Where we are with lasers performance for polarized e^+ sources ?

KEK, Junji Urakawa

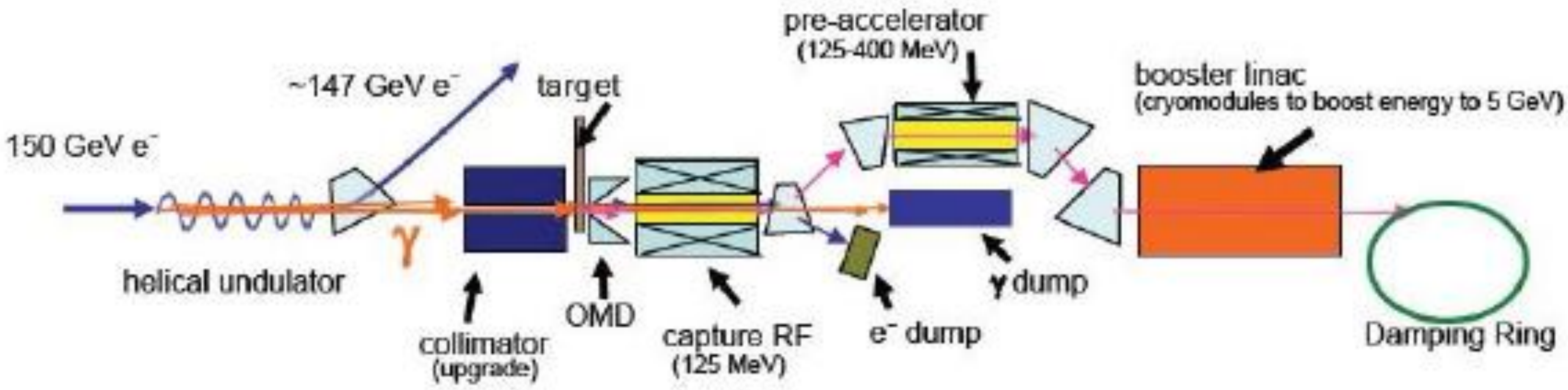
From two-mirror cavity to four-mirror cavity under International collaboration with LAL.

0.11 mJ / pulse, waist = 30 μm, 357MHz

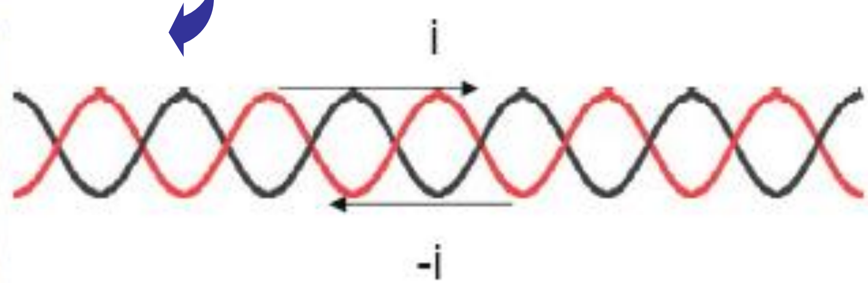
50 mJ / pulse, waist = 10 μm, 178.5MHz

1. Constraints for polarized e+ source
2. Short review of pulsed laser stacking
3. Burst Laser Amplification
4. Mirror damage which is caused by peak power density and average power density on the mirror.
5. Summary

Polarised positron source:
ILC baseline solution, the undulator scheme



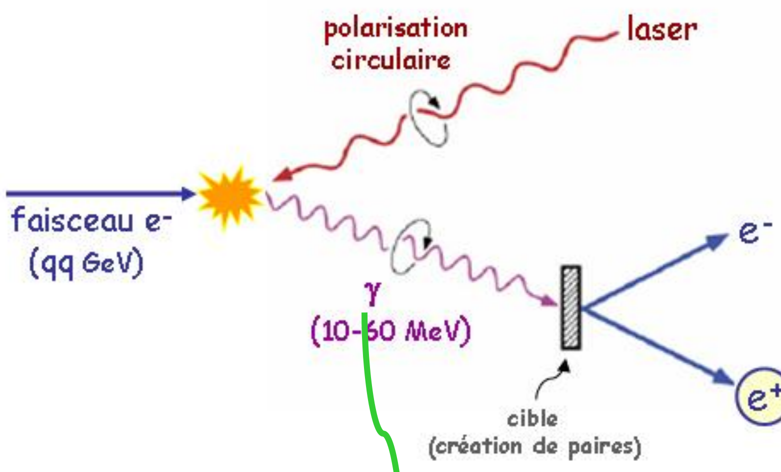
Requires ~200m of SC helicoidal undulator
6mm diameter beam pipe



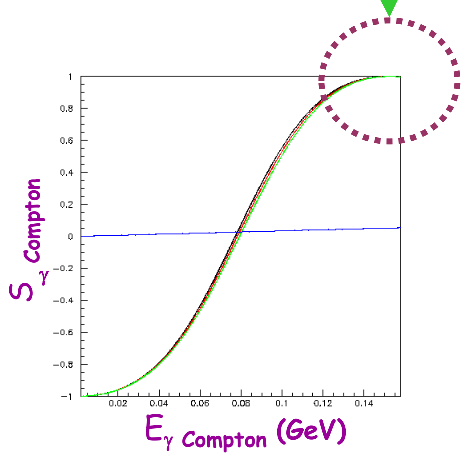
Supper conducting helix

Alternative solution
Compton polarised positron source for the ILC

Araki et al. arXiv:physics/0509016

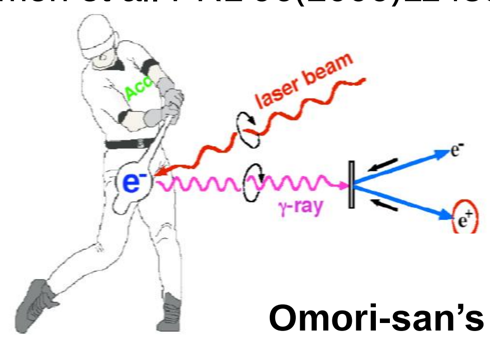


The e+ are longitudinally polarised



Experimental proof at ATF

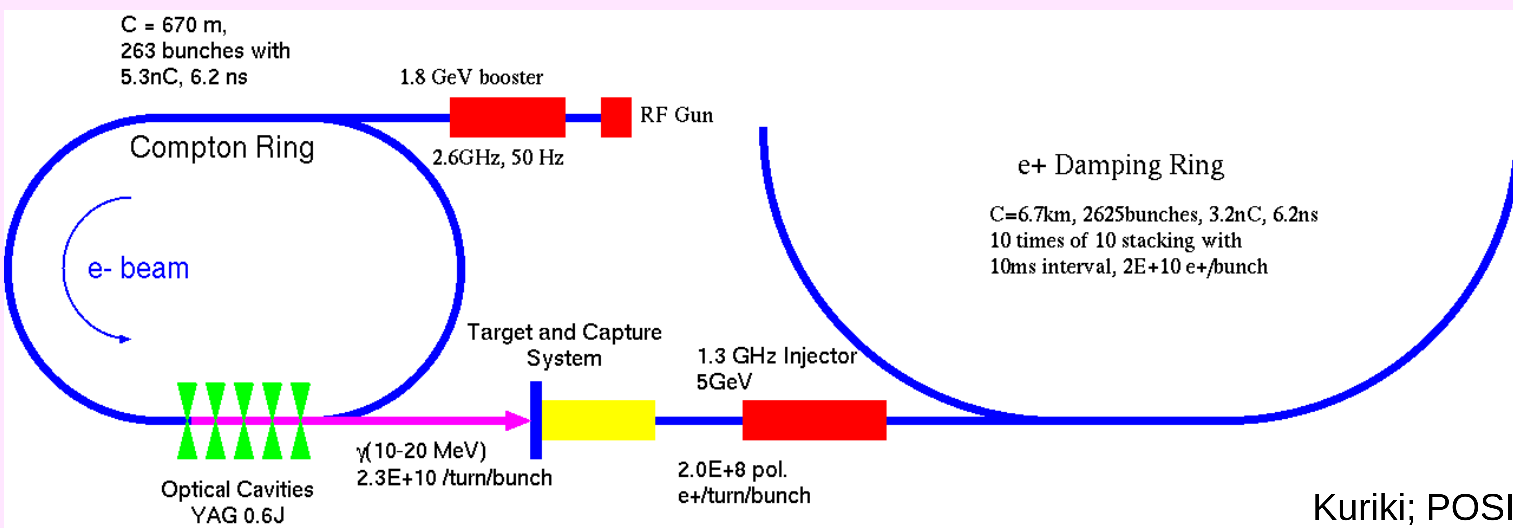
- Omori et al. PRL 96(2006)114801



Omori-san's picture

Compton Ring

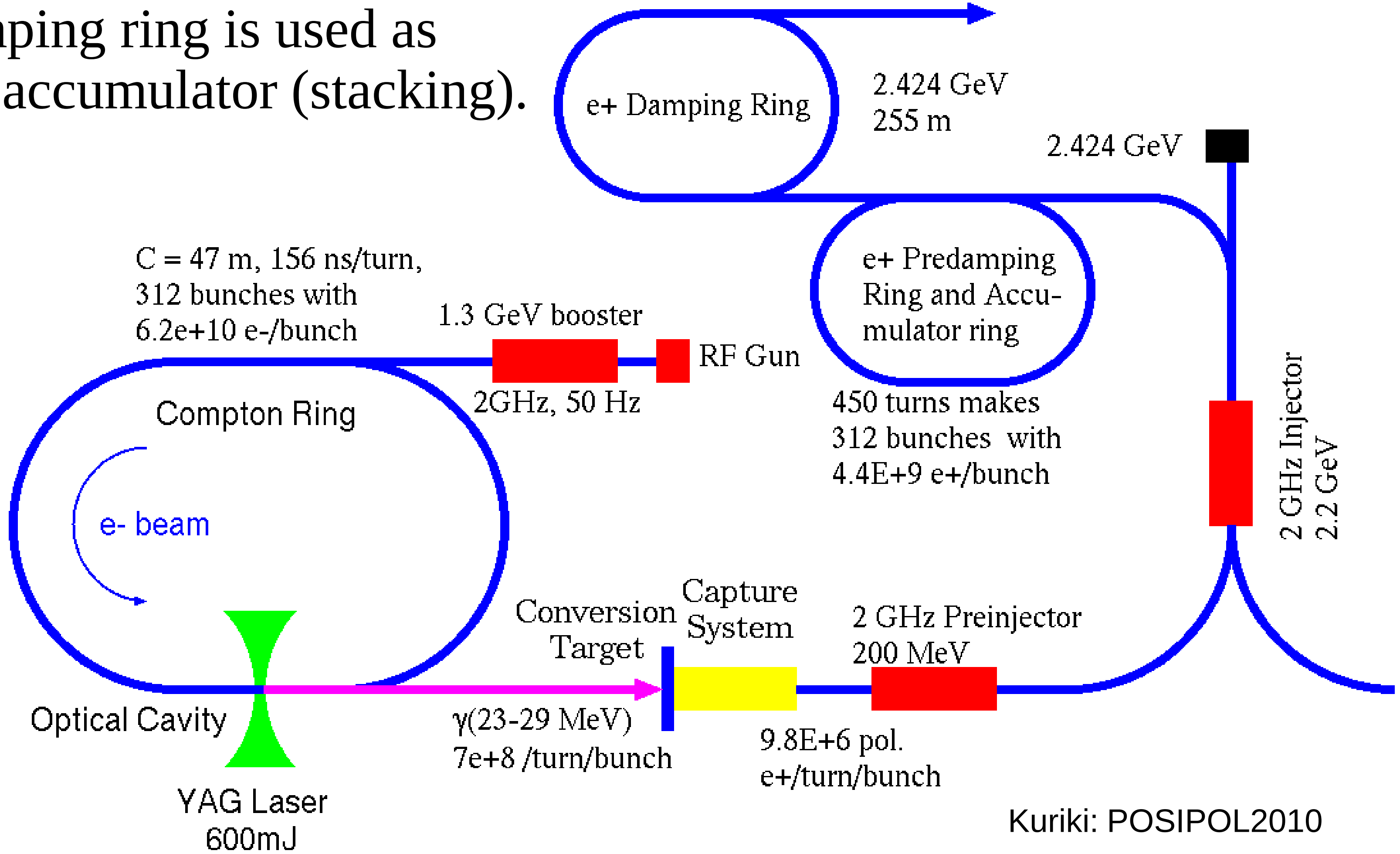
- Inverse Compton scattering between electron stored in a ring (CR) and laser light stored in optical cavities.
- Energy spread of the electron beam is increased by the scattering. 10 ms interval for the beam cooling.
- 100 times stacking in a same bucket of DR makes the required bunch intensity.



Kuriki; POSIPOL2010

CLIC Compton Scheme

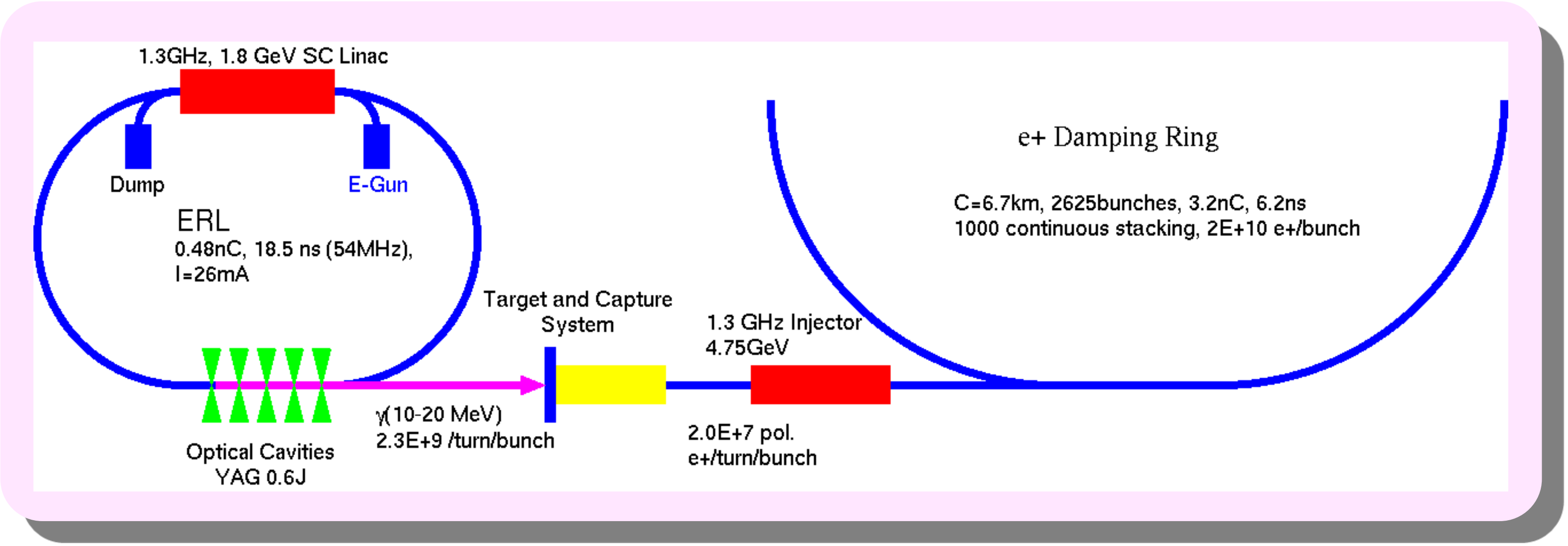
- It is based on CR scheme.
- Due to the less bunch intensity, it is slightly easier than that for ILC.
- Pre-Damping ring is used as positron accumulator (stacking).



Kuriki: POSIPOL2010

ERL scheme

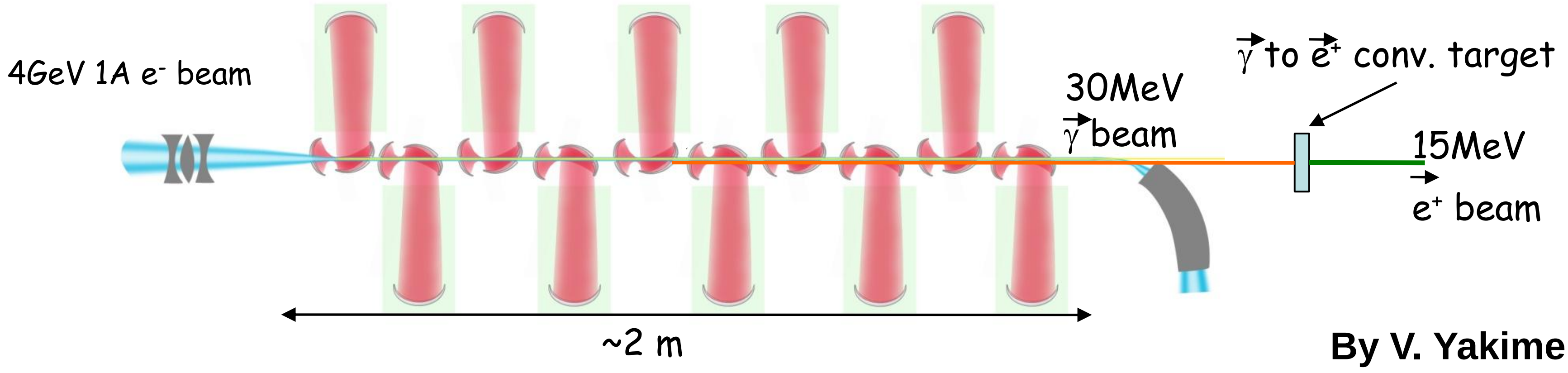
- Electron is provided by ERL (Energy Recovery Linac).
- Both advantages (high yield at Linac and high repetition at CR) are compatible in the ERL solution.
- Continuous stacking of e+ bunches on a same bucket in DR during 100ms, the final intensity is 2E+10 e^+.
- Another 100ms is used for damping.



Kuriki: POSIPOL2010

Linac Scheme

- ►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 generate 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 CO_2 laser pulse train.



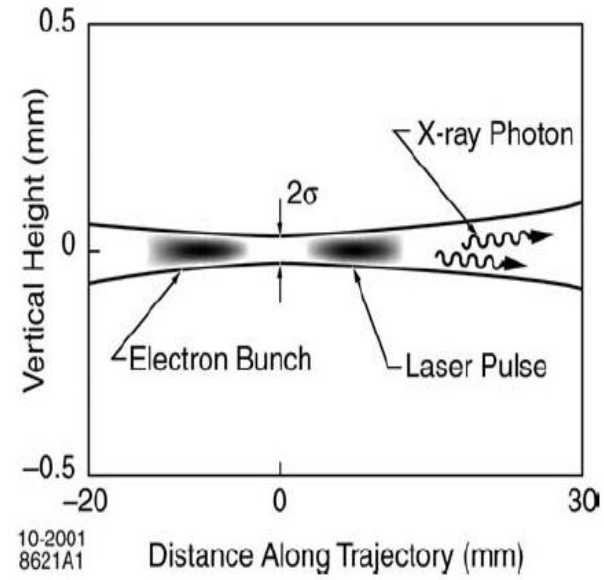
By V. Yakimenko

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

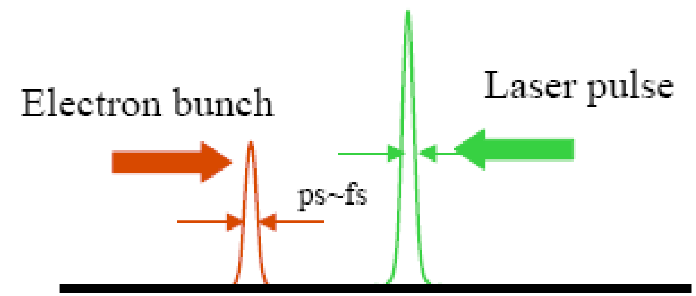
All that for picosecond laser beam

Best e_bunch length ~1ps

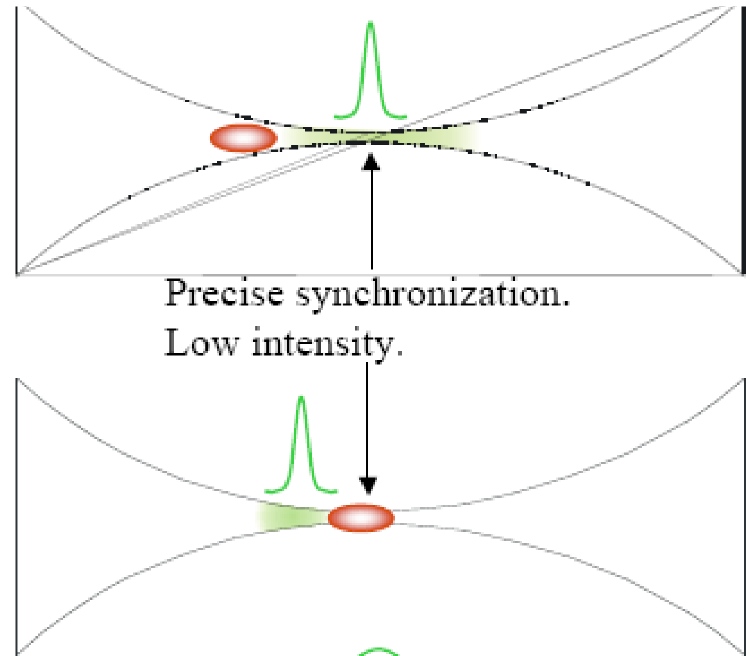
Techniques to increase the flux

KEK and LAL choice

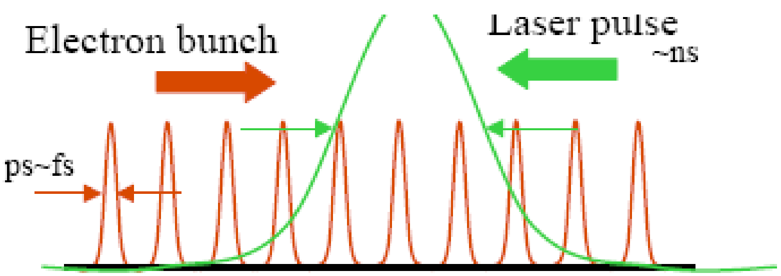
Single-collision scheme



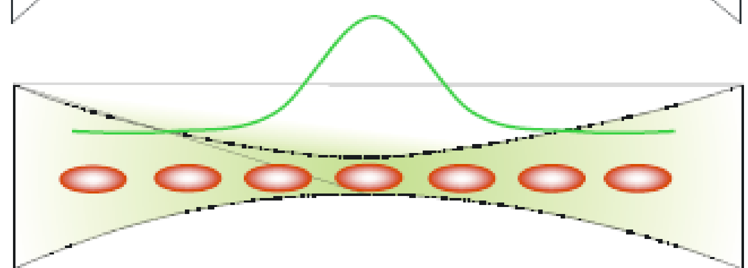
Collision between ultra-short (ps ~ fs) pulses.



Multi-collision scheme



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

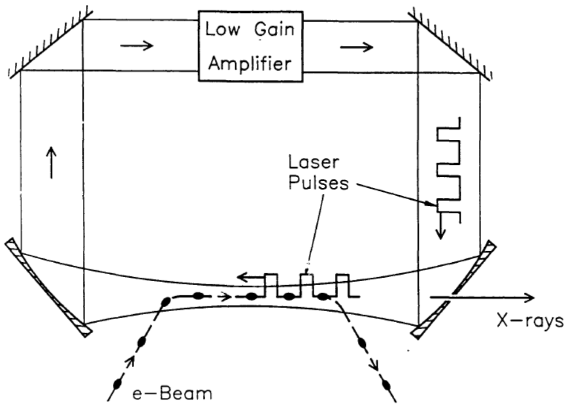


No requirements of precise synchronization.

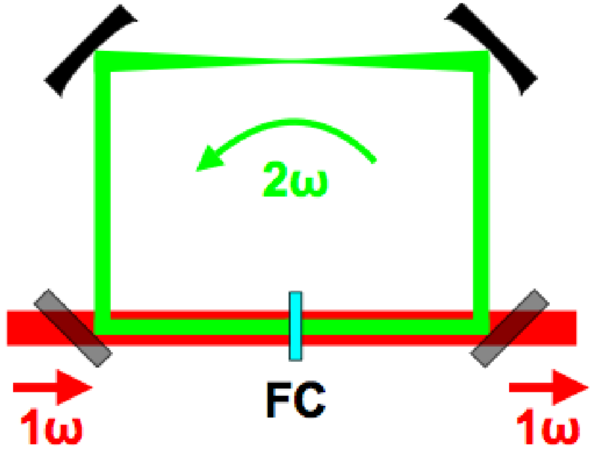
7

Tokyo University Compton machine

Single-Collision schemes



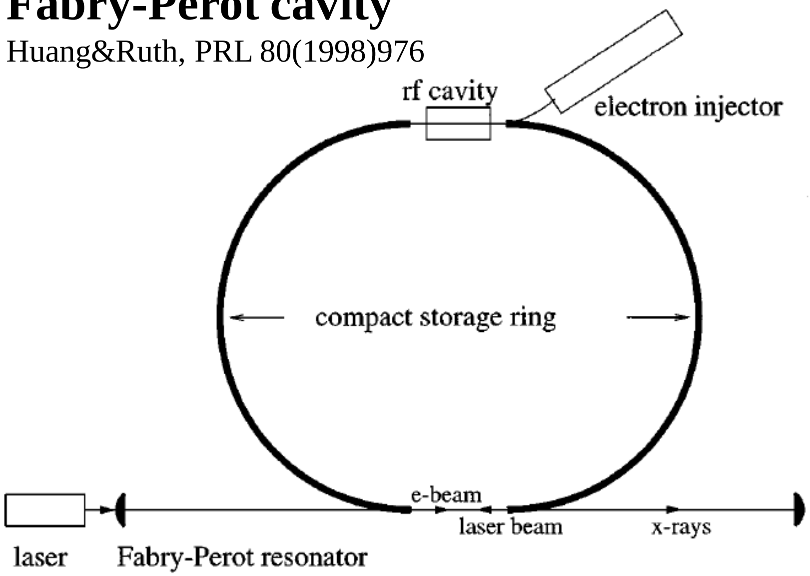
Regenerative cavity
Sprangle et al. JAP**72**(1992)5032



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

1. Constraints for polarized e^+ source

Laser pulse width : a few psec〜30psec (FWHM)

Closing angle <10 deg.

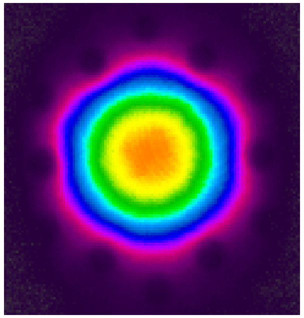
Laser rep. rate : 50MHz〜500MHz

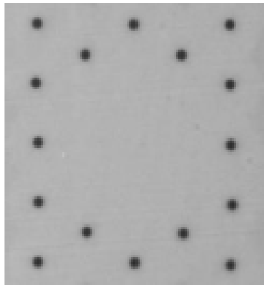
Laser energy for cavity injection: 50W〜500W

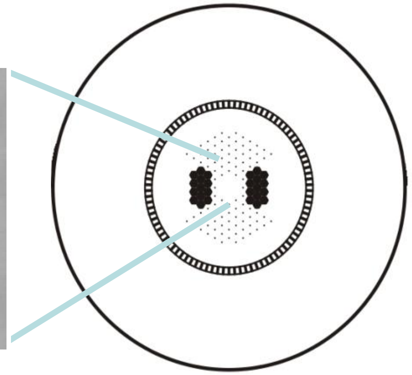
Optical cavity gain : 1000〜10000

Laser size<10μm

The laser amplification R&D

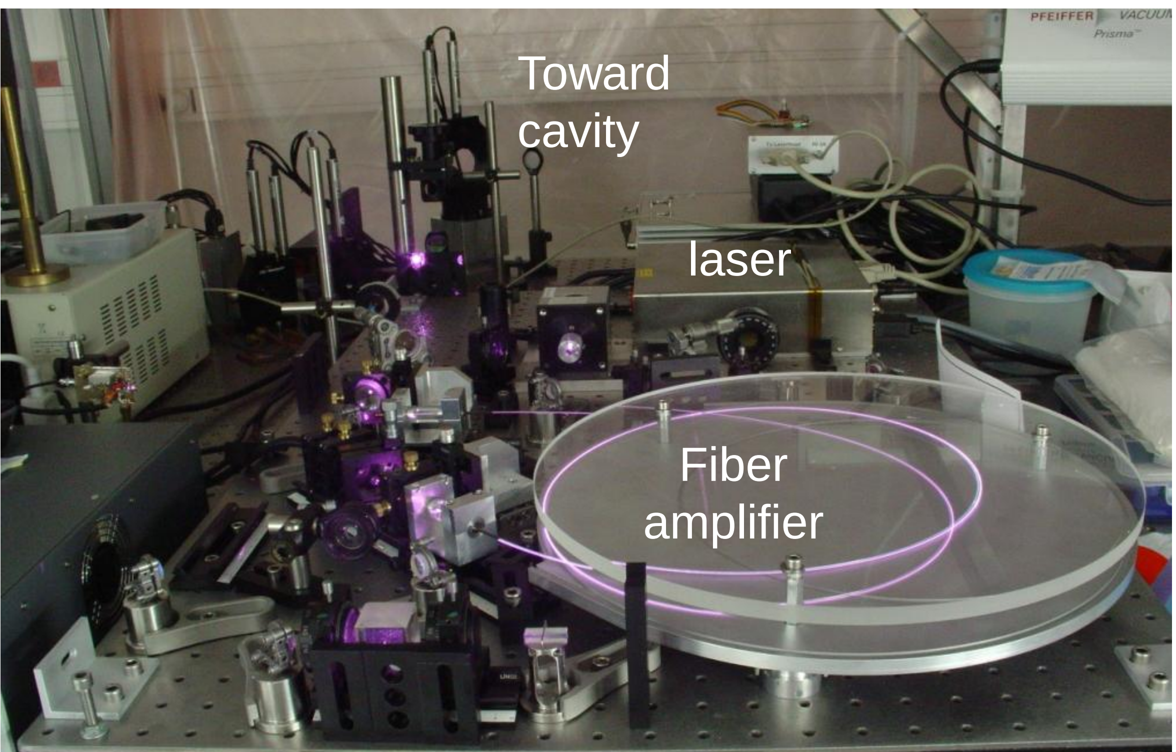






Ø core = 40 µm
Ø cladding = 200 µm

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

2. Short review of pulsed laser stacking

Continuous laser beam

1. JLab (CEBAF/polarimeter – gain ~10^4
   Falleto et al. (NIMA459(2001)412)
2. HERA/polarimeter – gain ~10^4
3. KEK-ATF/laser wire – gain ~1000, waist ~5μm

Pulsed laser beam

1. ~ 30ps pulses & gain ~6000, waist ~60μm (Lyncean Tech.)
2. 7ps @357MHz (Compton x-ray generation), R&D in progress
Total gain ~12000 with burst mode (cavity gain ~600),
waist ~30μm (KEK-ATF), average power =40kW
3. At LAL we locked ps Ti:sapph oscillator to 10000 gain cavity
(but few seconds…)
4. Garching (in 2010), gain=1800, **Power_inside = 72kW**

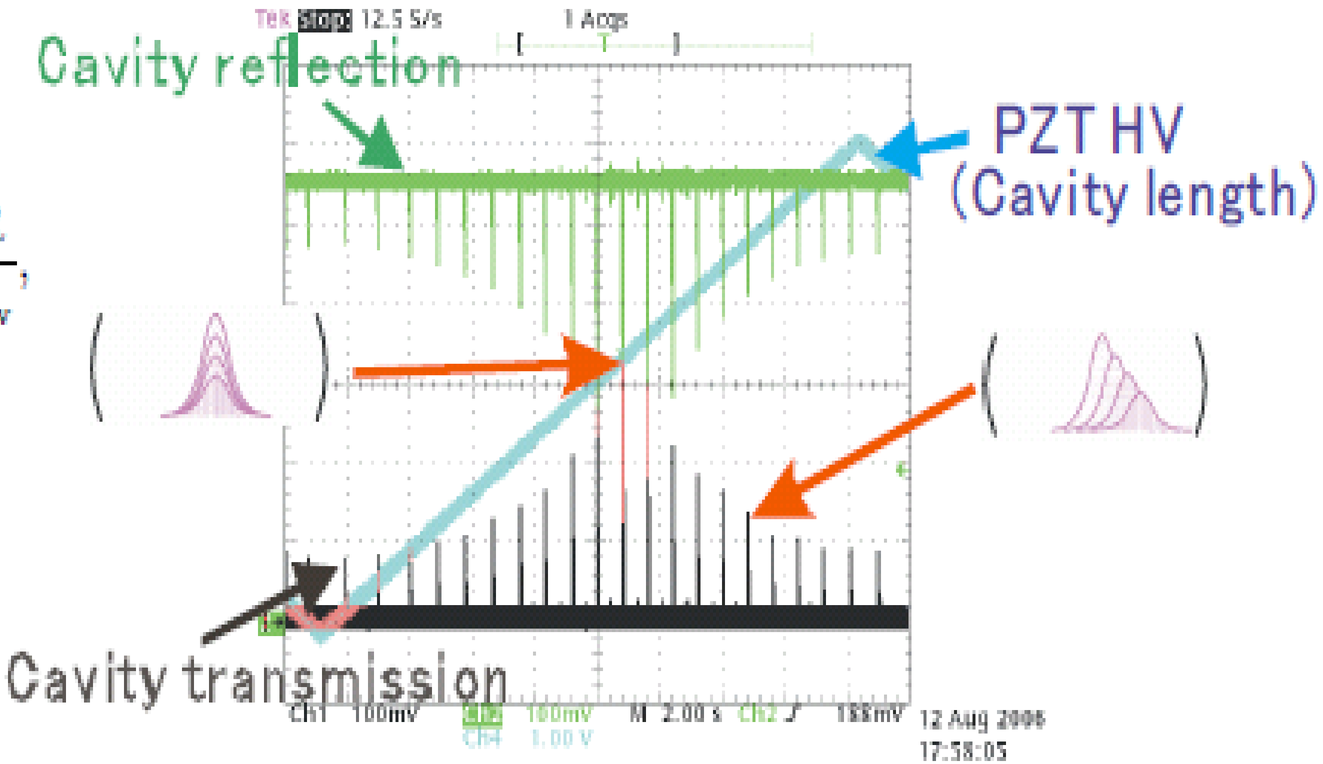
Considering two-mirror cavity,
reflectance R, transmissivity T, and losses L where R+T+L = 1 by energy conservation.
The "bounce number" *b* which is defined from the round-trip power loss in a cavity, $\propto e^{-1/b}$. FSR : free spectral range

$$b = \frac{1}{T_1 + L_1 + T_2 + L_2},$$

$$\mathcal{F} \equiv \frac{\pi \sqrt[4]{R_1 R_2}}{1 - \sqrt{R_1 R_2}} \simeq 2\pi b \simeq \frac{\mathrm{FSR}}{\Delta\nu_{\mathrm{cav}}},$$

If $R=R_1=R_2$

$$G = \frac{F}{\pi} = \frac{\sqrt{R}}{1-R}$$



Storage of laser pulse

Resonance condition :

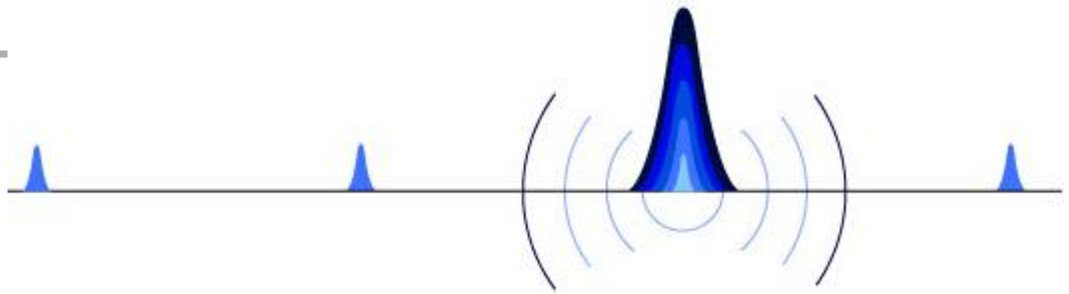
The relationship with laser and cavity :

$$L_{cav} = n \cdot \frac{\lambda}{2} ,$$

$$\Delta l = L_{laser} - L_{cav} , \quad \Delta l = 0 .$$

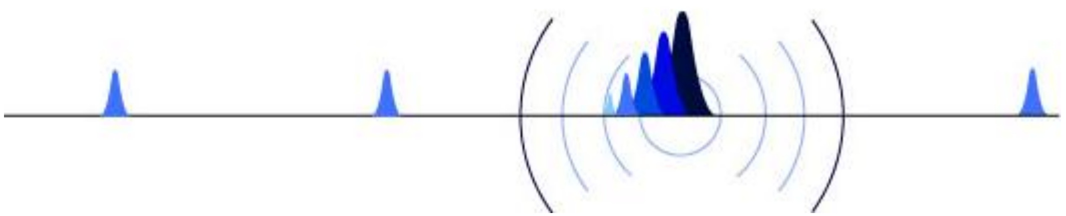
The enhancement factor is the function of reflectivity, Δl and laser pulse width.

Perfect resonance : $L_{laser} = L_{cavity}$



Imperfect Resonance : $L_{laser} \sim L_{cavity}$

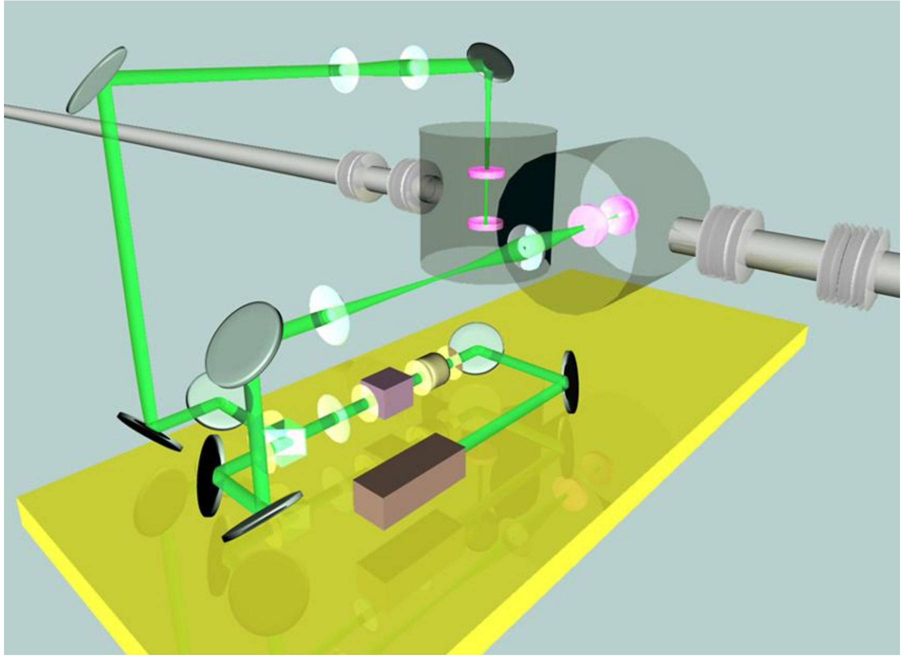
Not resonance : $L_{laser} \neq L_{cavity}$

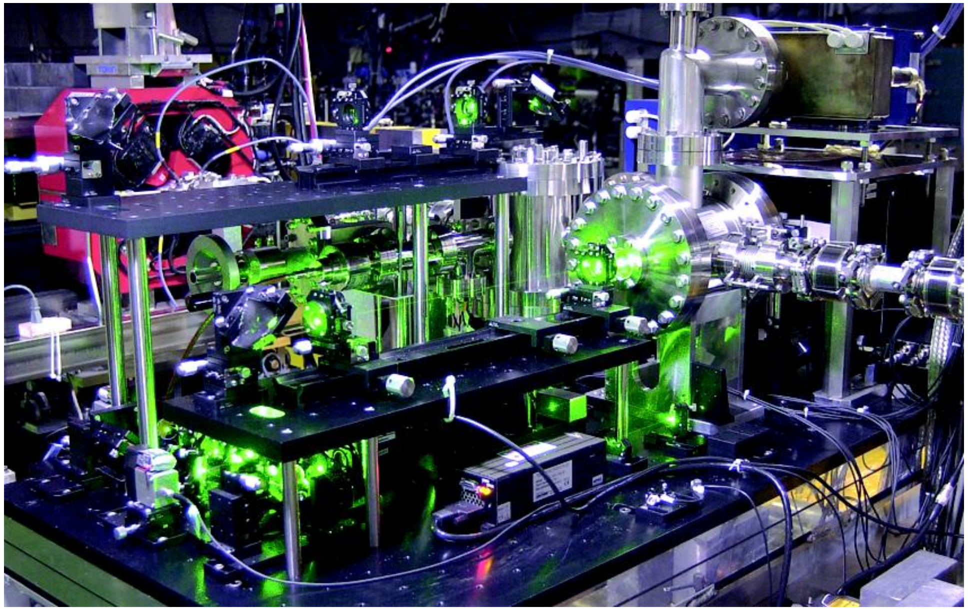


Achievement on related technique

JFY2003

CW Laser wire beam size monitor in DR

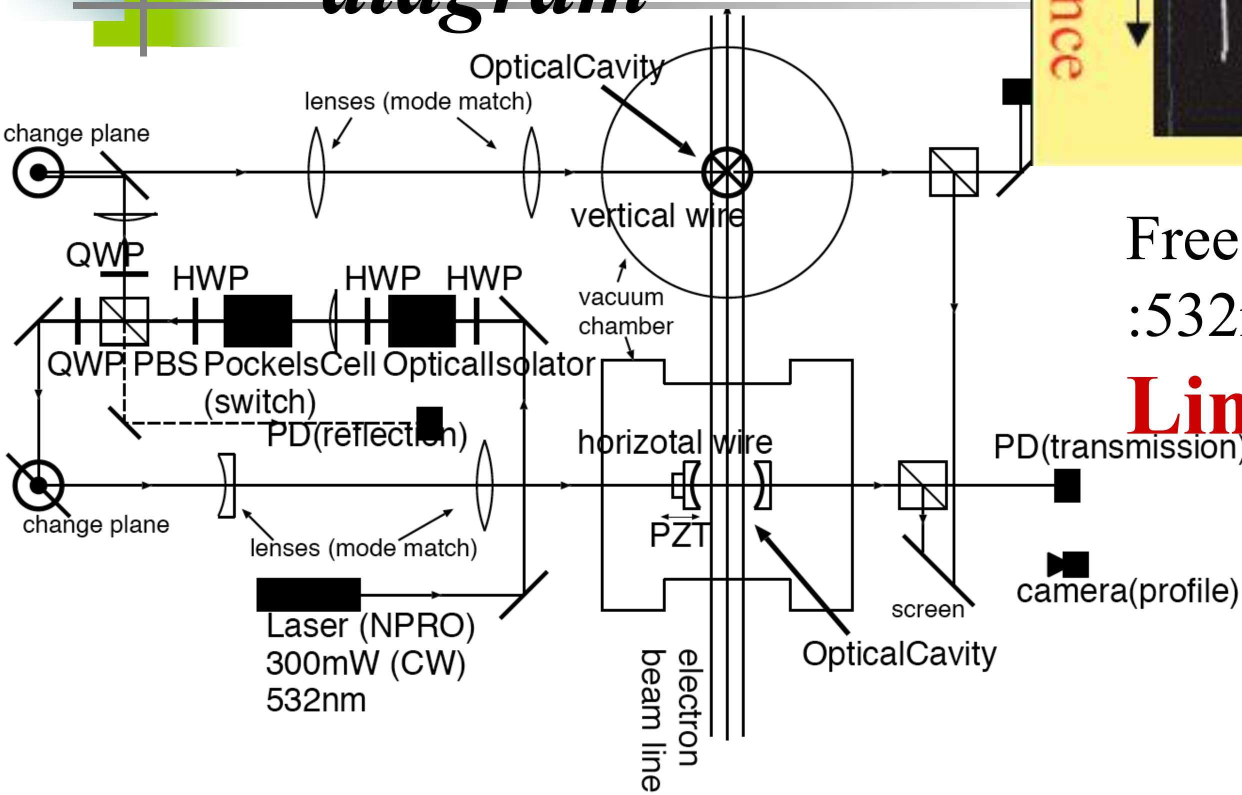


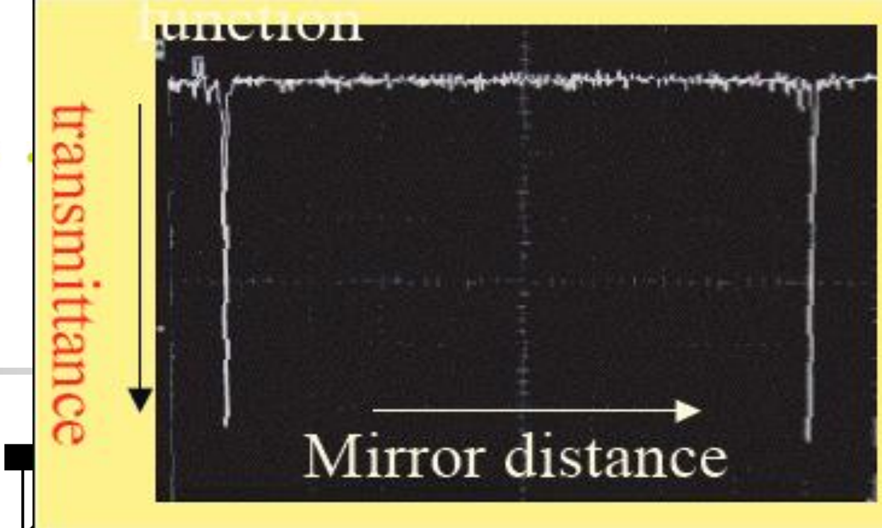


14.7μm laser wire for X scan
5.7μm for Y scan
(whole scan: 15min for X, 6min for Y)

300mW 532nm Solid-state Laser fed into optical cavity

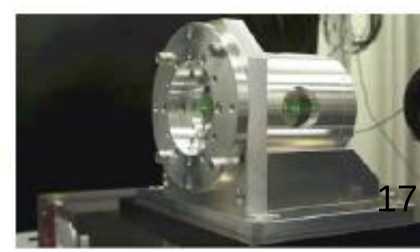
Laser wire block diagram





Free spectral range
:532nm/2=266nm

Line width=0.3nm

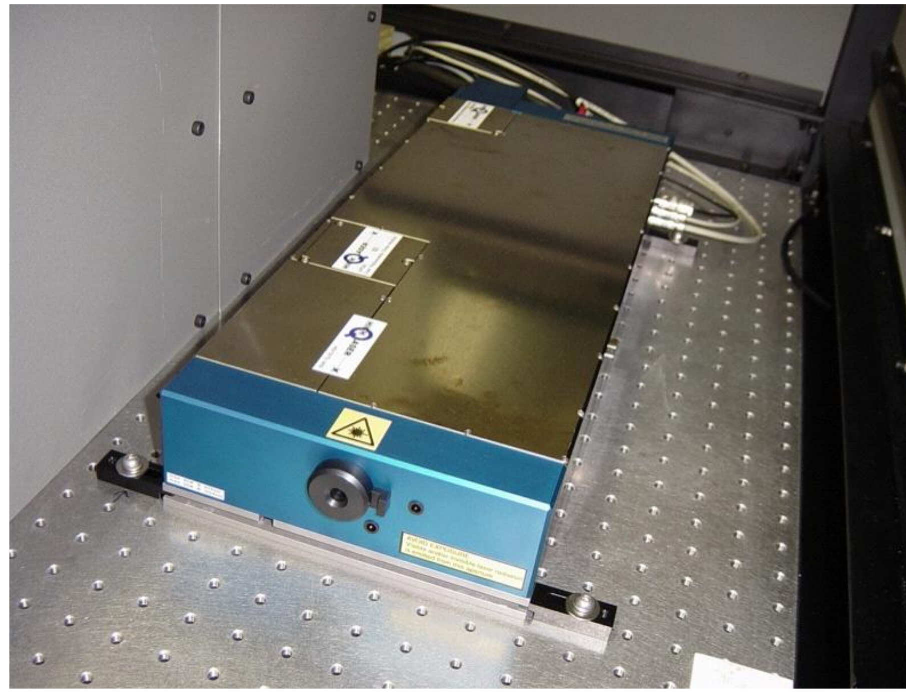


optical cavity resonance is kept by piezo actuator

Experimental results（Pulse Laser Storage）

Laser:

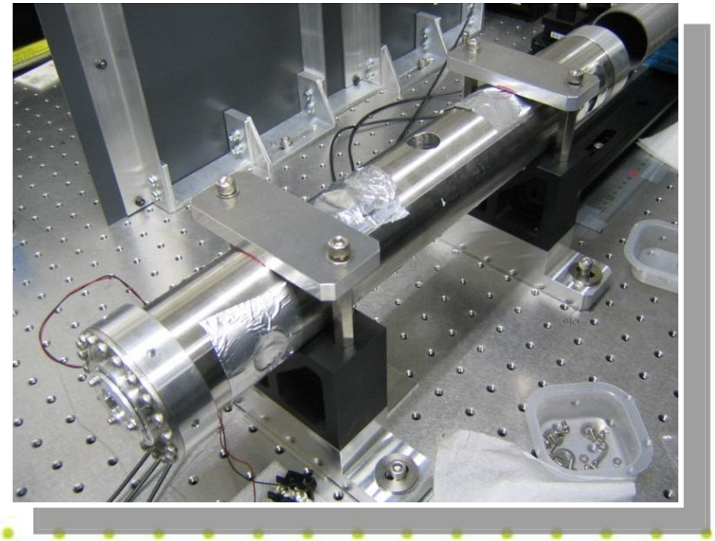
Mode Lock:	Passive SESAM
Frequency:	357MHz
Cavity length:	0.42 m
Pulse width:	7.3 p sec (FWHM)
Wave Length:	1064 nm
Power:	~ 6W



SESAM: SEmi-conductor Saturable Absorber Mirrors

Ext. Cavity:

Cavity:	Super Invar
Cavity length:	420mm
Mirrors:	
Reflectivity:	99.9%, 99.9% (maybe, 99.98%)
Curvature:	250 mm (σ_0 = 90μm)



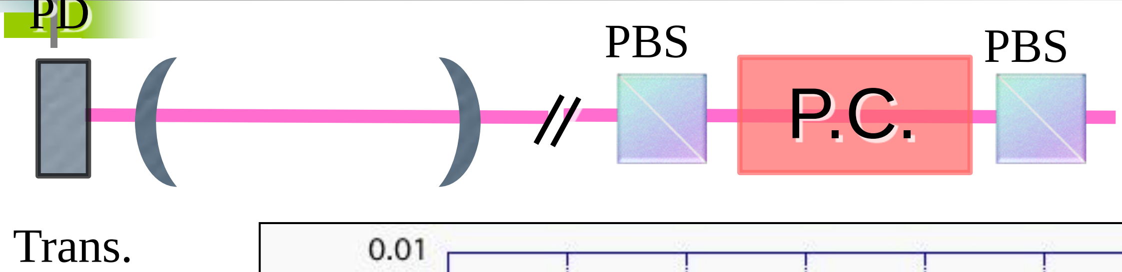
- Finesse: R = 99.98%

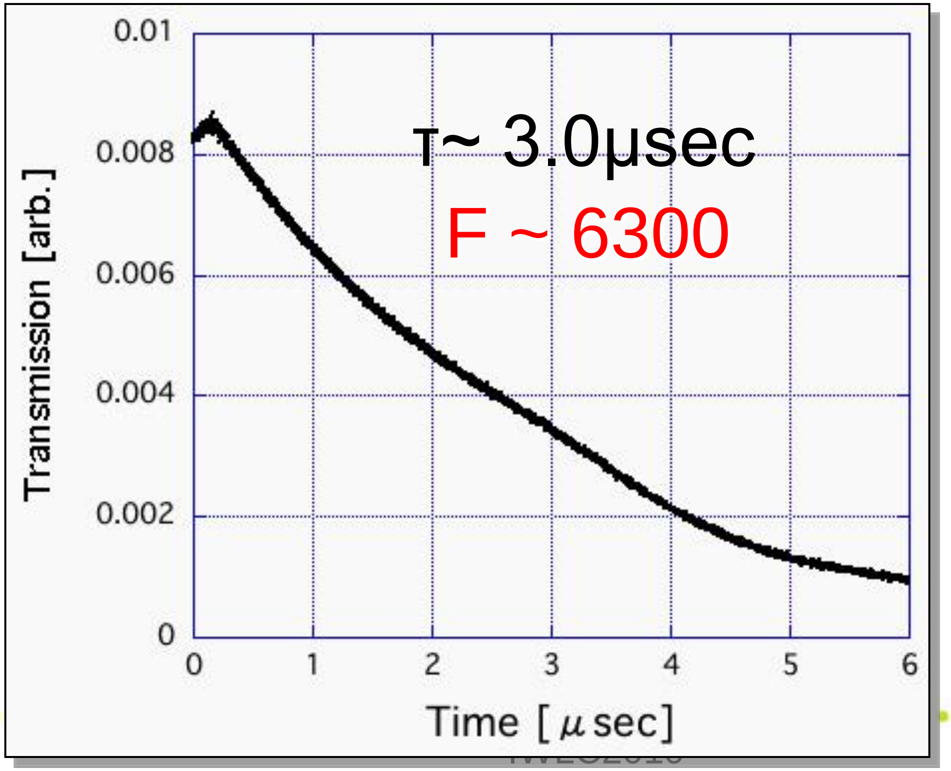
Finesse =πτc/l

τ:decay time

c: light verocity

l: cavity length

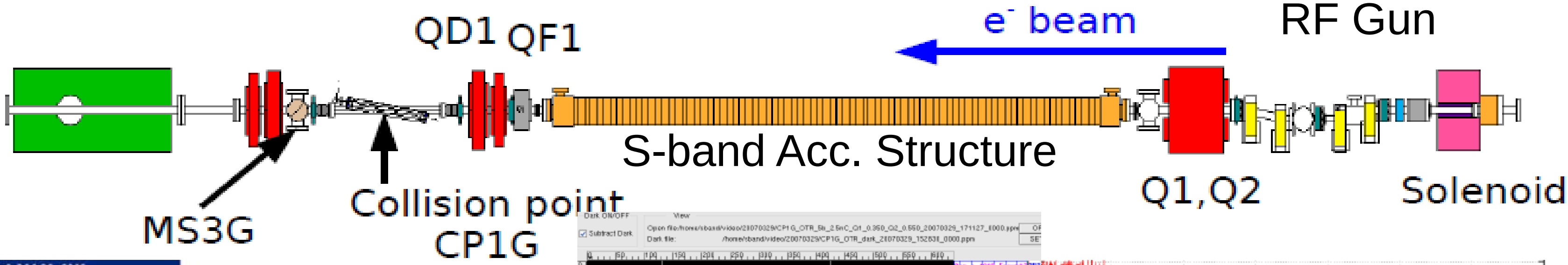


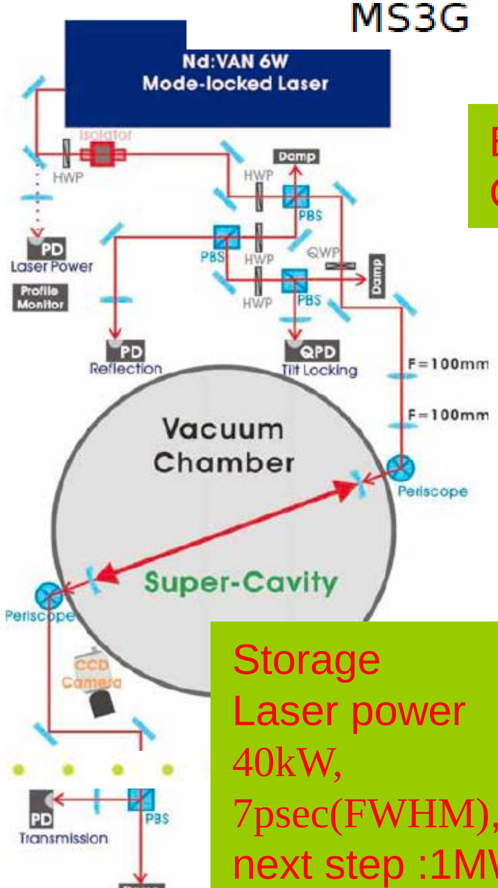


JFY 2004

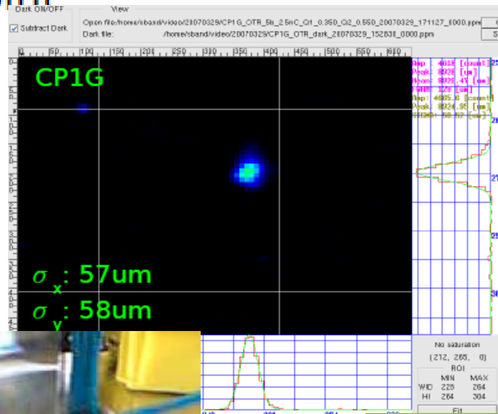
Laser Undulator Compact X-ray (LUCX) Project at KEK-ATF

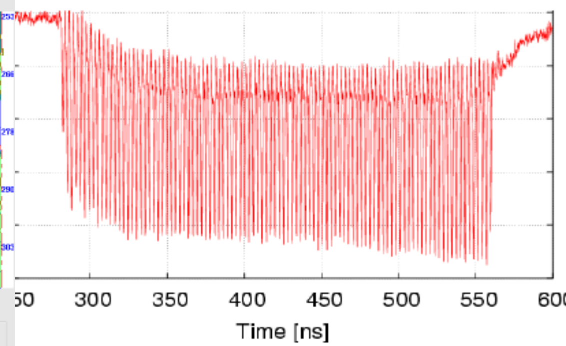
43MeV Multi-bunch beam+ Super-Cavity = 33keV X-ray.





Beam size at CP 60µm in σ





Multi-bunch e- beam 300nC at gun

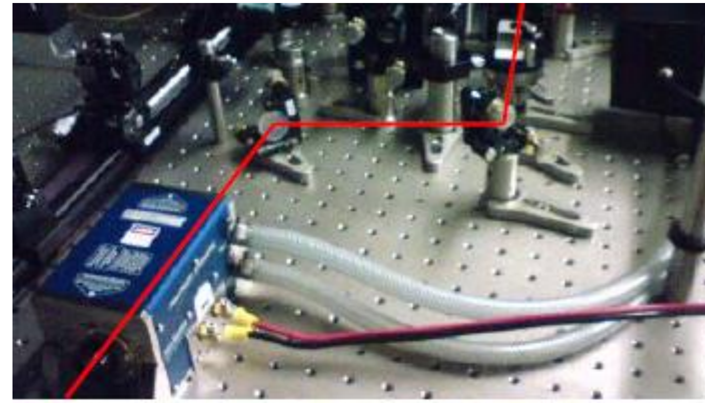
Storage Laser power 40kW, 7psec(FWHM), next step :1MW

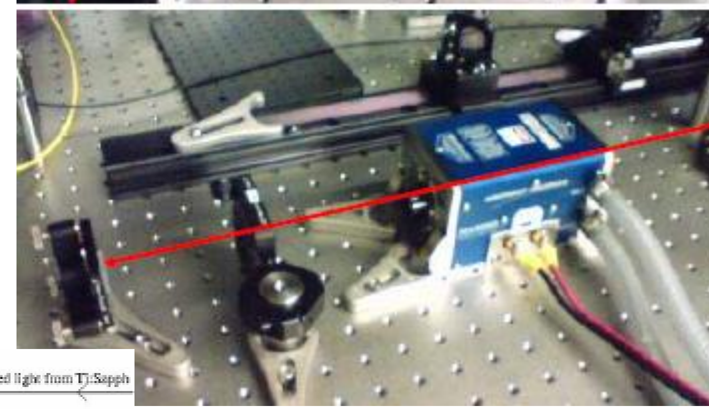
At present, laser waist size is 30µm in σ. We should reduce both beam size at CP down to 30µm.
33keV X-ray generation based on inverse Compton scattering was started from May 2007 with Super-Cavity.

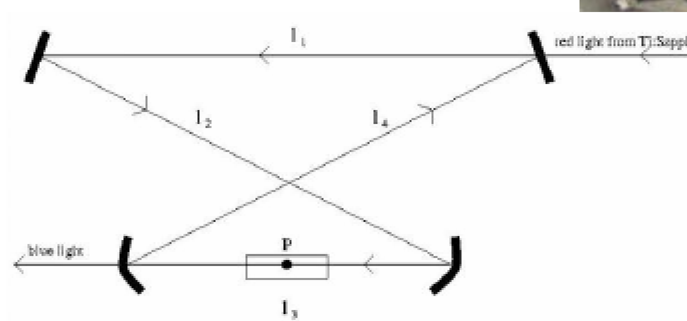
3. Burst Laser Amplification

Laser Diode Amplification
by 500

Operation test was done.







Cavity Structure:Bow-tie

Finesse:42000

Waist:40um

Input Power:5W

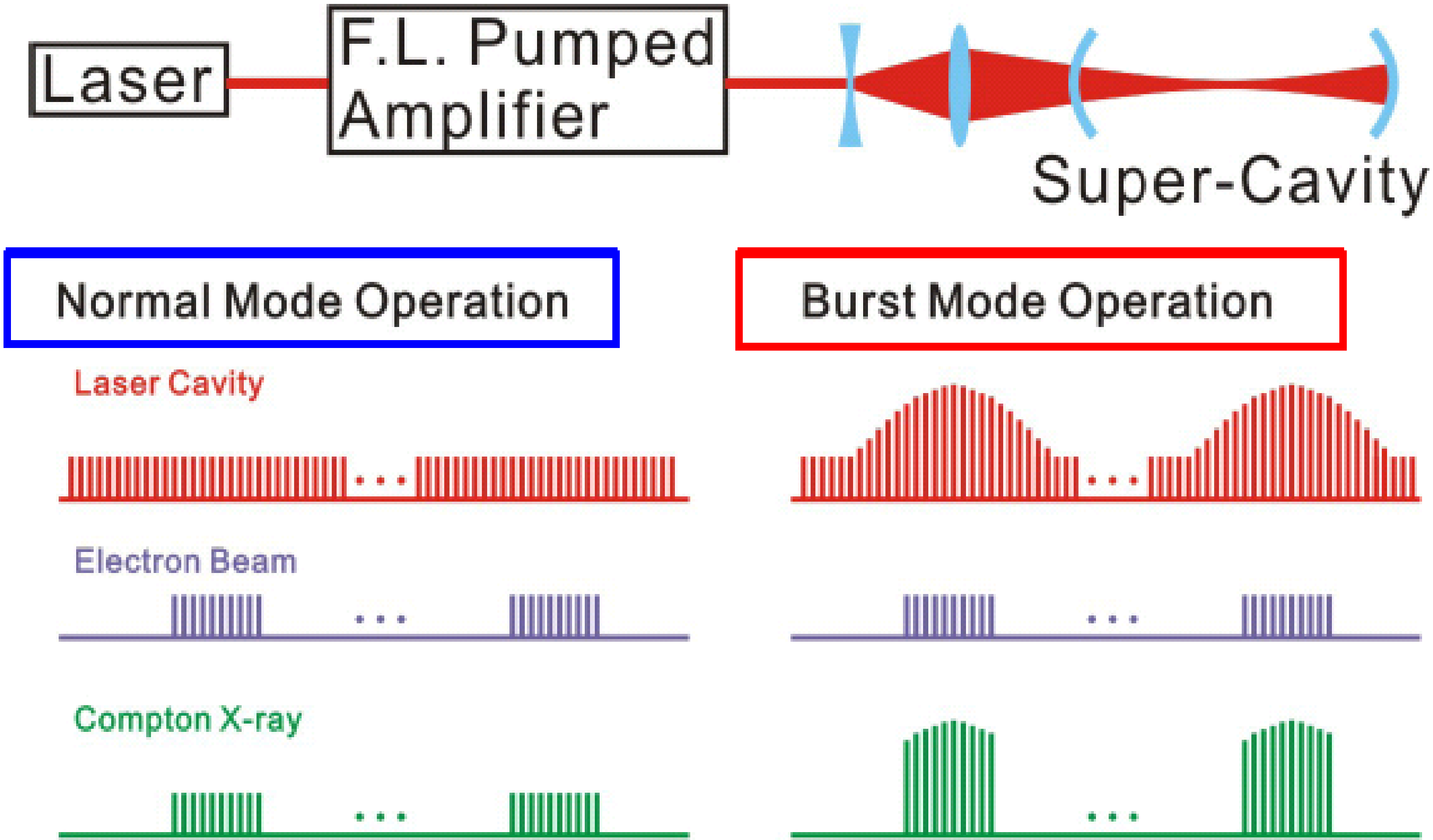
Stored Power:50kW

Average Power on Mirror:500kW/cm^2 <LIMIT

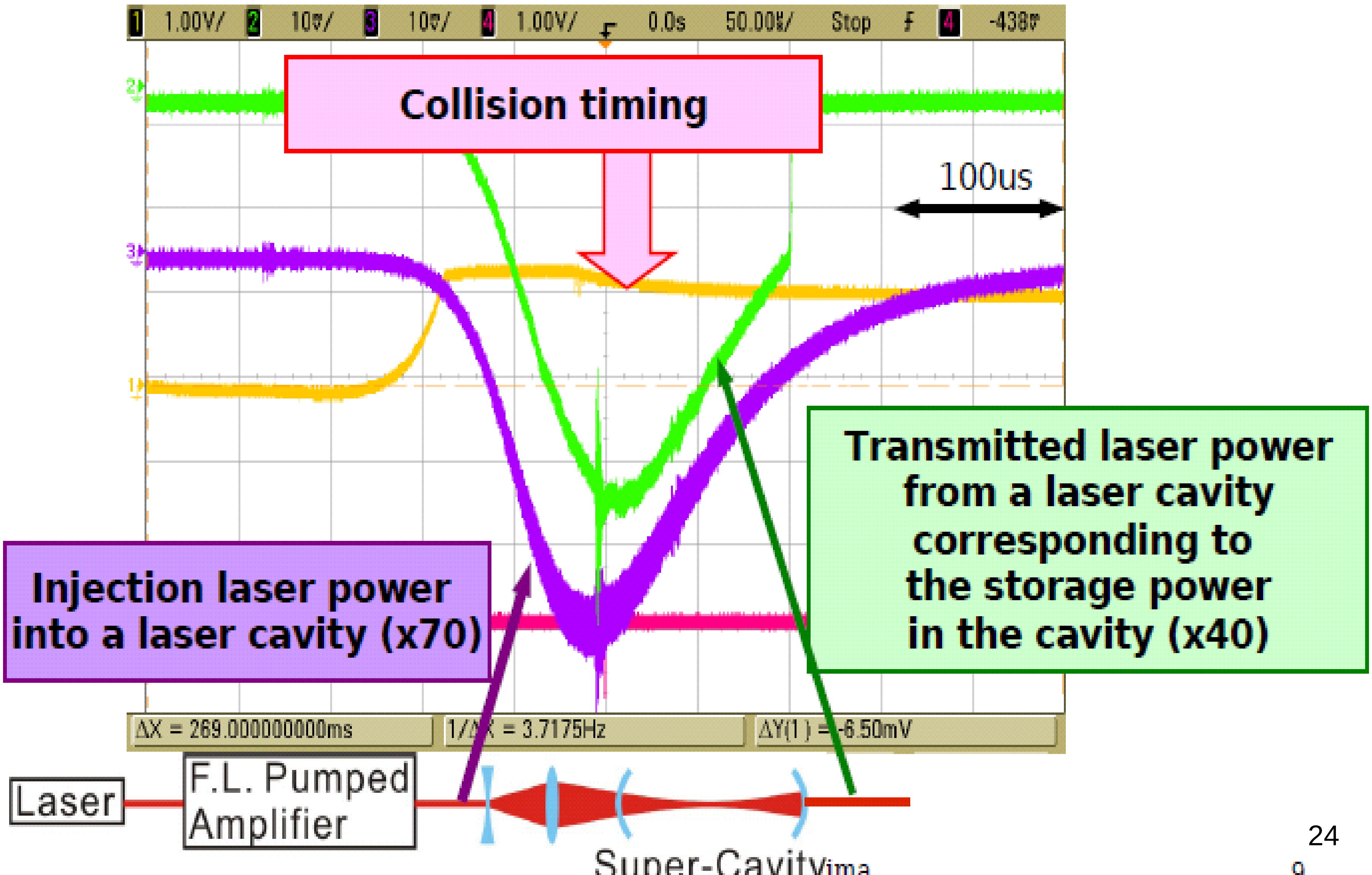
X-ray Flux:10^11photon/sec/0.1%b.w.

Burst mode Operation

In order to increase the number of x-rays,
A flash amplifier is installed before the laser cavity.



Burst mode Operation



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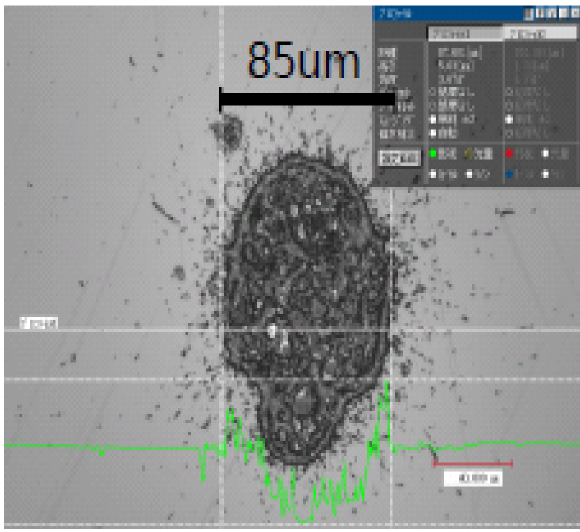
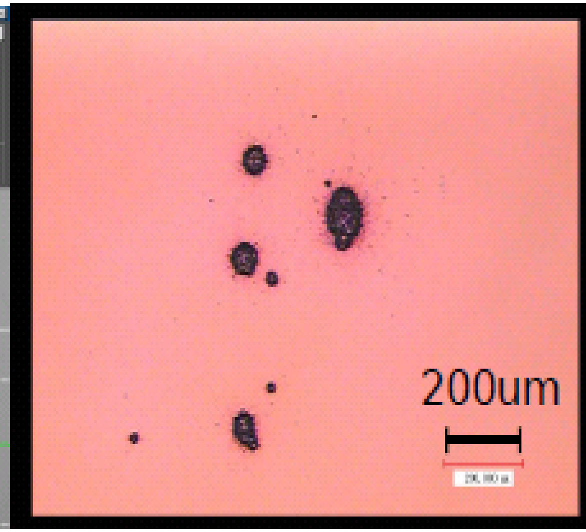
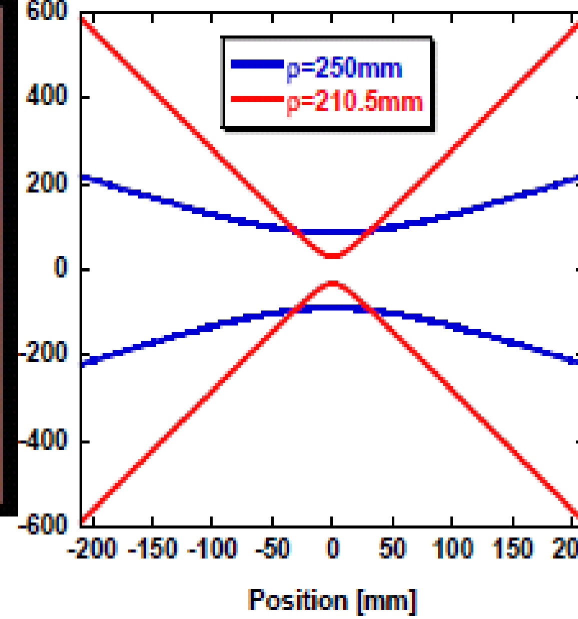
Damage on the mirror in Burst mode





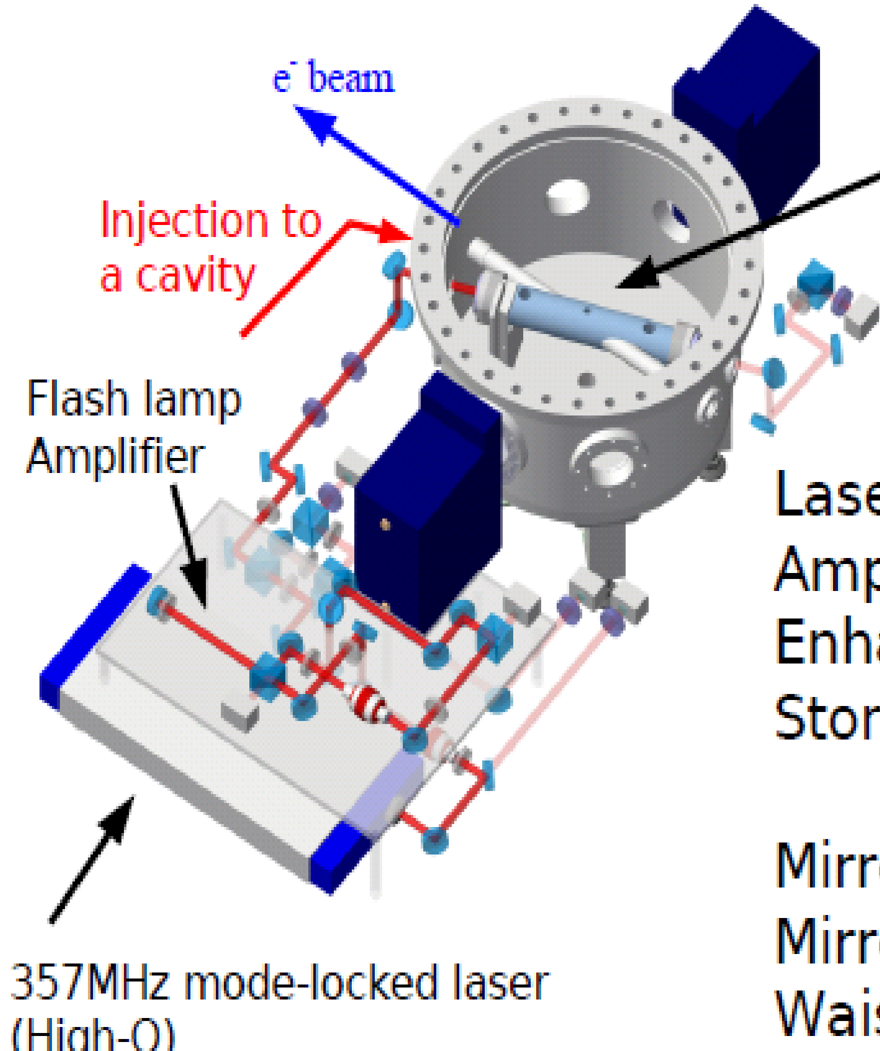
Size on the mirror
220um --> 587um



Depth(p-p) 5.5um
Measured by a color laser 3D profile microscope

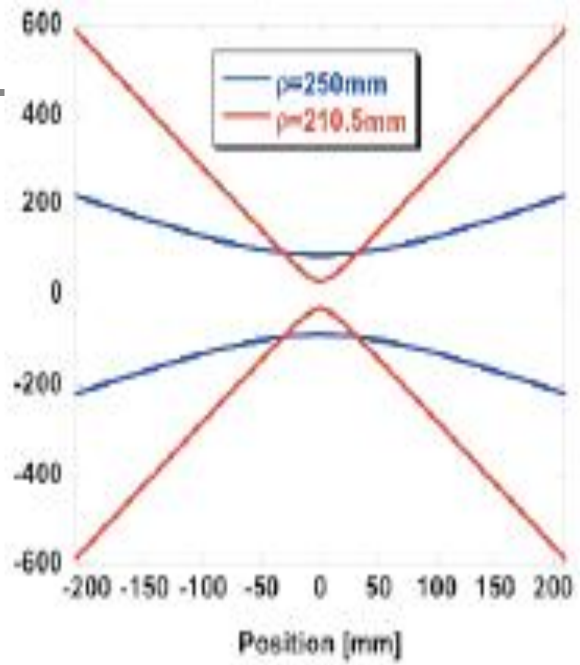
2Pass Amp Gain	Finesse	Waist Size	Size @ Mirror	Storage Peak Power
70	878.5	30.3μm	587μm	40kW

Burst mode cavity parameters

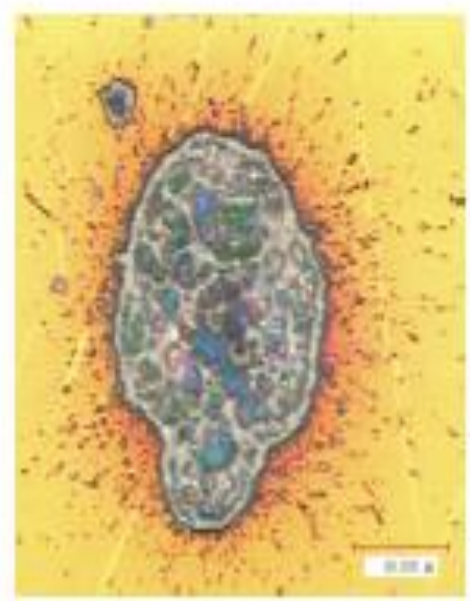


Laser power	2.5 W
Amp gain (2 pass)	80
Enhancement factor	200
Storage peak power	40 kW
	112 uJ/pulse
Mirror curvature	210.5mm
Mirror Reflectivity	99.6%
Waist size	30.3 um
Finesse	878.5
Cavity length	420 mm
Pulse length (FWHM)	7ps

4. Mirror damage which is caused by peak power density on the mirror.



Waist size in sigma from 80 μm to 30 μm



damaged coating size ~100 μm
Depth (p-p) 5.5 μm

Storage average power 40kW or more (maybe 120kW)
Laser size on mirror 440 μm

Then, reduce waist size from 160 μm to 60 μm.
Laser size on mirror 1174 μm

Good coating spherical mirror damage threshold :
Average power density on mirror ~10 MW/cm^2
Peak power density on mirror ~10 GW/cm^2

REO and SOC mirror threshold are a little small : 6.7 GW/cm^2 and 1.6 GW/cm^2

We designed asymmetric reflective mirror configuration to increase the coupling : 99.7% and 99.9% .
Then, we found damaged mirror was low reflective one.

When we introduced burst mode operation for x-ray generation with F.L. pumped amplifier, we might increase average power in the cavity until 120kW. It means ~20GW/cm^2.
Now we keep 40kW average power with larger beam size 1174 μm on the mirror ,which corresponds 0.8GW/cm^2.

Maybe, burst mode operation is interesting, I show several slides for this.

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

French Japanese Collaboration

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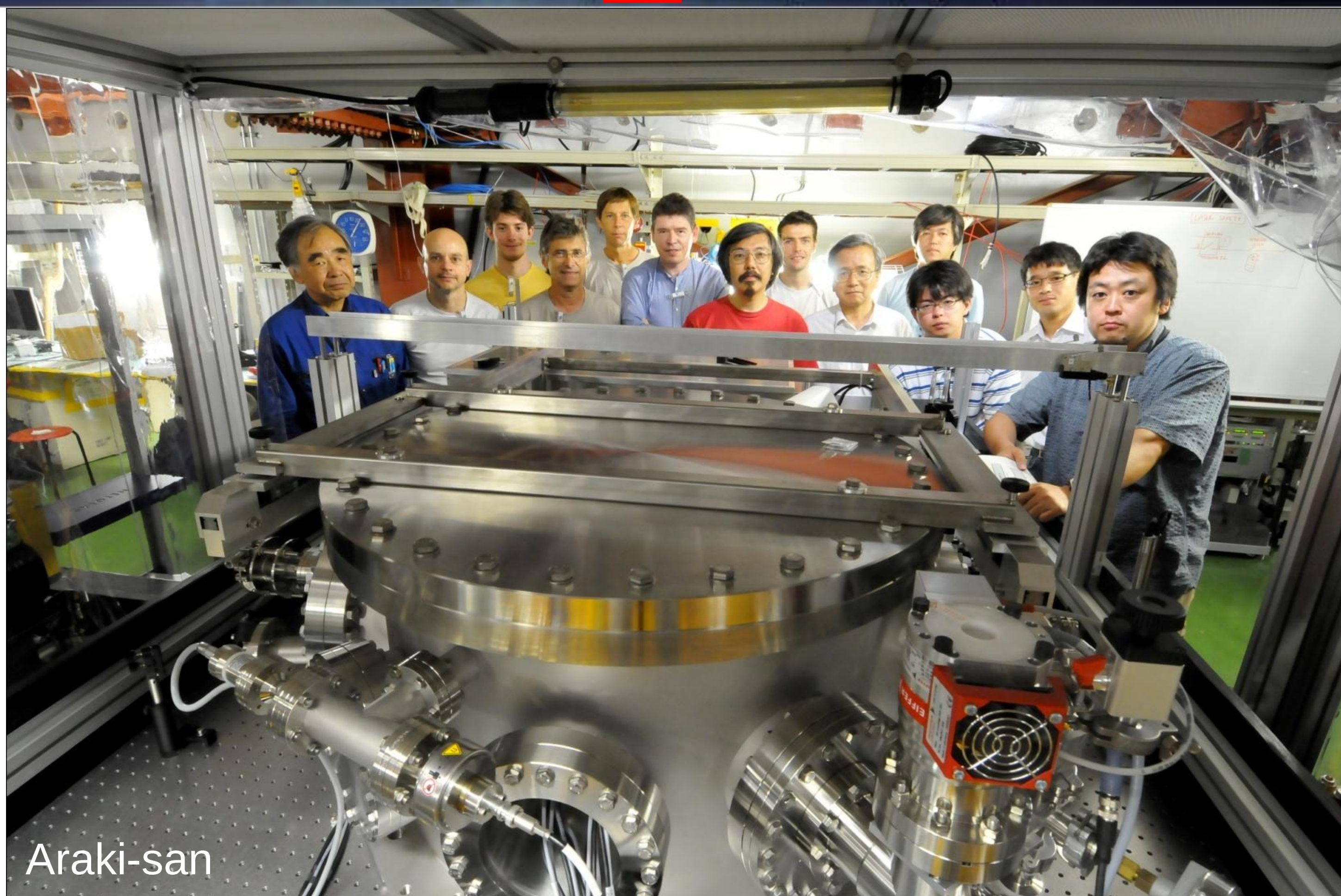
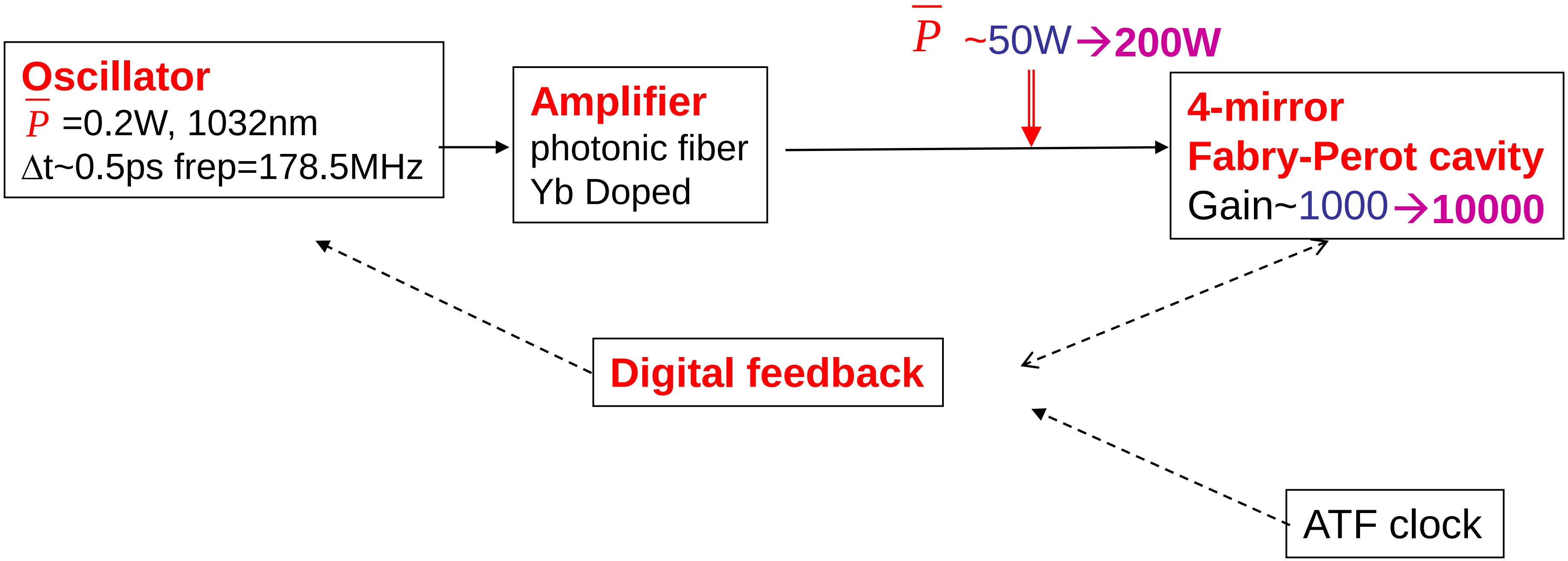


2 steps R&D

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

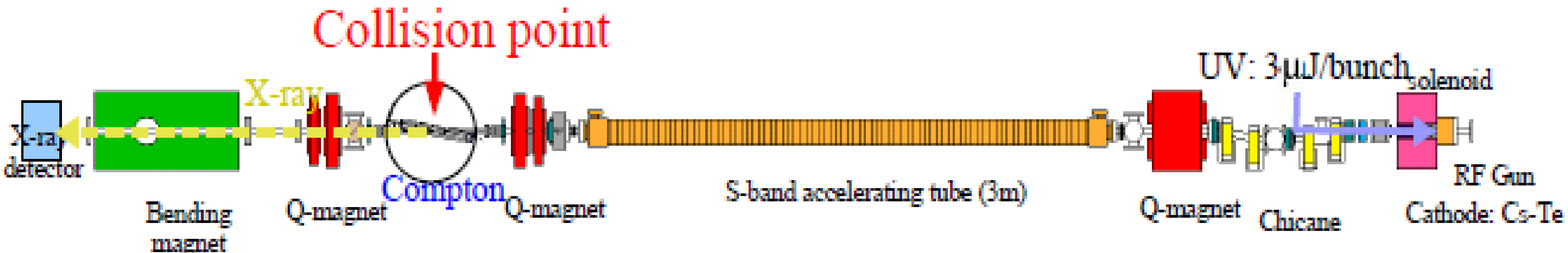
~2000x1.5 vs 2-mirror cavity
→~2 E11γ/s

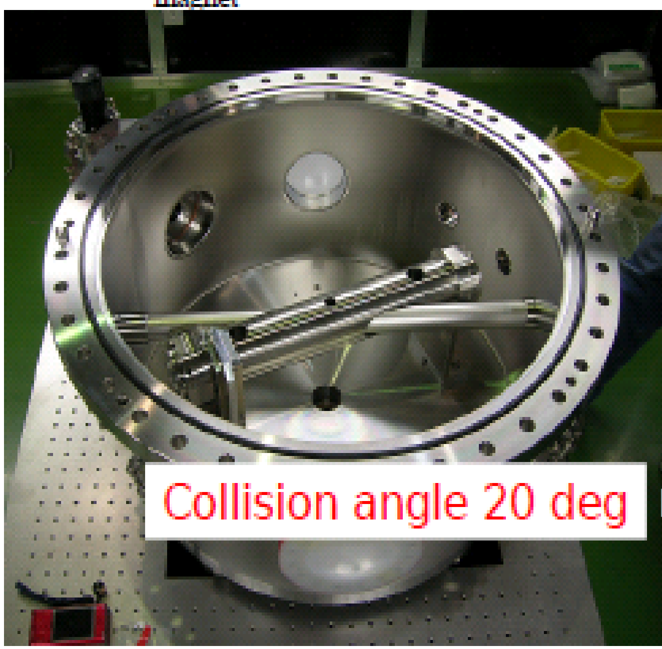
Goal: to reach the MW average power

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

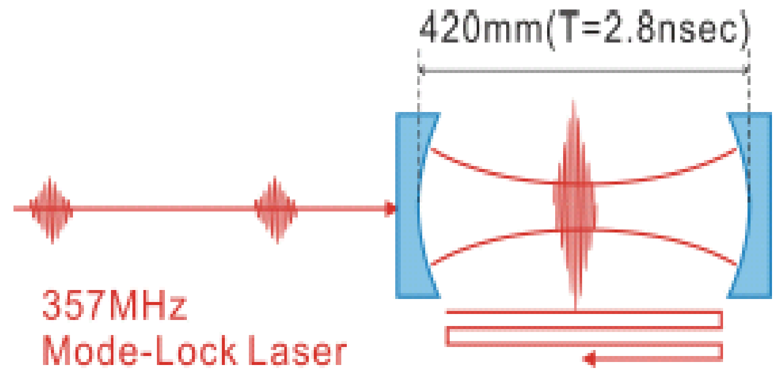
Pulsed Laser Cavity

The pulsed laser cavity is installed at the collision point.





→ 12 deg.



$$L_{cav} = n\lambda / 2$$

$$L_{cav} = mL_{laser}$$

Pulsed Laser cavity chamber

5. Summary

1. Establish feedback system to keep the resonance condition precisely.
2. 4-mirror ring cavity has a good tolerance to achieve gain near 10^4 and waist size 10 μm or less in sigma.
3. Take care of the mirror damage and need safety margin.

Proposal: Systematic Mirror Damage Experiment to JSPS.
If approve, start this experiment from April next year.

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

4-mirror cavity pulsed laser

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

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