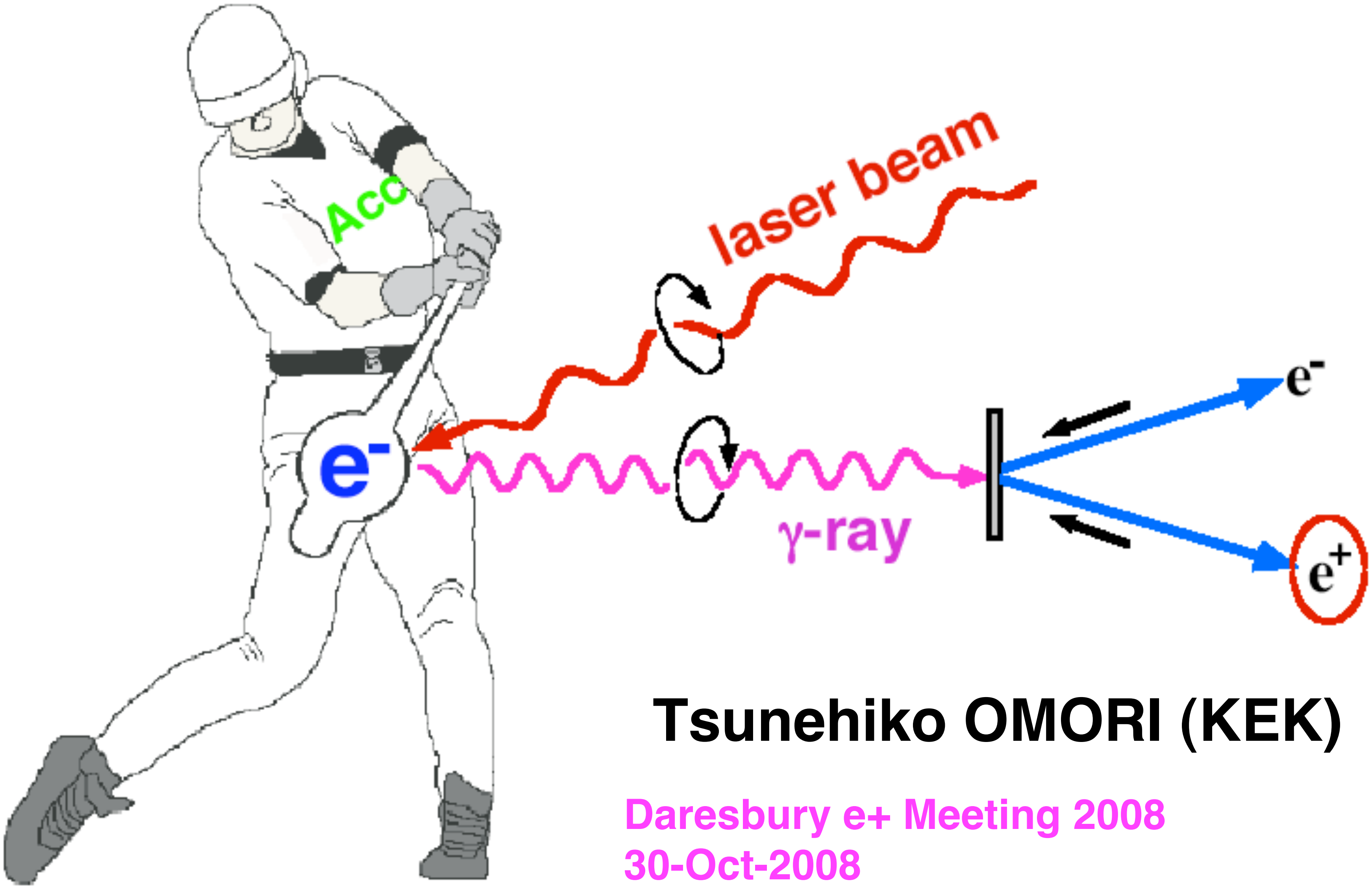
Ring/ERL Compton e+ Source for ILC



Tsunehiko OMORI (KEK)

Daresbury e+ Meeting 2008
30-Oct-2008

Why Laser-Compton ?

i) Positron Polarization.

ii) Independence

Undulator-base e^+ : use e^- main linac

Laser-base e^+ : independent

iii) Polarization flip @ 5Hz (for CLIC @ 50 Hz)

iv) High polarization (potentially <-- 1st harmonic)

v) Low energy operation

Undulator-base e^+ : need deceleration

Laser-base e^+ : no problem

vi) Synergy in wide area of fields/applications

Status of Compton Source

Proof-of-Principle demonstration was done.

ATF-Compton Collaboration

Polarized γ-ray generation: M. Fukuda et al., PRL 91(2003)164801

Polarized e+ generation: T. Omori et al., PRL 96 (2006) 114801

We still need many R/Ds and simulations.

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We still need many R/Ds and simulations.

We have 3 schemes.

Choice 1 : How to provide e- beam
Storage Ring, ERL, Linac
Choice 2 : How to provide laser beam
Wave length (λ=1μm or λ=10μm)
staking cavity or non stacking cavity
Choice 3 : e+ stacking in DR or Not

Laser Compton e^+ Source for ILC/CLIC

We have 3 schemes.

1. Ring-Base Laser Compton
   Storage Ring + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR
   S. Araki et al., physics/0509016

2. ERL-Base Laser Compton
   ERL + Laser Stacking Cavity (λ=1μm),
   and e+ stacking in DR

3. Linac-Base Laser Compton
   Linac + non-stacking Laser Cavity (λ=10μm),
   and No stacking in DR
   Proposal V. Yakimenko and I. Pogorersky
   T. Omori et al., Nucl. Instr. and Meth. in Phys. Res., A500 (2003) pp 232-252

Good! But we have to choose!

Laser Compton e^+ Source for ILC/CLIC

We have 3 schemes.

1. Ring-Base Laser Compton
   Storage Ring + Laser Stacking Cavity (λ=1μm), and e+ stacking in DR
   S. Araki et al., physics/0509016

   My talk today

2. ERL-Base Laser Compton
   ERL + Laser Stacking Cavity (λ=1μm), and e+ stacking in DR

3. Linac-Base Laser Compton
   Linac + non-stacking Laser Cavity (λ=10μm), and No stacking in DR

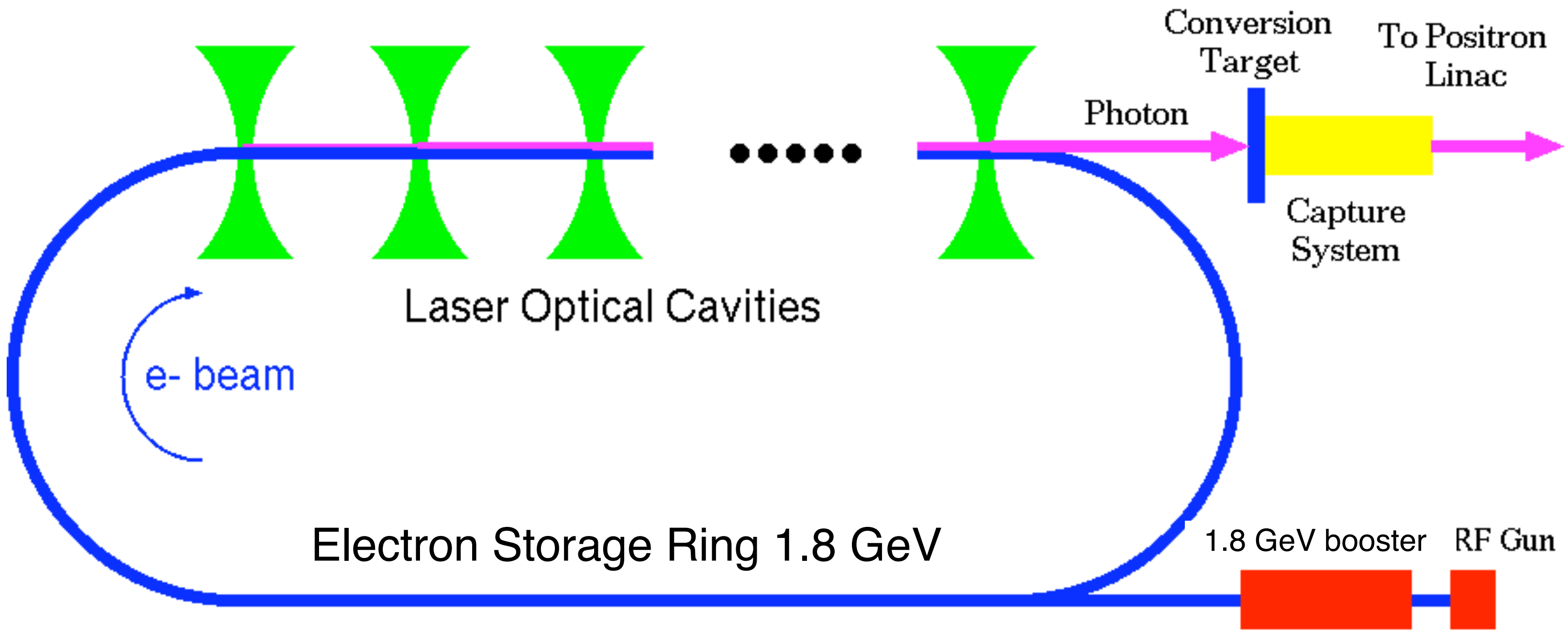
   Vitaly-san at Chicago

   Proposal V. Yakimenko and I. Pogorersky
   T. Omori et al., Nucl. Instr. and Meth. in Phys. Res., A500 (2003) pp 232-252

Ring/ERL Scheme for ILC

Compton Ring Scheme for ILC

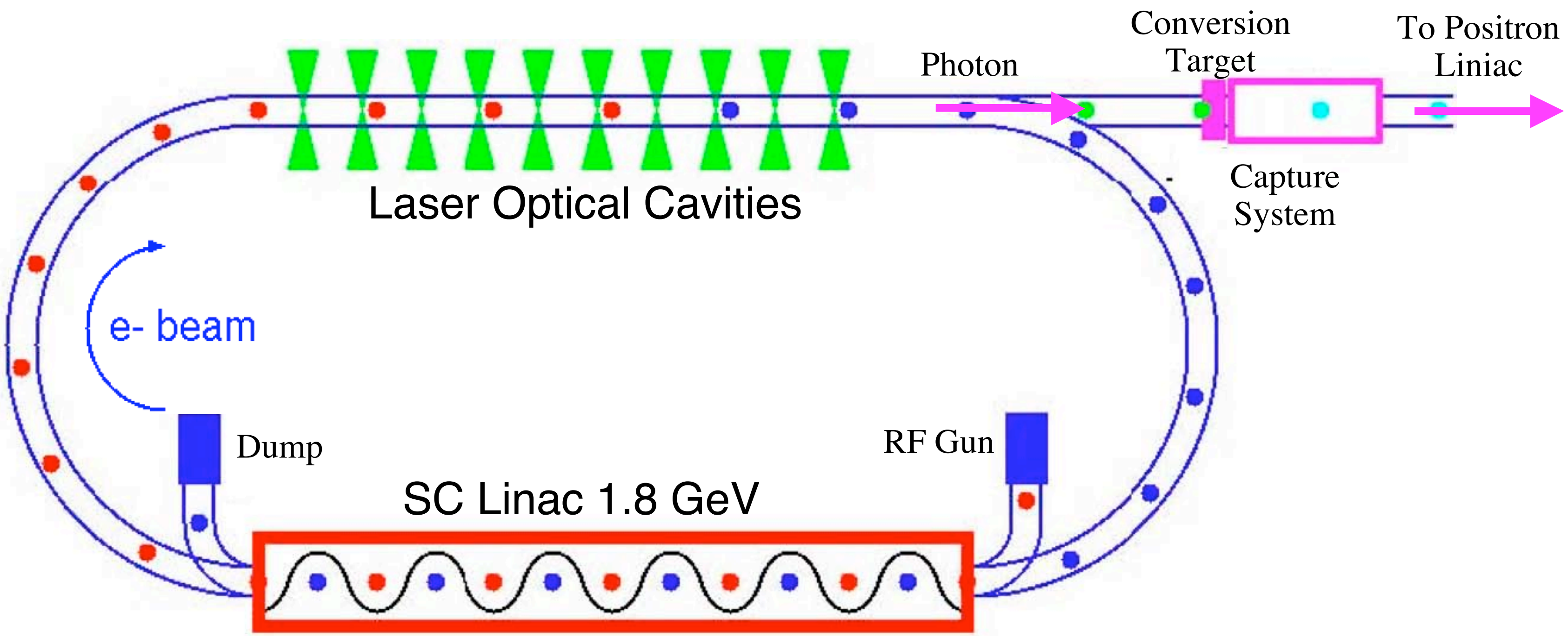
- Compton scattering of e- beam stored in storage ring off laser stored in Optical Cavity.
- 5.3 nC 1.8 GeV electron bunches x 5 of 600mJ stored laser -> 2.3E+10 γ rays -> 2.0E+8 e+.
- By stacking 100 bunches on a same bucket in DR, 2.0E+10 e+/bunch is obtained.



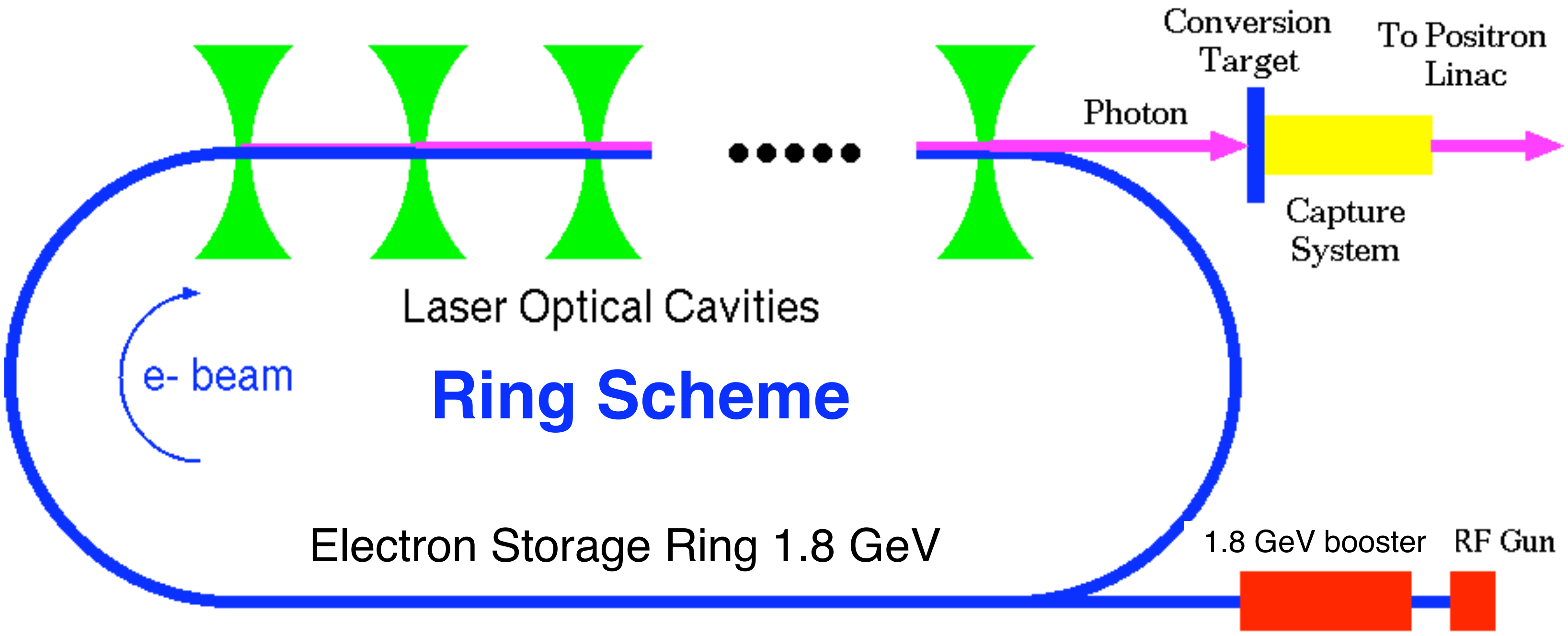
ERL scheme for ILC

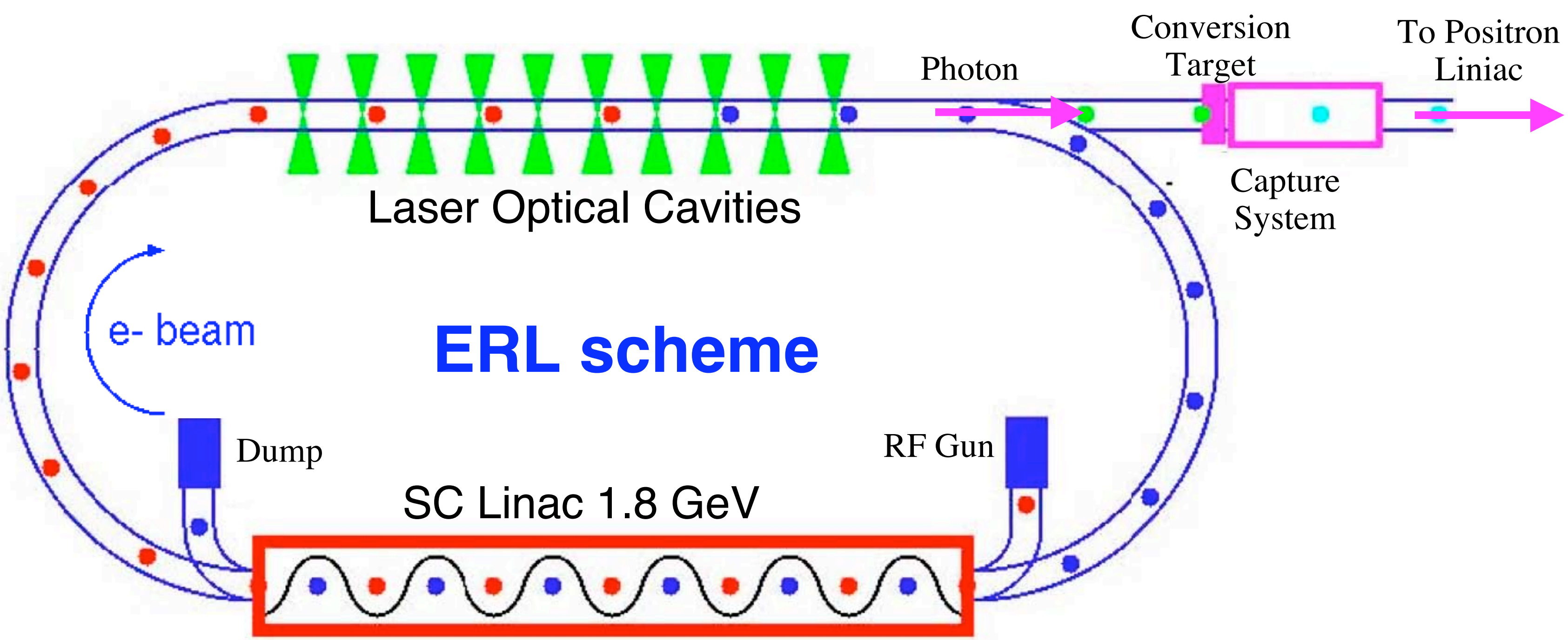
- High yield + high repetition in ERL solution.
  - 0.48 nC 1.8 GeV bunches x 5 of 600 mJ laser, repeated by 54 MHz -> 2.5E+9 γ-rays -> 2E+7 e+.
  - Continuous stacking the e+ bunches on a same bucket in DR during 100ms, the final intensity is 2E+10 e+.

1000 times of stacking in a same bunch



Ring scheme and ERL scheme are SIMILAR





What is the Difference? : Ring and ERL

What is Reused

Ring: Electron Beam

ERL: Energy of the electron beam

What is the Difference? : Ring and ERL

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- Ring: Electron Beam
- ERL: Energy of the electron beam

Collision / Operation

- Ring: Burst Collision (need cooling time)
- ERL: as CW as possible

What is the Difference? : Ring and ERL

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ERL: Energy of the electron beam

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ERL: as CW as possible

Bunch Length

Ring: Naturally Long (typically 30 psec)

ERL: Short (can be less than 1 p sec)

What is the Difference? : Ring and ERL

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ERL: Energy of the electron beam

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ERL: as CW as possible

Bunch Length

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ERL: Short (can be less than 1 p sec)

Bunch Charge

Ring: Larger

ERL: Smaller

Parameters and Choices

of Ring/ERL scheme

Ring Scheme Parameters

Ring Scheme Parameters

Burst Operation of Laser (Burst Collision)
- Need to cool Compton Ring
- Good for stacking in DR

Cooling time ~ 10 m sec

Ng / bunch = 2.3×10^{10} simulation by CAIN
- E=1.8 GeV, 0.6 J x 5 CP (assume)
- Ne- / bunch = 3.3×10^{10} (5.3 nC / bunch) (assume)
- Bunch length ~ 1 p sec (assume)

Ne+ / bunch = 2×10^{8}
- Ne+(captured) / Ng = 0.8 % (assume)

We need 100 times of stacking in a same DR bunch.

{10 stacking (<<1 ms) + cooling (~10 ms) } x 10

Burst Operation of Laser --> Burst Amplifier

ERL Scheme Parameters

Choice of ERL parameters

I = 26 mA

(a) Ne/bunch = 1 x 10^9 $T_{b\_to\_b}$ = 6.15 ns (160 pC x 160 MHz)

(b) Ne/bunch = 3 x 10^9 $T_{b\_to\_b}$ = 18.5 ns (480 pC x 54 MHz)

(c) Ne/bunch = 1 x 10^{10} $T_{b\_to\_b}$ = 61.5 ns (1.6 nC x 16 MHz)

(d) Ne/bunch = 3 x 10^{10} $T_{b\_to\_b}$ = 185 ns (4.8 nC x 5.4 MHz)

Choice of ERL parameters

I = 26 mA

(a) Ne/bunch = 1×10^9 $T_{b\_to\_b}$ = 6.15 ns   (160 pC … 0 MHz)

(b) Ne/bunch = 3×10^9 $T_{b\_to\_b}$ = 18.5 ns   (480 pC … 4 MHz)

(c) Ne/bunch = 1×10^{10} $T_{b\_to\_b}$ = 61.5 ns   (1.6 nC x … MHz)

(d) Ne/bunch = 3×10^{10} $T_{b\_to\_b}$ = 185 ns   (4.8 nC … 4 MHz)

more difficult

Choice of ERL parameters

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I = 80 mA (too ambitious !?)

(e) Ne/bunch = 3 x 10^9 $T_{b\_to\_b}$ = 6.15 ns (480 pC x 160 MHz)

(f) Ne/bunch = 1 x 10^{10} $T_{b\_to\_b}$ = 18.5 ns (1.5 nC x 54 MHz)

(g) Ne/bunch = 3 x 10^{10} $T_{b\_to\_b}$ = 61.5 ns (4.8 nC x 16 MHz)

Choice of ERL parameters

I = 26 mA

(a) Ne/bunch = 1×10^9 $T_{b\_to\_b}$ = 6.15 ns (160 pC [illegible]0 MHz)

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(c) Ne/bunch = 1×10^{10} $T_{b\_to\_b}$ = 61.5 ns (1.6 nC x [illegible] MHz)

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(g) Ne/bunch = 3×10^{10} $T_{b\_to\_b}$ = 61.5 ns (4.8 nC x [illegible]6 MHz)

ERL repetition ($R_{rep} = 1/T_{b\_to\_b}$)

ERL repetition and e+ Stacking

How many stacks do we need ?

Number of gamma-rays

Ng / bunch = 0.75×10^{10} simulation by CAIN

assume E=1.8 GeV, 0.6 J x 5 CP, Ne=1×10^{10}

Number of positrons

Ne+ / bunch = 0.6×10^{8}

assume Ne+(captured) / Ng = 0.8 %

I = 26 mA (assume)

R_{rep} (MHz)	160	54	16
Ne- /bunch	1×10^{9}	3×10^{9}	1×10^{10}
Necessary N stack	3300	1000	330

ERL repetition ($R_{rep} = 1/T_{b\_to\_b}$) continued

ERL repetition and e+ Stacking (continued)

Max N stack is limited by time.

T stack < 100 m sec

T stack = 3000 bunches x N stack / R_{rep}

I = 26 mA (assume)

R_{rep} (MHz)	160	54	16
Ne- /bunch	1×10^9	3×10^9	1×10^{10}
Necessary N stack	3300	1000	330
Max N stack	5000	1600	500

Max N stack is limited by DR.

How many stacks can we achieve ?

--> Need study --> talk F. Zimmermann

ERL repetition ($R_{rep} = 1/T_{b\_to\_b}$) continued

ERL repetition and Laser

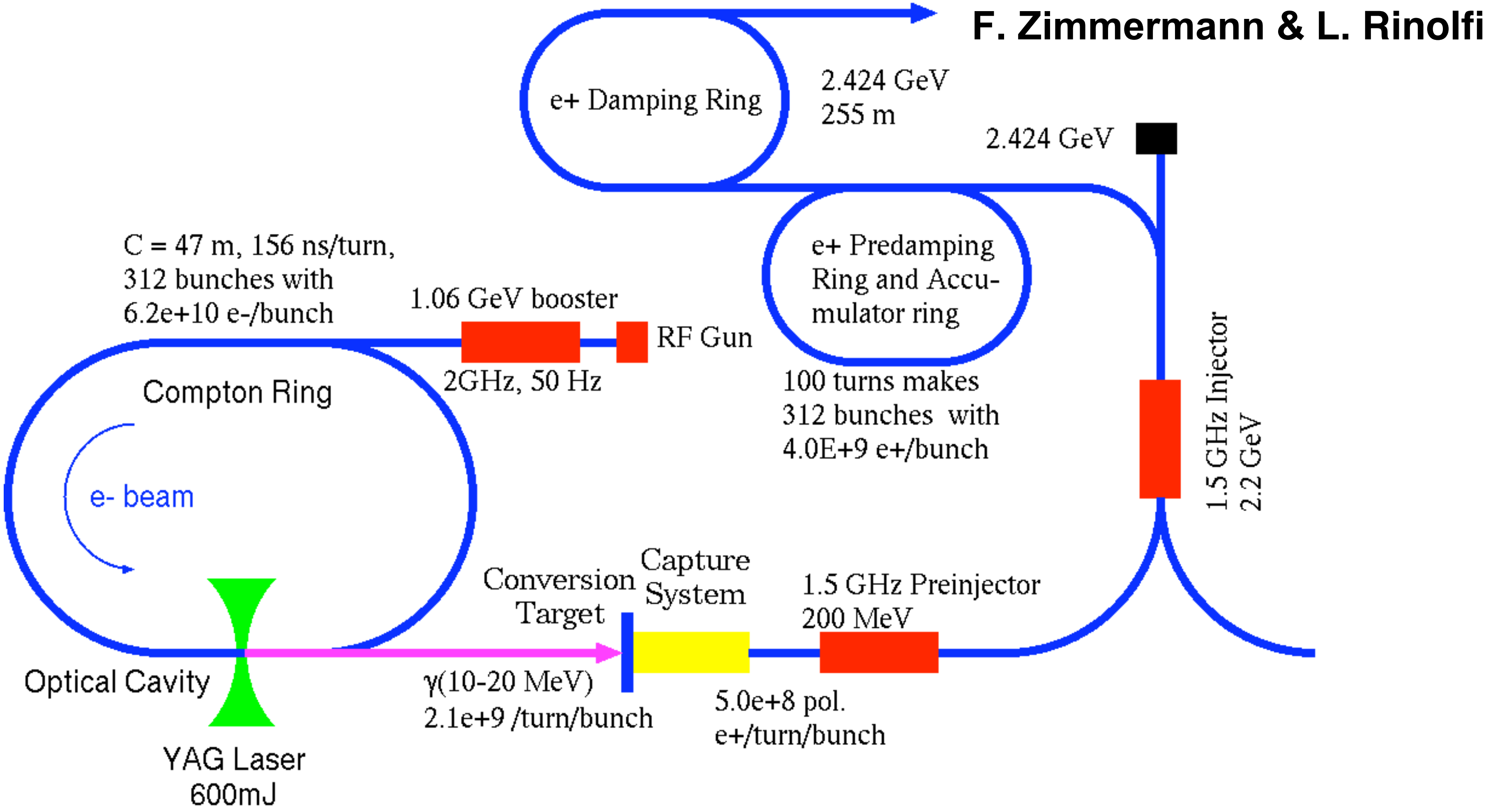
R_{rep} (MHz)	160	54	16
L cavity (round trip)(m)	1.9	5.6	19
L cavity (end-to-end*)(m)	0.46	1.4	4.6

Reasonable size of stacking cavity?

Reasonable size of laser oscillator?

* assume 4-mirror cavity

Compton e+ Source for CLIC



ILC/CLIC common issues on Compton

(1) Ne- in Compton Ring, beam stability
(2) optical cavity
(3) high quality and high power laser
(4) choice of ERL parameters
(5) energy compression before (pre-)DR
(6) short damping time
(7) e+ stacking

Necessary R/Ds

for Ring / ERL scheme

Ring / ERL scheme R&D List

e+ stacking in DR

    simulation studies

talk F. Zimmermann

Compton Ring simulation studies

ERL simulation studies

e+ capture (common in all e+ sources)

    Simulation study
    Collaboration with KEKB upgrade

e+ production target

Laser

    Fiber laser / Mode-lock laser

Laser Stacking Cavity

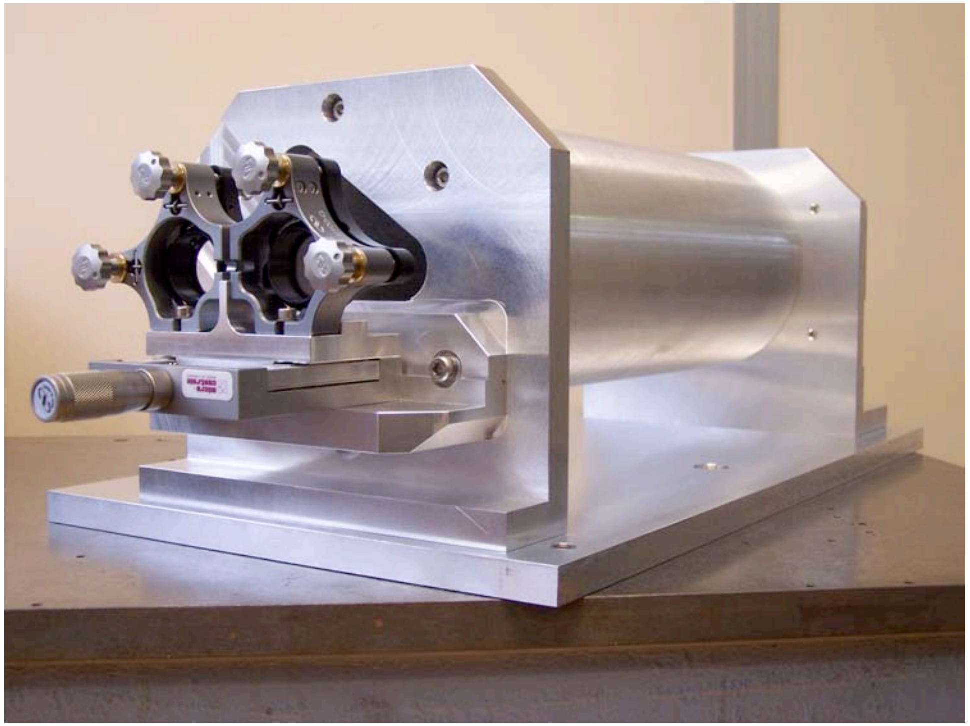
    experimental and
    theoretical studies

Prototype Cavities

2-mirror cavity (Hiroshima / Weseda / Kyoto / IHEP / KEK)

- moderate enhancement
- moderate spot size
- simple control

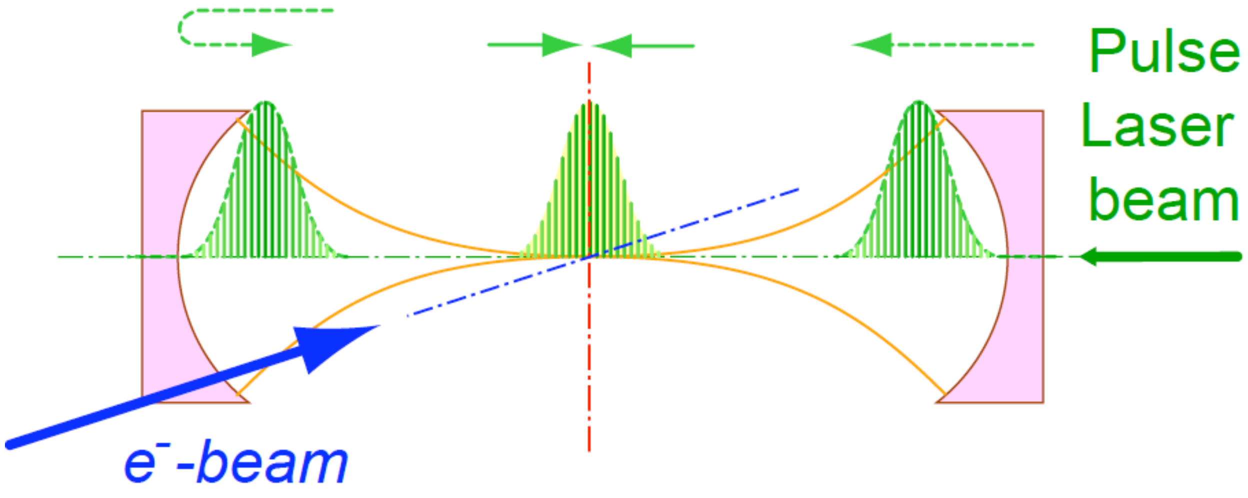
4-mirror cavity (LAL)



- high enhancement
- small spot size
- complicated control

Experimental R/D in ATF

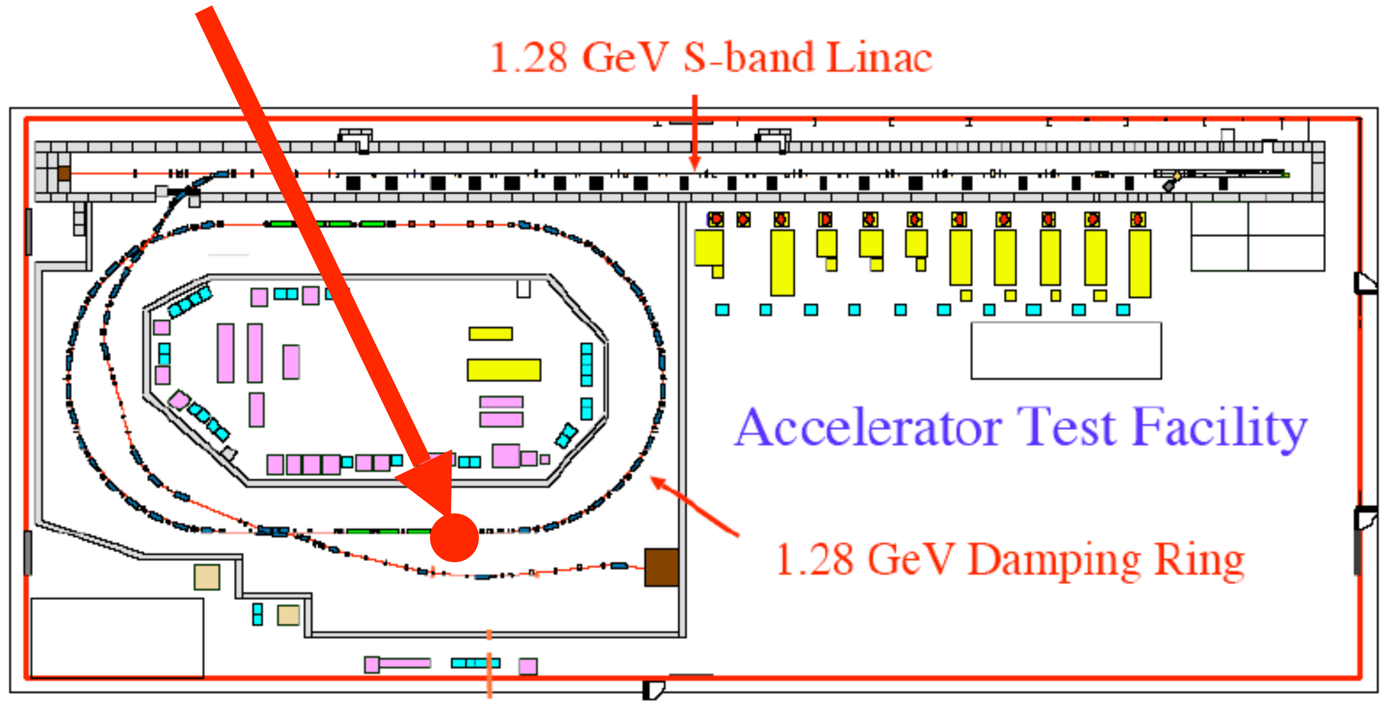
Hiroshima-Waseda-Kyoto-IHEP-KEK



Make a fist prototype 2-mirror cavity

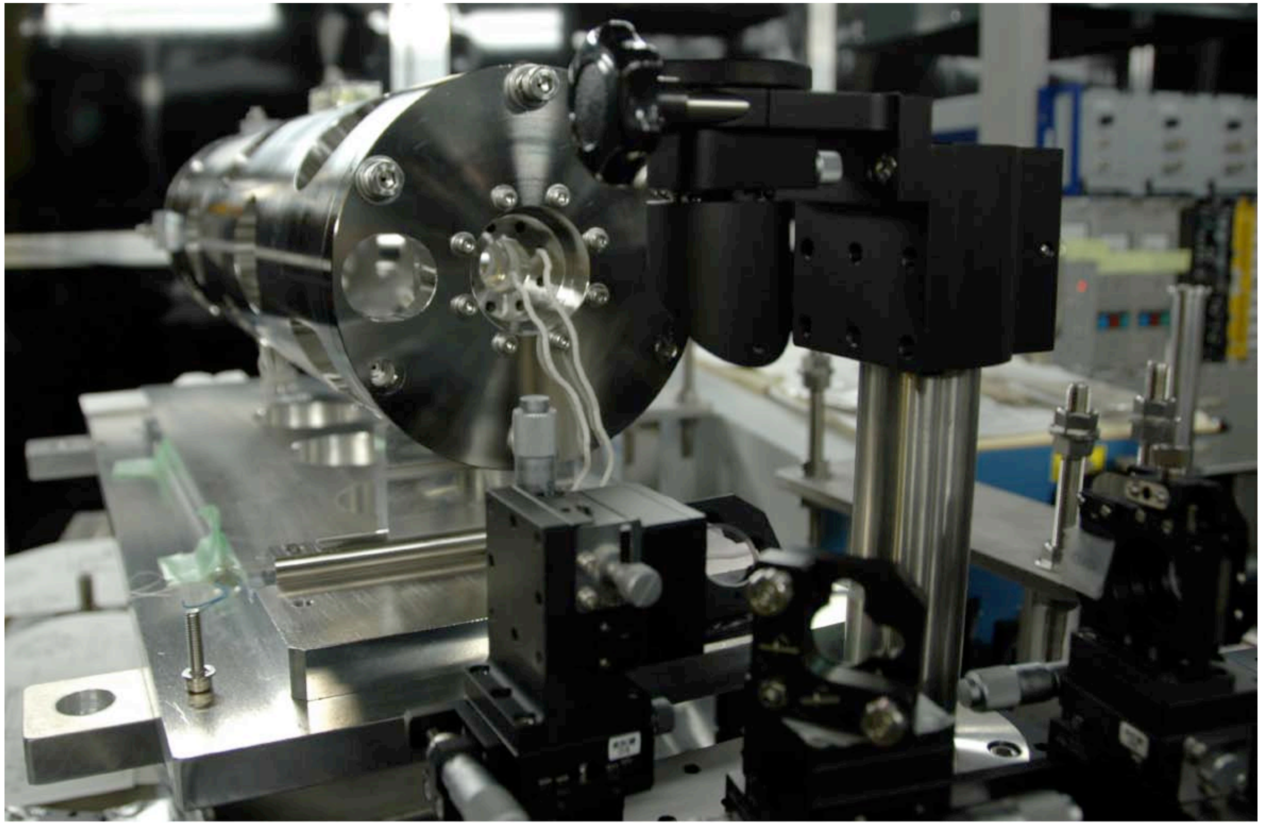
L_{cav} = 420 mm

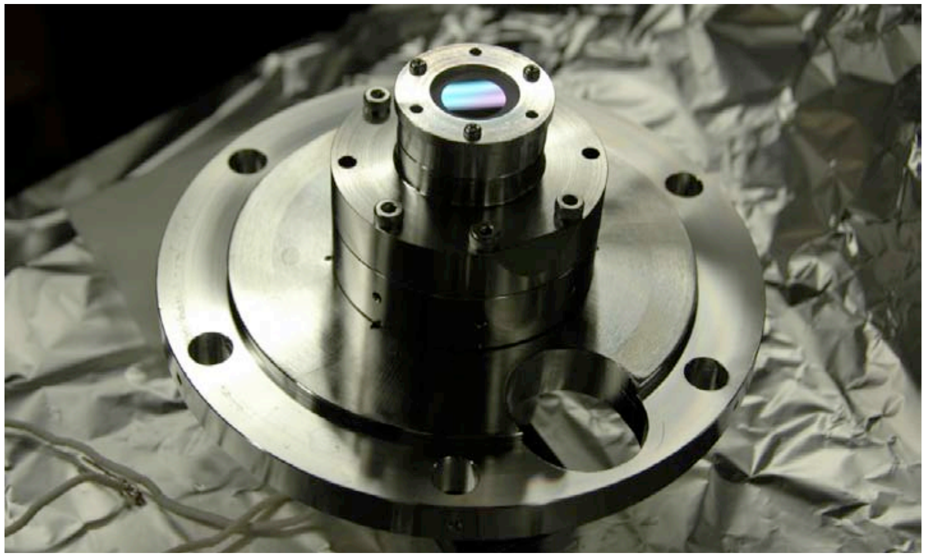
Put it in ATF ring



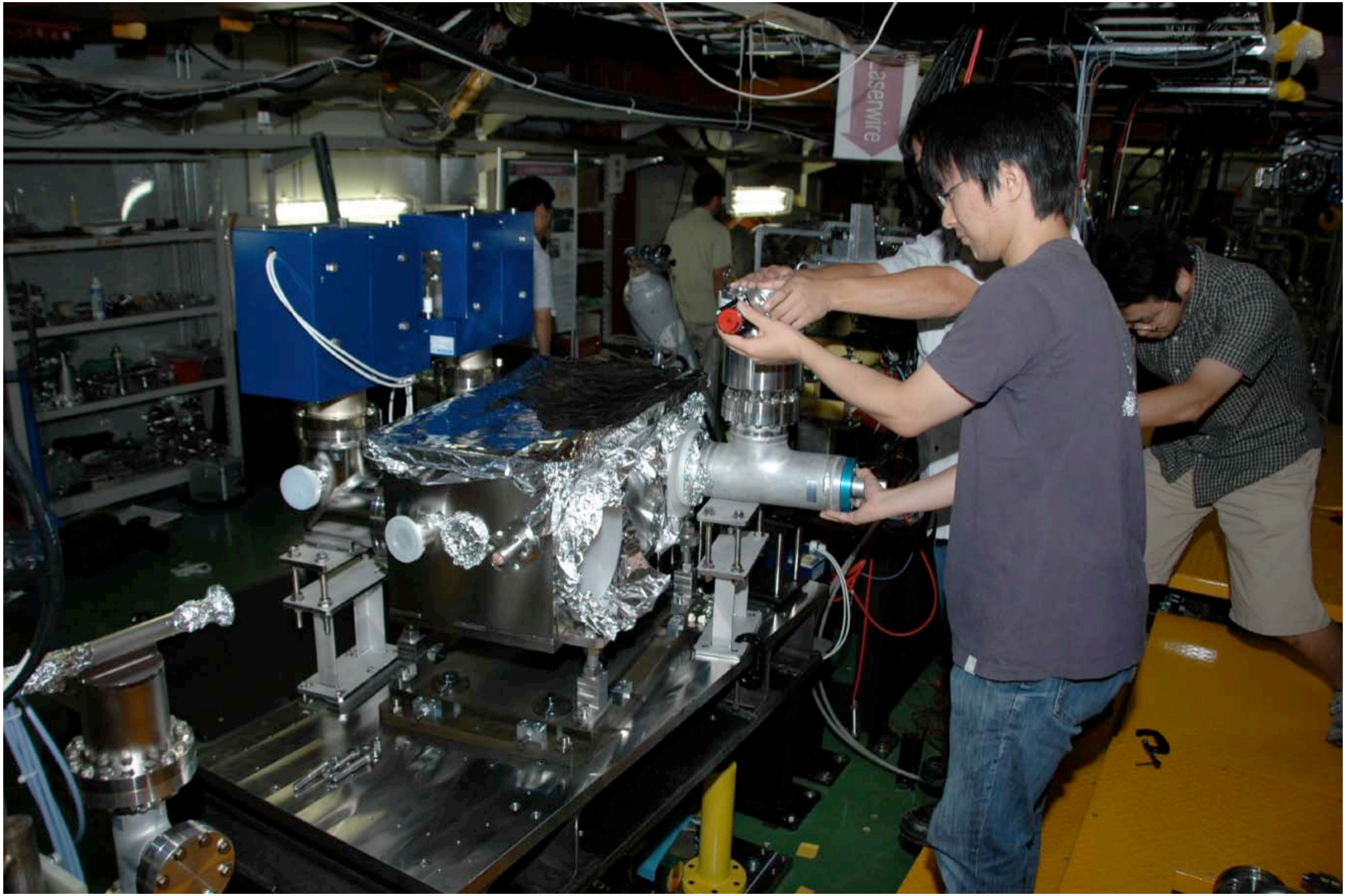
Laser Stacking Optical Cavity in Vacuum Chamber

Summer 2007: Assembling the Optical Cavity



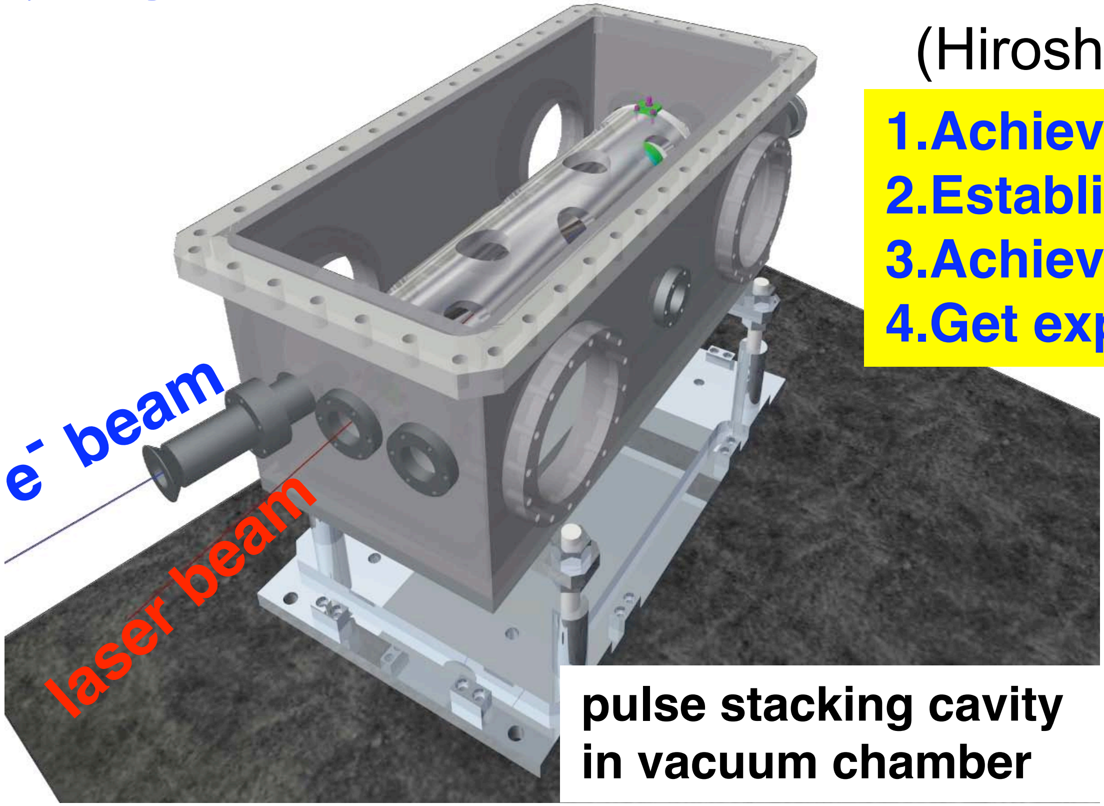


October 2007: Install the 2-mirror cavity into ATF-DR



γ-ray Generation with Laser Pulse Stacking Optical Cavity

(Hiroshima-Waseda-IHEP-KEK)



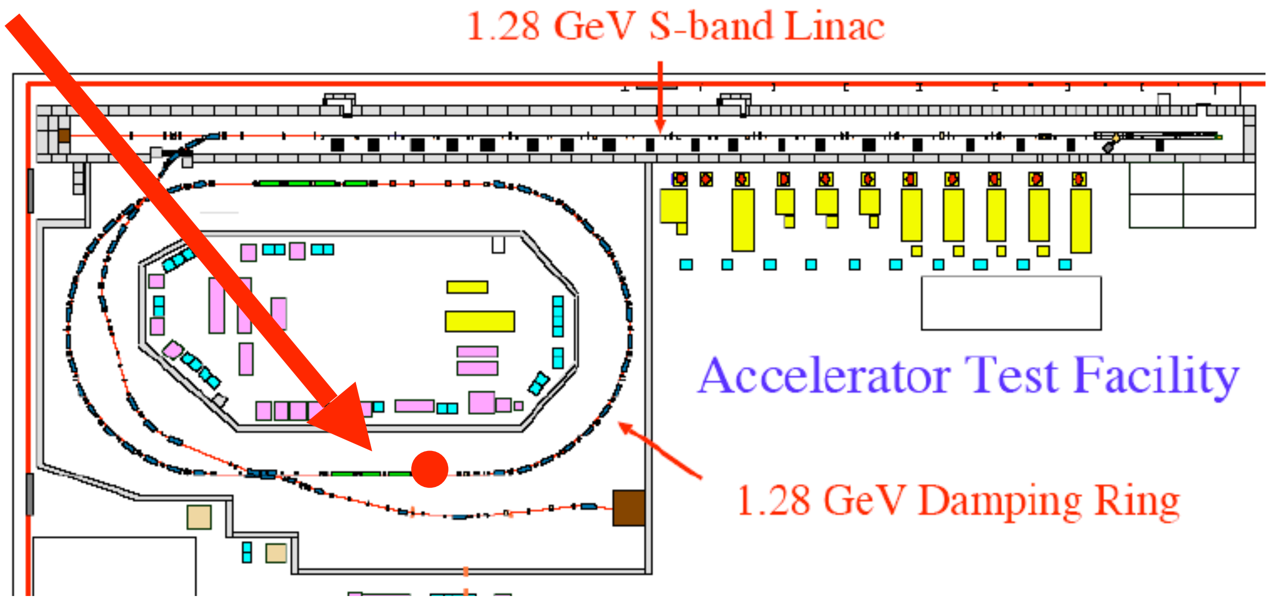
pulse stacking cavity
in vacuum chamber

1.Achieve high enhancement & small spot size
2.Establish feedback technology
3.Achieve small crossing angle
4.Get experience with e^- beam

We will detect 20 γ's/collision in current configuration.
Test is on going.
(so far achieved 3 γ's/collision)
Goal: detect 400 γ's/collision

Stack power estimate

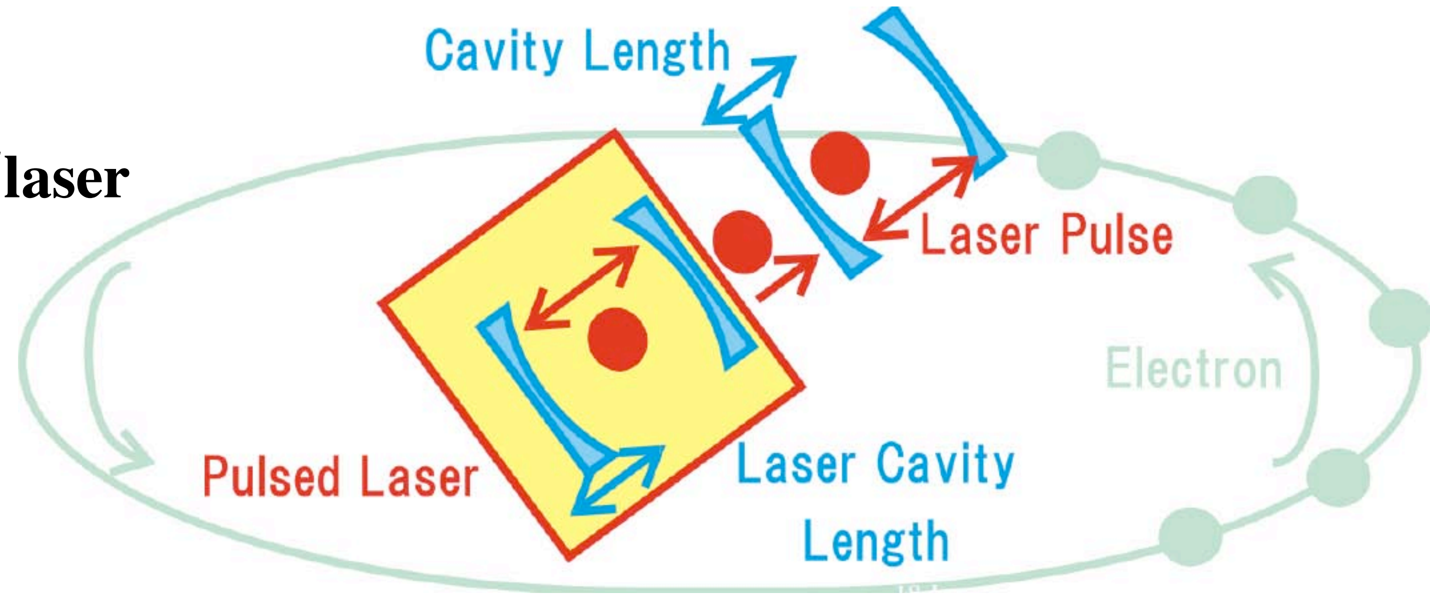
date	Finesse	electron	transmitted power	ncident power	reflected power	input power	λ	stack power
		1/pulse	W	W	W	W		transmi
8/3/14	200	?		6.2	6	0.2	1.1	-
8/4/10	218	2.9E+10	0.325	5.3	4.5	0.8	2.5	81
8/4/15	110	1.5E+10	0.119	5.3	5	0.3	2	30
8/4/22	486	2.2E+10	1.69	5.3	2.5	2.8	3	423
	486	2.3E+10	1.64	5.3	2.51	2.79	3	410
	486	2.6E+10	1.55	5.3	2.55	2.75	3.1	388



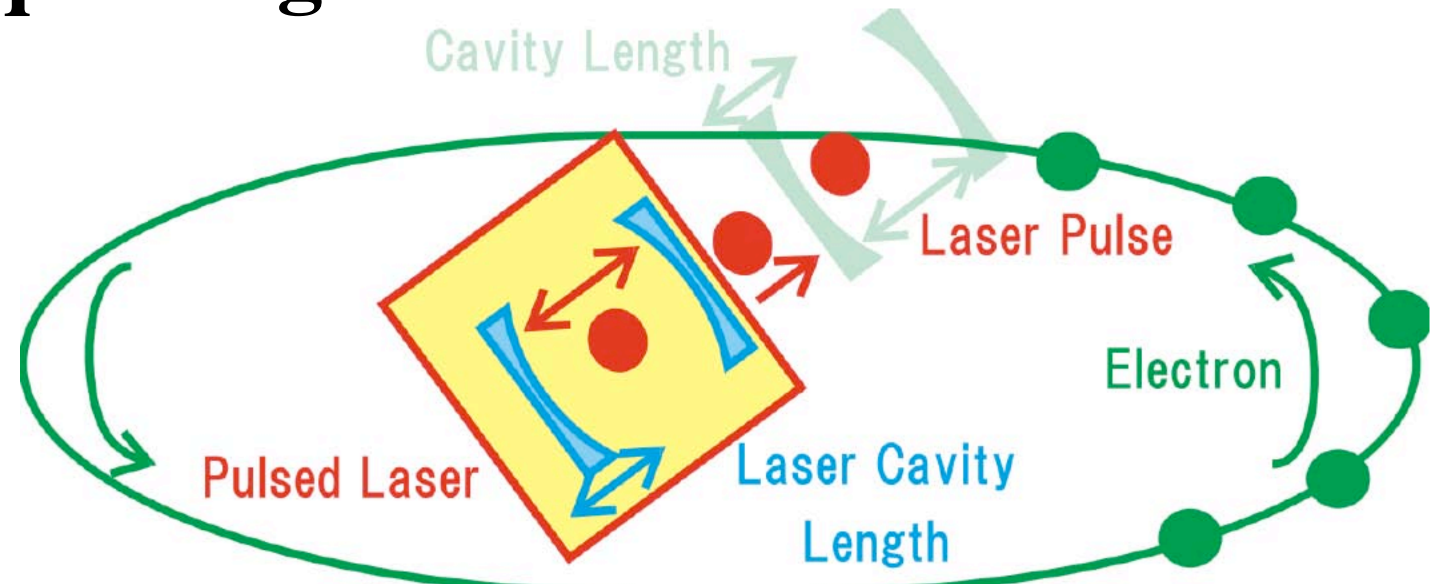
Feedback to Achieve 3 Conditions

$L_{cav} = n \lambda$

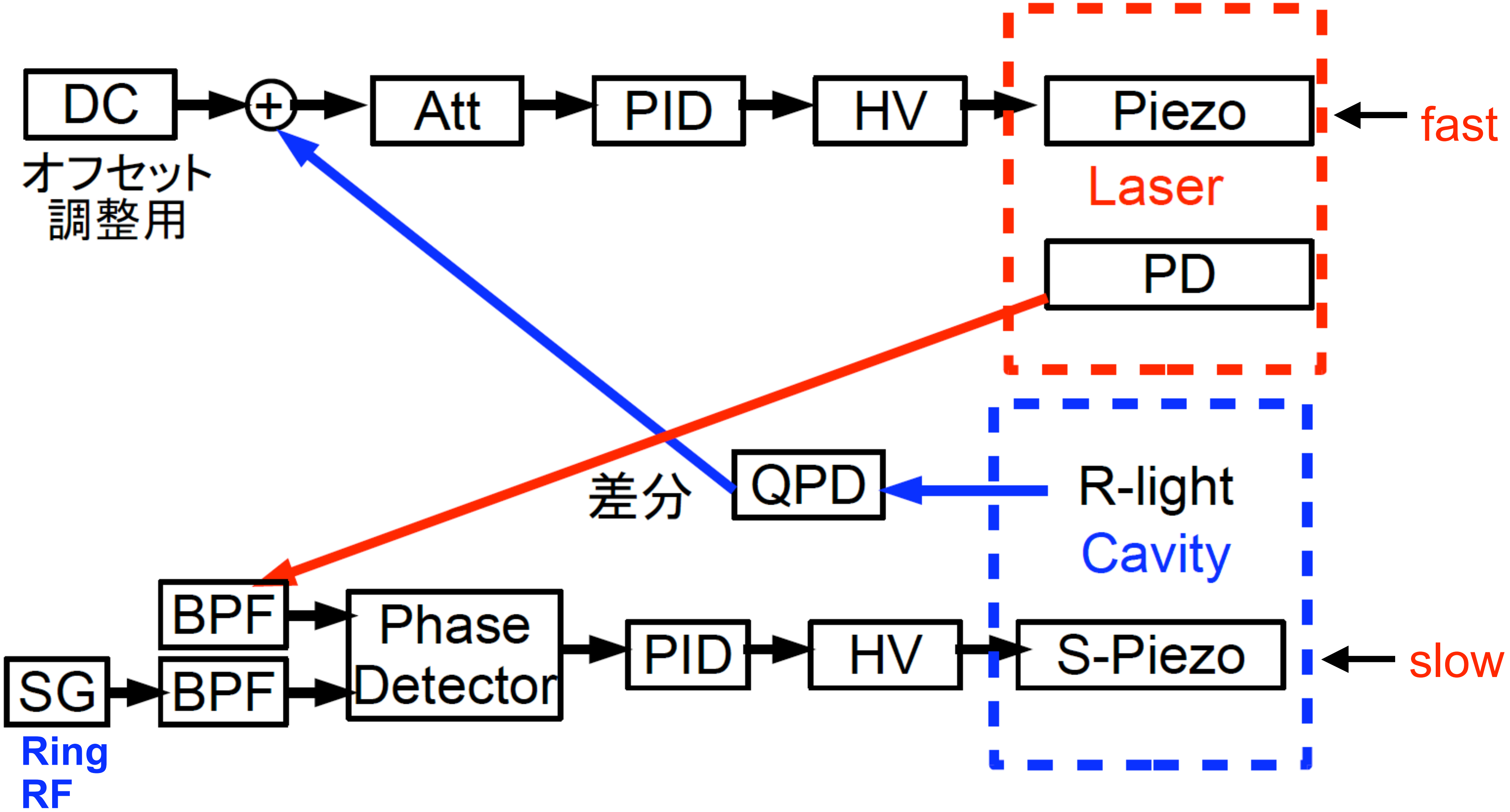
$L_{cav} = m L_{laser}$



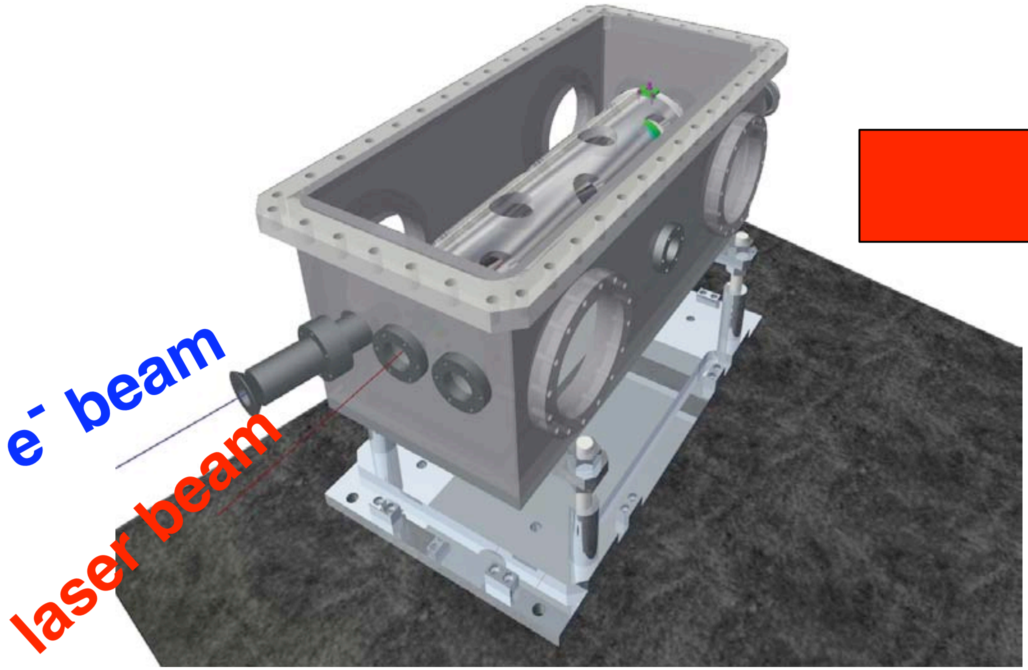
Laser freq = Ring RF

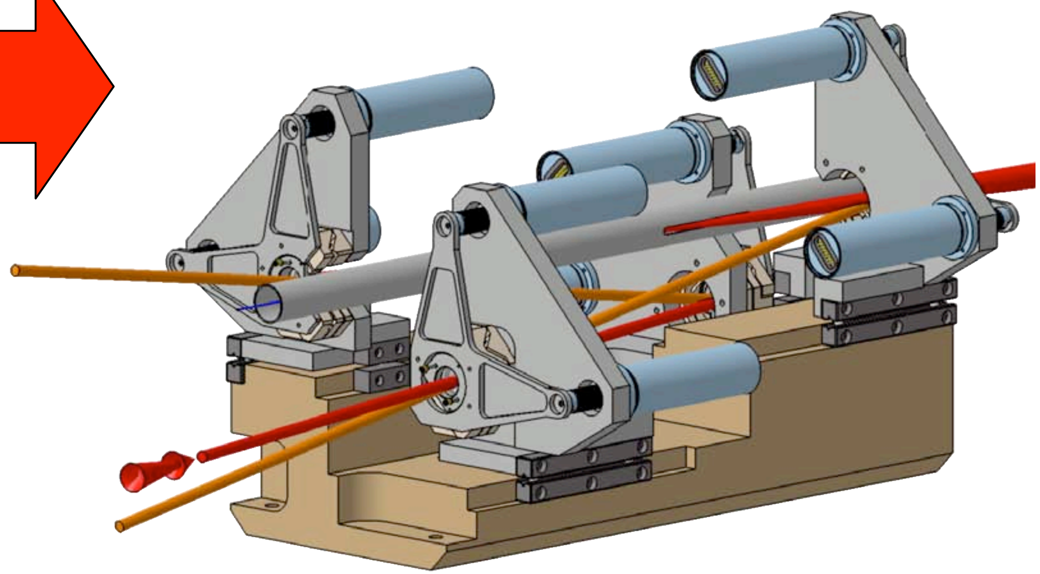


Cross Feedback Circuit (Sakaue)



We are moving from 2-mirror-cav to 4-mirror-cav.





R. Cizeron

Spot size = 30 um
Enhance = 1000

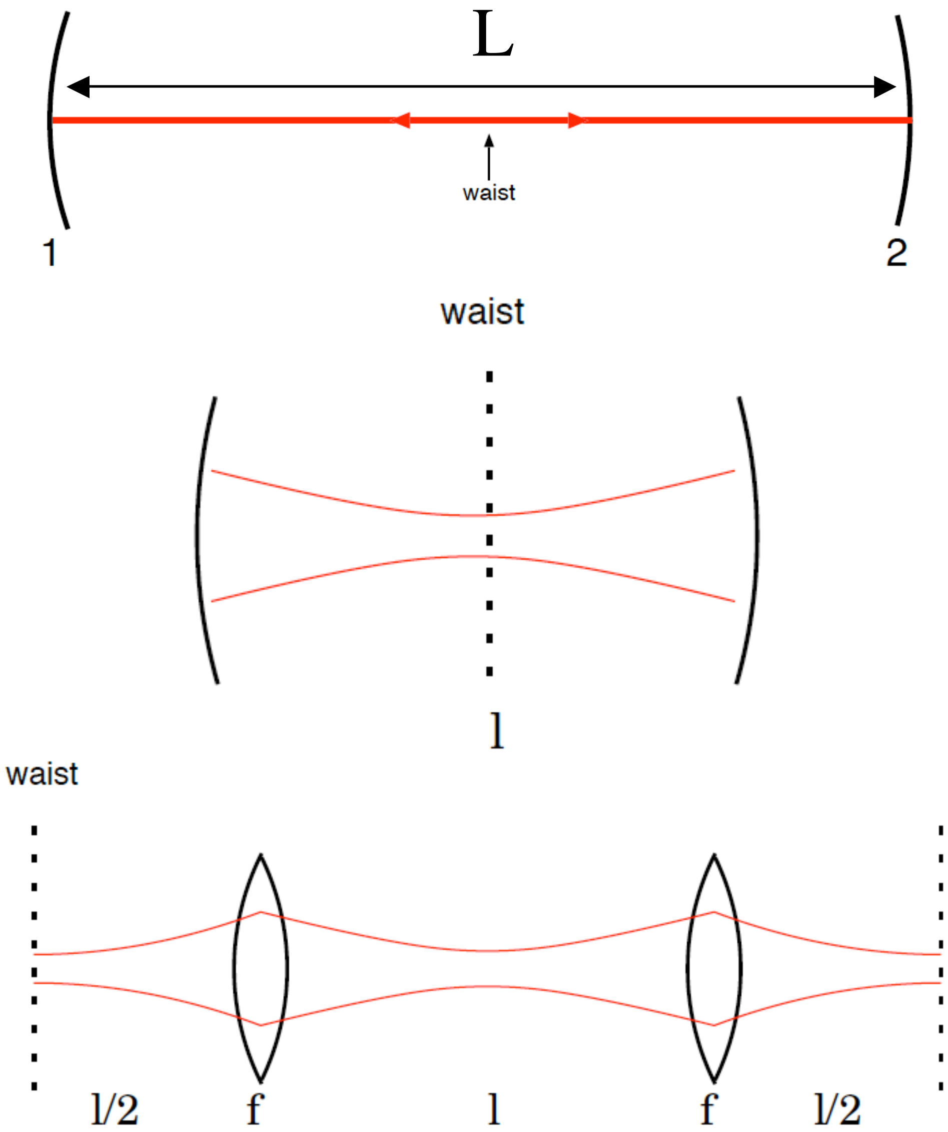
2-mirror cavity

Spot size = 10 um
Enhance = 10000

4-mirror cavity

2-mirror cavity

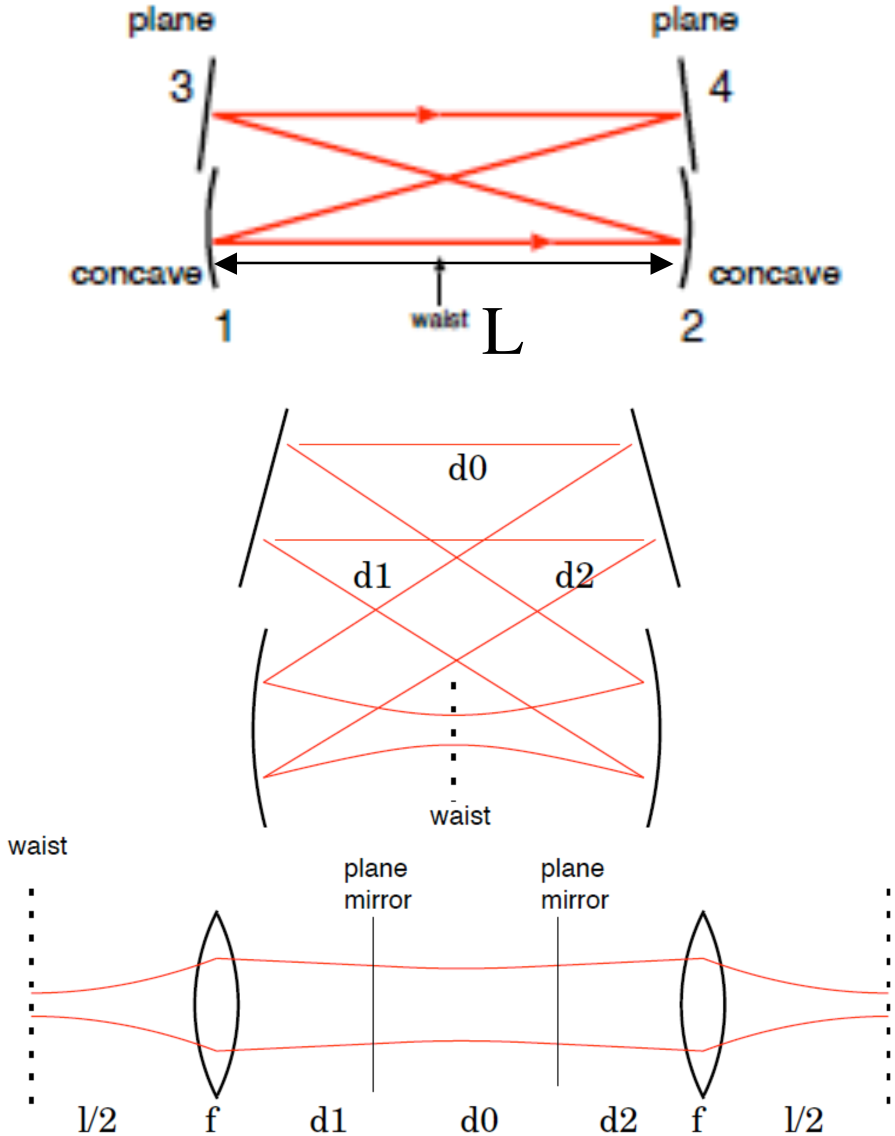
R1=R2=L/2



concentric

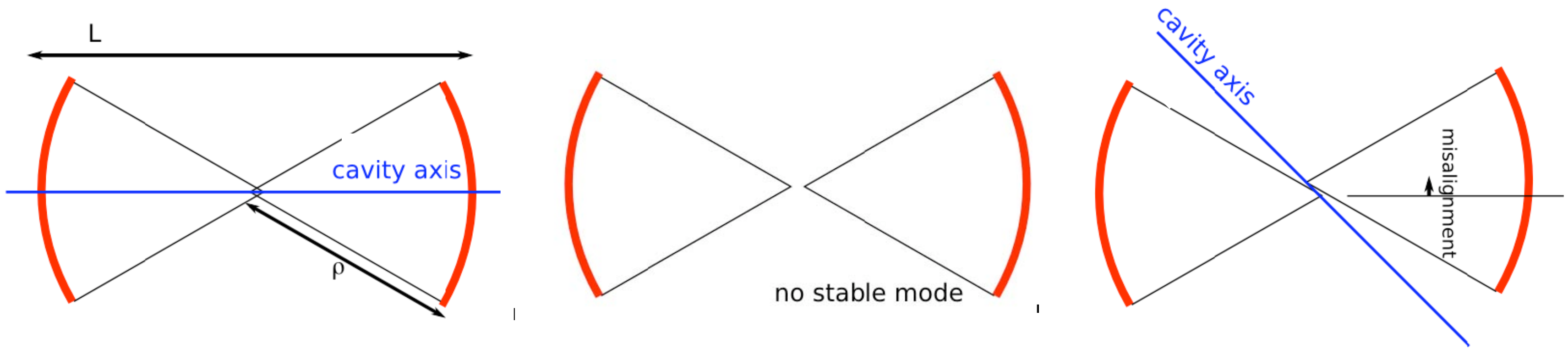
4-mirror cavity

R1=R2=L

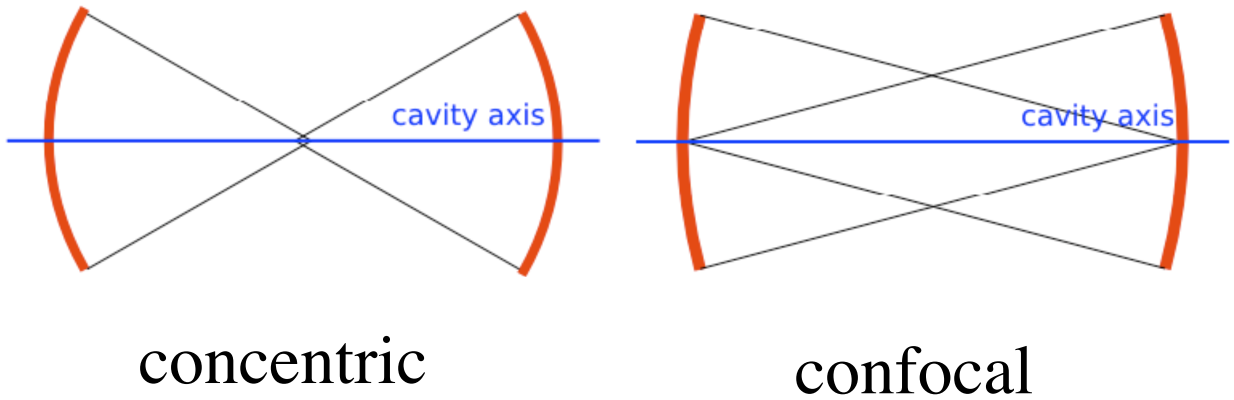


confocal

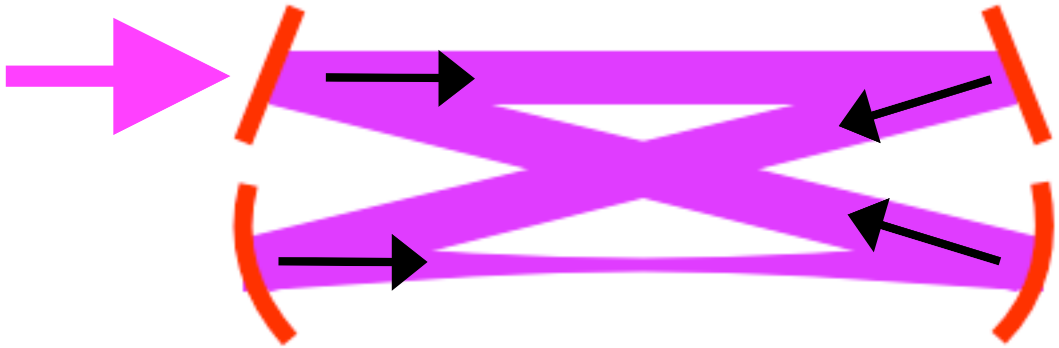
Tolerance of 2-mirror cavity

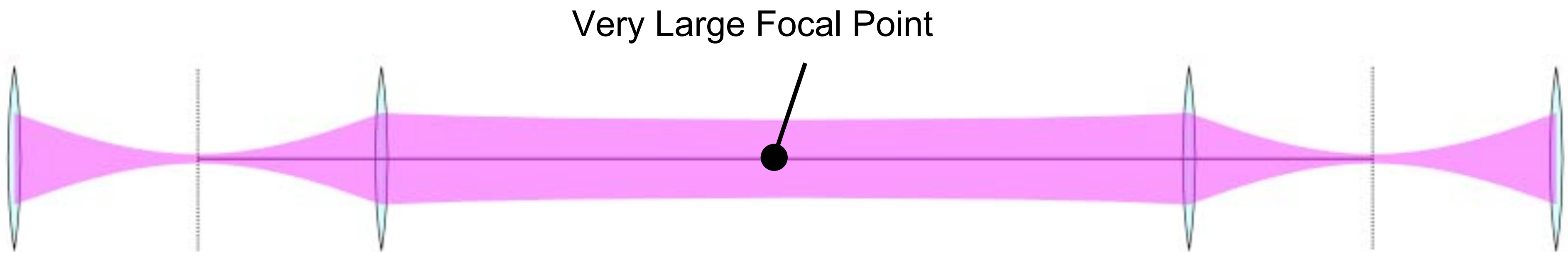


Concentric Configuration and Confocal Configuration



4-mirror ring cavity





Equivalent Optics of the 4-mirror Cavity

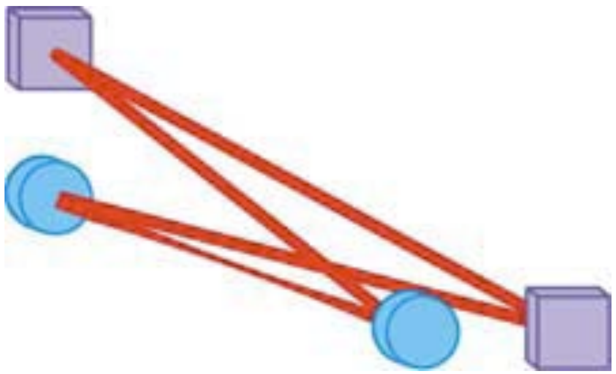
tolerance : 4-mirror = 100 x 2-mirror

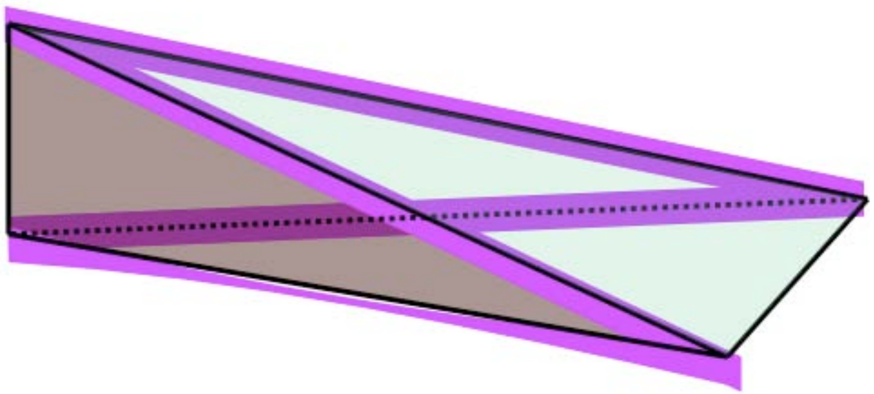
2D configuration

$$f_t = \frac{\rho}{2}\cos(\alpha/2)$$

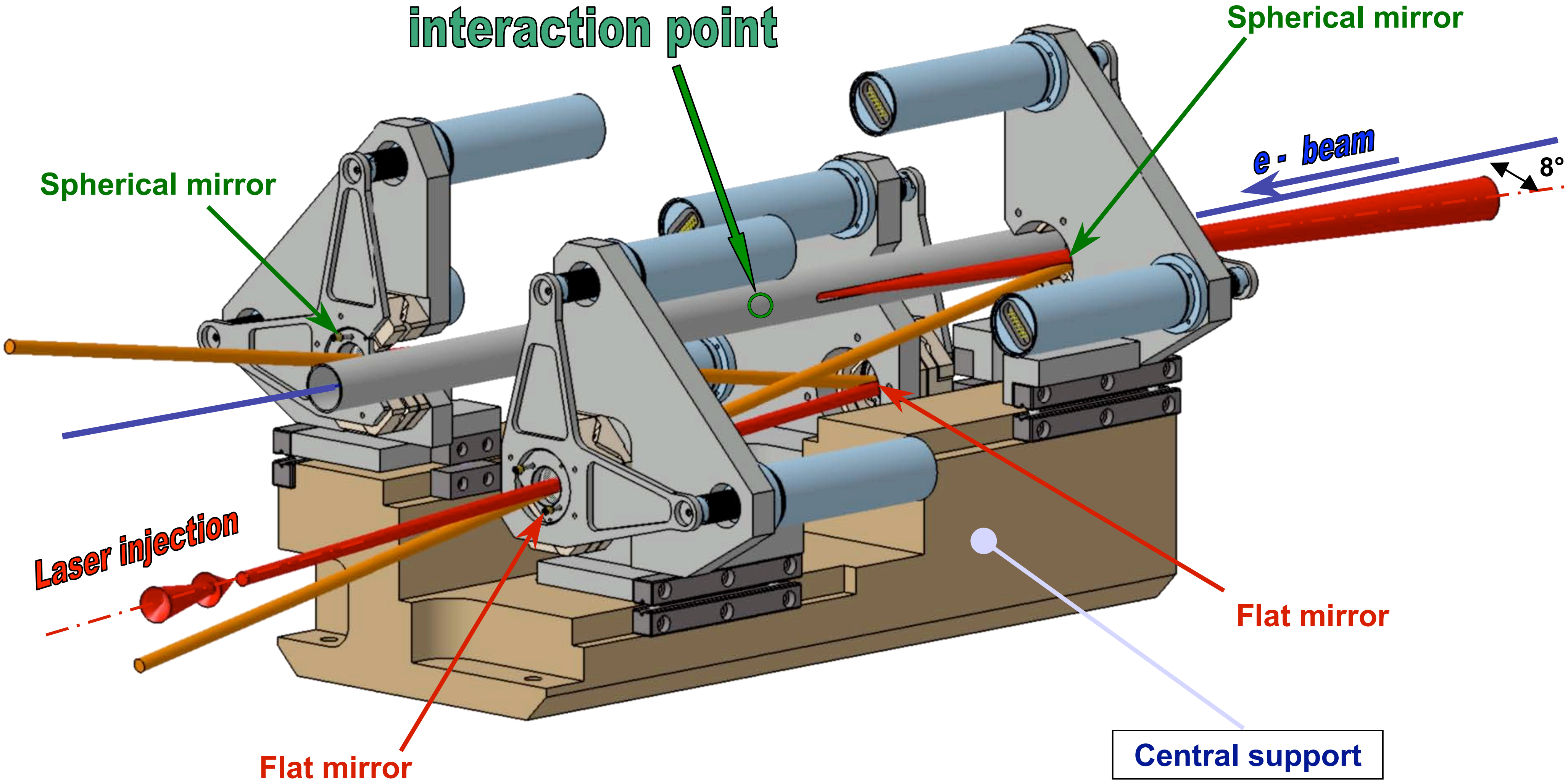
$$f_s = \frac{\rho}{2\cos(\alpha/2)}$$

3D configuration





e^- beam compatible 4-mirror cavity



R. Cizeron
LAL 30/01/2008

Summary

Summary 1

1. Laser Compton e+ source is attractive option for ILC/CLIC
   - Independent system
   - high polarization (potential)
   - 5 Hz polarization flip (for CLIC 50 Hz flip)
   - Operability
   - wide applications
2. Three schemes are proposed
   - Ring Laser Compton for ILC
   - ERL Laser Compton for ILC

   My talk Today

   - Linac Laser Compton
3. Ring: We have a design of ring --> But still many questions
   - What is the best way to cure long bunch length?
     - very small momentum compaction?
     - bunch compress/decompress?
     - crab crossing?
   - Do we need experiments (bunch compression, crab,,,,)?
   - Ring Circumference? (Energy spread of e- beam)

Summary 2

4. **ERL: Many basic parameters are NOT decided yet**
   Repetition Rate of ERL = Repetition Rate of Laser
   charge/bunch
   continuous e+ stacking is possible?

5. **We still need many R/Ds** ---> Good! We have many funs.
   (a) e+ stacking, (b) Ring, (c) ERL, (d) e+ capture
   (e) e+ production target, (e) Laser
   (g) Laser stacking optical cavity
   All of R/Ds are very important and correlated.
   "Choice of Ring or ERL" and "Choice of Parameters"
   are highly depends on the results of the R/Ds.

6. **We have the world-wide collaboration for Compton.**
   Not only for ILC/CLIC e^+ source.
   Also for many other applications.