Laser/cavity R&D for a polarised positron source

Collaborating Institutes:
Hiroshima, KEK, LAL

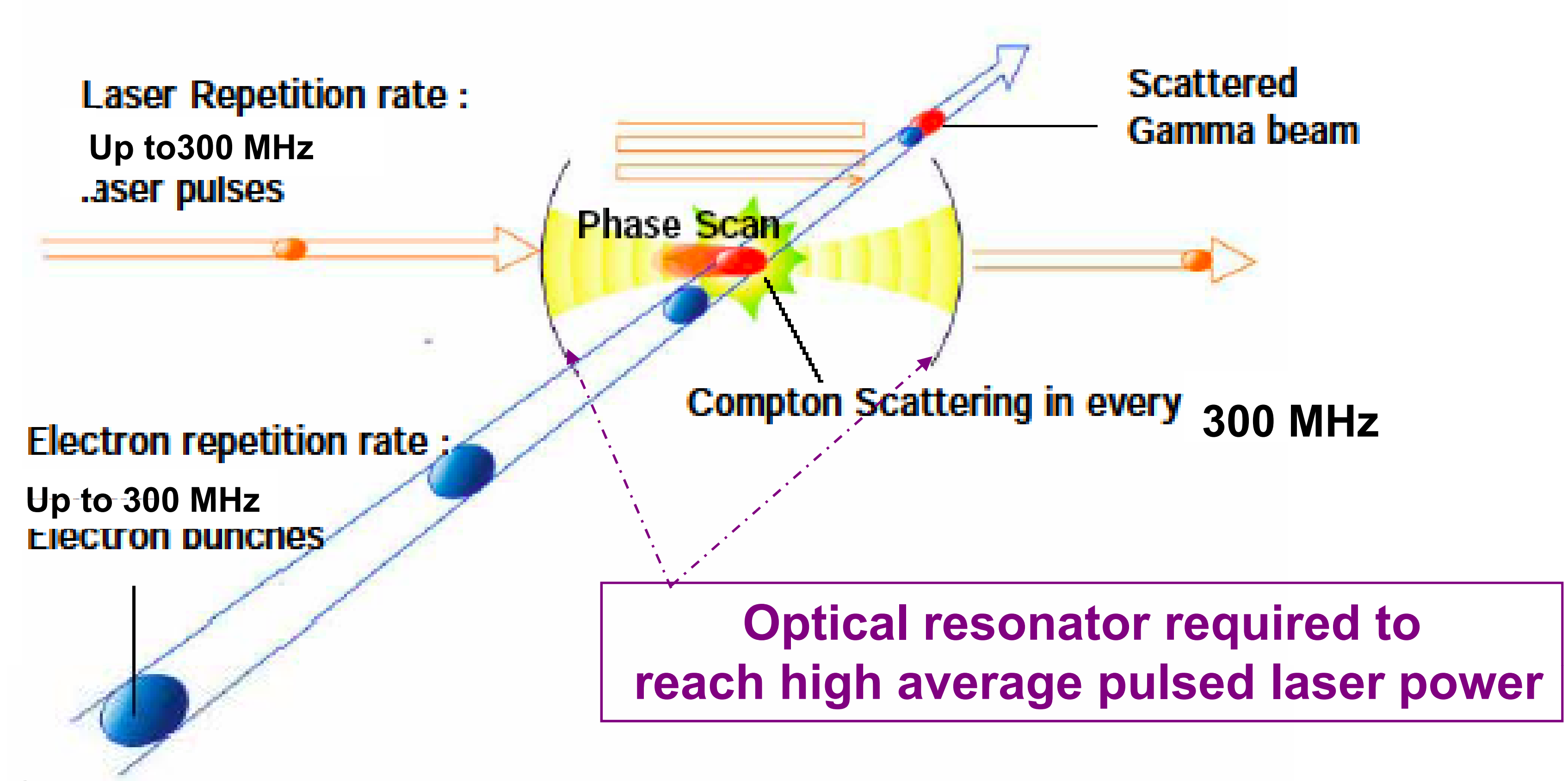
Outline
- Introduction
- Goal of the R&D
- Status
- Futur

Goal(s) of the R&D

Former goal : Compton based polarised positron source for ILC

➔ now a generic R&D on high flux [monchromatic] soft X-rays source

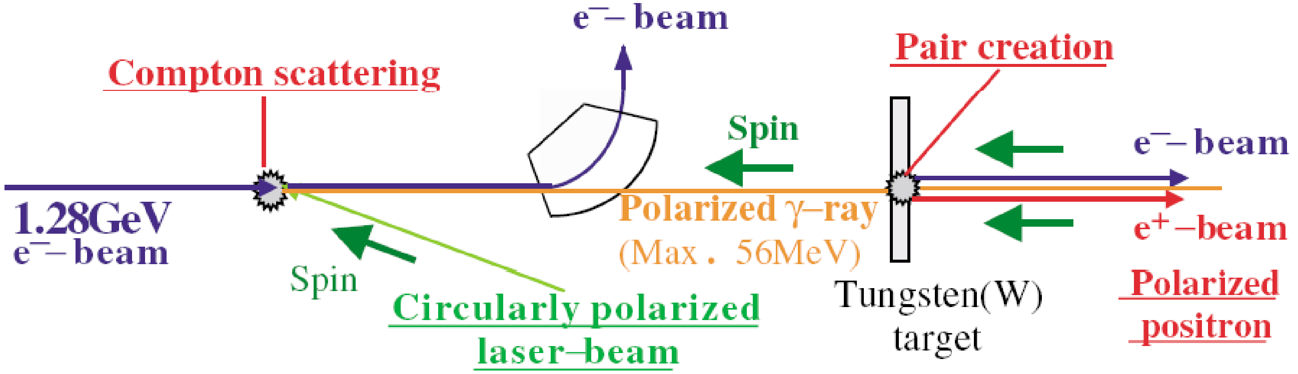
➔ e.g. production of 78keV X-rays for radiotherapy for brain cancer (glioblastom)



T. Omori

Introduction : e+ polarised source for the ILC

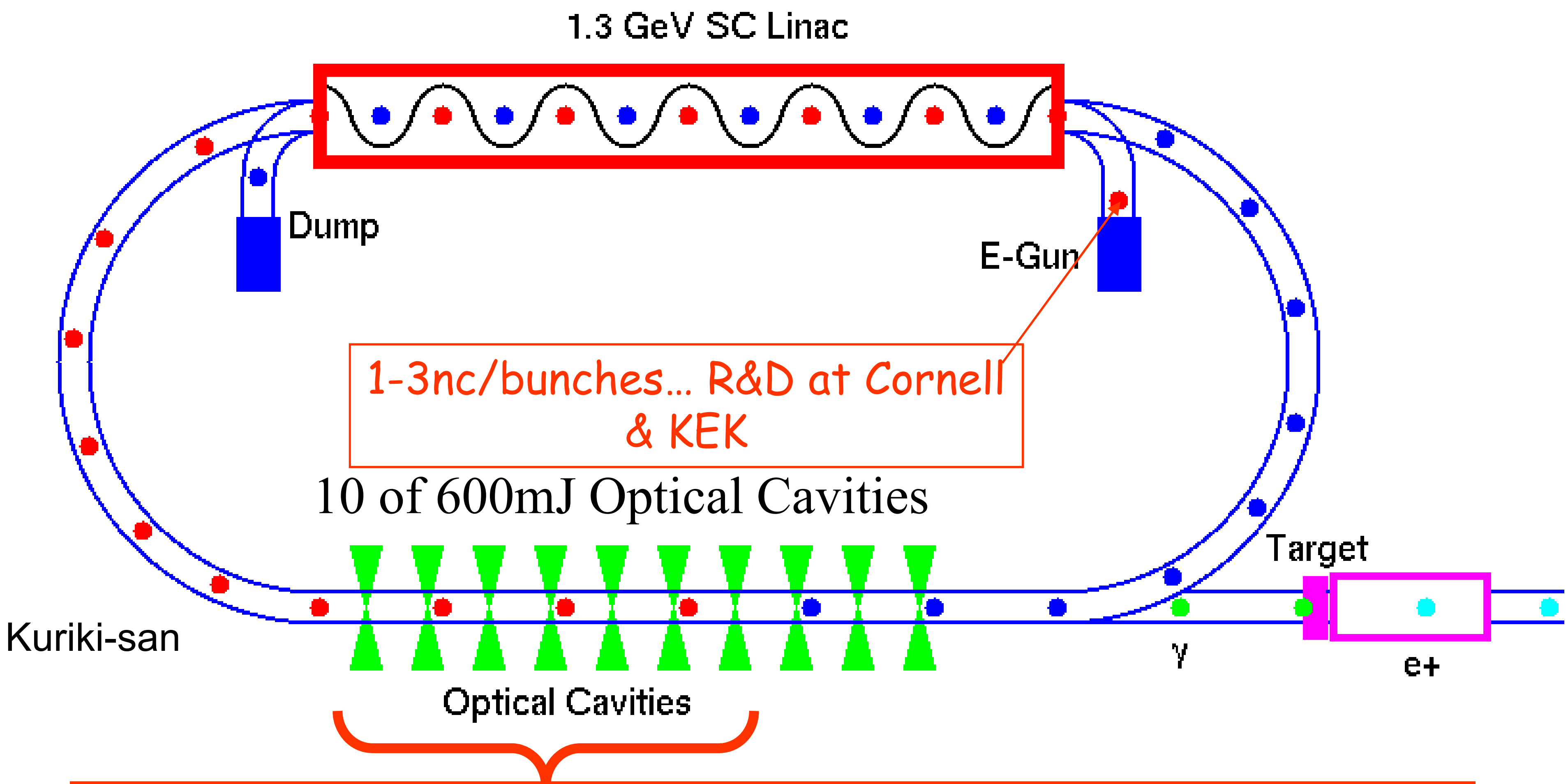
The original idea : the KEK scheme



K. Moenig idea to modify the KEK scheme
ILC beam = trains of~3000 bunchs
•AND Train frequency =5Hz

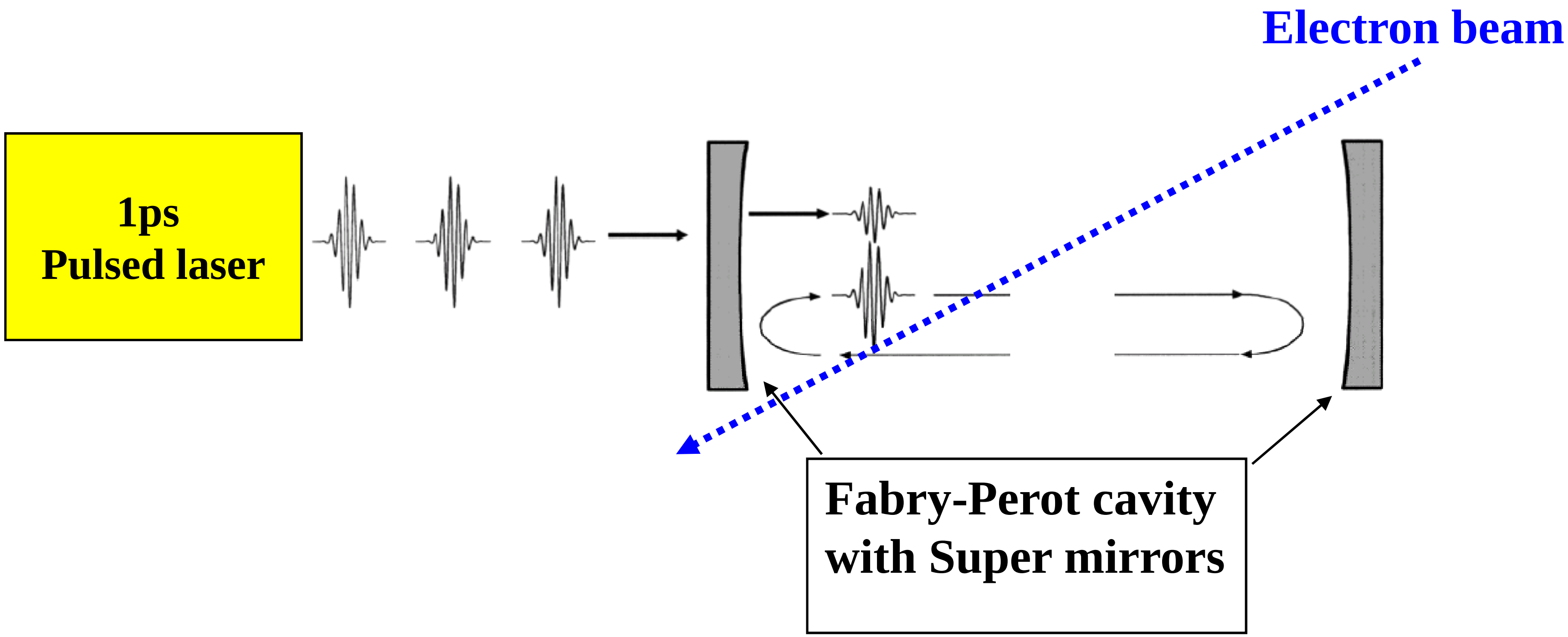
100ms to create & 100ms to cool the polarised e+

ERL scheme for the e+ polarised source
(proposed by A. Variola)



0.6J/pulse@1ps@60MHz ➔ <P>=36MW !!!
For 1 cavity ➔ **R&D !** (KEK, LAL)

Laser/cavity R&D to reach 600mJ/pulse@~100 MHz



R&D tasks on Fabry-Perot in 1ps pulsed regime:

- **Accelerator implementation & operations**
- **Max. power gain (=enhancement factor) achievable**

[published : gain 200/120fs in 2007 & gain 6000/30ps at SLAC]

- **Minimisation of laser beam spot size to optimize Compton X-section**

Complementary R/D in LAL and in KEK

R/D in LAL

Very High Enhancement ~ 20000-100000

R/D in KEK

Moderate Enhancement ~ 1000

Complementary R/D in LAL and in KEK

R/D in LAL

Very High Enhancement ~ 20000-100000

Small spot size ~ 10 micron

R/D in KEK

Moderate Enhancement ~ 1000

Moderate spot size ~ 30 micron

Complementary R/D in LAL and in KEK

R/D in LAL

Very High Enhancement ~ 20000 - 100000

Small spot size ~ 10 micron

Sofisticated cavity stucture with 4 mirrors

R/D in KEK

Moderate Enhancement ~ 1000

Moderate spot size ~ 30 micron

Simple cavity stucture with two mirrors

Complementary R/D in LAL and in KEK

R/D in LAL

Very High Enhancement ~ 20000 - 100000

Small spot size ~ 10 micron

Sofisticated cavity stucture with 4 mirrors

Digital feedback

R/D in KEK

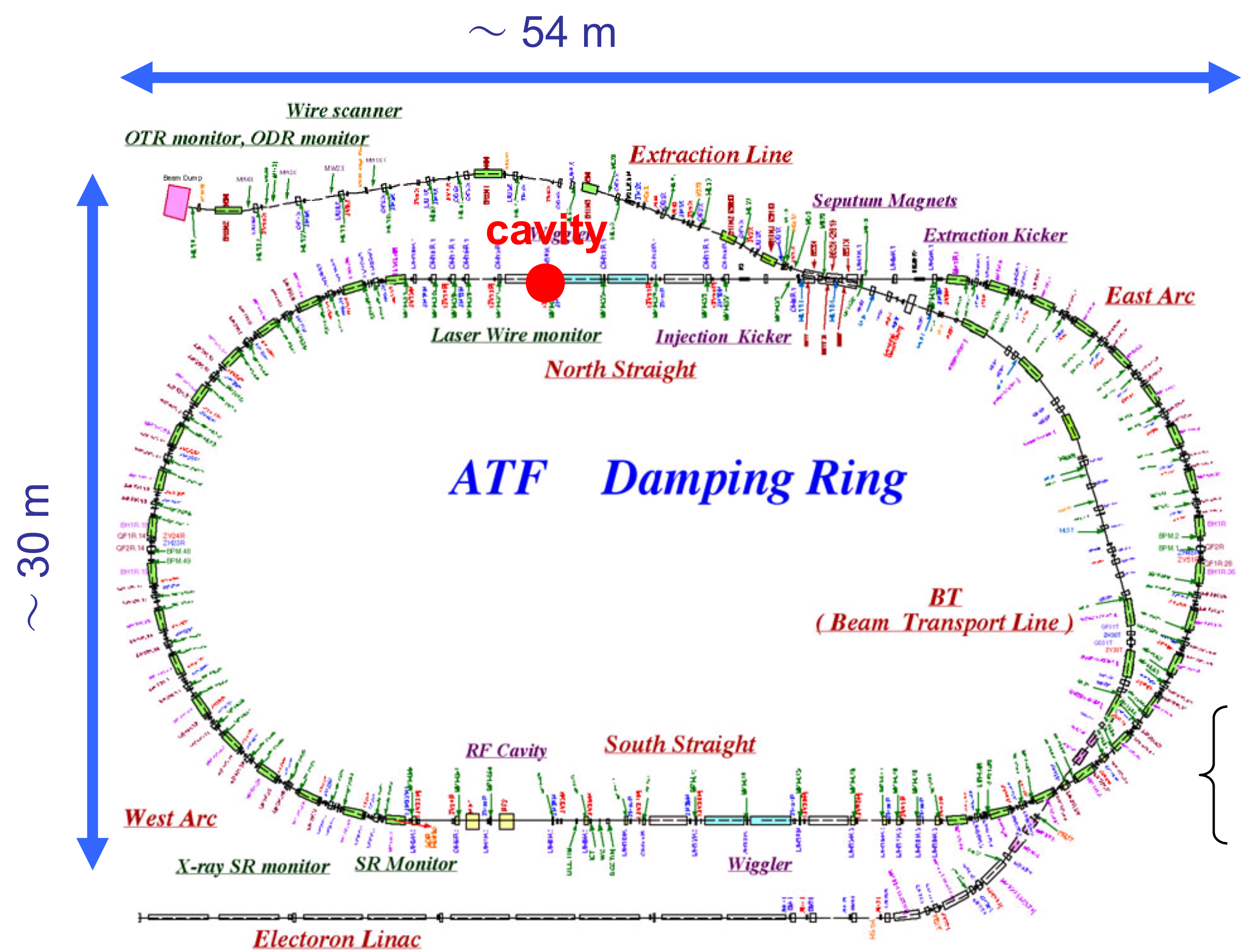
Moderate Enhancement ~ 1000

Moderate spot size ~ 30 micron

Simple cavity stucture with two mirrors

Analog feedback

R&D at KEK : Cavity installation on the Accelerator Test Facility (ATF)



Beam Energy

→ 1.28GeV

Beam Size

→ 100μm × 10μm

Emittance →

1.0×10^{-9} rad.m

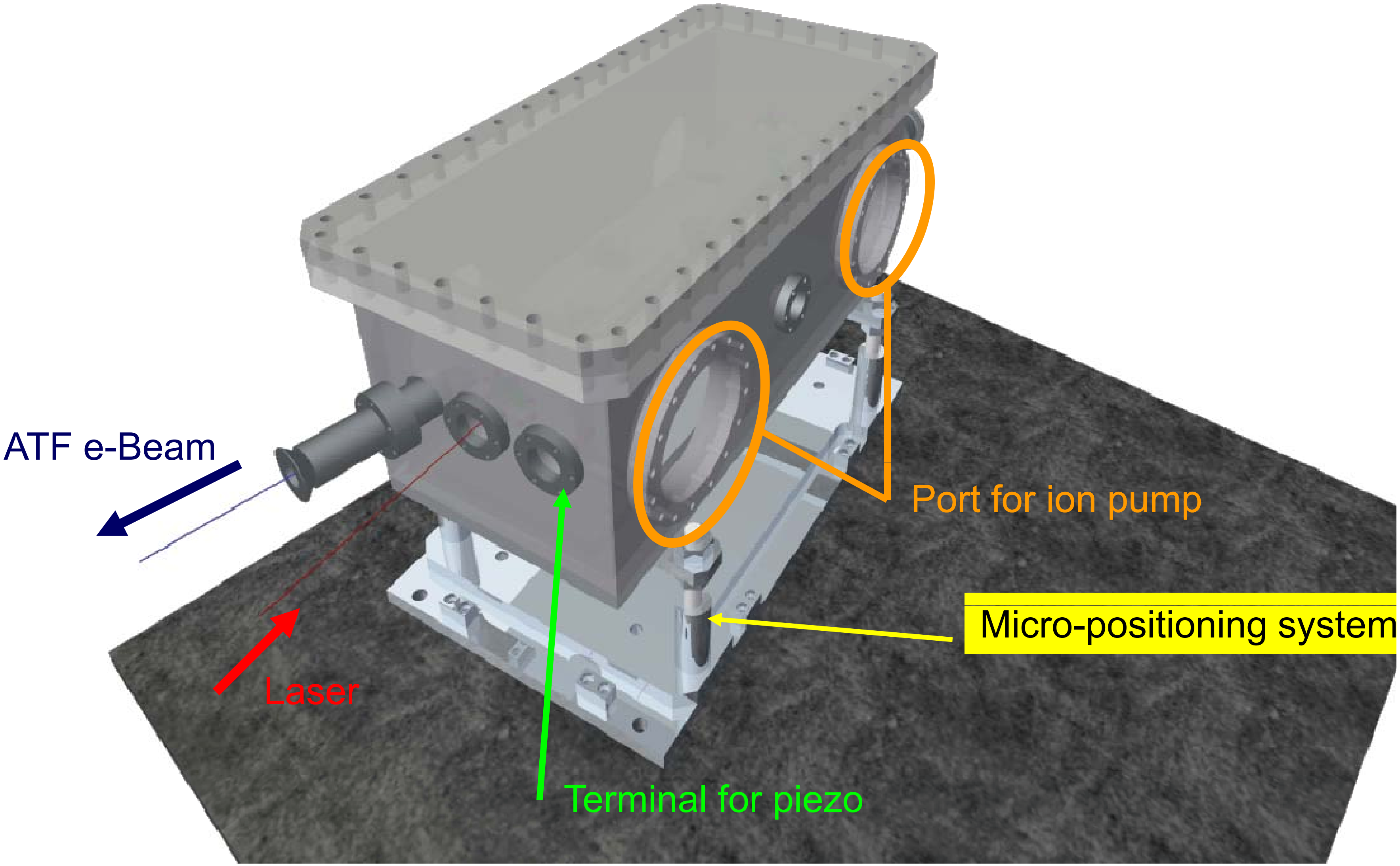
1.0×10^{-11} rad.m

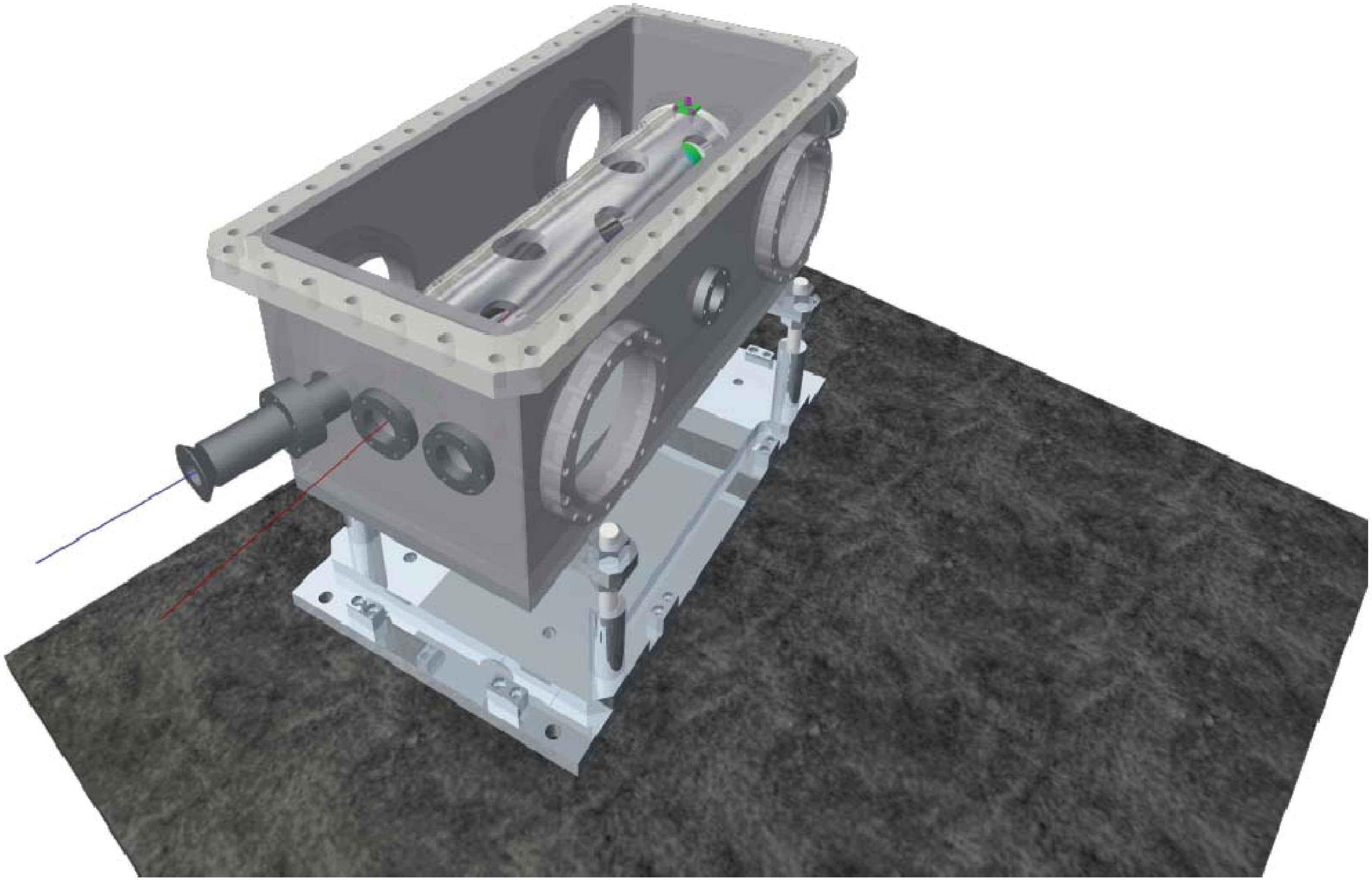
(Ultra Low !!)

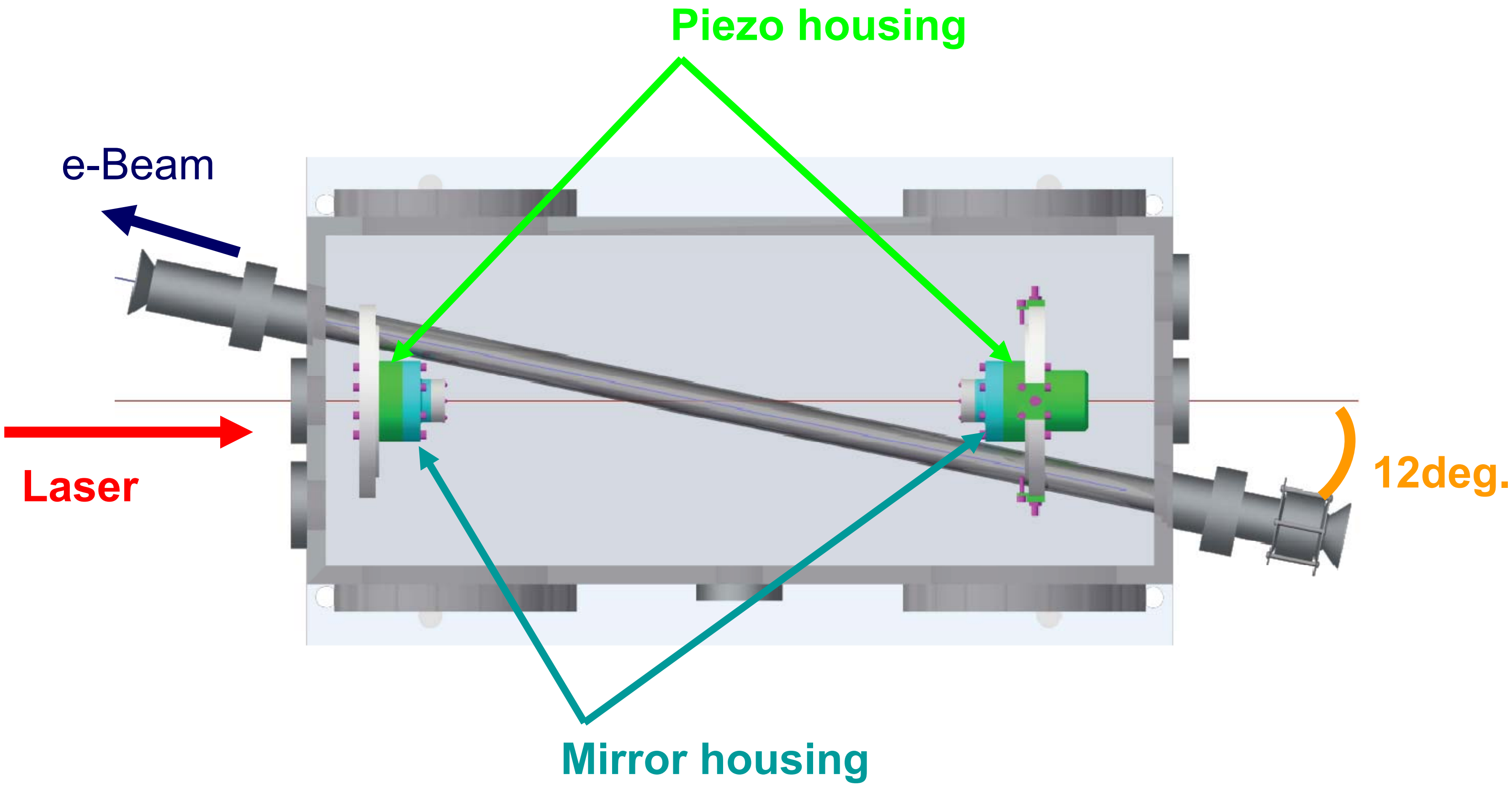
(H. Shimizu)

R&D Report in ATF

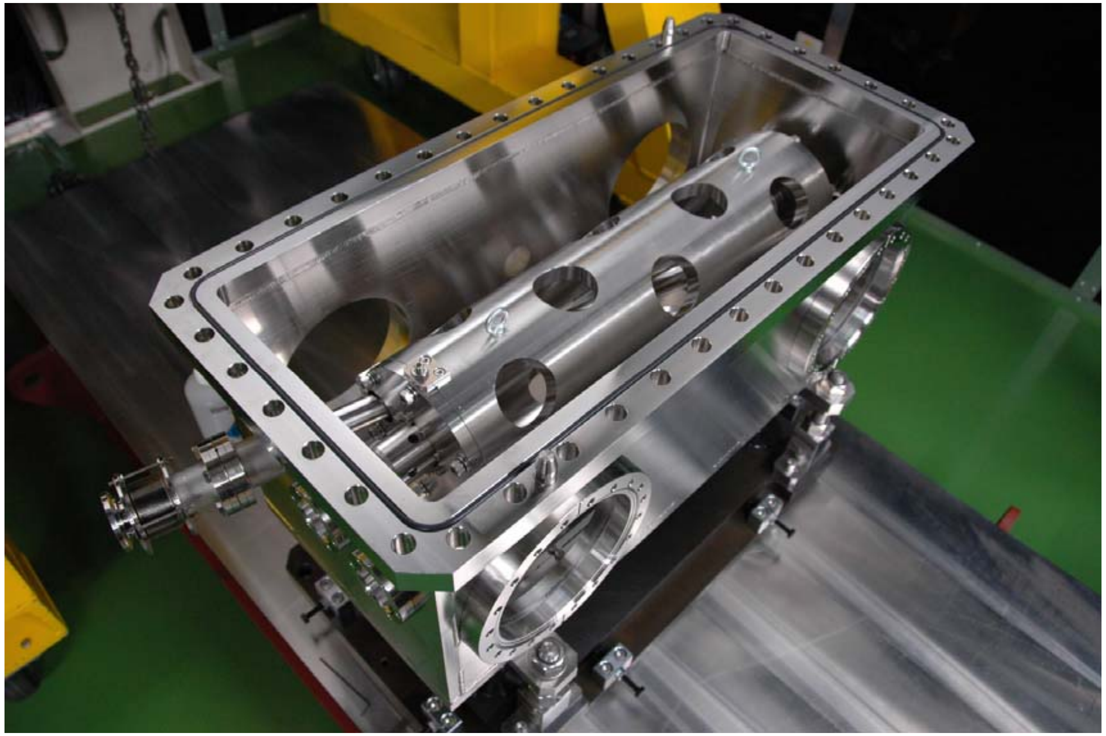
Laser Section	
Type	YAG-VAN (1064nm)
Power	10 W
Frequency	357 MHz
Pulse Width	10 ps
Cavity Section	
Length	420 mm
Mirror Reflection Coeff.	99.7 %
Beam Waist	60 μm (in 2σ)
Crossing Angle	12 degree


ATF e-Beam
Port for ion pump
Micro-positioning system
Laser
Terminal for piezo





Piezo housing
e-Beam
Laser
12deg.
Mirror housing

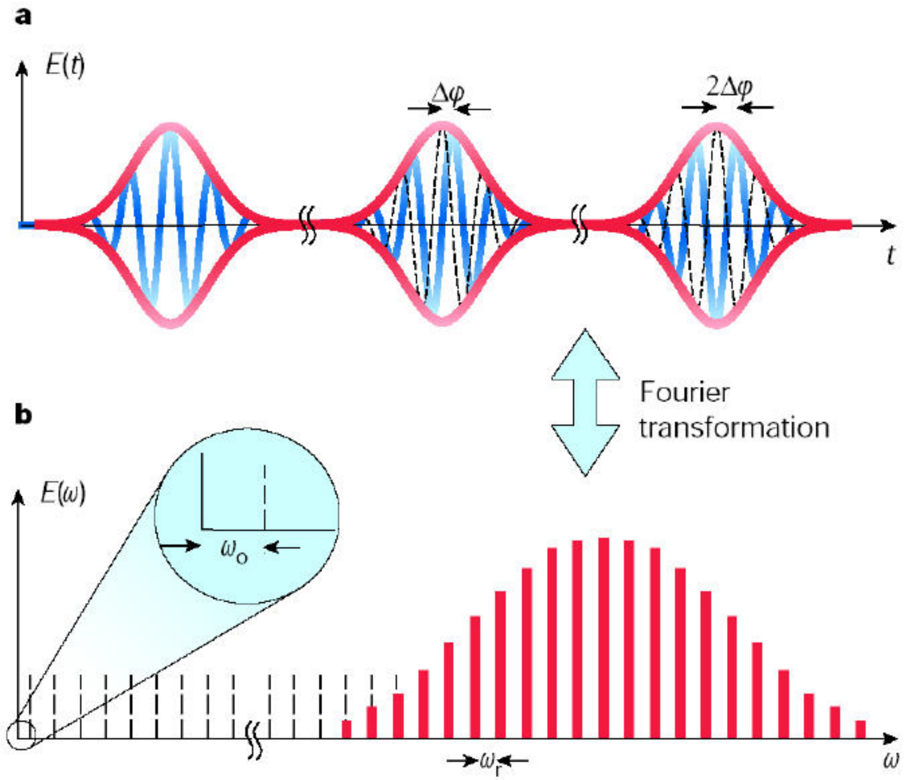


Status :

- Cavity received
- Enhancement ~ 1000
- Feedback under studies
- Installation ➔ automn 2007

R&D at LAL : toward very high power enhancement

Difficulty = properties of passive mode locked laser beams



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

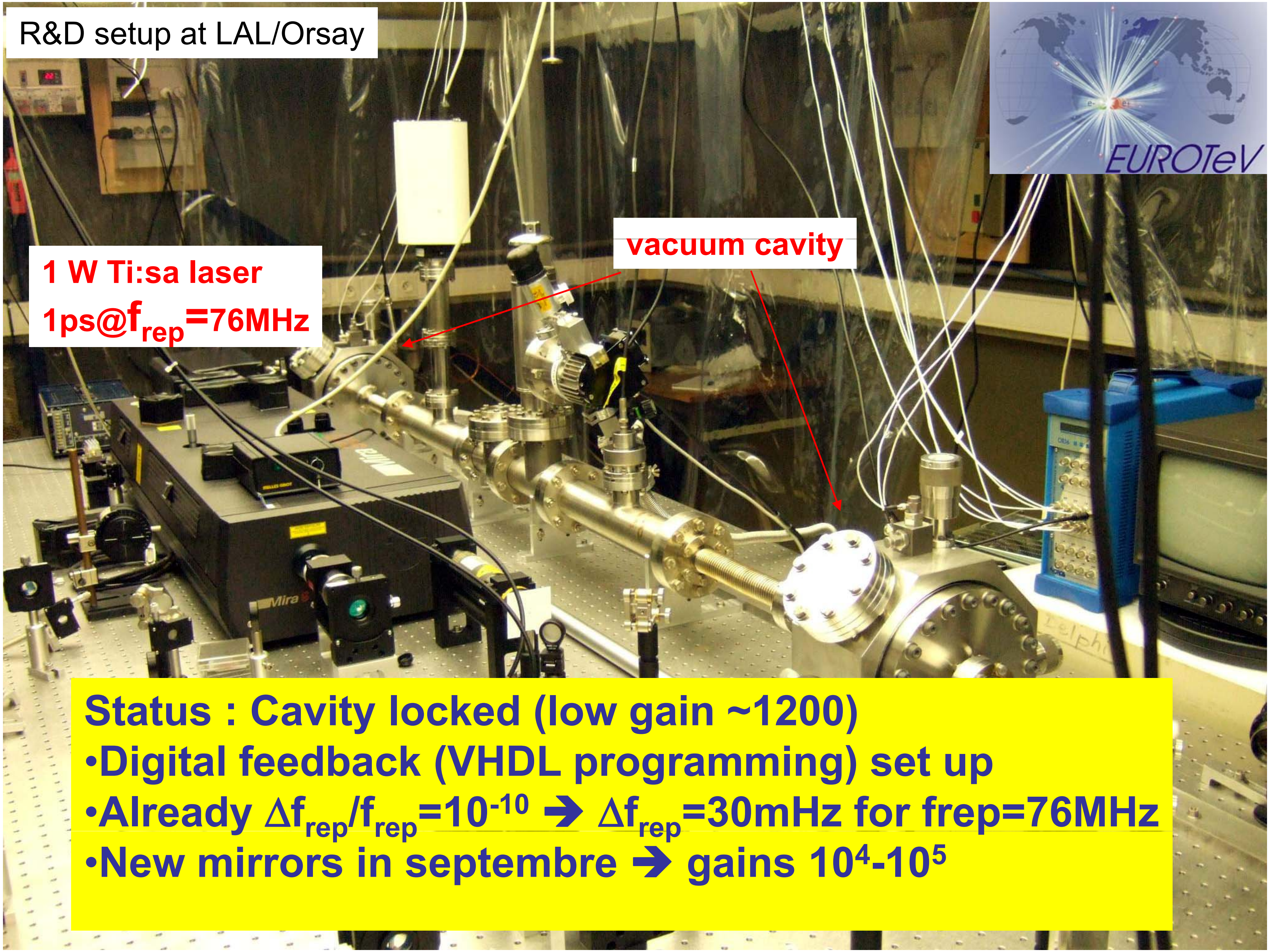
Frequency comb ➔ all the comb must be locked to the cavity

➔ Feedback with

2 degrees of freedom :

control of the

Dilatation & translation


R&D setup at LAL/Orsay
EUROTeV
1 W Ti:sa laser
1ps@f_{rep}=76MHz
vacuum cavity
Mira
Status : Cavity locked (low gain ~1200)
•Digital feedback (VHDL programming) set up
•Already $\Delta f_{rep}/f_{rep}=10^{-10}$ ➔ Δf_{rep}=30mHz for frep=76MHz
•New mirrors in septembre ➔ gains 10^4-10^5

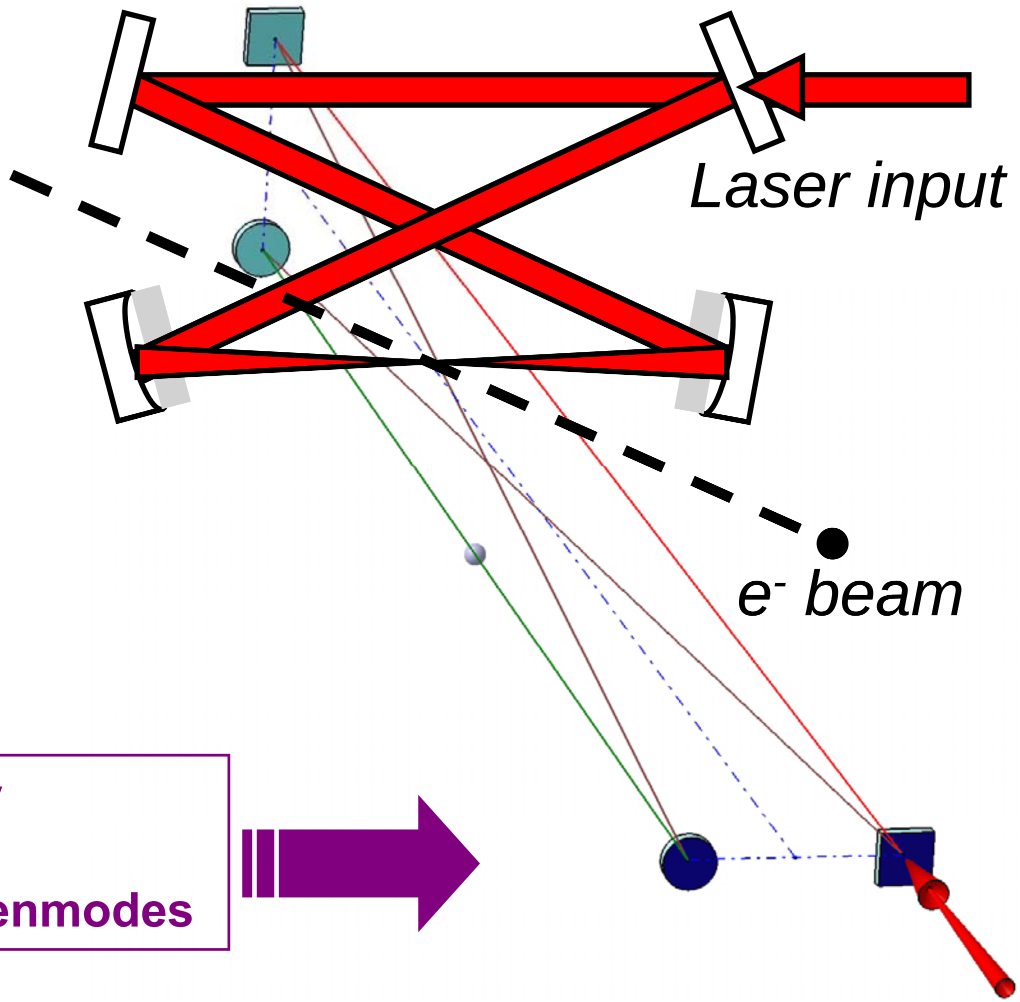
R&D at LAL : toward small laser spot size

Small laser spot size &2 mirrors cavity ➔ unstable resonator (concentric resonator)

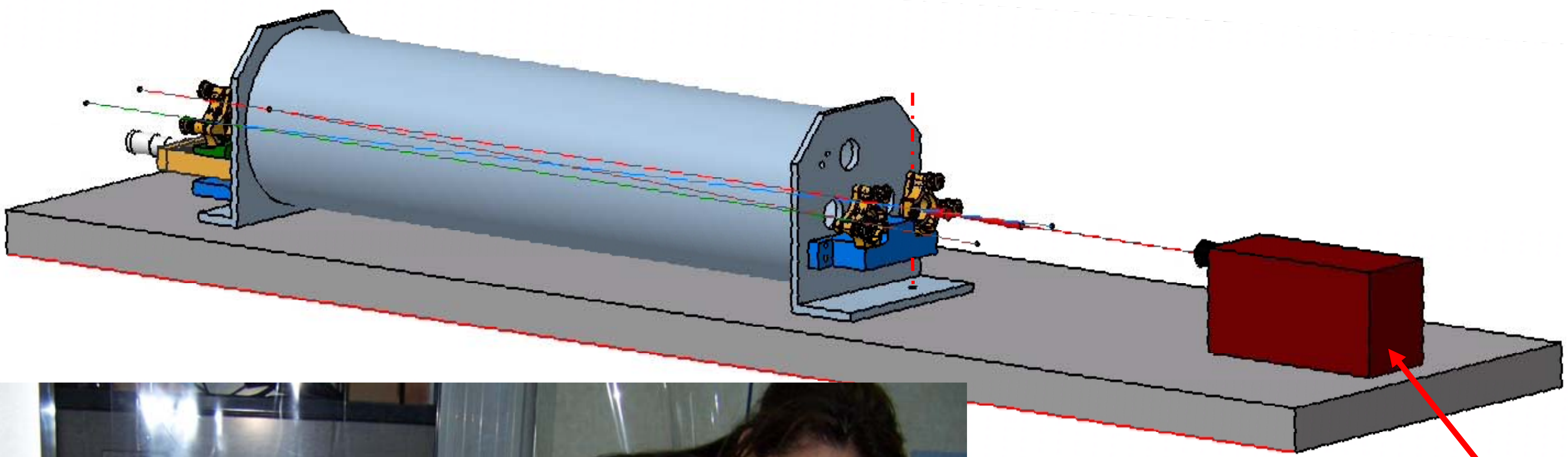
Stable solution: 4 mirror cavity as in Femto lasers

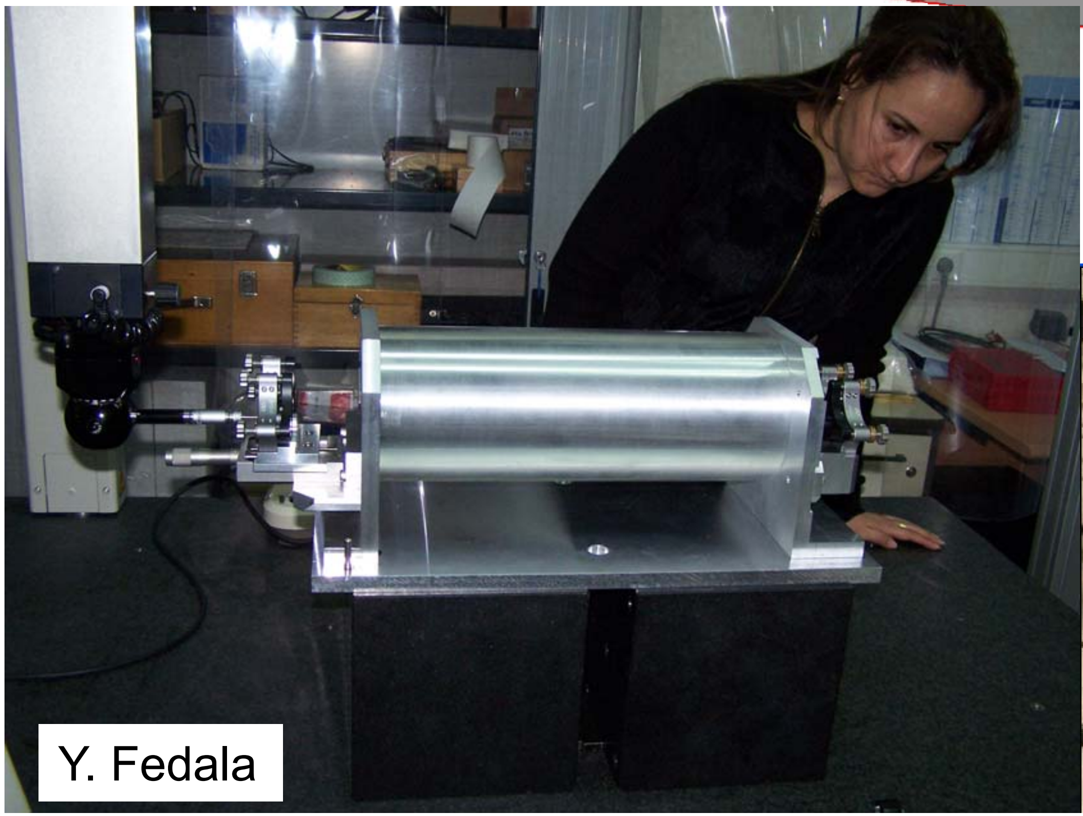
BUT➔ astigmatic & linearly polarised eigen-modes

Non-planar 4 mirrors cavity
➔Astigmatism reduced &
~circularly polarised eigenmodes

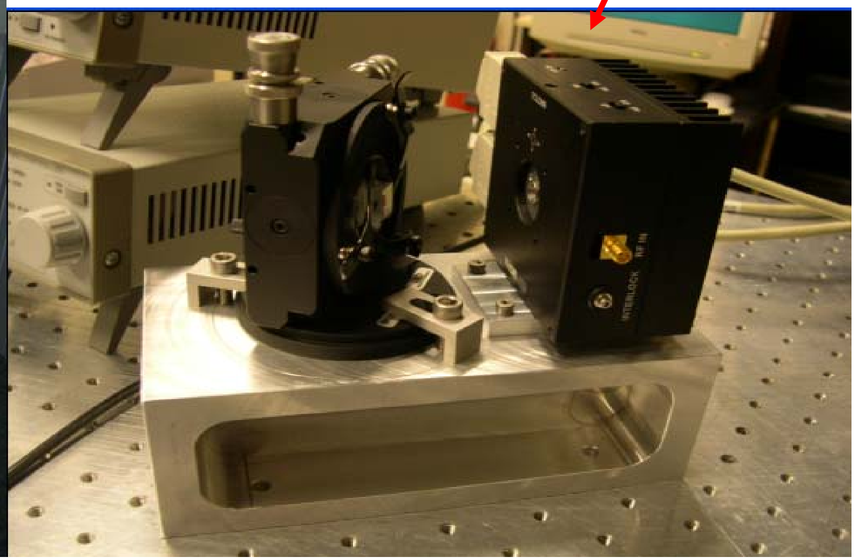


3D cavity prototype



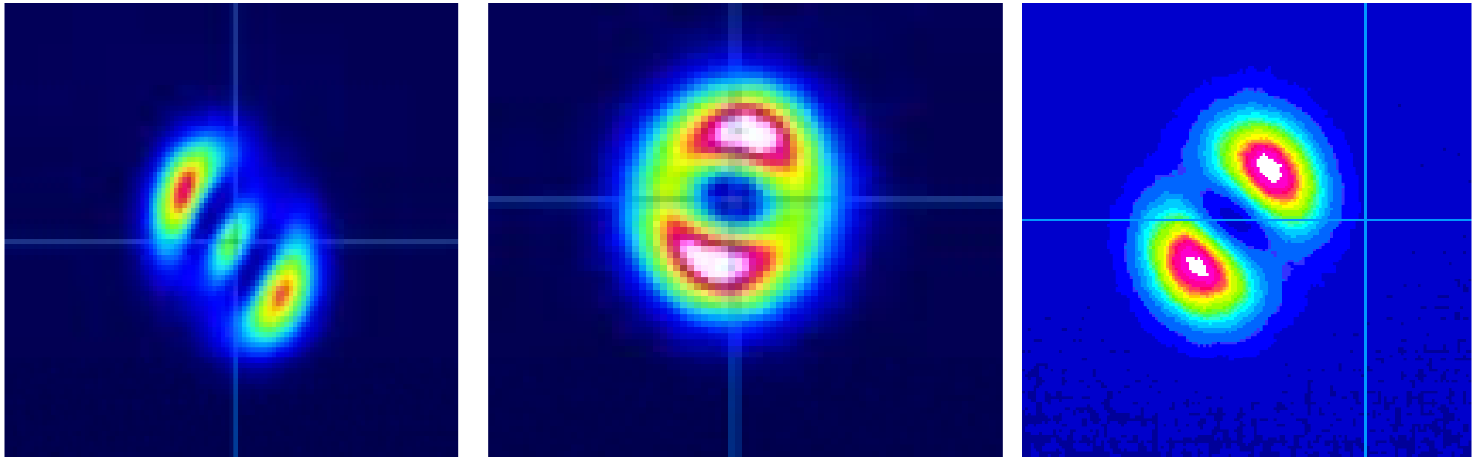


Cw laser diode in
extended cavity config
(Littrow configuration)

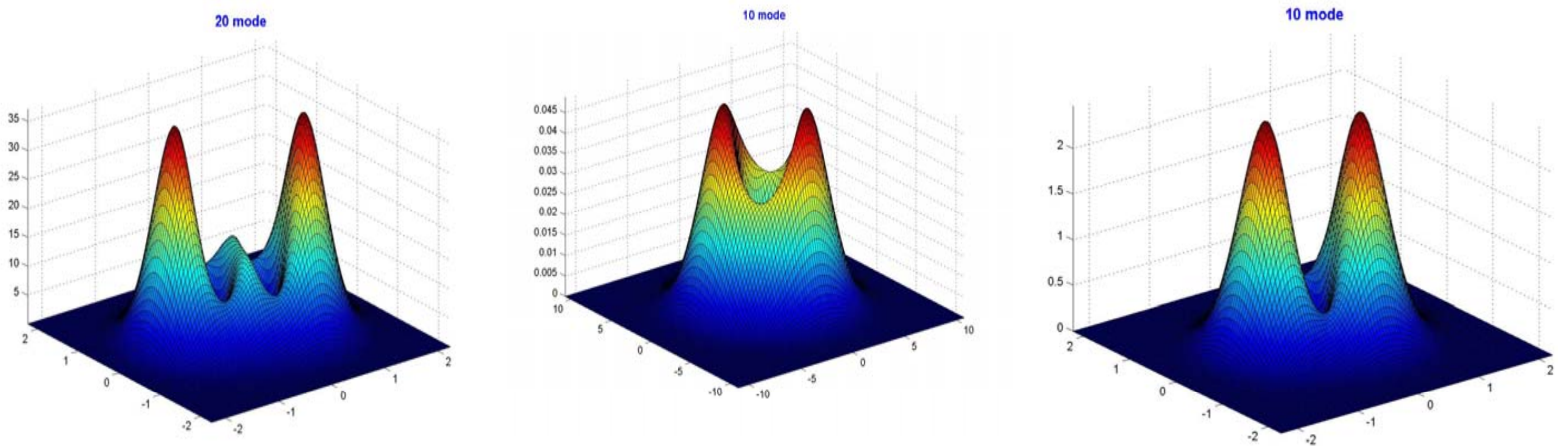


3D cavity modes

Exp.
Higher order
Modes



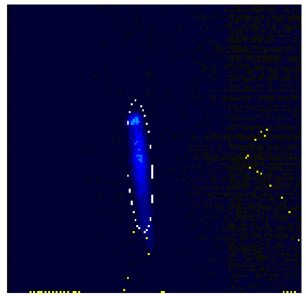
Th. results



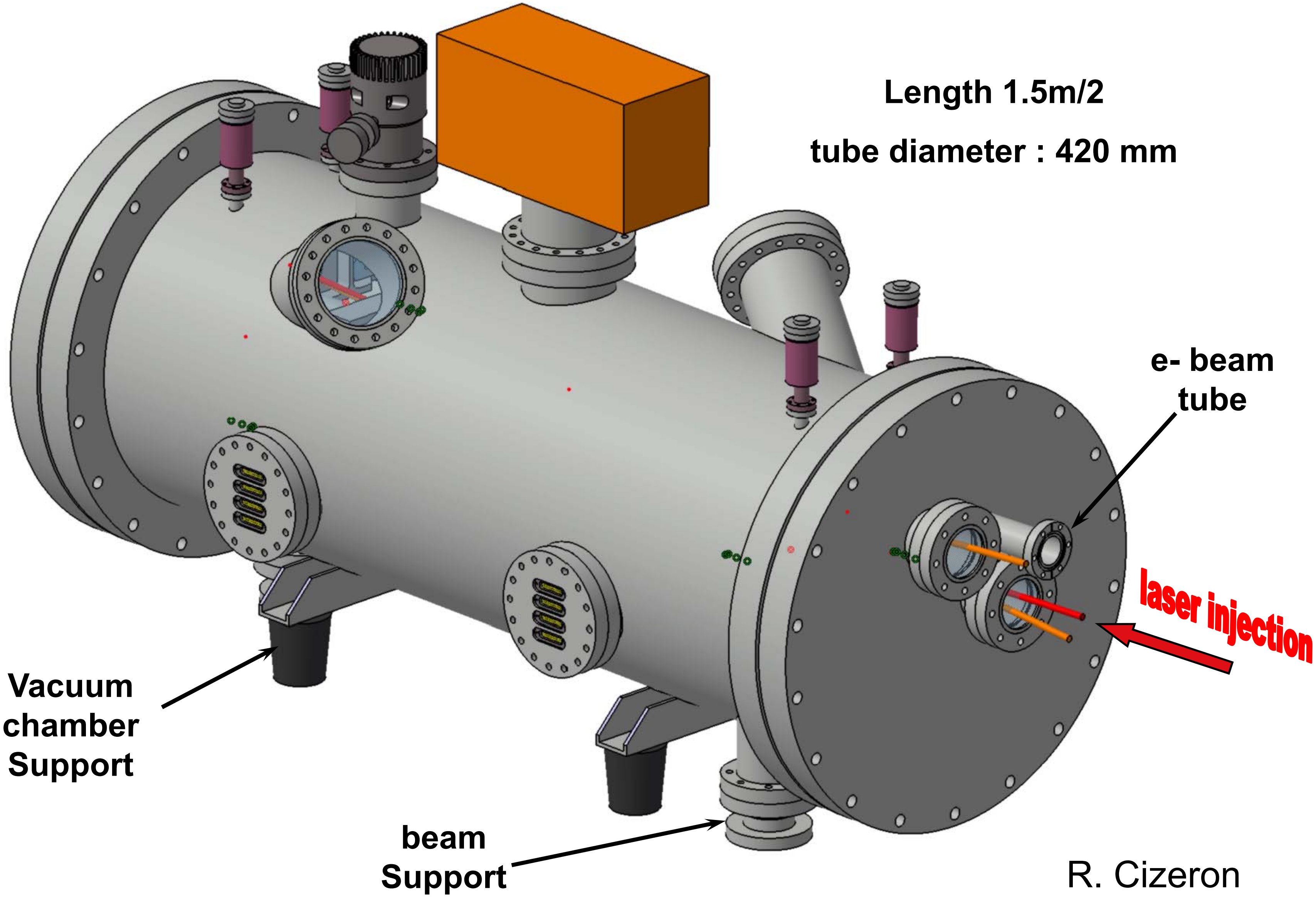
Eigenmodes well described (shape and size)

➔σ~10µm spot size achieved (limited by mirror edge diffraction) ➔

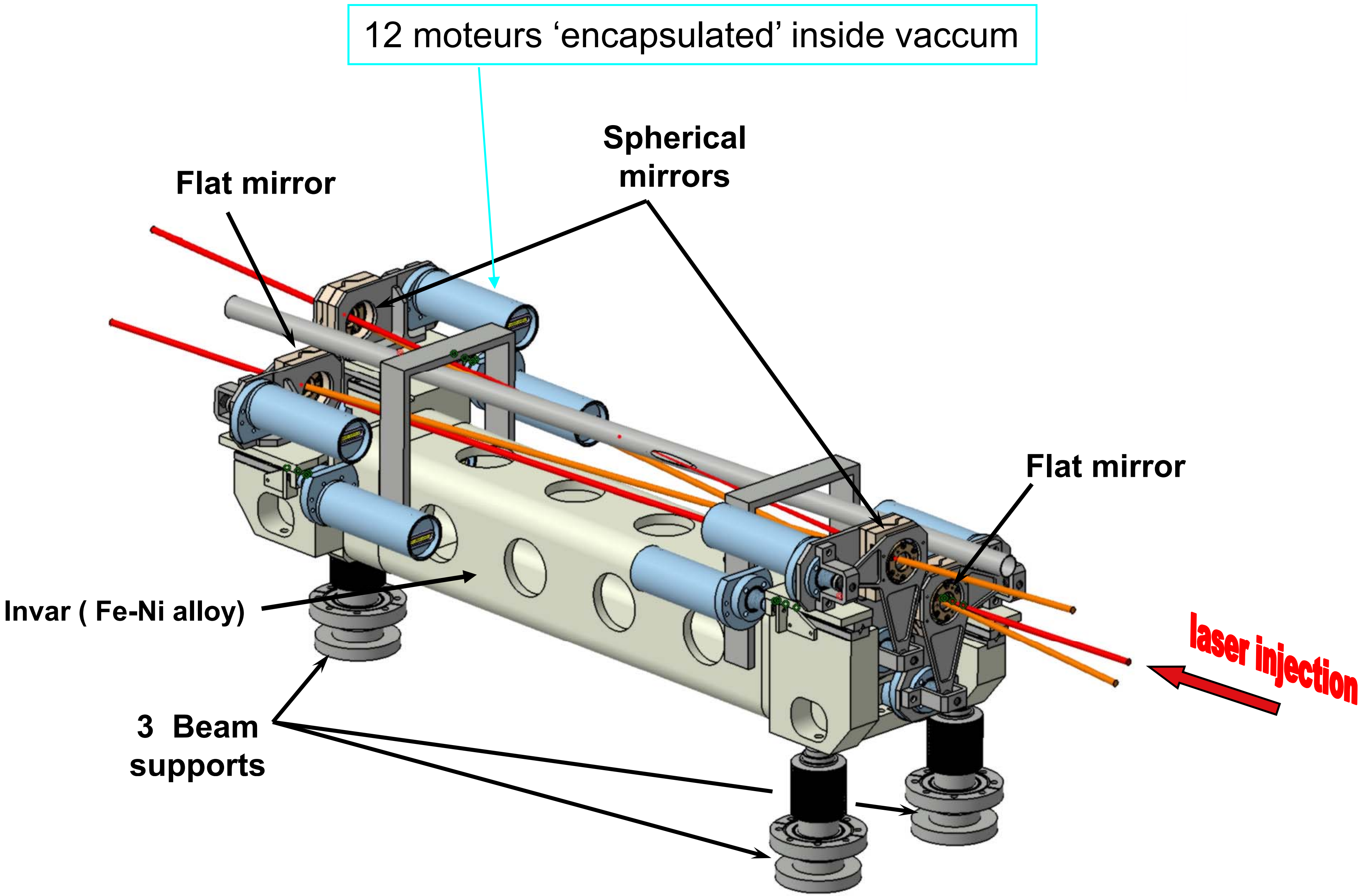
➔ mechanical stability measured



4 mirrors cavity design for ATF

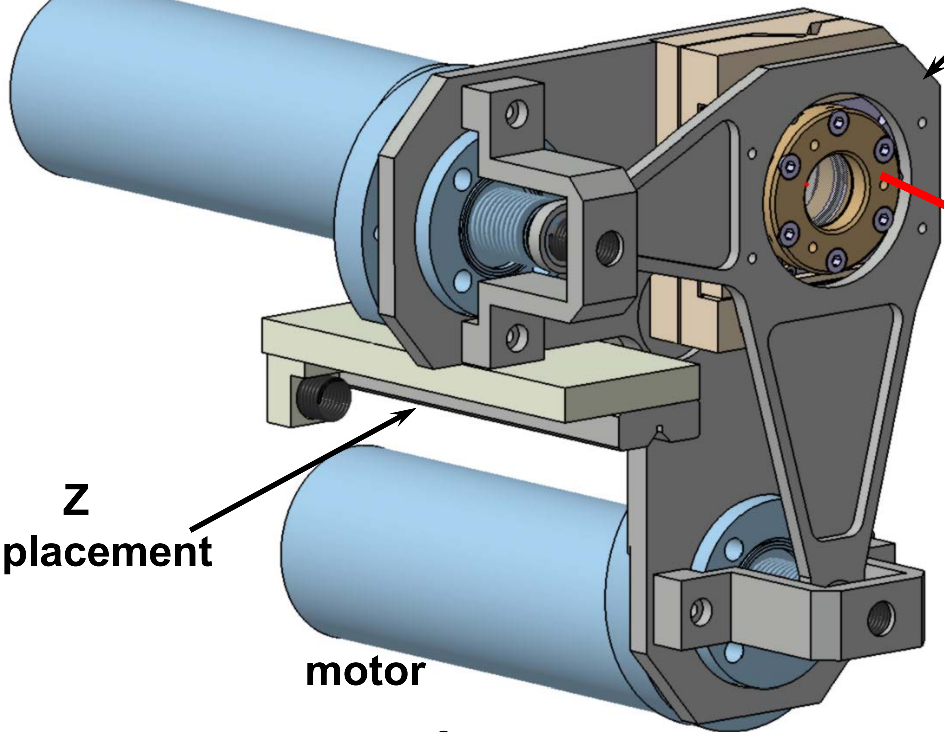


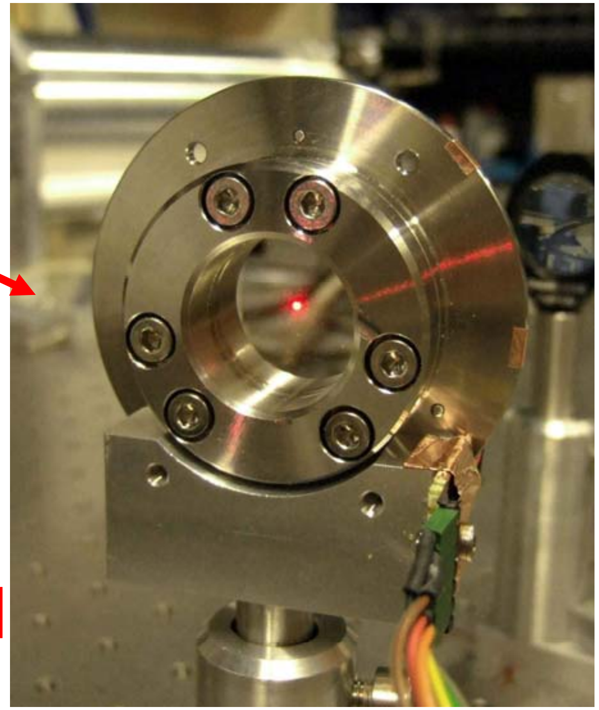
R. Cizeron

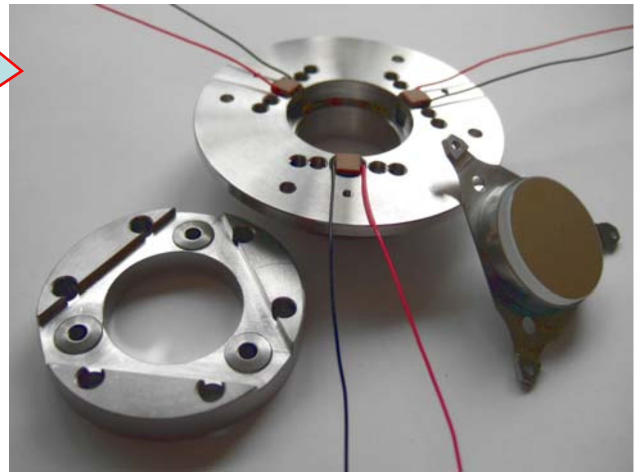


12 moteurs ‘encapsulated’ inside vaccum
Spherical mirrors
Flat mirror
Flat mirror
Invar (Fe-Ni alloy)
laser injection
3 Beam supports

Mirrors holders design study





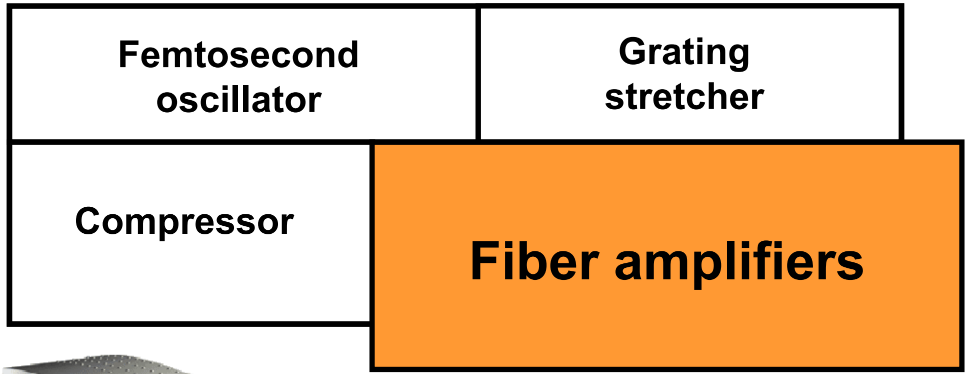


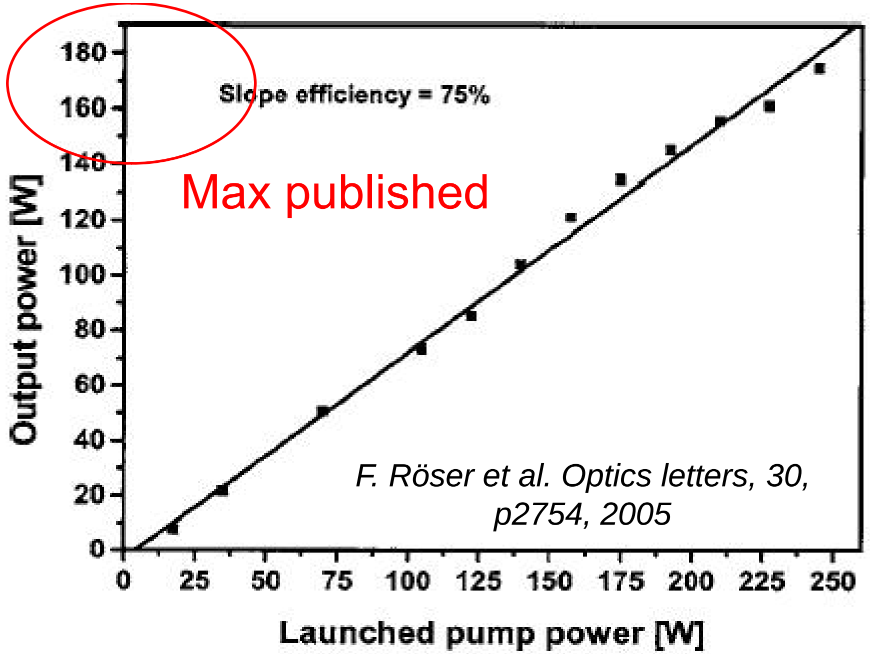
Builded & tested at LAL

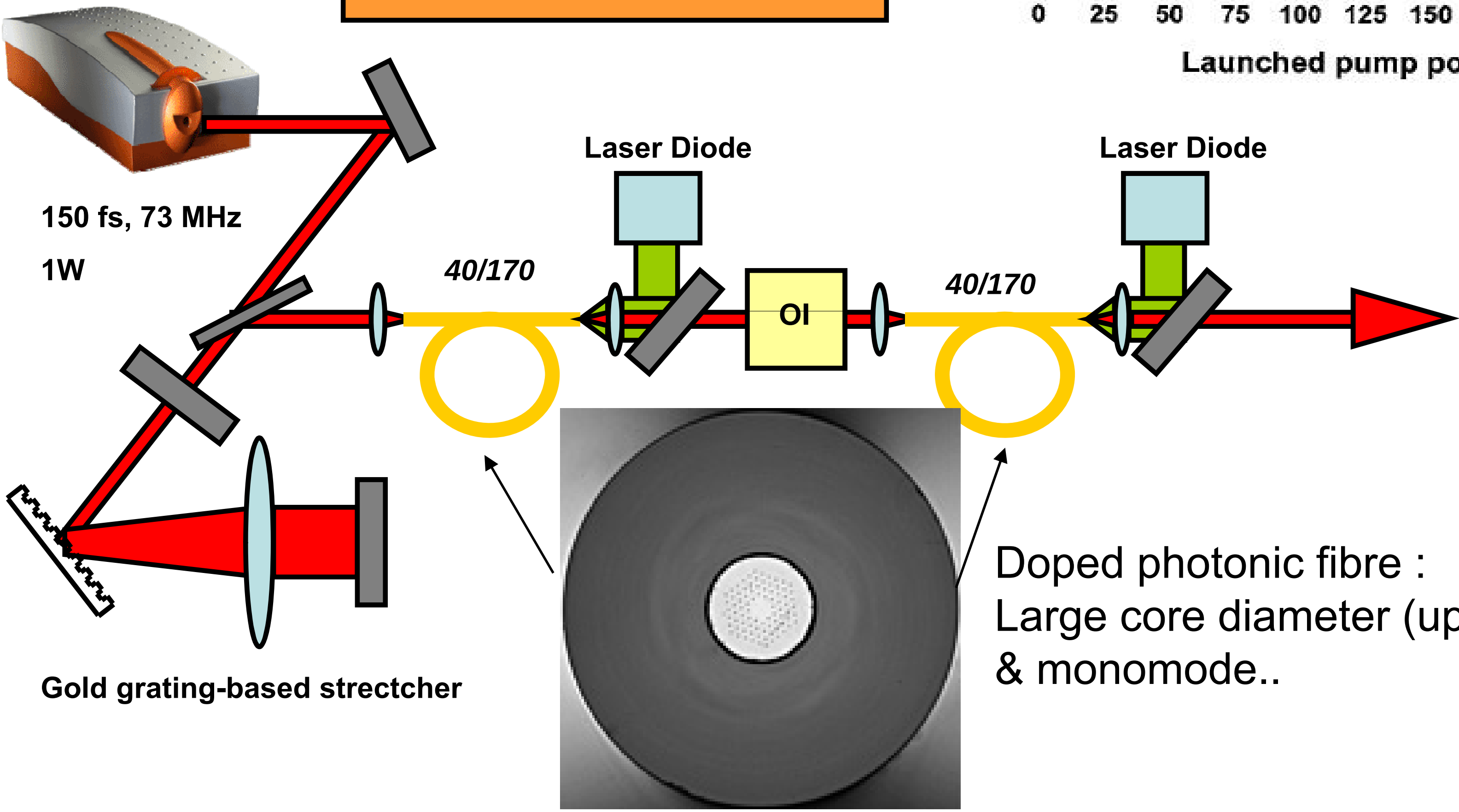
Futur: toward higher incident laser power

- Presently the laser average power is
  - 10W at KEK
  - 0.7W at Orsay
- Laser R&D
  - LAL : 150W average power (1ps@190MHz)
    - Started in june 2007➔2008
    - Installation at ATK with 4 mirrors cavity
  - KEK & LAL :
    - 150W➔kW level after 2008

High average power system





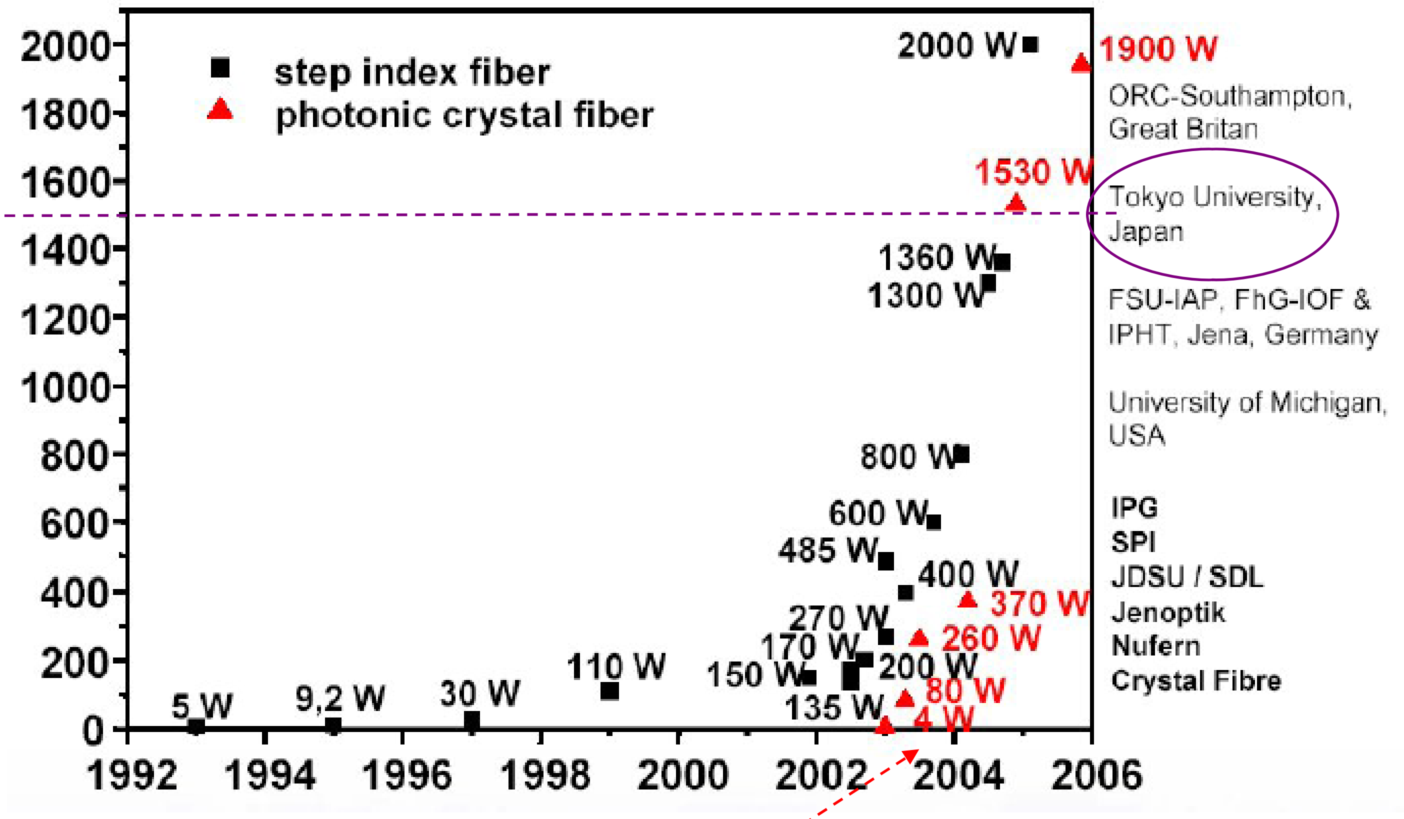


Doped photonic fibre :
Large core diameter (up to 100µm !!!)
& monomode..

•For most of laser applications :
Interests for high peak power, not for high average power and/or femto pulses
➔ we have to do laser R&D ourselves for high repetition rate and 1ps

Evolution of continuous wave fibre laser power

“4.8kW average power may be (hardly) achieved In the future” [131W today…]



Photonic fibre is a very recent promising technology …

Summary

- R&D on high flux soft X-rays based on Laser-e beam Compton scattering
  - Complementary R&D at KEK & LAL
    - 2 mirrors & *moderate* enhancement ~1000 installed at ATF/KEK
  - Very high enhancement factor studies at LAL & non planar resonator conception/construction
- New high average power laser source KEK/LAL R&D started
  - Needed to reach the required X-rays rate
    - ~1-10Mw average power inside cavity expected
    - = 20-200GW peak power
    - =8-80mJ/pulse
- Would this help for the Photon Linear Collider ?
  - Much more pulse power needed…
    - ➔ non-linear & thermal effects in the mirror coatings ?
    - ➔ huge cavity size

Backslides

Yield Evaluation

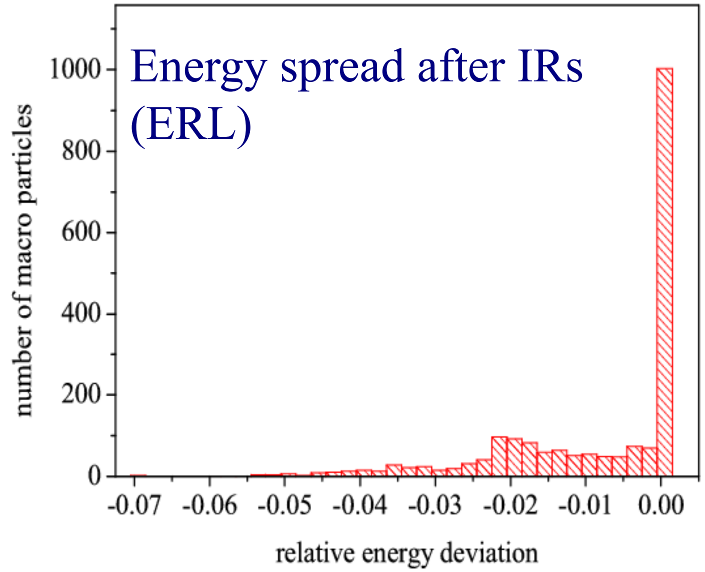
- 1.5×10^9 electrons/bunch generates 8.2×10^8 γ/collision.
- 10 collisions make 8.2×10^9 γ/bunch total, 2.4×10^9 γ/bunch in effective energy range.
- Assuming 0.3% efficiency γ for e+ conversion and capture, 7.5×10^6 e+/bunch is obtained.
- This bunch train continues 100ms with 6.2ns spacing.
- # of revolutions of DR(C~6.7km) in 100ms is 4000. Top-up injection up to 4000 bunches in a same bucket make 3.0×10^{10} e^+/bunch.
- Another 100ms is for damping

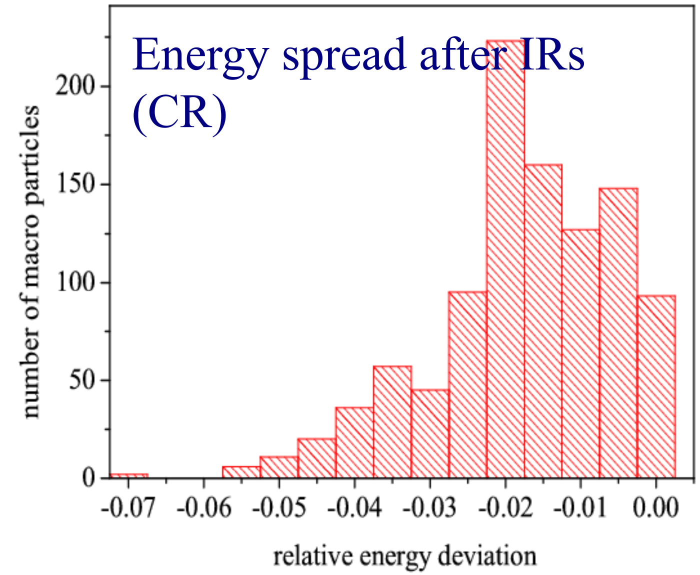
Yield Evaluation (2)

By E. Bulyak

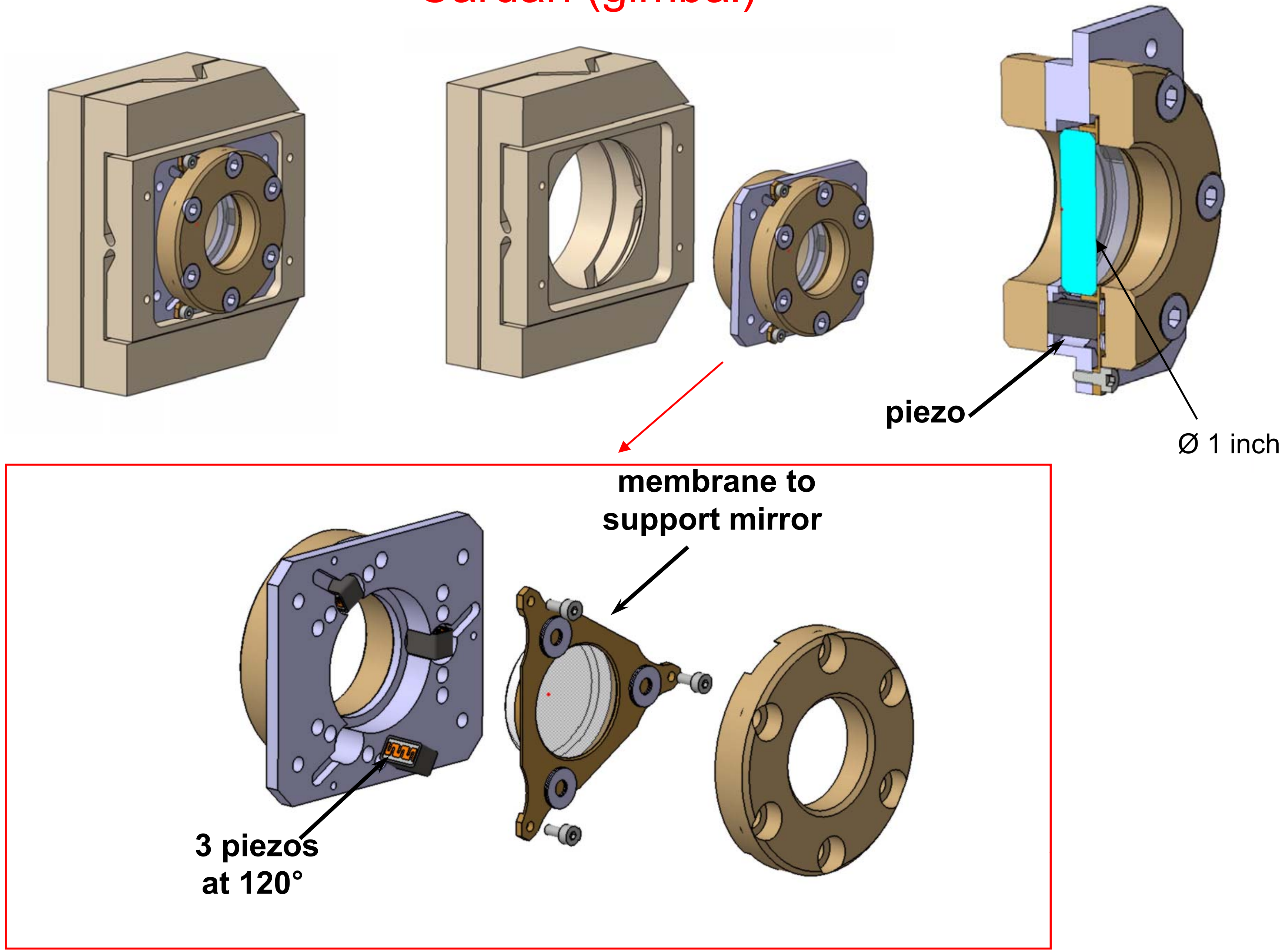
Table 1: Performance of Compton gamma sources

parameter / model	ILC/YAG	CLIC	ERL 1	ERL 2
Laser pulse energy (J)	17.76	0.592	6.0	6.0
Laser pulse radius (μm)	5	5	10	10
Laser pulse length (mm)	0.9	0.9	0.24	0.24
Max yield ($1/e/$J)	0.18	0.18	0.29	0.29
IP $\beta_{x,z}$ (m)	0.5	0.5	0.16	0.16
Init. bunch length (mm)	0.1	0.6	0.2	0.2
Init. hor. emittance (nm rad)	1	1	0.625	0.625
Init. ver. emittance (nm rad)	0.05	0.05	0.625	0.625
Bunch population ($\times10^{10}$)	6.2	6.2	3.5	0.1
Electron beam current (A)	3.01	15.6	0.03	0.03
Number of IPs passes / bunch	100	2546	1	1
Reduction factor	0.21	0.16	0.53	0.53
Aver gammas ($\times10^{9}$/bunch/turn)	58	2.8	32.3	9.2
Aver gammas/s ($\times10^{18}$)	12.6	1.68	0.173	0.173
Gamma train length (ms)	0.0924	0.357	100	100
# gammas / train ($\times10^{15}$)	1.16	0.6	17.3	17.3
Synch. losses, cont. (MW)	1.958	3.330	0.0026	0.0026
Compt. losses, train (MW)	30.31	3.99	0.415	0.415
Recov. losses, cont (MW)	0	0	0.3+	0.3+





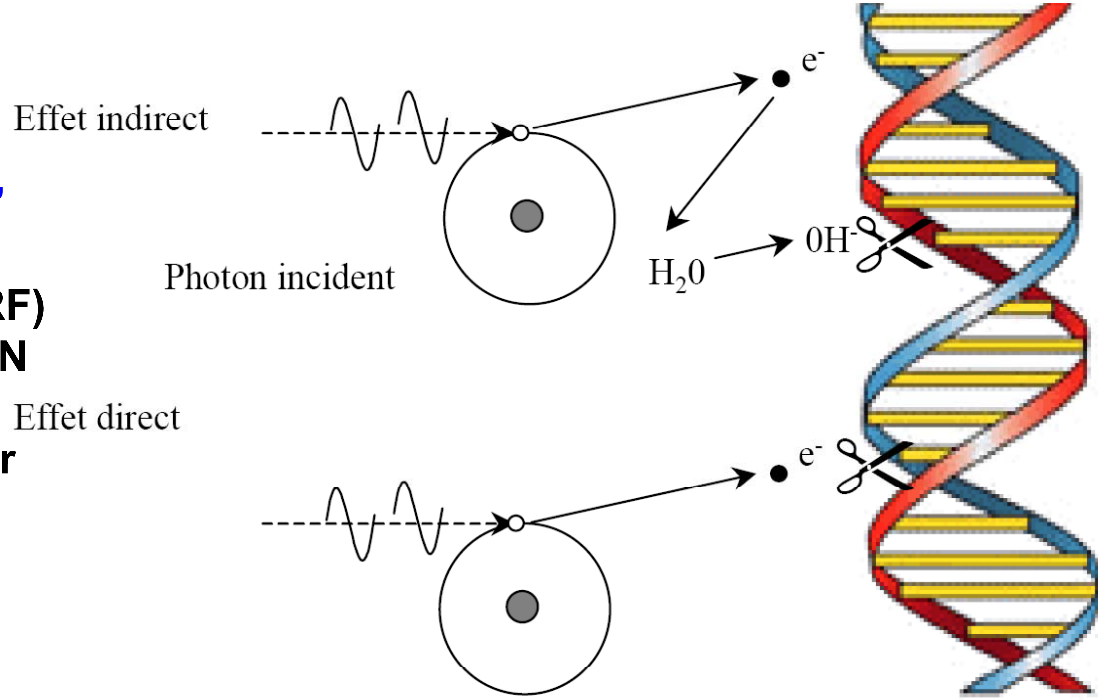
Cardan (gimbal)

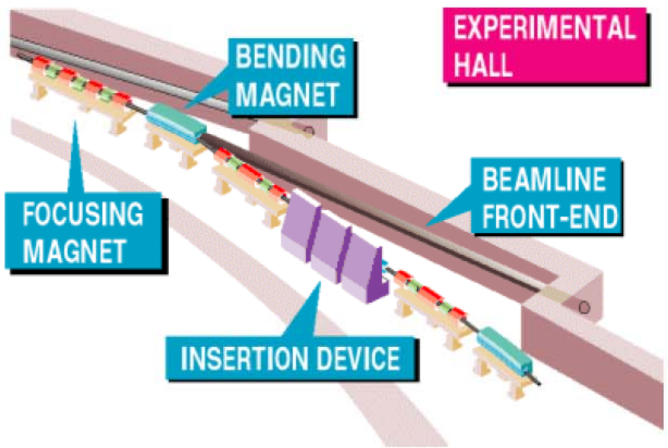


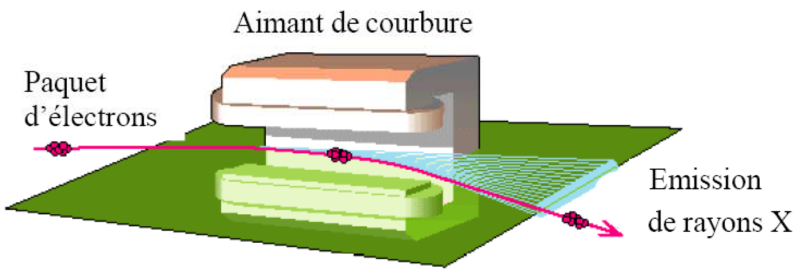
Une application médicale à l'ESRF (ligne ID17): radiothérapie pour le traitement des gliomes

Pas de traitement pour le 'glioblastome' aujourd'hui (& 7 cas/10^5 par an…) :

•Idée (cf these S. Corde, J.F. Adam, ESRF) fixer un élément lourd (platine) sur l'ADN cancéreuse puis exciter l'atome par un rayonnement X (78 keV=couche K) pour détruire cette ADN…



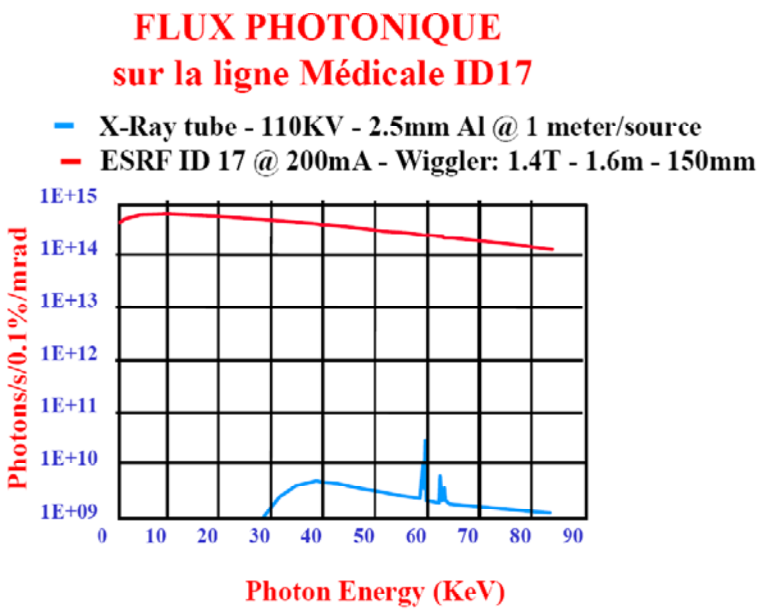


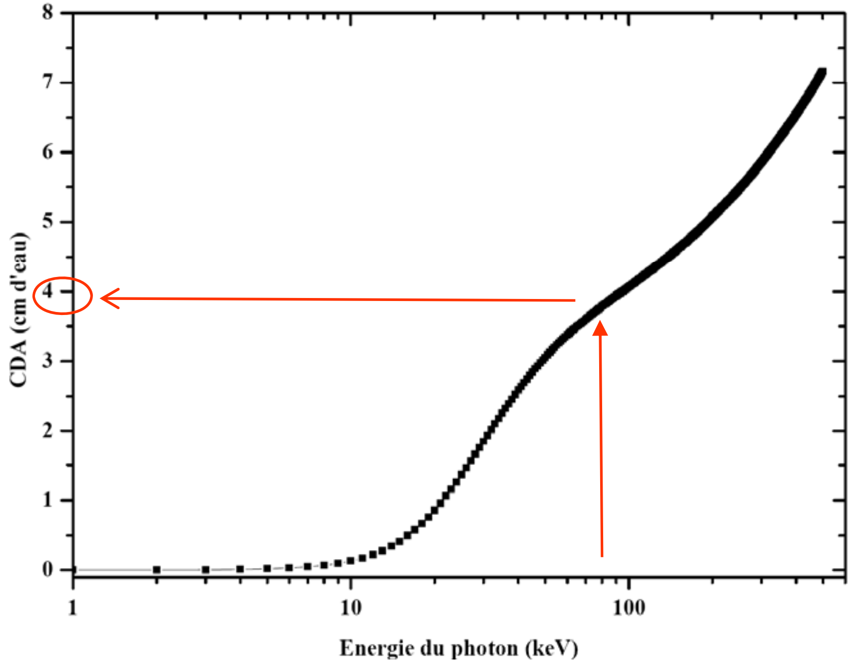


Sélection de l'énergie du rayonnement

Pourquoi du rayonnement synchrotron ?

Pourquoi un élément à grand Z (le platine)

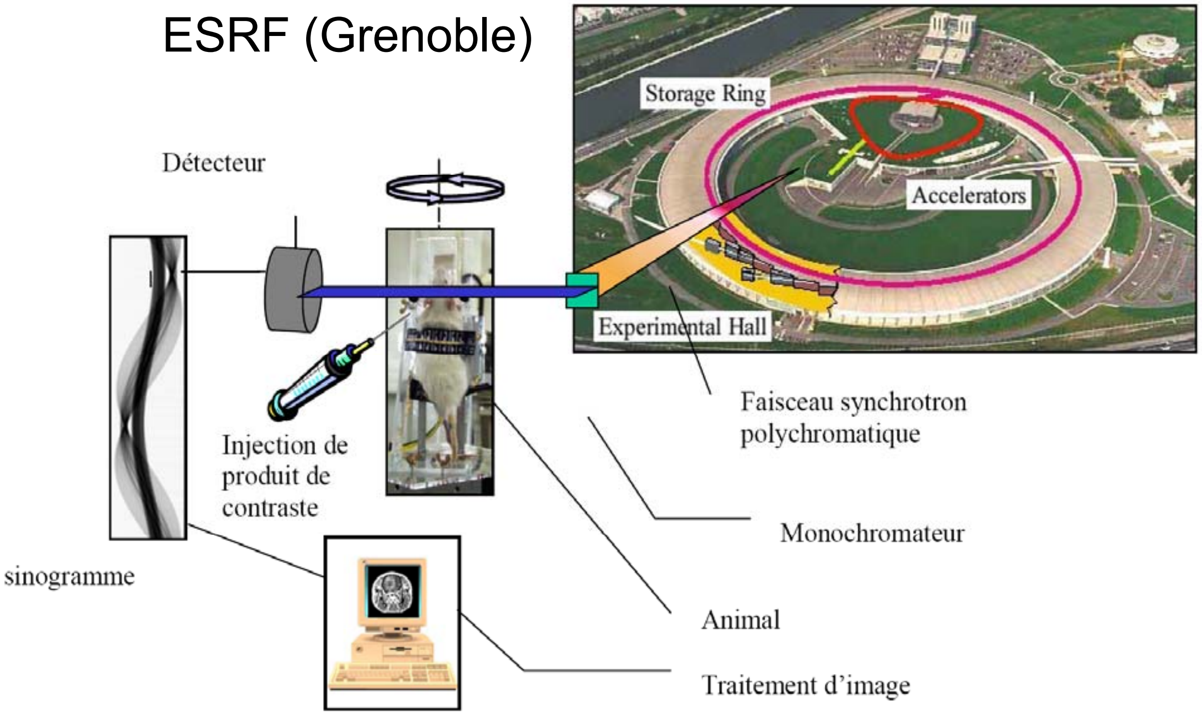




➔Haut flux de X monoénergétiques à 78 keV
➔Parcourt moyen de ces X dans l'eau convenable

Minimisation des pertes dans les tissus sains
&
maximisation de l'effet radiotérapeuthique

ESRF (Grenoble)



Résultat

[MC Biston et al. cancer reas. 64 (2004)2317]

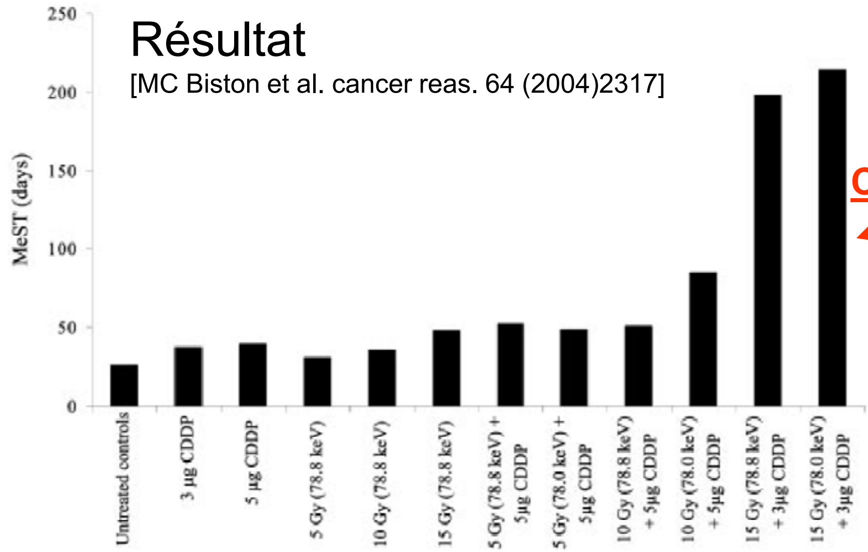


Fig. 4. Median survival time (MeST) expressed in days after tumor inoculation and indicated treatments of rats bearing F98 glioma. Because no significant differences have been observed between MeST from irradiation treatments alone at 78.0 and 78.8 keV, only the MeST from 78.8 keV irradiation is represented. Each group of treated rats contained at least six animals. The untreated control group contained at least 10 rats.

Cis-platine + rayons 78keV

Source rayons X Monoénergétique nécessaire

Nécessité aussi d'une machine à bas coup
➔Utilisation de l'interaction
Compton (e^{-}+laser → e^{-} + photon)
Laser pulsé 'amplifié' dans une cavité
Production de rayons X dont on peut choisir l'énergie (=longueur d'onde) à des flux de puissance tolérables par l'organisme

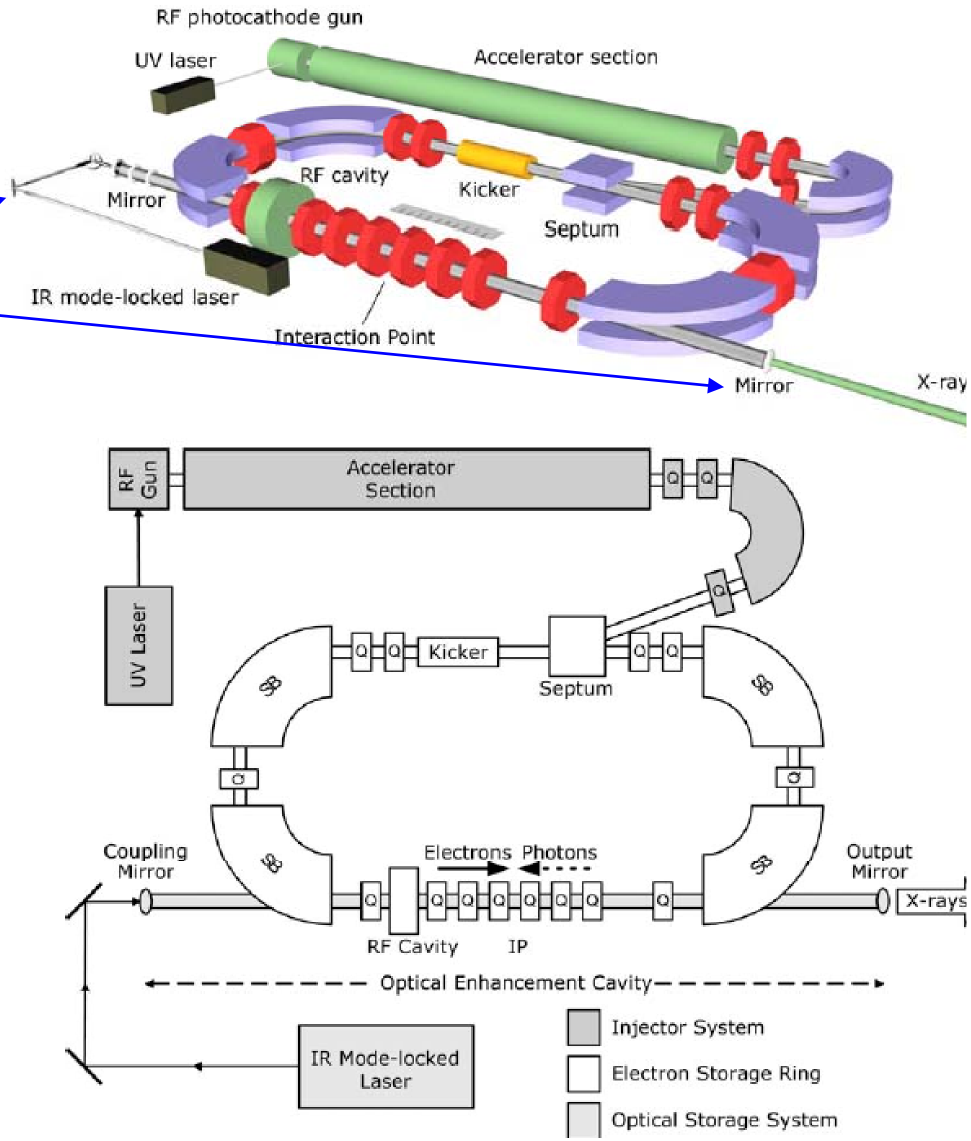


Figure 1.2: Concept drawing of a compact X-ray source. Major components a injector (electron gun and accelerator section), the electron storage ring (show focusing quadrupole and bending dipole magnets), and the integrated optic ity (between mirrors). Electron-photon scattering at the interaction point pr naturally collimated, narrow bandwidth X-rays.