LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE
IN2P3 Institut National de Physique Nucléaire et de Physique des Particules
UNIVERSITÉ PARIS-SUD 11

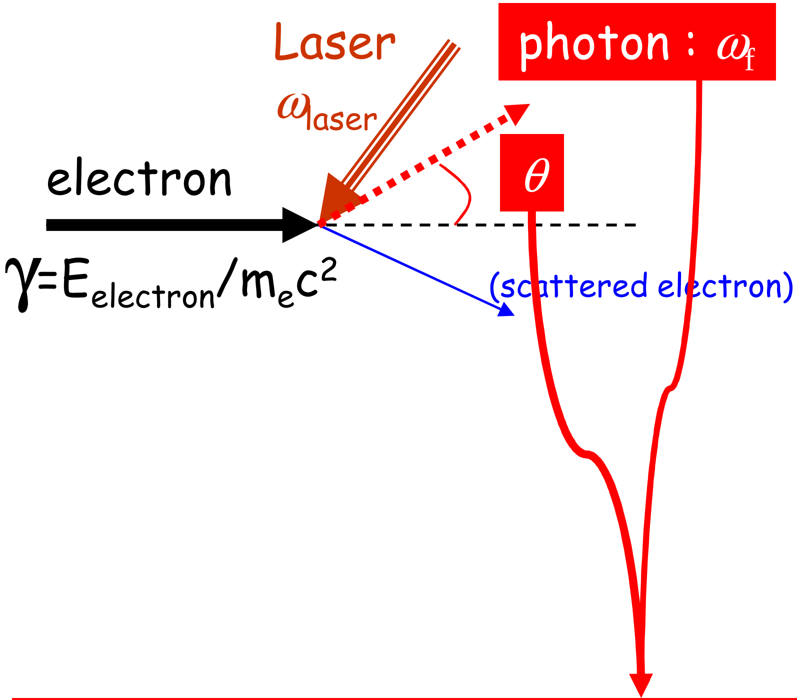
Laser beam - electron beam Compton scattering Technology and applications. Description of the new ATF four-mirror cavity

1. Properties and interests in Compton scattering
2. Laser systems for Compton scattering
   ➔Use of Fabry-Perot optical resonator
3. Applications
   Monochromatic X-ray imaging
   High Energy Physics
4. Fabry-Perot cavities in pulsed regime
5. Four-mirror cavity R&D at ATF
   Description of the apparatus
   Report on the installation at ATF

F. Zomer, 16/08/2010 KEK

Properties and interests in laser-electron Compton scattering

Properties of Compton scattering



Dynamics of the process

- **Thomson Scattering** (at 'low energy')
  - Electron+plane wave scattering
    - Jackson, *Classical Electrodynamics*
- **Compton Scattering γ(laser)+e→γ'+e'**
  - Photon(laser)+electron scattering
    - Fano, JOSA39(1949)859;
  - Simulation program: CAIN from Yokoya-san http://lcdev.kek.jp/~yokoya/CAIN/cain235/

We are interested by using the scattered photon

Scattered photon properties given by the Compton differential cross-section:

$$\frac{d\sigma}{d\Omega^*} = \sigma_0 + \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$$

Tolhoek, Rev.Mod.Phys.28(1956)277

σ_0: Independent of polarisations

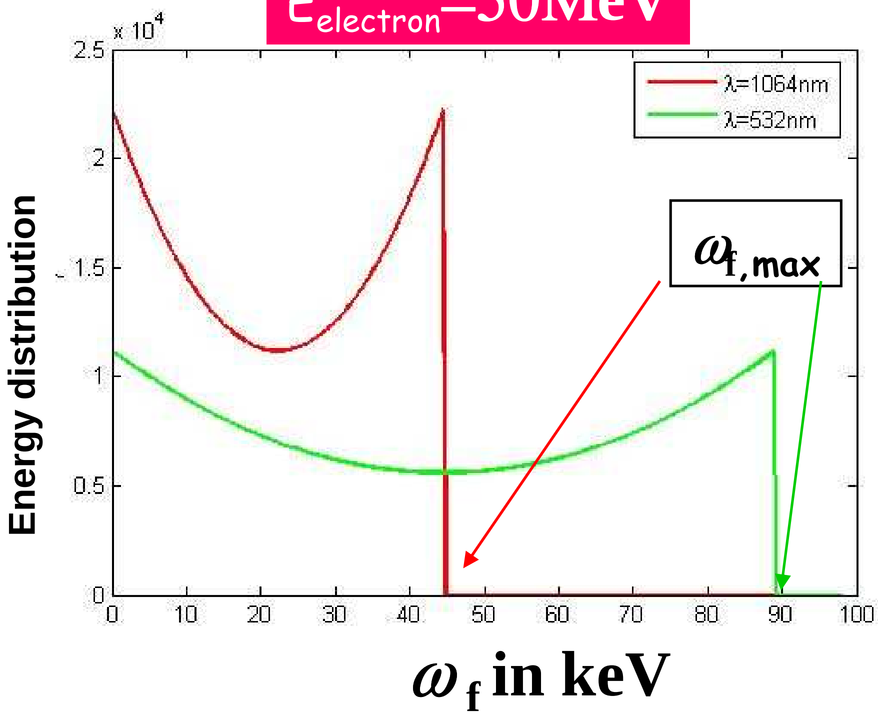
σ_4: Polarisation of the 4 particles are observed

Interests in Laser electron Compton scattering

1rst interest: the energy boost

(no polar. are observed)

$E_{electron}$=50MeV



Energy distribution ~flat with

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

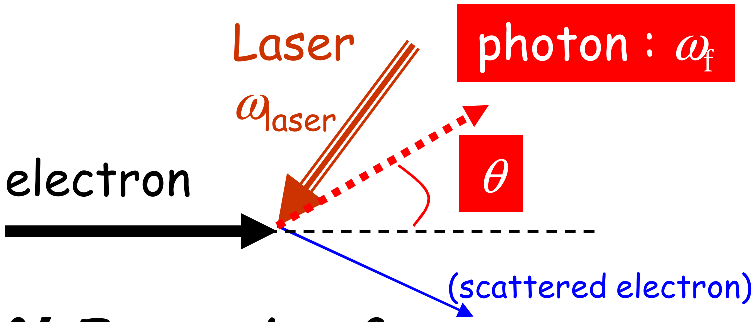
with γ~100 ($E_{electron}$=50MeV)

$\omega_{f,max}$=45000eV if $\omega_{laser} \approx$ 1eV

Compton scattering is the most powerful mechanism to boost photon energies

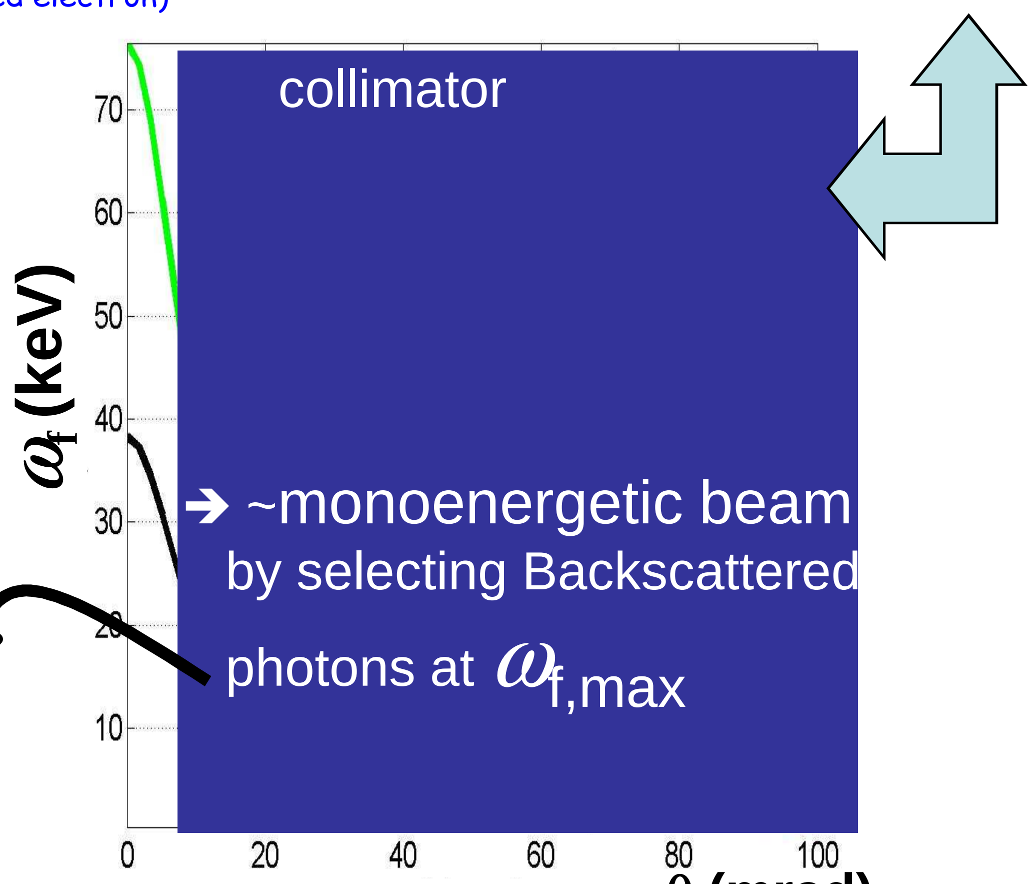
Sprangle et al. JAP**72**(1992)5032

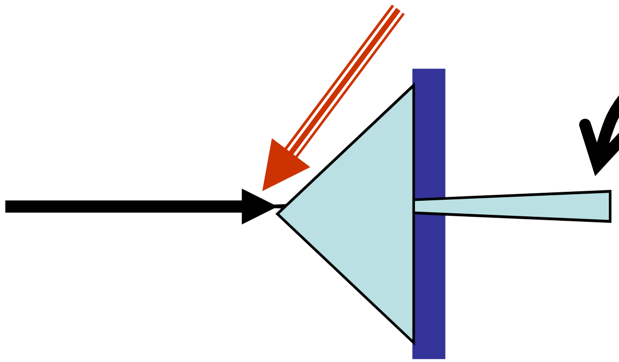
2nd interest: the angular energy correlation



$\gamma = E_{electron}/m_e c^2$

Compton scattering
Photon_laser+e→photon+e'
is a
2 body process ➔ $\omega_f = f(\theta)$





Sprangle et al. JAP**72**(1992)5032

3rd interest: incident electron and laser polarisation effects

(2 polar. are 'observed')

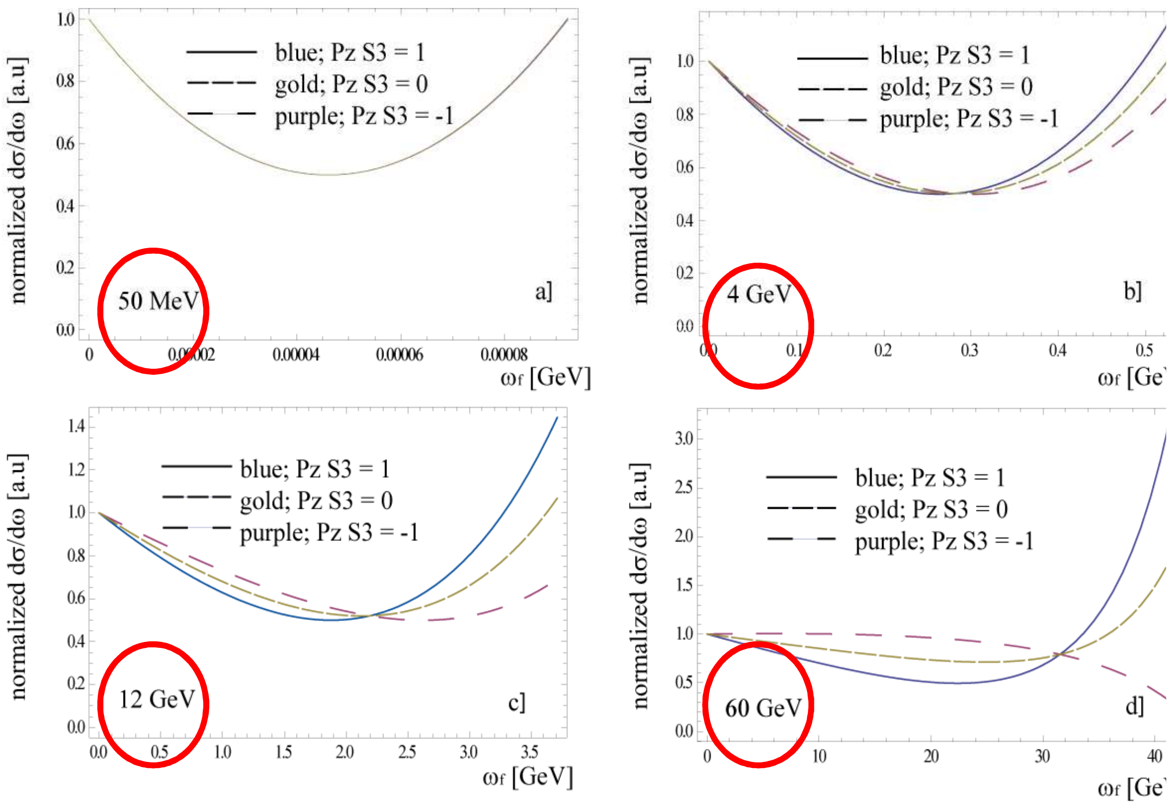
Differential Compton cross-section with 2 polarisations observed (energy distribution):

$$d\sigma/d\omega_f = A_0(\omega_f) - P_e S_3 A_1(\omega_f)$$

A_0, A_1: known (QED)

S_3: laser degree of circular polarisation

P_e: e^- longitudinal polarisation



→ **Knowing S_3 one can determine the polarisation of electrons above ~ 4GeV**

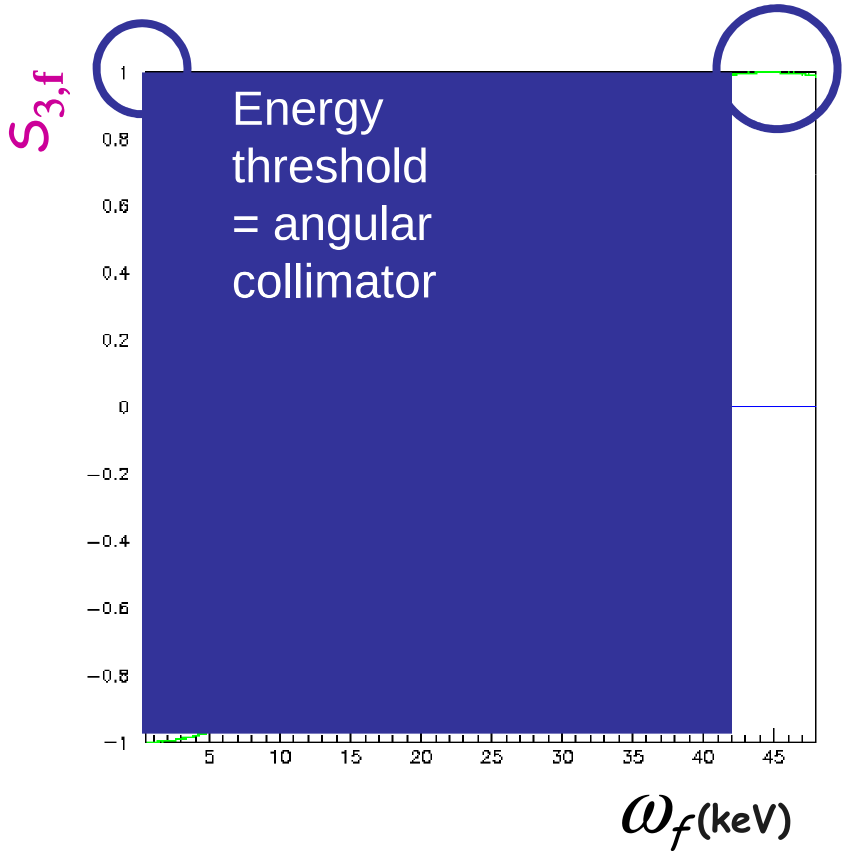
→ **electron/positron Compton polarimeters used in accelerators**

e.g. Barber at al. Nucl.Instrum.Meth.A329(1993)79

4th interest: polarisation effects in the final state

(3 polar. observed: incident e & laser, final photon)

— $(P_e , S_{3,laser}) = (0 , 1)$



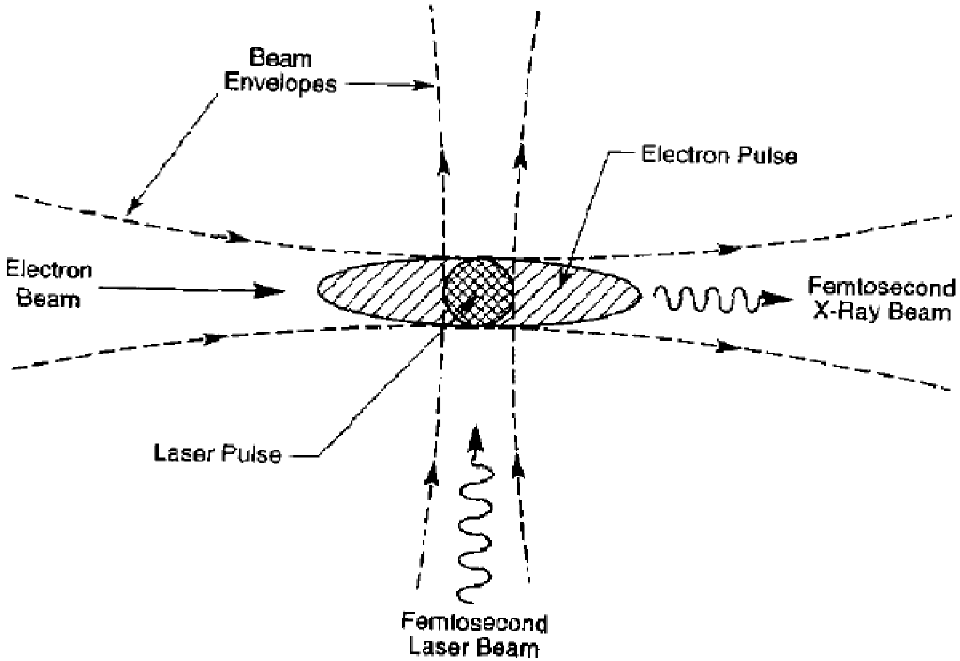
S_{3f} =1 for $\omega_f = \omega_{f,max}$ & $S_{3,laser}$=1

Compton scattering acts as a mirror for circular polarisation at low energy **if** highest values of ω_f are selected (i.e. backscaterred photons are selected)

➔**Polarised positron source ($E_{electron}$~1GeV)**
Omori et al. PRL 96(2006)114801

➔**γγ collider ($E_{electron}$~250-500 GeV)**
Ginzburg et al. NIM219(1984)5

5th interest: laser-electron beams crossing angle effects



➔ Femtosecond X ray pulses

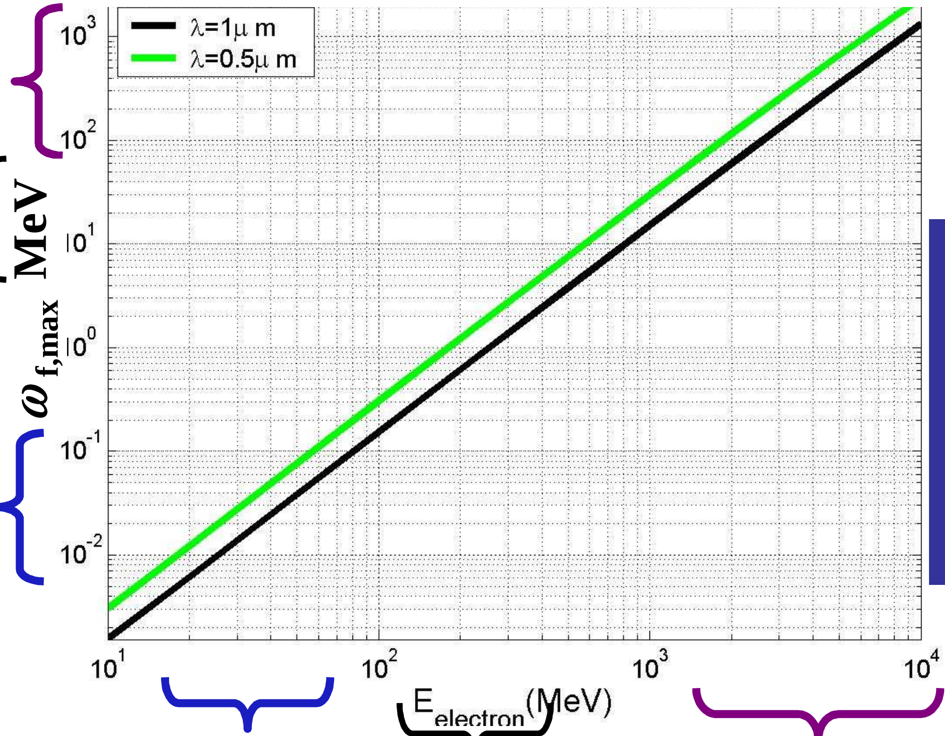
- Kim et al. NIMA341(1994)351
- Schoenlein et al., Science 274(1996)236
  - 300fs pulses @ 30keV (Berkeley)

Applications of Compton scattering: quasi monochromatic X/γ ray beam

γ 100 MeV

γ 1MeV

X ray ~10-100keV



LAL Accelerator group has now projects in the 3 energy domains

Elec.~20-100MeV

Elec.~100-500MeV

Elec. 1GeV

Low energy applications
- **Medical: radiography &radiotherapy**
- **Museology**
- **Material science**
- **crystallography**

Nuclear fluorescence applications
- **Nuclear survey**
- **Nuclear waste management**

High energy applications
- **Compton polarimeter**
  ➔LEP energy measurement
- **Laser wire**
- **γγ collider**
- **Polarised positron source**

Laser systems for Compton scattering

Very simple in principle:

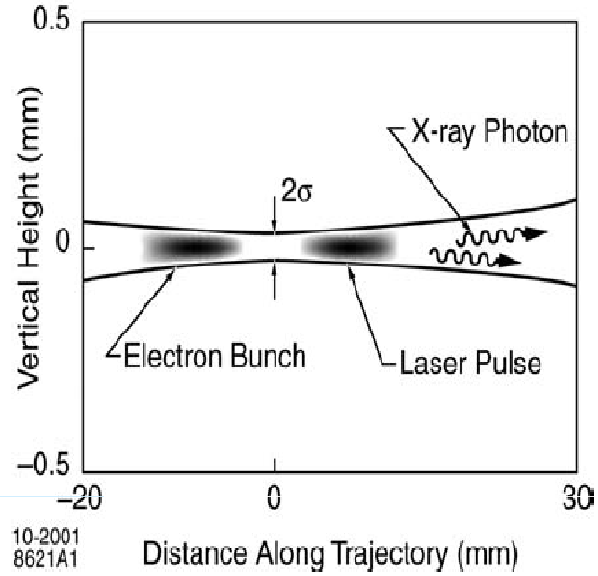
One has to shoot an electron beam with a laser

but much less easy in reality …

Main drawback of Compton scattering: the flux

Compton/Thomson cross section

σ_T is very small



$$Flux_{cw} \propto \frac{1}{\sin\alpha}\frac{\lambda P_L I_e \sigma_T}{\sqrt{\sigma^2_{electron}+\sigma^2_{laser}}}$$

I_e: electron beam intensity
P_L: laser power
λ: laser beam wavelength
α: crossing angle
$\sigma_{electron}$=electron beam size r.m.s
σ_{laser}=laser beam size r.m.s

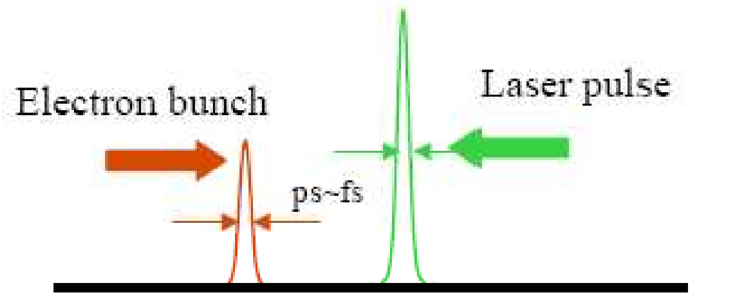
To reach high photon fluxes:
2 main technical issues

➔High laser power
Typically >1MW average power !
➔Small laser beam waist
Typically tens of microns or less
All that for picosecond laser beam
Best e_bunch length ~1ps

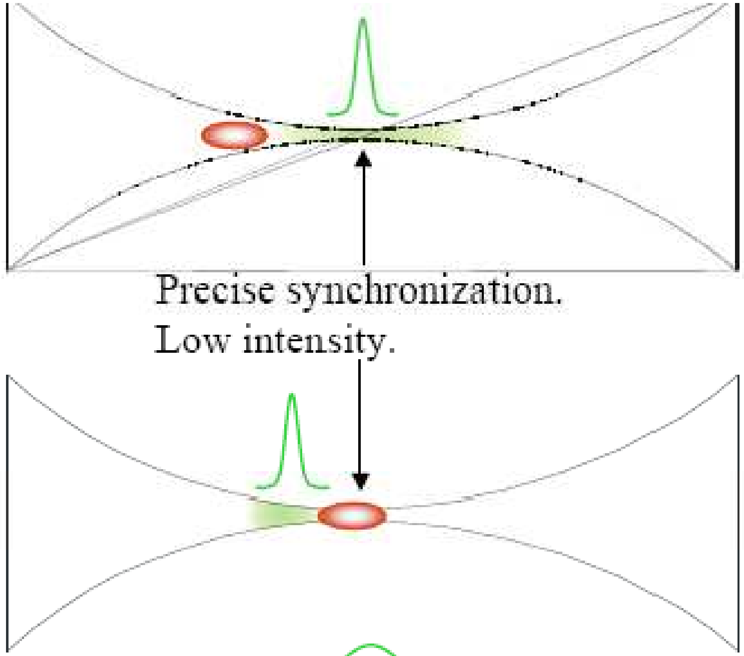
Techniques to increase the flux

KEK and LAL choice

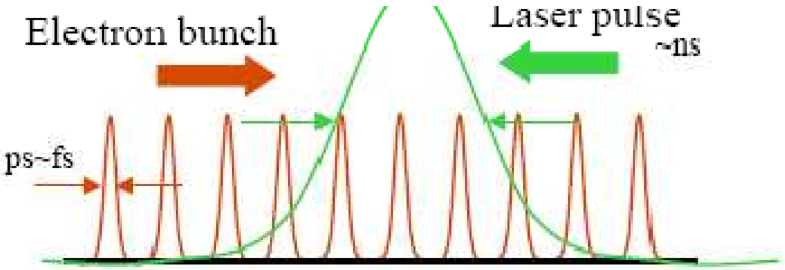
Single-collision scheme



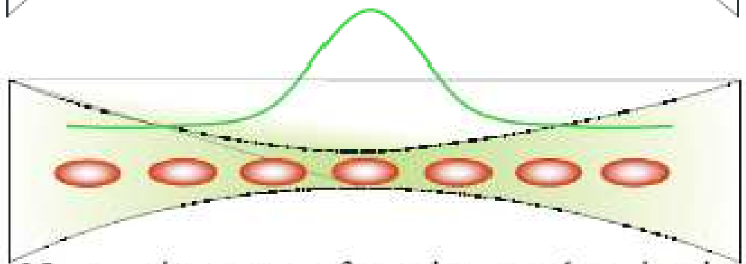
Collision between ultra-short (ps ~ fs) pulses.



Multi-collision scheme



Collision between ~ns laser pulse and multi-bunch electron beam



No requirements of precise synchronization.

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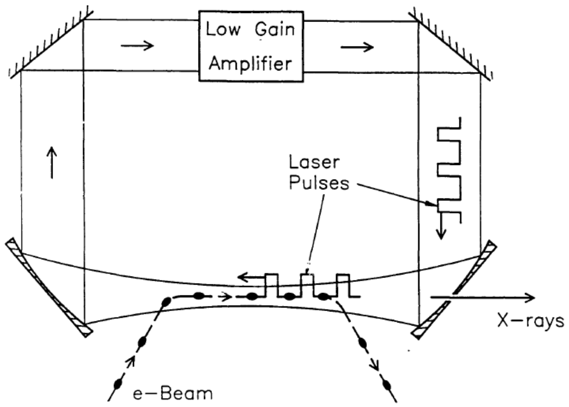
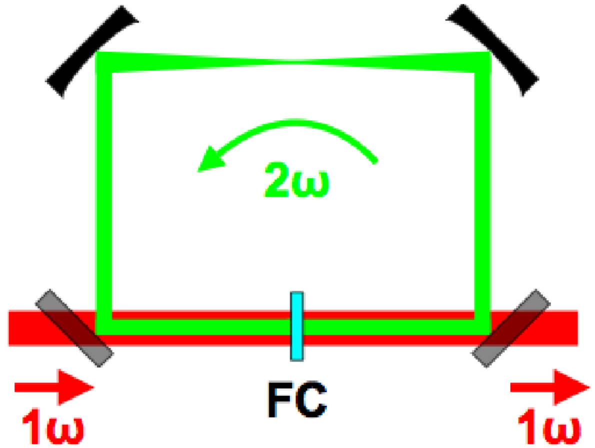
Tokyo University Compton machine

Single-Collision schemes



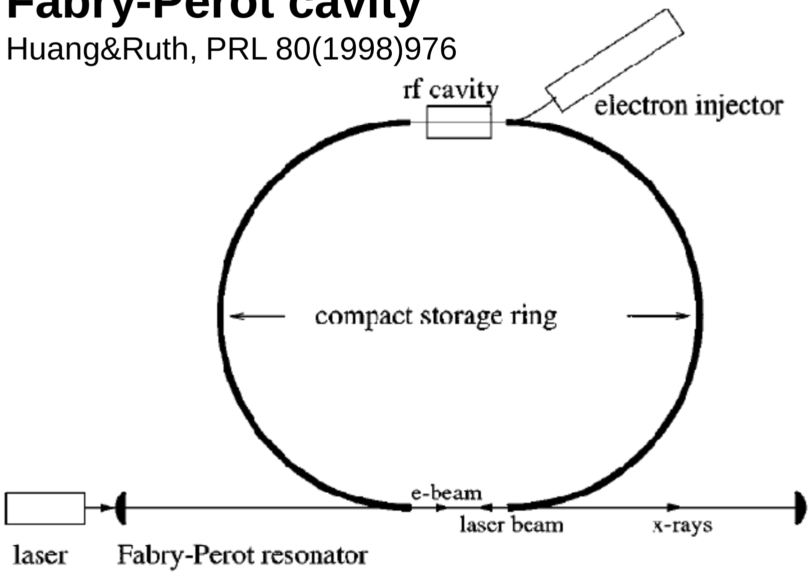
Regenerative cavity
Sprangle et al. JAP**72**(1992)5032



Non linear cavity (LLNL)
Jovanovic et al.,NIMA578(2007)160

TeraWatt, but
low rep rate …
(e.g. Chingua Univ.
& Daresbury project)

Fabry-Perot cavity
Huang&Ruth, PRL 80(1998)976



Mode lock laser beam can be stabilised to Fabry-Perot cavities:

- Jones et al., Opt.Comm.175(2000)409, Jones et al., PRA69(2004)051803(R)

A priori no limitation from dispersion induced by mirror coatings in picosecond regime:

- Petersen&Luiten,OE11(2003)2975,
Thorpe at al., OE13(2005)882

Applications of Compton scattering at low energy

X-ray imaging

(see also imaging in material science at AIST/Tsukuba)

X-ray imaging & radiotherapy applications

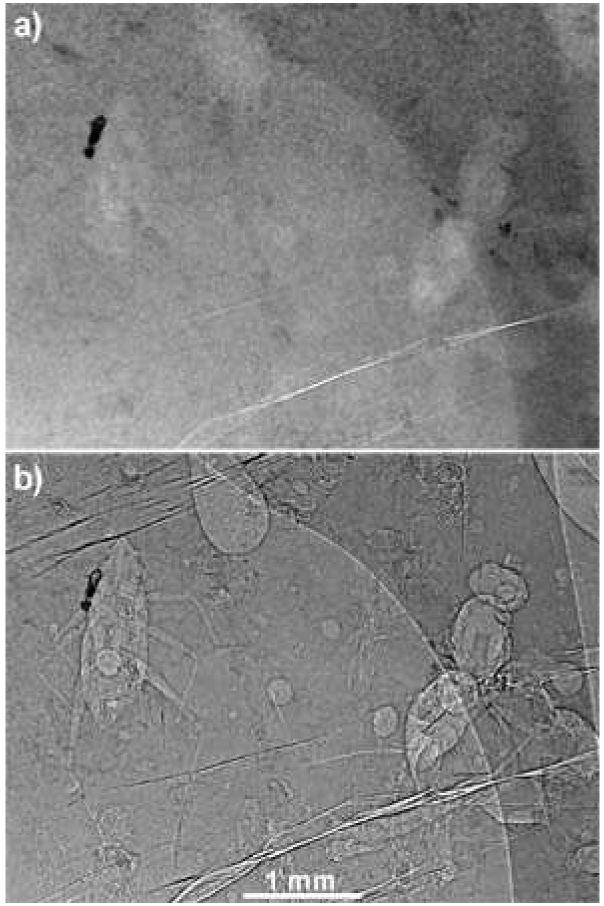
- *What has been done with synchrotron light that we would like to do in a museum, hospital or lab. room*
  - 1 example taken from results at ESRF synchrotron machine
    - Paleontology
    - (Painting analysis)
    - (Resonant radiotherapy)

Paleontology application

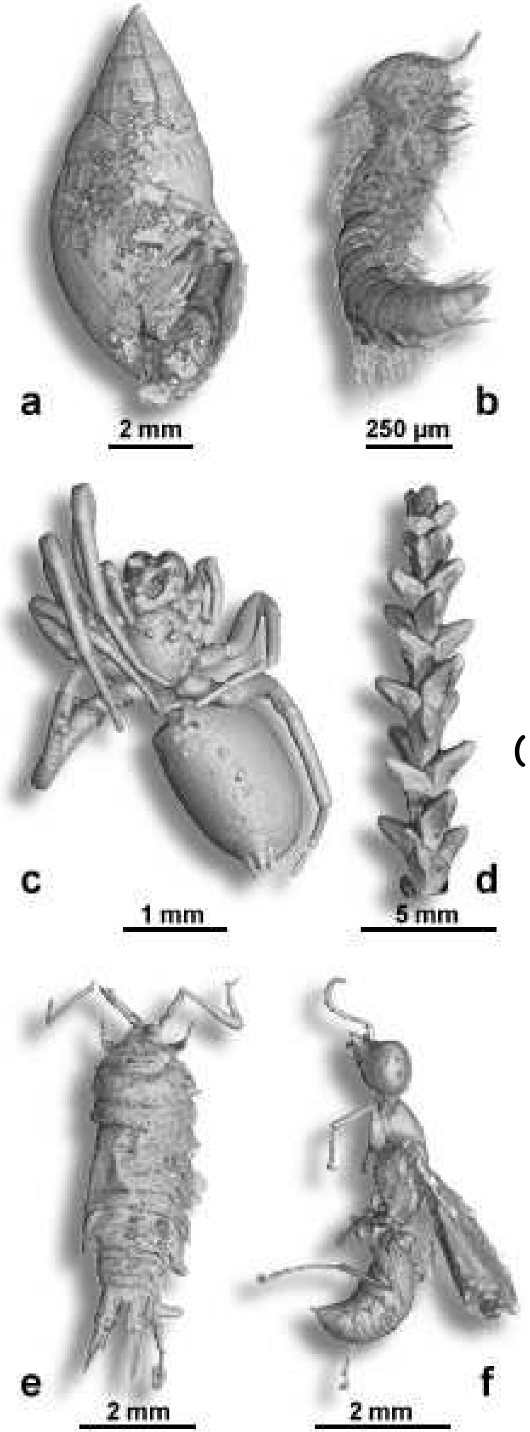
http://www.esrf.eu/news/general/amber/amber/

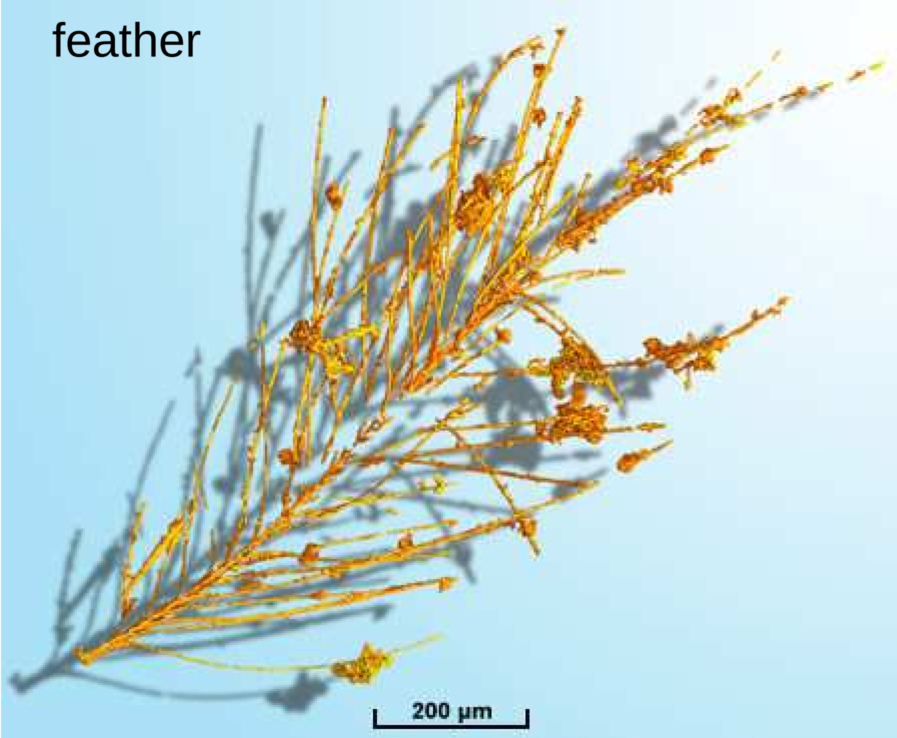
Piece of amber
100 millions years BC (France/Charentes)

~30keV monochromatic X-rays from ESRF

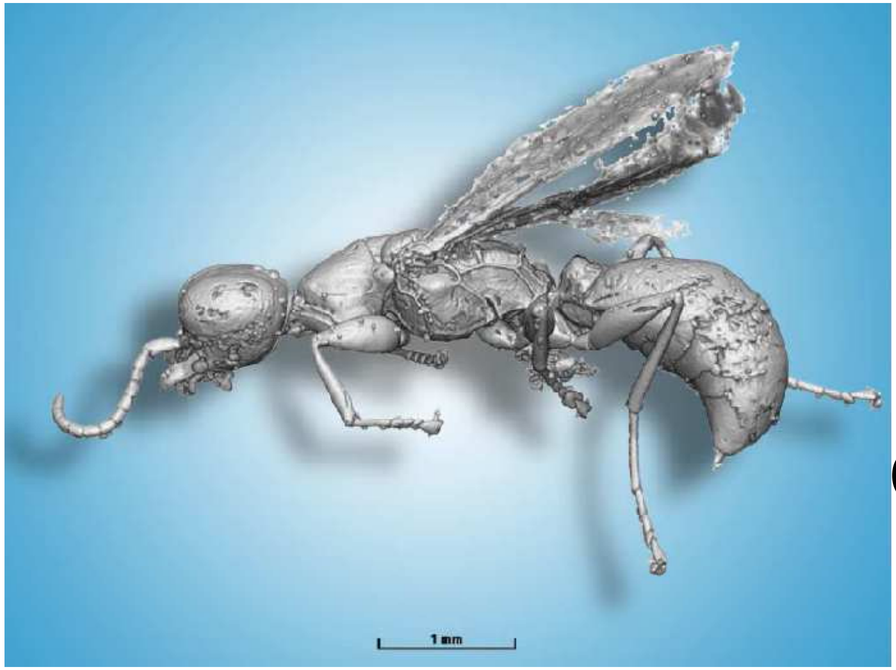


➔ non destructive 3D imaging
of elements contained inside the amber since more than 100M years



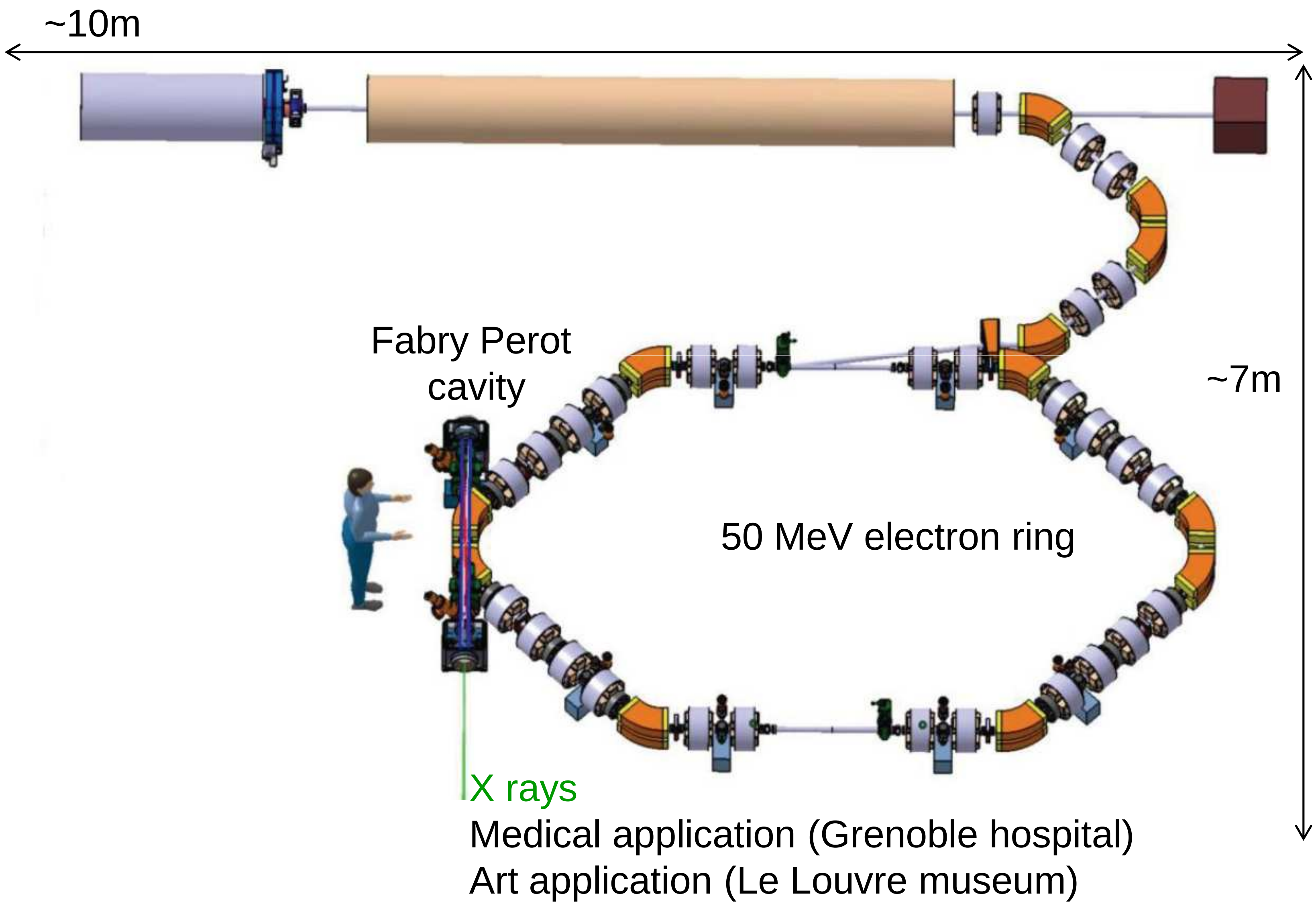


(Synchrotron Rad. 16(2009) 43-47)



(Tafforeau, ESRF)

Compact X-ray machine needed for monochromatic X-ray imaging
➔ on going project at LAL: ThomX



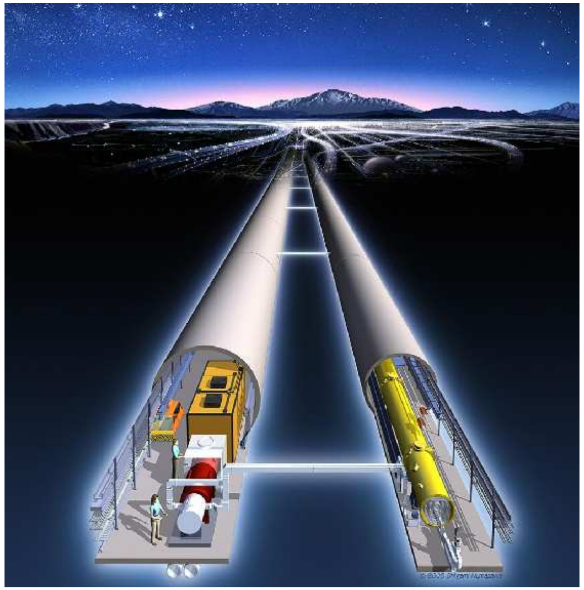
Applications of Compton scattering at High Energy

The polarised positron source

for ILC:

futur e+e- collider at

500GeV center of mass energy



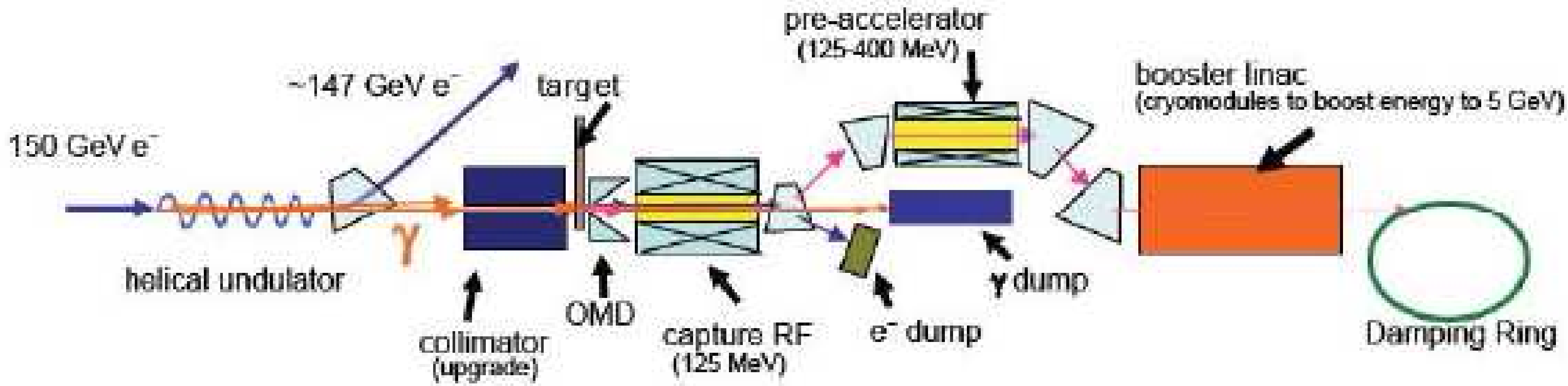
Why polarized e^- and e^+ beams?

- Comprehensive overview in *hep-ph/0507011, Phys.Rept.460 (2008), GMP et al.*
  - executive summary: http://www.ippp.dur.ac.uk/LCsources/
- Goals: Polarized beams required to
  - → analyze the structure of all kinds of physics
  - → improve statistics: enhance rates, suppress backgrounds
  - → get systematic uncertainties under control
- Discoveries via deviations from SM predictions in precision measurements !
  - → important in particular at sqrt{s}≤500 GeV! **(e.g. A_{LR})**

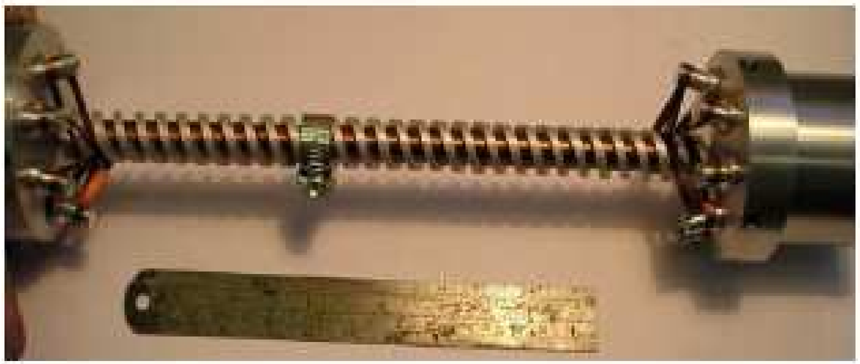
•e+ polarisation needed for the 3 scenarii !

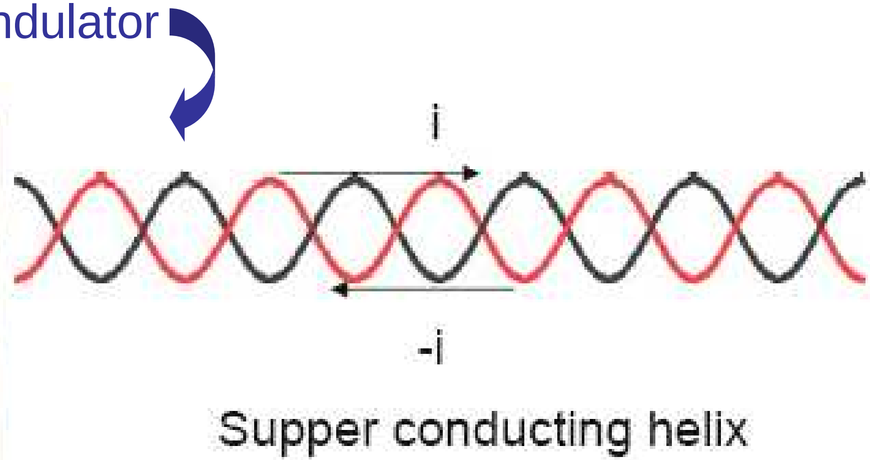
- LHC not detected anything
- LHC only detected SM-like Higgs
- LHC detected some new physics

Polarised positron source: baseline solution, the undulator scheme



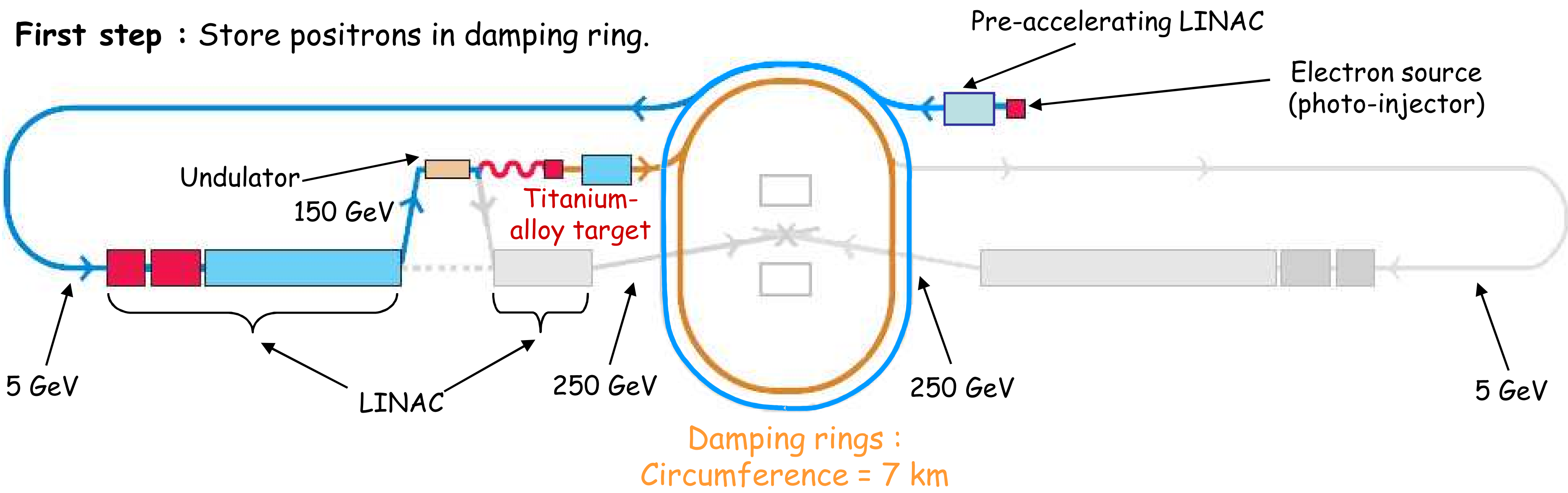
Requires ~200m of SC helicoidal undulator
6mm diameter beam pipe

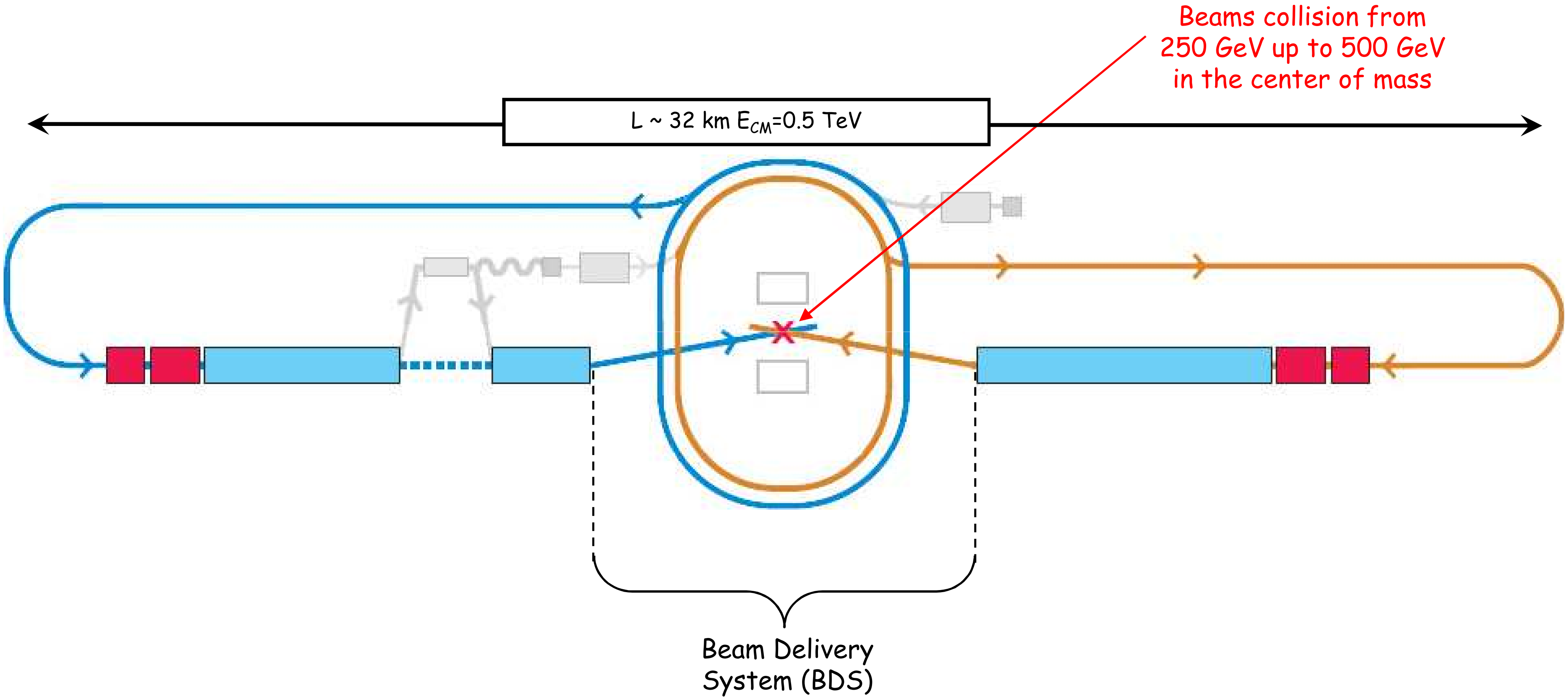




Simplified schematic view of the ILC

First step : Store positrons in damping ring.



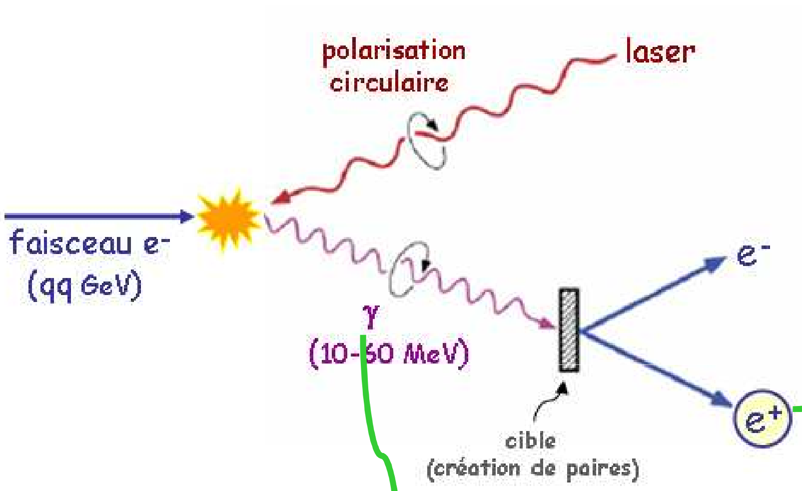


Beams collision from
250 GeV up to 500 GeV
in the center of mass
L ~ 32 km E$_{CM}$=0.5 TeV
Beam Delivery
System (BDS)

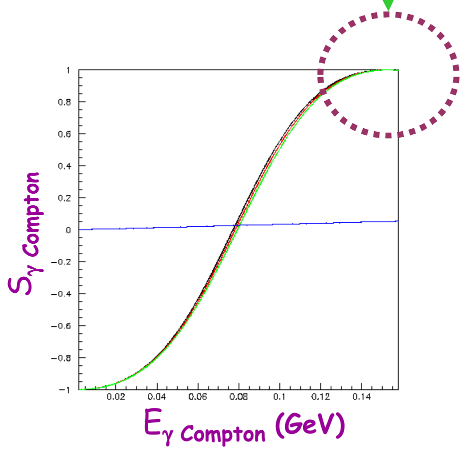
- The undulator solution for e+ polarised beams has some drawbacks
  - Complex accelerating structure with dependent e- and e+ sources
  - Very high gamma flux on target in short time (heat issue)
  - ‘Fast’ polarisation flip impossible
  - 150GeV e- beam needed, How to reduce the e- beam energy afterward ?

Alternative solution
Compton polarised positron source for the ILC

Araki et al. arXiv:physics/0509016

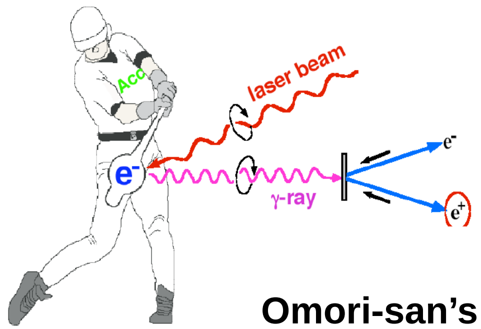


The e+ are longitudinally polarised



Experimental proof at ATF

- Omori et al. PRL 96(2006)114801



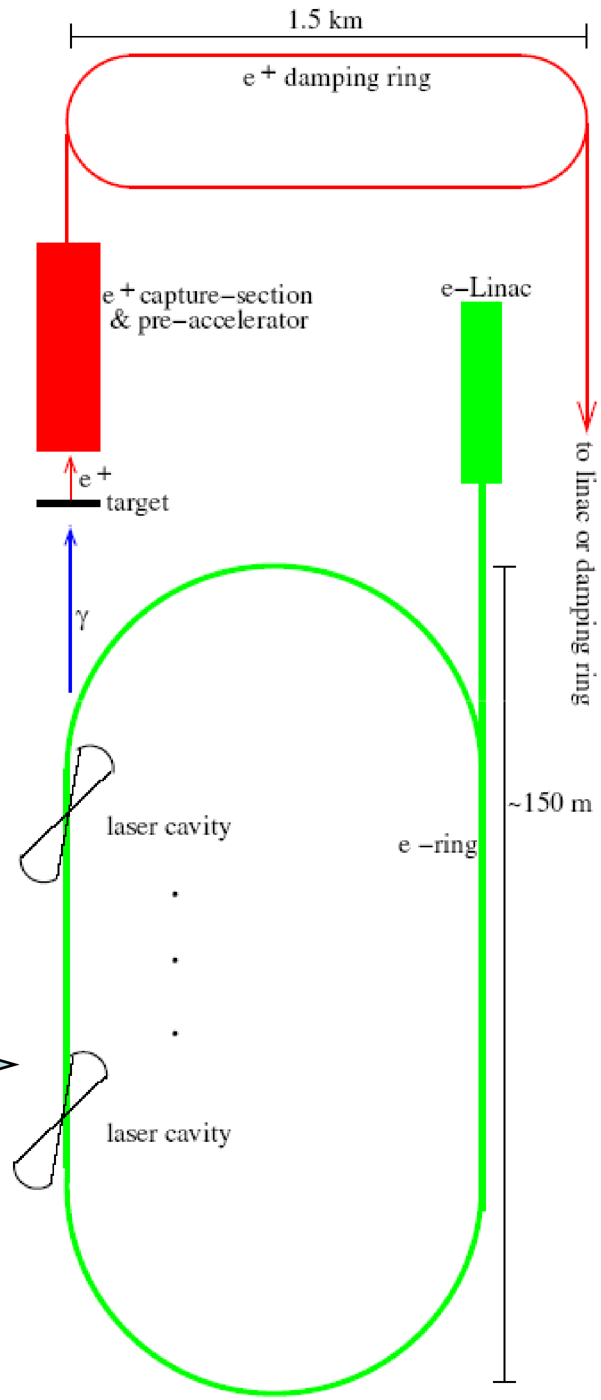
Omori-san's picture

Original idea for ILC (2005):

adaptation of JLC solution

- ILC beam= trains of ~3000 bunches
  - Train frequency=5Hz

200ms to create up to 90% polarised e+



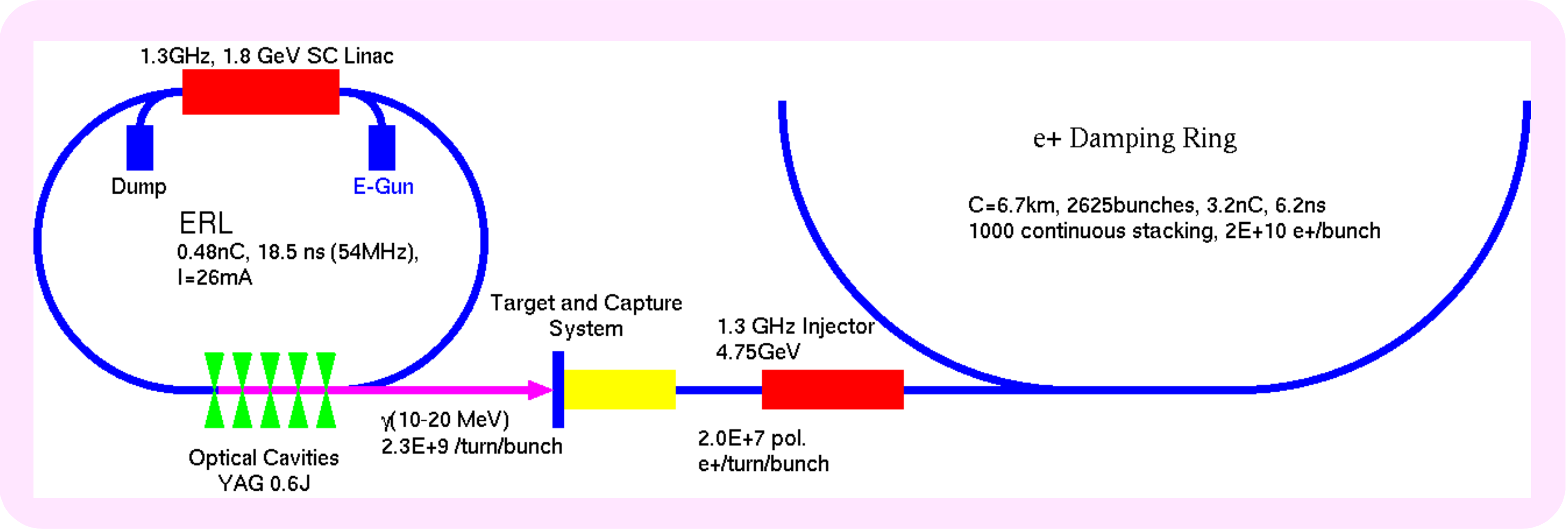
Araki et al. arXiv:physics/0509016

Now: 3 technical solutions

- Electron LINAC and CO_2 laser
  - No stacking in a damping ring
  - But less e+ polarisation due to higher harmonics contribution
  - Regenerative cavities for high power laser
- A ‘Compton’ electron ring
- A ‘Compton’ ERL (Energy Recovery Linac)

ERL scheme

- Electron is provided by ERL (Energy Recovery Linac).
- Both advantages (high yield at Linac and high repetition at CR) are compatible in the ERL solution.
- Continuous stacking of e+ bunches on a same bucket in DR during 100ms, the final intensity is 2E+10 e^+.
- Another 100ms is used for damping.



2 main issues for CR & ERL solutions

- e+ stacking in the damping ring

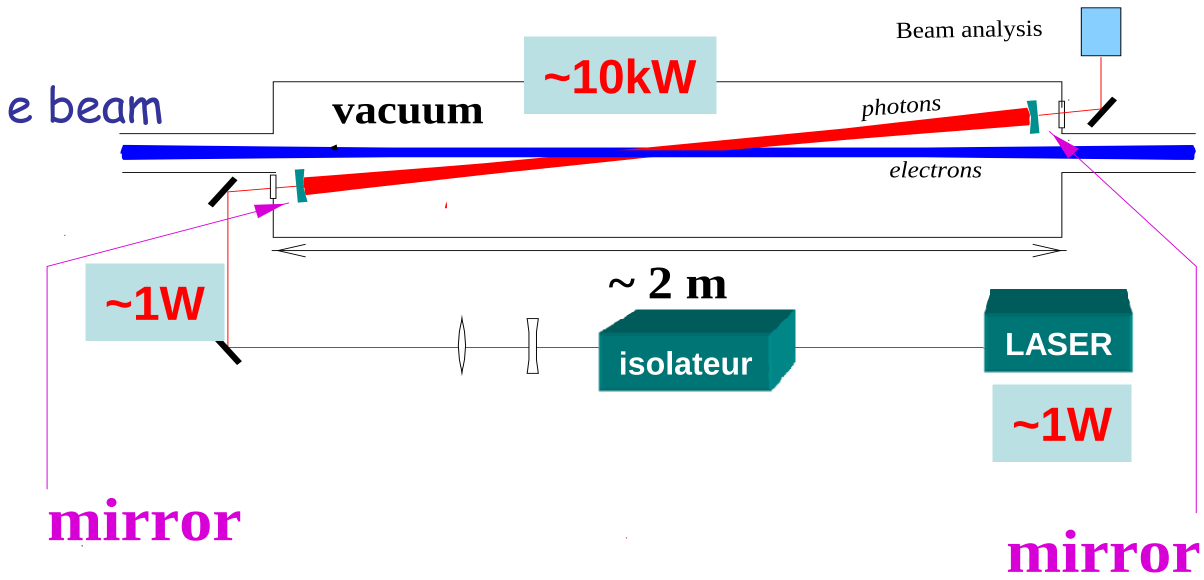
- The huge requested laser average power: 0.6J/pulse@54MHz~30MW !

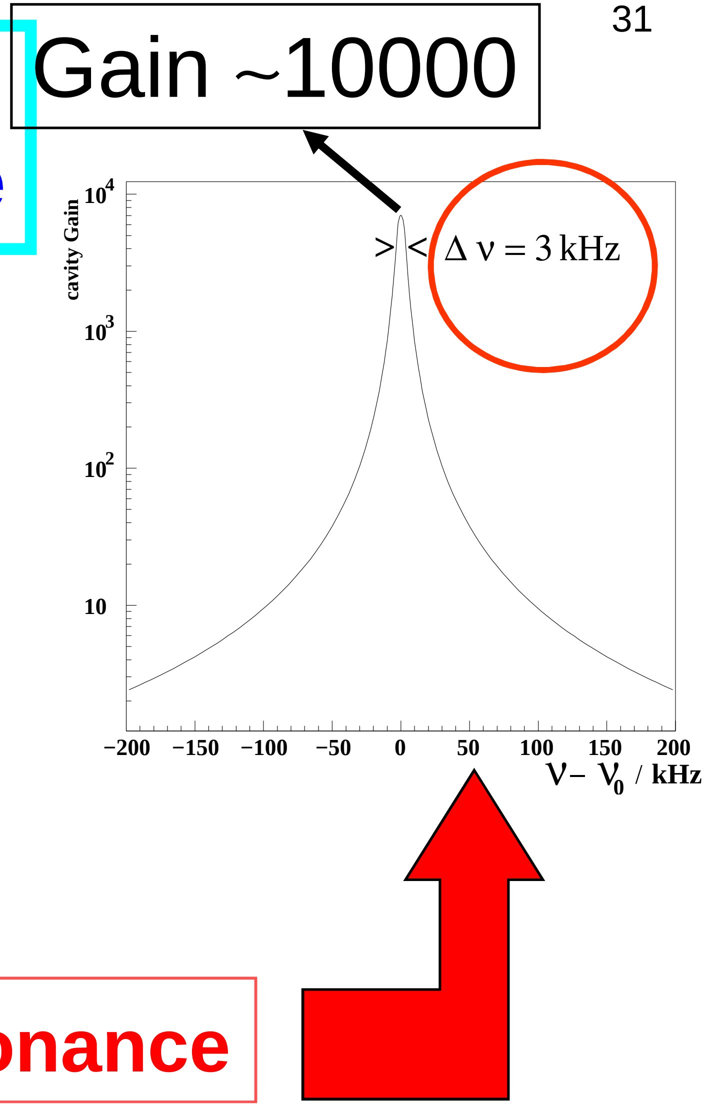
  ➔ *We are contributing to a R&D activity whose goal is to obtain very high average power with a Fabry-Perot cavity*

Fabry-Perot cavity

Principle and limitations

Fabry-Perot cavity: Principle with continuous wave

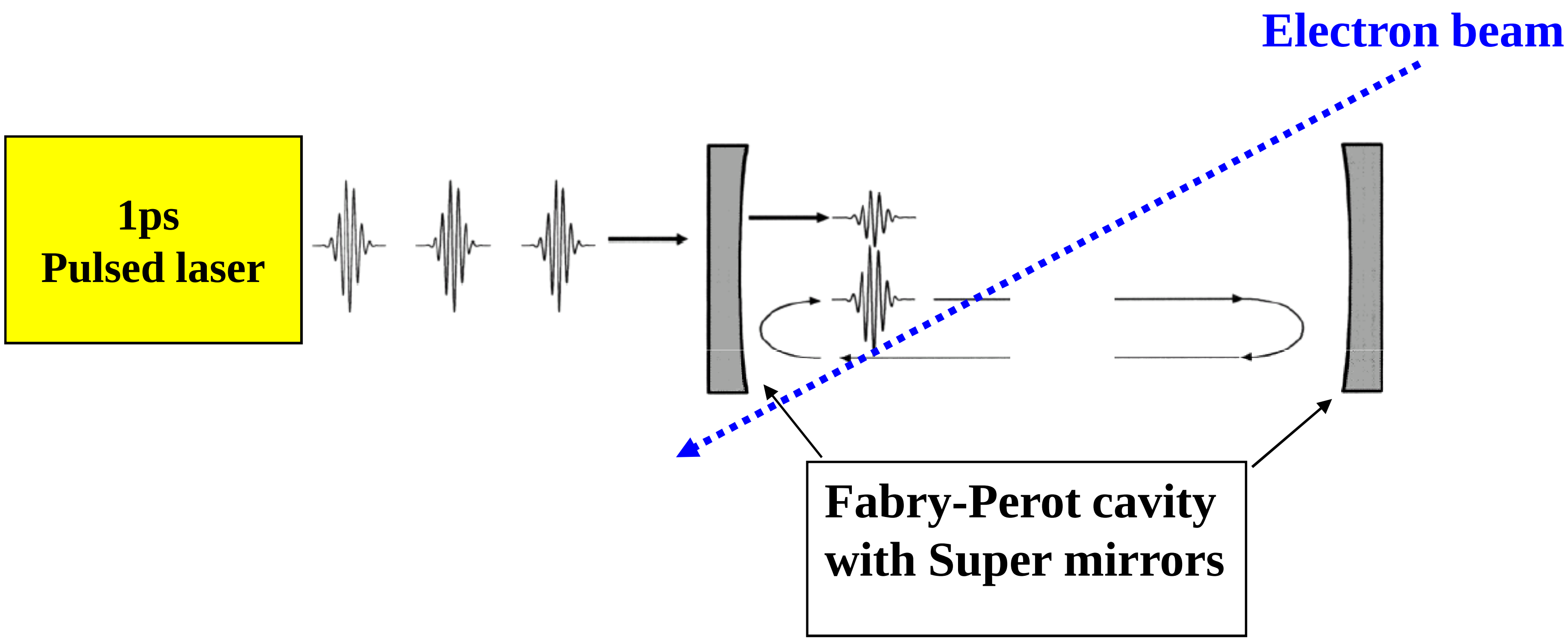




When $\nu_{Laser} \propto$ **c/2L $\Rightarrow$ resonance**

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

Fabry-Perot cavity in pulsed regime



Difference between continuous and pulsed regime

Pulsed_laser/cavity feedback technique

Specificity ➔ properties of passive mode locked laser beams

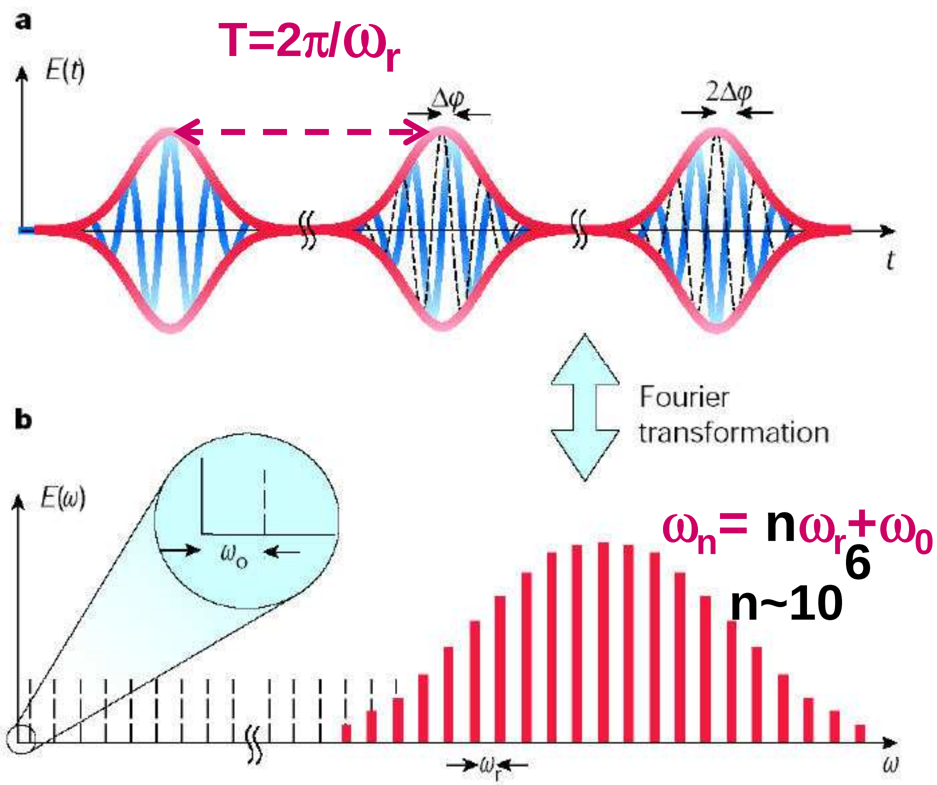
Frequency comb ➔ all the combs must be locked to the cavity

➔ Feedback with

2 degrees of freedom :

control of the

Dilatation & translation



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

Technical constraints

- **First technical constraint: laser phase noise**

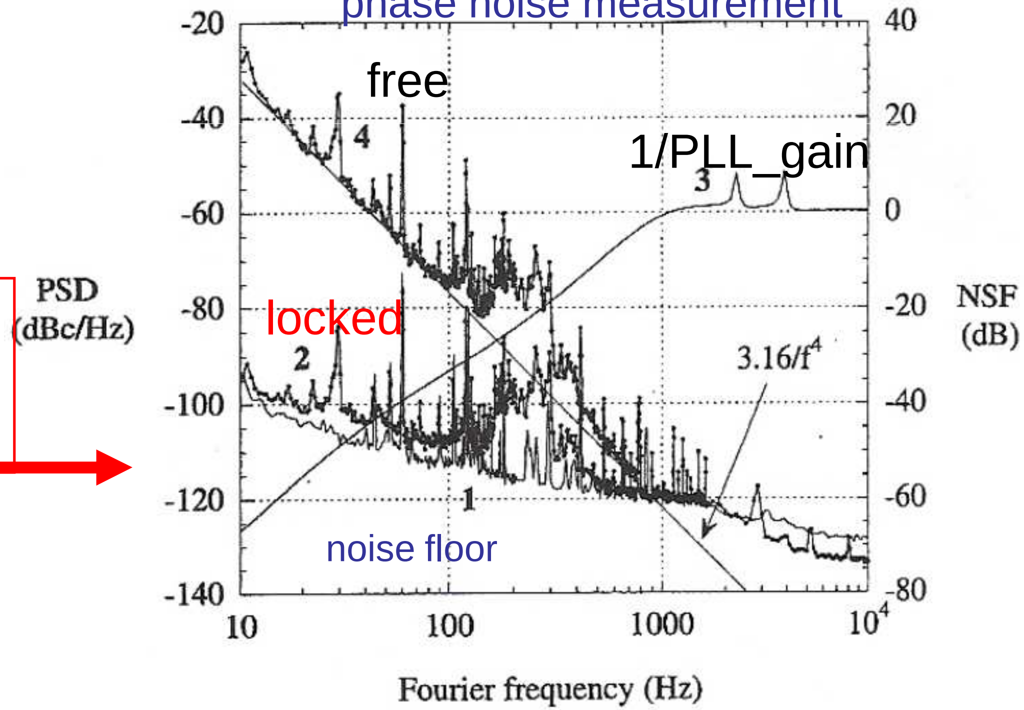
For all comb components $\omega_n = n\omega_r + \omega_0$ to be locked to a cavity of finesse F

$$\frac{\Delta\omega_r}{\omega_r} \approx \frac{1}{2n}\frac{1}{F} \quad \text{BUT: } n \approx 10^6 \text{ and } \omega_r \sim 2\pi \times 100 MHz$$

$$\Rightarrow \frac{\Delta\omega_r}{\omega_r} \sim 10^{-10}\text{-}10^{-11} \quad \text{for F=10000}$$

Possible with mode locked lasers
Ex.: almost no phase noise above ~10kHz in Ti:sa oscillators

Ti:sa oscillator
phase noise measurement

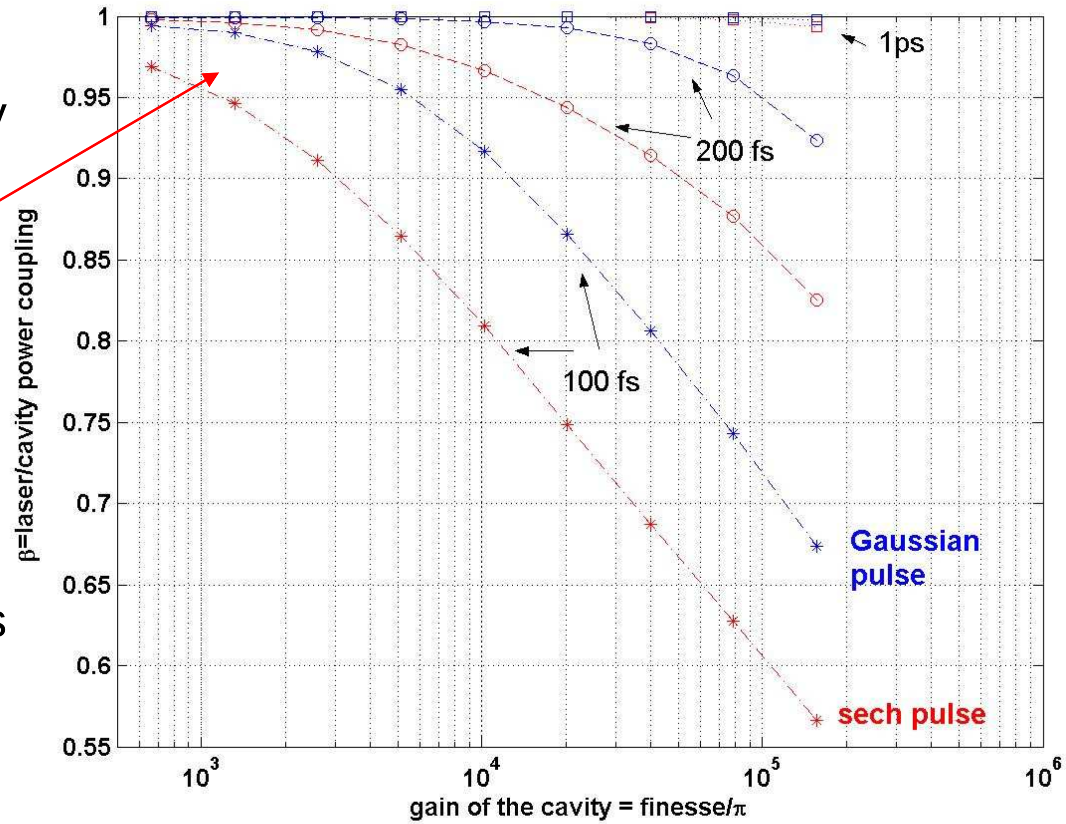


Ivanov et al. IEEE Trans Ultr, 50(2003)355

•Second technical constraint:

➔Chromatic dispersion of the cavity mirror coating gives a limit on laser pulse width

➔ No effect for ~1ps pulses



•Third technical constraint:

➔coating damage

➔ 10^{11}W/cm^2 average power for ps Pulses in the 100kW regime…

➔High finesse cavity could be operated in ps regime as in cw regime up to the MW average power regime

State of the art is ps regime:

•Loewen (PhD, SLAC), gain 6000 for ~30ps pulse width

•KEK/ATF cavities, gains ~1000 for ps lasers

•At LAL we locked ps Ti:sapph oscillator to 10000 gain cavity (but few seconds…)

•Garching (in 2010), gain=1800, **Power_inside = 72kW**

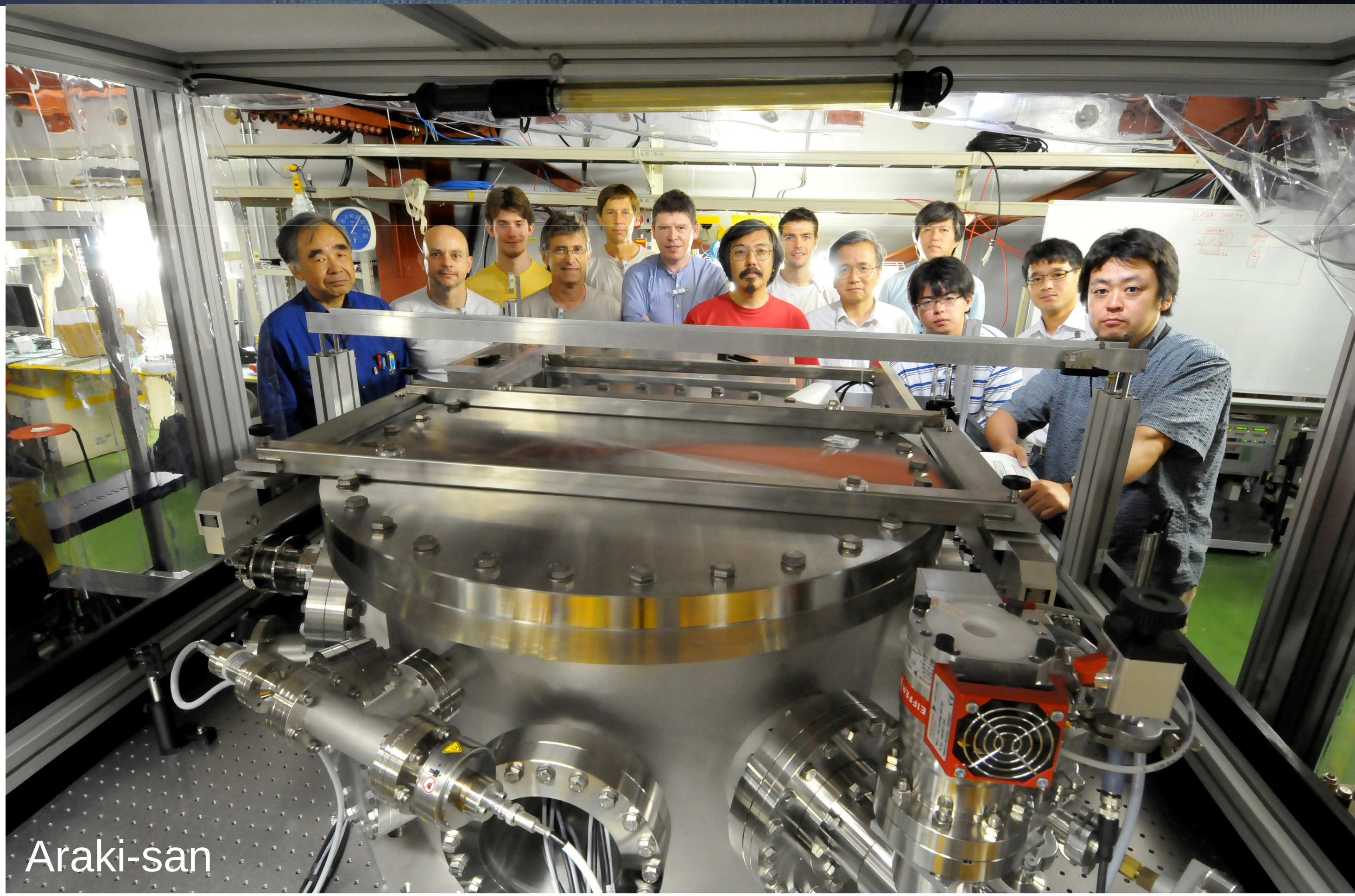
Four-mirror Fabry-Perot cavity R&D at ATF

1. Our setup/goal
2. Why 4 mirrors ?
3. The ATF 4-mirror cavity
4. The optical scheme
5. The laser/cavity feedback

French Japanese Collaboration

F. Labaye, E. Cormier, CELIA CNRS Université Bordeaux 1, Bordeaux, France
T. Akagai, S. Miyosohi, S. Nagata, T. Takahashi, Hishoshima University, Hiroshima, Japan
S. Araki, S. Funahashi, Y. Honda, T. Omori, H. Shimizu, T. Terunuma, J. Urakawa, KEK, Tsukuba, Japan
J. Bonis, R. Chiche, R. Cizeron, M. Cohen, J. Colin, E. Cormier, P. Cornebise, D. Jehanno, F. Labaye, M. Lacroix,
Y. Peinaud, V. Soskov, A. Variola, F. Zomer, LAL CNRS/IN2P3 Université Paris-Sud 11, Orsay, France
R. Flaminio, L. Pinard, LMA CNRS/IN2P3, Lyon, France

N. Delerue]

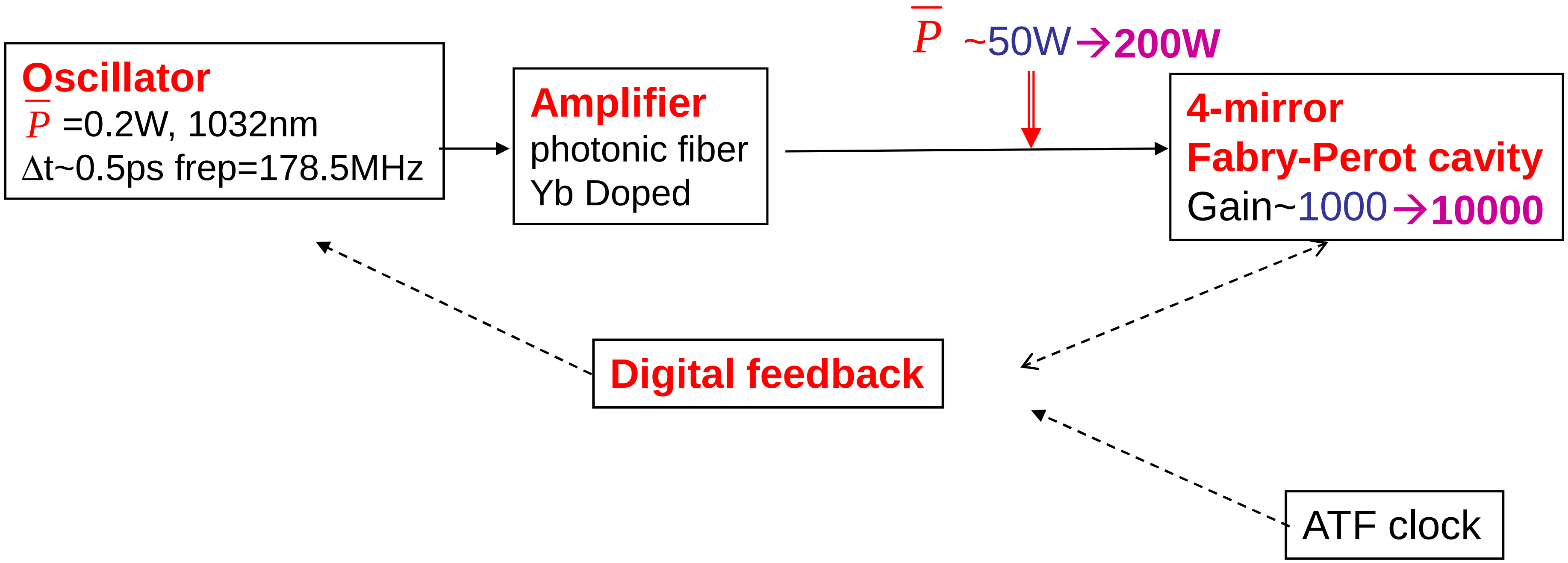


2 steps R&D

Started end 2008

STEP ONE: commissioning a 4-mirror cavity at ATF by end 2010

STEP TWO: upgrade mirrors & laser power



STEP ONE
With cavity laser/coupling ~50% → Power_cavity~25kW

~50x1.5 vs 2-mirror cavity
→~5 E9 γ/s (Emax=28MeV)

STEP TWO
With cavity laser/coupling ~50% → Power_cavity~500kW

~2000x1.5 vs 2-mirror cavity
→~2 E11γ/s

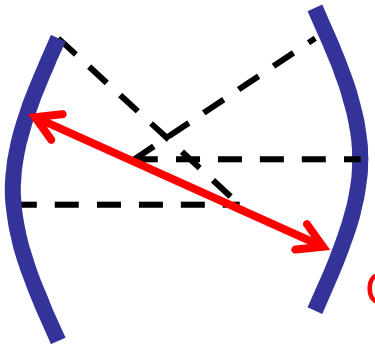
Goal: to reach the MW average power

ATF 2-mirror cavity paper: Miyoshi, arXiv:1002.3462v1

Why a four-mirror cavity ?

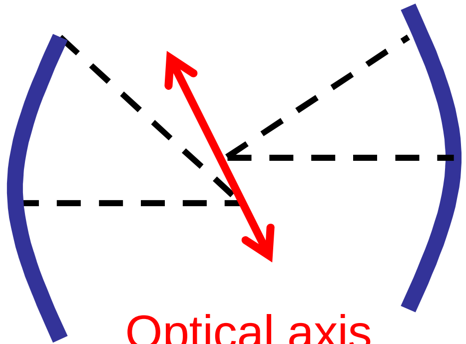
Optical axis in 2-mirror cavity:
Line joining the 2 center of curvature

Ex.: 2 misaligned mirrors



Optical axis

Laser beam spot size decreases
as the cavity becomes concentric
BUT



Optical axis
Outside cavity
Mirror acceptance
➔ Instability !

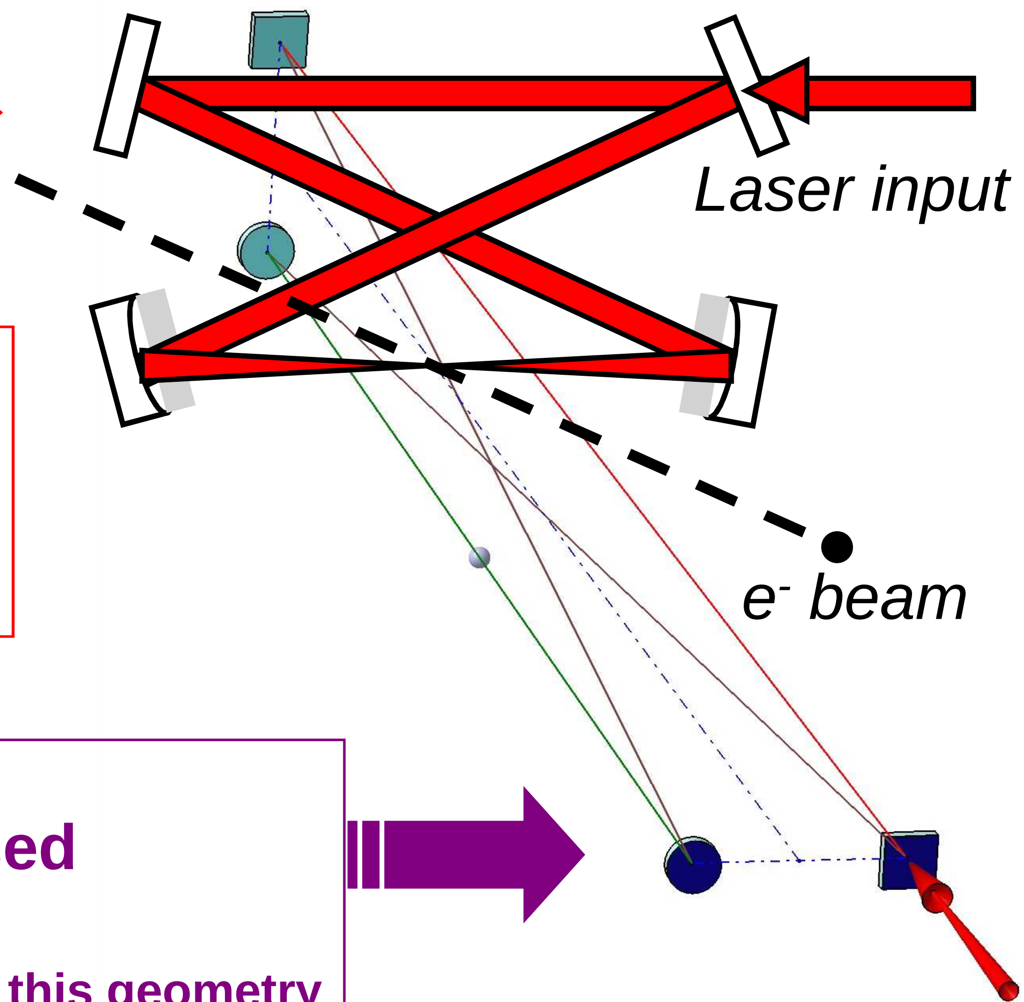
Solution : use a four-mirror cavity which avoids this instability

Why a non planar four-mirror cavity ?

Stable solution: four-mirror cavity
as in Femto laser technology

BUT
➔ astigmatic & linearly
polarised eigen-modes
which are instable because of vibrations
at very high finesse (AO48(2009)6651)

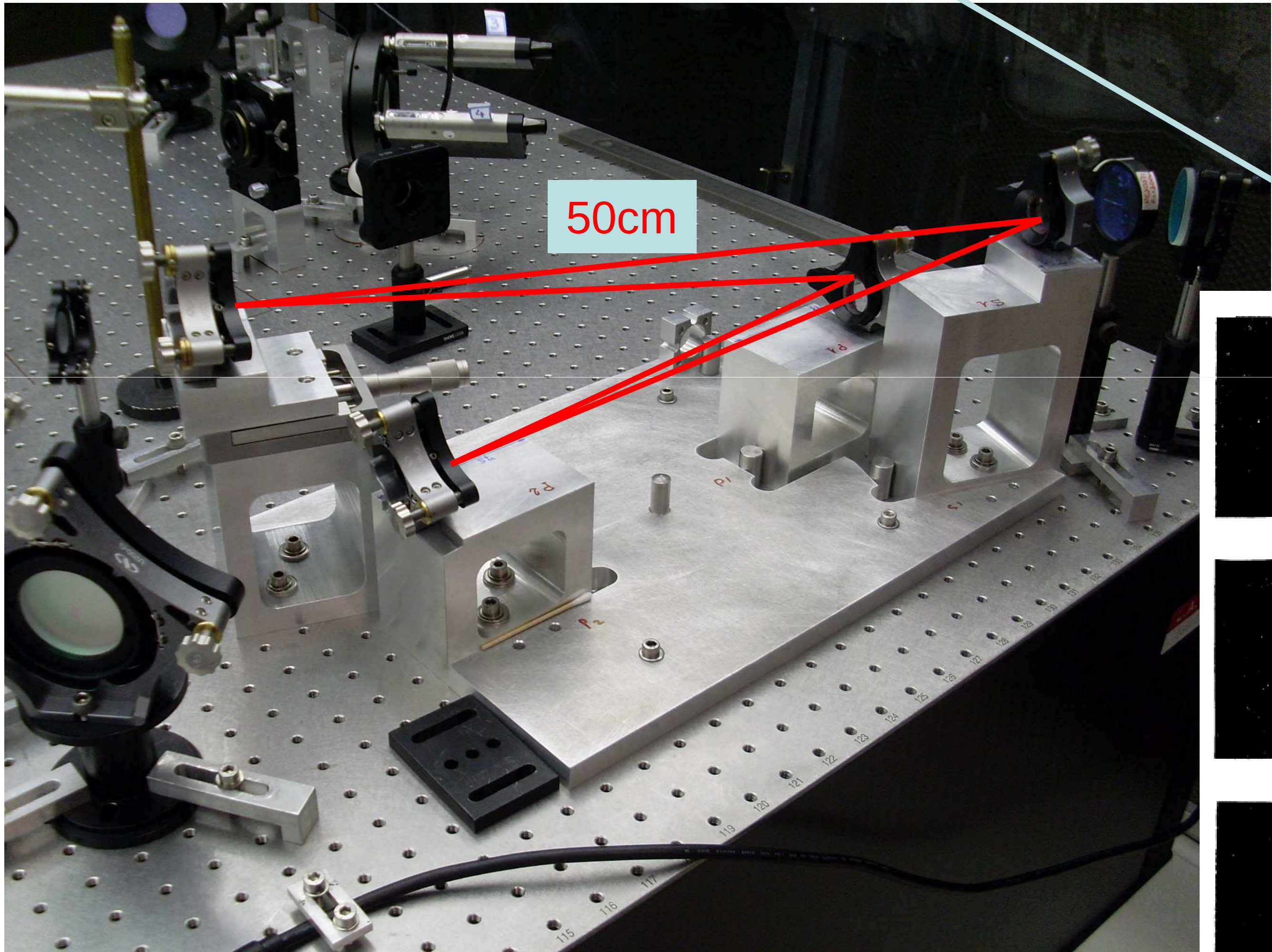
Non-planar 4-mirror cavity
➔Stable & circularly polarised eigenmodes (AO48(2009)6651)
- **New feedback techniques with this geometry (Honda, OC282(2009)3108)**



Prototype of nonplanar 4-mirror resonator (low finesse)

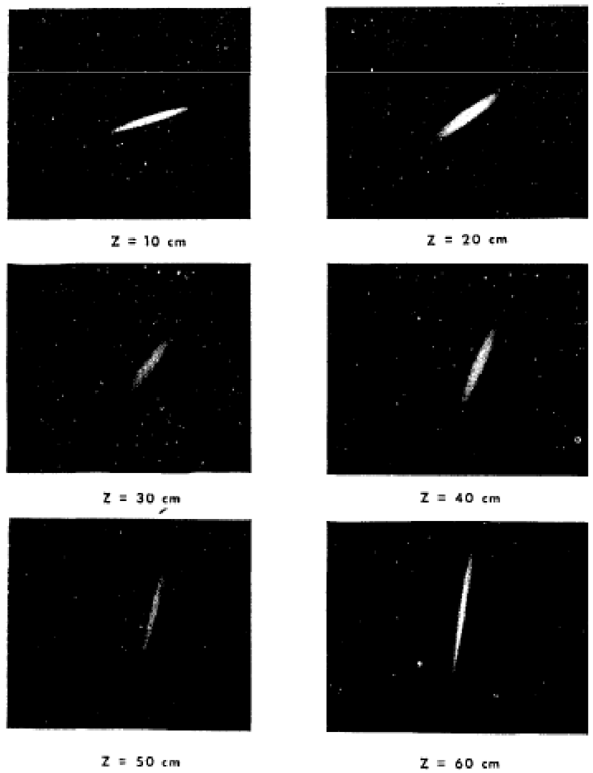
- Check the general astigmatism mode shape/propagation (*Arnaud, Bell Syst. Tech. (1970)2311*)

➔ ok

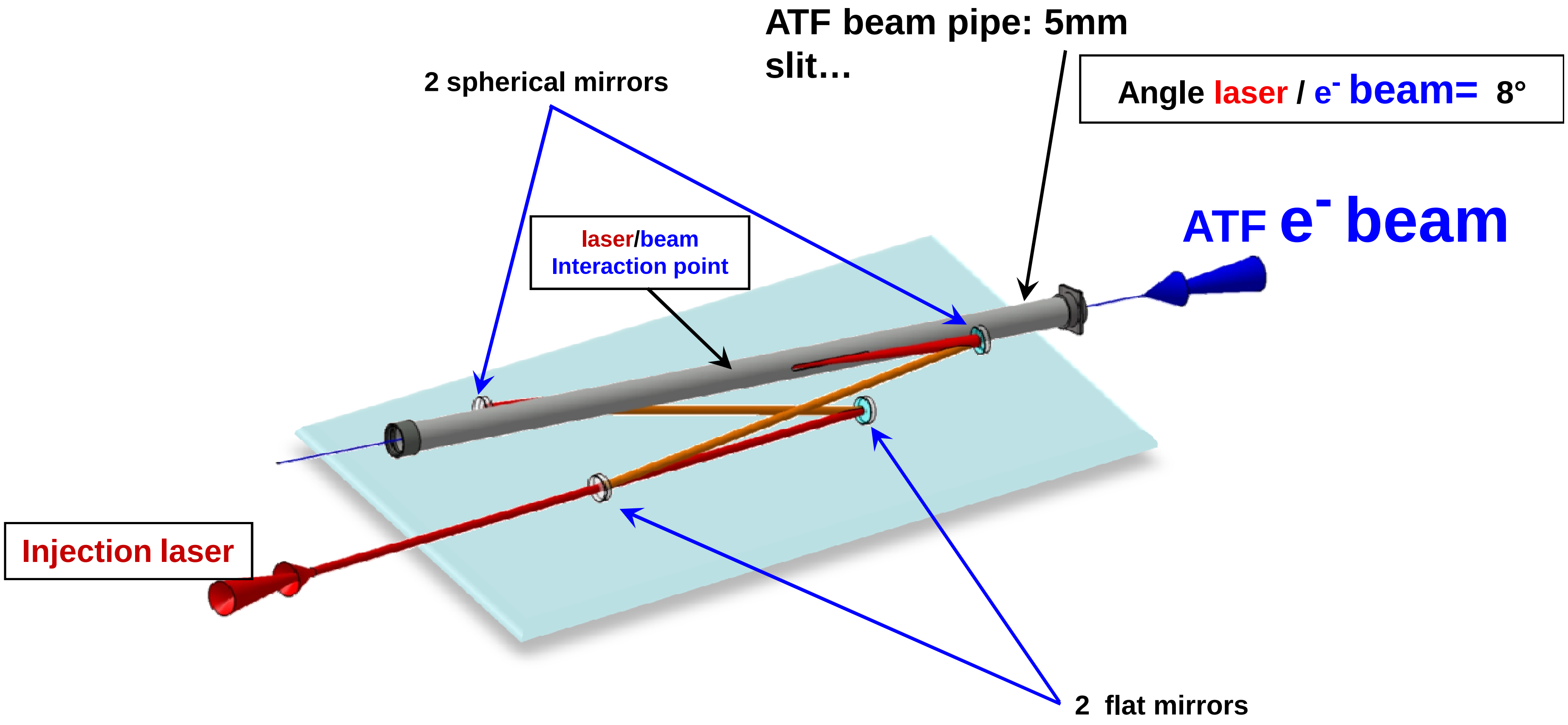


Ellipse intensity profile ‘turning’

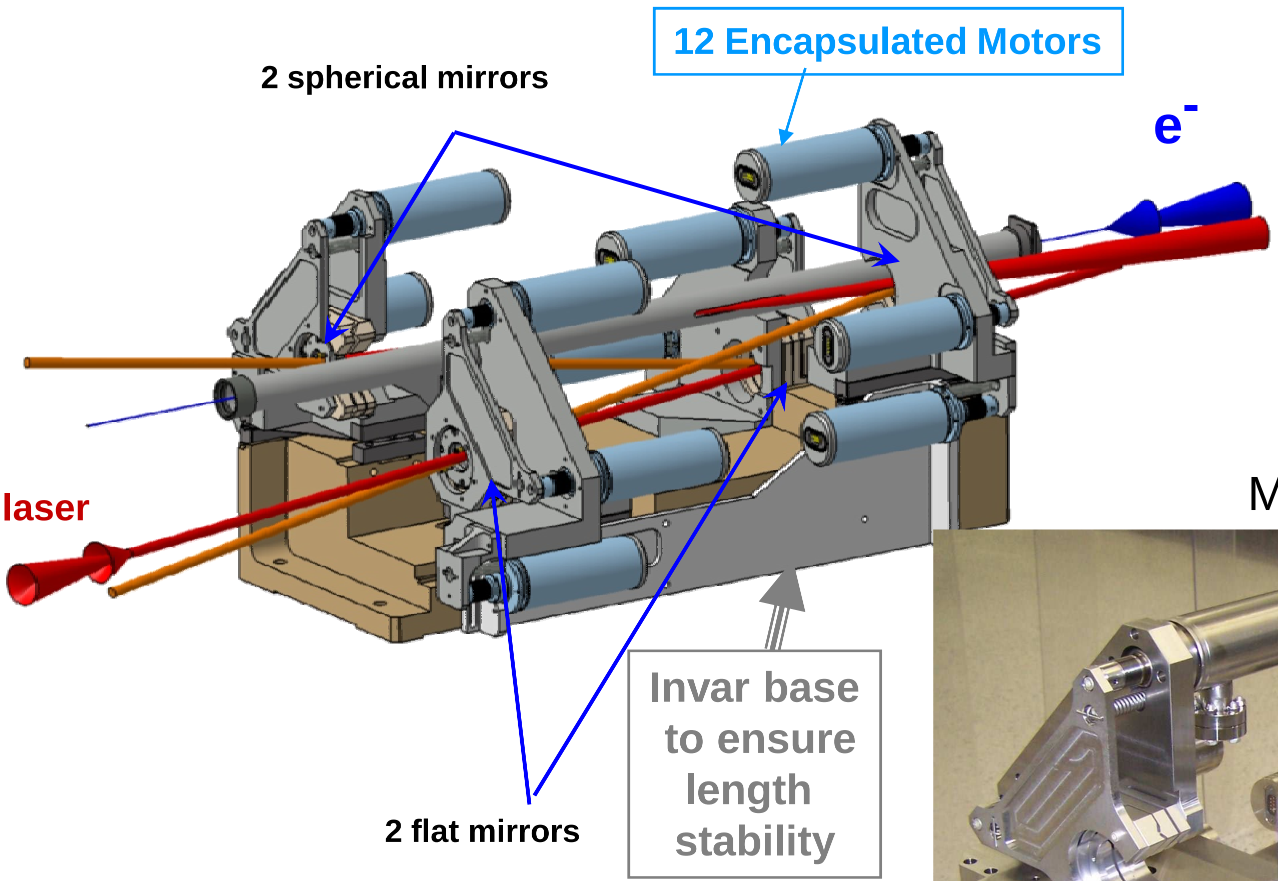
Kogelnik, Apl. Opt. 8(1969)1687



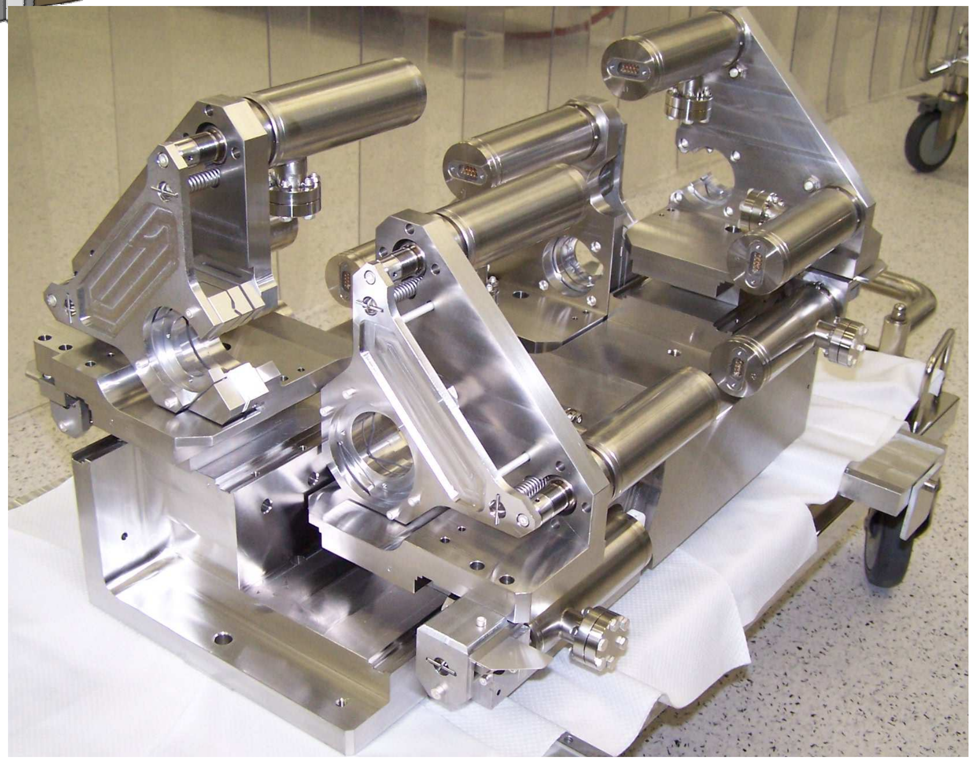
Non planar 4-mirror cavity design/construction for ATF



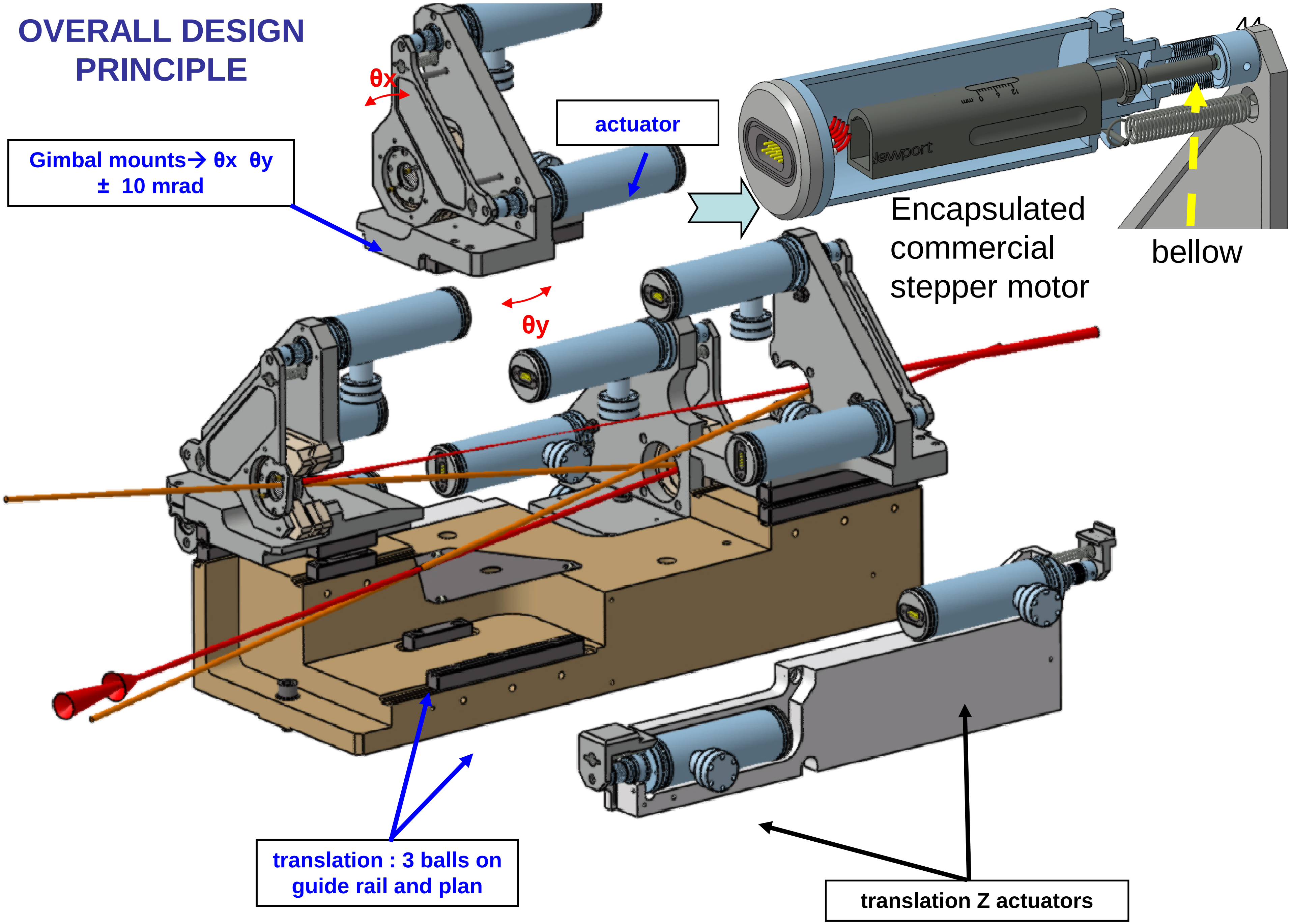
Mirror positioning system

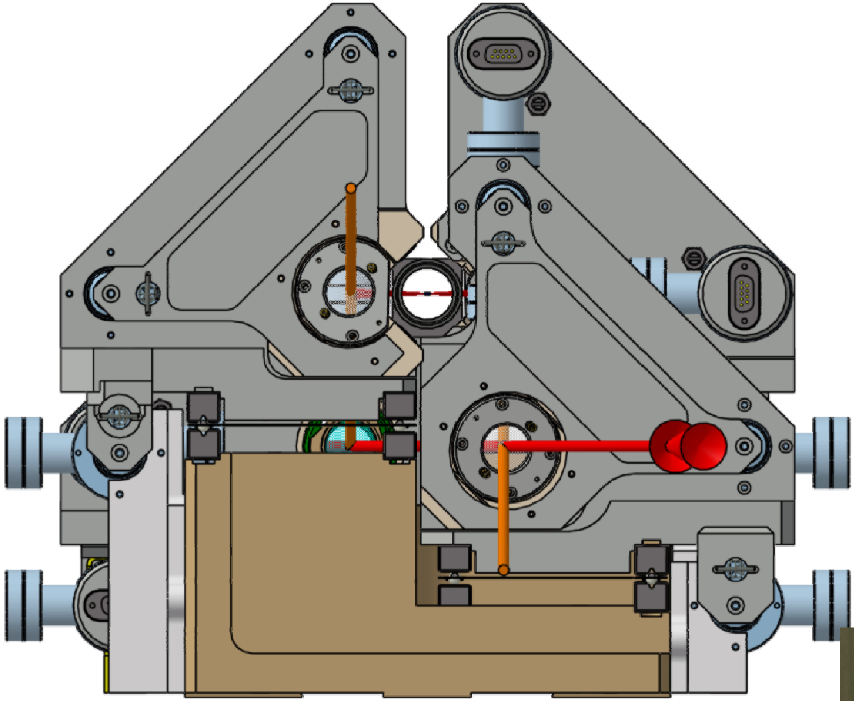


Mounting in class 10 room



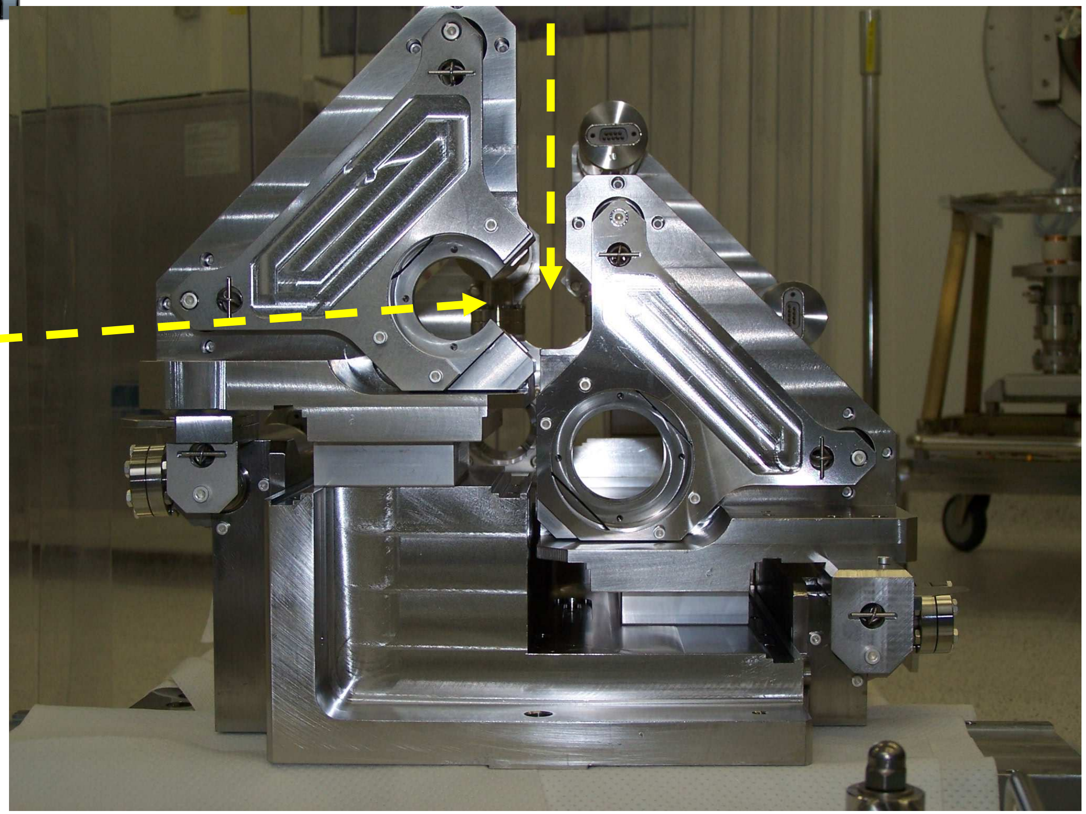
OVERALL DESIGN PRINCIPLE



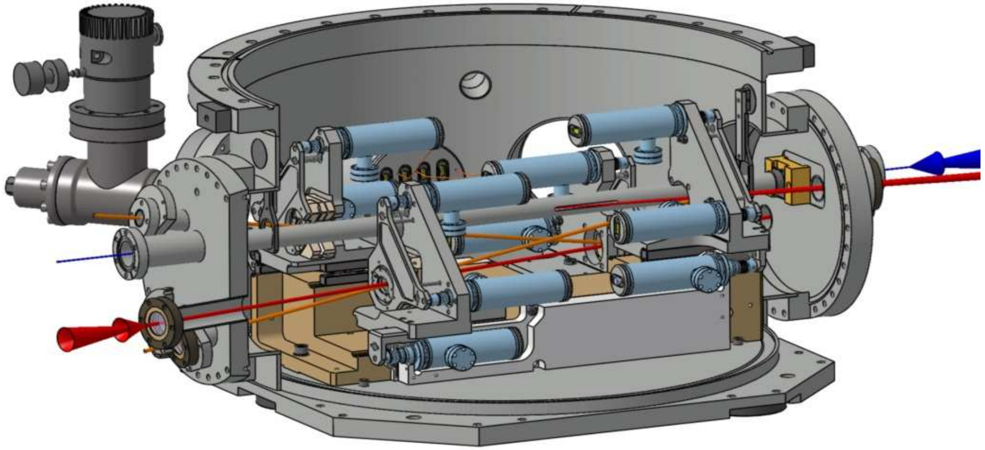


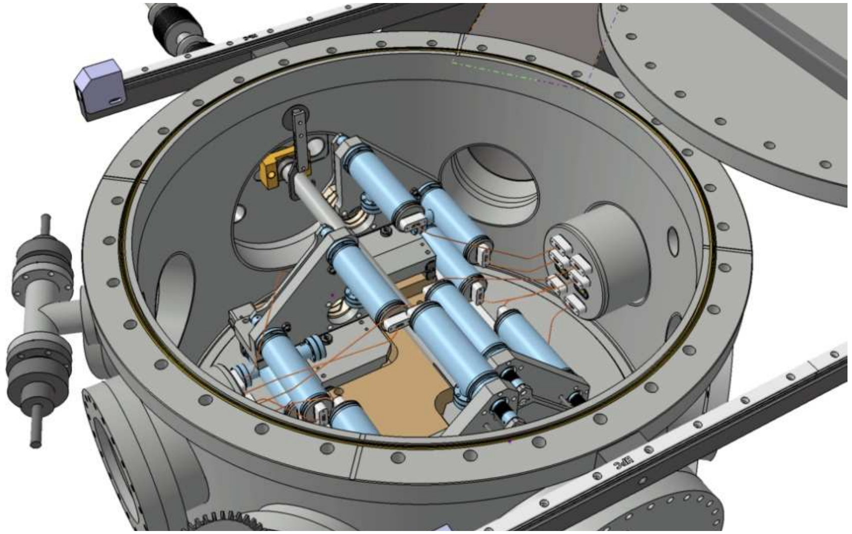
Place for ATF beam pipe

Mirror mount troncated to decrease incident angle : 8°



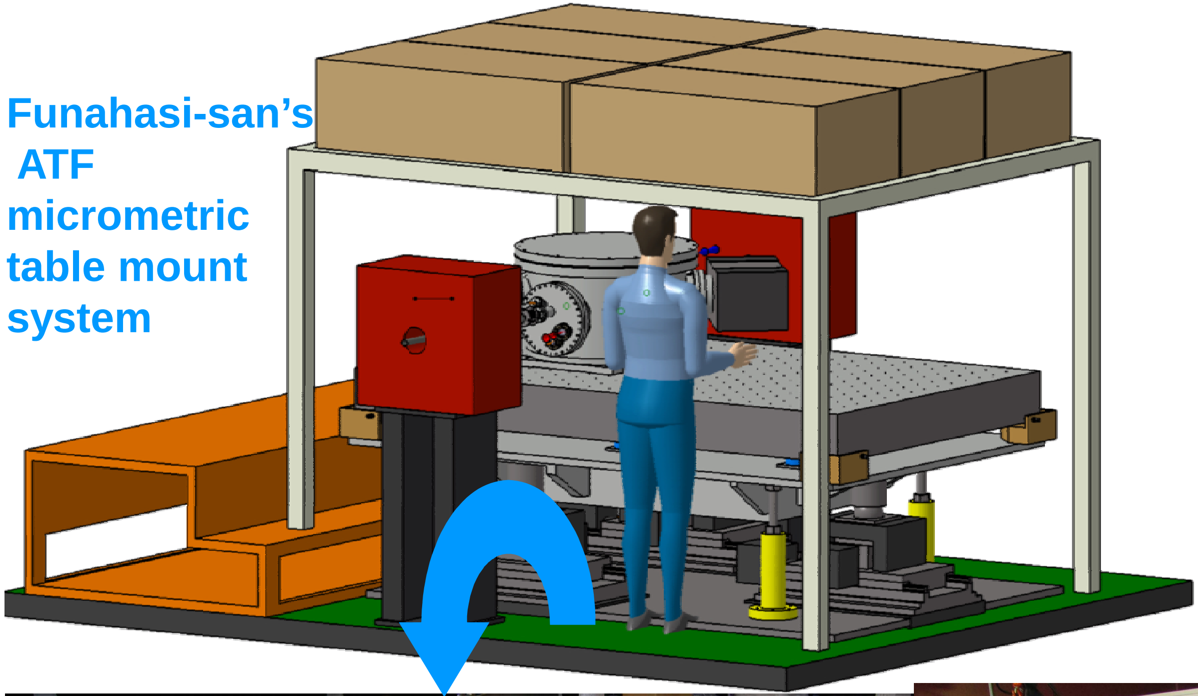
Vacuum vessel for ATF

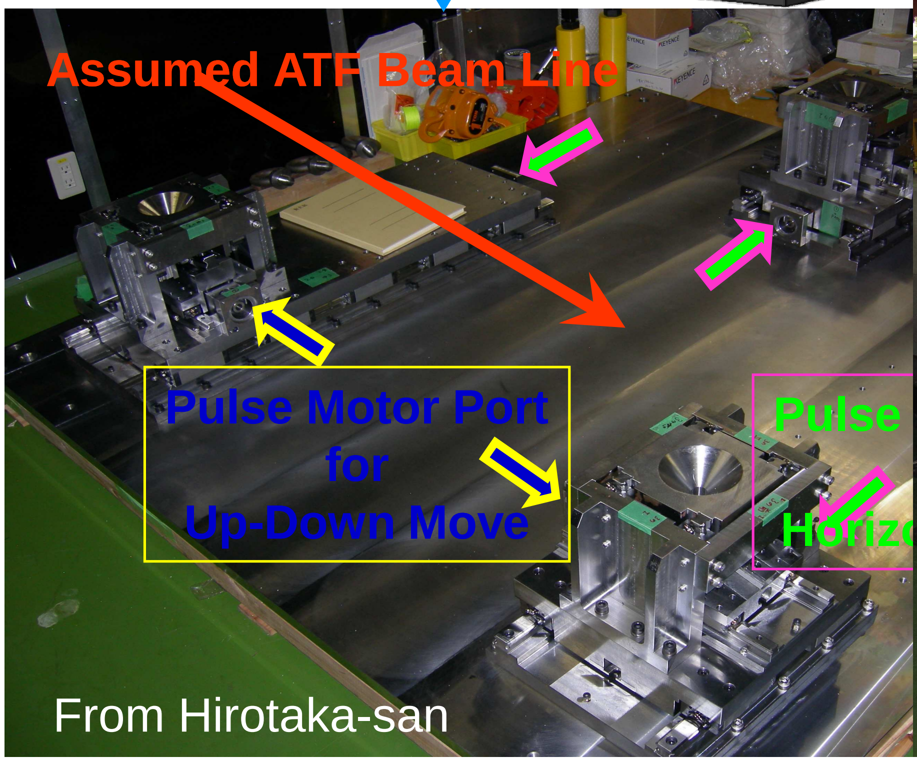




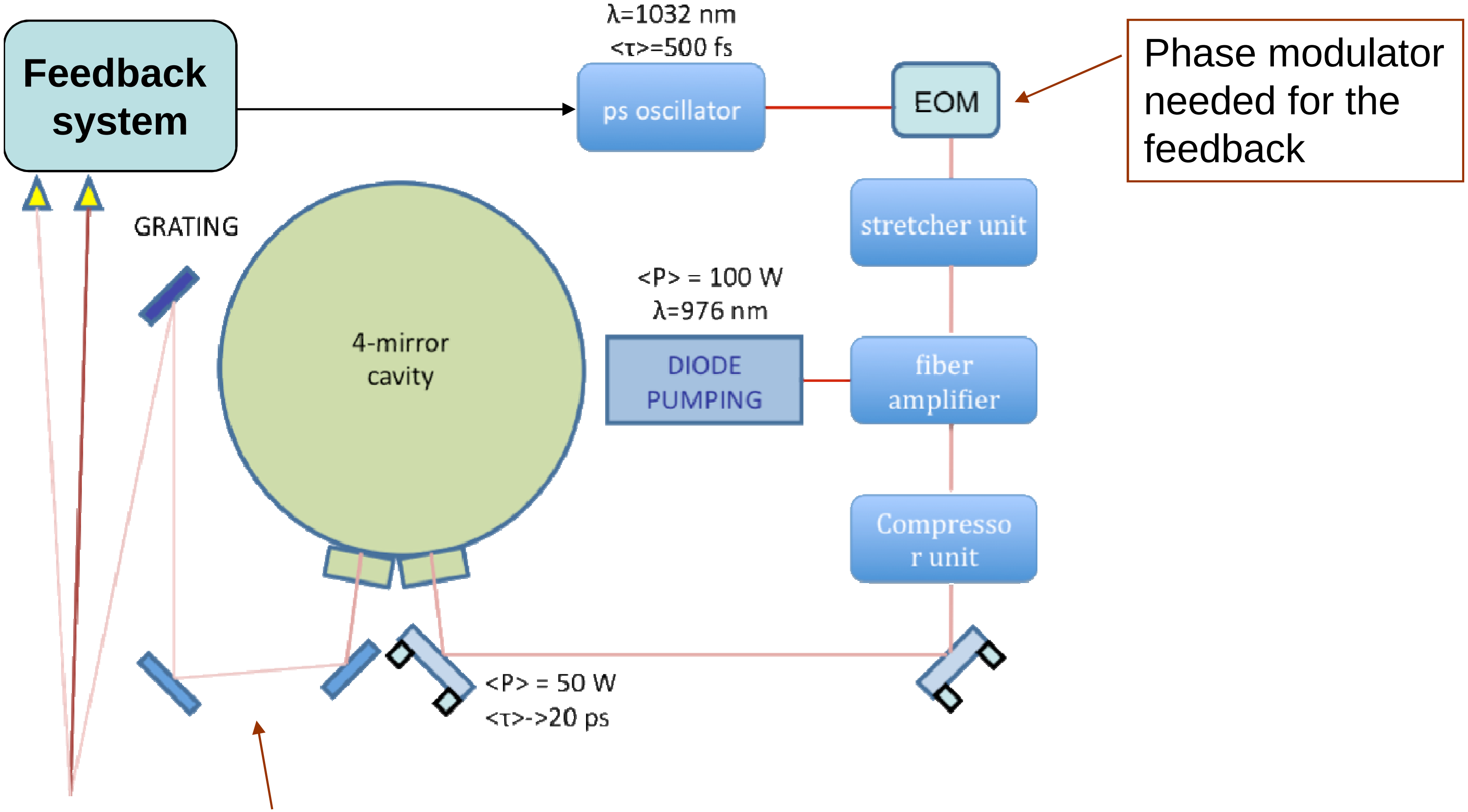
Implementation at ATF

Funahasi-san's ATF micrometric table mount system





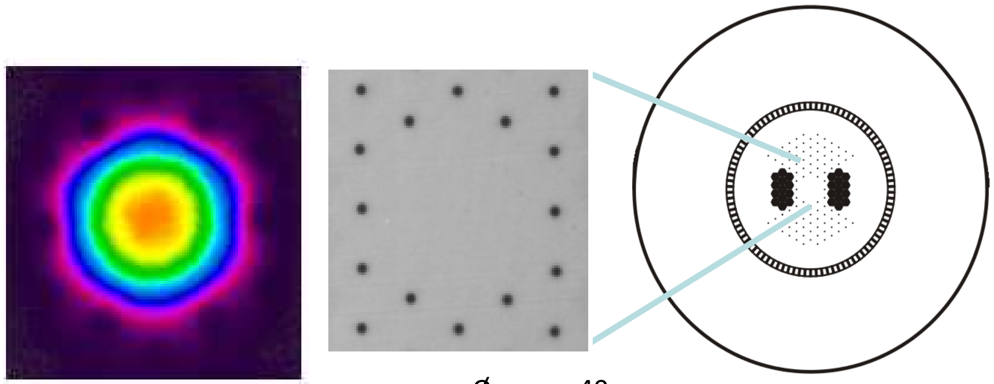
The optical scheme



•Signal reflected by the cavity used to build the laser/cavity feedback signal:

- •interference between the modulated incident laser beam AND the leackage on the beam circulating inside the cavity

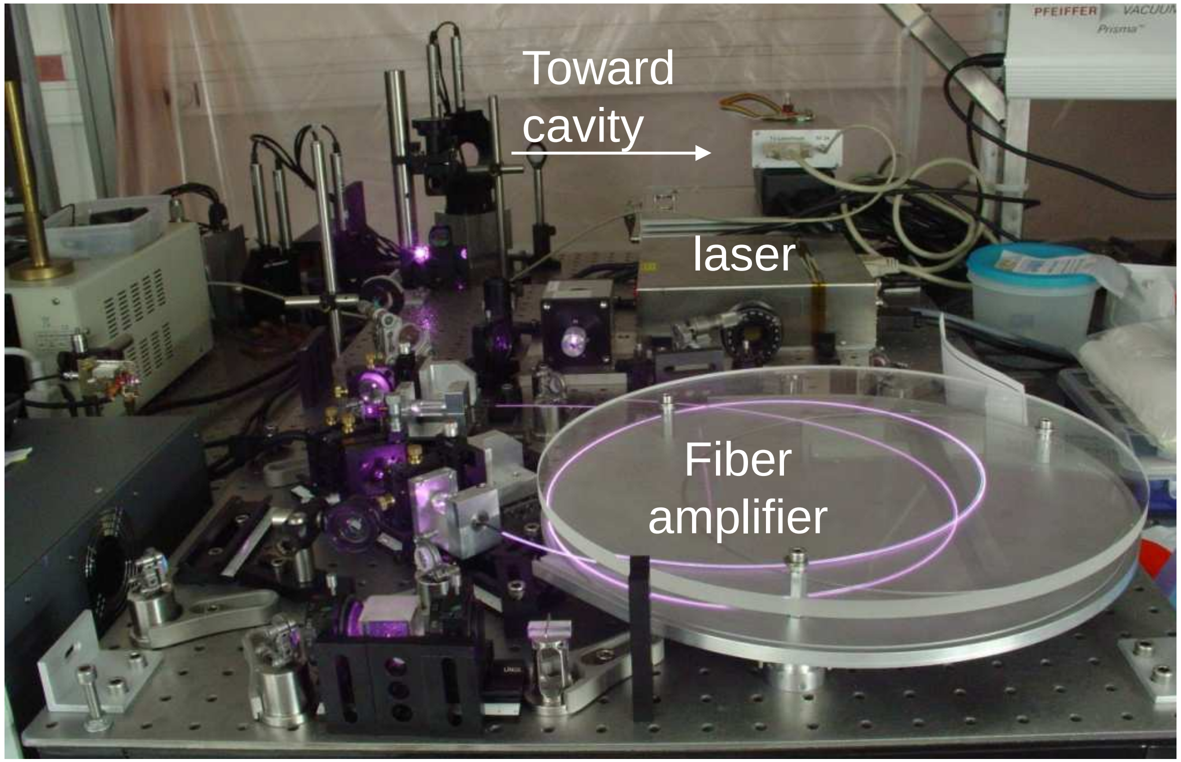
The laser amplification R&D



Ø core = 40 µm
Ø cladding = 200 µm

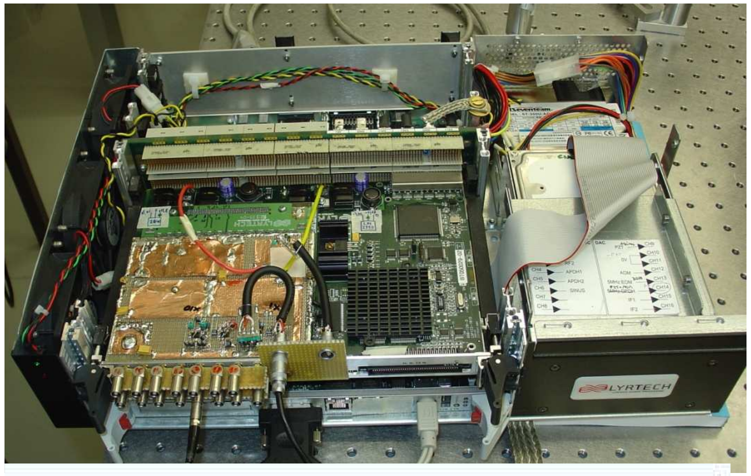
We use Ytterbium doped photonic crystal fiber as amplifier

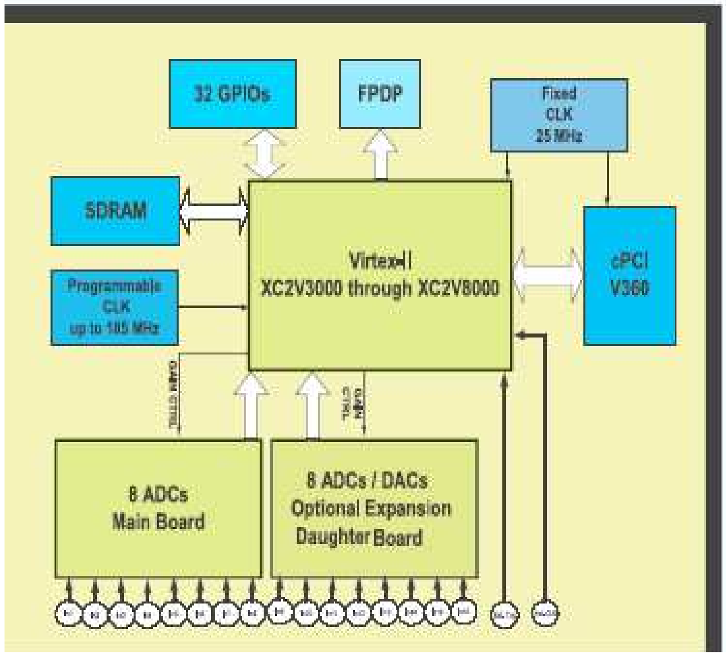
- We obtained 200W but spot was not stable
- We fix the power to ~50W to get stable laser beam
- Thermal control issues to be solved before increasing power
- Also damage protection issues are not easy to solve at very high power (we broke many fibers…)
- Recent publication shows 800W average power (11µJ/pulse) with same techniques **(Limpert,OL35(2010)94)**
- but we need long term stability and reliability…

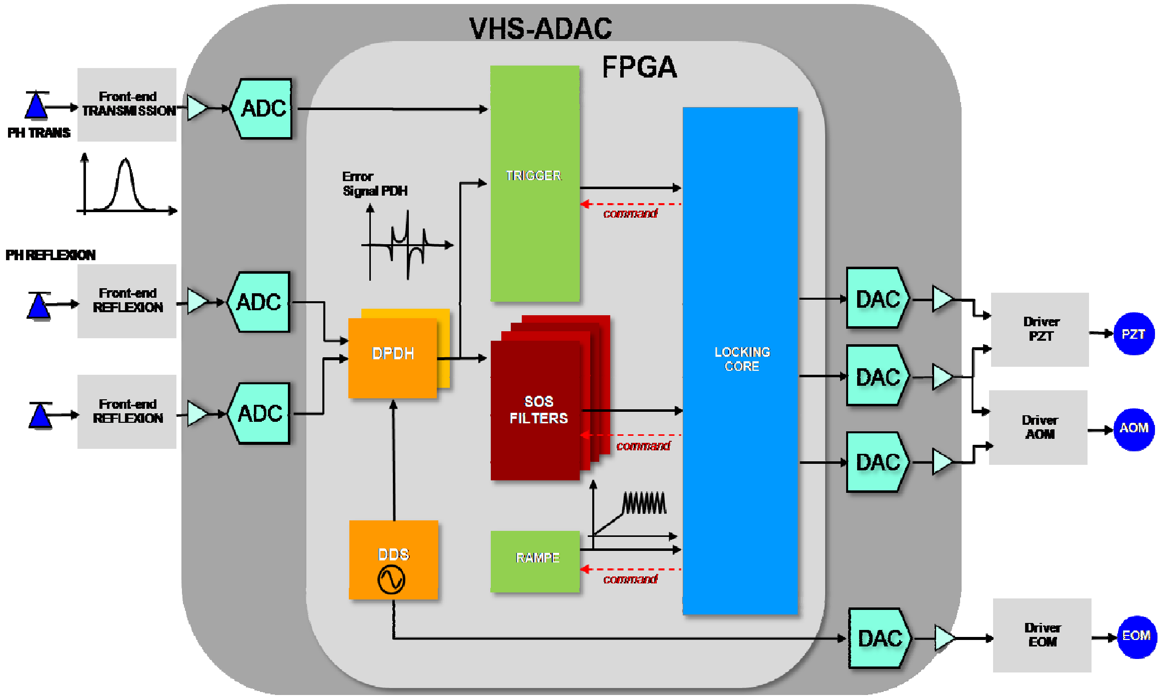


➔technological R&D

Digital Pound-Drever-Hall feedback







Feedback on laser frequency

Clk = 100 MHz
8x ADC 14 bits
8x DAC 14 bits
FPGA Virtex II

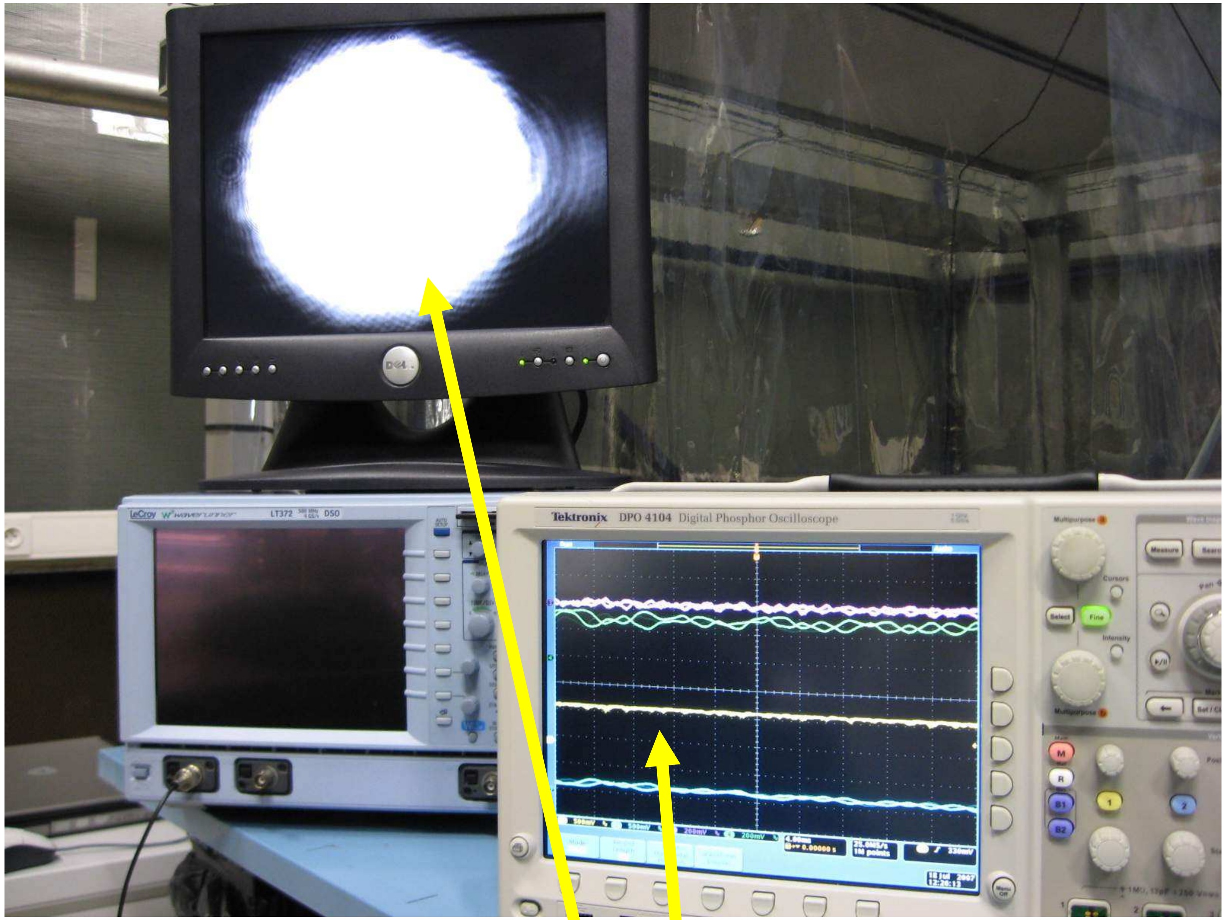
Cavity locked (*gain* ~10000)

•Digital feedback (5k lines of VHDL code)

•Already $\Delta f_{rep}/f_{rep}$~10^{-11} ➔ Δf_{rep}~7.6mHz for f_{rep}~76MHz

•We developed this feedback system to lock a Ti:sapph laser oscillator to a 30000 finesse cavity at Orsay

•We have also locked at Orsay the 4-mirror cavity installed at ATF

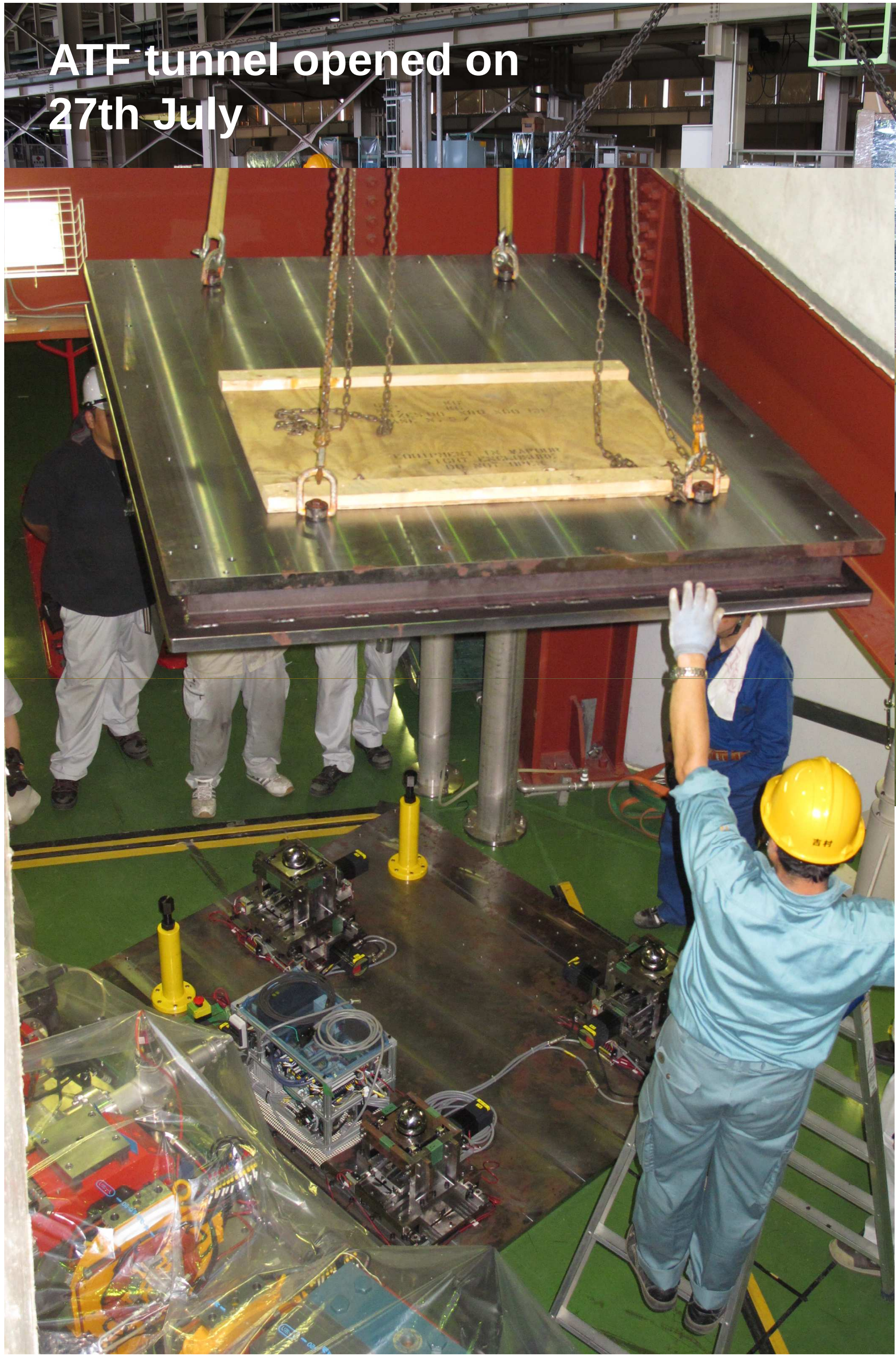


Cavity locked
With gain 10000

Installation of the experiment at ATF

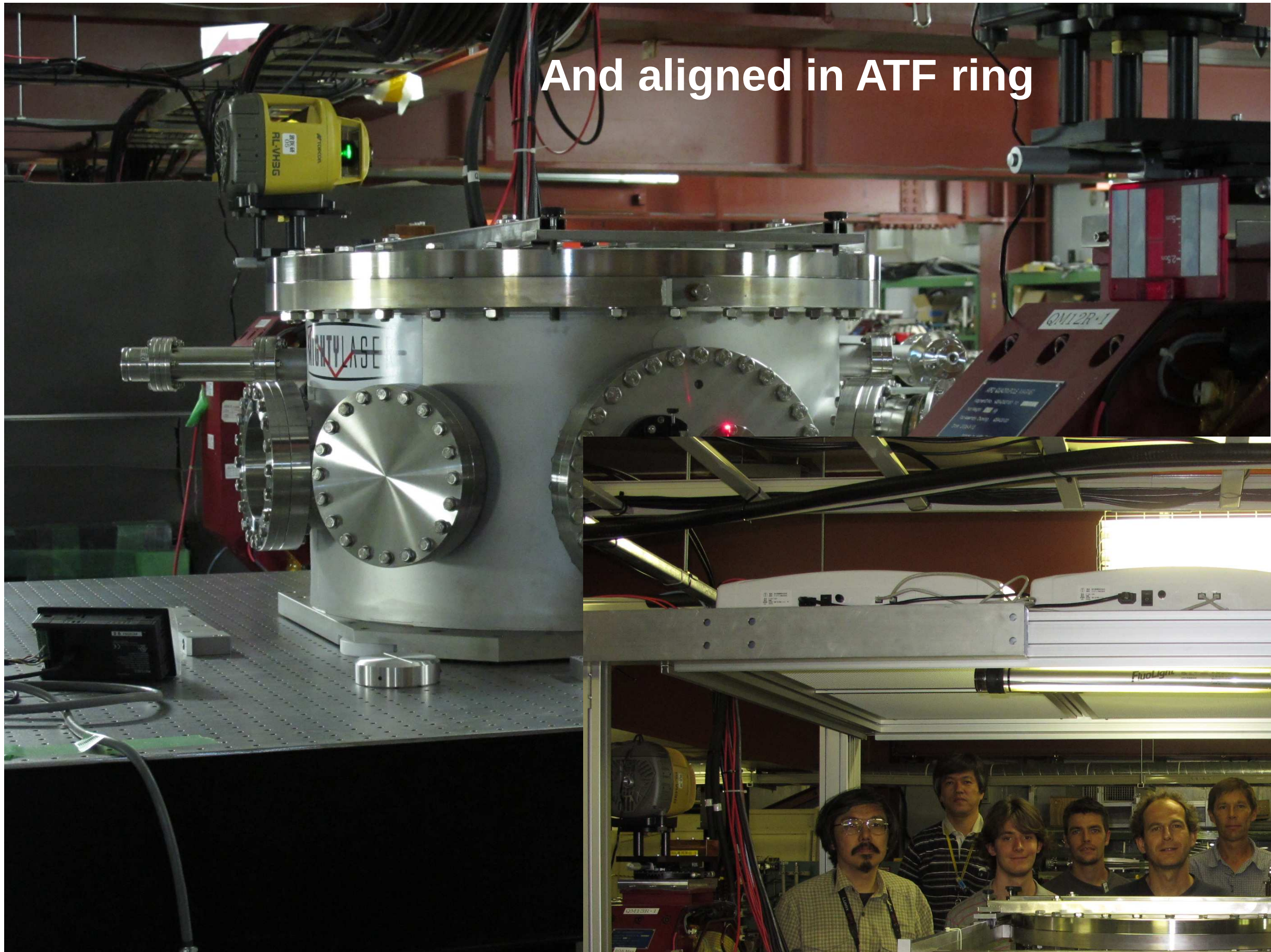
Sunday 25th july
Arrival of the
french team
at KEK

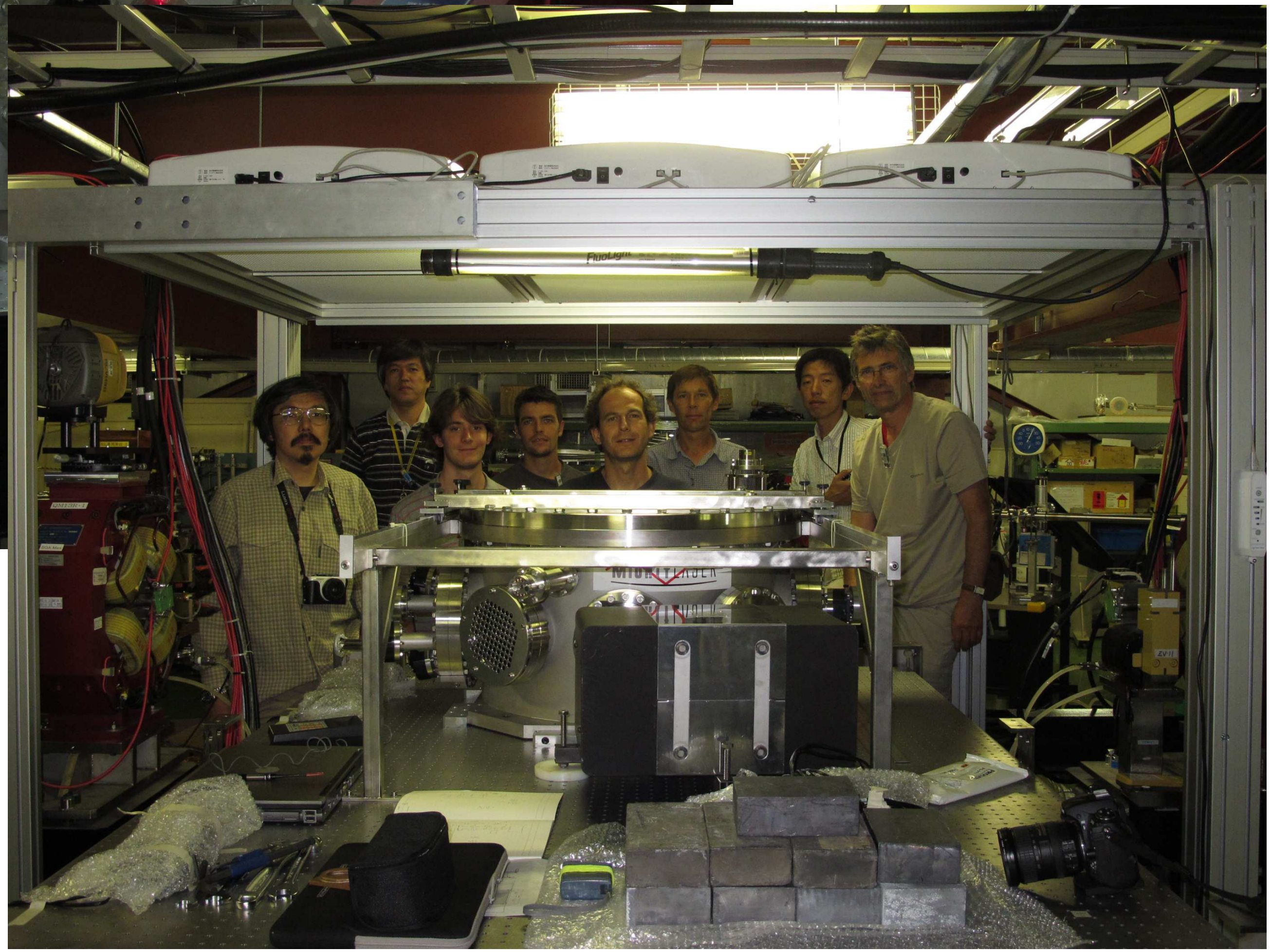
ATF tunnel opened on 27th July



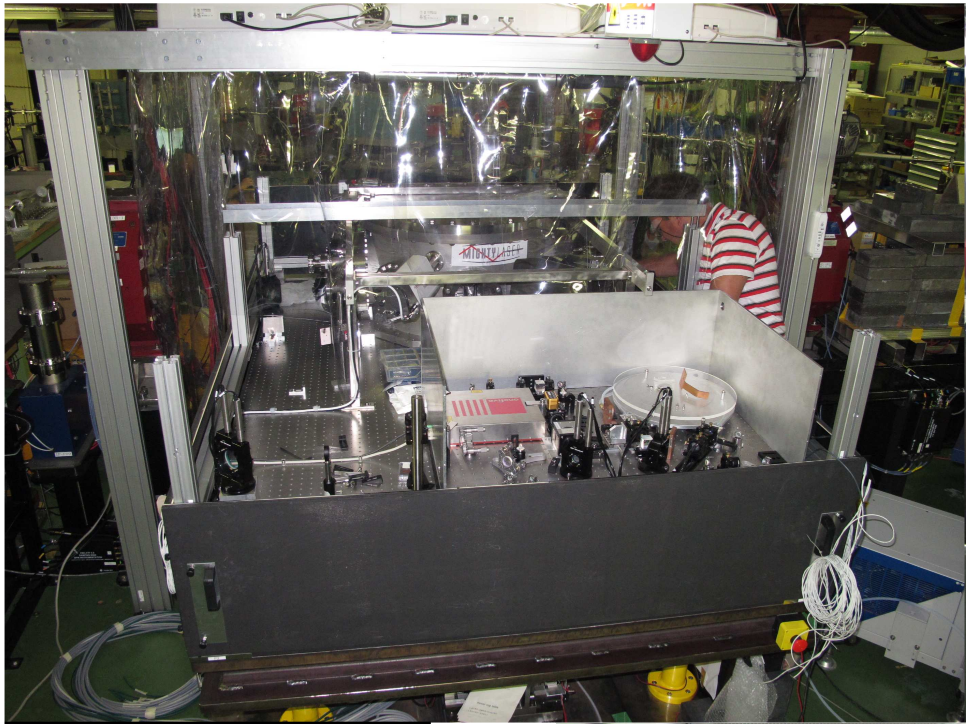
Cavity installed on 28th July

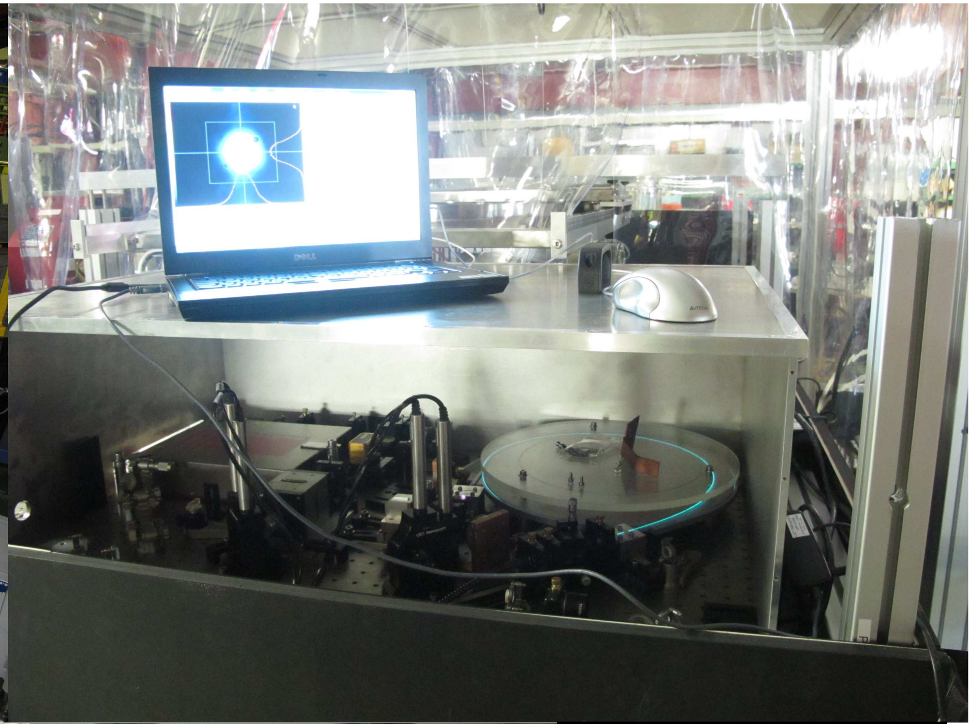
And aligned in ATF ring





29th July: after 3 days ready to install the experiment





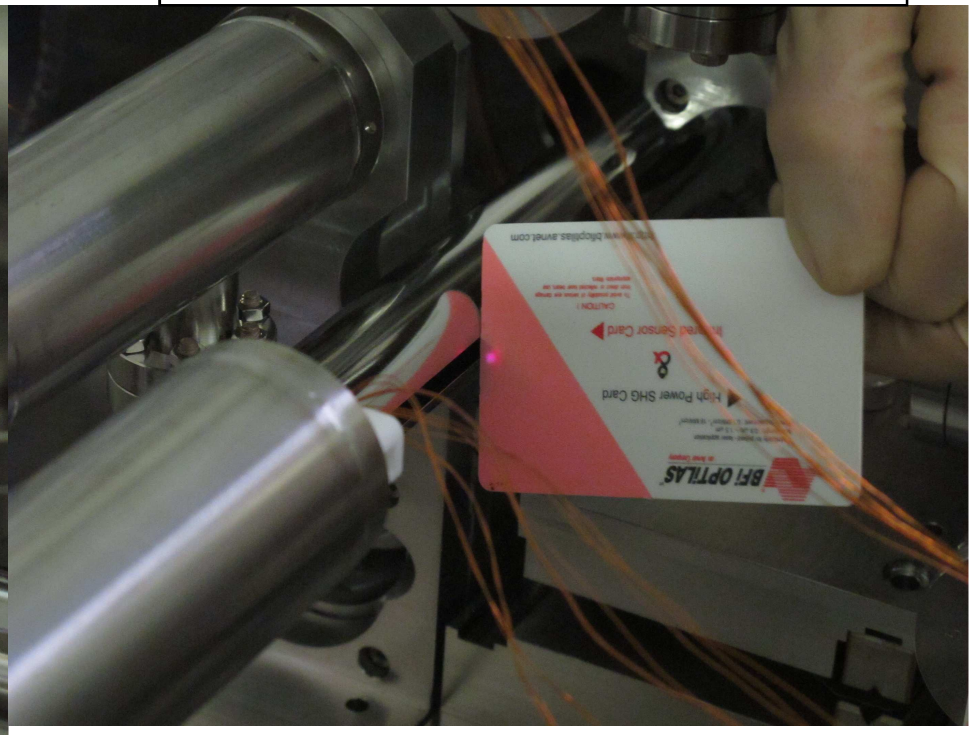
Optical elements mounted

10th August laser turned on (low power)
To start cavity mirrors installation

11th August : The laser passes through the 5mm beam pipe aperture
➔cavity mirrors aligned

Infrared laser marker before the slit

Infrared laser marker after the slit



Laser inspection tomorrow (17/08)

Summary

Compton scattering is a very useful process

- **But X-section is small➔huge laser power required➔R&D**
- **There is now a new 4-mirror fabry-perot cavities in ATF to contribute to this R&D effort**

2-mirror cavity pulsed laser

2X 2-mirror cavities cw laser (laser-wire)

4-mirror cavity pulsed laser

The new cavity has 4 mirrors and is non-planar to match requests of futur Compton e+ polarised sources or compact X-ray machines

Thanking

The whole french team would like to thanks the ATF group, KEK colleagues and KEK administration for their very efficient and competent collaboration, contribution and technical support.

And for the kindness of their welcome…

We also thanks the FJPPL who helped us to establish the French-Japanese collaboration since 2006

French fundings for the R&D project

IN2P3

Institut National de Physique Nucléaire et de Physique des Particules

Financé par

Agence Nationale de la Recherche GIP

ANR

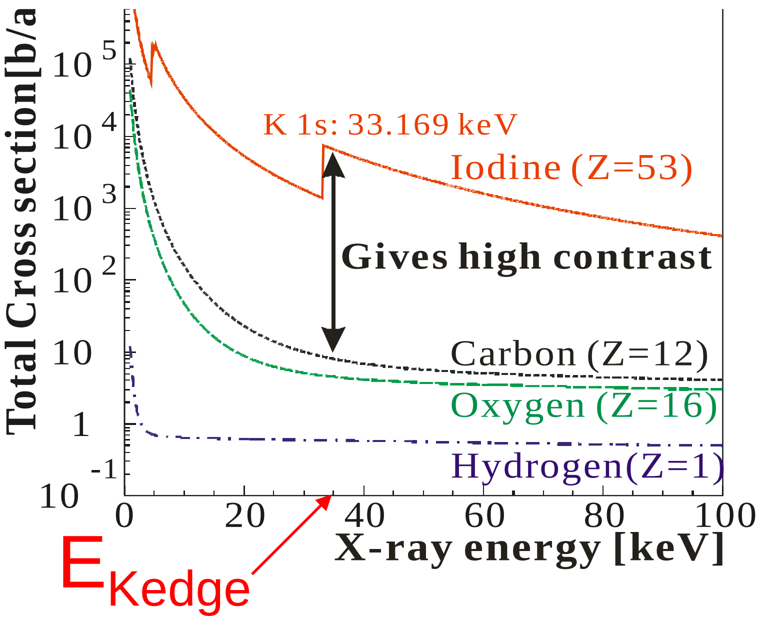
Painting analysis

'K edge imaging'

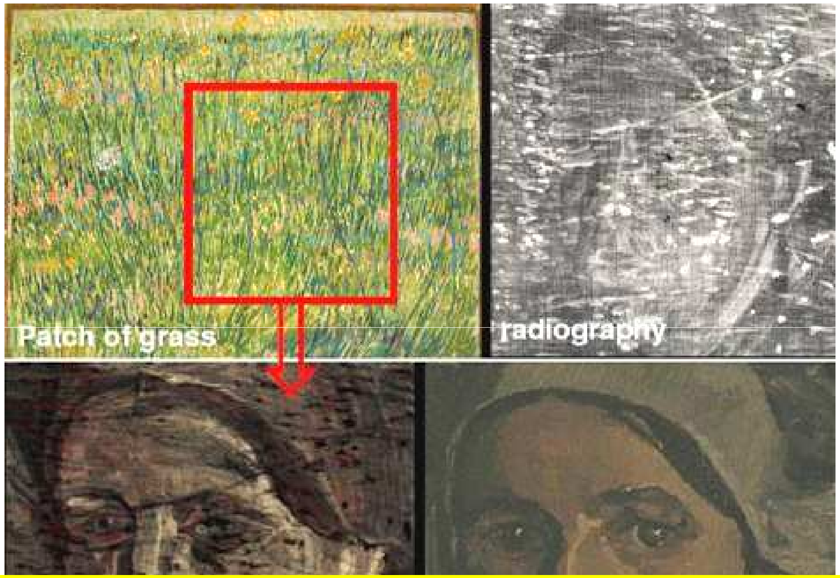
- Heavy chimical elements are contained in painting pigments
  - Characterised by K absorptsion edges

Total Cross Section of X-ray attenuation

for various elements



K-edge imaging
(Pb➔blanc, Hg➔ vermillion…)
of a Van-Gogh's painting

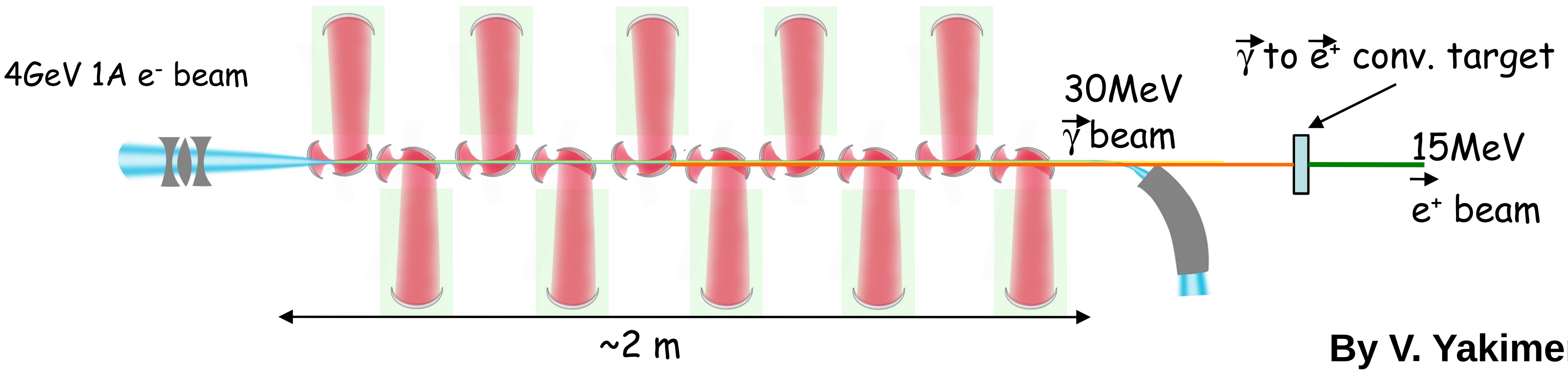


But ~30k€ insurance for 2 days
➔ Compact machine inside Le Louvre museum foreseen …

J. Dik et al., *Analytical Chemistry*, **2008**, *80*, 6436
http://www.vangogh.ua.ac.be/

Linac Scheme (1)

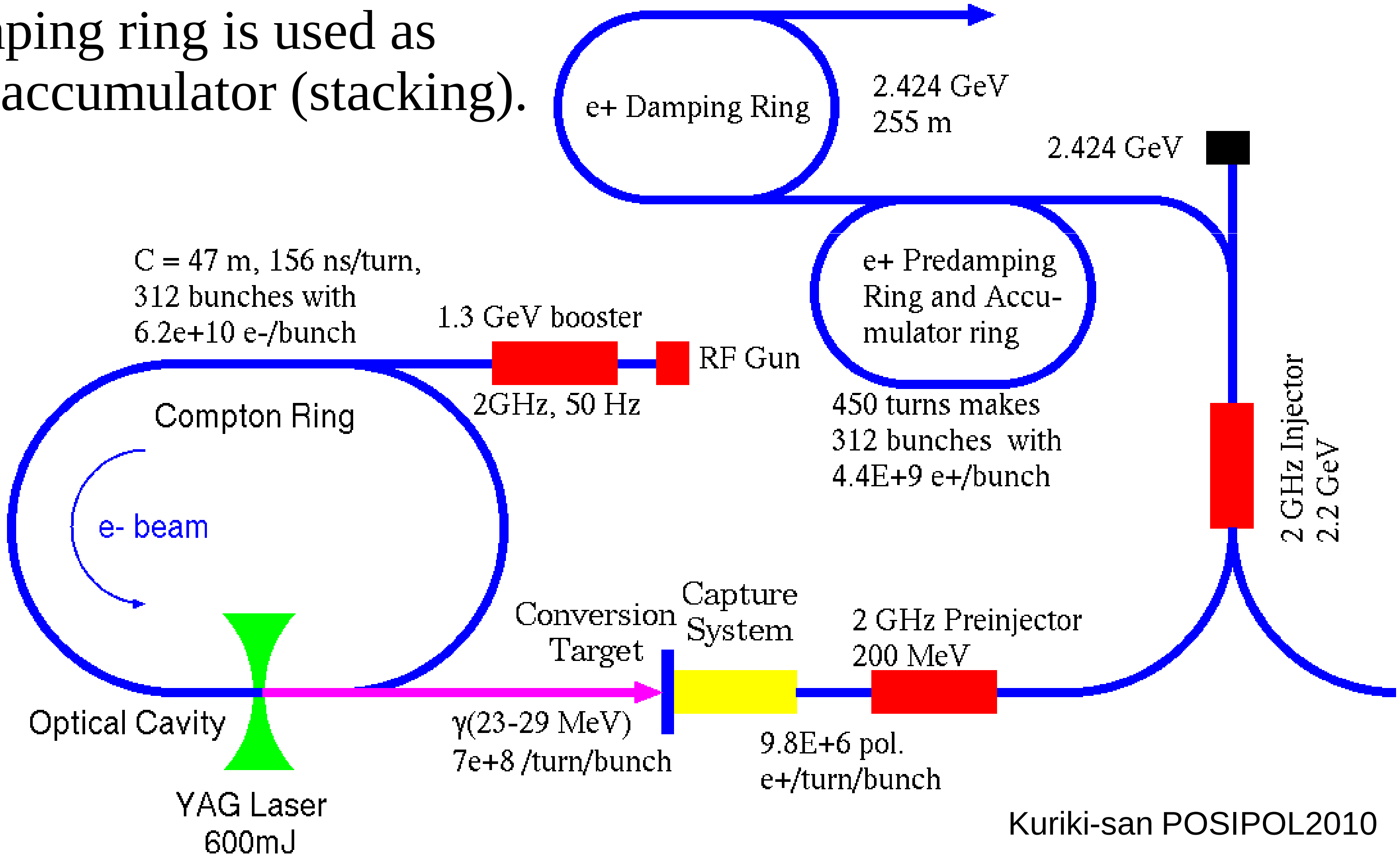
- ▶CO_2 laser beam and 4 GeV e-beam produced by linac.
  - **4GeV 15nC e- beam with 12 ns spacing.**
  - **10 CPs, which stores 10 J CO_2 laser pulse repeated by 83 Mhz cycle.**
- ▶5E+11 γ-ray -> 2E+10 e+ (2% conversion)
- ▶1.2μs pulse, which contains 100 bunches, are repeated by 150 Hz to generated 3000 bunches within 200ms.
  - Laser system relies on the commercially available lasers but need R&D for high repetition operation.
  - Ring cavity with laser amplifier realizes the C0₂ laser pulse train.



By V. Yakimenko

CLIC Compton Scheme

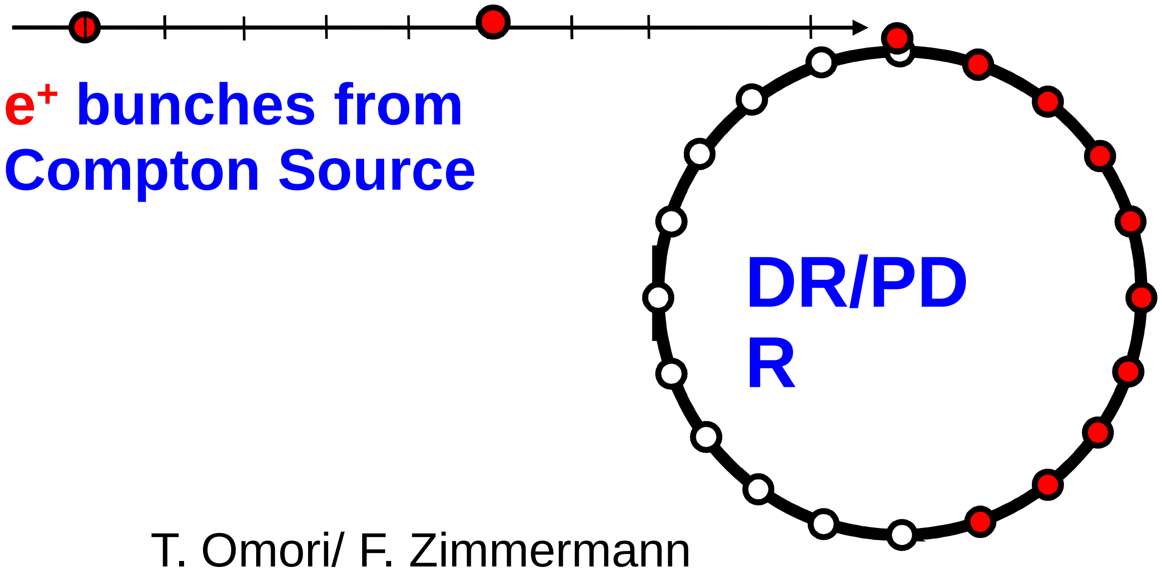
- It is based on CR scheme.
- Due to the less bunch intensity, it is slightly easier than that for ILC.
- Pre-Damping ring is used as positron accumulator (stacking).



Kuriki-san POSIPOL2010

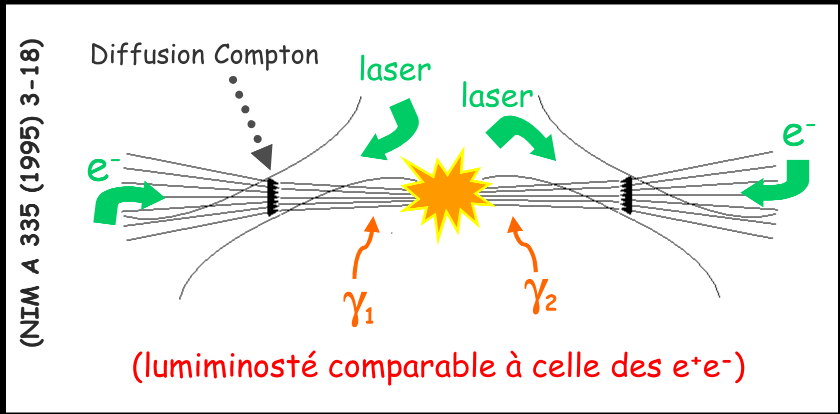
Positron Stacking (1)

- Except linac scheme, # of positron by a single collision is not sufficient.
- We need accumulate positrons from many collisions to achieve the required bunch intensity for ILC and CLIC.
- Positron stacking: many positron bunches are injected to a same bucket in DR/PDR.



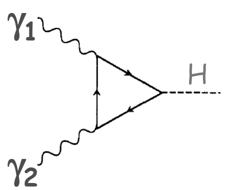
T. Omori/ F. Zimmermann

3. Collisonneurs $\gamma\gamma$ ~ TeV



- En utilisant la polarisation des γ Compton :

Test de la violation de CP dans le secteur des Higgs neutres h°, H°, A°



$$\sigma(\gamma\gamma \rightarrow \text{higgs}) \sim (1+\lambda_1\lambda_2) + (\lambda_1+\lambda_2) A_1 + \ell_{\gamma 1}\, \ell_{\gamma 2} \sin(2\varphi)\, A_2 + \ell_{\gamma 1}\, \ell_{\gamma 2} \cos(2\varphi)\, A_3$$

$|A_3| < 1$ ⟷ Signal de violation de CP

Lasers circulaires , puis linéaires

→ Mesure des 3 paramètres A_1 , A_2 , A_3

(Phys. Lett. B 294, 1992, 361-368)

- Couplages à 3 et 4 bosons

↓

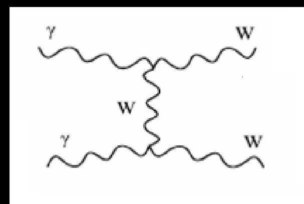
déviations (?) par rapport aux prédictions du MS

↓

Information sur le mécanisme de brisure de symétrie électrofaible

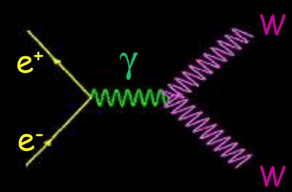
γWW :

à ~ 200 GeV



$\gamma\gamma \rightarrow WW$

$\sigma \sim 80$ pb



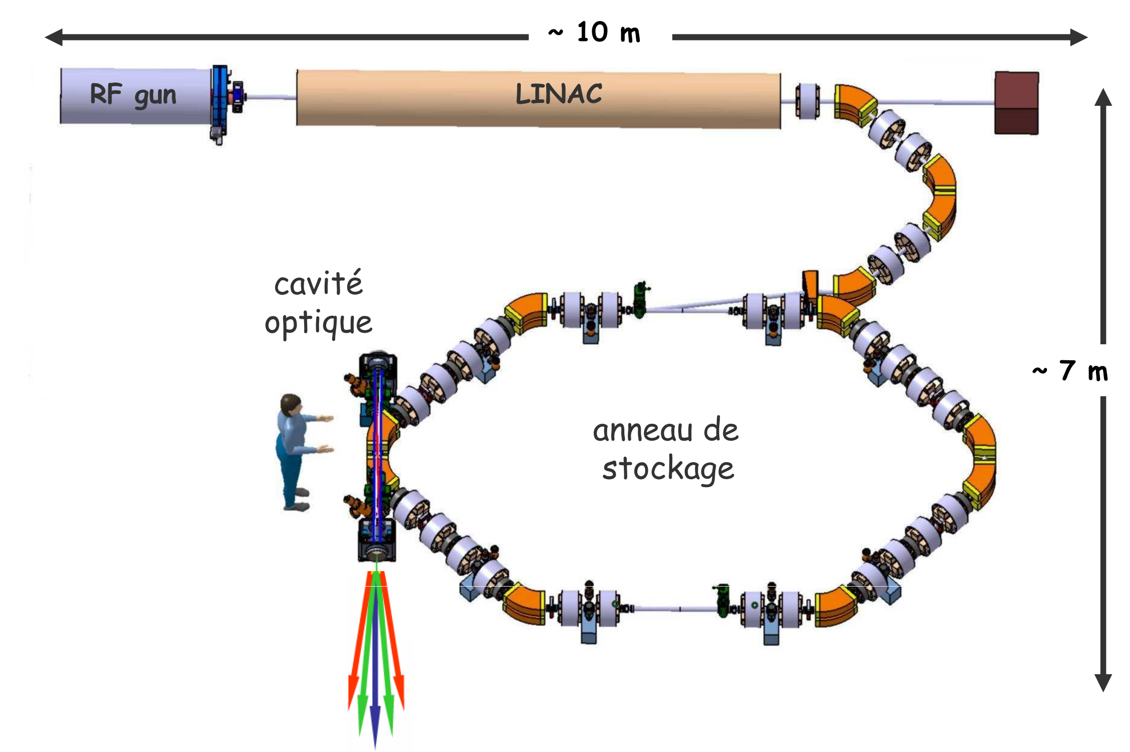
$e^+e^- \rightarrow WW$

$\sigma \sim 2$ pb

(↘ avec $\sqrt{s}$)

(NIMA 472, 2001, 100-120)

Le projet ThomX (LAL - SOLEIL - CELIA - C2RMF - ILE - L.M.A. - Thalès)



Flux ~ 10^{11} - 10^{13} ph/sec

Brillance ~ 10^{11} ph/sec/mm²/mrad²/0.1%bw

circonférence	~ 14m
énergie	50 MeV
bunch charge	1 nC
σ_T (rms)	70 µm
émittance	5.10^{-8} π m rad
longueur bunch	20 ps
Frép. injection	50-100 Hz
Laser σ_T (rms)	40 µm
Laser Frép.	40 MHz
longueur pulse	~ ps
< P > laser	100 W
gain cavité	~ 10000
< P > intra-cavité	~ MW
Frép. collision	20 MHz

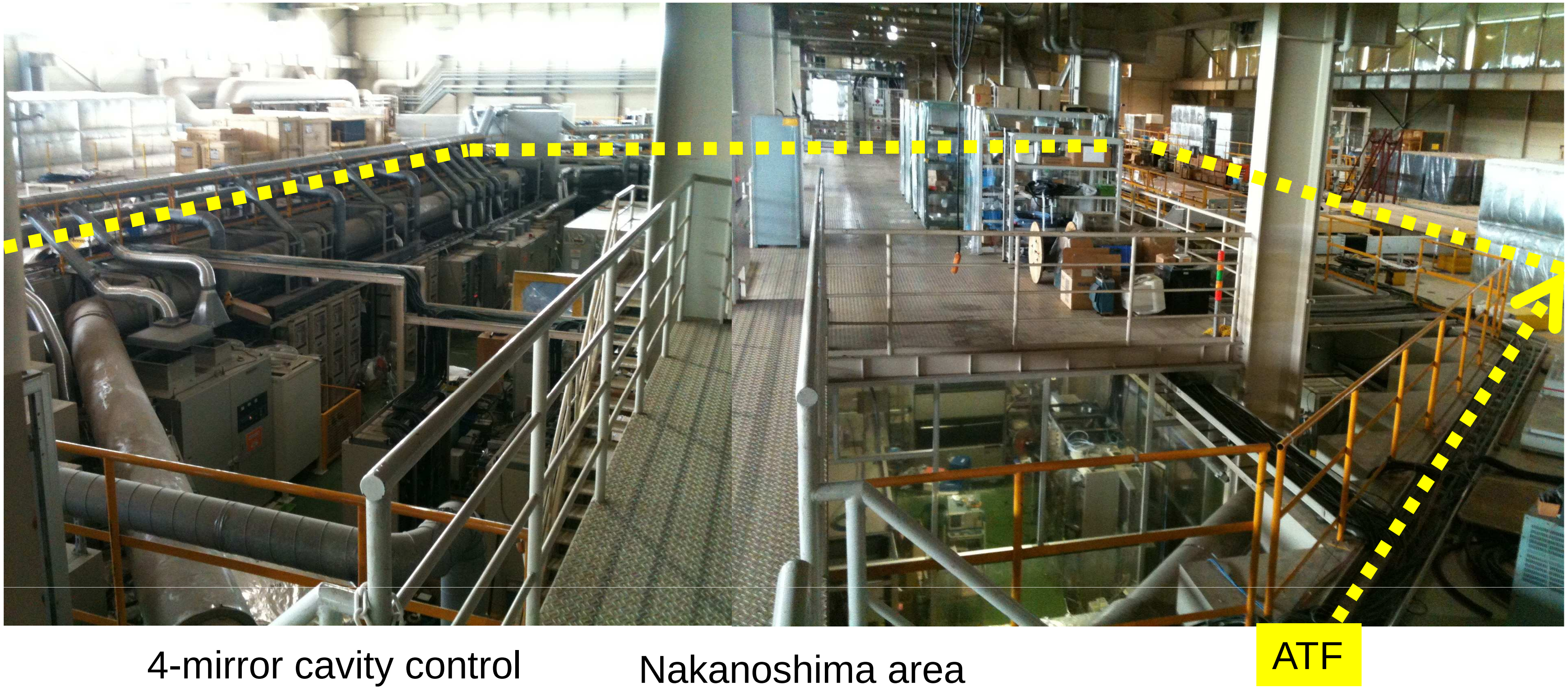
Cavité optique dans une des sections droites courtes (0.2 m)

- Les 2 sections droites longues (1.2 m) restent libres (cavité RF, injection)
- Miroirs cavité situés hors de l'anneau → accessibles.
- Extraction du cône Compton plus près de l' IP e-/laser.

ThomX parameters

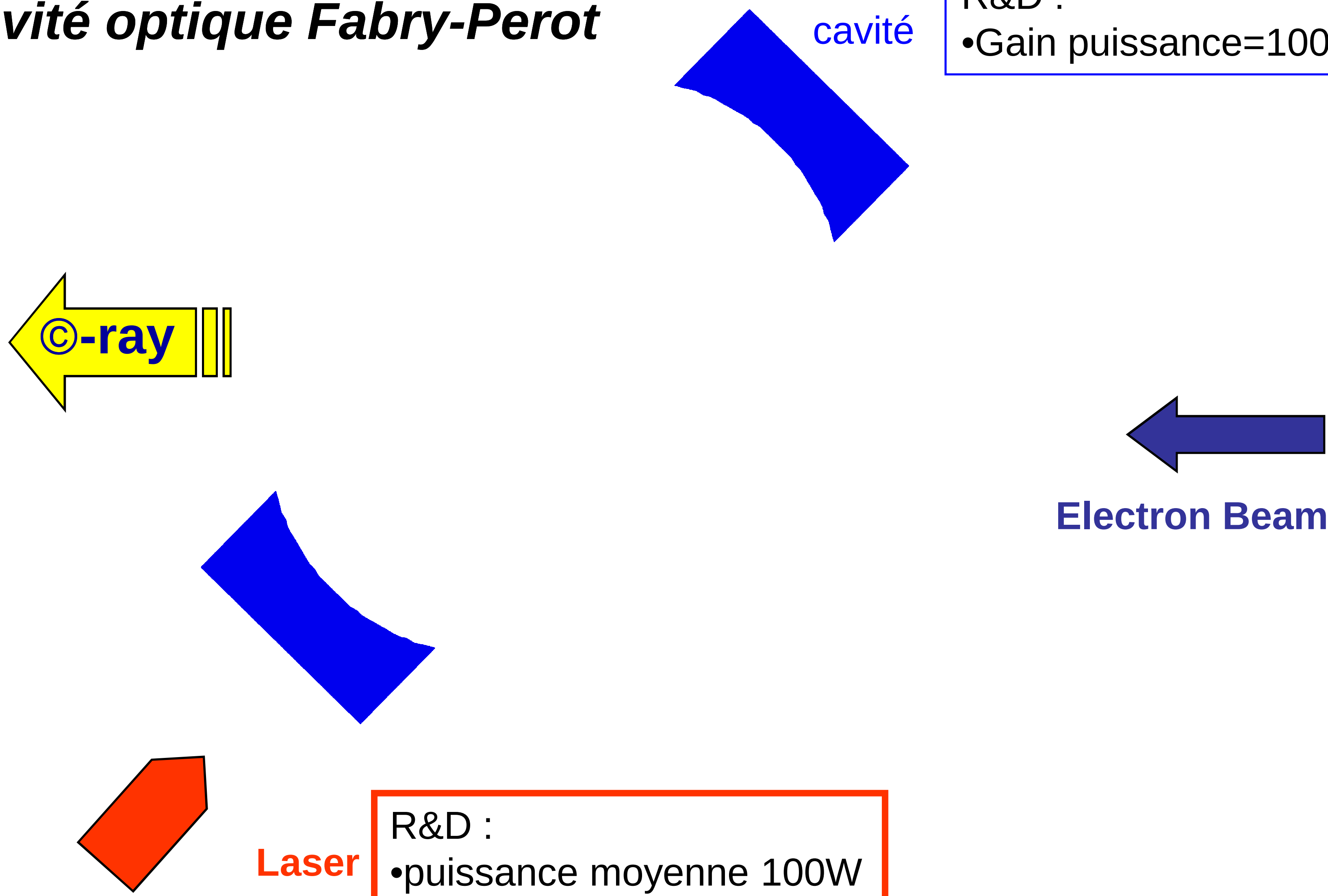
Energy	**MeV**	50
Relativistic gamma factor		97,84735812
Circumference	**m**	16,8
Crossing-Angle (full)	**degrees**	2
b_x @ IP	**cm**	20
b_y @ IP	**cm**	20
Emittance x (without IBS and Compton)	**nm**	100,00
Emittance x (with IBS and Compton)	**nm**	300,00
Emittance y (without IBS and Compton)	**nm**	100,00
Emittance y (with IBS and Comtpon)	**nm**	300
Bunch length (injection)	**mm**	4
Bunch length (@ 20 ms)	**mm**	10
Beam current	**mA**	10
Ion gap	**%**	0
RF frequency	**Hz**	5,00E+08
Revolution frequency	**Hz**	**1,78E+07**
Harmonic number	**#**	**28**
Number of bunches	**#**	1
N. Particle/bunch	**#**	6,60E+09

s_x @ IP (injection)	**microns**	**44,721**
s_y @ IP (injection)	**microns**	**44,721**
$s_{x'}$ @ IP (injection)	**mrad**	**2,2**
$s_{y'}$ @ IP (injection)	**mrad**	**2,2**
Hourglass reduction factor		0,020
Tune x		
Tune y		
Energy Loss/turn	**keV**	200
Momentum compaction factor αc		0,000000001
Momentum compaction		1,04E-04
Equilibrium Energy spread	**dE/E**	2,00E-02
Injection Energy spread	**dE/E**	3,00E-03


ATF
4-mirror cavity control room
Nakanoshima area

Mais la 'section efficace' Compton est très petite
➔ il faut de forte puissances laser

➔ cavité optique Fabry-Perot



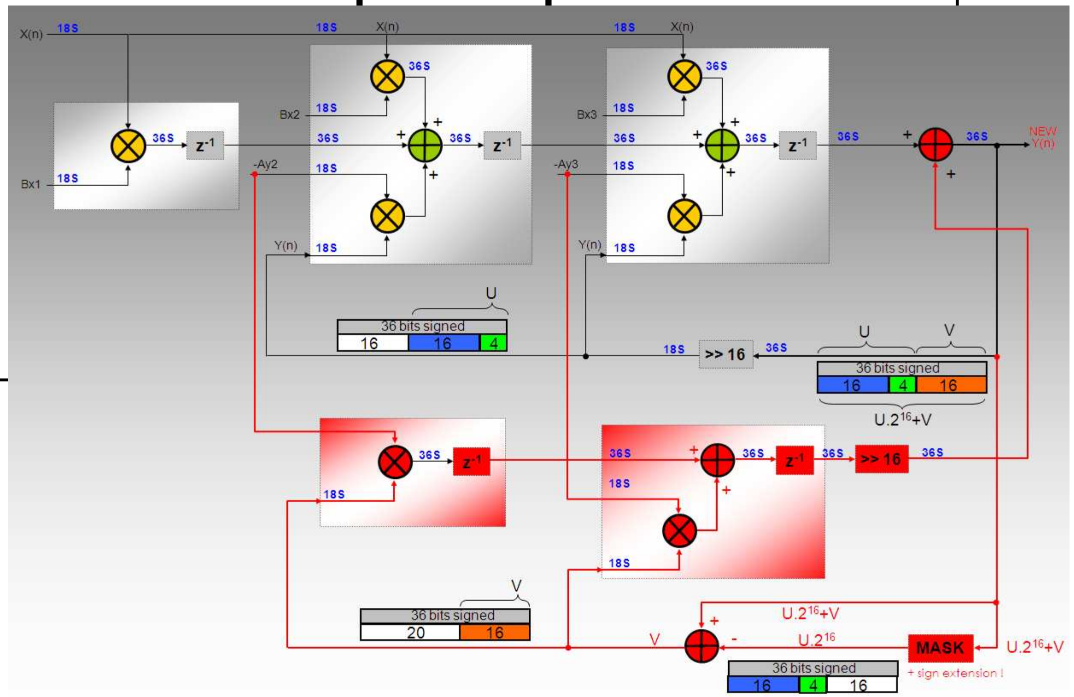
R&D :
•Gain puissance=10000

R&D :
•puissance moyenne 100W
•1ps @ 178MHz

From Shimizu-san
KEK

Feedback issues

- Complexity: (10k C++ + 5k VHDL) code lines
- Xilinx firmware : long compilation time > 1h
- Locking Feedback: 3 Integrators + Adaptive Feedback Multiple In/Out Different Dynamic Ranges
- Fixed point computation : complex filter synthesis and implementation to achieve required precision

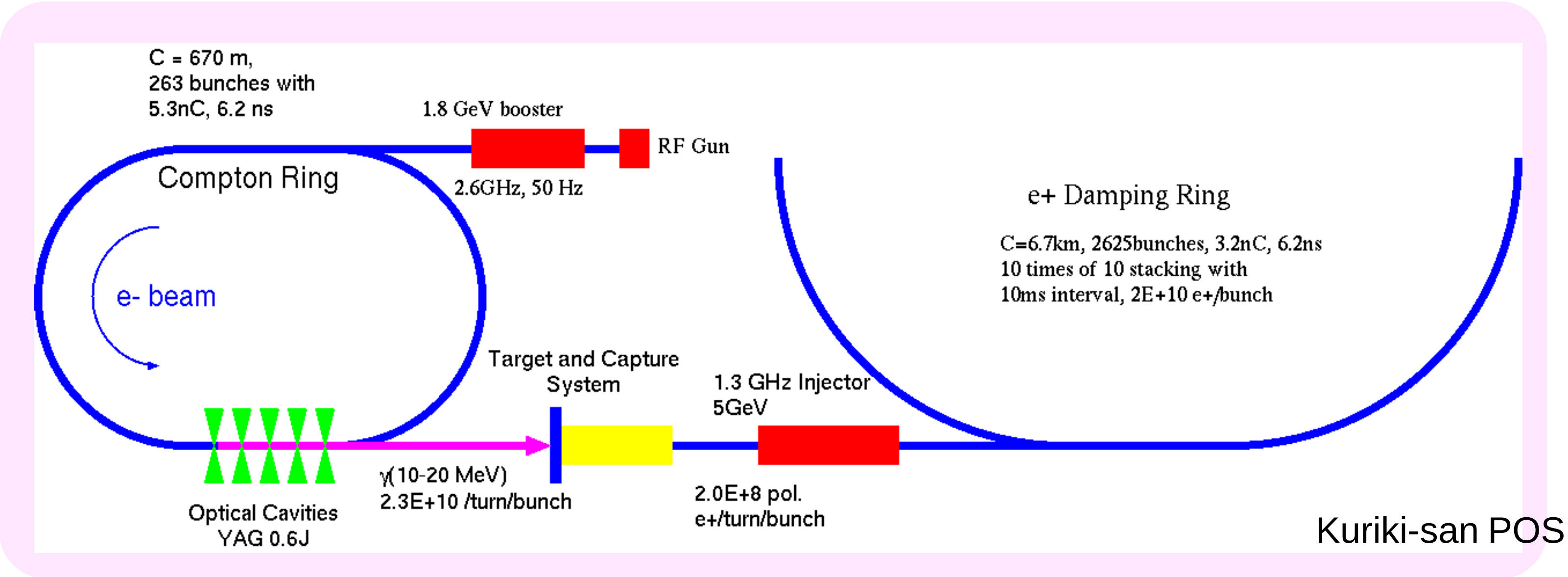


Second-Order-Section implementation with 18 bits Multipliers

Data path to increase loop computing precision to 36 bits

Compton Ring

- **Inverse Compton scattering between electron stored in a ring (CR) and laser light stored in optical cavities.**
- **Energy spread of the electron beam is increased by the scattering. 10 ms interval for the beam cooling.**
- **100 times stacking in a same bucket of DR makes the required bunch intensity.**



Kuriki-san POSIPOL2010