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**$^{\text{ème}}$ génération

free electron **L**aser **U**sing a **N**ew accelerator for the **E**xploitation of **X**-ray radiation of **5**$^{\text{th}}$ generation

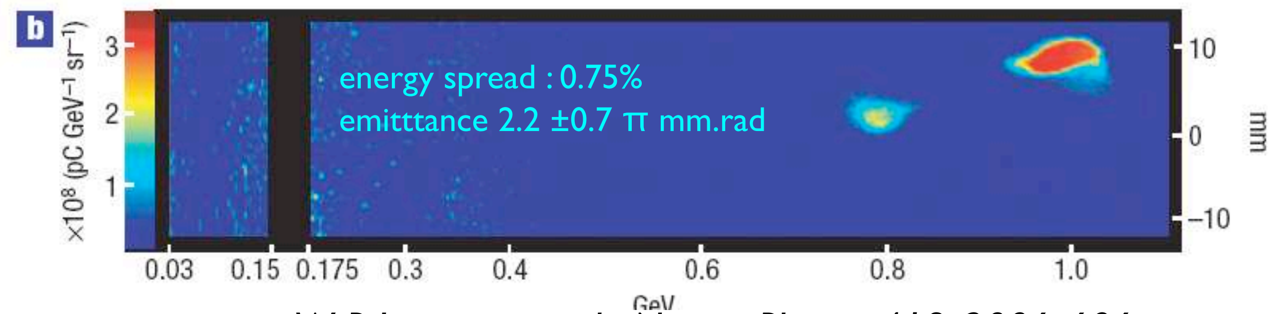
SACM

CILEX

I-Introduction : Scientific context

Laser WakeField Accelerators

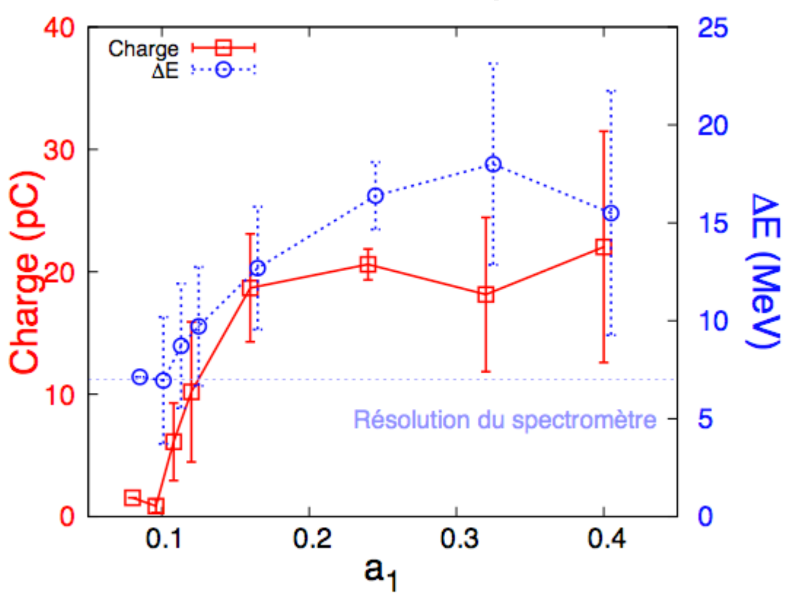
Intense laser focused in a gas jet / cell / capillary
=> ions : accelerator electric field



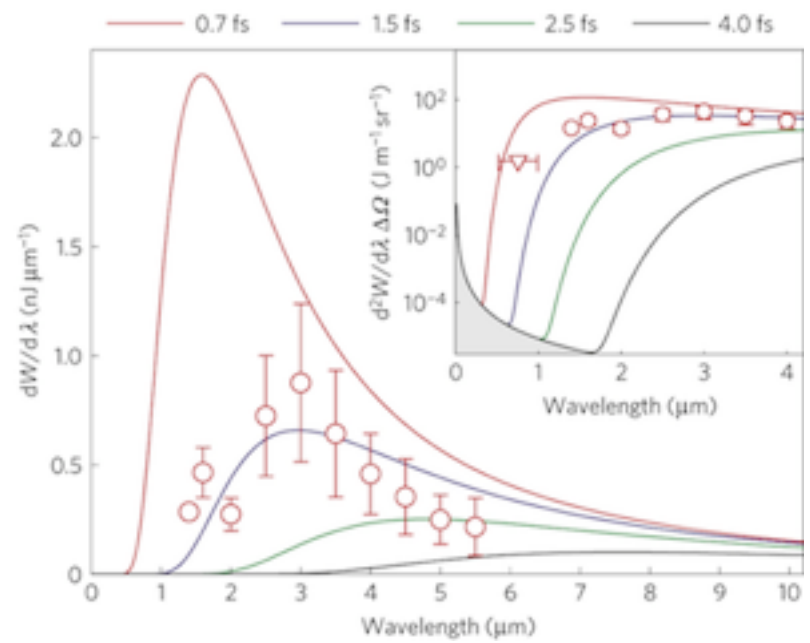
W. P. Leemans et al., Nature Physics 418, 2006, 696

Two laser colliding scheme

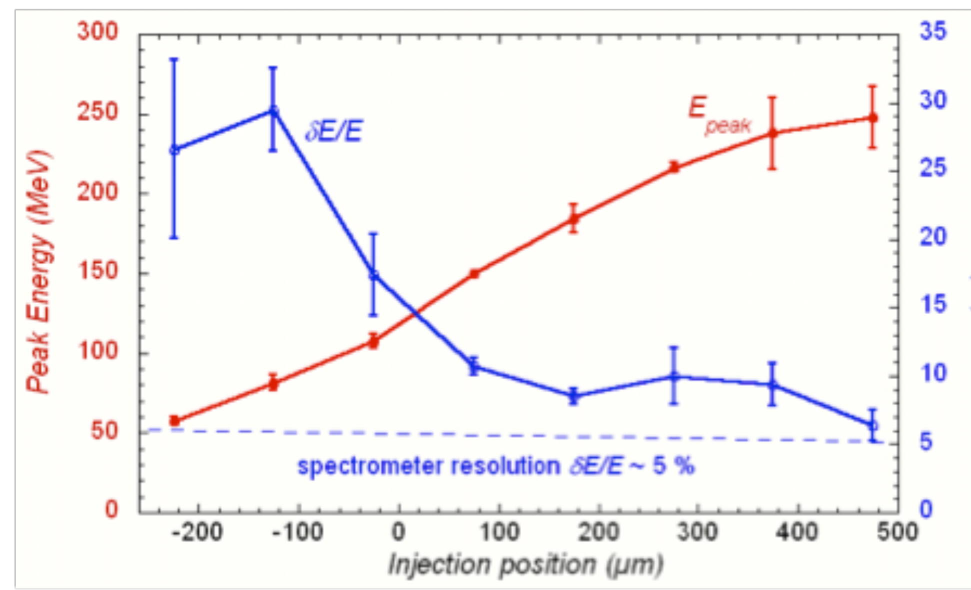
Electron beam production



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



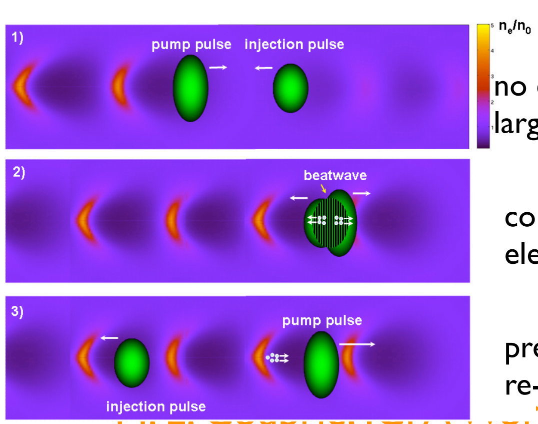
1.5 fs RMS duration : Peak current of 4 kA



	2002	2004	2009
Energy spread (%)	100	5	1

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

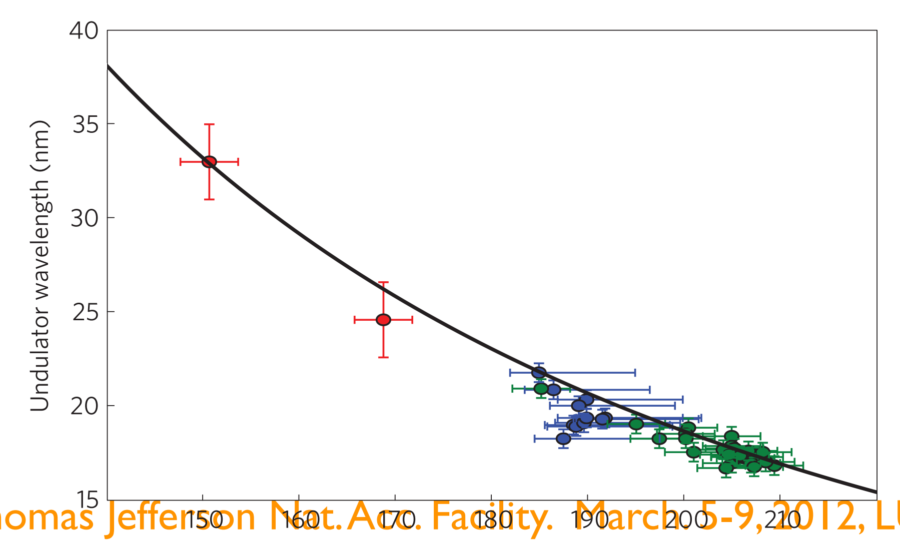
ex of the couterpropagating scheme



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



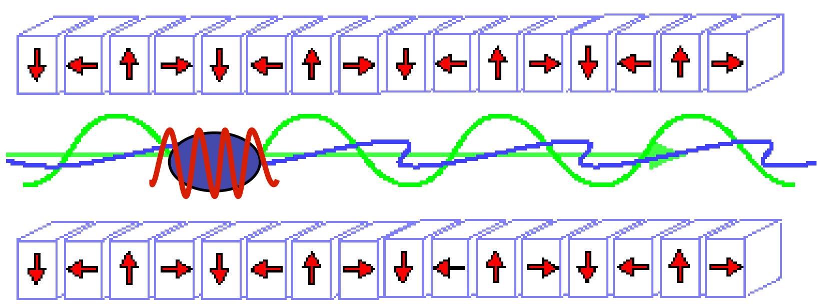
M. Fuchs et al. 5, 2009, 826

I-Introduction : Scientific context

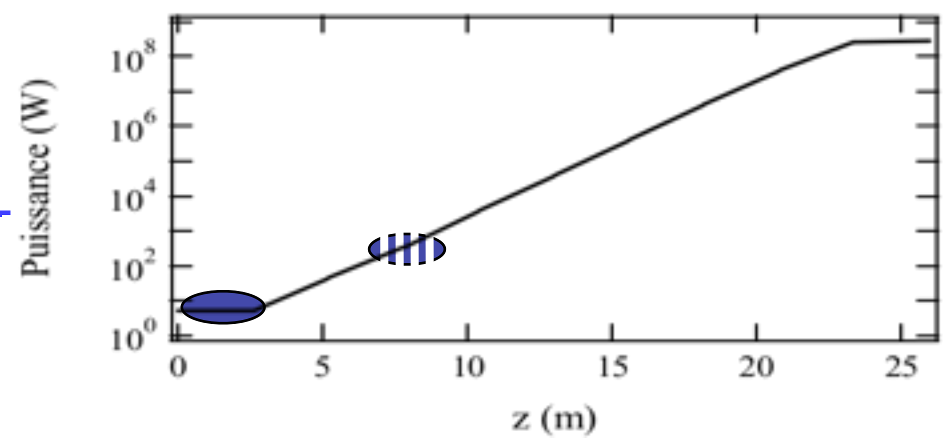
Free Electron Laser Configurations

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

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



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

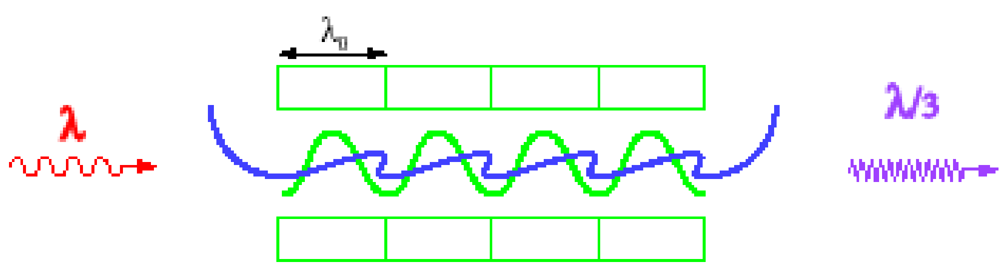


R. Bonifacio et al, Opt. Comm. 50, 1984, 376, K. J. Kim et al, PRL57, 1986, 1871, C. Pelligrini et al, NIMA475, 2001, 1, A.M. Kondratenko et al, Sou Phys. Dokl. 24 (12), 1979, 989

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

S. Reiche et al., NIMA 593 (2008) 45-48
L. Giannessi et al., Phys. Rev. Lett. 106, 144801 (2011)

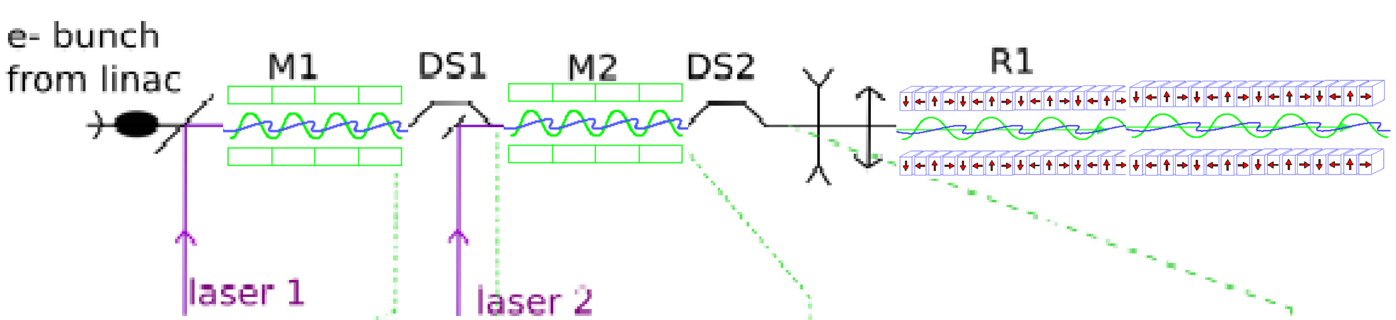
Seeding : one laser-electron interaction



- 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)

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

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

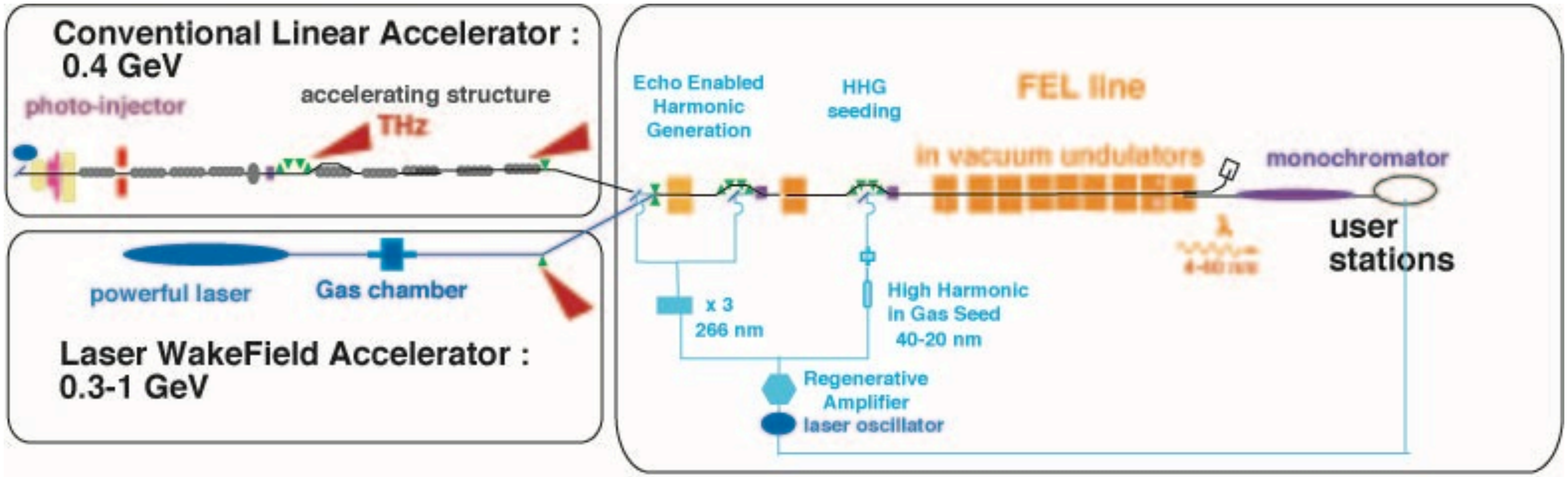


$$\frac{1}{\lambda_{echo}} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

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)

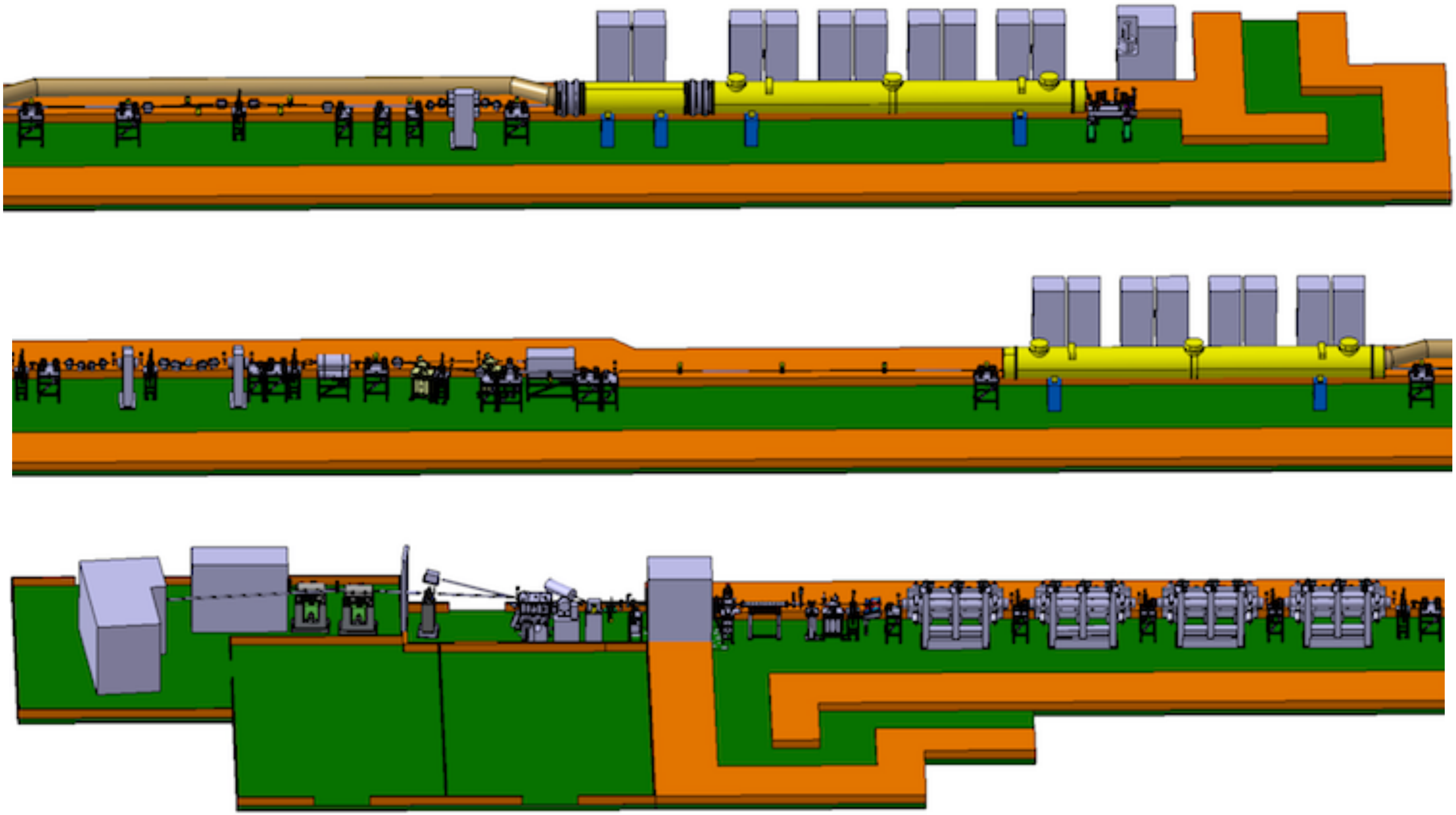
LUNEX5 PROJECT



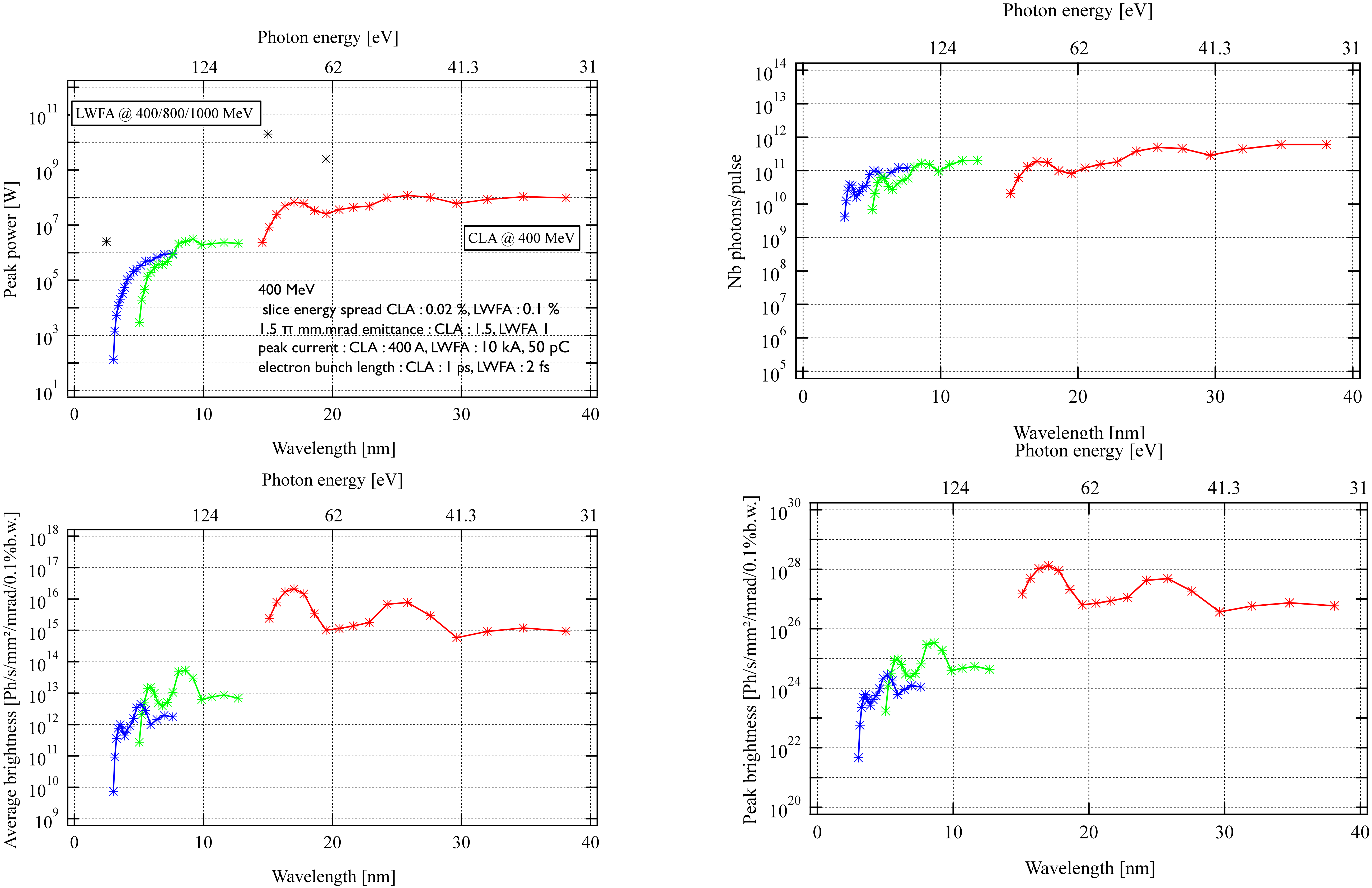
Motivations of LUNEX5 demonstrator

Beyond third generation light source (undulator spontaneous emission, partial transverse coherence),
progress towards fourth generation light sources (coherent emission, temporal and transverse coherence, femtoseconde 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

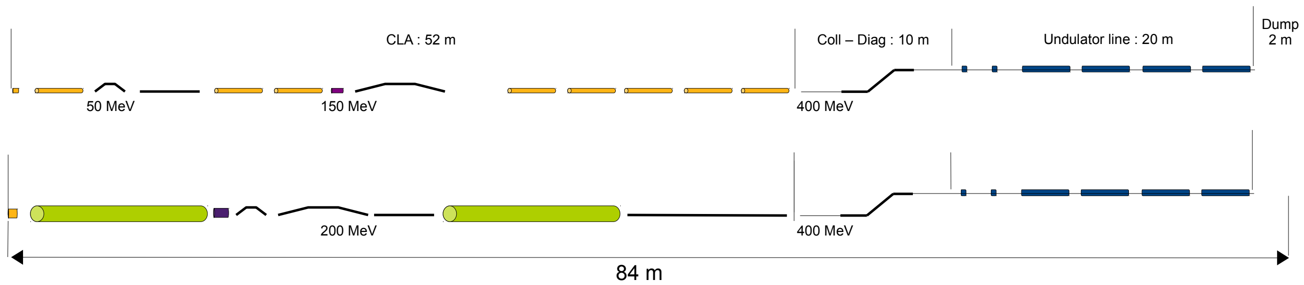
LUNEX5 PROJECT



LUNEX5 PERFORMANCES



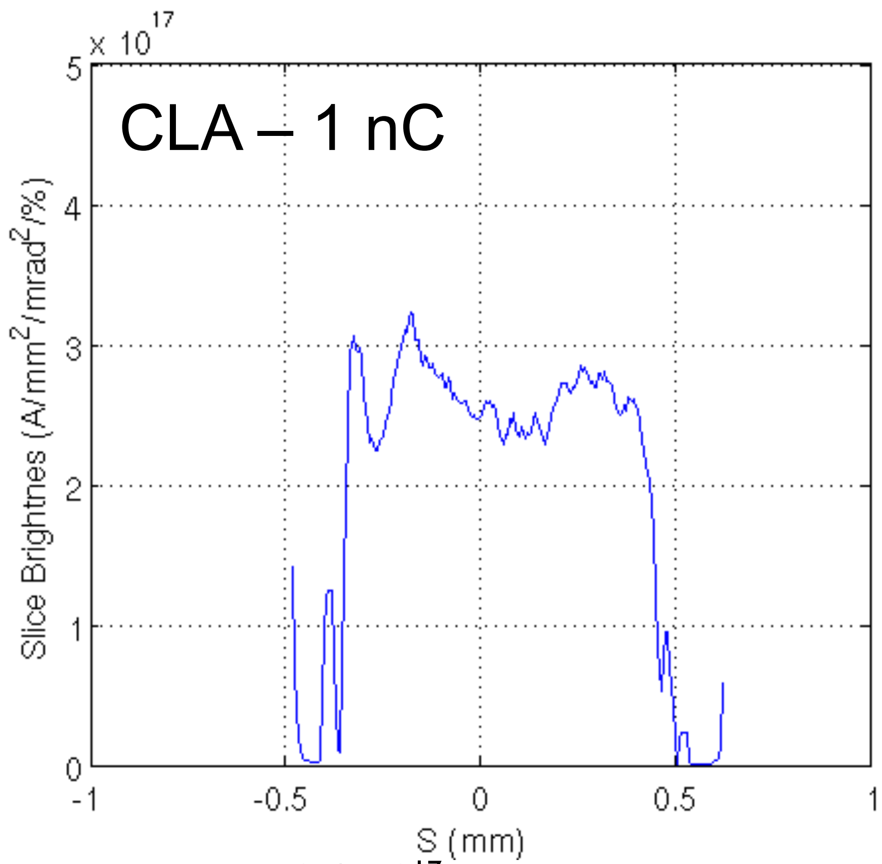
CLA and LWFA performances comparison



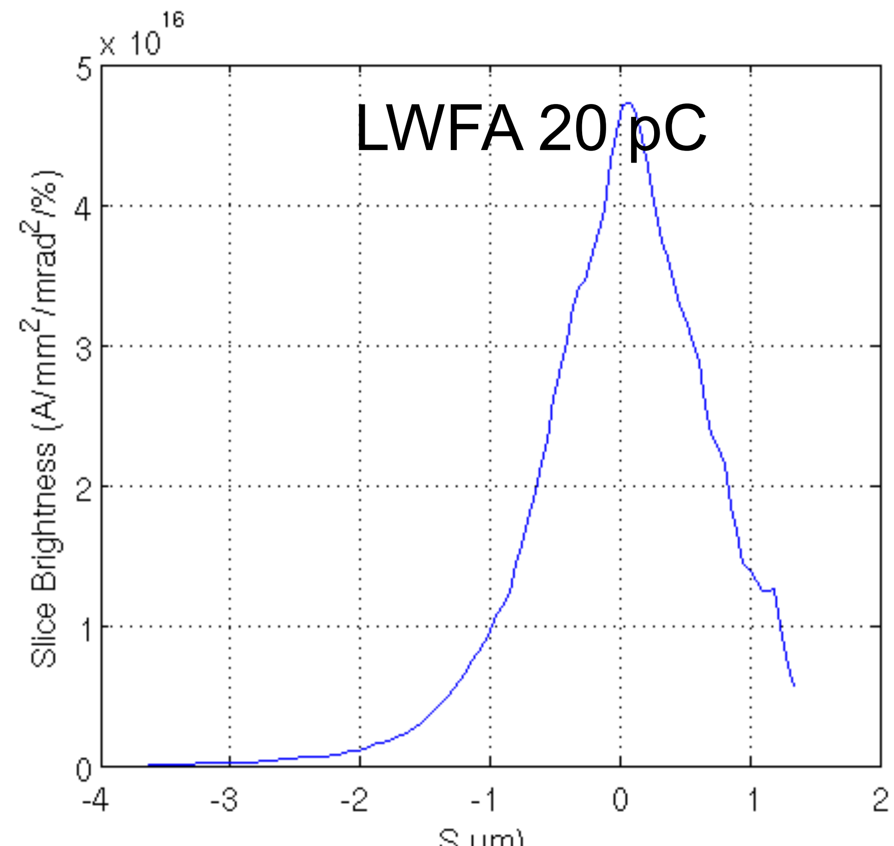
Large Optimistic !

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}

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

Brillances rather comparable

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

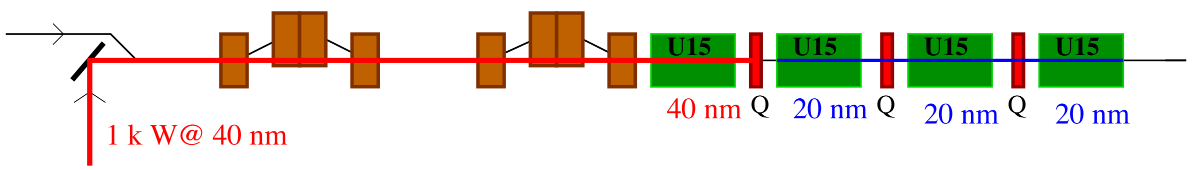
New promissing technology, to be qualifed on a laser application such as the FEL
Possibly single spike FEL operation
Critical parameter : energy spread

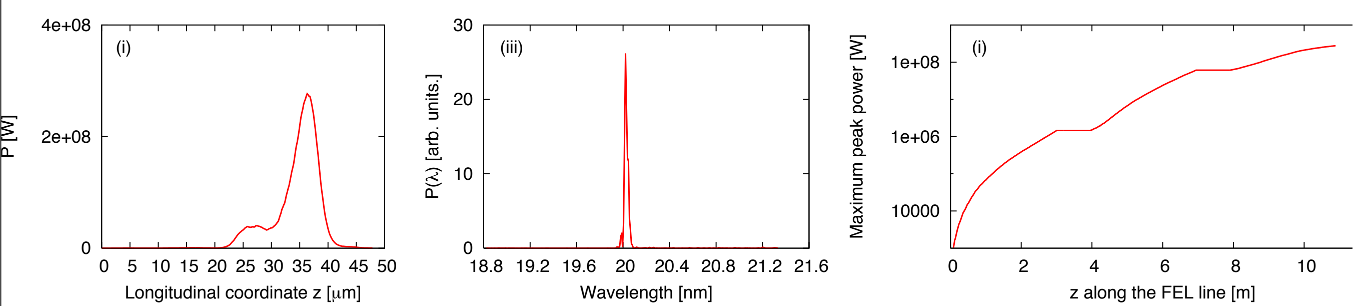
III- Modelling and simulations

Time dependant FEL calculation- 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

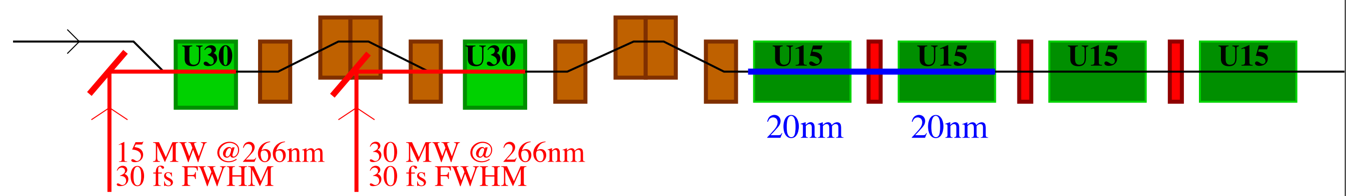
Cascade case

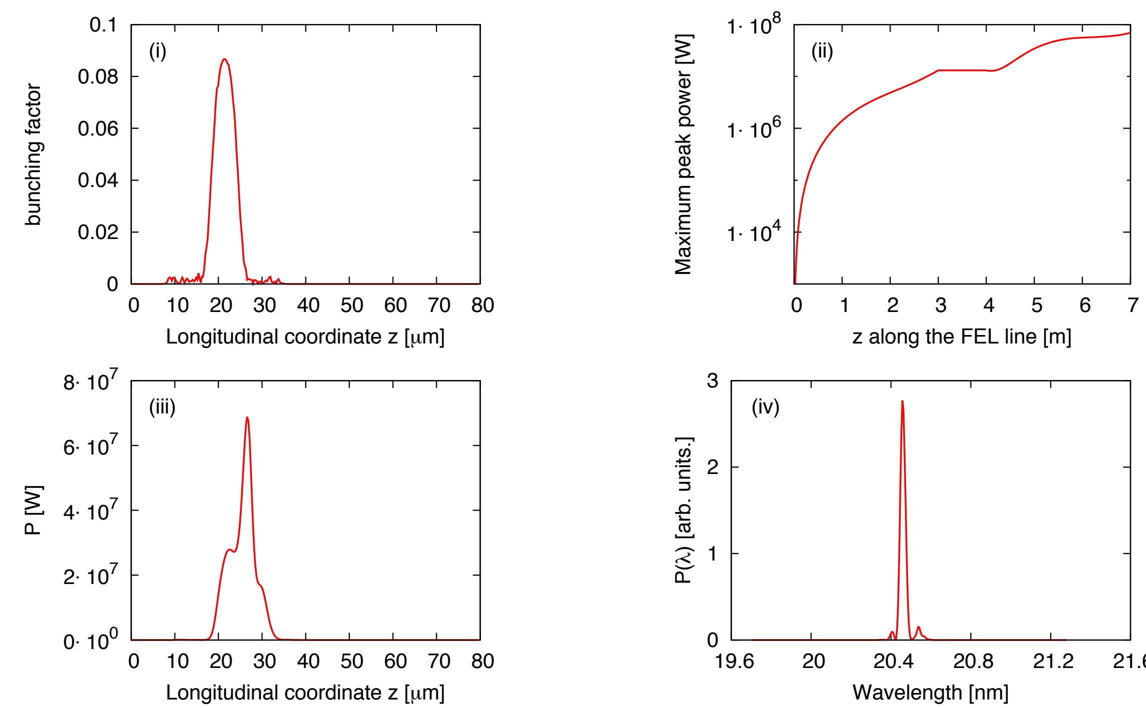




Saturation after 3 sections (z= 11 m), 0.27 GW, 17 fs FWHM, 0.02 nm FWHM, Fourier limit pulses

Echo case



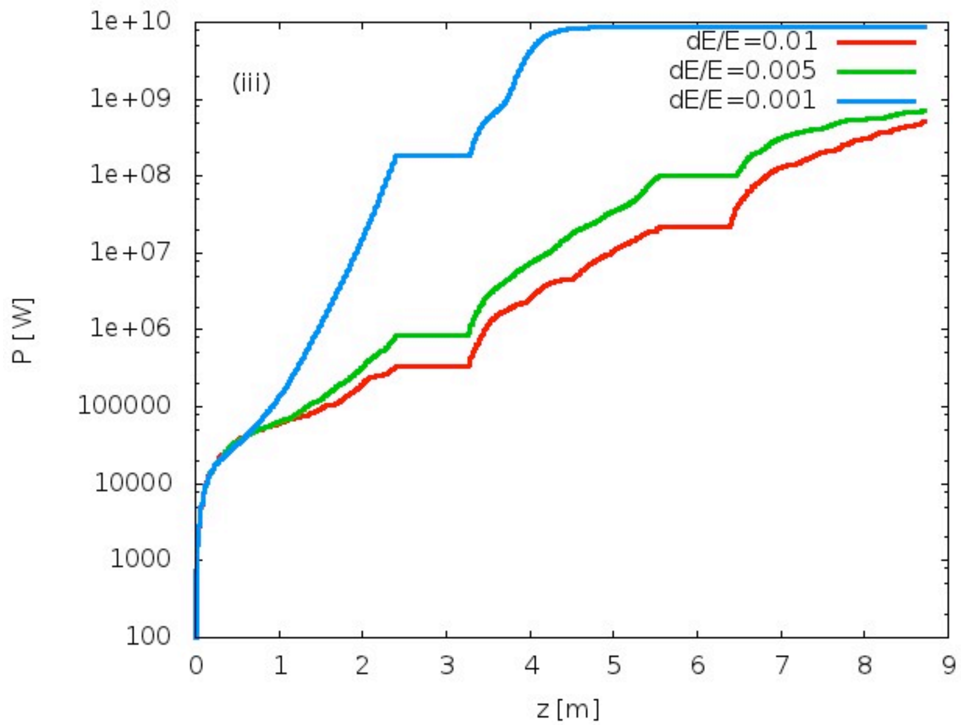


20 nm

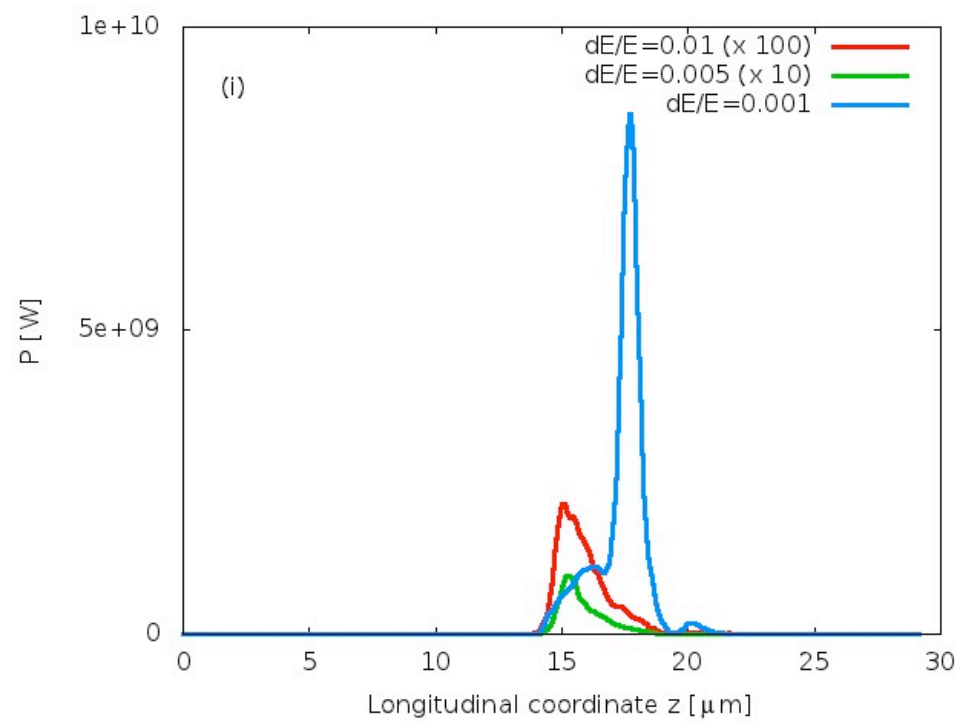
Saturation after 2 sections (z= 7 m), 65 MW, 24 fs FWHM, Fourier limit pulses

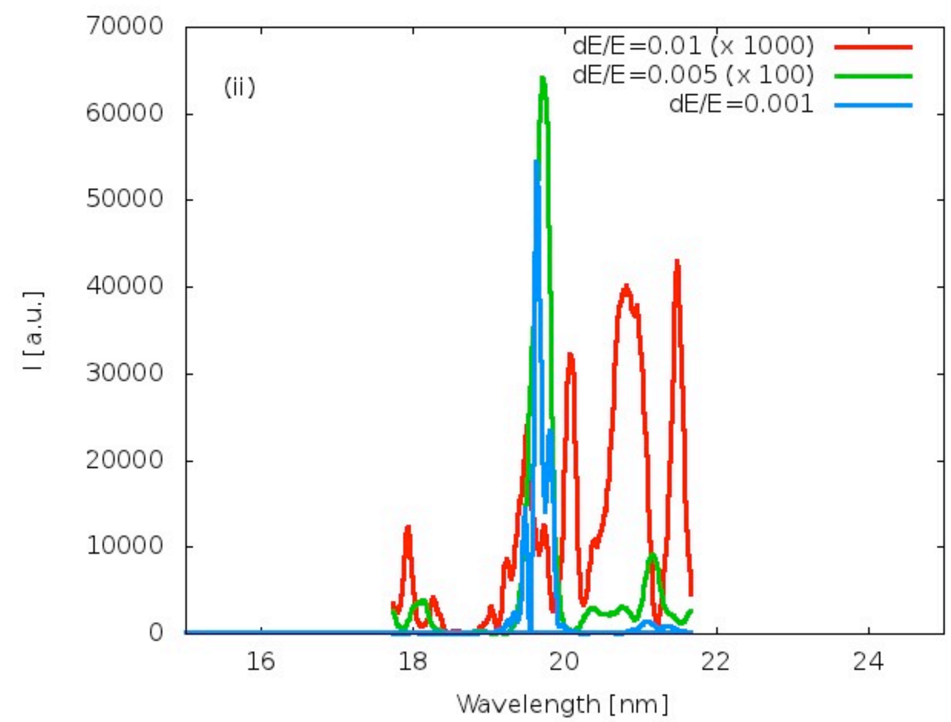
III- Modelling and simulations

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.

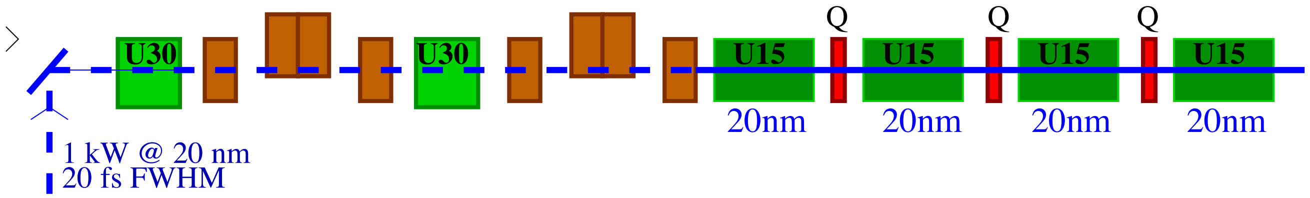




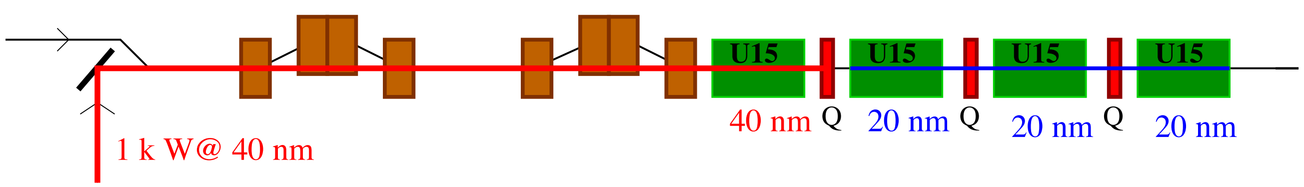
III- Modelling and simulations

FEL Sources on LUNEX5

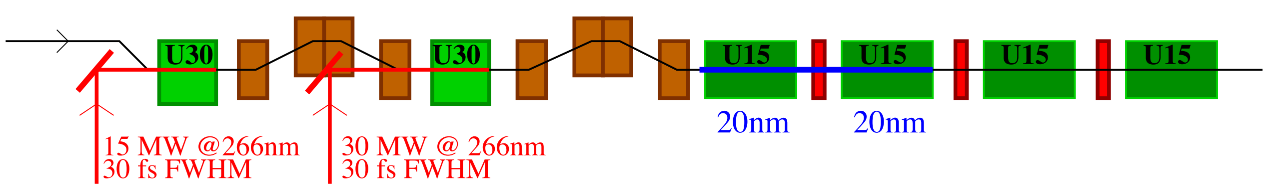
CLA : 400 MeV, 0.02% energy spread, 1.5 π mm.mrad, 400 A, 1 ps rms



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

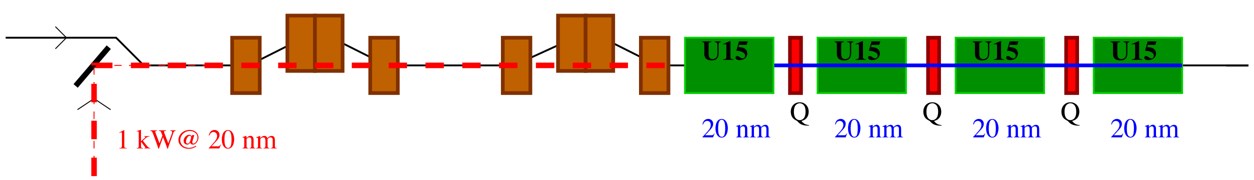


Cascade @ 20 nm,
saturation after 3 sections z = 11 m, 100 MW, 25 fs FWHM, FT



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



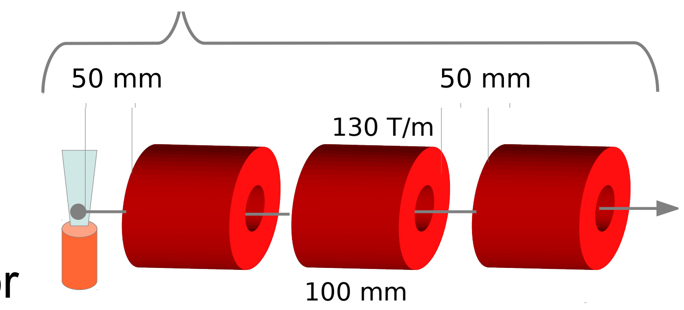
energy spread : 0.5 %, 20 fs rms;
@ 20 nm; so saturation after 3 sections, < MW, > 35 fs FWHM
energy spread : 0.1 %, 20 fs rms;
@ 20 nm; no saturation after 3 sections, 10 MW, > 20 fs FWHM
energy spread : 0.1 %, 2 fs rms;
SASE @ 20 nm, saturation after 2 sections z = 7 m, 2 GW, 7 fs FWHM, single spike

Progress on the LWFA electron beam transport

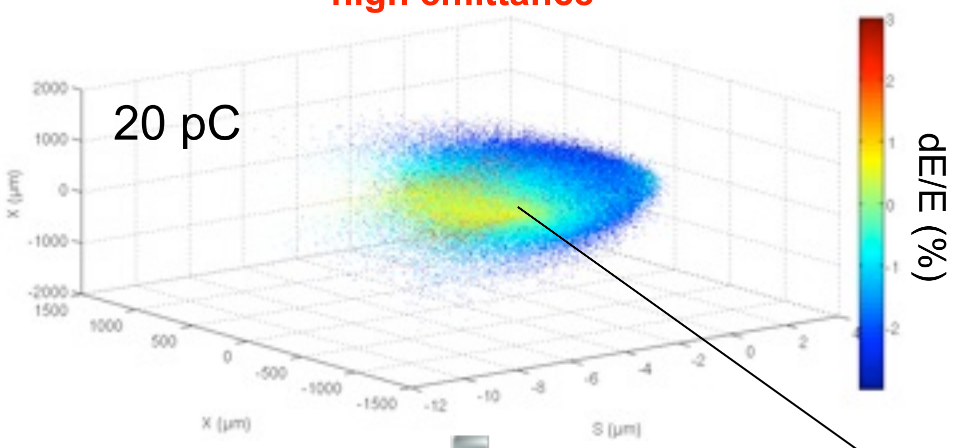
• Introduction of strong permanent magnet quadrupoles (130 T/m at 5 cm of the gas cell) + a 4 magnet chicane enabling to reduce the slice energy spread (0.06%) and emittance by demixing (1π))

Direct LWFA bunch

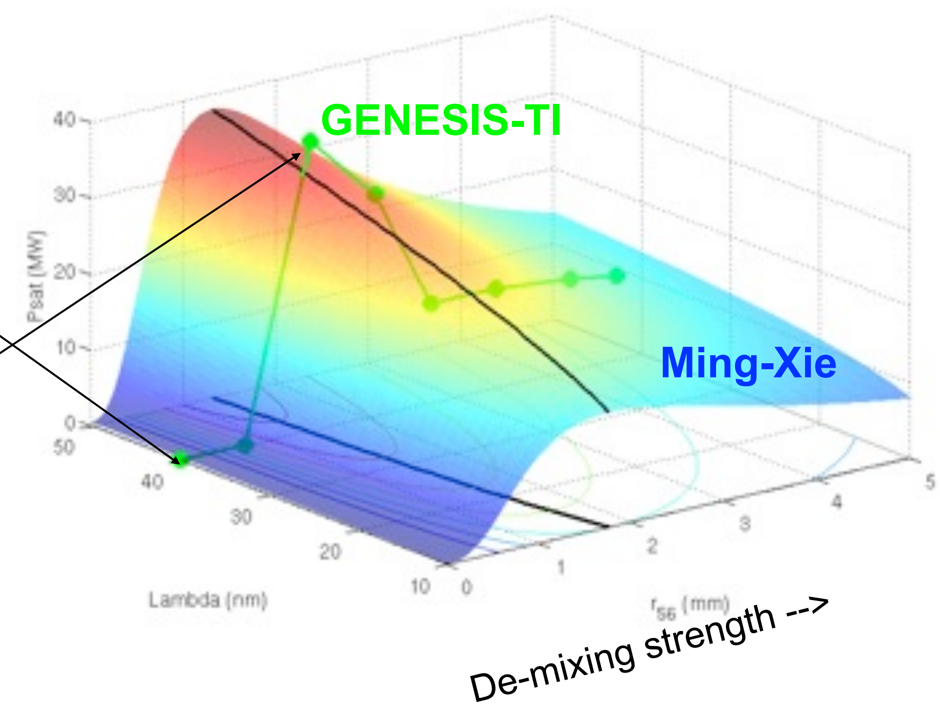
See A. Loulergue presentation

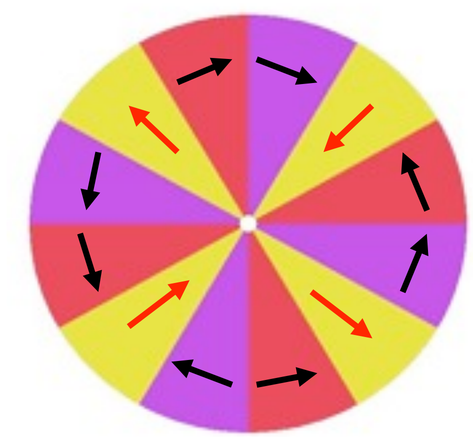


High peak current but high E-spread = FEL not possible
high emittance

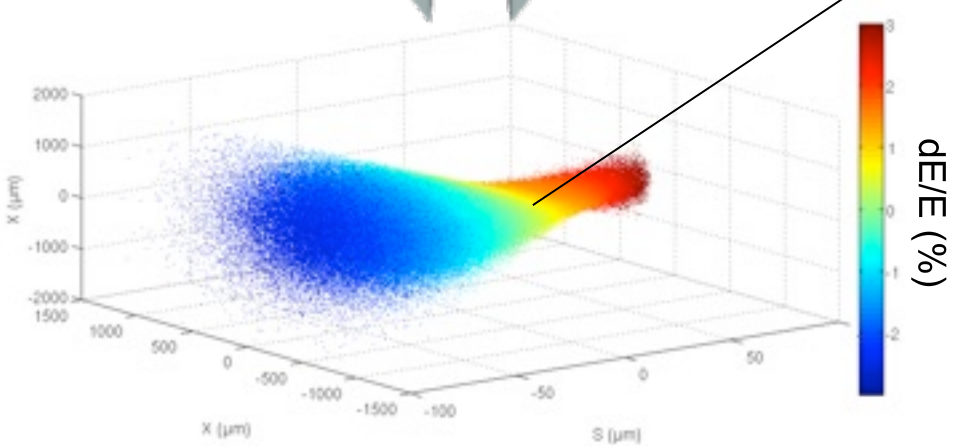


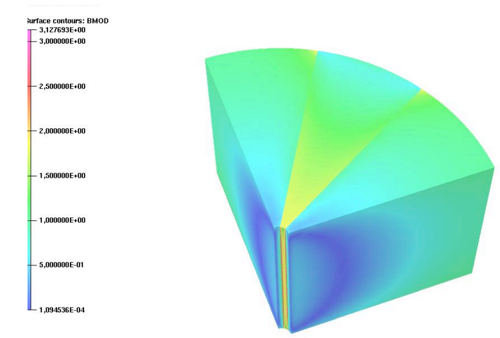
FEL Power over 15 m undulator





Chicane energy de-mixing





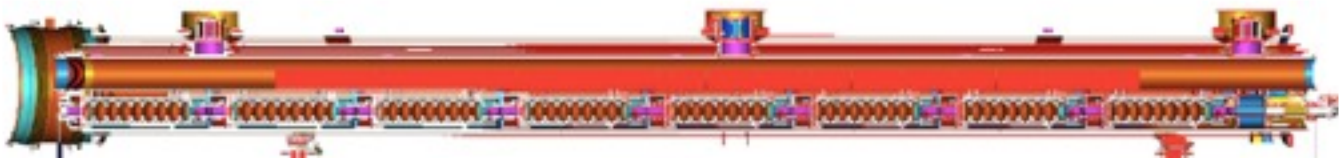
Optimum at few tens of MW peak !

Lower peak current and lower E-spread = FEL possible
lower emittance

LUNEX5 accelerators

CLA

400 MeV : superconducting technology, XFEL modules modified to evolve towards CW operation (coupleurs, tuning)



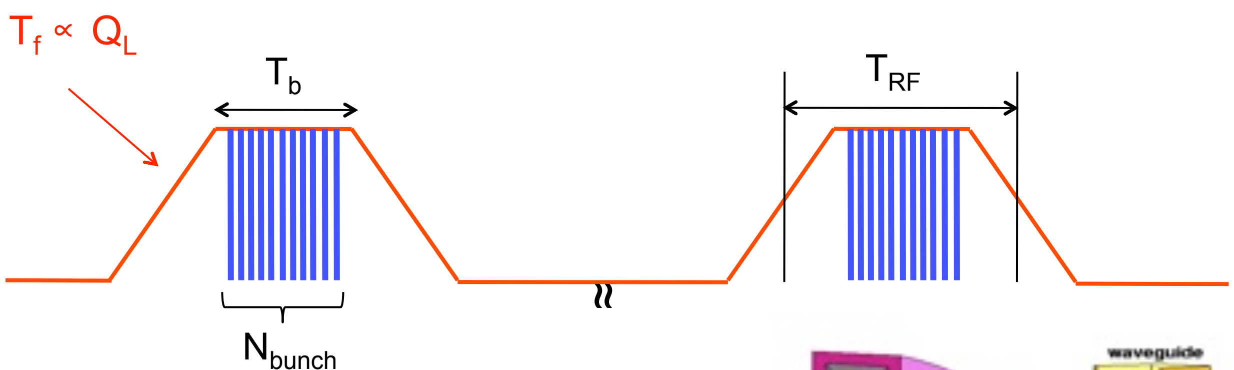
XFEL CM : 8 cavities, thermal shields (4-8 K & 50-80 K), He tranfer lines + Q-pole

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 liquefier capacity

P_{RF} :16 x 16 kW @ 1.3 GHz

rather than IOT, Solid State Amplifier



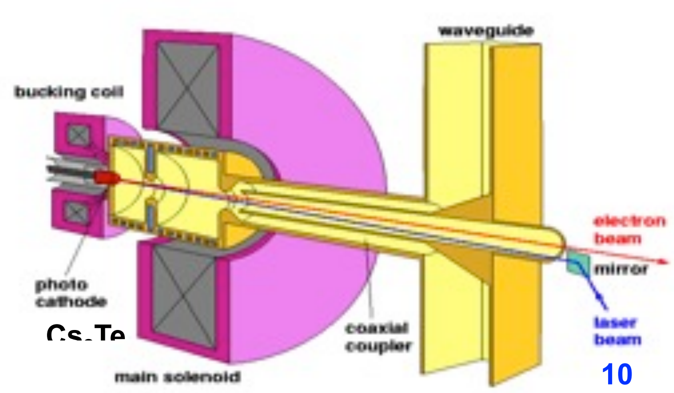
Beam macropulse (T_b) : 5 µs → 500 µs

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



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)*

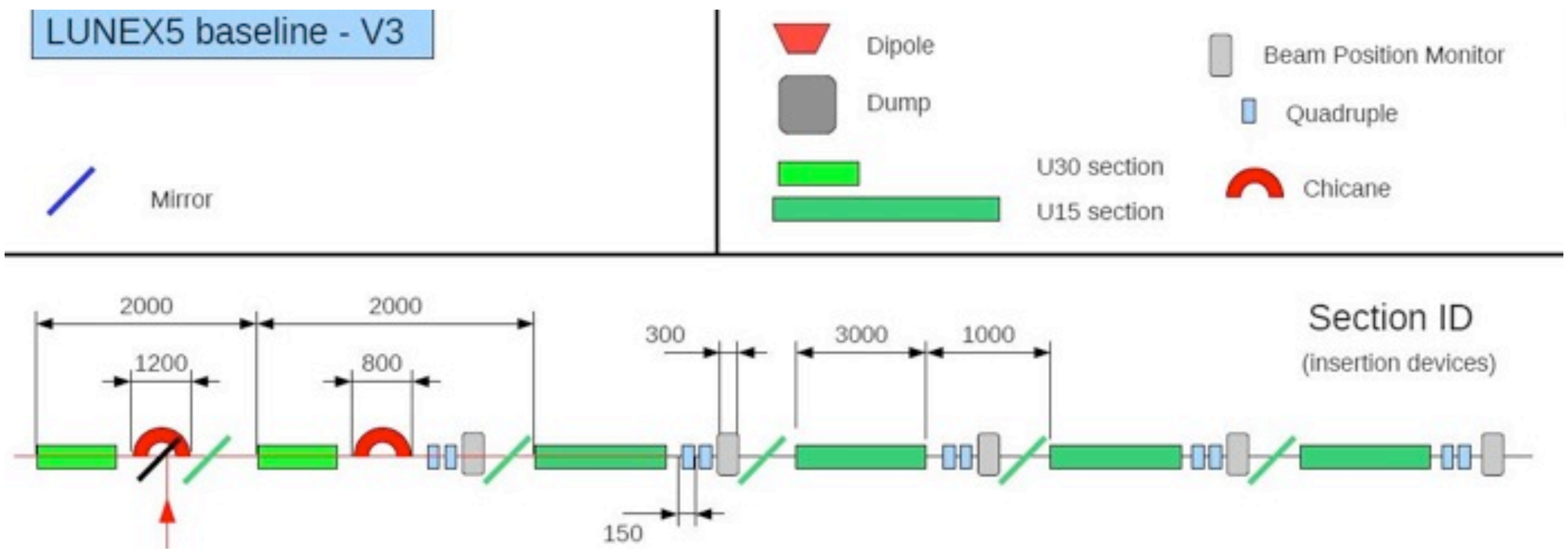
X. Davoine et al., Phys. Rev. Lett. ***102****, 6 (2009)*

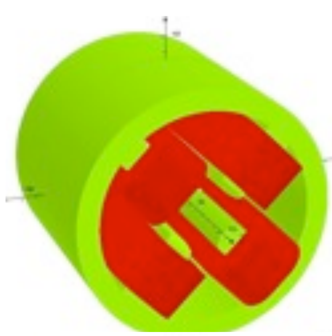
Synergy with LOA Salle Jaune: 2 beams of 60 TW each
=> preliminary tests for LUNEX5 (test of diagnostics, introduction of an undulator, tests of electron beam transport....)

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).
- limited access : not dedicated to electron acceleration
- Rather small repetition rate

=> a few tens of GeV with good electron quality targeted.

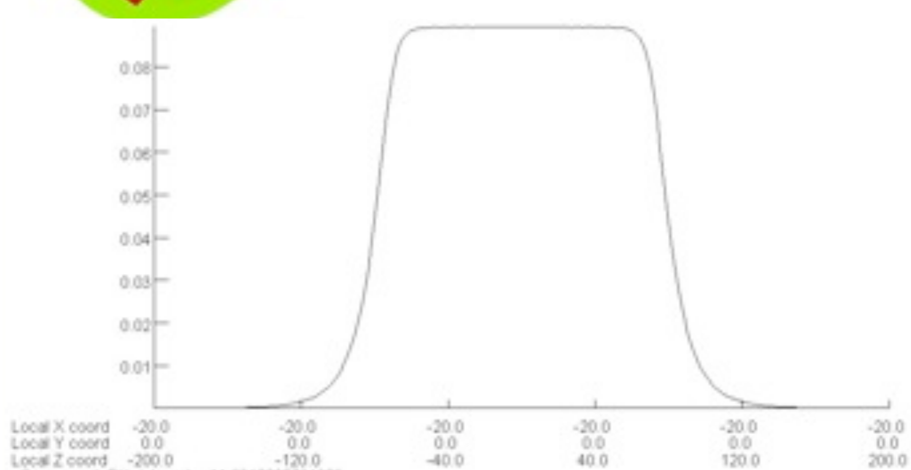
FEL line





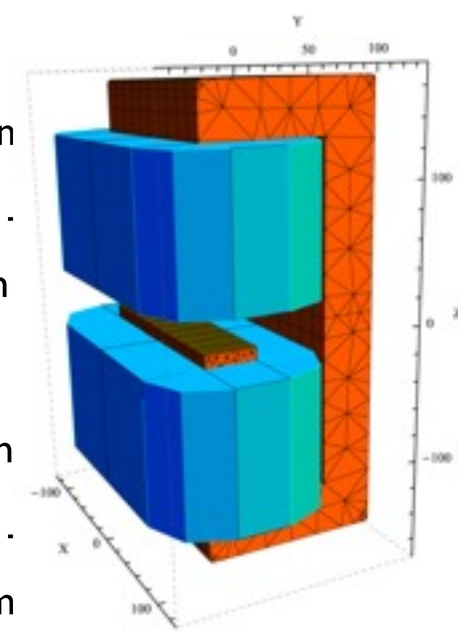
Quadrupoles

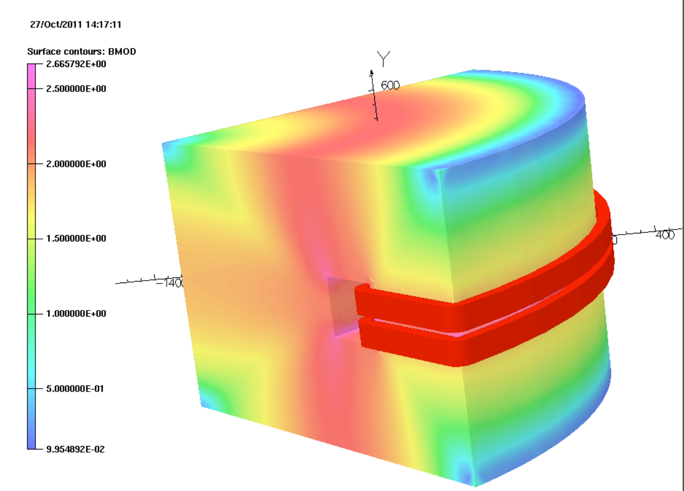
6T/m
150 mm de longueur
25 mm de cercle de gorge



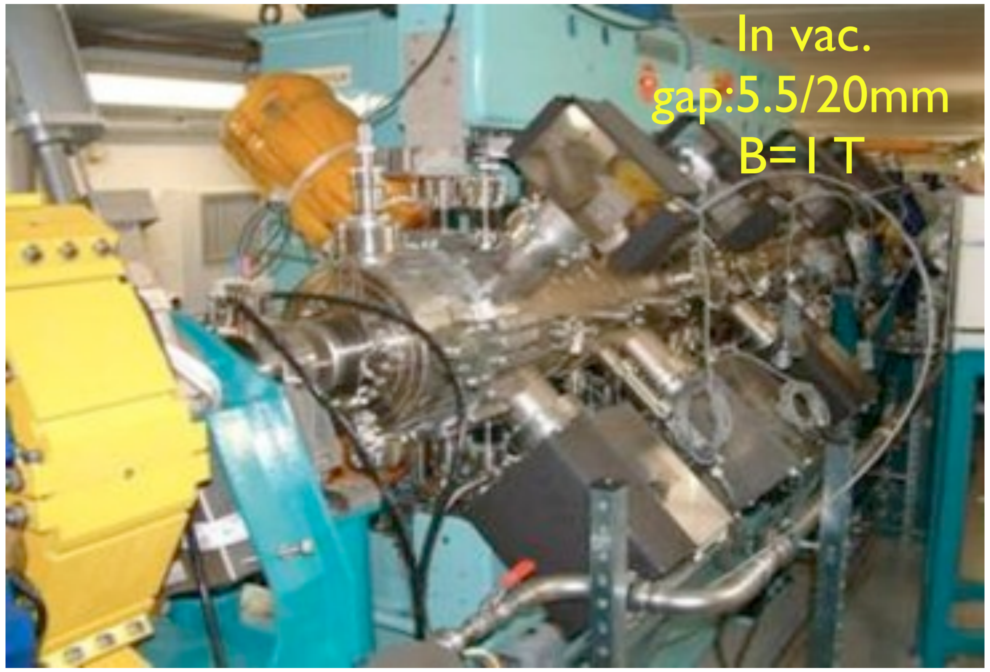
Chicane 1
Number of dipoles 4
Length : 1200 mn
Gap: 25 mm
Bz 0.38
L_d: 150 mm

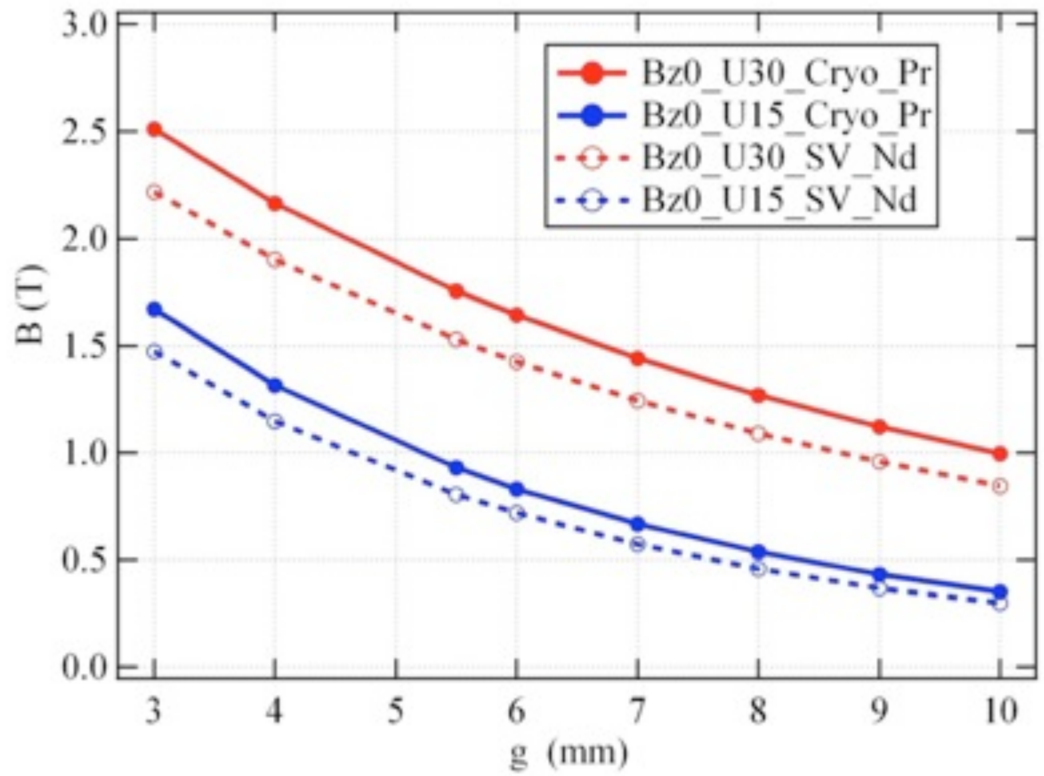
Chicane 2
Number of dipoles 4
Length 800 mm
Gap 25 mm
Bz 0.35
L_d 100 mm

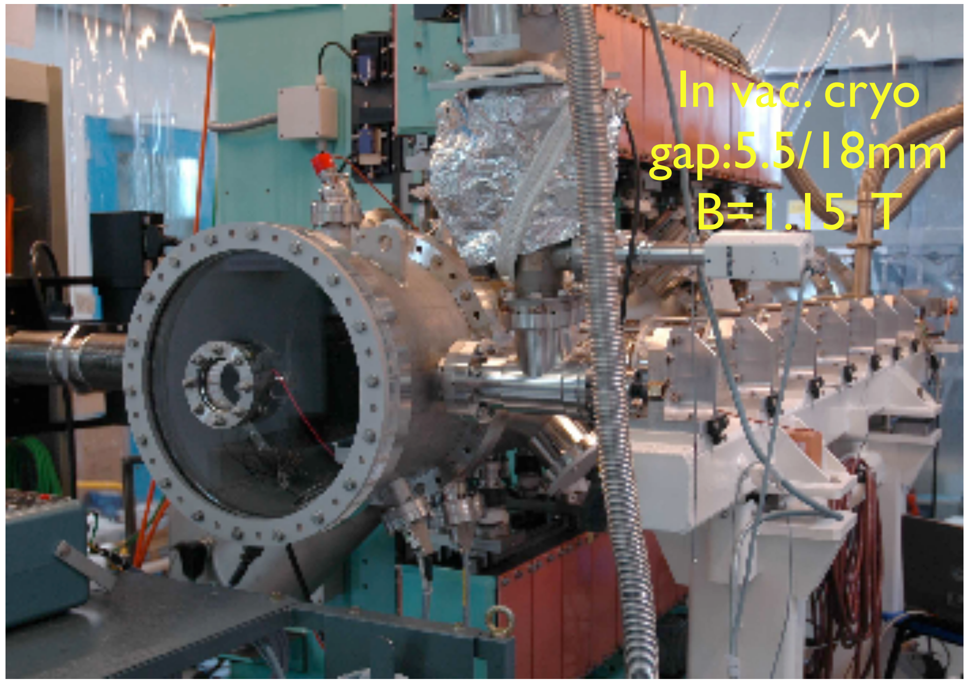


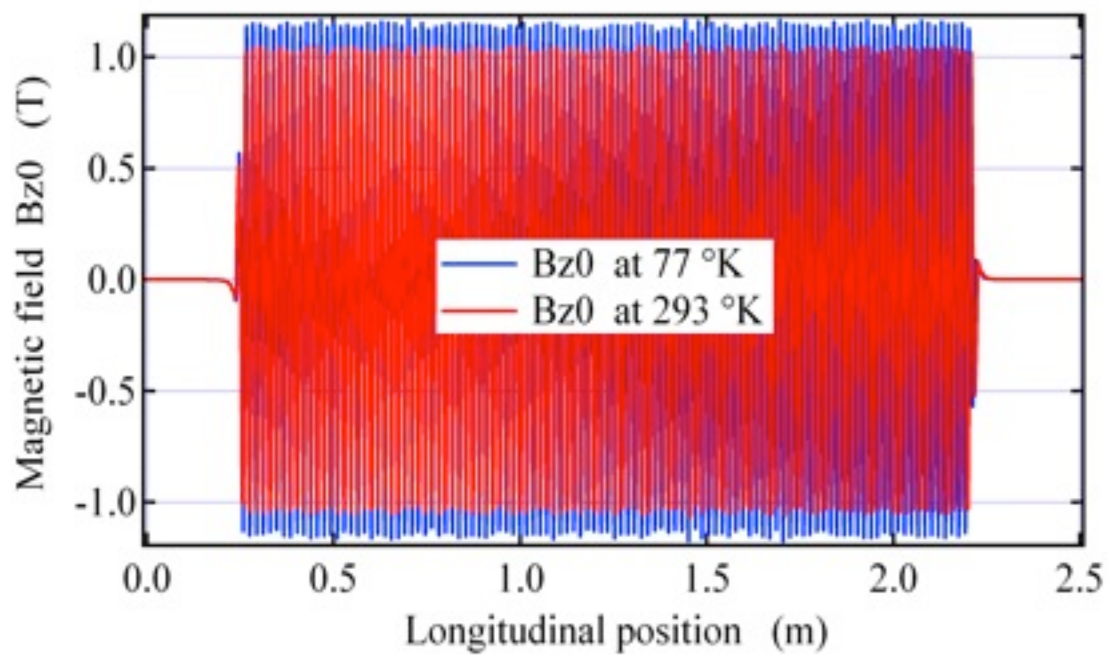


LUNEX5 Undulators and magnetic elements





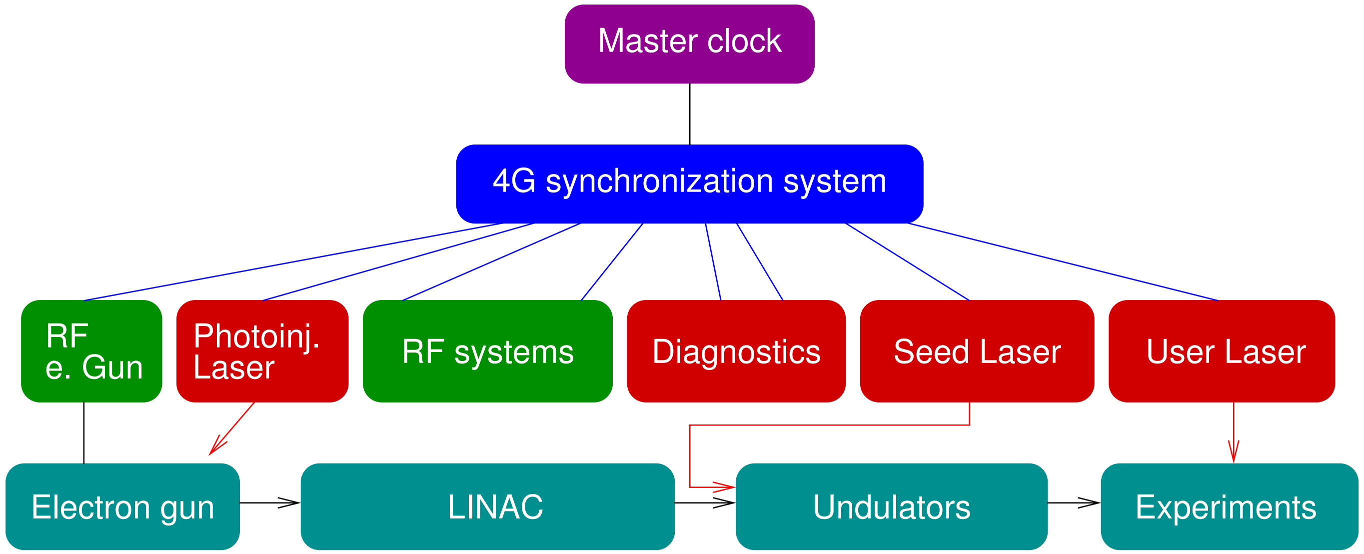


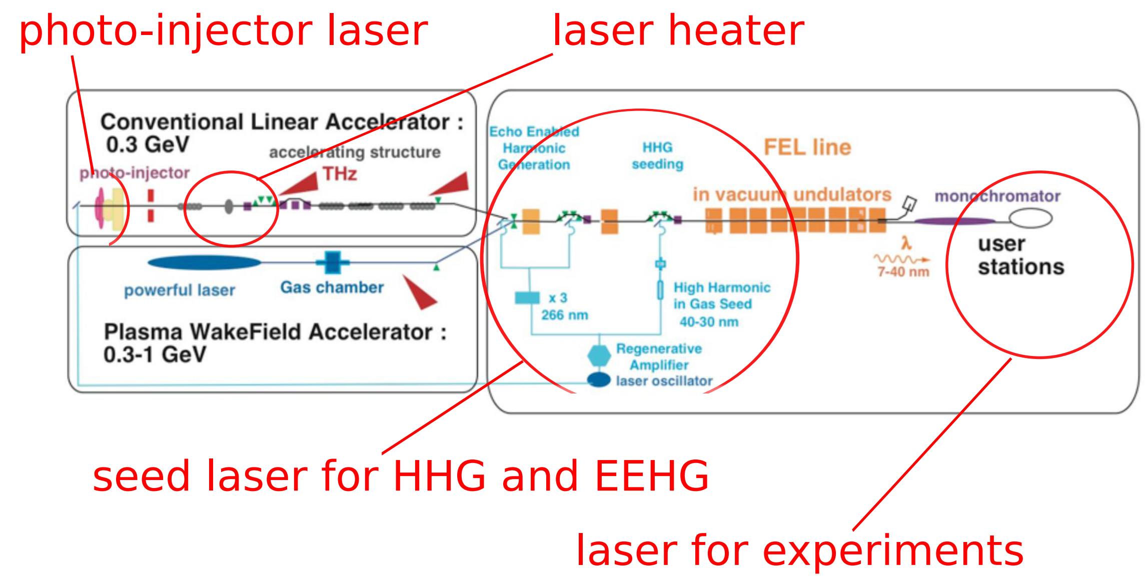


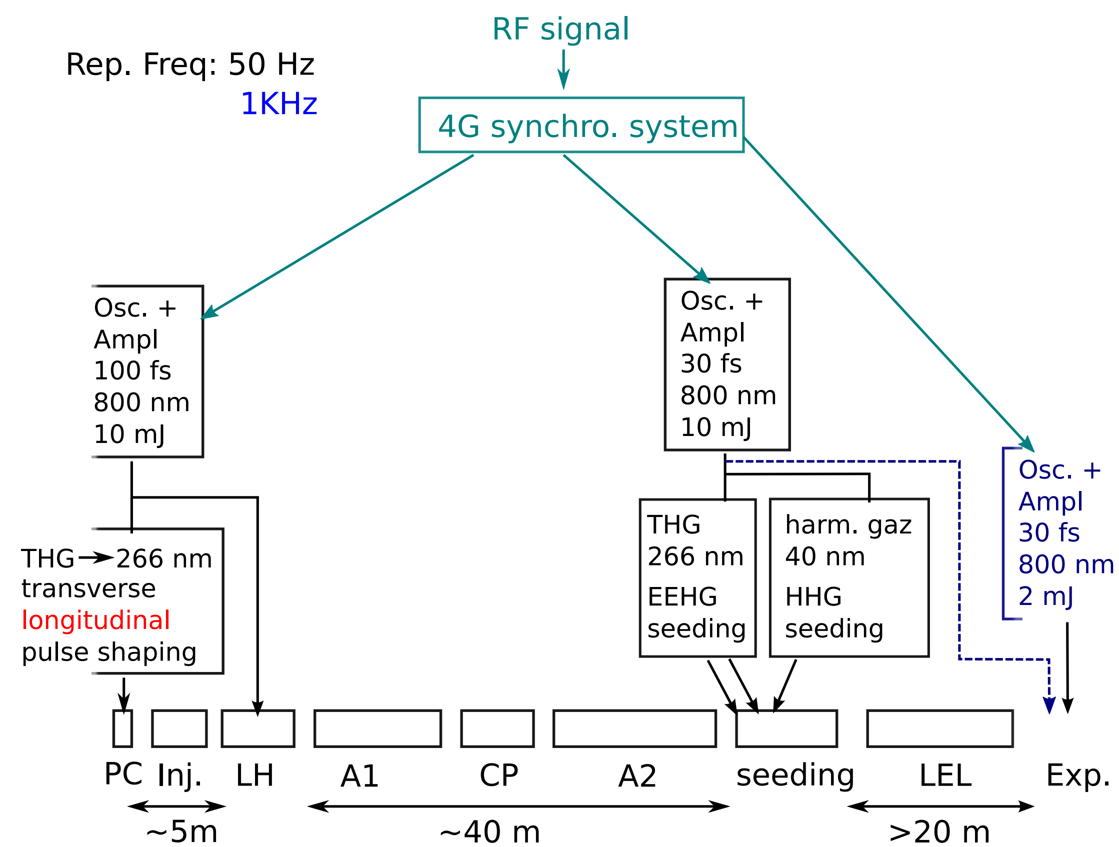
R&D on a 3-5 m cryo -reay undulator

$Nd_2Fe_{14}B$ 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

Synchronisation



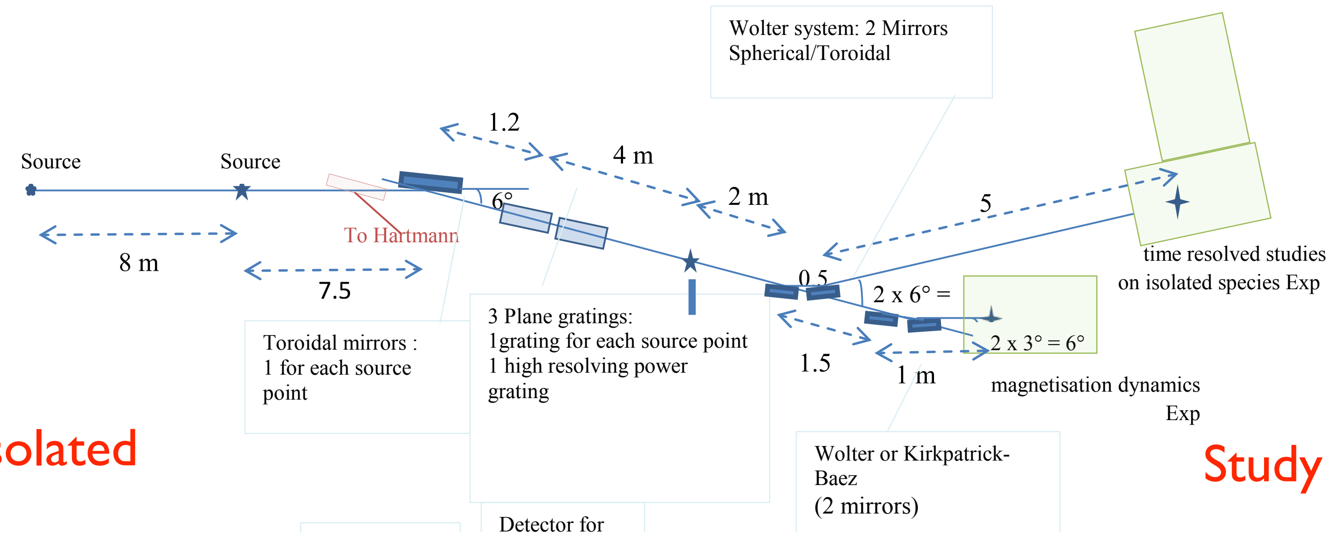




Proposed R&D on synchronisation of the gun laser with the seeding/ pilot user lasers (PhLAM, SOLEIL, LAL, CEA-SPAM ?):

- 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

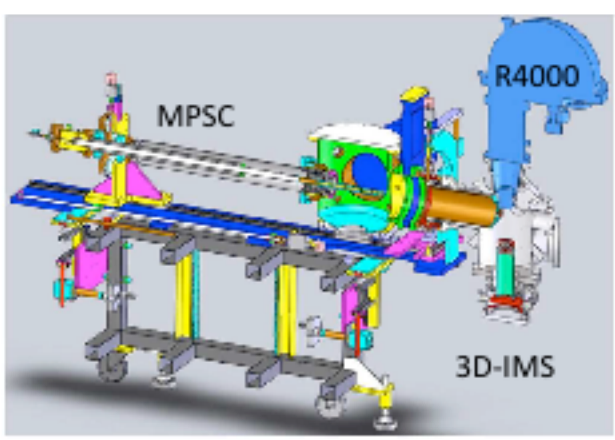


Time-resolved studies of isolated species in the x-ray range

- 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

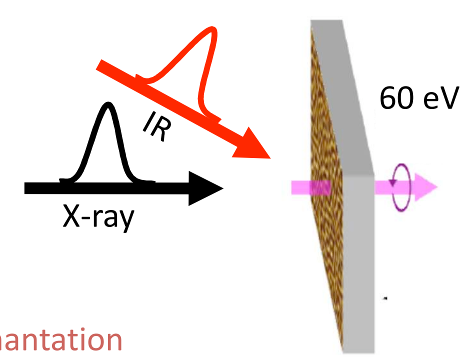


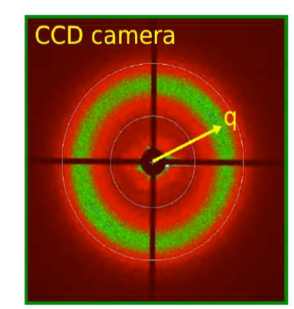
Full 3D ion momentum spectrometer

Study of magnetisation dynamics

- 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

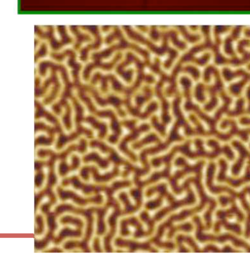
Expériences proposée:
Pompe IR – Sonde *diffusion résonante magnétique aux petites angles*





Intensité intégrée
→ mesure de l'aimantation

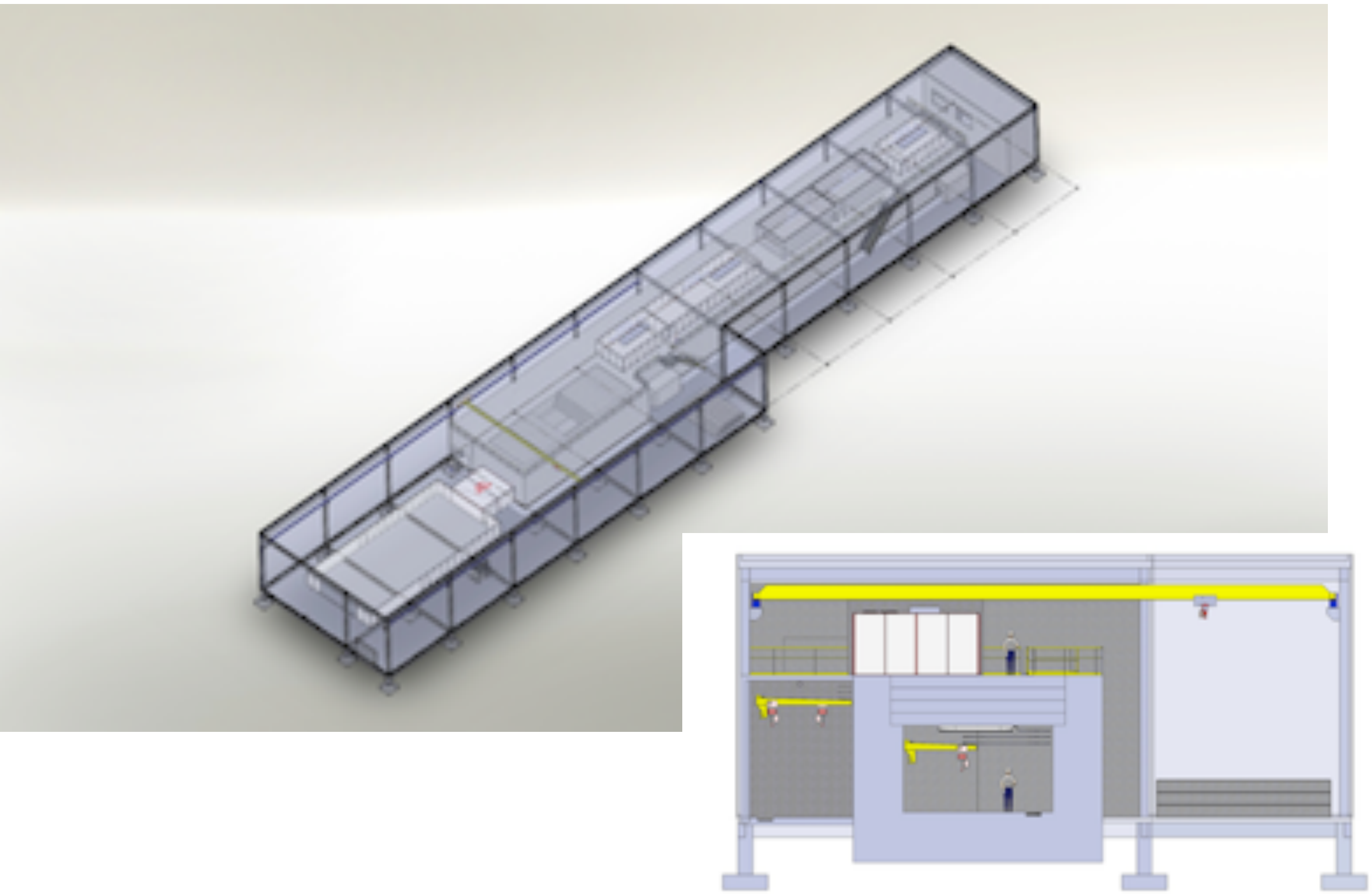
Distribution radiale
→ information spatiale

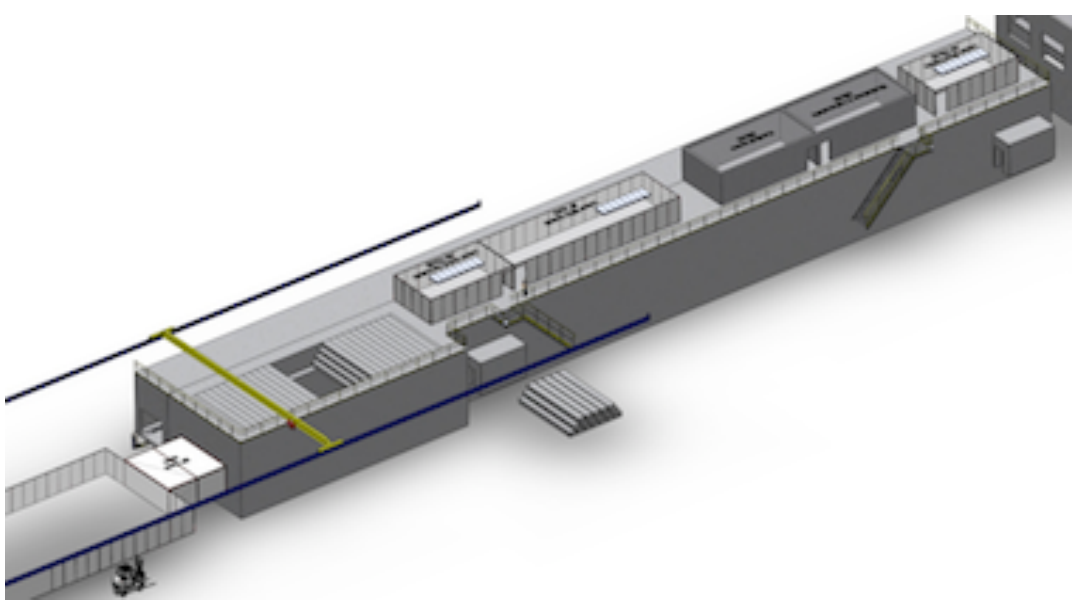


VIII- Building and infrastructure

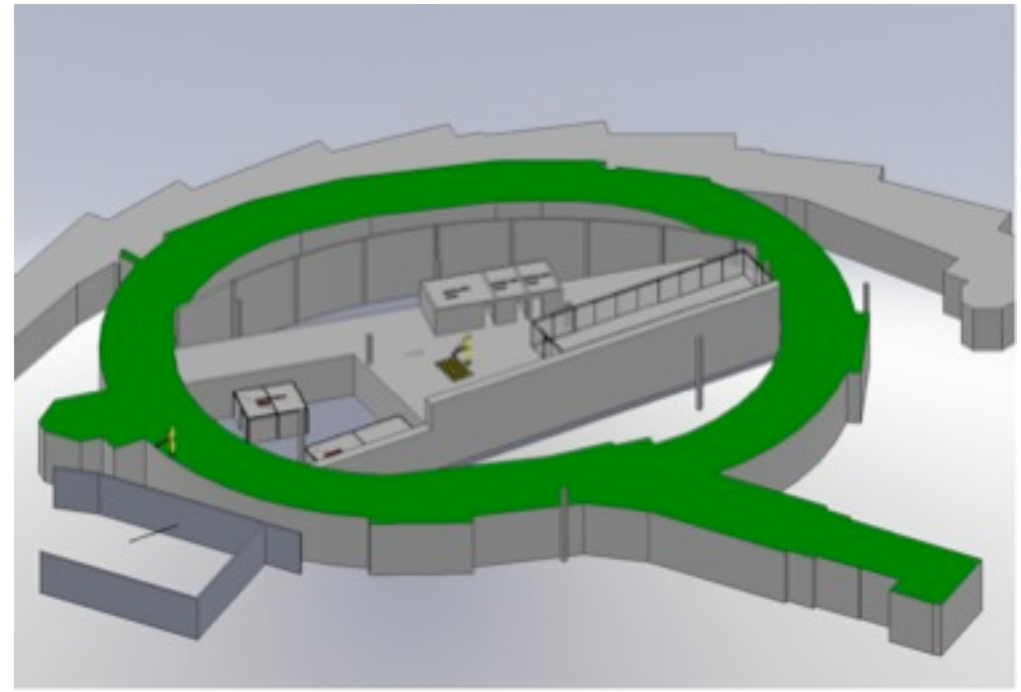
Infrastructure

Greenfield case

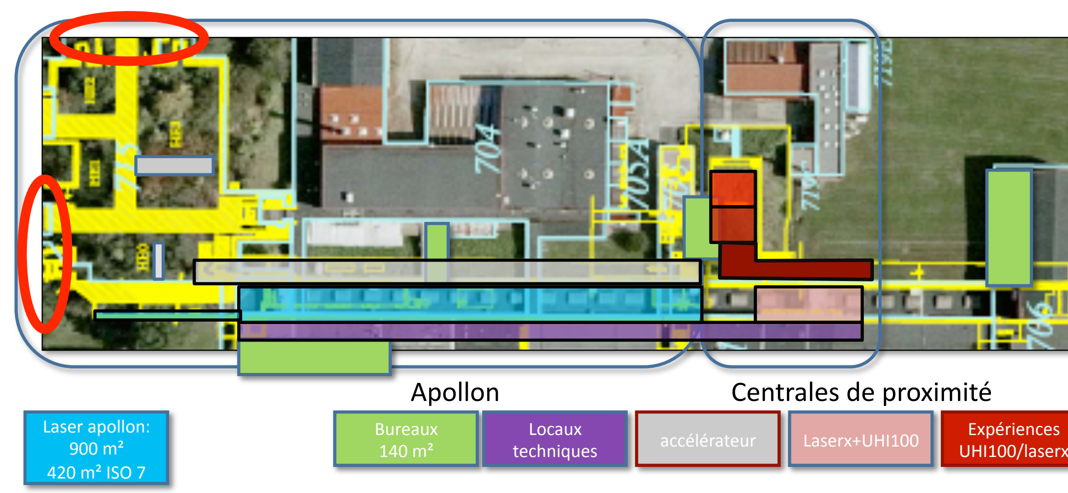




SOLEIL booster arena



ALS tunnel



other

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 M. E. Couprie, S. Bielawski, J. Lüning, C. Miron, Coll MAX-IV : cryo - ready undulator

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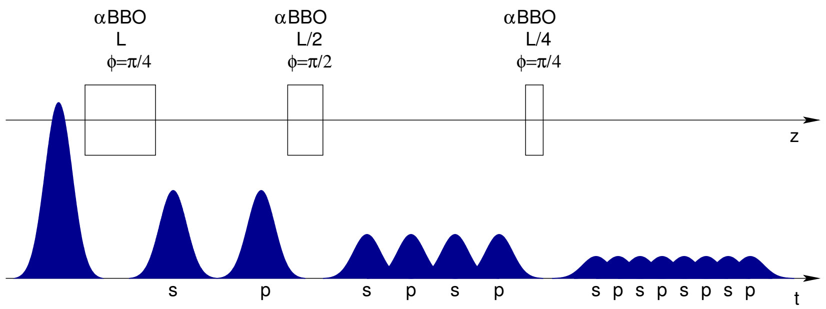
Conclusion

Challenges and outcomes of LUNEX5

Challenges	Outcomes
Success of the echo et seeding innovatie 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 LEL 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 brèves => 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

CLA proposed R&D

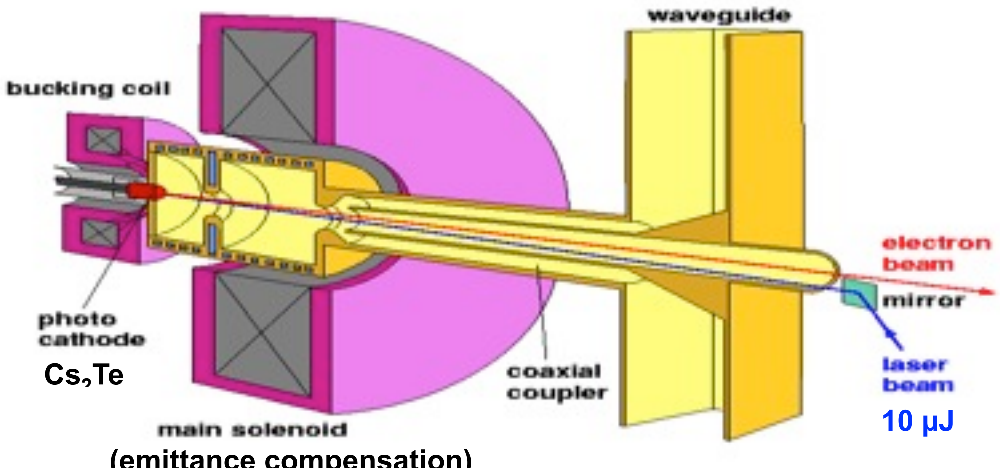
Electron Gun



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

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



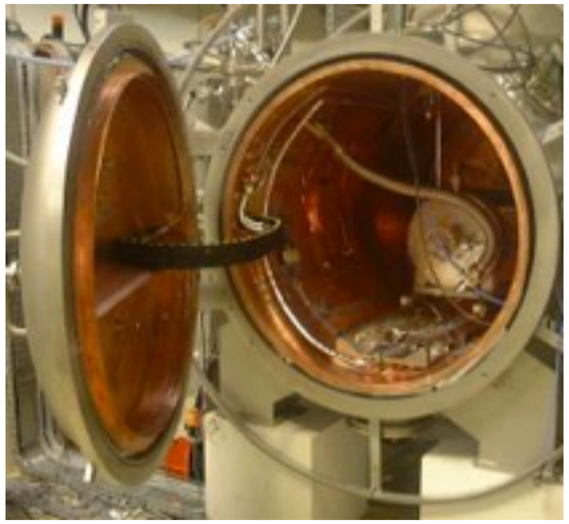
Elementary RF system Gun

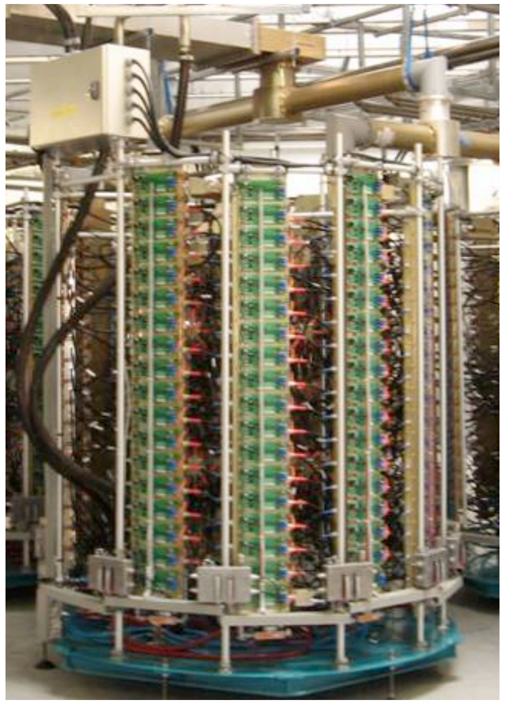
Fabrication :
- one 9 cell cavity (XFEL type), modified for CW operation;
- one solid state amplifier of 15 kW at 1.3 GHz *;
- un LLRF system synchronisation part.

Validation with cold tests in CryHolab cryogenic station at CEA, evaluation of the different compoenents 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





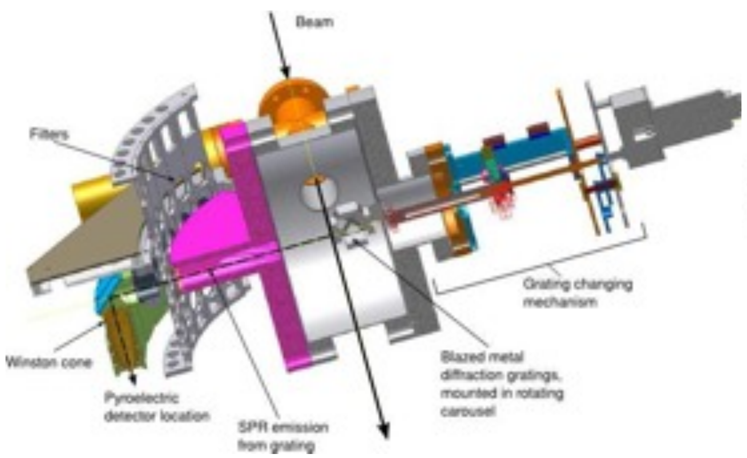
Proposed R&D on Diagnostics

Moniteur de Smith Purcell Monitor for bunch length measruement: CLA (1ps) LWFA (few fs)

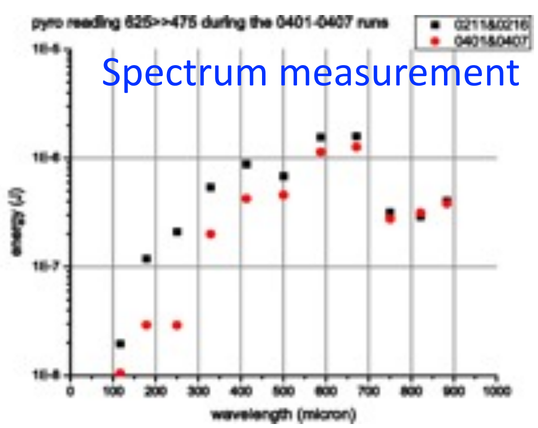
Ex of non invasive monitor tested at SLAC

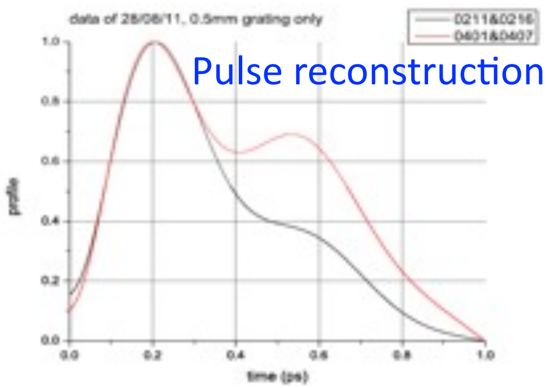
Build a <u>prototype</u> for 5ps to few fs durations

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).





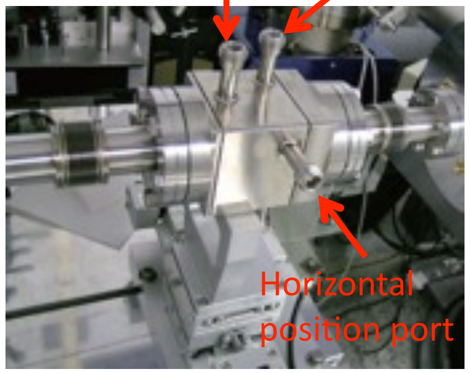
Beam profile monitor

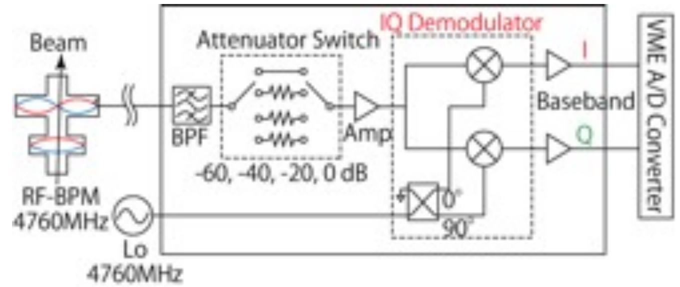
Question of COTR (LCLS, SACLA) du au microbunching après compression (*H. Tanaka talk at IPAC 11*).

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 1 (LCP-ELYSE, H. Monard (now at LAL), LULI (J. R. Marques)), adopté à DESY
- Prototype test on SOLEIL transfer line

Expected outcomes of LUNEX5

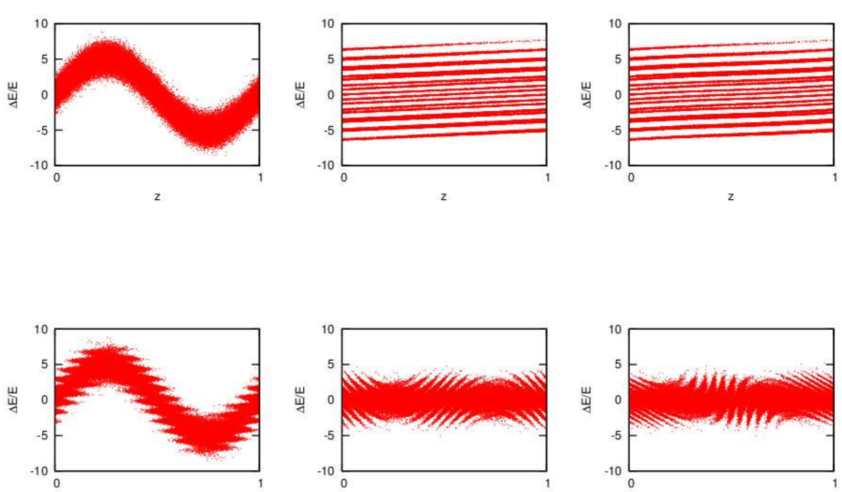
Innovation :

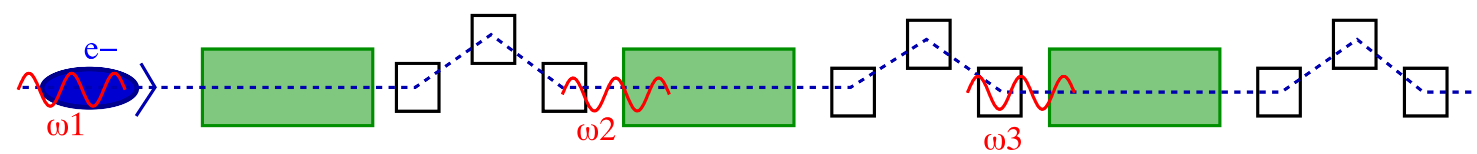
• Innovative FEL schemes (cf ANR DYNACO) : Echo Enable harmonic Generation / seeding High order harmonics in Gas at very short wavelength (40- 4 nm) range (multiple electron -photon interaction and HHG seeding) on the **same demonstator**

• Validation of the latest FEL schemes (4GLS+) with users

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

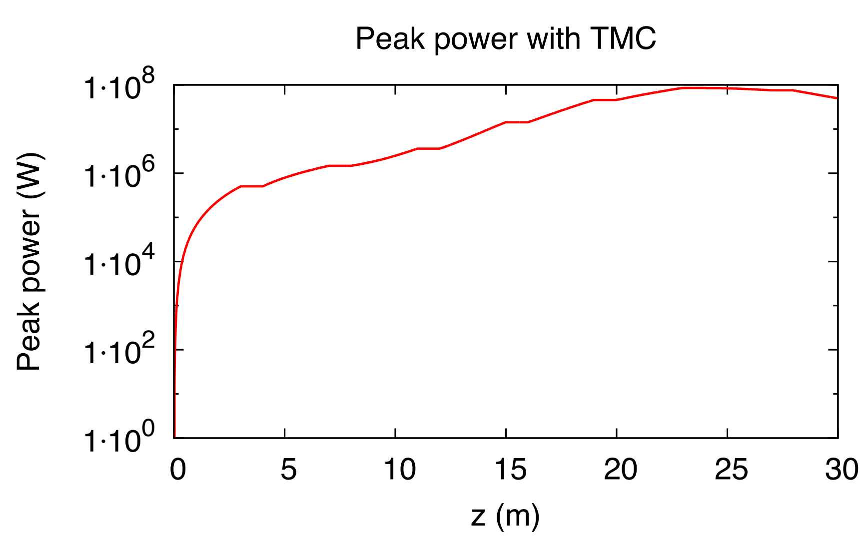
Example of the Triple Modulator Chicane

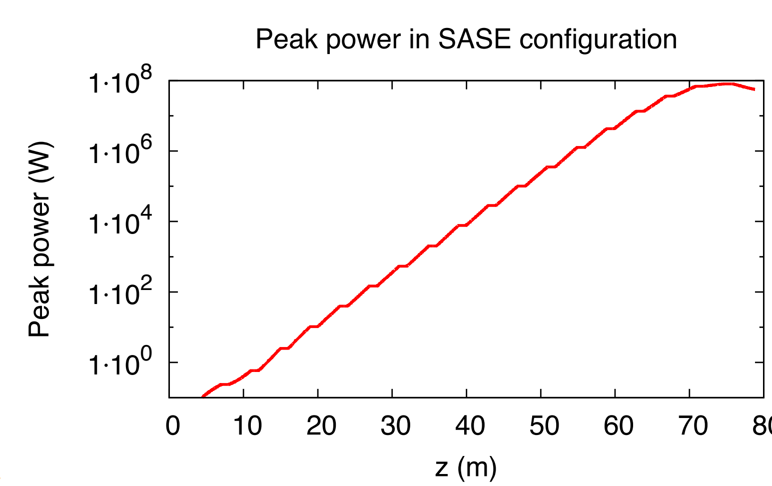




Triple Modulator Chicane Scheme :
Motivation : decrease the required undulator length to reach saturation
→ transpose to GeV machines for Xrays delivery at moderate cost

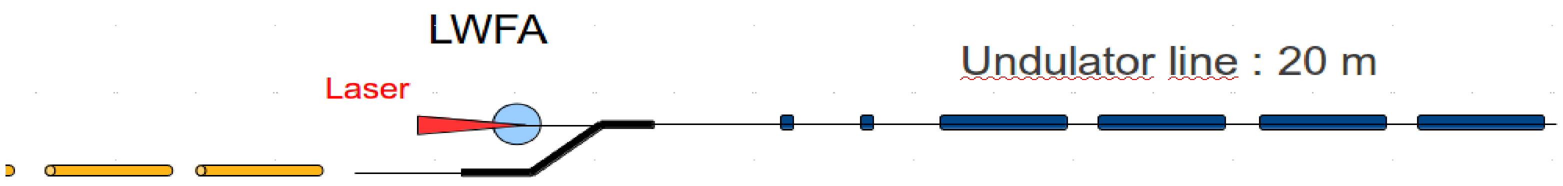
Exemple : TMC Scheme @ 1.3 nm with E=1.5 GeV :





Progress on the LWFA electron beam transport

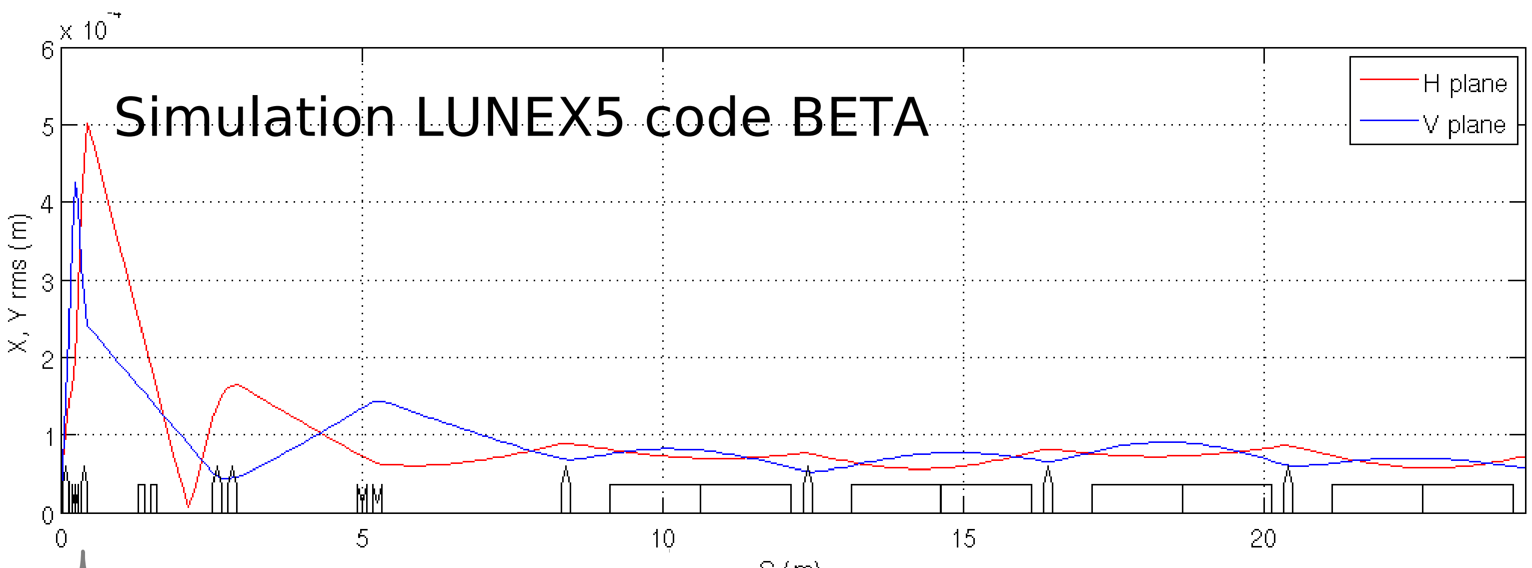
- Introduction of strong permanent magnet quadrupoles

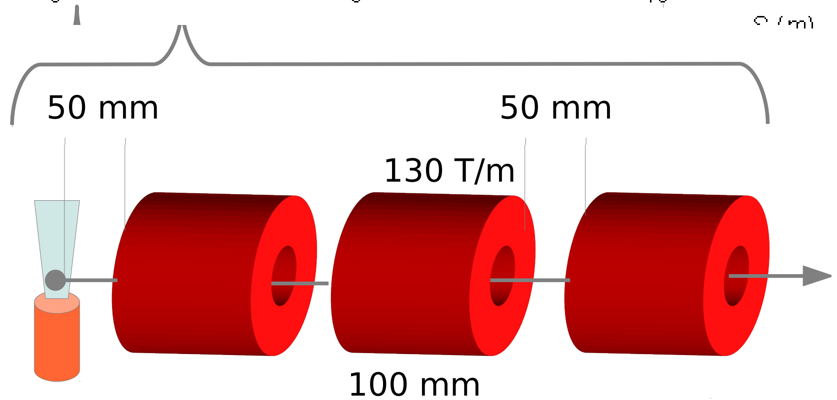


Large

Optimistic !

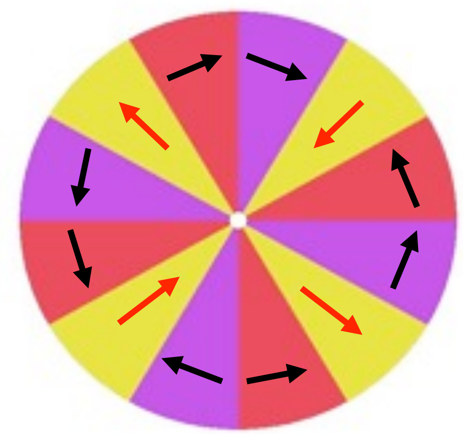
Size	Divergence	Norm. Emittance	Length	E-spread	Q	Peak current
1 µm	1.25 mrad	1 π.mm.mrad	2 fs	0.1%	20 pc	4 kA

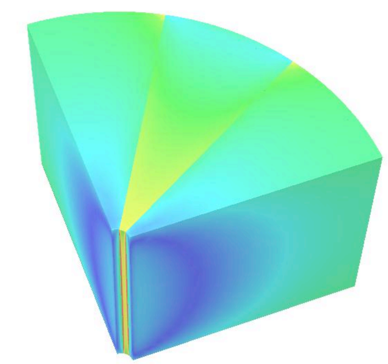




LWFA low energy spread electron beam
Start to end simulations
PIC- ASTRA/ELEGANT- GENESIS

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

Annexe- Expectations after the TDR Phase

Cost comparisons

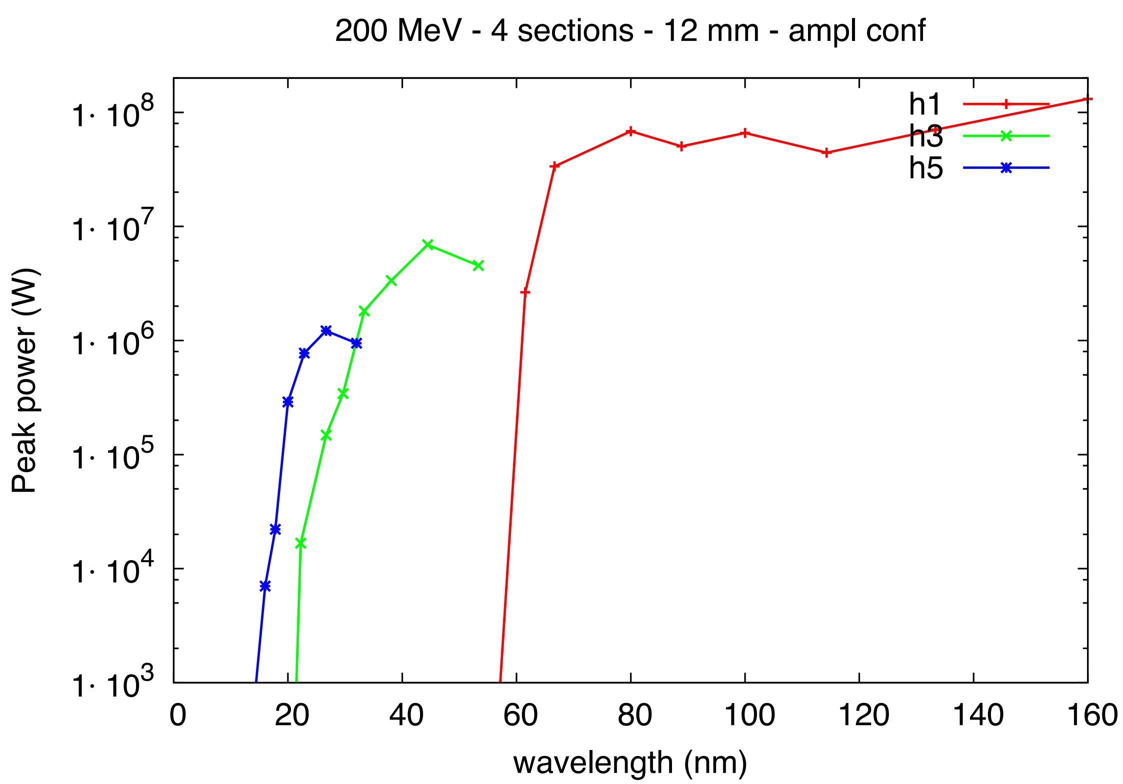
	Cold Linac@50 Hz, booster*	Complete (k€)	reduced (k€)	
WP1	CLA	11 965	9 165	no provision for CW , gun RF power split
WP2	LWFA	4 164	629	without dedicated laser
WP3	FEL line	5 533	4 027	without HHG seeding, echo only
WP4	Modelisation-Simulations	0	0	
WP5	Diagnostics	881	881	
WP6	Technical utilities	725	725	
WP7	Control-Electronics	1 432	1 409	
WP8	Radiation Safety	623	623	
WP9	Scientific applications	2 597	1 647	withoutIR
WP10	Building	3 689	3 689	
WP11	Management	35	35	
Total		31643	22 829	
	* without Harmonic cavity			
	200 MeV step	27578	20 612	

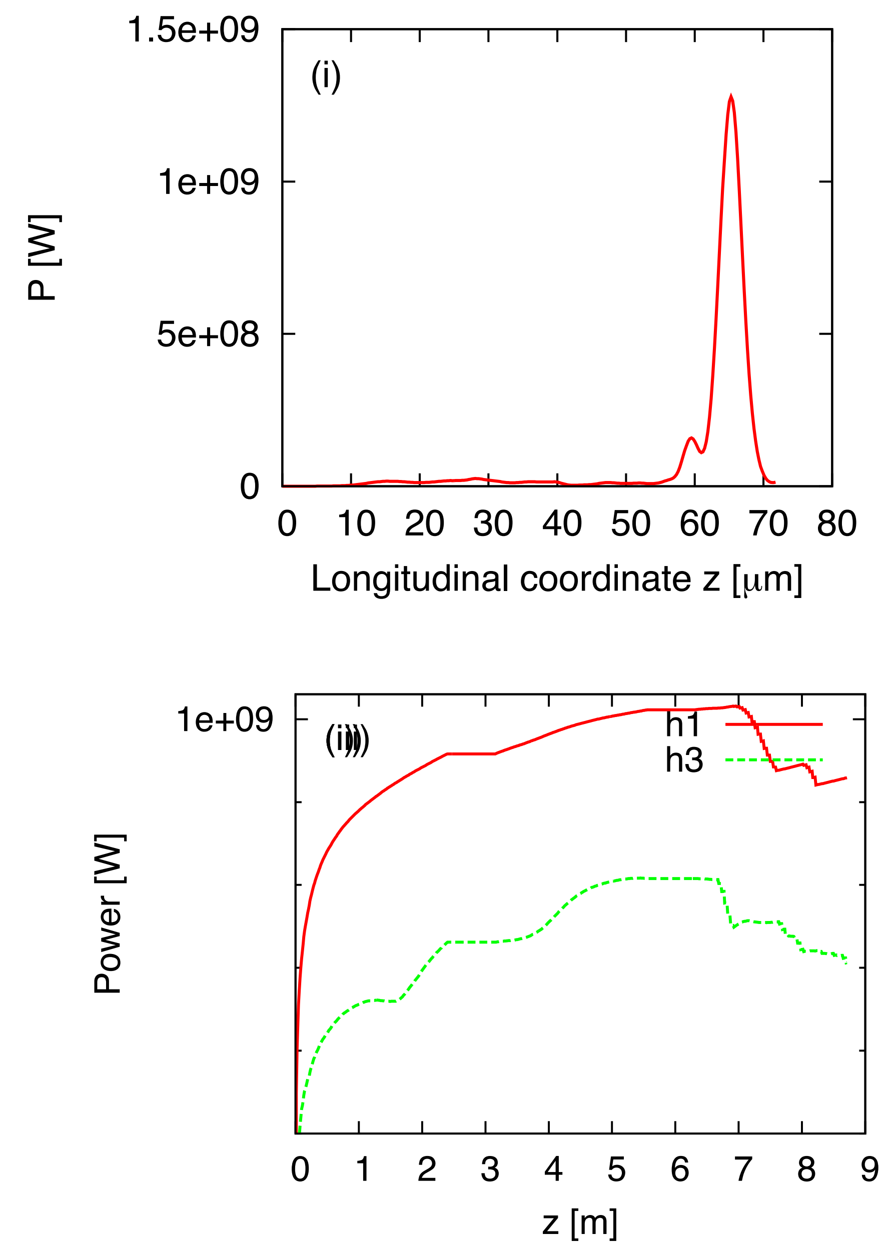
	Linac chaud@50 Hz, arène booster*	(k€)
		en k€
WP1	CLA	11 998
Total		31677

	Linac froid@50 Hz, site vierge	
		en k€
WP1	CLA	13 575
WP10	Building	10 370
Total		39935

Supplément

Étape à 200 MeV

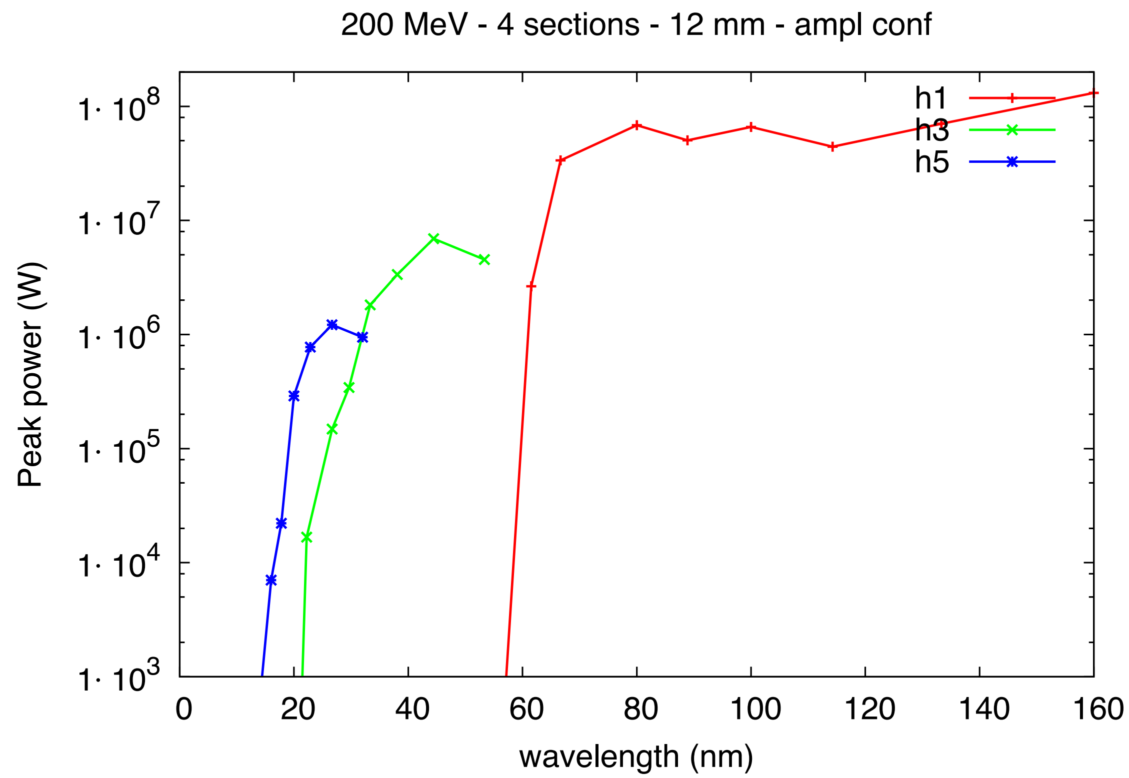


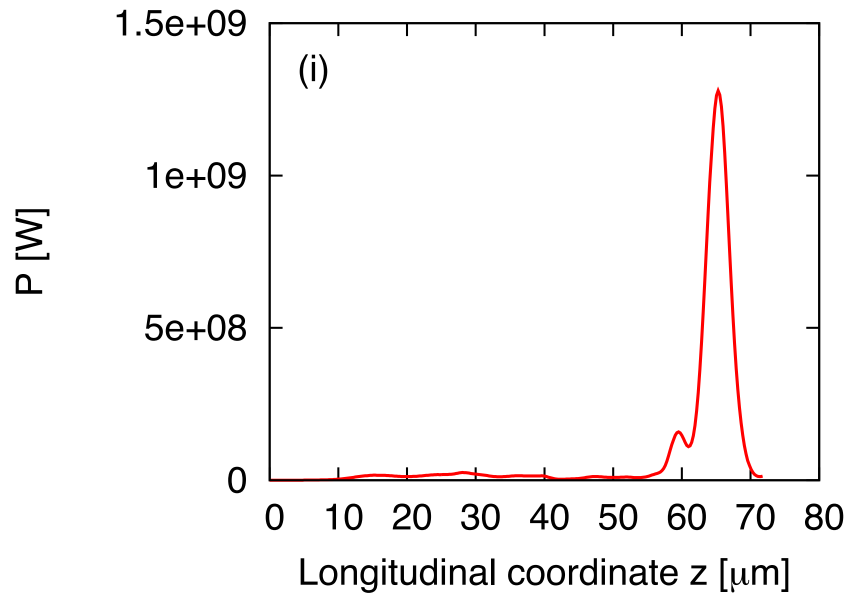


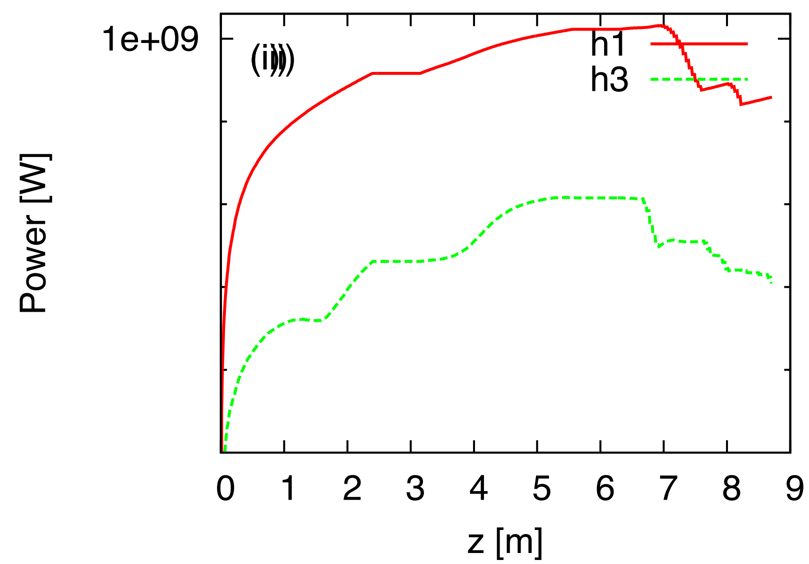
Cascade GENESIS avec :
1U15 @ 120 nm + seeding @ 120 nm
3U15 @ 60 nm
On sature seulement après 2 sections de radiateurs.

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

Étape à 200 MeV







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

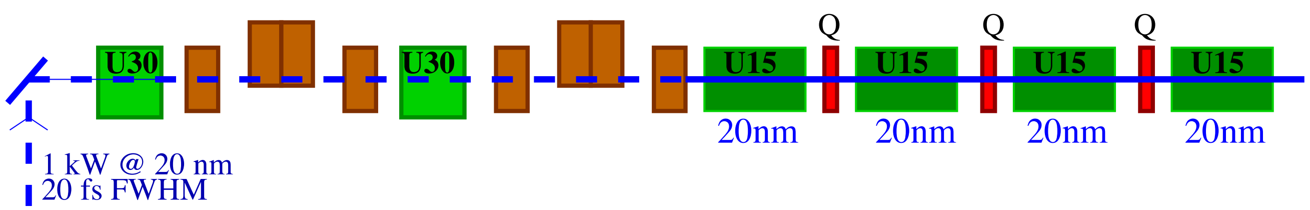
Mode super radiance en sortie, avec 1 GW à 60 nm et 12 MW à 20 nm (h3).

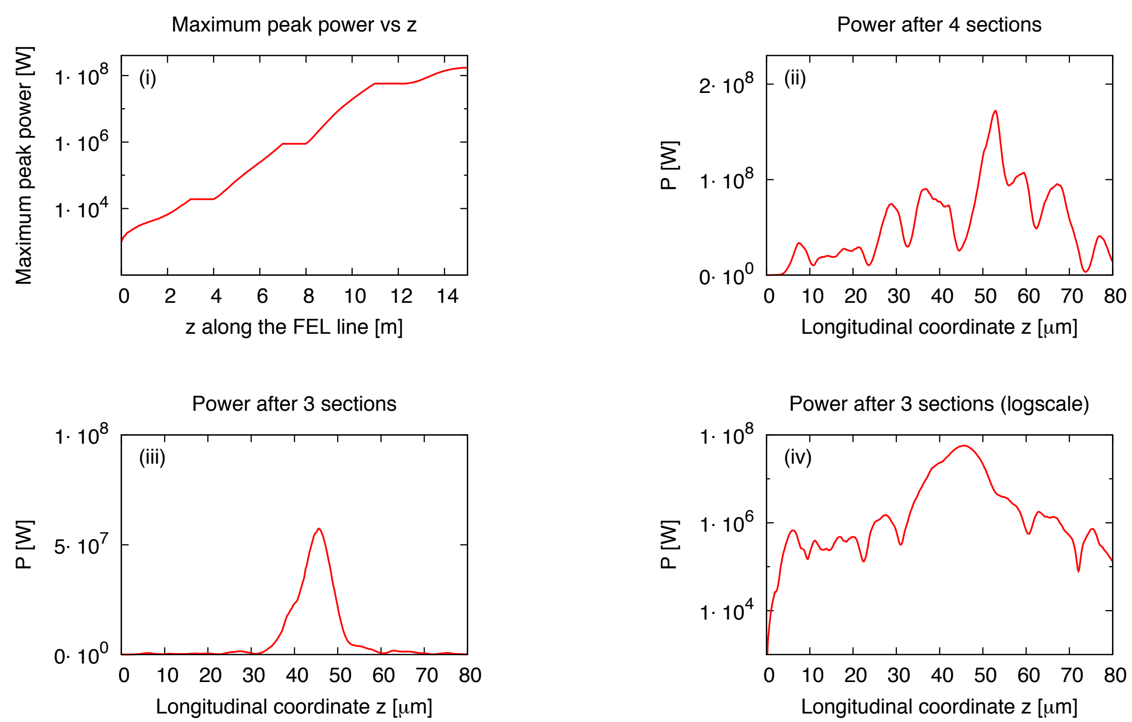
III-Présentation plus détaillée du projet

Calcul LEL Time dependant- CLA

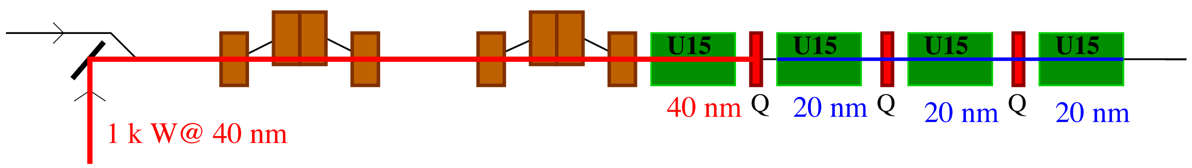
Énergie (MeV)	400
Dispersion en énergie relative	2e-4
Émittance $\epsilon_{x,y}$ (π mm.mrad)	1.5
Courant crête (A)	400
Longueur RMS (ps)	1

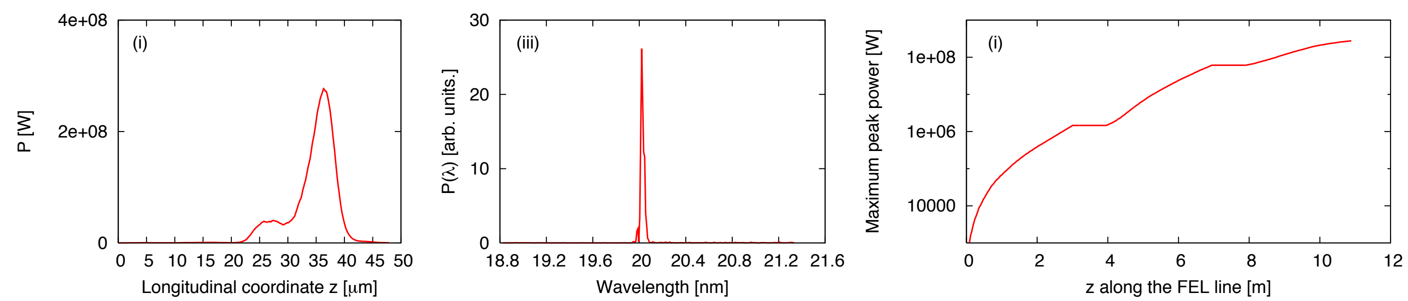
Cas amplificateur





Cas de la cascade



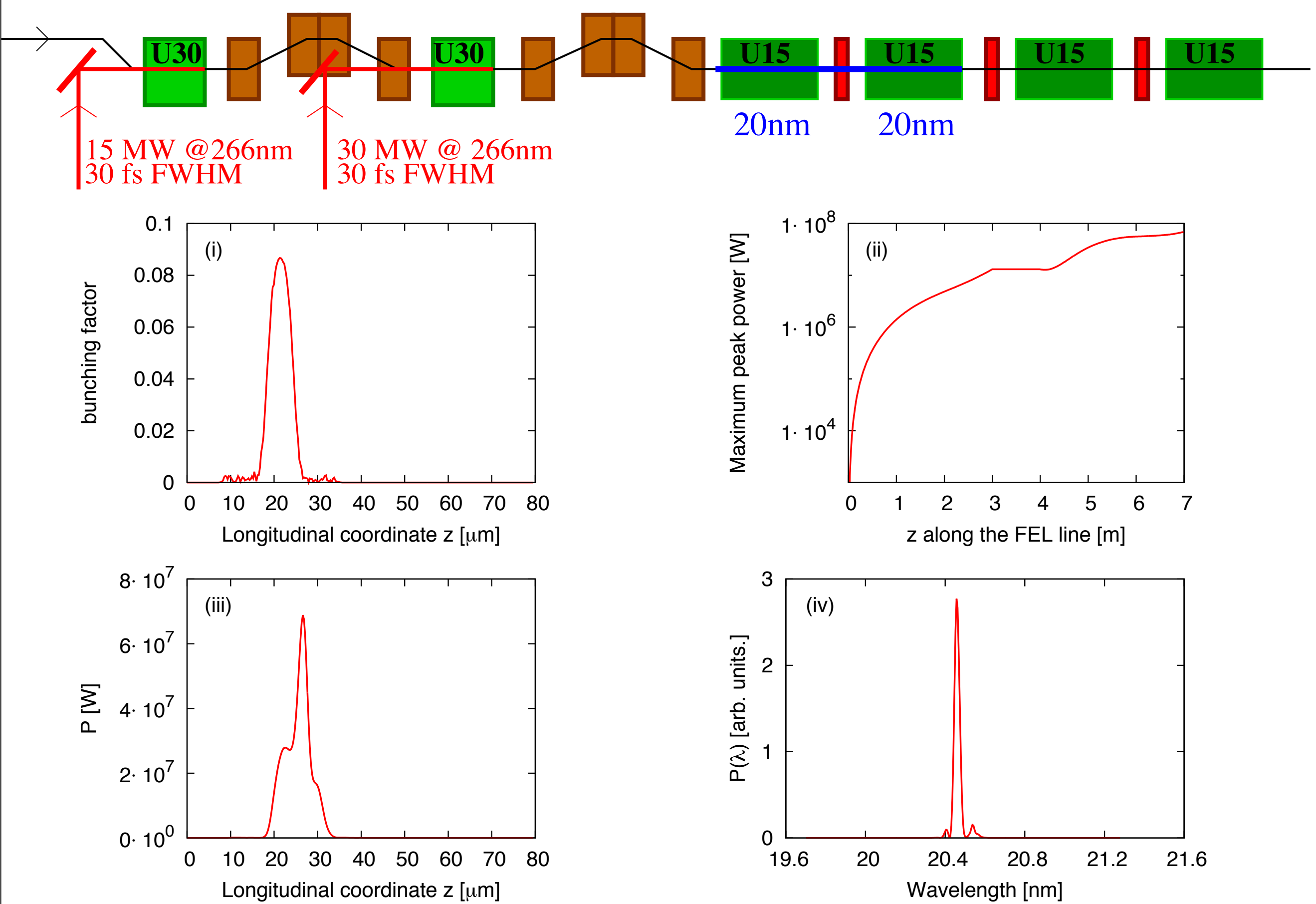


Après 3 sections (z= 11 m), 50 MW, 30 fs FWHM, rapport signal sur bruit = 3

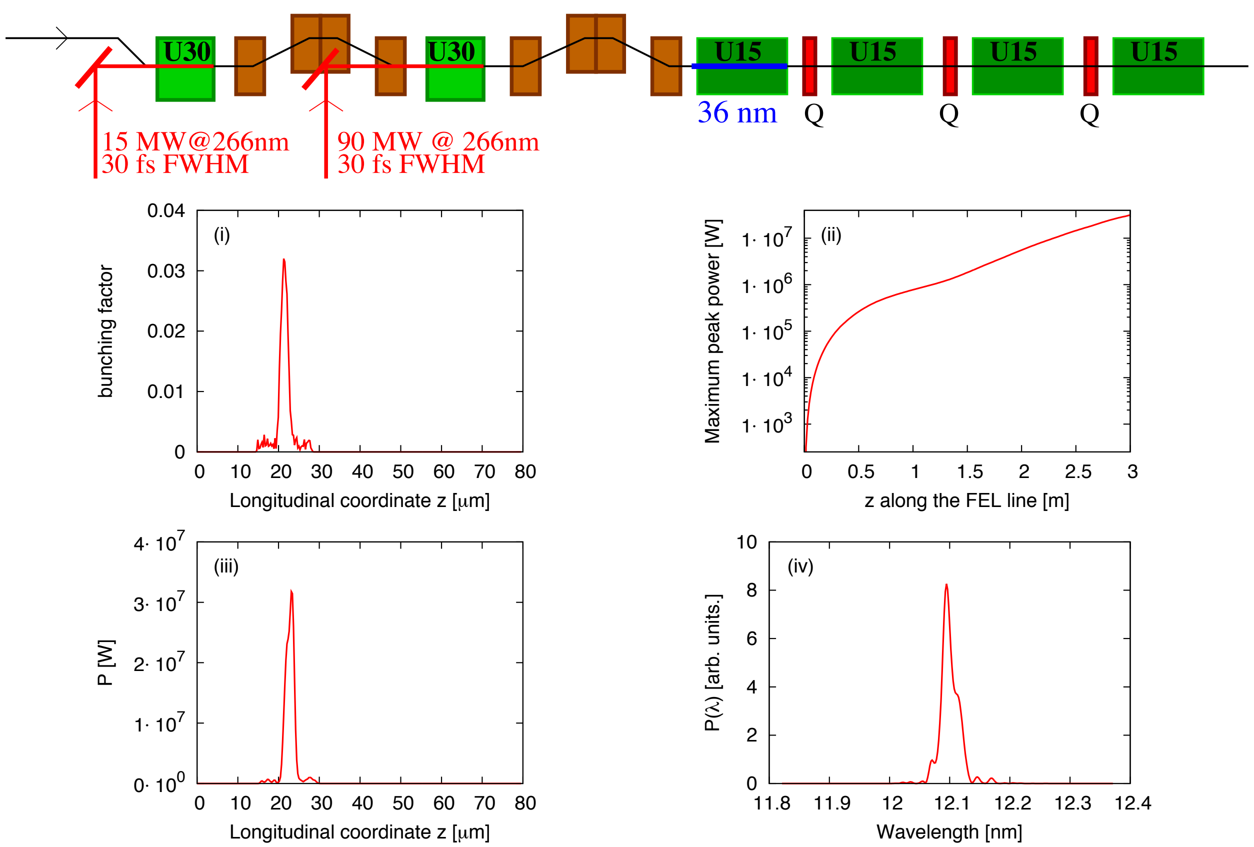
Saturation après 3 sections (z= 11 m), 0.27 GW, 17 fs FWHM, 0.02 nm à mi-hauteur, impulsions à la limite de Fourier

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

IV-Targeted complementary studies and associated R&D

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.

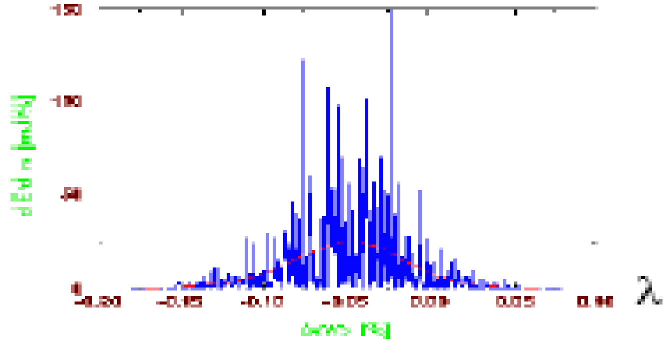
- Address with priority the following R&D:

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

I-Introduction : le contexte scientifique

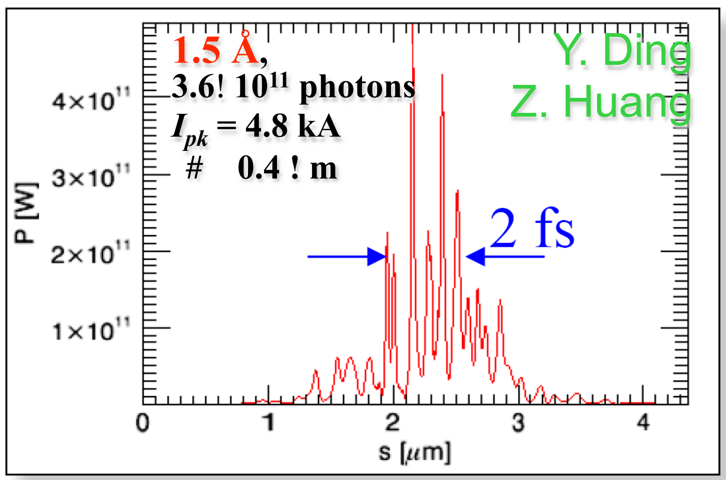
Cas sans interaction électron -laser externe



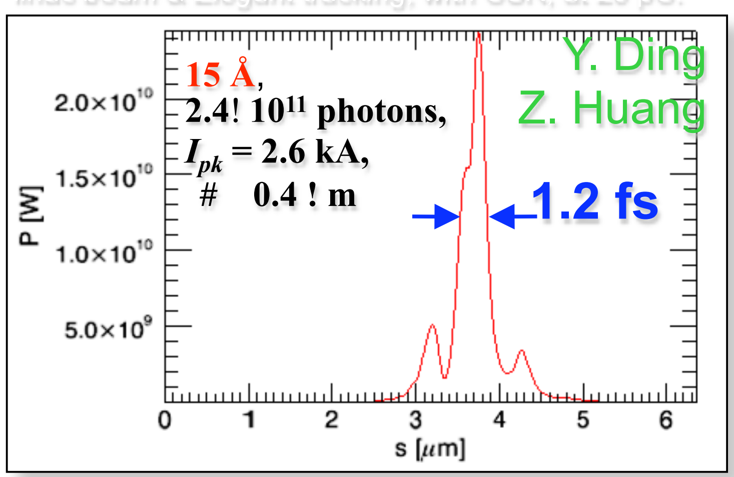
Low charge single spike operation

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

SIMULATED FEL PULSES



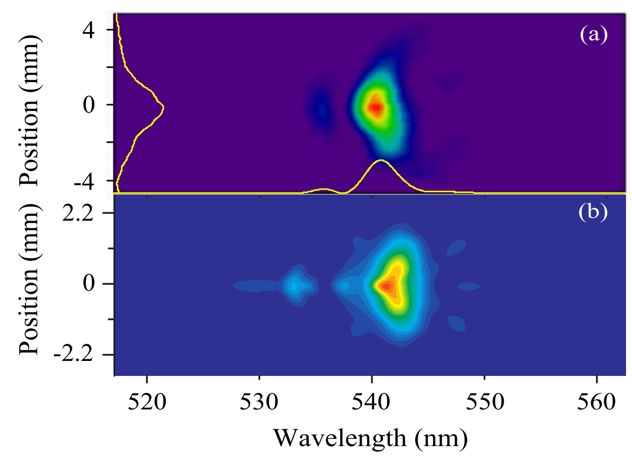
Simulation at 1.5 Å based on measured injector & linac beam & *Elegant* tracking, with CSR, at 20 pC.



Simulation at 15 Å based on measured injector & linac beam & *Elegant* tracking, with CSR & 20 pC.

Single spike operation with energy chirp and tapering

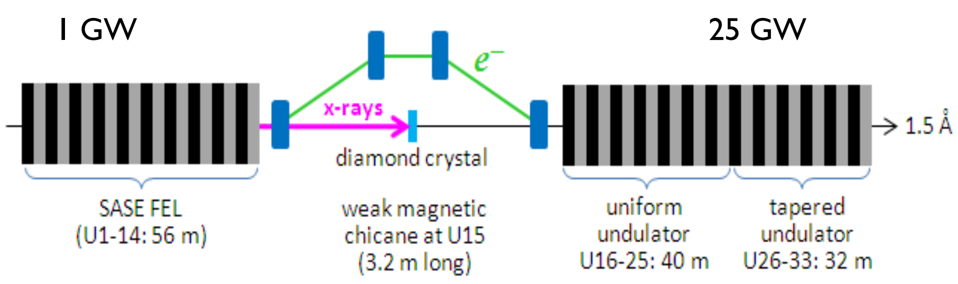
Chirp on the electron beam : detunes the local resonant frequency
Taper scalining preserving the resonant condition
the correlated energy spread is compensated only for spikes drifting with the appropriate velocity associated to the taper



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

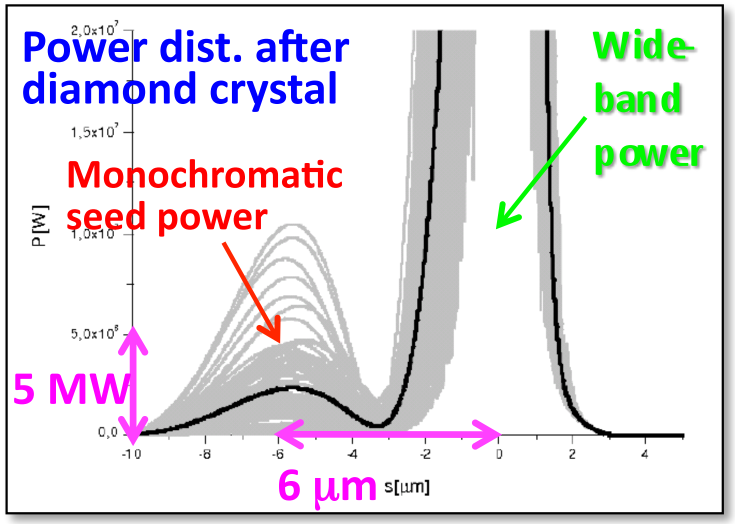
Self seeding démontré à LCLS

Courtesy B. Hettel (SLAC)



Self-seeding of 1-µm e^- pulse at 1.5 Å yields 10^{-4} BW with 20-pC mode. Und. taper provides 20brightness & 25 GW.

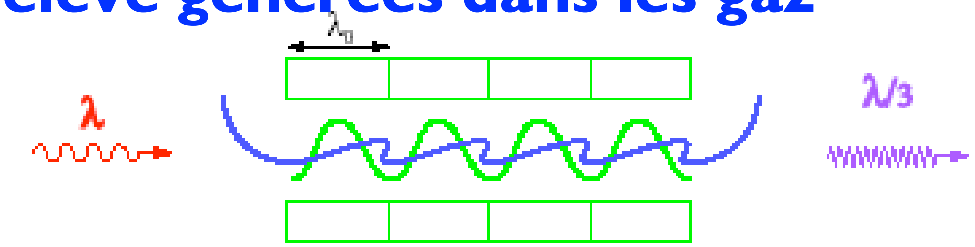
P. Emma (SLAC), A. Zholents (ANL)



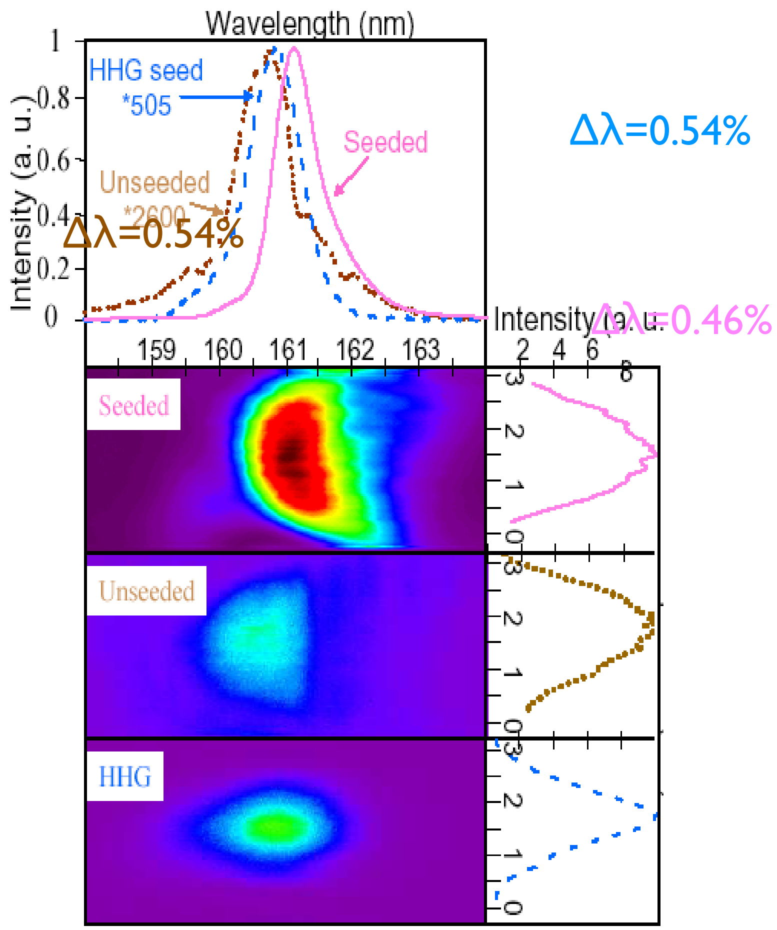
Cas d'une interaction électron -laser externe

Injection avec les harmoniques d'ordre élevé générées dans les gaz

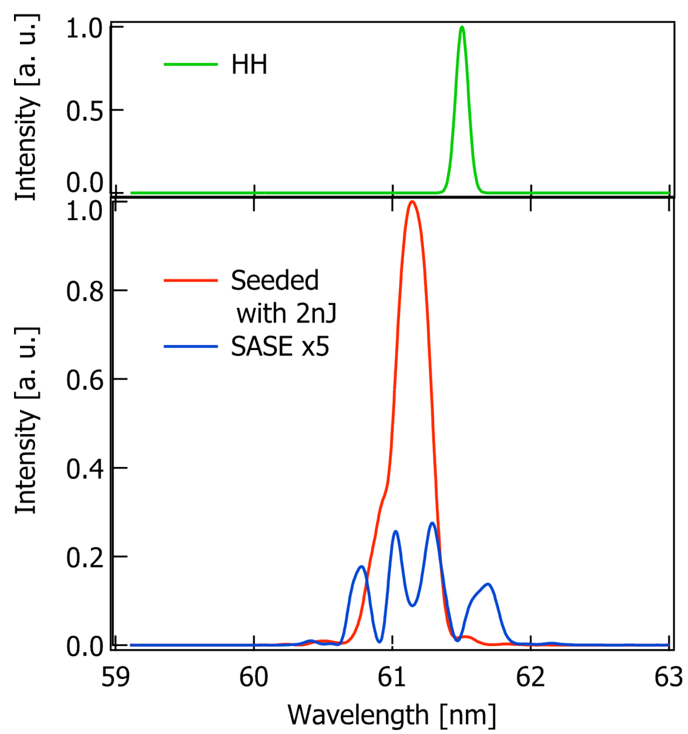
HHG seeding at 160 and 60 nm on SCSS Test Accelerator (coll. Franch-Jap), at 160 nm at SPARC :



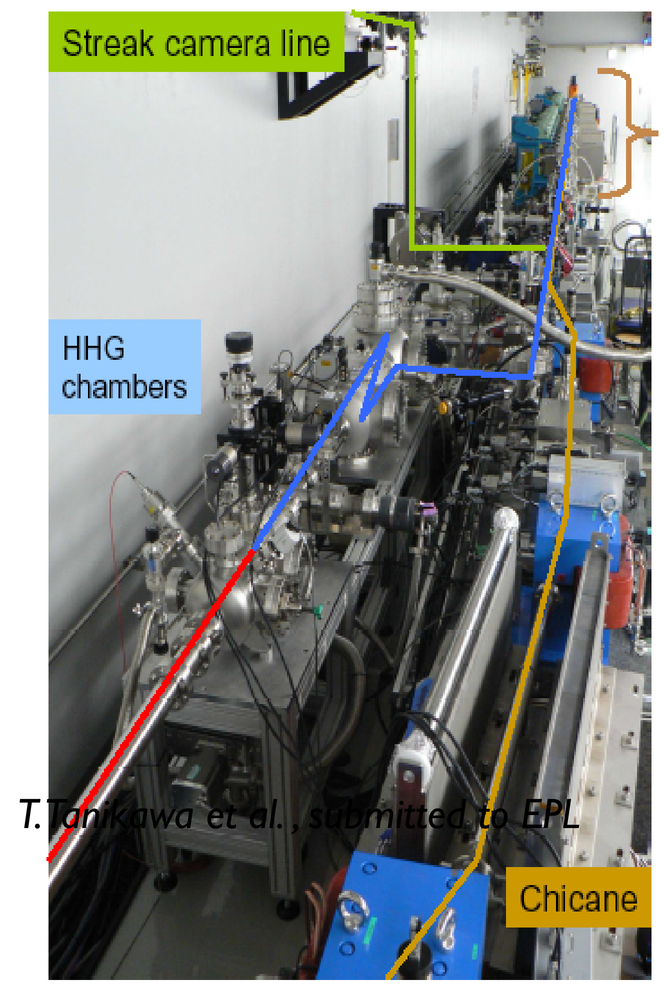
- improvement of temporal coherence,
- jitter reduction, quicker saturation,
- higher order harmonic level

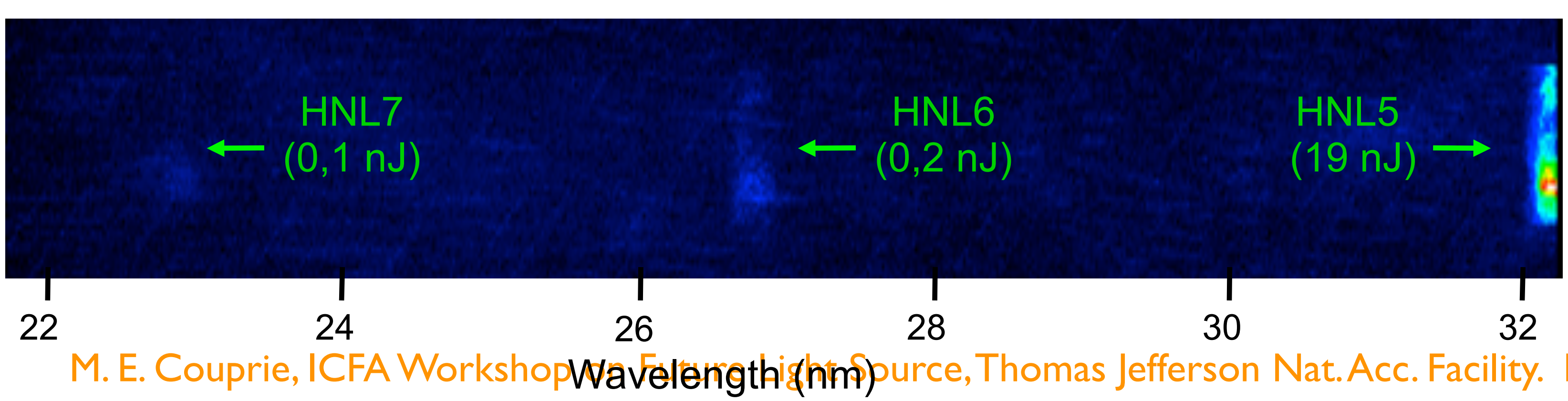


G. Lambert et al., Nature Physics Highlight, (2008) 296-300



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



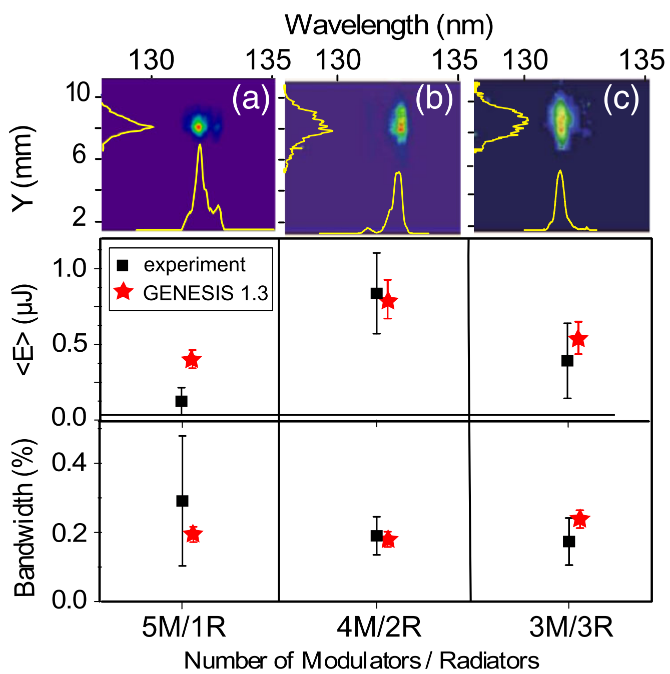


T. Tanikawa et al., EPL 106, 3 (2011) 34001

Cas d'une interaction électron -laser externe

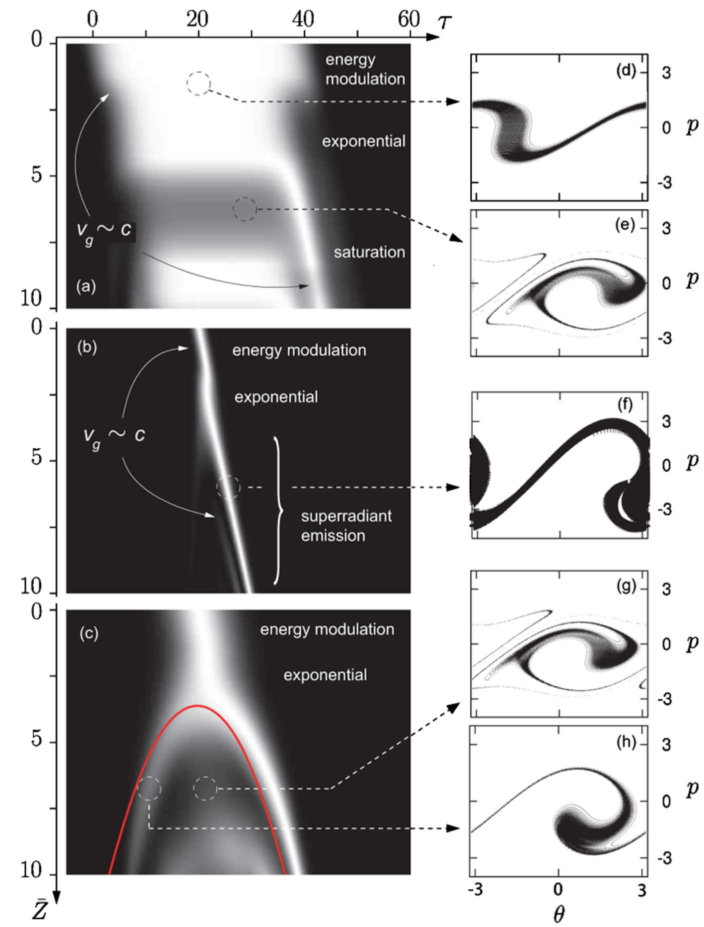
Dymanique complexe

Configuration en cascade des onduleurs
(entre modulateur et radiateur)



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

Seeding, super-radiance et pulse splitting

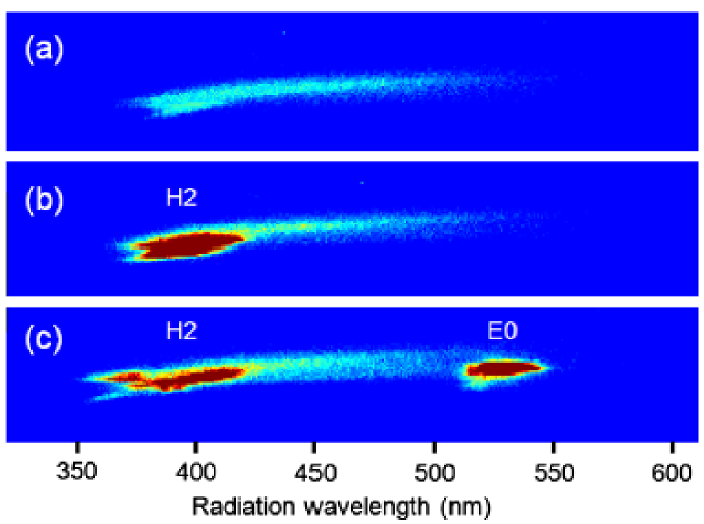


Pulse splitting in short wavelength free electron laser,
M. Labat, N. Joly, S. Bielawski, C. Swaj, C. Bruni, M. E. Couprie,
Phys. Rev. Lett. 103 (2009) 264801

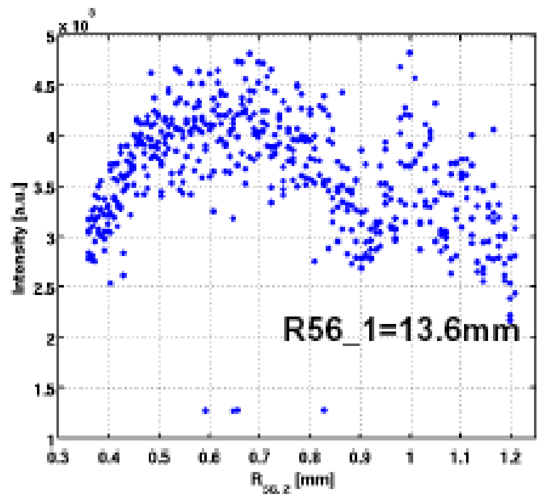
Cas de deux interactions électron - laser externe (écho)

- avec mise en phase des émetteurs sur linac :

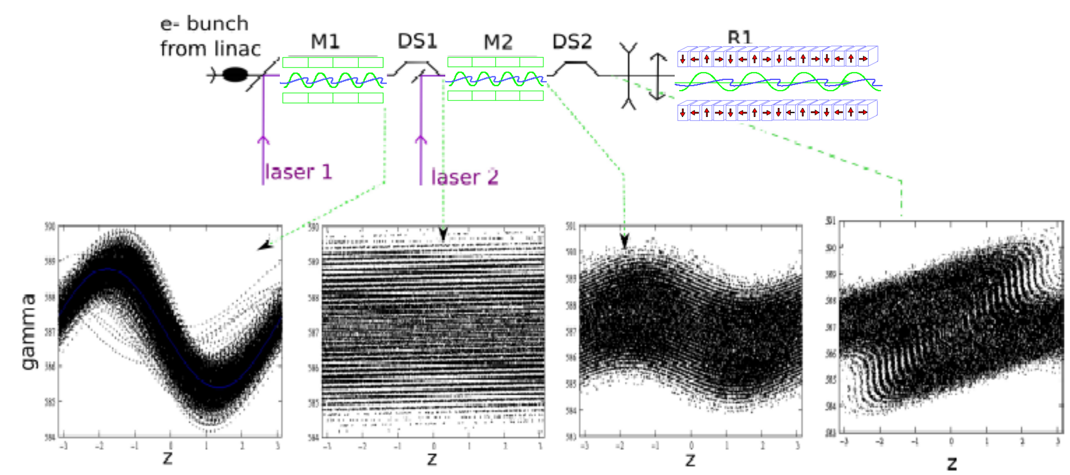
première proposition sur Linac pour LEL (Stanford)
Demo expérimentales à Stanford et à Shanghai dans le proche UV



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

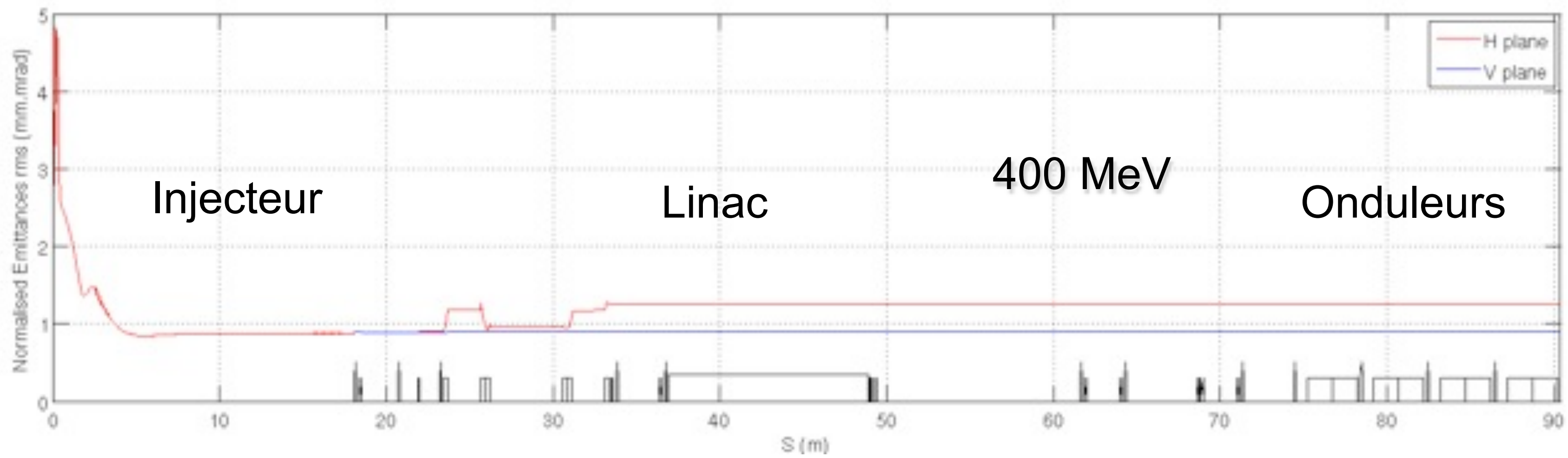


Zhao et al., Proceed FEL conf, Mamö (2010)

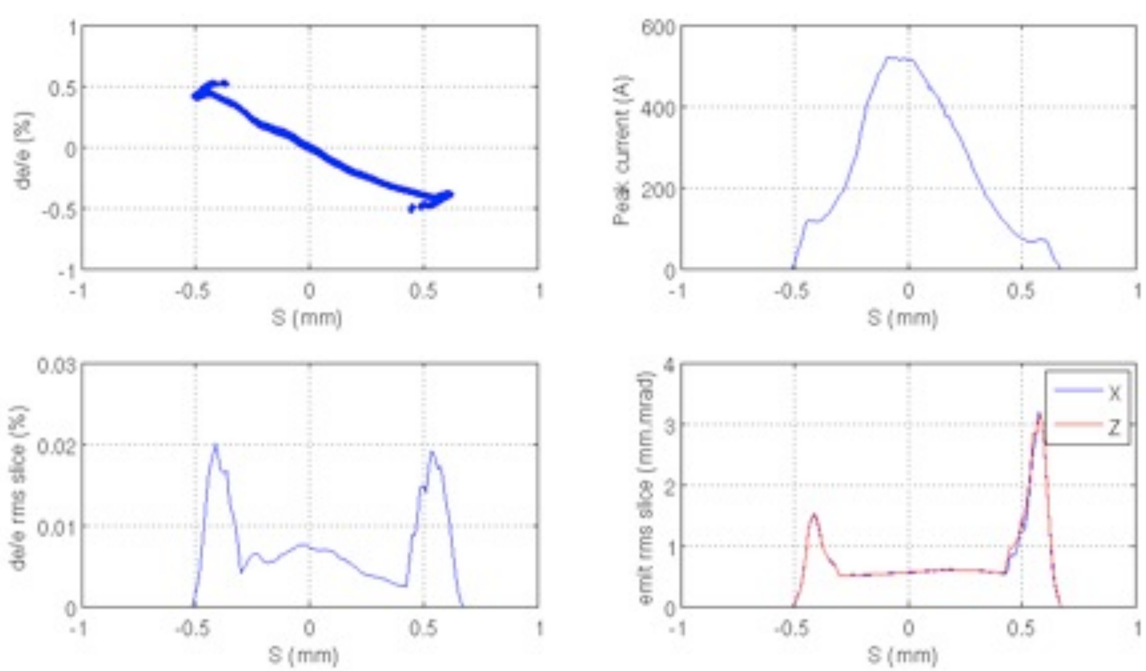


G. Stupakov., PRL 102, 074801 (2009)

CLA electron beam dynamics



Final slice parameters (1 nC)

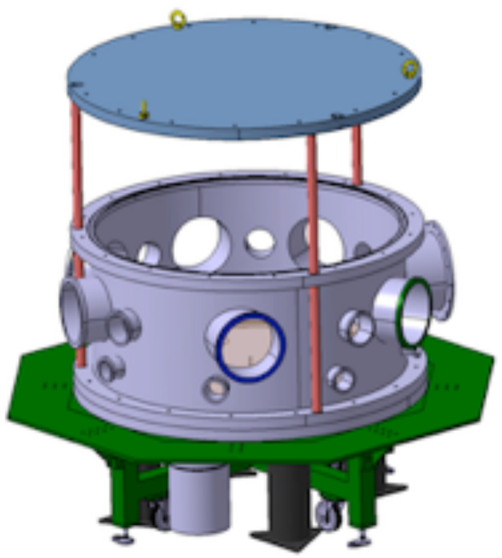


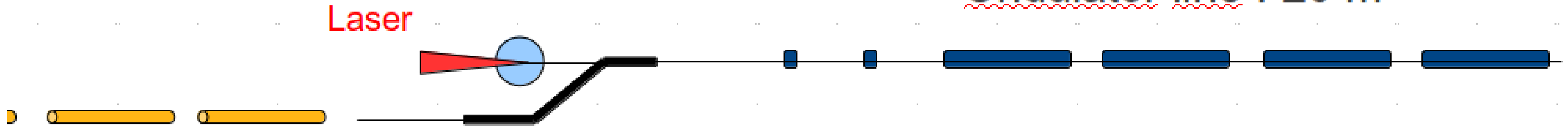
CLA@ undulator entrance

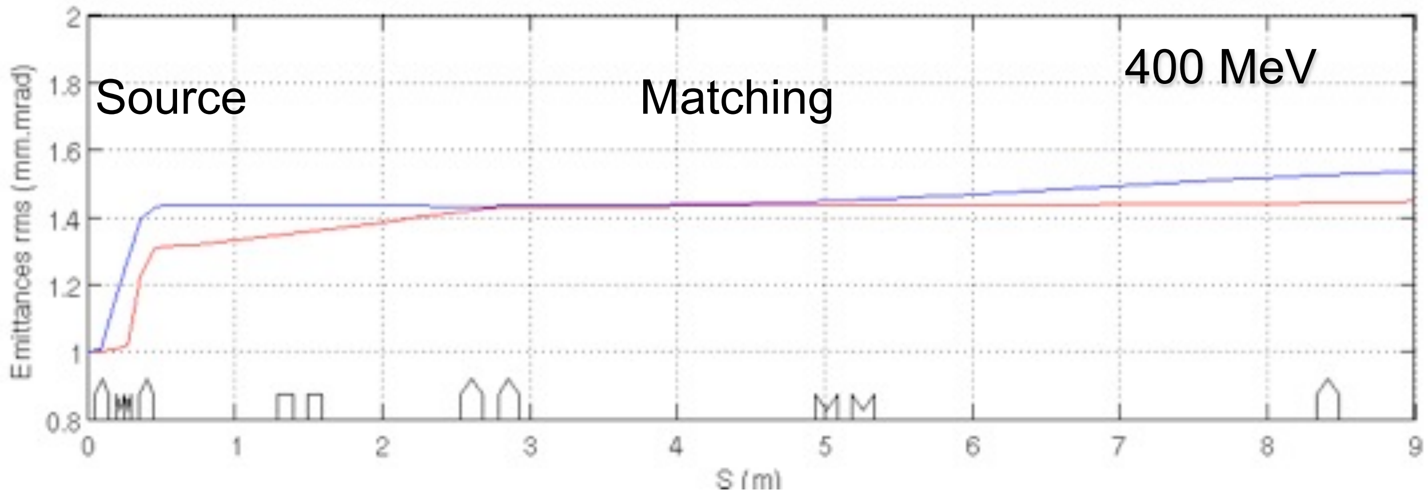
«Complete» modelling along the CLA and adaptation to the undulators

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







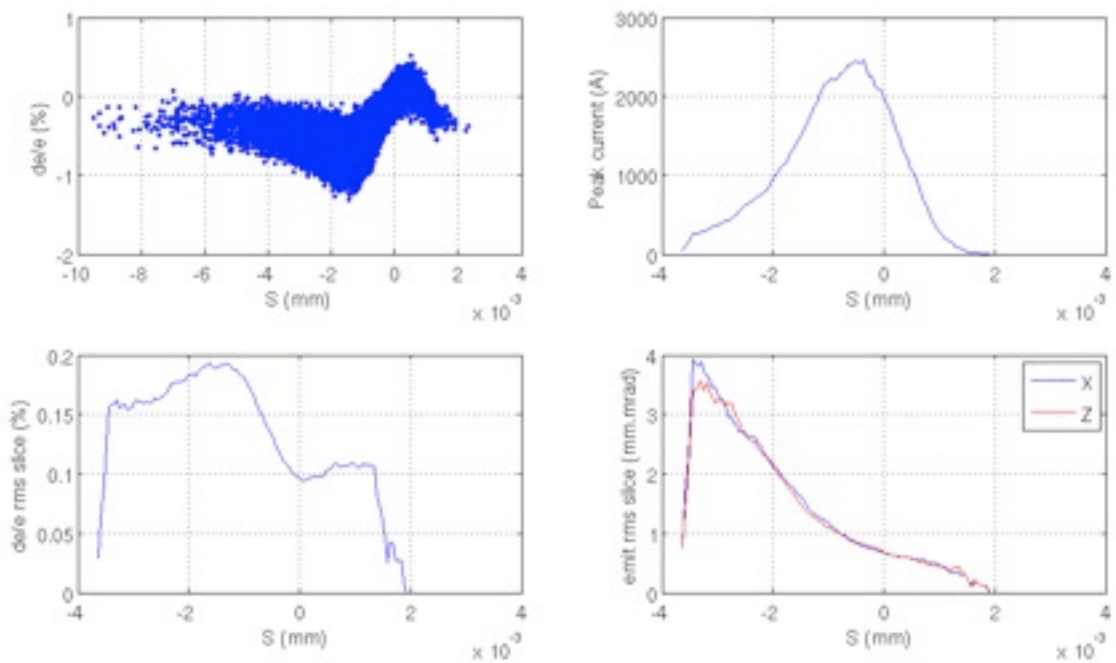
Undulators

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

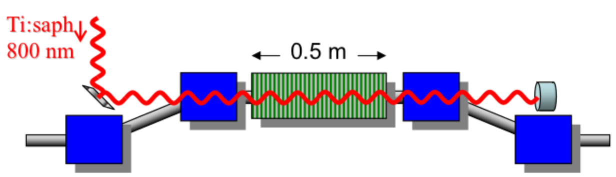
Emittance < 4. 10^{-6} mrad
dE/E < 2. 10^{-3}
FWHM duration ~ 10 fs
>2000 A peak

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

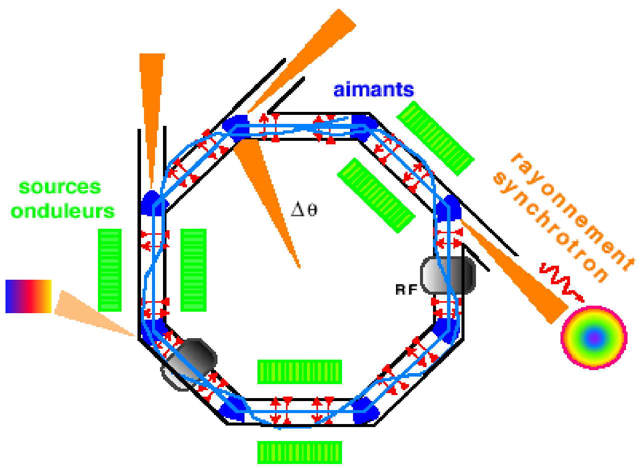
Compression Chicane : Reduction dof the bunch length to 1 ps

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

Accelerator choice for FEL

Storage ring



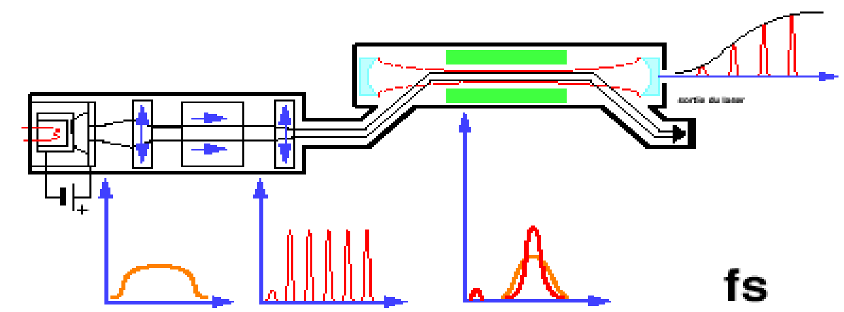
10–30ps,
$\varepsilon \alpha E^2$

Energy spread :
0.1 %

Linear accelerator

10 fs–10 ps,
$\varepsilon \alpha 1/E$

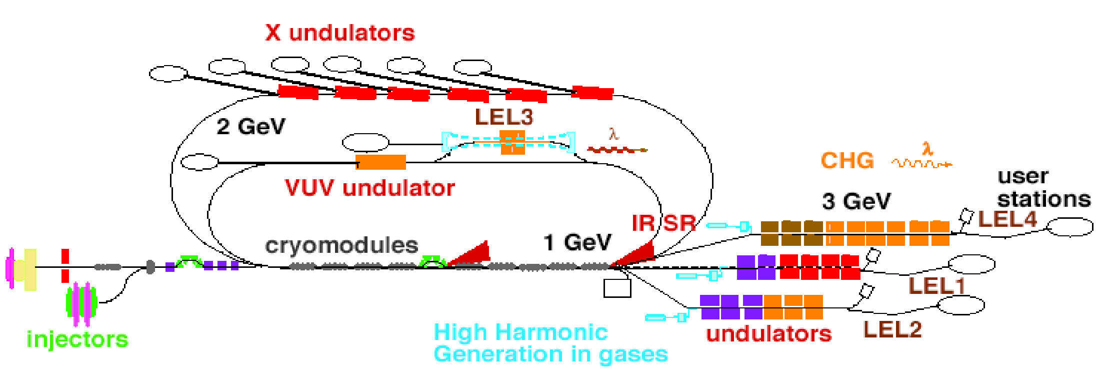
Energy spread : :
0.01 %



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