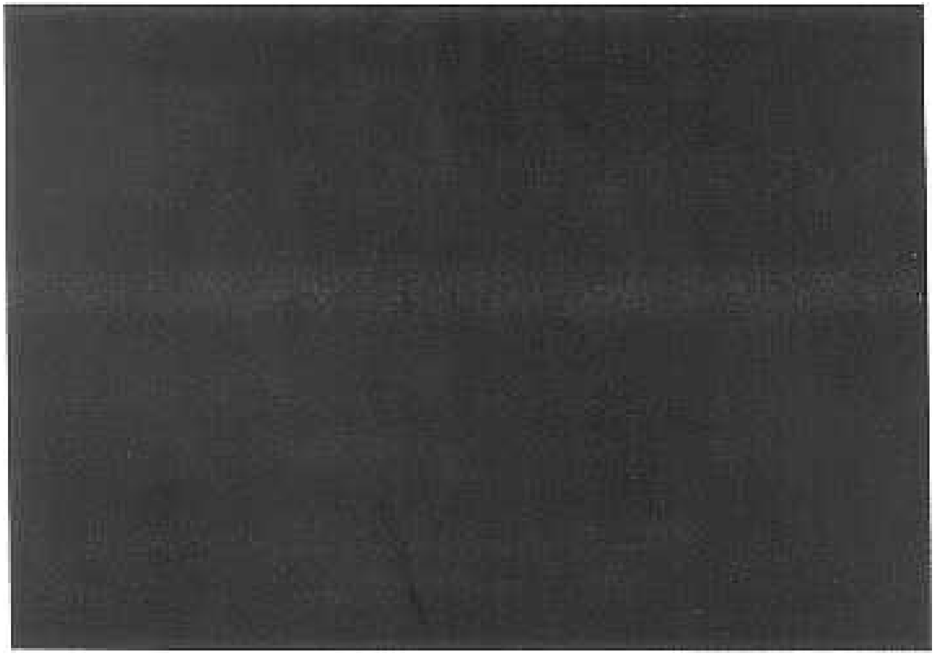
THE SOLEIL STORAGE RING FEL

M. E. Couprie and the FEL group

Service de Photons, Atomes et Molécules

Laboratoire d'Utilisation du Rayonnement Électromagnétique

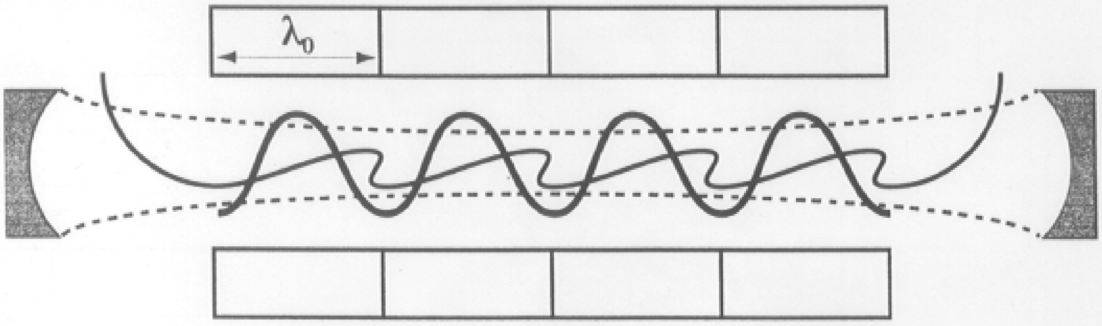


Satellite Workshop "Prospects for FELs in the VUV and Soft X-ray Region as Sources for Scientific Research"

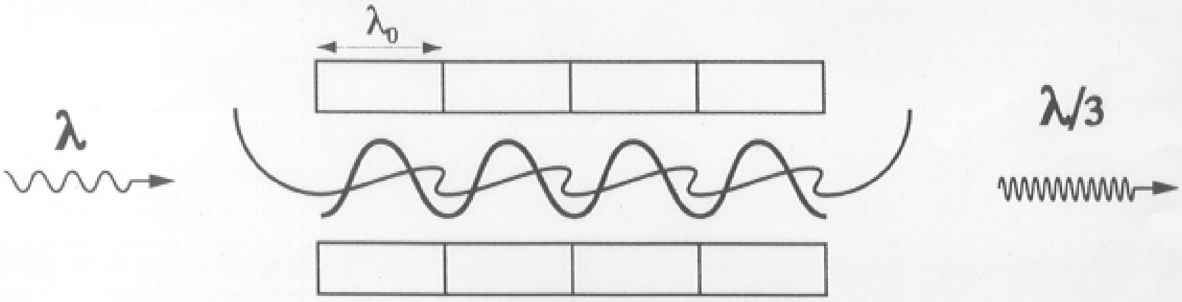
December 5th, 2001, ICIP - Trieste

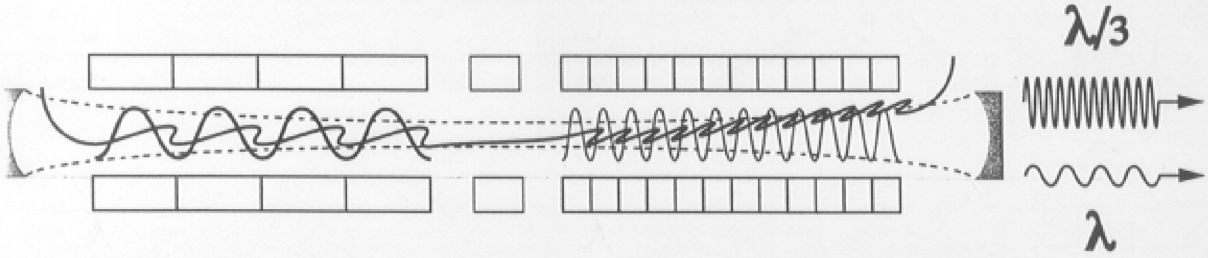
CONFIGURATIONS FOR FELs

oscillator

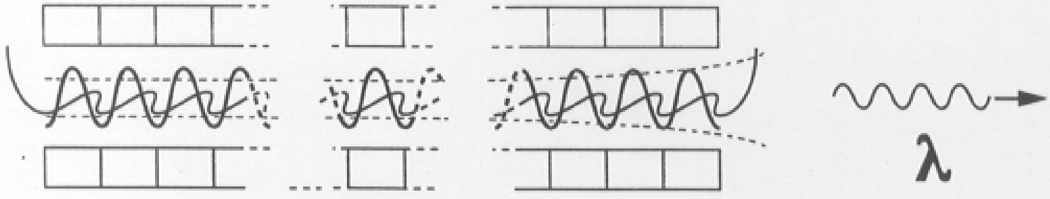


harmonic generation

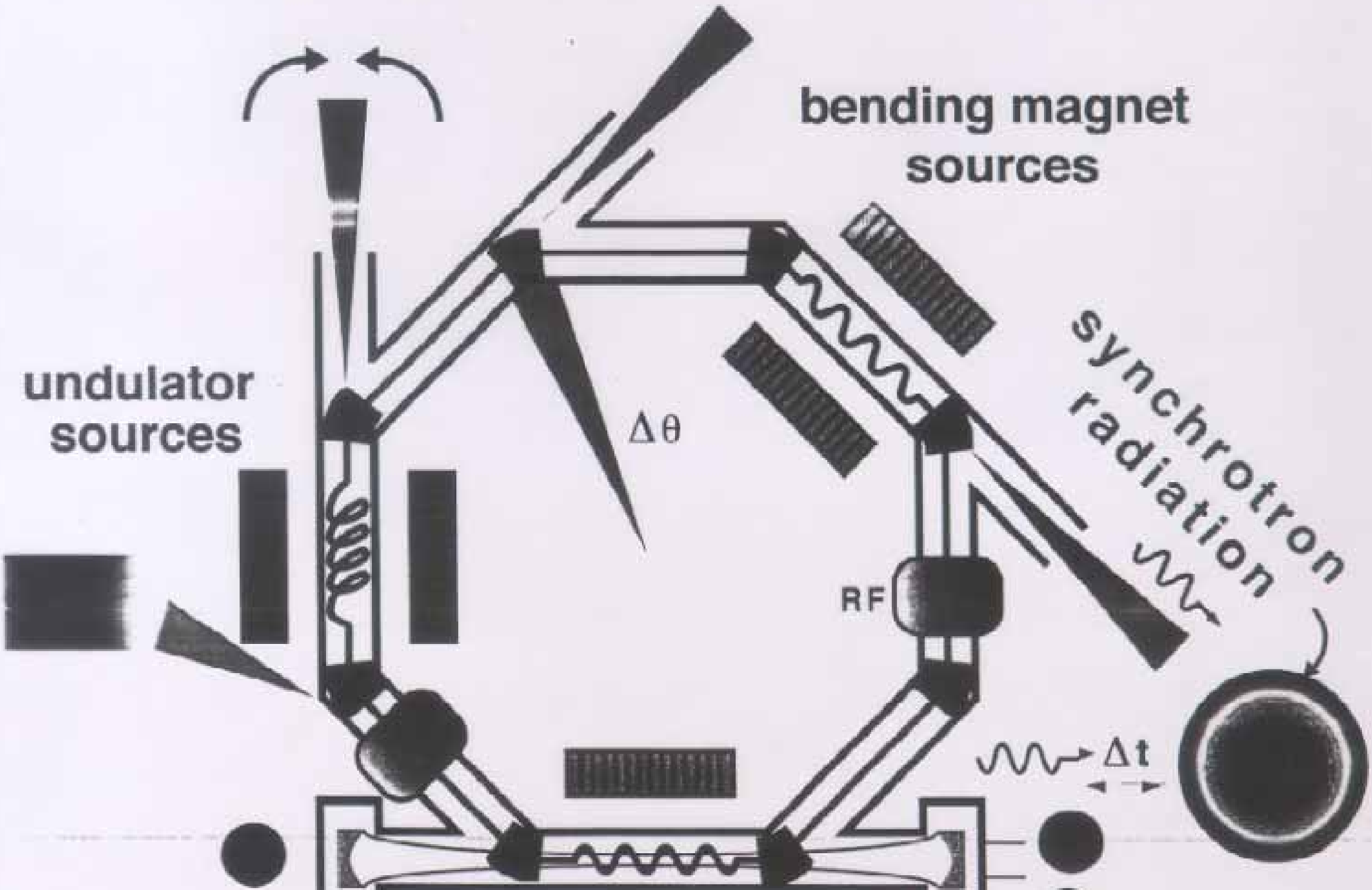




• SASE



STORAGE RING FEL CONFIGURATION



Recirculation
Synchronized synchrotron radiation
Two color pump probe experiments

THE SOLEIL OPERATION FOR THE FEL

E = 1.5 GeV

ε_x = 2.8 nm rad, ε_x = 1.2 nm rad

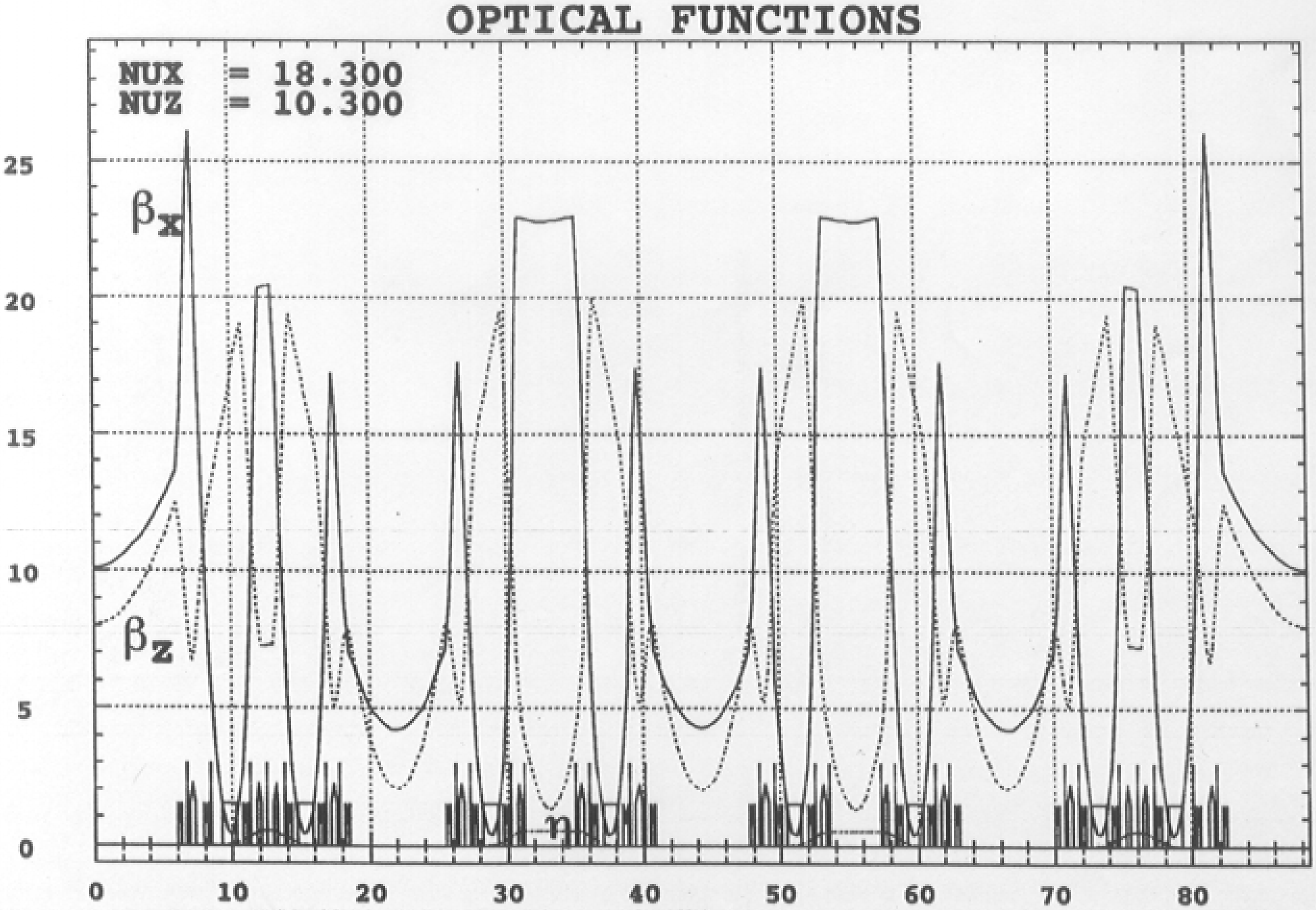
8, 4, 2 or 1bunches

I=4x20 mA

σ_l = 10 - 30 ps, $\sigma\gamma/\gamma$ = 0.1 %

σ_x = 167 μm σ_z = 105 μm

L_{sd}=12 (10.5) m

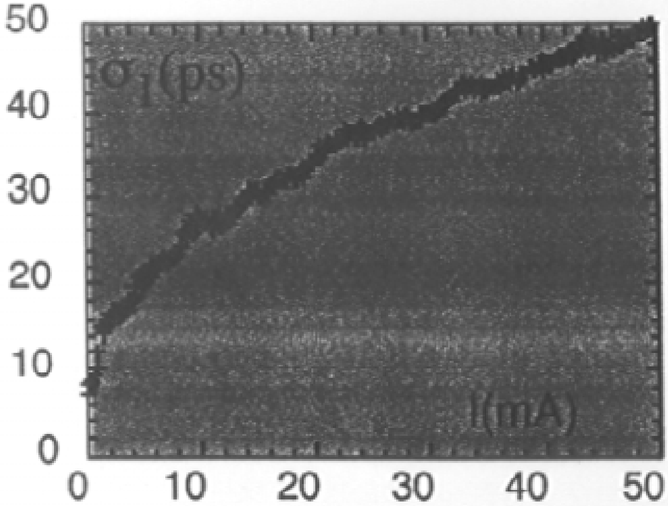


LEL

THE SOLEIL OPERATION FOR THE FEL

E = 1.5 GeV
8, 4, 2 or 1bunches
I=4x20 mA
lifetime : 9.4 h (coupling :50%)

Operation partially compatible with the VUV- temporal structure community (coincidence experiments for ex.)



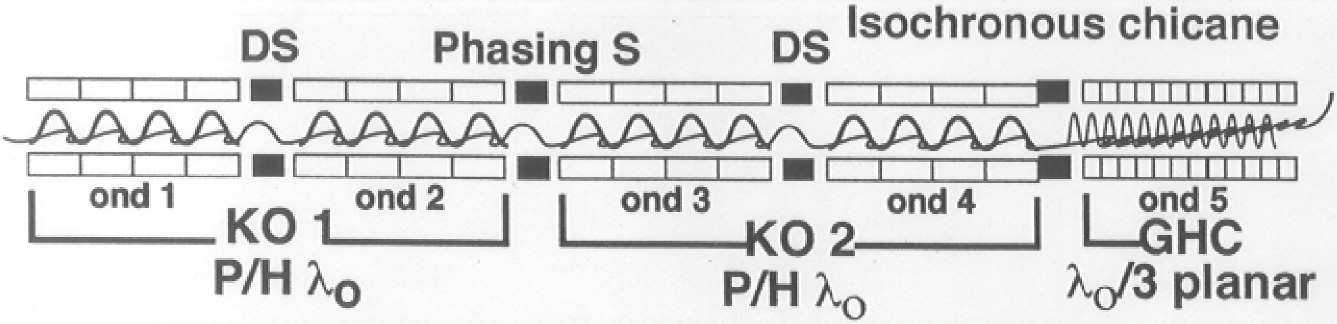
RF frequency = 352 MHz,
1.180 ns for one turn
n = 416, 2.837 ns

Optinal 8 bunches operation
for two independent systems:

γ-ray production

THE SOLEIL FEL INSERTION DEVICE

multiple adjustable optical klystron

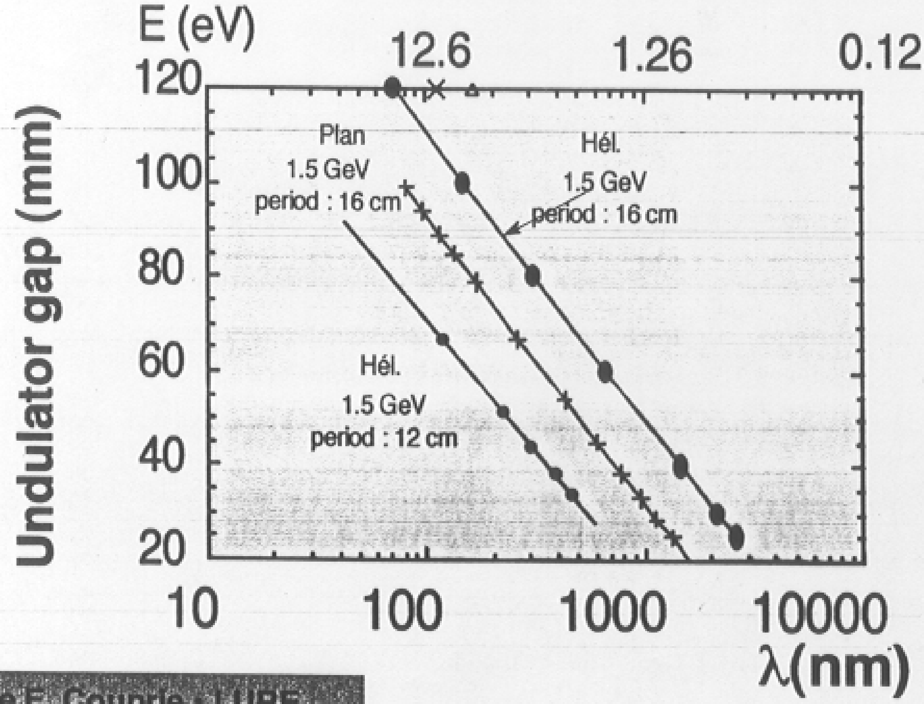


Choice of the parameters :

- total length of the ID : 14 m ⇒ 12 m
- undulator's section length : 2 m ⇒ 1.8 m
- period length : 16 cm ⇒ 12 cm
- minimum gap : 20 mm (17 mm)

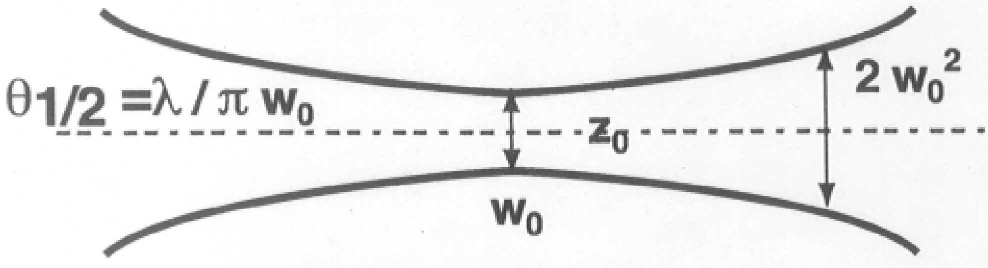
Criteria :

- covered spectral range
- synchrotron power on the front mirror
- gain
- two color FEL (≠ gaps for the two optical klystrons)



THE SOLEIL FEL OPTICAL CAVITY

optical cavity : L= 44.26 m ,
Rc = 30 m
waist = 300 μm, DV = 170 μrad

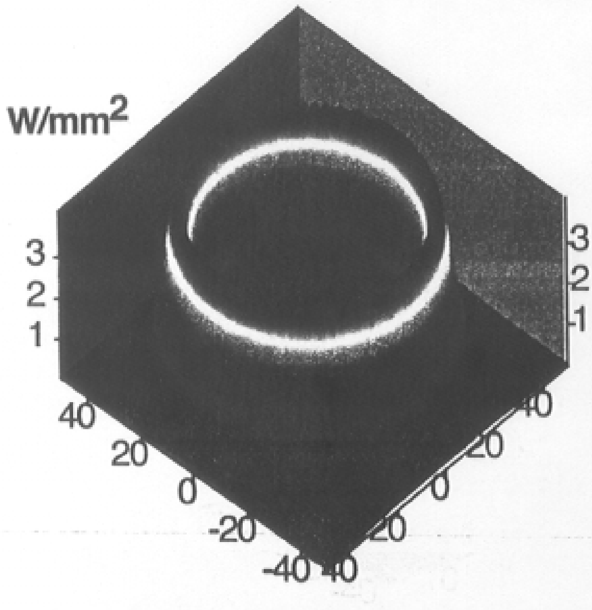


$z_0 = \pi w_0^2 / \lambda$

$w_0^2 \, \alpha \, \lambda$

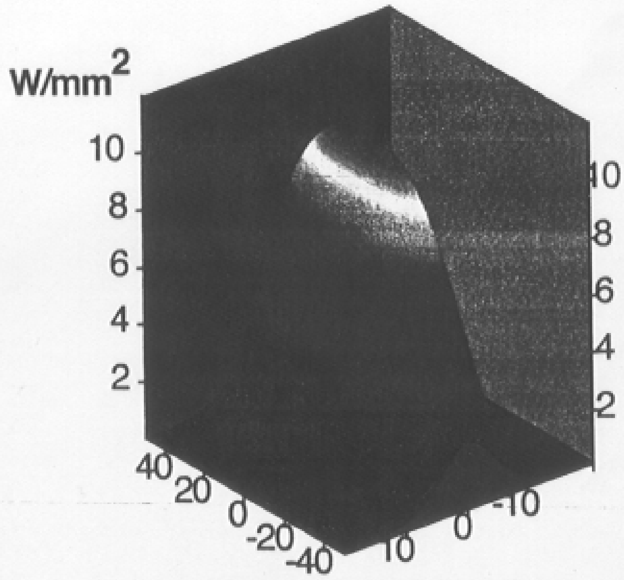
1 optical klystron

200 nm, 100 mA, period : 16 cm



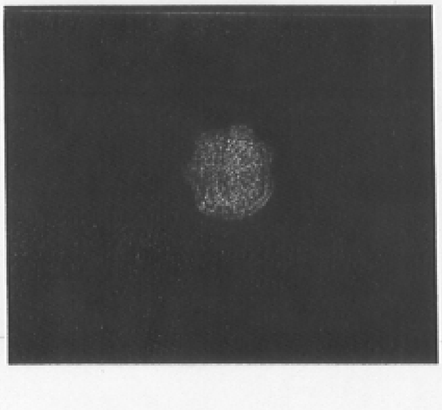
helical configuration
Kx-Ky = 4.302.

multidielectric mirror



planar configuration
Kplan =6.408

metallic mirror, hole coupling



MIRRORS FOR THE OPTICAL RESONATOR

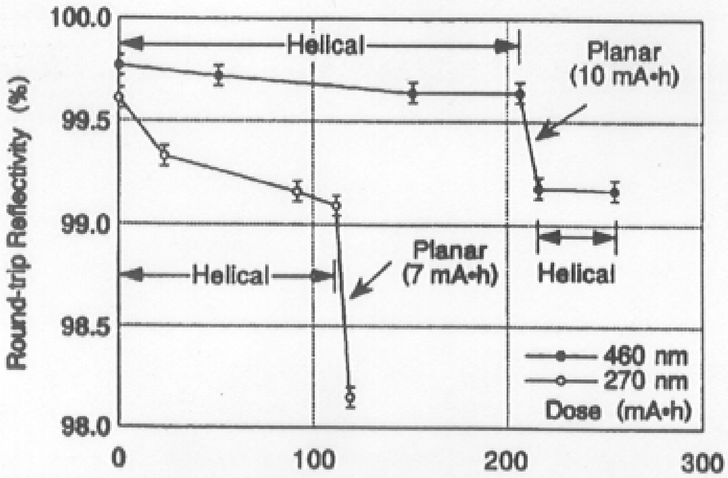
- Threshold condition

P < G   P = 1 - R = T + D + A

- Undulator synchrotron radiation:

- power ☞ heating
- Wide spectrum of harmonics (planar und.) ☞ losses increase

First harmonics (helical und.) ☞ reduced losses increase



Assisted Deposition techniques

Mirror performances:

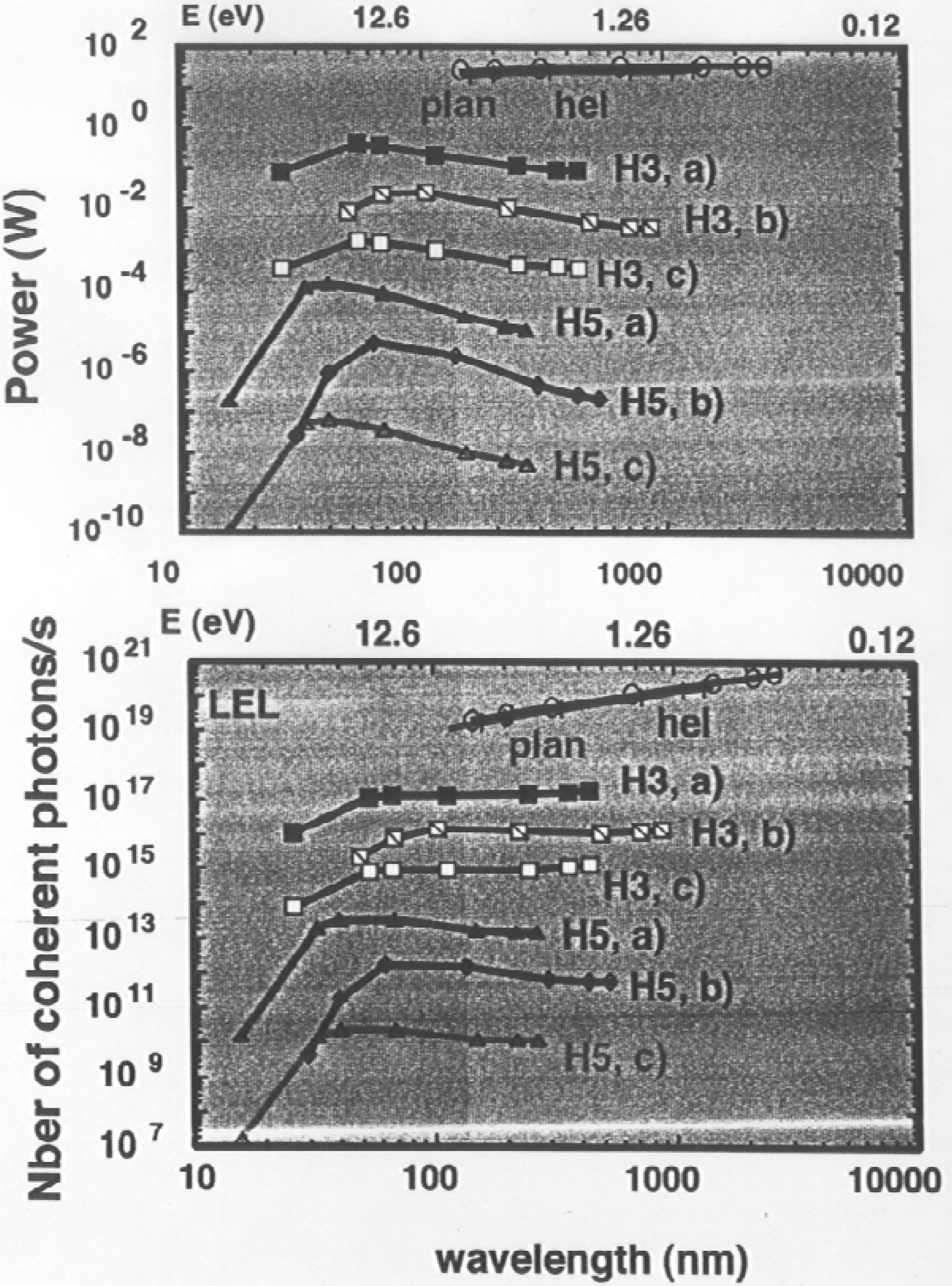
Vis-200 nm : oxides multilayers
200-140 nm : fluorides multilayers (+ protection)

R(140 nm) = 92 %

λ(nm)	248	157	13	3
D(%)	0.06	0.16	5	50

Sc/Si	R=77/48.1%	50-36 nm
Mo/Si	R=75/69.6%	36-12.5 nm
Mo/Be	R=78/70.2%	12.5-11.4 nm

THE SOLEIL FEL SPECTRAL RANGE



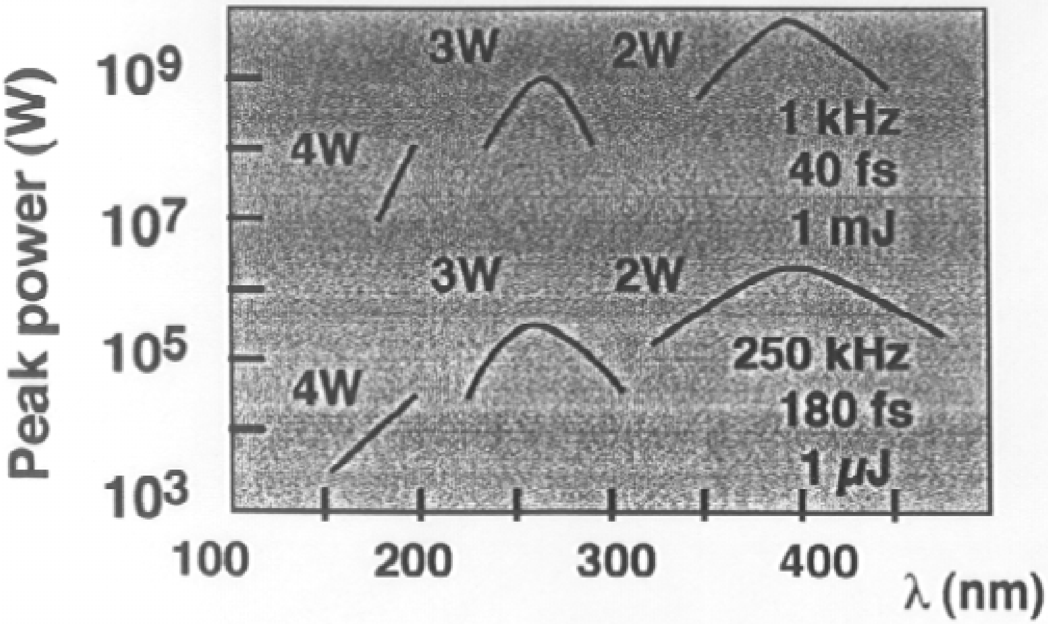
a) KO1 planar + und 5

b) KO1 hel + und 5

c) KO1 planar

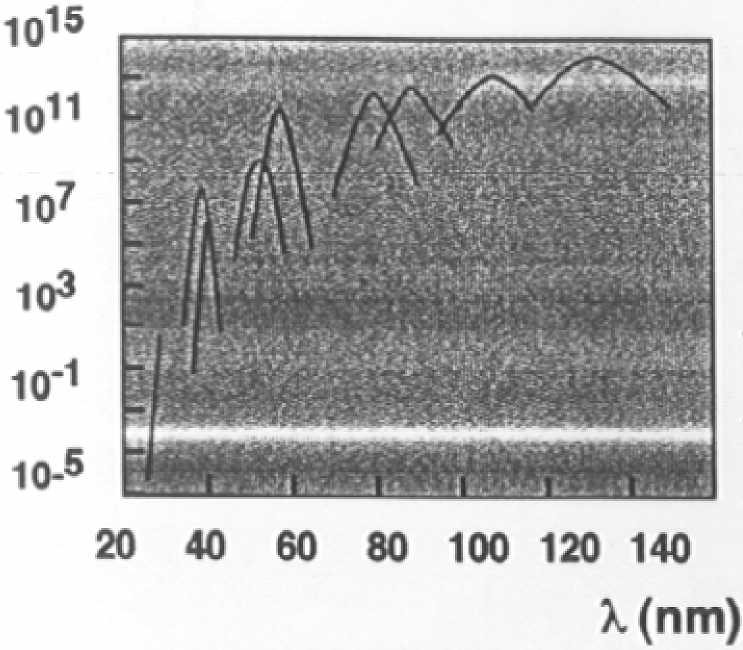
THE SOLEIL FEL SPECTRAL RANGE

Coherent harmonic Generation From a Ti:Sa Laser

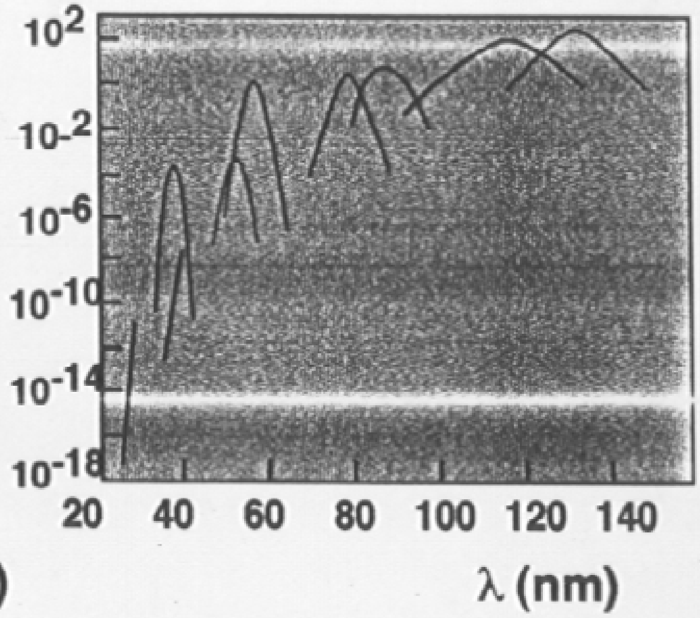


1 kHz system

Nber of coherent photons/s

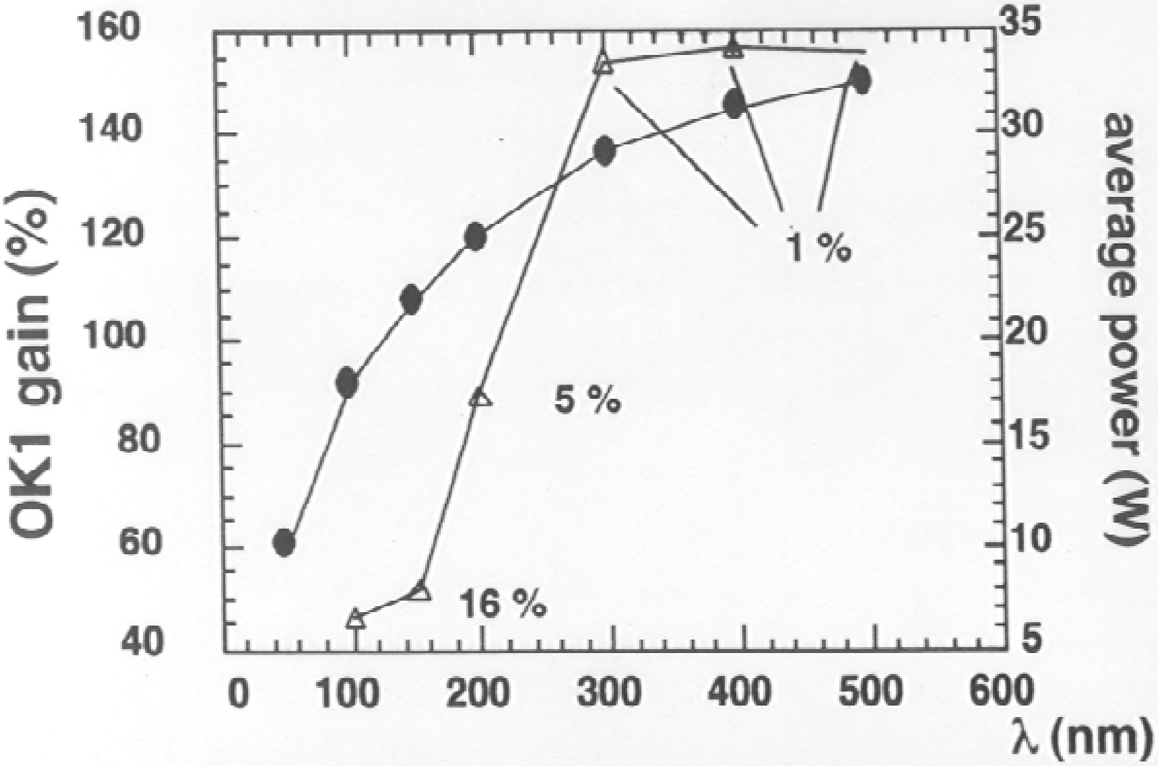


average power (mW)



THE SOLEIL FEL SPECTRAL RANGE: FURTHER PROSPECTS

- Shorter wavelength operation



influence of the optical losses on the FEL power

- Variety of combinations:

- two color FEL
  (different gaps for the two optical klystrons)

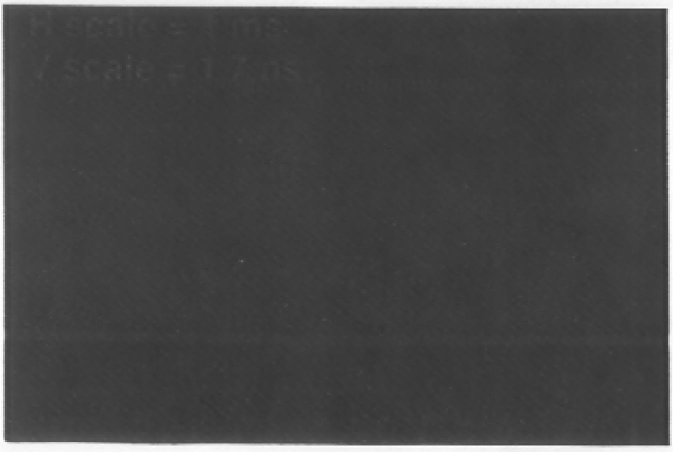
- 2 independant "4 bunches systems" :
  1 FEL + 1 for CHG from an external laser

- FEL in the Q-switched mode + CHG

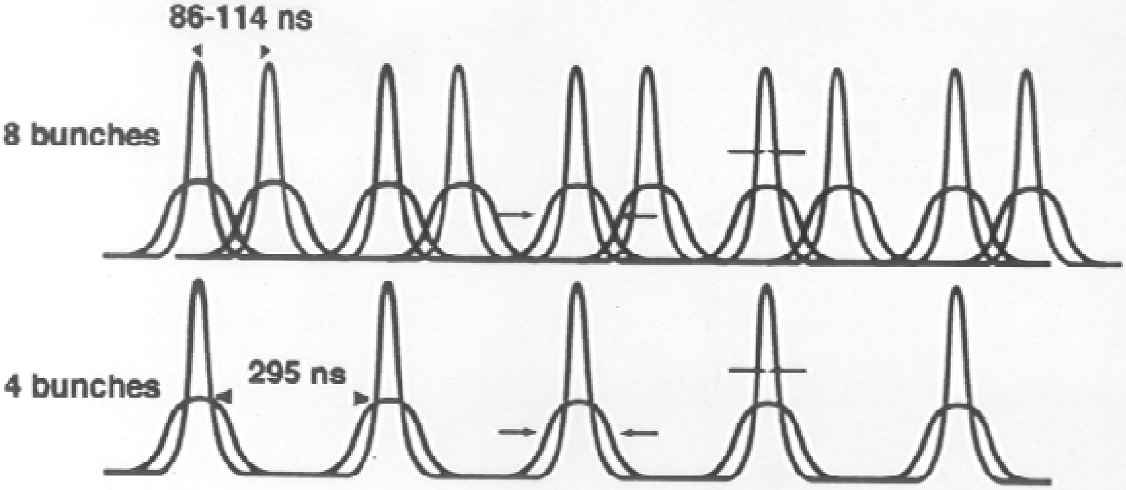
THE SOLEIL FEL TEMPORAL COHERENCE

Microtemporal structure

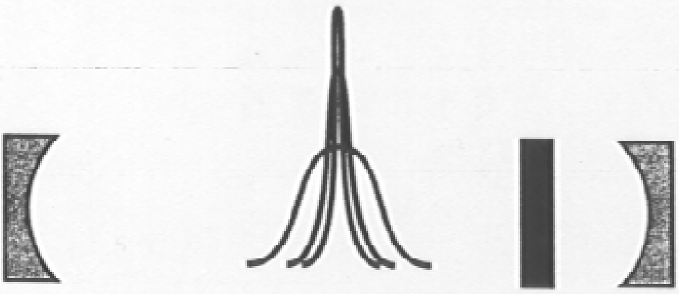
SR
σ = 10-30 ps
FWHM : 25-70 ps



FEL
FWHM : 1-5 ps



Spectral line



natural width

$$\frac{\Delta \lambda}{\lambda} \sim 10^{-4}$$

Fourier Limit

$$\frac{\Delta \lambda}{\lambda} = 1.5 \times 10^{-6} \frac{\Delta \lambda \text{ (nm)}}{\Delta t_{MH} \text{ (ps)}}$$

THE SOLEIL FEL TEMPORAL STRUCTURE

Macrotemporal structure

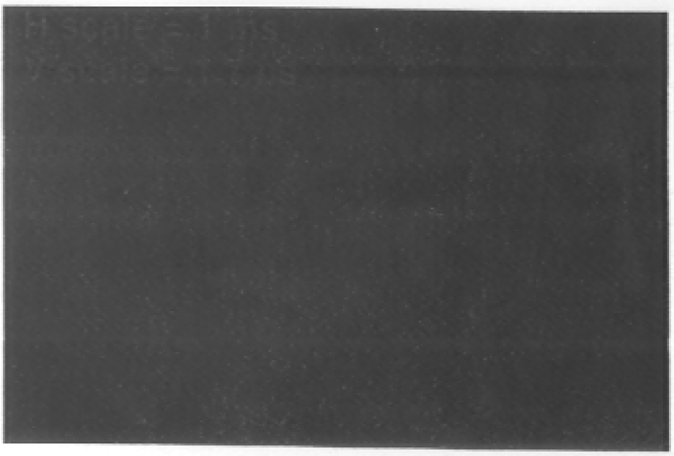
vs electron /photon synchronization (tuning)

«CW»

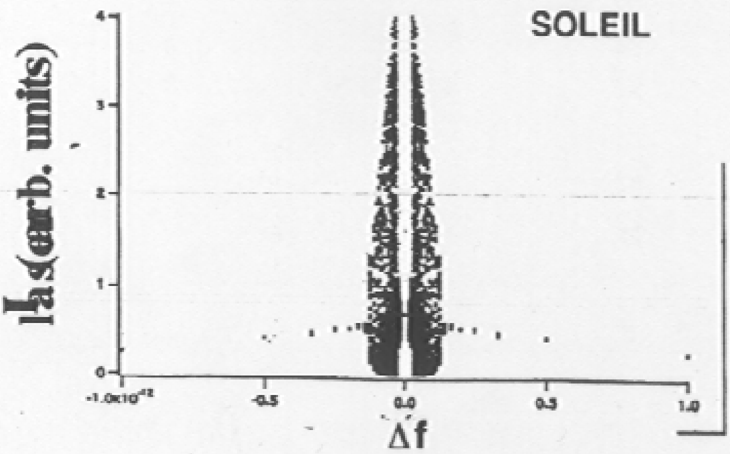
$$\tau_0 = \frac{T_{el}}{G\text{-}P} \quad \mu s$$

«pulsed»

$f_o = (2\tau_o\tau_s)^{-1/2}/\pi$ f_o = 50-1 kHz

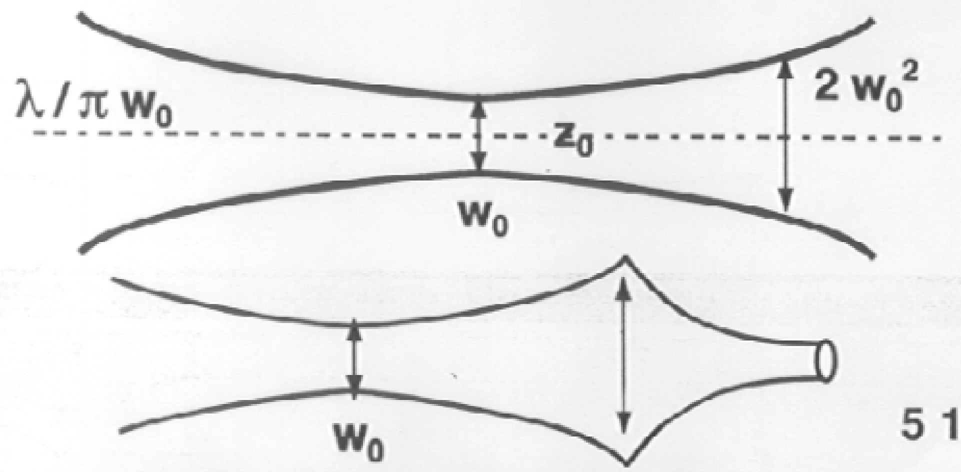


detuning curve



Q-switched FEL : kHz, higher peak power

THE SOLEIL FEL TRANSVERSE COHERENCE



$\theta_{1/2} = 170\ \mu rad$

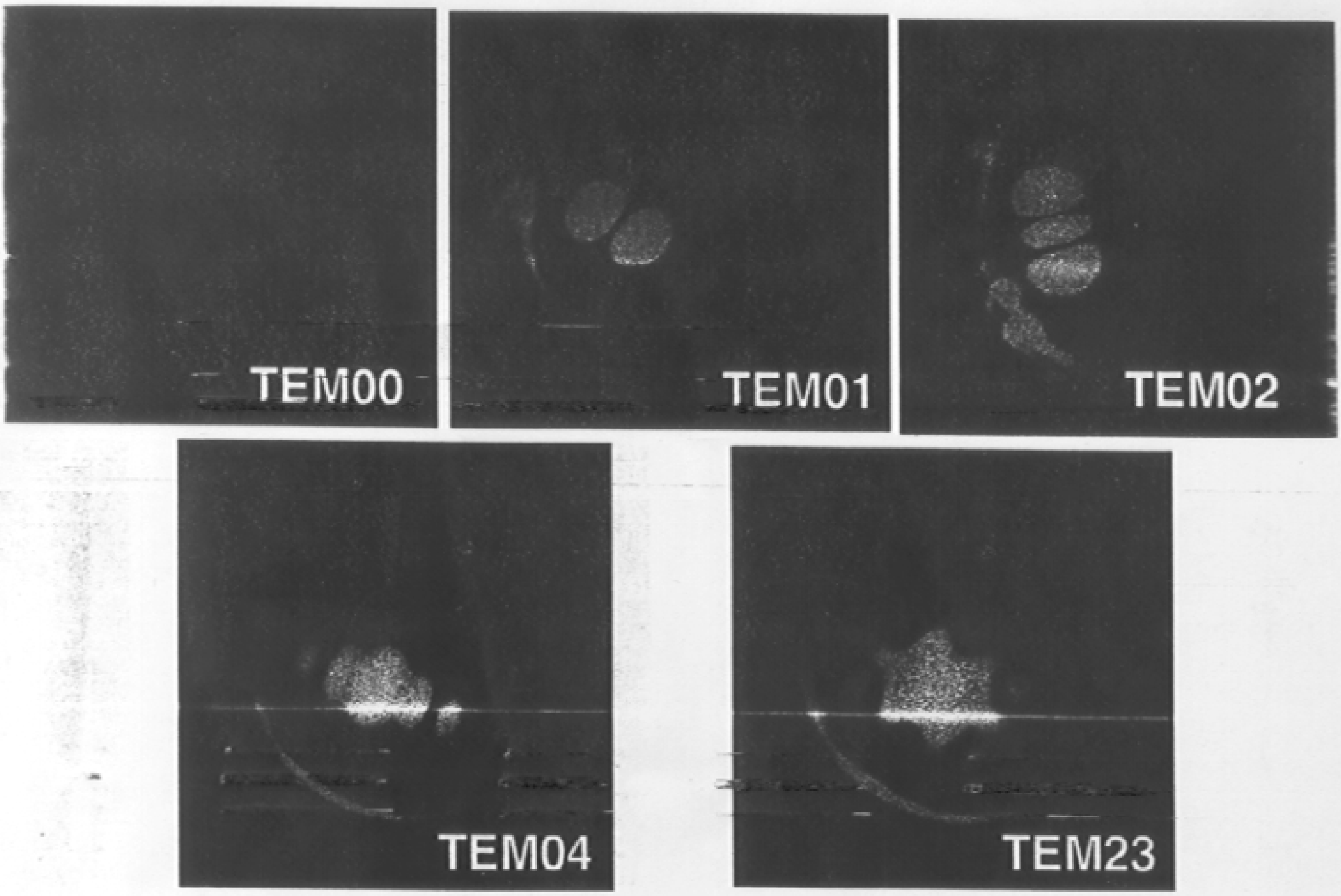
$z_0 = \pi w_0^2 / \lambda$

$w_0 = 300\ \mu m$

$w_0^2 \propto \lambda$

Focusing

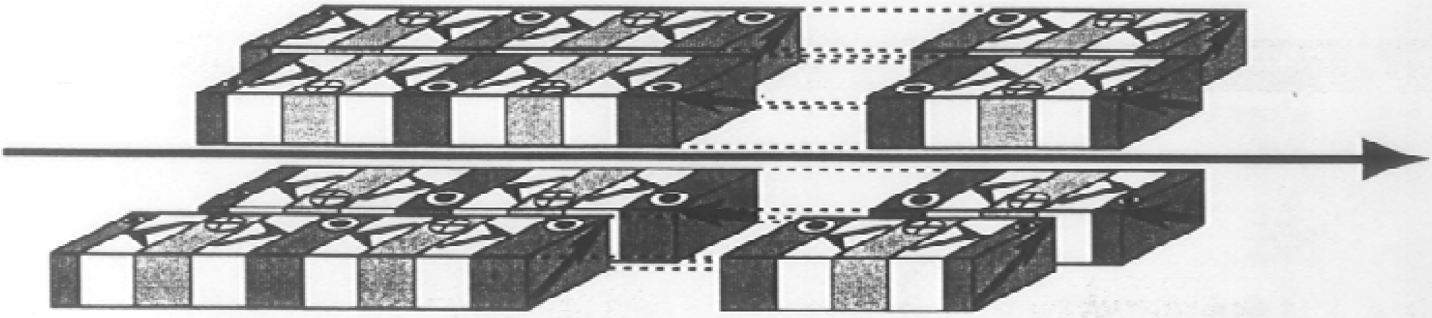
$5\ 10^{18}$ ph/s on 10 μm

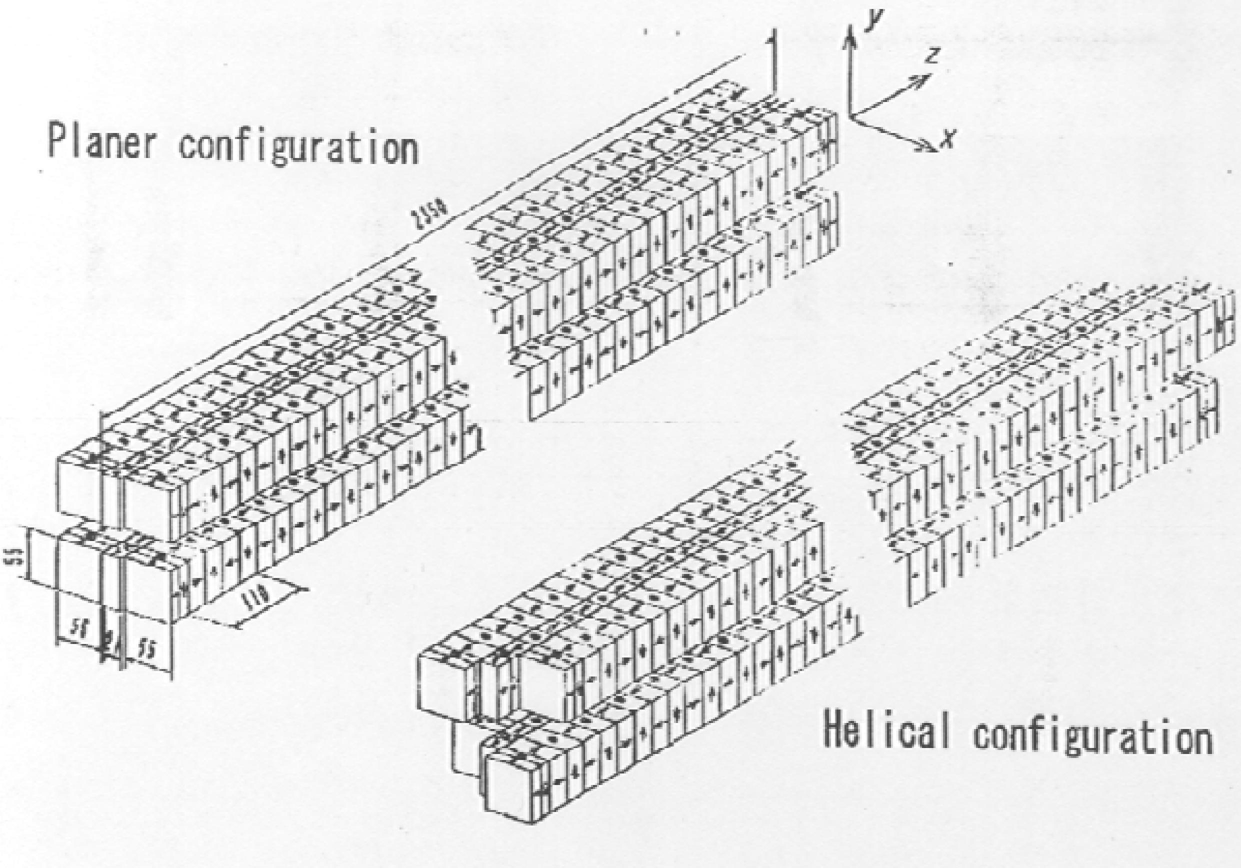


THE SOLEIL FEL POLARISATION

Linear: Planar undulator

Circular: Helical undulator



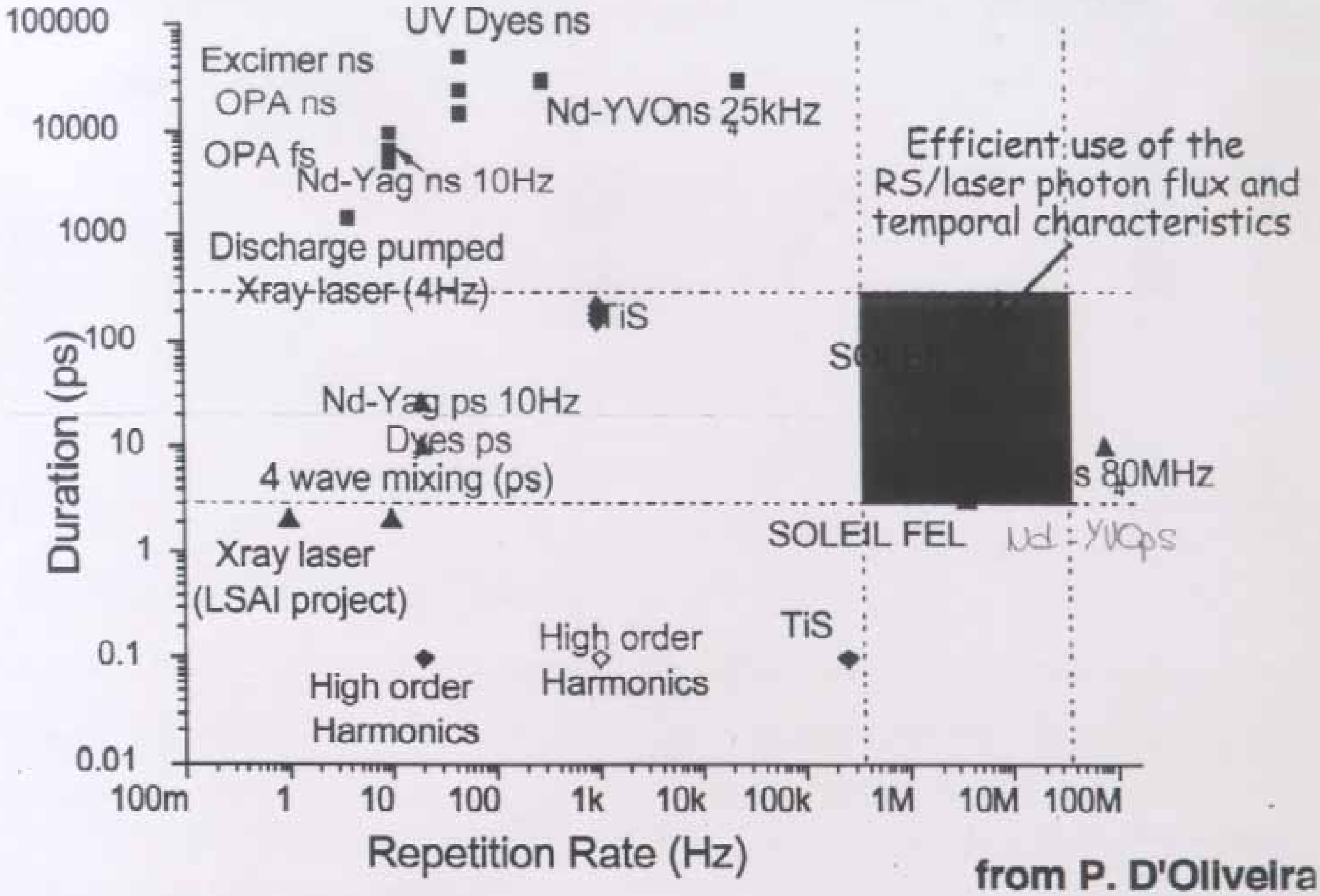


Comparison with other ps/sub ps UV source

TYPICAL ps/sub-ps UV SOURCES

Source:	Tunability	Wavelengths	Rep. Rate	Duration
Nd-Yag laser	No	355;266 nm	10 Hz	25 ps
ps dye laser	Yes	200-350 nm	10 Hz	10 ps
fs OPA	Yes	300-400 nm	1 k Hz	200 fs
fs Ti-S laser	Yes	190-450 nm (non continuously)	1 kHz	150 fs
High harmonics	Yes	17-170 nm	1 kHz	50 fs
Nd-YVO_4 laser	No	355 nm	80 MHz	10 ps

Pump-probe experiments with the RS



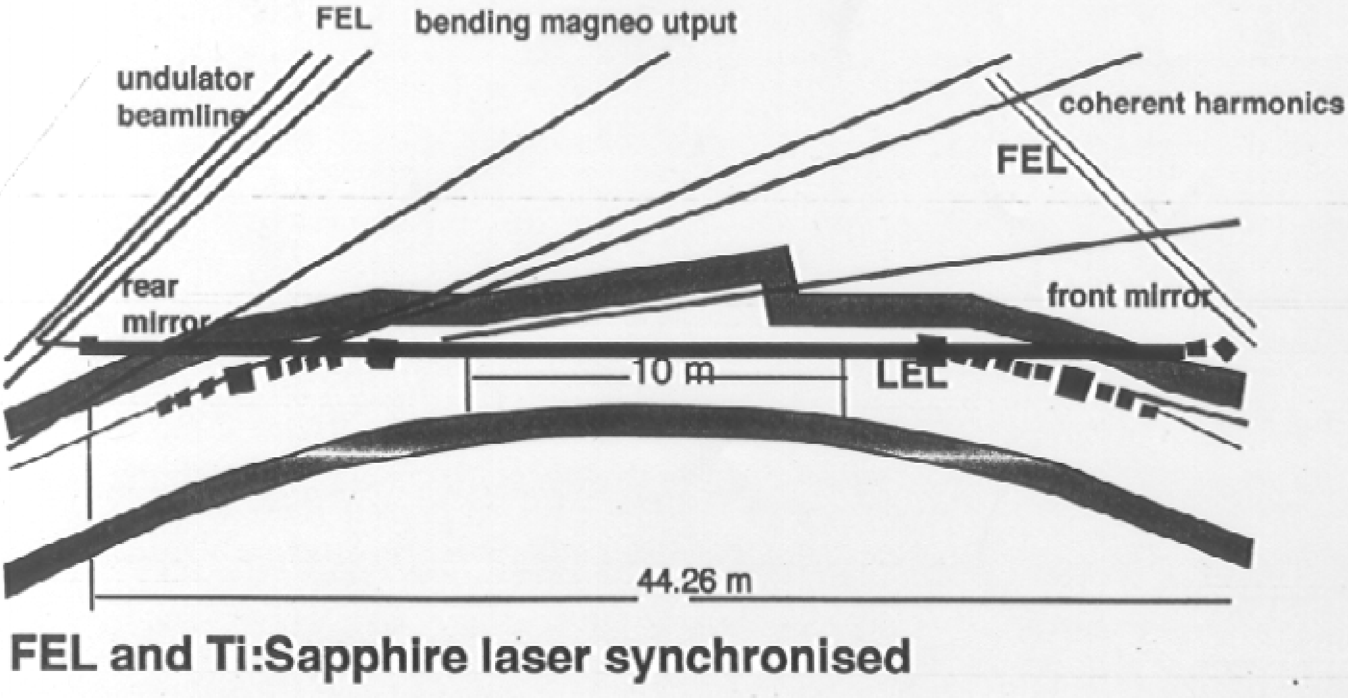
from P. D'Oliveira

PROSPECTS FOR THE SOLEIL FEL SCIENTIFIC CASE

• SOLEIL FEL properties :
- wide tunability in the UV-VUV
- high average and peak brilliance
- natural source for pump-probe experiements requiring synchrotron radiation as a probe

• Workshop "New prospects offered by the SOLEIL FEL" organised by M. E. Couprie and L. Nahon
ESPCI, 25 - 26 september 2001, 50 participants

⇒ FEL+Synchrotron radiation Combinaison:
- infra-red spectromicroscopy beamline
- visible-UV beamline
- VUV undulator beamline
- XUV undulator beamline



• FEL and Ti:Sapphire laser synchronised

PROSPECTS IN SURFACE AND MATERIAL SCIENCES

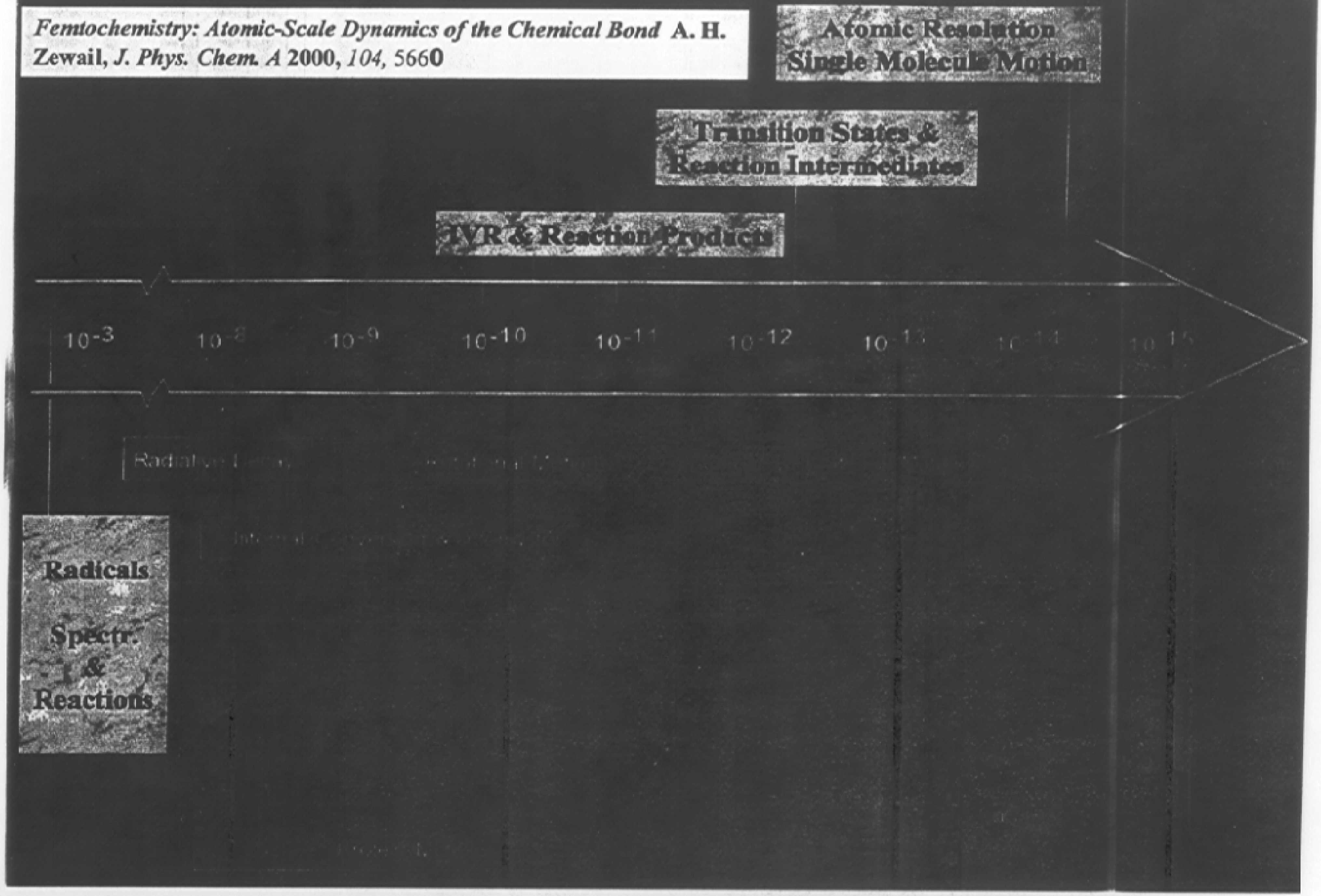
A. Rogalev "time-resolved polarization dependent spectroscopies of solids with FEL"
A. Belski "Solid State VUV-X Spectroscopy"
P. Dumas "IR spectro-microscopy on FEL-excited samples"
A.Taleb, M. Marsi "Applications of the SOLEIL FEL to photoemission experiments at surfaces and interfaces"
F. Sirotti "Magnetization Dynamics at Surfaces and Interfaces"

FEL Probe
Magnetization dynamics in solids, at surfaces and interfaces
⇒ polarization- / spin-resolved photo-e- spectroscopy (PES)

Studies on FEL (pump) excited samples
Electron relaxation/ energy transfer in large gap dielectrics
Transient charge carrier distribution at surfaces and interfaces
FEL+SR spectroscopy of unoccupied states in SC and metal
⇒ transient spectro-microscopy, fluorescence, PES ,
PEEM, X-ray diffraction

FEL : High UV-flux, focussing ⇒ high density of excitation
Tunability, stability

Femtochemistry: Atomic-Scale Dynamics of the Chemical Bond A. H. Zewail, *J. Phys. Chem. A* 2000, *104*, 5660



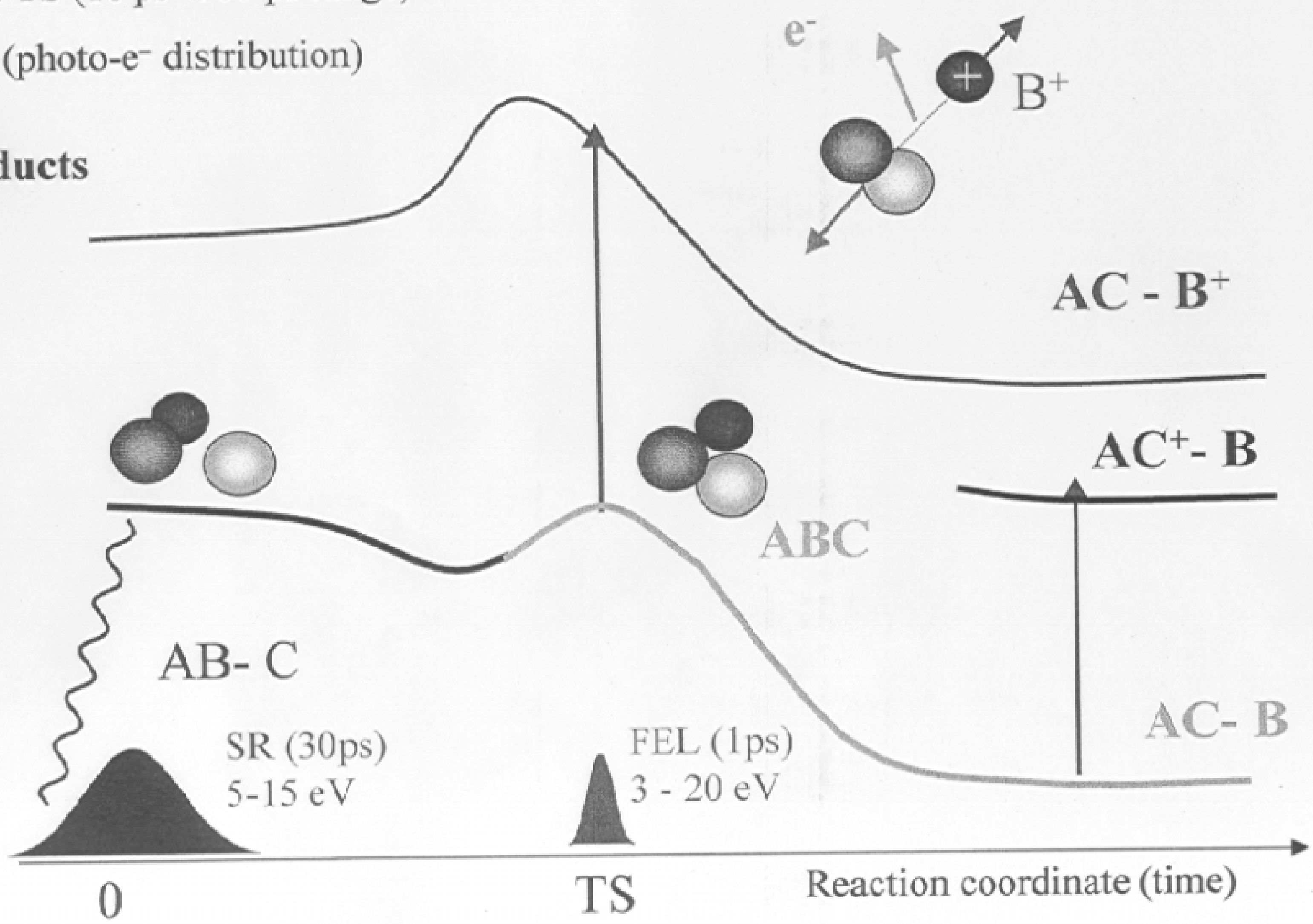
Reactive collision : Pump/Probe + Coincidences

B. Soep, Saclay

Single photon probe of ABC transition state (TS)

- evolution time to the TS (10 ps -100 ps range)
- symmetry of the TS (photo-e⁻ distribution)

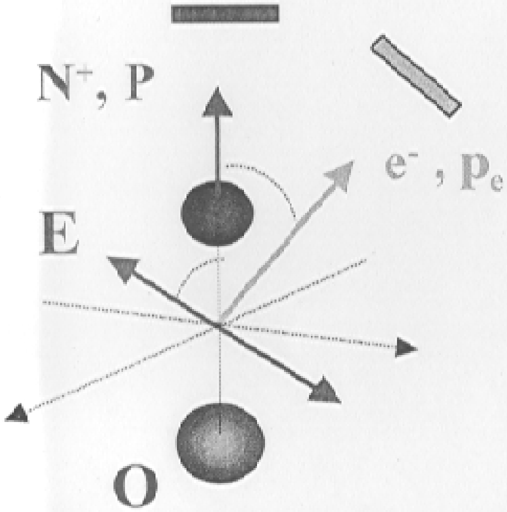
Probe AC- B products



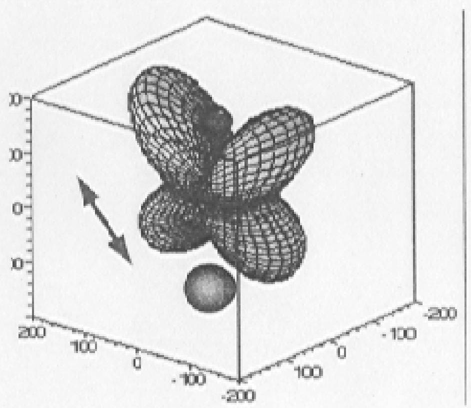
Vectorial Correlations : Complete experiments

LURE: Dissociative Photoionization | **SOLEIL: SR +FEL double ionization**

$NO + h\nu(23{,}7\ eV) \rightarrow N^+(P) + O + e^-(p_e)$

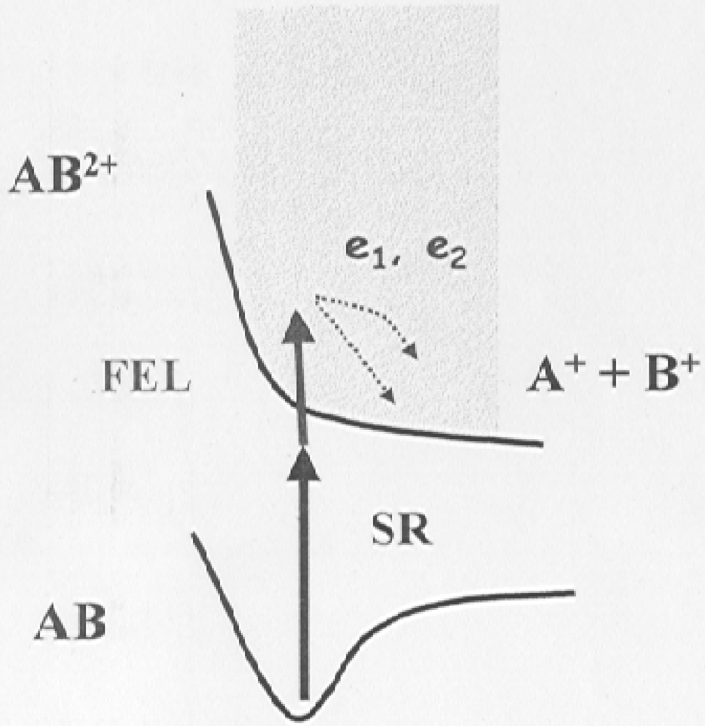


electron emission diagram



D. Dowek et al., LCAM Orsay

Coincidences (e_1, e_2, AB^{2+} or B^+)



D. Garzella et al. (CEA-SPAM, LSAI)

Coincidences ⇒ n mean number of events/pulse < 1

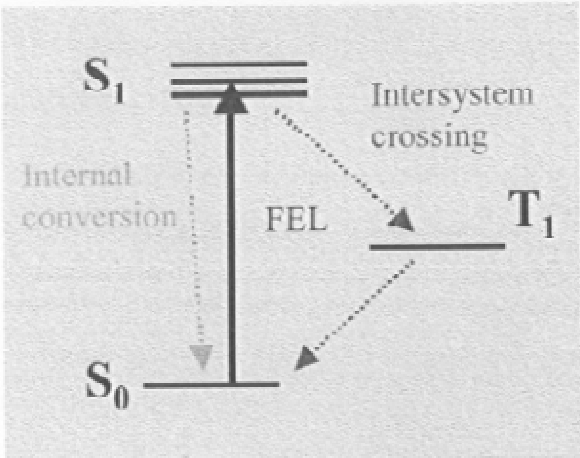
⇒ Acquisition time ~ 1/Reprate

PROSPECTS IN PHOTOCHEMISTRY AND PHOTOBIOLOGY

- Photochemistry and photobiology

F. Puizzi "Gas phase photochemistry on biomimetic systems"
E. Renault "Réactions Photoactivées en biologie"
F. Brower "Time-resolved spectroscopy in the photochemistry of supramolecular and biomolecular systems"
B. Barbier "The FEL source interest for exobiology experiments"

Transient Fluorescence / Absorption on FEL excited molecules (solution) ⇒ FEL : high UV-VUV flux + SR : pulsed white source



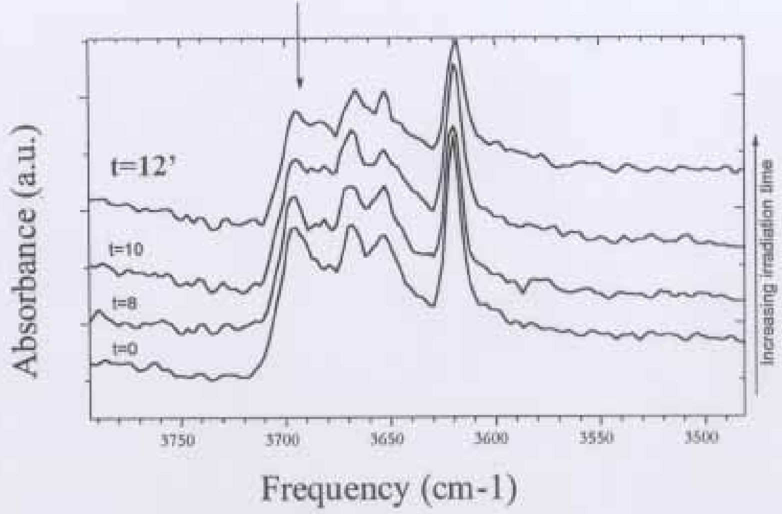
Internal conversion - intersystem crossing (S <->T)
NADH , POPOP, Acridine (E. Renault et al.)

e- and proton transfer, molecular motion (F. Brouwer)
FEL excited rotaxane investigated at LURE
⇒ Fourier Transform VUV-IR spectroscopy

Studies in chiral systems : exobiology (B. Barbier)
Induction of enantiomeric excess
⇒ FEL : high VUV flux, circular polarization, stability

Transient IR-Spectro-Microscopy on FEL excited sample

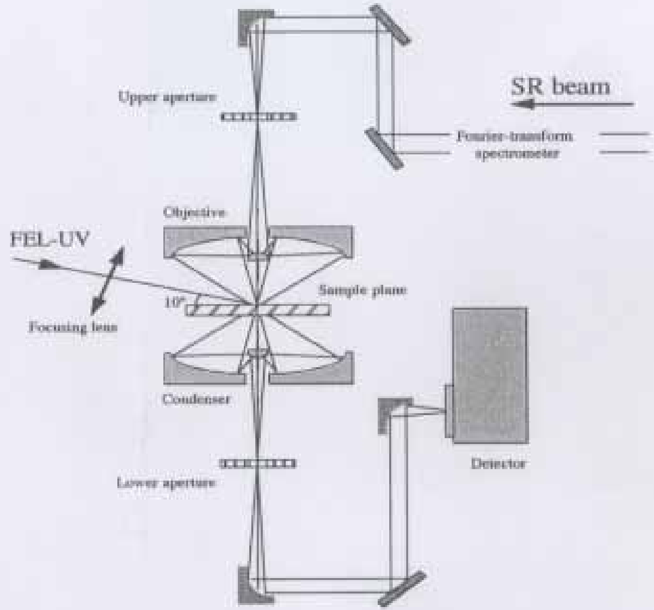
L. Nahon et al, SPIE Proceedings 2001



IR-absorption spectra of kaolinite after various FEL irradiation times

Fourier T. Spectroscopy

time, energy, space resolution



- ns dynamics : relaxation of FEL excited films with molecules adsorbed

SOLEIL FEL SCIENTIFIC PROSPECTS

PROSPECTS IN ATOMIC AND MOLECULAR DYNAMICS IN GAS PHASE

M. Vrakking (FOM, Amsterdam) "Time resolved Atomic and Molecular Physics using the SOLEIL FEL "

B. Soep "Intra-molecular dynamics and reactivity of small molecules and aggregates probed by time-resolved photoelectron spectroscopy"
S. Svensson (Uppsala University) " Inner shell electron spectroscopy studies of molecules: A FEL perspective"
T .Gejo (UVSOA, Okazaki) "Pump IProbe Experiments with FEL and SA Pulses at SOLEIL "
P. Agostini et al"Synchrotron-FEL Two-photon double ionization

Gas phase spectroscopy and molecular dynamics
Two-photon excitation in atoms, small molecules
Spectroscopy of multiply-excited states
Photo-ionization and Photo-fragmentation dynamics
Imaging: velocity mapping, atomic streak camera Coincidences: powerful techniques highly developed at LURE
major issue in gas phase physics at SOLEIL
~ **Complete experiments**

Reaction dynamics in the 10 ps-10 ns range
⇒Time-resolved analysis of transition states and products

Pump-Probe combined with coincidences

~

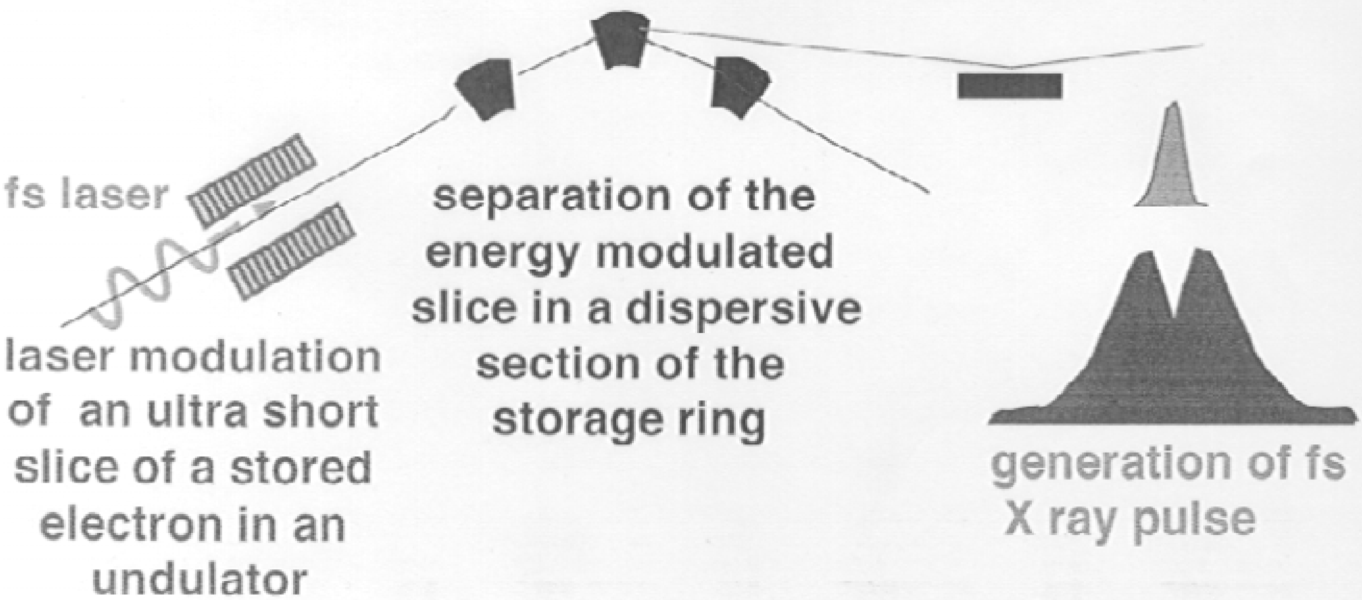
Soleit

FEL STRAIGHT SECTION USE AT 2.5/2.75 GeV

· Use of the insertion device for synchrotron radiation (keV) at 2.5-2.75 GeV

· X-ray femtosecond pulse production with the FEL Ti-Sa laser

Electron bunch slicing (Schoenlien, Zholents, Zolotorov):



· Experimental demonstration (ALS) Planned on SLS

4ω of the Ti:Sa laser

· Main advantages:
- fs, hard X ray, adjustable energy
- high repetition rate, brightness
- transverse coherence

F= 10^6-10^8 ph/s/0.1% BW