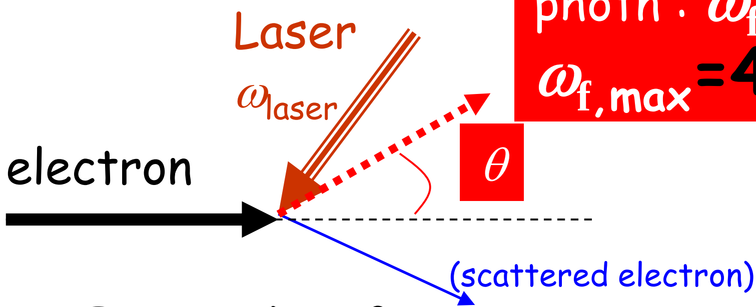
Photon beam generation at *PERLE*

Outline

- Introduction on Compton scattering
  - Expectations for the ERL facility
- Optical/laser system for high average laser power

F. Zomer LAL/Orsay

Compton scattering applications



photn : ω_f

$\omega_{f,max}=4\gamma^2\omega_{laser}$

Compton scattering

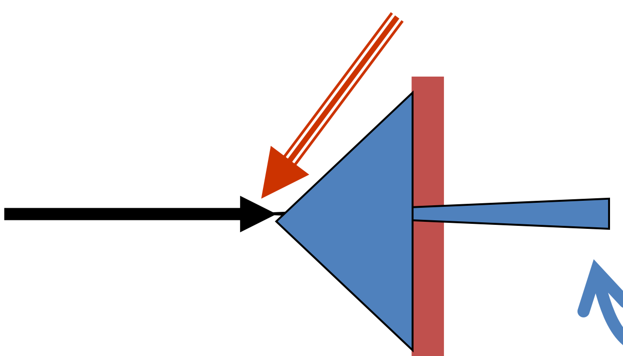
Photon_laser+e→photon+e'

is a

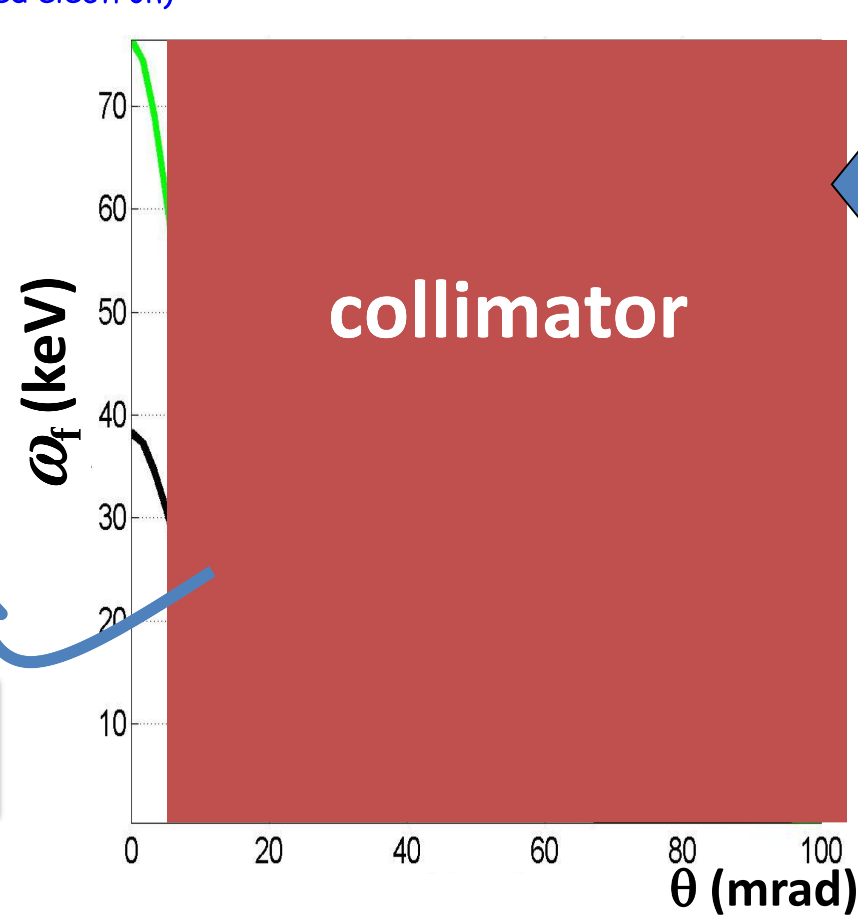
2 body process ➔ $\omega_f=f(\theta)$

$\gamma=E_{electron}/m_ec^2$

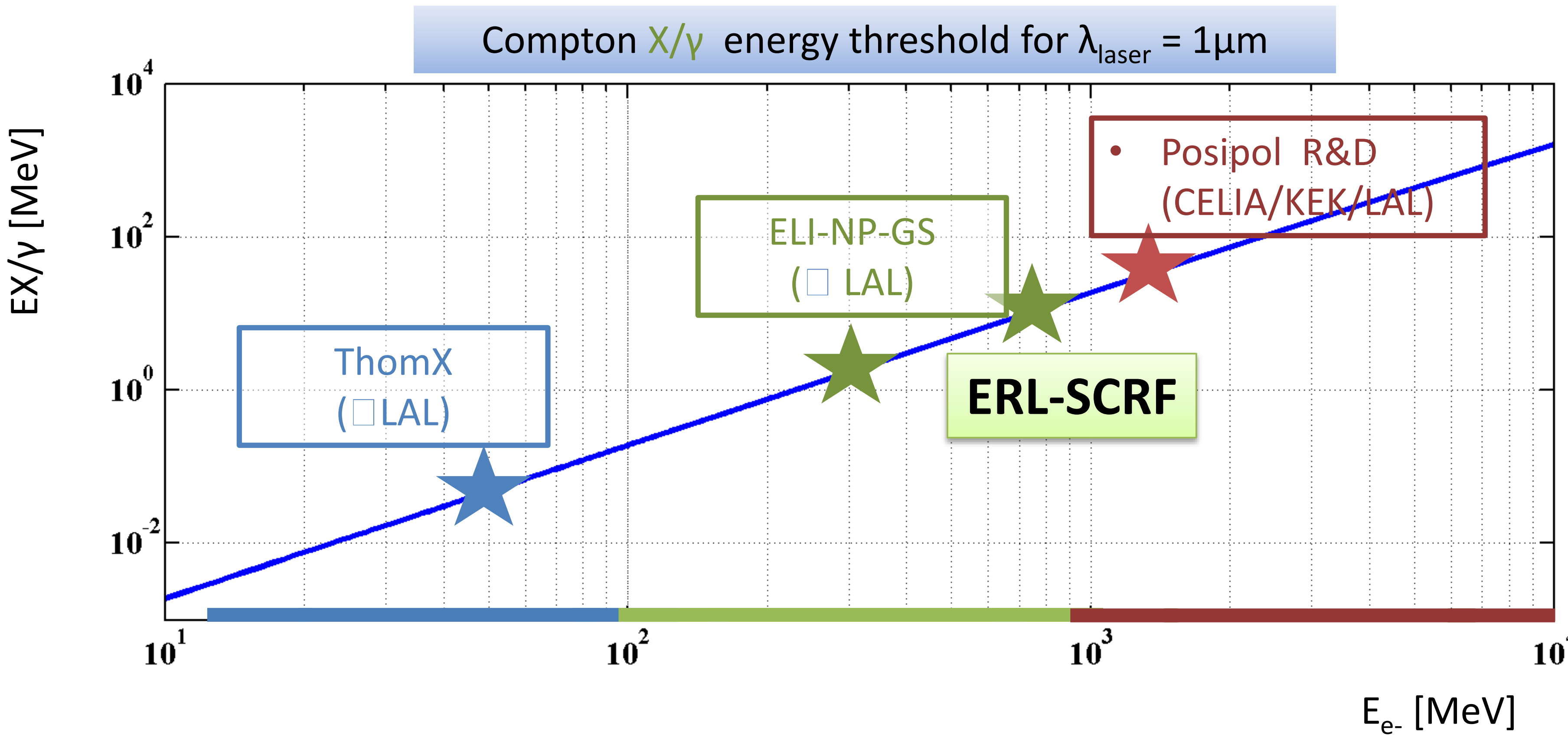
PRL138(1965)B1546



Quasi monochromatic X/gamma ray beam



Applications of Compton scattering: e⁻ + hν → e⁻ + X/γ



~10-1MeV
Low energy applications
Radiography & Radiotherapy
Museology
…

~1MeV-100MeV
Nuclear fluorescence
Nuclear physics
Nuclear survey
Nuclear waste management
…

>100MeV
High energy applications
Compton polarimeter
γγ collider
Polarised positron source
…

Photon beam properties

Total Scattered Photons

$$N_\gamma = 2.1\cdot 10^8 \frac{U_L[J]Q[pC]f_{RF}n_{RF}}{h\nu[eV]\sigma_x^2[\mu m]\sqrt{1+(c\sigma_t\phi/\sigma_x)^2}}$$

$$scattered - photons/sec \;\; over \;\; 4\pi \;\; and \;\; total \;\; spectrum$$

f_{RF} = RF rep rate
n_{RF} = #bunches per RF pulse

U_L = Laser pulse energy
Q = electron bunch charge

$h\nu$ = laser photon energy [eV]
σ_x = electron bunch spot size at collision point

ϕ = collision angle (<<1)
ϕ = 0 for head-on collision
σ_t = laser pulse length

N.B. **all sigma's and angles are intended as rms**,
all distributions are assumed as gaussians in (phase) space and time

Energy-angular Spectral distribution

$$N_\gamma^{bw} = 1.2\cdot 10^9 \frac{U_L[J]Q[pC]\,f_{RF}\,n_{RF}}{h\nu[eV]\sigma_x^2[\mu m]\sqrt{1+(c\sigma_t\phi/\sigma_x)^2}}\Psi^2$$

$scattered - photons/sec\ within\ \Psi \equiv \gamma\vartheta$

$and\ within\ rms\ bandwidth\ \Delta\nu_\gamma/\nu_\gamma$

Tomassini APB80(2005)419

$$Spectral\ Density\,[\#\ photons/s\cdot eV]\ SPD \equiv \frac{N_\gamma^{bw}}{\sqrt{2\pi}\,h\Delta\nu_\gamma}$$

RMS bandwidth, due to collection angle, laser phase space distribution and electron beam phase space distribution

$$\frac{\Delta \nu_\gamma}{\nu_\gamma} \cong \sqrt{(\gamma\vartheta)^4 + 4\left(\frac{\Delta\gamma}{\gamma}\right)^2 + \left(\frac{\varepsilon_n}{\sigma_x}\right)^4 + \left(\frac{\Delta\nu}{\nu}\right)^2 + \left(\frac{M^2\lambda_L}{2\pi w_0}\right)^4 + \left(\frac{a_{0p}^2/3}{1+a_{0p}^2/2}\right)^2}$$

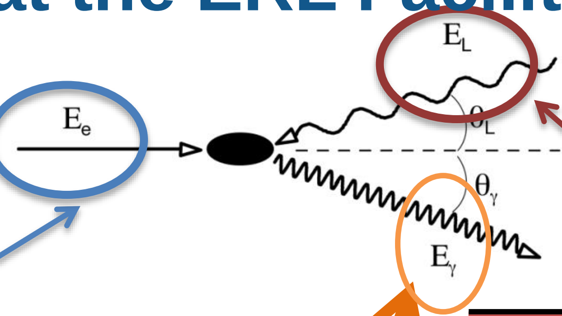
electron beam

laser

$\Psi = \gamma\vartheta$ *normalized rms collection angle*

Gamma beams at the ERL Facility

Incident electron beam



Incident laser beam

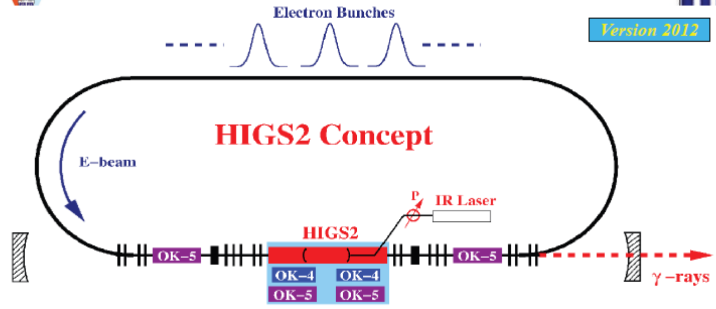
ELECTRON BEAM PARAMETERS	
Energy	900 MeV
Charge	320 pC
Bunch Spacing	25 ns
Spot size	30 um
Norm. Trans. Emittance	5 um
Energy Spread	0.1 %

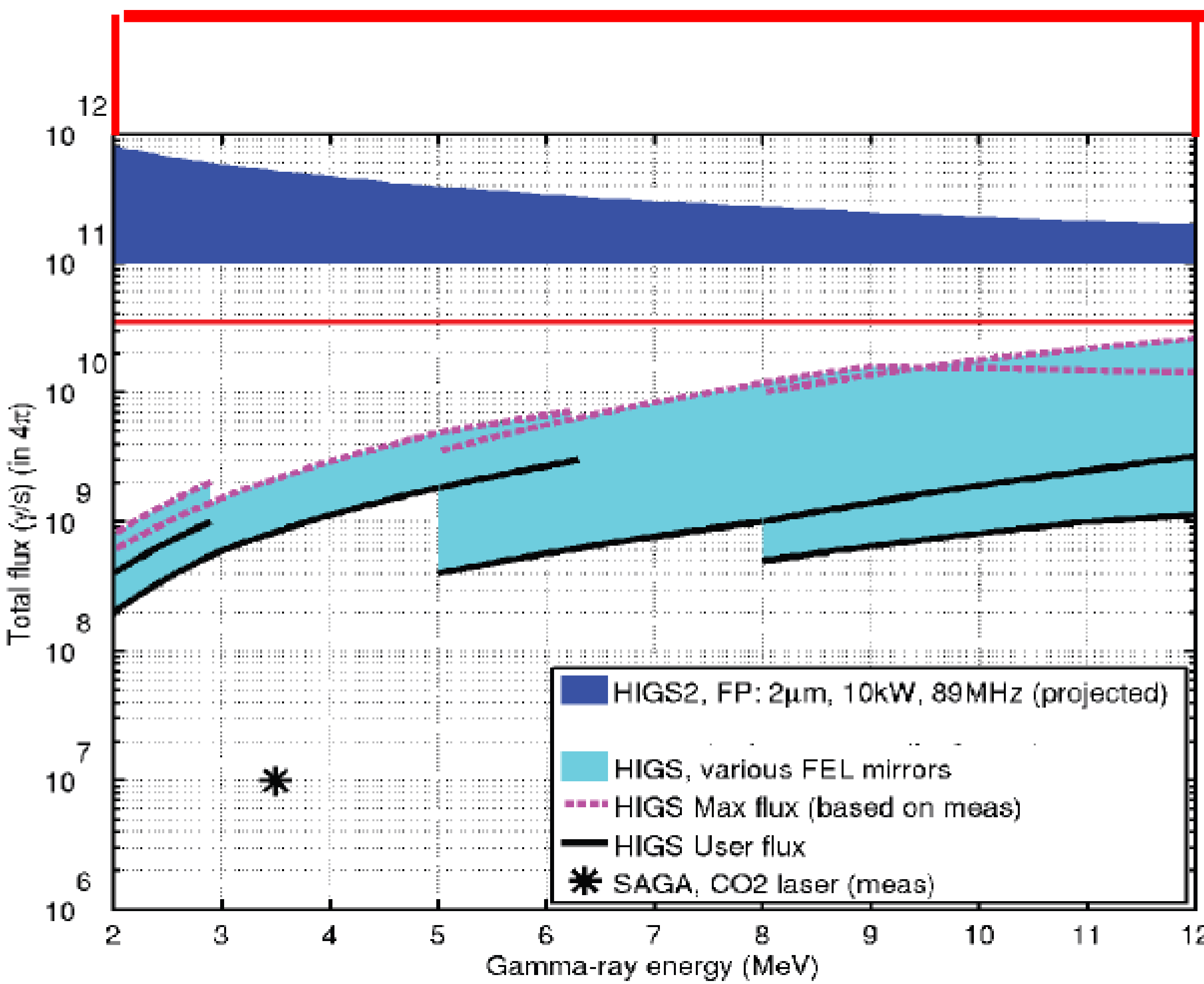
LASER BEAM PARAMETERS	
Wavelength	515 nm - 1030 nm
Average Power	300kW - 600 kW (**can be increased R&D**)
Pulse length	3 ps (**can be reduced**)
Pulse energy	7.5mJ - 15 mJ
Spot size	30 μm (**can be reduced**)
Bandwidth	0.02 %

GAMMA BEAM PARAMETERS (for λ=515nm)	
Energy	30 MeV
Spectral density	$9*10^4$ ph/s/eV
Bandwidth	< 5%
Flux within FWHM bdw	$7*10^{10}$ ph/s (total flux 9*10^12)
ph/e$^-$ within FWHM bdw	10^{-6}
Peak Brilliance	$3*10^{21}$ ph/s*mm^2*mrad^2 0.1%bdw

A. Valloni

Higs @ Duke Univ. World's most intense γ source





9×10^{12}
ERL facility
@ 30 MeV

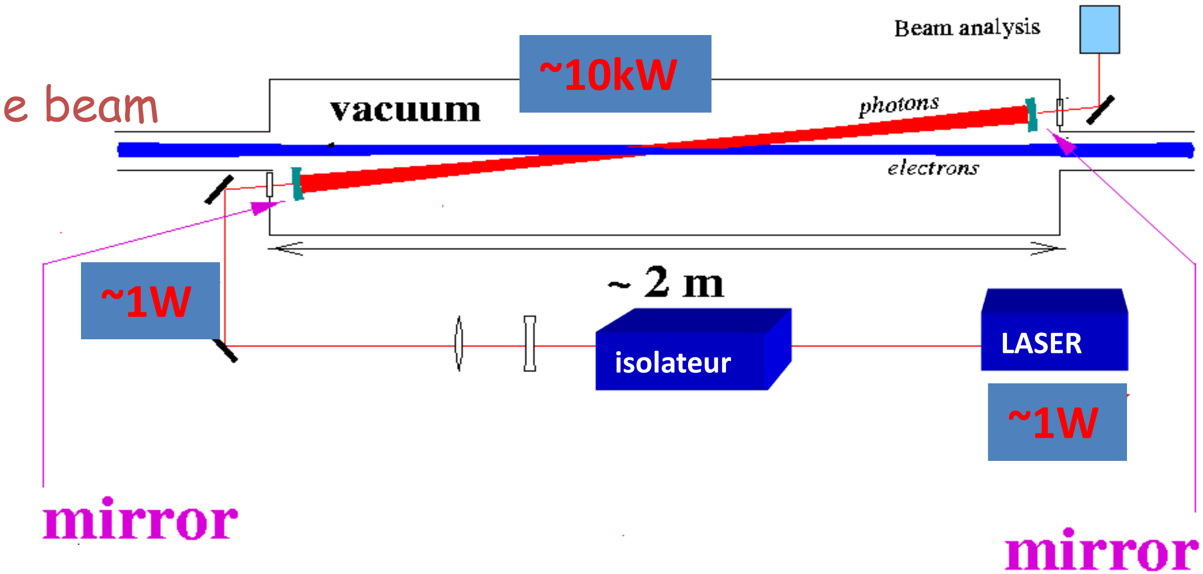
Optical systems

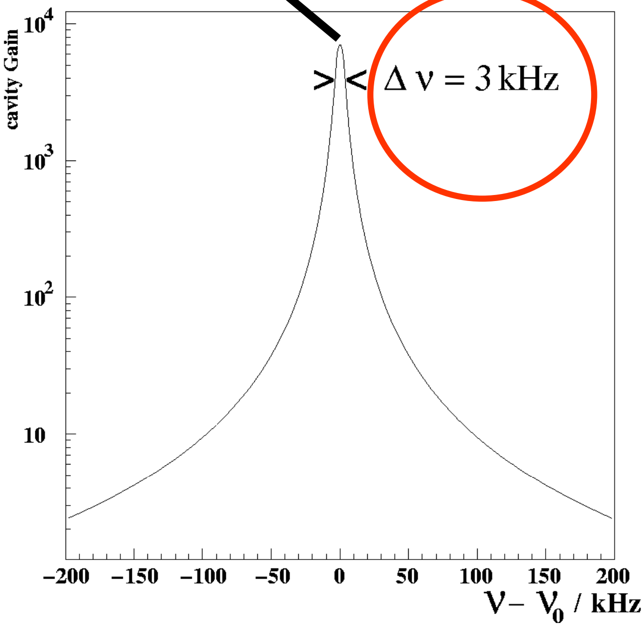
LASER BEAM PARAMETERS	
Wavelength	515 nm - 1030 nm
Average Power	**300kW - 600 kW**
Pulse length	**3 ps**
Pulse energy	7.5mJ - **15 mJ**
Spot size	30 um
Bandwidth	0.02 %
Repetition Rate	40 MHz

Optical resonator

Fabry-Perot cavity: Principle with continous wave

Gain=1/(1-R)~10000





When $\nu_{Laser} \propto c/2L \Rightarrow$ résonance

- But: $\Delta\nu/\nu_{Laser} = 10^{-11} \Rightarrow$ STRONG & ROBUST laser/cavity feedback needed

Pulsed laser/cavity feedback technique

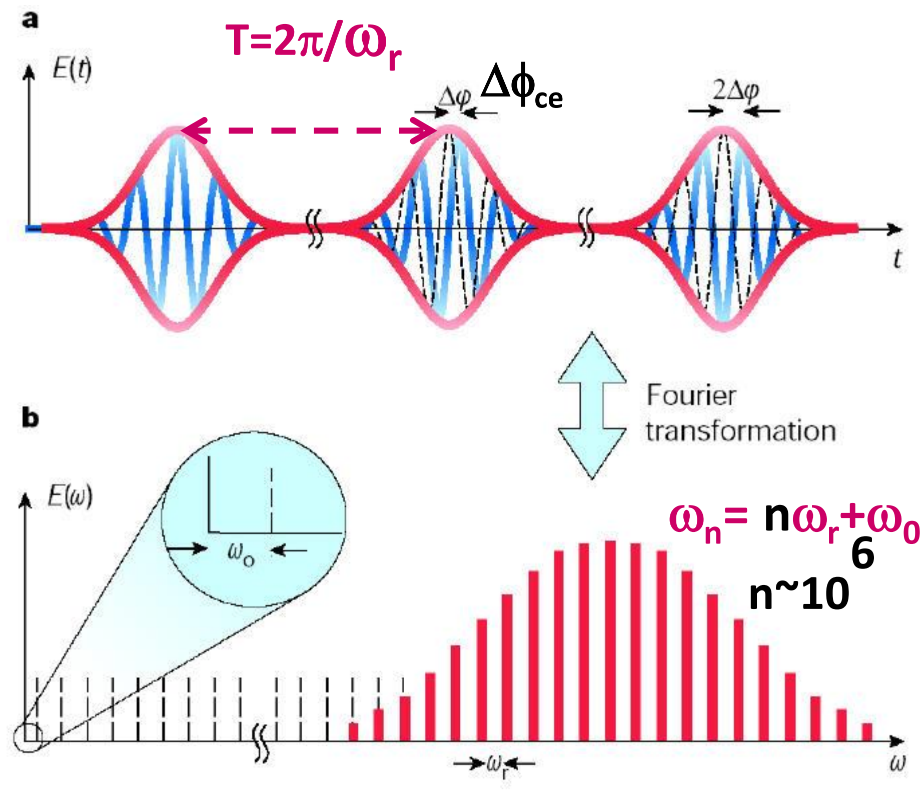
Specificity ➔ properties of passive mode locked laser beams

Frequency comb ➔ all the comb must be locked to the cavity

➔ Feedback with 2 degrees of freedom :

control of the Dilatation (rep. Rate) & Translation (CEP)

(well known metrological technics)



T. Udem et al. Nature 416 (2002) 233

Illustration of one issue : the laser cavity feedback

ERL Facility

Cavity finesse : $F \sim 10^4 \times \pi$

Optical path length : $L \sim 7.5$m

Cavity resonance frequency linewidth $\Delta\nu = c/(LF) \sim 1.3$ kHz !

$\Delta\nu/\nu = \lambda/(LF) = \sim 10^{-12}$

Same numbers as in metrology !!!

- Ultra-Low Expansion (ULE) Glass:

- Typical **length**: 10 cm

→Free spectral range ~ 1.5 GHz

- Typical **finesse**: 300,000

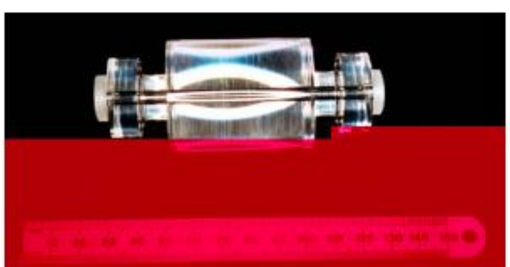
→ linewidth ~ 5 kHz

→ **power enhancement ~10^5**

[applied power (CW):

intracavity power (CW

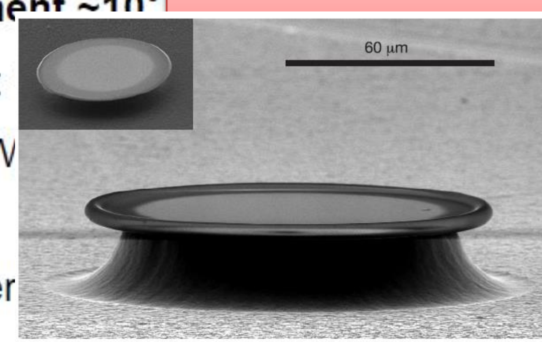
- Single-crystal Sapphire (cryogenic: ~4 K)



- Mirrors **optically contacted** to spacer

Linewidth 1.3kHz

➔F=10^6…

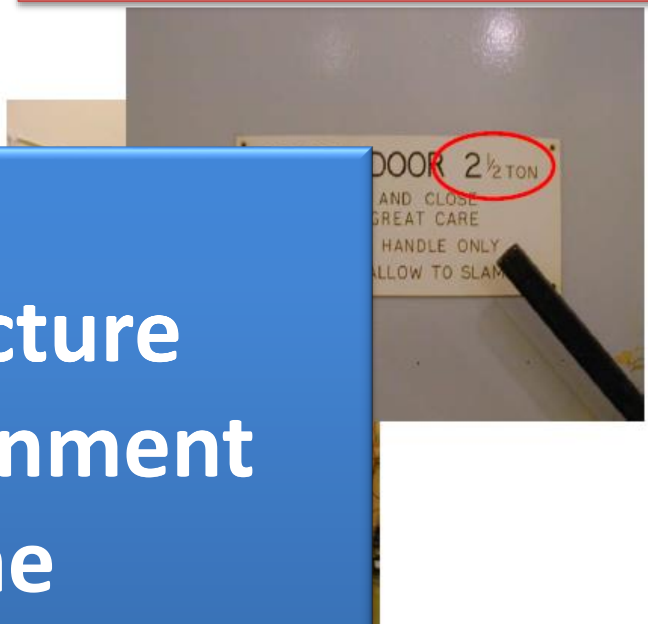


NPL M. Oxborrow

Besides
In metrology experiments :

The hyper stable small cavity is 'hyper' temperature stabilised

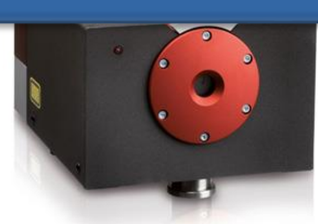
Into an hyper isolated room



Put on an

ser is used,

phisto



For γ Compton machines

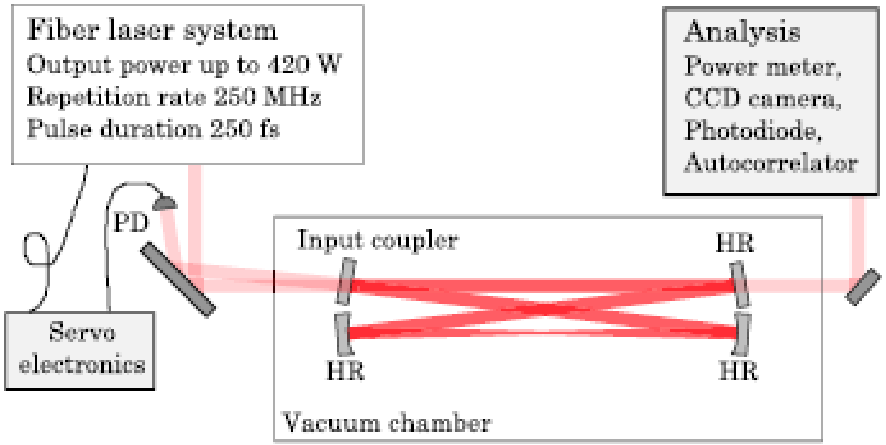
- ✓'Geant' mechanical structure
- ✓Noisy accelerator environment
- ✓Pulsed laser beam regime
  - ✓□ 1kHz linewidth oscillator
  - ✓'Huge' average & peak power !

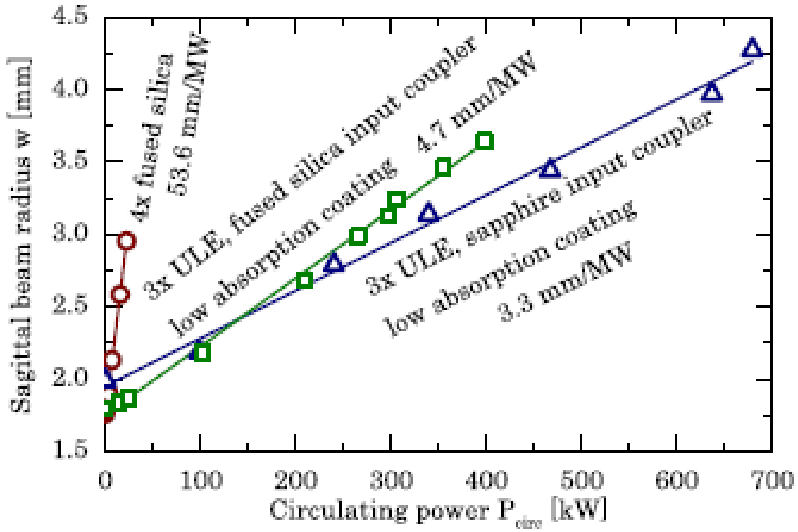
Stack power in pulsed regime

State of the art (Garching MPI):

~670kW, 10ps pulses, 1040nm @250MHz (F~5600)

OL39(2014)2595





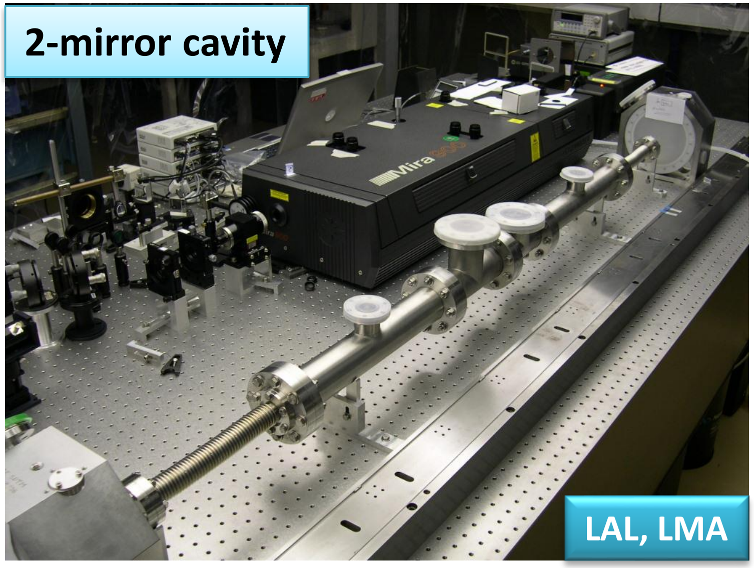
Issues

→ control of thermal lensing an thermoelastic effects

→ Damage threshold of mirror coatings

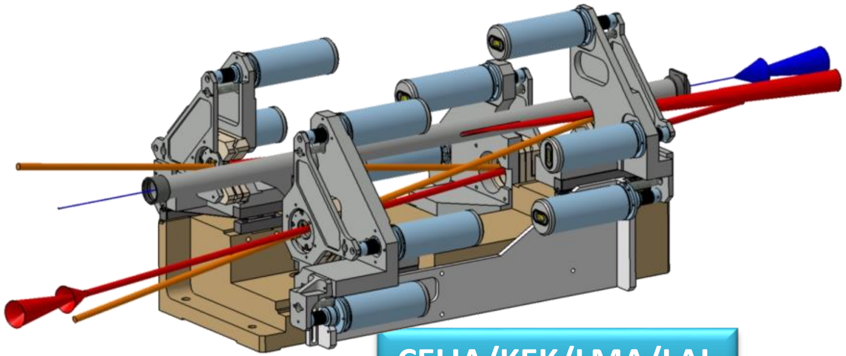
Highest cavity gain/finesse in pulsed regime

2-mirror cavity



LAL, LMA

Non planar 4-mirror cavity



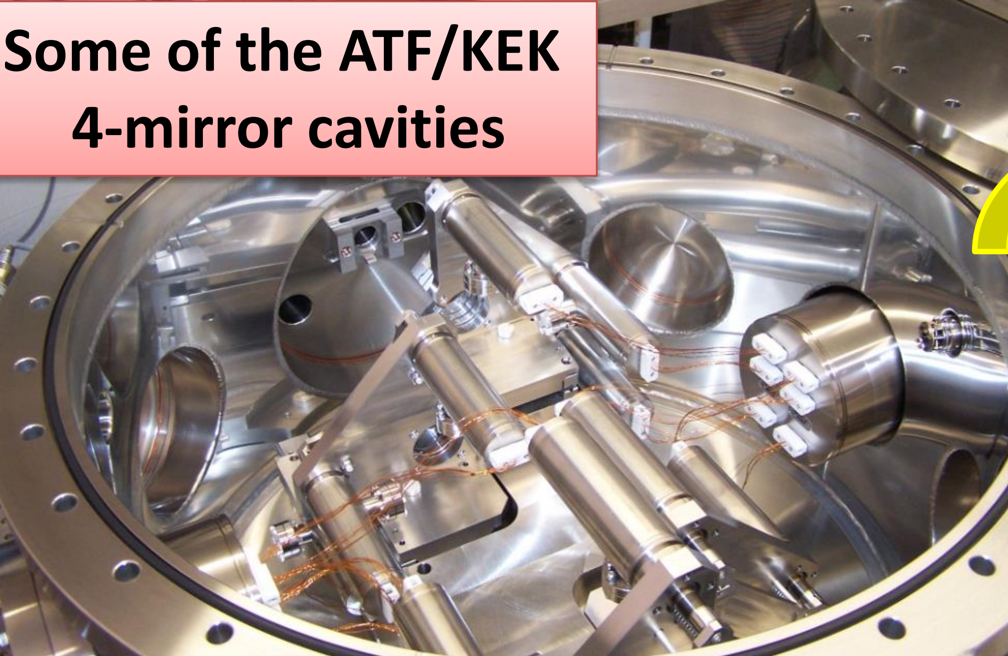
CELIA/KEK/LMA/LAL

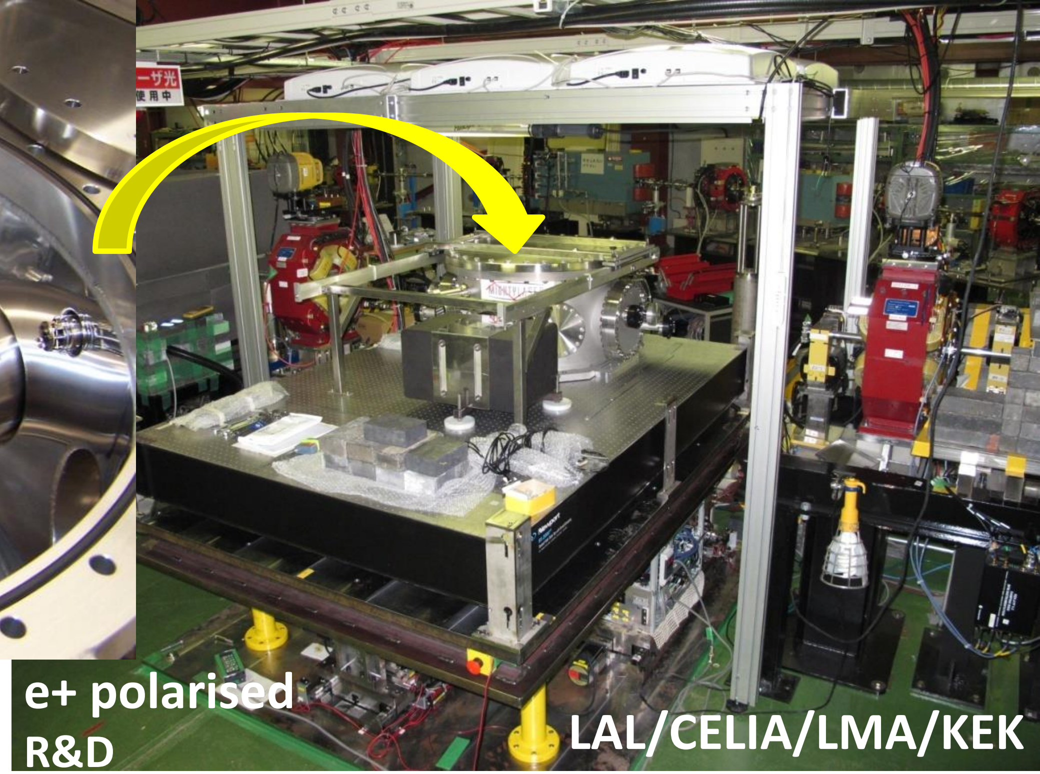
- Ti:sapph oscillator
- Picosecond pulses @ ~75MHz
  - Stable lock ,finesse~30000 (➔BW feedback~100kHz)

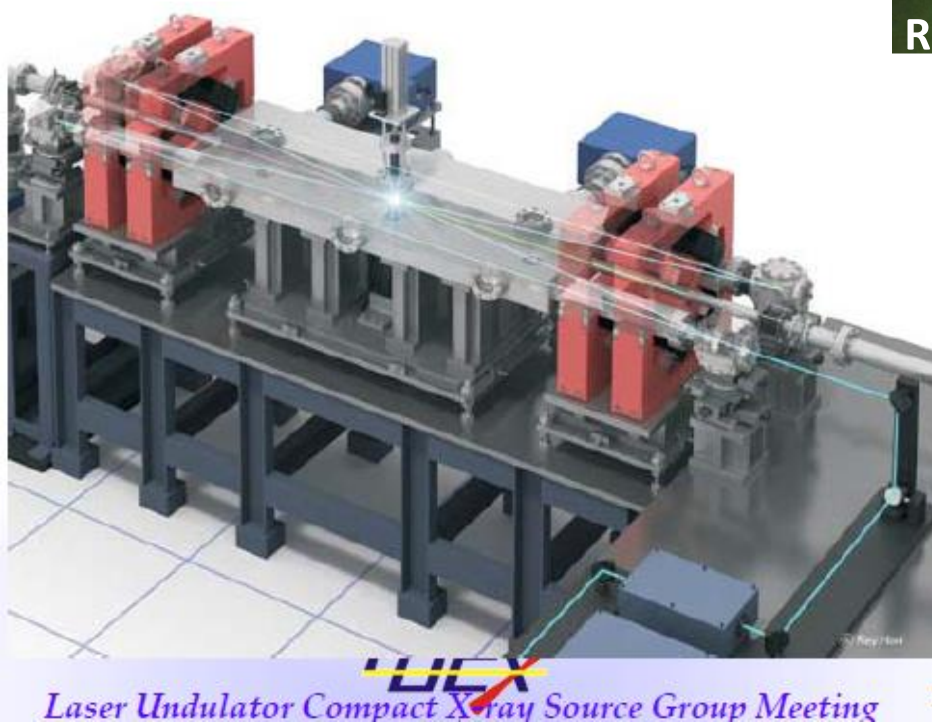
- Yb fiber oscillator
- 100fs pulses @ ~200MHz
  - Stable lock, finesse~30000 (➔BW feedback~10MHz)
- Yb fiber system amplifier

Installed /tested at ATF/KEK
(Compton e+ polarized source)

Some of the ATF/KEK 4-mirror cavities

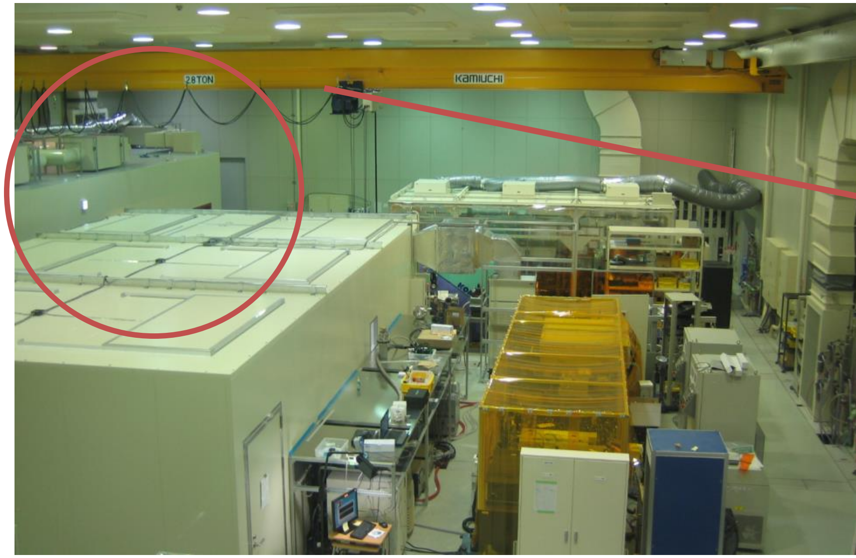


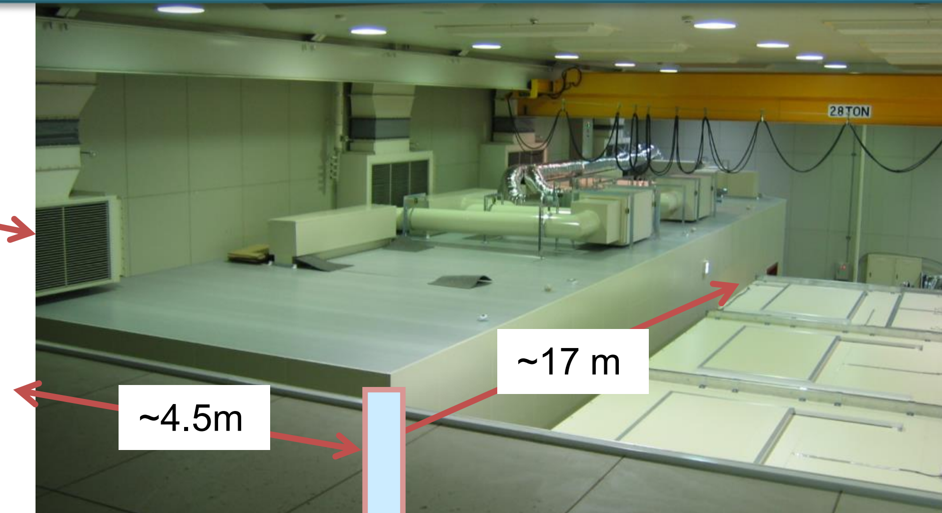




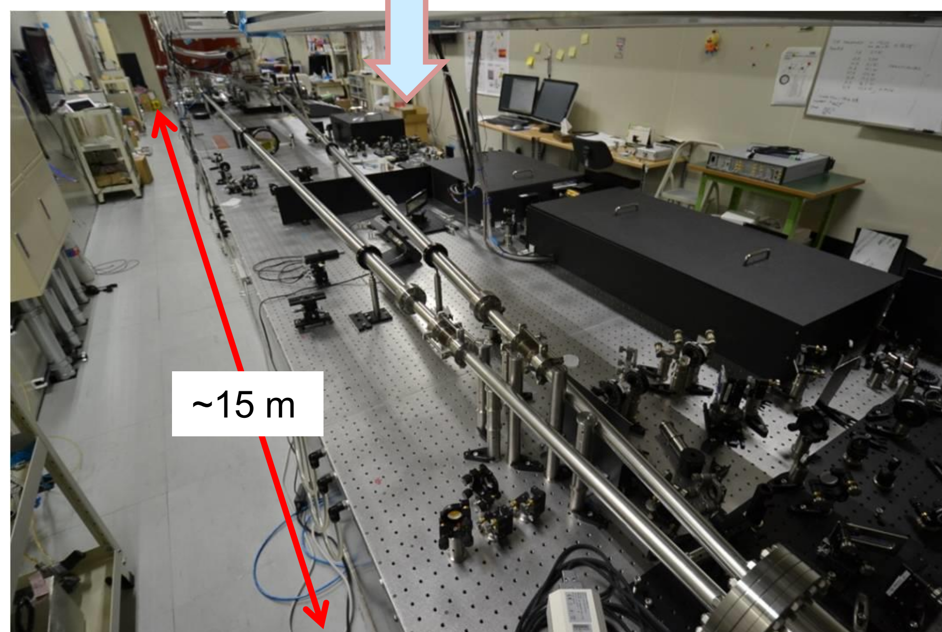
J. Urakawa KEK

Very long monolithic cavity setup (Finesse~300) for harmonic generation

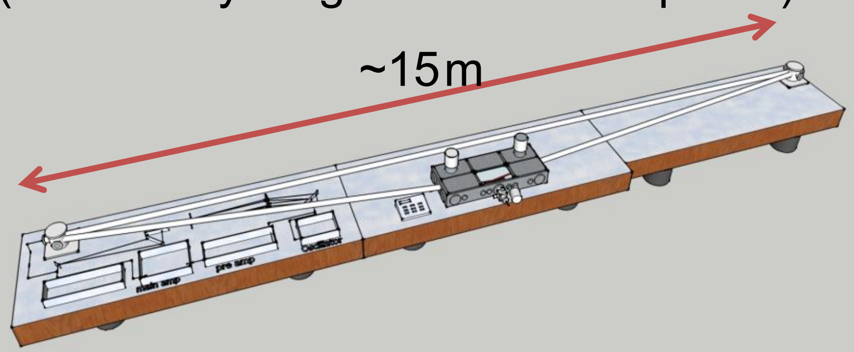




Vibration and sound isolation for external cavity



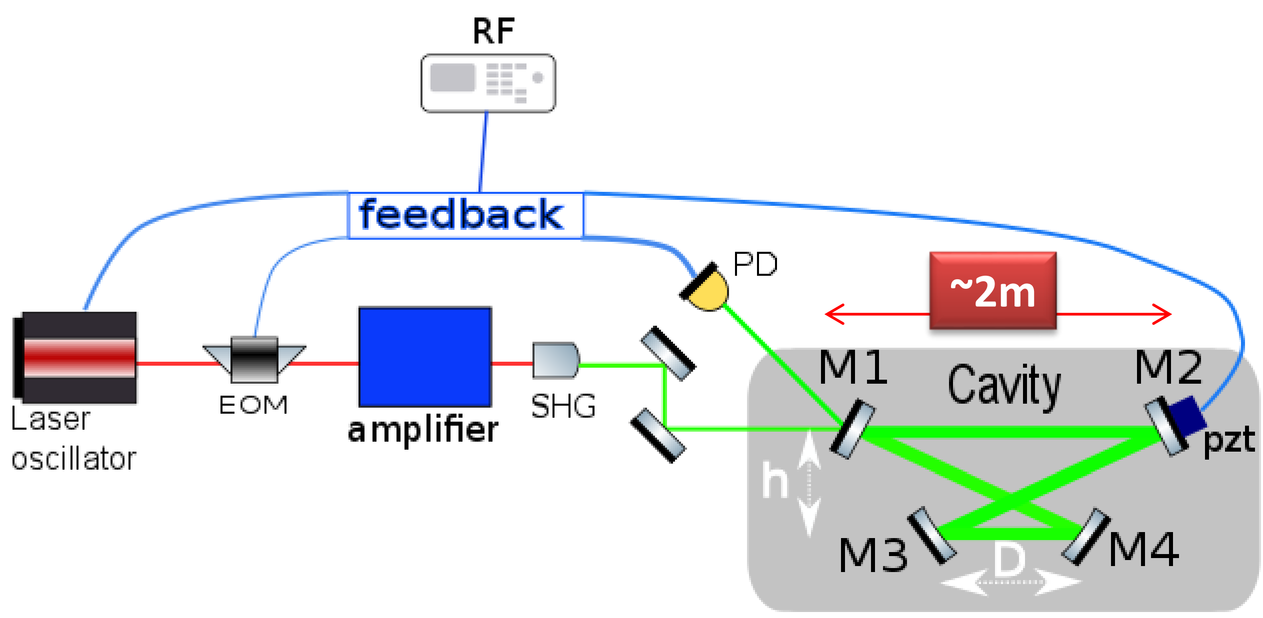
4-mirrors bow-tie cavity
(30m cavity length➔ 10MHz rep rate)



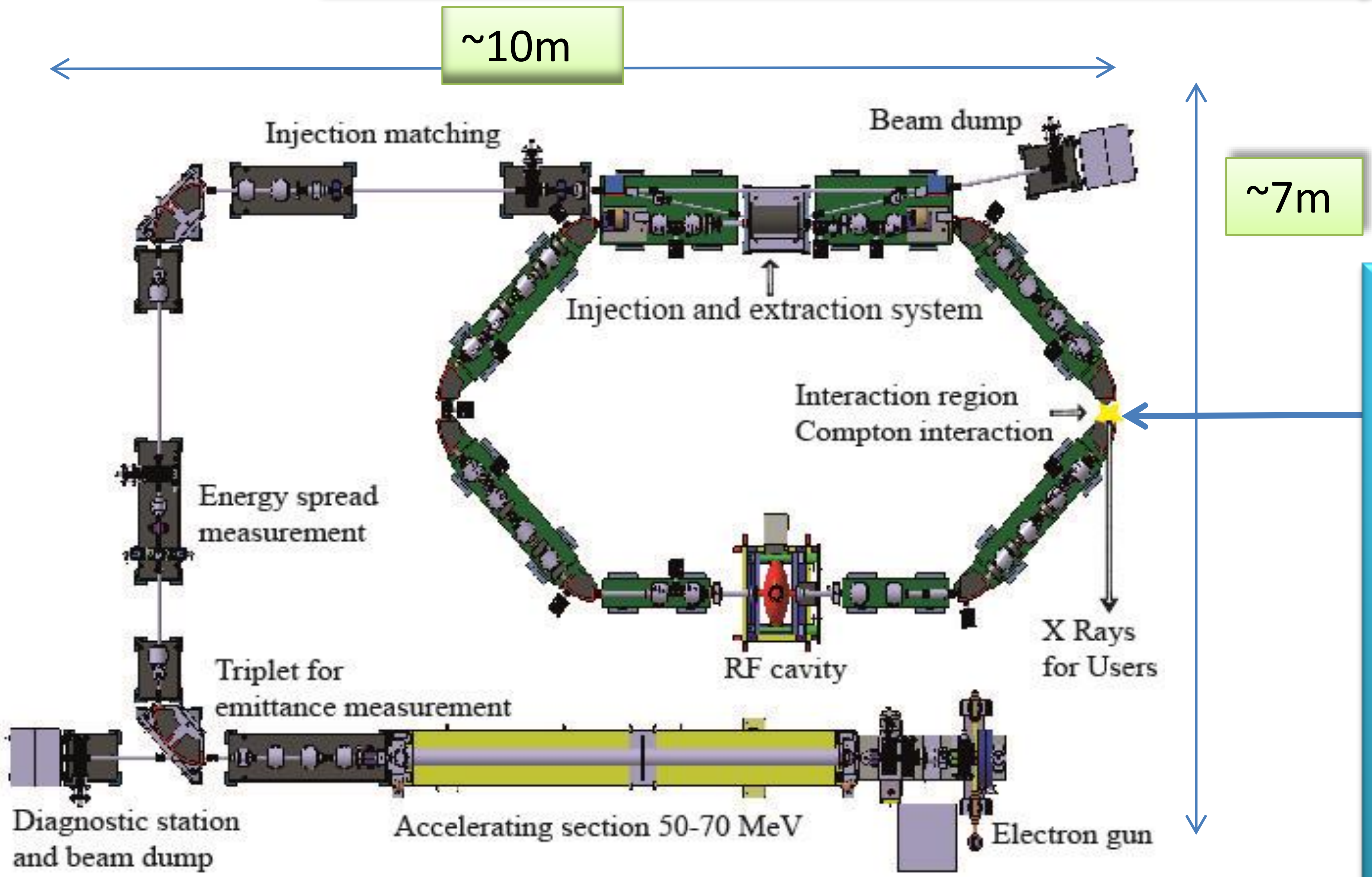
Ozawa-san, University of Tokyo, Japan. UFO2013/Davos

Cavity for the ERL Facility

- 4-mirror cavity of 7.5 m round-trip length
  - 1 inch mirror diameter
  - HR coatings
- 40 MHz Yb doped oscillator and fiber amplifier



Compact X ray source
ThomX machine
Under construction at Orsay

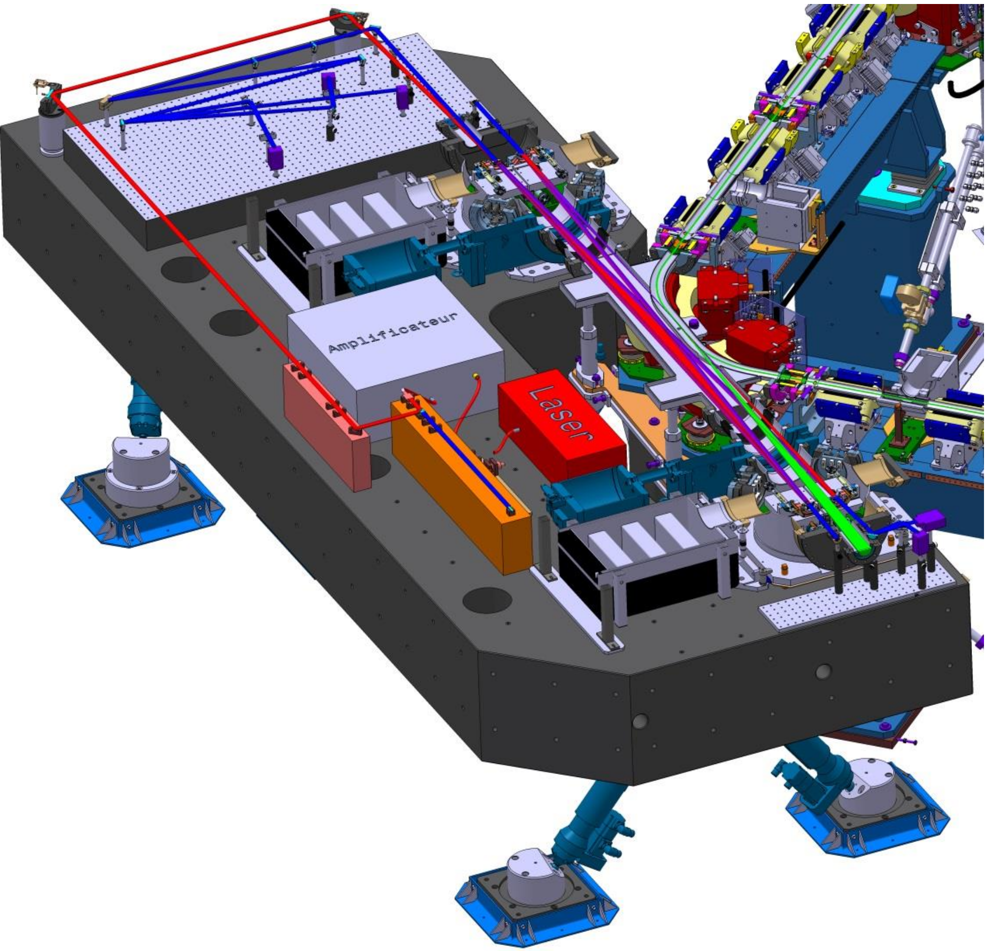


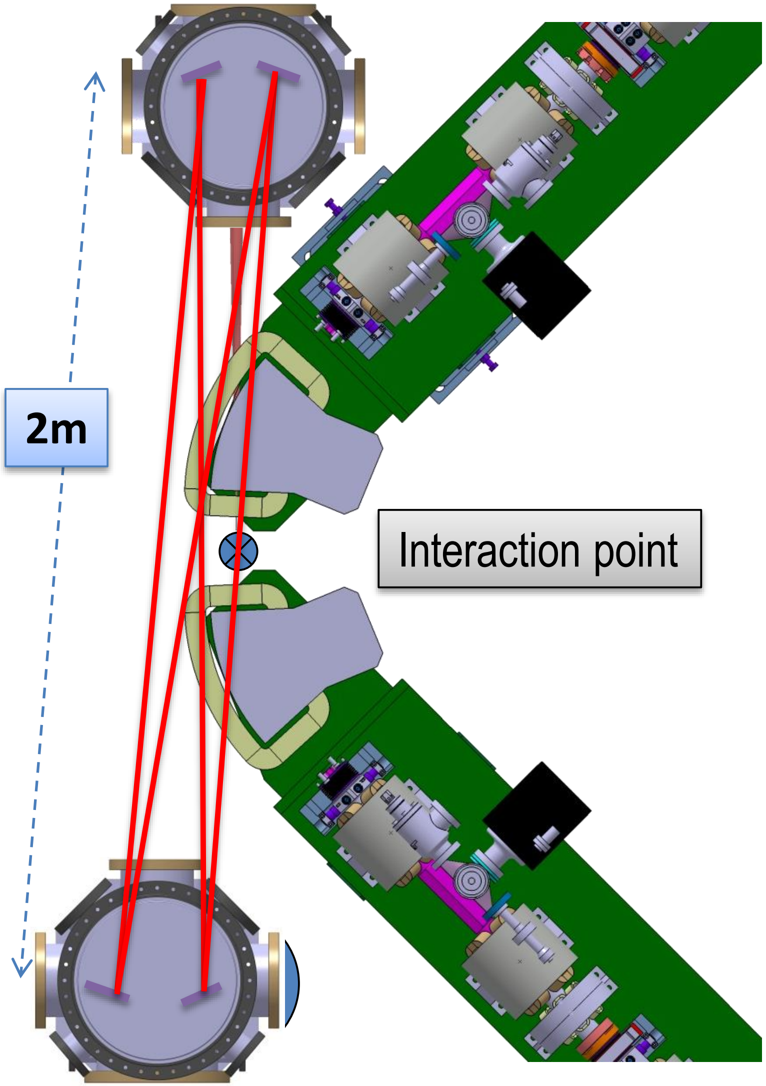
Optical resonator 37MHz

- ✓GOAL:
  - ✓10-20ps
  - ✓>150W incident power
  - ✓Cavity finesse~30000
  - ➔goal : 1MW average power

ThomX

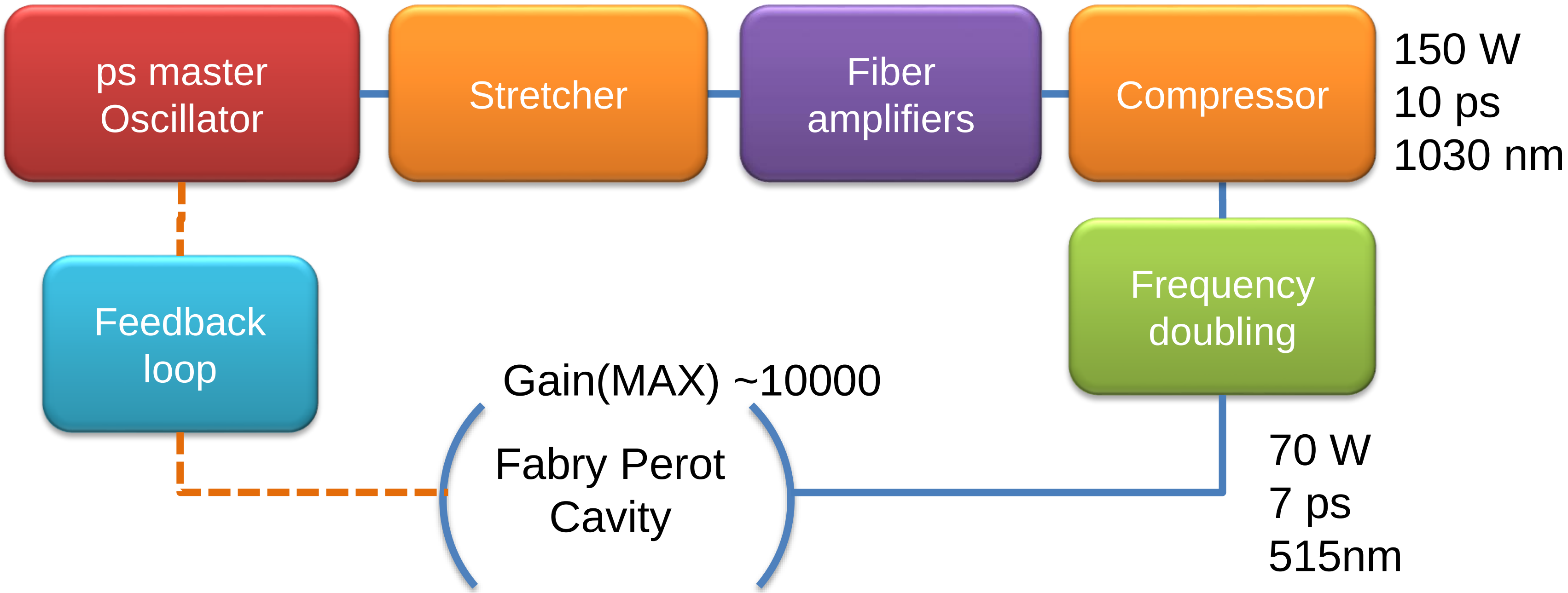
Mechanical stability
- ➔4-mirror cavity
- ➔8 m round-trip





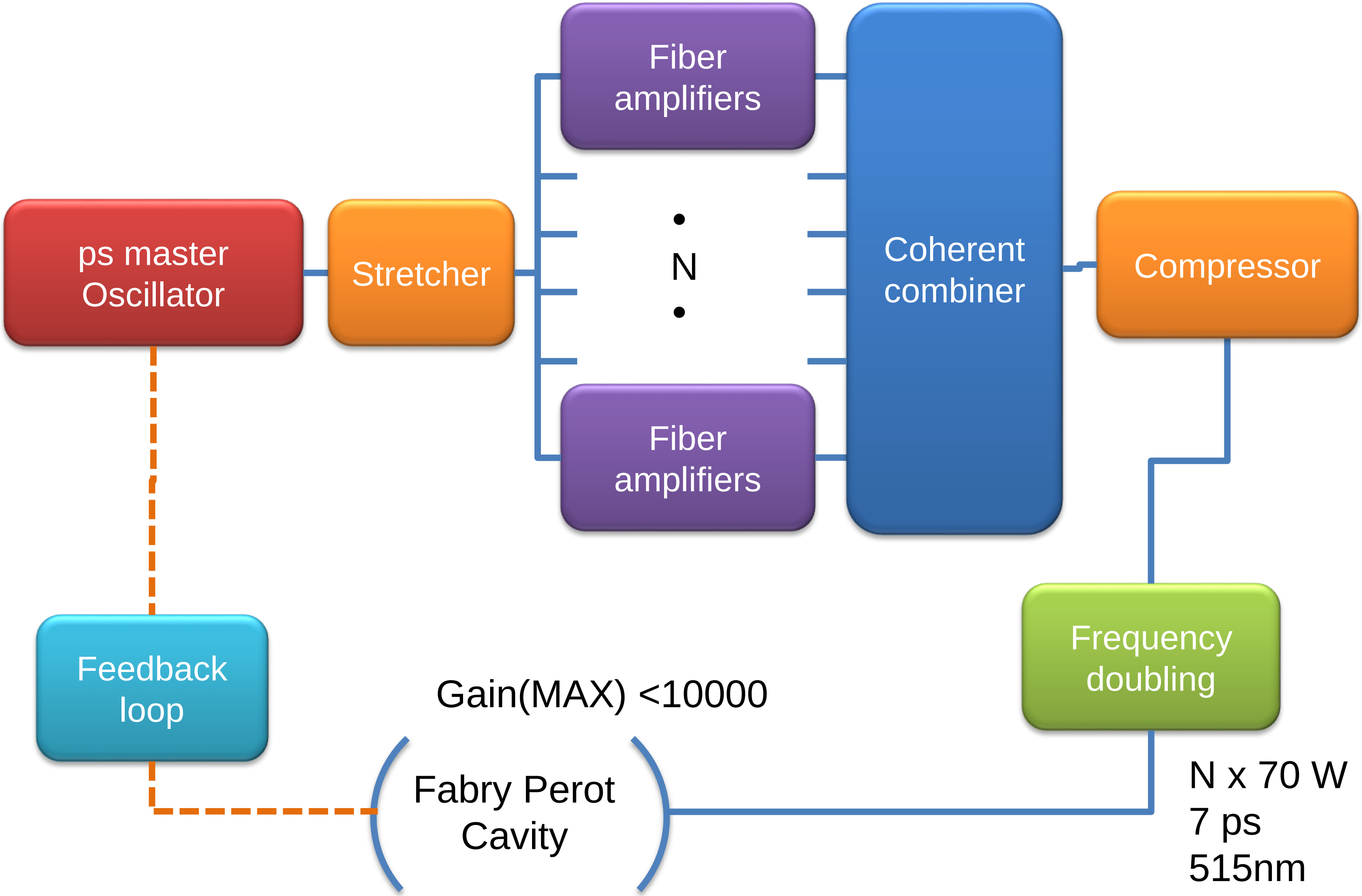
Input laser beam: Configuration 1
‘higher’ finesse / ‘lower’ input power

Configuration for LHec ERL gamma source :
~same as ThomX project (CELIA, LAL)
R&D going on at LAL and CELIA Labs.



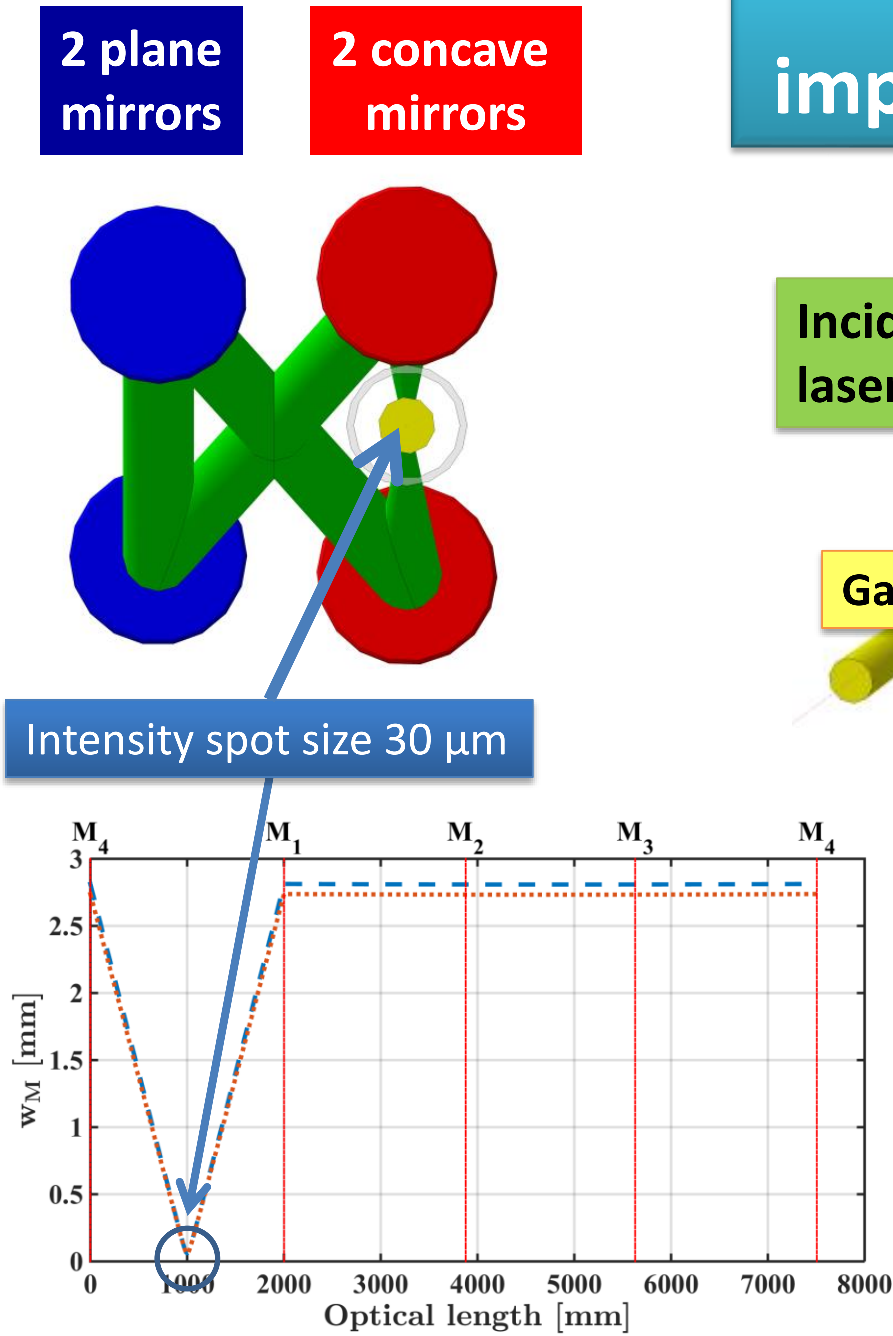
E. Cormier (CELIA)

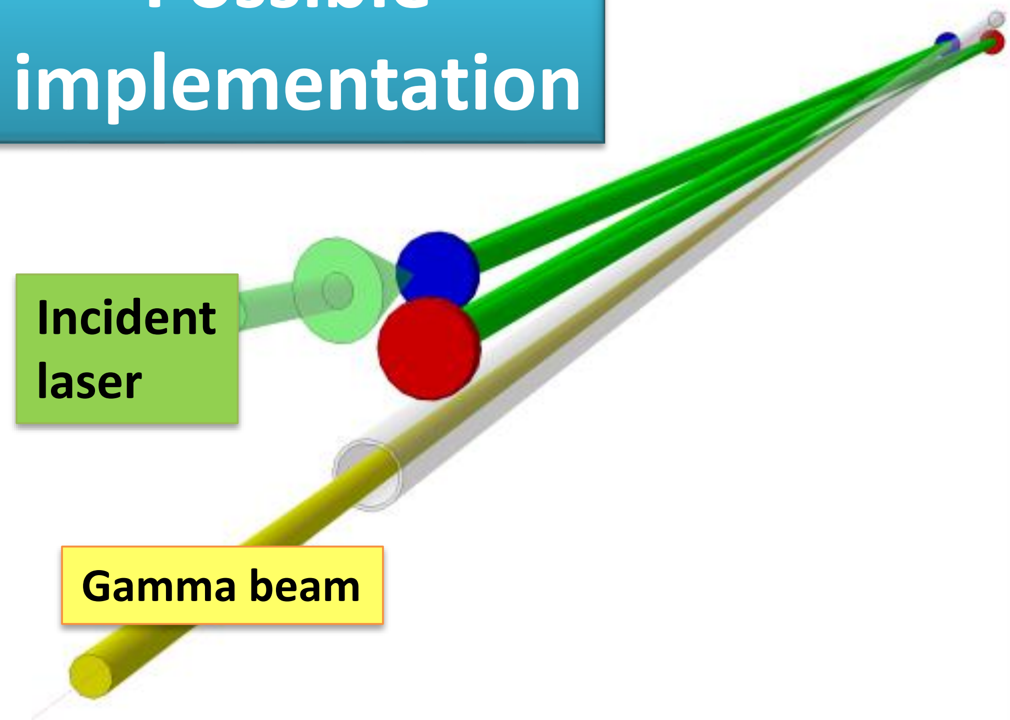
Input laser beam: Configuration 2
‘Lower’ finesse / ’higher’ input power



E. Cormier (CELIA)

Possible implementation





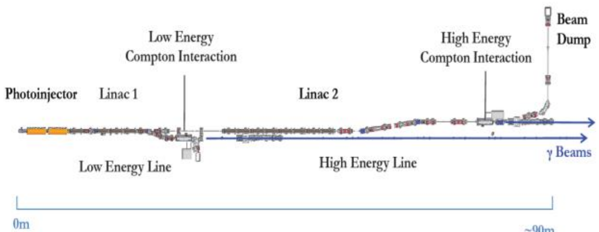
Room For optimization

Summary

- LHeC ERL offers the opportunity to provide gamma ray facility
  - Very high flux expected (at least 2 orders of magnitude above expected upgrades of existing facilities)
  - Spectral density above existing facilities
- Fabry-Perot cavities are suitable to produce this high gamma ray flux
  - 670kW average power demonstrated (@1040nm…)
  - Technology tested on accelerators (e.g. ATF/KEK)
  - Various projects are under-way to push the technology at its limits (➔1MW stacked power)
- High average power Yb doped fiber mature technology & related techniques mitigate the risks
  - Higher/lower cavity finesse % lower/higher input laser average power

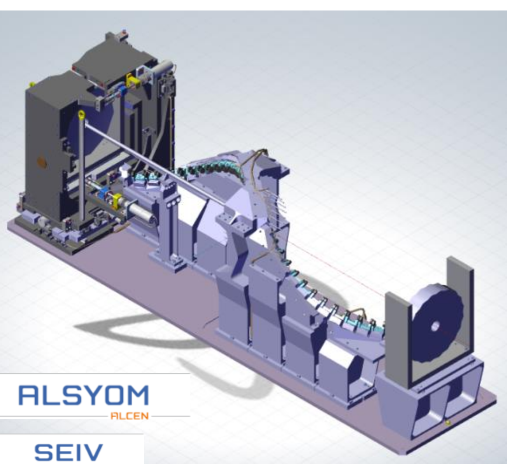
Low frequency e-bunch trains (□100Hz) & low nb bunch/train

e.g ELI-NP γ ray



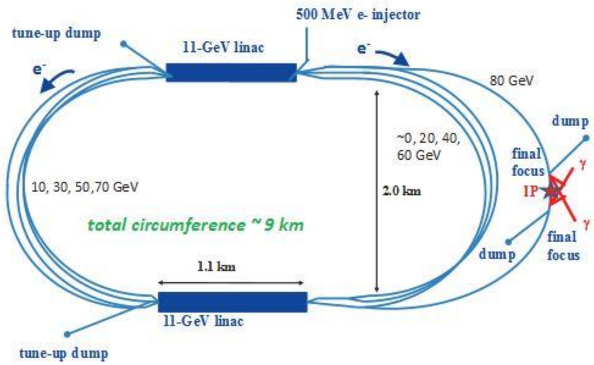
- ‘reasonable’ laser average power
- ‘Large’ peak power

➔ laser pulse recirculator



‘Low’ frequency cw e-beam (<1MHz)

e.g. γγ colliders
arXiv:1208.2827

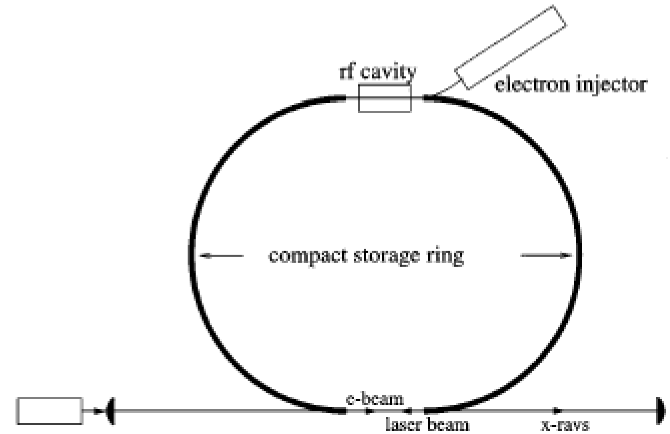


- Large average power 1MW
- Large peak power 1 TW

http://www.izest.polytechnique.edu

High frequency cw e-beam (□10MHz)

e.g. compact X ray Compton machines
Huang&Ruth PRL80(1998)977 (Lyncean Co.)



- Large average power
- ‘reasonable’ peak power

➔ Fabry-Perot cavity