The LUNEX5 project in France

M. E. Couprie, A. Loulergue, P. Morin

Laser à électrons libres **U**tilisant un accélérateur **N**ouveau pour **E**xploitation de rayonnement **X** de **5**ème génération

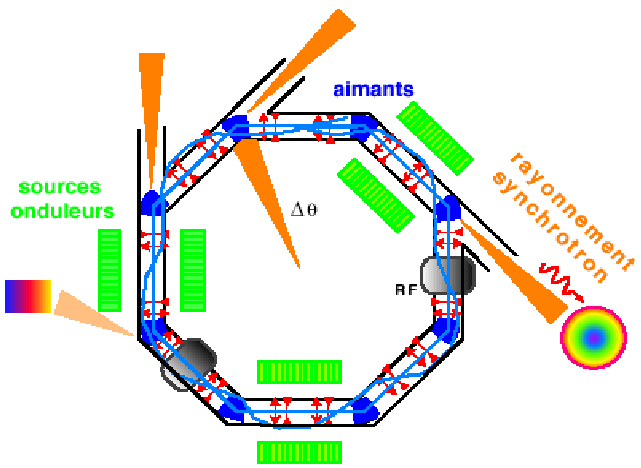
free electron **L**aser **U**sing a **N**ew accelerator for the **E**xploitation of **X**-ray radiation of **5**th generation

SACM

CILEX

Accelerator choice for FEL

Storage ring



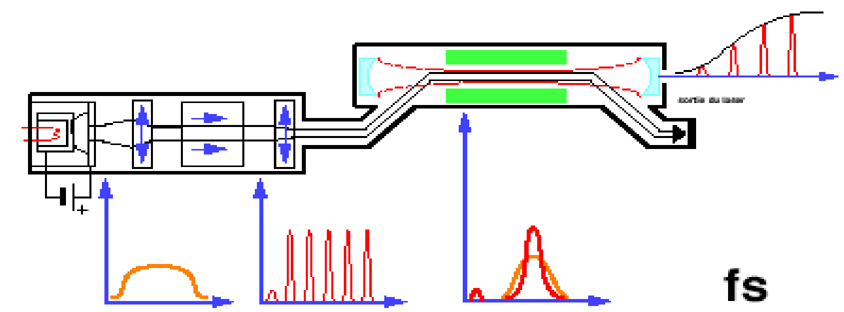
10–30ps,
$\varepsilon \alpha E^2$

Energy spread :
0.1 %

Linear accelerator

10 fs–10 ps,
$\varepsilon \alpha 1/E$

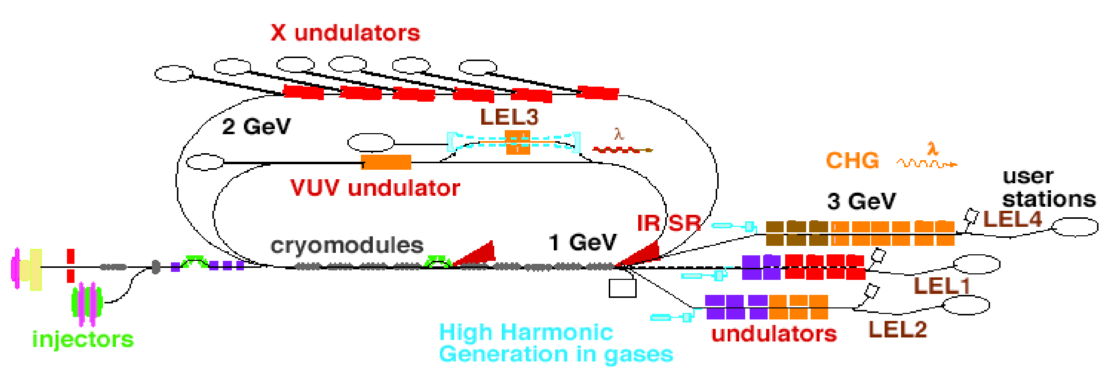
Energy spread : :
0.01 %



Repetition rate : depending on the linac (room temperature or superconducting)

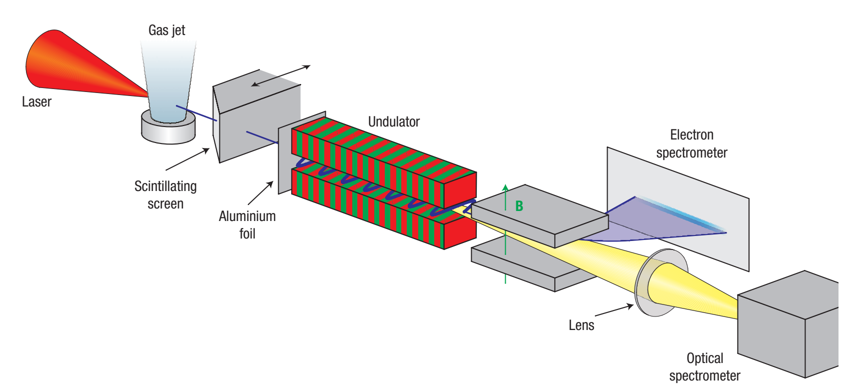
Energy recovery LINAC (ERL)

Accelerator Radiation Complex for ENhanced Coherent Intense Extended Light
http://arcenciel.synchrotron.fr/ArcEnCiel



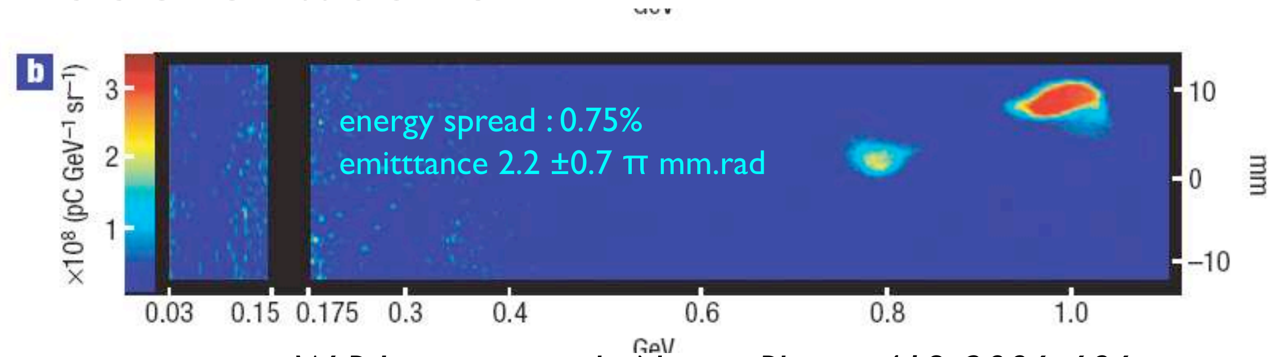
Laser WakeField Accelerator

few fs, 1 π mm.rad, few % of energy spread



Laser WakeField Accelerators

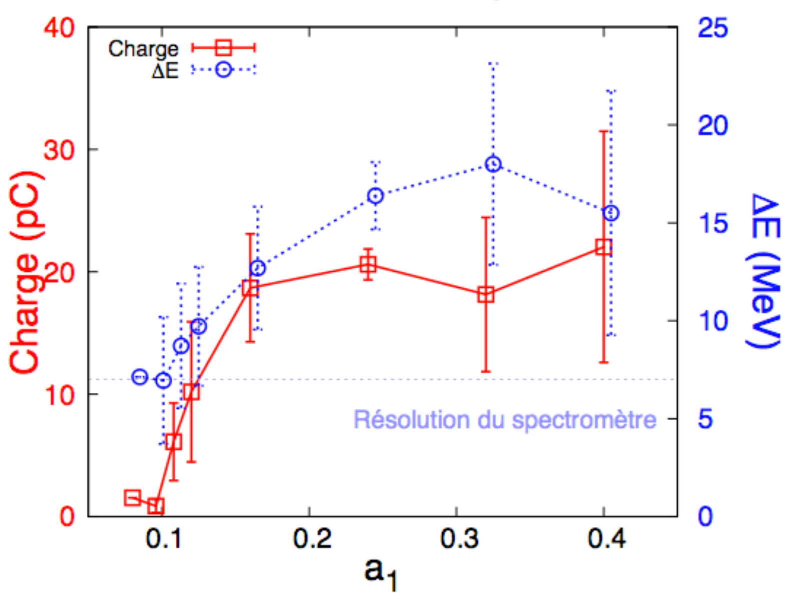
Intense laser focussed in a gas jet / cell / capillary
=> ions : accelerator electric field



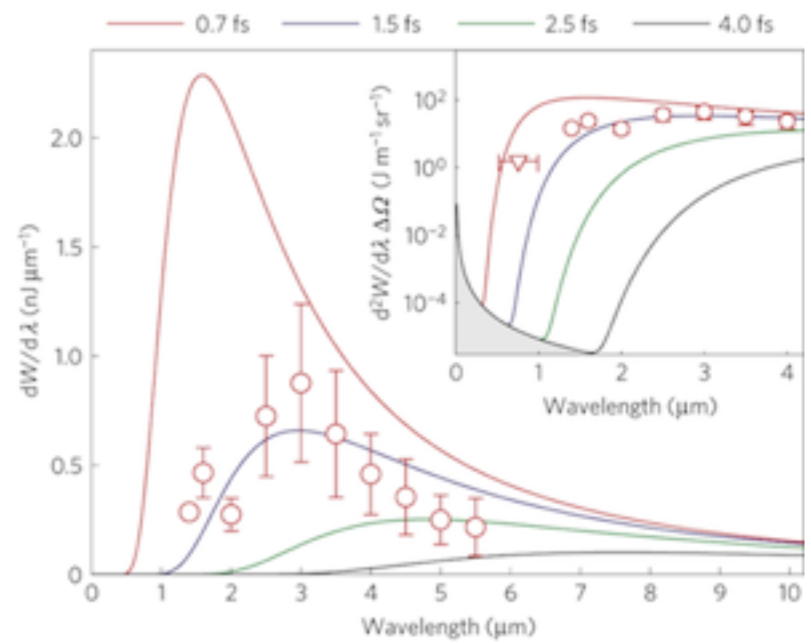
W. P. Leemans et al. , Nature Physics 418, 2006, 696

Two laser colliding scheme

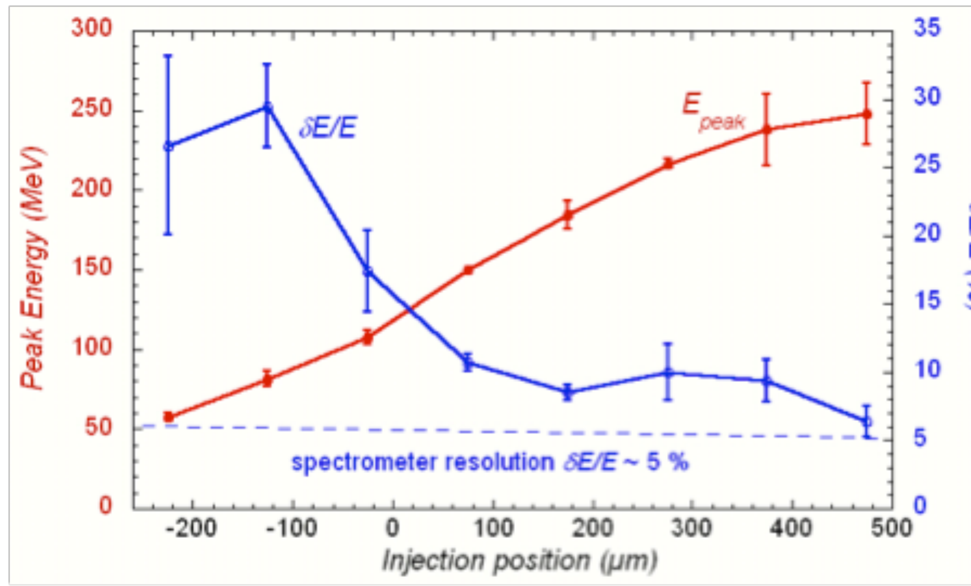
Electron beam production



C. Rechatin et al., Phys. Rev. Lett. ***102****, 194804 (2009)*



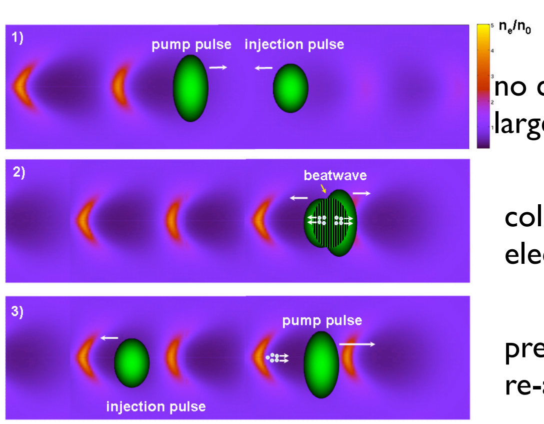
1.5 fs RMS duration : Peak current of 4 kA



	2002	2004	2009
Energy spread (%)	100	5	1

below : *C. Cipiccia et al. Nature Physics, 2011*

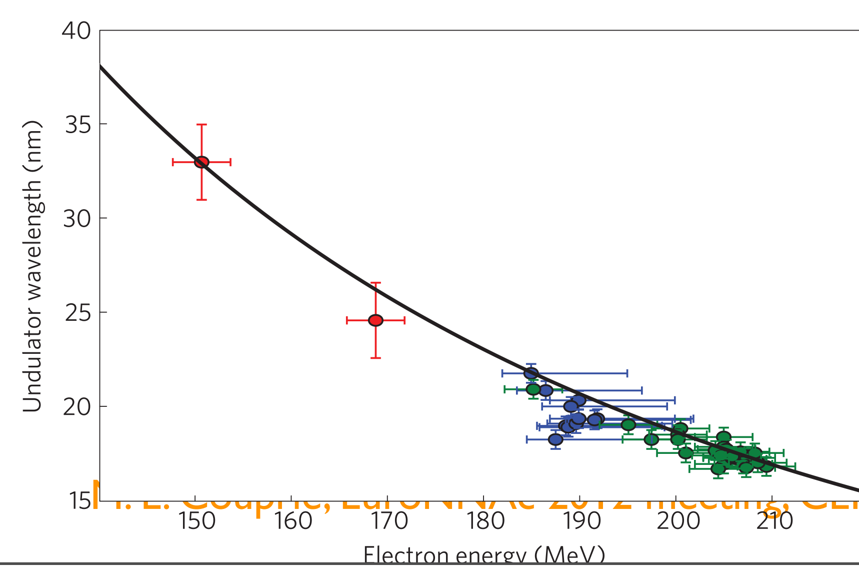
ex of the couterpropagating scheme



no collisions between the two lasers: large wakefield induced by the first laser

collision between the two lasers, beating => electron pre-acceleration

pre-accelerated electrons are trapped and re-accelerated

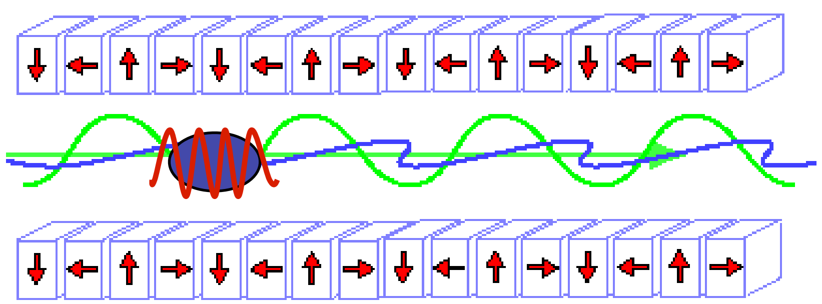


M. Fuchs et al. 5, 2009, 826

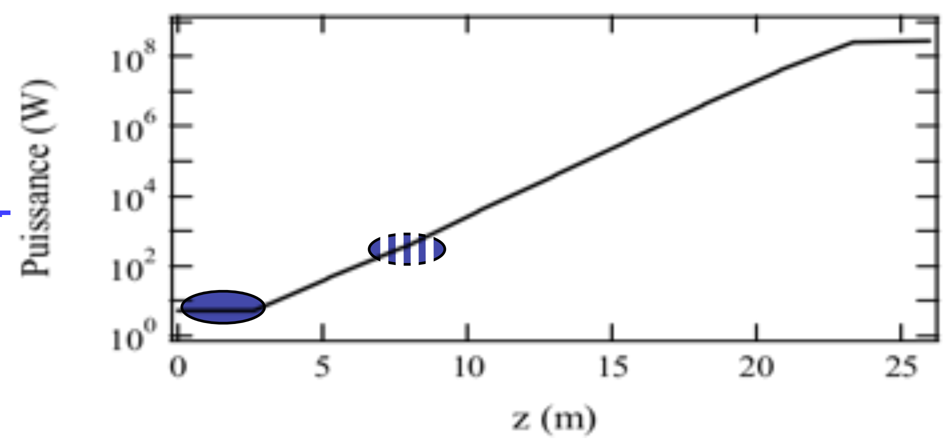
Free Electron Laser Configurations

Single optical pass FEL, high gain regime $G \alpha L_{ond}^2/\Upsilon^3$

SASE (Self Amplified Spontaneous Emission) : no laser - electron interaction



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



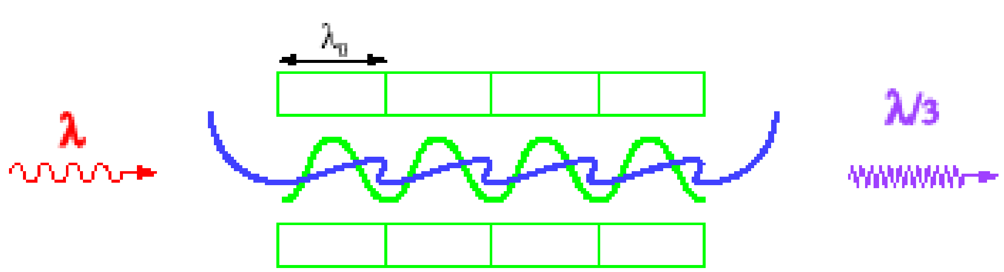
R. Bonifacio et al, Opt. Comm. 50, 1984, 376, K. J. Kim et al, PRL57, 1986, 1871, C. Pelligrini et al, NIMA475, 2001, 1, A.M. Kondratenko et al, Sou Phys. Dokl. 24 (12), 1979, 989

- short wavelength operation (1 Å)
- good transverse coherence => low emittance required=> gun, energy
- spike
- single spike (low charge, chirp/taper), self-seeding

S. Reiche et al., NIMA 593 (2008) 45-48

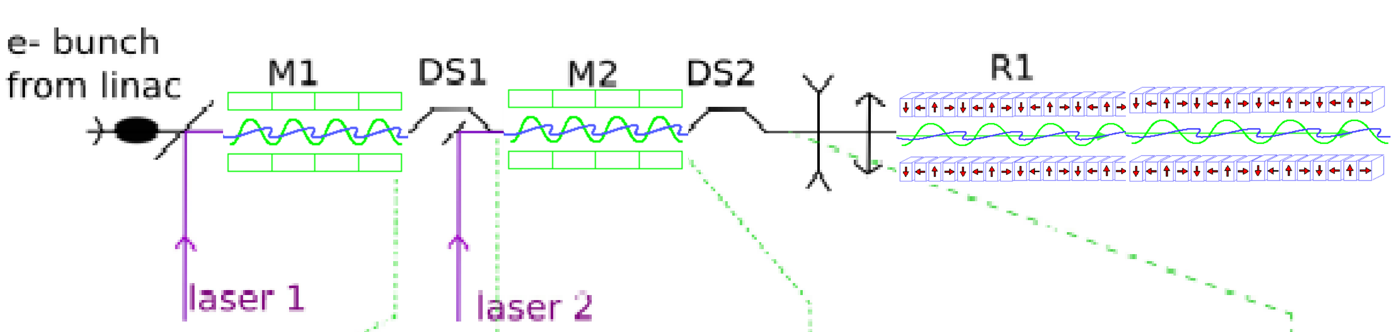
L. Giannessi et al., Phys. Rev. Lett. 106, 144801 (2011)

Seeding : one laser-electron interaction



- temporal coherence given by the external seed laser
- improved stability (intensity, spectral fluctuations and jitter) => pump-probe experiments
- quicker saturation => cost and size reduction
- good transverse coherence
- seed : laser and HHG (60 nm)

Echo : Echo Enable Harmonic Generation : two laser - electron interactions



$$\frac{1}{\lambda_{echo}} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

high order harmonics reached in a compact manner

G. Stupakov., PRL 102, 074801 (2009) *D. Xiang et al., PRL 105, 114801 (2010)*

Zhao et al, Proceed FEL conf, Mamö (2010)

I-Introduction : Scientific context

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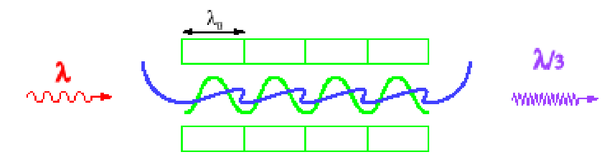
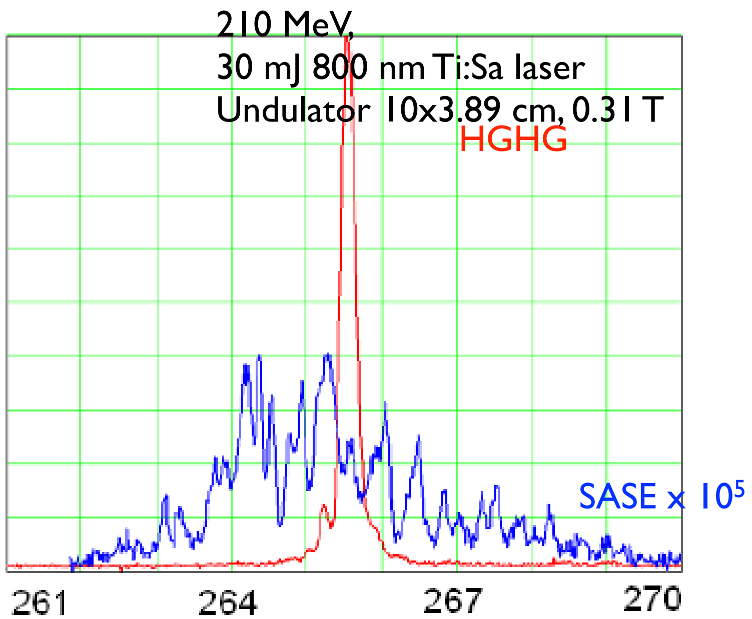
One laser seeding

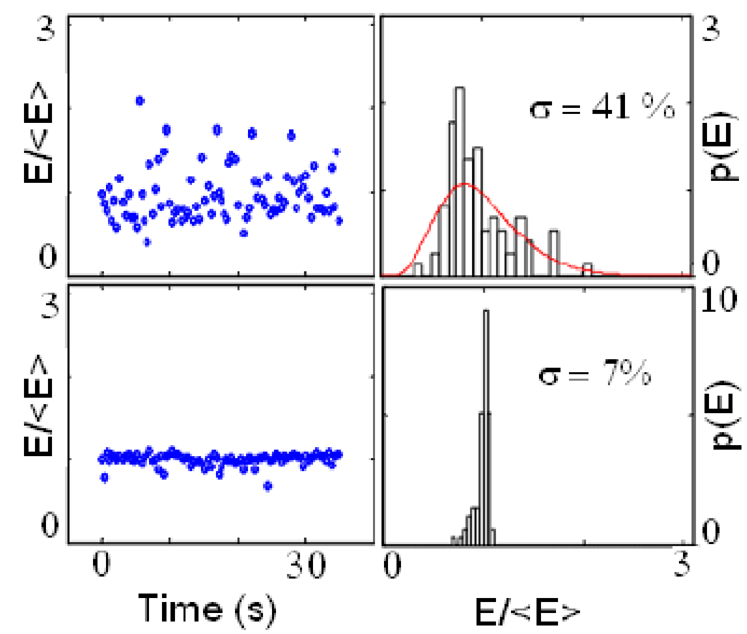


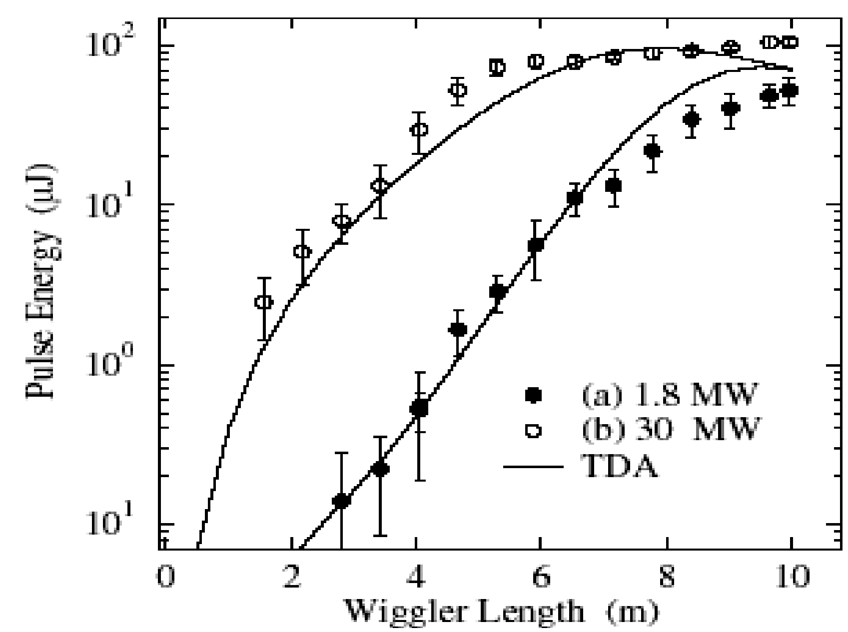
- enhanced temporal coherence,
- reduction of intensity fluctuations and jitter for pump-probe applications
- quicker saturation with respect to SASE (cost, compactness)

L. H. Yu et al, PRL91 2003, 074801
L. H. Yu et al, Science 289, 2000, 932
T. Saftan APAC 2004, Gyeongu

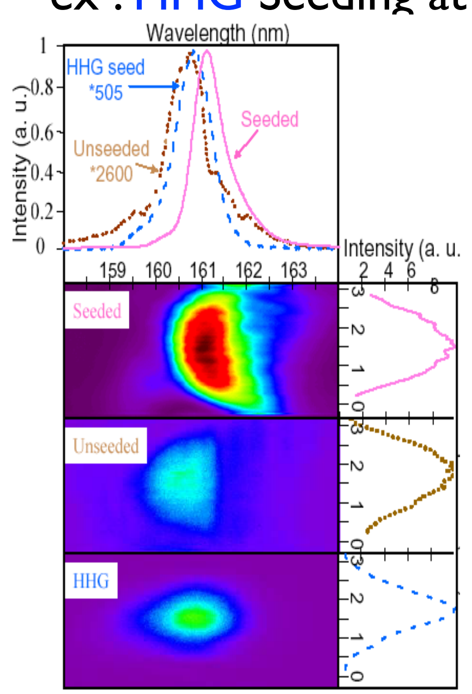
ex : Seeding at BNL with a conventional laser

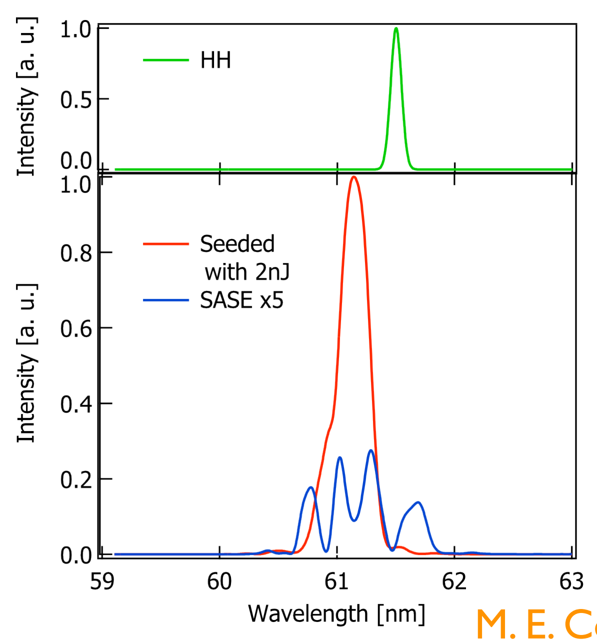


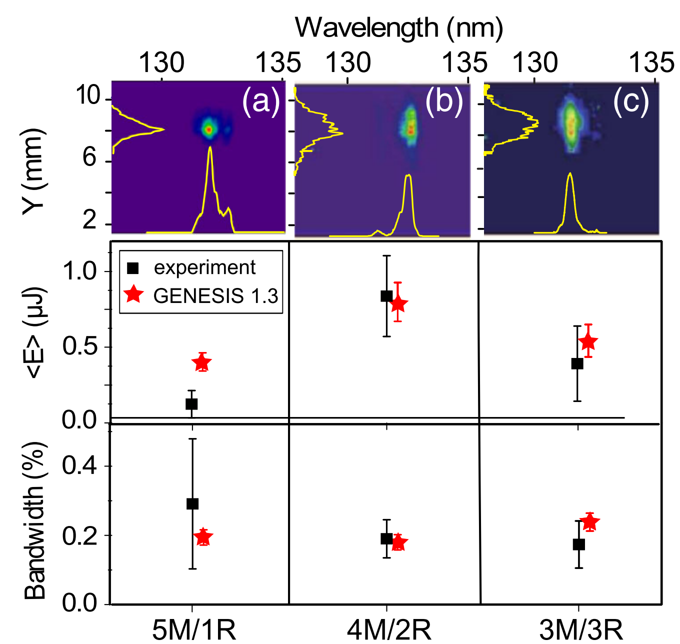




ex : HHG Seeding at SCSS Test Acc. (also SPARC...)







G. Lambert et al., Nature Physics Highlight, (2008) 296-300

T. Togashi et al., Optics Express, 1, 2011, 317-324

High-Gain Harmonic-Generation Free-Electron Laser Seeded by Harmonics Generated in Gas M. Labat, et al. , Phys. Rev. Lett. 107, 224801 (2011)

LUNEX5

PROJECT PHASES

First idea.....

2011 :
«Opportunity proposal at SOLEIL»
SOLEIL discussions with Council members, CNRS (B. Girard, C. Simon)
DSM (J. P. Duraud);

June 2011 SOLEIL Council:
CDR request
Review by an ad-hoc committee in connection with the SAC
Presentation to the dec. SOLEIL Council 2011

Conceptual Design Project Phase

Technical definition of the reference configuration with its different options options (accelerator, site), components, first simulations, description of pilot user experiment and its scientific vision

Planning, costing and ressources, Partnership

CDR draft : fin Nov. 2011

CDR Review, 2011 Dec-2

P. Georges (Institut d'Optique, France)
R. Bartolini (Diamond / Oxford, UK)
R. Assman (CERN, CH) EURONNAC
J. E. Rubensson (Uppsala, Sweden)
J. Feldhaus (DESY, Germany)
Carl Schroeder (Berkeley)

SOLEIL Council preparation
Dec-8, 2011
CNRS : B. Girard, C. Simon
CEA -DSM : J.P. Duraud
SOLEIL : J. Daillant, M. E. Couprie

SOLEIL Council
Dec-15, 2011

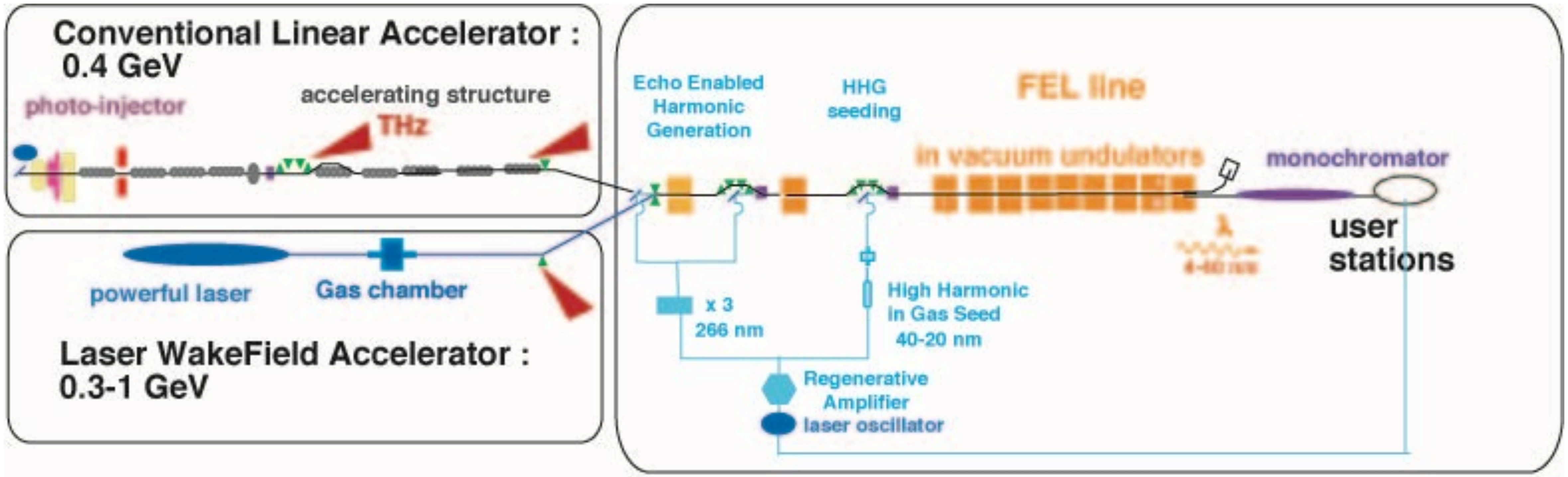
RESOLUTION XIII

The Council takes notice of the LUNEX5 CDR document and approves the start of a targeted complementary studies and associated R&D, on specific funding. He takes note of the coordination role of SOLEIL.

Targeted complementary studies and associated R&D Phase

- Start R&D programs and fund search
- Start complementary targeted studies, in particular with respect to the recommandations of the review committee.

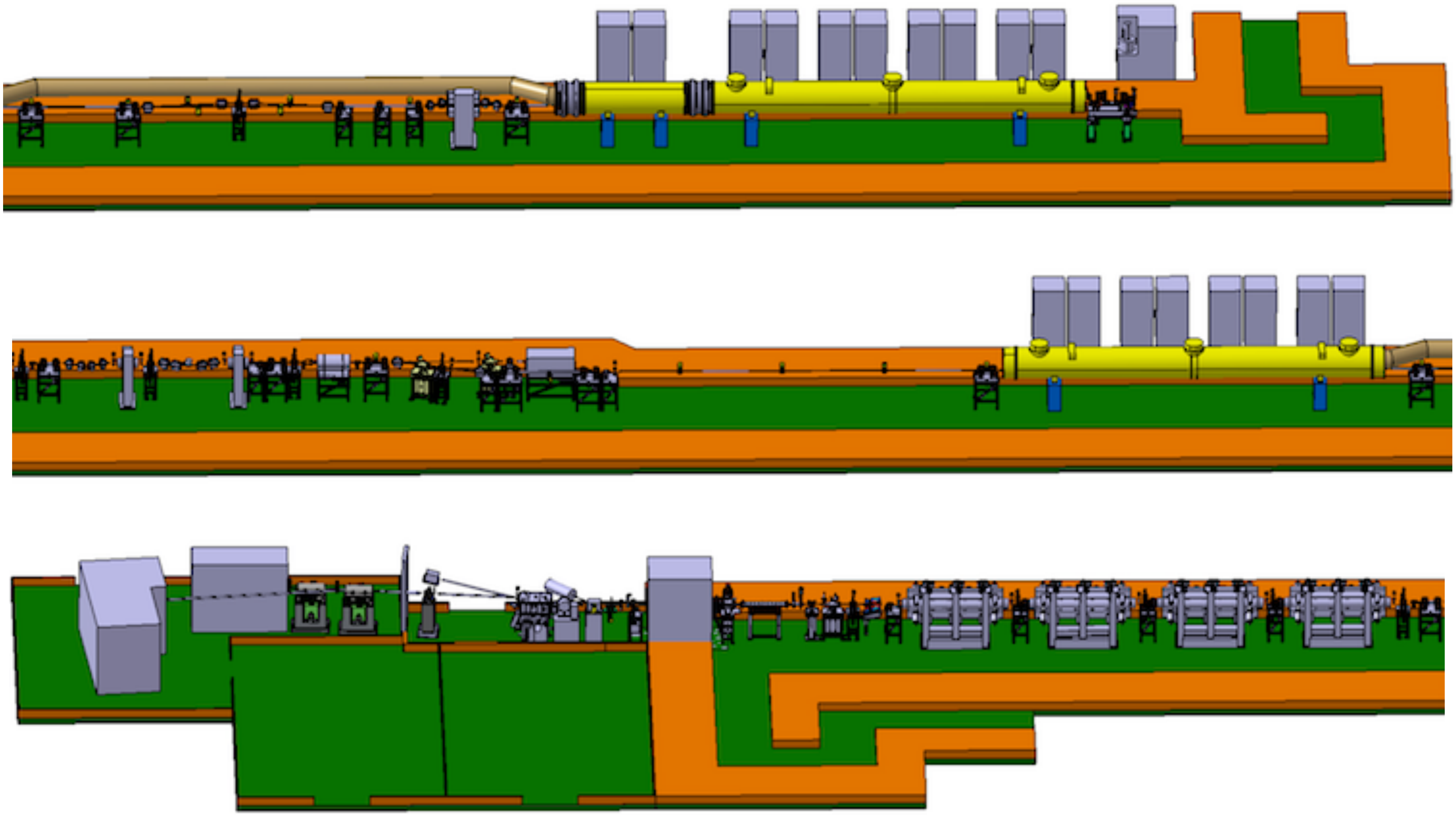
LUNEX5 PROJECT



Motivations of LUNEX5 demonstrator

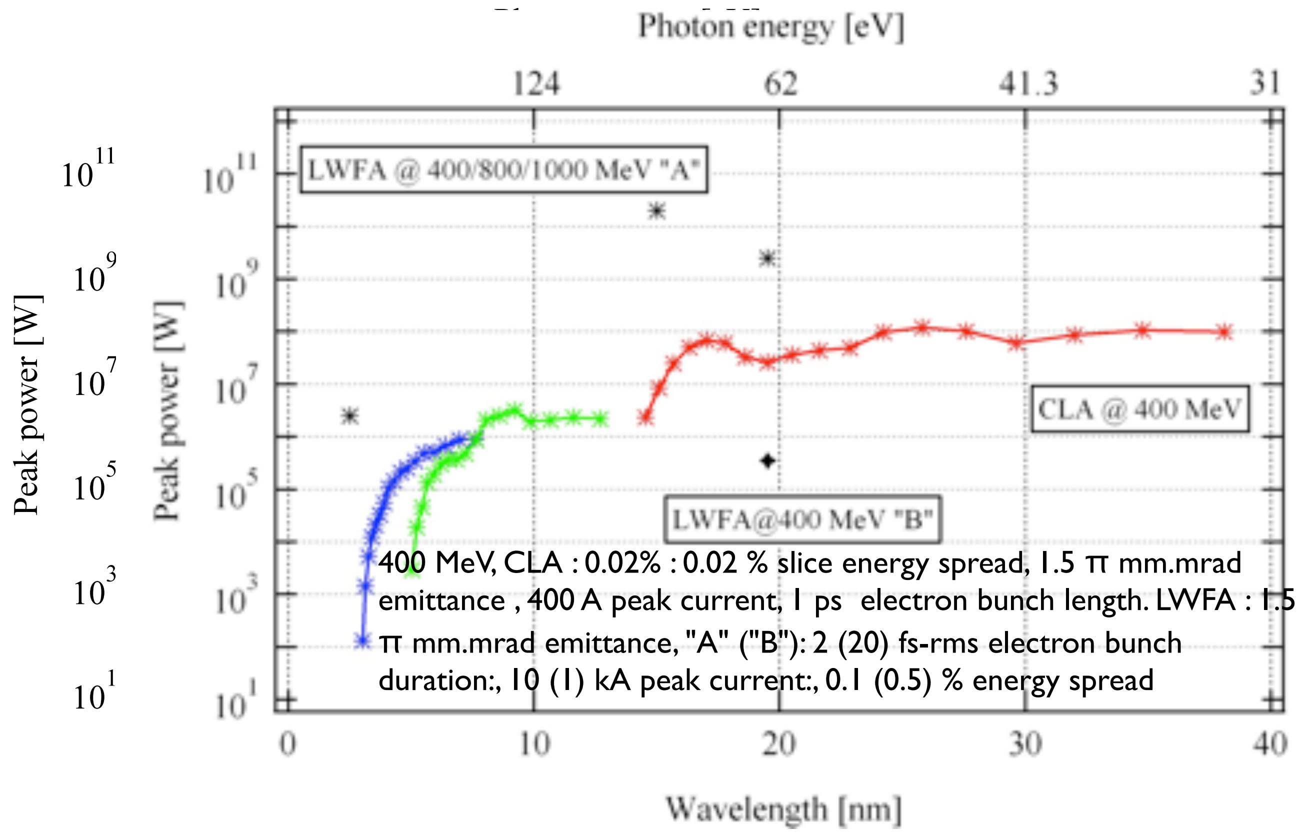
Beyond third generation light source (undulator spontaneous emission, partial transverse coherence),
progress towards fourth generation light sources (coherent emission, temporal and transverse coherence, femtosecond pulses, high brilliance) via the latest free electron laser seeding schemes, to be validated by pilot user experiments,
and towards fifth generation (Conventional Linac replaced by a LWFA), FEL being viewed as an qualifying LWFA application

LUNEX5 PROJECT

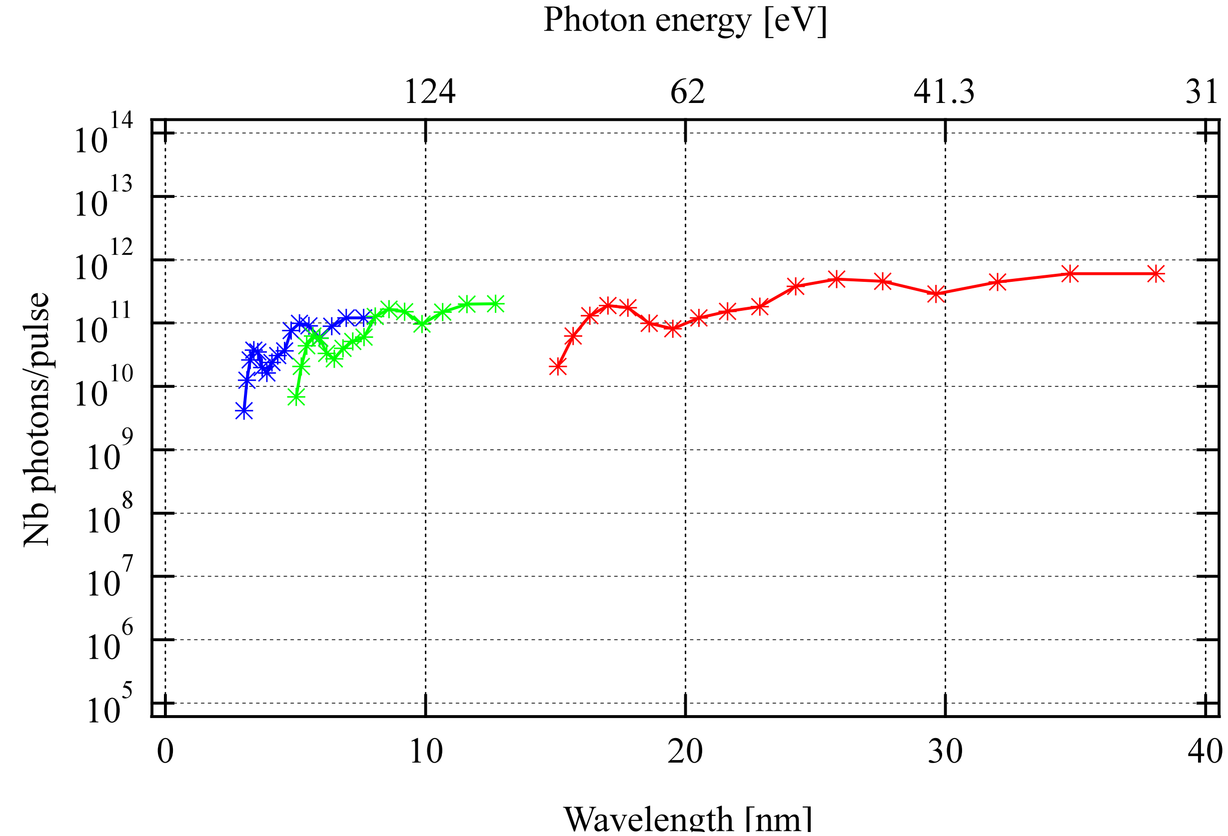


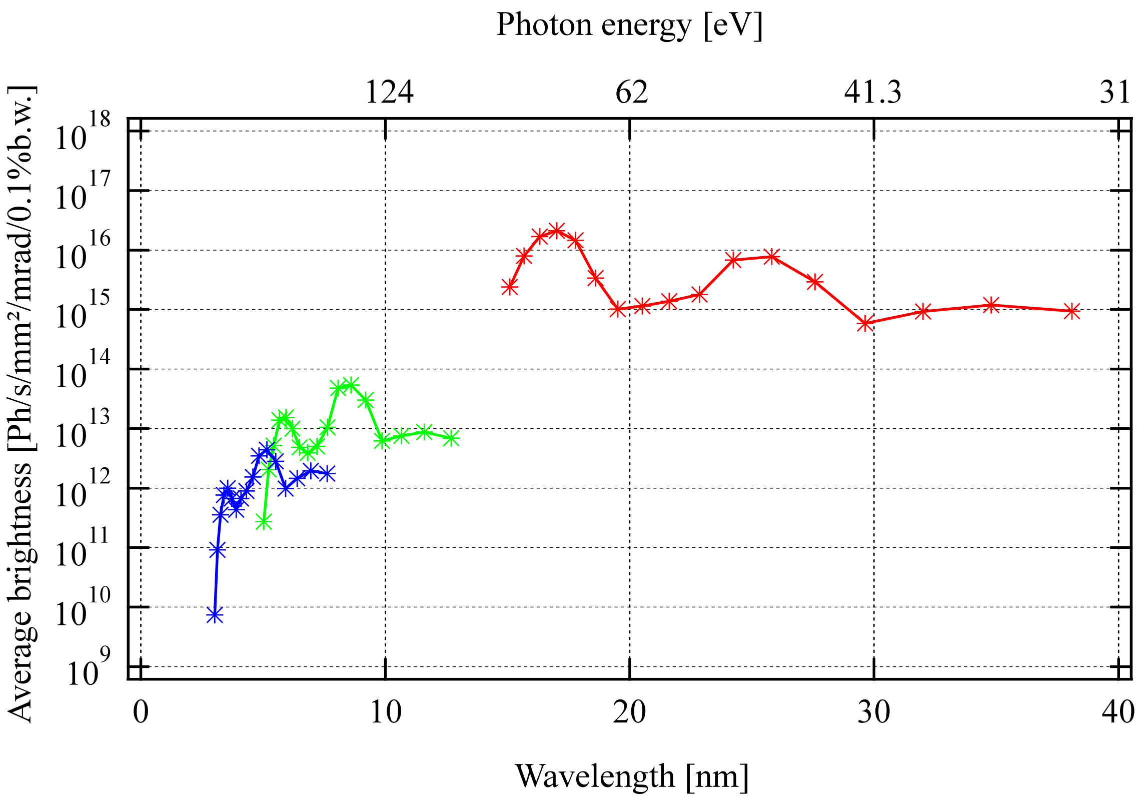
LUNEX5

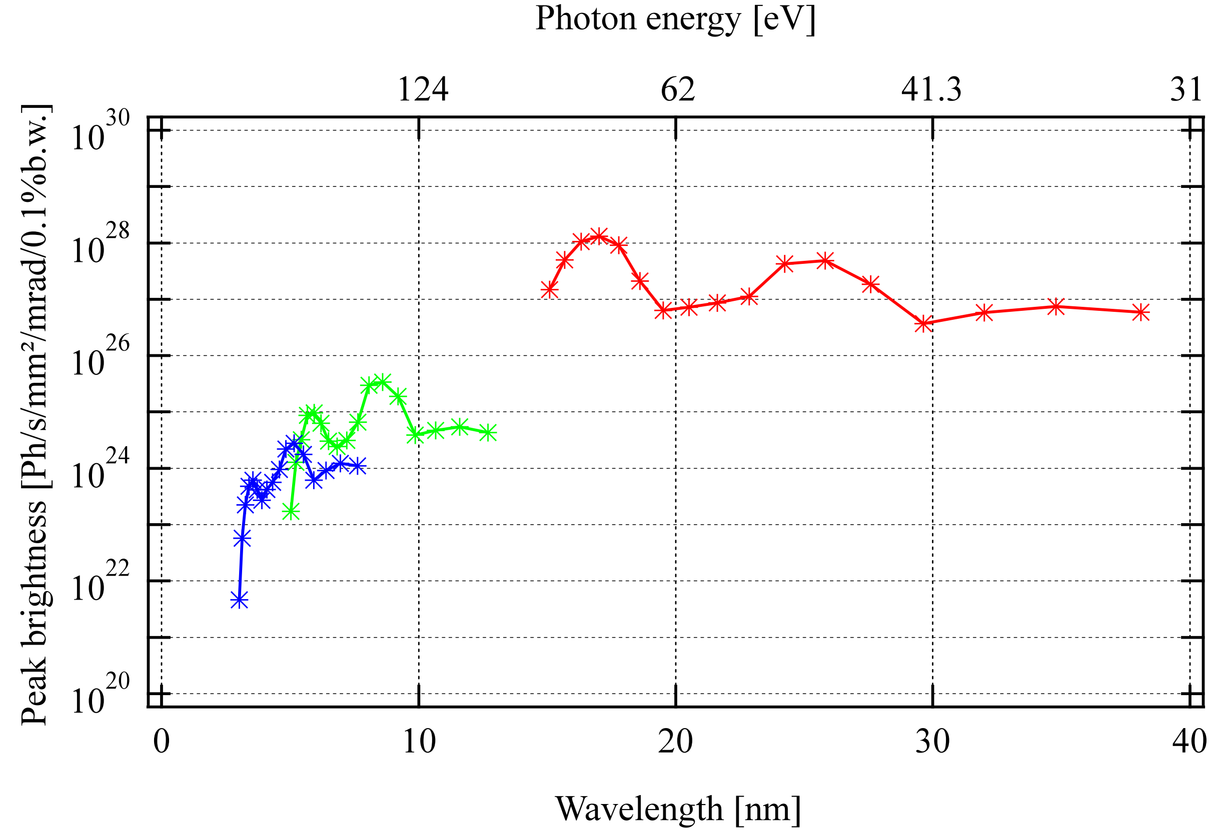
LUNEX5 PERFORMANCES



400 MeV, CLA : 0.02% : 0.02 % slice energy spread, 1.5 π mm.mrad emittance , 400 A peak current, 1 ps electron bunch length. LWFA : 1.5 π mm.mrad emittance, "A" ("B"): 2 (20) fs-rms electron bunch duration:, 10 (1) kA peak current:, 0.1 (0.5) % energy spread







LUNEX5 demonstrator objectives

4G+

- Build a demonstrator of advanced fourth generation light source between 40 and 4 nm, with typically 20 fs pulses, incorporating the latest seeding concepts and electron photon interaction combinaisons

=> *Demonstration of echo at short wavelength*

=> *FEL physics*

=> *Advanced design of FEL source for improved performances, associated with cost and size reduction*

- Perform pilot user experiments of this source

=> *Validation by user applications of echo and HHG seeding FEL based sources*

=> *Gather the French user community*

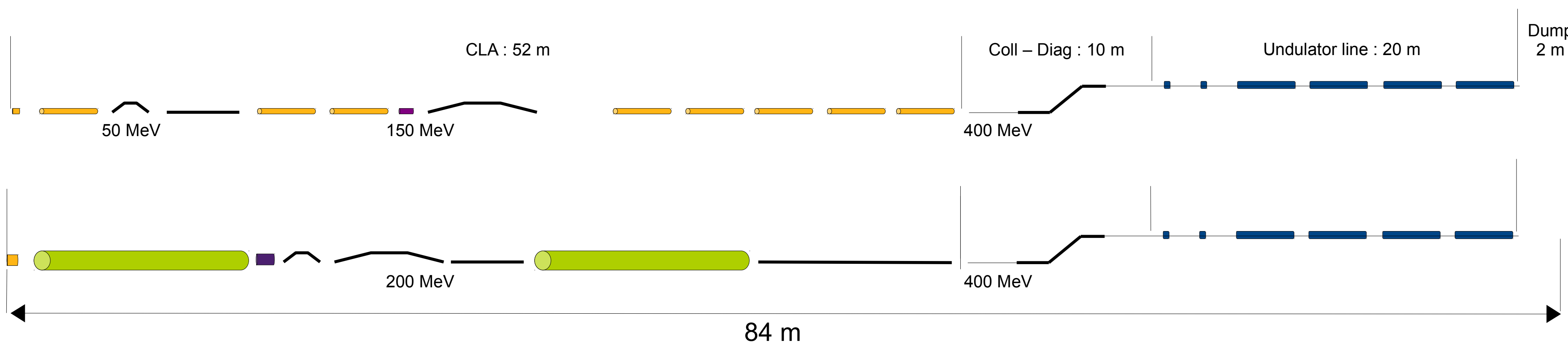
5G

- optimise the FEL line jointly between CLA/LWFA with the different seeding schemes
- use the CLA in low charge, short bunch regime, with spoiled energy spread to mimic LWFA conditions
- test spontaneous and amplified emission on the LWFA (cf CILEX program coordinating LWFA activities in France (60 TW salle jaune, APOLLON...))
- couple the FEL line to the LWFA for a demonstration of FEL on LWFA at short wavelength

Demonstrator combining 4G+ and 5G => *evaluation of the LWFA performances in «operation-like» conditions (cf EuRRONAC objectives)*

LUNEX5

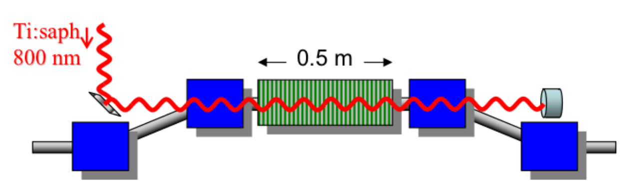
The Conventional Linear Accelerator (CLA)



High brilliance Photo-injector
typically 1 nC, 1 π mm.mrad, 4 ps rms,
100 A peak current
transverse and longitudinal laser flat-top distribution

Solutions :
RF gun type : FLASH, EXFEL type

Laser heater :
enlarges the energy spread
laser modulation laser in a wiggler to avoid the micro-bunching in the compressor



LCLS laser heater section

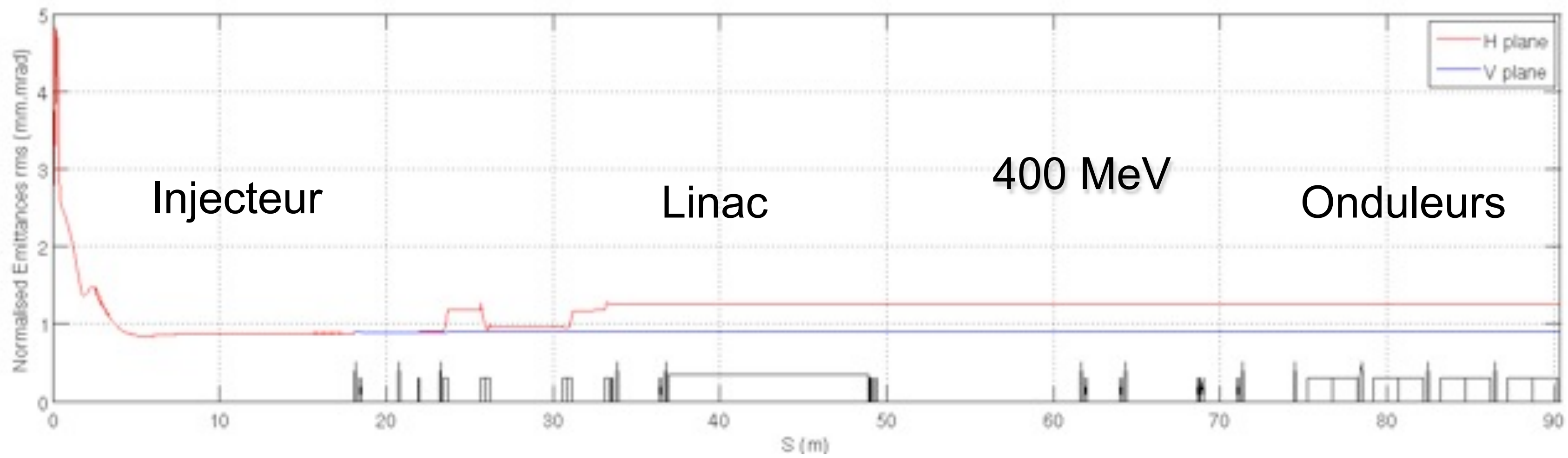
Compression Chicane : Reduction of the bunch length to 1 ps

Harmonic cavity (or chicanes) : Longitudinal phase space linearisation

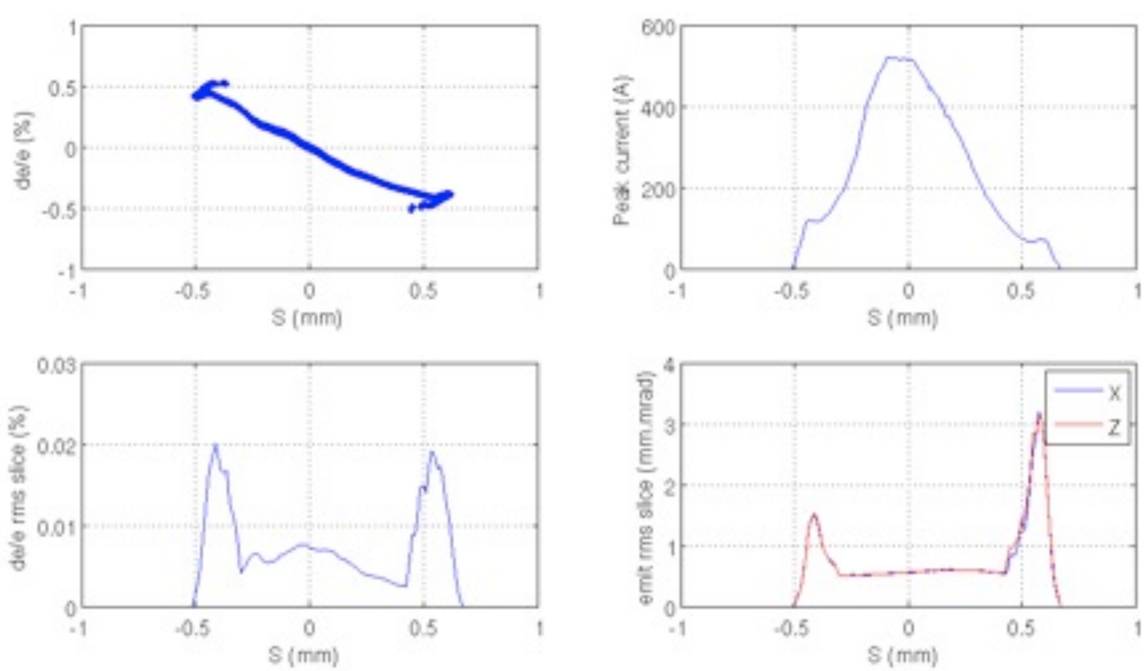
Collimation section : cleaning of the halo and of the dark current, undulator protection for small gaps
Composed of several dipôles and quadrupôles to preserve the emittance

LUNEX5

CLA electron beam dynamics



Final slice parameters (1 nC)

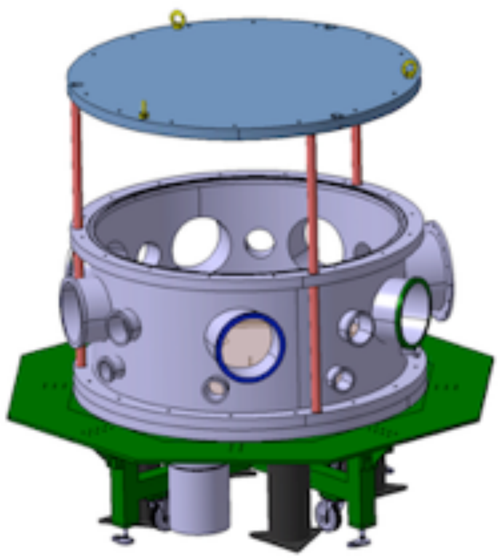


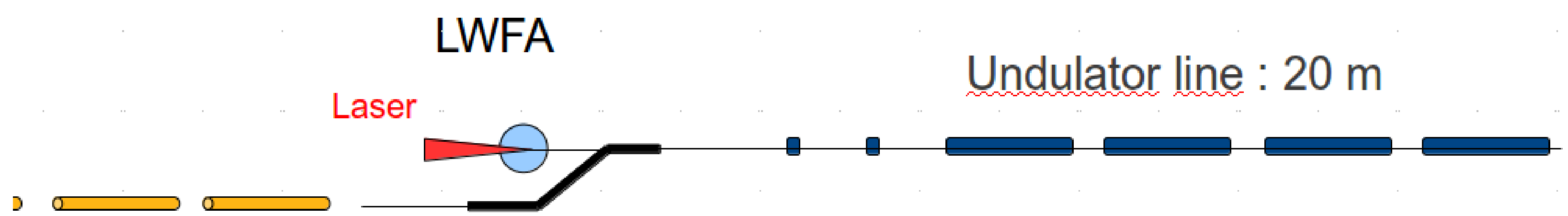
CLA@ undulator entrance

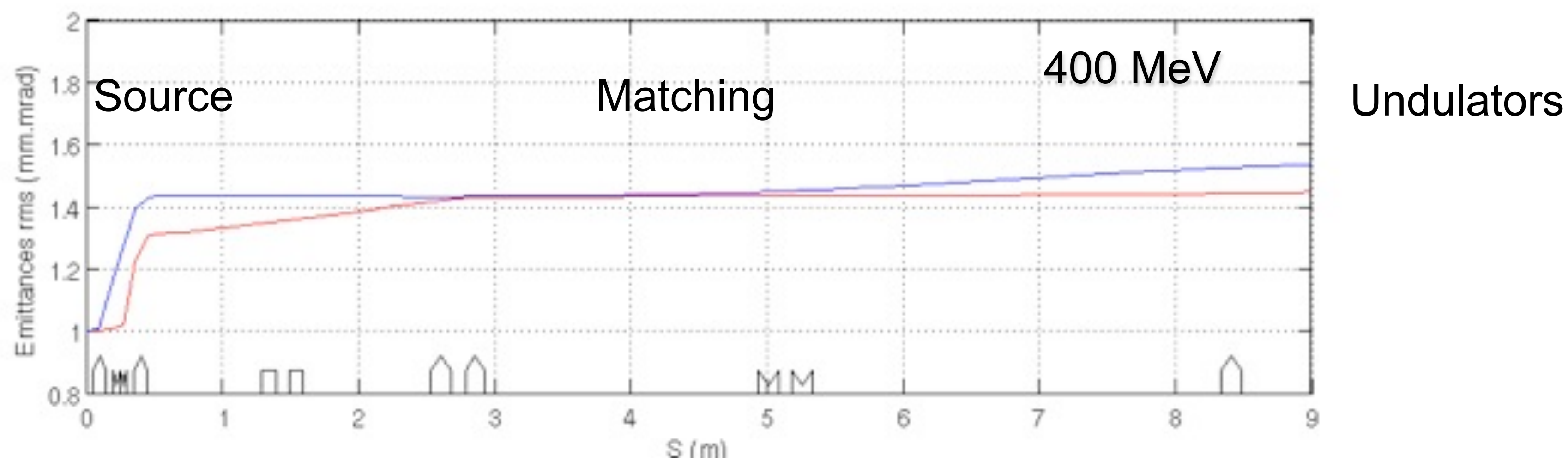
«Complete» modelling along the CLA and adaptation to the undulators

Low emittance < 1 10^{-6} mrad
Low dE/E < 1 10^{-4}
FWHM pulse duration ~ 0.5 ps
400 – 800 A peak

LWFA electron beam dynamics





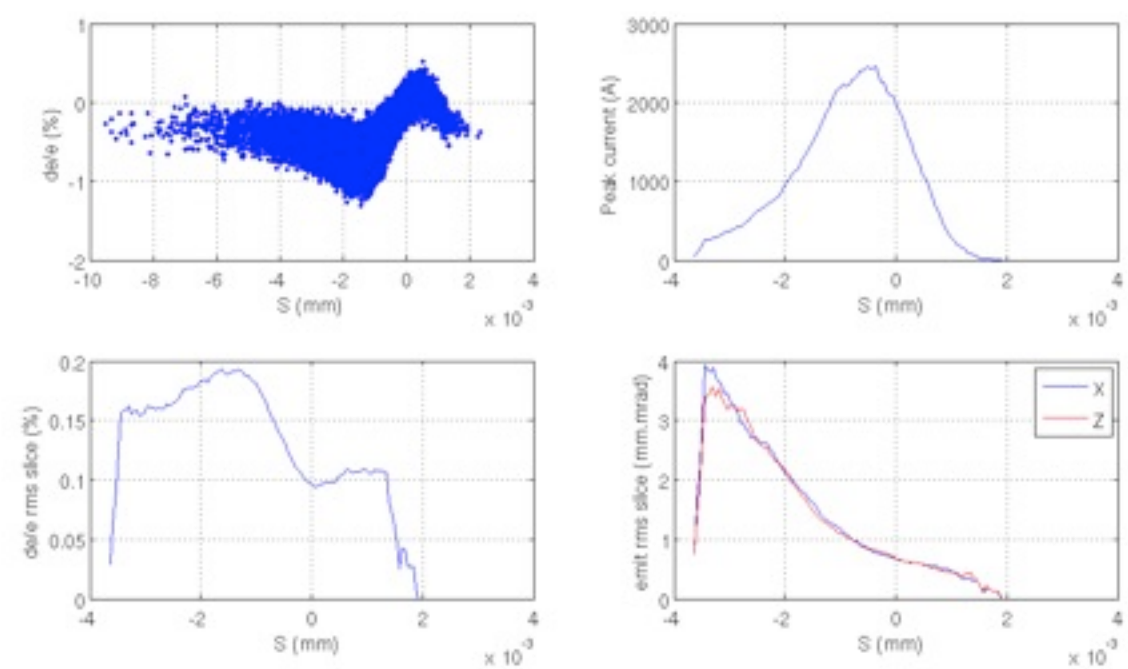


Energy : between 0.4 and 1 GeV
Few fs
High peak current : 10 kA
Normalised emittance $\gamma\varepsilon$= 1 π mm.mrad
Energy spread : between 1 % (present value) and 0.1 % (targeted value)

Injection in the dogleg

differential pumping

Final slice parameters (20 pC)



LWFA electron beam modelling du faisceau LWFA and adaptation to the undulators

Emittance < 4. 10^{-6} mrad
dE/E < 2. 10^{-3}
FWHM duration ~ 10 fs
>2000 A peak

LUNEX5

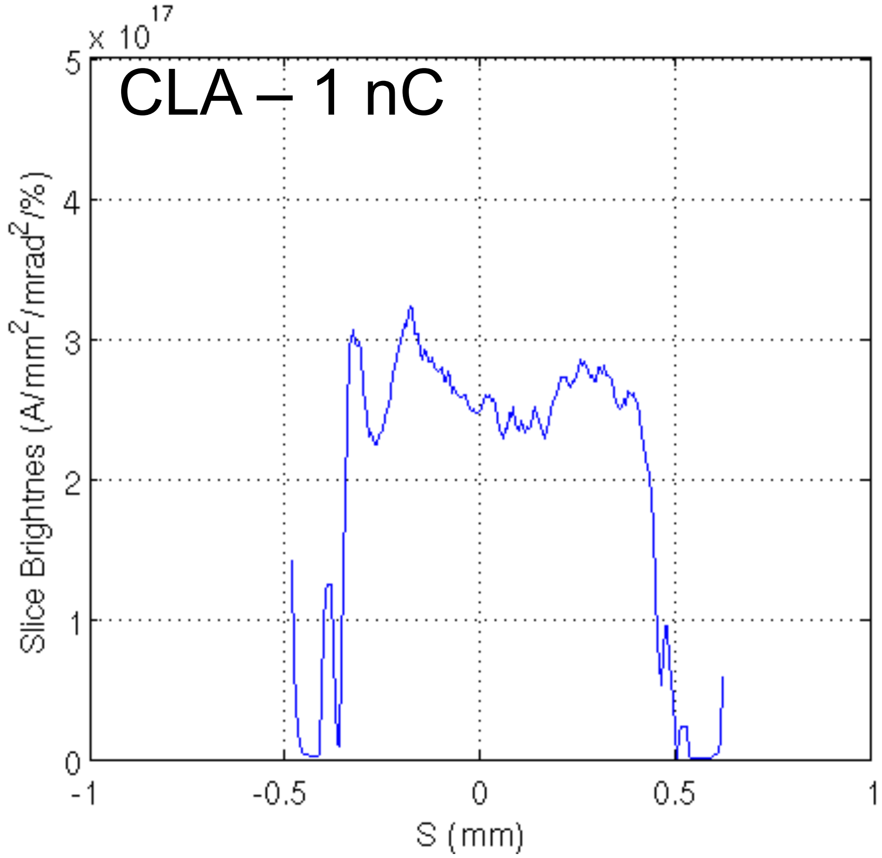
CLA and LWFA performances comparison

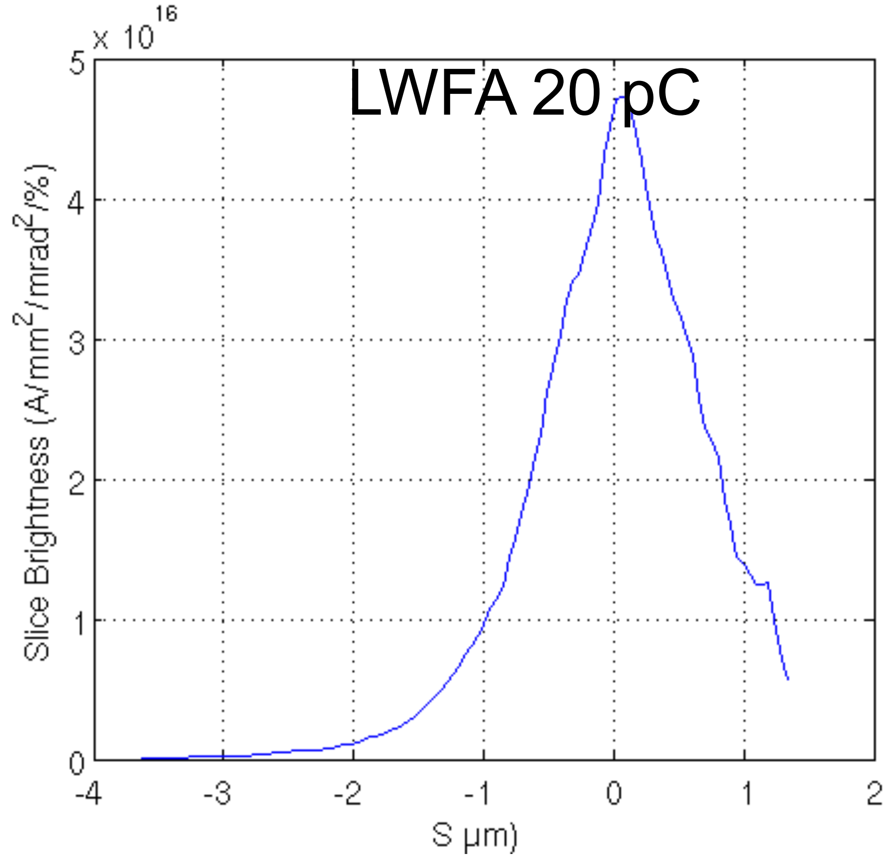
$$B_s = \frac{2I}{(\epsilon_{sx}\epsilon_{sz}\sigma_{se})}$$

Large — Optimistic !

Size	Divergence	Norm. Emittance	Length	E-spread	Q	Peak current
1 µm	1.25 mrad	1 π.mm.mrad	2 fs	0.1%	20 pc	4 kA

LWFA : 1 Hz, 400 MeV and possibly higher.





2-3 10^{17}

4-5 10^{16}

Brilliances rather comparable

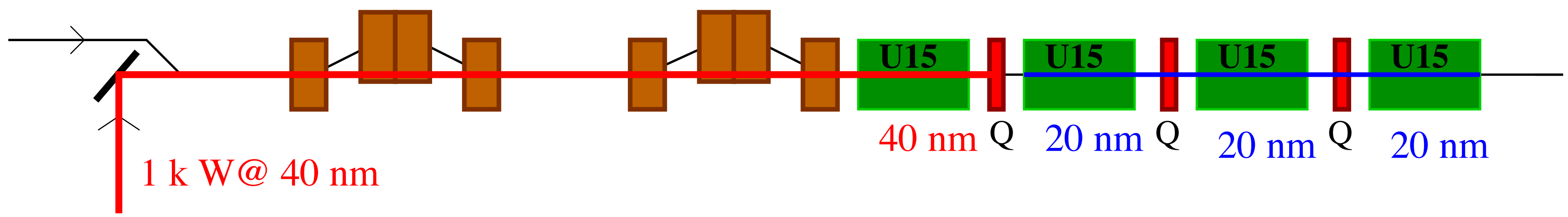
Mature and stable technology, solid and fertile base for 4G+ development (HHG, EEHG...)

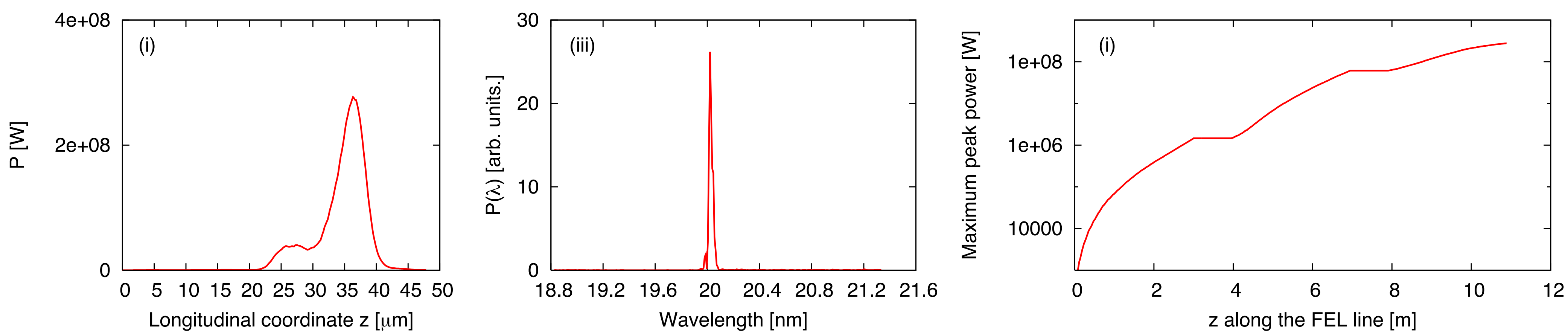
New promissing technology, to be qualifed on a laser application such as the FEL
Possibly single spike FEL operation
Critical parameter : energy spread

Time dependant FEL calculation- CLA

Cascade case

Énergie (MeV)	400
Dispersion en énergie relative	2e-4
Émittance $\epsilon_{x,y}$ (π mm.mrad)	1.5
Courant crête (A)	400
Longueur RMS (ps)	1



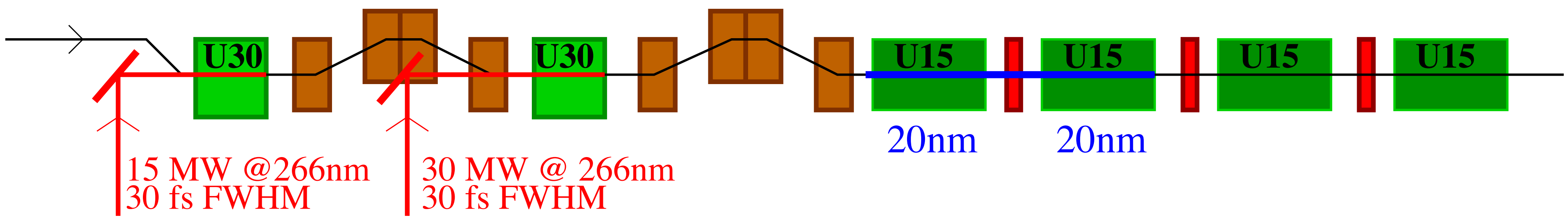


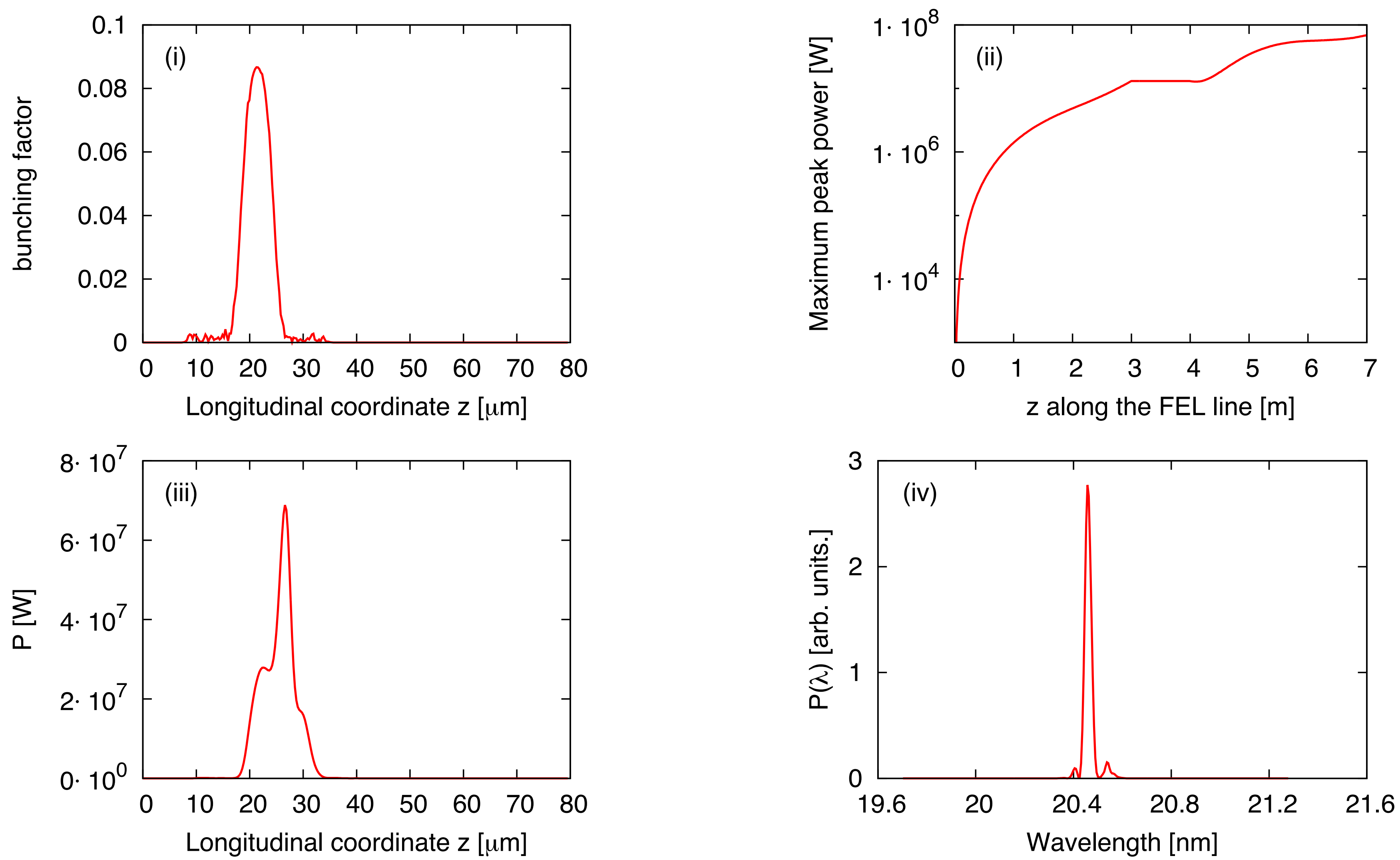
Saturation after 3 sections (z= 11 m), 0.27 GW, 17 fs FWHM, 0.02 nm FWHM, Fourier limit pulses

LUNEX5

Time dependant FEL calculation- CLA

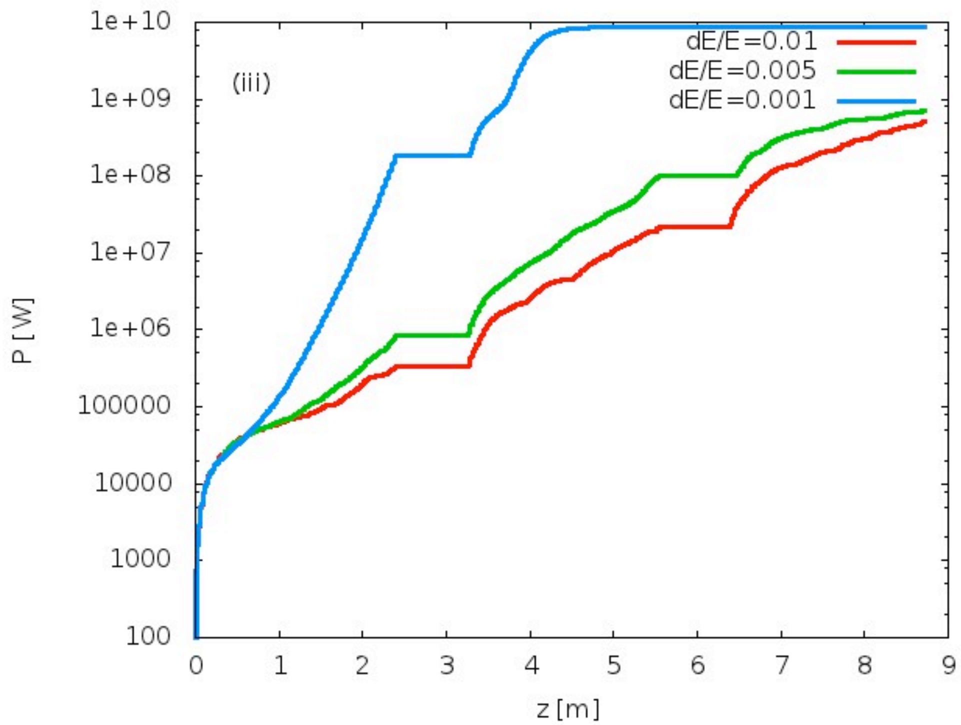
Echo case



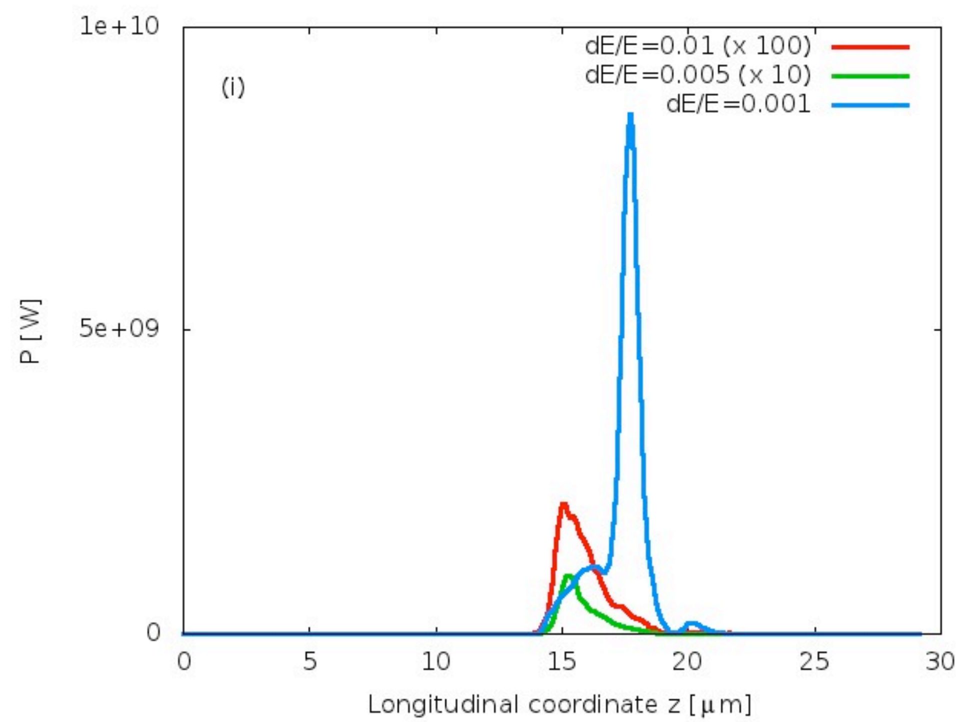


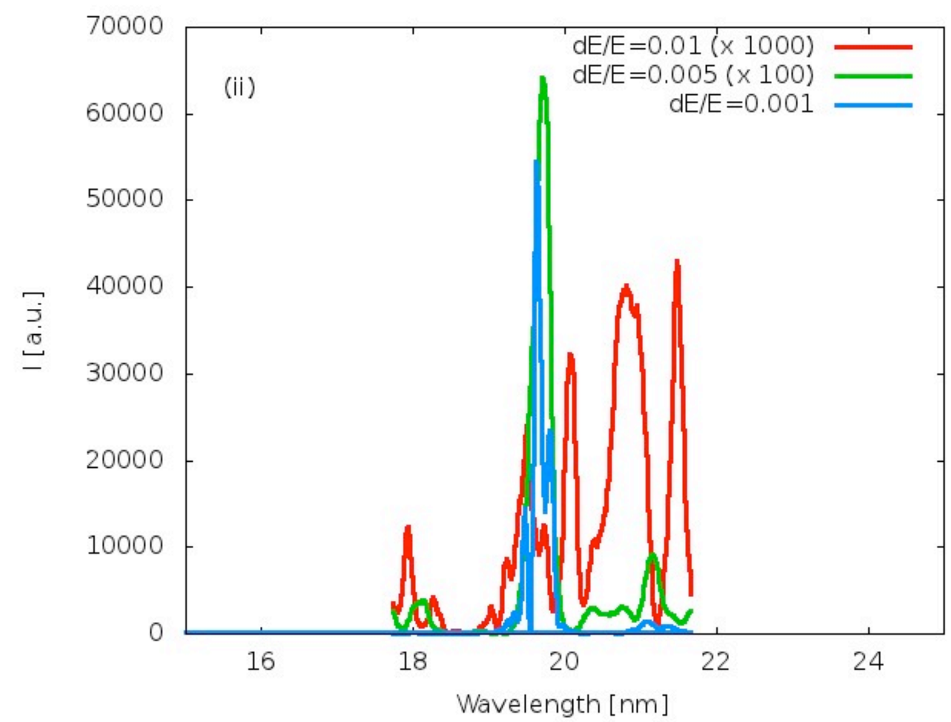
Saturation after 2 sections (z= 7 m), 65 MW, 24 fs FWHM, Fourier limit pulses

Time dependant FEL calculation- LWFA



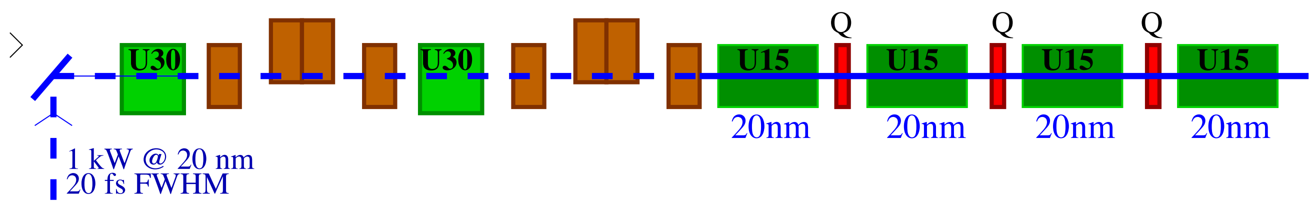
FEL performances at 19.5 nm in the SASE configuration with a LWFA beam.
Electron bunch: E=400 MeV, sigma_E=0.1/0.5/1 %, I=10 kA, sigma_Z=2 fs-rms.
Undulator: 200 periods of 12 mm, K=1.408, emittance=1.0 π.mm.mrad.



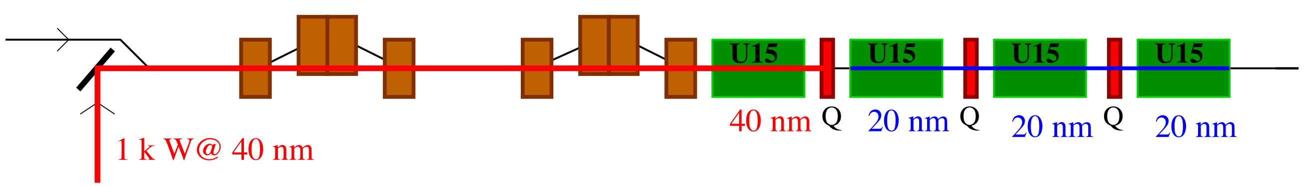


FEL Sources on LUNEX5

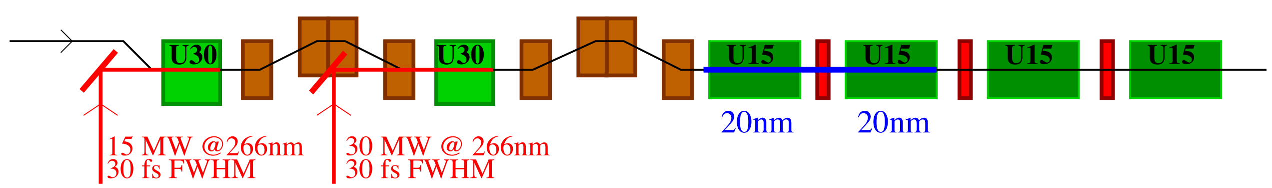
CLA : 400 MeV, 0.02% energy spread, 1.5 π mm.mrad, 400 A, 1 ps rms



Amplifier @ 20 nm,
after 3 sections z = 11 m, 50 MW, 30 fs FWHM, signal/ noise= 3

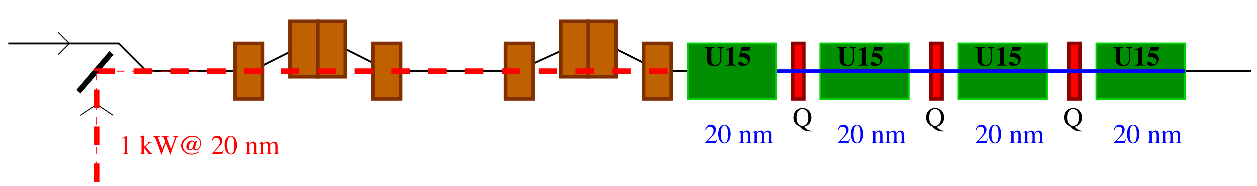


Cascade @ 20 nm,
saturation after 3 sections z = 11 m, 100 MW, 25 fs FWHM, FT



Echo @ 20 nm,
saturation after 2 sections z = 7 m, 65 MW, 24 fs FWHM, FT

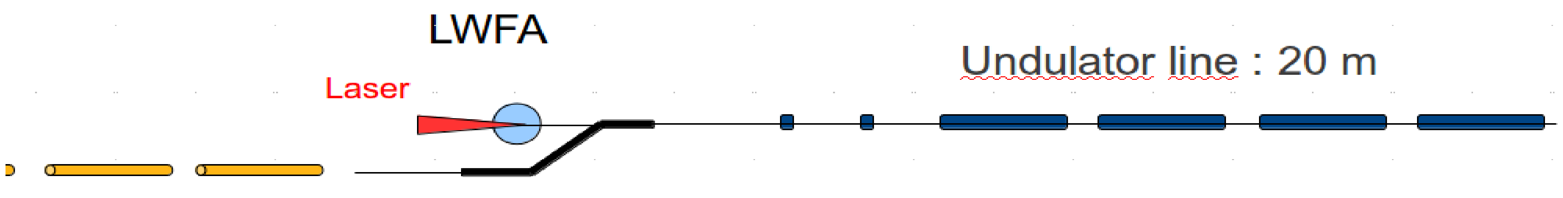
LWFA : 400 MeV - 1 GeV, 0.1% energy spread, 1 π mm.mrad,
10 k A, 2 fs rms



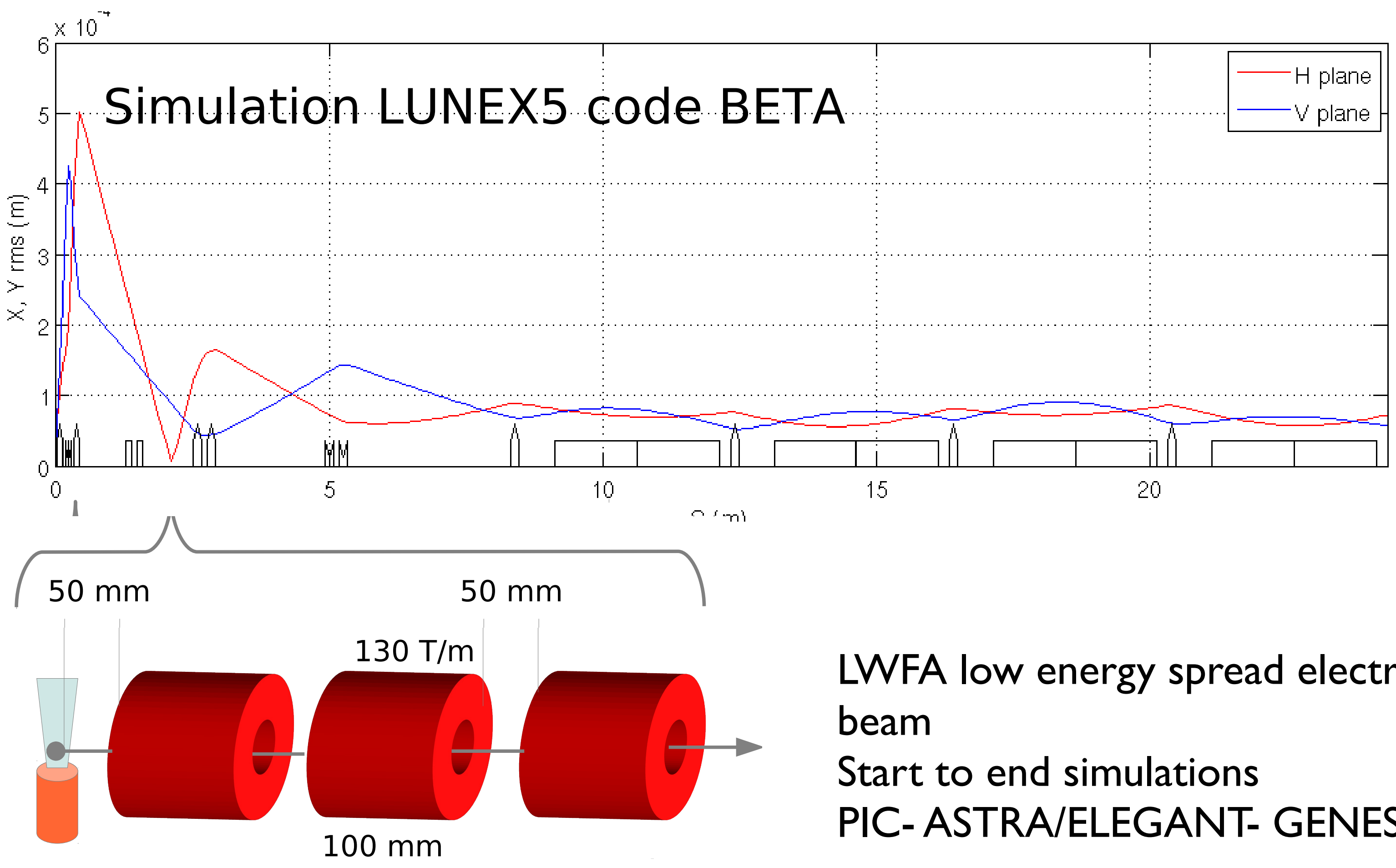
energy spread : 0.5 %, 20 fs rms;
@ 20 nm; so saturation after 3 sections, < MW, > 35 fs FWHM
energy spread : 0.1 %, 20 fs rms;
@ 20 nm; no saturation after 3 sections, 10 MW, > 20 fs FWHM
energy spread : 0.1 %, 2 fs rms;
SASE @ 20 nm, saturation after 2 sections z = 7 m, 2 GW, 7 fs FWHM, single spike

Progress on the LWFA electron beam transport

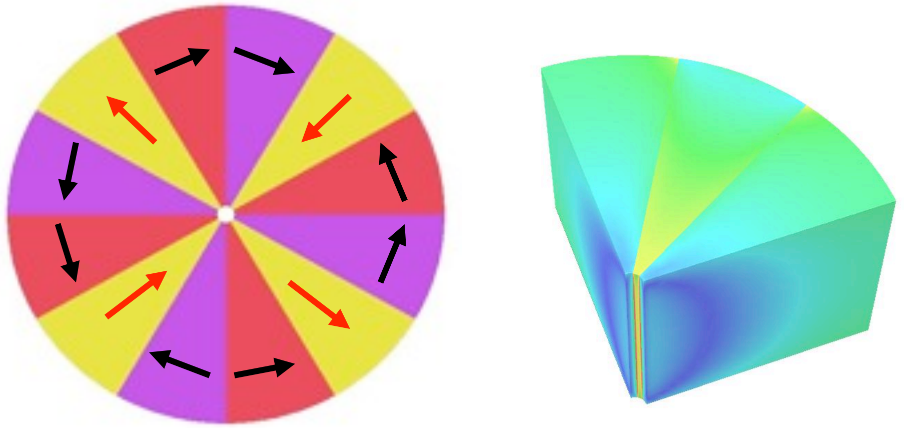
- Introduction of strong permanent magnet quadrupoles



Size	Divergence	Norm. Emittance	Length	E-spread	Q	Peak current
1 µm	1.25 mrad	1 π.mm.mrad	2 fs	0.1%	20 pc	4 kA



Development of a variable gradient permanent magnet quadrupole (SOLEIL, ESRF)
stretched wire measurement (cf ESRF)
=> design original, fabrication : T2M, SEF, SIGMAPHI (Fr), ...



Test at LOA- salle jaune

LWFA low energy spread electron beam
Start to end simulations
PIC- ASTRA/ELEGANT- GENESIS

LUNEX5

Complementary studies : Start-to-end Simulations

Electron beam

• CLA :
- tolerances and full parameter space
- benchmarking with other codes
- magnetic compression without harmonic cavity

• LWFA :
beam matching from LWFA. s2e simulations
0.1 % energy spread

• wakefields

• Tolerances calculations

FEL

• parameter analysis (laser, upgrades in energy of LWFA....)

• short pulse issues :
compression (magnetic chicane, singel spike, chirped pulse)
bunch manupulation (slotted foil, wavelength selection....)

• jitter studies (seeding...)

FEL radiation transport and monochromator

Further studies (conservation of the time structure...)
Extension with two FEL lines

LUNEX5 CLA main components

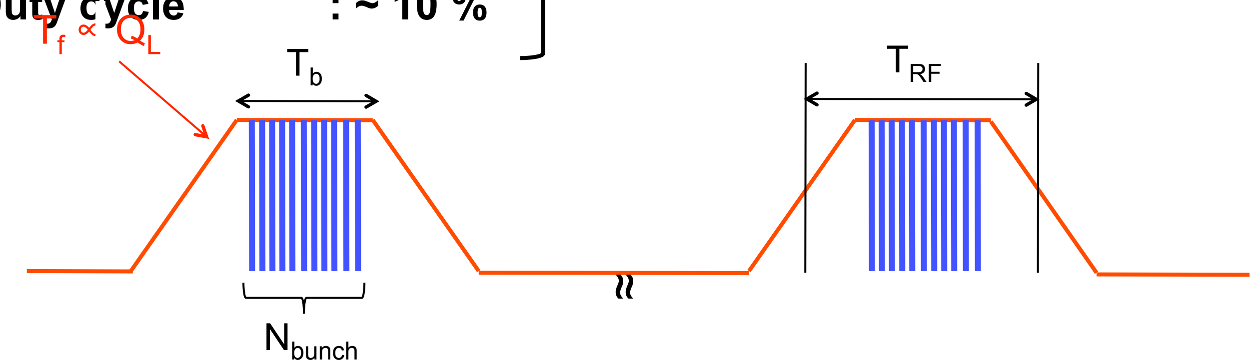
400 MeV : superconducting technology, XFEL modules modified to evolve towards CW operation (coupleurs, tuning), for an equivalent cost, and in taking adavantage of the expertise acquired by the CEA- SACM for the French in kind contribution to XFEL

XFEL CM : 8 cavities, thermal shields (4-8 K & 50-80 K), He tranfer lines + Q-pole

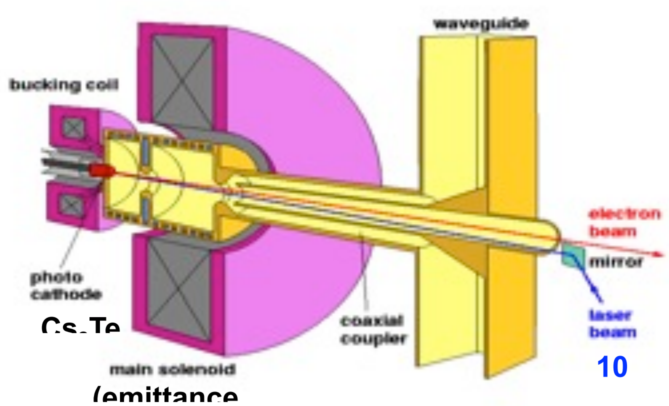
Energy : 400 MeV
Nb of CM : 2
E_{acc} : 24 MV/m
RF pulse (T_{RF}) : 1.5 ms
Rep rate : 50 Hz
Duty cycle : ~ 10 %

P_{cryo} ~ 100 W at 2 K, ok for « standard » He

P_{RF} :16 x 16 kW @ 1.3 GHz
rather than IOT, Solid State Amplifier

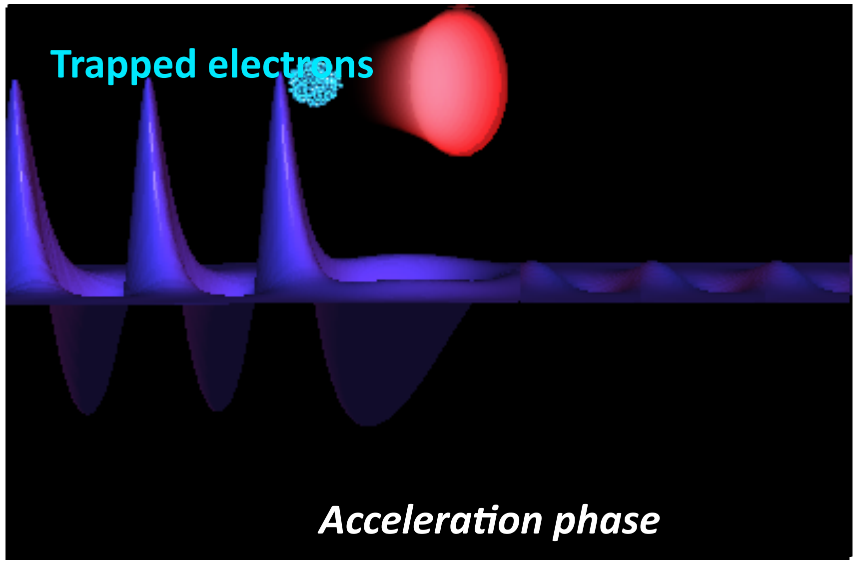


Beam macropulse (T_b) : 5 µs → 500 µs
Nb of bunches (N_{bunch}) : 1 to 100 (limited by seed laser rep. rate)
Bunch charge : 0.1 nC → 1nC
Peak I_{beam} : 1 µA → 100 µA



LUNEX5

LUNEX5 LWFA



Choice of the solution for LUNEX5 : the colloding scheme rather than the bubble regime or capillaries becasue of :
- Good beam quality & Monoenergetic dE/E down to 1 %
- Beam stability
- Tuneable Energy: up to 400 MeV
- Adjustable Charge: 1 to tens of pC
- Adjustable Energy spread: 1 to 10 %
- Ultra short e-bunch : 1,5 fs rms
- Low divergence : 4 mrad
- Low emittance[1-3] : π.mm.mrad

[1] *S. Fritzler et al., Phys. Rev. Lett.* ***92****, 165006 (2004)*, [2] *C. M. S. Sears et al., PRSTAB* ***13****, 092803 (2010)*
[3] *E. Brunetti et al., Phys. Rev. Lett.* ***105****, 215007 (2010)*

Choice of a cold injection scheme

X. Davoine et al., Phys. Rev. Lett. ***102****, 6 (2009)*

Pump laser: 0.8 µm, 4.2 J, τ =30fs, φ_0=18µm, I=3.46×10^{19} W/cm^2

Injection laser: 0.8 µm, 2 mJ, 30fs, φ_0=15µm, I=2.2×10^{16} W/cm^2

0.6 mm after collision (after 3.8 cm of propagation in a capillary):
Energy: E = 62 MeV (3 GeV)
Charge > 60 MeV (2.9 GeV): Q = 50 pC
E = 0.7 MeV rms ; ΔE/E = 1.1% (0.9 rms)
(only charge > 60MeV (2.9 GeV) considered)

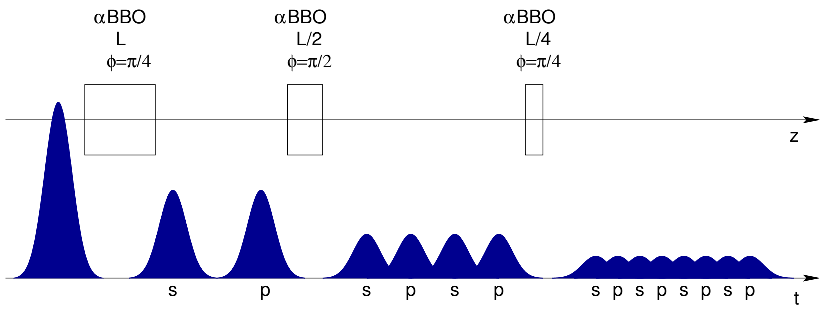
Energy spread still to be improved.....

Synergy with LOA Salle Jaune: 2 beams of 60 TW each
Limited number of shot a day (radioprotection).
• Exploration of very innovative injection schemes, beam transport, new physics phenomena by probing plasma with X ray, electron beam or proton beam created with the second laser pulse.
=> preliminary tests for LUNEX5 (test of diagnostics, introduction of an undulator, tests of electron beam transport....)

Synergy with APOLLON 10 PW:
• electron acceleration: validate scaling laws in the 100 J laser energy (bubble/blow out regime, colliding scheme, two stage accelerators).
• facility not dedicated for electron acceleration => limited access.
• Rather small repetition rate => special experiment preparation using lower laser platform.
=> a few tens of GeV with good electron quality is supposed to be produced.

LUNEX5

CLA proposed R&D

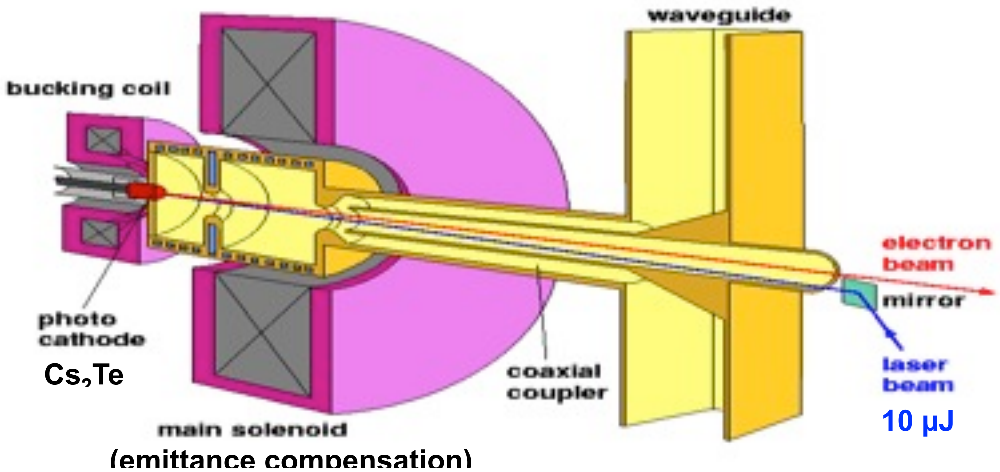


J.G. Power and C. G. Jing, AAC AIP Conf. Proc., 689 (2009); H.Tomizawa et al, Proc LINAC08, 1105 (2008)

Electron Gun

1) Longitudinal laser pulse shaping (PhLAM, CEA-SPAM, LAL, SOLEIL, Faslite ?)
1) pulse stacking on a laser at PhLAM (robust technics, but not very flexible)
2) Spectral components manipulation with a DAZZLER (CEA-SPAM, PhLAM); Enables to easily modify the pulse shape (*C.Vicaro et al., Proc. CLEO 2011 (2011)*)
3) application with a purchased laser on the PHIL electron gun at LAL and validation

2) Gun fabrication
- type PITZ (DESY-Zeuthen, cathode CsTe) /alternatives : C band gun (LAL)
- Tests on PHIL station at LAL with laser shaping



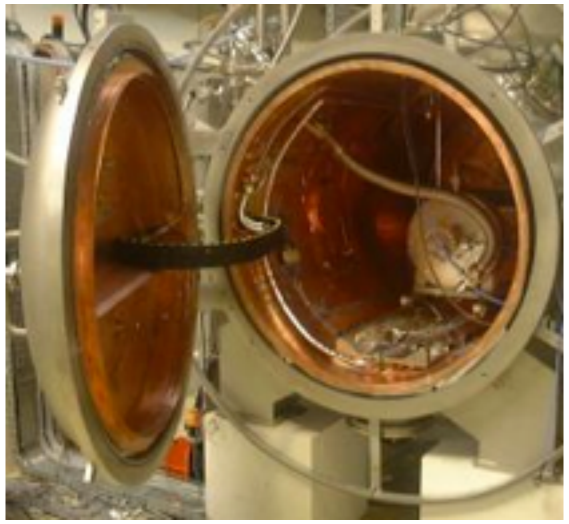
Elementary RF system Gun

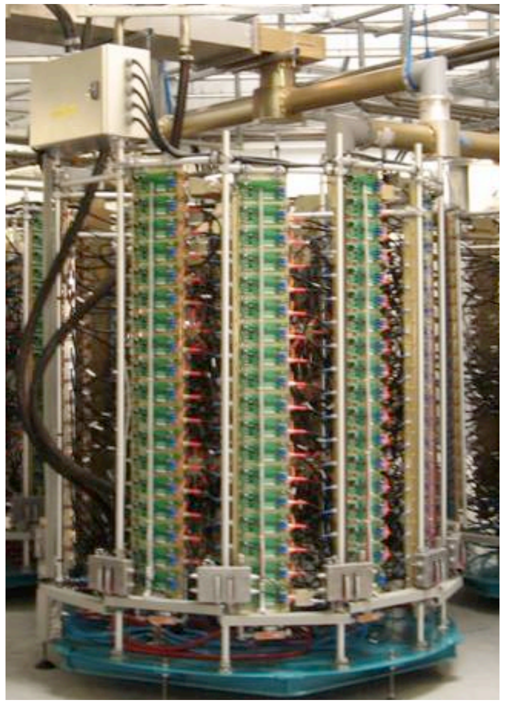
Fabrication :
- one 9 cell cavity (XFEL type), modified for CW operation;
- one solid state amplifier of 15 kW at 1.3 GHz *;
- un LLRF system synchronisation part.

Validation with cold tests in CryHolab cryogenic station at CEA, evaluation of the different components in pulsed and CW mode, comparison between 1.8K and 2K

Collaboration CEA-SACM and SOLEIL

* SOLEIL is pionneer for design, construction and exploitation of solid states amplifiers





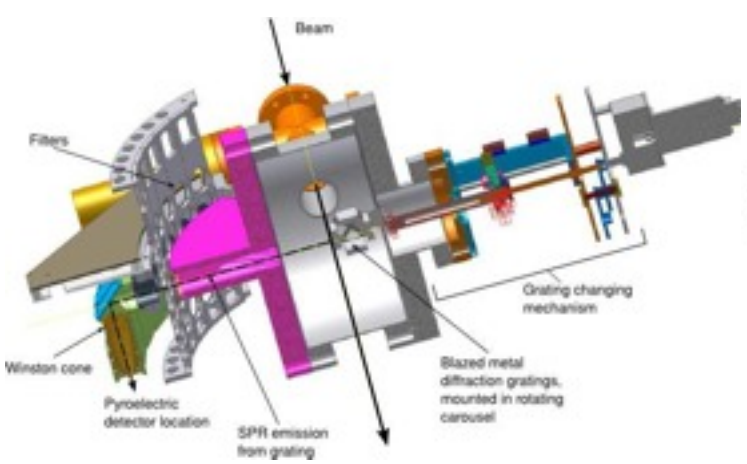
Proposed R&D on Diagnostics

Smith Purcell Monitor for bunch length measurement: CLA (1ps) LWFA (few fs)

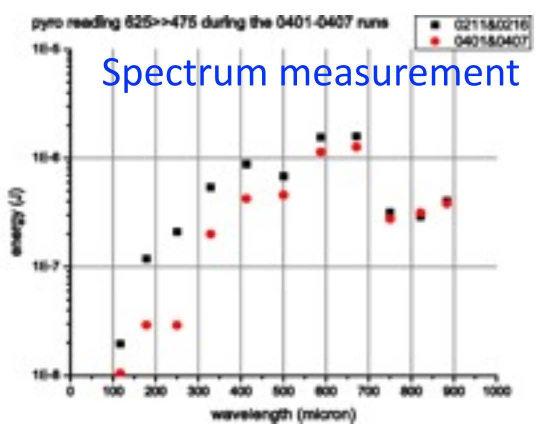
Ex of non invasive monitor tested at SLAC

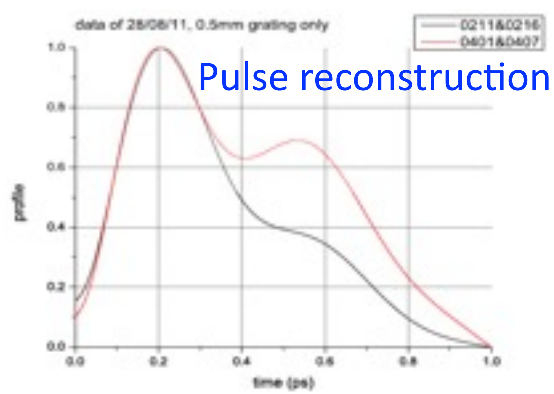
Prototype for 5ps to few fs durations

Tests of several systems on the SOLEIL Linac ~5ps; SPARC FEL~300 fs; LOA LWFA ~few fs



Electron bunch profile diagnostics in the few fs regime using coherent Smith Purcell radiation, R. Bartolini, C. Clarke, N. Delerue, G. Doucas, K. Pattle, C. Perry, A. Reichold and R. Tovey, Proceedings of IPAC2011, San Sebastián, Spain, 1970-1972 (2011).





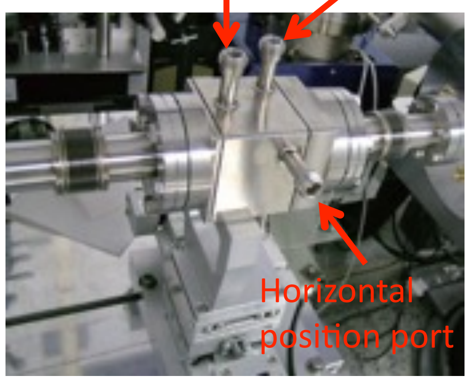
Beam profile monitor

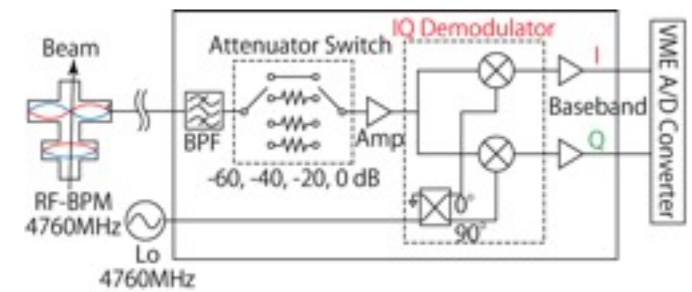
Question of COTR (LCLS, SACLA) du to microbunching after compression (*H. Tanaka talk at IPAC 11*).

Prototype, tests at SPARC (?) or FERMI (?), LWFA (LOA).

Cavity BPMs

- Needs: resolution : 5 μm 10 pC bunches
- A 20 mm beam pipe BPM at SACLA-Spring-8 yields a position resolution of less than 0.2 μm with a 0.3 nC bunch charge.
- Equivalent to about 6 μm with 10 pC bunch charge-invasive
- Build a prototye following the SPring-8 / Swiss FEL design

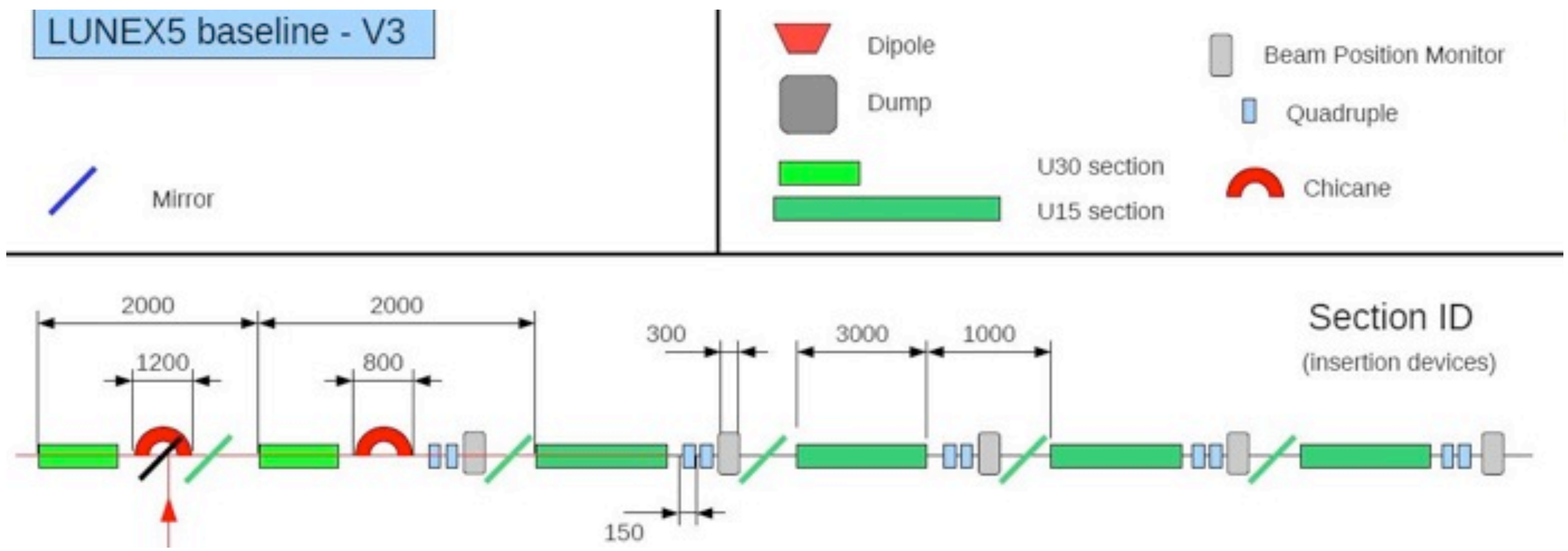


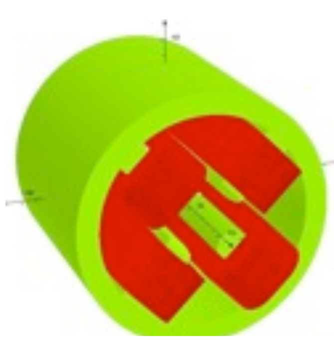


Time of Arrival Monitor

- Technics : Electro Optical Sampling (EOS)
- Developed in EUROFEL I (LCP-ELYSE, H. Monard (now at LAL), LULI (J. R. Marques)), adopté à DESY
- Prototype test on SOLEIL transfer line

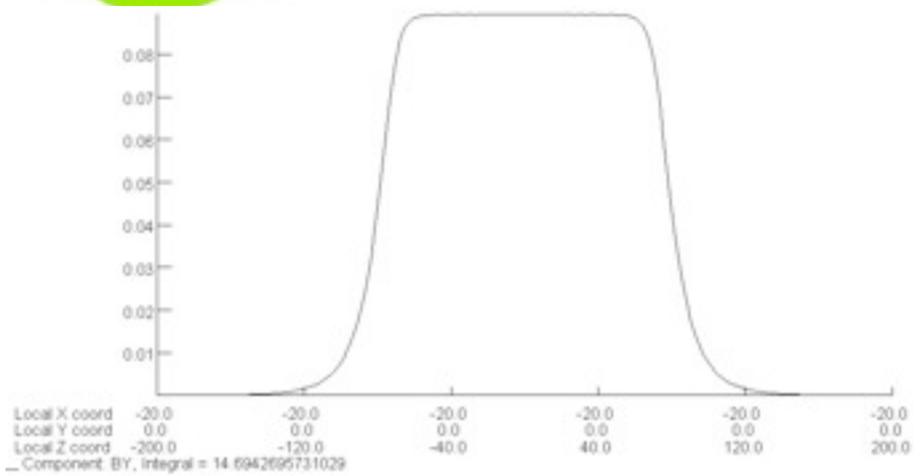
FEL line





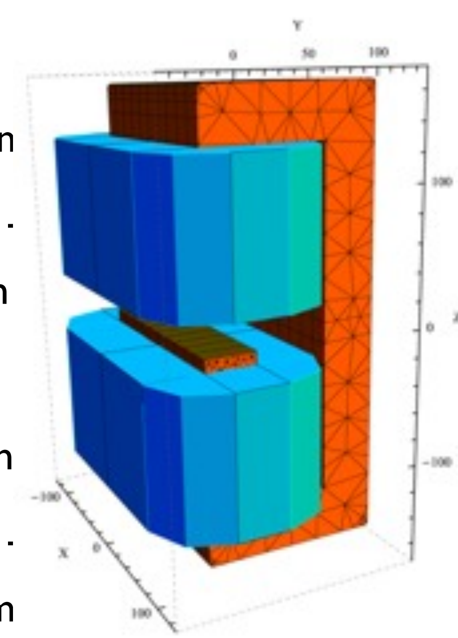
Quadrupoles

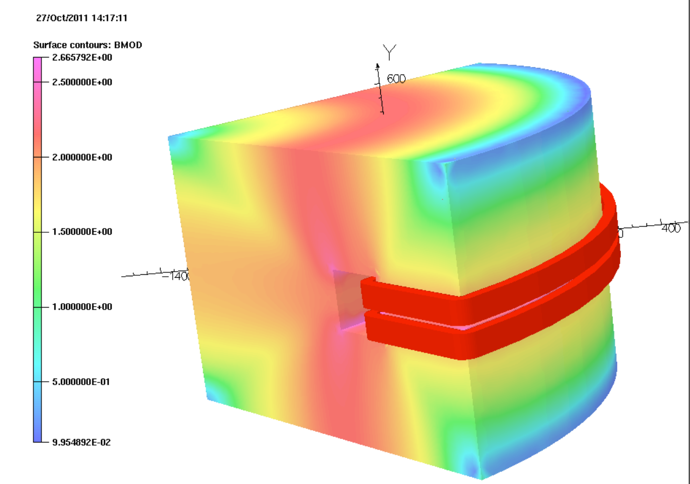
6T/m
150 mm de longueur
25 mm de cercle de gorge



Chicane 1
Number of dipoles 4
Length : 1200 mn
Gap: 25 mm
Bz 0.38
L_d: 150 mm

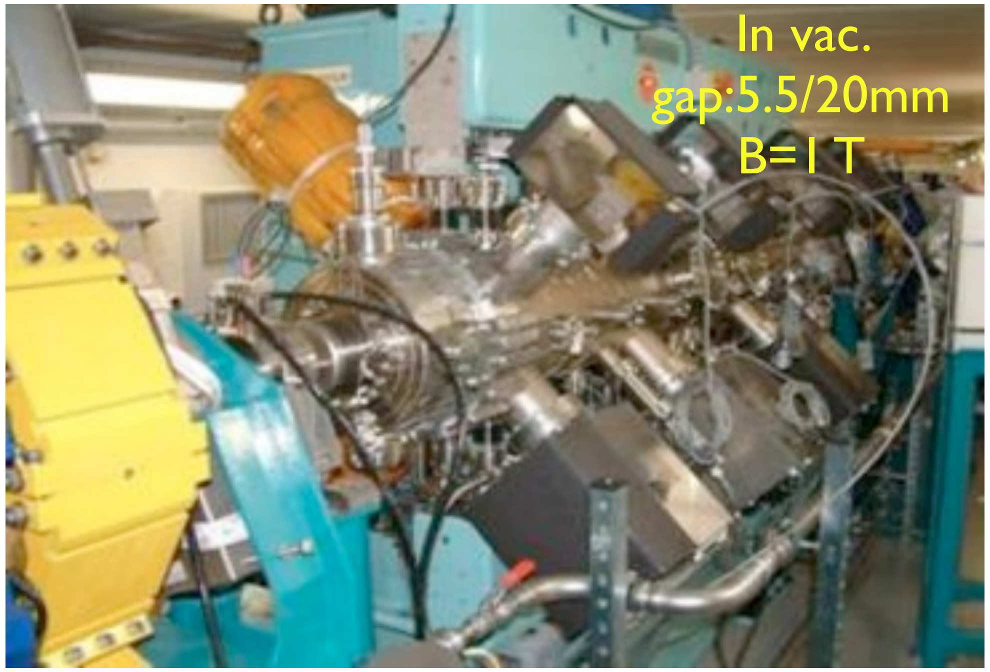
Chicane 2
Number of dipoles 4
Length 800 mm
Gap 25 mm
Bz 0.35
L_d 100 mm

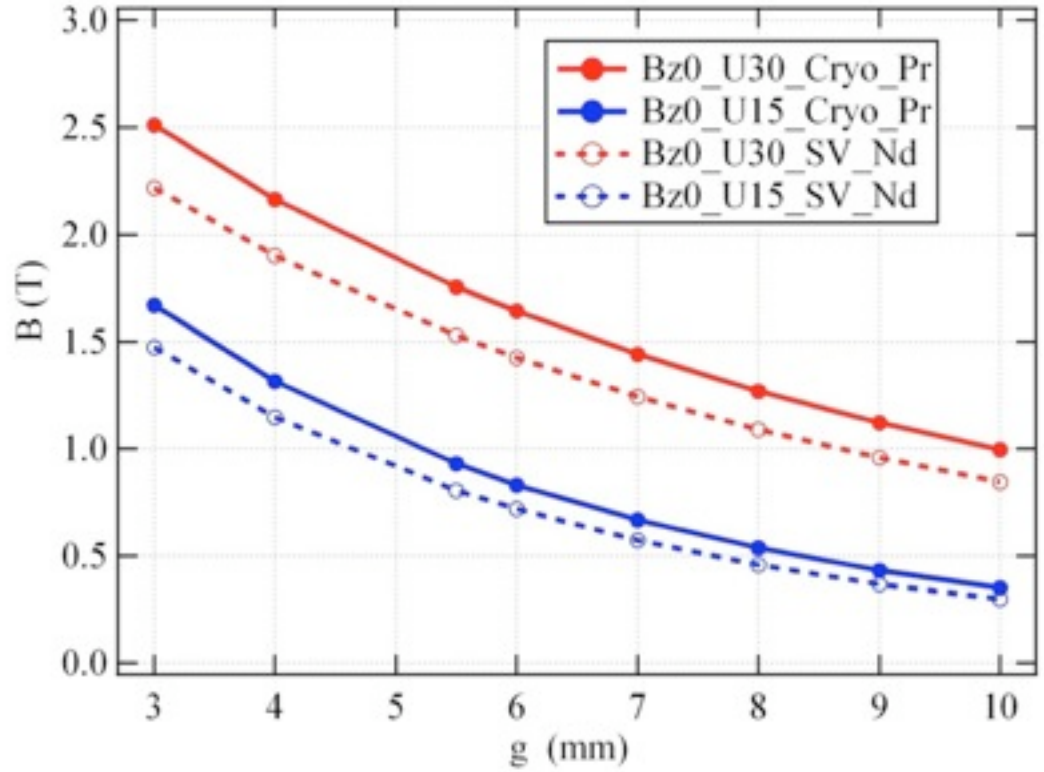


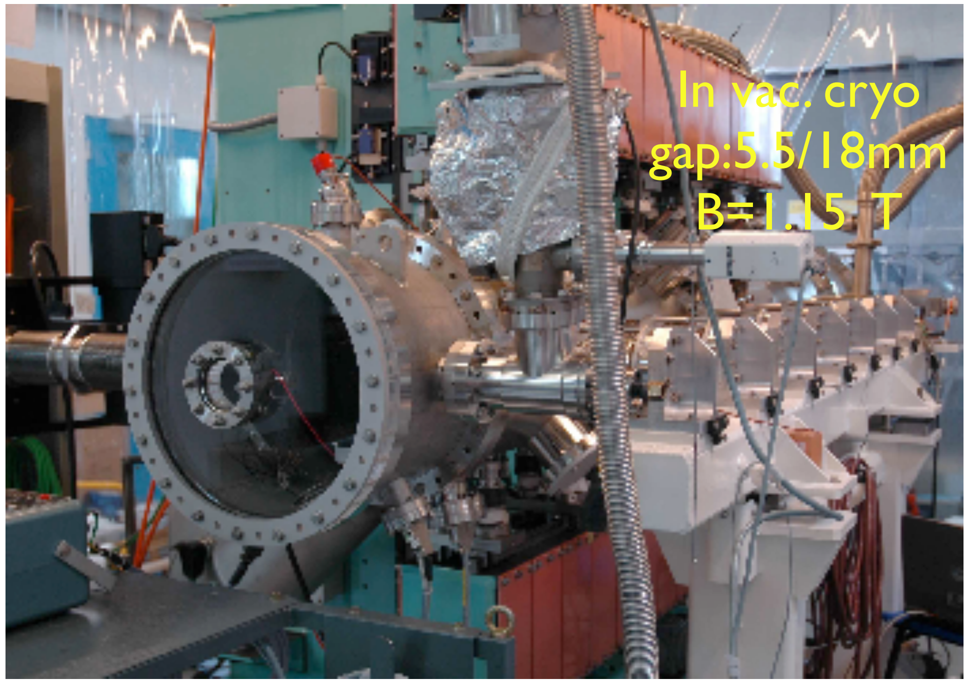


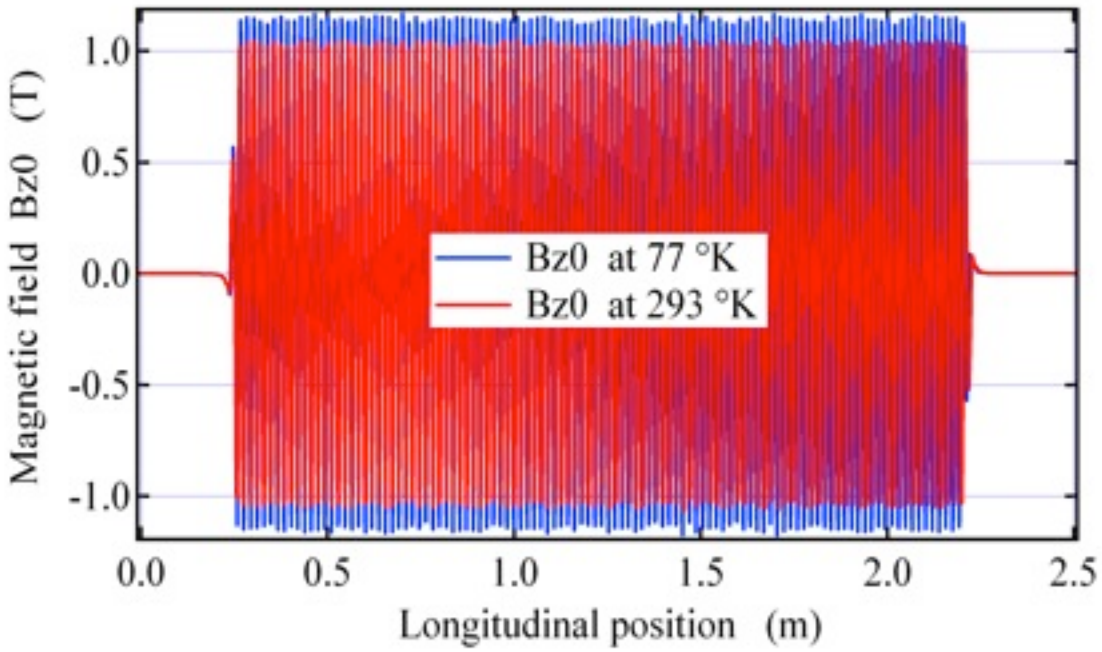
LUNEX5

LUNEX5 Undulators and magnetic elements

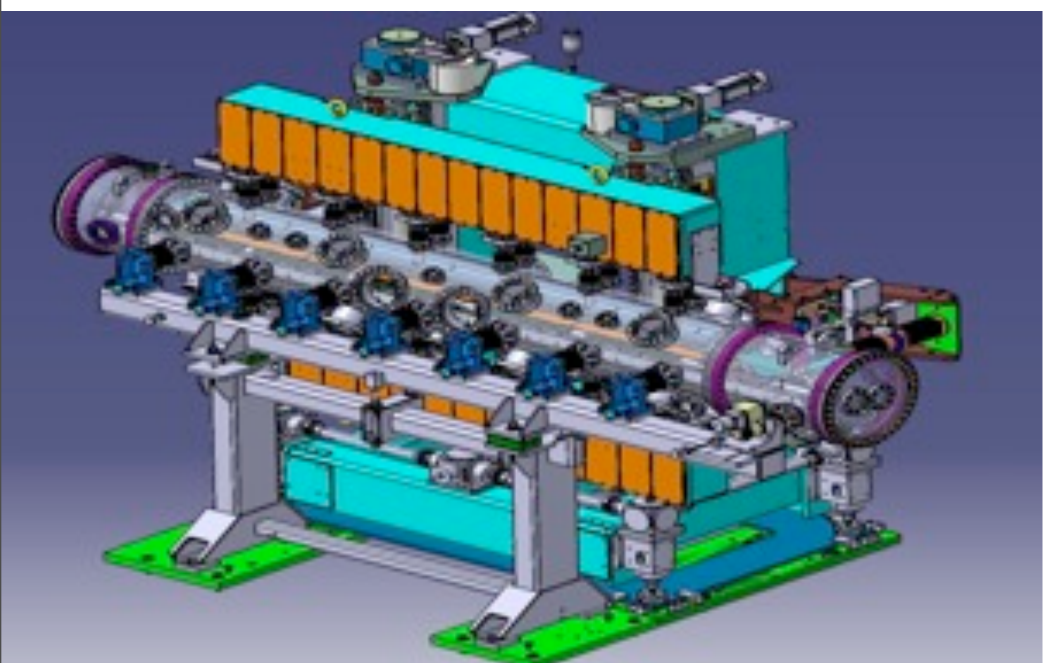




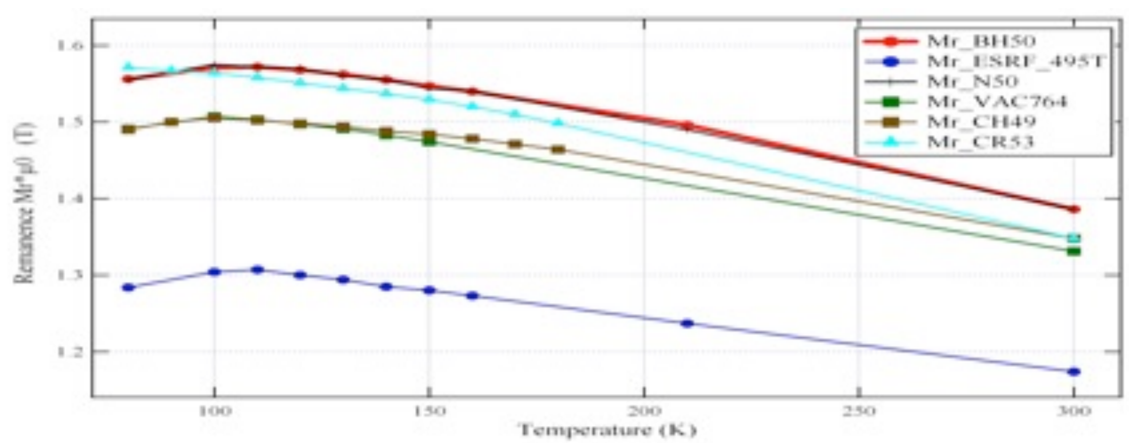




R&D on «3 to 5 m» cryo-ready in vacuum undulator segment development and test on a LWFA



- Study of short period undulator between 15 mm and 12 mm
- Study versus length (FEL simulations, slippage issues)
- Mechanical design (carriage and adaptation of the vacuum chamber)
- Magnetic design => Characterisation of $(Nd_{1-x}Pr_x)_2Fe_{14}B$ permanent magnet



$Nd_2Fe_{14}B$ and $Pr_2Fe_{14}B$ magnets characterisation and modelling for Cryogenic Permanent Magnet Undulator applications, C.Benabderrahmane et al, in Nucl. Inst. Meth.A 669 (2012) 1-6

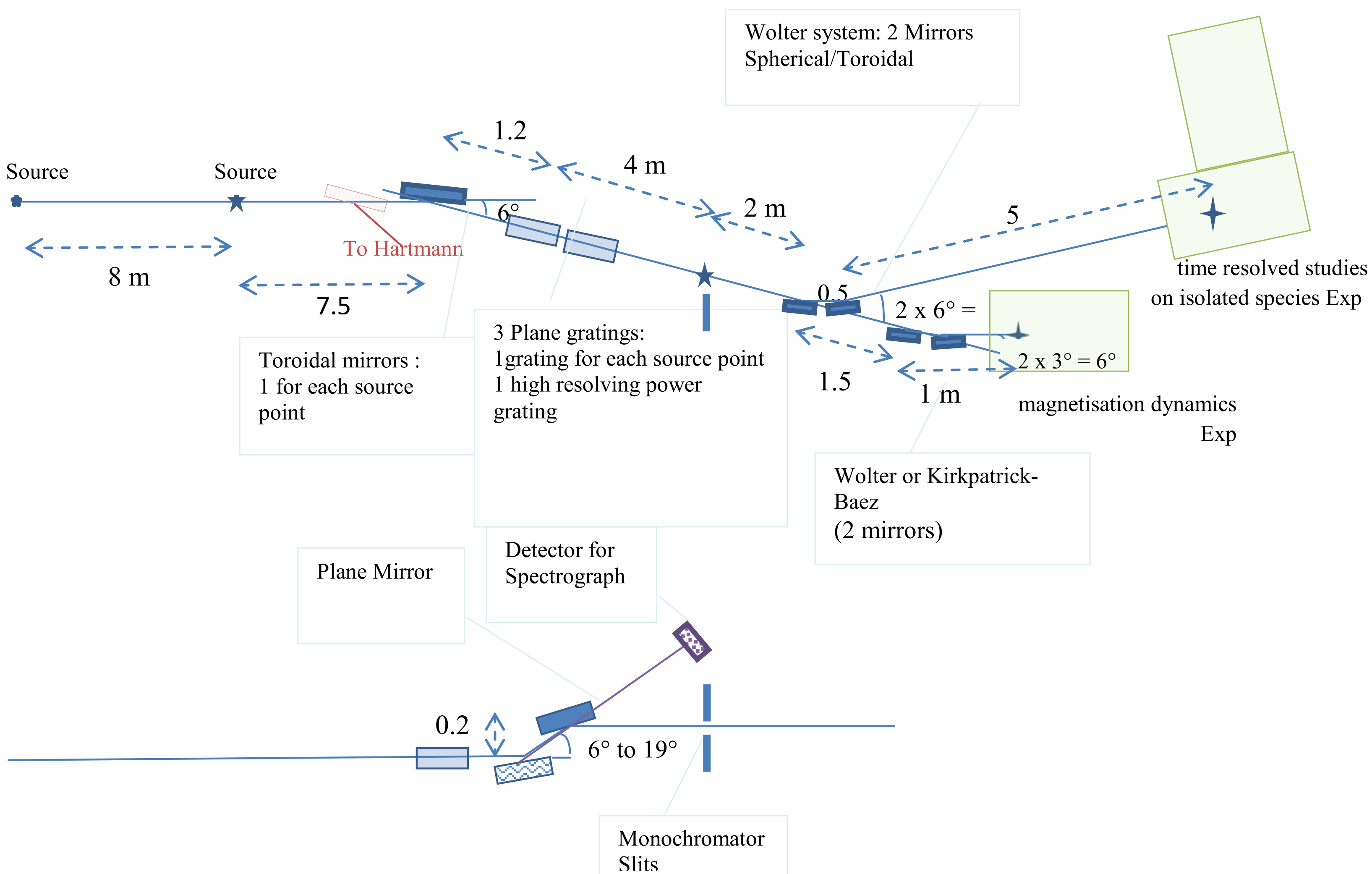
Expertise :
SOLEIL : 2 m, long hybrid in vacuum undulators cryo PrFeB cryo undulator
ESRF : 2.5 m in vacuum undulators, NdFeB cryo undulator

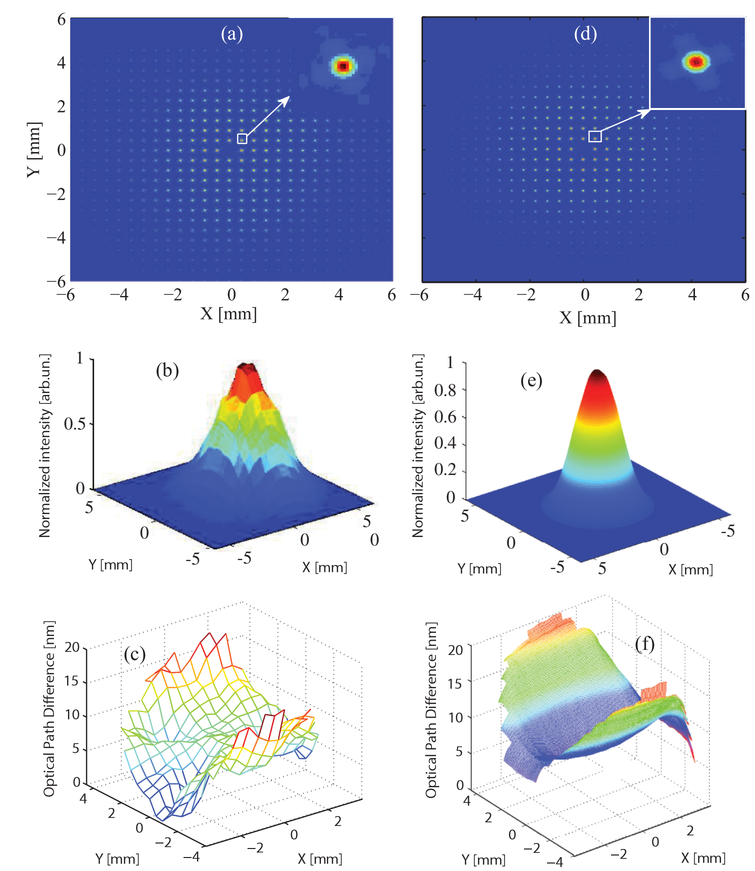
- Test of the radiation with one undulator segment on the Salle Jaune electron source

V- FEL line

LUNEX5

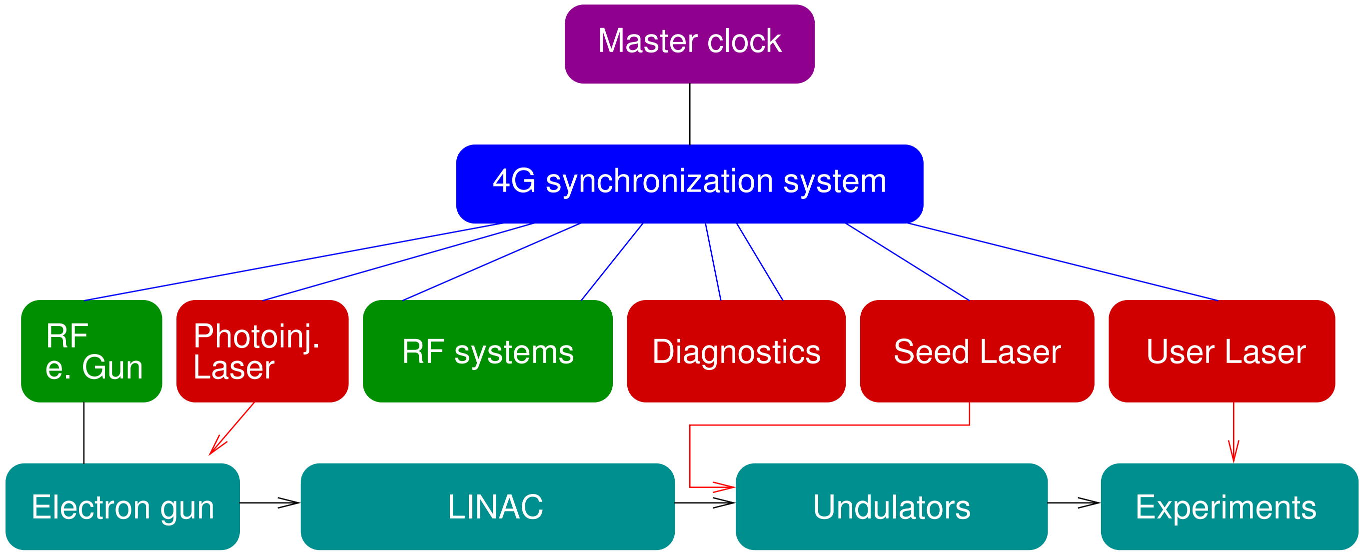
FEL Distribution du laser to pilot user experiments

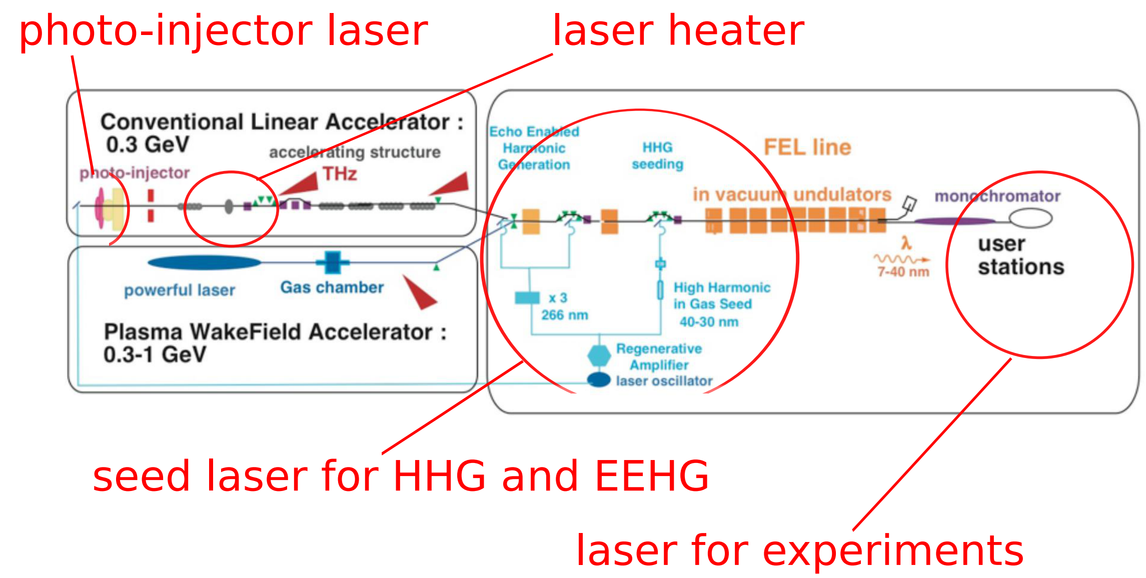


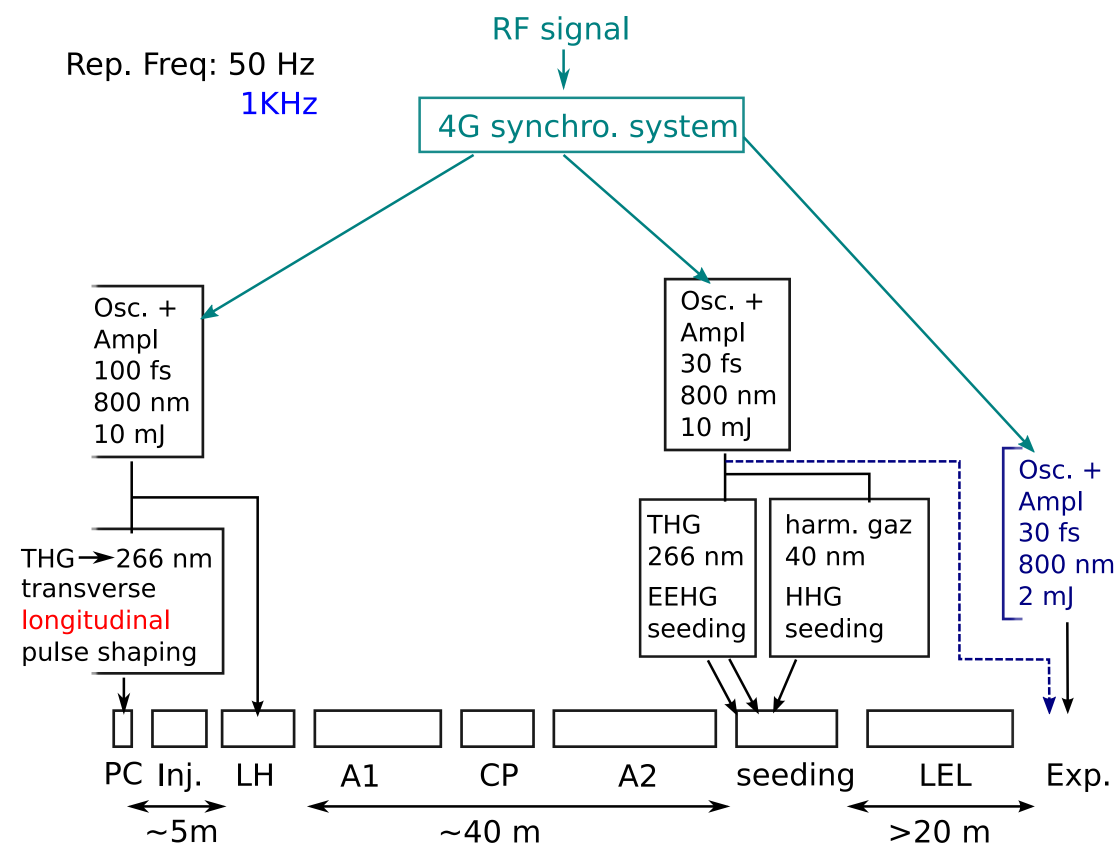


Single-shot wavefront analysis of SASE harmonics in different FEL regimes, R. Bachelard, P. Mercere, et al. Phys. Rev. Lett. 2011, 106 (23), 234801

Synchronisation







Proposed R&D on synchronisation of the gun laser with the seeding/ pilot user lasers (PhLAM, SOLEIL, LAL, CEA-SPAM ?):

- General study to the locking of laser to an external clock at PhLAM on home-made lasers (Yb:KYW). jitter study before and after the amplifier
- Study on a TiSa oscillator equiped with piezo
- Step 3 with a MEMLO commercail system
- synchronisation between two different lasers
- synchronisation between RF and the laser

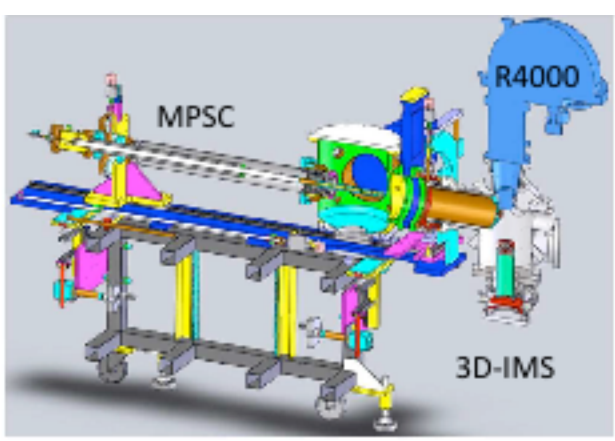
Pilot user experiments

Time-resolved studies of isolated species in the x-ray range: (C. Miron et al.)

- Electron and nuclear wave packet dynamics in molecules
- Molecular dissociative core-excited states (pump-probe)
- Ultrafast electronic decay processes in weekly bound systems (clusters)
- Time and energy resolved electron spectroscopy of isolated nanoparticles
- Coherence/decoherence and interference processes in inversion symmetric systems
- Auger-Doppler effects and electron tunneling
- Electron streaking measurements to correlate emission delay and structure

Techniques : time-resolved electron spectroscopy - electron-ion correlation methods (coincidences or "covariance mapping")

Multipurpose source chamber for isolated species production under UHV

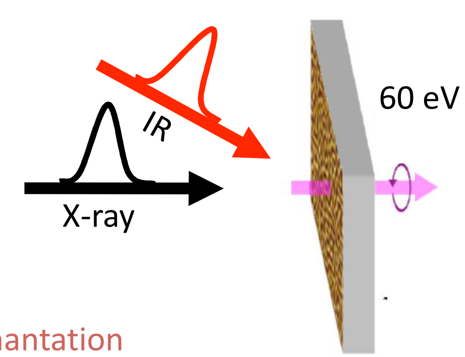


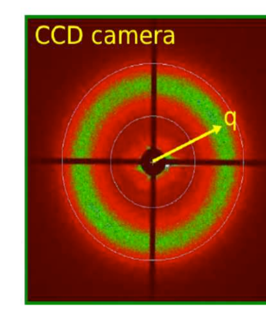
Full 3D ion momentum spectrometer

Study of magnetisation dynamics. Lüning, LCPMR)

•1996: Observation of a sub-picosecond reduction of remanent magnetisation after an optical excitation
=> How does occur the kinetic momentum transfer considering a ~ 10 ps spin-phonon relaxation?
• IR pump:
-magneto-optical probe < 50 fs of pumped electrons
-XMCD probe (magnetic moments) 150 fs

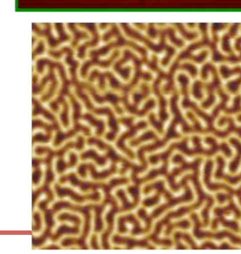
Expériences proposée:
Pompe IR – Sonde *diffusion résonante magnétique aux petites angles*





Intensité intégrée
→ mesure de l'aimantation

Distribution radiale
→ information spatiale



LUNEX5

Science vision beyond pilot user experiments

Scientific case:
"pilot user experiments" (and not "user's facility")

experiments to be developed with the CLA first
energy limitation : 20 nm (M 2,3 métaux de transition), 12 nm (Si)
experiments to be developed with the LWFA
-> higher energies (1.2 GeV?) for the generation of shorter wavelengths (4 nm?) (C (K))

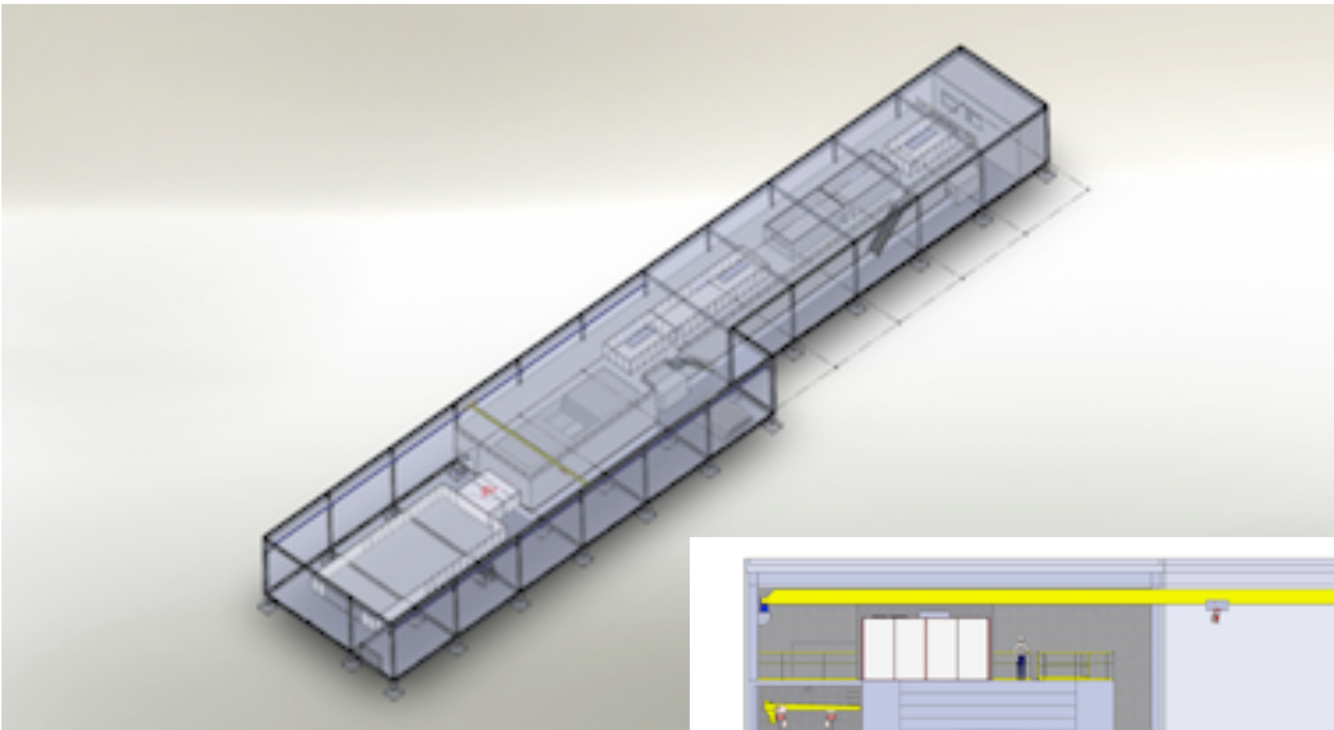
Vision beyond LUNEX5
LUNEX demonstrator of further facilities enabling :

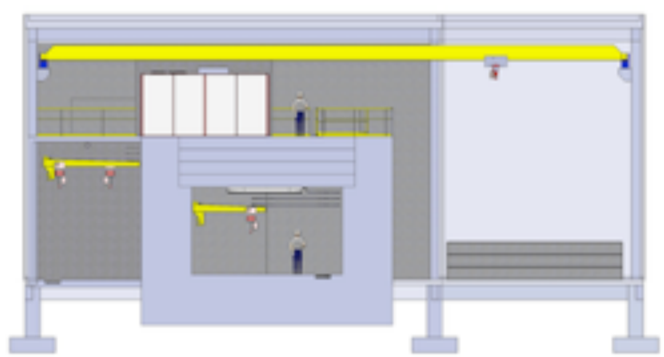
- the generation of ultra-short pulses (attosecond?)
- access to K levels of C,N,O and L ones of transition metals (< 4 nm)
- "single shot"
- dilute phase – nanoparticules
- magnetism
- chemical reactivity
- biology (time resolved)

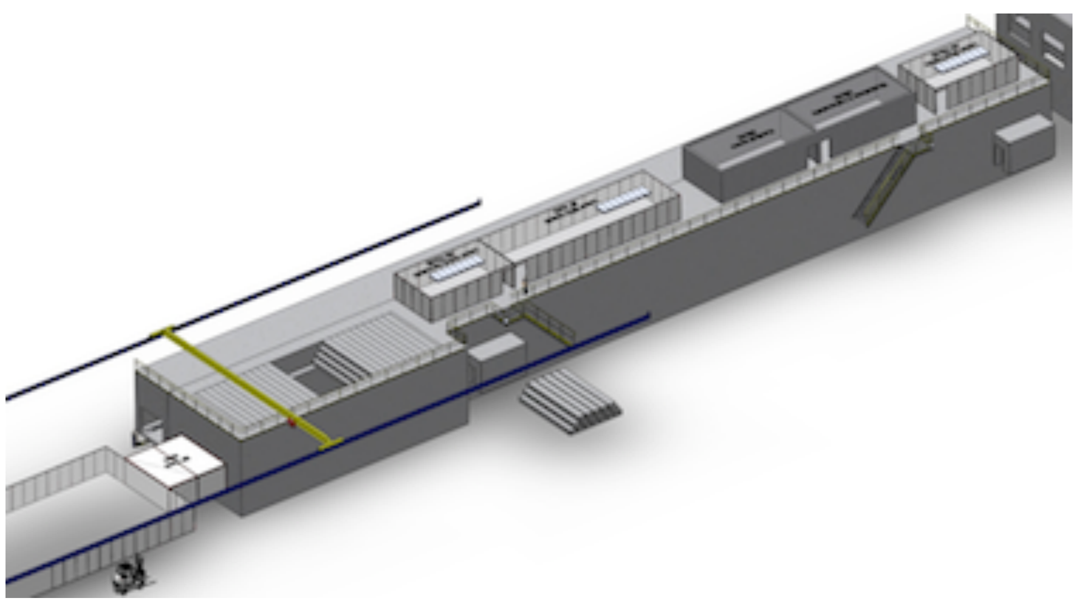
VIII- Building and infrastructure

Infrastructure

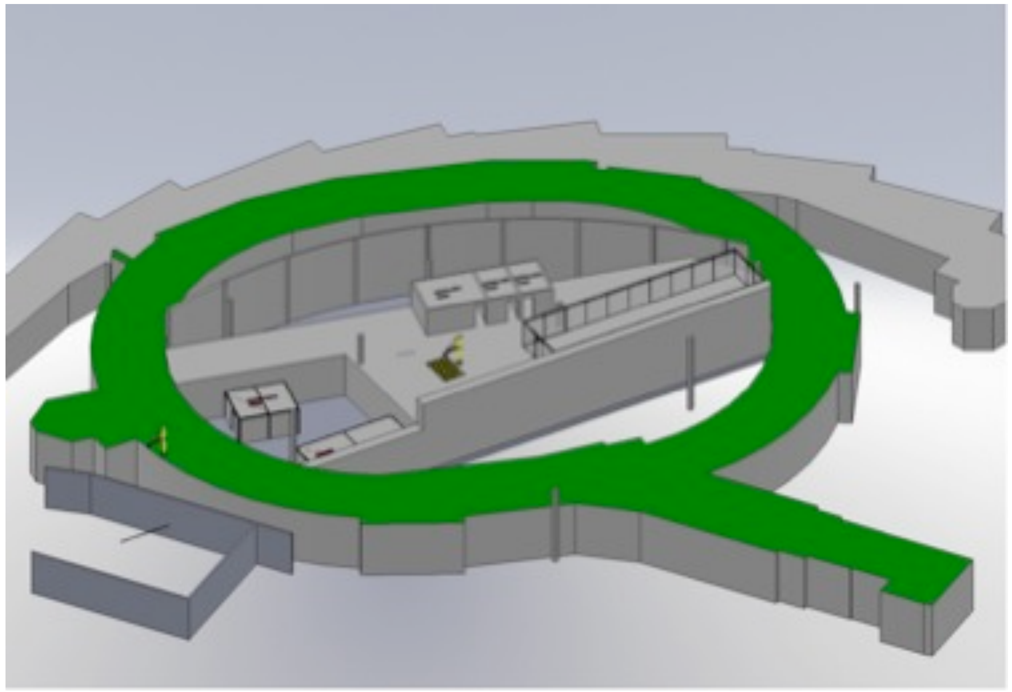
Greenfield case



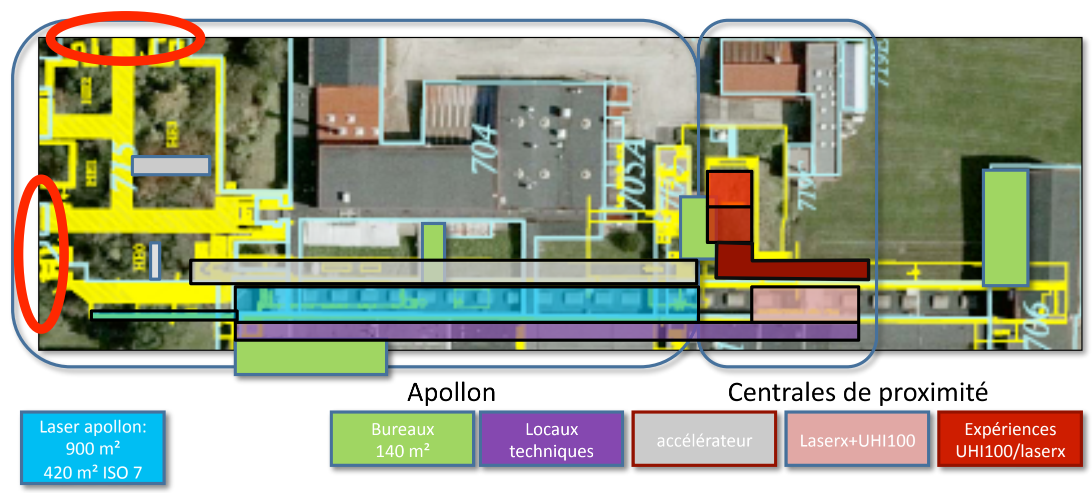




SOLEIL booster arena



ALS tunnel



other

Conclusion

LUNEX5

Challenges and outcomes of LUNEX5

Challenges	Outcomes
Success of the echo et seeding innovative schemes at short wavelength (40 - 4 nm)	Component development in close link with industry
Pilot user experiments (seeding with 1-2 lasers)	Gathering of FEL users around LUNEX5
Qualification of a LWFA by an FEL application with the different regimes	A step before the collider LWFA application LWFA, contribution to EURONNAc ("Distributed accelerator test facility for synchrotron science and particle physics")
Handling of the fs ultrashort pulses for the LWFA and 4G+ based FELs	New applications of ultra-short pulses => elaboration of a scientific vision beyond LUNEX5 and exploitation of ultra short sources => new science
Commun language between laser, LWFA, conventionnel accelerator communities	Bridges between scientific domains (multidisciplinary investigations, laser/accelerator synergy)
Structuration of the activities	Reinforcement of structuration of the local scientific landscape (Saclay area, ESRF, LABEX, EQUIPEX...)
Scientific excellence and training of future generations	Maintenance and growth of expertise via synergy and mutual exchanges

LUNEX5

Conclusion

We continue in the LUNEX5 adventure for ultra short FEL pulses quest, production and use:

- for creating a unique center of exchange of ideas and works,
- for setting a bridge between different scientific and technical domains,
- for providing a coupled CLA-LWFA based test facility for FEL for complementary use
- for searching of scientific excellence in setting a new collaborating project in the Saclay Plateau area
- for involving our brilliant young collaborators and training new ones
- for paving the path towards a next generation of light sources (4GLS+, 5GLS) with its vision of science

LUNEX5 is open to new collaborations, in particular for joint R&D or targeted complementary studies.

LUNEX5 project is still very flexible, aiming at advancing on the differents R&D subjects.

• Funding.... : ÉQUIPEX CILEX (Laser Apollon 10 PW, LWFA), ANR DYNACO
• Submitted Funding. proposals : ANRJCJC M. Labat OCTOPUS (LWFA start to end and tests at LOA), ANRJCJC N. Delerue (LAL), SP (Smith Purcell); ERC Synergy CUSFEL M. E. Couprie, S. Bielawski, J. Lüning, C. Miron

Conclusion

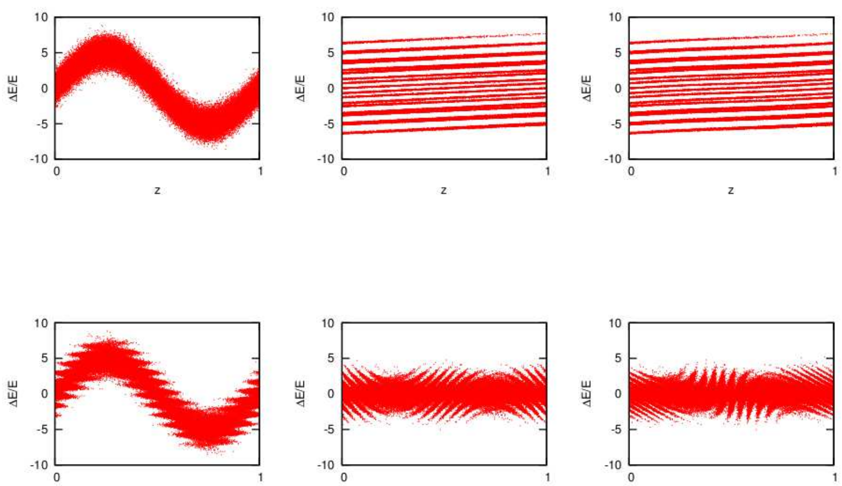
Expected outcomes of LUNEX5

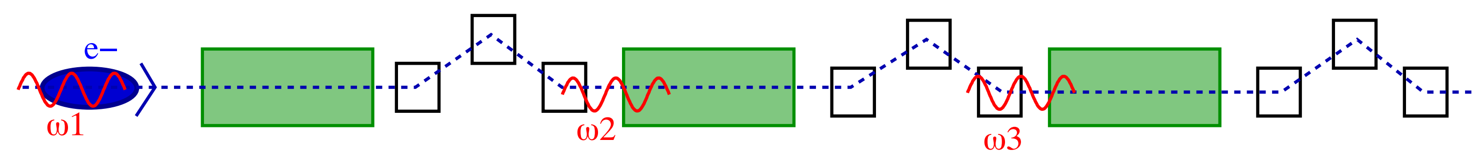
Innovation :

- Innovative FEL schemes (cf ANR DYNACO) : Echo Enable harmonic Generation / seeding High order harmonics in Gas at very short wavelength (40- 4 nm) range (multiple electron -photon interaction and HHG seeding) on the **same demonstator**
- Validation of the latest FEL schemes (4GLS+) with users

=> Contribution to the design of Fourier transformed limited, compact and cost efficient X FEL source

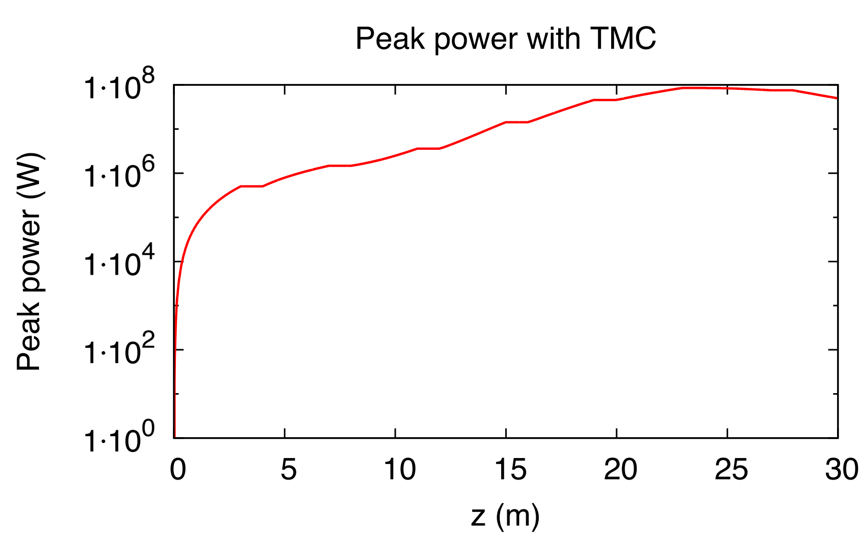
Example of the Triple Modulator Chicane

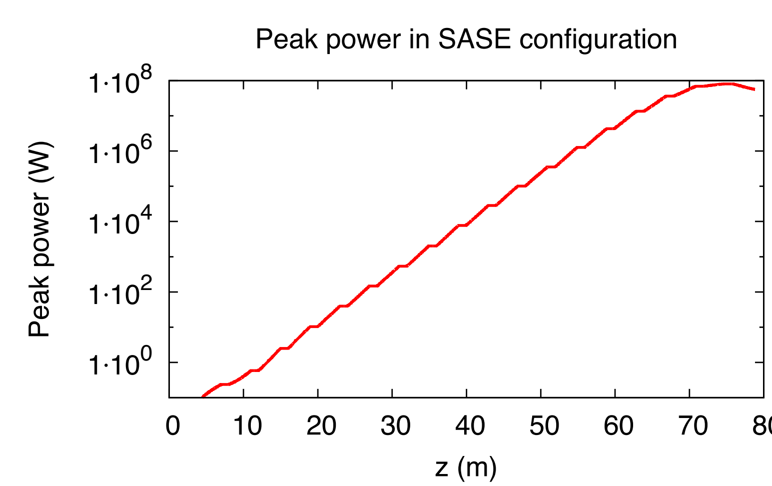




Triple Modulator Chicane Scheme :
Motivation : decrease the required undulator length to reach saturation
→ transpose to GeV machines for Xrays delivery at moderate cost

Exemple : TMC Scheme @ 1.3 nm with E=1.5 GeV :





M. E. Couprie, ... 2-4, 2012

Conclusion

LUNEX5

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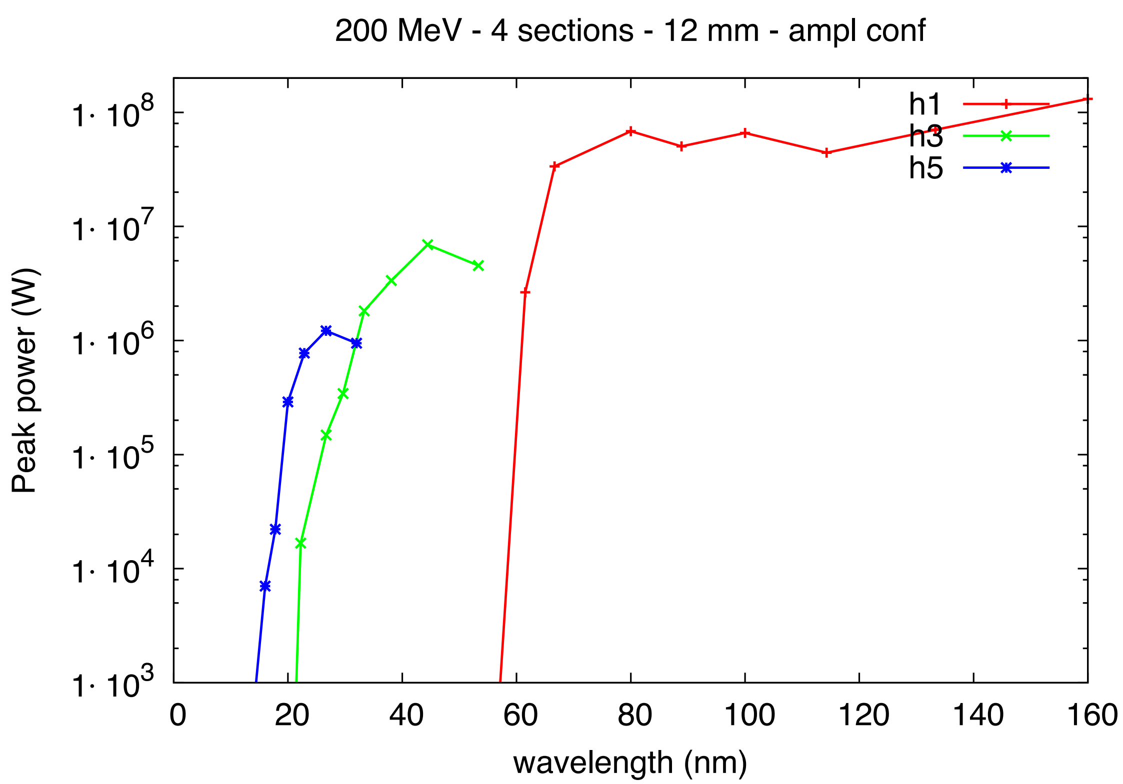
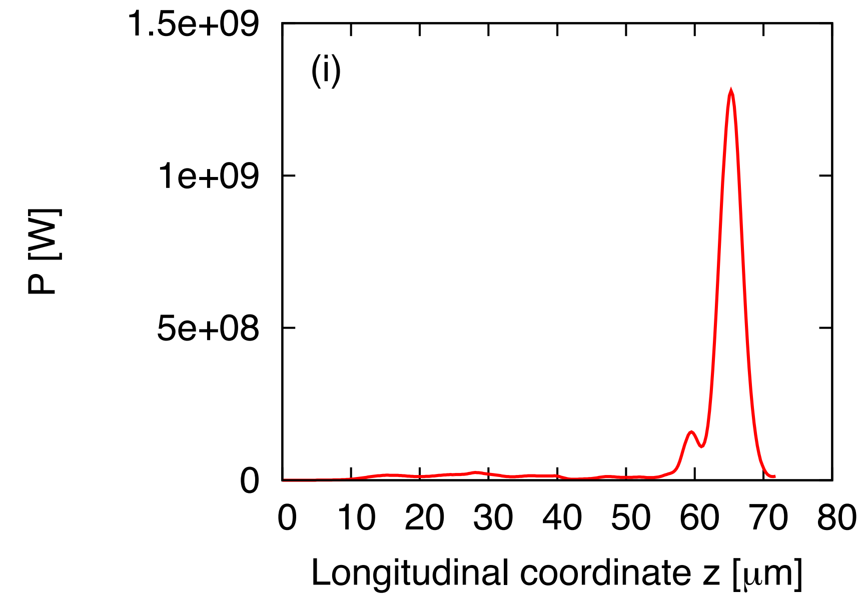
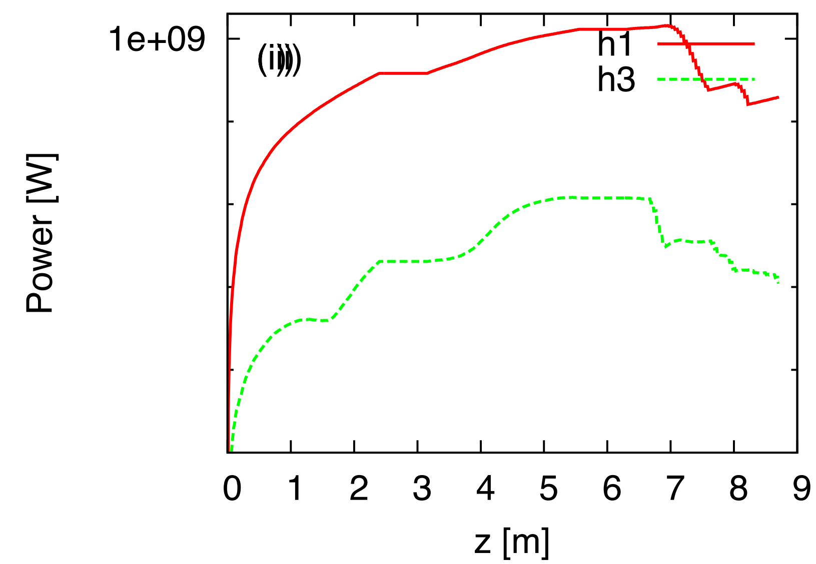
LUNEX5

Étape à 200 MeV







Cascade GENESIS avec :
1U15 @ 120 nm + seeding @ 120 nm
3U15 @ 60 nm
On sature seulement après 2 sections de radiateurs.

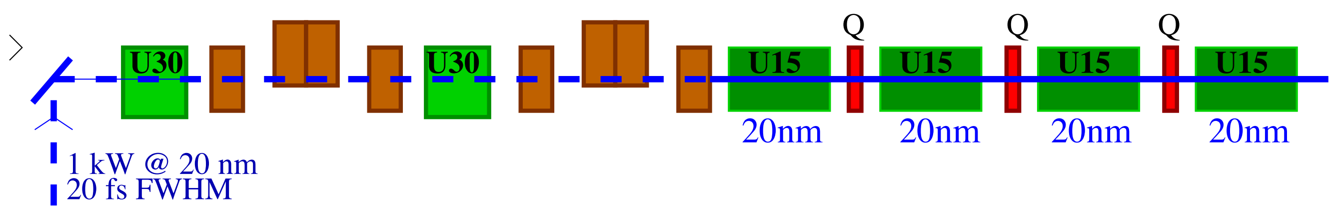
Mode super radiance en sortie, avec 1 GW à 60 nm et 12 MW à 20 nm (h3).

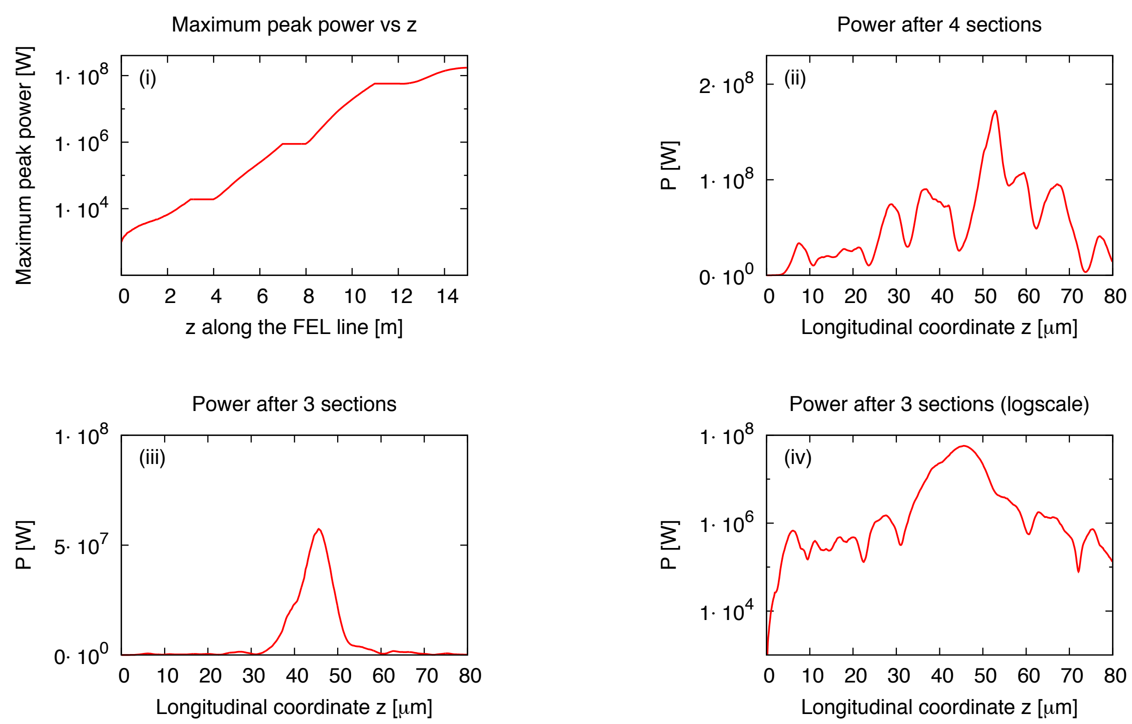
III-Présentation plus détaillée du projet

Calcul LEL Time dependant- CLA

Énergie (MeV)	400
Dispersion en énergie relative	2e-4
Émittance $\epsilon_{x,y}$ (π mm.mrad)	1.5
Courant crête (A)	400
Longueur RMS (ps)	1

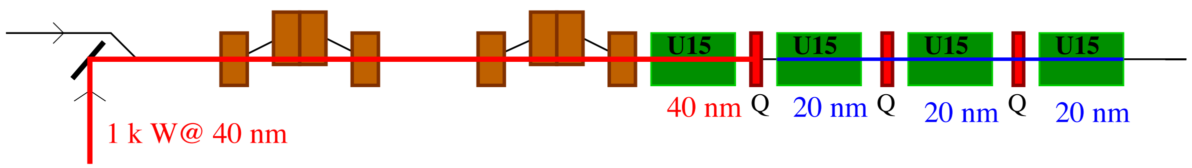
Cas amplificateur

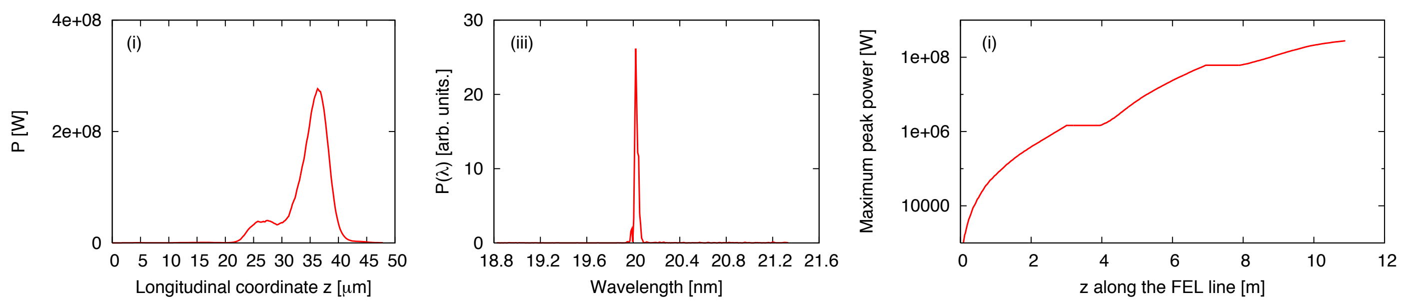




Après 3 sections (z= 11 m), 50 MW, 30 fs FWHM, rapport signal sur bruit = 3

Cas de la cascade

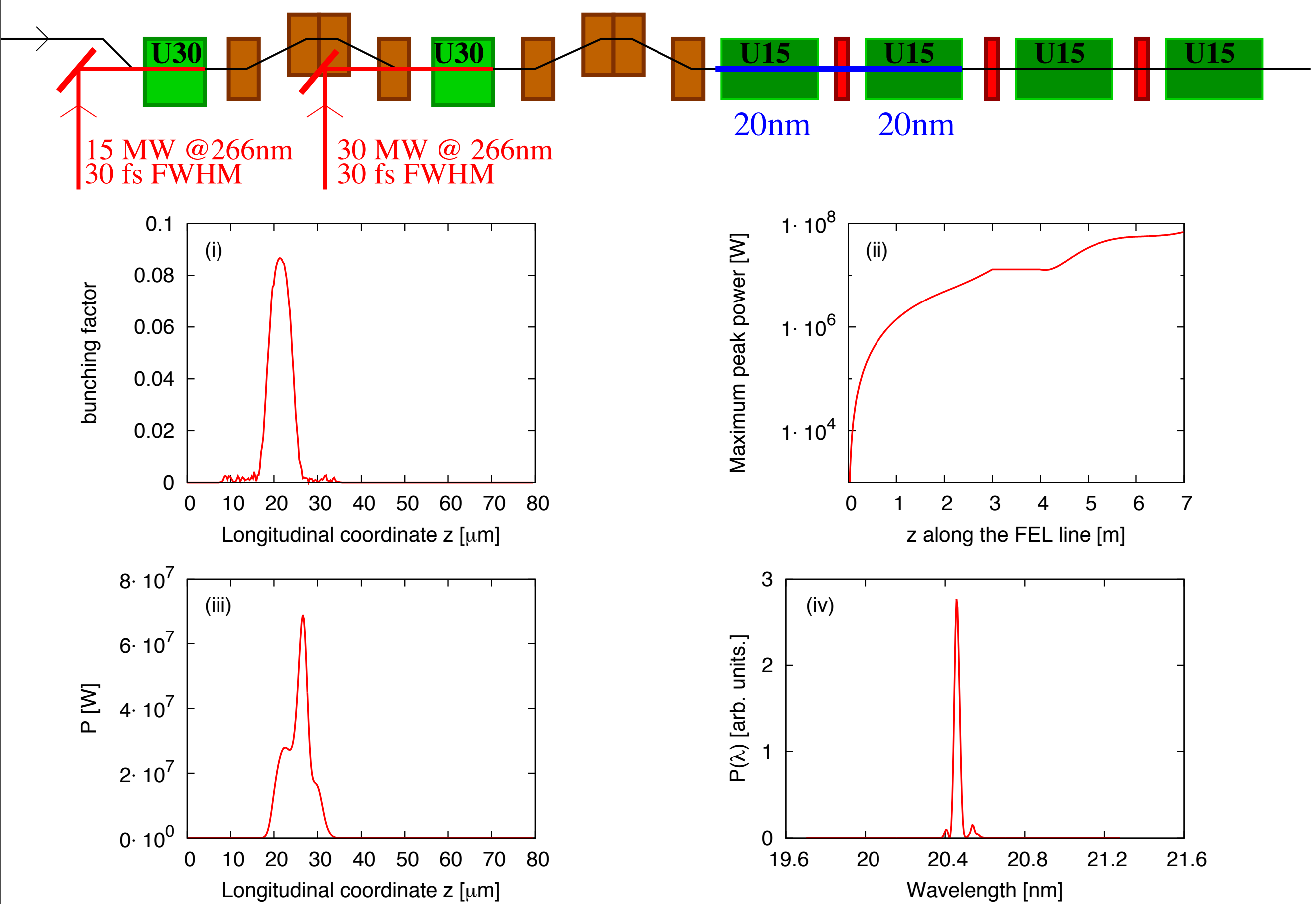




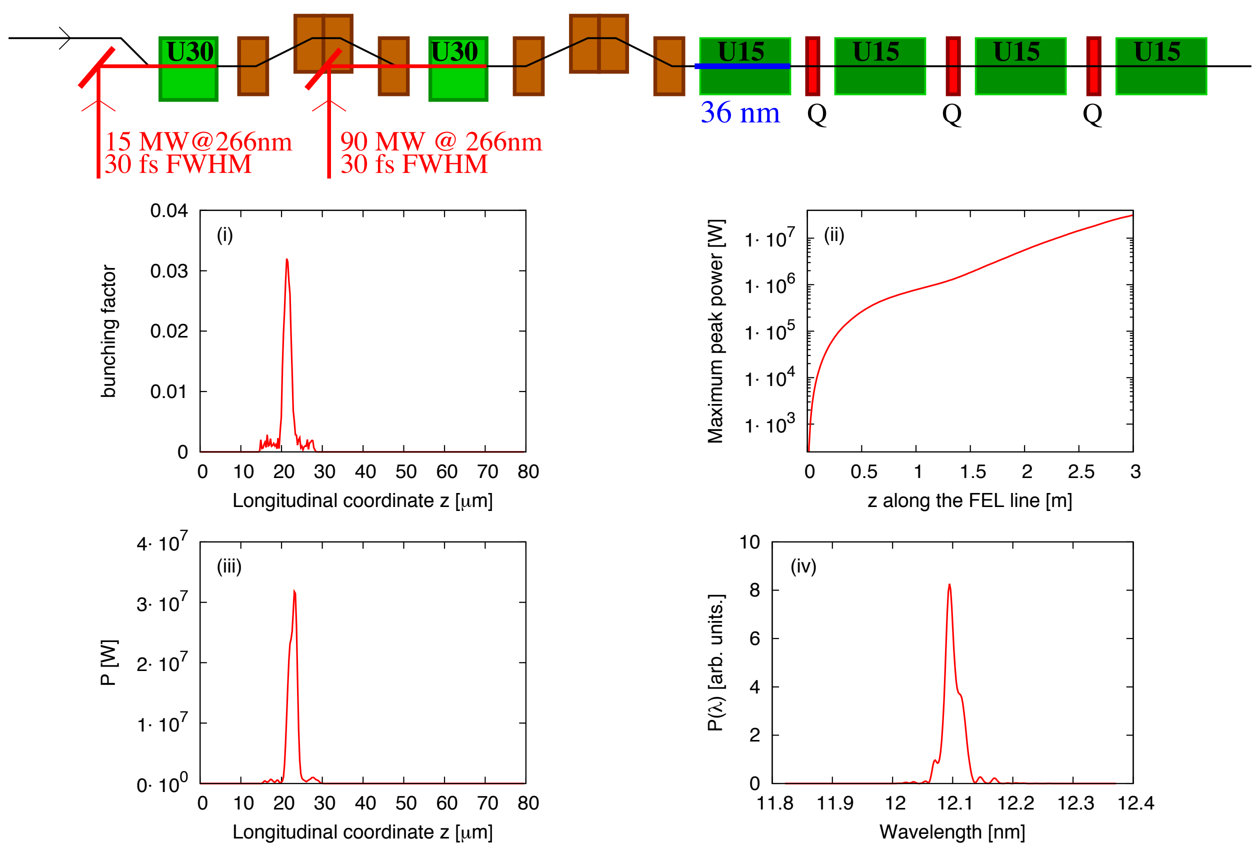
Saturation après 3 sections (z= 11 m), 0.27 GW, 17 fs FWHM, 0.02 nm à mi-hauteur, impulsions à la limite de Fourier

CALCUL LEL TIME DEPENDENT- CLA

Cas de l'écho



20 nm



12 nm

Saturation après 2 sections (z= 7 m), 65 MW, 24 fs FWHM, impulsions à la limite de Fourier

après 1 section (z= 3 m), 30 MW, 7 fs FWHM,, impulsions à la limite de Fourier

LUNEX5

Revue de l'Avant-Projet Sommaire

extrait:
«The committee congratulates the project team on the impressive progress achieved in the limited time available.
The committee supports the scientific relevance of the proposal. LUNEX5 will open new scientific opportunities in France for seeding and first pilot experiments. It could demonstrate the first operational LWFA linac and FEL.
The committee is confident that all technical feasibility issues have been identified and will be further addressed in the TDR. The proposal is challenging and sound.»

General Recommandations

- Start the TDR phase.
- Address with priority the following critical issues:

RC Studies Priority1. Generation of the low energy spread LWFA beam.
RC Studies Priority2. Diagnostics needs.
RC Studies Priority3. Analysis of timing jitter and stability.

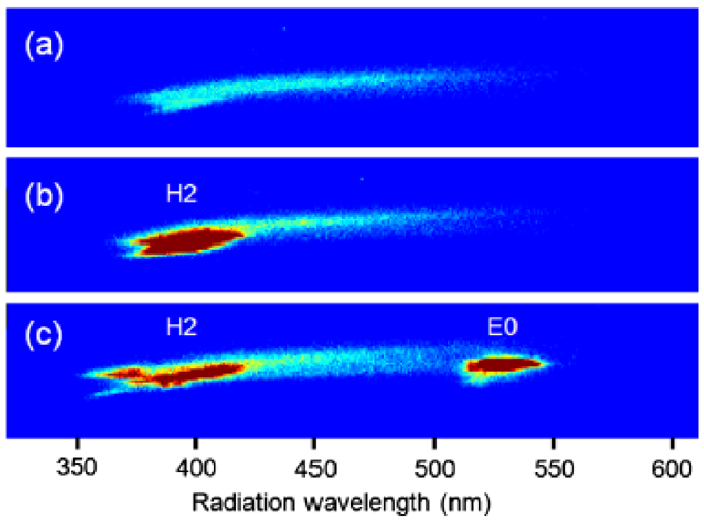
- Address with priority the following R&D:

RCR&DPriority1. R&D on permanent magnet quadrupoles for matching the LWFA beam to the undulator
RCR&DPriority2. Test of a 3 m long cryo-ready undulator
RCR&DPriority3. R&D on femtosecond synchronisation.
RCR&DPriority4. R&D on pulse length measurements for electron beam and photons

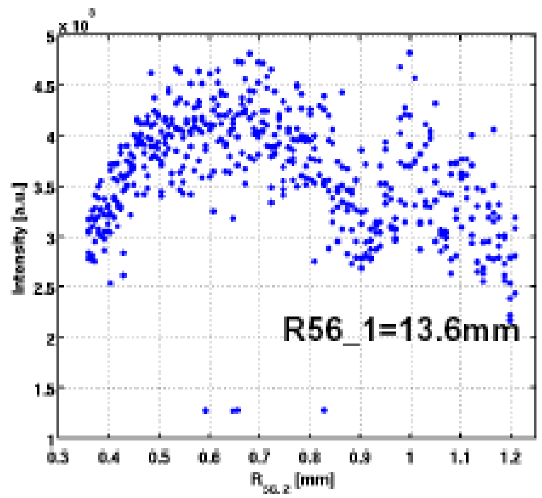
- Study possibilities to extend LUNEX5 to two FEL lines in the future, which would allow to make simultaneous use of the two electron beams.
- Investigate in more detail the Orme des Merisiers

Cas de deux interactions électron - laser externe (écho)

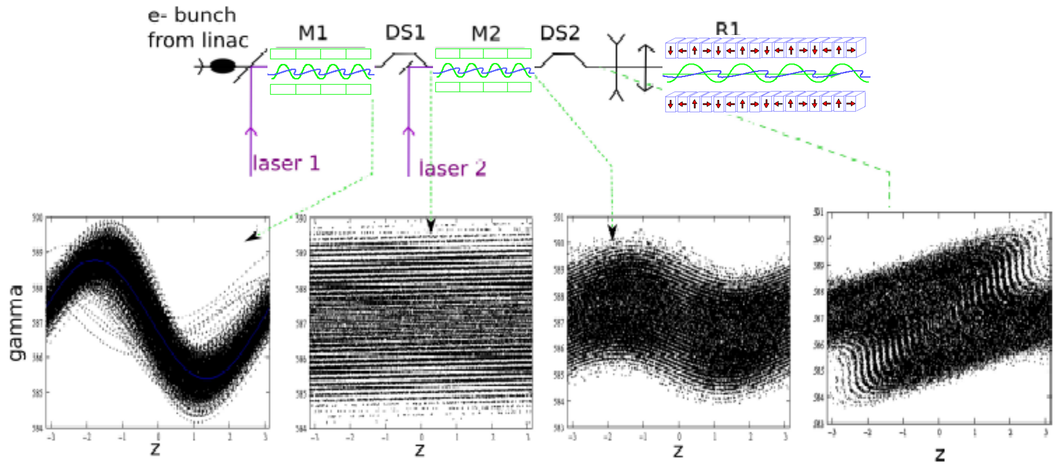
• avec mise en phase des émetteurs sur linac :
première proposition sur Linac pour LEL (Stanford)
Demo expérimentales à Stanford et à Shanghai dans le proche UV



D. Xiang et al., PRL 105, 114801 (2010)



Zhao et al., Proceed FEL conf, Mamö (2010)



G. Stupakov., PRL 102, 074801 (2009)