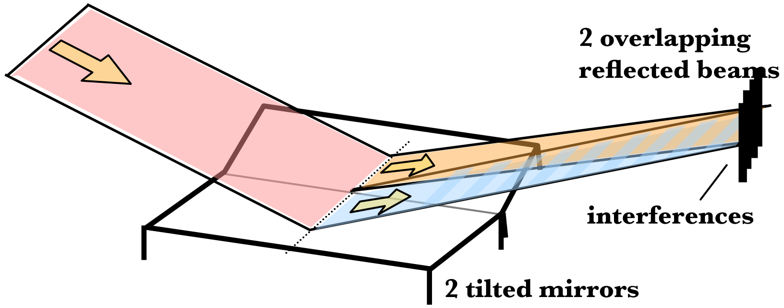


Ultimate PALS X-UV laser properties

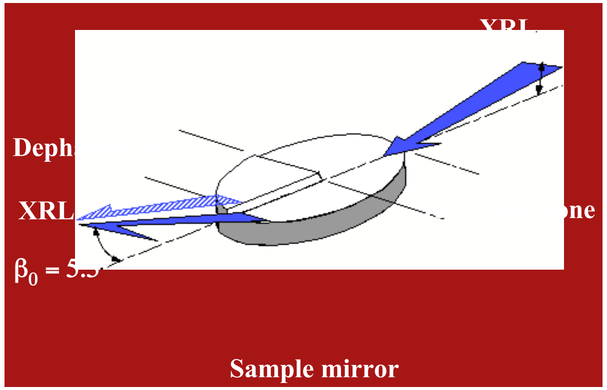
Prepulse-pulse delay	10 ns	50 ns
XRL pulse energy	4 mJ	**10 mJ**
Pulse duration	80-100 ps	
Peak power	40 MW	**100 MW**
Photons per pulse	3×10^{14}	1.2×10^{15}

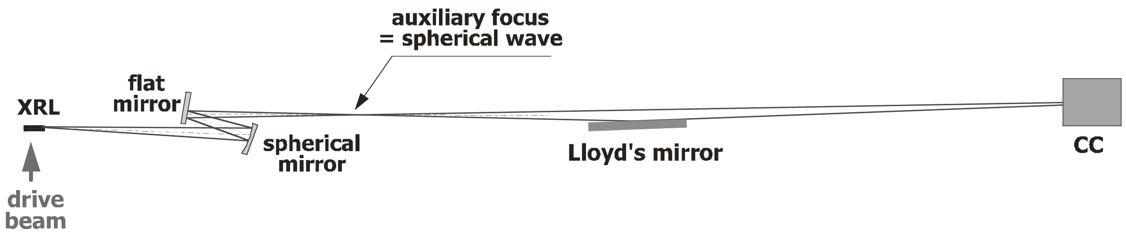
XRL department of x-ray lasers

X-UV interferometry : an efficient technique combined with UV lasers

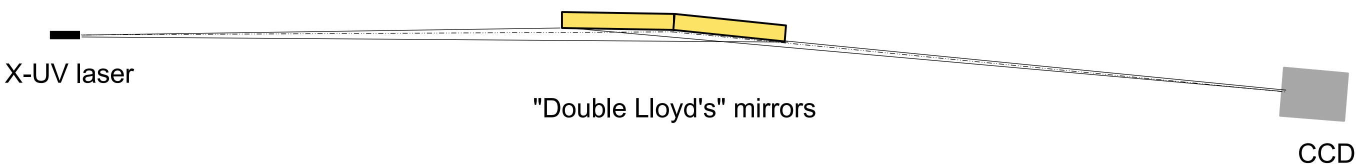


Denis Joyeux (LCFIO) : Fresnel bi-mirror.

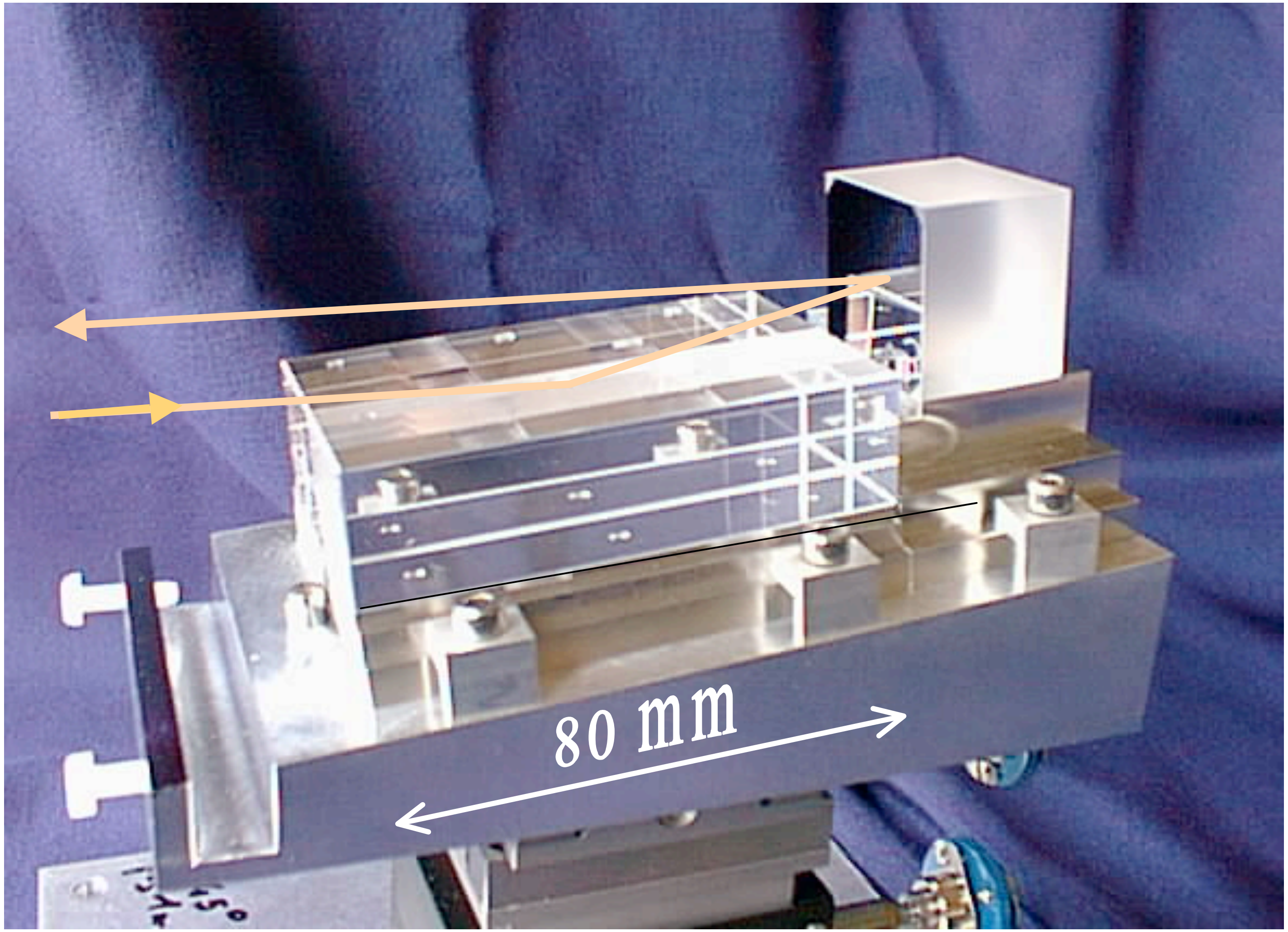




Bedrich Rus (PALS)

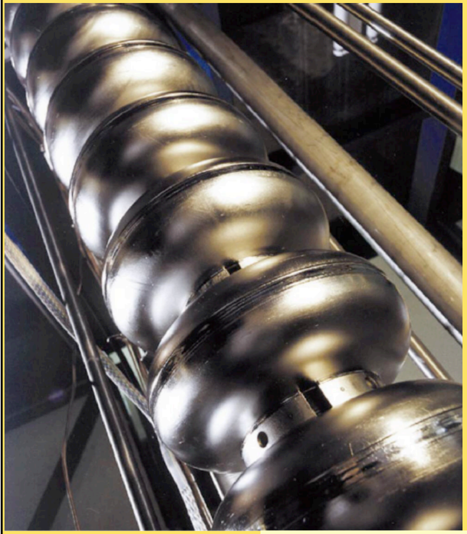


Fresnel interferometer (D. Joyeux, LCFIO)



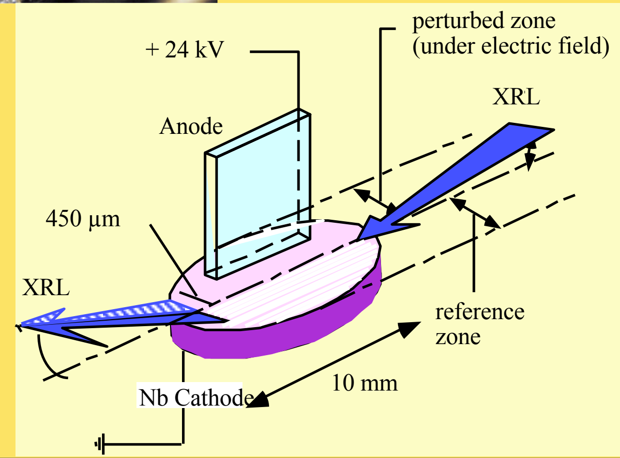
How to make defects on a surface

Electric field (Coll CEA Saclay) 2001



Breakdown in accelerating cavities under theoretical value of the field (50 MV/m)

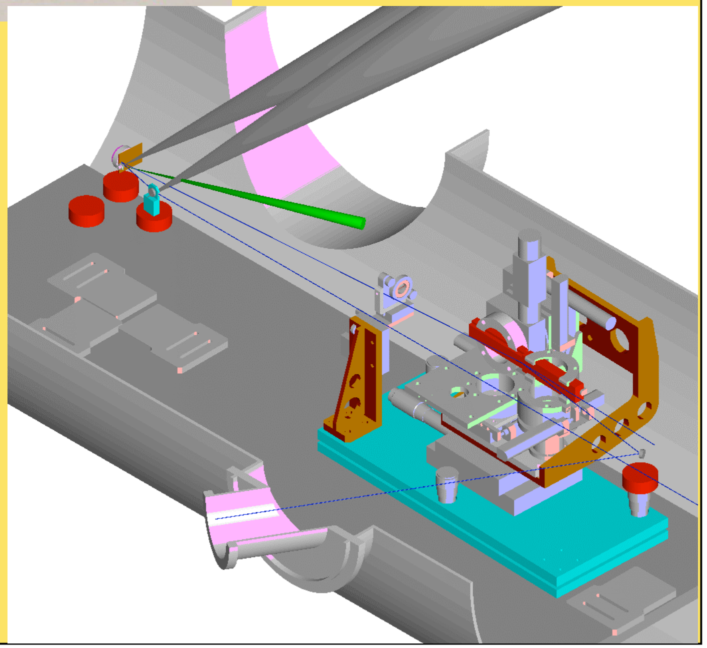
Research of modifications of the Nb surface by moderate electric fields



Optical field (Coll CEA LMJ) 2005

Laser delamination of the rear surface of a BK7 thin plate

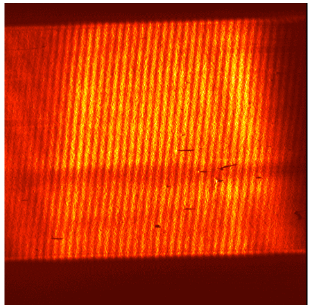
Experimental device for the PALS - LIXAM - CEA experiments



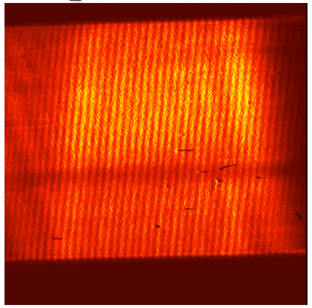
Interferograms of a Nb surface under increasing E-field

(thin niobium layer (2 μm) deposited on glass)

0 - field



1/ positive voltage on knife



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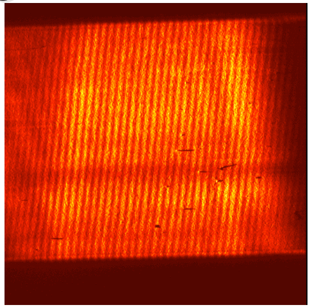

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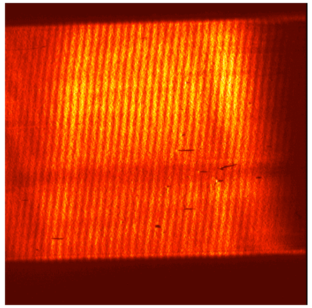
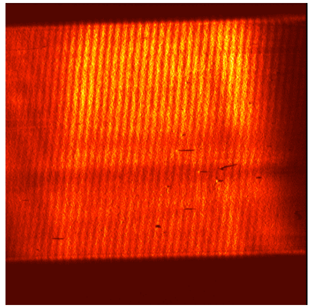
E-field in MV/m

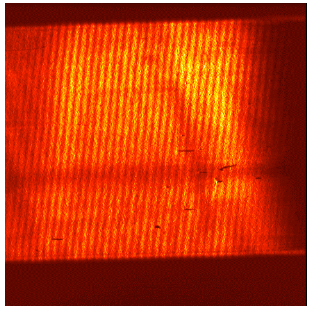


62.5



78

2/ negative voltage on knife



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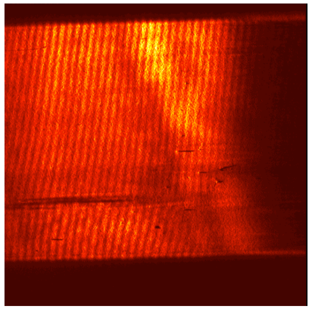

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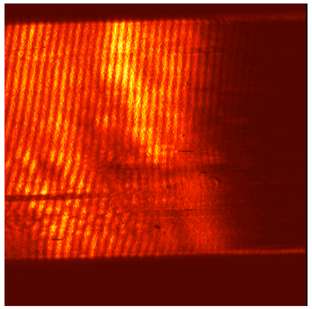
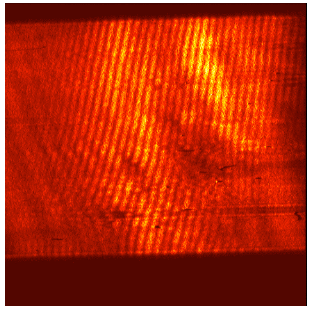
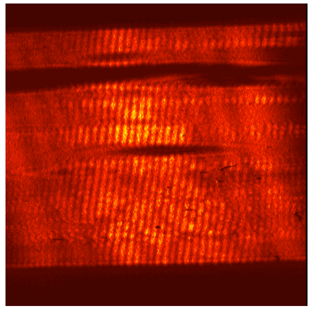


56.25



62.5



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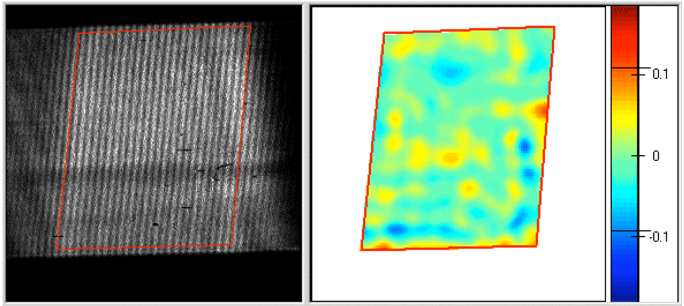
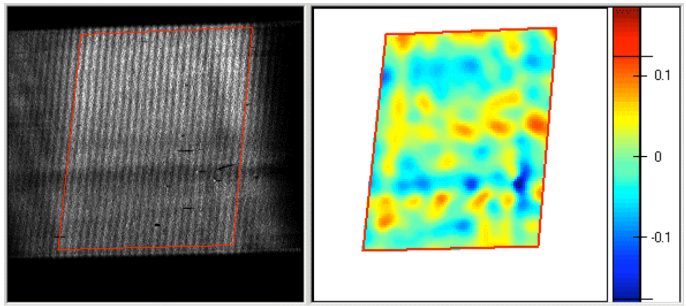
Institut d'Optique

Phase image of the thin niobium layer surface

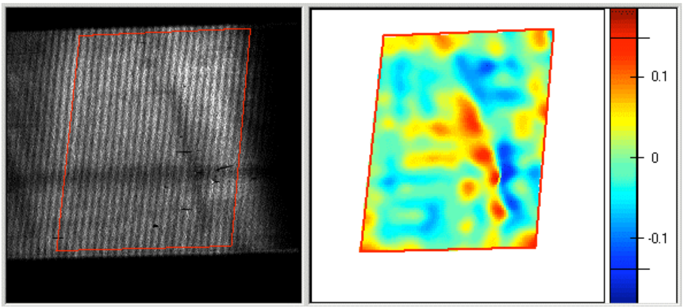
0 - field



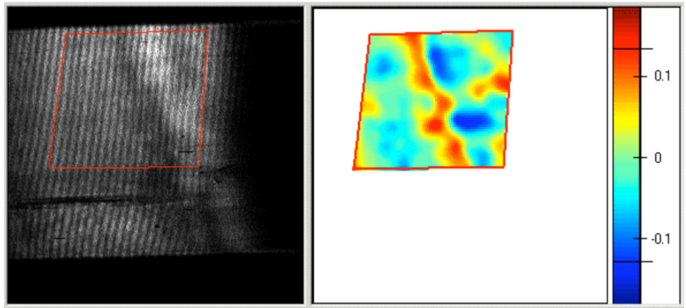
78 MV/m, positive voltage on knife



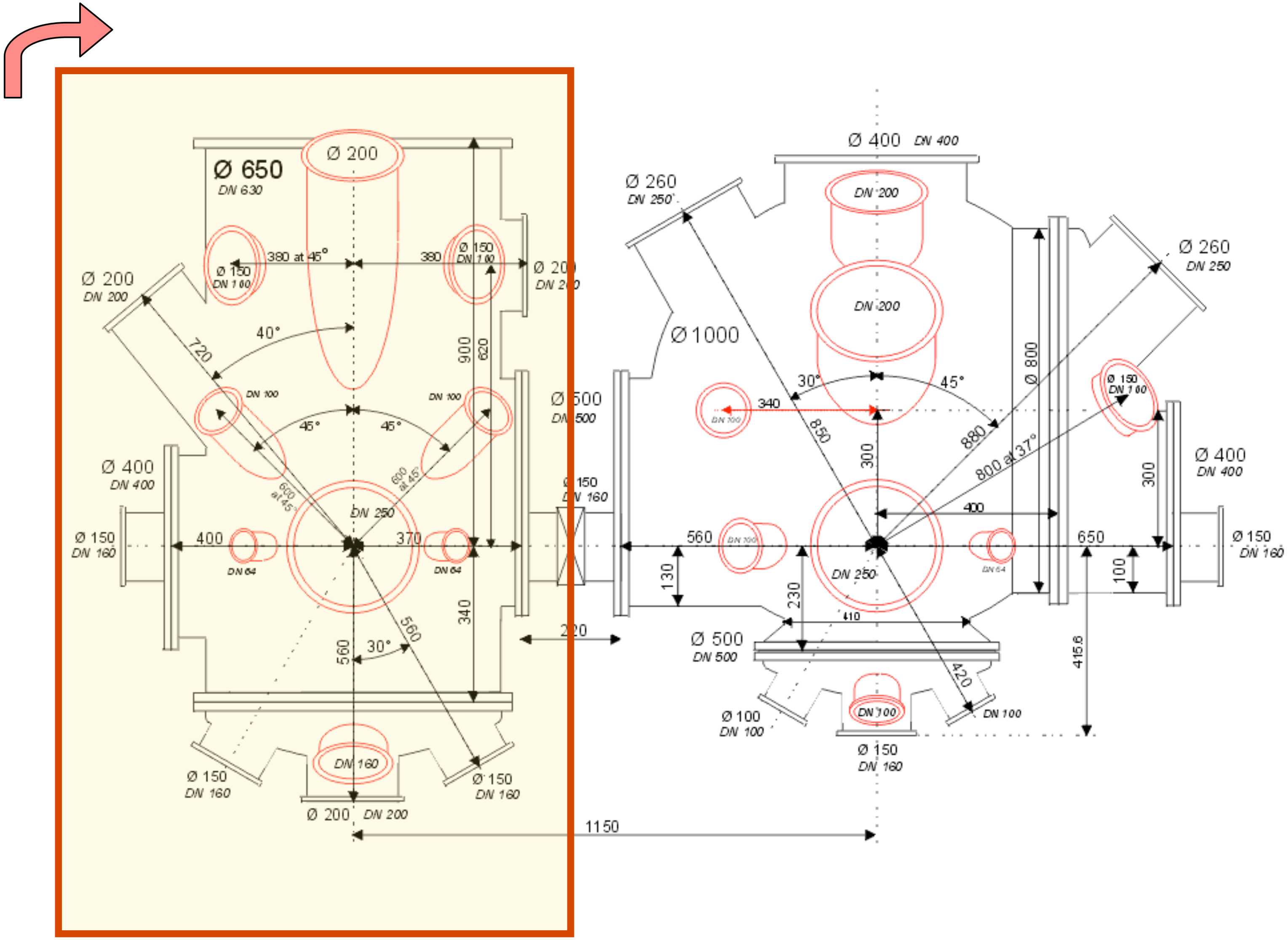
37.5 MV/m, negative voltage on knife



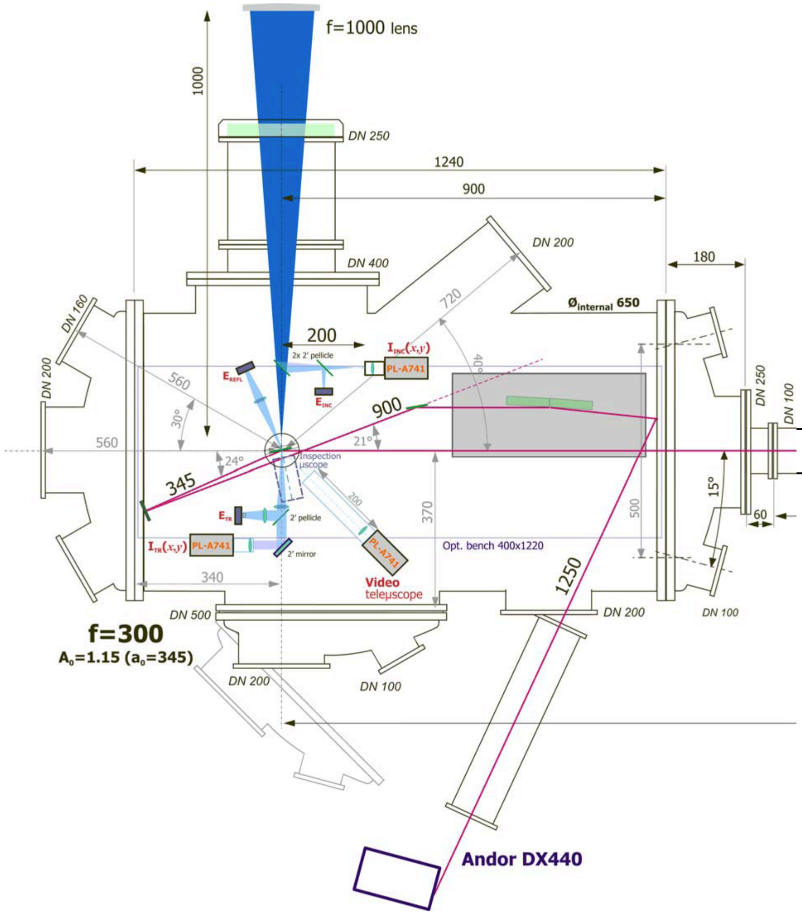
50 MV/m, negative voltage on knife

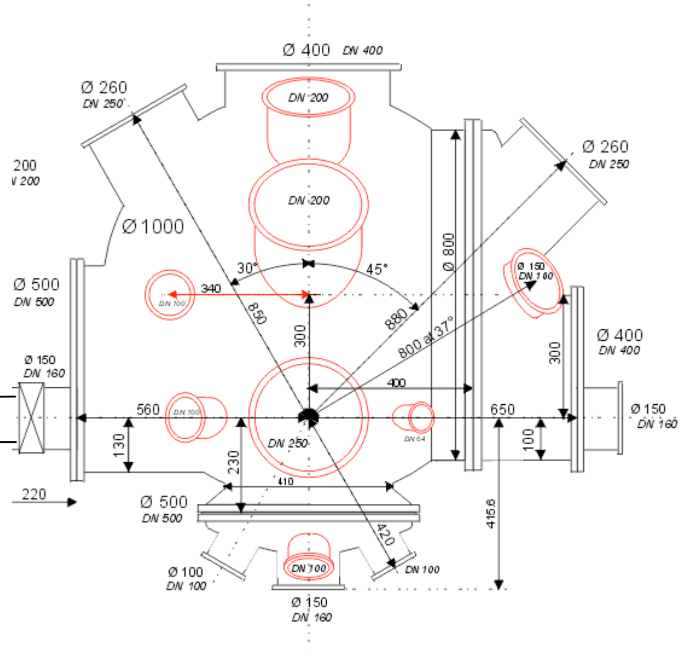


Study of laser damages on optical surfaces (2005)



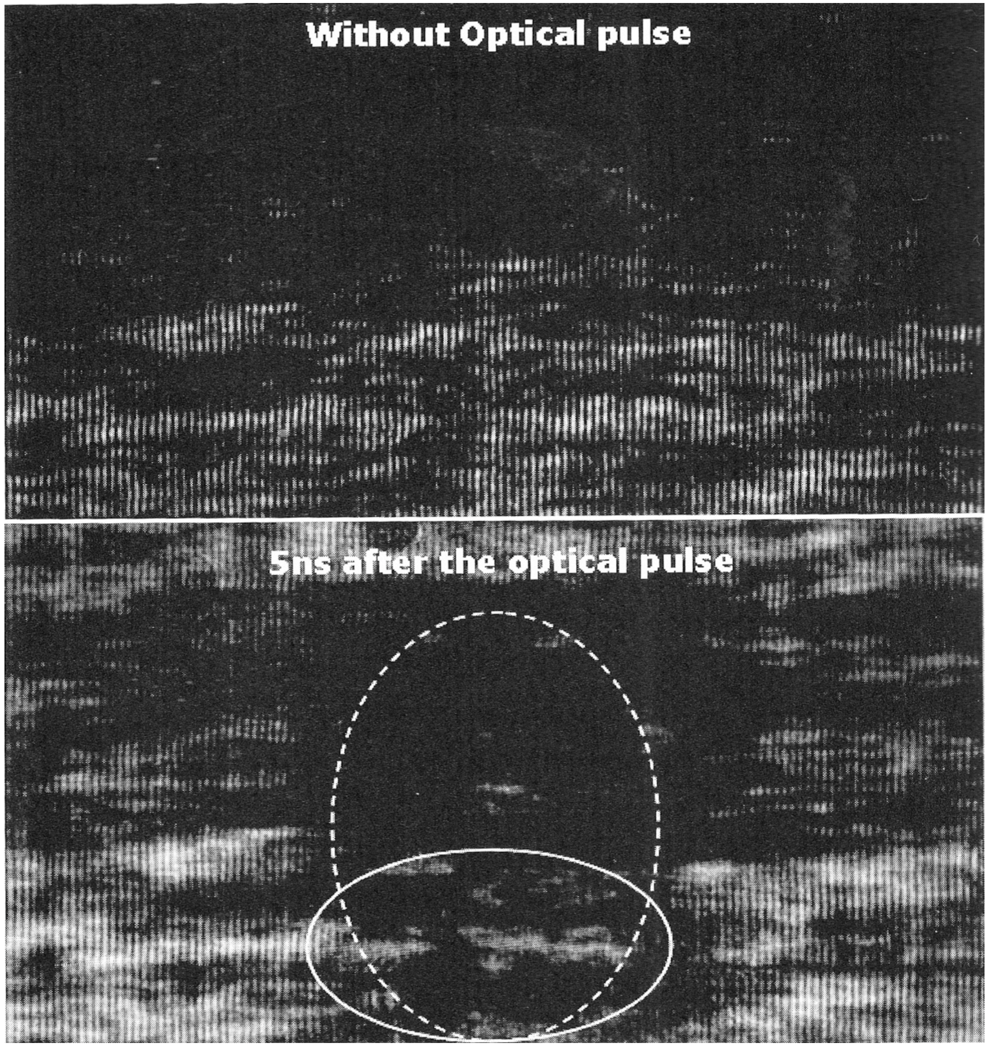
Laser produced damages : experimental arrangement

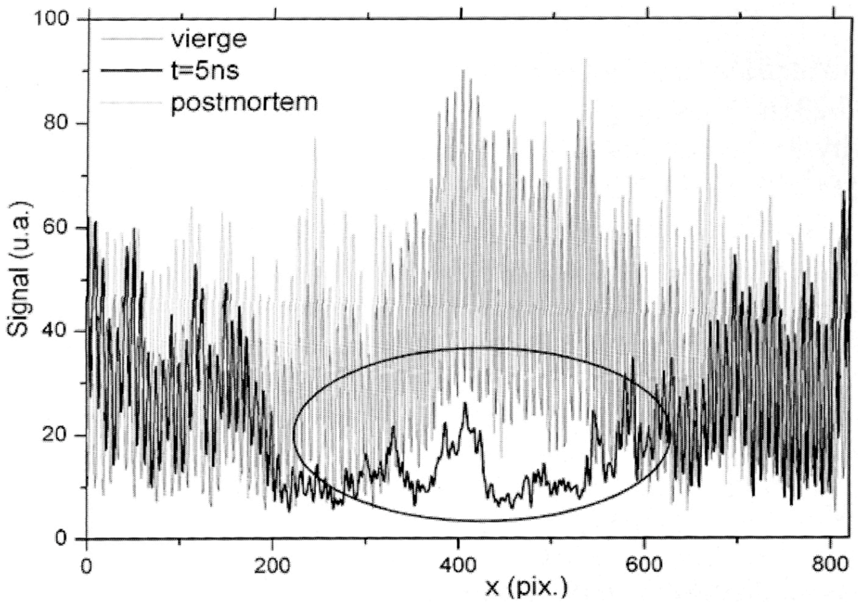




Results : what happens 5 ns after the damaging laser passed through the thin glass plate ?

Damaging laser : 438 nm, 10 Jcm^{-2}

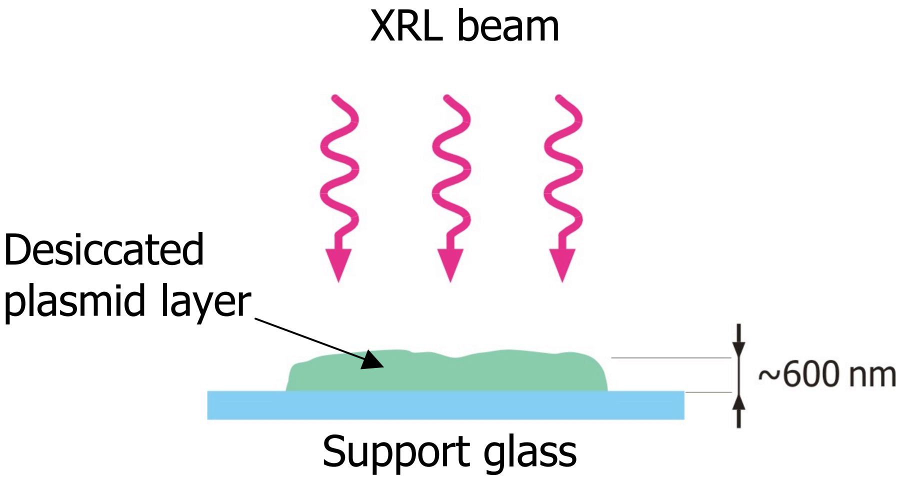




Interaction of a X-UV laser with matter.

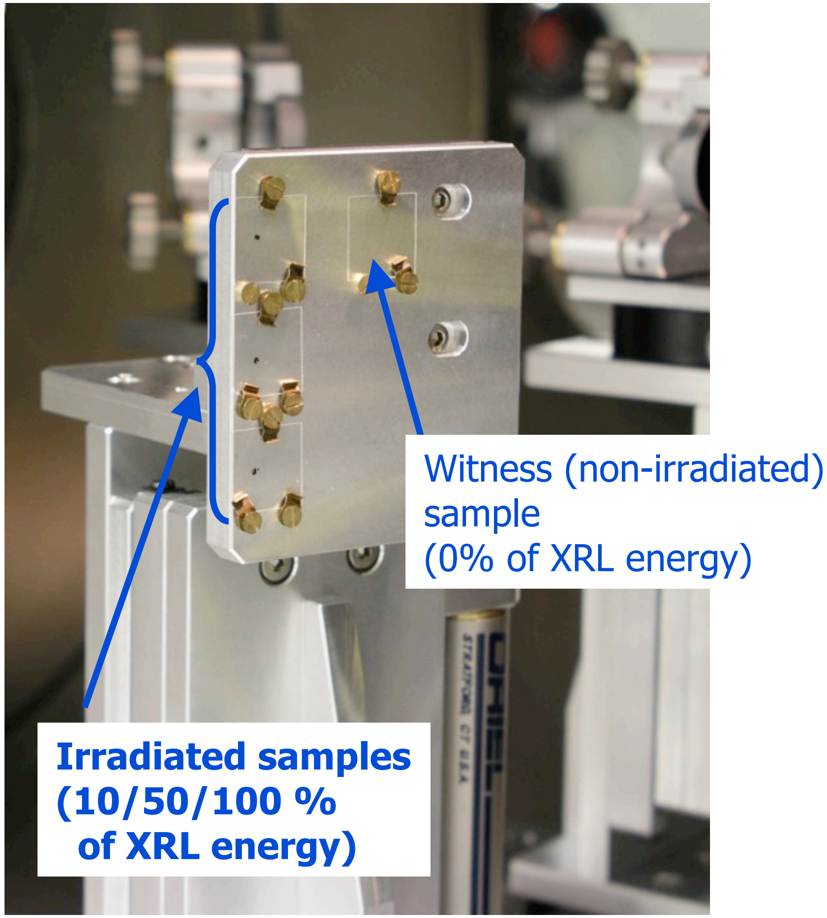
- High flux (focussed X-UV lasers)
  - Plasma creation and heating.
  - Ablation. Creation of craters, holes, …
- Low flux (non focussed X-UV lasers)
  - Interaction with biological samples.
    Damage to DNA plasmids

Damage processes to DNA plasmids by XRL: experimental arrangement



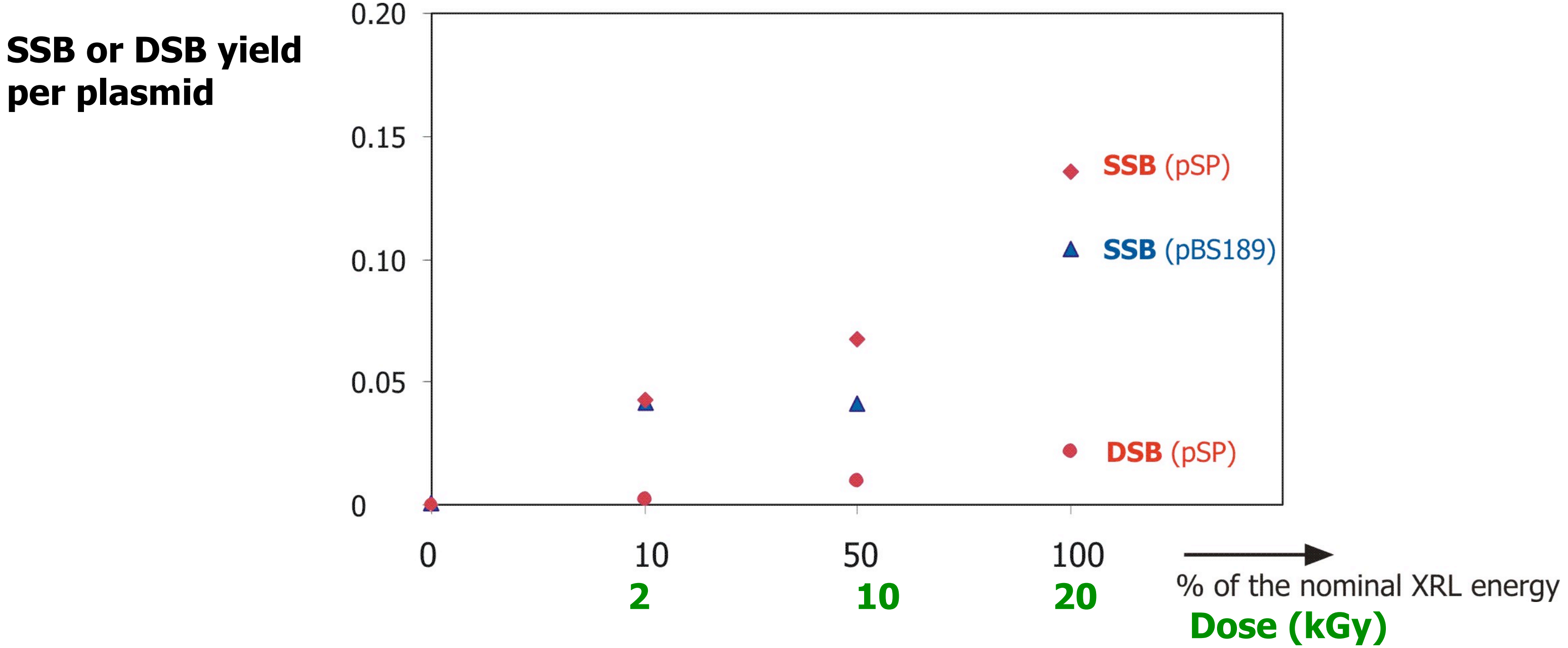
Absorption occurs predominantly in the front ~100 nm layer

Samples withstand ~2 hr under vacuum conditions:
Control sample not exposed to vacuum compared to a "witness" sample inserted to vacuum along with the irradiated samples



After irradiation, samples are dissolved in H_2O + analysed by electrophoresis.

Damage processes to two kinds of DNA plasmids – quantitative analysis



Conclusions:

- First ever DNA damage experiments in this wavelength range
- Damage yields increase with dose; <u>dependence is complex and not simply linear!</u>
- Ratio of DSB to SSB significantly higher than for DNA in water solution
  -> direct ionisation of DNA more significant than indirect effects (by OH radicals)
- Comparison will "conventional" ionisation sources (e.g. Co^{60}) to be made

Message

1. Long live to the PALS

2. Long live to ASTERIX IV

3. X-UV laser is a tool. Give it longer time for for making application experiments useful.

4. Go to http://www.laserix.u-psud.fr/

LASERIX