Laser applications at accelerators

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Principal laser applications

I. **Particales generation (photoinjector)**

laser of UV range, energy ~100μJ, pulsewidth up to 10fsec
make possible to generate very short bunch with a small emittance

II. **Particales acceleration**

laser of the extreme intensity 10^{18} -10^{20}W/cm^2
allow to reach a high-gradient acceleration ~1GV/m

III. **Laser application for particle beams monitoring and**

X- γ photons generation.
particularity: small cross-section -> high energy laser pulses are needed
-> laser energy losses is very small->
laser pulse may be used many times -> recycling or optical cavity

Direct laser beam – particles interaction with recycling

Extreme Light Infrastructure – Nuclear Physics
ELI – NP project

Electron beam parameters

Energy	80-720 MeV
Bunch charge	25-400 pC
Bunch length	100-400 µm
$\varepsilon_{n\_x,y}$	0,2-0,4 mm-Rad
Sport size	>15 µm
Bunch separation	16 nsec
Bunches in train	≤32

Laser parameters

Pulse energy	200mJ
Rep.rate	100Hz
Wavelength	515nm
Pulsewidth(FWHM)	3,5psec
Jitter to external clock	< 200fsec

Recirculator allows of
one laser pulse
Interaction with 32electron bunches

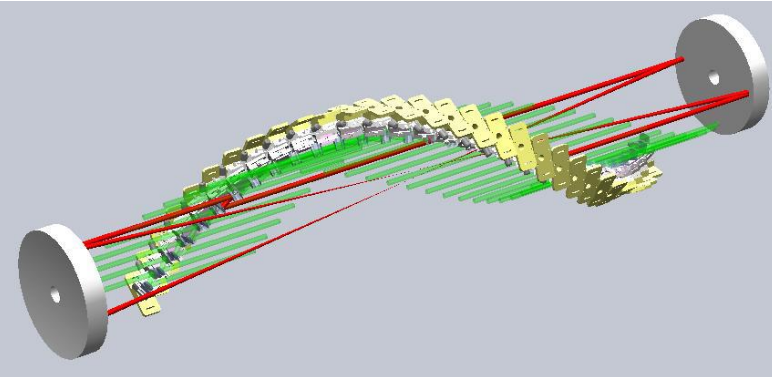


Table 1. Summary of Gamma-ray beam Specifications

Photon energy	0.2-19.5 *MeV*
Spectral Density	$0.8\text{-}4 \cdot 10^4$ *ph/sec.eV*
Bandwidth (rms)	≤ 0.5%
# photons per shot within FWHM bdw.	$\leq 2.6 \cdot 10^5$
# photons/sec within FWHM bdw.	$\leq 8.3 \cdot 10^8$
Source rms size	10 - 30 μm
Source rms divergence	25 - 200 μrad
Peak Brilliance ($N_{ph}/sec \cdot mm^2 mrad^2 \cdot 0.1\%$)	10^{20} - 10^{23}
Radiation pulse length (rms, *psec*)	0.7 - 1.5
Linear Polarization	> 99 %
Macro rep. rate	100 *Hz*
# of pulses per macropulse	≤ 32
Pulse-to-pulse separation	16 *nsec*

Coherent laser beam combining

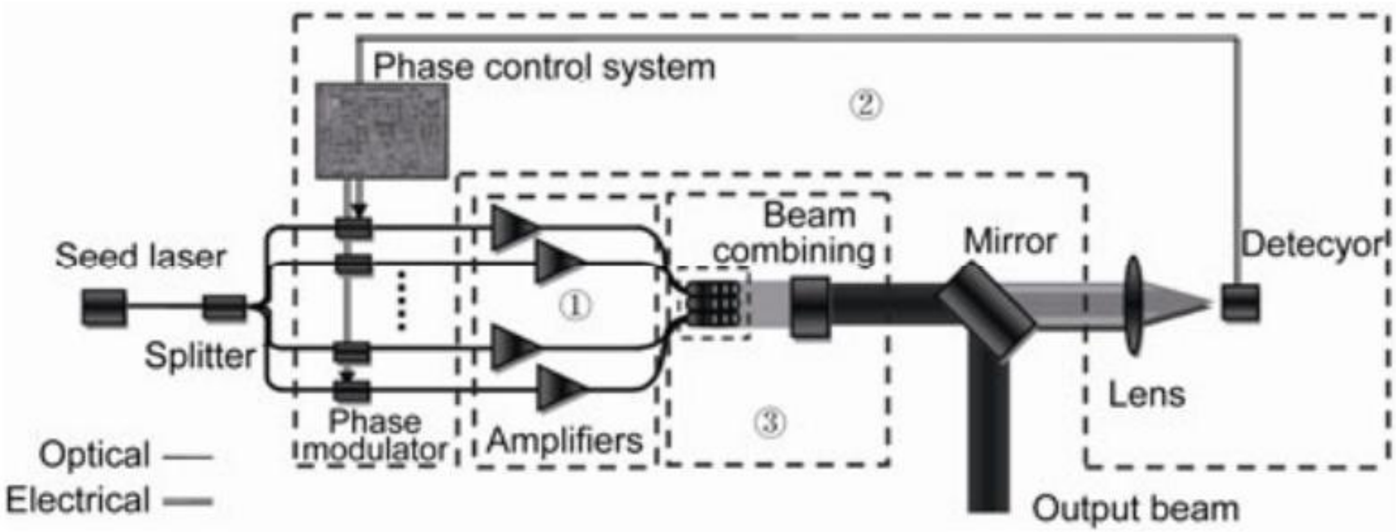
Use a high coherence of the laser beam to

1. **combine several coherent laser beams into one power beam**

2. **accumulate (amplificate) a laser beam inside a passive optical cavity**

Principle of coherent beams combining

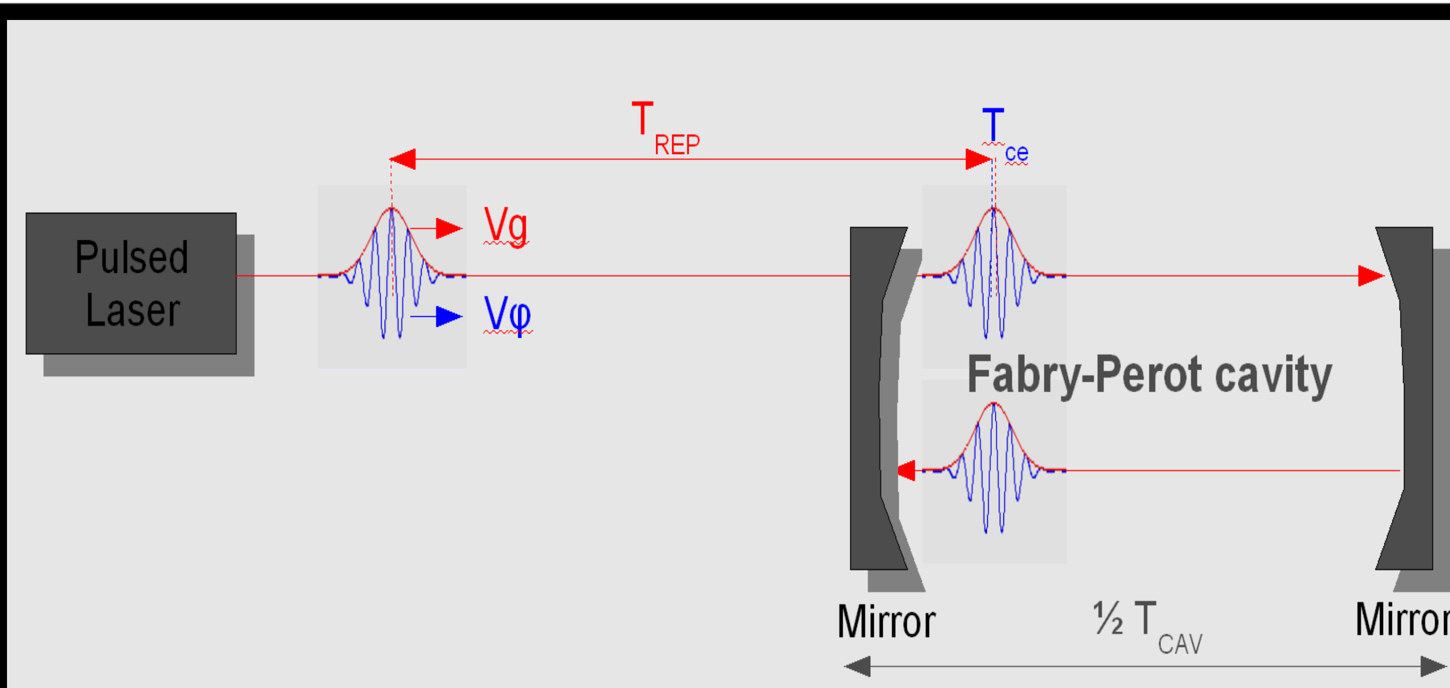
Several coherent laser beams are synchronized and combined in one power beam



Combined power 1-1,5 kW
for 10-15 fiber laser beams

Drawback: beam quality

Pulsed laser amplifying principle in time domain



Laser pulses are amplified if laser field overlays with FP cavity field :

- Vg : Group Velocity
- Vϕ : Phase Velocity
- Lrep : Laser repetition Length
- Lcav : Fabry-Perot cavity Length

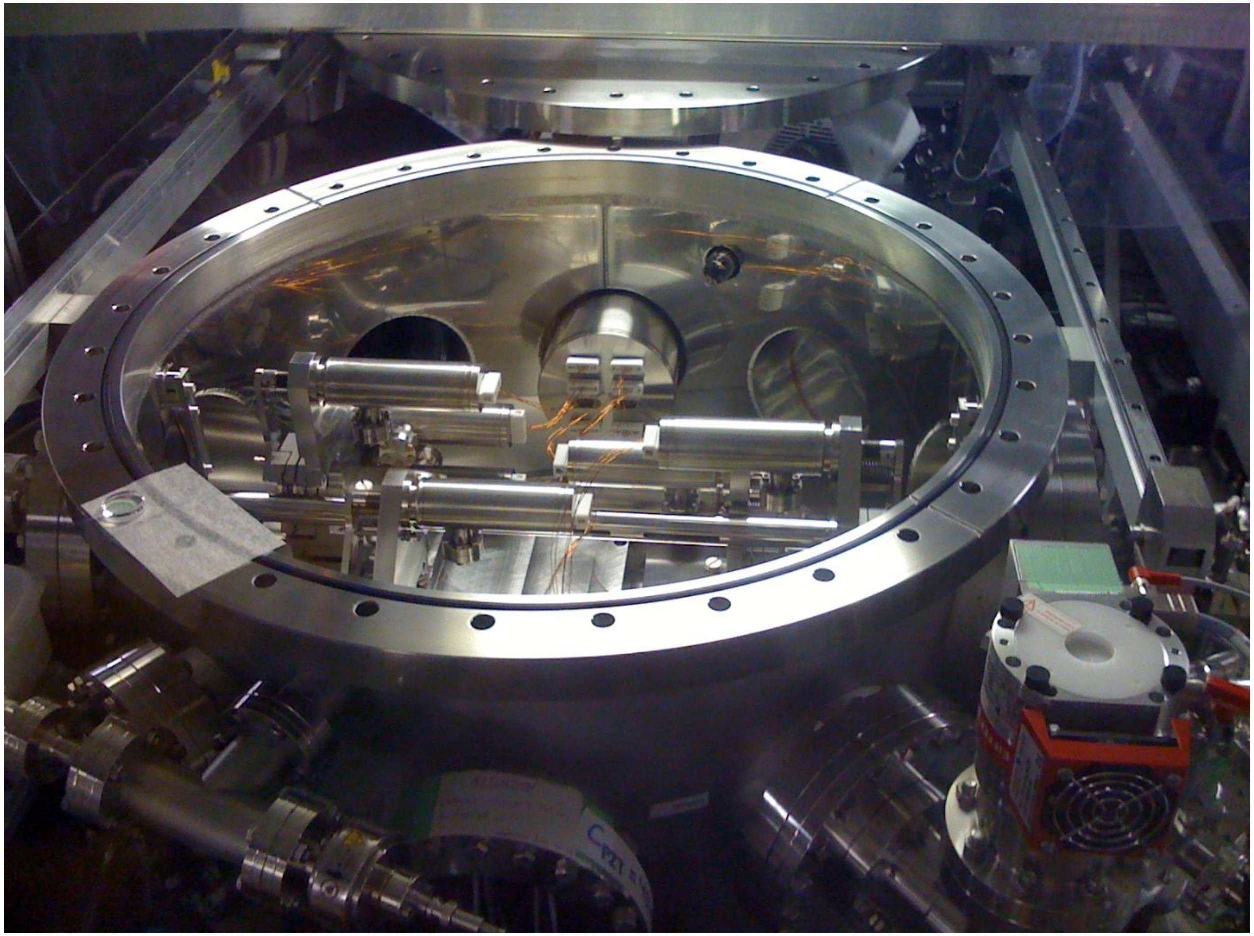
MightyLaser setup at ATF (KEK)

All fiber laser:

Oscillator: Orange (Menlo-Systems), λ=1030nm, $\Delta\lambda$=9.6nm, τ=2.5ps,
F_{rep}=178.5MHz,P_{out}=23mW

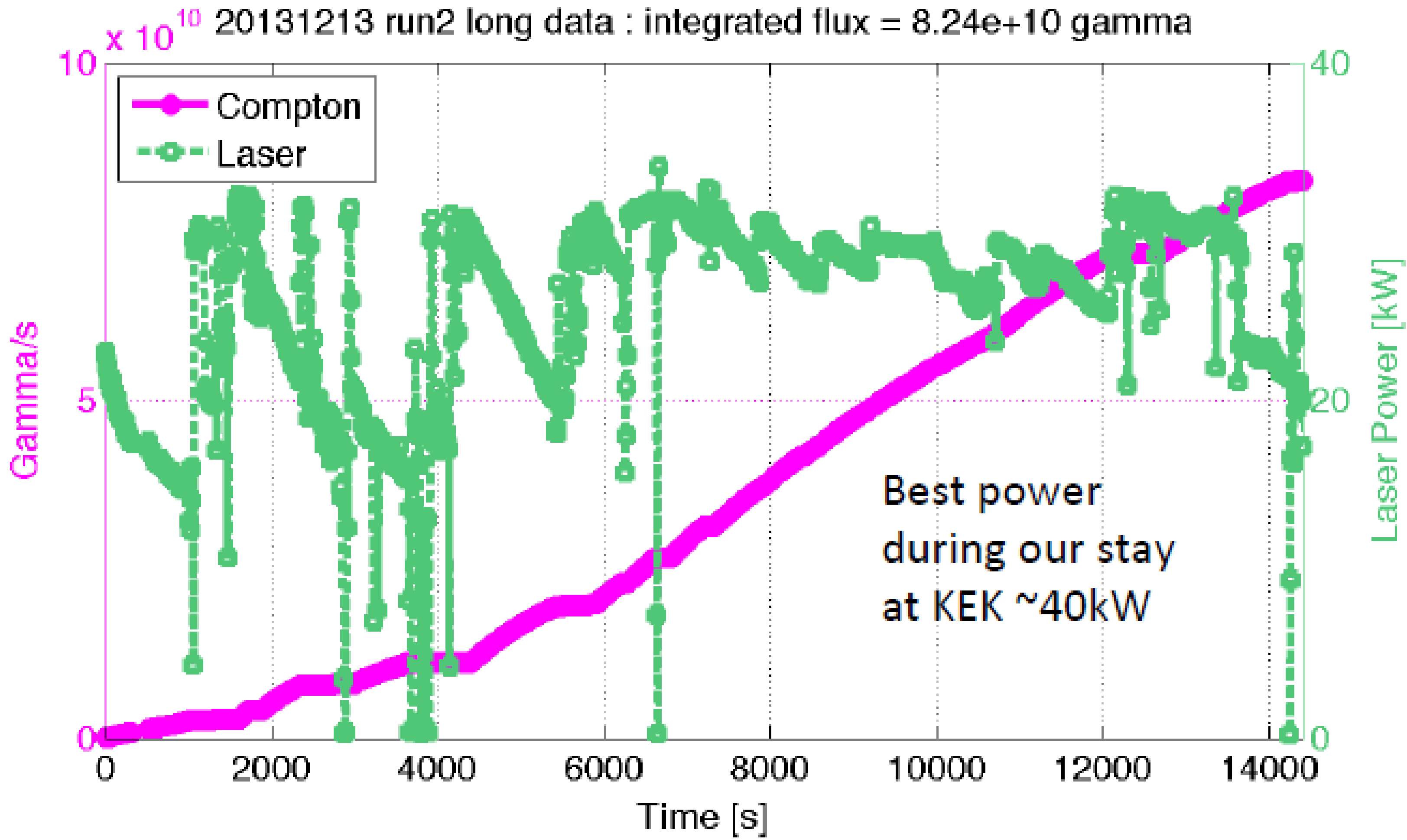
Amplifier: CELIA (Bordeaux) P_{out} =50W

Optical cavity (MightyLaser, ATF,KEK)

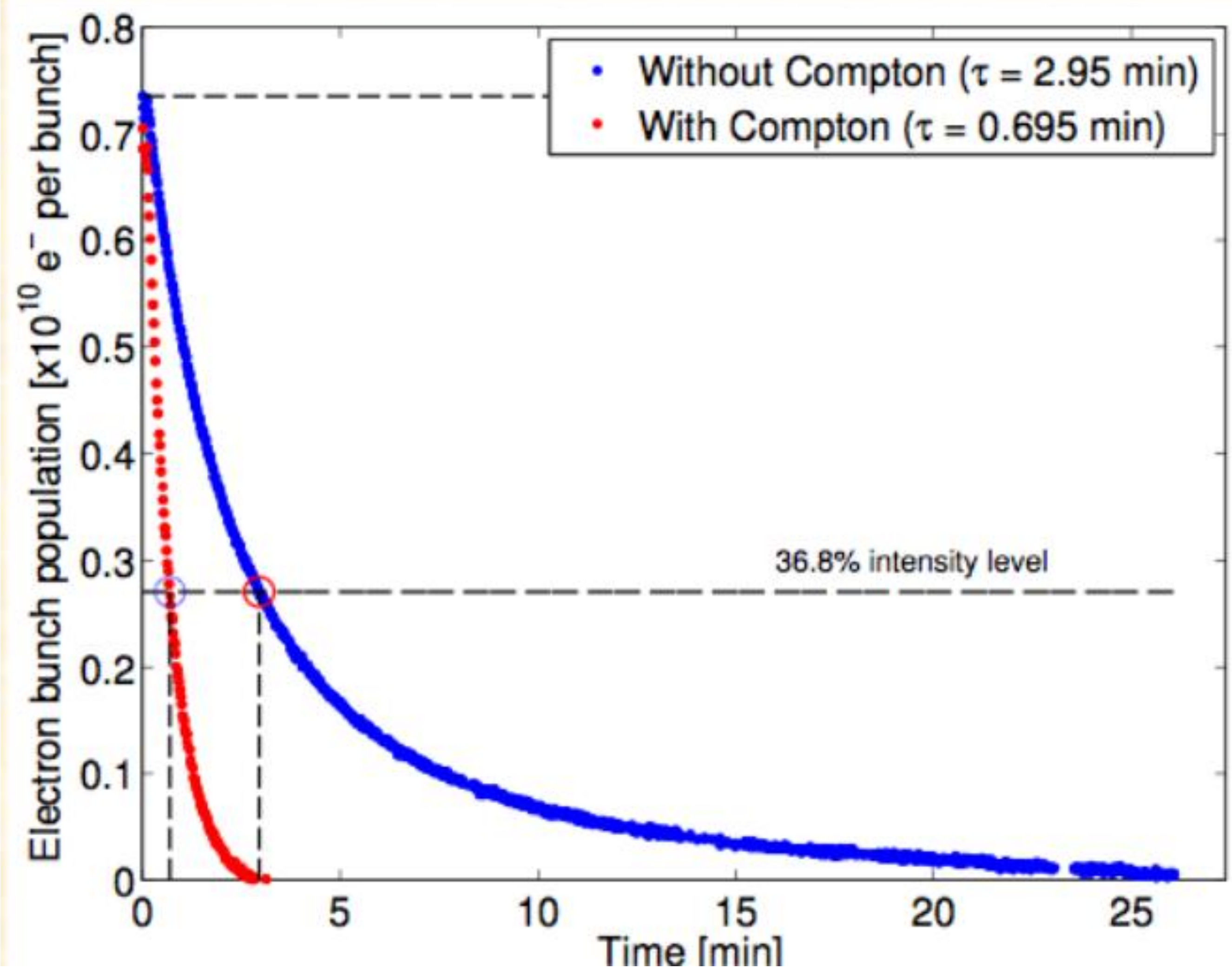


Nonplanar 4-mirrors optical cavity LAL(Orsay)

Long run with high power



Beam lifetime decrease



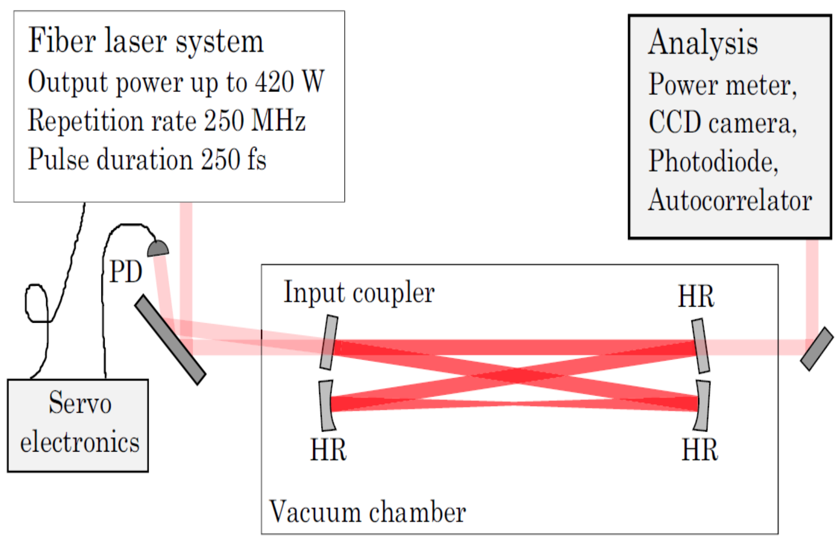
Limitation owing to particels losses

Megawatt-scale average-power ultrashort pulses in an enhancement cavity

H. Carstens, N. Lilienfein, S. Holzberger, C. Jocher, T. Eidam, J. Limpert, A. Tünnermann,J. Weitenberg, D. C. Yost, A. Alghamdi, Z. Alahmed, A. Azzeer,
A. Apolonski, E. Fill F. Krausz, and I. Pupeza

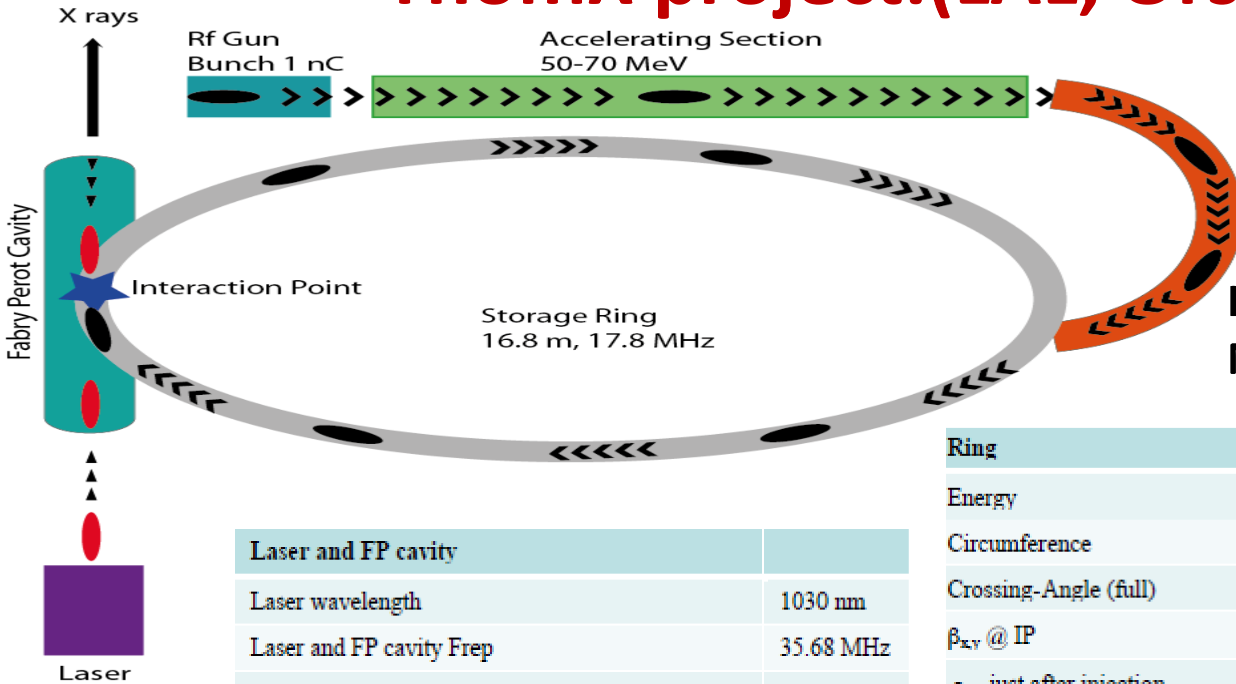
Was demonstrate 400 kW of average power with 250 fs pulses and 670 kW with 10 ps pulses at a central wavelength of 1040 nm and a repetition rate of 250 MHz.

Input: 420W fiber laser



Limitation owing to thermal deformation of cavity mirrors

ThomX project.(LAL, Orsay)



High finesse optical cavity
Non-stationary ring condition

Laser and FP cavity	
Laser wavelength	1030 nm
Laser and FP cavity Frep	35.68 MHz
Laser power	50 – 100 W
Laser pulse energy	1.4 – 2.8 μJ
Fabry-Perot pulse energy	28 mJ
Fabry-Perot pulse length (rms)	5 ps
FP cavity finesse/Gain	3000-30000 /
FP waist	70 μm
Power circulating in the FP cavity	~ 0.07 – 0.7

Source	
Photon energy cut-off	46 keV (@50 MeV), 90 keV (@ 70 MeV)
Total Flux	10^{11}-10^{13} photon/s
Bandwidth (with diaphragm)	1 % - 10%
Divergence	10 mrad (1/γ) without diaphragm @ 50 MeV

Ring	
Energy	50 MeV (70 MeV possible)
Circumference	16.8 m
Crossing-Angle (full)	2 degrees
$\beta_{x,y}$ @ IP	0.1 m
$\varepsilon_{x,y}$ just after injection	$5\ 10^{-8}$ m
Bunch length just after injection (rms)	4 ps
Bunch length at the end of a 20 ms storage cycle	50 ps (rms)
Beam current	17.84 mA
RF frequency	500 MHz
Transverse/longitudinal damping time	1 s /0.5 s
RF Voltage	300 kV
Revolution frequency	17.84 MHz
σ_x @ IP (just after injection)	70 μm
Tune x/y	3.17 /1.74
Momentum compaction factor α_c	0.0136
Initial/Final relative energy spread (with IBS and Compton back-scattering)	0.4%/0/6%