ARC-EN-CIEL
Accelerator Radiation Complex for ENhanced Coherent Intense Extended Light

THE ARC-EN-CIEL PROPOSAL

SOURCE OF COHERENT LIGHT TUNEABLE FROM UV TO X RAYS, IMPLEMENTED ON A LINEAR ACCELERATOR

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Acknowledgments to J. R. Marquès (LULI), L. Giannessi (ENEA)

MOTIVATION

- **FEL History in France**

ACO (1983), Super-ACO (1989), CLIO (1992),
First pump-probe two-color experiments using a UV FEL and synchrotron radiation (1994)

- **FEL source for 1 keV for user applications**

- **FEL physics : to exploit harmonic generation and seeding schemes**

- **"CW" operation**

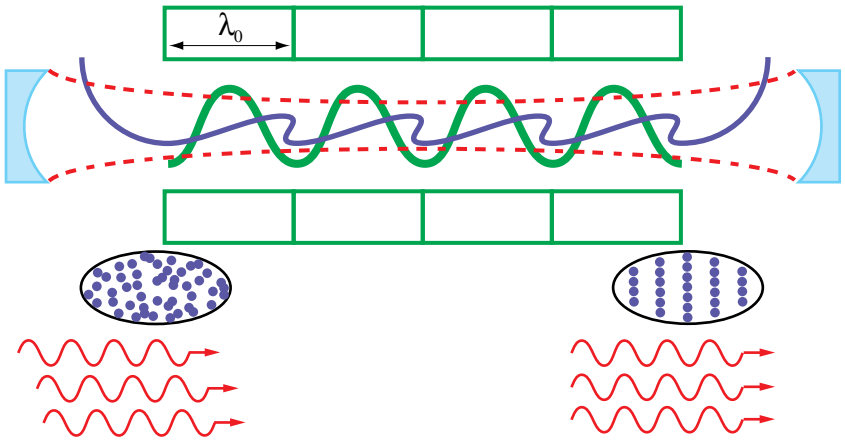
- **Expertise on accelerators (SC...)**

- **Close synergy between FEL and conventional laser sources communities in the same facility**

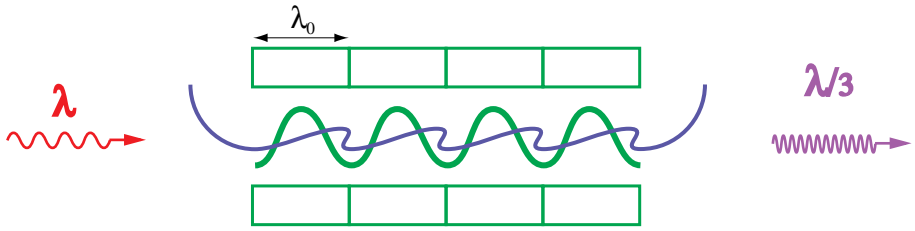
FEL CONFIGURATIONS

$$\lambda = \frac{\lambda_0}{2n\gamma^2}\left(1+\frac{K^2}{2}\right) \qquad K = 0.94\,\lambda_0\,(\text{cm})\,B_0\,(\text{T})$$

Oscillator

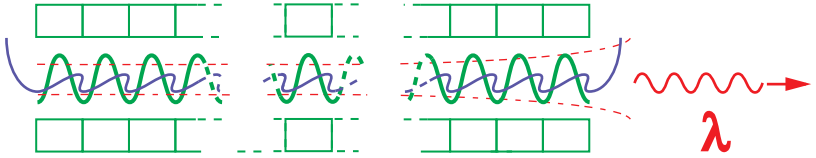


Harmonic Generation

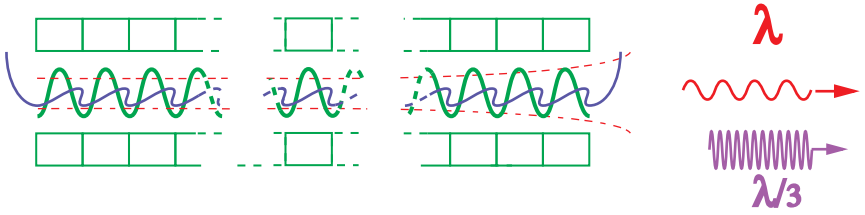


HGHG

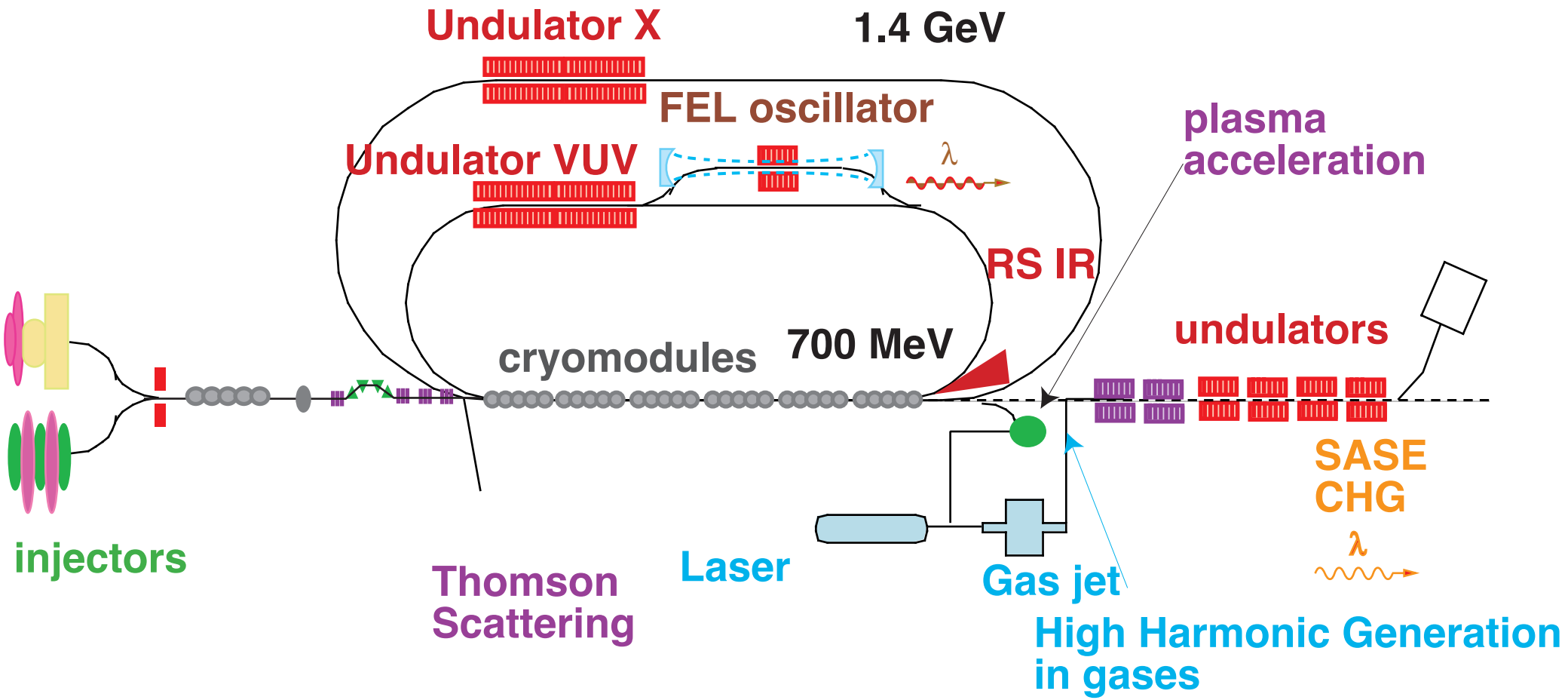
SASE



NHG

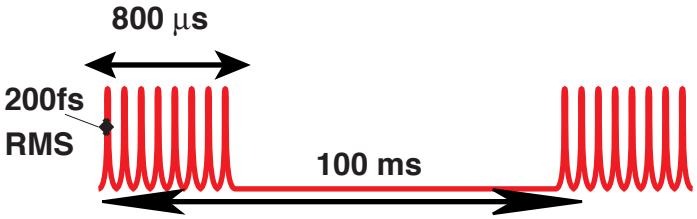


SCHEME


Undulator X
1.4 GeV
FEL oscillator
Undulator VUV
λ
plasma
acceleration
RS IR
undulators
cryomodules
700 MeV
SASE
CHG
λ
injectors
Thomson
Scattering
Laser
Gas jet
High Harmonic Generation
in gases

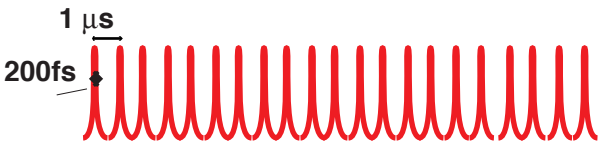
INJECTORS

Injector 1

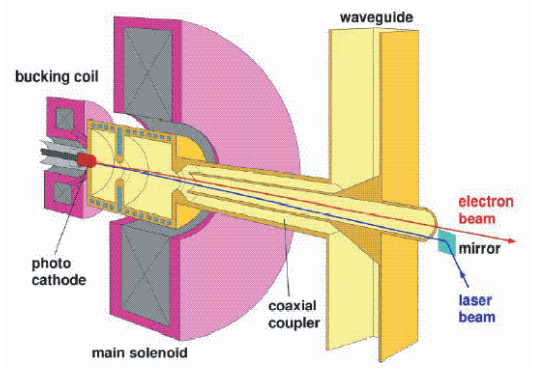


Injector 2

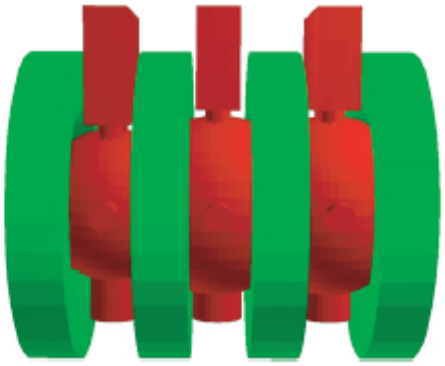
Injector 2 bis

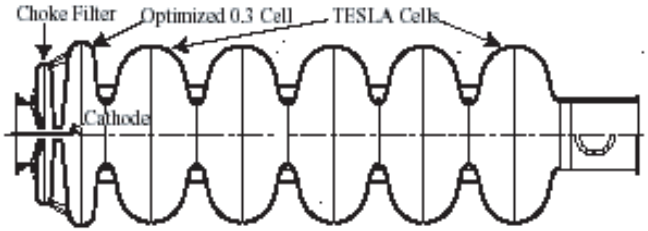


emittance : 2π mm.mrad, charge : 1nC



RT pulsed RF gun (TTF 2)



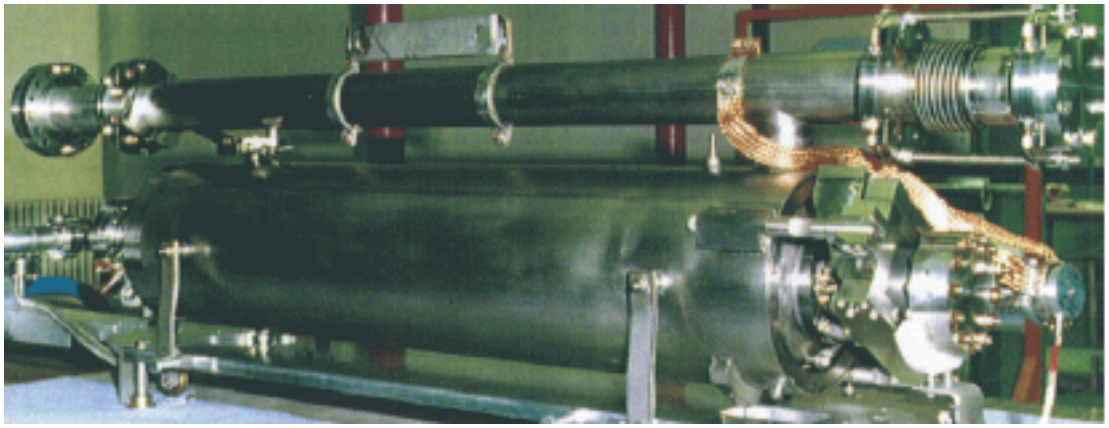


SC RF gun (Rossendorf)

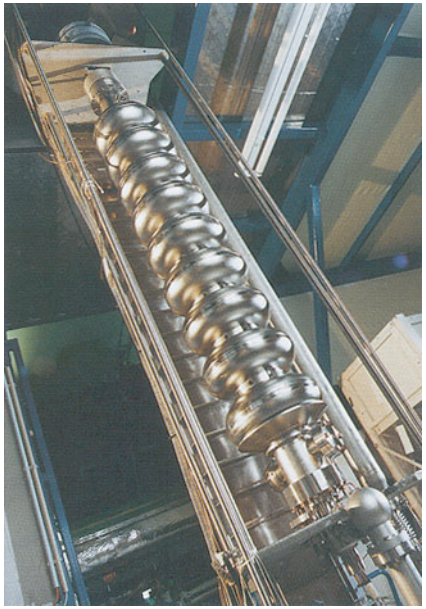
R&D :

- Emittance compensation
- "cw" operation
- Reliability

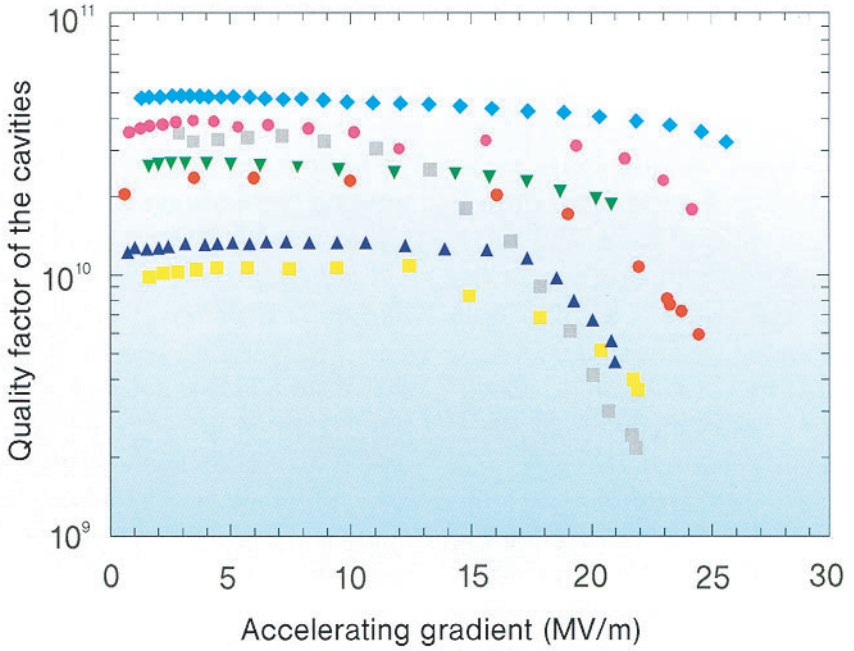
THE LINAC CAVITIES



E=700 MeV
L=72 m
I=1mA/pass (ER : 5-10 mA)
emittance : 2π mm.mrad
charge : 1nC
energy spread : 0.1 %
Î=3kA, <I> = 0.1 mA

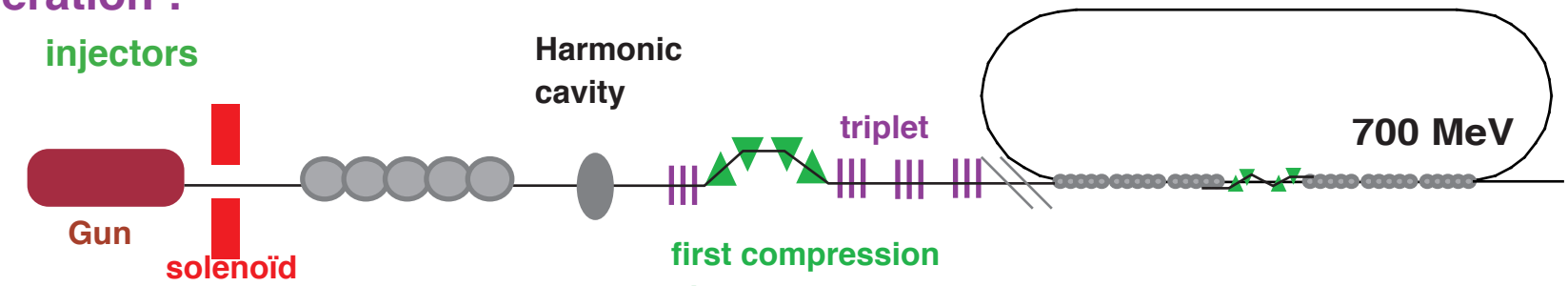


TESLA type superconductiong accelerator
6 cryomodules (1.3 GHz)



PRE-ACCELERATION - COMPRESSION

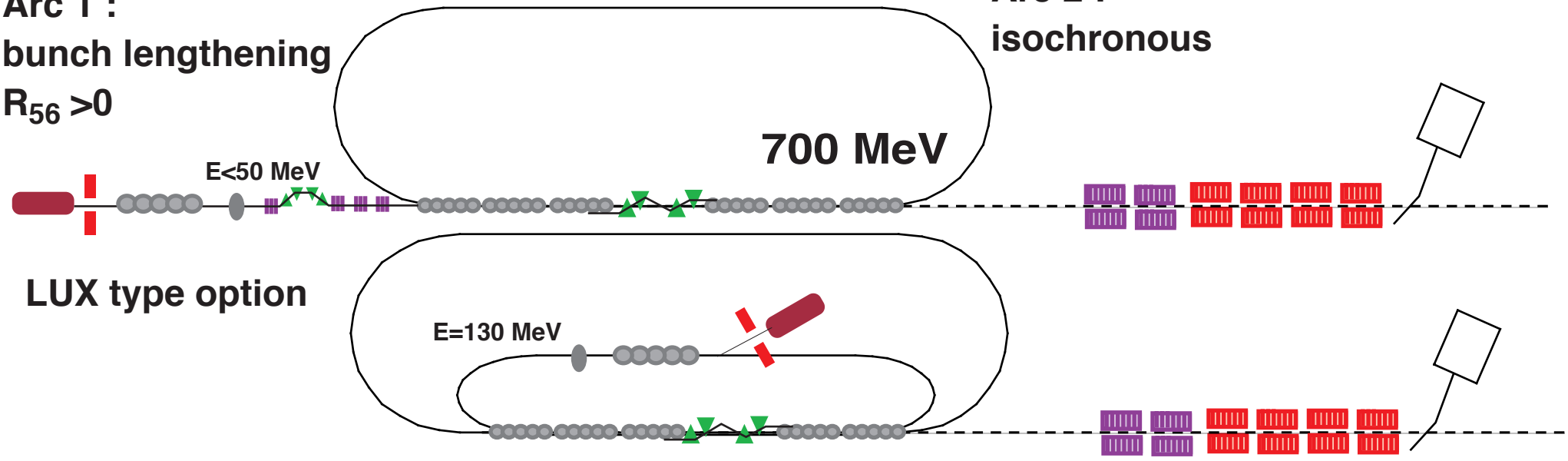
Pre-acceleration :



Bunch Compression :

Arc 1 :
bunch lengthening
R_{56} >0

Arc 2 :
isochronous

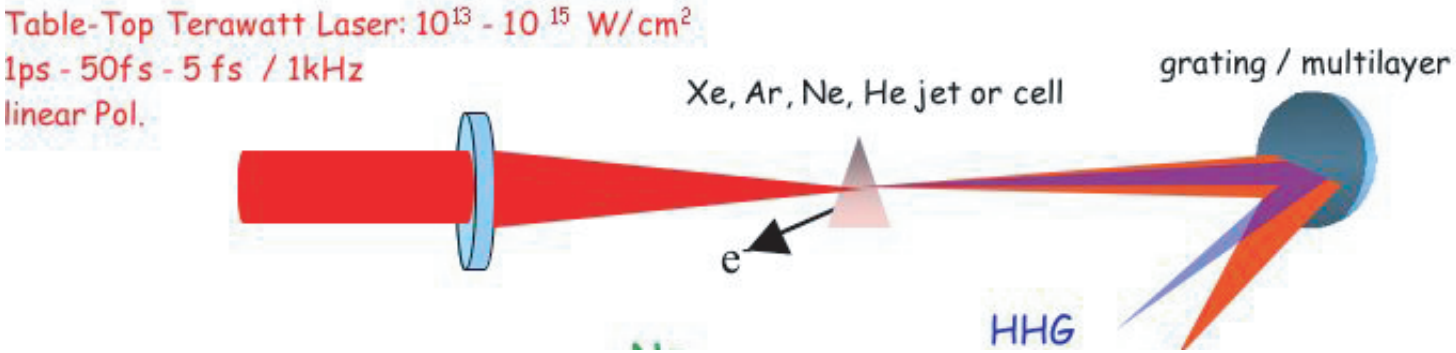


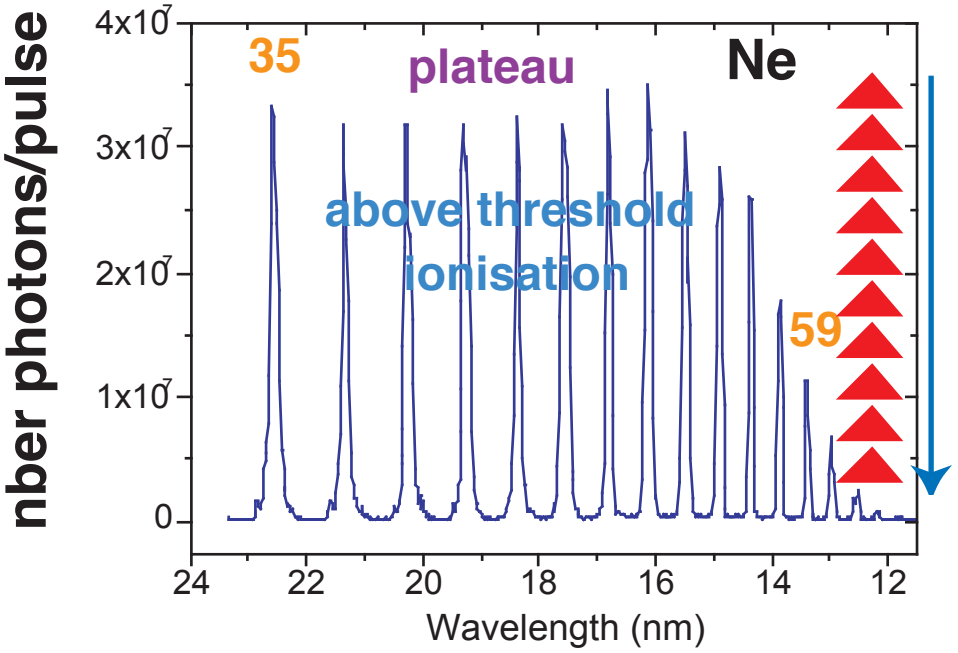
LUX type option

LASER SOURCES

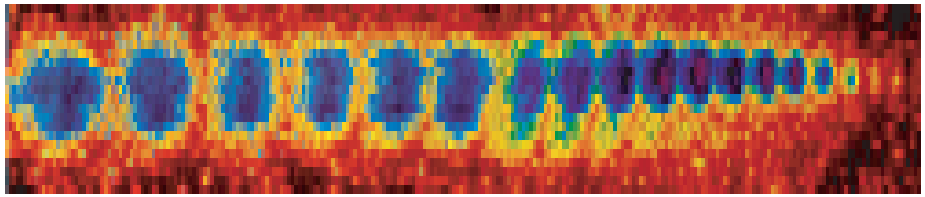
Infra-red laser system Ti:Sa, mJ, 1-10 kHz, frequency conversion

High Gain Harmonic Generation in gas





linear polarisation
tuneability
spatial and temporal coherence



LASER SOURCE

Infra-red Ti:Sa laser system, mJ, 1-10 kHz, frequency conversion

amplification chain : few J, 10 Hz, 30 TW, 10^{20}W/cm^2

Plasma Acceleration

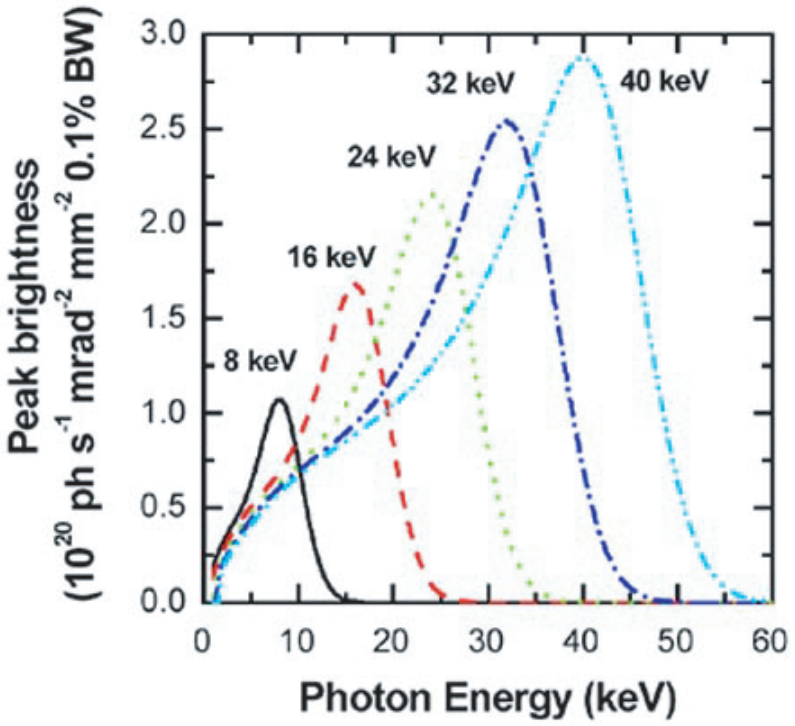
Intense Laser (30 TV/m)

↓ **plasma wave**

progressive wave
(longitudinal electric field, velocity close to c)

E_{in}	Δt	emitt	L_{acc}	E	spot	E_{fin}
MeV	fs	mm.mrad	cm	J	μm	GeV
10	200	1	0.5-3	1	20	1.6
700	200	1	8-32	100	100	1.6

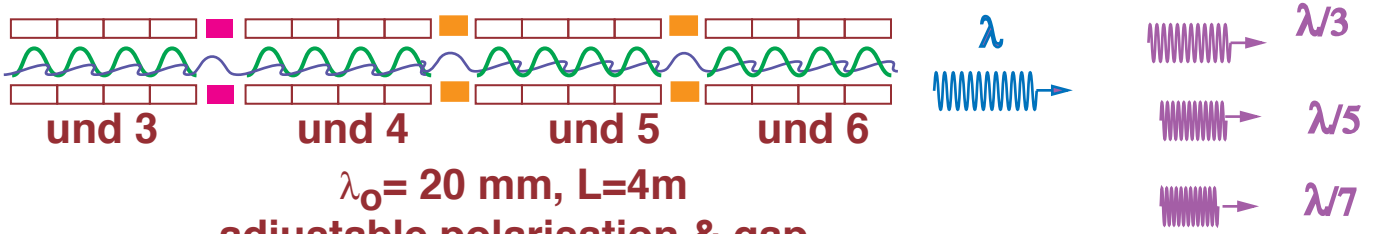
Thomson Scattering



8-40 keV, 100 fs FWHM
3 10^7ph/pulse/0.1%BW
12 mrad, 50 μm

SINGLE PASS FEL SOURCES

- **SASE**

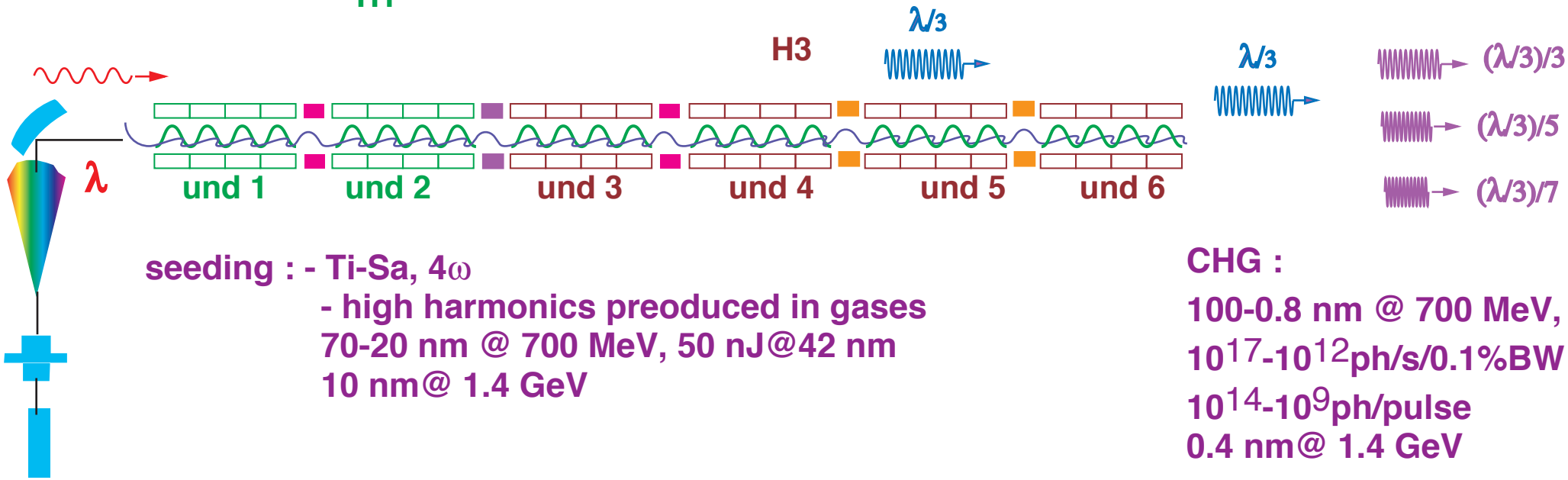


λ_o= 20 mm, L=4m
adjustable polarisation & gap

SASE :
200-7 nm@700 MeV
10^{17}-10^{16}ph/s/0.1%BW
10^{15}-10^{13}ph/pulse

- **Harmonics generation**

λ_o= 30 mm, L=4m
adjustable polarisation & gap
H1



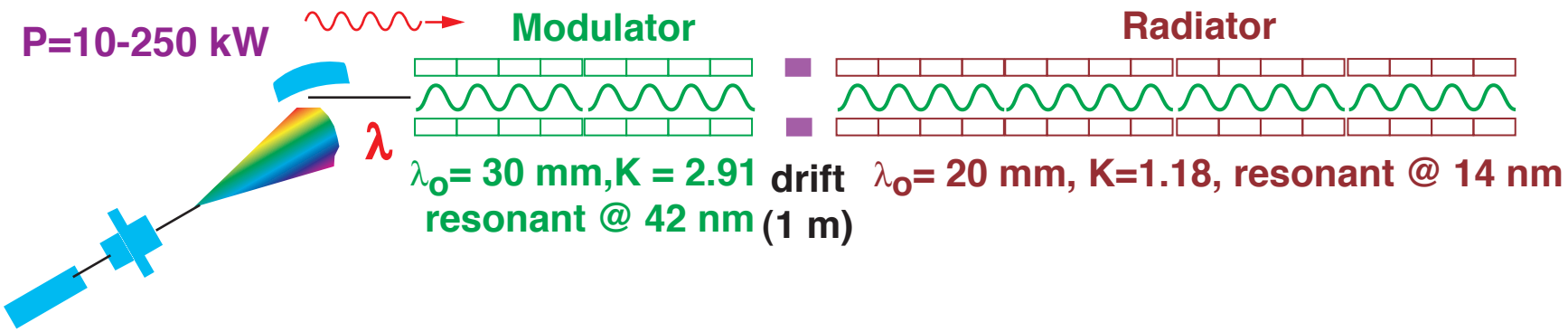
seeding : - Ti-Sa, 4ω
- high harmonics preoduced in gases
70-20 nm @ 700 MeV, 50 nJ@42 nm
10 nm@ 1.4 GeV

CHG :
100-0.8 nm @ 700 MeV,
10^{17}-10^{12}ph/s/0.1%BW
10^{14}-10^{9}ph/pulse
0.4 nm@ 1.4 GeV

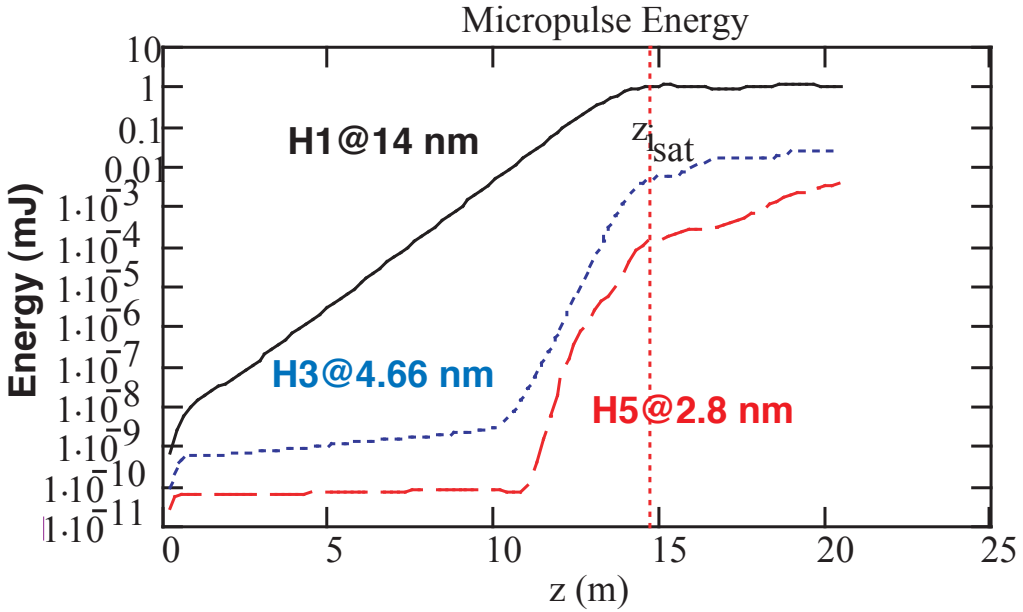
PERSEO CALCULATIONS

1D steady state (L. Giannessi)

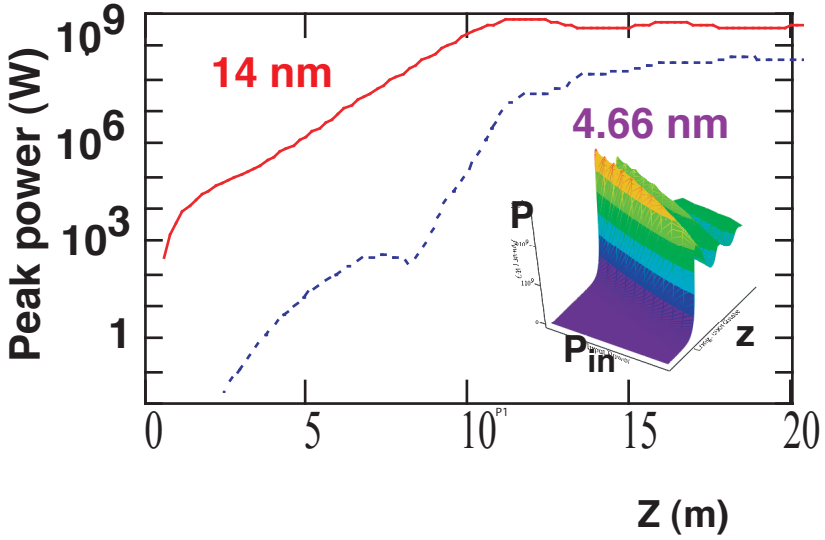
** Perseo Mathcad library, available @ http://www.perseo.enea.it*



Radiator as a SASE FEL

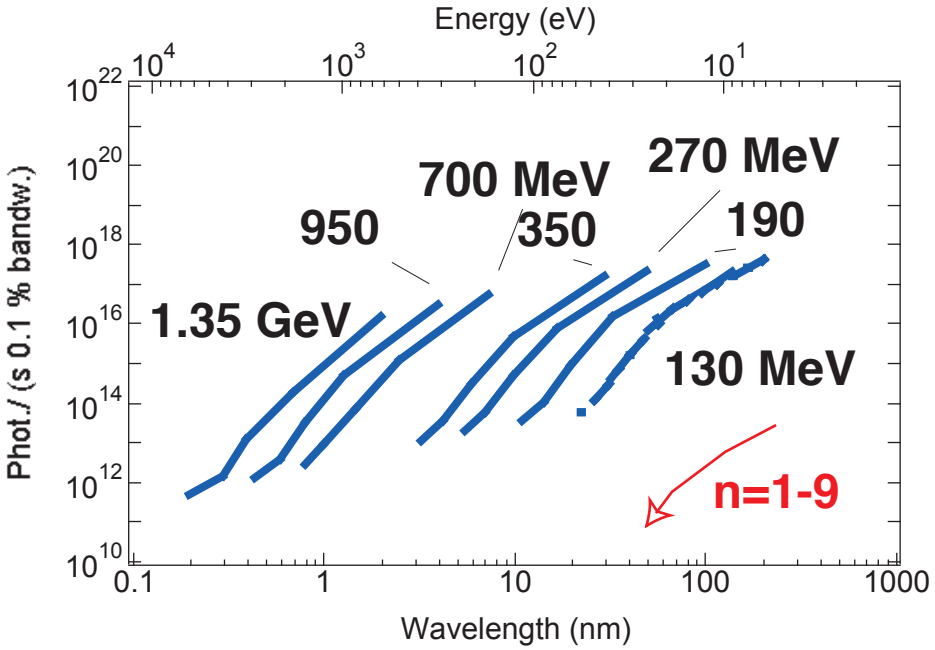


HGHG from HH in gases 42 nm, 50 kW

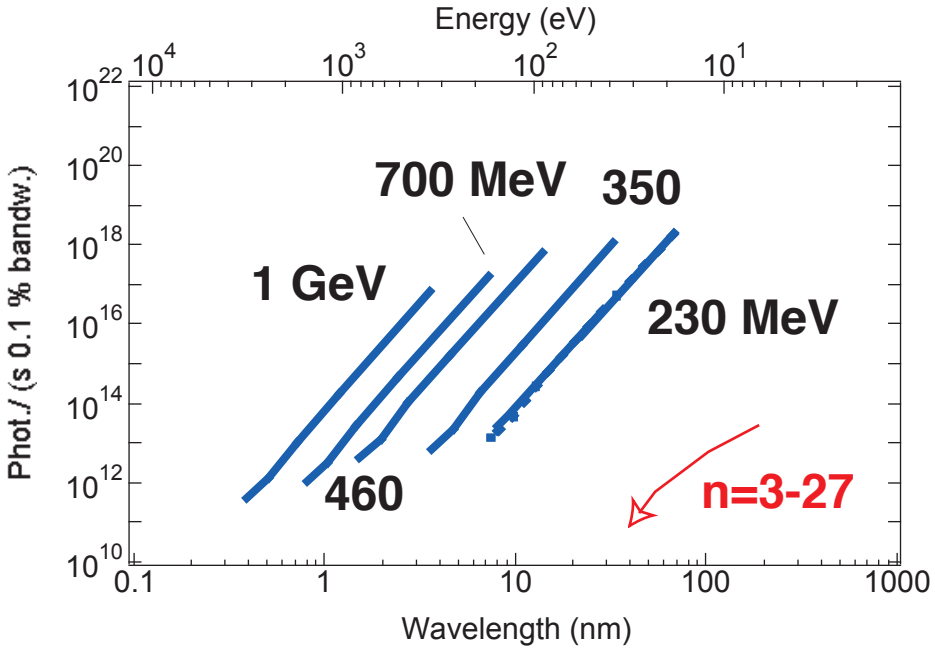


NON LINEAR HARMONICS

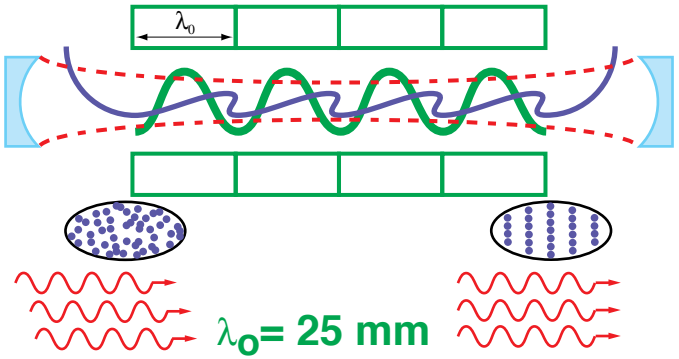
SASE



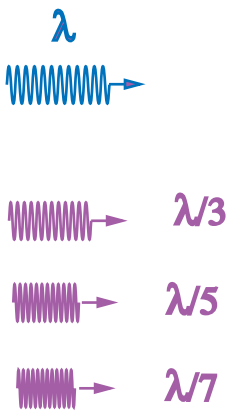
CHG

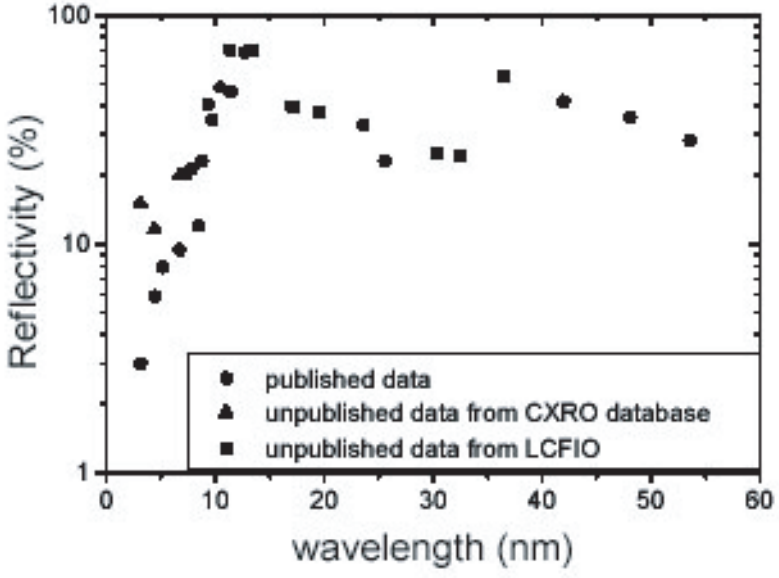


THE FEL OSCILLATOR



λ_o= 25 mm
L=5m
polarisation ajustable
outside vacuum



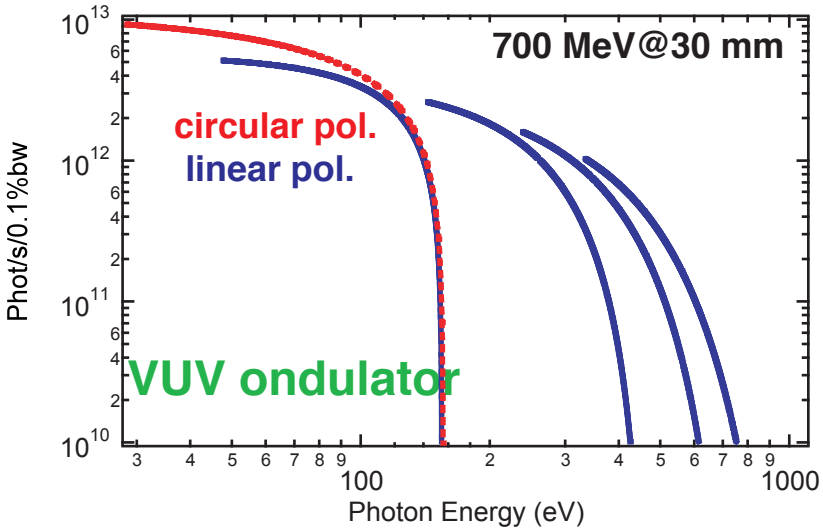


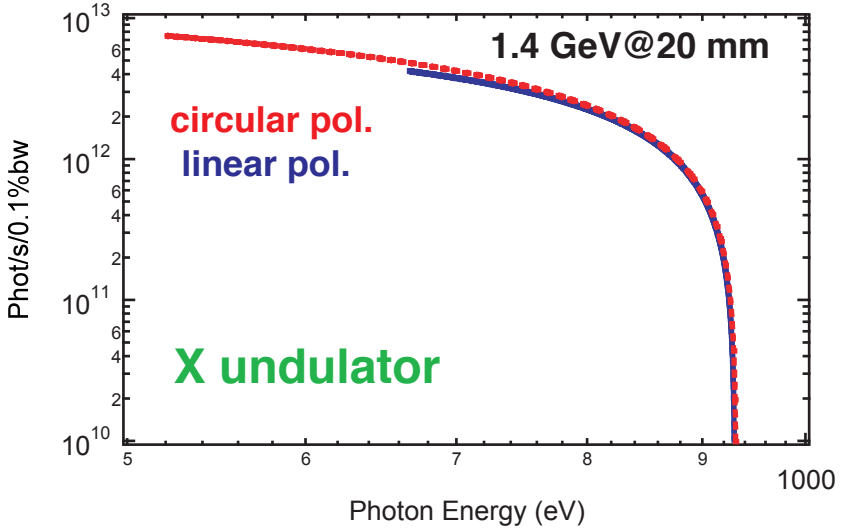
130-13 nm

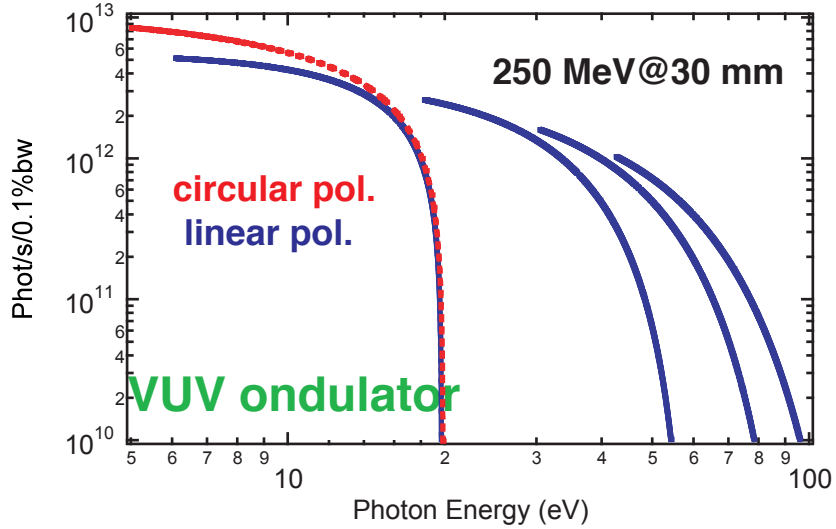
<P> = 100W-1kW

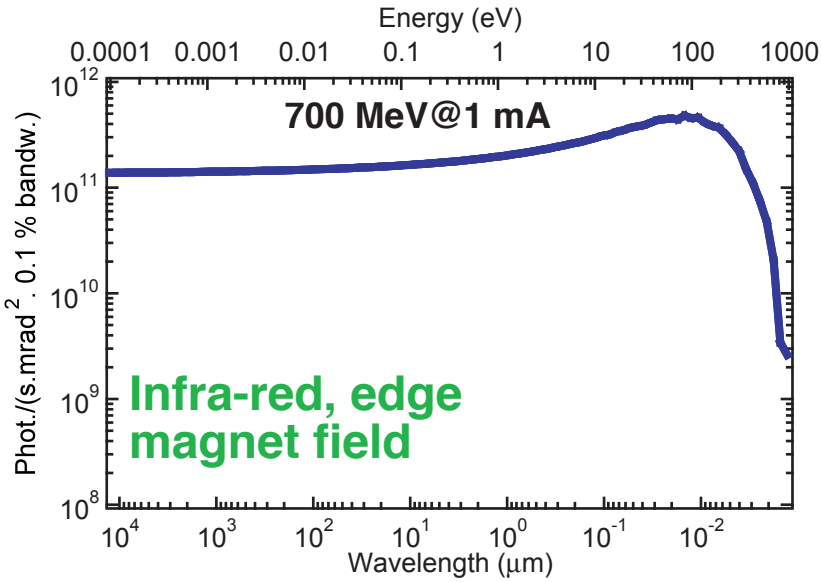
adjustable polarisation

ERL SOURCES


700 MeV@30 mm
circular pol.
linear pol.
VUV ondulator
Phot/s/0.1%bw
Photon Energy (eV)

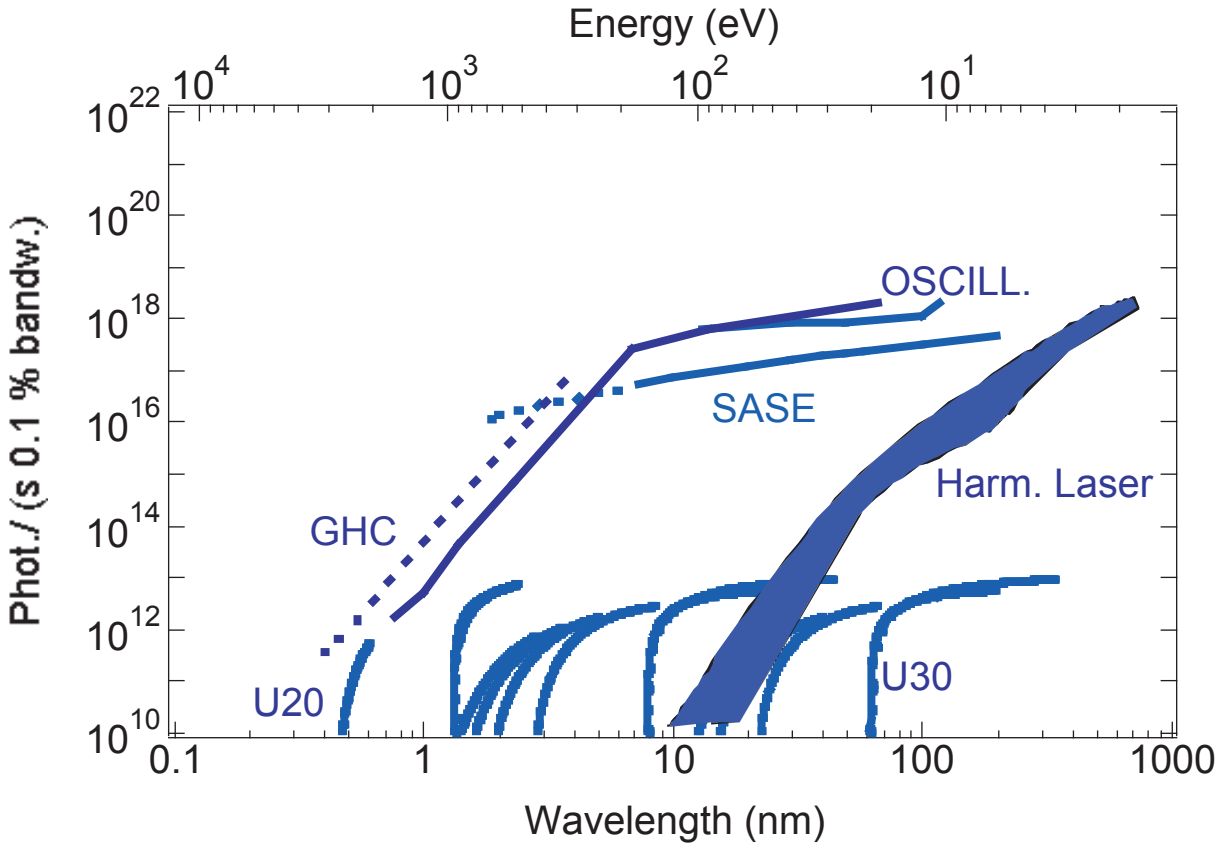

1.4 GeV@20 mm
circular pol.
linear pol.
X undulator
Phot/s/0.1%bw
Photon Energy (eV)


250 MeV@30 mm
circular pol.
linear pol.
VUV ondulator
Phot/s/0.1%bw
Photon Energy (eV)


Energy (eV)
700 MeV@1 mA
Infra-red, edge
magnet field
Phot./(s.mrad^2. 0.1 % bandw.)
Wavelength (μm)

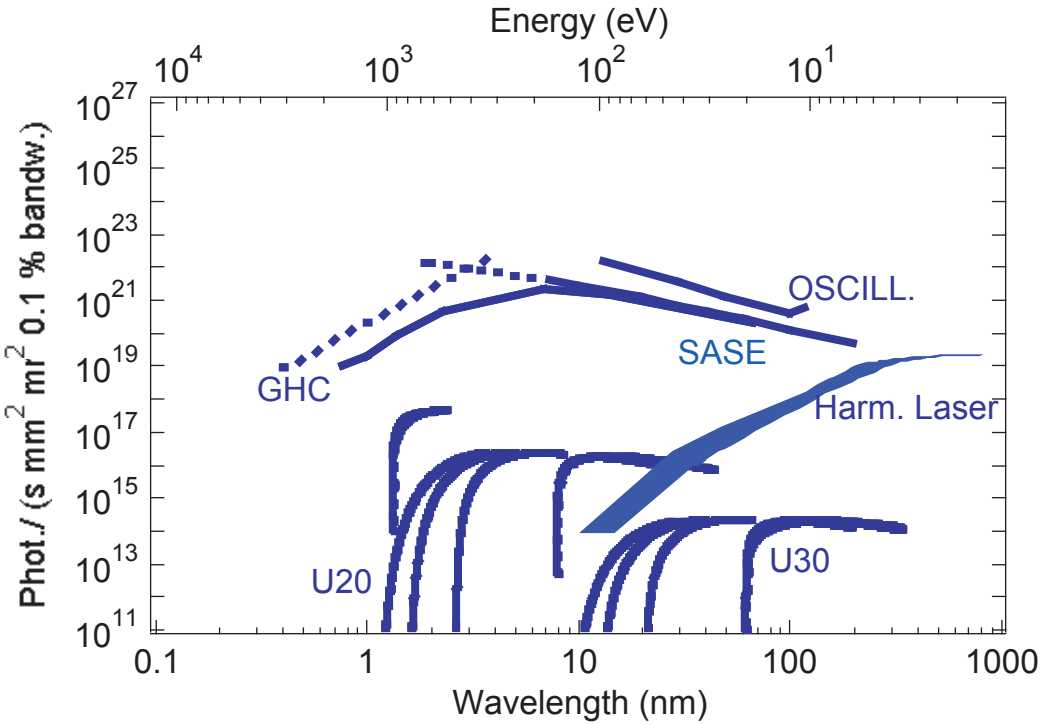
ARC-EN-CIEL PERFORMANCES

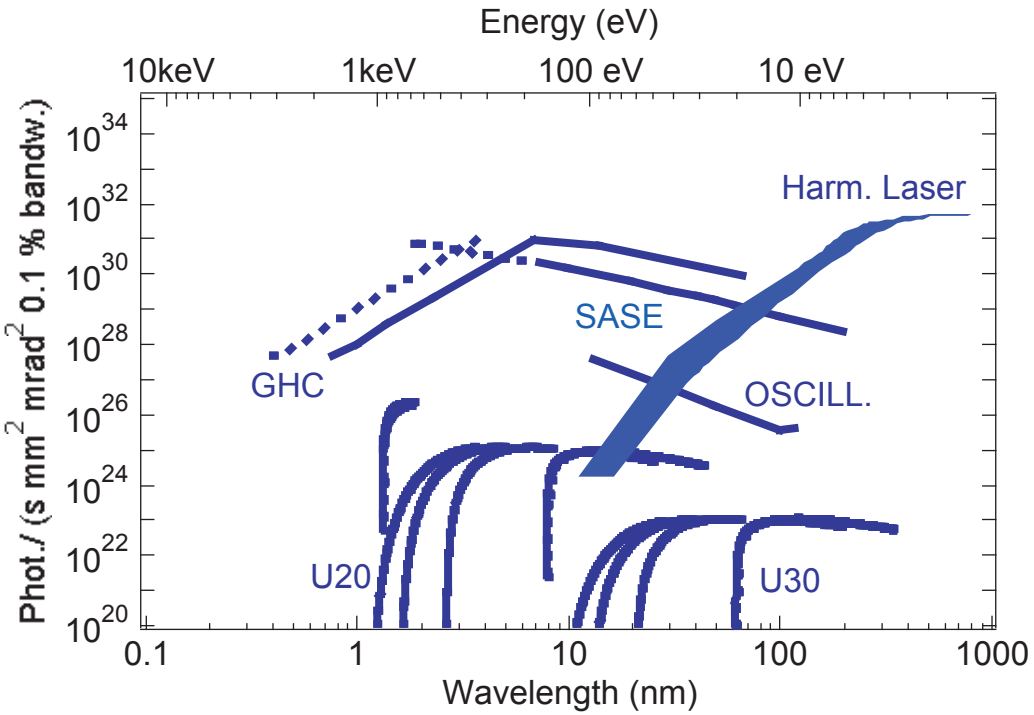
Flux



ARC-EN-CIEL PERFORMANCES

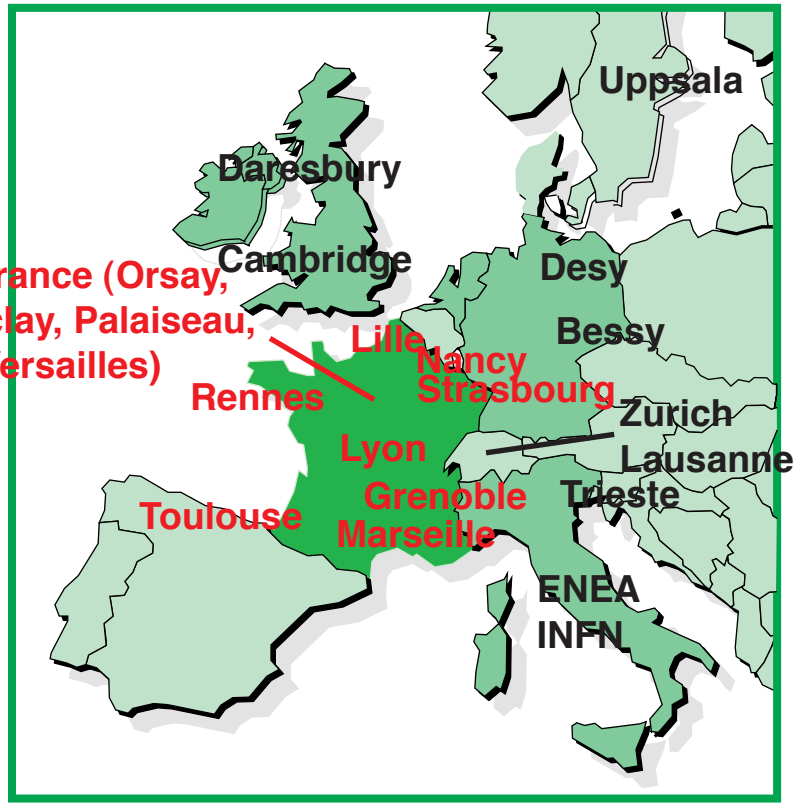
Brilliance





VUV-X fs SCIENCE USER WORKSHOP

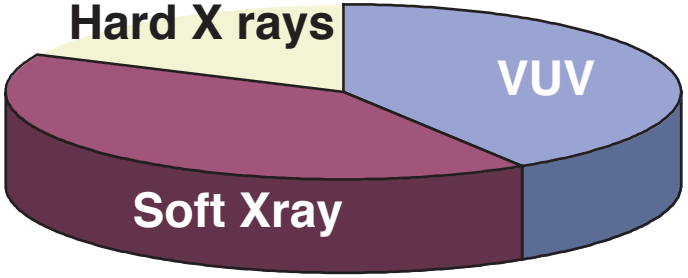
- 154 participants
  - 136 from France
  - 2 companies
  - from abroad : Belgium (1), Germany (4), Italy (5), Sweden (3), Switzerland (2), UK (2), USA (1)
- 40 different French Laboratories



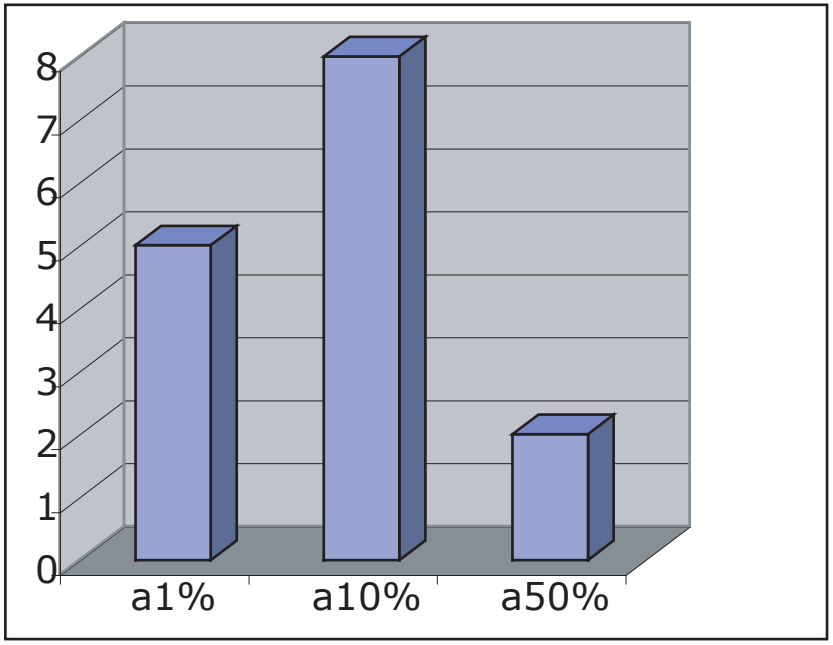
QUESTIONNAIRE

- answers from 22 research teams + oral presentations
  - 11: Material ans surface science + 1 theory
  - 13 : atomic and molecular physics + 1 theory
  - 4 : plasma physics
  - 5 : biology and chemistry + 1 theory

- Spectral range



Stability

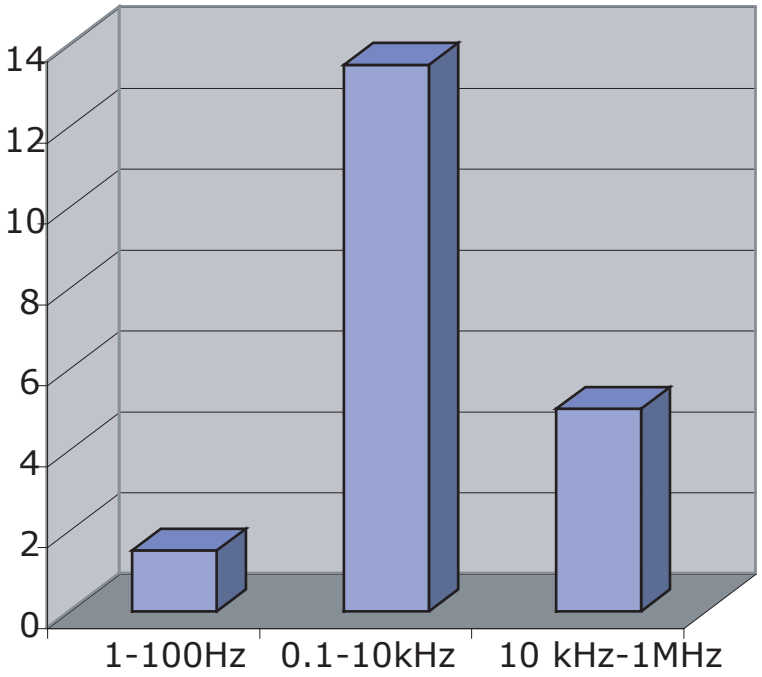


- Spectral resolution : 1-0.01%
- Tuneability : yes
- Transverse coherence : yes
  focalisation on 0.5 μm to 100 μm
- Pump-probe experiments : 72 %
  focalisation on 0.5 μm to 100 μm
- Adjustable polarisation: 63 %

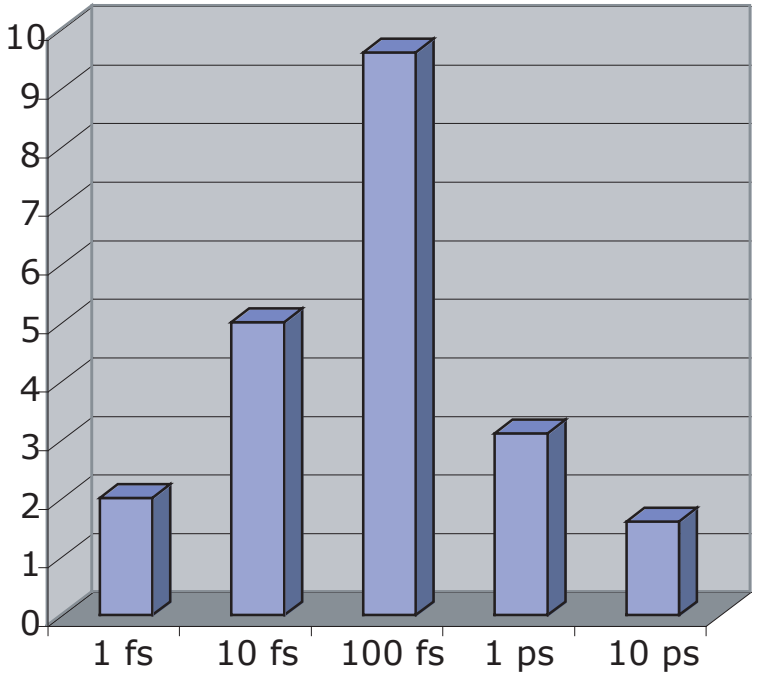
QUESTIONNAIRE

Temporal structure

Repetition rate



Pulse duration



• answers	No (%)	Yes	Indifferent
Several micropulses (few nsrep. rate) in a macropulse at 1 Hz :	66	22	11
Spiking structure of the FEL pulse	55	30	15
Gaussian distribution	28	61	11
Measurement and not control of the pulse temporal start	59	41	

Accumulation (72 %) vs single shot (28%)

GAS PHASE

- femtophotochemistry (mol. dynamics in gas phase)

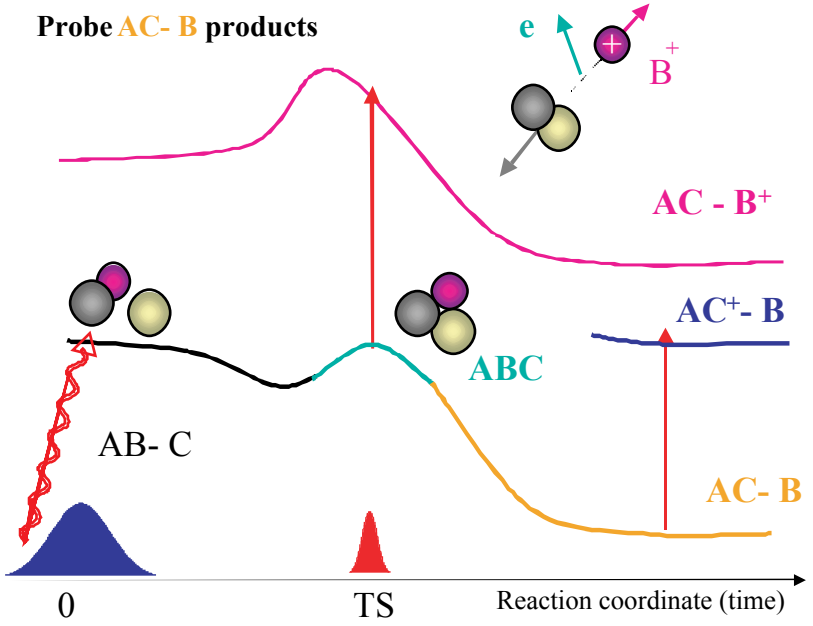
- femtochemistry of molecules absorbed on surfaces

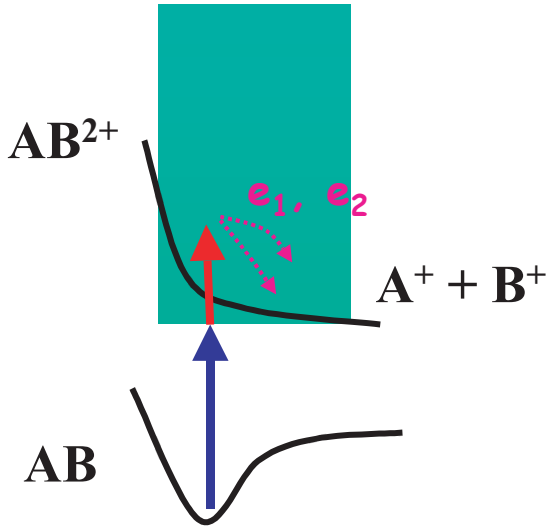
- alignment and photoionisation dynamics

- high average flux spectroscopy

- atomic physics in non linear regime

- agregates under high field



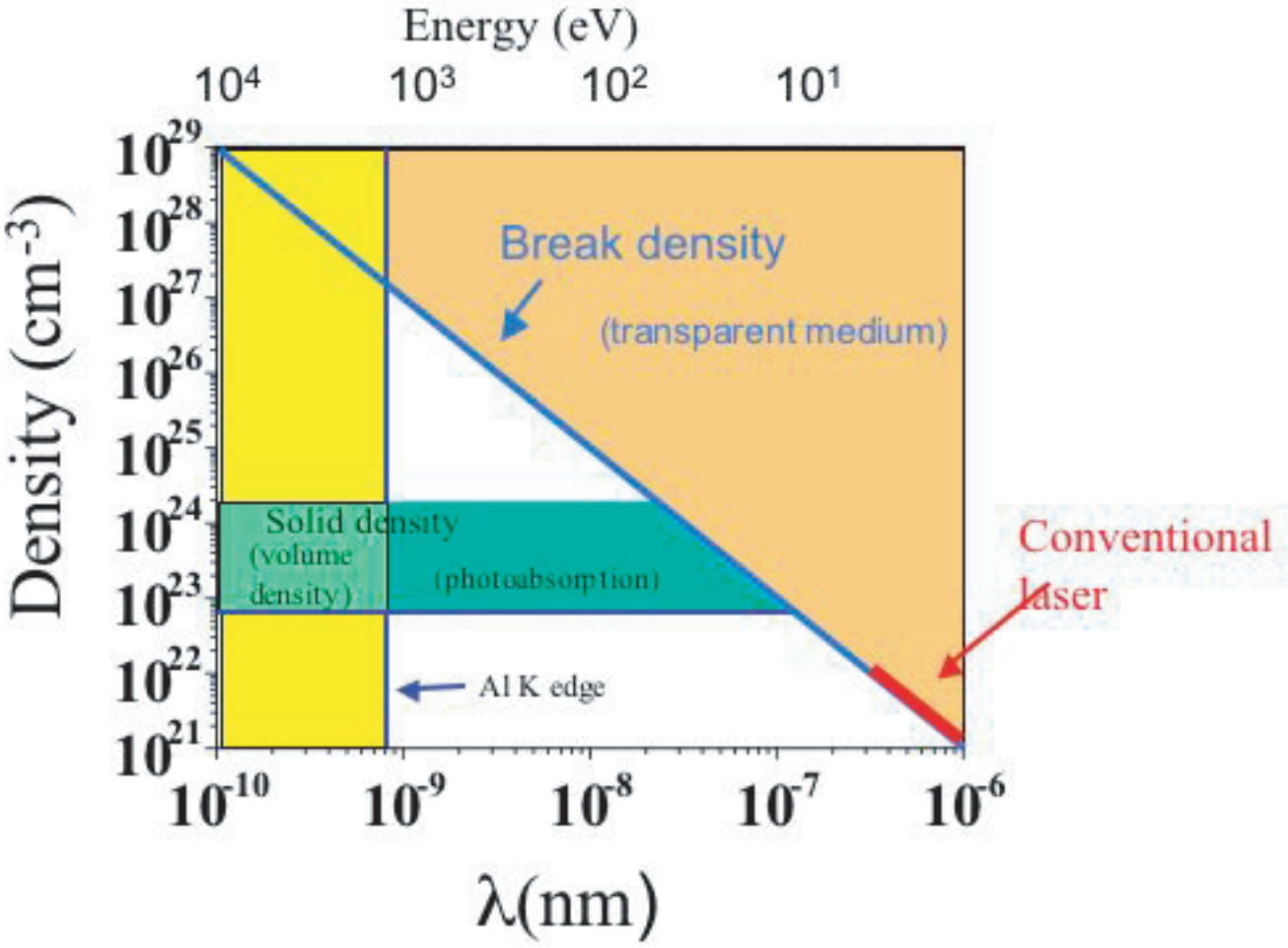


PLASMA PHYSICS

- generation of hot dense plasma

- Caracterisation of plasmas at solid density

- plasma acceleration



CONDENSED MATTER-CHEMISTRY

- free agregates

agregates : magnetic, semi-conductors-> information storage, noble materials ->catalysis

Technique : Spectromicroscopy IR/ excit.UV

- magnetism spin valve, magnetic semi-conductors

Technique : Photoemission 1-2 photons

- surfaces and interfaces interface solid/liquid, surface magnetometry, adsorbates, desoprtion of a polymer layer on a surface

- complex materials oxides of transition metals, phase transition, defects formation

Technique : Diffusion inélastique

- large gap solids, dynamics of excited states

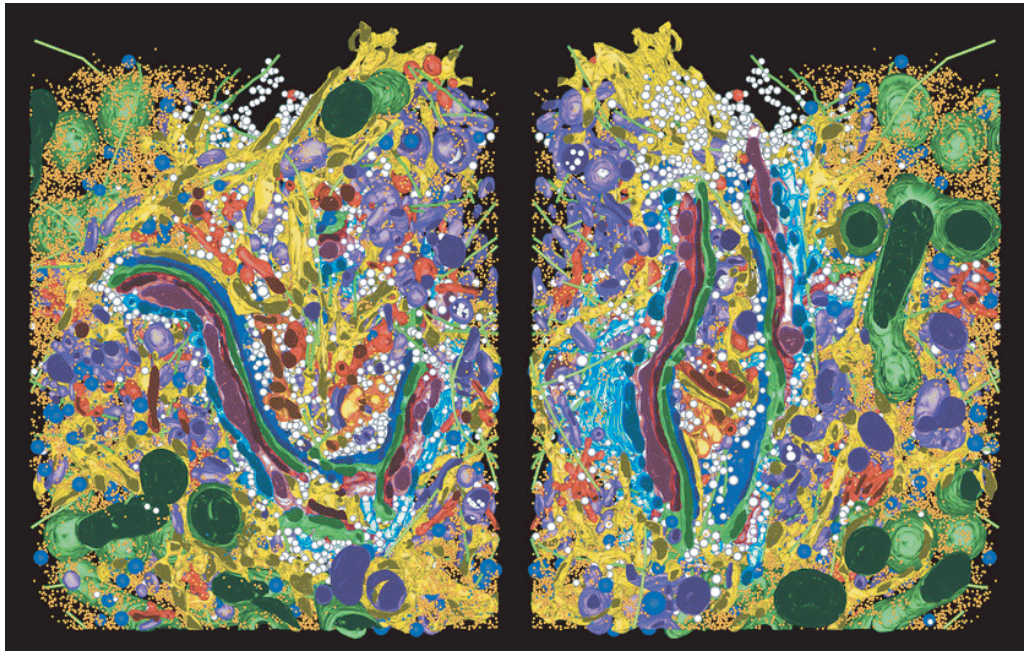
- Electrochemistry

- Catalysis

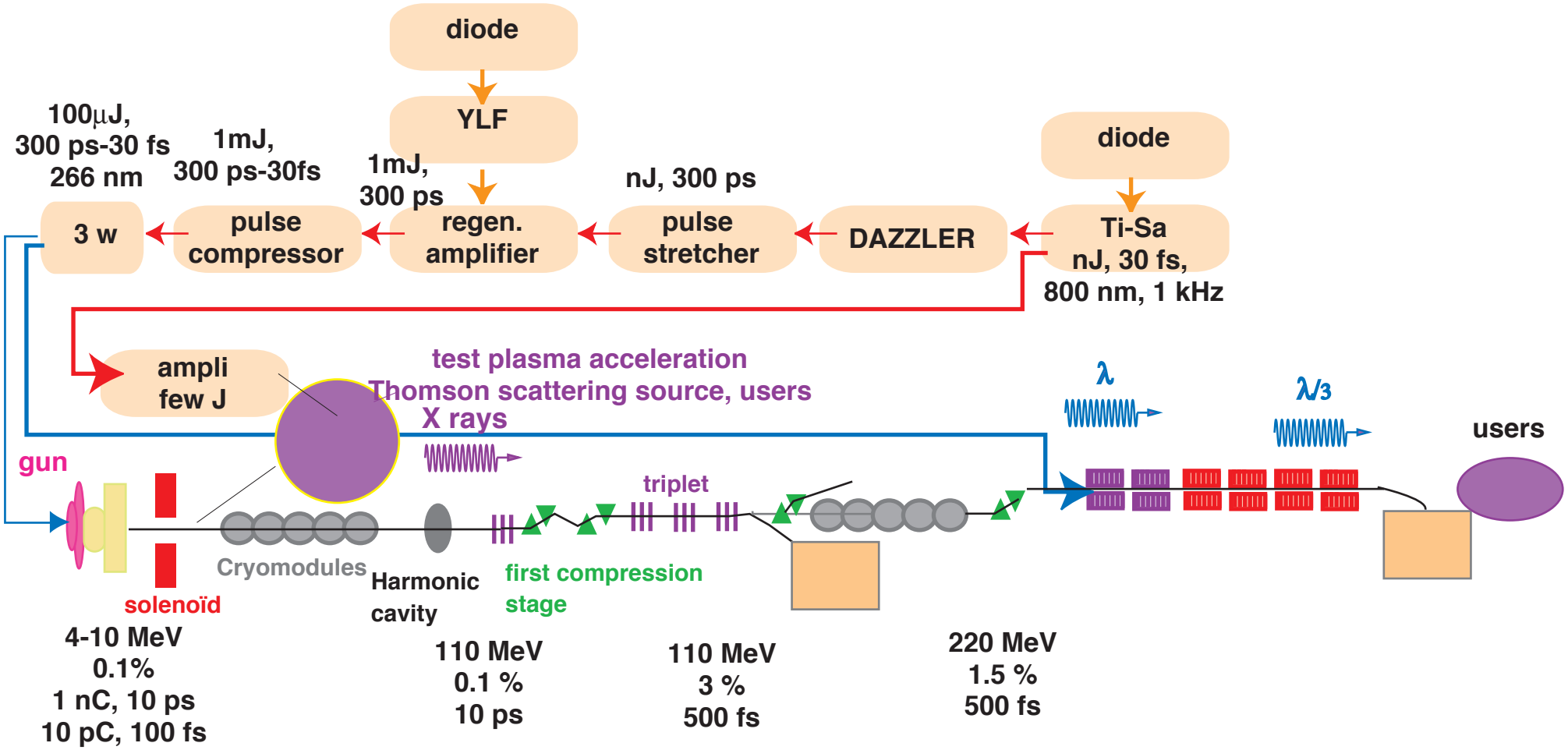
BIOLOGY

- atomic mechanism of protein folding

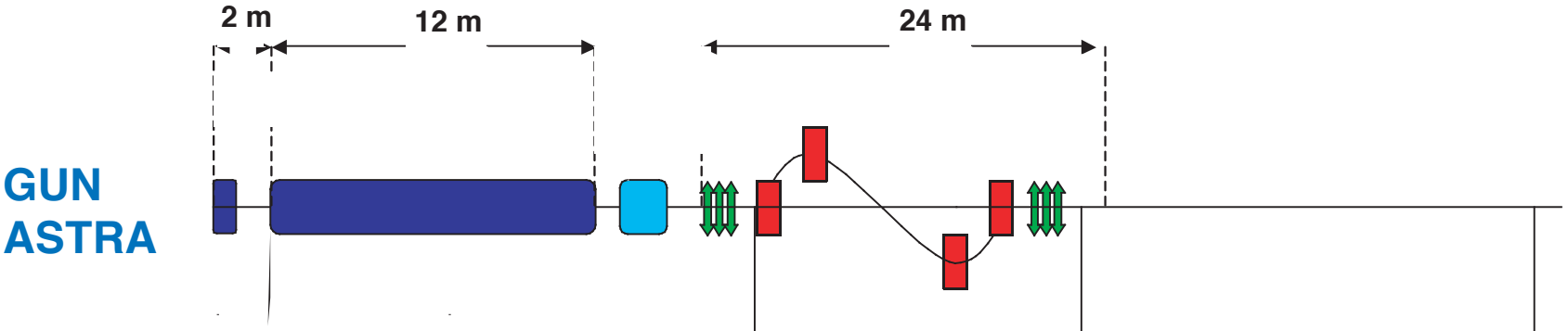
- X ray microscopy cell study



PHASE 1


diode
YLF
100µJ,
300 ps-30 fs
266 nm
1mJ,
300 ps-30fs
1mJ,
300 ps
nJ, 300 ps
diode
3 w
pulse compressor
regen. amplifier
pulse stretcher
DAZZLER
Ti-Sa
nJ, 30 fs,
800 nm, 1 kHz
ampli
few J
test plasma acceleration
Thomson scattering source, users
X rays
λ
λ/3
users
gun
triplet
Cryomodules
Harmonic cavity
first compression stage
solenoïd
4-10 MeV
0.1%
1 nC, 10 ps
10 pC, 100 fs
110 MeV
0.1 %
10 ps
110 MeV
3 %
500 fs
220 MeV
1.5 %
500 fs

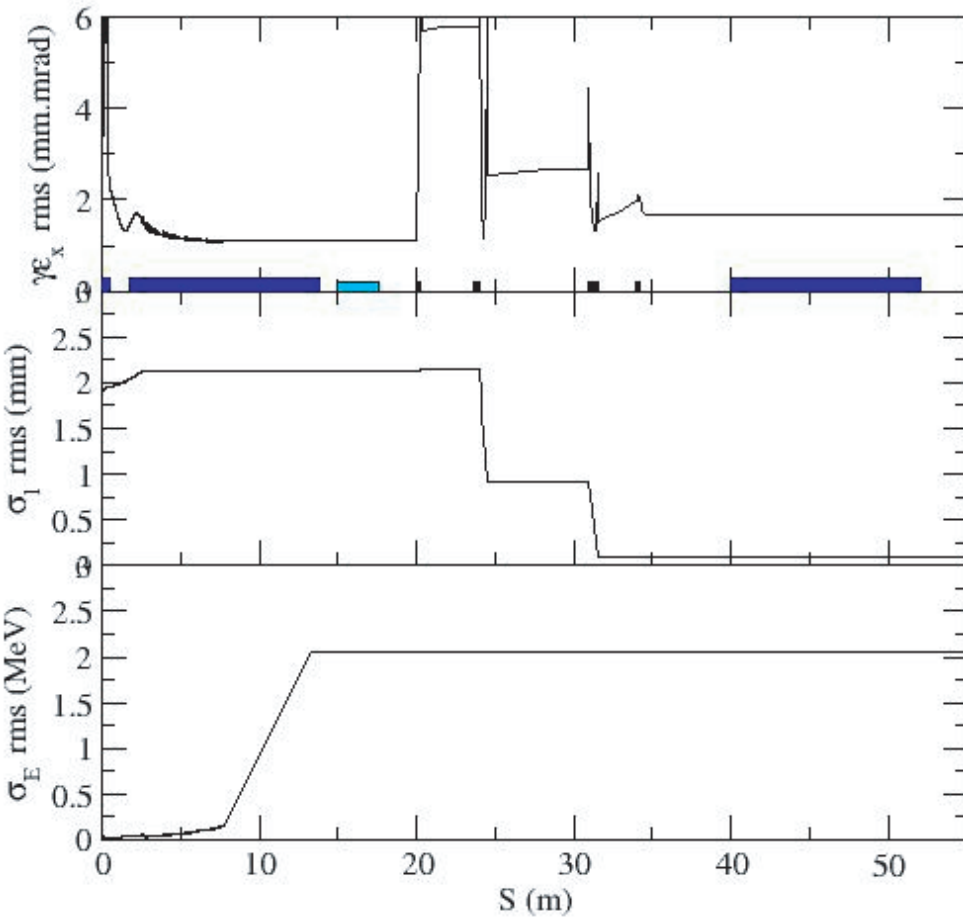
S2E SIMULATIONS



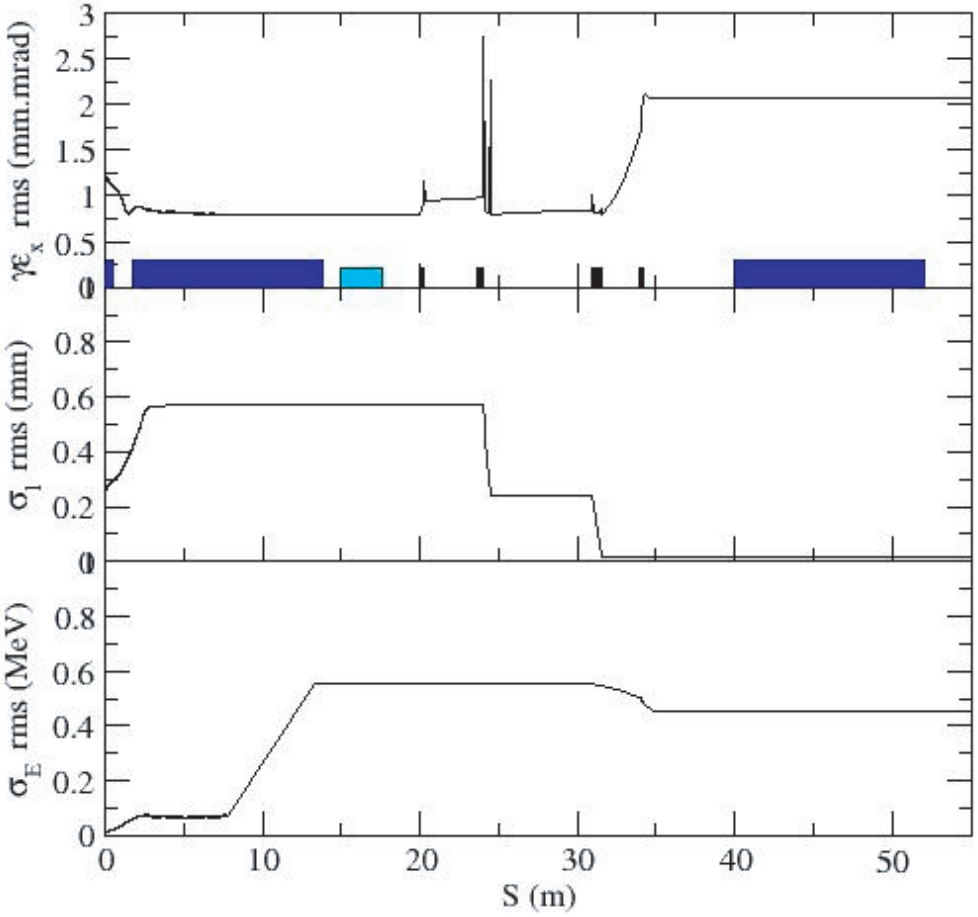
Q (nC)	1	0.1	1	0.1	1	0.1	1	0.1
E (MeV)	4	4	101	101	101	101	220	220
ΔE (keV rms)	10	5	2	0.5	2	0.5	2	0.5
ds (mm rms)	2	0.6	2	0.6	0.1	0.02	0.1	0.02
ds (fs rms)	6000	2000	6000	2000	300	60	300	60
γε (π mm.mrad rms)	1.1	0.8	1.1	0.8	1.7	2.1	1.7	2.1

S2E SIMULATIONS

1 nC, laser 20 ps
bunch compressed to 300 fs (100 μm)



0.1 nC, laser 2 ps
bunch compressed to 60 fs



INFRASTRUCTURE